OPERA: waiting for the τ!

XXVIII Physics in Collision
26 June 2008 Perugia, Italy

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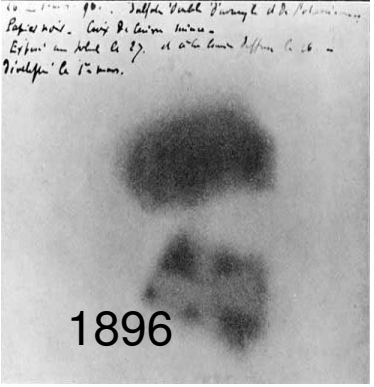
Bari University

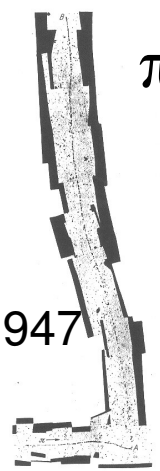
on behalf of the OPERA Collaboration

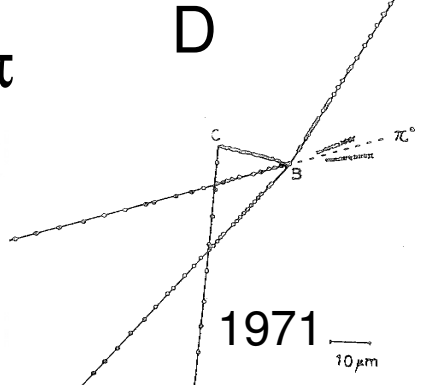
37 INSTITUTIONS ~ 160 PHYSICISTS

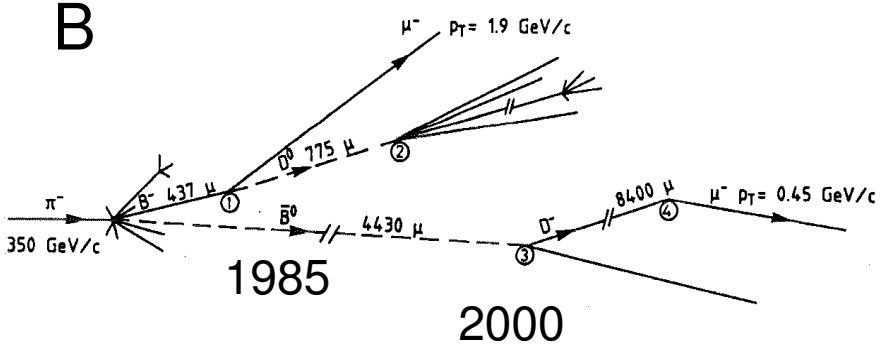
IPNL, IRES, LAPP
Hamburg, Münster, Rostock
Zagreb
L'Aquila, Bari, Bologna, Napoli, Padova, Roma, Salerno, LNF, LNGS
Aichi, Toho Kobe, Nagoya Utsunomiya
METU Ankara

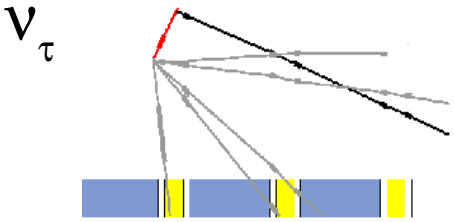
Technion Haifa
Bern Neuchatel Zurich
Gyeongsang University
IHEP Beijing Shandong
Sofia
INR ITEP JINR, Obninsk
Brussels

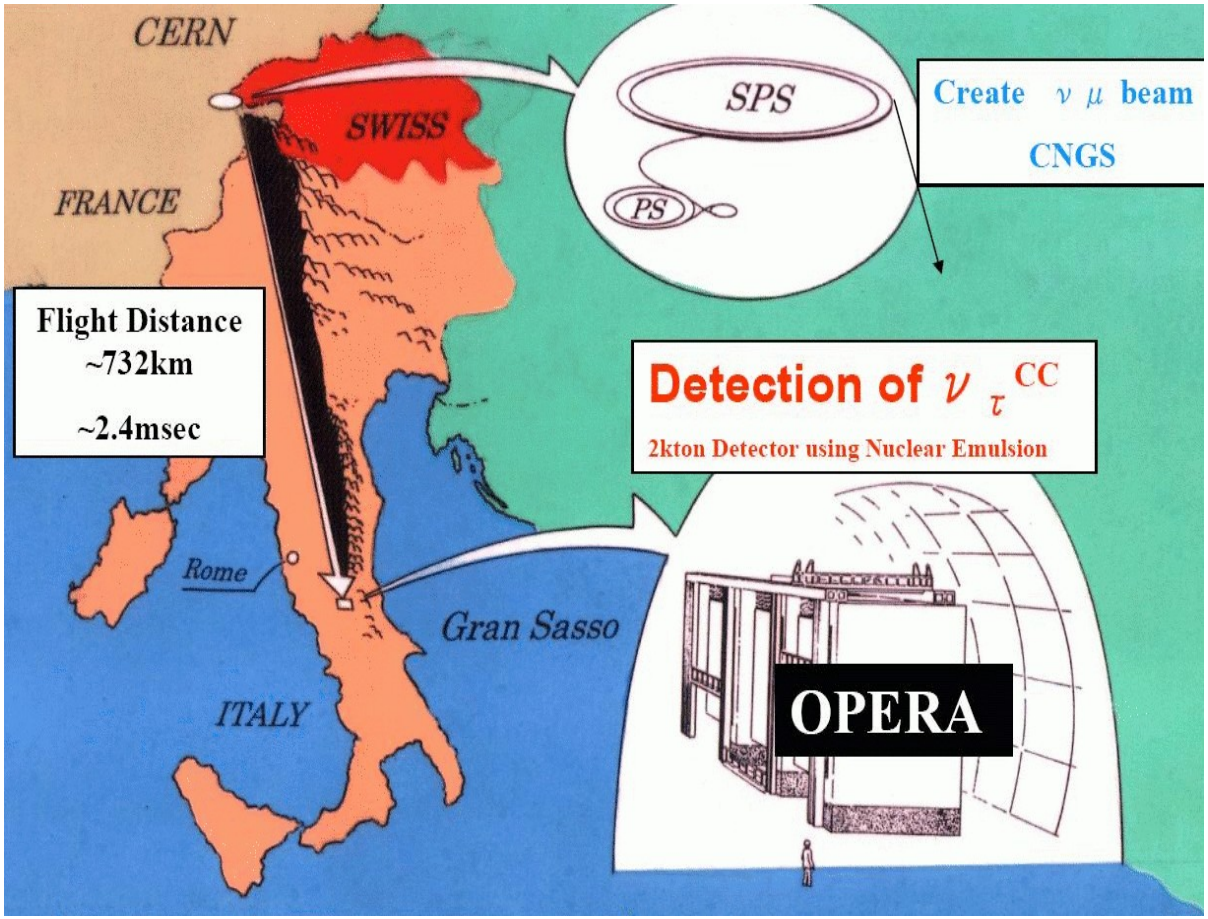










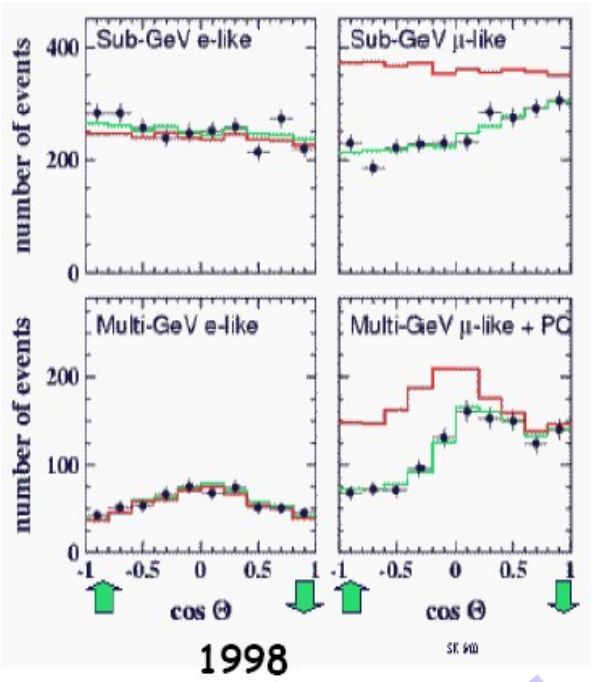


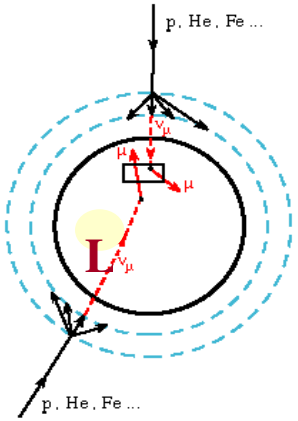
Outline

- Physics motivation
- Experimental strategy
- First results
- Physics potential
- Conclusions

The road to OPERA

1998 SK atmospheric neutrino anomaly: deficit of ν_μ (and not ν_e) with zenith angle dependence: **OSCILLATION !**





Can provide an unambiguous evidence for $\nu_\mu \rightarrow \nu_\tau$ oscillation in the region of atmospheric neutrinos by looking for

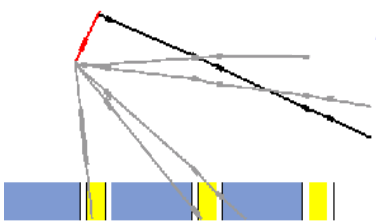
ν_τ appearance

in a pure ν_μ beam

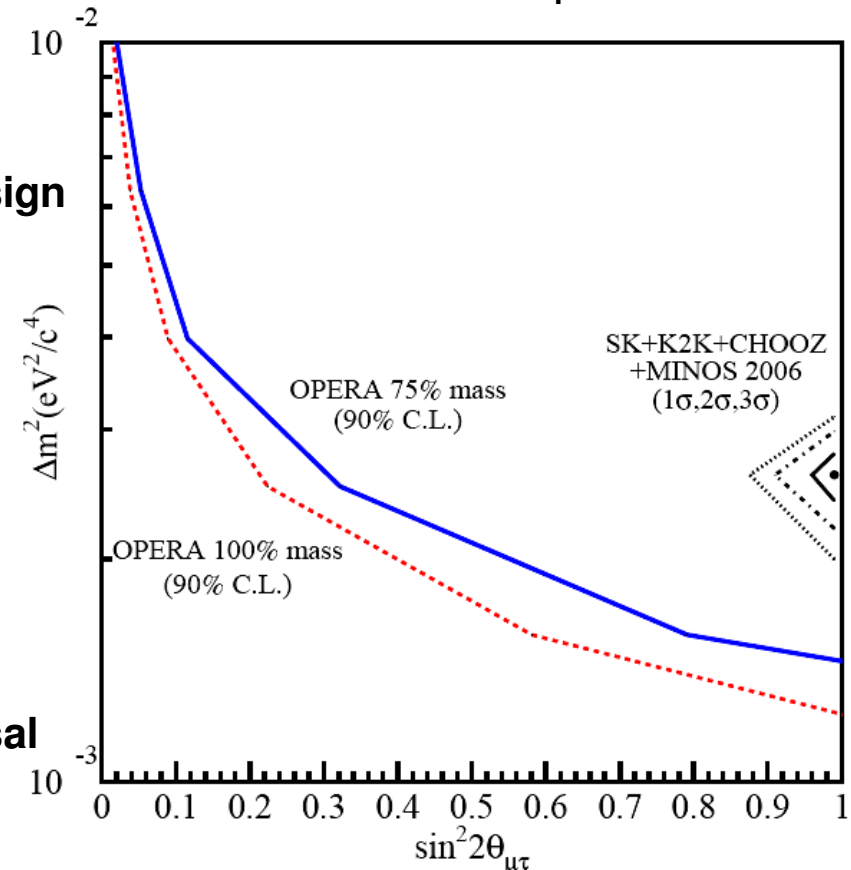
CHOOZ: final flavour not ν_e ...

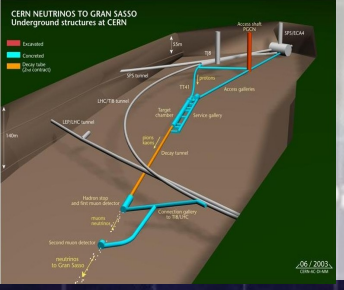
1999 CNGS beam design

2000 DONUT "sees" the ν_τ in the nuclear emulsions



2000 OPERA proposal





The CNGS beam

ν (mass) tourism

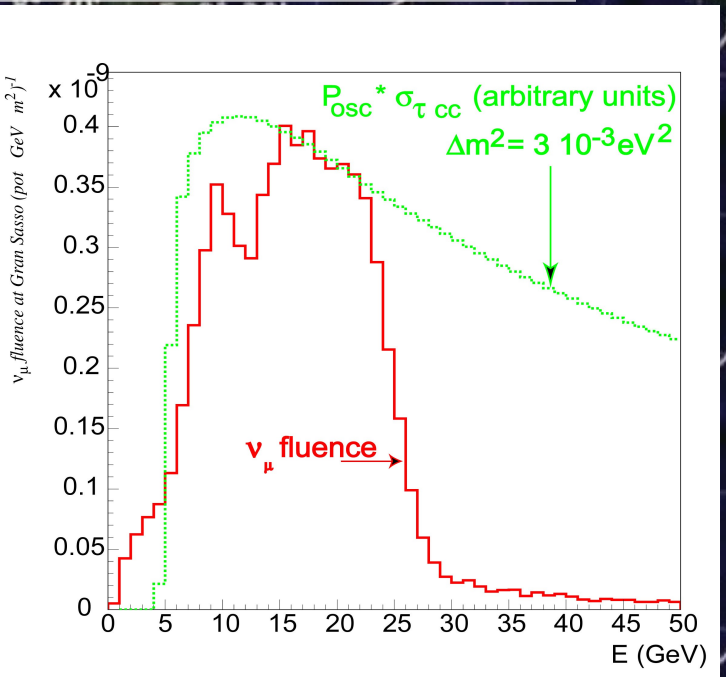
Cern Neutrinos to Gran Sasso

Beam main features	
L	732 km
$< E_\nu >$	17 GeV
$L / < E_\nu >$	43 km/GeV

$\nu_\mu \rightarrow \nu_e$

$(\nu_e+\bar{\nu}_e) / \nu_\mu$	0.87%
$\bar{\nu}_\mu / \nu_\mu$	2.1%
ν_τ prompt	negligible

$Pr(\nu_\mu \rightarrow \nu_\tau)$ & $\sigma_{\nu(\tau)CC}(E)$ convolution maximized -> high E beam ("appearance"-optimized)



4.5·10^{19} p.o.t./year, 200 days/year for OPERA (~1.35 Kton) means:

~ 19572 ν_μ CC + 5880 ν_μ NC

~ 411 anti ν_μ + 156 ν_e + 13 anti ν_e

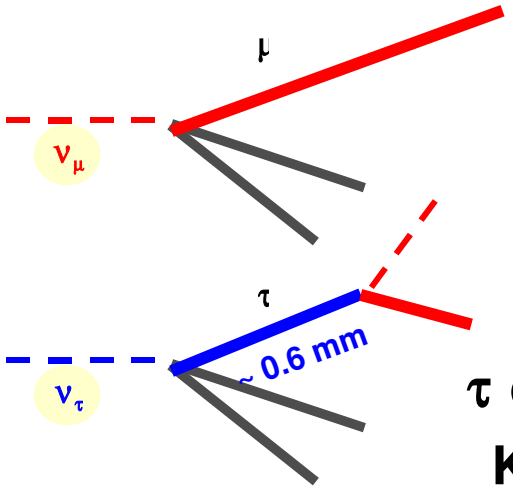
26032 in total

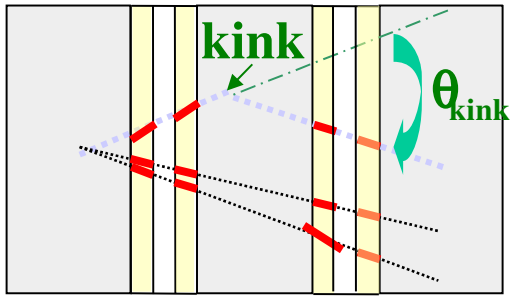
~> 24 evts/day

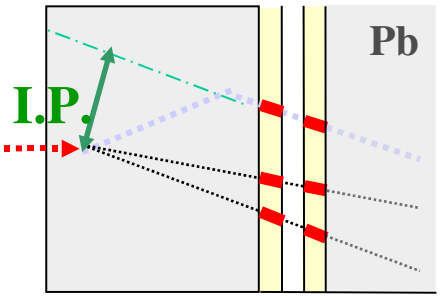
additional 10k in the OPERA magnets

~ 100 produced ν_τCC for Δm^2 = 2.4·10^{-3} eV^2

The OPERA challenge: "seeing" the ν_τ appearance







τ decay topology

Kink signature

kink

$\tau \Rightarrow \mu^- + \nu_\tau + \nu_\mu$ 17 %

$\tau \Rightarrow e^- + \nu_\tau + \nu_e$ 18 %

multi-prong

$\tau \Rightarrow h^- + \nu_\tau + n(pi^0)$ 50 %

$\tau \Rightarrow pi^+ pi^- pi^- \nu_\tau n(pi^0) 14$ %

Emulsion Cloud Chamber detector

two conflicting requirements:

- **Large mass** $N_\tau \propto (\Delta m^2)^2 M_{target}$

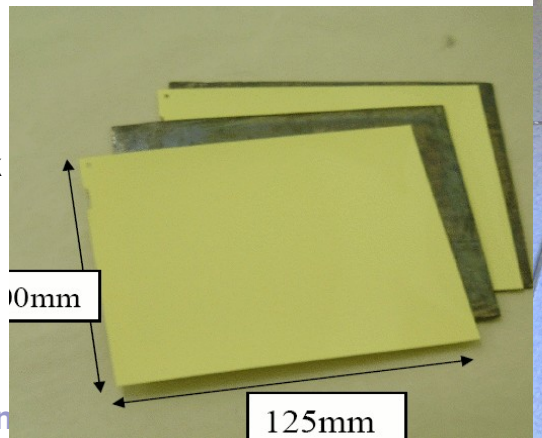
  ***O(1 Kton)* for $\Delta m^2 = O(10^{-3}\ eV^2)$**

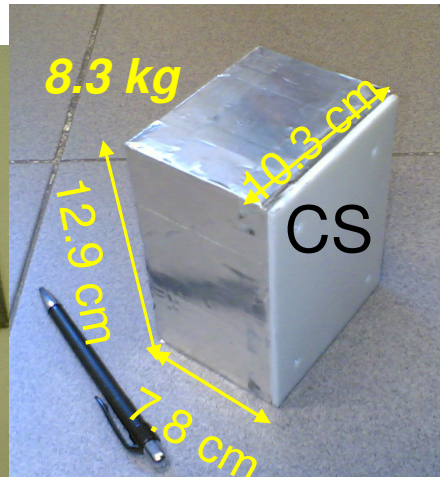
- **High granularity**: (~ μm res.)

  signal selection +background rejection

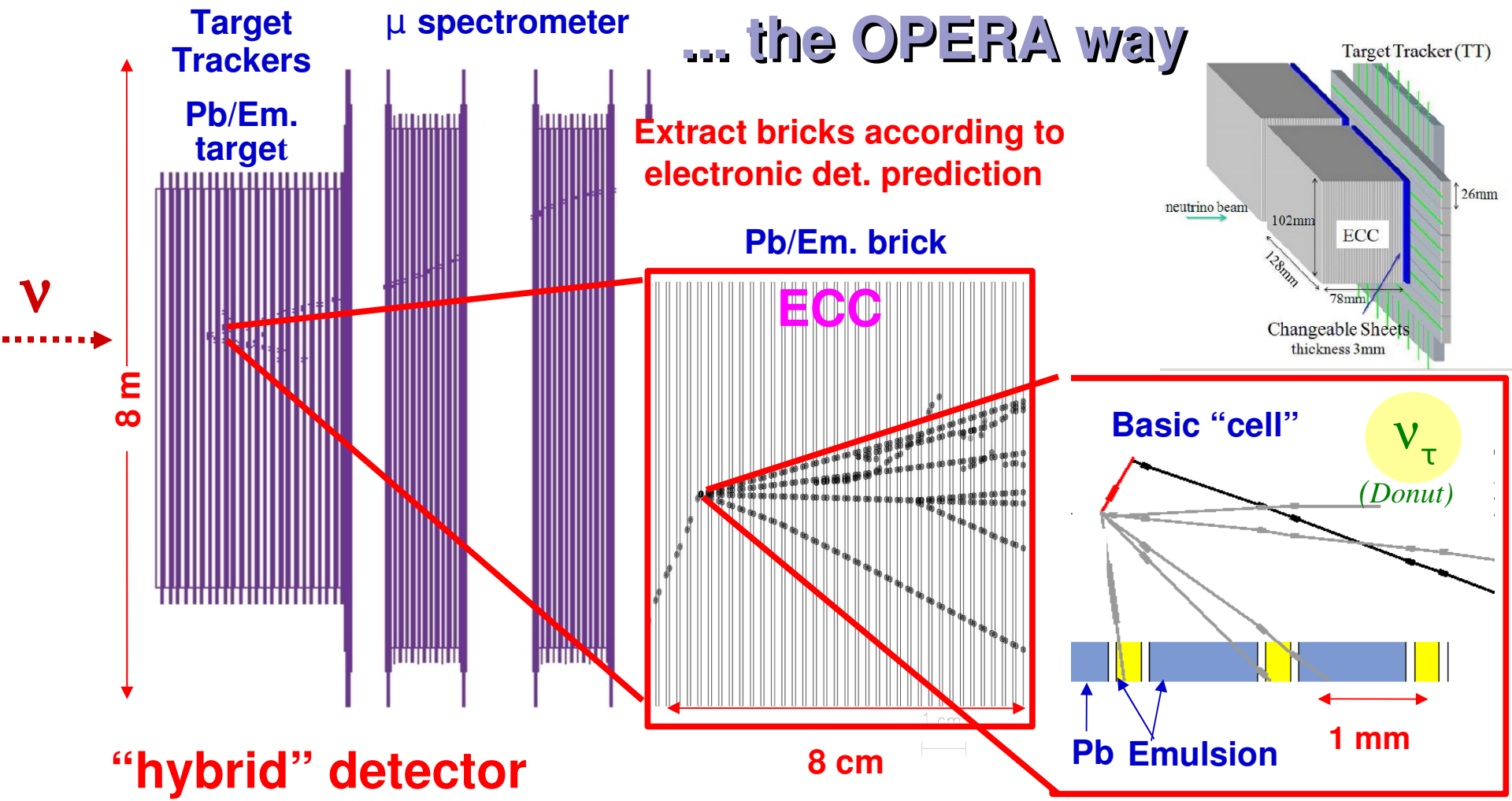
- **Brick** 56 lead plates (1 mm) + 56 emulsion sheets (300 μm)
- **Changeable Sheet:** low background removable emulsion doublet attached downstream of brick.
  - validates the occurrence of event in the selected brick before unpacking and developing.
  - "Bridge" between el. detectors and brick.

p measurement (with MCS), e energy (10 X_0), pi/mu and pi/e PID : practically a "stand-alone" detector





... the OPERA way



"hybrid" detector

Electronic detectors

detect ν interaction, brick finding

μ ID, Q and p : background suppression

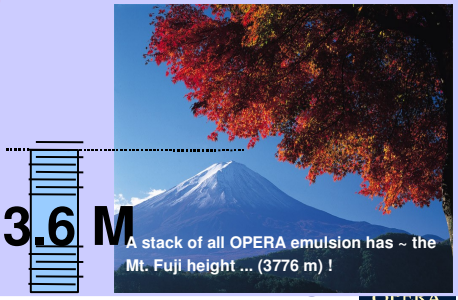
Emulsion detectors:

modular structure of 154750 ECCs

mass industrial production with high standards

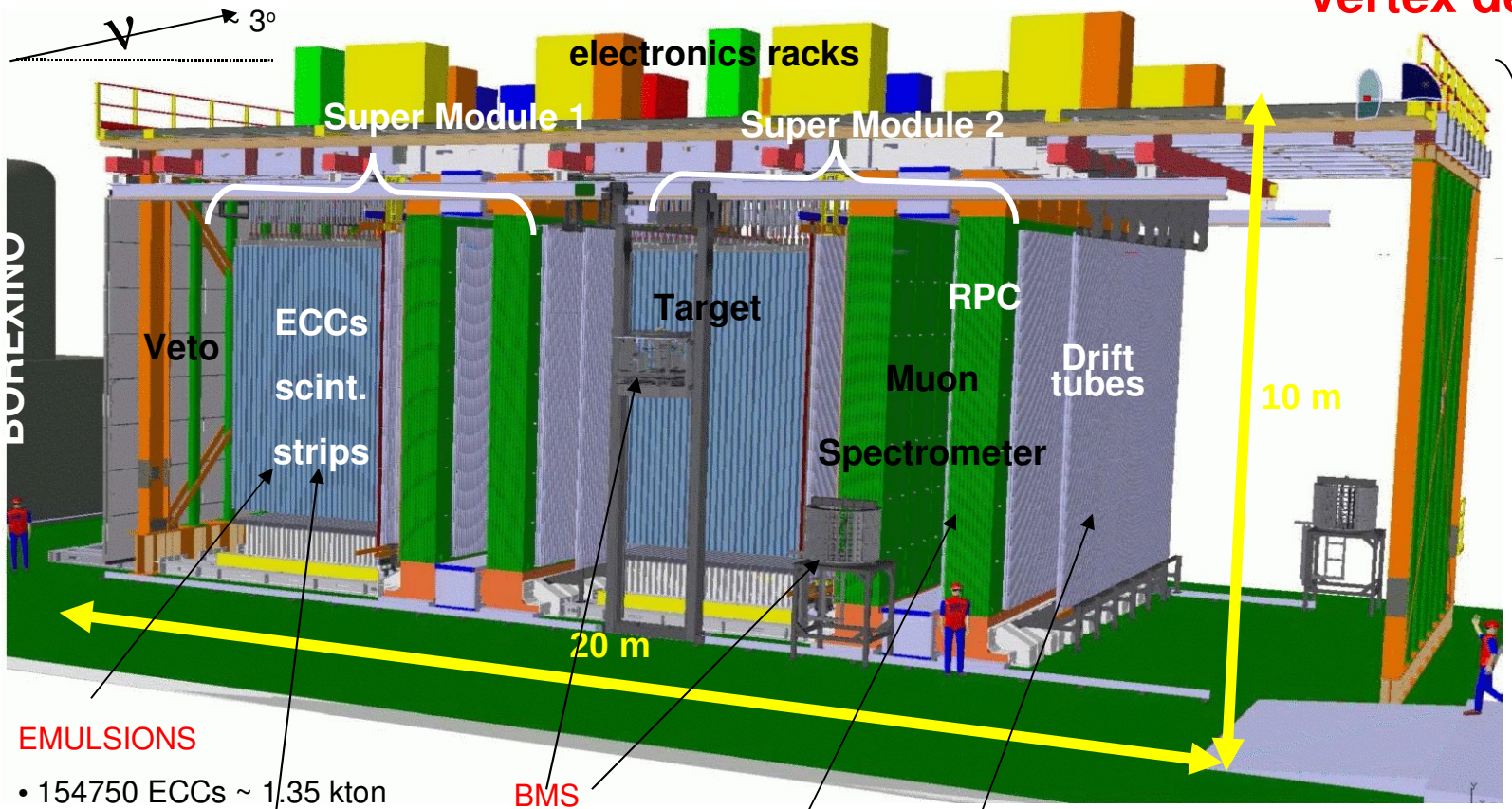
FAST-AUTOMATIC scanning

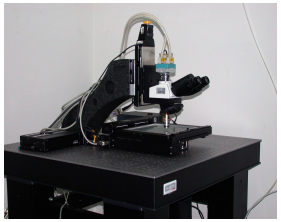
vertex search, decay search, e/μ ID, event kinematics

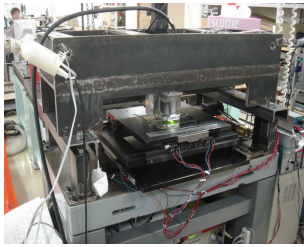


The detector

a quite large fine grained "vertex detector" !







EMULSIONS

• 154750 ECCs ~ 1.35 kton

TARGET TRACKERS

• 2 x 31 scintillator strips walls
• 256+256 X-Y strips/wall
• both-sides readout, WLS fiber
• 64-channel H7546 PMT
• 63488 channels
• σ ~ 0.8 cm (2.6 cm pitch)
• ε ≅ 99%
• rate ≅ 20 Hz/pixel @1 p.e.

BMS

Brick Manipulator system

INNER TRACKERS

• 990-ton Fe dipole magnets (B= 1.55 T) instrumented with
• 22 RPC planes (streamer mode)
• 3050 m^2 surface
• σ ~1.3 cm spatial resolution
• ε ≅ 96% (geometrical)

HIGH PRECISION TRACKERS

6 drift-tube layers/spectrometer
spatial resolution < 0.5 mm

+ several essential "off-site" facilities:

- **emulsion "refreshing",**
- **brick assembly/disassembly**
- **labelling**
- **automatic development**
- **scanning**

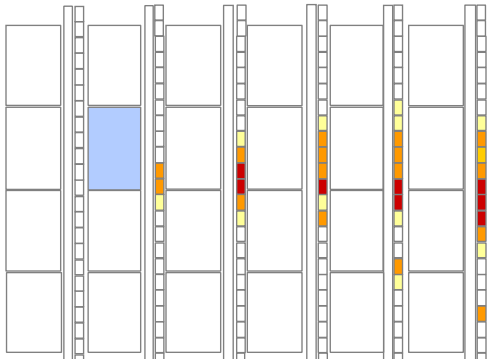
Analysis flow

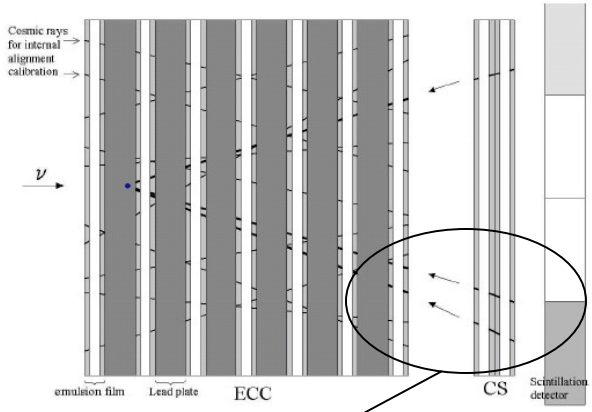
Electronic detectors
Emulsions interplay

- Predictions from electronic detectors are searched in the CS doublet.
- If an interaction is detected in the CS, the brick is exposed to cosmic rays (alignment) and the emulsions are developed and sent to scanning stations/labs
- The tracks measured in CS are followed back inside the brick until tracks stop (prediction scanning is fast !).
- A volume scanning around neutrino interaction vertex is performed (~ cm^2 for few plates)
- Finally the event topology & kinematics reconstruction is performed
- Eventually more bricks can be extracted to increase accuracy of kinematic reconstruction

Trigger

Brick finding





if tracks compatible with electronic detectors are found in the CS the brick finding is validated and brick extracted

Vertex location

decay search

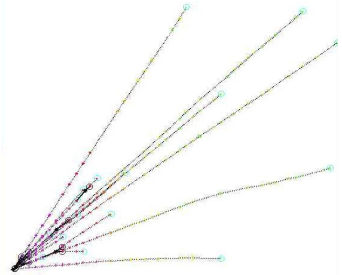
μ / e
@ 1_ry vtx ?

yes

$\nu_{\mu\,/e}$

no

τ decay mode



Kinematics

ν_τ !

A sample of " minimum bias" events will be fully studied in order to assess experimentally efficiencies & background (absolute normalization, e.g. charm).

Electron identification will be applied to ~all the NC events (ν_μ ~> ν_e search).

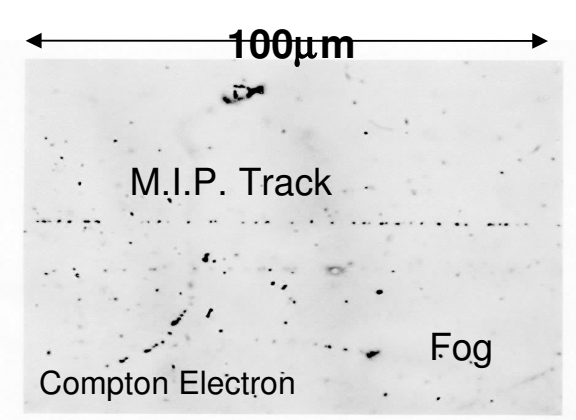
"Offline" data taking

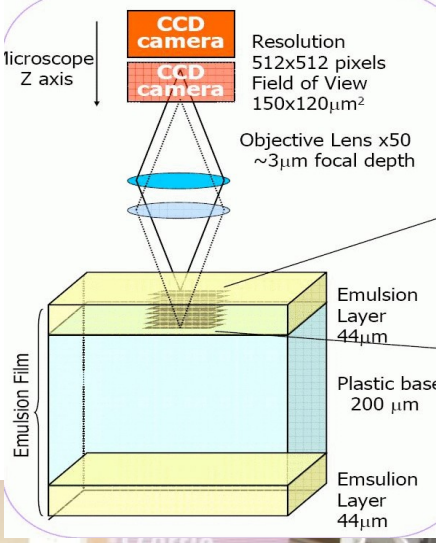
~ 24 bricks will be daily extracted and analysed using high-speed automatic systems

~ 40 microscopes distributed in Europe and Japan

2 "schools". Many useful cross checks are possible !

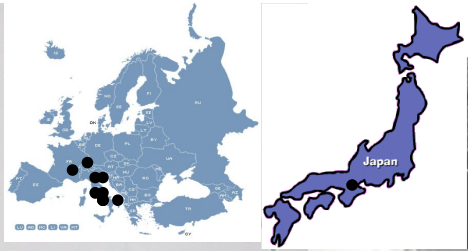
Common Data Base for data sharing/publication



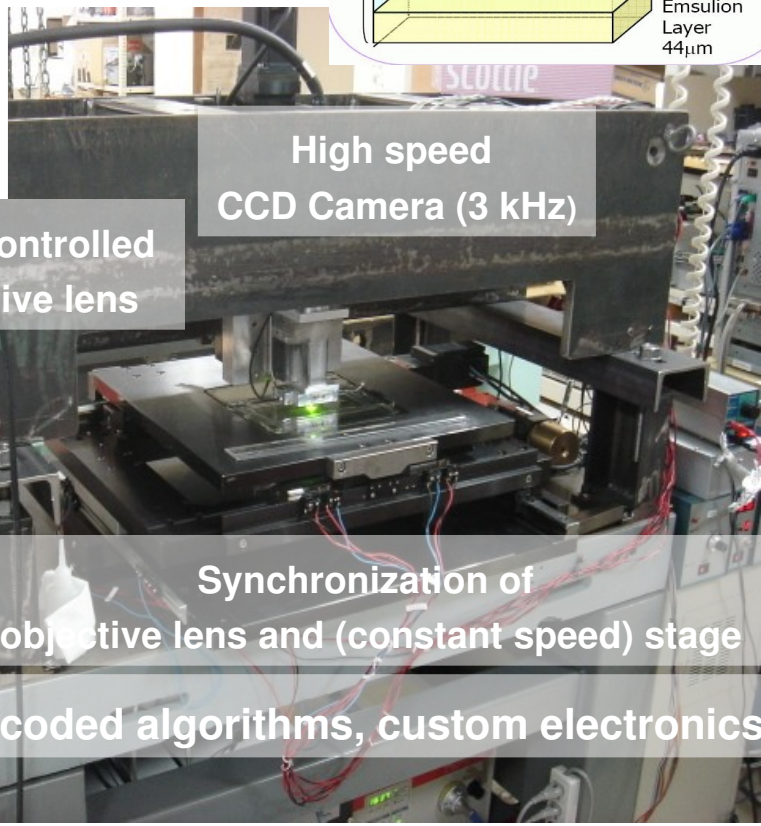


European Scanning System

x 40



S-UTS (Japan)



High speed CCD Camera (3 kHz)

Piezo-controlled objective lens

Customized commercial optics and mechanics + asynchronous DAQ software modular, de-centralized, approach

Synchronization of objective lens and (constant speed) stage

Hard-coded algorithms, custom electronics

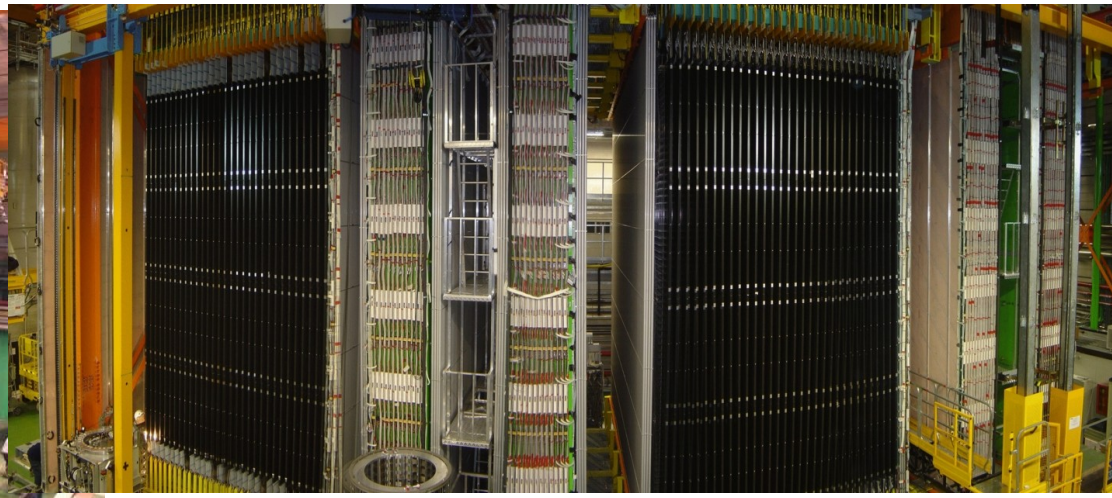
scanning speed ~ 20 cm² / h **proposal goal**

~ 40 cm² / h

September 2003

... 2004

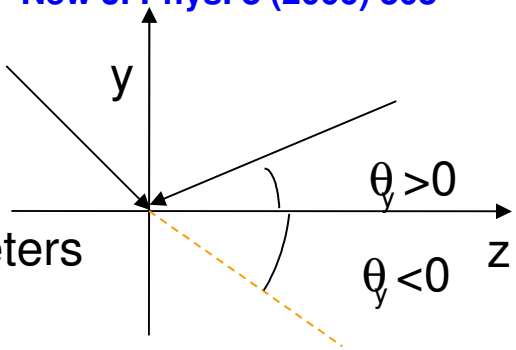
... 2005



Installation completed with VETO and HPT before first half of 2007

The OPERA 2006 run

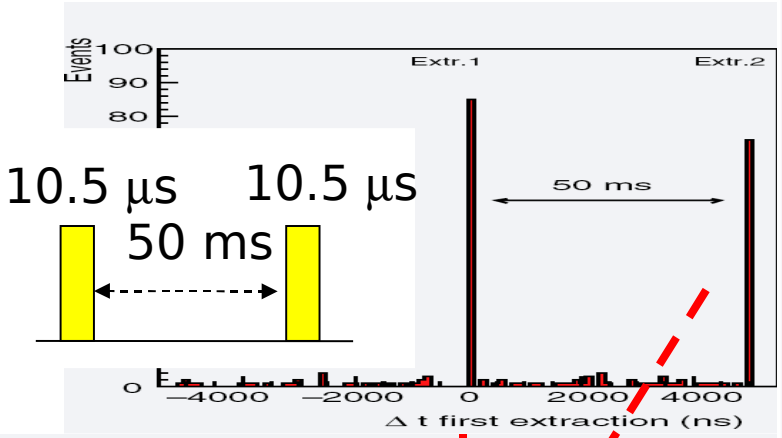
R. Acquafredda et al., New J. Phys. 8 (2006) 303

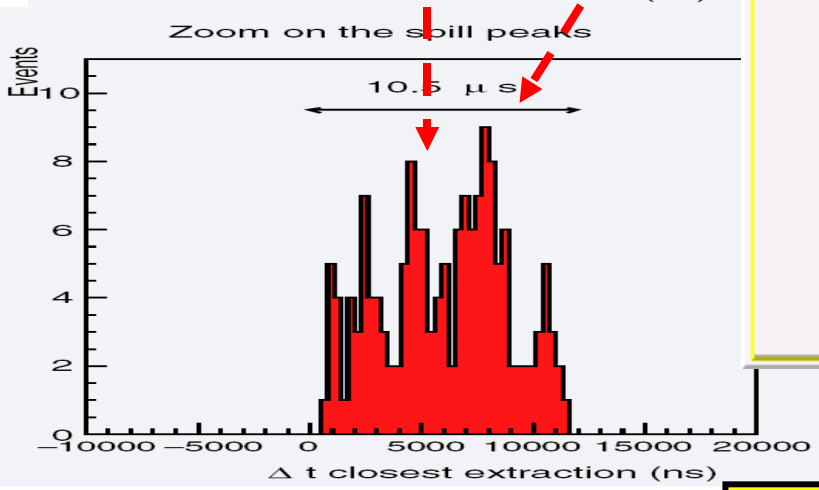


Aug 2006: technical run, **0.76*10^{18} pot** collected

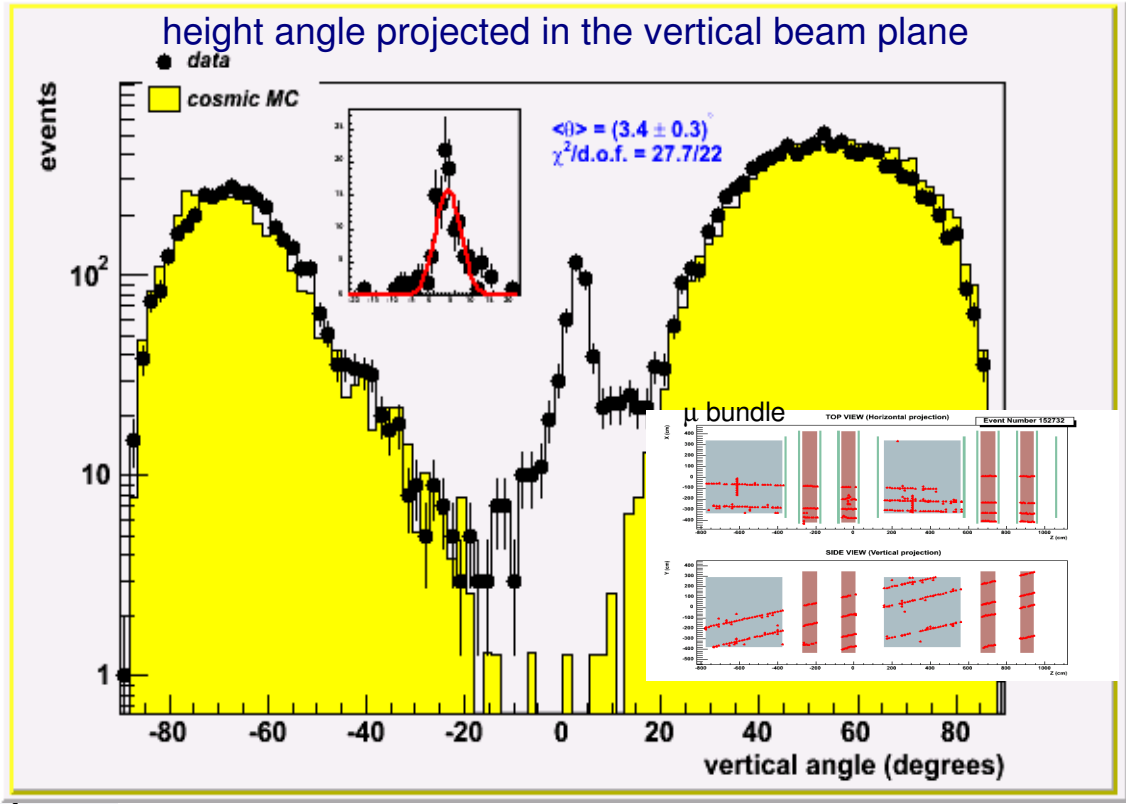
319 interactions in the rock, mechanical structure and spectrometers

GPS time correlated with CERN beam spill time





Extraction length = 10.5 μs



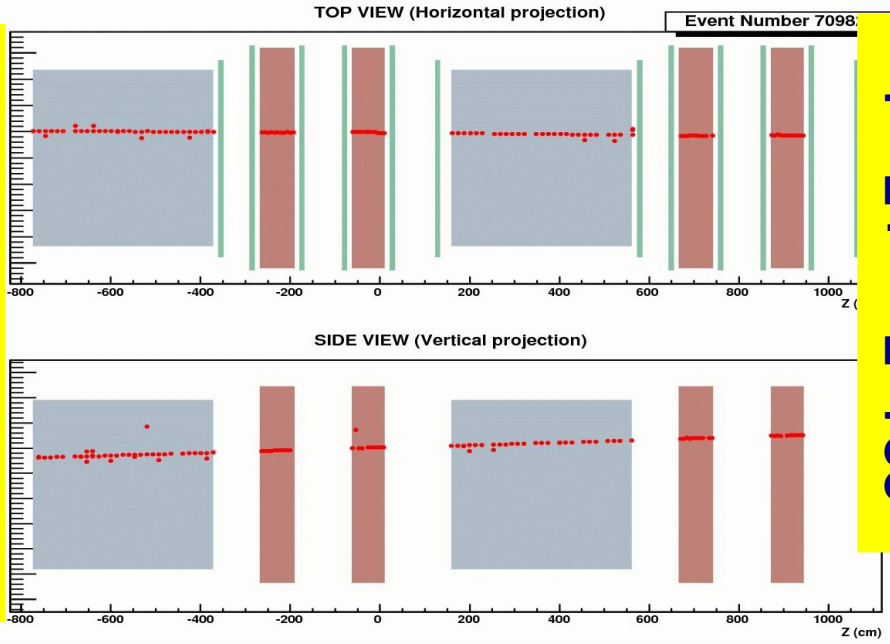
August Run result: <θ>= (3.4 ± 0.3) °

(statistically dominated))

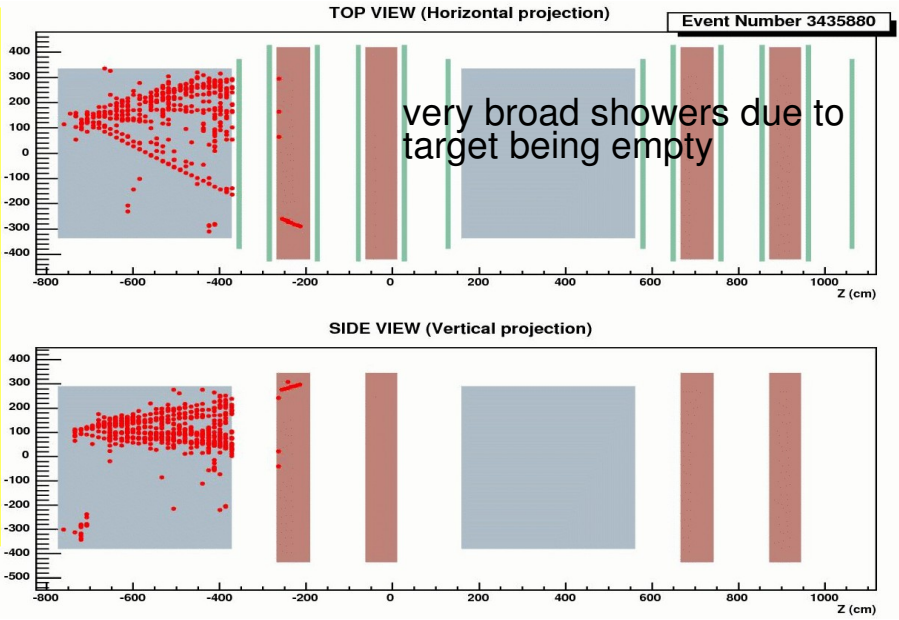
MC: simulation from MACRO parametrization, ABSOLUTE normalization

The OPERA 2006 run: event gallery

νCC in rock (rock muon)

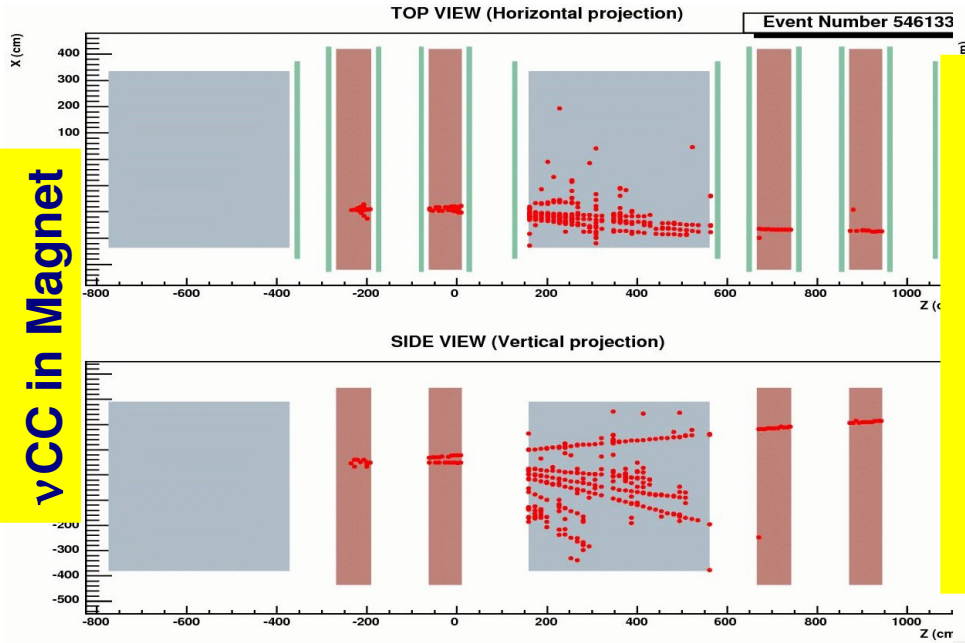


νCC in Target Tracker

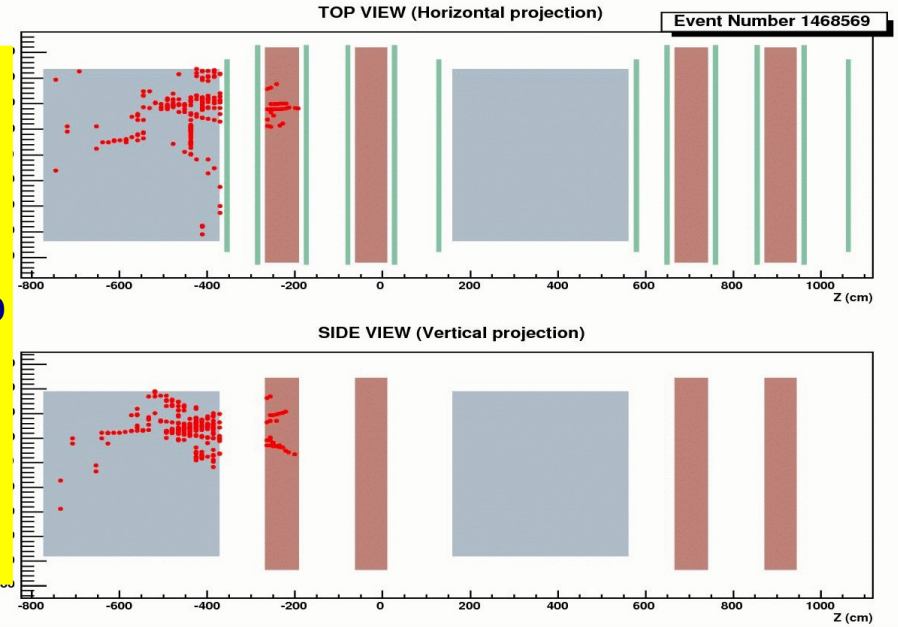


very broad showers due to target being empty

νCC in Magnet



νNC in Target Tracker



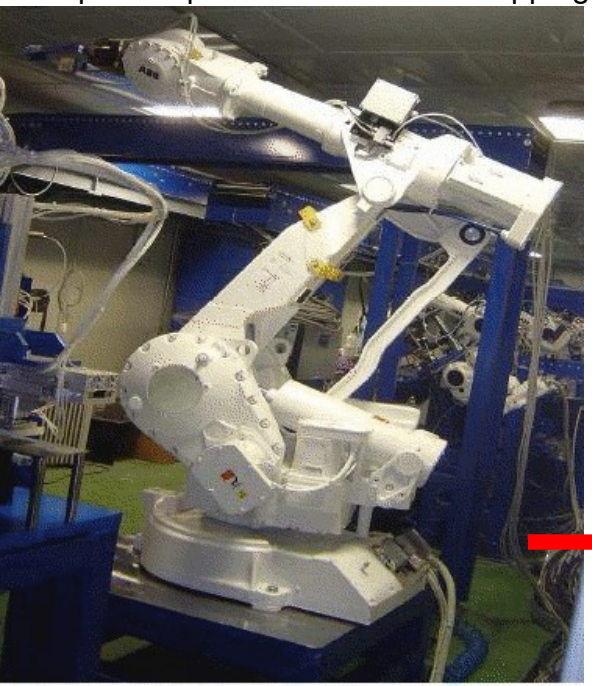
The brick assembly and detector filling

Brick Assembly Machine

Robotised parallel stations.

Underground dark room.

Antrophomorphic robot for brick wrapping



Automatic stacking and packaging of ~150 K bricks (~9M emuls. & lead plates)

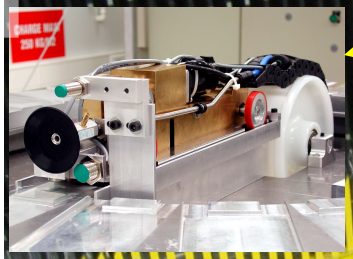
BAM started in Oct. 2006.

Production rate is now ~700 bricks/day

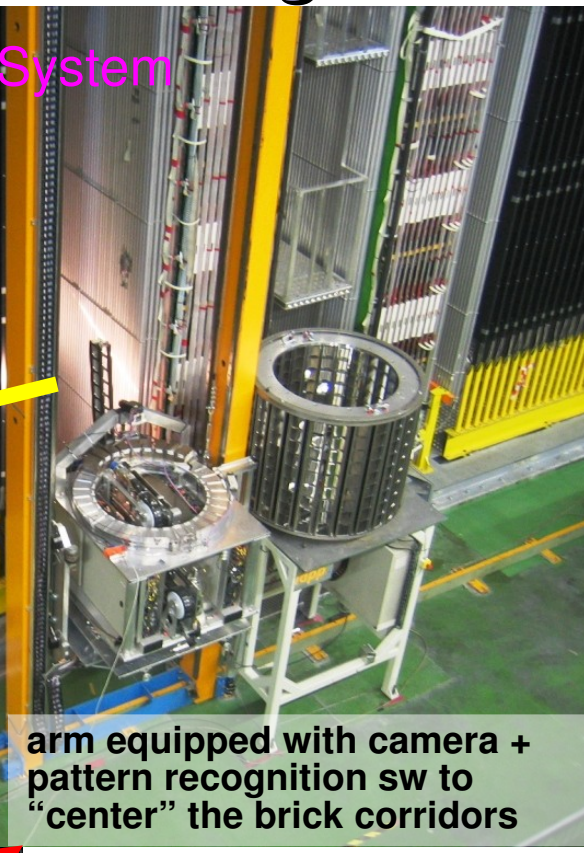
Brick Manipulator System

detector filling routine extractions

suction cup vehicle



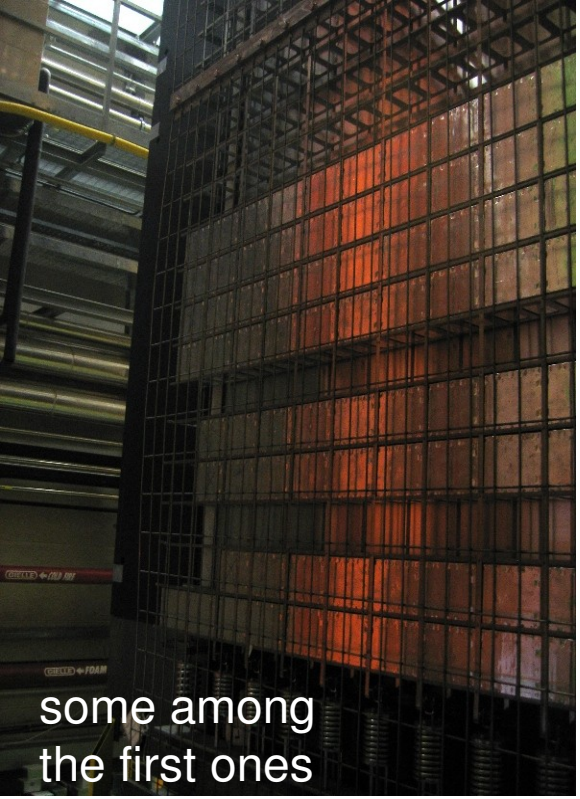
replicated on both detector sides



arm equipped with camera + pattern recognition sw to "center" the brick corridors

Continuous brick mapping (extraction/reinsertion) managed by a relational DB

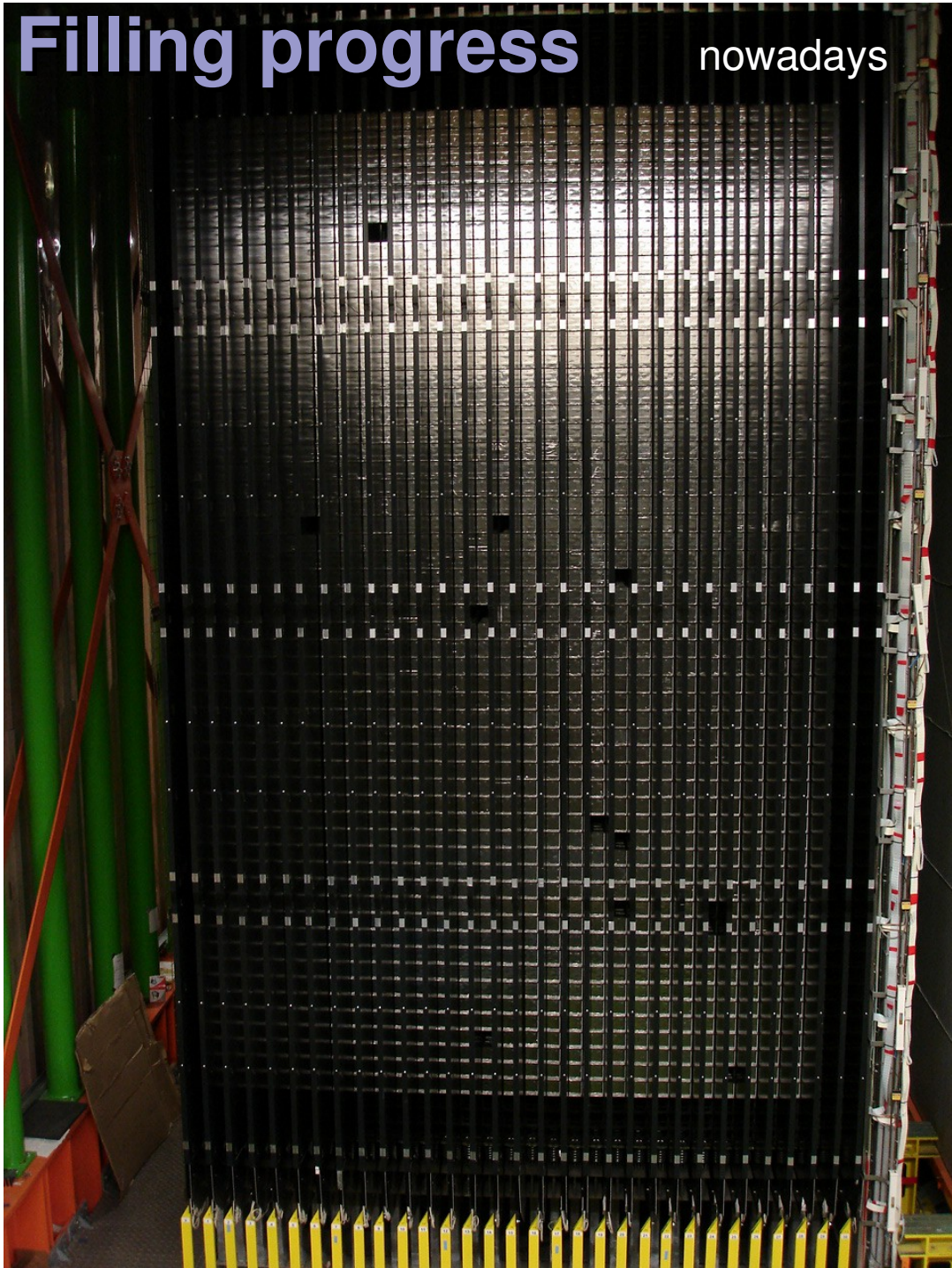
For efficient tracing and retrieval of etherogeneous data: brick and film handling, DAQ, scanning data in various labs, etc.. are also managed by DB



22 June 2008

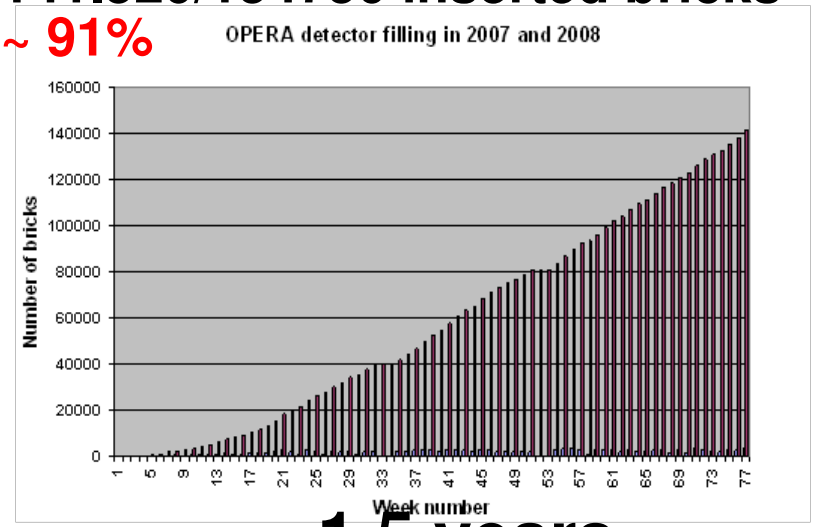
Filling progress

nowadays



141.520/154750 inserted bricks

~ 91%



~ 1.5 years

The OPERA 2007 run

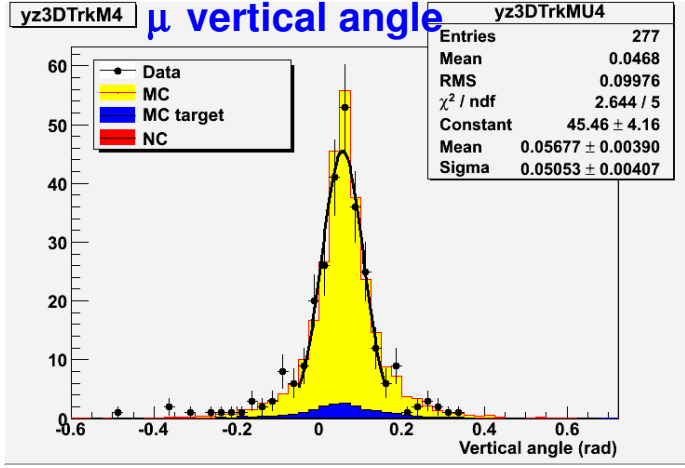
Short physics run (~40% target) **0.824*10^{18} pot**

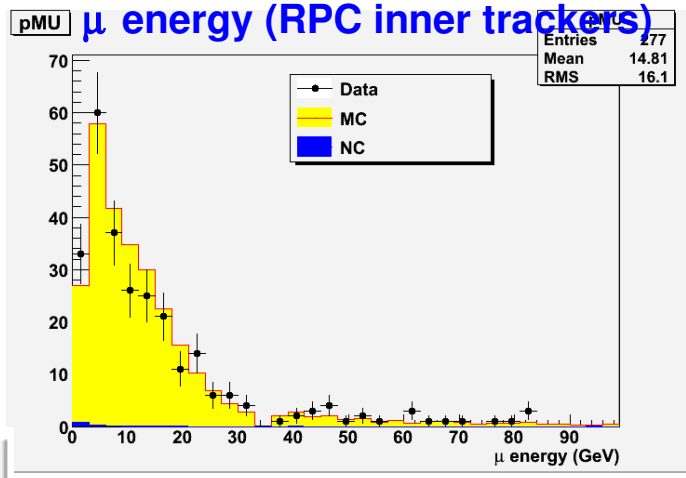
31.5 ± 6 expected events in bricks
38 events registered in the target
(29 CC-like and 9 NC-like)

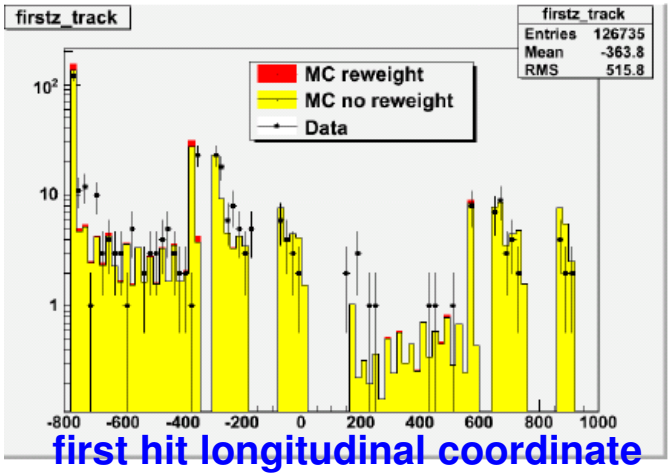
Out of target interactions (rock muons, vtx in the spectr.):
331 events passed the analysis cut
303 expected

First test on real neutrino interactions for Brick handling, Film Processing, Scanning

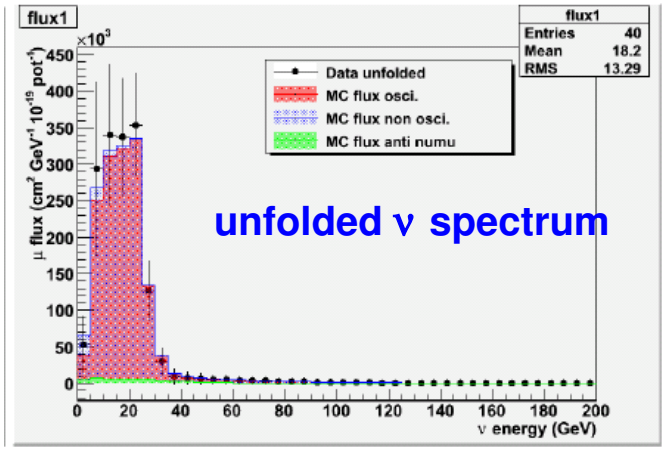
Analysis almost completed. Unfortunately statistics has been limited:
problem at CERN for cooling/ventilation and monitoring electronics







first hit longitudinal coordinate



unfolded ν spectrum

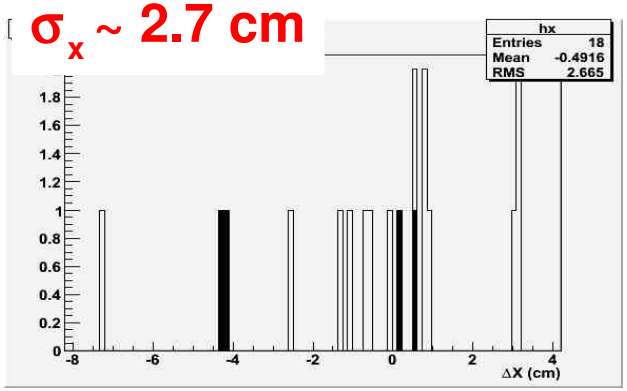
Interconnection between electronic counters and emulsions

physics events !

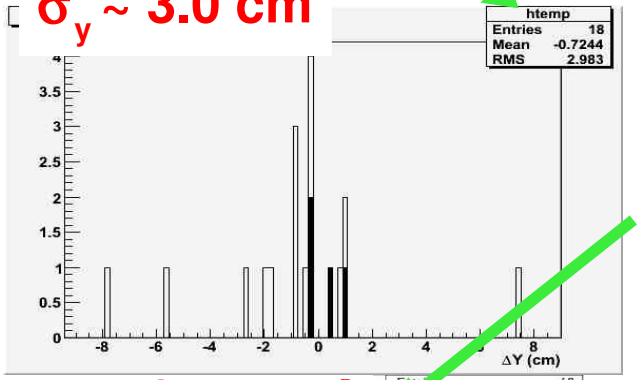
see also arXiv:0804.1985v1

leap of a factor 10000 in precision !

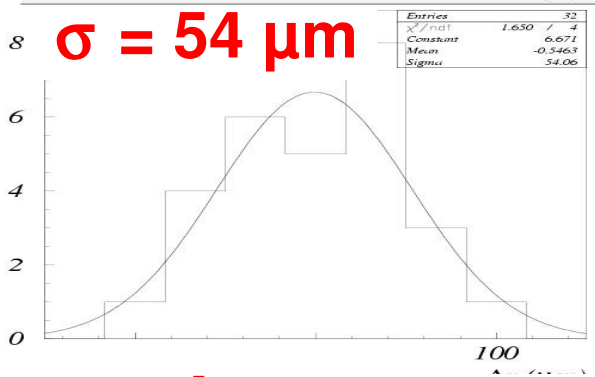
$\sigma_x \sim 2.7$ cm



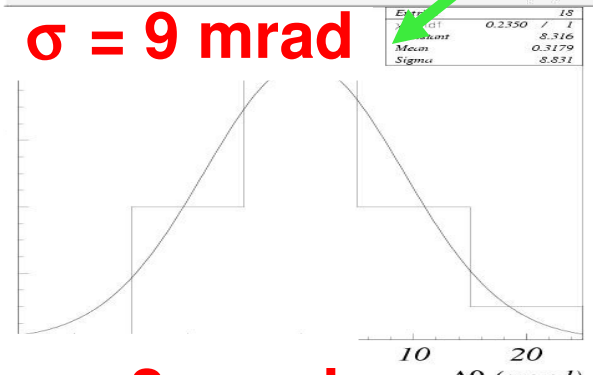
$\sigma_y \sim 3.0$ cm



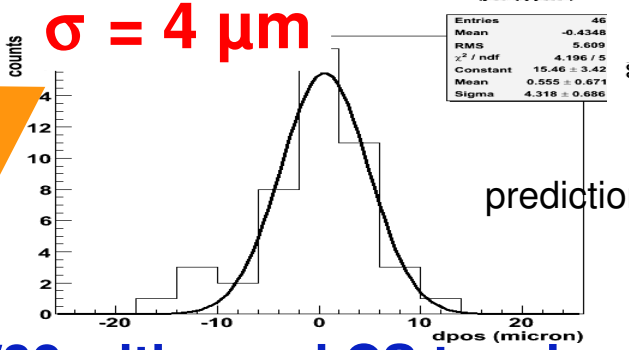
$\sigma = 54$ μm



$\sigma = 9$ mrad

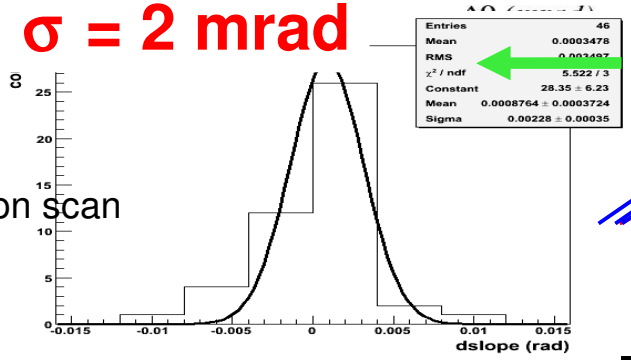


$\sigma = 4$ μm



prediction scan

$\sigma = 2$ mrad



36/38 with good CS tagging

Wall Finding: > 95%

Brick Finding: (80 ± 7) %

• **cosmic rays used for local alignment. Exposure at surface done in a pit designed to suppress low-E component.**

Electronic-detector to CS

• **position of bricks known from extensive alignment measurements + mechanical model of structure deformation**

CS-brick connection

• **marking with 4 X ray beams to fix CS-1st plate relative position.**

• **Also performed for all plates with thin lateral X beams to get fast alignment pattern to be used in tracks follow-down**

• **CS-CS align: Compton tracks.**

X ray marking machine

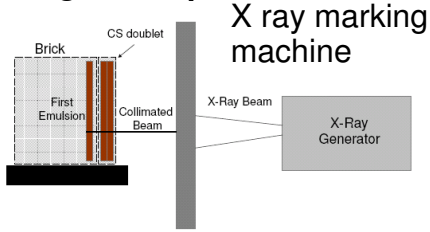
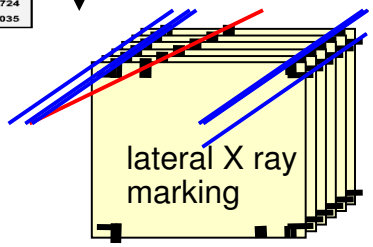
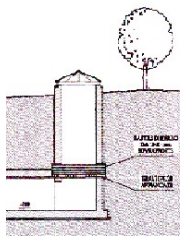
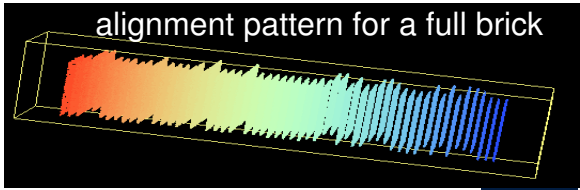


Plate-plate connection

cosmic ray pit



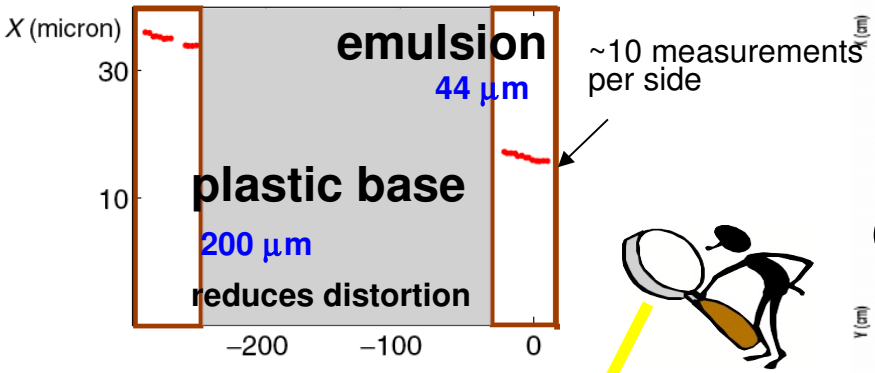


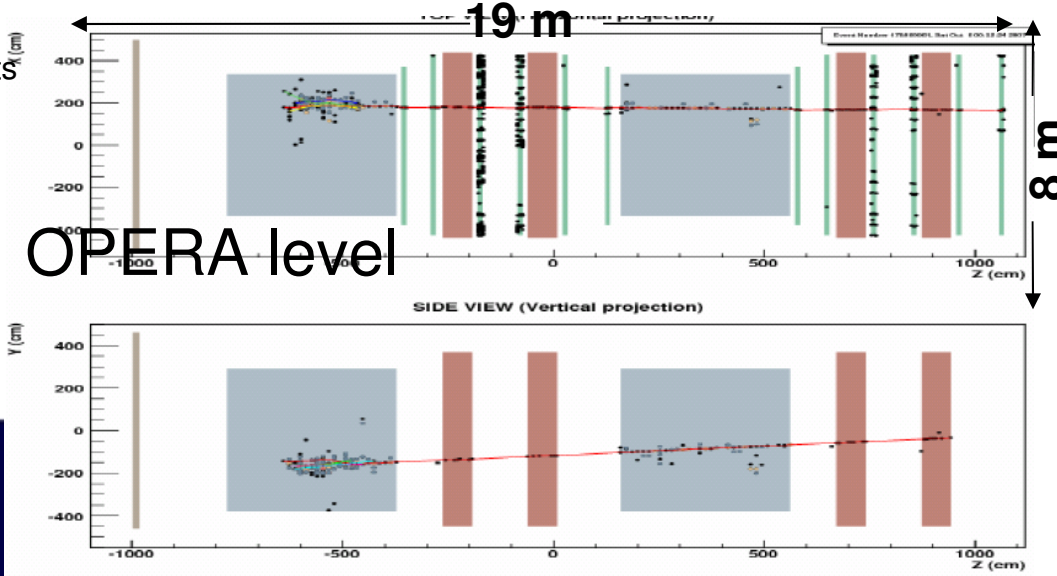


And now let's “open the box” ... !

A selection of neutrino vertices reconstructed in the emulsion detectors

~>

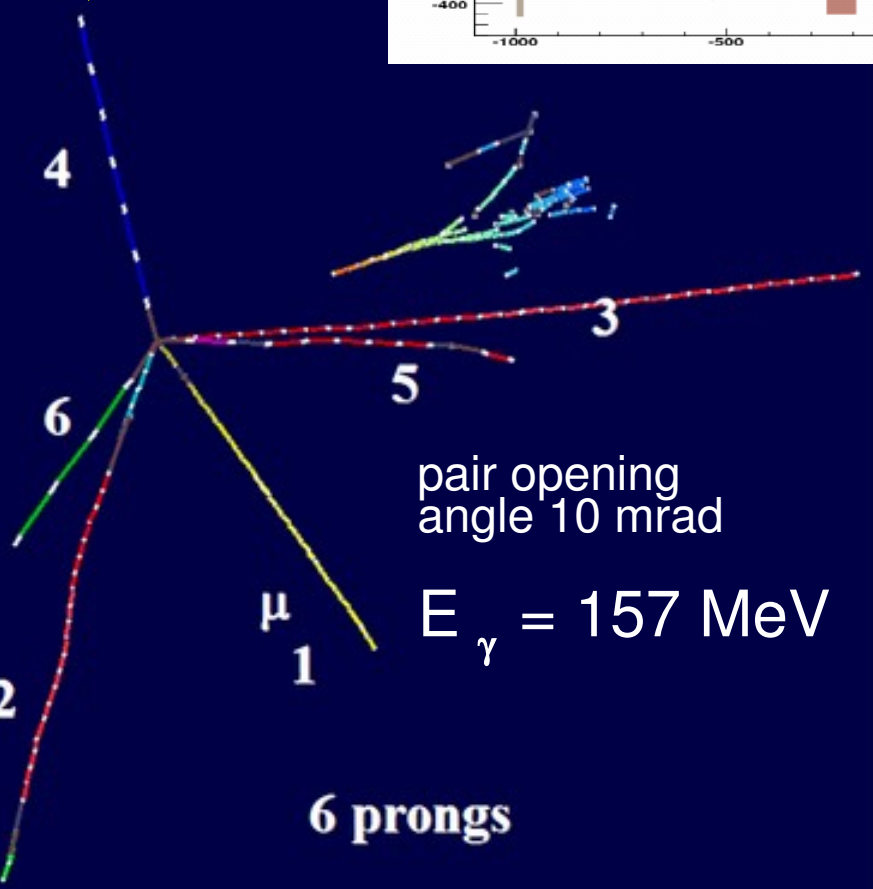




XY

A beautiful ν_μ CC

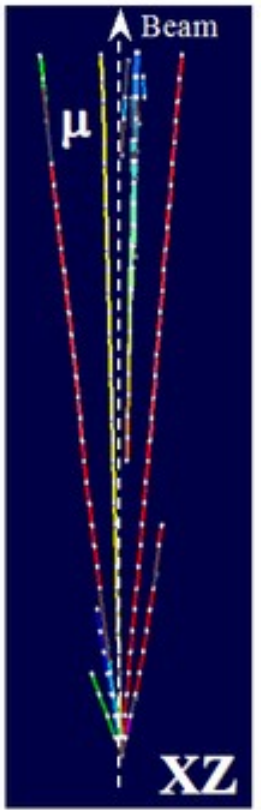
ECC level

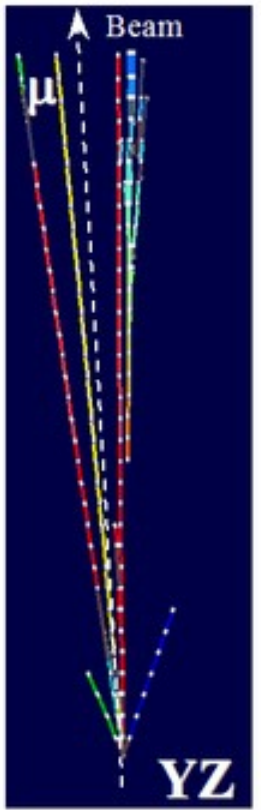


pair opening angle 10 mrad

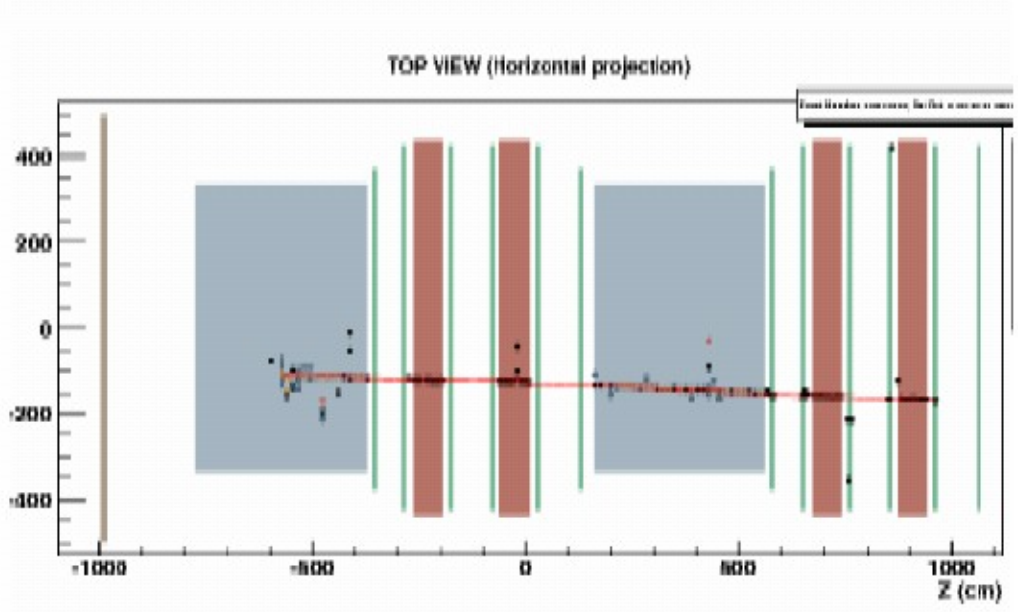
E_γ = 157 MeV

low p track

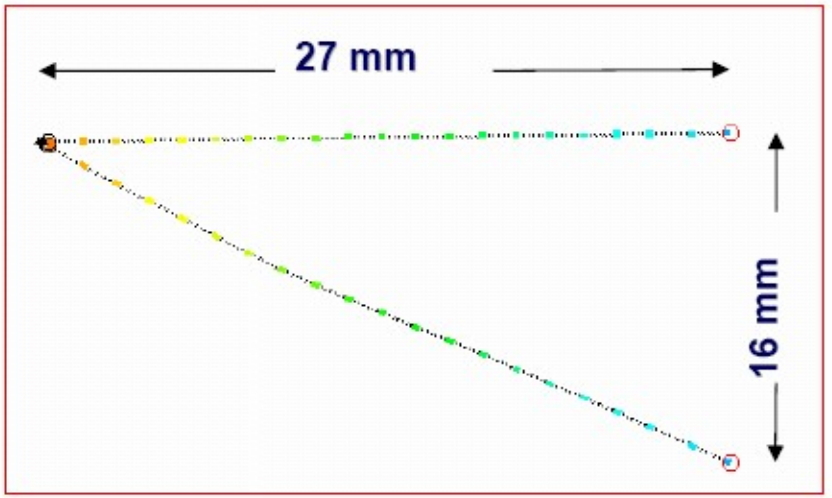


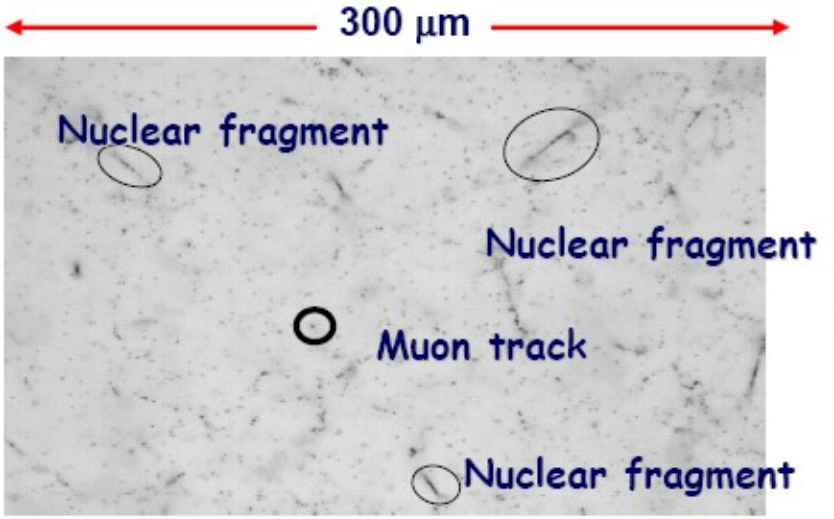


A ν_μ quasi-elastic CC interaction

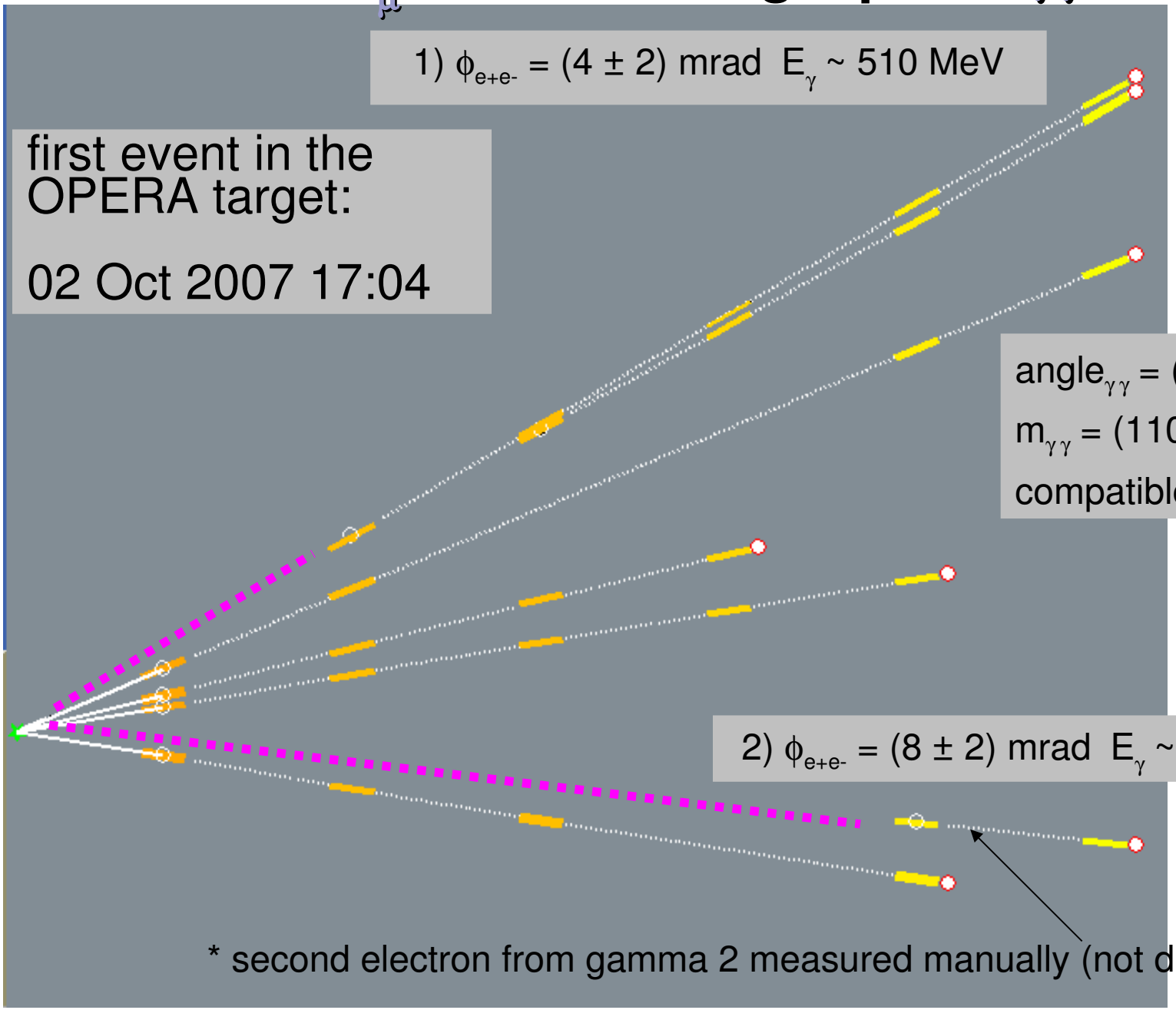


Event 179673325 QE-like topology

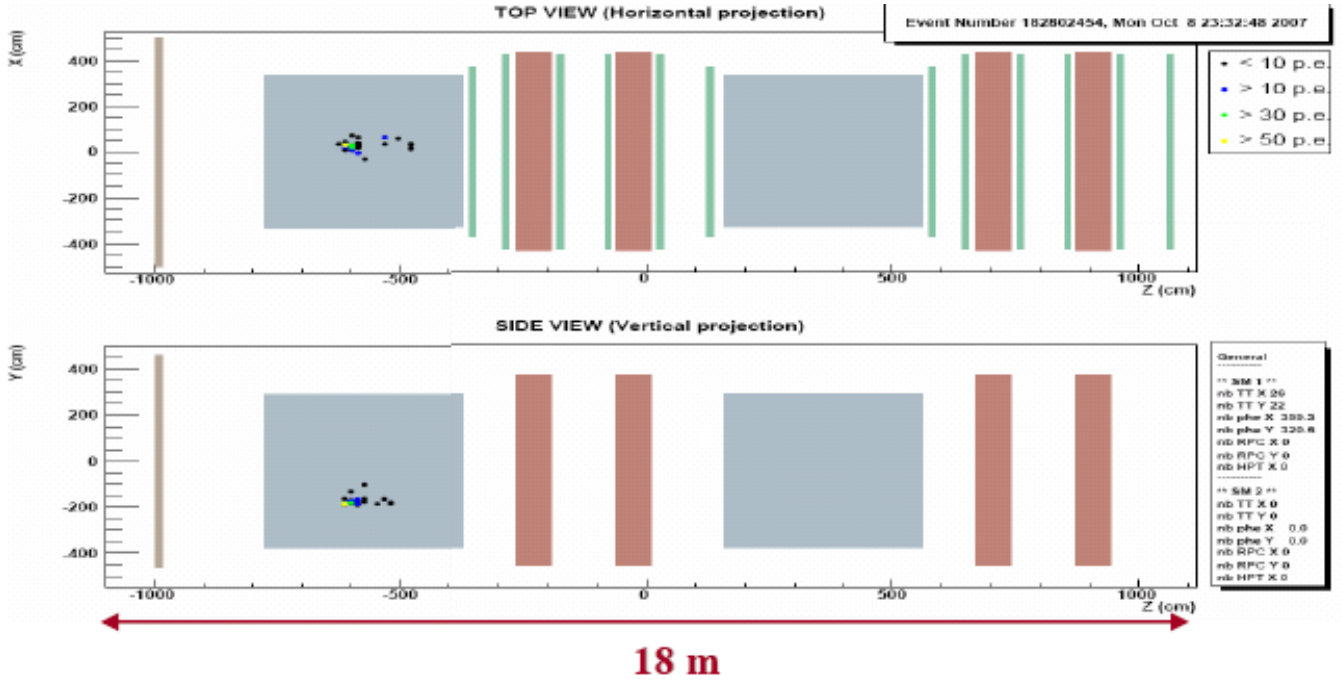




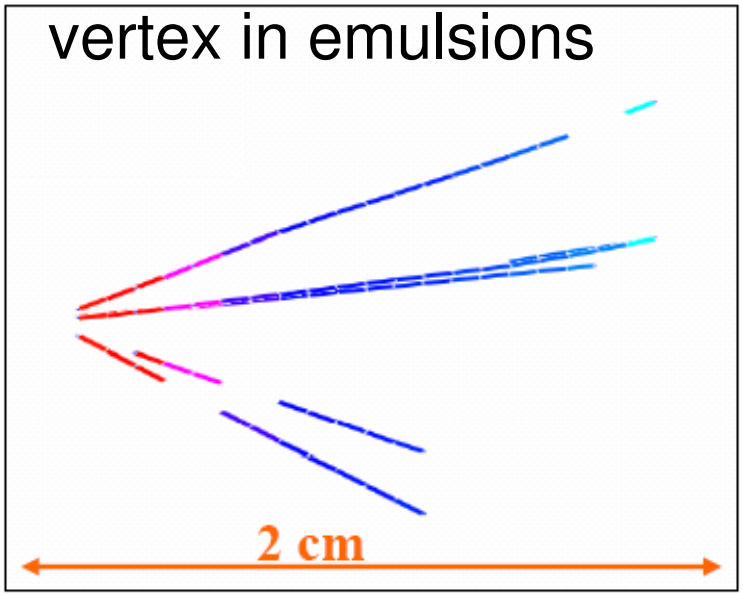
ν_μ CC containing a pi ^{0} -> $\gamma\gamma$



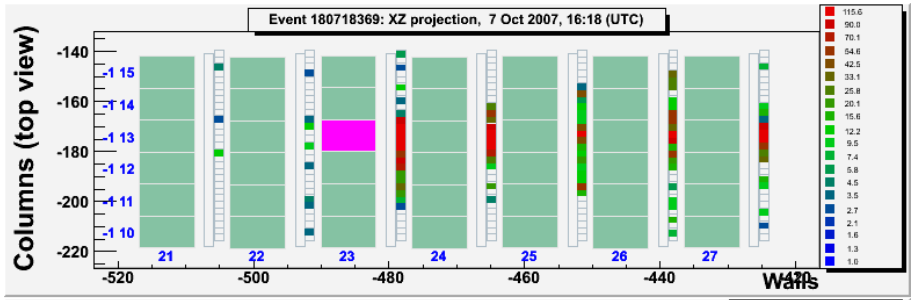
A ν_μ NC interaction

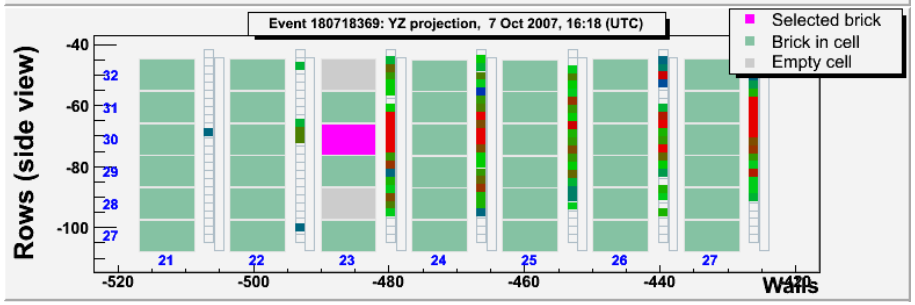


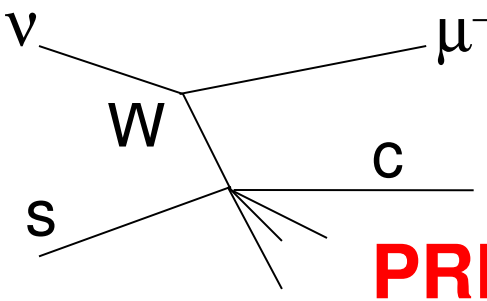
These are the “tough” events due to the lack of a clear vertex pointing high energy track ! ~> larger area to be scanned in Changeable Sheets



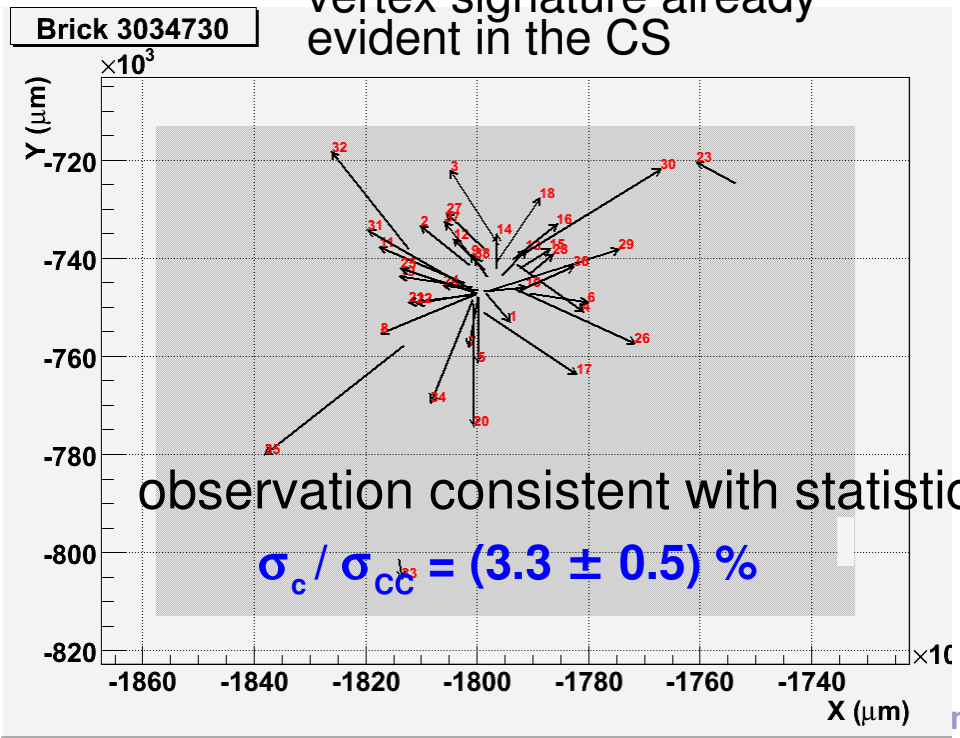
A charm candidate!

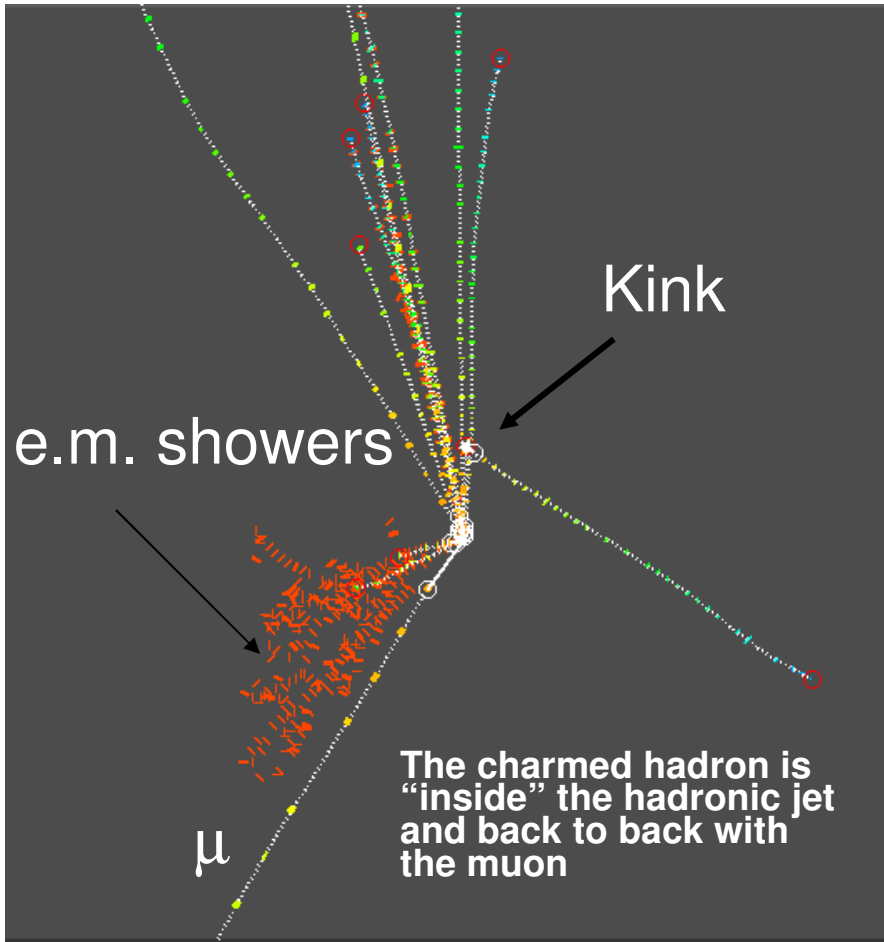






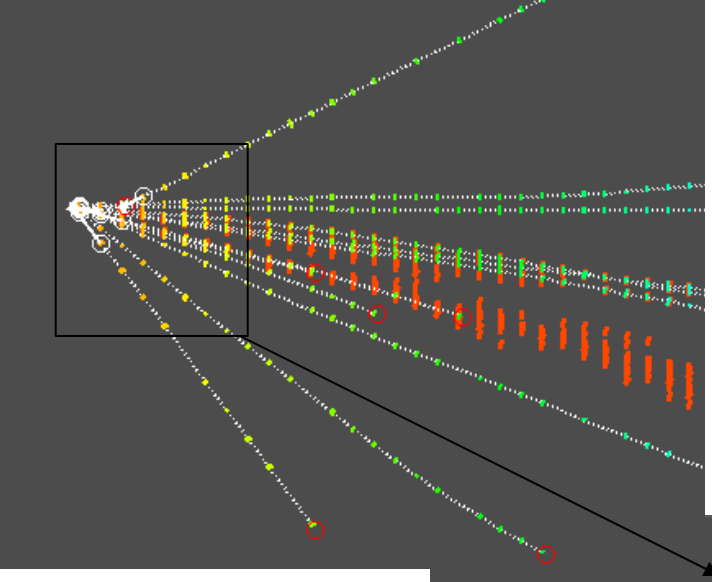
PRELIMINARY

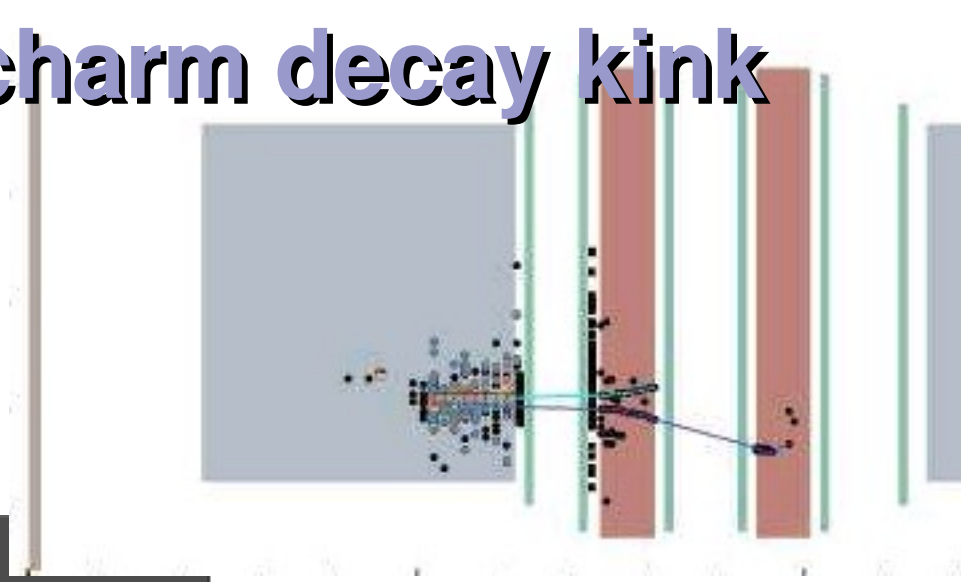


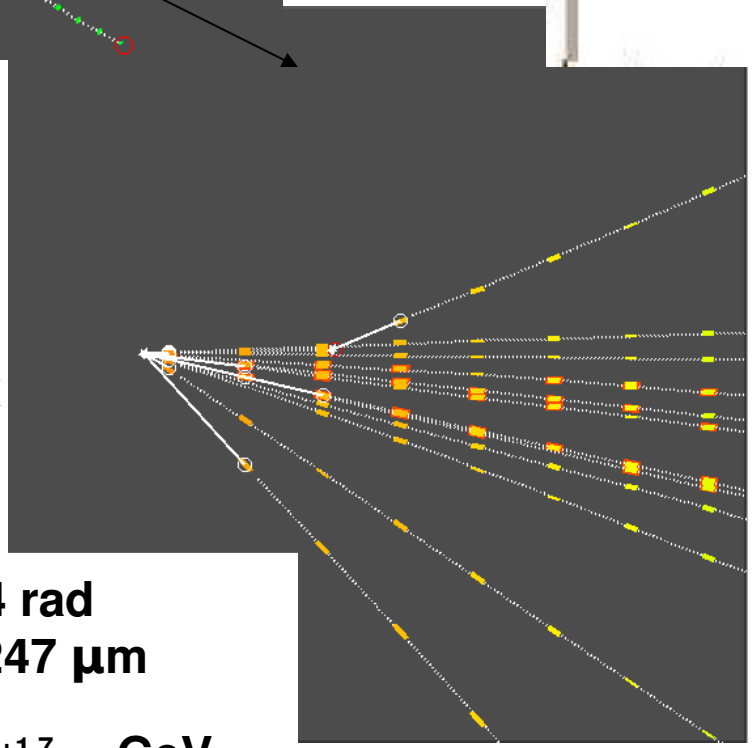


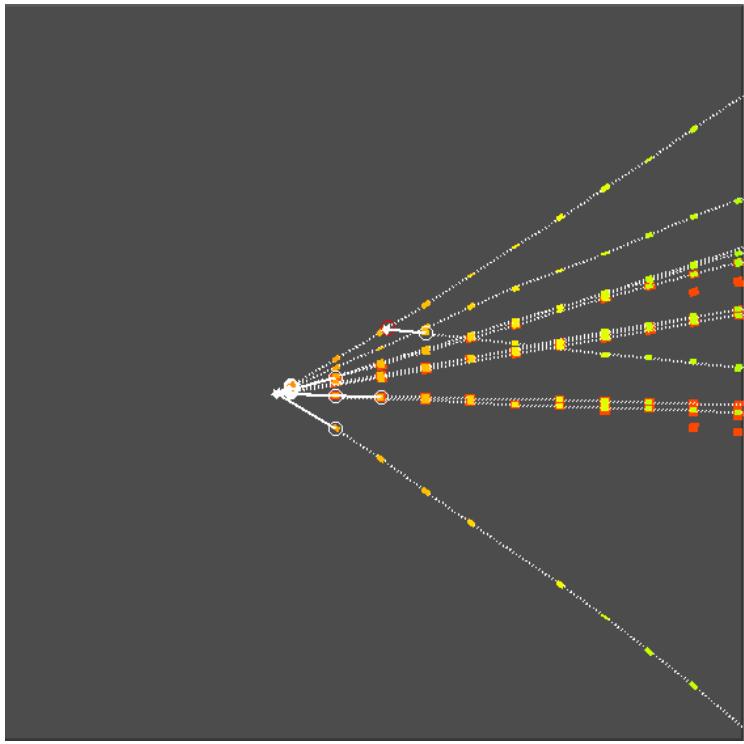
nghin

The charm decay kink









Secondary Vertex (1 prong decay)

kink angle = 0.204 rad
Decay length = 3247 µm

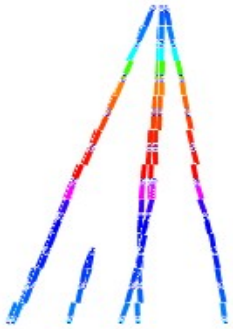
p(daughter) = 3.9 $^{+1.7}_{-0.9}$ GeV
p_t = 796 MeV
p_t^{MIN} = 606 MeV (90% C.L.)

brick - brick connection

improvement of momentum resolution with track length

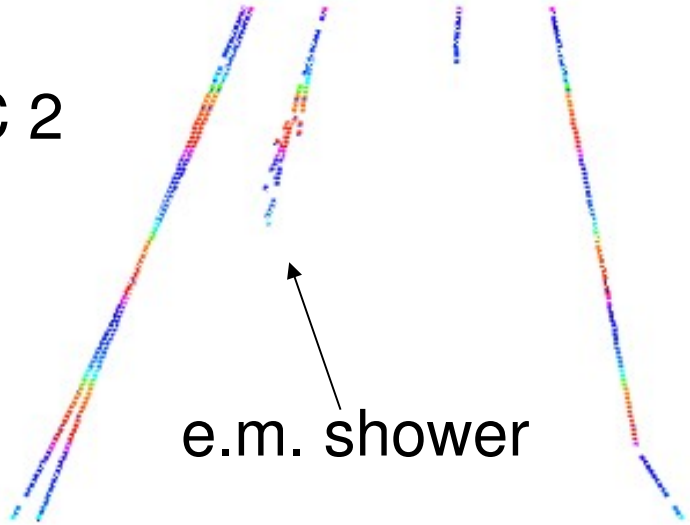
real ν_μ CC from Oct 2007 run

ECC 1

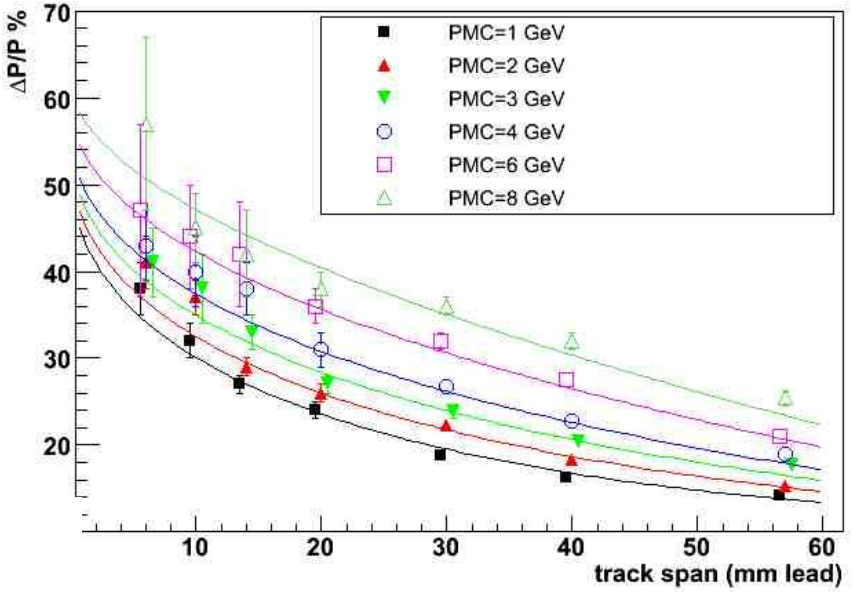


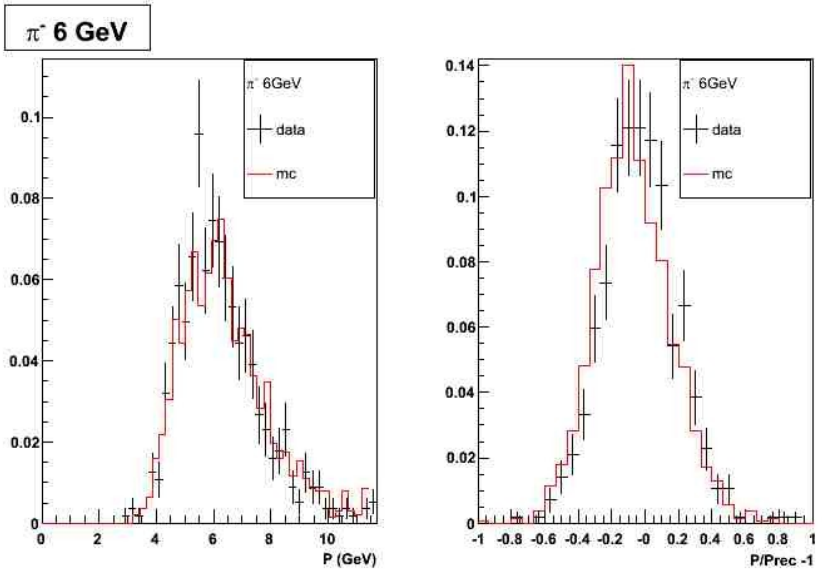
5.5 cm

ECC 2



e.m. shower

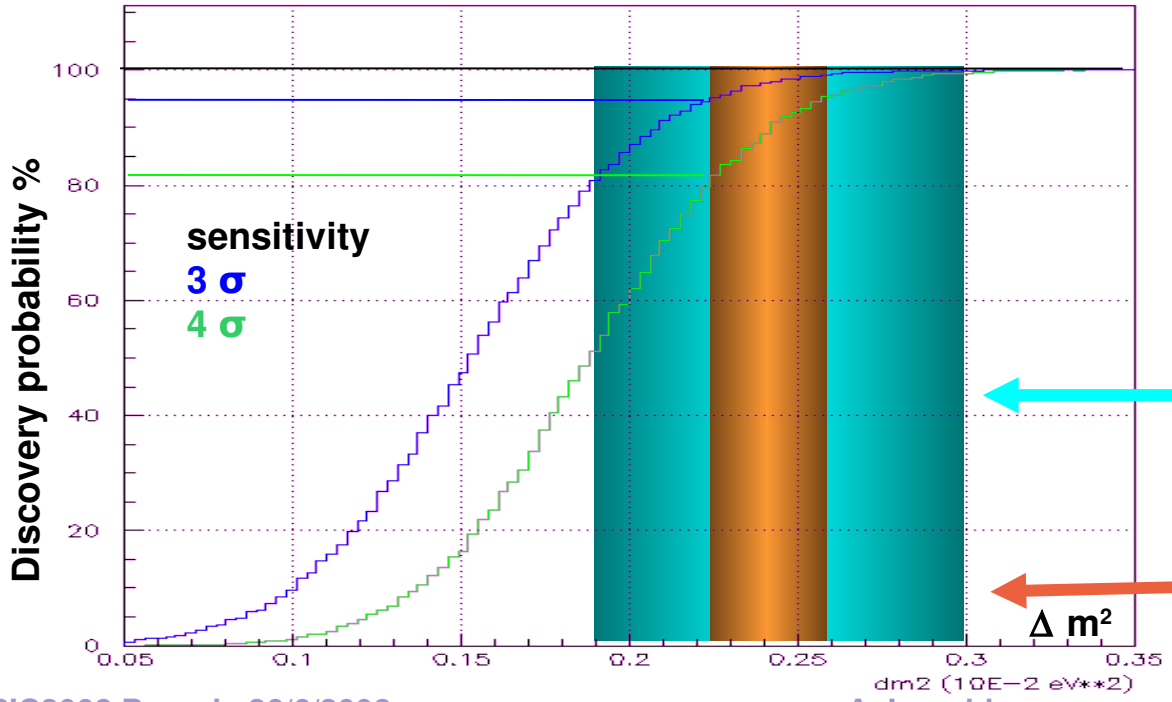




Expected ν_τ events

full mixing, 5 years run @ 4.5×10^{19} p.o.t. / year
1.35 ktons target mass

τ decay channel	Signal		Background
	$\Delta m^2 = 2.5 \cdot 10^{-3}$ eV^2	$\Delta m^2 = 3.0 \cdot 10^{-3}$ eV^2	
τ => μ	2.9	4.2	0.17
τ => e	3.5	5.0	0.17
τ => h	3.1	4.4	0.24
τ => 3h	0.9	1.3	0.17
ALL	10.4	15.0	0.76



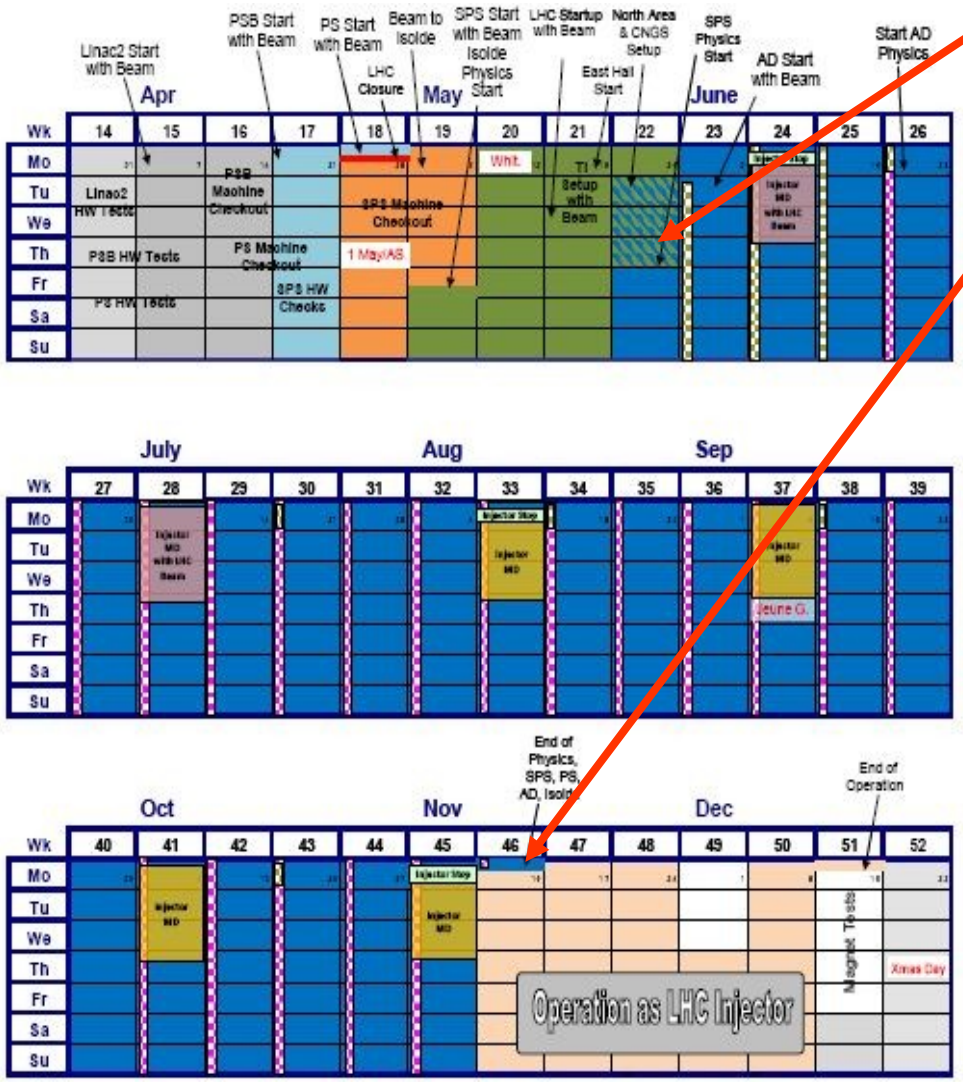
Main background sources:
- charm production and decays
- hadron re-interactions in lead
- large-angle muon scattering in lead

SK 90% CL (L/E analysis)

Last MINOS measurement

The 2008 OPERA run

Start: ~ June 25th
End: Nov 10th



130 days for the CNGS (200)
$2.1*10^{19}$ p.o.t ($4.5*10^{19}$)

Total number of interactions	2000
ν_μCC events	1500
ν_μNC events	450
$\nu_e/\overline{\nu}_e$ events	13
Charm decay	85
τ candidate (@2.5 10^{-3} eV^2)	~ 1

Conclusions

The OPERA experiment is running

- Electronic detectors fully commissioned
- Target filling will be completed by July

Scanning labs are ready (~40 microscopes available)

The OPERA 2007 run allowed to test the full operation chain:

- Test electronic detectors and data acquisition
- Test the brick finding algorithm
- Test brick handling
- Test CS doublet scanning
- Test the target tracker to brick matching and scanning strategy

The concept of the OPERA detector has been experimentally validated by measuring neutrino events in the detector.

The first high luminosity OPERA run is starting these days. With some luck we will measure the first ν_τ candidate event by the end of this year!

Backup slides

OPERA sensitivity to θ_{13}

Search for $\nu_\mu \rightarrow \nu_e$ oscillation

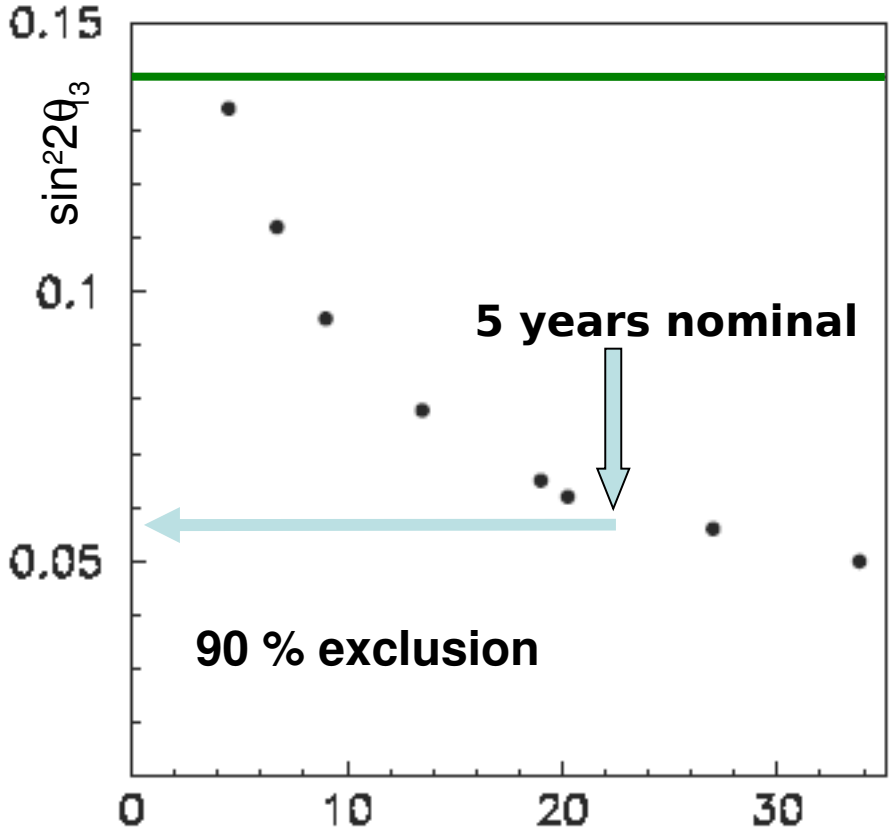
Simultaneous fit of
E_e, missing p_T and E_{vis} distributions

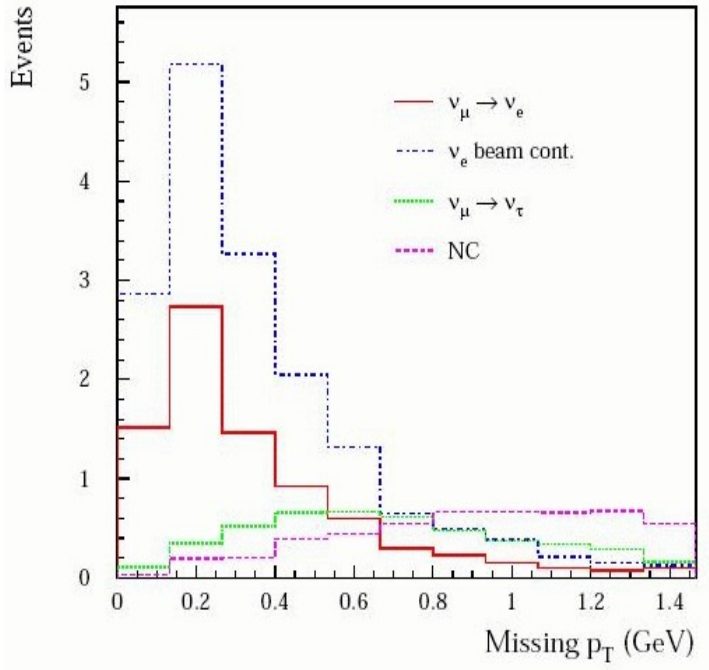
Assuming : $\theta_{23} = \pi/4$,

$\Delta m^2_{23} = 2.5 \times 10^{-3}$ eV^2

events
(5 years)

Signal @ CHOOZ lim.	13.0
$\tau \rightarrow$ e	4.5
ν_μ CC	1.0
ν_μ NC	5.2
ν_e CC beam	18.0

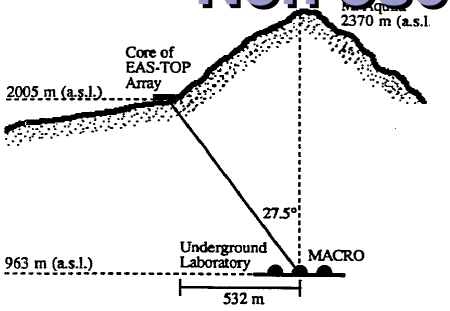


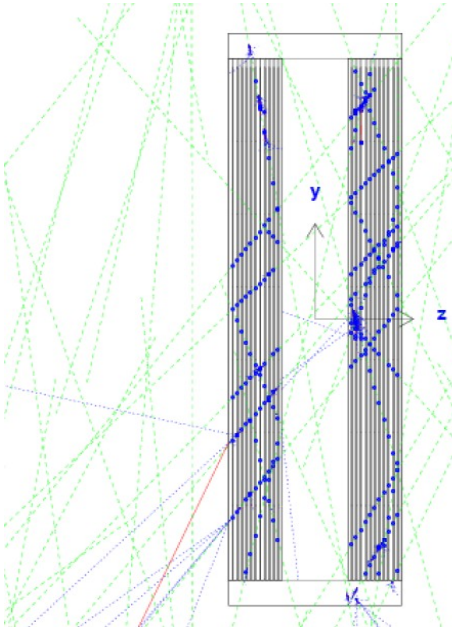


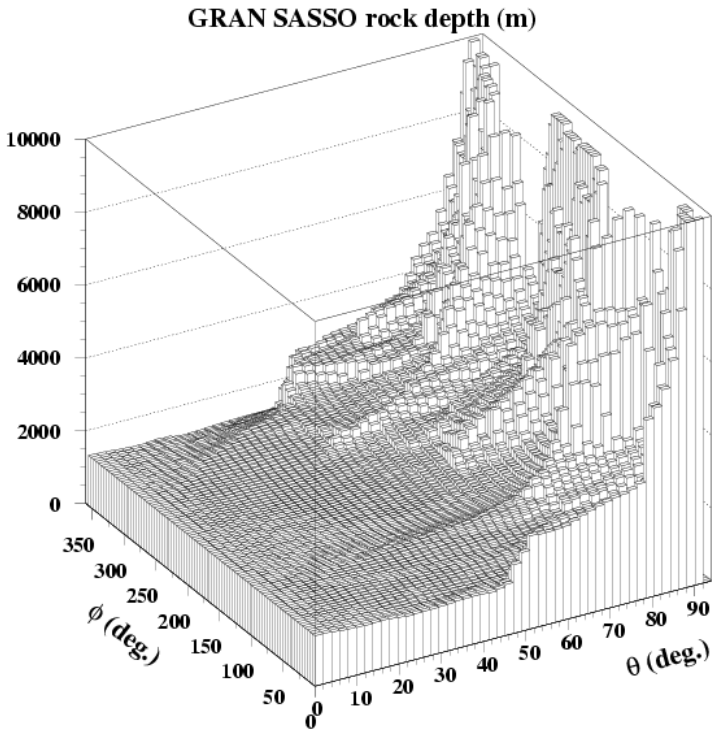
J.Phys.G29:443,2003

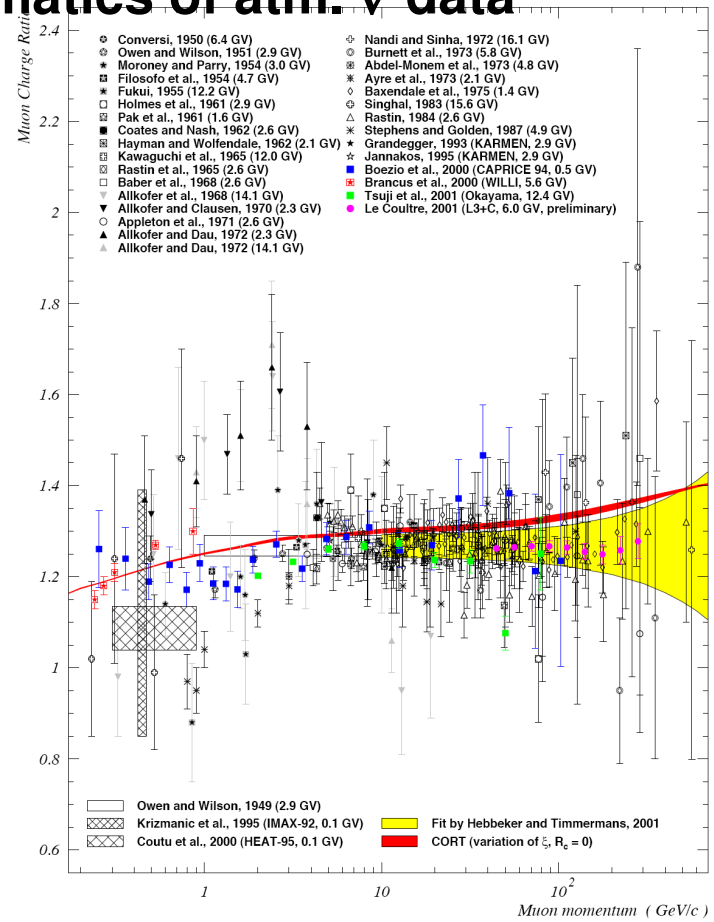
Non oscillation physics: high-E μ charge ratio

- cosmic ray composition studies
- TeV muon E-loss
- hor. muons: systematics of atm. ν data

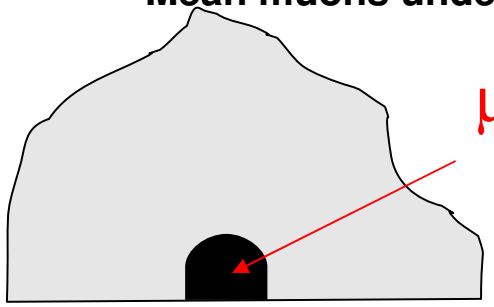








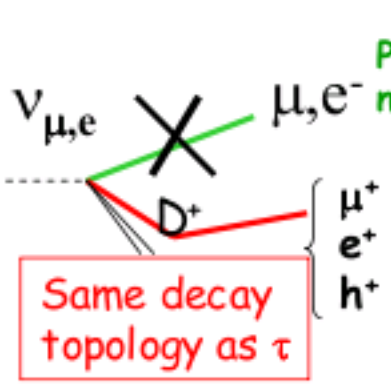
- Mean muons underground energy: 300 GeV



threshold energy at LNGS ~ 1 TeV

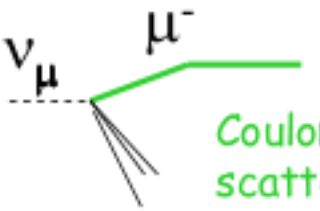
Underground experiments measure the charge ratio in a higher energy region: muons are energy-selected with the overburden

τ search : Backgrounds

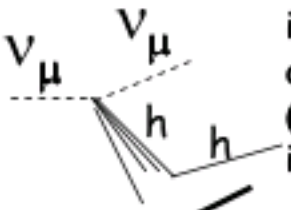


Charm production in CC, common to the 3 channels

Good muon identification is fundamental



Coulombian large angle scattering of muons in Lead : Bck. to $\tau \rightarrow \mu$



Hadronic interactions in Pb: Bck. to $\tau \rightarrow h$ or to $\tau \rightarrow \mu$ (if hadron mis-identified as muon)

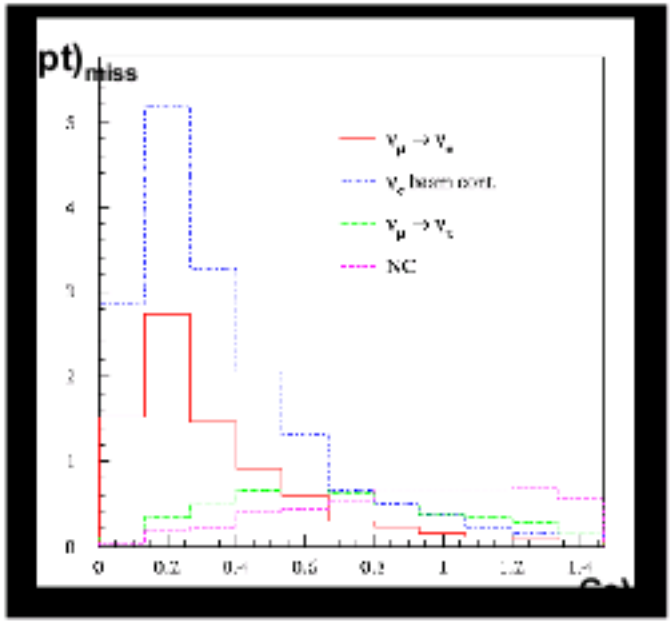
Expected number of background events after 5 years running with nominal beam:

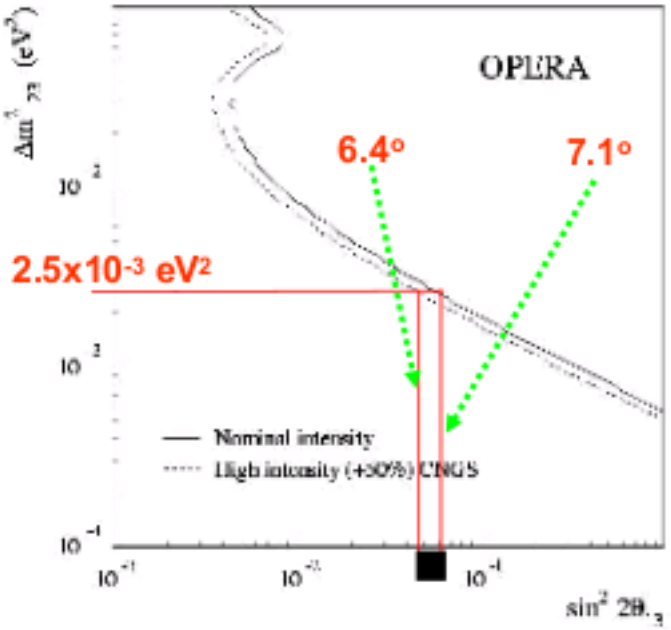
	$\tau \rightarrow e$	$\tau \rightarrow \mu$	$\tau \rightarrow h$	$\tau \rightarrow 3h$	Total
Charm background	.173	.008	.134	.181	.496
Large angle μ scattering		.096			.096
Hadronic background		.077	.095	.	.172
Total per channel	.173	.181	.229	.181	.764

Θ_{13}	SIGNAL	ν_e beam	$\tau \rightarrow e$	ν_μ NC	ν_μ CC
9°	9.3	18	4.5	5.2	1.0
7°	5.8	18	4.5	5.2	1.0
5°	3.0	18	4.6	5.2	1.0

$\Delta m_{23}^2 = 2.5 \times 10^{-3}$ eV^2 $\quad \Theta_{23} = 45°$

nominal CNGS beam $\quad$ 5 years



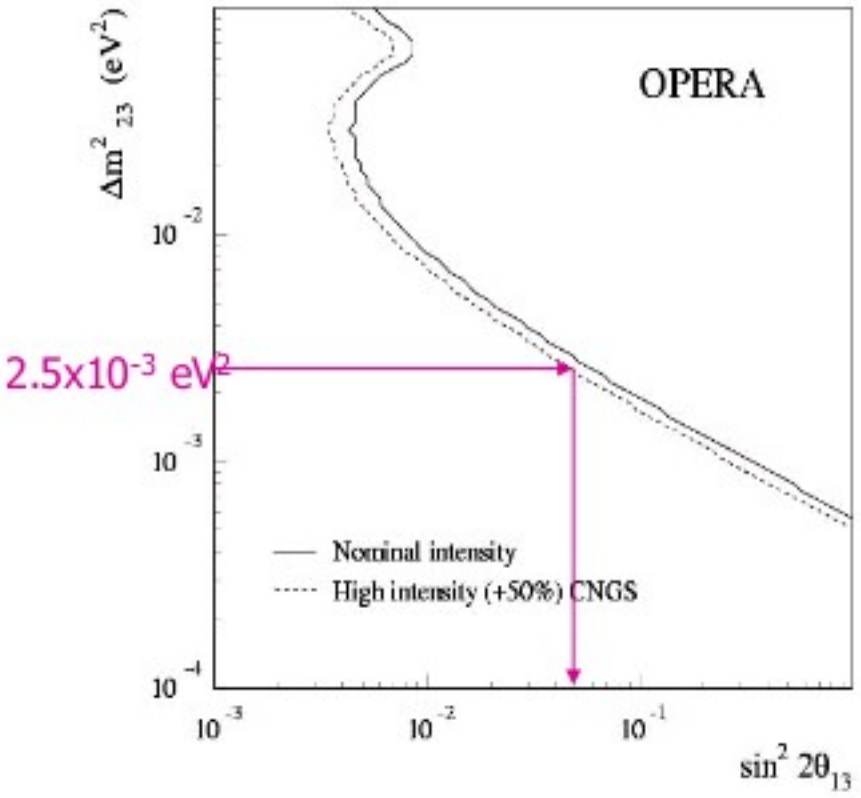


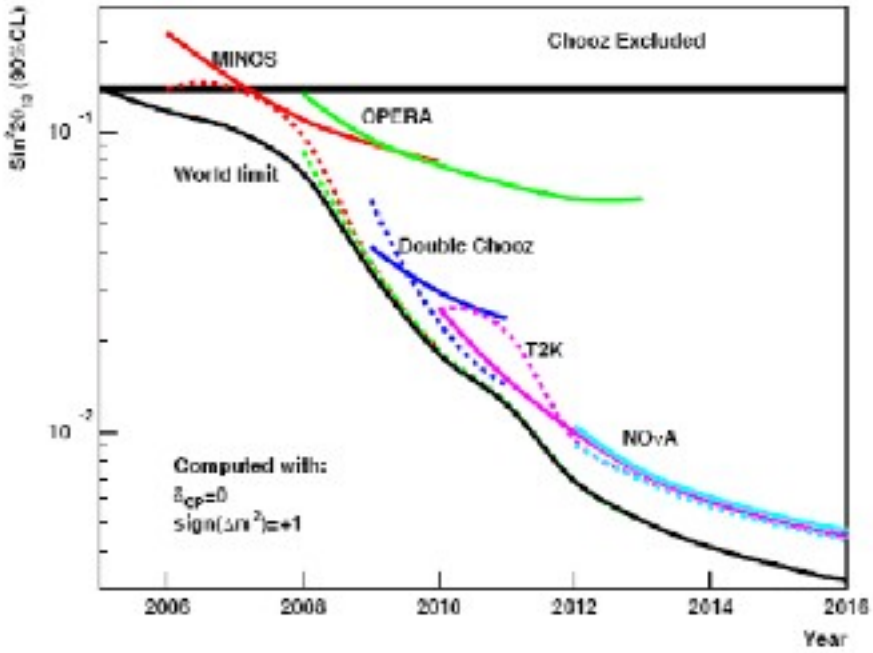
Combined fit of E_e, E_{vis}, $(pt)_{miss}$ to improve S/B ratio

90% C.L. limits on $\sin^2(2\Theta_{13})$ and Θ_{13} :

$\sin^2(2\Theta_{13}) < 0.05 \quad \Theta_{13} < 7.1°$

$\nu_\mu \rightarrow \nu_e$ oscillation search





$\Delta m^2_{23} = 2.5 \times 10^{-3}$ eV^2 $\quad \Theta_{23} = 45°$

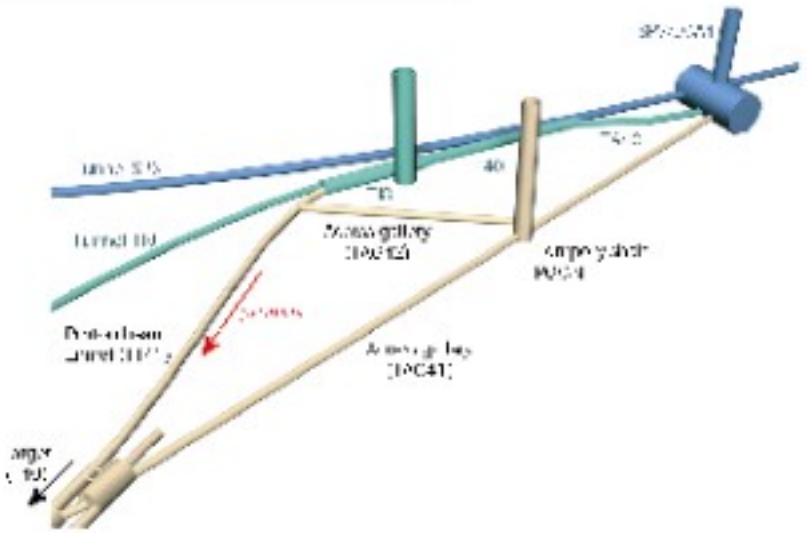
nominal CNGS beam 5 years

Combined fit of E_e, E_{vis}, $(pt)_{miss}$

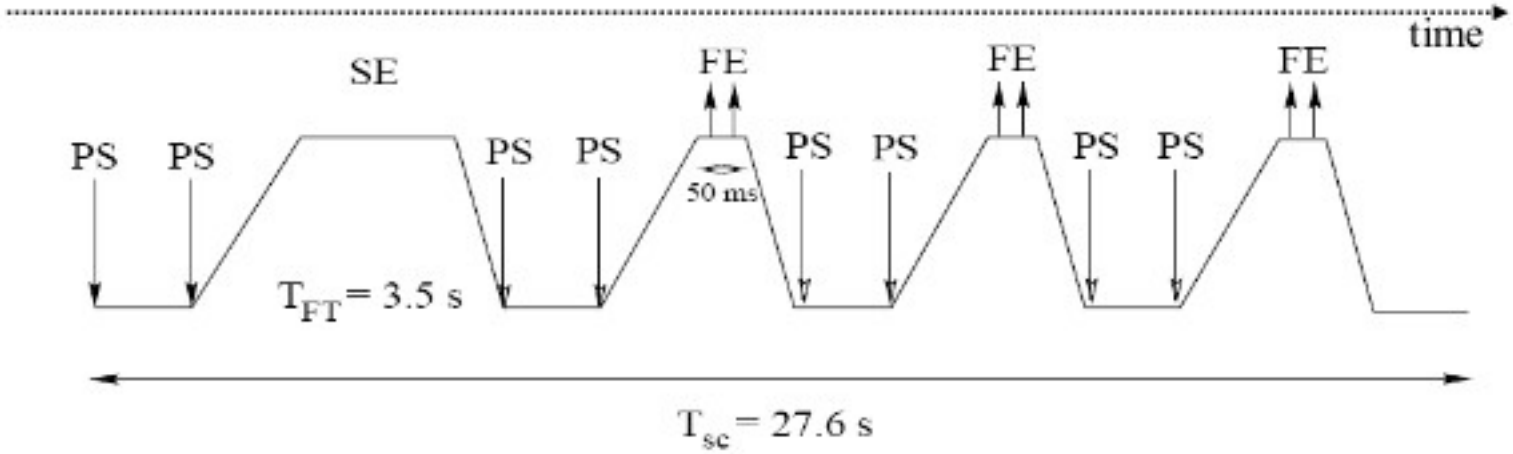
90% C.L. limits on $\sin^2(2\Theta_{13})$ and Θ_{13} :

$\sin^2(2\Theta_{13}) < 0.06 \quad \Theta_{13} < 7.1°$

CNGS beam @ CERN:



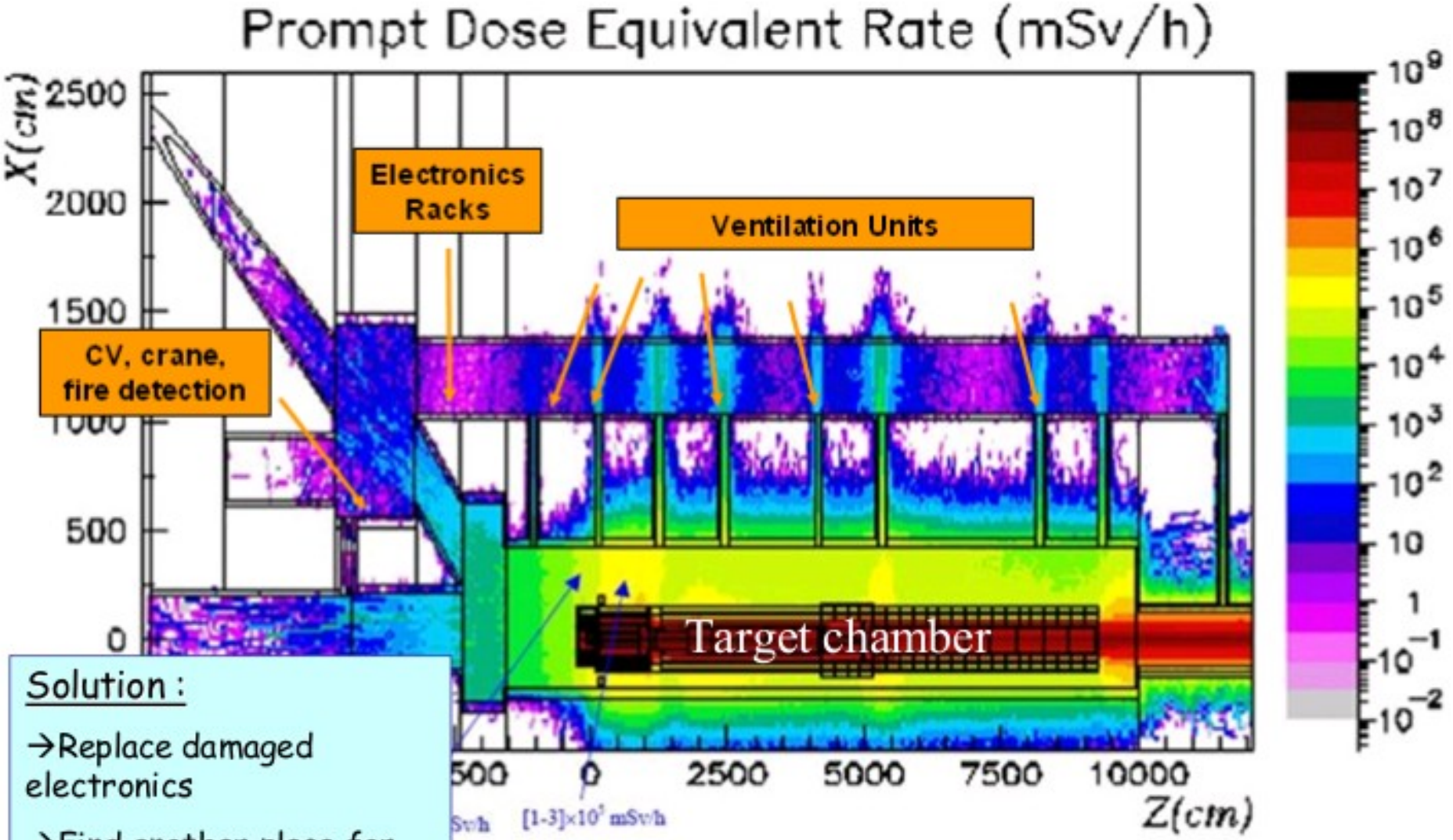
Proton extractions from SPS with 3 cycles of 6s each : 2 extractions of 10.5 μs, separated by 50 ms.



Beam event selection : $T_{OPERA} - (T_{SPS} + TOF) < T_{gate}$

~2.4ms ~1extraction

Nominal intensity : 4.5 10^{19} pot /yr, with **2.4 10^{13} pot/extraction (FE)**



Solution :

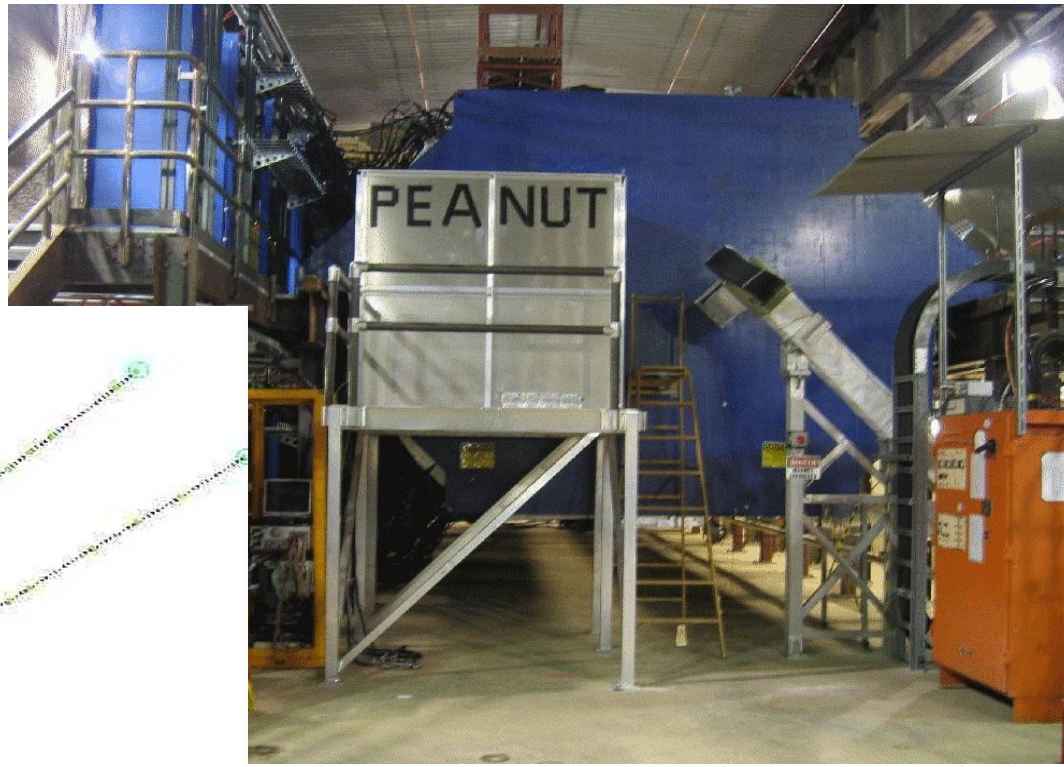
→Replace damaged electronics

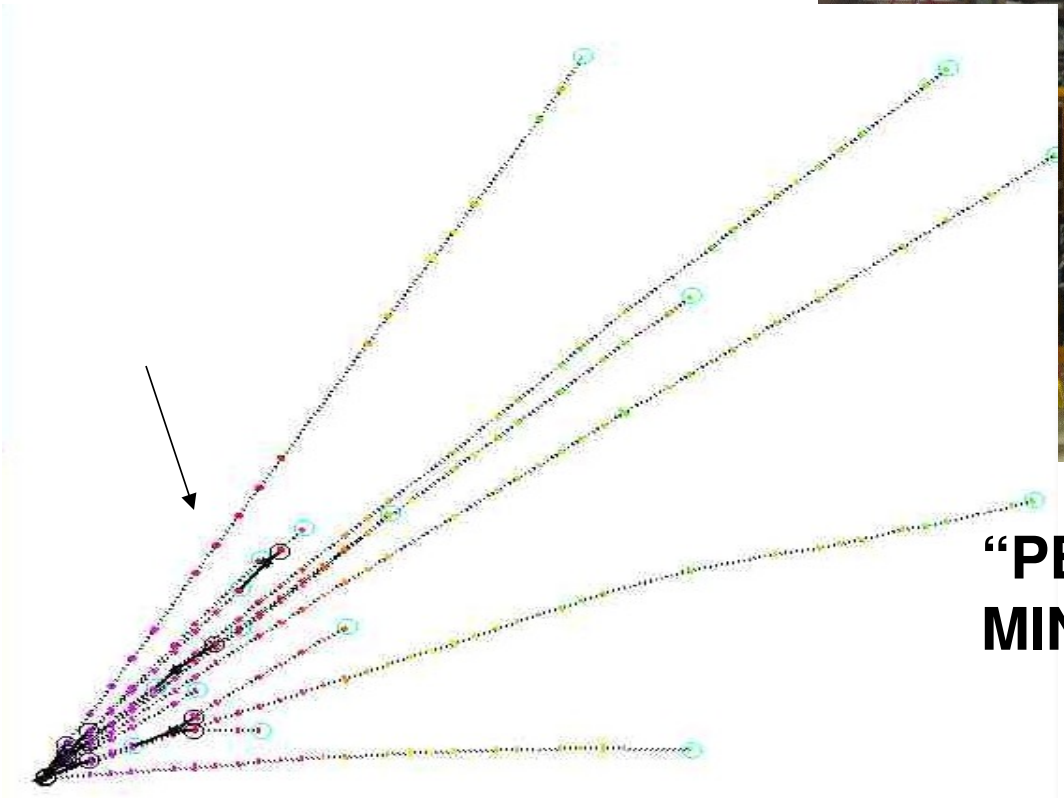
→Find another place for ventilation control units

M. Sentis et al. AB/ATB. CERN-OPEN-2006-09. 2005

These doses were computed by the Fluka group and known since many years !!
They were not just taken into account when the ventilation was installed
Radiation protection measurements confirm the calculations

Experience with PEANUT

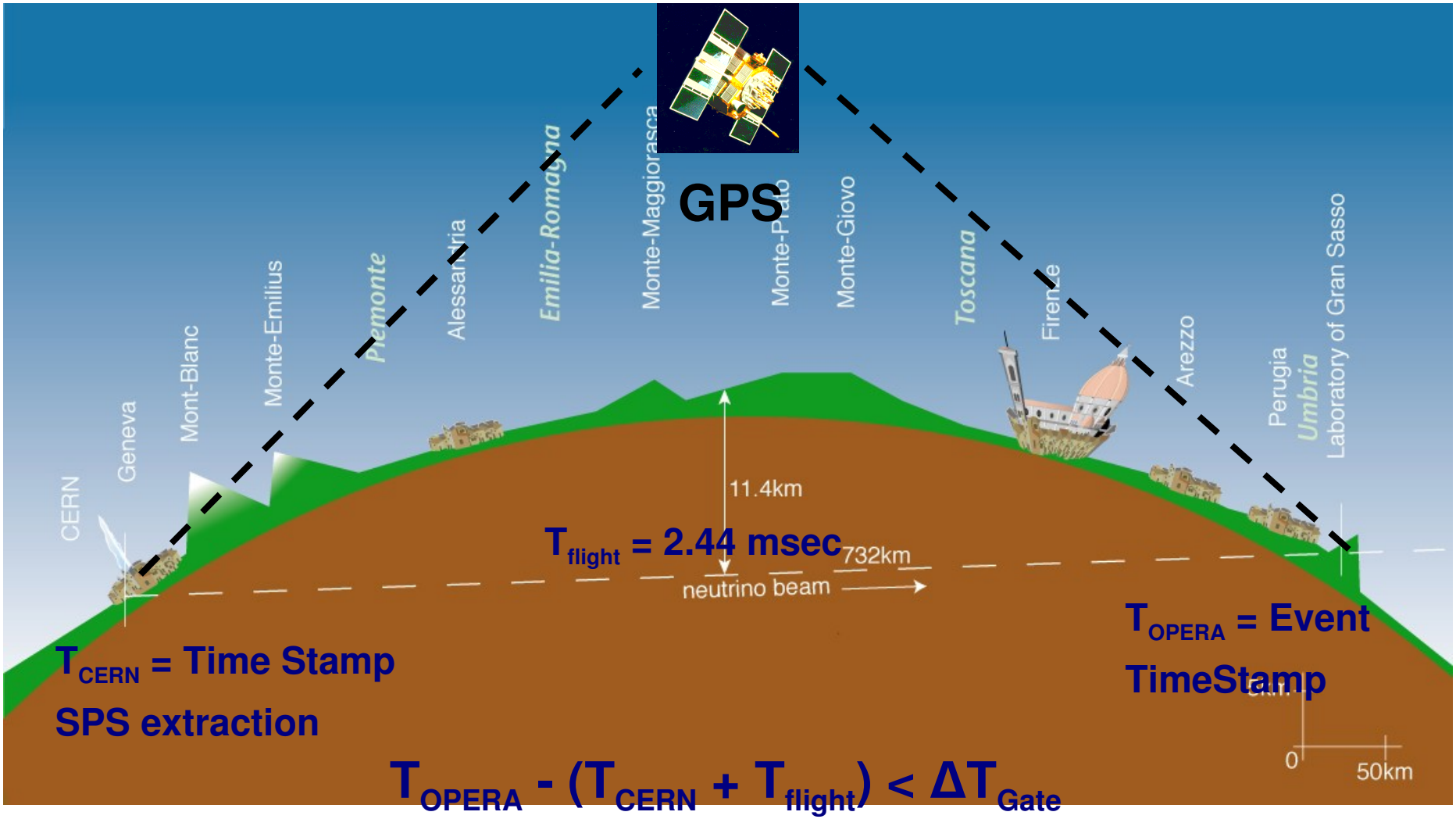




“PEANUT” in front of the MINOS near detector

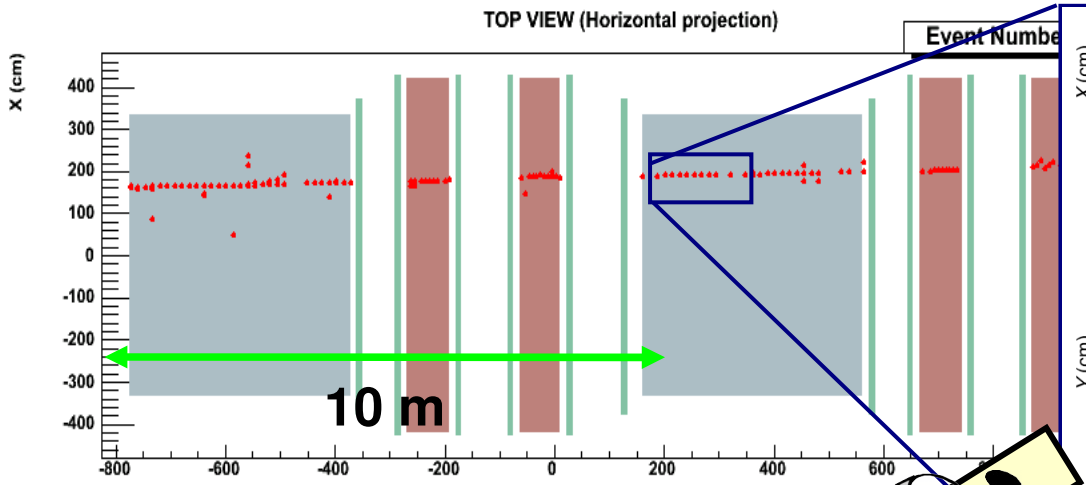
high multiplicity ν-Pb interaction
(real data: NUMI test beam exposure “PEANUT” 2005)
NB. ν energy is just ~ 3 GeV

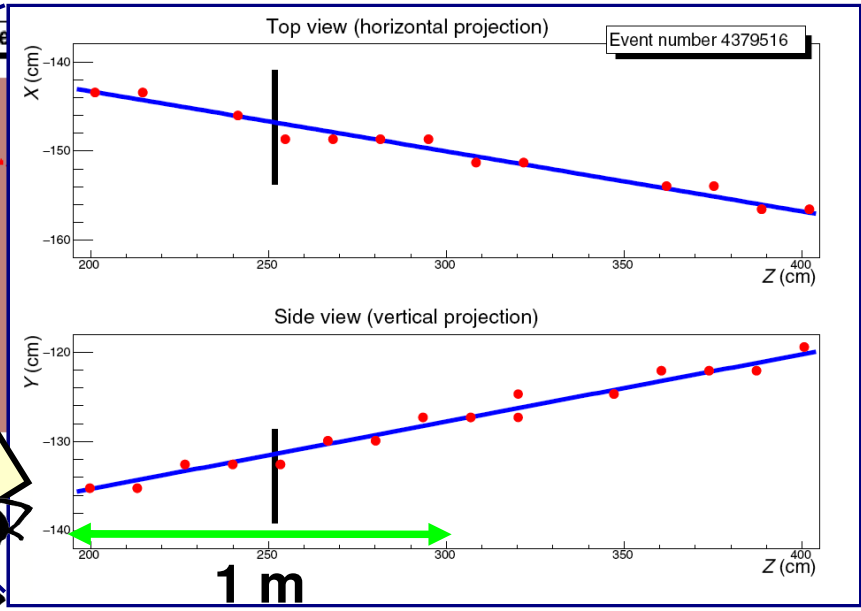
Time selection of beam events

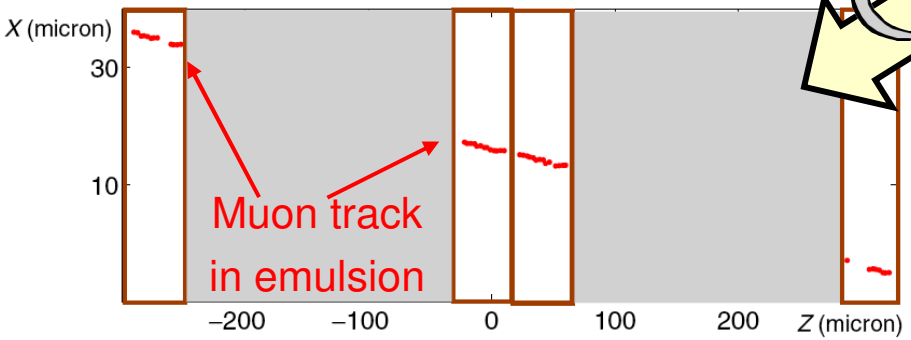


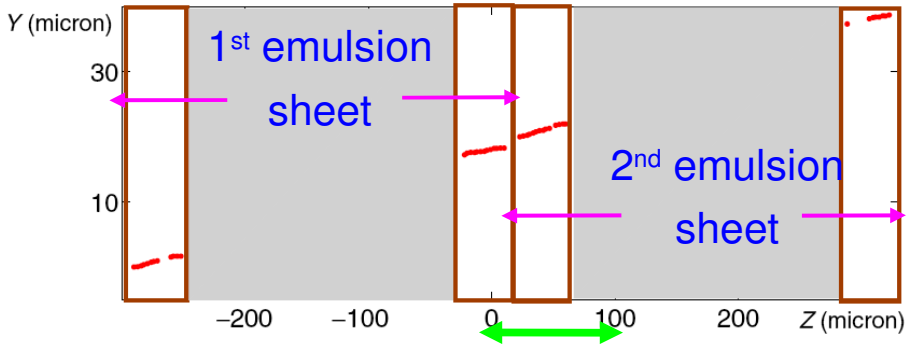
GPS Time Stamp resolution ~ 100 ns

Target Tracker - CS connection



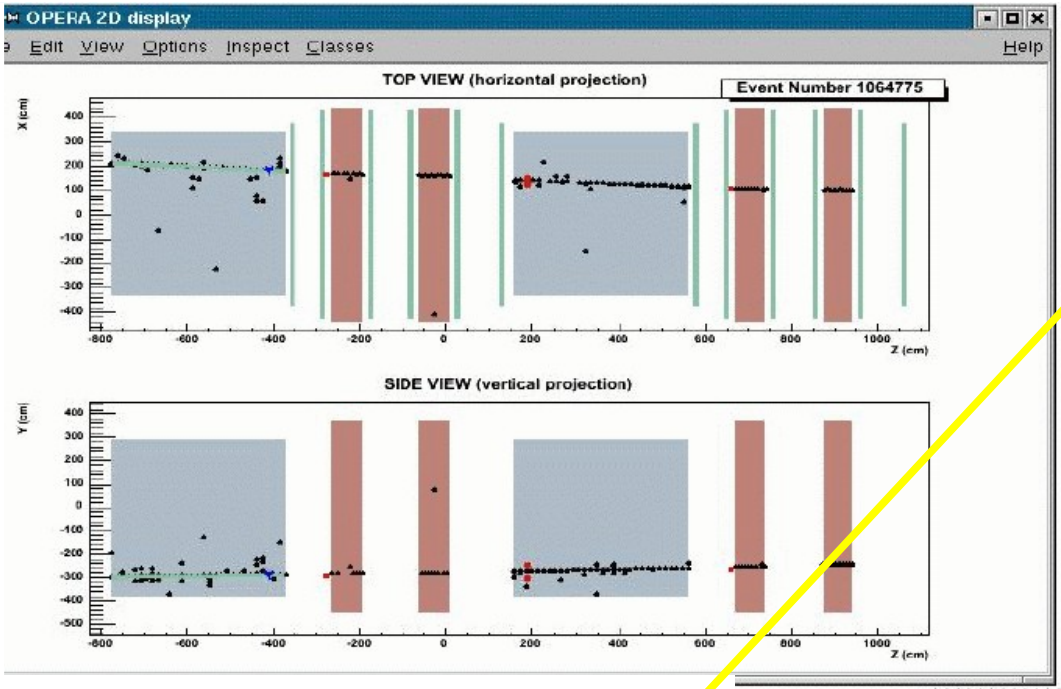






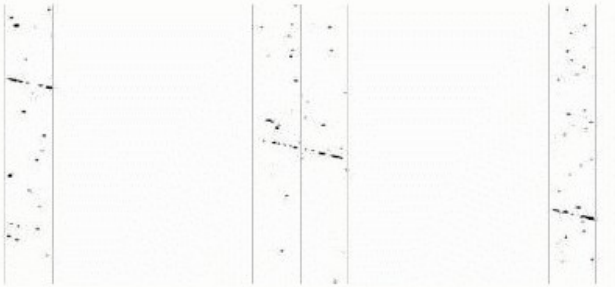
- One target wall partially instrumented with dummy bricks with real Changeable Sheet (CS) doublet to test the Target Tracker to Brick connection
- Muon tracks predicted by target tracker found in the CS doublets.
- Angular difference between prediction and found track <10 mrad, dominated by electronic detector resolution

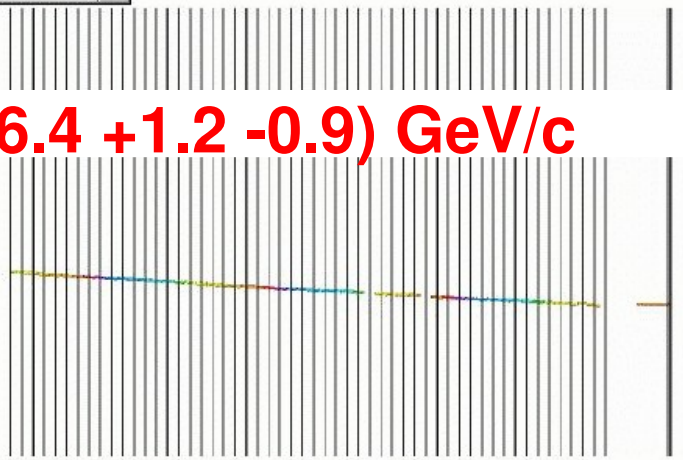
Momentum in the emulsions (Oct 06)



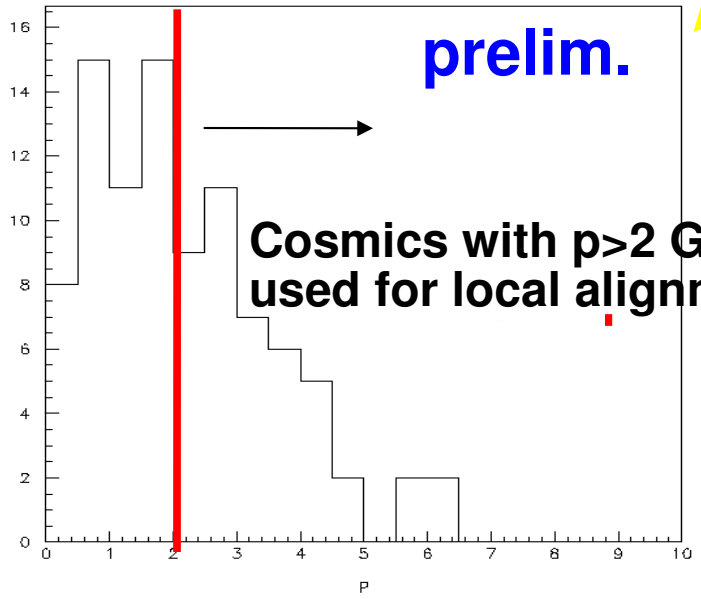
cosmics spectrum after surface exposure measured in emulsions with multiple scattering (angular method)

CS doublet





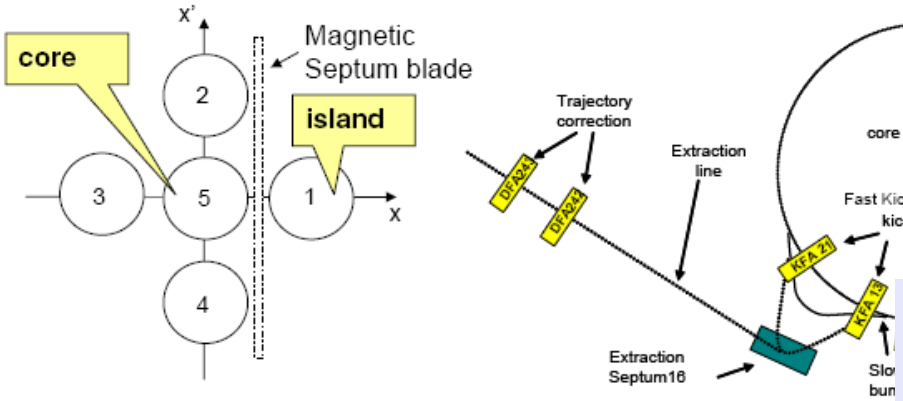
p = (6.4 +1.2 -0.9) GeV/c

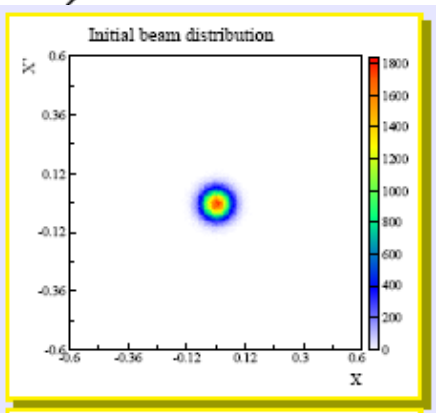


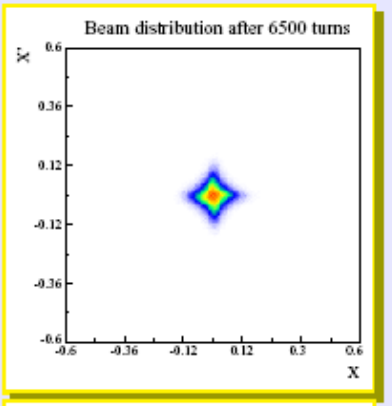
Multi-turn extraction

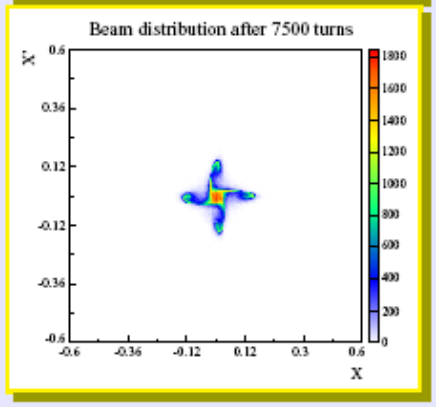
- The beam is separated into a central beam and four islands by means of non-linear magnetic elements like sextupoles and octupoles.
- Each beamlet is ejected using fast kickers and a magnetic septum

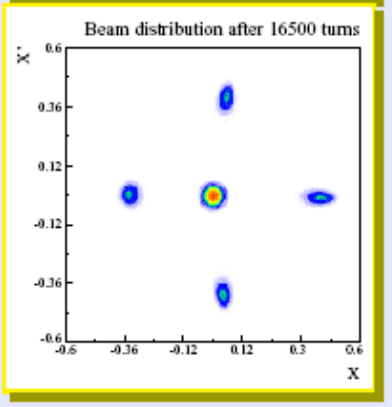
Virtually loss-less











2001 First proposal (linked to 1.5 intensity increase for CNGS)

R&D and tests 2002-2004

Implementation study group 2005

March 2006 TDR
October 2006 Project approved !

Important step for a safe achievement of the goal of 4.5 10^{19} pot

τ events topology

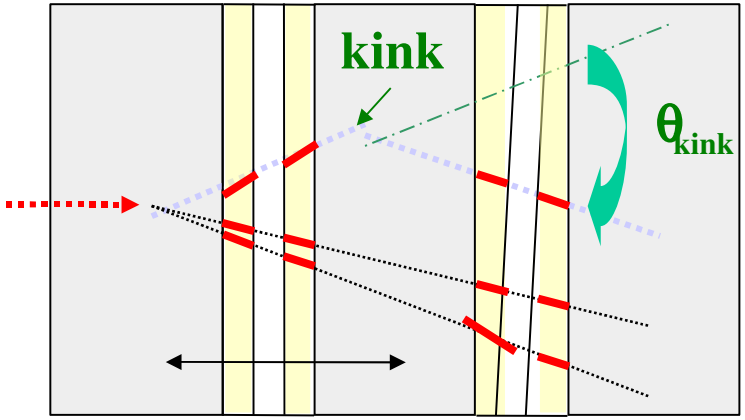
"Long" decays ~40%

kink angle (in 3D) (θ_{kink} > 20 mrad)

$\tau \rightarrow e$ $\sigma(\theta_{kink})$ ~ 3 mrad (normal)

$\tau \rightarrow \mu$ < 1 mrad (special)

$\tau \rightarrow h\,(n\pi^0) + \rho$



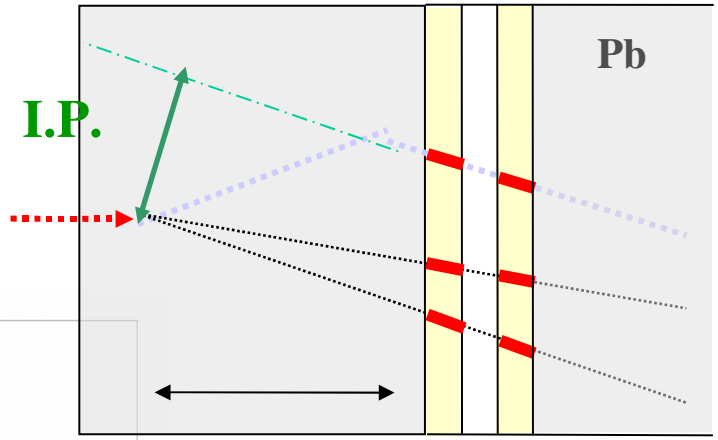
"Short" decays ~60%

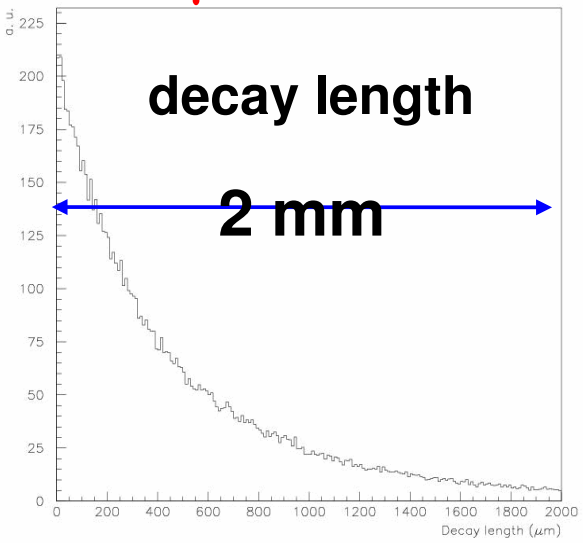
impact parameter ([5,20] μm)

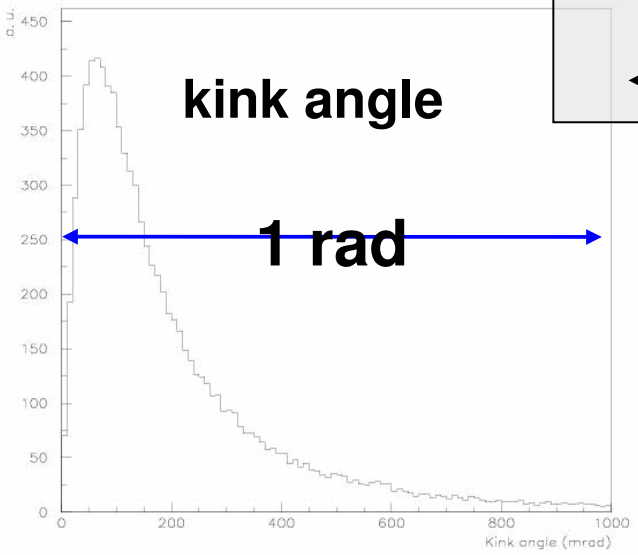
$\tau \rightarrow e$ (DIS)

$\tau \rightarrow \mu$

σ(IP) ~ 0.3-0.6 μm







higher final efficiency for long decays.

τ channels and backgrounds

$\nu_\tau + N \rightarrow \tau^- + X$

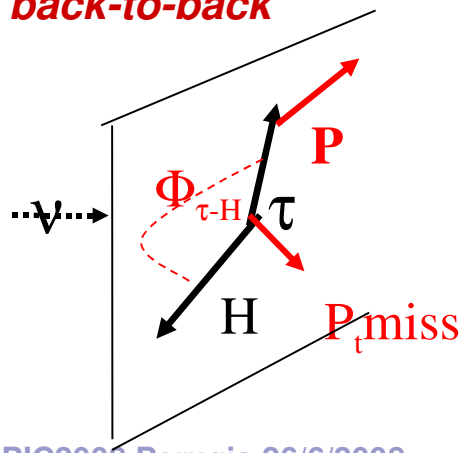
	signature	background
$\tau^- \rightarrow e^- \nu_e \nu_\tau$	e.m. shower in the ECC	charm production in ν_μ CC with e- decay without primary μ identification
$\tau^- \rightarrow \mu^- \nu_\mu \nu_\tau$	μ ID (MS + Spectr.)	Large angle μ scattering
$\tau^- \rightarrow h^- \nu_\tau$ $(n\pi^o)$	Events with a kink without muon or electron	charm production with hadronic decays + reinteractions

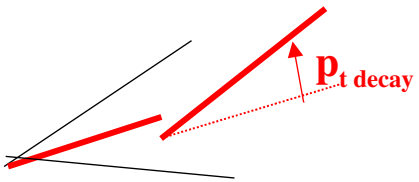
Dedicate kinematic analysis for each channel

Selection and backgrounds

TOPOLOGY	BCKG	CUTS	EFFECT
SHORT DECAY	CHARM PROD.	$M_{had} > 2$ GeV	Signal/15 bckg/1000
LONG DECAY – LEPT.	beam mis-ID	2 GeV < $p_{daught.}$ < 15 GeV $p_T^{@decay.vtx}(e^-_{channel}) > 100$ MeV $p_T^{@decay.vtx}(\mu_{channel}) > 250$ MeV	bck to reas. level
LONG DECAY – HADR.	hadronic re-interactions	$p_{daught.} < 2$ GeV $p_T^{@decay.vtx}$ (w γ) > 300 MeV $p_T^{@decay.vtx}$ (w/ρ^*) γ) > 600 MeV $p_T^{miss} < 1$ GeV ; $\Phi_{\tau-H} > \pi/2$	ν_μ NC bck suppressed (high p_T^{miss} low $\Phi_{\tau-H}$)

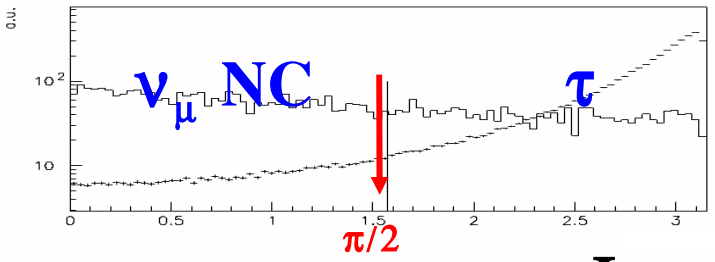
signal: τ & hadrons are *back-to-back*

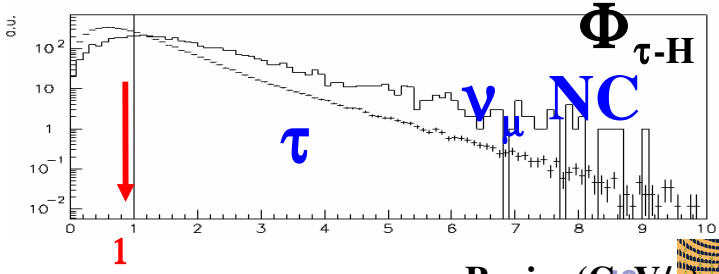




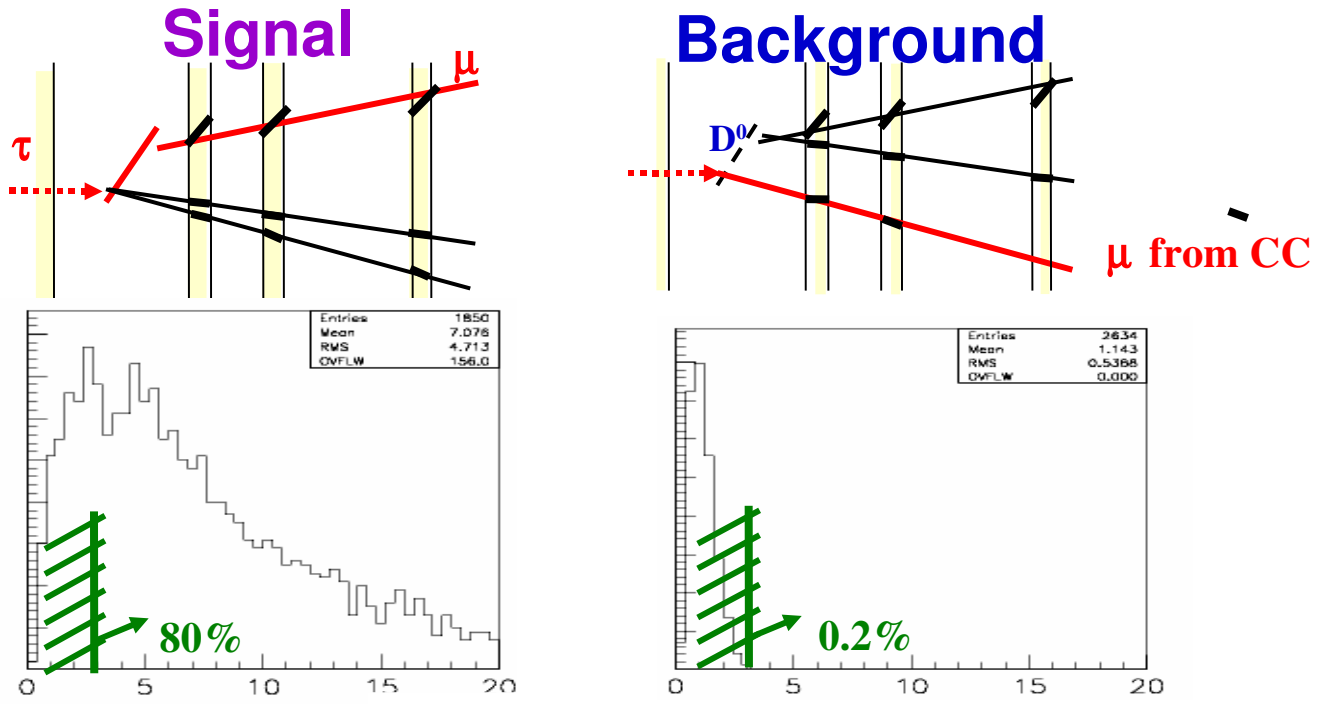
(*): due to low % of ν_μ NC evt with prompt γ.

If γ –> measured p_T, higher so higher eff. at same bckg.





"short decays" muonic IP



Event selection

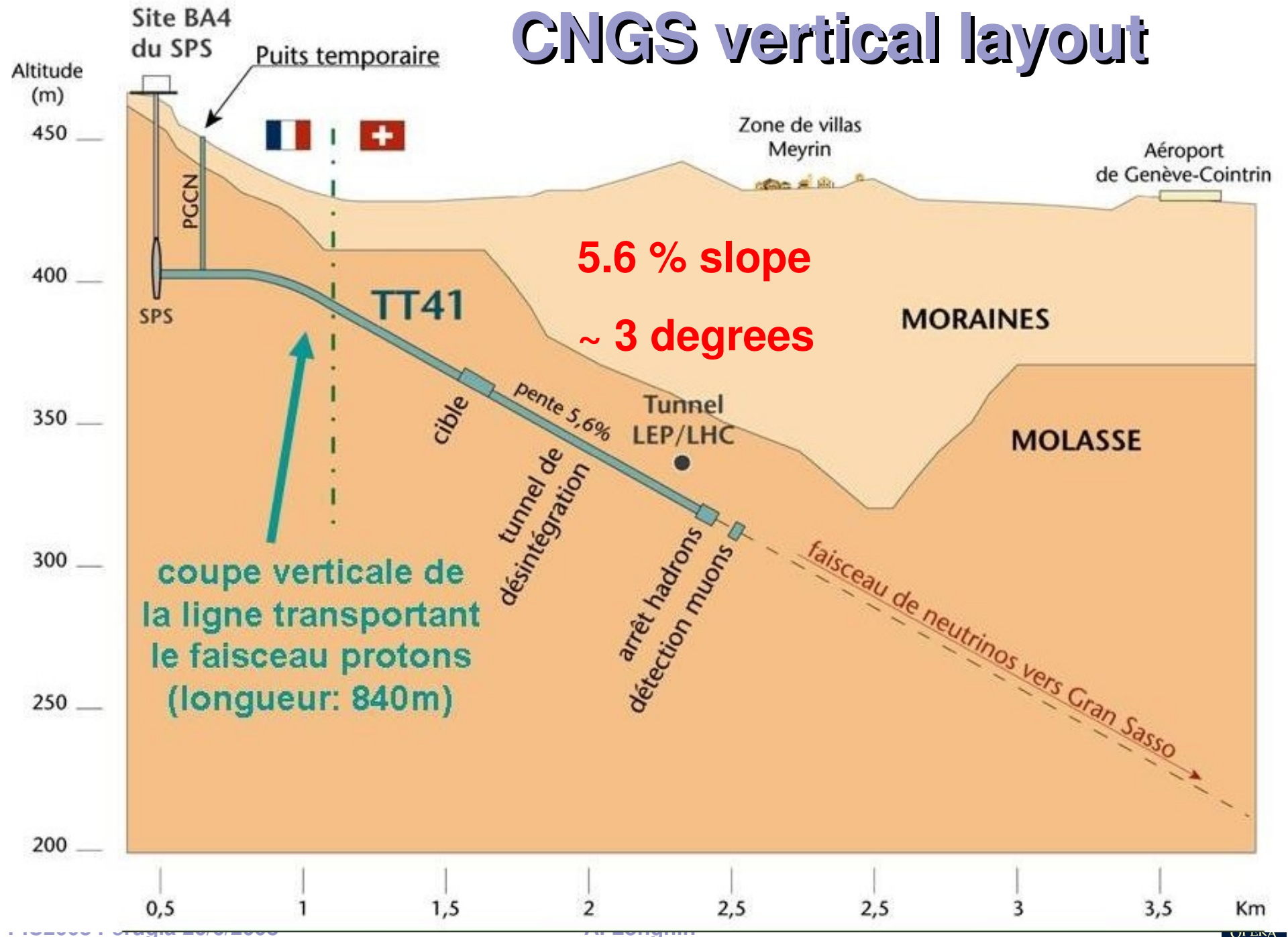
- with 50 % mass resolution & M > 3 GeV/c² 0.2% of c bckg survives

Main backgrounds

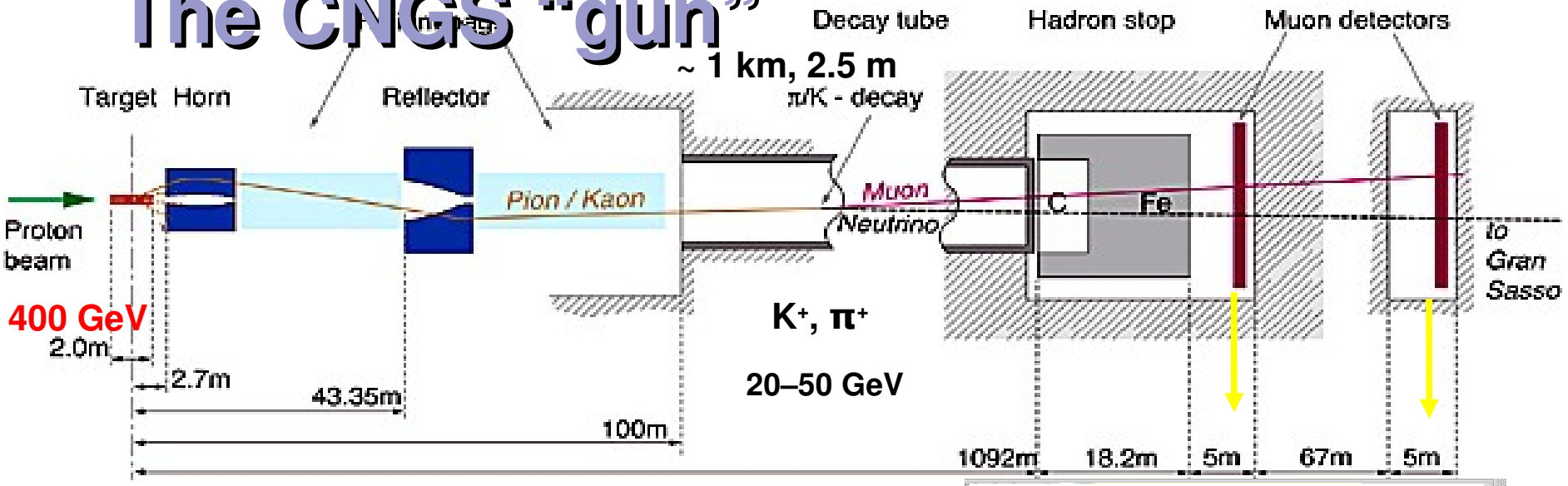
- charm decay vtx confused with primary vtx
- μ from ν_μCC mimicking $\tau \rightarrow \mu$ because of large IP

Contribution to the tau detection efficiency x BR : 0.7 %

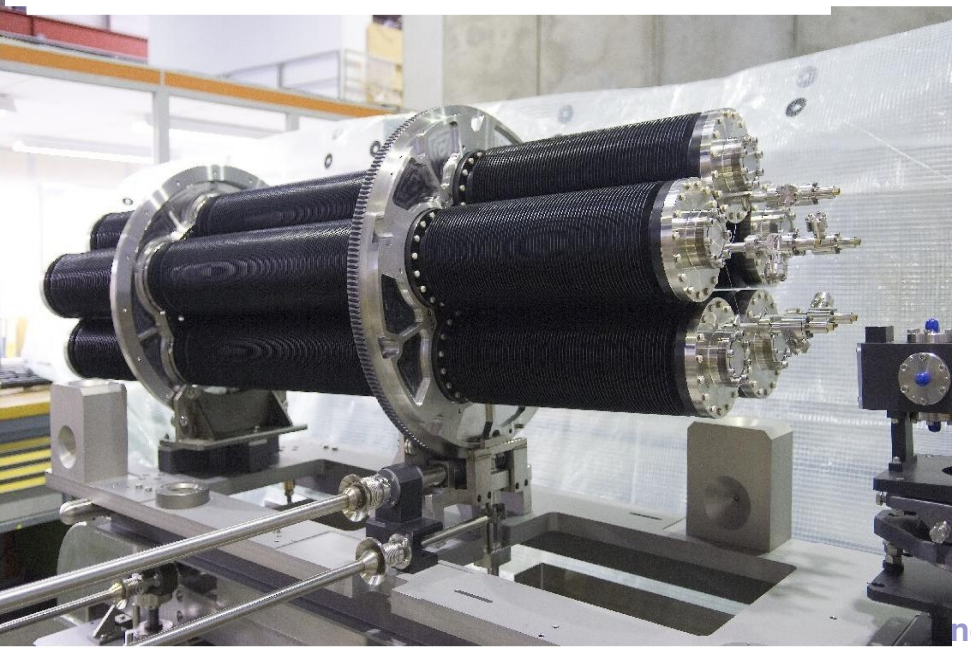
CNGS vertical layout



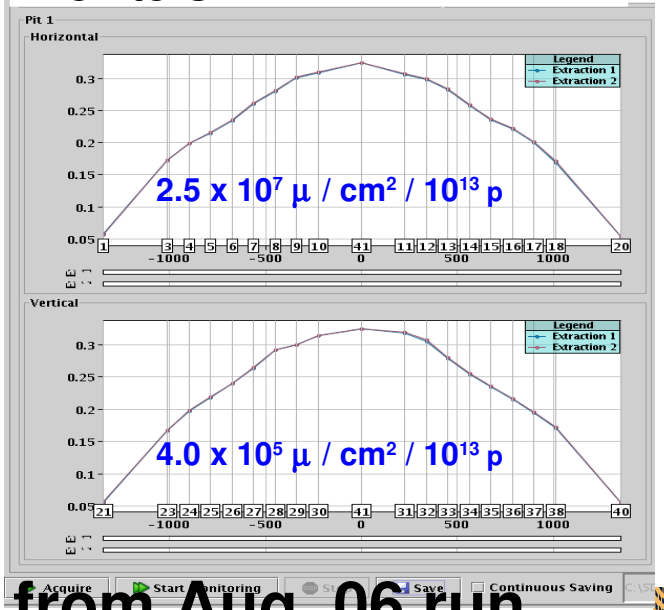
The CNGS "gun"



graphite rods target "revolver"
cooled by recirculated He flow



beam profiles with silicon μ monitors



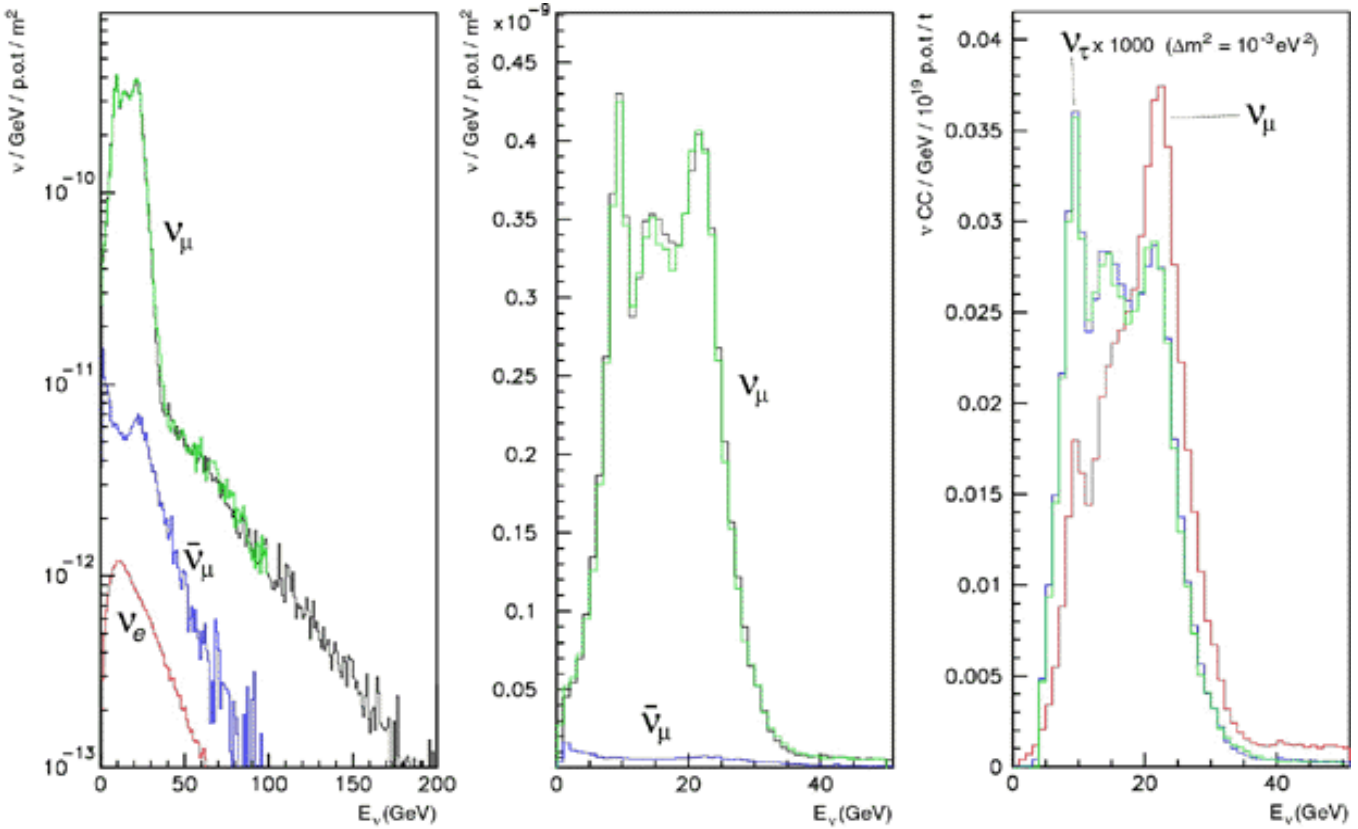
from Aug. 06 run

Beam composition

$(\nu_e+\bar{\nu}_e) / \nu_\mu$	0.87%
$\bar{\nu}_\mu / \nu_\mu$	2.1%
ν_τ prompt	negligible

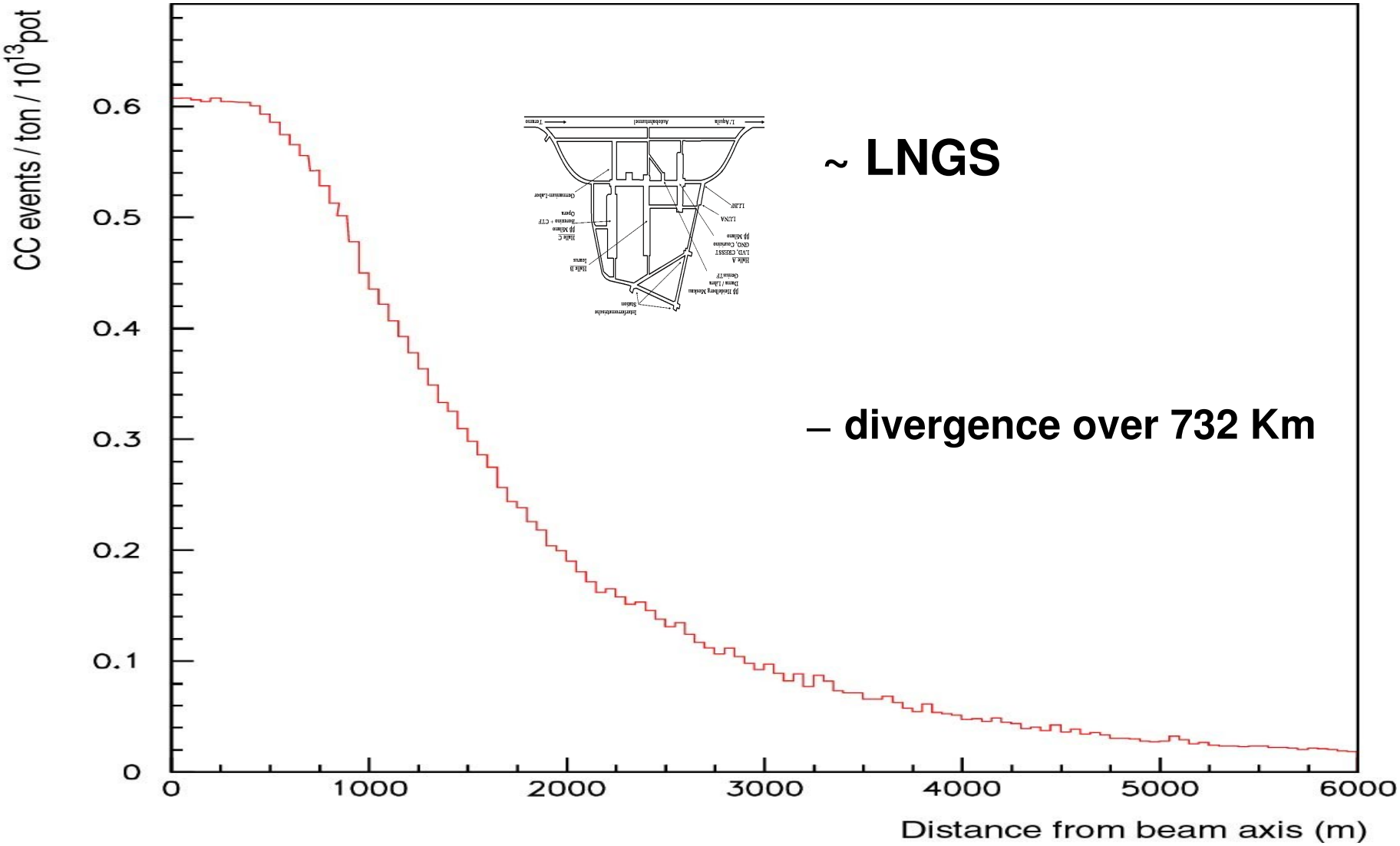
relevant for $\nu_\mu \rightarrow \nu_e$ search

FLUKA simulation



http://www.mi.infn.it/~psala/Icarus/cngs.html

FAQ: radial beam profile at Gran Sasso ?



~ LNGS

– divergence over 732 Km

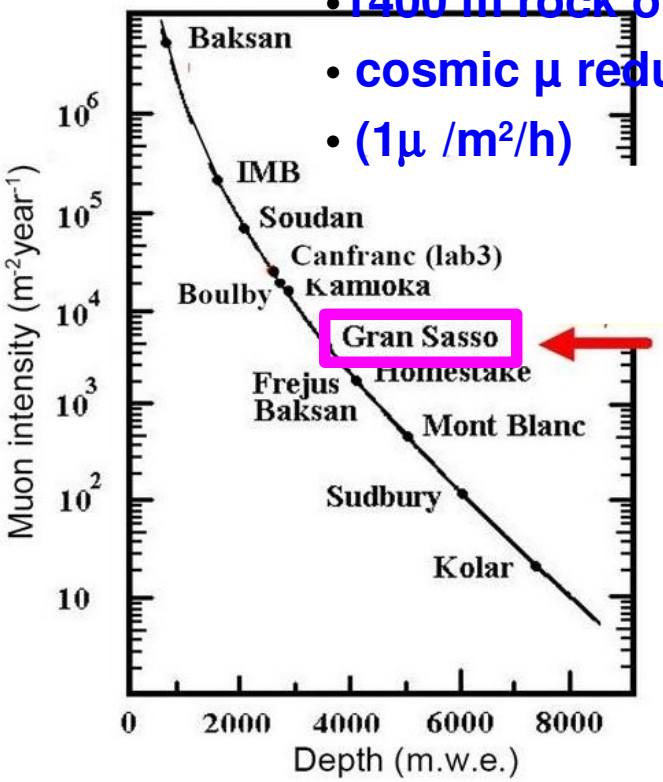
Final resort LNGS

Laboratori Nazionali del Gran Sasso

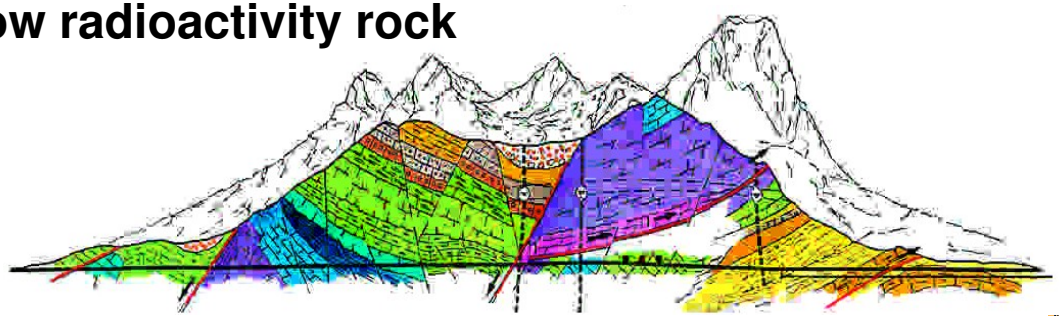
2912 m. The Gran Sasso highest peak (Corno grande ("big horn")

Surface INFN laboratory. 980 m Natural Park. The underground lab is at about the same altitude

- **1400 m rock overburden**
- **cosmic μ reduction ~ 10^6**
- **(1μ /m²/h)**

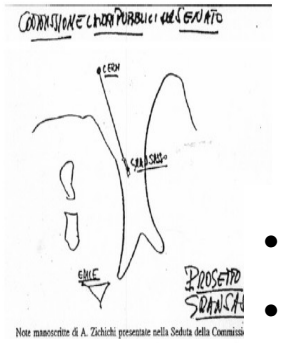


low radioactivity rock



1982

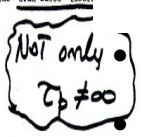
1979



Note manoscritte di A. Zichichi presentate nella Seduta della Commissi

To summarize, the scientific aims of the "Gran Sasso" Labor
the study of:

1) nuclear stability;
2) neutrino astrophysics;
3) new cosmic phenomenology;
4) neutrino oscillations;
5) biologically active matter;
6) ground stability.



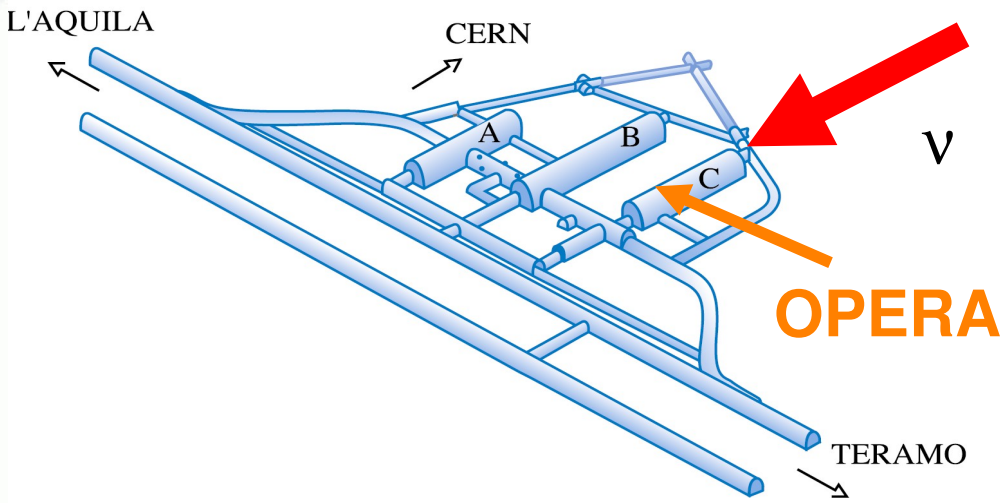
- 3 **big experimental halls**
- ~ 100 X 20 X 20 m
- ~ 18 000 m² underground
- **easy access** (motorway)
- **aligned to CERN to ~1° level !**

OPERA

Laboratori Nazionali del Gran Sasso - INFN

The [illegible] laboratory for astro-particle physics

current experiments



- ~ 750 scientists from 25 countries

- **Neutrino physics (double β, solar, atmosferic, long baseline osc.)**

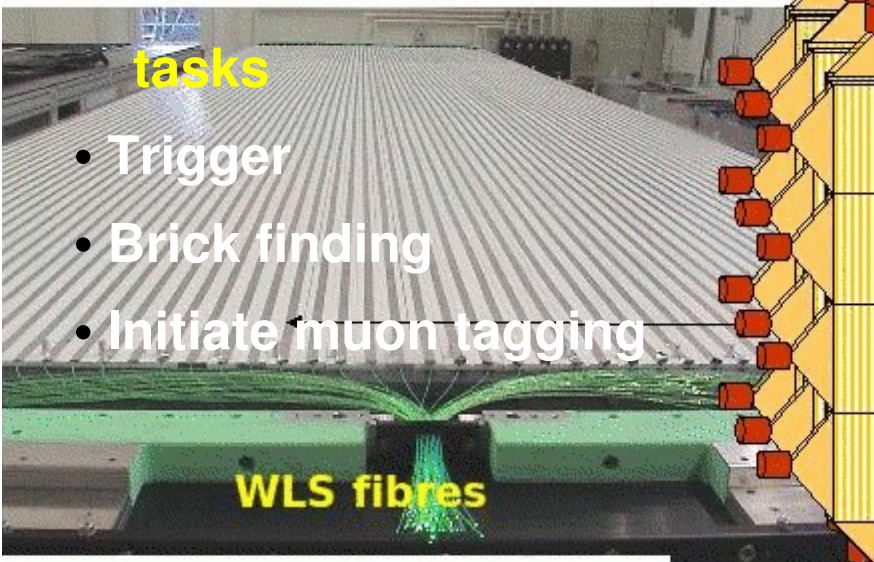
HMββ, MACRO, GNO, BOREXINO, OPERA, ICARUS, CUORICINO, COBRA, CUORE, GERDA

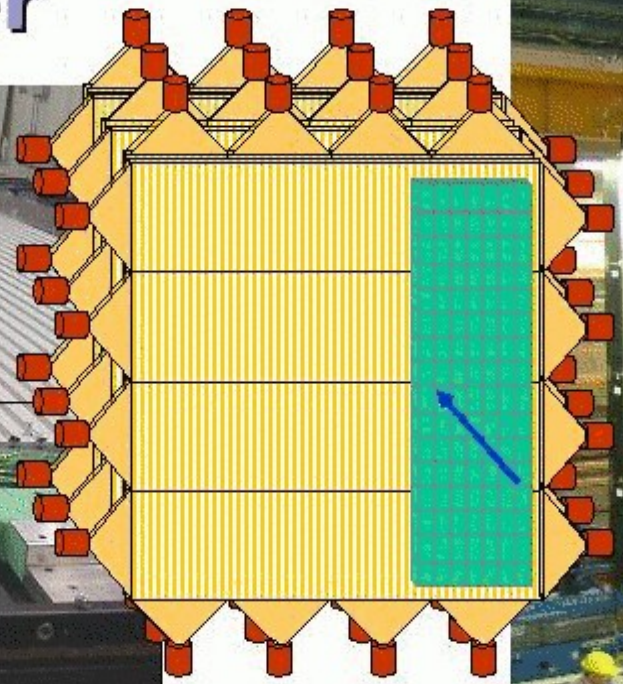
- **Dark matter -** CRESST, DAMA, LIBRA, HDMS, GENIUS-TF, XENON, WARP
- **Particle & nuclear astrophysics -** EASTOP, LVD, LUNA, VIP
- **Gravitational waves -** LISA
- **Geophysics, seismology -** ERMES, UNDERSEIS, TELLUS, GIGS

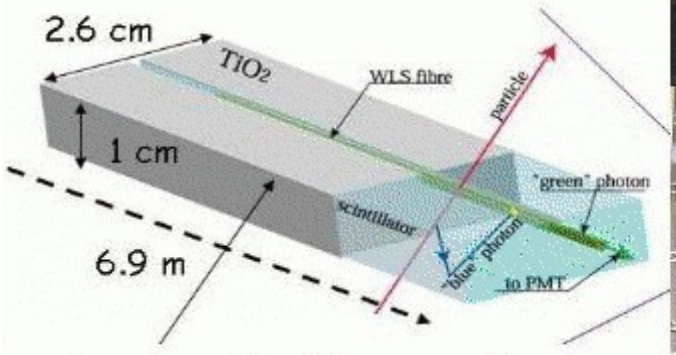
Target Tracker

tasks

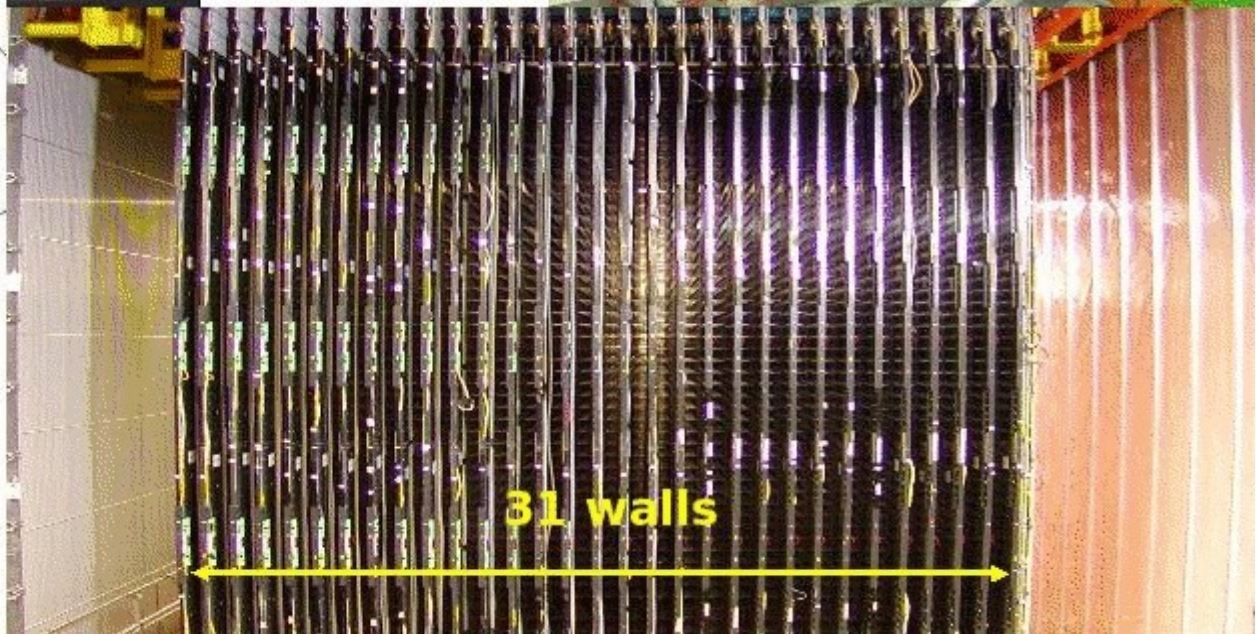
- Trigger
- Brick finding
- Initiate muon tagging



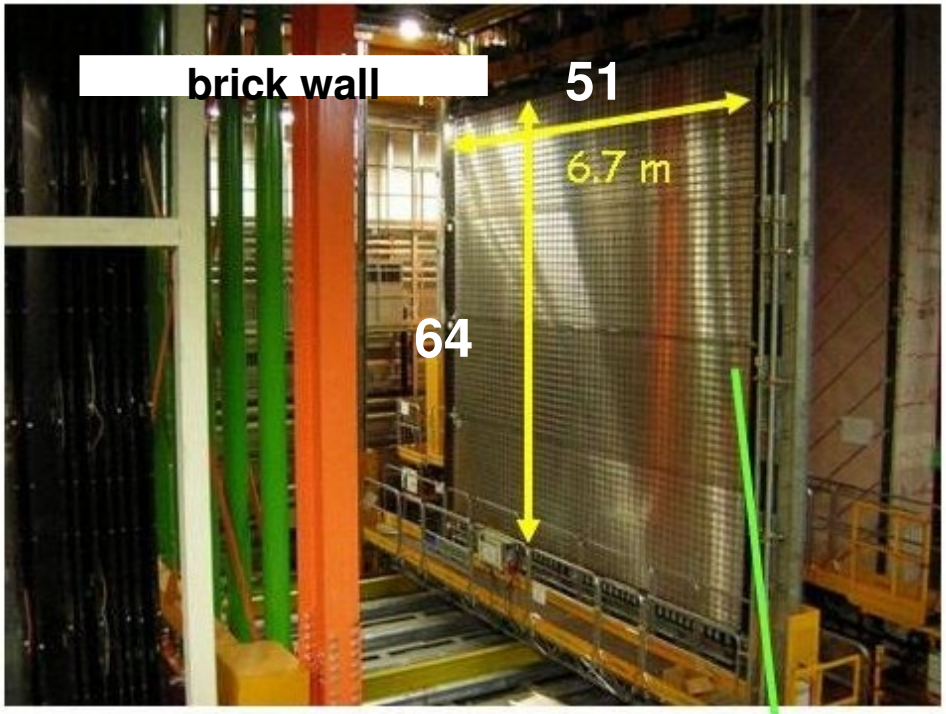




- Plastic scintillator strips
- 670 x 2.6 x 1 cm
- R/O by WLS fibres
- 2 ends R/O
- Hamamatsu PMT's (64 ch.)
- 6 p.e. minimum
- Probability 0 p.e. = 0.2 %



Target tracker plane photo-grammetry

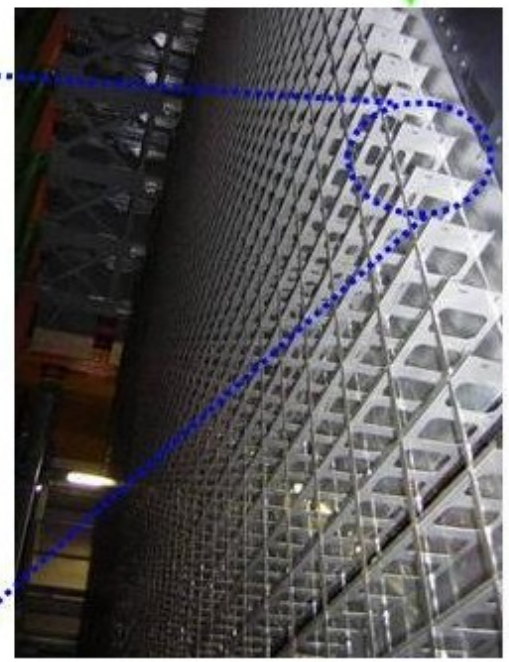


The target wall

51 x 64 bricks (27 tons)

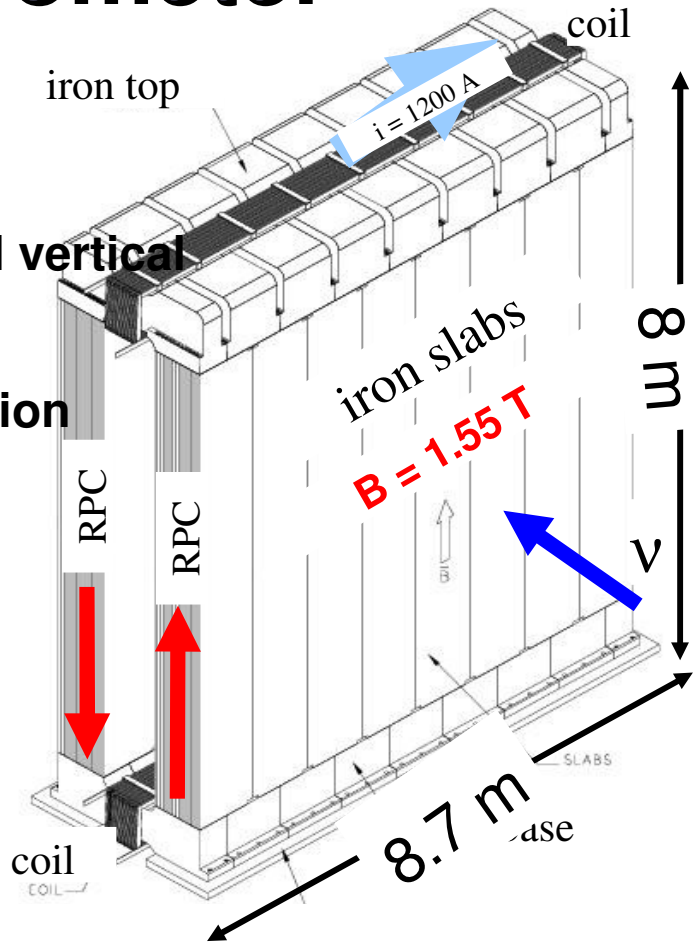
light (0.5 % of weight)

robust structure



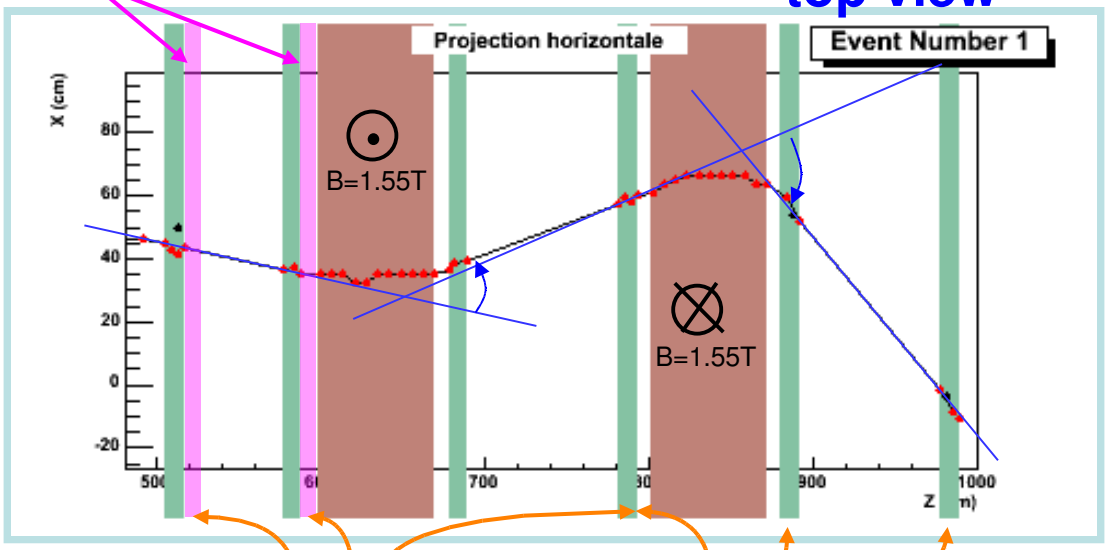
The muon spectrometer

- Dipolar magnet (B=1.55 T)
- 24 iron slabs, 5 cm thick + 2 cm gap
- Gaps instrumented with RPCs with horizontal and vertical strips with digital readout (inner trackers)
- 6 vertical Drift Tubes stations with 0.3 mm resolution (precision trackers)



RPC with inclined strips
(to solve PR ambiguities)

top view

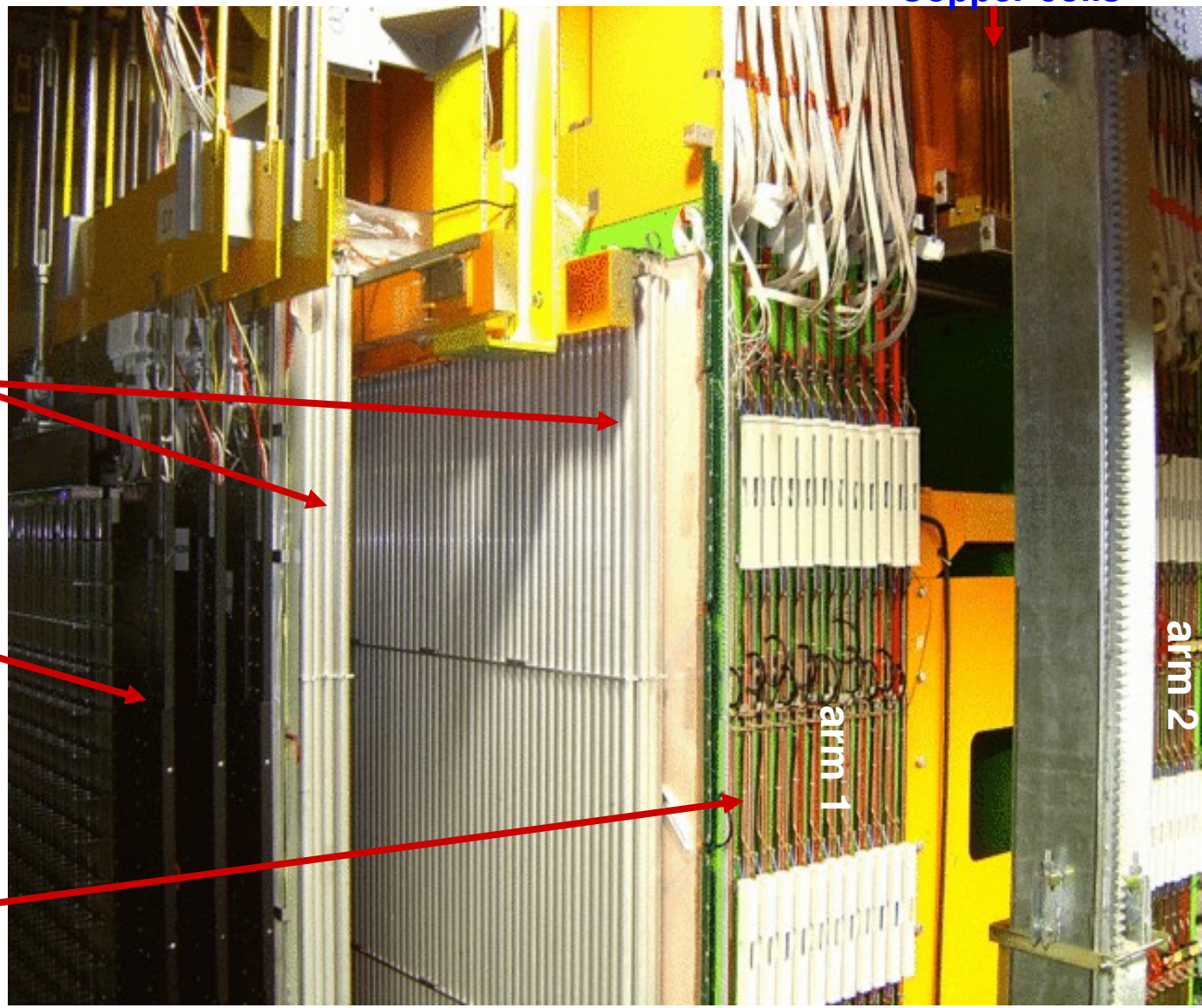


Drift tubes

Total iron mass

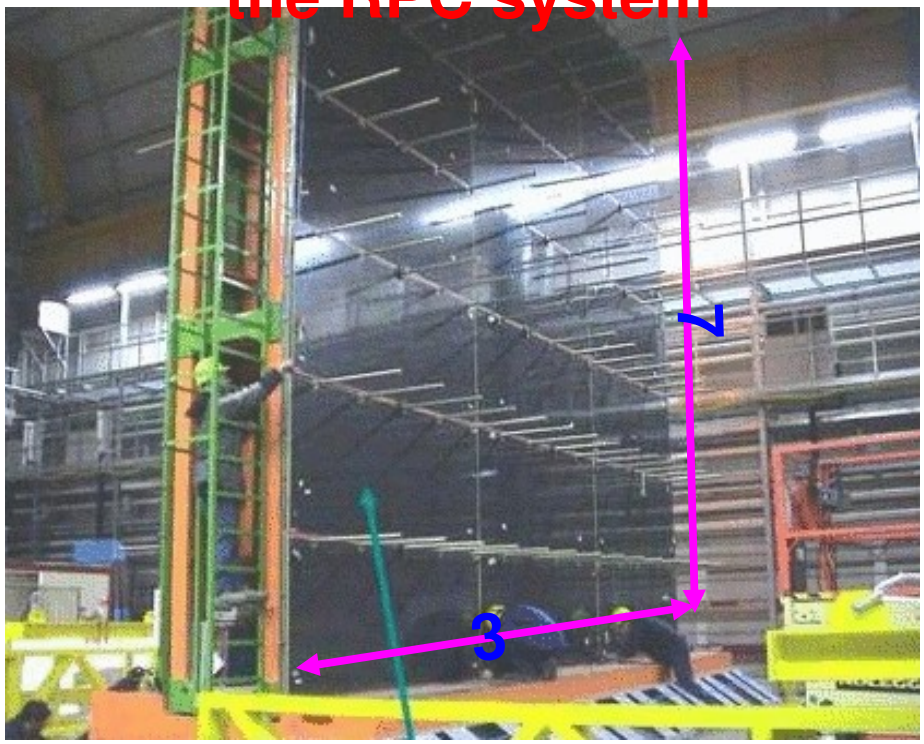
1.3 Kton

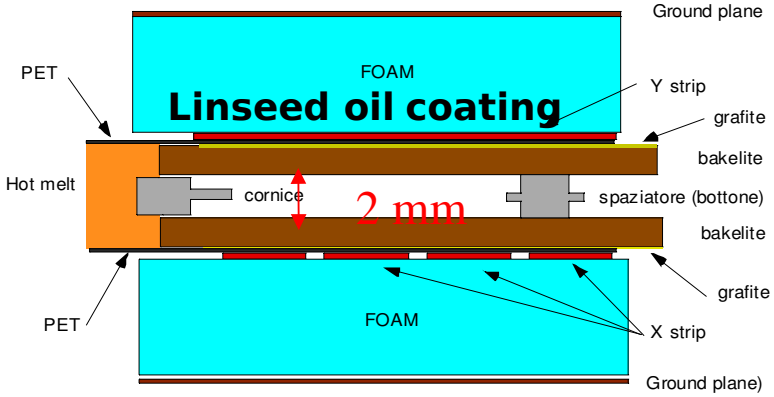
Muon spectrometer close-up



The inner trackers

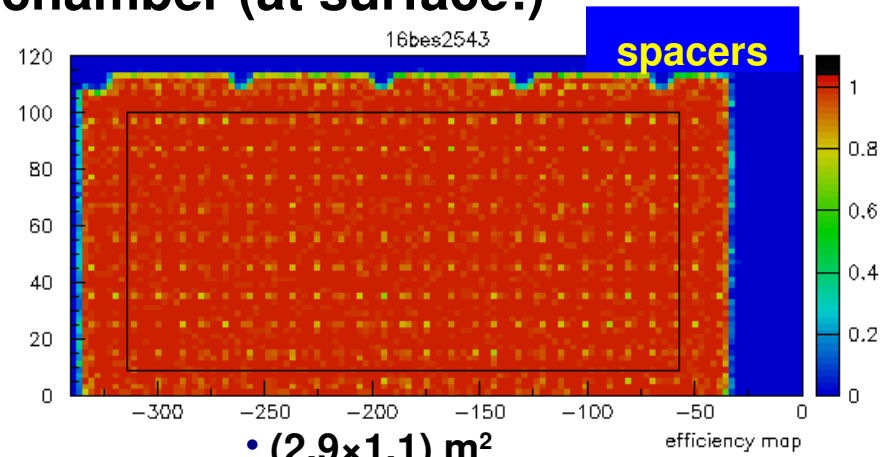
the RPC system



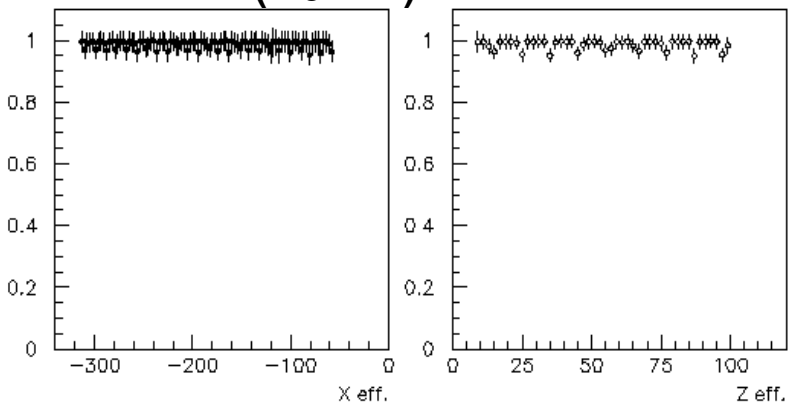


- 462 (bakelite RPC) + 42 (XPC) x 2 ~ 1000
- tot. surface: 3326 m^2
- digital channels: ~ 27000
- strip pitches: 2.6, 3.5 cm (Vert, Hor)
- Front-End Boards: 468
- Controller Boards: 52
- Gas: 76%Ar+20%TFE+4%Iso+0.6%SF_6

cosmic ray efficiency map for 1 chamber (at surface!)



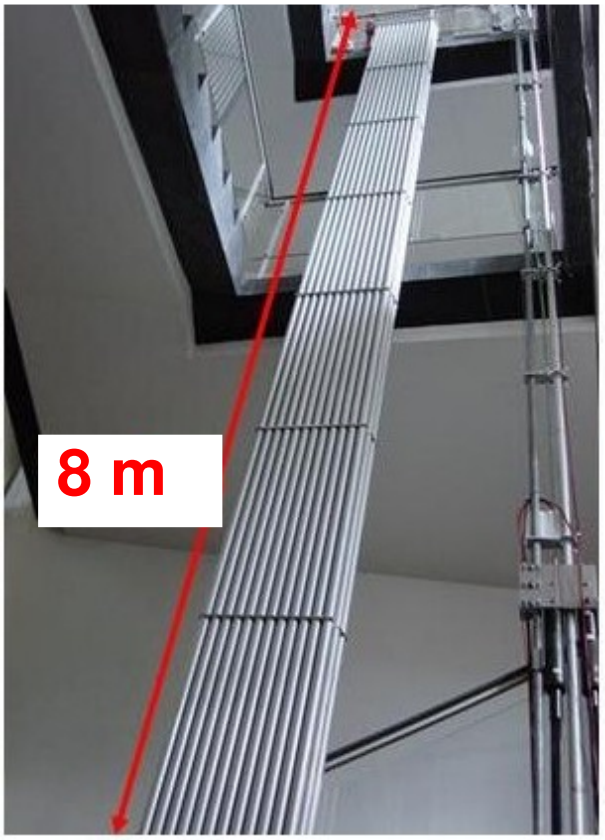
- (2.9×1.1) m^2



The precision trackers

drift tubes

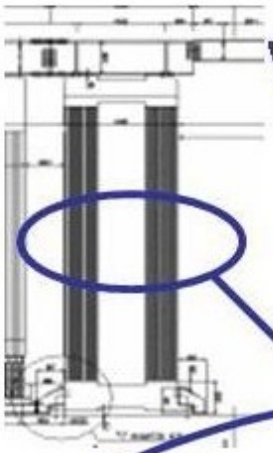
prototype in Hamburg

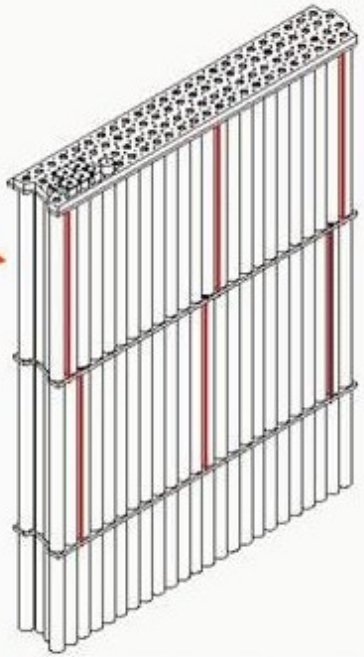


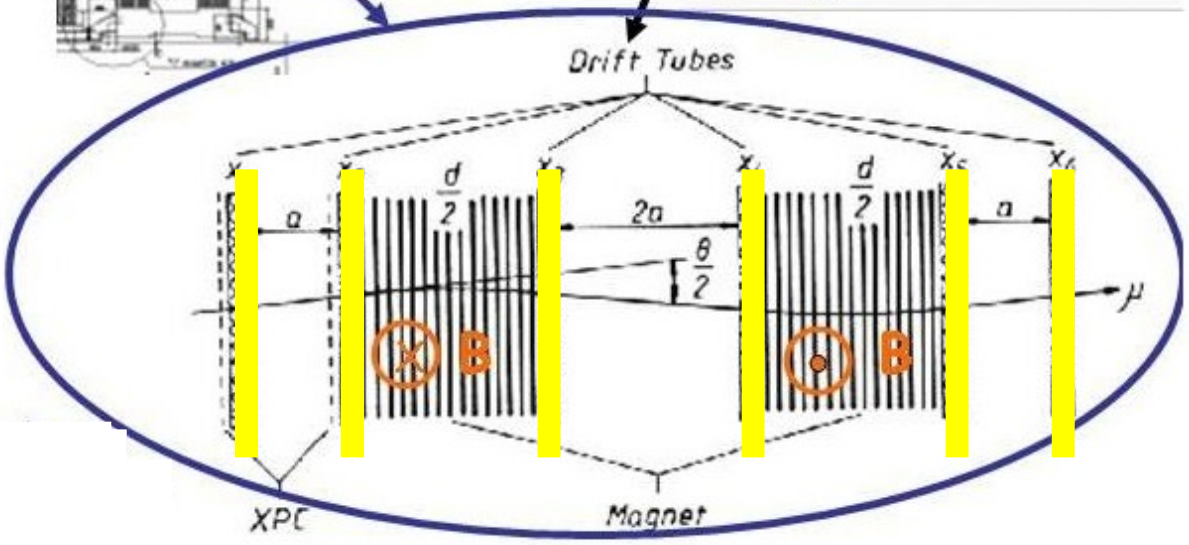
38 mm diam. 8 m long tubes

4 layer modules (staggering)

~ 10.000 drift tubes



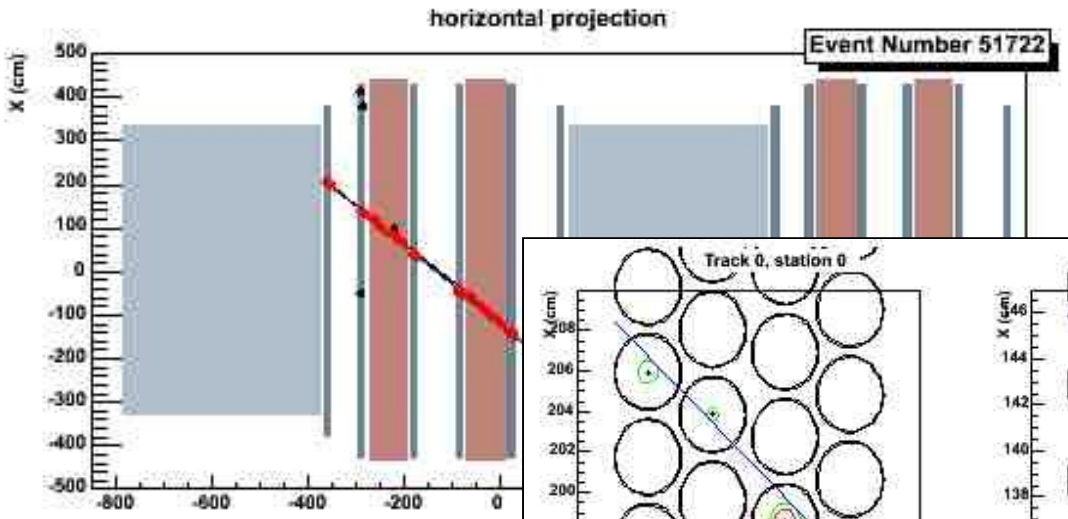




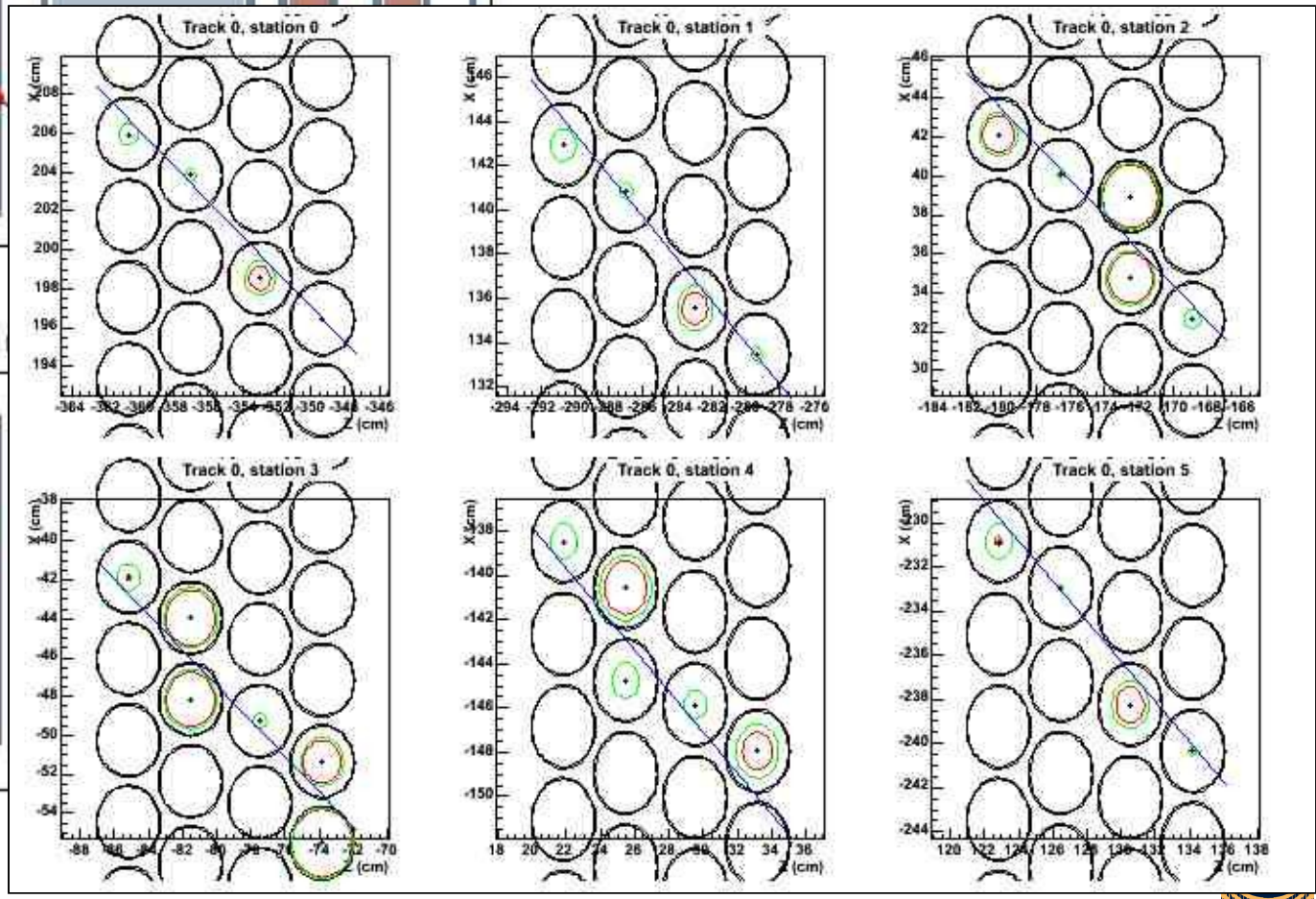
Spatial resolution

< 300 μm

The precision trackers at work!



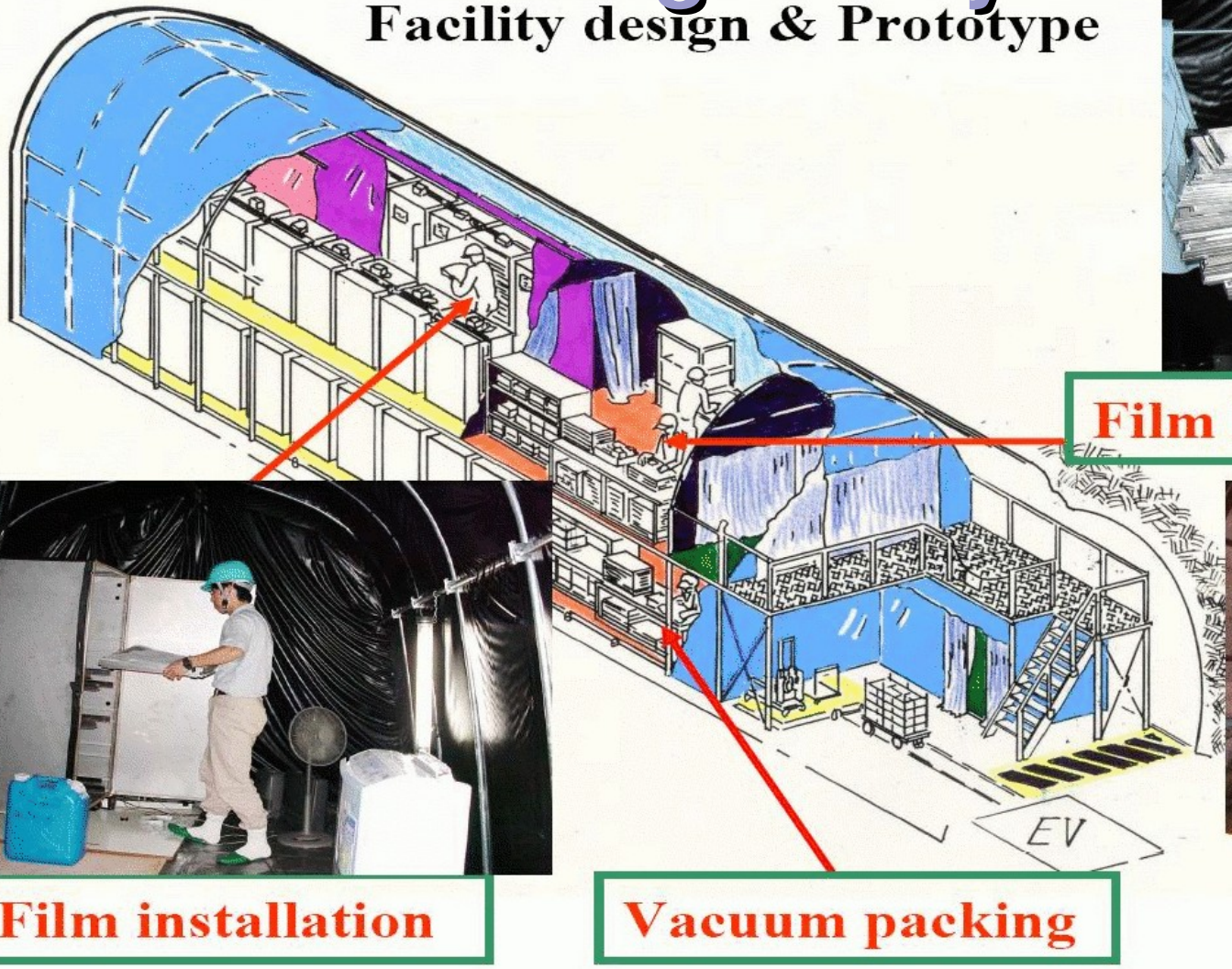
A cosmic ray event crossing all the 6 stations (24 layers)



The refreshing facility

R&D @ Nagoya & Fujifilm

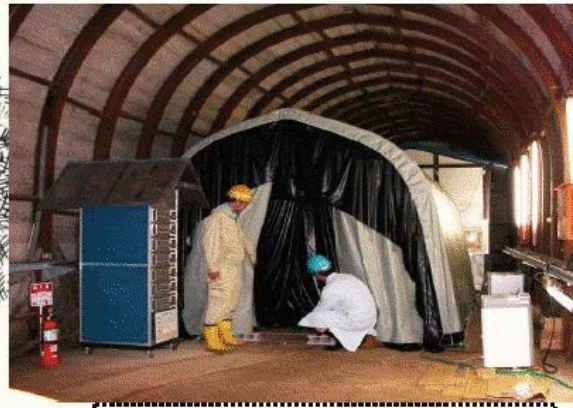
Facility design & Prototype



Film lay out on the plate

Film installation

Vacuum packing



Room Size

4.5m × 4.5m × 20m

emulsions are treated in a very humid (> 95%) and warm environment (30°) for ~ 3 days in Tono mine (Japan) to erase the previous "history" of the emulsion (track latent image fading). Repeated for Changeable Sheets in Gran Sasso.

Lead production

- Pb + 0.7% Ca
  - ✓ good mechanical properties
  - ✓ low radioactivity
- produced in Germany (Goslar)
- sent by trucks (~ 100 shipments)

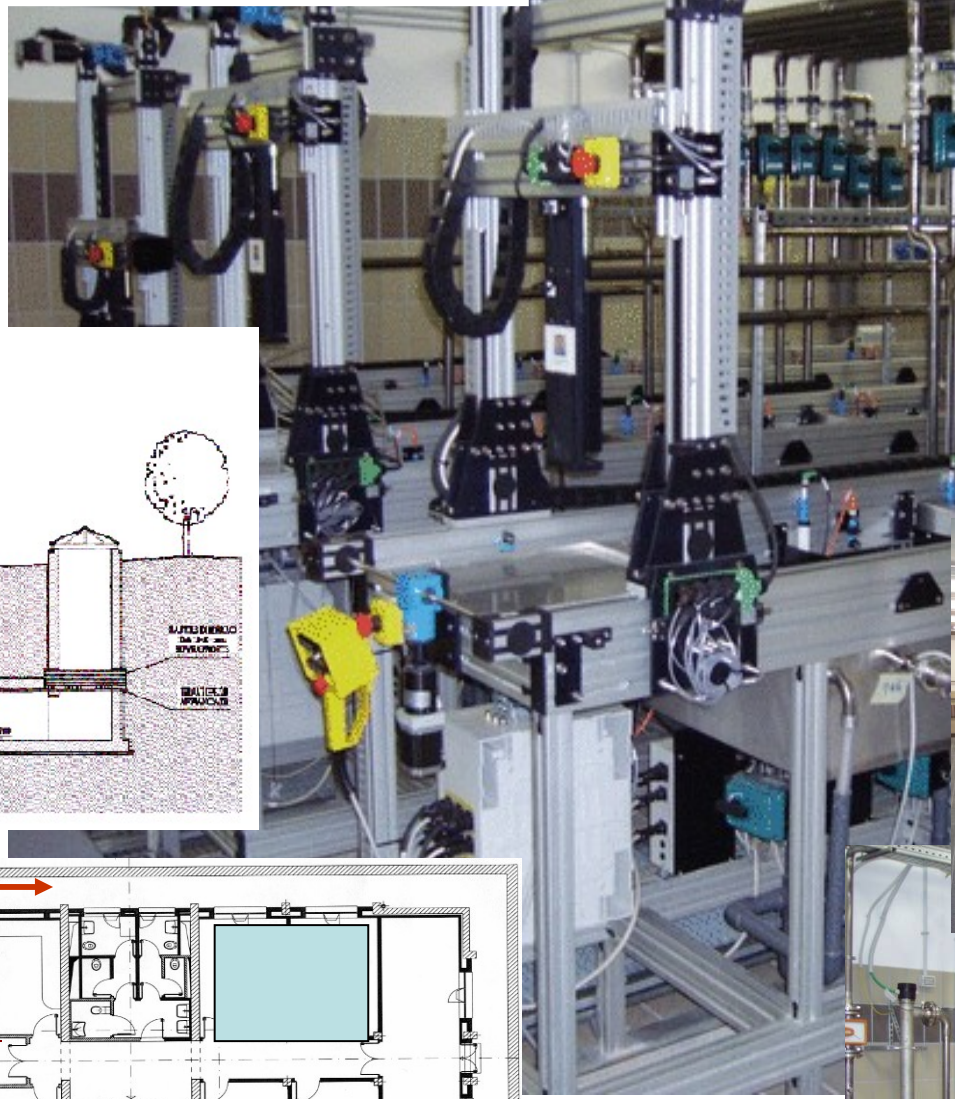
Emulsion delivery (2005)

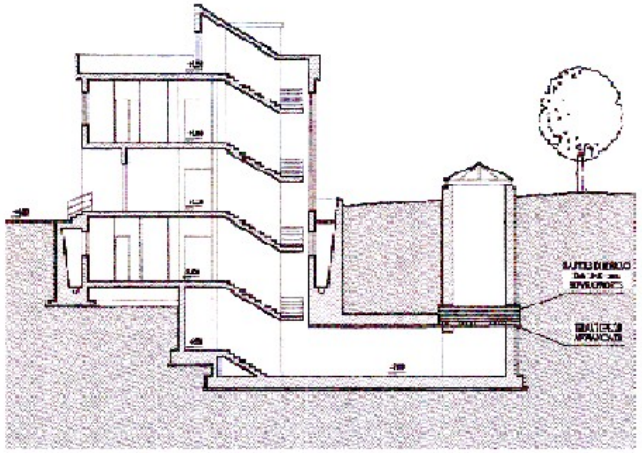
- Shipment to Gran Sasso by sea
- Underground storage
- Memory of emulsion order during transportation (from Japan to Europe) is kept and taken into account during brick assembly.

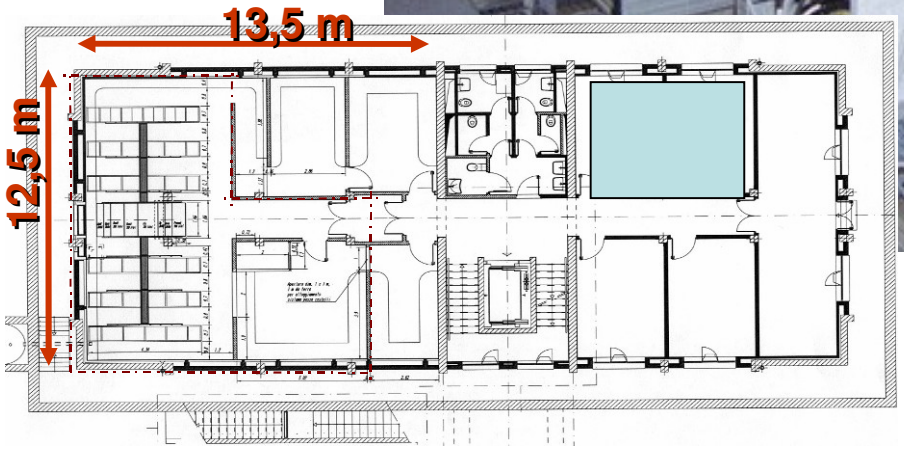
•Segments which are aligned assuming a spacing equal to the emulsion thickness (cosmics recorded during transportation) are discarded at analysis level : "virtual erasing" concept

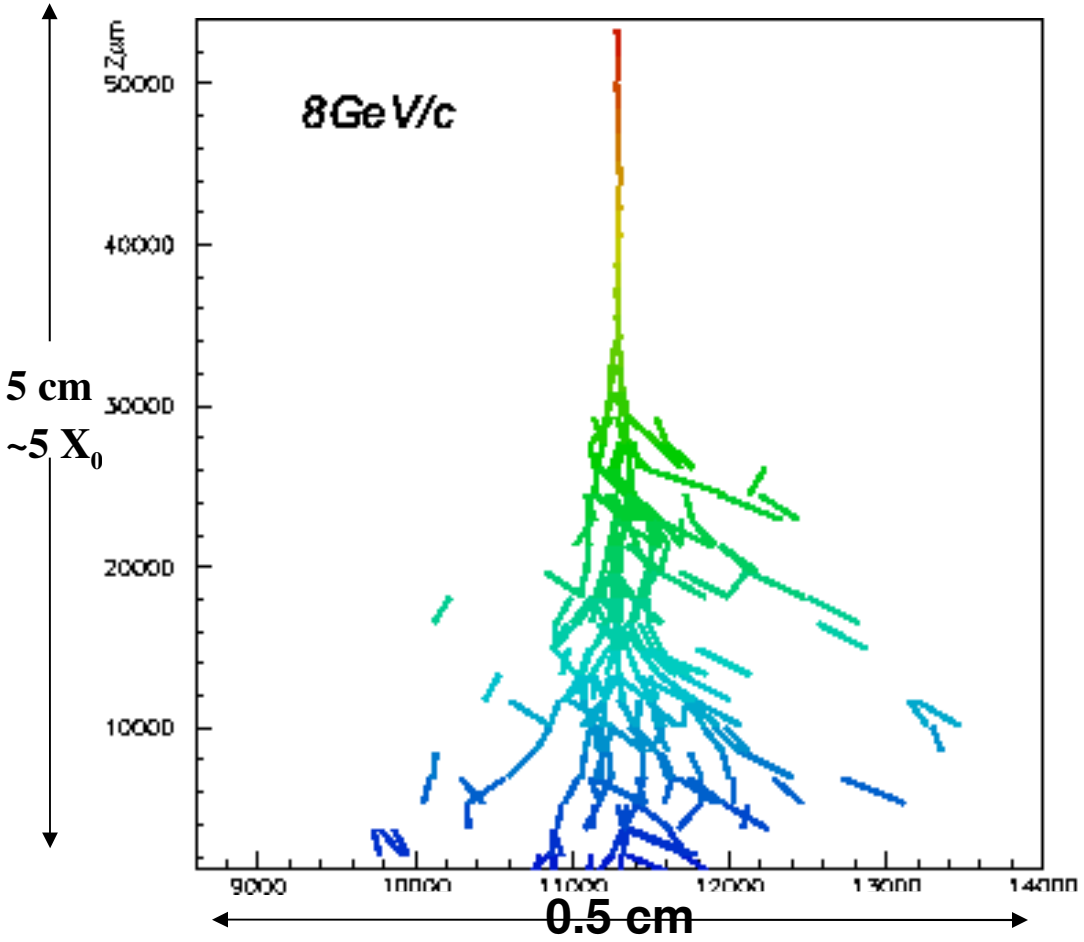
Development lab

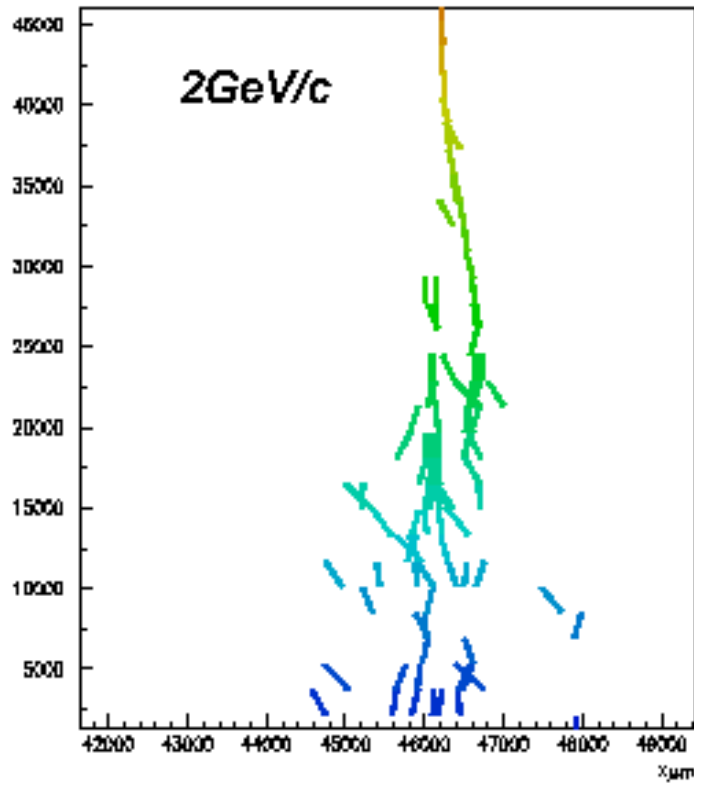
at surface
~ chemical plant
6 parallel motorized stations
for automatic development of bricks.





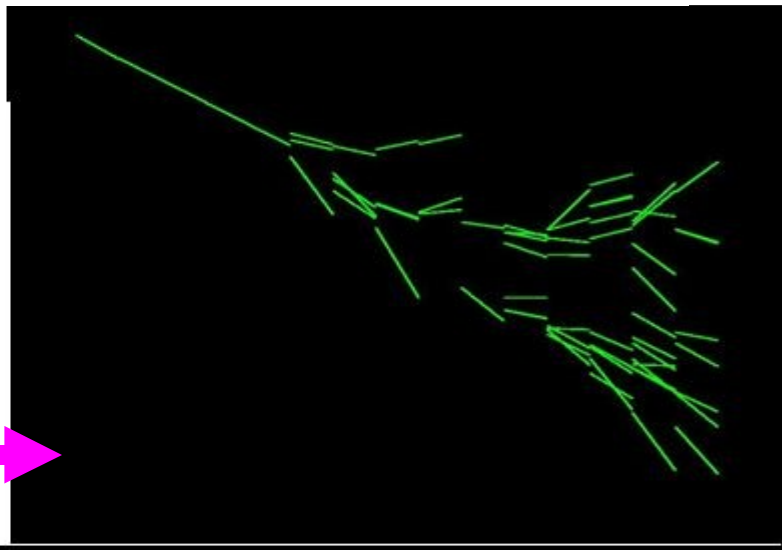




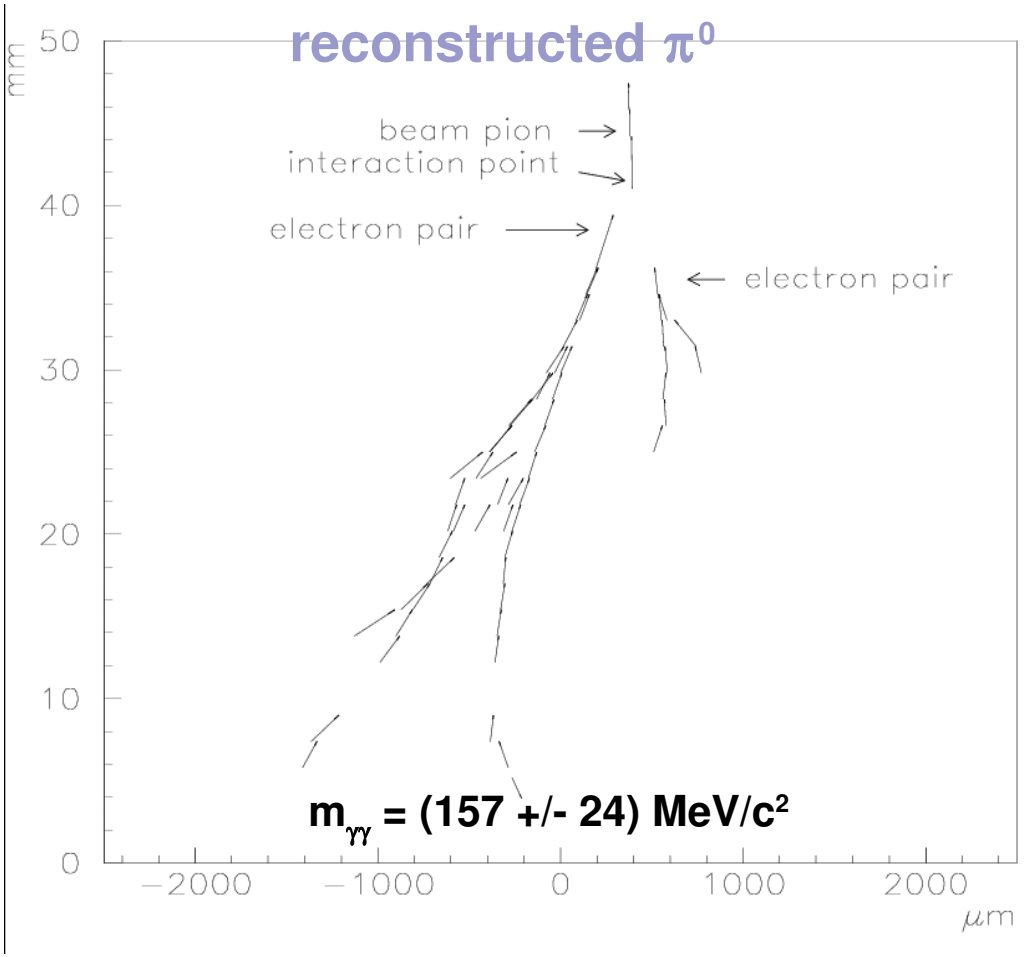


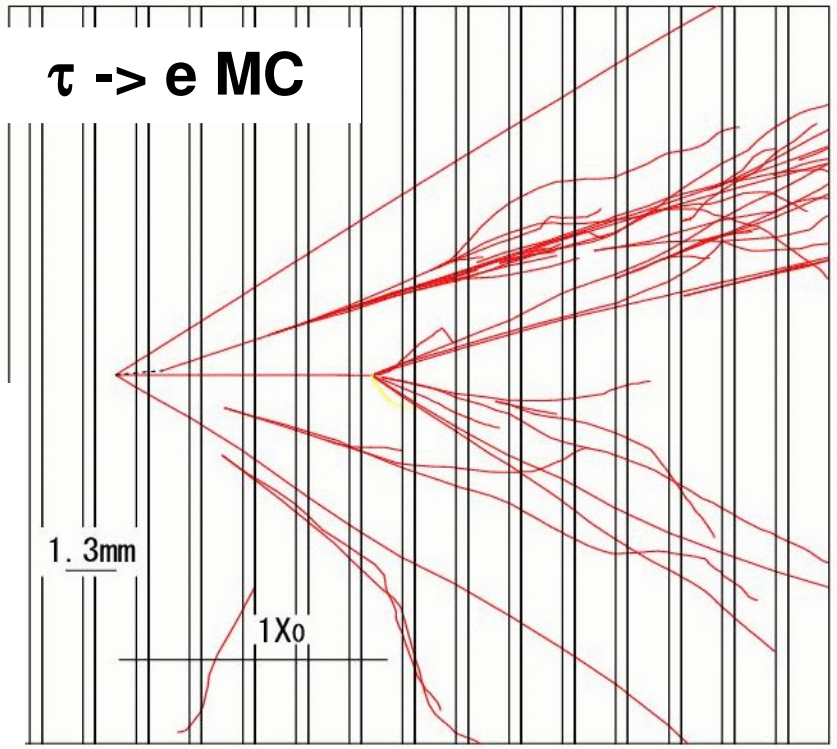
Electron identification in the ECC

DESY 2003 e-test beam: 6 GeV

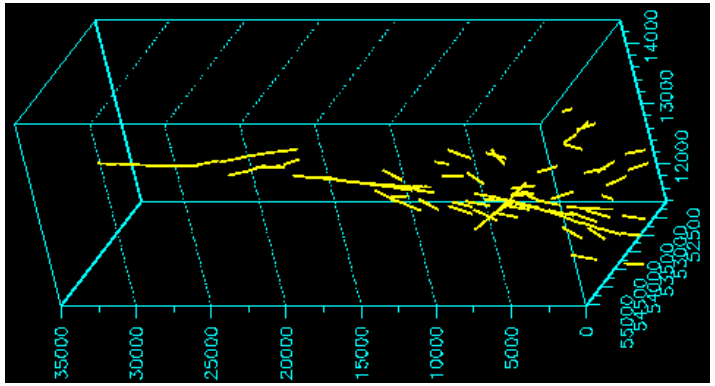


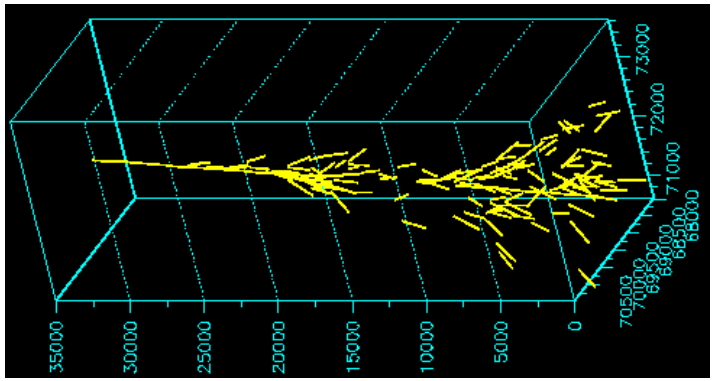
Electron identification



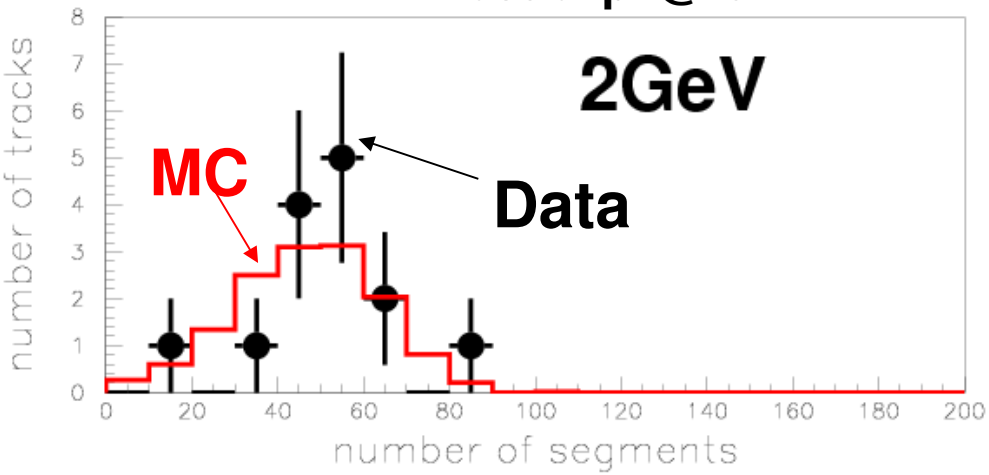


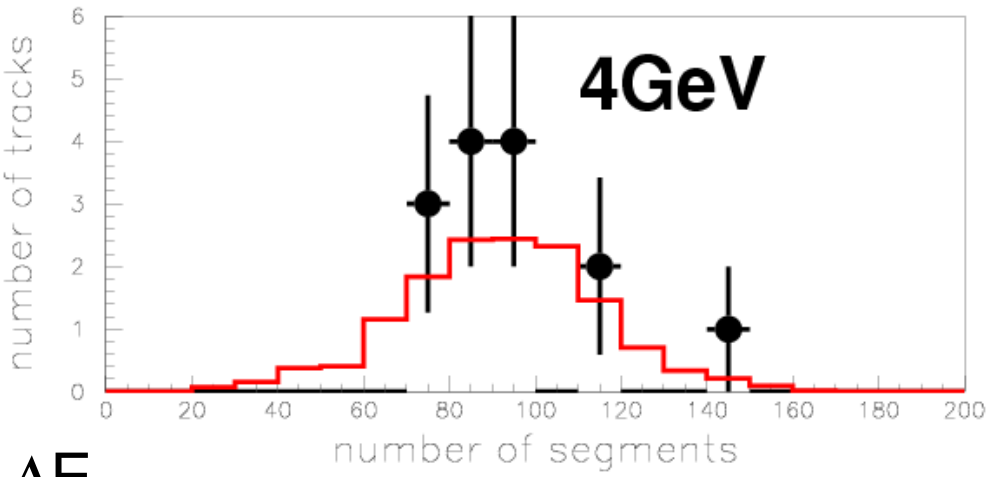
Electron energy measurement





Test exp. @ CERN





Energy determination by calorimetric method

$$\frac{\Delta E}{E} \sim \frac{0.4}{\sqrt{E(GeV)}}$$

@ a few GeV

dE/dx measurement

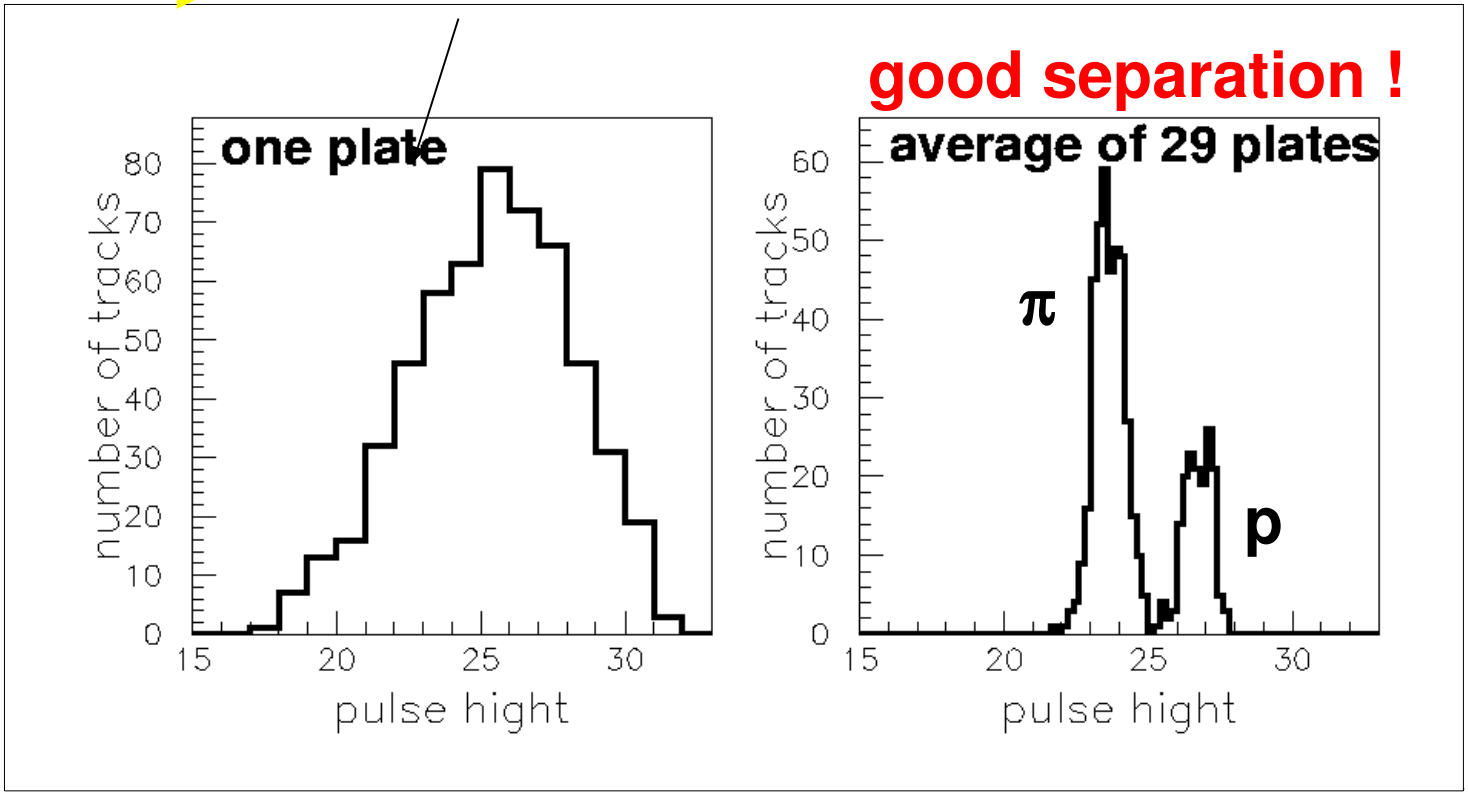
dE/dx ~ spatial density of grains

$I := dE/dx = k / \beta^2$, $E = M\beta^2/2$

→ $M \sim 4 I^2 x / k$ $\delta M/M = 0.12$

10 emulsions before stop point → $\delta M(\pi) = 16$ MeV

p = 1.2 GeV/c p, π^+ @ KEK/PS



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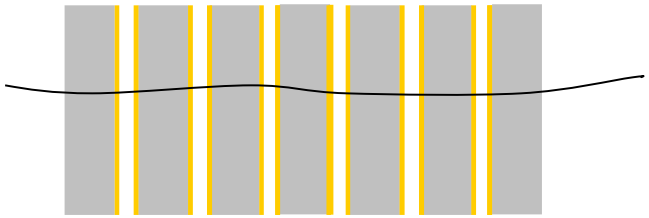
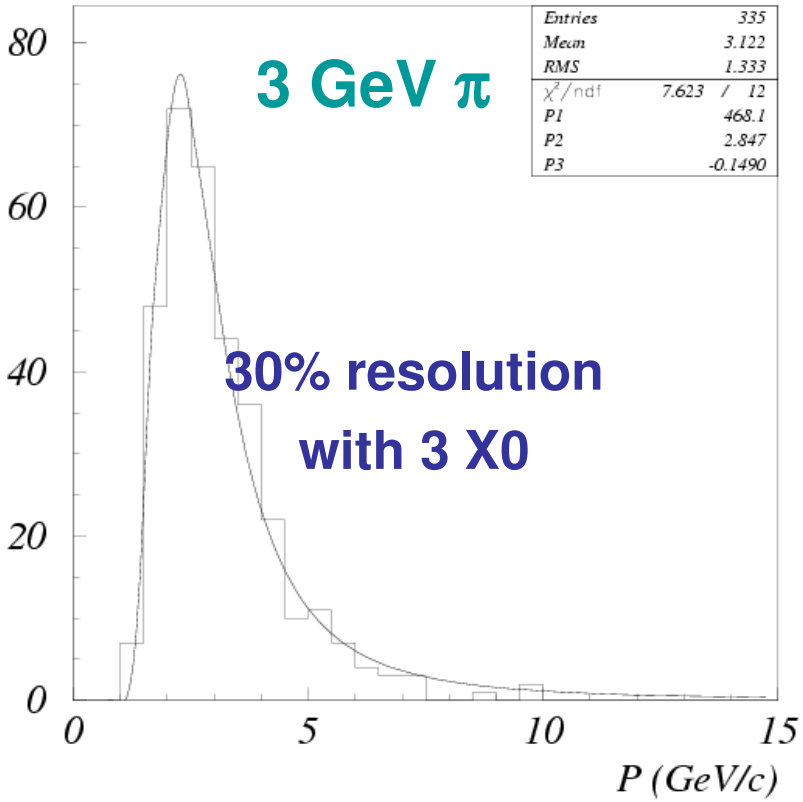
Momentum by multiple scattering

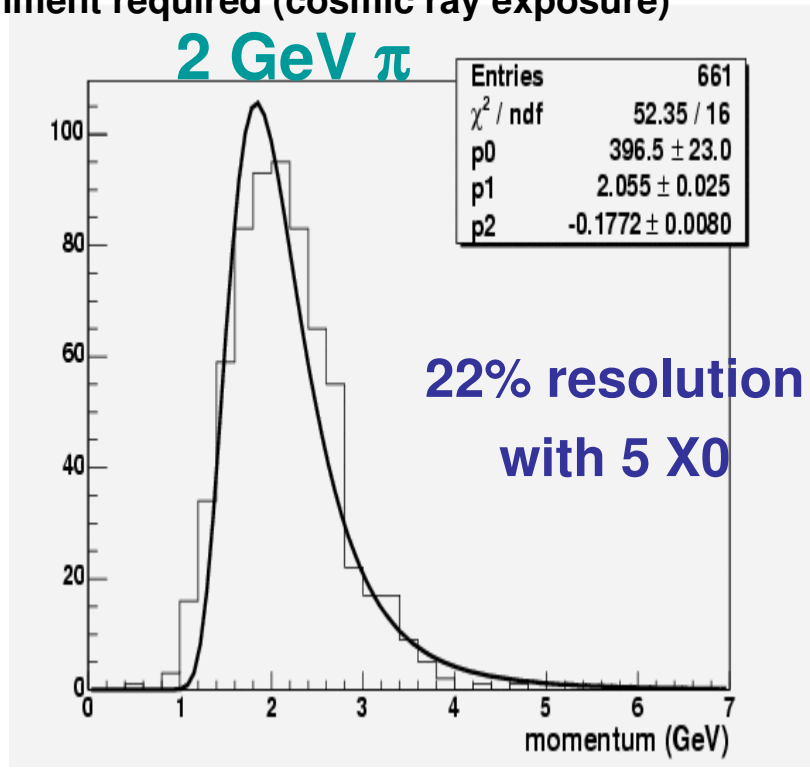
$$\theta_0 = \frac{13.6\ MeV/c}{p\beta}\sqrt{X}$$



- **Angular method**
- based on angular difference btw adjacent base tracks
- not sensitive to relative shift but
- good parallelism of surfaces required

- **Coordinate method**
- based on displacements btw adjacent base tracks
- Longer lever arm (high p).
- Good local alignment required (cosmic ray exposure)





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Nuclear emulsions "curriculum"

1896: radioactivity

Bequerel U salts

1947: pion

discovered in cosmic rays

1971: charmed mesons

Pb+emulsion sandwich

formerly seen as '*X-particle*' in cosmic rays

1985 : beauty mesons

WA75 hybrid experiment

first observation of B product & decay

nowadays

2000 : tau ν

Large scale automatic scanning

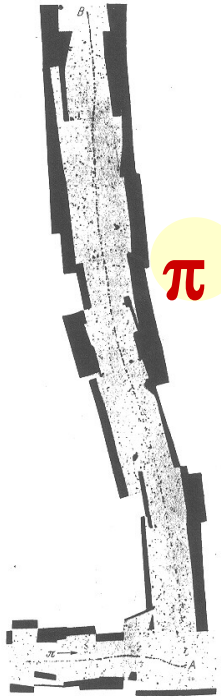
DONUT "beam-dump" exp.

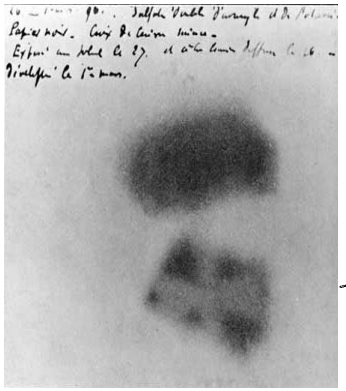
+ massive targets

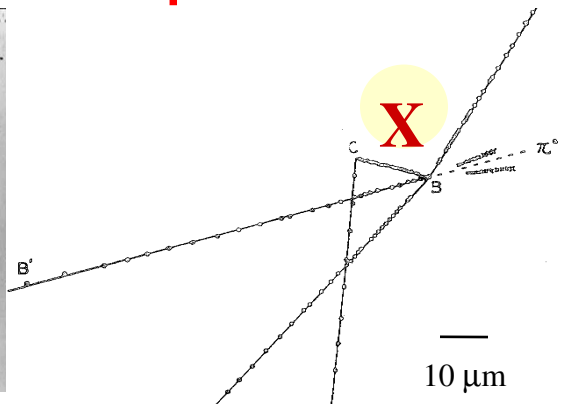
τ decay search in ν_τ CC interactions

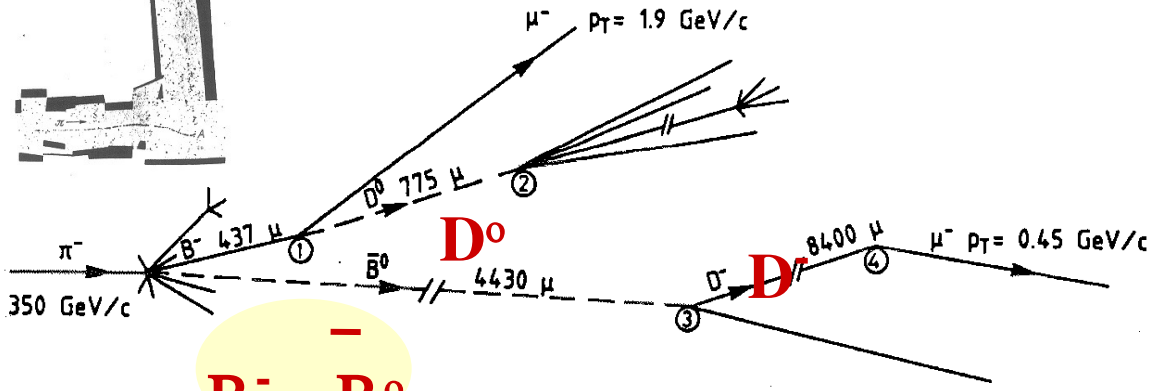
Unique tool to "see" the decay short-lived particles

- **Established technique**









B^- , $\bar{B}^0$

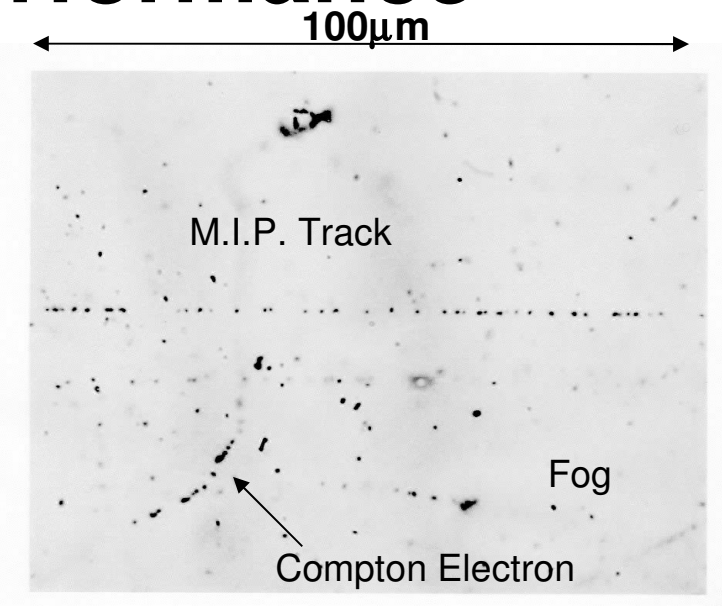
~ "zero background" exp. small statistics is acceptable

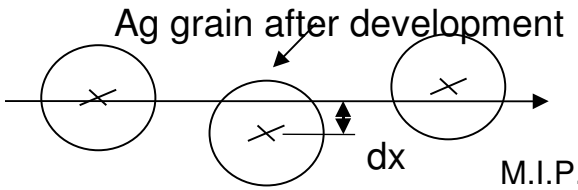
Further experience of E531, CHORUS

The ECC detector performance

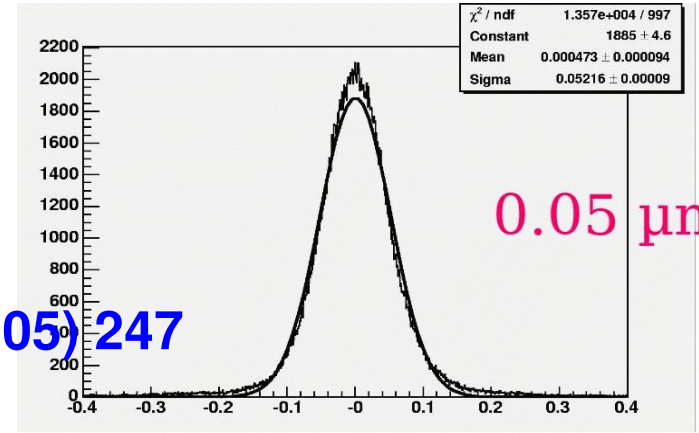
- **High precision tracking (δx<1μm, δθ< 1mrad)**
  - **Kink decay topology**
  - **Electron and γ/pi⁰ identification**
- **Momentum and Energy measurement**
  - **Multiple Coulomb Scattering**

  (Δp/p < 0.2 after 5 X_0 up to 4 GeV)
  - **Track counting (σ/E = 40%/√E)**
- **Ionization (dE/dx measurement)**
  - **pi/μ separation**
  - **e/pi⁰ separation**

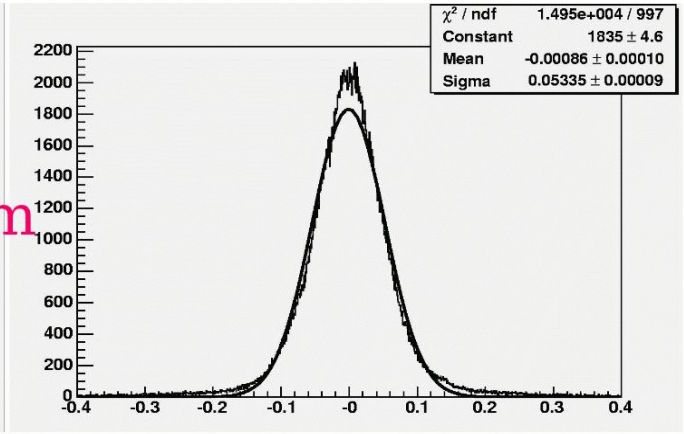




M.I.P. Track



0.05 μm



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OPERA milestones

May 2003: start of detector construction

May 2006: completion of electronic detectors commissioning

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

Aug 2006: technical run, **0.76*10^{18} pot** collected

319 interactions in the rock, mechanical structure and iron of the spectrometer

Oct 2006: start of brick production

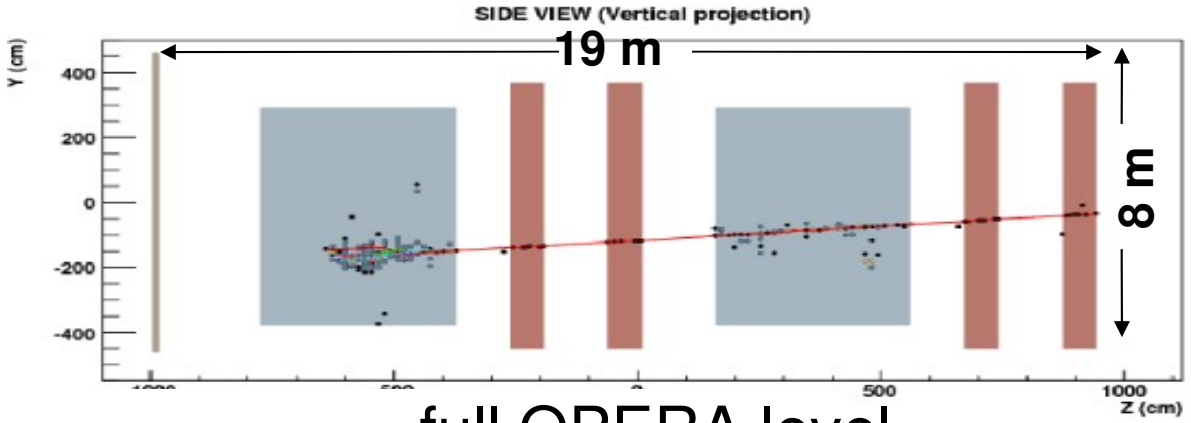
Oct 2007: short physics run (~40% target) **0.824*10^{18} pot** collected

38 events collected in the target

May 2008: 135000 bricks inserted (~88% target)

Jun 2008: OPERA target will be completed. Start of full data taking, expected about **2.1*10^{19} pot** in 130 days of SPS running.

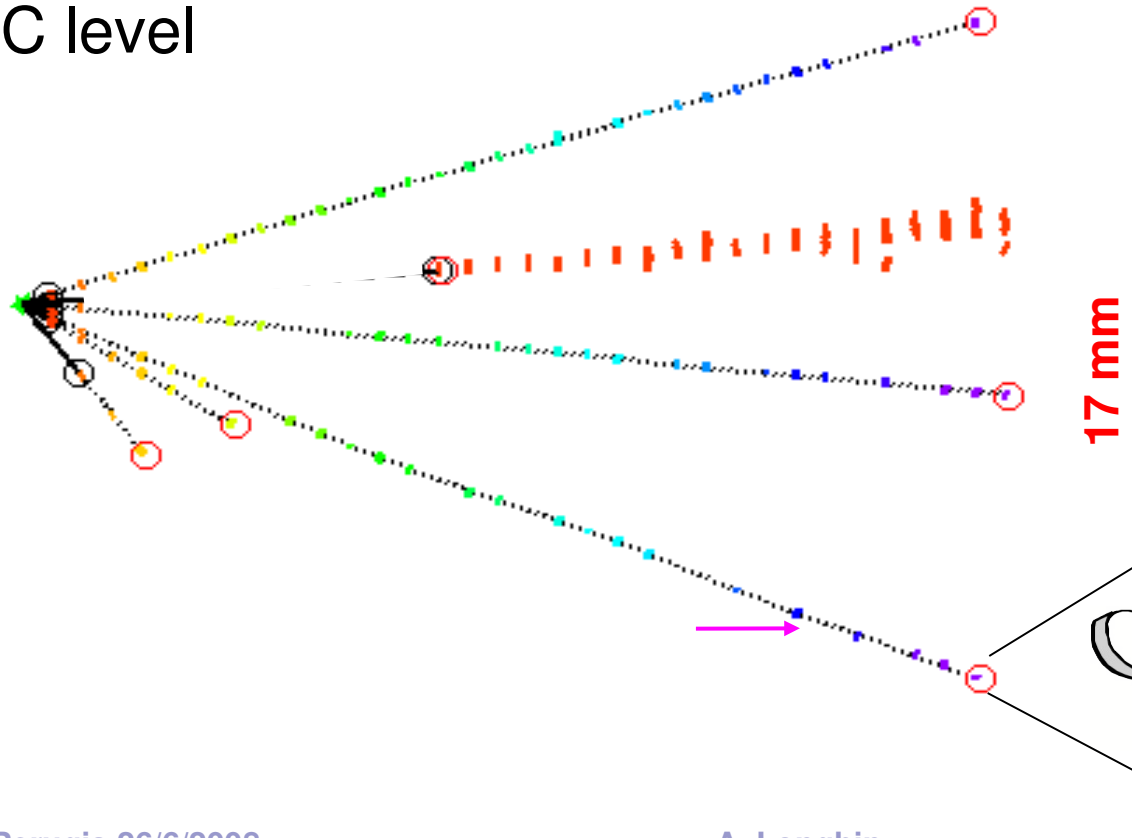
A ν_μ CC interaction



full OPERA level

43 mm

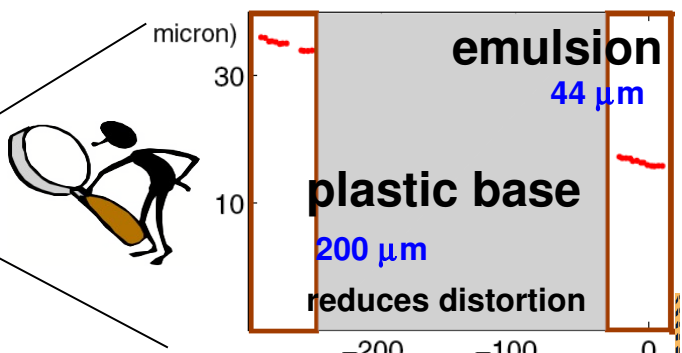
ECC level



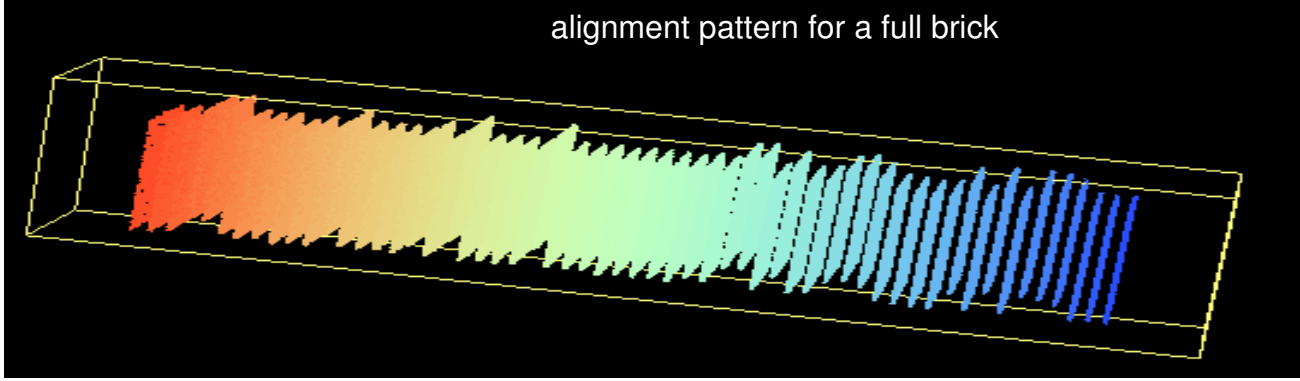
5 prongs with mean impact parameter 9 μm

e.m. shower from γ conversion pointing to the vertex

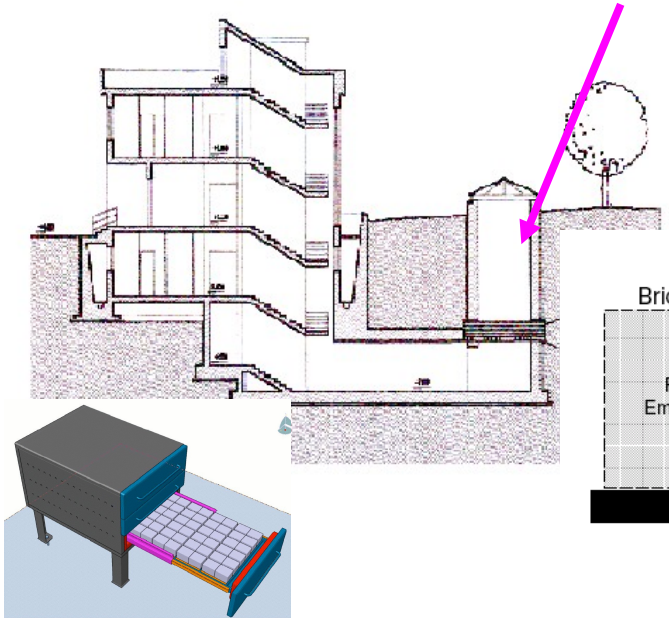
•AgBr crystals diluted in a gelatine matrix



Emulsion alignment



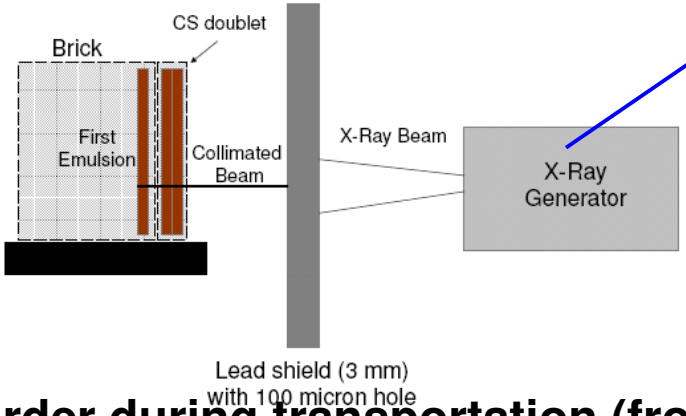
•high energy cosmic rays used for **local alignment** ("pins") of different emulsions in the brick (mechanical accuracy ~ μm). Exposure at surface done after brick extraction in a properly designed **pit** (to suppress the low E component).

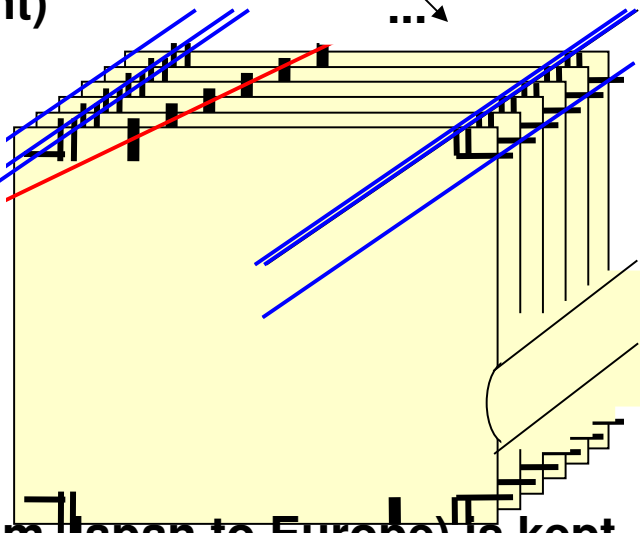


•faster global alignment using **X-ray marks**

•same technique for CS-brick alignment (+Compton tracks for CS-CS alignment)

...





•Memory of emulsion order during transportation (from Japan to Europe) is kept and taken into account during brick assembly. Segments aligned assuming a spacing equal to the emulsion thickness (cosmics recorded during transportation) can be discarded at analysis level : "virtual erasing"