BDSIM Applications for Proton Therapy

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on behalf of BDSIM group:

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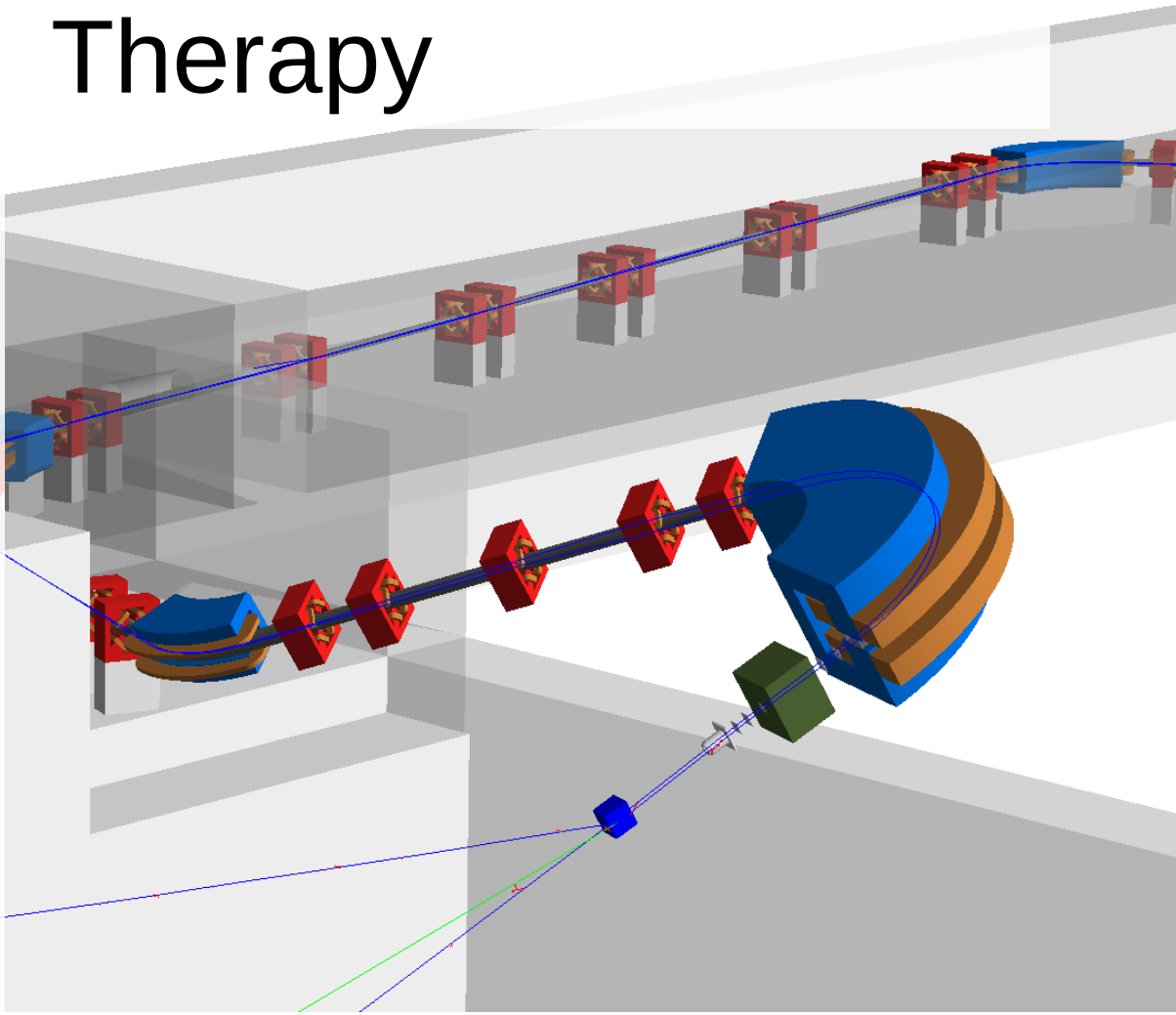
BDSIM*:*

https://arxiv.org/abs/1808.10745

http://www.pp.rhul.ac.uk/bdsim

7th December 2018, JAI Fest – RHUL.



John Adams Institute for Accelerator Science

ROYAL HOLLOWAY UNIVERSITY OF LONDON

Outline

1. Introduction.

2. Building a BDSIM model.

3. Proton therapy gantry example.

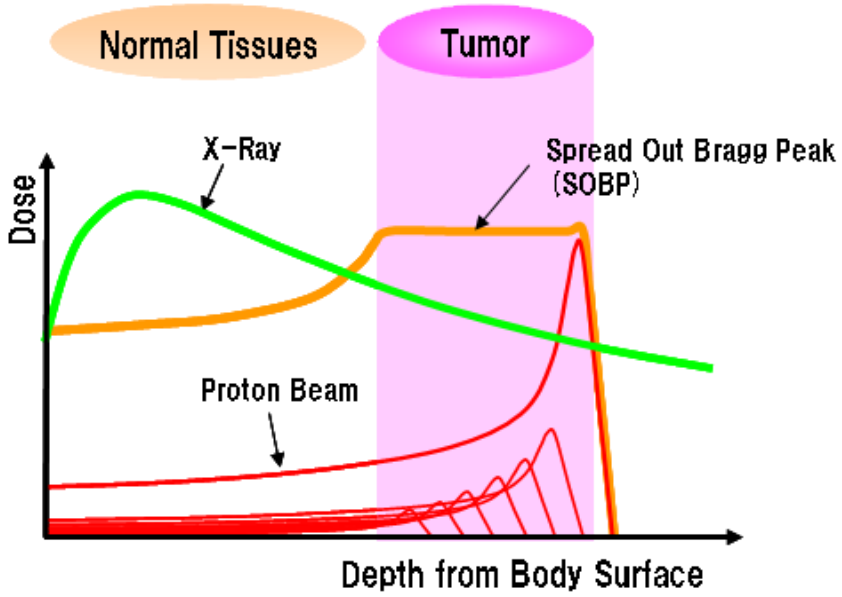
4. Collaboration.

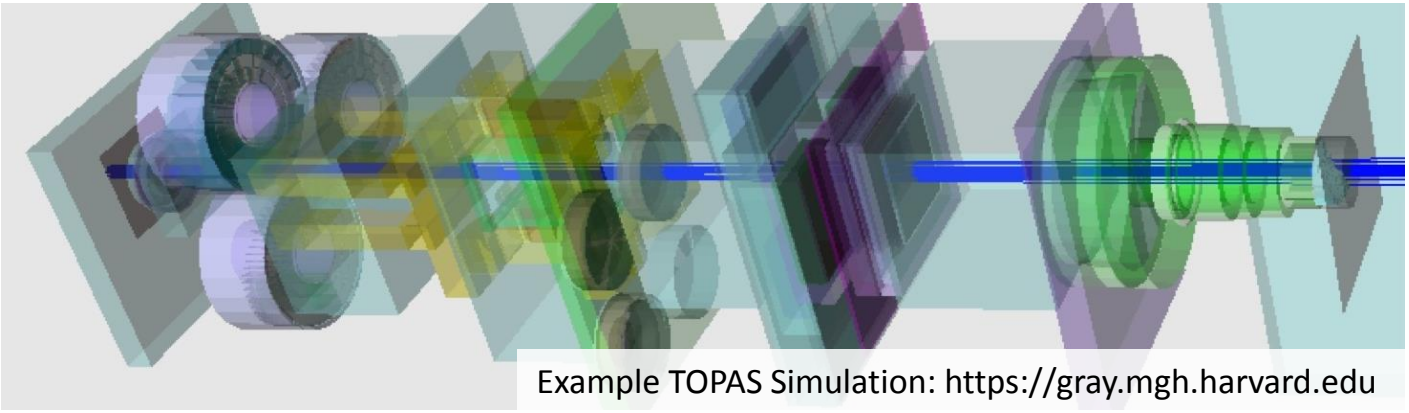
5. Summary & outlook.

Proton Therapy Simulations

- Radiotherapy technique using high energy protons.
- Dose deposited at a precise depth.
- Vary beam energy to build up Spread Out Bragg Peak.
- Correct dose is crucial – energy, size, shape, etc.
- Gantry nozzle simulations – no prior accelerator.

http://www.shi.co.jp/

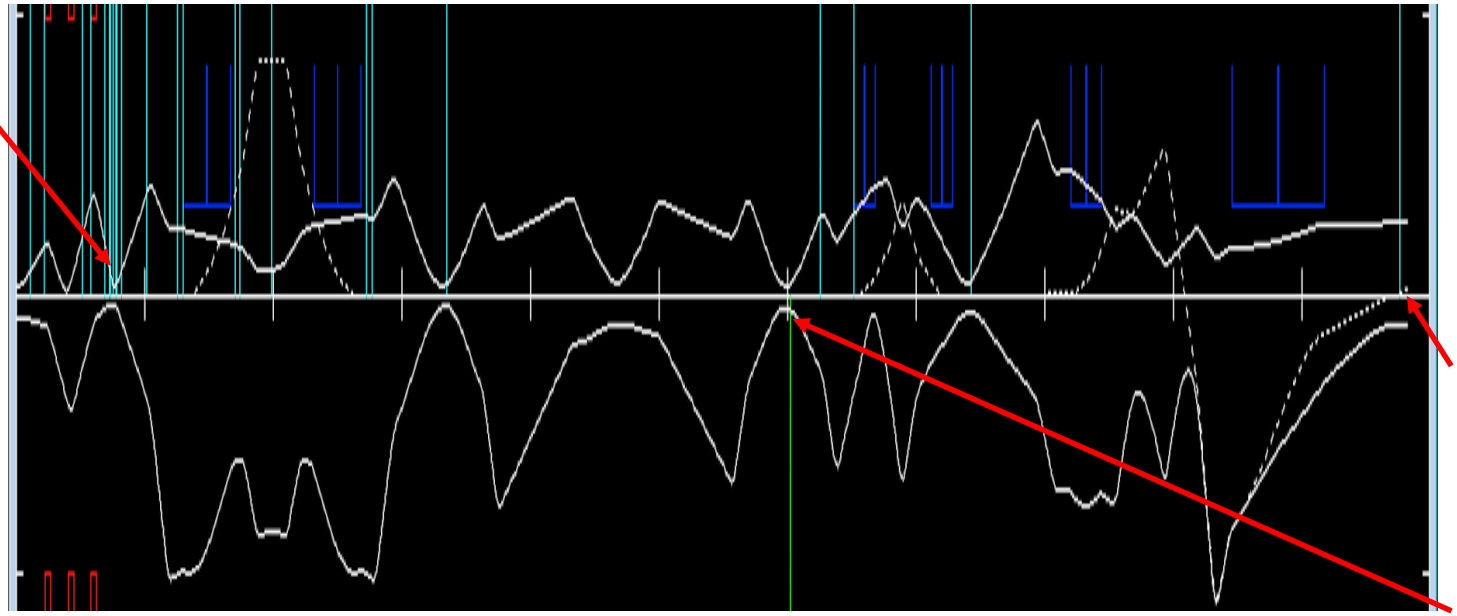




Example TOPAS Simulation: https://gray.mgh.harvard.edu

Standard Approach

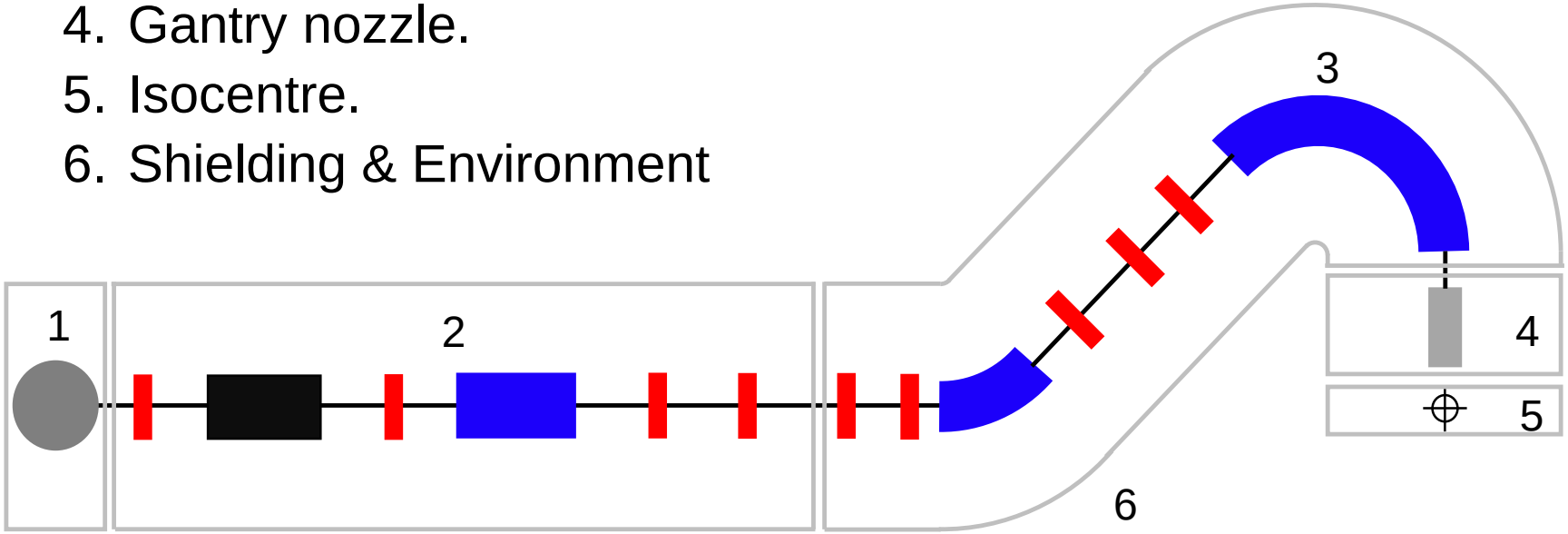
- Inspect machine optics and identify regions of interest.
  - Develop Monte Carlo simulations as required.



- Simulation challenges - high precision, many particles:
  - Computationally expensive.
  - Separate simulations.

Simulating a Beam Line

- Regions of a proton therapy beamline:
  1. Particle source / acceleration.
  2. Beam transport to gantries.
  3. Gantry beam transport.
  4. Gantry nozzle.
  5. Isocentre.
  6. Shielding & Environment



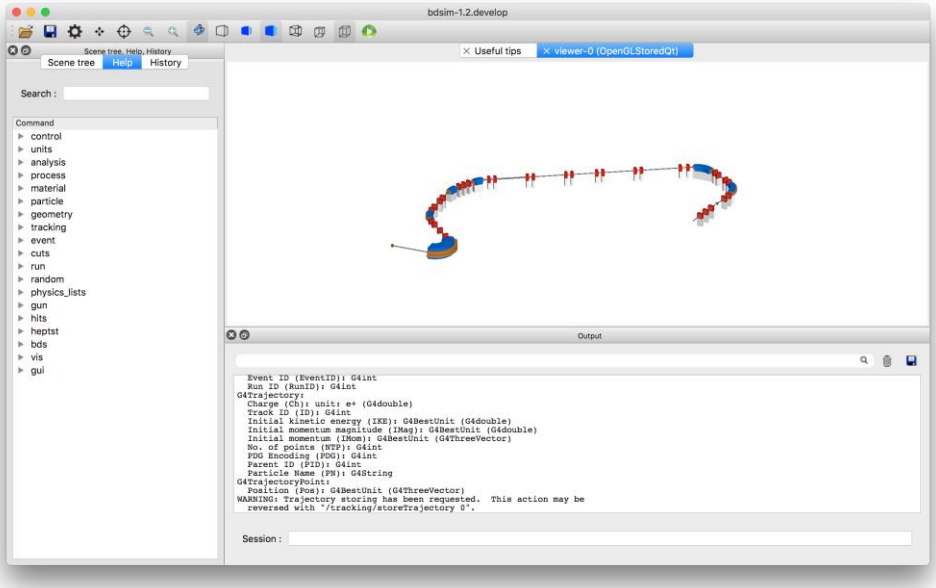
- Our aim: To demonstrate a start-to-end model of a proton therapy gantry in a single simulation.

Building a BDSIM Model

BDSIMGantry.gmad

```
1  ! pybdsim.Builder Lattice
2  ! number of elements = 101
3  ! total length       = 50.48259 m
4
5  DR1: drift, l=0.5507;
6  DR2: drift, l=0.5507;                    ← Components
7  QD1: quadrupole, k1=-9.5527, l=0.25;
8  ...
9  ...
10
11 l0: line = (DR1, DR2, QD1, DR3 ...
12 ...                                      ← Sequence
13 lattice: line = (l0, l1a, l2, l3);
14 use, period=lattice;
15
16
17 beam,    distrType="gauss",
18     energy=1.188190*GeV,                 ← Beam
19     particle="proton",
20     sigmaX=1.363*mm,
21     ...
22     ...
23
24 option, beampipeRadius=3.75*cm,          ← Options
25     beampipeThickness=2*mm,
26     physicsList="em em_extra hadronic_elastic qgsp_bic",
27     worldGeometryFile="gdml:./Shielding.gdml",
28     ...
29
30
31 !place element support blocks
32 QD1_support  : placement,                 ← User geometry placement
33      referenceElement="QD1",
34      referenceElementNumber=0,
35      y = -0.62501 *m,
36      geometryFile="gdml:./QD1_support.gdml";
37
38 sample, all;
```

- Python utilities for automatic conversion:
  - Pybdsim, pymadx, pymad8, pytransport
- Optimise model with options.

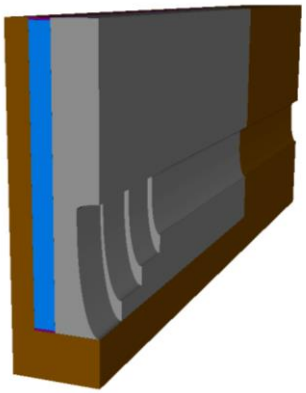


BDSIM Geometry

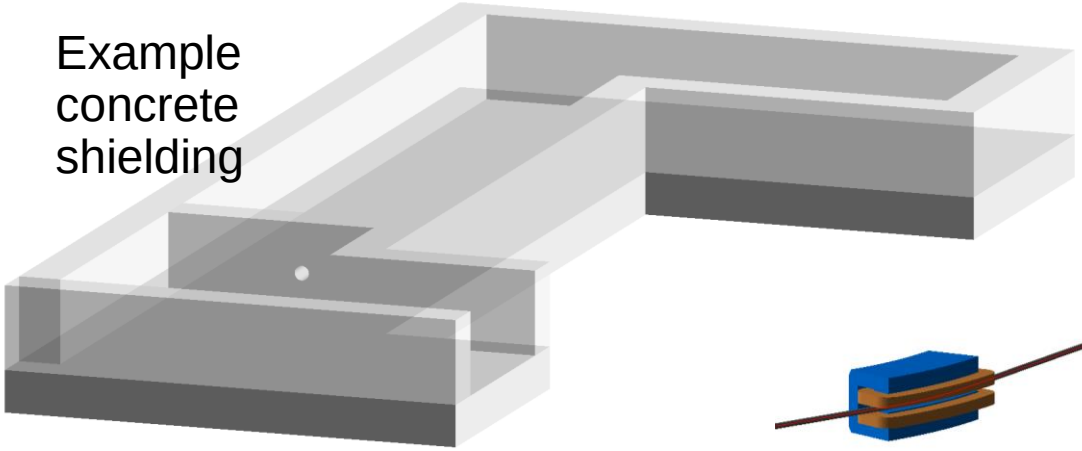
- Custom external geometry can be placed and field maps overlaid.
- Geometry e.g. GDML can be placed in the beam line.
- Python package pyg4ometry to create Geant4 geometry
  - https://bitbucket.org/jairhul/pyg4ometry/
  - STL/STEP meshes.

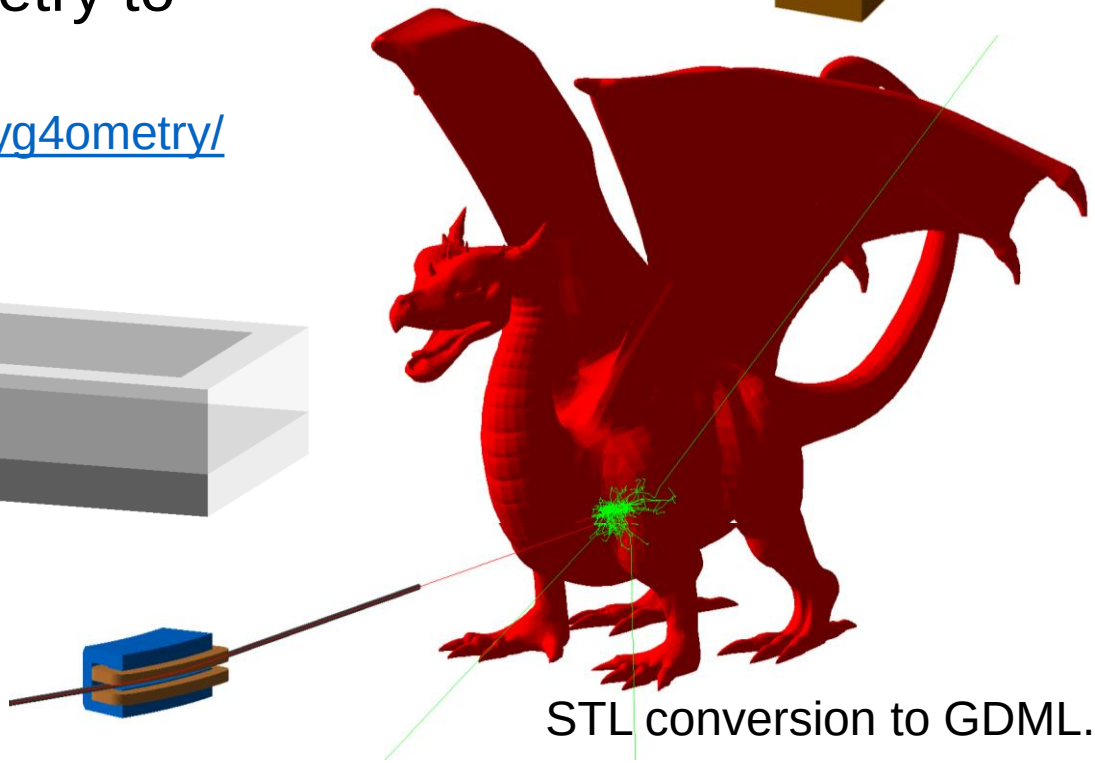
Custom GDML collimator.

R. Bodenstein & A. Abramov.



Example concrete shielding

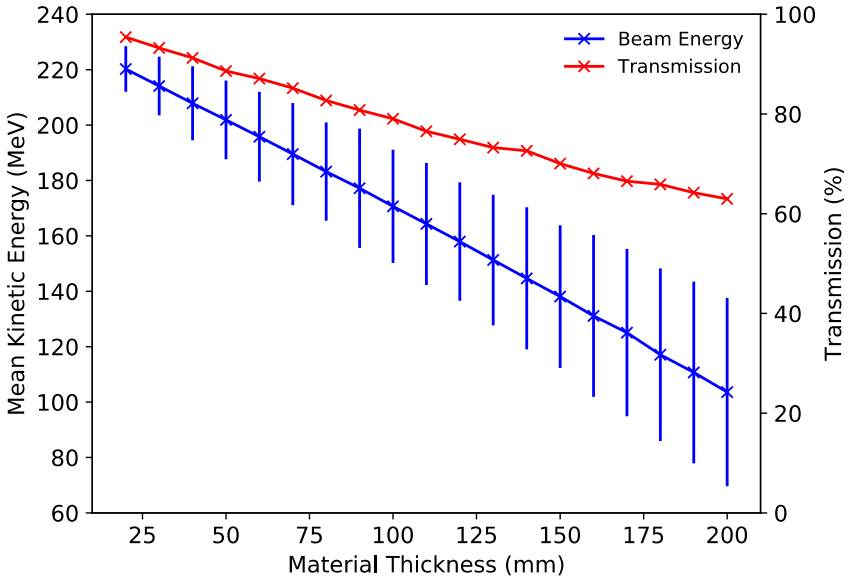


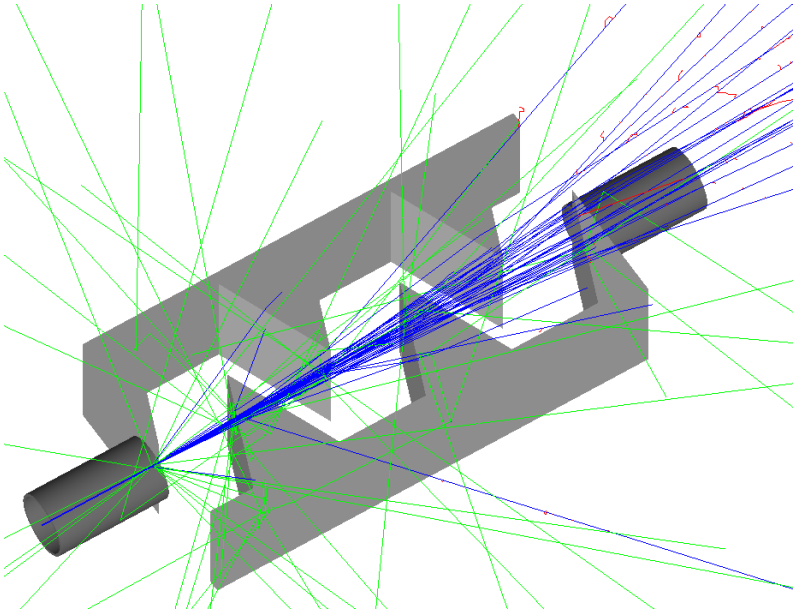


STL conversion to GDML.

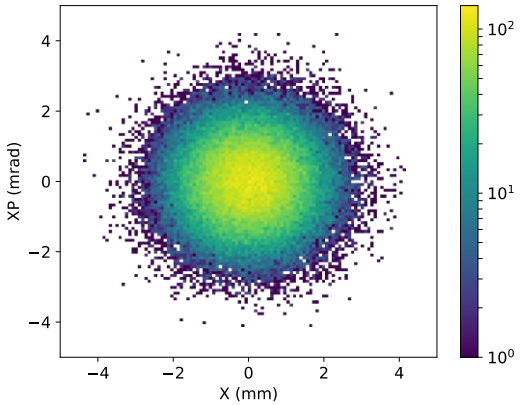
Energy Degrader

- Interleaved wedge degrader based on design from Center for Proton Therapy at PSI .
- Significant impact on beam phase space distribution and spectrum.

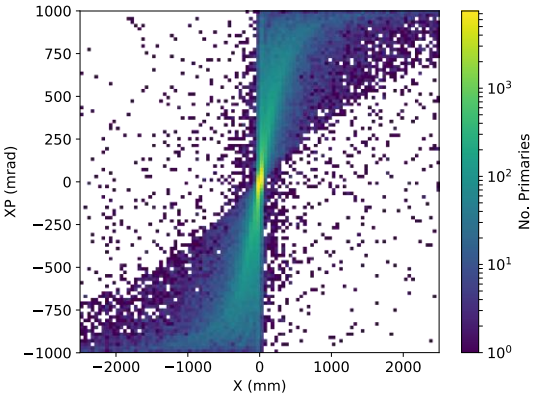




Before

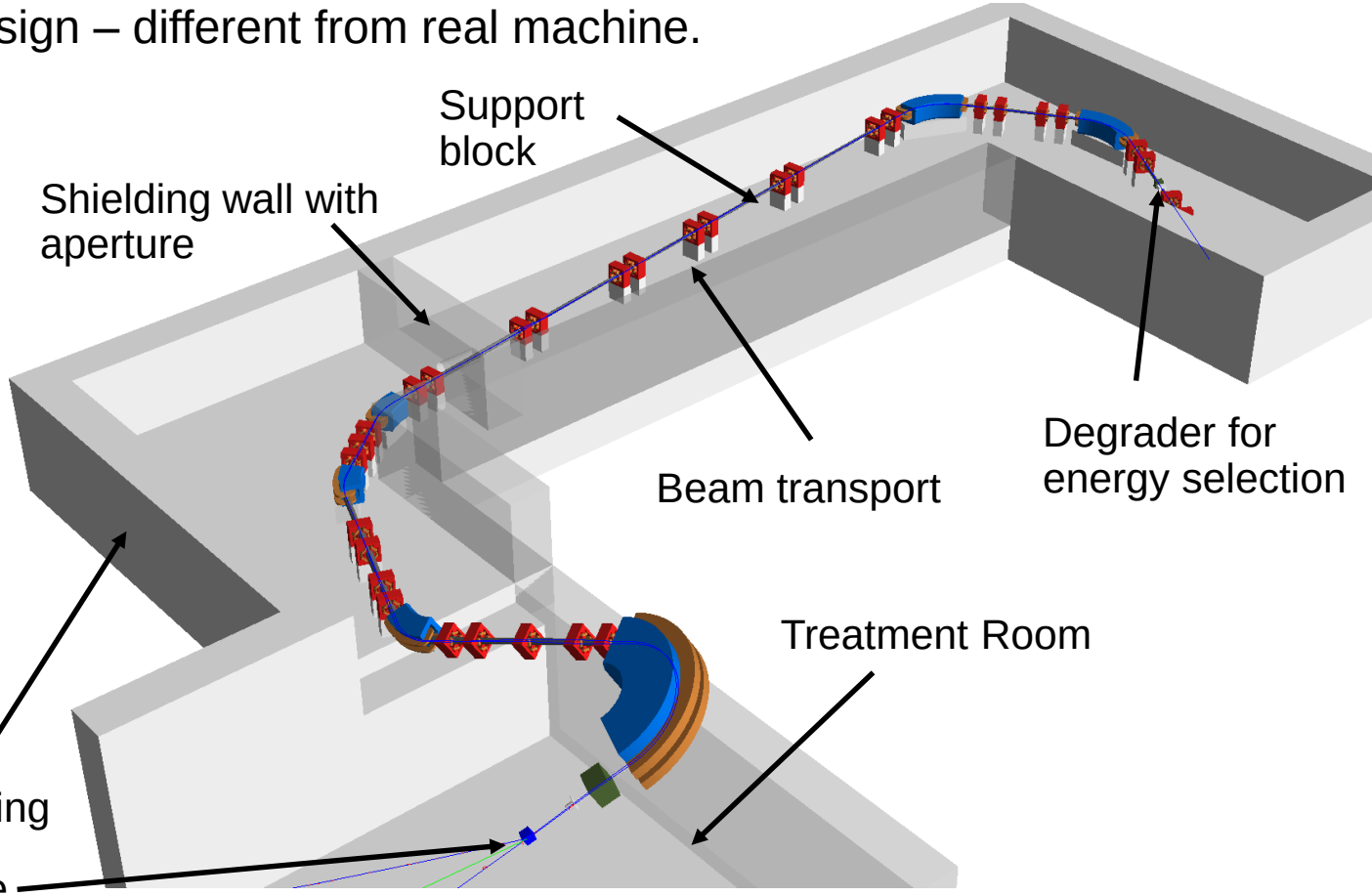


After



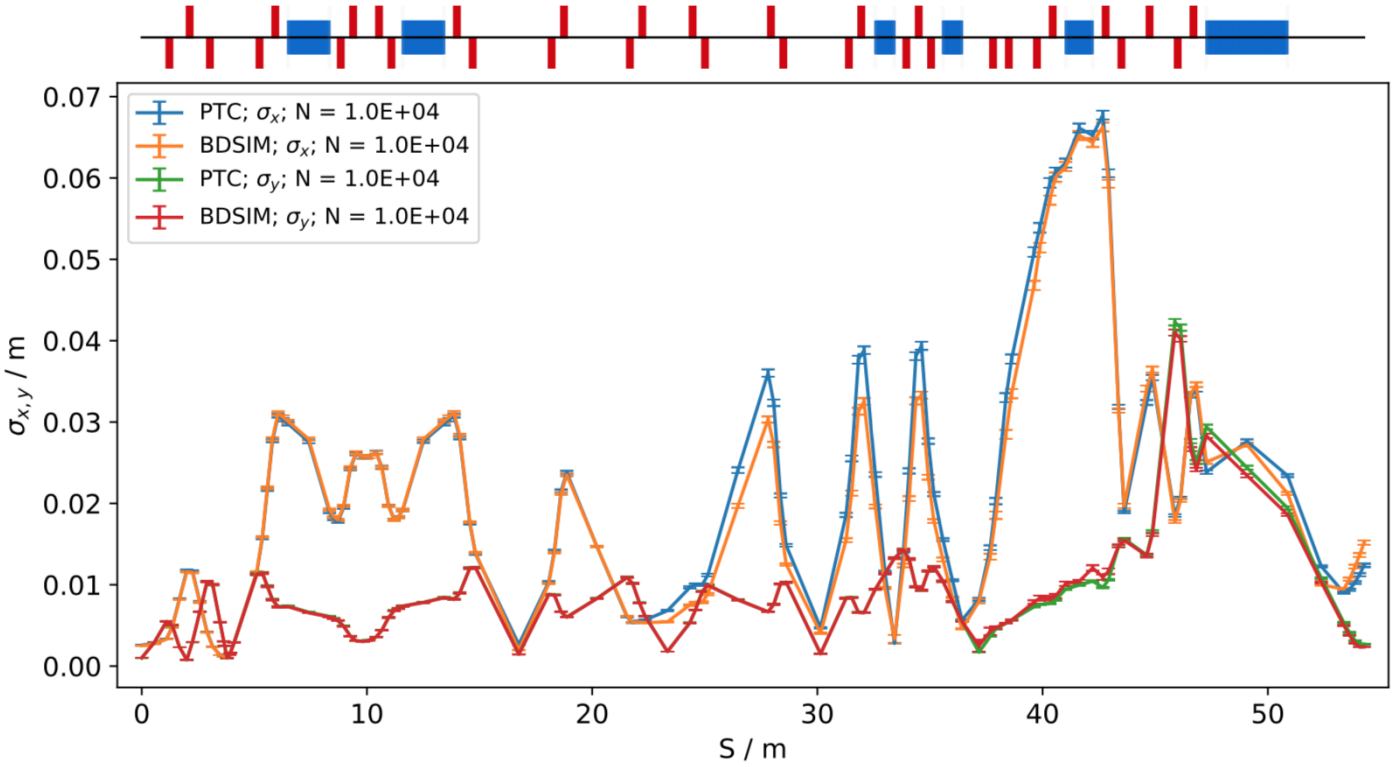
Example Proton Therapy Gantry

- Gantry 2 from Paul Scherrer Institute in Switzerland.
  - Lattice publicly available: http://aea.web.psi.ch/Urs_Rohrer/MyFtp
  - Conceptual design – different from real machine.
- Degrader and collimators added.
- Example shielding and element support block geometry generated.



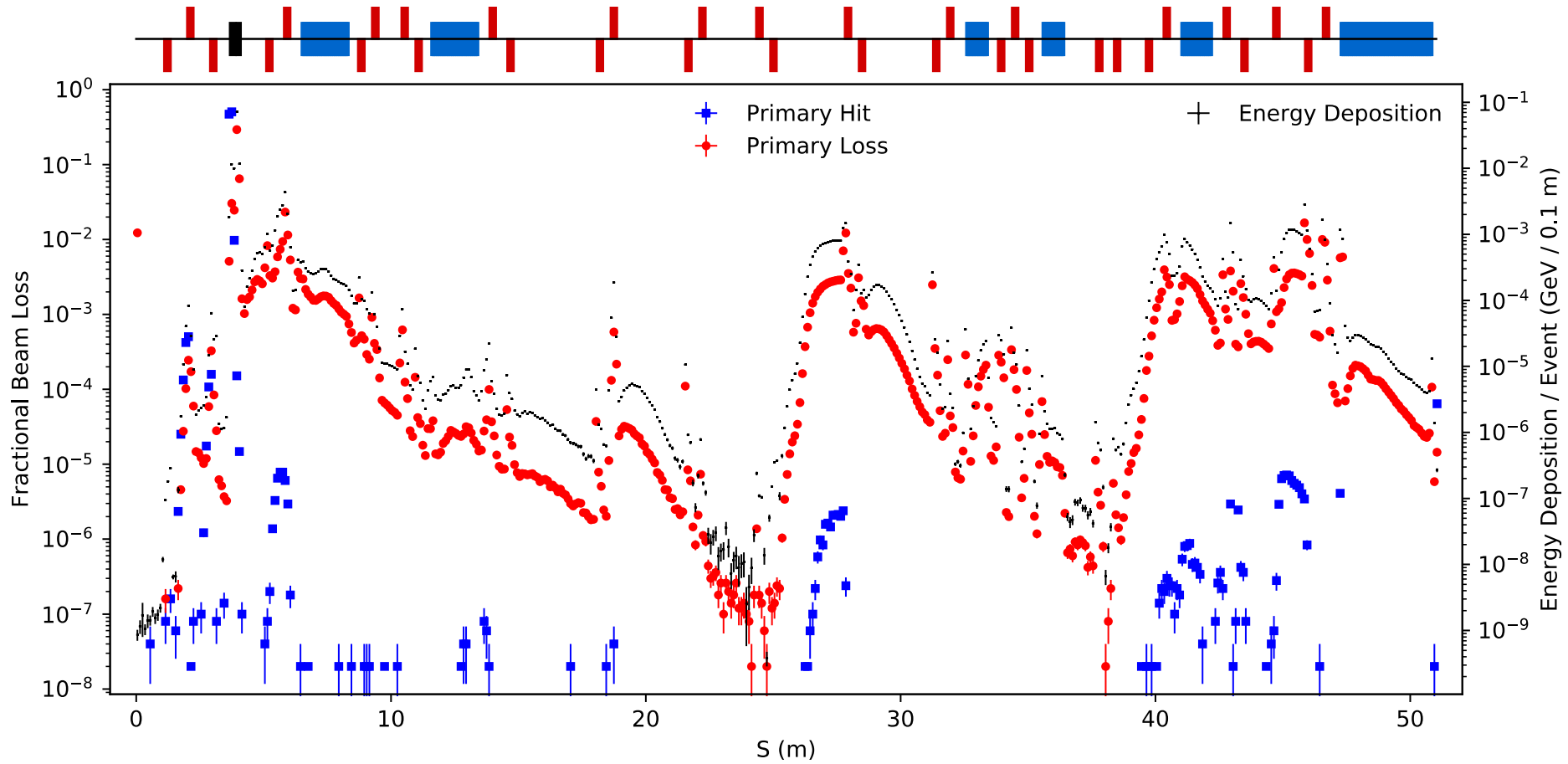
Lattice Optics

- Particle properties recorded after every element (position, momentum, energy etc).
- Twiss functions calculated with full statistical uncertainties.
- Excellent agreement with PTC tracking routines.

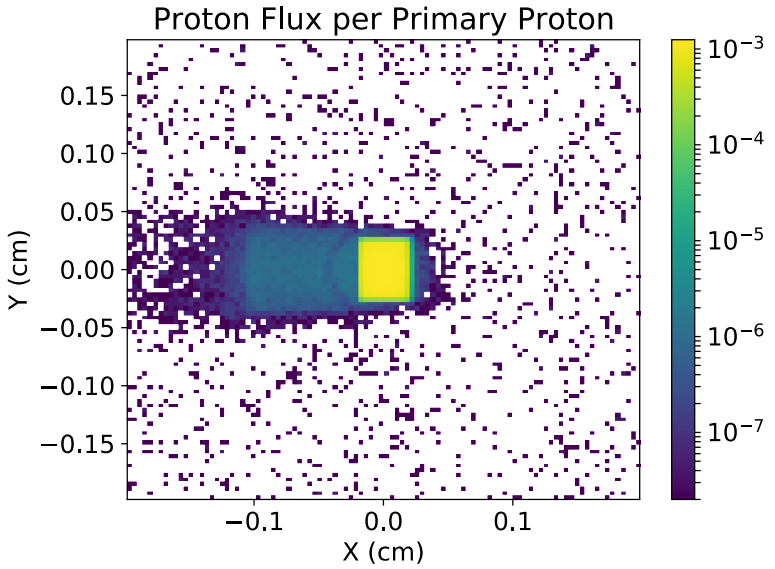


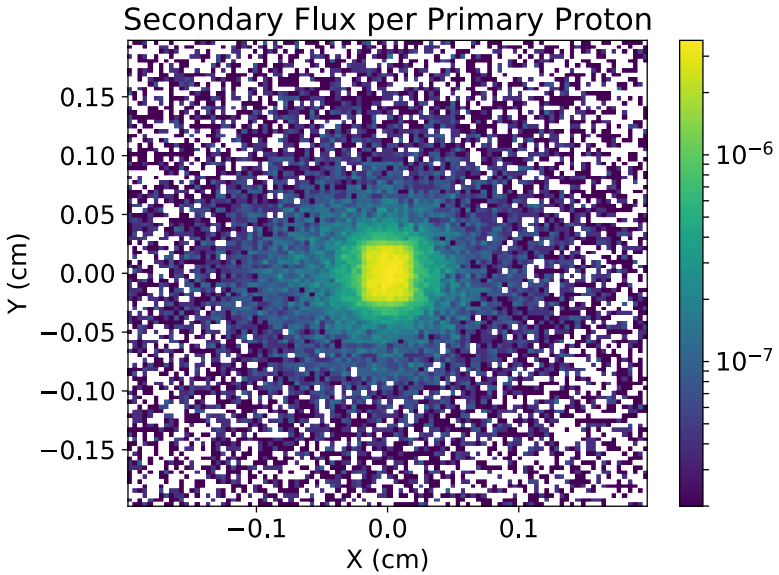
Loss Map and Energy Deposition

- Energy deposition per 10 cm along curvilinear axis for full machine length.

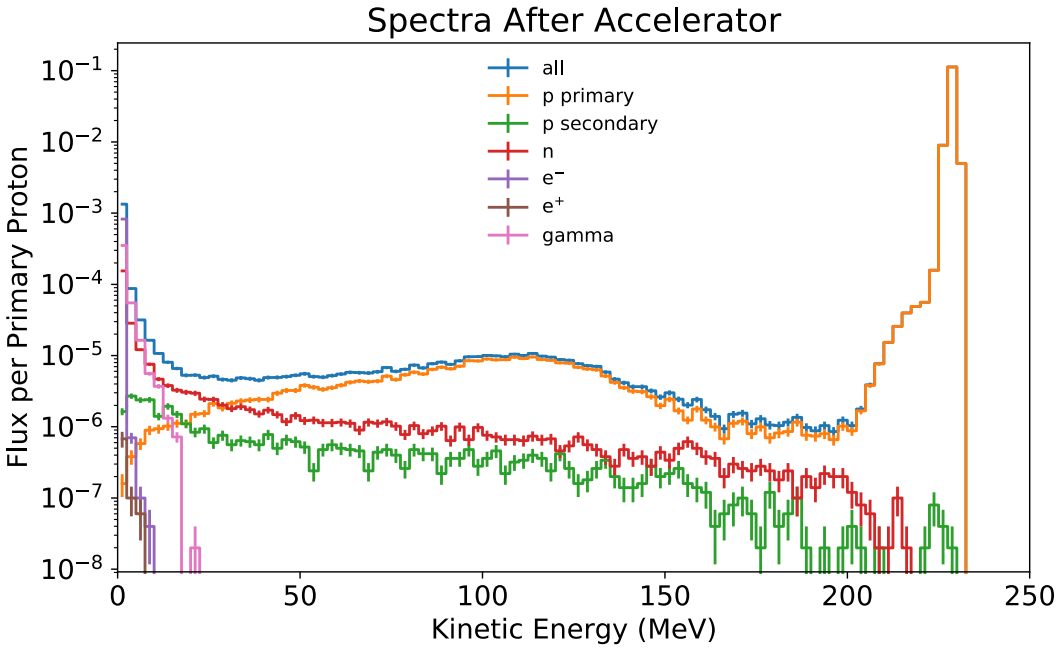


Spectra and Lateral Beam Profiles



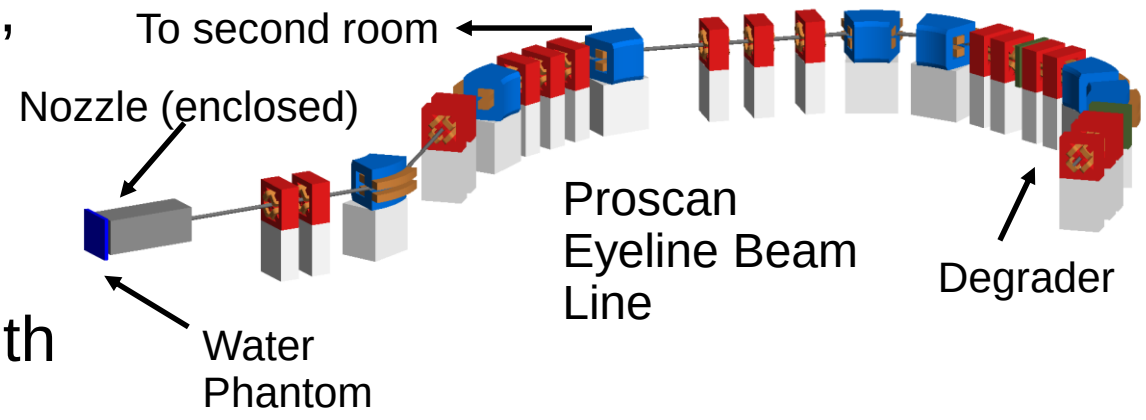


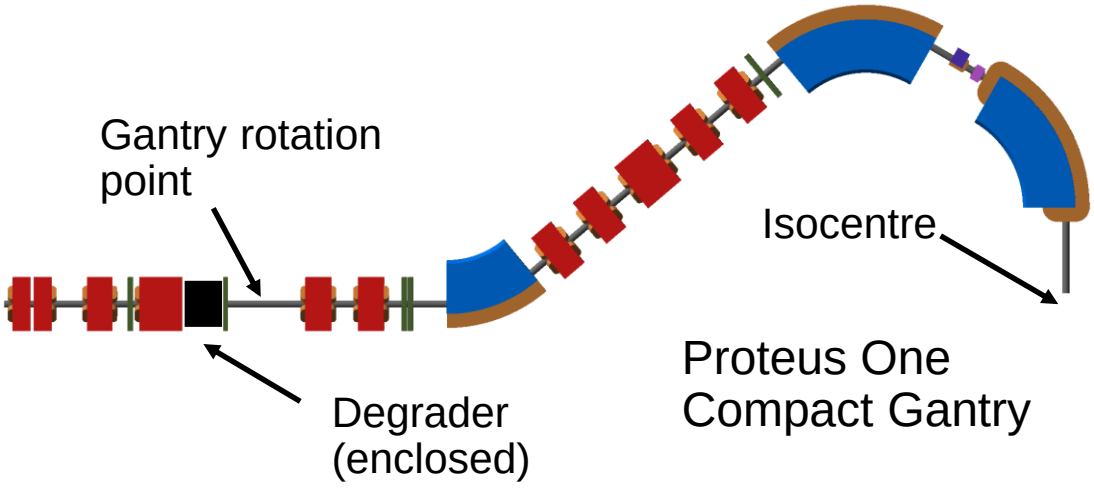
- Profiles prior to nozzle section.
  - Primary protons and secondary particles.
- Spectra of all particle species.



Collaboration with IBA

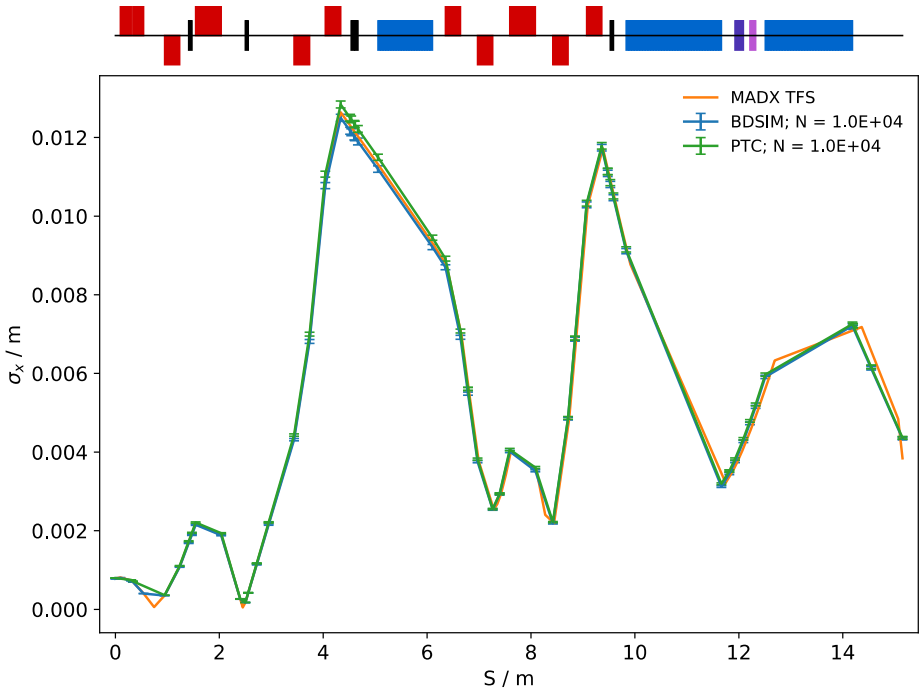
- Collaboration with IBA (Ion Beam Applications), Belgium.
- Simulation of two beam lines.
- Improve beam profile with optimised nozzle and optics.
- Enhanced dose rate from degrader efficiency studies.
- Loss maps for shielding activation.
- Publish next year.

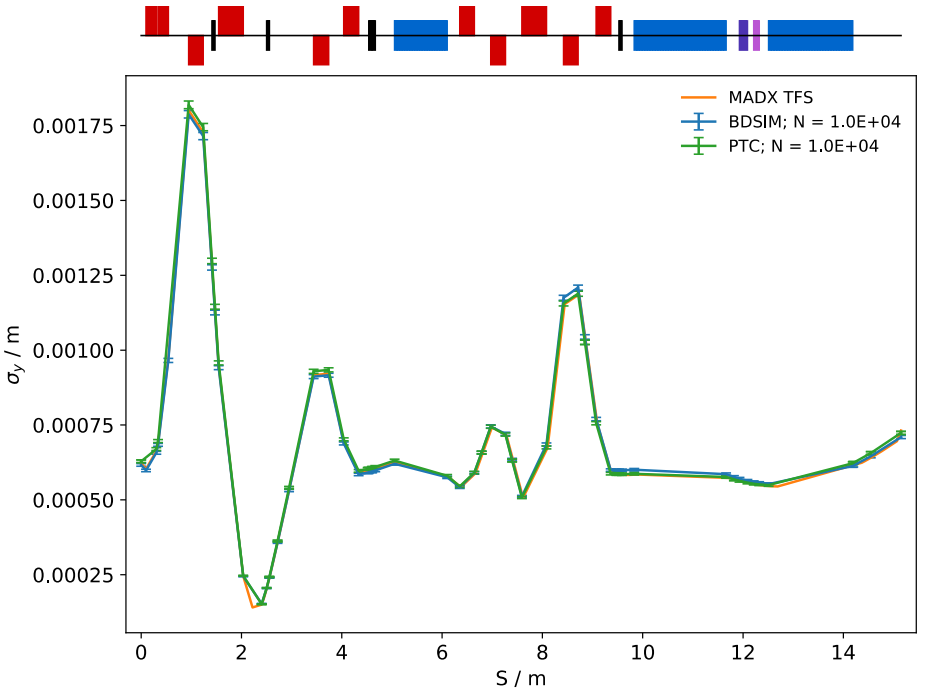




IBA Compact Gantry Optics

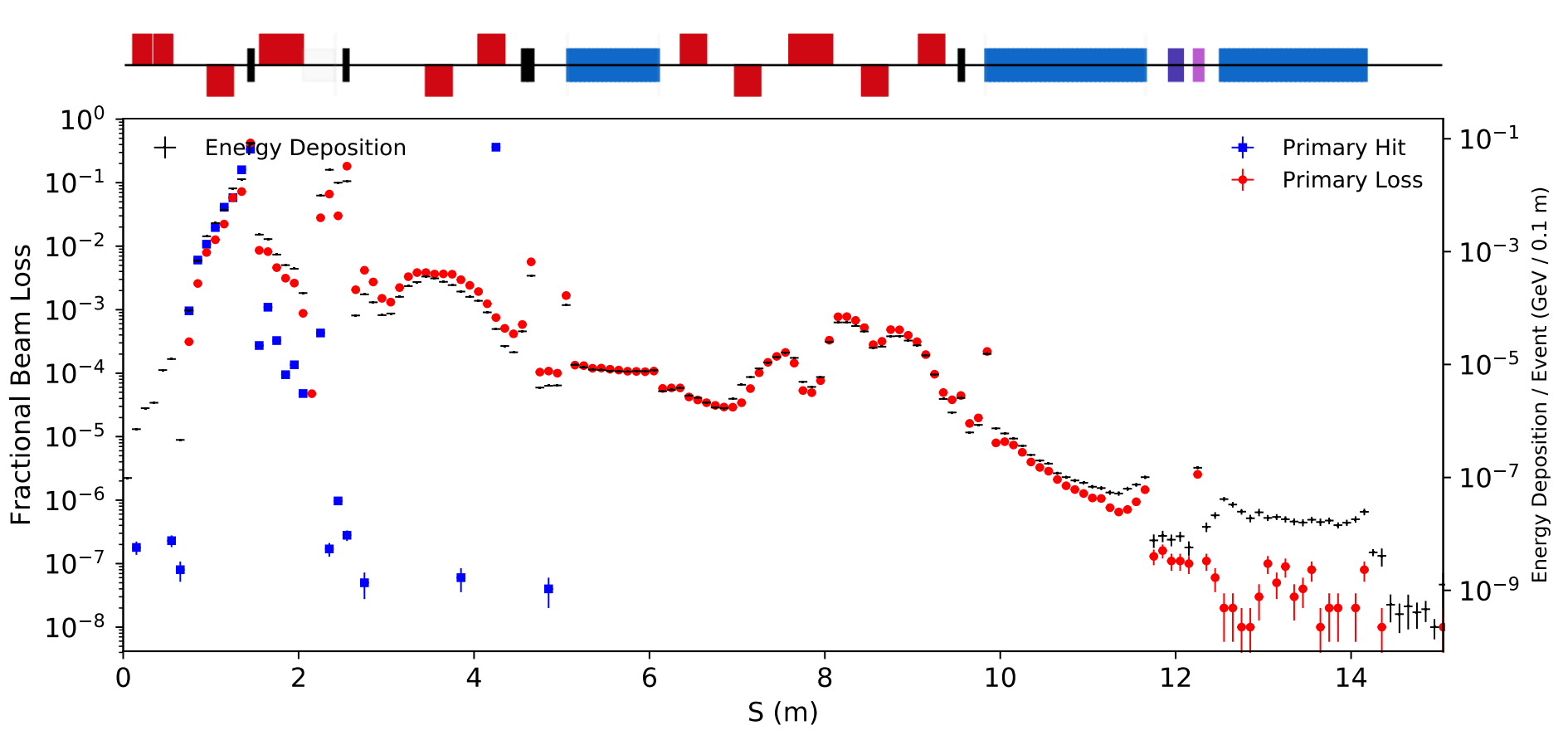
- Excellent agreement with BDSIM and other tracking codes.





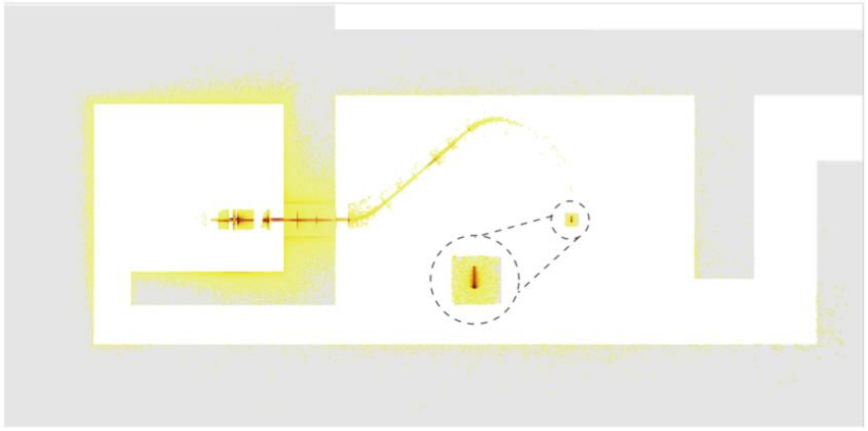
IBA Compact Gantry Loss Map

- Loss map for 70 MeV beam.



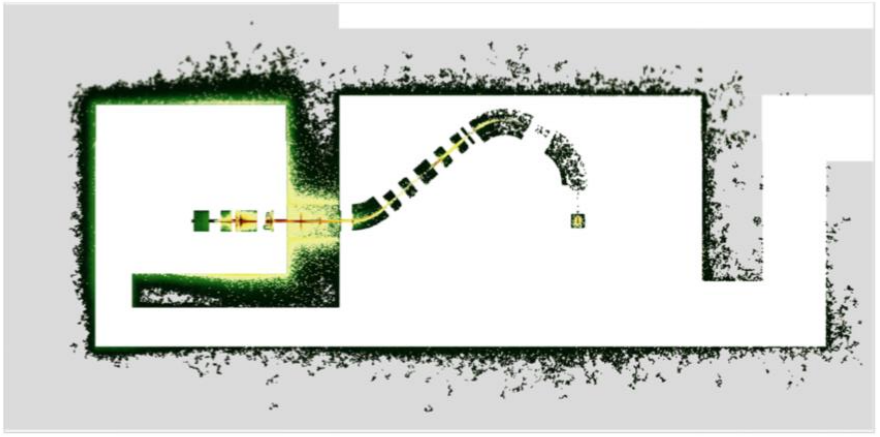
IBA Shielding Activation Studies

Proton interactions

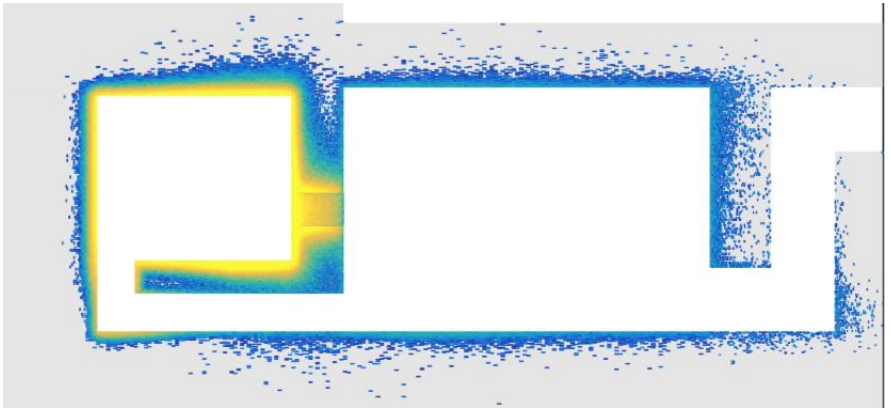


- Calculate shielding activation rate.
- Presented in Robin Tesse PhD thesis (ULB).
- ICAP 18 (20-24th Oct, Key West, Florida).

Protons & Neutron interactions



Shielding only



Summary & Outlook

- First start-to-end simulations of proton therapy beam lines.
- Verified optics, generated loss maps, shown spectra and lateral profiles, and demonstrated potential for shielding & dosimetry.
- BDSIM development:
  - Dosimetry, further fringe fields, nozzle components.
- Expanded analyses.
- More detailed model.
- Watch this space!

Thank you

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http://www.pp.rhul.ac.uk/bdsim/