The CNGS
Operation and Perspectives

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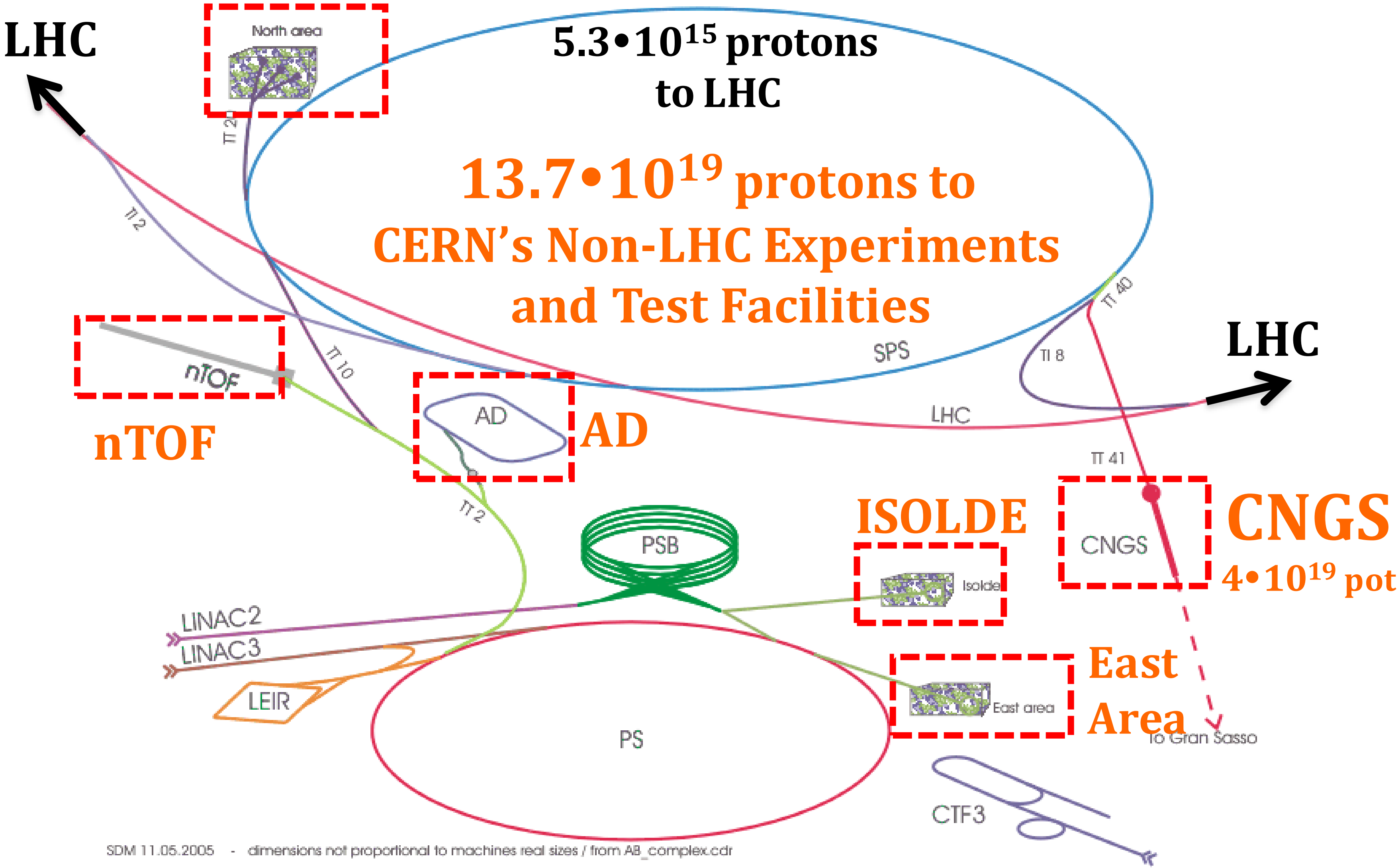
Outline

- Introduction
- CNGS Facility
- Performance and Operational Challenges
- Perspectives
- Summary

Beam Facilities at CERN

North Area

2010



LHC

5.3•10^{15} protons to LHC

13.7•10^{19} protons to CERN's Non-LHC Experiments and Test Facilities

nTOF

AD

LHC

ISOLDE

CNGS

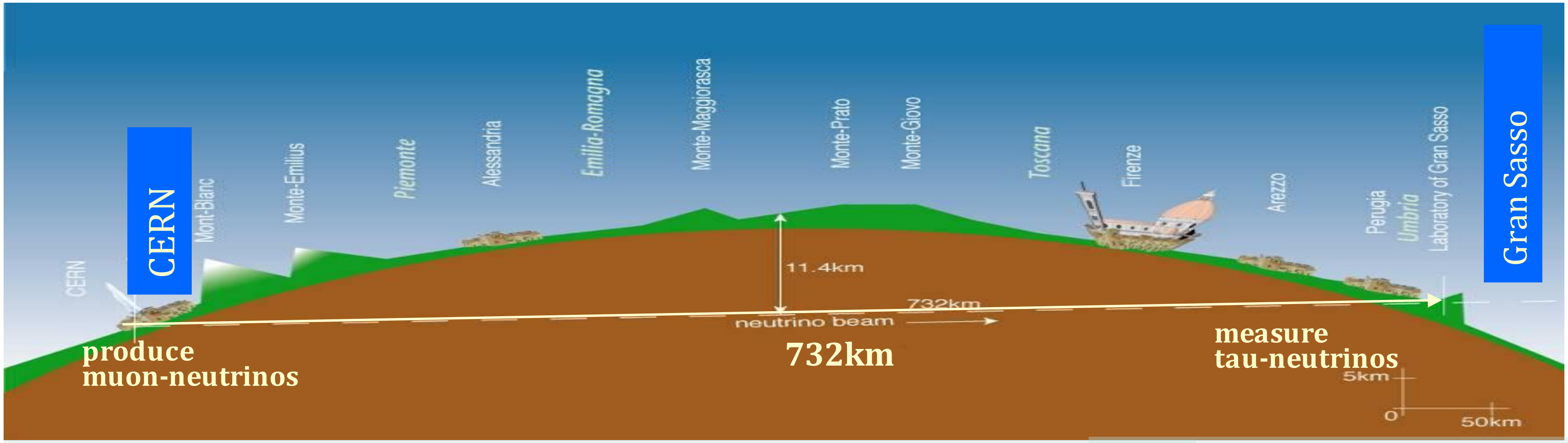
4•10^{19} pot

East Area

Neutrino Introduction

→ **CNGS (CERN Neutrinos to Gran Sasso):**
long base-line **appearance experiment**:

- Produce muon neutrino beam at CERN
- **Measure tau neutrinos in Gran Sasso, Italy (732km)**



~$4 \cdot 10^{19}$ p/year   ~$2 \cdot 10^{19}$ ν_μ/year   **~2 ν_τ/year** (~$1 \cdot 10^{17}$ ν_μ/year)

Approved for **$22.5 \cdot 10^{19}$ protons on target** i.e. 5 years with $4.5 \cdot 10^{19}$ pot/ yr
(200 days/yr, intensity of $2.4 \cdot 10^{13}$ pot/extraction) **→Expect ~10 ν_τ events in OPERA**

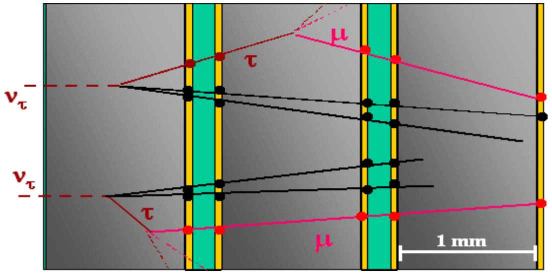
Physics started in 2008 → today: **$12.7 \cdot 10^{19}$ pot**

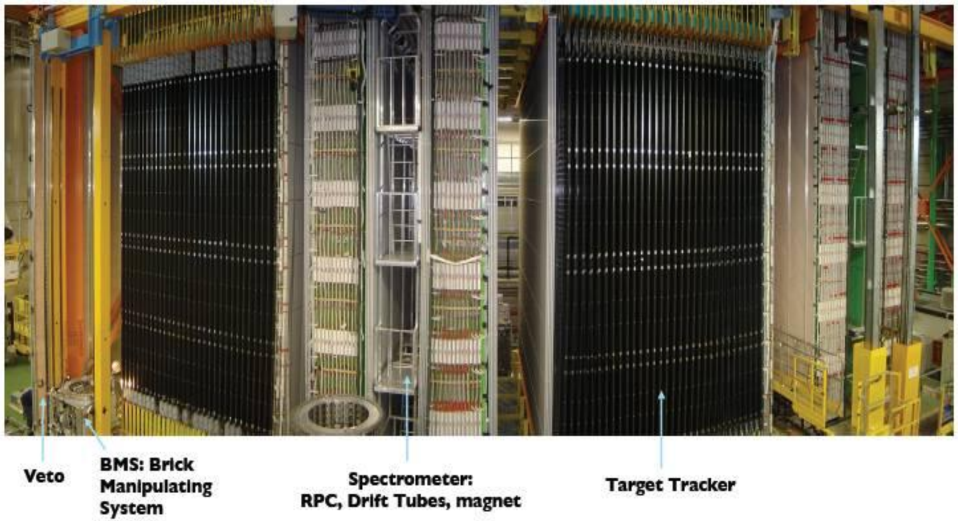
Neutrino Detectors in Gran Sasso

OPERA

1.2 kton emulsion target detector

~146000 lead emulsion bricks

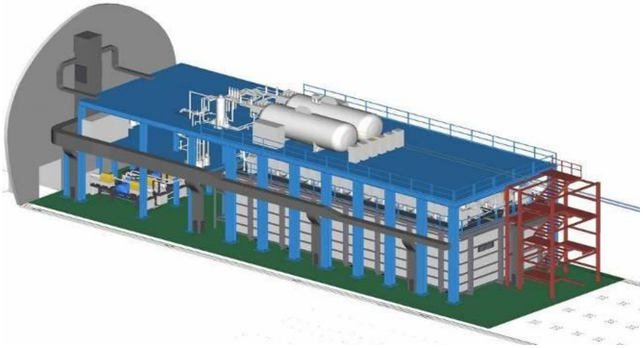




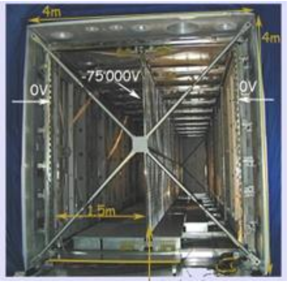
→ ***A. Ereditato, Tue, 10:15***

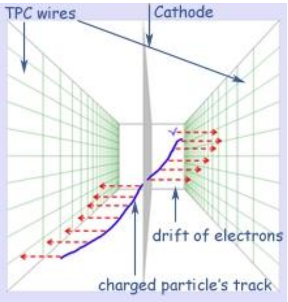
ICARUS

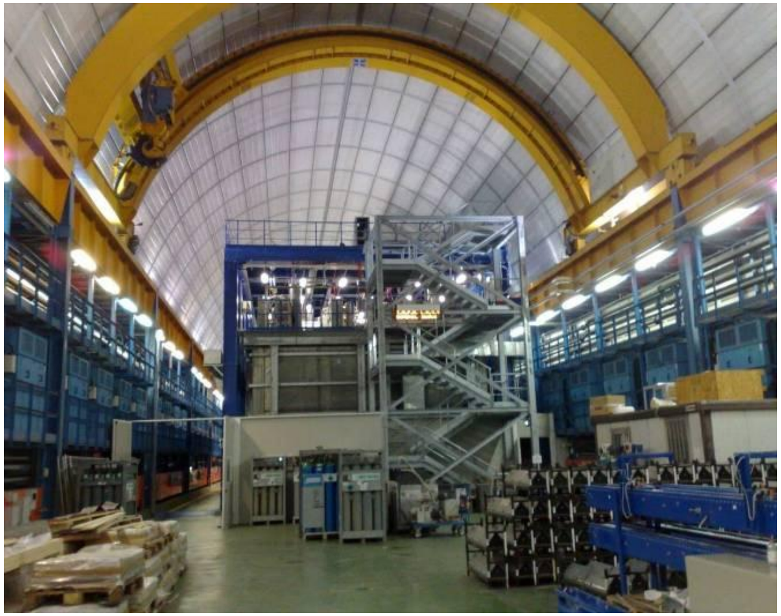
600 ton Liquid Argon TPC



→ ***F. Pietropaolo, We, 9:50***





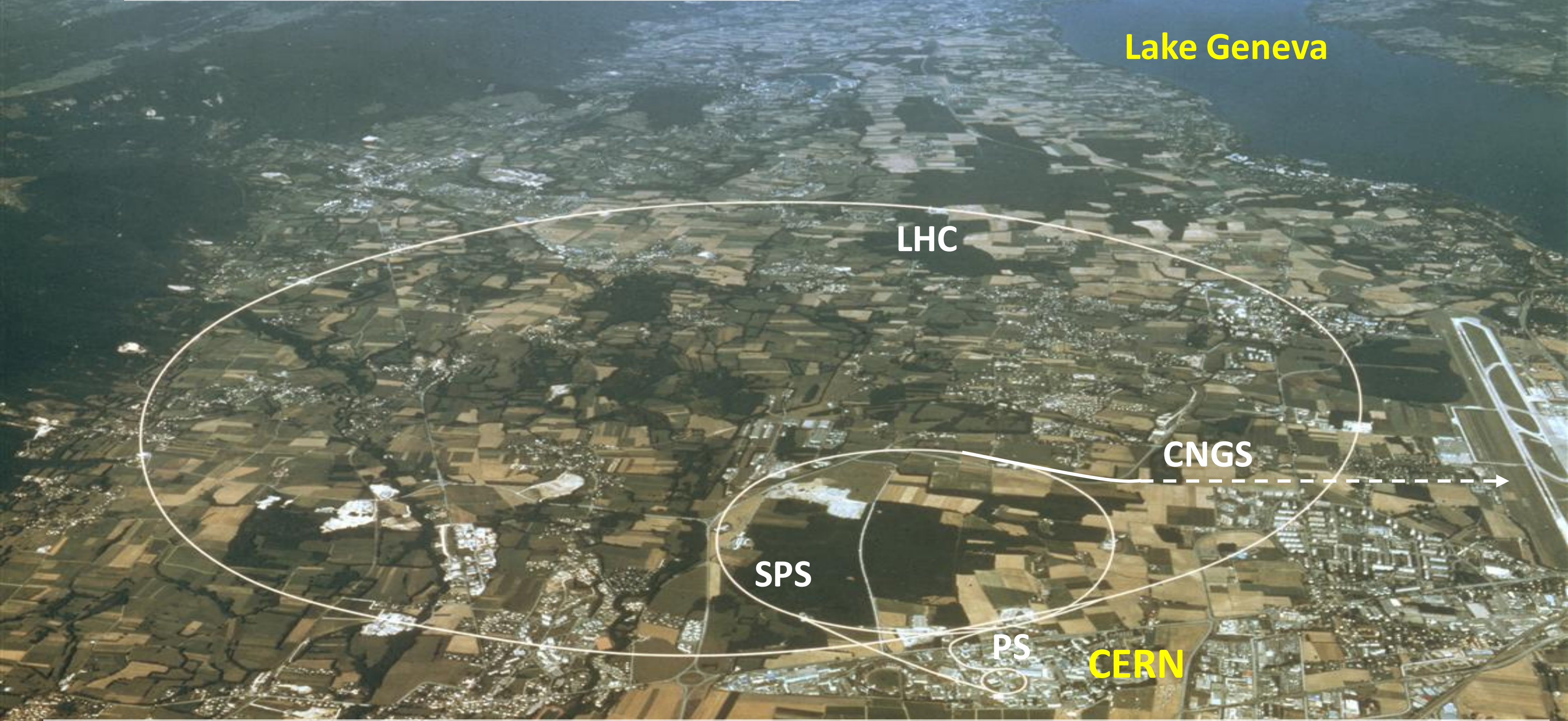


CNGS: Conventional method to produce neutrino beam

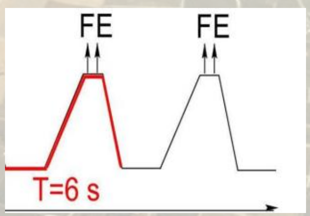
→ **Produce high energy pions and kaons to make neutrinos**

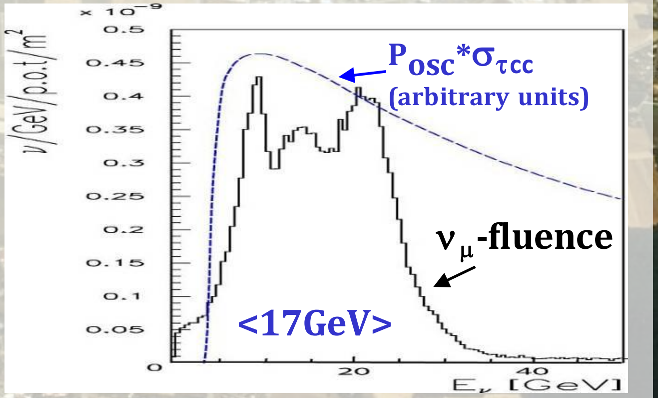
$$\boxed{p + C \rightarrow \text{(interactions)} \rightarrow \pi^+,\ K^+ \rightarrow \text{(decay in flight)} \rightarrow \mu^+ + \nu_\mu}$$

CNGS Beam at CERN

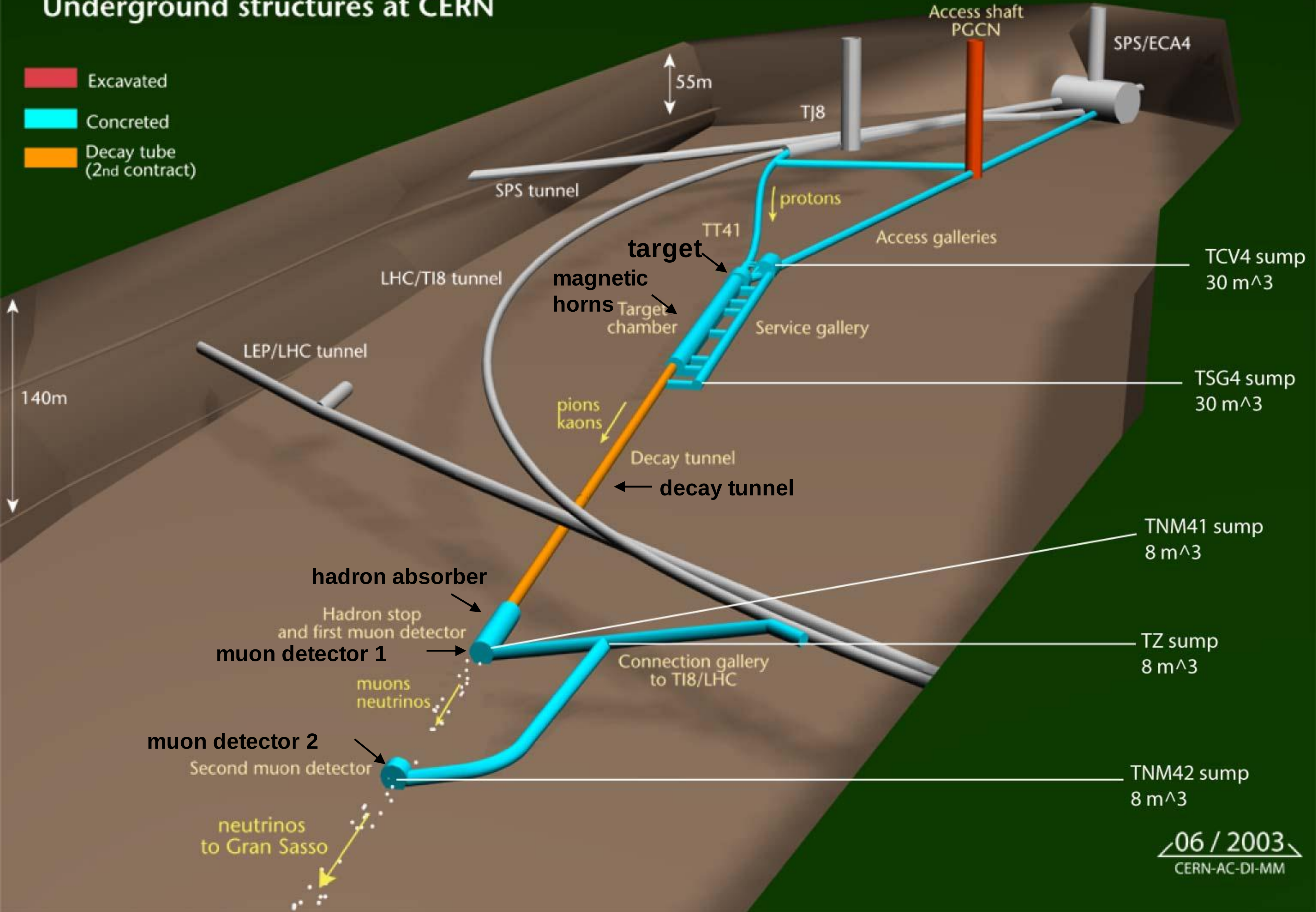


- From SPS: **400 GeV/c**
- Cycle length: **6 s**
- **2 Extractions**: separated by **50ms**
- Pulse length: **10.5μs**
- Beam intensity: **2x 2.4 · 10^{13} ppp**
- Beam power: up to **500kW**
- σ ~**0.5mm**





CERN NEUTRINOS TO GRAN SASSO
Underground structures at CERN



CNGS Primary Beam Line

100m extraction together with LHC, 620m long arc to bend towards Gran Sasso, 120m long focusing section

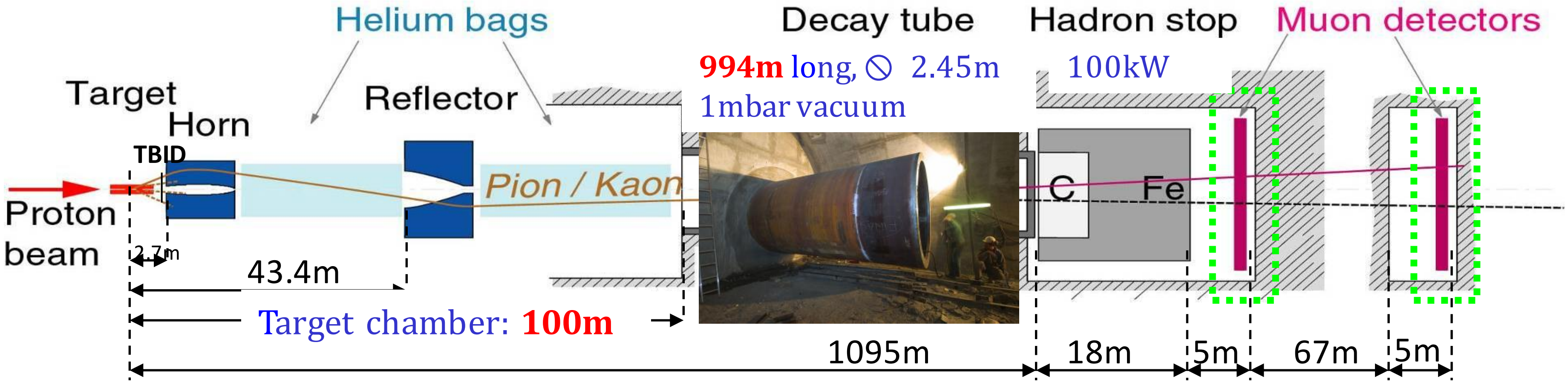
Magnet System:

- 73 MBG Dipoles
  - 1.7 T nominal field at 400 GeV/c
- 20 Quadrupole Magnets
  - Nominal gradient 40 T/m
- 12 Corrector Magnets

Beam Instrumentation:

- 23 Beam Position Monitors (Button Electrode BPMs)
  - recuperated from LEP
  - Last one is strip-line coupler pick-up operated in air
  - mechanically coupled to target
- 8 Beam profile monitors
  - Optical transition radiation monitors: 75 μm carbon or 12 μm titanium screens
- 2 Beam current transformers
- 18 Beam Loss monitors
  - SPS type N_2 filled ionization chambers

CNGS Secondary Beam Line


Helium bags

Decay tube

Hadron stop

Muon detectors

Target

Horn

Reflector

TBID

Proton beam

Pion / Kaon

994m long, ⃠ 2.45m

1mbar vacuum

100kW

C

Fe

2.7m

43.4m

Target chamber: **100m**

1095m

18m

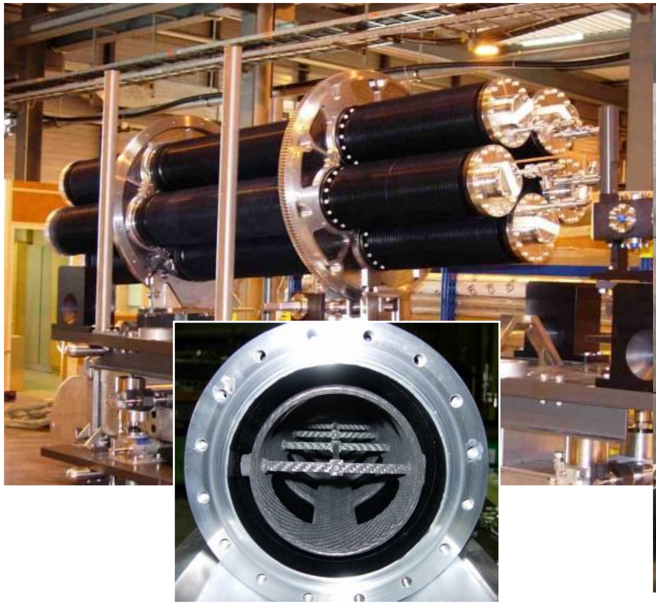
5m

67m

5m

1 Target unit: 13 graphite rods 10cm

1 Magazine: 1 unit used, 4 in situ spares




2 HORNS:

7m long, 150/180kA pulsed

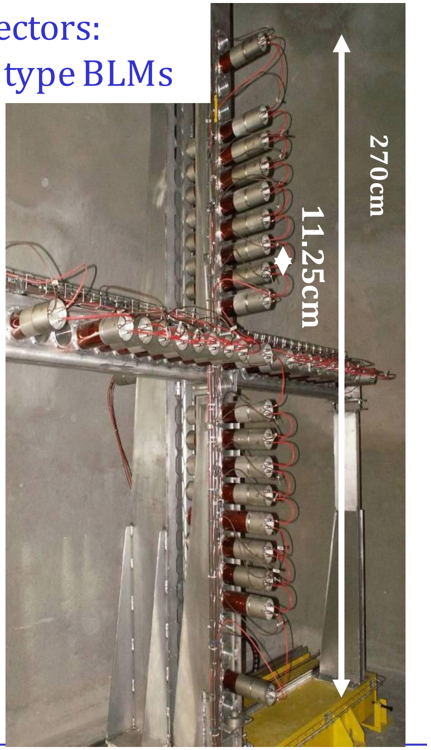
Water cooled

Remote polarity change

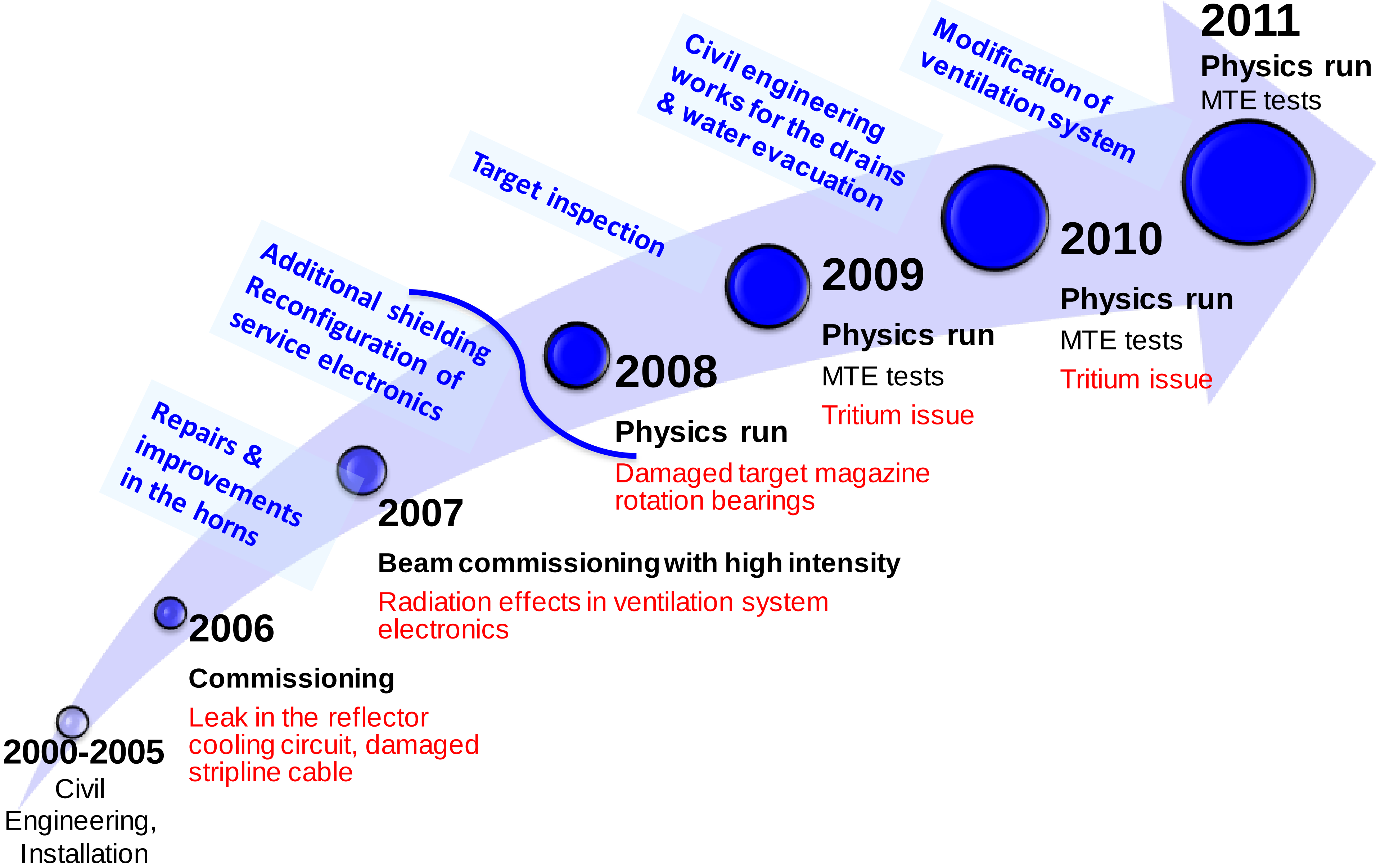
1.8mm inner conductor

Muon detectors:

2x41 LHC type BLMs



CNGS Timeline until Today



2000-2005
Civil Engineering, Installation

2006
Commissioning
Leak in the reflector cooling circuit, damaged stripline cable

Repairs & improvements in the horns

2007
Beam commissioning with high intensity
Radiation effects in ventilation system electronics

Additional shielding
Reconfiguration of service electronics

2008
Physics run
Damaged target magazine rotation bearings

Target inspection

2009
Physics run
MTE tests
Tritium issue

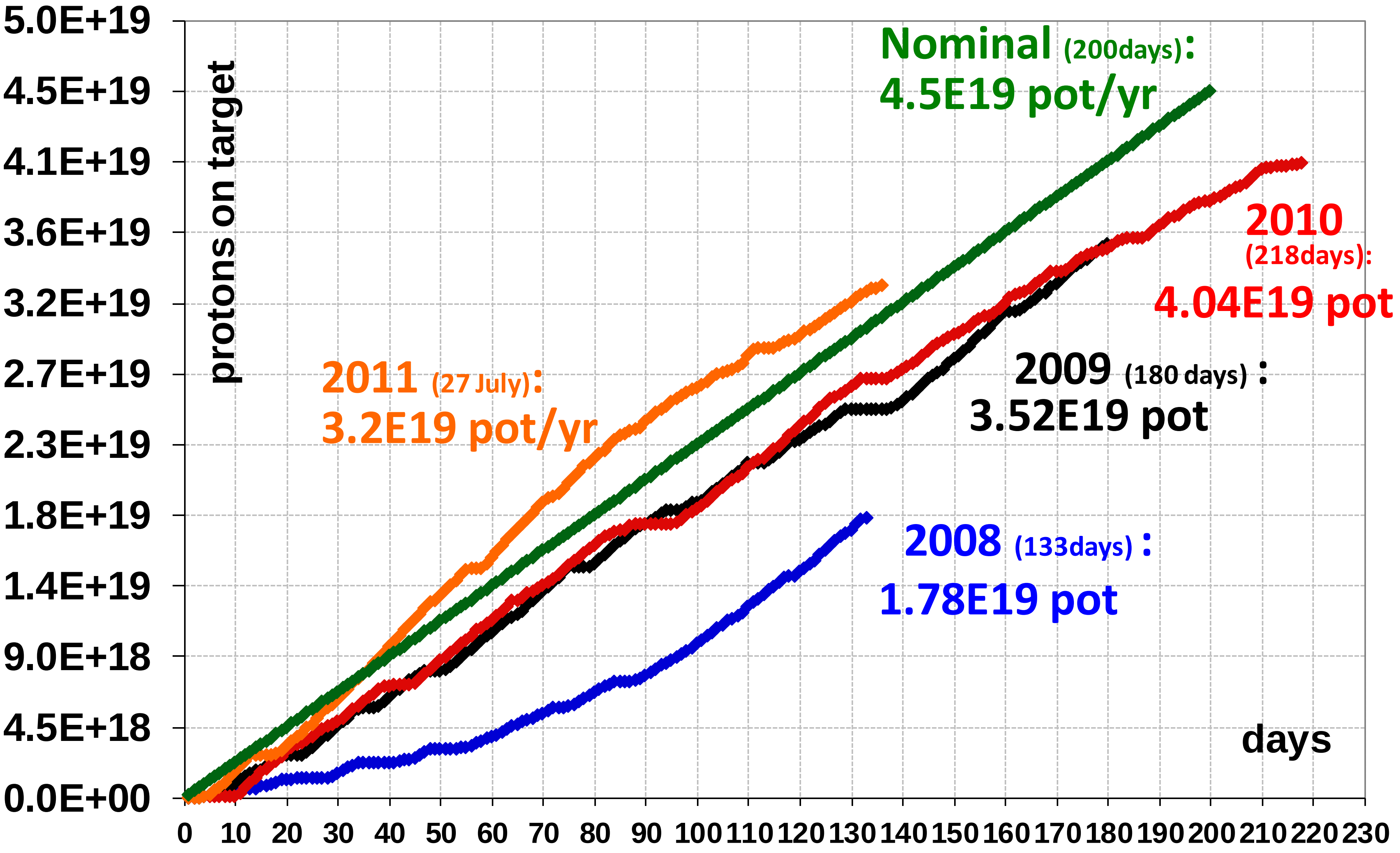
Civil engineering works for the drains & water evacuation

2010
Physics run
MTE tests
Tritium issue

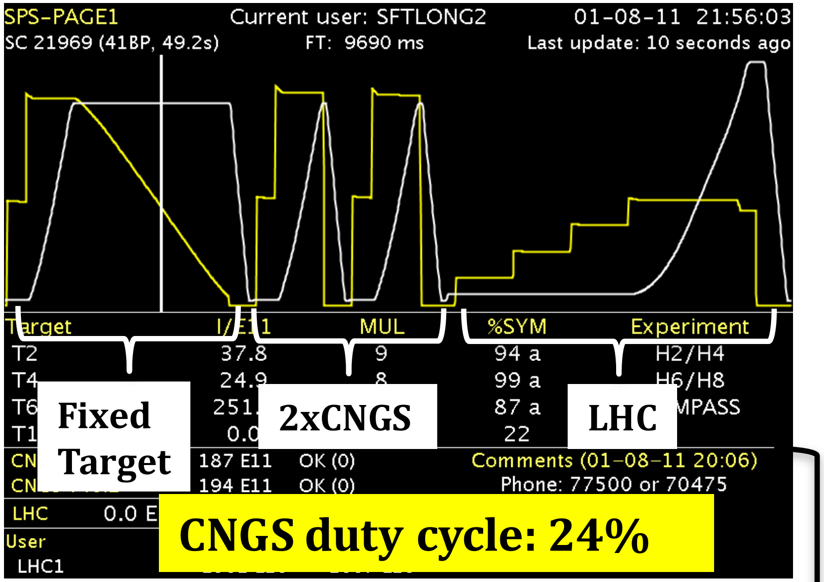
Modification of ventilation system

2011
Physics run
MTE tests

CNGS Physics Run: Comparison of Yearly Integrated Intensity



Different CNGS Duty Cycles (2011)



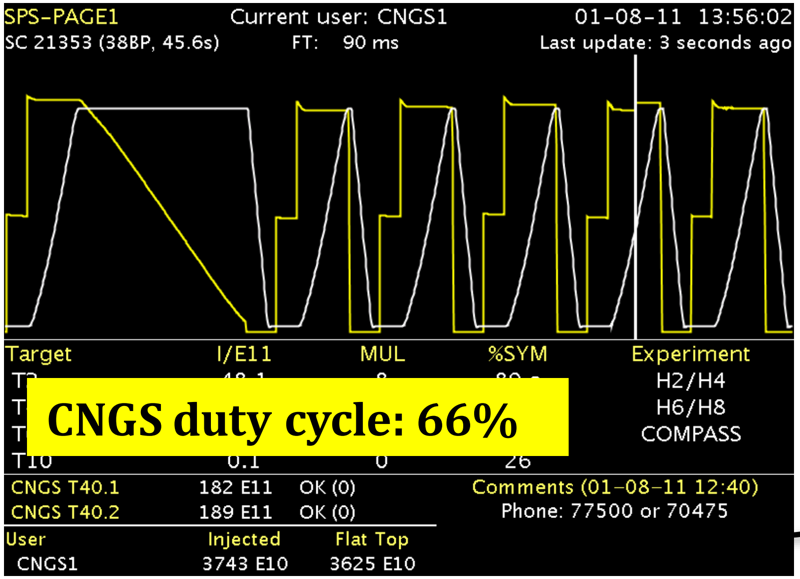
```
SPS-PAGE1            Current user: SFTLONG2        01-08-11  21:56:03
SC 21969 (41BP, 49.2s)        FT:  9690 ms    Last update: 10 seconds ago

Target                I/E11        MUL        %SYM        Experiment
 T2                    37.8          9        94 a          H2/H4
 T4                    24.9          8        99 a          H6/H8
 T6                    251.                   87 a           MPASS
 T1                    0.0                    22
 CN                   187 E11     OK (0)      Comments (01-08-11 20:06)
 CN                   194 E11     OK (0)       Phone: 77500 or 70475
 LHC        0.0 E
User
 LHC1
```

Fixed Target

2xCNGS

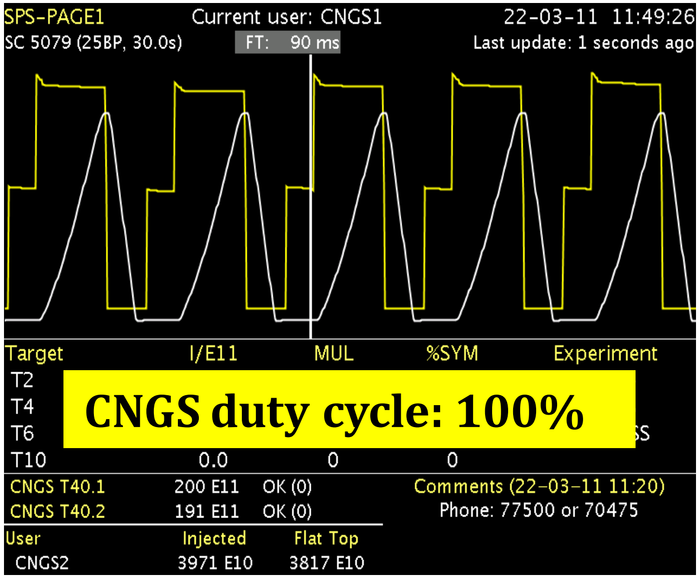
LHC

CNGS duty cycle: 24%



```
SPS-PAGE1            Current user: CNGS1           01-08-11  13:56:02
SC 21353 (38BP, 45.6s)        FT:   90 ms      Last update: 3 seconds ago

Target                I/E11        MUL        %SYM        Experiment
 T                                                          H2/H4
 T                                                          H6/H8
 T                                                         COMPASS
 T10                    0.1          0         26
 CNGS T40.1           182 E11     OK (0)      Comments (01-08-11 12:40)
 CNGS T40.2           189 E11     OK (0)       Phone: 77500 or 70475
User                 Injected    Flat Top
 CNGS1               3743 E10    3625 E10
```

CNGS duty cycle: 66%



```
SPS-PAGE1          Current user: CNGS1           22-03-11  11:49:26
SC 5079 (25BP, 30.0s)     FT:   90 ms       Last update: 1 seconds ago

Target               I/E11        MUL        %SYM        Experiment
 T2
 T4
 T6                                                            SS
 T10                   0.0          0          0
 CNGS T40.1          200 E11     OK (0)      Comments (22-03-11 11:20)
 CNGS T40.2          191 E11     OK (0)       Phone: 77500 or 70475
User                Injected    Flat Top
 CNGS2              3971 E10    3817 E10
```

CNGS duty cycle: 100%

<77%> duty cycle for CNGS with LHC Operation

<57%> duty cycle for CNGS with LHC Operation and Fixed Target program

CNGS Challenges and Design Criteria

→ **Geodesic alignment**

Examples:	effect on ν_τ cc event
horn off axis by 6mm	< 3%
reflector off axis by 30mm	< 3%
proton beam on target off axis by 1mm	< 3%
CNGS facility misaligned by 0.5mrad (beam 360m off)	< 3%

High intensity, high energy proton beam with short beam pulses and small beam spot

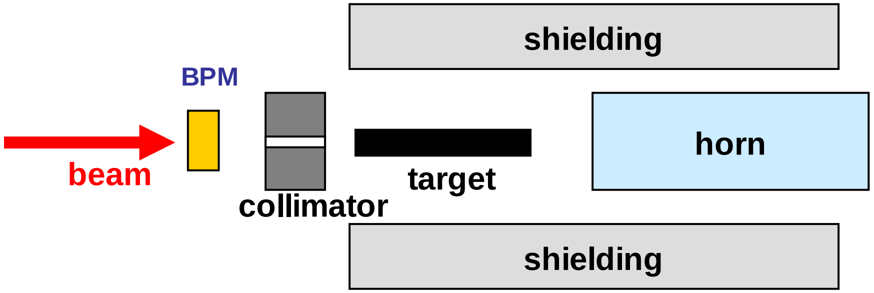
- Thermomechanical shocks by energy deposition (target, windows, etc…)
- Induced radioactivity
- Remote handling and replacement of equipment

→ **Good tuning and interlock system**

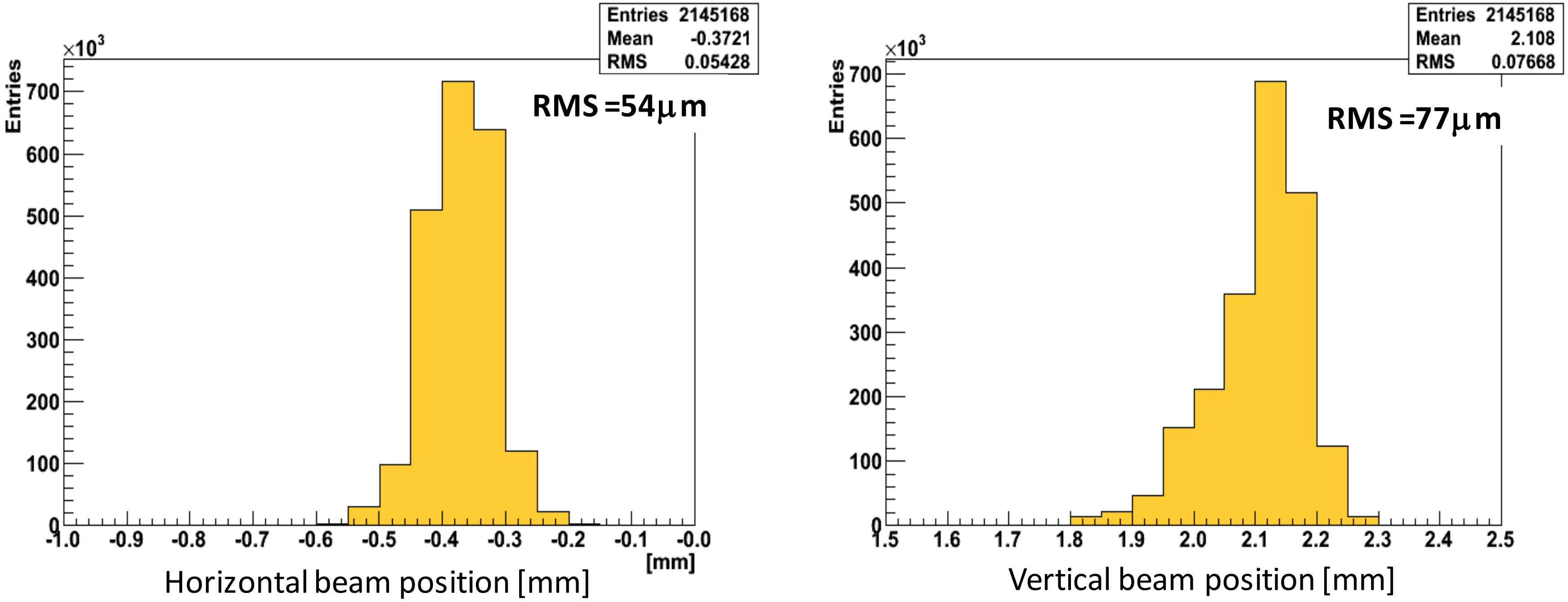
→ **Monitoring of beam and equipment**

Beam Position on Target

Beam trajectory tolerance on target must be below 0.5mm

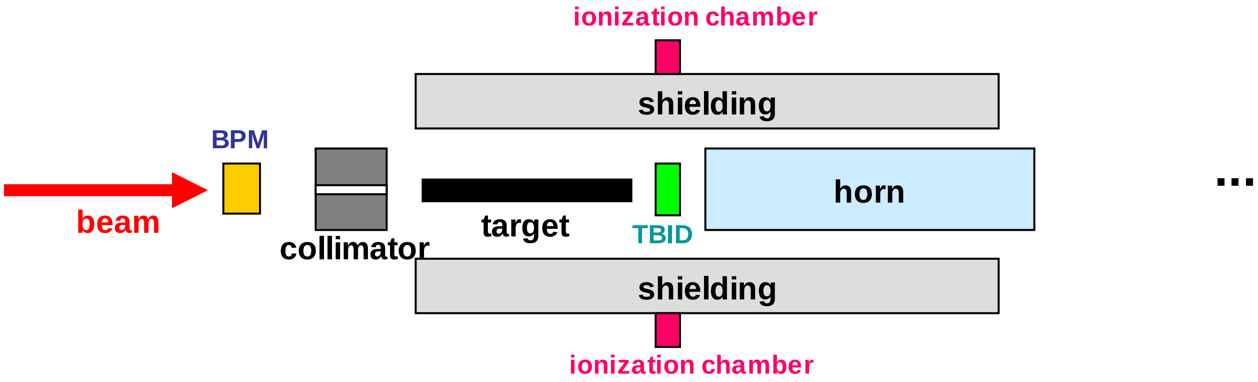


- Excellent position stability; ~50 (80) µm horiz (vert) over entire run.
- No active position feedback is necessary
  - 1-2 small steerings/week only

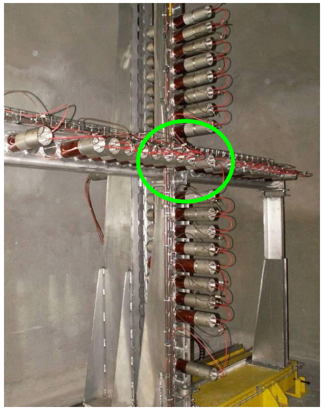


Horizontal and vertical beam position on the last Beam Position Monitor in front of the target

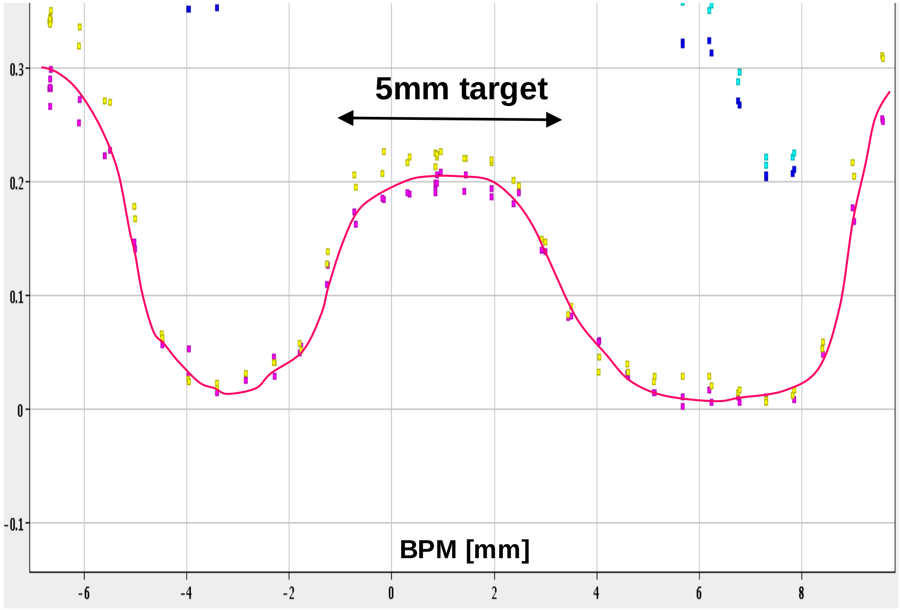
CNGS Performance Monitoring



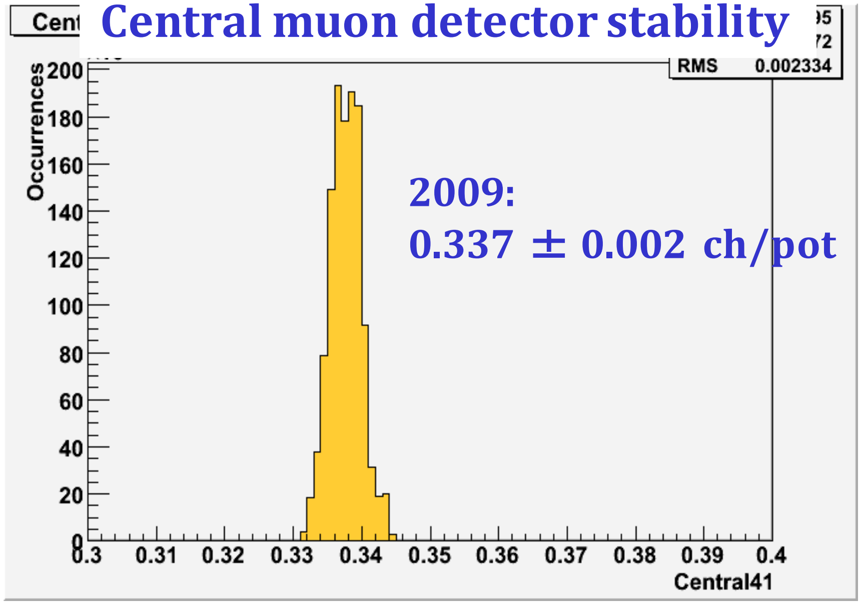
Muon detector



Intensity on Ionization Chambers vs BPM

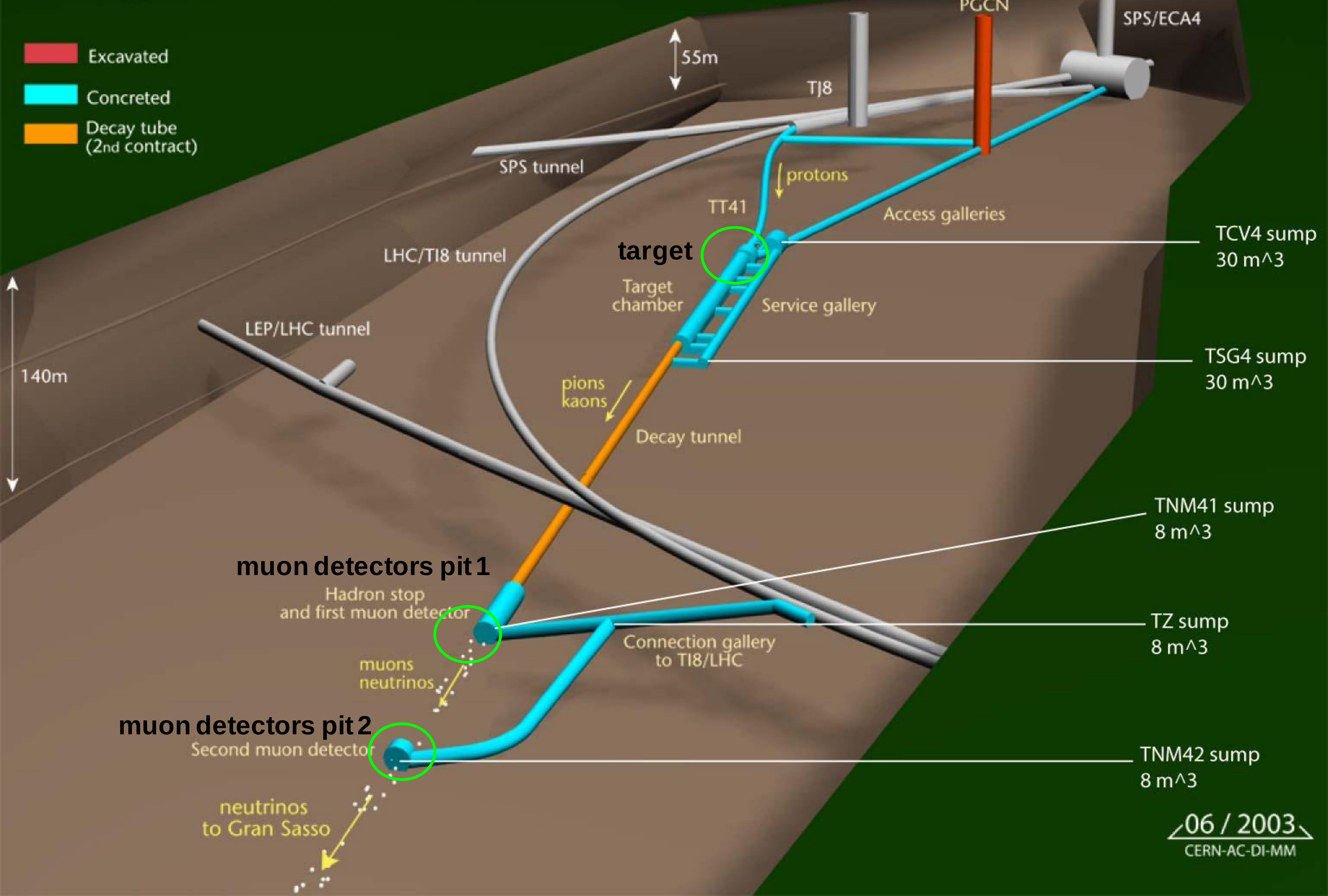


Central muon detector stability



2009:
0.337 ± 0.002 ch/pot

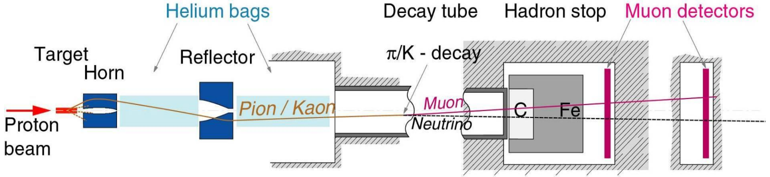
CERN NEUTRINOS TO GRAN SASSO
Underground structures at CERN

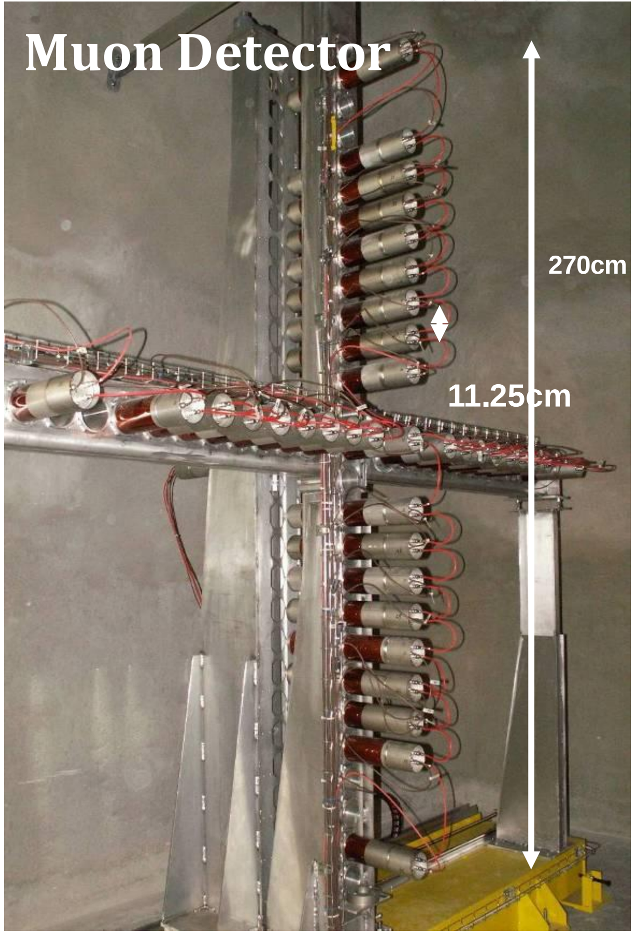


06 / 2003
CERN-AC-DI-MM

Muon Monitors: Online Feedback

Very sensitive to any beam changes! → **Online feedback on quality of neutrino**



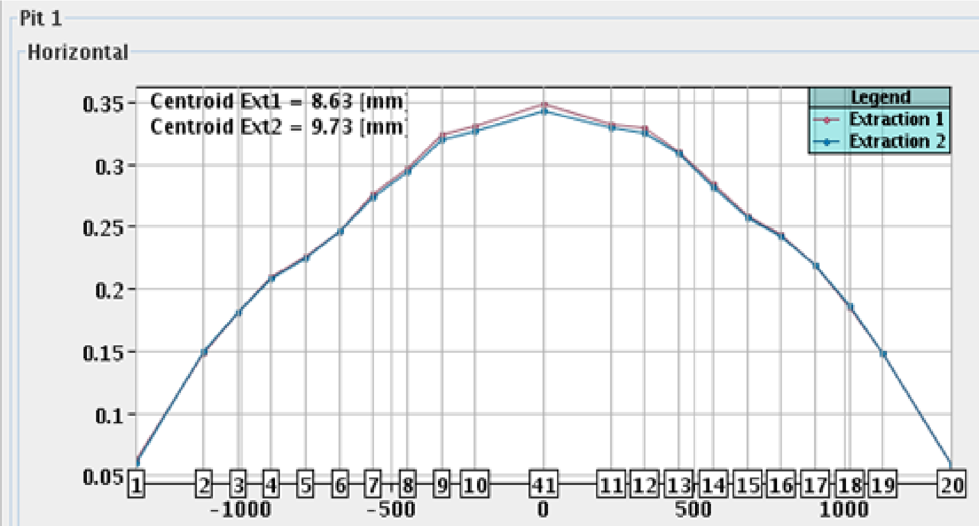


- **Offset of target vs horn at 0.1mm level**
  - Target table motorized
  - Horn and reflector tables not

→ Muon Profiles Pit 1

- **Offset of beam vs target at 0.05mm level**

→ Muon Profiles Pit 2

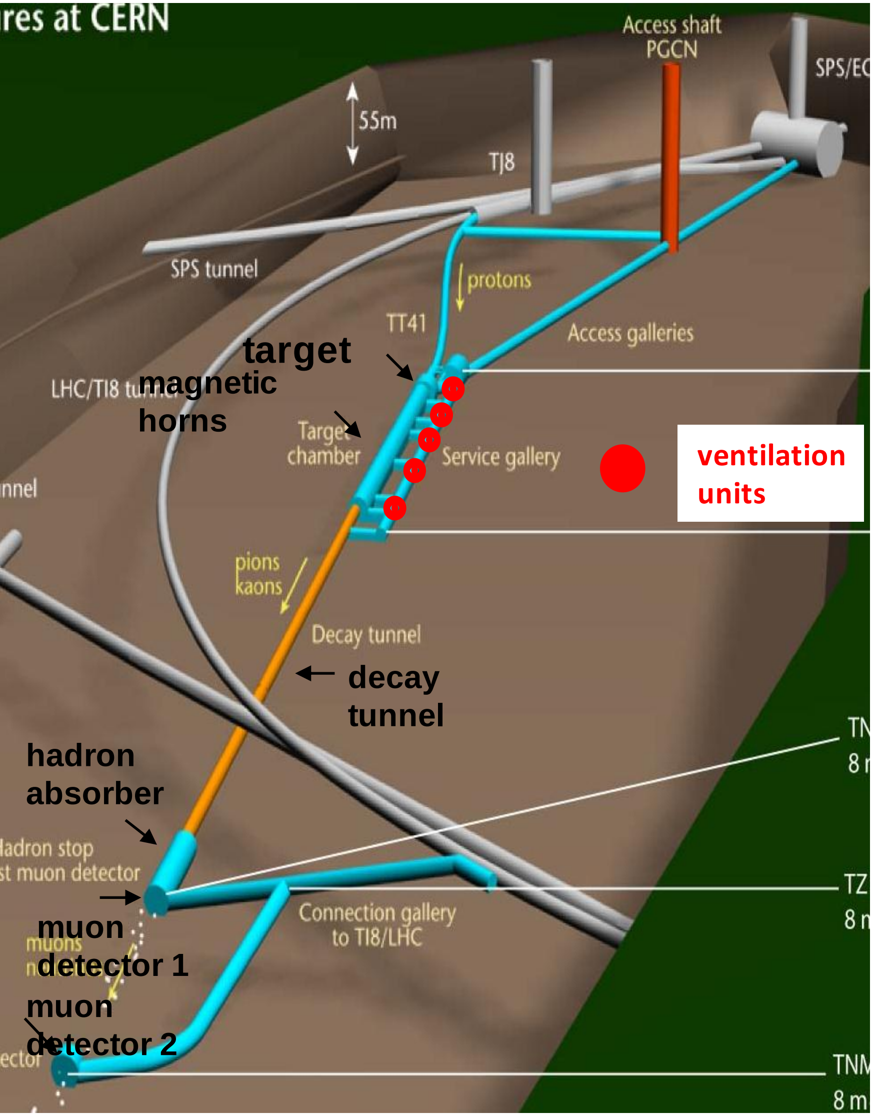


Centroid = $\sum(Q_i * d_i) / \sum(Q_i)$

Q_i is the number of charges/pot in the i-th detector,

d_i is the position of the i-th detector.

CNGS Radiation Issues I



No surface building above CNGS target area
→ large fraction of electronics in tunnel area

Failure in ventilation system installed in the CNGS Service gallery

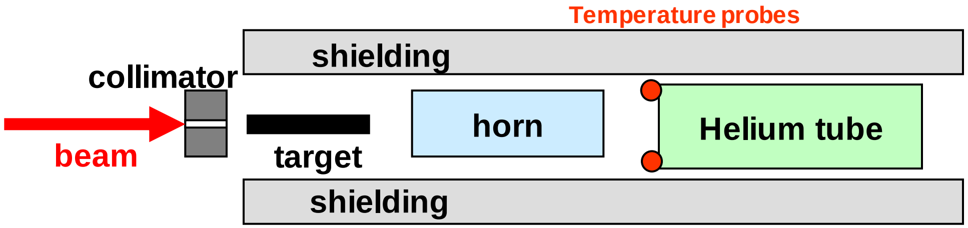
→ due to radiation effects in electronics (**SEU**- Single Event Upsets- from high energy hadrons)

Modifications during shutdown 07/08:

- Move most of the **electronics out** of CNGS tunnel area
- **Create radiation safe area** for electronics which needs to stay in CNGS
- **Add shielding** → $53m^3$ concrete → up to $6m^3$ thick shielding walls

→ triggered a huge radiation to electronics campaign at LHC!!!

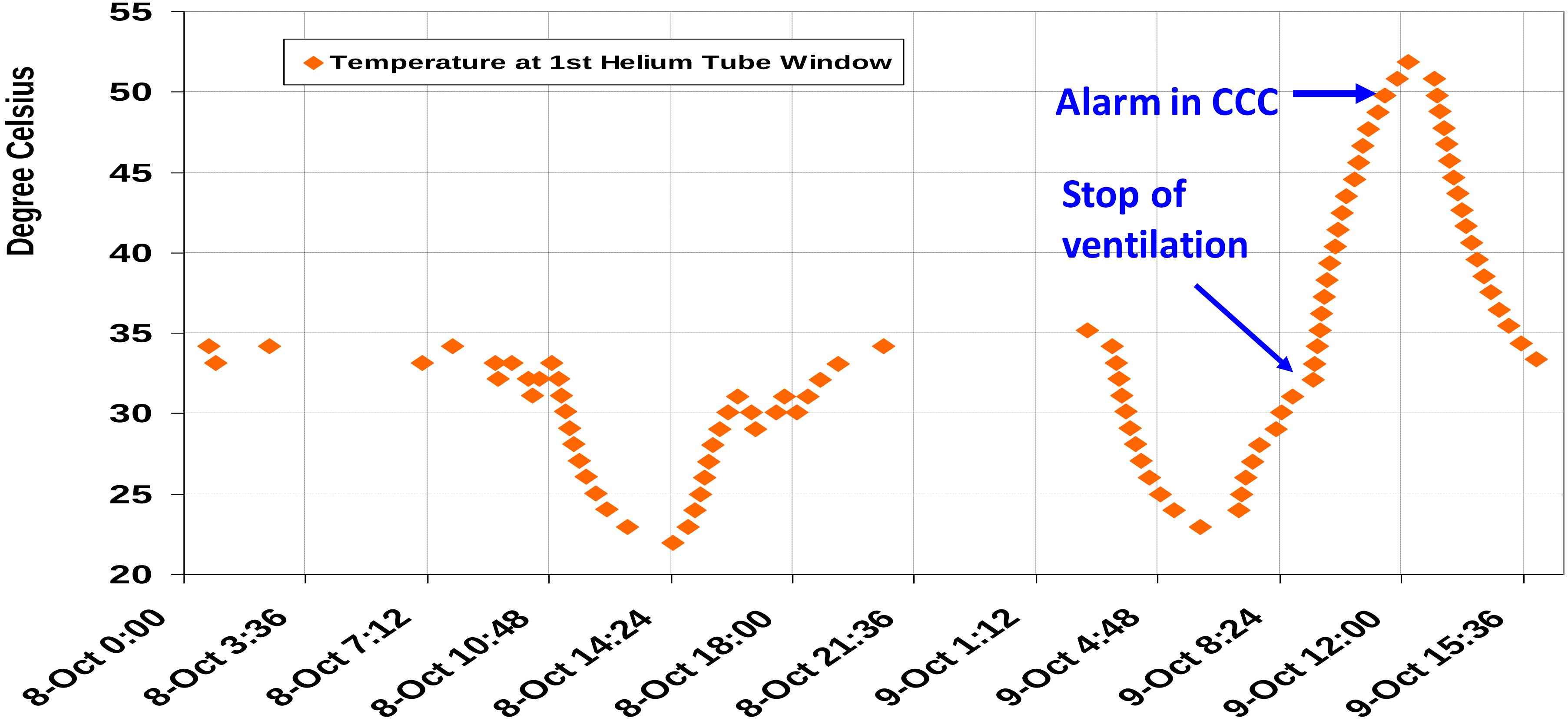
CNGS Radiation Issues II



Temperature probes reacted immediately on failure of the ventilation system

→Alarm in CERN Control Centre

→Switch off beam



Alarm in CCC

Stop of ventilation

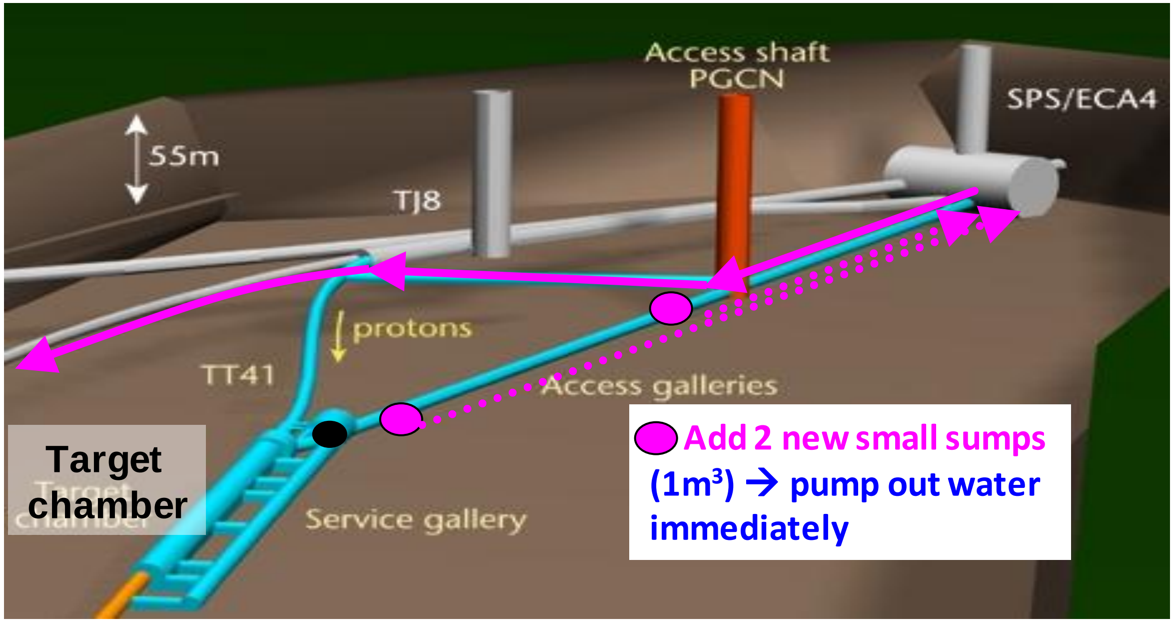
CNGS Radiation Issues III
Sump and Ventilation System

After 1st year of high intensity CNGS physics run: Modification needed for

- Sump system in the CNGS area

  → **avoid contamination** of the drain water by tritium produced in the target chamber
  - Try to remove drain water before reaches the target areas and gets in contact with the air
  - Construction of two new sumps and piping work

- **Ventilation system configuration and operation**
  - Keep target chamber under under-pressure with respect to all other areas
  - Do not propagate the tritiated air into other areas and being in contact with the drain water



● Add 2 new small sumps $(1m^3)$ → pump out water immediately

→ Radiation monitors

CNGS – Perspectives

Approved for **22.5 ·10^{19} protons on target**

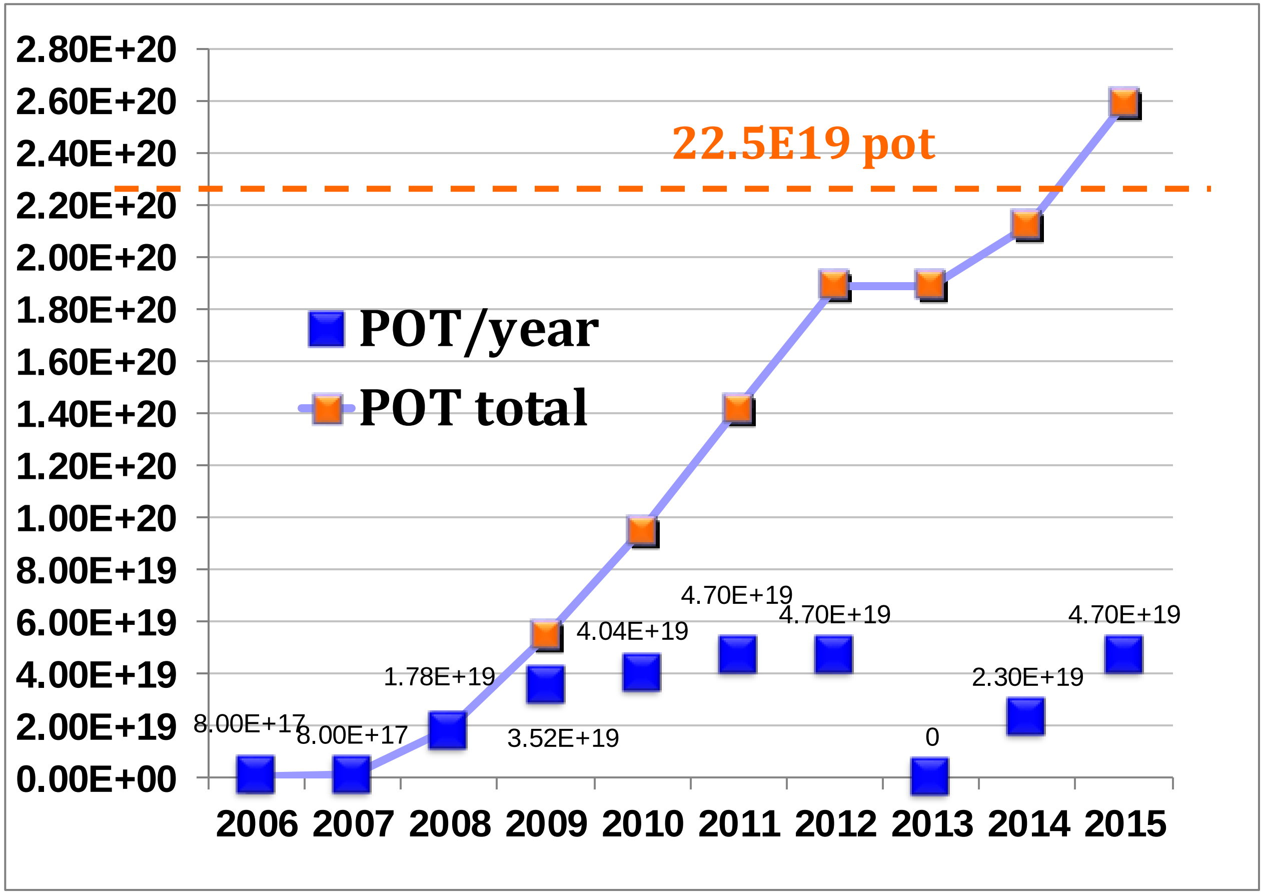
i.e. 5 years with **4.5·10^{19} pot/ year** → **Expect ~10 ν_τ events in OPERA**

2011, 2012: 4.7E19 pot
2013: 0 pot
2014: 2.3E19 pot
2015: 4.7E19 pot

LS1

→Physics program would **finish in 2015**

→By end **2012** we would have reached **~19E19 pot**



CNGS Facility: Intensity Limitations

→ Design of secondary beam line elements, RP calculations

→ (Horn designed for 2E7 pulses, today we have 1.5E7 pulses → spare horn)

→ Intensity upgrade from the injectors are being now evaluated within the LHC Injector Upgrade Project (LIU)

Intensity per PS batch	**# PS batches**	**Int. 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 target, horn, kicker, instrumentation

Design limit for horn, shielding, decay tube, hadron stop

Working hypothesis for RP calculations

CNGS working hypothesis

Summary

- Beam performance since start of physics run in 2008 CNGS is very good
  - Today we have already delivered more than half of the approved total protons on target.
  - Looking forward to seeing more tau-neutrinos
- CNGS program beyond 2013 not yet approved
  - Statement from OPERA in summer 2012
- Operating and maintaining a high-intensity facility is very challenging
  - Possibility for early repair must exist
  - Consider radiation effects on nearby electronics
  - Intervention on equipment 'impossible' after long operation
    - → Remote handling, replacement
  - Ventilation system is a key item
    - Temperature and humidity control
    - Radioactive air management
  - H-3 creation in air and water is an issue
  - Keep redundancy of monitoring
  - Beam-line instrumentation is crucial

Additional Slides

Total Integrated Intensity since CNGS Start 2006