EN Engineering Department

CERN

CNGS target operation and modified design

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Acknowledgments

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- L. Bruno, D. Grenier, O. Aberle, A. Ferrari, P. Sala, R. Losito, C. Maglioni, M. Delonca, A. P. Bernardes, N. T. Vuong, M. Meddahi, K. Cornelis, K. Elsener, E. Gschwendtner, J. Wenninger, I. Efthymiopoulos, CRS4, and many others.

Outline

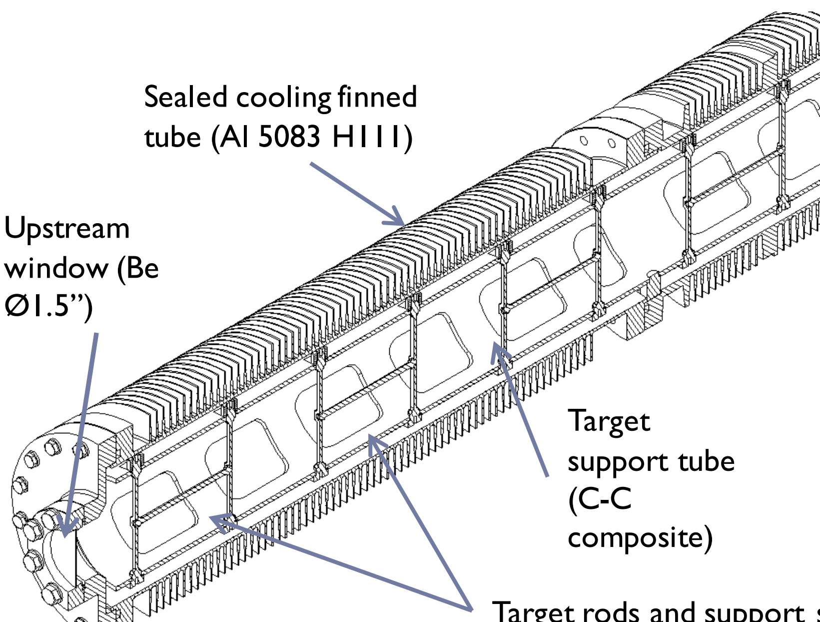
- Introduction to beam parameters
- Review of CNGS target design
- Selected issues encountered during the operation of the CNGS target
- Preparation of the CNGS spare target
- Conclusions

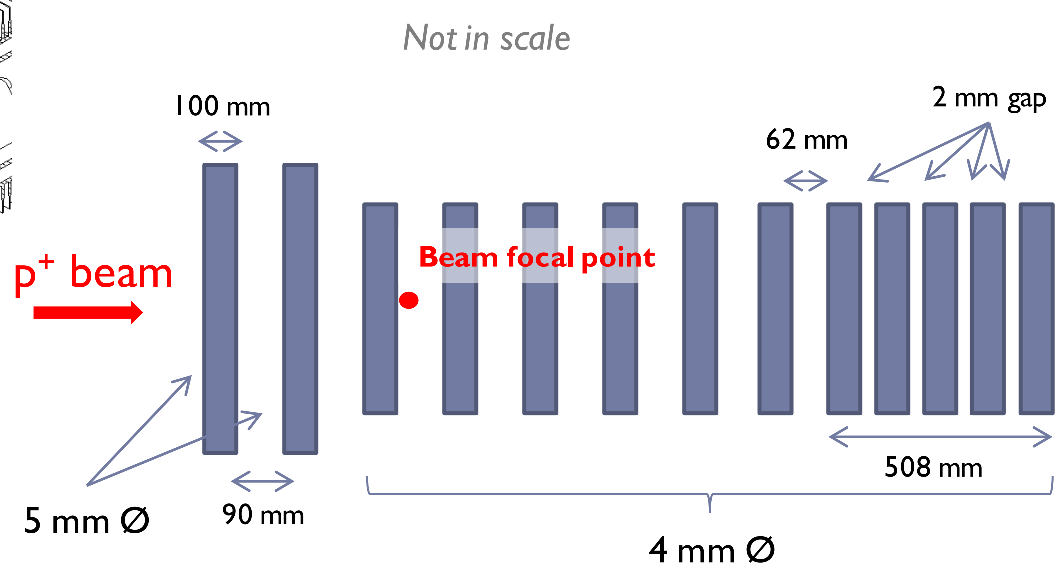
Primary beam parameters

- **400 GeV/c** primary beam momentum, 2 fast extraction every 6 seconds
- Nominal beam intensity **$2x2.4*10^{13}$ p+/pulse** in **10.5 μs**, interleaved by **50 ms**
  - Ultimate beam intensity ~$2x3.5*10^{13}$ p+/pulse
- Nominal beam power **~500 kW**
  - Ultimate beam power ~750 kW
- $1\sigma_{x,y}$ beam on target: **0.53 mm**
- Beam divergence at focal point: $0.053(\sigma_x) – 0.03(\sigma_y)$ mrad

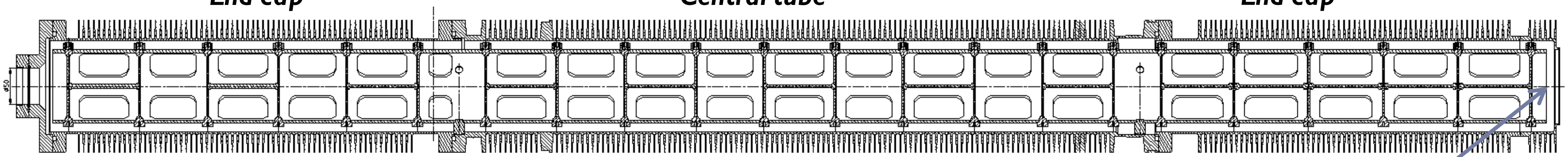
Review of the CNGS design

- The CNGS target unit is conceived as a **static sealed system filled with 0.5 bar of He**
  - 130 cm long graphite target (~3 λ_L)
  - Cooling of target rods by radiation towards the Al tube and partly by convection
  - Target revolver flushed with air which keep Al temperature <100 °C





Review of the CNGS design



- Tube has **annular fins** to enhance the convective heat transfer
  - Ni-coated Be window (380/630 μm), e-welded to Al
- **Target rods** installed on a **carbon support structure** with holes in order to increase the thermal exchange

CNGS target rods

5 UNITS ARE INSTALLED IN A SINGLE MAGAZINE

1. **Graphite** target with baseline geometry under **He**
   1. 2020PT Carbone Lorraine
   2. Best understood carbon (ρ=1.76 g/cm3) → standard target
2. **Carbon** target with baseline geometry under **He**
   1. Sintered carbon SC24 by Sintec Keramik
3. **C-C composite** target with baseline geometry under **He**
   1. Aerolor A035 Carbone Lorraine
4. **Graphite** target with baseline geometry under **vacuum**
   1. 2020PT Carbone Lorraine
   2. Vacuum for possible concern of stress cycling on the Be windows from thermal expansion of gas
5. **"Safe" target**: graphite target with all 5 mm diameter rods under He

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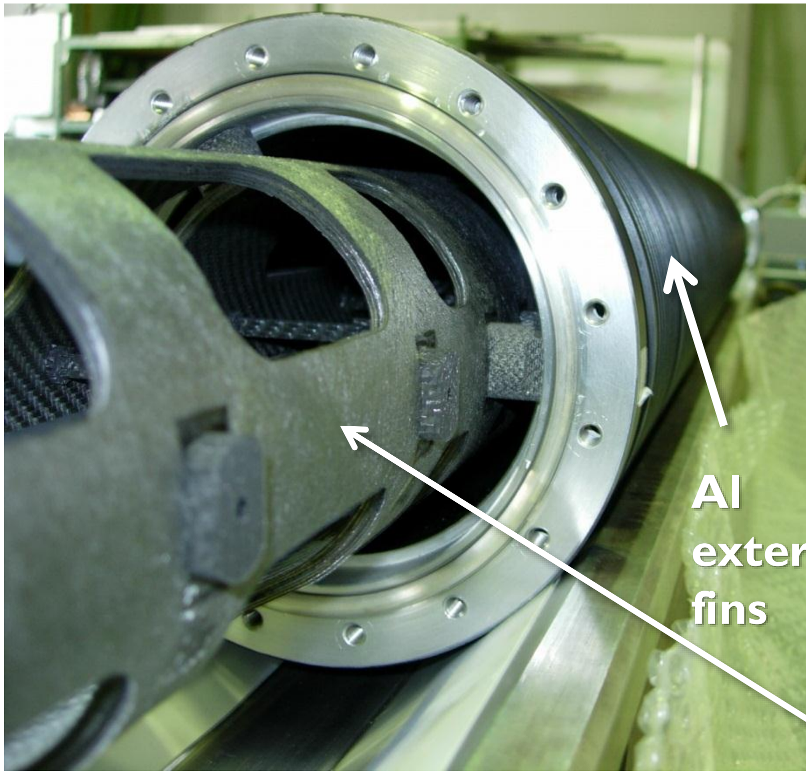
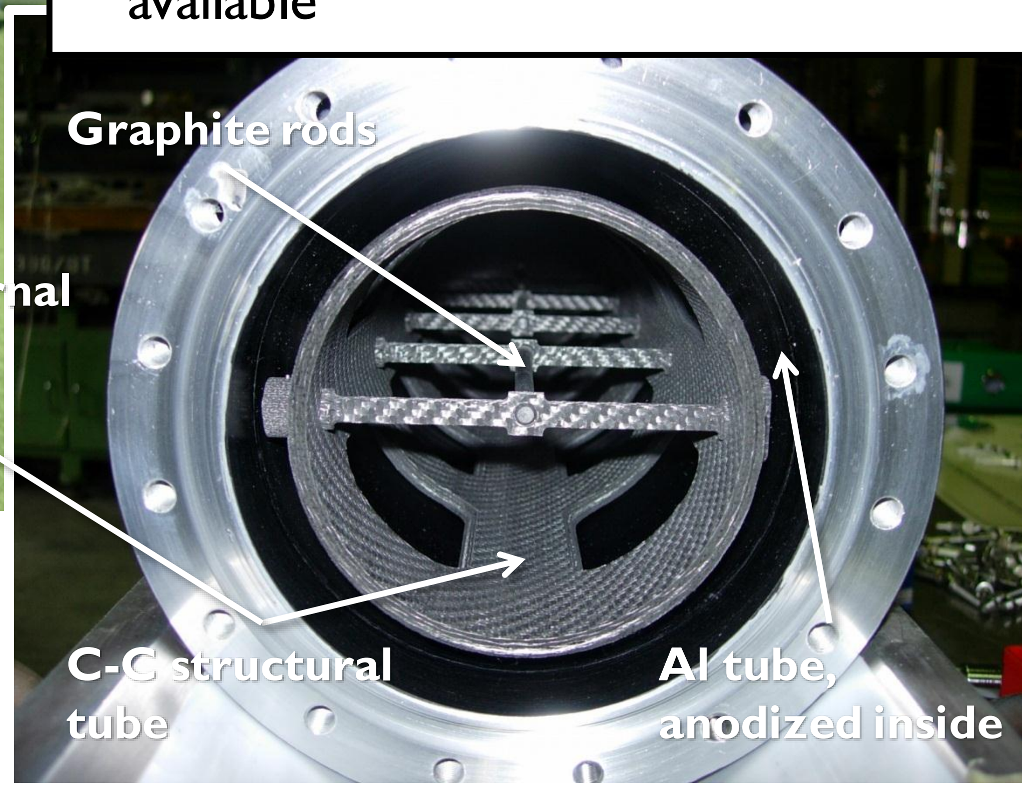
CNGS target unit as built

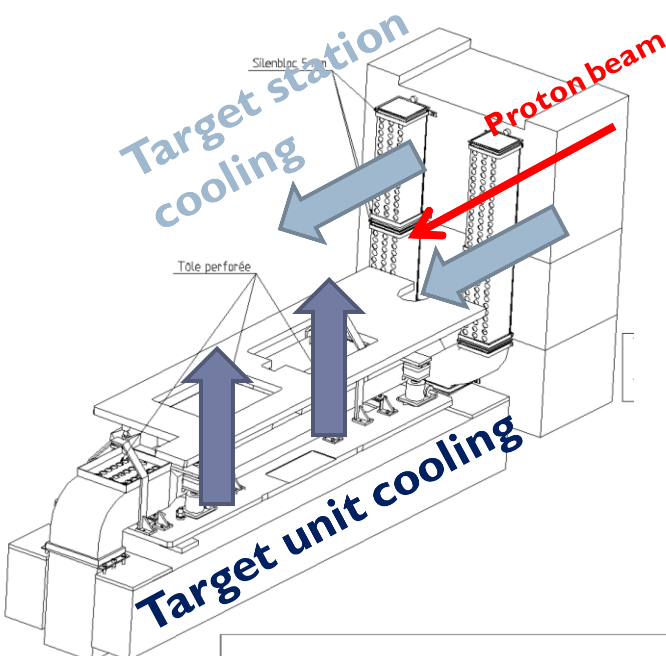
- 5 units (1 active + 4 in-situ spares) are hosted in a target magazine
- An additional spare magazine is available

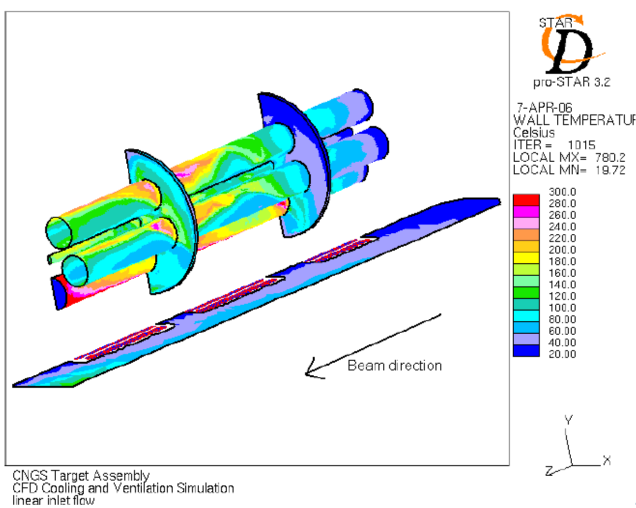




$T_{graphite} \sim 990\ ^{\circ}C$
$T_{C\text{-}C} \sim 375\ ^{\circ}C$
$T_{He} \sim 365\ ^{\circ}C$

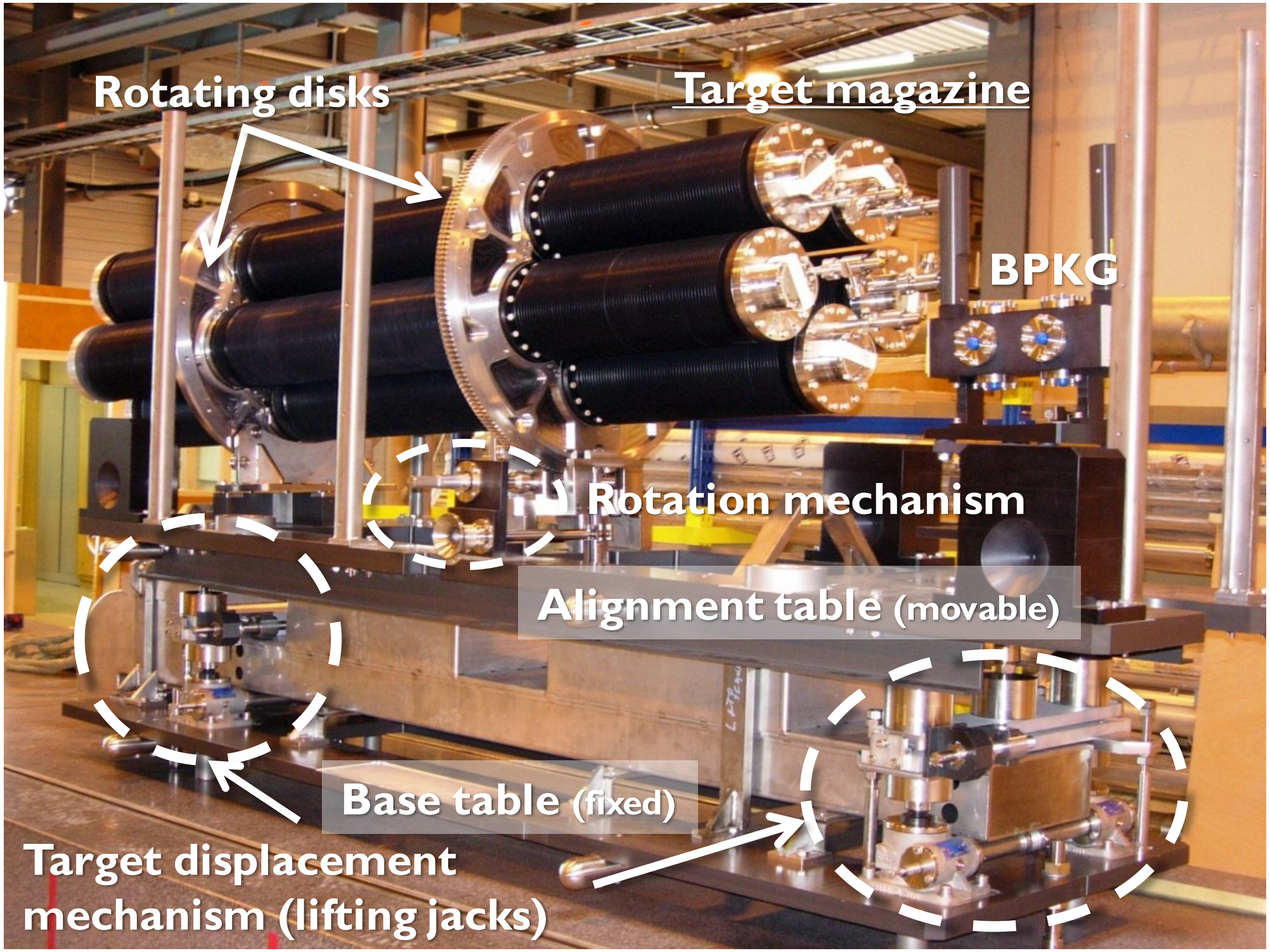
Target assembly and shielding cooling





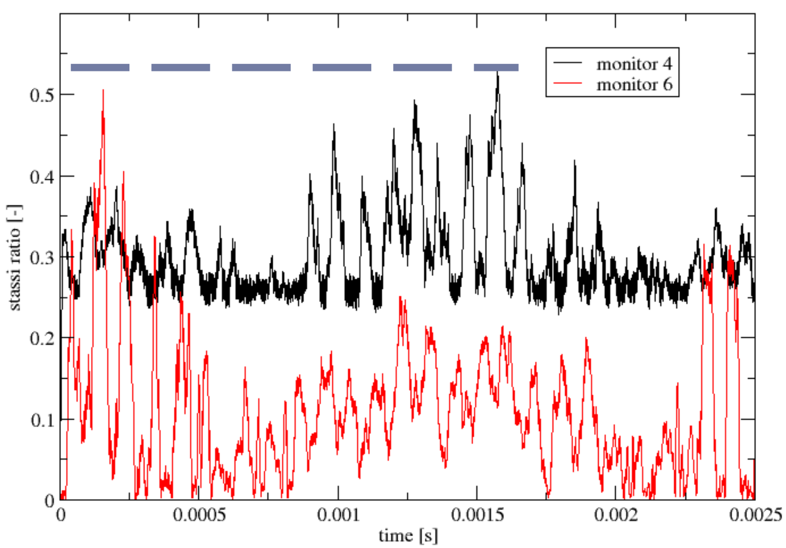
- Two air streams in the TS, not affected by each other (3600 m^3/h)
  - Vertical airflow parallel to the fins of the target assembly → **TARGET**
    - **~6 kW** to evacuate
    - T_{av} = 85/93.5 °C
  - Horizontal airflow parallel to the fins of the shielding → **SHIELDING**
    - **~15 kW** (~13 kW side wall shielding)
    - T_{avsh} = 40-300 °C

Target unit as built and installed in CNGS



Stresses on the CNGS target rods

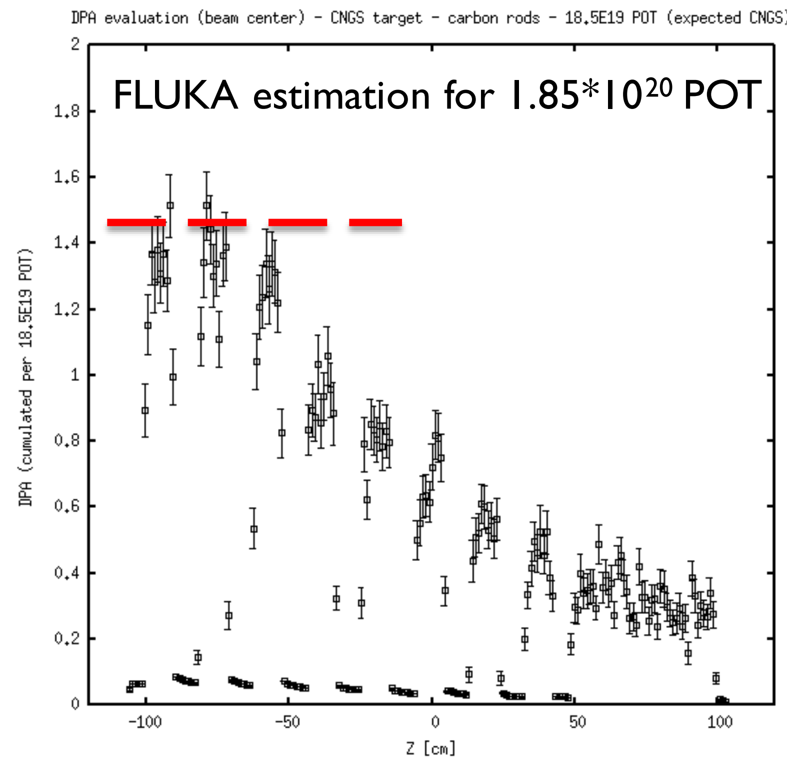
- Critical point in the design for CNGS was the **resistance to off-axis beams**
  - Worst loading (1.5 mm OA, ultimate intensity, cold target, no damping)
  - Temperature increase & boundary conditions → dynamic stresses on rods → rapid transversal vibration
    - Stassi ratio **always lower than 0.7 for a single bunch**



- Effect of the 2nd extraction:
  - Time for equilibrium > bunch spacing → 1st bunch effect still present when 2nd bunch comes
  - ~32 Mpa at 1.5 mm OA → **Stassi ratio 0.89**

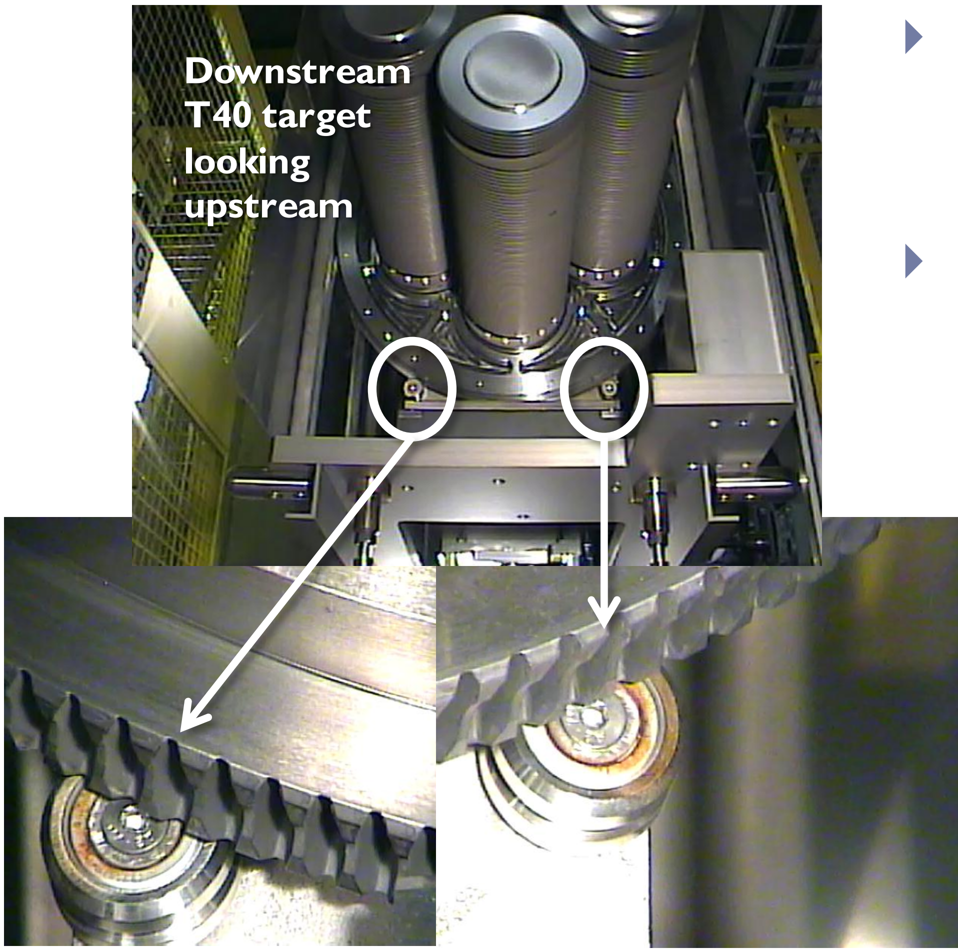
Radiation effects on the target

- Cumulated POT on target up to now: **$1.76*10^{20}$ POT**
  - **~1.5 DPA** expected (averaged around 0.3 mm) at the end of 2012 for the first three rods



- Operation at high temperature:
  - Minimization of shrinkage and reduction of thermal conductivity
  - Favour annealing and reduction of imperfection

Target rotation system failure

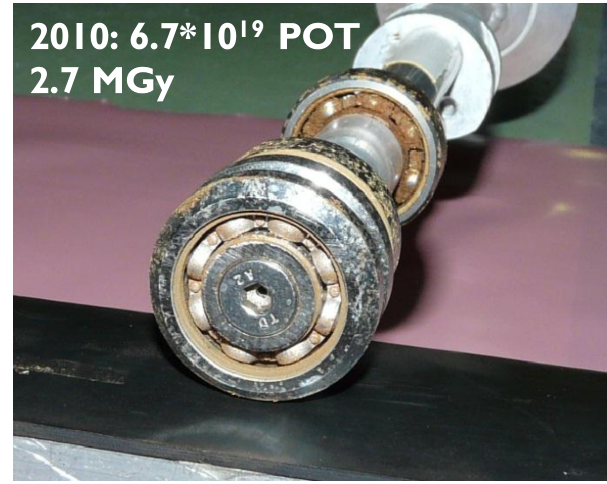


- 2009: unexpected **increased torque in the magazine rotation motor**
- April 2009 → in-situ inspection of the target via remote-controlled webcam endoscopy

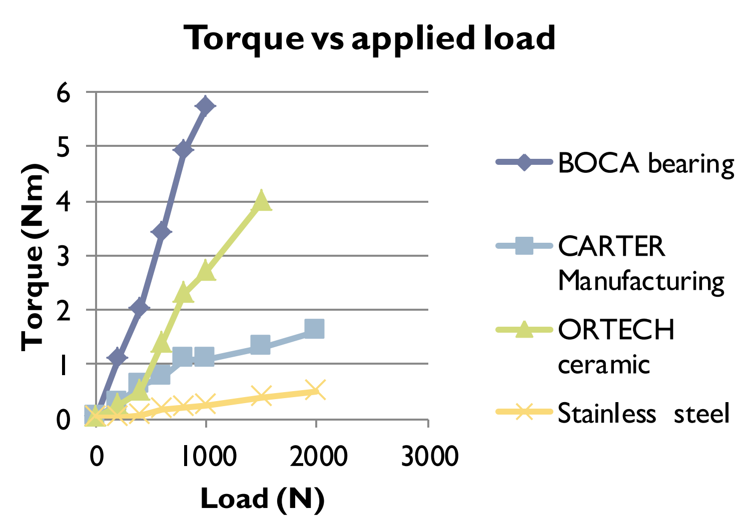
- All bearings has signs of **rust**, now all of them **do not move**
  - Measured torque of ≥30 N*m vs. design value of 8 N*m

Bearing irradiation and observation

- Original bearings:
  - Martensitic SS440C (inner and outer races)
  - Martensitic SS X46Cr13 (balls)
  - **Tested at CNGS during 2009/2010**

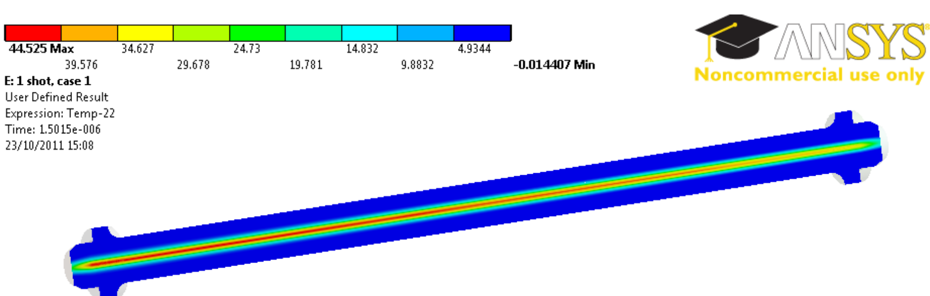


- Significant **rust/pitting corrosion** present (10 N*m estimated torque)
- Low grade of X46Cr13 likely the cause of observed failure (no alloying elements, low Cr/high C content)
- Ceramic (Si_3Ni_4/ZrO_2) bearings presently under test

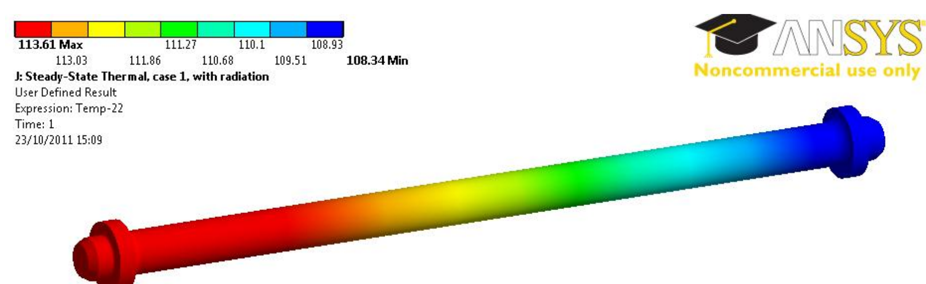


CNGS bunched beam calculations

- Two runs with **LHC-type bunches** has been performed:
  - CNGS-type beam: 2100 bunches @1*10^{10} p/bunch, 5 ns bunch spacing, 2 extraction (50ms)
  - LHC-type beam: 16 bunches @1*10^{11} p/bunch, 100 ns bunch spacing, 4 batches
- Thermo mechanical analysis proven that:
  - Batch spacing has no significant effect on the target cooling
  - Bunching/batching structure has no effect on the wave propagation and on the quasi-static stresses



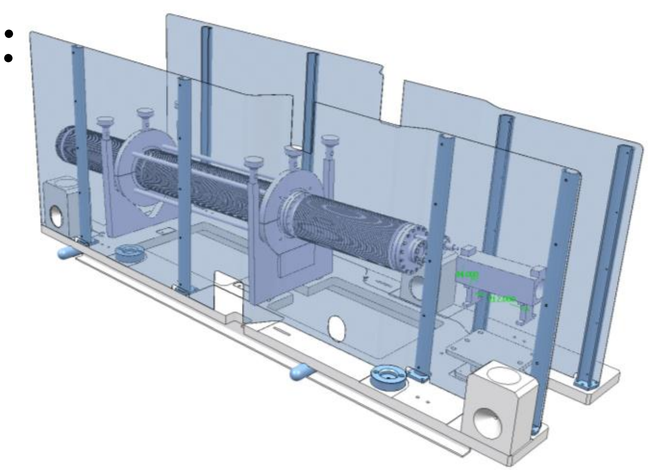
Max ΔT (instantaneous) ~45 K



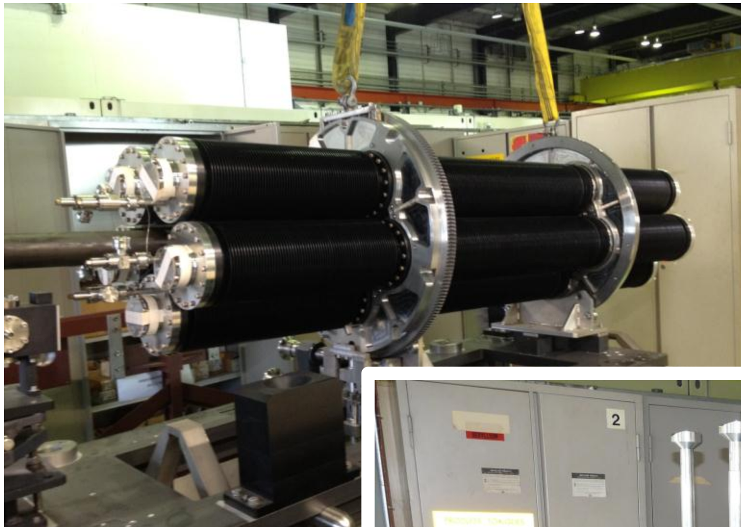
Max ΔT steady state ~114 K

Preparation of a CNGS spare target

- During the study of the bunched beam operation we started worrying about the **status of the target**
  - The same since first beam in 2006 (6 years of running)!
  - Corrosion of ball bearings for the magazine rotation do not allow anymore to user the spare targets: 4 magazine lost!
- Needed to guarantee **whole 2012 operation**!
- Preparation of the spare CNGS target:
  - Installation of a single magazine
  - Completely remote installation



CNGS spare target



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CNGS spare target ready for installation

CNGS spare target

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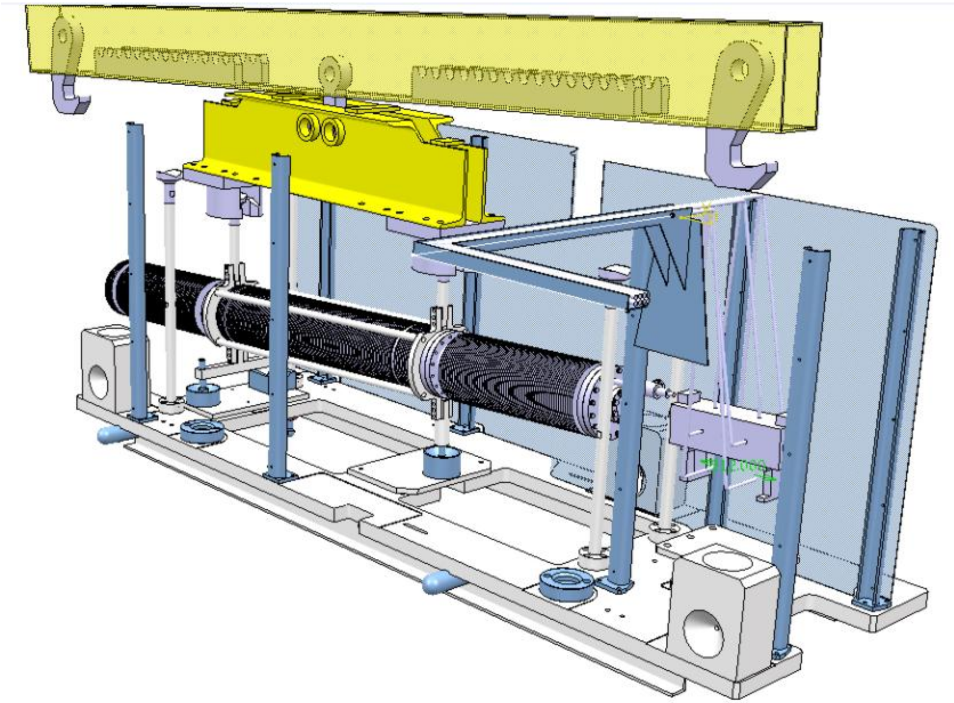
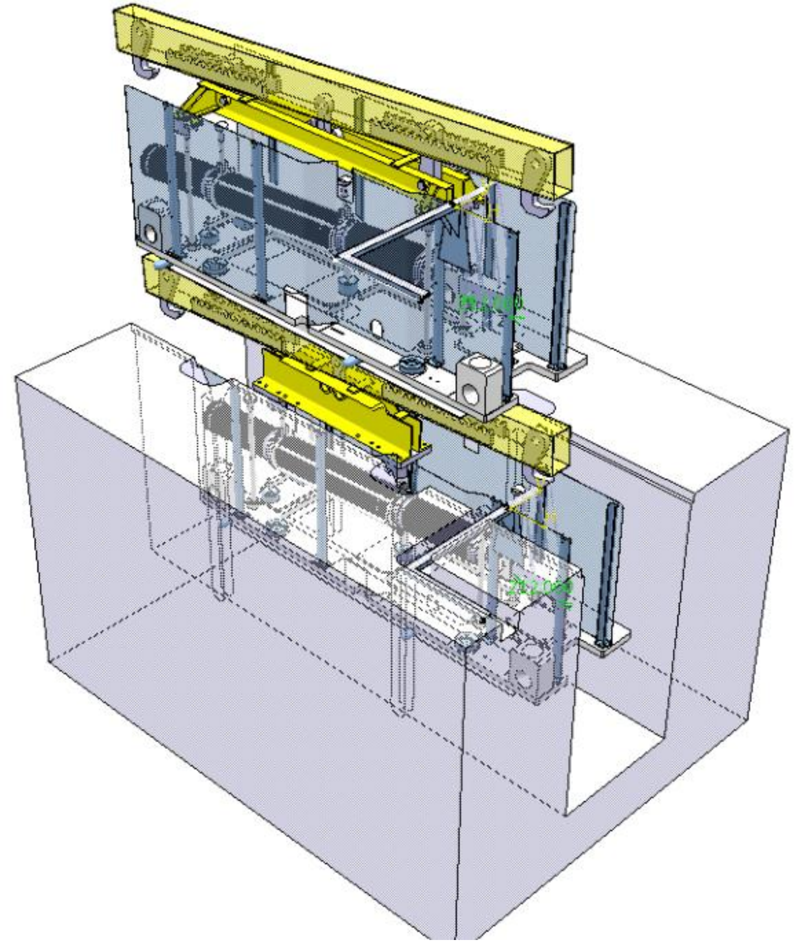




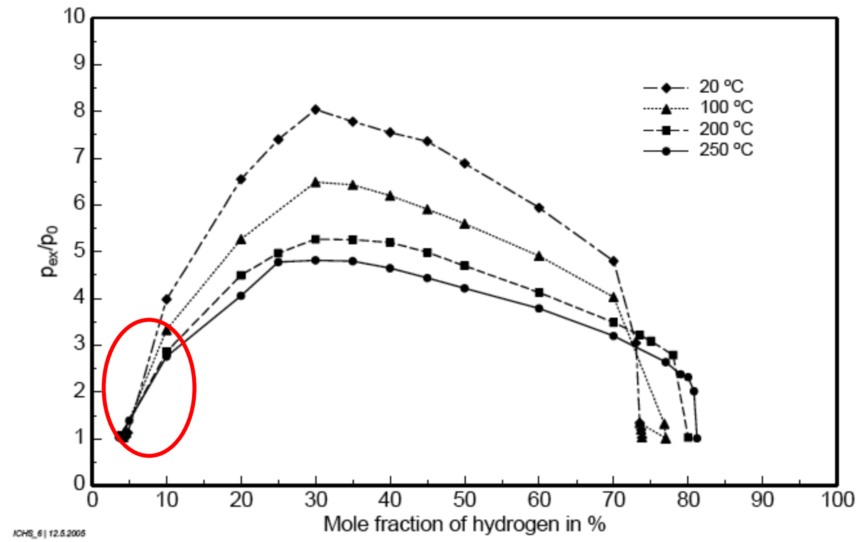
- New CNGS spare target – completely **remotely handled**

Hydrogen production in the CNGS target

- Spallation reactions in C: production of variety of particles including ^{1}H, ^{2}H and ^{3}H
  - The least energetic can stop in the target giving rise to an **hydrogen build-up**
- FLUKA simulations: for $1.2*10^{20}$ POT → **$3.5*10^{21}$ H** atoms produced up to know (safety factor 2/3x)
- Assuming all H atoms desorbed from target solid structures:
  - **~65-195 ml** of atomic H at atmospheric pressure
  - **~0.4-1.1% H_2** in the target box
  - Target pressure ~1.2 bar during operation
    - Max resistance of Be windows at the extremities ~2 bar

Explosion risk analysis

- During **operation**:
  - Overpressure in case of explosion remains quite low (~2-3 bars)
  - Risk real only in case of a dramatic failure of one window
  - Spread of contaminated powder in close vicinity (horn?)
- During **maintenance**:
  - The low temperature reduce the risks and the associated overpressure
  - No special precautions needed



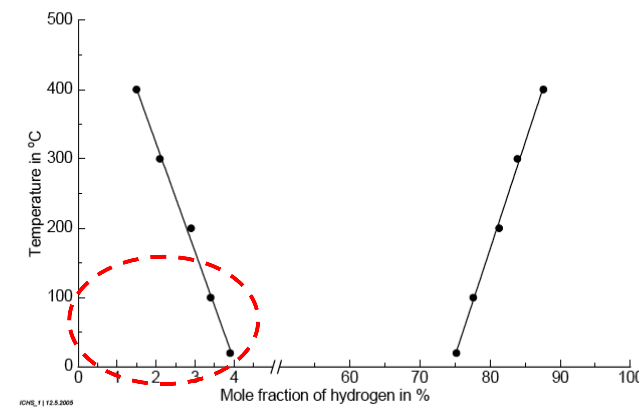
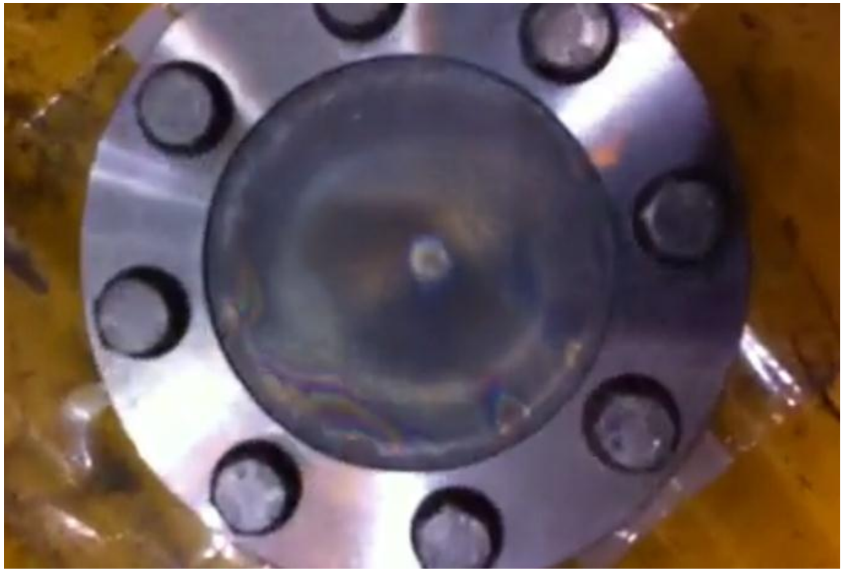


Figure 1. Influence of the temperature on the explosion limits of hydrogen-air mixtures, measured at atmospheric pressure according to DIN 51649 [8]

Failed Be window picture

- No analysis done for the moment due to the very high residual dose rate



Conclusions

- **CNGS target successfully operating since 2006**
  - It has received up to $1.76*10^{20}$ POT up to now, out of the approved $2.25*10^{20}$ POT – no target exchange needed
- Target design has drawn experience from past CERN fixed targets, with **increased challenges due to high proton beam power** (750 kW → 1.5 MW possible)
- Operational issues encountered in operation are similar to those observed at other high power neutrino facilities
- A **spare target has been prepared** in case of a possible target failure – complete remote handled
  - Useful experience for future new targets