IMCC Annual Meeting 2023 - Orsay

Design of the target system and shielding

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CERN – Systems Department, Sources Targets Interaction (STI), Targets Collimators Dumps (TCD)

2023/06/20

Outline

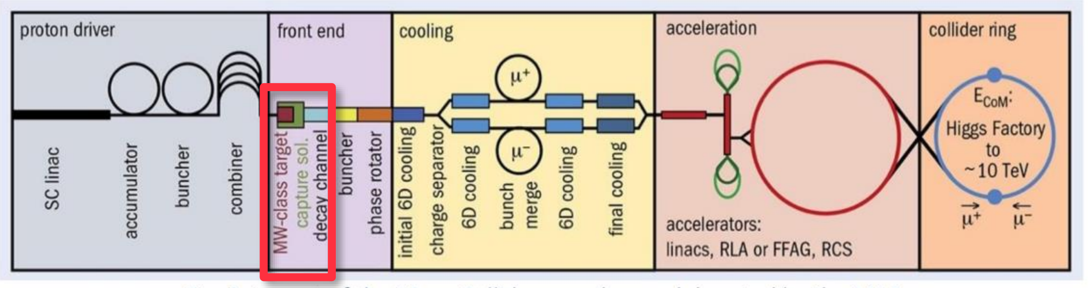


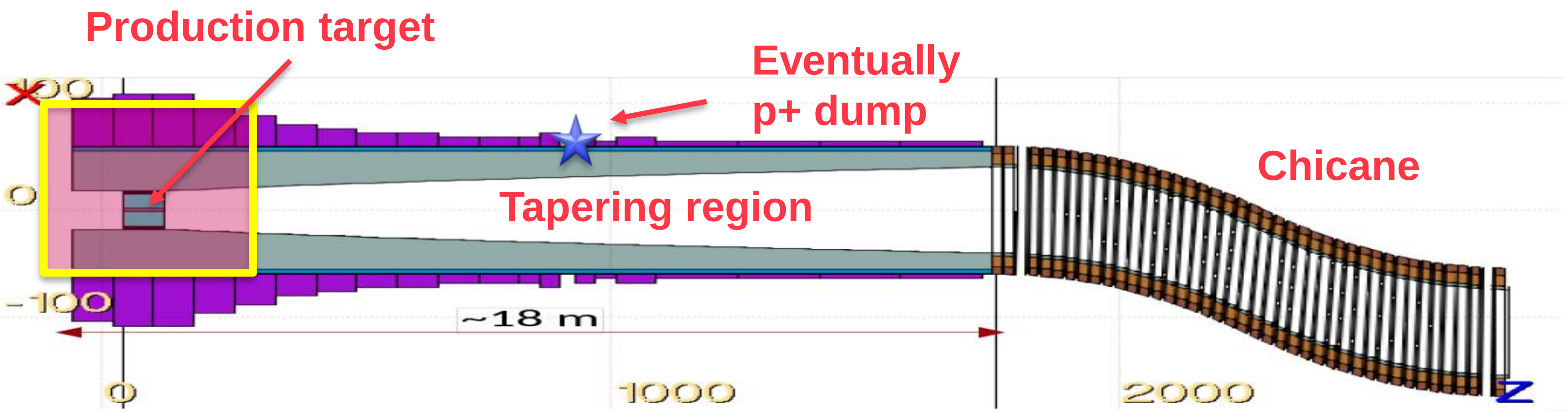
Fig. 2: Layout of the Muon Collider complex as elaborated by the MAP

WP4.2 - Target system development

- Establish a baseline target
- Identify technological limits and R&D.
- **Define a system conceptual design**
- Estimate pion yield, target lifetime, heat load on the surrounding magnets.
- Define the required shielding and associated magnet aperture

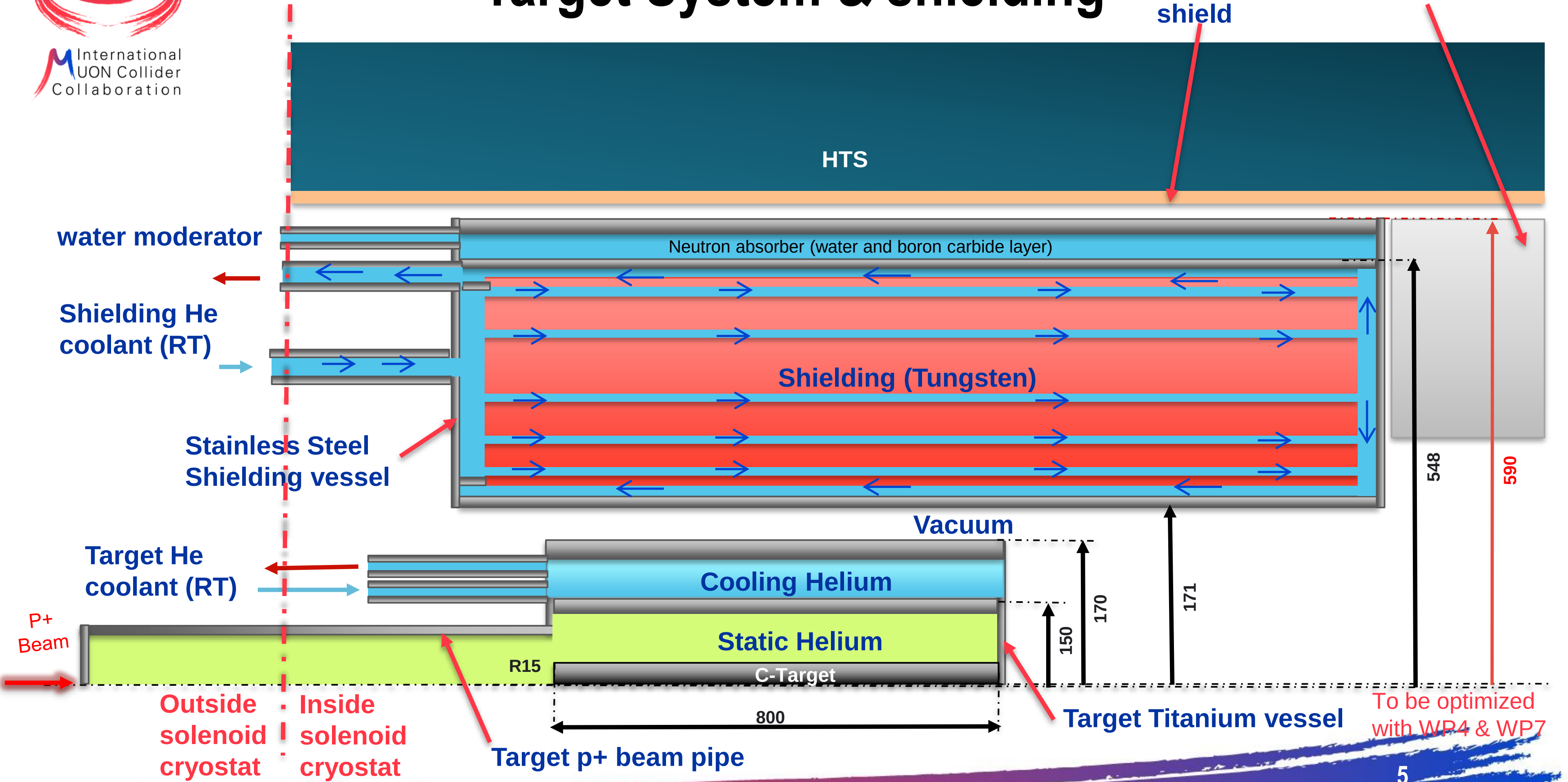
Carbon target & target systems considerations

- **Energy deposition & dpa studies** on the Target, windows, shielding, magnets, chicane
- Parameterization study in view of **pion/muon yield optimization**
- **Conceptual Engineering study** of Target & Target Systems, shielding, p+ dump -> feasibility
- **++ iteration loops with p+ driver, magnets, cooling**



TARGET SYSTEM & SHIELDING DESIGN & INTEGRATION

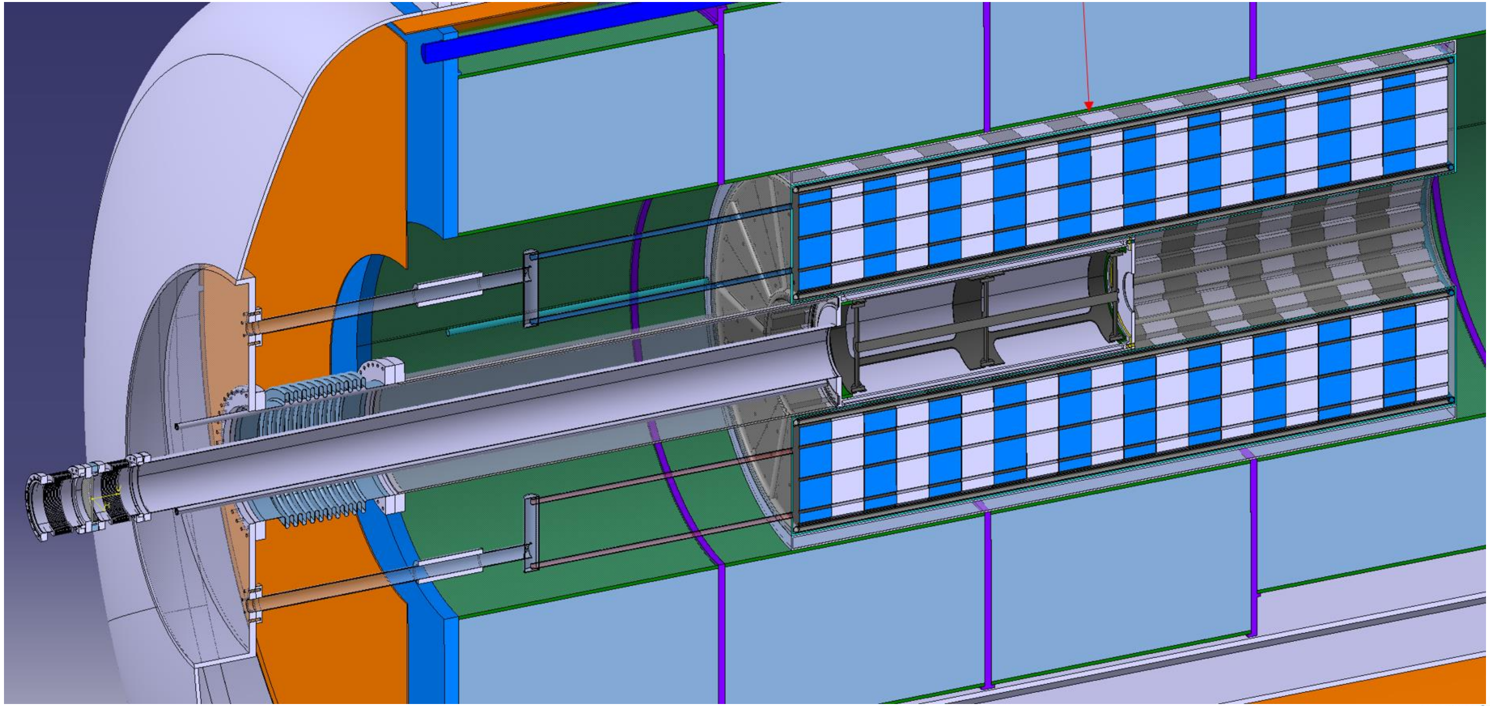
Target System & shielding



Carbon Target Systems

- Integration of Target System in cryostat*

*Solenoid cryostat design >> See Carlotta Accettura & Antti Kolehmainen presentation (WP7)



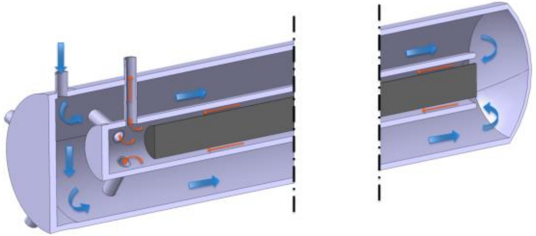
Carbon Target: engineering feasibility

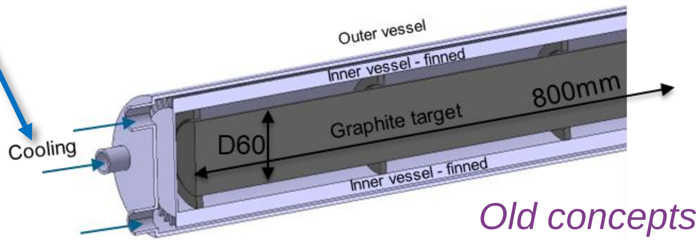
Direct cooling considerations

Temperature (°C)	sigma 5/5Hz – 1.5MW	
Only radiation	T max	2801
	T max surf	2240
Radiation + natural convection	T max	2768
	T max surf	2207
Radiation +Forced convection (He, 20 bar, 0.1 kg/s)	T max	573
	T max surf	278

*Maximum temperature and power deposition for **1.5 MW** as function of the beam sigma.*

T peak (°C)	Transient				Steady state	Power deposited
σ_{beam} (mm)	5 Hz	10 Hz	20 Hz	50 Hz	Average	(W)
1	4301	3908	3735	3641	3583	44832
2	331[illegible]	3221	3177	3152	3135	59000
5	2740	2721	2713	2708	2704	90632
10	2305	2297	2293	2290	2288	129207
15	1947	1943	1940	1938	1938	163214



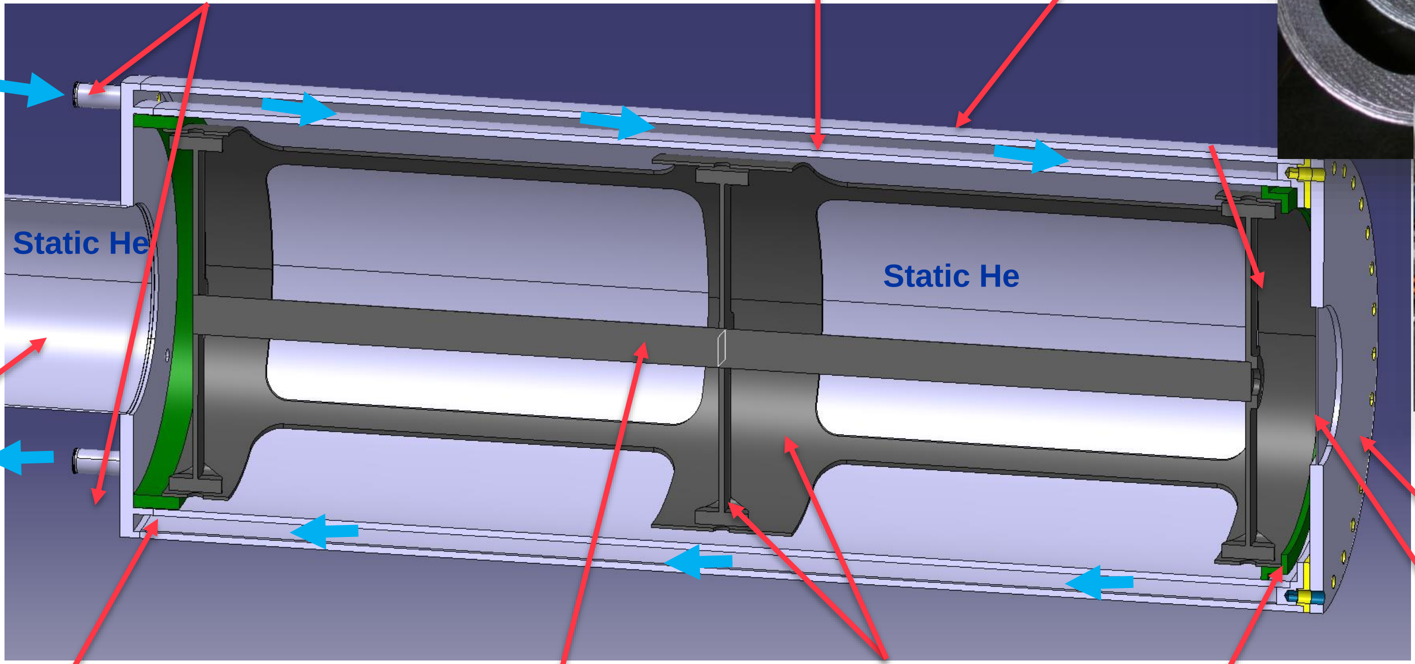


Old concepts

Target Cooling

- Due to high T and sublimation of graphite, an enclosed 'pressurized' atmosphere is required.
- However, active cooling can be made indirectly. Heat dissipation mostly via radiation and natural convection. → target confinement / separation of cooling system is advantageous (maintenance, RP, disposal, cooling services requirements).

Carbon target

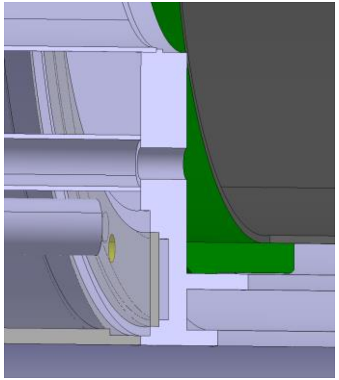


CERN's CNGS Target

Carbon target

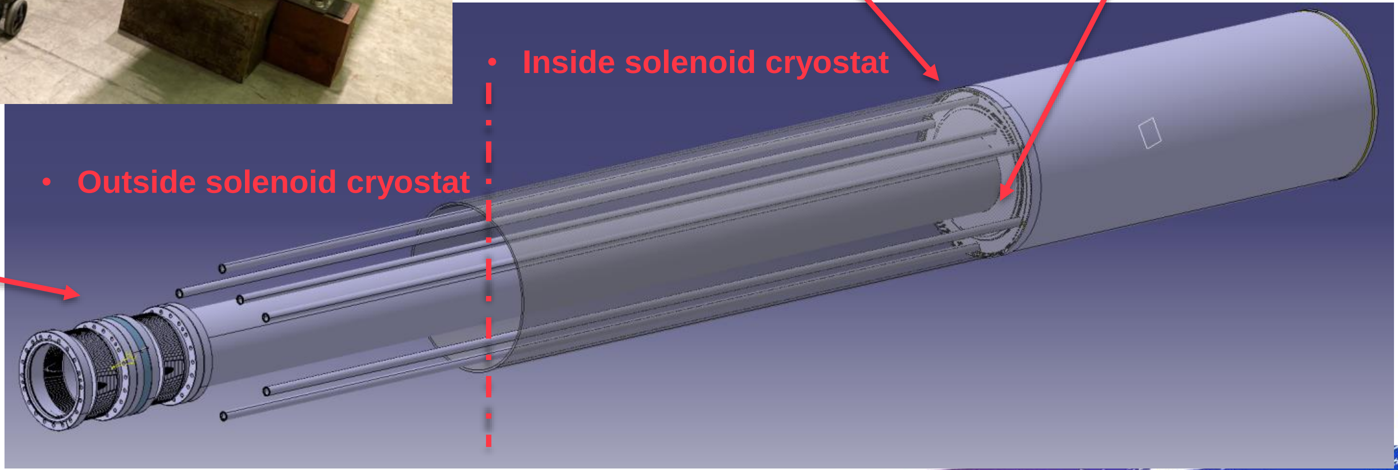
Look-alike services routing at CERN's SPS internal dump (TIDVG5)

- Target cooling system routed upstream.
- Either contained in outer tube or "free"



- All welded connections, except downstream target flange
- Plenum for He distribution

- P+ window outside cryostat assembly
- More accessibility for maintenance, replacement, etc



Beam windows

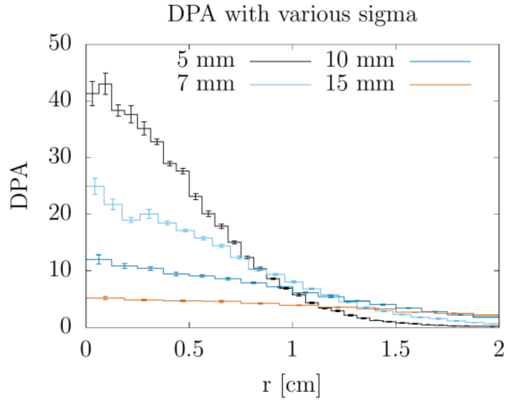
Carbon Target

For these beam parameters, C-Target seems feasible.

However, for the **p+ beam window** :

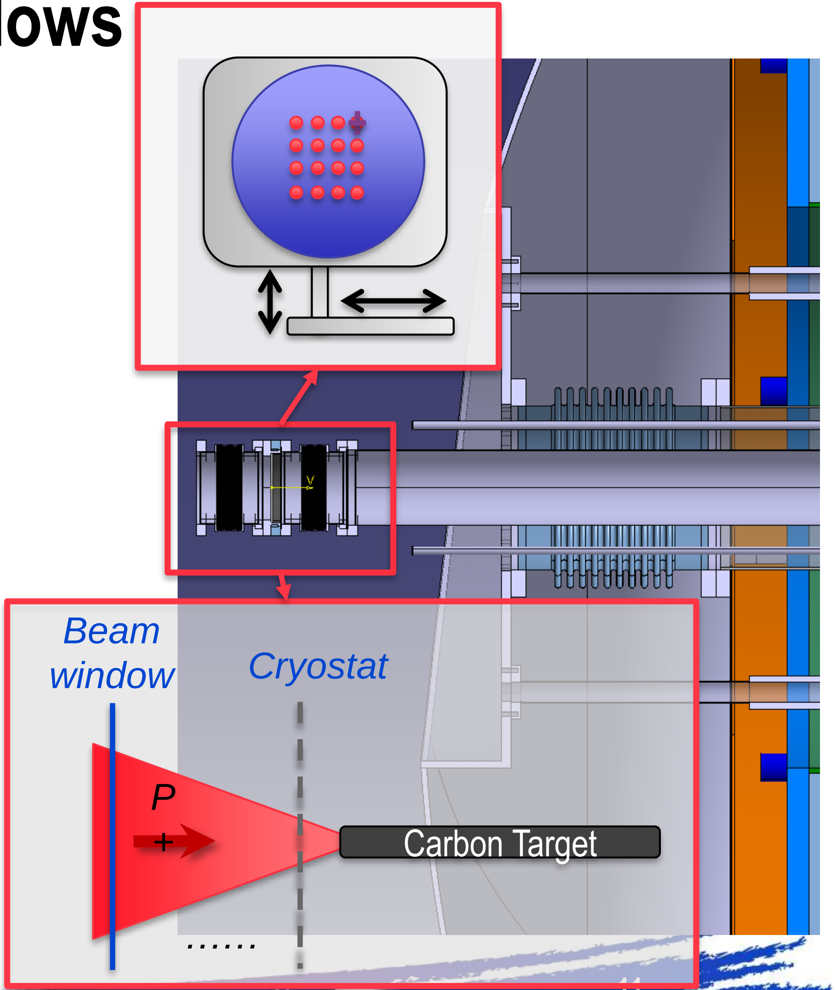
- **Fatigue**: extensive load cycles to be experienced by the target & windows (10^8 /y) at very high temperature.
- **DPA**: >>1 dpa levels on the beam windows.
  - Possible strategies: windowless, blown-up beam somewhere upstream, dual bunch, rotating window "dilution", frequent window exchange.
- **High power deposition:** 50-650 W (0.1 – 1 mm)

DPA on proton beam window.
Ti, 2 MW, 200 days of operation



DPA on proton beam window.
Be, 2 MW, 200 days of operation is approximately 50x lower! Work on going

Beam windows



P+window

Location:

- P+ window outside cryostat assembly
- More accessibility for maintenance, replacement, etc

Beam dilution

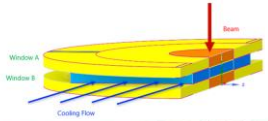
- Mechanical dilution (window moves periodically)
- Beam position change
- Wide beam spot size. How much is reasonable?
- Multi bunch pulse?

Materials

- Low density. Be, Al, Glassy Carbon?
- Radiation damage robustness. Inconel 718 ?

Cooling

- Dedicated, shared with Target?



Target Shielding

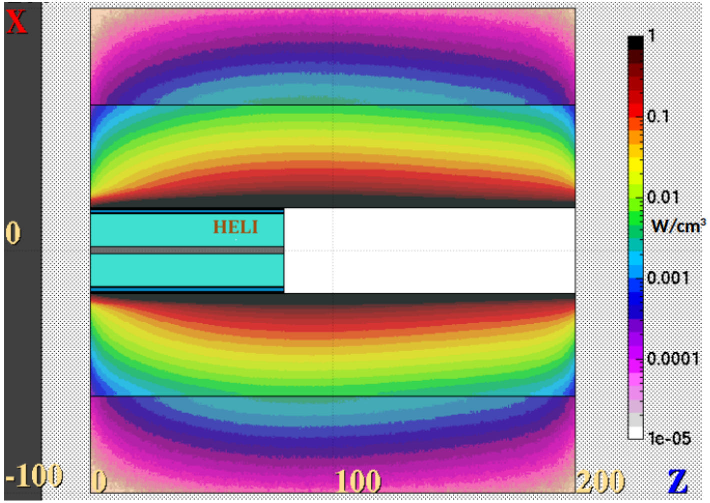
Energy deposition

- The energy deposited on the target is only 5.6 % (D30xL800 mm) of the total beam power
- Most of the thermal energy is deposited on the shielding (33.7 %).

2 MW Beam power

Parameter	Thermal power	% of Beam Power
Shielding	**674 kW**	**33.7 %**
Target	**111 kW**	**5.6 %**
Ti Vessel	24 kW	1.2 %
Water*	11 kW	0.6 %
Helium**	~0 kW	~0 %
TOTAL	~820 kW	~41 %

*New baseline is He cooled Target
**He coolant of the shielding



Power deposition provided by Daniele Calzolari SY-STI-BMI
https://indico.cern.ch/event/1176034/contributions/4939053

Target Shielding

Shielding water cooled

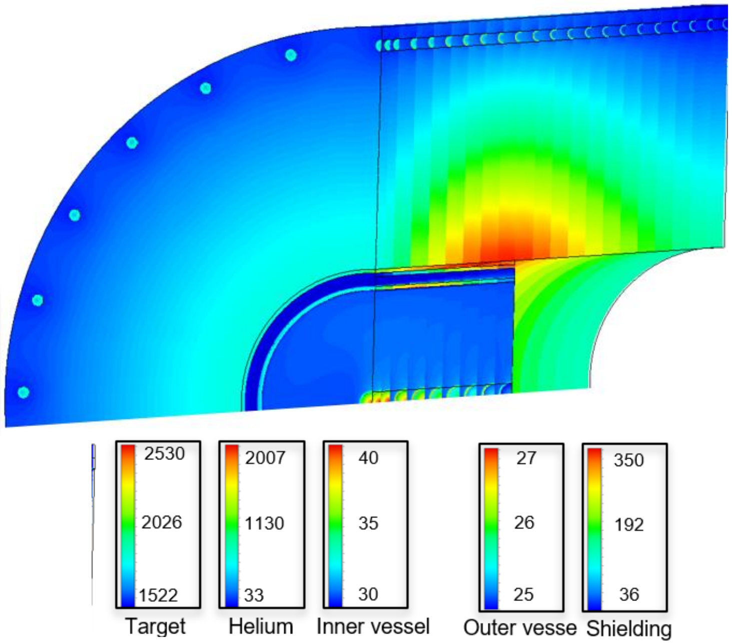
- Cooling of the shielding is required but not a showstopper

Example of reasonable parameters: (1.5MW, initially study)

Target
- Annular RT water @ 3m/s
- Max T = 2530 °C
- Al vessel max T: of = 40 °C

Shielding
- 26 pipes w/ RT water @ 3m/s
- max T = 350 °C
- External max T = 80 °C

Water cooled



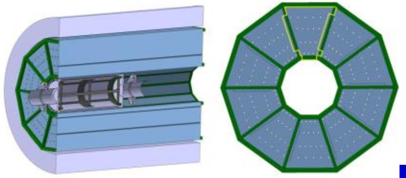
1.5 MW (initially assessment)

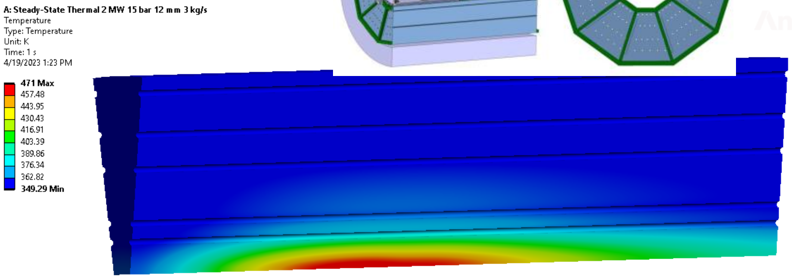
Challenges

- Radiolysis
- Pressure bursts during pulse
- Requirement of corrosion-erosion protection of W

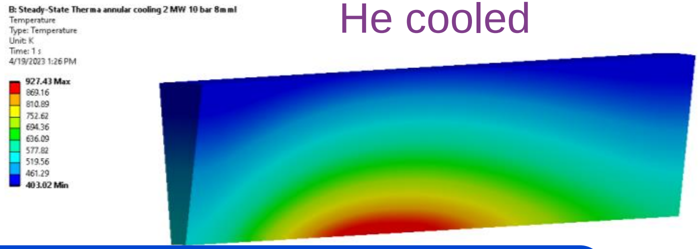
Target Shielding

Shielding He cooled: Feasible for 2 MW





Shielding "pie slices" + He via holes
- He (gas cooled, 3-5kg/s at few bar)
- Frame with 40 mm square SS profiles
- Temperatures below 100 °C



He cooled

Shielding "pie slices" + He in outer Diameter
- He (gas cooled, 3-5kg/s at few bar)
- Frame with 40 mm square SS profiles
- Temperatures 150 – 750 °C

Shielding "donuts" + He in pipes & outer Diameter
- 150x D5mm pipes; 0.0022 kg/s/pipe; 10 bar; Mach 0.1 (high HTC); 570 C max W temperature.

Tunning cooling parameters (HTC, pressure drop, speed, mass flow)

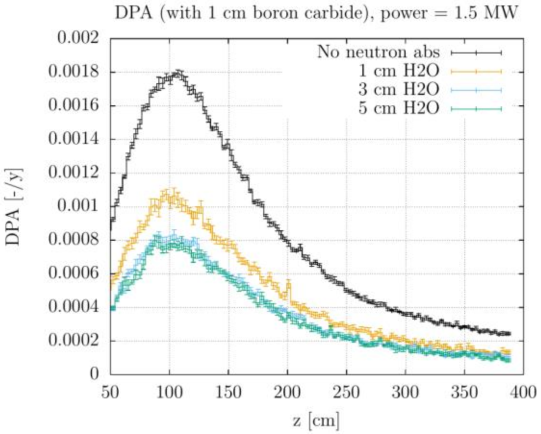
>> See Francisco Esteban presentation tomorrow

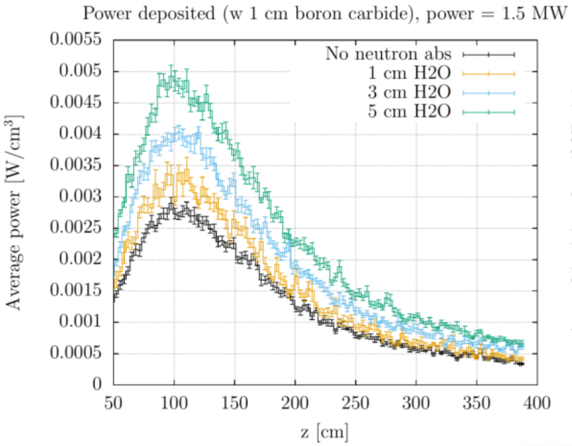
Target Shielding

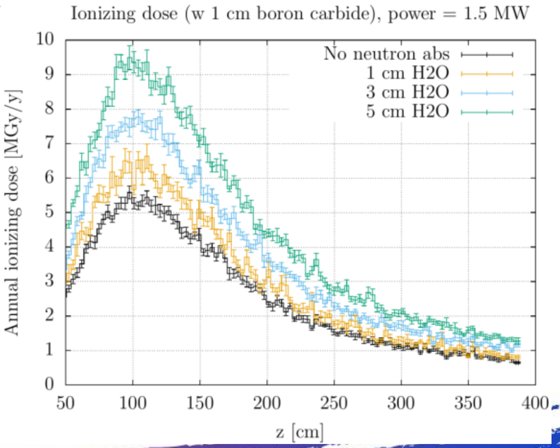
Possible optimization to reduce radiation damage in HTS coils:

- With neutron absorber, DPA reaches values of 8×10^{-4} DPA after 1 year
- However, due to less W the Ionizing dose increases: >70 MGy after 10 years (3 cm H2O)

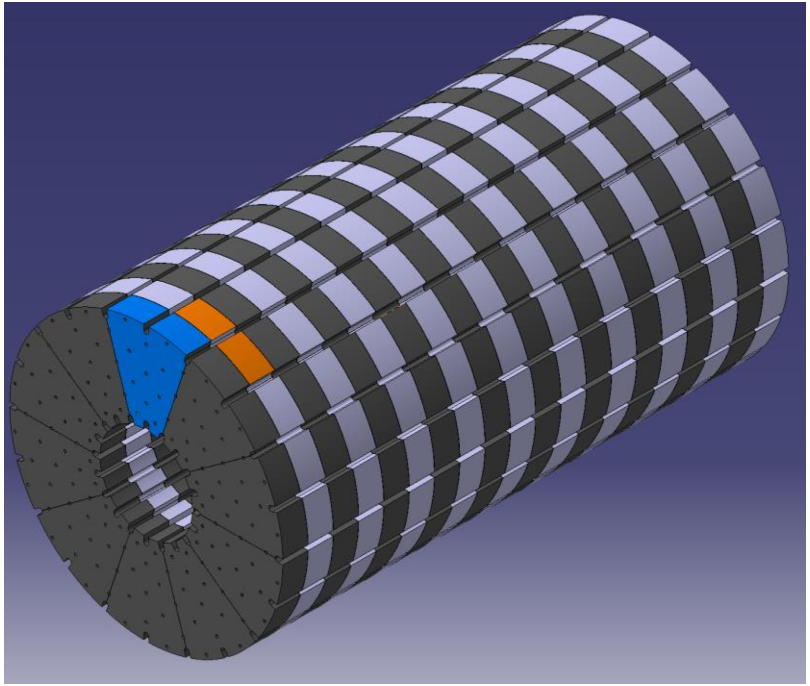
1.5 MW (initially assessment)





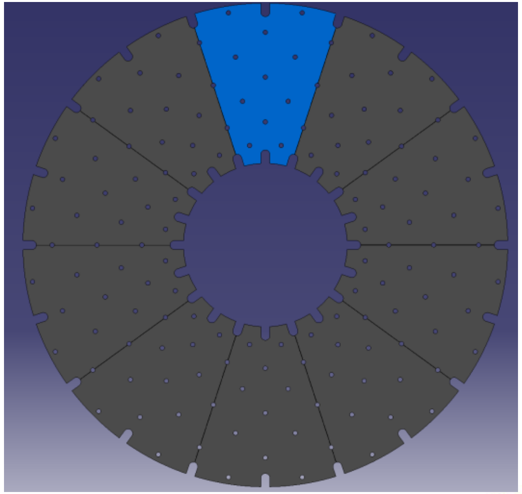


Target Shielding



Considerations

- Material choice (W, W heavy alloys)
- Manufacturing & machining
- Handling
- Integration of cooling system
- Shielding assembly

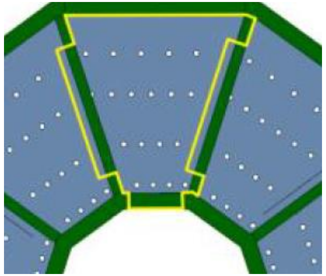


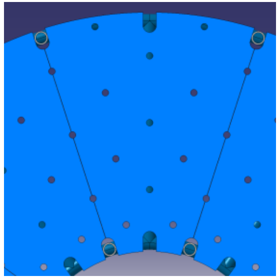
Conceptual Design

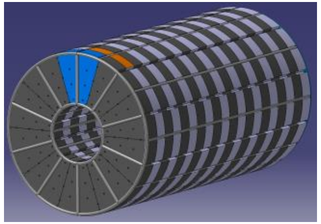
- Donut + Pie blocks due to manufacturing limitations & to ease assembling.
- Inner holes for bulk cooling. Return circuit on the outer radius.
- Longitudinal slots for locking & alignment pins.

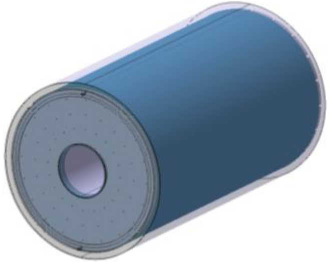
...

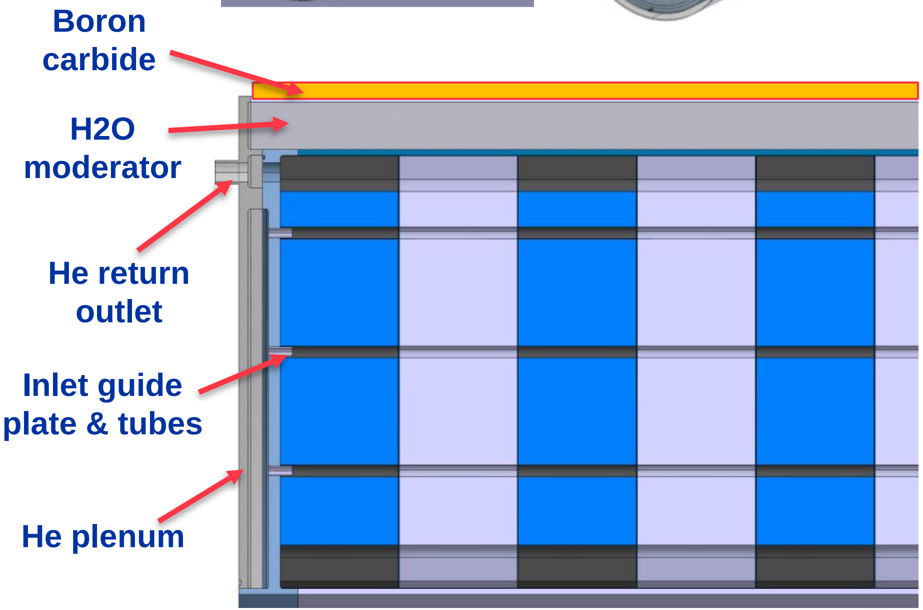
Target Shielding











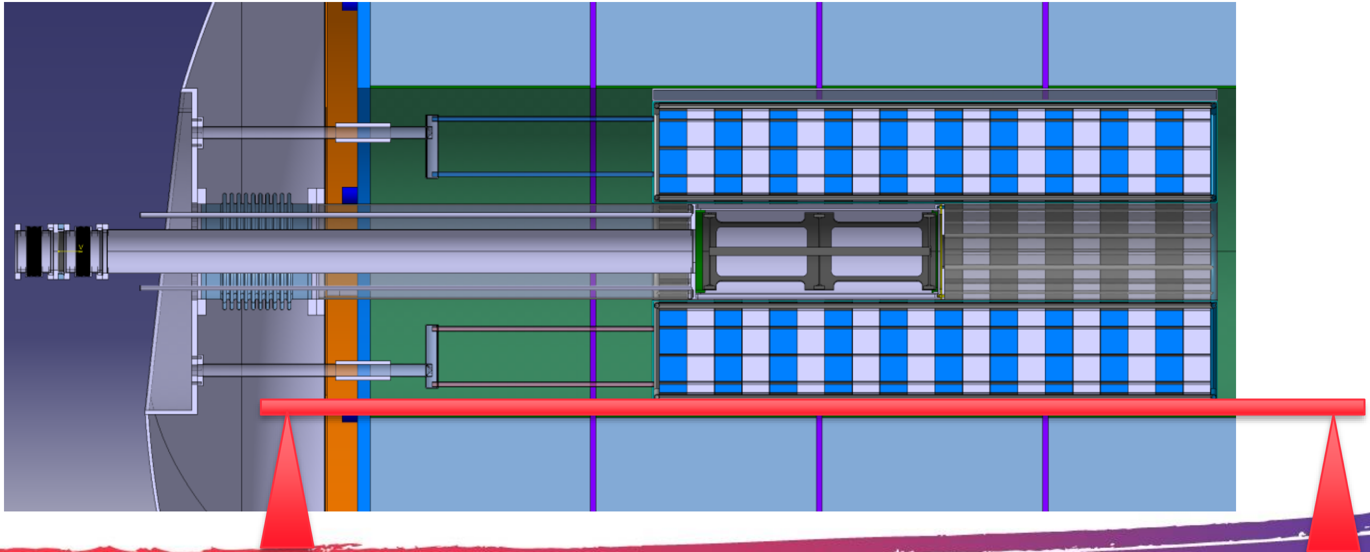
Conceptual Design

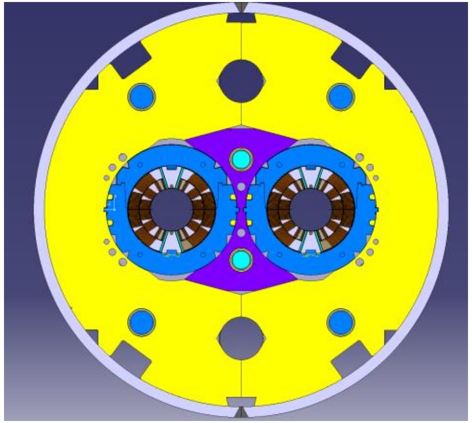
- Holding the assembly (23 tonnes).
  - Self-holding assembly, e.g. puzzle-like shape.
  - Alignment pins & structural rods
- He distribution
- Water moderator & neutron absorber

Target Shielding

Shielding vessel

- Two half-shells pressed and welded; Loose fitting seamless/welded, other..
- Shielding (vessel) supported via structural beam+ feet at the extremities of the cryostat. Avoid mechanical and thermal load on the solenoid





e.g. 11 tesla magnets pressed + welded half-shells

Conclusions

- Main objective is to have a high-level design, integrated with WP3 and pinpoint key design, manufacturing and integration directions. Potentially identify key constrains and limitations of the whole assembly and possible prototyping directions.
- Conceptual 3D design of the target systems & integration in the solenoid cryostat just started.
  - Mostly de-coupled Target and shielding assemblies
  - Services routed upstream. Fine integration of connections with the cryostat vessel is required
  - Target assembly with p+ beam window outside cryostat for easier maintenance/replacement & possibly to allow implementing a solution for the high yearly radiation damage & thermal power during operation.
- Integration of P+ dump to be addressed.

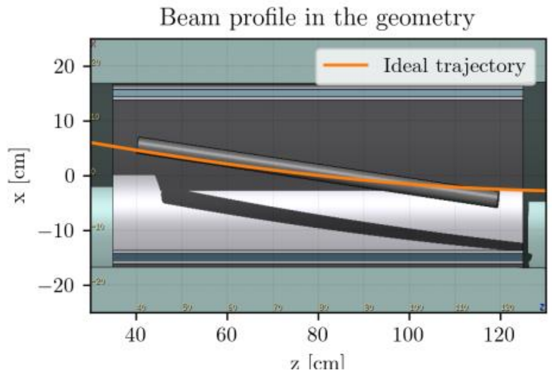
International
MUON Collider
Collaboration

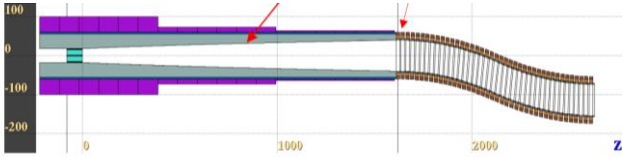
CERN

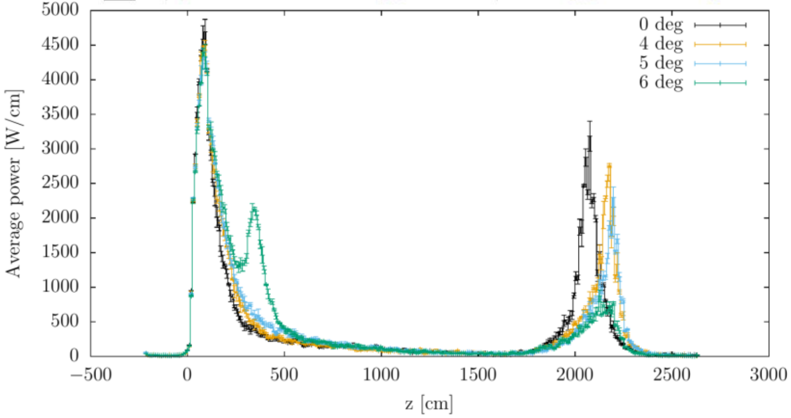
Thank you very much for your attention

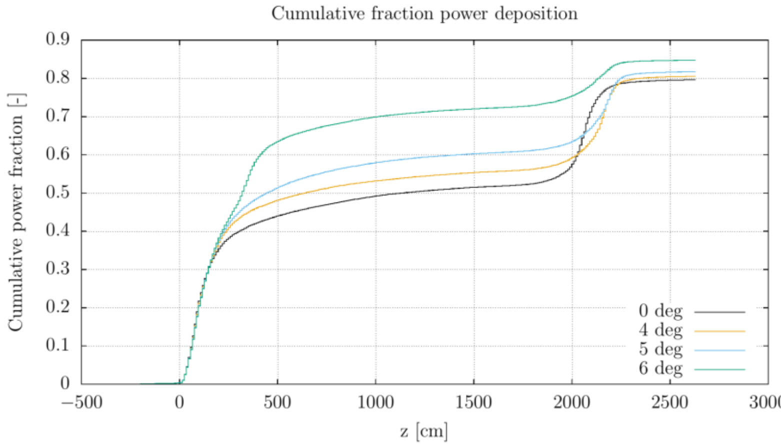
Proton dump beam extraction

- Extraction in the chicane is very challenging.
- Tilted beam required to extract in the tapering region



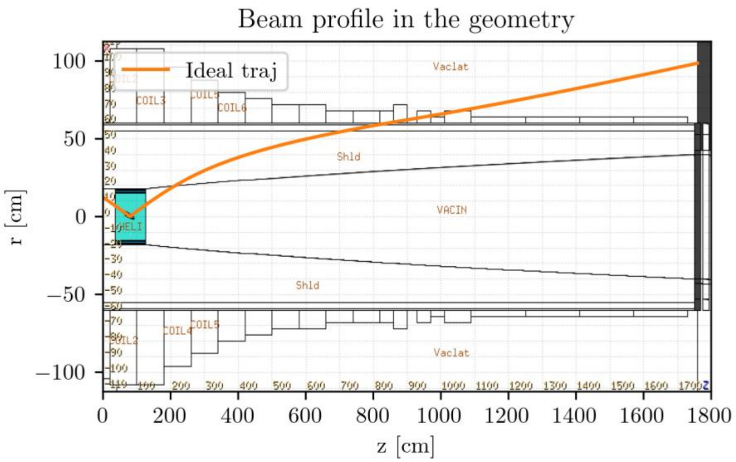


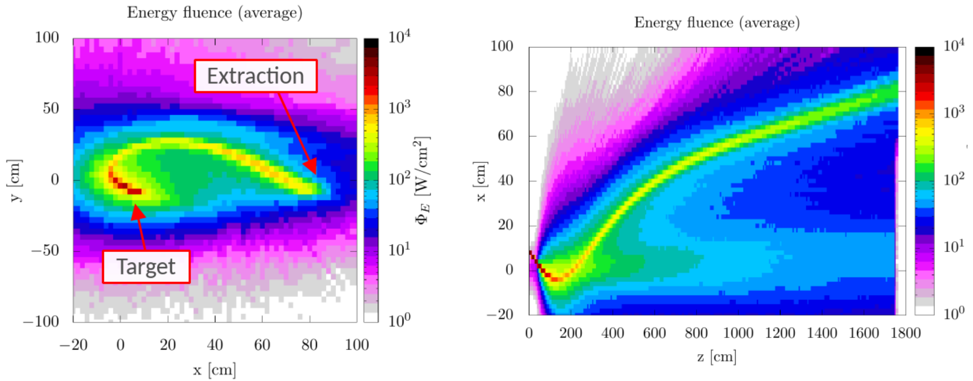




Proton dump beam extraction

- ➢ 9 deg angle to extract before chicane.
- ❑ Integration with the magnets to be done (~10x10cm aperture)
- ❑ Target response to be checked





Particle fluence profile (axial direction & transverse direction)

by Daniele Calzolari
https://indico.cern.ch/event/1256505/contributions/5277355/

Conclusions

- Interaction between different groups (proton driver, magnets, target, muon cooling, service groups) is key for efficient feasibility studies and optimization.
- Possible to select range of beam parameters compatible with C-Target (both thermally and structurally). Pion/muon yield near optimal range following parametric study.
- Fatigue and radiation damage will be a major challenge of a solid target and of the beam windows. Topic to be discussed in the framework of the RaDIATE Collaboration
- Shielding design highly coupled with Target/solenoid design and respective radiation damage limitations. (O)700kW cooling needs for 2 MW facility.
- P+ dump required. Challenging integration.
- Feasibility of liquid lead target being studied (ongoing collaboration between CERN-STI & ENEA). Alternative for > 2MW range operation, but with challenges to be addressed.
- W powder target studies to ramp-up, built on current experience at RAL.

Prospects

- Develop the conceptual design of the target systems (Target, Shielding, cooling, etc) and its integration in the solenoid cryostat.
- Address the high levels of dpa in the proton window & cooling needs.
- Assess the mechanical response of the target vessel and shielding assembly.
- Continue interaction/iterations with WP7 & WP3.
- Carry-on the required energy & dpa studies through the target complex & provide pion/muon yield calculations to the cooling team.
- Continue the development of the liquid Pb curtain target
- Ramp-up fluidized W target studies