ARIES-ADA Topical Workshop

Simulation, Design & Operation of Ionization Profile Monitors

Darmstadt, Germany, 21st to 24th May, 2017

INDICO-site: http://indico.gsi.de/event/5366/

Workshop Summary

Organiser: Peter Forck, Mariuz Sapinski – GSI, and Kenichiro Satou – J-PARC

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Workshop introduction and goals

In May 2017, a Topical Workshop took place at GSI (Darmstadt, Germany) concerning 'Simulation, Design & Operation of Ionization Profile Monitors' with 33 international participants; the INDICO-site is https://indico.gsi.de/event/5366/. GSI organised it with support from J-PARC. The workshop comprises 18 talks related to the hardware, operational experiences and simulation tool for Ionization Profile Monitors design, operations. Moreover, the workshop included a guided tour at GSI and an entire session for hands-on possibilities for the newly developed simulation package IPMSim.

An Ionization Profile Monitor (IPM) is based on spatially resolving the ions or electrons generated from residual gas ionisation through beam impact. These monitors deliver the beam profile in a non-destructive manner with a spatial resolution of typically 50 µm and time gating down to the ten ns level. They are installed at both hadron synchrotrons and LINACs. Due to the increase in the beam power of future LINACs (e.g. at CERN, ESS, FAIR, ISIS), these IPMs will substitute the traditional invasive wire-based diagnostics. Even though the principle is well known, there are many technical challenges for the reliable operation of IPMs.

The experience and technical solutions from installations worldwide were presented by the experts in the field, with the results extensively discussed and the related contributions serving as a comprehensive catalogue of such systems.

One purpose of the workshop was to introduce the community to a recently completed simulation package called IPMSim (see https://twiki.cern.ch/twiki/bin/view/IPMSim/), which is freely accessibly. This code was produced with the input of several experts to simulate the related physical processes (cross-section for electron and ion production) under various conditions (beam distribution, space charge, external field configurations) from non-relativistic beams at LINACs to highly energetic beams at synchrotrons. The code features a modern programming style, a user-friendly GUI and can easily be expanded to include new physical models and applications. The code is freely available, and its benchmarking was successfully demonstrated. Further extensions of the code (e.g. for Beam Induced Fluorescence Monitors) are currently included. Various laboratories produced different codes, a standard set of beam parameters were agreed on to perform such benchmarking between those codes. Possible experimental verifications of such simulations were put forward at this workshop.

This workshop acted as a follow-up to a previous workshop held at CERN in February 2016 https://indico.cern.ch/event/491615/. Due to the significant interest in this field, a third workshop will be executed at J-PARC (Tokai, Japan) in autumn 2018, see https://conference-indico.kek.jp/indico/event/55/.

The workshop was dedicated to the memorial of Dr. Bernd Dehning, who passed away in January 2017 due to fast-developing cancer disease. Bernd Dehning was born in Germany in 1957. Starting in 1987 he worked at CERN Beam Instrumentation Group on transverse profile measurements and beam loss detection. He made many valuable contributions to the field of beam diagnostics and participated in numerous conferences and workshops. Moreover, he supervised several master and PhD theses. We lost an excellent scientist, a competent colleague, and a good friend.

Session 1: Design and technologies I (chair: Mariusz Sapenski - GSI)

Preliminary Study on IPM for CADS Injector

Jun He, IHEP, Beijing, China

The talk summarises the present status of the IPM development, which serves as a prototype for the Chines ADS and the neutron spallation source CSNS and the heavy-ion facility HIAF. The IPM detector consists of a round ∅ 75 mm Multi-Channel Plate (MCP) with an optical readout. For calibration purposes, an Electron Generation Array (EGA) is installed. Jun He reported on the experiences at the LINAC with moderate vacuum pressures. The signal is sufficient and, due to the beam current, transverse size (standard deviation during the tests was $\sigma > 10$ mm), and bunch length, the space charge broadening is at an exceptional level without applying a magnetic field. Some operational challenges due to electromagnetic interference are reported and significant background contributions related to the test installation close to a beam dump. The latter should not be relevant for the installation at the foreseen locations within the LINAC sections.

Current status of the BGI profile monitor for the CERN PS based on the Timepix3 hybrid pixel detector

Swann Levasseur, CERN, Geneva, Switzerland

For the injector upgrade at CERN, new diagnostics are required to operate the high-brilliant beams required for the High Luminosity LHC beam parameters. An IPM for PS is under development. This IPM for the horizontal plane was recently installed and tested some weeks before the workshop. The IPM uses electron detection mode for a time resolution of about 1 ms in the integration mode (high resolution) and a turn-by-turn mode on the 1 µs time scale with a storage capacity of 5000 turns. The vacuum pressure is in the order of 10^{-9} mbar. It is surrounded by a large dipole magnet commonly mounted together with the corresponding corrector dipoles to correct the proton beam closed orbit; this leads to a compact installation of only 80 cm insertion length.

In contrary to other IPMs, this monitor does not use an MCP but a silicon pixel detector. This so-called Timepix3 detector is a joint development of several high-energy physics and medical imaging groups. It consists of a 256 x 256 matrix of pixels with 55 x 55 µm pixel size. This ASIC chip is fully equipped with readout digitalisation based on FPGA technology enabling several readout methods. Four Timepix3 chips are mounted to cover the required range for the transverse beam profile measurement. It is the first time that such a pixel detector and its active electronics is installed in a vacuum. Cooling of the electronics was an issue but could be solved; the detector is now in operation. First beam images are presented in the talk showing the potential of this readout technology.

GSI IPMs

Tino Giacomini, GSI, Darmstadt, Germany

Since several years, IPMs have been in operation at GSI synchrotron and storage rings using an ion detection mode. The detection is based on a 100 x 50 mm Chevron MCP read by a wire array of 2.1 mm spacing. The time resolution of the related electronics is 10 ms. To increase the spatial resolution, an IPM under development uses a phosphor readout. A camera performs the digitalisation in the so-called high resolution mode with about 10 ms time resolution. In future, fast photodetectors are foreseen for a turn-by-turn readout (due to the vacuum pressure in the order of 10^{-11} mbar, the signal strength is only sufficient for ion beams). The high voltage of the monitor's field cage can be connected such that alternatively ion or electron detection is possible. The IPM installation comprises large aperture dipole magnets (about 50 cm aperture) and corresponding corrector dipoles, leading to an insertion length of about 2.5 m. The mechanical design considerations, the software status and the first experiences from bench tests are reported. A monitor without a magnetic field (and hence with ion detection mode only) is installed in the GSI storage ring ESR and at FZ-Jülich COSY ring (see below for the talk by Christian Böhme). Both installations show good performance and are well suited to monitor the beam cooling process.

For the MCP calibration, GSI has very positive experiences using a UV lamp (deuteron lamp, emission maximum 115 nm) mounted outside of the vacuum chamber and illuminating the MPCs via MgF_2 window.

Session 2: Design and technologies II (chair: James Storey - CERN)

IPM Experience at SNS

Alexander Aleksandrov, SNS, Oak Ridge, USA

In the SNS accumulator ring, a test IPM is installed. The installation aims for a turn-by-turn resolution, corresponding to about 1 µs for the full beam of up to 10^{14} protons. A movable channeltron is used for the detection. To enable the required time resolution for the electron detection mode, a very high electric field is foreseen with an electrode voltage up to 120 kV. This high voltage requires a dedicated design and special insolation. Problems are reported related to signal oscillations for the electron detection mode, which depend on the field cage voltage. A large-aperture dipole magnet is installed; dedicated correctors are not required as existing steerers can correct the closed orbit distortions. However, the IPM required large insertion space and was very expensive. An ion detection mode does not require a magnet; however, the achievable time resolution does not fulfil the turn-by-turn readout requirement.

Presently, the IPM is not used anymore as it is a too expensive device and difficult to operate. Instead, SNS is in favour of an electron beam scanner mounted in the accumulator ring. For the detection in the LINAC, a laser wire scanner is in preparation. Photo-detachment is a suitable method for the accelerated H^- atoms, which provide transverse and longitudinal diagnostics. The laser scanner layout is briefly discussed.

Supersonic gas-jet beam profile monitor

Hao Zhang, Cockcroft Institute, Warrington, UK

For several applications, e.g. at low current medical synchrotrons, the signal strength of an IPM operated with the ambient vacuum pressure is too low. To increase the gas density in the interaction region, a gas jet can be used instead. At Cockcroft Institute, an IPM with a supersonic gas jet is under development. The gas jet is created by a nozzle enabling a supersonic expansion to create cold gas with a defined velocity profile. Two skimmers form a gas jet that interacts with the beam. The jet is caught by a chamber extension opposite to the nozzle and efficiently pumped by a turbo-molecular pump. The arrangement barely influences the ambient pressure of the vacuum chamber. The gas-jet properties are investigated with a movable gauge proving the correct supersonic expansion and the skimmer functionality. The layout of the gas system and the IPM is presented. The device was extensively tested with a low current electron beam. The same type of gas-jet can be used for the Beam Induced Fluorescence (BIF) detection, where an image-intensified camera can monitor photons from the excited gas (e.g. nitrogen). The latter system is foreseen as a profile monitor at LHC. The possibility of gas-jet focusing by Fresnel zone plates is proposed in the talk.

Session 3: Operational issues I (chair: James Zagel - Fermilab)

Current status of the optical-based SPS and LHC BGI Profile Monitors

James Storey, CERN, Geneva, Switzerland

The IPM installed at CERN SPS and LHC is a bit older construction. It uses electron detection mode amplified by an MCP and P46 phosphor. For compact installation, the phosphor is deposited on a prism used as a mirror to guide the light towards a camera. A magnet of 200 mT is used; the insertion space is not an issue in this synchrotron. Some recent technical problems are reported. In particular, the ageing of the MCP is a problem as well as a degradation of the phosphor efficiency. An Electron Generation Array (EGA) is used for the MCP calibration. For the nominal LHC beam in SPS some image broadening is observed, calling for an increase of the magnetic field to at least 1 T. Moreover, a beam-

based heating by wake-fields is observed for such high current beams, which destroyed one prims. The main goal for the near future is an improvement of the user software to enable operational usage.
For the intense beams in LHC, further upgrade, e.g. a stronger magnetic field, is urgently required as the accelerated beam's space charge is so large that significant image distortion is expected even in the case of electron detection. It might be required to change the IPM installation significantly.

News from J-PARC: the system, the data and the simulation code

Kenichirou Satou, J-PARC, japan

The contribution discusses the Main Ring IPM installation. The monitor comprises an electric field cage operated by a relative voltage up to 50 kV. The MCP signal is read by a strip array of 2.5 mm pitch. The MCP calibration is realised by an Electron Generation Array (EGA). An electromagnet surrounds the IPM with 250 mT field strength. Corrector magnets are installed close by to correct the proton beam closed orbit. The magnet design is discussed in the talk, including the requirements for the field quality and the 'cross talk' between the main magnet and the close-by corrector magnet with inverse field direction.
A pulse mode operation was recently commissioned, which allows a turn-by-turn reading without too high risks for an MCP destruction; a duty factor of 1 % is typically chosen (1ms profile measurements per second); the MCP lifetime should increase than be roughly a factor of 100. This setup is comparable to the one designed by Fermilab. A beam-based calibration was realised by scanning the beam across the detection area, which might offer some significant advantages compared to using an EGA. With those advanced methods in operation, the IPM is used frequently for beam alignments.

Operational experience of the electron collecting IPM at AGS/ BNL

Chuyu Liu, BNL, Brookhaven, USA

BNL has many years of experience in the construction and operation of IPMs, and several variants were tested. Electron detection is nowadays used in the AGS and RHIC. After amplification by a single MCP, the electrons are collected by an anode board of 64 channels of 0.5 mm strip width. The total detection width is 3.2 cm only. To increase the signal strength, a controllable vacuum valve is used with an inlet of CO_2 gas. The IPM is surrounded by a magnet to guide the residual gas electrons. One operational problem is related to a beam movement larger than the detection widths of 3.2. cm, which might lead to a wrong interpretation of the profile reading. Beam-based calibration by a moving beam across the detection area is used at BNL. Besides profile measurements on a turn-by-turn basis, the system is used for beta-function measurements.

Session 4: Operational issues II (chair: Alexander Aleksandrov - SNS)

Beam Profile Monitors at Fermilab, a 2017 update

James Zagel, Fermilab, Batavia, USA

IPMs are installed in all synchrotrons at Fermilab. They use electron detection mode and a Chevron MCP of typical 100 x 100 mm size for single-particle amplification. The readout is performed by a wire array on a Printed Circuit Board with a 0.5 mm strip width. In the booster, no magnetic field is required related to the large beam size. In the Main Ring, permanent magnets are installed, offering a more compact installation compared to electromagnets. Several improvements are discussed in the contribution.
The operational usage is mainly related to injection optimisation, which is performed by turn-by-turn detections. Switching of the electric field is required to enhance the MCP lifetime, which was recently realised by the modulation of the guiding electric field. A performant user interface is available, allowing the usage by non-expert during daily operation.
The efficiency and spatial homogeneity of the MCPs is an essential topic for the image reproduction of the beam profile. Fermilab operates a dedicated test chamber for MCPs; a filament of a vacuum gauge

acts as a source of electrons. Test results concerning the MCP characterisation are discussed in the contribution.

Analysis of optical IPM data

Mariusz Sapinski, GSI, Darmstadt, Germany

The contribution concerns the data analysis for the recently installed IPM at CERN LHC; the hardware is described in the talk by James Storey, see above. Due to the small size of $\sigma \approx 300$ µm and the large bunch current, space charge effects are dominant, even in the case of electron detection with a magnetic field of ≈ 200 mT. This leads an image deformation, which has a non-linear dependence on the profile shape and bunch current.

The second source of image deformation is related to the secondary ion suppression wires (mounted opposite to the MCP), optical system, and camera noise. The latter manifests itself in strips on the image and interleaving products of the Thermo Scientific Charge Injection Device (CID) camera. To eliminate the regular readout pattern with a 25 Hz noise structure, Image reconstruction methods were tested. The application of an FFT filter was only partly successful as frequency mixing products were not entirely compensated by the FFT filter. As a second method, the deconvolution using a calculated Point Spread Function of the entire system was applied. The work is ongoing, so no defined conclusion can be drawn for the time being concerning the best operational usage.

Operational Experience with the Ionization Beam Profile Monitor at COSY

Christian Böhme, FZJ-COSY, Jülich, Germany

FZJ and GSI commonly developed the IPM hardware at COSY. Ion detection is applied at COSY as the beam current for most experiments is low such that space effects are not expected; therefore, no magnetic field is required. The monitor comprises an electric field cage optimised for a homogeneous electric field in the interaction region, uses a Chevron MCP with a phosphor readout by a standard CCD camera with a GigE interface. The related data acquisition software is based on Labview, and a reasonable performant user interface is available.

Reflections of the light from the phosphor at the vacuum chamber wall lead to some image distortions; however, this could be subtracted from the correct beam image. Some modifications of the phosphor thickness or efficiency occurred for unknown reasons. In future, a software upgrade using EPICS is planned.

Beam Ionisation Profile Monitor Proposal for ELENA

Pierre Grandemagne, CERN, Geneva, Switzerland

The ELENA ring at CERN is used to decelerate anti-protons from 5.3 MeV to 100 keV with the application of electron cooling at intermediate and final energy. The main goal for the IPM is the observation during the entire cycle. The recently constructed mechanics is depicted. In contrary to other IPMs, a Z-stack (triple) MCP is used to increase the amplification. Moreover, a gas injection system for CO_2 is required to increase the signal strength for the low current anti-proton beam; the related average vacuum pollution in the ring stays at an acceptable level (below 9 %); no significant decrease of the beam lifetime was observed. The evolution of the beam profile was recorded with sufficient statistical accuracy in the case of a CO_2 gas inlet.

Session 5: Simulation I (chair: Kenichirou Satou – J-PARC)

Summary of the outcome of the first workshop

Mariusz Sapinski, GSI, Darmstadt, Germany

The talk summarises the results from the preceding workshop called 'IPM Simulation kick-off Workshop', INDOC site https://indico.cern.ch/event/491615/, which was organised by CERN and held on 3rd to 4th of May 2016 in Geneva. An almost complete survey of the existing simulation codes of the space charge broadening for IPMs was executed at this workshop. A contribution to the conference

IBIC in 2016 summarises the status [1]; the table from this publication is shown below. The publication contains an excellent overview of the various methods used in those codes; some comments are included in the paragraphs below related to the individual codes. Compared to the status of the first workshop in March 2016, some progress has been achieved up to now: Several codes were compared to assess the influence on theoretical assumptions and numerical accuracy. Some of the codes are benchmarked with respect to each other using the same input parameters. This led to debugging and significant improvements of some codes. Most participants of the preceding workshop attended the actual workshop, leading to an intensified discussion on the simulation methods.
It is a solid proposal to focus the investigations towards a single code development. The package IPMSim3D is best suited for this purpose, as it uses only freeware and is written in the performant language Python [2]. The code is available at https://gitlab.com/IPMsim/Virtual-IPM and the documentation at https://ipmsim.gitlab.io/Virtual-IPM/. Dominik Vilsmeier reported on the code layout in a separate talk; see below. The leadership is in the hand of GSI, and most participants explain their interest to participate in the joint development with a contribution to the code development. However, for comparison, some of the existing codes will be maintained by the corresponding institutes.

Tabulated overview on IPM simulation codes in the year 2016, published with more details in [1]

Name/Lab	Language	Ionization	Guiding field	Beam shape	Beam field	Tracking
GSI code	C++	simple DDCS	uniform E,B	parabolic 3D	3D analytic relativ.	numeric R-K 4th order
PyECLOUD-BGI /CERN	python	realistic DDCS	uniform E,B	Gauss 3D	2D analytic relativ. only	analytic
FNAL	MATLAB	simple SDCS	3D map E,B	arbitrary	3D numeric relativ. (E and B)	num. MATLAB rel. eq. of motion
ISIS	C++	at rest	CST map E only	arbitrary (CST)	2D numeric (CST) non-relativ.	numeric Euler 2nd order
IFMIF	C++	at rest	Lorenz-3E map E only	General. Gauss	numeric (Lorenz-3E) non-relativ.	
ESS	MATLAB	at rest	uniform E,B	Gauss 3D	3D numeric (MATLAB) relativ.	numeric MATLAB R-K
IPMSim3D /J-PARC	python	realistic DDCS	2D/3Dmap E, B	Gauss 3D	2D numeric (SOR) relativ. only	numeric R-K 4th order

[1] M. Sapinski et al., "Ionization Profile Monitor Simulations - Status and Future Plans",
in Proc. 5th Int. Beam Instrumentation Conf. (IBIC'16), Barcelona, Spain, Sep. 2016, pp. 520-523.
https://doi.org/doi:10.18429/JACoW-IBIC2016-TUPG71
[2] D. Vilsmeier, P. Forck, and M. Sapinski, "A modular Application for IPM simulations",
in Proc. IBIC'17, Grand Rapids, MI, USA, Sep. 2017, pp. 335-338.
http://jacow.org/ibic2017/papers/wepcc07.pdf

IPM simulations in Fermilab

Randy Thurman-Keup, Fermilab, Batavia, USA

The code at Fermilab is written in MATLAB as it was initially foreseen to be used by the experienced programmer only. Several advanced features are included now. Single differential cross sections are implemented to describe the electron generation process. The tracking part for the residual gas electrons uses full relativistic equations; a Runge-Kutta algorithm will be implemented soon. Since the proton bunches' field is evaluated externally and imported, the bunch shape is not limited to any functional form. Interpolated field maps are used for guiding electrical and magnetic fields. The contribution discusses several interesting simulation results and their physical interpretation.
One recent topic is related to the switching requirement to prolong the lifetime of the MPCs by the modified potential at the electrodes, as mentioned in the talk by James Zagel. To fix the related

parameters, the code calculates the electric field and the electron trajectories in the switch-off state. Recently, the functionality was experimentally demonstrated.
In addition, the code was successfully applied for the simulation of the electron trajectories for a laser wire scanner (photo-detachment from an H^- beam, available at the Fermilab LINAC) and an electron beam scanner (deflection of external 60 keV electrons by the beam space charge) as installed in the main injector.

Space charge studies for the ESS Ionization Profile Monitor

Francesca Belloni, CEA/Saclay, Saclay, France

Motivated by the layout of IPMs for the ESS LINAC, a code was developed at CEA/Saclay to test possible image deformations for the nominal beam parameters. Due to the enormous beam power, non-intersecting profile detection is required. The code solves the classical equation of motion for any charged particle in an electromagnetic field. A Gaussian distribution is assumed in the rest frame for the proton beam and then Lorentz-transformed to the lab frame. Non-linear Runge-Kutta tracking is applied. The code is written in MATLAB.
For the ESS IPMs, ion detection is foreseen, as the insertion space does not allow for extra magnet installation. Possible image deformations are discussed in the contribution. For the typical beam parameters, acceptable deformation is achieved if a relatively high electric field of 300 kV/m is applied. This high voltage might lead to a technical challenge for the required high voltage.

Session 6: Simulation II (chair: Jacques Marroncle – CEA/Saclay)

Follow up on old GSI code

Serban Udrea, GSI, Darmstadt, Germany

Starting in the year 2004, a code was developed at GSI for the IPM and Beam Induced Fluorescence (BIF) simulations. It is based on an analytic solution for parabolic transverse distribution and either coasting or bunched beams using elliptical coordinates. The advantage of the analytic solution is the significantly faster processing time. However, electrical boundaries cannot be included, e.g. related to the vacuum pipe. Tracking is performed by the Runge-Kutta method. The guiding electric and magnetic fields must be homogeneous. The code is written in C++ using a nowadays obsolete Borland compiler. The package has a reasonably good graphical user interface: Input parameters are well-arranged, and intermediate results are depicted. The output is stored in several formats.
Several bugs of the code are discovered during the benchmark period, which is corrected, or will be corrected soon. The GSI code will be available for some time as it allows more straightforward usage; even though the IPMSim package is more performant and better maintainable,

Simulations and Studies of IPMs at ISIS

Chris Wilcox, ISIS, Rutherford Appleton Laboratory, UK

Contrary to other IPM realisations with a rectangular electric field box, a unique mechanical arrangement is realised at the ISIS synchrotron. The field forming electrodes are longitudinally shifted with respect to the detectors for the horizontal and vertical plane. This allows a compact installation for both planes. As caused by a resulting longitudinal electric field component, the movement of the residual gas ions follows a curved trajectory. This results in a more complex simulation of the space charge induced image broadenings. The monitor uses ion detection by an array of 40 channeltrons.
The ISIS code uses field maps generated by 3-dim CST calculations for the external guiding electric field and the bunched beam, allowing for arbitrary proton beam distributions. A homogeneous residual ion distribution is generated within the beam volume; the ion tracking is performed by a 2nd order Euler method to solve the equation of motion. The code is realised in a C++. Post-processing is applied to achieve realistic proton beam distribution by weighting the initially homogeneous start distribution.

Code validation is performed at a transfer line IPM by comparison to the profile measurement by an SEM-grid. Due to the more complex monitor arrangement, a direct comparison to simulation results obtained for other accelerators is difficult.

A new, modular framework for IPM simulations

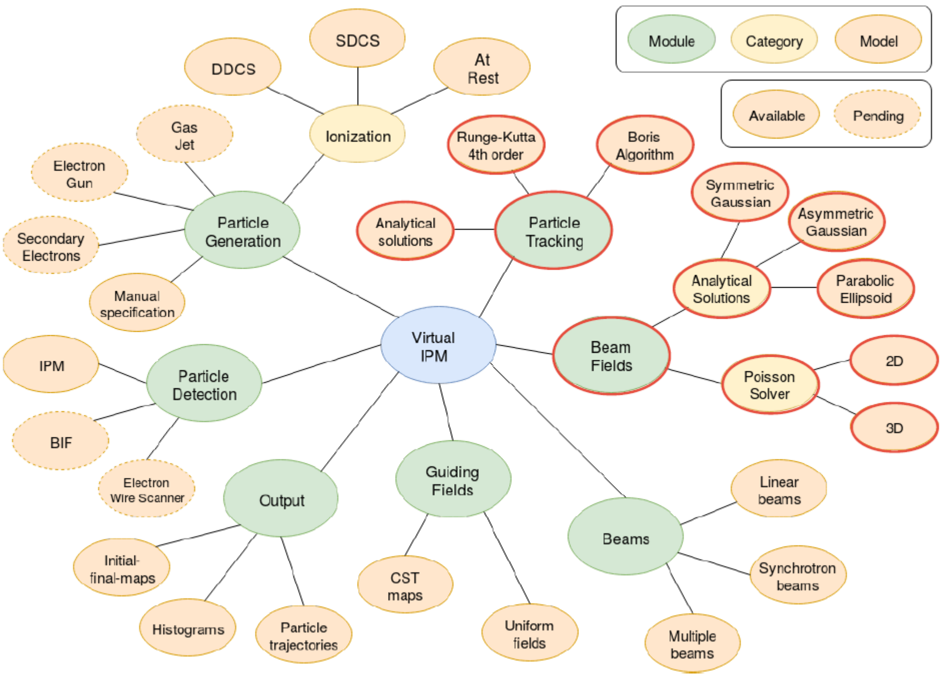
Dominik Vilsmeier, GSI, Darmstadt, Germany

It was one of the workshop goals to introduce the participants to the recent development of the newly developed code IPMSim (or alternatively called Virtual-IPM) at GSI. The code is available at https://gitlab.com/IPMsim/Virtual-IPM and the documentation at https://ipmsim.gitlab.io/Virtual-IPM/. The primary motivation was to focus the simulation efforts on one code, which is commonly developed; GSI will overtake the maintenance issues. The code is written in Python 3, including the scientific packages 'numpy' and 'scipy'.

The figure below shows the global architecture of the software package. For electron generation, the simulation uses realistic double differential cross-sections. For the residual gas electron or ions tracking, a Runge-Kutta or Boris algorithm can be chosen. External electric and guiding magnetic fields can either be assumed as homogeneous, or maps can be imported from field solvers such as CST and COMSOL. The field of the proton or ion beam can be generated either by analytical descriptions (e.g. for Gaussian- or parabolic distributions) or is calculated via a 3-dim Poisson solver. This is important for 'exotic' beam distributions, e.g. for beams generated by multi-turn injection or cooled beam resulting in non-Gaussian distributions. For the case of an IPM simulation, the residual gas electrons or ions are stopped at a barrier. The code can simulate the situation relevant for Beam Induced Fluorescence, where photons are emitted after a specific (exponentially distributed) lifetime. Moreover, the code can calculate the field by multiple beams, e.g. the merged electron and proton beam for the planned, hollow electron lens at High-Luminosity LHC.

A graphical user interface allows for well-controlled input parameter choice and can depict intermediate results, e.g. single electron trajectories. The user can specify several output formats; e.g. a map comparing the initial and final electron or ion coordinates is also available. Further modules can be included in the package on demand. The IMPSim package was benchmarked versus other codes.

Some hand-on demonstration followed the talk to motivate the package usage, call for comments, and eventually contributions to the development.



The modular components of the IPMSim package

Session 7: Special presentations (chair: Peter Forck – GSI)

Storage of ions at low energies at GSI and Precision Experiments over 12 Decades

Frank Herfurth, GSI, Darmstadt, Germany

The talk intended to introduce recent developments at the GSi facilities dedicated to highly charged ions stored at low energies. The HITRAP facility is discussed, where heavy ions are accelerated with the UNIVAC & SIS facility to typically 400 MeV/u and stripped to a high charge state. Then they are decelerated in the ESR storage ring, where an electron and stochastic cooling is applied. A LINAC further decelerates the beam down to 100 keV/u to enable the injection into a trap. Here cooling is applied by collision with cold helium gas. Finally, the ions can be used for atomic physics experiments, e.g. for basic research in additional Penning traps to measure the g-factor of those highly charged ions. The actual achievements concerning the accelerators and experimental setup at GSI are reported. This type of cold, highly charged ion generation is compared to achievements using an EBIS ion source.
A low energy storage ring will be installed at GSI soon, a refurbishment of the CRYING from Manne Siegbahn Institute in Stockholm. It fits well into the GSI facility as highly charged ions will be stored, cooled and decelerated. Atomic physics investigations will be possible, e.g., measuring the Lamp-shift of highly charged ions as a precision study of QED.
The talks served as an introduction to the guided tour at GSI.

IPM Profile Reconstruction using Neural Networks

Rahul Singh, GSI, Darmstadt, Germany

IPMs with ion detection is realised when insertion space is limited (e.g. at LINACs), leading to a significant image broadening. However, even for the case of electron detection, a magnetic guiding field of about 300 mT might not be sufficient to guaranty an undistorted electron transport (e.g. for small beams at LHC). Moreover, the initial velocity of the electron, as generated by the kinematic of the collision with the beam particles, leads to some deformation of the measured profile. As shown by various simulation codes, the measured distribution might deviate in a non-linear manner from the initial beam profile. Non-linear reconstruction techniques could be applied for these beam parameters. Machine Learning by Artificial Neural Network (ANN) could be an appropriate method to achieve an efficient reconstruction. Using the available simulation results as generated, e.g. by IPMSim, a basis for the ANN training can be generated on a considerable large span of beam parameters such as transverse and longitudinal beam distribution as well as beam currents. The contribution discusses the basics of supervised ANN and shows a route for realising a matched network and its parameter. First tests were executed using a dedicated MATLAB toolbox applying various ANN parameters.
The novel method of Machine Learning by supervised ANN seems to be a forward-looking technology for such image reconstruction and will be investigated intensively in the future.