Hui Zhang:: HIPA/GFA :: Paul Scherrer Institute

BDSIM SIMULATION OF THE COMPLETE RADIONULCLIDE PRODUCTION BEAM LINE FROM BEAM SPLITTER TO TARGET STATION AT THE PSI CYCLOTRON FACILITY

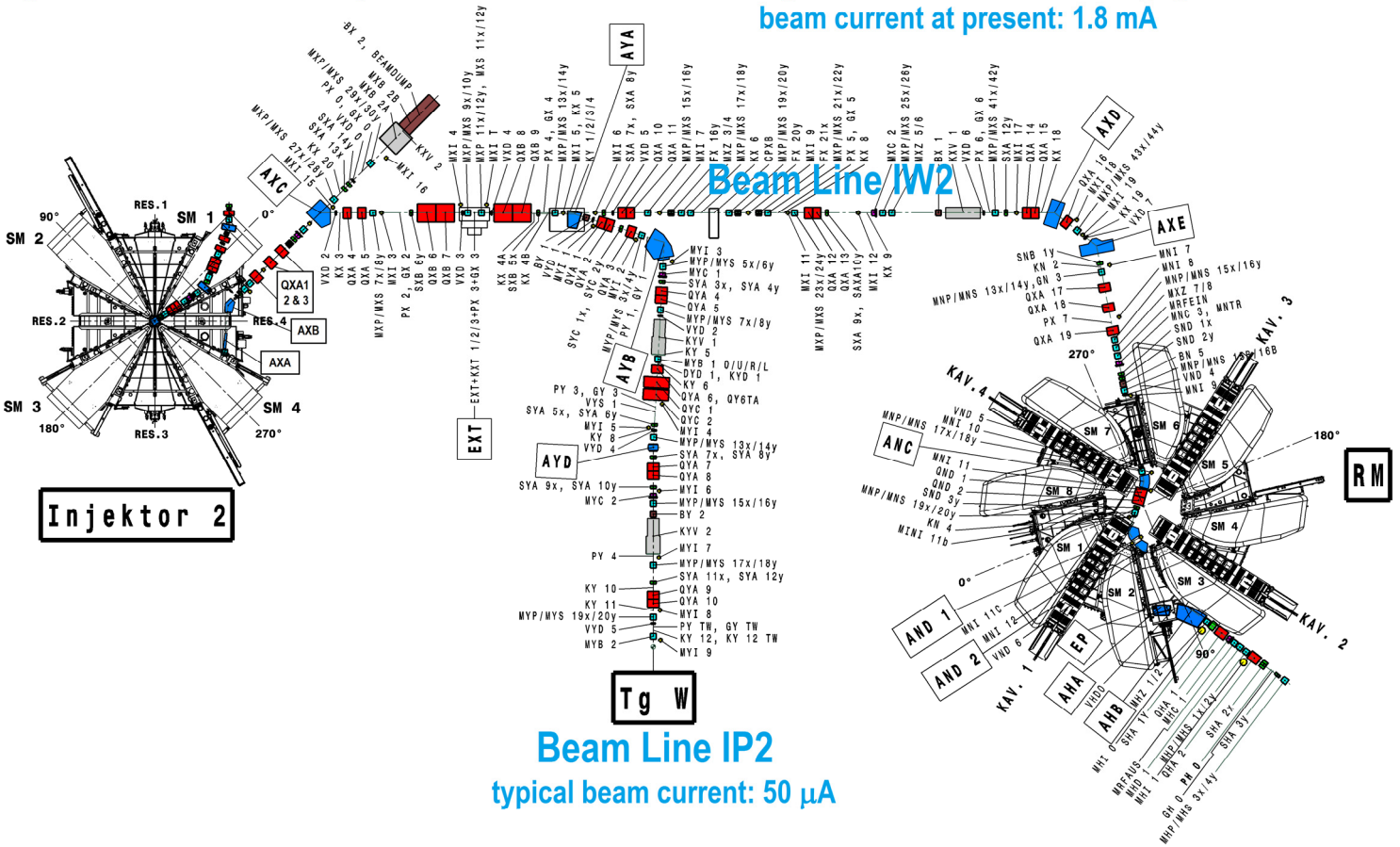
CYC2019, Cape Town, South Africa, 25 Sep. 2019

72 MeV Beam Lines IW2 and IP2

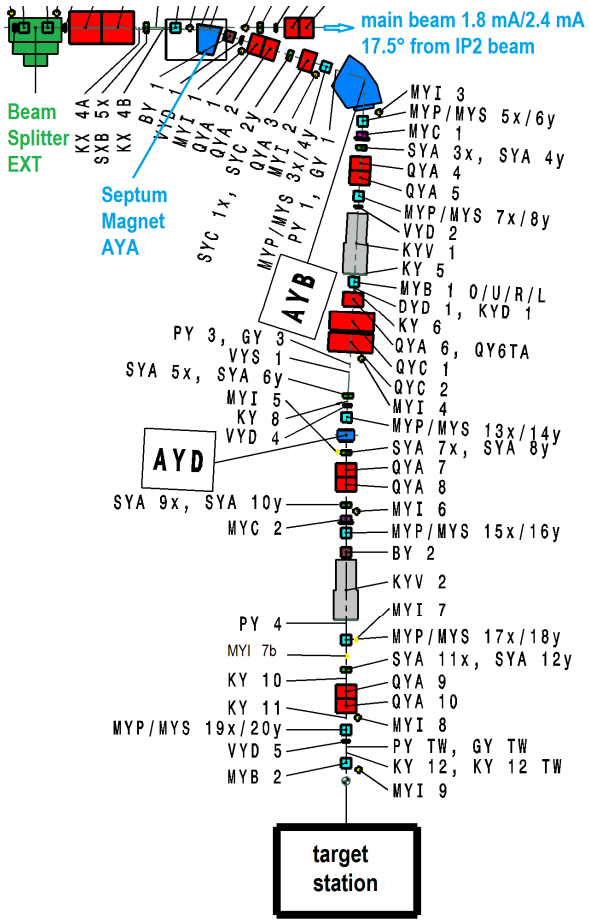
highest beam current from Injector II: 2.7 mA

highest beam current from Ring cyclotron: 2.4 mA

beam current at present: 1.8 mA

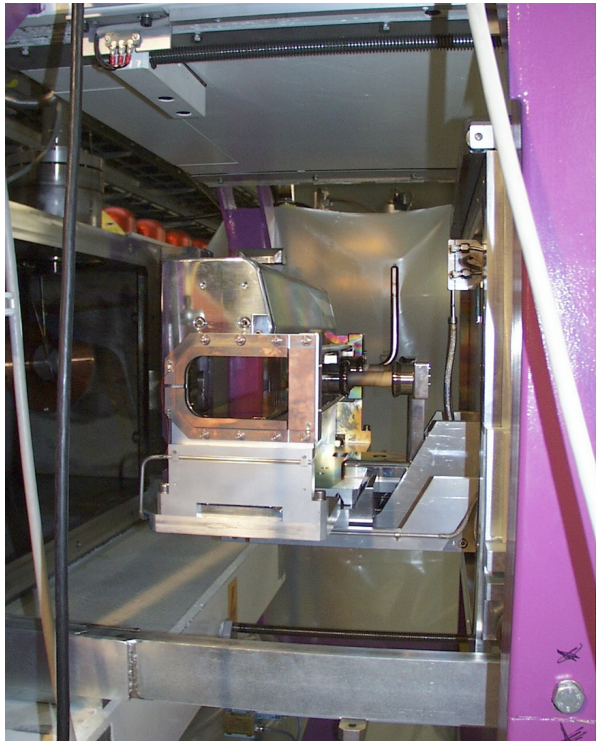


Beam Line for Radionuclide Production



- Beam splitter peels a beam of desired intensity
- Total of ca 14 mrad kick to the peeled beam
- > 40 mm clearance for septum magnet AYA
- After AYA: 17.5° between main and IP2 beams
- EXT essential for beam transportation
- EXT not yet included in beam optics calculation
- Special geometrical form + 3D electrostatic field
- Not integrated into TRANSPORT/MADX
- Beam Delivery Simulation: Geant4 based tool
- BDSIM: dipoles and quadrupoles
  collimators, degraders, and beam pipes
  user-built element + EM field

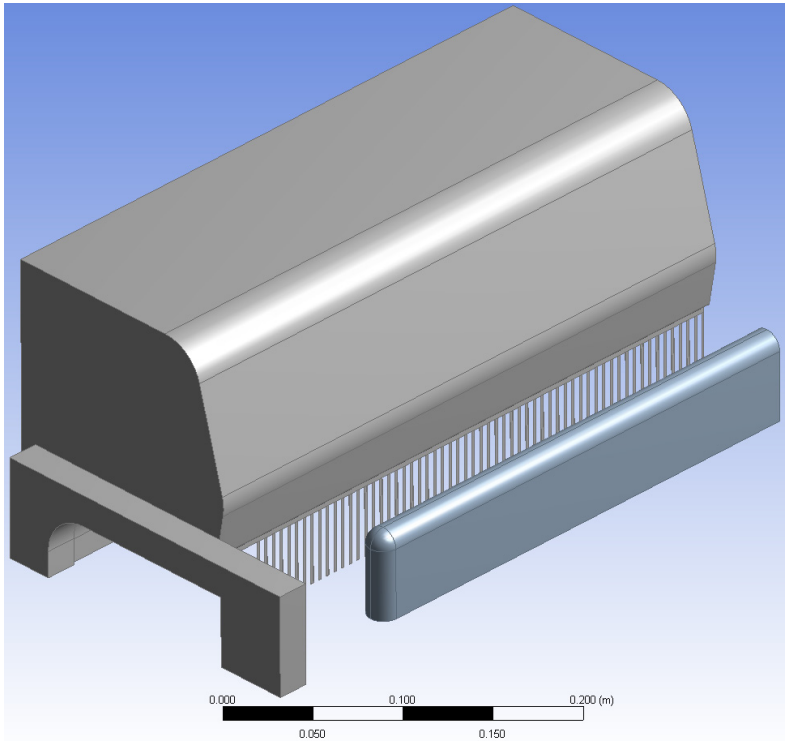
Beam Splitter



Beam splitter at PSI

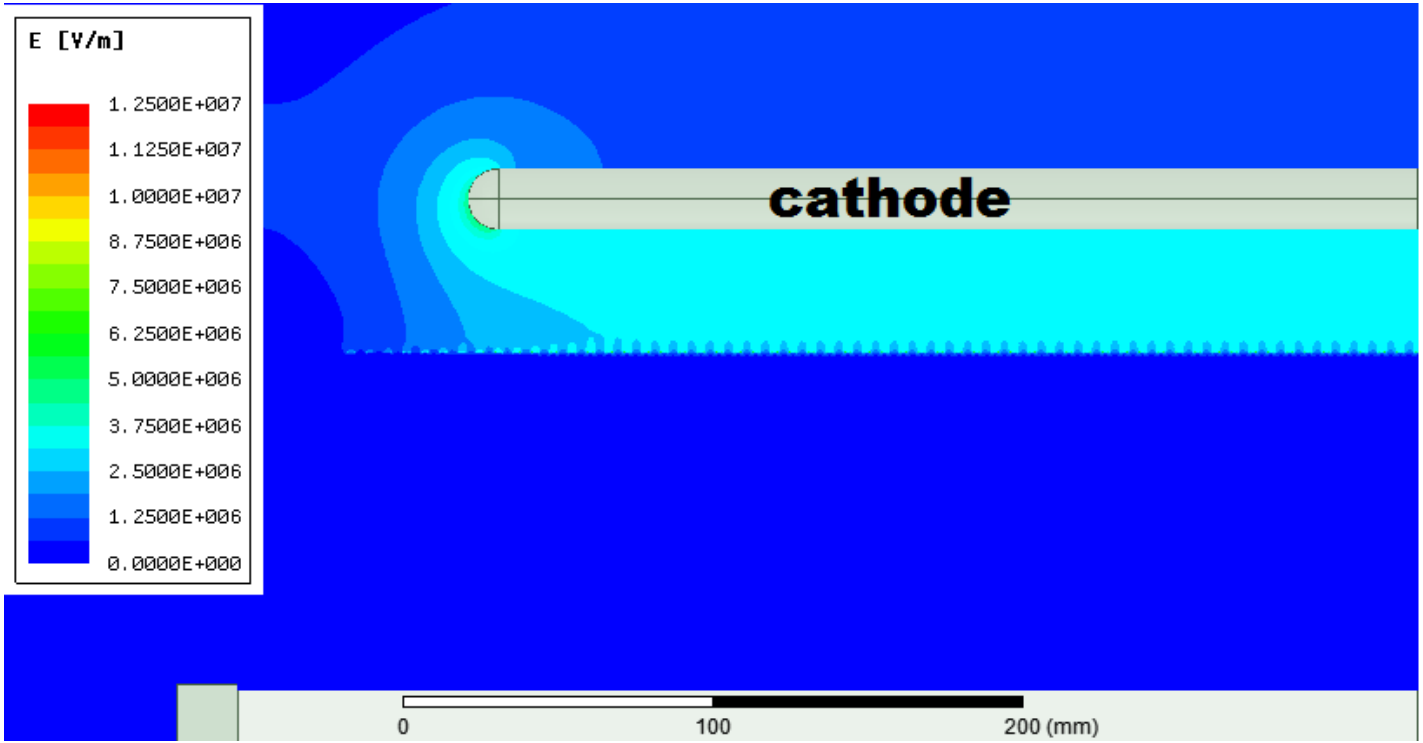
Beam splitter at iThemba

Electrostatic Field Analysis for Beam Splitter



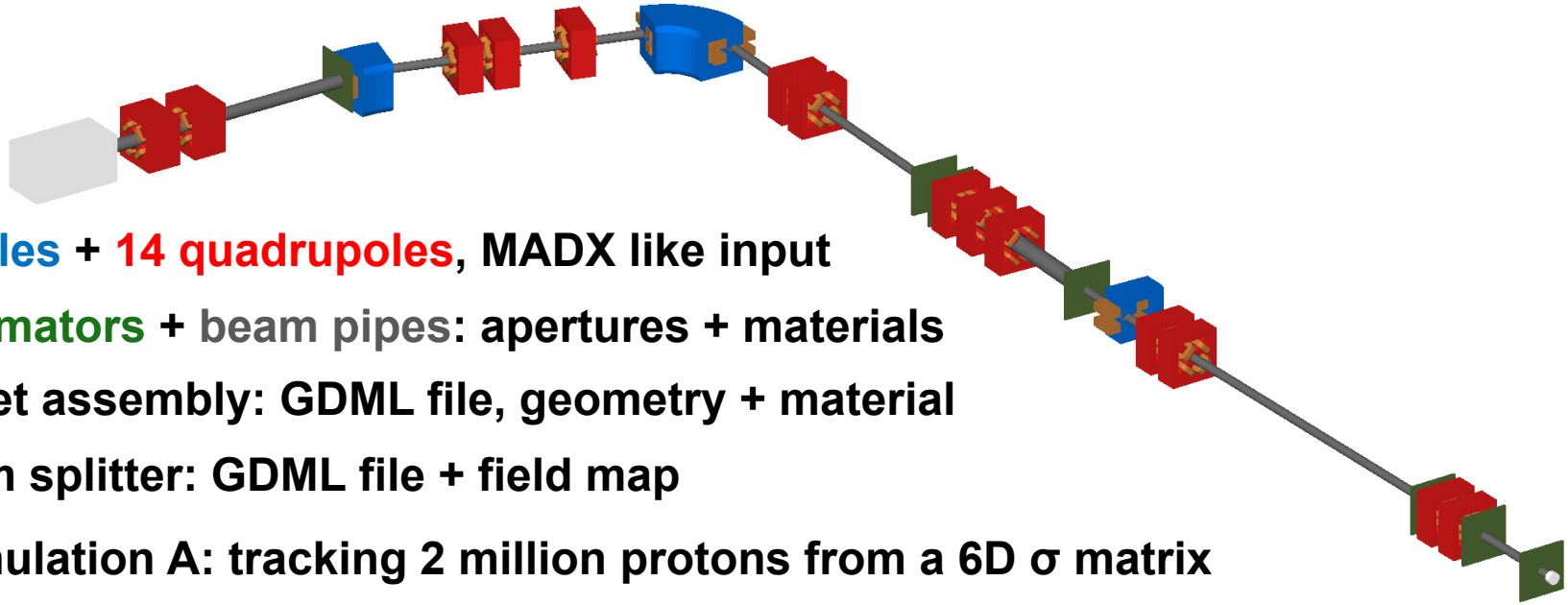
- 1/4 of geometrical model
- Septum: 117 tungsten strips
  50 µm thick, 2 mm wide, 4 mm distance
  698 mm long along beam direction
- Strips are tensioned onto a C-structure
- Cathode: 20 mm thick, 110 mm high and 620 mm long, -105 kV, 40 mm from the septum
- Average field: 2.625 MV/m
- Kick to beam: ca 13 mrad
- Field-free inside C-structure
- Main beam not affected

Electrostatic Field Map



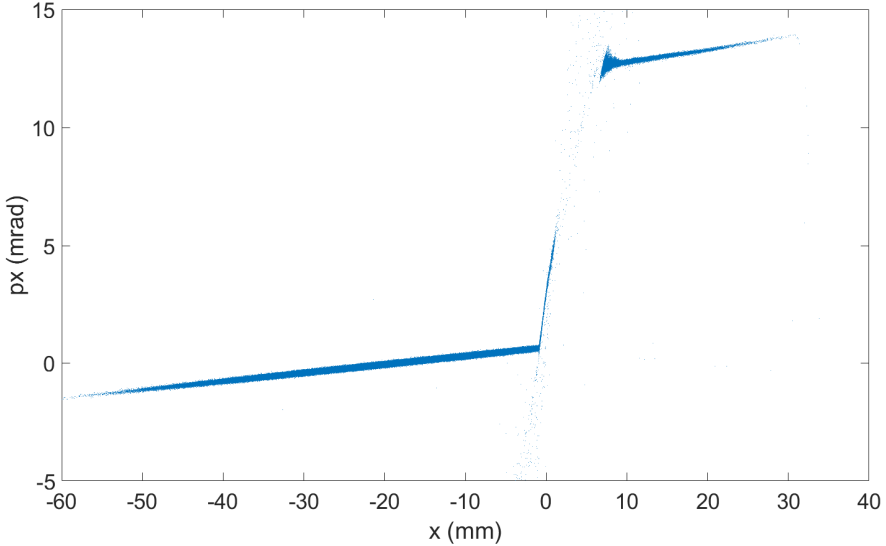
- Average field + entrance/exit fringe field + fluctuation near strips
- Step size in (x, y, z): (0.05, 5, 2) mm; Map size: 0.7 GB

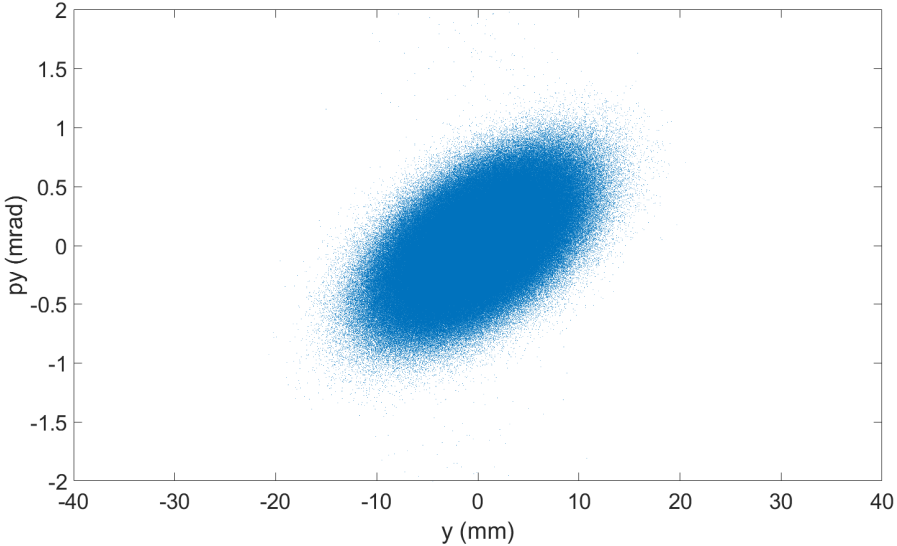
Beam Line for BDSIM Simulation



- 3 dipoles + 14 quadrupoles, MADX like input
- 7 collimators + beam pipes: apertures + materials
- Target assembly: GDML file, geometry + material
- Beam splitter: GDML file + field map
- Simulation A: tracking 2 million protons from a 6D σ matrix
- Simulation B: 40 million protons from a 6D σ matrix, but only protons hitting strips/passing on to IP2 line started, ca 1.2 million protons
- EM, hadronic, decay, ion, stopping, and qgsp activated for simulation

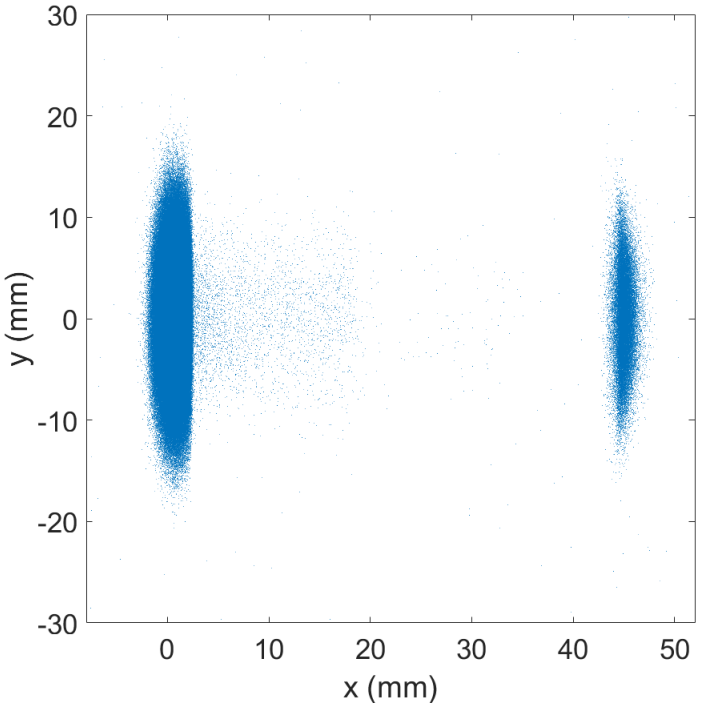
x-p_x/y-p_y plots at Exit of Beam Splitter EXT

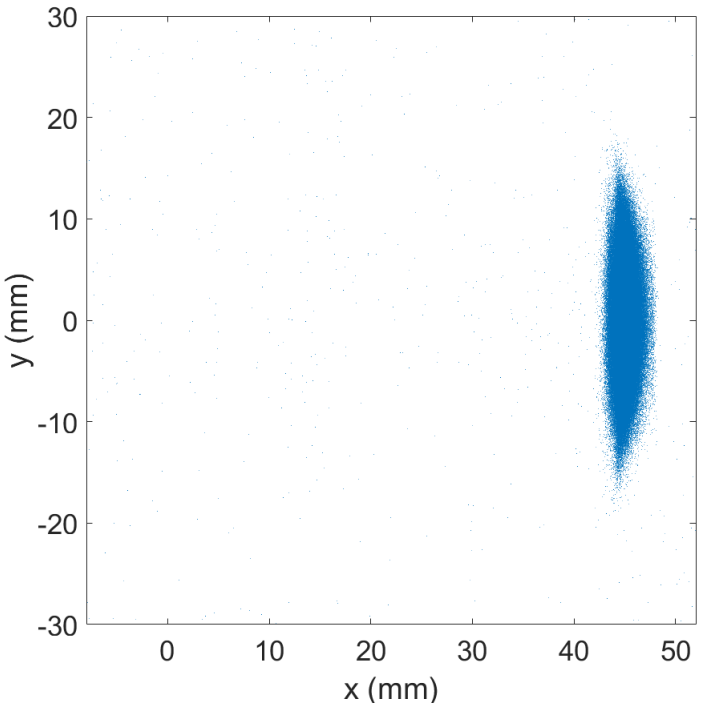




- ca 13 mrad kick to IP2 beam
- Protons scattered by W strips
- Influence from field fluctuation
- No elliptical shape in x-p_x phase space
- No average shift to p_y
- Elliptical shape in y-p_y phase space
- Fit between the simulated and measured beam profiles much easier

x-y plots at Entrance of Septum Magnet AYA





2 million protons started

56000 protons in IP2 beam

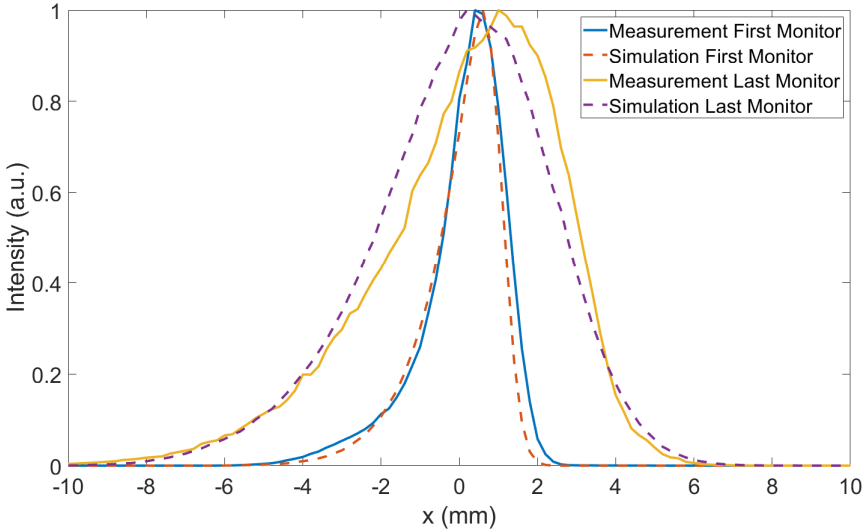
1.927 million protons in main beam

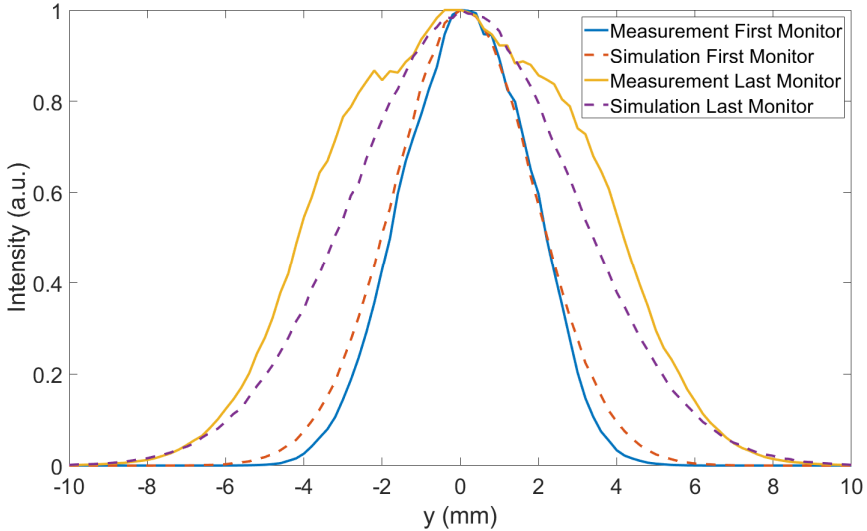
40 million protons sampled

1.227 million protons started

1.113 million protons in IP2 beam

Beam Profiles from Simulation/Measurement





Horizontal RMS Beam Size (mm)

	Simulated	Measured
First	1.0	1.1
Last	2.3	2.4

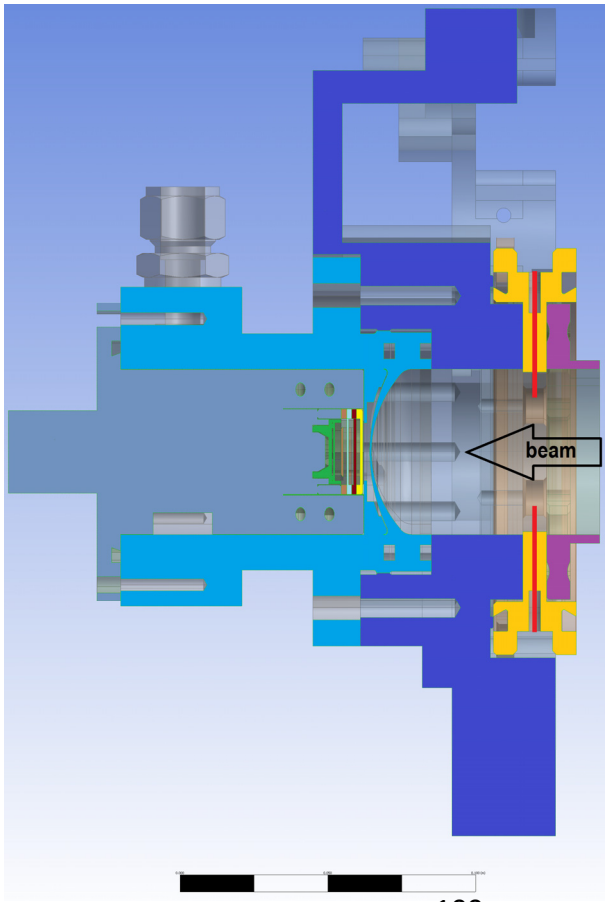
Vertical RMS Beam Size (mm)

	Simulated	Measured
First	1.8	1.7
Last	2.8	3.0

Discussion

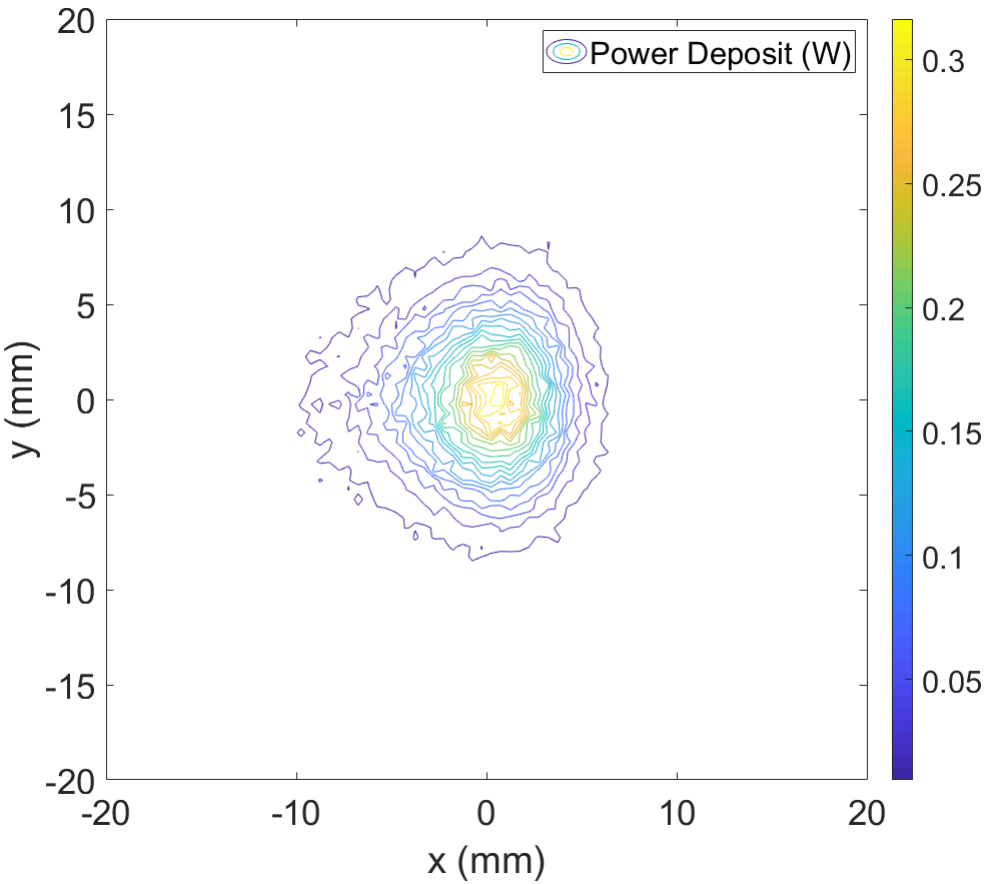
- The simulated RMS beam width fits well with the measured one
- The simulation predicts correctly the longer tails of horizontal profiles
- The exact shape differs somewhat from each other
- The discrepancy may arise from
  1. The main beam can not be simply described by a σ matrix
  2. The field map is not accurate enough, especially in the region near the tungsten strips. The inaccuracy is from field analysis, as well as from map construction
  3. The fringe field of a quadrupole with large aperture can no longer be ignored
- There is room for improvement

Design of a New Target Station



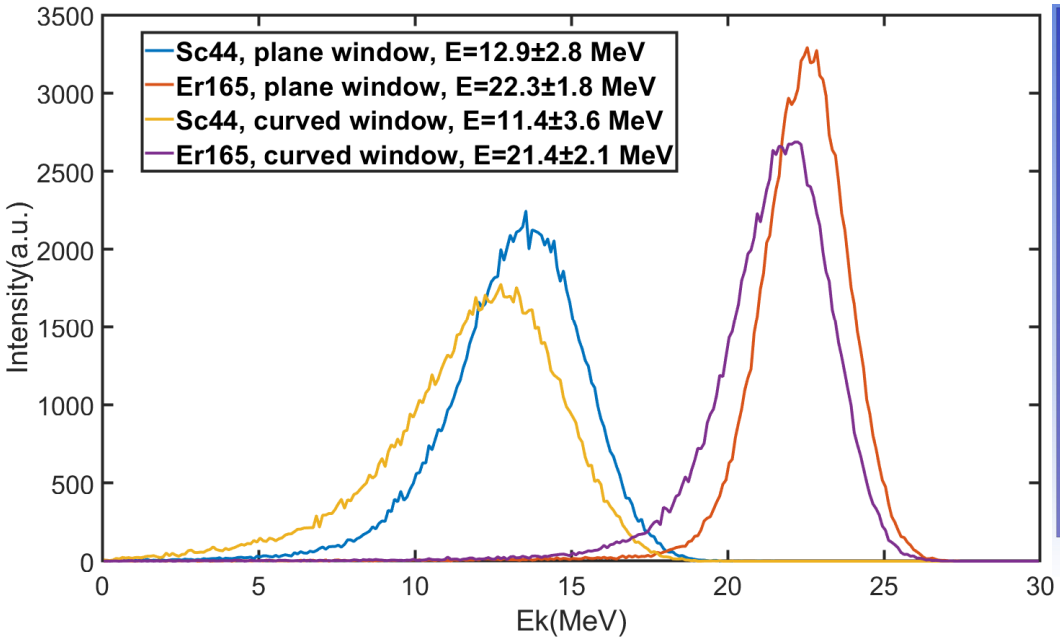
- A new target station with thermocouple in front
- Two pairs of thermocouples for beam position/size
- New design of cooling channel, cooling more efficient
- Degrader assembly, practical for installation
- Water flow and temperature simulations next
- Energy spectrum for protons upon reaching the target?
- Power deposited in vacuum window, degraders, cooling water?
- BDSIM simulation answers such questions

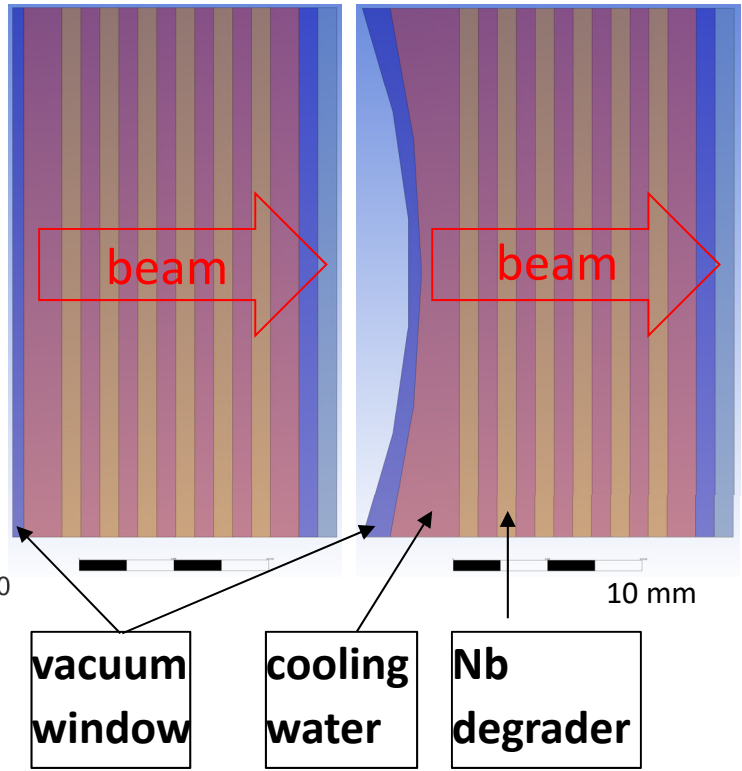
Power Deposited in Vacuum Window



- **Contour plot of power deposited in 0.6 mm thick Al vacuum window**
- **Total power deposited: 63.3 W**
- **Beam power: 3.6 kW**
- **Peak power on a 0.5×0.5 mm^2: ca 0.3 W, or 1.2 MW/m^2**
- **1 million protons seems to be not enough for power deposit calculation**

Energy Spectrum upon Reaching Target





- For ^{44}Sc, Nb 1 mm thick, water 1 mm thick
- For ^{165}Er, Nb 0.8 mm thick, water 1.2 mm thick
- Curved window mechanically more stable

Summary

- **BDSIM simulates the complete radionuclide production line from the beam splitter to the target**
- **The simulation delivers beam profile at a given position, power deposited in a chosen component, beam transmission after penetrating cooling water and degraders, and energy spectrum upon reaching the target**
- **The simulation is of importance not only for present operation but also for further development**

- **The program may be improved**

  1. The fringe field effect may be included

  2. Searching for a fit between simulation and measurement may be made more efficient

Acknowledgement

My sincere thanks to all my co-authors, especially J. Snuverink and L. J. Nevay for their support on BDSIM simulation.

Many thanks for your attention.