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Update on radiation studies for the target area

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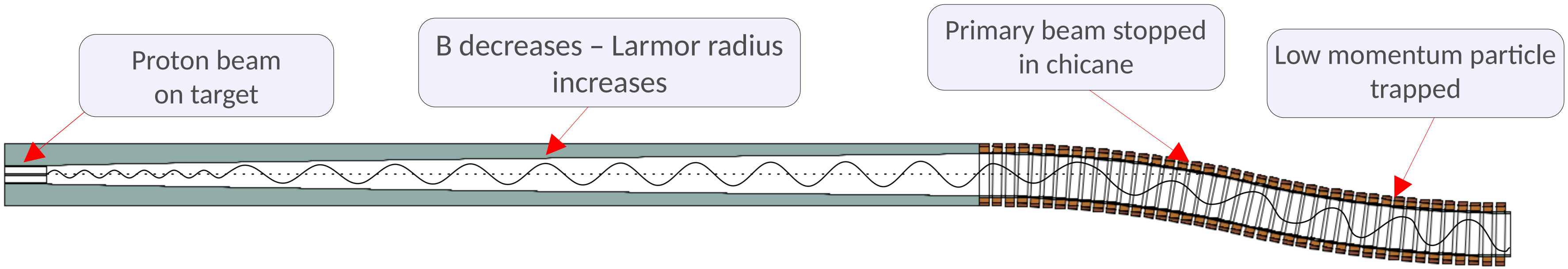
Outline

- **Geometry update**
  - New HTS coil configuration from magnet working group
  - Computed magnetic field for FLUKA simulations
- **DPA in coils mitigation techniques**:
  - Neutron moderation and capture via water and boron carbide layers
- **Physics performance changing parameters:**
  - Proton energy
  - Proton beam size
  - Target angle with the solenoid axis
  - Target size
  - Target length
- **Exploratory study towards the proton beam extraction and dump**

Introduction

- The MC under current investigation is proton driven. **Protons** impact on a solid or liquid target **generating pions** by inelastic collisions. [1] In this study, we considered a graphite target.
- The generated pions travels through a tapering region where the **magnetic field** is **adiabatically decreasing**. The effect of this section is to decrease the angular divergence of the produced pions. [2,3]
- Finally, the beam enters a **chicane** where the high energy component of the beam is intercepted. Low momentum components (muons and pions) are forced to follow the field lines generated by a series of solenoids. [4]
- **The scope of these studies is to assess the radiation load to the equipment in the target area (target and magnets) and develop a shielding design.** We used a HTS coil configuration as proposed by the magnet working group in December. All the simulation are conducted using **FLUKA**.
- All the **results** will be **normalized per 1.5 MW proton beam** intensity with 200 days of operation per year.



Parameters considered for these radiation studies

Table 1: Parameters table.

Material	Graphite ($1.8\,g/cm^3$)	Liquid lead ($10.5\,g/cm^3$)
Inelastic scattering length	44.94 cm	17.34 cm
Target radius	15 mm	15 mm (+ 5 mm vessel)
Target length	80 cm [3]	29.7 cm (+2 cm vessel)
Beam size (round)	5 mm	
Beam power (normalization purposes)	1.5 MW	
Beam energy	5 GeV	
Shielding thickness	42.2 cm	
Magnet aperture (radius)	60 cm	
Peak magnetic field	20 T	

Realistic values under consideration can be higher (1.5-4 MW)

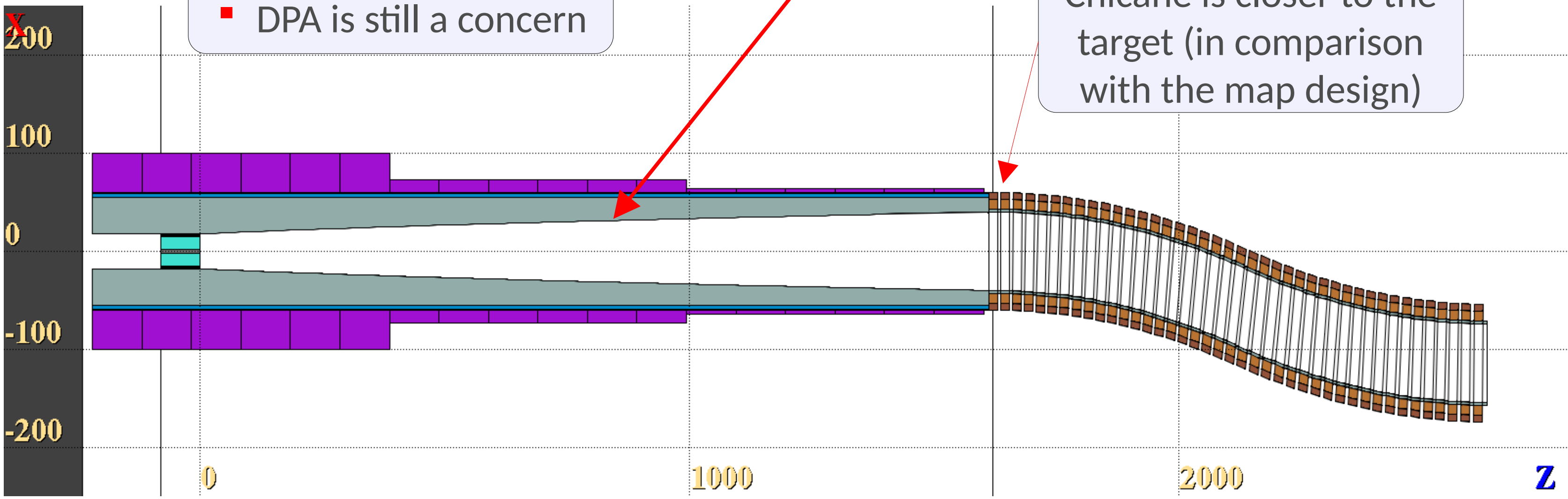
New geometry

New HTS (VIPER) coils:

- Higher power deposition and dose allowed.
- DPA is still a concern

Internal shielding radius following parabolic shape (from C. Rogers) and map studies

Chicane is closer to the target (in comparison with the map design)



Geometry from L. Bottura, P. Testoni and A. Portone:
Https://indico.cern.ch/event/1183570/

Target geometry

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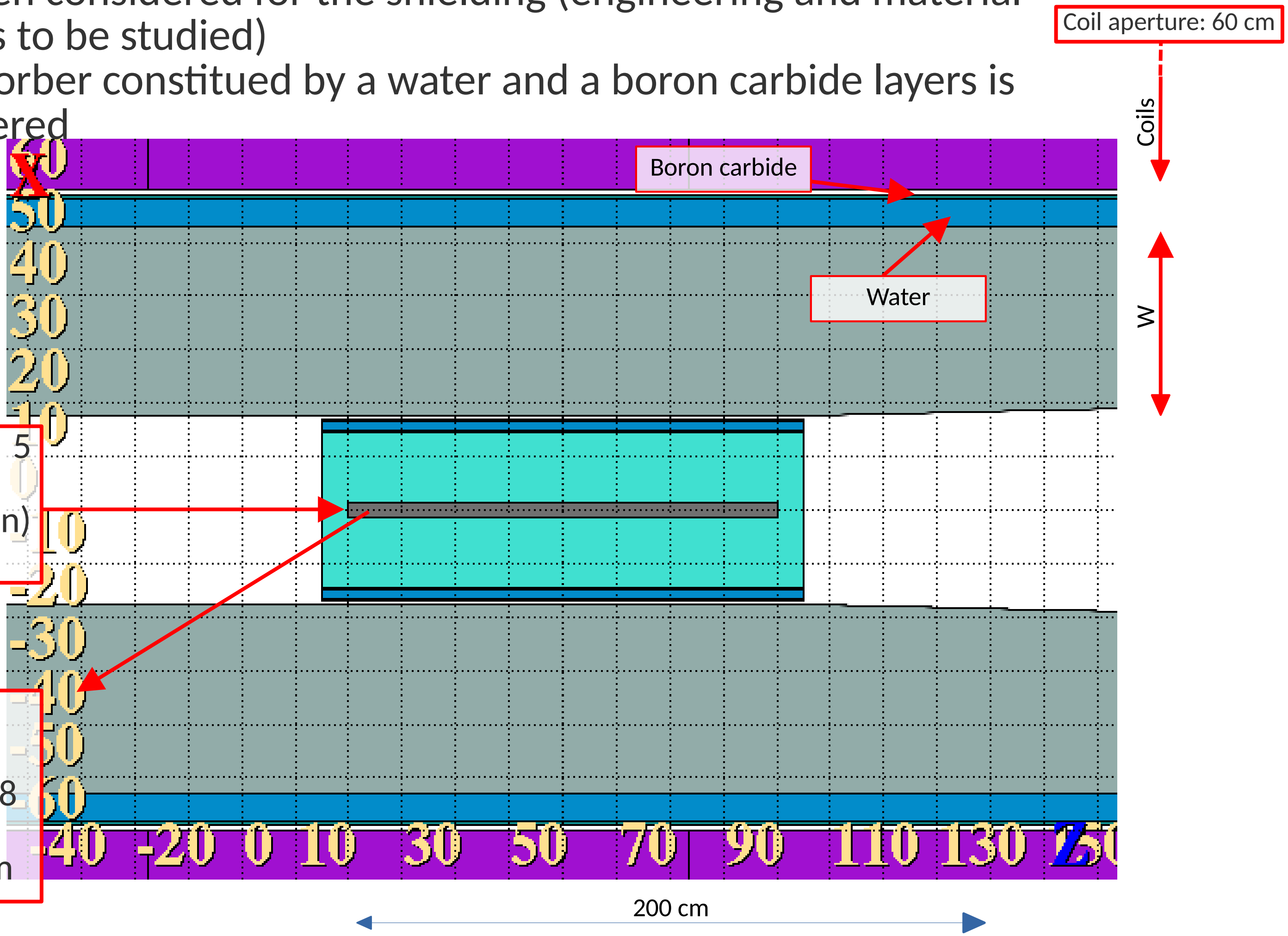
Generic shielding and magnet geometry:

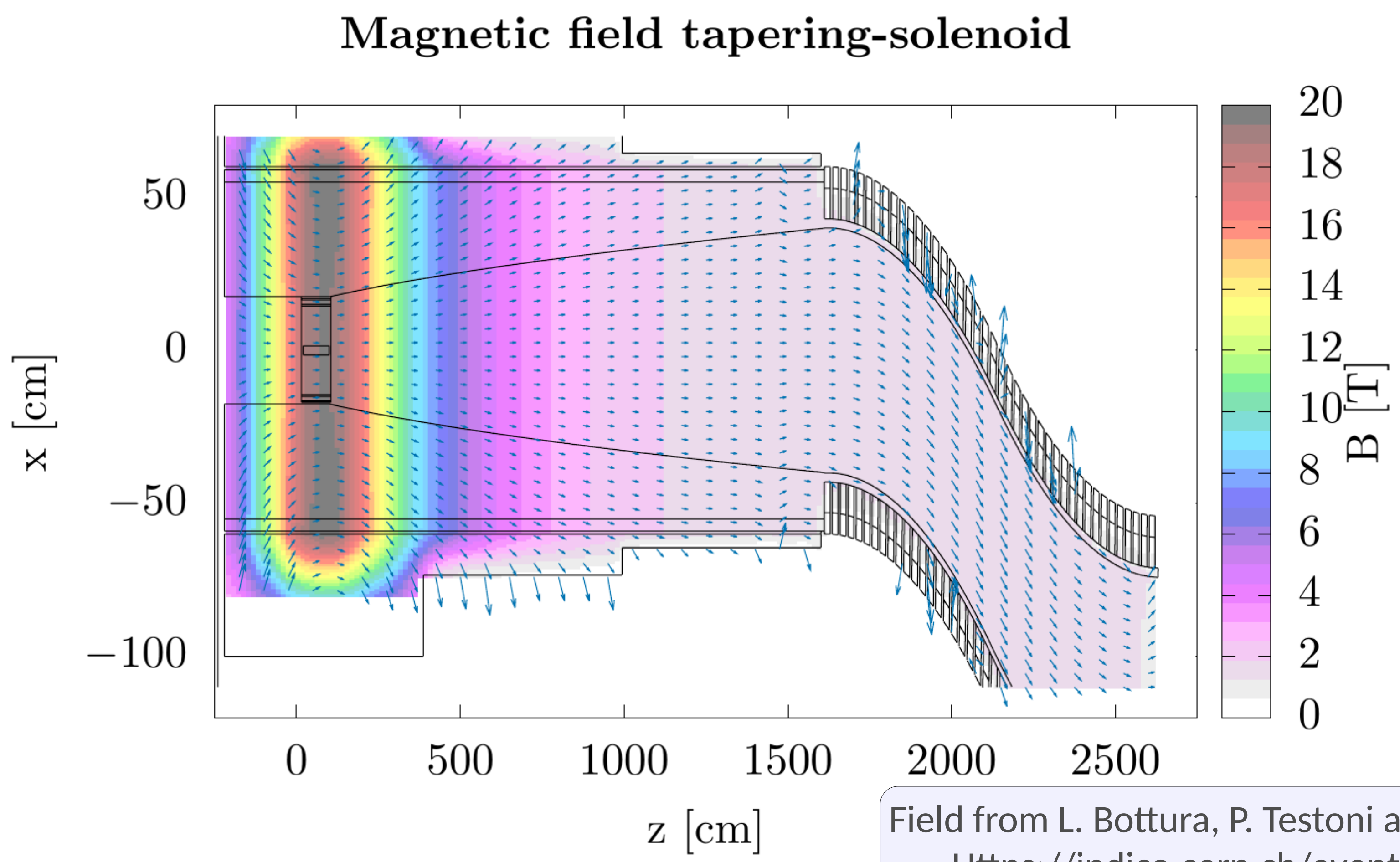
- Tungsten considered for the shielding (engineering and material aspects to be studied)
- An absorber constitued by a water and a boron carbide layers is considered



Proton beam (sigma 5 mm):
- 1.5 MW (normalization)
- 5 GeV beam energy

Target:
- Graphite: 80 cm
- It corresponds to 1.78 interaction lengths
- Target radius: 1.5 mm

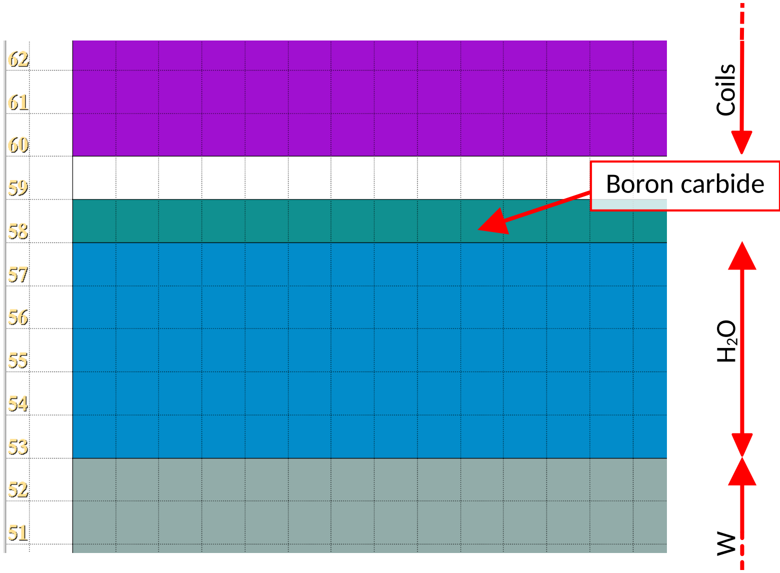
Magnetic field definition: FLUKA

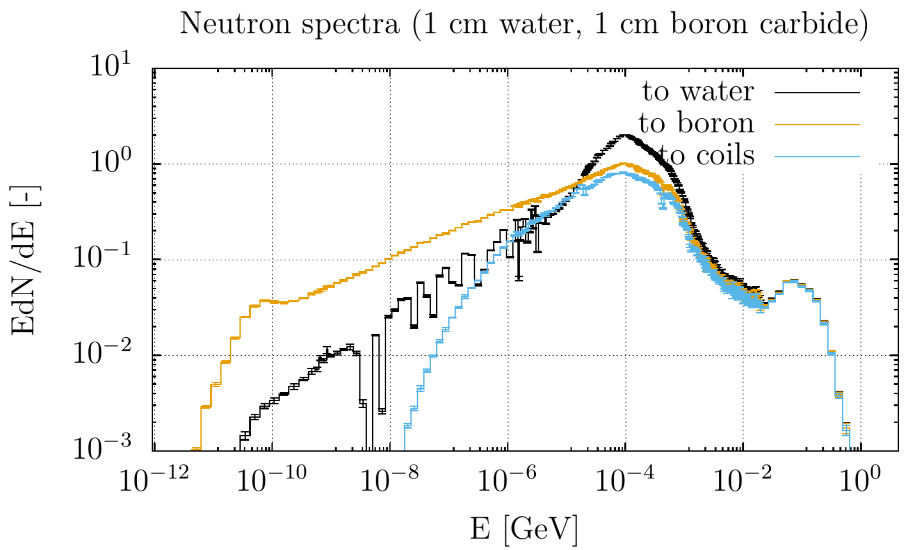


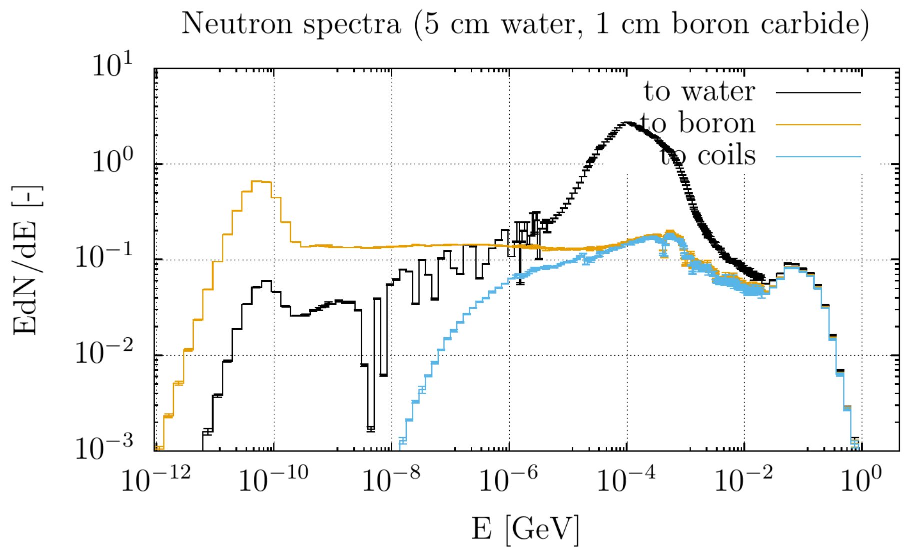
Field from L. Bottura, P. Testoni and A. Portone:
Https://indico.cern.ch/event/1183570/

Neutron absorber

- Neutrons are the main source of the displacement damage in the coils. While tungsten is very efficient in shielding electromagnetic component, it lacks the capability to stop neutrons.
- We considered a possible scheme to reduce the neutron component using a layer of water to moderate them and finally a layer of boron carbide (1 cm) to capture them at thermal energy.

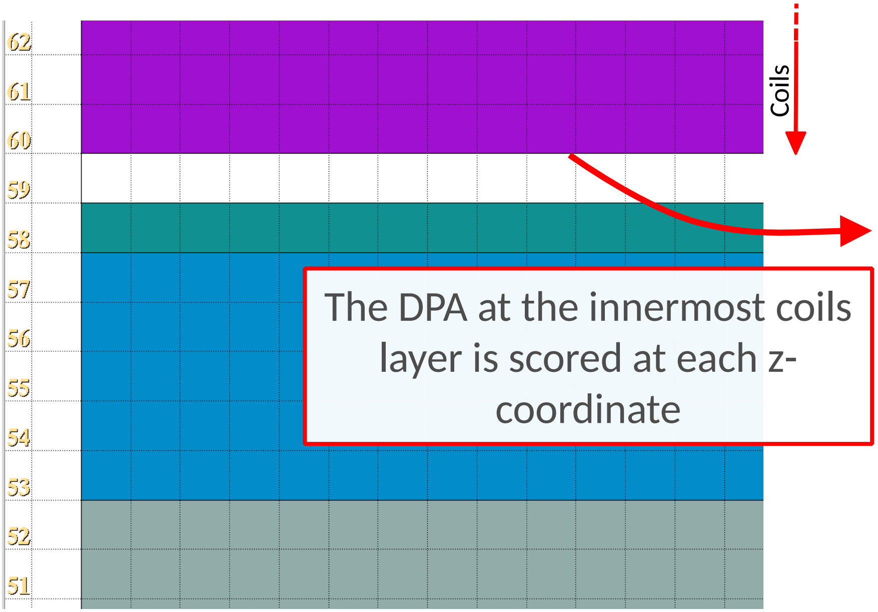


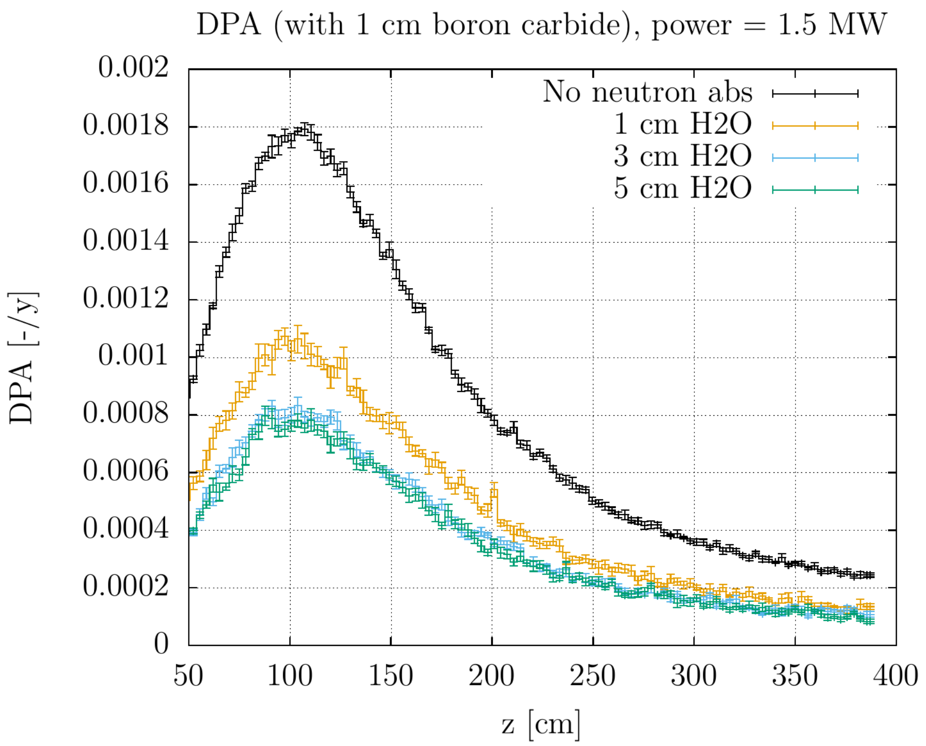




Neutron absorber: DPA in the coils

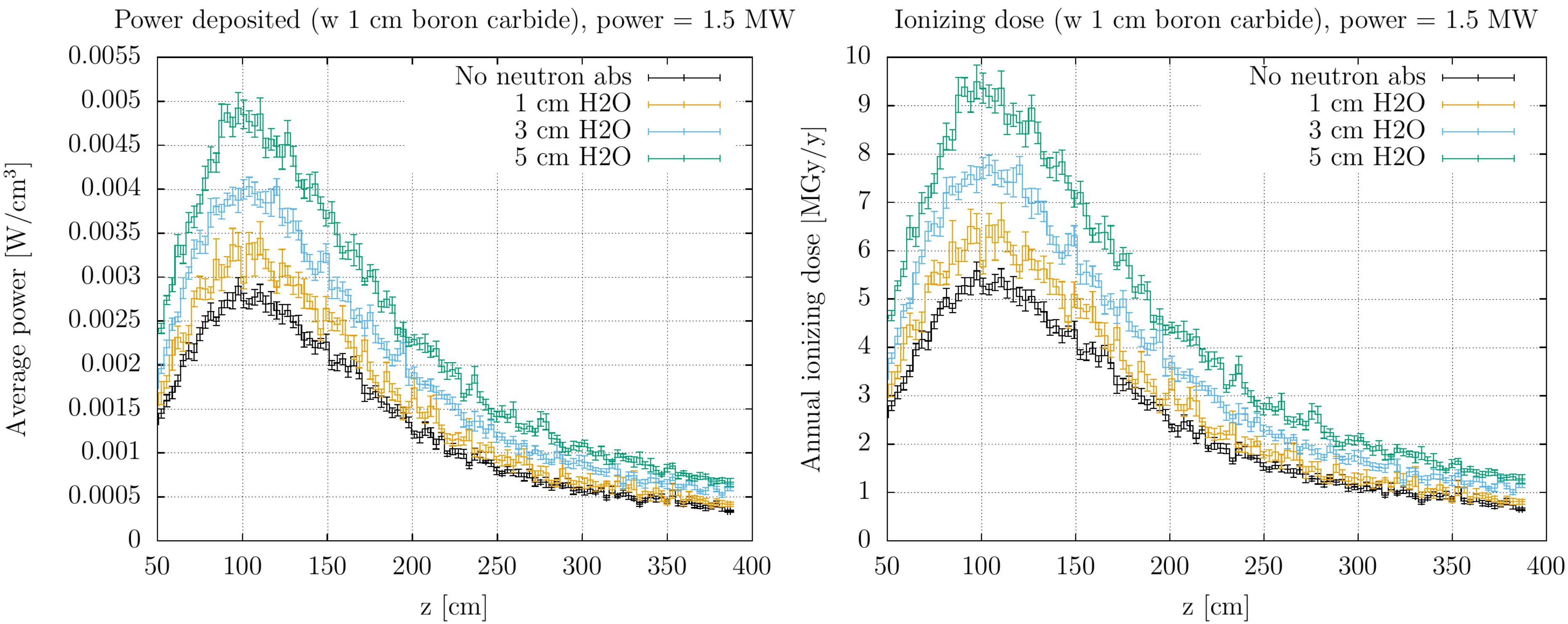
- In the most efficient configuration, the **DPA** reaches values of **8 × 10^{-4} DPA after 1 year**. The acceptable levels might be exceeded after a few years of operation. More shielding (i.e. larger coil apertures) might be needed to sustain the full collider lifetime.





Neutron absorber: effect on energy deposition due to reduced tungsten shielding

- Reducing the tungsten thickness (replacing it with water and boron carbide) increases the power and the ionizing dose to the coils.
- The ionizing dose, is beyond **70 MGy after 10 years** (with 3 cm of water). Acceptable for HTS coils **without** insulation(?)

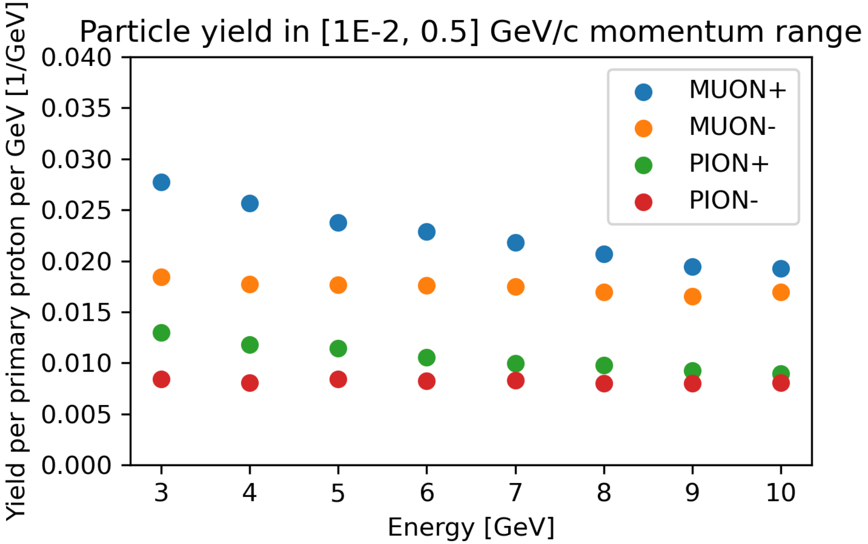


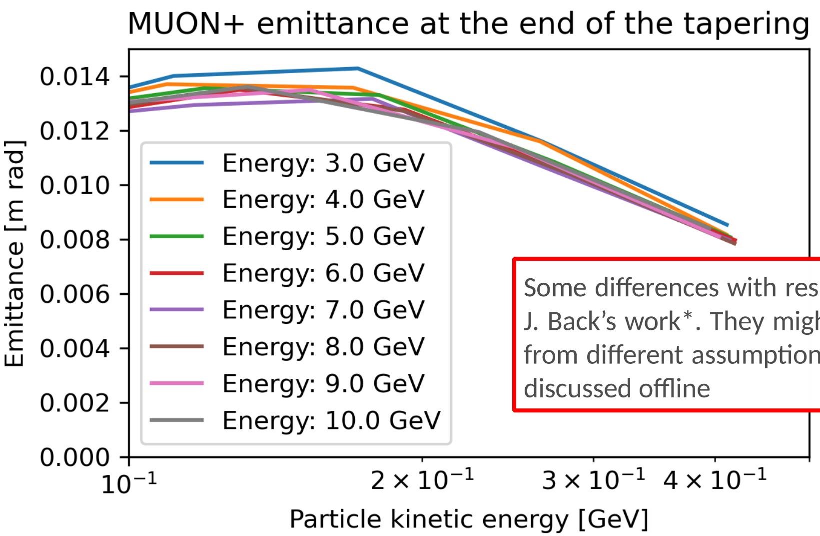
Parametric scan: beam parameters

- The muon yield is calculated summing up all the muons produced up to 500 MeV/c momentum. The emittance is calculated from the 4D emittance formula (determinant of the covariance matrix).

Proton beam energy:

We will continue to assume the 5 GeV as fixed parameter. Nevertheless, we observed an asymmetry in the mu+/mu- production and larger starting emittances at lower energies





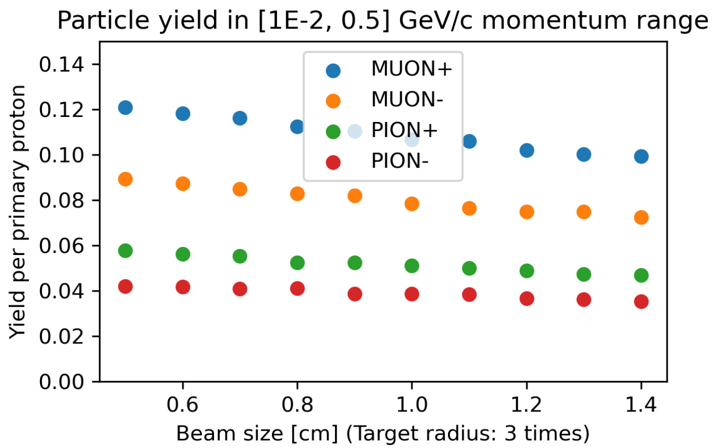
Some differences with respect to J. Back's work*. They might arise from different assumption. To be discussed offline

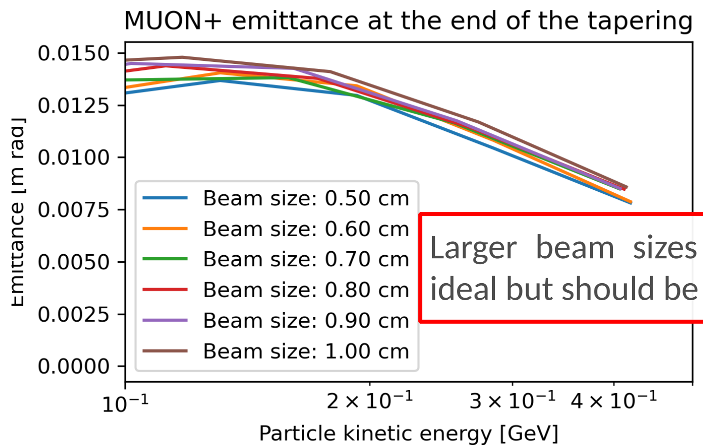
*https://indico.cern.ch/event/1175126/contributions/5024015/

Parametric scan: beam size and transverse target size

Proton beam size:

The default case is a 5 mm beam size, and the target size is always 3 times the beam size

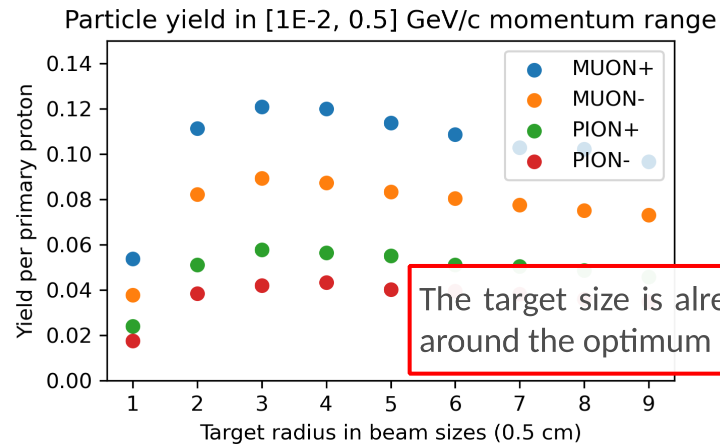




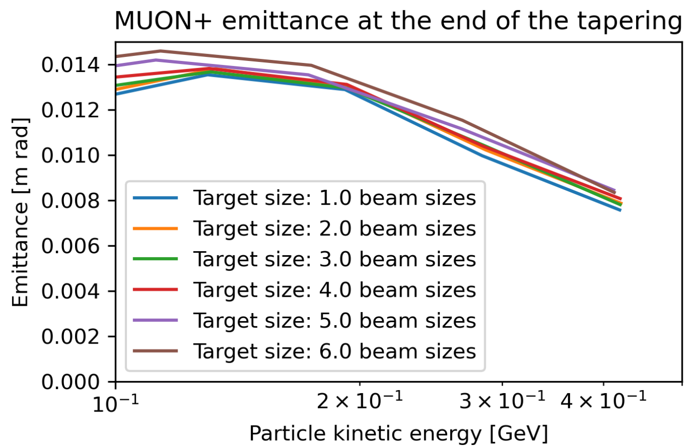
Larger beam sizes are not ideal but should be feasible

Target transverse size:

The default case is 3 times the beam size, and the beam size is always 5 mm



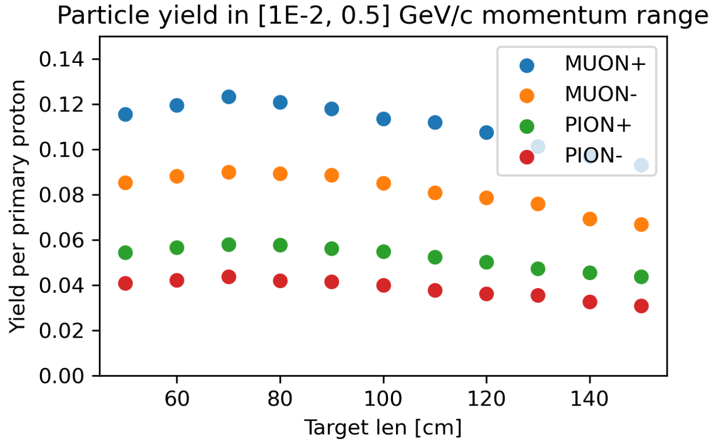
The target size is already around the optimum

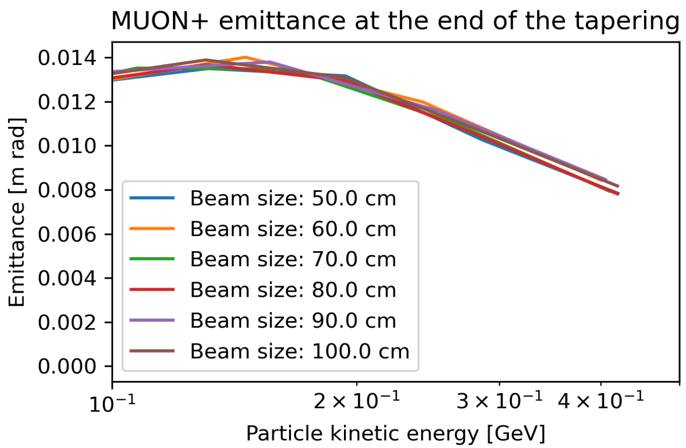


Parametric scan: target length and shielding aperture

Target length:

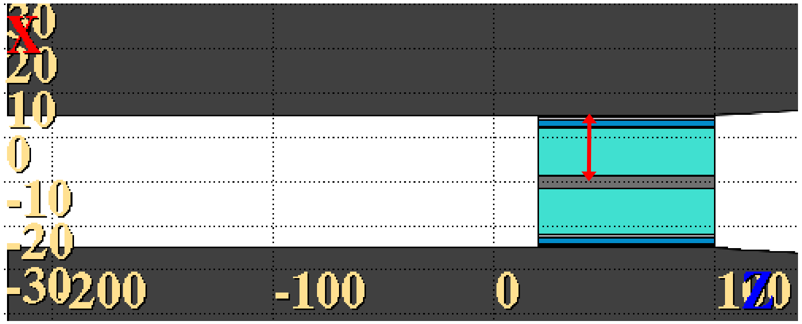
The default case is a 80 cm graphite rod

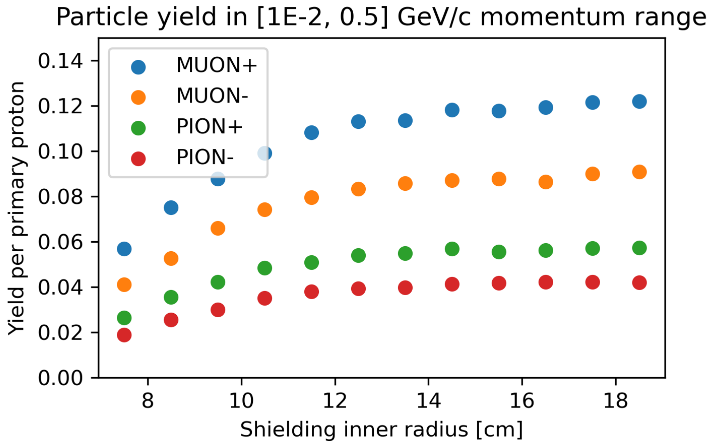




Shielding aperture

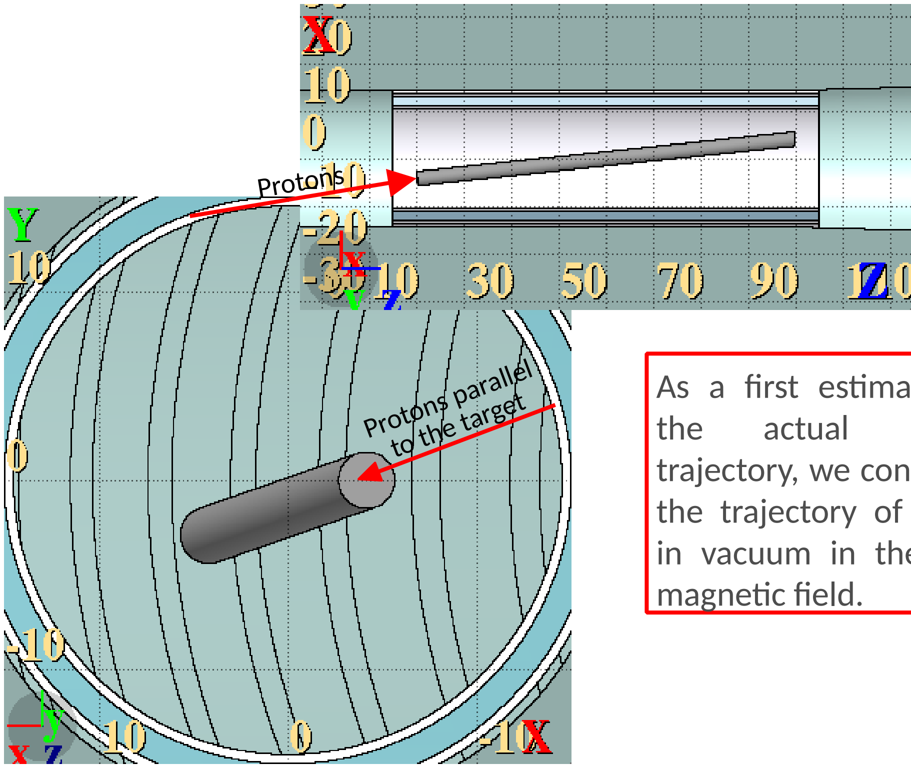
The default case is 17.8 cm



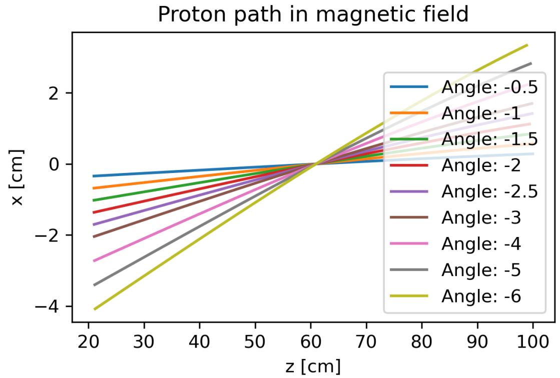


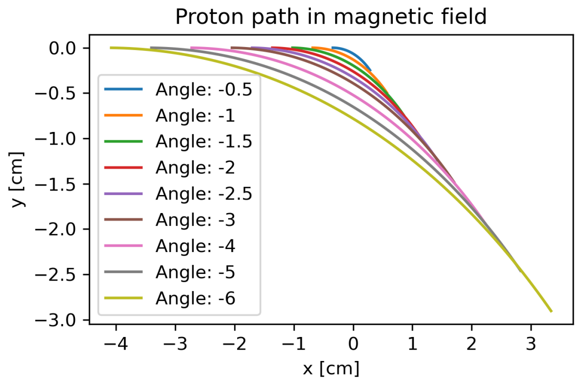
Angle of incidence of proton beam

- The proton drive beam deposits a considerable amount of power in the shielding. A beam dump has been considered as necessary in past studies. A first approach is to consider what happens to the proton trajectory when a non-zero angle is considered.



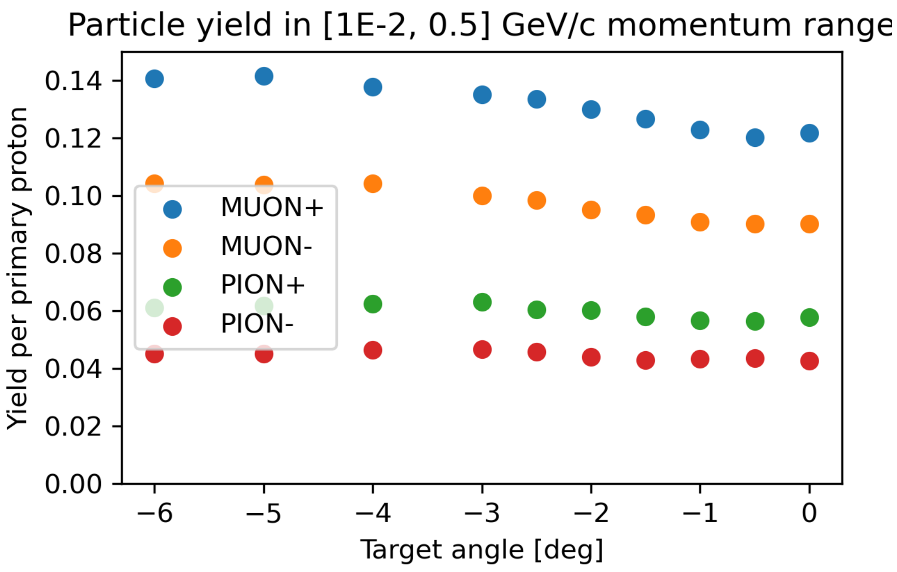
As a first estimation of the actual particle trajectory, we considered the trajectory of proton in vacuum in the same magnetic field.

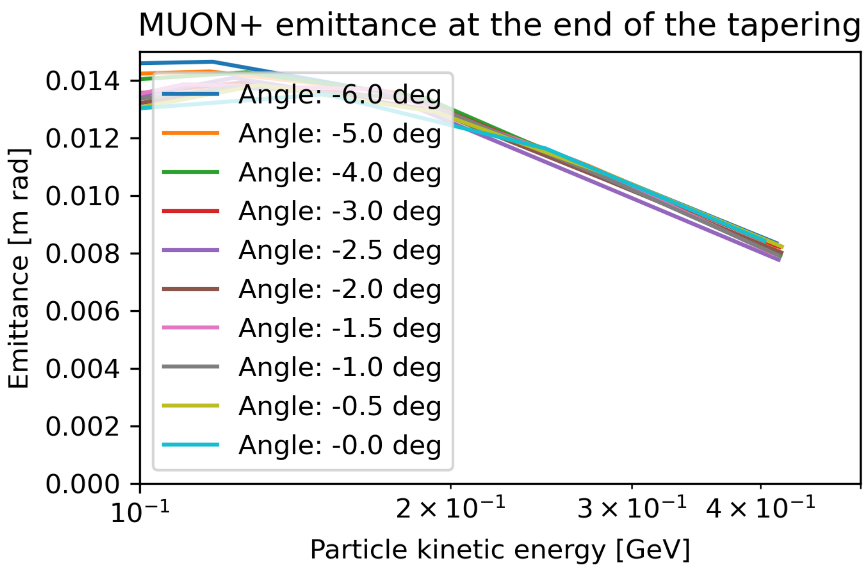




Effect on the muon yield

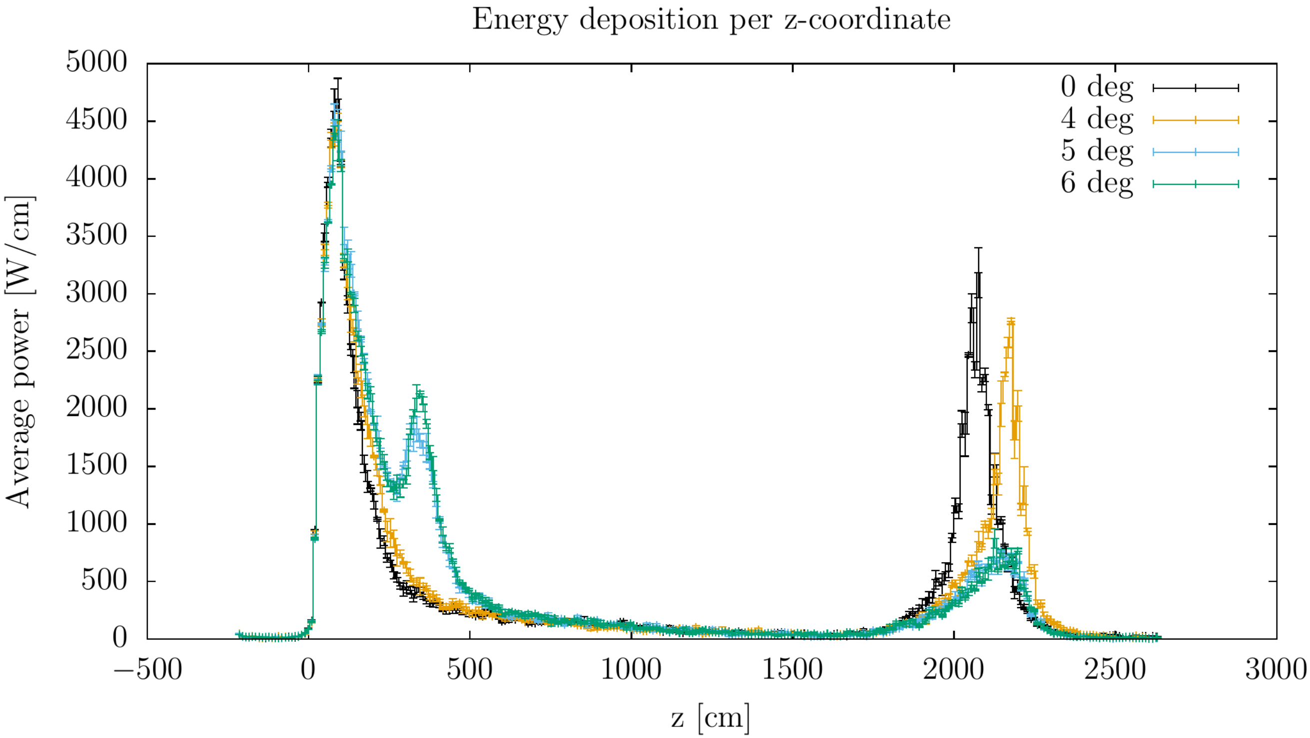
- Considering the amount of muons produced and their emittance, having a tilted proton beam has small effect on the yield.

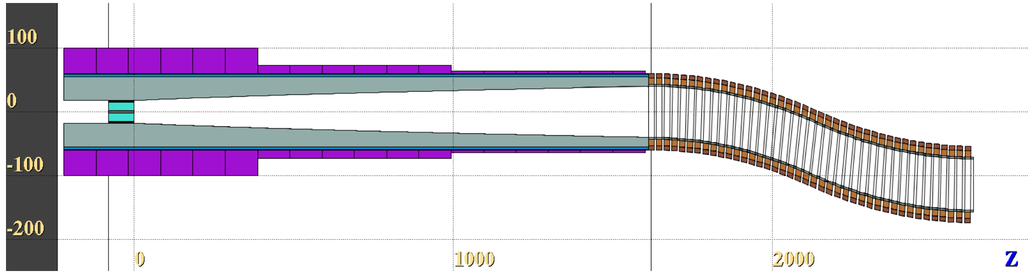




Change in the energy deposition profile

- With a zero angle, a relevant part of the energy will inevitably be deposited in the chicane region. Increasing the angle, the spent beam is intercepted by the shielding before the chicane.
- Integrate beam dump in the shielding? Or design extraction channel?





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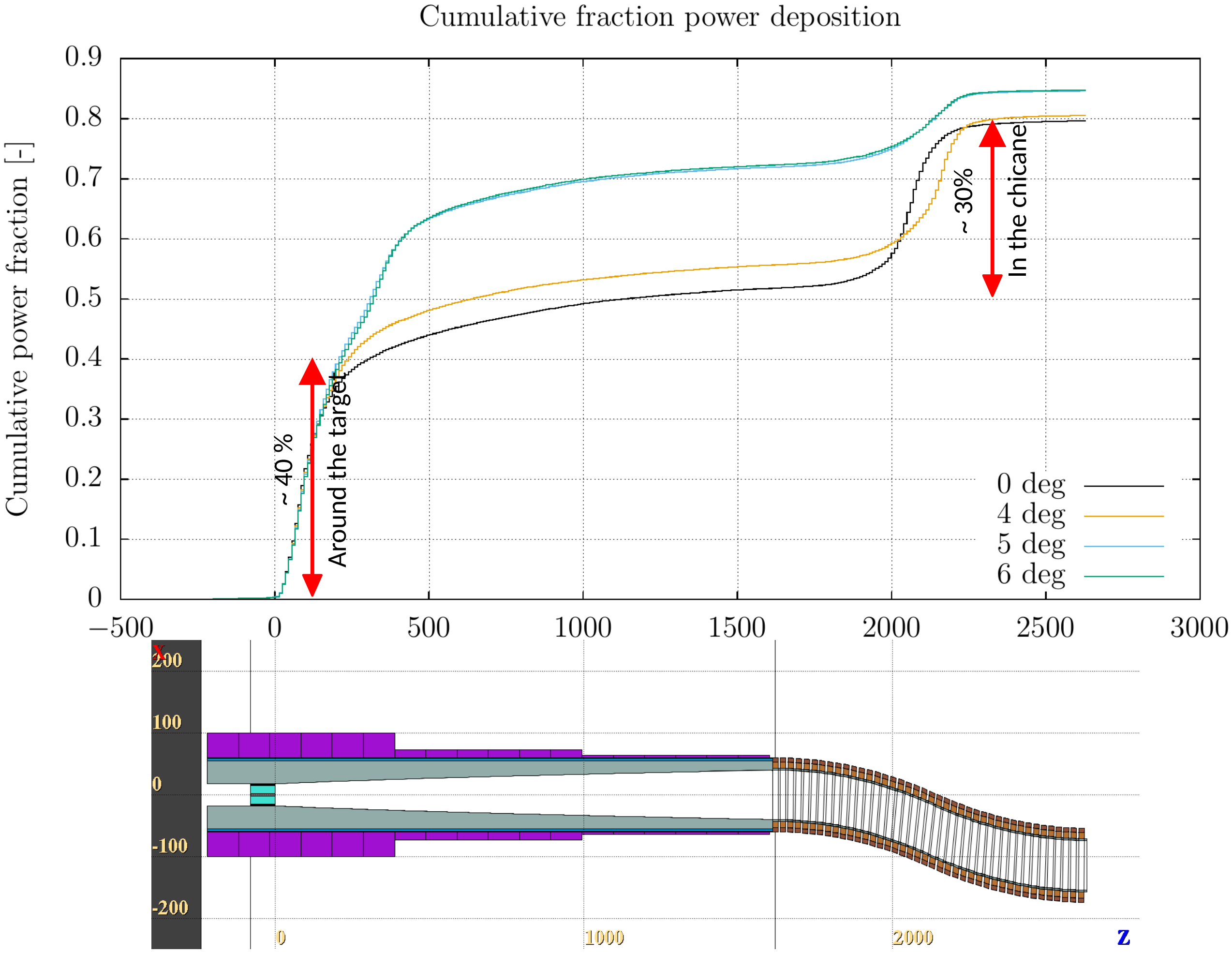

Conclusions

- The new HTS coils model is implemented in FLUKA and can be used for radiation load studies.
- First studies have shown the possibility of reducing the DPA of a factor ~2, when employing a layer of water for neutron moderation and a boron carbide for absorption. The values are still too high for sustaining the full collider lifetime.
- Further evaluation on this side will be done considering some new materials (W_2B-W) currently under study for nuclear fusion applications (https://doi.org/10.1016/j.nme.2022.101349)
- However, reducing the tungsten layer to make room for the neutron absorber increases the energy deposition and the ionizing dose in the coils.
- A parametric scan has been conducted for many different parameters in the target configuration. In most of the cases, the optimum is very close to the working point. The effect on the emittance at different energy is evaluated and shows variation less than 10%.
- A possible beam extraction is under consideration to avoid the power deposition in the chicane. To begin with, we studied different proton angles in respect to the beam line. Having a (slightly) tilted target do not impede the muon production significantly.
- With the current shielding profile, the power deposition is under study.

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Thank you!

$$B_\rho = \frac{\mu_0 I}{4\pi}\frac{2}{l}\sqrt{\frac{R}{\rho}}\left[\frac{k^2-2}{k}K(k^2)+\frac{2}{k}E(k^2)\right]_{\zeta_-}^{\zeta_+},$$

$$B_z = \frac{\mu_0 I}{4\pi}\frac{1}{l}\frac{1}{\sqrt{R\rho}}\left[\zeta k\left(K(k^2)+\frac{R-\rho}{R+\rho}\Pi(h^2,k^2)\right)\right]_{\zeta_-}^{\zeta_+}.$$

$$\zeta_\pm = z \pm \frac{l}{2},$$
$$h^2 = \frac{4R\rho}{(R+\rho)^2},$$
$$k^2 = \frac{4R\rho}{(R+\rho)^2+\zeta^2},$$