5th High Power Target Workshop, FNAL

Design, optimization and operation of beam intercepting devices for CERN's fixed target physics

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Outline

- CERN's fixed target physics program
- Review of CERN's accelerator complex
- Low-Z devices
- High-Z devices
- Conclusions

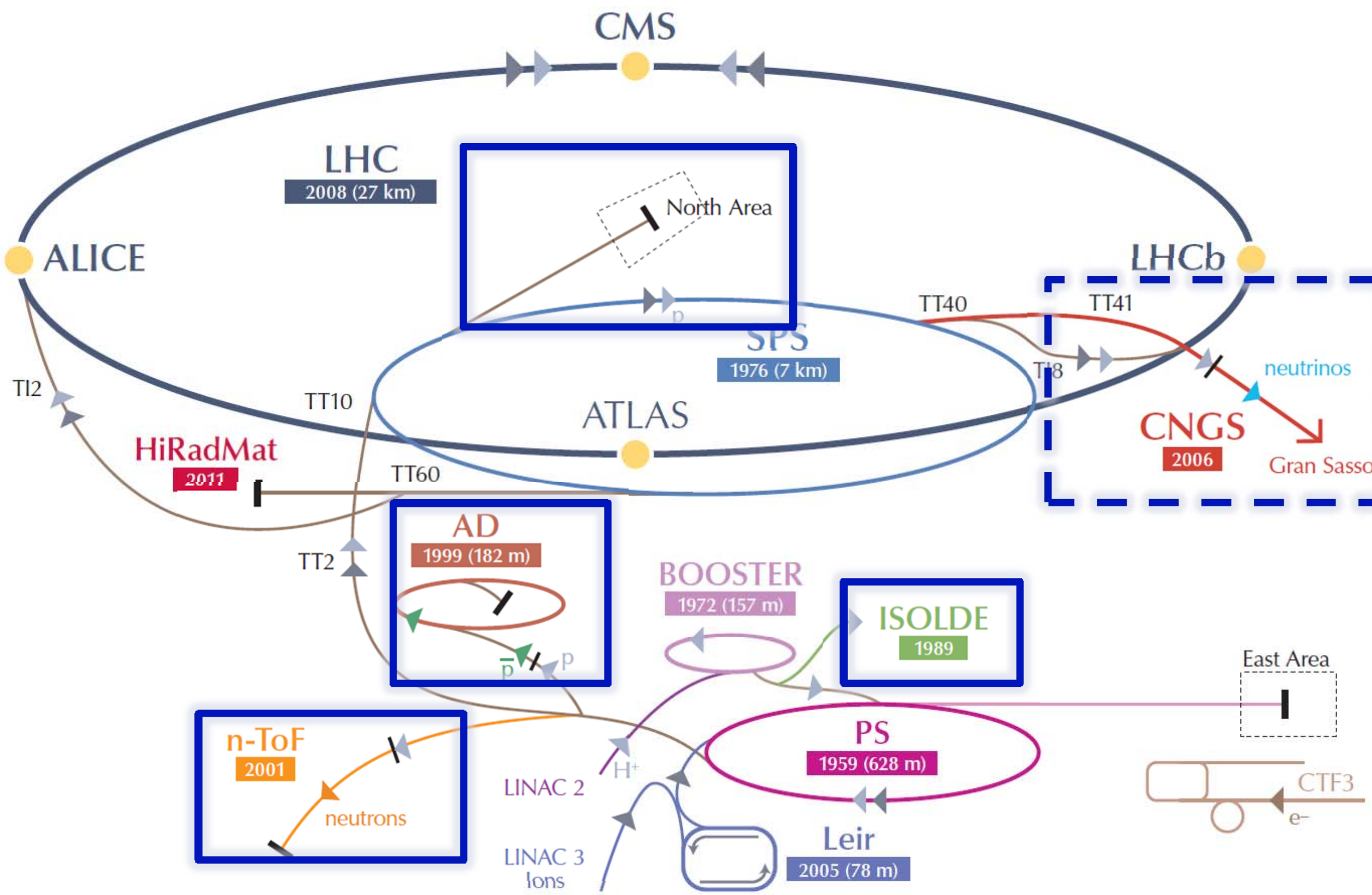
Review of CERN's fixed target physics

- CERN has a long and varied history of fixed target experiments, contributing to a diverse program of research
  - Essential part of the lab's scientific program
- Hadrons physics (COMPASS, NA61...)
- Nuclear physics (ISOLDE)
- Neutron physics (n_TOF)
- Antimatter physics (AD)
- Neutrino physics (WANF, CNGS...)

Review of CERN's fixed target physics

- **Some of the challenges**:
  - Cohabitation with collider physics and beam sharing
  - Different facilities operating at the same time
  - High intensity pulsed beams
  - High reliability required

CERN's accelerator complex



~10^{15} proton/year to LHC

>10^{20} protons/year to fixed targets

LHC Large Hadron Collider SPS Super Proton Synchrotron PS Proton Synchrotron

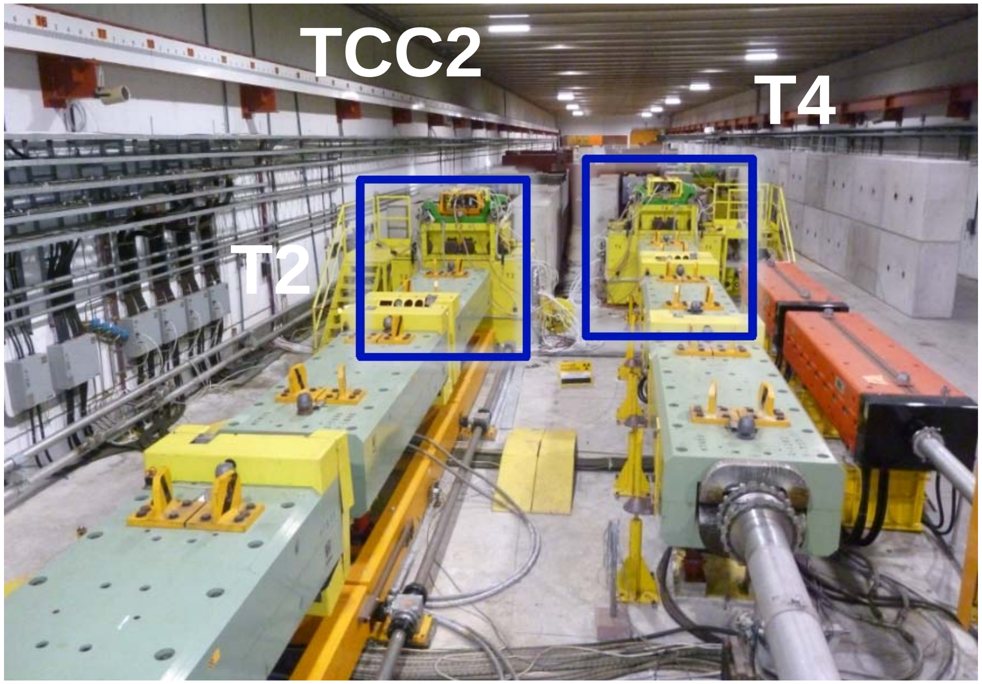
AD Antiproton Decelerator CTF3 Clic Test Facility CNGS Cern Neutrinos to Gran Sasso ISOLDE Isotope Separator OnLine DEvice
LEIR Low Energy Ion Ring LINAC LINear ACcelerator n-ToF Neutrons Time Of Flight HiRadMat High-Radiation to Materials

Low-Z targets

- Operational experience:
  - North Area general purpose targets
  - CNGS HE neutrino target
- Future projects
  - CENF LE neutrino target

North Area targets

- 4 multipurpose target stations
  - Beryllium S-200-F
  - Slowly extracted 400 GeV/c
  - 2.5×10^{13} p/spill → 1.6 MJ/spill
  - Beam energy **~330 kW** over spill, ~100 kW over supercycle



- Why beryllium?
  - Most of the time physics requires mixed hadron/electron beams → largest X_0/λ_{int} are preferred
  - Target lengths from 5 to 50 cm

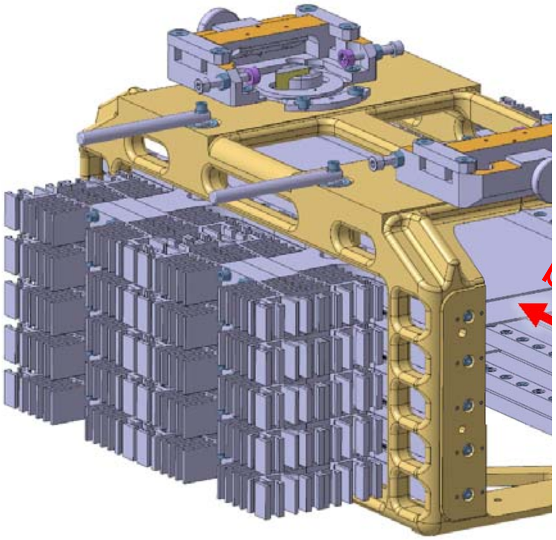
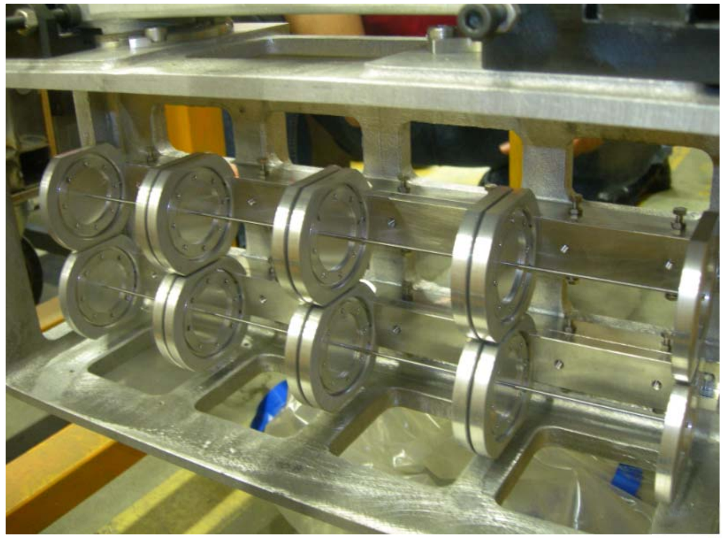
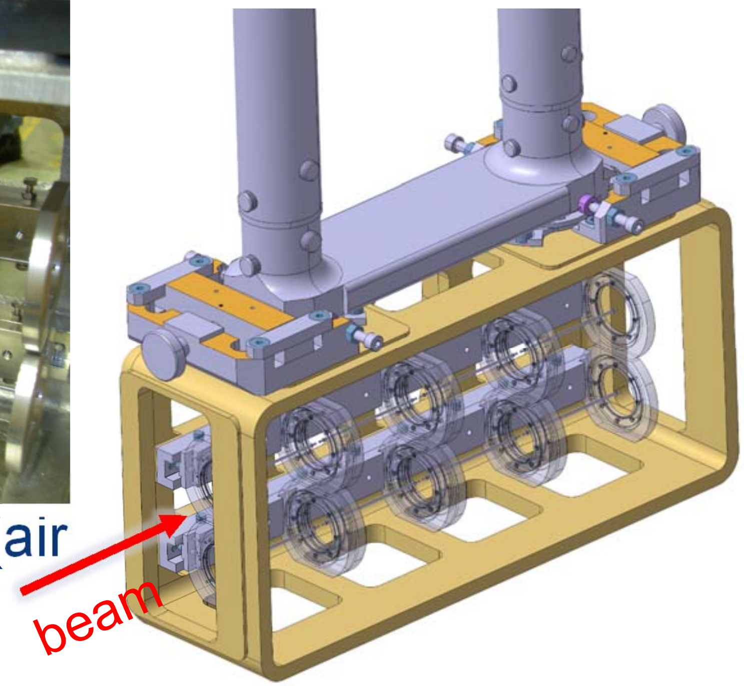
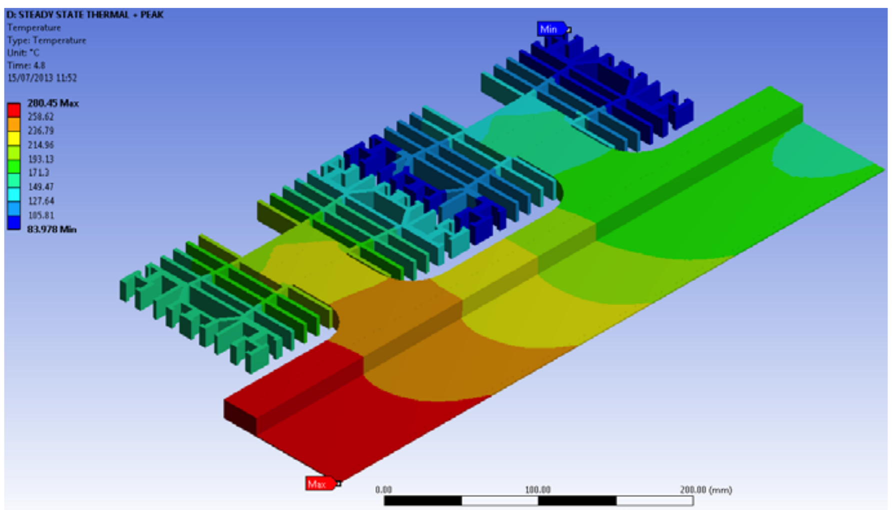


Plate targets (air cooled)



- Rod targets (air cooled)

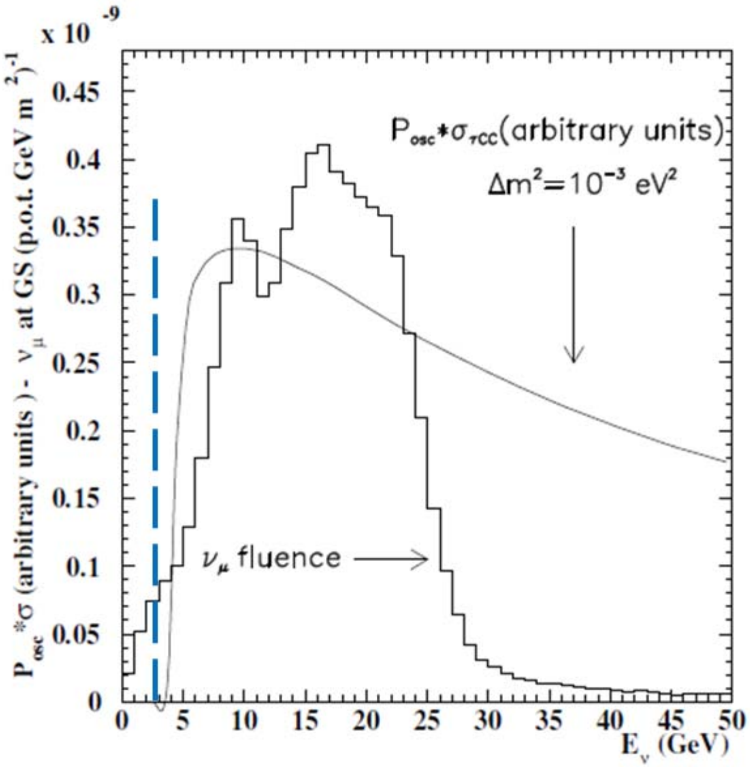


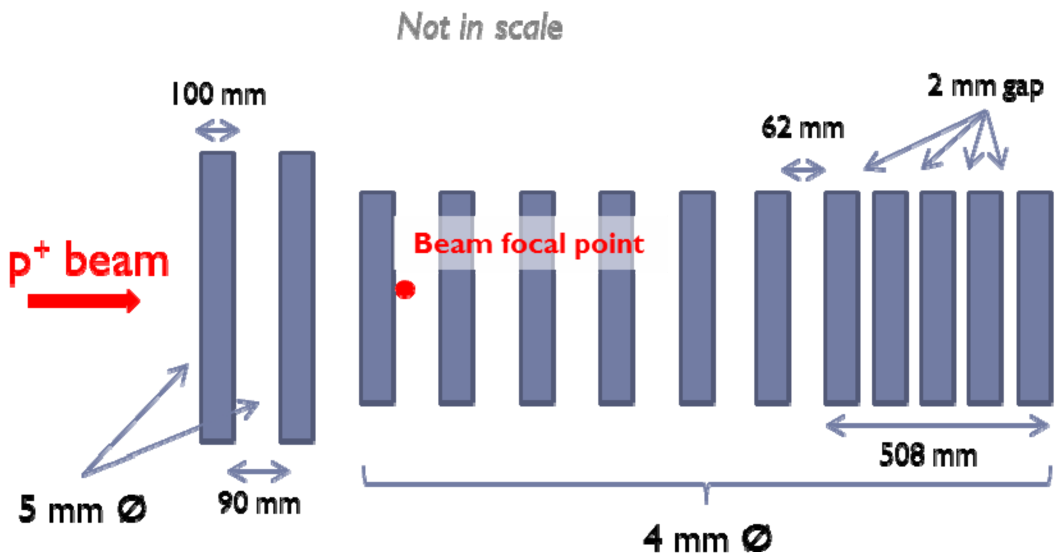


- Operational temperature ~280 °C, ~60 MPa tensile stresses
- **High reliability** required – no exchange expected in 20 years operation!
- Global consolidation ongoing, irradiated Be plates ~O(several 10^{20} POT)

CNGS target design

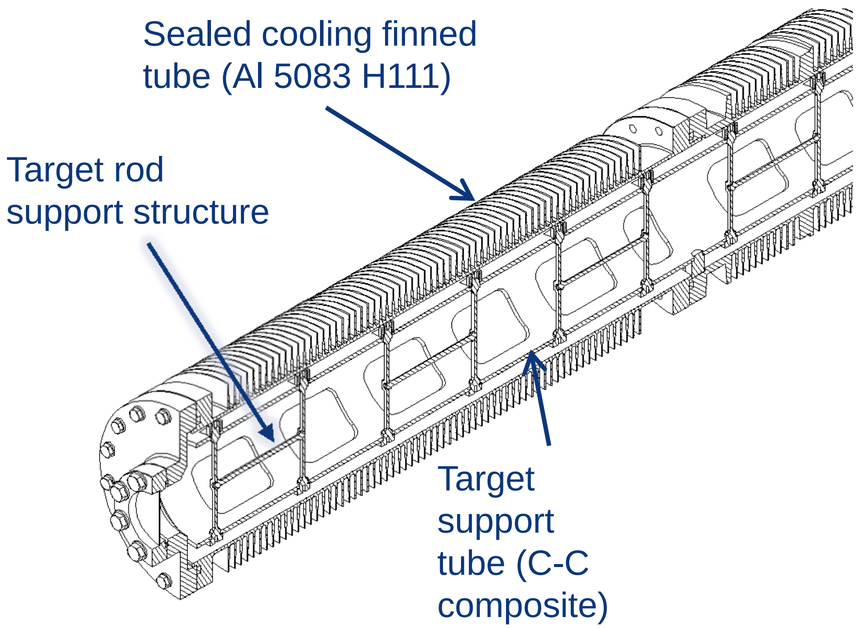
- Long baseline neutrino appearance experiment
- Optimized for high energy (~15-20 GeV) neutrino production – segmented target, outside horn
- Designed for 750 kW, operated at max **~500 kW**
- 4 mm Ø, 0.53 mm (0.32 mm) 1σ beam





CNGS engineering challenges

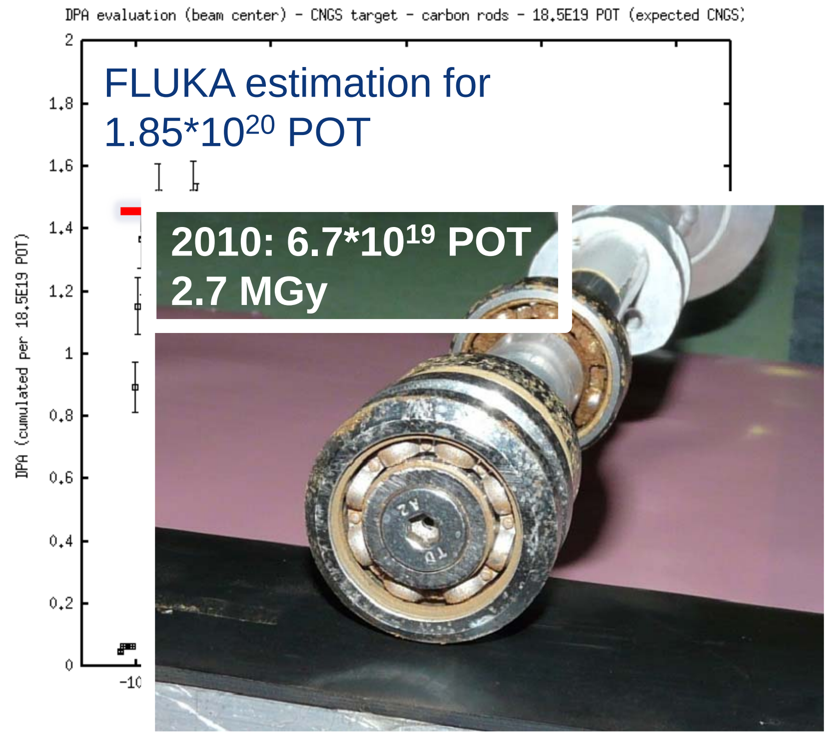
- CNGS target unit conceived as a static sealed system with 0.5 bar of Helium
  - 130 cm long graphite target (~3λ)
  - Radiative-cooled target ~1200 °C
  - Radiation resistance of employed graphite (2020PT, C-C composites, etc.)

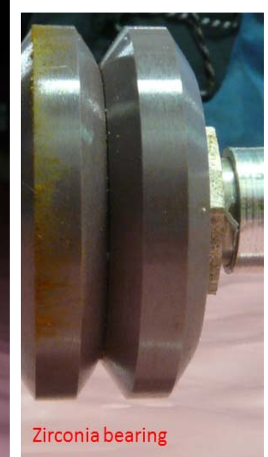


CNGS operational experience

- **No physical failure of the target** obs f operation (
  1.5 DPA
  Advantage high tempe

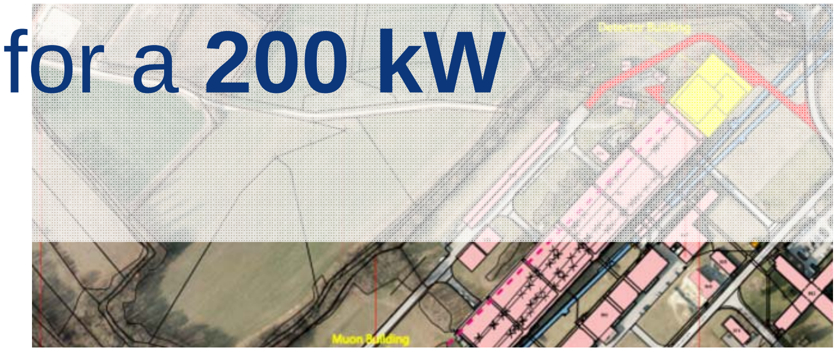
- …But **failu rotation m**
  - Rust/pitting corrosion due to use of low grade X46Cr13 balls
  - ZrO_2 bearings tested and presently under analysis





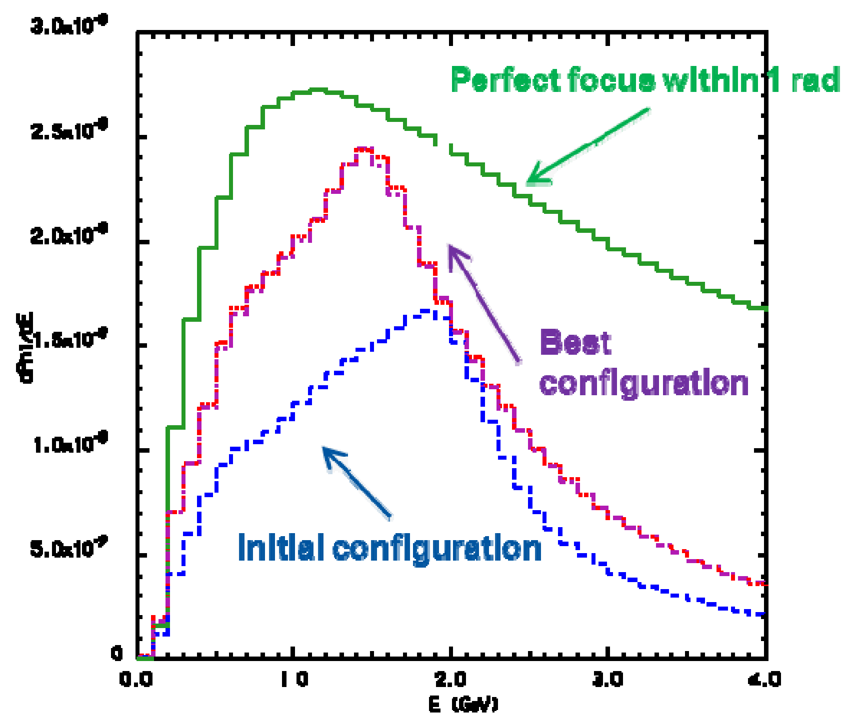
Future projects (CENF)

- CERN is designing a short baseline shallow installation (link)
- Design include the study for a **200 kW** graphite target



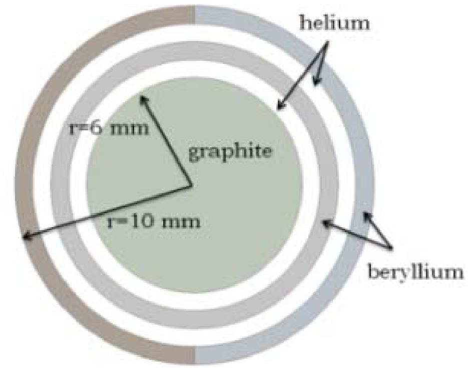
See poster session C. Strabel & V. Venturi

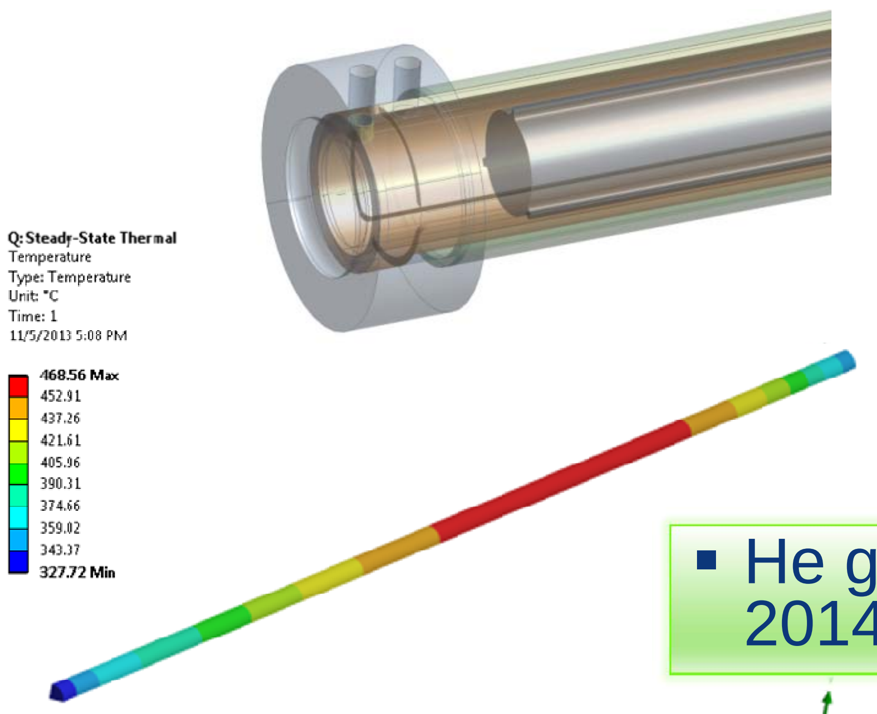
- 5 GeV pion focusing – central ν_μ energy **~1.8 GeV**
- Target inside horn, followed by a reflector

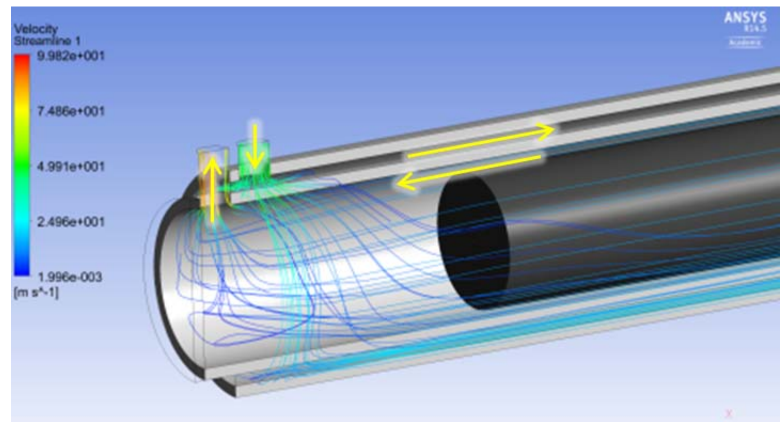


CENF target R&D

- 100 cm long, 12 mm Ø
  - ~2 kW deposited power, He-cooled graphite 2020PT
- Graphite to be maintained at 600-700K
- Baseline fully cantilever inside horn
- External retaining structure in beryllium
  - Guarantee sufficient rigidity and low pion reabsorption
- Full FEM/CFD analysis performed







See poster session V. Venturi

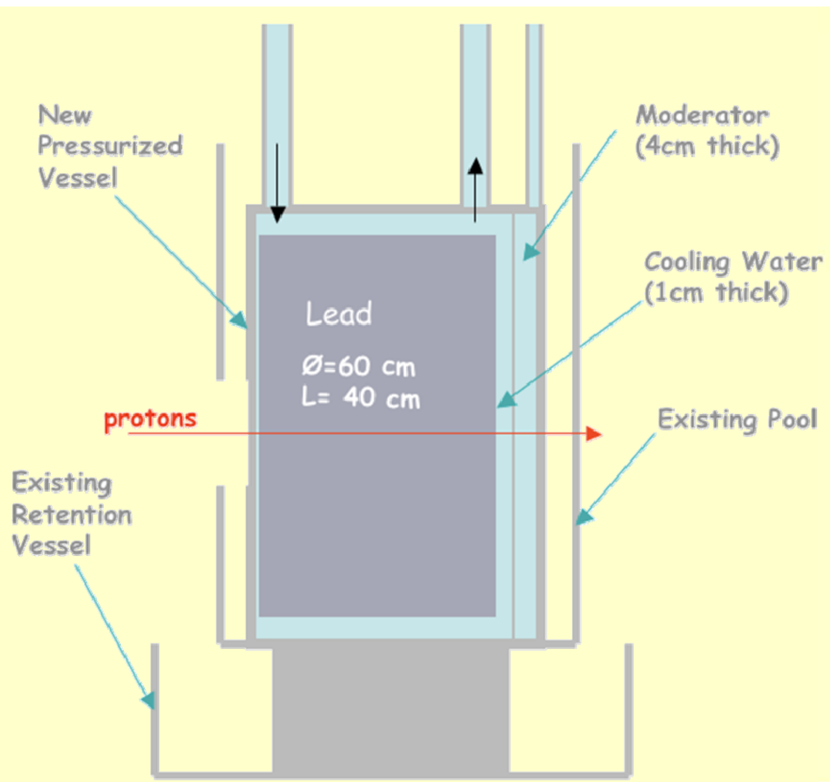
- He gas cooling test loop will be studied in 2014/2015

High-Z targets

- Operational experience:
  - n_TOF - neutron spallation source
  - Antiproton production (AD)
  - ISOLDE – radioactive beam
- Future projects:
  - SHIP

n_TOF

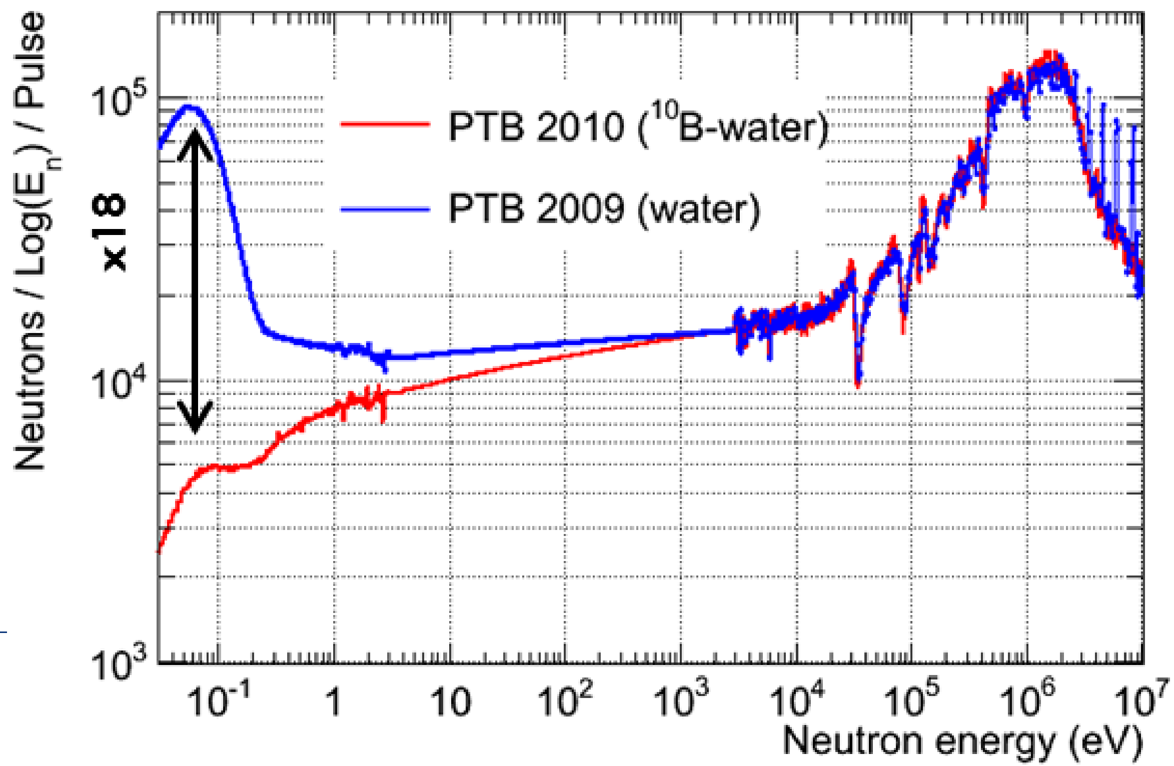
- CERN's **20kW** neutron spallation source!
  - White neutron source, ^{nat}Pb based
  - TOF experiment, 3800 hours operation
  - 20 GeV/c proton, $8.5*10^{12}$ p/spill, 7 ns spill



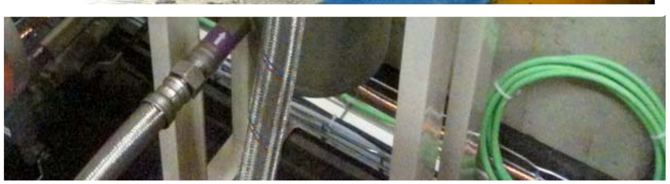
- Neutron window material budget is <3 mm
  - Material selection extremely important
    - EN AW-5083-H111
  - Water chemistry control
    - O_2, ρ, pH

n_TOF target operation

- Cooling circuit:
  - H_2O flow, 6 m^3/h demineralized water
- Separated moderator circuit
  - 1.28% ^{10}B enriched water, 0.5 m^3/h
  - Nuclear-grade cationic resin IRN9882



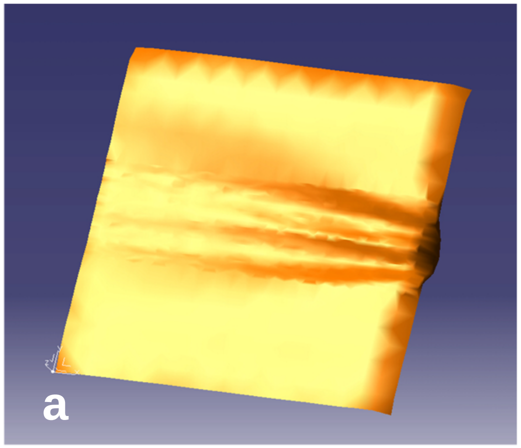
- O_2 content maintained <80 ppb
- Conductivity at 0.045 μS/cm (ultra-pure water!)
  - Maintained by purified N_2 flush … men…

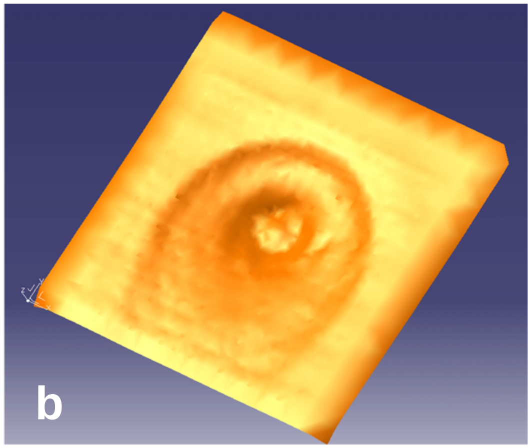


- Constant boron concentration maintained by a recirculating box at low temperature
  - Conductivity ~60 μS/cm
  - Boron crystal formation @end of run

n_TOF material selection

- Unavoidable galvanic contact between Pb and Al alloys
- Dedicated analyses allowed to quantify max. of 6 μm/y (~50 μm/y for ^{10}B circuit) for AW5083-H111
  - Thanks to water chemistry control
- Erosion/corrosion of 99.99% Pb significant
  - ~900 μm/y average

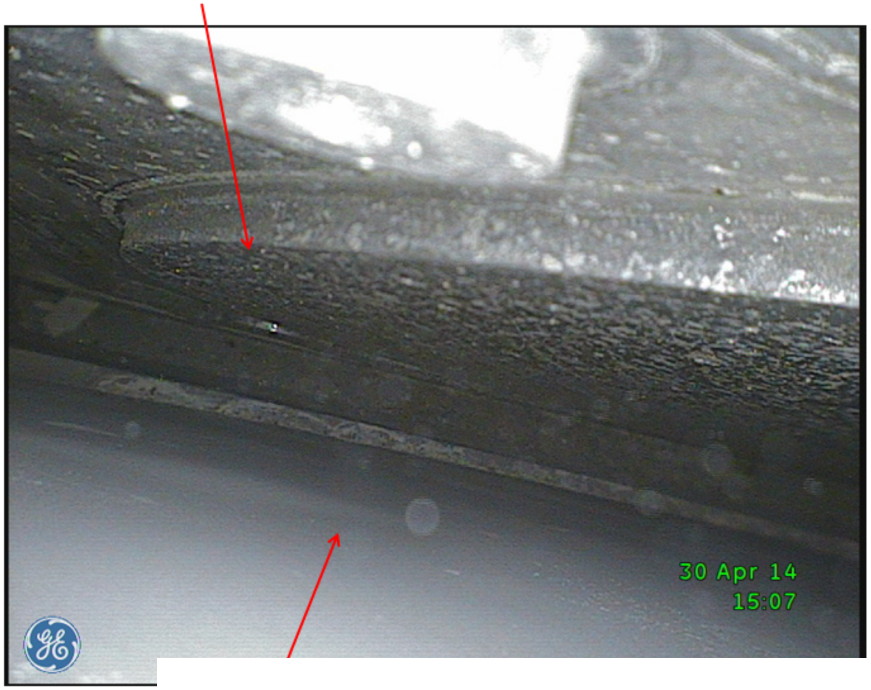




n_TOF target inspection

- External inspection performed in April 2014
- Only surface oxidation stains have been observed, due to humid atmosphere

Target neutron window (AW 5083) (3mm)



TOF tube

Target proton window (AW 5083)

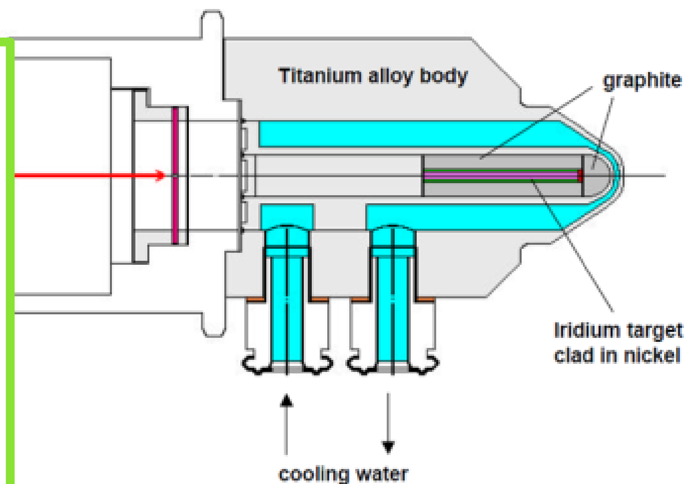
Beam impact spot

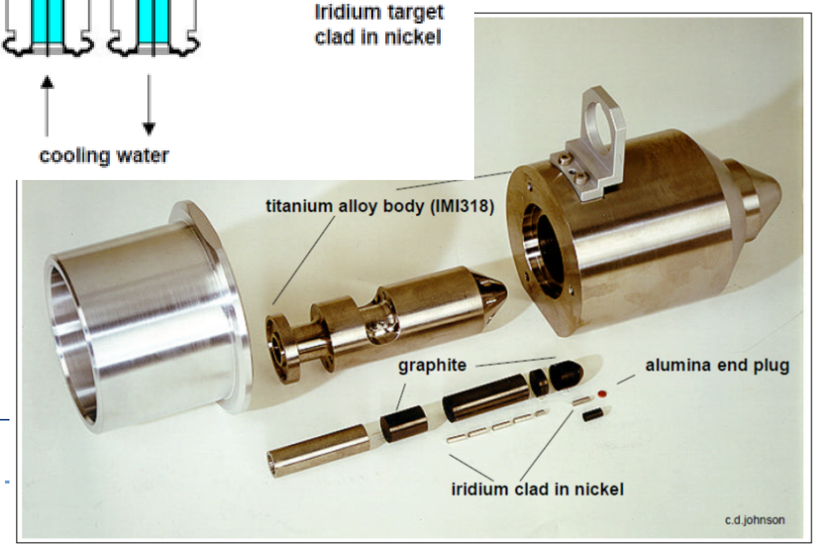
COMPLETE ANALYSIS ONGOING

Antiproton Decelerator (AD)

- Antiproton production for CERN's antimatter physics
  - ELENA ring under construction (100 keV pbars)
  - Operation foreseen for the next 20 years

- 26 GeV/c primary beam
- 0.5x1mm 1σ
- 1.5*10^{13} p/pulse
- 430 ns pulse length
- Rep rate ~60 s
- Iridium core





Antiproton Decelerator (AD)

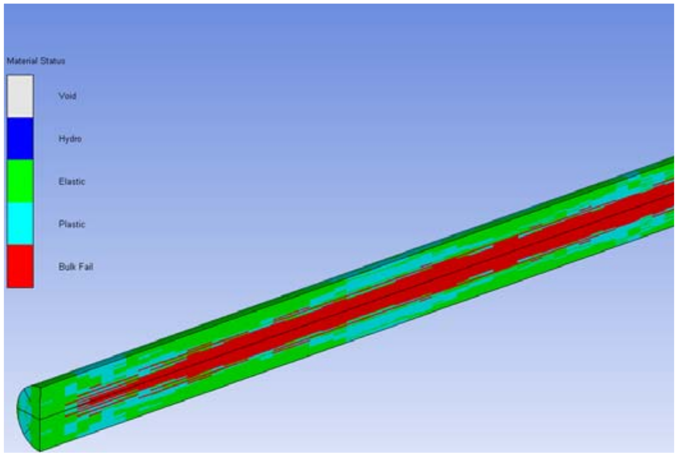
- Consolidation of target area until 2018, including the construction of a new optimized production target

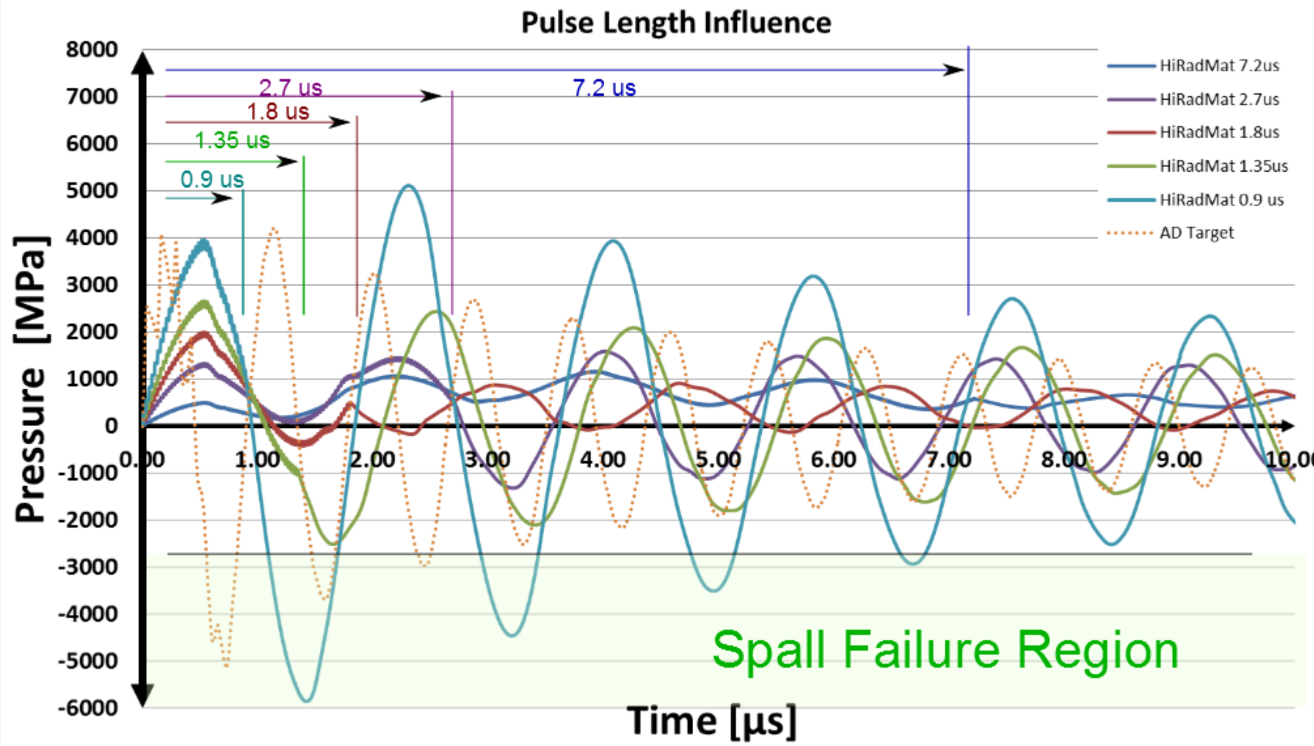
- Requirements for physics:
  - Compact target
  - High-Z material
  - Very focused primary beam

→

- Challenges:
  - Thermal shocks can damage target material
  - Extremely high energy density coupled with short pulse
    - 7.5 kJ/cm^3/pulse
    - **~17 GJ/cm^3/s**

Antiproton D



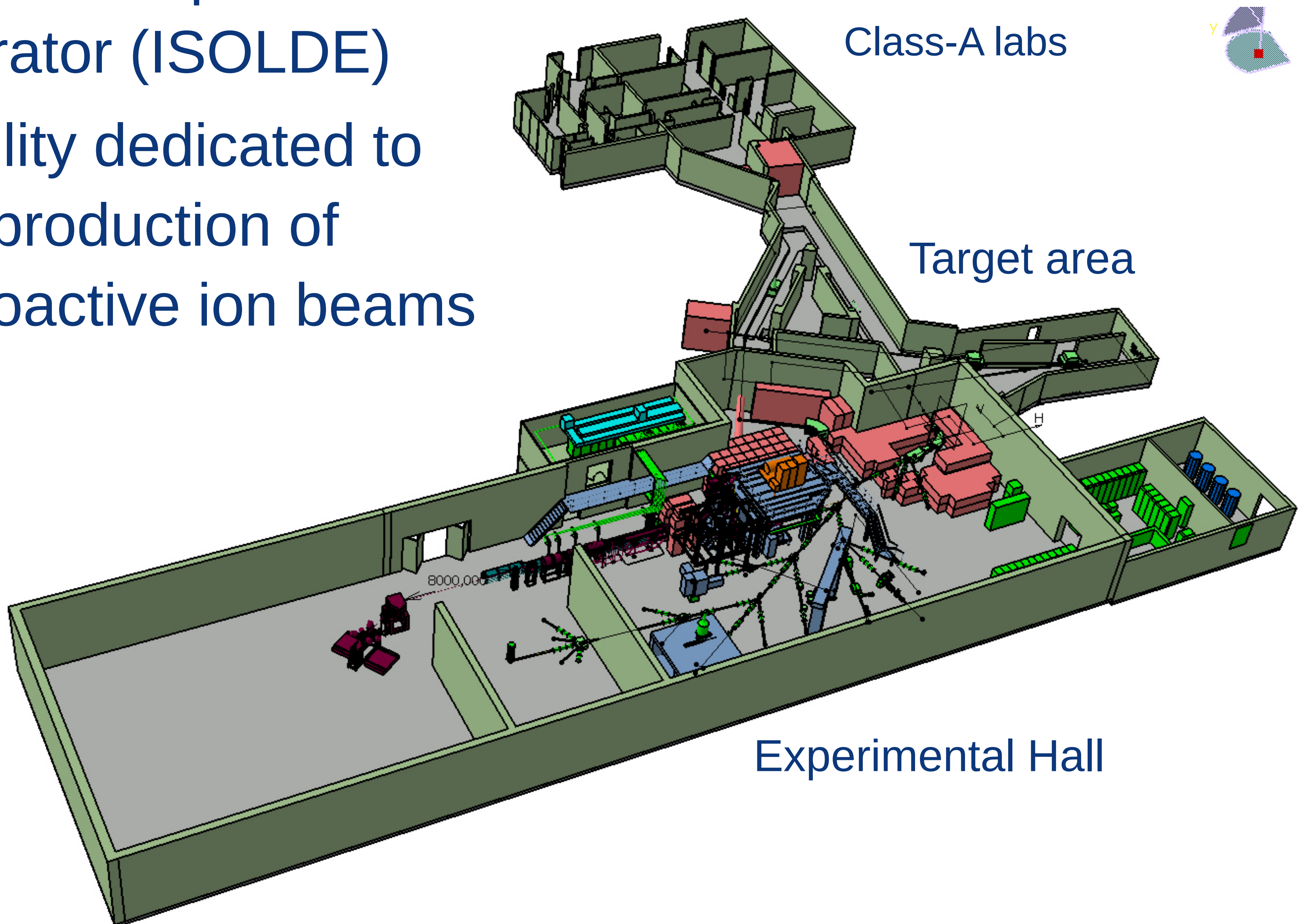


- **Hydro codes** being used to fully simulate plastic wave propagation
  - Material strength beyond plasticity
  - Material damage and failure

1. Pulse time influences dramatically the dynamic response
2. Experimental tests under proton beam is necessary
   - Validate numerical results & gain experimental insights on material response
3. **HiRadMat tests foreseen in 2015**

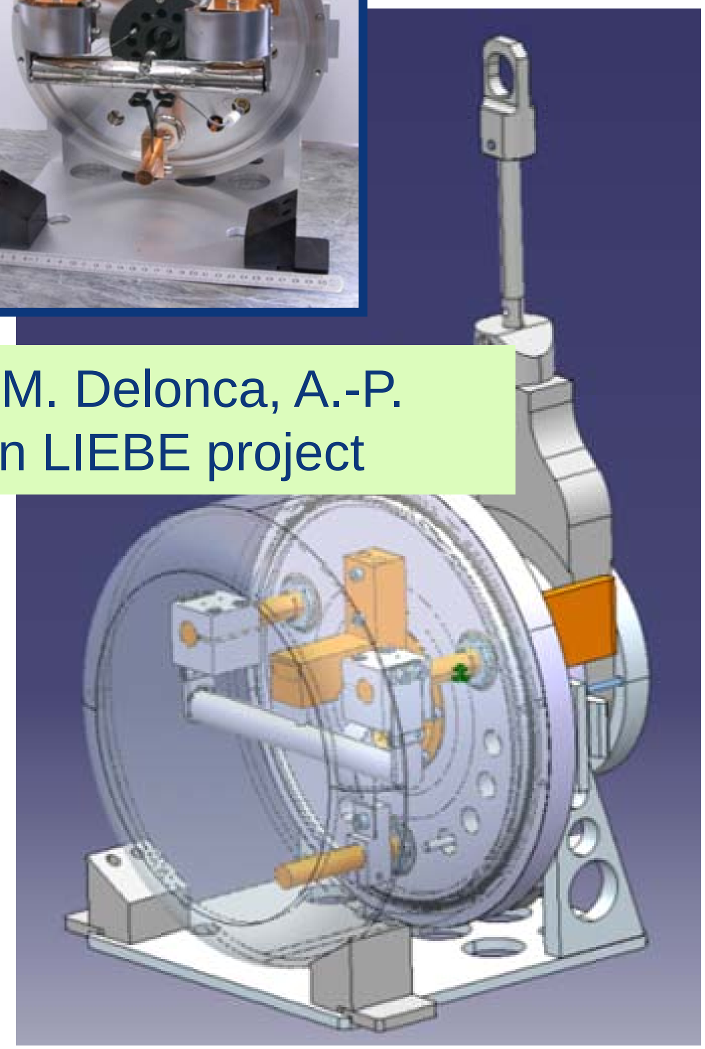
ISOLDE

- On-line Isotope Mass Separator (ISOLDE)
  - Facility dedicated to the production of radioactive ion beams



ISOLDE targets

- Different target materials employed
  - UC_x, SiC, Pb, Ta, Ti, MgO, CeO
  - ~30 units produced and operated per year
  - Remote handling and monitoring
- Lots of development going on



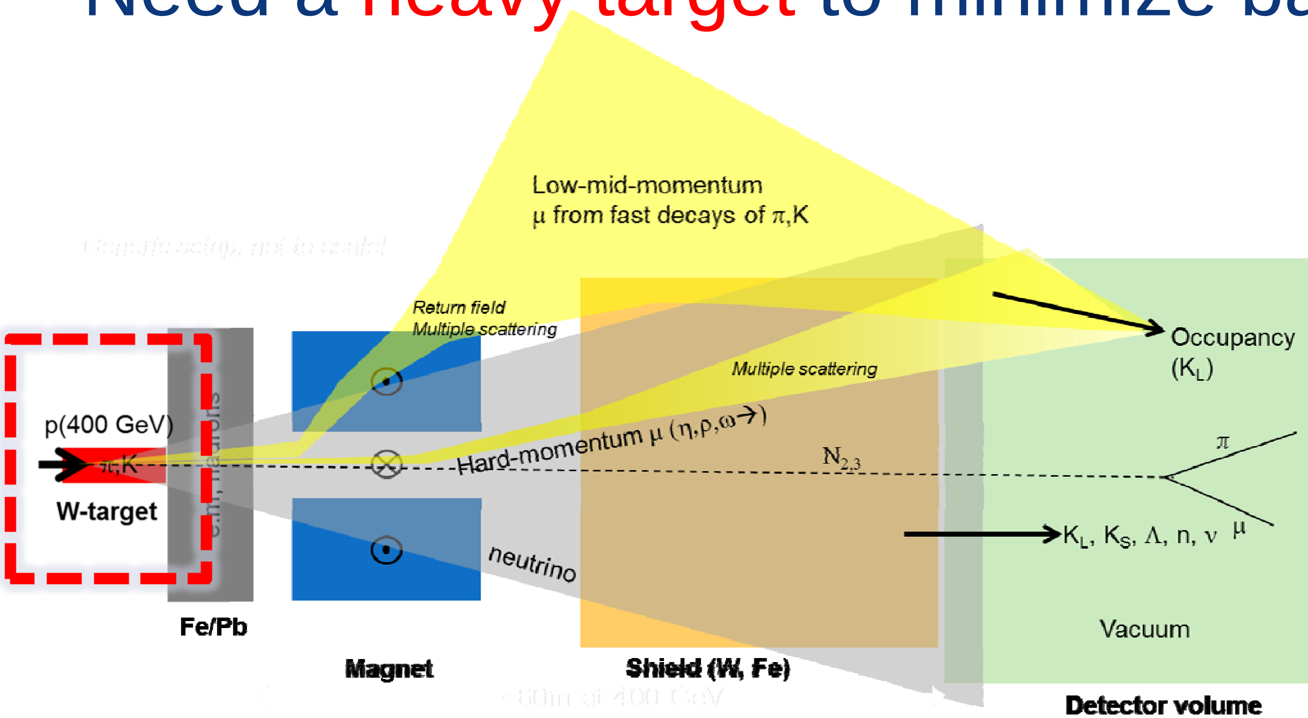
See talks of M. Delonca, A.-P. Bernardes on LIEBE project

- ISOLDE beam parameters:
  - 0.8-2.4*1013 p/pulse @1-1.4 GeV/c
  - 1.4-5.7 kW
  - 2.4-40 μs pulse, 1.2 cycle

SHIP – Search for Hidden Particles

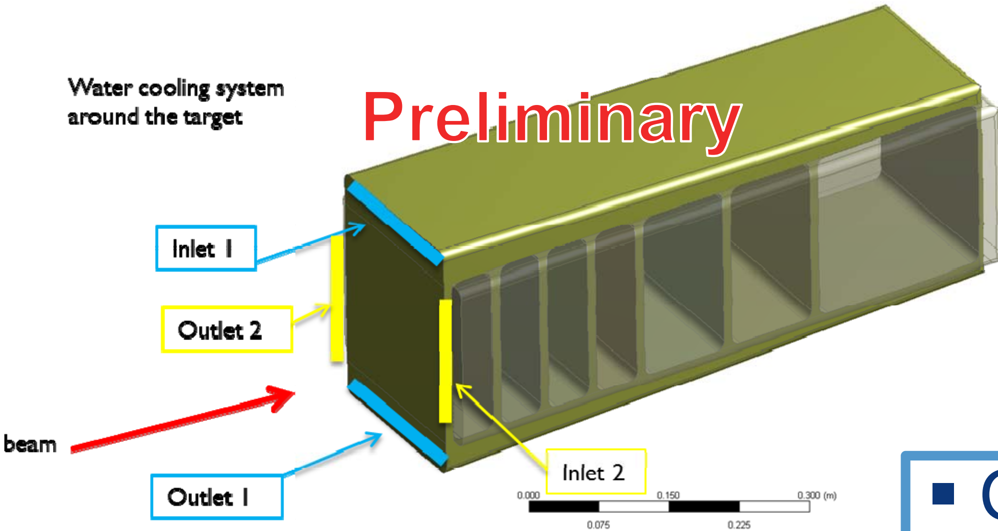
- New proposal at CERN aiming for a new fixed target experiment searching for very weakly interacting and longlived particles ~O(MeV-GeV)
  - http://arxiv.org/abs/1310.1762
  - Production through mesons decays (π, K, D, B)
  - Need a heavy target to minimize background

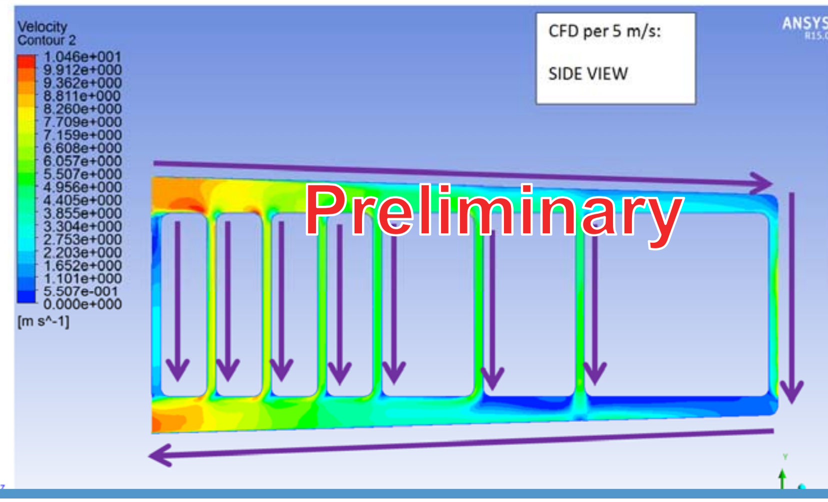
R. Jacobsson (CERN)



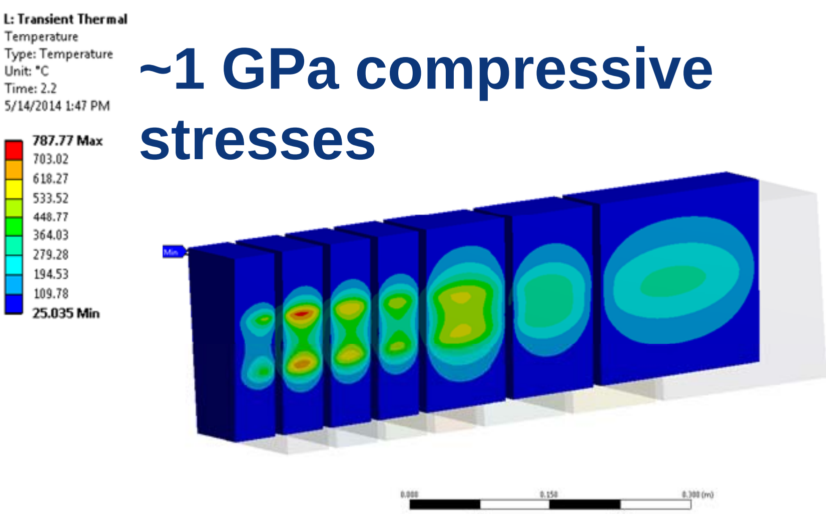
- **~530 kW** @400 GeV/c
- Slow extraction (~few seconds)
- High intensity (4.5-7.0*10^{13} p/pulse)

- W-based target
  - Inermet® and Densimet ® alloys being investigated
  - Target must be segmented to withstand beam power





~1 GPa compressive stresses



- Challenges:
  - High water flow rate (~10 m/s)
    - Corrosion/erosion - Water chemistry
  - High compressive stresses due to pulsed beam
  - R&D on material properties, degradation of properties with radiation (RaDIATE?)

Conclusions

- Fixed target experiments a backbone of CERN's programs
- Several different operating target stations
- Consolidation programs ongoing
- New challenging projects are being proposed

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North Area targets