NO - VE
25/7/2001

OPERA

COLLABORATION

29 groups
~ 130 physicists

Belgium
IIHE(ULB-VUB) Brussels

China
IHEP Beijing, Shandong

CERN

Croatia
Zagreb

France
Annecy, Lyon, Orsay, Strasbourg

Germany
Berlin, Hagen, Hamburg, Münster, Rostock

Israel
Technion Haifa

Italy
Bari, Bologna, Frascati, Naples, Padova, Rome, Salerno

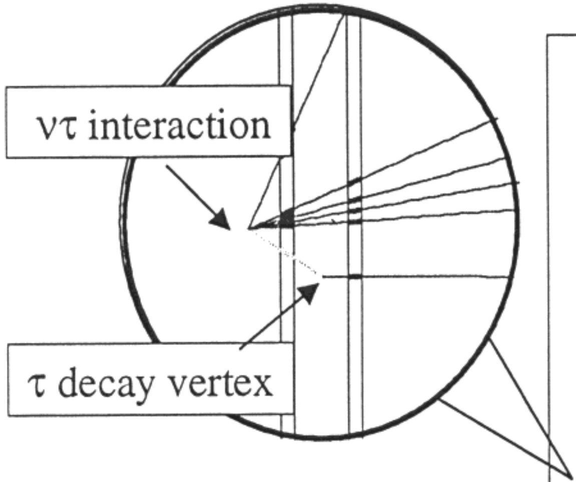
Japan
Aichi, Toho, Kobe, Nagoya, Utsunomiya

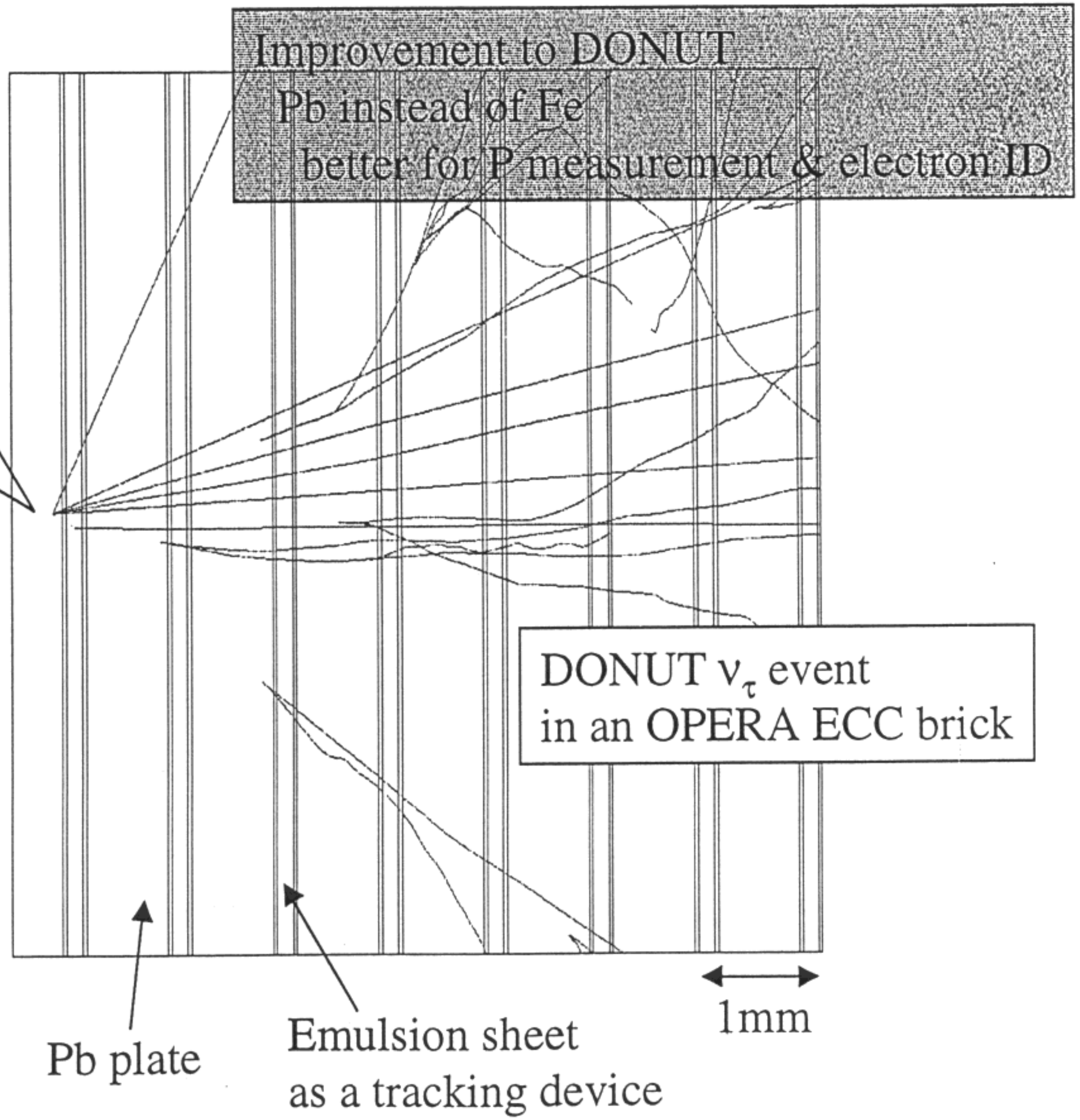
Switzerland
Bern

Turkey
METU Ankara

Russia: ITEP Moscow (contributions to Proposal and interest)

Detect τ decay in **E**mulsion **C**loud **C**hamber





Detect 'Kink' decays

$\tau^- \rightarrow e^- \overline{\nu}_e \nu_\tau$ 17.8%

$\tau^- \rightarrow \mu^- \overline{\nu}_\mu \nu_\tau$ 17.4%

$\tau^- \rightarrow h^- \overline{\nu}_\tau (n\pi^0)$ 49.5%

Kink = single charge prong

OPERA

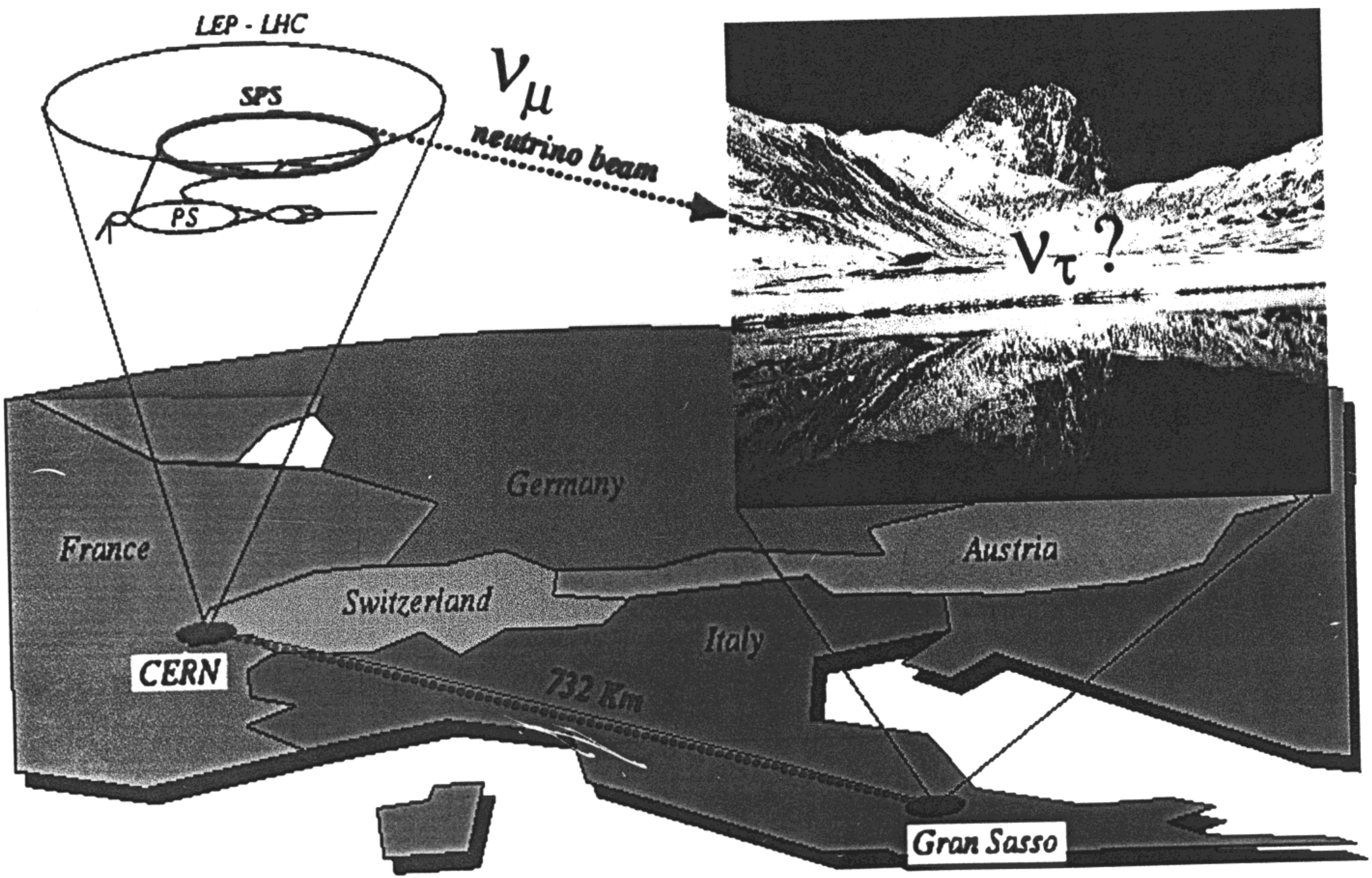
The approach of the experiment

- CNGS long baseline beam → optimal for $\nu_\mu - \nu_\tau$ appearance
- *Direct* detection of τs by decay topology ($\gamma c\tau \sim 1$mm)
- Vertex detector → high resolution ($\sim 1\mu$m)
  → large mass ($\sim$ 2kton)
- Re-birth of *old technique* → Emulsion Cloud Chamber (**ECC**)
- Feasibility → - today's nuclear emulsion:
  high density data storage device

  - Industrial emulsion sheets (ES)

  - high-speed automatic scanning systems

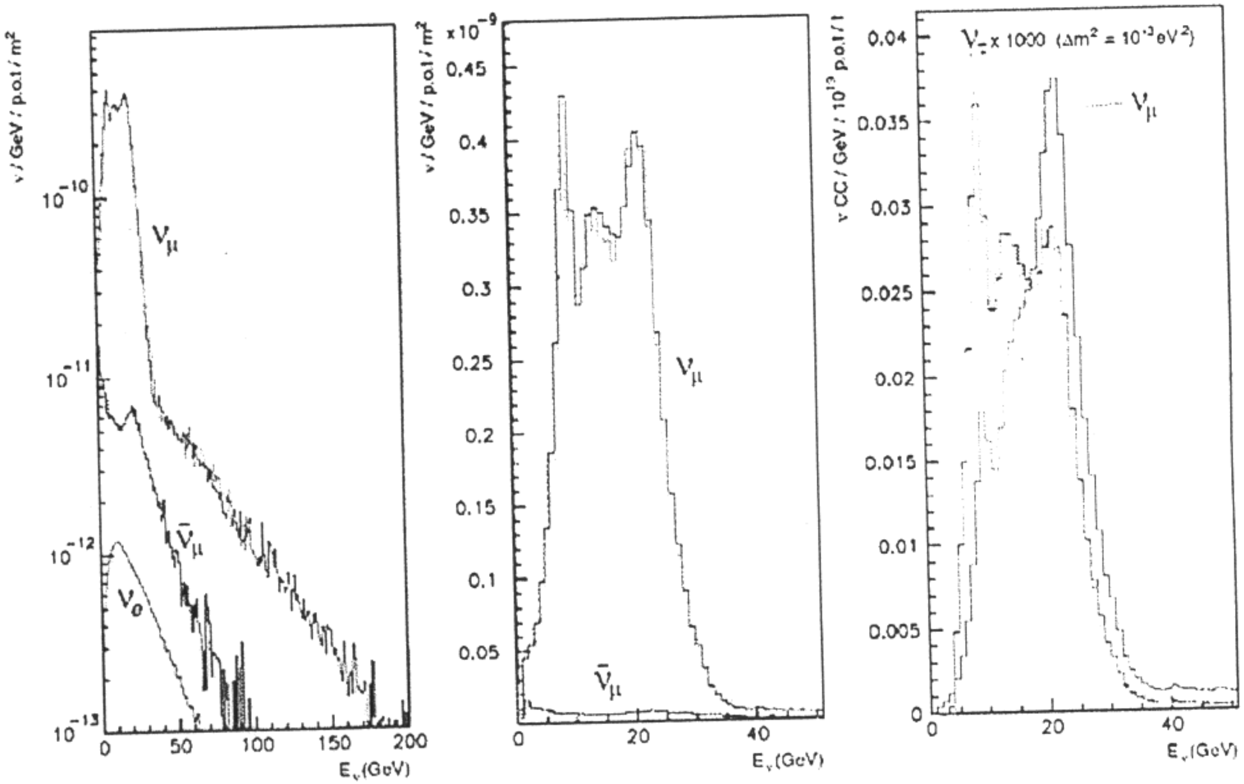
CERN to Gran Sasso Neutrino Beam



The CNGS beam

Nominal ν beam

ν_μ (m^{-2} / pot)	7.78×10^{-9}
ν_μ CC / pot / kton	5.85×10^{-17}
$\langle E \rangle_\nu$ (GeV)	17
$(\nu_e + \bar{\nu}_e) / \nu_\mu$	0.87 %
$\bar{\nu}_\mu / \nu_\mu$	2.1 %
ν_τ prompt	negligible



Shared SPS operation

200 days/year

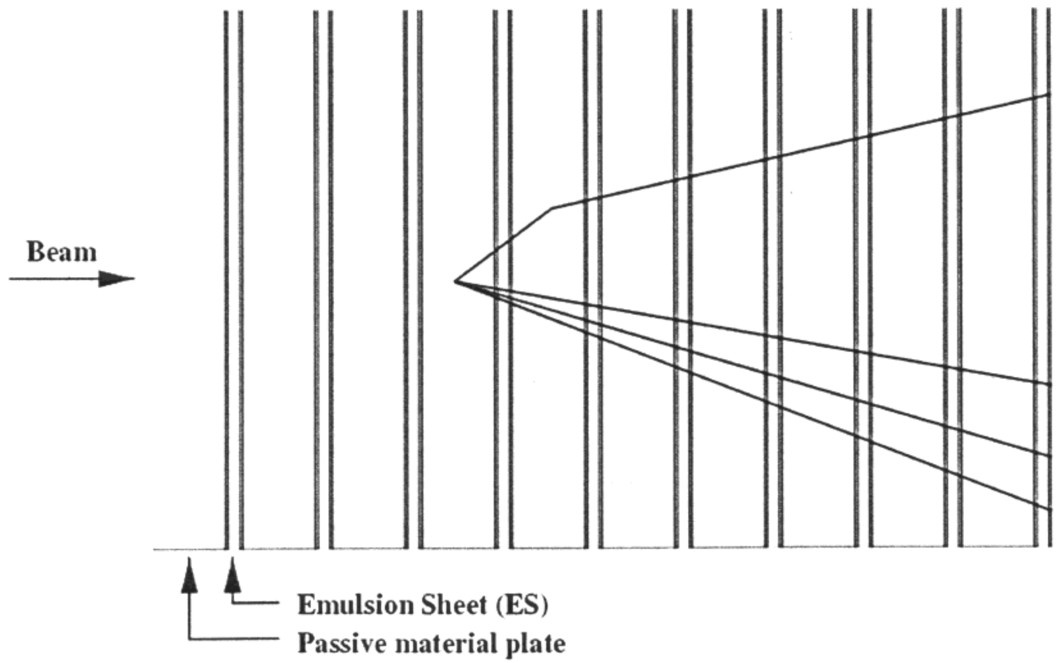
4.5×10^{19} pot / year

Basic ECC concept:

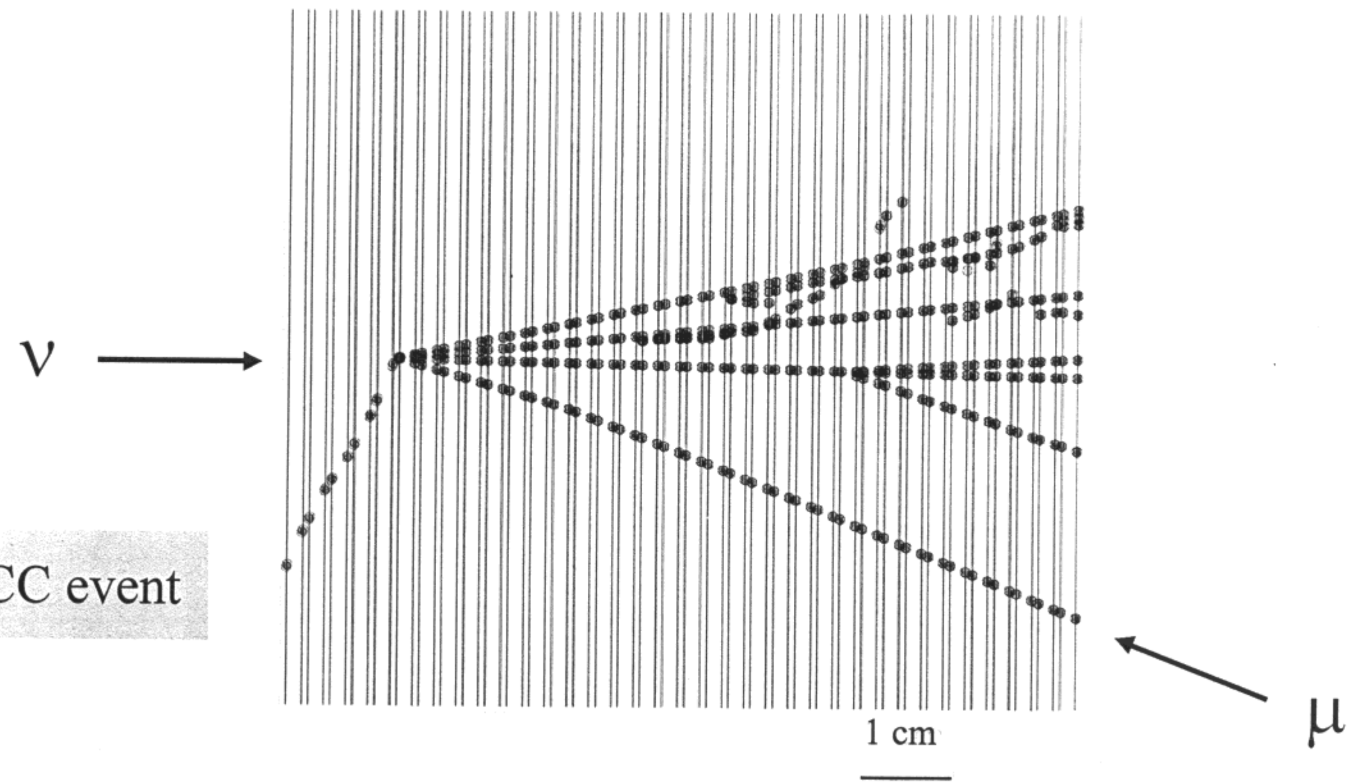
Passive target material → large mass

and

emulsion tracking → high space resolution



A sequence of cells (~10x13 cm² x-section) forms a brick: building block of a massive target (walls and supermodules)

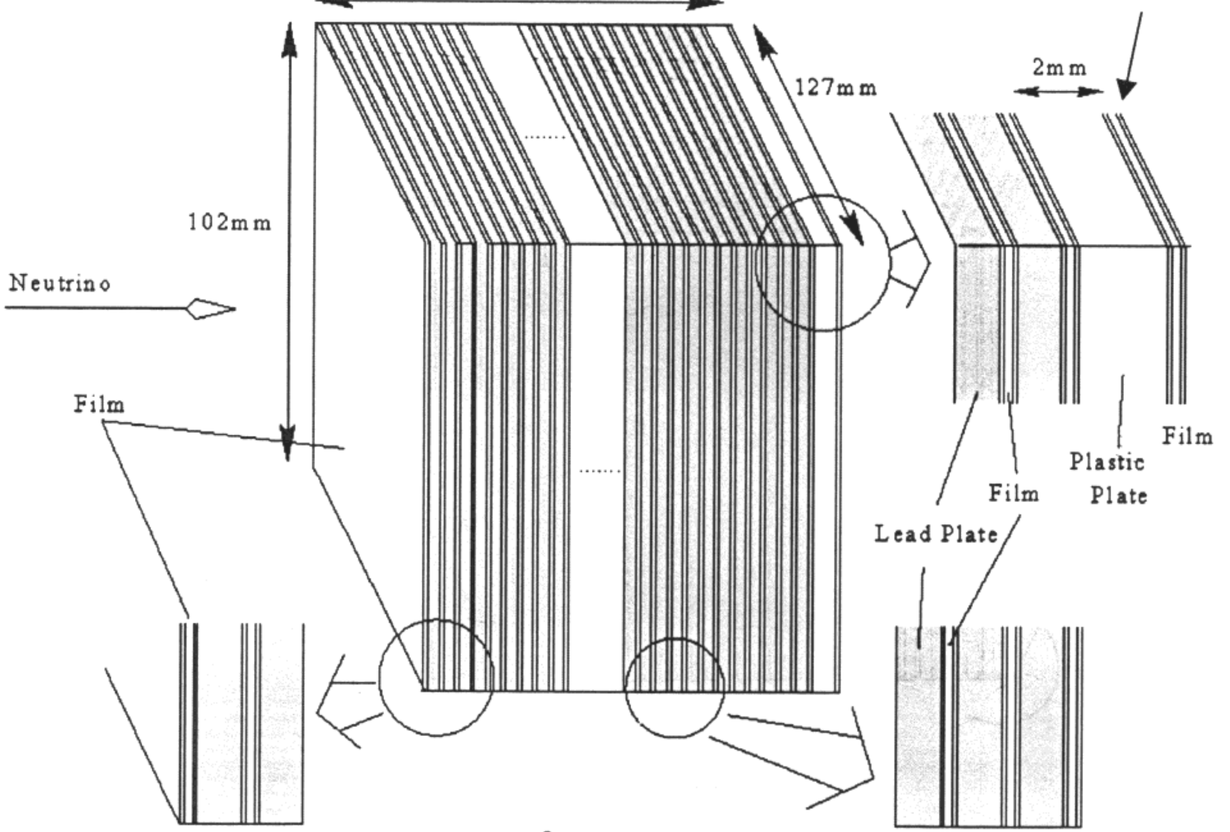


simulated ν_μ CC event

56 CELLS = 1 BRICK
DEPTH = 7.5 cm $\Leftrightarrow$ 10 X_0

ECC brick for OPERA

SS emulsion film for event location



~ 10 X_0

Industrially produced emulsion film + Pb plate(1mm Thick)

The detector at Gran Sasso

(modular structure, configuration with three "supermodules")

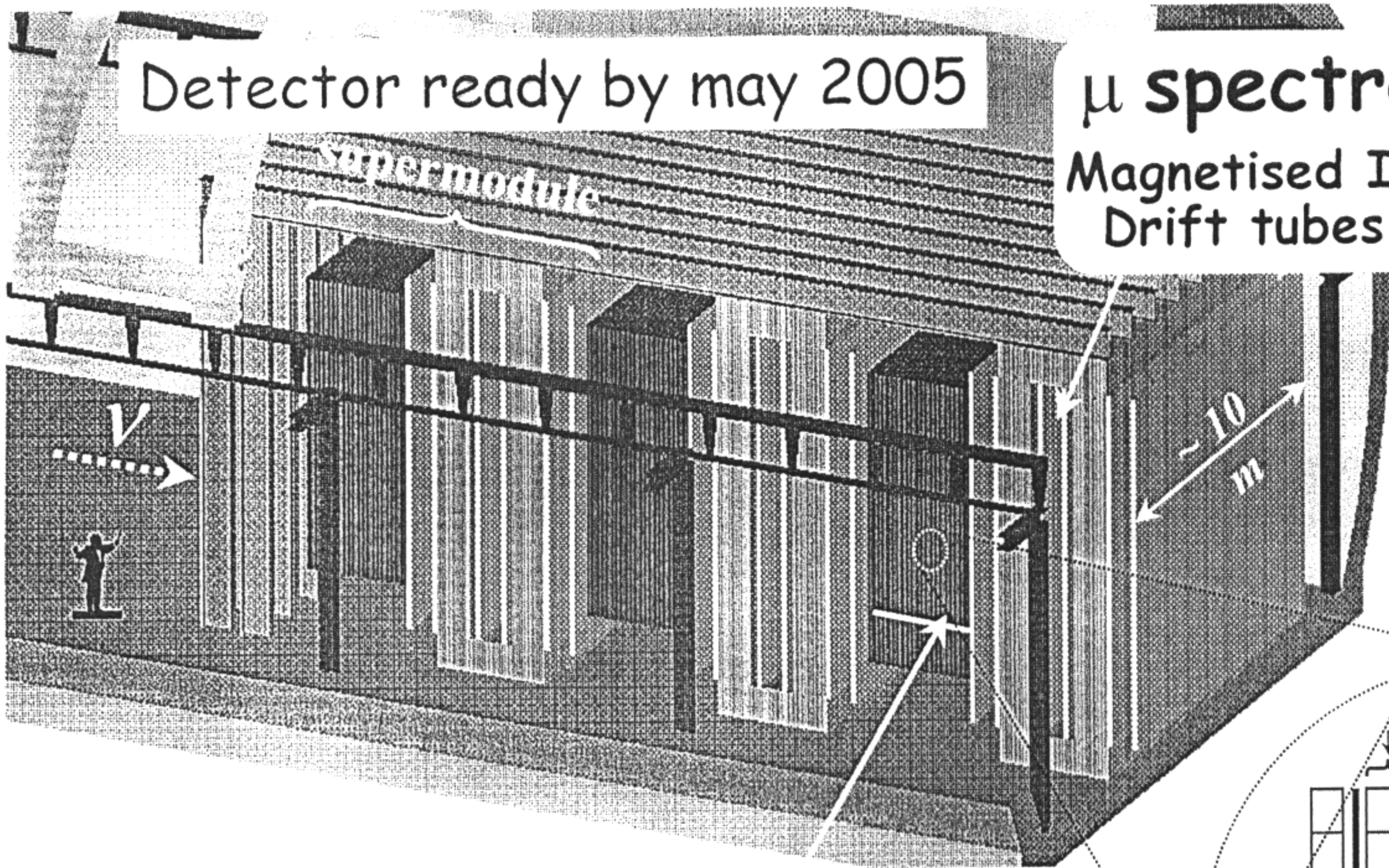
↳ ~ 135 k bricks

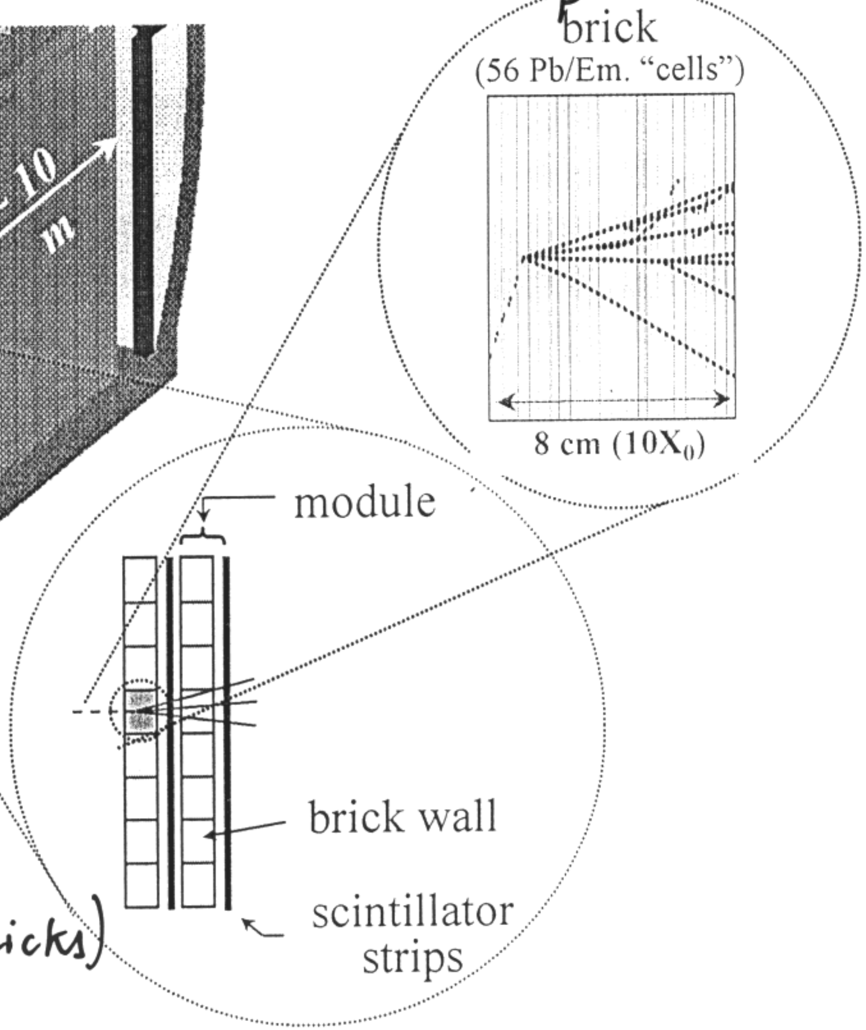
Detector ready by may 2005

μ spectrometer ~ 1k ton

Magnetised Iron Dipoles
Drift tubes and RPCs

$\frac{\Delta p}{p} \approx 10\%$



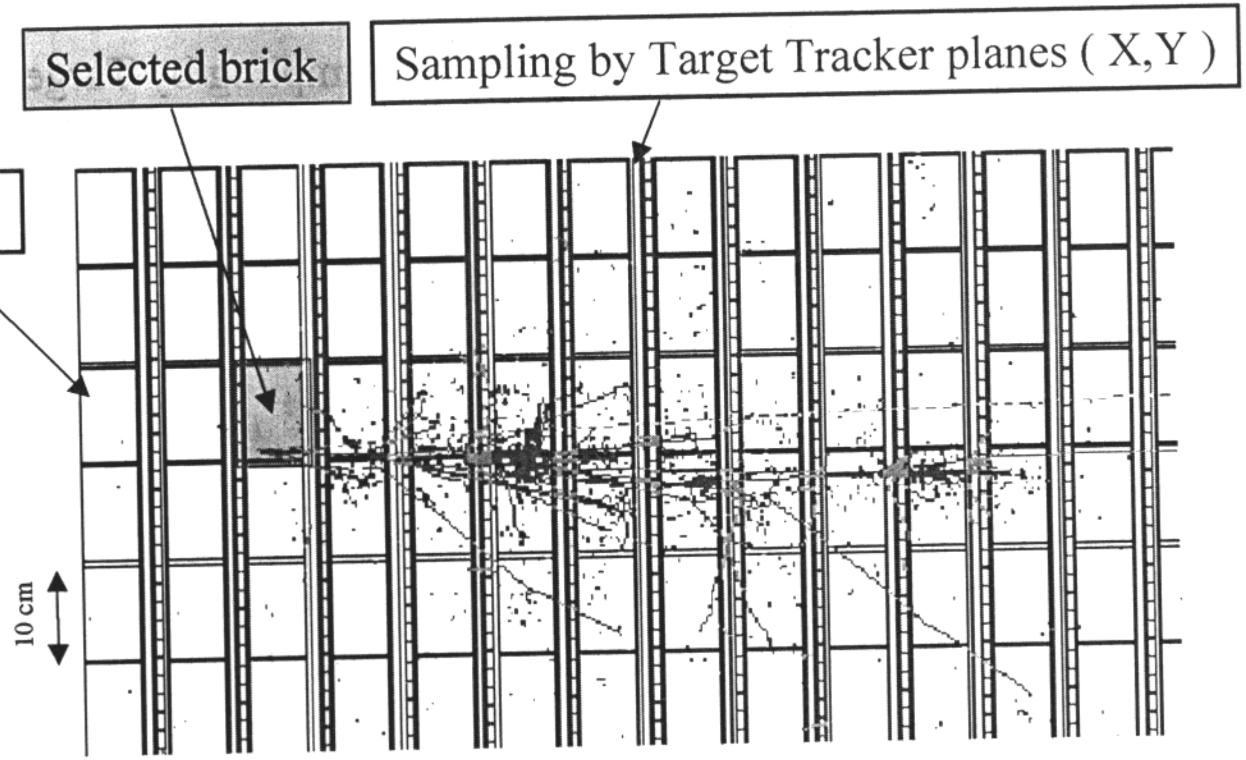


ν target and τ decay detector

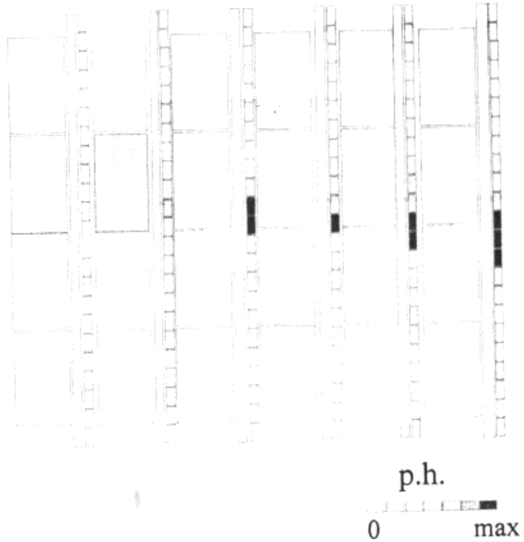
Each "supermodule" is
a sequence of 24 "modules" consisting of

- a "wall" of Pb/emulsion "bricks" (3264 bricks)
- planes of orthogonal scintillator strips

How to select the ν interaction brick ?



Event as seen
by the target tracker

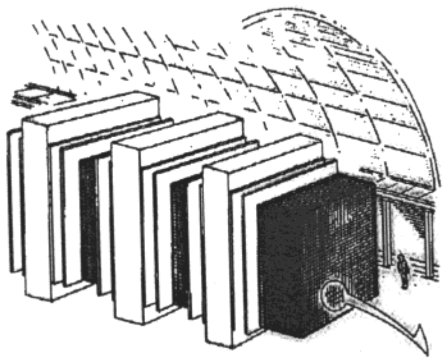


Emulsion-Scintillator strip Hybrid Target

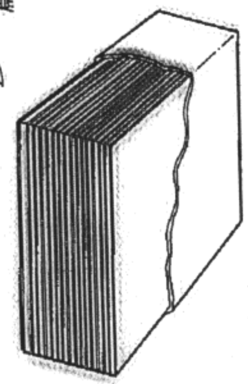
- **Tracker task**
  select bricks efficiently
- **High scanning power + low background**
  allow coarse tracking

Selected bricks extracted daily
using dedicated robot

Operation of the Experiment

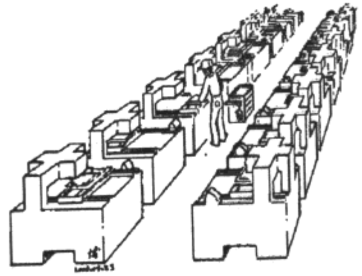


Gran Sasso
- tag ν interaction
- extract ECC brick



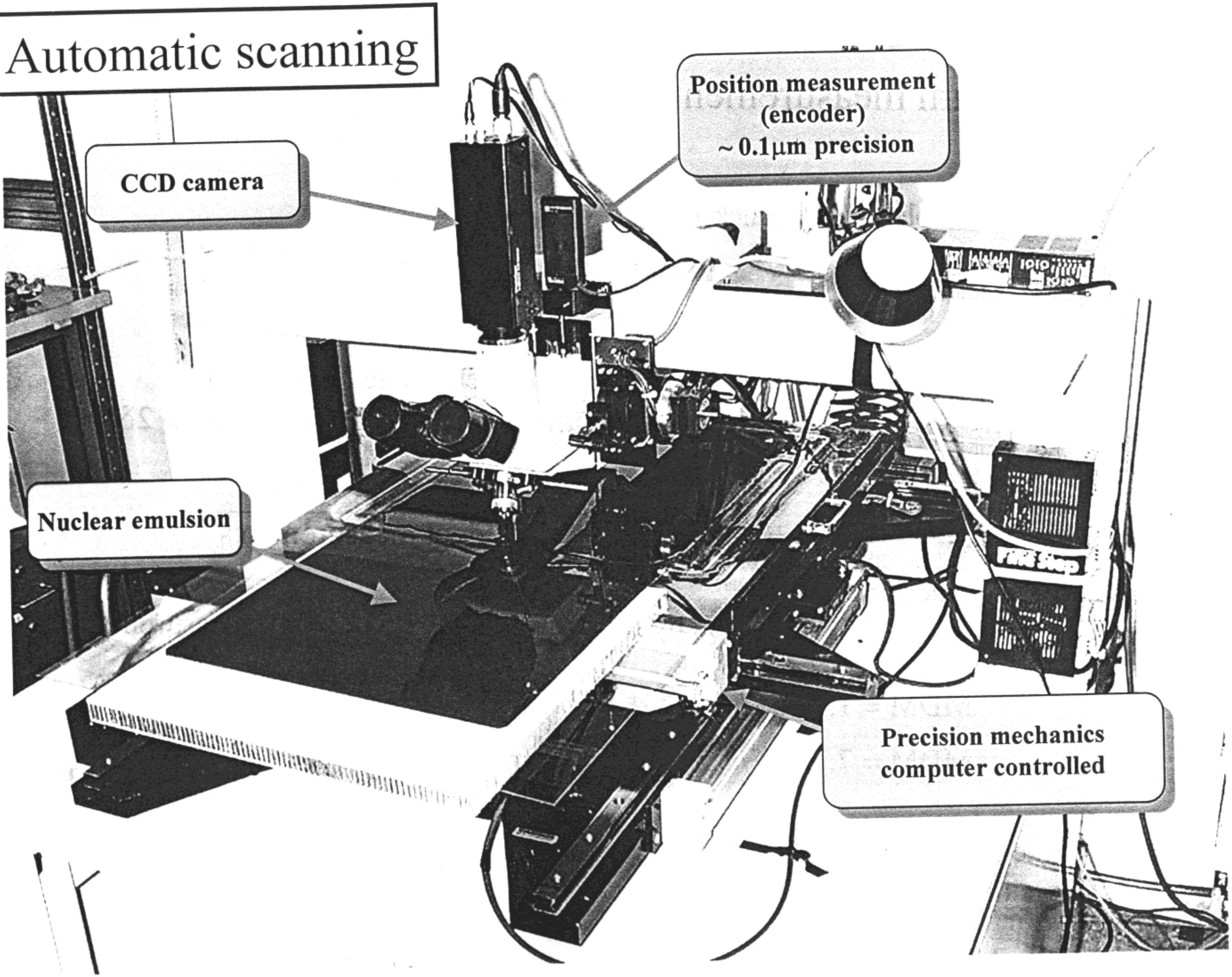
ECC brick

30bricks/day
- cosmic ray exposure
- develop emulsion sheet etc.



Emulsion Scanning station
- locate ν interaction
- τ detection

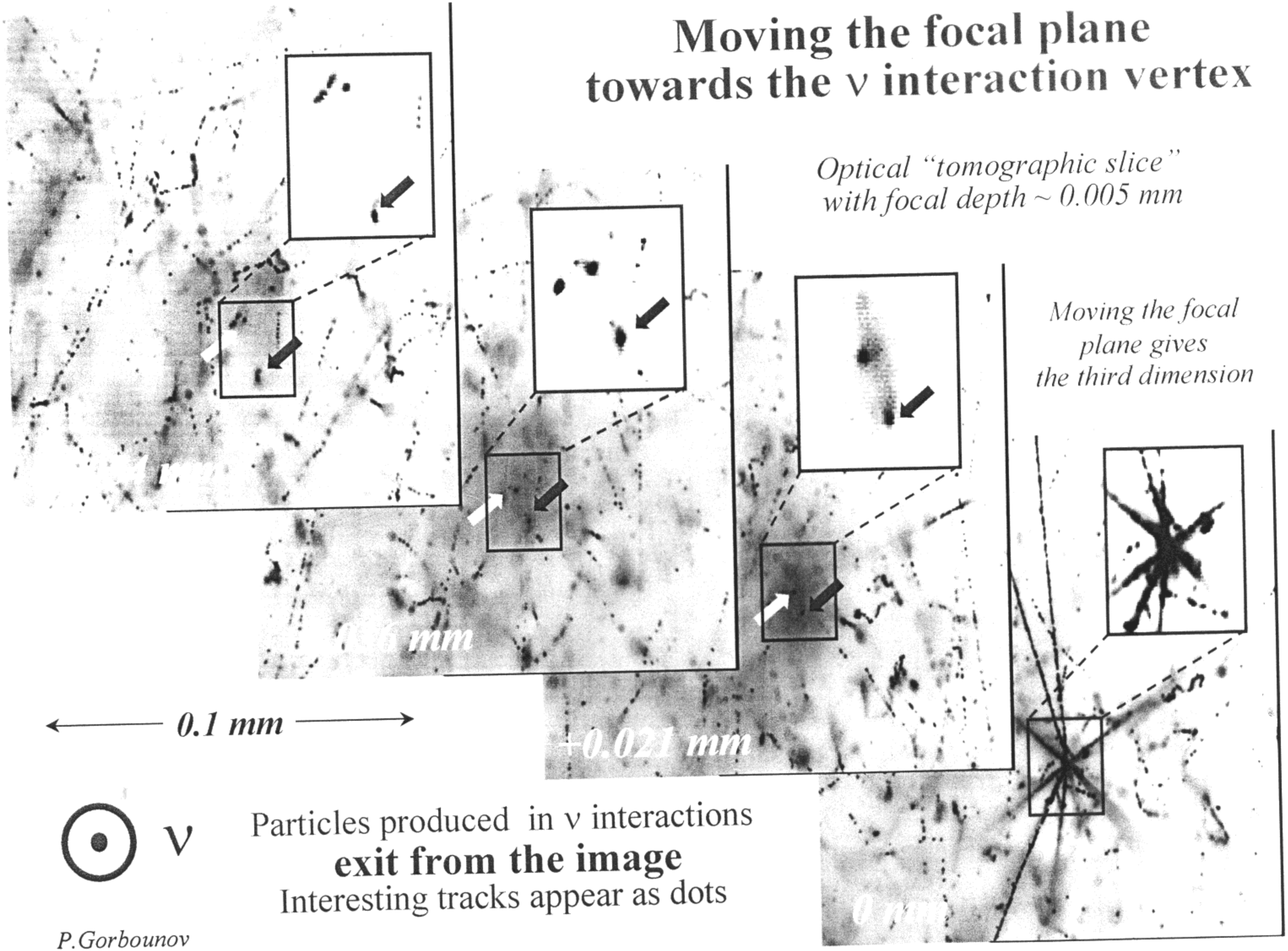
Automatic scanning



Moving the focal plane towards the ν interaction vertex

Optical "tomographic slice" with focal depth ~ 0.005 mm

Moving the focal plane gives the third dimension

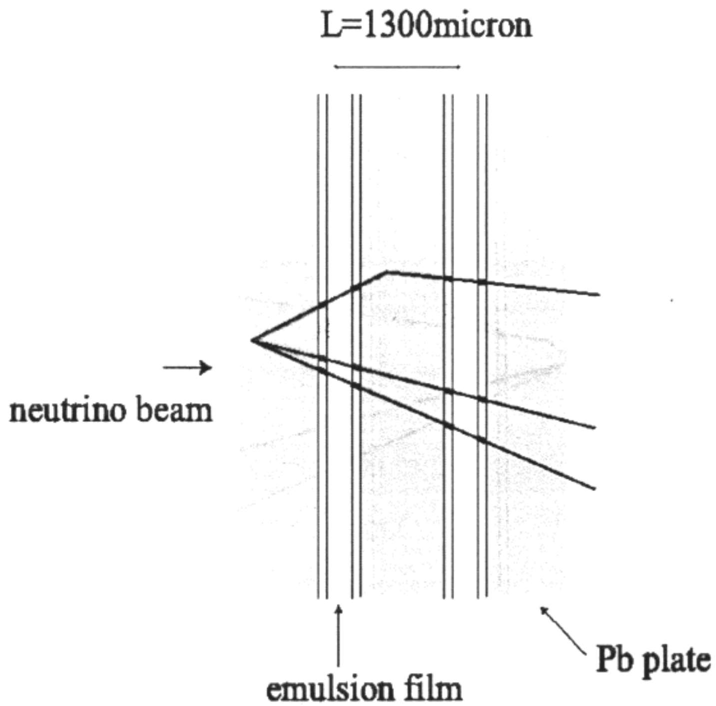


ν

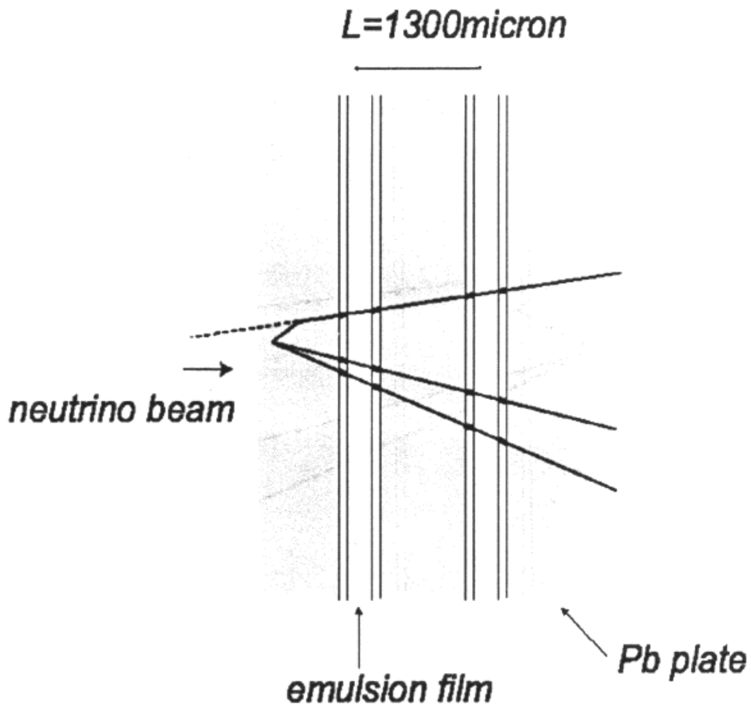
Particles produced in ν interactions
exit from the image
Interesting tracks appear as dots

P.Gorbounov

Select ν_τ candidates to be passed to the FULL data taking



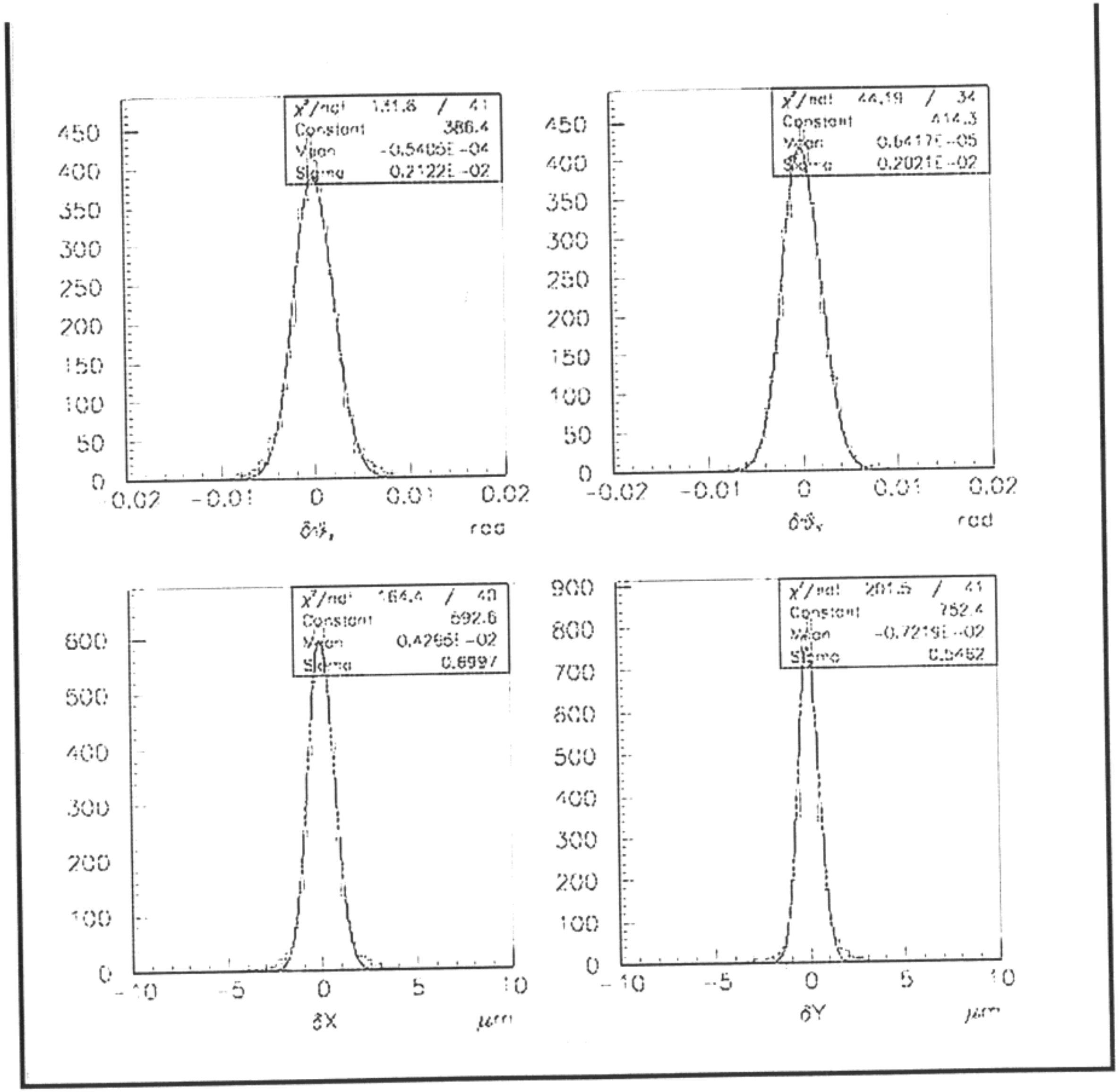
Long decays"
reconstruct kink topology



Short decays "
detect large impact parameter track

Loose cut to reject low momentum tracks

Small fraction of the located events are passed to the FULL DAQ

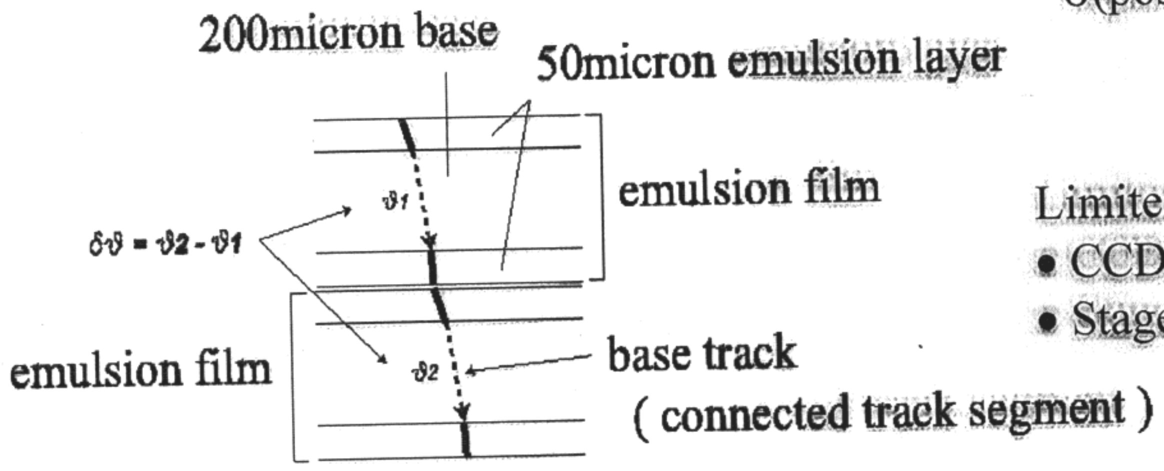


Measured angular and position resolution with 100 μm segments:

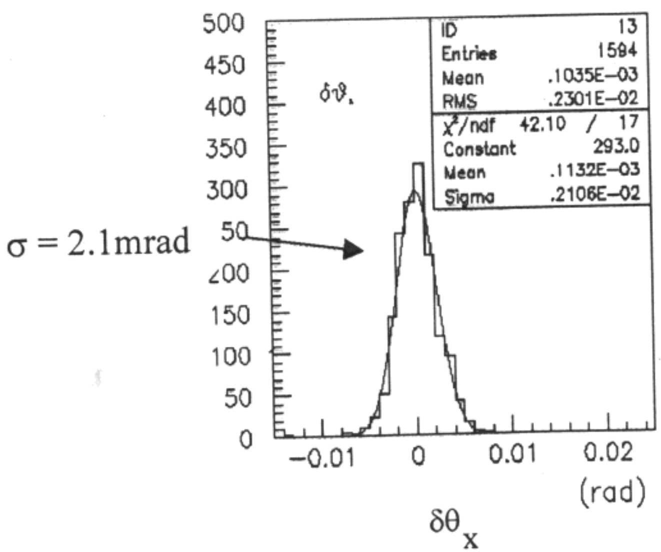
~2 mrad in angle and ~0.6 μm in position

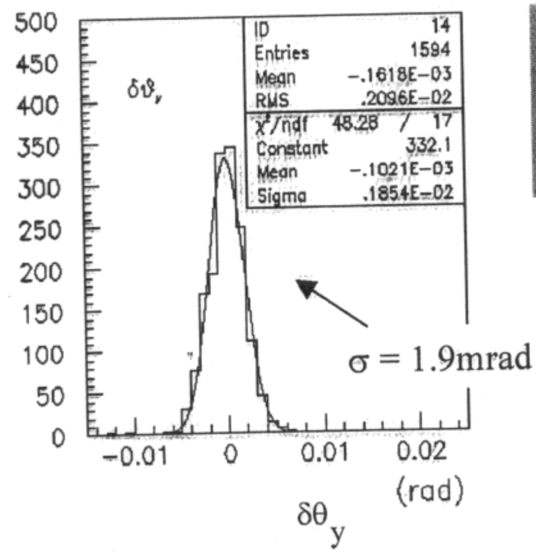
Tracking Accuracy (current readout system)

σ(angle) = 2.1mrad
σ(position) = 0.21μm
for base track



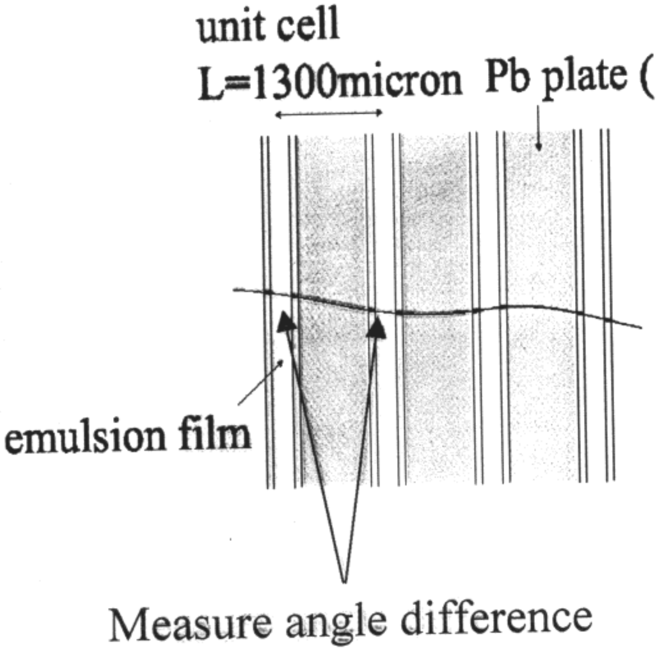
Limited by
- CCD camera pixel size (0.3μm)
- Stage coordinate readout pitch (0.5μm)





Intrinsic accuracy is …
σ(angle) = 0.4mrad
σ(position) = 0.06μm

Momentum measurement by Angular Method



$$\mathrm{MDM} = \frac{13.6\mathrm{MeV}/c}{2\delta\theta}\sqrt{\frac{1\mathrm{mm}}{5.6\mathrm{mm}}} \quad \frac{x}{X_0}$$

Maximum Detectable Momentum

scattering in a unit cell (1mm Pb) > $2\delta\theta$

$$\frac{\Delta p}{p} \propto \sqrt{\#\ \text{of independent measurements}}$$

~10% by following 1ECC (55×2=110 measurements)

MDM = 1.4GeV/c with σ_θ= 2.1mrad (current readout)

MDM = 7.1GeV/c with σ_θ= 0.4mrad (intrinsic limit)

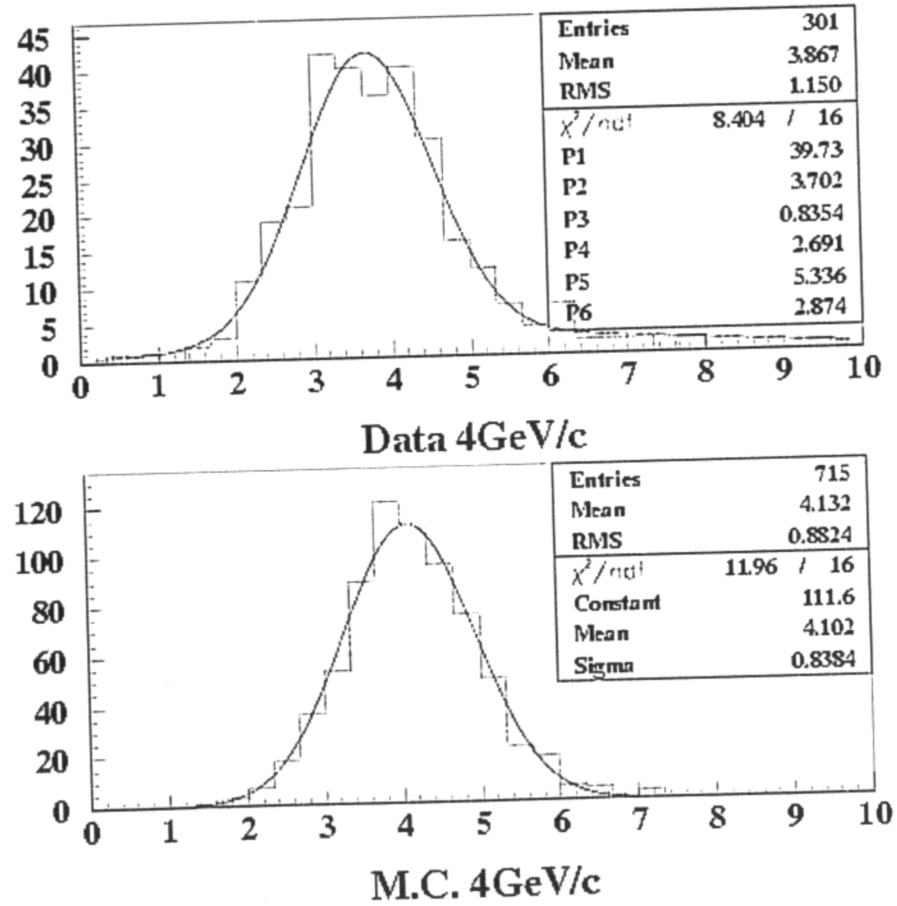
NO Fine Allignment required

Pb plate thickness must be flat (better than 2.1mrad for current readout)

Momentum measurement by MS in the cells

- Momentum measurement: tool for BG reduction and candidate event kinematics
- Detect track deviations in the ECC structure (lead/ES cells)

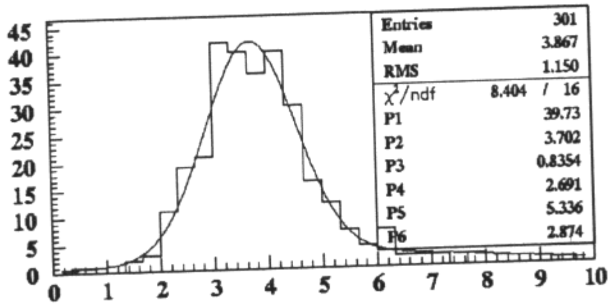
4 GeV/c pions: momentum measurement (data and MC events)



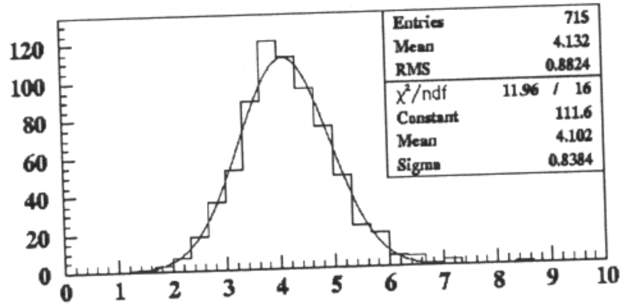
Momentum measurement (coordinate method)

MDM is higher than angular method
measure scattering with longer lever arm

MDM = 5.9 GeV/c with σ=0.21μm



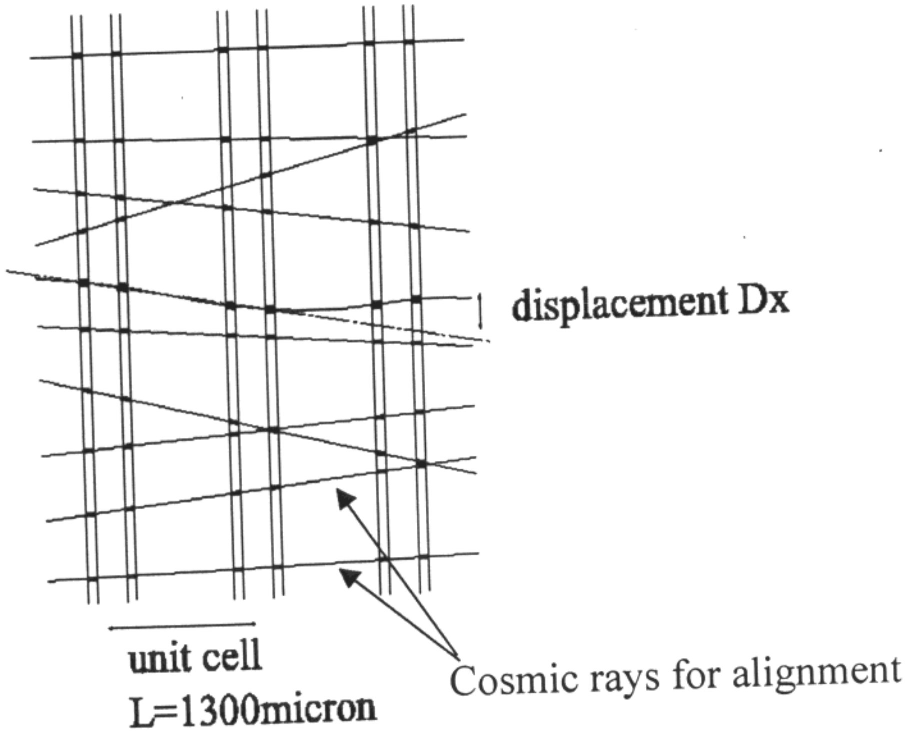
Data 4 GeV/c



M.C. 4 GeV/c

TEST experiment at KEK PS

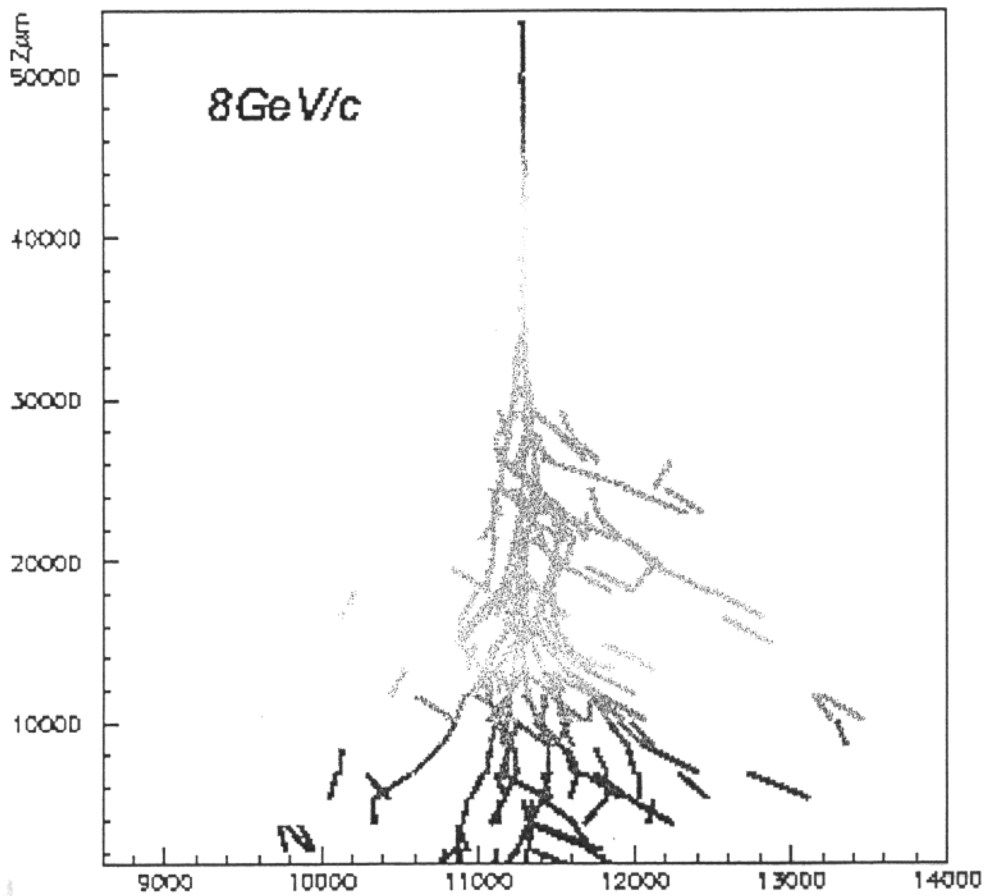
requires precise alignment
using cosmic rays exposure after extraction
cosmic ray density of several/mm²
alignment accuracy → OK

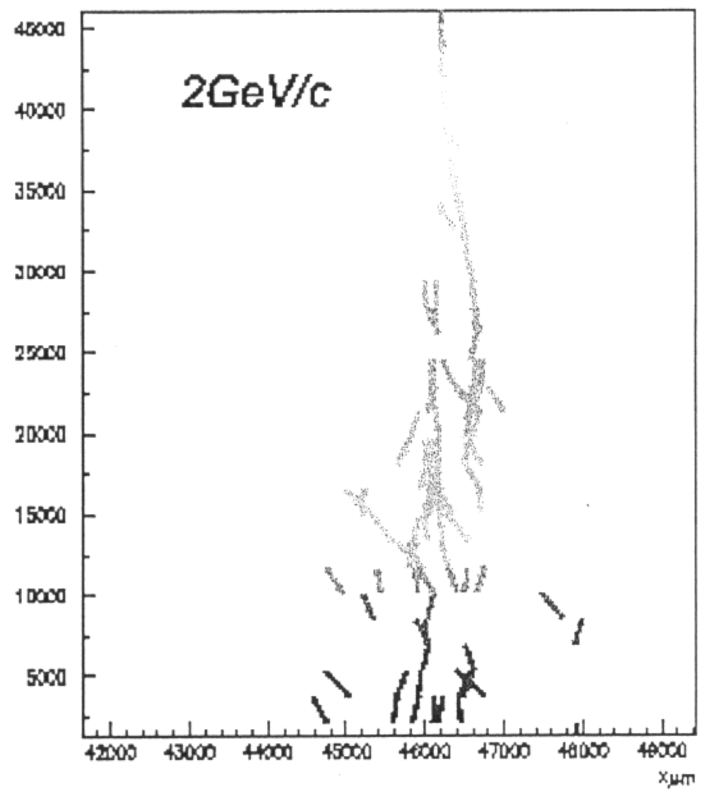


MDM becomes 39.1GeV/c with σ=0.06μm (intrinsic limit)

Electron ID in Emulsion Module

To reject β from lead:
i tracks connected on both em. sh.
$\delta\theta \leq 50$ mrad $\quad \delta r \leq 6\ \mu m$





<u>B.G.</u> β's connected : 1/mm^2 for 10^5/cm^2 β density

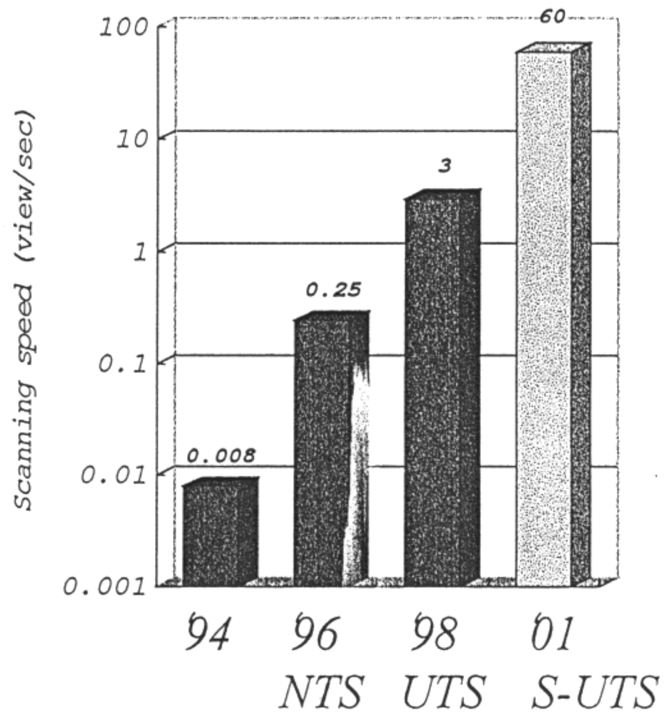
Readout improvement

S-UTS Scanning speed: $20 cm^2/h$
$\times 20$ faster than the current system (UTS)

Real time 10^{-5} data reduction
from pixels to base tracks

Will be realized by
- Fast CCD camera (3 k frames/sec)
- Continuous movement of the X-Y stage
  Z movement controlled by piezo actuator

Scanning Power Roadmap



OPERA scan area ~ $8500 cm^2/day$ ~ 20 S-UTS

<u>late summer 2001 → first S-UTS</u>

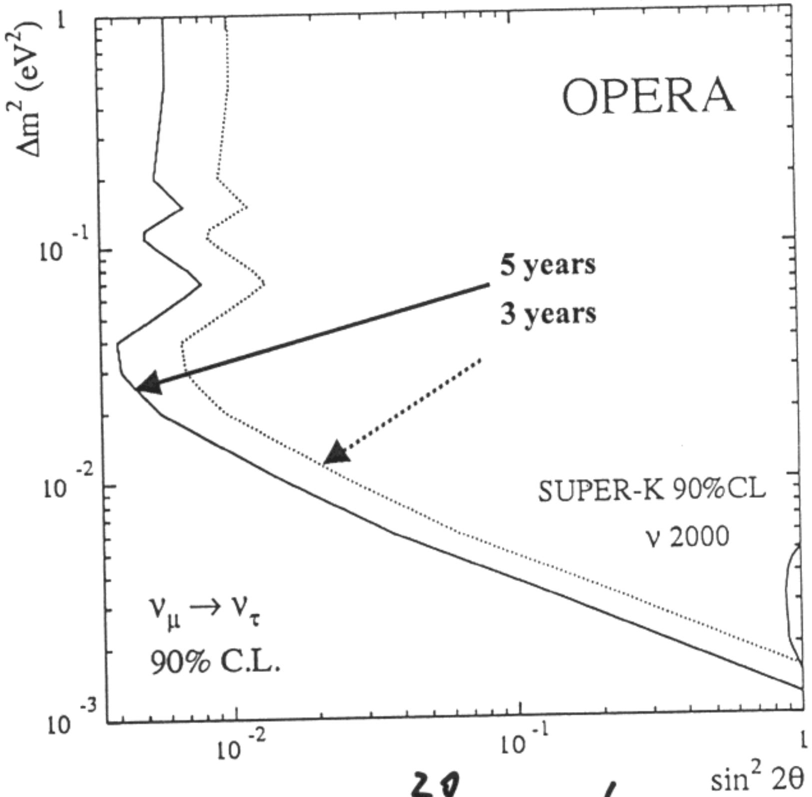
Sensitivity to $\nu_\mu \rightarrow \nu_\tau$ oscillations

Summary of τ detection efficiencies
(in % and including BR)

Decay mode	DIS long	QE long	DIS short	Overall
$\tau \rightarrow e$	3.0	2.6	1.3	3.7
$\tau \rightarrow \mu$	2.7	2.8	-	2.7
$\tau \rightarrow h$	2.2	2.8	-	2.3
Total	8.0	8.3	1.3	8.7

Expected background
(5 years data taking)

	$\tau \rightarrow e$	$\tau \rightarrow \mu$	$\tau \rightarrow h$	Total
Charm production	0.15	0.03	0.15	0.33
$\nu_e CC$ and π^0	0.01	-	-	0.01
Large μ scattering	-	0.10	-	0.10
Hadron reinteractions	-	-	0.10	0.10
Total	0.16	0.13	0.25	0.54
Total	0.19	0.13	0.25	0.57



$2.25 \cdot 10^{20}$ p.o.t.

After 5 years data taking

$\Delta m^2 = 1.2 \times 10^{-3}$ eV^2 at full mixing

$\sin^2(2\theta) = 6.0 \times 10^{-3}$ at large Δm^2

Expected ν_τ events

$\Delta m^2 (10^{-3}\ eV^2)$

2.5

τ decay	1.6	2.5	4.0	b.g.
e	1.9	4.7	11.8	0.19
μ	1.5	3.5	8.8	0.13
h	1.3	3.0	7.6	0.25
Total	4.7	11.2	28.2	0.57

✓ Full mixing

✓ 5 years with shared SPS operation (2.25×10^{20} pot)

✓ Average target mass = 1.8 kton (accounting for mass reduction with time, due to brick removal for analysis)

✓ Uncertainties on background and efficiencies accounted for in the following

Summary and Outlook

OPERA is $\nu_\mu \to \nu_\tau$ appearance experiment detecting τ decay

ECC (Emulsion Cloud Chamber) can provide
- vertex and τ decay topology
- momentum measurement of hadron and μ
- electron identification and energy measurement

each is ancient technique in cosmic ray experiment
(but it had taken enormous time)

S-UTS + Net-Scan realize systematic study in revolutional speed
- Detection efficiency = 8.7%
- possible to detect 3.66 τ decays / year ($\Delta m^2 = 3.2 \times 10^{-3} eV^2$)

Sensitivity improvement is under study
- to add efficiency to $\tau \to \rho\nu$ decay mode
- by $\pi^0 \to \gamma + \gamma$ detection

First beam is scheduled on May 15 in 2005