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Ion Beam Simulator

Taneli Kalvas

Department of Physics, University of Jyväskylä, Finland

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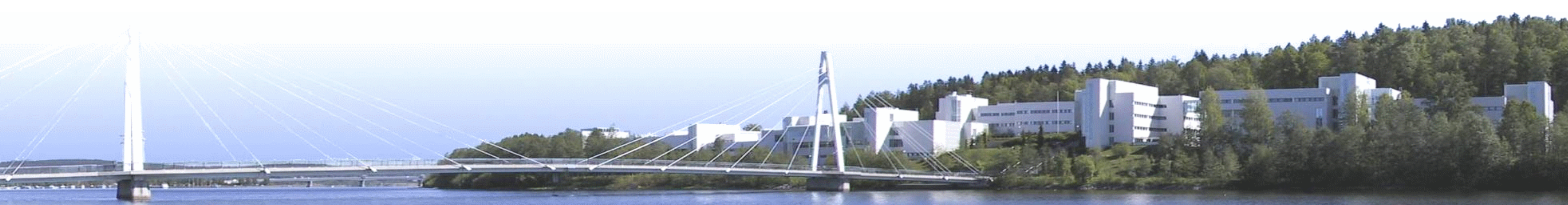
Contact: T. Kalvas <taneli.kalvas@jyu.fi>

Outline

1. What is IBSIMU and why?
2. What it does and how
3. Examples of use
4. Overview of project



What is IBSIMU

IBSIMU is an ion optical computer simulation package especially for the ion source community.

Capabilities:

- Definition of electrode geometry and calculation of electric fields in 1D, 2D, 3D and cylindrical symmetry.
- Non-relativistic CW or pulsed particle trajectory calculation in electric and magnetic fields.
- Space charge density from trajectories and self-consistent transport of space-charge dominated beams.
- Positive and negative ion (and electron) plasma extraction.
- DXF import, diagnostics tools, etc, ...

History

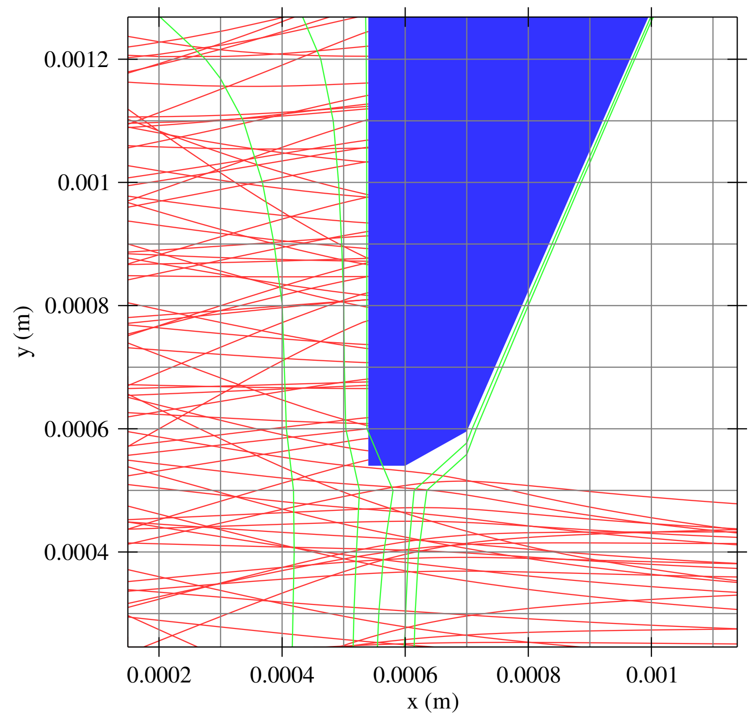
Birth history

- Other codes with similar capabilities include IGUN, PBGUNS, SIMION, KOBRA and LORENTZ for example.
- For some work they are limited in features.
- New problem specific codes are developed for these problems.
- Development of IBSIMU was started at LBNL in 2004 in such a situation for a specific project.
- Work continued at JYFL in 2007 by making the code more general purpose, highly modular and open.
- At ICIS 2009 the code was announced to the community and made publicly available.

What is it based on?

Calculation is based on evenly sized square cartesian grid(s):

- Solid mesh (node type): vacuum, solid, near solid, neumann boundary condition, ...
- Electric potential
- Electric field
- Magnetic field (imported)
- Space charge density
- Trajectory density

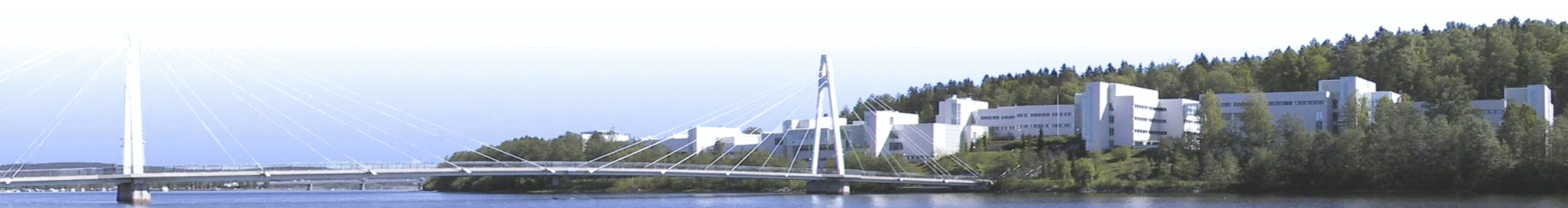


Fields and particle trajectories

Electric potential is solved using FDM representation of Poisson's eq.

$$\nabla^2 \phi = -\frac{\rho}{\epsilon_0}$$

Electric field is derived from potential and particle trajectories are ray-traced through the fields using adaptive Runge-Kutta iterator.



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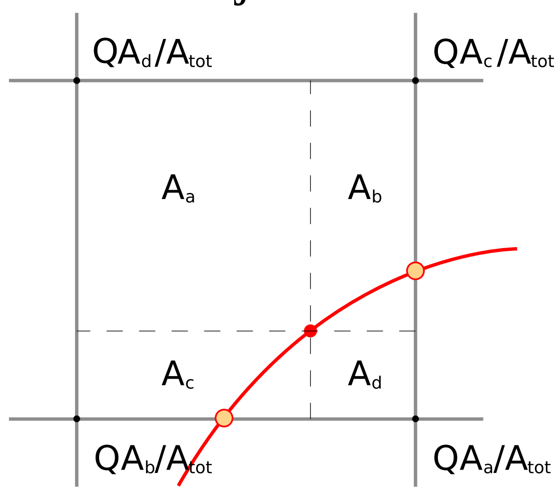
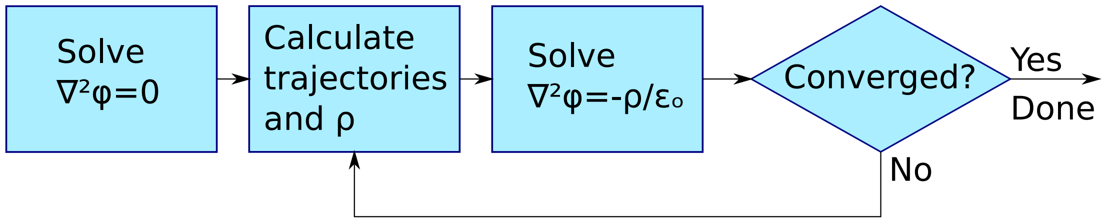
Space charge is calculated from trajectories with PIC type of method



Need for several particles/grid unit for smooth space charge field.

Vlasov iteration

Self-consistent solution for space charge problem is found iteratively



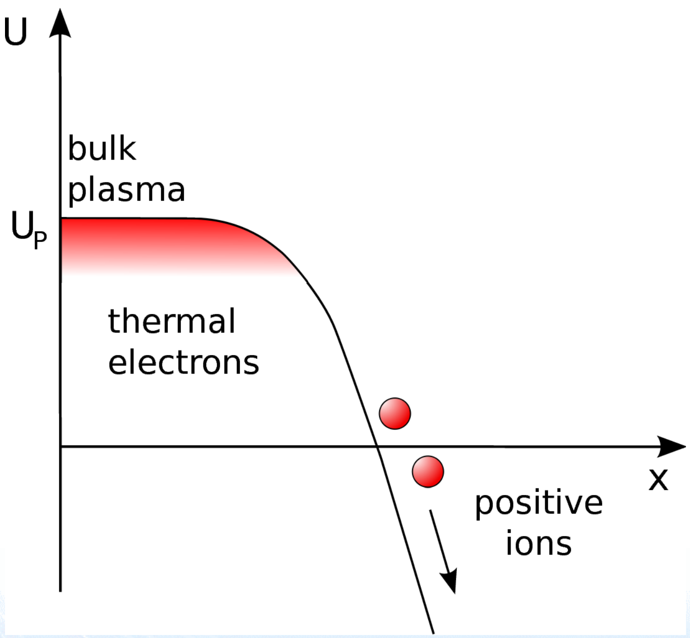
Under-relaxation of space charge may be needed to achieve convergence with high space charge systems.

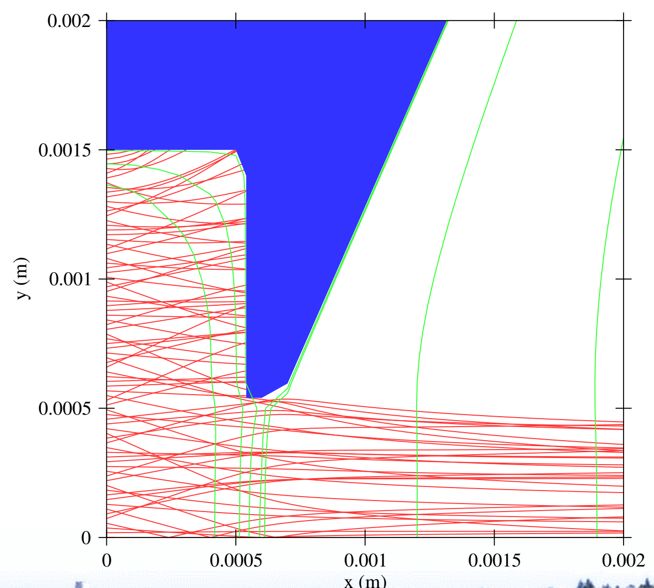
Plasma models

Modelling of positive ion extraction

- Ray-traced positive ions
- Nonlinear space charge term (analytic in Poisson's equation):

$$\rho_{\mathrm{e}} = \rho_{\mathrm{e0}} \exp\left(\frac{\phi - \phi_P}{kT_e/e}\right)$$

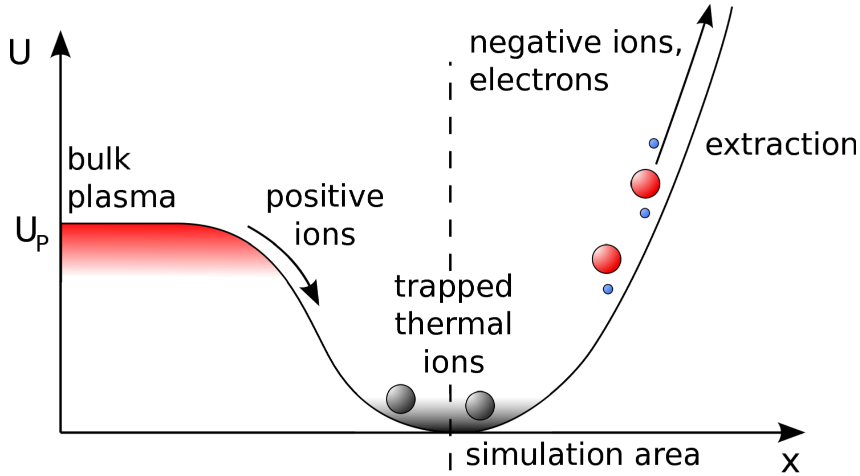




Plasma models

Modelling of negative ion extraction

- Ray-traced negative ions and electrons
- Analytic thermal and fast positive charges
- Magnetic field suppression for electrons inside plasma



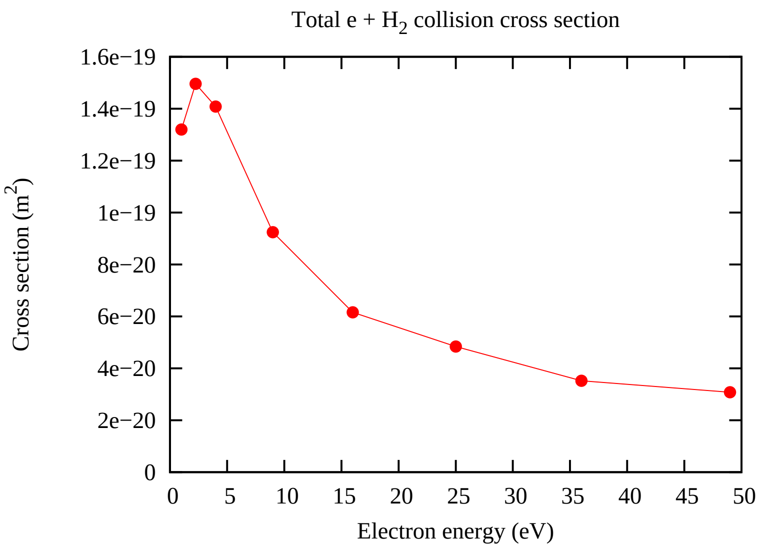
$$\rho_{\mathrm{th}} = \rho_{\mathrm{th0}} \exp\left(\frac{-eU}{kT_i}\right)$$

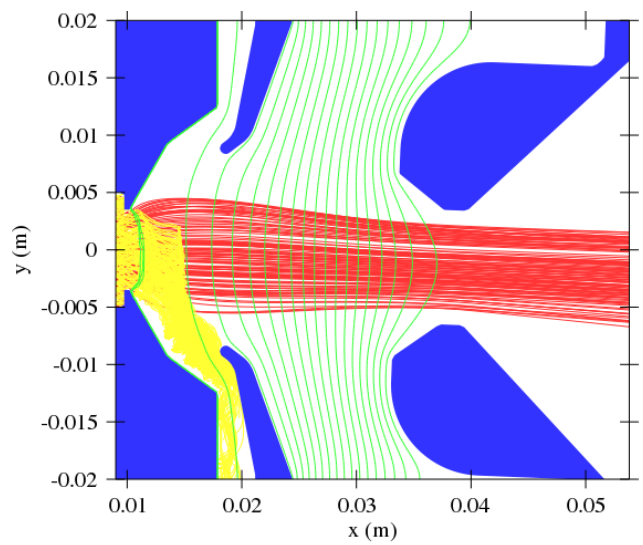
$$\rho_{\mathrm{f}} = \rho_{\mathrm{f0}} \left(1 + \mathrm{erf}\left(\frac{eU}{E_i}\right)\right)$$

Plasma models

Magnetic field suppression for electrons inside plasma

- Electrons highly collisional until velocity large enough
- Magnetic field suppression for electrons inside plasma





Miscellaneous methods

- Visualization: interactive, png, pdf, eps, svg
- Geometry views with solids, trajectories, beam density, space charge density, field plots, equipotential lines, etc.
- Emittance, profile plots and statistics
- Field diagnostics: 1d plots of fields and ascii exports
- Binary data saving and loading (for post processor)

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New features developed during CERN IBSIMU Workshop:

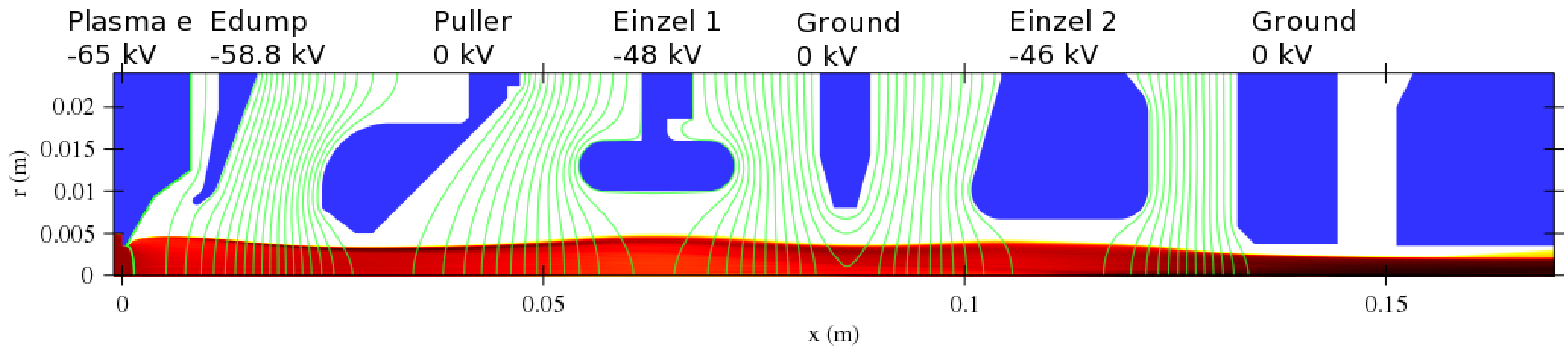
- Output particle data to Path Manager.
- Power density on electrode surfaces
- Secodary electron emission on surfaces
- Modelling of background gas ionization and ray-tracing of generated ions

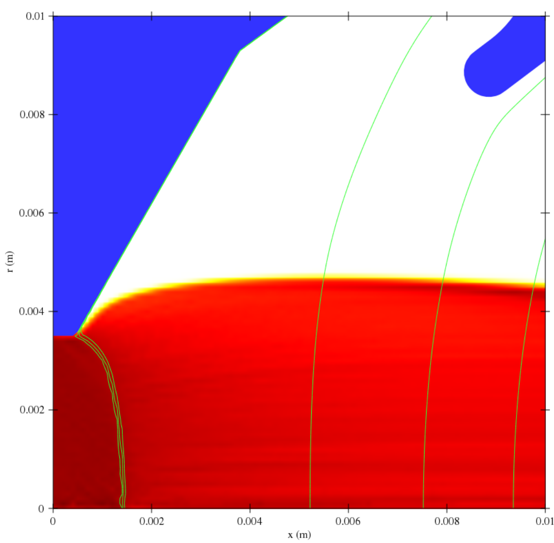
Work done with IBSimu

- Design of 50 mA, 30 keV H^+/T^+ slit-beam extraction with integrated nanosecond chopper for neutron generator.
- Several 80–120 keV D^+ CW neutron generator designs (by J. H. Vainionpaa).
- Modelling of existing LIISA 1 mA, 5.9 keV H^-/D^- ion source at JYFL for validation. Experimental verfication of results.
- Original design work: 1 mA, 5–15 keV H^-/D^- extraction for K150 cyclotron at the Texas A&M.
- Various designs of ion source extraction test stands, Faraday cup suppression modelling, emittance scanner calibration, electron gun modelling, etc.

SNS: Overview

High current density extraction reference point for many codes





- Low electric field at plasma meniscus.
- Highly convex plasma-meniscus shape.
- Discrepancy between PBGUNS and (positive) IGUN reported in ICIS2001. Later solved with NIGUN.

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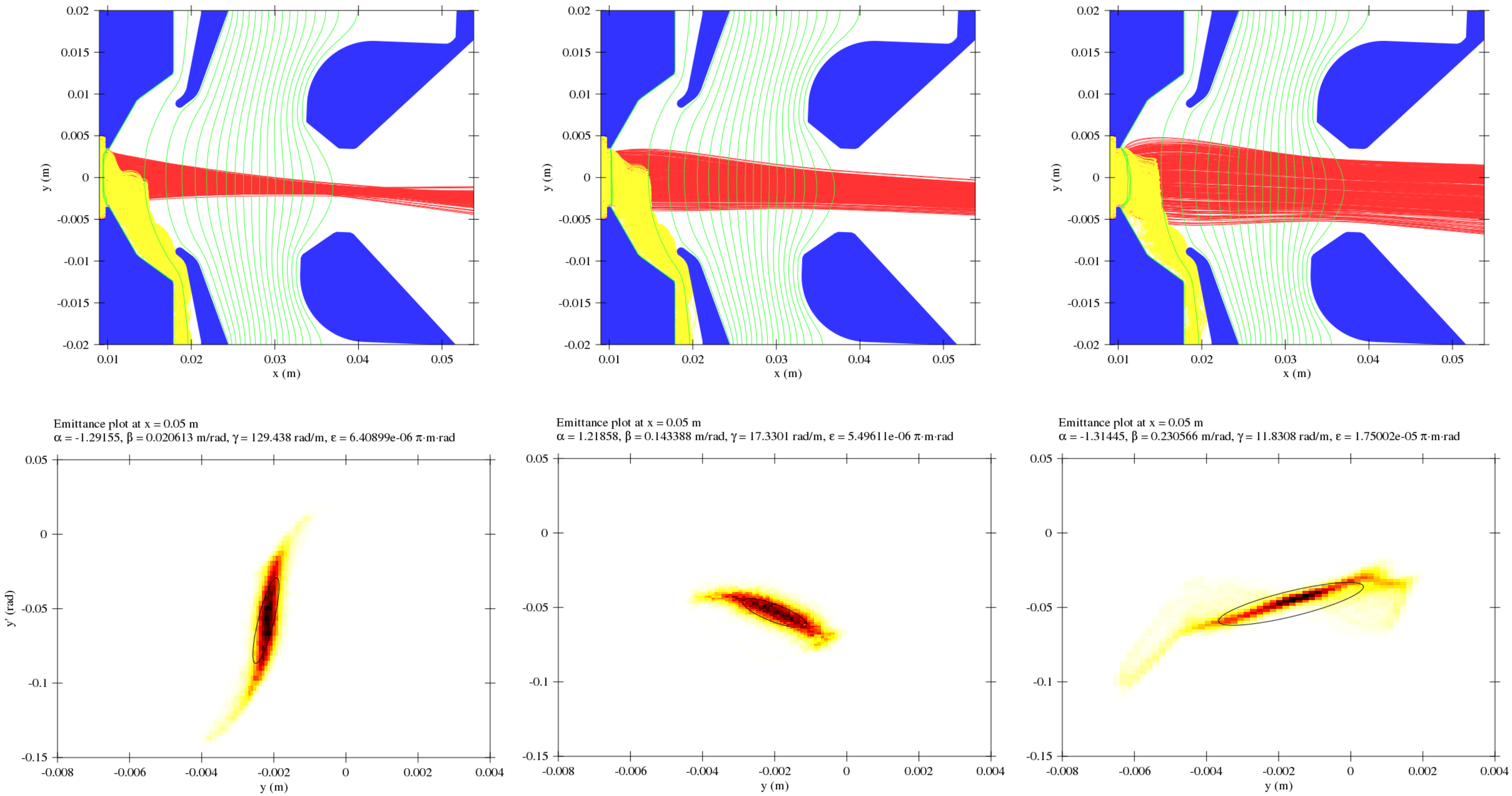
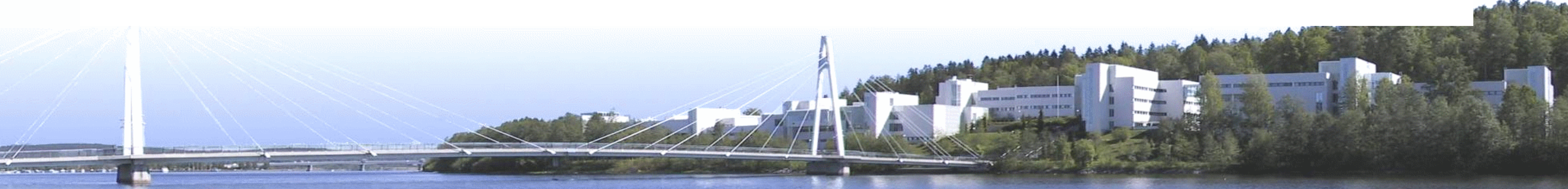
SNS: Plasma meniscus

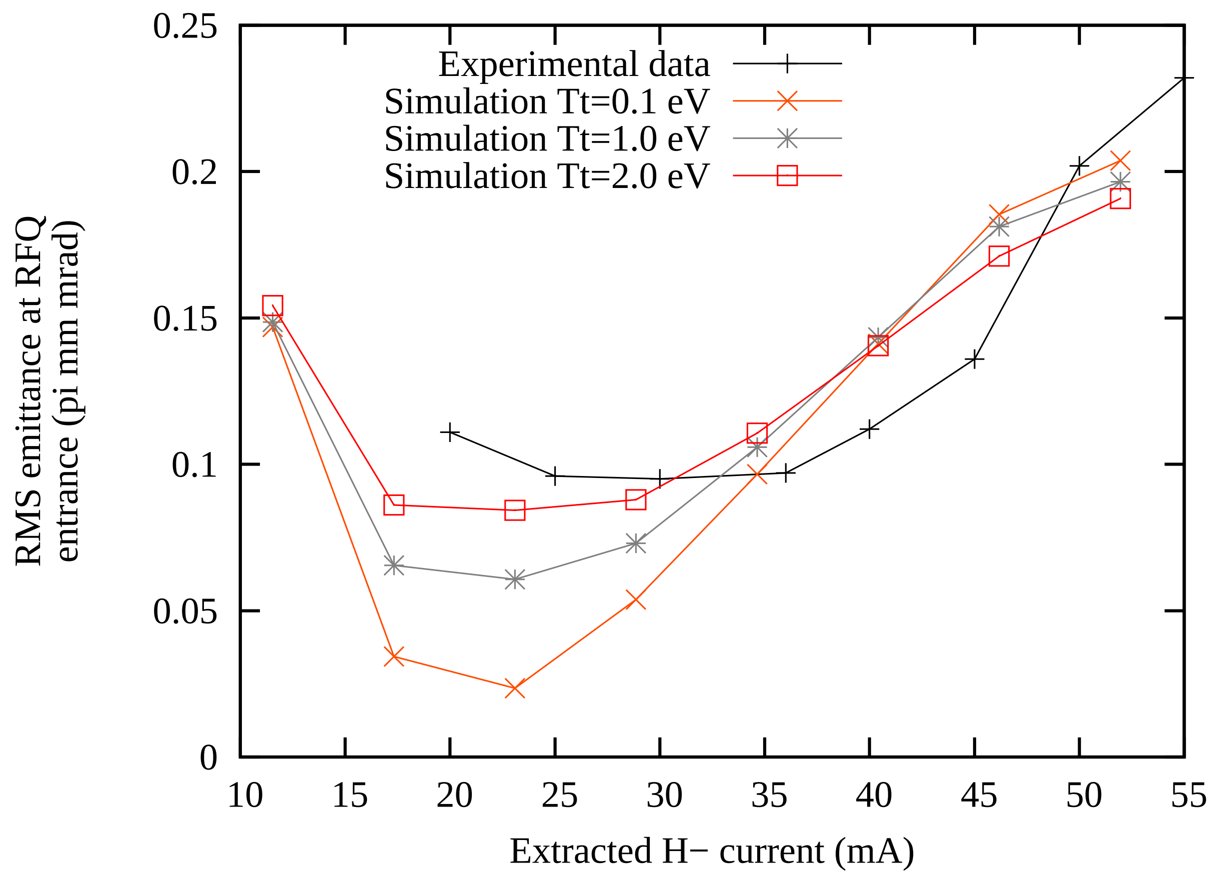
30 mA/cm^2 | 60 mA/cm^2 | 120 mA/cm^2





SNS: Emittance at RFQ entrance

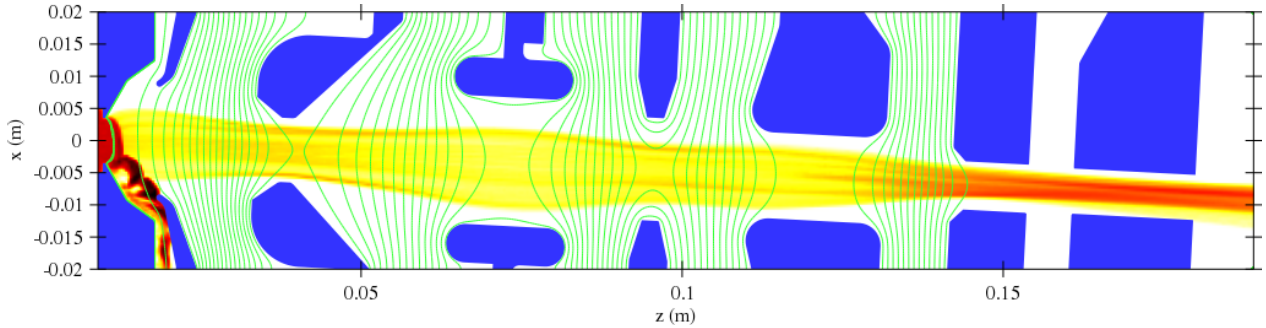
SNS has problems getting high beam currents through the RFQ.



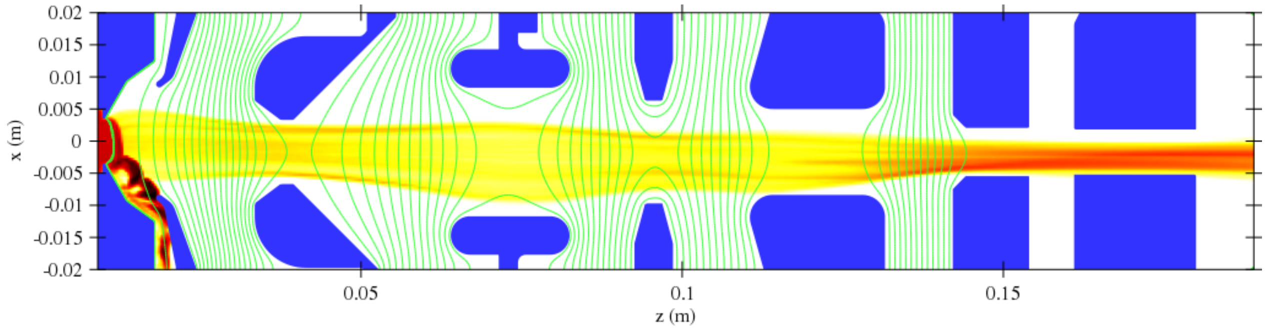
Experimental data: B. X. Han, ICIS2009, Gatlinburg, Tennessee

SNS: Angle/offset effects

Original design: angle: 52 mrad, offset: 0.0 mm



Recent production parameters: angle: 0 mrad, offset: 1.7 mm



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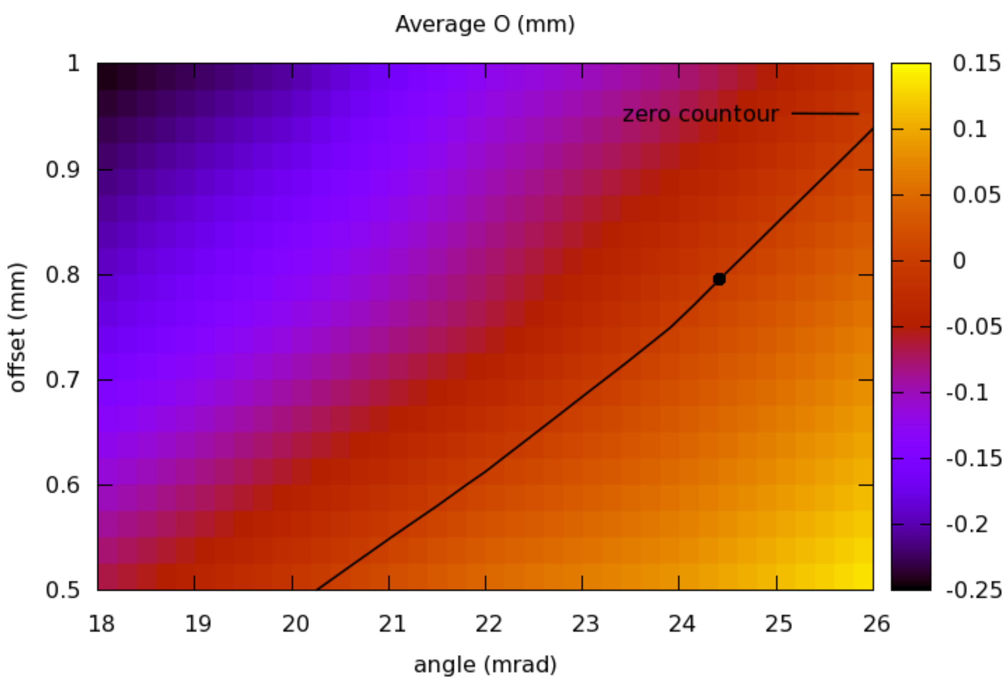
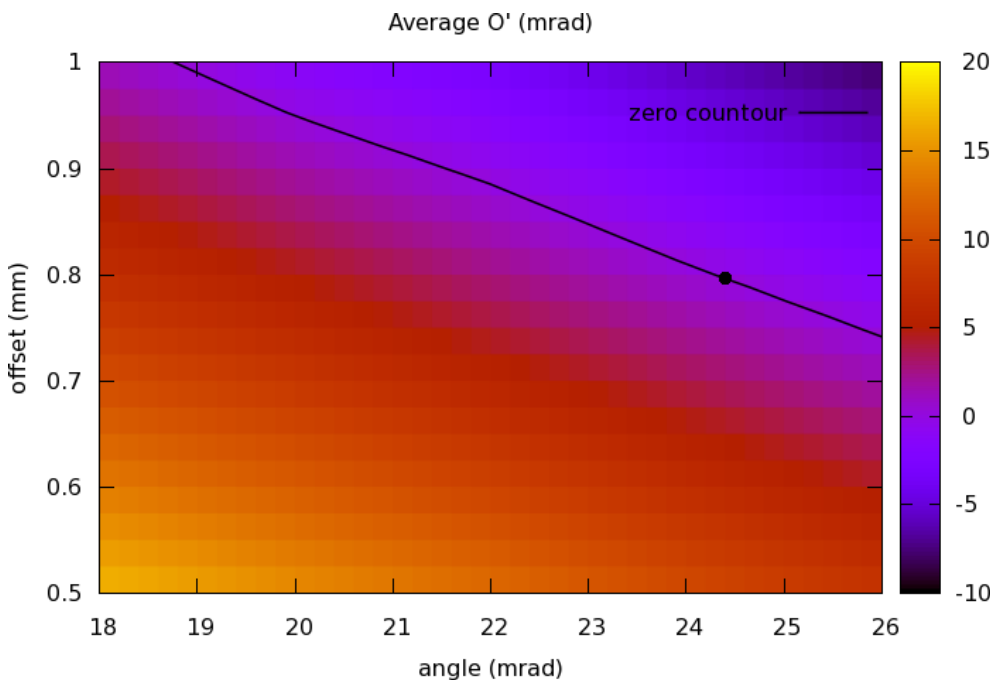
SNS: Angle/offset optimization

Search for optimal angle and offset to get centered, straight going beam.

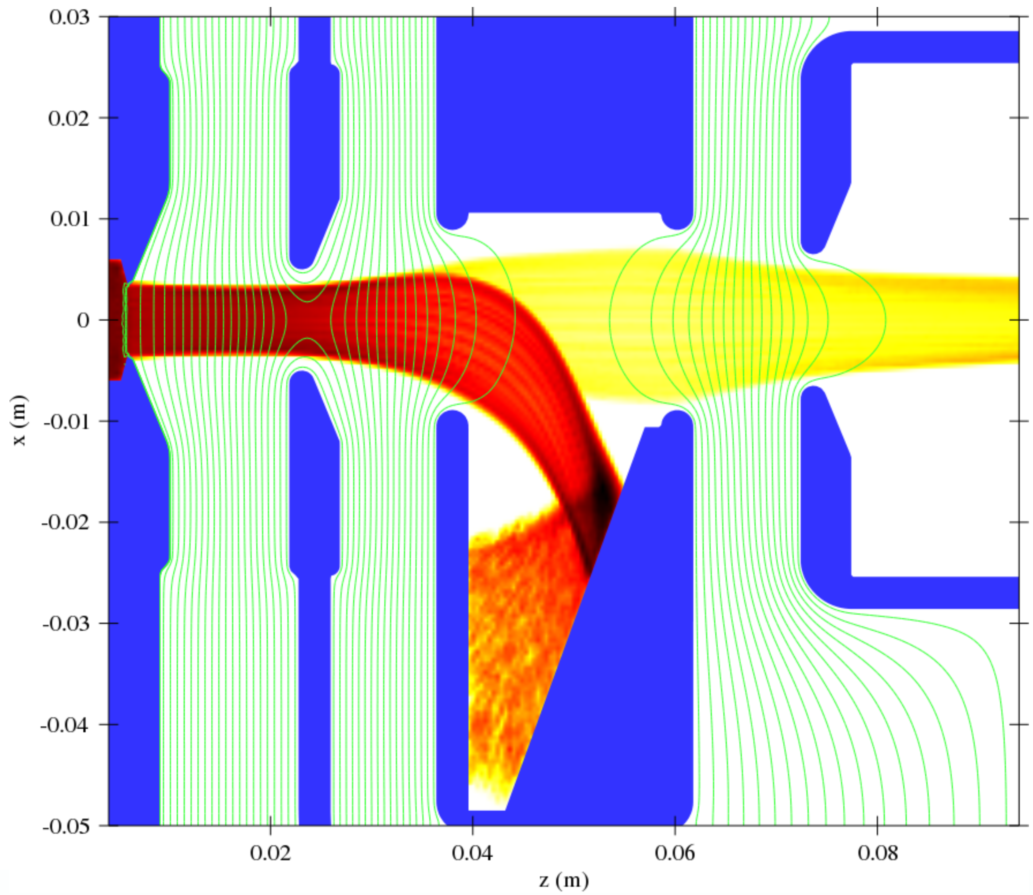




Found optimum at 24.4 mrad angle and 0.8 mm offset.

SNS: Proposed new extraction design

- Higher electric field close to plasma meniscus.
- Low magnetic field at extraction aperture.



R. Welton, NIBS2010, Takayama, Japan

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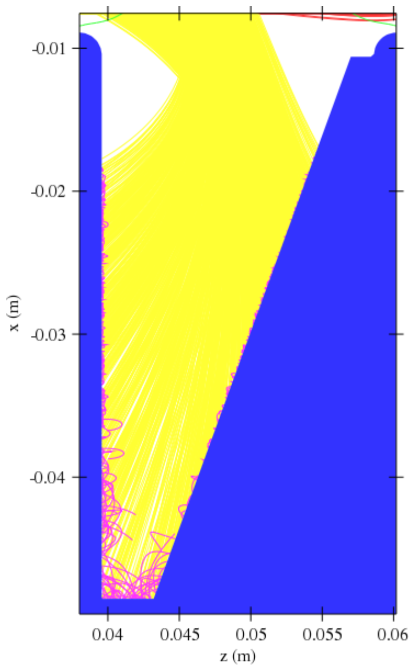
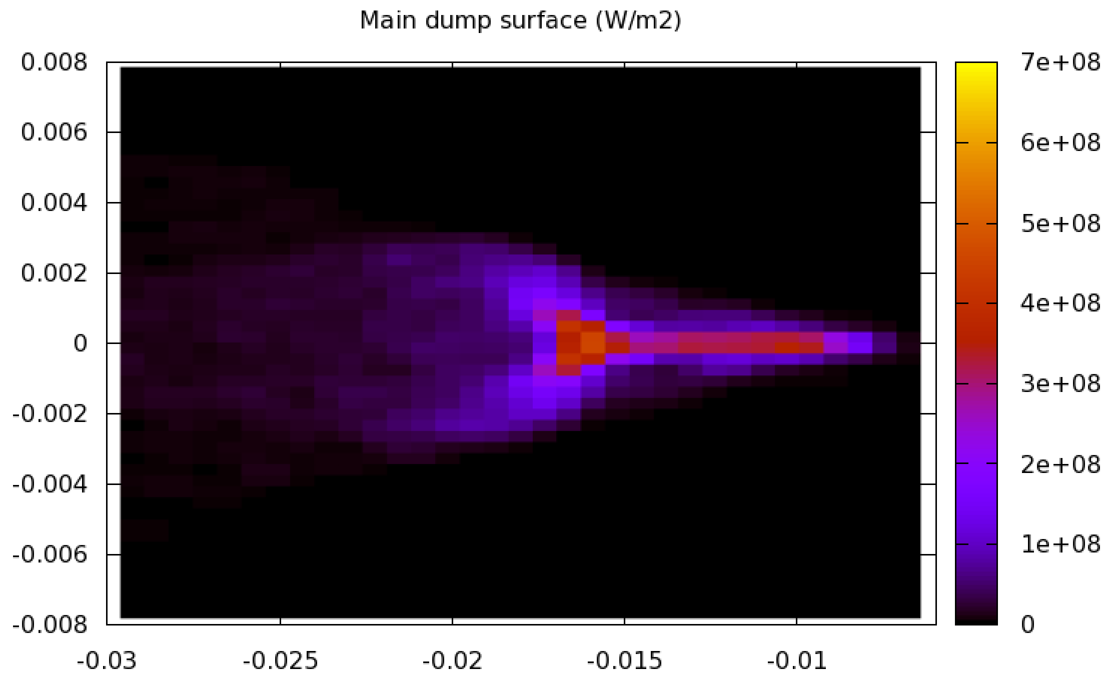
SNS: Electron dump design

Optimization in progress, but it can already be seen that secondary electrons are not a problem and the power density is manageable.





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Overview of IBSimu

IBSimu is a project — not a product.

- It is documented open source code (GPL).
- Openly distributed and developed:
  - Contributions and requests are invited
  - Development versions are also available to users
- Several parallel versions exist:
  - Official release: `ibsimu 1.0.4` (December 2010)
  - Main development branch: `master` (Yesterday)
  - Research branch: `new_solver`, others as needed
- Current statistics: 1 developer, $\sim$10 users

Overview of IBSimu

My ongoing projects:

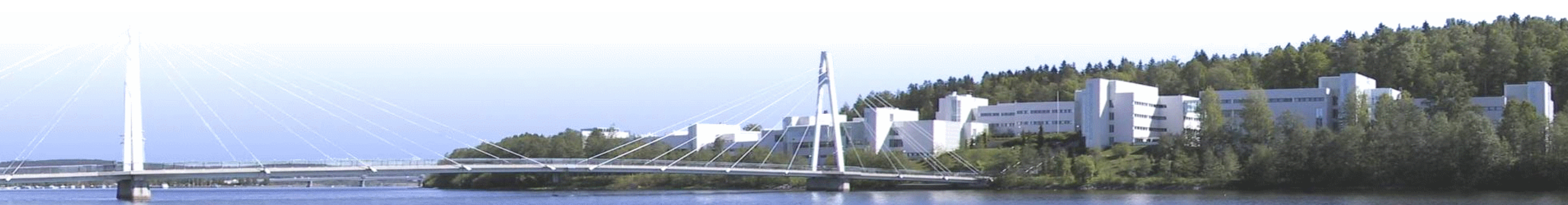
- JYFL Pelletron 1–100 μA H^- ion source for microbeam production
- JYFL RF 1–5 mA, 20–30 keV H^-/D^- ion source
- Collaborations with SNS and CERN

Physics goal for H^- simulation:

- Direct comparison of experimental and simulated emittances for validating plasma model.

Technical goals:

- Higher efficiency solvers, magnetic field calculation, IGES geometry import, fine grid area, …



More information

Website: http://ibsimu.sourceforge.net/

Contains

- Short tutorials for new users
- Reference manual
- Email list
- Contact information
- Bug reporting, feature request lists, etc