Simulation of Proton and Carbon-Ion Beams at MedAustron

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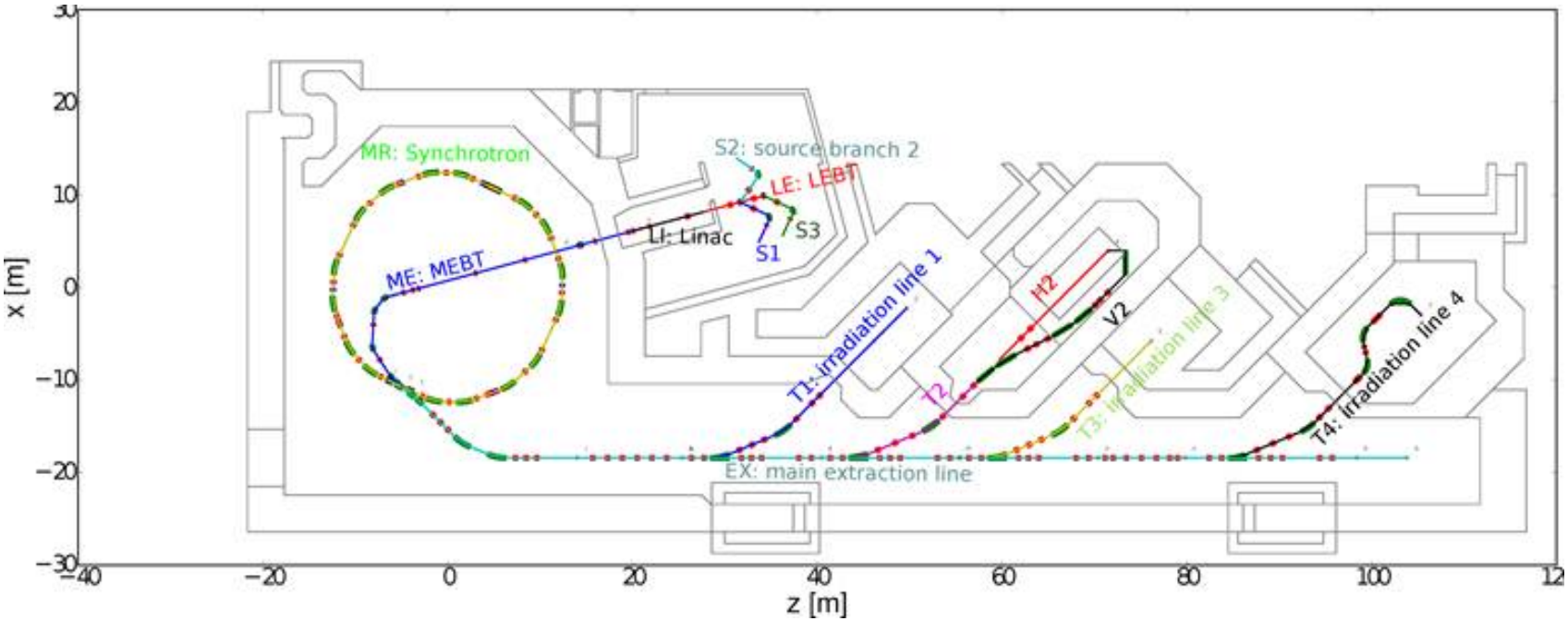
1 MedAustron Overview

2 MedAustron: Spot Size Task

3 MedAustron: Collimator Task

MedAustron Facility



- MedAustron designed to deliver both proton/carbon, began treatments with protons in 2016.

HEBT and Treatment Rooms

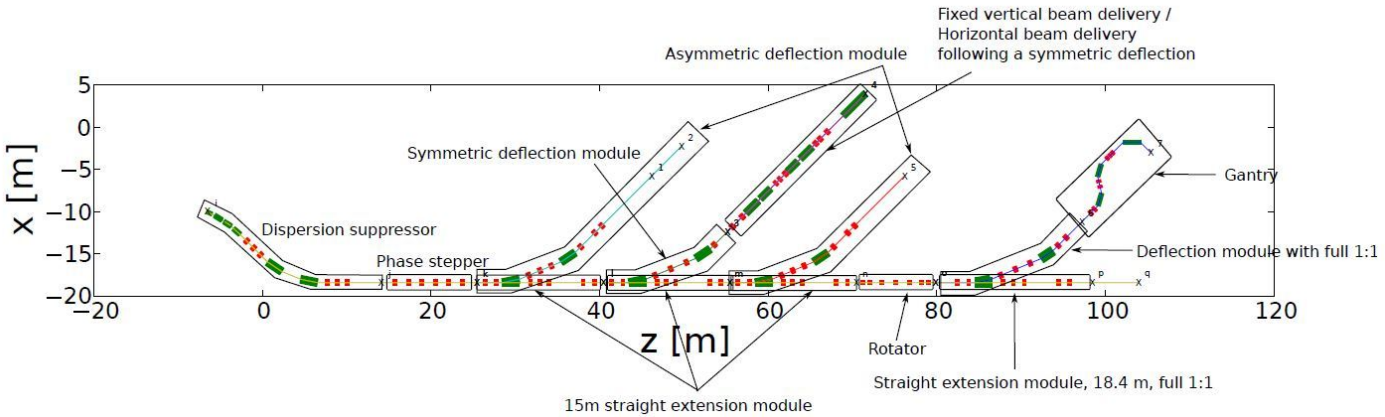


Figure: Sketch of the MedAustron HEBT.

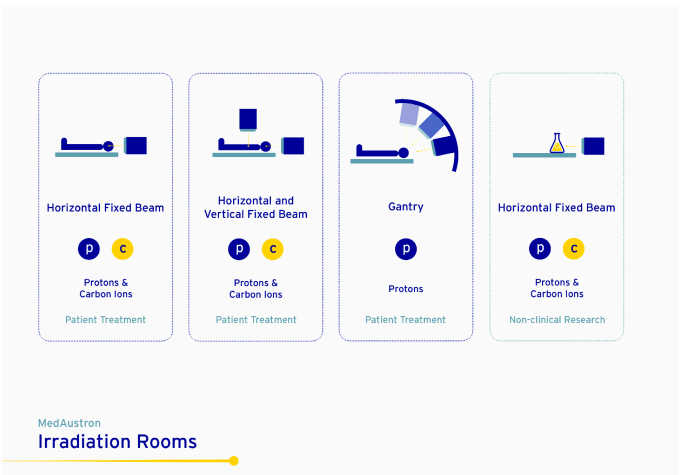


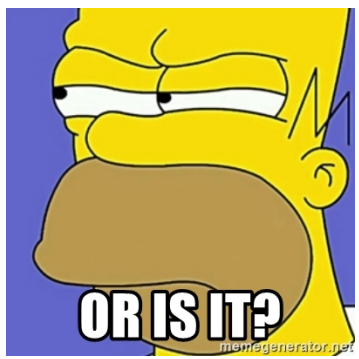
Figure: From left to right: T3, T2 (H2/V2), T4, T1.

Spot Size Task

- The carbon-ion beam energy will be between between 120 MeV/u and 400 MeV/u.
- Medical physicists want a symmetric beam at isocentre to be between 6 mm and 10 mm.

How to Simulate?

- Modify quadrupole settings in the beam line.
- MAD-X (Methodical Accelerator Design) can simulate beam dynamics and perform particle tracking.
- BDSIM (Beam Delivery Simulation) can take care of scattering as well.



Phase Space Distributions in HEBT

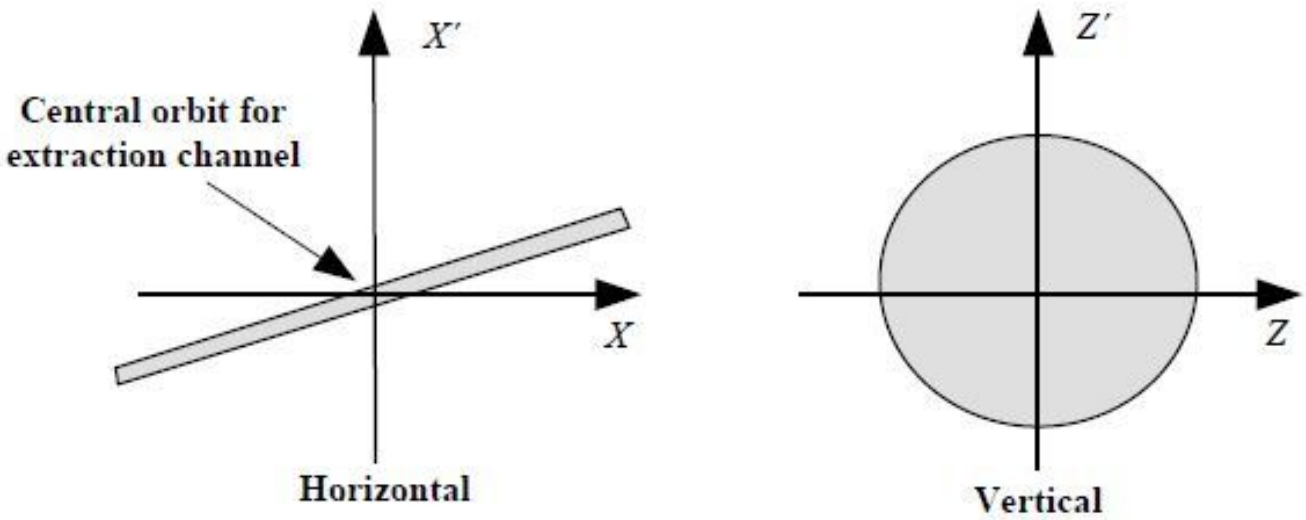


Figure: Theoretical distributions in normalised phase space as specified in PIMMS report.

- Slow extraction done horizontally which gives a phase space distribution resembling a ‘bar of charge’.
  - $\Rightarrow$ ‘Bar of charge’
- Vertically, phase space shape is the same as circulating beam to first order.
  - $\Rightarrow$ Gaussian distribution

Vertical Phase Space

Twiss parameters (α, β, and γ) and emittance ϵ are used to describe the phase space distribution.

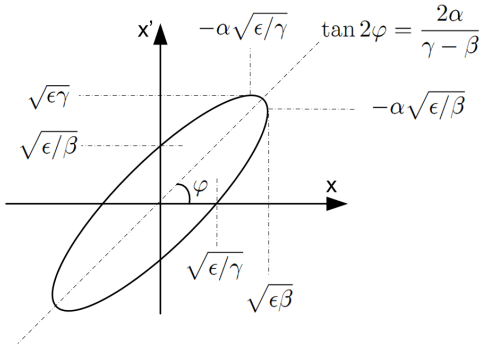
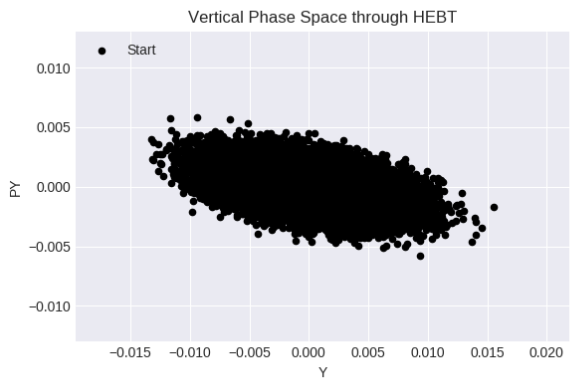


Figure: Image taken from (http://emmanuel.branlard.free.fr/work/papers/html/2009fermi/node18.php)

MAD-X provides Twiss parameters throughout the beamline, from which one can reproduce a phase space distribution if the emittance is known.

$$\beta = 3.0 \text{ [m]}$$
$$\alpha = 0.5 \text{ [m]}$$
$$\epsilon = 4.45 \times 10^{-6} [\pi \cdot \text{m} \cdot \text{rad}]$$

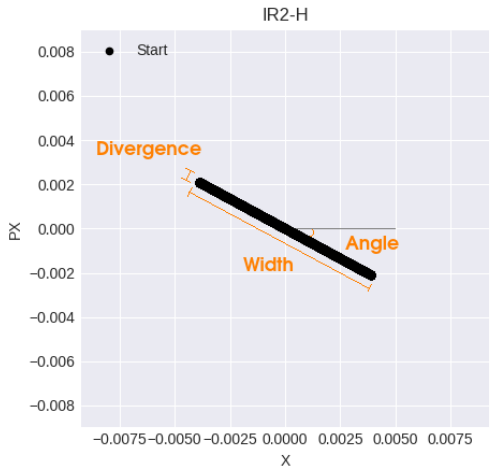
$\Rightarrow$



Horizontal Phase Space

To characterize the horizontal bar of charge, need to fit to data:

$$\begin{aligned} \text{Width} &= 0.00888 \text{ [m]} \\ \text{Divergence} &= 0.0000250 \text{ [rad]} \\ \text{Angle} &= 28.36^\circ \end{aligned} \quad \Rightarrow$$

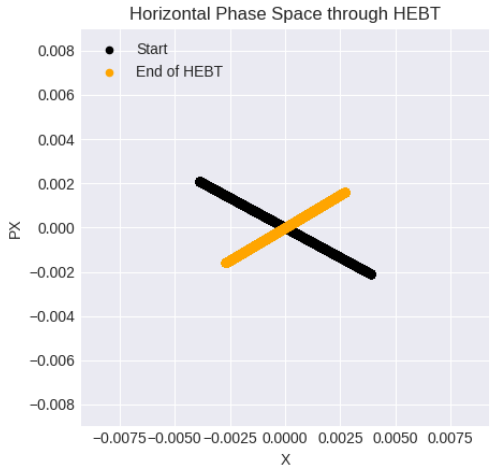


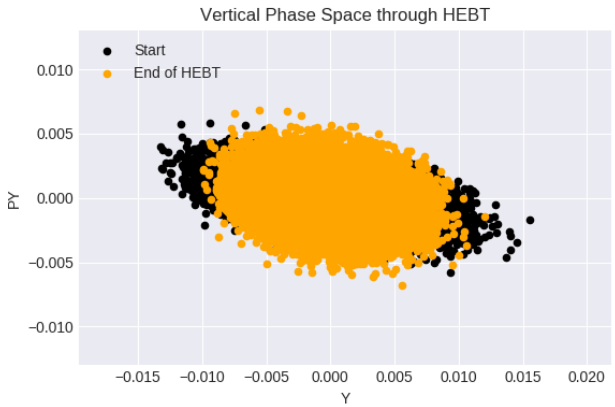
MAD-X gives Twiss parameters but that does not necessarily give information about the bar of charge.

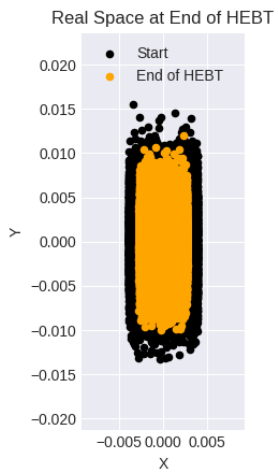
- Can try to relate to Twiss parameters by ‘indirect fitting’.
- Extracted beam is treated as part of an ‘unfilled’ ellipse.
- Unfortunately, in practice it cannot be applied so easily.

PTC Tracking with MAD-X

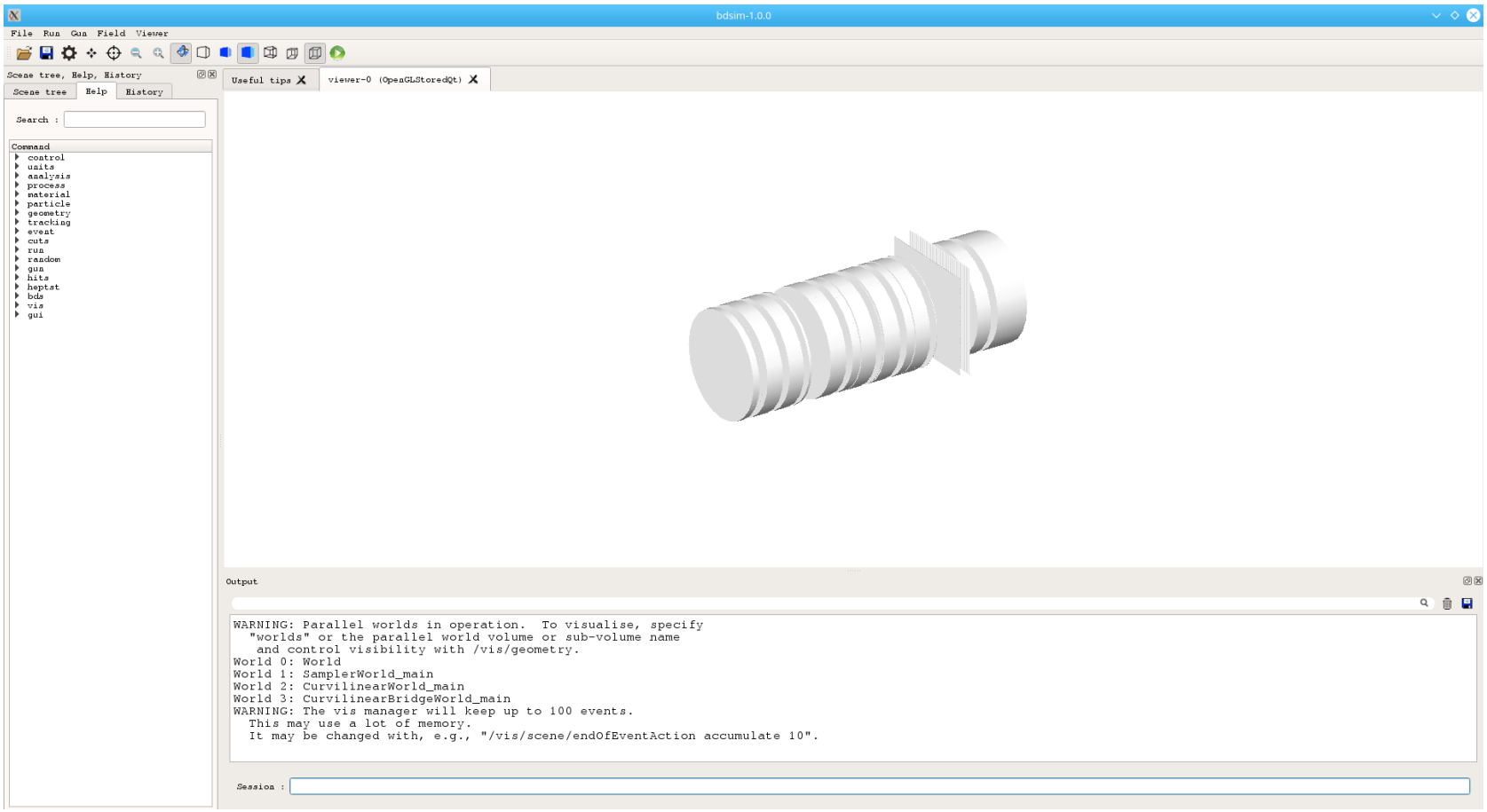
Plots below are the results of PTC from MAD-X. Black is at the start of T2 beamline, and orange at the end of beamline before the medical nozzle.





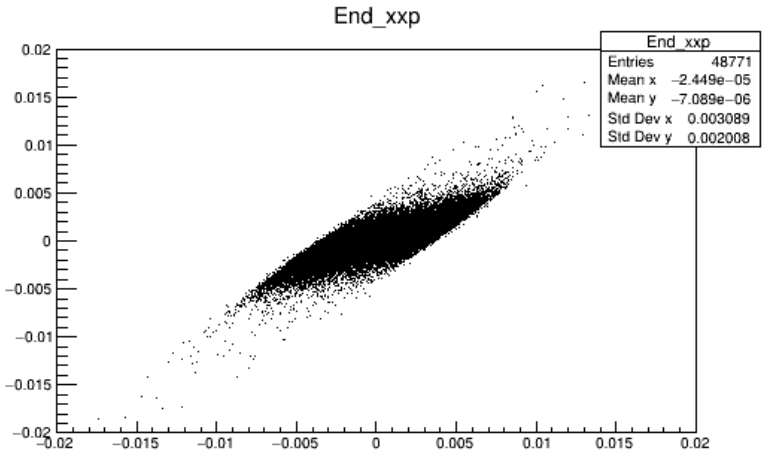


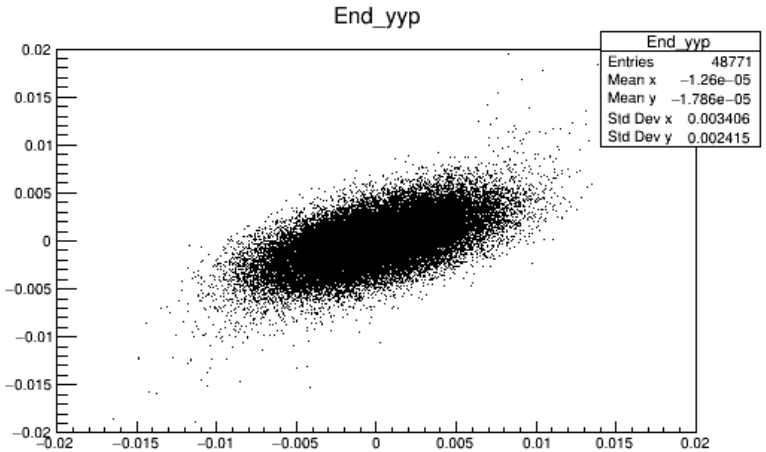
Scattering Simulation with BDSIM

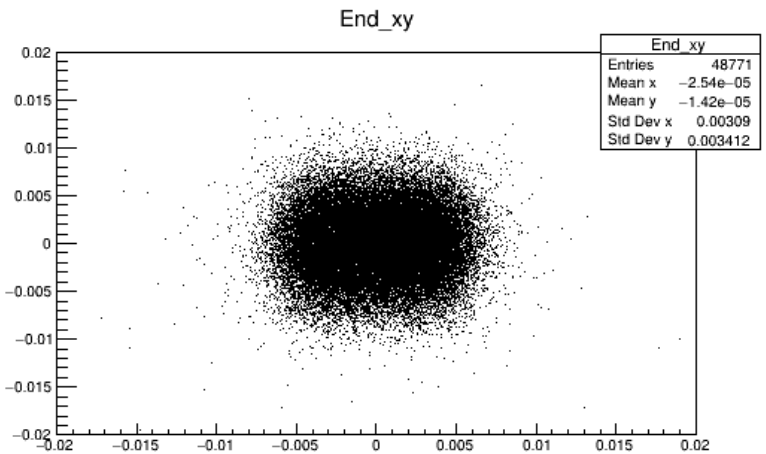


BDSIM Particle Tracking

Simulating for scattering in the nozzle and air with BDSIM, the beam reaching the patient is as follows:

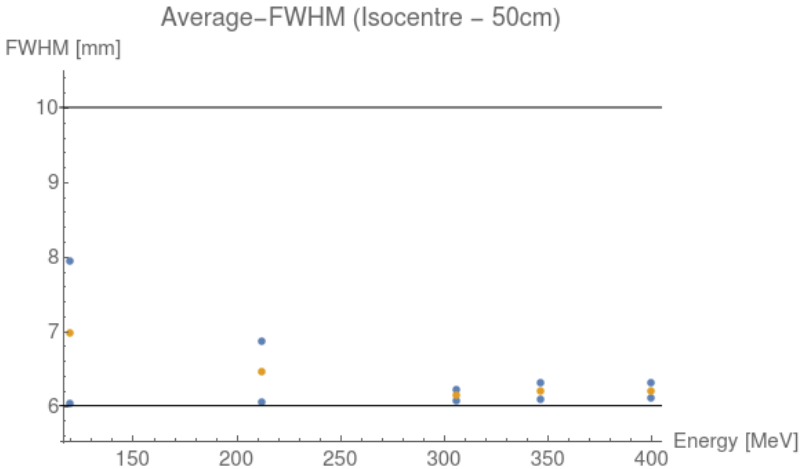


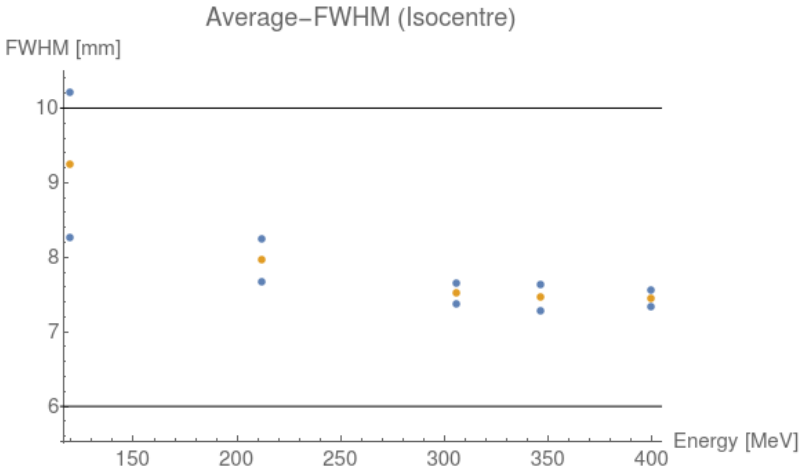




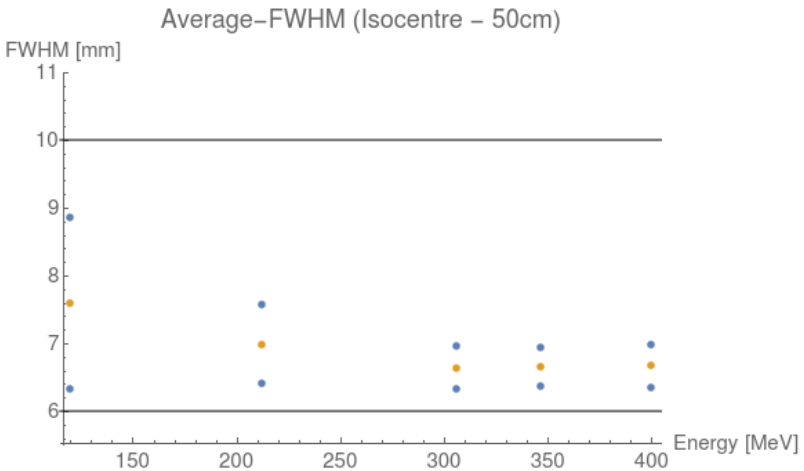
Spot Size Comparisons between the Two Rooms

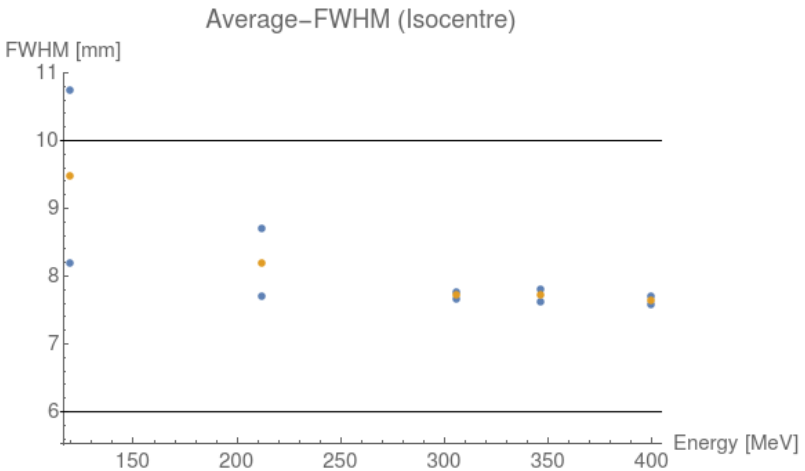
H2 Beamline Result for one set of settings



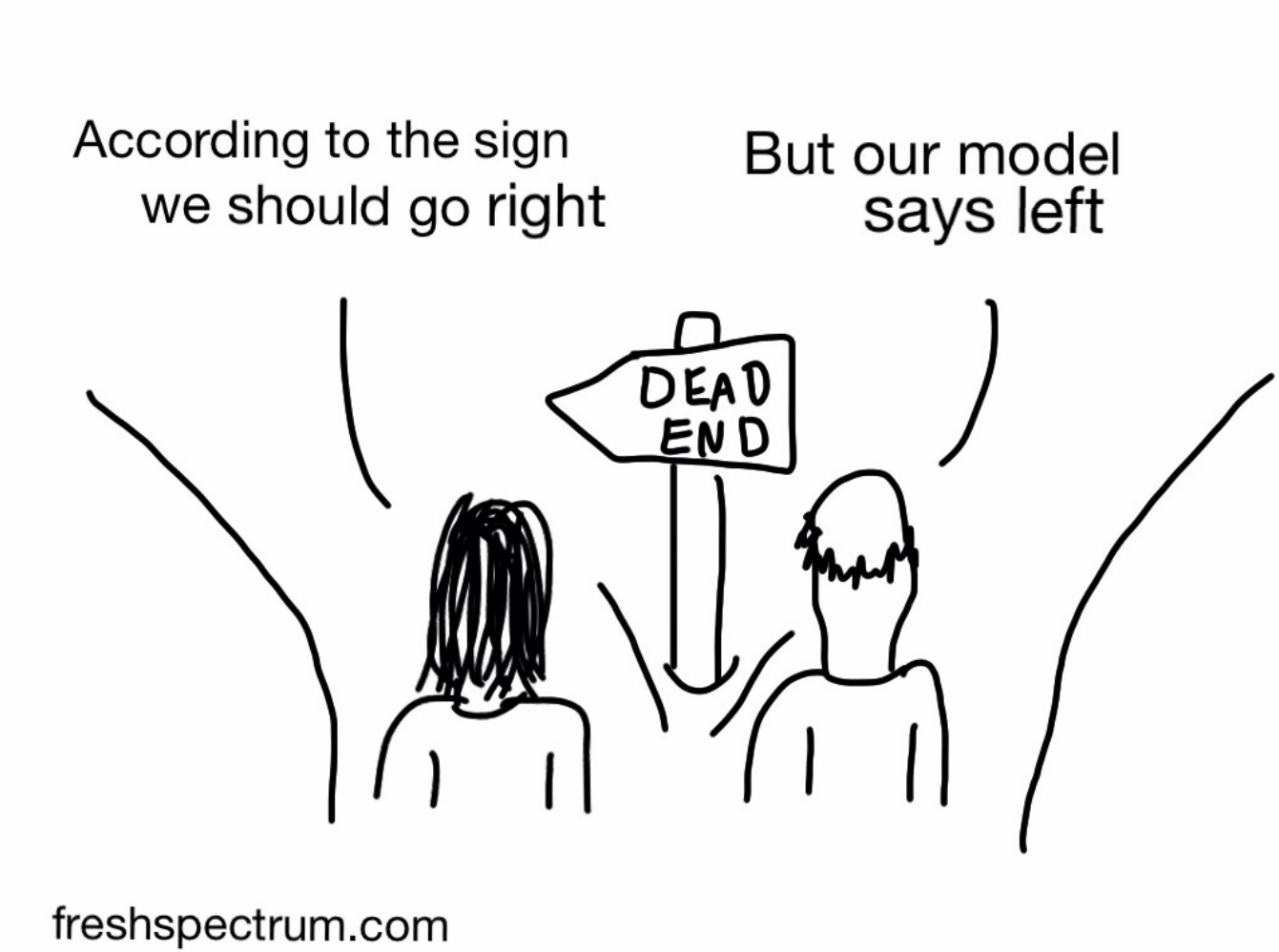


T3 Beamline attempting to match to above



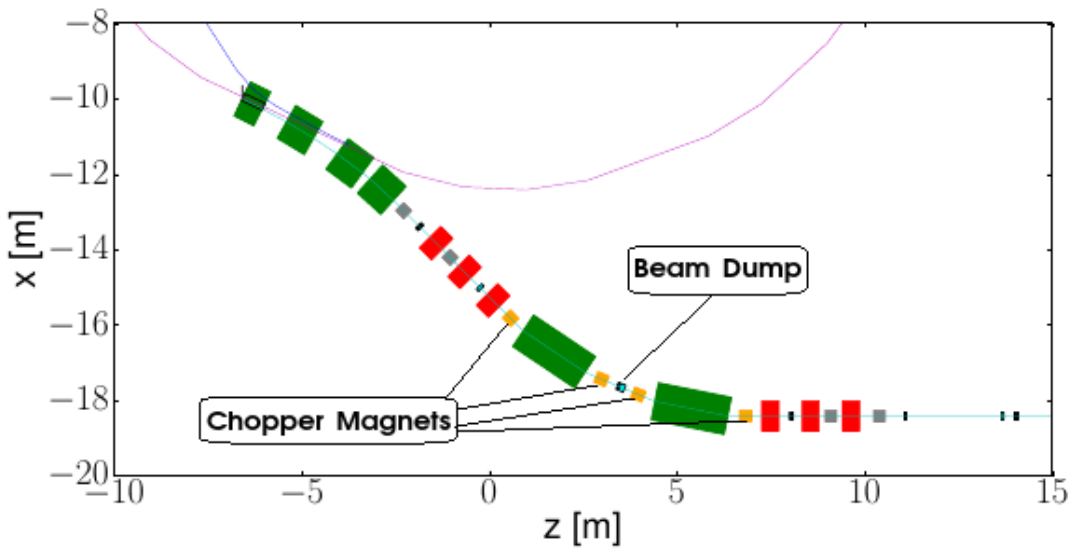


Collimator Task



Collimator Task

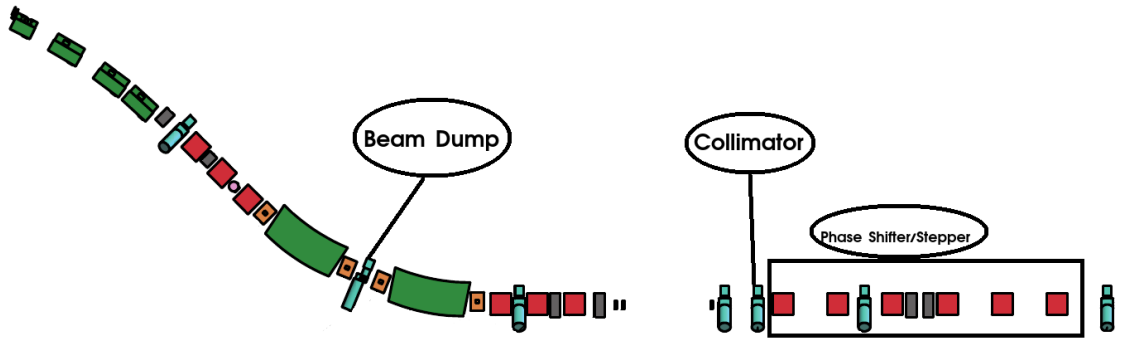
- The extracted beam from the synchrotron is directed towards a beam dump for safety purposes.
- Chopper magnets are in place which when powered allows the beam to bypass the beam dump.

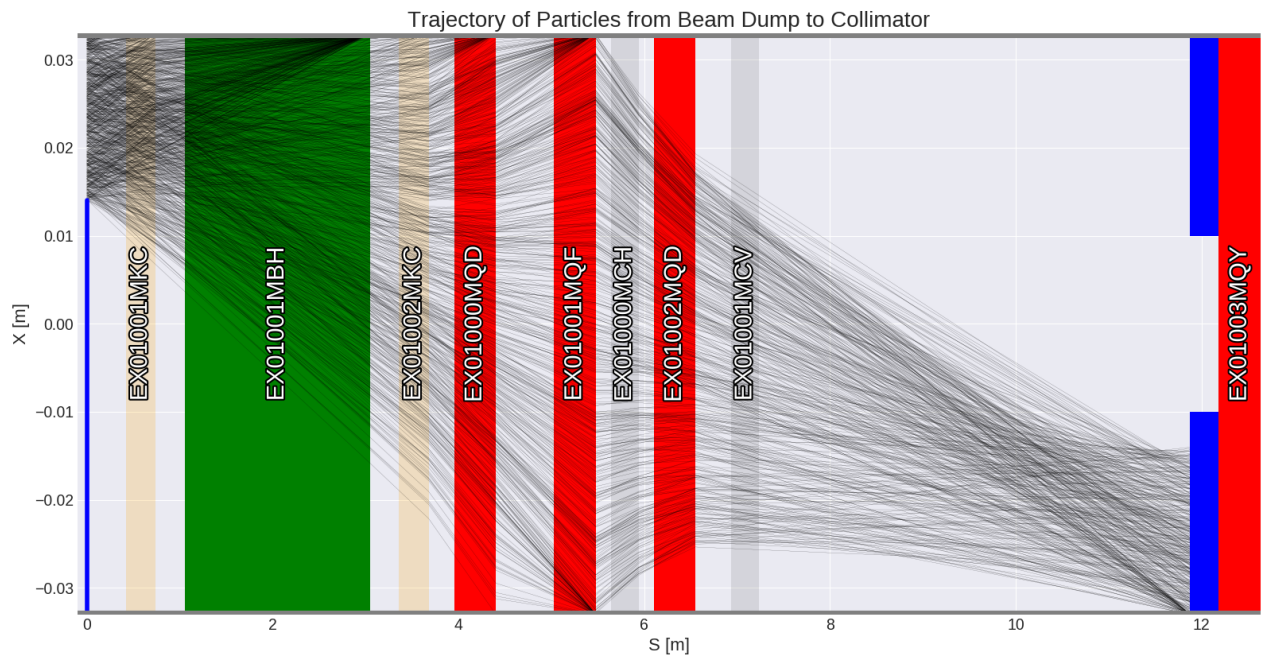


For safety concerns a situation must be considered where ions with strange configurations bypass the beam dump.

Collimator Task – Trajectory Visualization

To avoid unwanted irradiation of the rooms, a collimator was added in order to capture unwanted particles.

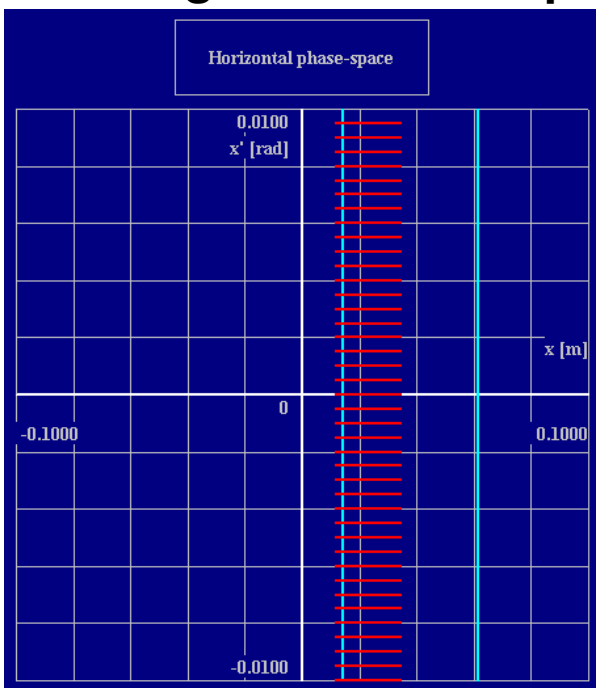




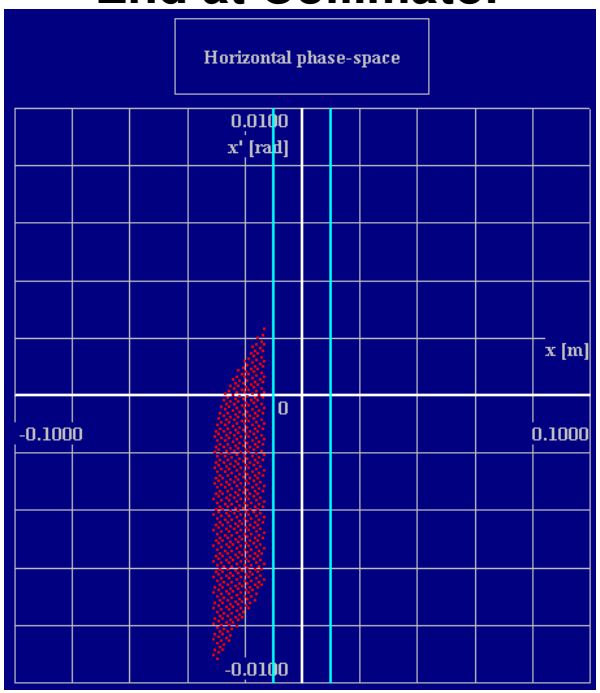
Previous Simulation for Protons

Dr. Marco Pullia from CNAO assisted previously for simulations with protons using WinAgile:

Starting at Beam Dump



End at Collimator



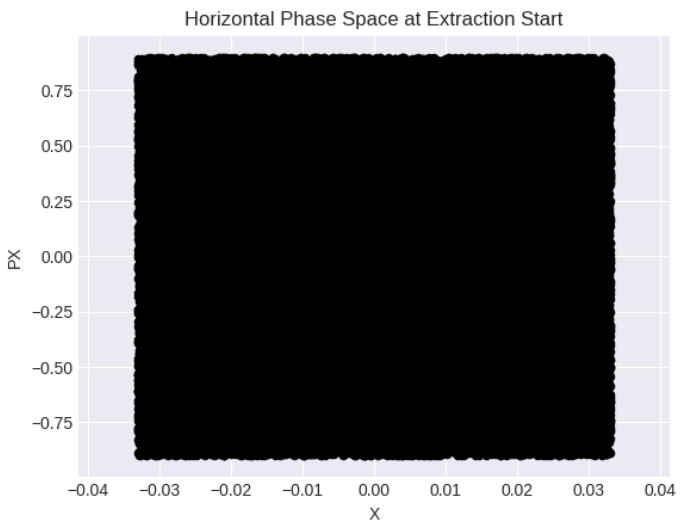
On the right image, the cyan lines representing the opening is from -10 mm to 10 mm. He showed that all particles which bypassed the beam dump are intercepted by the collimator.

Starting Beam Distribution

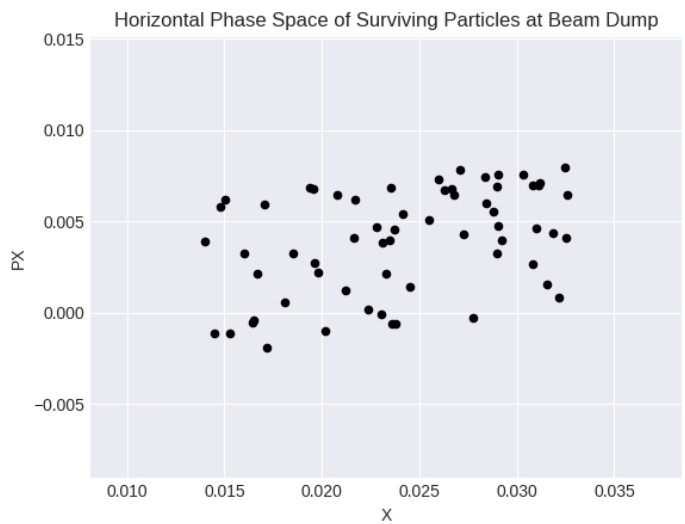
Determining the Configuration at Beam Dump

1. Start with a very extreme configuration of particles.
   - Fill whole beam pipe at extraction start with particles with an extreme set of divergence values.
2. Track until the beam dump and apply cuts to see what bypasses the beam dump.

Start of Extraction Beamline

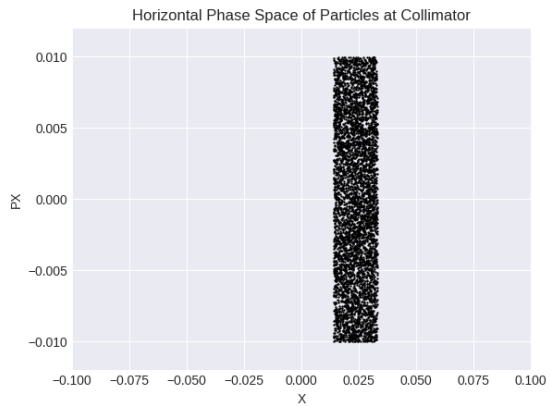


Surviving Particles at Beam Dump

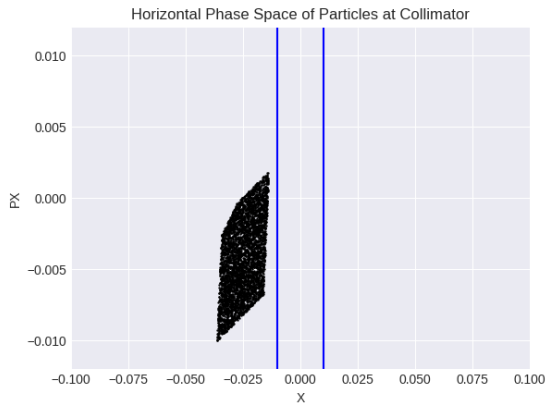


Simulation Agreement

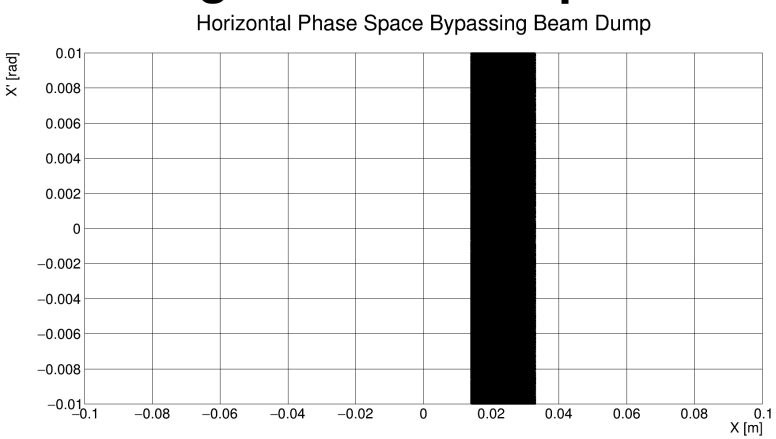
Starting at Beam Dump – MAD-X



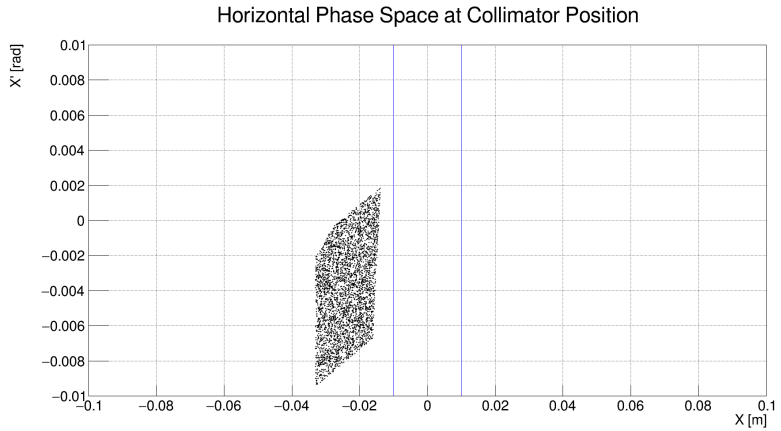
End at Collimator – MAD-X



Starting at Beam Dump – BDSIM

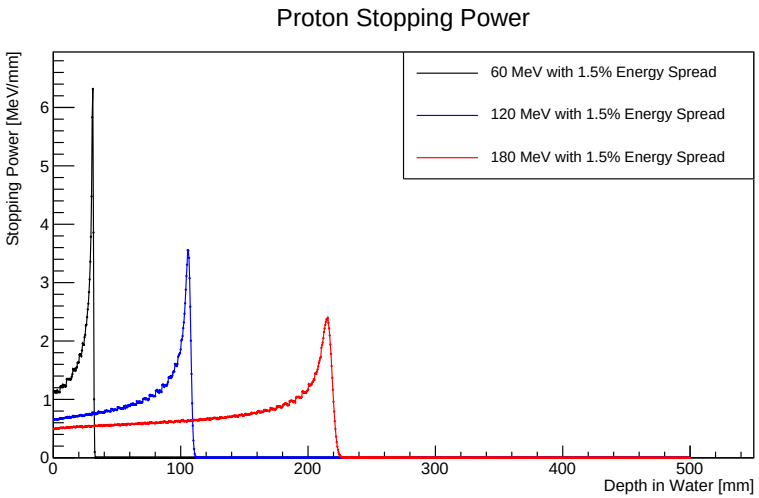


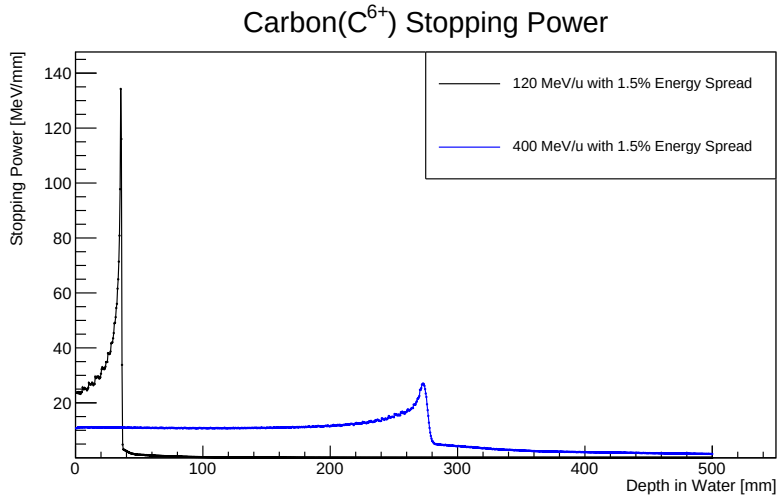
End at Collimator – BDSIM



Teaser

- BDSIM not limited to just accelerator beamline simulations.
- Protons and carbon for stopping power in water was plotted from simulations by BDSIM.





More in Ajit's talk!

Thanks for Listening!