The Tenth International Particle Accelerator Conference

STUDENT POSTER SESSION GUIDE

19 - 24 May 2019
MCEC
Melbourne Australia
Particle Accelerator Projects
and Upgrades
For Industry Collaboration in the Field of Particle Accelerators
11th Edition
Compiled by Madeleine Chalmers
Australian Synchrotron - ANSTO
Student Poster Session

The Organising Committee of the International Particle Conference series recognizes the significant contribution of the students everywhere. They are the next generation of scientists and engineers that strive to push past the known boundaries of what can be achieved by accelerators.

This poster session has been created to provide a platform for such students to showcase their work before leading into the conference’s welcome reception.

Date: Sunday 19th May 2019
Time: 14:00 to 18:00 (setup 13:30 to 14:00)
Location: Main Foyer (Convention Centre)

Students are required to be at their posters during this period to interact with arriving delegates and the selection jury to be in the running for one of two best student poster prizes. The selection jury is mainly comprised of members from the Scientific Program Committee and Organising Committee. The process involves two evaluation rounds, the first will shortlist up to 10 posters followed by the final selection in the second round. The prizes will be presented during the Awards Session on Thursday 23rd May.
Student Grant Sponsors

The accelerator community and the organising committee of the International Particle Accelerator Conference recognises the significant contribution by students. To support their development it is crucial that they are given the opportunity to interact with their peers from around the world at this conference. For this reason, this conference series makes a point of coordinating with numerous organisations and institutes internationally to fund the student grants. Moreover the profits from this conference goes towards supporting more students to attend future IPAC’s.

For IPAC19 a total of AUD$267,354 has been raised to support 80 students from 15 different countries (222 applicants from 25 countries).

Our sponsors for the IPAC19 student grants are -
SUSPFO — Student Poster Session

A recent upgrade to the high power RF network of the linac at the Australian Synchrotron included a SLED Type 1 Pulse Compressor allowing for the operation of its 100 MeV linac using a single klystron. We explore the effects of the SLED installation on the properties of the beam extracted from the linac with a particular focus on the energy spread and bunch train profile. Additionally, the optical fibre beam loss monitor (oBLM), also recently commissioned, was employed to provide shot-by-shot feedback on loss location and intensity to investigate the change in beam losses.

Design Status of an Electron Source Test Lab at the Canadian Light Source

An electron source test laboratory is being designed and implemented at the Canadian Light Source. Scientists at the CLS will investigate both the properties of different gun designs and the production of femtosecond pulsed, bright, low emittance beams. This lab is a means to determining the proper gun design required as a backup in the current synchrotron, and the future facility electron source. The lab’s location, next to the 250 MeV electron linac, requires sufficient radiation shielding and integration into the existing access control and interlock system, as well as sufficient power and cooling supplies for the lab equipment. Currently, a budget is being developed for the lab by considering the requirements of various electron guns and their diagnostics.
We will report on a system (ps-BPM) that can measure the electron source vertical position and angular motion along with the vertical source size and angular size at a single location in a synchrotron bend magnet beamline*. This system uses a combination of a monochromator and a filter with a K-edge to which the monochromator was tuned in energy. The vertical distribution of the beam with and without the filter was simultaneously visualized with an imaging detector. The small range of angles from the source onto the monochromator crystals creates an energy range that allows part of the beam to be below the K-edge and the other part above. Measurement of the beam vertical location without the absorber and edge vertical location with the absorber allowes measurement of the source position and angle. The beam width and edge width give information about the vertical electron source size and angular distribution. The ps-BPM measurements have been made where the electron beam size and angular distribution was adjusted using skew quads. The ps-BPM measurements correlate well with modeling of the ps-BPM system as well as conventional beam size measurements using a pinhole.


**Beam Instability Induced by Rf System of an FEL-Terahertz Source**

An SLAC type compact Linac has been used as an injector at the HUST FEL-THz to produce high power THz radiation. To meet the requirement of monochromaticity and repeatability for FEL, performance of electron beam and stability of RF system should be taken into account strictly. According to the measurement results of RF dither at the existing facility, instability of beam parameter, for example, emittance, energy and energy spread, has been
estimated by using Parmela and MATLAB, which was also verified in experiments. Furthermore, an Analog-Digital hybrid Low Level RF controller based on FPGA has been designed to ensure the overall required field stability better than 0.15% (FWHM) in amplitude and 2.5° in phase at the cavity operating frequency of 2.856 GHz. In addition, based on RF system modeling and PI control strategy simulation, an applicative AD/DA transform scheme and algorithms will be discussed.

**Robust Iterative Learning Control to Cancel Beam Loading Effect for TRIUMF e-Linac**

Iterative learning control (ILC), also referred to as adaptive feed-forward, performs the same control task multiple times and improves its performance as a result of repetition and learning. Beam loading effect in cavity resonators can be considered as a repetitive disturbance, and ILC can be used to compensate this effect. The error information from the previous trials as well as the previous controller output is stored in the memory. ILC uses the stored information to improve its time response over the iterations. Assuming that the beam loading is identical for all trials, ILC has access to 'future' error data, thus it can use non-causal filters to cancel the beam loading effect in advance and considerably reduce the transient time. Since ILC is essentially a feed-forward controller, it may become unstable due to perturbations or un-modeled dynamics. In this work, we aim to design a robust ILC scheme using the pseudo-spectra of the transfer matrix. Pseudo-spectra determines how the eigenvalues of the transfer matrix, therefore the stability of the system, change as a result of perturbations. Using pseudo-spectra analysis one can design an iterative learning controller robust against bounded perturbations.
**Dynamic Pressure in the LHC - Influence of Ions Induced by Ionization of Residual Gas by Both the Proton Beam and the Electron Cloud**

Ultra-High Vacuum is an essential requirement to reach design performances in high-energy particle colliders. For the future HL-LHC or FCC study, the understanding of the beam interactions with the vacuum chamber is fundamental to provide solutions to mitigate the pressure rises induced by electronic, photonic and ionic molecular desorption. Studies were performed on the ions, produced by molecular ionization generated by the proton beam and the electron cloud, and stimulating molecular desorption by the surface bombardment. In-situ measurements were carried out, on the LHC Vacuum Pilot Sector (VPS)*, to monitor the dynamic pressure, and to collect the electrical signals due to the electron cloud and to the ions interacting with the vacuum chamber walls. In parallel, the ions behaviour in the VPS was simulated to determine the longitudinal and transversal velocity kicks, and the energy spectra. Computation of the dynamic pressure in the VPS was also performed.


**Funding:** work supported by FCC project (CERN & LAL-CNRS-IN2P3)

**Wire Scanner for High Intensity Ion Beam**

The goal of the project is to develop a wire-scanner compatible with low energy - high intensity ion beams and adaptable to various beam chamber diameters. A scanner with three conductive wires on a fork has been developed. The purpose is, for the wires, to pass through the particle beam at a high speed to avoid "disrupting" the passage of the beam. Wires heating and measuring issues have been solved by using tungsten wires kept in tension by a mechanical system. All driving and signal measurements are performed by a PXI based system. The synchronization of the measurements...
is guaranteed by an analog input board recovering the wires current and the translator position, the latter being carried out by a laser sensor. Besides this technological aspect, an optimization algorithm for beam profile reconstruction from measured data under Gaussian hypothesis has been developed. The standalone whole system and first experimental results are presented. 

Funding: Part of this work supported by the European Atomic Energy Community (EURATOM) H2020 Program under grant agreement n°662186 (MYRTE project).

100MeV-4mA Protons Beam Dynamics and Diagnostics for the HEBT of MINERVA Project at SCK-CEN

H. Kraft, L. Perrot (IPN)  
MYRRHA will be the first prototype of a sub-critical nuclear reactor driven by a 600 MeV particle accelerator (ADS). This project aims to explore the transmutation of long lived nuclear waste. A first phase is planned to validate the reliability of a 100 MeV/4 mA Protons LINAC carrying the beam toward an ISOL facility, prefiguring the real MYRRHA demonstrator at 600 MeV. This paper present the status of the beam dynamic studies for the high energy beam transport lines at 100 MeV. In agreement with the project requirements we will describe the specificities of these beam lines for which it is needed to implement a fast kicker-septum system in order to realise a beam separation between the two main lines: toward the beam dump or the ISOL facility. We will also describe the studies on the Beam Position Monitor (BPM) selected for MYRRHA. Part of this work was support par MYRTE project of the European Union.

Effect of Electrostatic Deflectors and Fringing Fields on Spin for Hadron Electric Dipole Moment Measurements on Storage Rings

J. Michaud, J.-M. De Conto, Y. Gómez Martínez (LPSC)  
The observed matter-antimatter asymmetry in the universe cannot be explained by the Standard Model. An explanation is a non-vanishing Electric
Dipole Moment of subatomic particles. The JEDI (Jülich Electric Dipole moment Investigations) collaboration is preparing a direct EDM measurement of protons and deuterons first at the storage ring COSY (COoler SYnchrotron) and later at a dedicated storage ring. To achieve this, one needs a stable polarization, i.e. around 1000 seconds for spin coherence time. One source of decoherence are the electrostatic deflectors, and this must be quantified. We developed an analytical model for cylindrical deflectors, including fringing fields, and the associated beam and spin transfer functions, integrated over the deflector. All boundaries (including ground) are considered, giving a realistic, accurate field map up to any order. We get universal formulas, the only adjustable parameter being the deflector gap/radius ratio, all other terms being numerical. This has been implemented in BMAD. We present the mathematical, physical and numerical developments, as well as results for a proton storage ring.

**Development of a Beam Loss Monitor and Transverse Beam Dynamics Studies at ARRONAX C70XP Cyclotron**

The ARRONAX Interest Public Group uses a multi-particle, high energy and high intensity industrial accelerator which has several beamlines used for various purposes. For improvement of operations, ARRONAX has foster and installed robust air-based Beam Loss Monitors (BLMs) outside the beam pipes. BLMs consist of four active detecting plates and are integrated within the experimental physics and industrial control system (EPICS) monitoring and data acquisition system. Each BLM has been tested for the pre-commissioning phase with beams at low intensity (600pA to 6nA on target). Comparative studies and selection of the BLMs has led to their installation at high intensity beam lines. BLMs are now used in beam dynamics studies to investigate transverse characteristics while in regular operation. They support present and future operations extension foreseen at ARRONAX. The results from experimental studies on BLMs at low beam intensity and status of beam dynamics studies at high intensity (A) are presented here. Keywords: BLM, beam dynamics, EPICS, Gas ionization detector, cyclotron, proton.
Spin Decoherence in the Frozen Spin Storage Ring Method of Search for a Particle EDM

A.E. Aksentyev (FZJ) A.E. Aksentyev (MEPhI) V. Senichev (RAS/INR)

Spin coherence refers to a measure of preservation of polarization in an initially polarized beam. The spin vector of a particle injected into a storage ring starts to precess about the vertical magnetic field vector in accordance with the Thomas-BMT equation. The precession frequency is dependent on the equilibrium-level energy, which differs across the beam particles. This does not pose a problem when the initial polarization is vertical; however, the Frozen Spin Storage Ring EDM search method [*] requires beam polarization along the momentum vector, i.e., in the horizontal plane. In the present work we analyze the source of decoherence, and investigate the way it can be suppressed in the horizontal plane in a perfectly aligned ring by means of sextupole fields. We also consider the case of an imperfect ring: transference of decoherence into the vertical plane induced by vertical plane spin precession, and the effect of sextupole fields.

* D. Anastassopoulos et al. AGS Proposal: Search for a permanent electric dipole moment of the deuteron nucleus at the 10−29 e · cm level. BNL report, 2008.

Measurement and Optimization of TRIBs Optics at BESSY II

F. Armborst, P. Goslawski (HZB)

Transverse Resonant Island Buckets (TRIBs *) correspond to a second stable orbit, longitudinally winding around the core orbit in the transverse $x$-$x'$-phasespace. The exploitation possibilities for stable TRIBs are under investigation at the third generation light source BESSY II in Berlin. The applicability for bunch separation is a main subject of these studies. Stable operation of TRIBs optics with a single or few bunches on
the second orbit and a multibunch train on the main orbit has been shown **. Photons emitted on the second orbit are well separated from those of the main orbit at all beamlines. This provides the possibility of bunch separation by beamline adjustment for the timing community without significant impact on the average brightness for other users. Simulations based on linear optics from closed orbits (LOCO) and on nonlinear optics derived from the measured chromaticity and tune shift with action (TSWA) predict this separation well. Friendly user experiments in 2018 confirmed these results. The scheduled upgrade BESSY VSR *** features simultaneously stored long and short bunches. Then TRIBs optics would in principle enable the separation of the different bunches at every beamline offering unique possibilities to our users. Simulations and measurements aiming to investigate further possible optimization of the TRIBs optics are presented.


Funding: Federal Ministry of Education and Research

HOM Damping Options for the Z-Pole Operating Scenario of FCC-ee

The Z-pole option of FCC-ee is an Ampere class machine with a beam current of 1.39 A. Due to high HOM power and strong HOM damping requirements, the present baseline of FCC-ee considers a single cell cavity at 400 MHz. In this paper different HOM damping schemes are compared for the Z-pole operating scenario with the aim of lowering the longitudinal and transverse impedance. The HOM power for each damping scheme is also calculated to determine the power handling capabilities required for the respective scheme.
Simulation Studies for a EEHG seeded FEL in the XUV

V. Grattoni, R.W. Assmann, C. Lechner, G. Paraskaki (DESY) W. Hillert (University of Hamburg, Institut für Experimentalphysik)

Echo enabled harmonic generation (EEHG) is a promising technique for seeded free electron lasers not only to go down to wavelengths of 1 nm, but also to simplify the schemes that are currently used to achieve a similar wavelength range (double-cascaded HGHG). Thus a study optimizing the EEHG performance in the wavelength range from 60 to 4 nm is performed, assuming a linear accelerator operated at electron beam energies of 750 MeV and 1.35 GeV. These two working points are analyzed in detail for two different seed laser frequencies: visible and UV.

Applications & Operation of an Inverse Compton-Source in User Mode


Synchrotron radiation in the lab? Inverse Compton scattering of infrared photons from relativistic electrons generates brilliant quasi-monochromatic X-rays with a storage ring of a few meters circumference, e.g. at the Munich Compact Light Source (MuCLS)*. The availability of synchrotron light in a laboratory enables broader access to synchrotron techniques, especially in (but not limited to) clinical imaging and preclinical biomedical applications. Since commissioning of the MuCLS, we have been exploring the latter in daily user operation. So far, the focus has been on dynamic in-vivo small animal respiratory imaging**, grating-based phase-contrast imaging, e.g. for quantitative material decomposition***, and spectroscopic imaging, e.g. for angiography****. We demonstrate significantly improved results over conventional clinical imaging as well as new ways of investigating lung disease development and treatment response. Key to performing such studies in user operation is stable X-ray beam delivery, even though the possibility for operator interventions is limited during these runs. We present our experiences of running an inverse Compton source in
user mode and how we address the challenges arising with it, in particular through our system for online monitoring and active stabilization of the electron-photon interaction point.


**Funding:** We acknowledge financial support by the Centre for Advanced Laser Applications, DFG Cluster of Excellence Munich-Centre for Advanced Photonics (DFG EXC-158) and DFG Gottfried Wilhelm Leibniz program.

---

**Single Shot Thermal Momentum Imaging for High Brightness Photoinjector Cathodes**

In state of the art photoinjector electron sources, cathode performance determines the lower limit of achievable beam emittance. Measuring the intrinsic emittance at the photocathodes in electron guns is of vital importance for improving the injectors. Traditional methods, like solenoid scan, pepper-pot, need multi-shots and therefore suffer from shot to shot jitter and are time-consuming. Here we propose a new method, named thermal momentum imaging. By tuning the gun solenoid focusing, the electrons’ transverse momentum at cathode is imaged to a downstream screen. The new method enables a single shot measurement of cathode intrinsic emittance by measuring the beam spot size. An experiment is done at Photo Injector Test facility at DESY, Zeuthen site (PITZ) with Cs2Te cathode. Measurements of cathode intrinsic emittance, thermal momentum distribution, map of cathode intrinsic emittance and its correlation with QE are presented.
Synchrotron radiation (SR) reflection is an important issue to study for future linear colliders. SR reflection might impact the performance of the detector, through irradiation of the forward luminosity and beam quality calorimeters or the innermost layers of the vertex detector. Photons’ reflections depend on the beam pipe apertures, their shape, and used materials with various surface roughness. In this poster, we present a study of this problem for the 350 GeV, 380 GeV and 3 TeV beam parameters and optics of the Compact Linear Collider’s Beam Delivery System. The simulations of the SR reflections using Synrad+ software are presented and the impact on the detector is discussed.

**Vertical Beam Size Diagnostics at BESSY II: A Comparative Study**

**M. Koopmans, J.G. Hwang, P. Kuske, M. Ries, G. Schiwietz (HZB)**

With the VSR upgrade for the BESSY II electron storage ring* bunch resolved diagnostics are required for machine commissioning and to ensure the long-term quality and stability of operation. For transverse beam size measurements we are going to use an interferometric method, which will be combined with a fast intensified CCD camera at a subsequent stage. A double-slit interferometer method has already been verified successfully at BESSY II**. In addition the obstacle-bar method*** is presently being tested as an alternative interferometric technique. It uses diffraction from a centered horizontal X-ray blocker for vertical beam-size determination. This technique will lead to enhanced photon statistics and possibly improve monitor resolution. We are using either pi- or sigma-polarized synchrotron radiation at the first of the new diagnostic beamlines for BESSY VSR. Measurements of the two interferometer schemes and X-ray pinhole as function of a vertical electron beam excitation are compared. The results will be presented and discussed at the conference.
The MYRRHA (Multi-purpose hYbrid Research Reactor for High-tech Applications) Project is a planned accelerator driven system (ADS) for the transmutation of long-living radioactive waste. In order to test the reliability of the planned 17 MeV injector, a shortened injector with 5.9 MeV LLN consisting of the ion source, a 4-Rod RFQ, 2 Quarter Wave Rebunchers (QWRs) and a total of 7 normal conducting CH structures is currently being installed in Louvein-la-Neuve (LLN, Belgium). This paper describes the status of the first 2 CH structures and shows the results of the Low-Level measurements done at IAP Frankfurt and of the conditioning of the cavities.

The MYRRHA (Multi-purpose hYbrid Research Reactor for High-tech Applications) Project is a planned accelerator driven system (ADS) for the transmutation of long-living radioactive waste. In order to test the reliability of the planned 17 MeV injector, a shortened injector with 5.9 MeV is currently being installed in Louvein-la-Neuve (LLN, Belgium). During the conditioning process, the power fed into the cavity is slowly increased until the cavity finally fully assumes the power required for operation, taking care not to damage the structure by flashovers, discharges or other effects. This paper will report on the status of the conditioning of the 176.1 MHz 4-Rod RFQ and the two Quarter Wave Rebunchers (QWRs) of the MYRRHA injector.
B. Ledroit (IKP) K. Aulenbacher (HIM)

The Mainz Energy-recovering Superconducting Accelerator (MESA) will be an electron accelerator allowing operation in energy-recovery linac (ERL) mode. It provides the opportunity to operate scattering experiments at energies of ~100MeV with thin gas-targets. The MESA Internal Gas Target Experiment (MAGIX) aims to operate windowless jet targets and different gases up to Xenon to search for possible dark photon interactions, to precisely measure the magnetic proton radius and astrophysical S-factors. Investigations on the impact of the target on beam dynamics and beam losses are required for machine safety and to examine limits to ERL operation. The goal of this work is to understand target induced halo in the different experimental setups, track halo particles through downstream sections to examine beam losses and include a suitable collimation system and shielding into the accelerator layout to protect the machine from direct and indirect damage through beam losses and radiation. The present status of the investigations is presented.

**Funding:** Supported by the DFG through GRK 2128

---

**Further Designs of HOM Couplers for Superconducting 400 MHz RF Cavities**

N.F. Petry, K. Kümpel, O. Meusel, H. Podlech (IAP)

The Future Circular Collider (FCC) is one possible future successor of the Large Hadron Collider (LHC) at CERN. The proton-proton collider center-of-mass collision energy is set to 100 TeV with a beam current of 0.5 A. To achieve this energy a stable acceleration is critical and therefore higher order modes (HOM) need to be damped. HOM dampers, further characterized as couplers, need to fulfill several criteria to be efficient. As a first property the couplers should assure a longitudinal impedance of higher order modes of below 10 kW. Furthermore, the loaded Q-factor should be below 1000 and the corresponding R/Q value should be in the range of 1 Ω. Besides the Hook-type and Probe-type HOM coupler two additional designs were simulated.
The recent results of the different couplers attached to a superconducting 400 MHz RF cavity will be presented.

**Search for Electric Dipole Moments at COSY in Jülich - Spin Tracking Simulations using Bmad**

V. Poncza, A. Lehrach (FZJ) A. Lehrach, V. Poncza (RWTH)

The observed matter-anti-matter asymmetry in the universe cannot be explained by the Standard Model (SM) of particle physics. In order to resolve the matter dominance an additional CP violating phenomenon is needed. A candidate for physics beyond the SM is a non-vanishing Electric Dipole Moment (EDM) of subatomic particles. Since permanent EDMs violate parity and time reversal symmetries, they are also CP violating if the CPT -theorem is assumed. The JEDI (Jülich Electric Dipole moment Investigations) collaboration in Jülich is preparing a direct EDM measurement of protons and deuterons first at the storage ring COSY (COoler SYnchrotron) and later at a dedicated storage ring. In order to analyse the data and to disentangle the EDM signal from systematic effects spin tracking simulations are needed. Therefore a model of COSY was implemented using the software library Bmad. It includes the measured magnet misalignments of the latest survey and a simplified description of the RF-Wien Filter device that is used for the EDM measurement. The model was successfully benchmarked using analytical predictions of the spin behavior. A crucial point regarding the data analysis is the knowledge of the orientation of the invariant spin axis with vanishing EDM at the position of the RF-Wien Filter. Especially its radial component is unknown and spin tracking simulations can be used to determine this missing number. Tracking results as well as the algorithm to find the invariant spin axis will be presented.
Research and development in preparation of the proposed HElimholtz LInear ACcelerator (HELIAC) is performed by a collaboration of GSI, HIM and Goethe University Frankfurt. It is intended for various future experiments with special focus on heavy ion energies near the coulomb barrier for super-heavy element research. The linac will be operated in cw-mode and with a mass-to-charge-ratio up to 6. With a required minimum energy spread over a wide output energy range from 3.5 to 7.3 MeV/u the beam dynamics design is challenging. It is based on EQUUS (equidistant multi-gap structure) using highly efficient superconducting (sc) CH-DTL cavities with an accelerating gradient up to $E_a = 7.1$ MV/m. The worldwide first beam test with a sc multi-gap CH-DTL cavity in 2017 was a milestone in the R&D work of GSI, HIM and IAP. The layout for the entire linac has recently been updated and optimized and an advanced beam dynamics design for the HELIAC was developed.

**Funding:** Work supported by BMBF contr. No. 05P15RFRBA, EU Framework Programme H2020 662186 (MYRTE) and HIC for FAIR

Beam Breakup Simulations for the Mainz Energy Recovering Superconducting Accelerator MESA

MESA is a two pass energy recovery linac (ERL) currently under construction at the Johannes Gutenberg-University in Mainz. MESA uses two 1.3 GHz TESLA type cavities with 12.5 MV/m of accelerating gradient in a modified ELBE type cryomodule with improved thermal connection of the HOM antennas and cw operation. In the first stage of
MESA operation 1mA of beam current is foreseen, which will later be upgraded to 10mA. One potential limit to maximum beam current in ERLs is the transverse beam breakup (BBU) instability induced by dipole Higher Order Modes (HOMs). These modes can be excited by bunches passing through the cavities off axis. Following bunches are then deflected by the HOMs, which results in even larger offsets for recirculated bunches. This feedback can even lead to beam loss. Simulation results for HOM spectra of a single TESLA cavity are available for example in *. It was possible to measure the HOM spectra in the cold, not tuned cavities at DESY and in the cold string tuned to the 1.3 GHz fundamental mode at Mainz. Results for the maximum beam current for MESA, limited by BBU, for the various HOM spectra are presented.


Funding: We are grateful for the financial support provided by DFG through GRK 2128 Accelence.

Feasibility Study of Active Halo Control at the LHC with the Transverse Damper System using Colored Noise

In the scope of complementing the LHC beam collimation system for its High Luminosity upgrade (HL-LHC Project) with a necessary active halo control technique several methods are under investigation such as electron lenses. This paper summarizes the undertaken simulation studies and machine development experiments of depleting the beams halo with the LHC transverse damper system as a fall-back scenario in case of issues with the implementation of the hollow-electron lens in the LHC. A benchmarking of tracking simulations with MD data and the most recent results of experiments with the novel method of colored noise will be shown. The method’s feasibility and performance comparison with other techniques will be discussed.
Beam-based Alignment at the Cooler Syncrotron (COSY)

T. Wagner (FZJ)

There is a matter-antimatter asymmetry observed in the universe that can not be explained by the Standard Model of particle physics. To resolve that problem additional CP violating phenomena are needed. A candidate for an additional CP violating phenomenon is a non-vanishing Electric Dipole Moment (EDM) of subatomic particles. Since permanent EDMs violate parity and time reversal symmetries, they also violate CP if the CPT-theorem holds. The Jlich Electric Dipole moment Investigation (JEDI) Collaboration works on a direct measurement of the electric dipole moment (EDM) of protons and deuterons using a storage ring. The JEDI experiment requires a small beam orbit RMS in order to measure the EDM. Therefore an ongoing upgrade of the Cooler Syncrotron (COSY) is done in order to improve the precision of the beam position. One of part of this upgrade is to determine the magnetic center of the quadrupoles with respect to the beam position monitors. This can be done with the so called beam-based alignment method. The first results of the beam-based alignment measurement performed in February 2019 will be presented.

Study for the Alignment of Focusing Solenoid of ARES RF Gun and Effect of Misalignment of Solenoid on Emittance of Space Charge Dominated Electron Beam

S. Yamin, R.W. Assmann, B. Marchetti (DESY)

SINBAD (Short and INnovative Bunches and Accelerators at DESY) facility will host multiple experiments relating to ultra-short high brightness beams and novel experiments with ultra-high gradient. ARES (Accelerator Research Experiment at SINBAD) LINAC is an S-band photo injector to produce such electron bunches at around 100 MeV for injection into novel accelerators e.g. dielectric Laser acceleration (DLA) and Laser Driven Wakefield acceleration (LWFA). The LINAC will be commissioned in stages with the first stage corresponding to gun commissioning. The gun commissioning status has been reported earlier. In this paper, we present studies about the scheme adopted for the alignment of focusing solenoid for the ARES gun based on transfer
matrices. The method is bench marked using ASTRA simulations. Moreover the effect of misalignment of the solenoid on the emittance of space charge dominated scheme and its compensation is also discussed.

Analytical Study of Bubble Wakefield Acceleration

The particle accelerators are the most promising and useful devices for mankind. Plasma-based accelerators are fascinating as there is no problem of electrical breakdown and these can generate large accelerating fields*. Laser wakefield acceleration is one of the techniques that employs plasma and high-intensity laser pulses. Here plasma electrons are expelled by the short intense laser pulse and electron wave is excited in the plasma which acquires high electric field. This field is used for the particle acceleration. When the laser intensity exceeds some limit, plasma electrons can be expelled by the ponderomotive force of laser pulse in such a manner that electrons free region can be created which is called ions cavity and the situation corresponds to bubble regime**. On the other hand, the electrons in plasma wakefield acceleration are expelled by space charge force, creating a blowout or ions cavity in underdense plasma. In the present work, we focused on the laser generated a bubble in underdense plasma. For this, we used different Gauge conditions and obtained wakefield potential for controlling the bubble shape for electrons acceleration with the help of d’Alembert differential equations in an electromagnetic field. We also carried out analytical calculations for finding the different shapes of the bubble, enabling us to realize longitudinal and ellipsoid bubbles instead of a spherical bubble regime on which people have generally worked on. In addition, we considered the presence of residual electrons in the bubble regime and found that the shape of the bubble can be controlled by the bubble velocity. We also found electric and magnetic fields for different Gauge conditions.


Funding: Indian Institute of Technology Delhi, Delhi, India.
This work will describe Fermilab experiments that focus on the optimization of doping parameters to achieve low sensitivity to trapped magnetic flux while maintaining very high Q characteristic of nitrogen doped cavities and same or higher quench fields. Working partially in the context of LCLS-2 higher energy upgrade, new doping recipes are pursued and have been found to vary the mean free path of the resonator which is related to the sensitivity to trapped magnetic flux. Moreover, a correlation has been found between lighter doping and higher quench fields while maintaining sufficiently low surface resistance.

**ESR Bumps Calculation and Simulation**

The commissioning of the ESR with a new control system based on the LSA (LHC System Architecture) will be start in near future. A new control system is under development that considers all aspects of the expected functionality to operate the GSI/FAIR machines and incorporates the present GSI controls infrastructure*. Two years ago, the old control system which was based on outdated computers and operating system, was discontinued. So both synchrotron, the SIS-18 and the ESR storage ring operation from now on have to be performed with the new FAIR control system. Due to the control system changing, new calculations and simulations for SIS and ESR are necessary. In this report we summarise the results of bumps calculation in ESR which is done with three different codes, namely: ELEGANT**, MAD-X and MIRKO and compare the simulation result with measurement.

* R. BaÌr, DEVELOPMENT OF A NEW CONTROL SYSTEM FOR THE FAIR ACCELERATOR COMPLEX AT GSI. Kobe. ** Borland, M., elegant: A Flexible SDDS-Compliant Code for Accelerator Simulation.
One of the limiting factors of electron beam lifetime in low emittance storage rings is Head-Tail (HT) instability. All the storage rings typically have a large negative natural chromaticity due to the strong quadrupoles. Large negative natural chromaticity leads to large tune shift and Head-Tail instability, which both of them limit the beam lifetime. Since Threshold current of HT instability is directly related to linear chromaticity, Increasing the linear chromaticity to slightly positive value is a solution to prevent HT instability. In order to investigate the beam dynamics of Iranian Light Source Facility (ILSF) storage ring in high chromaticity, we have studied a high chromaticity optics for ILSF 3GeV storage ring lattice. For reaching this aim we have used two families of sextupoles for chromaticity correction and then optimized them to maximize the dynamic aperture and Touschek lifetime. The beam dynamics of high chromaticity lattice is presented and we have compared some of the results of high chromaticity lattice with the design lattice.

**Design of Beam Position Monitoring System for IPM Low Energy Electron Linac**

A beam position monitor (BPM) is a common device used in particle accelerators to measure the position of a beam of charged-particles. The goal of this project is to simulate and build prototype of different parts to be used for IPM low energy electron Linac being developed at Institute for Research in Fundamental Sciences. The IPM low energy electron Linac will initially be operated at a 7μsec pulse duration and 250 Hz repetition rate with 2.998 GHz bunching frequency. A 4.5-MeV electron beam will be available in the second phase of
commissioning. The device is composed of two pickup S-band cavities and a detection circuit to read out the electron beam’s position. The electrode pickup sensors will sense the mode strength generated by the passing beam of electrons. The working modes are TM110 (dipole) for the so called position cavity and TM010 (monopole) for the reference cavity. When the beam crosses the two cavity gaps it induces signals proportional to the product of charge and position offset in the position cavity, and to the charge only in the reference cavity. The position cavity has four rectangular waveguides that couple to the dipole mode while rejecting the monopole mode that would otherwise limit the resolution of the electronics. This signal will be input to a detection circuit that will be used to calculate the signals detected by four antennas arranged. A 180 degree hybrid at the first stage reduce the monopole and a heterodyne receiver principle was used to down-convert the signal frequency in about MHz IF frequency. These signals can then be used to determine the beam’s displacement from the center.

**The Hybrid Method for Production Mo-99 Isotope Using High Power Linac**

A. Taghibi Khotbeh-Sara, F. Rahmani (KNTU) F. Ghasemi (NSTRI) H. Khalafi (AEOI) M. Mohseni Kejani (Shahid Beheshti University)

The radionuclide 99mTc, is the most used radiopharmaceutical in the diagnostic nuclear medicine. Recent interruption in operation of supplier reactors or retirement of aged ones (such as NRU reactor, the last major producer) caused a shortage in 99Mo isotope supply. Therefore, the alternative production methods, especially non-reactor based methods have been on progress. In this study, the idea of production of 99Mo radioisotope (the mother nucleus of 99mTc) using high energy and high power electron Linac has been discussed. Two different main production channels: 100Mo(γ,n)99Mo and 98Mo(n,γ)99Mo can be used in production. By considering 30 MeV electron beam with 1 mA average beam current, using 100Mo(γ,n)99Mo reaction in the optimized 100Mo target, it is predicted considerable activity can be achieved in this way. Threshold of this reaction is about 8 MeV, so the large number of produced bremsstrahlung photons cannot participate in this reaction. In other hand, threshold of photoneutron
reaction in deuteron nuclide is about 2.45 MeV that is partly low. Therefore, enough low energy photons and subsequently neutrons flux is available using high power electron beam. Heavy water known as a proper neutron moderator, so we propose the use of low energy photons in a heavy water tank that can be located beside the 100Mo target to increase the production yield using neutron absorption reaction in 98Mo.

Ultra high-gradient accelerating structures are in strong demand for the next generation of compact light sources. In the framework of the Compact Light XLS project, we are studying a high harmonic traveling-wave accelerating structure operating at a frequency of 35.982 GHz, in order to linearize the longitudinal space phase. In this paper, we propose a new analytical approach for the estimation of the group velocity in the structure and we compare it with numerical electromagnetic simulations that are carried out by using the code HFSS in the frequency domain.

**Simulation of the Transition Radiation Transport Through an Optic System**

Optical Transition Radiation (OTR) screens are widely used for beam profile measurements. The radiation is emitted when a charged particle beam crosses the boundary between two media with different optical properties. The main advantages of OTR are the instantaneous emission process allowing fast single shot measurements (i.e. bunch by bunch measurements in a multi bunch machine), and the good linearity with the beam
charge (if coherent effects can be neglected). Furthermore, OTR angular distribution strongly depends on beam energy. Since OTR screens are typically placed in several positions along the Linac to monitor beam envelope, one may perform a distributed energy measurement along the machine: this will be useful, for instance, during the commissioning phase of a machine. This paper deals with the studies of an algorithm to generate and transport the transition radiation through an optic system using a simulation tool like Zemax. The algorithm, in combination with a particle tracking code (i.e. Elegant), will allow to simulate the radiation generated by a beam and, so, to take into account beam divergence and energy spread or chromatic effects in the optic system.

High Level Software for Beam 6D Phase Space and Trajectory Characterization

V. Martinelli, D. Alesini, A. Gribono, S. Pioli, C. Vaccarezza, A. Variola (INFN/LNF)

Operation of modern particle accelerators require high density and sensitive diagnostic system in order to monitories and characterize the beam during the acceleration and transport. A turn-key high level software has been designed to fully characterise the 6D beam phase space and the trajectory in order to help operator during commissioning with an easily scalable suite for any high brightness LINAC. In this work will be presented the high level software designed for the ELI-NP Gamma Beam System (GBS) providing tunable gamma rays with narrow bandwidth (0.3%) and a high spectral density ($10^4$ photons/sec/eV) by the Compton backscattering effect. Currently the diagnostic tool interfaced with EPICS control system, manages automatically accelerator devices to allow electron beam diagnostic measurements. Simulation of raw data of the ELI-NP-GBS accelerator affected by misalignments, jitter and magnetic errors has been used to test the sensitivities of the diagnostic tool. Such simulation has been performed for the injector, with ASTRA tracking code, to get RF-gun energy measurements. While booster and transfer lines tolerances have been investigated with Elegant suit to get measurement of Beam Energy (using dipole magnet as spectrometer), beam length (using the Radio Frequency Deflector (RFD)), longitudinal phase space (using both RFD and
dipole) and beam emittance (using the quadrupole scan technique). The diagnostic tool is part of BOLINA (Beam Orbit for LINAC Accelerators) suits that provides the simultaneous optimization of trajectory, dispersion and final focus at the interaction point granting the beam trajectory which reduces the emittance dilution through the accelerator to reach accelerator's nominal parameters needed to maximize the luminosity.

Local power distribution system (LPDS) of International Linear Collider (ILC) can transmit RF power from 10 MW klystron to cavity. The basic model of LPDS has already discussed in ILC technical design report. More compact LPDS is expected to solve assembled difficulty and decrease finance cost. Due to the different required power of each cavity, the variable hybrid is used to adjust the power distributed ratio and the variable phase shifter is used to compensate the phase drift caused by the variable hybrid. Margin of power ratio and phase range is expected to be ±20% which means the transmitted power ratio is from -0.60 dB to -4.00 dB and the coupling power ratio is from -2.00 dB to -9.00 dB for hybrid, and the phase range is ±50° for phase shifter. We redesign the variable hybrid and phase shifter to meet these parameter. Measured data is satisfied to the simulation and VSWR is less than 1.1. More compact LPDS is modeled based on these new RF component.

Analysis and Correction for the Effect of Multipoles with Skewed Errors on IP Beam Dynamics in SuperKEKB

The beam dynamics at the interaction point (IP) in the accelerators which has the nano-beam scheme like as SuperKEKB is extremely sensitive for skewed error of final focusing magnets (QCS). As proceeding the beta squeezing in the interaction region (IR), the effect of optics
aberrations at IP is enhanced. In the SuperKEKB Phase-2 commissioning, there was the problem come from skewed quadrupole fields in IR. The dominant skew parameters "R" for this problem is very hard to see directly by using beam position monitors, thus it was corrected by scanning R parameters. In the next commissioning Phase-3 which is just before the operation with the Belle II experiment, it is planned that the IP beta squeezing is going forward to design parameters which is smaller than it achieved in Phase-2 by the factor of 4 (for horizontal beta) and 10 (for vertical beta). Hence the effect of skew error will be considerable larger and it is estimated that skew sextupoles will emerge as a serious cause for the aberration from the orbit. This report is the study of analysis and correction results for the effect of QCS skewed errors in the SuperKEKB commissioning.

Longitudinal-Phase-Space Manipulation for Efficient Beam-Driven Structure Wakefield Acceleration

W. Tan, P. Piot (Northern Illinois University) P. Piot (Fermilab) A. Zholents, A. Zholents (ANL)

Beam-driven structure wakefield acceleration (SWFA) is an advanced acceleration technique that can provide a compact, high repetition rate, high current, and high energy beam to drive a future free-electron-laser x-ray light source *. Producing an ideal shaped driver beam through phase space manipulation is crucial for an efficient SFWA. Here we report our recent effort in the beam dynamics studies of driver beam longitudinal-phase-space manipulation. This paper describes the preliminary design of longitudinal-phase-space manipulation beamlines used to produce an optimized driver beam for SWFA. Simple analytical models and simulation results are presented, with both forward and backward tracking techniques are employed to guide our studies. This paper also highlights the future plan of expanding our studies to the beam stability in transverse dynamics.

* A. Zholents, et al., Dielectric wakefield accelerator to drive the future FEL light source

Funding: This work is funded by the United States Department of Energy awards DE-SC0018656 with Northern Illinois University and DE-AC02-06CH11357 with Argonne National Laboratory.
An inter-digital H-mode drift-tube linac (IH-DTL) is developed in a muon linac at the J-PARC muon g-2/EDM experiment. In order to perform the experimental requirement of a small transverse divergence angle of $10^{-5}$, a muon must be accelerated to a kinetic energy of 212 MeV, without the emittance growth. IH-DTL will accelerate muons from 0.34 MeV to 4.5 MeV at an operational frequency of 324 MHz. Since IH-DTL adopts the APF method, with which the beam is focused in the transverse direction using the rf field only, the proper beam matching of the phase-space distribution is required before the injection into the IH-DTL. Therefore, an IH-DTL prototype was designed and fabricated to evaluate the performance of the cavity. We conducted the bead-pull measurement for a low-power and confirmed that the prototype was fabricated as we designed. Moreover, as a preparation of the high-power test, tuners and rf coupler are designed and fabricated. In this paper, the results of the low-power measurement for the prototype cavity and the detailed simulation of the tuner and the coupler will be presented.

**Funding:** This work is supported by JSPS KAKENHI Grant Numbers JP15H03666, JP18H03707, JP16H03987, and JP16J07784.
Beam Control and Monitors for the Spiral Injection Test Experiment

M.A. Rehman (Sokendai) K. Furukawa, H. Hisamatsu, T. Mibe, H. Nakayama, S. Ohsawa (KEK) H. Iinuma (Ibaraki University)

A new experiment at J-PARC (E34) is under construction in order to measure the muon’s g-2 to unprecedented precision of 0.1 ppm and electric dipole moment up to the sensitivity of $10^{-21}$ e.cm in order to explore new physics beyond the standard model. A novel three-dimensional spiral injection scheme has been devised to inject and store the beam into a small diameter MRI-type storage magnet for E34. The new injection scheme features smooth injection with high storage efficiency for the compact storage magnet. However, spiral injection scheme is an unproven idea, therefore, a Spiral Injection Test Experiment (SITE) is underway to establish this injection scheme. The SITE is consist of 80 keV thermionic electron gun, two-meter-long beamline, and a solenoidal storage magnet. In order to match the beam with the solenoidal field, several optical elements have been placed on the beamline to control the beam phase space. The DC electron beam spiral track has been confirmed by the de-excitation of the nitrogen gas in the vacuum chamber of the storage magnet. A current monitor system has been developed in order to extract the beam current and geometrical information of three-dimensional trajectory. An electric chopper system to produce the pulsed beam and beam monitors to detect the pulsed beam will also be discussed in this paper.
Development of a variable polarized THz light source using a crossed undulator system has been carried out at Research Center for Electron Photon Science (ELPH), Tohoku University.

The proposed light source is composed of horizontal and vertical planar undulators arranged in series and an optical phase shifter between them. Two linearly polarized coherent radiations in THz region are generated from an extremely short electron bunch of approximately 100 fs. They are superimposed in both temporally and spatially by delaying the first radiation in the phase shifter. Polarization can be controlled by adjusting the optical path length in the phase shifter so as to change the phase difference. Optical path length from each undulator to an observation point as well as wavelength of undulator radiation has angular dependence in this configuration. Polarization of the crossed undulator radiation is dependent on observation angle and therefore ideal polarization control can be realized only in the central part. Analytical discussion of such polarization properties and a design of the crossed undulator system for a demonstration experiment at ELPH will be shown in this presentation.

Multi-Ribbon Profile Monitor for High Power Proton Beam at J-Parc MR Abort Line

J-PARC Main Ring (MR), the world-class high intensity proton synchrotron, provides proton beam to two experimental facilities with two extraction modes: Fast extraction (FX) and Slow extraction (SX). The number of protons in FX records $2.6 \times 10^{14}$ protons per pulse (ppp) and MR has an upgrade plan for
improving power to 1.3 MW with $3.3 \times 10^{14}$ ppp. One of the main issues in the upgrade plan is the beam loss caused by betatron resonances. Hence beam profile information is important to discuss its beam dynamics. However, the profile monitor in the ring destructs the circulating beam by the interaction and leads another beam loss. In MR, a beam circulates $3 \times 10^5$ turns in FX operation. Therefore, profile monitor is needed to install except at circulating orbit for its durability and measurement accuracy. Another concern in beam operation is how figure out the beam emittance not only at injection, but also during acceleration. These points lead the motivation for installation of new emittance observing system at Abort Line: the beam line which transports extracted beam to beam dump safely. The system consists of the Fast extraction system in arbitrary energy, new Multi-ribbon profile monitor (MRPM) and Abort Quadrupole doublet (Abort Q). Performing the single-pass profiling with MRPM and changing the transfer matrix by sweeping field strength of Abort Q, the emittance of the extracted beam will be observed. We will perform beam study in 2019 and discuss the high-intensity beam properties.

### Alumina Capillary Compact Microwave Ion Source

**Y. Shimabukuro, F. Ikemoto, M. Wada, I. Yamada (Doshisha University, Graduate School of Engineering)**

We have been developing a novel fragmentation technique to determine unknown primary biomolecular structures by mass analyzing the cracking pattern of the target molecule through fragmentation induced by atom injection. Our LICP (Locally Inductively Coupled Plasma) source employs completely electrodeless configuration under vacuum condition to prevent contaminant emission from the parts to exposed to the plasma. A 2.45 GHz microwave power induces the microwave to a 0.3 mm thick copper spiral antenna wound around a quarter inch alumina tube through which the supply gas is injected. The input power up to 50 W excites a plasma in the tube stably. Toroidal permanent magnets arranged outside of the antenna assist ignition and sustain LICP with electron cyclotron resonance. An optical emission spectrum of hydrogen LICP shows a high atomic fraction with the intensity two orders of magnitude higher than those of excited molecules in the Fulcher band. The high degree
of dissociation plasma source should have a potential application to a proton beam source. In this paper, selected ion species ratio by magnetic mass analyzer extracted from a high atomic ratio plasma source are discussed.

A Bunch Structure Measurement of Muons Accelerated by RFQ Using a Longitudinal Beam-Profile Monitor With High Time-Resolution

J-PARC E34 experiment intends to measure the anomalous magnetic moment and electric dipole moment of muon precisely by a different way from the previous experiment. In this experiment, a low-emittance muon beam is provided using the muons with the thermal energy and the four-stage linac. The demonstration of the first muon RF acceleration with an RFQ linac was conducted and the transverse profile of the accelerated muons was measured last year. As one of the remaining issues for the beam-diagnostic system, the longitudinal beam profile after the RFQ should be measured to match the profile to the designed acceptance of the subsequent accelerator. For this purpose, the new longitudinal beam monitor using the micro-channel plate is under development. The time resolution aims to be around 30 to 40 ps corresponding to 1 % of a period of an operation frequency of the accelerator, which is 324 MHz. On November 2018, the bunch structure of accelerated muons of 89 keV with the RFQ was measured using this monitor at the J-PARC MLF. The latest analysis result of this measurement will be reported in this poster.

Funding: This work is supported by JSPS KAKENHI Grant Numbers JP15H03666, JP15H05742, JP16H03987, JP16J07784, JP18H03707 and JP18H05226.

Y. Sue, K. Inami (Nagoya University, Graduate School of Science) K. Futatsukawa, N. Kawamura, T. Mibe, Y. Miyake, M. Otani, T. Yamazaki (KEK) K. Hasegawa, R. Kitamura, T. Morishita (JAEA/J-PARC) T. Iijima (KMI) H. Inuma, Y. Nakazawa (Ibaraki University) K. Ishida (RIKEN Nishina Center) Y. Kondo (JAEA) N. Saito (J-PARC, KEK & JAEA) Y. Takeuchi (Kyoto ICR) T. Ushizawa (Sokendai) H.Y. Yasuda (University of Tokyo) M. Yotsuzuka (Nagoya University)
Simulations and Experimental Plans for a High-Repetition-Rate Field-Enhanced Conduction-Cooled Superconducting RF Electron Source


We present a novel RF design for a field enhanced electron source driven by field emission cathodes. The proposed electron source relies on the enhanced high electric field gradients at the cathode to simultaneously extract and accelerate electrons. The system will be tested in a conduction-cooled superconducting radiofrequency cavity recently demonstrated at Fermilab. In this paper, we present beam-dynamics simulations of the setup that support the feasibility of the design. We discuss our experimental plans together with the applications of the formed electron beam.

Funding: Work supported by DOE awards DE-SC0018367 with NIU and DE-AC02-07CH11359 with Fermilab.

Bypass Design for Testing Optical Stochastic Cooling at the Cornell Electron Storage Ring (CESR)

W.F. Bergan, M.B. Andorf, M.P. Ehrlichman, V. Khachatryan, D. L. Rubin, S. Wang (Cornell University (CLASSE), Cornell Laboratory for Accelerator-Based Sciences and Education)

Optical Stochastic Cooling (OSC) is a promising method for cooling very dense stored particle beams through the interference of radiation created in an upstream ‘pickup’ undulator and a downstream ‘kicker’ undulator. By correlating a particle’s path length via a bypass chicane between the two undulators with its betatron coordinates in the pickup, the particle will receive a kick in energy which, through coupling introduced by non-zero horizontal dispersion in the kicker, can reduce its betatron amplitude, thus cooling the beam. A proof-of-principle test of this technique is being planned at the Cornell Electron Storage Ring (CESR). In addition to maintaining standard requirements such as a large dynamic aperture and acceptable lattice functions throughout the ring, the design of the bypass is guided by the mutually
competing goals of maximizing the cooling rate while maintaining a sufficiently large cooling acceptance with properly-corrected nonlinearities. We present a design of such a bypass and ring optics so as to best achieve these objectives.

**Funding:** NSF-1734189 DGE-1650441

---

**Development of a Gas Distribution Measuring System for Gas Sheet Beam Profile Monitor**

The beam profile monitor is needed for measuring one of the beam parameters of high intensity accelerator to avoid radioactivating the systems. A monitor with sheet-shaped gas that can measure the beam profile nondestructively in two dimensions is developing. One of issues to introduce the monitor in accelerator is that the gas distribution is not uniform. Obtaining correct beam profile data needs to measure the gas distribution data because signal from the monitor is in proportion to beam intensity and gas distribution. A system analyzing distribution of ions produced from the gas using electron beam to measuring gas distribution in three dimensions is developing. An electron gun that produces ideal narrow beam, electrodes that forms parallel electric field toward micro-channel plate (MCP), and phosphor constitute the system. The electron beam that ionizes the gas which needs to be measured, produced ions are induced to MCP, and image on phosphor gives gas distribution data. In preliminary experiment for inspecting the measuring principle, experimental results agreed with simulation. The details of this system and the results of gas measuring experiment are reported.

**I. Yamada** (Doshisha University, Graduate School of Engineering) Y. Hikichi, J. Kamiya, M. Kinsho (JAEA/J-PARC) N. Ogiwara (J-PARC, KEK & JAEA)
Muon linac is developed for the muon g-2/EDM experiment at J-PARC. In this experiment, ultra slow muon is accelerated to a momentum of 300 MeV/c with the four linac structures. This scheme offers new opportunity for precise measurements; it enables us to reverse muon polarization at early stage of acceleration. The reversal of polarization is a common method of precision polarization measurements as it can be used to identify or reduce systematic uncertainties dependent on time. It is necessary to accelerate muons and flip its spin without substantial emittance growth for the experimental requirement. As one of the candidates for our spin rotator, we are developing the Wien-filter type. In this poster, the design of the Wien-filter type spin rotator for the low emittance muon beam will be presented.

Funding: This work was supported by JSPS KAKENHI Grant Numbers JP18J22129, JP18H03707.

Tune Shifts and Optics Modulations in the High Intensity Operation at J-PARC MR

J-PARC Main Ring (MR) is the intensity-frontier proton accelerator. The beam intensity of $2.6 \times 10^{14}$ protons per pulse has been achieved for the current user operation. In this high-intensity operation, the tune spread caused by the space-charge is one of the main reasons for beam loss. The modulation of the betatron function and the tune shift were simulated with a PIC algorithm calculation code*. The simulation results showed that the space-charge effects were dominant in small particle action, and the sextupole fields effects were dominant in large particle action. Because sextupole strength is large in MR, sextupole fields induce substantial
tune shifts. At the benchmark of the space-charge simulation, the simulation results matched the analytical space-charge calculations performed without sextupoles. It was found that the betatron function was modulated at most 6% by the space-charge effects and at most 8% by the effects of sextupoles in J-PARC MR. These effects to the injection beam optics matching and to the beam aperture will be investigated.


**Funding:** This study is supported by the MEXT program "Advanced Leading Graduate Course for Photon Science (ALPS)"

---

**Performance of the Longitudinal Beam Monitor With High Time Resolution for a Muon Linac in the J-PARC E34 Experiment**

The J-PARC E34 experiment aims to measure the muon anomalous magnetic moment and the electric dipole moment with a high precision. In this experiment, ultra-slow muons generated from thermal muonium production and laser resonance ionization are accelerated in a multistage muon linac. In order to satisfy the experimental requirements, a suppression of the emittance growth between different accelerating cavities is necessary, and the transverse and longitudinal beam matching is important. Longitudinal beam monitor has to measure the bunch width with a precision of 1% corresponding to several tens of picoseconds. In addition, the beam monitor should be sensitive to a single muon, because the beam intensity during the commissioning is lower than the designed intensity. Therefore, we are developing a longitudinal beam monitor...
monitor using a microchannel plate (MCP), and a measurement system using photoelectrons to estimate the performance of the beam monitor. On November 2018, the beam monitor has been successfully used in the muon RF acceleration test at the J-PARC. In this presentation, the results of the performance evaluation for this beam monitor are reported.

Funding: This work is supported by JSPS KAKENHI Grant Numbers JP15H03666, JP15H05742, JP16H03987, JP16J07784, JP18H03707 and JP18H05226.

Operational Results of LHC Collimator Alignment Using Machine Learning

G. Azzopardi, A. Muscat, G. Valentino (University of Malta, Information and Communication Technology) S. Redaelli, B. Salvachua (CERN)

A complex collimation system is set up in the Large Hadron Collider (LHC) to protect sensitive equipment from unavoidable beam losses. The collimators are positioned close to the beam in the form of a hierarchy, which is guaranteed by precisely aligning each collimator with a precision of a few tens of micrometers. During past years, collimator alignments were performed semi-automatically*, such that collimation experts had to be present to oversee and control the alignment. In 2018, machine learning was introduced to develop a new fully-automatic alignment tool, and this new tool was used for collimator alignments throughout the year. This paper discusses how machine learning was used to automate the alignment, whilst focusing on the operational results obtained when testing the new software in the LHC. Automatically aligning the collimators requires no human intervention, thus decreasing the alignment time by a factor of three and making the results more reproducible, which are both particularly important when performing angular alignments**.

The ultrafast electron microscopy (UEM) is a useful tool for exploring fine structure and observing dynamic process at nanometer and picosecond scale, which is widely used in chemistry and biological field. It consists of many parts such as electron sources, sample plane, imaging system, vacuum system. The imaging system is one of the most important part for UEM, because it decides space and time resolution of the image projecting on the screen after magnification, which would present the details of samples. In this paper, a three lens imaging system is used which includes an object lens, an intermediate lens and a projection lens. The goal space resolution of the system is about 1 nm.

**Noise Analysis in Linear Systems with Applications to Accelerator Physics**

In this paper, we present a general framework of noise analysis in linear systems with applications to accelerator physics. Different noises like quantum excitation, RF noise and intra-beam scattering can be treated the same way on equal footing. A numerical code is developed based on the formalism with which some noises analysis for a new light source concept called steady state microbunching (SSMB) is conducted.

**Rainforcement-Learning Based Compensation-Rematch for Linear Accelerators**

In recent years, many effective researches have been done on reinforcement-learning and other artificial intelligence algorithms. The application of reinforcement-learning (RL) for failure-compensation in the superconducting linac is initiatively implemented to meet the extremely high reliability requirement of ADS driven linac. The scheme mainly
consists of RL-based model training in virtual linac, stable beam-operation oriented strategy optimization and data base built including cavity-failure cases. The automatic and feasible compensation scheme is studied and applied in China initiative Accelerator System linac. The study and results is described detailly in the paper.

X.Q. Ge, Y. Wang (USTC/NSRL) The new generation of accelerators places higher demands on the surfaces of vacuum chamber materials. For modern and future cyclic accelerators, especially high-intensity proton synchrotrons or colliders, the electronic cloud effect is a key issue. Therefore, the search for low secondary electron yield materials and an effective vacuum chamber surface treatment process are important early work for the new generation of accelerators. In this article, we studied the SEY characteristics of Ti-Zr-Hf-V NEG films and Ti-Zr-V NEG films which were deposited on Si (111) substrates using direct current magnetron sputtering. The surface morphology and surface chemical bonding information were revealed by scanning electron microscopy (SEM) and Synchrotron Radiation X-ray photoelectron spectroscopy (SRXPS). With the same parameters, the maximum SEY of Ti-Zr-Hf-V NEG films and Ti-Zr-V NEG films are 1.24 and 1.51, respectively. These results are of great significance for the next-generation particle accelerators.

Stimulated Excitation by Seed of Wakefield in an Open Resonator

S.M. Jiang, Z.G. He, Q.K. Jia, W.W. Li, Wang, W.X. Wang, Z. Zhao (USTC/NSRL) By seed of narrow-band wakefield from a dielectric loaded waveguide, stimulated excitation of an optical cavity is shown by the method of theory and numerical calculation. In this scheme, the wakefield is excited by the relativistic electron bunch with low repetition rate and enhance the high order mode in the open resonator. The results show that narrow band radiation with high power can be export from
the resonator and it also has the potential to be expanded into the terahertz spectrum.

Funding: This research was funded by National Foundation of Natural Sciences of China (11705198, 11775216, 11675178, 11611140102).

Proton beam with different energies less than 10 MeV, <1% energy spread, several to tens of pC charge can be stably produced and transported in Compact LAser Plasma Accelerator (CLAPA) at Peking University. Combined with the Beamline, the primary application experiments have been carried out, including irradiating semiconductor sensors for simulation of space irradiation environment, irradiating biological cells for the next step of proton radiotherapy and systematic study of proton radiograph with various proton parameters. Laser-accelerated proton beam has also been used for stress testing for tungsten, which is usually used in harsh conditions. With the plasma lens created by a deliberately introduced ps pre-pulse and the microstructure targets manufactured by laser machining, the proton beam quality has also been improved to higher charge and more homogeneous spatial profile. It is important for the applications of laser-driven proton beam such as cancer therapy and generation of warm dense matter.

Experiments of Double-Frequency and Three-Frequency Heating in SECRAL II

SECRAL II is a third generation fully superconducting ECRIS (electron cyclotron resonance ion source) and nearly a duplicated one of SECRAL. When the microwave frequency is equal to the Lamo frequency of the electron in the magnetic field, the electron resonance will absorb energy greatly from the microwave, and then collide with the neutral atom to ionize it to produce the plasma. Due to its high working frequency and multi frequency heating, many good results had been obtained as 6000euA O$^{6+}$, 610euA Ar$^{16+}$, 14.5euA Ar$^{18+}$, 7euA Kr$^{31+}$, 870euA Xe$^{27+}$ and 1.3euA...
Xe\textsuperscript{45+}. In order to explore the effect of magnetic field on high-charge ions under multi-frequency heating, experiments were carried out under microwave waves of 18+28GHz, 28+45GHz and 18+28+45GHz.

**Design of a MeV Ultrafast Electron Diffraction Based on 1.4 Cell RF Gun**

J.J. Li, K. Fan, P. Yang, Y.T. Yang (HUST) Ultrafast Electron Diffraction (UED) is a powerful tool to investigate the dynamic structure with the time scale of 100 femtosecond and the spatial scale of atomic length. To achieve good diffraction patterns, space charge effect should be overcome, which means shorter bunch length and lower emittance. MeV UED, using RF gun instead of traditional DC gun, is developed to provide high quality electron bunches. We design a MeV UED based on a 1.4 cell photocathode RF gun which can provide high acceleration gradient. In this paper, the layout design of the MeV UED is proposed with parameters of the system, as well as the ASTRA simulation results of optimization aimed at low emittance.

**A New Development in Coherent Pulse Stacking That Produces Highly Stable Linearly Polarized Variable Picosecond Laser Pulses for High Brightness Electron Bunches**

F.M. Liu, S. Huang, K.X. Liu (PKU) S. Zhang (JLab) We report the study and experimental demonstration of a new variable temporal shaping method capable of generating linearly polarized picosecond laser pulses with basically any predefined shapes including symmetric intensity distributions such as parabolic, flattop, elliptical shapes, as well as non-symmetric distributions such as sawtooth shapes, etc., which are highly desired by various applications including low emittance high brightness electron bunch generation in photocathode guns. It is found that both high transmittance and high stability of the shaped pulse can be achieved simultaneously when crystals are set at a specific phase delay through the fine control of the crystal temperature. Such variable temporal shaping technique may lead to new opportunities for many potential applications over a wide range
A Design of a C-Band High-Efficiency Multi-Beam Klystron

A 32-beam klystron working at 5.712 GHz has been designed with efficiency of 70% and output power of about 3.44 MW. Core oscillations method (COM) is chosen to bunch the electrons. The code KlyC is used for 2D design and a series of parameters are given after optimizing, including the position, frequency, R/Q, Q0 and Qe of the cavities. CST-PIC is used to make the final design and coaxial cavities are used. This paper describes the beam dynamics design of the klystron and the analysis of the effect of magnetic fields on efficiency.

The Dependence of Wakefield Suppression on the HOM Load in the Main Linac of the Klystron-Based First Stage of CLIC at 380 GeV

An alternative klystron-based scenario for the first stage of Compact Linear Collider (CLIC) at 380 GeV center-of-mass energy was proposed. To preserve the stability and luminosity of beams in CLIC, the long-range transverse wakefield in main linac must be suppressed to an acceptable value. The high-order-mode (HOM) damping load has been designed to provide broad-band absorption to the dipole modes. In this paper, the dependences of wakefield suppression on the material properties and length of HOM load based on the are presented.
Design of Fast Corrector Magnet Power Supply for HEPS

High energy photon source is a fourth-generation synchrotron radiation light source with energy of 6 GeV and ultra-low emittance (<0.1 nm/ rad). The ultra-low beam emittance requires high beam stability. Therefore, we develop a fast correction power supply with high bandwidth and low current ripple to improve the performance of the fast close orbit correction system to prove the high beam stability. The power supply adopts FPGA for full-digital control and use high speed ADC and self-developed high precision DCCT for current feedback control. The ADC system has temperature control and the temperature variation could be controlled lower than ±0.1°C. The DCCT has a small signal bandwidth of 300 kHz. The power supply has a small signal bandwidth of 10 kHz and output current ripple could be lower than 18 ppm. In this paper, we will describe the hardware design and software control methods and the test results will be demonstrated.

Microphonics Simulation and Parameters Design of the SRF Cavities for CiADS

J.Y. Ma (IMP/CAS) The CiADS proton linac is designed to accelerate CW beams of up to 500 MeV and 5 mA. Since the beam power will eventually reach 2.5 MW, the beam loss should be restricted, which is sensitive to the SC cavity stability. On CW operating mode, the main perturbation to the cavity is microphonics. This paper will describe a set of tools to simulate performance of the cavity and its LLRF control system in order to ensure proper cavity operation under microphonics. The simulation tools describes a relationship between microphonics and the RF parameters. The microphonics affection to the cavity and the response of the LLRF system is traced. The basic parameters of RF system are optimized, to make the tradeoff between the cost of RF power and the requirements of the cavity stability. The tolerated intensity of microphonics is determined by simulation, In order to satisfy the stability of amplitude and phase with 0.1% and 0.1 degree respectively.
The Beam Dynamics Design of the Proton Synchrotron Linear Injector for Proton Therapy

J. Qiao, Y.H. Pu, X.C. Xie (SINAP)

A compact room-temperature injector is designed to accelerated 20 mA proton beam from 30 keV TO 7.0 MeV for the purpose of the Proton Synchrotron Linear Injector for Proton Therapy. The main feature of this linac injector is that the Radio Frequency Quadrupole (RFQ) and the Drift Tube Linac (DTL) section are merged in one 3.9 m cavity in total. The beam is matched from the first RFQ section to the second DTL section in traverse and longitudinal directions. This design has reached a higher average accelerating gradient up to 1.7 MV/m with transmission efficiency of 96%. This injector combines a 3 m long 4-vane RFQ from 30 keV to 3.0 MeV with a 0.9 m long H-type DTL section to 7.0 MeV. In general, the design meet the requirements of the Proton Synchrotron and the Terminal treatment.

Research Progress of Power Supply System in HALS

Z.X. Shao, H. Gao, L. Wang, H.Y. Zhang (USTC/NSRL)

HALS is the fourth generation light source in China’s planning and construction. In order to achieve the diffraction limit of the emission and improve the beam quality, the research on magnet power supply (MPS) technology is essential. We have designed a variety of solutions for different power supplies. Our pre-research system has developed a correction magnet power supply with a small signal response bandwidth higher than 5 kHz. The developed power prototypes all use self-developed controllers, and the test results can meet the requirements. In order to achieve long-term current stability of less than 10ppm, we also investigated and tried some high-precision power supply solutions. This article describes the progress of the HALS power supply system Funding: Supported by the Hefei Advanced Light Source Pre-research Project.
Recent research indicates that ultrafast electron diffraction and microscopy (UED/M) have unprecedented potential in probing ultrafast dynamic processes, especially in organic and biological materials. However, reaching the required brightness while maintaining good beam quality for high spatiotemporal resolution requires new design of electron source. In order to produce ultrashort electron beam with extreme high quality, a 1.4 cell RF gun is being developed to reach higher acceleration gradient near the photocathode and thus suppress the space charge effect in the low energy region. Simulation of the 1.4 cell RF photocathode gun shows considerable improvement in bunch length, emittance and energy spread, which all lead to better temporal and spatial resolution comparing to traditional 1.6 cell RF photocathode gun. The results demonstrate the feasibility of sub-ps temporal resolution while maintaining 1pC electron pulse.

**Preliminary Research of HOM for 100MHz Superconducting Cavity in HALS**

A 100MHz QWR cavity may be used in Hefei Advanced Light Source (HALS). HALS is a diffraction limited storage ring. Higher order modes damping is a big challenge for achieving good light source performance. In this paper, we first apply the choke-mode damped structure to the 100MHz QWR cavity in order to damping the HOM. We study the HOM in the QWR cavity and obtain the parameters of the main harmful higher order modes. The broad-band HOM impedance spectrum of the cavity was evaluated by calculating the beam induced wake potential in time domain and applying a Fourier Transform. The results show that choke-mode damped structure has a good HOM damping effect on the QWR cavity.
The electronic cloud problem is an urgent problem for the new generation of accelerators. Reducing secondary electron yield (SEY) is a very effective way to solve the electronic cloud problem. At present, there are many methods for reducing the secondary electron yield, for example, coating a low SEY film (carbon film) on the surface of a vacuum chamber, adding a weak trapping magnetic field (20 Gauss) outside the vacuum chamber, and the like. The author of the article uses laser etching to treat the surface of copper, which is commonly used in accelerator vacuum chambers, and the secondary electron yield on the surface of the material is reduced after treatment.

**Generation of Two Color Terahertz Radiation Pulses With Continuously Tunable Frequency and Time Delay**

We propose to generate two color narrow band terahertz pulses radiated from two temporally modulated relativistic electron beams. The frequencies of the two terahertz pulses can be independently tuned by adjusting the bunching frequencies of the two pre-bunched electron beams through a pair of temporally shaped photo-cathode drive lasers at separate repeat frequencies. We modulate the temporal profile of the drive laser by means of two-way chirped pulses beating technique which allows the continuously change of the time delay between the two color terahertz pulses. Particle tracking simulation and analysis show that the frequency tuning range of two color terahertz pulses is within 0.5~5.0 THz and the time delay is between several pico-seconds.

We report that using femtosecond prepulse can improve the cutoff energy of protons significantly. It is demonstrated that an intensity-adjustable prepulse with ultrashort duration of 33fs before the ultraintense laser-interaction with CH targets on the Compact Laser Plasma Accelerator at Peking University. Both of the prepulse and main pulse were aligned well focused onto targets at normal incidence by an f/3.75 off-axis parabola. Targets with different thicknesses were studied by varying the intensity of prepulse. The results show that a significant enhancement can be observed when the intensity of prepulse is optimal using um-scale-thickness CH targets. PIC simulations reveal that the preplasma generated by fs prepulse increase the absorption of main laser.

Diffusion map Analysis in High Energy Storage Ring Based e⁺/e⁻ Collider

J. Wu, Q. Qin, Y. Zhang (IHEP) J. Wu, Y. Zhang (University of Chinese Academy of Sciences)

In a very high energy e⁺/e⁻ storage ring collider, e.g. Circular Electron Positron Collider (CEPC), the dynamic aperture is limited by the strong synchrotron radiation especially in the vertical direction. Some tracking results also shows that the beam lifetime does not correspond well to the dynamic aperture. Here we develop a method called diffusion map analysis, aiming to describe the beam distribution diffusion in transverse amplitude space by tracking less turns. The diffusion may come from quantum fluctuation of SR, beamstrahlung effect and nonlinearity. Comparing cases with different configuration of sextupoles, the diffusion map analysis presents good consistency with beam lifetime that needs much more turns of tracking. Constraints based on the diffusion map is applied to our dynamic aperture optimization, which could help us achieve enough long beam lifetime.
Magnetic Alloy Cavity Design and Simulation for Csns Upgrade Project

The dual harmonic RF system will be adopted to increase the bunch factor in order to promote the beam power up to 500kW for China Spallation Neutron Source upgrade in the future. Up to now eight fundamental RF cavities loaded by ferrite run well in CSNS RCS and limited locations are reserved to install additional three second harmonic cavities. Due to the finite space of CSNS ring tunnel the cavity loaded by magnetic alloy (MA) material have to be adopted. MA material have the advantages of high accelerating gradient, high saturation flux density and wide bandwidth which will bring great benefits in the length of cavity and avoiding complex tuning system. Because of the low Q factor of the MA core, the cavity cooling becomes a very important issue in cavity design. Based on the demand of CSNS upgrade, a test MA cavity cooled by water has been designed for high power test to estimate the property of the MA core and cooling effectiveness. The direct, indirect and air-force cooling method were considered. The electromagnetics and fluid thermodynamics results simulated by HFSS and ANSYS which considered the anisotropy of permeability and thermal conductivity will be discussed in detail here. The temperature rise curve in the water outlet was measured to obtain the heat transfer efficiency. Experimental investigation of cooling effectiveness keep good consistency with simulation result. The result concluded that the indirect cooling effectiveness (141 W/m²/K) is lower than direct cooling (>500 W/m²/K) and better than air-force cooling (71.203 W/m²/K). But for the condition of average power density around 0.1W/cm³, indirect cooling method may be a feasible scheme because of its simple structures.
Orbit Correction With Machine Learning

**D.J. Xiao, Y. Bai, C.P. Chu, Y.S. Qiao**
(IHEP)

Orbit correction is usually an important task in the operation of accelerators. In practice, due to various errors, many devices cannot operate in an ideal state. By correcting the errors of magnets with corrector magnets, the beam can return to the correct position to ensure the stable operation of the accelerator. In the process of orbit correction, inaccurate BPM output will lead to incorrect correction magnet strength setting, so that the orbit correction will be impacted. BPM may make mistakes in the process of signal acquisition and current conversion. A BPM anomaly detection and predict method based on machine learning and its using in orbit correction optimization is reported in this paper. This method does not need to observe the details of BPM system, electronics technology and so on. It can monitor and predict the BPM status directly by machine learning with the information of the beam inferred from BPM and others, and optimize the orbit correction.

Design and Analysis of the Cold Cathode Ion Source for 200 MeV Superconducting Cyclotron

**S.W. Xu (USTC) L. Calabretta (INFN/LNS) G. Chen, M. Xu (ASIPP) O. Karamyshev, G.A. Karamysheva, G. Shirkov (JINR)**

SC200 is a superconducting isochronous cyclotron which generates 200 MeV, 400 nA proton beam for particle therapy. The cold-cathode-type Penning ion gauge (PIG) ion source for the internal ion source of SC200 has been selected as an alternative and preliminary designed. In this paper, design of ion source and test bench are demonstrated. Currently, the properties of ion source have been simulated for a variety of electric field distributions and magnetic field strengths. The secondary electron emission in electromagnetic field has been simulated. It provides reference for the optimization design of arc chamber. In addition, the sample of cold-cathode-type ion source has been tested on the test bench and extracted beam intensity has been measured over 200 μA.
A New RF Structure: Bent-Vane Type RFQ

A new cavity structure of RFQ accelerator with bent vanes is proposed to meet the miniaturization requirement of low frequency accelerators. The new structure has a downsized cross section by bending vanes while keeping a certain vane lengths. It also possesses the advantages of simple cooling structure in low frequency field. The new structure has obvious advantages in reducing manufacturing difficulty of cavity, cutting down project cost, enhancing facility reliability and stability.

Comparison of Optimization Methods for Hybrid Seven-Bend-Achromat Lattice Design

Although the hybrid multi-bend achromat (MBA) lattice has a low emittance and a good nonlinear performance, it has little potential to further optimize the nonlinear dynamics due to its limited free knobs. For better nonlinear dynamic performance, the exploration of the diversity of linear optics is suggested and nonlinear factors had better be considered in the linear optics designs. In this paper, we proposed a new optimization method to design hybrid MBA lattices, where two nonlinear dynamic indicators, the integral strengths of sextupoles and natural chromaticities were employed as objective functions in linear optics design. And to evaluate the effectiveness of this method, the comparison of two kinds of optimization methods are presented. A hybrid 7BA lattice with an energy of 2.4 GeV and an emittance about 60 pm·rad is taken as an example.
Design of TE11p Mode Cylindrical Cavity and Particle-Tracking Simulation in Cyclotron Auto-Resonance Accelerator

Y.T. Yuan (HUST) K. Fan (Huazhong University of Science and Technology, State Key Laboratory of Advanced Electromagnetic Engineering and Technology,) Y. Jiang (Yale University, Beam Physics Laboratory)

The cyclotron auto-resonance accelerator (CARA) is a novel concept of accelerating continuous-wave (CW) charged-particle beams, which can be used as high power electron sources. This type of accelerator has applications in environment improvement area, particularly in the flue gas pollution remediation. In CARA, the CW electron beam follows a gyrating trajectory while undergoing the interaction with a rotating TE-mode rf field and tapered static magnetic field. TE11p mode cylindrical cavity is adapted to accelerate electron beam. The effect of the cavity size on the CARA parameters is analysed, then a design procedure for the TE11p acceleration cavity is described here. Moreover, regardless of space charge effect, several particle-tracking simulations under only axial initial velocity are showed.


Y.X. Zhang, Y. Wang (USTC/NSRL)

In modern particle accelerators, the build-up of electron cloud is a main limiting factor for the achievement of high-quality beam. Among the techniques to mitigation it, coating the internal walls of the beam pipes with a thin film which has a low secondary electron yield (SEY) is considered to be one of the most effective means. From several earlier studies, it was found that amorphous carbon(a-C) and diamond-like (DLC) are potential. This paper is mainly about the researches on secondary electron emission characteristics of amorphous carbon and DLC thin films. The secondary electron yield (SEY) tests were done at temperatures of 25°C and vacuum pressure of (2-6)×10^-9 torr, both with and without Faraday cylinder. The SEY of
a-C and DLC films with different incident electron dose and with various angles was also measured, respectively. To investigate the ageing of the two thin films, samples were exposed to atmosphere for one month, three months and one year. The experiment results indicated a-C film is robust against air.

The High Energy Photon Source (HEPS) is a 6-GeV, ultralow-emittance light source to be built in China. The preliminary design of the 500 MeV Linac has been completed. According to the bunch structure requirement of the Booster, a conventional bunching system is adopted and the required pulse charge of electron gun is from 0.3 nC to 4 nC accordingly, which is a wide charge range, depending on different operation modes. So the bunching system should be optimized at different pulse charge to obtain high transmission efficiency and control emittance growth. For this purpose, the Multi-Objective Genetic Algorithms (MOGA) is introduced to optimize bunching system of HEPS Linac and the results is presented and discussed.

**THz-Pump and UV-Probe Scheme Based on Storage Ring**

We propose a THz-pump and UV-probe scheme based on storage ring for ultrafast dynamics experiment. It mainly includes two undulators. In an undulator (modulator), two sequential laser pulses, one of which has a periodic intensity envelope, simultaneously interact with different parts of the long electron beam from ring; after a chicane, the part interacts with the periodic pulse will bunching at THz domain and radiate through a bend magnet, another based on high-harmonic generation will bunching at UV domain and radiate at another undulator (radiator). The electron beam can be utilized circularly through the damping in the storage ring, which will increase its average power. The feasibility of this THz-pump and UV-probe scheme will be verified in both theory and simulation.
**Design of a 217 MHz VHF Gun at Tsinghua University**


A 217 MHz VHF gun operating in CW mode is in development at Tsinghua University. The gun is designed to generate an electric field at the cathode of 30 MV/m to accelerate the electron bunches up to 900 keV with an input power of 100 kW. The peak surface electric field is reduced to 37 MV/m by a comprehensive gun shape optimization to reduce the breakdown rate and dark current. Meanwhile, the peak wall power density is minimized to 25 W/cm², which significantly relaxes the requirement of cavity cooling. Multipacting analysis, thermal analysis, and HOM fields are also presented in this paper.

**Single-Shot Cascade High Energy Electron Imaging Based on Strong Permanent Magnet Quadrupole Composed Imaging Lens**

**Z. Zhou, Y.-C. Du, W.-H. Huang (TUB)**

High energy electron imaging, an extension of conventional transmission electron microscopy, is suitable for imaging of thicker objects and expected to be a promising tool for diagnostics of high energy density physics (HEDP). A cascade high energy electron imaging system using two-stage imaging lenses based on strong permanent magnet quadrupoles is designed, optimized and finally installed at Tsinghua university. Encouraging result of 1.6 μm space resolution is obtained in our primary experiments, along with the clear imaging of a spherical capsule as a substitute of the targets used in inertial confinement fusion. Successful implement of cascade high energy electron imaging system is necessary for reaching better resolving power of the imaging system, and well matching of design, simulation with experimental results paves the way to high energy electron microscopy to provide full capacities for diagnostics of HEDP with sub-um and picosecond spatiotemporal resolutions.
Synchrotron-based or Free-Electron-Laser-based light sources have proven to be an essential tool in many areas of research, including physics, materials science, chemistry, biophysics and biochemistry, medicine, and national security. And novel electron beam source with high beam brightness is important for the achievement of this fields. The electron source which is currently under development, is using two-frequency superposition in a half cell to increase acceleration gradient and improve output beam quality without increasing the RF breakdown probability. By the Cathode-anode Like Effect, this strategy can lower the breakdown possibility, thus allow the structure to support a higher gradient. The emittance will benefit from this by the reduce of space charge effect. Also, by selecting the proper amplitude ratio and phase relationship between the two resonate frequency, superposition of harmonic field components can provide a lower pulse heating than the structure with only one mode. This effect is called Quadratic Dependence Effect. The recent status of bimodal electron gun R&D is presented, including the designs of novel two frequency directional coupler, rectangular-to-coaxial mode launchers and beam dynamic simulation.

**Initial Beam Commissioning of LEAF**

A Low Energy intense-highly-charged ion Accelerator Facility (LEAF), which mainly includes an ECR ion source, LEBT, MEBT, series of terminals and an 81.25 MHz RFQ, was designed to produce and accelerate heavy ions, from helium to uranium with A/Q between 2 and 7, to the energy of 0.5 MeV/u. The normalization root-mean-square emittance of particles at the end of LEBT is less than $0.06\pi \text{mm}\cdot\text{mrad}$. The typical beam intensity is designed up to 2 emA CW for the uranium beam. The facility has been successfully commissioned with He$^+$ (A/Q=4) and N2+ (A/Q=7) beams and accelerated the beams in the CW regime to the designed energy of 0.5 MeV/u. Beam properties and transmission efficiency were measured, indicating a good consistency with simulated data. Recently, a third-harmonic-buncher being used at the beginning of RFQ cavity and it increases the acceleration of RFQ to 89%. Another project of accelerated
beams called ‘cocktail beam’ was proposed, it’s a mixed beam extracted by ECR ion source, and format at beam line. Cocktails can be mixed by different beams from the similar charge-to-mass ratio to any r/q beams, and it can be accelerate simultaneously and divided by energy dispersive detector.

**Development of the W-band Accelerating Structure of Cavities**

In this work excitation of the W-band structure is studied. The structure consists of cylindrical cavities with the operating frequency of about 96 GHz. It will be excited by the electron beams generated from the photocathode RF gun. In order to choose structure geometry and beam duration, analytical estimations and numerical simulations were performed. Taking into account feasible parameters of the photocathode RF gun such as the beam size and emittance, we studied exciting beam
transverse dynamics to define its other characteristics required (energy and charge). To lead the beam from the whole structure, a focusing system is needed. Required magnetic field has been estimated, several options of the focusing systems were discussed. Prototype of the W-band structure has been manufactured, its measurements are presented.

The research concerns the design of a drift tubes linear accelerator (DTL) with permanent quadrupole magnets (PMQ) placed inside some of the drift tubes for focusing. The study was conducted using Comsol Multiphysics software, where electromagnetic fields and particle dynamics in the cavity were calculated. The proton beam is accelerated up to 10 MeV. Initial beam is assumed to come from Radio Frequency Quadrupole accelerator (RFQ). Mathematical methods of control theory are used for particles dynamics optimization. Different focusing lattices are examined and variations of the gradient of the magnetic lenses are analyzed with respect to output beam parameters. Effectiveness of the optimization is estimated by the transmission rate and the emittance growth.

**Combined Field Emission and Multipactor Simulation in High Gradient RF Accelerating Structures**

Field emitted electrons play an important role in the operation of high gradient RF accelerating structures, by generating so-called dark currents, and acting as the initiators of RF Breakdown, which limits the performance in such devices. Another kind of vacuum discharge that commonly affects to the operation of lower-field RF components, for example in space applications, is the Multipactor effect. Theoretical simulations have been developed using CST Particle Studio, which show that field emitted electrons generated in the high field regions of the accelerating cavities, migrate...
to low field regions, pushed by the ponderomotive force, and trigger multipactor there. This phenomenon is a unique interplay between high field and low field processes which may have as a consequence that multipactor actually affects to the performance of high gradient cavities, and can reduce the timescales for the onset of multipactor.

**Dc Beam Space-Charge Modeling for OpenXAL**

**B.E. Bolling, N. Milas (ESS)**

OpenXAL is an open source multi-purpose accelerator physics software platform based on a pure Java open source development environment used for creating accelerator physics applications, scripts and services. Currently, the software has been used with an ellipsoidal (bunched) beam to account for space-charge effects. Applications developed so far for ESS, such as the Virtual Machine for the ESS Low Energy Beam Transport (LEBT) section, would profit from a DC beam description. In this paper, the space-charge component for a continuous beam is derived taking into account beams with different transverse charge distributions (uniform, gaussian, etc). The implementation in OpenXAL and a comparison with other simulation codes is also presented.

**Particularities of Implementing the ECHO Scheme for Different FEL Studied by Simulations**

**M.A. Pop (MAX IV Laboratory, Lund University)**

As the ECHO enabled harmonic generation (EEHG) scheme draws such intense focus from the FEL community, we conduct simulations to evaluate the challenges of implementing said scheme in different FEL layouts. Nonlinear processes such as this require extensive simulations to harmonize all system specific properties like seed lasers and electron beam properties. Along with optimizing the original EEHG scheme* one can consider, for example, altering the seed laser pulse to optimize the bunching for a machine specific chirp. We study the EEHG as a possible seeding method aimed at increasing coherence of the photon beam for the prospective SXL FEL beamline at MAXIV.
The particular chirp of the electron beam through the MAXIV LINAC generates some specific requirements in implementing EEHG but may also offer an opportunity for exotic operation modes of this FEL.

* Xiang D. and Stupakov G. Echo-enabled harmonic generation free electron laser 10.1103/PhysRevSTAB.12.030702

The space-charge field at the cathode limits the current density extracted from particle sources such as photoinjectors. For a long time, the maximum current has been estimated by using the classical Child-Langmuir law, which is derived with an assumption inconsistent with the conditions of modern laser-driven electron guns. Here, we introduce a theoretical model that accurately accounts for space-charge effects in transversely confined particle beams emerging from photocathodes. The model enables us to (i) determine the maximum current density extractable from the photocathode for an arbitrary cathode radius, (ii) reveal its dependence on the transverse profile of the particle beam and (iii) predict its upper limit for structured beams such as the ones produced by surface-plasmon resonance-enhanced photocathodes.

**Field Control Challenges for Different Linac Types**

FEL linacs typically require cavity field stabilities of 0.01% and 0.01 degree, while the requirements for high-intensity proton linacs are on the order of 0.1–0.5% and 0.1–0.5 degrees. From these numbers it is easy to believe that the field control problem for proton linacs is many times easier than for FEL linacs. In this contribution we explain why this is not necessarily the case, and discuss the factors that make field control challenging. We also discuss the drivers for the stability requirements in different linac types, and how high-level decisions in the linac design (driven by experiment considerations), affect the difficulty of the field control problem.
The injection kicker system for the Future Circular Collider (FCC-hh) must satisfy demanding requirements. To achieve low pulse ripple and fast field rise and fall times, the injection system will use ferrite loaded transmission line type magnets. The beam coupling impedance of the kicker magnets is crucial, as this can be a dominant contribution to beam instabilities. In addition, interaction of the high intensity beam with the real part of the longitudinal beam coupling impedance can result in high power deposition in the ferrite yoke. This gives a significant risk that the ferrite yoke will exceed its Curie temperature: hence, a suitable beam screen will be a critical feature. In this paper, we present a novel concept - a spiral beam screen. The fundamental advantage of the new design is a significant reduction of the maximum voltage induced on the screen conductors, thus decreased probability of electrical breakdown. In addition, the longitudinal beam coupling impedance is optimized to minimize power deposition in the magnet and impact on beam stability.

Unsupervised Machine Learning for Detection of Faulty BPMs

Unsupervised learning includes anomaly detection techniques that are suitable for the detection of unusual events such as instrumentation faults in particle accelerators. In this work we present the application of decision trees-based algorithm to faulty BPMs detection at the LHC. This method achieves significant improvements in quality of optics measurements and allows to identify relevant signal properties that contribute to fault detection.
The effect of Landau damping is often calculated based on a Gaussian beam distribution in all degrees of freedom. The stability of the beam is however strongly dependent on the details of the distribution. The present study focuses on the change of bunch distributions caused by the decoherence of the excitation driven by an external source of noise, in the presence of both amplitude detuning and a transverse feedback. Both multiparticle tracking simulations and theoretical models show a similar change of the distribution. The possible loss of Landau damping driven by this change is discussed.

Measurements of Stray Magnetic Fields at CERN for CLIC

Simulations have shown that the Compact Linear Collider (CLIC) is sensitive to external dynamic magnetic fields (stray fields) to the nanoTesla level. Magnetic fields are not typically measured to this precision at CERN. Past measurements of the background magnetic fields at CERN are limited and have only measured the temporal variation. In this paper new measurements of the background magnetic field on and around the CERN site are presented. Details of the sensors used for these measurements are also included.

Dust Analysis From LHC Vacuum System to Identify the Source of Macro Particle Beam Interactions

Particle accelerators require ultra-high vacuum systems for their operation. From previous accelerators with negatively charged beams it is well known that particulate contamination inside the beam pipes can interact with the beam. These interactions between macro particles and beam
result in beam losses and emittance growth. It came as a surprise that LHC was also suffering from macro particles interacting with the proton beams from the start of beam operation. Macro particle beam interactions have been responsible for numerous beam dumps and reduced luminosity production. To identify the macro particles involved in this phenomenon, dust samples were extracted from several LHC vacuum components. Subsequent analysis by electron microscopy revealed the size distribution and material composition of the dust found within the different components. The results of this dust survey help to model the interaction between macro particles and beam and thus improve understanding, mitigation and prevention of macro particle beam interactions in the LHC and other accelerators. This is also of relevance for future projects, in particular for the Future Circular Collider (FCC) under study.

Dynamic Aperture at Injection for the HE-LHC

M. Hofer, M. Giovannozzi, J. Keintzel, R. Tomas, F. Zimmermann (CERN) L. van Riesen-Haupt (JAI)

As part of the Future Circular Collider study, the High Energy LHC (HE-LHC) is a proposed hadron collider situated in the already existing LHC tunnel. It aims to achieve a center of mass energy of 27 TeV, almost doubling the design c.o.m. energy of the LHC. This increase in energy relies on the use of 16 T Nb3Sn dipoles developed for the FCC-hh. The field quality of these dipoles is expected to have a big impact on the Dynamic Aperture (DA) at injection energy and subsequently thorough tracking studies are conducted to evaluate the impact of magnetic field errors on the beam dynamics. In the following the results of these studies for the different injection energies considered for the HE-LHC are presented and possible strategies for increasing the DA are discussed.

Moving Long-Range Beam-Beam Encounters in Heavy-Ion Colliders

M.A. Jebramcik, J.M. Jowett (CERN)

Asymmetric ion beam collisions like proton-lead in the LHC or gold-deuteron in RHIC have become major components of heavy-ion physics programmes. The injection and ramp of two different ion species
with the same magnetic rigidity and consequently unequal revolution frequencies generate moving long-range beam-beam encounters in the interactions regions of the collider. These encounters led to fast beam losses and can cause emittance blow-up as observed in RHIC in the early 2000s and, more recently, in 2015. Yet such effects are absent at the LHC so the difference between the two colliders requires explanation. Tools and models have been developed to describe the beam dynamics of moving long-range beam-beam encounters and to predict the evolution of emittance and other beam parameters. Besides presenting results for RHIC and the LHC we give an outlook for the HL-LHC and potential operational restrictions.

The High Energy Large Hadron Collider (HE-LHC), a possible successor of the High Luminosity Large Hadron Collider (HL-LHC) aims to reach a centre of mass energy of about 27 TeV using 16 T dipoles specially designed for the hadron-hadron Future Circular Collider FCC-hh. Designing the HE-LHC results in a trade off between energy reach, beam stay clear as well as geometry offset with respect to the LHC. In order to best meet the requirements, various arc cell and dispersion suppressor options have been generated and analysed, before concluding on two baseline options, which are presented in this paper. Merits of each design are highlighted and possible solutions for beam stay clear minima are presented.

**Intensity Dependence Effects at ATF2, KEK**

The Accelerator Test Facility 2 (ATF2) at KEK is a prototype for the Final Focus Systems of the future e^+e^- linear colliders, ILC and CLIC. In this paper both simulation and experimental results are presented with special emphasis on intensity-dependent effects. The importance of these effects is shown using the PLACET code and realistic ATF2 machine simulations (including beam...
jitter, misalignment, wakefield, BBA correction, ...). The latest experimental results are also presented, in particular the impact of the beam charge on the orbit along the extraction line and on the beam size at the IP.

In 2018 a large fraction of the physics data taking at the Large Hadron Collider has been performed with a beam energy of 6.5 TeV, the nominal bunch spacing of 25 ns and beta functions at the high luminosity interaction points of 30 cm. In order to maximize the integrated luminosity, the crossing angles are gradually reduced as the beam intensity reduces due to luminosity burn-off. In these conditions the beam lifetime is visibly affected by collective effects and in particular by beam-beam interaction and electron cloud effects. By analyzing the beam losses at a bunch-by-bunch level it is possible to disentangle the contributions from different effects and to assess the impact on the losses of changes applied to the machine configuration.

**Spatially Resolved Dark Current in High Gradient Traveling Wave Structures**

High-gradient accelerating structures are known to produce field-emitted current from regions of high surface field, which are captured and accelerated by the fields within the structure. This current is routinely measured in structures under test in the CLIC high-gradient test stands using Faraday cups. This paper presents a novel technique to spatially resolve the longitudinal distribution of field emitted current by analysing downstream Faraday cup signals when the structure is fed with RF pulses much shorter than its filling time. Results from this method applied to X-band cavities operating at 100 MV/m are presented,
and are compared to breakdown position distributions. A decay in emitted current as conditioning progressed in regions with a low breakdown rate and large jumps in regions with a large breakdown rate are observed.

Transverse Emittance Measurement in the CERN Proton Synchrotron in View of Beam Production for the High-Luminosity LHC

In the framework of the LHC Injectors Upgrade project the improvements required to achieve the parameters of the future beams for the High-Luminosity LHC are being studied and implemented. In order to deliver high brightness beams, control over the beam intensity and emittance is fundamental. Therefore, a highly accurate and reliable transverse emittance measurement is essential. Presently at the CERN Proton Synchrotron, the only operationally available emittance monitors not impacting the facility beam production are the flying wire scanners used to measure the circulating beam profile. The wire scanners will be replaced with a new generation in the next two years and a prototype is already installed. The prototype has been commissioned with beams featuring a wide range of intensities and emittances. This paper evaluates the performance of the prototype with respect to the present system via beam-based measurements. The transverse emittance measurement is discussed, considering the different potential error contributions to the measurement, such as knowledge of the machine optics and the dispersive contribution to the beam size.

Quadrated Dielectric-Filled Reentrant Cavity Resonator as a Proton Beam Position Diagnostic

Low proton beam intensities (0.1-40 nA) are used for medical treatment of tumours at the PROSCAN facility in Paul Scherrer Institut (PSI). A beam current monitor as a dielectric-filled reentrant cavity resonator measures the
beam current down to few hundreds of pA*. A new cavity resonator using 4 quadrants matched to the dipole mode resonance has been developed to measure beam positions at these low intensities. The dipole mode resonance frequency of 145.7 MHz is matched to the 2nd harmonic of the beam pulse repetition rate (i.e. 72.85 MHz). HFSS provides the BPM geometry and important parameters such as pickup position; dielectric dimensions etc. Comparison of test bench measurement and simulation provides good agreement. The measured position and signal sensitivity are within our expectation limits. Potential reasons for the observed difference are discussed. We expect noise to limit the sensitivity of the BPM to few tenths of nA for a given energy and potential remedies are discussed. We propose the dipole cavity resonator to be a promising candidate as a non-invasive position diagnostic for low proton beam intensities

*Continuation of project: https://doi.org/10.3390/instruments2040024

**Funding:** This project has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 675265

---

**Measuring Beamsize with the LHC Beam Gas Vertex Detector**

**B. Würkner, A. Alexopoulos, R. Kieffer, S. Vlachos (CERN)**

The Beam Gas Vertex detector (BGV) is an innovative beam profile monitor being developed as part of the High Luminosity LHC (HL-LHC) project at CERN. The goal is to continually measure the transverse beam size by reconstructing beam-gas interaction vertices using high precision tracking detectors. To confirm the feasibility of such a device, a demonstrator based on eight modules of scintillating fiber detectors has been constructed, installed in the LHC and operated for the past 3 years. It will be shown that using the BGV the average transverse beam size can be obtained with a statistical accuracy of better than 5μm (for a gaussian beam with a sigma of 200μm). This precision is obtained with an integration time of less than one minute. In addition, the BGV measures the size of individual bunches with a statistical accuracy of better than 5% within 5 minutes. The results obtained from all the data gathered over the past 3 years will be presented and compared to measurements...
from other beam profile monitors. Some ideas for improvements for the final HL-LHC instrument will also be discussed.

**Beam Characterisation Using Medipix3 and EBT3 Film at the Clatterbridge Proton Therapy Beamline**

The Clatterbridge Cancer Centre (CCC) in the UK is a particle therapy facility providing treatment for ocular cancers using a 60 MeV passively scattered proton therapy beam. A model of the beamline using the Monte Carlo Simulation toolkit Geant4 has been developed for accurate characterisation of the beam. In order to validate the simulation, a study of the beam profiles along the delivery system is necessary. Beam profile measurements have been performed at multiple positions in the CCC beam line using both EBT3 Gafchromic film and Medipix3, a single quantum counting chip developed specifically for medical applications, typically used for x-ray detection. This is the first time its performance has been tested within a clinical, high proton flux environment. EBT3 is the current standard for conventional radiotherapy film dosimetry and was used to determine the dose and for correlation to fluence measured by Medipix3. The count rate linearity and doses recorded with Medipix3 were evaluated across the full range of available beam intensities, up to \(3.12 \times 10^{10}\) protons/s. These measurements are compared with the simulation before the applicability of Medipix3 for proton therapy dosimetry is discussed and compared against the performance of EBT3.

**Funding:** EU FP7 grant agreement 215080, H2020 Marie Skłodowska-Curie grant agreement No 675265 - Optimization of Medical Accelerators (OMA) project and the Cockcroft Institute core grant STGA00076-01.
Collimation of Heavy Ion Beams in the HE-LHC

A. Abramov (JAI) R. Bruce, M.P. Crouch, N. Fuster-Martinez, A. Mereghetti, J. Molson, S. Redaelli (CERN)

A design study for a future collider to be built in the LHC tunnel and provide proton collisions at a centre-of-mass energy of 27 TeV (High Energy Large Hadron Collider -HE-LHC) has been launched as part of the Future Circular Collider (FCC) study at CERN. HE-LHC has been designed under the stringent constraints of the existing tunnel and the resulting lattice and optics differ in layout and phase advance from the LHC. It is necessary to evaluate the performance of the collimation system for ion beams in HE-LHC in addition to the proton beams. In the case of ion beams, the fragmentation and electromagnetic dissociation that relativistic heavy ions can undergo in collimators and the unprecedented energy per nucleon of the HE-LHC require dedicated simulations. Results from a study of collimation efficiency for the nominal lead ion (Pb-82-208) beams performed with the SixTrack-FLUKA coupling framework are presented. These include loss maps with comparison against an estimated quench limit as well as detailed consideration of loss spikes in the superconducting aperture for critical sections of the machine such as the dispersion suppressors.

A Simulation Framework for Photon-Particle Interactions for Laserwires and Further Applications

S. E. Alden, S.M. Gibson, L.J. Nevay (JAI)

A model has been developed for simulating photon-particle interactions with Beam Delivery Simulation (BDSIM). BDSIM is a high energy physics program that utilises the Geant4, CLHEP, and ROOT libraries to seamlessly track particles through an accelerator. The photon-particle interactions introduce the capability for modelling a range of applications in accelerator physics. One such application is a laserwire which is a minimally invasive diagnostic technique to measure beam profiles and emittance. In this paper we describe the recent implementation of inverse Compton scattering and electron stripping of Hydrogen ions. This is demonstrated on an
example beamline where we show the resulting beam profile, transverse, and longitudinal emittance.

Externally injected electrons are captured and accelerated in the plasma wake of a self-modulated proton beam at AWAKE. The energy and energy spread of the accelerated electron beam are measured using a dipole spectrometer in combination with a scintillator screen, with two upstream quadrupoles providing energy-dependent focusing. Measuring the vertical beam size variation with horizontal position along the scintillator screen, and therefore energy, results in an effective quadrupole scan permitting single shot vertical geometric emittance measurements. Limitations of the method due to effects such as dipole focusing and finite resolution are explored via simulations using the beam tracking code BDSIM. The vertical geometric emittance of the accelerated beam is typically measured to be on the order of a few mm.mrad, and its variation with experimental parameters such as plasma density and injection position within the longitudinal growth of the wakefields are discussed.

**Design of the Cockcroft Beamline: Adjustable Transport of Laser Wakefield Electrons to an Undulator**

The Cockcroft Beamline is being designed to transport 1 GeV laser wakefield accelerated (LWFA) electrons to a pair of planar undulators at the Scottish Centre for the Application of Plasma-based Accelerators (SCAPA) in Glasgow, UK. In order to demonstrate undulator radiation in the X-ray region and potentially free-electron laser (FEL) gain, a good beam transport solution is required between the LWFA source and the undulators. In this paper we present an adjustable beam transport line option that will allow the LWFA electrons to be matched into the undulators, whilst also offering flexibility in chirp control of the short LWFA electron bunches.
Funding: This work was supported by the UK Science and Technology Facilities Council, Grant No. ST/G008248/1

Ultra-low emittance lattices are being studied for the future upgrade of the 2.75 GeV SOLEIL storage ring. The candidate baseline lattice was inspired by the ESRF-EBS-type Multi-Bend-Achromat (MBA) lattice, introducing a (-I) transformation to compensate the nonlinear impact of sextupoles thanks to the lattice symmetry and tight control of the betatron phase advance between sextupoles. Whilst the final performance is still being optimized, other types of lattices are being considered for SOLEIL: This includes the so-called High-Order Achromat (HOA) lattice. Though the (-I) scheme provides a large on-momentum transverse dynamic aperture in 4D, its off-momentum performance is rather limited. 6D studies reveal intrinsic off-momentum transverse oscillations which are likely to result from a nonlinear increase in path length. This contribution presents the effects from the inhomogeneous sextupole distribution in the (-I) scheme and compares them with the HOA lattice.

Re-optimisation of the ALICE Gun Upgrade Design for 500 pC Bunch Charge Operation for PERLE

B. Hounsell, M. Klein, C.P. Welsch (The University of Liverpool) W. Kaabi (LAL) B.L. Militsyn, T.C.Q. Noakes (STFC/DL/ASTeC) B.L. Militsyn, T.C.Q. Noakes, C.P. Welsch (Cockcroft Institute)

The injector for PERLE, a planned ERL test facility, must be capable of delivering 500 pC bunches at a repetition rate of 40.1 MHz to provide a beam with 20 mA average current. The PERLE injector will be based on an upgrade of a DC photocathode electron gun earlier operated at ALICE ERL at Daresbury. The upgrade will add a load lock system for photocathode interchange as
well as an adjustable position of the anode electrode for optimal operation at different voltages. This contribution presents the results from a re-optimisation of the electrode system as ALICE operated with a bunch charge of around 80 pC while PERLE needs a bunch charge of 500 pC. This re-optimisation was done using a multi-objective genetic algorithm to minimise both the slice emittance growth and transverse beam size.

**Can a Paul Ion Trap Be Used to Investigate Nonlinear Integrable Optics?**

Here we describe the design of an experimental setup using the IBEX Paul trap to test nonlinear integrable optics, an accelerator lattice design to create stable high intensity beams. High intensity hadron beams are challenging to create and store as they are susceptible to resonant excitation. Most accelerators are based on linear magnetic fields, where theoretically the motion of stored particles is bounded. However, any realistic accelerator cannot be perfectly linear, so chaotic motion is introduced into the system. A nonlinear accelerator lattice with integrable equations of motion should create conditions in which the motion of the stored particles is bounded. In 2010 Danilov and Nagaitsev found a realisable nonlinear potential which can create an integrable accelerator when embedded in a linear lattice that provides round beams. This concept will be tested in the IOTA ring, under construction at Fermilab. It is important to further test this concept over a wide parameter range, preferably in a simplified experimental setup such as IBEX. The IBEX Paul trap is capable of replicating the transverse dynamics of a high intensity accelerator without dispersion or chromaticity.
A high-resolution, low-latency stripline beam position monitor (BPM) signal processor has been developed for use in an intra-train feedback system for the Compact Linear Collider (CLIC). The processor was designed to have extremely low latency of order nanoseconds and a target position resolution of order 1 micron. The processor consists of a pair of diodes to form the difference and sum of a pair of stripline BPM inputs with microstrip filters to reduce out-of-band noise. The assembled prototype was optimized for use with the electron beam in the extraction line of the Accelerator Test Facility at the High Energy Accelerator Research Organization (KEK) in Japan but the underlying design is readily scaleable to a higher frequency response relevant for CLIC. A latency of 3 ns was measured in a testbench setup. We report the results of performance tests with beam in which the position resolution was measured to be c. 325 nm.

A Comparative Study of Biological Effects of VHEE, Protons and other Radiotherapy Modalities

Very High-Energy Electron (VHEE) therapy is a rapidly developing field motivated by developments in high-gradient linacs. Advantages include sufficient penetration (>30 cm) for treatment of deep-seated tumours, measured insensitivity to inhomogeneities and rapid delivery time, making VHEE viable for treatment of heterogeneous regions, e.g. lung or bowel. Researchers at the University of Manchester and CERN have routinely produced accelerating gradients of \( \sim 100 \text{ MeV/m} \) for the CLIC project. Suitable modification can result in a high gradient medical linac producing 250 MeV electrons within a treatment...
room. Radiobiological research for VHEE is vital to understand its use in radiotherapy and how it compares with conventional modalities. The goal of radiotherapy is to destroy tumour cells while sparing healthy cells, primarily by damaging DNA within the cancer cell. The study aim is to understand the fundamental interactions between VHEE and biological structures through plasmid irradiation studies - both computational, using the Monte Carlo GEANT4-DNA code, and experimental. Plasmid irradiation experiments have been carried out at the CLARA electron facility at the Cockcroft Institute, UK, over 15 - 40 MeV to determine the type and quantity of damage caused to DNA by VHEE irradiation. These experiments are a world first in VHEE radiobiology, with further studies planned at higher energies using the CLARA and CLEAR facilities at Daresbury and CERN. These studies will also consider the effective dose range of VHEE with energy, as well as implications of damage on DNA. Research into this area of radiotherapy can provide a valuable addition to tools currently available to physicians in the fight against cancer.

**Barrier Bucket Studies in the CERN PS**

Part of the residual beam loss during the Multi-Turn Extraction (MTE) of fixed target beams from the CERN Proton Synchrotron (PS) can be attributed to kicker magnets switching while the beam is coasting with the main RF systems off before extraction. Generating a barrier bucket to deplete the longitudinal line density of the coasting beam during the kicker rise time can reduce these losses. Beam tests have been performed with an existing Finemet cavity in the PS, which is normally operated as a wideband feedback kicker. To drive the cavity, a beam synchronous waveform synthesizer based on programmable logic has been developed. It produces a pre-distorted signal which ideally results in a single period sinusoidal voltage pulse with programmable parameters at the gap of the cavity, once or multiple times per revolution. The modelling of the behavior of the power amplifier and the cavity is essential to achieve an anti-symmetric voltage pulse with little pre- and post-pulse ripple. The design of the beam-synchronous waveform generator is presented together with results from initial beam studies with the created barrier buckets in the PS.
Precision Modelling of Energy Deposition in the LHC using BDSIM


A highly detailed model of the Large Hadron Collider (LHC) has been built using Beam Delivery Simulation (BDSIM) for studying beam loss patterns and is presented and discussed in this paper. BDSIM is a program which builds a Geant4 accelerator model from generic components bridging accelerator tracking routines and particle physics to seamlessly simulate the traversal of particles and any subsequent energy deposition in particle accelerators. The LHC model described here has been further refined with additional features to improve the accuracy of the model, including specific component geometries, field maps, tunnel geometry, optical misalignments, field imperfections, and more. Individual beam loss monitors (BLMs) have been added to the model and the simulated dose is compared with real BLM data from recent 2018 operations. The influence of the model details on these loss patterns are compared and contrasted. To efficiently generate the number of events for the required statistical precision for these comparisons, BDSIM has been supplemented with a dedicated, fast, symplectic tracker and is presented in this paper.

First Measurements of the Magnetized Thermionic Gun

M.S. Stefani (ODU)

The study of magnetized electron beam has become a high priority for its use in ion beam cooling as part of Electron Ion Colliders and the potential of easily forming flat beams for various applications. The demand for high average current for effective ion beam cooling has caused consideration of using bunched magnetized electron beam produced by a gridded thermionic electron gun. This paper presents the first measurements characterizing the beam properties of a magnetized thermionic gun.

Funding: This manuscript has been authored by Jefferson Science Associates, LLC under Contract No. DE-AC05-06OR23177 with the U.S. Department of Energy.
Advances in the algorithmic control of accelerators are an active area of research promising significant improvements in machine performance. To facilitate rapid algorithm prototyping, we have developed a generic interface between accelerator controls and beam physics modelling software. The interface is first tested offline with various algorithms of choice and afterwards allows rapid deployment on real machines via the Experimental Physics and Industrial Control System (EPICS) API. We include noise in our simulations in order to mimic realistic accelerator behaviour and to evaluate robustness of algorithms to experimental uncertainties and long-term drifts. Simulations enables control algorithms to infer physical variables of the real machine, for example, orbits at positions where there are no detectors. The results of several test cases of using this framework are presented, including emittance tuning of the Cornell Electron Storage Ring (CESR), correction of diurnal drift in CESR steering, orbit correction on the Cornell-BNL ERL Test Accelerator (CBETA), and the control of a space-charge dominated photoinjector optimized for ultrafast electron diffraction experiments.

**Funding:** US Department of Energy DE-SC 0013571

---

**The Effects of Stochastic Space Charge in High Brightness Photoelectron Beamlines for Ultrafast Electron Diffraction**

As we move to ultra-high brightness photocathodes and ultra-cold beams, we may become more sensitive to stochastic, point-to-point effects such as disorder induced heating and the Boersch effect, given the failure of Debye screening. In this study, we explore the effects of stochastic scattering. Modern beam dynamics codes often approximate point to point interactions with a potential created by smoothing the charge over space, removing sensitivity to stochastic effects. This approximation is often used in beamline optimization, because it is much faster. We study the limits...
of validity of this approximation. In particular, we will simulate effects of stochastic space charge on two high brightness photoemission beamlines: an ultrafast electron diffraction beamline with a photocathode temperature of 5 meV with a final beam energy of 200keV, and a single-shot ultrafast electron diffraction beamline with a MeV scale pulsed photoinjector. Both total and core emittance dilution in the transverse and longitudinal planes relative to smooth space charge simulations will be presented.

**Funding:** This work was supported by the U.S. National Science Foundation under award PHY-1549132, the Center for Bright Beams.

---

**Study of Integrable and Quasi-Integrable Sextupole Lattice**

L. Gupta, Y.K. Kim (University of Chicago) S. Baturin (Enrico Fermi Institute, University of Chicago) I.V. Bazarov (Cornell University (CLASSE), Cornell Laboratory for Accelerator-Based Sciences and Education) S. Nagaitsev (Fermilab)

In order to maximize beam lifetime in circular particle accelerators, the nonlinear beam optics are optimized to maximize the dynamic aperture of the beam. The dynamic aperture (DA), which is a 6-D phase space volume of stable trajectories, depends on the strength of the nonlinearities in the machine, and is calculated via particle tracking. Current DA optimization processes include multi-objective genetic algorithm optimizers, and relies on minimizing the magnitudes of resonance driving terms (RDT), which are calculated from the nonlinear contribution to the one-turn-map. The process of searching through the parameter space for an ideal combination that maximizes DA is computationally strenuous. Here, we present results for RDT minimization such that the dynamics in a simple sextupole channel are ideal a priori. The system uses the Danilov-Nagaitsev matched-optics prescription for sextupole magnets placed in the channel at equal phase advance. This lattice set-up increases the integrability of the system and improves the dynamics in 1-d without lengthy optimization.

**Funding:** Funded through Center for Bright Beams, NSF award PHY-1549132
Experimental Demonstration of the Henon-Heiles Quasi-Integrable System at the Integrable Optics Test Accelerator

N. Kuklev, Y.K. Kim (University of Chicago) A. Valishev (Fermilab)

The Integrable Optics Test Accelerator is a research electron and proton storage ring recently commissioned at the Fermilab Accelerator Science and Technology facility. Its research program is focused on testing novel techniques for improving beam stability and quality, notably the concept of non-linear integrable optics. In this paper, we report the first results of experimental investigation of a quasi-integrable system with one invariant of motion, a Henon-Heiles type system implemented with octupole magnets. Good agreement with simulations is demonstrated on key parameters of achievable tune spread and dynamic aperture preservation. Resilience to perturbations and imperfections in the lattice is explored. We conclude by outlining future research plans and discussing design constraints and applicability to future high intensity accelerators.

Funding: Work supported by National Science Foundation award PHY-1549132, the Center for Bright Beams. Fermi Research Alliance operates Fermilab under Contract DE-AC02-07CH11359 with the US Dept. of Energy.

Design of a High Gradient THz-Driven Electron Gun

S.M. Lewis, E.A. Nanni, S.G. Tantawi (SLAC) M. A. K. Othman (UCI)

We present the design of a high gradient electron gun. The goal of this gun is to generate relativistic electrons using GeV/m accelerating gradients. The initial design is a standing wave, field emission gun operating in the pi-mode with a cavity frequency of 110.08 GHz. A pulsed 110 GHz gyrotron oscillator will be used to drive the structure with power coupled in through a TM01 circular waveguide mode. The gun is machined in two halves which are bonded. This prototype will be used to characterize the electron beam and study RF breakdown at 110 GHz.

Funding: This work was supported by Department of Energy contract DE-AC02-76SF00515. This work was also supported by NSF grants PHY-1734015.
In this paper, we describe a study of statistical properties of the spontaneous undulator radiation, more precisely, a variance of the number of photons, emitted by a bunch of electrons, circulating in a storage ring. The aim of our study is to reproduce previous experiments and to investigate a long-standing question, brought up in *, where the measured variance was larger than predicted from a single-particle statistics by several orders of magnitude. We present a detailed description of an experimental apparatus in the IOTA ring at Fermilab and report on the progress of this experiment.


**Phase-Stable Self-Modulation of a Relativistic Electron Beam**

J.P. MacArthur (Stanford University)

We report on the self-modulation of a relativistic electron beam in a six-period magnetic wiggler. The current horn on the tail of the LCLS electron beam radiates coherently at the resonant wavelength of the wiggler, producing a six-period carrier-envelope-phase (CEP) stable infrared field with gigawatt power. We describe how this field creates a sinusoidal modulation in the electron beam using a 3D model based on Maxwell’s equations and a 1D Liénard-Wiechert model. The 1D model is integrated into start-to-end particle tracking simulations and compared with experimental data at a range of resonant wavelengths. We show that the modulation wavelength and phase exhibit sub-femtosecond stability. Such a stable sinusoidal modulation is ideal for producing one or more sub-femtosecond x-ray pulses. The CEP-stable infrared field is also potentially useful as an independent timing diagnostic with sub-femtosecond stability relative to the electron beam.
Most X-ray Free Electron Lasers (FELs) emit linearly polarized X-ray pulses. Recently, a device called the Delta undulator has been installed at the Linac Coherent Light Source (LCLS) to provide tuneable polarization. The electron beam is first microbunched by the LCLS normal undulators, then the microbunched beam is kicked prior to the Delta undulator, and an intense circularly polarized X-ray pulse is generated in the Delta undulator towards the kicked direction and is spatially separation from the linearly polarized radiation from upstream undulators. Coherent off-axis radiation is usually strongly suppressed because the microbunches themselves cannot rotate. The talk will show that microbunches can in fact rotate towards the new direction of travel if the kick is applied in a quadrupole focusing channel and also will clarify characteristics of the coherent undulator radiation from a tilted microbunch in the far-field and will compare simulations with experiments. This microbunch rotation can explain the unexpectedly large amount of off-axis radiation that was observed during Delta undulator experiments at LCLS and may have other applications to the advanced X-ray manipulations.

Theoretical Analysis of Quasiparticle Overheating, the Anti-Q-Slope, and Vortex Losses in SRF Cavities

The surface resistance of an SRF cavity is an important measure of its performance and utility: lower resistance leads directly to lower cryogenic losses and power consumption. This surface resistance comprises two components, namely the "BCS resistance", which depends strongly on the quasiparticle temperature, and a temperature-independent "residual resistance", which is often dominated by losses due to trapped magnetic vortices. Both components are generally dependent on the RF field strength. Here we present a summary of
recent theoretical advances in understanding the microscopic mechanisms of the surface resistance, in particular addressing quasiparticle overheating (using the tools of density functional theory) and discussing issues with existing models of the anti-Q-slope, a field-dependent decrease in the BCS resistance, and possible paths for improvement of these models. We also discuss trapped flux losses using ideas from collective weak pinning theory.

Beams with large transverse emittance ratios (flat beams) have received renewed interest for its possible applications in future colliders and novel light sources. A flat beam can be produced by generating a magnetized beam and then repartitioning its emittance using three skew quadrupoles. In this contribution, we report on the experimental generation of 1nC flat beams at the Argonne Wakefield Accelerator. The emittance ratio of the flat beam is demonstrated to be continuously variable by adjusting the magnetic field on cathode. Our results are compared with numerical simulations in IMPACT-T.

Funding: This work is supported by the U.S. DOE contracts No. DESC0017750, DE-SC0018656 with NIU, and No. DE-AC02-06CH11357 with ANL.

Recent Results from Nb3Sn Coated Single-cell Cavities Combined with Sample Studies at Jefferson Lab

U. Pudasaini, M.J. Kelley (The College of William and Mary) G.V. Eremeev, M.J. Kelley, C.E. Reece (JLab)

The critical temperature (~18 K) and superheating field (~400 mT) of Nb3Sn are almost twice that of niobium, thereby pledging the higher quality factor and accelerating gradient at any given temperature compared to that of traditional SRF cavities made of niobium. It can enable higher temperature for cavity operation (4 K Vs. 2 K), resulting in significant reduction in both capital and operating cost for the cryoplant. Several single-cell cavities along with witness samples were coated
with Nb3Sn to explore, understand and improve the coating process for betterment of cavity performance. RF measurements of coated cavities combined with material characterization of witness samples were employed to update the coating process. Following some modifications to the existing coating process, we were able to produce Nb3Sn cavity with quality factor $\geq 2.10^{10}$ for accelerating gradient up to 15 MV/m at 4 K, without any significant Q-slope. In this article, we will discuss recent results from several Nb3Sn coated single-cell cavities linked with material studies of witness samples, and the coating growth.

**Funding:** Partially authored by Jefferson Science Associates under contract no. DEAC0506OR23177. Work at College of William & Mary supported by Office of High Energy Physics under grant SC0014475.

### Transformer Ratio Measurements from Ramped Beams in the Plasma Blowout Regime using Emittance Exchange

We present progress on a UCLA-Argonne Wakefield Accelerator collaborative plasma wakefield acceleration (PWFA) experiment aimed at demonstrating the dependence of transformer ratio, the relation between maximum acceleration observed in a plasma wake to the maximum deceleration of the driving beam, on beam shape. Utilizing the unique capabilities of the emittance exchange (EEX) beamline, we may obtain transformer ratios in excess of six in a $\sim 100$ MeV/m PWFA. We show experimental results regarding hollow cathode arc plasma production and beamline characterization results from the recent upgrade to the AWA EEX beamline. These experiments are a crucial step in enabling applications ranging from compact X-ray free electron laser (FEL) light sources to TeV-class linear colliders for high energy physics.

**Funding:** Work is supported by DOE contract DE-SC0017648.