CNGS - CERN Neutrinos to Gran Sasso

- "Neutrinos" and "Gran Sasso"
- Main components, layout at CERN, "magnetic horns",
  expected CNGS beam performance
- Status of works - Schedule
- Summary

A sincere " THANK YOU ! "

to the many colleagues who are contributing,
at CERN and elsewhere, to the CNGS project

- special thanks: Francesco Pietropaolo (INFN / CERN)
- Jean-Luc Caron (AC-DI-MultiMedia)

What are Neutrinos (ν) ?

- ⇨ elementary particles
- ⇨ come in three flavors (LEP)
  (pistachio, chocolate, vanilla)

- ⇨ electric charge: zero !
- ⇨ mass: very small zero?
- ⇨ interaction with matter: "very weak"

" the elusive particle "

Leptons

particle	electric charge
e	-1
ν_e	0
μ	-1
ν_μ	0
τ	-1
ν_τ	0

+ antiparticles

Where are the Neutrinos ?

⇨ "all around us"

-> radioactive decay of atomic nuclei (e.g. in granite)

$$n \rightarrow p + e + \nu_e$$

-> nuclear reactors

-> from the sun

-> at accelerators… (high energy neutrinos)

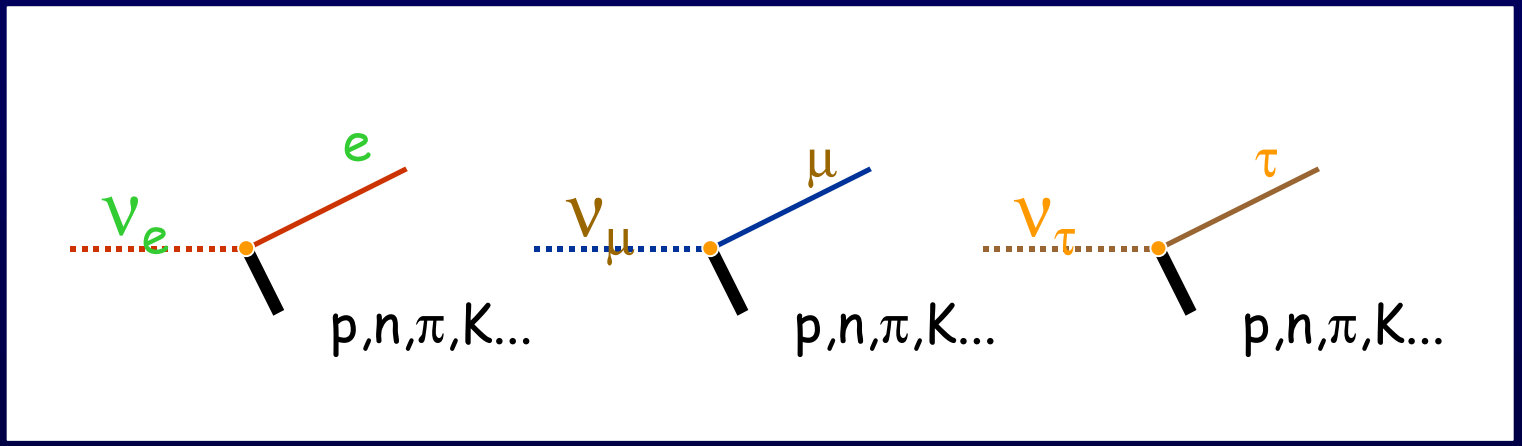
$$\pi \longrightarrow \mu + \nu_\mu$$

-> from reactions of cosmic rays in the atmosphere

….

How do we detect neutrinos ?

neutrinos interact VERY rarely with matter - when they do, they often produce a lepton of their "own character":



NOTE: a minimum amount of energy is needed (to create the mass of the lepton):

m_e = 0.5 MeV, - m_μ = 106 MeV - m_τ = 1770 MeV

The higher the neutrino energy, the more likely the interaction !

Neutrino mass ?

- ⇨ Standard model of particle physics: ν masses "ZERO"
- ⇨ "Direct" mass measurements -> upper limits

  (in decay experiments measuring kinetic energy of "the partner")

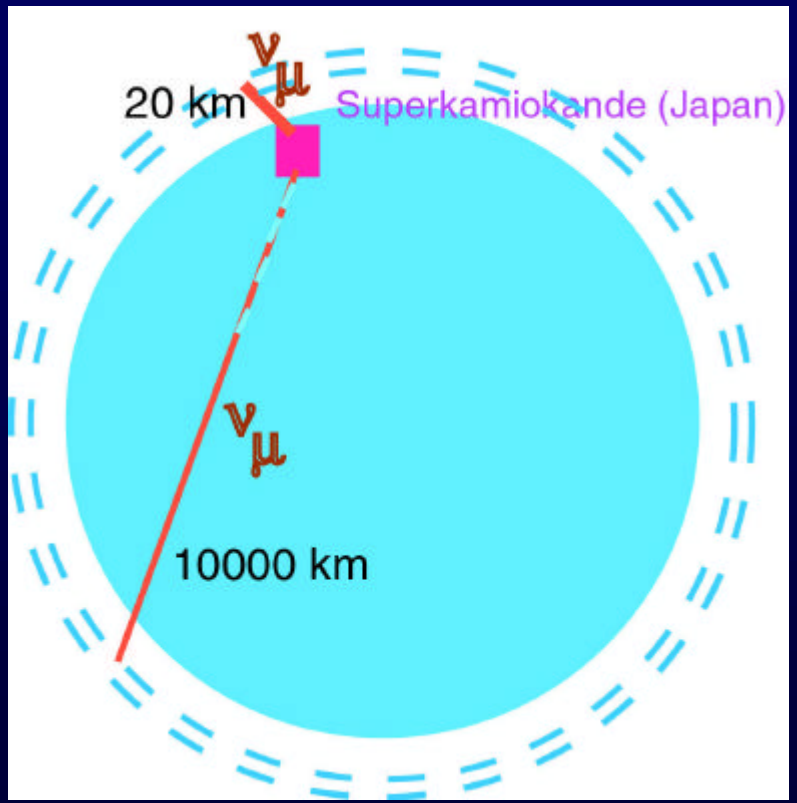
  $m_{\nu e} < 5$ eV $m_{\nu \mu} < 170$ keV $m_{\nu \tau} < 18$ MeV
- ⇨ What's the problem ?
  - ⇨ OBSERVATION 1 : SOLAR NEUTRINO "DEFICIT"

    only about 50% of the ν_e expected are actually observed: ν_e disappear "en route" from the sun to the earth ...

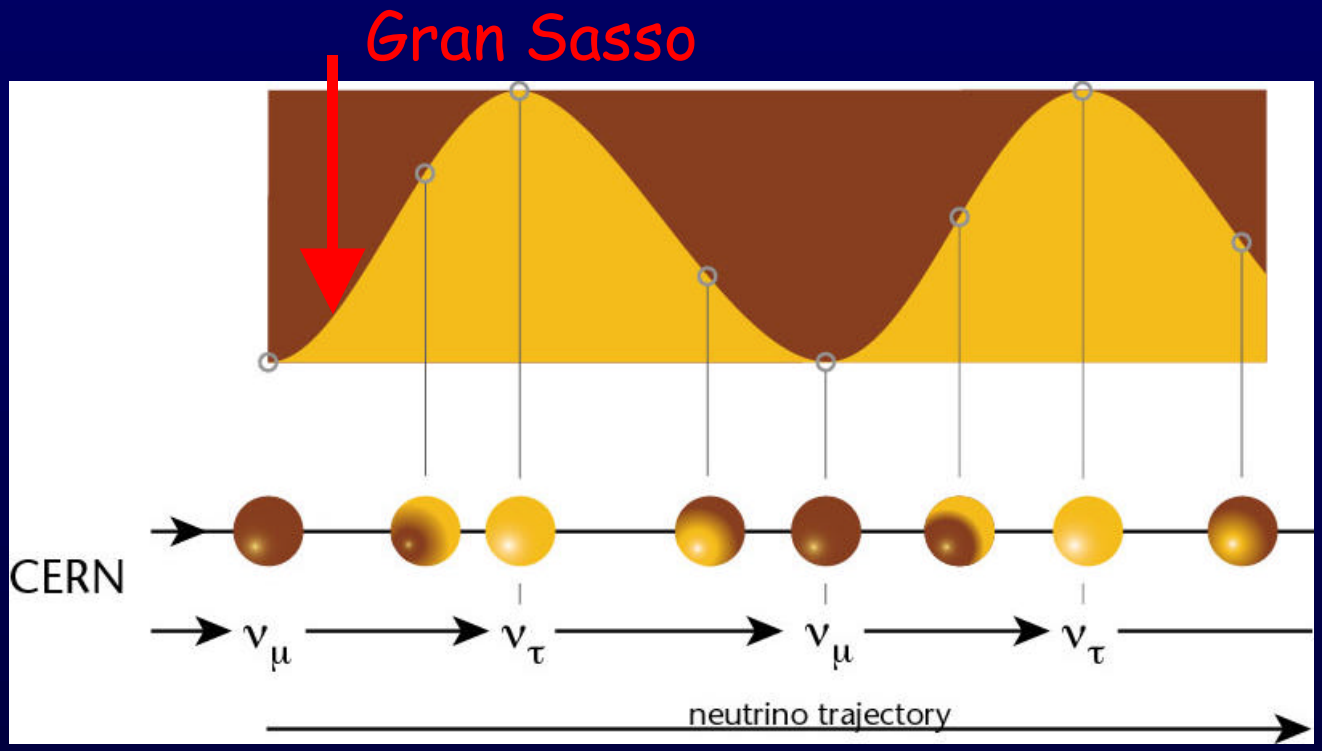
OBSERVATION 2 : "ATMOSPHERIC NEUTRINO ANOMALY"

much less ν_μ "from below" observed w.r.t. expectations

ν_μ disappear "en route" over 10'000 km … ?

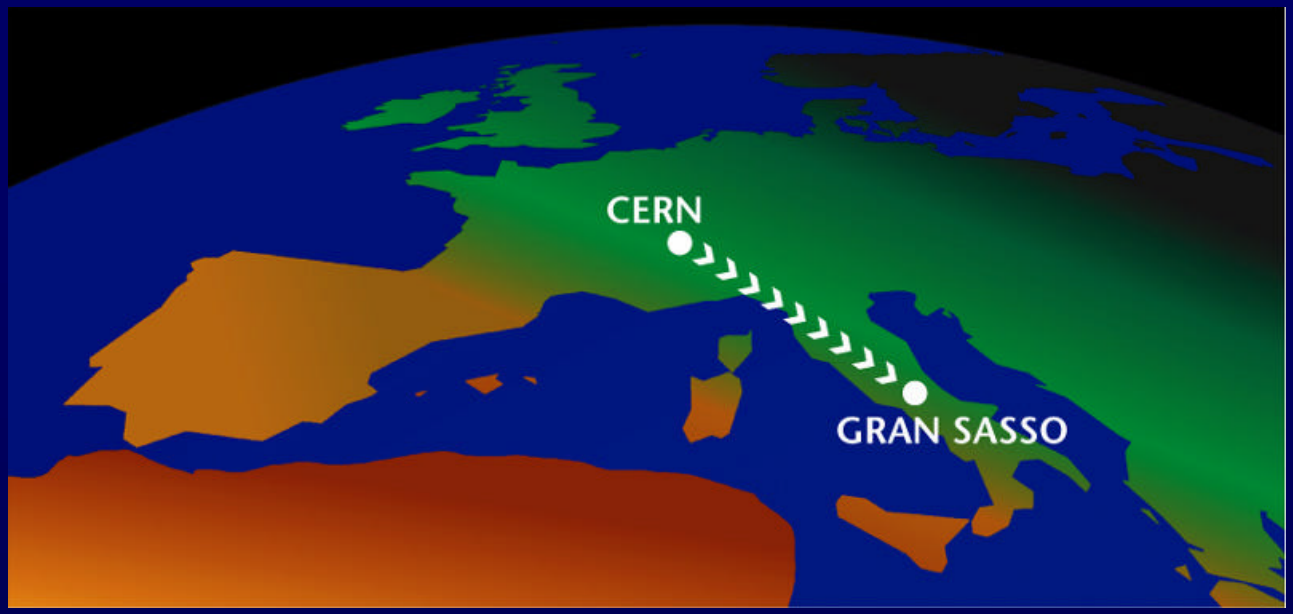


Neutrino Oscillation



ν's change flavor ! Is this possible?

--> Yes, "if neutrinos have mass"!

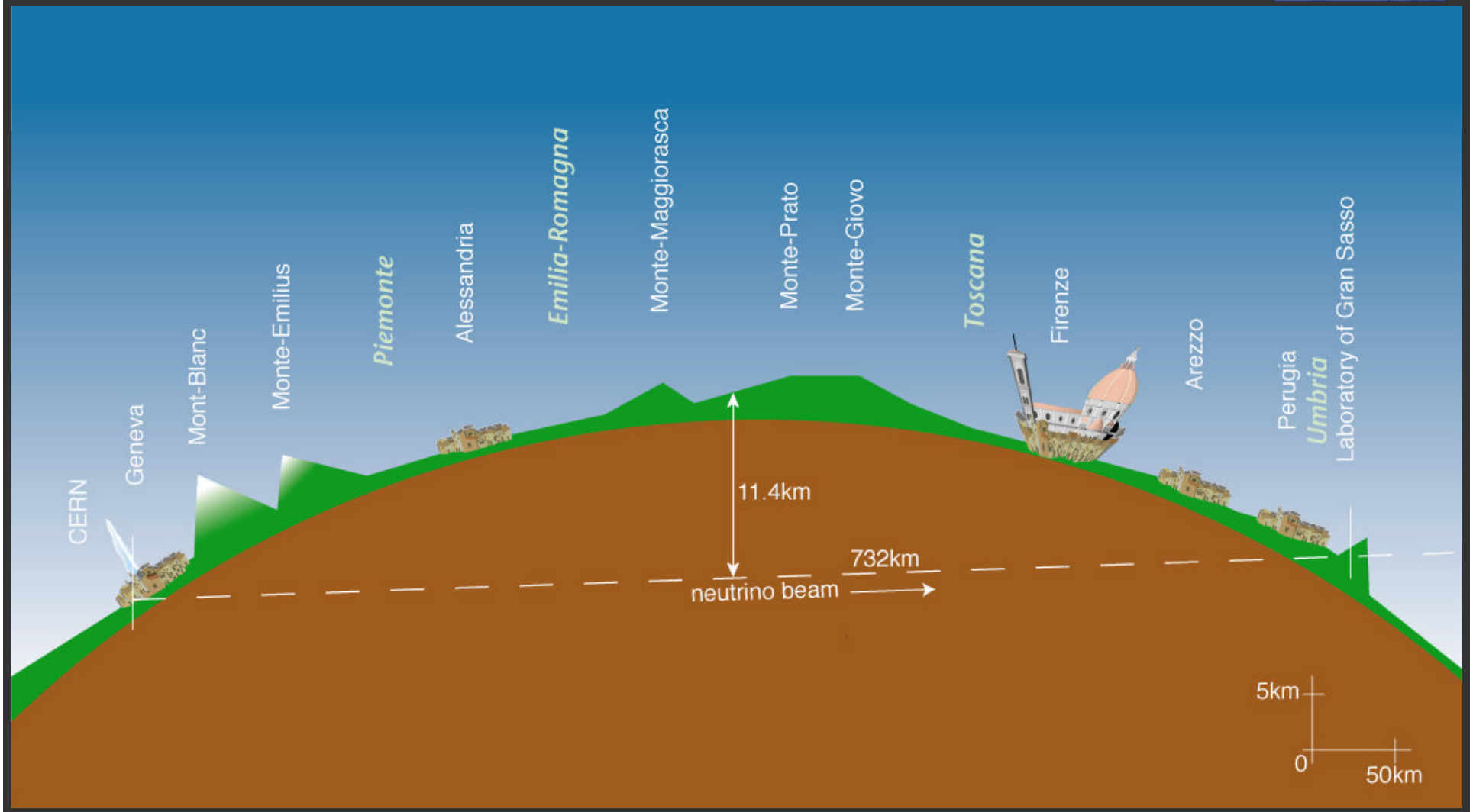


In Dec. 1999, CERN council approved the CNGS project:

- build an intense ν_μ beam at CERN-SPS
- search for ν_τ appearance at Gran Sasso laboratory (730 km from CERN)

"long base-line" ν_μ -- ν_τ oscillation experiment

note: K2K (Japan) running; NuMI/MINOS (US) under construction


CERN
Geneva
Mont-Blanc
Monte-Emilius
Piemonte
Alessandria
Emilia-Romagna
Monte-Maggiorasca
Monte-Prato
Monte-Giovo
Toscana
Firenze
Arezzo
Perugia
Umbria
Laboratory of Gran Sasso
11.4km
732km
neutrino beam
5km
0
50km

ORGANISATION of CNGS

CERN

Convention

INFN

bilateral co-ordination committee

CERN and LNGS scientific committees

builds and operates
CNGS neutrino beam

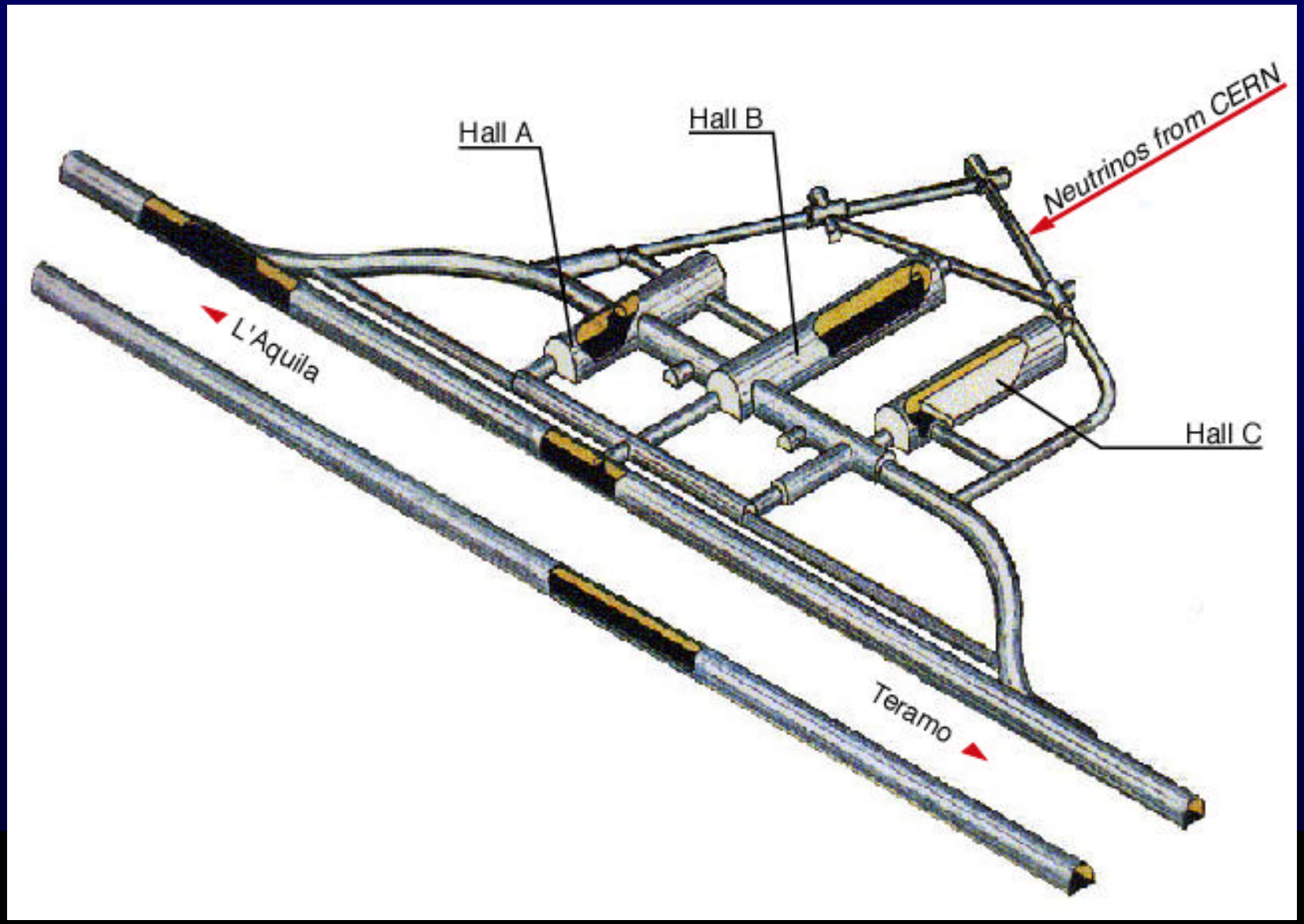
operates the Gran Sasso underground Laboratory, which houses detectors

special contributions
finance large part of CNGS

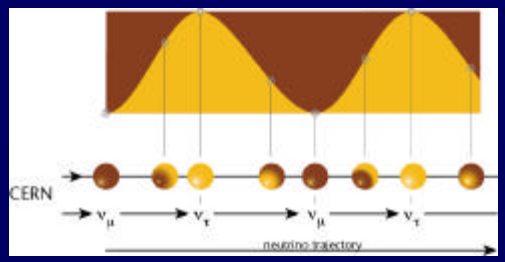
International Collaborations

The Gran Sasso Laboratory (LNGS)

The Gran Sasso Laboratory (LNGS)

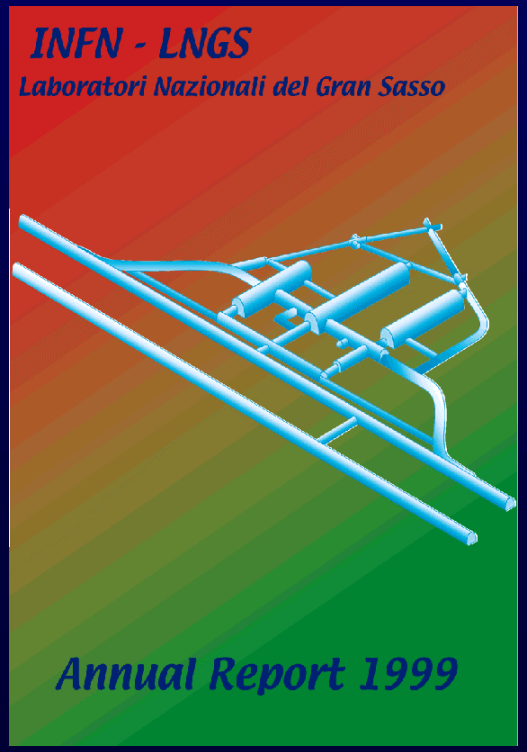


730 km might seem too short -
but look at the details :
Background low enough,
event rate still acceptable
--> 730 km almost perfect



AND, VERY IMPORTANT:

- existing laboratory with its infrastructure (since 1987)
- large halls directed to CERN
- caverns in the GS mountains: 1500 m of rock shielding
- tradition in very successful neutrino physics experiments (solar ν's)

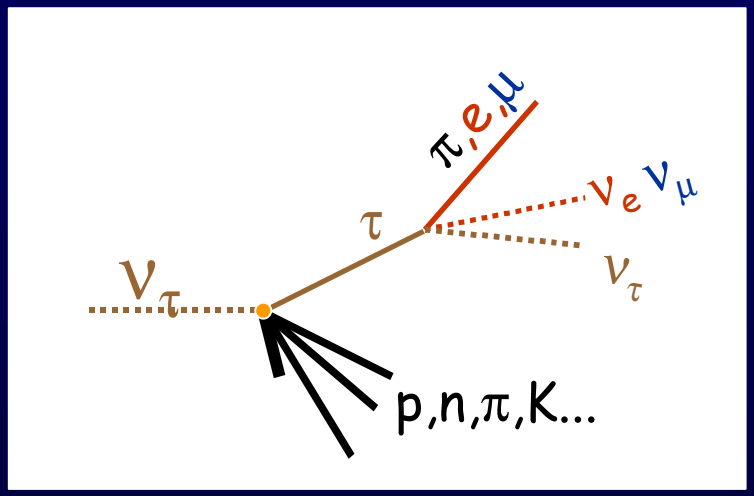


Detecting ν_τ at Gran Sasso

-> look for the τ lepton:

extremely difficult -

τ travels only about 1 mm before decaying



-> two approaches:

(a) very good position resolution (see the decay "kink") -> OPERA

(b) very good energy and angle resolution -> ICARUS

OPERA:

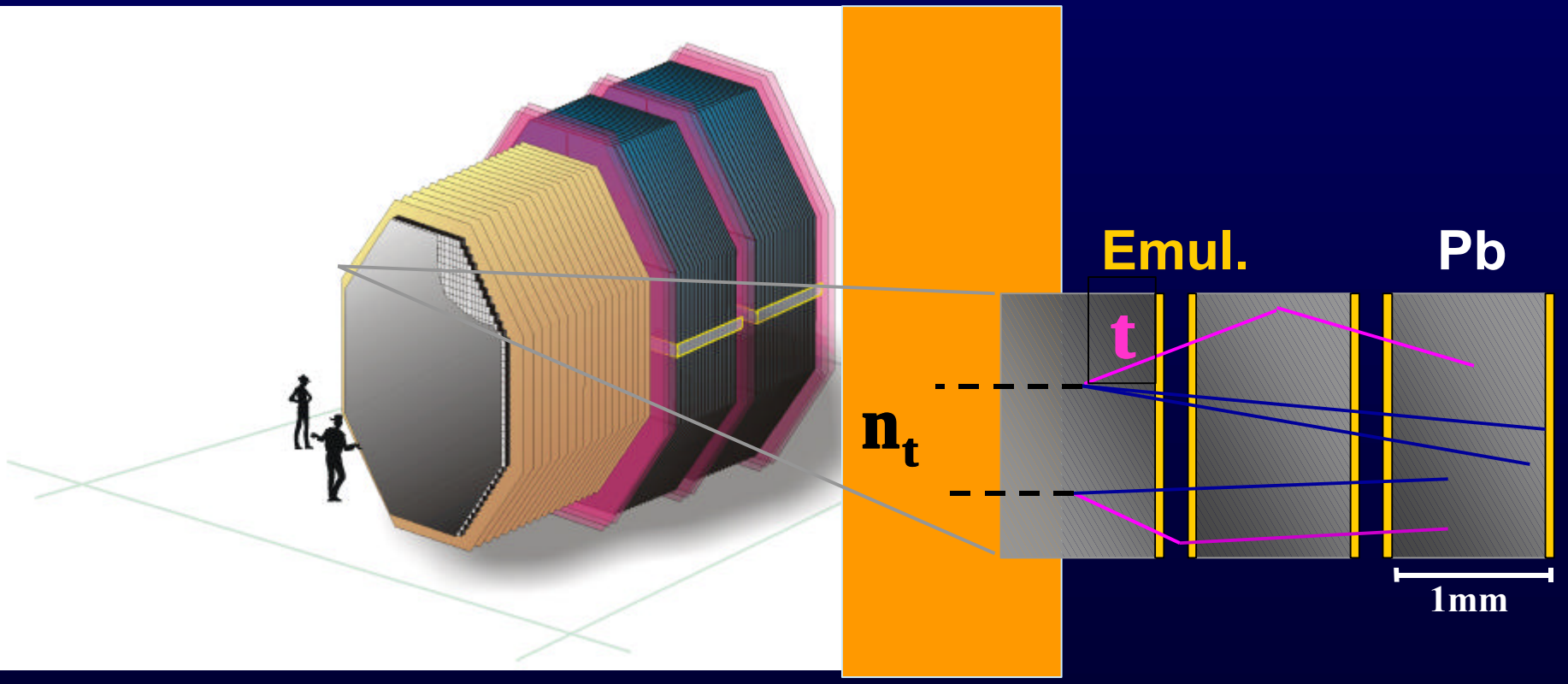
2000 tons of "detector mass"

walls made of bricks (total more than 200'000)

-> bricks made of "sandwiches"

-> sandwiches made of lead and nuclear emulsion

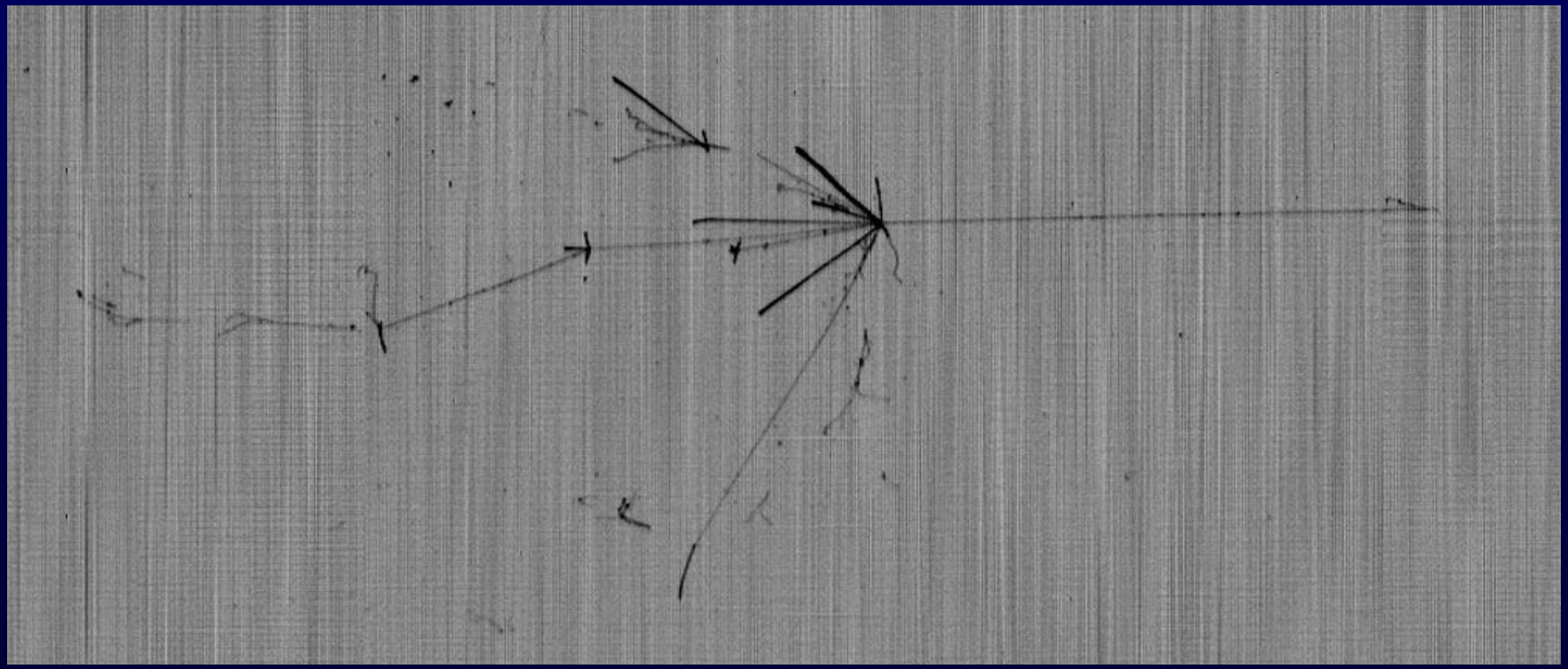
(type of "photographic" film)



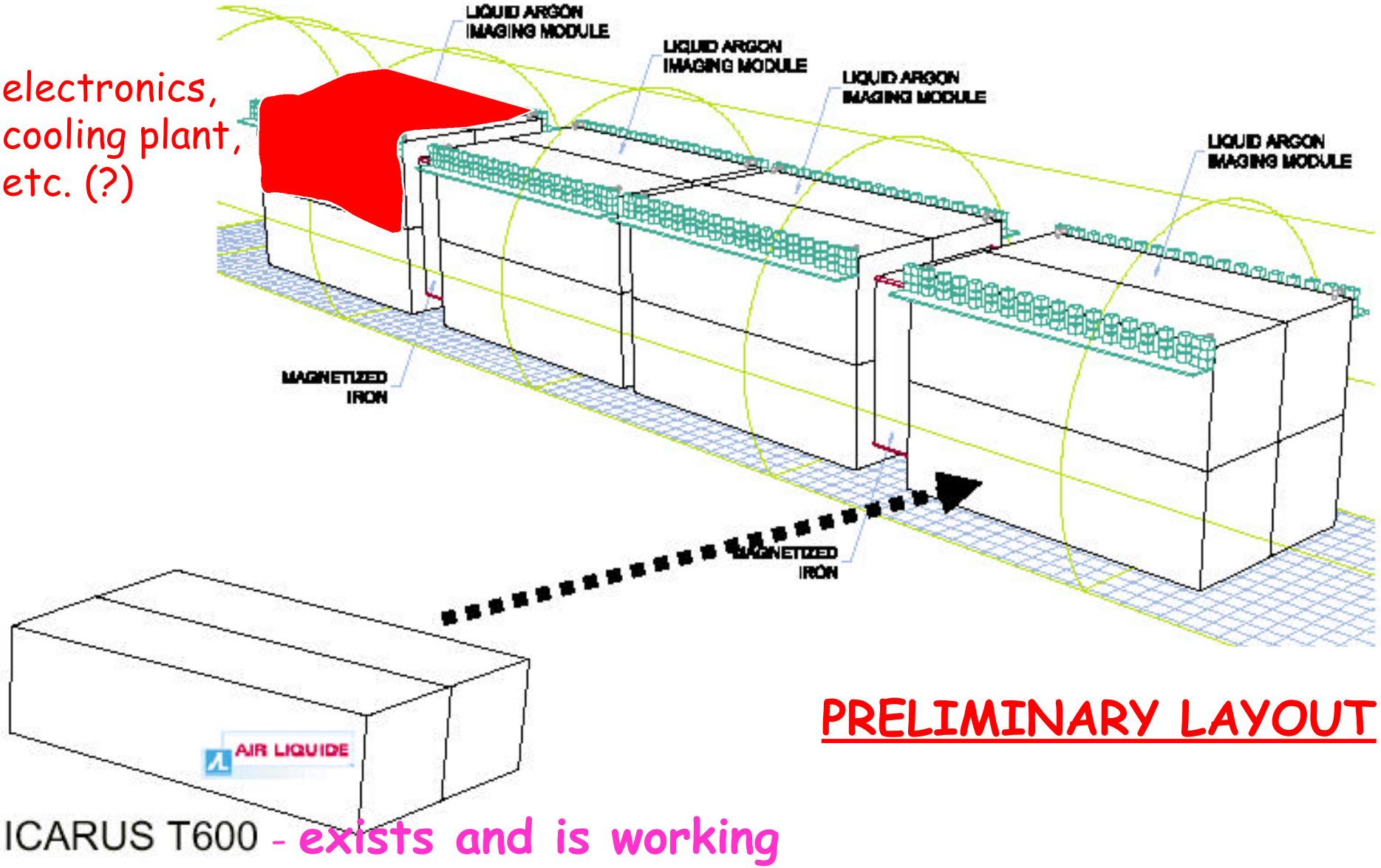
ICARUS: multi-purpose detector !

- 5000 tons ultra-pure liquid argon
- provides "electronic" picture of interactions

-> example from 600 t module (2001 - cosmic ray):



electronics,
cooling plant,
etc. (?)



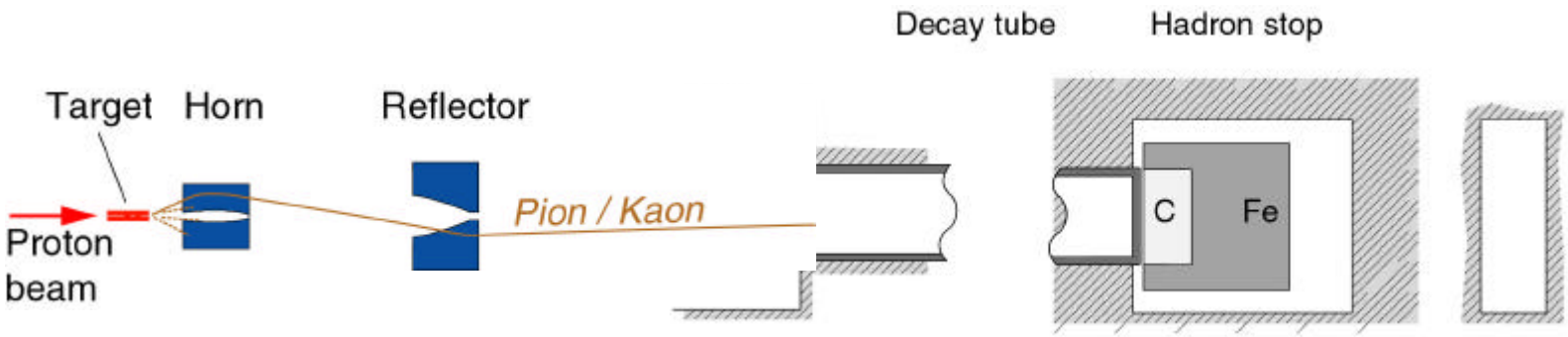
PRELIMINARY LAYOUT

ICARUS T600 - **exists and is working**

"back to CERN"...

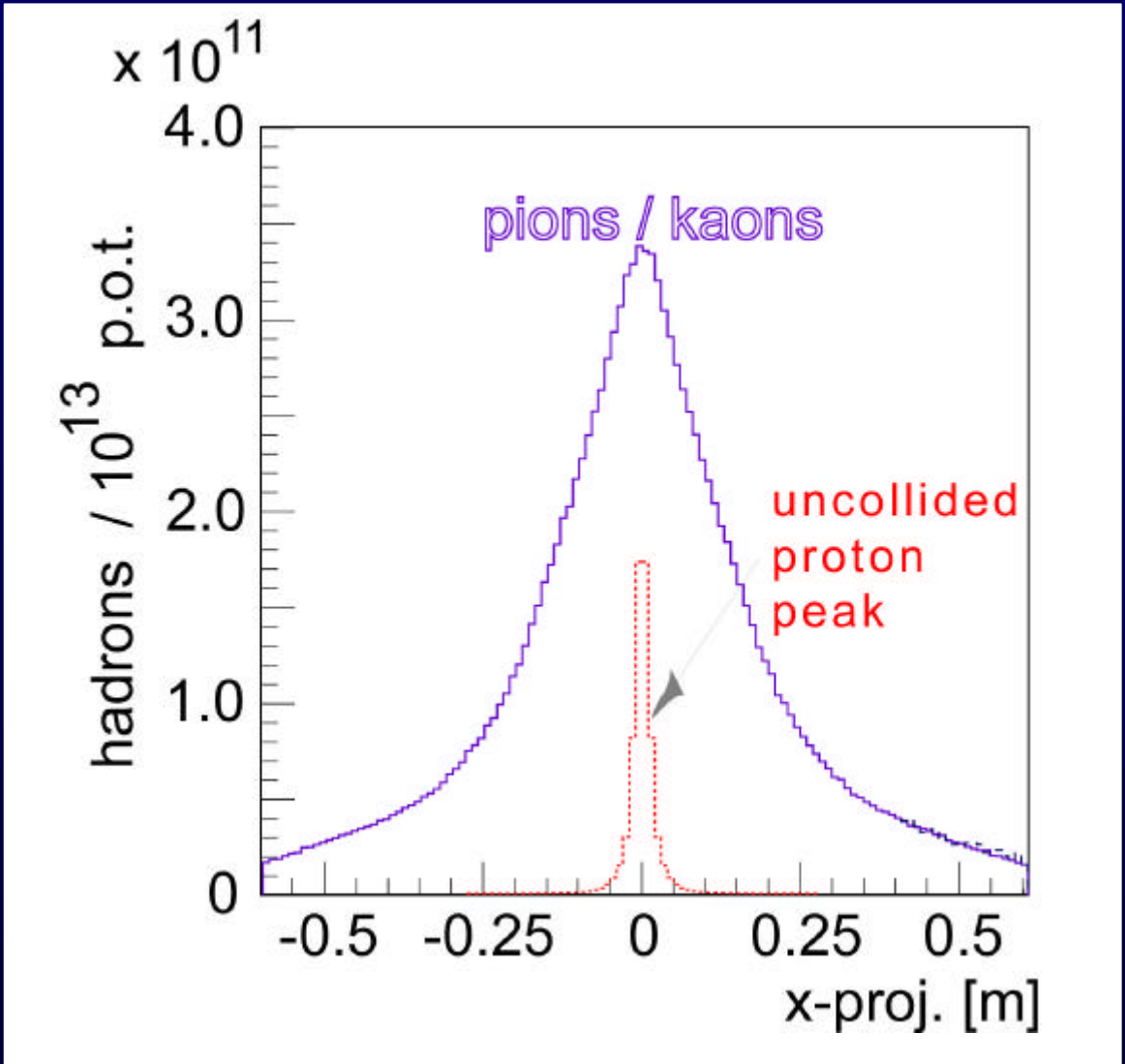
CNGS beam-line: the main components (1)

(based on CERN experience: PS / SPS neutrino beams -> WANF)

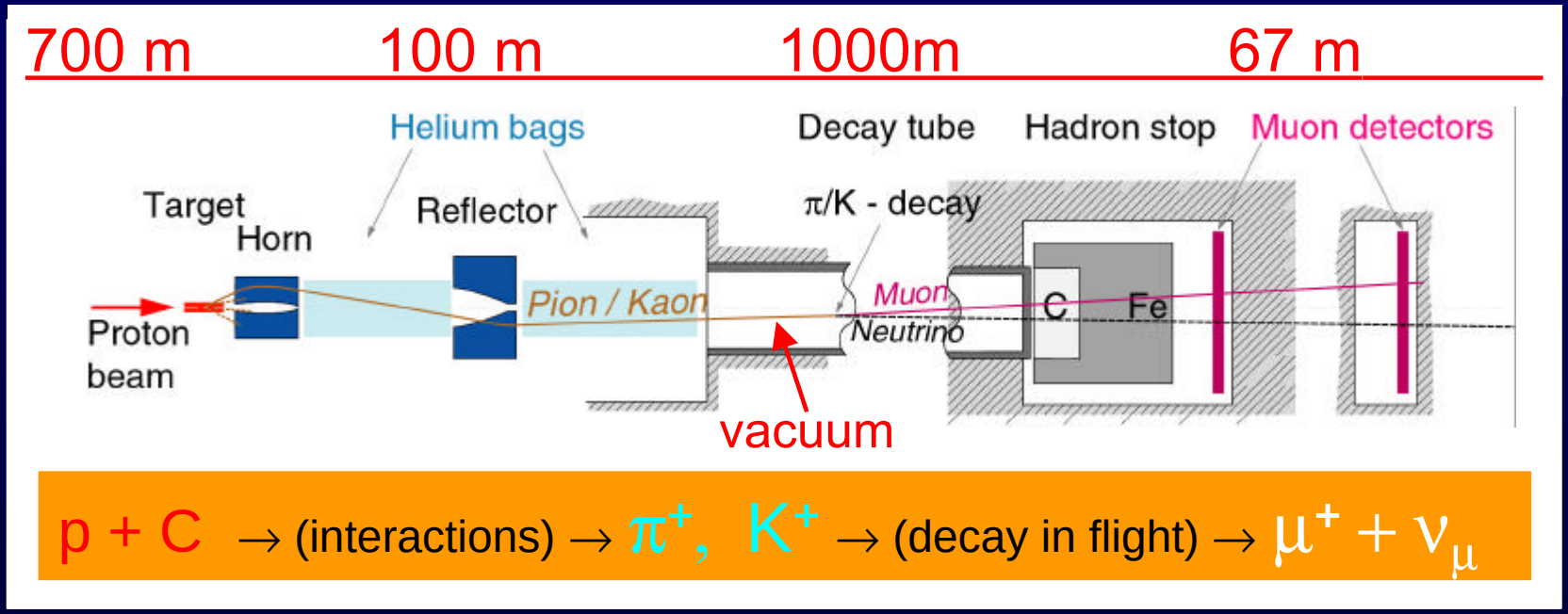


$p + C \rightarrow$ (interactions) $\rightarrow \pi^+, K^+ \rightarrow$ (decay in flight) $\rightarrow \mu^+ + \nu_\mu$

p / K profile at entrance to decay tunnel



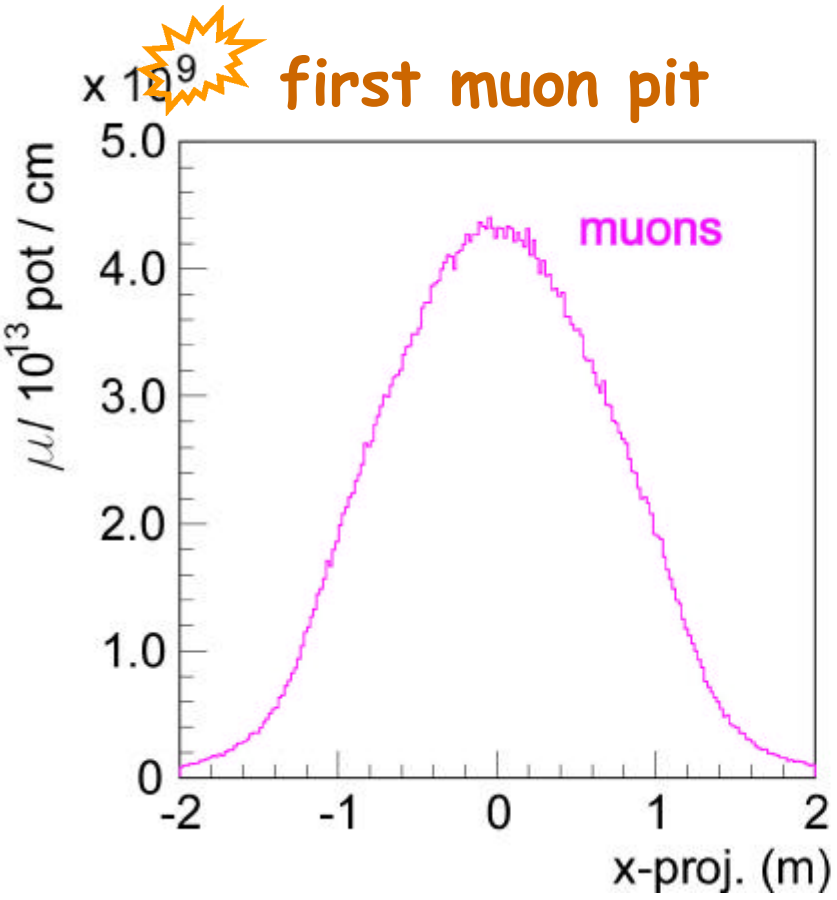
CNGS: the main components (2)

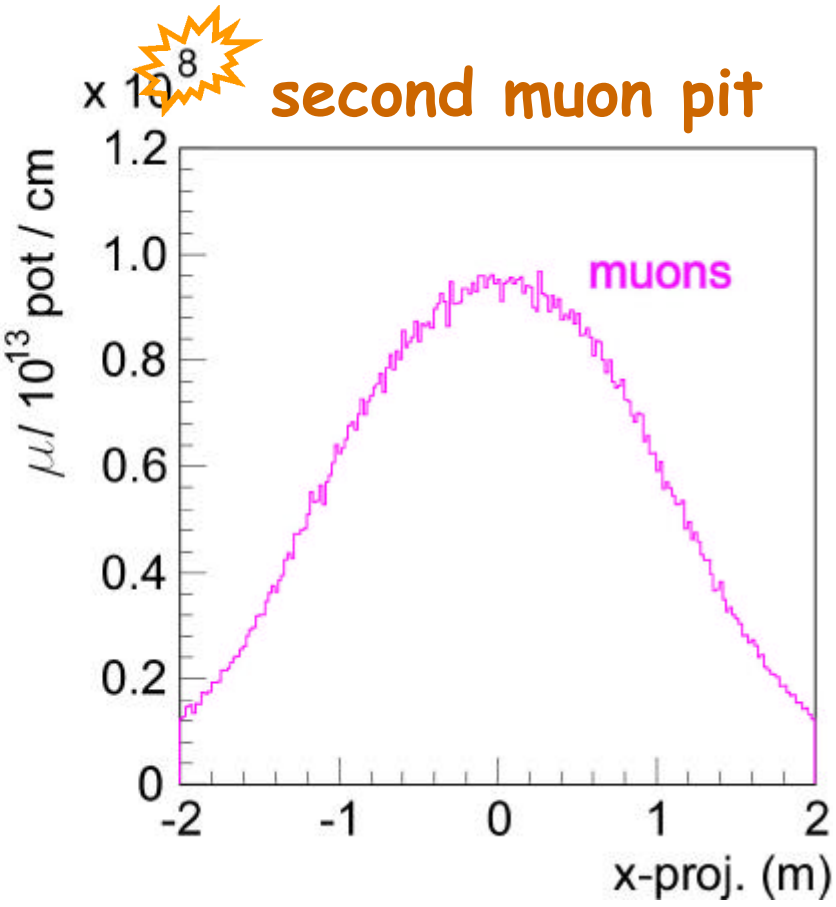


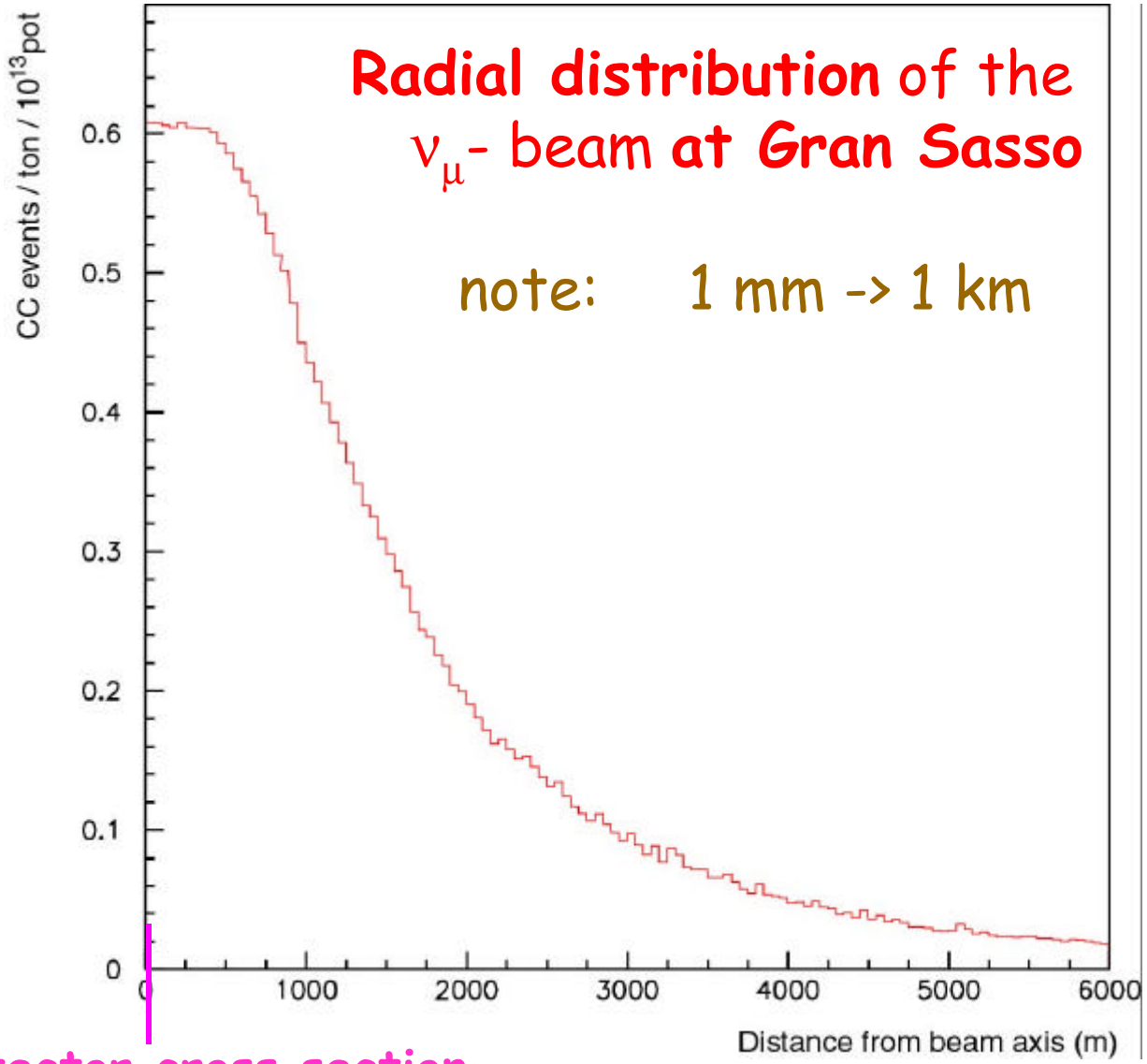
$p + C \rightarrow$ (interactions) $\rightarrow \pi^+, K^+ \rightarrow$ (decay in flight) $\rightarrow \mu^+ + \nu_\mu$

$\pi^+ \rightarrow \mu^+ + \nu_\mu$

expected CNGS muon profiles






Radial distribution of the
ν_μ- beam at Gran Sasso
note: 1 mm -> 1 km
CC events / ton / 10^{13}pot
0.6
0.5
0.4
0.3
0.2
0.1
0
1000
2000
3000
4000
5000
6000
Distance from beam axis (m)
detector cross section

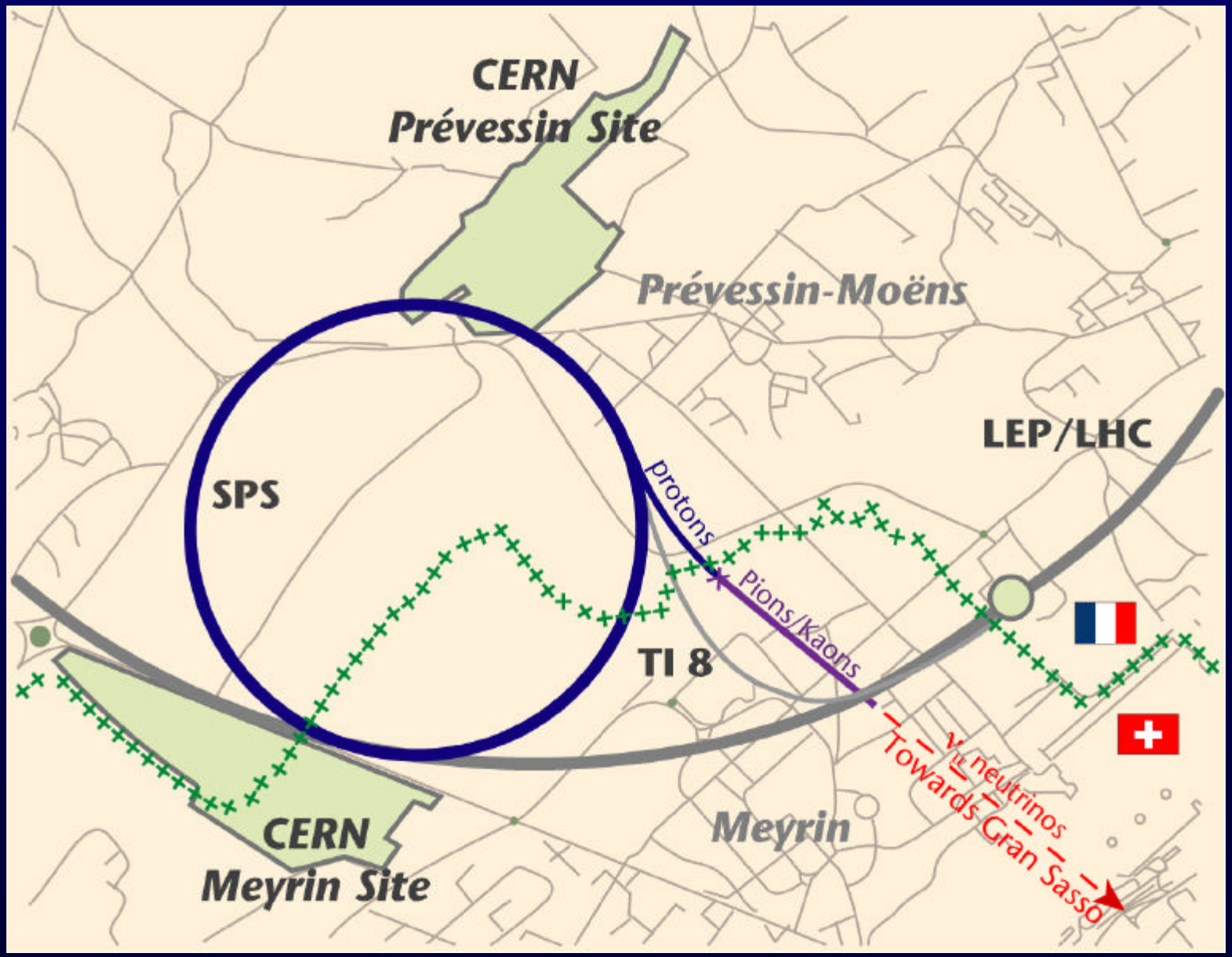
Number of particles expected per year:

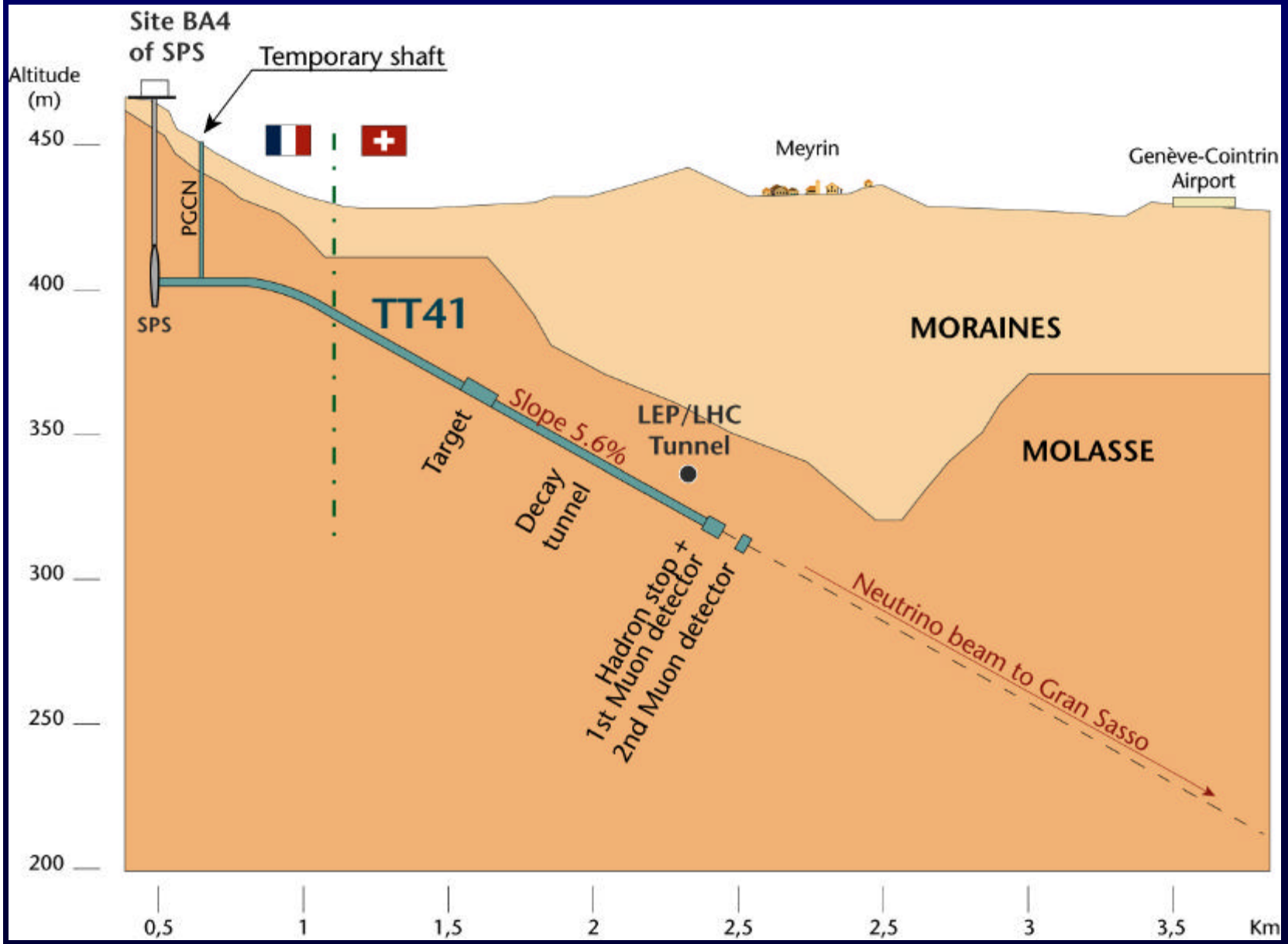
For 1 year of CNGS operation, we expect:

(4.8x10^{13} protons in SPS, 55% efficiency -- 1997)

protons on target	4.5 x 10^{19}
pions / kaons at entrance to decay tunnel	5.8 x 10^{19}
muons in first / second muon pit	3.6 x 10^{18} / 1.1 x 10^{17}
ν_μ in 100 m^2 at Gran Sasso	3.5 x 10^{12}
ν_μ "charged current" events per 1000 t (ν + N -> N' + μ)	$\approx$ 2500
ν_τ events (from oscillation)	$\approx$ 20 "detectable"

n_t events detected "in OPERA" **» 2.5 (b.g. 0.15)**


CERN
Prévessin Site
Prévessin-Moëns
LEP/LHC
SPS
protons
Pions/Kaons
TI 8
Towards Gran Sasso
ν neutrinos
CERN
Meyrin Site
Meyrin


Site BA4
of SPS
Temporary shaft
Altitude
(m)
450
400
350
300
250
200
PGCN
SPS
TT41
Meyrin
Genève-Cointrin
Airport
MORAINES
MOLASSE
Target
Slope 5.6%
LEP/LHC
Tunnel
Decay
tunnel
Hadron stop +
1st Muon detector
2nd Muon detector
Neutrino beam to Gran Sasso
0,5
1
1,5
2
2,5
2,5
3
3,5
Km


CERN NEUTRINOS TO GRAN SASSO
Underground structures at CERN
CNGS Works
55m
SPS tunnel
TI8
Access shaft
PGCN
SPS/ECA4
protons
TT41
Access galleries
LHC/TI8 tunnel
Target
chamber
Service gallery
Decay tunnel
140m
LEP/LHC tunnel
pions
kaons
Hadron stop
and first muon detector
Connection gallery
to TI8/LHC
muons
neutrinos
Second muon detector
neutrinos
to Gran Sasso

CNGS civil engineering

more than 3 km of tunnels and caverns
(diameter 3.1 m -> 6.0 m)

more than 45'000 m^3 rock
to be removed

more than 12'000 m^3 concrete
to be "sprayed" or poured

CNGS -- proton beam (1)

-> protons from SPS
-> NEW fast extraction under construction in point 4

-> this extraction system needed for TI8 -> LHC transfer line (but modified for CNGS)

-> CNGS p-beam branches off after ≈ 100 metres

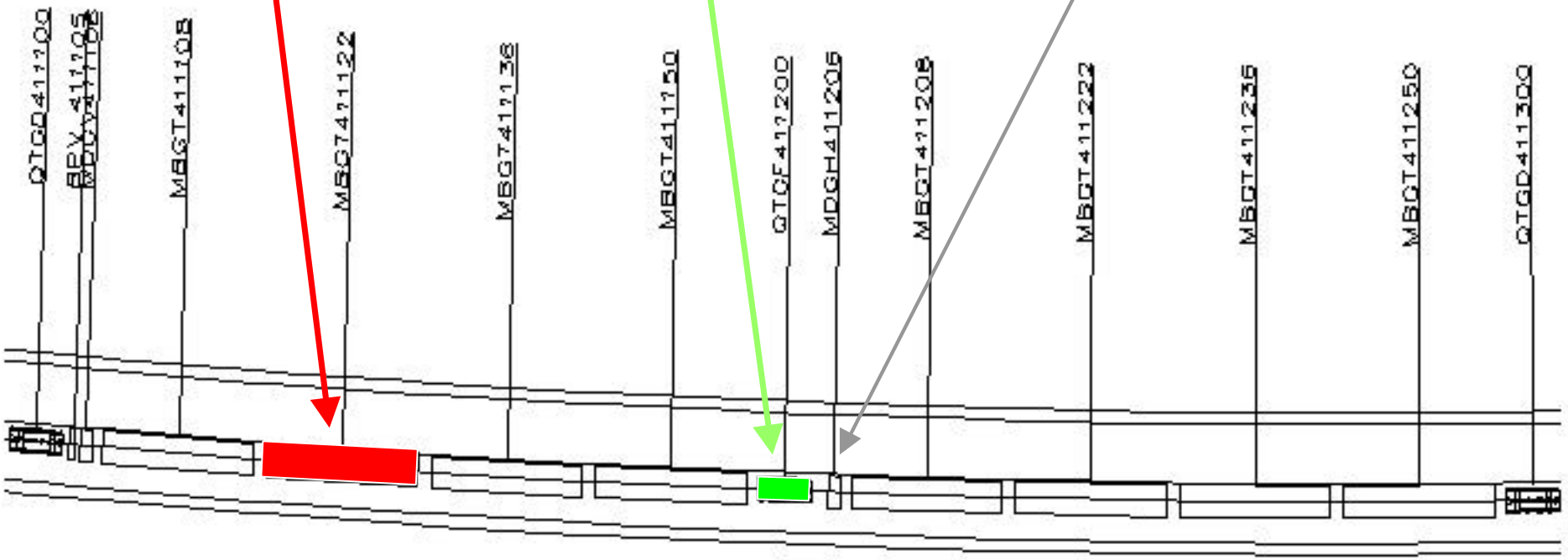
-> 700 metres of proton beam line to CNGS target

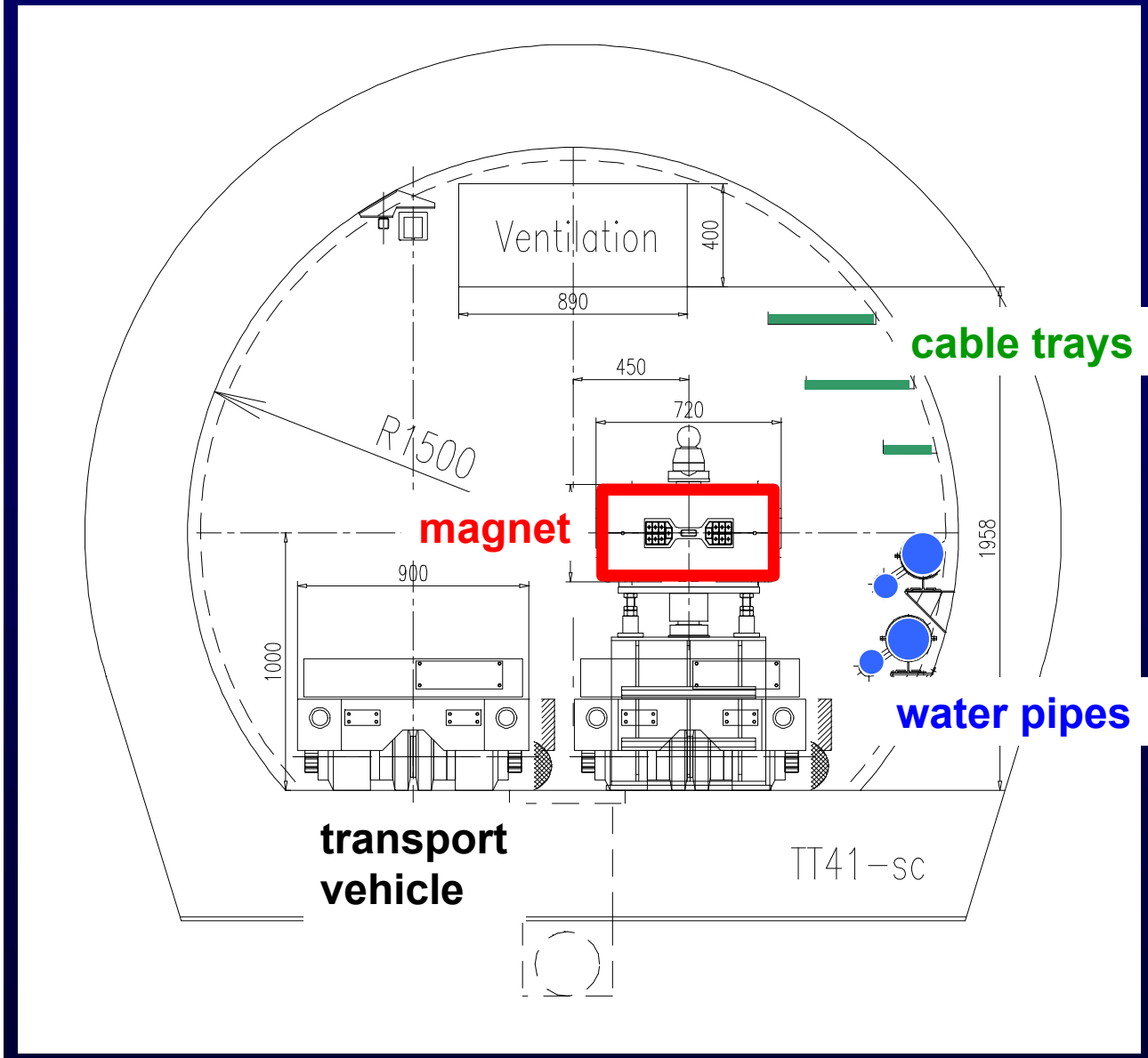
CNGS -- proton beam (2)

73 deflection (dipole) magnets (6.4 m long) +

21 quadrupole magnets + correction dipoles

+vacuum + beam observation + ...

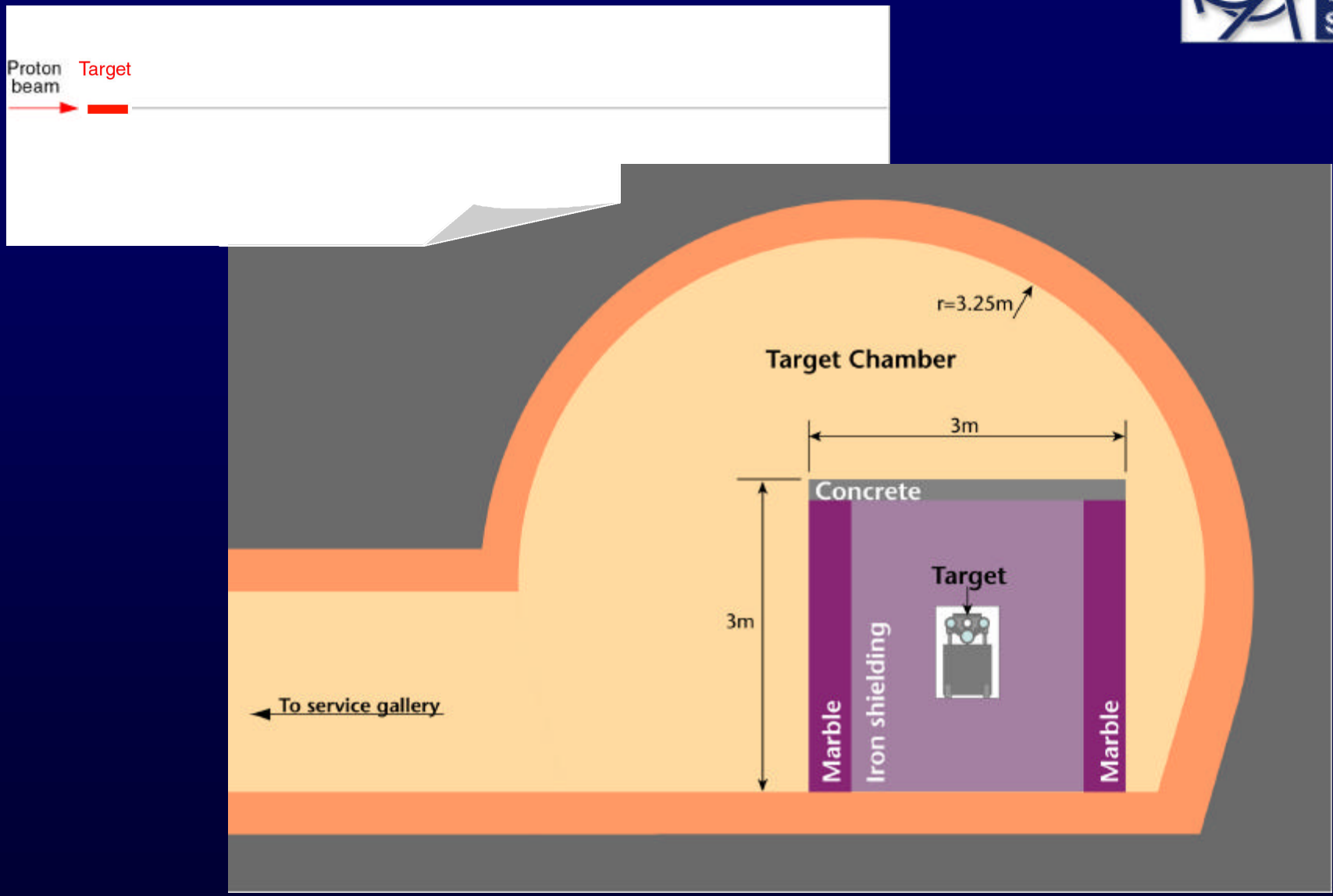




proton beam tunnel cross section
(preliminary)

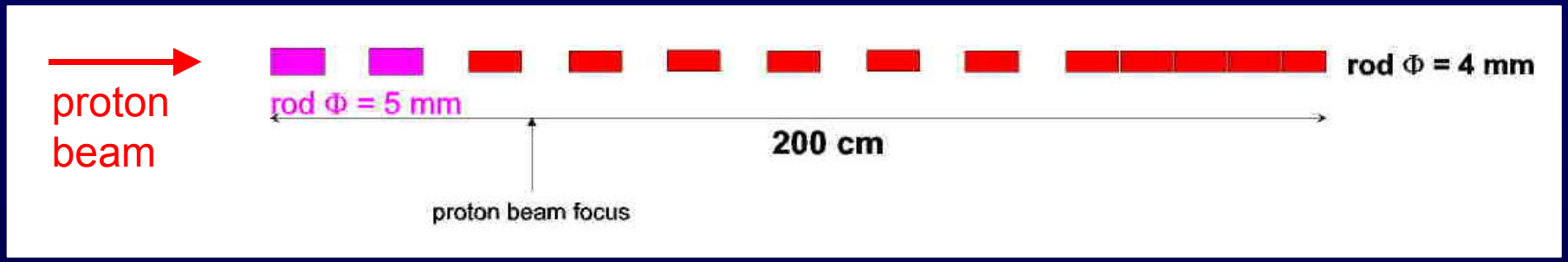
warning:
there is "no space"

CNGS -- target station (1)



CNGS -- target station (2)

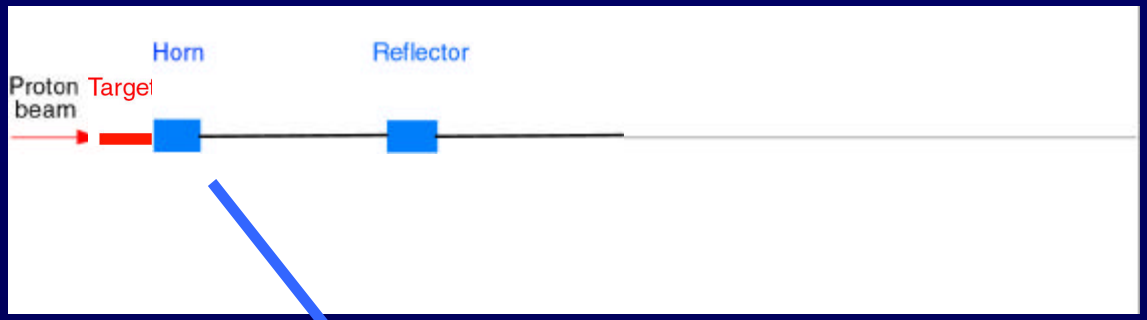
-> 10 cm long graphite rods, Ø = 5mm and/or 4mm



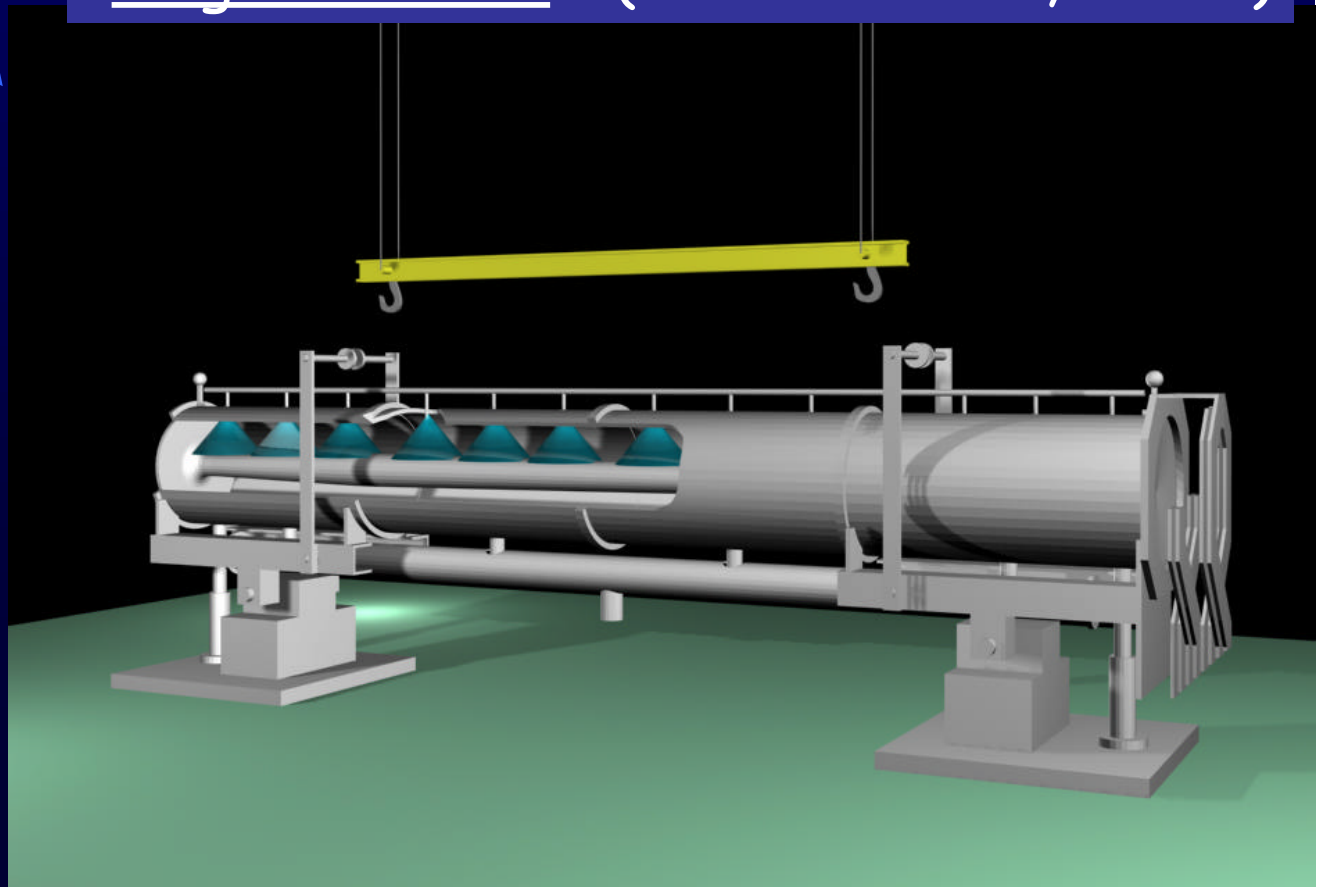
Note: - target rods interspaced to "let the pions out"

- target is helium cooled
  (remove heat deposited by the particles)

CNGS -- focusing devices (1)



"Magnetic Horn" (S. v.der Meer, CERN)



length: 6.5 m
diameter: 70 cm
weight: 1500 kg

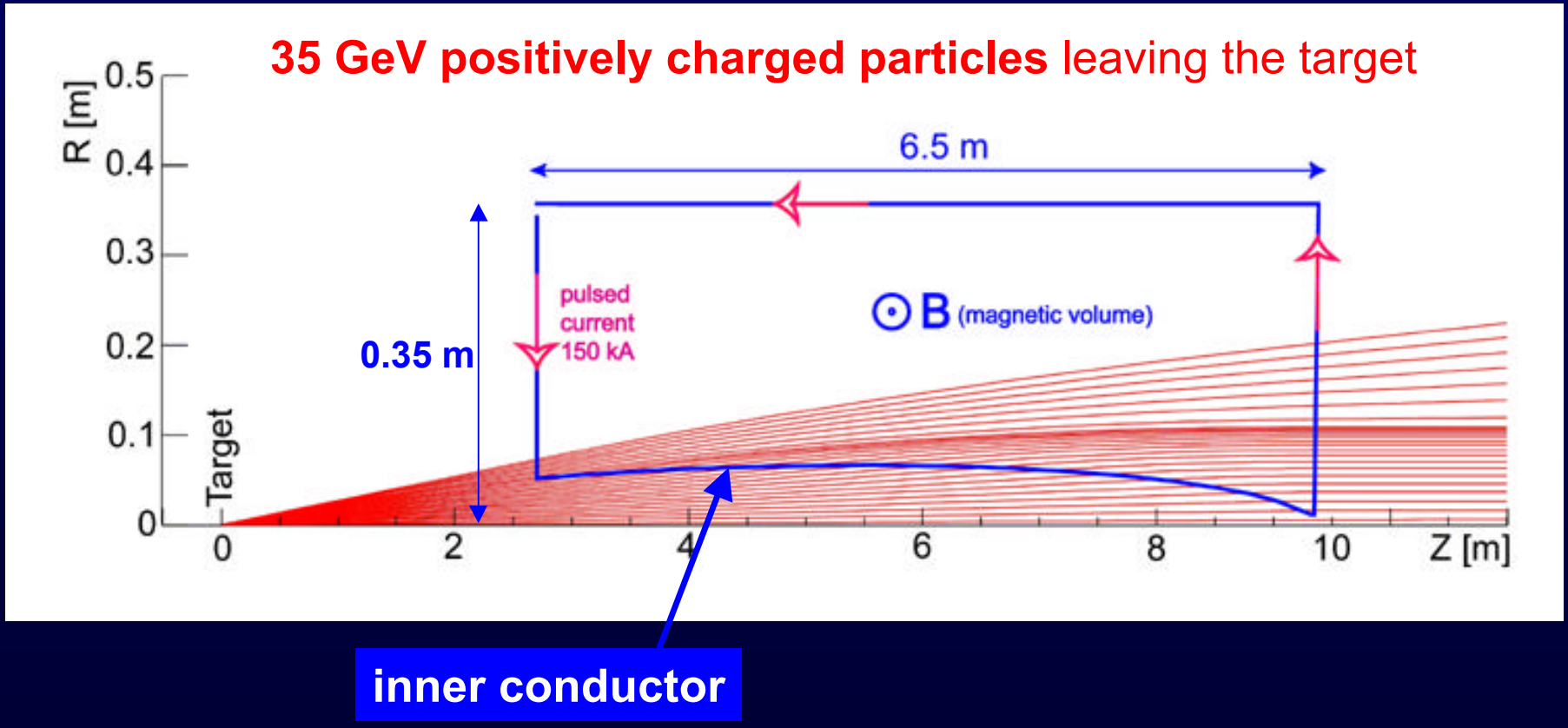
Pulsed devices:
150kA / 180 kA, 1 ms

water-cooled:
distributed nozzles

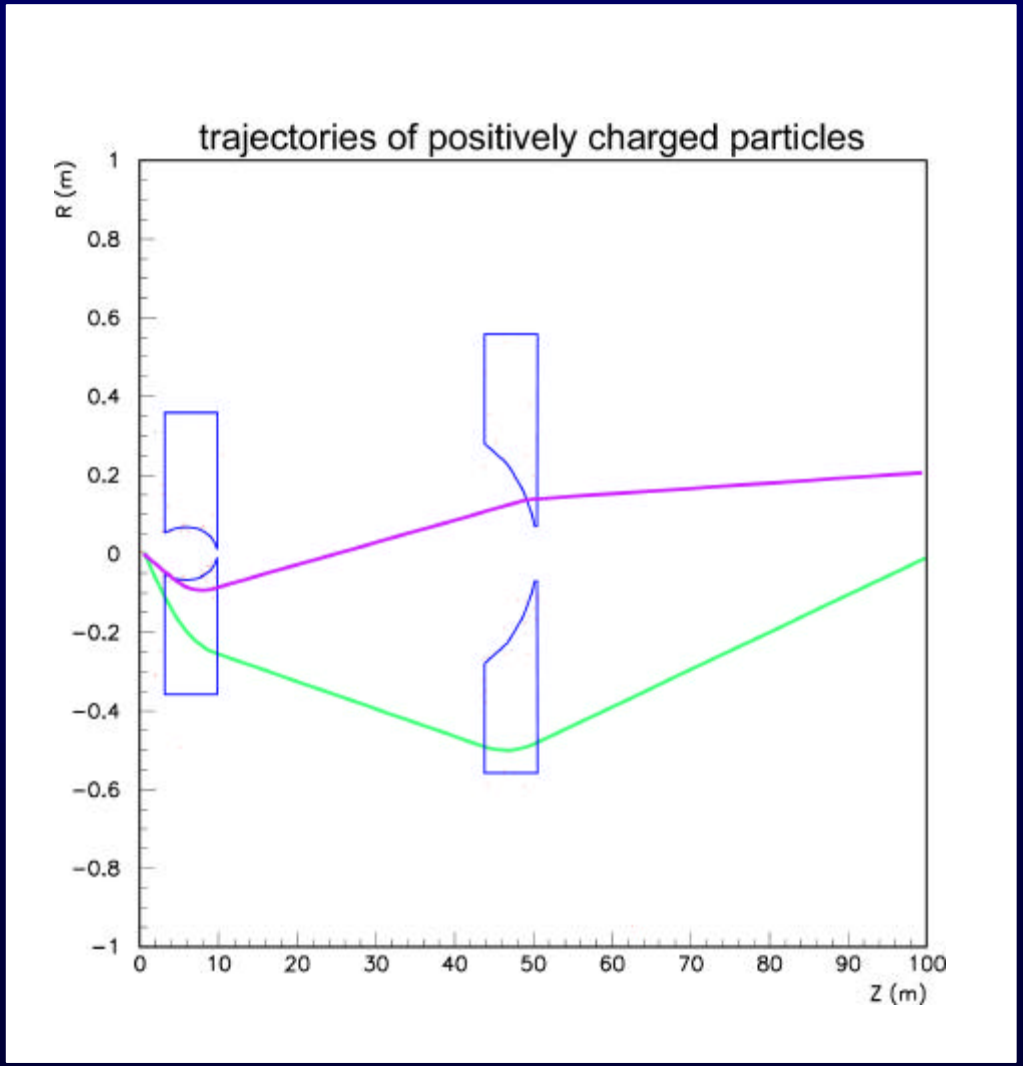
Principle of focusing with a Magnetic Horn

magnetic volume given by "one turn" at high current:

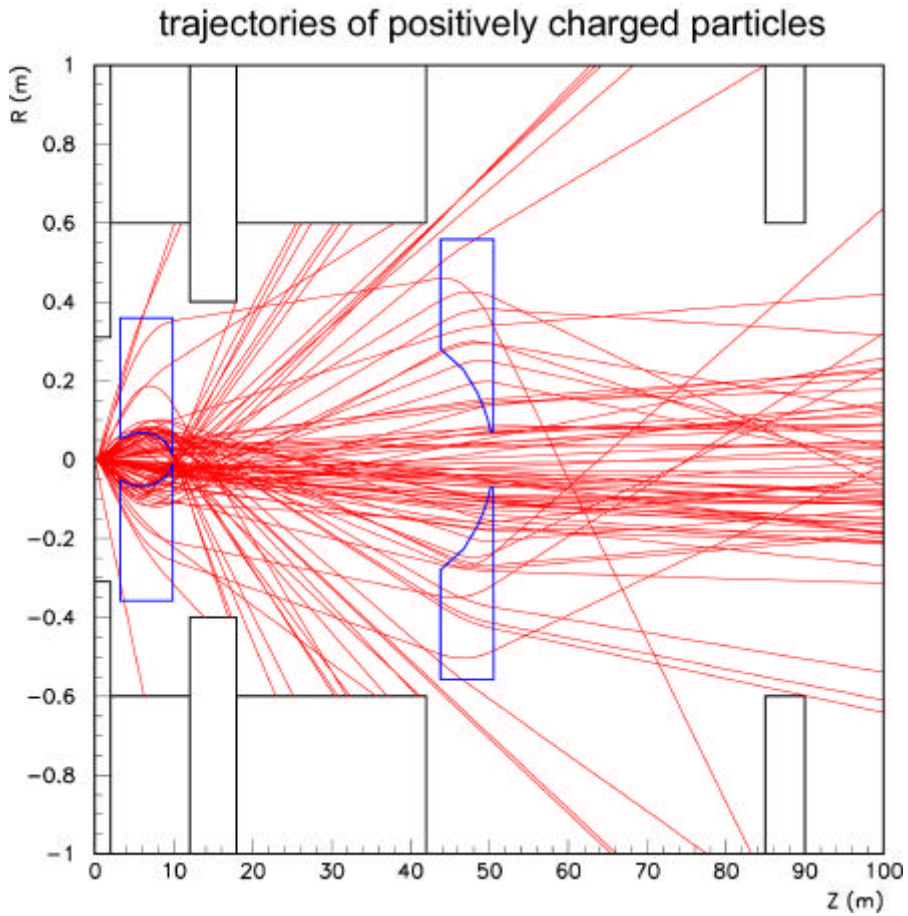
- ♦ specially shaped inner conductor
- \- end plates
- ♦ cylindrical outer conductor

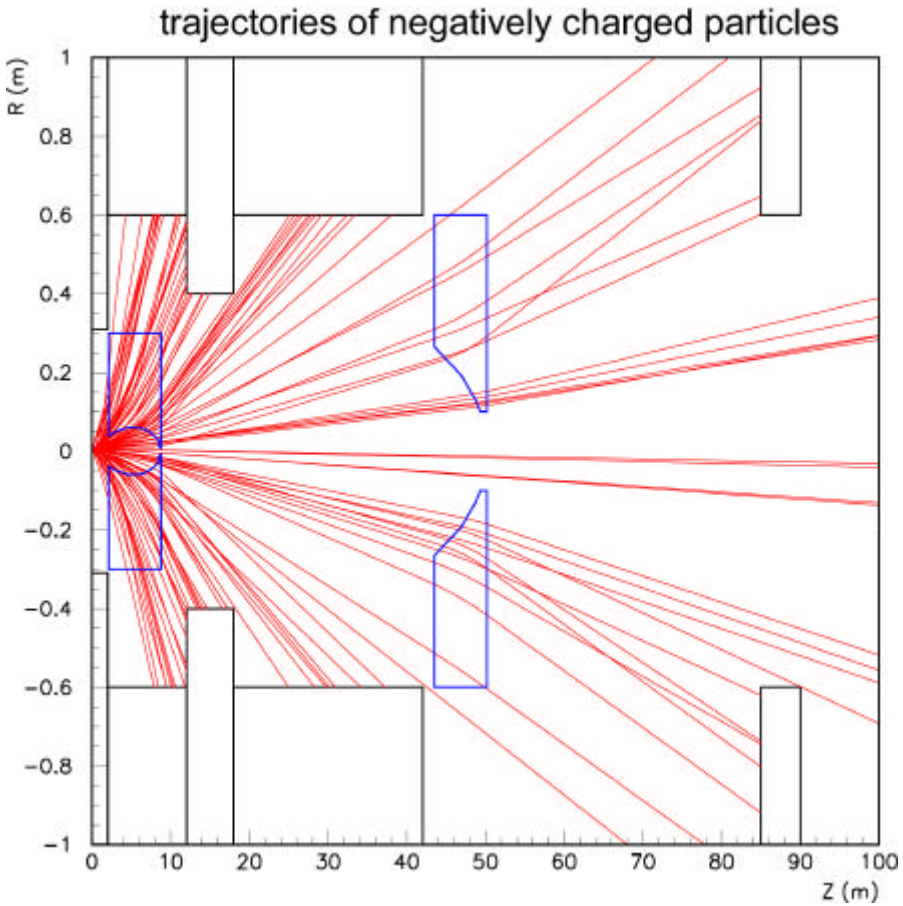


secondary beam focusing with horn/reflector



secondary beam focusing with horn/reflector

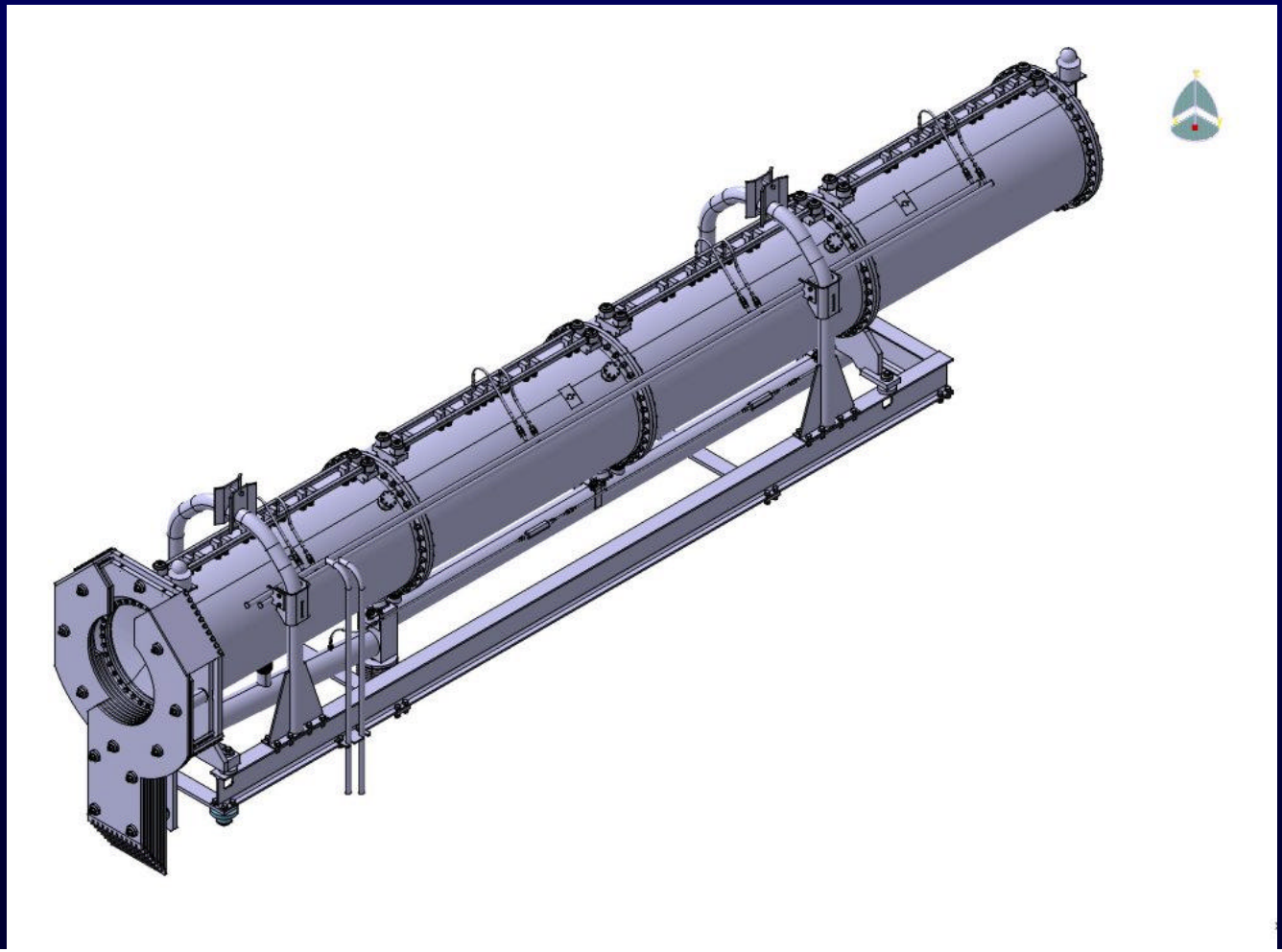




CNGS -- focusing devices (2)

(collaboration with IN2P3, Paris)

Design criteria:
>95% probability to work for 5×10^7 pulses

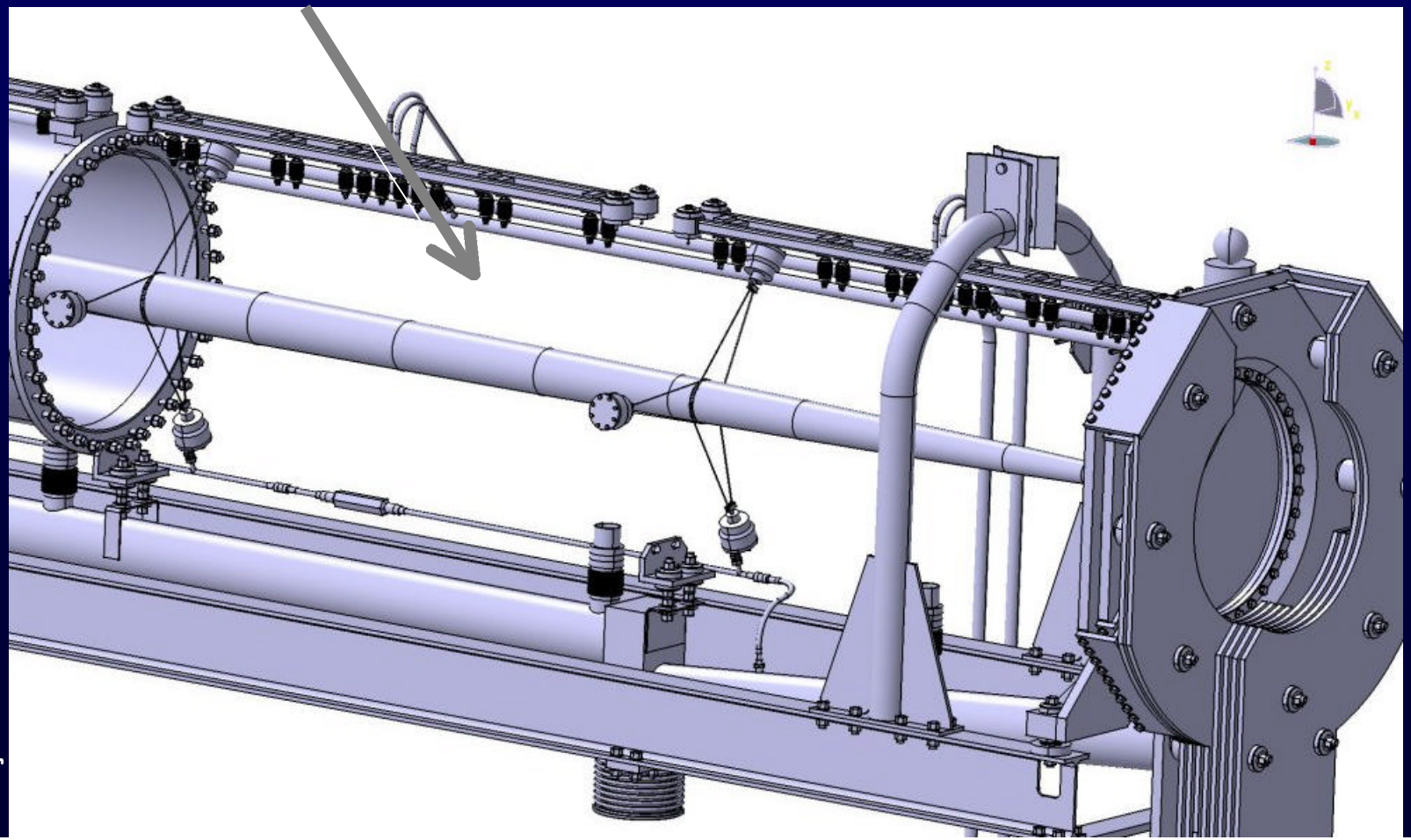


CNGS -- focusing devices (2)

(collaboration with IN2P3, Paris)

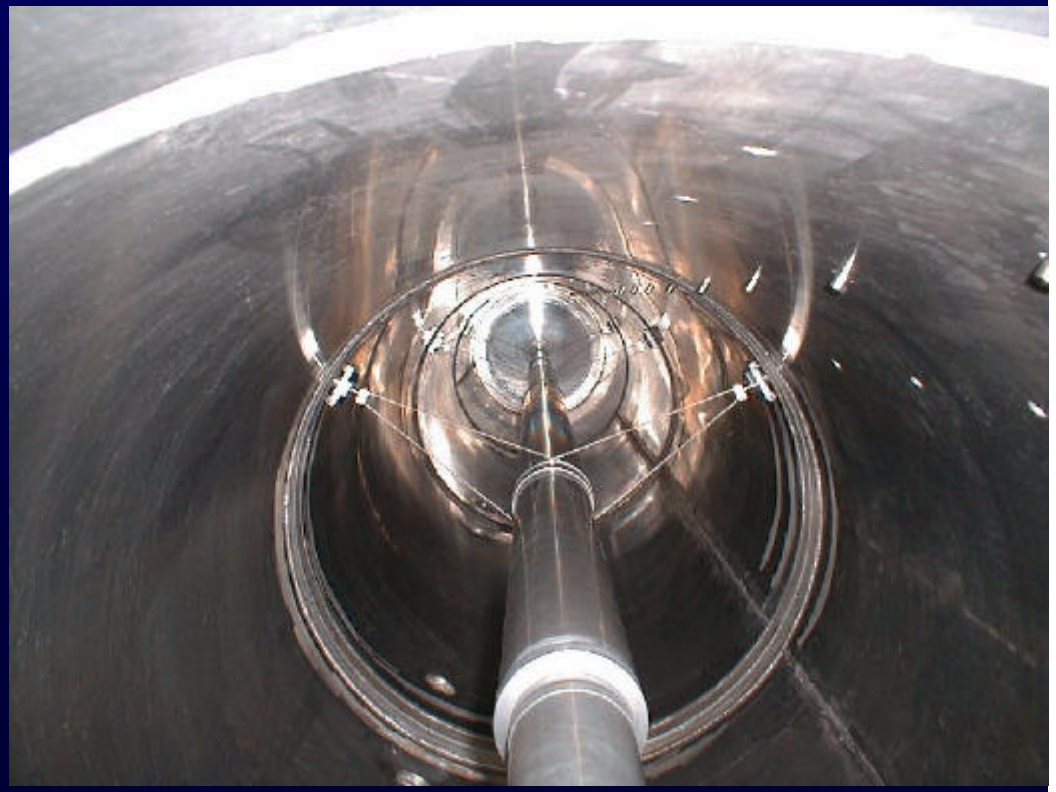
The inner conductor:

- as thin as possible (particle absorption)
- as thick as necessary (mechanical stability)

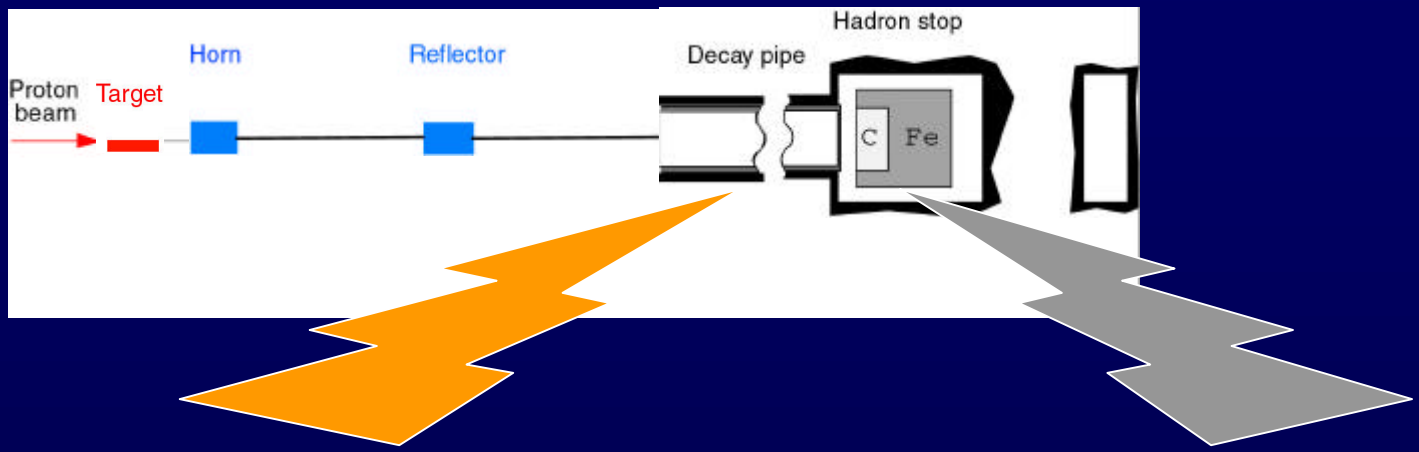


CNGS -- focusing devices (3)

Horn prototype tests in BA7:
1.5 Mio pulses in 2000



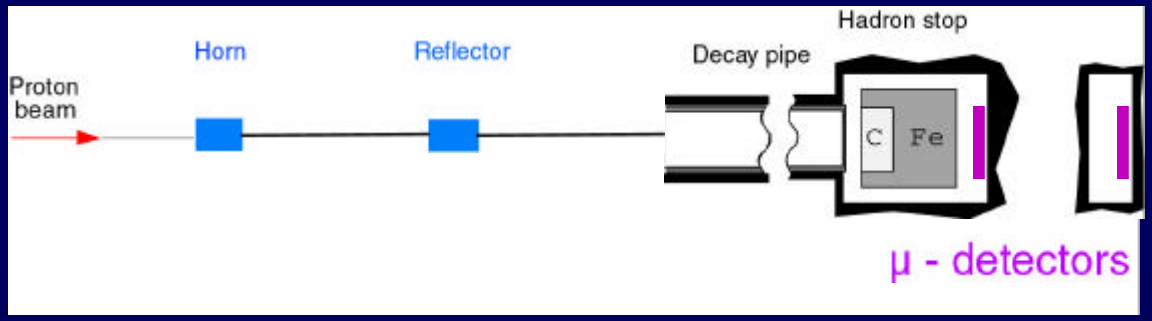
CNGS -- decay tube + hadron stop



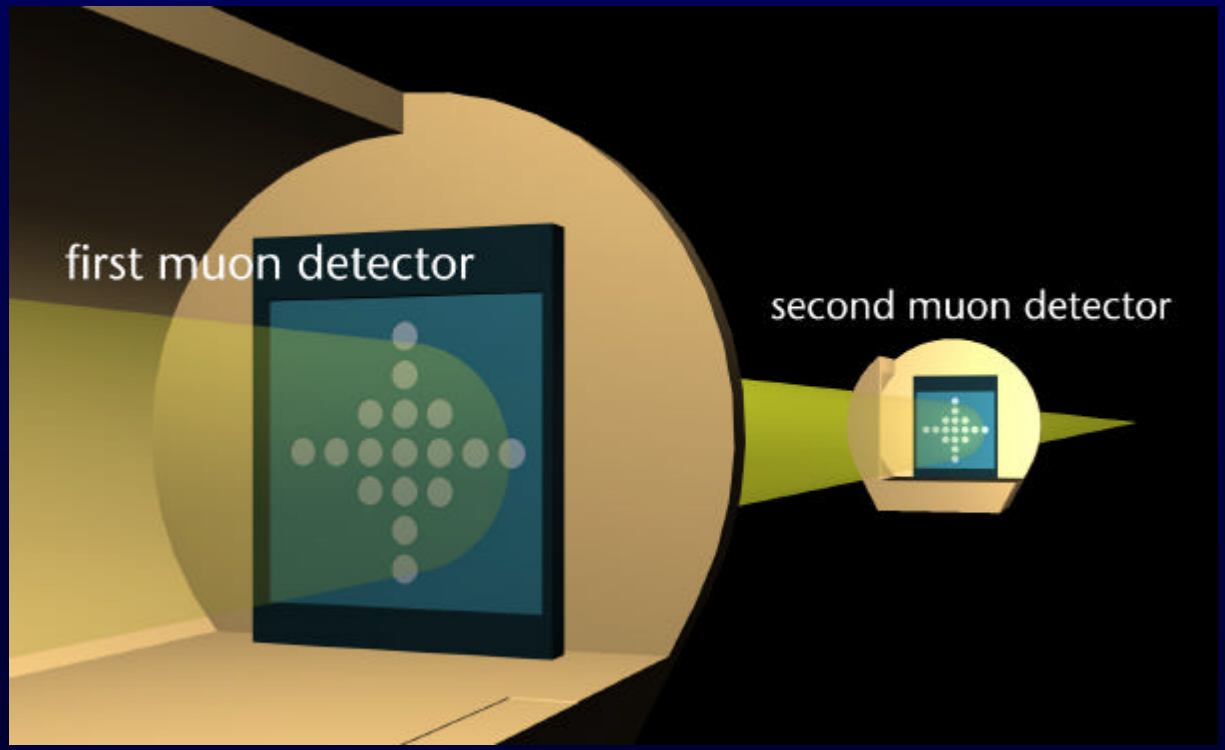
- dimensions of decay tube:
- 2.45 m diameter steel tubes, 6 m long pieces, **1 km total**
- welded together in-situ
- vacuum: ~1 mbar
- tube embedded in concrete

- hadron stop:
- 3.2 m graphite
- 15 m iron blocks
- upstream end: water cooled

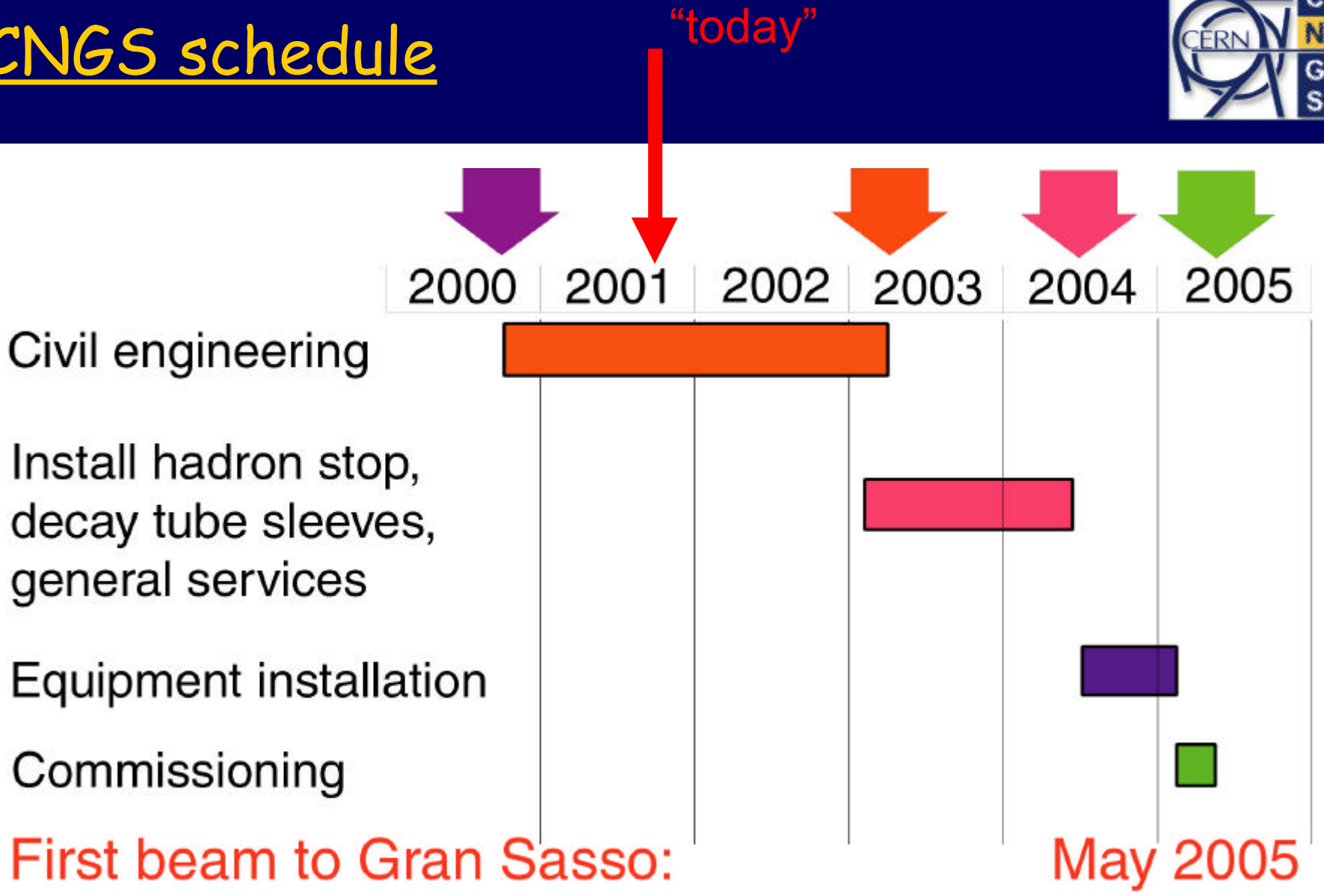
CNGS -- muon detectors



$\pi \longrightarrow \mu + \nu_\mu$



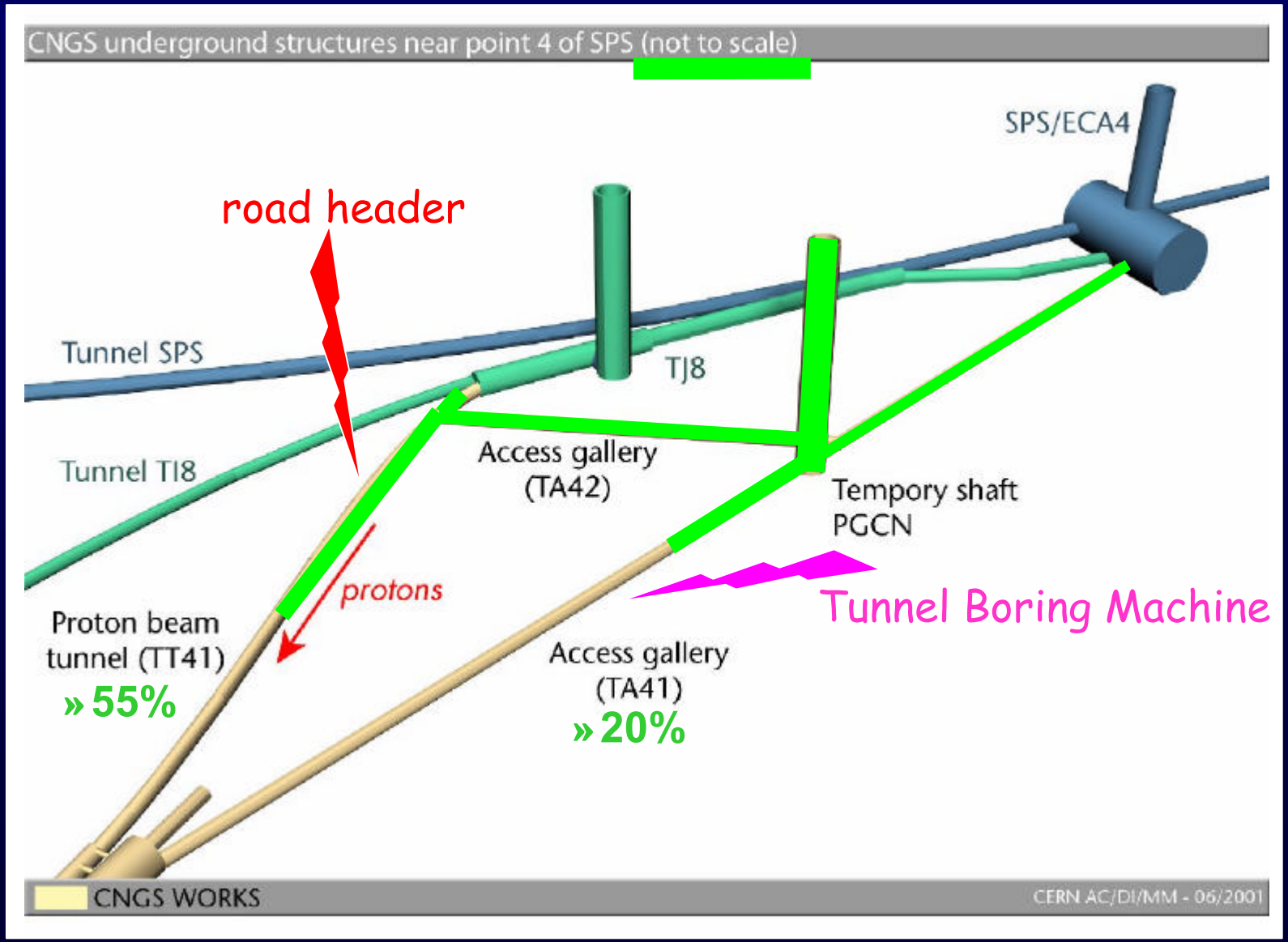
CNGS schedule



CNGS status -- Civil Engineering (1)

- ground breaking ceremony:
  12 October 2000

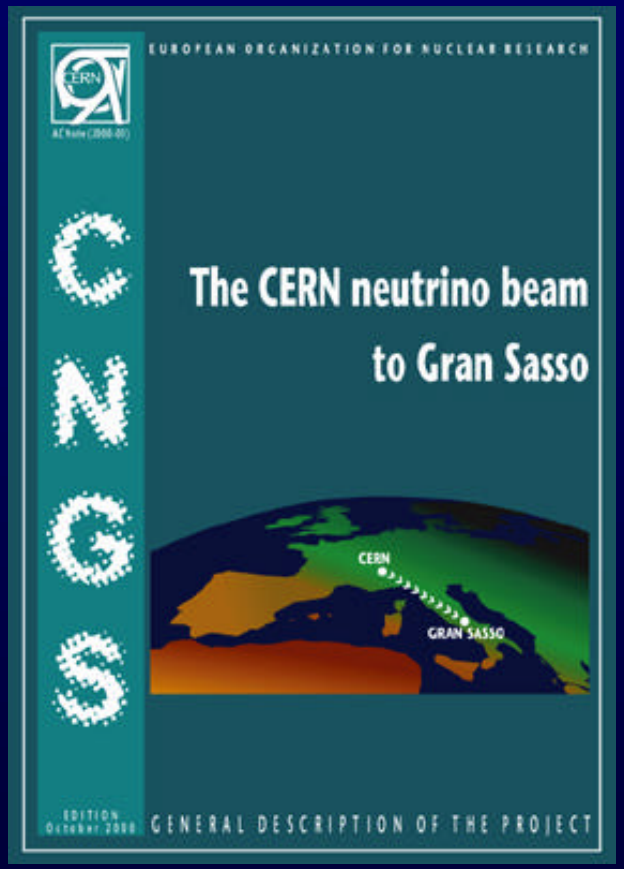
CNGS status -- Civil Engineering (2)



CNGS status -- Civil Engineering (3)

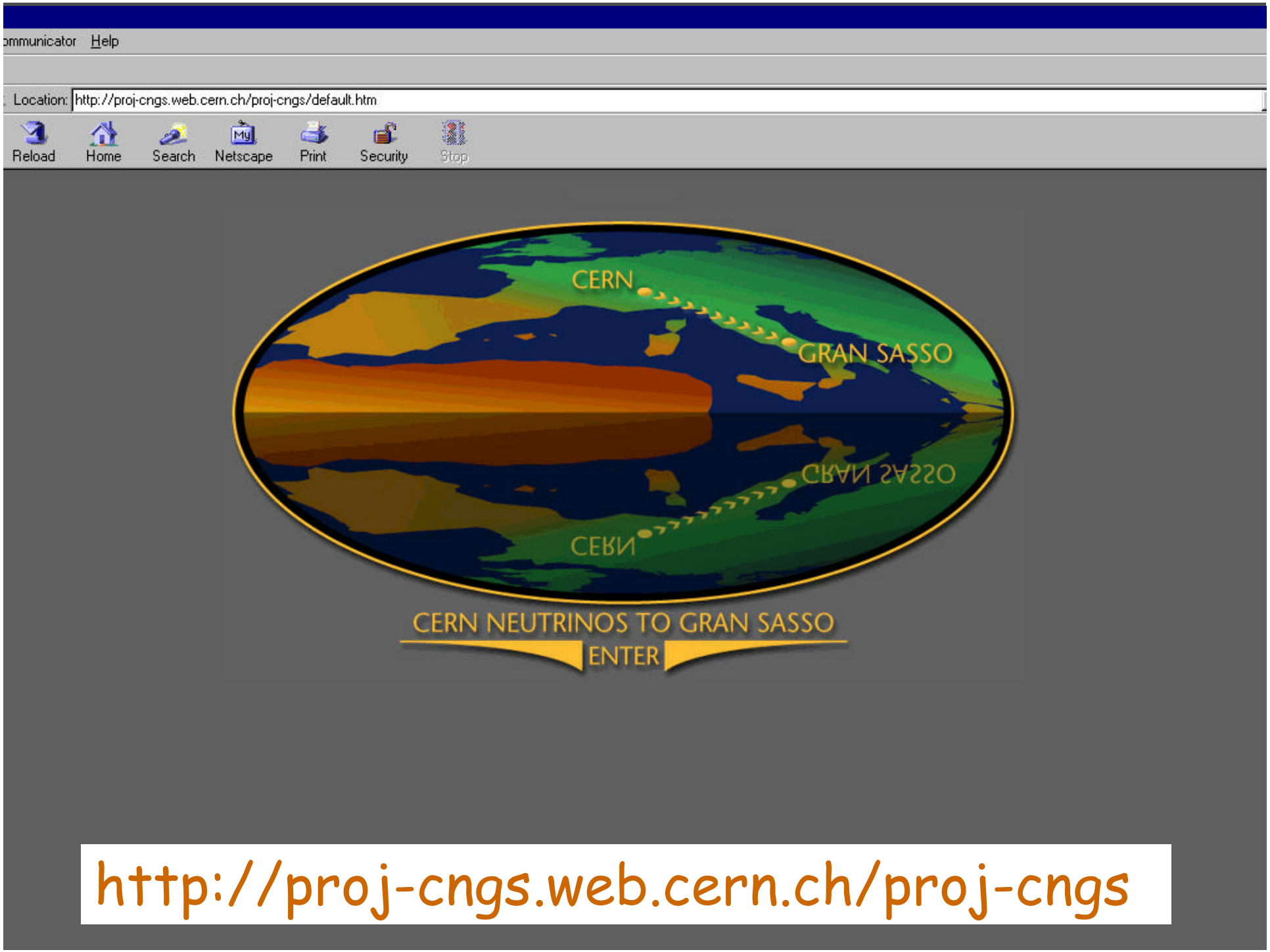
...before the summary...

for more information:



- CNGS general description

+ web pages



http://proj-cngs.web.cern.ch/proj-cngs

SUMMARY … (the movie)