Proton beam dump at the muon collider

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Outline

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  - Parameters table
- **Target and target area geometry**
  - Target
  - Tapering region
  - Chicane and extraction channel
- **Work toward a tentative extraction channel and beam dump**
  - Spent proton beam trajectory in the tapering field
  - Fluences and radiance at the extraction point
- **Conclusions**
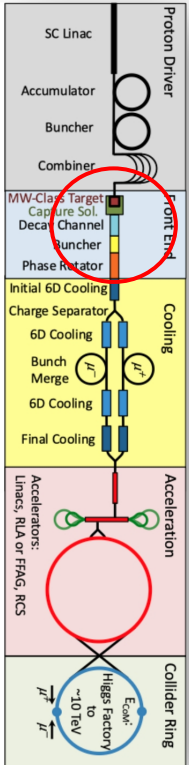
Introduction

- 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.
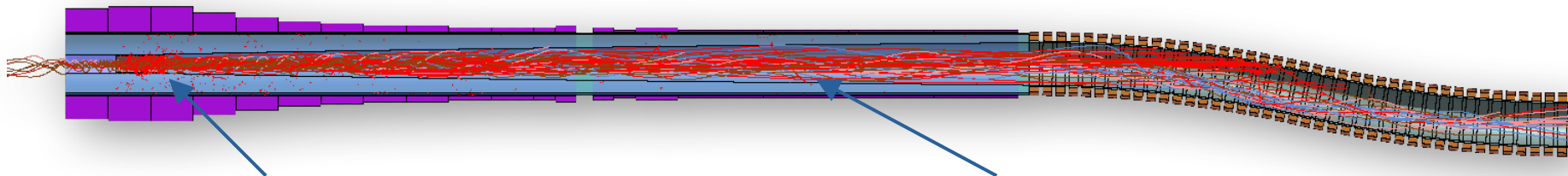
p impacting on a target, producing $\pi^{\pm}$

...decaying in μ^{-} and μ^{+}

Parameters

Table 1: Parameters table.

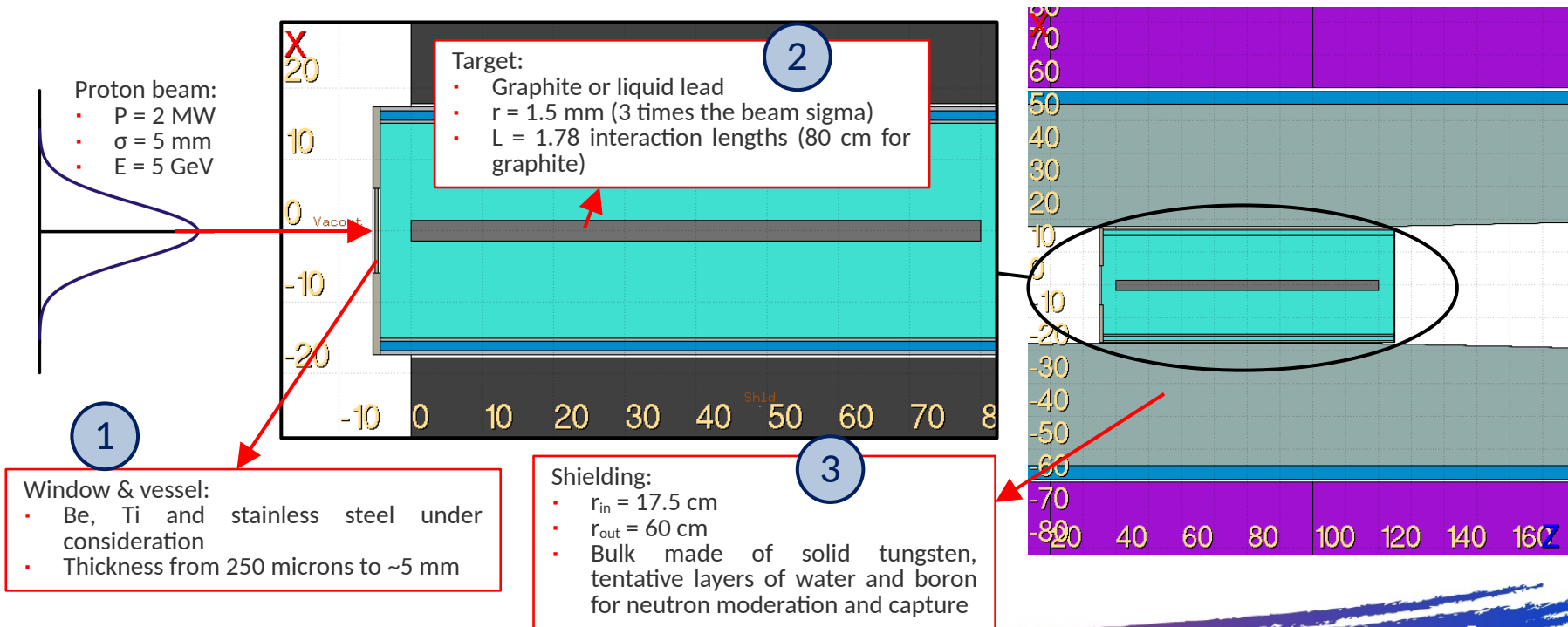| Material	Graphite (1.8 g/cm^3)	Liquid lead (10.5 g/cm^3)
Inelastic scattering length	44.94 cm	17.34 cm
Target radius	15 mm	15 mm (+ 5 mm vessel)
Target length	80 cm	29.7 cm (+2 cm vessel)
Beam size (round)		5 mm
Beam power (normalization purposes)		1.5 MW → Now 2 MW
Beam energy		5 GeV
Shielding thickness		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
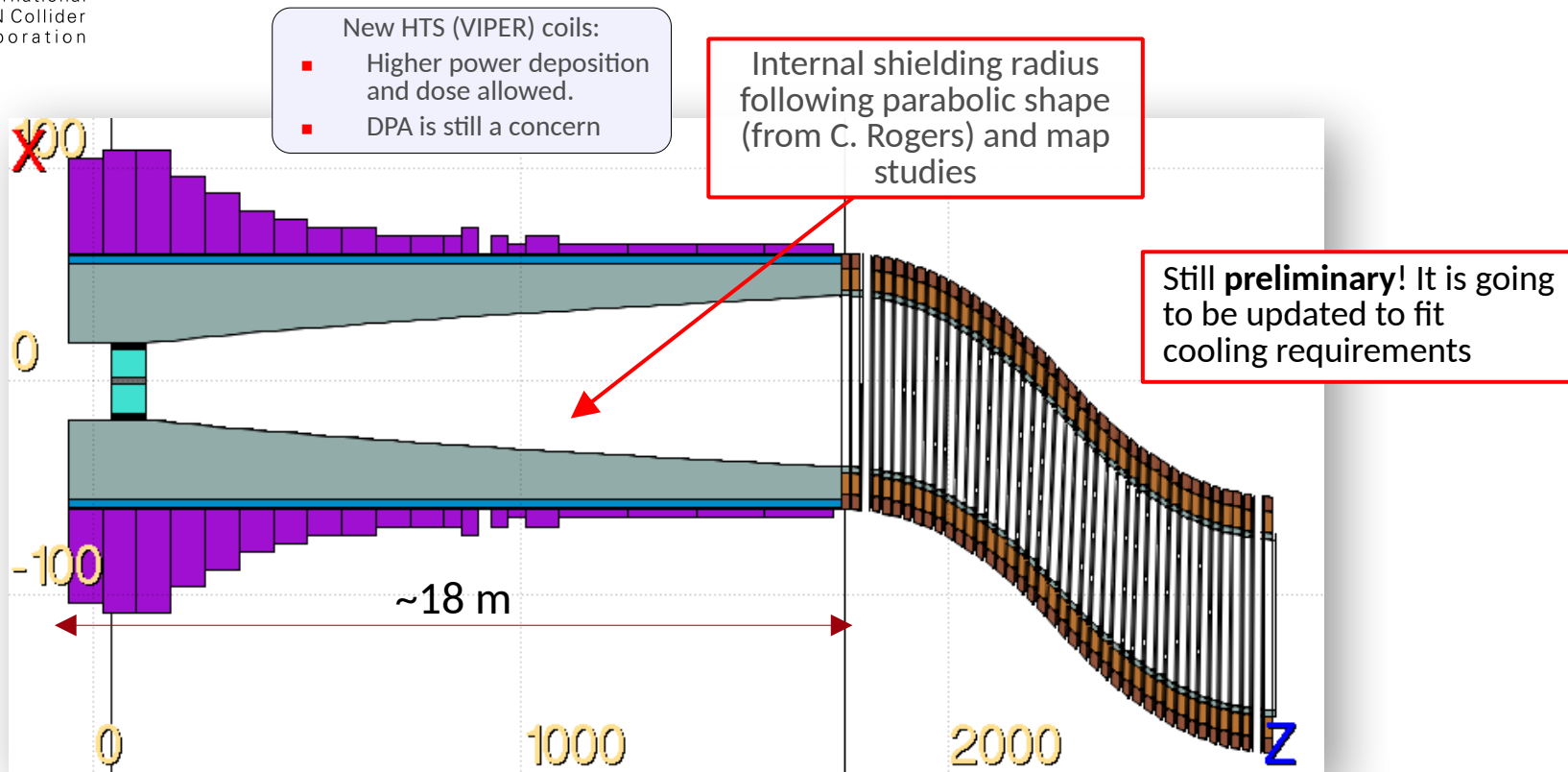
International MUON Collider Collaboration

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

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

1 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

~18 m

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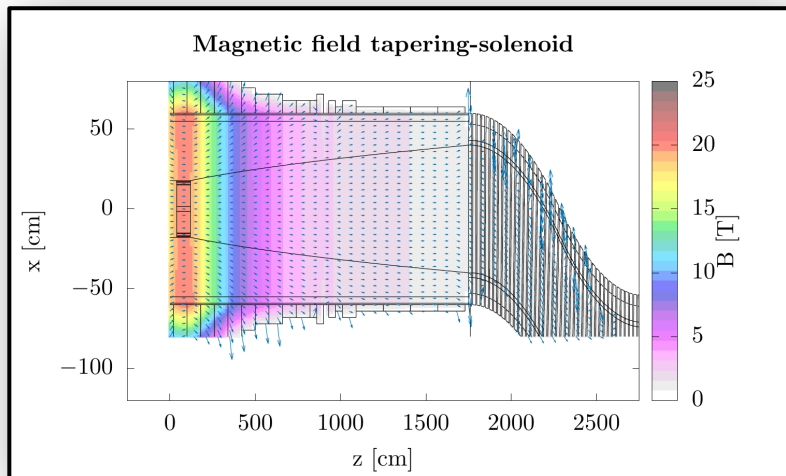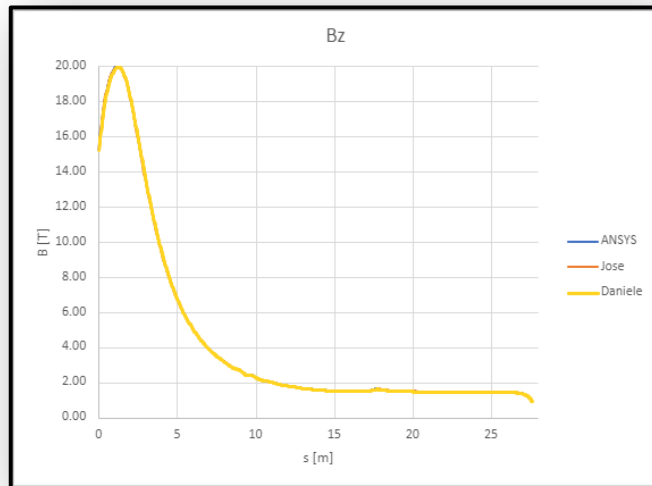
https://indico.cern.ch/event/1240042/

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.

■ Various injection angles can provide different point for the extraction
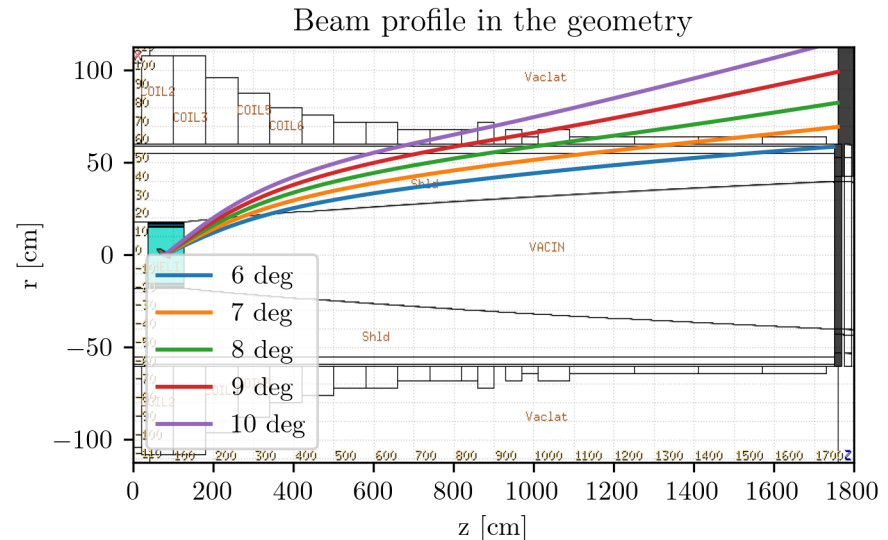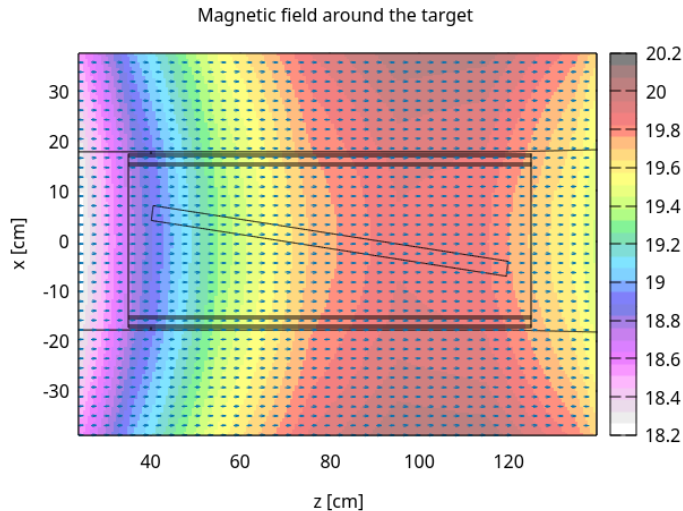
Magnetic field around the target

Beam profile in the geometry

6 deg
7 deg
8 deg
9 deg
10 deg

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.

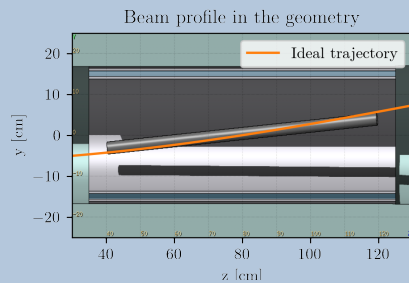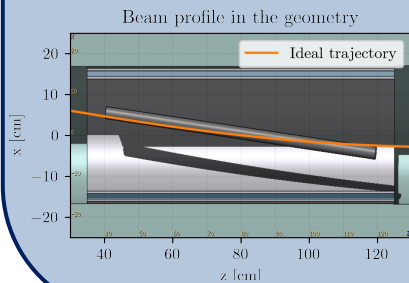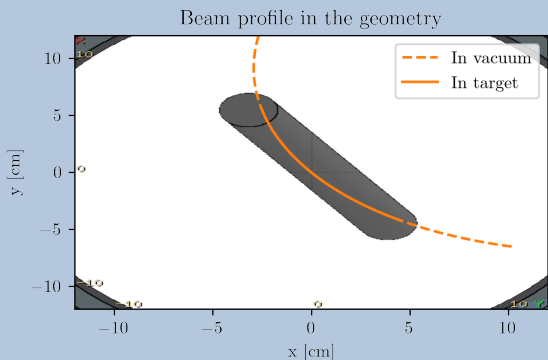Particle trajectory: max precision vs 1 cm stepsize

Beam profile in the geometry

The coil profile will need to be altered
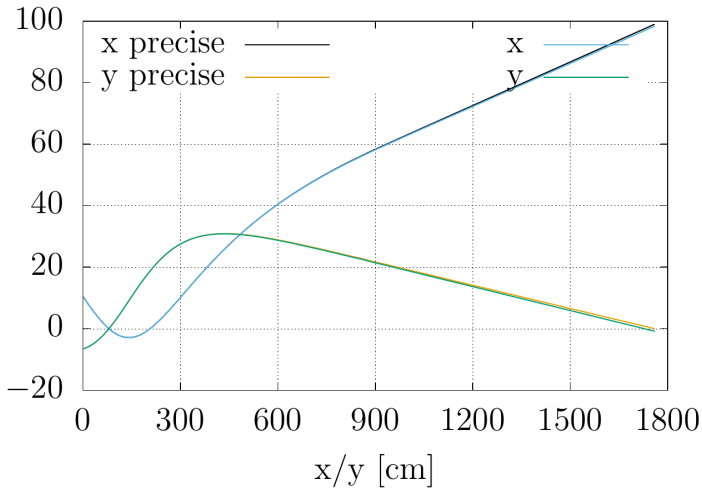
Target (graphite) tilted

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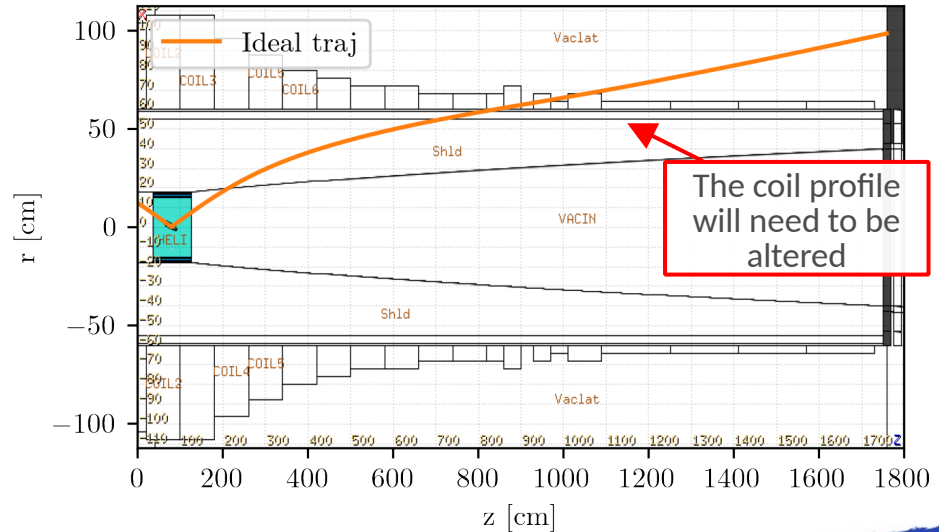
- With a tilted target, part of the beam is entering from the lateral side
  - Lower peak power
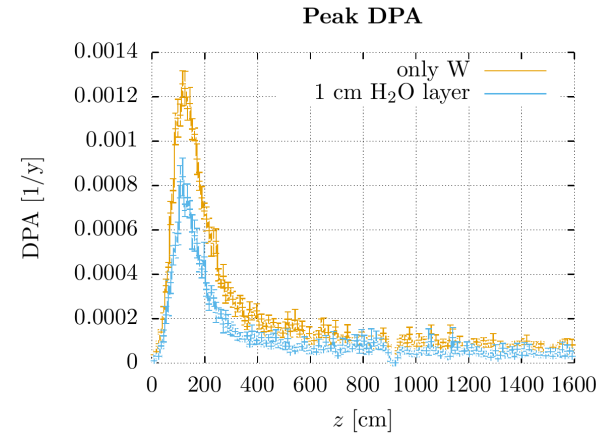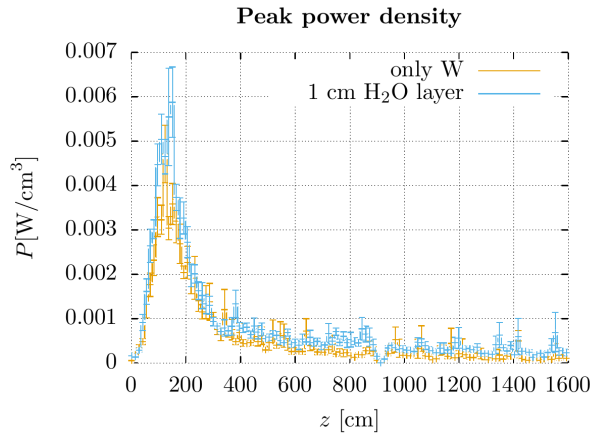 - Beam and target tilted with 9 deg inclination (useful for spent beam extraction)
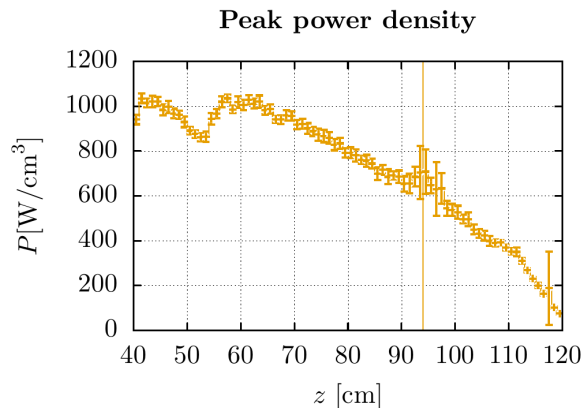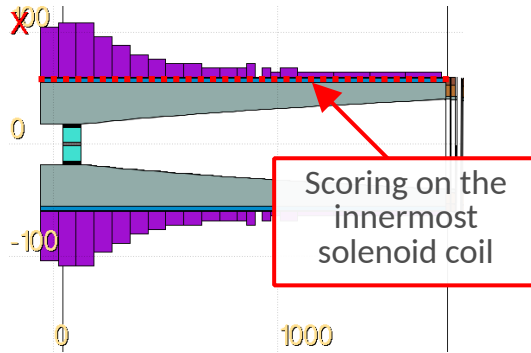

Peak power density

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

Scoring on the innermost solenoid coil

Peak power density

only W
1 cm H_2O layer

$P[W/cm^3]$

z [cm]

Peak DPA

only W
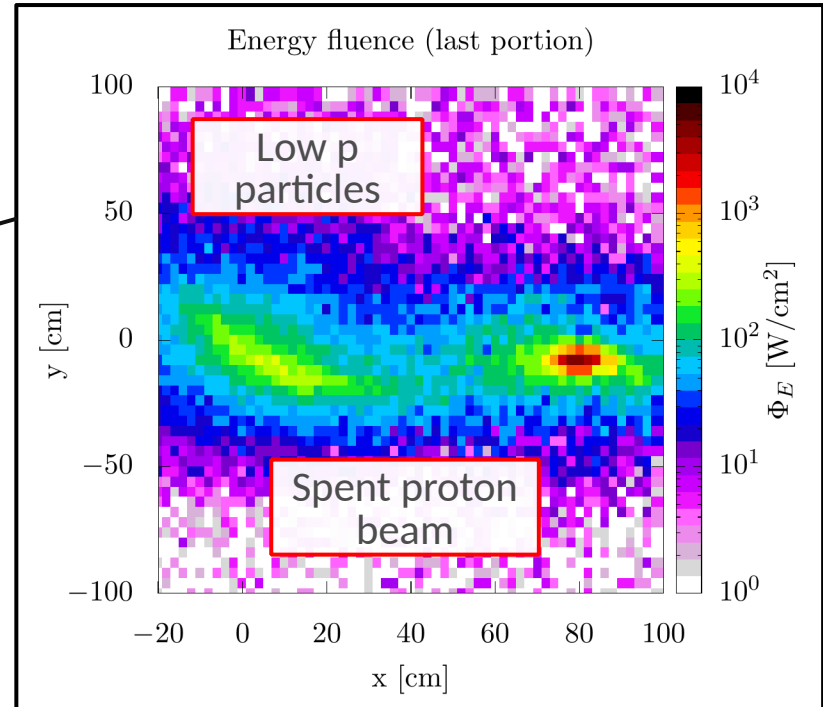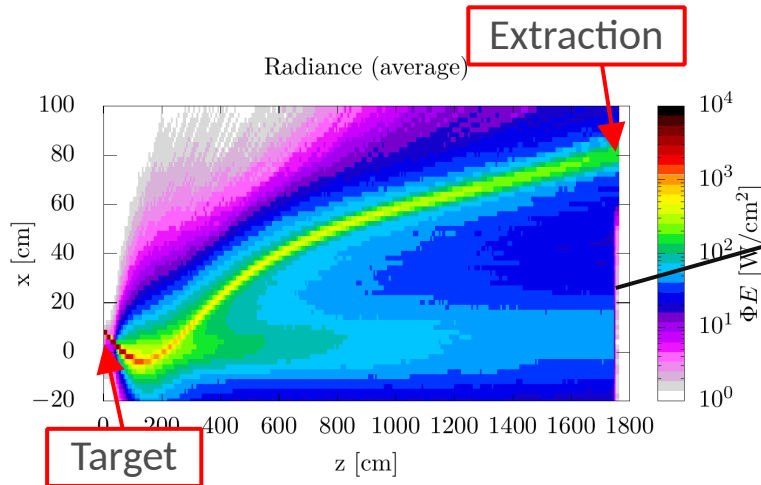1 cm H_2O layer

DPA [1/y]

z [cm]

- 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(?)

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.
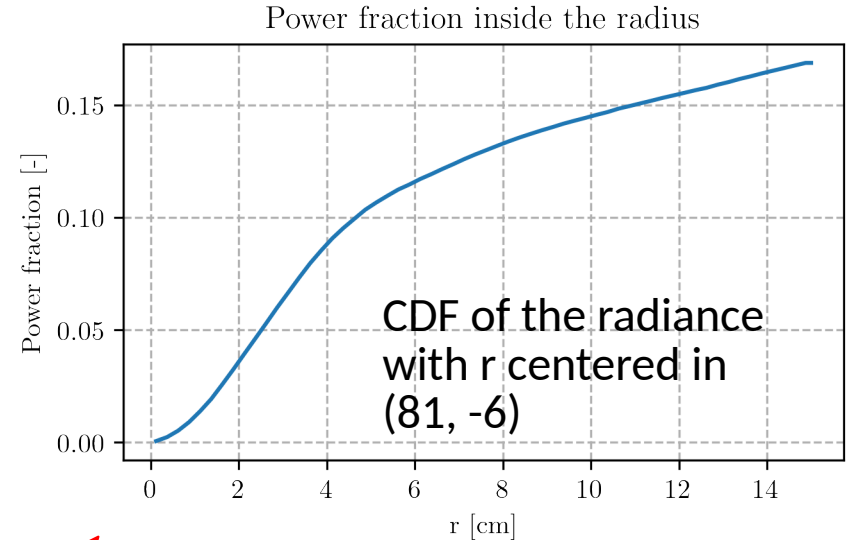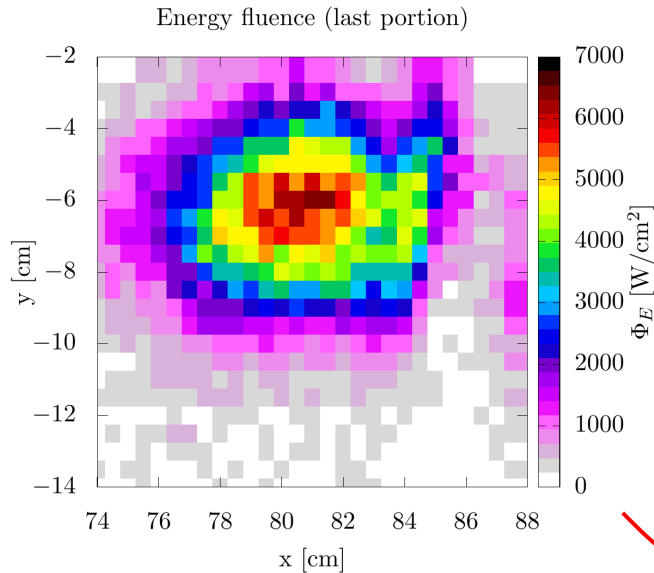

Radiance (average)

Extraction

Target

Energy fluence (last portion)

Low p particles

Spent proton 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)

Energy fluence (last portion)

Power fraction inside the radius

CDF of the radiance with r centered in (81, -6)

Conclusions

- The new geometry of the coils has been implemented in FLUKA. The past benchmarks show excellent agreement for the **magnetic field evalutation**

- 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.

- The effects on the magnetic field engineerability have to be assessed in the presence of an extraction channel and a beam dump.
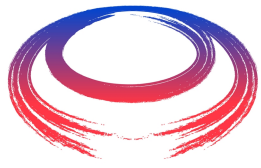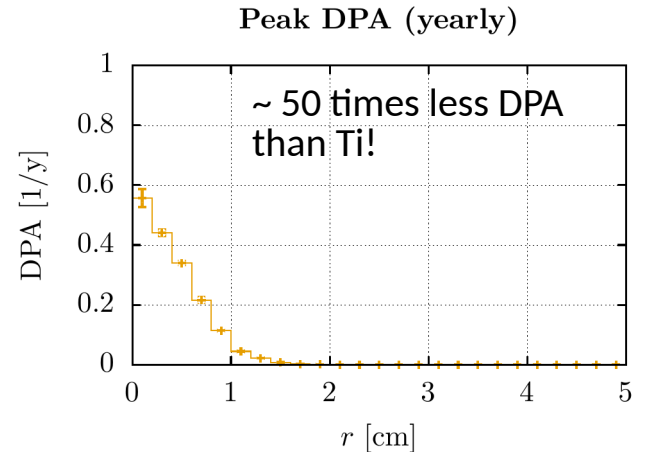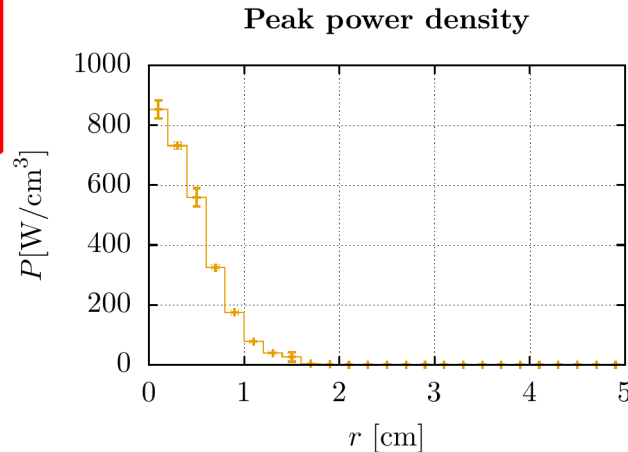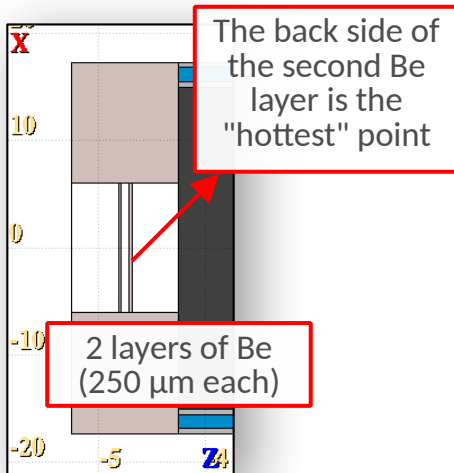
Thank you
for your attention!

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

The back side of the second Be layer is the "hottest" point

2 layers of Be (250 μm each)

Peak power density

Peak DPA (yearly)

~ 50 times less DPA than Ti!

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

Peak power density

Peak DPA (yearly)
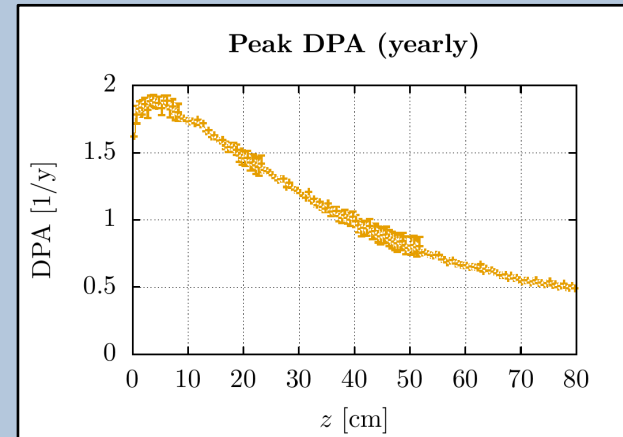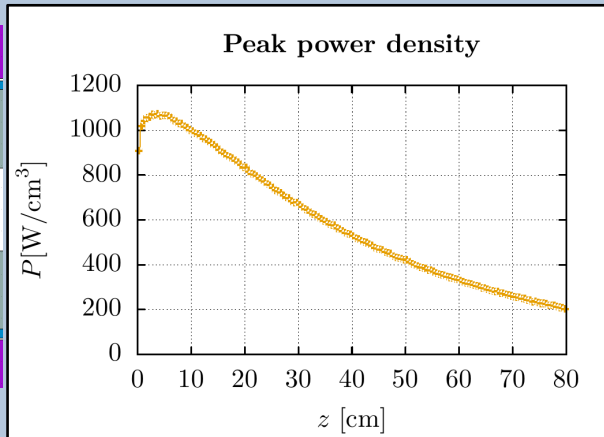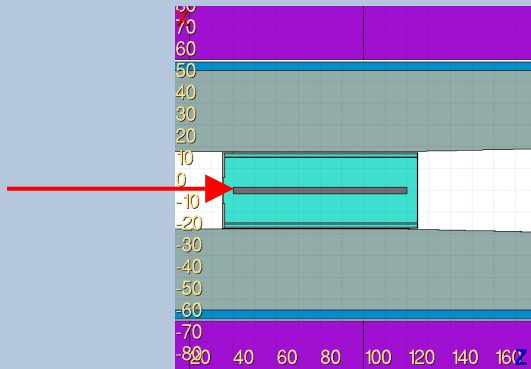
Muon yields

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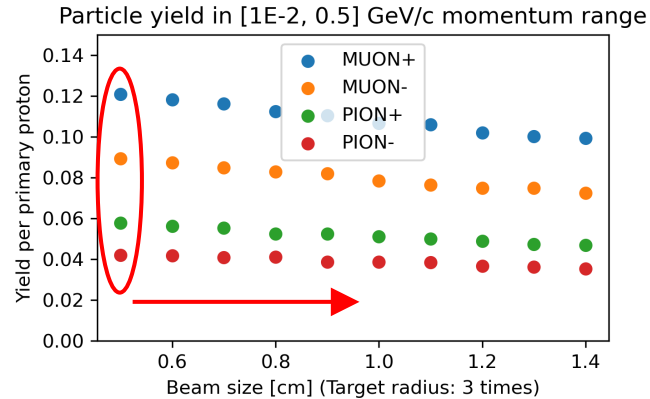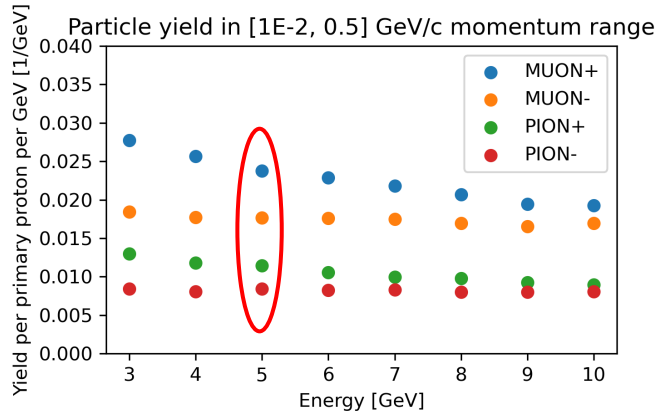
Could we consider larger beam spot sizes to simplify the window and target engineering?

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