The OPERA experiment

Oscillation **P**roject with **E**mulsion t**R**acking **A**pparatus

Direct search for the $\nu_\mu \rightarrow \nu_\tau$ oscillation by looking at the appearance of ν_τ in a pure ν_μ beam

- CNGS program
- OPERA detector and experimental strategy
- Physics potential
- First operations of CNGS and OPERA

Collaboration:

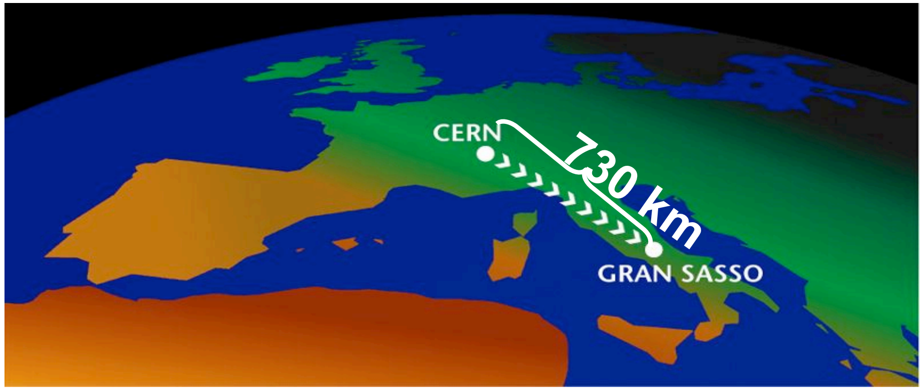
Belgium (IIHE(ULB-VUB) Brussels), **Bulgaria** (Sofia University), **China** (IHEP Beijing Shandong University), **Croatia** (Zagreb University), **France** (LAPP Annecy, IPNL Lyon, LAL Orsay, IPHC Strasbourg), **Germany** (Berlin Humboldt University, Hagen, Hamburg University, Münster University, Rostock University), **Israel** (Technion Haifa), **Italy** (Bari, Bologna, LNF Frascati, L'Aquila, LNGS, Naples, Padova, Rome, Salerno), **Japan** (Aichi, Toho, Kobe, Nagoya, Utsunomiya), **Russia** (INR Moscow, ITEP Moscow, JINR Dubna, Obninsk), **Switzerland** (Bern, Neuchâtel, Zürich), **Tunisia** (Tunis University), **Turkey** (METU Ankara)

Cécile Jollet, IN2P3-ULP Strasbourg on behalf of the OPERA collaboration

TAUP07 Conference - Sendai - September 11-15, 2007

The Cern Neutrino to Gran Sasso (CNGS) program

Motivated by the atmospheric neutrino disappearance



CERN ν_μ beam optimized to study the ν_τ appearance by τ detection in the parameters region:

$\Delta m^2 \approx 2.4\times10^{-3}$ eV^2 and $\sin^2 2\theta \approx 1.0$

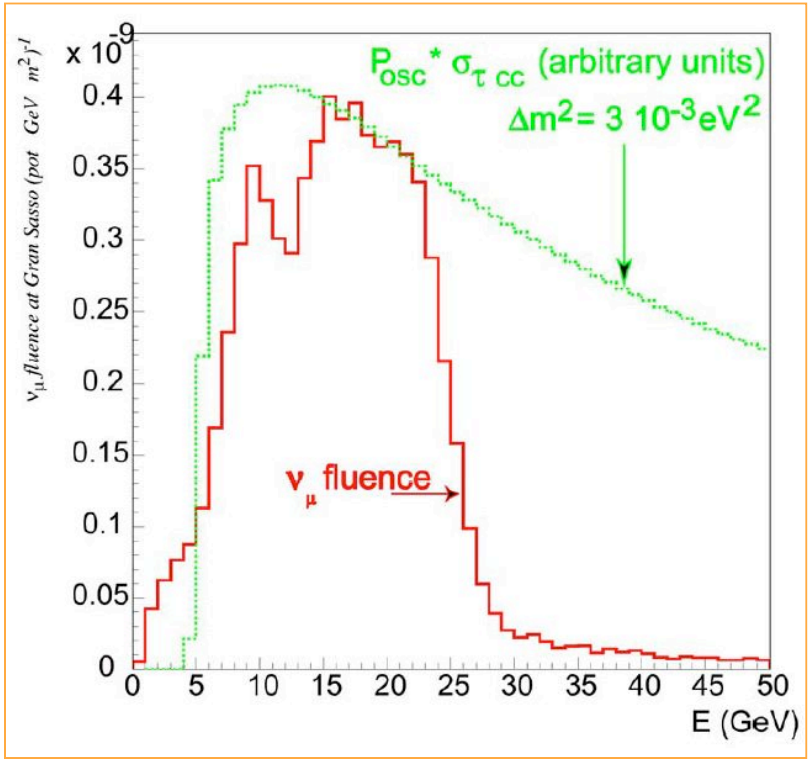
τ production threshold=3.5 GeV

$$N_\tau = N_A M_D \int \phi_{\nu_\mu}(E) P_{\nu_\mu \to \nu_\tau}(E) \sigma^{CC}_{\nu_\tau}(E) \varepsilon(E) dE$$

Beam mean features:

L=730 km ; $\langle E_{\nu\mu} \rangle$=17 GeV

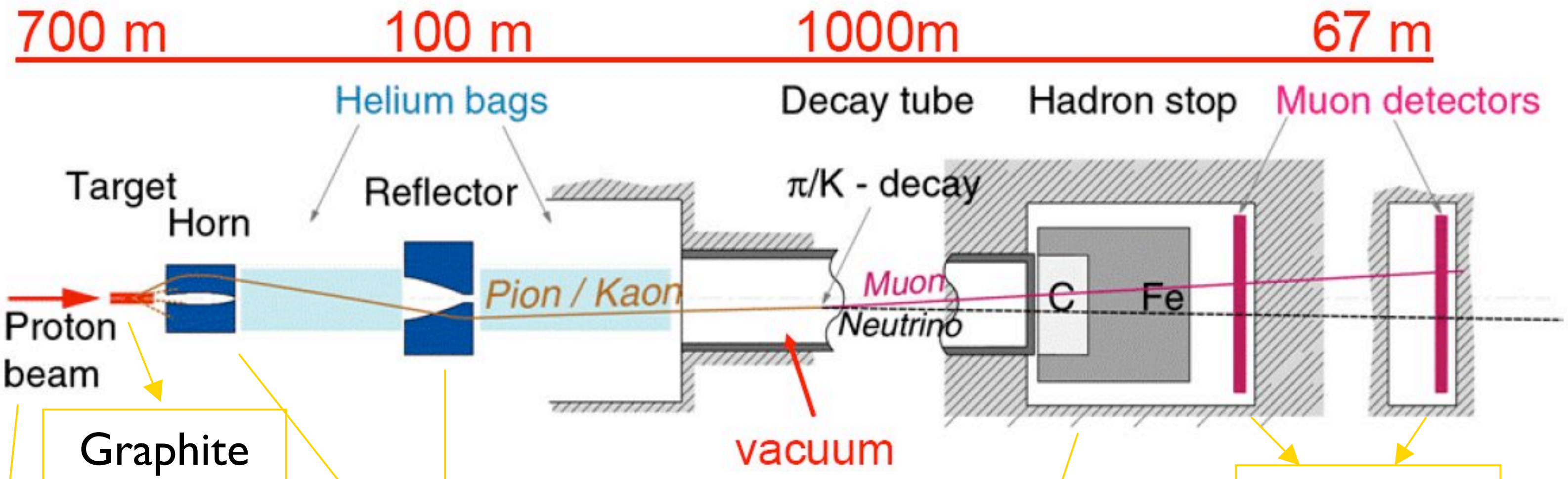
$(\nu_e+\bar{\nu}_e)/\nu_\mu$=0.87% ; ν_τ prompt negligible



In shared mode → $4.5\text{x}10^{19}$ pot/year

$\Rightarrow$ 2900 ν_μ CC/kton/year
$\Rightarrow$ 13 ν_τ CC/kton/year
} expected at Gran Sasso

The CNGS beam



Graphite
2 m length

SPS
400 GeV

Diameters: 80 cm & 115 cm
Current: 150 kA & 180 kA
Aluminum 6082

19 silicium
diodes

CNGS beam fully completed and operational since August 2006

The OPERA experimental design

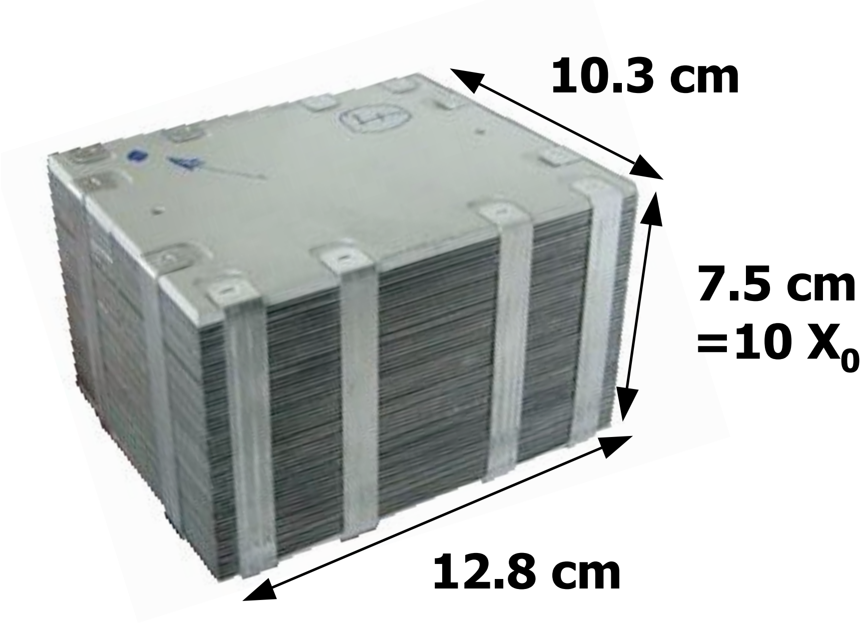
Detection of τ decay (~10^{-13} s ; cτ~87 μm) topologies created by ν_τ CC interactions

μm resolution
⇒ Photographic emulsions (DONUT)

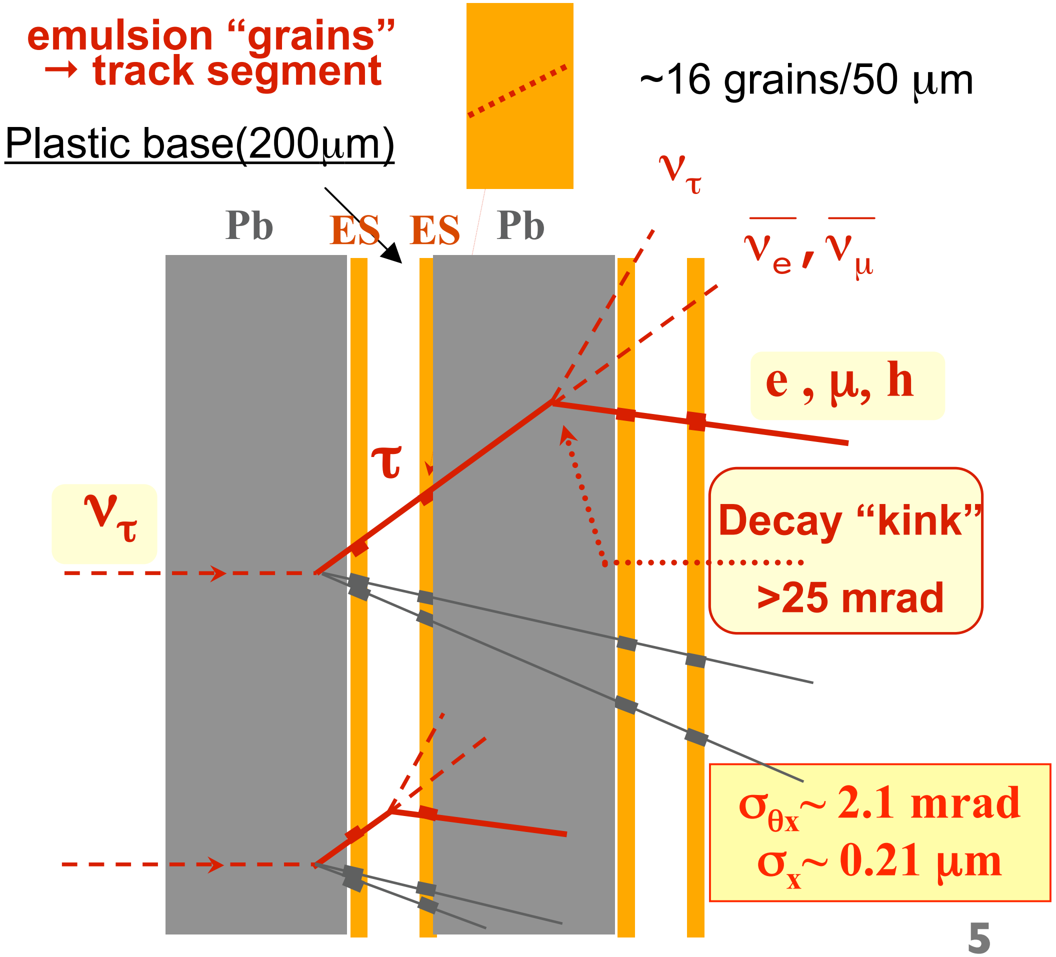
Large target mass
⇒ Lead materials

⇒Detector based on bricks:

Sandwich of 56 (1mm) Pb sheets
+ 57 FUJI emulsion layers
+ 1 changeable sheet

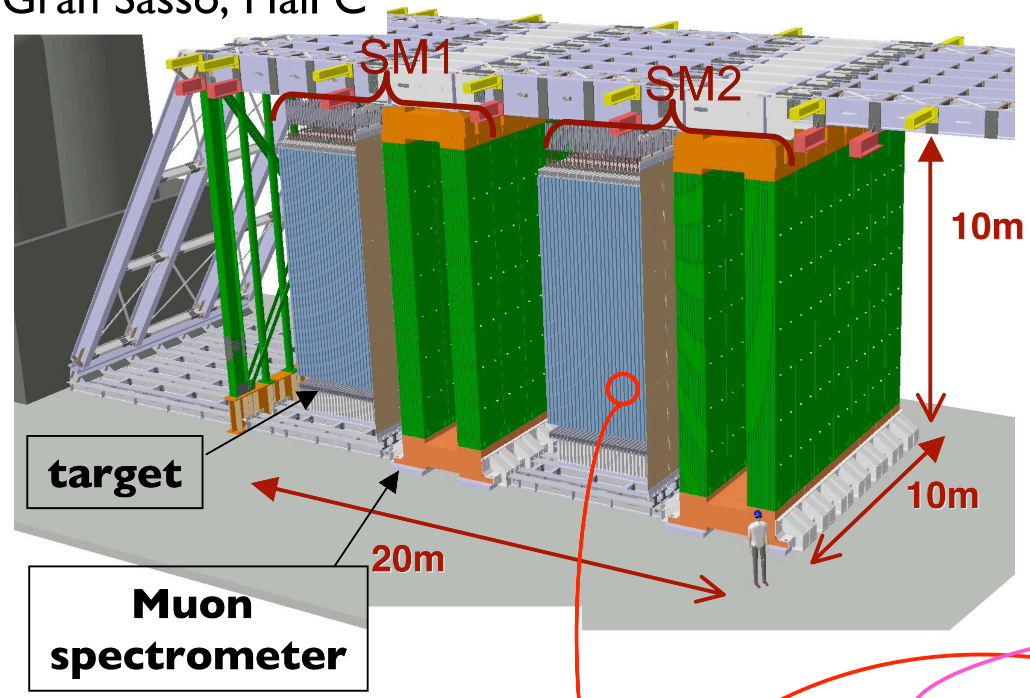


Brick weight: 8.3 kg



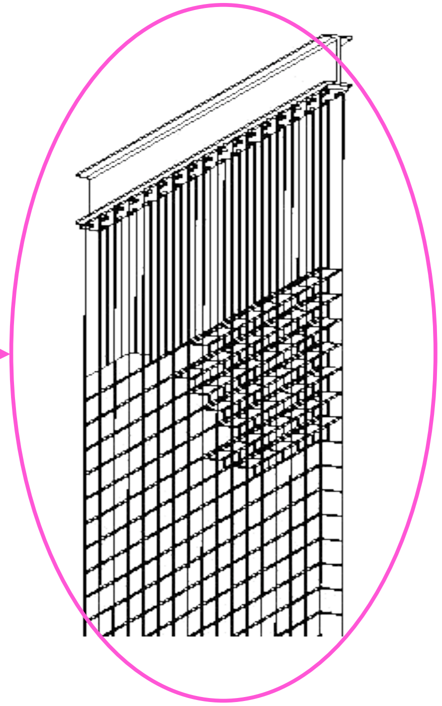
The OPERA detector

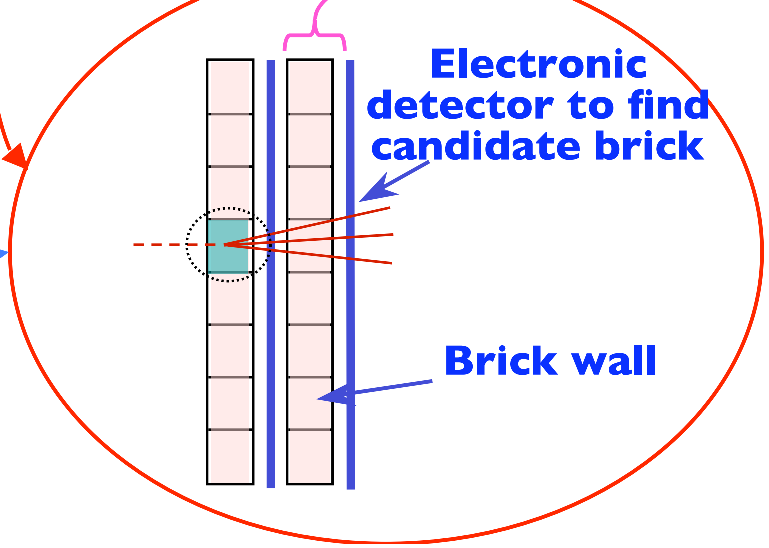
Gran Sasso, Hall C



2 supermodules.
Target: 31 walls/supermodule
with ~2500 bricks each

Target mass: 1.35 ktons



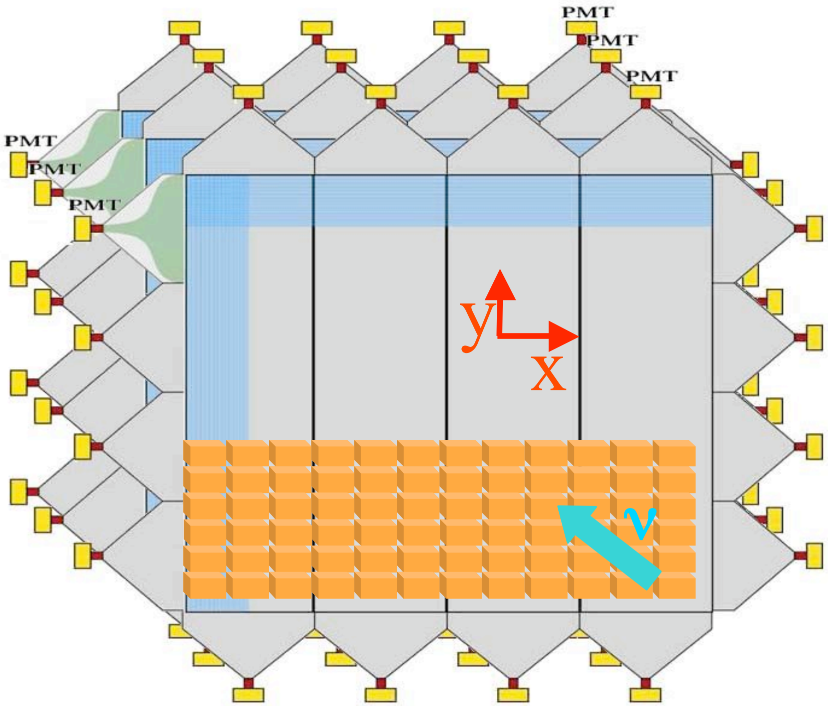


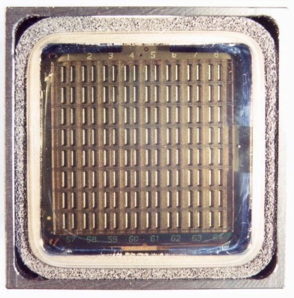
- **Robot to remove the candidate brick**
- **Scan by automatic microscope**

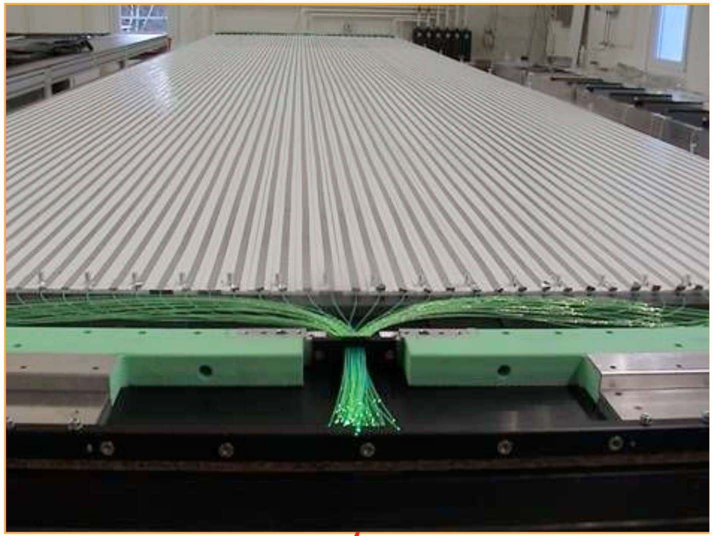
The OPERA Target Tracker

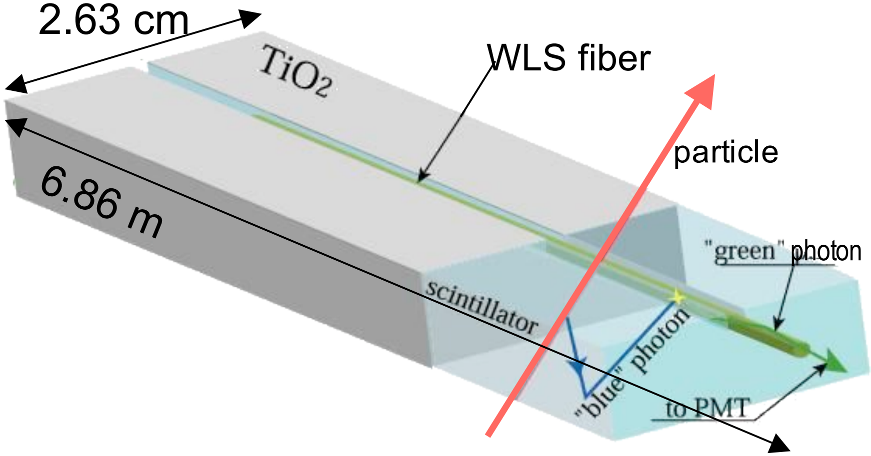
⇒ **Find the right brick to extract**

Plastic scintillator + wave length shifting fiber
+ 64 channel multi-anode Hamamatsu PM





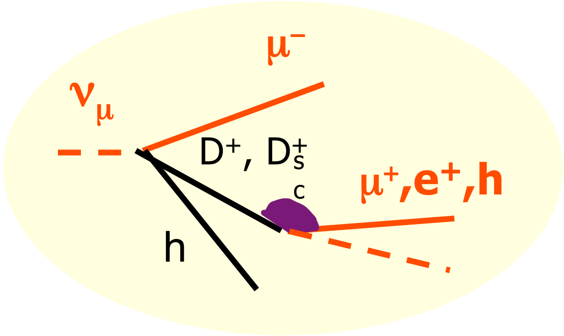




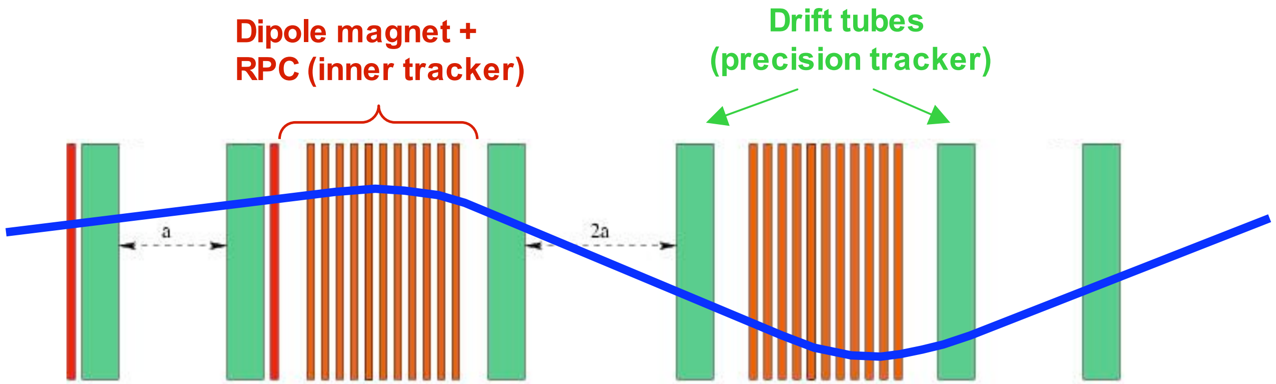
- N_{pe}>5 p.e. for a mip (2.15 MeV)
~ 99% detection efficiency ⇒ trigger
- brick finding: ϵ_{brick} ~ 80%
- initiate muon tagging

The OPERA Muon Spectrometer

- Performant μ tagging (improvement of $\tau \rightarrow \mu$ efficiency and tag of ν_μCC events)
- μ charge measurement to reduce background induced by charm decay:

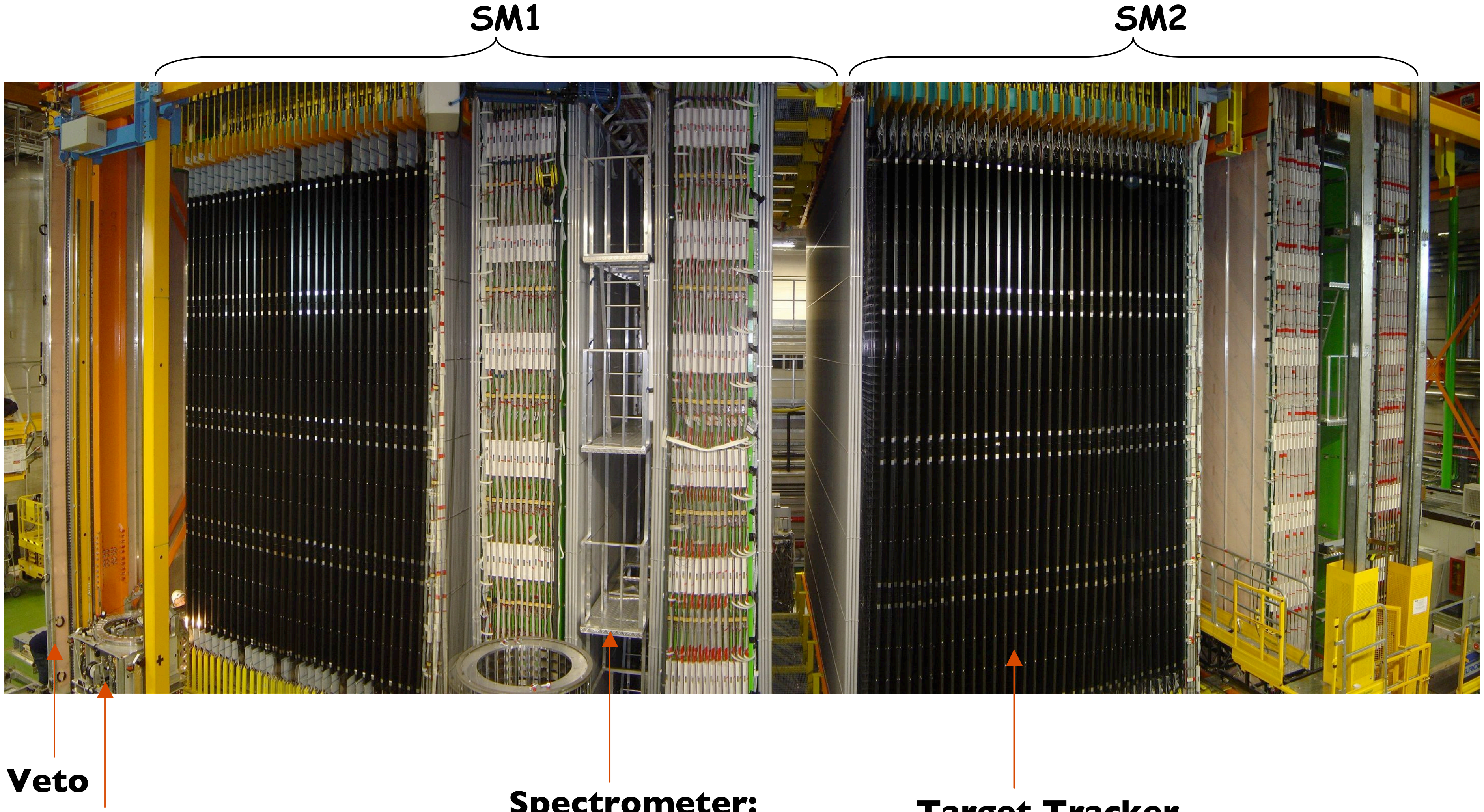


$\Rightarrow$ Inner tracker (RPC in magnet) and precision tracker (drift tube, 8 m length)

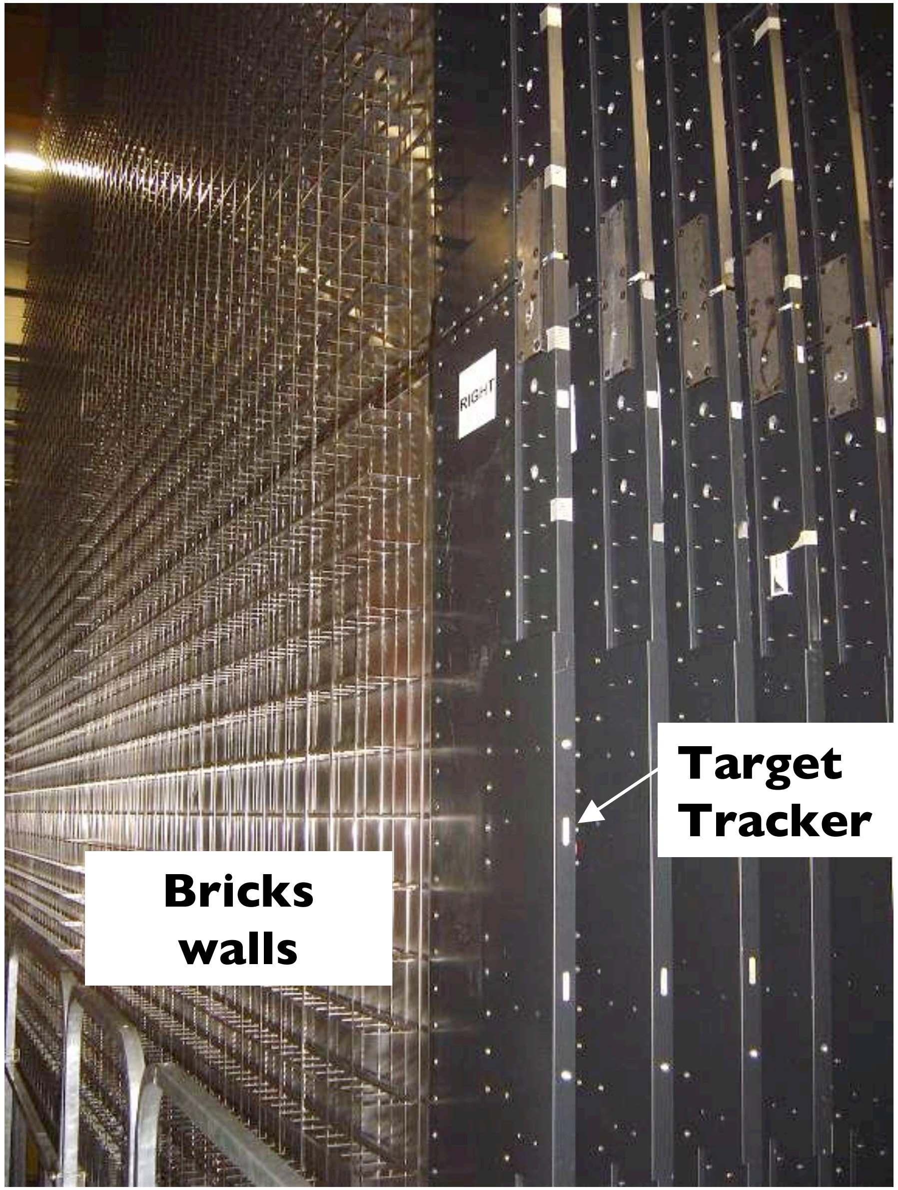


- $\epsilon_{\text{miss charge}} \sim (0.1 - 0.3)\%$
- $\Delta p/p < 20\%$ for $p < 50$ GeV
- μid > 95% (with target tracker)

The OPERA detector

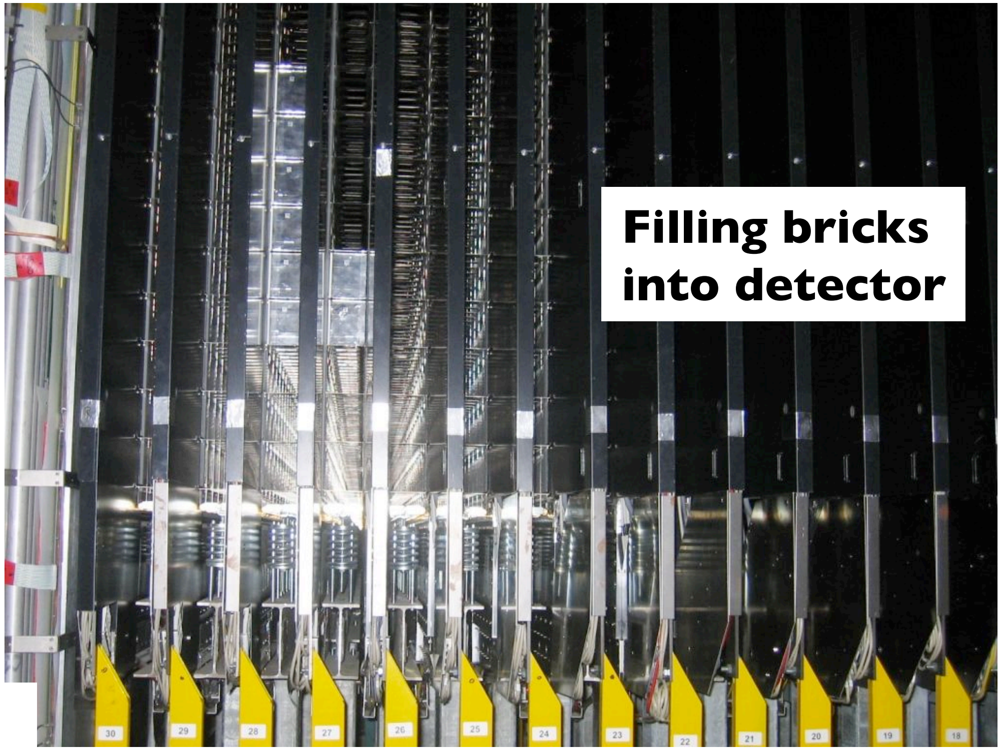


The OPERA detector



Target Tracker

Bricks walls



Filling bricks into detector

Bricks elements and production

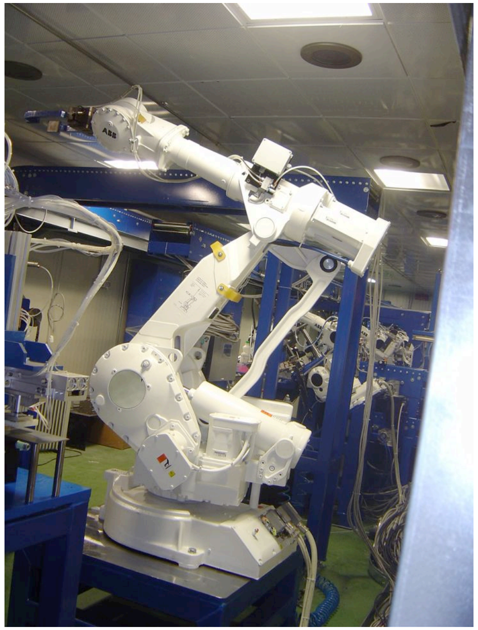
- Lead (PbCa colaminated) mass production in JL Goslar firm (Germany)
- Emulsion Refreshing Facility in Tono Mine (Japan)
- Brick mechanical packaging demanded for custom metal and plastic components

154 750 bricks to produce ⇒ automatically using a Brick Assembling Machine (BAM)

5 piling-up and compression stations

Hall B,
Gran Sasso

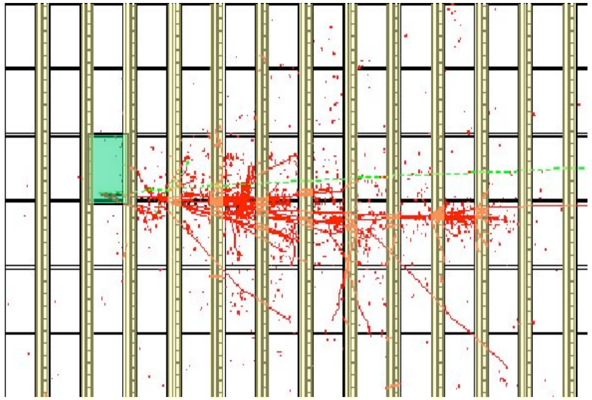
1 packaging station



Goal: construct 936 bricks/day
Detector fully filled by April 2008
At now: ~ 45000 bricks inside the detector

Events detection sequence

1- Brick tagging by Target Tracker:



2- Brick removed with the BMS (Brick Manipulating System)

3- Brick exposed to cosmic rays for sheets alignment

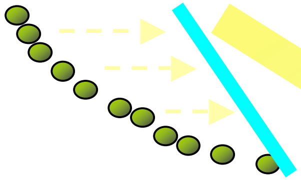
4- Brick disassembled and emulsions developed

Automatic emulsions scanning:

- ~30 bricks will be daily extracted from the target
- Distributed to several labs in Europe and Japan
- 2 high-speed automatic scanning systems:
  - The European Scanning System *(commercial products, software algorithms)*
  - The S-UTS (Japan) *(Dedicated hardware, hard coded algorithms)*
- Scanning speed: 20 cm^2/h

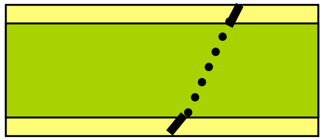
Off-line emulsions scanning

3D Microtracks
reconstruction

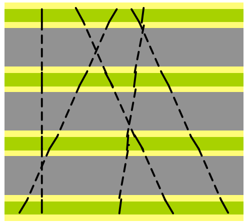


Microtracks alignment
via the plastic base

BASETRACK

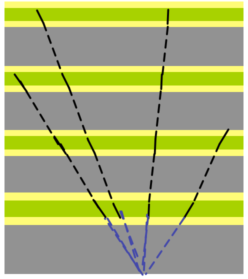


Basetracks alignment
of several emulsions

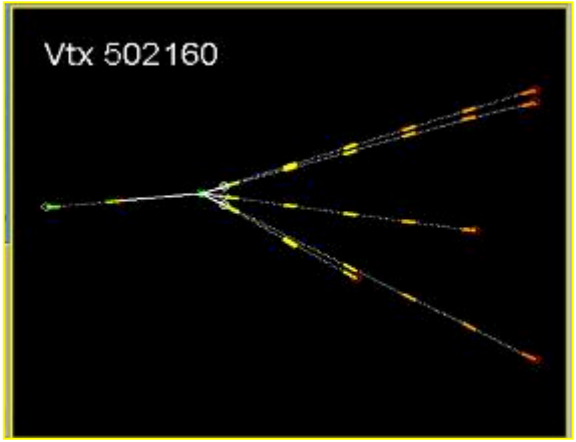


Reconstruction

Vertex/Decay



Vertex reconstruction



- Momentum measurement by Multiple Scattering
- Electron identification and energy measurement
- dE/dx for π/μ separation at low energy

$\nu_\mu \to \nu_\tau$ oscillation sensitivity

full mixing, 5 years run @ 4.5x10^{19} pot / year

Efficiency: $\varepsilon_{trigger} \times \varepsilon_{brick} \times \varepsilon_{geom} \times \varepsilon_{primary\_vertex}$

$99\% \times 80\% \times \underbrace{94\%}_{\text{fringe effect for scanning}} \times 90\%$

τ decay channels	ε(%)	BR(%)	Signal		Background
			$\Delta m^2 = 2.5 \times 10^{-3}$ eV^2	$\Delta m^2 = 3.0 \times 10^{-3}$ eV^2	
τ → μ	17.5	17.7	2.9	4.2	0.17
τ → e	20.8	17.8	3.5	5.0	0.17
τ → h	5.8	50	3.1	4.4	0.24
τ → 3h	6.3	15	0.9	1.3	0.17
ALL	ε×BR=10.6%		10.4	15.0	0.76

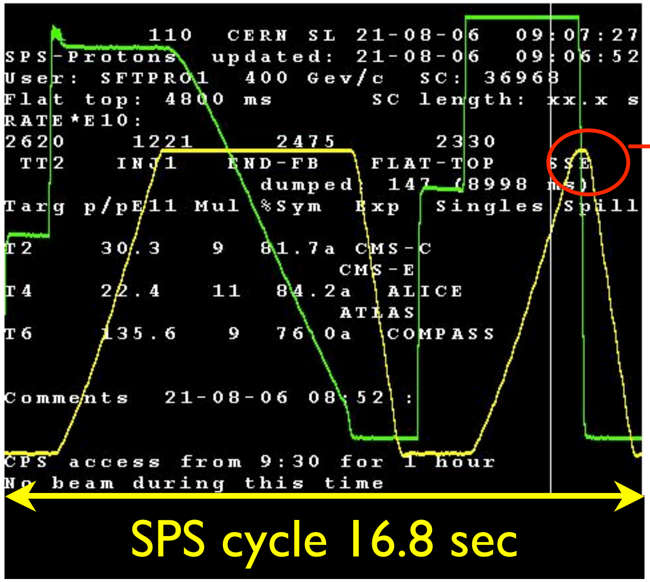
Main background sources:

- charm production and decays
- hadron re-interactions in lead
- large-angle muon scattering in lead

1st CNGS run: August 2006

- 121 hours of real beam operation
- Used for electronic detectors, DAQ, GPS commissioning and tests of CNGS-OPERA information exchange
- No bricks in the detector
- 70% of nominal intensity → 1.7×10^{13} pot/extraction

CNGS beam:



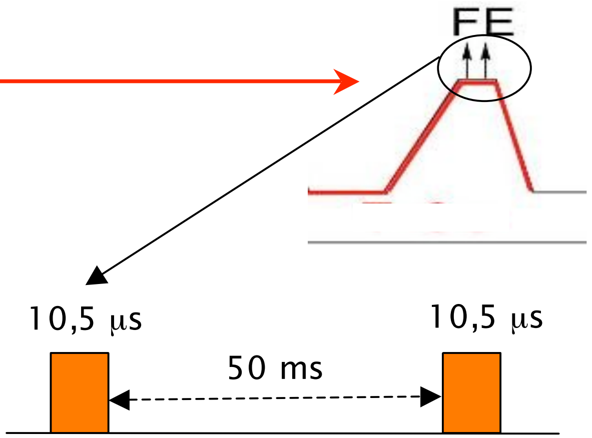
```
          110   CERN SL 21-08-06   09:07:27
SPS-Protons  updated: 21-08-06   09:06:52
User: SFTPRO1  400 Gev/c   SC: 36968
Flat top: 4800 ms        SC length: xx.x s
RATE*E10:
2620      1221      2475        2330
 TT2     INJ1    END-FB    FLAT-TOP    SSE
                dumped: 147 (8998 ms)
Targ p/pE11 Mul %Sym   Exp   Singles Spill

T2      30.3    9   81.7a CMS-C
                           CMS-E
T4      22.4   11   84.2a  ALICE
                           ATLAS
T6     135.6    9   76.0a  COMPASS

Comments  21-08-06 08:52 :

CPS access from 9:30 for 1 hour
No beam during this time
```

SPS cycle 16.8 sec

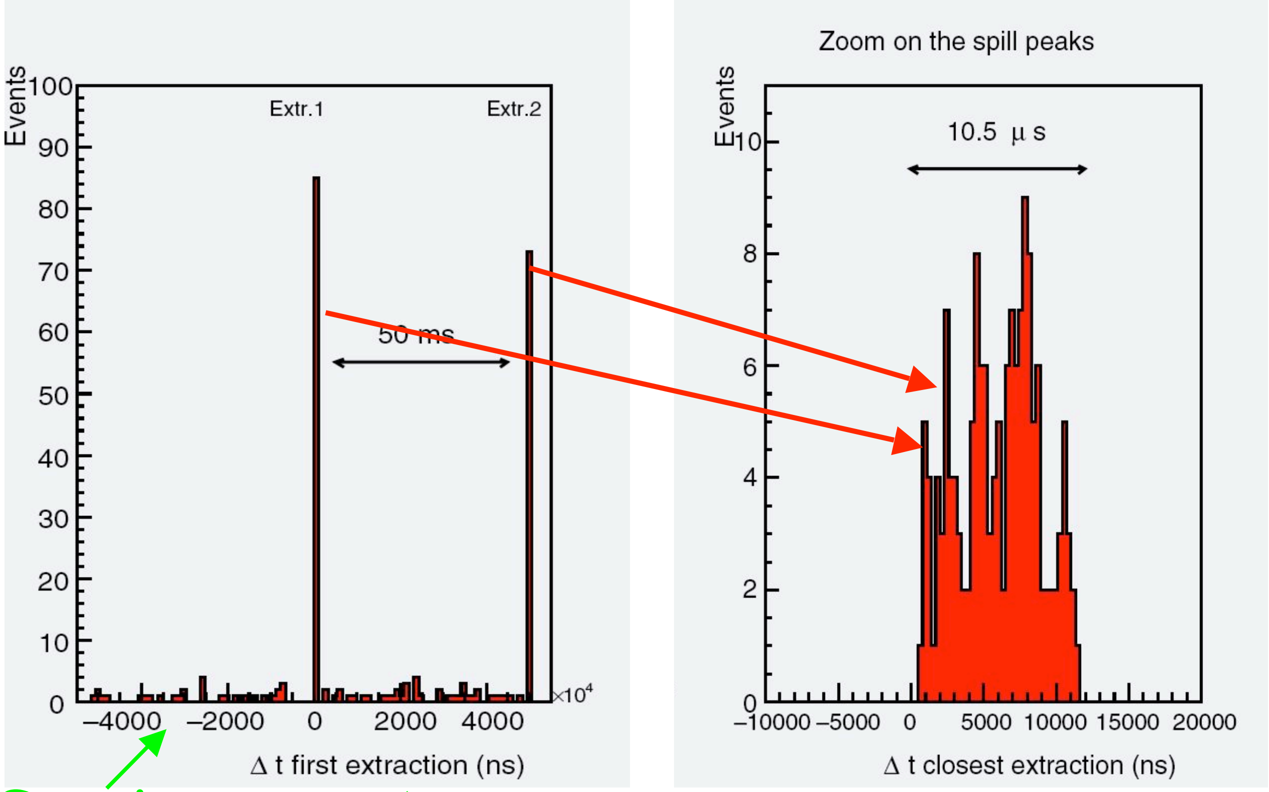


Events time structure

Time selection of beam events:

$T_{OPERA} - (T_{CERN} + T_{flight}) < \Delta T_{gate}$

$T_{flight} = 2.44$ ms
GPS Time Stamp resolution ~ 100 ns
$\Delta T_{gate} \sim 10.5\ \mu s$



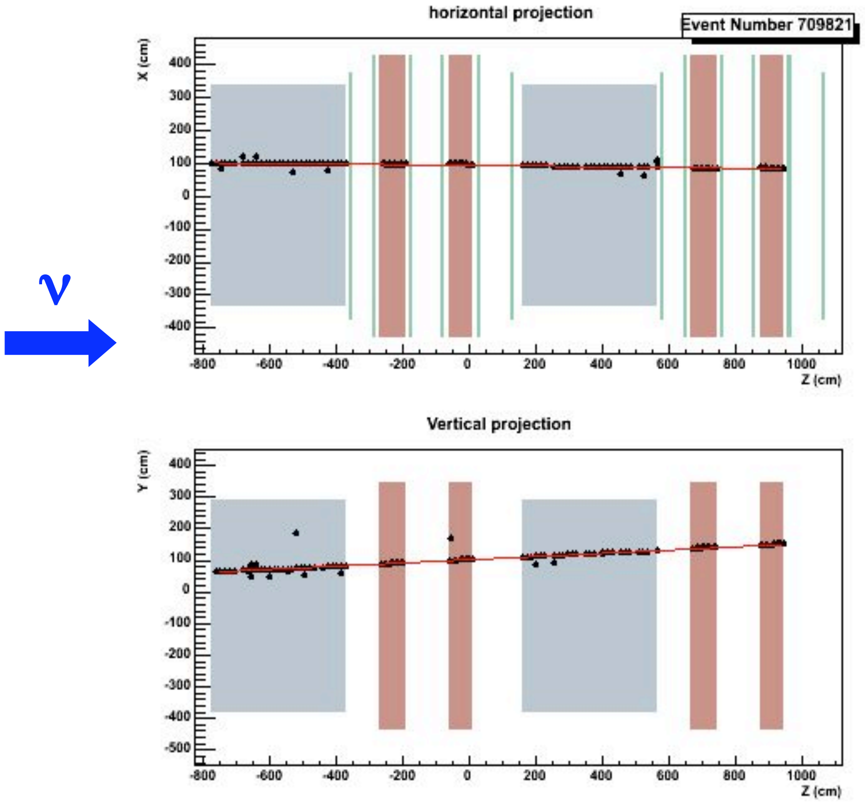
Cosmic ray events

⇒The events time distribution is peaked around the 2 extractions peak times within negligible cosmic-ray background

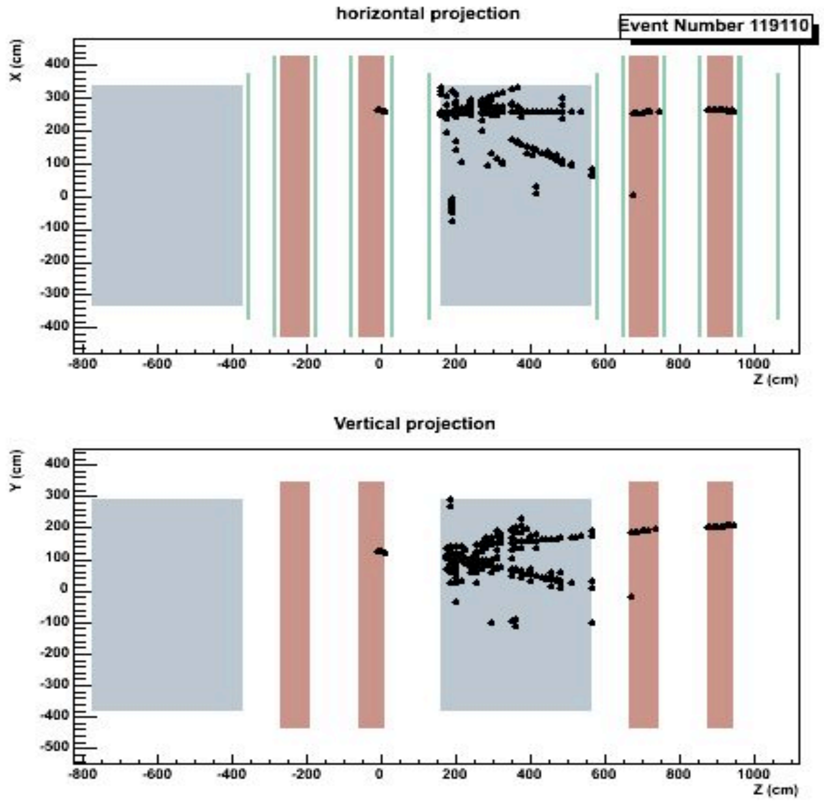
OPERA beam events

- 319 beam events collected:
  - 3/4 external events (interaction in the rock)
  - 1/4 internal events (interaction in the detector)

ν_μCC in rock (rock muons)

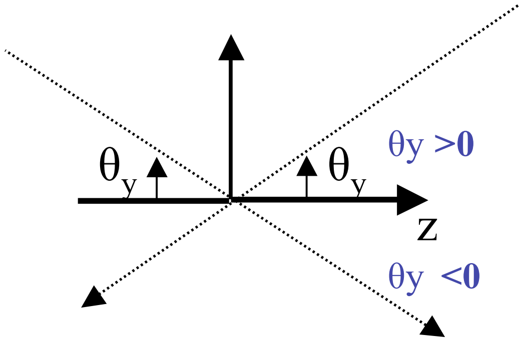


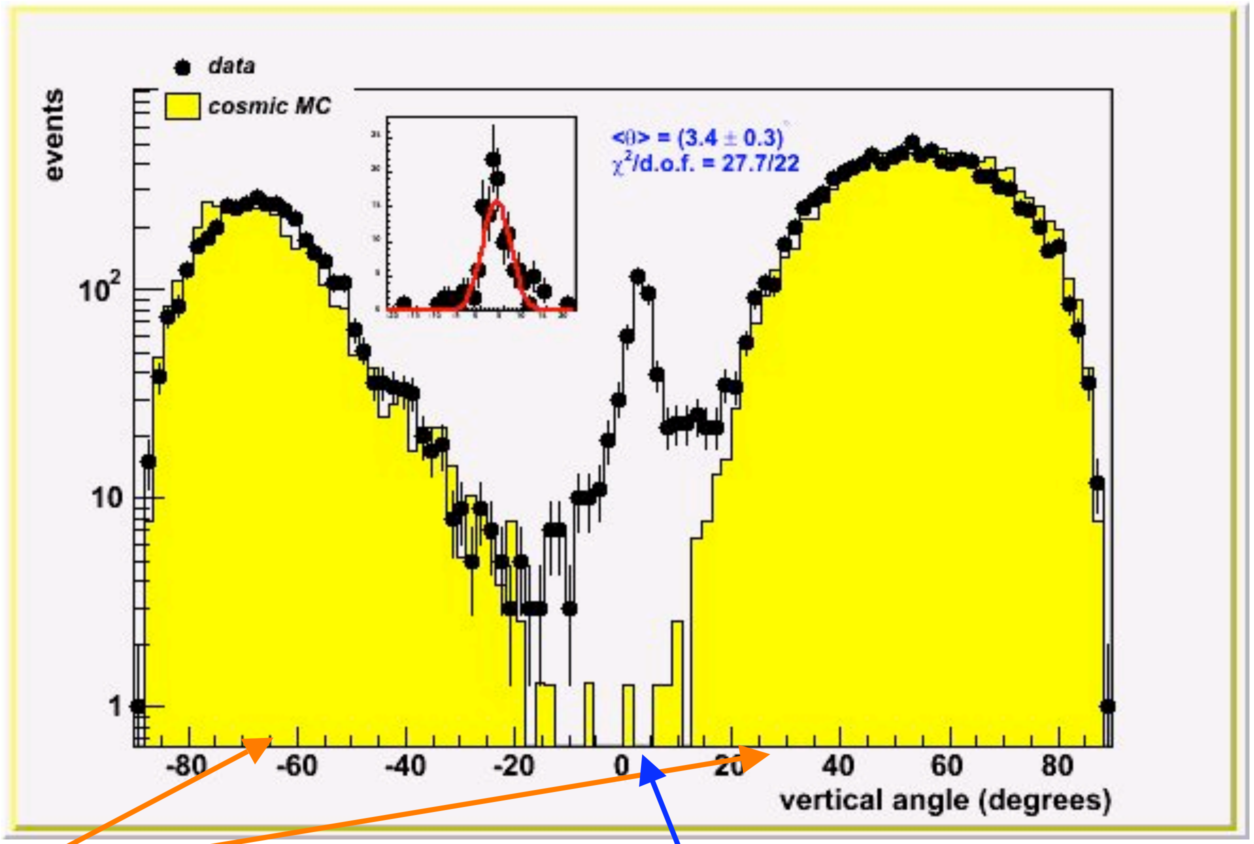
ν_μCC in the magnet



Events direction

Zenith angle of muon track:





Cosmic ray
MC simulation from MACRO parametrization

Beam events:
$<\Theta_y> = 3.4 \pm 0.3°$ *(as expected)*
(statistically dominated)

Physics commissioning runs

- CNGS run in October 2006:
    - 3 double fast extraction distant by 6 seconds per 36 seconds SPS cycle
    - 0.6×10^{17} pot delivered and 30 events stored
    - Run stopped due to a water leak in the reflector (2nd horn) → CNGS "reparation"

- Cosmic runs for commissioning of electronic detectors, target-tracker to brick connection

- Beam runs (CERN, Desy…) for emulsion development commissioning, scanning strategy, and tune the vertex finding methods

- CNGS run in 2007 (beginning 18 September):
    - 3 weeks of CNGS commissioning
    - 3 additional weeks of physics run
    - 70% of nominal intensity: 1.7×10^{13} pot/extraction
    - 505 tons (~59000 bricks) at the start of the run
    - 616 tons (~72000 bricks) at the end of the run

Conclusions

- The OPERA experiment has completed almost entirely the construction of all electronic detectors and faces the last effort of brick production and insertion.

- The electronic detectors took data almost continuously and with the expected tracking performances.

- The electronic detectors-brick connection has been tested with success.

- First, low intensity, CNGS run operated smoothly for both beam and detector with good quality and stability.

- The detector is ready for the next phase: observing neutrino inside bricks.

More details in R. Acquafredda et al., New J. Phys.8 (2006) 303

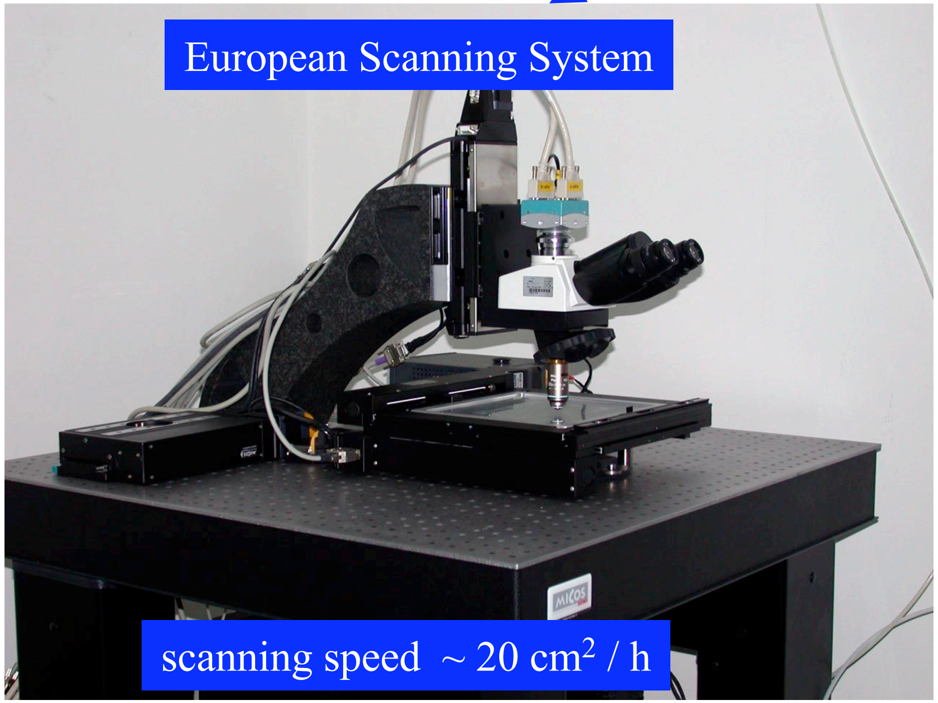
Backup Slides

Automatic emulsions scanning

Off-line Data Taking

~ 30 bricks will be daily extracted from target and analyzed using high-speed automatic systems

Several labs distributed in Europe and Japan

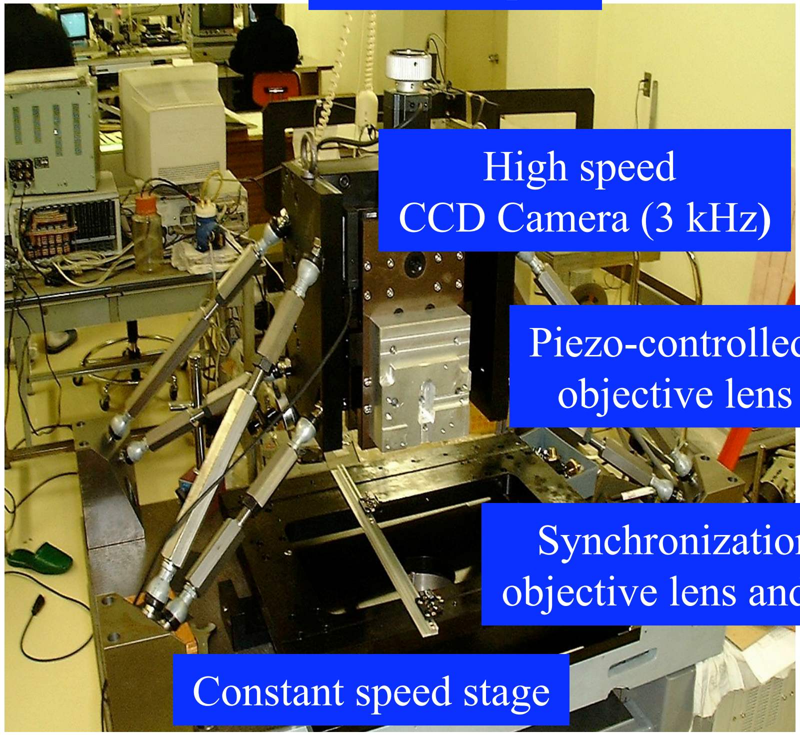


European Scanning System

scanning speed ~ 20 cm^2 / h

Customized commercial optics and mechanics + asynchronous DAQ software

S-UTS (Japan)



High speed CCD Camera (3 kHz)

Piezo-controlled objective lens

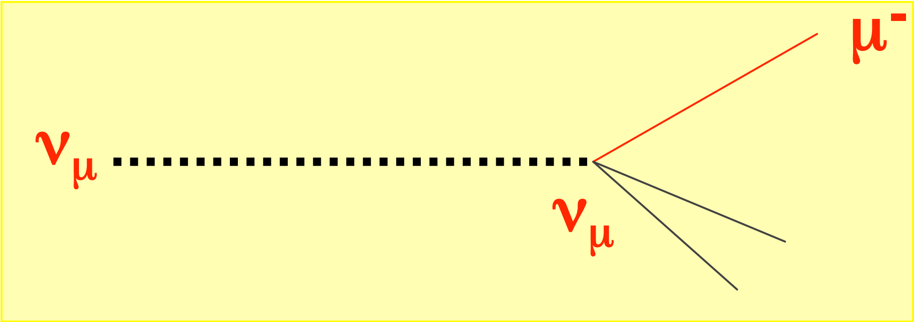
Synchronization of objective lens and stage

Constant speed stage

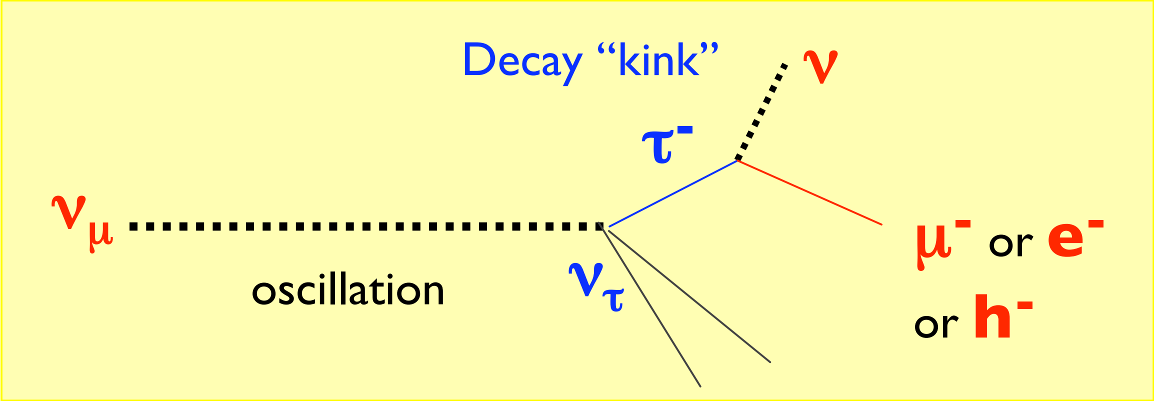
Hard-coded algorithms

OPERA goal: ν_τ appearance signal detection

The challenge is to identify ν_τ interactions from ν_μ interactions



ν_μ **CC events**



ν_τ **CC events**

Topology selection: kink signatures

Principle of OPERA experiment:

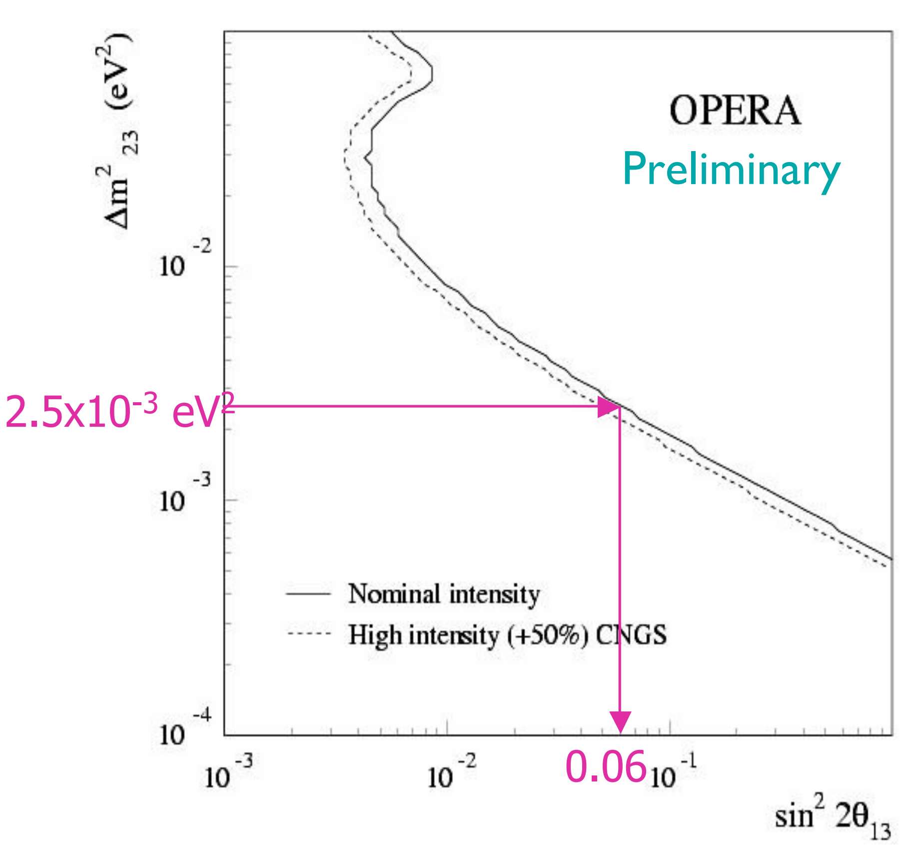
Detection of τ decay (~10^{-13} s ; $c\tau$~87 μm) topologies created by ν_τ CC interactions

μm resolution
⇒ Photographic emulsions (DONUT)

Large target mass
⇒ Lead materials

Sensitivity to Θ_{13}

Simultaneous fit on:
E_e, missing p_T and visible energy



full mixing, 5 years run @ 4.5x10^{19} pot / year

Θ_{13} (deg)	Signal $\nu_\mu \rightarrow \nu_e$	Background			
		$\tau \rightarrow e$	ν_μCC	ν_μNC	ν_eCC beam
9	9.3	4.5	1.0	5.2	18
7	5.8	4.5	1.0	5.2	18
5	3.0	4.5	1.0	5.2	18

Limits at 90% CL for
$\Delta m^2 = 2.5\text{x}10^{-3}$ eV^2 full mixing

	$\sin^2 2\Theta_{13}$	Θ_{13}
CHOOZ	<0.14	11°
OPERA	<0.06	7.1°

OPERA discovery probability vs Δm^2