Early considerations for Muon Collider targetry systems at CERN

M. Calviani, F. Cerutti, S. Gilardoni, A. Lechner
EN-STI

Muon Collider meeting 14th Dec 2020

EDMS 2455802

CERN | EN ENGINEERING DEPARTMENT | STI

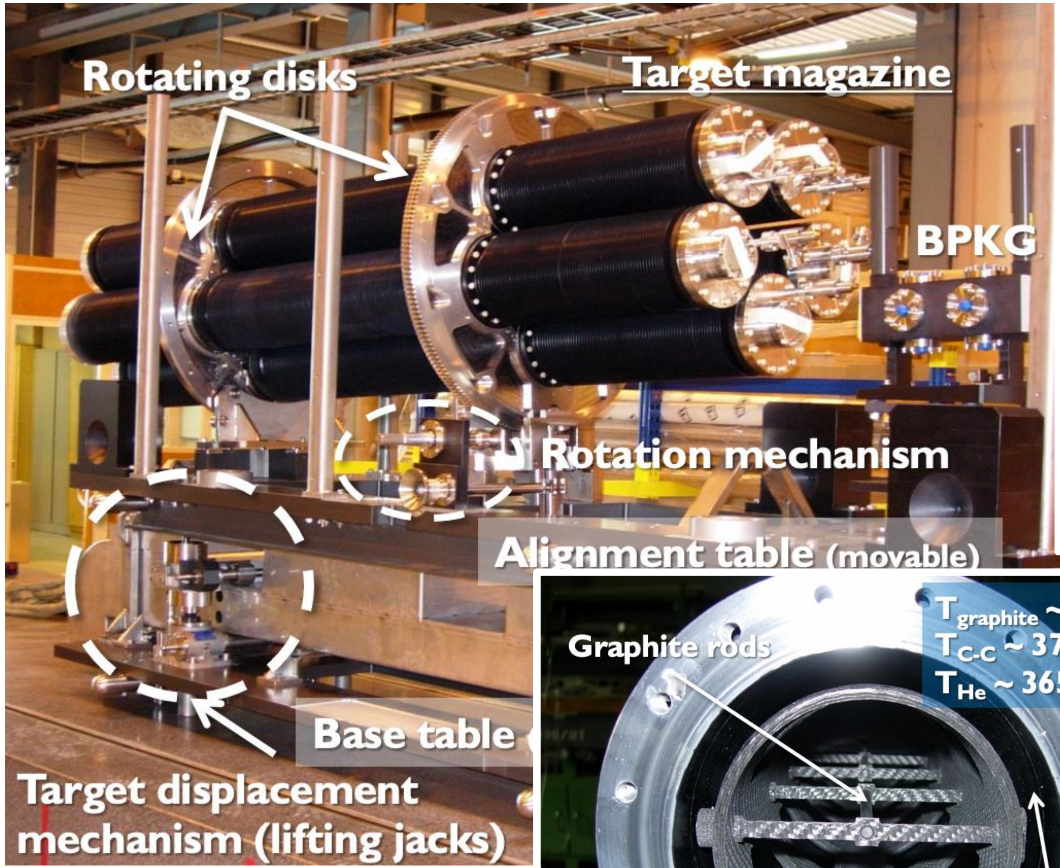
Disclaimer

- General considerations about Muon Collider Targetry – focusing mainly on proton-driven (at the moment)
- Not assumed to be a general collection of ideas and background, but rather as a (new) starting point for MUC targetry work at CERN
- Lots of studies already done in the framework of the Neutrino Factory and MAP in the past (early 2000s) – may be revisited following new developed technologies and new laws (see use of Hg)
- **Present more a list of comments and questions to kick-off this new phase…**

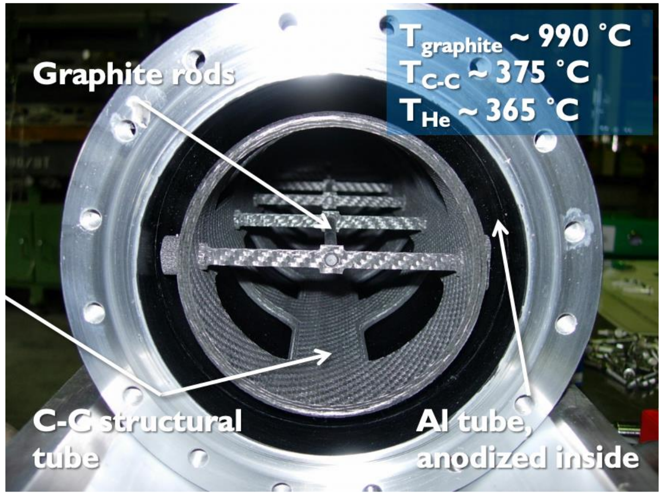
Introduction to STI

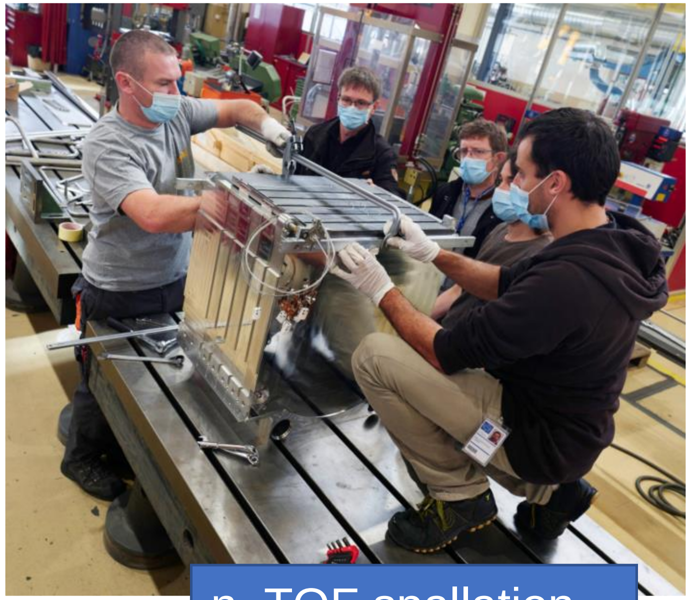
- STI Group is responsible for all beam intercepting devices (BIDs) in CERN's accelerator complex
- Responsible for executing design, construction, integration, operation and maintenance on BIDs, such as production **targets**, beam shaping **collimators**, **dumps/absorbers** as well as **horns**
- In charge of beam-matter interaction studies – FLUKA development & applications for accelerator complex
- Design and operation of present and future target areas (ISOLDE, Antiproton, n_TOF, CNGS target, BDF)
- Execution of experimental programs related to R&D (e.g. HiRadMat experiments, autopsies of spent equipment)
- Decommissioning of HW components related to BIDs

Examples of targetry systems

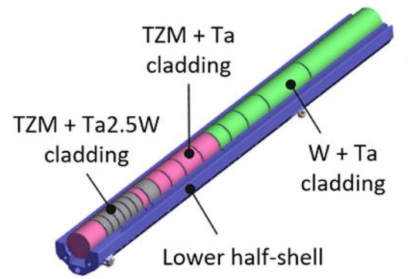


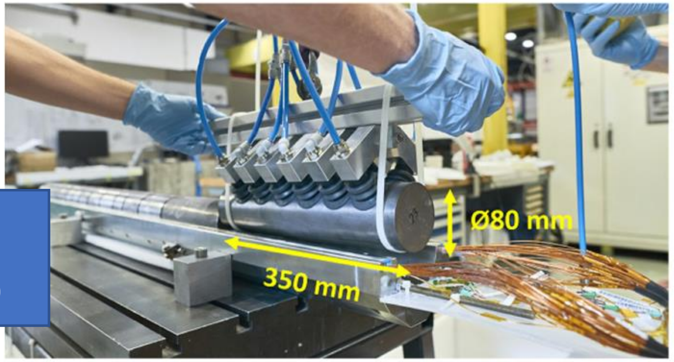
CNGS target





n_TOF spallation target

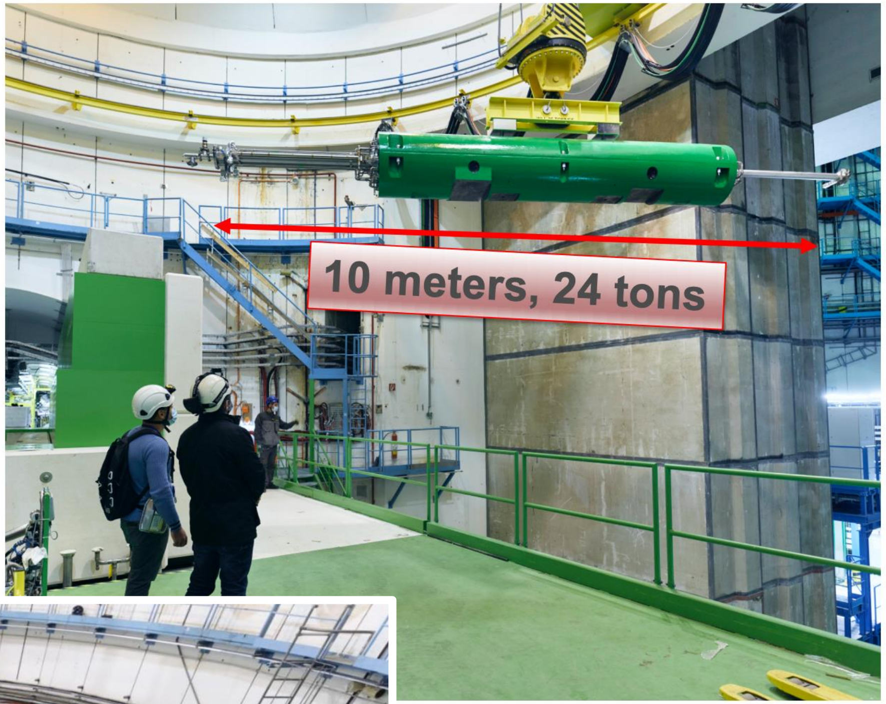




Beam Dump Facility (BDF)

Examples of targetry systems

SPS internal beam dump



Examples of targetry systems

LHC collimators

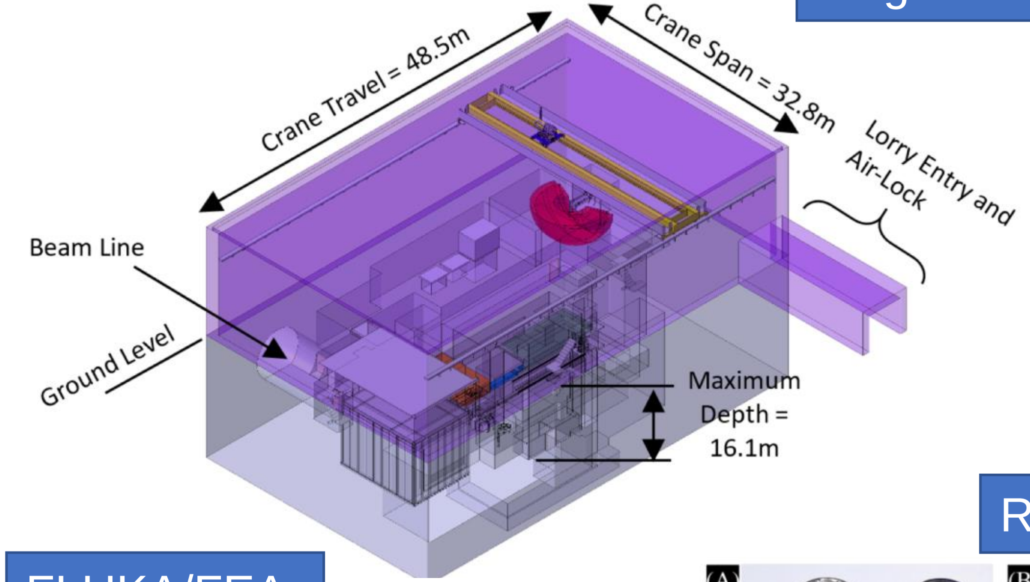
LHC external beam dump

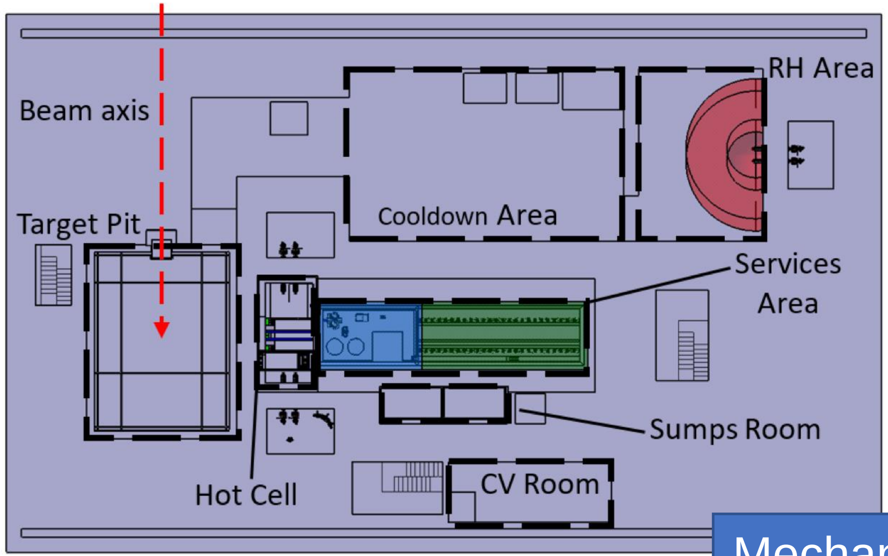
Antiproton target autopsy

Examples of a potentially similar study

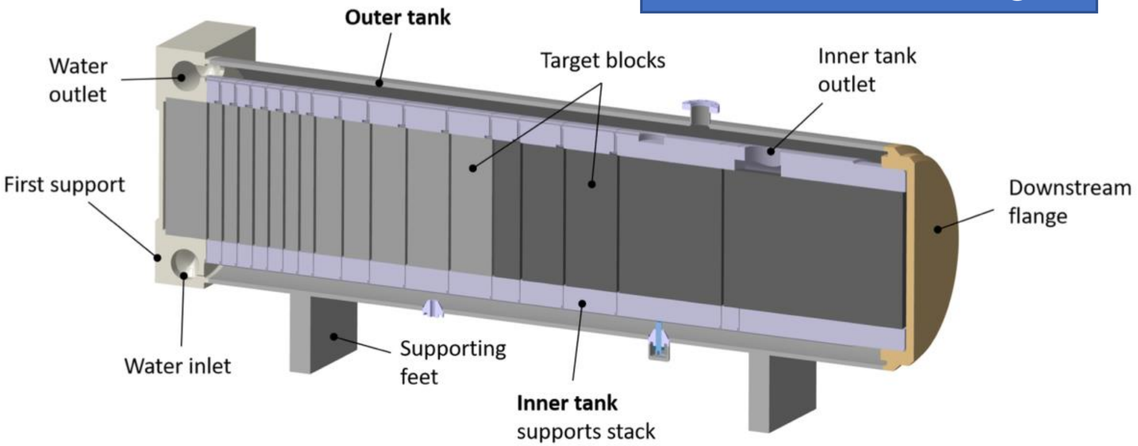
Beam Dump Facility

Target Complex

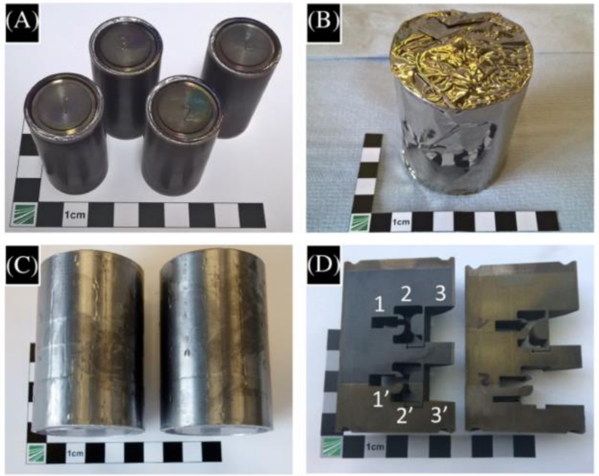




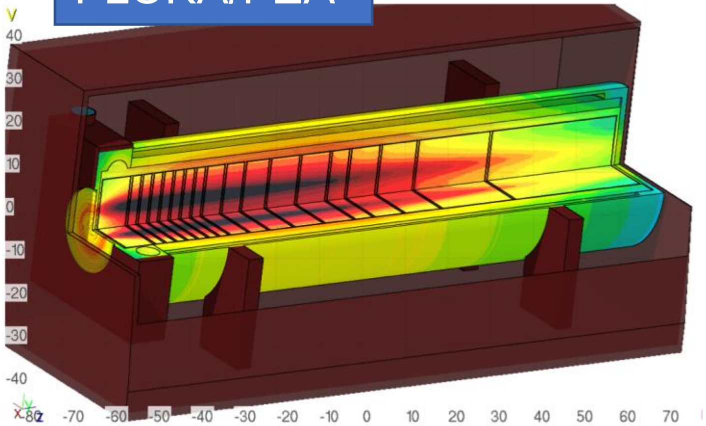
Mechanical design



R&D

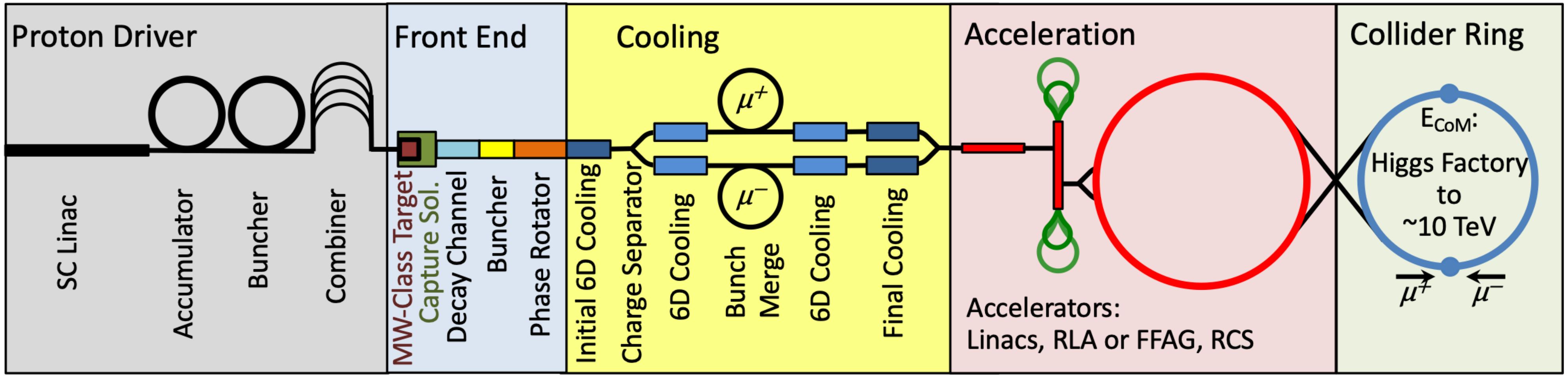


FLUKA/FEA

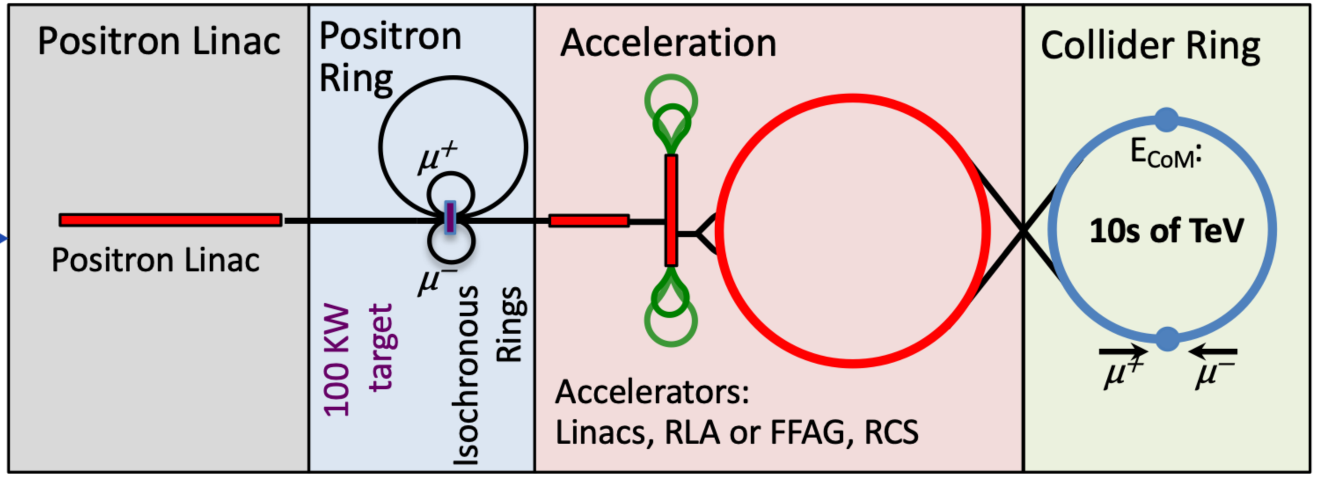


10.1103/PhysRevAccelBeams.22.113001
10.1088/1748-0221/13/10/P10011
10.1002/mdp2.101
10.23731/CYRM-2020-002

Targetry activities for Muon Collider

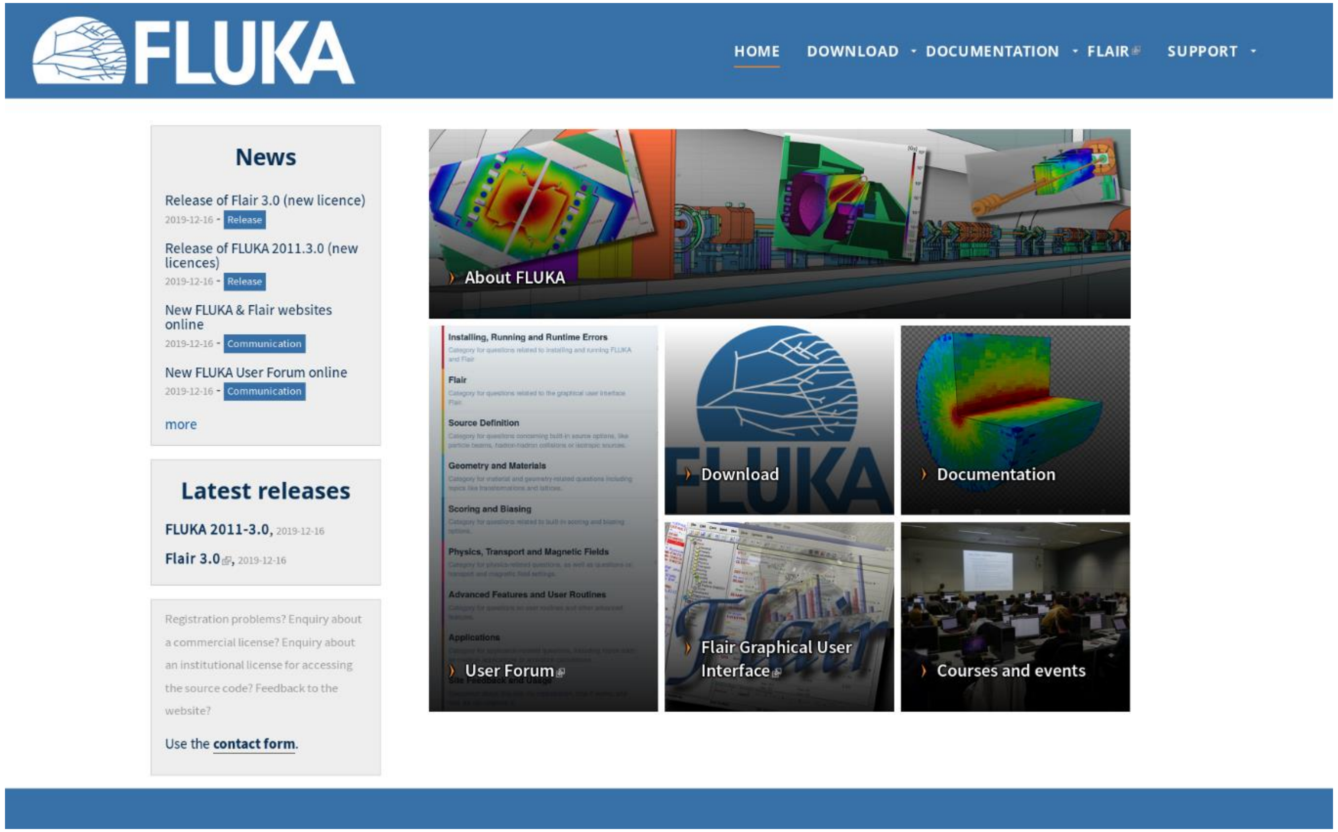


Low EMmittance Muon Accelerator (LEMMA):
10^{11} μ pairs/sec from e^+e^- interactions. The small production emittance allows lower overall charge in the collider rings – hence, lower backgrounds in a collider detector and a higher potential CoM energy due to neutrino radiation.



Beam matter calculation capabilities

- Energy deposition on target and magnets
- Radiation damage (DPA and gas production)
- Particle yield optimization
- Radiation field [and background] characterization
- Radiation to electronics issues
- [Radiation Protection aspects by HSE-RP with the same tools and models]

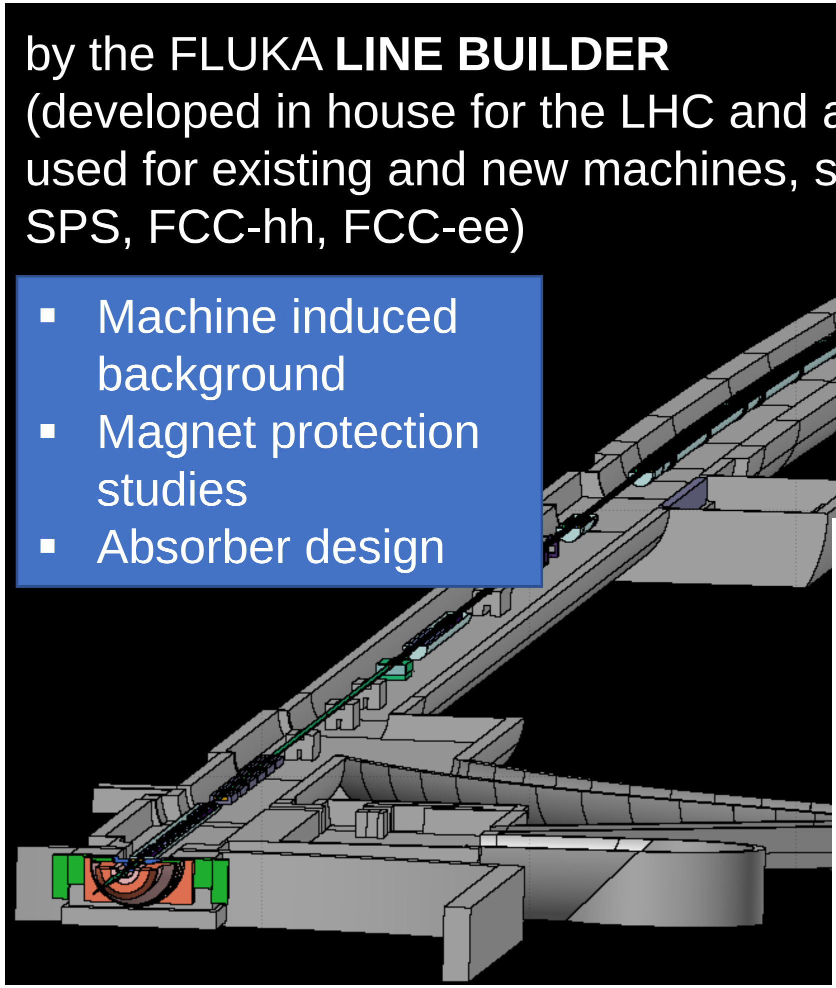


https://fluka.cern

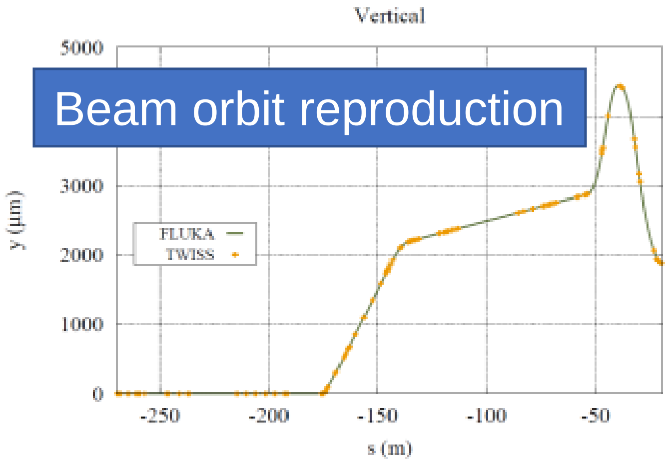
Machine modelling and simulation validation

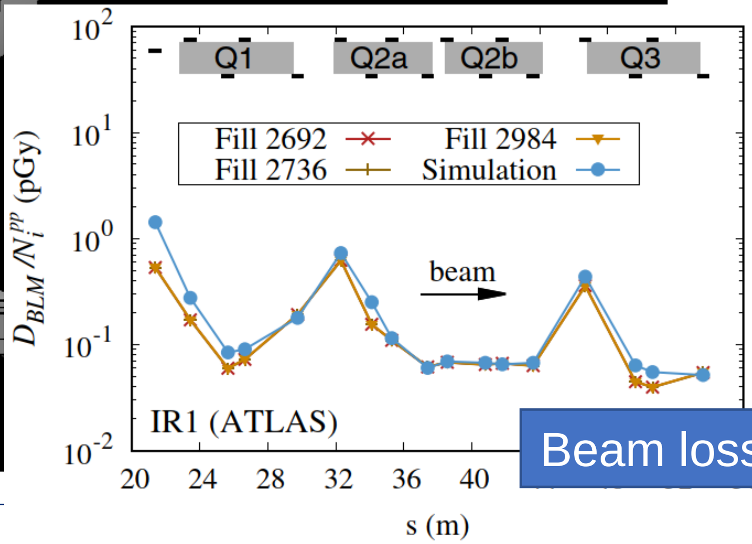
by the FLUKA **LINE BUILDER**
(developed in house for the LHC and already used for existing and new machines, such as SPS, FCC-hh, FCC-ee)

- Machine induced background
- Magnet protection studies
- Absorber design

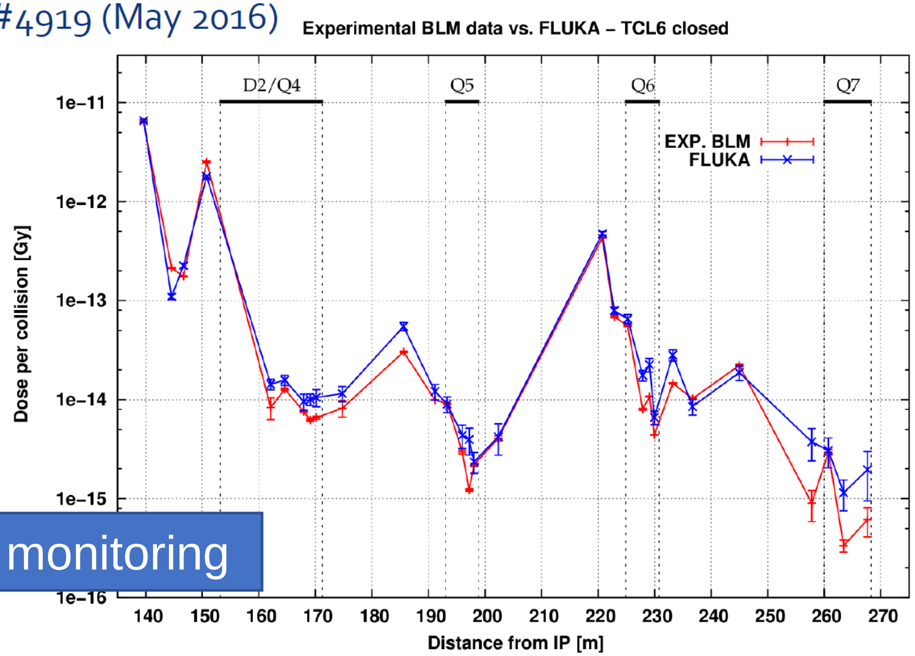


Beam orbit reproduction





- Fill #4919 (May 2016)



Beam loss monitoring

Targetry activities for Muon Collider

- Expected challenges of Muon Collider Target System, coming from significant studies worldwide in the last ±20 years, with different degrees of analyses
- What should/could be intended as a MUC Target System ?
  - Proton delivery system
  - Production Target
  - Proton and secondary particle beam dump
  - Capture/focusing solenoid or horn system
  - Decay channel (?)
  - Shielding system for neighboring equipment
  - Target Complex and remote handling equipment

Targetry activities for Muon Collider
Assumptions

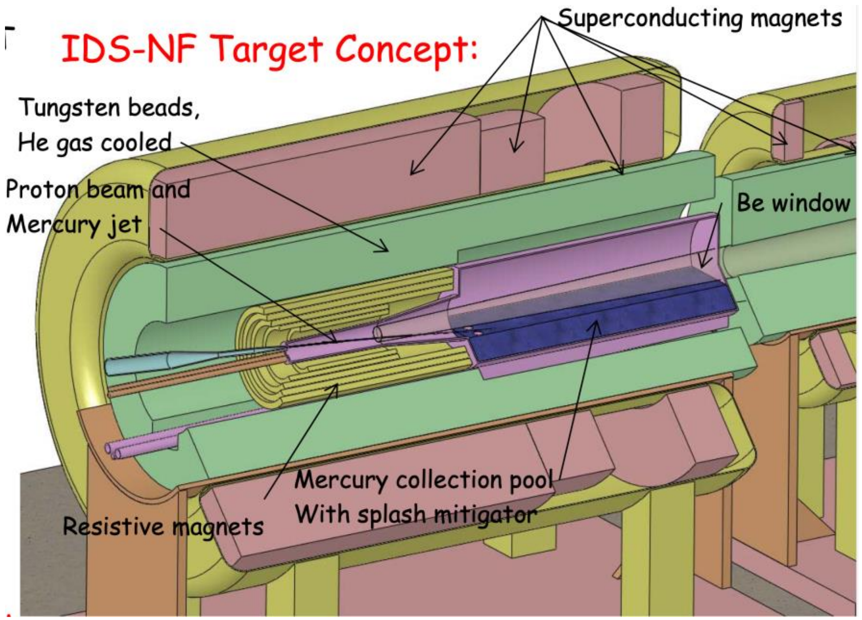
- **Multi-MW pulsed proton beam** (albeit recent proposal with electrons appeared) (e.g. 1-4 MW, 5-10 GeV range)
- Target materials ranging **from graphite to Hg/Ta**, with different performances for the FE and later section – nuclear interaction length at around 2-3 λ
- Deposited power in target **O(10-50) kW**, to be followed by a main dump where most of the rest is deposited
- Large fraction of energy still released in the neighboring equipment, whether solenoid or horns

Targetry activities for Muon Collider
Requirements

- Target and dump robustness – minimum lifetime of the target could be an important parameter
  - e.g. max 1 exchange per year?
  - SNS Hg targets are exchanged ±3/year…
- Lifetime of solenoids should be at least equivalent or larger
- Radiation to neighboring equipment
  - Energy deposited in shielding and solenoids/horns – quenching of SC – what are the limits to be respected?
  - Radiation damage & R2E (Radiation to Electronics) integration
- Integration with front-end
- Need to think about waste disposal

Considerations about Hg target

- Historically the baseline target for MUC targetry
- Clear advantages in terms of density, already liquid, radiation damage prone, probably the only solution at 4 MW, etc.
  - π^+/π^- ratio more convenient than low Z material
- MERIT experiment @CERN proof-of-principle
- **Could it be *realistically* considered as a solution for a MUC (at least at CERN)?**



KT McDonald, NuFact15

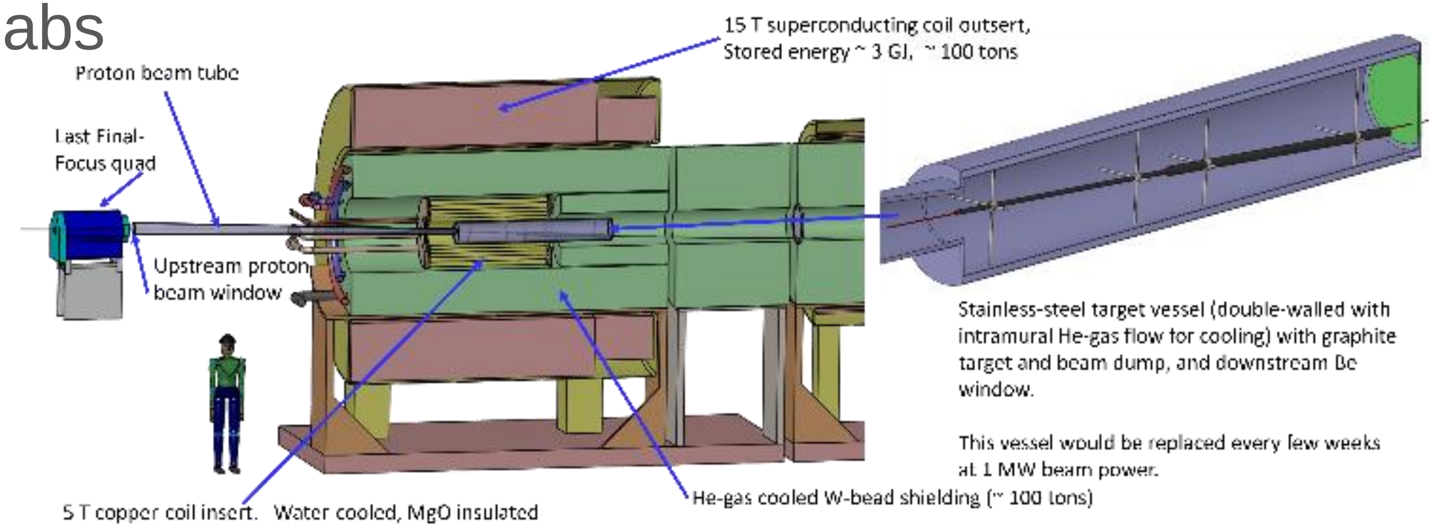
Considerations about Hg target

- Operational experience of the only operational mercury targets shows massive challenges – including high operational costs
  - SNS operates at 1.4 MW, need to change 2-3 targets/y
  - Facilities are moving away from such technologies (STS & JSNS2)
  - Waste path is still unknown and certainly extremely expensive (toxic & radioactive)
- EU signed the Minamata Convention on Mercury in 2017
  - Unlikely that massive quantity of Hg could be allowed (20 tons in SNS)
  - EU stopped Hg production in 2003
- Potential emission of activated Hg from a CERN-based MUC will be a major environmental risk
  - The design of a MUC production system is very different from a spallation neutron source (confinement easier)
  - Constraint on targets coming from muon phase space requirement different from isotropic neutron production

What about alternative scenarios?

1. Solid graphite target à-la-CNGS (used already by MAP)
   - CNGS operated at 500 kW, but capable up 750 kW
   - Design operations existed in the past to increasing further beam power to **1.5 MW** or even larger with some design adjustments
   - Large experience across labs

2. Flowing powder tungsten developed by STFC/RAL team (see Chris's talk)



X. Ding, IPAC16, TUPMY044

LEMMA scheme

- Positron driven muon source for a muon collider (1905.05747)
- Several tens of kW to be deposited in very thin (0.3 X_0) targets in C or Be proposed by the LEMMA Collaborators
- Lithium targets also proposed
- Options to be further investigated, probably tested – synergies with existing programs at CERN possible
- R&D required!

MUC Target Complex considerations

- Will need to comply with stringent radiation protection
  - Installation in the molasse (as CNGS) will largely simplify many radiation protection constraints (water ingress, air activation, stray radiation, neutron streaming, etc.)
- Likely ±Sv/h dose rate of large volumes
- Fully remote handling of components mandatory
- Should favor vertical handling (ITER remote handling code of practice)
- Need to think in advance of environmental impact (air release, etc.) as well as radioactive waste considerations
- Accessibility, costs, etc.
- **Does not appear to have been developed at all for the MAP or IDS-NF studies**

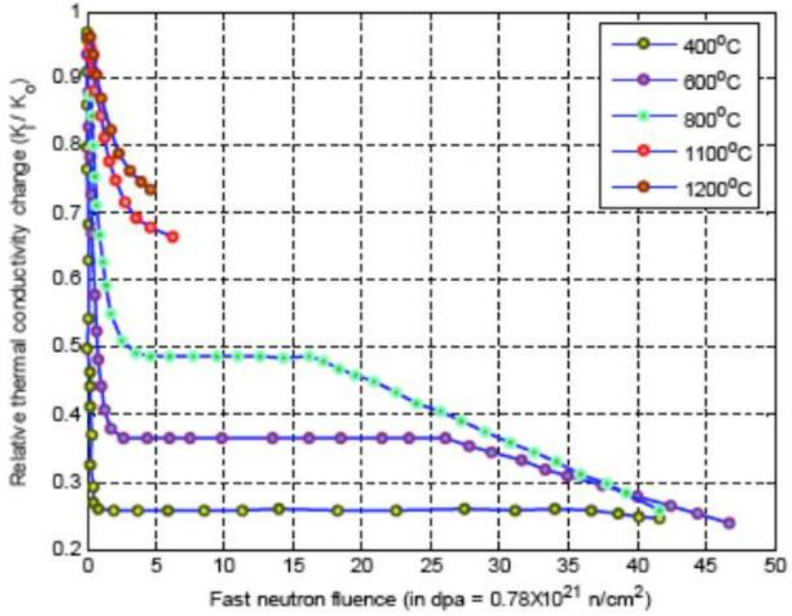
Proposal to proceed forward

- **Parameter space is currently huge**
  - no clear and defined specification are available at this moment
- **What is the required π/μ yield and 6D phase space at the entry of the decay section ?**
- Proposal:
  - First *physics* optimisation of the Target Systems
  - Definition of driver parameters and variable definition
  - Extensive physics optimisation of target coupled with early conceptual engineering design
- Target Complex design and optimisation
- Early prototyping of key technologies once defined

A possible R&D: CNGS target autopsy

- One of the important question on a graphite-based target for MUC is radiation damage and properties modifications
- AWAKE project is currently proposing the dismantling of TCC4 (CNGS target area) → CNGS Target will be removed and considered as radioactive waste
- ±2 DPA reached in CL 2020PT graphite, running at 1000 °C (damage annealing)
- MUC could envisage the possibility to finance the **PIE/autopsy of the CNGS target** and the extraction & analysis of the carbon target

Thermal conductivity change for IG-110 graphite†



†Mohanty, S. and Majumdar, S. (2011). *HTGR Graphite Core Component Stress, Analysis Research Program*, Argonne, Argonne National Lab, p.58

Credits: P. Loveridge (RAL/STFC)

Other possible R&D works

- Investigate use of **3D carbon/carbon composites** (already in production for the CERN's LIU TCDIL collimators) 10.1002/mdp2.33
  - Enhanced robustness for challenging applications
  - Synergies with HL-LHC external beam dump upgrade in LS3 (2026-2027), including HiRadMat experiments to be executed in 2021 and 2022/2023
  - Unknown radiation damage tolerance
- Continue Collaboration with **RaDIATE** partners on radiation damage studies

Proposal to proceed forward

- Definition of a **dedicated WG on MUC Targetry activities**:
  - Physics optimisation
  - Beam-matter interaction
  - Engineering early studies
  - Design and consideration about Target Complex
  - Definition of prototyping steps
  - Radiation protection early studies
  - Experimental program at HiRadMat possible but to be defined
  - Autopsies / PIE of relevant irradiated equipment (e.g. CNGS target)

Conclusions

- MUC Targetry is one of the most challenging targetry systems currently being explored (in both p^+ and e^+ driven schemes)
  - Could be one of the bottleneck of the MUC
- Priority #1 is to "constrain" the parameter space and focus on a couple of valid options to be investigated in order to propose a feasible MUC Front-End scheme
- Dedicated WG should be set in order to tackle these challenges, including topical R&D relevant for the schemes

Thank you for your attention!