Muon production

The subtle art of proton targetry: how to maximize the yield without harming the machine components

Daniele Calzolari
Early Career Researchers & Muon Colliders / 28 Aug 2024

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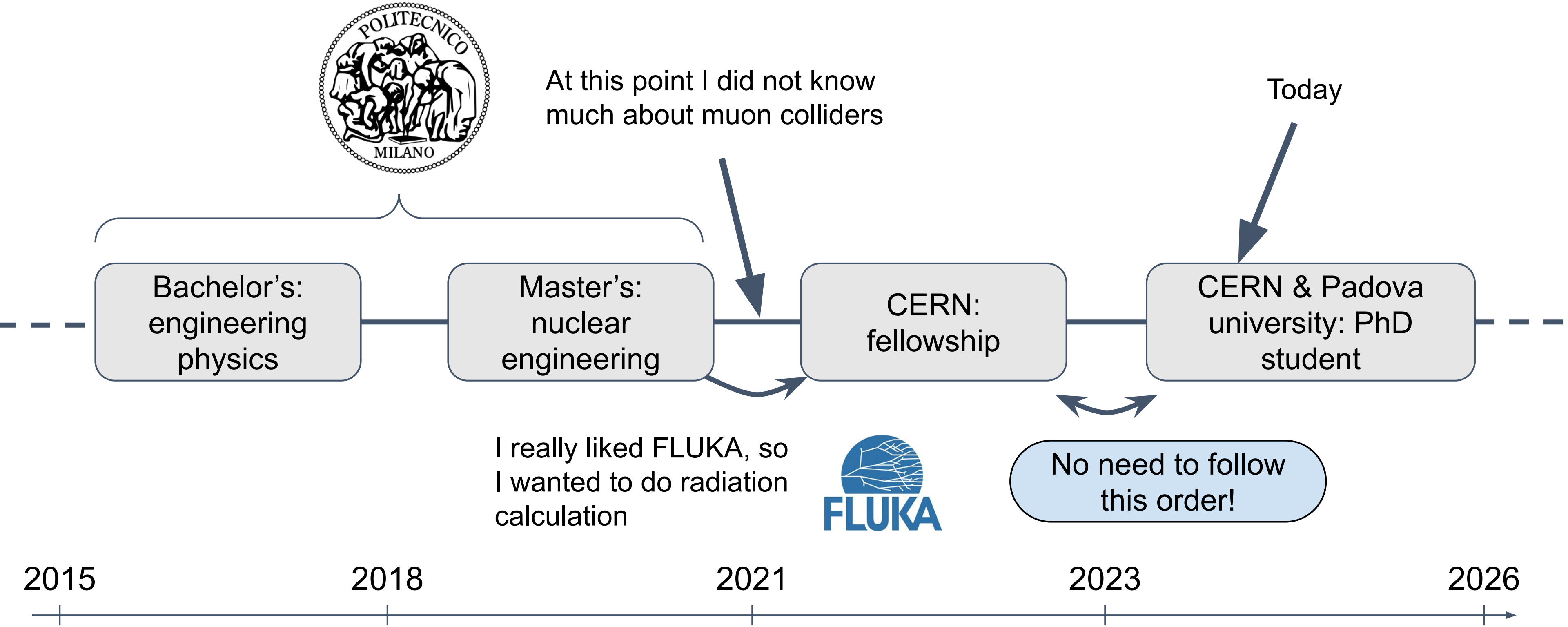
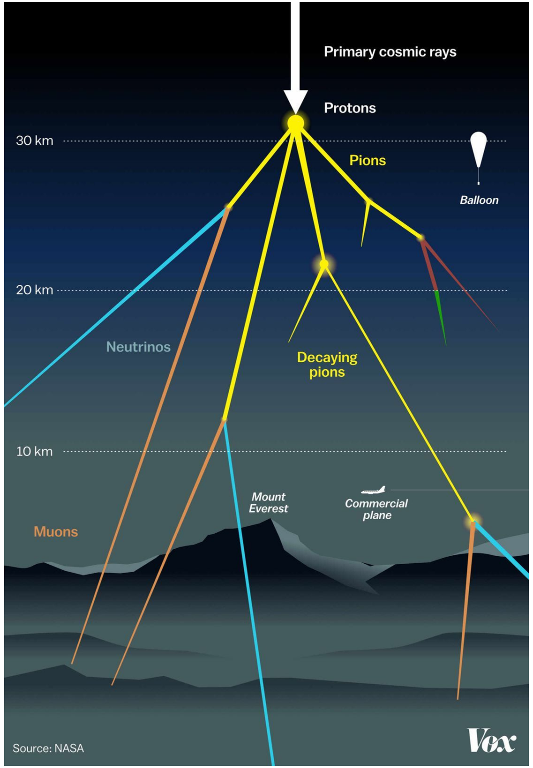
How did I arrive here?

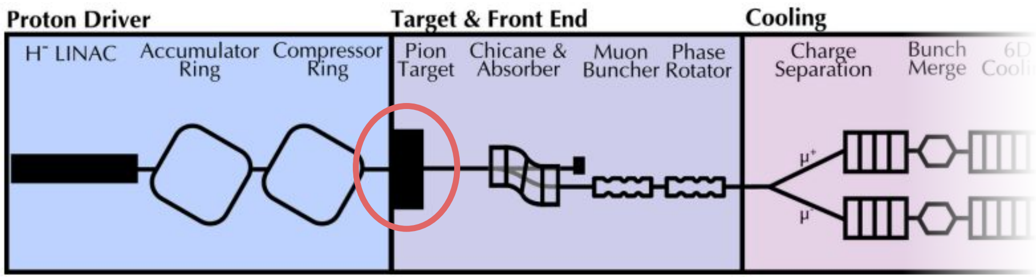


How is a muon produced?



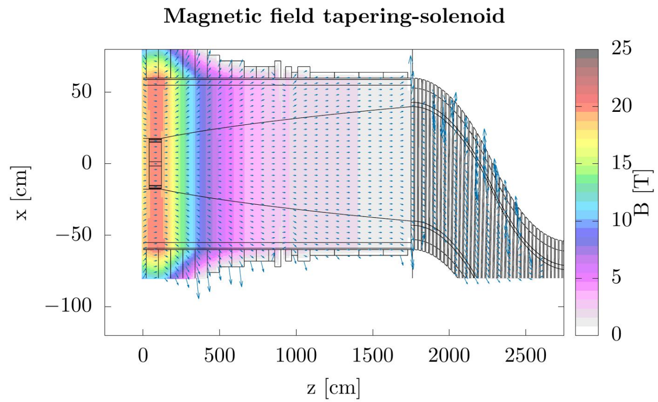
The main mechanism of production is via inelastic interactions of high energy protons.

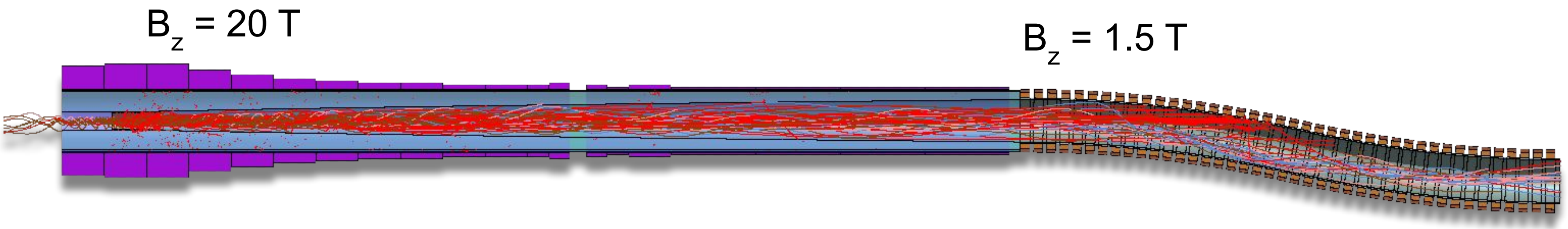
Protons — Via inelastic interaction with a nucleus → Pions — Spontaneous decay → Muons



Muon collider production target

- For the muon collider, we accelerate protons onto a solid or liquid target generating inelastic collisions. The target is placed in a solenoid field
- The generated pions travels through a **tapering region** where the magnetic field is adiabatically decreasing
- The **chicane** removes the high momentum component. Particles with p < 500 MeV/c pass through it and follow the solenoidal field

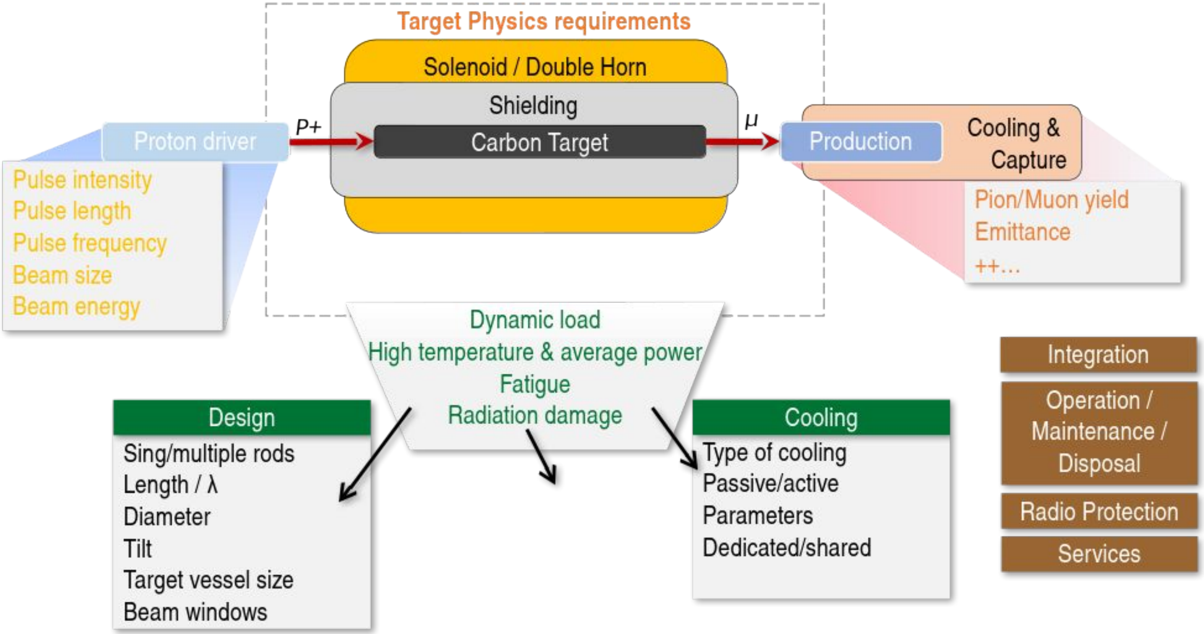




p impacting on a target, producing $\pi^{\pm}$ ...decaying in μ^- and μ^+

Carbon target & target systems considerations

- The target systems have multiple parameters and expertises involved.
- The ultimate goal is to provide the **maximum number of usable muons to the systems downstream**.
- For this presentation I will focus on a carbon based target, but other options (liquid metals, tungsten powders, etc.) are under consideration.

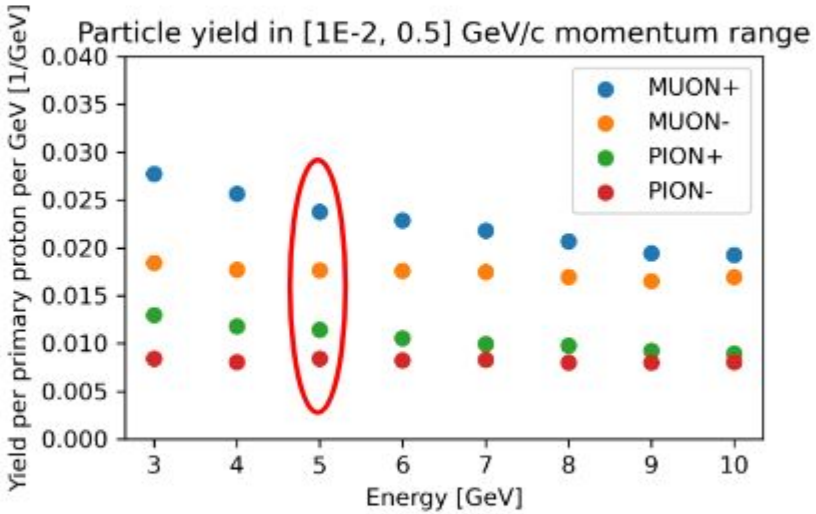


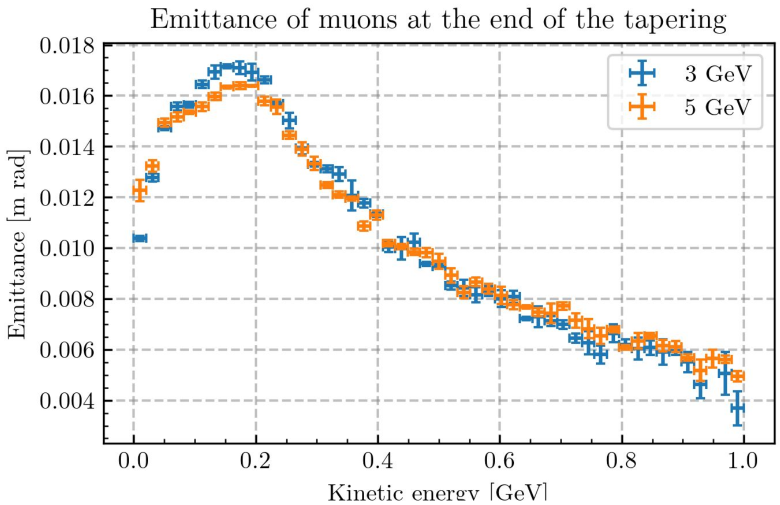
Slide by Rui Franqueira Ximenes:
https://indico.cern.ch/event/1325963/contributions/5793130/

How many muons?

We need to provide as many usable muons as possible. To do so, the target and the capture system have to be optimized.

The **emittance** describes the area occupied in the position-and-momentum phase space





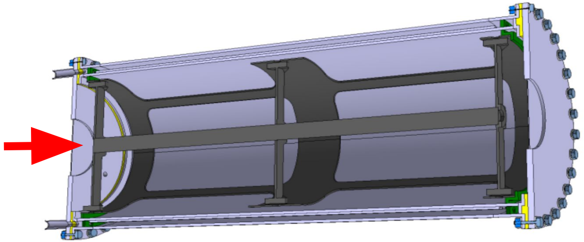
Problems: energy deposition

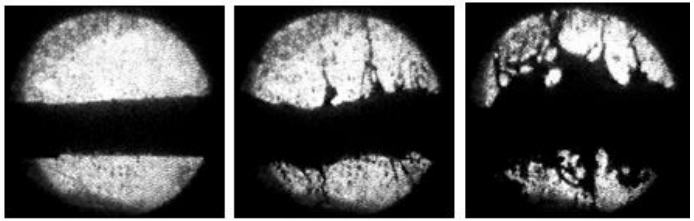
- The proton beam carries energy, focusing all of it in a small volume for a short time. The targets need to sustain enormous **power deposition.**

Challenges:
- Target cooling
- Shockwaves
- Fatigue
- Integration with the magnetic field

Possible technology:
- Graphite
- Liquid metals (curtains, jets)
- Tungsten powders or bearings


SLAC Damage Test on Cu Block


Baseline IMCC graphite target

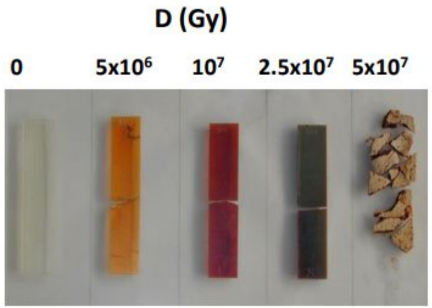

Impact of a single pulse on a 1cm-wide jet of mercury

Problems: radiation damage

Total ionizing dose (TID)

Charged particles deliver energy to the material, ionizing it and breaking covalent bonds

Damages **organic components** (insulations, resins, coil impregnation, etc…)



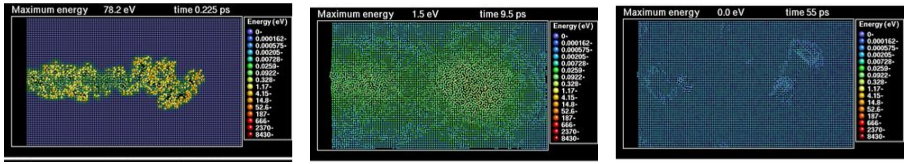
D[Gy] = E[J]/m[kg]

Limiting factor in the accelerator and collider ring

Displacement damage (DPA)

Nuclear scattering events produce defects displacing atoms from the crystal lattice

Damages **metals and non organic components** (loss of ductility, superconducting coils quenches, etc)



1) Primary knocks-on

2) Recombinations

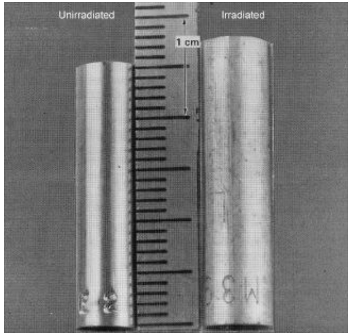
3) Residual defects

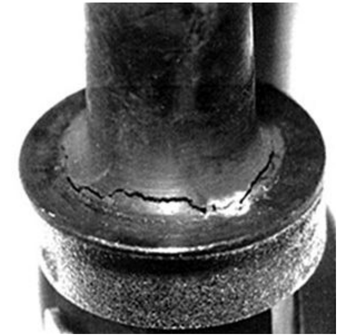
Limiting factor in the production target!

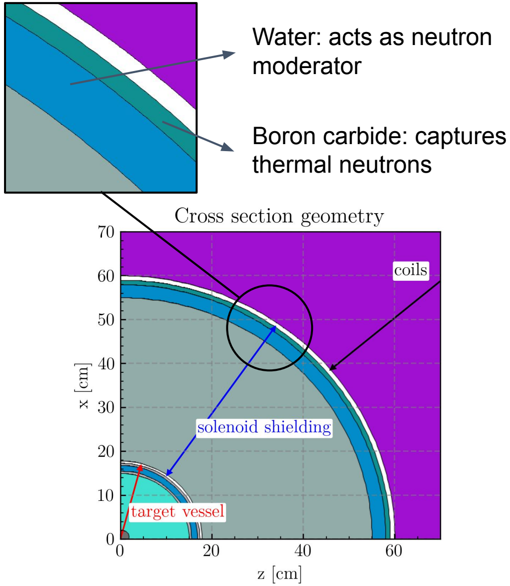
Shielding design

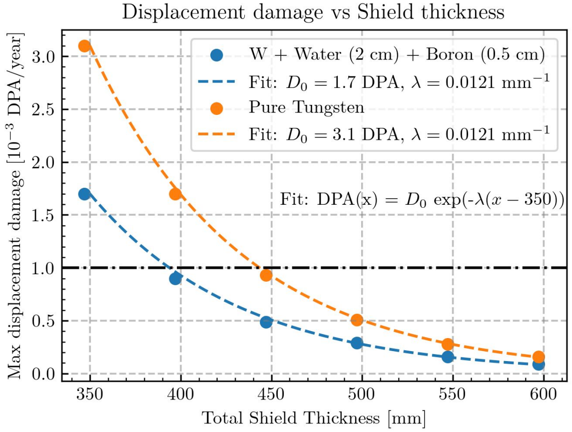
- The assumed limit for superconducting HTS is around ~10^{-3} DPA. Above that, the superconducting properties are lost. With annealing, the damage can be recovered via thermal treatment
- With the assumption of operating for 5 to 10 years we need to design an adequate shielding

Neutron irradiation: well known problem in nuclear industry





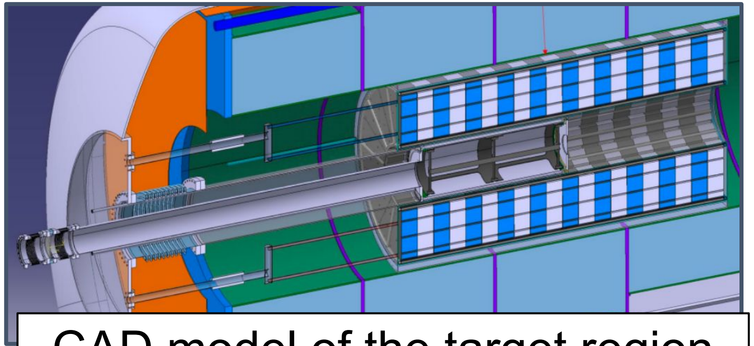




Last simulations by J. Manczak

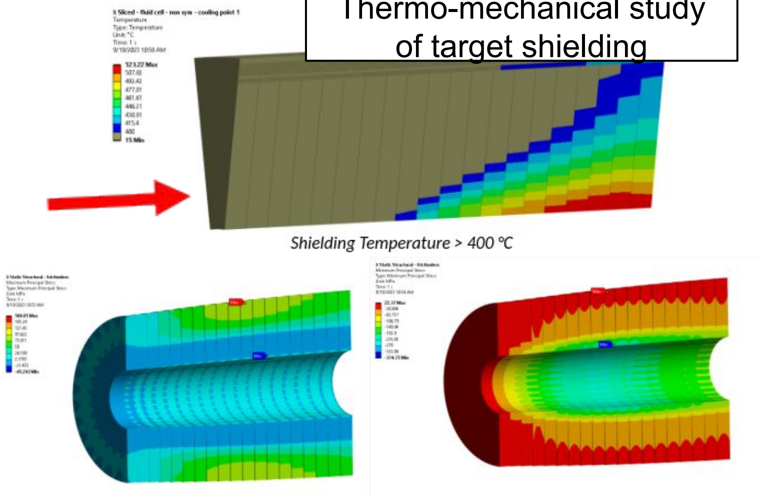
Target integration

- Several area of expertise have to be involved, among which:
  a. Thermomechanical engineering
  b. Solenoid design (synergy with nuclear fusion: working with experts from F4E)
  c. Cryogenics
  d. Radioprotection
  e. … and many other!



CAD model of the target region

Thermo-mechanical study of target shielding



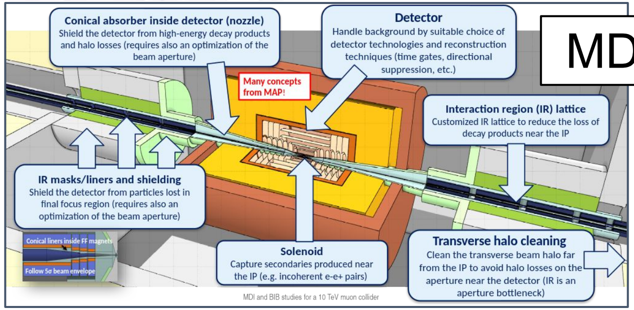
Max stress on external cooling pipe (169 MPa) center

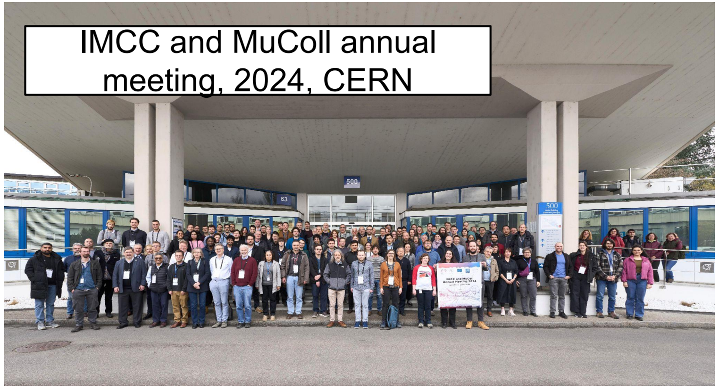
Min stress on internal cooling pipe (374 Mpa) center

Images by Rui Franqueira Ximenes:
https://indico.cern.ch/event/1325963/contributions/5793130/

Present and future

- I am still working on the muon collider. My core activity is not the muon production anymore, but the Machine-Detector Interface (MDI)
- Many people are working on several aspects of the muon collider. **Lot of work** to do!




IMCC and MuColl annual meeting, 2024, CERN

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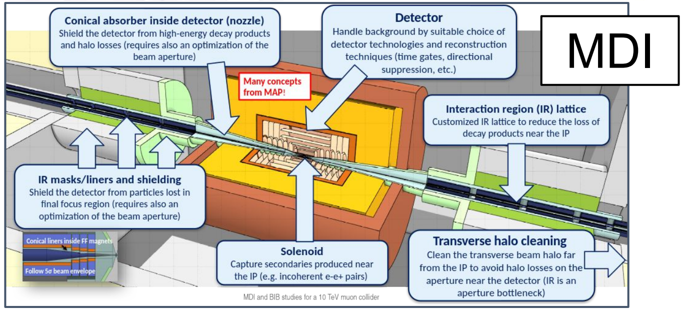
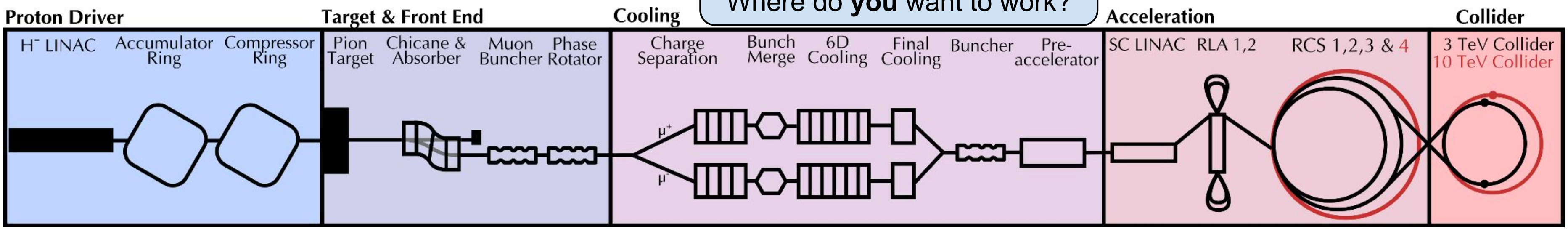


Where do **you** want to work?



Thank you

International MUON Collider Collaboration

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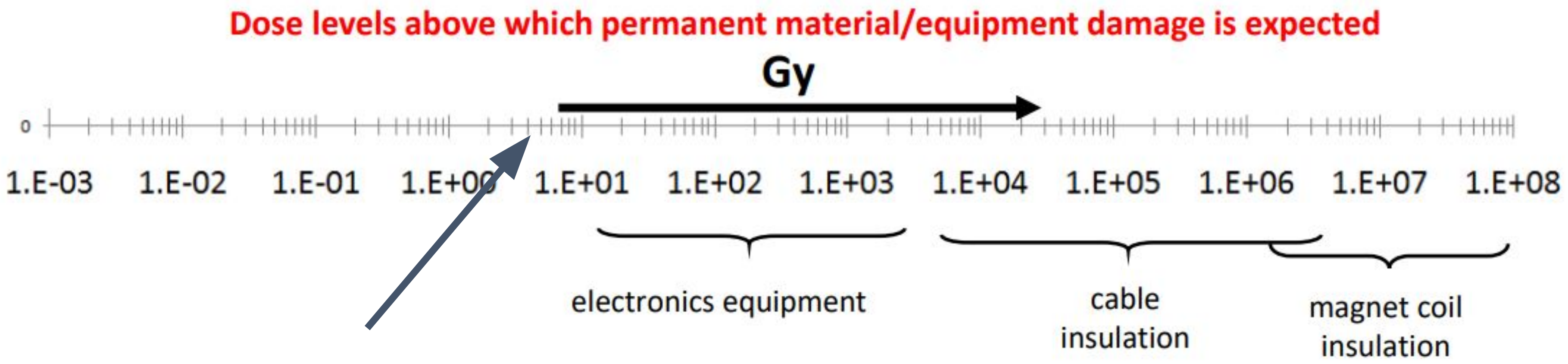
More on TID



Around half of us are dead here
(LD50 ~ 2 - 5 Gy)