International
MUON Collider
Collaboration

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Radiation studies for the target area

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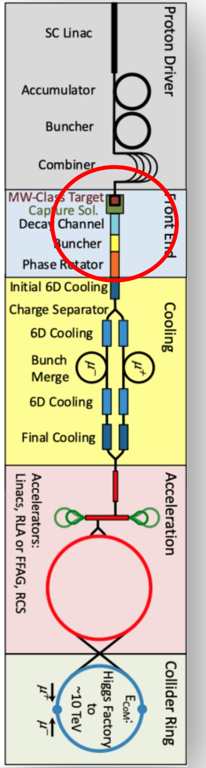
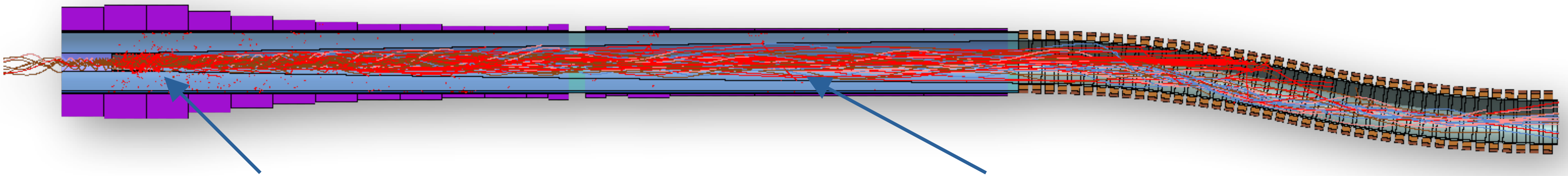
Outline



- **Introduction**
  - General target overview
  - Target geometry
  - Adiabatic tapering and chicane: geometries and magnetic field
- **Radiation load to the target**
  - Energy deposition and long-term radiation damage in the target
  - Heat load and radiation effects on the front window
- **Radiation load to the target solenoid**
  - Heat load and long-term radiation damage in the superconducting coils
  - Total power to the cold mass
- **Adiabatic tapering and chicane (only for graphite target)**
  - Pions/muons energy spectrum
  - Work toward a tentative extraction channel for the spent beam
- **Conclusions**

Introduction

- The MC under current investigation is proton driven. **Protons** impact on a solid or liquid target **generating pions** by inelastic collisions. [1]
- 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 momentum 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.** All the simulation are conducted using **FLUKA**.
- All the **results** will be **normalized per 2 MW proton beam** intensity with 200 days of operation per year.



p impacting on a target, producing $\pi^{\pm}$ ...decaying in μ^{-} and μ^{+}

Parameters

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~~ → Now 2 MW	
Beam energy	5 GeV	
Shielding thickness	42.2 cm	
Magnet aperture (radius)	60 cm	
Peak magnetic field	20 T	

Note on the long term radiation damage: we considered 139 days of operation per year (1.2×10^7 s). In the general parameters table, we assume to operate for 10^7 s per year. All the results are given per year of operation.

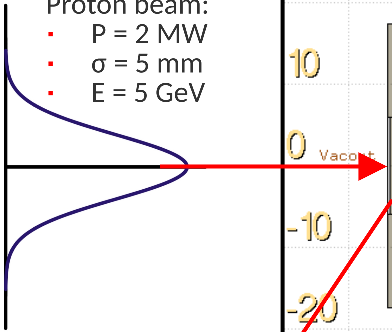
Target geometry: graphite option

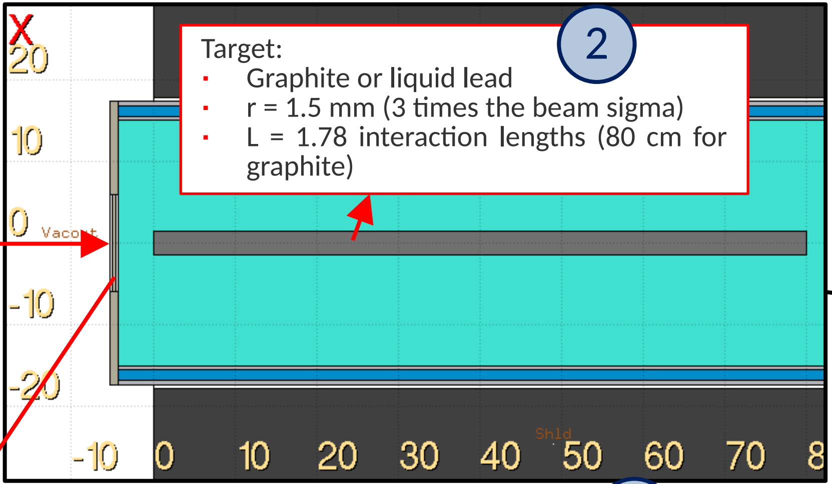
Generic target and shielding geometry:

- Tungsten considered for the shielding (engineering and material aspects to be studied)
- Neutron absorber currently under study

Proton beam:

- P = 2 MW
- σ = 5 mm
- E = 5 GeV





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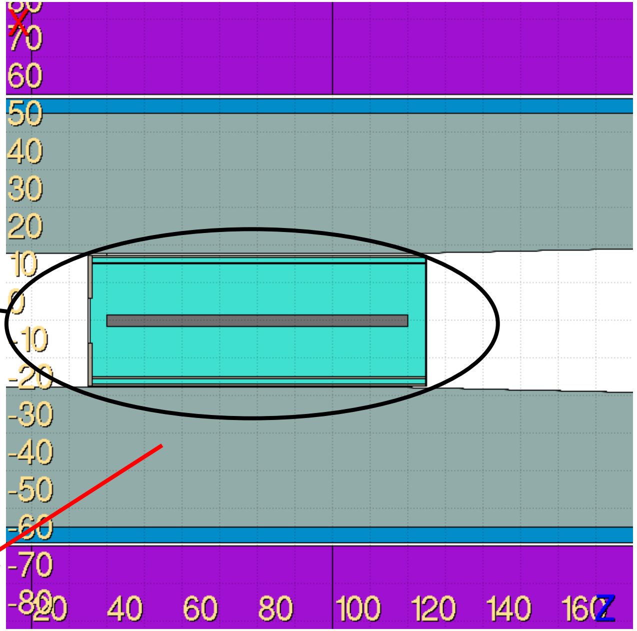
Target:

- Graphite or liquid lead
- r = 1.5 mm (3 times the beam sigma)
- L = 1.78 interaction lengths (80 cm for graphite)



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Window & vessel:

- Be, Ti and stainless steel under consideration
- Thickness from 250 microns to ~5 mm

3

Shielding:

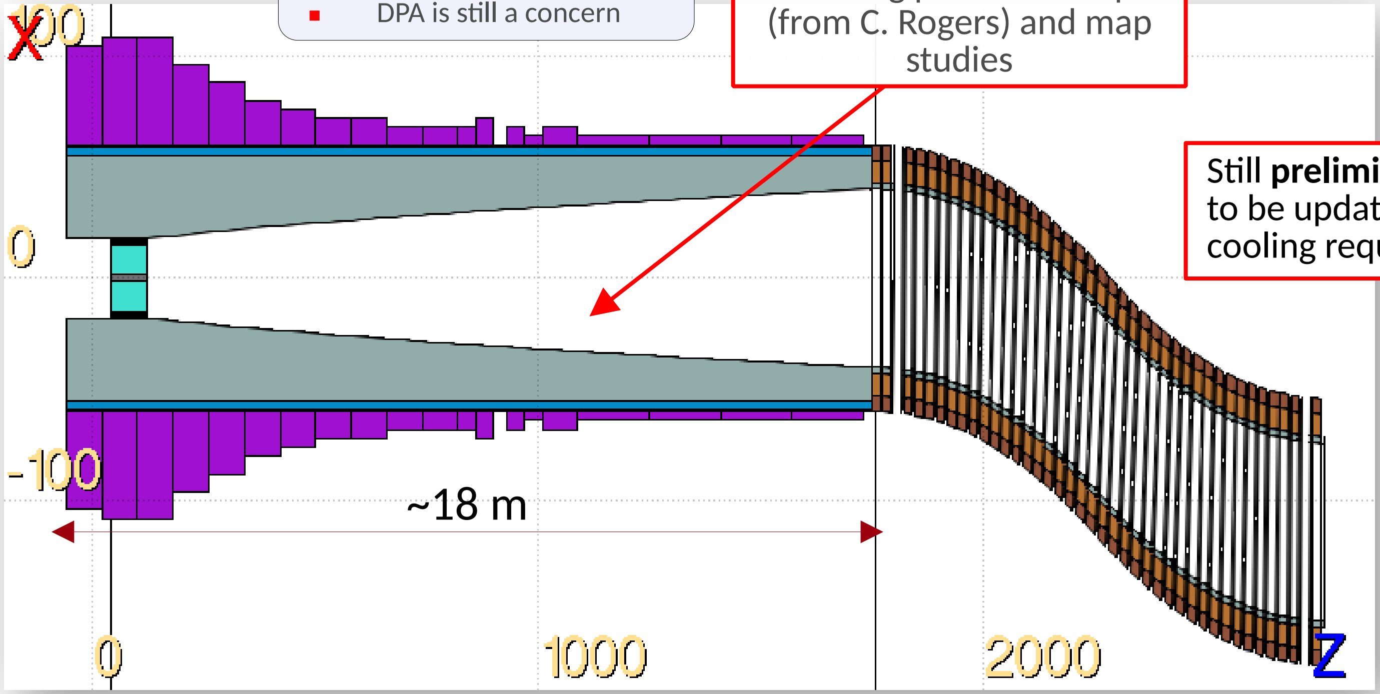
- r_{in} = 17.5 cm
- r_{out} = 60 cm
- Bulk made of solid tungsten, tentative layers of water and boron for neutron moderation and capture

Geometry: adiabatic tapering and chicane (v0.2)

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

Still **preliminary**! It is going to be updated to fit cooling requirements

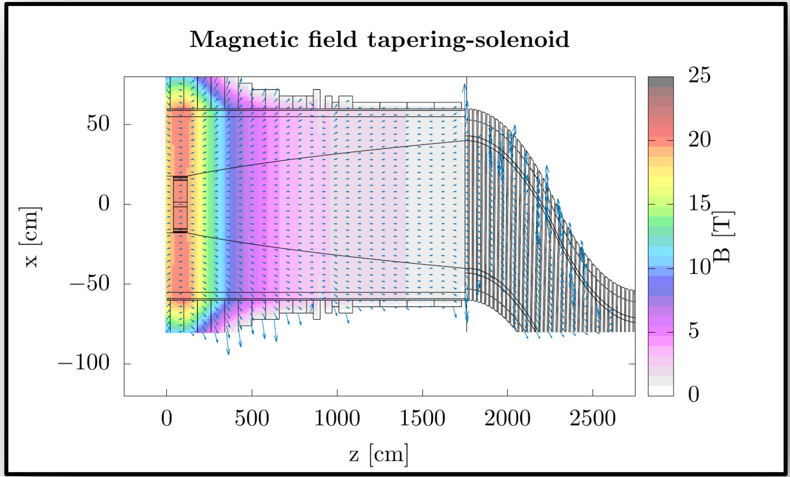


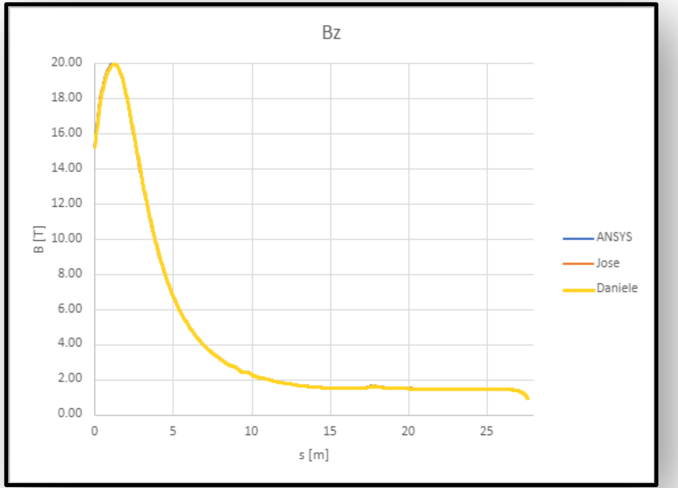
Geometry from L. Bottura, P. Testoni and A. Portone: Https://indico.cern.ch/event/1183570/

Magnetic field: adiabatic tapering and chicane

- For the magnetic field around the target, we used an in-house code around the beginning of the IMCC to have results set up quickly
- Together with colleagues from the magnets WG, we benchmarked the results, with existing codes and the results matches

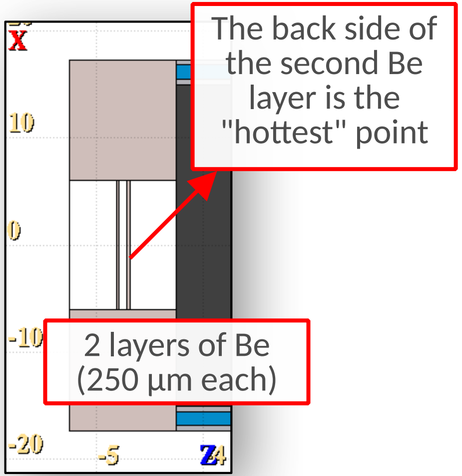
https://indico.cern.ch/event/1240042/

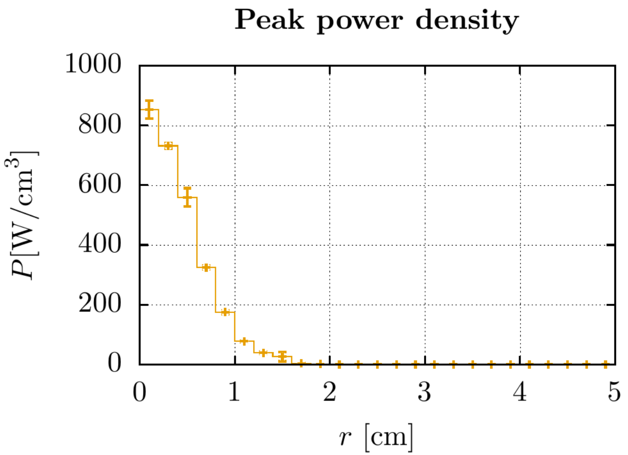


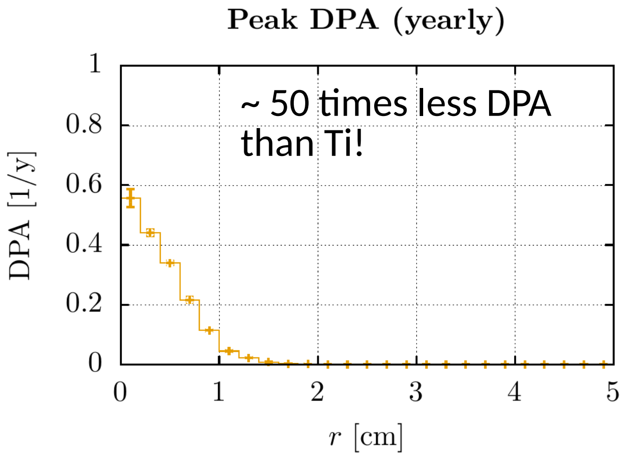


Target window

- The front window is the most radiation exposed component of the target. Back and lateral sides of the target are less exposed
- Several options have been considered and discarded (single and double layers of titanium, aluminum, stainless steel)
- The current material under consideration is Beryllium: low density, low Z → less energy deposition



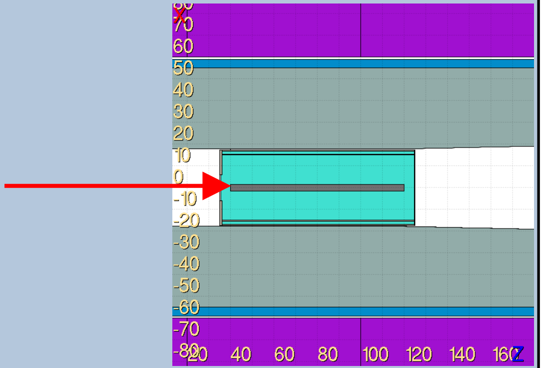


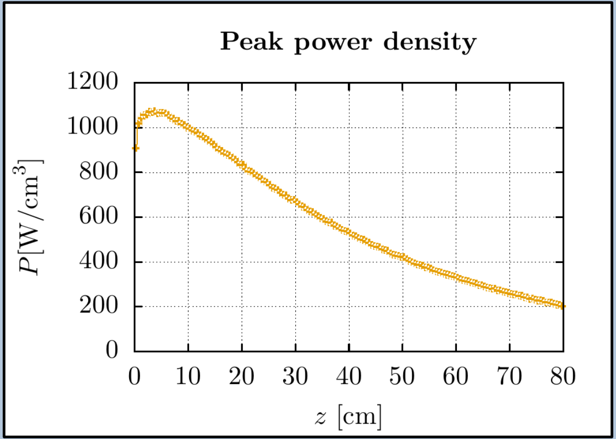


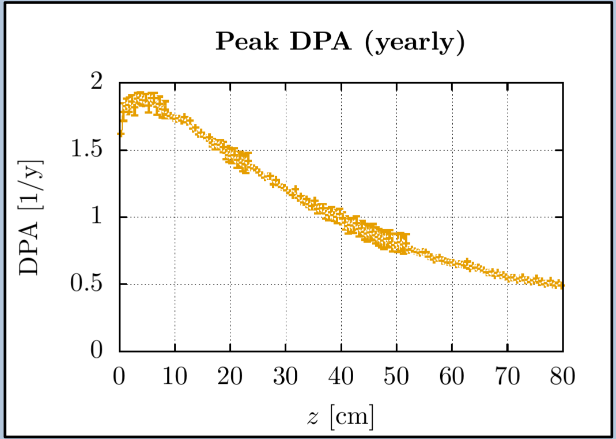
Target (graphite)

- The power deposition in the target depends on several parameters. We considered two possible cases:
  - Beam and target parallel to the solenoid axis
  - Beam and target tilted with 9 deg inclination (useful for spent beam extraction)

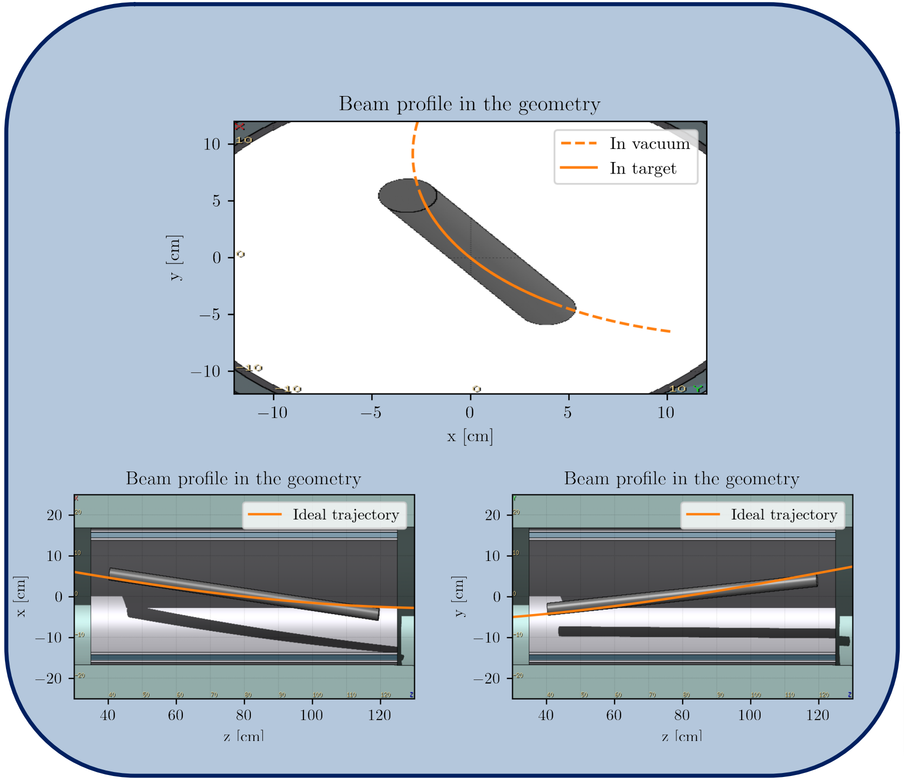
Target parallel to solenoid axis



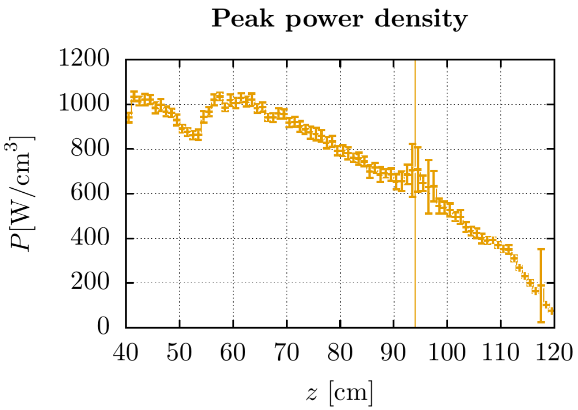




Target (graphite) tilted



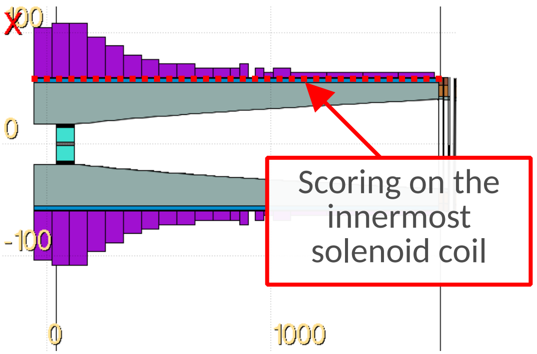
- With a tilted target, part of the beam is entering from the lateral side
  - Lower peak power
  - Beam and target tilted with 9 deg inclination (useful for spent beam extraction)

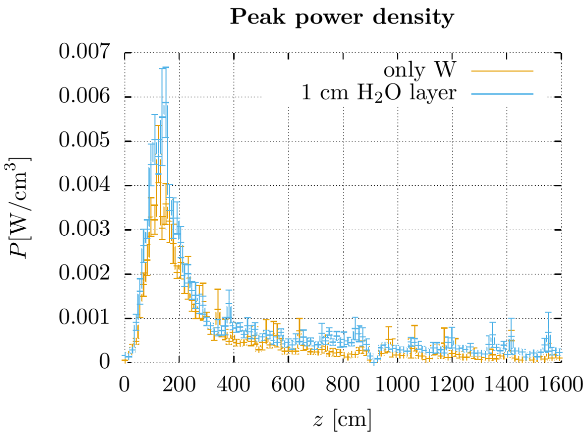


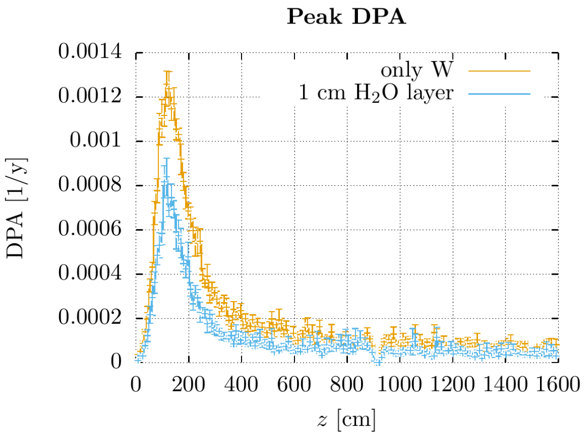
More details tomorrow morning:
https://indico.cern.ch/event/1250075/contributions/5348856/

Radiation effects in superconducting solenoids

- A thick shielding is required to protect the coils from the secondary particles coming from the target
- In case of liquid lead (or heavier) targets, the peak power density and DPA are higher



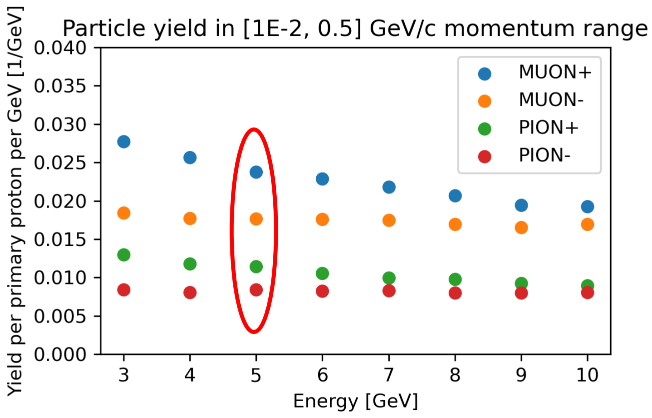


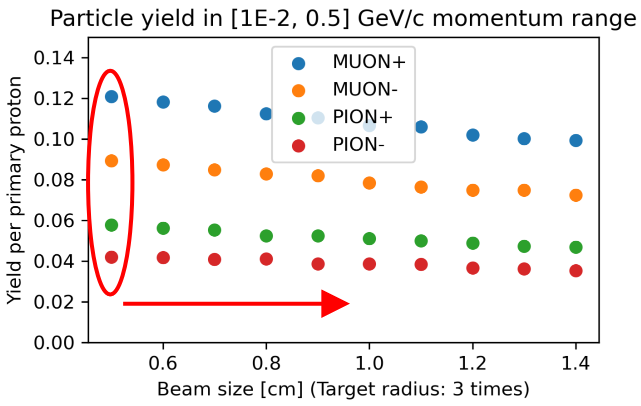


- Optimization process ongoing:
  - Identifying minimal requirement for shielding in order to operate the magnets
  - Increasing the magnet aperture in the hotspot and reducing it elsewhere(?)

Muon yields

- We conducted a parametric scan to assess the muon yield (and emittance) depending on various parameters (beam energy, angle of impact, target and beam sizes, target lenght)
- While there is a slight variation in the total muon yield, the emittances are practically always the same



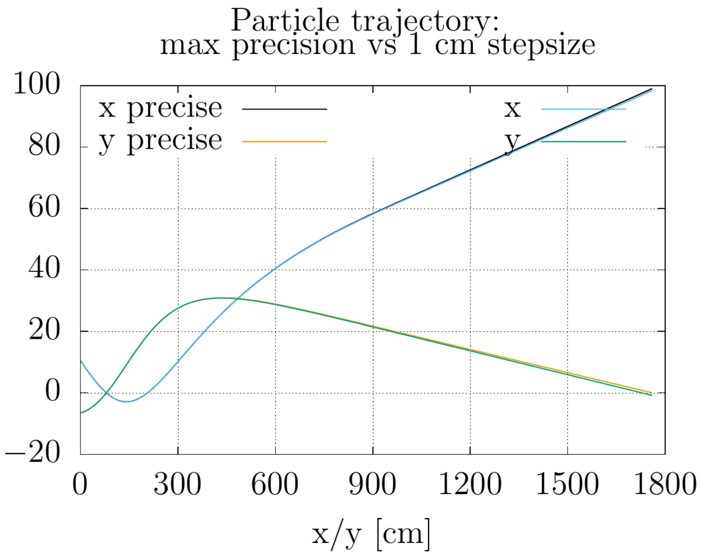


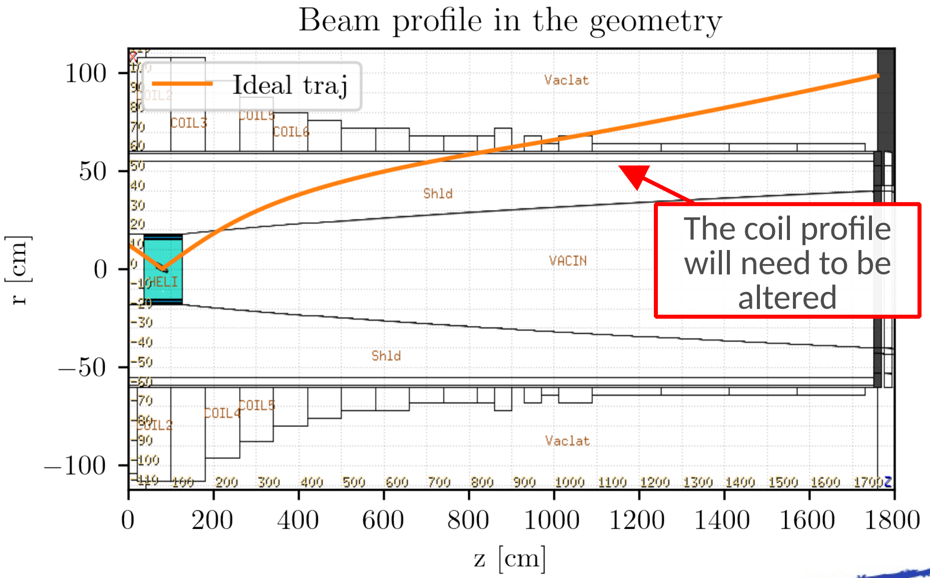
Could we consider larger beam spot sizes to simplify the window and target engineering?

More details here:
https://indico.cern.ch/event/1237101/contributions/5204412/attachments/2575066/4440149/angle_dpa_updateJan23.pdf

Tentative extraction channel

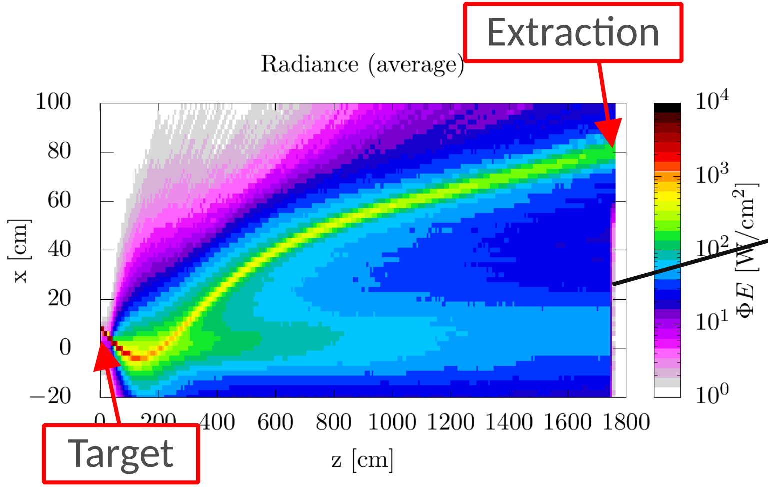
- With 1.8 interaction lengths, $e^{-1.8}$=16.5% of the protons do not interact with the target. We want to extract those together with the high energy products of the interactions.
- A 9 degree tilted beam in the center could be a reasonable assumption to extract the beam.

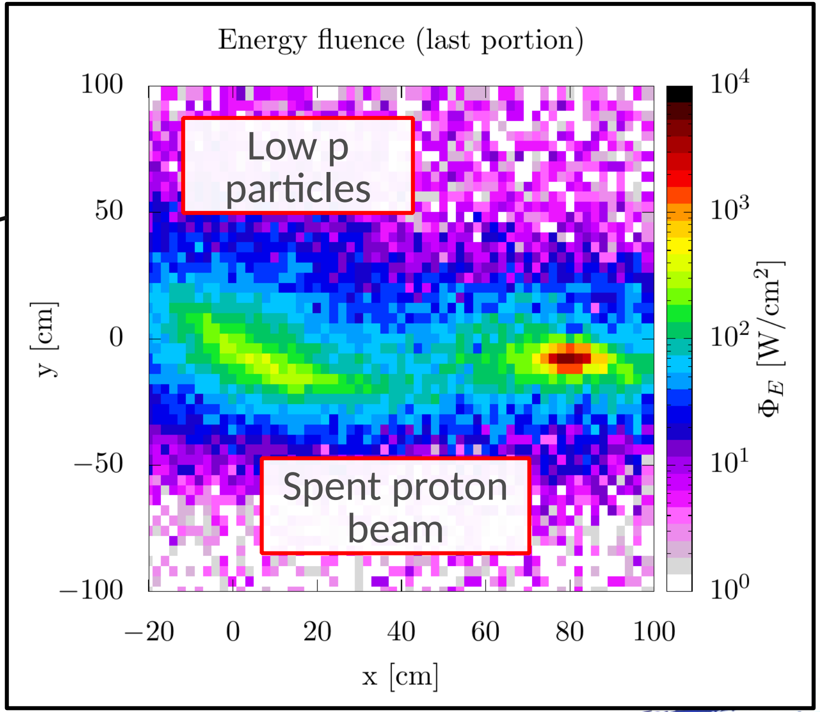




Energy fluences: general profiles

- Considering the kinetic energy of the particles, the fluences profiles are drawn. With those, we can estimate the aperture needed to extract the spent beam.



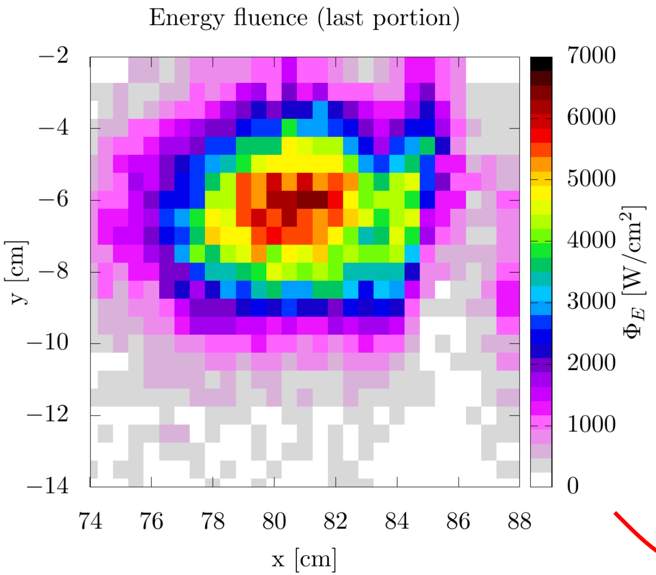


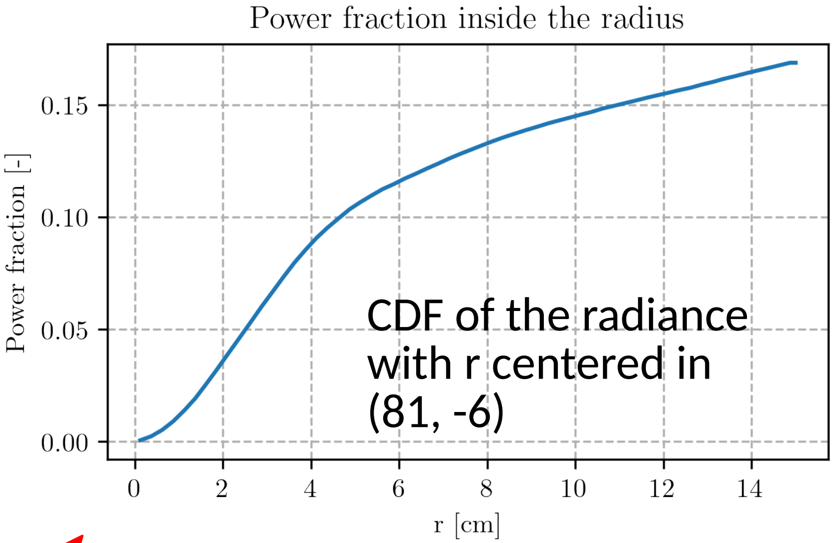
Relative power fluence per particle species

p	Π^+/Π^-	μ^+/μ^-	γ	e^+/e^-
0.38	0.037 / 0.019	0.014 / 0.008	0.001	0.0058 / 0.0058

Spot size

- To extract a significant fraction of the beam power, a large aprterure is needed. To extract 10% of the beam power, the aperture should be larger than 4 cm (radius)





Conclusions

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- The new geometry of the coils has been implemented in FLUKA. The past benchmarks show excellent agreement for the **magnetic field evalutation**
- **Beryllium** seems to be the proper choice for the **target window**. Past simulation with Ti showed unsustainable level for displacement damage
- The **DPA and energy deposition in the window** are still a problem for the target. Increasing the beam size of the proton beam can mitigate this phenomenon
- The **target energy deposition and DPA** have been calculated. Their effect have to be evaluated with the help of thermomechanical calculation
- The energy deposition and displacement damage has been evaluated in the **superconducting solenoids**. The shielding has to be optimized around the target region to further reduce the **displacement damage**
- **Muon yield and emittances** dependencies have been studied with a broad range of **parameters**
- A possible **extraction channel** has been devised. With a significant alteration of the tapering region it can be possible to extract ~10/15% of the driver power

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Thank you
for your attention!