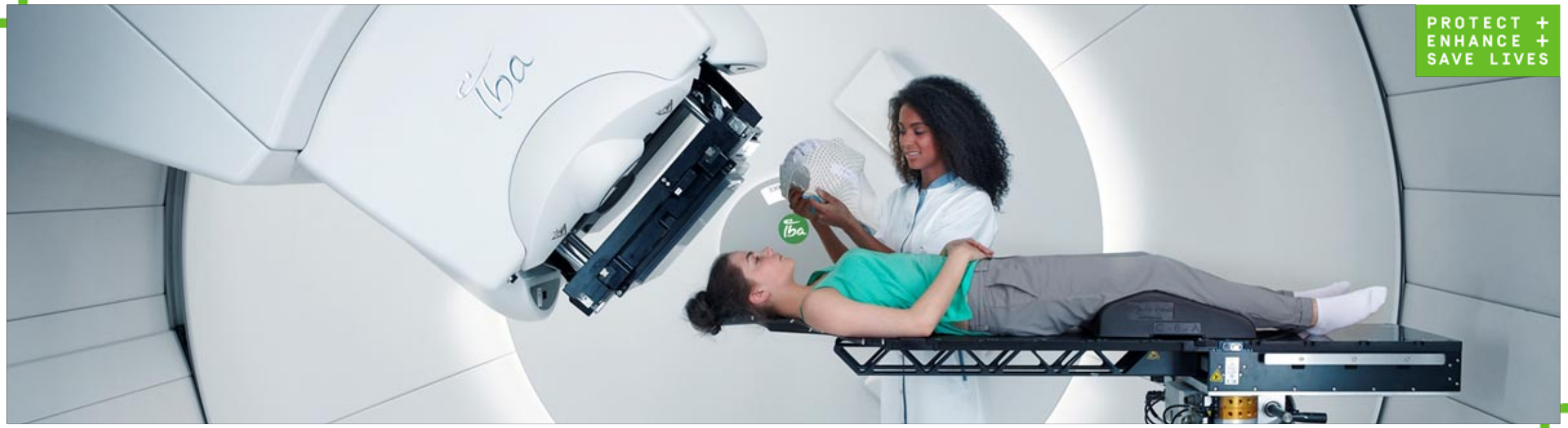


# Seamless beam and radiation transport simulations of IBA Proteus systems using BDSIM

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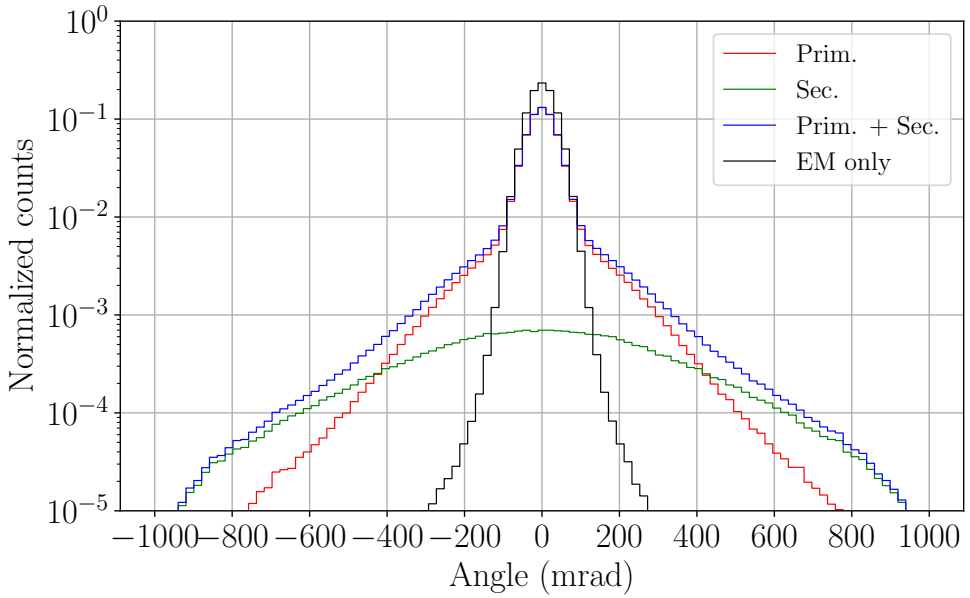
# Outline

- Specifics of beam and radiation transport for proton therapy systems
  - *A challenge for our usual simulations tools*
- BDSIM: Beam Delivery Simulation
  - *Toward seamless simulations of complete PT systems*
- IBA Proteus Plus for eye treatment
- IBA Proteus One compact gantry simulations
- Shielding activation studies using BDSIM
- Summary and future work

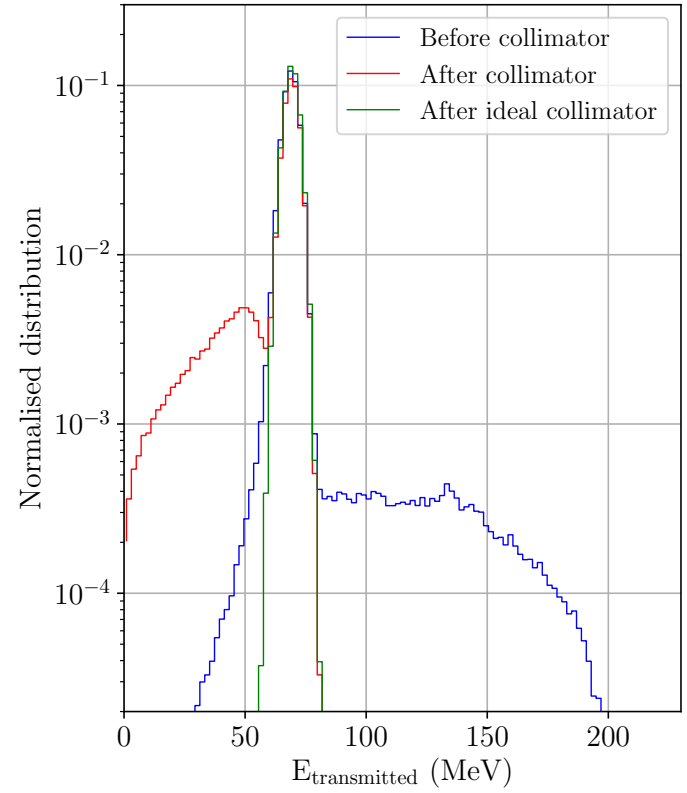
# Beam and radiation transport for proton therapy simulations

- Energy modulation in cyclotron-based PT systems performed with energy degrader
  - Importance of particle-matter interactions at low energy
  - Large emittance: beam transport is often aperture dominated
  - Beam halo (cleaning): low energy tails and large transverse momentum halo




230 MeV protons degraded to 70 MeV with a beryllium block

**Degrader effect on transverse distribution**

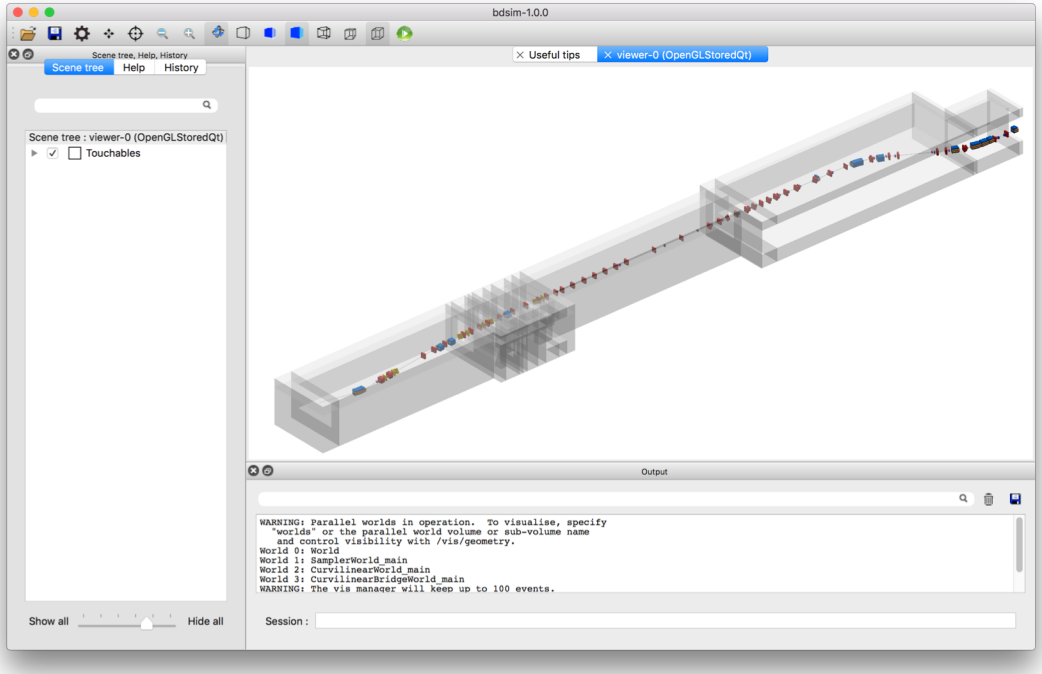


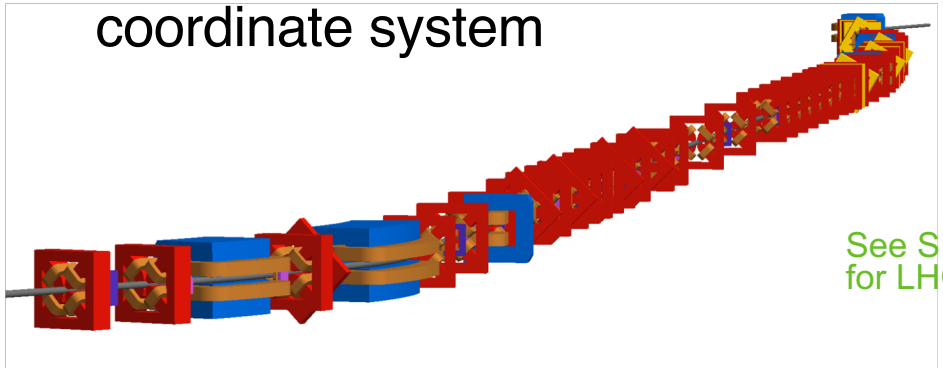

**Collimation effect on energy spectrum**

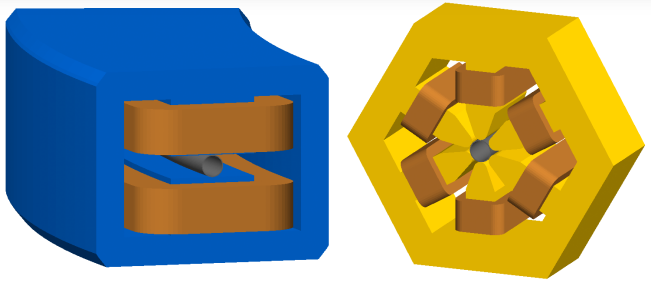
# BDSIM - Beam Delivery Simulation

Beam Delivery Simulation

- Create 3D Geant4 model from accelerator optical description in minutes
- Library of generic accelerator geometry in Geant4 C++
  - you can learn a lot with generic geometry
  - scalable with variable proportions and safe from overlaps
- MAD-X style input syntax in ASCII
- Can overlay other geometry and fields maps for more detail
- Thick lens 1st order matrices used for in-vacuum tracking
  - replaces Geant4's 4th order Runge-Kutta (in the paraxial case)
- Automatic parallel world for curvilinear coordinate system





See S. Walker talk on Tuesday for LHC collimation with BDSIM

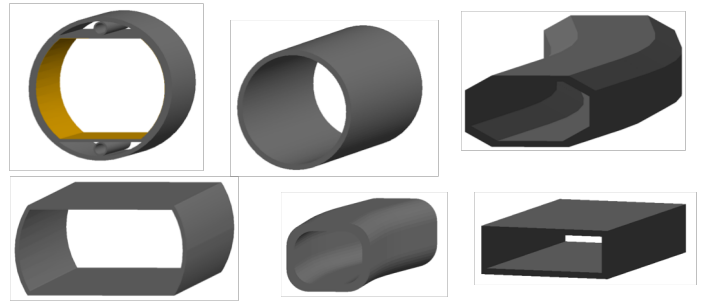
http://www.pp.rhul.ac.uk/bdsim

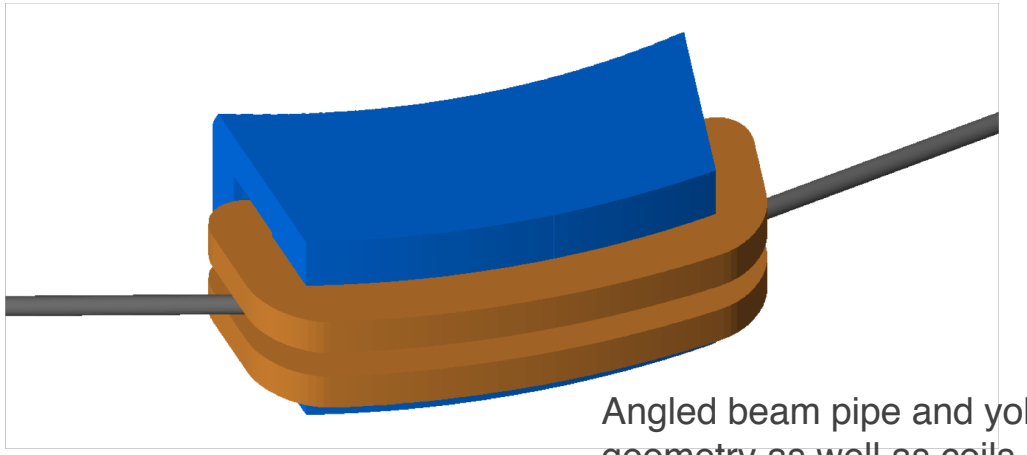
https://arxiv.org/abs/1808.10745

# BDSIM - Beam Delivery Simulation

- Imperfections usually implemented via thin elements in tracking
  - entrance / exit or in the middle of magnet
- Pole face rotations contribute significantly to optics
  - crucial for low energy applications
  - Implementation using 1st order matrix formalism
- Curvilinear coordinate system provided by parallel world geometry

all aperture types
from MADX available

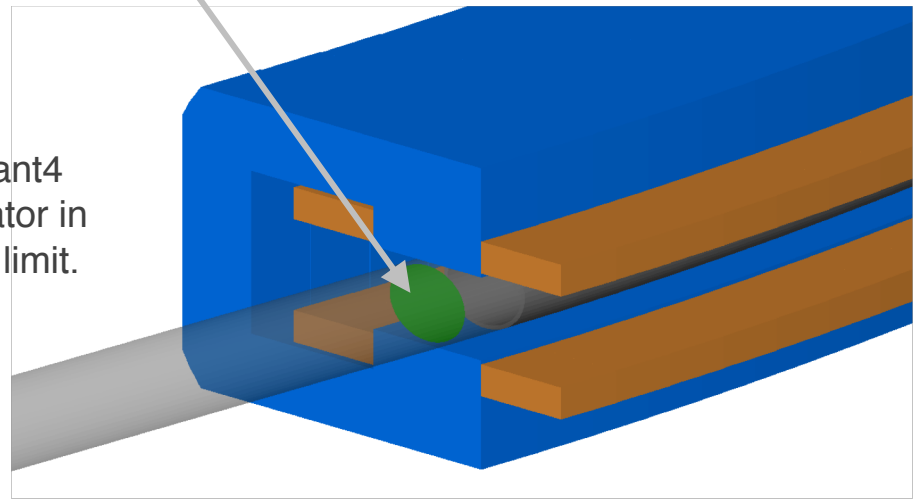




Angled beam pipe and yoke geometry as well as coils

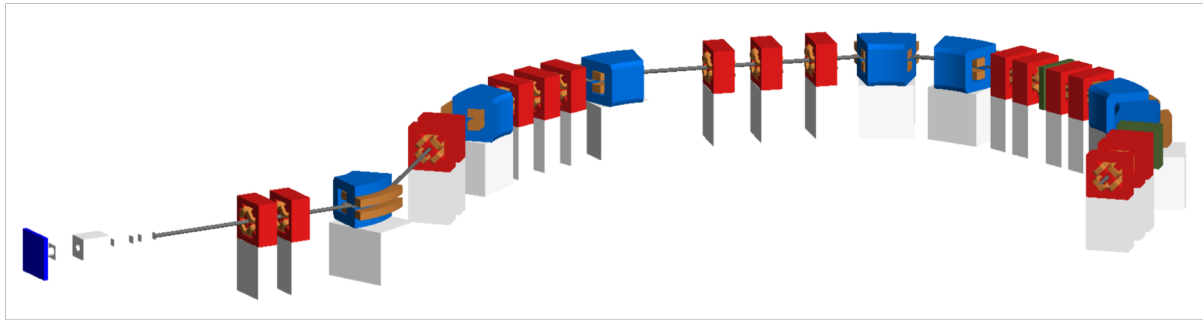
Thin element for fringe field

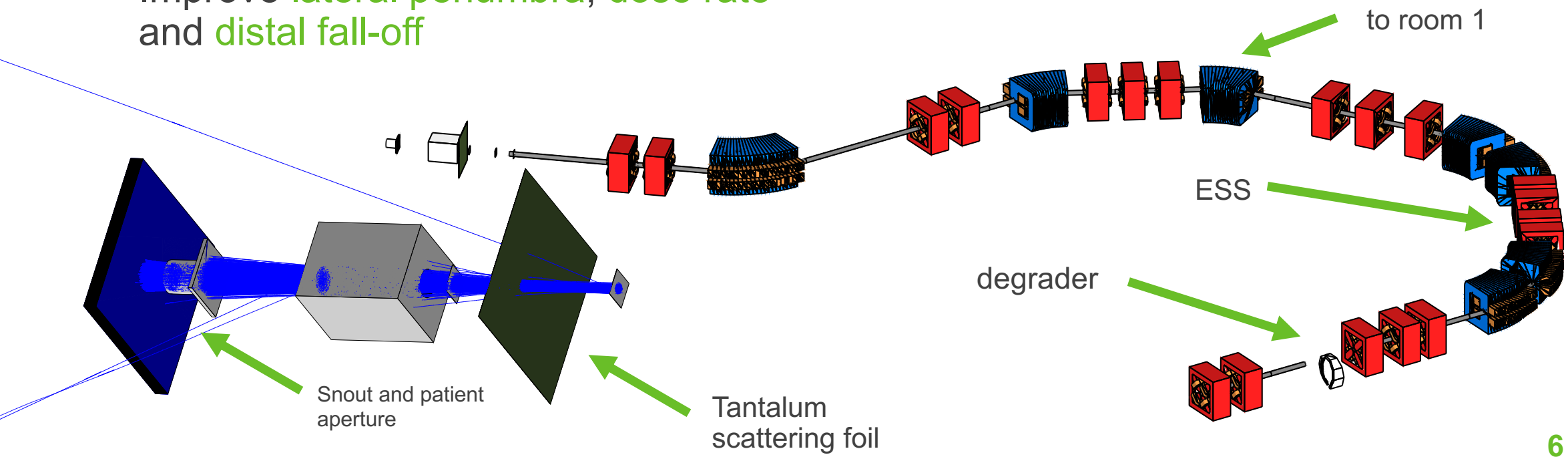
Revert to Geant4 based integrator in non–paraxial limit.



# IBA Proteus Plus for eye treatment

- Small field single scattering nozzle
- Challenges
  - Coupled beamline / nozzle optimization
  - Improve lateral penumbra, dose rate and distal fall-off



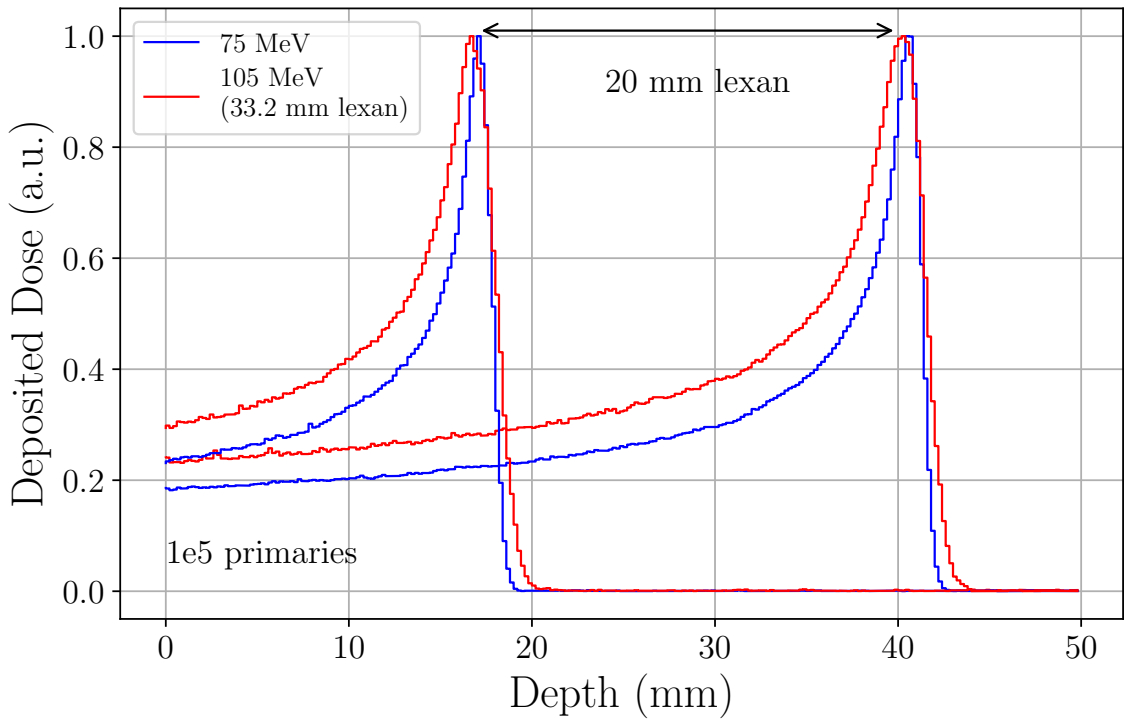


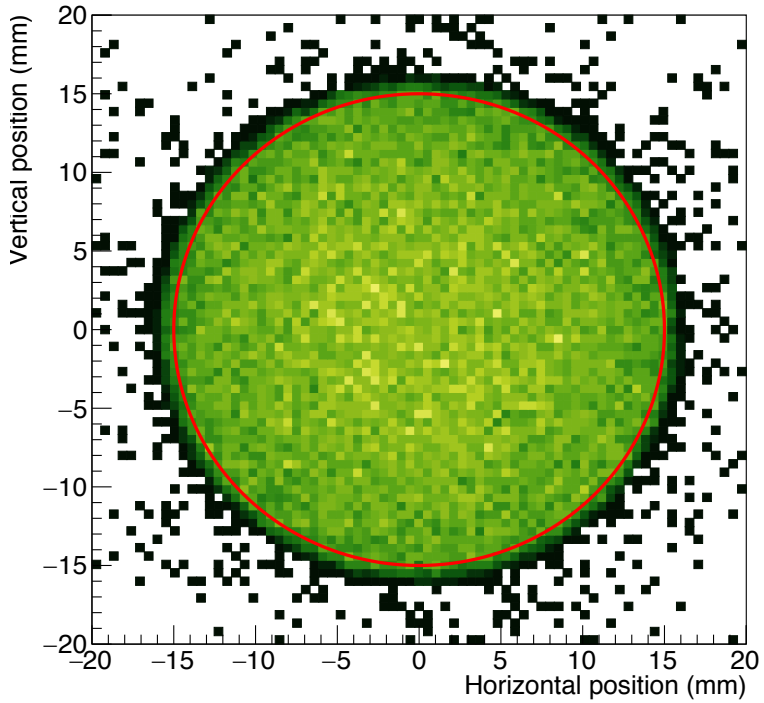

**Scattering nozzle**

# IBA Proteus Plus for eye treatment

- Nozzle redesign for improved distal fall-off
- Lower energy at nozzle entrance (no range shifting in the nozzle)
- Tight settings for the energy selection system

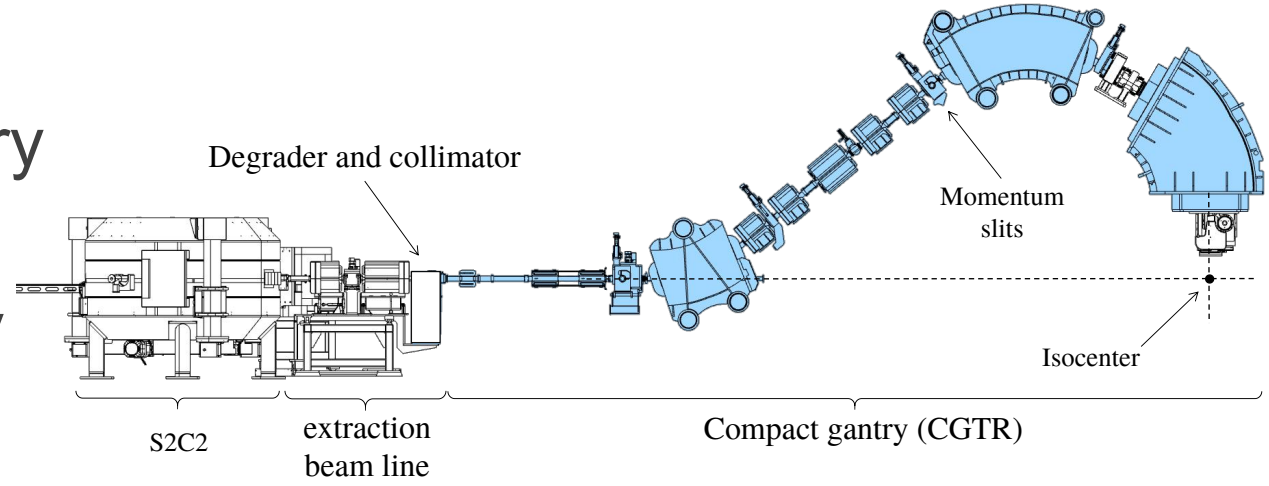
- Impact on lateral uniformity (optics and scattering foils re-optimization)
- Impact on dose rate (degrader efficiency)



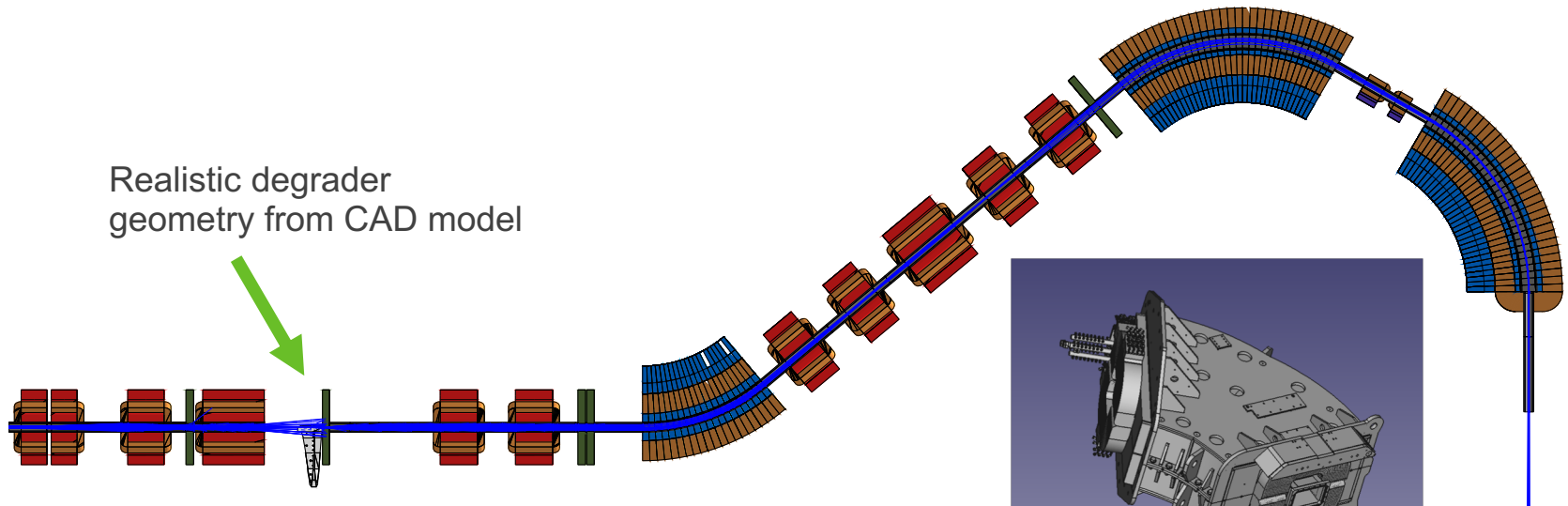
# IBA Proteus One compact gantry

- Superconducting cyclotron + compact normal conducting gantry
- Challenges
  - Detailed degrader/collimator energy and transverse spectra modeling
  - Loss maps for shielding activation studies




Generic geometry from BDSIM

Realistic degrader geometry from CAD model



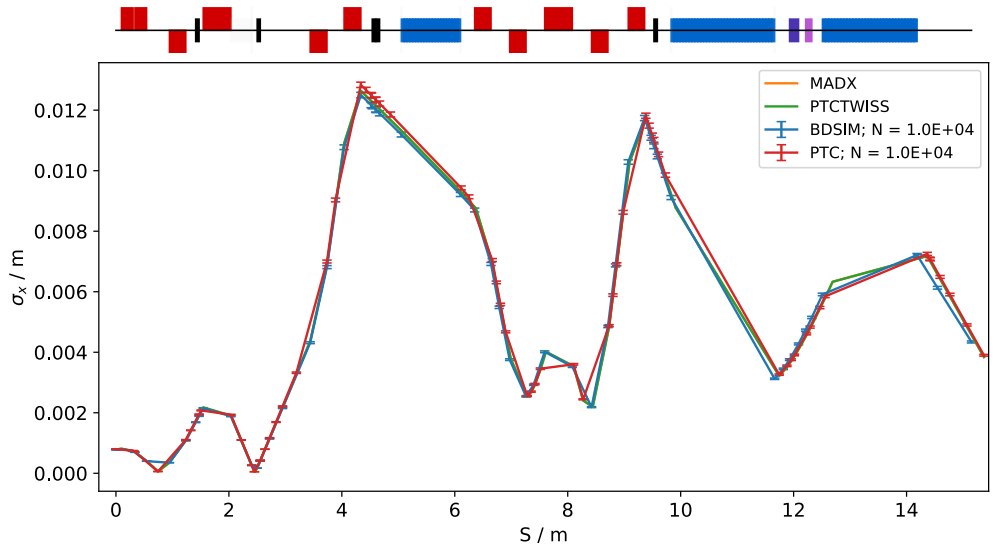


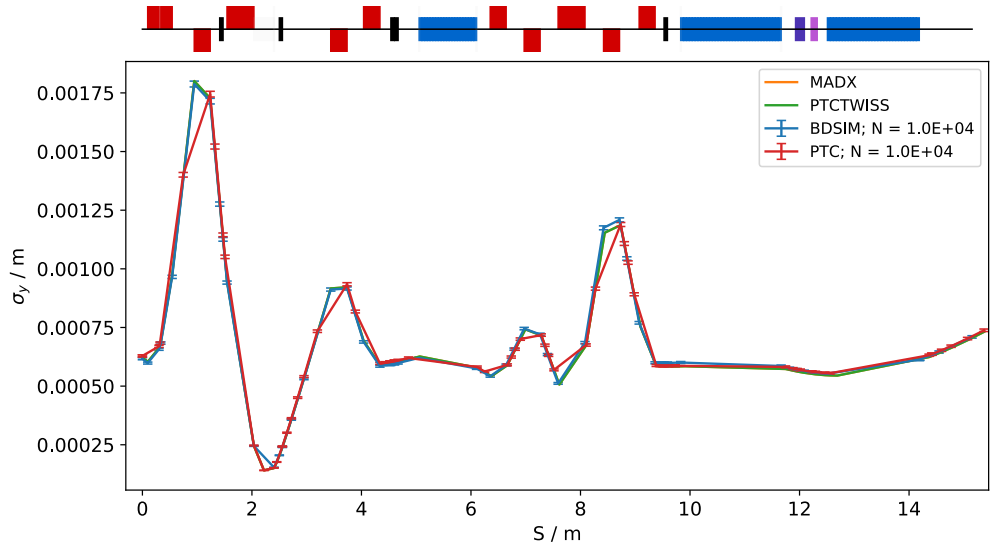
On-going:
3D geometry of scanning section with field maps (OPERA)

# IBA Proteus One compact gantry

- Optics and tracking validation
  - Operational values for magnets and collimators setpoints
  - **BDSIM**: enlarged apertures for optimal comparison with other codes (no losses and to maintain Gaussian distributions)
  - ✓ **PTC**: twiss and tracking
  - ✓ **MAD-X**: twiss

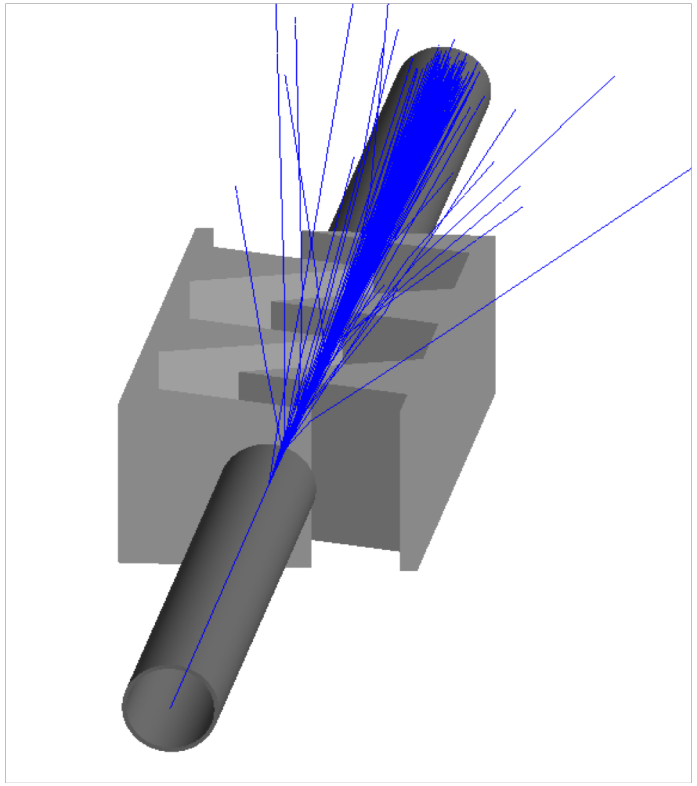
- Excellent agreement found between BDSIM and other codes



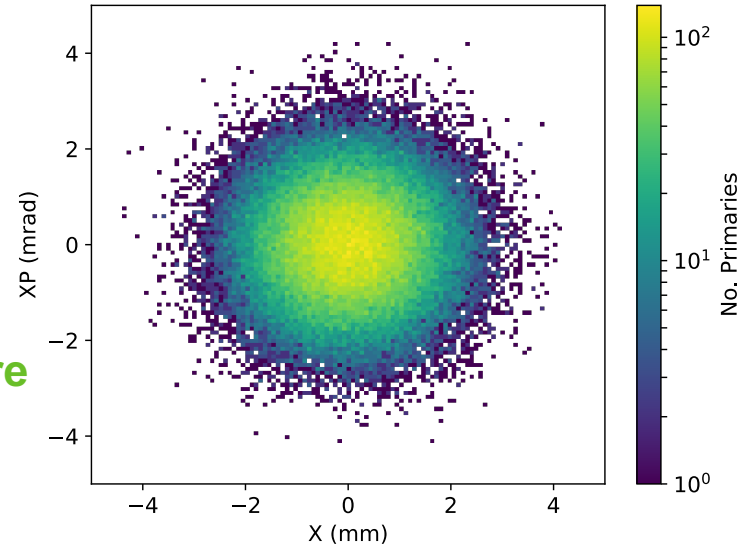



# Beam and radiation transport for proton therapy simulations

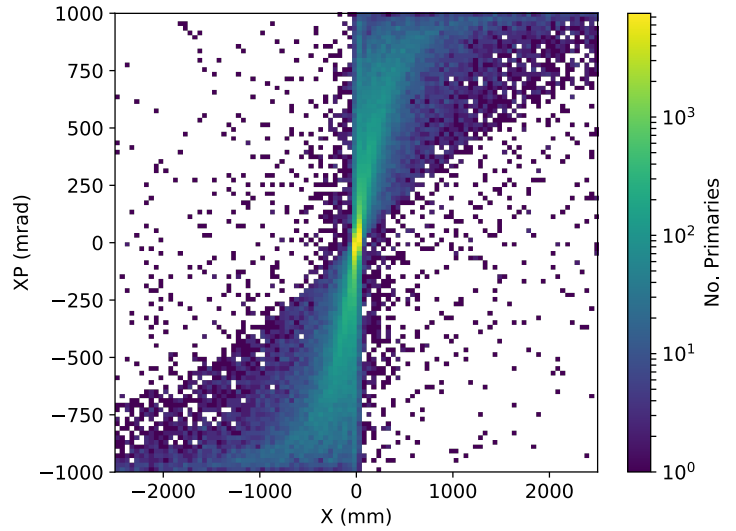
- Hadron therapy degrader
  - Use variable material depth to degrade beam energy
  - PSI wedge degrader



Before

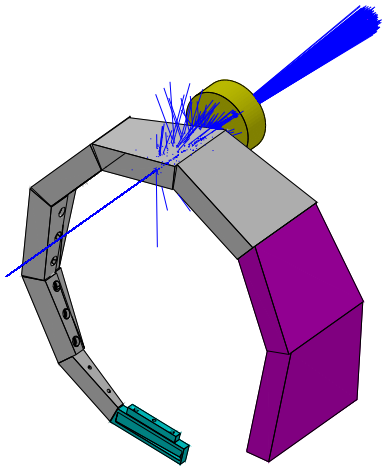



After

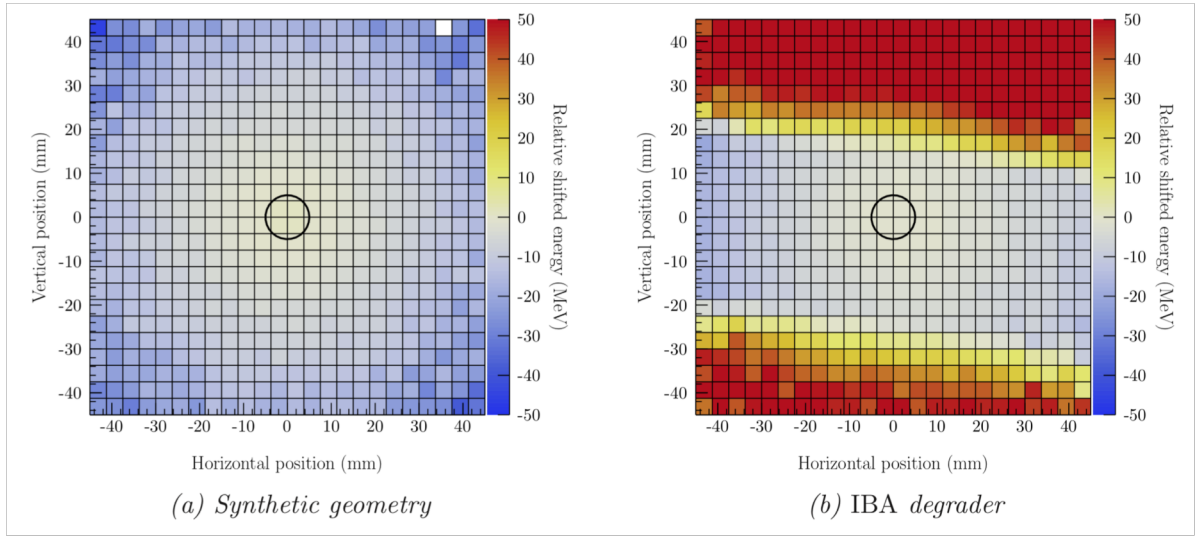


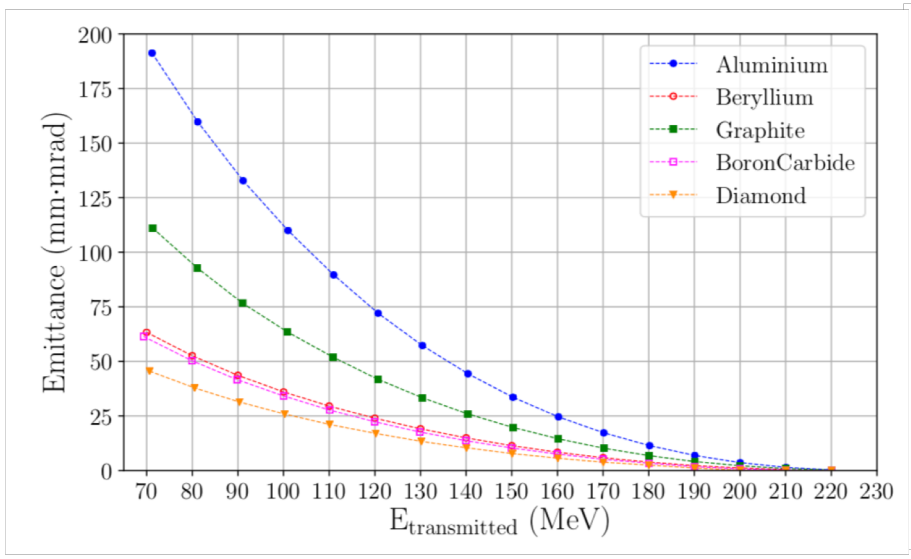
# IBA Proteus One compact gantry

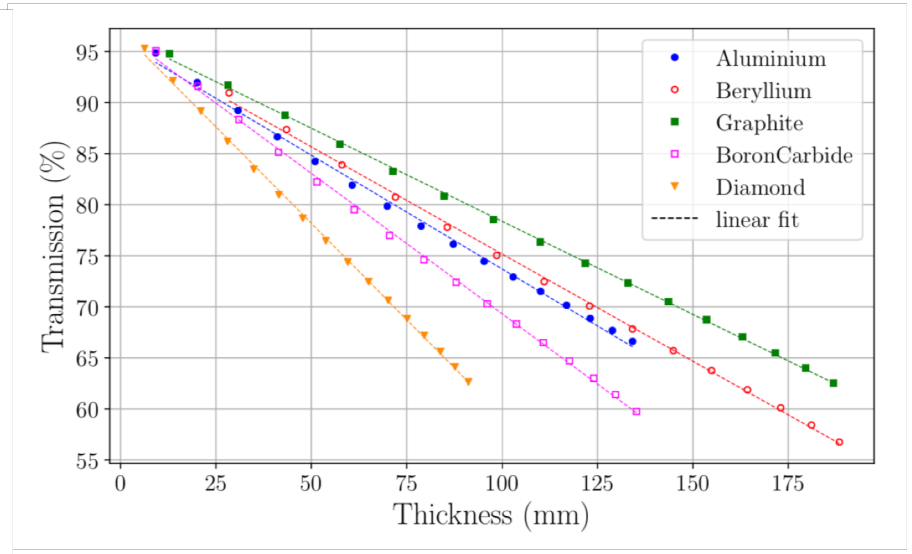
- Degrader modeling



Based on realistic geometry of the IBA “wheel” degrader



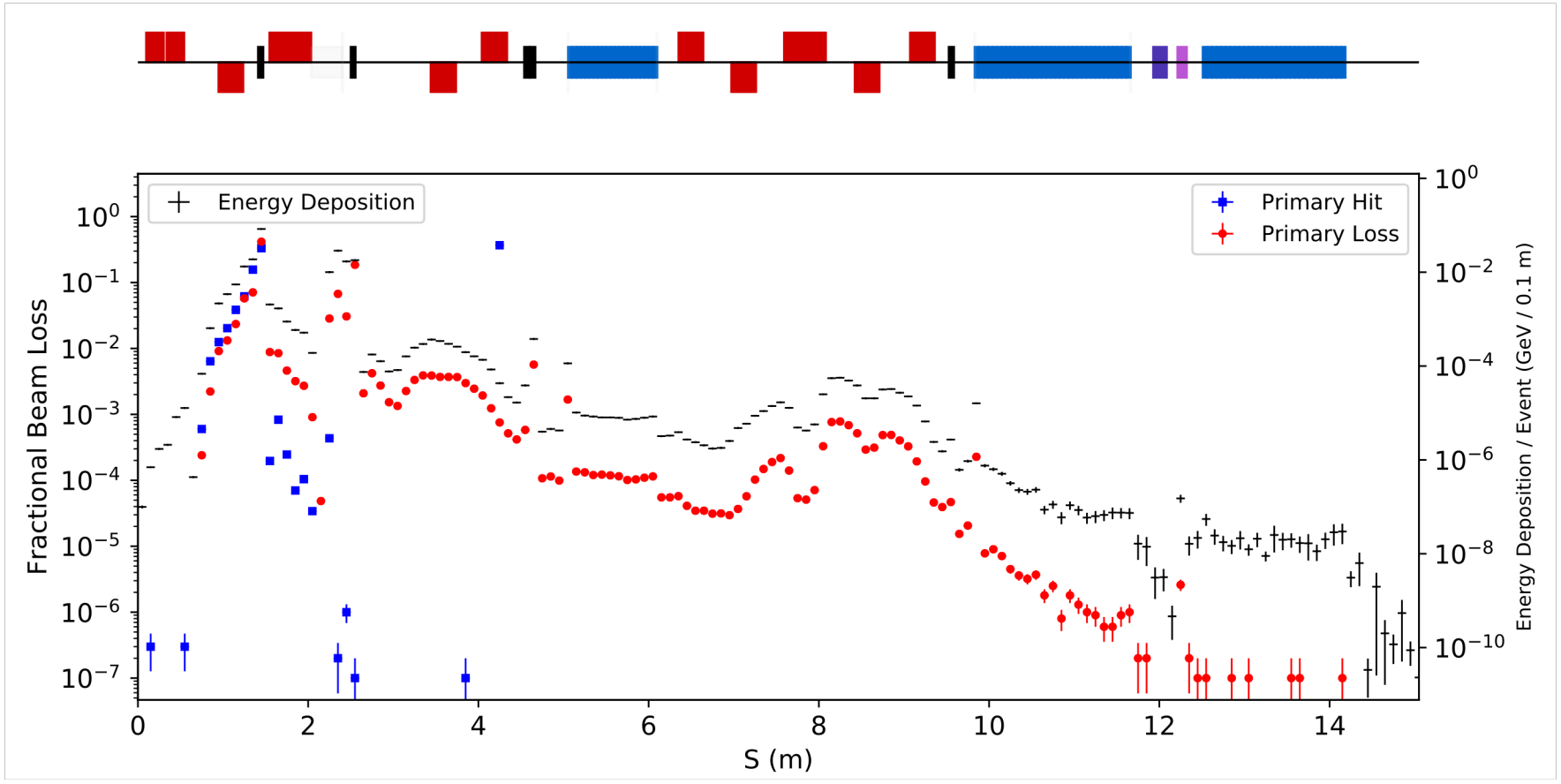



# IBA Proteus One compact gantry

- Loss maps (losses per 10cm on the curvilinear coordinate)

**70 MeV**

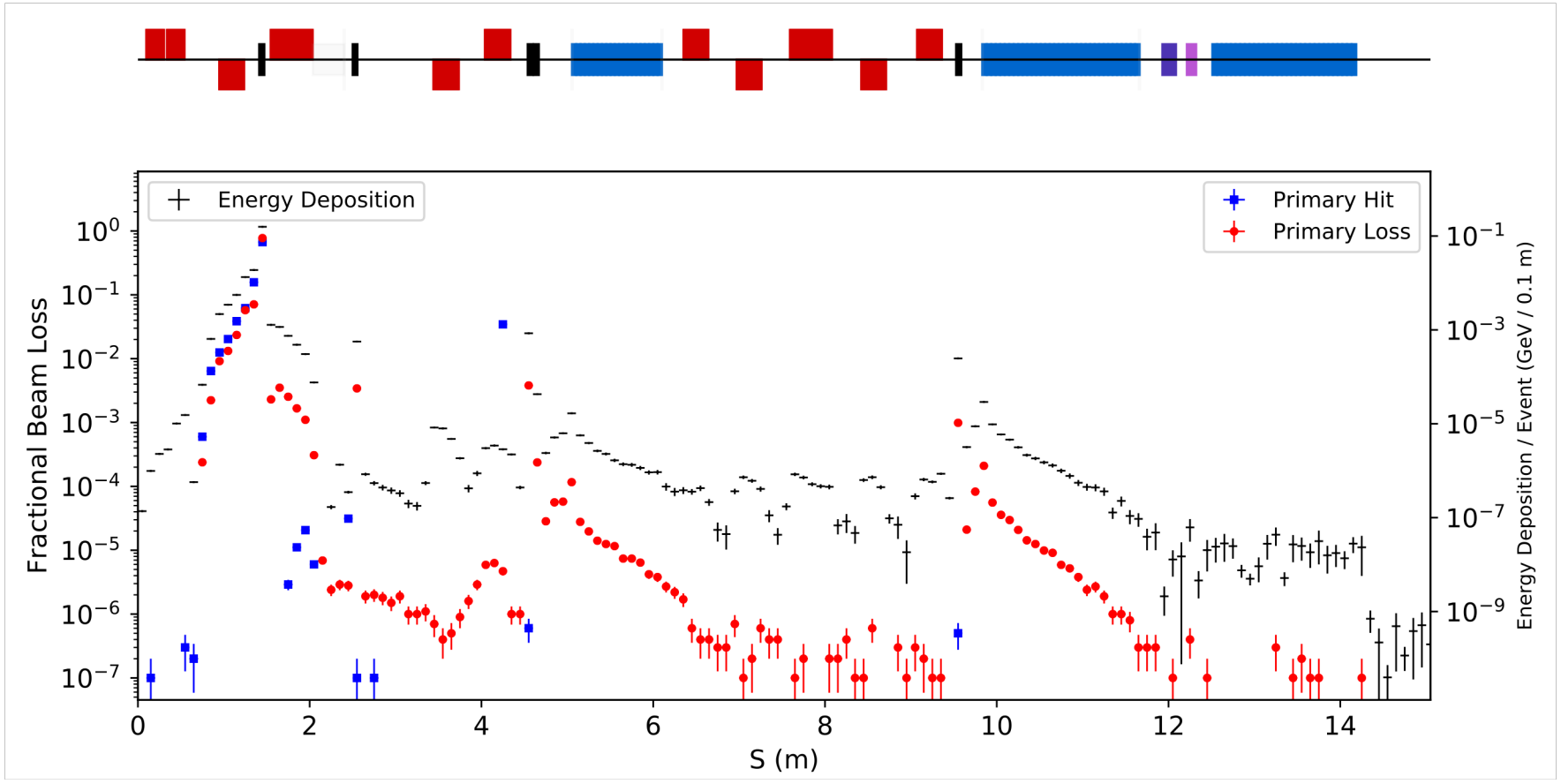



- Enables single-code seamless simulations for energy deposition and shielding activation

# IBA Proteus One compact gantry

- Loss maps (losses per 10cm on the curvilinear coordinate)

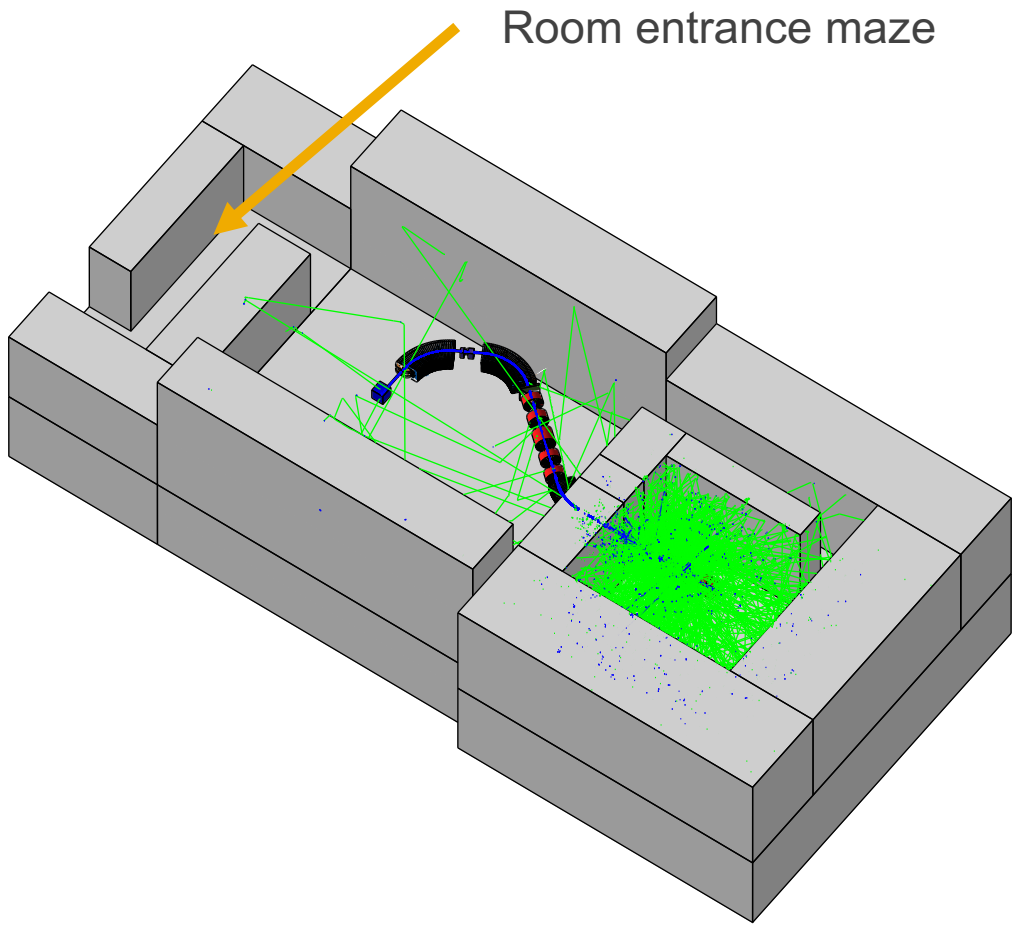
**230 MeV**

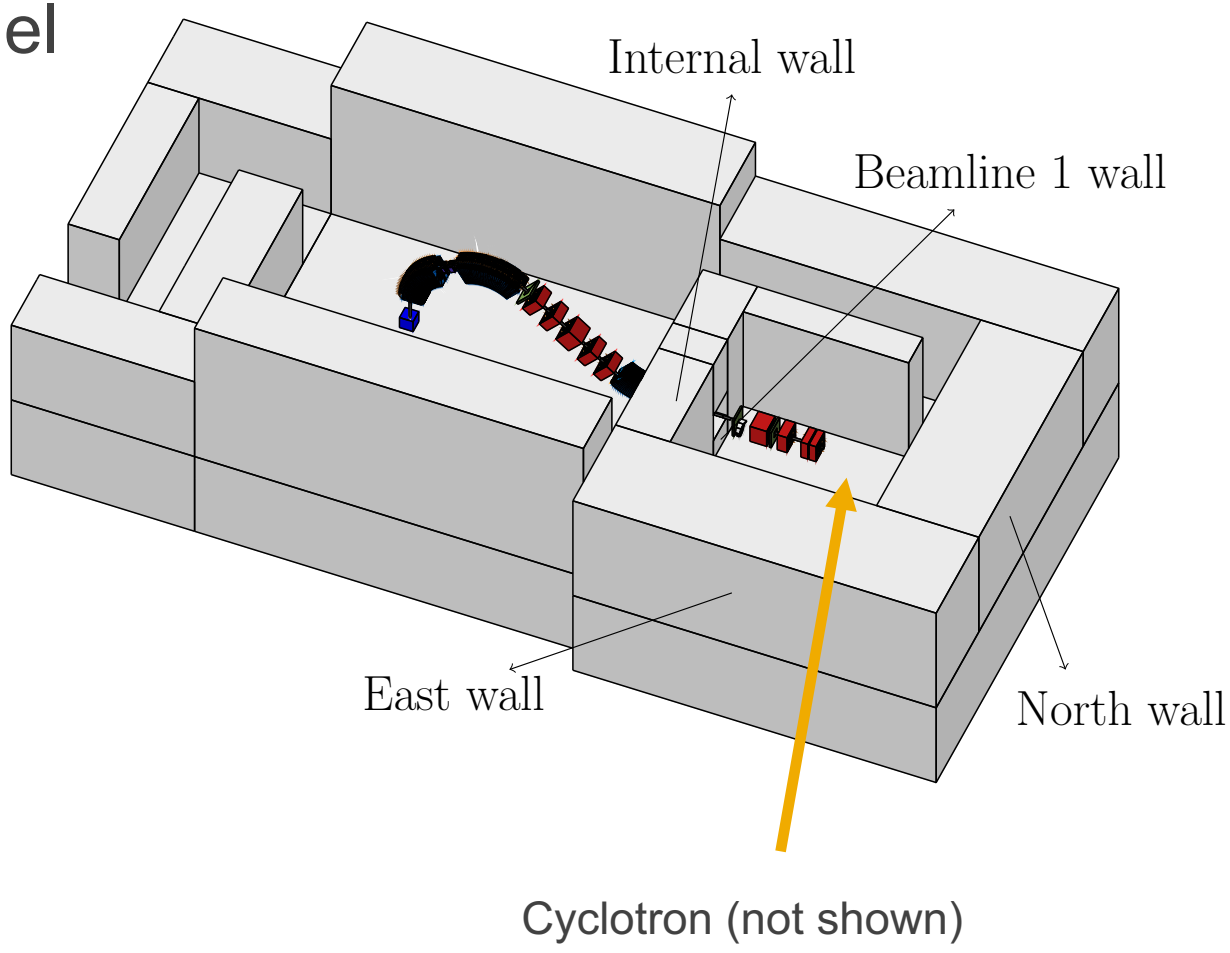



- Enables single-code seamless simulations for energy deposition and shielding activation

# Shielding activation studies with BDSIM

- Shielding blocks added to the model

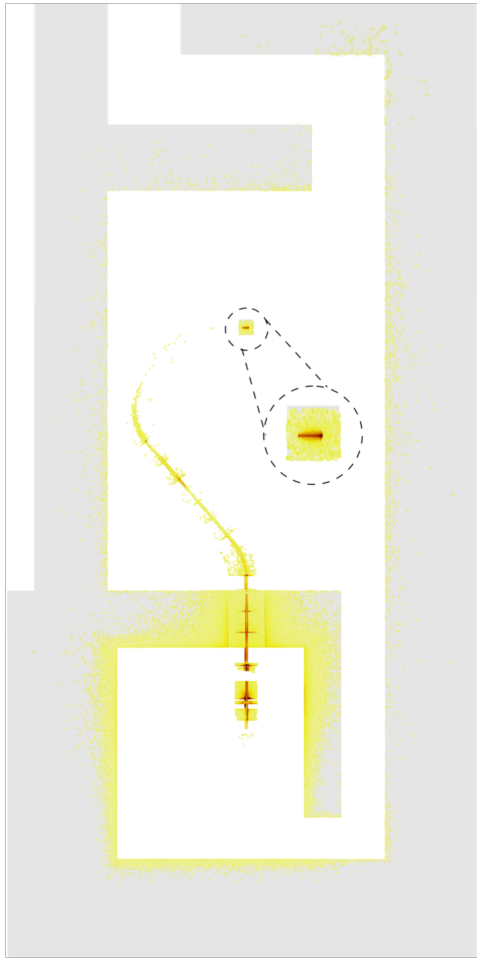


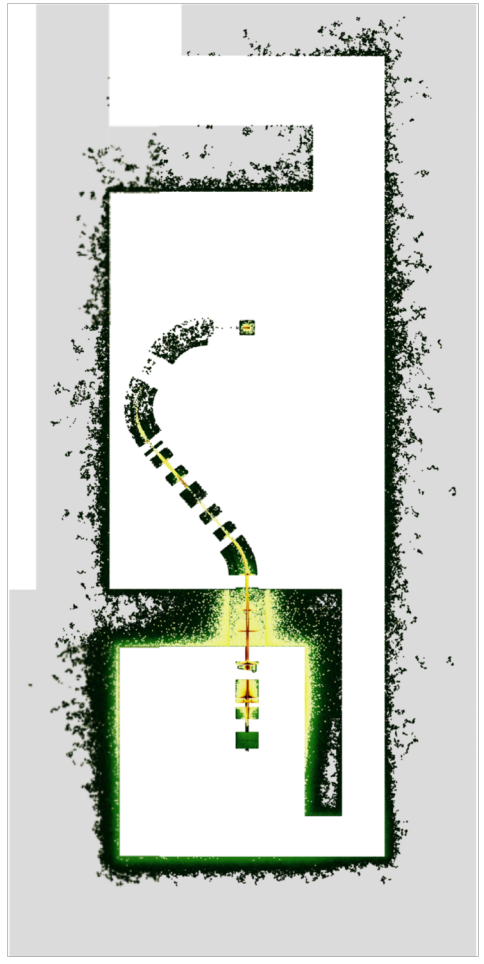

Top shielding block cut away for visualisation

# Shielding activation studies with BDSIM

Proton interactions



Proton + neutron interactions

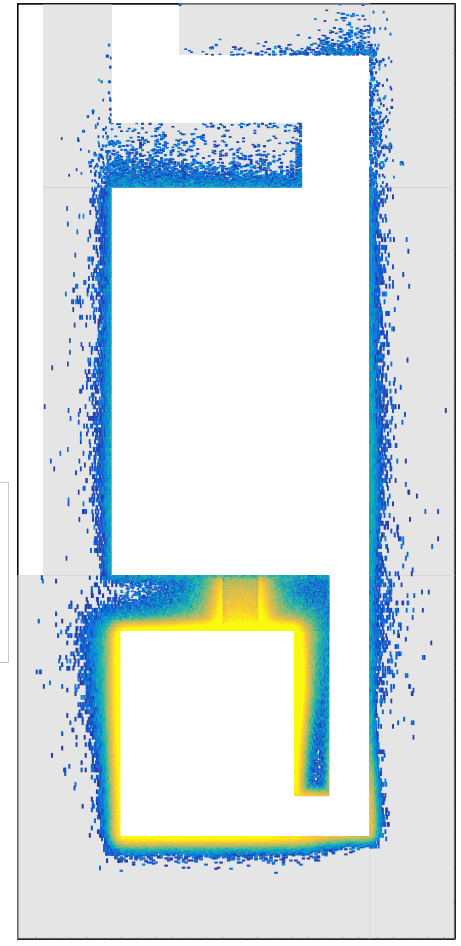


- Activation of concrete shielding: spallation reactions and neutron capture reactions

$$^{151}Eu + n^0 \rightarrow ^{152}Eu$$

- Reaction rate

$$R = N \int \phi(E)\sigma(E)dE$$



# Summary and future work

- Seamless simulation of IBA Proteus systems
  - Proteus Plus eye treatment single scattering nozzle

Detailed studies for distal fall-off, lateral penumbra and dose rate optimization

  - Proteus One compact gantry

Single-pass shielding activation simulations
Beam optics with detailed energy and transverse halos

- Next steps
  - Incorporate realistic fringe fields for scanning studies (“pillow-effect”)
  - CAD models for dipole beam pipes (more detailed loss maps)