TARGET SYSTEMS AT THE FRONT END OF THE INTERNATIONAL MUON COLLIDER

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International Muon Collider Collaboration

ID91

Introduction

- Muon colliders offer enormous potential for research of the particle physics frontier. Leptons can be accelerated without suffering large synchrotron radiation losses.
- In the core of the **Muon Collider facility** lays a **MW class production target**, which will absorb a high power (**1 to 3 MW**) proton beam to **produce muons** via pion decay.
- The target must withstand **high dynamic thermal loads** induced by 2 ns pulses at 5-50 Hz. Also, **operational reliability** must be guaranteed to reduce target exchanges to a minimum.
- **Different target technologies** with different levels of technological maturity are being explored.
- **An overview of the different target** technologies is presented, as well as details about the **target-systems engineering design for a C-Target** option.

Pb-Liquid Target

Opportunities

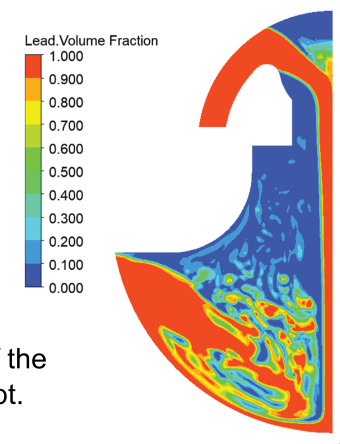
- **Known** liquid-Pb / LBE **thermo-hydraulics**
- **Cooling** outside vacuum chamber.
- **Radioisotopes** mostly **retained.**
- **No degradation** of target material.
- **Synergies** between different projects at CERN such as **FCCee**.

Challenges

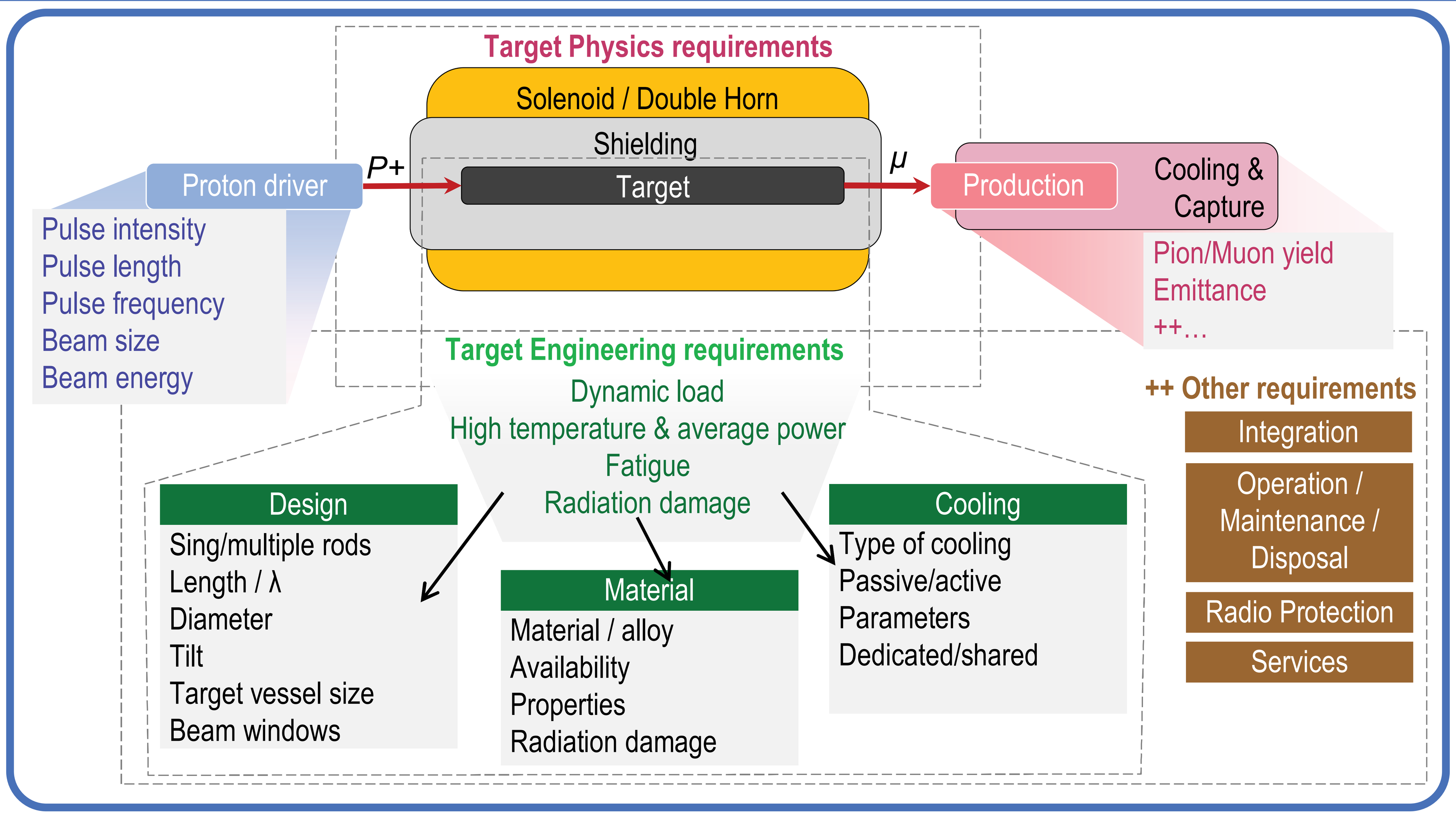
- Liquid-Pb containment **vessel and windows** (material, temperatures, DPA).
- **MHD** interaction.
- Cavitation-induced **erosion.**
- **Temperature and dynamic effects.**
- Dynamic multi-phase flow **simulation complexity.**

Conceptual designs

- Pipe flow.
- **Vertical curtain.**
- Jet stream.



CFD modelling of the Pb curtain concept.



W-Fluidized Target

Advantages

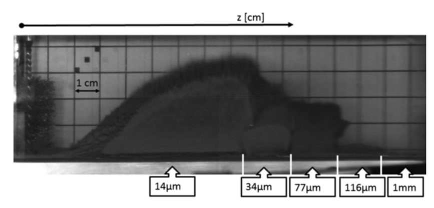
- **No cavitation, corrosion, radiochemistry damage.**
- High **thermal-shock resistance.**
- **Heat removal.**

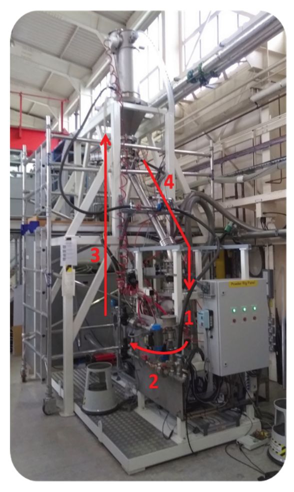
Challenges

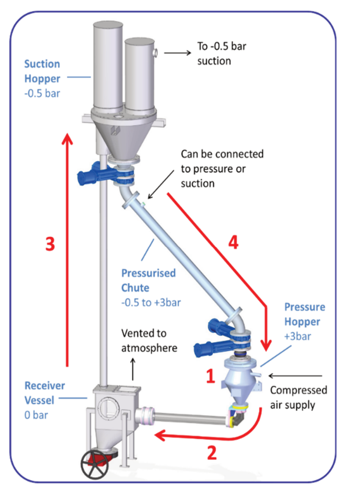
- **Erosion** management & powder **handling.**
- Reduced **experience** in operational facilities

Offline tests at RAL & HiRadMat beam test

Response of various size spherical tungsten particles to $2x10^{11}$ p+ at HiRadMat (CERN)



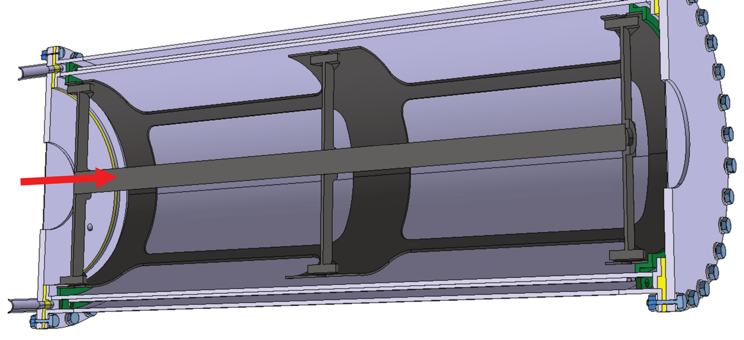




Test rig built and operated at Rutherford Appleton Laboratory from 2009-2018

C-Target

Target Concept



- **Based on the CNGS target**, which operated up to 520 kW but could operate up to 750 kW.
- **80 cm isostatic graphite** rod (1.79 nuclear inelastic scattering lengths).
- Internal **Titanium vessel filled with static helium** (1 bar) to enhance natural convection and minimize graphite sublimation.
- Cooling water flowing between internal and external vessel.
- **Water cooled tungsten shielding**.
- The whole assembly will be surrounded by a superconductive solenoid.

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	3318	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

Maximum temperature and power deposition for 1.5 MW as function of the beam sigma. Thermal simulations run in ANSYS Mechanical for a radiation-only cooled target (No natural convection around the target).

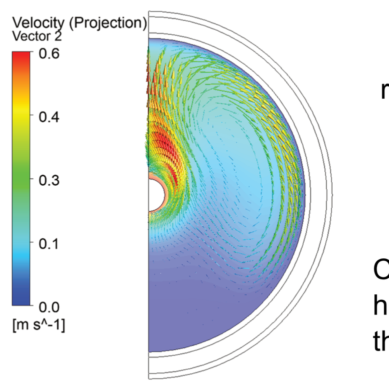
Fluka Monte Carlo & Thermodynamic Parametric Analysis

- Parametric study on **beam sigma** and pulse **frequency**.
- Rod radius kept proportional to three times the beam sigma.
- Considered the **worst-case scenario**: only radiation cooling (No natural convection around the target).

Proton driver beam parameters				
Parameter	**Symbol**	**Unit**	**Baseline**	**Range**
Beam power	P	MW	2	1.5 - 3.0
Beam energy	E_{target}	GeV	5	2 - 10
Pulse frequency	-	Hz	5	5 - 50
Pulse intensity	n_p	10^{14} protons	5	3.7 - 7.5
Bunches per pulse	-	Number	1	1
Pulse length	σ_z	ns	2	1 - 2
Beam size	σ_x	mm	5	1 - 15
Impinging angle	-	degree	0.0	0.0 - 10

Cooling assessment via CFD

- Cooling & design optimization via CFD.
- Target vessel cooled by Helium at 3 m/s.
- Heat from graphite diffused by radiation +natural convection.

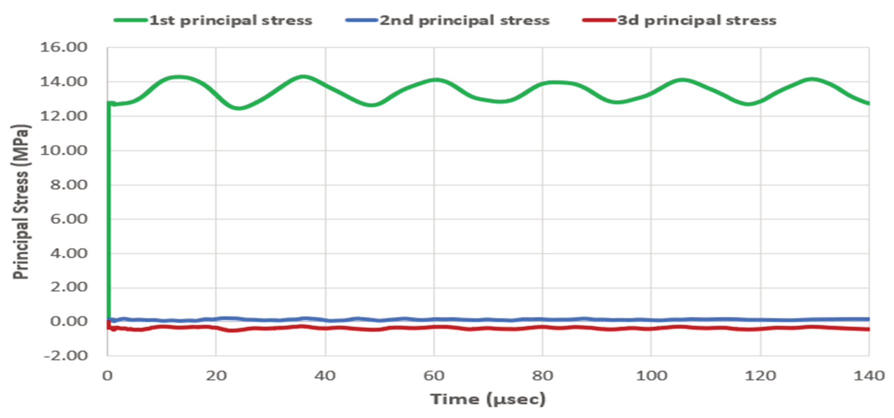


CFD computation of the static helium natural convection inside the target vessel.

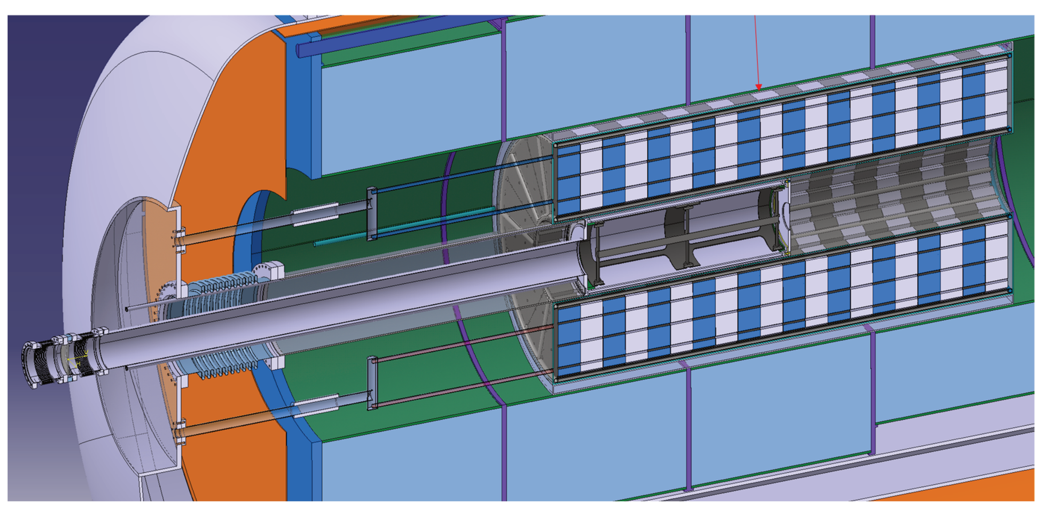
Dynamic response

- Case assessed: **sigma = 5 mm** / 5Hz.
- Maximum **energy density**: 173 J/cm³/pulse.
- Natural convection and radiation cooling considered.
- Dynamic stress waves assessed through the **explicit thermo-mechanical solver** LS-Dyna.
- Acceptable response due to large beam sigma and reduced interaction length.

Principal stresses over time, which result following a single beam impact from a steady state initial condition. (At the most stressed point).

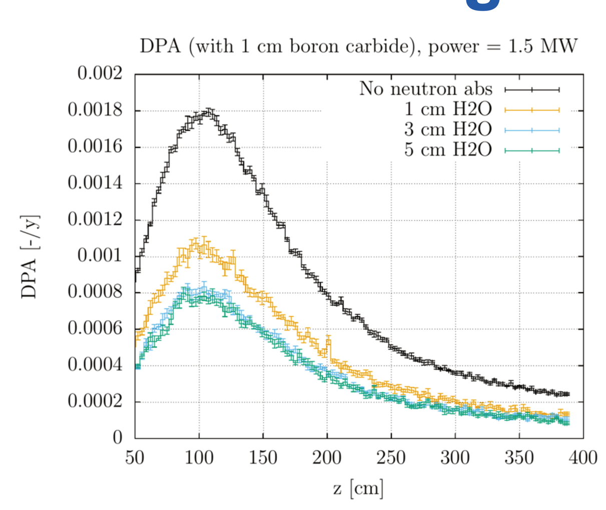


C-Target systems



Shielding design

- **Tungsten** shielding (23 tonnes).
- Most of the **thermal energy** is deposited on the shielding (34 %). The energy deposited on the target is 5.6 %.
- Donut + Pie blocks due to manufacturing limitations & to ease assembling.
- Longitudinal slots for locking & alignment pins.
- Helium cooled.
- Inner holes for bulk cooling. Inlet plenum for flow distribution.
- Outer layer with Boron carbide and H_2O moderator.
- Routing and integration challenging inside SC Solenoid cryostat.

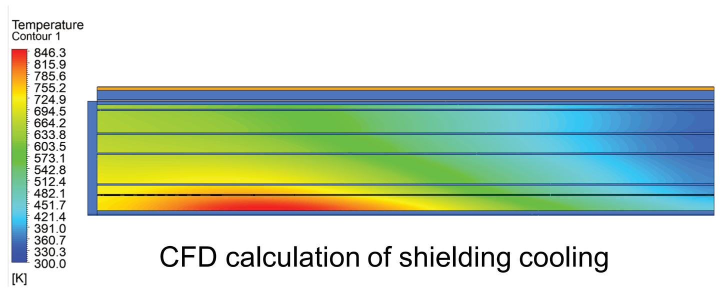


Shielding optimization

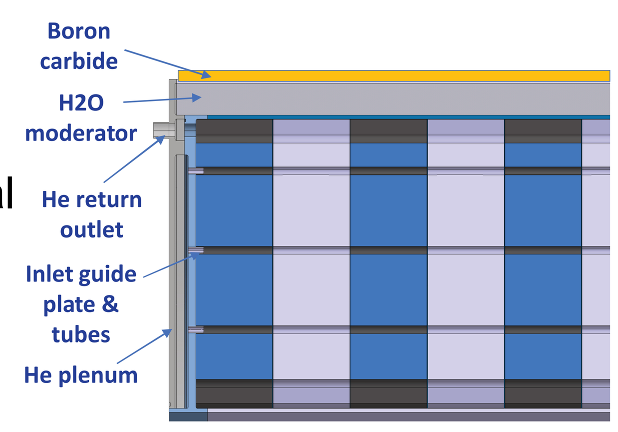
- With neutron absorber, DPA reaches values of $8×10^{-4}$ DPA after 1 year.
- However, due to less W the Ionizing dose increases: >70 MGy after 10 years (3 cm H2O).

Shielding cooling assessment

- Numerical analytical code to run across different parameters (flow, pressure, dimensions) to choose optimum operational point.
- Subsequent CFD calculation.



CFD calculation of shielding cooling

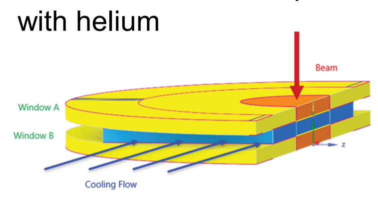


Conceptual design of shielding cooling vessel

Beam windows

- **Location:** p+ window outside cryostat assembly for better accessibility (maintenance, replacement, etc).
- **Fatigue**: extensive load cycles to be experienced by the target & windows (10^8/y) at very high temperature.
- **DPA**: radiation damage may reach high values (>1 dpa) depending on material.
- **High power deposition**: e.g. 50-650 W (0.1 – 1 mm) for Titanium.
- **Possible strategies**: windowless, blown-up beam somewhere upstream, dual bunch, rotating window "dilution", frequent window exchange.

Double window concept cooled with helium



Conclusions

- Three different target concepts being explored. C-Target is baseline option and being used for the Front-hand target systems conceptual design and physics optimization.
- Heavy liquid metal target and a W fluidized target concepts are also being explored. Presenting a promising technological prospect for a 3-4 MW Muon Collider facility.
- In parallel to the target developments, the surrounding systems (shielding, beam windows and other) are being studied.

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