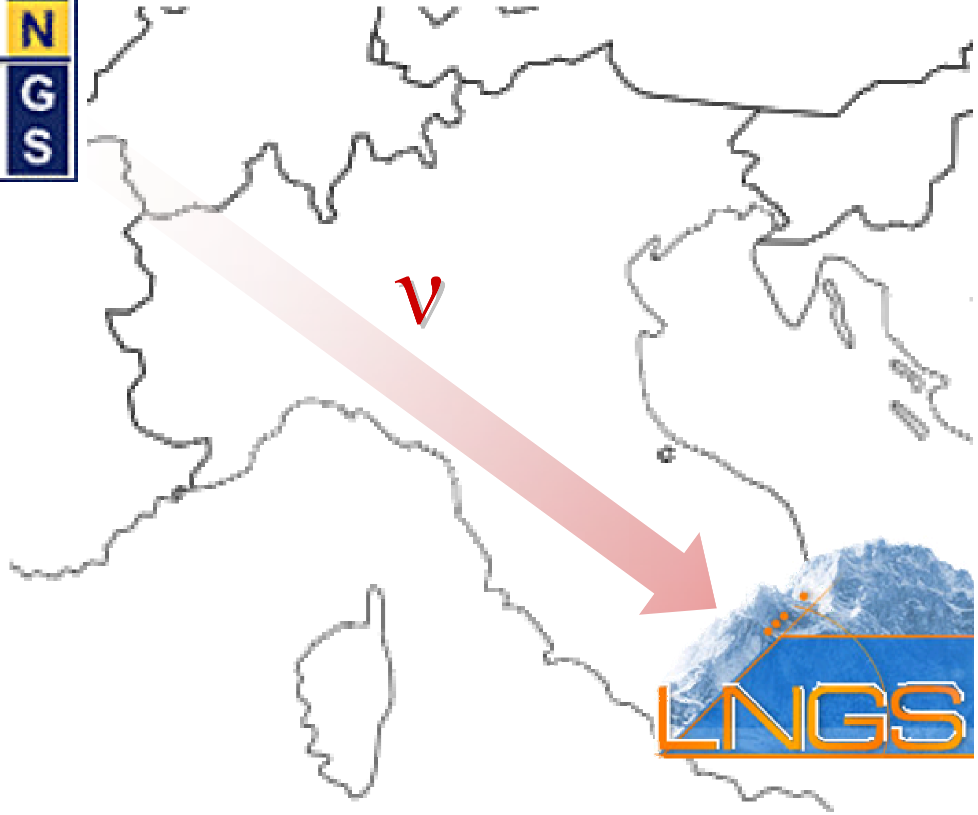
10th Topical Seminar on
Innovative Particle and Radiation Detectors (IPRD06)
1 - 5 October 2006 Siena, Italy



The CNGS neutrino beam

G. Sirri

INFN Bologna

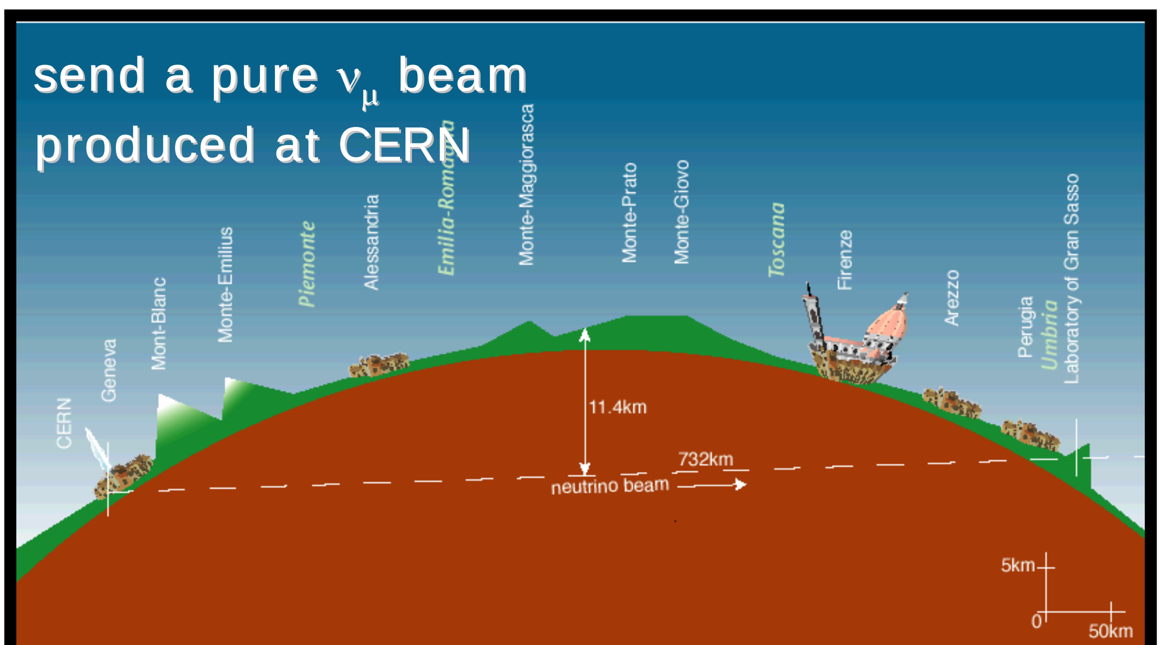
CNGS (CERN Neutrinos to Gran Sasso)

The project is motivated by the results obtained by atmospheric neutrino detectors (Super-K, MACRO, Soudan2) and supported by other experiments (K2K, MINOS), observing a significant deficit in the flux of detected muon-type neutrinos produced by cosmic rays in the atmosphere (explained by the hypothesis of neutrino-oscillations).

The CNGS aims at

- Providing an unambiguous evidence for $\nu_\mu \rightarrow \nu_\tau$ oscillations
- Searching for the sub-leading $\nu_\mu \rightarrow \nu_e$ oscillations

Long base-line neutrino beam facility (732km)



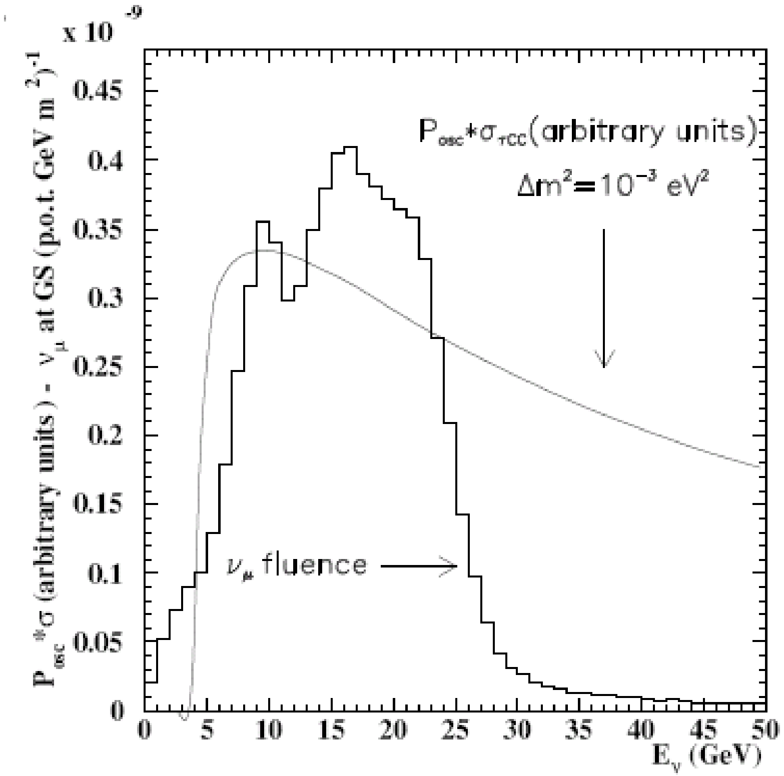
detect ν_τ appearance in experiments at Gran Sasso

- CNGS1 *OPERA*
- CNGS2 *ICARUS*

CNGS optimized for ν_τ appearance

optimized to maximize ν_τCC interaction rate at LNGS

- *for* $\Delta m^2_{23} \sim 10^{-3}$ *eV*^{2}, $\nu_\mu \to \nu_\tau$ *oscillation probability over* $L = 732$ *km is* $P_{osc} \propto (\Delta m^2_{23})^2 L^2 / E^2_\nu$
- *the rate of detected* ν_τ *oscillation events* $\propto P_{osc} \cdot \sigma_{\tau CC}$: $R \propto (\Delta m^2_{23})^2\ L^2 \int \phi_\nu(E_\nu) \frac{\sigma_{\tau CC}(E_\nu)}{E^2_\nu}\ dE_\nu$
- $\to$ *the energy* E_ν *spectrum of* ϕ_ν: *well matched to* $\sigma_{\tau CC}/E^2_\nu$ *at* ~ 15 *GeV to maximize the signal rate*



Design goal:

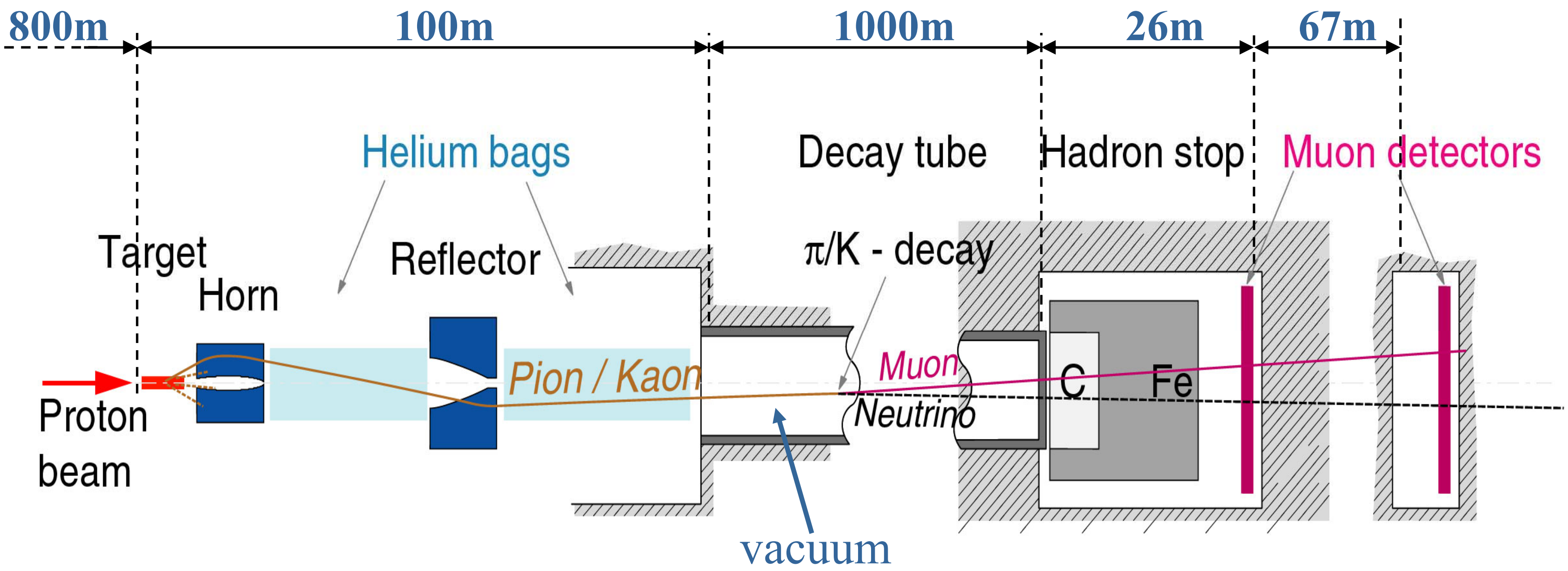
$\langle E\nu_\mu \rangle$	**17 GeV**
$(\nu_e + \bar{\nu}_e) / \nu_\mu$	**0.87%**
$\bar{\nu}_\mu / \nu_\mu$	**2.1%**
ν_τ **prompt**	**negligible**

- 4.5×10^{19} p.o.t./year
- 200 days/year

Interactions in the 1.8 kton OPERA detector at Gran Sasso

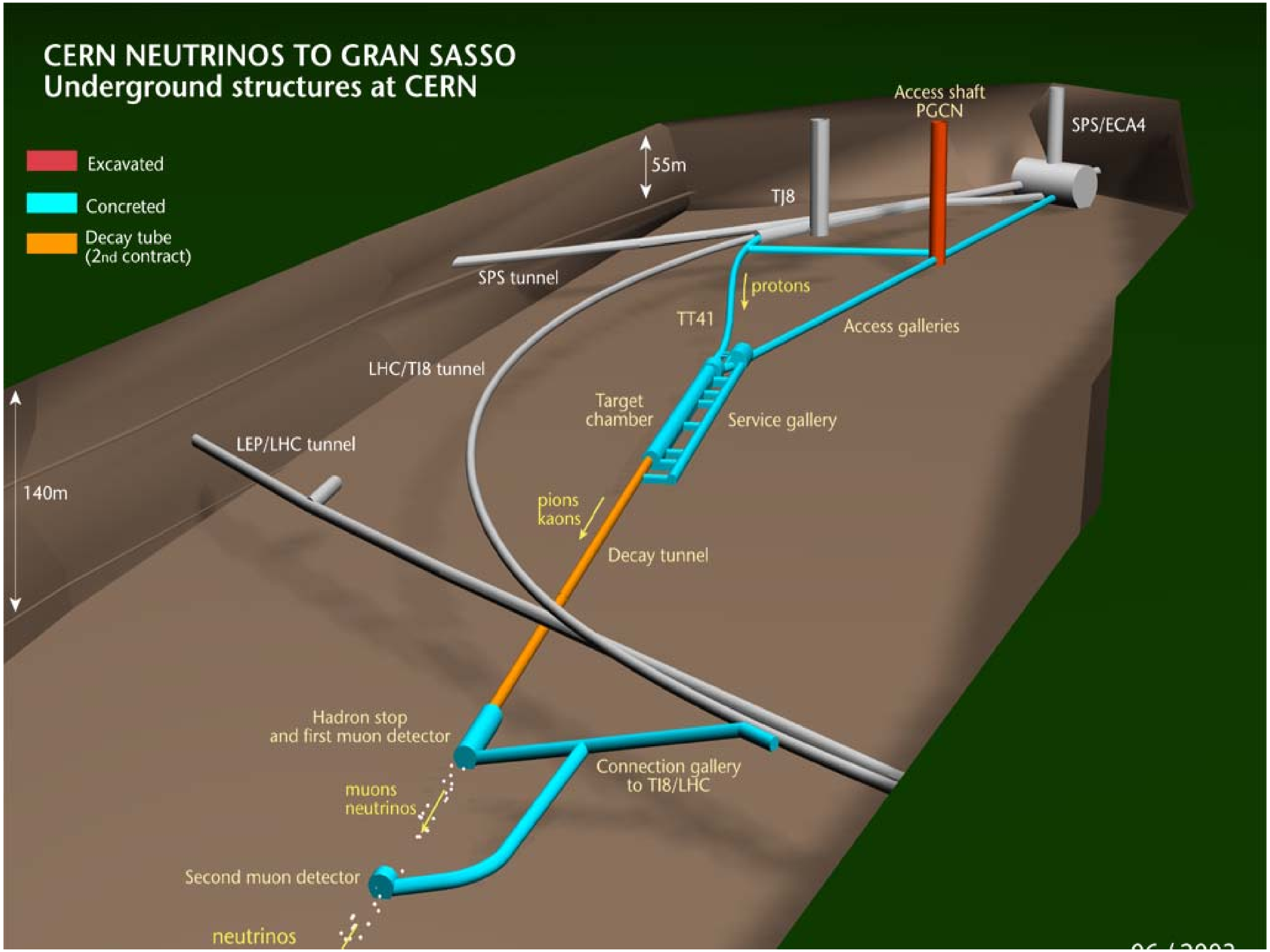
ν_μ **(CC + NC) /year**	**~ 6200**
ν_τ **CC /year**	**~25**
($\Delta m^2 = 2.4\ 10^{-3}$ eV^2, maximal mixing)	

Scheme for the production of neutrinos



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

- 400 GeV/c protons extracted CERN SPS, directed on a carbon target where mesons are produced
- positive (negative) secondary mesons: focused (defocused) by magnetic Horn + Reflector in 1 km decay tunnel toward Gran Sasso Lab where ν's are generated in the decay in flight of π's and K's
- two He bags to minimize meson absorption before the decay
- residual mesons are absorbed in a massive C+Fe dump at the end of the beam line



The beam layout

CNGS excavation and installation: 2000-2006

Proton Line

- *two fast extractions of 400 GeV/c protons every 6 s,* $2.4 \cdot 10^{13}$ *ppp in* $\Delta t = 10.5\ \mu s$ *interleaved by 50 ms, for a total of* $4.5 \cdot 10^{19}$ *pot/y, ultimate intensity:* $3.5 \cdot 10^{13}$ *ppp (tested)*
- *spatial, angular profile of proton spills:* $\sigma_X = \sigma_Y = 0.53$ *mm,* $\sigma_\theta = 0.053$ *mrad*

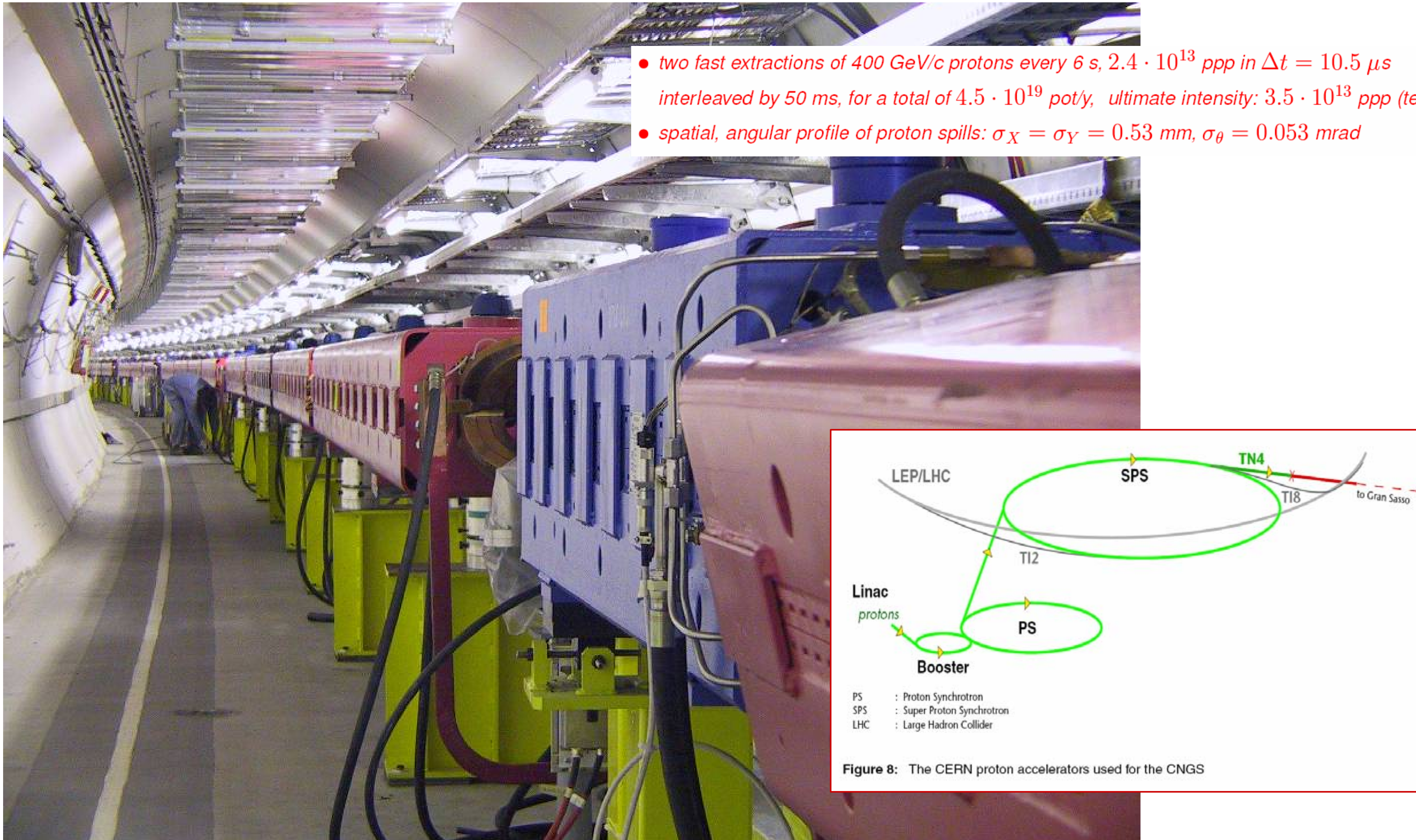
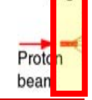


Figure 8: The CERN proton accelerators used for the CNGS

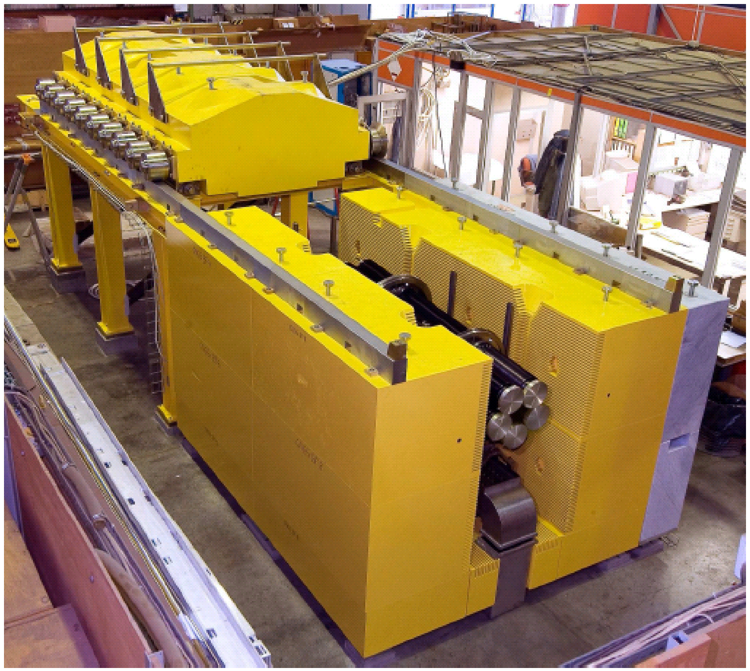
Acceleration chain: Linac (50 MeV), Booster (1.4 GeV), PS (14 GeV), SPS (400 GeV). Then protons are ejected and transported to a transfer line (825 meters) oriented in Gran Sasso direction (vert. deflection = 3.2 degrees) .

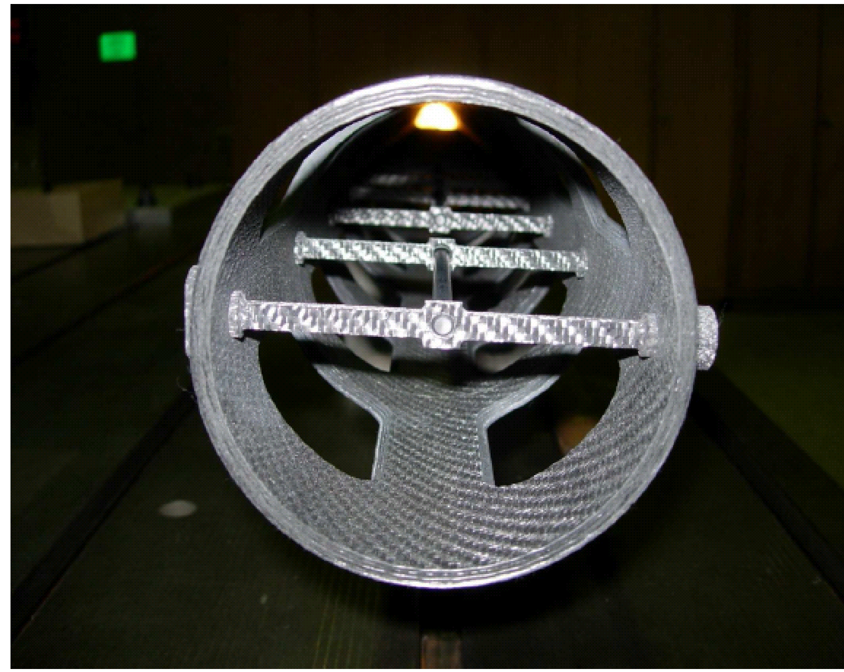
73 dipoles (bending magnets) and 28 quadrupoles (focussing magnets)

Graphite Target



The size has been chosen in order to provide as many secondary particles as possible. In addition the graphite cylinders must absorb the great heat and thermo-mechanical shock due to energy deposited by proton beam. Cooled by a jet of high-pressure helium gas.





- *"revolver target magazine": 5 He tubes with inserted nominal + spare targets*
- *nominal target: 13 graphite rods, $\ell = 10$ cm each for a total 3.3 λ_I, $\phi = 4$ mm ,*

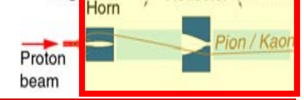
  $\phi = 5$ mm the first 2, the more fired, to better dissipate heat

  first 8 rods: separated by 9 cm each to better develop meson production

  last 5 rods: packed to reduce longitudinal smearing in π production for a better focalisation

  can works at $3.5 \cdot 10^{13}$ ppp, 0.75 MW, for $7.6\ 10^{19}$ pot/y (dedicated beam operation) !

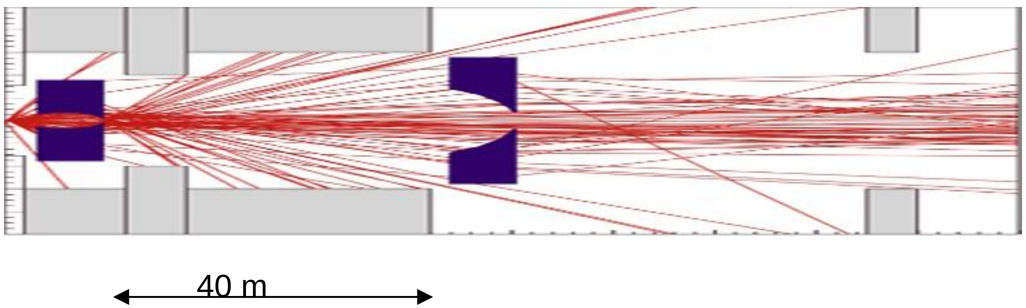
Horn and Reflector



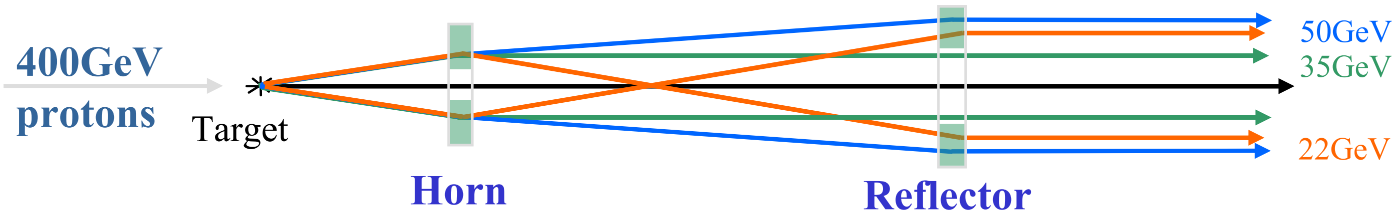
The particles produced in the target enter a system of magnetic horns to focus positive particles and defocus negative particles.

horn

Focalising many particles:



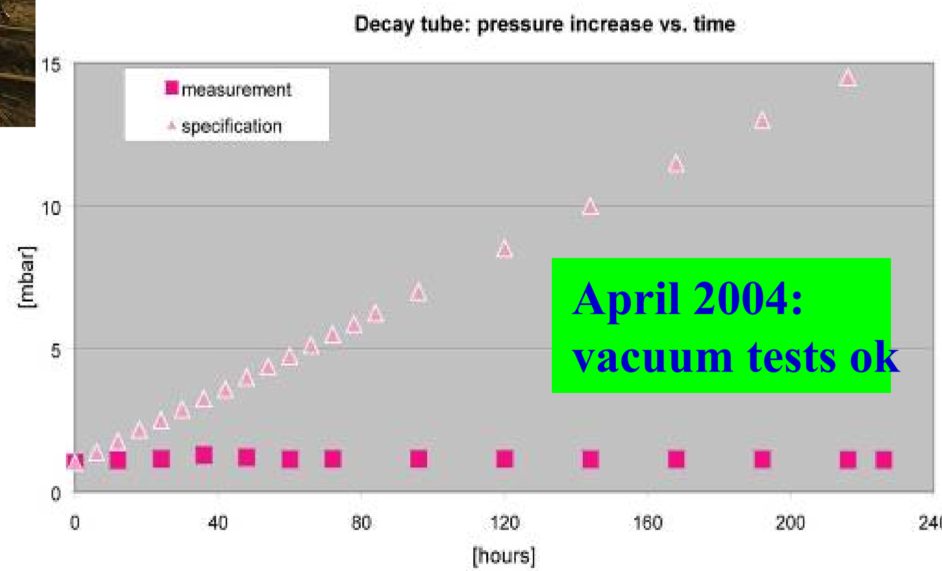
Focalising particles of all energies:



- *Horn & Reflector, $\ell = 6.5$ m each, magnetic lenses to focus π^+, K^+ in the 30-50 GeV range toward Gran Sasso by a pulsed currents $I_{horn} = 150$ KA and $I_{refl} = 180$ KA*
- *Horn: at 1.2 m from target to maximize angular acceptance/ focusing*

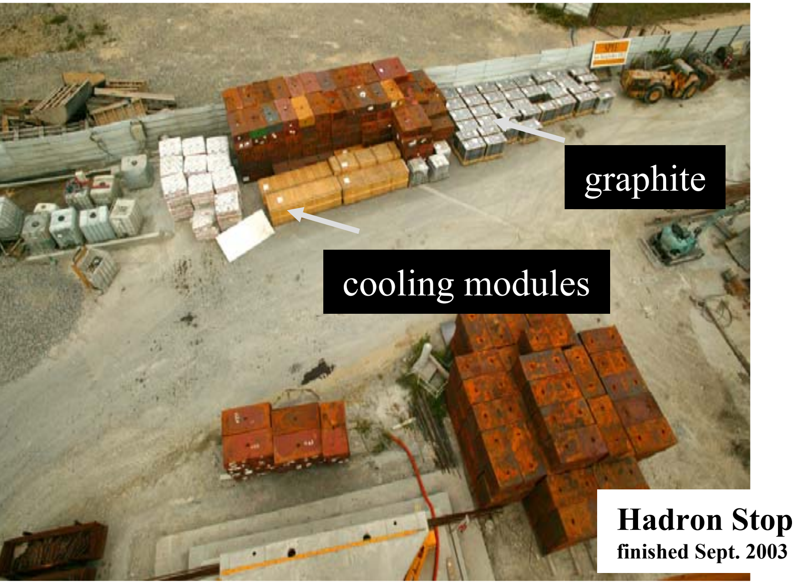
  Reflector at 42 m from target to complete the higher energy particle focusing

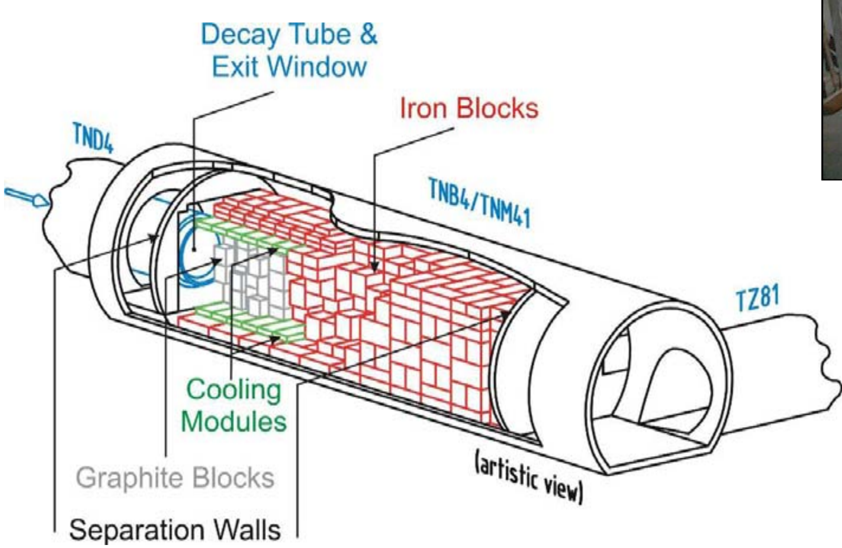
Decay Tube



- steel pipe sealed in the rock
- 994m long (compromise between costs and number of neutrinos in CNGS)
- 2.45m diameter
- entrance window: 3mm Ti
- exit window: 50mm carbon steel, water cooled
- 1mbar

Hadron Stop





Located at the end of the decay tunnel

Consists of 3 meters of graphite followed by 15 meters of iron

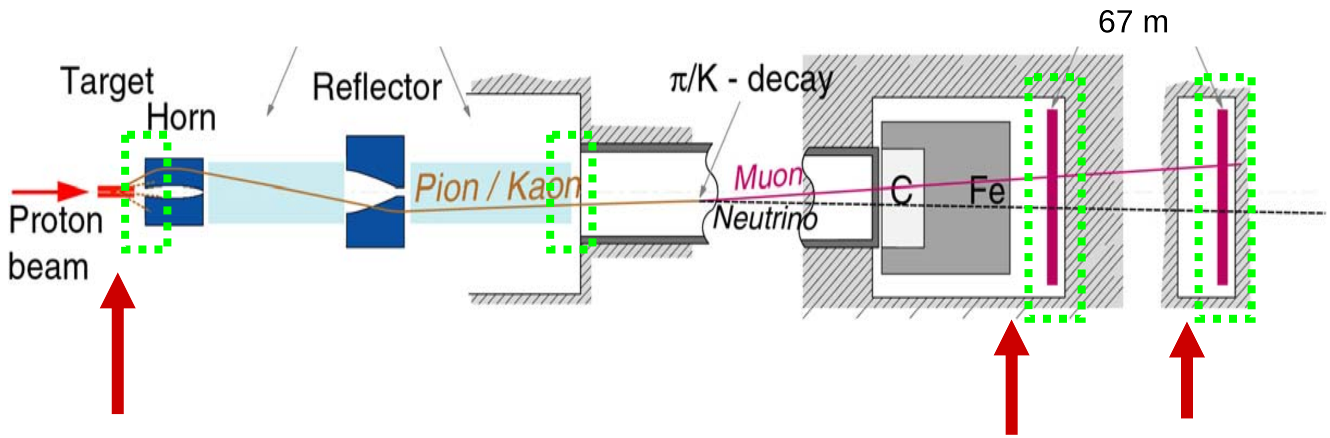
Absorb protons not interacting in target or horns together with all remaining pions and kaons.

The quantity of energy to be absorbed is relatively high → closed-circuit water cooling is provided.

Muons absorbed further within a kilometer behind the hadron stop

Beam Instrumentation for CNGS facility

23 Beam Position Monitors (BPM) in the proton line



Target Beam Instr. Downstream (TBID)
+ 2 Ionization Chamber

Check efficiency with which protons are converted into secondaries

- ⟶ Multiplicity (Compare with BFCT upstream of the target)
- ⟶ Misalignment of the Beam

Ionization Chamber used as back-up

2 Muon Detector stations

Measure the trajectory of the muons is the most practical way of checking the position, angle intensity of a neutrino beam

Monitoring of:
- muon intensity
- muon beam profile shape
- muon beam profile centre

Muon intensity:
- Up to $7.7\text{x}10^7$ per cm^2 and 10.5µs

Monitors:
- 2 muon detectors with each 17 fixed monitors + 1 movable monitor (ionization chambers)

Beam at Gran Sasso

Event rates

- **ν interactions in the detector (1.8 kton)**:
  ν_μ (CC + NC) /year ~ 6200

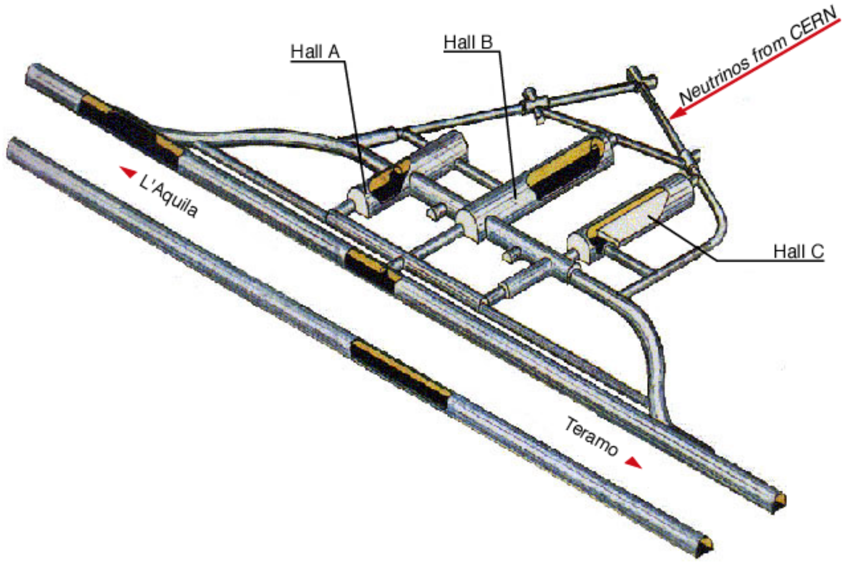
- **ν interactions in the Gran Sasso rock…used for <u>beam monitoring</u>:**

  ~ 1 μ / m2 / day

Time synchronization

- **EarlyWarning** (UDP packets)
  To facilitate synchronous behavior of equipment in the Gran Sasso laboratory with the extracted CNGS Neutrino beam at CERN, UDP packets are transmitted from CERN. <u>The next neutrino spill time can be predicted in advance of several seconds.</u>

- **Event selection by GPS Timing Info**
  Inter-laboratory GPS synchronization (accuracy in the region of 100 ns)

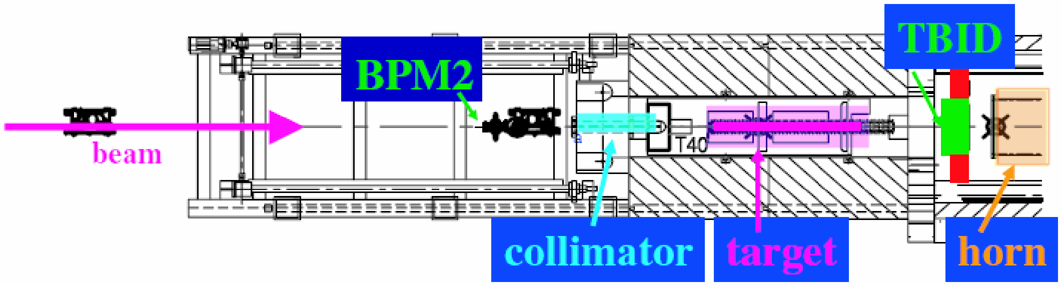


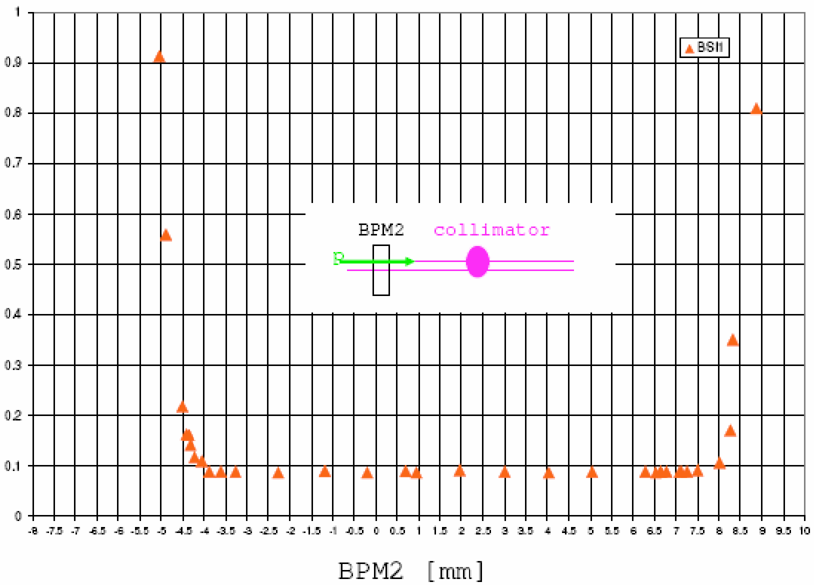
CNGS beam commissioning

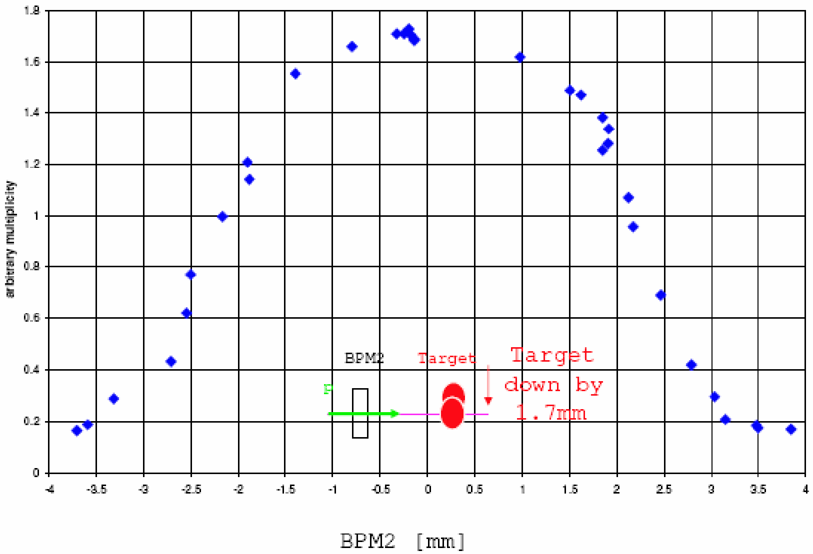
3 week from July 10 2006, intensity up to 10**13 pot

The beam and the target must be perfectly aligned in order not to shock the target and lose intensity.

centering of proton beam, collimator and target







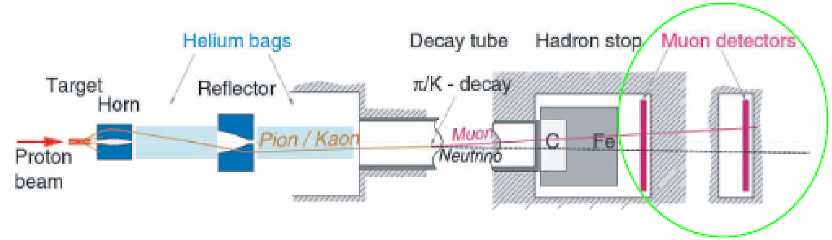
collimator ($\phi = 1.4$ cm): horiz. beam position scan target OUT, reading from TBID

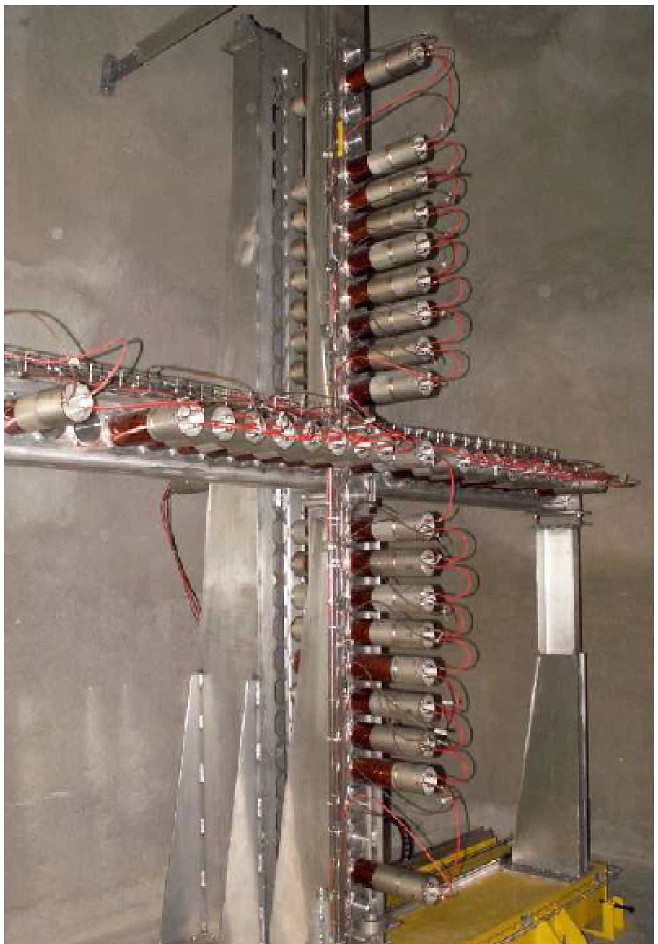
horiz. beam position scan target IN, intensity on TBID vs. BPM2 position

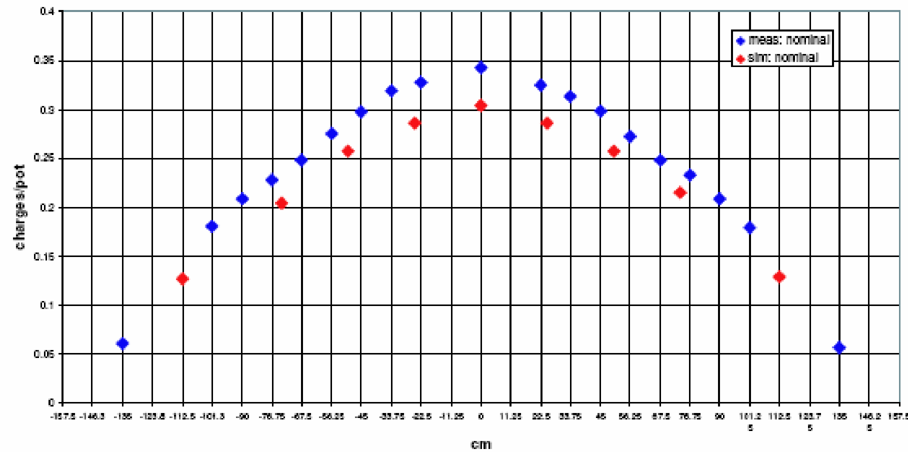
During the commissioning phase the relative alignment between beam and target stayed within 50 microns.

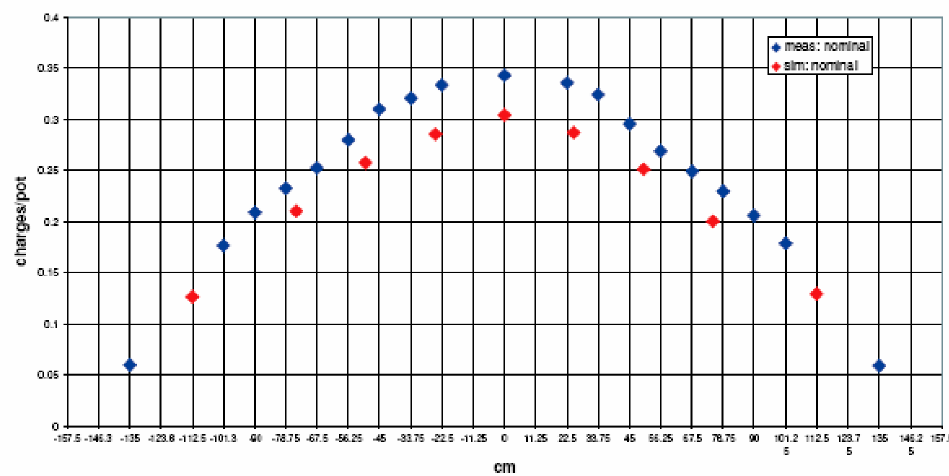
absolute μ signal in first μ-pit PRELIMINARY

37 fixed BLM monitors + 1 movable









horizontal (top) - vertical (bottom) profiles

neutrino beam: well centered, good initial agreement of data vs. expectations !

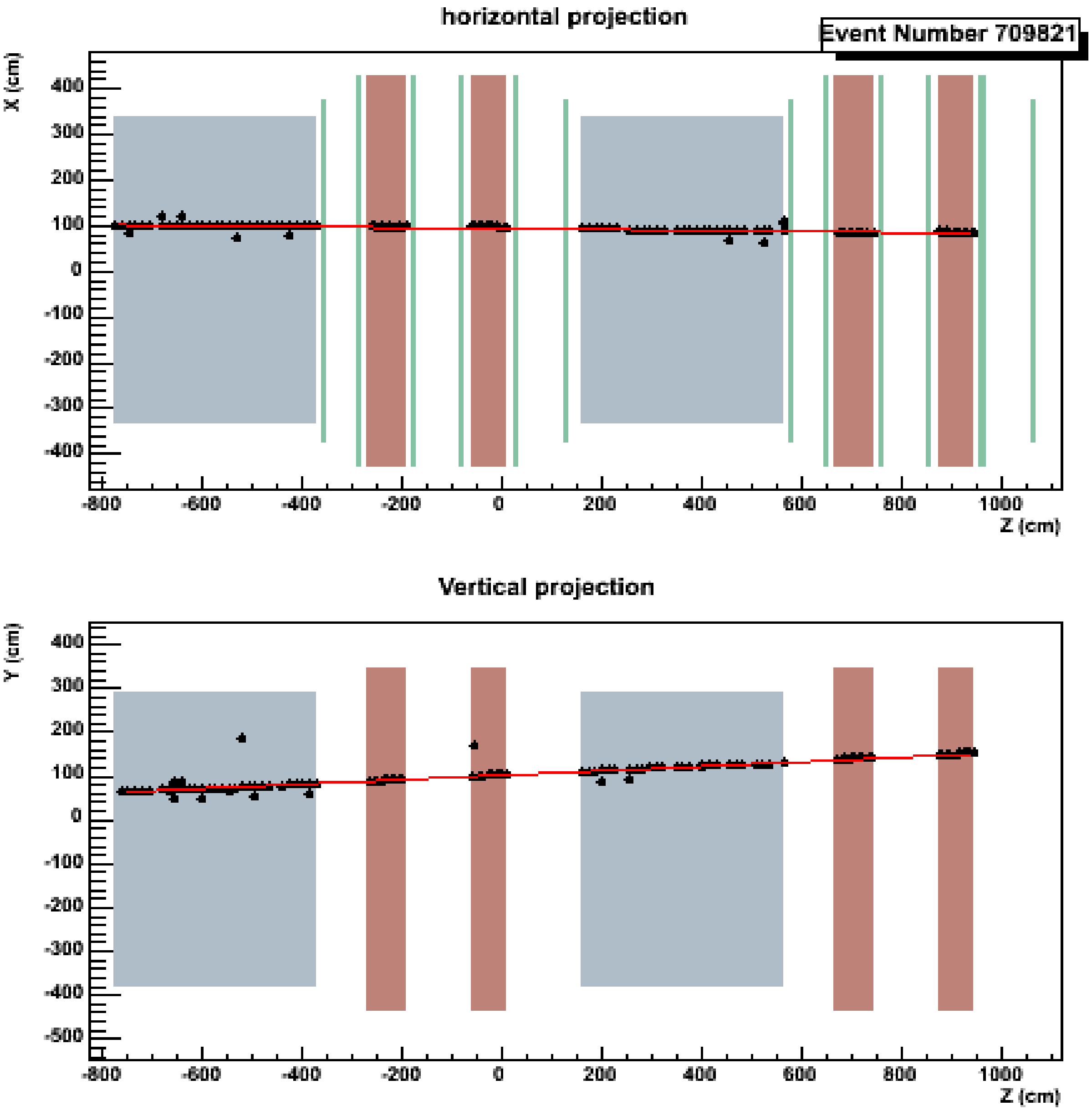
For CNGS performance, a critical issue is the geodesic alignment wrt. Gran Sasso

Examples:	effect on ν_τ cc events
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 0.5 mrad (beam 360m off)	< 3%

Considering the commissioning results: no alignment problem foreseen for the run

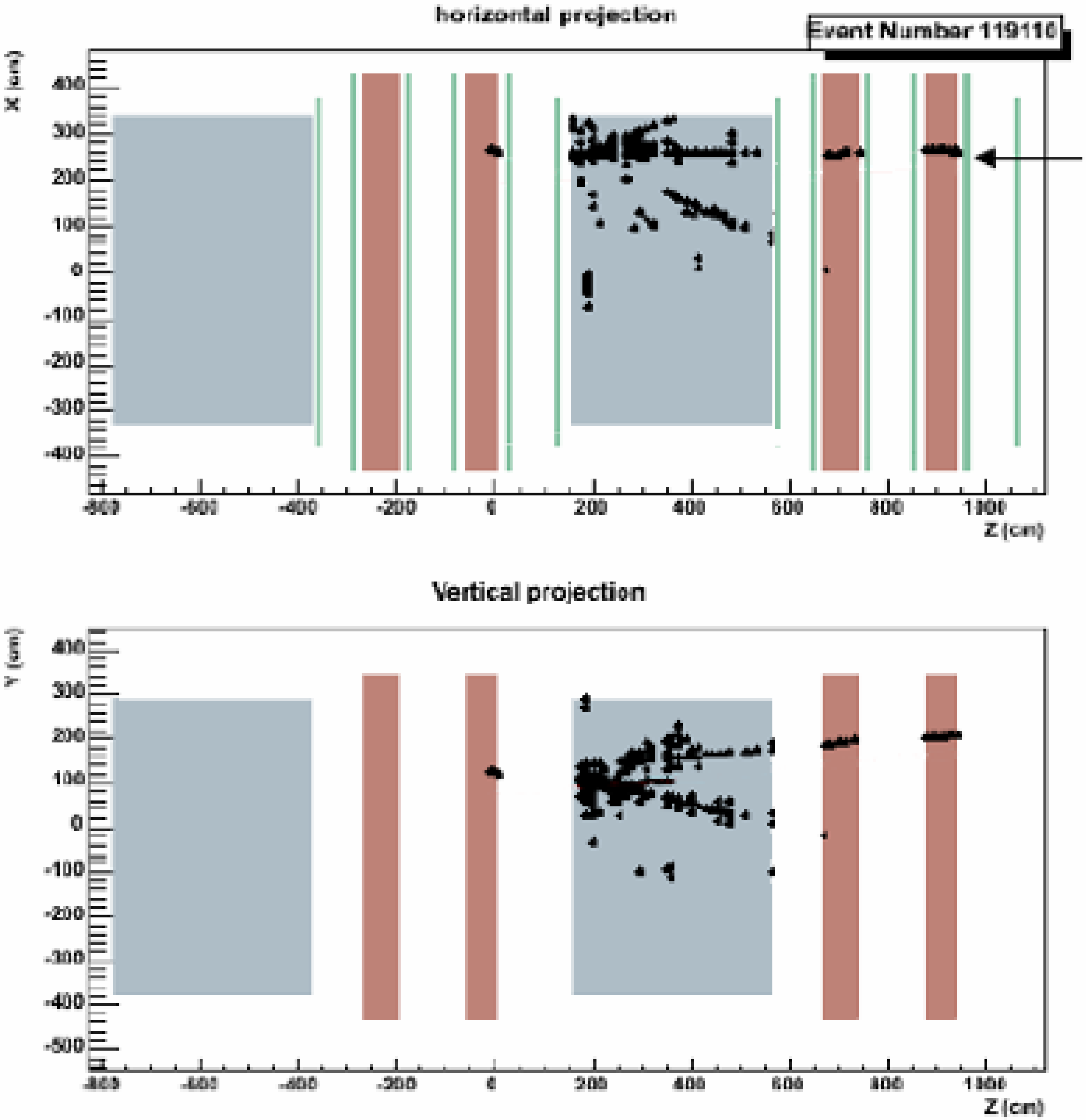
CNGS Operation and First events at Gran Sasso (OPERA)

18 – 30 August 2006



Beam event

Muon from CC interaction in the material in front of the detector (BOREXINO, rocks)

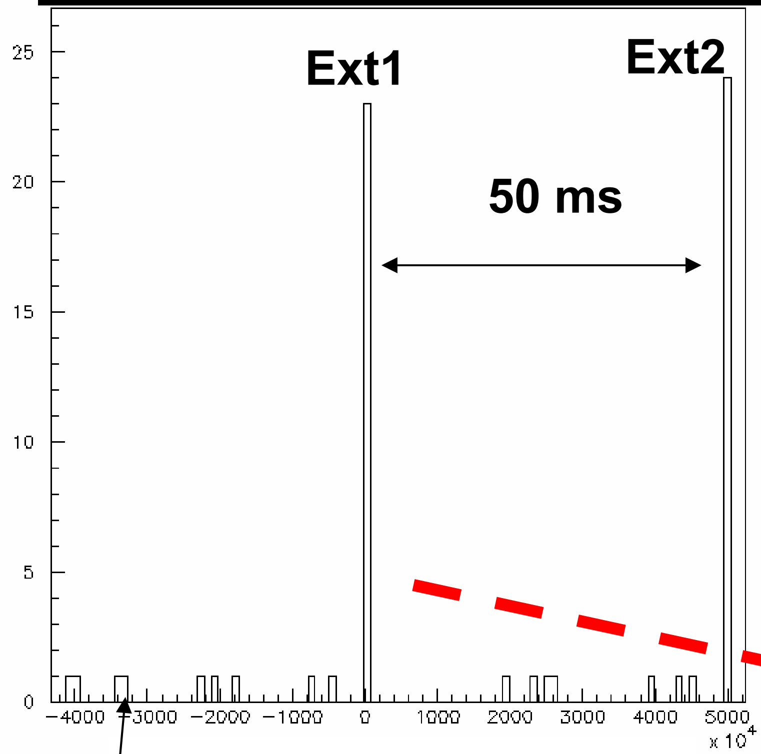


μ-track

Beam event

CC event in the first OPERA spectrometer

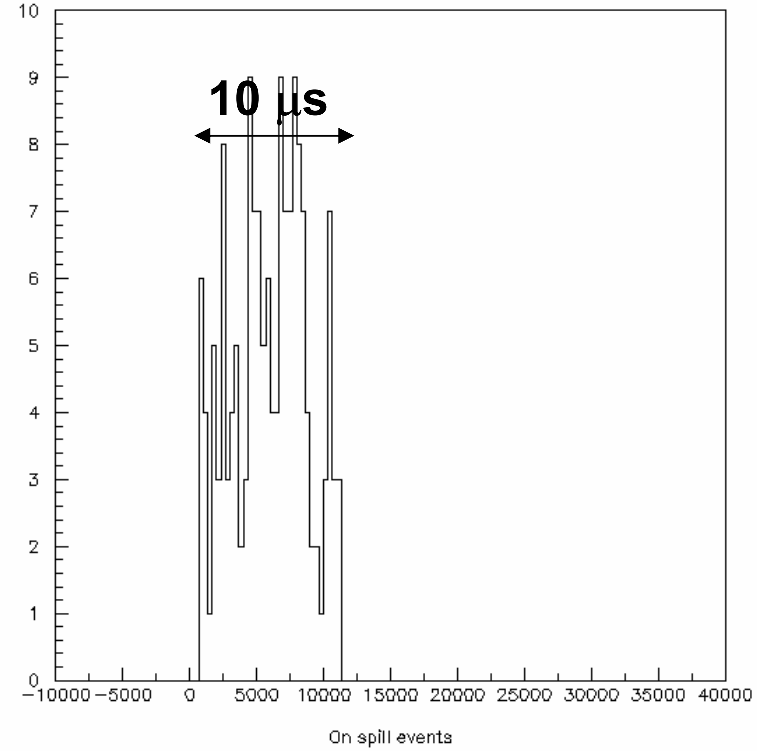
Event selection by using GPS timing informations



Δt first extraction (ns)

Cosmic rays background events

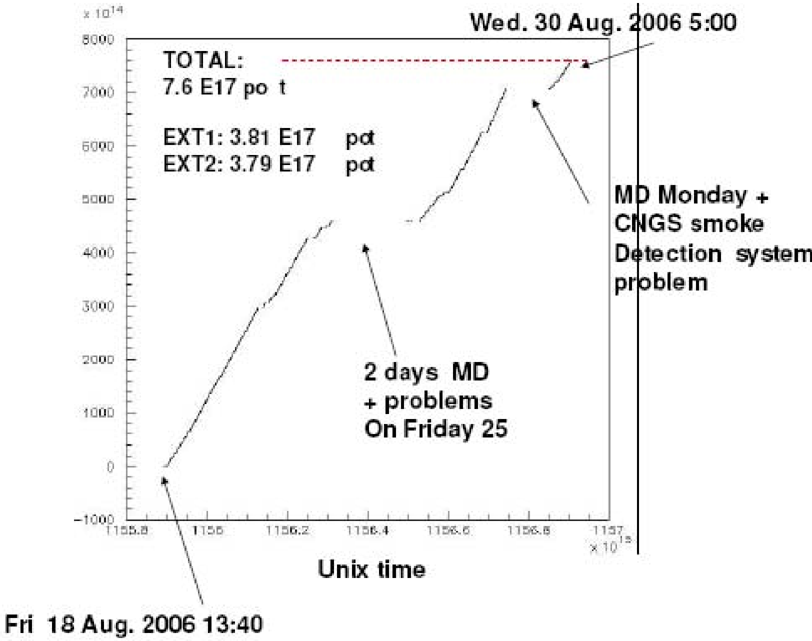
Zoom on the spill peaks



Δt closest extraction (ns)

Conclusions

- *CERN to Gran Sasso CNGS ν beam was designed for $\nu_\mu \rightarrow \nu_\tau$ oscillation search looking for ν_τ appearance, Δm^2_{23} in $1.5 \div 3.5 \times 10^{-3}$ eV^2*
- *the project was approved on December 1999*
- *civil engineering- equipment design- production and installation phases lasted 6 years and handed over to operation on 18 August 06*
- *commissioning showed that proton beam and secondary beam parameters are within specification*



CNGS operations:
1.7×10^{13} *ppp*, 7.6×10^{17} *pot*

The CNGS beam is operating smoothly with very good quality

Next step : end of october run !

CNGS neutrino beam commissioning

three weeks from July 10 increasing proton intensity up to 10^{13} ppp,

to monitor and align beam components - only 10^{17} pot used:

- *proton beam horizontal/vertical/angular scans on the target:*

  multiplicity optimization to check efficiency with which protons are converted into secondaries

  - *multiplicity: compare TBID signal downstream the target with beam current monitor upstream*
  - *alignment of beam elements*

  BPM2 proton position monitor + TBIDs: Sec. Emission Monitor, 12 μm Ti foils, different shape +...

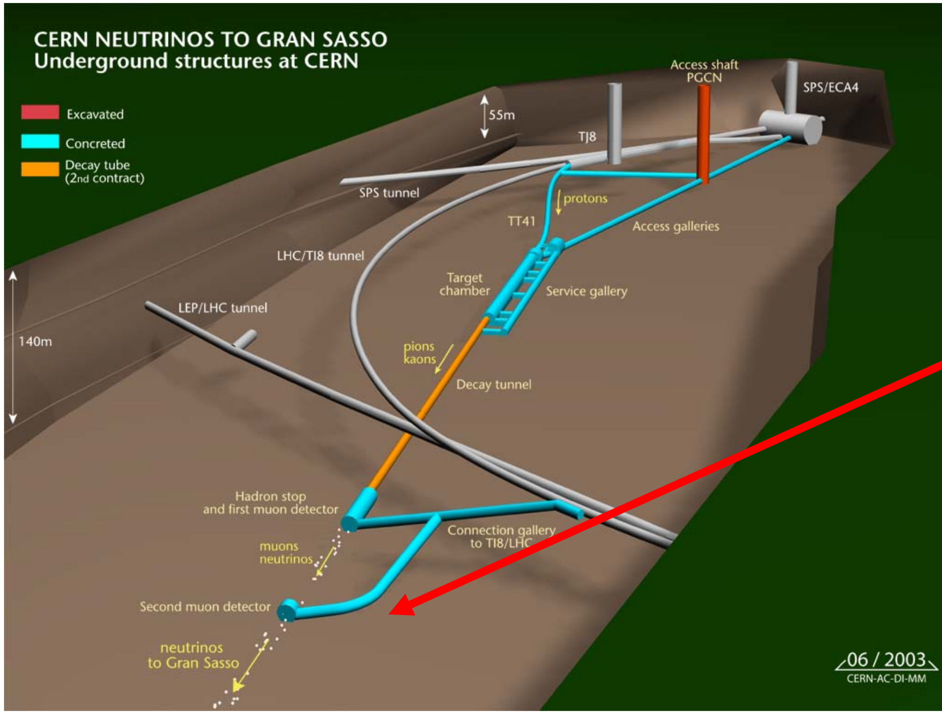
- *monitoring of μ in the muon pits downstream Hadron-stop:*

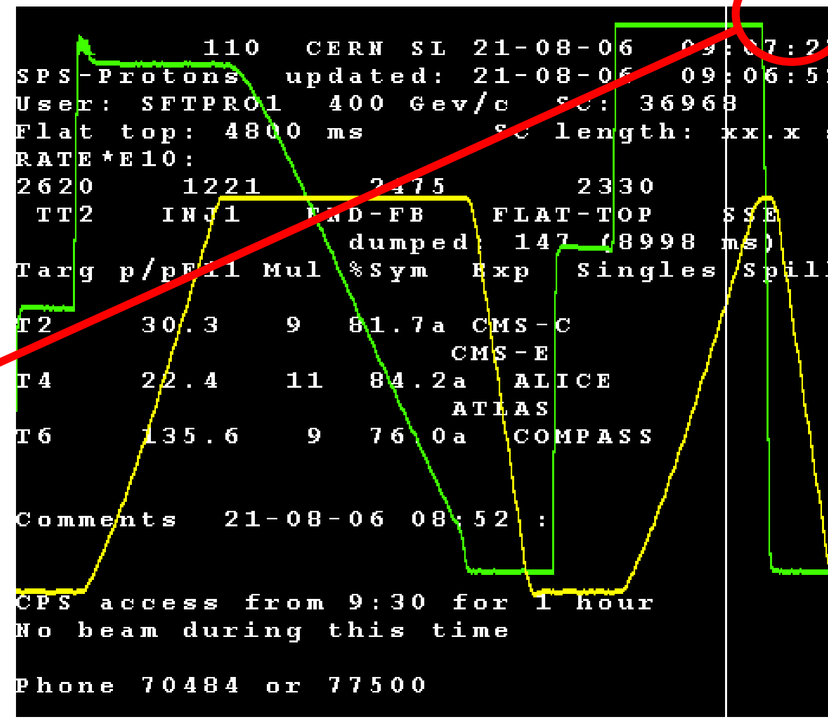
  - *absolute μ intensity*
  - *μ beam horizontal/vertical profile shape*
  - *μ beam horizontal/vertical profile center*

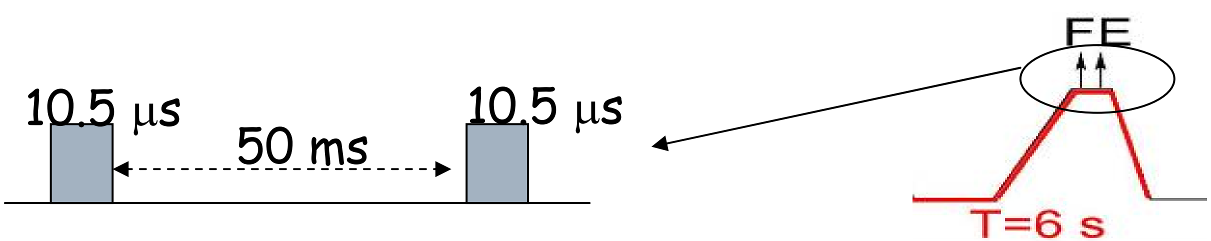
  many BLMs (Beam Loss Monitor, N_2 ionization chambers), up $7.7 \times 10^7 \mu$ per cm^2 and 10.5 μs

comparison data vs expectations in order to align the different elements...

August 2006 : first neutrinos from the CNGS detected







SPS Supercycle 16.8 s
CNGS cycle 6 s
Two extraction/cycle lasting 10.5 us and separated by 50 ms