MOPGW094 **First Machine Developments Result with HL-LHC Crab Cavities in the SPS**

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Crab cavities are a critical component within the High Luminosity upgrade project for the Large Hadron Collider (HL-LHC). It is foreseen to use crab cavities in order to compensate the geometric luminosity reduction factor (reduction of the luminous region at the Interaction Point [IP]) due to the beam crossing angle (required for minimizing the impact of the long range beam-beam effects on the single particle beam dynamics) and increase the number of collisions per bunch crossing. In 2018 the first beam tests of crab cavities with protons were performed in the Super Proton Synchrotron (SPS) at CERN. Two vertical superconducting cavities of the Double Quarter Wave (DQW) type were fabricated and installed in the SPS to verify some key components of the cavity design and operation. This paper will present some of the first results relating to the proton beam dynamics in the presence of crab cavities.

MOPGW095 **Beam Dynamics Simulations with Crab Cavities in the SPS Machine**

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The LHC Upgrade, called High Luminosity LHC, aims to increase the integrated luminosity by a factor of 10. To achieve this, the project relies on a number of key innovative technologies, including the use of superconducting Crab Cavities with ultra-

precise phase control for beam rotation. A set of prototype Crab Cavities has been recently installed in the second largest machine of CERN, the Super Proton Synchrotron (SPS), that operated as a test-bed from May to November of 2018. The tight LHC constraints call for axially non-symmetric cavity designs that introduce high order multipole components. Furthermore, the Crab Cavities in the presence of SPS non-linearities can affect the long term stability of the beam. This paper presents how the SPS dynamic aperture is affected for different cavity, machine and beam configurations.

MOPGW096 **Beam Dynamics in MBA Lattices with Different Chromaticity Correction Schemes**

SUSPFO115 **use link to see paper's listing under its alternate paper code**

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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.

MOPGW097 **SOLEIL Storage Ring Upgrade Performance in Presence of Lattice Imperfections**

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The design for the upgrade of the SOLEIL third generation light source is progressing. At the present stage, different lattices are evaluated as possible candidates for the storage ring upgrade and an important factor for the comparison of their performances is the robustness against lattice imperfections. The strategy for this study consists in defining a set of misalignments of the lattice elements and field errors of the magnets that are expected to be attained after the commissioning, applying them to the lattice models and correcting them using response matrix based techniques. A dedicated algorithm was developed in Accelerator Toolbox in order to accomplish this procedure and compare the different lattices. In this paper the results of this study at the current state are presented, including the considered lattice imperfections, the correction method applied and the final performance of the lattices.

MOPRB005 **Study of Higher-Order Achromat Lattice as an Alternative Option for the SOLEIL Storage Ring Upgrade**

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A ring composed of 20 symmetrical 7BA cells in which of a pair of chromaticity correcting sextupoles placed around horizontal dispersion bumps à la ESRF-EBS was developed as a baseline lattice for the SOLEIL storage ring upgrade (presented at IPAC2018). The strict phase relation between the two dispersion bumps provides an efficient way of optimizing the (on-momentum) nonlinear optics with a limited number of sextupoles. As an alternative, a scheme known as Higher-Order Achromat (HOA) develops a MBA (Multi-Bend Achromat) lattice where chromaticity correcting sextupoles are distributed in each M unit cell with a strict phase relation cell-wise such as to cancel basic geometric and chromatic resonance driving terms. The beam dynamics in a 20-fold 7BA HOA ring is compared with those of the baseline lattice, with focus on off-momentum properties such as Touschek lifetime, which are important for medium energy rings like SOLEIL. The robustness against errors, the reduction of the ring symmetry by introducing 4 longer straight sections, as well as a horizontal dispersion bump to cope with longitudinal on-axis injection scheme are also presented.

MOPRB060 **Simulating Novel Collimation Schemes for High-Luminosity LHC With Merlin++**

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Due to the large stored beam energy in the HL-LHC new collimation technologies must be used to protect the machine. Active halo control of the proton beam halo with a Hollow Electron Lens can give a kick to protons at the edge of the beam without effecting the core. Various modes of operation are possible for example the electron lens can have a continuous current or it can be pulsed to different amplitudes for each passage of the proton beam. In this article we use Merlin++ simulations to show the performance of these modes for HL-LHC parameters. We also present recent simulations comparing scattering models in Merlin++.

MOPRB061 **Simulations and Measurements of Coherent Synchrotron Radiation at the MAX-IV Short Pulse Facility**

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The Coherent Synchrotron Radiation (CSR) interaction is a source of unwanted correlated energy spread in short-bunch Free-Electron Lasers (FEL), diluting the desired FEL spectrum and reducing the total brightness of the light source. Many accelerator codes make use of 1-dimensional approximations in the calculation of the CSR-wake, which breaks down for bunch dimensions typical within bunch compressor dipoles in FELs. General Particle Tracer simulations of the CSR interaction make use of the 3-dimensional bunch distribution, making it advantageous in modelling the short-bunch, high aspect ratio regimes typical of modern 4th-generation light sources. Measurements of THz CSR emitted from the final bunch compressor dipole of the SP02 beamline at the MAX-IV Short Pulse Facility (SPF) were used, alongside start-to-end GPT and Elegant simulations, to characterize coherent radiation emission across a broad range of bunch lengths.

MOPRB062 **nuSTORM Decay Ring**

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Precise neutrino cross section measurements and search for sterile neutrinos can be done with neutrino beams produced from muons decaying in a storage ring due to its precisely known flavour content and spectrum. In the proposed nuSTORM facility pions would be directly injected into a racetrack storage ring, where circulating muon beam would be captured. The storage ring has three options: a FODO solution with large aperture quadrupoles, a racetrack FFA (Fixed Field Alternating gradient) using the recent developments in FFAs and a hybrid solution of the two previous options. Machine parameters, linear optics design and beam dynamics of the hybrid solution are discussed in this paper.

MOPRB065 **Enhancing Experimental Prospects With Low Energy Antiprotons**

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Funding: This project has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie SkłodowskaCurie grant agreement No 721559.
The Extra Low Energy Antiproton ring (ELENA) is a critical upgrade to the Antiproton Decelerator (AD) at CERN and saw the first beam in 2018. ELENA will significantly enhance the achievable quality of low energy antiproton beams and enable new experiments. To fully exploit the potential of this new facility, advances are required in numerical tools that can adequately model beam transport, life time and interaction, beam diagnostics tools and detectors to fully characterize the beam’s properties, as well as in novel experiments that take advantage of the enhanced beam quality that ELENA can provide. These research areas are in the heart of the pan-European research and training network AVA (Accelerators Validating Antimatter physics) which started in 2017. This contribution presents research results within AVA on the performance of ultra-thin diamond membranes, electron cooling and beam life time studies of low energy ion and antiproton beams, as well as efficient

integration and performance optimization of cryogenic detectors in ELENA and associated trap experiments. These results are used to describe the optimum layout of a state-of-the-art low energy antiproton facility and associated experiments.

TUPMP051 **MULTIPACTOR SUPPRESSION BY LASER ABLATION SURFACE ENGINEERING FOR SPACE APPLICATIONS**

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Developing a surface with low Secondary Electron Yield (SEY) is one of the main ways of mitigating electron cloud and beam-induced electron multipacting in high-energy charged particle accelerators and space-borne RF equipment for communication purposes. In this study we report on the secondary electron yield (SEY) measured from silver coated aluminium alloy as-received and after laser ablation surface engineering (LASE). Analysis shows the SEY can be reduced by 43% using LASE. EDX and SEM analysis shows it is possible to reduce the SEY whilst maintaining the original surface composition.

TUPGW008 **PERLE: A High Power Energy Recovery Facility**

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PERLE is a proposed high power Energy Recovery Linac, designed on multi-turn configuration, based on SRF technology, to be hosted at Orsay-France in a col-laborative effort between local laboratories: LAL and IPNO, together with an international collaboration involv-ing today: CERN, JLAB, STFC ASTeC Daresbury, Liverpool University and BINP Novosibirsk. PERLE will be a unique leading edge facility designed to push advances in accelerator technology, to provide intense and highly flexible test beams for component development. In its final configuration, PERLE provides a 500 MeV elec-tron beam using high cur-rent (20 mA) acceleration during three passes through 801.6 MHz cavities. This presenta-tion outlines the technological choices, the lattice design and the main component descriptions.

TUPGW085 **A Hard X-Ray Compact Compton Source at CBETA**

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Compton backscattering at energy recovery linacs (ERLs) promises high flux, high energy x-ray sources in the future, made possible by high quality, high repetition rate electron beams produced by ERLs. CBETA, the Cornell-BNL ERL Test Accelerator currently being built and commissioned at Cornell, is an SRF multi-turn ERL using Non-Scaling Fixed Field Alternating-gradi-ent (NS-FFA) arcs. CBETA has high quality design parameters with an anticipated top energy of 150 MeV on the fourth pass. The expected parameters of a Compton source at CBETA include a top x-ray energy of over 400 keV with a flux on the order of 1012 ph/s. In this paper, we present anticipated parameters and potential applications in science and engineering for this source.

TUPRB075 **Higher Order Mode Spectra Study of 3.9 GHz Superconducting Radio Frequency Cavities for the European XFEL**

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Funding: The work is part of EuCARD2 and was partly funded by the European Commission, GA 312453.
It is important to verify both by simulation and experiments the wakefields in superconducting radio frequency (SRF) cavities, which can degrade the electron beam quality considerably or impose excessive heat load if left undamped. In this paper, we investigate the Higher Order Mode (HOM) spectra of the 3.9 GHz SRF cavities, which are assembled in a cryogenic module and are used to linearize the longitudinal phase space of the electron beam in the injector of the European XFEL. The HOM spectra are significantly different from the ones from a single cavity due to the coupling of the modes amongst cavities. The measurements not only provide direct input for the beam dynamics studies but also for the beam instrumentation utilizing these modes. The mode spectra are also investigated with a number of numerical simulations and the comparison with measurements shows favorable agreement.

TUPRB083 **Status of Clara Front End Commissioning and First User Experiments**

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CLARA (Compact Linear Accelerator for Research and Applications) is a test facility for Free Electron Laser (FEL) research and other applications at STFC's Daresbury Laboratory. The first exploitation period using CLARA Front End (FE) provided a range of beam parameters to 12 user experiments. Beam line to Beam Area 1 (BA1) was commissioned and optimised for these experiments, some involving TW laser integration. In addition to the user exploitation programme, significant advances were made to progress on machine development. This paper summarises these developments and presents the near future plan for CLARA.

TUPRB084 **High Level Software Development Framework and Activities on VELA/CLARA**

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The success of modern particle accelerators depends on good high level software. Over the past few years an integrated framework has been developed to better connect machine physicists to VELA/CLARA at the STFC's Daresbury laboratory. This framework is comprised of a number of tools, including, a c++/Python API to interface to the EPICS control system with which all High Level Software can be developed. The API is encapsulated, extensible and designed to grow as further Phases of CLARA are installed. The API is seamlessly integrated with the VELA/CLARA virtual accelerator and other activities by the simulations group. As well as presenting the design choices and methodology we will give an overview of the first control room applications built using our tools and how they will form the basis for a new programme of machine learning and optimisation on CLARA.

TUPRB108 **Mechanical Design of a Dielectric Wakefield Dechirper System for CLARA**

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STFC Daresbury Laboratory are developing a compact electron beam energy dechirper system, based on dielectric wakefield structure, for the on-site electron accelerator CLARA (Compact Linear Accelerator for Research and Applications). CLARA will be an experimental free electron laser (FEL) facility operating at 250MeV and will be a test bed for a variety of novel FEL schemes. The dechirper dielectric quartz plates will induce wakefields within the structure which can remove the beam chirp that is initially introduced to compress the electron bunch longitudinally. Removing or adjusting the amount of chirp enables researchers to reduce or adjust the bunch energy/momentum spread, expanding the FEL capabilities. The attachment and alignment of the quartz plates present numerous mechanical design challenges that require high precision manufacturing and quartz plate positioning via fiducialisation. This paper will review the dechirper specifications, the chosen design solutions, measured mechanical performance, and the expected effect of the dechirper on CLARA FEL operation.

TUPTS065 **RF Conditioning of the CLARA 400 Hz Photoinjector**

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Automated conditioning of the 400 Hz photoinjector for CLARA was begun and the conditioning program refined. The conditioning was performed at 100 Hz. Masks were used to detect breakdowns in the reflected power and phase, and the breakdown rate was limited to 5x106 breakdowns per pulse. The cavity gradient and breakdown rate evolution over the conditioning time is presented. Post-pulse multipactor and other evidence of electron effects were detected. Possible mechanisms for this are discussed. The conditioning was interrupted by breakdown in the waveguide after reaching 2.5 MW, and will be resumed after the planned 6 month shutdown of CLARA.

TUPTS066 **Re-optimisation of the ALICE Gun Upgrade Design for the 500-pC Bunch Charge Requirements of PERLE**

SUSPFO116 **use link to see paper's listing under its alternate paper code**

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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 with a projected rms emittance of less than 6 mm mrad. This must be achieved at two different operational voltages 350 kV and 220 kV for unpolarised and polarised operation respectively. The PERLE injector will be based on an upgrade of a DC photocathode electron gun operated previously at ALICE ERL at Daresbury. The upgrade will add a load lock system for photocathode interchange. This paper presents the results of 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 the many-objective genetic algorithm NSGAIII to minimise both the slice emittance and transverse beam size for both required operational voltages.

WEPGW090 **Emittance Evolution of Low Energy Antiproton Beams in the Presence of Deceleration and Cooling**

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The commissioning of the Extra Low Energy Antiproton (ELENA) ring has been completed before the start of the second long shutdown (LS2) at CERN. First beams to an experiment in a new experimental zone have as well already been delivered. ELENA will begin distributing 100 keV cooled antiproton beams to all antimatter experiments in 2021. This contribution presents measurements made using a novel scraping algorithm capable of determining the emittance of non-Gaussian beams in the presence of dispersive effects. The emittance is sampled during various sections of the ELENA deceleration cycle, investigating the efficiency of the electron cooler and extracting additional information from the beam. The electron cooler is shown to effectively reduce the transverse phase space after blow-up during deceleration. The beam is characterised before extraction for the purpose of tracking and optimisation of the new electrostatic transfer lines currently being installed. Finally, the application of the scraping algorithm to other machines with a scraper located in a dispersive region is discussed.

WEPGW093 **Commissioning of the Prototype for a New Gas Curtain Beam Profile Monitor Using Beam Induced Fluorescence for HL-LHC**

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Funding: This work is supported by the HLLHCUK project and the STFC Cockcroft Institute core grant No. ST/G008248/1.
A new supersonic gas-jet curtain based beam profile monitor is under development for minimally invasive simultaneous transverse profile diagnostics of proton and electron beams, at pressures compatible with LHC. The monitor makes use of a thin gas-jet curtain angled at 45 degrees with respect to the charged particle beams. The fluorescence caused by the interaction between the curtain and the beam can then be detected using a dedicated imaging system to determine its transverse profile. This contribution details design features of the monitor, discusses the gas-jet curtain formation and presents various experimental tests, including profile measurements of an electron beam using nitrogen and neon curtains. The gas-jet density was estimated by correlating it with the number of photons detected by the camera. These measurements are then compared with results obtained using a movable pressure gauge. This monitor has been commissioned in collaboration with CERN, GSI and the University of Liverpool. It serves as a first prototype of a final design that will be placed in the LHC beam line to measure the profile of the proton beam.

WEPGW095 **Coherent Transition Radiation Spatial Imaging as a Bunch Length Monitor**

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Funding: This work was supported by the EU under Grant Agreement No. 624890 and the STFC Cockcroft Institute core Grant No. ST/G008248/1.
High-resolution bunch length measurement is a key component in the optimisation of beam quality in FELs, storage rings, and plasma-based accelerators. Simulations have shown that the profile of a coherent transition radiation (CTR) image produced by a charged particle beam is sensitive to bunch length and can thus be used as a diagnostic. This contribution presents the development progress of a novel bunch length monitor based on imaging the spatial distribution of CTR. Due to the bunch lengths studied, 10fs-100fs FWHM, the radiation of interest was in the THz range. This led to the development of a THz imaging system, which can be applied to both high and low energy electron beams. The associated benefits of this imaging distribution methodology over the typical angular distribution measurement are discussed. Building upon preliminary multi-shot proof of concept results last year, a new series of experiments have been conducted in the short pulse facility (SPF) at MAX IV. Single-shot measurements have been used to measure the exact point of maximum compression. Analysis from the proof of concept results last year, and initial results from the new measurements this year are discussed.

WEPGW096 **Development of Supersonic Gas-Sheet-Based Beam Profile Monitors**

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Funding: HL-LHC project funded by STFC and CERN, and the STFC Cockcroft core grant No. ST/G008248/1.
Non-destructive beam profile monitoring is very desirable, essentially for any particle accelerator but particularly for high-energy and high-intensity machines. Supersonic gas jet-based monitors, detecting either the ionization or fluorescence of a gas sheet interacting with the primary beam to be characterized, allow for minimally invasive measurements. They can also be used over a wide energy range, from keV to TeV beams. This contribution gives an overview of the jet-based ionization and fluorescence beam profile monitors which have been developed, built and tested at the Cockcroft Institute. It discusses gas sheet generation, vacuum considerations, choice of gas species and detection methods.

WEPRB063 **Connection of 12 GHz High Power RF from the XBOX 1 High Gradient Test Stand to the CLEAR Electron LINAC**

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A new RF system is being established at XBOX1 to drive two §I{100}{MV/m} CLIC structures in the CLEAR electron linac. In the past, these structures had been powered by RF from PET structures excited by a drive beam. This drive beam is no longer available. The upgrade will reroute power from the §I{50}{MW} klystron and pulse compressor which was previously used to power the structure in XBOX1. During the upgrade, the LLRF system will be optimised to improve the modulation of the output signals and down-mixing of the returning signals to obtain accurate phase and amplitude information. The design of the improved LLRF and software, along with phase noise measurements and comparisons with the old system are made in this paper.

WEPRB068 **Ka-Band Linearizer Studies for a Compact Light Source**

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Funding: This project has received funding from the European Union’s Horizon2020 research and innovation programme under grant agreement No 777431.
The CompactLight project is currently developing the design of a next generation hard X-ray FEL facility, based on high-gradient X-band (12 GHz) structures, bright electron photo-injectors, and compact short period undulators. However, to improve

the brightness limitations due to the non-linear energy spread of the electron bunches, a K-band (36 GHz) linearizer is being considered to provide a harmonic compensation during the bunch compression. In this paper, we analyze the feasibility of such linearizer.

WEPRB069 **Wakefield Suppression in a Manifold Damped and Detuned Structure for a 380 GeV CLIC Staged Design**

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The first stage of the Compact Linear Collider (CLIC) project aims to collide electrons and positrons at a 380 GeV center of mass energy. In the baseline design the main linacs for this staged approach are required to achieve a gradient of 72 MeV/m, with the surface electromagnetic fields (EM) and the transverse long-range wakefields bound by beam dynamics constraints. The baseline design utilizes heavy damping in a traveling wave (TW) structure. Here we report on an alternate design, which adopts moderate damping along with strong detuning of the individual cell frequencies. In the context of this Damped and Detuned Structure (DDS) design, we study Gaussian and hyperbolic secant dipole distributions, together with interleaving of successive structures, to effect long-range transverse wakefield suppression. Both analytic and modal summation approaches, in the quasi-coupled approximation, produce consistent results. In the optimisation scheme we opt for a dipole frequency bandwidth of 17.7 % (2.92 GHz)

WEPRB070 **Facile Deposition of Superconducting MgB2 Thin Films on Substrates: A Comparative Investigation of Electrochemical Deposition and Magnetron Sputtering Techniques**

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Funding: Authors acknowledge the funding received under the Rutherford International Postdoctoral Fellowship Programme
Coating of Copper cavities with a superconducting layer of MgB2 thin film is an attractive alternative to bulk Nb cavities. In this work, we investigate the application of two approaches-electrochemical deposition and magnetron sputtering of MgB2, to fabricate MgB2 films with potential accelerator applications. In the first approach, MgB2 powder dispersed in acetone was used as an electrolytic medium. Application of a DC voltage of 400 V between a graphite anode and a Copper film (serving as cathode), with the electrode distance maintained at ~2cm, resulted in the electrochemical deposition of MgB2 on the Cu surface. In an alternate approach, MgB2 in powder form was used directly for sputtering based deposition. The powder

was initially compacted to form a thin layer that served as the magnetron target. Application of a pulsed DC power of 25W for 4 hours yielded MgB2 thin film on Si substrates. Samples were characterized by XPS analysis to ascertain their elemental composition, which confirmed the presence of Mg and B, in addition to traces of C and O as impurities. Surface morphology was determined using SEM characterization technique. Further work to determine the superconducting properties of the samples and fine tune the deposition processes for large scale MgB2 deposition inside actual RF cavities is in progress.

WEPRB098 **Cryogenic RF Performance of Double-Quarter Wave Cavities Equipped with HOM Filters**

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Funding: Work supported by US DOE through BSA LLC under contracts No. DE-AC02-98CH10886, No. DE-SC0012704, and the US LHC Accelerator Research Program (LARP) and by the EU HL-LHC Project.
Crab cavities are one of the several components included in the luminosity upgrade of the Large Hadron Collider (HL-LHC). The cavities have to provide a nominal deflecting kick of 3.4 MV per cavity while the cryogenic load per cavity stays below 5 W. Cold RF tests confirmed the required performances in bare cavities, with several cavities exceeding the required voltage by more than 50%. However, the first tests of a Double-Quarter Wave (DQW) cavity with one out of three HOM filters did not reach the required voltage. The present paper describes the studies and tests conducted on a DQW cavity with HOM filter to understand the limiting factor. The recipe to meet the performance specification and exceed the voltage requirement by more than 35% is discussed.

WEPTS011 **Intra-Beam Scattering Effect in the SOLEIL Storage Ring Upgrade**

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As the work on the design of the upgrade of SOLEIL storage ring advances, the study of the impact of Intra-Beam Scattering (IBS) on the equilibrium emittance is also progressing, showing a significant contribution of this effect. Different measures can be taken to mitigate the emittance dilution, like operating the machine with full transverse coupling and using harmonic cavities to increase bunch length. The calculation of the IBS effect needs then to take into account the different beam dynamics and its effect on the particle distribution. In this paper the current state of the ongoing study is presented, reporting on the results obtained for the different options considered, and comparing the results of different codes and their implicit assumptions.

WEPTS059 **Electron Cooling Simulations for Low Energy Storage Rings**

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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 721559.

Electron cooling is an effective method to reduce the phase space volume of a circulating beam of heavy particles, such as protons, antiprotons and ions in a storage ring. The Coulomb interaction between the co-moving electron beam of low temperature and the ions results in a cooling force acting on the heavy particles. This process can be described by two approaches: Dielectric theory and binary collision approximation. However, neither of these models provide a closed solution for the resulting cooling force. It is therefore necessary to find appropriate numerical approximations. Betacool and RF-Track are two beam tracking codes commonly used to simulate ion beam cooling. This contribution compares the accuracy of simulations performed using both codes by against measurements carried out at the LEIR facility at CERN. Simulations of the resulting cooling force are presented, benchmarked against experimental data and shown to agree well. The models are then used to predict cooling performance and optimum cooler settings for the low energy antiproton storage ring ELENA.

WEPTS060 **Multi-objective Optimization of 3D Beam Tracking in Electrostatic Beamlines**

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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 721559.
After CERN’s Long Shutdown 2 (LS2) the Extra Low Energy Antiproton (ELENA) ring will begin providing extremely low energy (100 keV) antiproton beams to the antimatter experiments in the AD hall. To allow for simultaneous operation and guarantee maximum efficiency, all transfer lines will be based on electrostatic optics and short pulse (∼100 ns) deflectors. Currently, only a limited number of simulation codes allow a realistic representation of these elements, limiting the capabilities for beam quality optimization. In this contribution methods for modelling realistic electrostatic optical elements and perform 3D tracking studies through these are presented. A combination of finite element methods and experimental measurements are used along with a modified version of the G4Beamline and BMAD codes. Multi-objective optimization techniques are then applied to optimize beam transfer and beam quality at various points along the transfer lines.

WEPTS106 **Accelerator Optimization using Big Data Science Techniques**

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Funding: This project has received funding from STFC under grant reference ST/P006752/1.
Managing, analyzing and interpreting large, complex datasets and high rates of data flow is a growing challenge for many areas of science and industry. At particle accelerators and light sources, this data flow occurs both, in the experiments as well as the machine itself. The Liverpool Big Data Science Center for Doctoral Training (LIV. DAT) was established in 2017 to tackle the challenges in Monte Carlo modelling, high performance computing, machine learning and data analysis across particle, nuclear and astrophysics, as well as accelerator science. LIV. DAT is currently training 24 PHD students, making it

one of the largest initiatives of this type in the world. This contribution presents research results obtained to date in projects that focus on the application of big data techniques within accelerator R&D.

WEPTS107 **Designing the European Spallation Source Tuning Dump Beam Imaging System**

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Funding: In-Kind Agreement, ESS/Norway

The first section of the European Spallation Source (ESS) to receive high-energy protons when live operation begins will be the Tuning Dump beam-line. The dump line will be used during accelerator commissioning to tune the linac, and must accept the full range of ESS energies up to 2 GeV, from 5µs probe pulse to full 2.86ms pulse length, and beam sizes up to the 250 mm limit of the physical aperture, although the allowed pulse rate will be restricted by the thermal capacity of the dump. An imaging system has been developed to view remotely the transverse beam profile in the section immediately before the dump entrance, using insertable scintillator screens. This contribution presents the principal design parameters for this system, with particular reference to the techniques used in assessing the radiation and thermal environments and their impact on the selection of locations for the imaging cameras, and the specification of the mechanical screen actuators. The predicted optical performance of the system is also summarised.

THPMP033 **Beam Characterisation Using MEDIPIX3 and EBT3 Film at the Clatterbridge Proton Therapy Beamline**

SUSPFO110 **use link to see paper's listing under its alternate paper code**

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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.
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 x 1010 protons/s. The applicability of Medipix3 for proton therapy dosimetry is discussed and compared against the performance of EBT3.

THPMP035 **Tactile Collider : Accelerator Outreach to Visually Impaired Audiences**

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Funding: STFC (UK)
The Large Hadron Collider (LHC) has attracted significant attention from the general public. The science of the LHC and Higgs

Boson is primarily communicated to school children and the wider public using visual methods. As a result, people with visual impairment (VI) often have difficulty accessing scientific communications and may be culturally excluded from news of scientific progress. Tactile Collider is a multi-sensory experience that aims to communicate particle accelerator science in a way that is inclusive of audiences with VI. These experiences are delivered as a 2-hour event that has been touring the UK since 2017. In this article we present the methods and training that have been used in implementing Tactile Collider as a model for engaging children and adults with science. The event has been developed alongside experts that specialise in making learning accessible to people with VI.

THPMP036 **Beam Dynamics of Novel Hybrid Ion Mass Analysers**

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Fourier transform (FT) mass spectrometers achieve high resolution using relatively long transient times by trapping ions and measuring the frequency of their motion (inductively) inside an electrostatic potential. By contrast, time-of-flight (ToF) mass spectrometers measure the time of flight between an initiation pulse and contact with a destructive detector positioned on a plane of space focus after flying along a predetermined route. These devices have relatively short flight times and, generally, lower resolution. A class of hybrid analysers have been proposed and studied, utilising a quadro-logarithmic potential to reflect ions multiple times past an inductive detector, with the potential for the short transient of ToF devices - and the high resolution of FT devices. In this paper we compute the ion dynamics inside such devices, tracking bunches of ions and studying induced signals.

THPMP038 **Collaborative Strategies for Meeting the Global Need for Cancer Radiation Therapy Treatment Systems**

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The idea of designing affordable equipment and developing sustainable infrastructures for delivering radiation treatment for patients with cancer in countries that lack resources and expertise stimulated a first International Cancer Expert Corps (ICEC) championed, CERN-hosted workshop in Geneva in November 2016. Which has since been followed by three additional workshops involving the sponsorship and support from UK Science and Technology Facilities Council (STFC). One of the major challenges in meeting this need to deliver radiotherapy in low- and middle-income countries (LMIC) is to design a linear accelerator and associated instrumentation system which can be operated in locations where general infrastructures and qualified human resources are poor or lacking, power outages and water supply fluctuations can occur frequently and where climatic conditions might be harsh and challenging. In parallel it is essential to address education, training and mentoring requirements for current, as well as future novel radiation therapy treatment (RTT) systems.

THPMP041 **A Comparative Study of Biological Effects of Electrons and Co-60 Gamma Rays on pBR322 Plasmid DNA**

SUSPFO119 **use link to see paper's listing under its alternate paper code**

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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 ~100 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 using Co-60 gammas at the Dalton Cumbrian Facility and using 6-15 MeV electrons at the Christie NHS Foundation Trust to determine the type and quantity of damage caused to DNA by electron 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.

THPMP042 **Performance Optimization of Ion Beam Therapy**

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Funding: This project has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie SkłodowskaCurie grant agreement No 675265.
Proton beam therapy promises significant advantages over other forms of radiation therapy. However, to assure the best possible cancer care for patients further R&D into novel beam imaging and patient diagnostics, enhanced biological and physical models in Monte Carlo codes, as well as clinical facility design and optimization is required. Within the pan-European Optimization of Medical Accelerators (OMA) project collaborative research is being carried out between universities, research and clinical facilities, and industry in all of these areas. This contribution presents results from studies into low-

intensity proton beam diagnostics, prompt gamma-based range verification in proton therapy, as well as prospects for a new proton irradiation facility for radiobiological measurements at an 18 MeV cyclotron within OMA. These results are then connected to the wider project aims of enhancing ion beam therapy. A summary of past and future events organised by the OMA consortium is also given.

THPMP043 **Non-Invasive Beam Monitoring Using LHCb VELO With 40 MeV Protons**

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- R. Schnuerer, C.P. Welsch, J.S.L. Yap, H.D. Zhangpresenter
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Funding: EU grant agreements 215080 and 675265, the Cockcroft Institute core Grant (ST/G008248/1), national agency: MNiSW and NCN (UMO-2015/17/B/ST2/02904) and the Grand Challenge Network+ (EP/N027167/1).

In proton beam therapy, knowledge of the detailed beam properties is essential to ensure effective dose delivery to the patient. In clinical practice, currently used interceptive ionisation chambers require daily calibration and suffer from slow response time. This contribution presents a new non-invasive method for dose online monitoring. It is based on the silicon multi-strip sensor LHCb VELO (VErtex LOcator), developed originally for the LHCb experiment at CERN. The semi-circular detector geometry offers the possibility to measure beam intensity through halo measurements without interfering with the beam core. Results from initial tests using this monitor in the 40 MeV proton beamline at the University of Birmingham, UK are shown. Synchronised with an ionisation chamber and the RF cyclotron frequency, VELO was used as online monitor by measuring the intensity in the proton beam halo and using this information as basis for 3D beam profiles. Experimental results are discussed.

THPMP054 **Superconducting Dipole Design for a Proton Computed Tomography Gantry**

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Funding: This project has received funding from the European Union’s Horizon 2020 research and innovation programme under the MSC grant agreement No 675265, OMA - Optimization of Medical Accelerators.
Proton computed tomography aims to increase the accuracy of proton treatment planning by directly measuring proton stopping power. This imaging technique requires a proton beam of 330 MeV incident kinetic energy for adult patients. Employing superconducting technology in the beam delivery system allows it to be of comparable size to a conventional proton therapy gantry. A superconducting bending magnet design for a proton computed tomography gantry is proposed in this paper. The 30 deg, 3.9 T canted-cosine-theta dipole wound with NbTi wires is used to steer 330 MeV protons in an isocentric beam delivery system which rotates around the patient. Two methods of magnetic field shielding are compared in the context of proton therapy facility requirements; traditional passive shielding with an iron yoke placed around the magnet and an active shielding option utilising extra layers of the superconducting coil.

THPGW010 **ATHENA - The Laser-Plasma Accelerator Project of the Helmholtz Association**

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The accelerator centers in the Helmholtz association perform since 2012 a dedicated accelerator R&D program (ARD) with four pillars, one of them being novel accelerators, in particular plasma accelerators. The involved centers DESY, GSI, HZB, HZDR, FZJ, KIT, together with the Helmholtz institute Jena, University Hamburg and University Strathclyde, have proposed the ATHENA project (Accelerator Technology HElmholtz iNfrAstructure) for the development of laser plasma accelerators with the ultimate goal of compact applications. The project will combine the technical capabilities of the partners, world-class R&D infrastructure and experience in user facilities in an inter-disciplinary environment. The ATHENA project has received full funding and was put into operation during 2018. During the construction phase the consortium will upgrade the R&D infrastructure in the involved Helmholtz partners in a coordinated effort and will set up two common laser plasma accelerator flagship projects in Germany: a laser-plasma electron accelerator at a DESY site and a laser-plasma hadron accelerator at a HZDR site. During the ATHENA operational phase from 2022 onwards various applications will be developed, including an FEL line, X ray based medical imaging, material testing, higher flux irradiation of tumors and high energy density physics. The paper describes the setup and goals of the ATHENA project.

THPGW070 **Design of the Cockcroft Beamline: Adjustable Transport of Laser Wakefield Electrons to an Undulator**

SUSPFO114 **use link to see paper's listing under its alternate paper code**

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The Cockcroft Beamline is being designed to transport 1 GeV electrons from a laser wakefield accelerator (LWFA) to an undulator at the Scottish Centre for the Application of Plasma-based Accelerators (SCAPA) in Glasgow, UK. To demonstrate undulator radiation in the X-ray spectral region and potentially free electron laser (FEL) gain, electrons should be transported between the LWFA and the undulators with high fidelity. In this paper we present the design of an adjustable beam line to transport LWFA electrons to the undulator for a range of energies, from 0.5 GeV to 1 GeV, while preserving the electron beam properties and matching the undulator-beam coupling.

THPGW072 **Seeded Self-Modulation of Transversely Asymmetric Long Proton Beams in Plasma**

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Funding: This work is supported by Science and Technology Facilities Council grant ST/P006752/1.
The AWAKE experiment at CERN recently demonstrated the world's first acceleration of electrons in a proton-driven plasma wakefield accelerator*. Such accelerators show great promise for a new generation of linear e-p colliders using ~1-10 GV/m accelerating fields. Effectively driving a wakefield requires 100-fold self-modulation of the 12 cm Super Proton Synchrotron (SPS) proton beam using a plasma-driven process which must be care-fully controlled to saturation. Previous works have modelled this process assuming azimuthal symmetry of the transverse spatial and momentum profiles **, ***. In this work, 3D particle-in-cell simulations are used to model the self-modulation of such non-round beams. Implications of such effects for efficiently sustaining resonant wakefields are examined.
* Adli, E., et. al. (2018). Nature, 561(7723), 363-367.
** Lotov, K. V. (2015). Physics of Plasmas, 22(10), 103110.
*** Schroeder, C. B., et. al. (2011). Phys. Rev. Lett., 107(14).

THPRB097 **Analysis of RF System Stability on CLARA**

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The Compact Linear Accelerator for Research and Applications (CLARA) facility at STFC Daresbury Laboratory will test underpinning concepts and technology for a next generation X-ray free electron laser (FEL). CLARA will use four S-band normal conducting traveling wave linacs to accelerate electron bunches to a maximum energy of 250 MeV. The amplitude and phase stability of the collected RF systems is critical in enabling CLARA to achieve low (10 fs) shot-to-shot timing jitter of the photon output. Here we present initial measurements and model of the amplitude and phase jitter of the CLARA RF systems, achieved by experimentally correlating the klystron output with controls from modulator, driver, and other environment parameters. The effect of the RF jitter on the CLARA beam momentum is also integrated in the model.