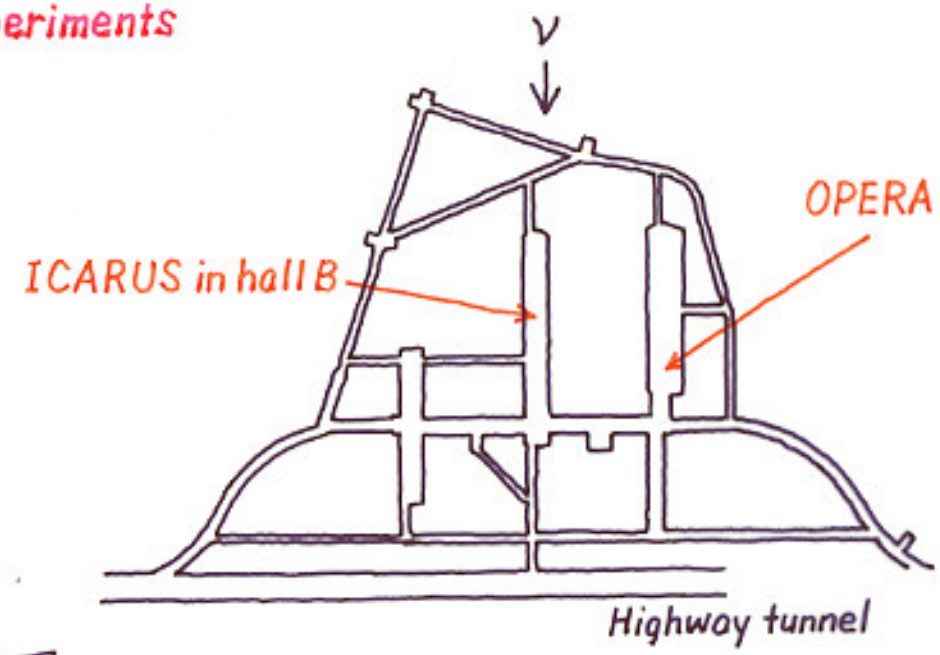
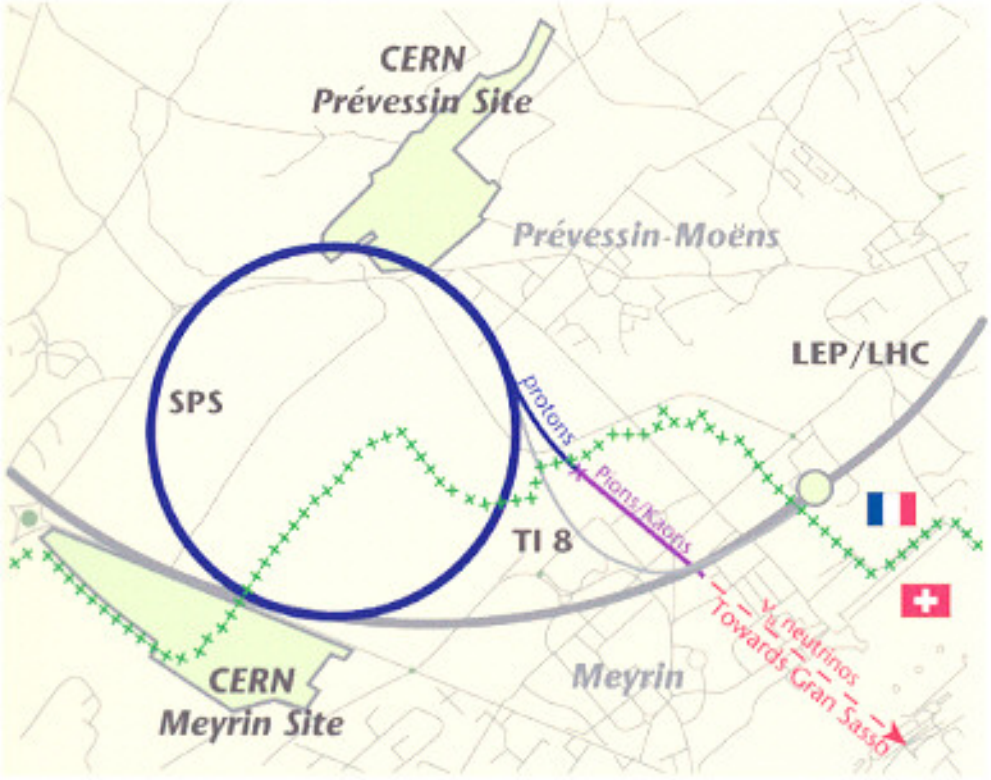
CNGS, OPERA and ICARUS status

long baseline ν_τ appearance experiments



Koichi Kodama
OPERA collaboration

CNGS (CERN Neutrino to Gran Sasso)



400GeV/c proton beam

4.5×10^{19} pot/year in shared mode

Average ν_μ energy = 17GeV

$\nu_\mu:\bar{\nu}_\mu:\nu_e:\bar{\nu}_e = 1 : 2\times10^{-2} : 8\times10^{-3} : 5\times10^{-4}$

2600 ν_μCC events/kton/year

22 ν_τCC events/kton/year

assuming $\sin^2 2\theta = 1$, $\delta m^2 = 3\times10^{-3}\text{eV}^2$

First beam to Gran Sasso in May 2006

Target Chamber – December 2002

COLLABORATION

36 groups
~ 165 physicists

Japan - Europe collaboration

Belgium
IIHE(ULB-VUB) Brussels

Bulgaria
Sofia University

China
IHEP Beijing, Shandong

Croatia
Zagreb University

France
LAPP Annecy, IPNL Lyon, LAL Orsay, IRES Strasbourg

Germany
Berlin, Hagen, Hamburg, Münster, Rostock

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

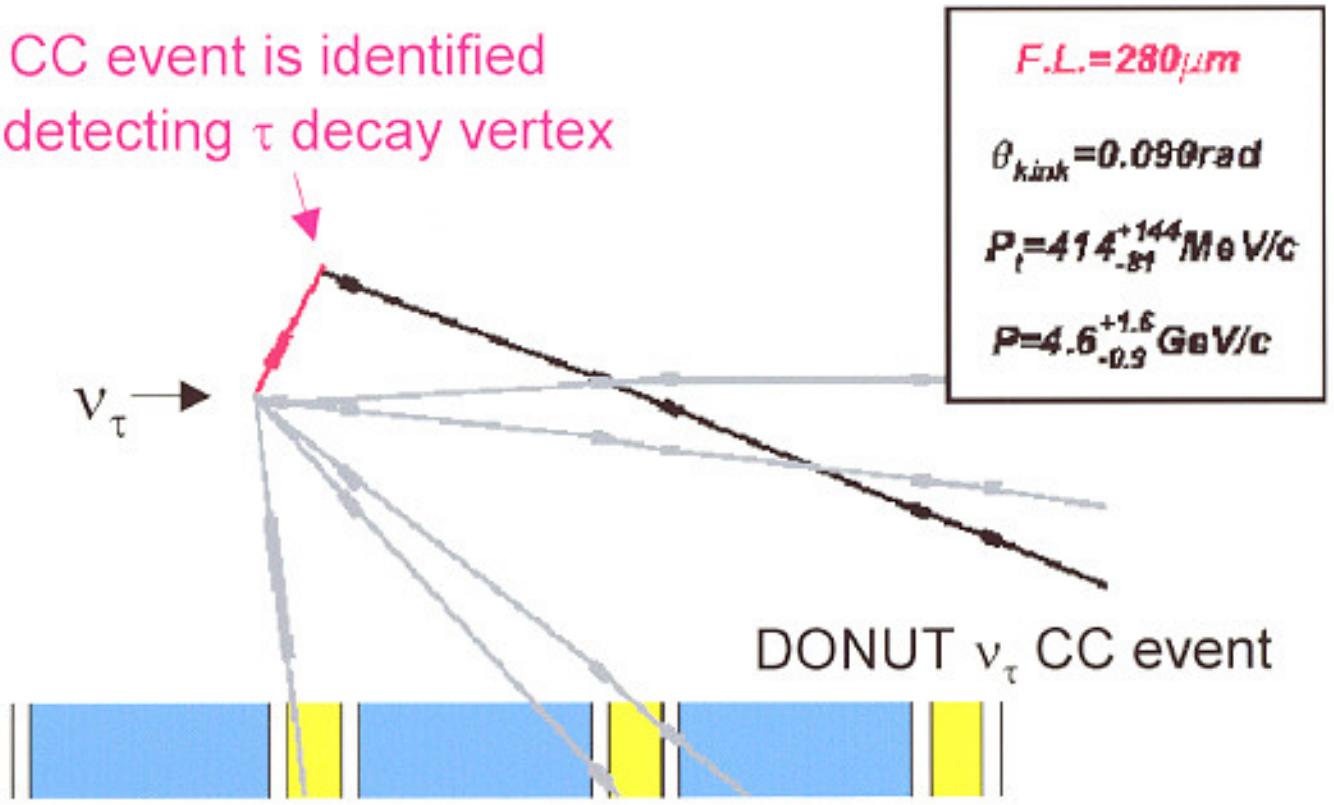
Switzerland
Bern, Neuchâtel

Turkey
METU Ankara

Underlined : groups having joined since last year

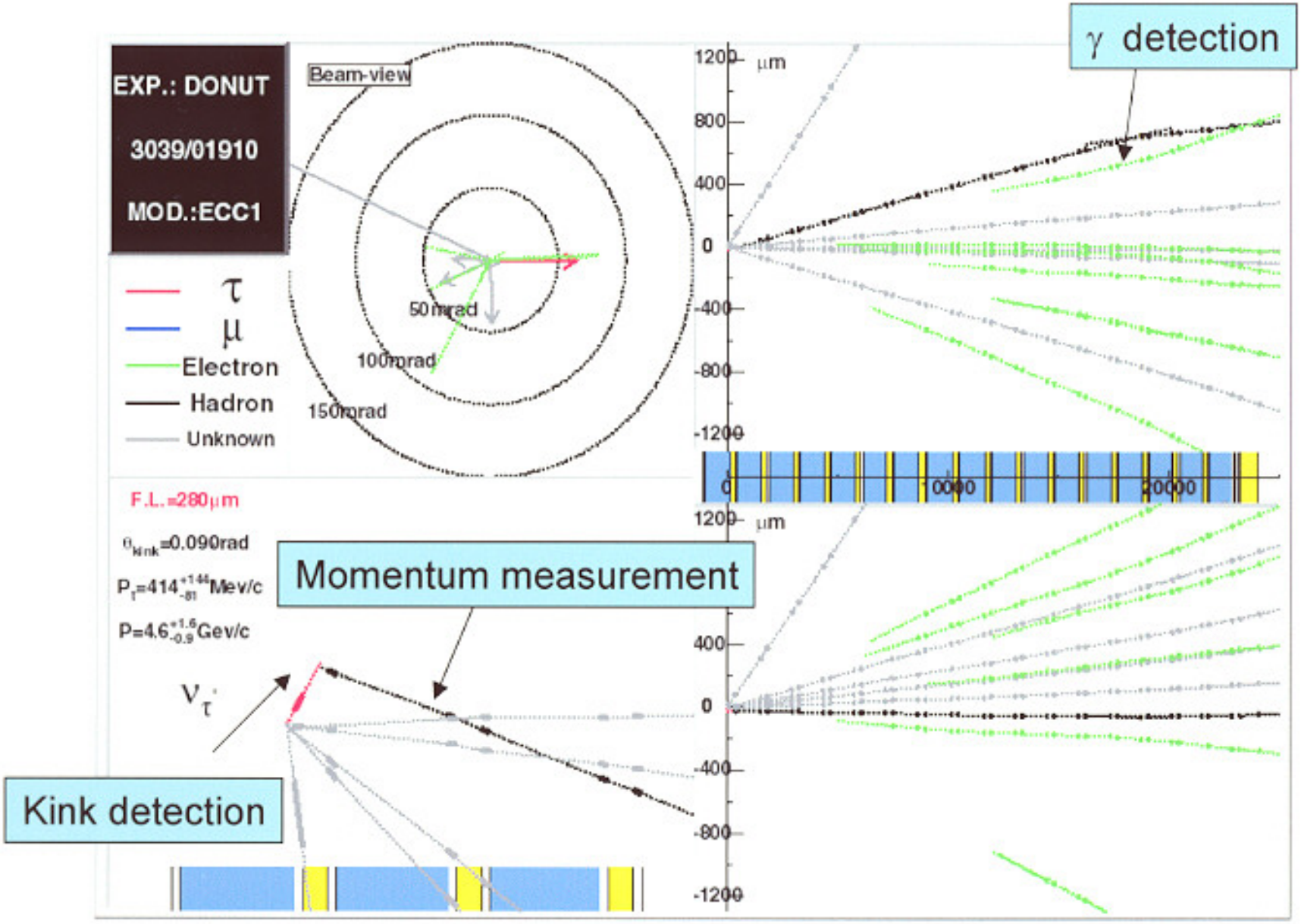
OPERA is an emulsion experiment similar to DONUT

ν_τ CC event is identified
by detecting τ decay vertex

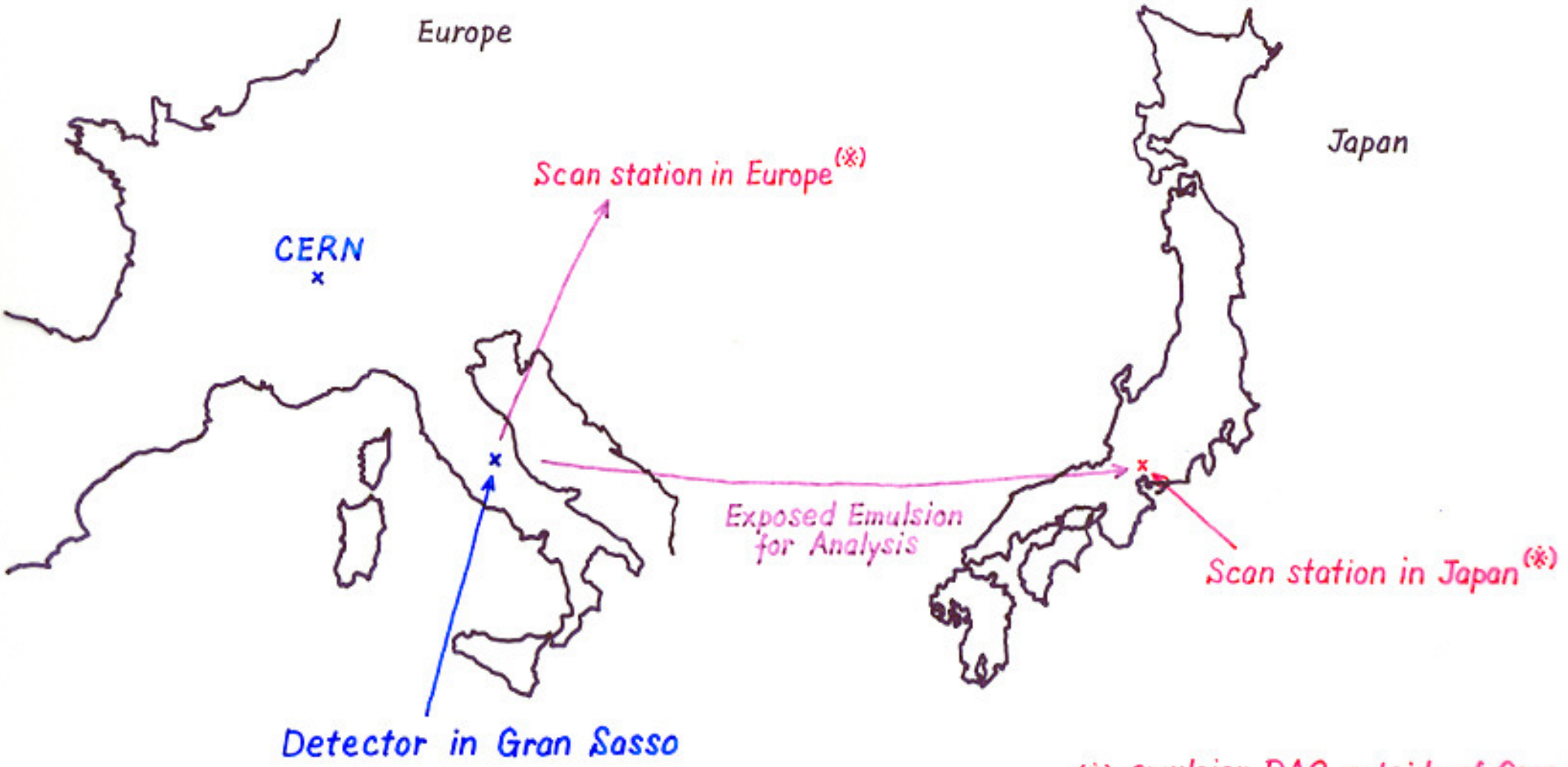


closeup view near the neutrino interaction

Electron ID in emulsion
μ ID in emulsion and in electronic detector
Momentum measurement in emulsion
} to reject backgrounds


γ detection
EXP.: DONUT
3039/01910
MOD.:ECC1
Beam-view
τ
μ
Electron
Hadron
Unknown
50mrad
100mrad
150mrad
F.L.=280μm
θkink=0.090rad
Pt=414+144-81Mev/c
P=4.6+1.6-0.9Gev/c
Momentum measurement
Kink detection
νμ
1200 μm
800
400
0
-400
-800
-1200
10000
20000

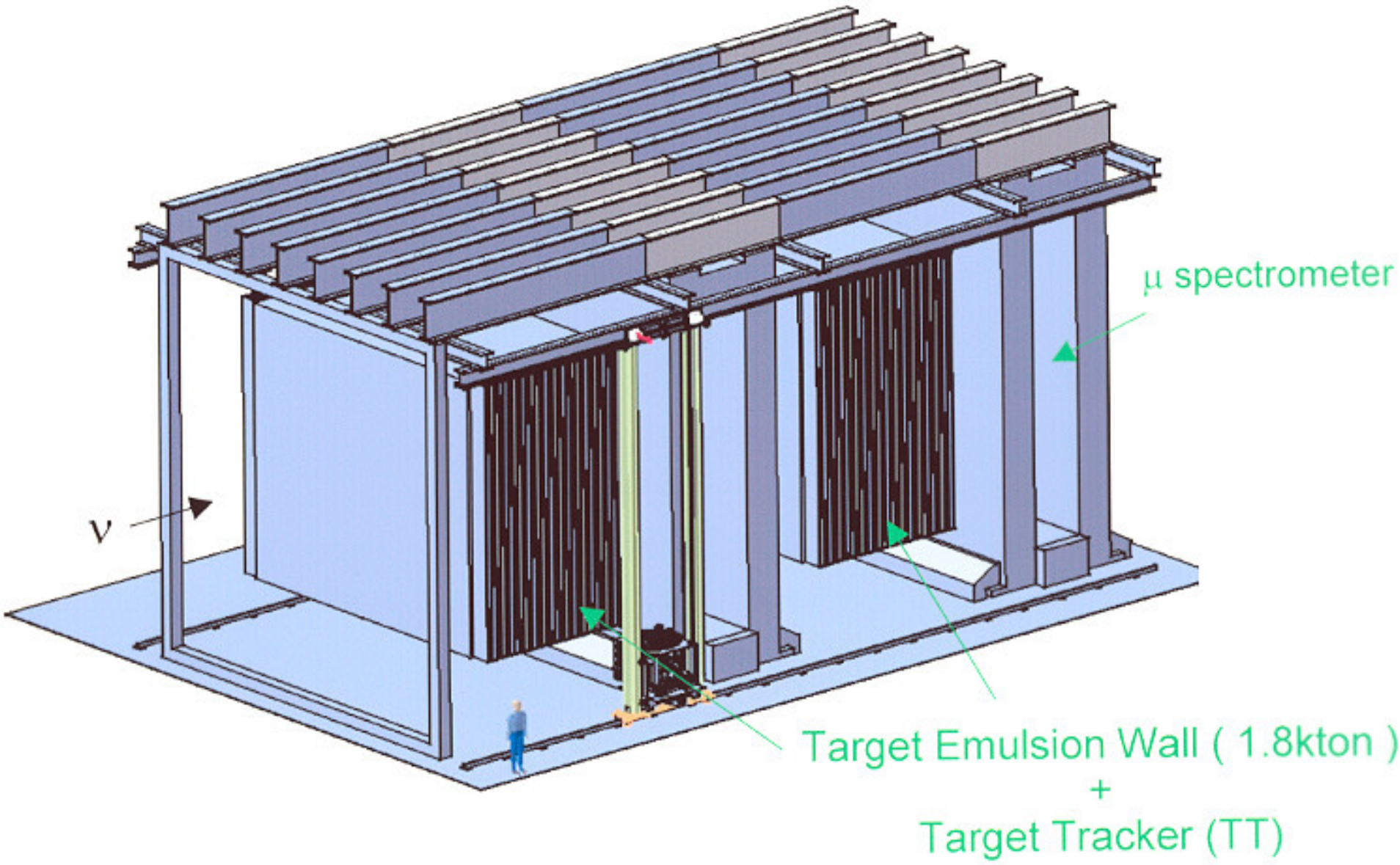
OPERA Construction



(※) emulsion DAQ outside of Gran

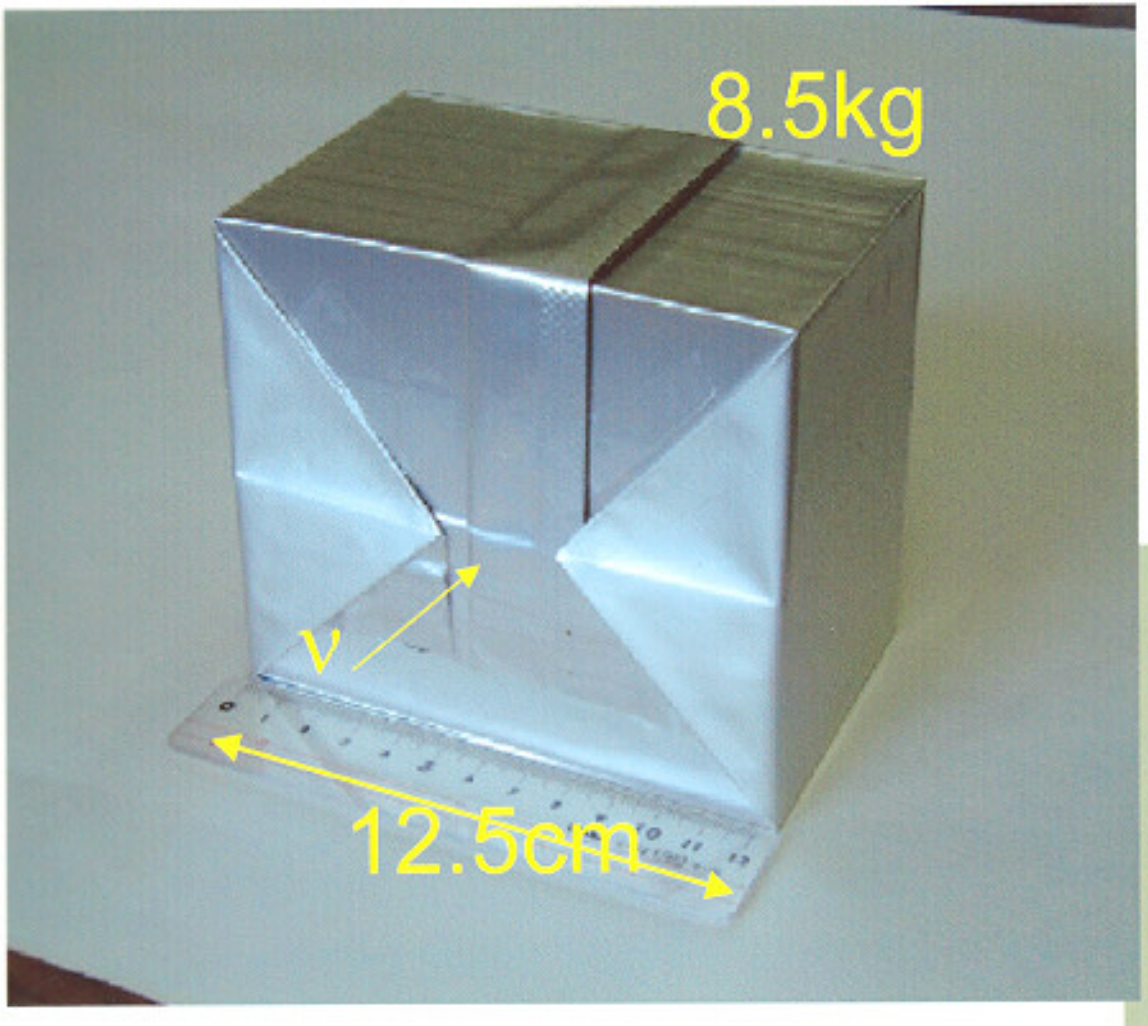
→ Analysis begins when the beam

OPERA Detector in Gran Sasso

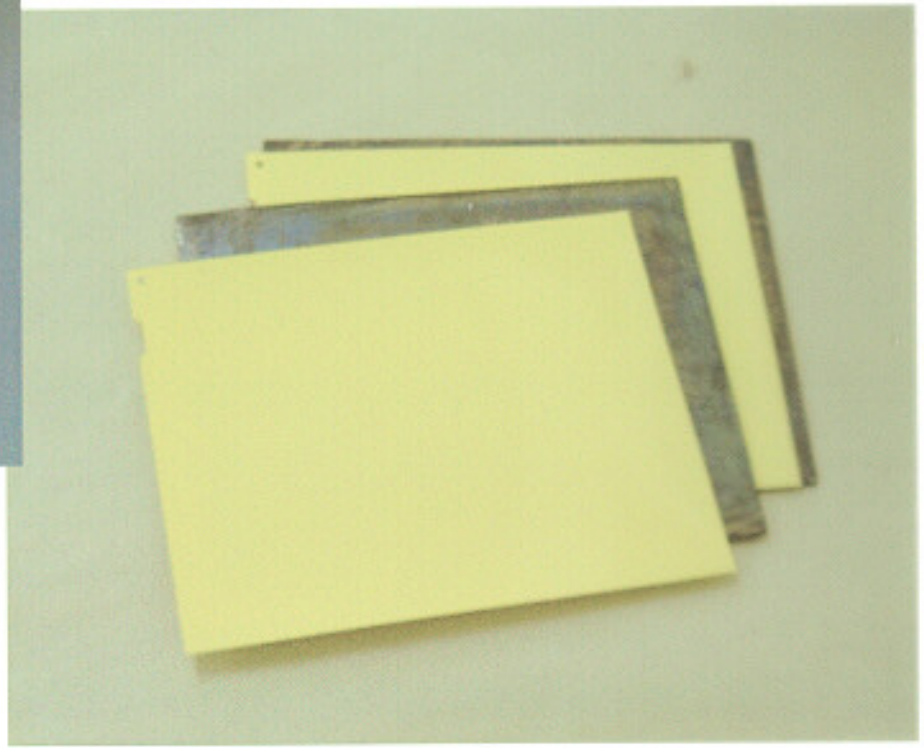


Emulsion Brick for OPERA

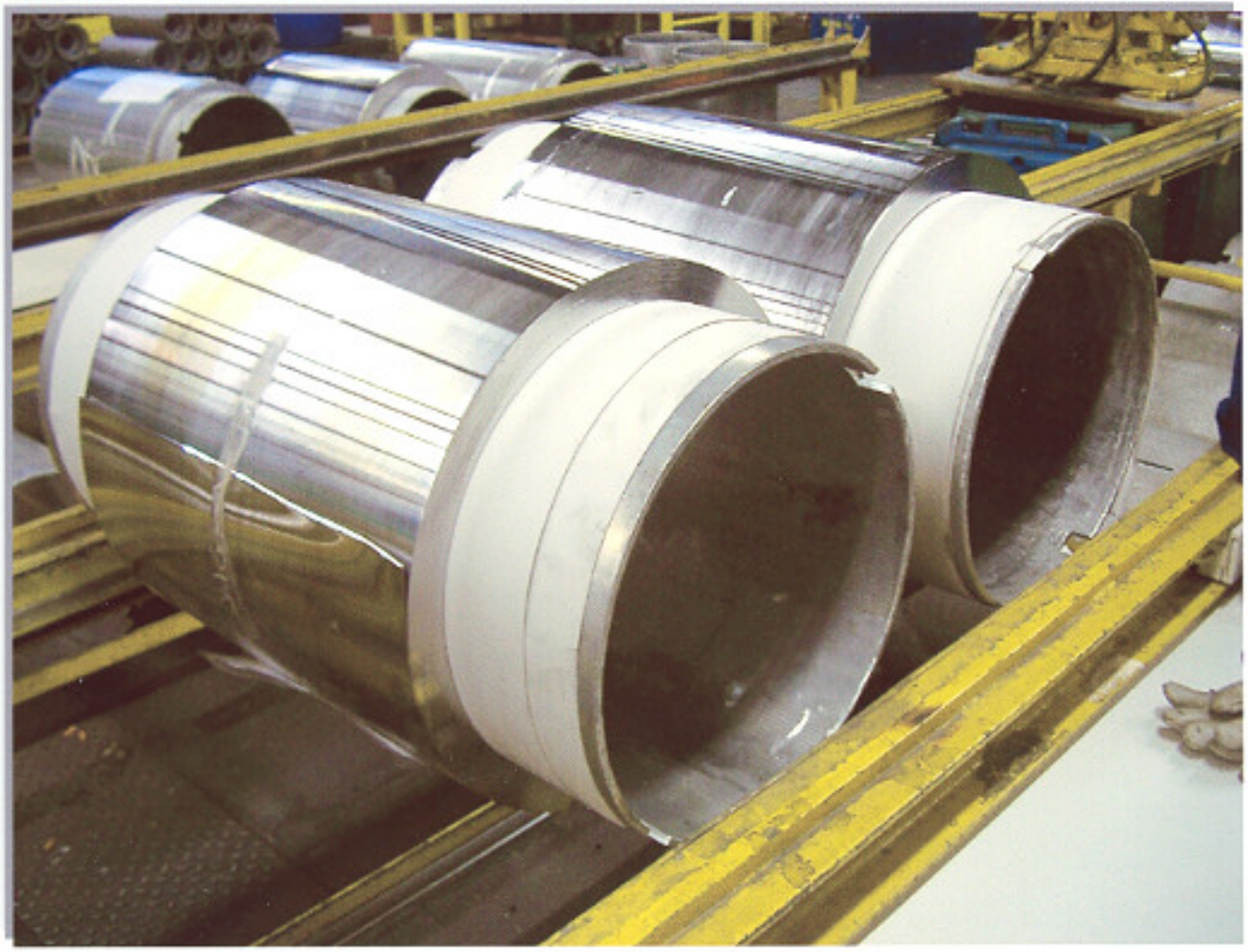
use 200k bricks



57 emulsion sheets and
56 lead plates are
vacuum packed



Lead Production (Germany)



Low radiation lead

10t Boliden Pb + 0.6t Britannia Pb

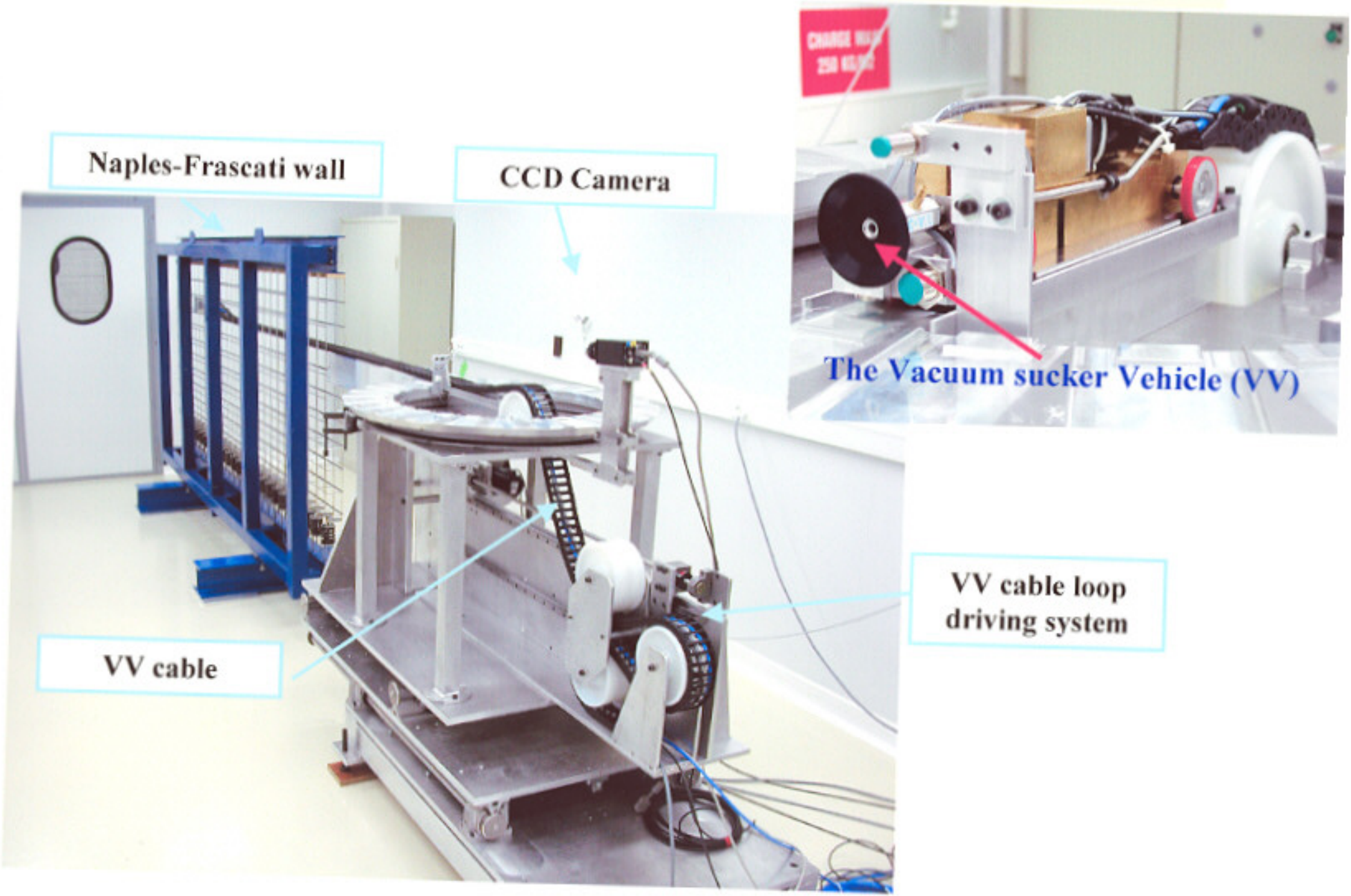
rolled and ready for prototype mass production (25t)

OPERA Target Wall (Italy)

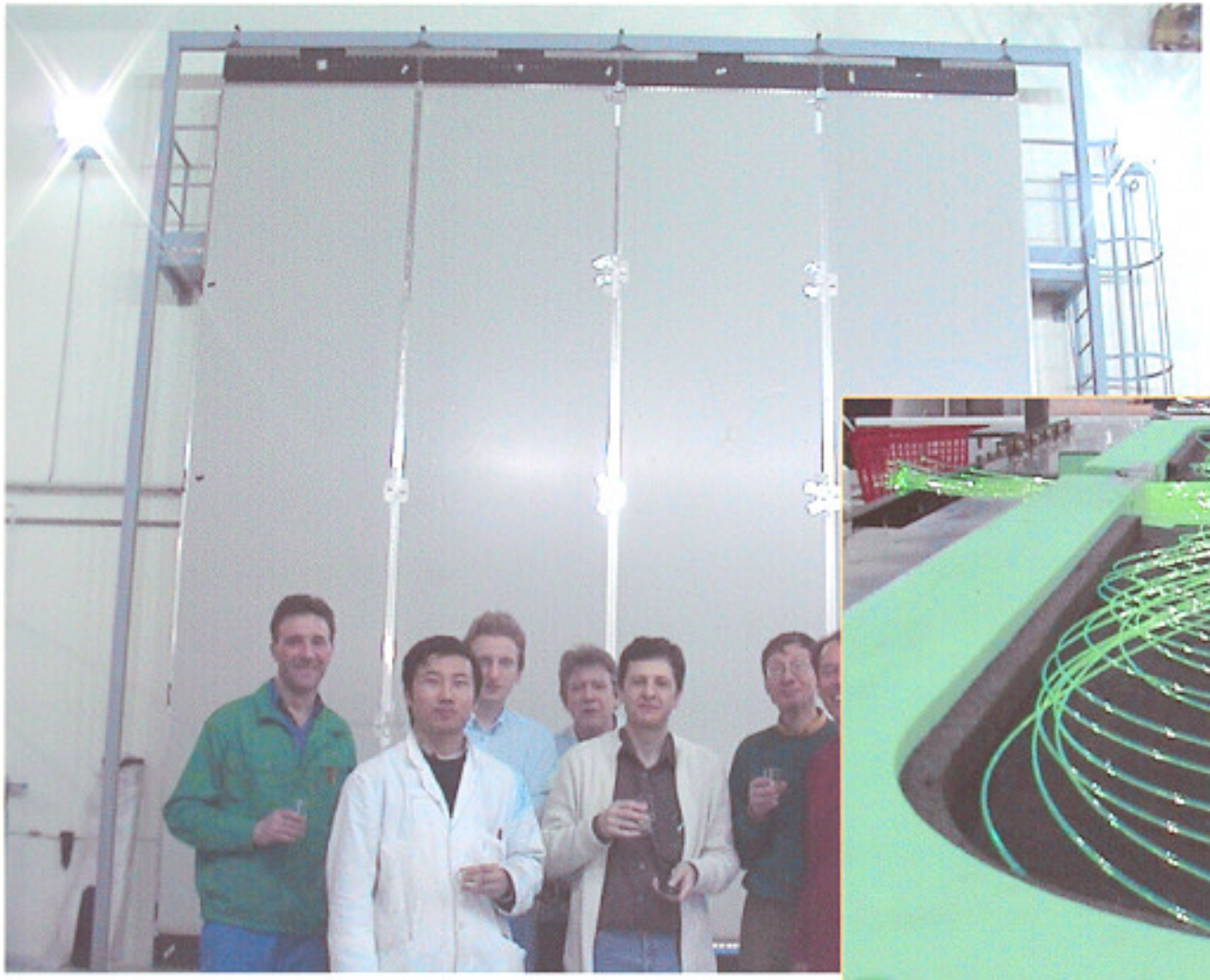
Brick loading test

- Full size proto built by ILMA
- Delivery at LNGS : June 2004

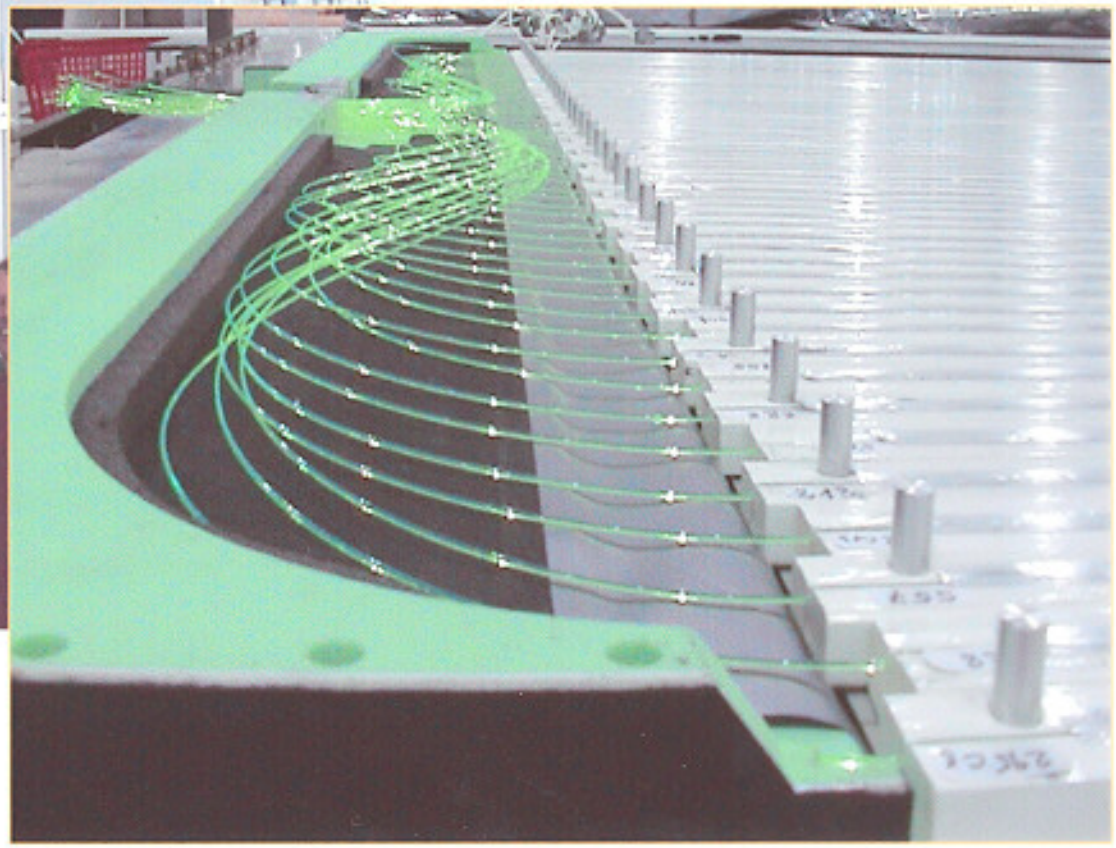
Brick Manuputating System Prototype Tests



OPERA Target Tracker (France)



First TT vertical plane



τ Decay analysis is no problem

Enough experience from DONUT and CHORUS physics analysis

< 100 k ν interactions in OPERA

DONUT

Observation of tau neutrino interactions

- Phys. Lett. B504 (2001) 218 — 4 ν_τ CC events among 203 ν interactions
  → 7 ν_τ CC now

CHORUS ~ 140 k ν interactions now

Measurement of D^0 production in neutrino charged-current interactions

- Phys. Lett. B527 (2002) 173 — 283 D^0 decays among ~ 25 k ν_μ CC events

Measurement of Λ_c^+ production in neutrino charged-current interactions

- Phys. Lett. B555 (2002) 156 — 338 Λ_c^+ candidates among ~ 50 k ν_μ CC events

Determination of the semi-leptonic branching fraction of charm hadrons produced in neutrino charged-current interactions

- Phys. Lett. B549 (2002) 48 — 956 charm candidates among ~ 56 k ν_μ CC events

Improvements in OPERA

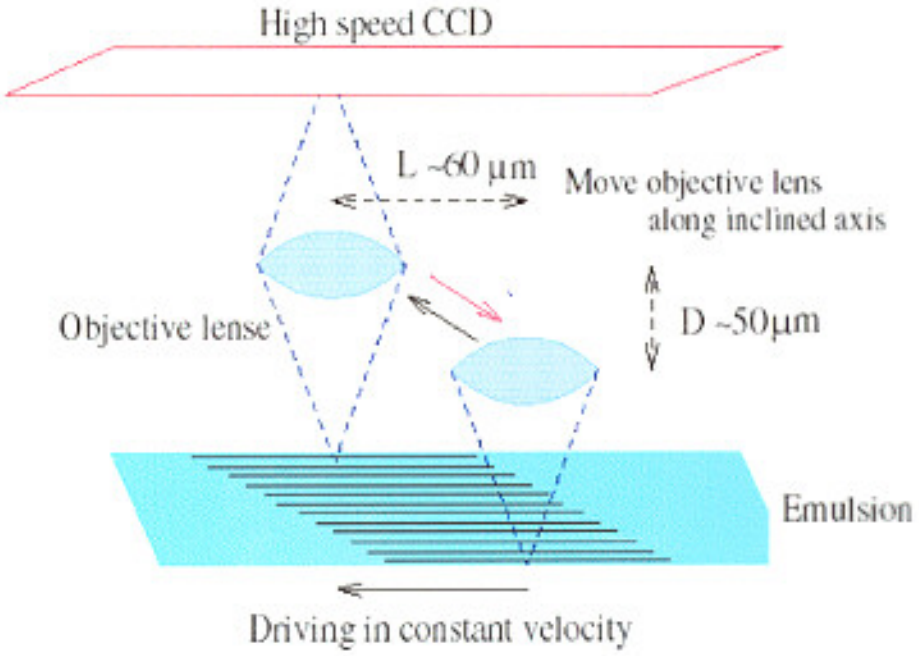
- S-UTS (faster emulsion DAQ) 1 cm²/h → > 20 cm²/h
- dE/dx (i.e. β) measurement (low momentum μ ID)
- Better electron ID and energy measurement ← clean emulsion by refresh + Pb instead of F

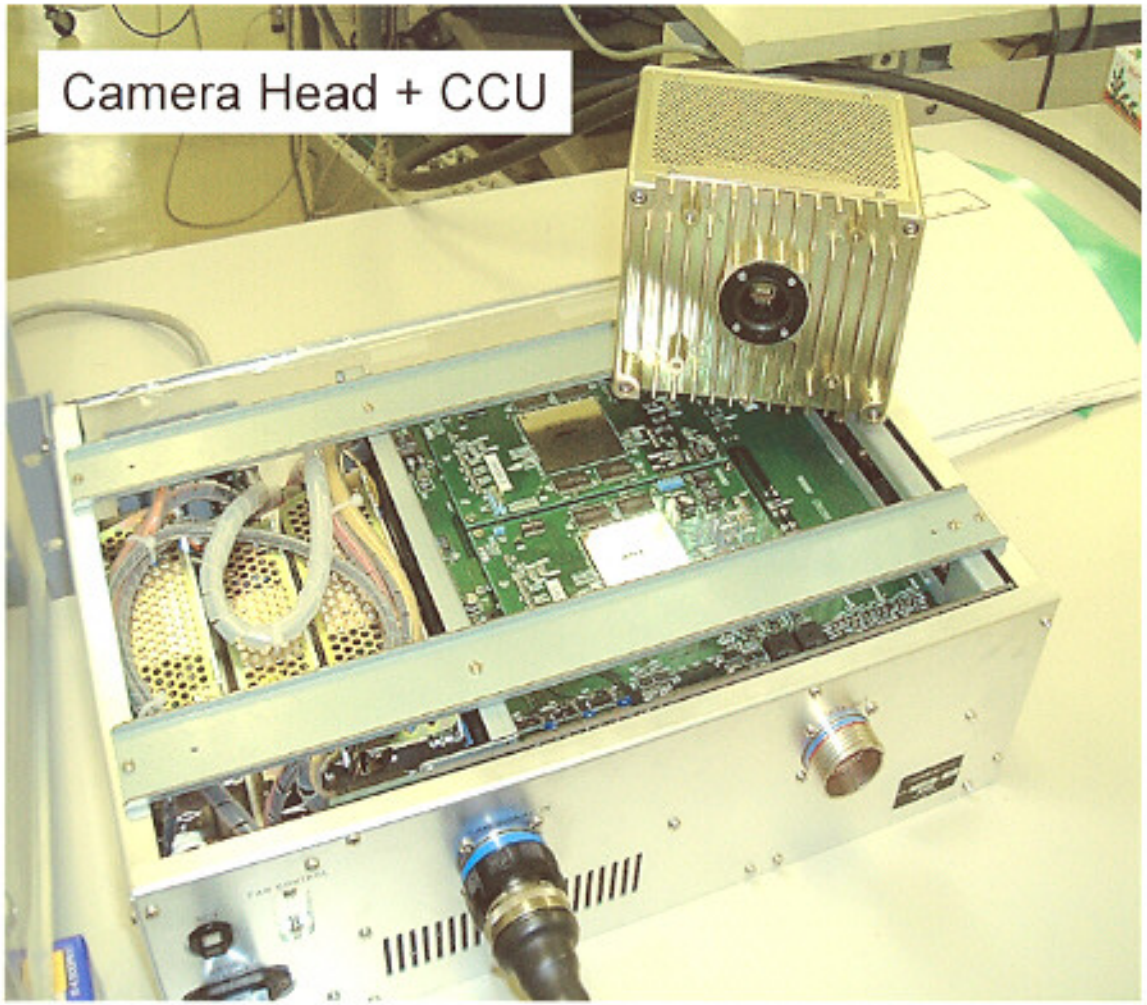
Emulsion Scanning Station in F-Lab (Japan)

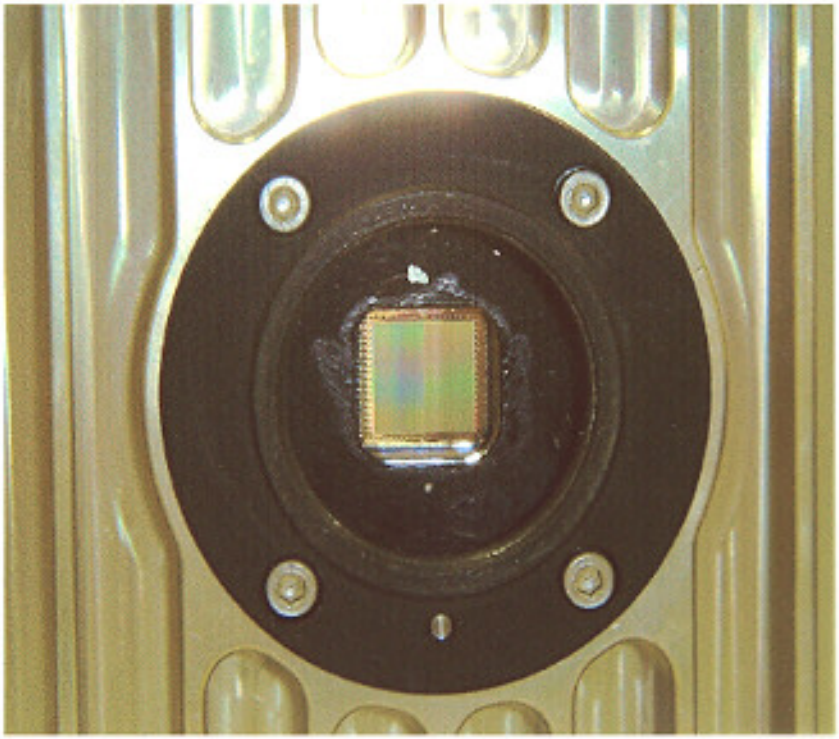
S-UTS (new emulsion DAQ system)

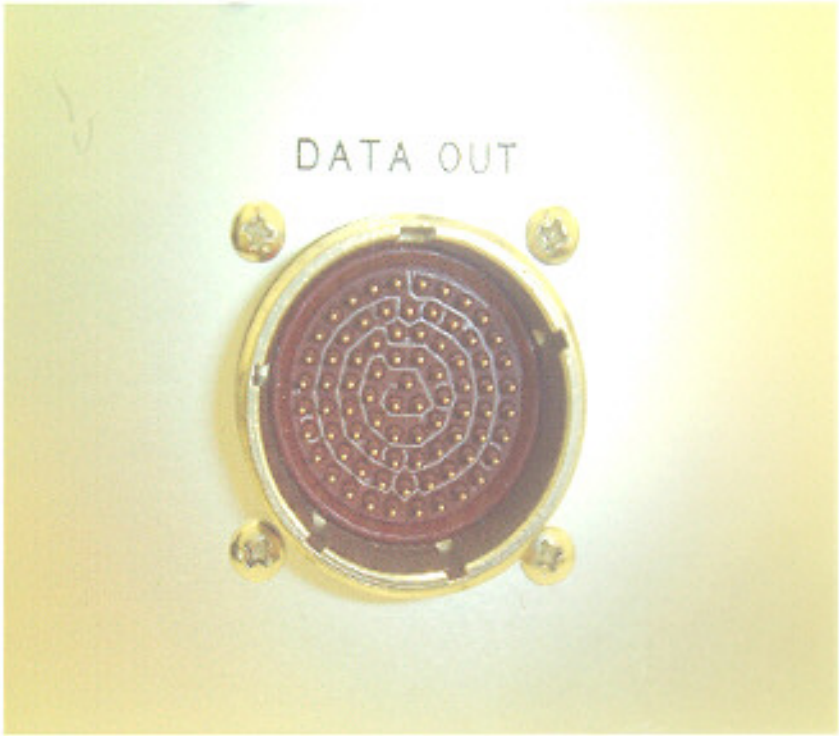
UTS (current system) runs at 1cm2/h
→ S-UTS is designed to run at 20cm^2/h or faster

- Ultra High Speed Camera
  - Up to 3k frames per second.
    → Max 100views/sec
- Image taking by follow shot
  - No go-stop operation to avoid a mechanical bottleneck.









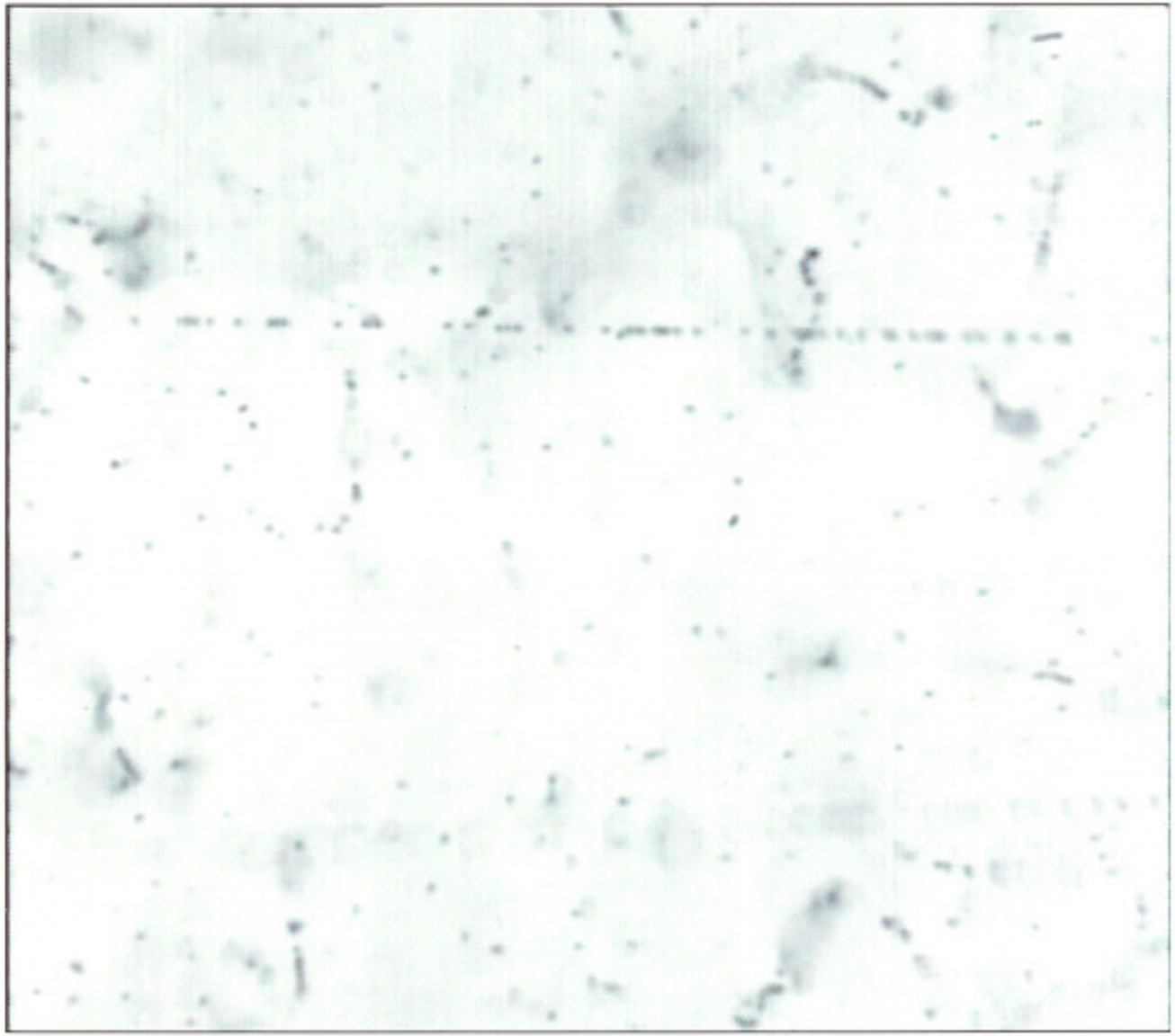
Ultra High Speed CCD Camera for S-UTS

- 512(H)×504(V) pixels
- 3k frames/sec
- Digital output via LVDS, 1.3Gbyte/sec

↓

real time processing

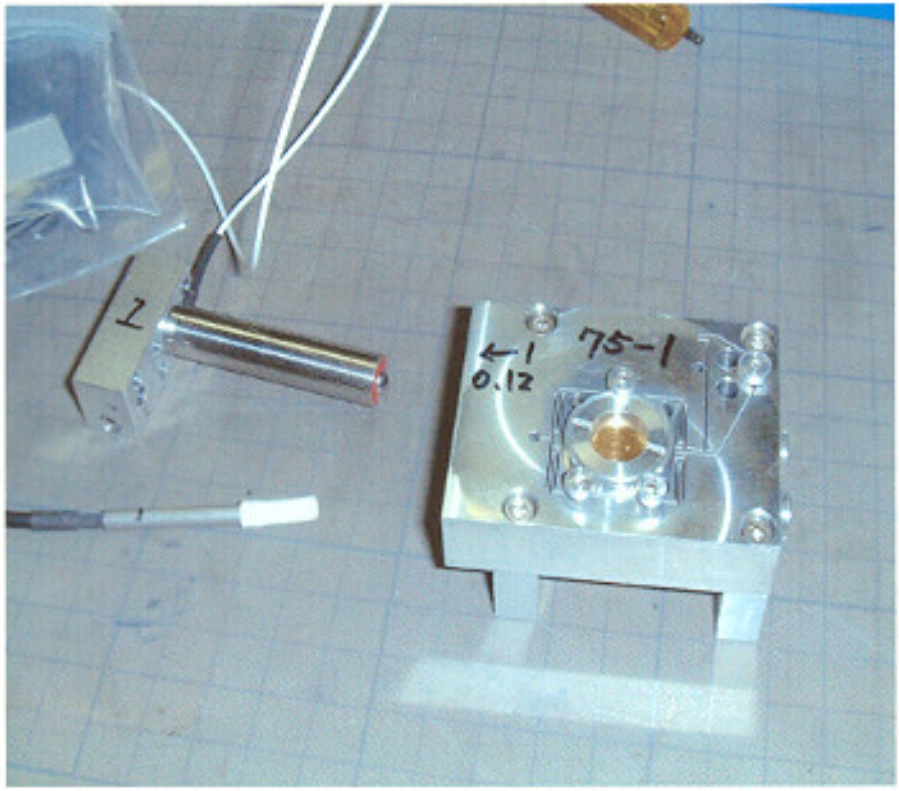
S-UTS camera image consists of 32 readout channels



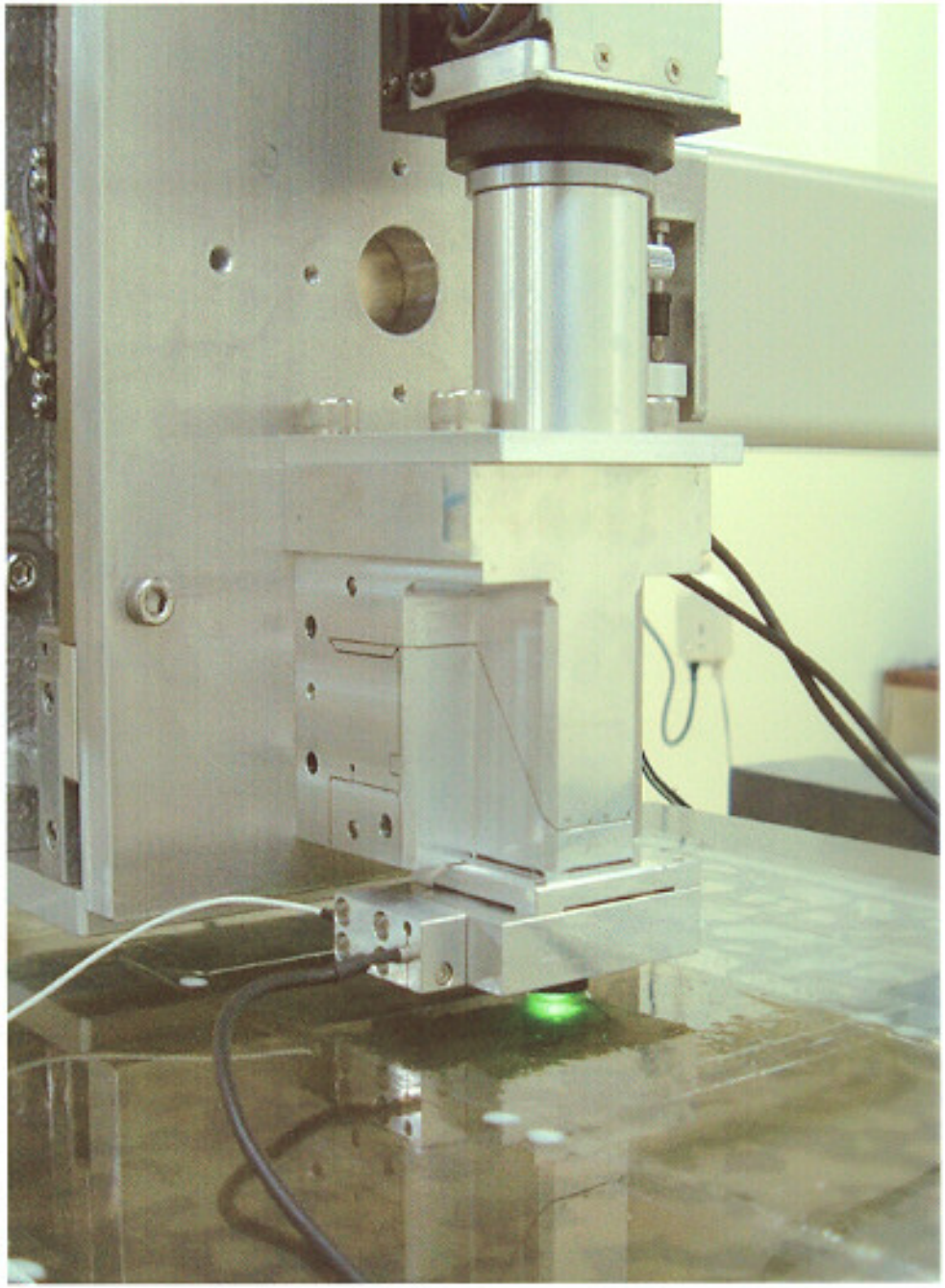
Objective lens actuators for S-UTS

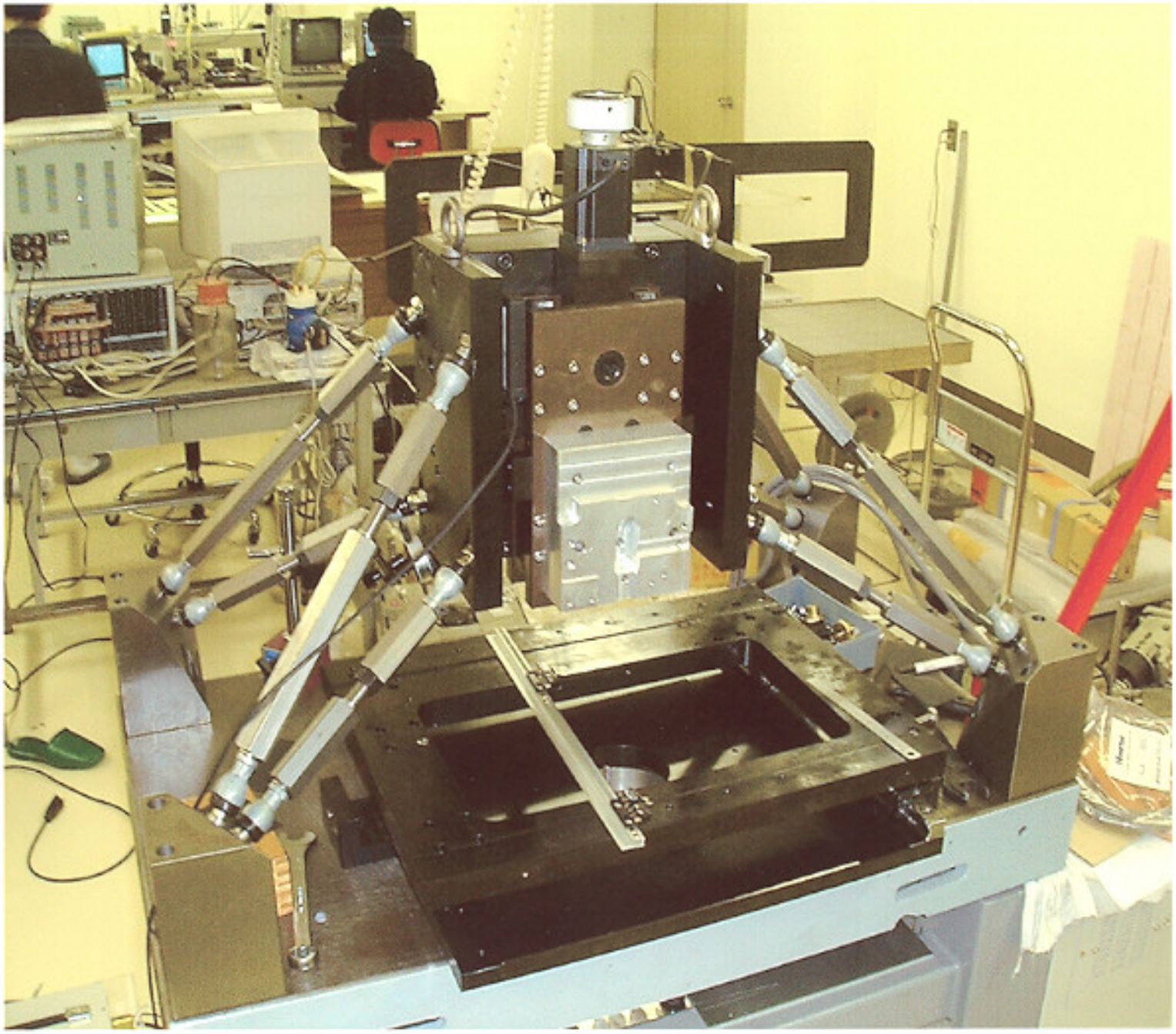
made by S.ISHIKAWA

Horizontal



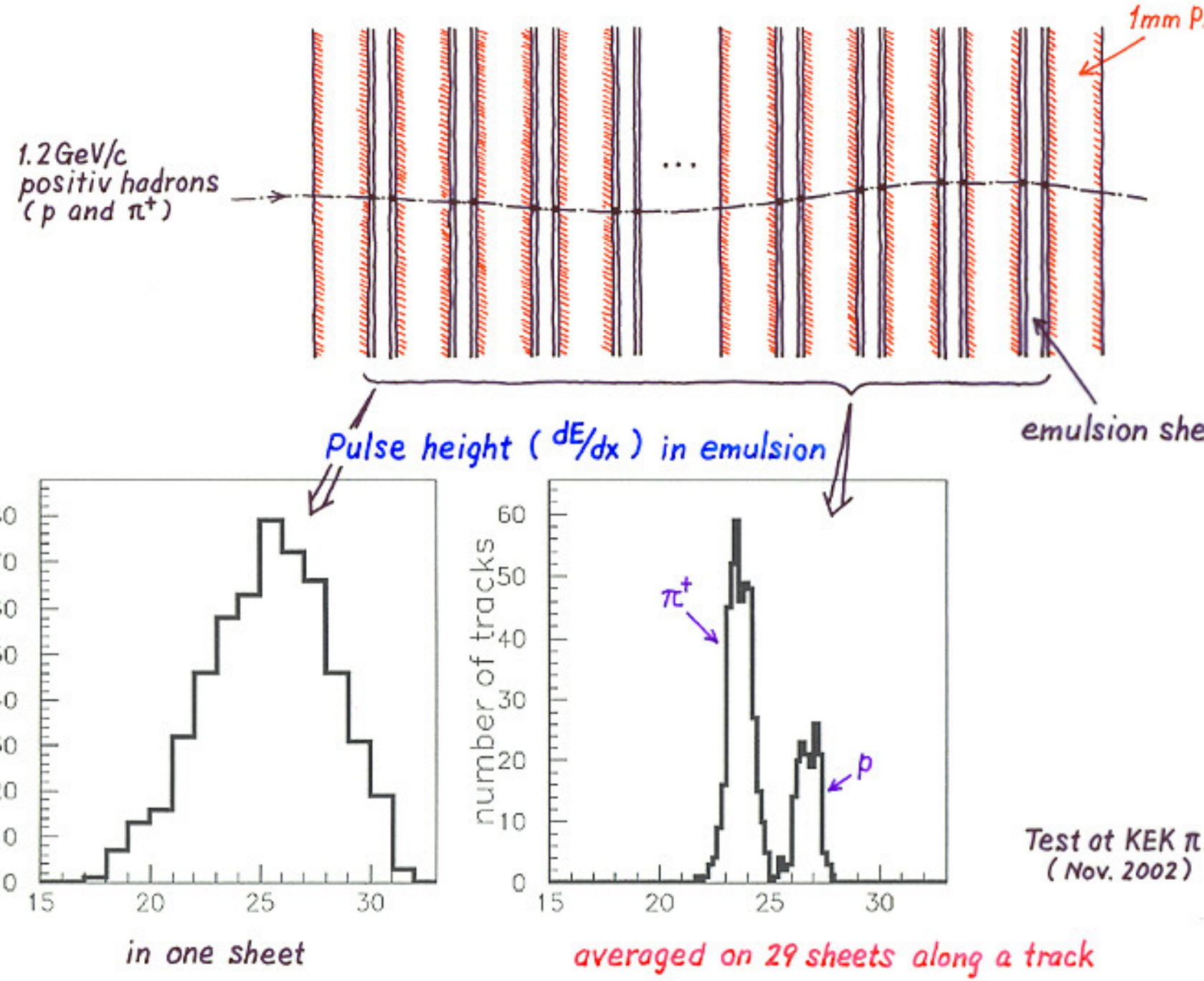
Horizontal + Vertical



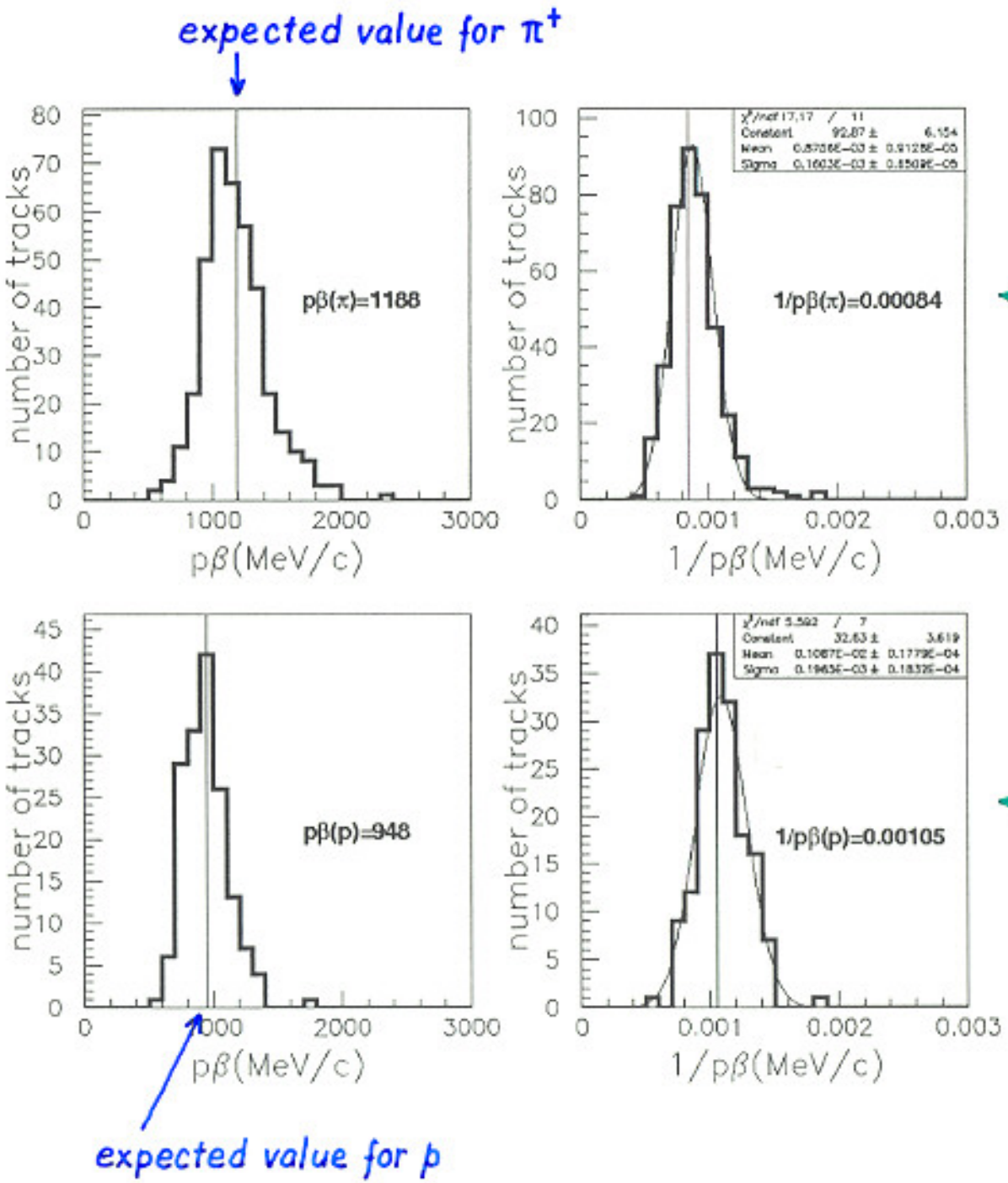


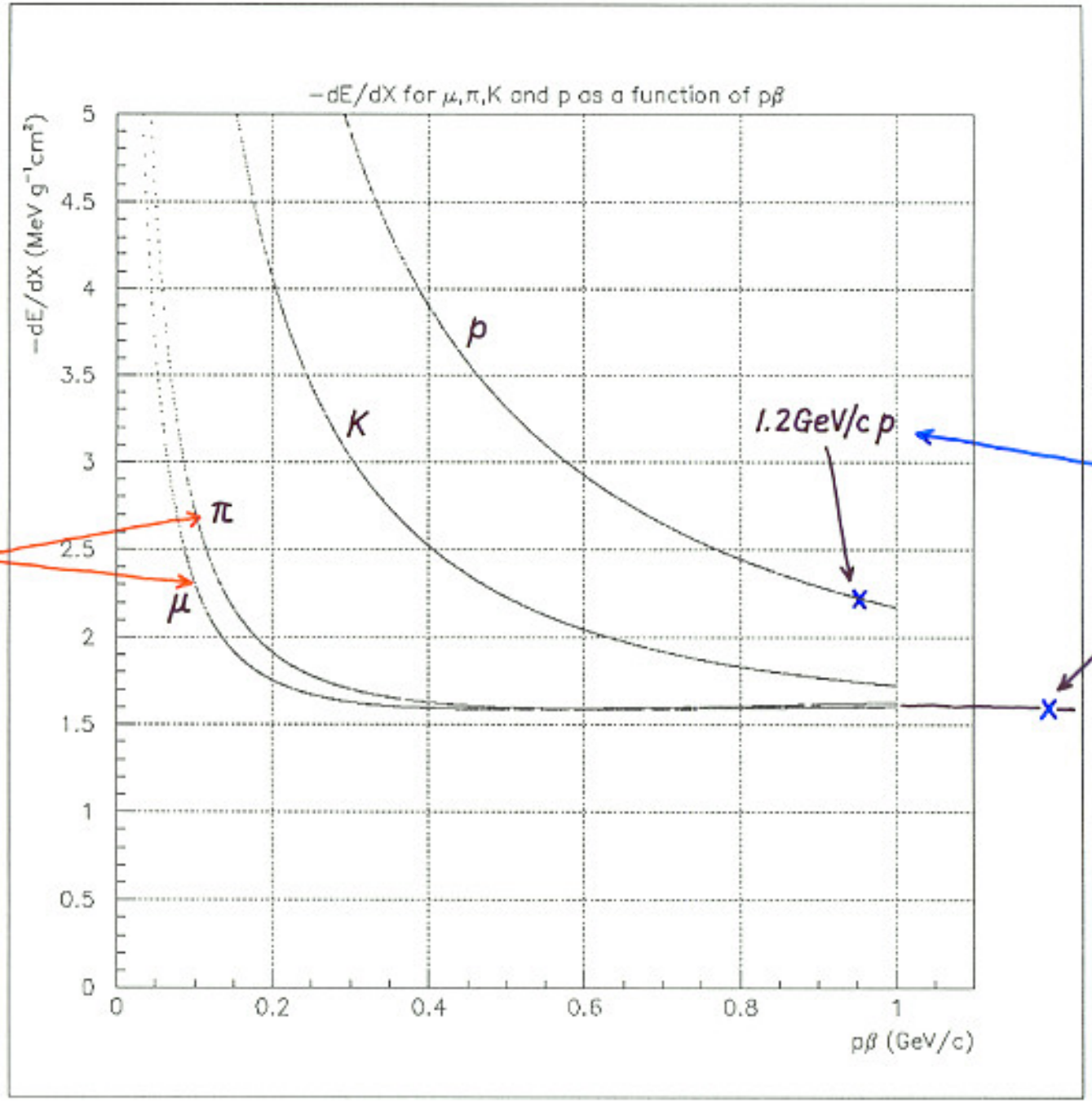
Prototype stage for S-UTS by T.KAWAI

dE/dx (or β) in emulsion is a measurable quantity in automated scan (Track Selector)

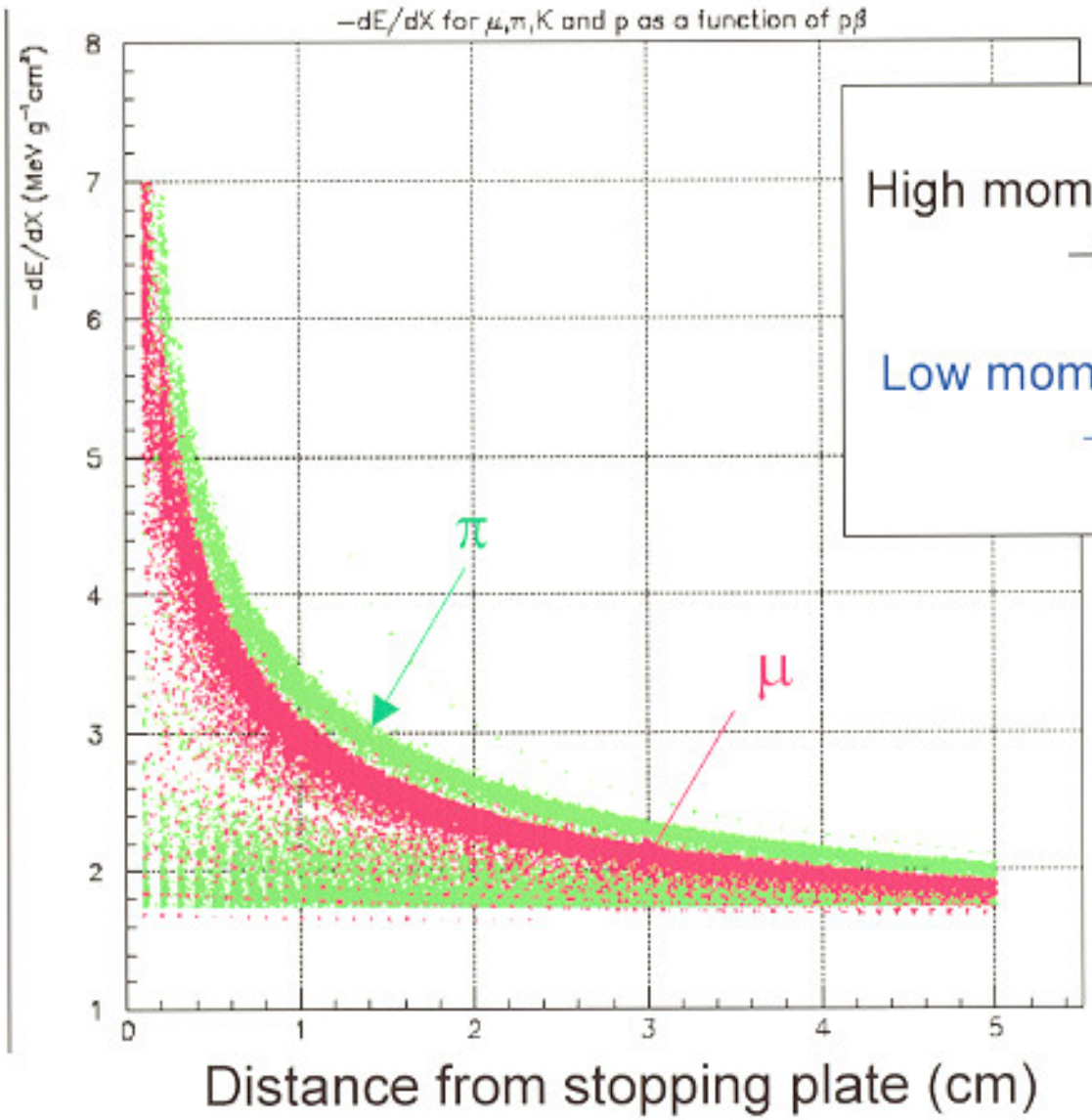


Test at KEK π
(Nov. 2002)


expected value for π+
number of tracks
pβ(π)=1188
pβ(MeV/c)
1/pβ(π)=0.00084
1/pβ(MeV/c)
Low pulse height gro
has pβ consistent wi
pβ(p)=948
1/pβ(p)=0.00105
High pulse height gro
has pβ consistent wi
expected value for p


−dE/dX for μ,π,K and p as a function of pβ
−dE/dX (MeV g⁻¹cm²)
pβ (GeV/c)
p
K
π
μ
1.2GeV/c p
1.2GeV/c π
identify stopping μ
to kill charm BG
clear separation

μ identification

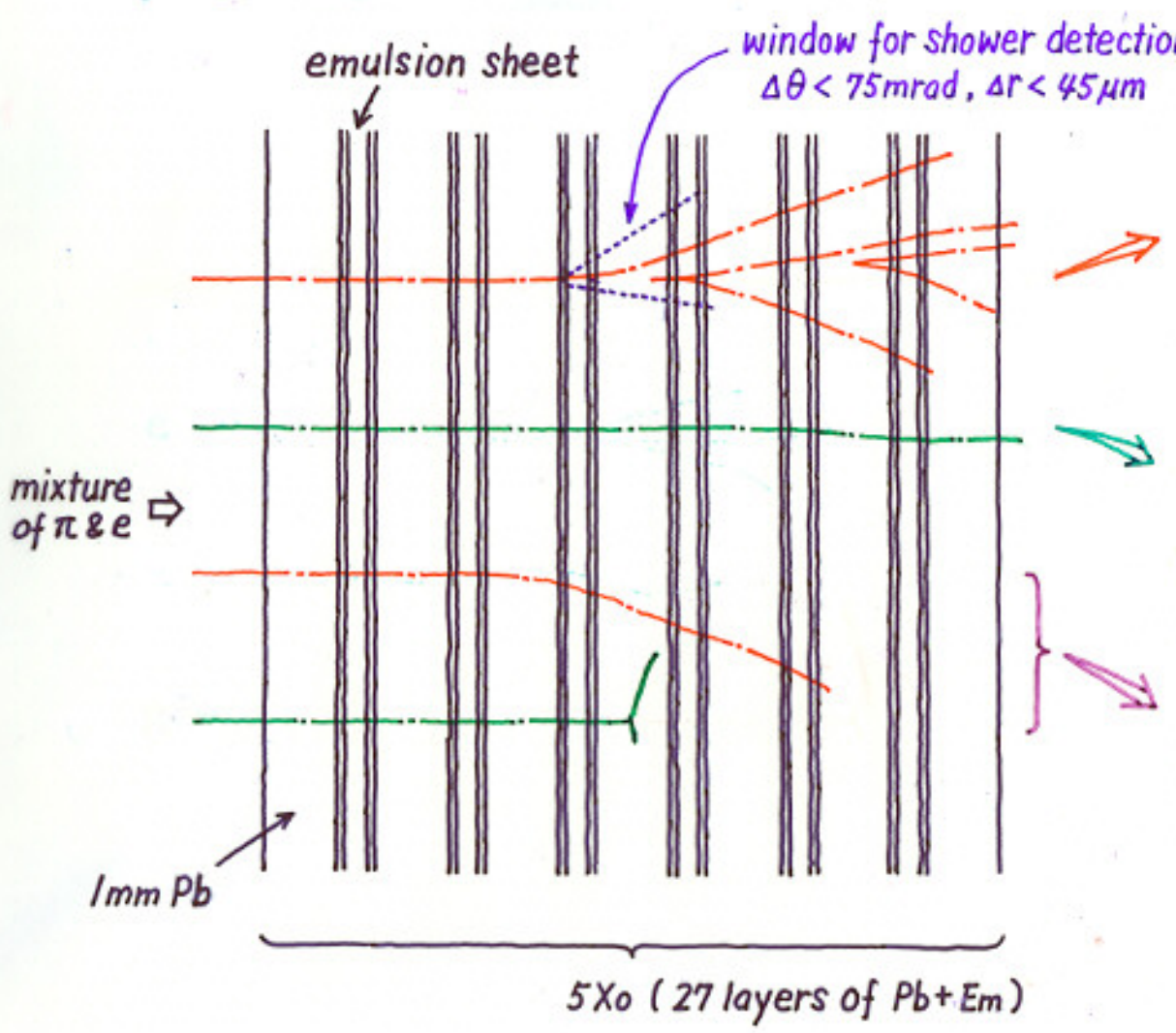


High momentum μ (range ≥ $4\lambda_{INT}$)
→ range measurement in TT

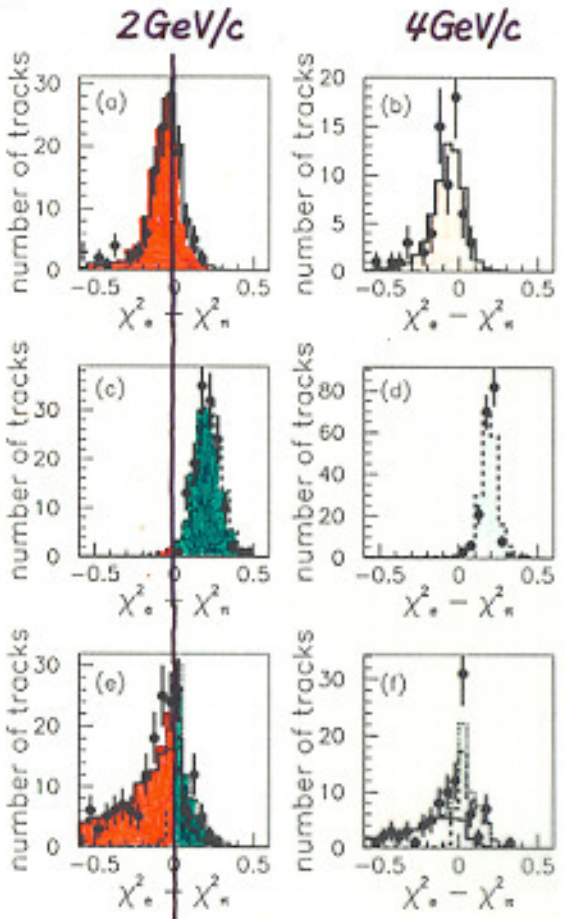
Low momentum μ (range ≤ $4\lambda_{INT}$)
→ dE/dx measurement in emulsion

further reduction of charm BG

Electron ID = detect shower + measure energy loss due to bremsstrahlung



small due to high BG track density



with shower
→ electrons

passing thro
w/o shower
→ pions

stop w/o sho
→ electrons+

eff.~90%, mis-id ~5%

e-like energy loss ⇐ ⇒ π- like energy loss

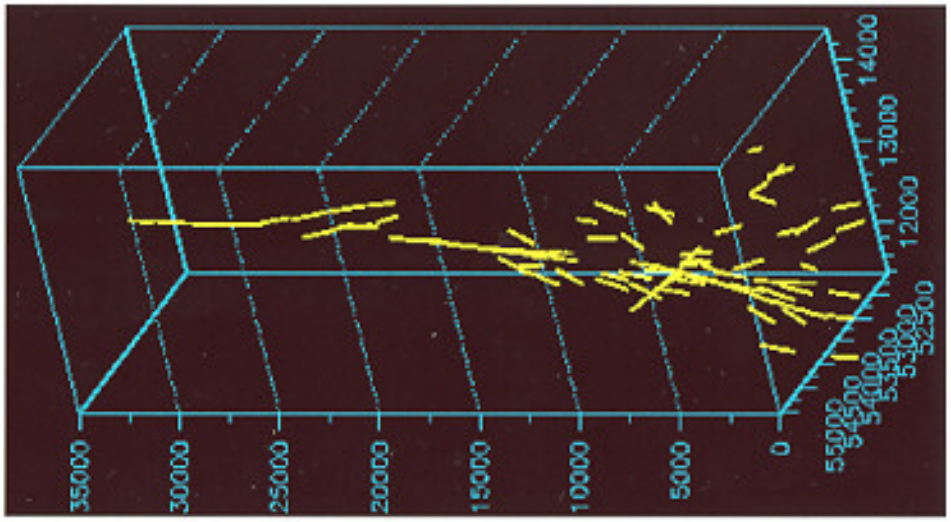
$E \sim E_0 e^{-\frac{x}{X_0}}$ $E \sim E_0$

Test @ CERN PS
(May 2001)

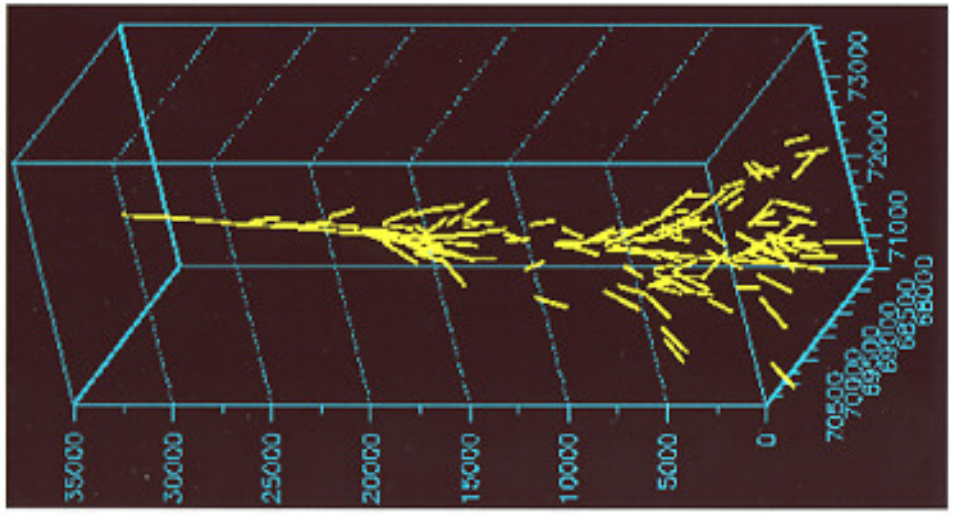
Energy loss measurement by multiple scattering

Electron energy measurement by counting track segments in a horn

2GeV/c



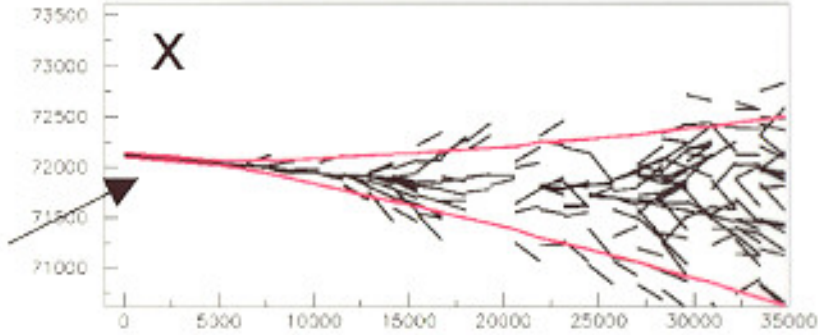
4GeV/c

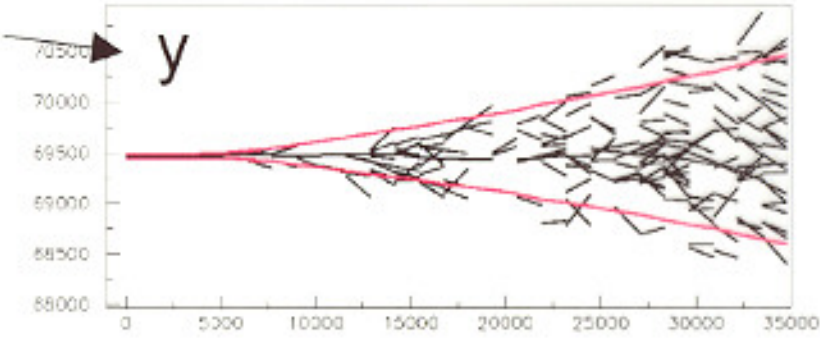


$E_{electron} \propto$ # of track segments

$\Delta\theta_{beam}$<250mrad

68% of shower tracks are contained @ 4GeV





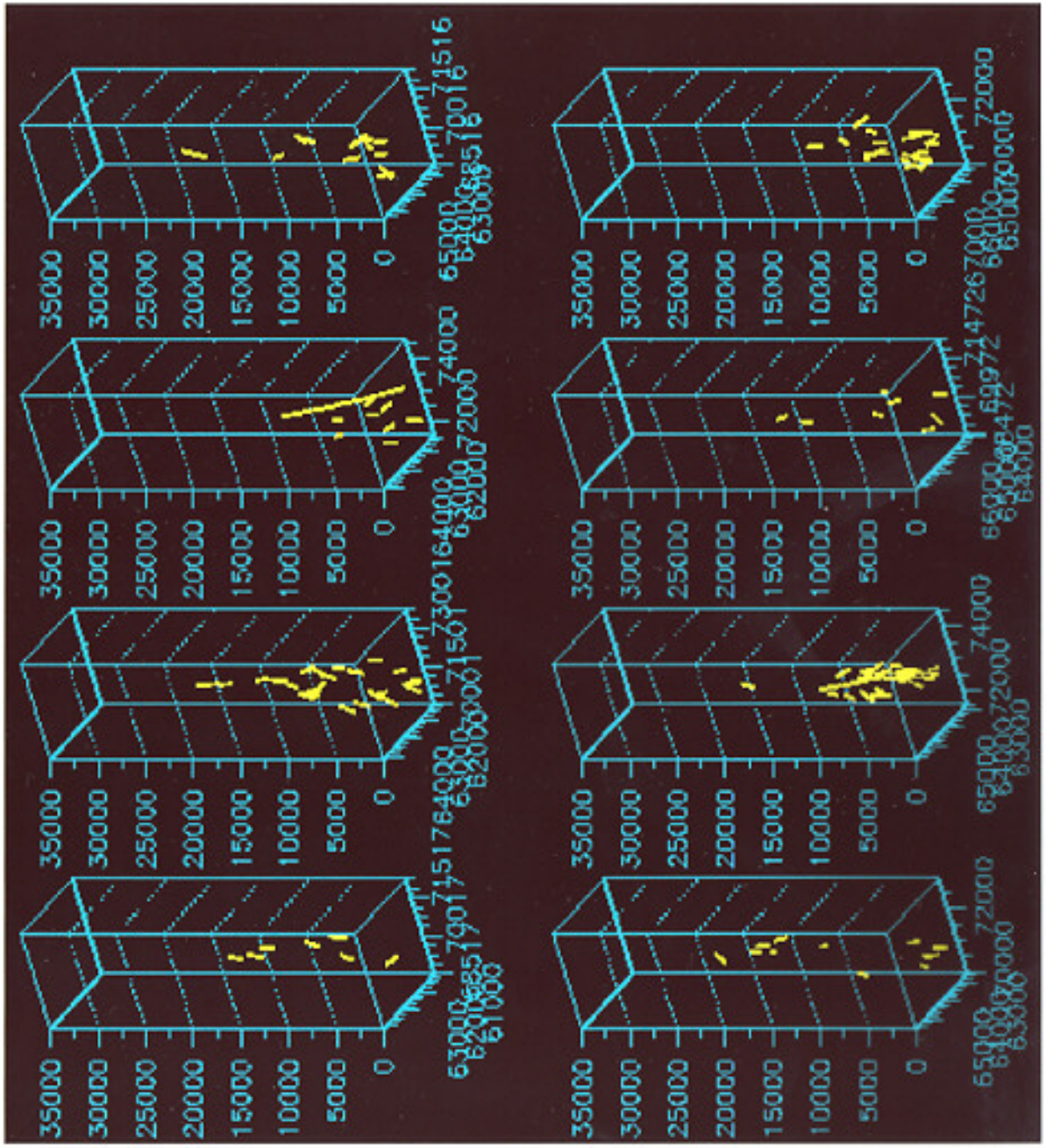
Test @ CERN PS
(May 2001)

Estimation of background

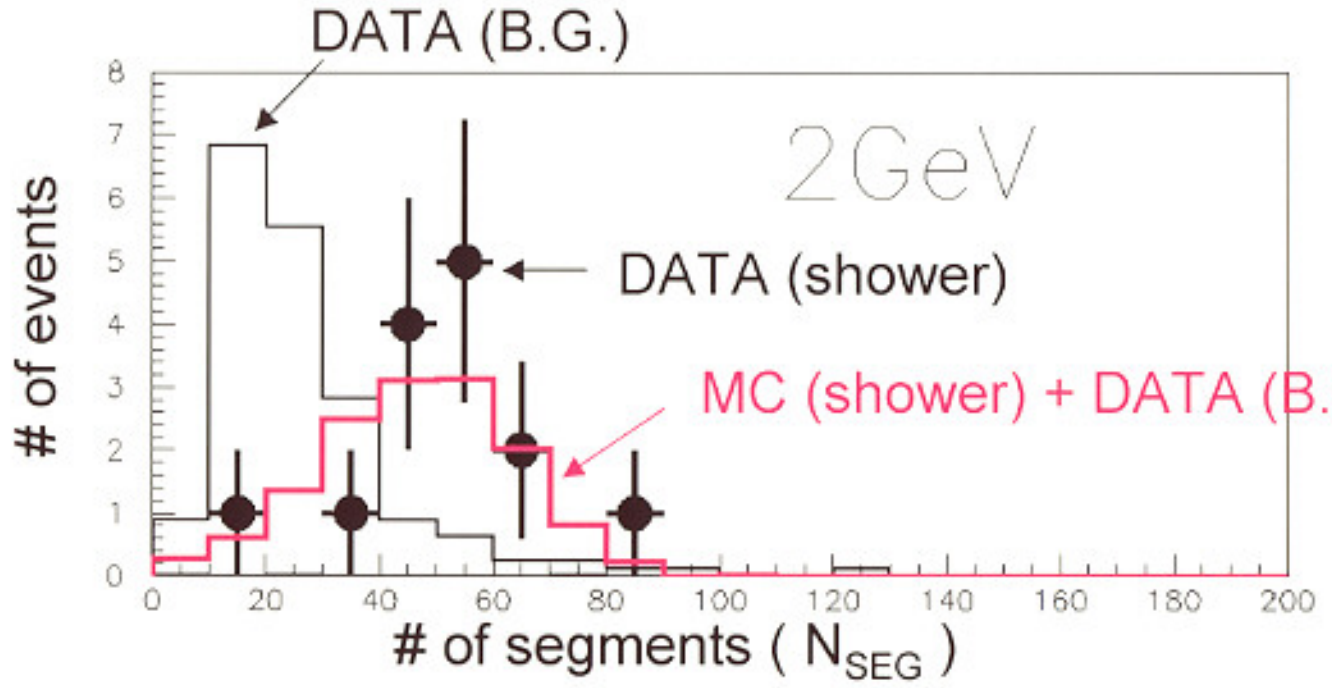
at random volume

Track segments from another electron and interaction are seen.

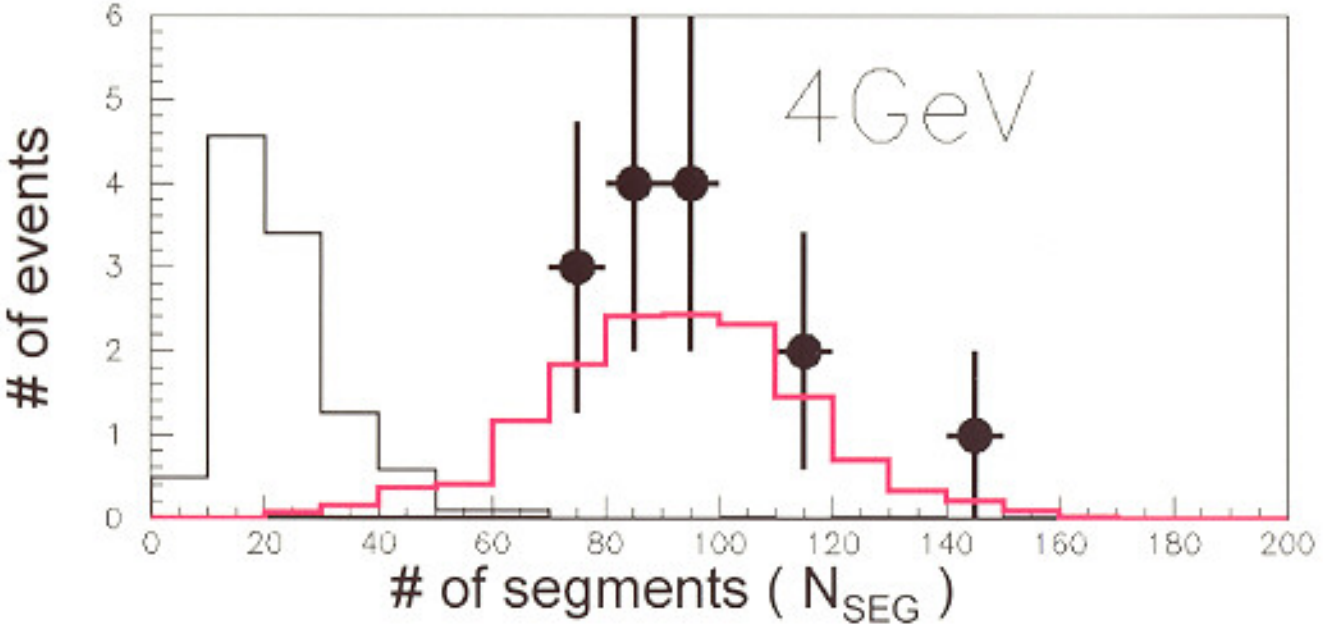
Random background ~1track/mm^2



$E_{electron} \propto$ # of segments



$N_{SEG} = 51 \pm 14$



$N_{SEG} = 94 \pm 18$

Electron ID and its energy measurement are done in emulsion

using...

(1) energy loss measurement by multiple scattering

energy loss difference between electrons and pions

$$\begin{cases} E_e(z) \sim E_0 e^{-\frac{z}{X_0}} & \leftarrow \text{bremsstrahlung} \\ E_\pi(z) \sim E_0 \end{cases}$$

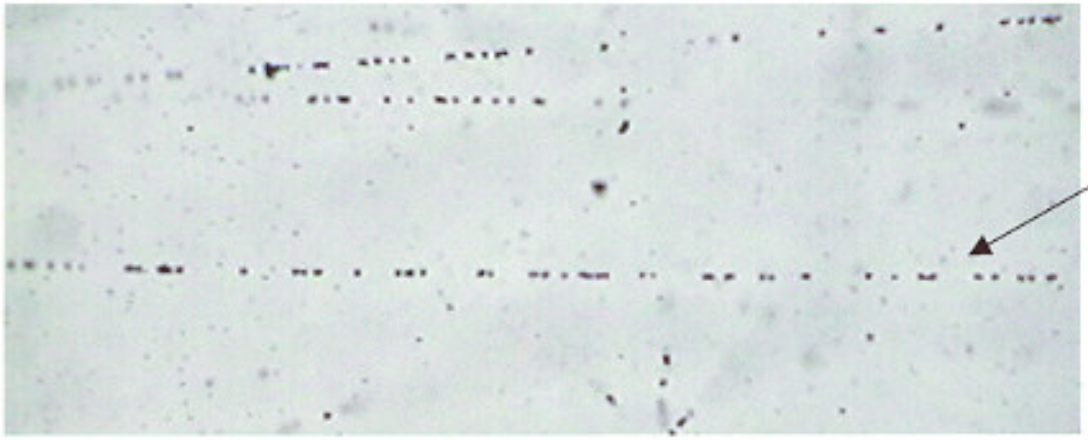
(2) cascade shower detection

Our data from tests are well understood and reproduced by Monte Carlo.

- identification eff. ~ 90%, mis-id probability ~ 5%
- energy measurement $\frac{\Delta E}{E} \sim \frac{0.4}{\sqrt{E(\text{GeV})}}$ @ a few GeV

These performances can be improved in lower BG condition ! ⟹ refreshable em

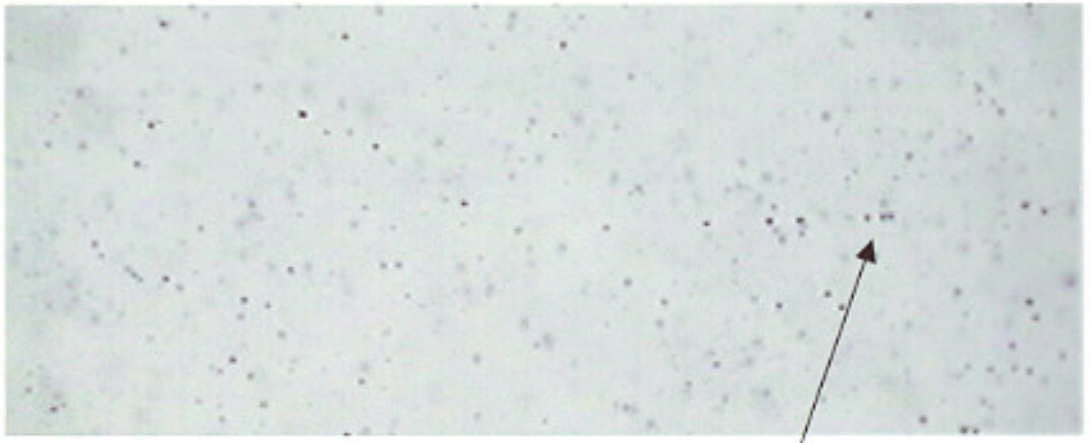
Refreshable Emulsion



Trajectory of a charged particle

~35grains/100micron

Refresh (3days in 30°C and 98% RH)



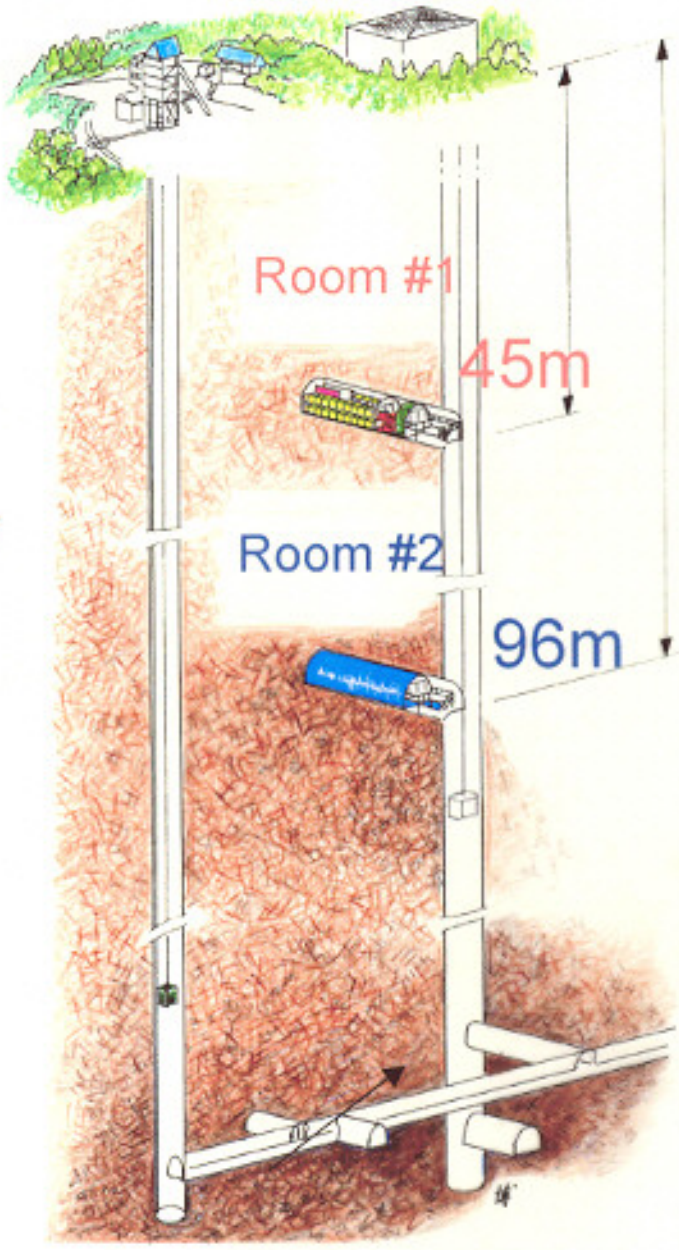
~ 8grains/100μm remains

Refresh Facility in Tono Mine

Cosmic ray shielding

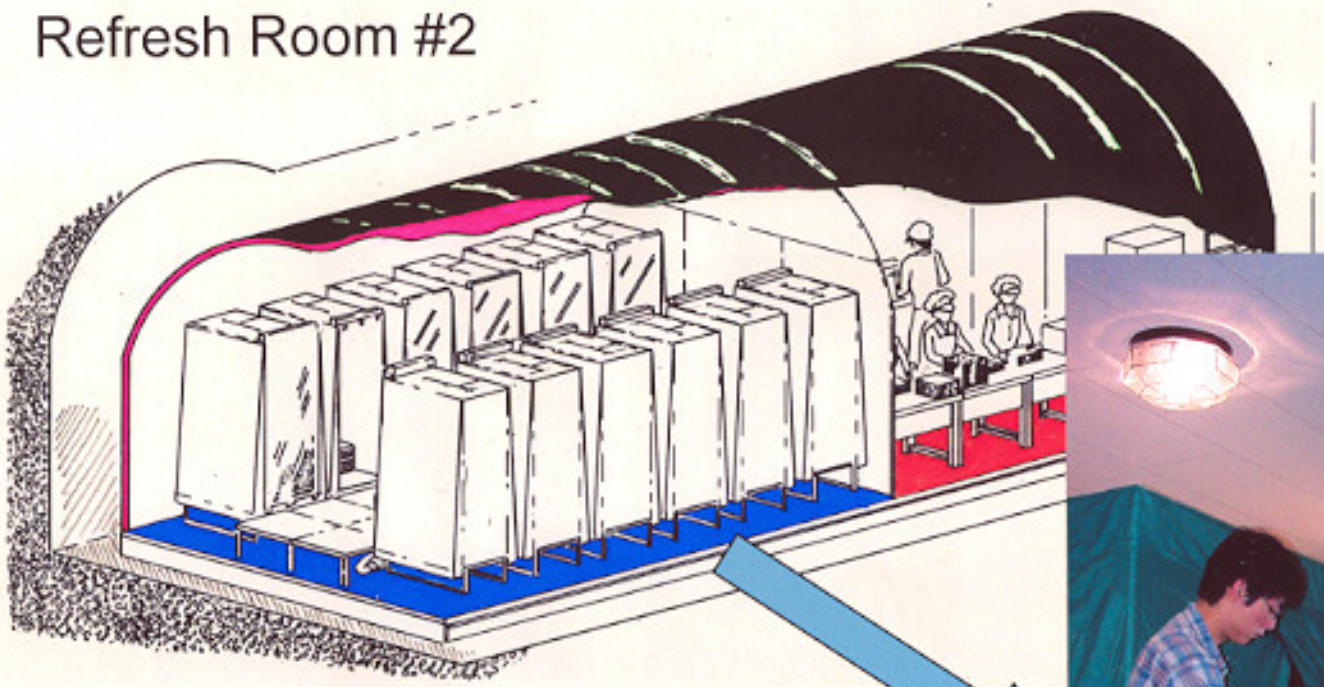
Room#1 1/50 of a ground level (115m.w.e.)

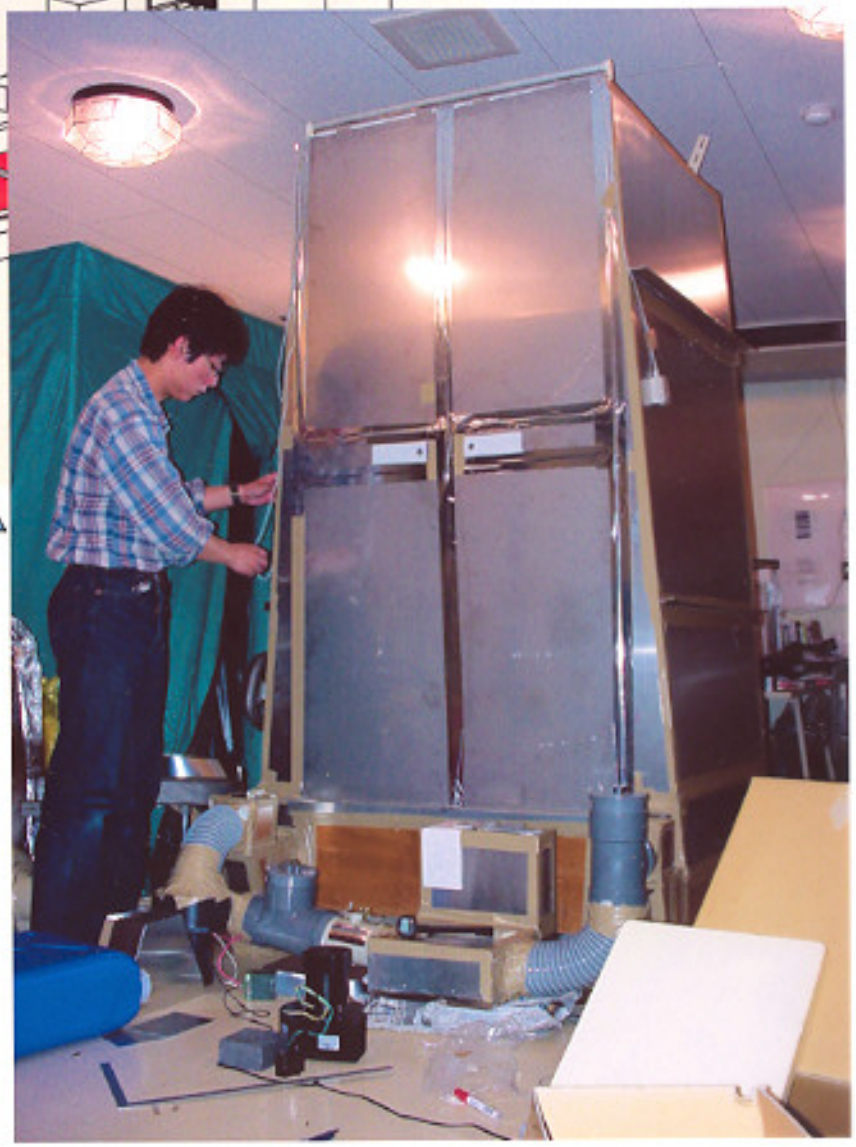
Room#2 1/400 of ground level (220m.w.e.)



Emulsion delivery to Gran Sasso begins in Aug. 2003

Refresh Room #2





Refresh chamber

Refresh Room #2 on 05-Jun-2003

τ decay analysis is no problem but event location is a hard job...

Poor resolution of a tracking detector

DONUT, CHORUS 0.5mmϕ fiber tracker → OPERA 2.6cm width strips

Larger area must be scanned → Ultra fast emulsion DAQ by S-UTS

Quasi-online event location

Event location begins when beam is ON

Well organized analysis procedure

CNGS dedicate mode will acceptable

Emulsion analysis chain for event location must be ready before having REAL events ! (not the case for CHORUS nor

⇩

Rehearsal must be done !

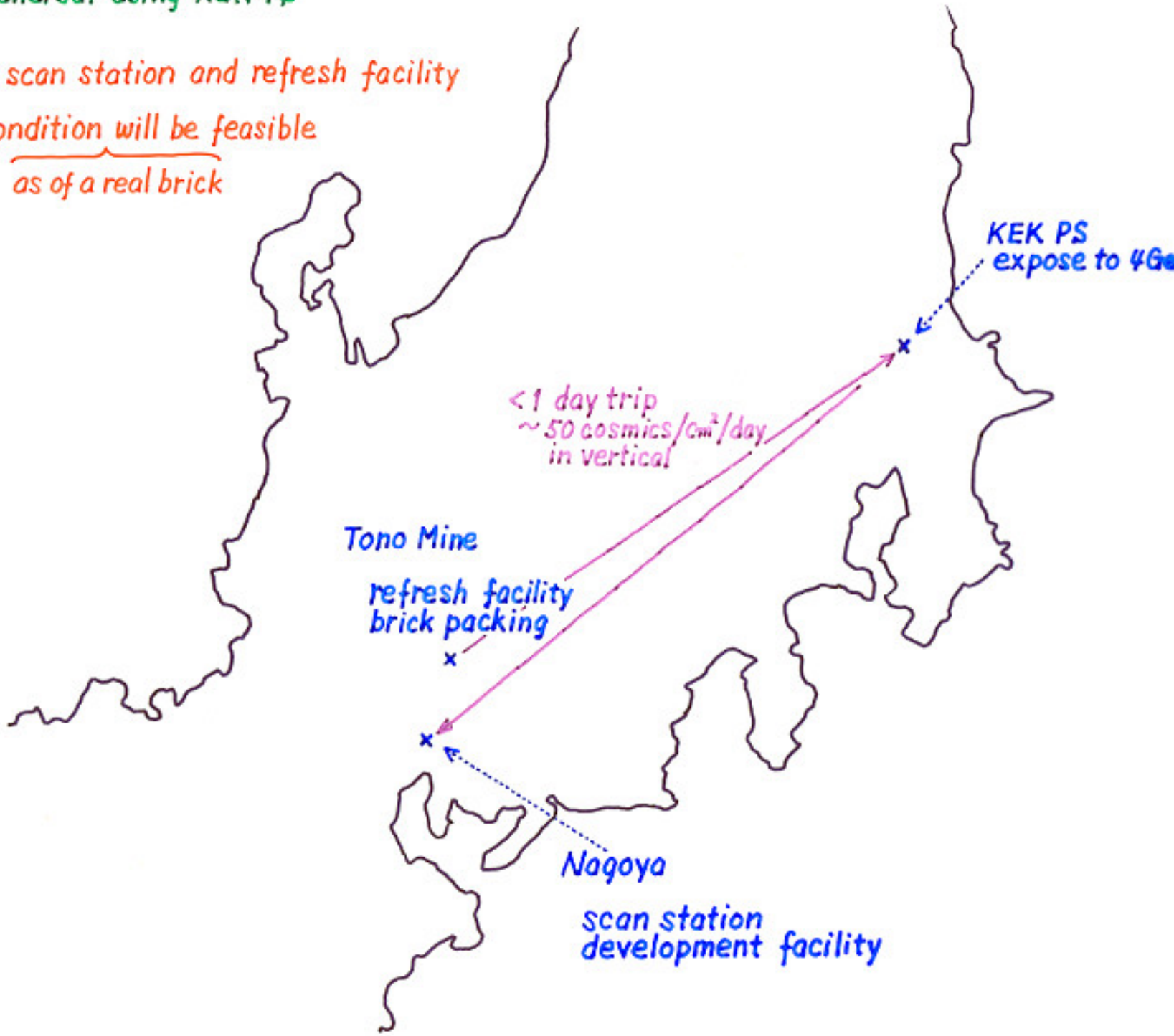
CERN is not in OPERA

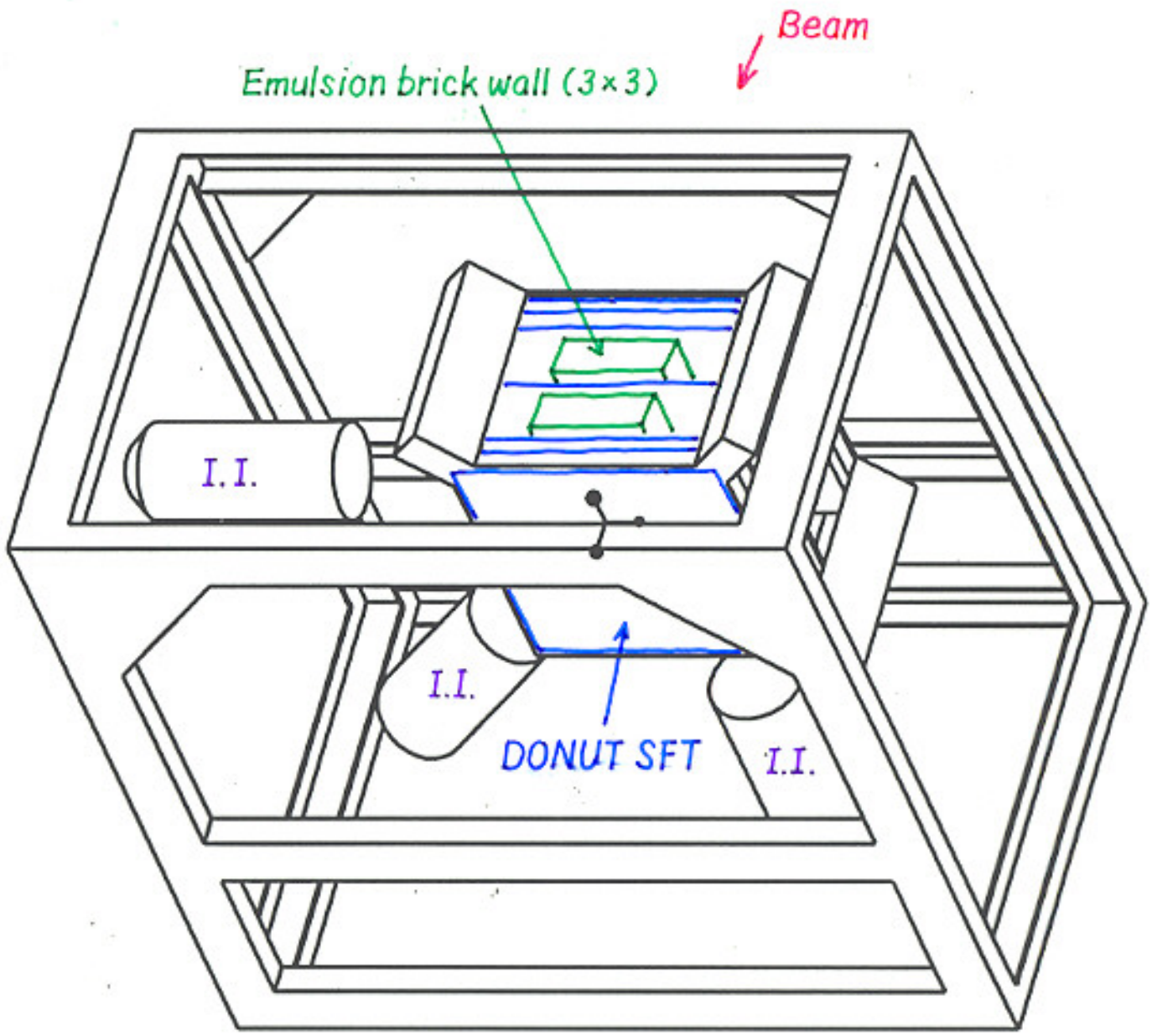
CERN PS and SPS is down in 2005

⇒ Rehearsal at KEK PS

Event location rehersal using KEK PS

- close to our scan station and refresh facility
- similar BG condition will be feasible
  as of a real brick

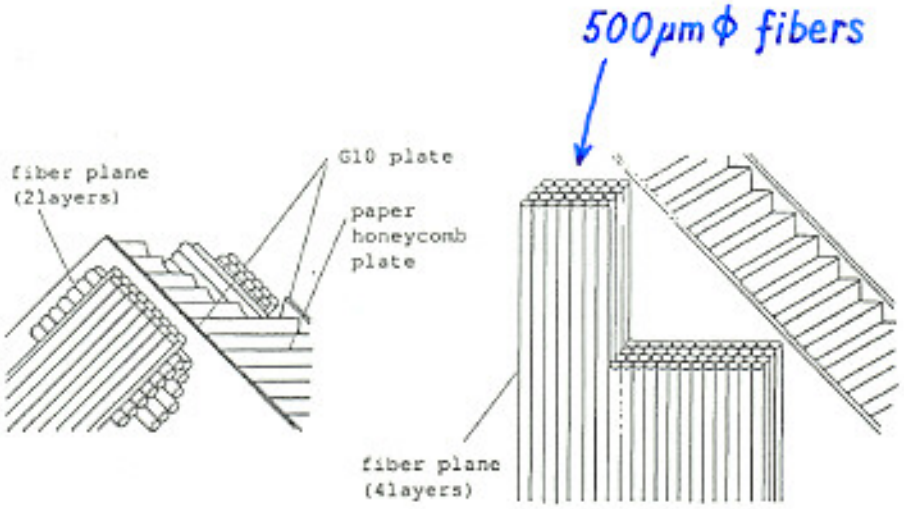




Expose > 100 bricks for event location rel

Mini OPERA setup

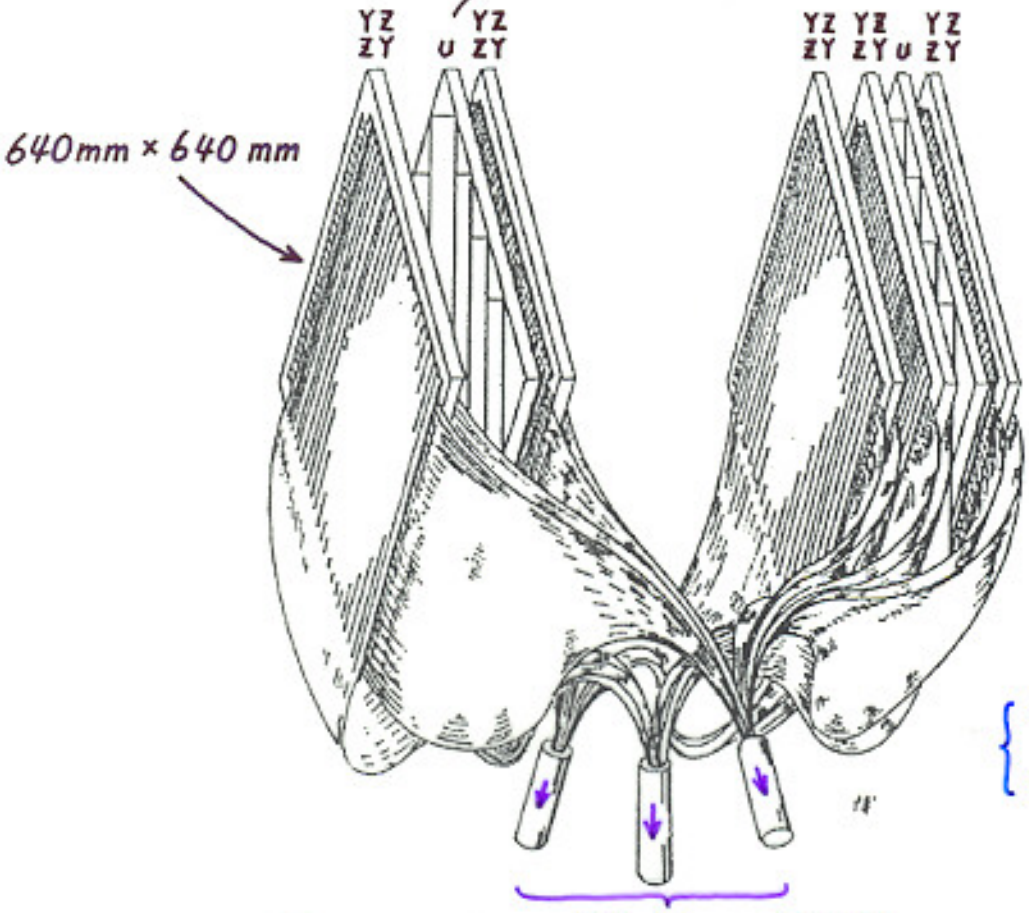
DONUT Scintilation Fiber Tracker reused in Mini OPERA

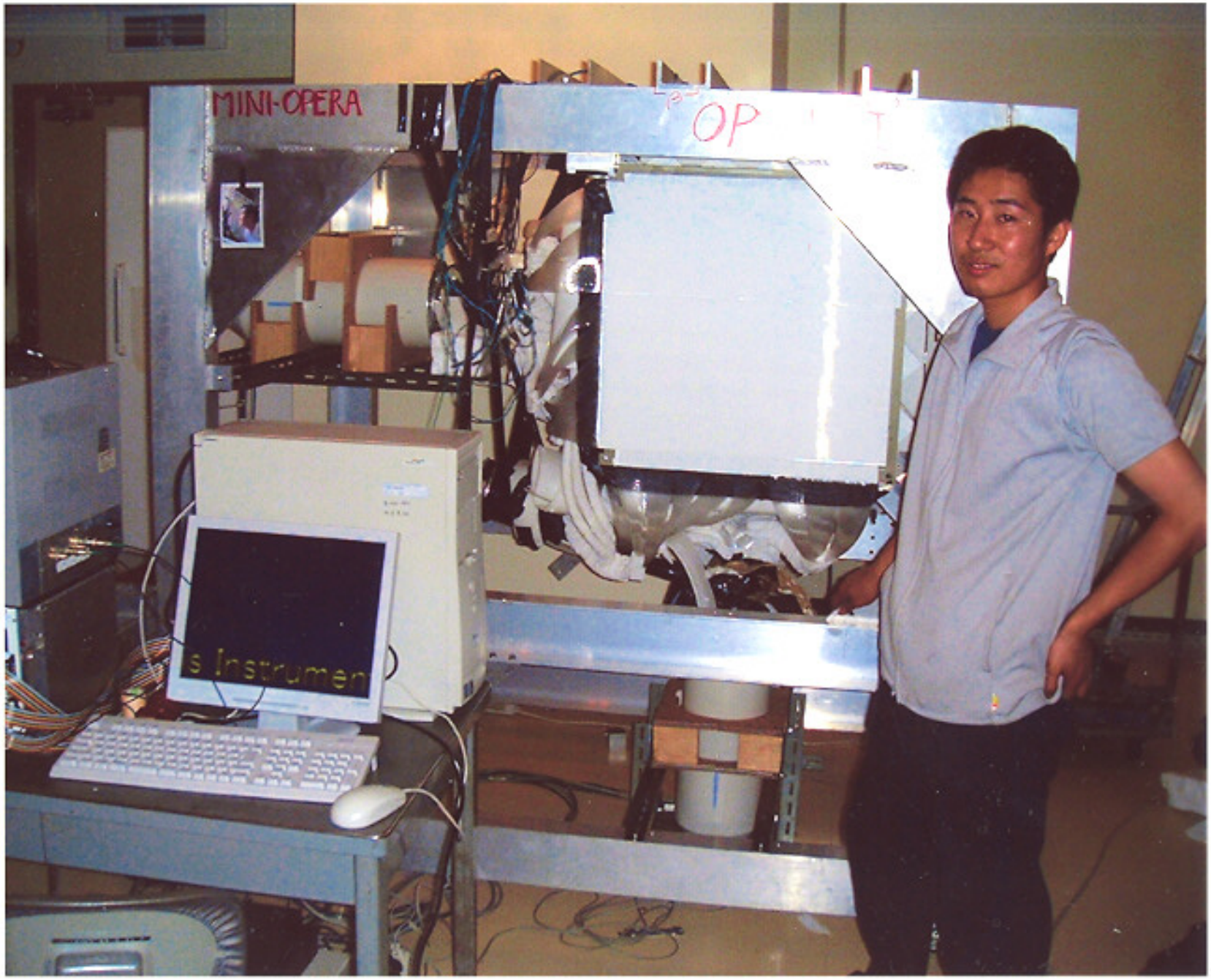


YZZY plate

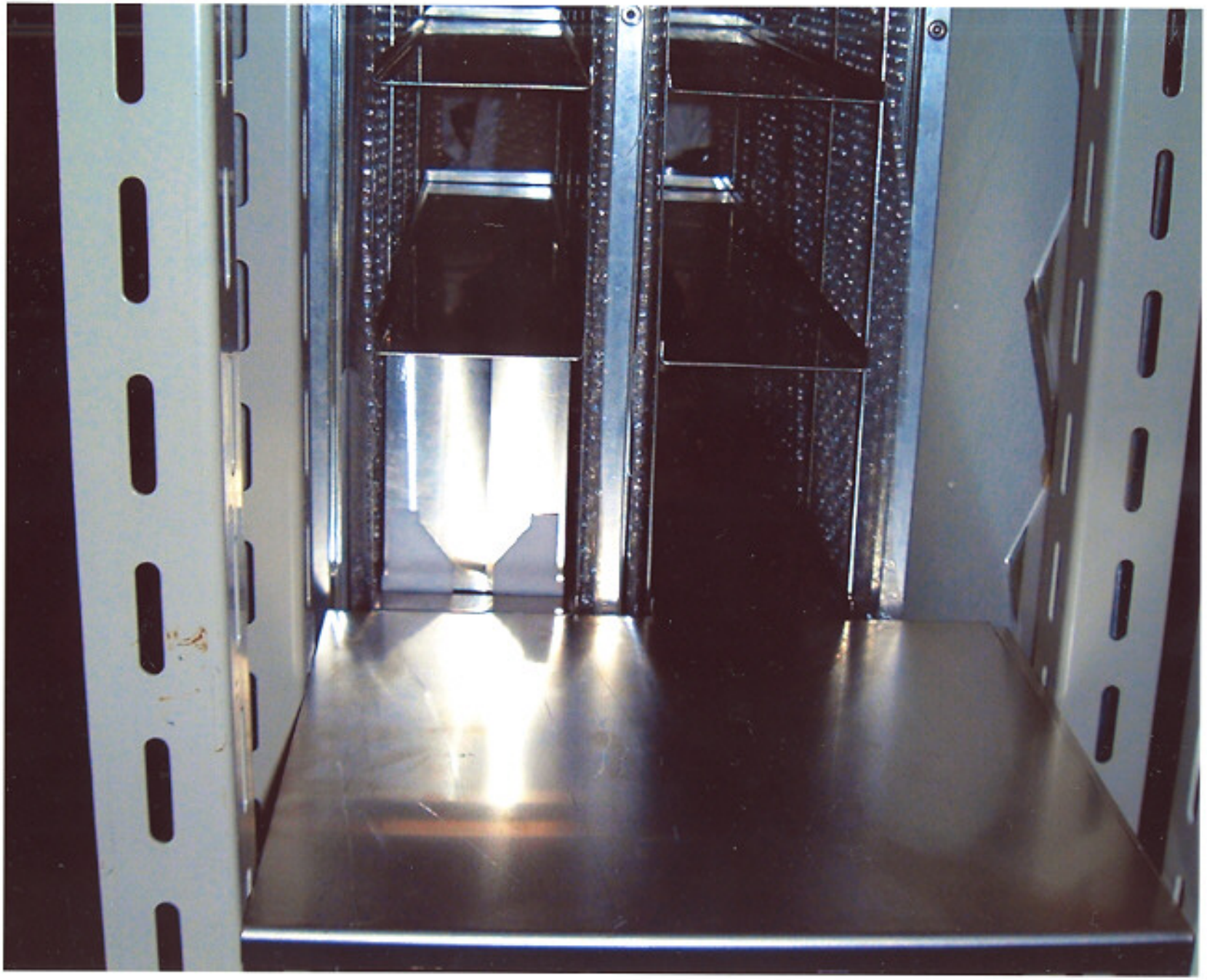
U plate

distances between plates are flexible





Mini OPERA setup (07-Jun-2003)

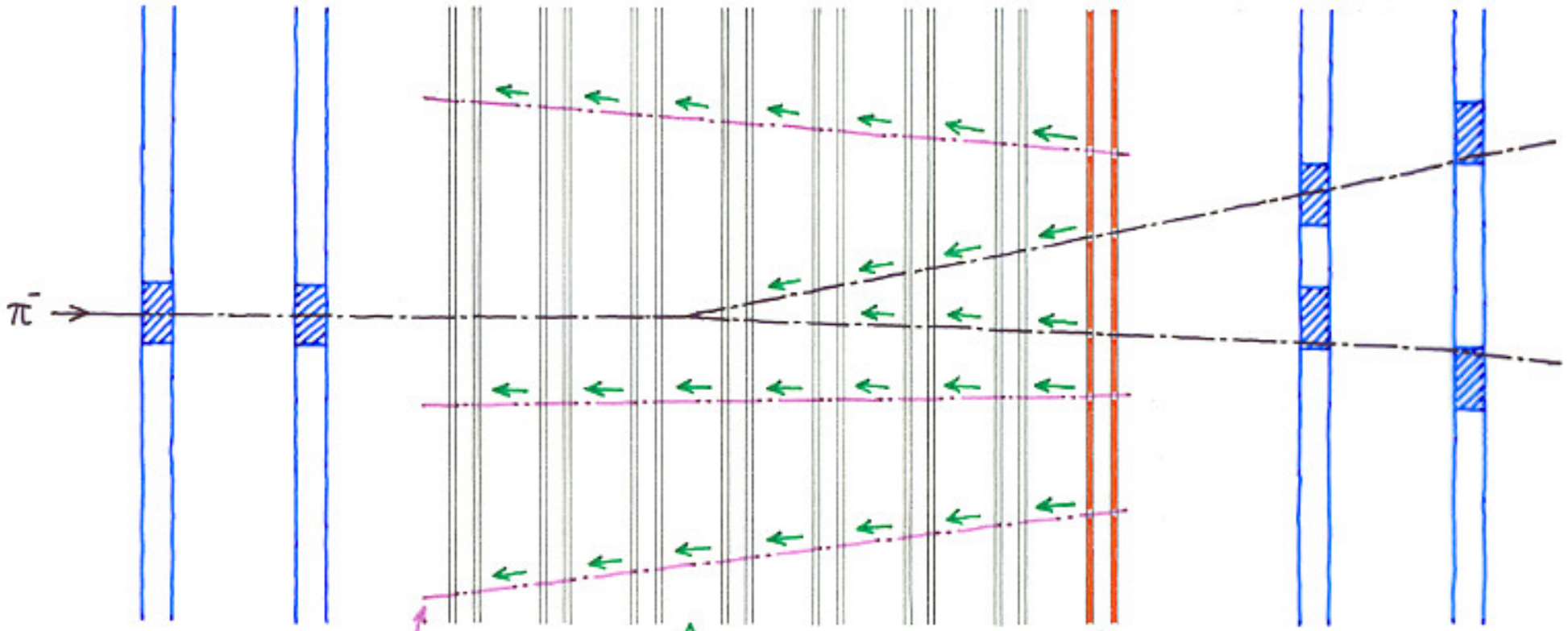


Mini brick walls in Mini OPERA

Rehearsal scheme

know the truth by SFT

(2) Scan back pickuped tracks



cosmic ray

(3) Find a vertex

(1) General scan to pickup all tracks

Ultra low density exposure < 10 beam over 100 cm^2

Mini OPERA schedule

2003 Jun	Submit proposal to KEK
	Minimal setup ready
	Test in F-ken (Nagoya) using cosmics
	Beam line study at KEK PS
2004 Feb	Full setup (add mini TT) ready in KEK
	KEK PS slow extraction
	Begin event location rehearsal
2004 Oct	Full running of event location rehearsal
	↑
	Tuning and improving event location
	↓
2006 May	1st beam to Gran Sasso

The ICARUS Collaboration

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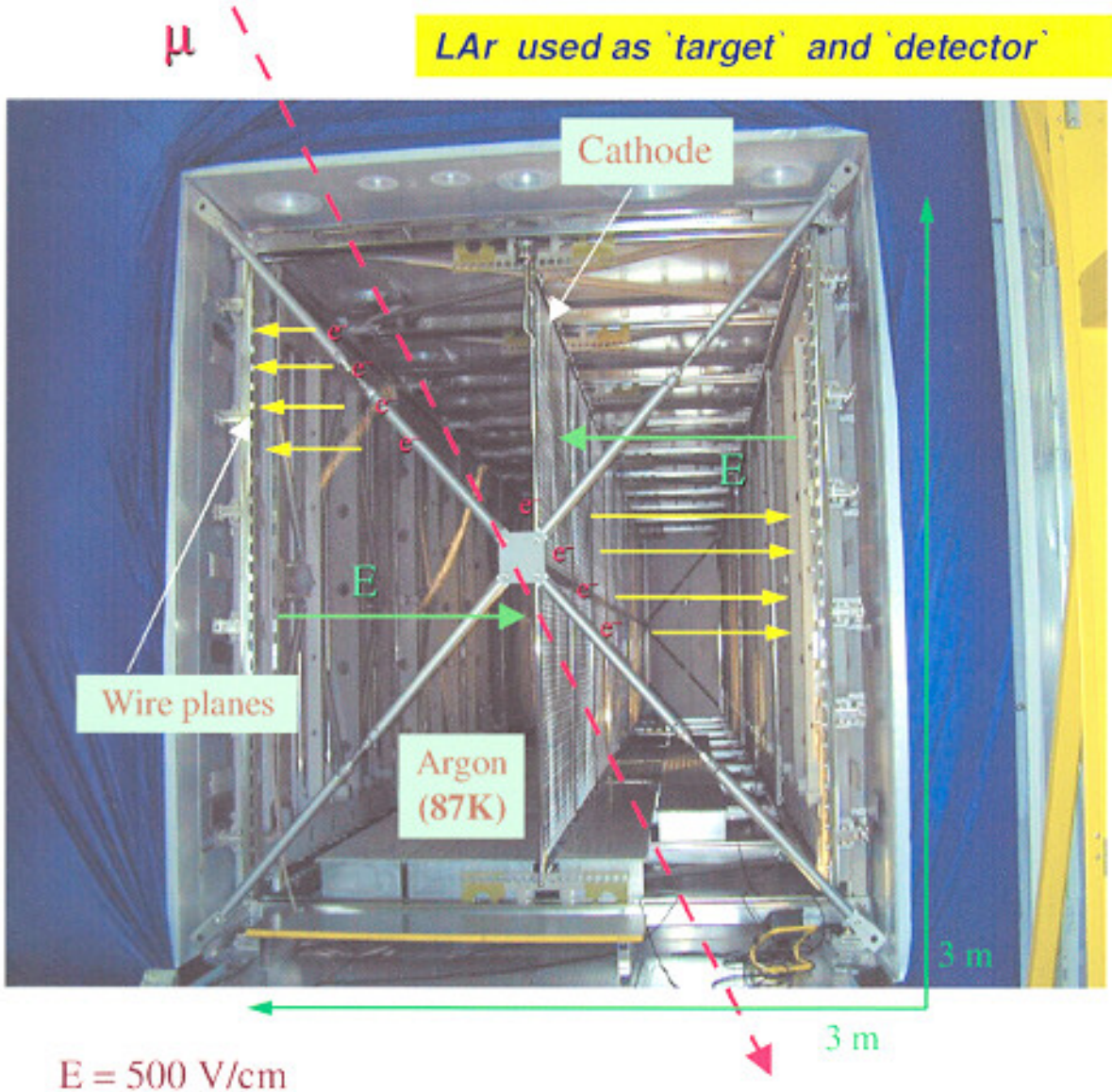
ITALY: L'Aquila, LNF, LNGS, Milano, Napoli, Padova, Pavia, Pisa, CNR Torino, Politec. Milano.
SWITZERLAND: ETHZ Zürich.
CHINA: Academia Sinica Beijing.
POLAND: Univ. of Silesia Katowice, Univ. of Mining and Metallurgy Krakow, Inst. of Nucl. Phys. Krakow, Jagellonian Univ. Krakow, Univ. of Technology Krakow, A.Soltan Inst. for Nucl. Studies Warszawa, Warsaw Univ., Wroclaw Univ.
USA: UCLA Los Angeles.
SPAIN: Univ. of Granada.

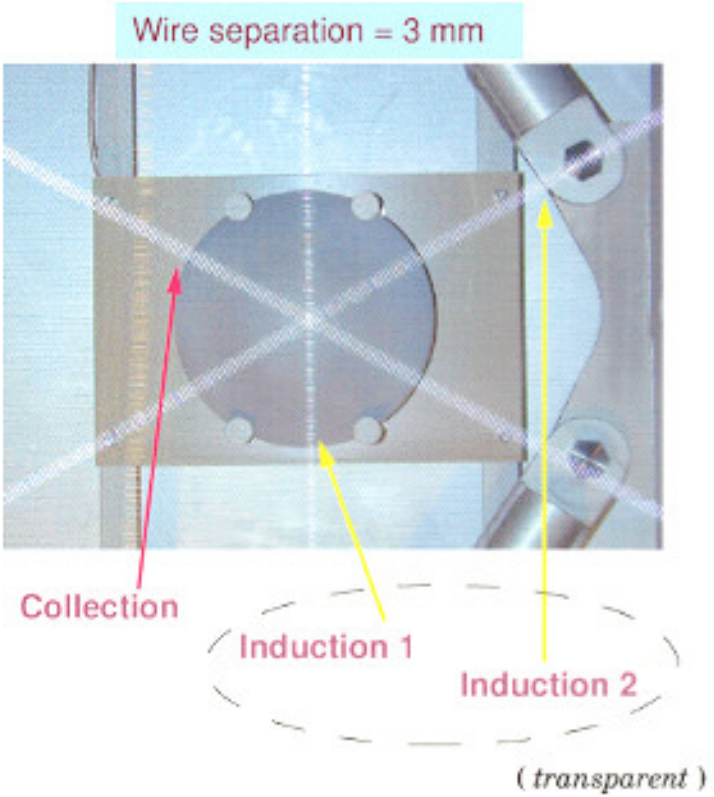

ICARUS T600 (1 half-module out of 2)
≈300‘000 kg LAr
= T300

Detection technique



Anode: multiplane readout

3 wire planes at 0 and ± 60 deg



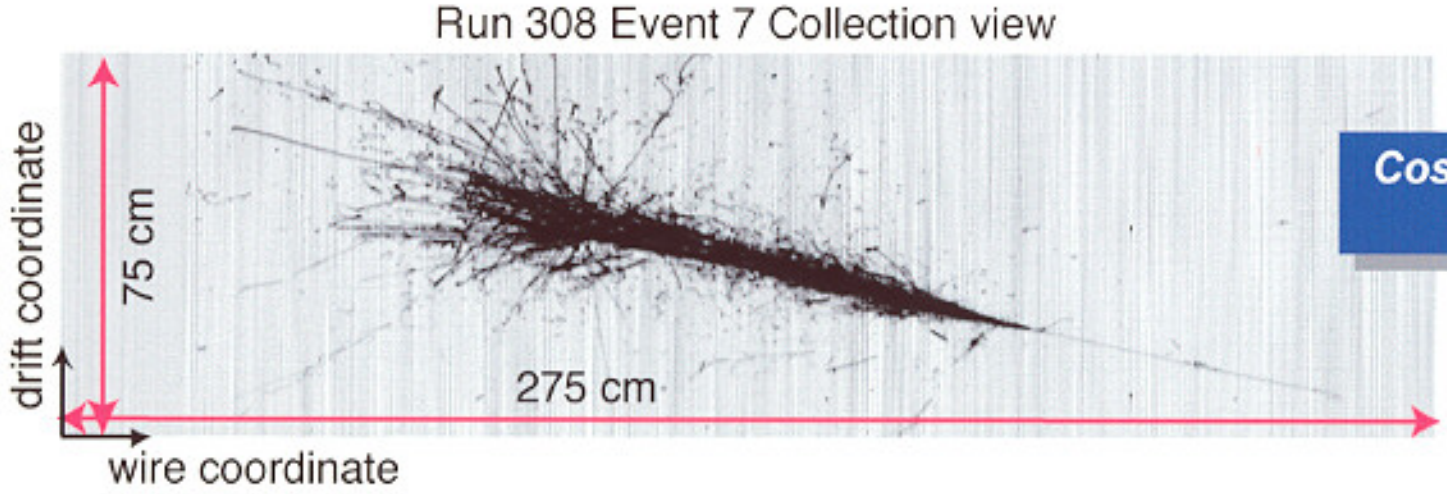
Examples of events: "electronic" bubble chamber (I)

Hadronic interaction (T600)

$\sigma_{x,y} \sim 1\,mm$

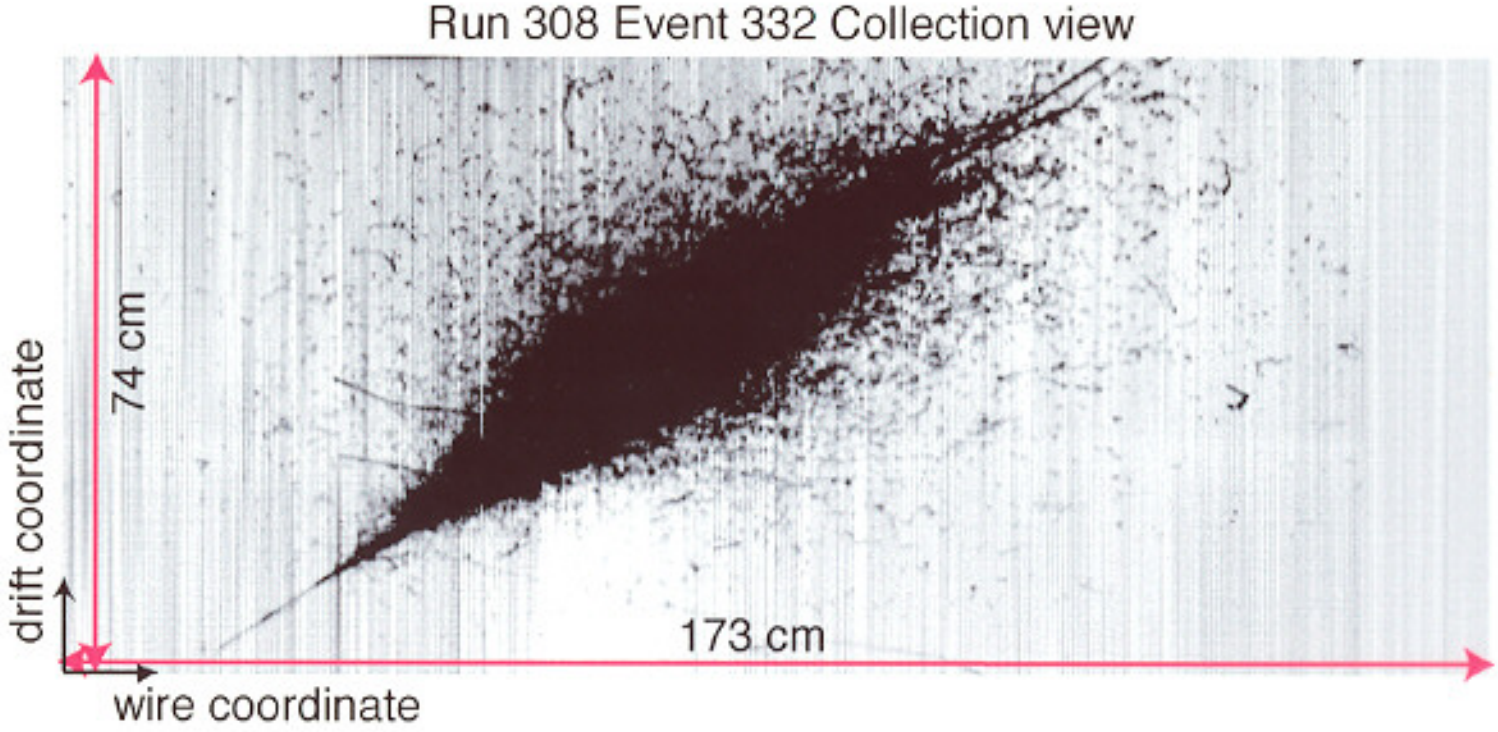
$\sigma_z \sim 0.4\,mm$

"Electronic" bubble chamber (II)



Cosmic ray showers (T600)

$$\frac{\Delta E}{E} = \frac{3\%}{\sqrt{E(GeV)}}$$

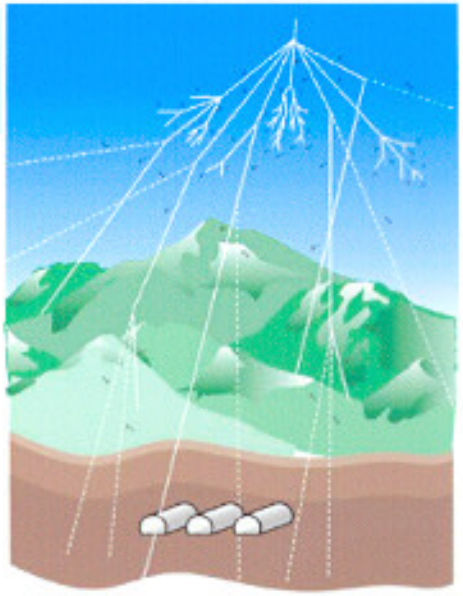


A vast physics program ...

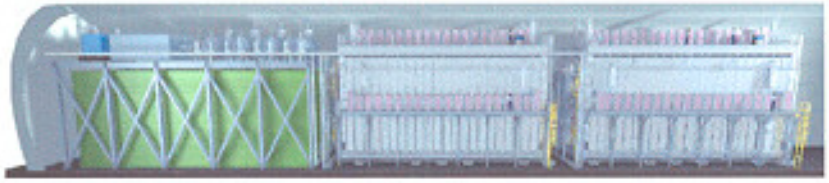
hep-ex/0103008

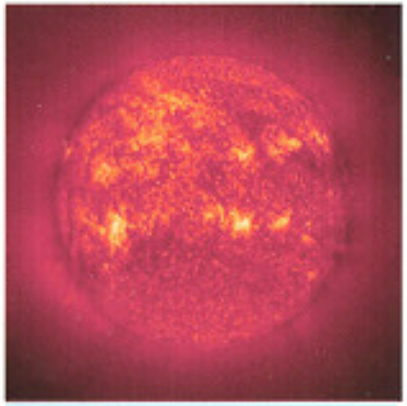
Supernova neutrinos

Atmospheric neutrinos

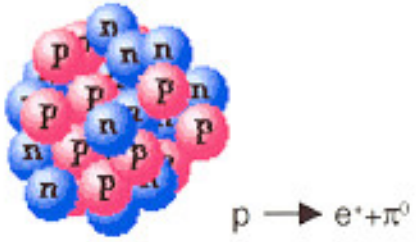


T3000

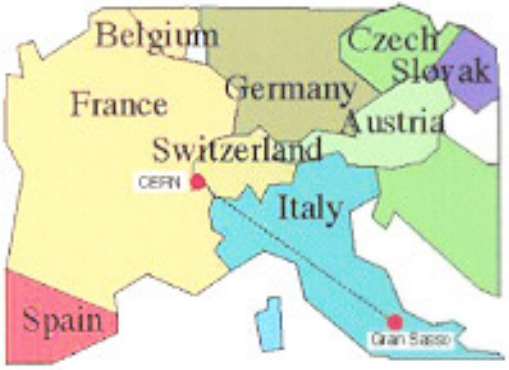




Solar neutrinos



Nucleon stability



Long Baseline neutrinos

$\nu_\mu \rightarrow \nu_\tau$ appearance search summary

T600+2 x T1200 modules

(2.35 kton active LAr, 1.5 kton fiducial)

5 year CNGS shared running

(2.25 × 10^{20} p.o.t.)

Super-Kamiokande:

$1.6 < \Delta m^2 < 4.0$ **at 90% C.L.**

τ decay mode	Signal $\Delta m^2 = 1.6 \times 10^{-3}$ eV^2	Signal $\Delta m^2 = 2.5 \times 10^{-3}$ eV^2	Signal $\Delta m^2 = 3.0 \times 10^{-3}$ eV^2	Signal $\Delta m^2 = 4.0 \times 10^{-3}$ eV^2	BG
$\tau \rightarrow e$	3.7	9	13	23	0.7
$\tau \rightarrow \rho$ DIS	0.6	1.5	2.2	3.9	< 0.1
$\tau \rightarrow \rho$ QE	0.6	1.4	2.0	3.6	< 0.1
Total	**4.9**	**11.9**	**17.2**	**30.5**	**0.7**

- Several decay channels exploited (golden channel = electron)
- (low) backgrounds measured in situ (control samples)
- High sensitivity to signal; oscillation parameters determination

Summary

CNGS 1st beam in May 2006

Long baseline $\nu\tau$ appearance experiments in Gran Sasso run from the 1st day

OPERA

τ decay vertex detection

refreshed emulsion → low noise → better in electron ID and energy measurement

dE/dx is a measurable quantity → low momentum μ ID to kill charm BG

S-UTS

reheasal for event location using mini-OPERA at KEK

ICARUS

3000 t LAr TPC

$\nu\tau$ detection by kinematical analysis