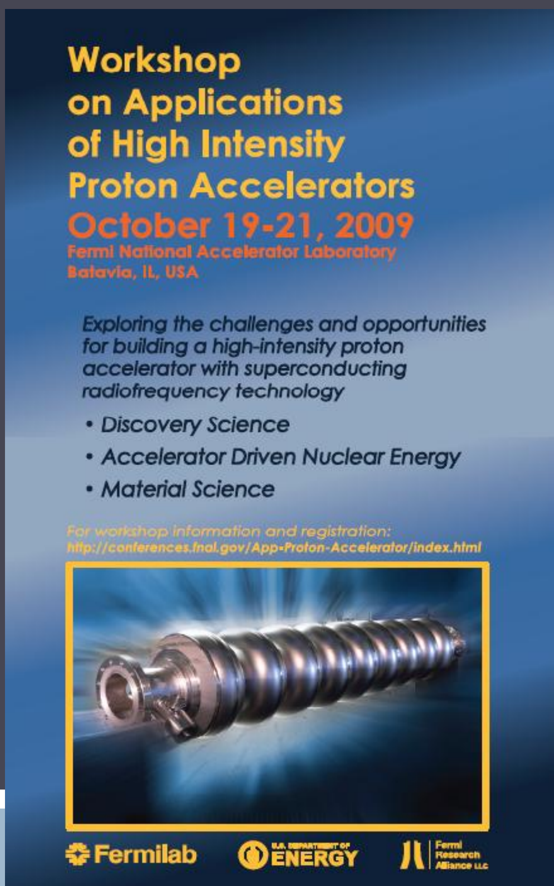
TARGET STATION INFRASTRUCTURE THE CNGS EXPERIENCE



Outline

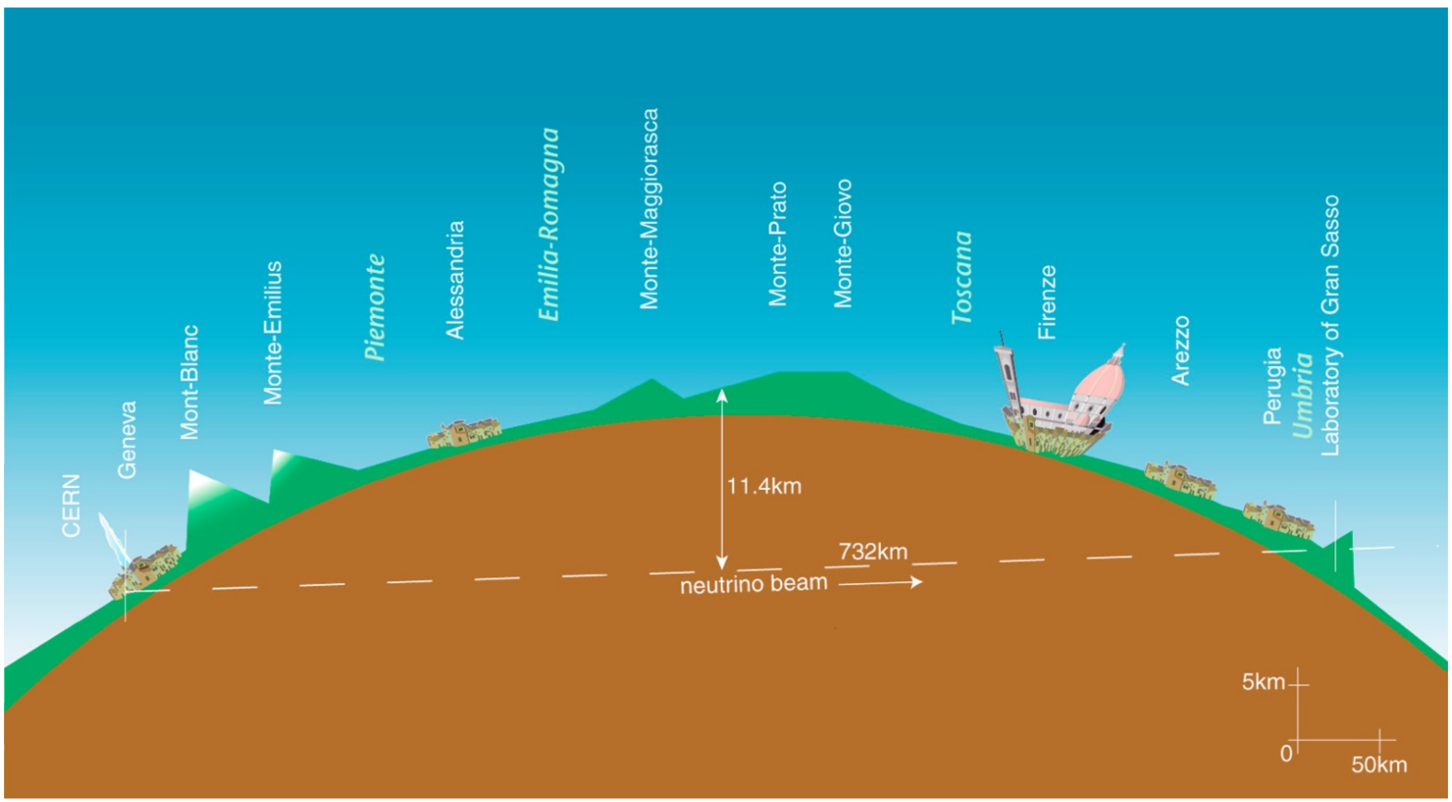
- Introduction to CNGS
- Review on issues since the startup of the facility in 2006
- Lessons learned – things we would do differently today

D. Autiero, **I. Efthymiopoulos**, A. Ferrari, E. Gschwendtner, A. Guglielmi, A. Pardons, P. Sala, H. Vincke, J. Wenninger

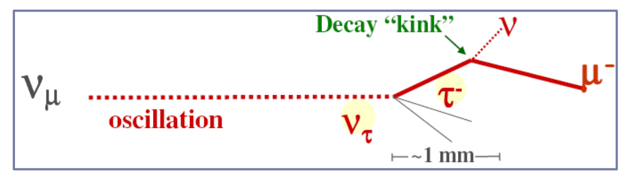
Introduction

Principle

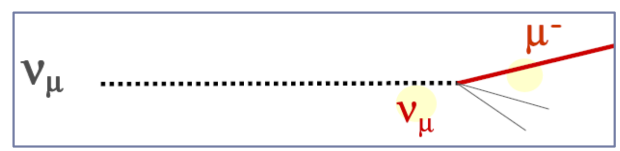
- At CERN: Produce a beam of ν_μ neutrinos at CERN pointing towards Gran Sasso using an intense proton beam extracted from SPS at 400 GeV/c impinging a graphite target
- At Gran Sasso: detect the ν_τ neutrinos resulting from the oscillation of ν_μ neutrinos in the ~730K km of earth
  - ν_τ **appearance** optimized experiments: **OPERA** (~1.2kt), **ICARUS**(600 t)



- Signal event

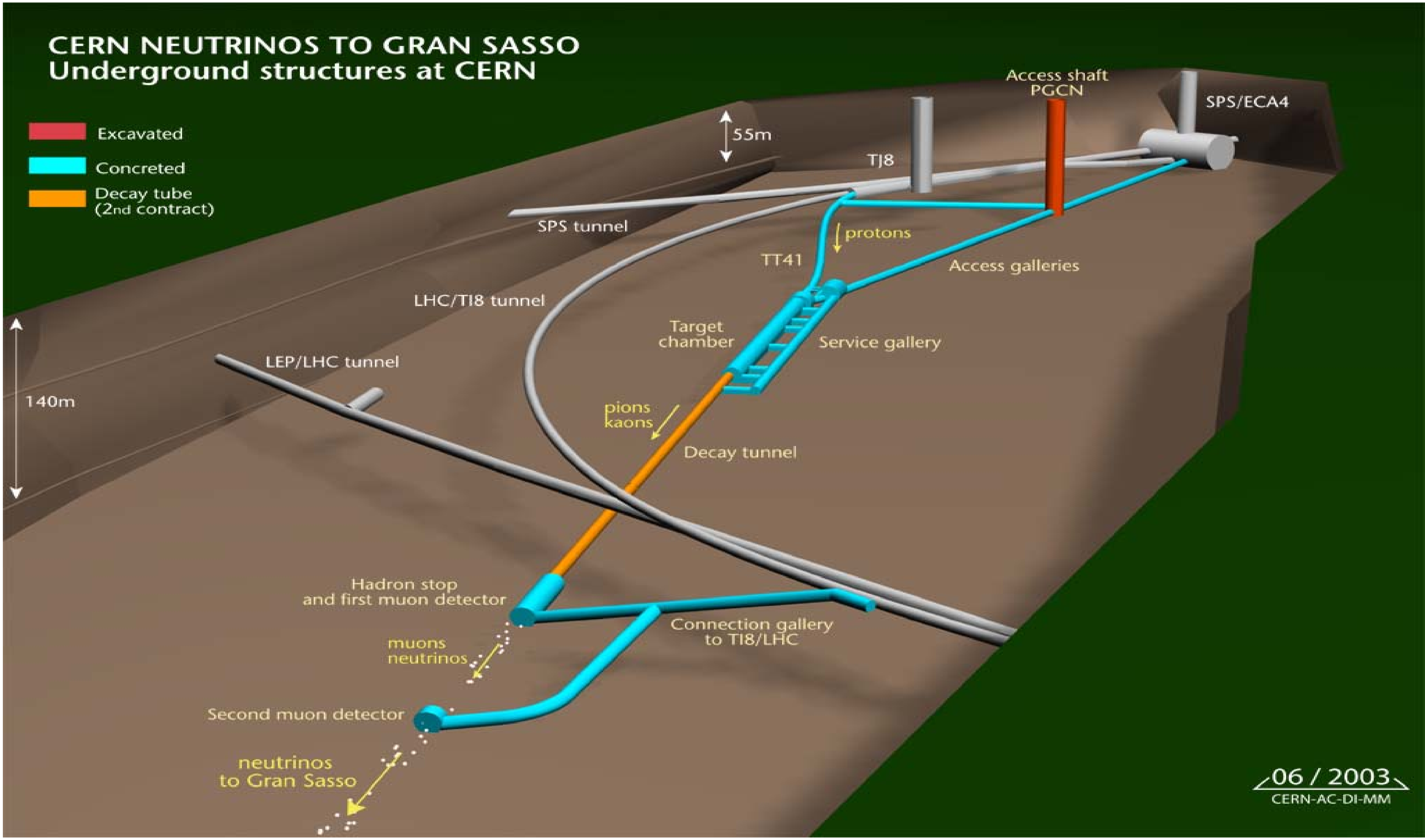


- Background event



CERN Neutrinos to Gran Sasso

Facility layout

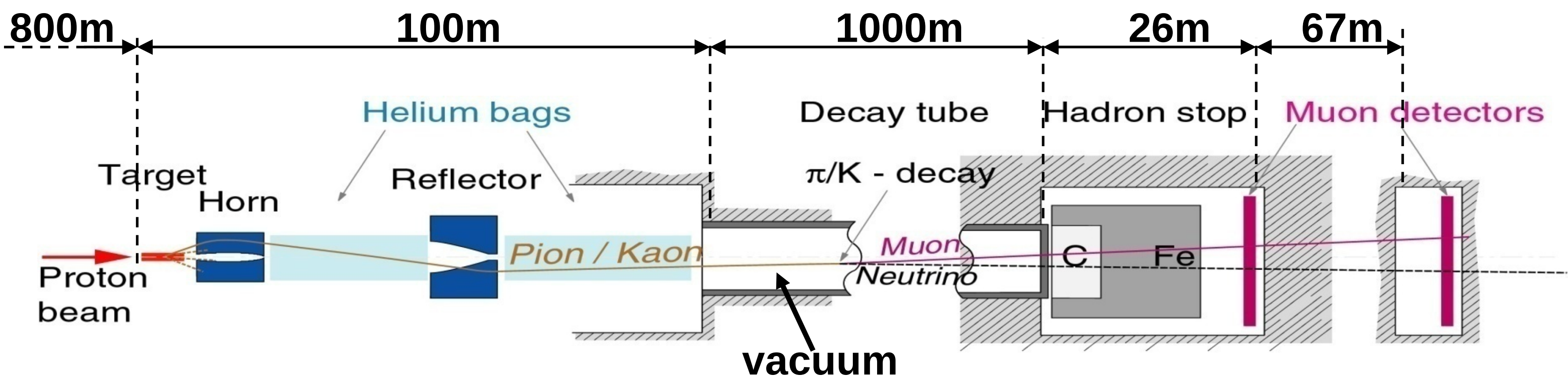


I.Efthymiopoulos, CERN

CERN Neutrinos to Gran Sasso

The secondary beam

$$p + C \rightarrow \text{(interactions)} \rightarrow \pi^+,\ K^+ \rightarrow \text{(decay)} \rightarrow \mu^+ + \nu_\mu$$



Proton beam parameters	
Energy	400 GeV/c
Cycle length	• 6 seconds • 2 extractions/cycle, 50ms apart
Extraction	• 2.4×10^{13} protons • 10.5 μs long pulse
Beam power	• **510 kW**

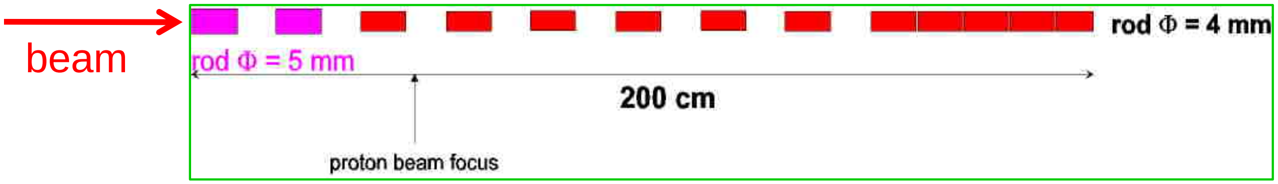
- Installation completed in **June 2006**
- Commissioning in 2006
- In operation since **2007**

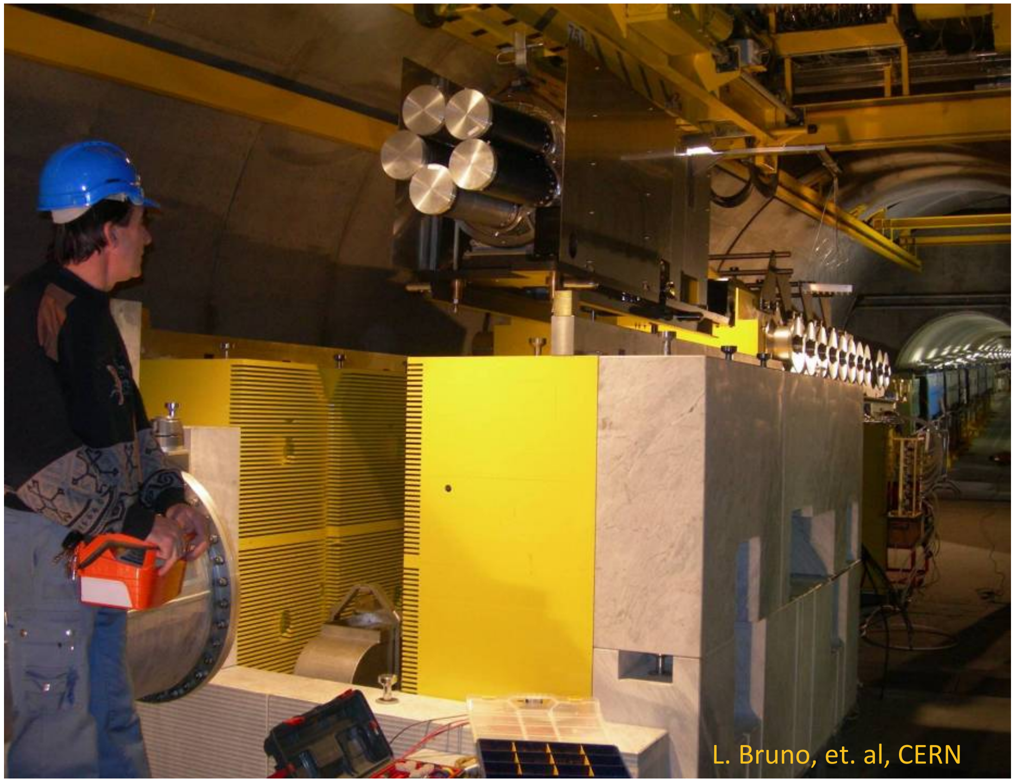
- **4.5×10^{19} protons/year** – 5 year program
  - ~3.5×10^{11} ν_μ / year at Grand Sasso
  - ~3000 CC ν_μ interactions/kt/year at the experiment
  - **~2÷3 ν_τ interactions detected/year** (OPERA)

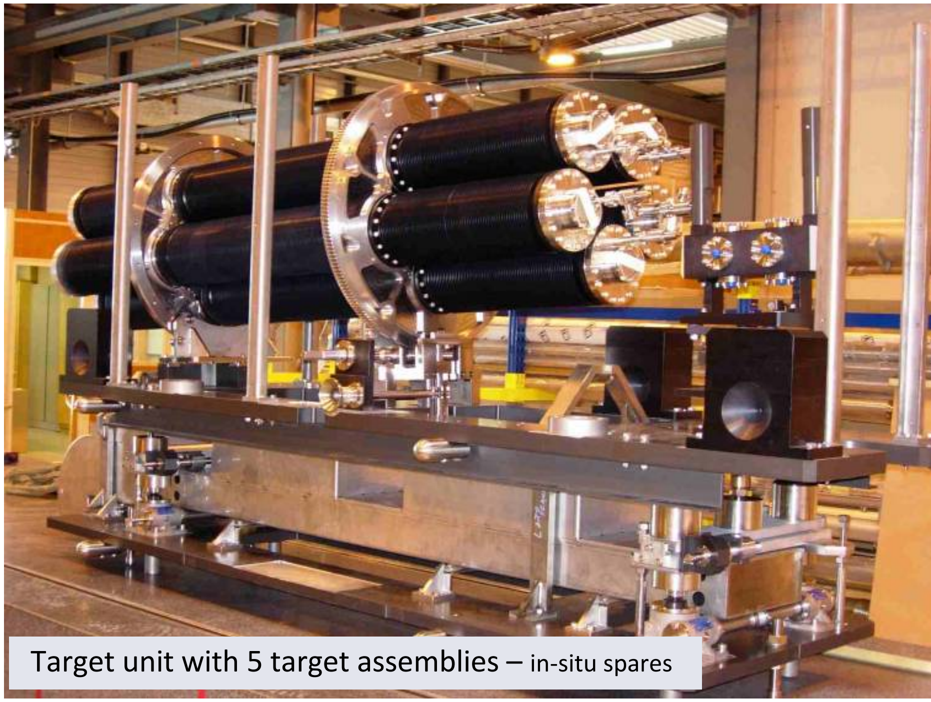
Key elements of the secondary beam

The target station

- Interspaced **graphite rods**, to optimize pion production
  - 10cm long, 5(4) mm Ø, 200 cm (~2.7 λ_{int}) total length







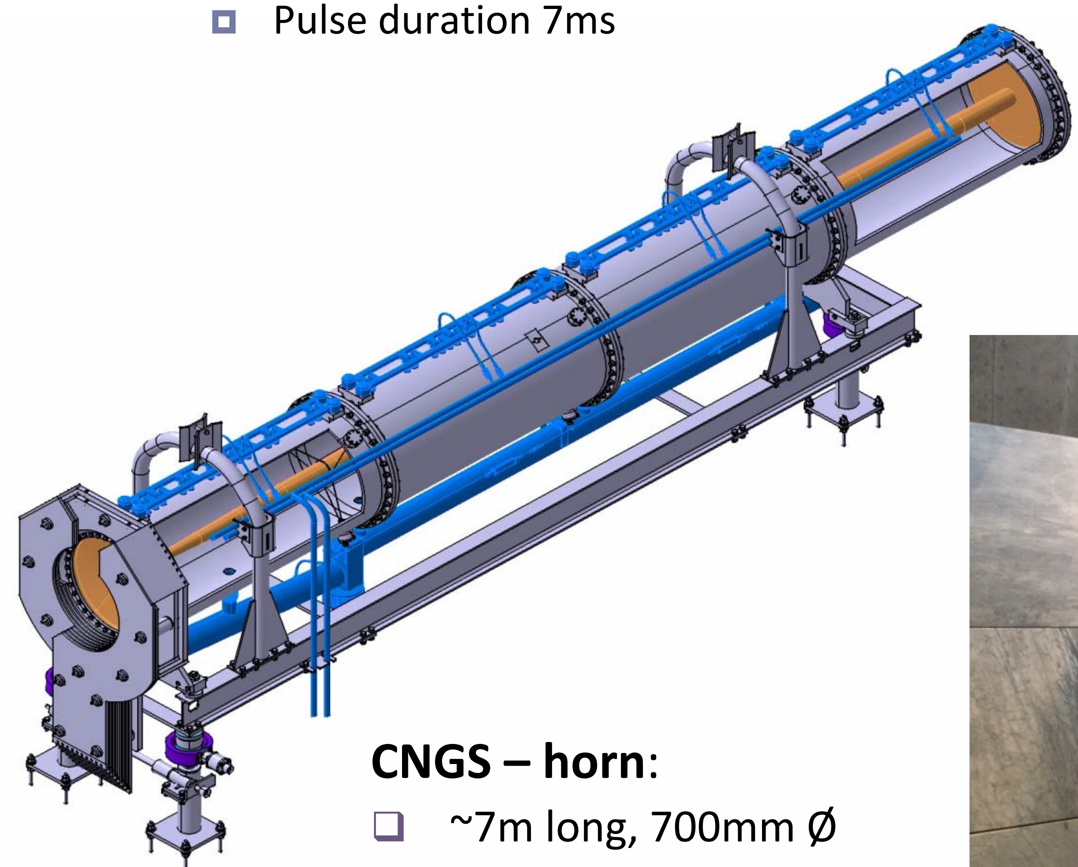
Target unit with 5 target assemblies – in-situ spares

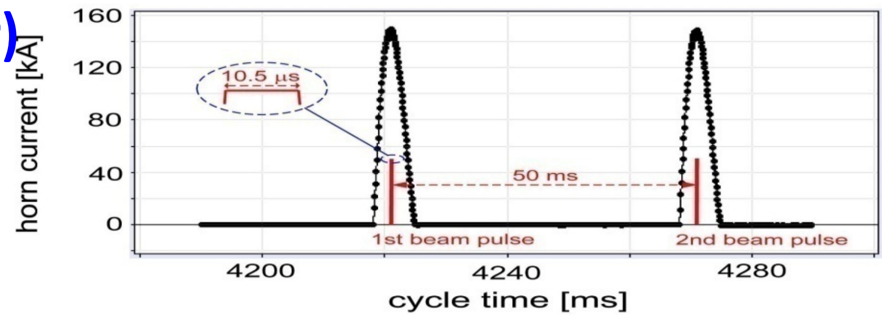
I.Efthymiopoulos, CERN

Key elements of the secondary beam

The magnetic horns

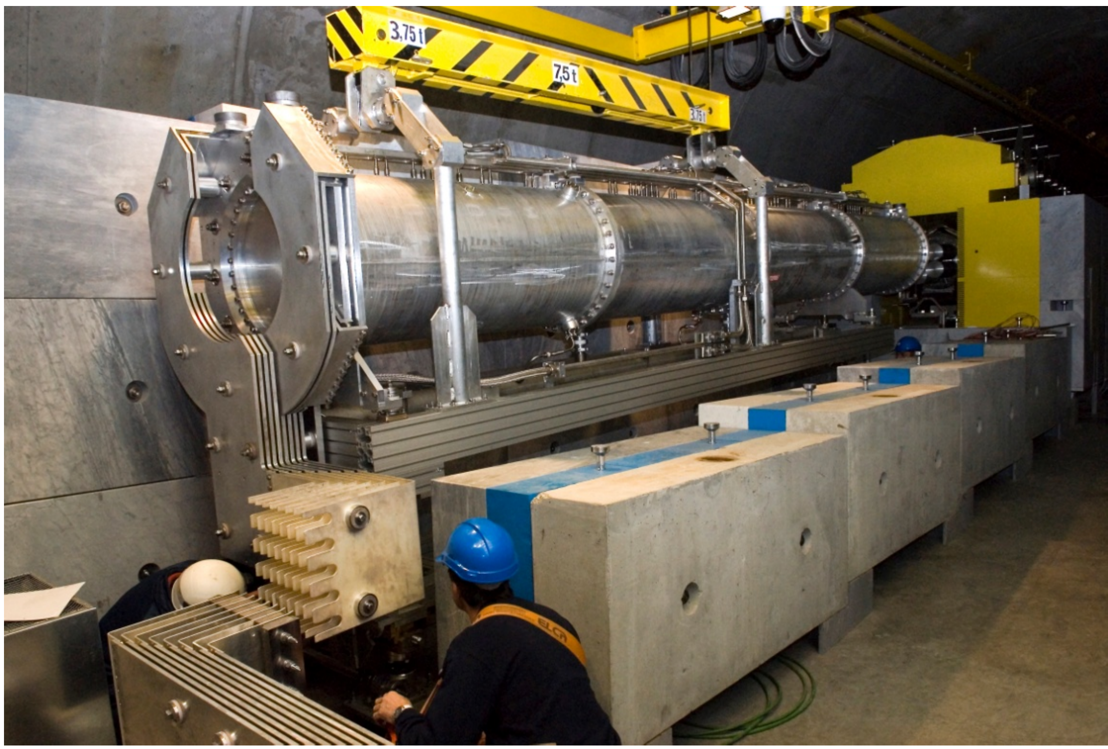
- Current: **150kA (horn) – 180 kA (reflector)**
  - Pulse duration 7ms





CNGS – horn:

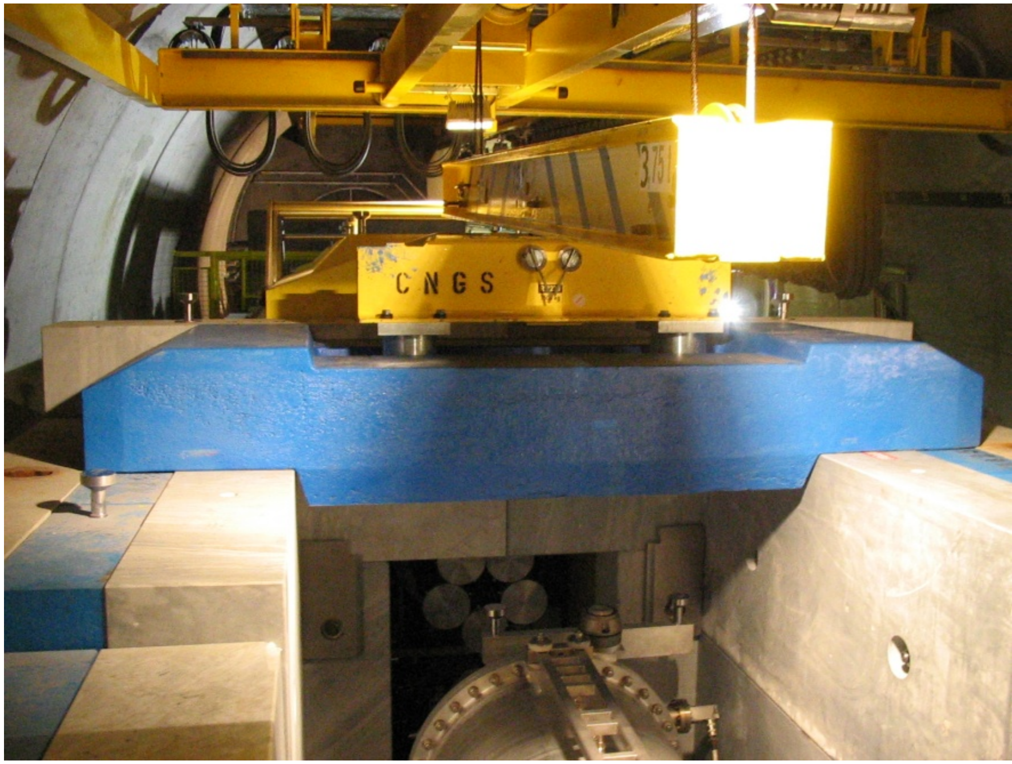
- ~7m long, 700mm Ø
- Inner conductor: 1.8mm thick, 30÷136mm Ø
- Made of Aluminum
- Water cooled



Key elements of the secondary beam

Radiation environment

- Optimized shielding
  - Marble – iron – concrete
  - Remote handling



- Remote station for radiation survey in the target chamber

CNGS Target Area

Design baseline

- The target area design in a high-power ν-beam is always very challenging :
  - the target must sustain the energy deposition and induced stress waves from the beam impact
  - the choice of materials has to be adopted to the high-radiation environment
  - the high remnant radiation environment limits access possibilities for service & maintenance

- CNGS baseline :
  - over-designed using safety factors for present and future intensity upgrades
  - provision for spares of the most sensitive equipment and well studied exchange procedures (HAZOP)

M.Meddahi, E.Schaposnicova - CERN-AB-2007-013 PAF

I per PS batch	# PS batches	I per SPS cycle	200 days, 100% efficiency, no sharing	200 days, 55% efficiency, no sharing	200 days, 55% efficiency, 60% CNGS sharing
		[prot./6s cycle]	*[pot/year]*	*[pot/year]*	*[pot/year]*
2.4×10^{13} - Nominal CNGS	2	4.8×10^{13}	**1.38×10^{20}**	**7.6×10^{19}**	**4.56×10^{19}**
3.5×10^{13} - Ultimate CNGS	2	**7.0×10^{13}**	(2.02×10^{20})	(1.11×10^{20})	(6.65×10^{19})

Design limit for the target

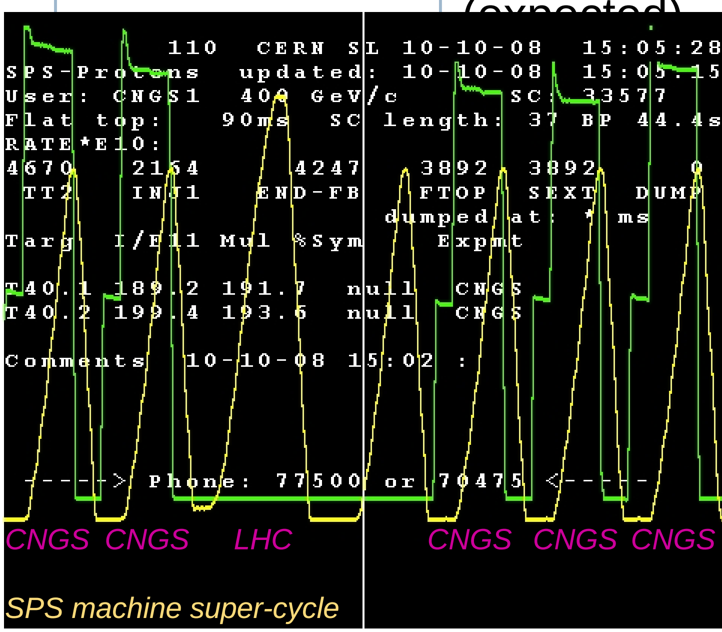
working hypothesis for RP calculations

CNGS working hypothesis

CNGS Operation

9 Summary

Year	Protons on target
2006-comm.	6.87×10^{15}
2006	8.48×10^{17}
2007-comm.	5.0×10^{16}
2007	7.86×10^{17}
2008	1.78×10^{19}
2009	2.55×10^{19} (today) 3.20×10^{19} (expected)



- **2006- run**
  - failure in reflector cooling circuit
- **2007- run**
  - radiation effects on ventilation system electronics
  - broken flexible stripline cable
- **2008- shutdown**
  - failure in target rotation mechanism – inspection
  - horn/reflector cooling system filter improvements
  - handling of tritiated water

☞ *further info on CNGS operation performance: talk by **E. Gschwendtner (WG1 - Tuesday PM)***

Summary

- Focusing on the problems we had, should be balanced with the smooth startup, commissioning and operation of the facility which will soon complete a second year of physics with the maximum available intensity from CERN/SPS.

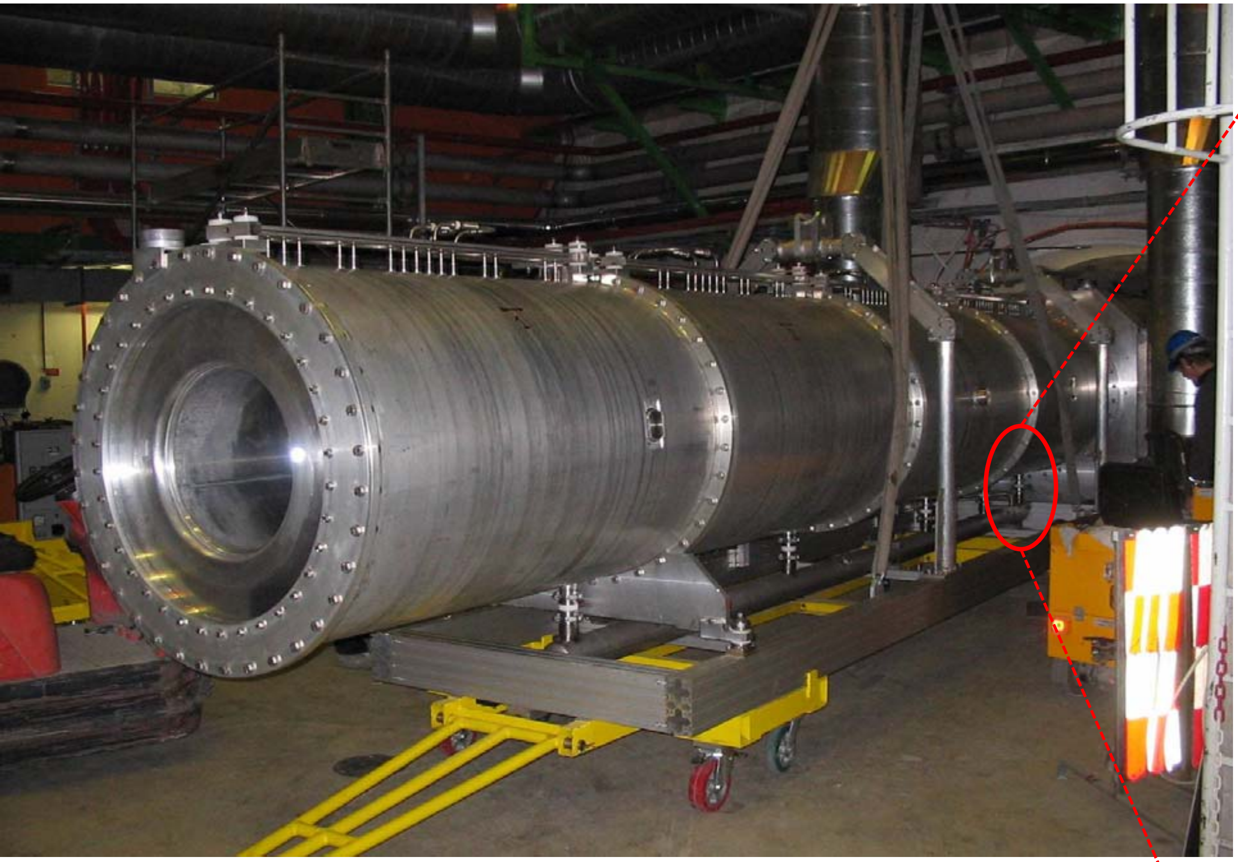
- Important to notice the early failures we had or “teething problems”, were on peripheral components
  - Lesson #1 : the design of the identified critical items typically receives most of the attention and is well done – or at least we know what to do in case of failures. The reality says the problem often comes from the peripheral components receiving less of attention or not subject to the same rigorous quality assurance
    - the LHC experience for the QRL installation and cable splicing problem confirms it as well

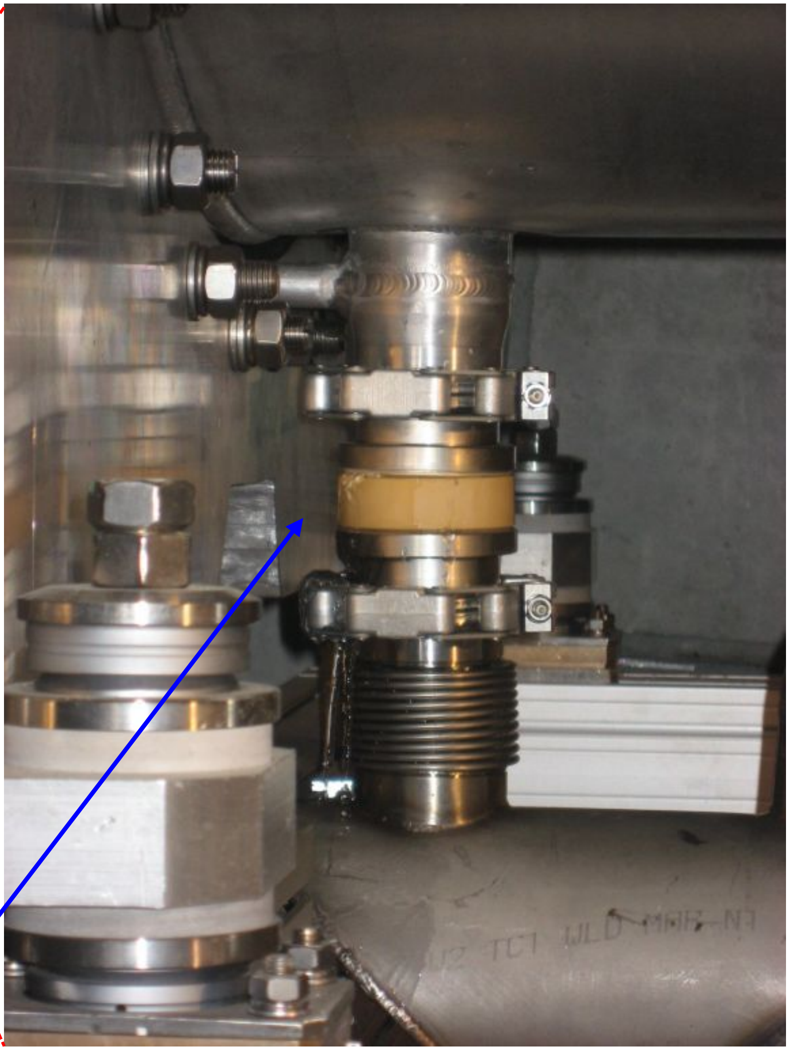
- Since the failures happened too early, we were forced to do unforeseen interventions for repairs – too early to waste our spares!
  - Lesson #2 : tooling and procedures for interventions to repair early failures should be included in the design of a facility

- We profited from the repair work to do improvements and preventive maintenance on similar elements installed on other equipment

Horn & Reflector issues

Reflector water leak



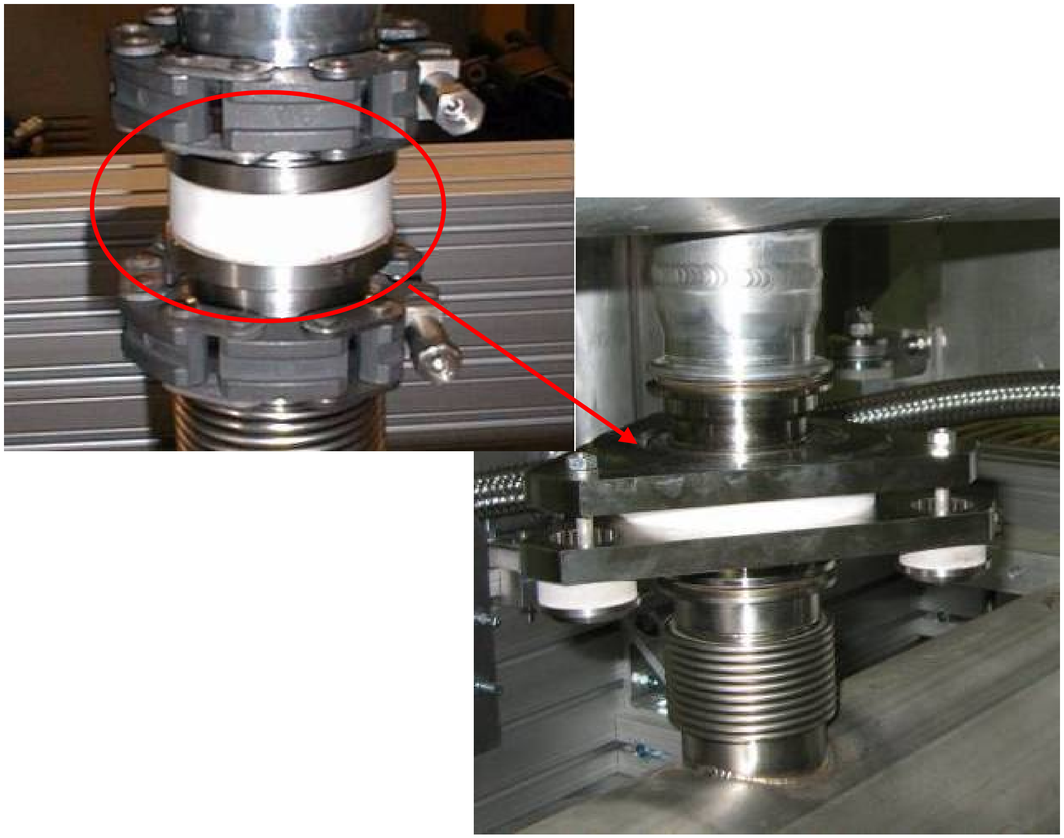


- Observed high refill rate in the closed circuit water cooling system of the reflector, and increased water level in the sumps
  - fault in one of the ceramic insulating connectors of the reflector

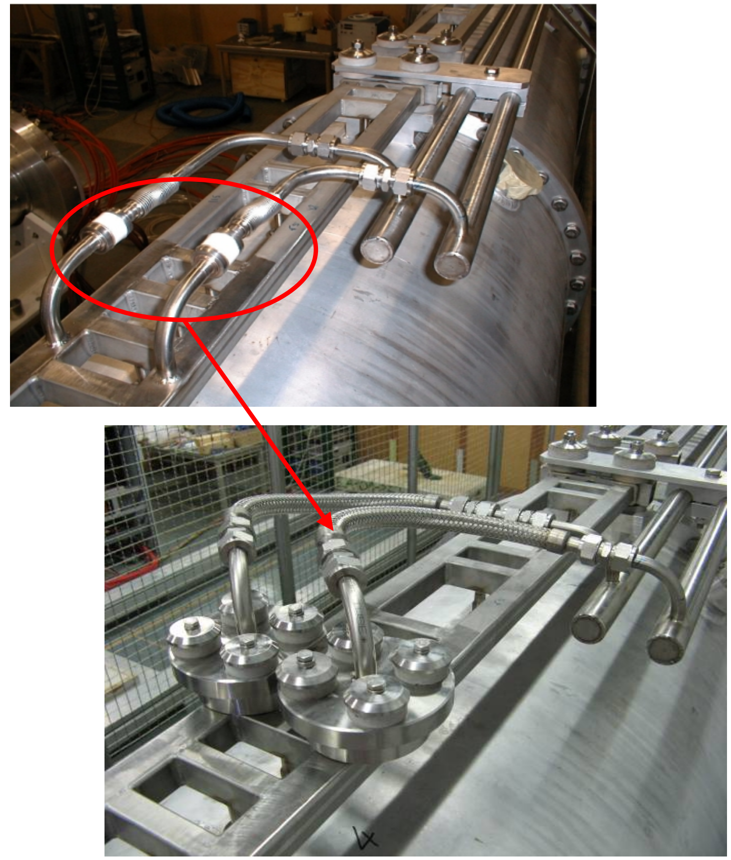
Horn & Reflector issues

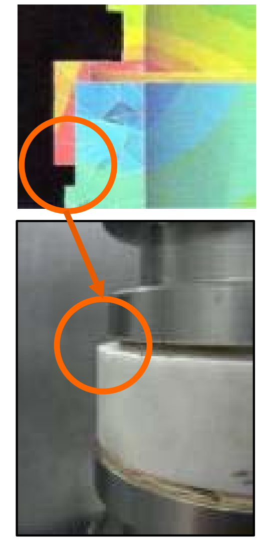
Water inlets & Outlets repair & improvements

Water outlets



Water inlets





- **Old design**
  - Ti-ceramic assembly, machined, brazed
  - Bellows absorbs misalignments
  - Shear stress from brazing (thermal) too high
  - Non optimal geometry for the ceramic

- **New design**
  - No brazing, no machining, soft seal, **ceramic only in compression**
  - Thorough testing in the spare horn
  - Replaced all water inlets & outlets in horn & reflector

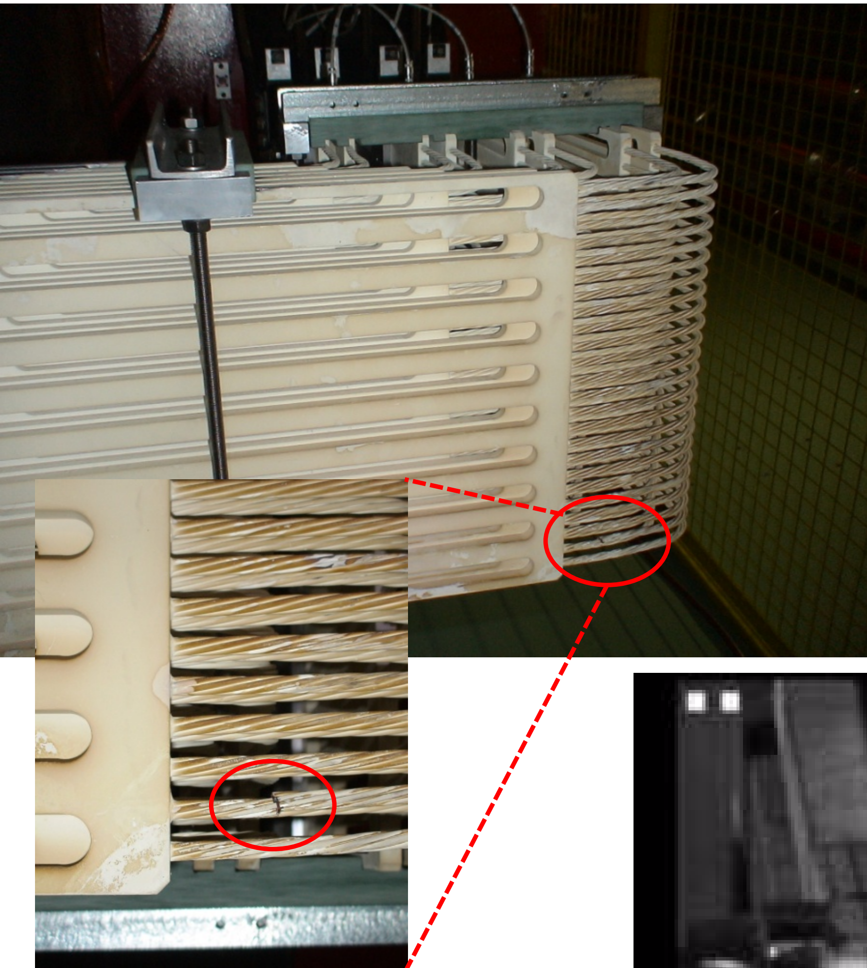
Horn & Reflector issues

Water inlets & Outlets repair & improvements

- Only possible since we haven't been running for long
- Work in a radioactive environment:
  - detailed radiation dose planning and minimization before intervention
  - practice sessions with spare horn
  - dose sharing
  - additional mobile local shielding

Horn & Reflector issues

Stripline repair & improvements



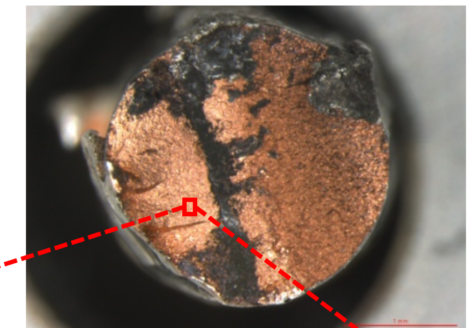
- Stripline plates and cables during pulsing
- Images recorded at 1kHz, play-back 40 times slower

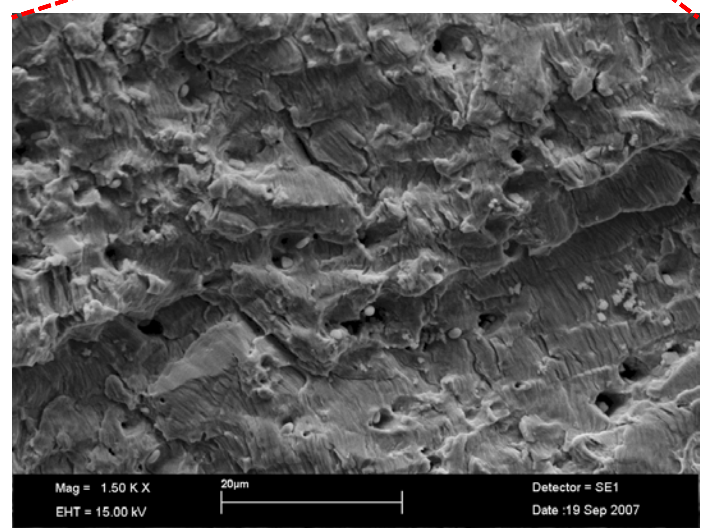
❑ **Old design for flexible part**

- Clamped plates, twisted cables, brazed
- No control of the large magnetic forces during pulsing (measured ±2mm)
- The cable was finally broken due to fatigue after ~300k pulses

Metallurgical analysis of the broken cable:

- Beach marks
- Striations
- Secondary cracks

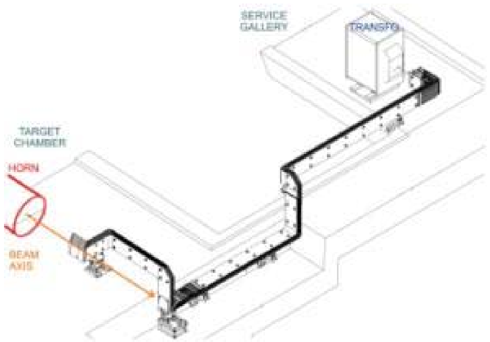




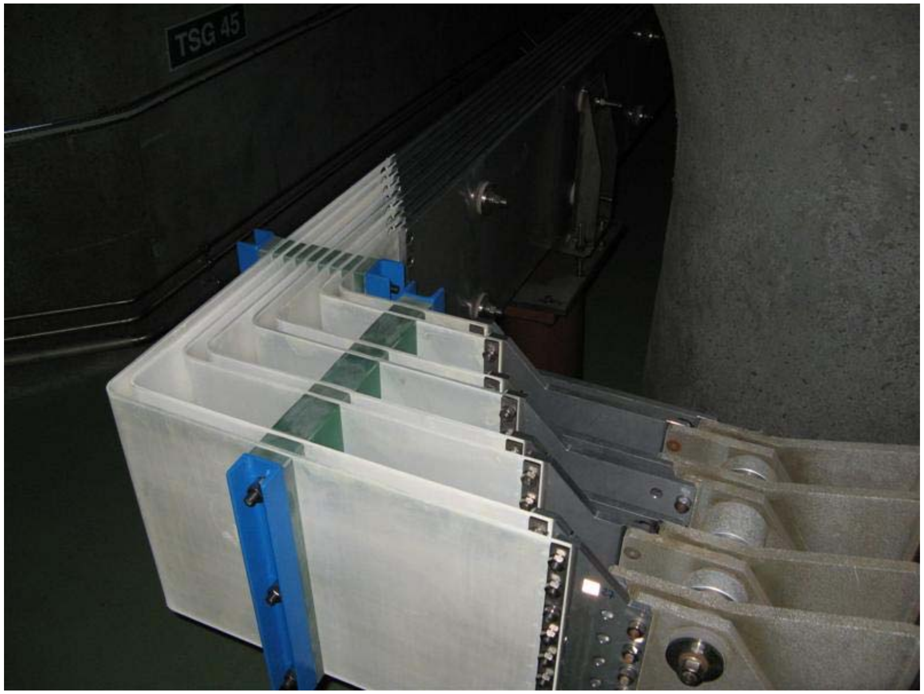
A. Gerardin, G. Arnau Izquierdo, CERN – TS/MME

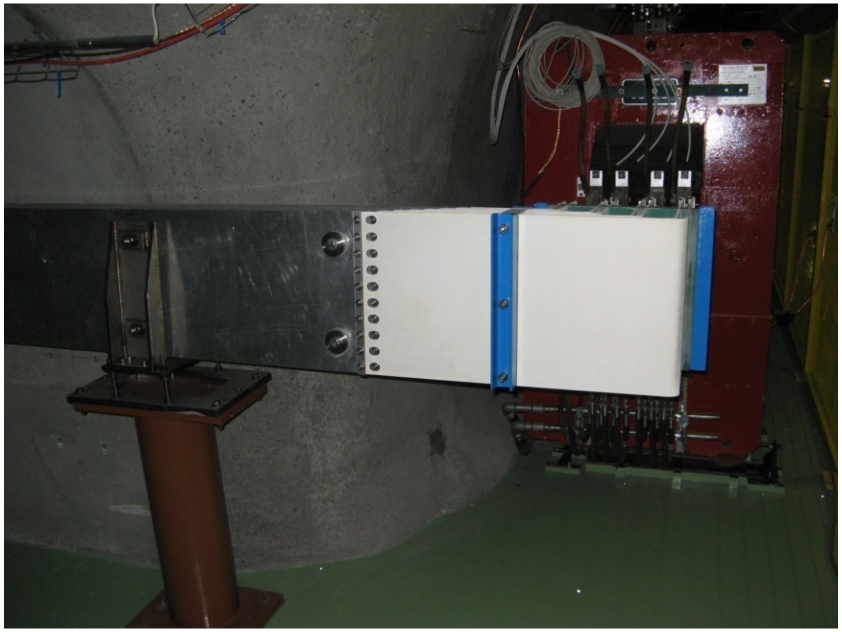
Horn & Reflector issues

Stripline repair & improvements



- **New design**
  - No brazing, semi-flexible (allows for thermal dilatation) fully clamped plates
  - Vibrations during pulsing reduced to ±0.2 mm
  - No change in the impedance or current flow properties





- Preventive maintenance : replace all flexible striplines of both horns

Horn & Reflector issues

Cooling system filters lifetime

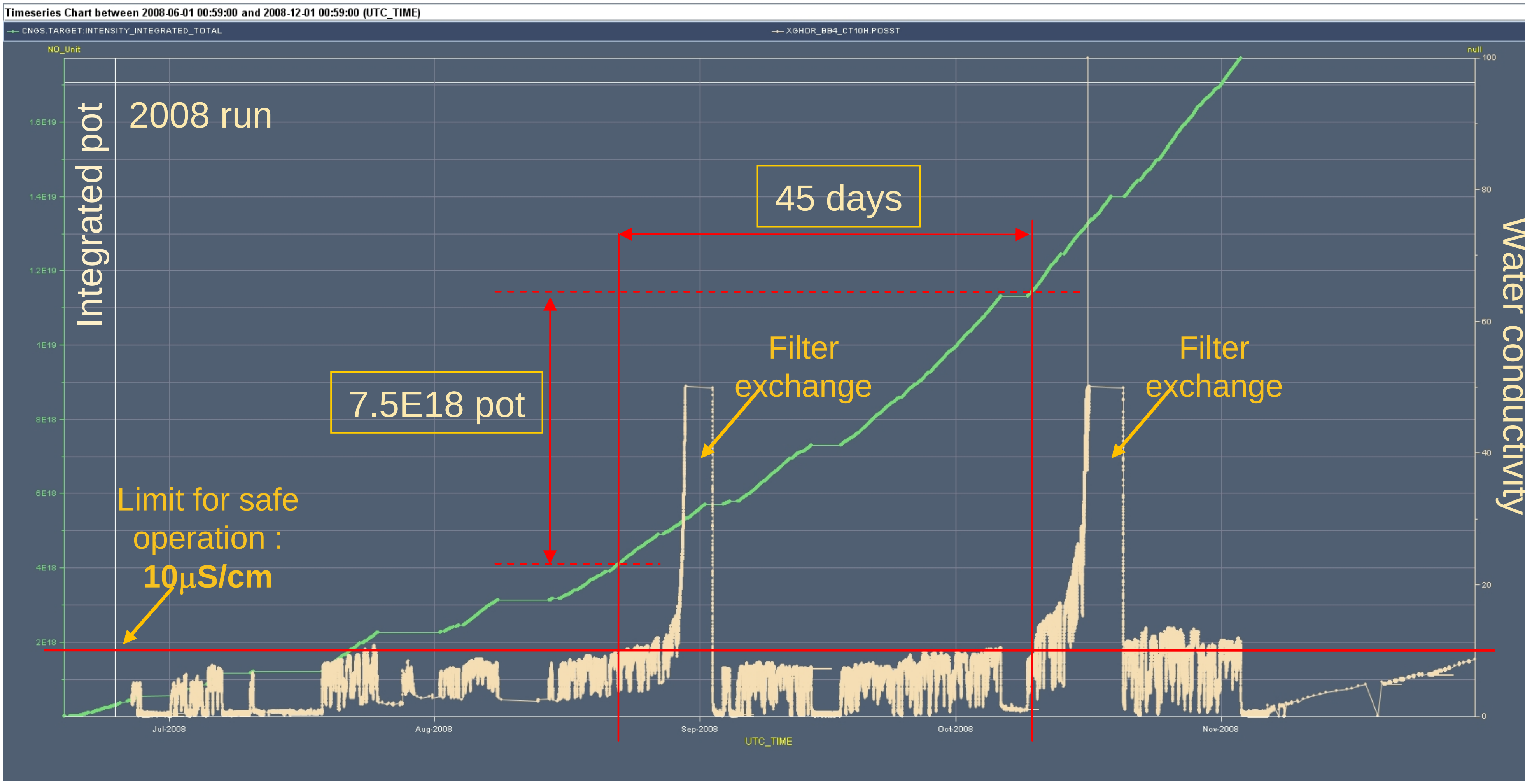
- Resin filters are used to maintain a low conductivity level in the cooling circuit
  - Two reasons:
    - avoid short-circuit inside the horn
    - limit long-term corrosion effects
  - About 1/3 of the flow goes through the filters
  - Required level: [**0.1,10.0]μS/cm**
- Two filters in place (active + spare) equipped with quick connectors
  - Filters get activated – moved to temporarily storage for initial cool-down before taken to waste

Main issues:

- Filter lifetime - saturation
  - wished to be one year, but difficult to estimate
  - 2008 run showed they saturate much sooner !!
  - long access (>20h stop) each time to replace them (10min)
- We discovered the filters had plastic pieces (tubes) inside; not a real issue but better to avoid
- The filters are radioactive waste, their use must be optimized

Horn & Reflector issues

Cooling system filters lifetime



- Use of original filter cartridges would imply **~6** filter exchanges for a nominal CNGS year (4.5×10^{19} pot) !

Horn & Reflector issues

Cooling system filters lifetime

New home-made cartridge design

- Increase × 2.5 the filter capacity of the system → one exchange / year
  - modify piping to accept more filters in parallel
- Optimized design
  - maintain the quick connectors and optimize manipulation (installation/removal) operations
  - easy emptying of the resin material allows re-use of the cartridges → less waste

Horn & Reflector issues

Lessons learned

3. Careful and "safe" engineering with well known and calculable techniques should be preferred
   - brazing better to be avoided ; use ceramics in compression only
   - design modifications should be accompanied with studies and calculations – e.g. avoid last minute machining
   - sounds trivial but for screws/bolts : use same size for same purpose, think their position and manipulation in a future intervention
   - maintain a good record of installed elements with photos/videos

4. Forces in high-current conductors should be considered in the design
   - include dynamic studies not only static
   - risky to extrapolate from known configurations

5. In high-radiation environment interventions, planning, analysis and practice is essential to minimize the dose

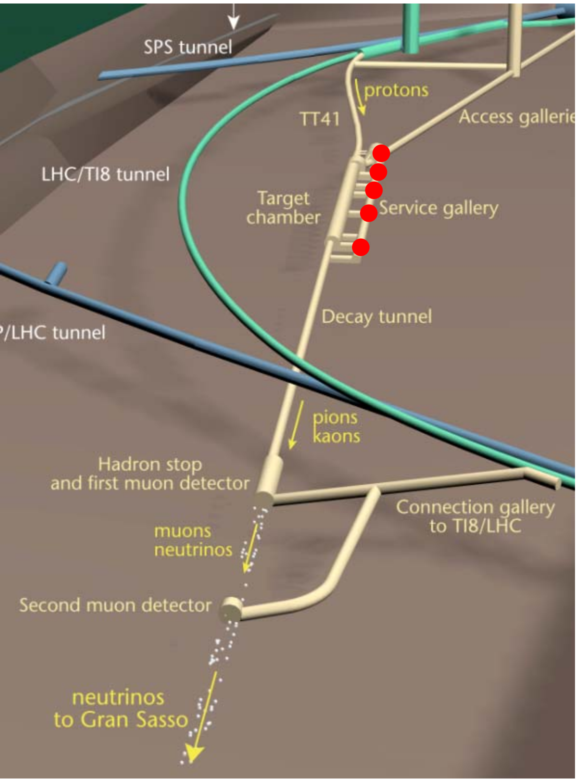
6. For "consumables" , optimization of the radioactive waste should be included in the design
   - balance between commercial (easy to get) components and home-made designs

Radiation effects on electronics

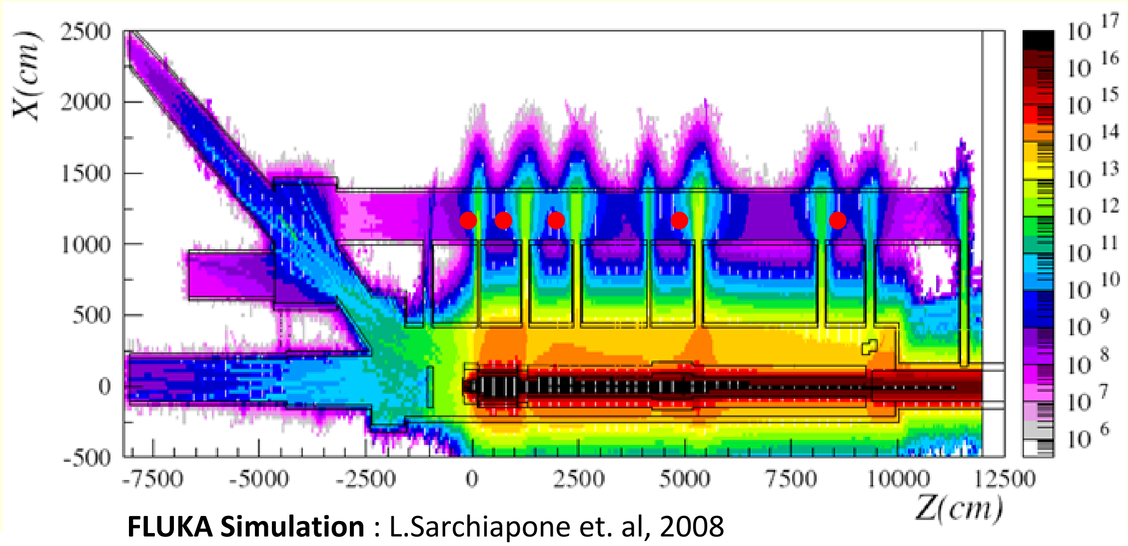
20 Failure of ventilation system electronics

- All CNGS electronics were installed in the service gallery and upstream cavern
  - At that time only personnel dose and not SEE to electronics were considered
  - Radiation levels during operation exceed the limits COTS electronics can withstand → also triggered a LARGE campaign for LHC !!

- The ventilation system electronics in the service gallery failed first (only at **10^{16} pot**!), all the rest would have followed if we had been running longer



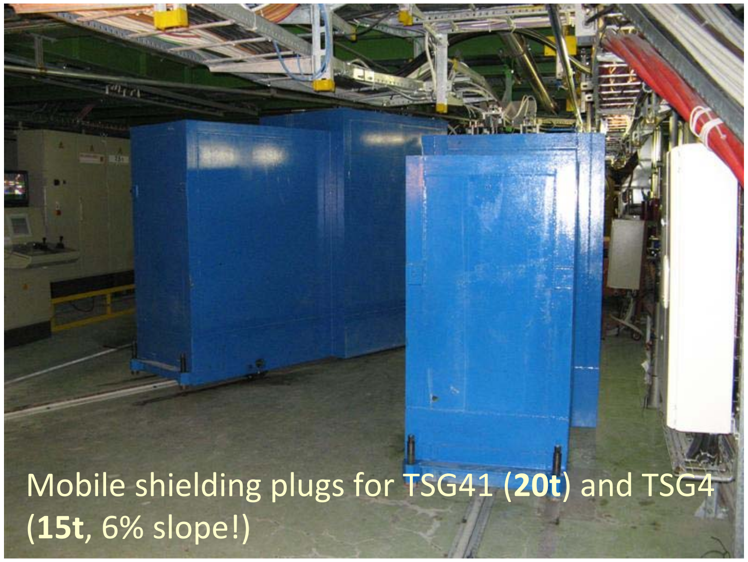
High-energy (>20MeV) hadrons fluence (h/cm²) for 4.5E19 pots (1-year)



FLUKA Simulation : L.Sarchiapone et. al, 2008

Radiation effects on electronics

Protecting the electronics – additional shielding



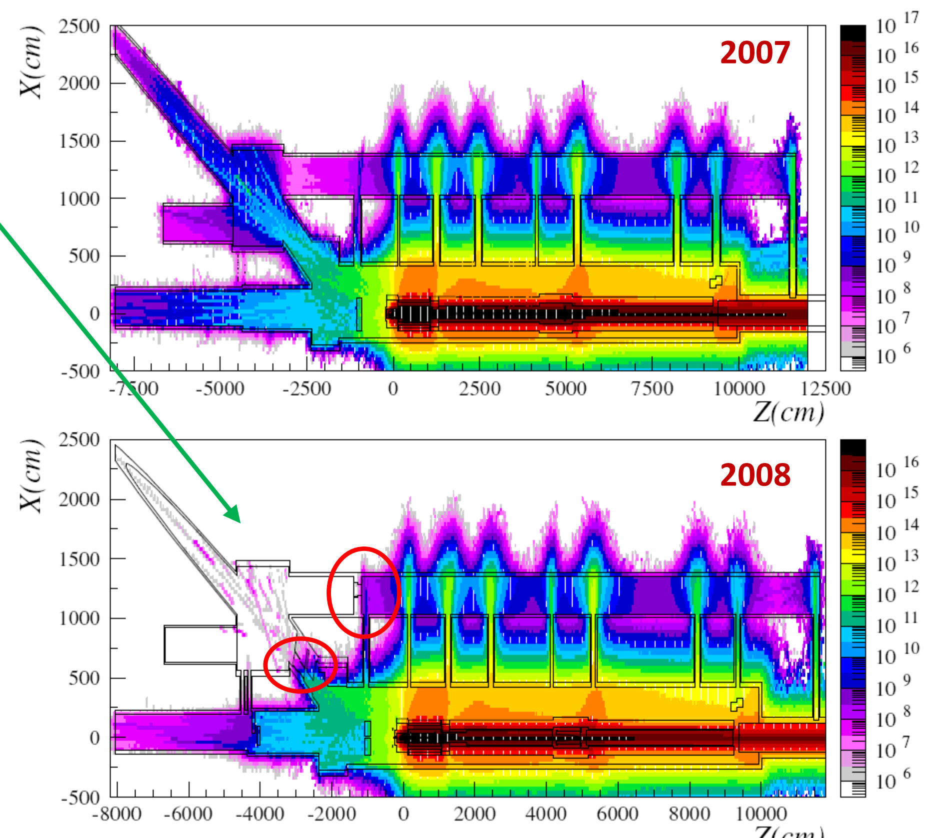
- Group all the electronics in a single area
- Add shielding to reduce the radiation levels ; opted for × 1000 reduction
  - Concrete walls up to 6m thick, **~53m³ of concrete** in total were installed!

"radiation safe" areas for electronics

Shielding in TSG41 tunnel

Towards the target chamber

High-energy (>20MeV) hadrons fluence (h/cm²) for 4.5E19 pot



FLUKA Simulation : L.Sarchiapone et. al, 2008

Radiation effects on electronics

Lessons learned

7. Radiation effects (singe event effects) to commercial electronics (COTS) is a reality and must be taken seriously into account
   - installed electronics – typically from services (ventilation, power, access systems, cranes, etc.)
   - but also for equipment during interventions

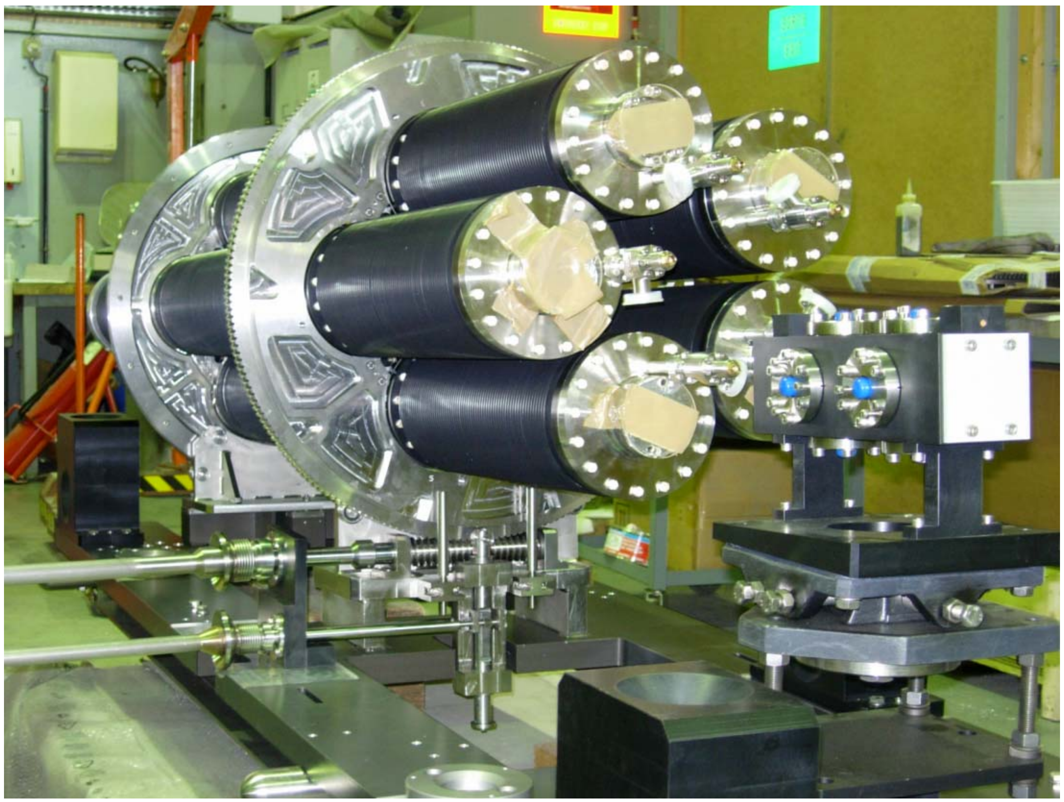
8. Recommendation: no electronics in beam tunnels, target and proximity areas where streaming radiation (neutrons) can exceed normal "office" limits
   - customizing COTS components would increase substantially the cost and doesn't really save the problem for installations with >10 years lifetime – new versions, upgrades, etc.

9. Availability of "as build" simulations is a mandatory tool to understand and evaluate the radiation environment in a facility
   - helps primarily for personnel protection, but also to schedule works during interventions

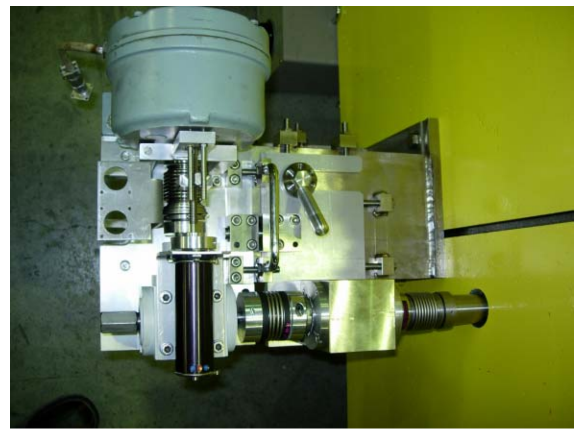
Target motorization failure

Target station design with in-situ spares

- Target assembly:
  - 5 target units (almost identical)
  - empty positions in between for beam tuning
  - rotation with DC motors and torque limiter outside the shielding.



- Increased torque observed in the rotation motor during annual maintenance on March’09
- From a first inspection outside the shielding signs of rust observed in parts of the motorizations and limit switches
  - Expected due to the radiation environment

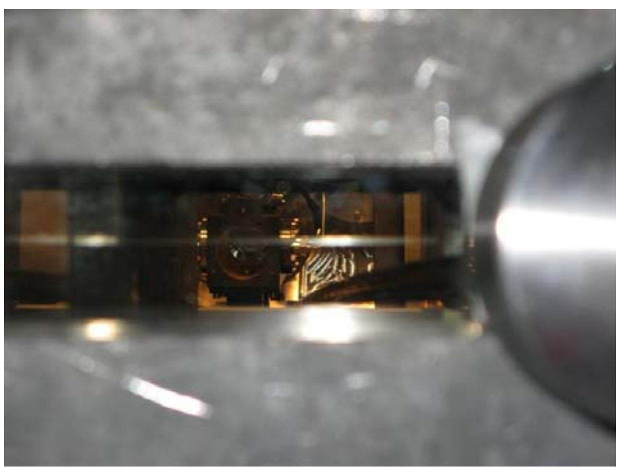


Target motorization failure

In-situ inspection (April 8-9, 2008)

Target rotation mechanism – view from web cam

Area preparation : additional shielding & protection

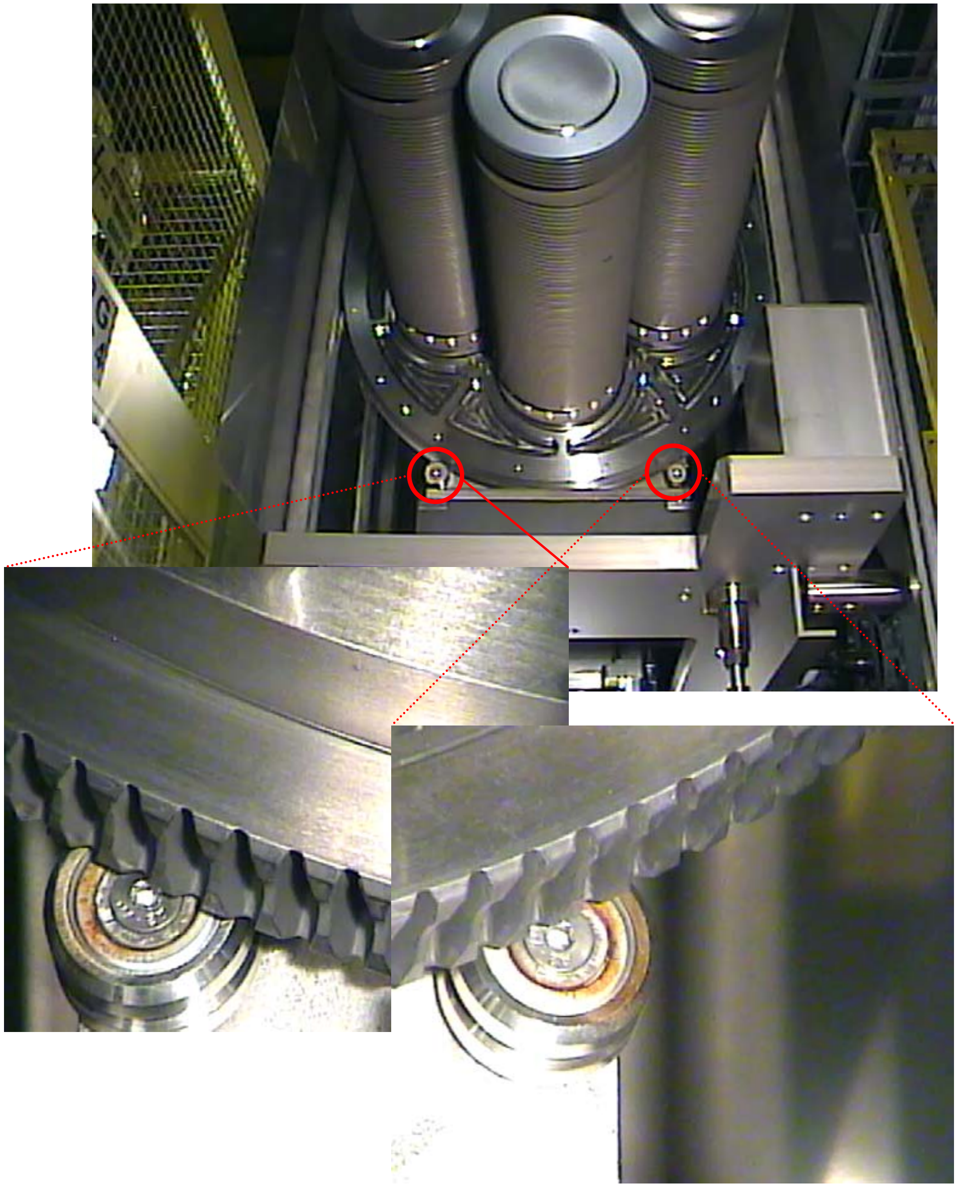


Target view through the Pb-glass window

The operations were monitored remotely using the crane and additional web cameras

Target motorization failure

In-situ inspection (April 8-9, 2008)



Summary of observations:

- all four ball-bearings have signs of rust
- 3 turn when the barrel moves but with difficulty
- 1 doesn't turn at all in one direction (at least at startup)

- Discussing again with the supplier we discovered that contrary to the specifications the pieces delivered were treated with a lubricant (YVAC3) thought to be radiation hard

- New set without lubricant ordered and is under test in the target. Another alternative is the use of ceramic ball-bearings (higher cost)

Target motorization failure

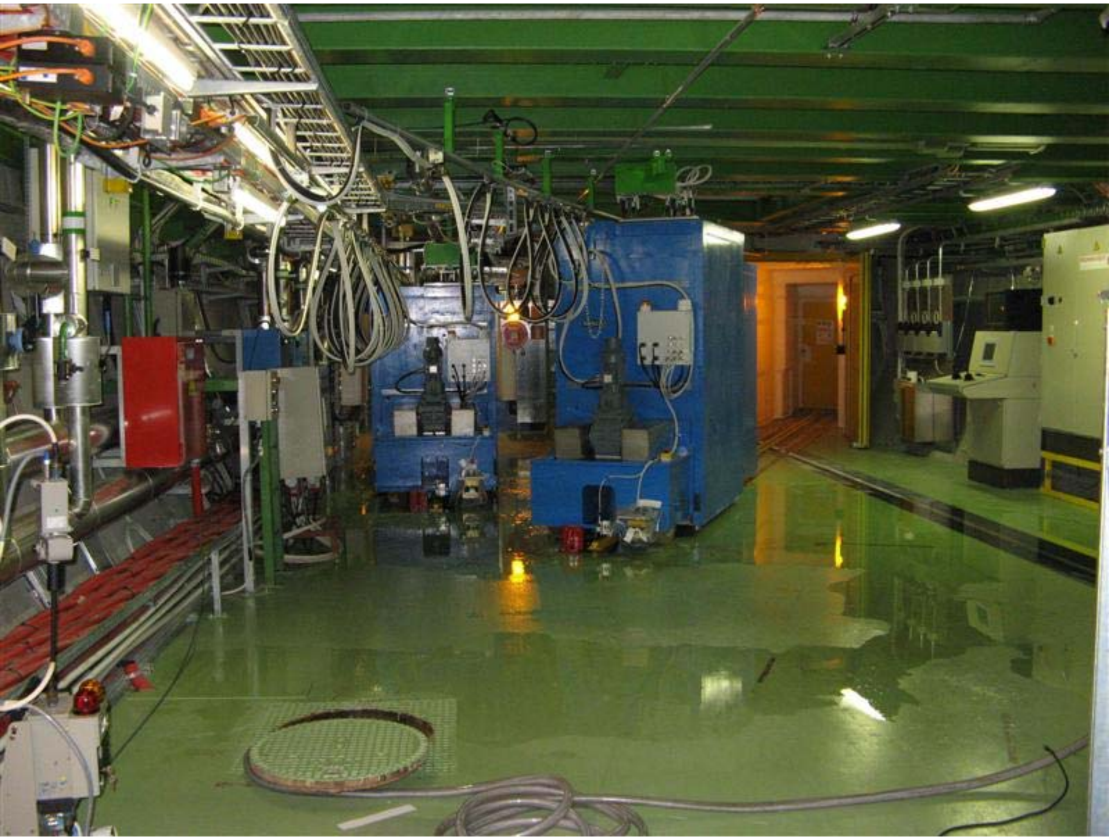
Lessons learned

10. Rigorous quality assurance for all pieces is vital
    - a chain is as strong as it weakest link

11. Foresee tooling and procedures to observe the components that fail, before exchange them with spares
    - understanding the origin of the failure may impact on the decision of using the available spares!

CNGS - water issues

Leak in the TCV4 ventilation unit



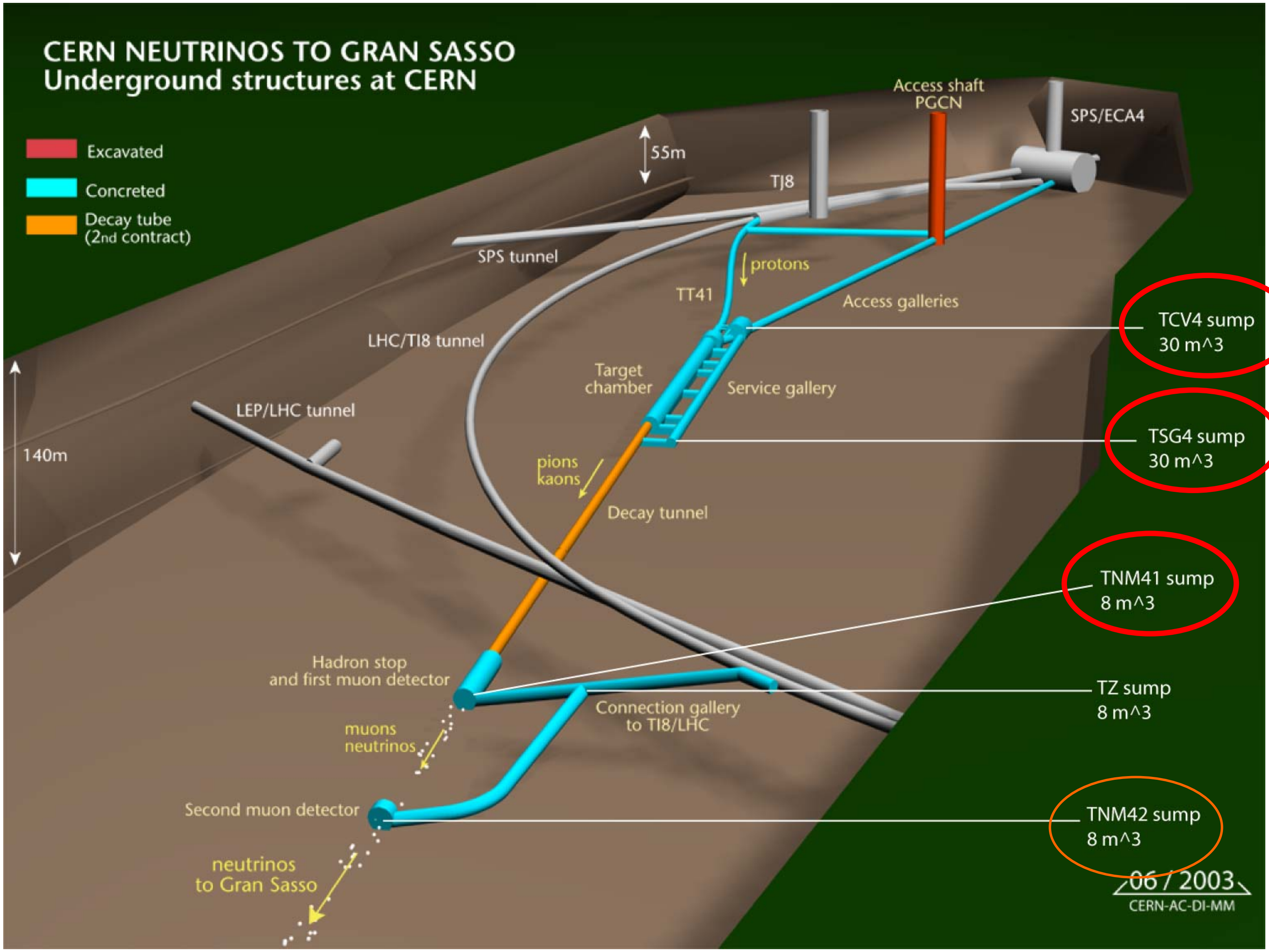
- Leak of chilled water circuit in one of the TCV4 units installed in the access cavern (1st floor)
  - small leak, triggered no alarm, but until it was detected **~2.5m3 of water** dripped on the floor and on equipment
  - fortunately only minor damages
  - the water became radioactive as it washed the nearby filters of the ventilation unit
  - ended up in the sump of the cavern contaminating the clean drain water in there that had to be pumped
- Repaired on time for the 2009 startup with beam

Lesson #12 : A clear separation between the systems that service the radiation areas from the rest should be made

- This may imply constructing **additional tunnel/cavern** with initial cost increase, but certainly pays off later during operations in case of problems!

CNGS – water issues

CNGS water sumps - layout



CNGS – water issues

CNGS water sumps - overview

Sump	Water source	Flow	Emptying	Volume	Comments
TCV4	▪ drain pipe work from upstream tunnels	0.5m^3/d	20 days	180 m^3/y	▪ can receive radioactive water in case of leaks in the ventilation system
TSG4	▪ target chamber drains ▪ condensation water from ventilation system	3-20 lt/h	4-5/year	100 m^3/y	▪ radioactive water (mainly H3) from the target area ▪ manual emptying to containers
TNM41	▪ drains along the decay tube and hadron stop area	1-2 lt/h	4 fois/an	20 m^3/y	▪ radioactive water along the decay tube ▪ hadron stop cooling system water in case of leak ▪ high PH value 12
Horns	▪ cooling system	Closed circuit (2×600lt)	~2-years	1.2 m^3/2y	▪ radioactive water

CNGS – water issues

Handling

- Dealing with the drain or infiltration water in underground areas is not trivial.
  - it took ~2 years to have infiltrations and thus (radioactive) water in the sump at the end of the decay tube
  - Sump at the end of the access tunnels is finally too close to the target area and its services
    - since this year we observe increased radioactivity levels in there without being able to identify the source
- Getting the water out of the sumps at the end of the target chamber and decay tube not a trivial exercise

- **Lesson #12** : the issue of the drain water (piping, sumps, service & maintenance) needs to be carefully studied for future facilities
  - may impact on civil engineering costs
  - separate and isolate as much as possible the radioactive areas and tunnels – if something goes wrong we may end up with large quantities of water to handle
  - transporting water tanks (or pipes) in steep slopes (i.e future installations !!) not an easy issue

Summary

- Making and operating high-intensity beam facilities is always an interesting challenge !!
- In CNGS lot of effort was put in the project/design phase to address most of the issues and learn from the available expertise and experience
- We are now collecting experience in operating the facility that is important to share with other colleagues
- The problems we faced were successfully resolved thanks to the competences and motivation of several colleagues from many CERN groups and external teams
- We hope our problems were really child diseases of the facility and we look forward to the interesting physics results from the Grand Sasso experiments - hopefully soon!