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# Target Radiation Studies: Spent Beam Impact

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With inputs from C. Rogers, L. Bottura, P. Testoni and A. Portone
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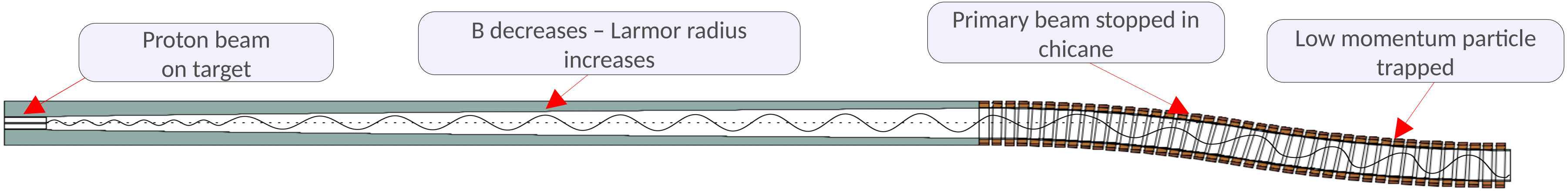
# Outline

- **Geometry of the target area:**
  - FLUKA implementation of the HTS magnets from the magnet working group.
- **Spent proton beam:**
  - Trajectory in the tapering region at various angles of injection
  - Position of impact on the shield aperture
  - Local and global energy deposition on the aperture
- **Muon yield:**
  - First consideration in case of the liquid lead

# Introduction

- The MC under current investigation is proton driven. **Protons** impact on a solid or liquid target **generating pions** by inelastic collisions. In this study, we considered a graphite target.
- **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.
- Particularly, this talk will focus mostly on the **spent proton beam**, to understand the position and size of impact, and to calculate the corresponding load on the equipment



# Parameters table

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 | 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 | |

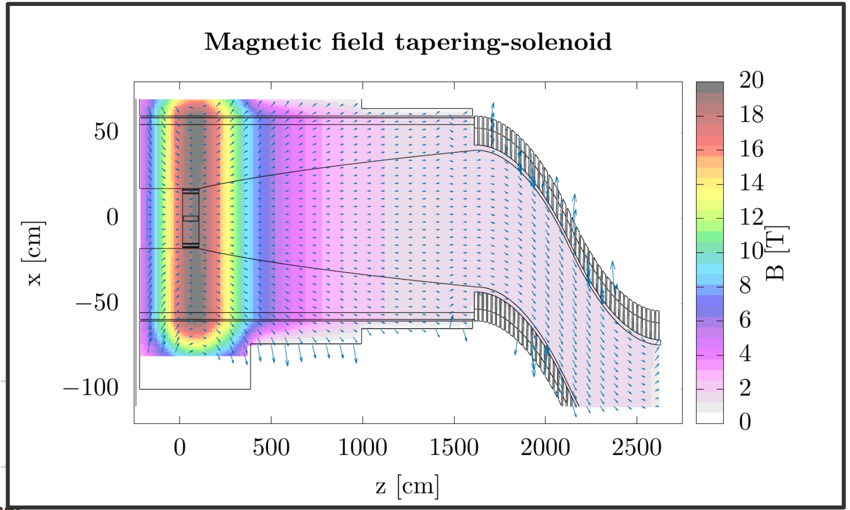
Realistic values under consideration can be higher (1.5-4 MW)

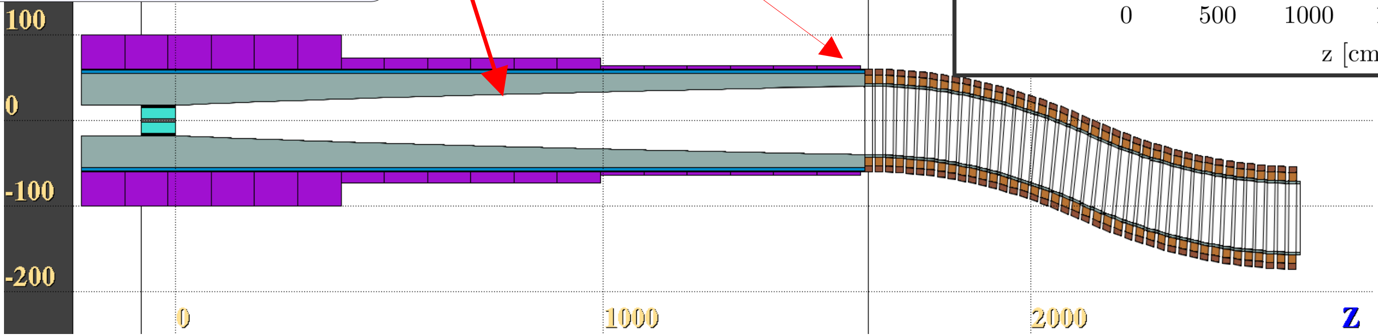
# Geometry

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

New HTS (VIPER) coils:
- Higher power deposition and dose allowed.
- DPA is still a concern

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

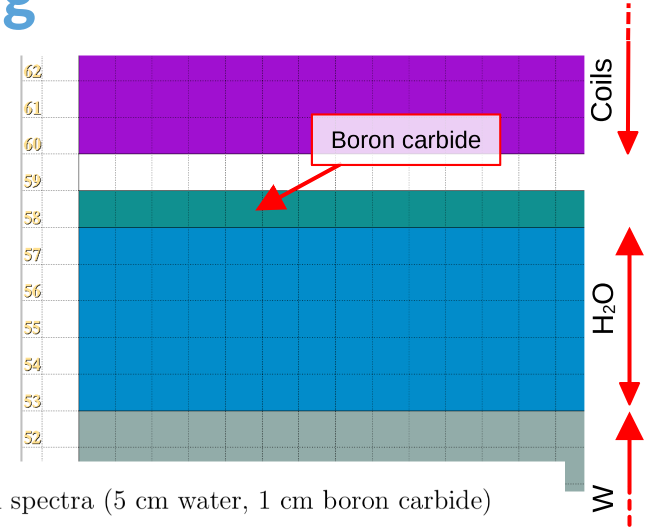


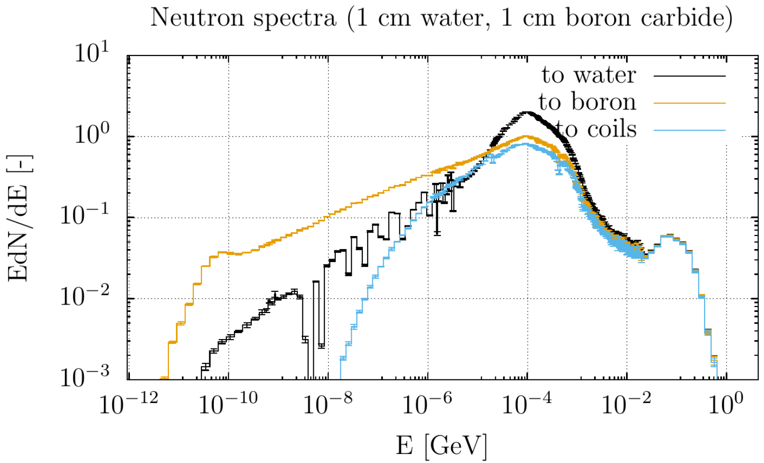



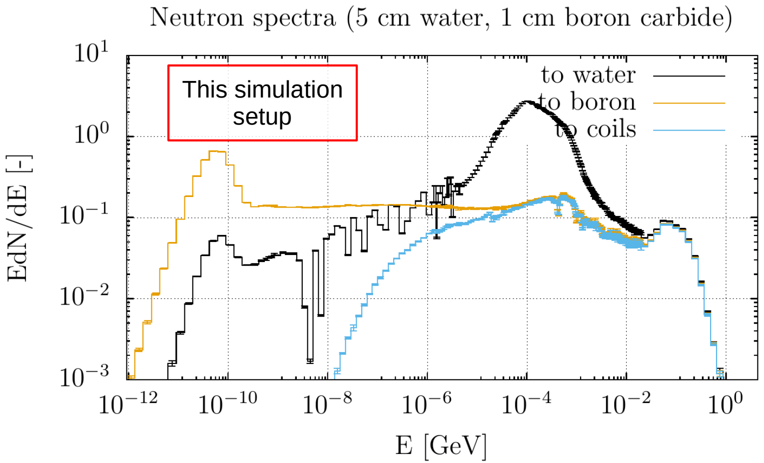

Geometry and fields from L. Bottura, P. Testoni and A. Portone: Https://indico.cern.ch/event/1183570/

# Detail shielding

- **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.

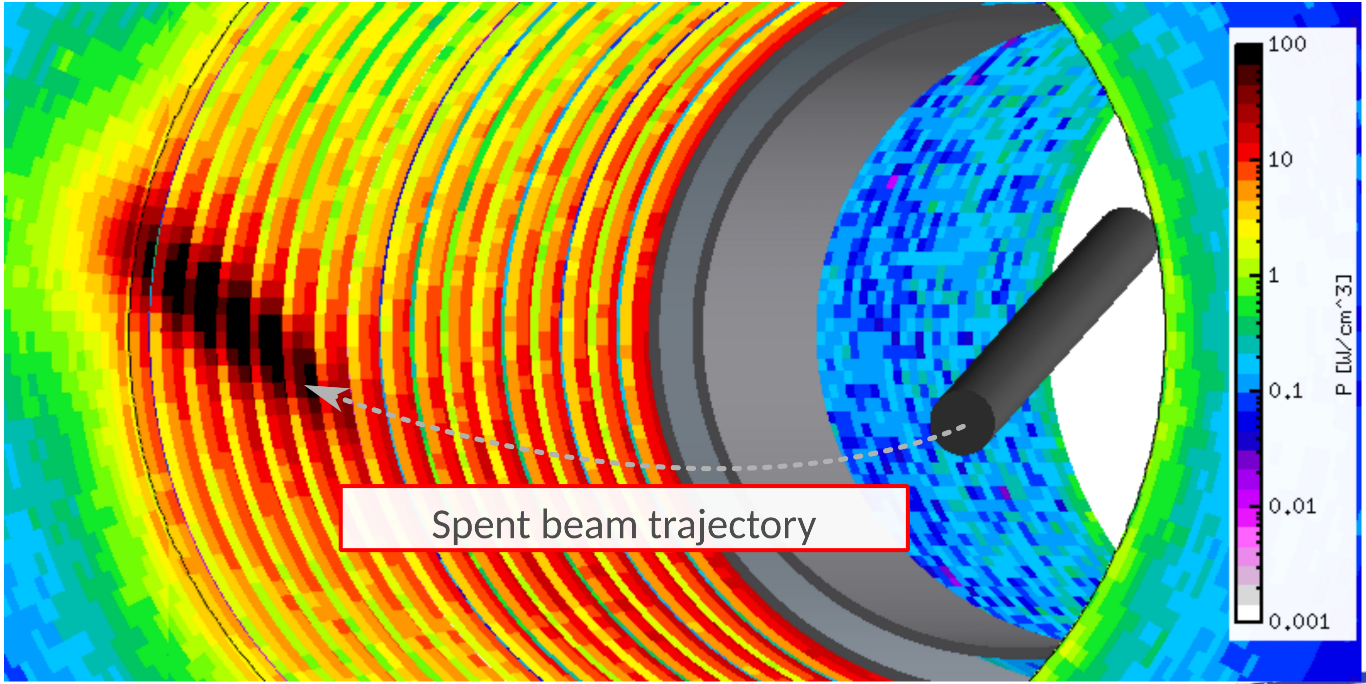


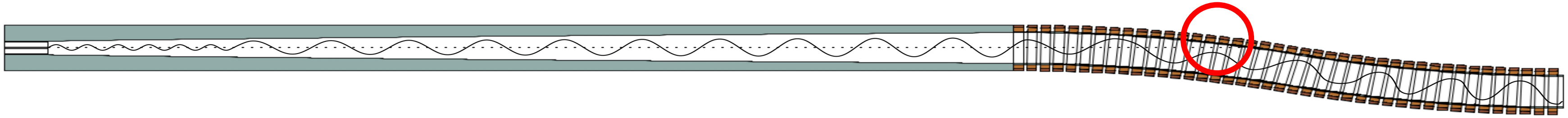



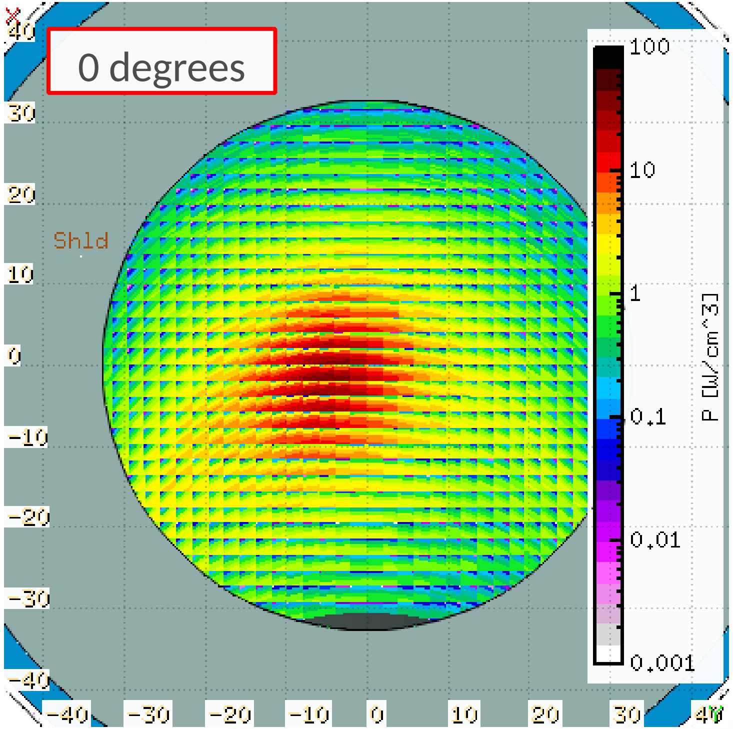
# Non zero angle: spent proton beam on tapering

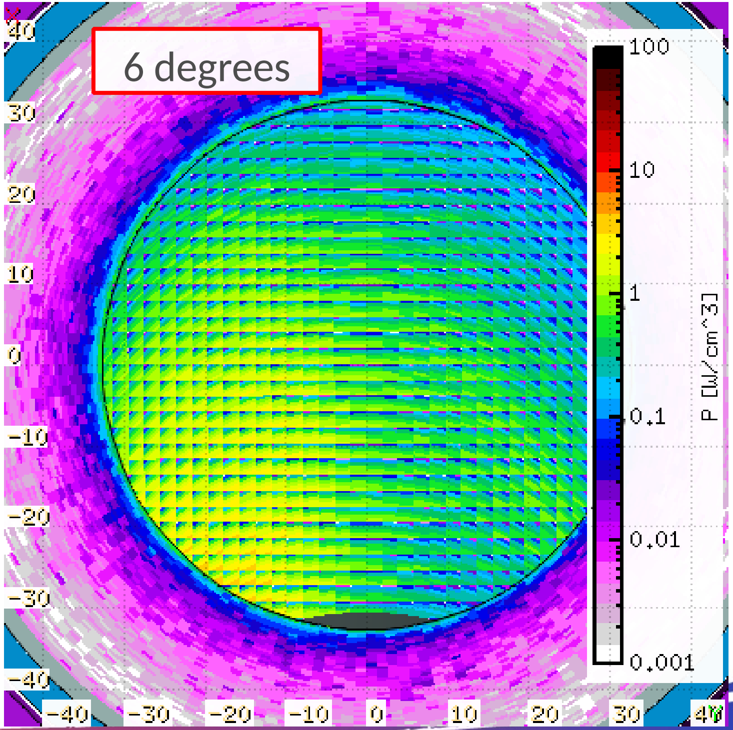
- When the beam angle is equal to 6 degrees, we observed a **second peak in the tapering region** where the spent proton beam impacts on the aperture. This leads to a local hotspot in the energy deposition.



# Comparison spot size in the chicane

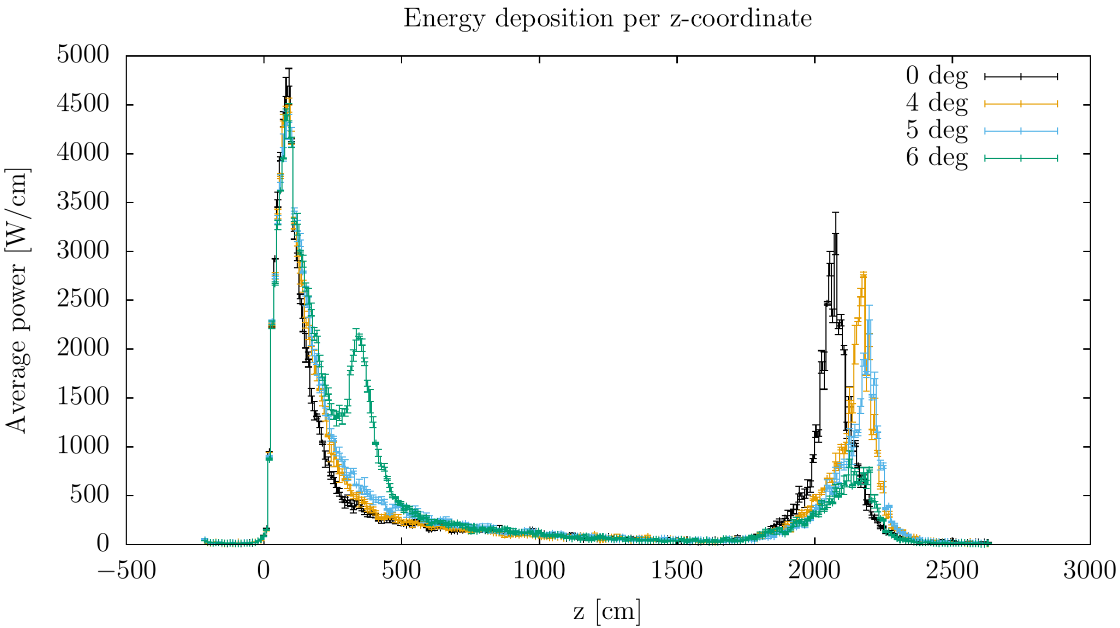


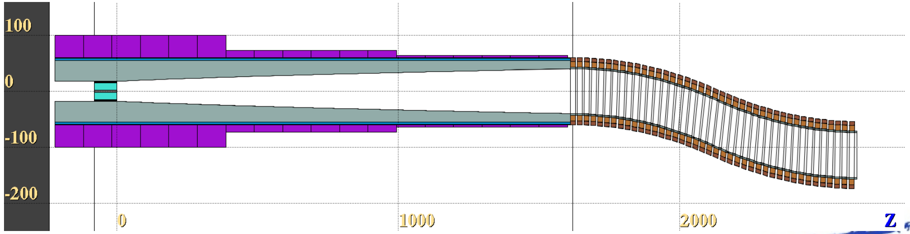


# Global energy deposition profile

- 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**?

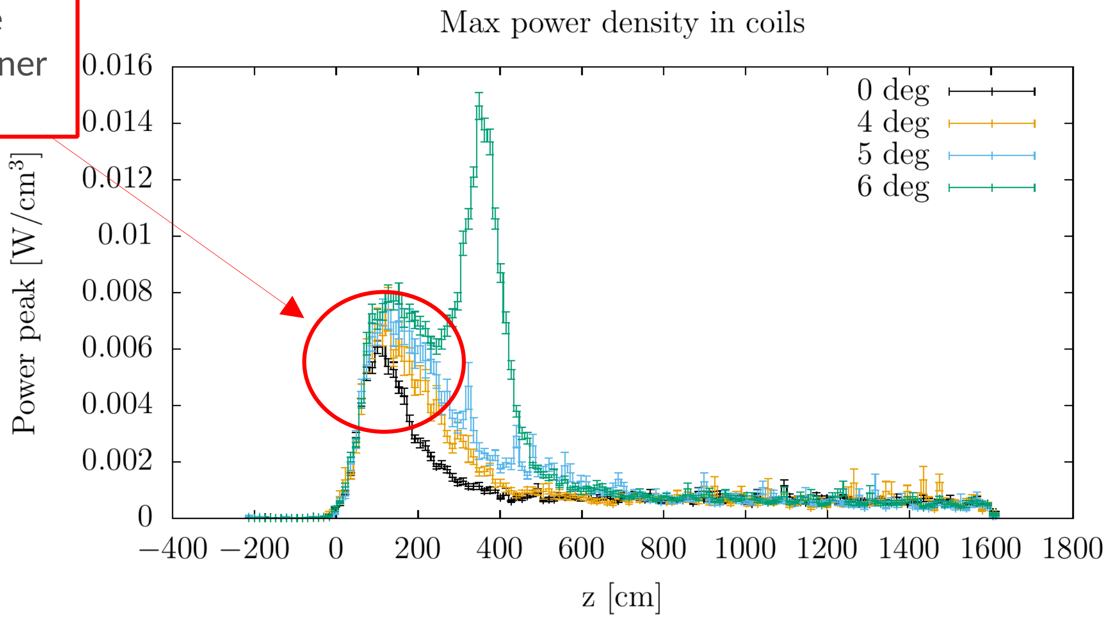


# Effect on coils: power density

- While having a large angle might appear beneficial to avoid the power peak in the chicane, the energy deposition can increase beyond a factor 2 in the superconductive coils.

In line with the past studies. Can be reduced with thinner water layer



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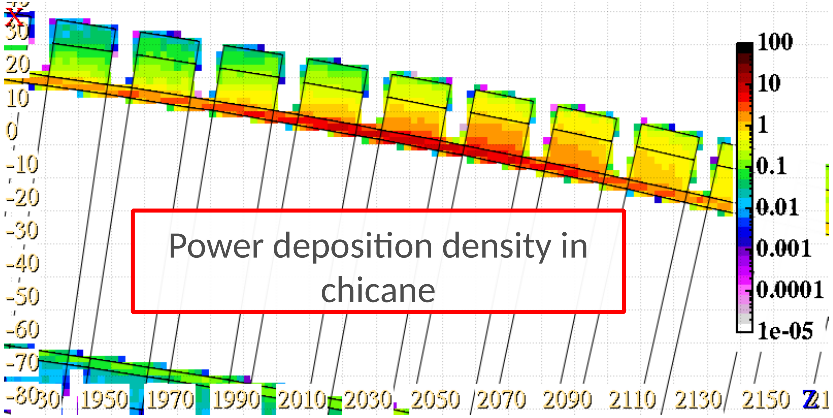
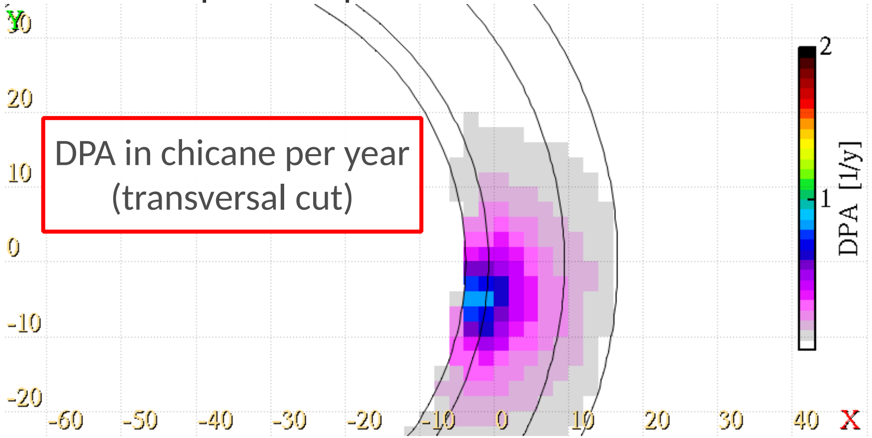
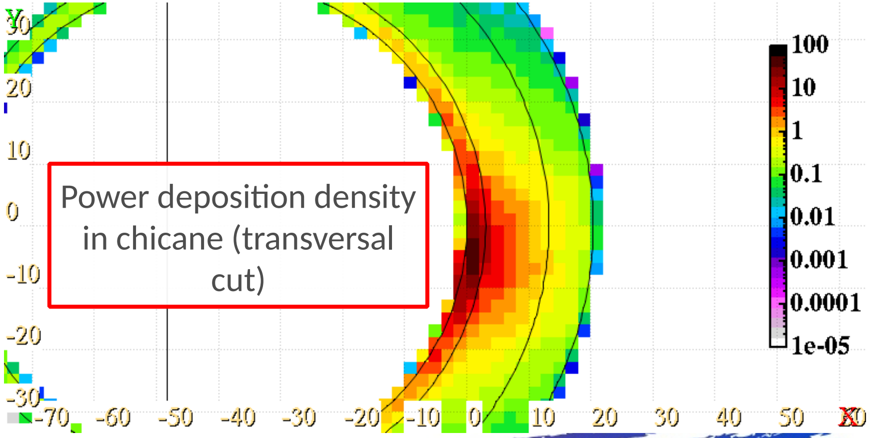
# Zero angle: spent beam impacts on the chicane

- When the beam is parallel to the line, the spent beam will impact directly on the chicane walls.
- The energy deposition is substancial, as the displacement damage.
- The current setup consider a 2 cm shielding, which certainly will have to be increased. The shielding shall accommodate both magnet and muon capture requirements.

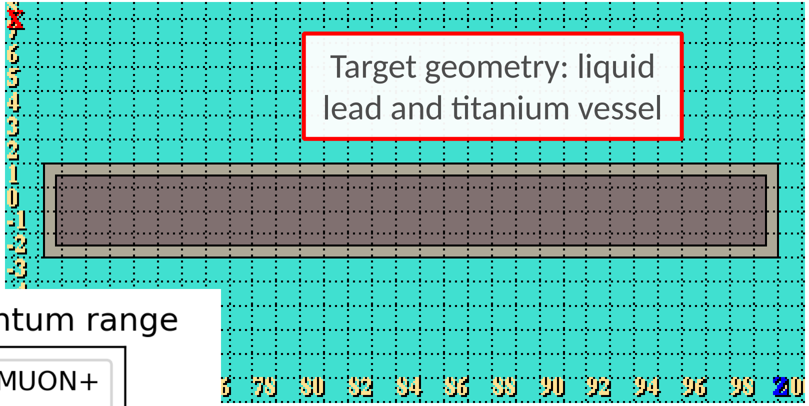


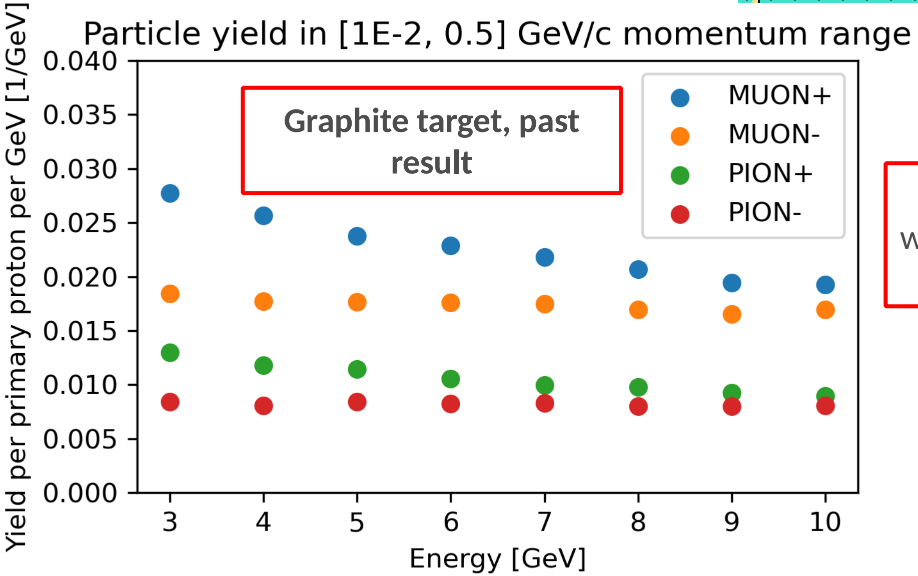



# Liquid lead target

- In the past studies we explored the muon yield in case of a graphite target.
- Today, I want to report the status in case of a liquid lead one.




Satifactory agreement when we apply the same energy cut as J. Back

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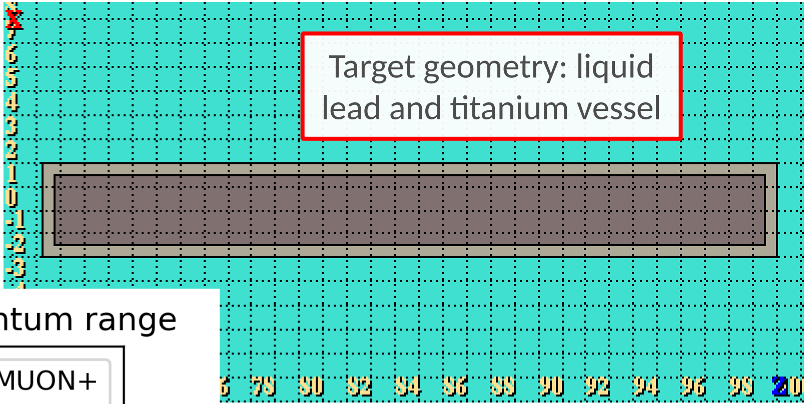


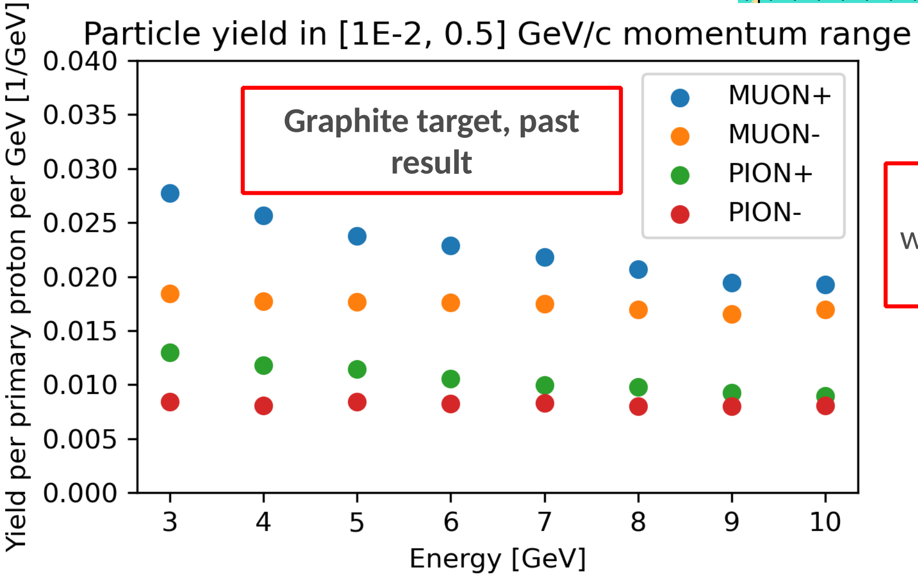


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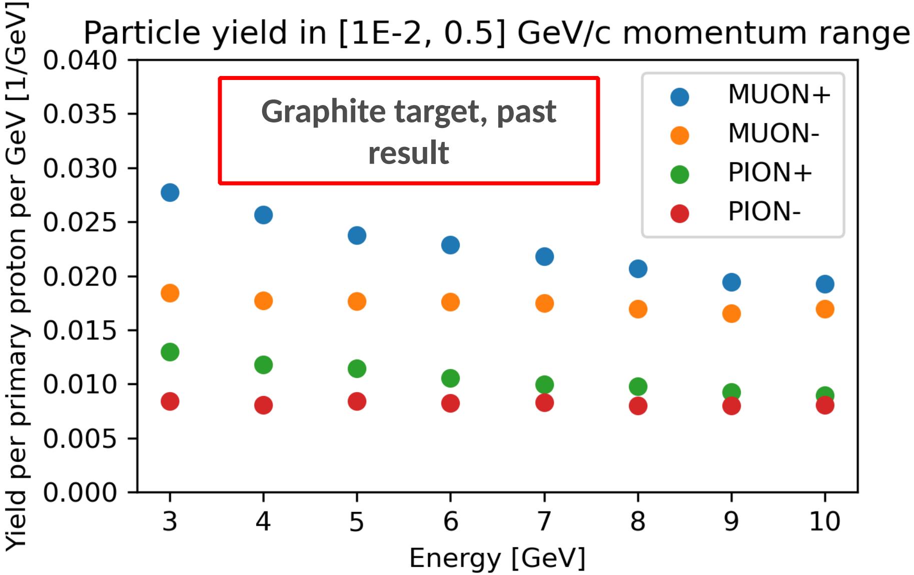
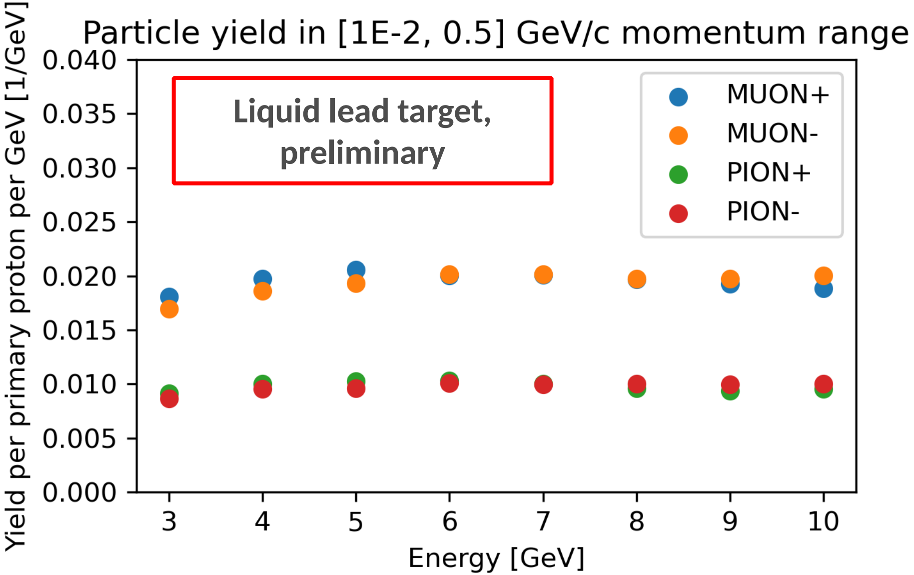
# Muon yield: proton energy

- The muon yield in case of liquid lead target is rather low. Results will be double checked.

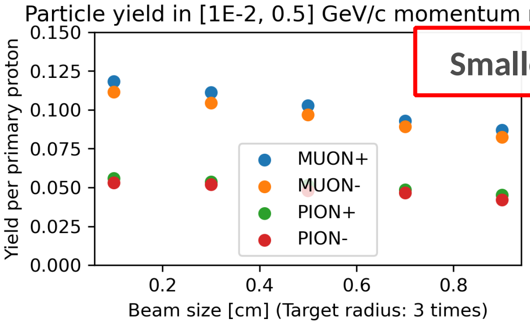


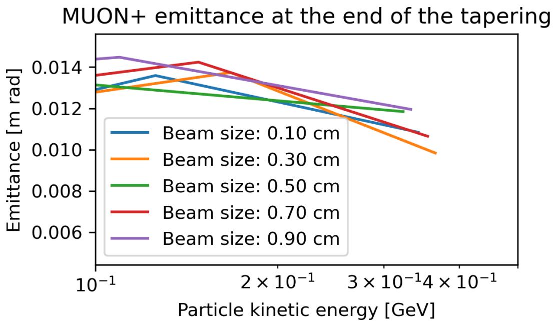
# Liquid lead target: transversal side

## Proton beam size:

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




Smaller is better

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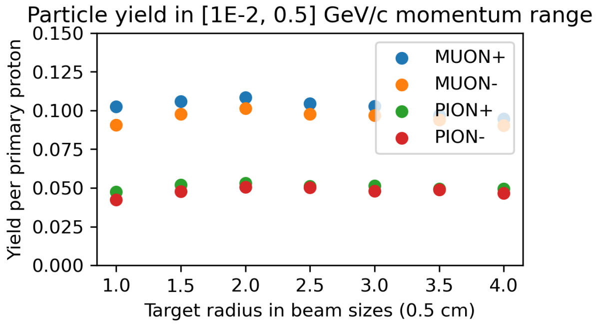
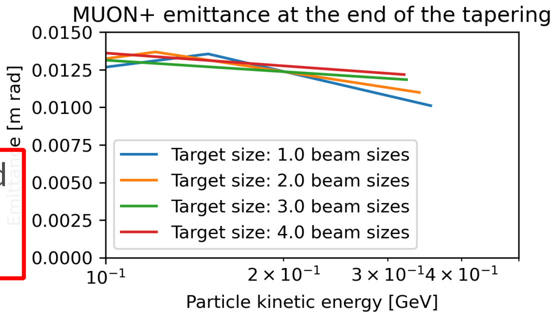



Statistics to be improved to evaluate the emittances

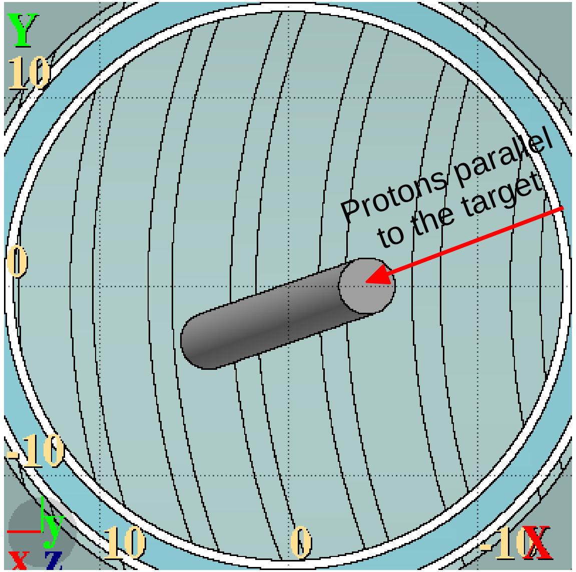
# Conclusions

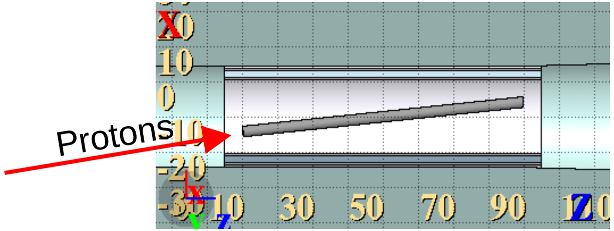
- The **spent beam** deliver a considerable amount of **power**, up to **40%** of the original proton drive power.
- Two main issues have to be considered: the **total heat removal** and the **local damage** to the machines.
- The **angle** at which the proton driver beam is injected strongly **affects** the spent beam **position of impact**, while it doesn't influence the energy deposition profile around the target.
- Changing the angle, the hotspot from the spent protons moves from the chicane toward the tapering shielding.
- For the next steps, the **shielding optimization process** will continue, both in the **target solenoids** (neutron absorber layer optimization) and the **chicane region** (shielding thickness, materials, interconnects).
- The muon yield in case of a liquid lead target is under investigation. So far the results do not show a clear advantage in comparison with the graphite one.

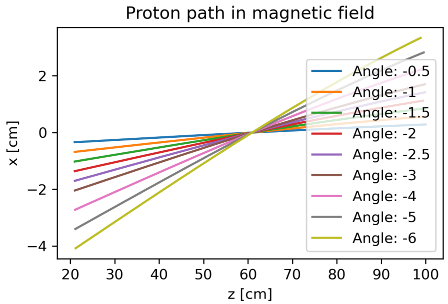
# Thank you for your attention!

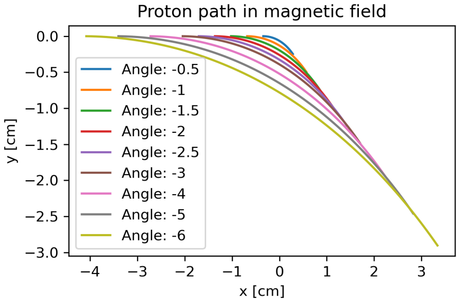
# Angle of incidence of proton beam

- The **spent 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.



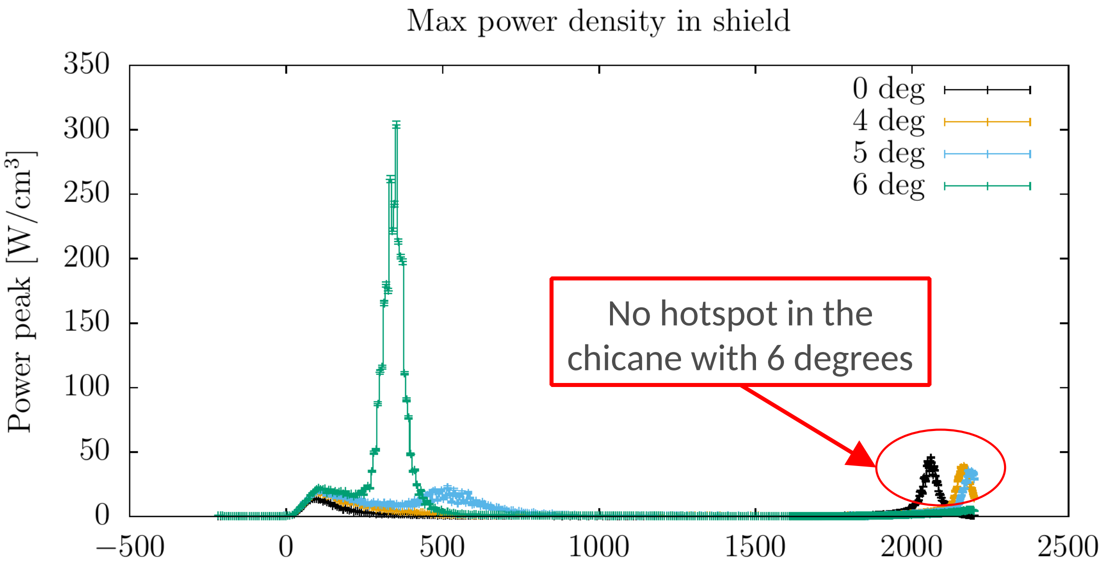



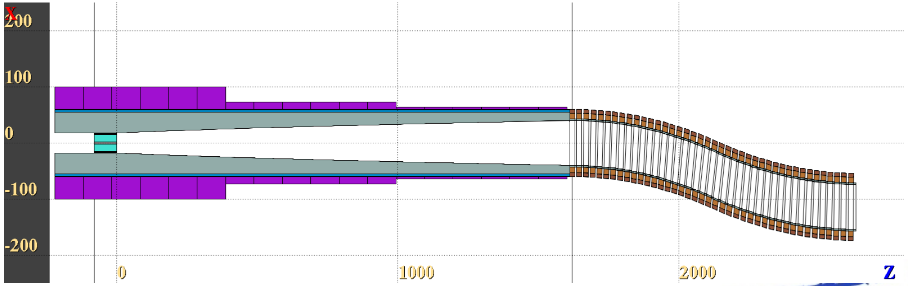




As a first estimation of the actual particle trajectory, we considered the trajectory of proton in vacuum in the same magnetic field.

# Maximum longitudinal power density

- 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**?

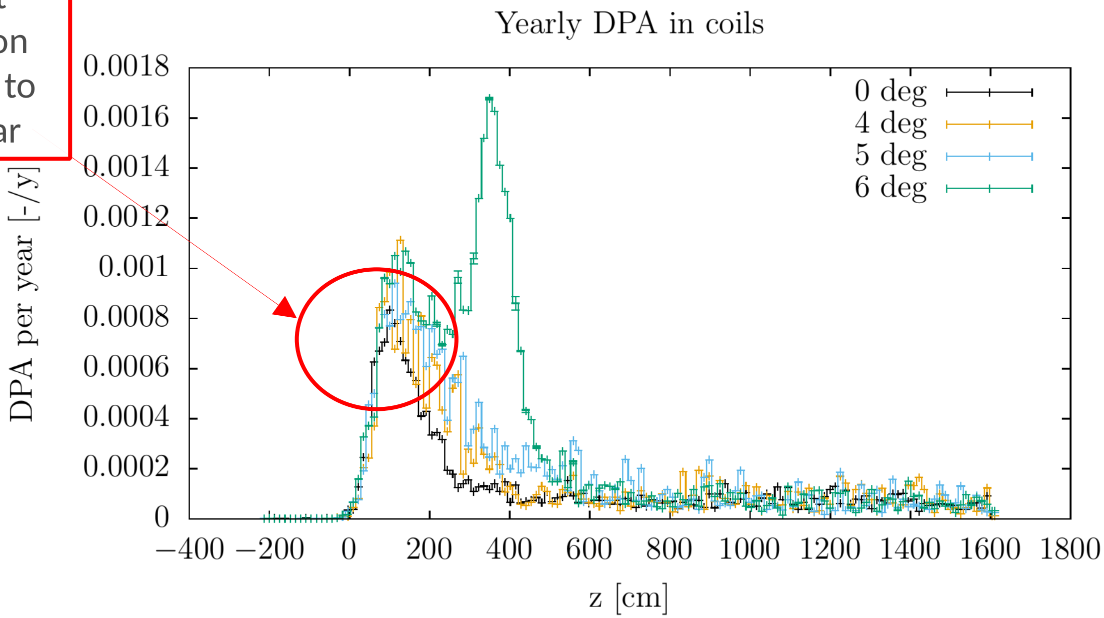


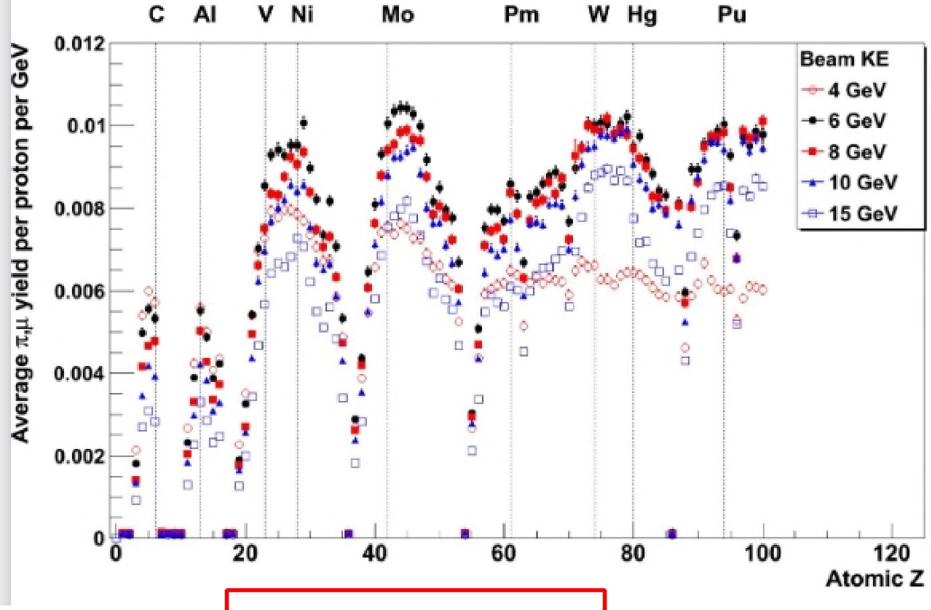
# Effect on coils: DPA

- Even with a thick layer of water and boron carbide (5 + 1 cm respectively), the displacement per atom profile follow the power deposition one.

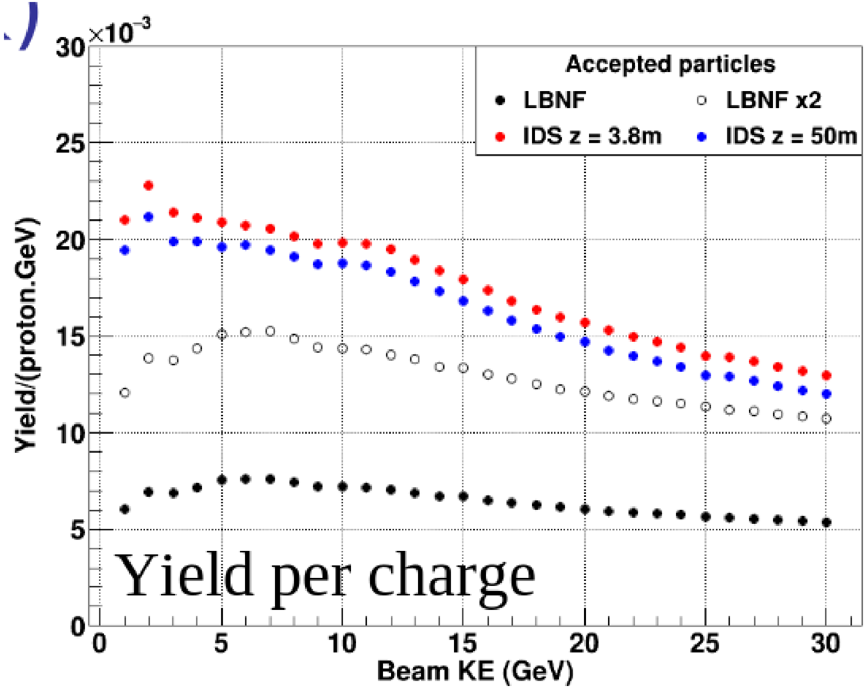
In line with the past studies. Without neutron absorption layer increases up to 1.8 mDPA per year



# J. Back studies




'LBNF' Horn focused




'IDS' Solenoid focused