CNGS – CERN neutrino beam towards Gran Sasso:

a long baseline neutrino beam facility in Europe

presented by

Konrad Elsener, CERN SL Division

Outline

- "A word" about neutrinos and oscillation
- Solar and Atmospheric neutrino experiments
- Long baseline neutrino beams and experiments
  - -> Japan: K2K (in operation)
  - -> USA: NuMI/Minos (in construction)
- CNGS – CERN neutrino beam towards Gran Sasso (Italy)
  - -> physics goal
  - -> design features
  - -> main components
  - -> layout / schedule
  - -> status
- Summary

Neutrinos and Oscillation

72 years after their "invention" (Pauli & Fermi) and
48 years after their discovery (Reines)

We "know" that…

⇒ ν are elementary particles (Standard Model)

⇒ ν interact "weakly" with matter (10^{-6} to 10^{-9} for ν traversing the earth)

⇒ there are 3 (non-sterile) species of ν (LEP experiments, 1990's)

- ν_e – Reines (nuclear reactor, 1954)
- ν_μ – Ledermann, Schwartz, Steinberger (accelerator beam, Brookhaven, 1962)
- ν_τ – DONUT collaboration (accelerator, beam dump experiment, Fermilab 2000)

Neutrinos and Oscillation

…we "know" that… (cont.)

⇒ ν have very small mass – mass not (yet) directly measured

⇒ IF ν have mass, they can "mix" between species

- analogy to the quark sector
- when propagating through space, ν may "oscillate"

(from species to species, e.g. $\nu_e - \nu_\mu$ $\nu_\mu - \nu_\tau$ etc.)

(prediction: B. Pontecorvo in the 50's)

Neutrinos and Oscillation

For the case of two neutrinos, e.g.:

$$P_{oscillation}(\nu_\mu - \nu_\tau) = \sin^2(2\theta) \times \sin^2\{1.27\ \Delta m^2 \times L / E_\nu\}$$

"mixing angle" (θ)

Δm^2: mass difference [eV²/c⁴]

L: [km]

E_ν: [GeV]

Example:

$\sin^2(2\theta) = 1$ (maximum mixing – cf. expt. results !)

$E_\nu = 1$ GeV (**<u>not CNGS case</u>**, see later…)

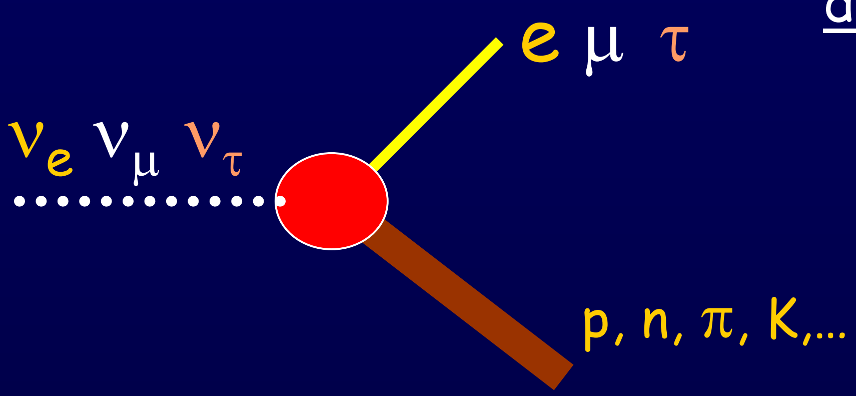
$\Delta m^2 = 10^{-3}$ eV^2/c^4 (presently best fit is 2.5 x that, see later…)

-> first oscillation maximum is at L = 787 km

"long base-line" experiments…

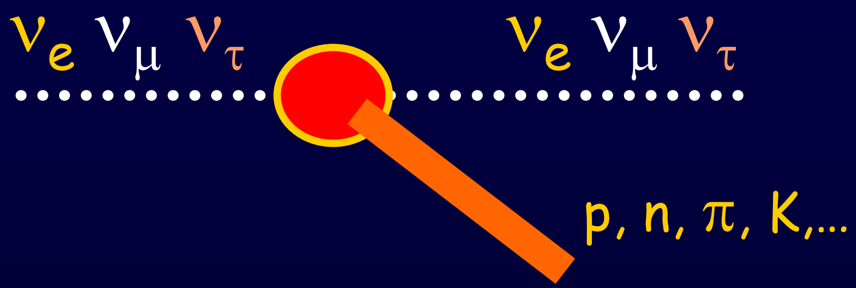
(Interaction of neutrinos with matter)

"charged current interactions"



detect lepton ->
know about neutrino flavor

"neutral current interactions"



Experiment (1): Solar Neutrinos

since the '60s: SOLAR NEUTRINO DEFICIT

Experiments measuring ν_e from the sun (E = 1-10 MeV, L = 1.5 10^8km, 10^8 per s per m^2) see only 35-50% of the flux expected according to (now VERY sophisticated) solar models:

Homestake (Cl), Gallex, Sage, Kamiokande, Superkamiokande…

today we know (2002): due to NEUTRINO OSCILLATION

ν_e --- (ν_μ, ν_τ)

SNO (Sudbury Neutrino Observatory)

Heavy Water Cerenkov Detector

SNO looking at the sun...

detect electrons from

$\nu_e + d \rightarrow p + p + e$

only ν_e can do this !!!

find 65% deficit...

detect neutrons from

$\nu_x + d \rightarrow p + n$

$\nu_e\ \nu_\mu\ \nu_\tau$ can all do this !!!

find <u>no deficit</u>

Experiment (2): Atmospheric Neutrinos

"the atmospheric neutrino anomaly" (SUPERKAMIOKANDE)

ν_e ν_μ from hadronic showers induced by cosmic rays (mostly protons) in the atmosphere;

Super-K 50 kt water detector - can distinguish e -- μ

RESULT:

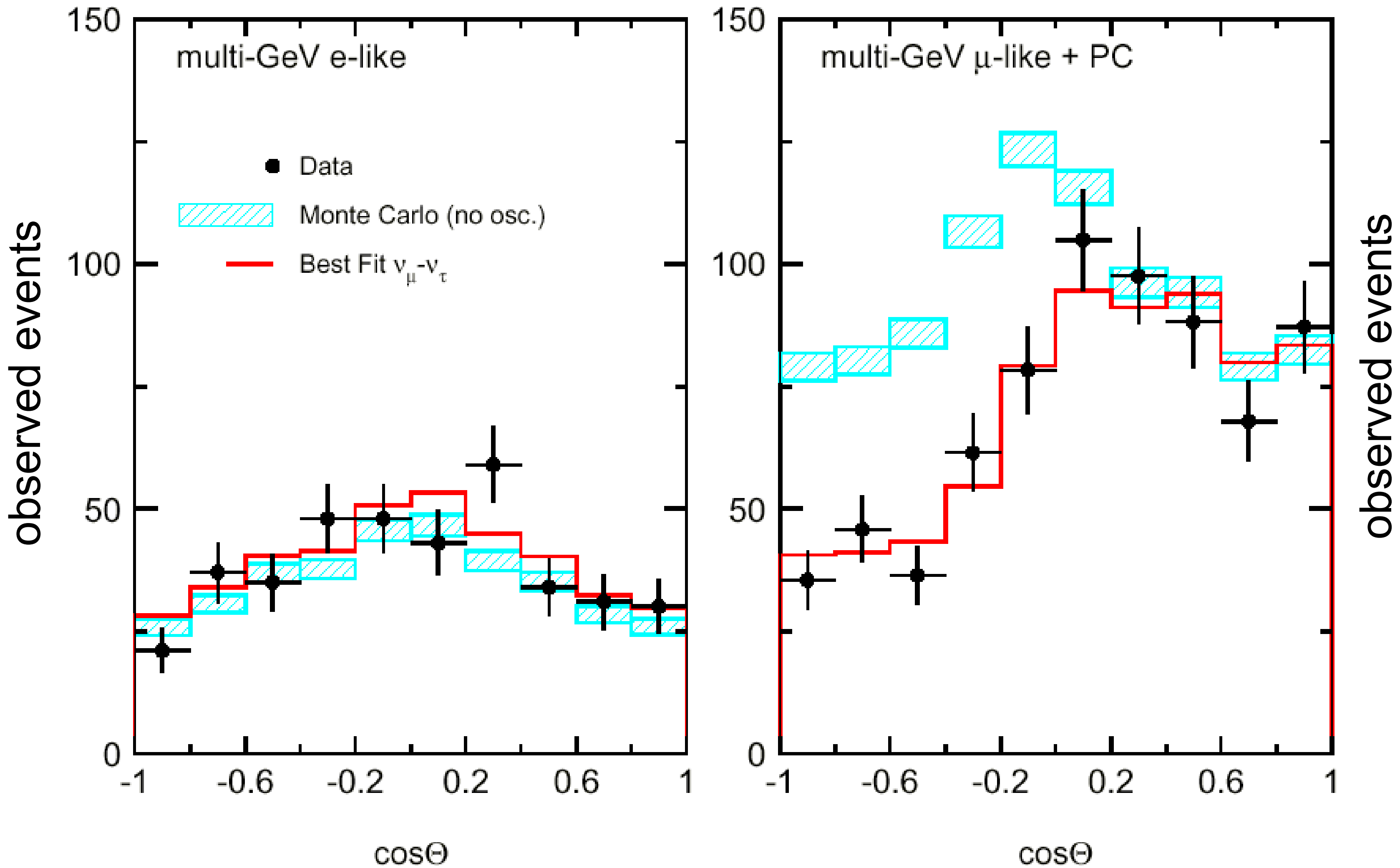
ν_e observed as expected

ν_μ "from above" (10-20 km) as expected

"from below" (10000 km) large deficit

Experiment (2): Atmospheric Neutrinos

"the atmospheric neutrino anomaly" (SUPERKAMIOKANDE)



Suspicion:

the atmospheric neutrino anomaly is due to the oscillation

$$\nu_\mu - \nu_\tau$$

i.e.

ν_μ of a few GeV "disappear" over distances of 1000 – 10000 km

-> test this hypothesis with accelerator experiments !!

ν_τ "appear" as a result of oscillation

-> test with another accelerator experiment !!

"Disappearance" Experiments using particle accelerators

(1) K2K experiment in Japan

250 km baseline, KEK to Superkamiokande, E ~ 1.5 GeV
experiment "running" – 3 near detectors to monitor beam
Results (May 2002): observed 56 evts., expected 80 evts.

a) ν_μ are missing

b) full error analysis -> oscillation parameters consistent with Super-K atmospheric results

2) NuMI/MINOS experiment in USA

730 km baseline, Fermilab to MINOS detector (iron/scintillator)
E ~ 1-10 GeV
experiment + beam "under construction"
1 near detector to monitor beam

first beam expected in early 2005

CNGS – a ν_τ "appearance" experiment

- send intense ν_μ beam from CERN
- look for ν_τ at Gran Sasso, 732 km away

final proof of ν_μ -- ν_τ oscillation

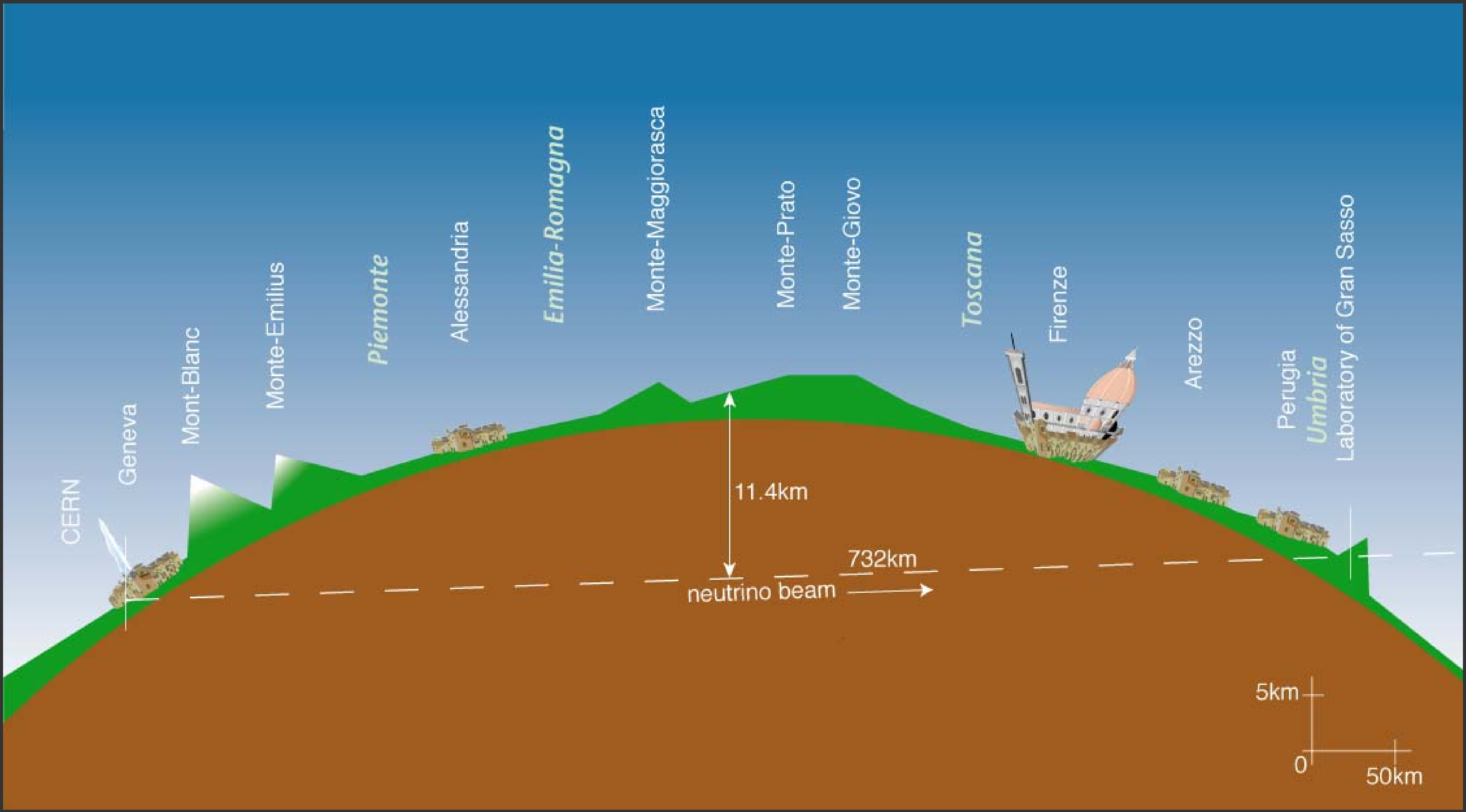
"Gran Sasso": EUROPEAN RESEARCH FACILITY

- mountain range 100 km east of Rome
  "Laboratori Nazionale di Gran Sasso"
  existing underground laboratory

CNGS – a ν_τ "appearance" experiment

- send intense ν_μ beam from CERN
- look for ν_τ at Gran Sasso, 732 km away

CNGS ν trajectory:



ν_τ "appearance" experiment

beam optimisation:

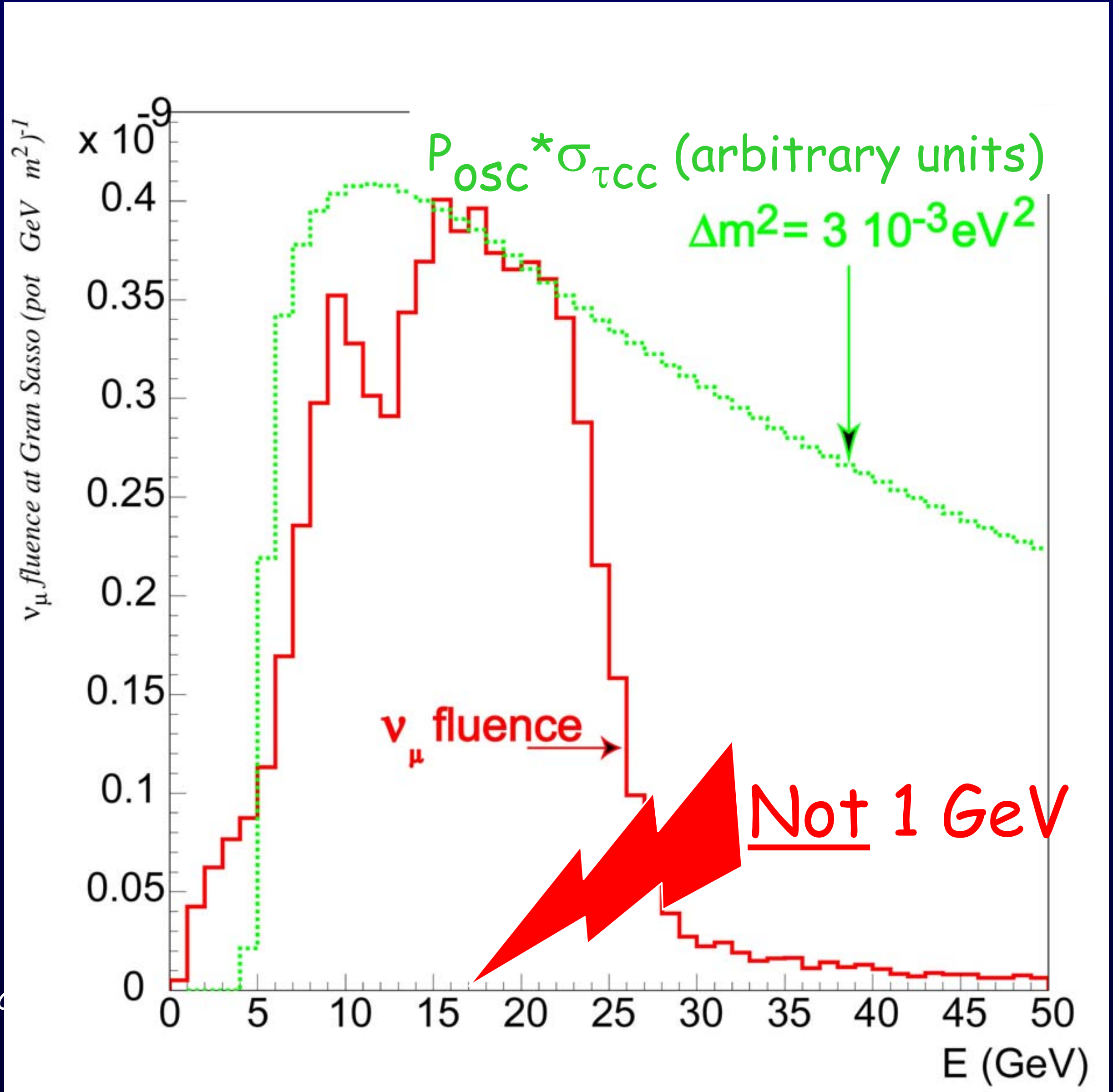
product of

(1) ν_μ flux

(2) oscill. probability
ν_μ —— ν_τ

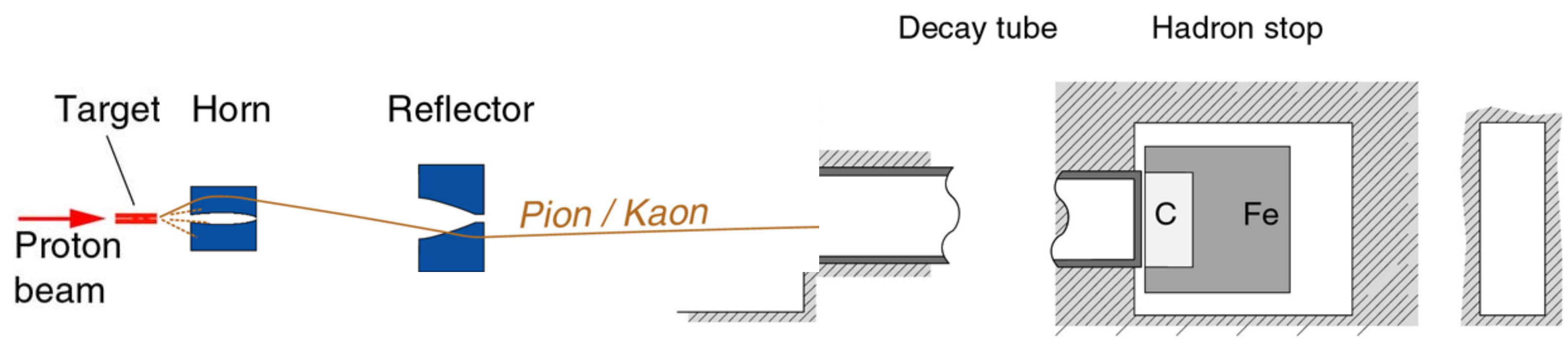
(3) production
cross section
ν_τ with matter
(to get a τ - meson)

\+ detection efficiency in the experiment



CNGS: the main components (1)

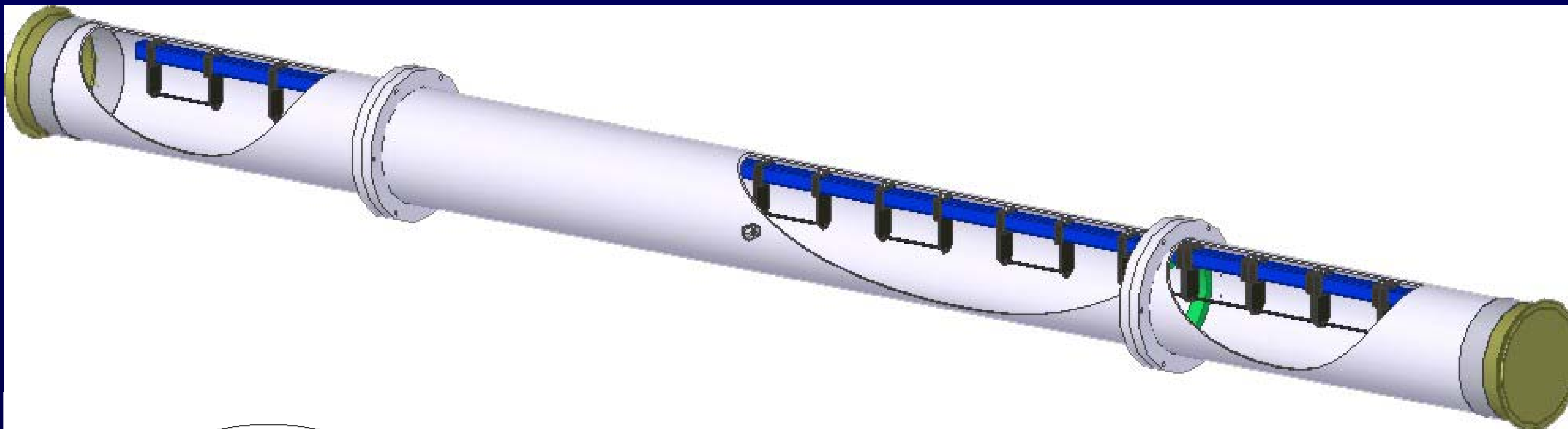
(based on CERN experience: PS / SPS neutrino beams -> WANF)

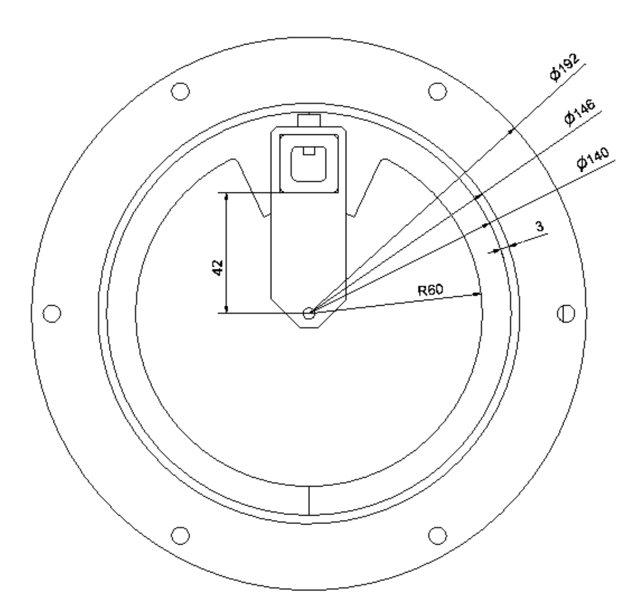


$$p + C \rightarrow \text{(interactions)} \rightarrow \pi^+,\ K^+ \rightarrow \text{(decay in flight)} \rightarrow \mu^+ + \nu_\mu$$

protons from SPS: 400 GeV/c, beam-size σ = 0.5mm

Target Unit



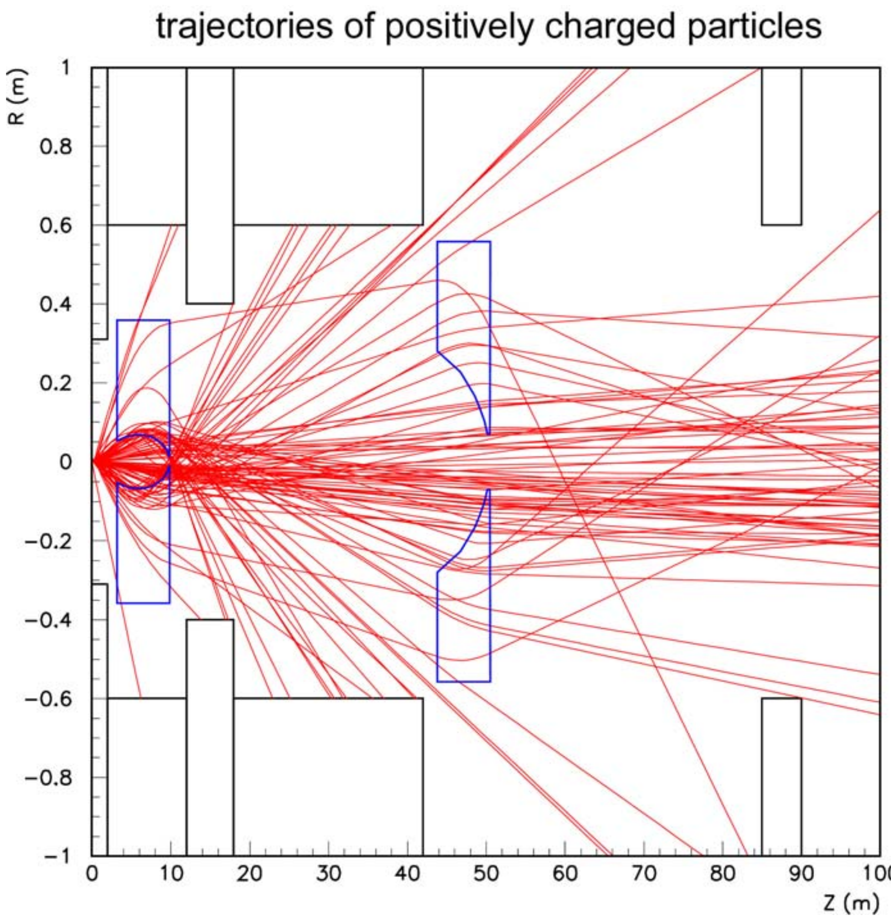


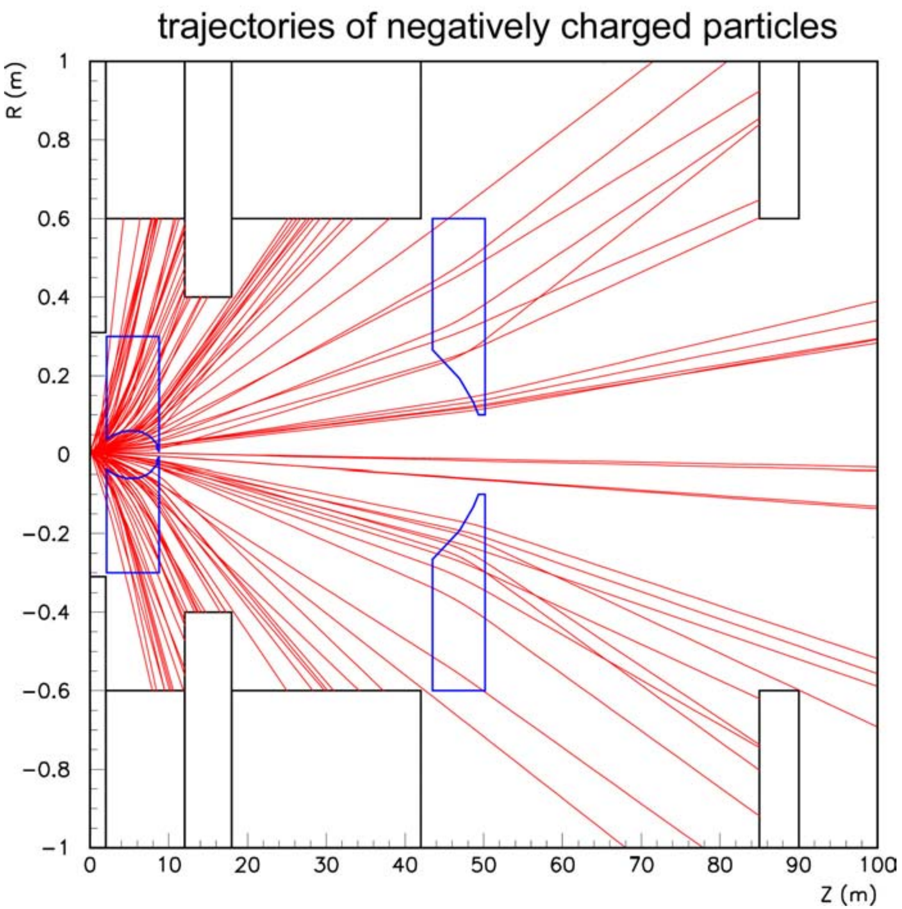
13 graphite elements, 10 cm long, Ø 4 or 5 mm

elements held by C-C "cards", inside Ti tube

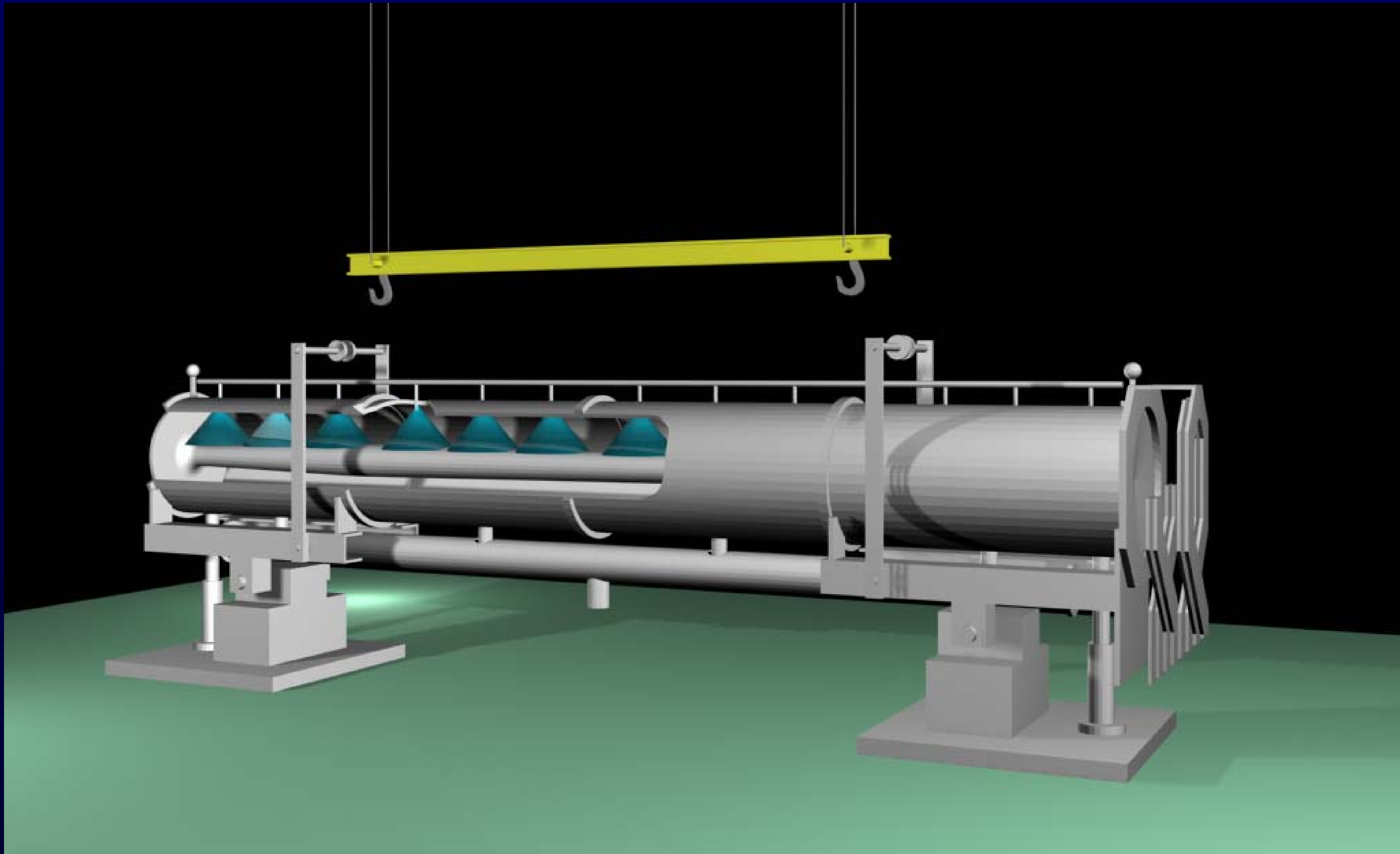
overall target length: 2 metres

Horn / Reflector: secondary beam focusing



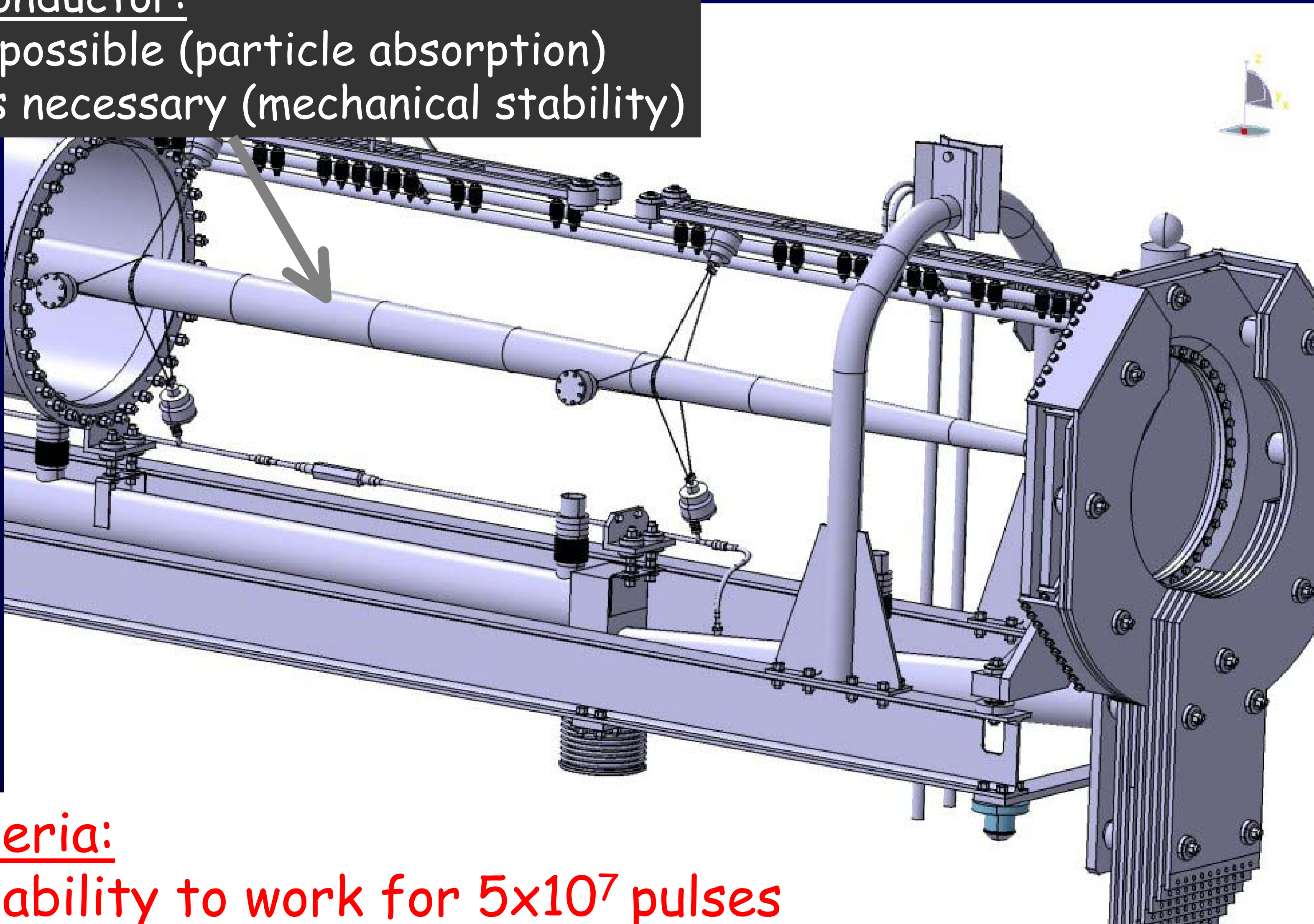


magnetic horn: pulsed - I= 150 kA, t = 1 ms



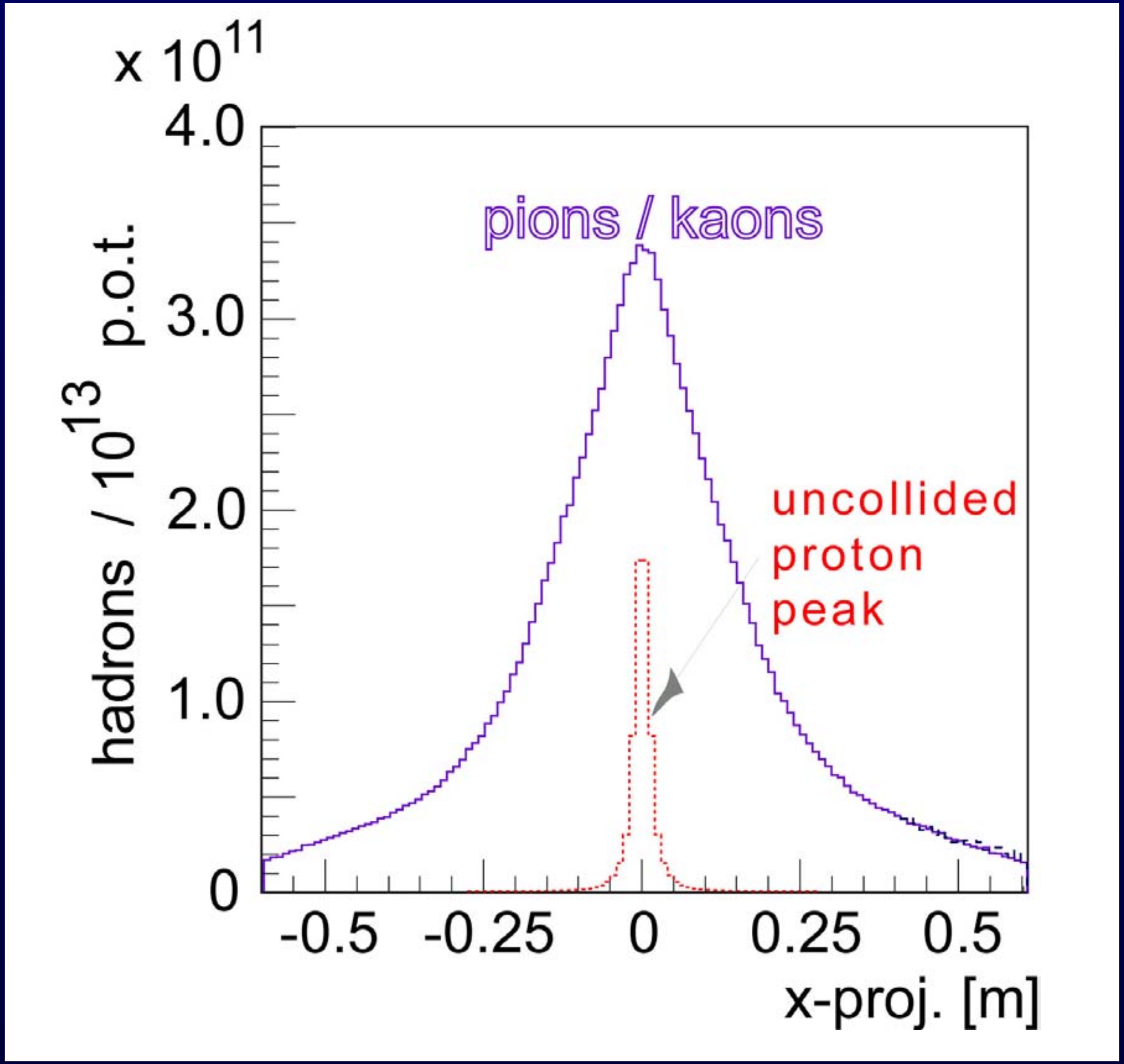
magnetic horns
(contribution of IN2P3, Paris)

The inner conductor:
- as thin as possible (particle absorption)
- as thick as necessary (mechanical stability)

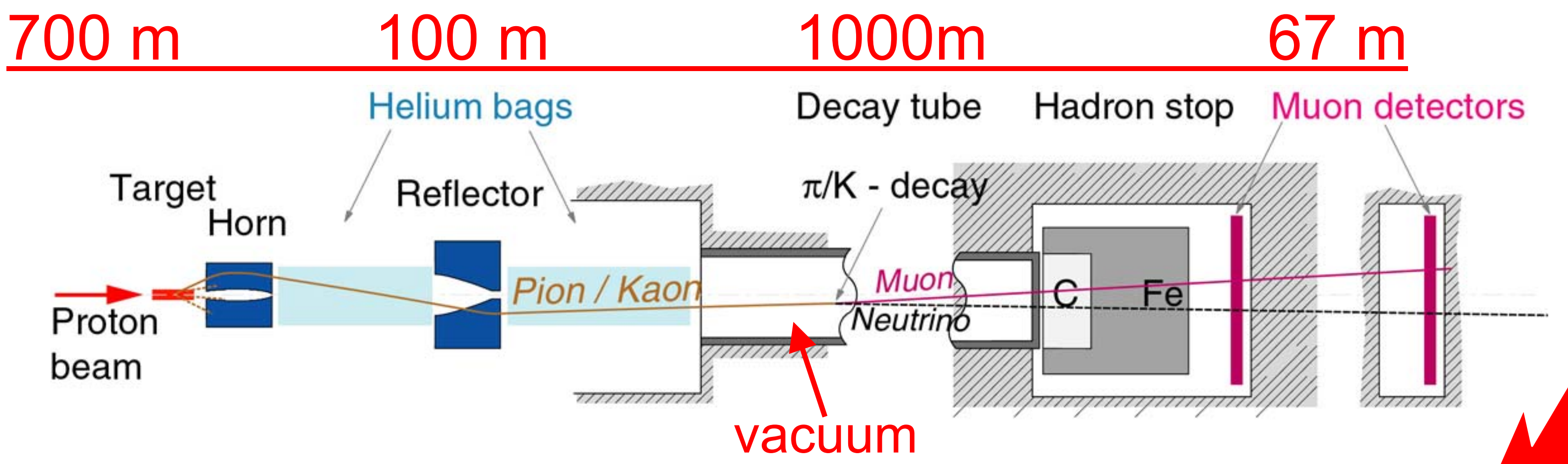


Design criteria:
> 95% probability to work for $5x10^7$ pulses

π / K profile at entrance to decay tunnel



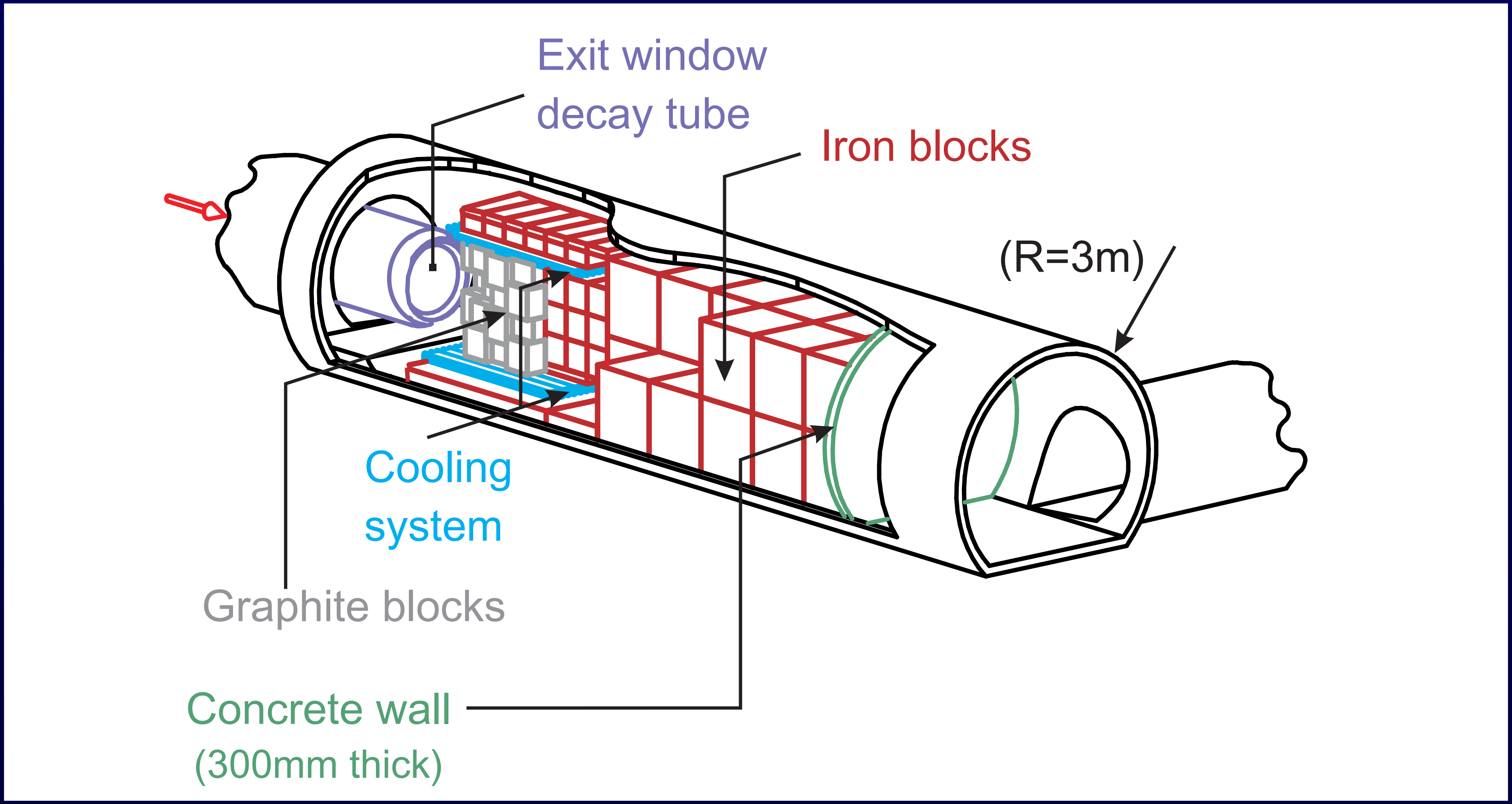
CNGS: the main components (2)



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

NO NEAR DETECTOR

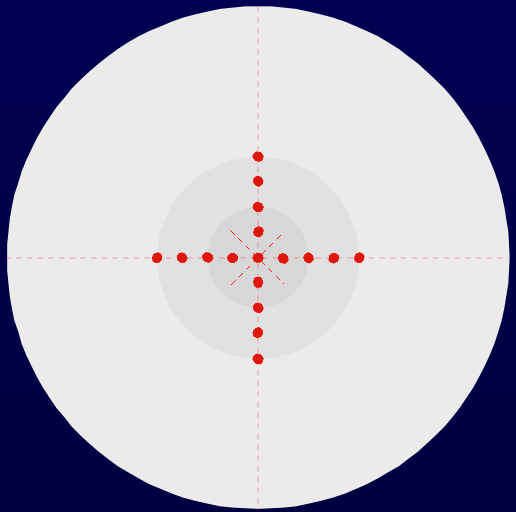
Hadron stop (beam dump)

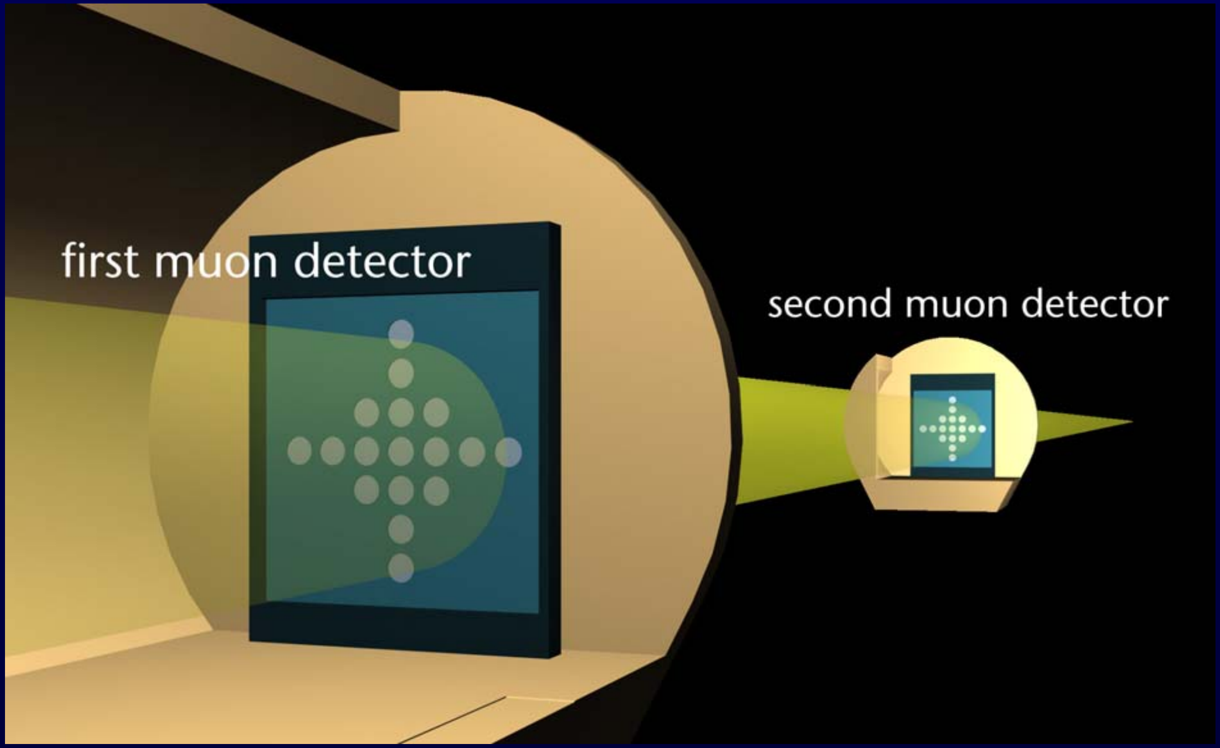


Muon detectors

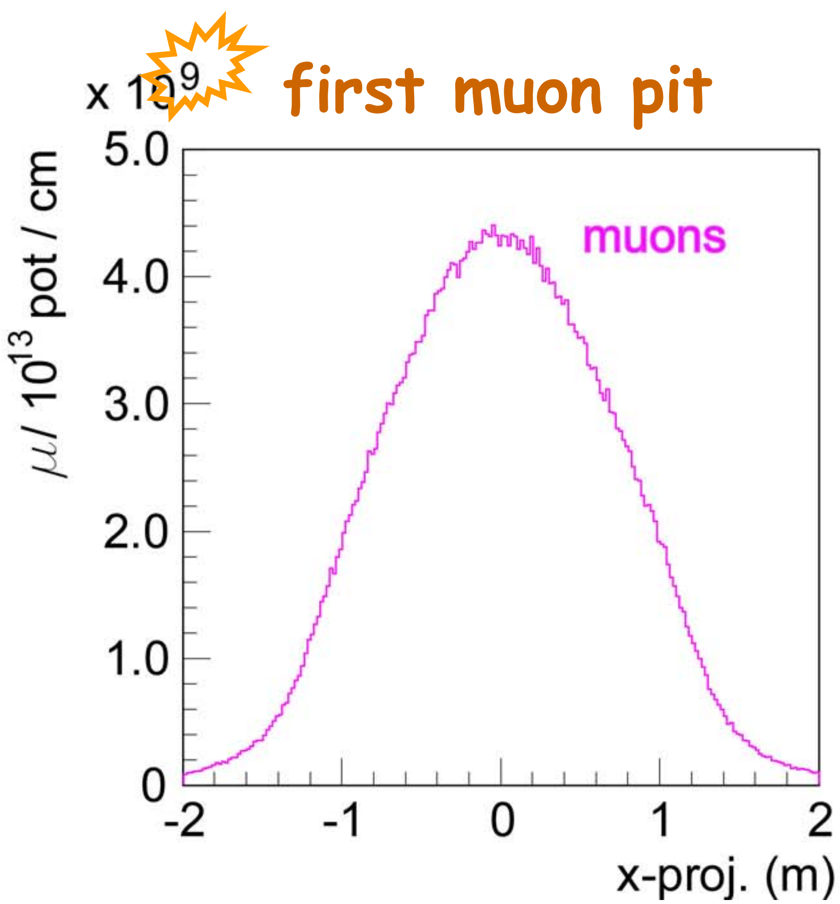
17 air filled ionisation chambers (x 2)

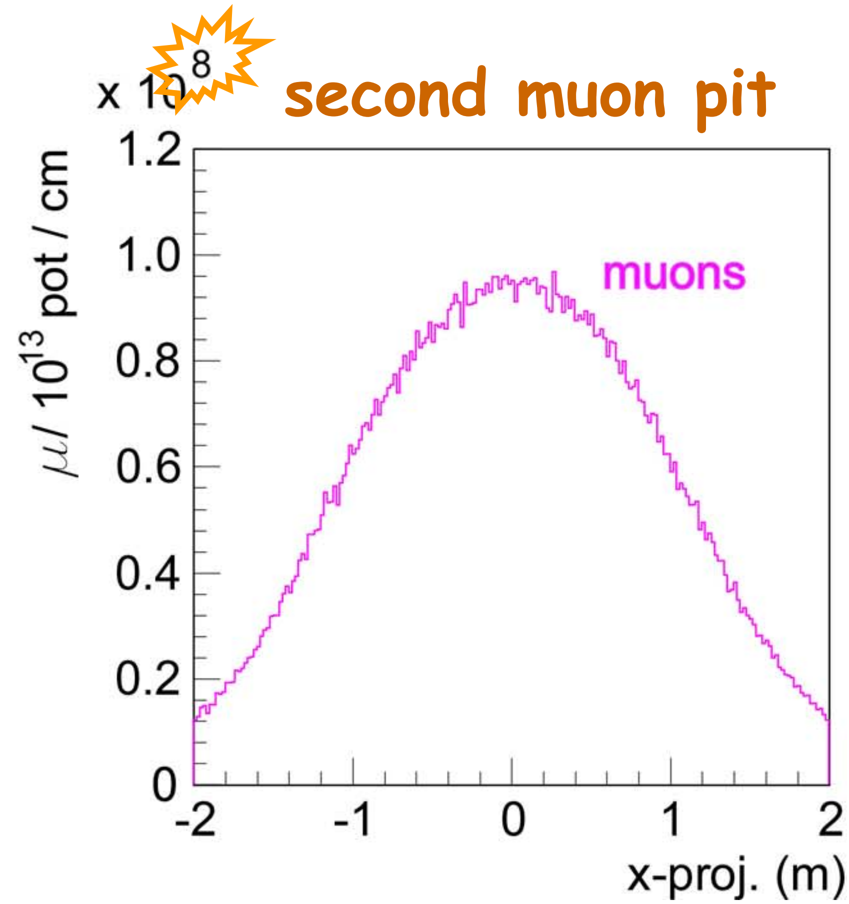
monitoring beam misalignments, instabilities "on line"

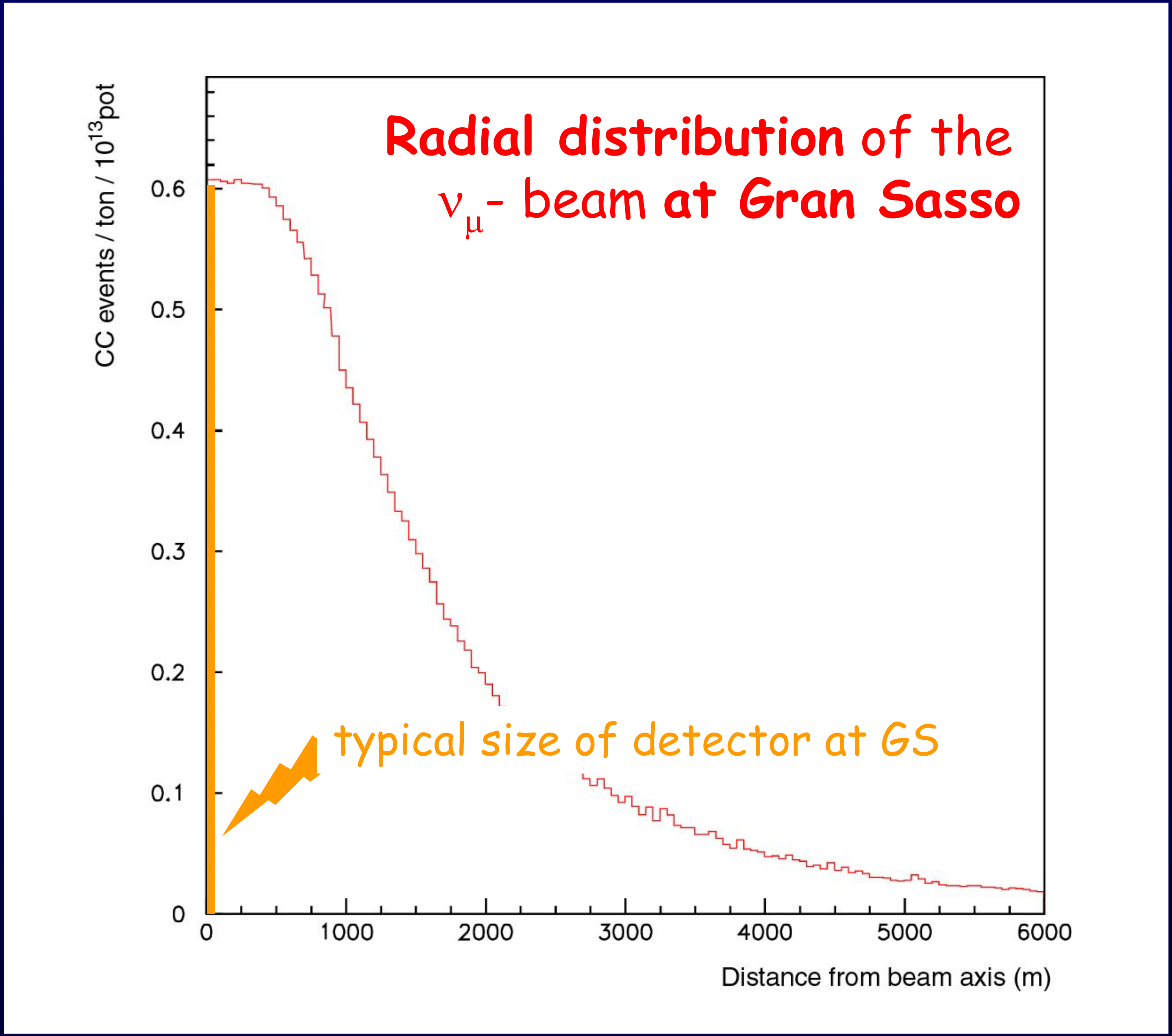




expected CNGS muon profiles







Radial distribution of the
ν_μ- beam at Gran Sasso
typical size of detector at GS
CC events / ton / 10^{13}pot
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1000
2000
3000
4000
5000
6000
Distance from beam axis (m)

Number of particles expected per year:

For 1 year of CNGS operation, we expect:

protons on target	4.5×10^{19}
pions / kaons at entrance to decay tunnel	5.8×10^{19}
muons in first / second muon pit	3.6×10^{18} / 1.1×10^{17}

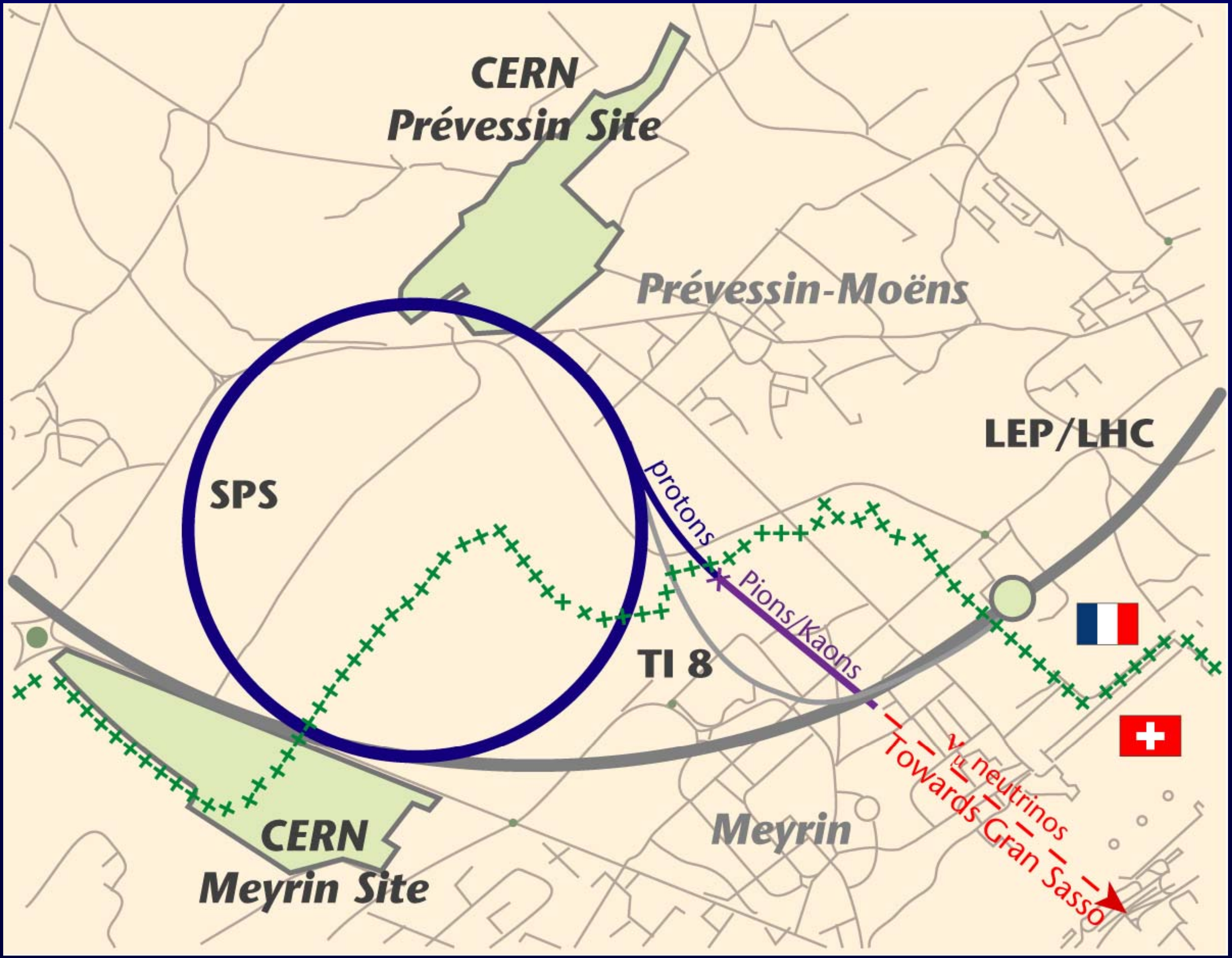
ν_μ in 100 m^2 at Gran Sasso — 3.5×10^{12}

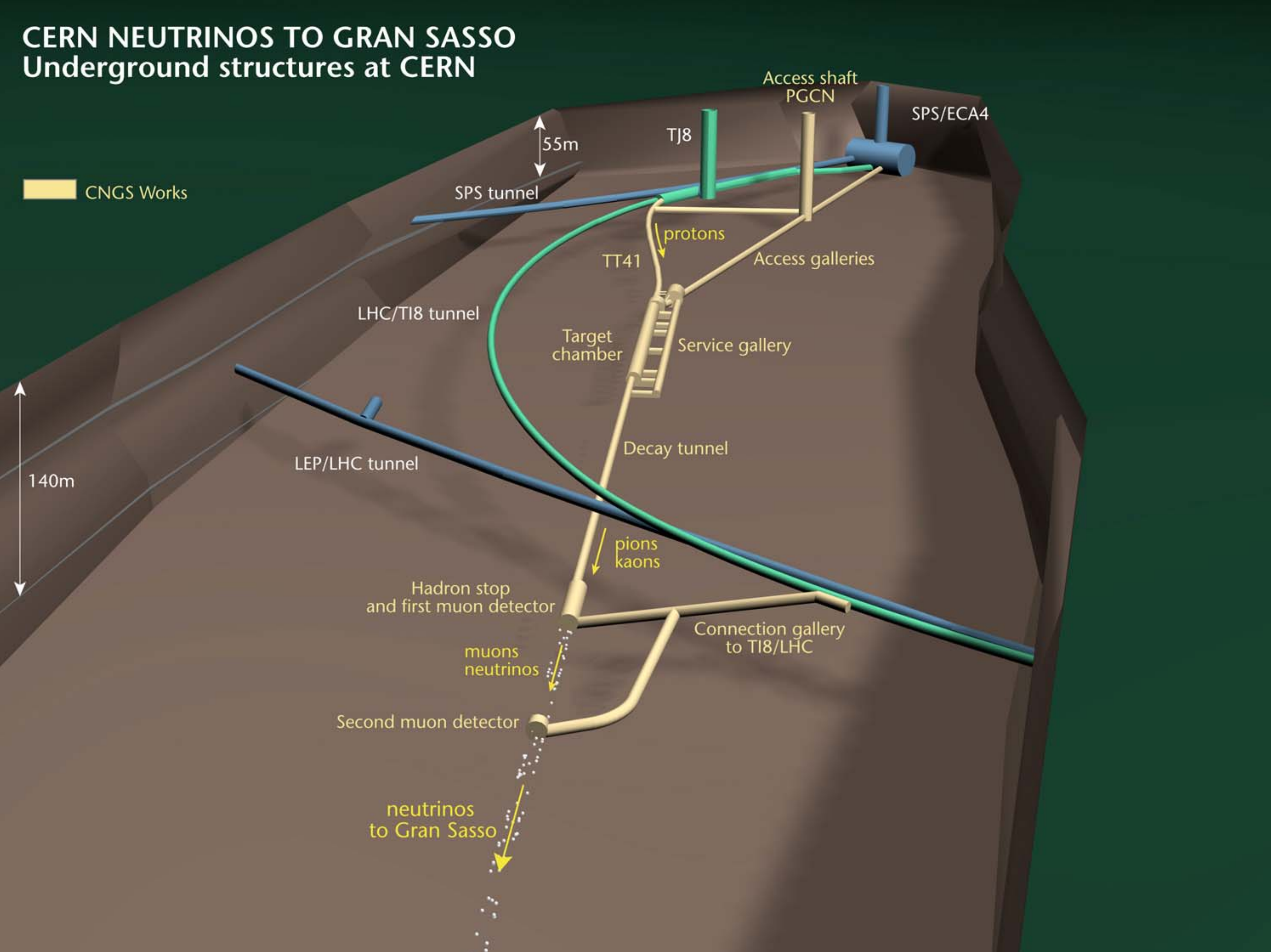
ν_μ "charged current" events per 1000 t — ≈ 2500

($\nu + N \to N' + \mu$)

ν_τ events (from oscillation) — ≈ 20

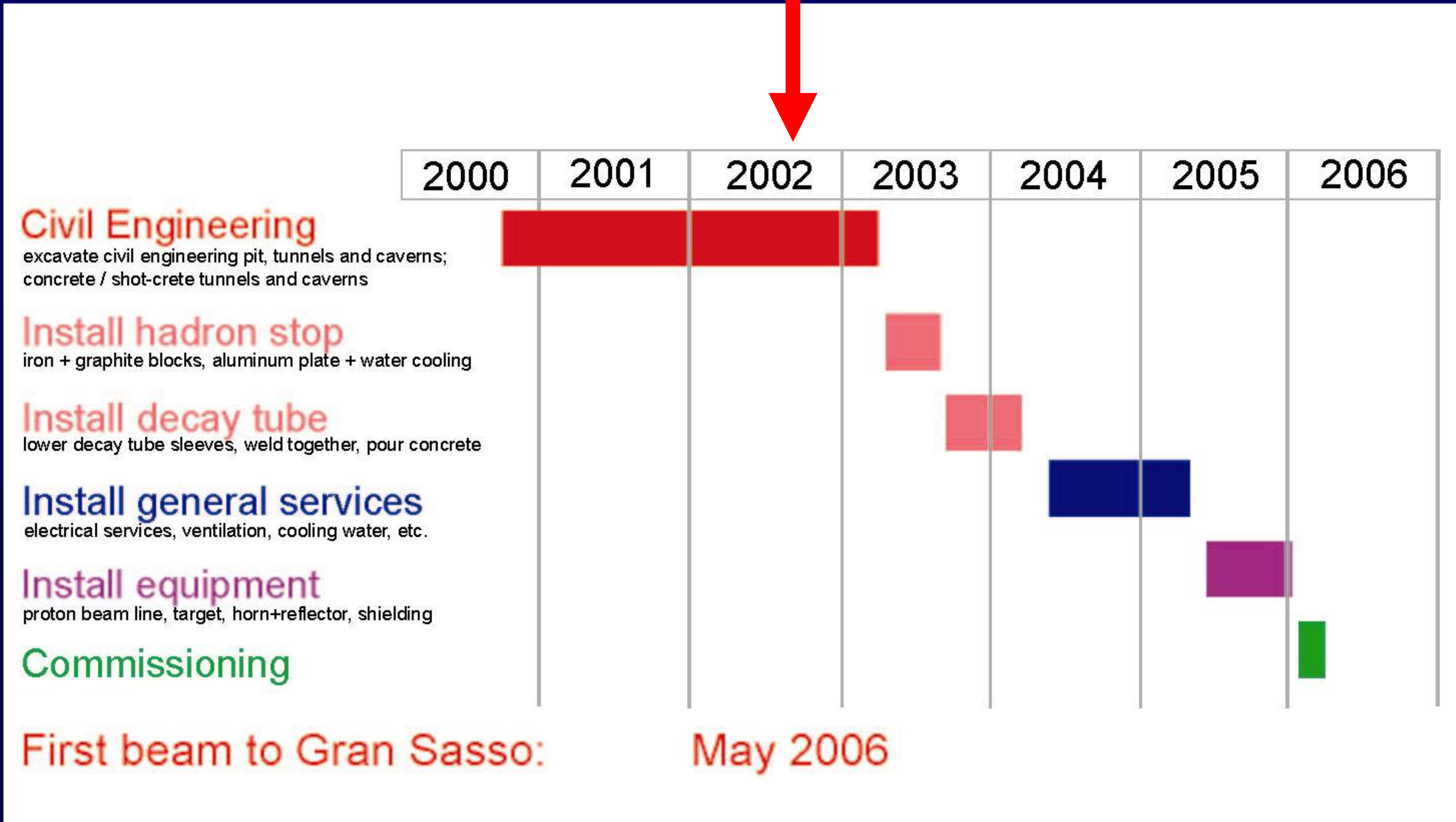
(for 100% detector efficiency)

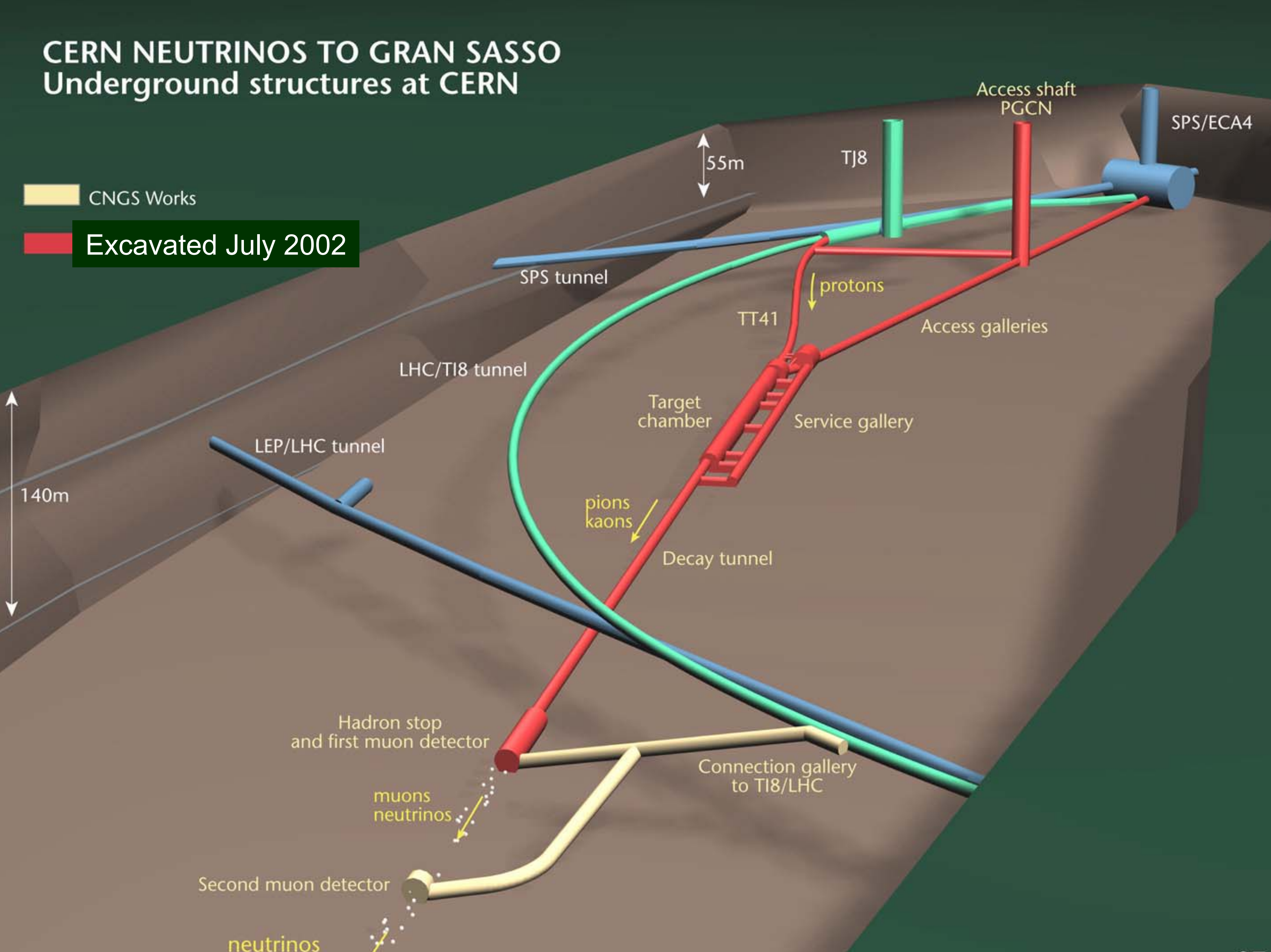

CERN
Prévessin Site
Prévessin-Moëns
SPS
LEP/LHC
protons
Pions/Kaons
TI 8
ν_μ neutrinos
Towards Gran Sasso
Meyrin
CERN
Meyrin Site


CERN NEUTRINOS TO GRAN SASSO
Underground structures at CERN
CNGS Works
55m
140m
SPS tunnel
TJ8
Access shaft PGCN
SPS/ECA4
protons
TT41
Access galleries
LHC/TI8 tunnel
Target chamber
Service gallery
LEP/LHC tunnel
Decay tunnel
pions kaons
Hadron stop and first muon detector
Connection gallery to TI8/LHC
muons neutrinos
Second muon detector
neutrinos to Gran Sasso

CNGS schedule

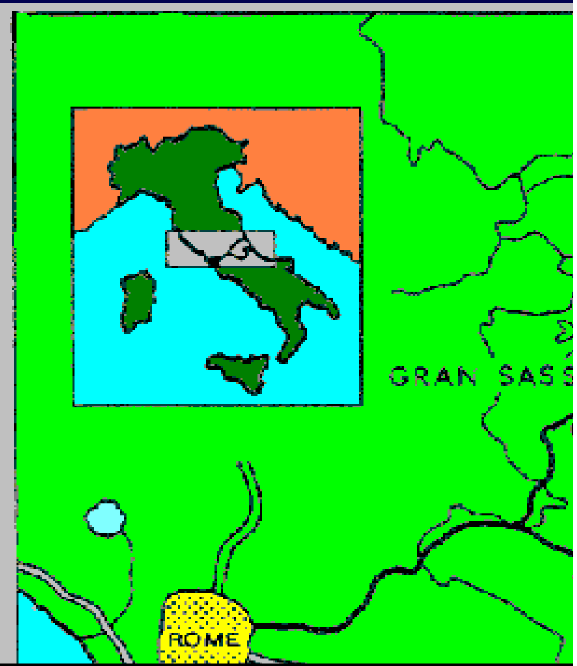
“today”

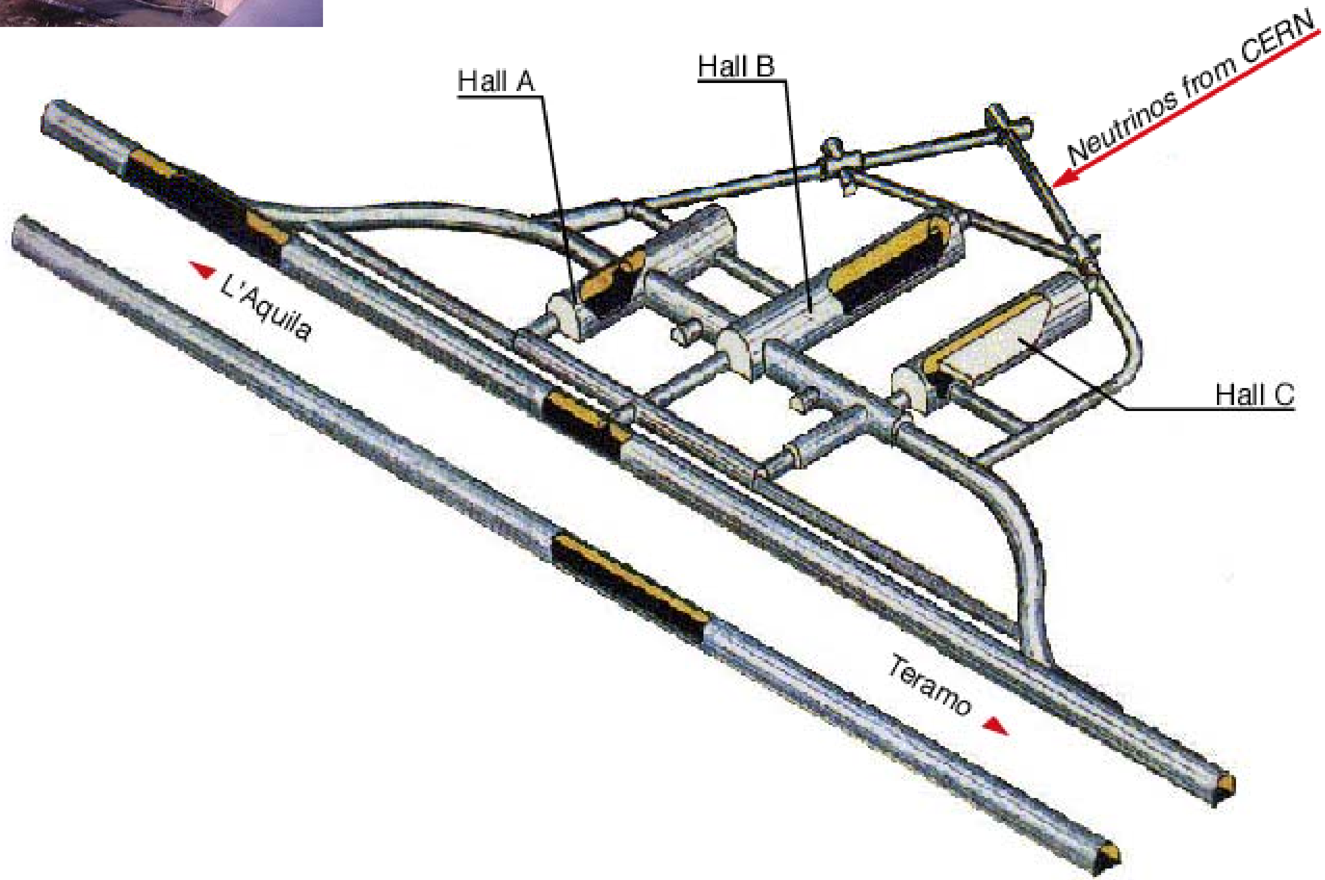




CERN NEUTRINOS TO GRAN SASSO
Underground structures at CERN
CNGS Works
Excavated July 2002
55m
TJ8
Access shaft
PGCN
SPS/ECA4
SPS tunnel
protons
TT41
Access galleries
LHC/TI8 tunnel
Target
chamber
Service gallery
LEP/LHC tunnel
140m
pions
kaons
Decay tunnel
Hadron stop
and first muon detector
Connection gallery
to TI8/LHC
muons
neutrinos
Second muon detector
neutrinos

The Gran Sasso Laboratory
(LNGS)

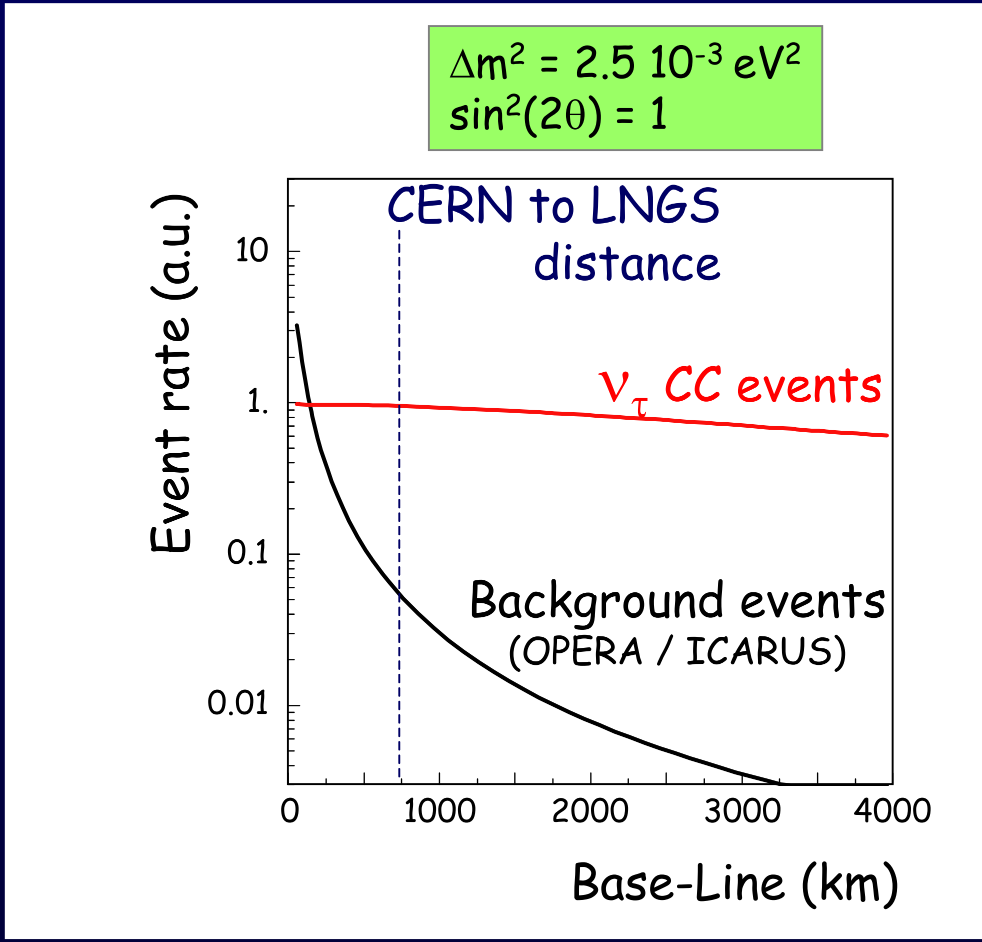




730 km might seem too short –
mean energy of neutrinos 17 GeV…
but look at the details :
Background low enough,
event rate still acceptable

AND, VERY IMPORTANT:

- existing laboratory with its infrastructure
- large halls directed to CERN
- caverns in the GS mountains: 1500 m of rock shielding

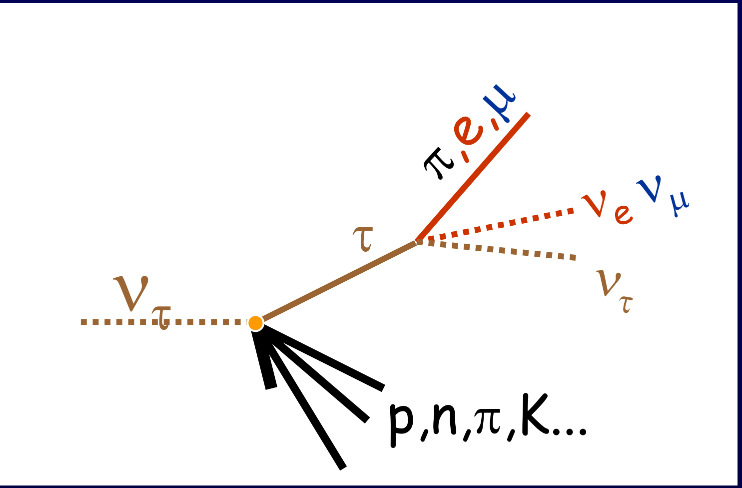


Detecting ν_τ at Gran Sasso

-> look for the τ lepton : *)

extremely difficult -

τ travels only less than 1 mm before decaying



-> two approaches:

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

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

*) Sensitivity in both ICARUS and OPERA also for ν_e appearance

OPERA:

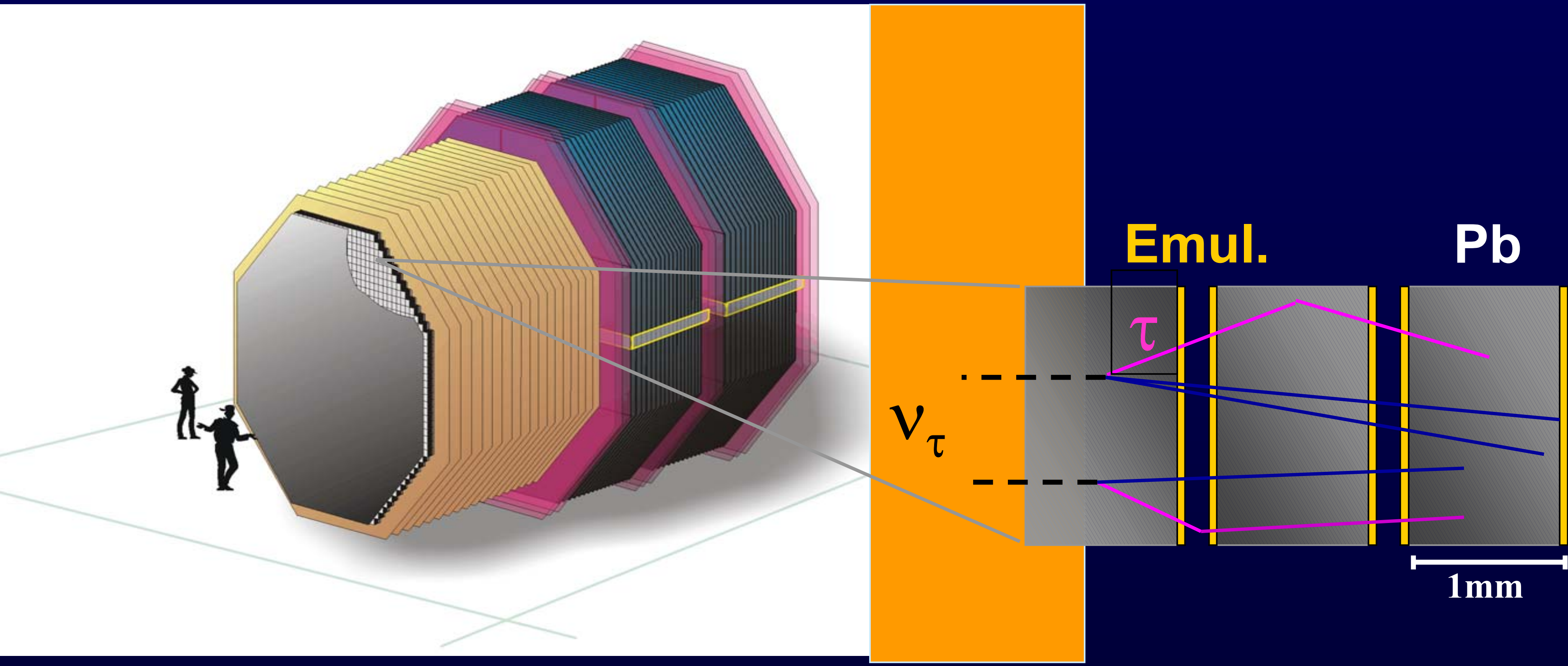
<u>1800 tons of "target mass"</u>

walls made of bricks

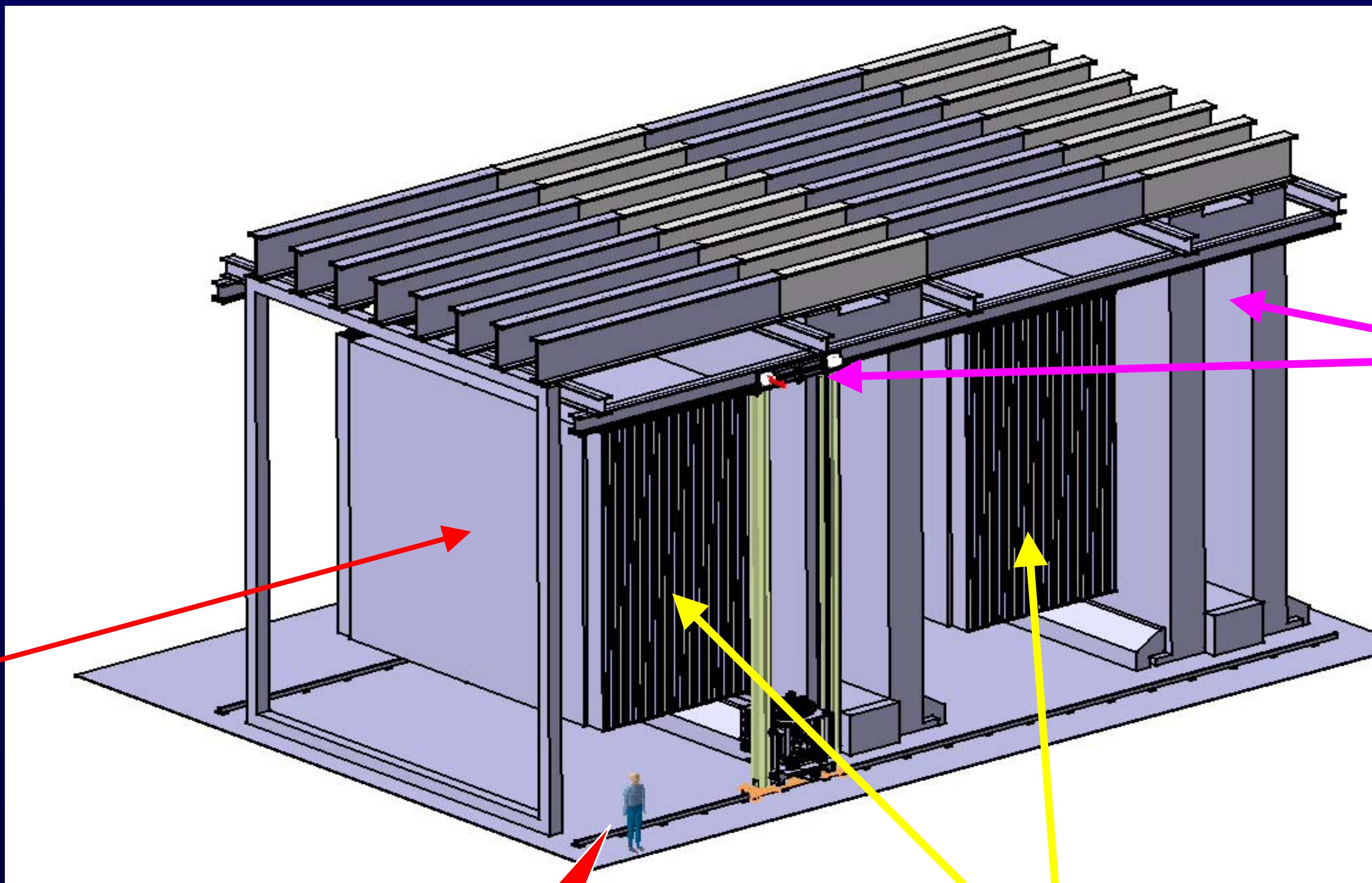
-> bricks made of "sandwiches"

-> sandwiches made of lead and nuclear emulsion

(type of "photographic" film)



more recent OPERA layout (artist's view)

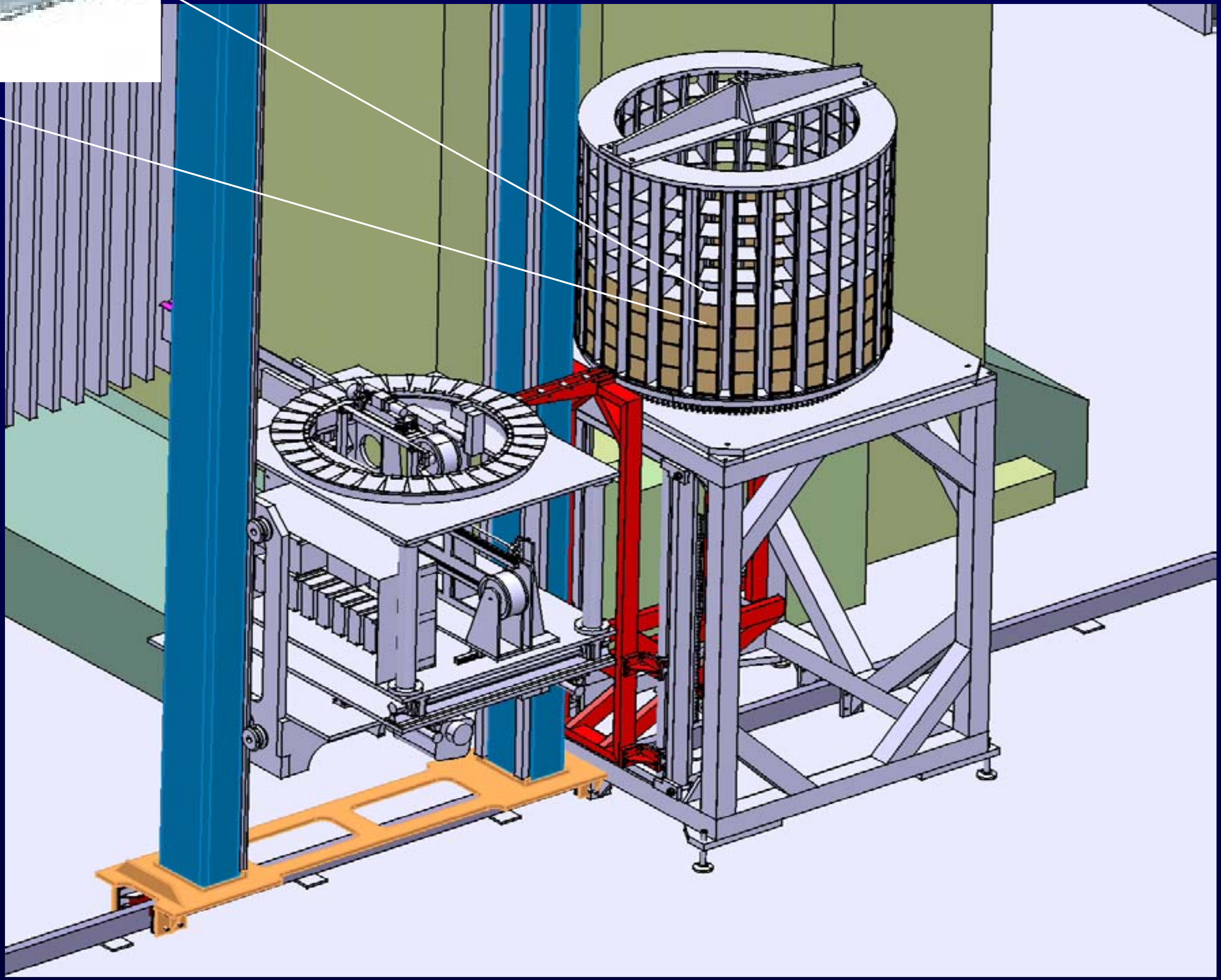


spectrometers
(magnets +
drift tubes)

"targets" – Pb + emulsion + tracker

“a brick”
≈ 8 kg
≈ 10x10x13 cm

Total > 200’000 bricks



OPERA brick-loading machine

ICARUS: multi-purpose detector !

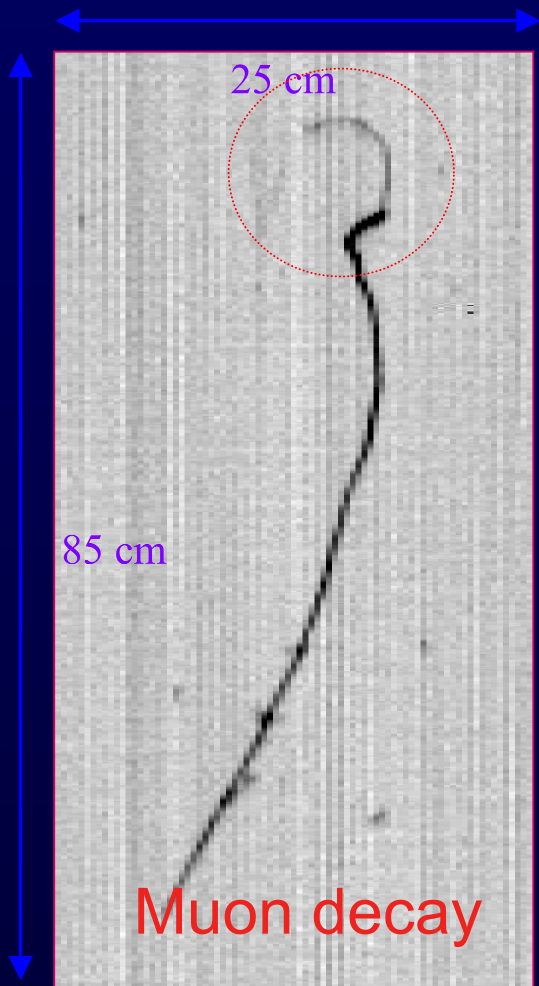
- 3000 tons ultra-pure liquid argon
- provides "electronic" picture of interactions:

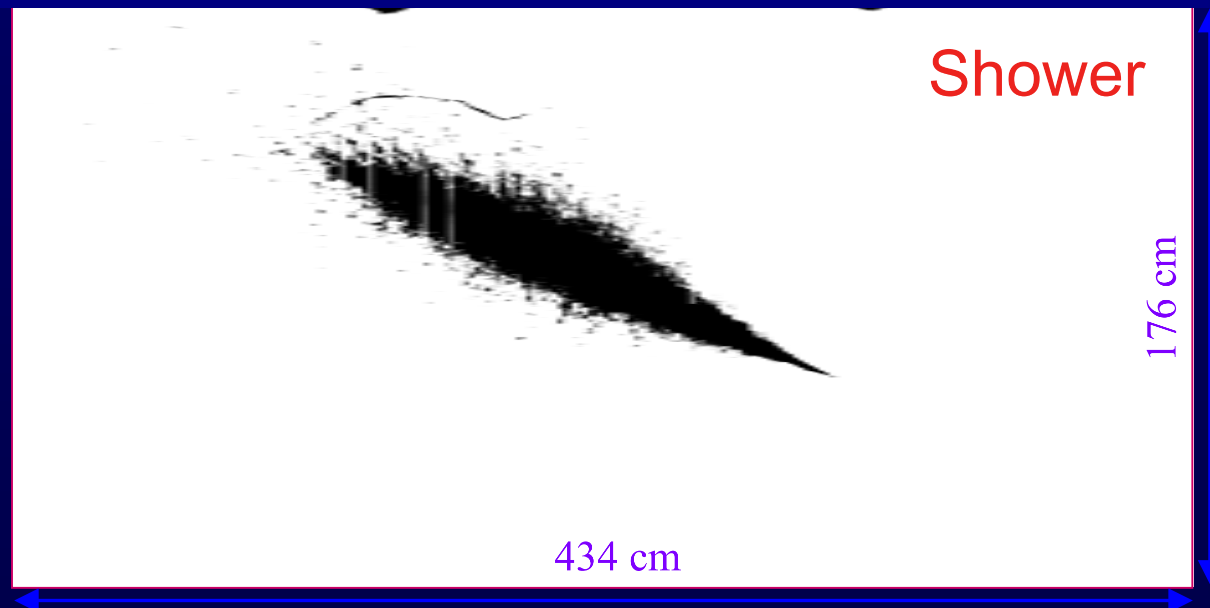
  a) particles ionize the argon
  b) charges DRIFT to sense wires (field applied)
  c) drift time gives information on co-ordinates
  -> quasi 3-D image of event (computers !!)

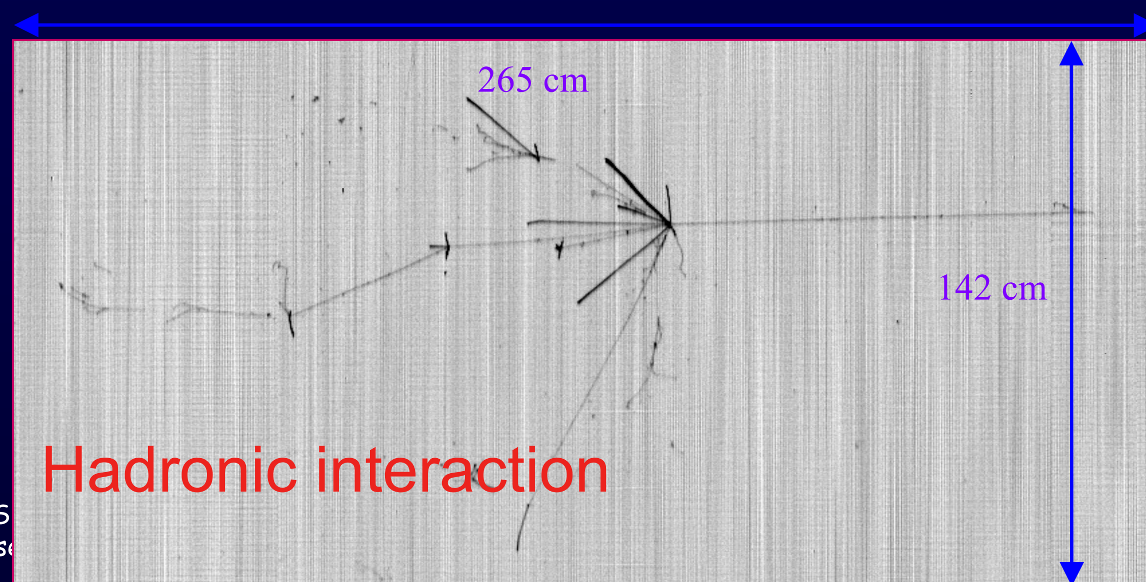
-> examples from 600 t module built in collaboration with industry
(2001 – 100 days of cosmic ray data, selective trigger)

-> to be installed at Gran Sasso: towards end of 2003

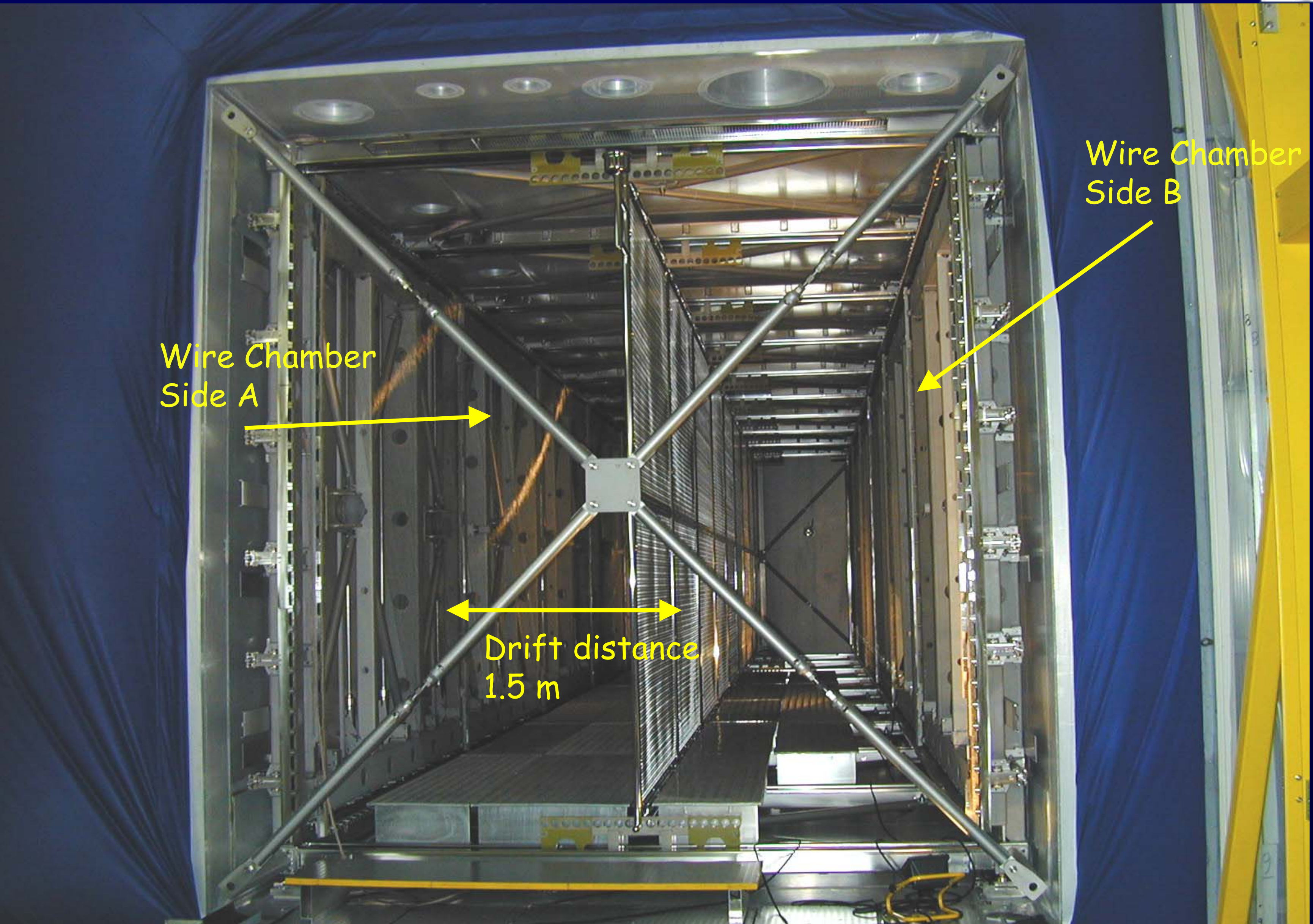
"Electronic bubble chamber"





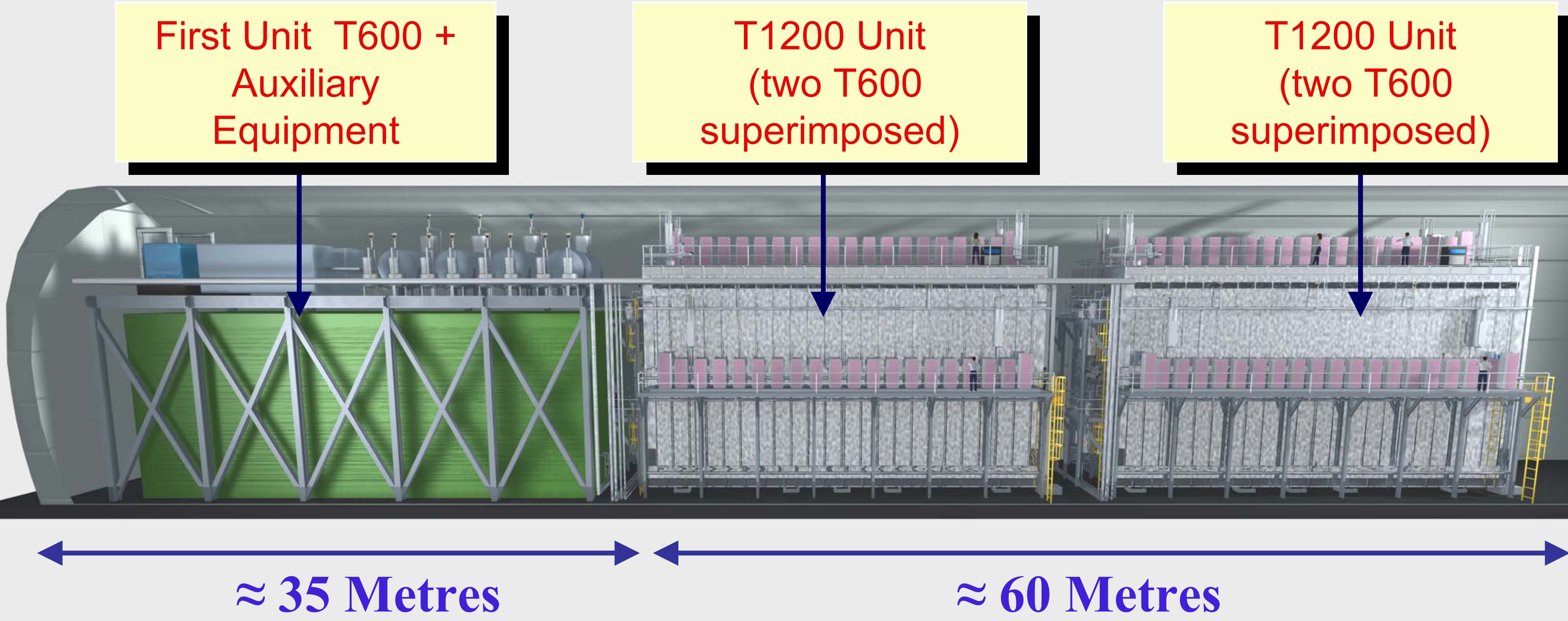


Internal Detector view (300 t)



First half-module delivery in Pavia (Feb 29, 2000)

for CNGS: *ICARUS detector in LNGS Hall B (T3000)*



Reminder:

ν_τ events (from oscillation) ≈ 20

per 1000 t detector mass per year

BUT, for a "real" detector:

ICARUS T3000 LAr detector (2350 t active, 1500 t fiducial),
5 years of running (150 detectable events!):

signal 11.9 events, background 0.7 events

OPERA emulsion detector
5 years of running:

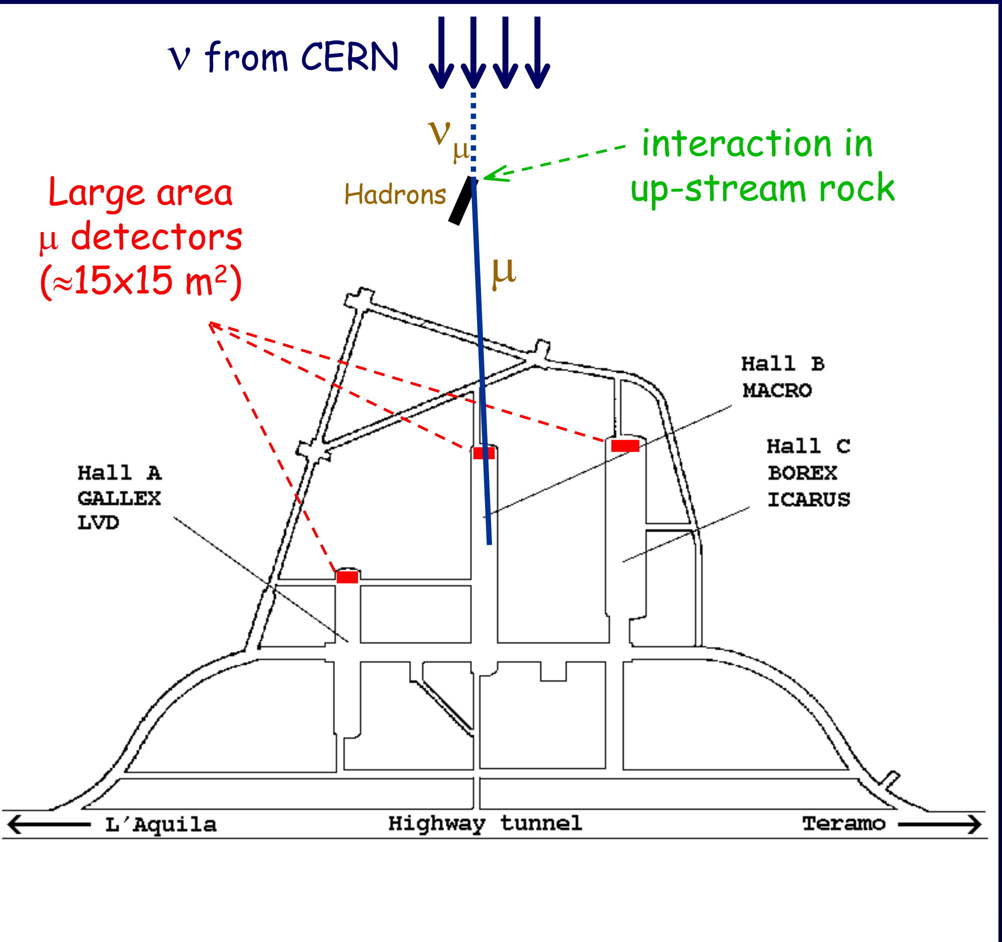
signal 10.3 events, background 0.7 events

These are extremely difficult, huge experiments !

"to get some feed-back":

Neutrino flux monitors at Gran Sasso

monitor intensity and time-stability of beam



Up-stream rock --> large target mass (equivalent to tens of kt)

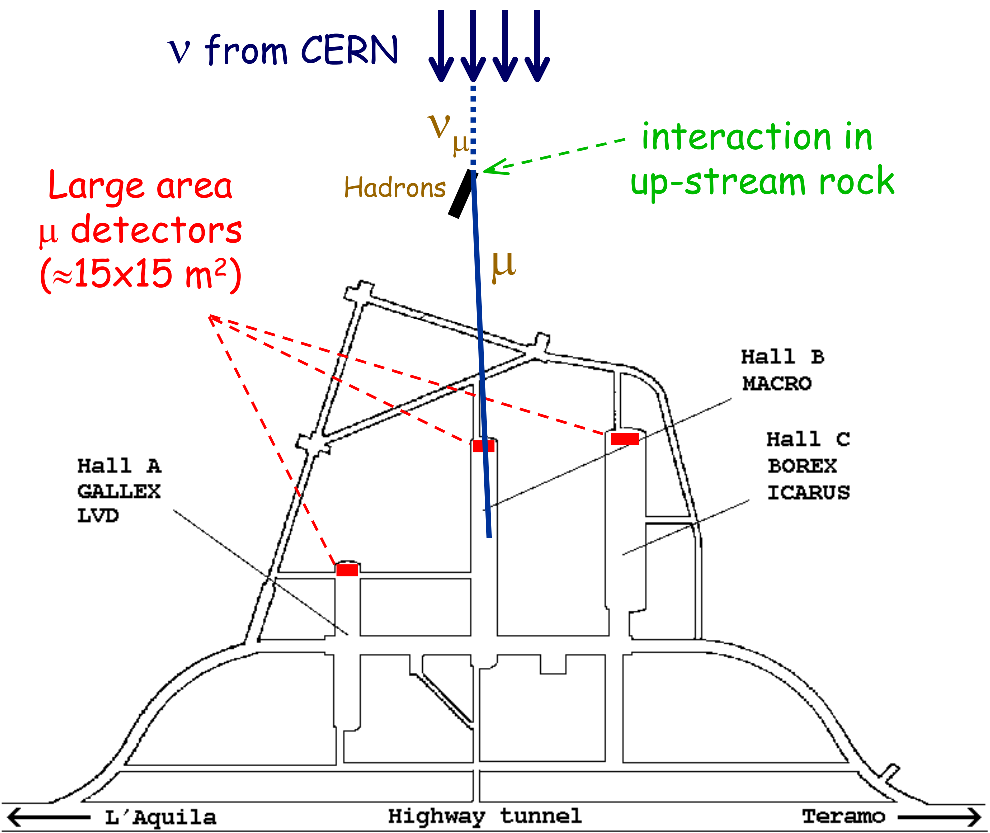
Muons emerging in the GS halls --> proportional to neutrino flux

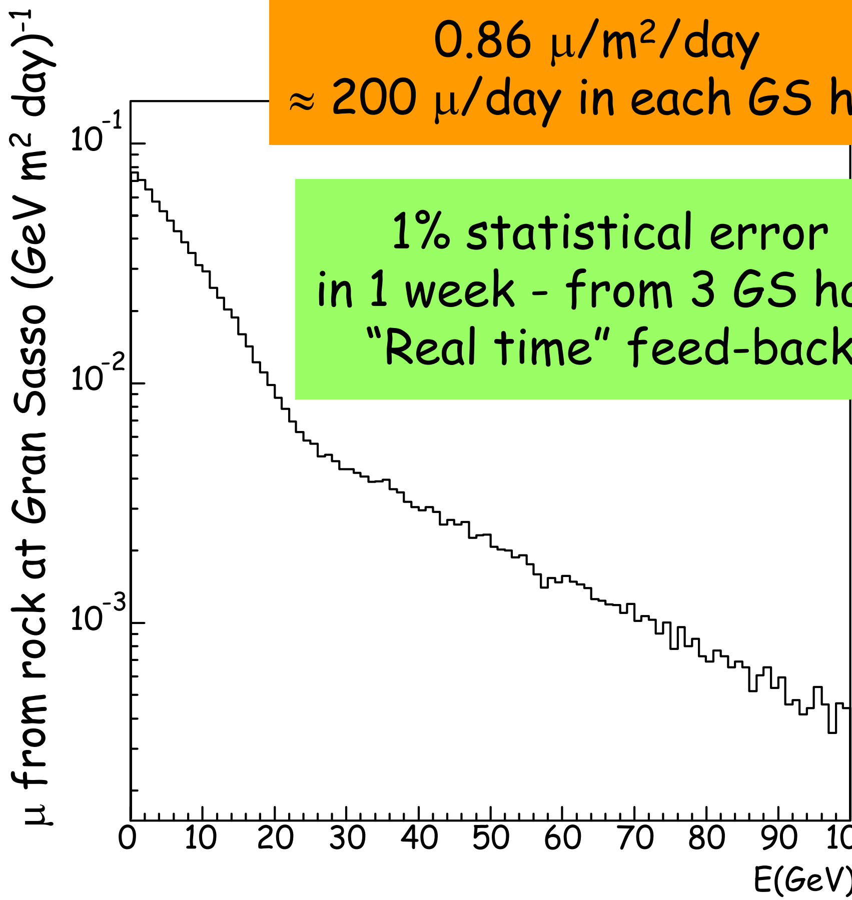
"Simple" large area muon detectors: (vertical planes of streamer tubes / RPC's)

In coincidence with beam spill ($10.5\ \mu s$ --> no background) "to get some feed-back":

Neutrino flux monitors at Gran Sasso

monitor intensity and time-stability of beam





$0.86\ \mu/m^2/day$
$\approx 200\ \mu/day$ in each GS hall

1% statistical error
in 1 week - from 3 GS hall
"Real time" feed-back

SUMMARY

- "A lot of action" in neutrino physics
  (solar, atmospheric, accelerator and reactor neutrinos)

- Two disappearance long-baseline experiments, in Japan and USA

- CNGS: ν_τ appearance experiment in Europe
  -> approved in December 1999
  First beam from CERN to Gran Sasso expected in May 2006

many thanks:

…to Aarhus University, for the invitation !

… for contributions from …

Jean-Luc Caron (graphics + web-site)

Francesco Pietropaolo (physics,beam simulations)

OPERA (Y. Declais) and ICARUS (A. Rubbia)

+ their collaborators

+ …