Ionization Profile Monitor Simulations
Status and Future Plans

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Abstract

Nonuniformities of the extraction fields, the velocity distribution of electrons from ionization processes and strong bunch fields are just a few of the effects affecting Ionization Profile Monitor measurements and operation. Careful analysis of these phenomena require specialized simulation programs. A handful of such codes have been written independently by various researchers over the recent years, showing an important demand for this type of study.

In this paper we describe the available codes and discuss various approaches to Ionization Profile Monitor simulations. We propose benchmark conditions to compare these codes among each other and we collect data from various devices to benchmark codes against the measurements. Finally we present a community effort with a goal to discuss the codes, exchange simulation results and to develop and maintain a new, common codebase.

The collaboration

Goals

→ Exchange of experience

→ Benchmarking of codes against each other and against measurements

→ Development and maintenance of a complete, modular codebase

Infos

→ First kick-off workshop took place at CERN in March 2016

→ Future meetings are planned to discuss the results and next steps

→ You are welcome to join our collaboration or just visit our webpage to obtain more information!

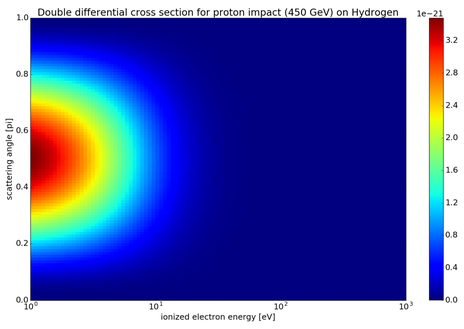
https://twiki.cern.ch/twiki/bin/view/IPMSim

Simulation components

Ionization

Methods

- Particles at rest
- Experimental data
- Double differential cross sections



- Tracked particles are created in the ionization process (electrons + ions)
- Positions are generated according to the charge distribution of a bunch while generation of momenta needs to take into account the interaction between the beam and the gas target

Particle Tracking

Methods

- Analytic solution of e.q.m.
- Runge-Kutta-method
- Boris algorithm

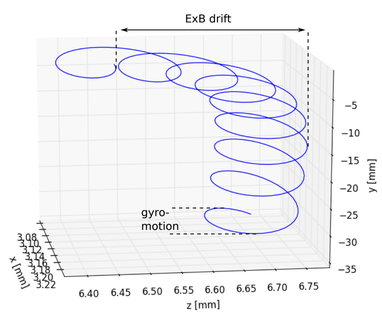
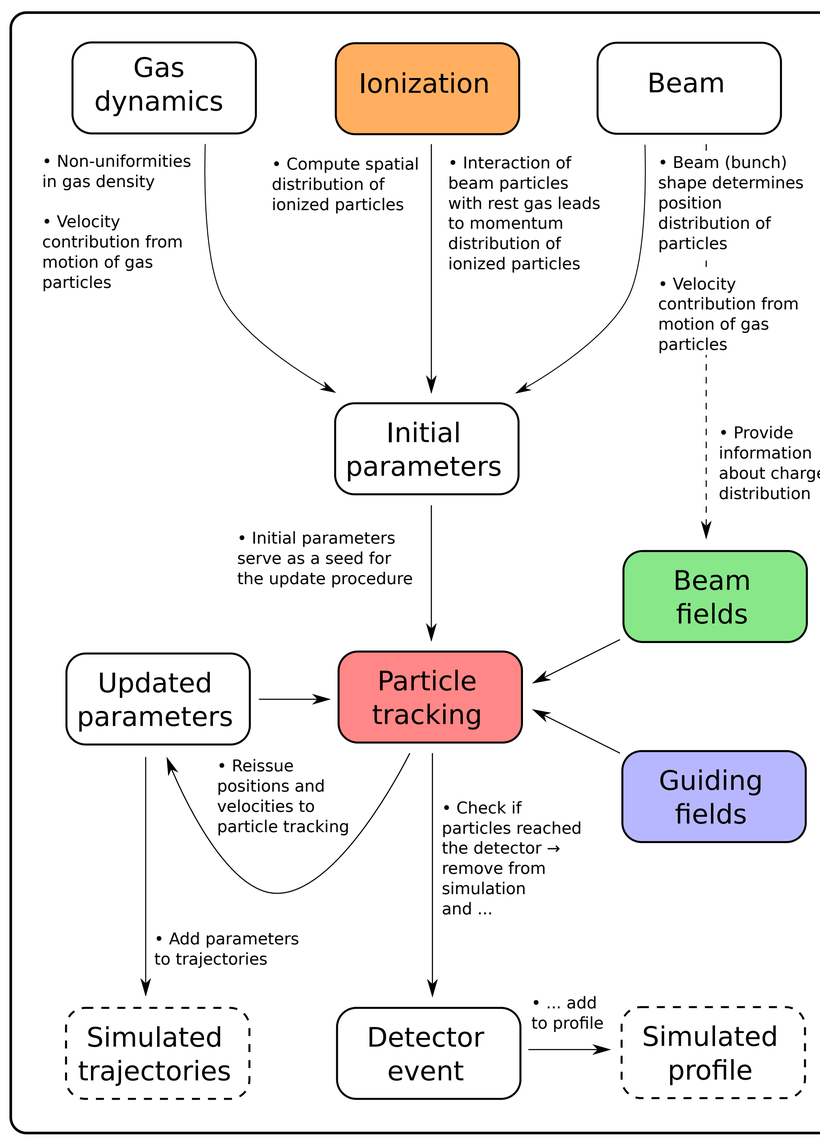


Fig.: Example of a particle trajectory under the influence of the beam electric field and a magnetic guiding field.

- Positions and velocities of tracked particles are updated every timestep during the simulation
- The error which is introduced by the discrete updates must be kept small



Beam fields

Methods

- Analytic solution for specific charge distributions
- FEM solvers
- PIC solvers

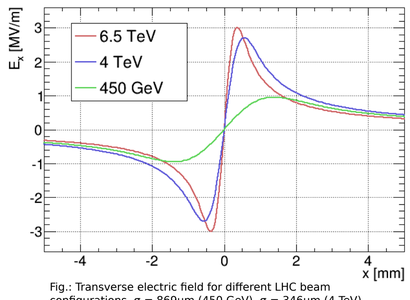


Fig.: Transverse electric field for different LHC beam configurations. σ = 869μm (450 GeV), σ = 346μm (4 TeV), σ = 229μm (6.5 TeV).

- To investigate the influence of beam space charge the beam electric (and magnetic) fields need to be taken into account
- This is mainly important for high energy and high brightness beams as they generate a strong electric field

Guiding fields

Methods

- Uniform fields
- FEM solvers

- Field non-uniformities - resulting from the design of the HV-cage - can lead to noticeable profile distortions
- Knowledge about the field non-uniformities might be essential to recontruct the actual beam profile

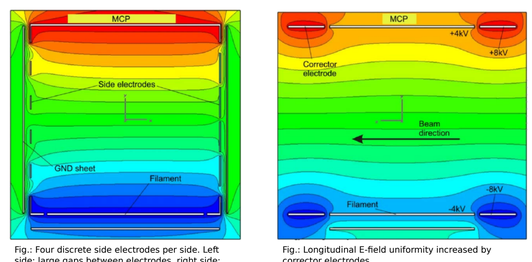


Fig.: Four discrete side electrodes per side. Left side: large gaps between electrodes, right side: small gaps.

Fig.: Longitudinal E-field uniformity increased by corrector electrodes.

Common tools

XML data format

- XML based format for storing data related to transverse beam profile measurements
- Stores a number of profiles or images along with important meta data
- The goal is to facilitate comparison and processing of data among the different parties

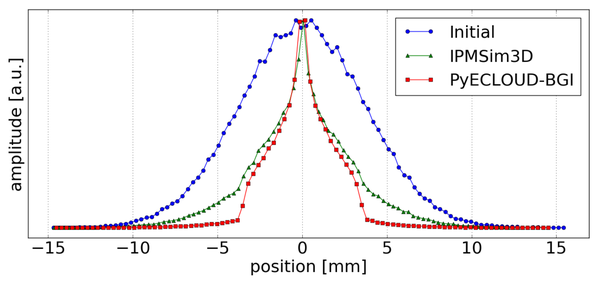


Fig.: Comparison of different codes for a benchmark case (PS case).

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        <Date>2016-06-22</Date>
        <Contact>
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            <Email>d.vilsmeier@gsi.de</Email>
        </Contact>
        <Comment>This is a comment about the measurement.</Comment>
    </Meta>
    <Device>
        <Id>pyECLOUD</Id>
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                <Gas>
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                </Gas>
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            </IPM>
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    </Device>
    <Beam>
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```

Fig.: Excerpt from an example data file using the XML format.

Data analysis GUI

- A software - written in Python - has been developed for visualizing and processing data that uses the above mentioned format
- The software works with images and profiles and can perform common tasks such as normalizing, centering or fitting profiles

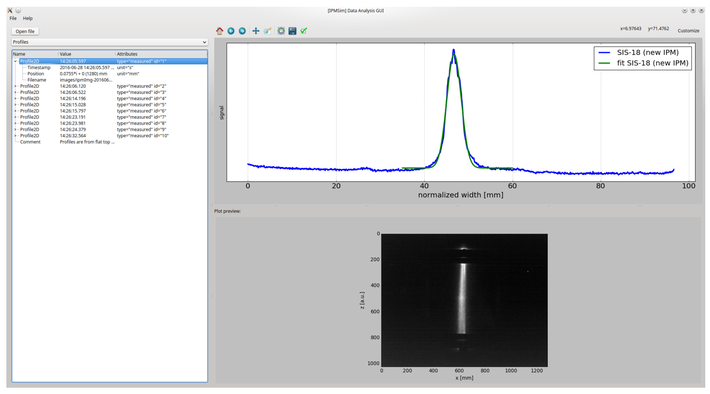

Fig.: Screenshot from the Data Analysis GUI.

Known simulation codes

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

Summarization of the known codes within the collaboration. Only PyECLOUD-BGI and IPMSim3D are public so far, however GSI code and ESS code are planned to be released as well.

- PyECLOUD-BGI is the only code using an analytic solution for the equations of motion (for the special case of no longitudinal electric field component and only one magnetic field component)
- IPMSim3D is the only code that uses a self-built solver for the beam fields
- FNAL code is the only one using relativistic equations of motion

Conclusions

- The goals are to exchange information between researchers working in different laboratories and share experience in designing and understanding these devices.
- Currently a few of the described codes are still under independent development, however a common effort to develop a universal, modular multi-purpose approach is also ongoing.