OPERA: hunting for the τ

SPP seminar
11 May 2009 Saclay, Fr

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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

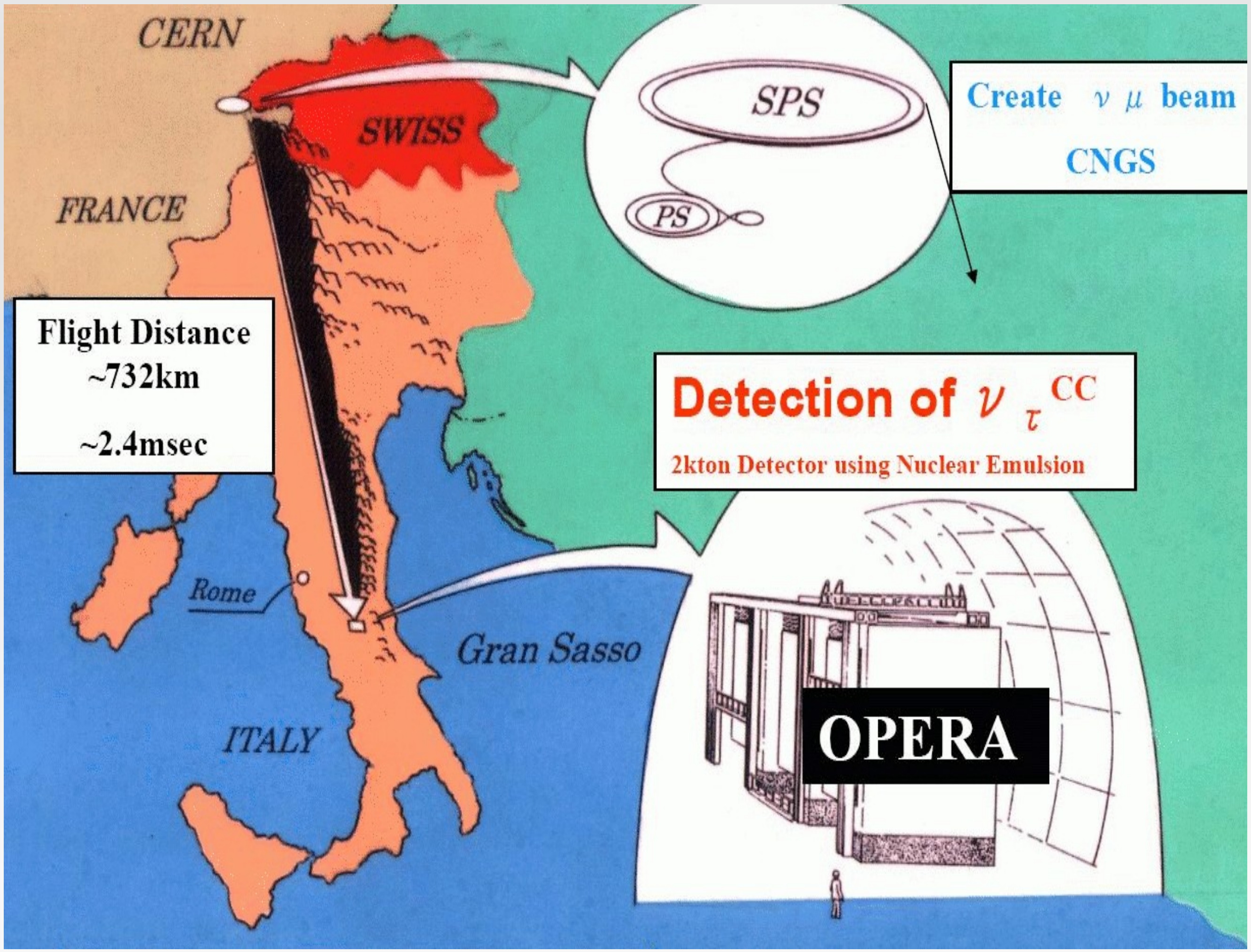
IHEP Beijing Shandong

Sofia

INR ITEP JINR, Obninsk

Brussels

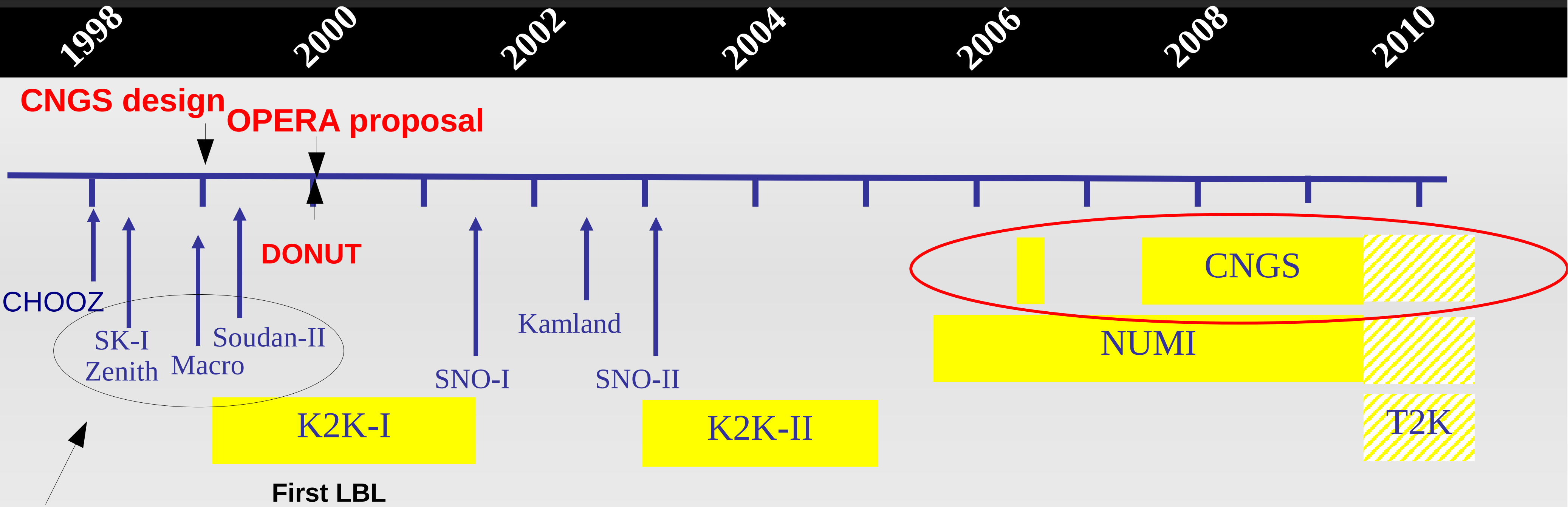
Outline



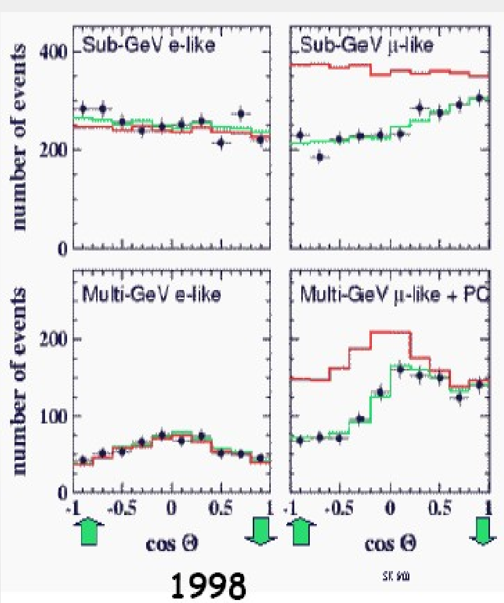
- –Physics potential and goals
- –Experimental strategy
- – the CNGS neutrino beam and the OPERA detector
- –Results from first running
- –Conclusions

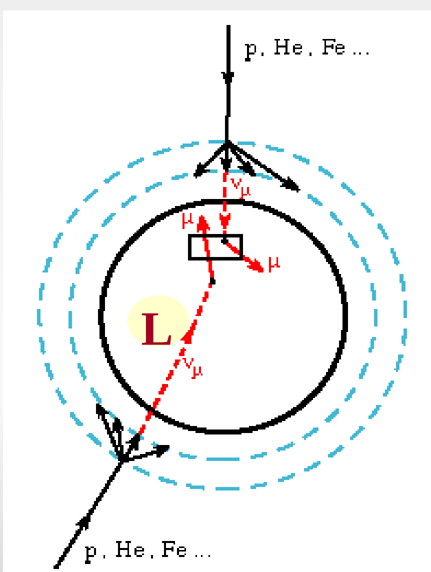
The road to OPERA

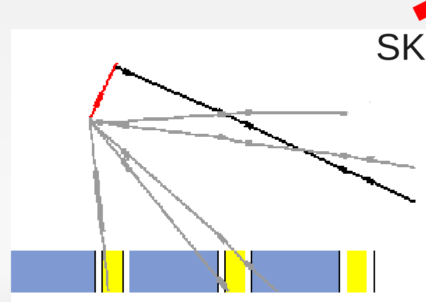
Cern Neutrinos to Gran Sasso



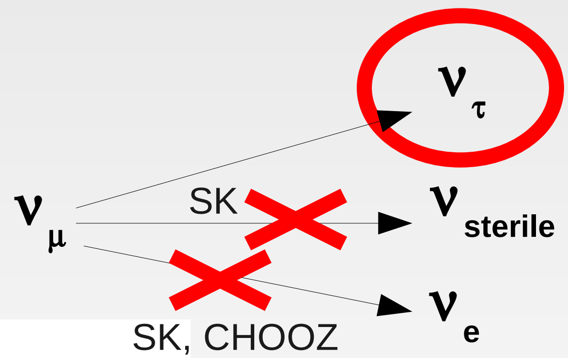
atmospheric neutrino anomaly: deficit of ν_μ (and not ν_e) with zenith angle dependence: **OSCILLATION !!!**





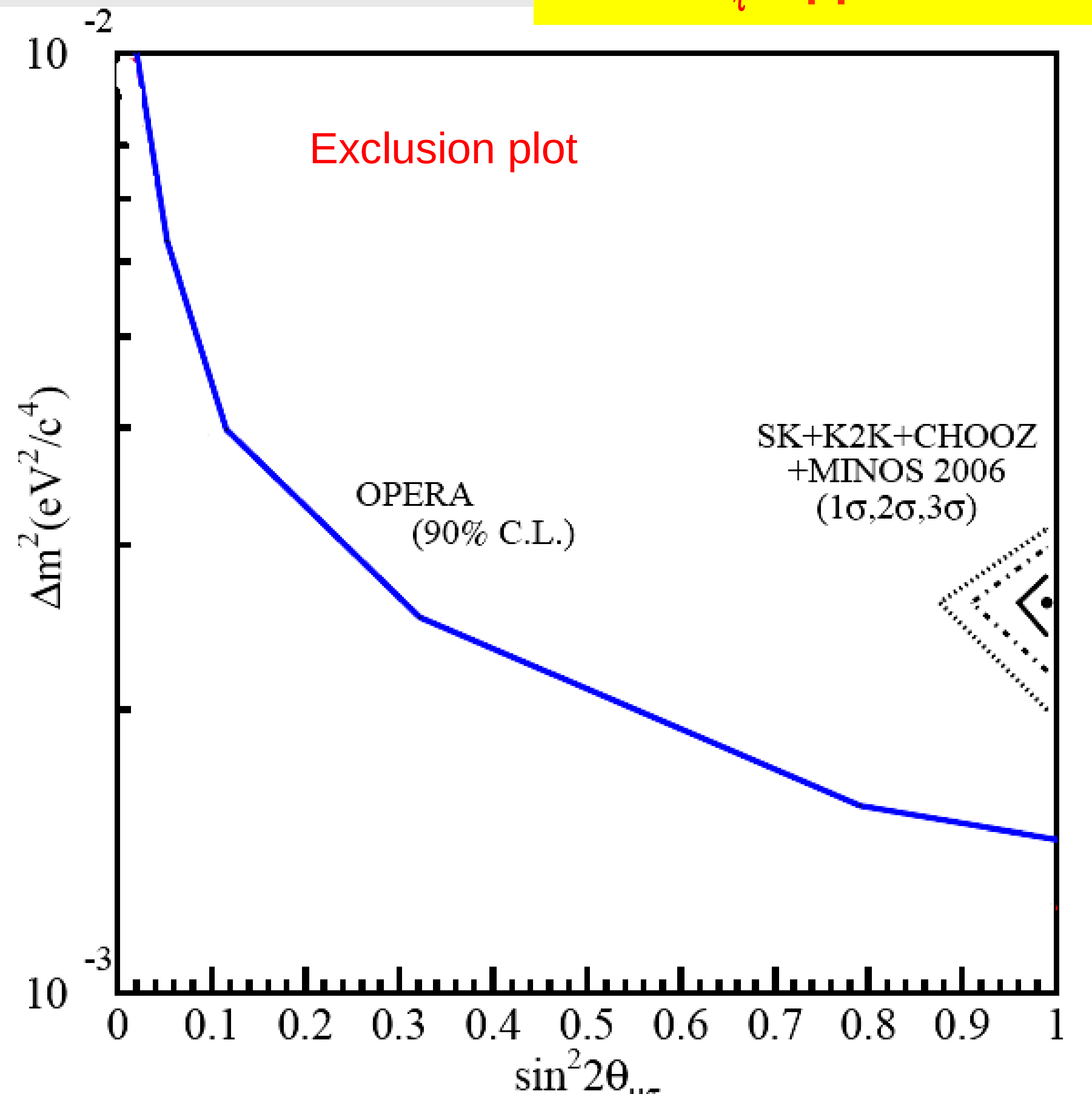


DONUT ν_τ in emulsions



OPERA task

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



2008 MINOS results:

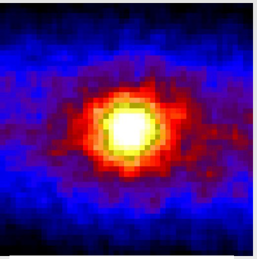
Δm_{23}^2 = (2.43 ± 0.13) 10^{-3} eV^2 (68% C.L.)
$\sin^2 2\theta_{23}$ > 0.90 (90% C.L.)

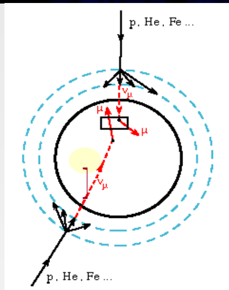
J.Phys.Conf.Ser.136:022014,2008

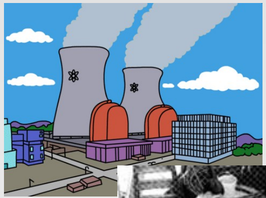
A hard path towards appearance !

- Nature has been kind with us since it provided sources where oscillations are a leading effect: atmosferic ν_μ disappearance (oscillations discovered)

  - It has also been a bit malicious:







At **solar scale**, you cannot see explicitly a $\nu_\varepsilon \to \nu_\mu$ transition through μ CC production: no natural (Sun) or man-made source (rectors) are beyond the kinematical threshold for μ production

At the **atmospheric scale** you have powerful ν_μ source (atmospheric, artifical beams) but... $\nu_\mu \to \nu_e$ transitions are suppressed ("θ_{13} dilemma"). **We must resort to looking for $\nu_\mu \to \nu_\tau$!**

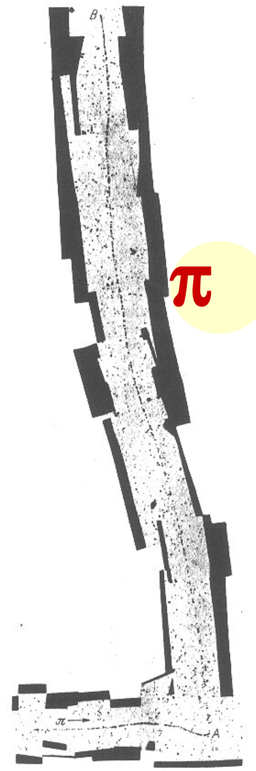
– At long baseline (small Δ m^2) **seeking for taus on an event-by-event basis is a major engineering and experimental challenge**:

- It requires a beam **O (10) more energetic** than any other LBL (m_τ!))
- It requires a fine grained far detector **O(100) more massive** than its short-baseline ancestors (kton-size i.e. CHORUS)

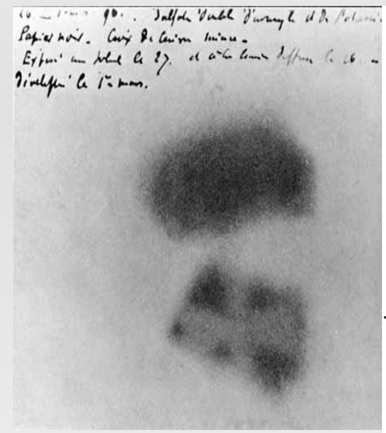
Nuclear emulsions: a "curriculum" of discoveries

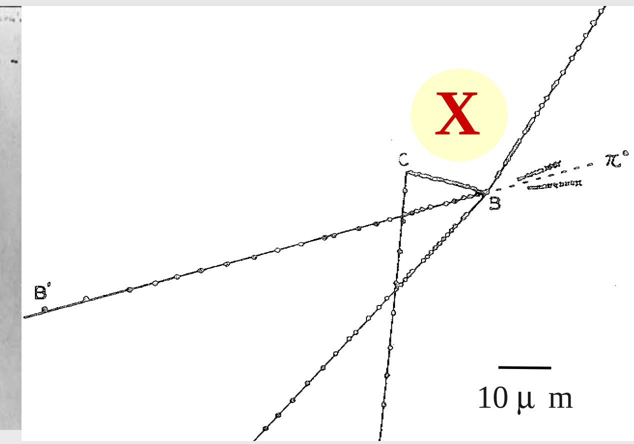
Unique tool to "see" the decay short-lived particles

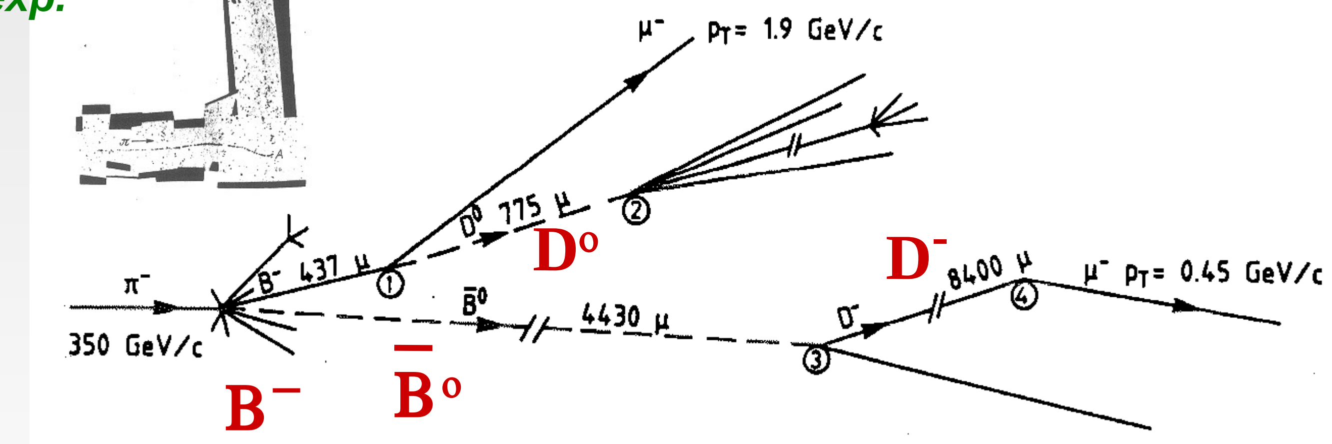
1896 : radioactivity Bequerel U salts
1947 : pion
discovered in cosmic rays
1971 : charmed mesons
Pb + emulsion sandwich
formerly seen as '*X-particle*' in cosmic rays
1985 : beauty mesons
WA75 hybrid experiment
first observation
2000 : tau ν *DONUT "beam-dump" exp.*



- **Established technique**





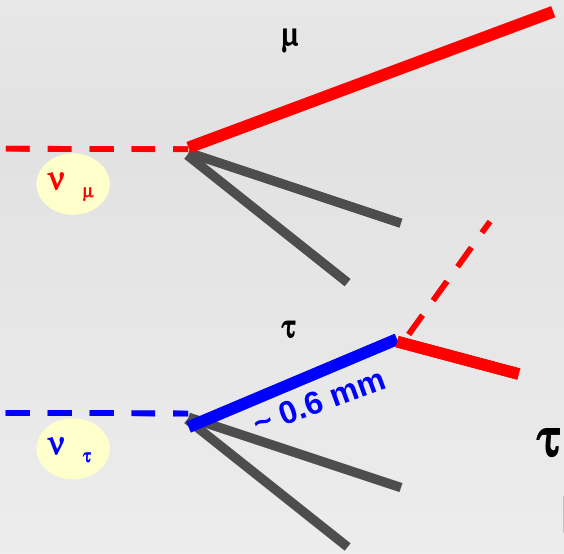


nowadays
Large scale automatic scanning
+ massive targets
τ decay search in ν_τ CC

~ "zero background" exp. small statistics is acceptable

Further experience of E531, CHORUS

The ν_τ appearance challenge

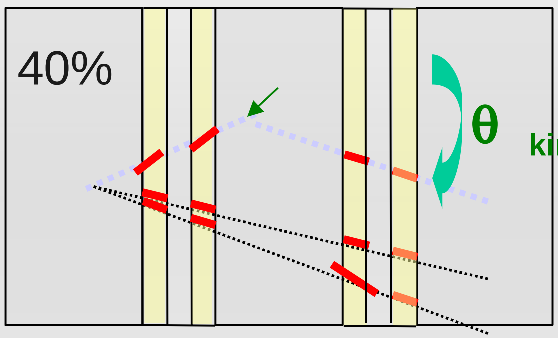


$c\tau = 87\ \mu m$

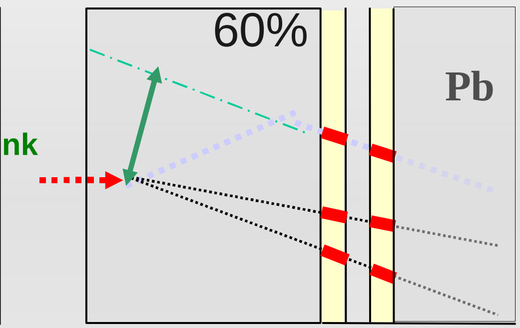
τ decay topology

Kink signature

Kink ("long decays")

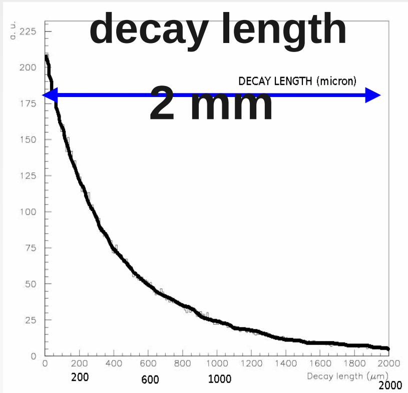


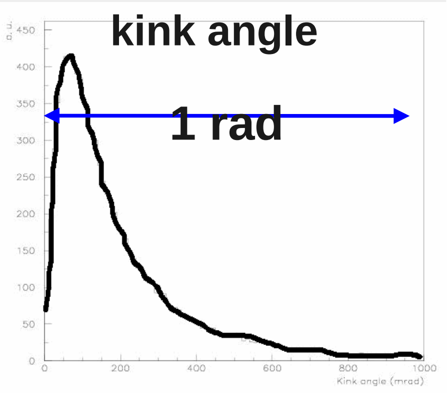
I.P. (short decays)



kink	$\tau \Rightarrow \mu^- \nu_\tau \nu_\mu$	17 %
kink	$\tau \Rightarrow e^- \nu_\tau \nu_e$	18 %
kink	$\tau \Rightarrow h^- \nu_\tau\ n(\pi^0)$	50 %
multi-prong	$\tau \Rightarrow \pi^+\pi^-\pi^-\ \nu_\tau\ n(\pi^0)$	14 %

"Emulsion Cloud Chamber" detector reconciles two conflicting requirements:





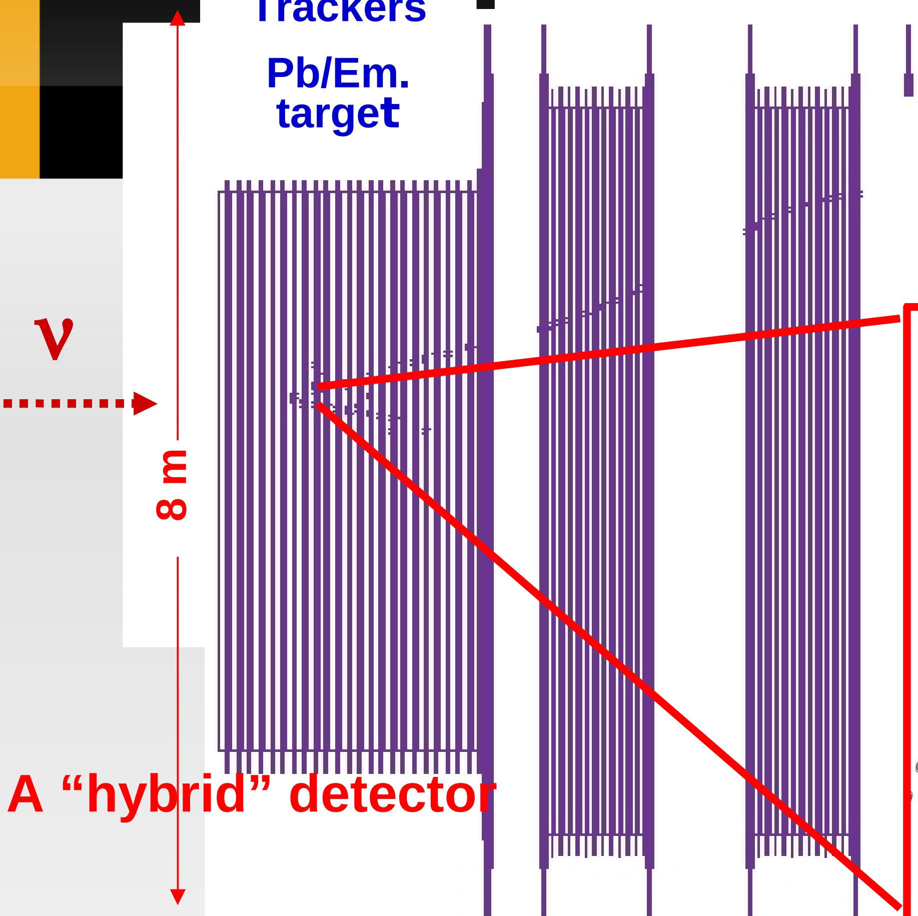
- **Large mass** $N_\tau \propto (\Delta m^2)^2 M_{target}$

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

- **High granularity: (~ μm res.)**

  signal selection + background rejection

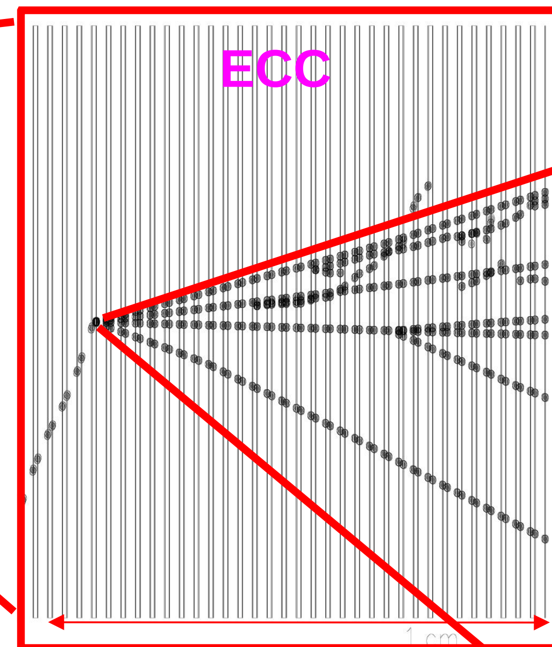
The OPERA way

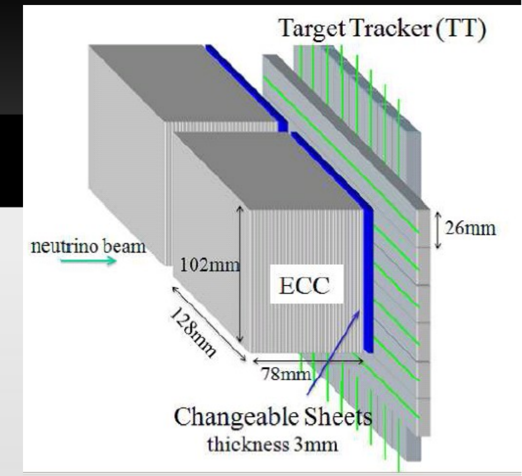


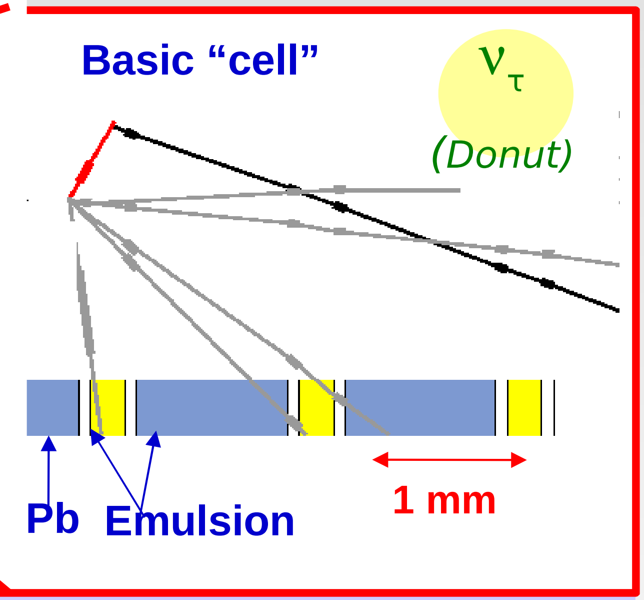
A “hybrid” detector

Extract bricks according to electronic det. prediction

Pb/Em. brick







Electronic detectors

detect ν interaction, brick finding

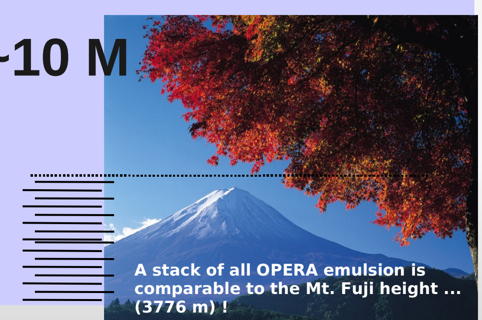
μ -ID, Q and p : bckg suppression

based on the only proven technology (DONUT) to identify ν_τ on an event-by-event basis (nucl.emuls.&lead driven by real time detectors).
A major engineering achievement: brought such technology to an immense size (1.25 kton)

Emulsion detectors:

modular structure of 150000 ECCs
mass industrial production with high standards
FAST-AUTOMATIC scanning
vertex search, decay search, e/μ ID, event kinematics

~10 M

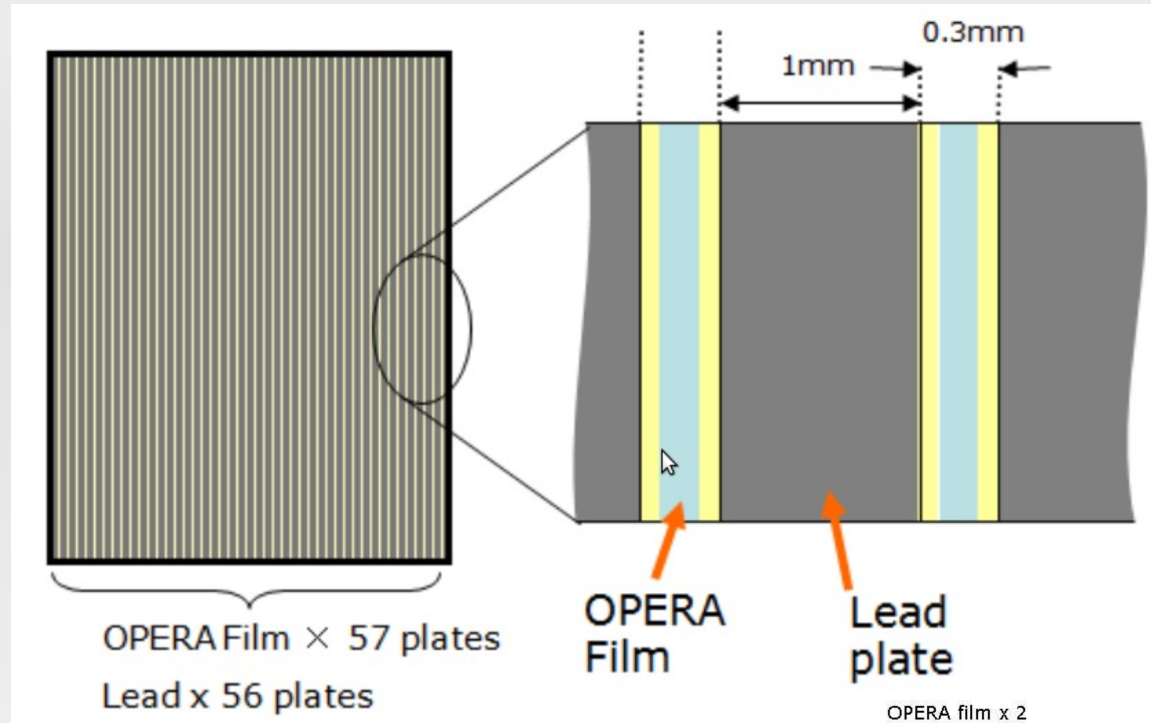


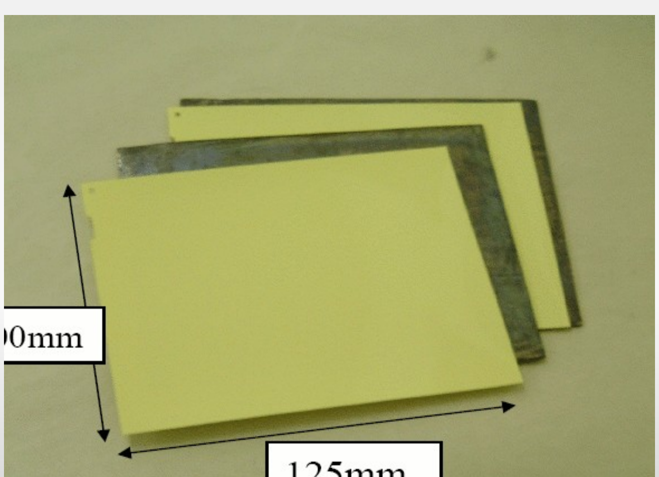
The ECC (emulsion cloud chamber)

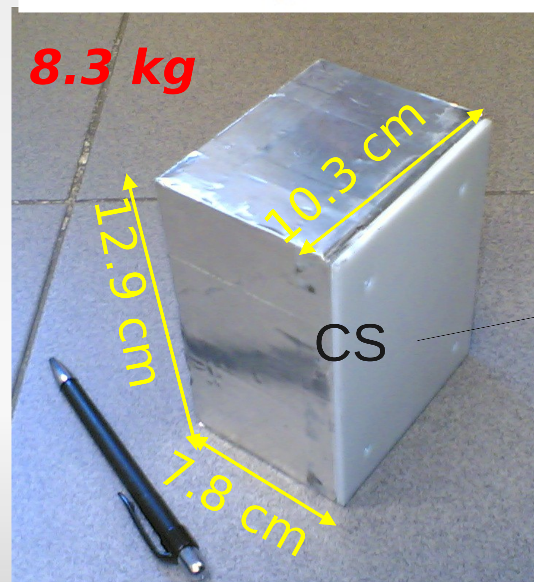
- Brick

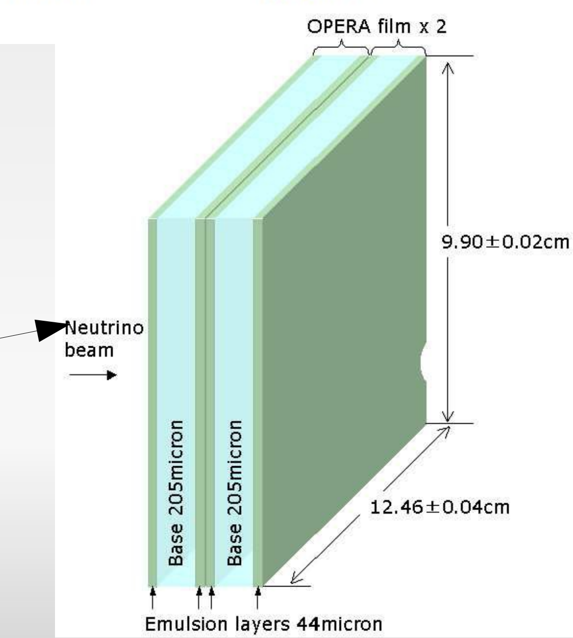
- 57 lead plates (1 mm) + 56 emulsions (300 μm)

- Changeable Sheet (CS)
  low-background removable emulsion doublet attached downstream of brick
  - validates the occurrence of event in the selected brick before unpacking and developing
  - "Bridge" between electronic detectors and brick. (thanks to low track density obtained with a special treatment)
  - Triggers the prediction scanning which leads to vertes identification ("scan-back")

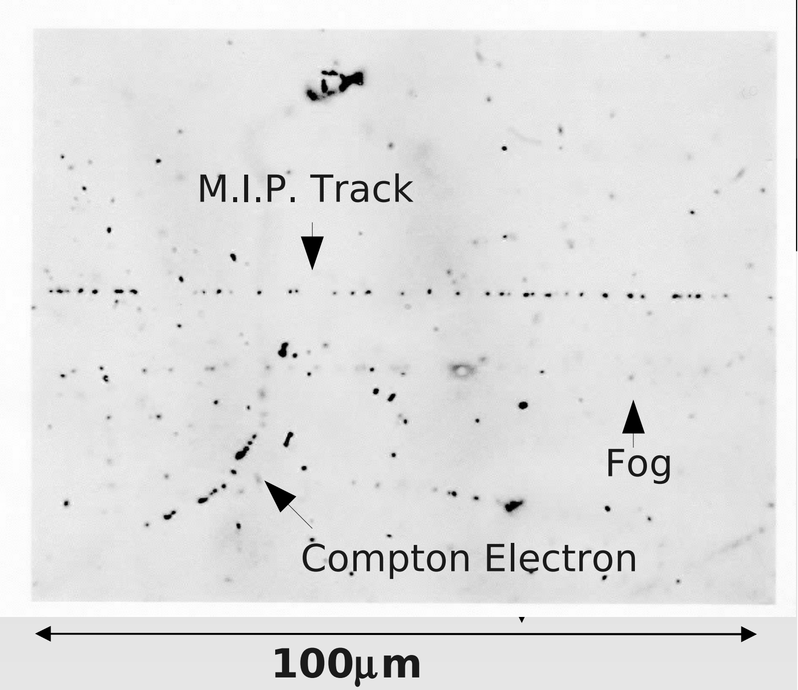








ECC detector performances



High precision tracking: **$\delta x < 1\mu m$, $\delta\theta < 1 mrad$**

- Kink decay topology
- Electron and γ/π^0 identification

Momentum and Energy measurement

- Multiple Coulomb Scattering
  - $\Delta p/p < 0.2$ after 5 X_0 up to 4 GeV
- Track counting $\sigma/E = 40\%/\sqrt{E}$

Ionization (dE/dx measurement)

- π/μ separation
- e/π^0 separation

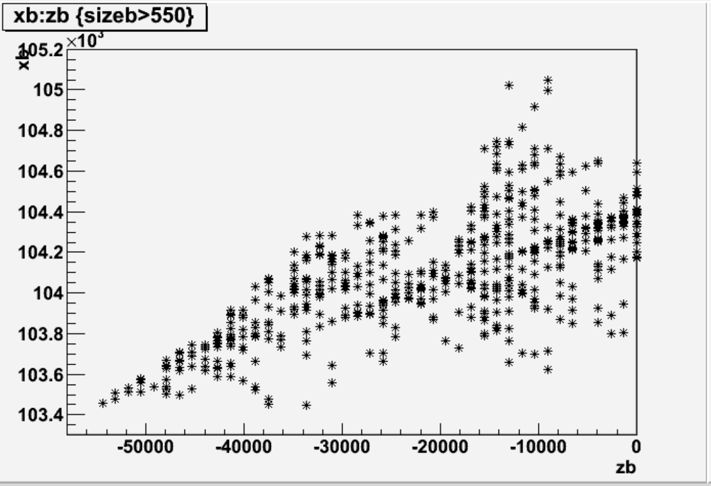
1 brick ~ 10 X_0

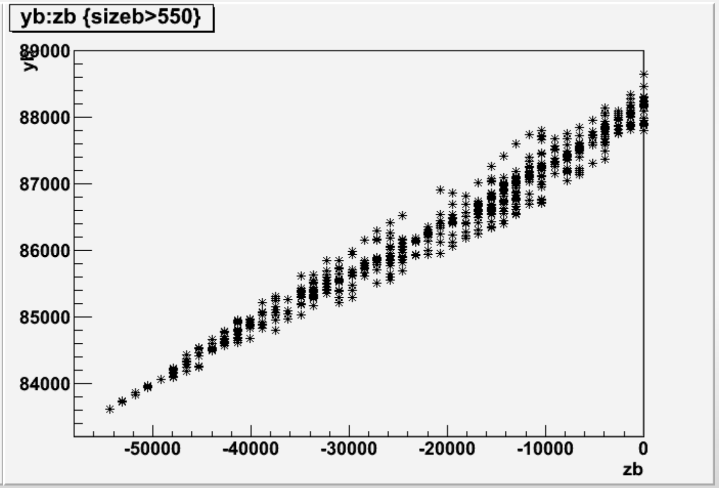
Sensitivity: ~ 36 grains/100 µm for a m.i.p.
Random noise ("fog") ~ 6/(10µm)^3

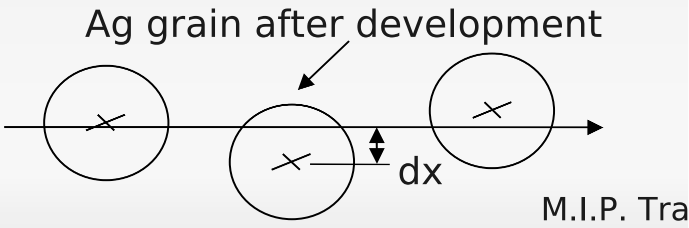
Practically a "stand-alone" detector. Some more examples will be shown later on real neutrino events

high density + small radiation length: event containment: lots of information !

A ~20 GeV shower (CNGS ν)







NIM A554 (2005) 247

An “appearance” optimized beam

Beam main features	
L	*732 km*
< E$_\nu$ >	*17 GeV*
L / < E$_\nu$ >	*43 km/GeV*

To sit on the oscillation probability maximum at 732 km one would need a lower energy (~3 GeV cfr the Numi setup) but OPERA aims to produce taus

$Pr(\nu_\mu \rightarrow \nu_\tau) * \sigma_{\nu(\tau)CC}(E) * flux$

convolution maximized -> high-E

- ~ 18100 ν_μ CC + 5400 ν_μ NC
- ~ 380 anti ν_μ + 144 ν_e + 12 anti ν_e
- ~ 100 produced ν_τCC
- ~ 24 evts/day

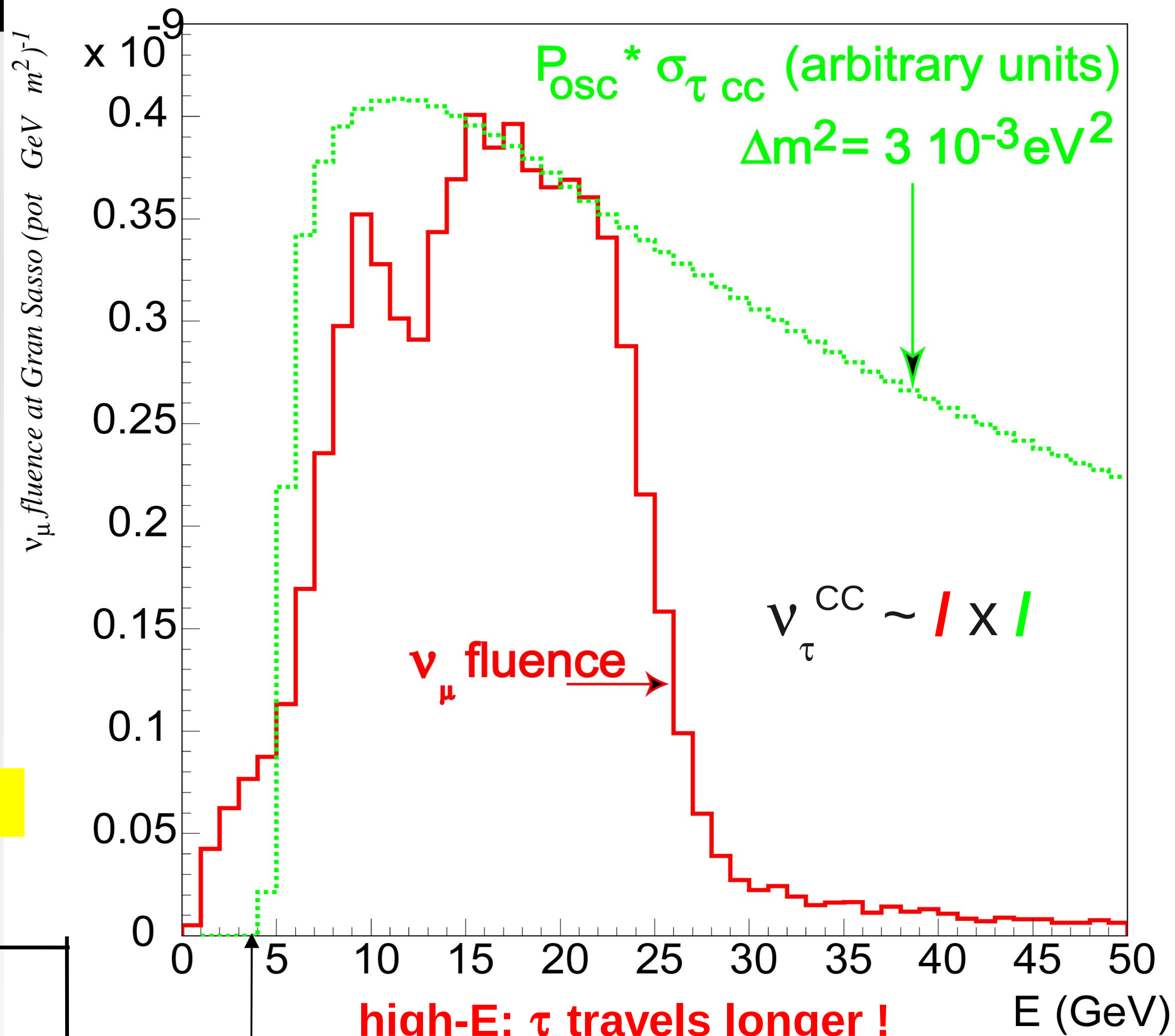
1.25 Kton

$\nu_\mu \rightarrow \nu_e$ search

$(\nu_e+\overline{\nu}_e) / \nu_\mu$	*0.9%*
$\overline{\nu}_\mu$ / ν_μ	*4 %*
ν_τ *prompt*	*negligible* (from D_s)

FLUKA based

DESIGN: $4.5 \cdot 10^{19}$ pot./year, 200 days/y for 5 y



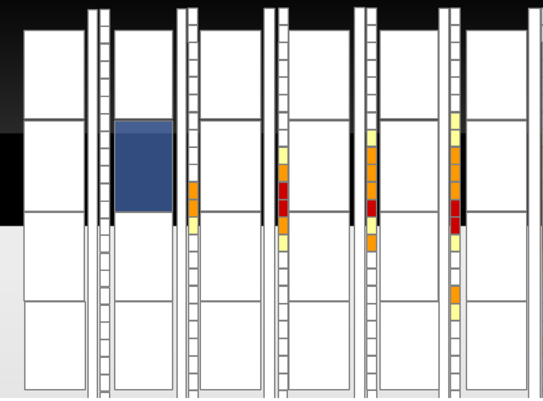
high-E: τ travels longer !

τ production threshold at ~3.5 GeV

slow rise $[(m_\tau+m_p)^2 - m_p^2] / 2m_p$

Analysis flow

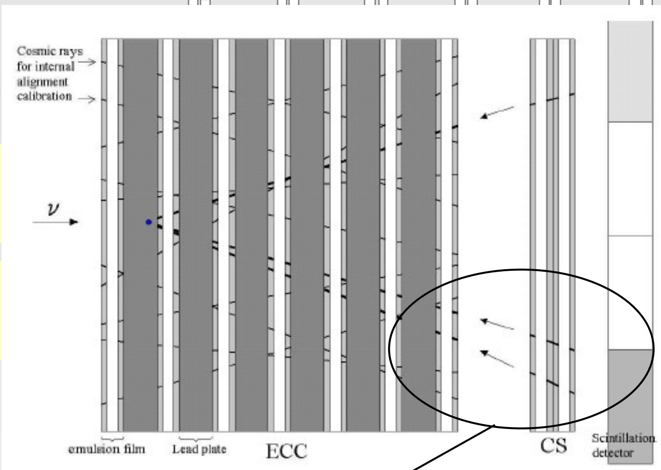
Electronic detectors
Emulsions interplay



Trigger

Brick finding

- Predictions from electronic detectors are searched in the changeble sheet doublet.
- if tracks compatible with electronic detectors are found in the CS the brick finding is validated and brick developed, the brick is exposed to cosmic rays (alignment), 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 (~ cm² for few plates)
- Finally the event topology & kinematics reconstruction is performed
- more bricks can be extracted if necessary to increase accuracy of kinematic reconstruction



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

Vertex location

decay search

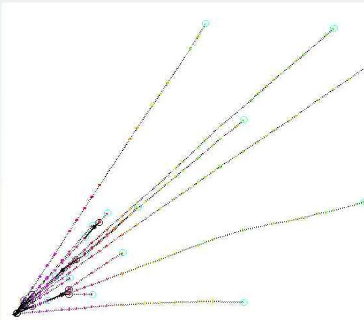
μ / e^- @ 1_ry vtx ?

yes → ν_μ /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 ID applied to ~all the NC events (ν_μ ~> ν_e search)

Signal and background estimation

Full mixing, 5 years run, 4.5×10^{19} pot/year, 1.25 kton fiducial mass

~20000 ν_μ CC interactions expected

Signal ~ $(\Delta m^2)^2$

Efficiency before tau identification = $\underset{99\%}{\varepsilon_{Trigger}} * \underset{80\%}{\varepsilon_{Brick\ finding}} * \underset{94\%}{\varepsilon_{Geometrical}} * \underset{90\%}{\varepsilon_{Vertex\ location}}$

τ decay channel	B.R. (%)	ε (%)	signal ($\Delta m^2 = 2.5 \times 10^{-3}$ eV^2)	signal ($\Delta m^2 = 3.0 \times 10^{-3}$ eV^2)	background
$\to$ e	17.8	20.8	**2.9**	4.2	0.17
$\to \mu$	17.4	17.5	**3.5**	5.0	0.17
$\to$ h	49.5	5.8	**3.1**	4.4	0.24
$\to$ 3h	15.0	6.3	**0.9**	1.3	0.17
Total	B.R. * ε = 10.6%		**10.4**	14.9	0.75

Backgrounds (channel dep.):

Charm production

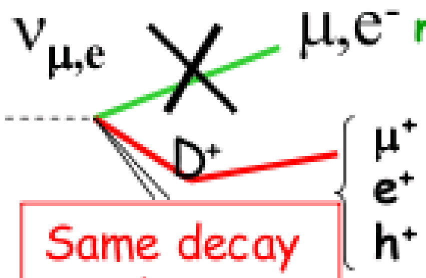
Large angle muon scattering

Hadronic reinteraction

Only if primary muon is not detected.
Muon ID is a crucial issue for the experiment

Further contributions: $\varepsilon_{kinematic.\ cuts} * \varepsilon_{Brick\ to\ brick\ connection} * \varepsilon_{particle\ ID}$

τ search : Backgrounds

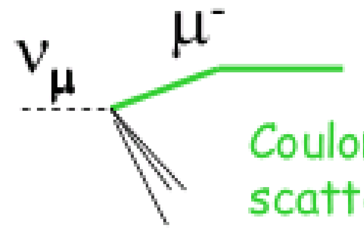


Primary lepton not identified

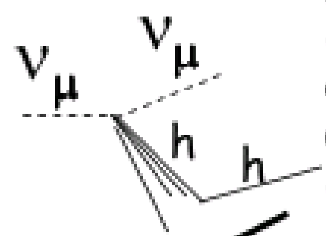
Same decay topology as τ

Charm production in CC, common to the 3 channels

Good muon identification is fundamental



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



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

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

	$\tau \to e$	$\tau \to \mu$	$\tau \to h$	$\tau \to 3h$	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

Not the main goal! but ... sensitivity to θ 13

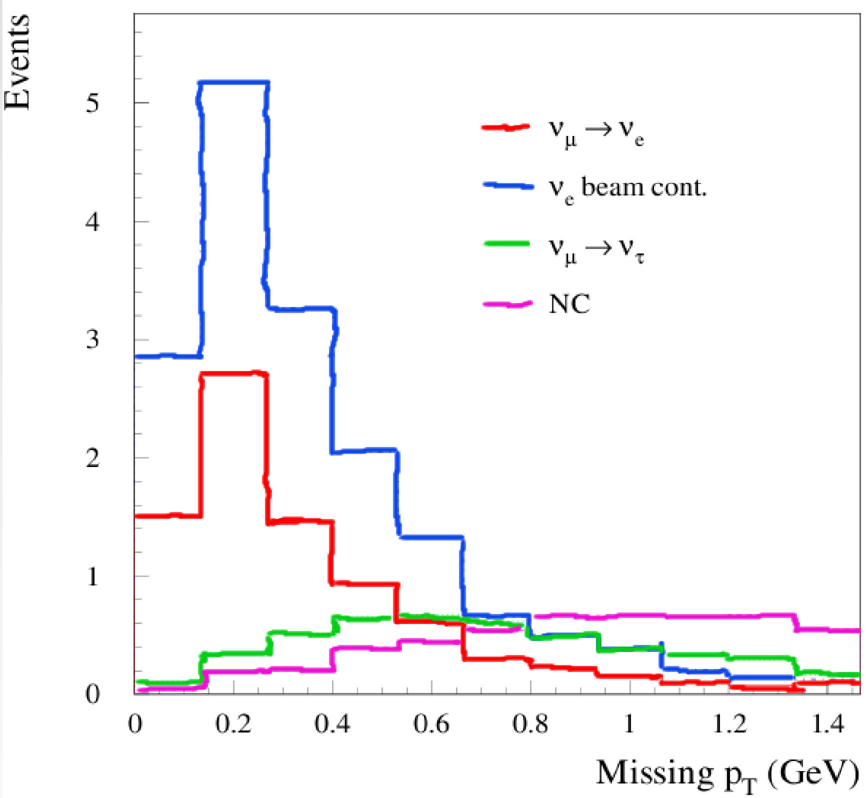
Θ_{13}	SIGNAL	ν_e beam	$\tau \to e$	ν_μ NC	ν_μ CC
9°	9.3	18	4.5	5.2	1.0
7°	5.8	18	4.5	5.2	1.0
5°	3.0	18	4.6	5.2	1.0

NB. Nominal mass 1.77 kton

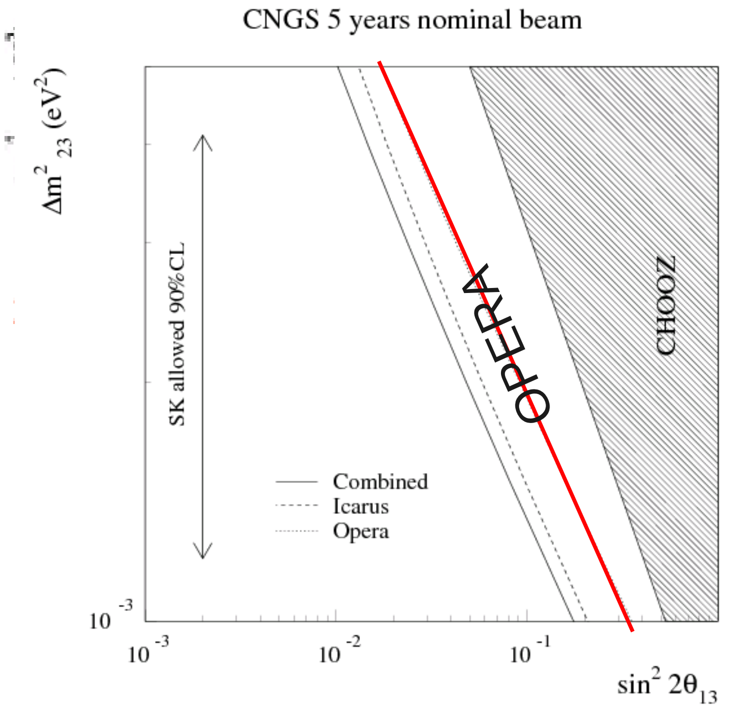
$\Delta m^2_{23} = 2.5 \times 10^{-3}\ eV^2$ $\Theta_{23} = 45°$

nominal CNGS beam   5 years

- Excellent e ans π^0 recon.
- moderate ν_e contam. (0.9%)



J.Phys.G29:443,2003.hep-ph/0210043



"Spin-off" of tau analysis

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} :

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

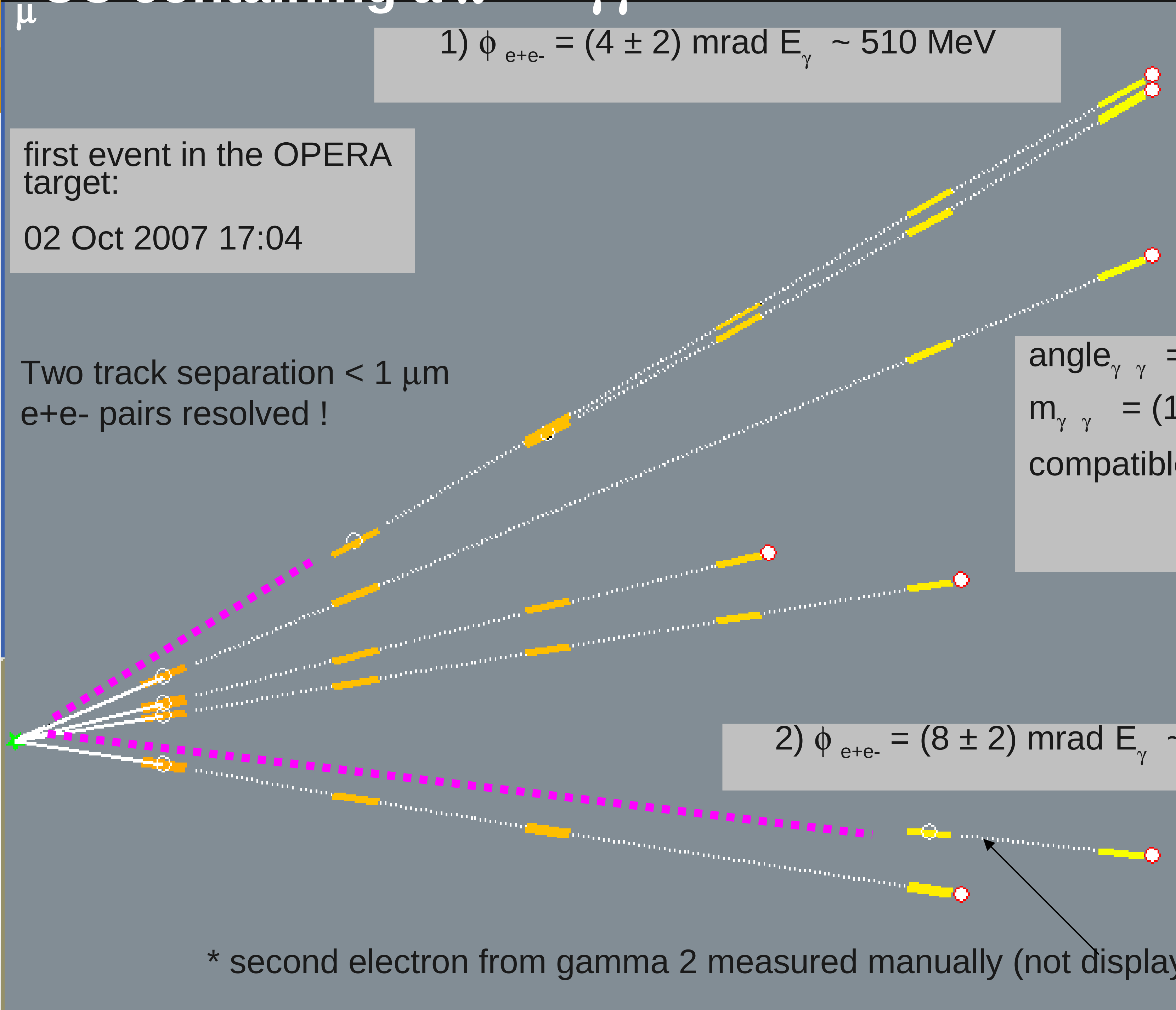
~ X 3 improved limit w.r.t. CHOOZ

ν_μ CC containing a π^0 -> $\gamma\gamma$

1) $\phi_{e+e-} = (4 \pm 2)$ mrad $E_\gamma \sim 510$ MeV

first event in the OPERA target:

02 Oct 2007 17:04



Two track separation < 1 μm
e+e- pairs resolved !

angle$_{\gamma\gamma}$ = (300 ± 20) mrad

$m_{\gamma\gamma}$ = (110 ± 30) MeV

compatible with π^0 mass

2) $\phi_{e+e-} = (8 \pm 2)$ mrad $E_\gamma \sim 260$ MeV*

* second electron from gamma 2 measured manually (not displayed)

OPERA roadmap

ν mass “tourism”!

620 m arc + 120 m focusing section

LHC or CNGS ?!

E: 350-450 GeV

73 dipoles: 1.7 T @ 400 GeV
20 quadrupoles: 40 T/m
12 corrector magnet: max. defl. 80 µrad.

5.6 % slope ~ 3 degrees

32 horizontal dipoles tilted by 12.8 deg.

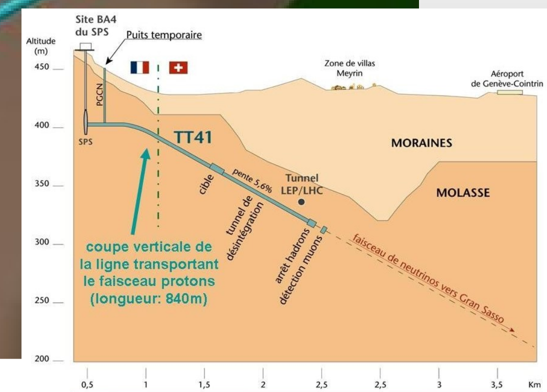
22+1 BPM (Beam Position Monitors)
button electrode monitors from LEP. tol ± 0.6 mm

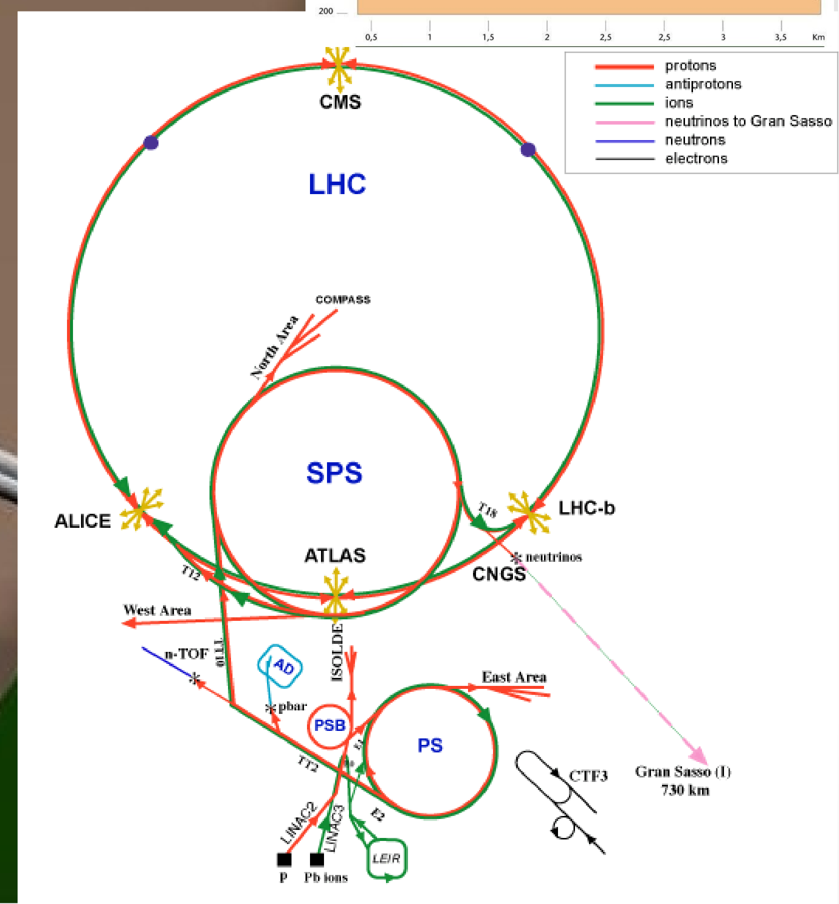
last BPM: tol ± 0.035 mm
strip-line coupler pick-up mechanically connected with target

8 BPM (beam profile monitor)
OTR (optical transition radiation monitors)
75 μm C(high.int) 12 μm Ti (low int.)

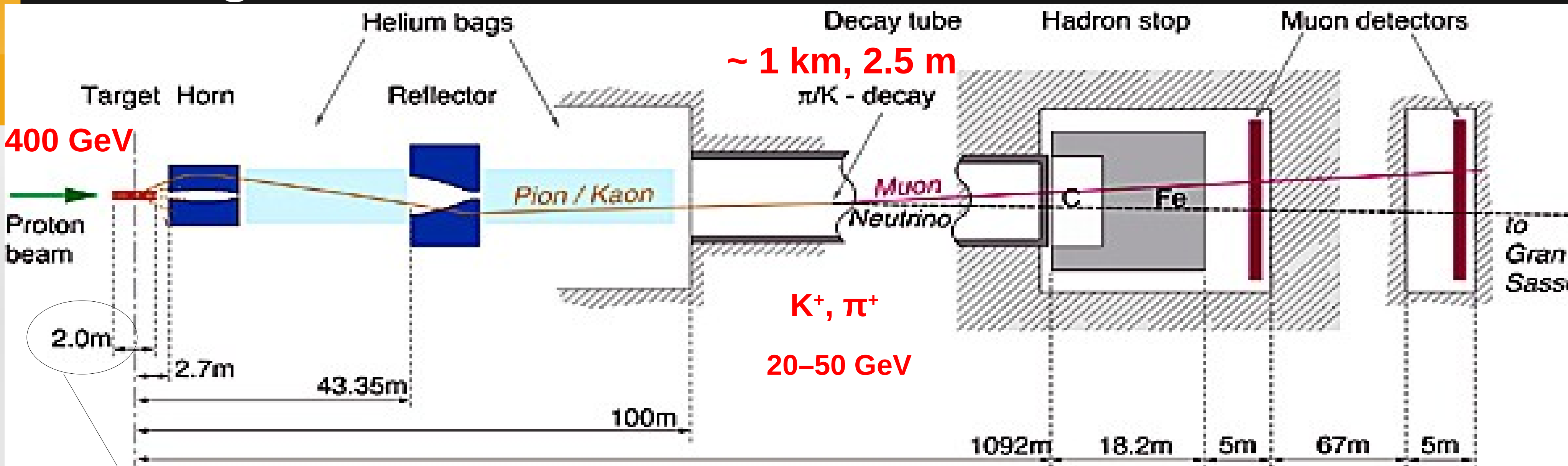
2 BCT (beam current transformer):
beam intens. at start and end.

18 BML (beam loss monitor)
N_2 filled ioniz. chambers



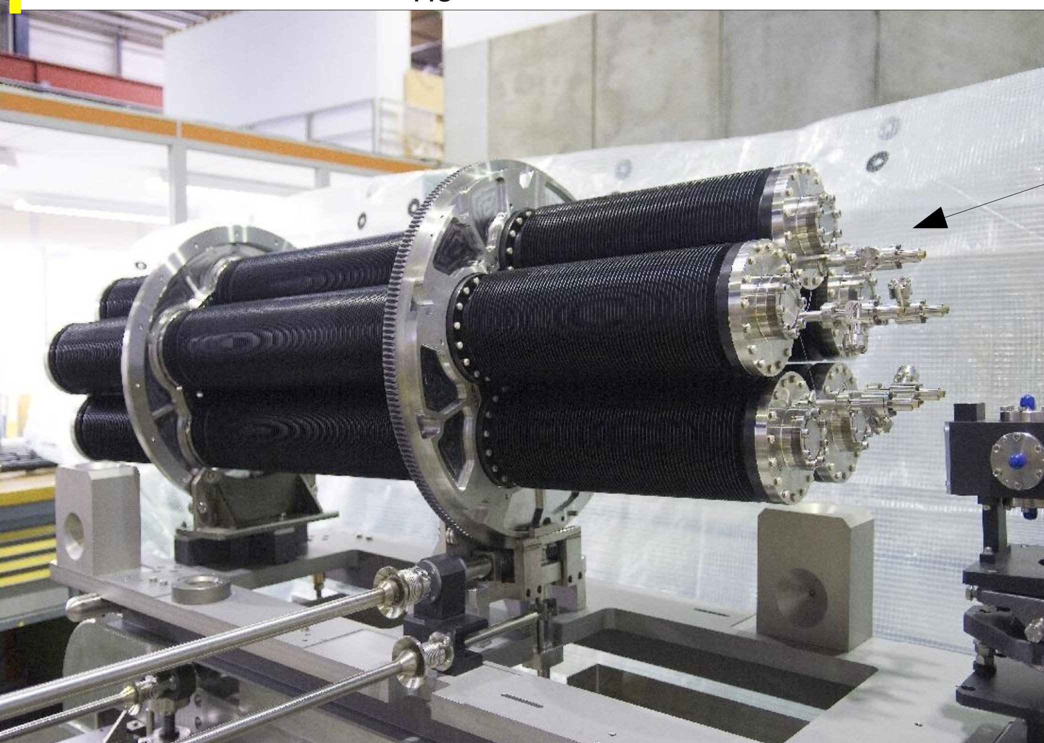


The target downstream beamline



Be

13 10cm-long graphite rods separated by 9 cm gaps. r=4 mm (5mm the first).

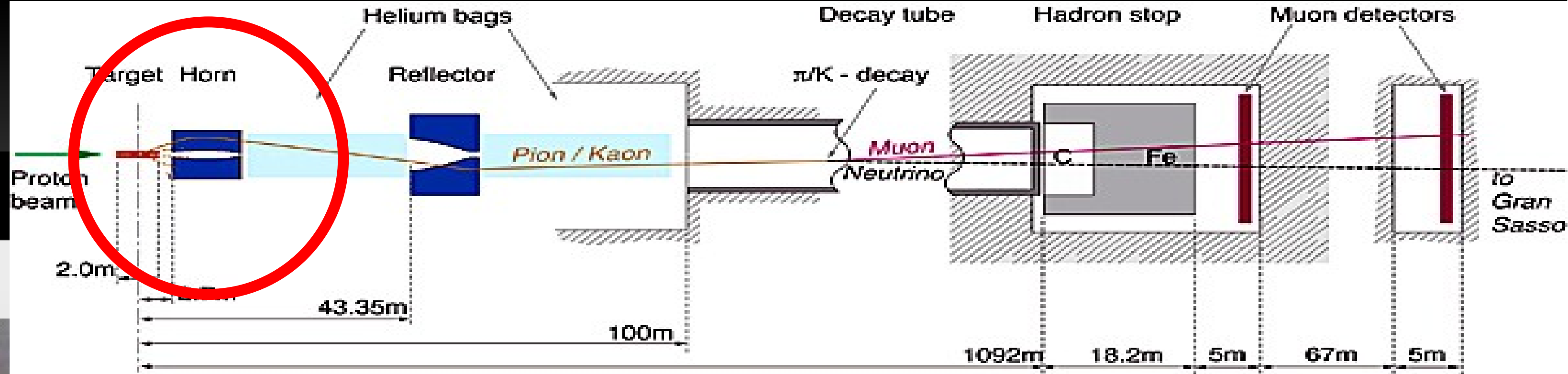


”Revolver” design. 1 target + 4 in situ spares

designed to withstand beam induced stress up to 3.5 10^{13} p/extraction with 400 GeV (up to **750kW** average power)

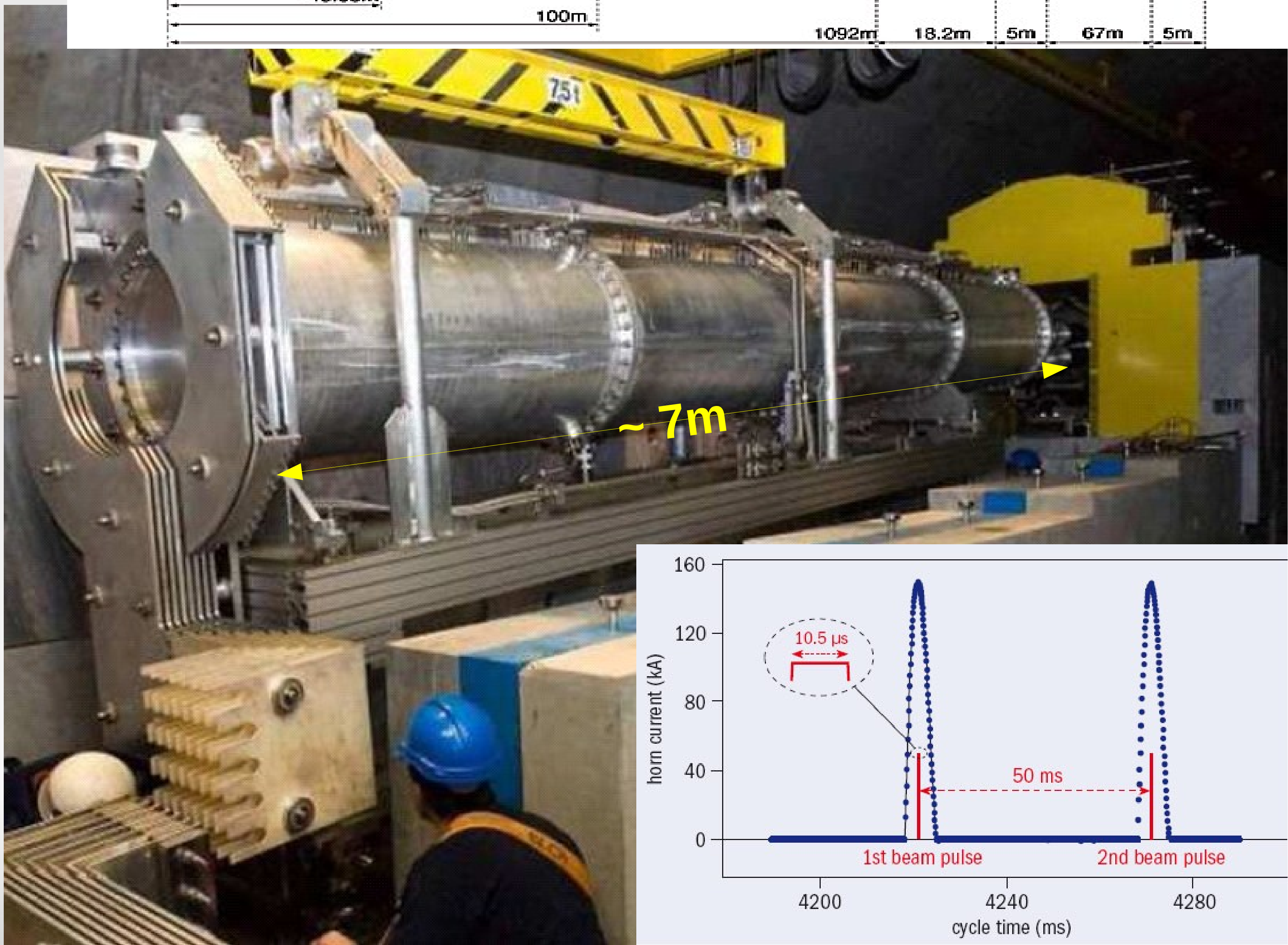
σ = 0.5 mm (tunable in 0.25-1 mm)
beam position stability onto the target averaged over several days **~ 50 μ m** (r.m.s.)

Horn

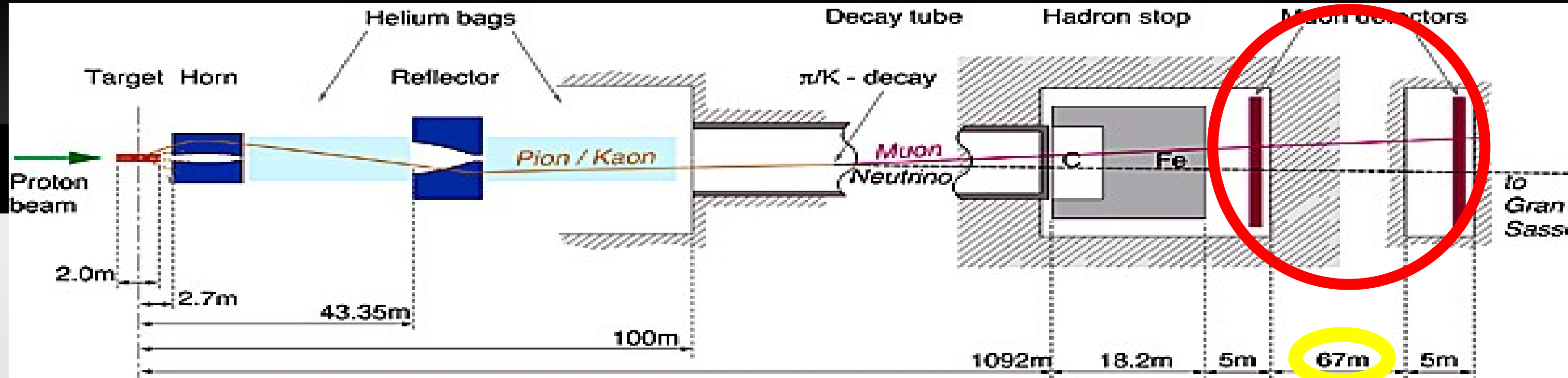


i=150kA for a few ms (180 kA for the reflector)

water cooled



μ monitors



2 stations. 67 m rock in between

Station1: 4.0 x 10^5 μ / cm^2 / 10^{13} p

Station2: 2.5 x 10^7 μ / cm^2 / 10^{13} p

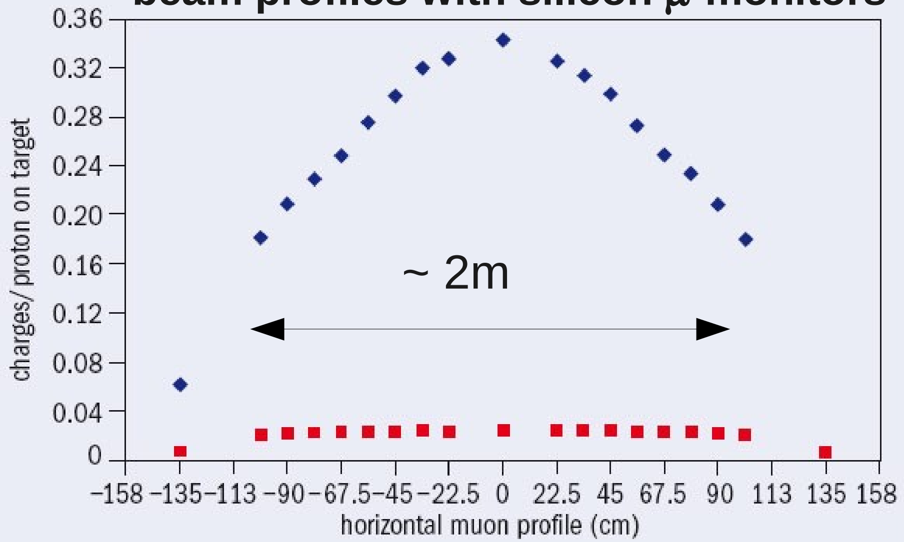
from Aug. 06 run

10^8 μ/cm^2/10 μs: high rate!

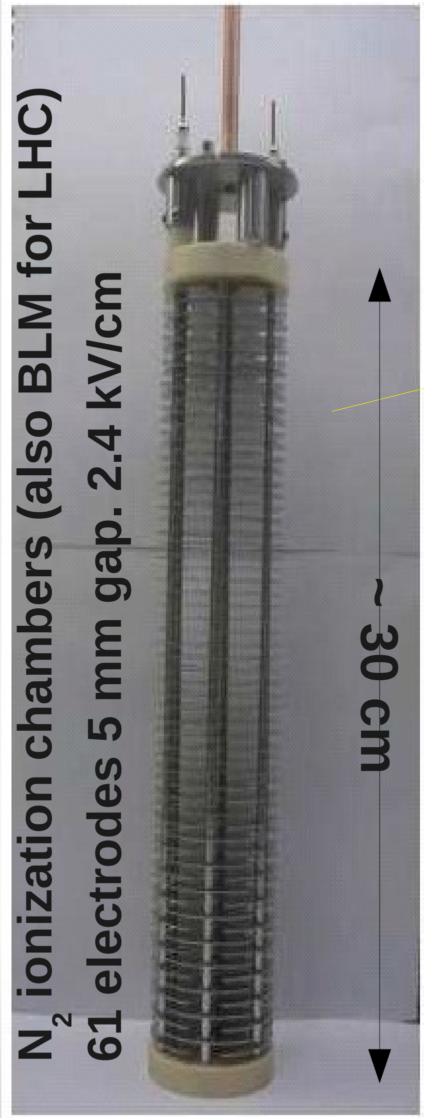
Stat. 1: E_μ > 20GeV. Target-horn alignm.

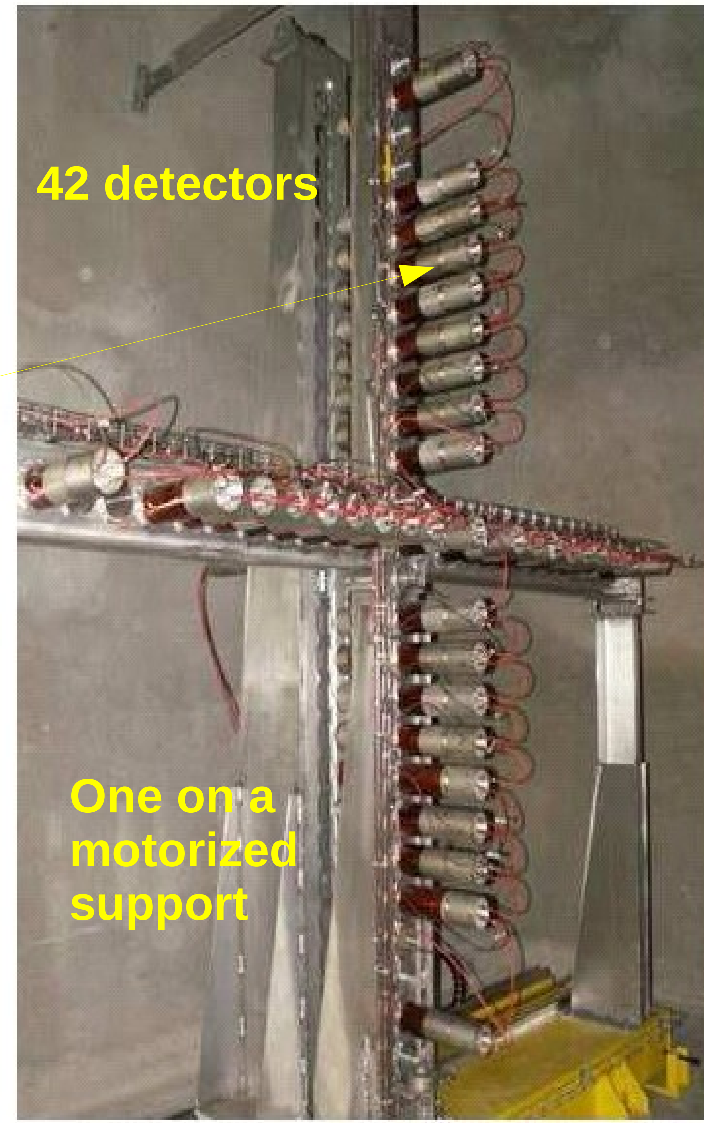
Stat. 2: E_μ > 50GeV. beam-target alignm.

beam profiles with silicon μ monitors



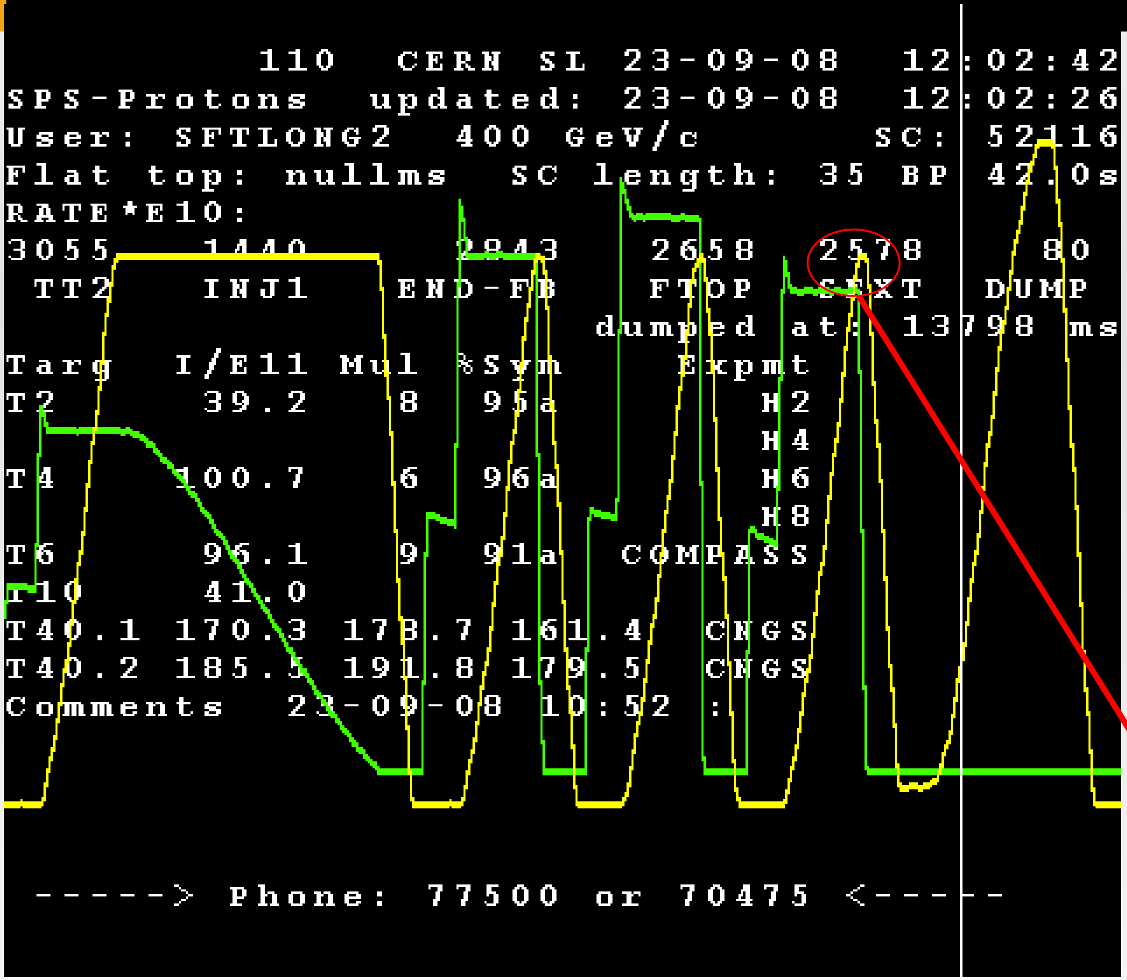
Horn ON/OFF





Proton extraction from SPS to CNGS

SPS magnetic field
SPS current



Energy 400 GeV (from SPS)

2 extractions/cycle 50 ms apart

10.5 µs extraction batch length

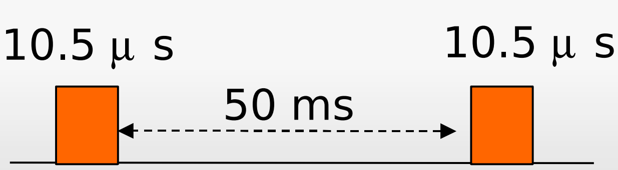
2.4 10^{13} p/extraction (nominal)

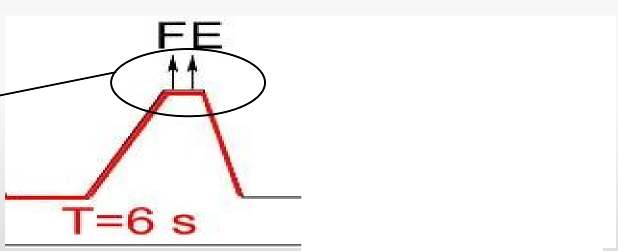
- 2100 bunches/extraction
- 2 ns bunch length
- 5 ns bunch spacing

3 CNGS cycles (6 s each)

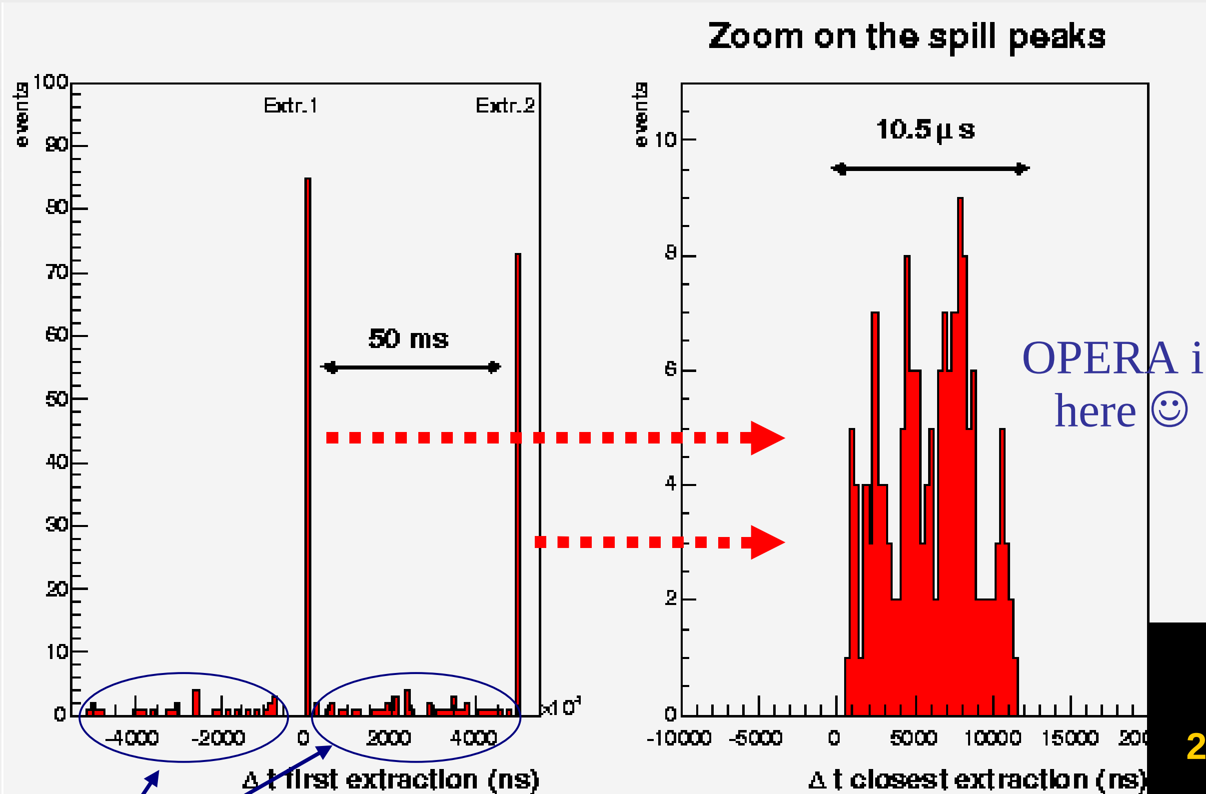
SPS supercycle in September 2008

Other fixed target SPS users
COMPASS, NA48, NA61/SHINE





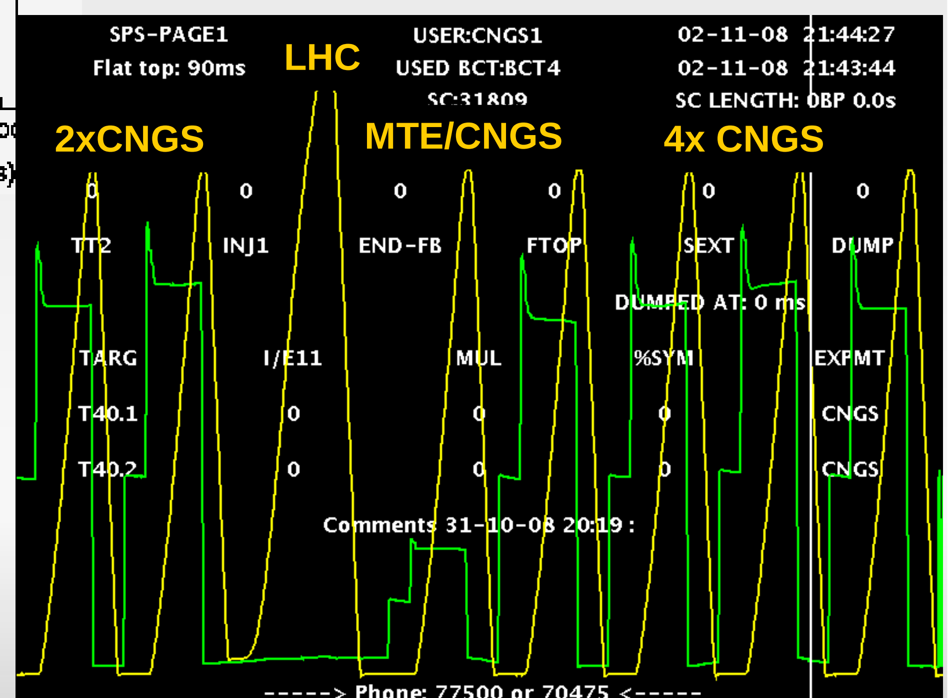
Time structure observed by OPERA



Cosmics

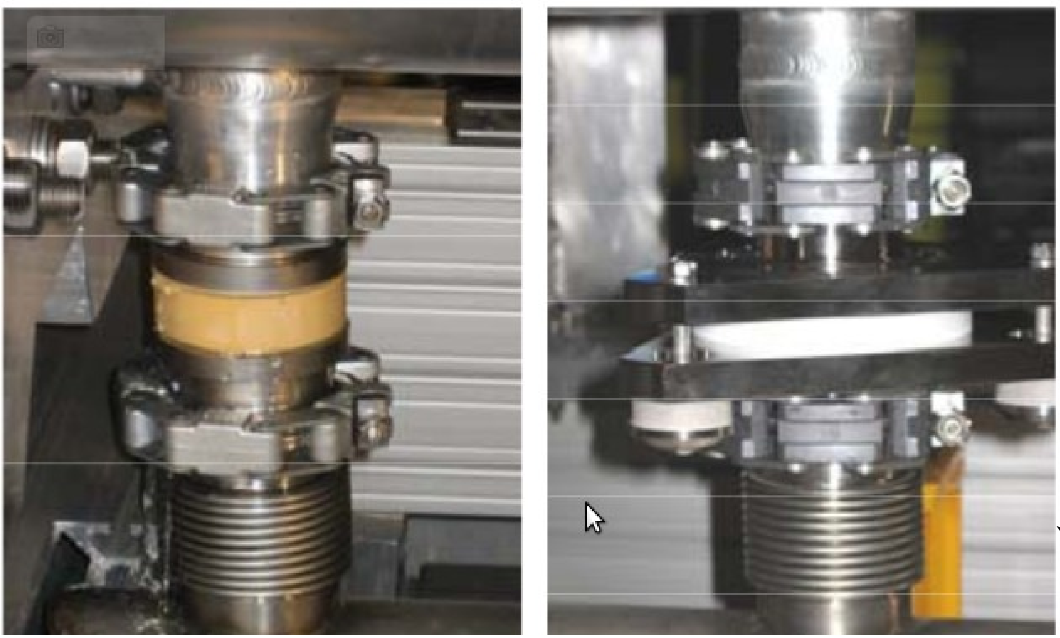
Aug 2006

OPERA is here ☺



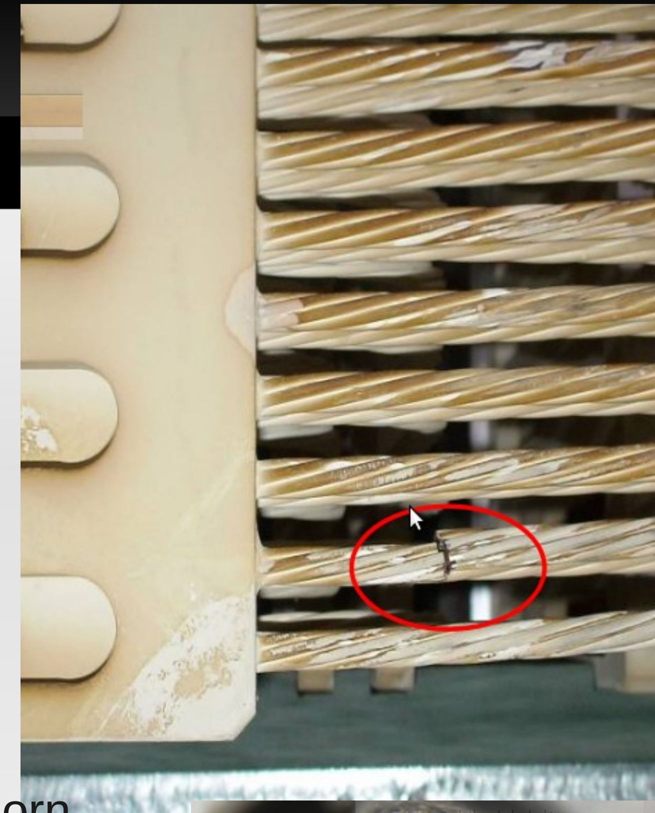
- After the LHC accident, further increase of the integrated intensity for OPERA (duty cycle 37.5% → 83%). 6 CNGS cycles!

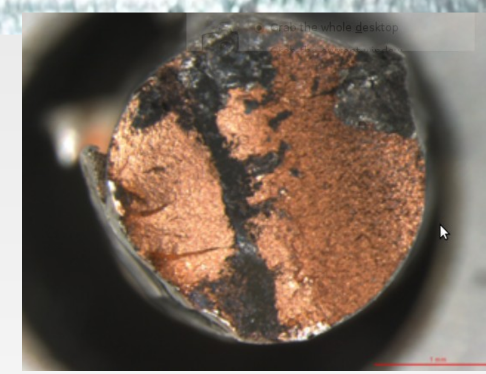
Problems ... and fixes !

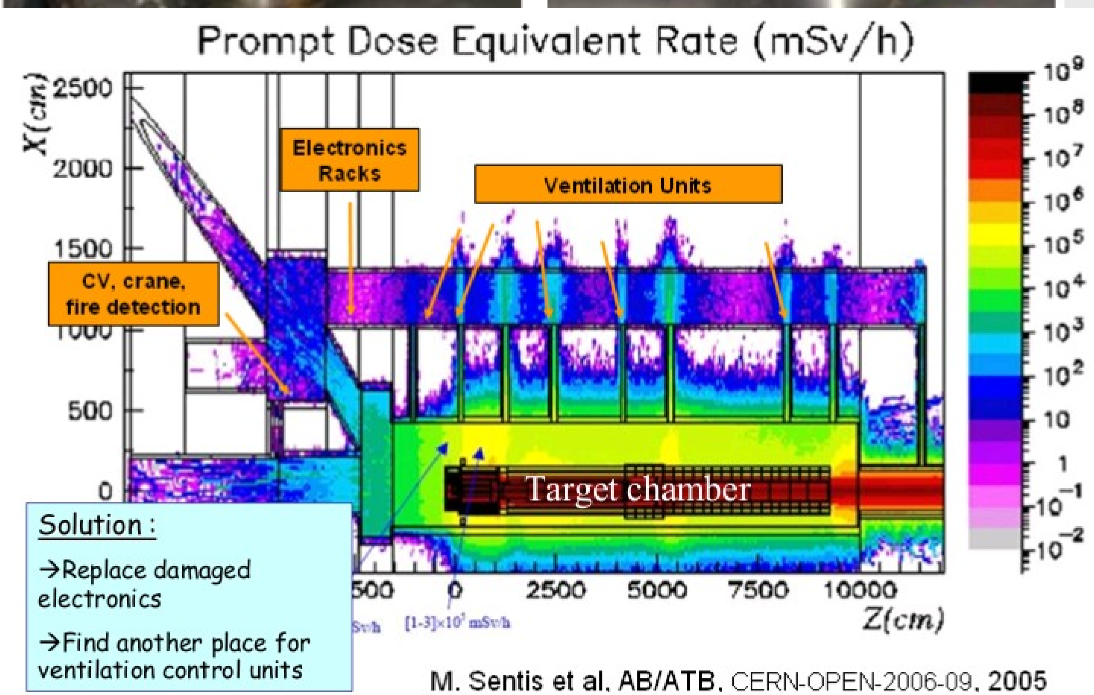


Water leak in horn cooling system (2006)

Broken stripline (2007)





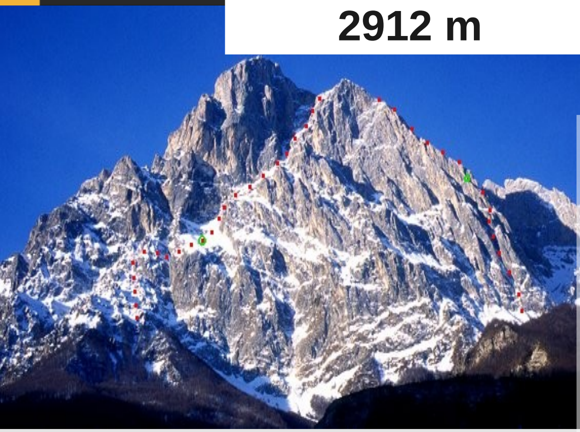


These doses were computed by the Fluka group and known since many years !!
They were not just taken into account when the ventilation was installed
Radiation protection measurements confirm the calculations

Electronics fault due to excessive irradiation (2007). Improved design now implemented.

Finally at LNGS !

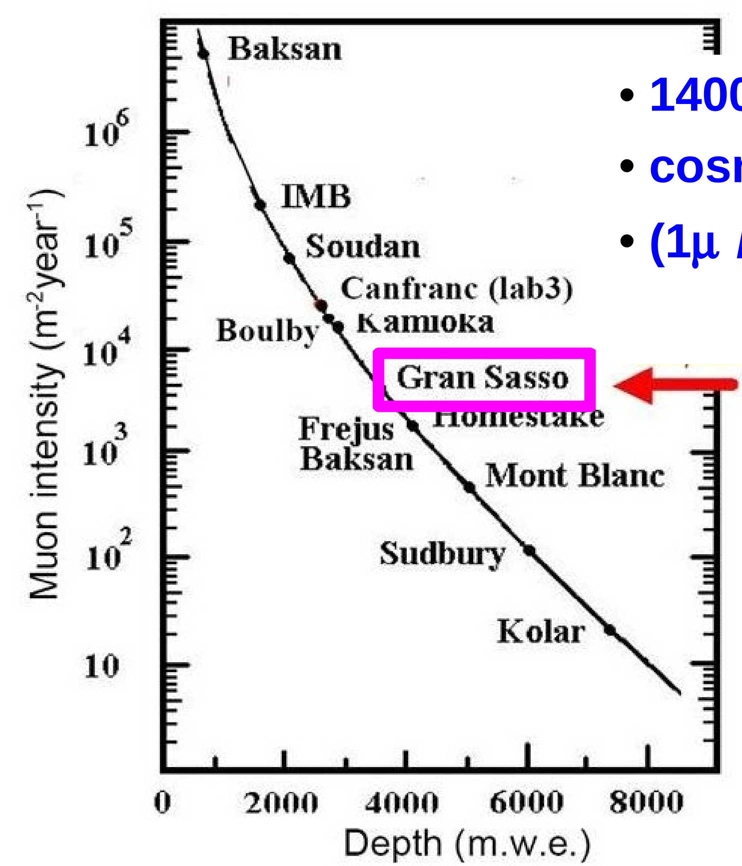
Laboratori Nazionali del Gran Sasso (the largest underground lab)



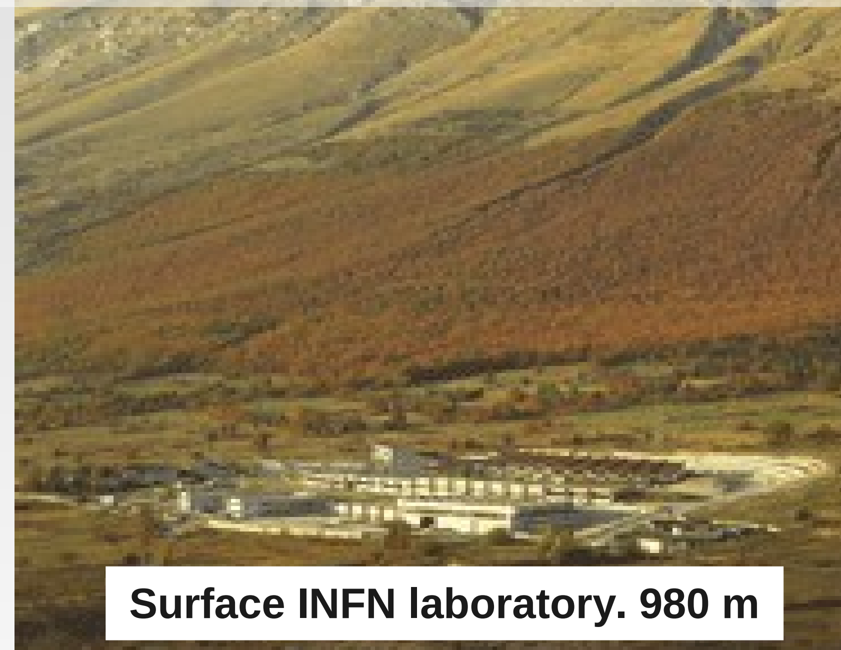
- ν phys. (ββ0ν solar-ν, atm.-ν, LB ν-osc.)

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

- DM - CRESST, DAMA, LIBRA, HDMS, GENIUS-TF, XENON, WARP
- Particle & nuclear astrophysics - EASTOP, LVD, LUNA, VIP
- Gravitational waves - LISA / Geophys., seismology - ERMES, UNDERSEIS, TELLUS, GIGS. Biology - ZOO, CRYO-STEM



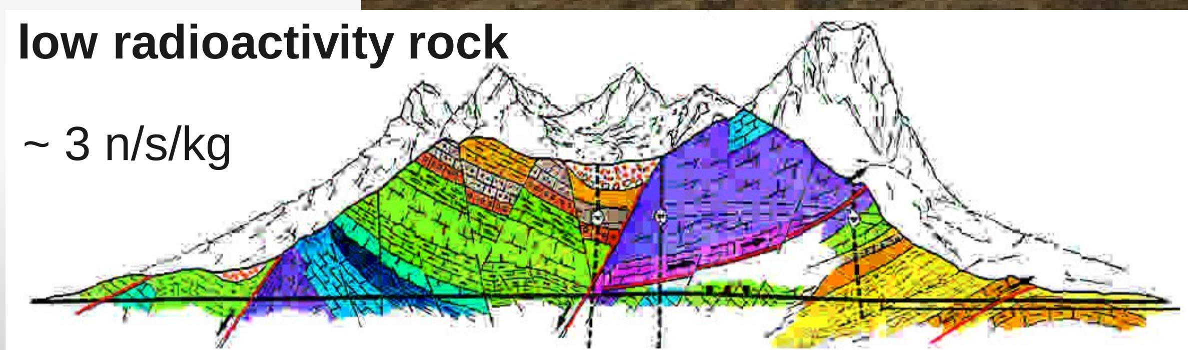
- 1400 m rock overburden
- cosmic μ reduction ~ 10^6
- (1μ /m^2/h)



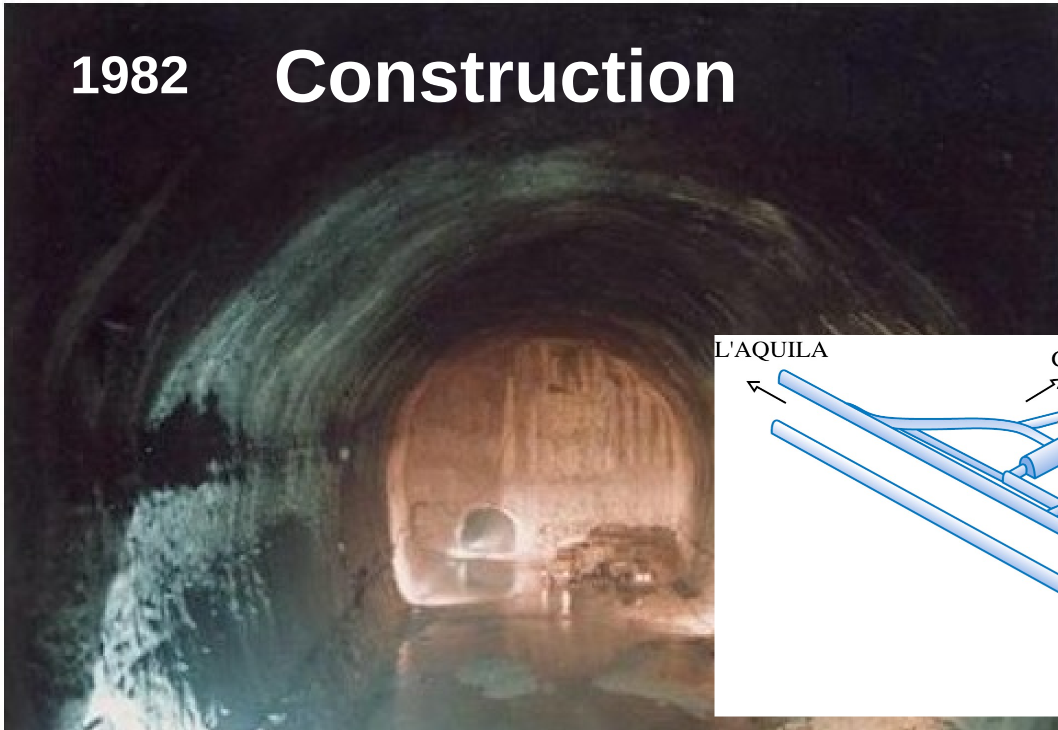
Surface INFN laboratory. 980 m

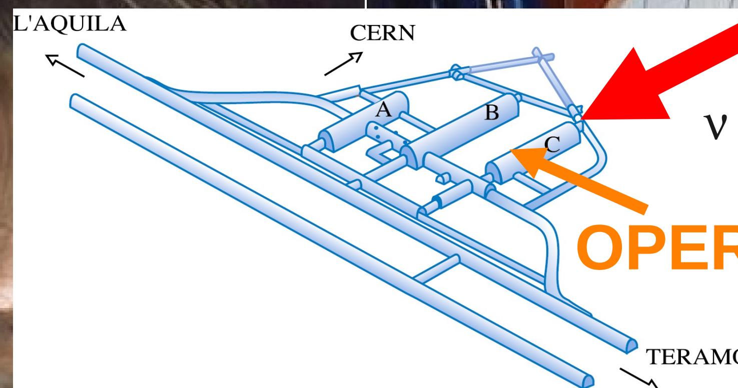
low radioactivity rock

~ 3 n/s/kg



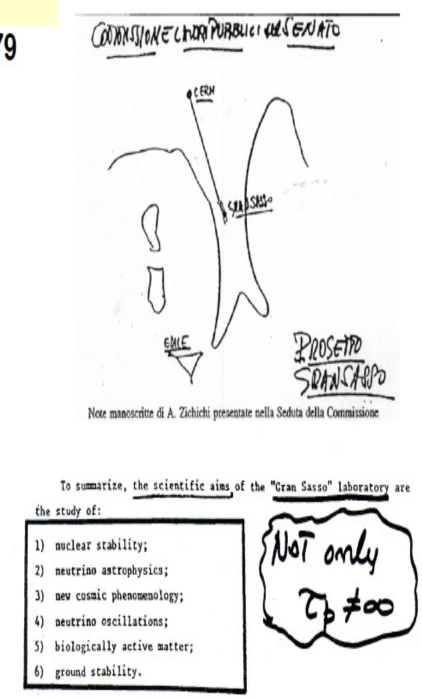
1982 Construction





- ~ 750 scientists from 25 countries

1979

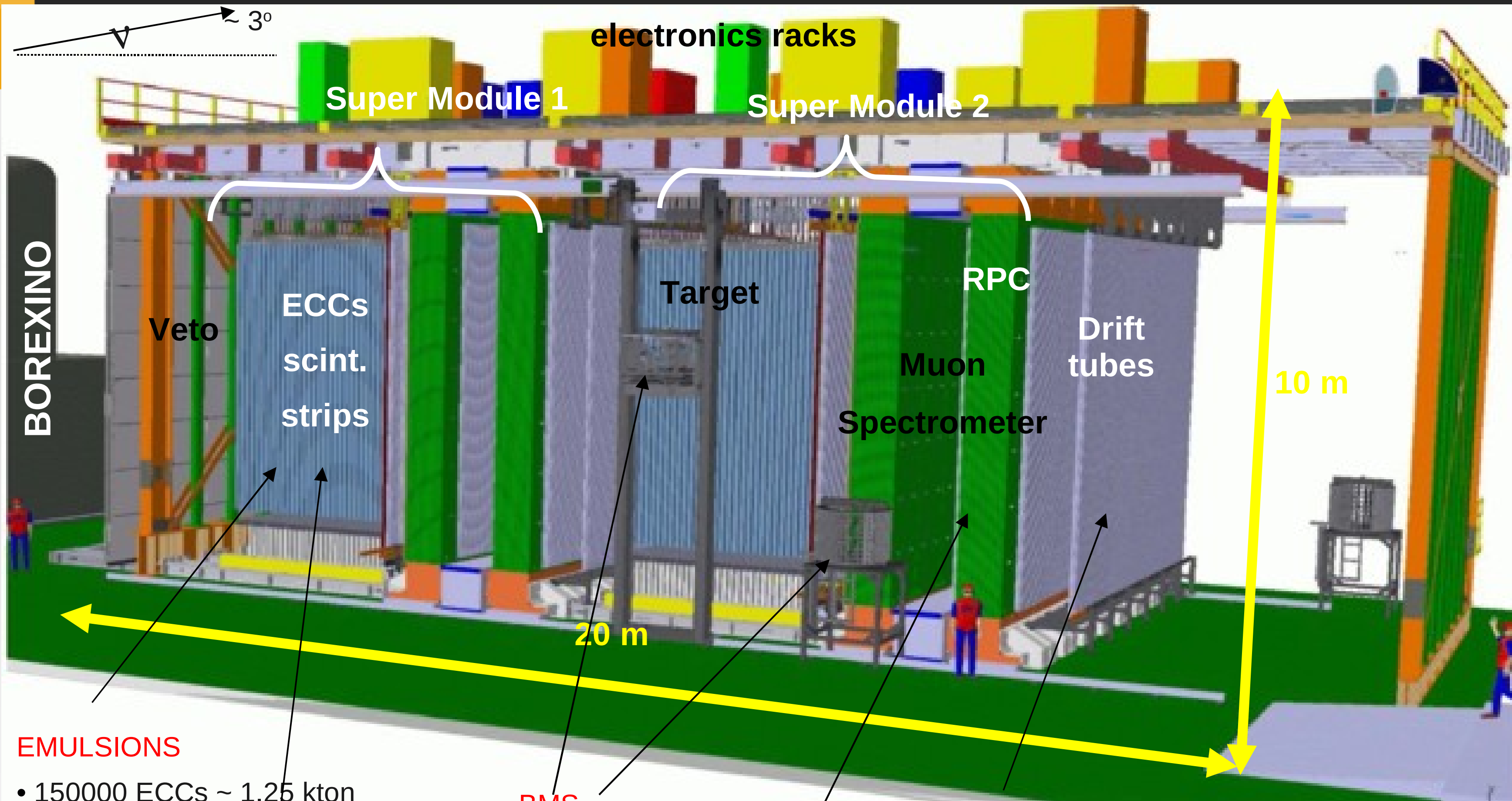


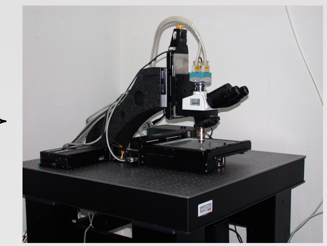
Note manoscritte di A. Zichichi presentate nella Seduta della Commissione

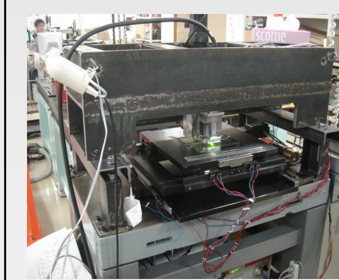
- 3 big experimental halls
- ~ 100 X 20 X 20 m
- ~ 18 000 m^2 underground
- easy access (motorway)
- aligned to CERN to ~1^o level !

The detector

a quite large fine grained "vertex detector" !







EMULSIONS

- 150000 ECCs ~ 1.25 kton

BMS

Brick Manipulator system

HIGH PRECISION TRACKERS

6 drift-tube layers/spectrometer
spatial resolution < 0.3 mm

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.

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)

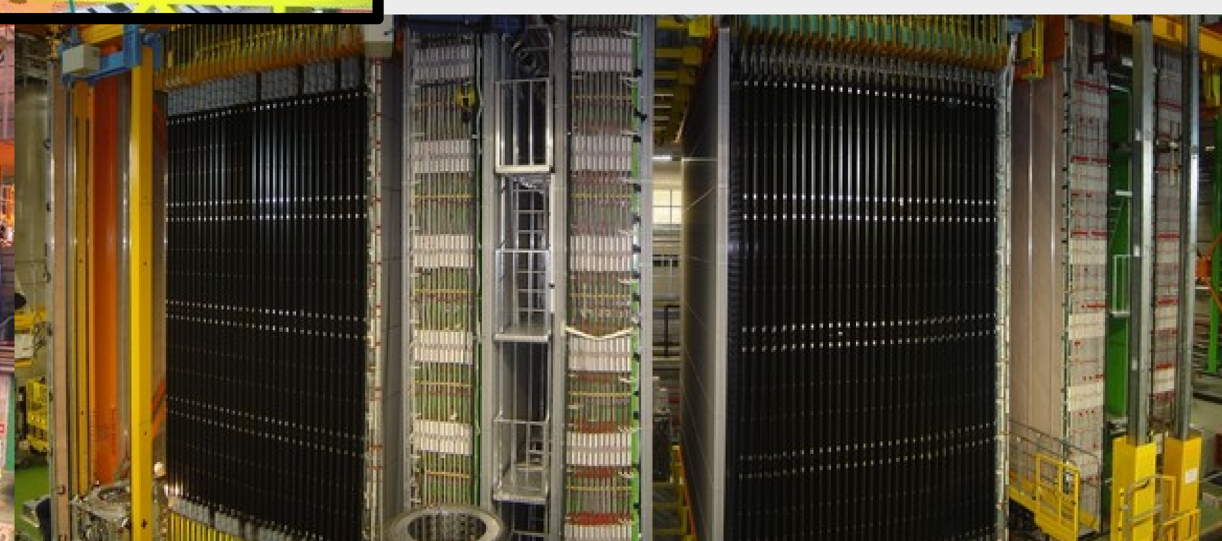
+ several essential ancillary facilities:

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

September 2003

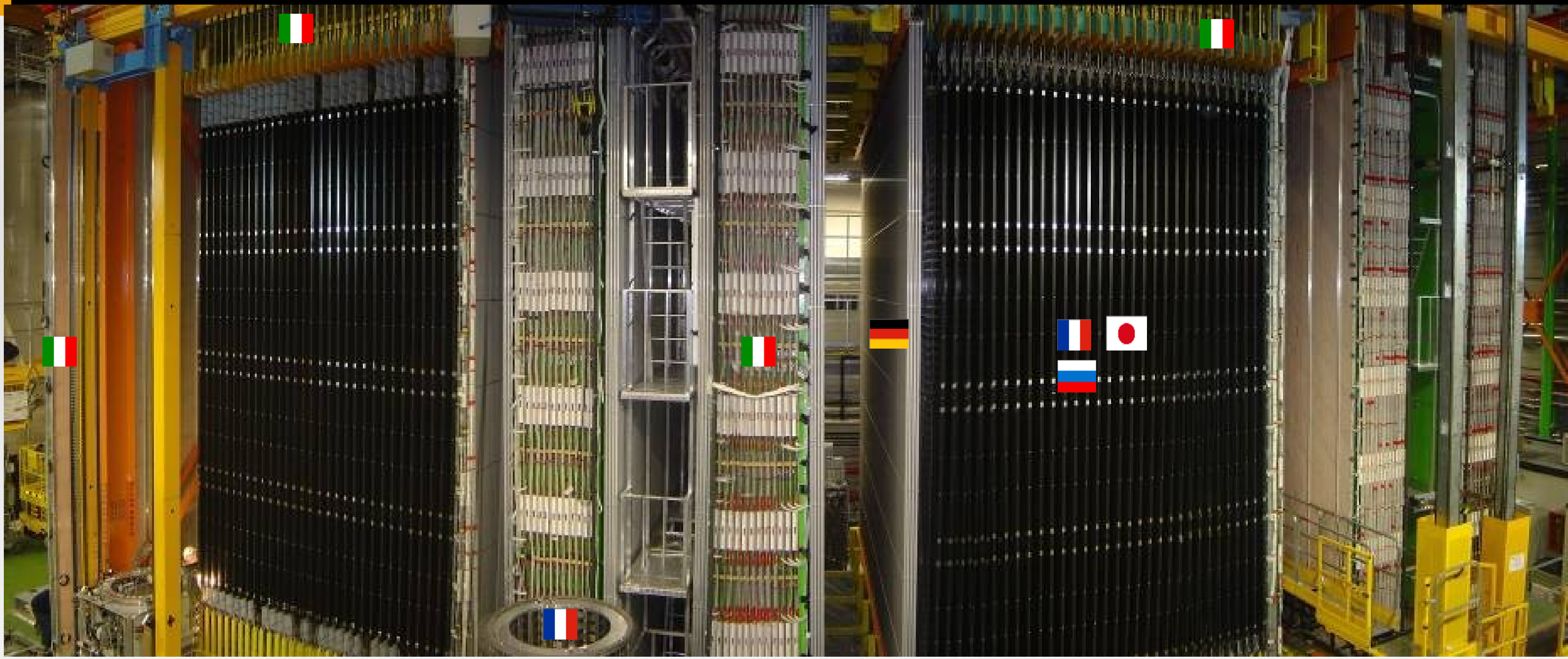
... 2004

... 2005



Installation completed with VETO and HPT before first half of 2007

The OPERA detector fish-eye



Electronic detectors fully instrumented and tested since 2007

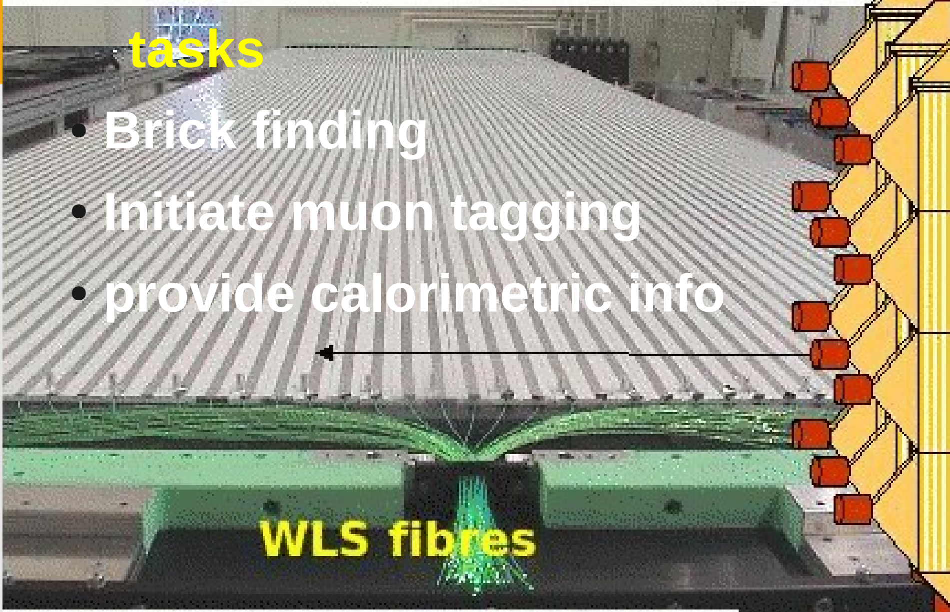
French contributions:

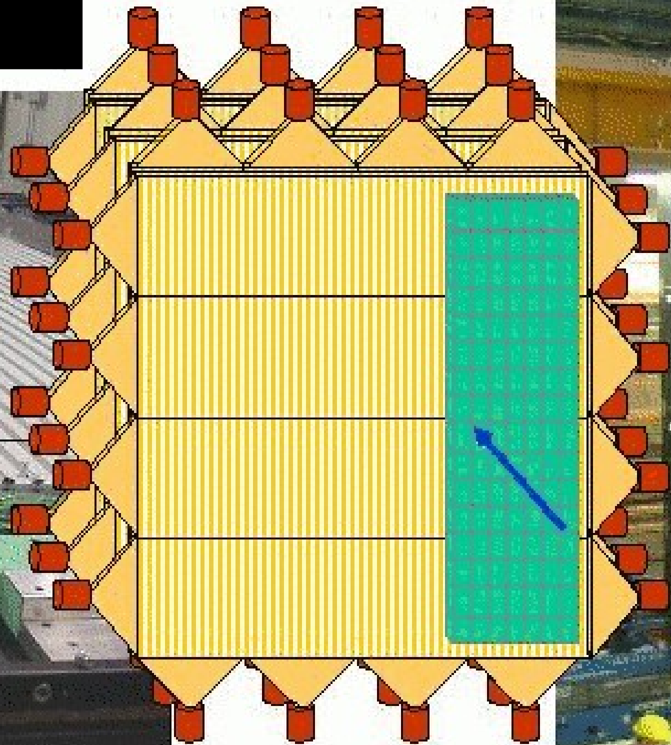
- Target Tracker (IrES Strasbourg)
- Brick manipulator system (LAPP Annecy),
- DAQ (IPNL Lyon + scanning)

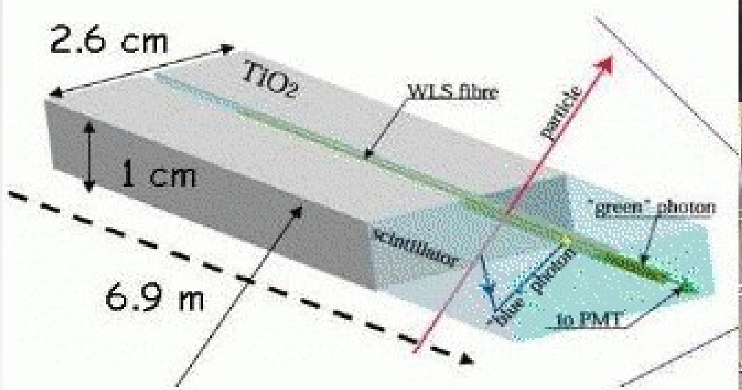
Target tracker

tasks

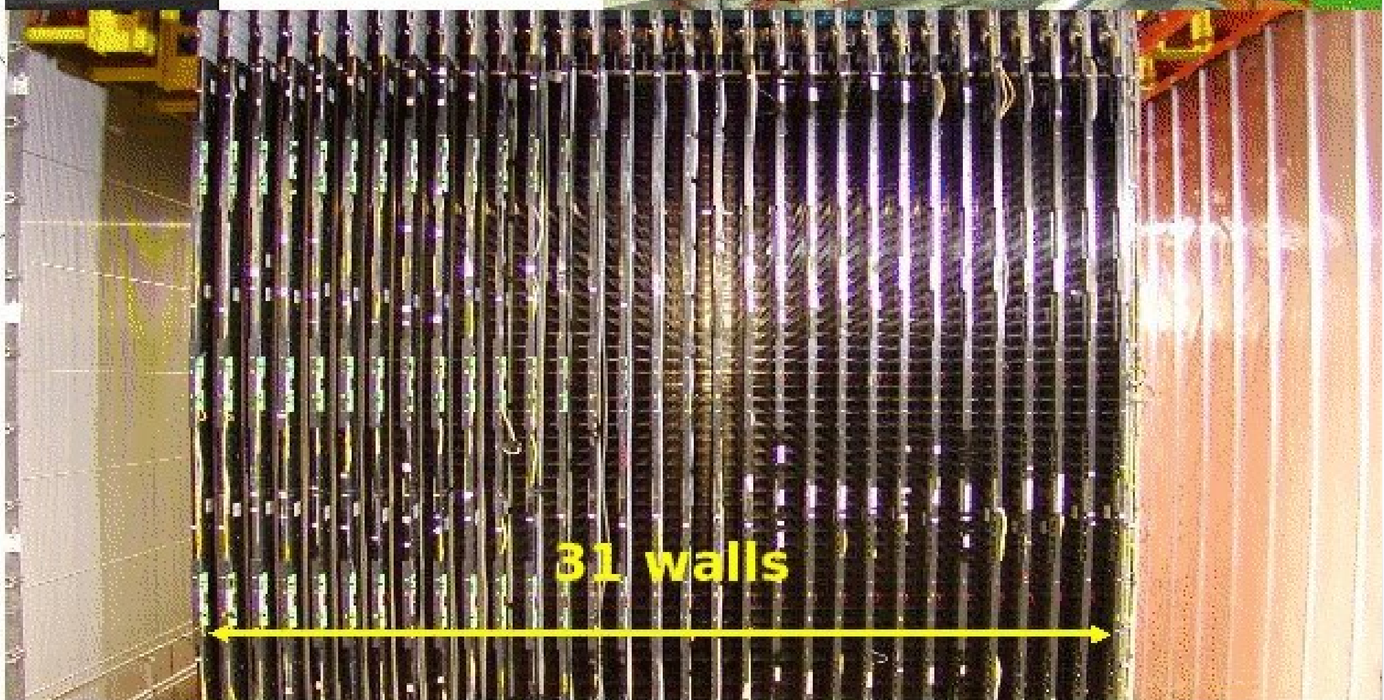
- Brick finding
- Initiate muon tagging
- provide calorimetric info







- 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 %



Lead production

- Pb + 0.07% Ca with packaging in air
  - ✓ good mechanical properties
    - 10 μ m planarity and 100 μ m at edge
  - ✓ low radioactivity
- produced in Germany (JL Goslar GmbH)
- sent by trucks (~ 100 shipments)

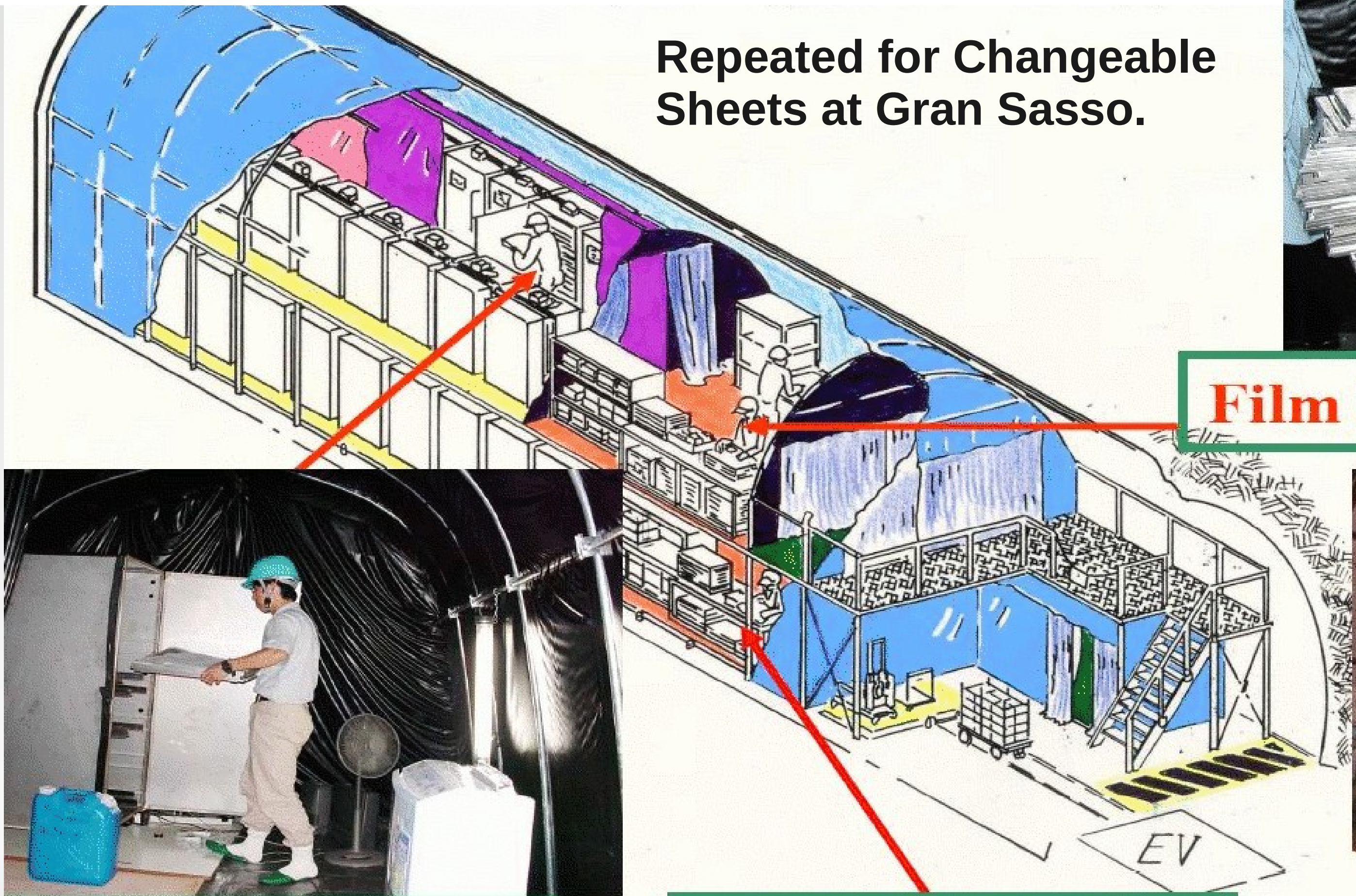
The refreshing at Tono mine (a huge work!)

Production ~ 1 month ~ 3k tracks/cm^2 (cosmic) >> max density = 100 tracks/cm^2 for brick analysis =>
REFRESHING (stimulated fading of latent image, ”erasing” of previous history)
3days @ 98% RH and 27°C: grain density of tracks: 36 → <10 grains/100µm with unvaried sensitivity (34 grains/100µm)

Depth of 50 m and 100 m: cosmic flux ~ 1/50 and 1/400
- ~ 10M emulsions treated by hand
- ~ 3k tracks/cm^2 → ~100 tracks/cm^2
- fog increase 3 → 6 grains/1000 µm^3

R&D @ Nagoya & Fujifilm

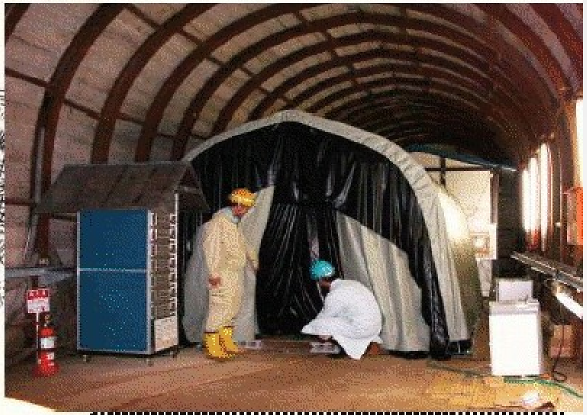
Repeated for Changeable Sheets at Gran Sasso.



Film lay out on the plate

Film installation

Vacuum packing



Room Size
4.5m × 4.5m × 20m

Emulsion delivery (2005)

• Shipment to Gran Sasso by sea in ~ 1 month (kept at 15 C and vertical: less cosmics, especially electrons w.r.t. Aircraft): ~ 1000 /cm^2

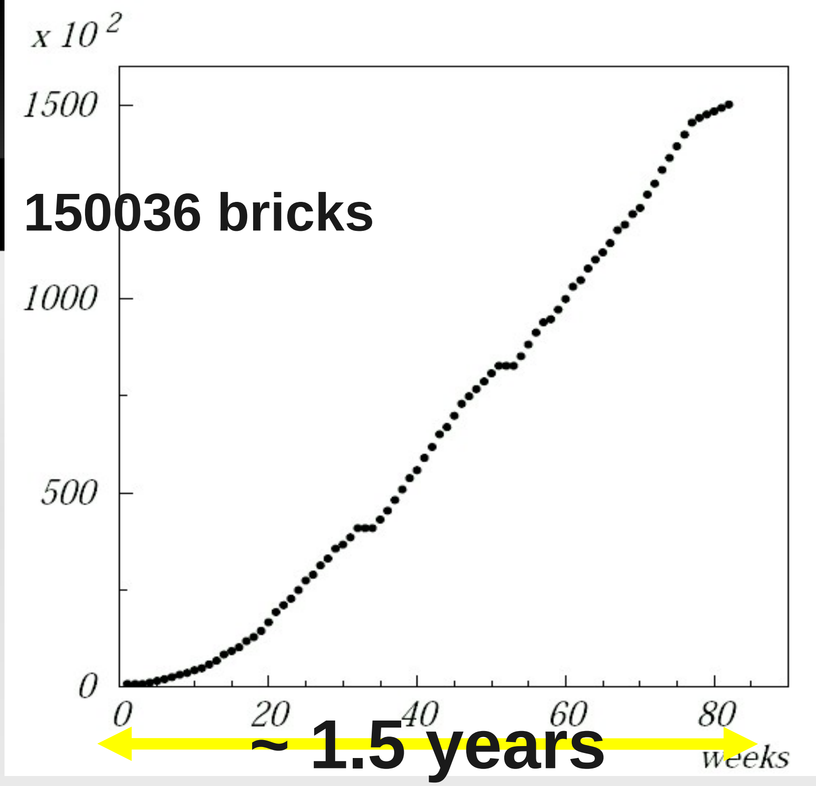
• Special underground storage at Gran Sasso (Hall B). 5 cm Fe shielding @ 15-18 C (1 μ/m^2/h)

• 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. Very powerful technique:

• 43±4 (Tono) → 113±20 tracks/cm^2 with virtual erasing and 1000±50 /cm^2 without !

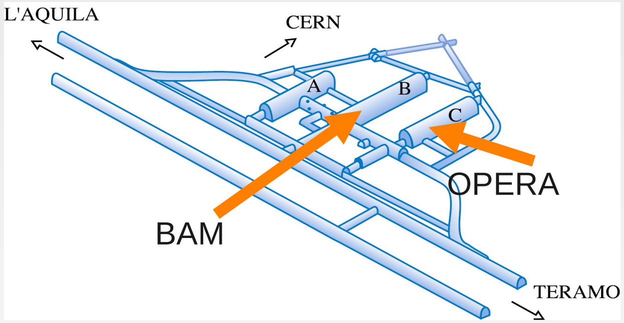
The BAM (brick assembly machine)

5 robotised parallelpiling stations.
Operation Underground in dark room (Hall B).



Anthropomorphic robot for brick wrapping

Automatic stacking and packaging
150K bricks ~> 9M emulsions & lead plates



- 07/2006 @ LNGS
- 09/2006 operational
- 02/2007 commissioning completed
- 03/2007 <- production-> 06/2008: production

On average ~650 bricks/day 2 (8h long) shifts/day * 5 days/week
(7 operators+1 site manager)

01/2009 production resumed (1 shift/day) in Jan 2009 after JL Goslar accident in 06/2008
(+3415 bricks)

The BMS (brick manipulator system)

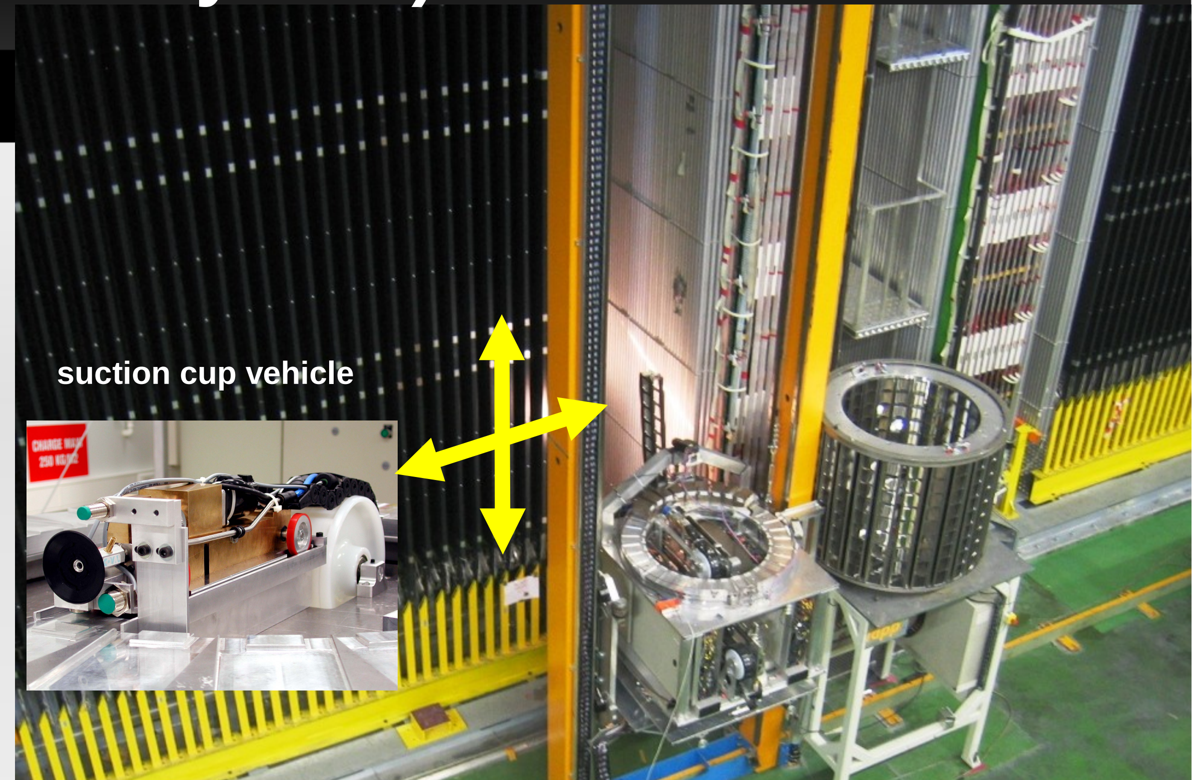
- Automated **detector filling**
- **Routine extractions** of bricks containing ν interactions
- “**holes-filling**” to keep the detector compact (no refilling of extracted bricks foreseen ~ -10%/5y)

Replicated on both detector sides

0.1 mm accuracy in positioning over ~ 8 m
platform weight: 1.3 tons

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

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

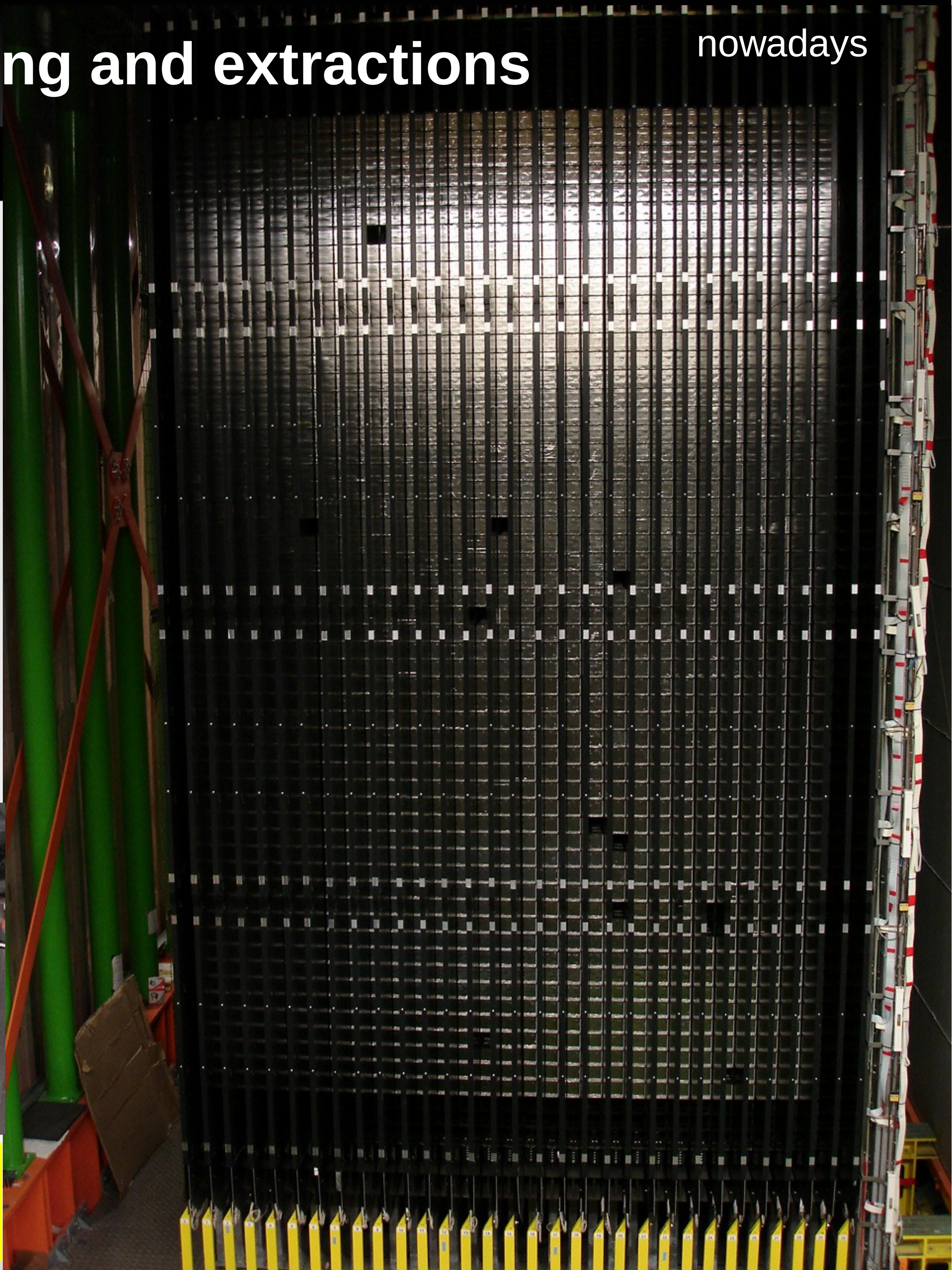


arm equipped with camera + pattern recognition sw to “center” the brick corridors

loaded “drum”: 256 bricks filled automatically by the BAM

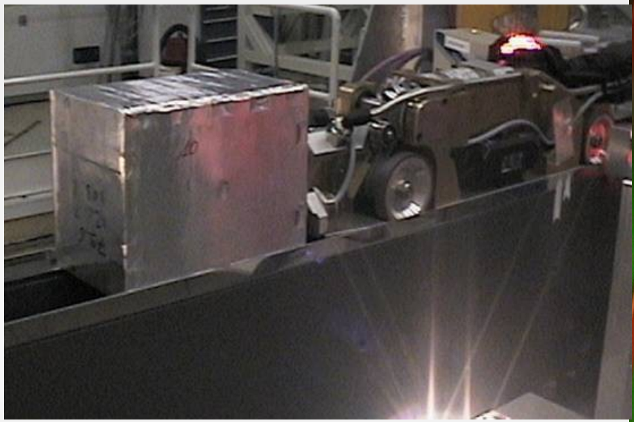
Brick filling and extractions

LAPP Annecy



Accomplished smoothly in parallel to brick production in ~ 1.5 y

Routine extractions in 2008 run:



Up to 25 bricks per shift (8h). OK!

The muon spectrometer

(one per supermodule)

Charm background rejection

Muon identification (Spectrometer+TT) > 95%

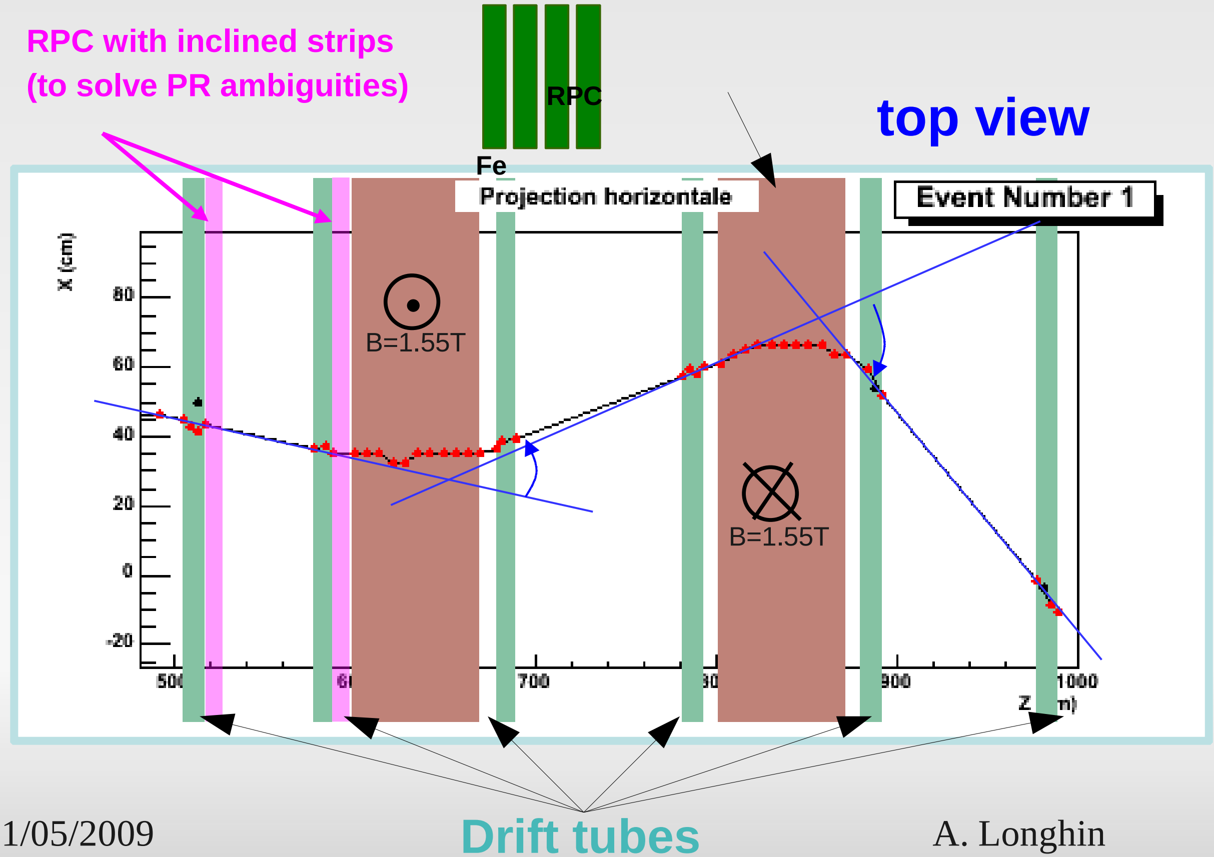
Δ p / p < 20% for p<30 GeV

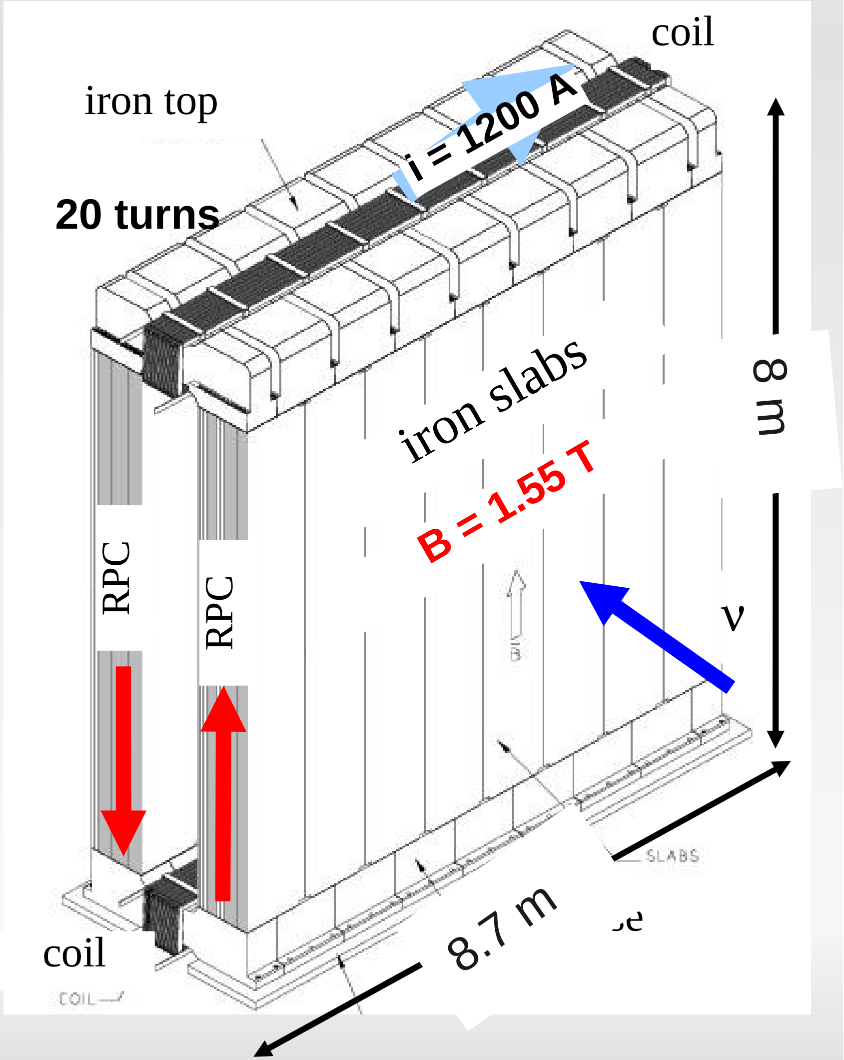
Charge misidentification < 0.3%

- **Inner trackers** iron yoke gaps instrumented with **RPCs**
  horizontal and vertical strips with digital readout σ ~ cm
  - **Tracking and p from range for stopping mu**
- **Precision trackers** 6 vertical **drift tubes** stations. σ ~ 0.3 mm
  - **Precise charge mis-ID / p measurement**

- **Bipolar magnet (B=1.55 T)**

- **24** iron slabs, **5 cm** thick + **2 cm** gap





Muon spectrometer close-up

38 mm diam. 8 m long tubes.
(never so long before!)

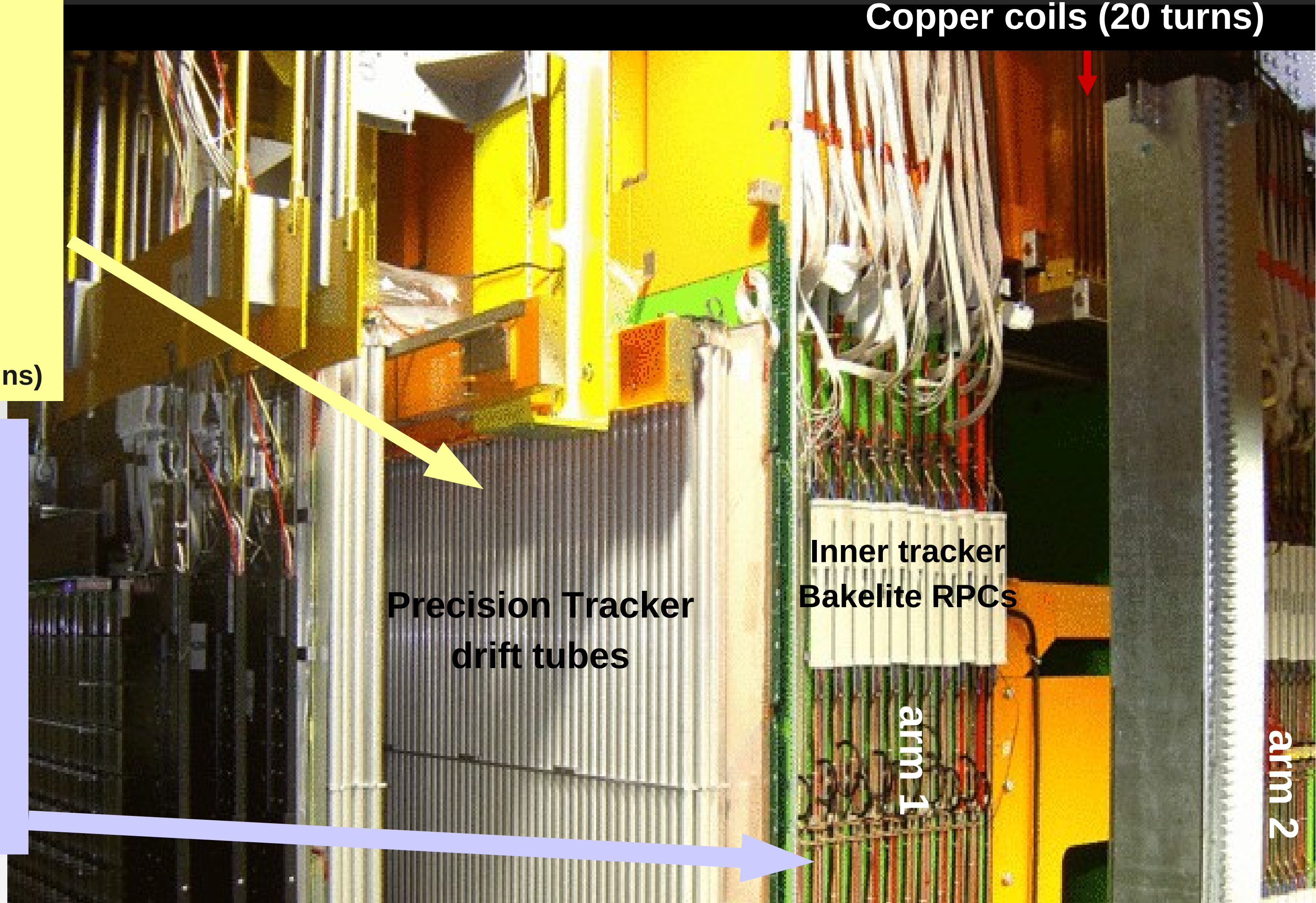
10.000 drift tubes
4 layers modules (staggered)

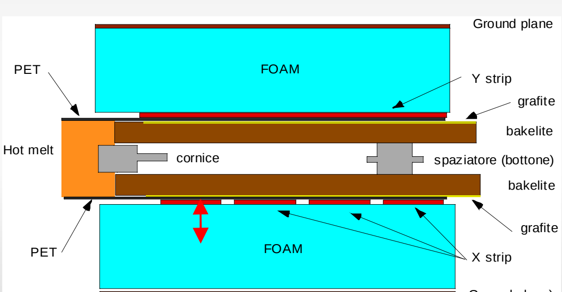
Ar/CO_2: 80/20% @ 1005±5 mbar
(80 m^3 exchange 1m^3/h)

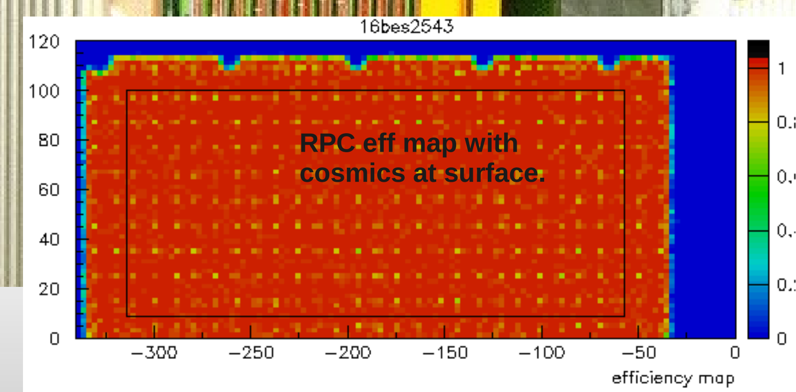
0.85 mm thick. 45 μm wire.

RPC-triggered, 3.2 μs TDCs (LSB 1.5 ns)

- Bakelite RPC (streamer mode)
- 462 RPC + 42 (XPC) x 2 ~ 1000
- 3326 m^2 (2.9 x 1.1 m^2 each)
- digital channels: ~ 27000
- Strips pitch: 2.6, 3.5 cm (Vert, Hor)
- Front-End Boards: 468
- Controller Boards: 52
- 76%Ar+20%TFE+4%Iso+0.6%SF_6
- 8 kV / 2mm



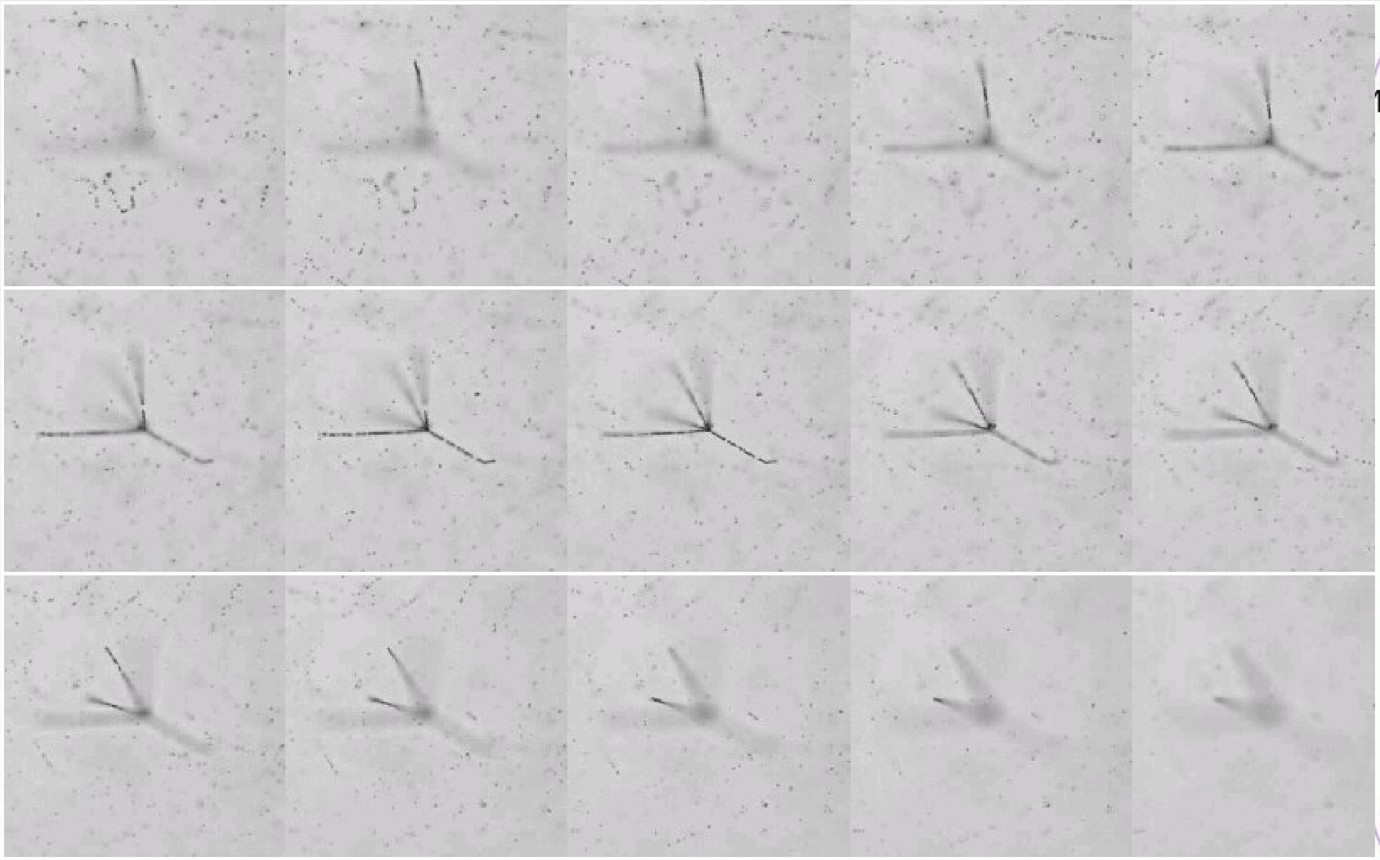


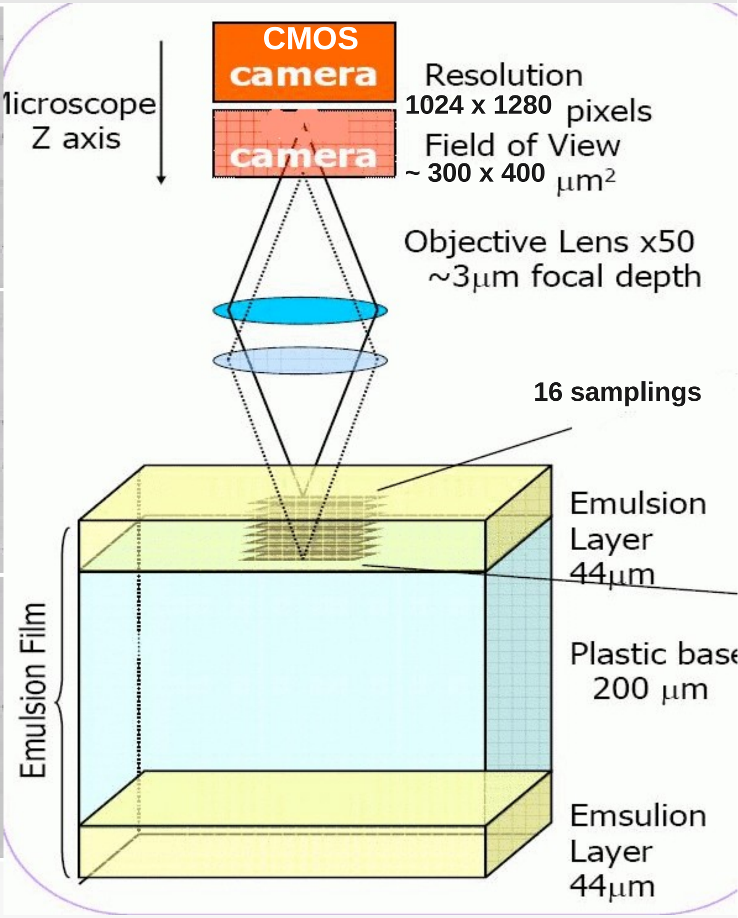


Scanning principle

tomographic image sequence

Emulsion cuts at different "z"





From the cascade alpha decays of heavy elements in natural deacy chains (i.e. U and Th) present in emulsions

The shown zone is only a small fraction of the microscope view (~ 300x400 μm)

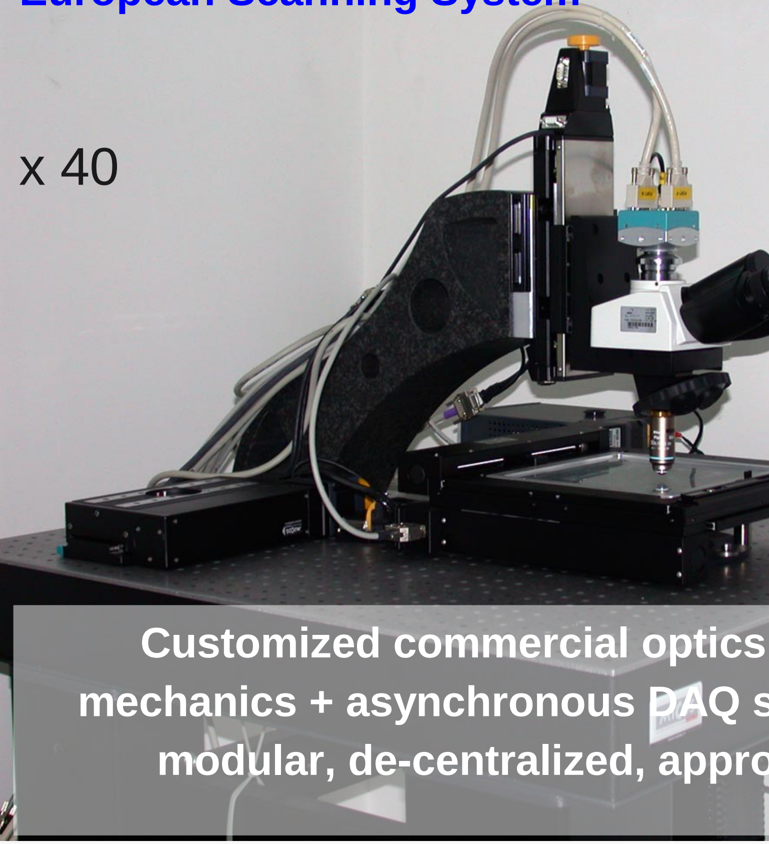
Emulsion scanning: 'offline' ... data taking !

~ 24 bricks will be daily extracted and analysed using high-speed automatic systems
~ 40 microscopes distributed in Europe and Japan

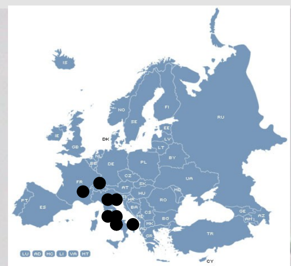
2 “schools”. Many useful cross checks are possible !
Common Data Base for data sharing/publication

European Scanning System

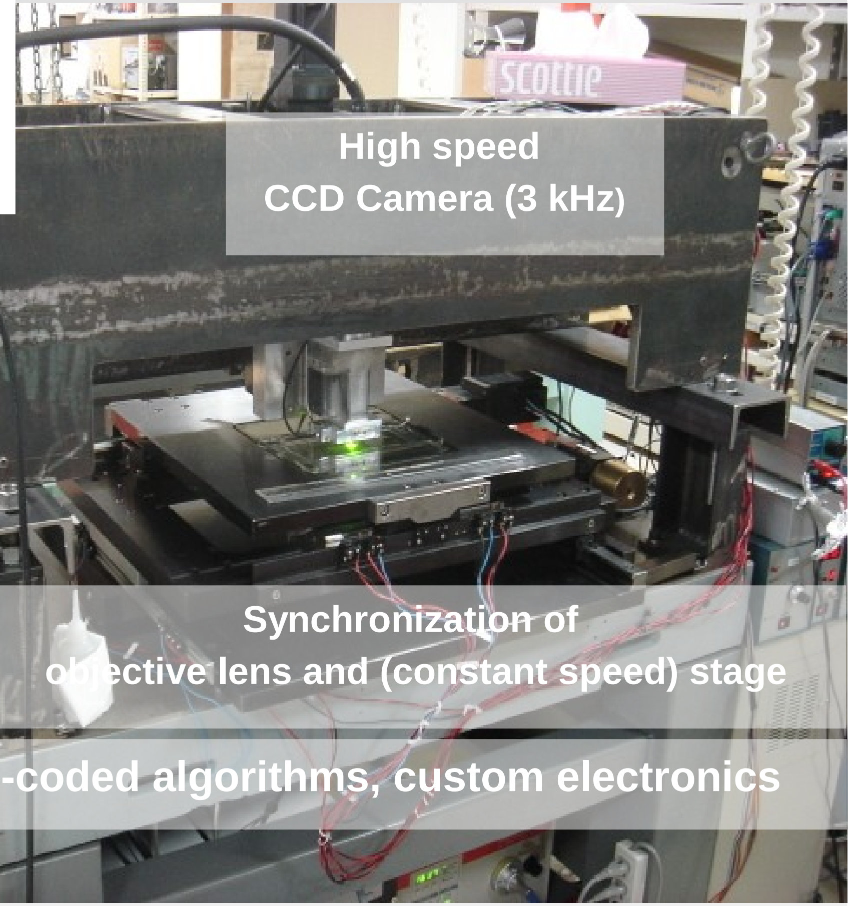
x 40



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



S-UTS (Japan)



High speed
CCD Camera (3 kHz)

Synchronization of objective lens and (constant speed) stage

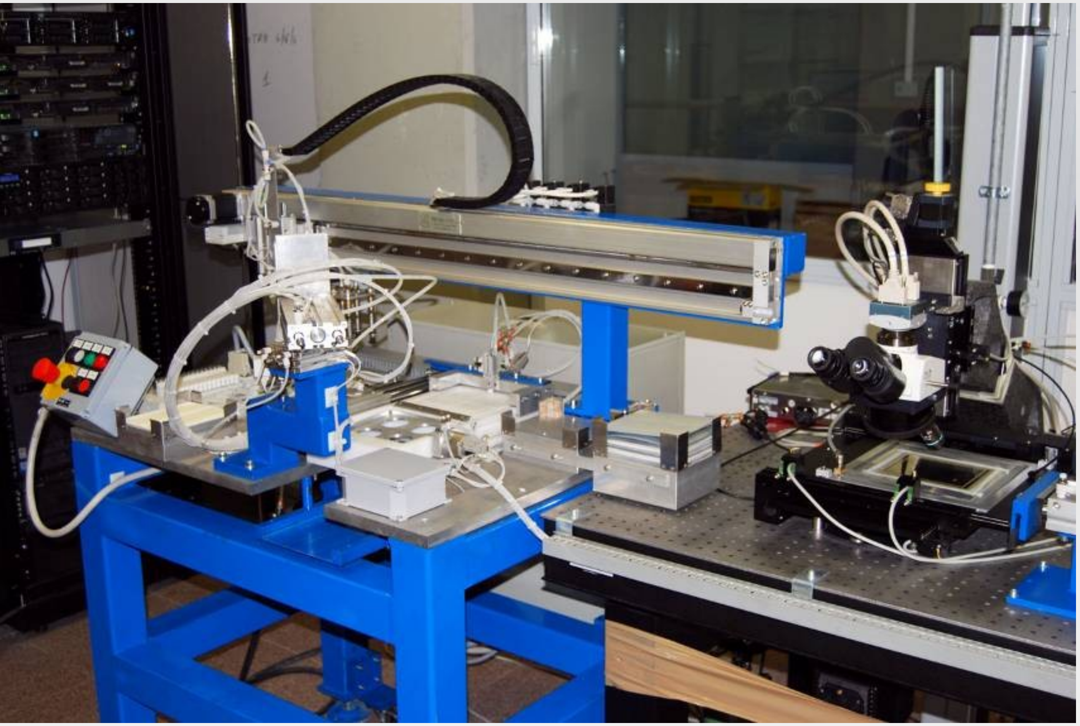
Hard-coded algorithms, custom electronics

scanning speed ~ 20 cm^2 / h

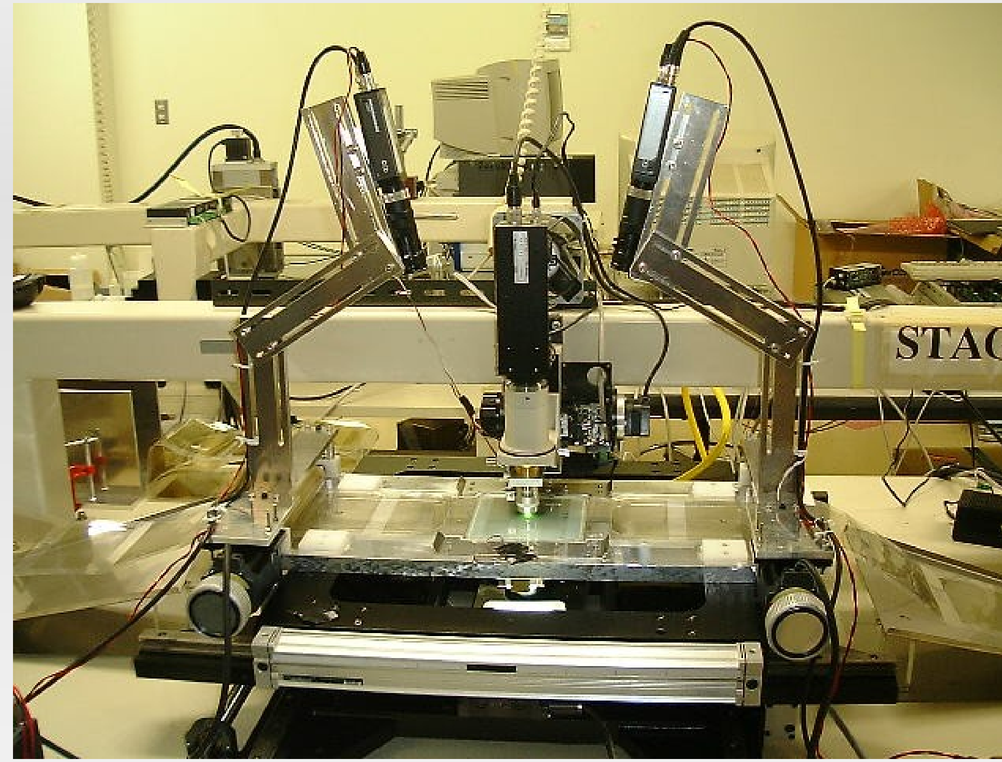
Up to ~ 50 cm^2 / h

Auxiliary systems to automate the scan-back procedure

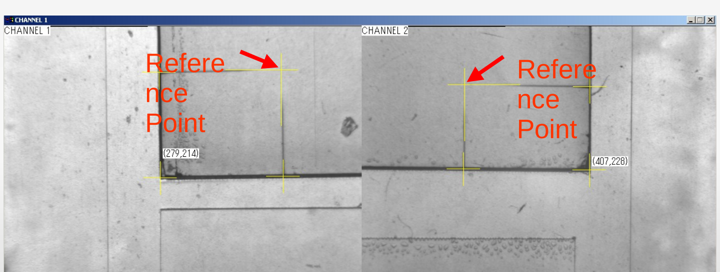
Europe: mechanical plate changer

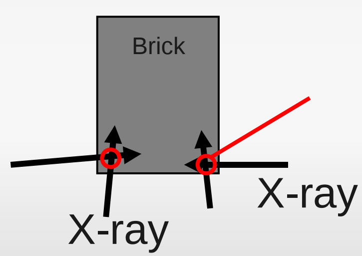


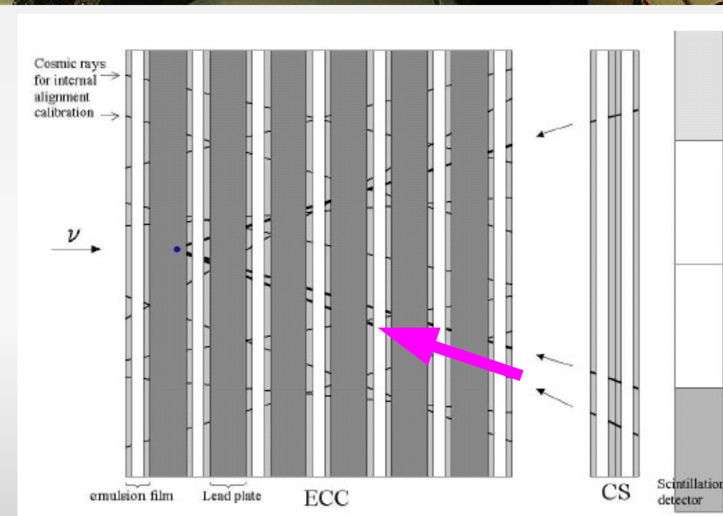
Japan- emulsion glued to a rolling strip



Allows to run the scan-back procedure without human intervention (i.e. overnight)

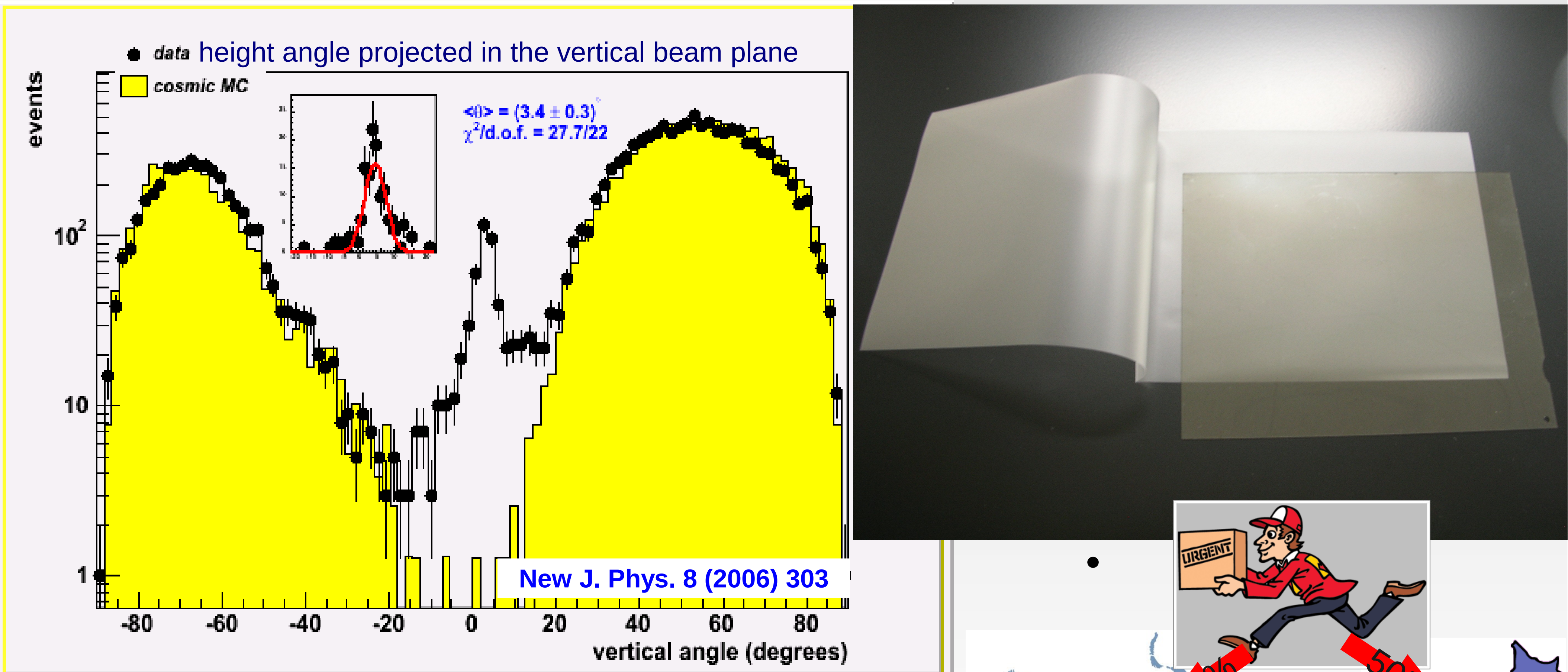






Running an hydrid experiment quasi-online !

Description of running ... and first achievements

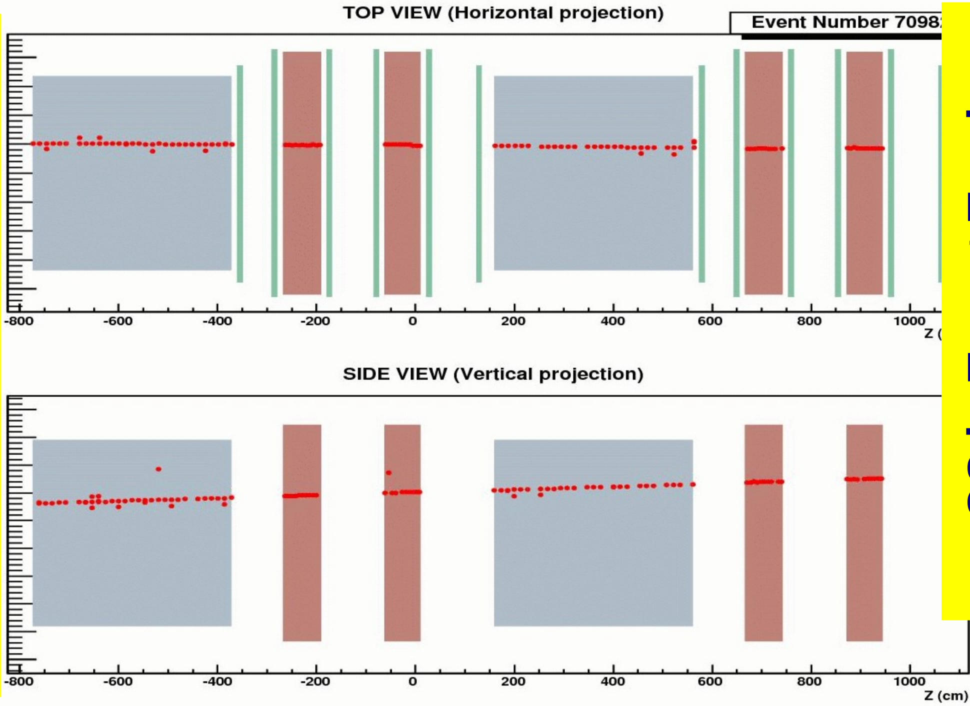


August 2006: **$<\theta>= (3.4 \pm 0.3)$ °** *(statistically dominated))*

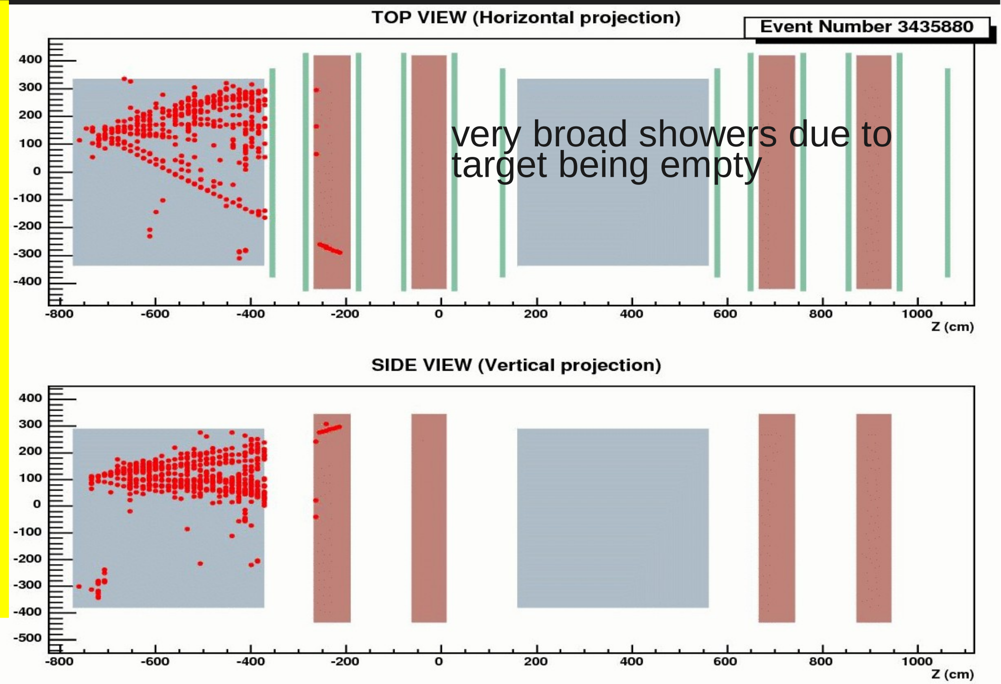
MC: simulation from MACRO parametrization, ABSOLUTE normalization

The 2006 run event gallery

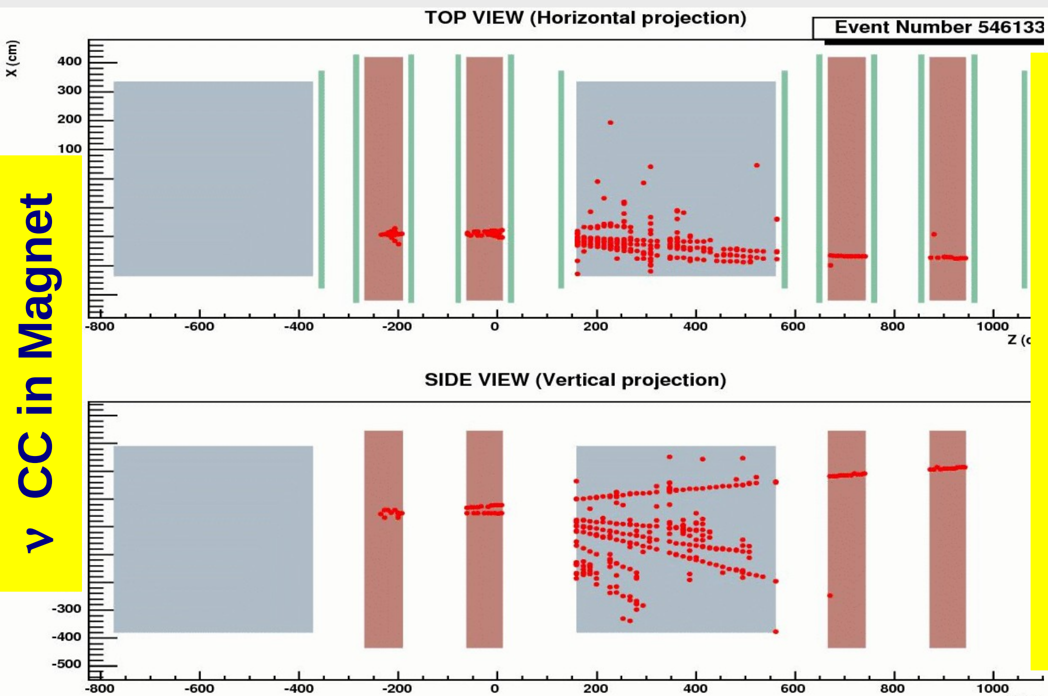
ν CC in rock (rock muon)



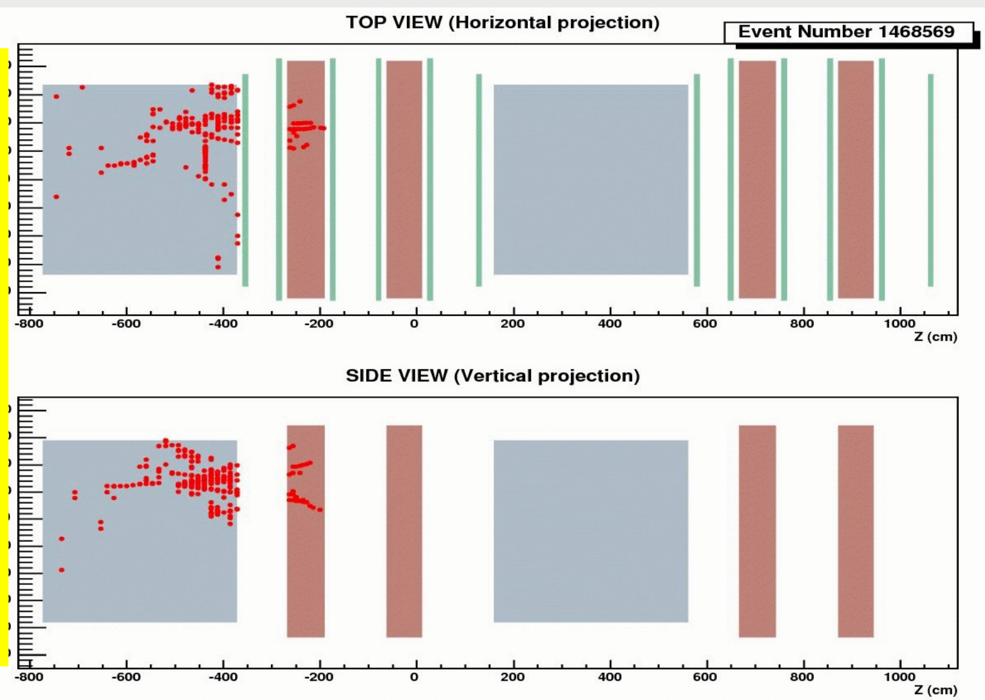
ν CC in Target Tracker



ν CC in Magnet



ν NC in Target Tracker



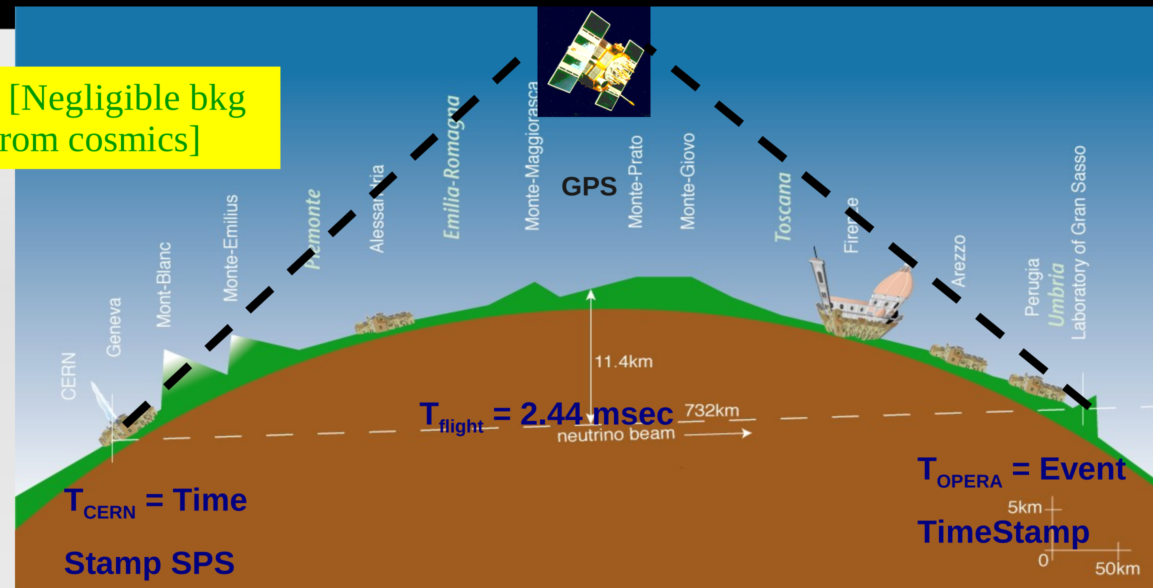
CNGS + OPERA run summary

Events in the electronic detectors are time-stamped and correlated through GPS with CNGS *beam*

OK [Negligible bkg from cosmics]

GPS Time Stamp resolution ~100ns

- 2006 Pilot run: after commissioning in Aug, no follow-up in October due to a problem in the cooling of one horn. Moreover, no bricks in OPERA.
- 2007: Major problems in the radiation shielding of the ventilation system. Only 8·10[17] pot. Significant interventions during winter shutdown.



T_{CERN} = Time Stamp SPS extraction

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

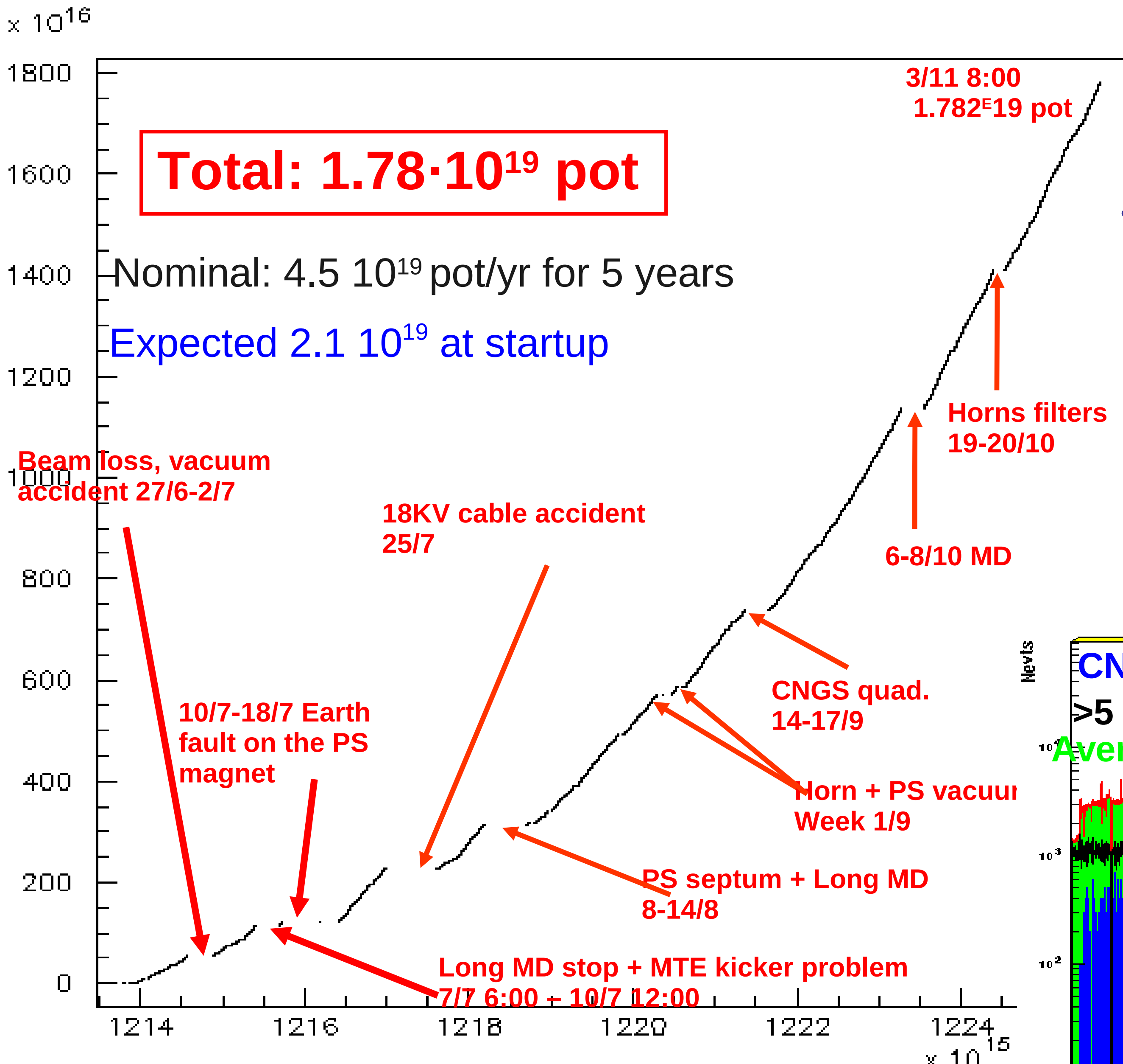
	Delivered pot	Target filling	On-time events	Target events
2006	$8.2 \cdot 10^{17}$	Empty	347	0
2007	$8.24 \cdot 10^{17}$	80% of first Target	393	38
2008	$1.78 \cdot 10^{19}$	Full	10058	1690

Mainly in surrounding material ("rock mu")

- 2008 OPERA fully operational. Some more details next →

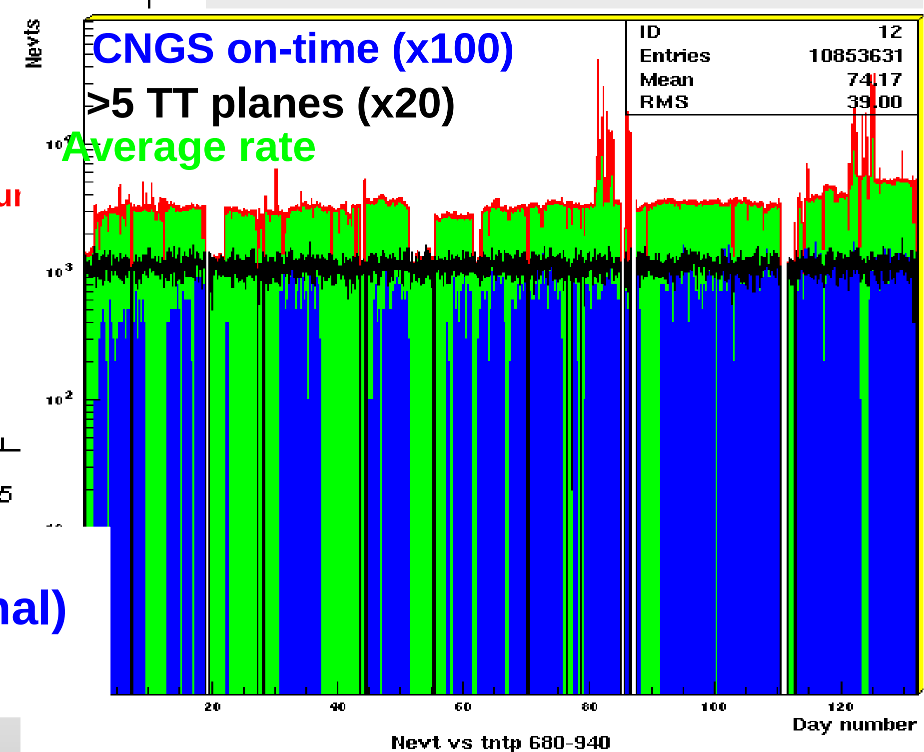
Perspectives for 2009 CNGS run: $4.5 \cdot 10^{19}$ pot requested ($3.5 \cdot 10^{19}$ scheduled)

2008 run: 18 June- 03 Nov 2008 (~137 days)



- Performance of the CERN injection complex **poor at beginning but steadily improving.**

  The electronic detectors and the DAQ ran smoothly (99.96% efficiency for the target tracker during operation, loss of 2×10^{17} pot due to power cuts in LNGS)



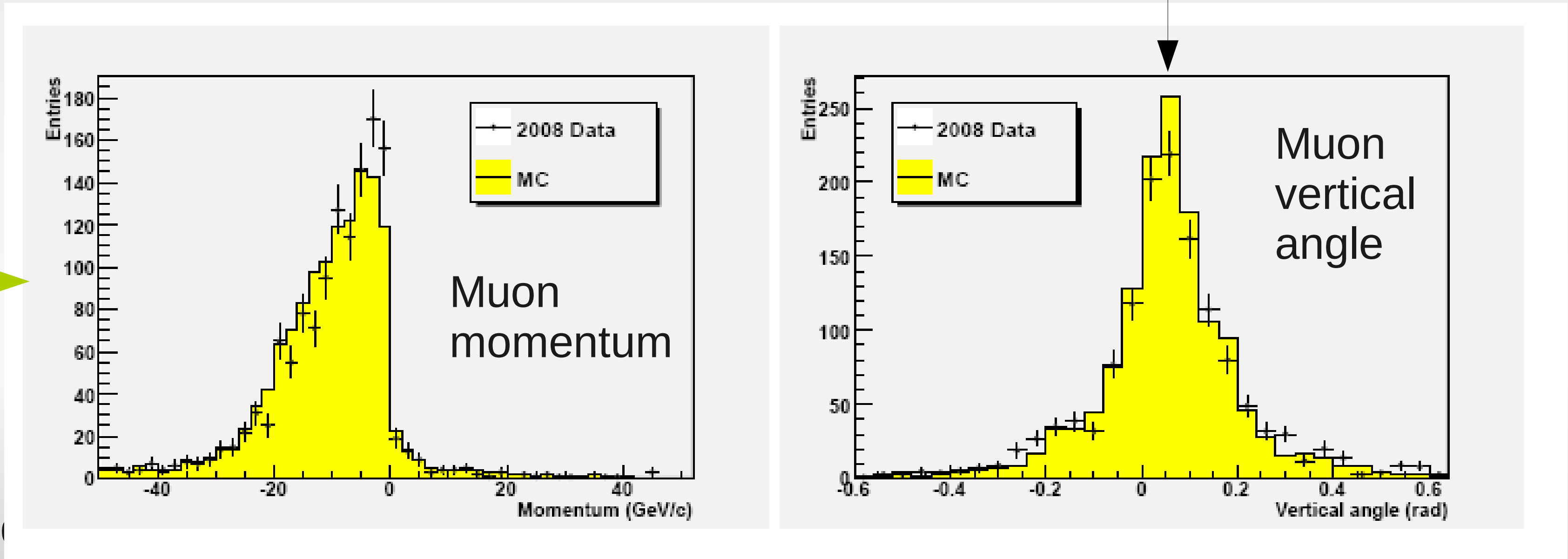
expected taus : 0.7

Peak intensity: 2.0 10^{13} pot/extraction (83% of nominal)

Average efficiency = 60% (nominal = 80%)

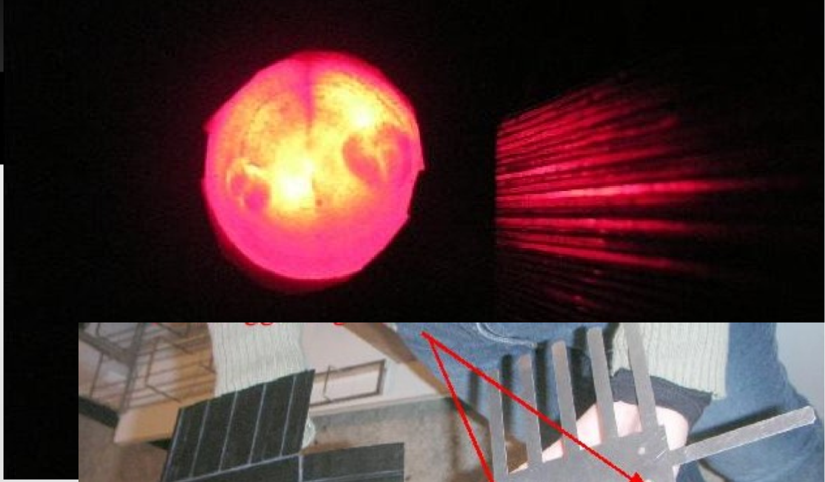
OPERA as a hybrid detector: the status

- Direction and momentum reconstruction for CNGS events — OK
- *q and p reconstruction for off-time events (cosmicray analysis)* — In progress
- Prediction of the brick where the interaction occurred ("brick finding") — In progress
- Alignment and development of the Changeable Sheets — Fully validated
- Scanning of the Changeable Sheets — Fully validated
- Extraction of the Bricks at the rate of CNGS events — Fully validated
- *Identification of the primary vertex* — In progress
- *Kinematic reconstruction and decay search* — In progress

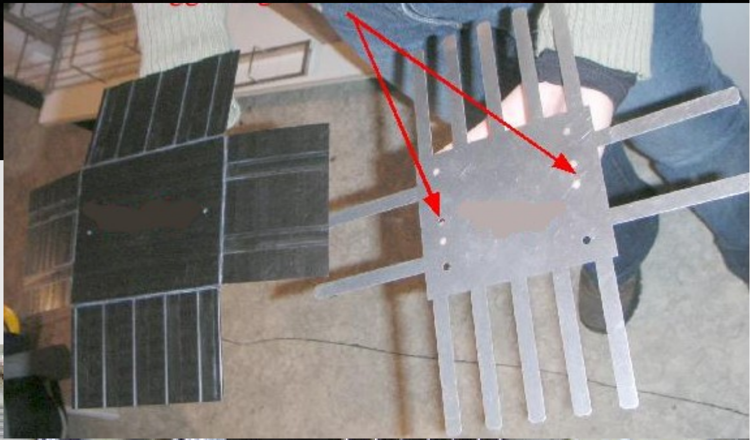


Brick operations at surface

Darkroom operations

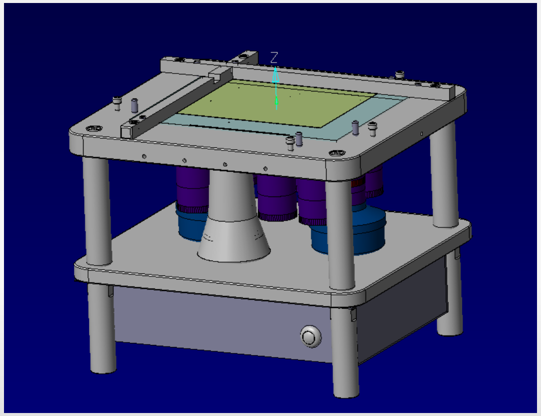


1) brick unpacking. → semi-automatic tools
2) occasional piling defects (e.g. double emulsion or lead layers, or damaged emulsions) recorded
3) film labelling by light exposure (binary code)
4) development of bricks with automatic chains

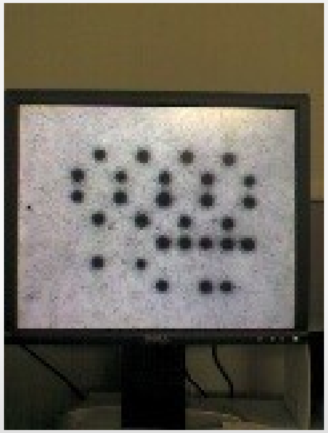


Commercial up-to-date technologies
Chemical solutions are prepared by an industrial-type plant
fully automated up to 3000 films/day (~53 bricks)

Gridding machine



Binary code



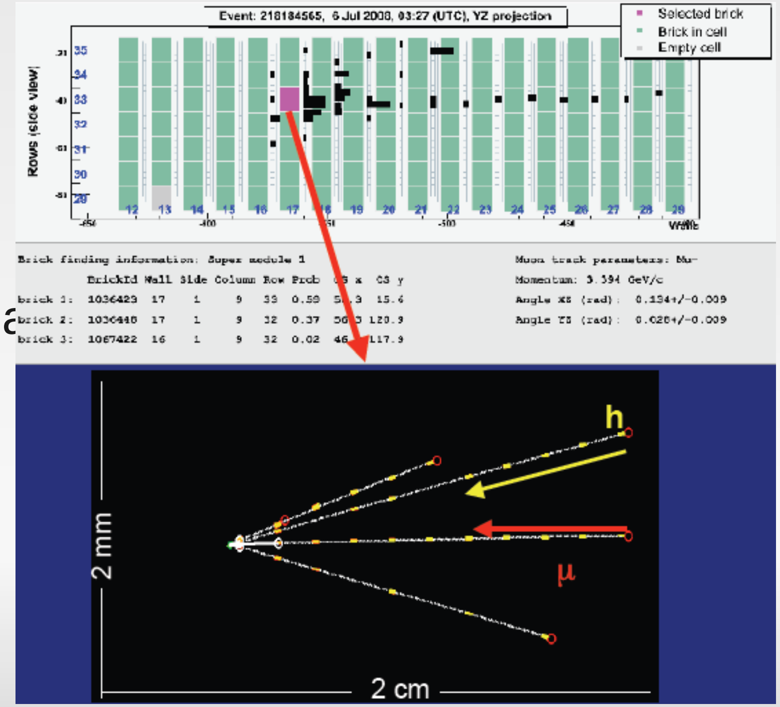
Brick finding

- Use data from the real-time detectors (scint hits, # p.e., identified tracks in the target and spectrometers) to build a probability map of the bricks where the interaction might have occurred
- The most probable brick is extracted and the corresponding Changable Sheet is detatched and scanned
- If tracks are found compatible with the expectations from the real time detectors -> the brick is developed
- Otherwise try again with the second most probable brick

brick finding efficiency after having disentangled the CS inefficiency and the interactions occurring in the dead materials

1st brick BF efficiency: 72.8% +/- 1.7% (MC expectation 72%)
2nd brick BF efficiency: 56.9 +/- 6.1%

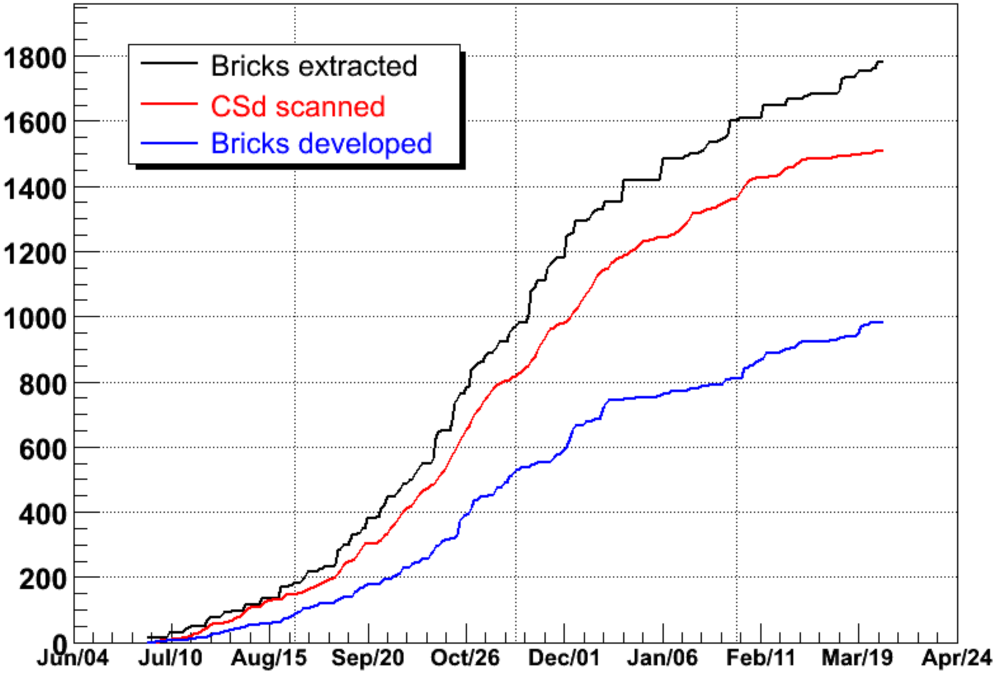
BF efficiency combined 1st+2nd brick: 88.3 +/- 5%
(MC expectation 80%)



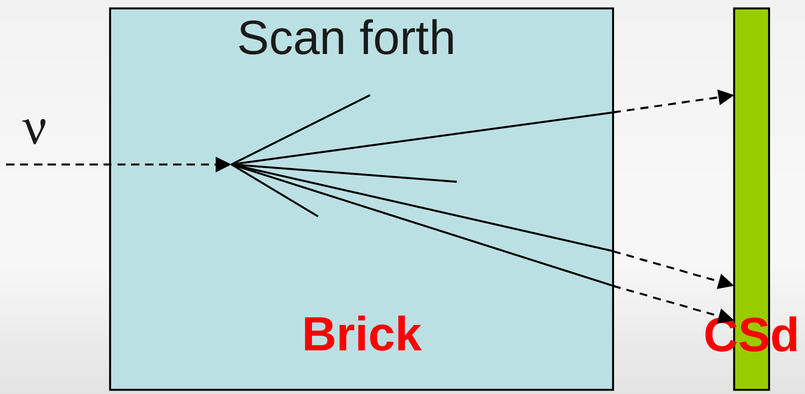
- Many ongoing studies on the first data (alternative algorithms, undestanding of backscattering)

Scanning of the Changeable Sheets

~ 100 CS/week managed

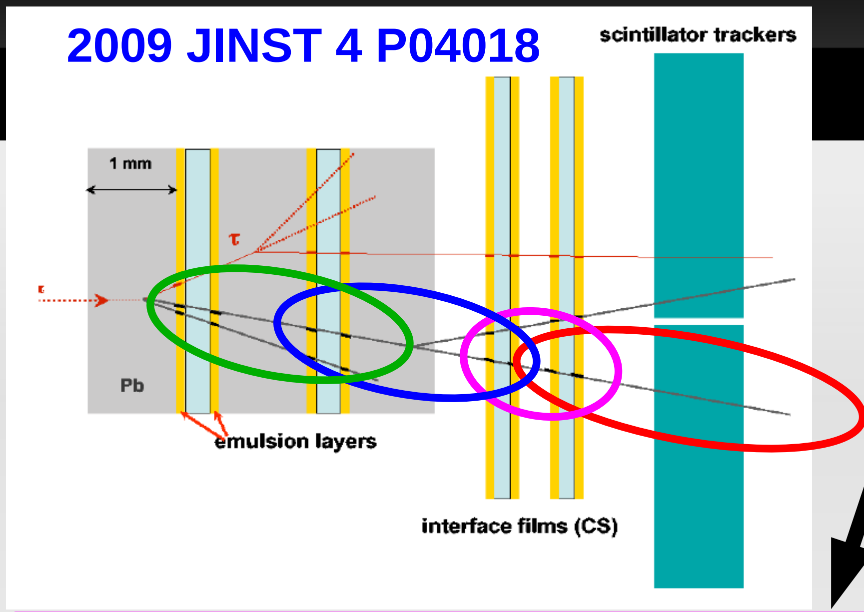


MC independent test of track finding efficiency in CS in a subsample of fully located event (ε_{sb} ~ 90%) OK!



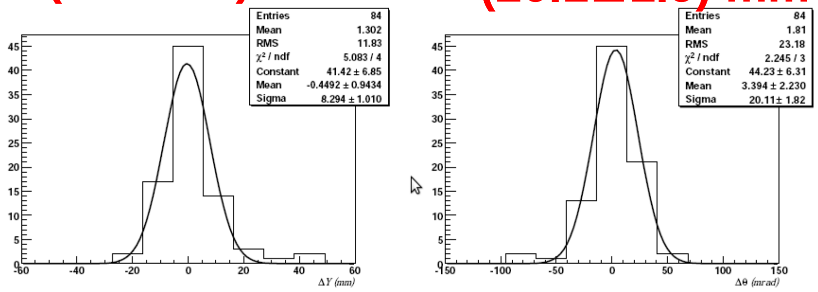
From electronic detectors to vertices in emulsions

2009 JINST 4 P04018

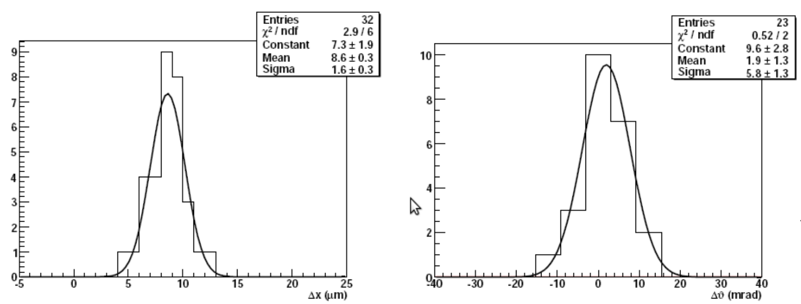


Electronic detectors - Changeable sheet

(8.3±1.0) mm (20.1±1.9) mm



CS1-2 (1.6±0.3) µm (6.8±1.3) mrad



74 µm 8.2 mrad **CS brick**

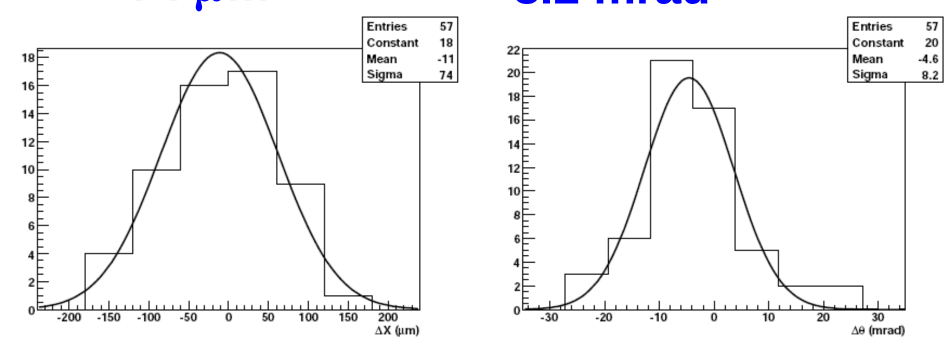
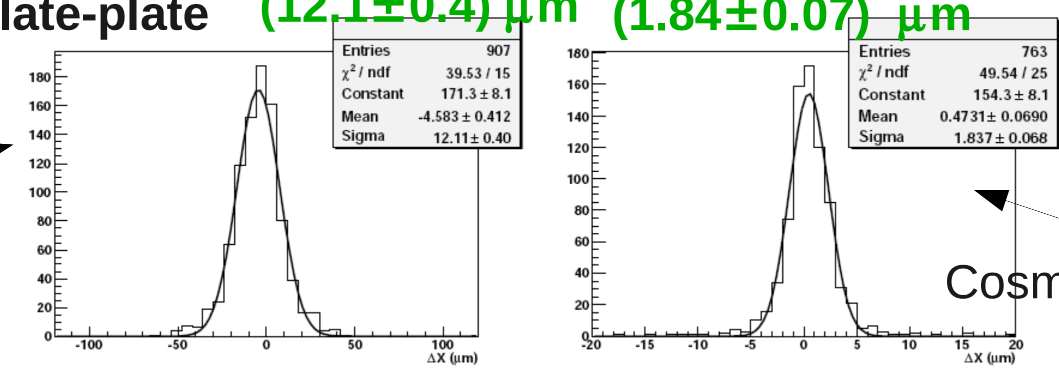


plate-plate (12.1±0.4) µm (1.84±0.07) µm



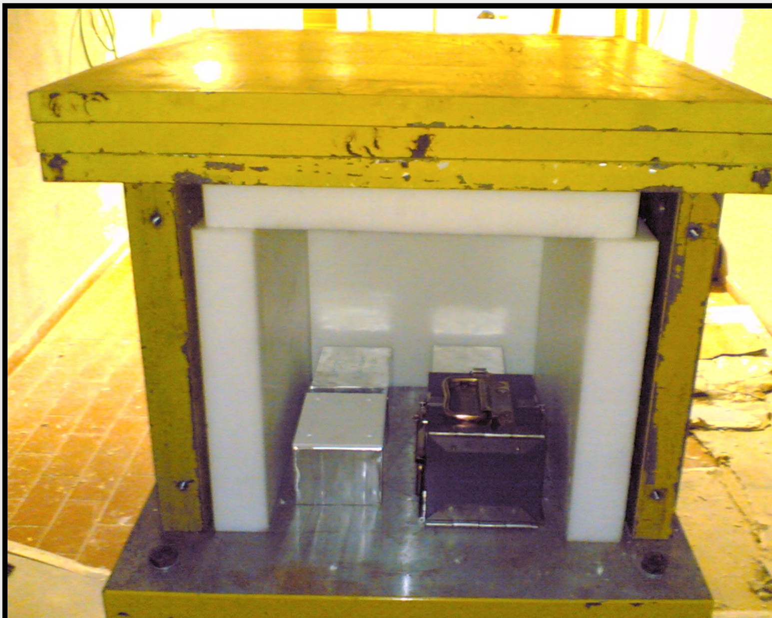
Lateral X-ray marks

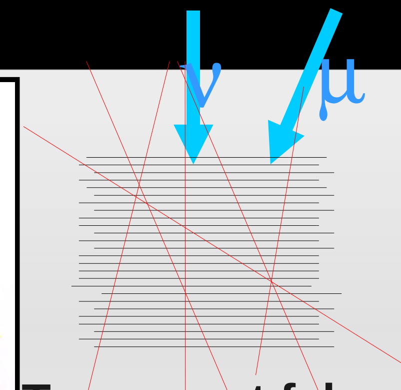
Cosmic ray alignment

leap of a factor 10000 in precision !

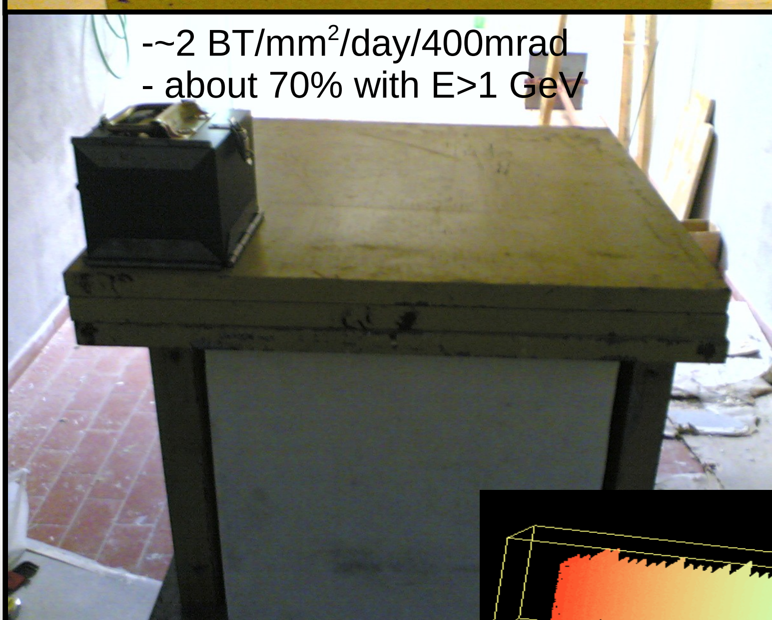
Cosmic ray exposure

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

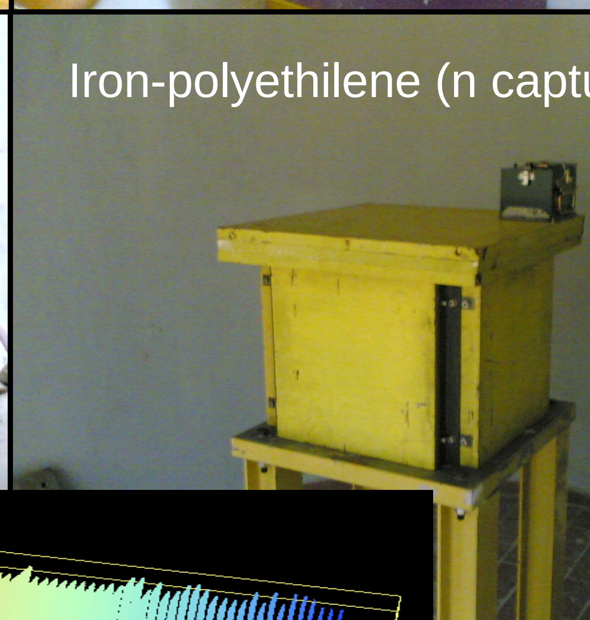




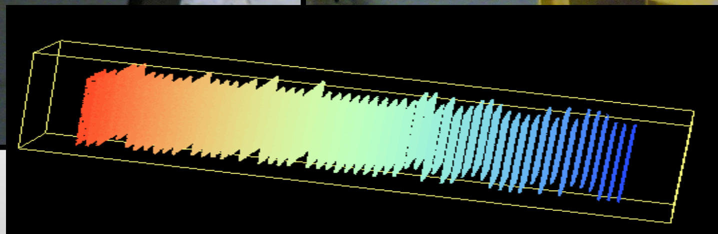
To prevent fake stopping points

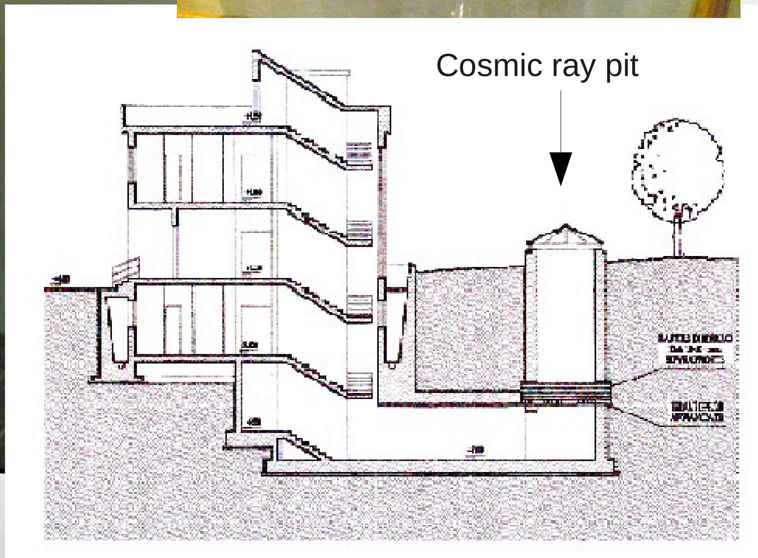


-~2 BT/mm^2/day/400mrad
- about 70% with E>1 GeV



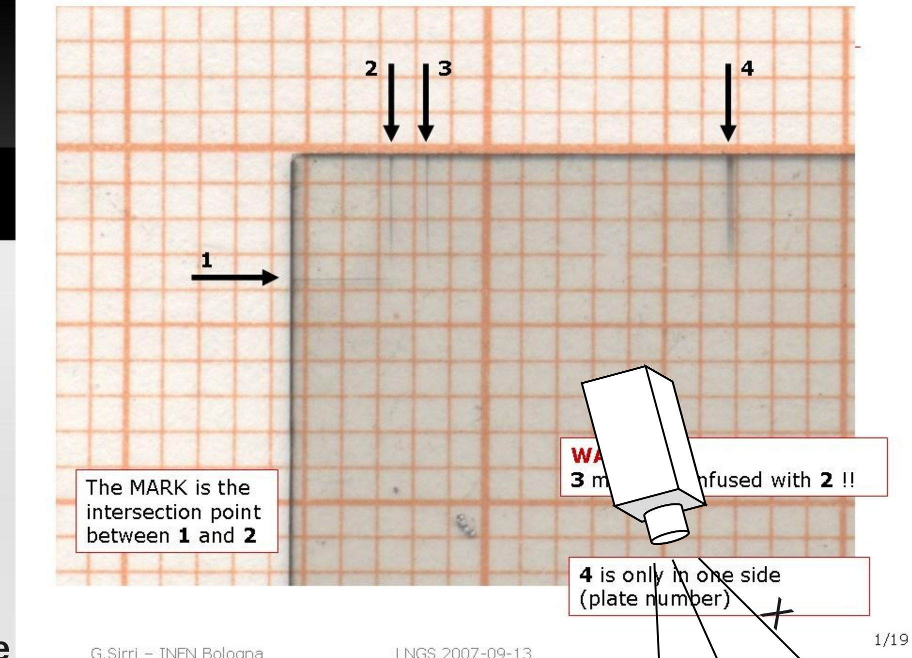
Iron-polyethilene (n capture)



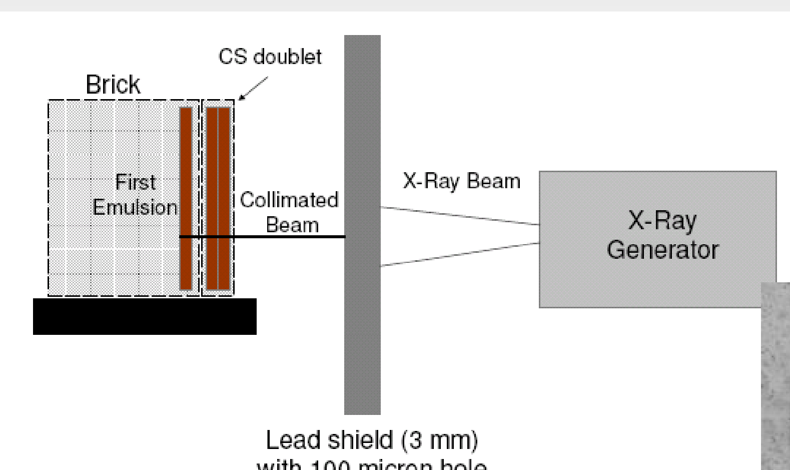


X-ray marking

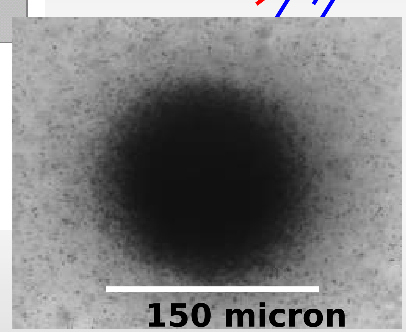
- Faster global alignment using **X-ray marks**
- **Marks are automatically detected by a** pattern recognition software and affine transformations among plates are calculated. This procedure allows to perform the scan back procedure in a fast and effective way while cosmics alignment is more accurate but slow (a zone of ~1 cm2 needs to be scanned to perform the alignment with reasonable statistics). Also provide plate numbering.
- same technique for CS-brick alignment

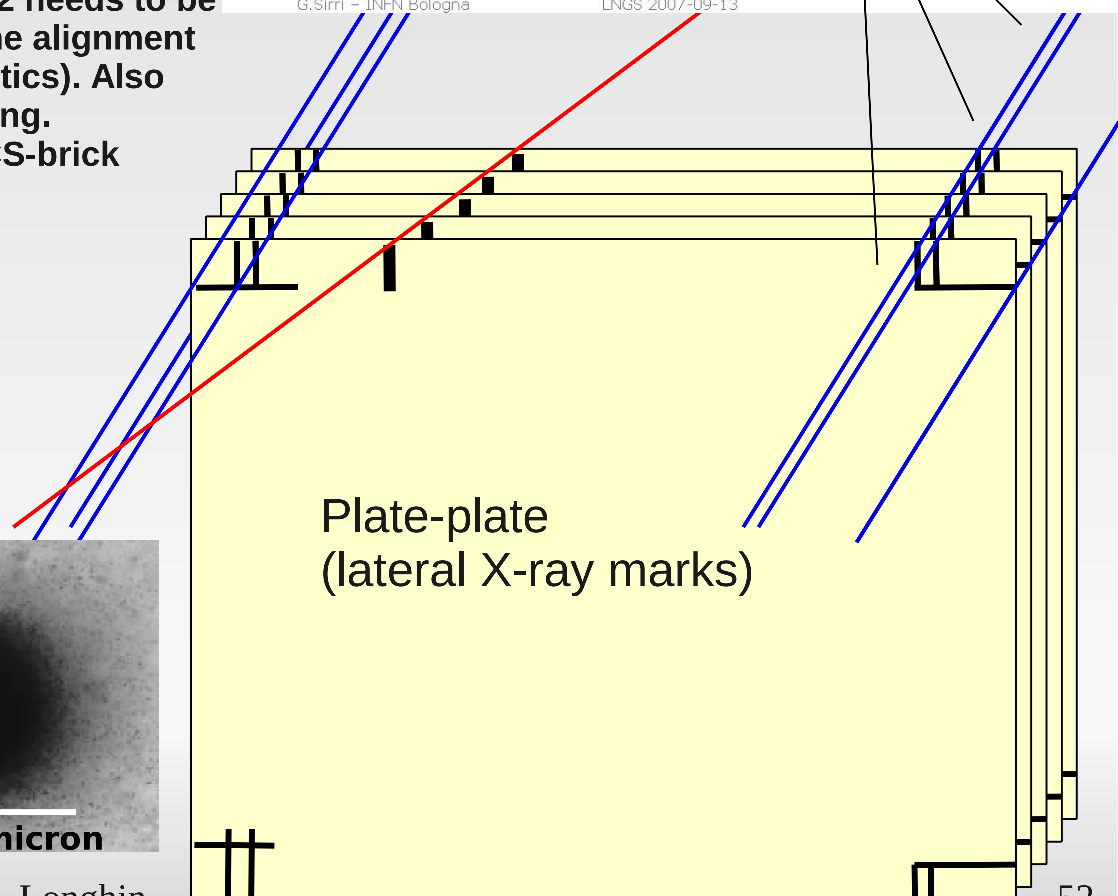


CS-brick (frontal Xray marks)

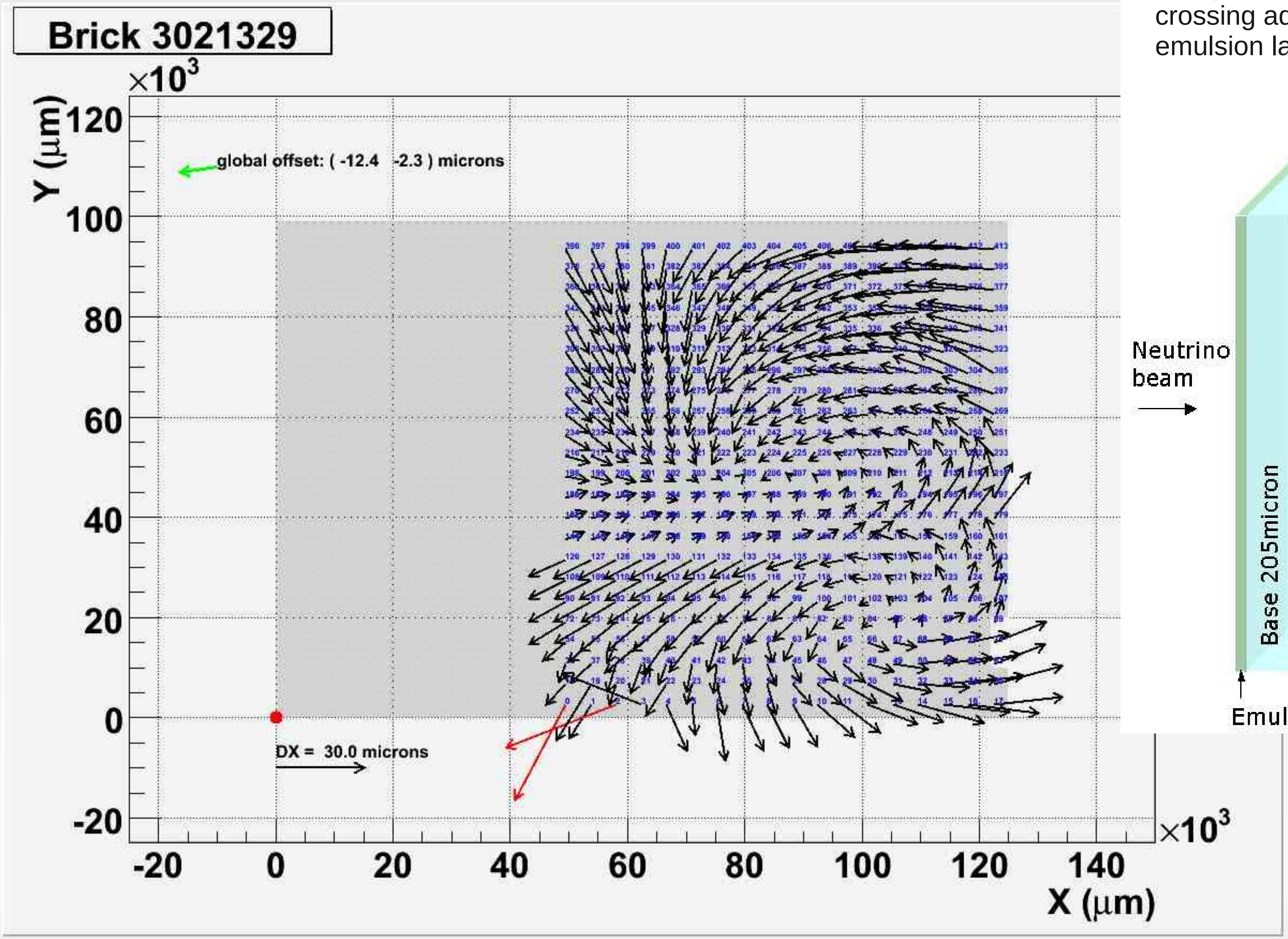


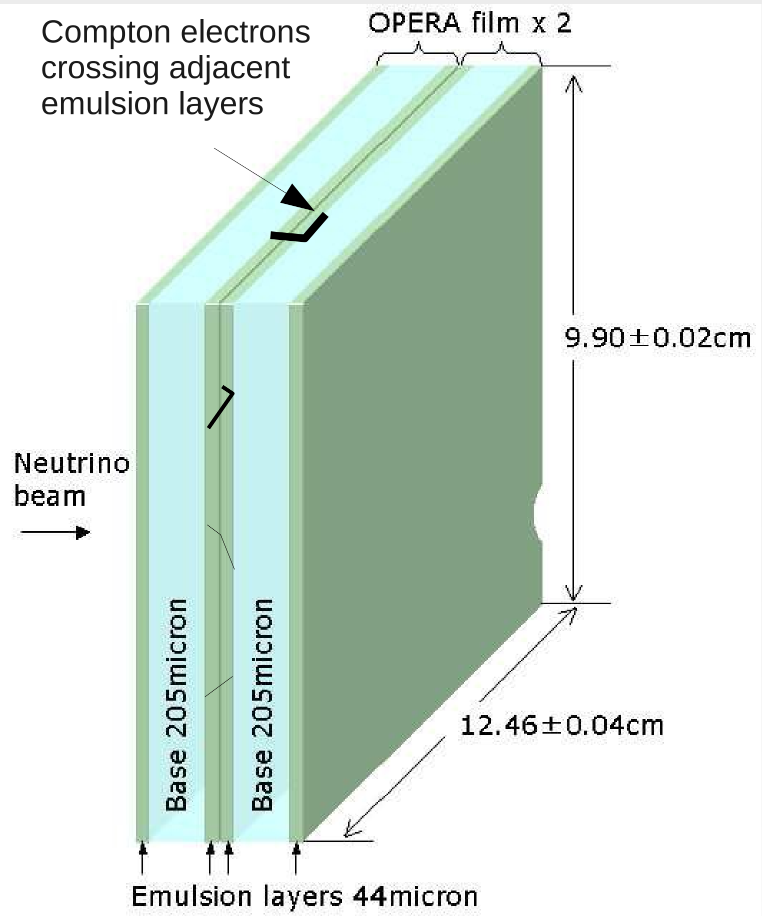
5 circular spots on CS films and most downstreamfilm of the brick.
precise alignment btw CS1-2 and brick





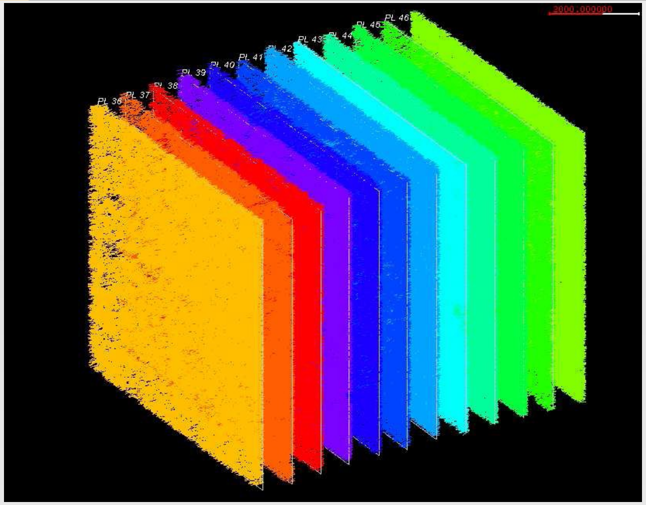
CS1-CS2 matching: Compton tracks

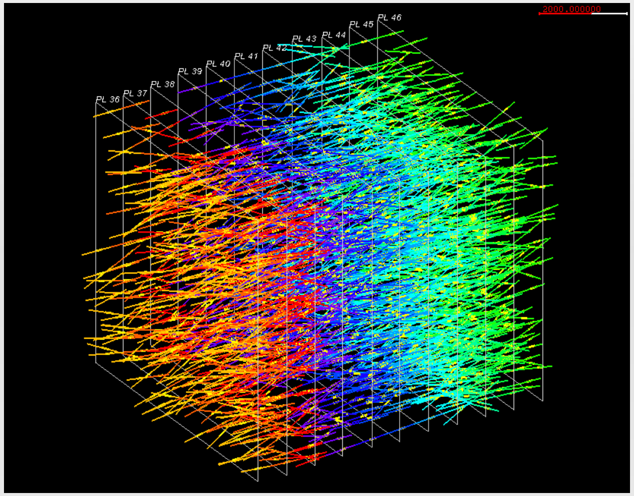


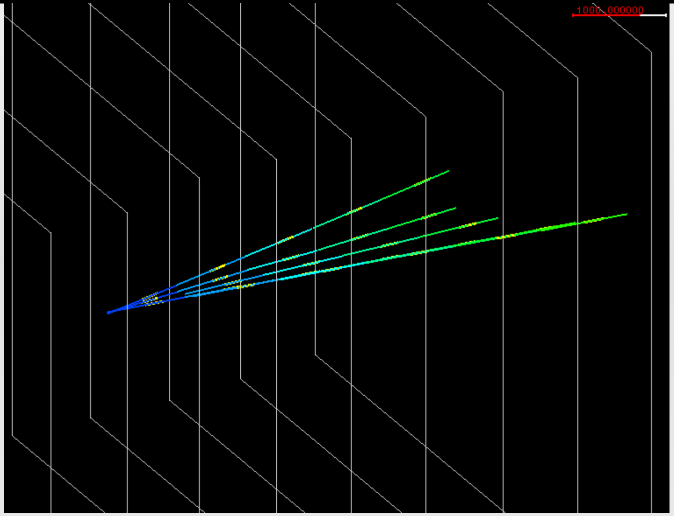


Steps of volume scanning

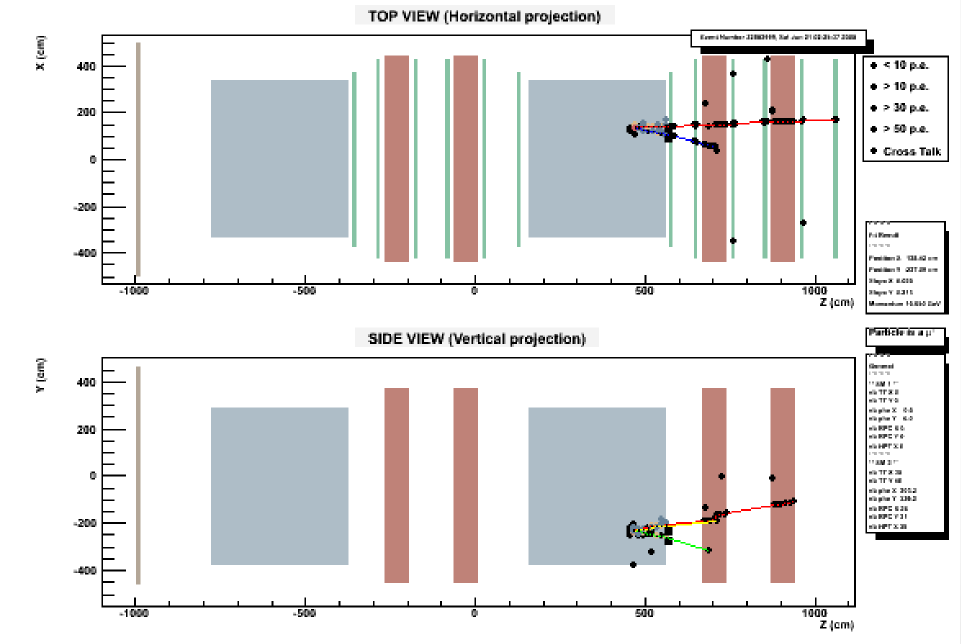
1 2 3

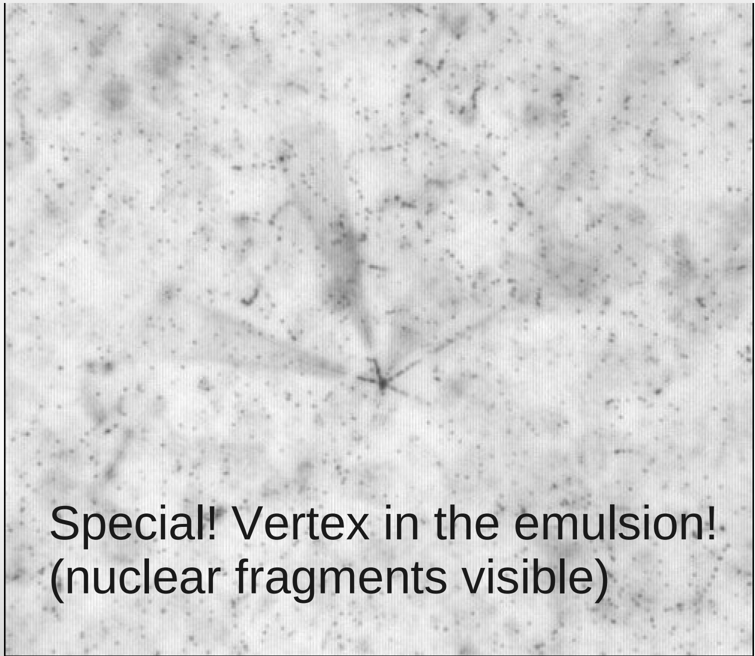






1) all base-tracks in the 11 films of the volume are reconstructed
2) they participate to the alignment process from which tracks are reconstructed
3) passing-through tracks are discarded and the vertexing algorithm reconstructs the vertex.





A. Longhin

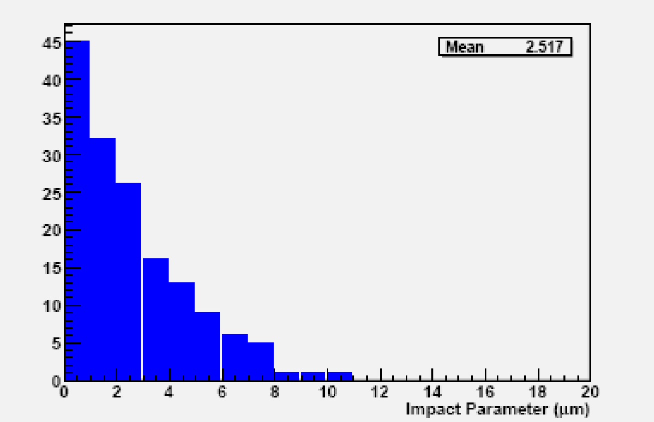
Vertex location progress

EU subsample	NC	CC	Total
Bricks assigned	84	455	539
Bricks received in the labs	81	425	506
Scanning started	78	413	491
CS to brick connected	71	391	462
Vertices located in the brick	48	322	370
Passing through	8	22	30
Vertices in the dead material	1	7	8

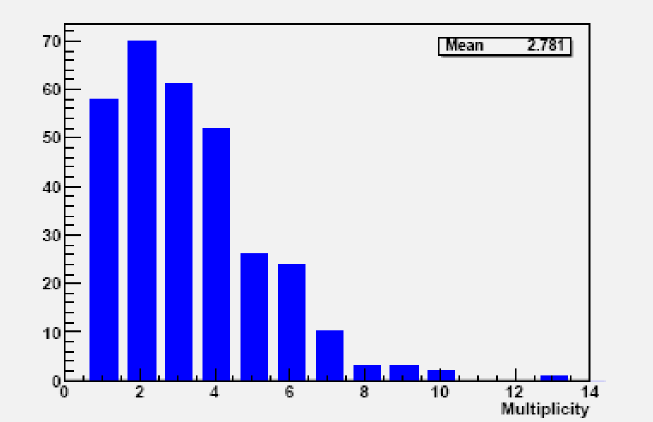
Event location
Upper limit : NC: 91% CC: 95%
Lower limit: NC: 70% CC: 84%
Proposal 81 % 93 %
OK!
Dead material: 8/370 = 2.2%

Lots of activity in the scanning labratories
Ongoing process!

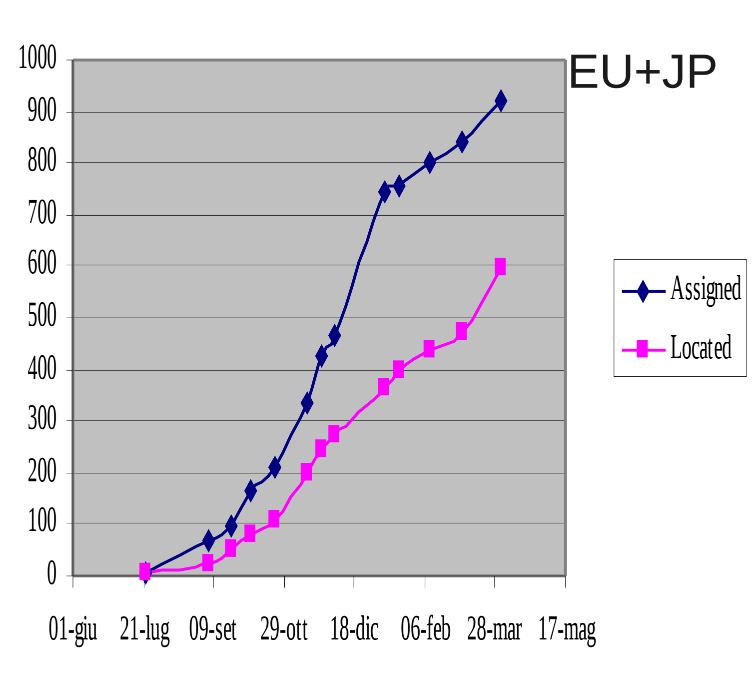
arXiv:0903.2973v1 [hep-ex]



Muon Impact parameter



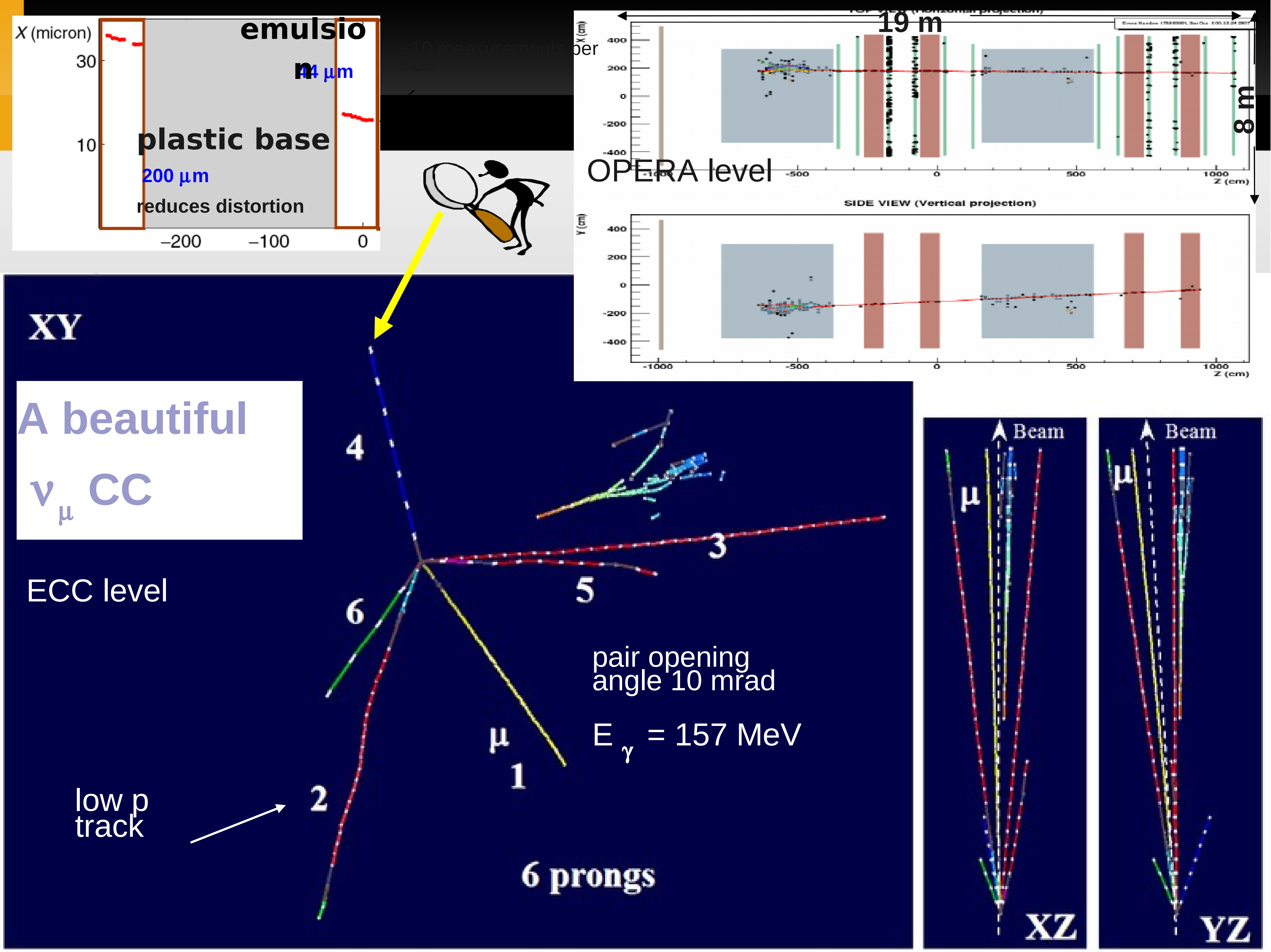
Vertex multiplicity



And now let's "open the box" ... !

A selection of neutrino vertices reconstructed in the emulsion detectors

~>

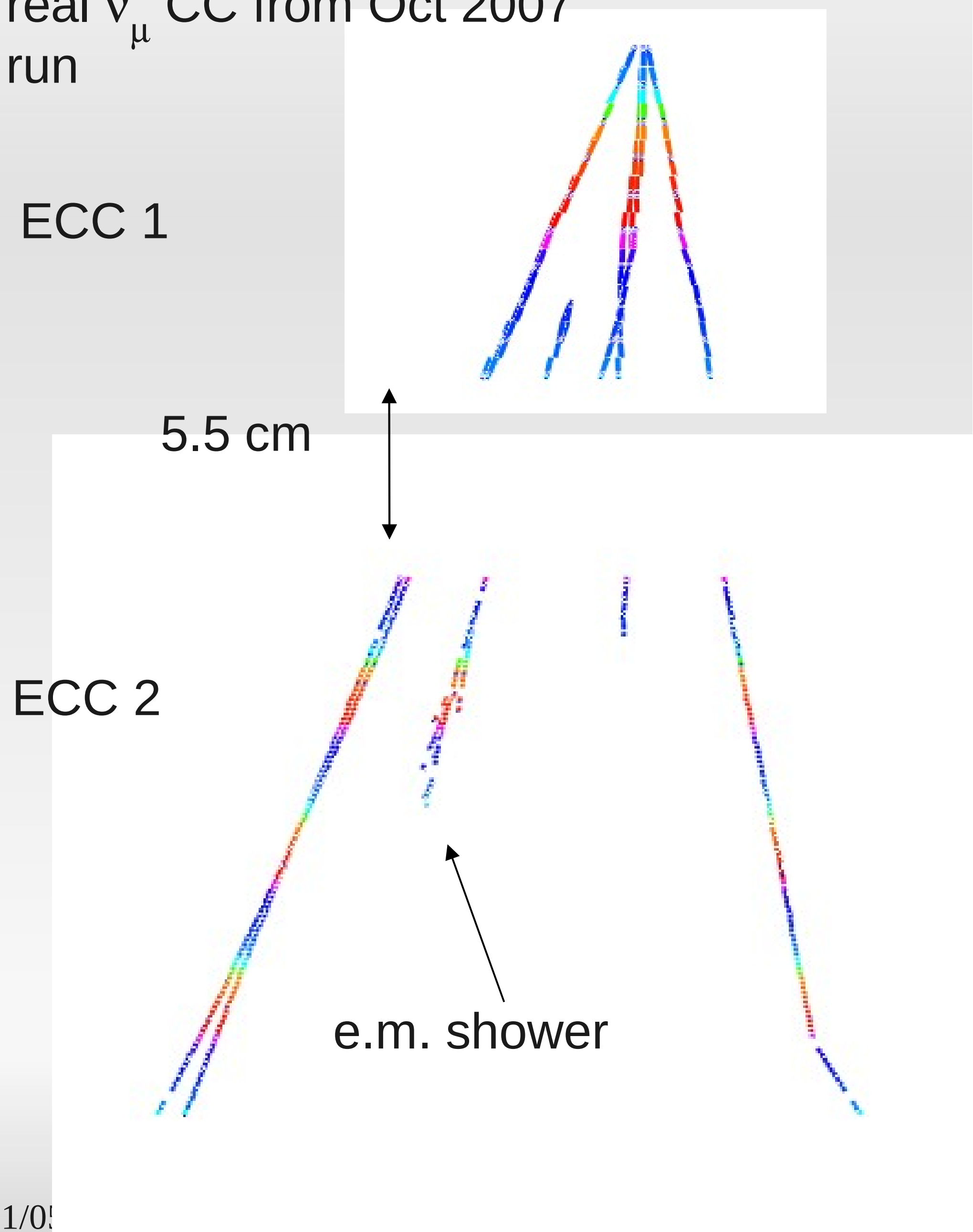


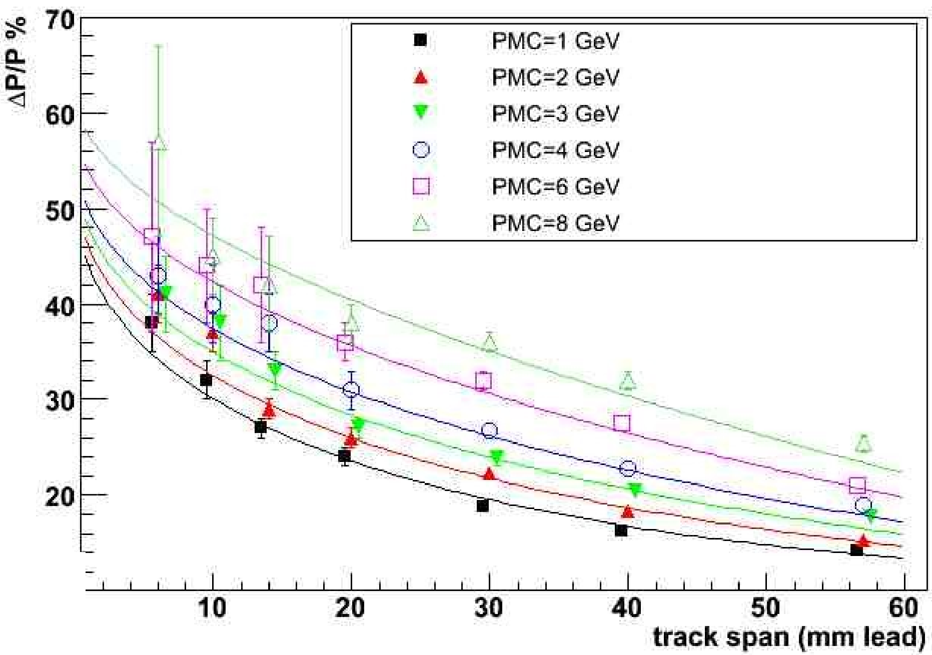
X (micron)
30
10
emulsion
44 μm
plastic base
200 μm
reduces distortion
−200
−100
0
19 m
8 m
OPERA level
SIDE VIEW (Vertical projection)
Z (cm)
Y (cm)
A beautiful
ν_μ CC
XY
4
3
5
6
2
μ
1
ECC level
pair opening
angle 10 mrad
E_γ = 157 MeV
low p
track
6 prongs
Beam
μ
XZ
Beam
μ
YZ

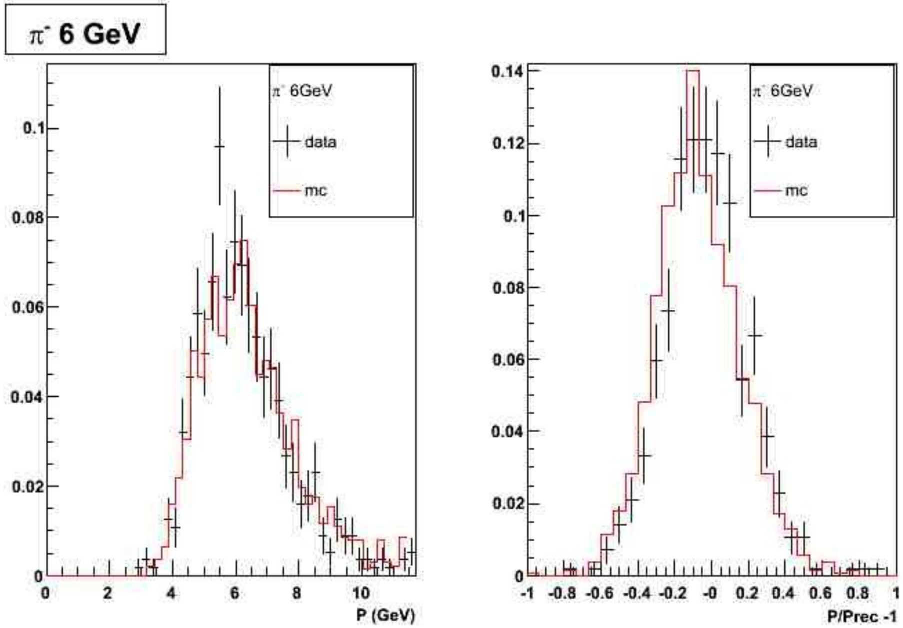
brick - brick connection

improvement of momentum resolution with track length

real ν_μ CC from Oct 2007 run







Background studies

The accumulated statistics allows the study of backgrounds on real data and to validate estimates based on simulation

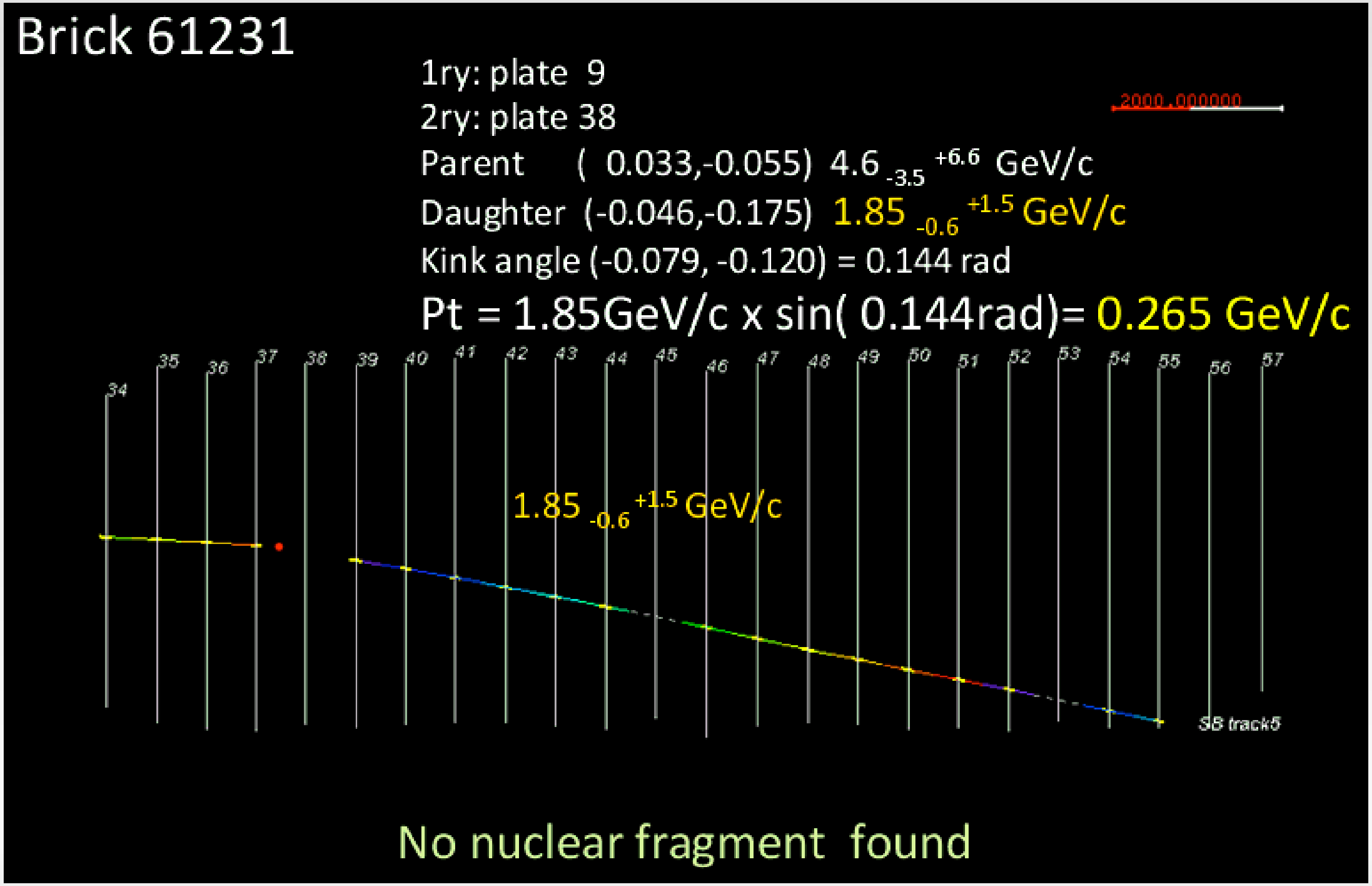
Scan-forth of muon and hadronic tracks from the primary vertex

direct measurement of
- Coulomb scattering and
- hadronic interactions

~100 m of hadronic track length needed to have a reasonable stat of background events. So far 3.85 m

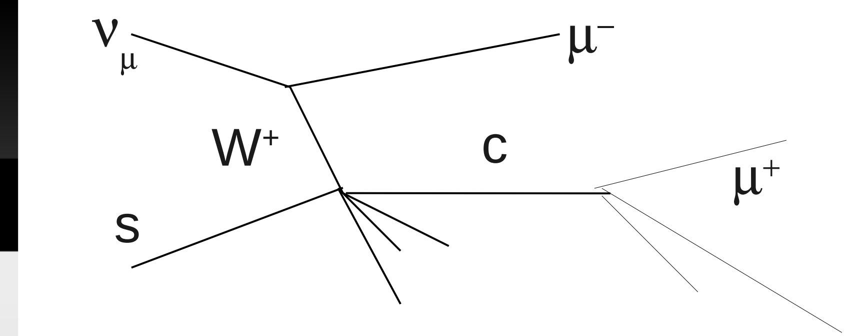
8 secondary interaction vertices have been found.

1 “white kink” candidate
kink: 144 mrad
p_T = 265 MeV/c

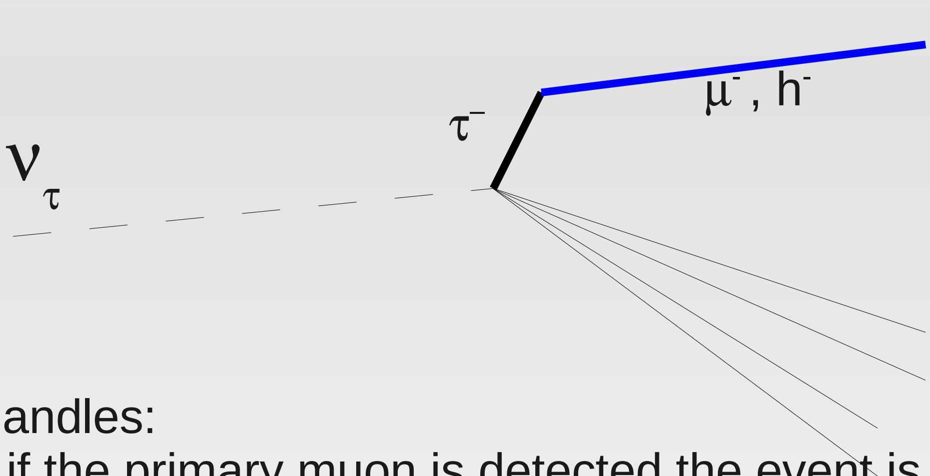


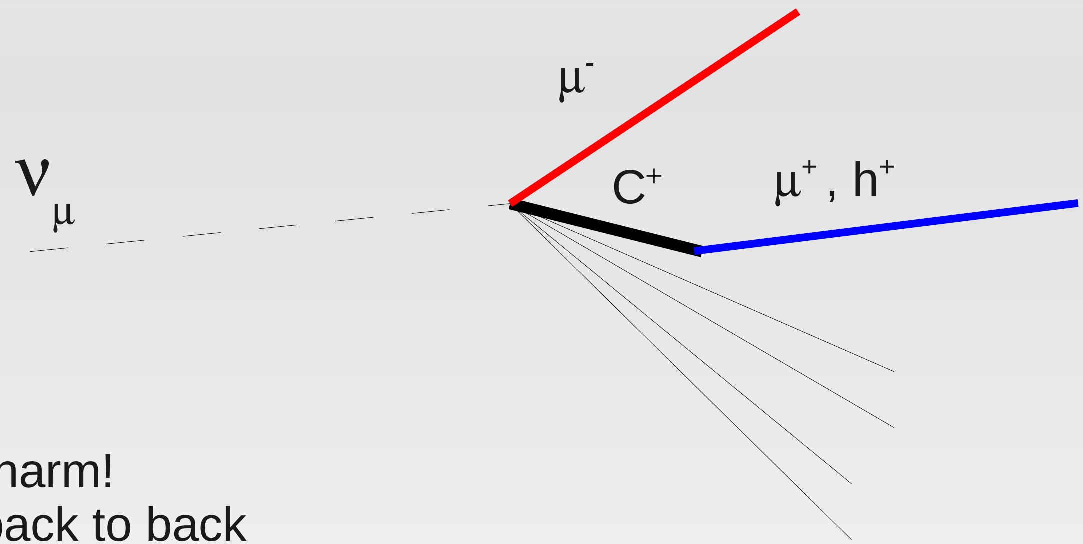
τ ->1h analysis requires a p_T larger than 600 MeV/c

Charm searches



Similar topology: general validation of tau reconstruction efficiencies !





handles:
- if the primary muon is detected the event is charm!
- charm is within the hadronic remnant, tau is back to back

2007+2008 550 numu CC analysed → **8 candidates**, rough efficiency estimation ~44%
Background ~ 0.1 events. **~10 expected**

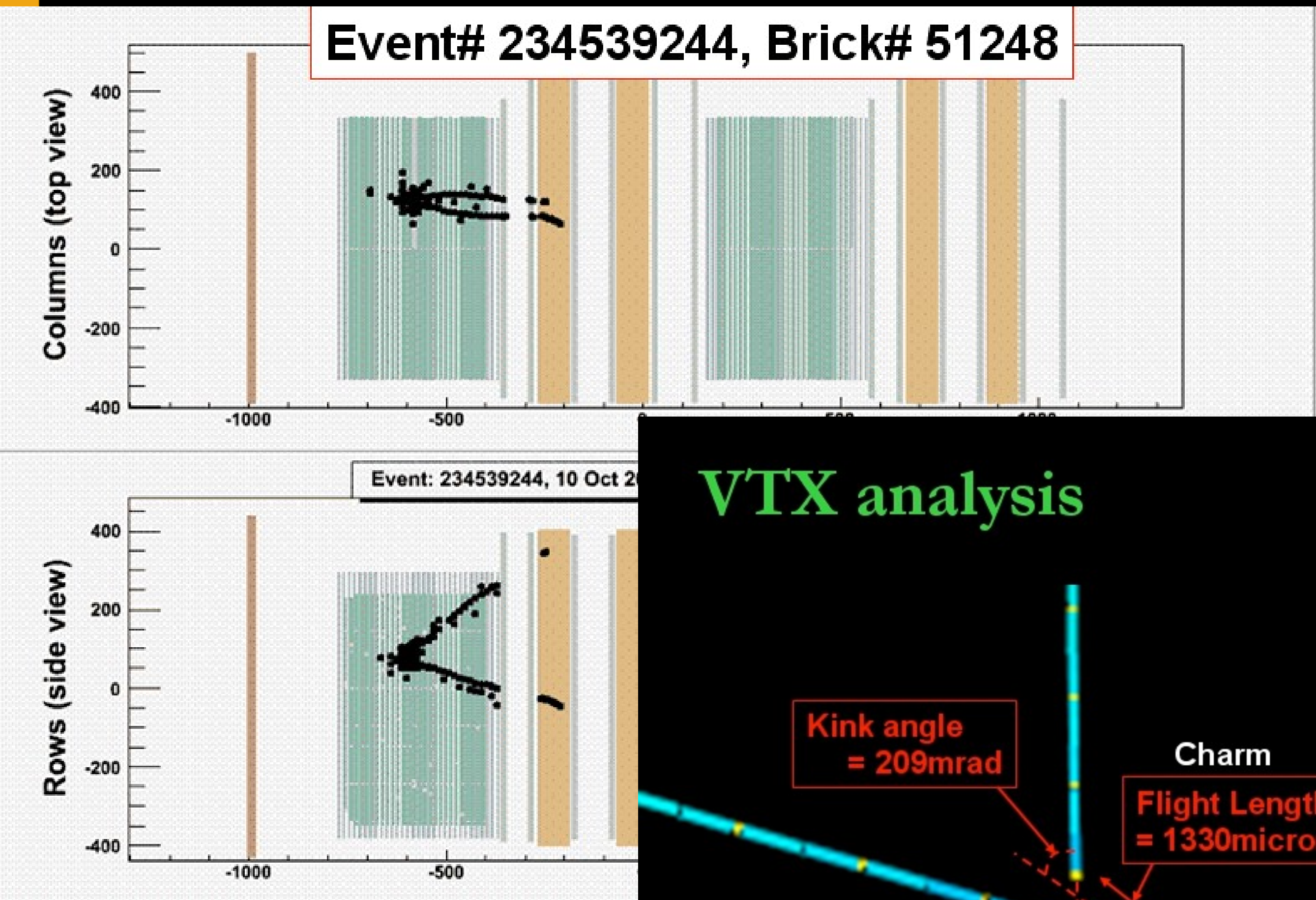
From CHORUS (>~10^3 charm statistics)

$\sigma(C^+)/\sigma(CC) = (2.47 \pm 0.22)\%$

Topology	Expected	obs
1 prong	3.86	3
3 prongs	2.03	1
2 prongs	3.25	3
4 prongs	0.67	1
Total	9.82	8

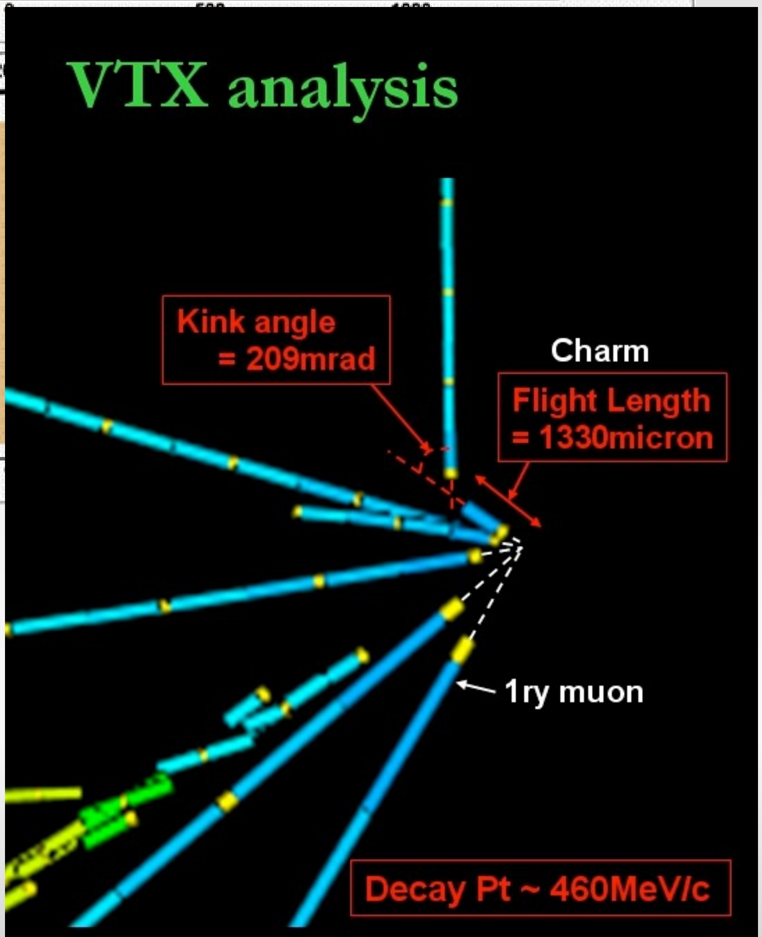
35% statistical accuracy

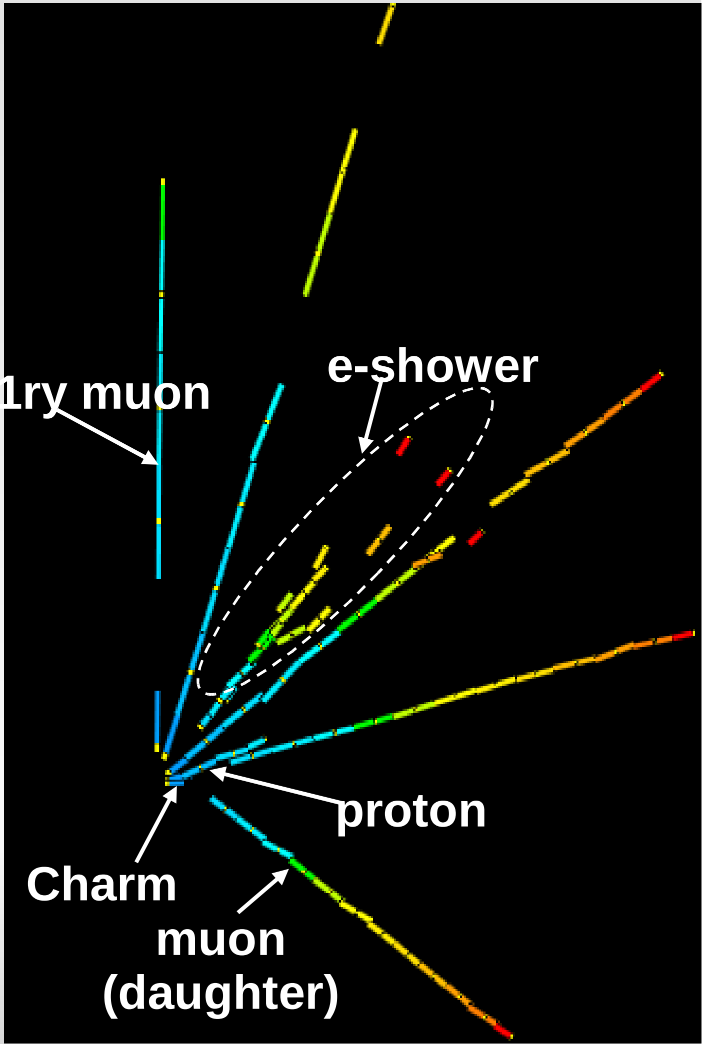
A charm dimuon candidate !



charm daughter is a μ^+

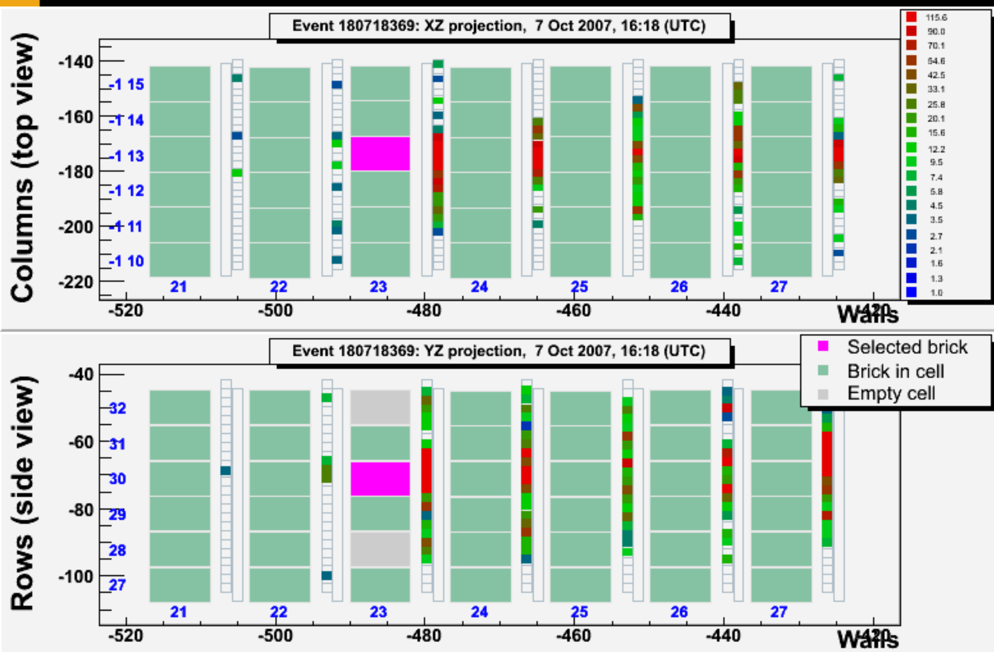
p = 2.0 GeV (1ry)
p = 2.3 GeV (2ry)
(from range)



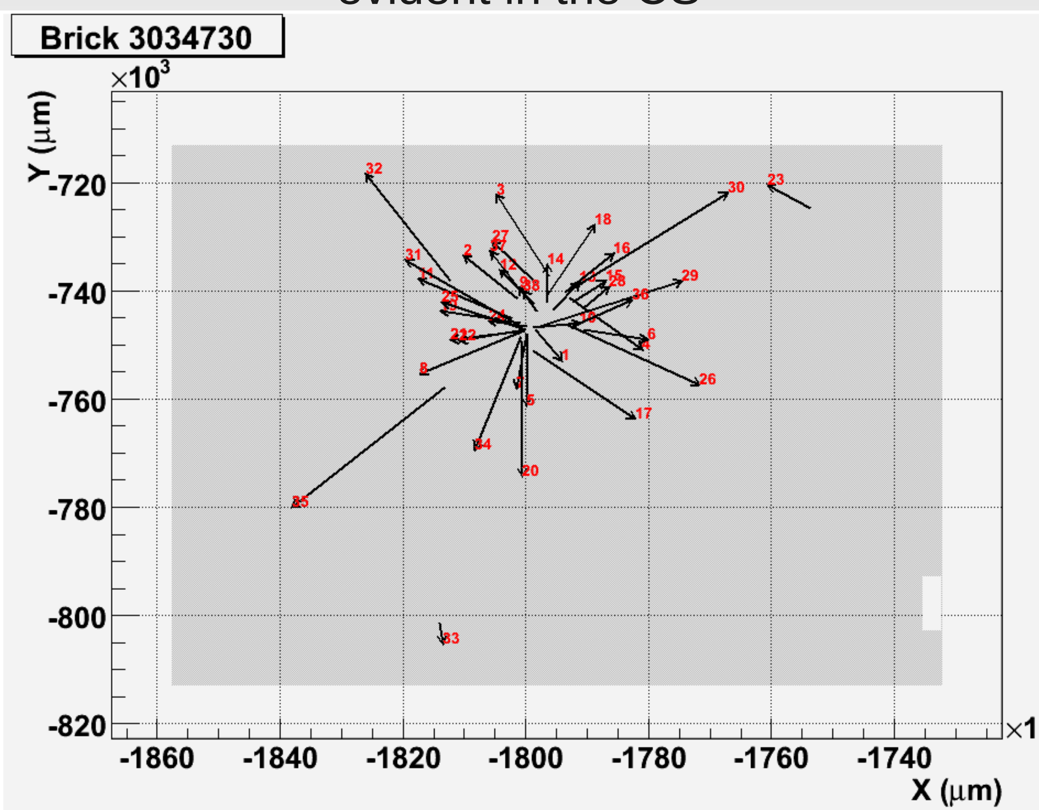


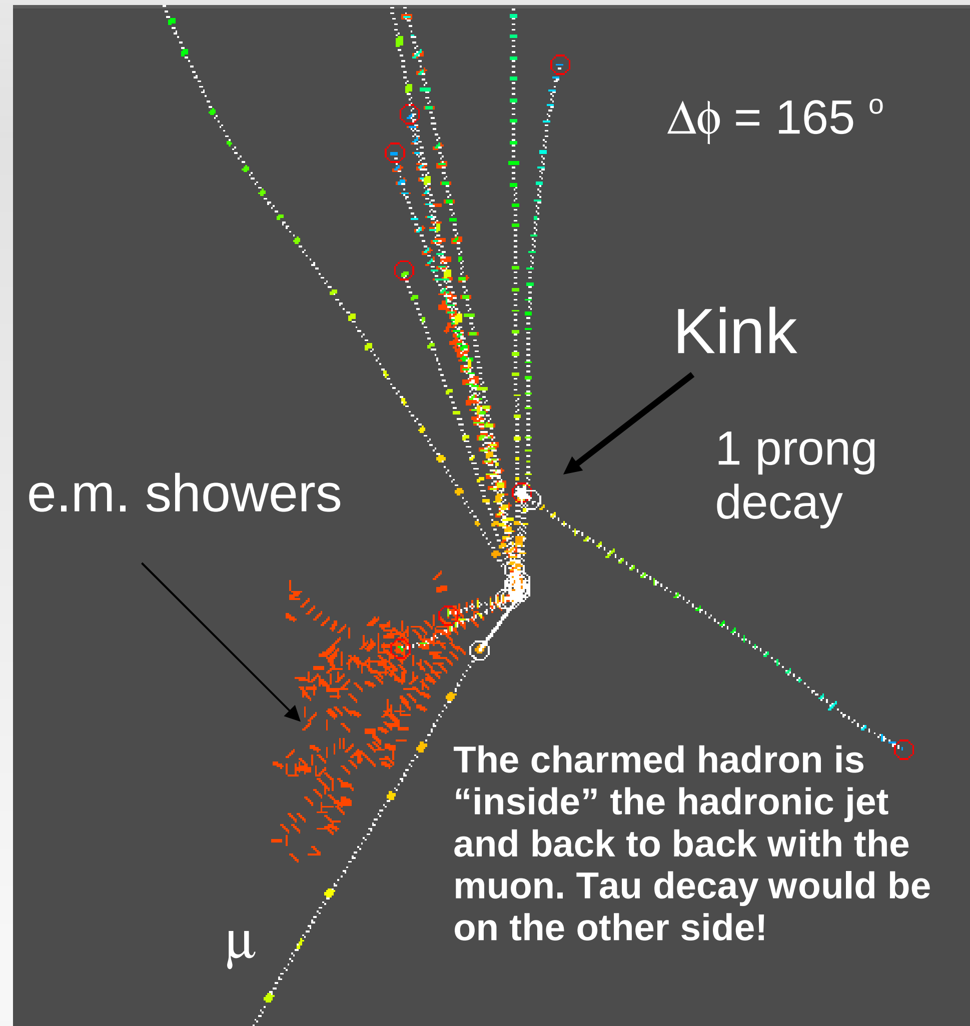
flight length: 1330 μm
kink: 209 mrad
p_T ~ 460 MeV/c

A charm single prong candidate

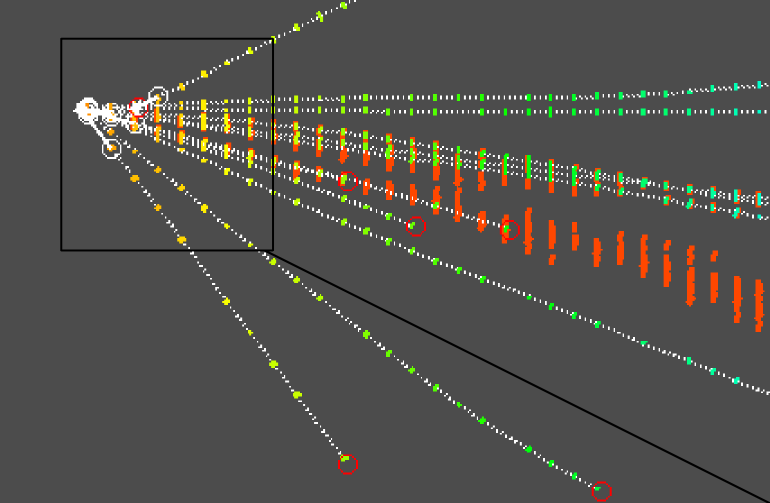


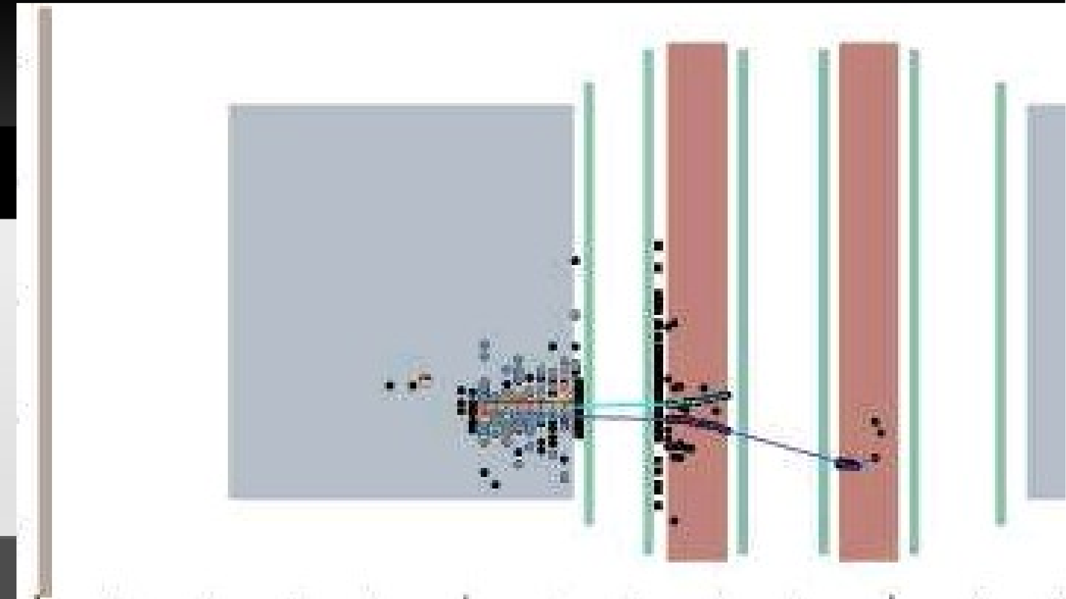
vertex signature already evident in the CS



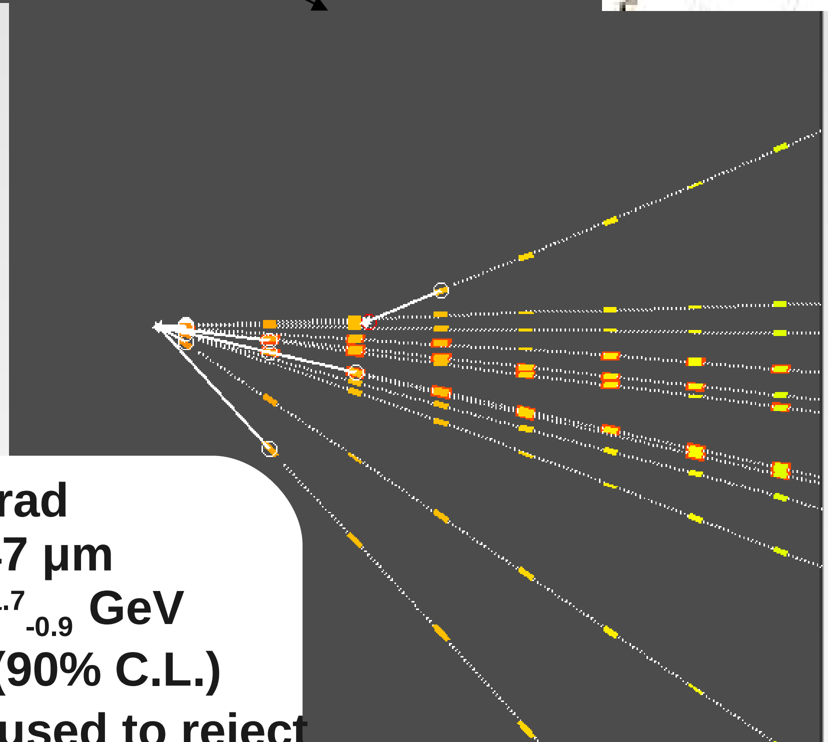


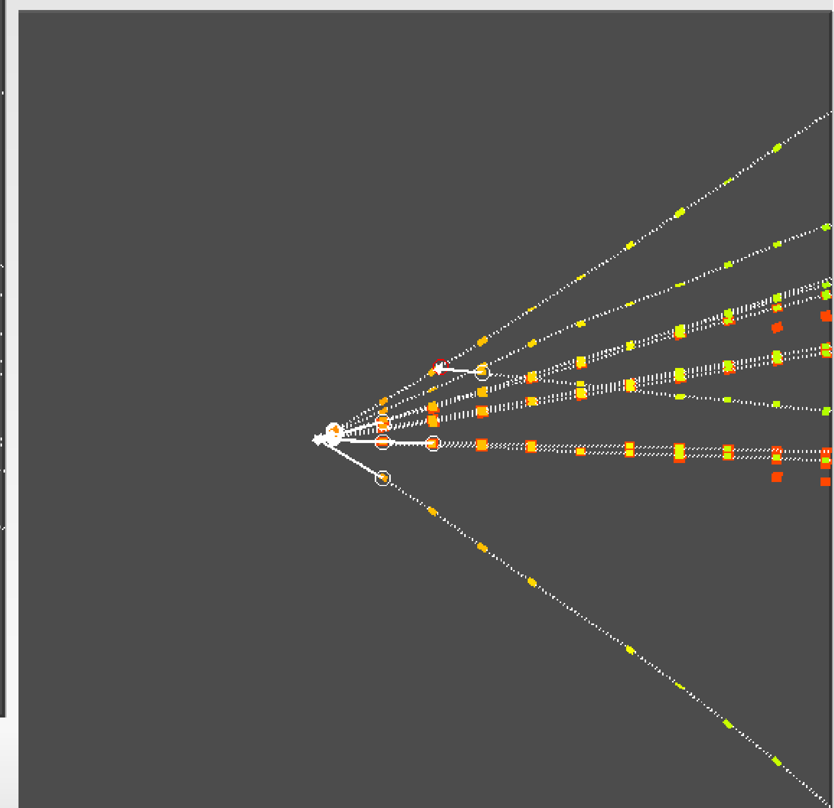
... more views





Secondary Vertex (1 prong decay)





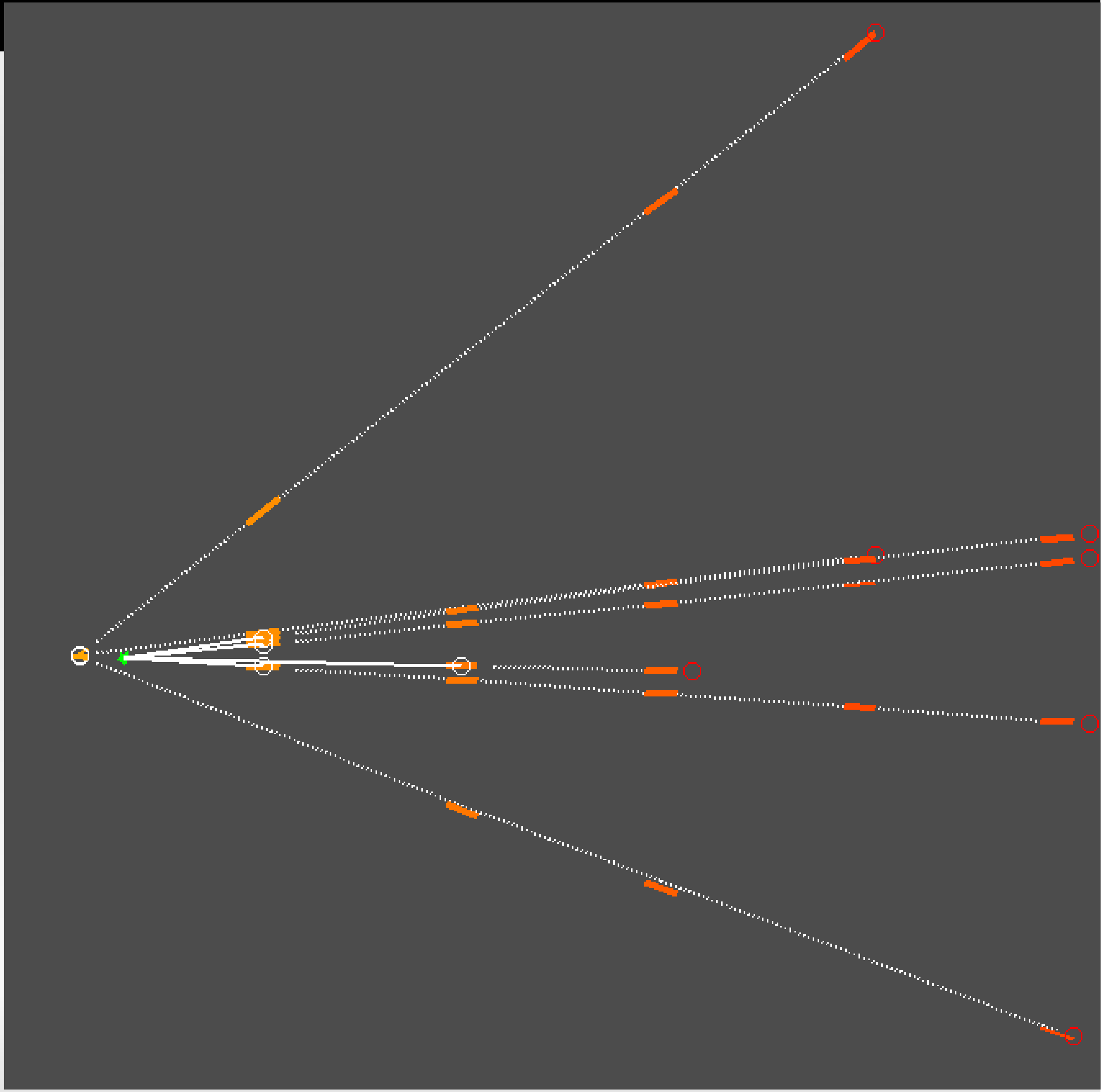
kink angle = 204 mrad
Decay length = 3247 μm
p(daughter) = 3.9 $^{+1.7}_{-0.9}$ GeV
p_t = 600-1150 MeV (90% C.L.)
well above the cut used to reject hadronic decays (250 MeV)

A D^0 candidate

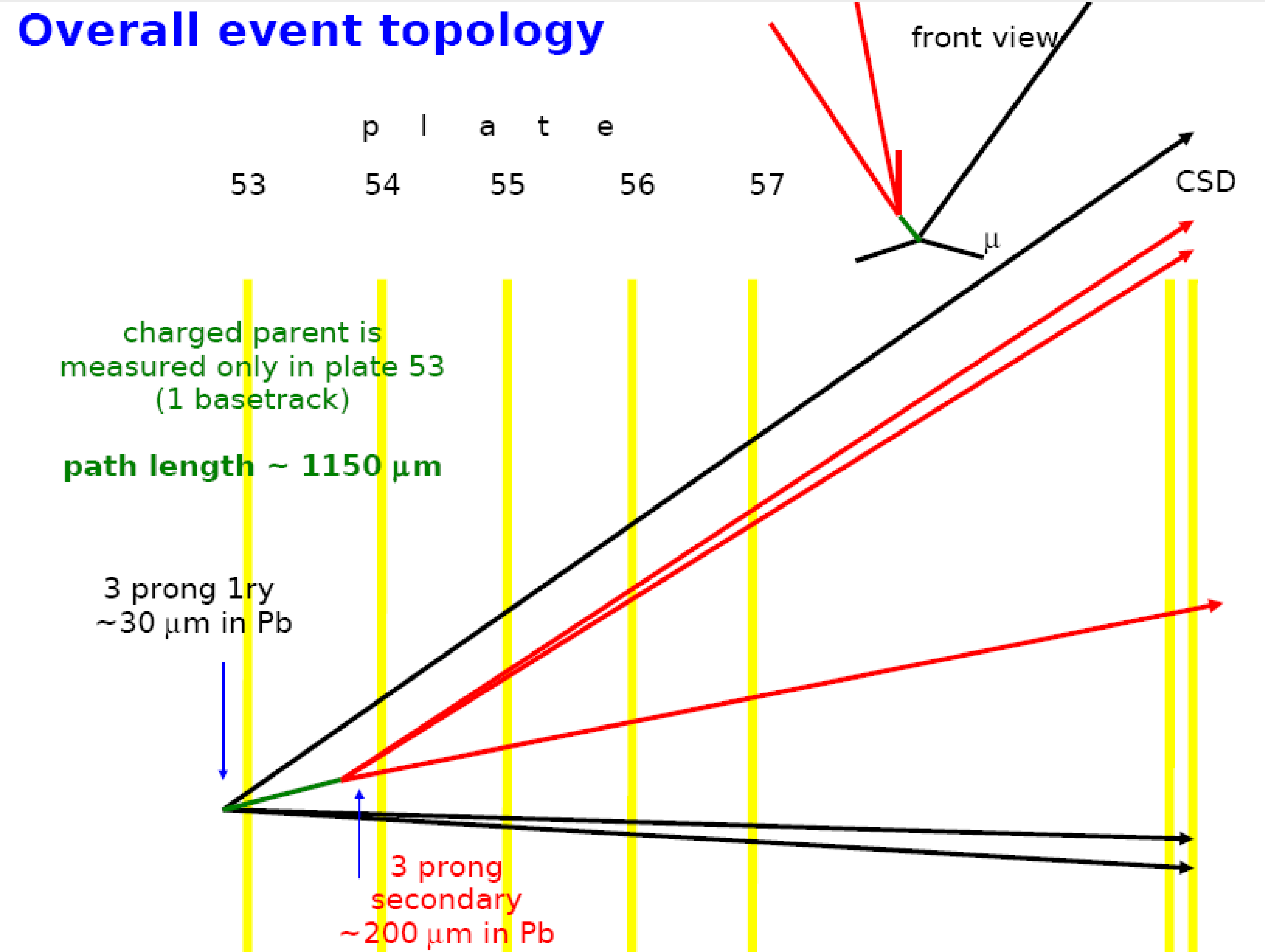
Flight Length = 315 µm

Tracks at 1ry	IP (µm)
1	1.36
2	0.88
3	0.51

Tracks at decay	IP (µm)
1	1.33
2	1.81
3	1.99
4	1.39

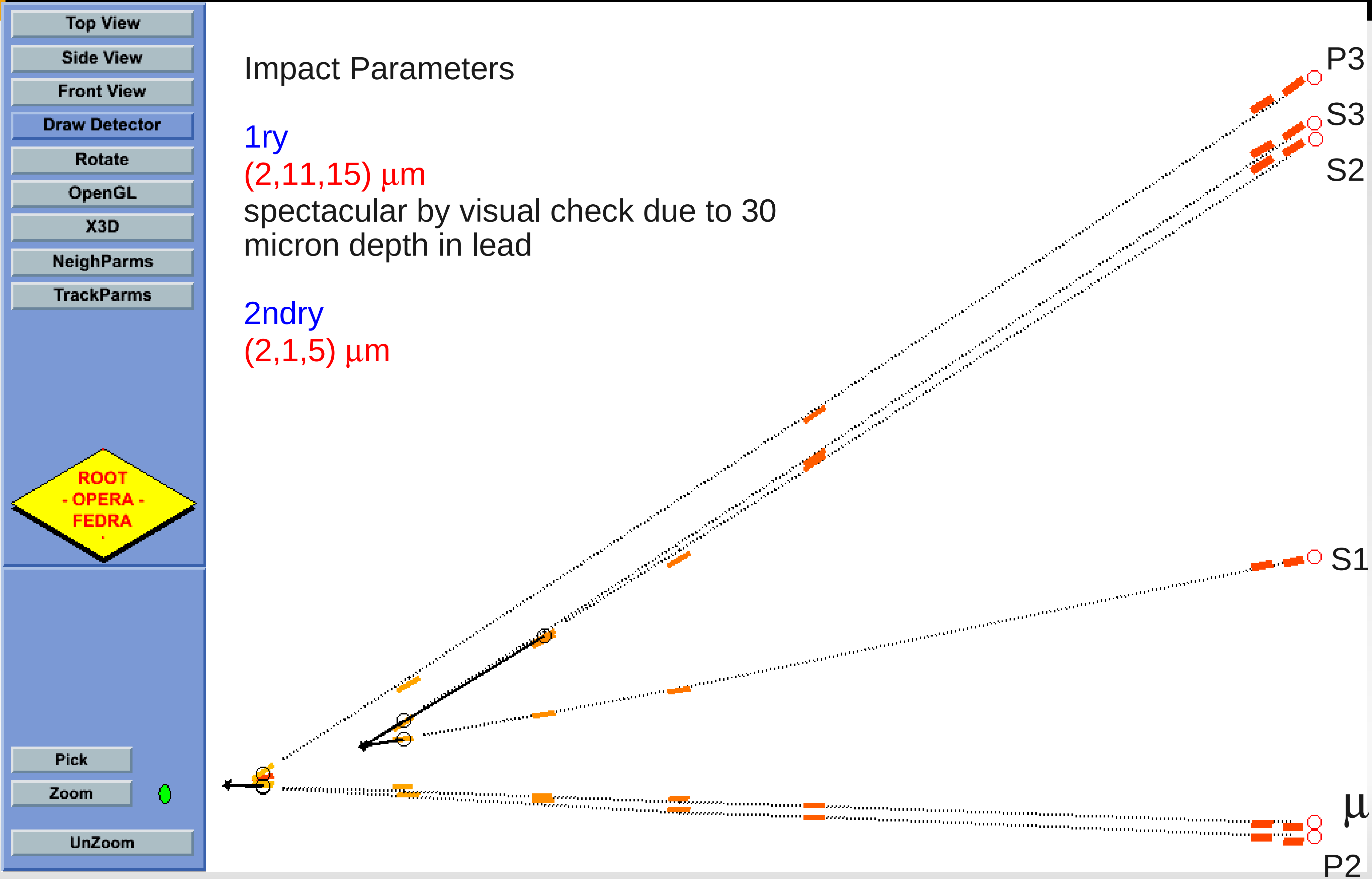


A 3-prong charm candidate



(Proudly) found in Padova !

A 3-prong charm candidate (I)

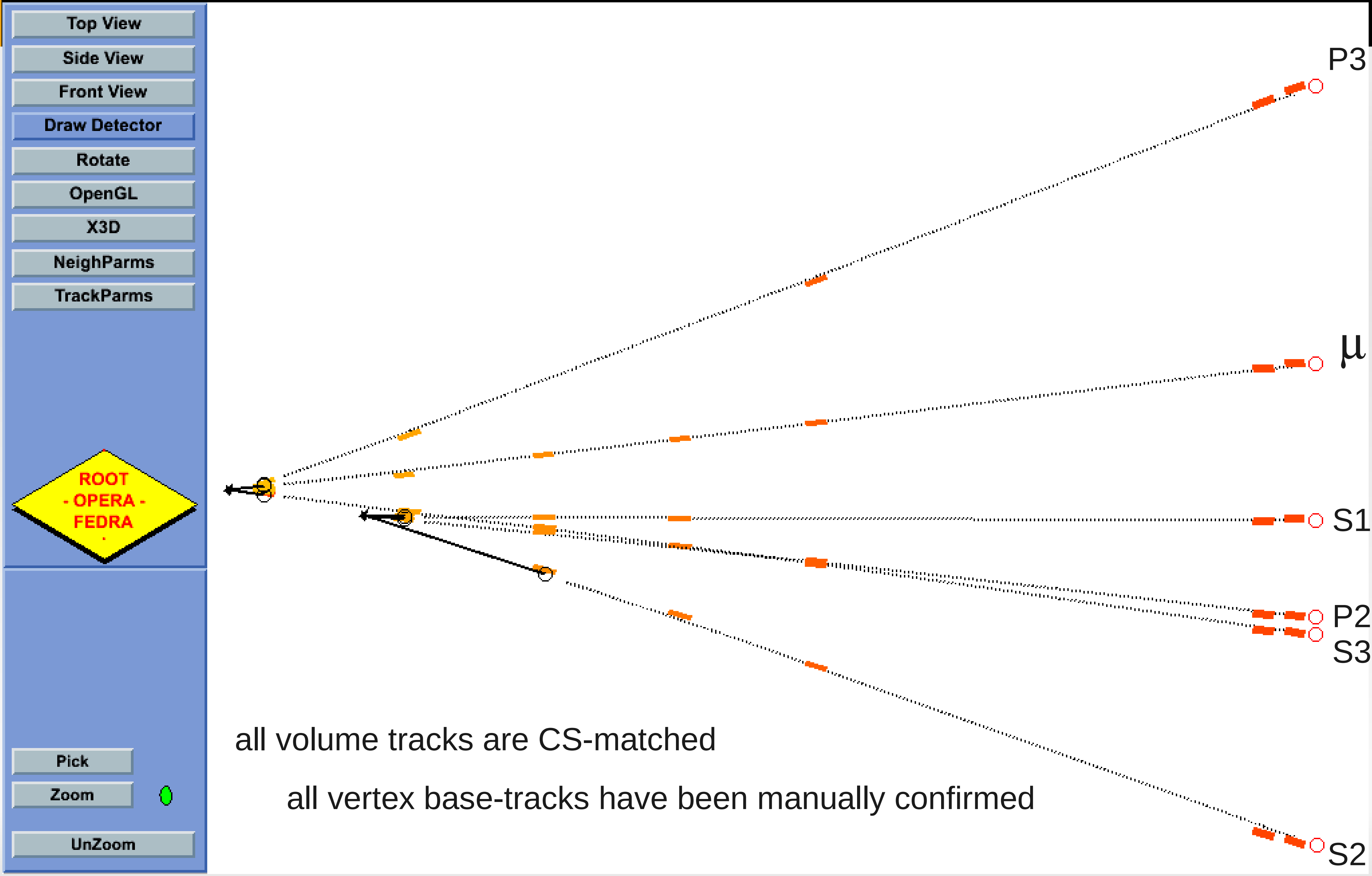


Impact Parameters

1ry
(2,11,15) μm
spectacular by visual check due to 30 micron depth in lead

2ndry
(2,1,5) μm

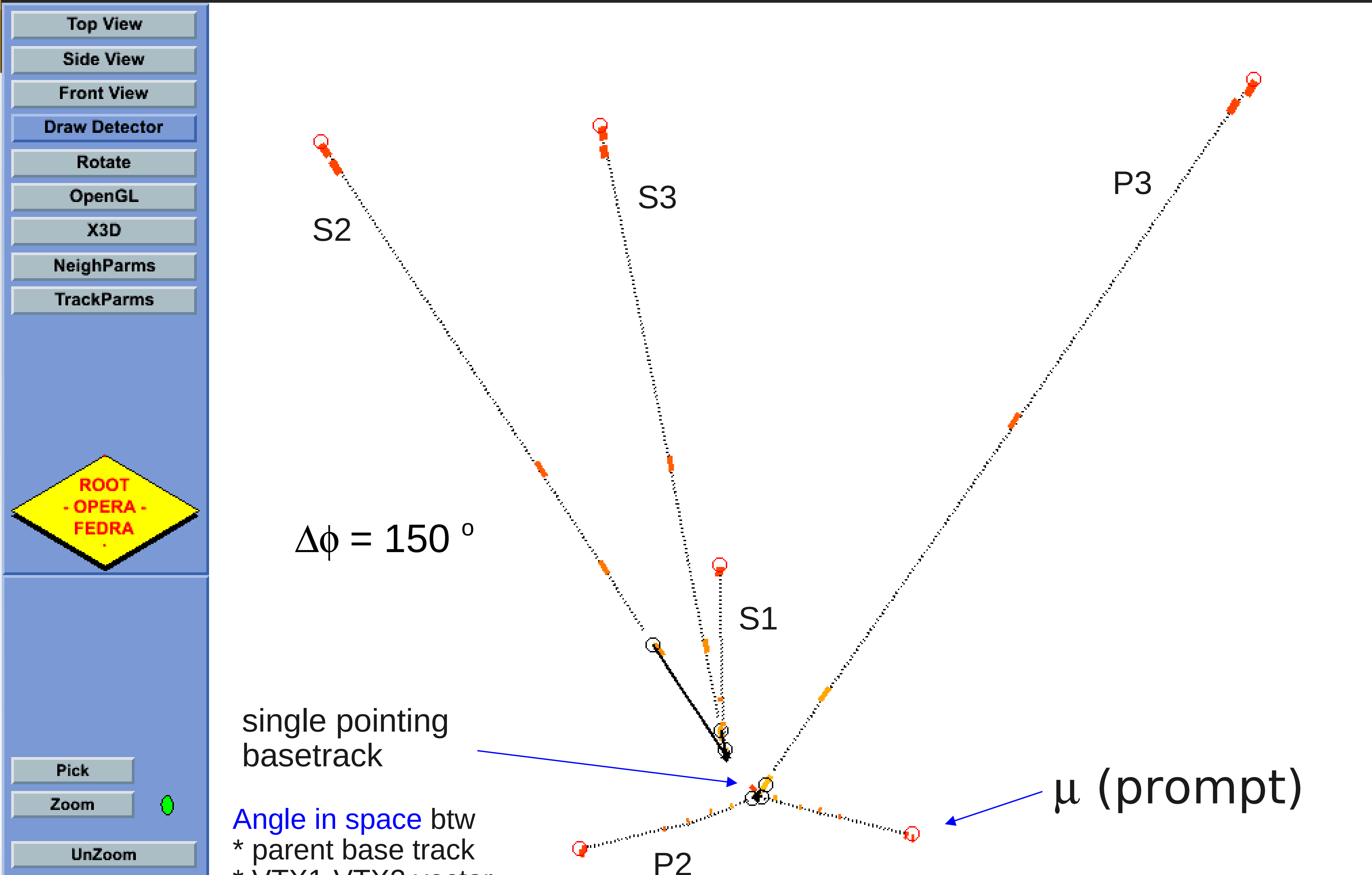
A 3-prong charm candidate (II)



all volume tracks are CS-matched

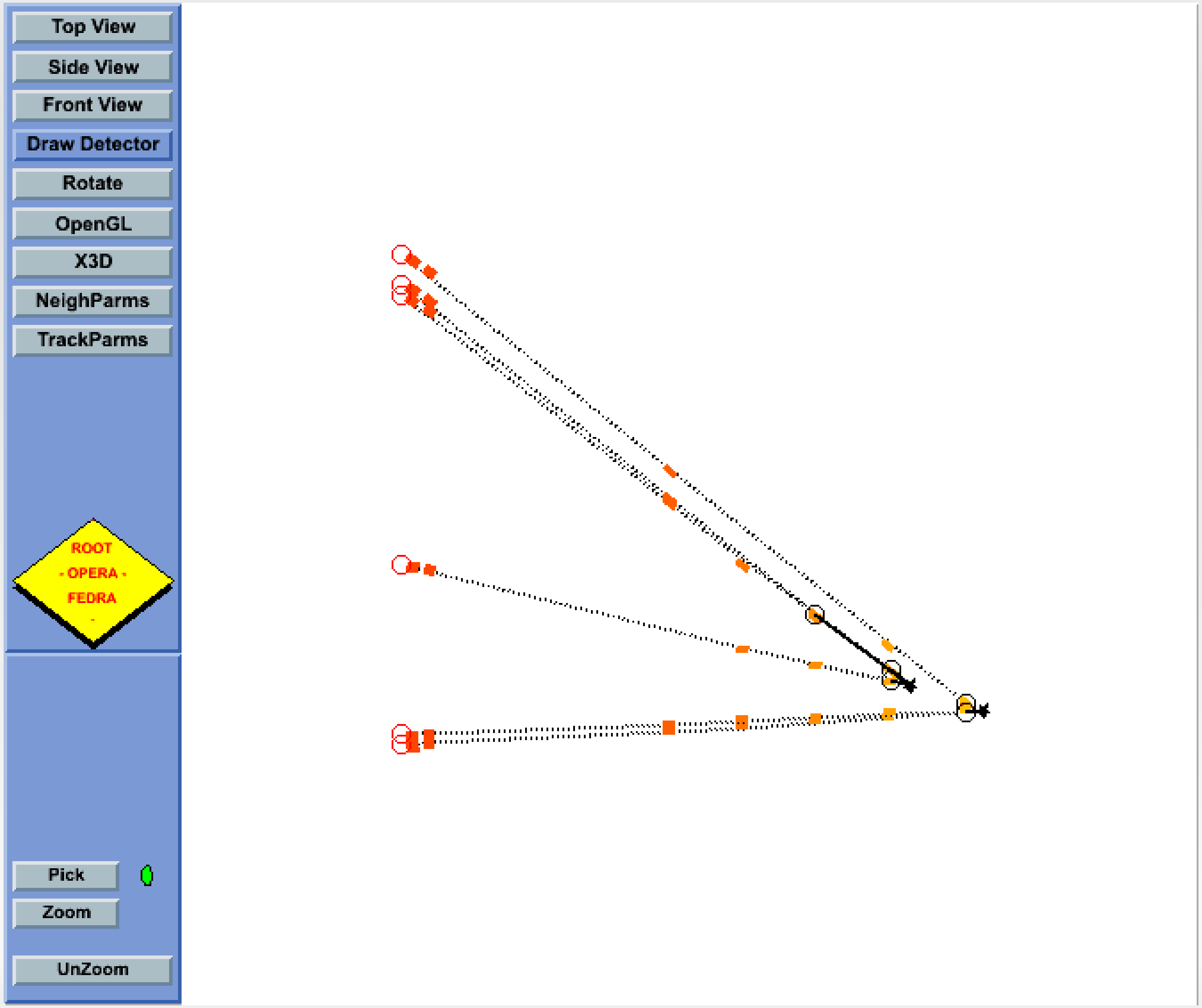
all vertex base-tracks have been manually confirmed

A 3-prong charm candidate (III)

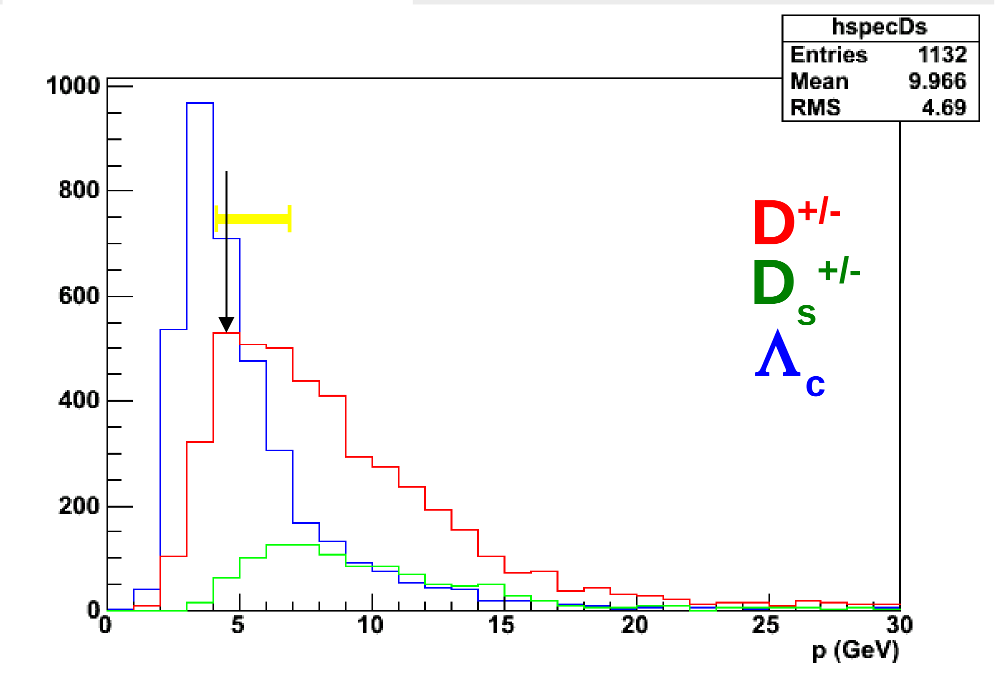


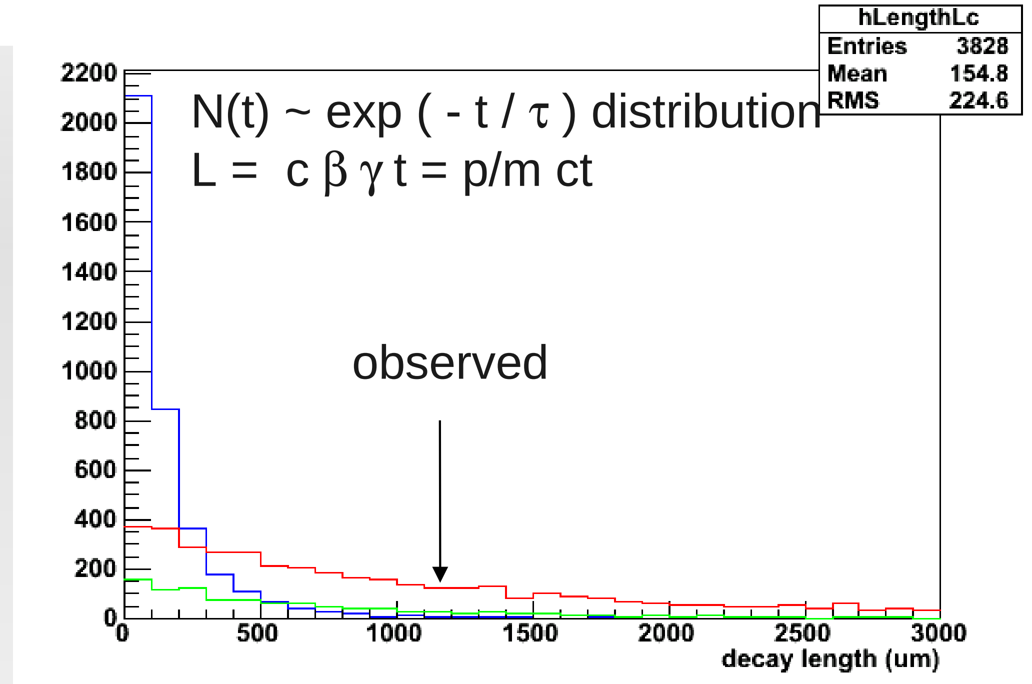
Angle in space btw
* parent base track
* VTX1-VTX2 vector
= 6 mrad : GOOD AGREEMENT

Animated display



Kinematic analysis and Monte Carlo expectations





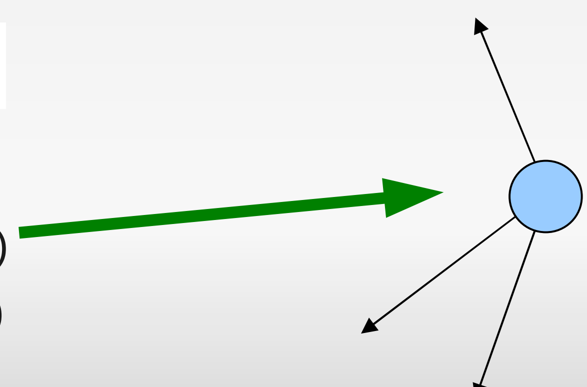
D interpretation favoured by measured decay length assuming expected spectra & relative abundances

After brick-brick connection and kinematic analysys of the downstream brick momenta were measured from multiple scattering:

$$p_1 = 2.4^{+1.3}_{-0.6},\ p_2 = 1.3^{+0.4}_{-0.3}\ \text{and}\ p_3 = 1.2^{+1.7}_{-0.4}\ \text{GeV}/c$$

$p_{tot} = 4.8^{+2.2}_{-0.8}$ GeV/c

Secondary tracks in the trasverse plane wrt parent flight direction

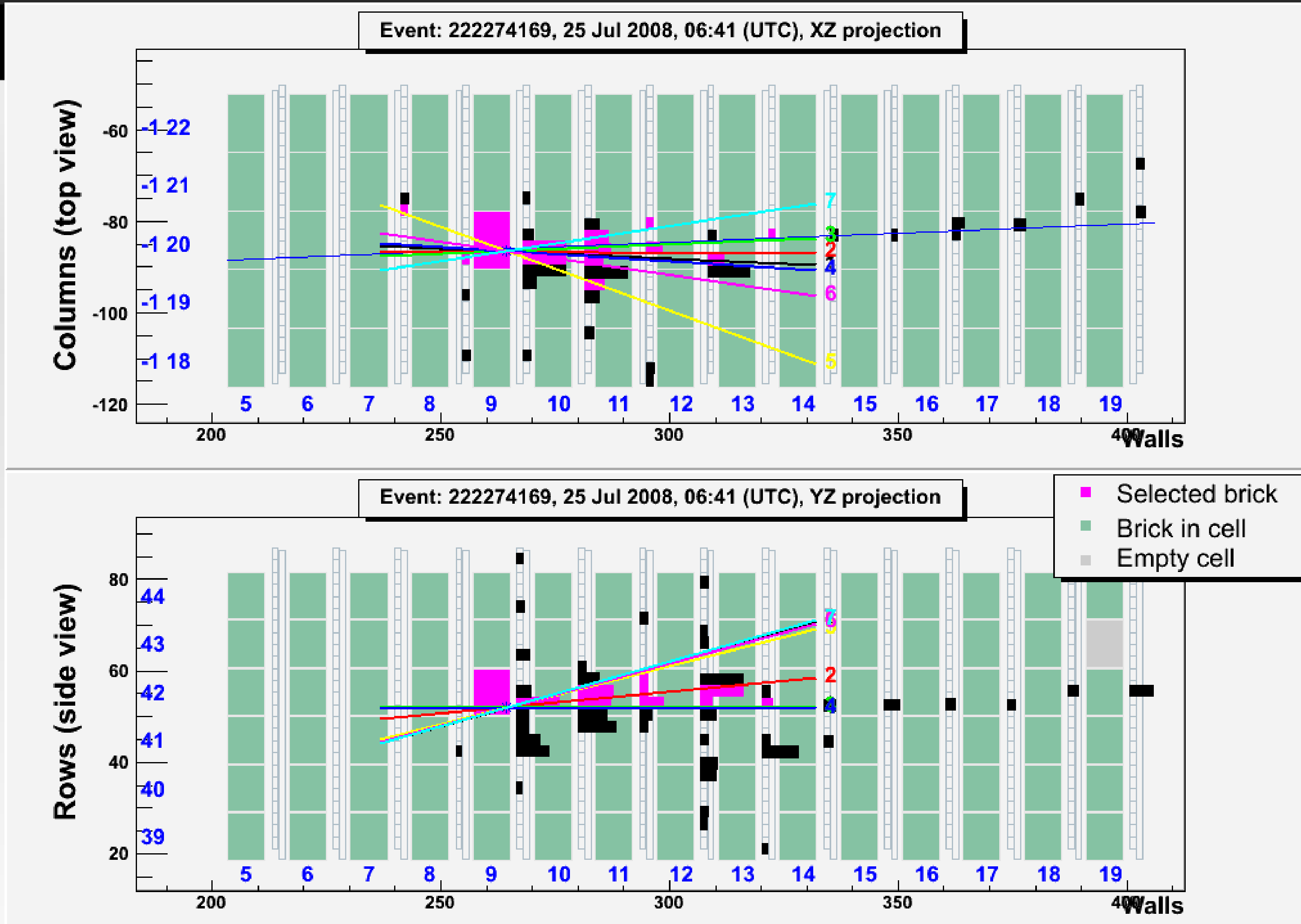


$D \rightarrow K\pi\pi$ hyp.: m = $1.1^{+0.2}_{-0.1}$ GeV/c^2 (missing π^0 ?)

$D_s \rightarrow KK\pi$ hyp.: m = $1.5^{+0.4}_{-0.1}$ Gev/c^2 (compatible)

Emulsion tracks superimposed to electronic deector

no clear evidence of missing tracks in emulsions



Brick finding information: Super module 2

	BrickId	Wall	Side	Column	Row	Prob	CS x	CS y
brick 1:	1127653	9	-1	20	42	0.82	-1.0	-1.0
brick 2:	1127679	9	-1	20	41	0.11	-1.0	-1.0
brick 3:	1127757	10	-1	20	42	0.06	-1.0	-1.0

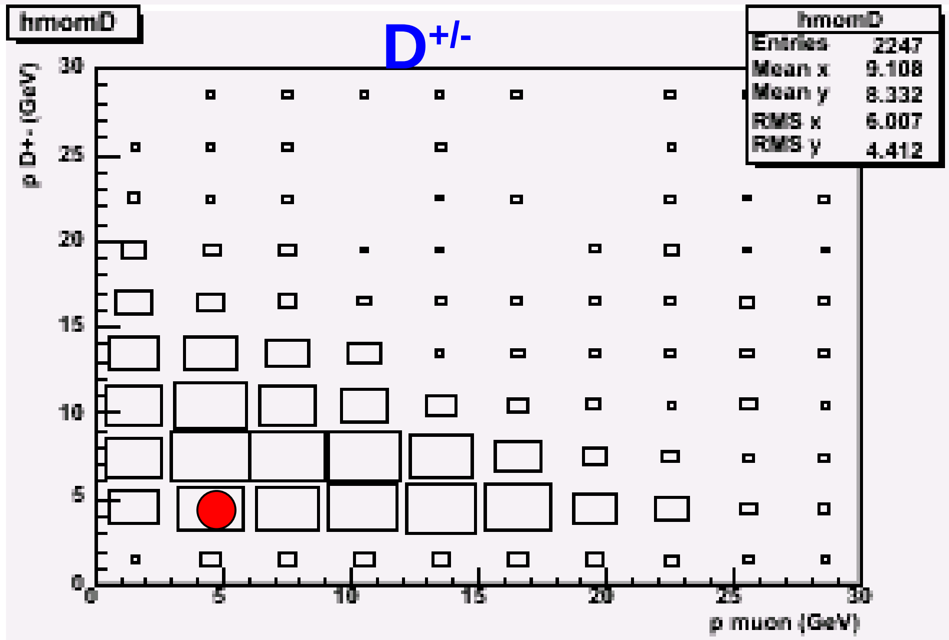
Muon track parameters: Mu-

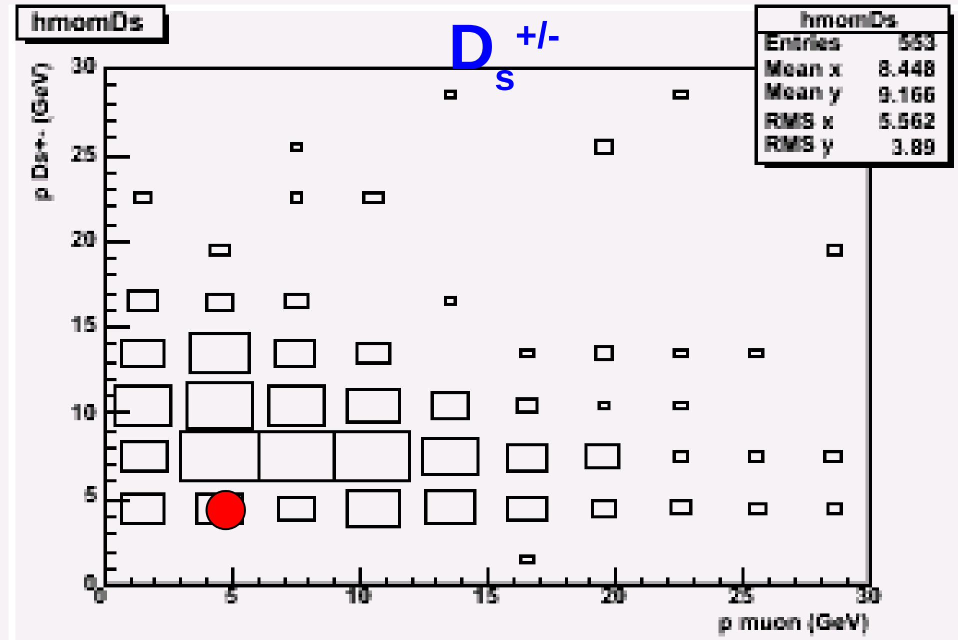
Momentum: 4.666 GeV/c

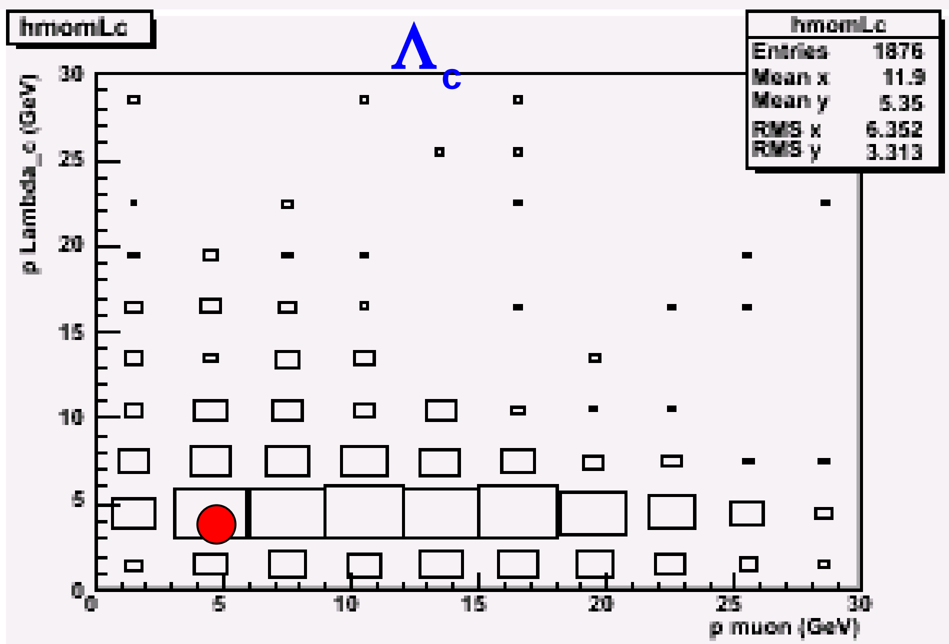
Angle XZ (rad): 0.041+/-1.571

Angle YZ (rad): N/A

Monte Carlo muon charm (anti)correlations







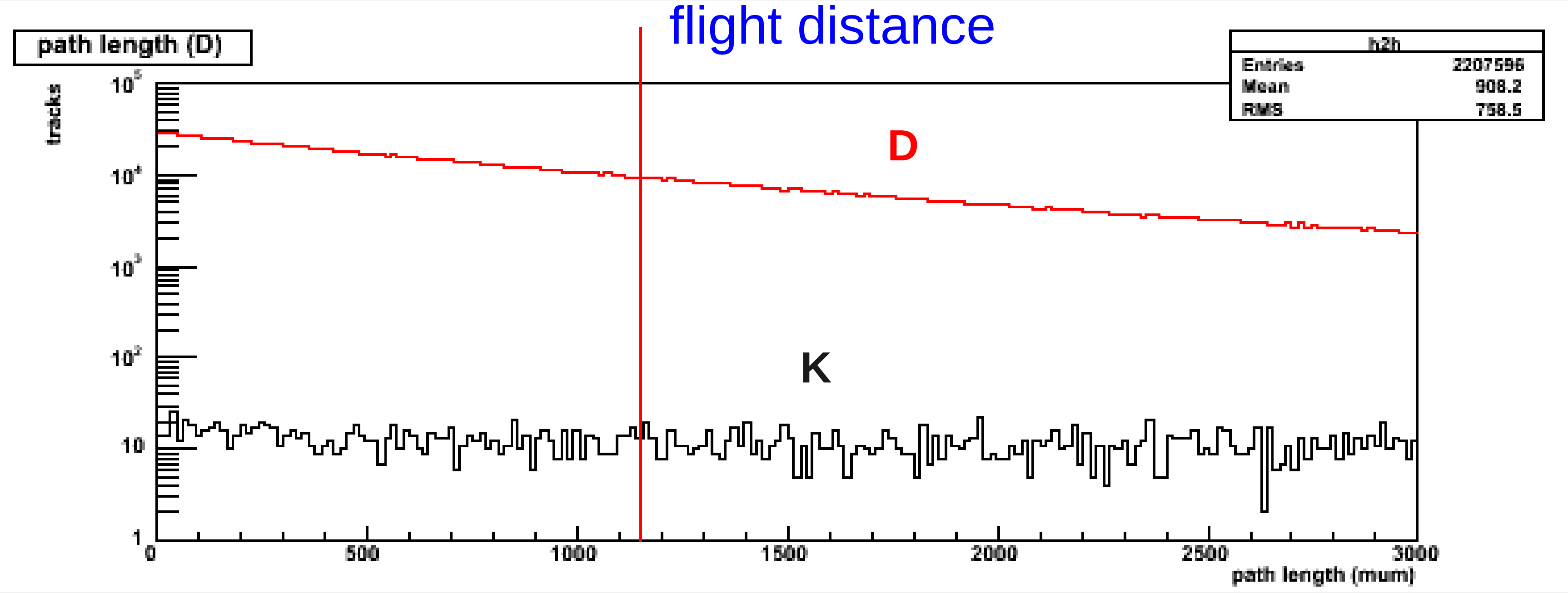
p(mu) = 4.7 GeV
from spectrometer: quite on the “peak”

p (charm):
from opening angles

NB. disk size has nothing to do with errors!

Backgrounds to charm interpretation

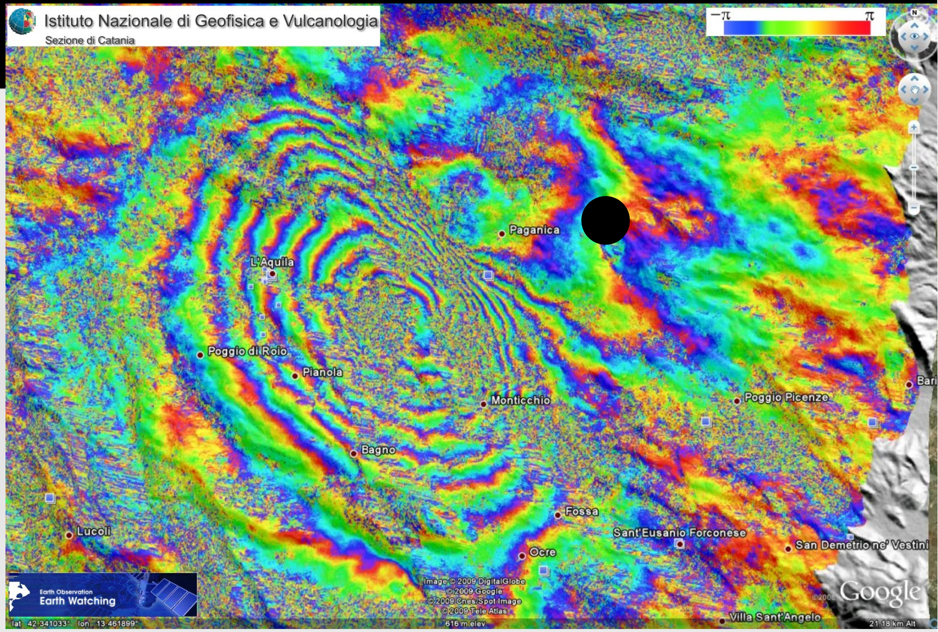
K decay in flight probabilty ~ 10^{-3}



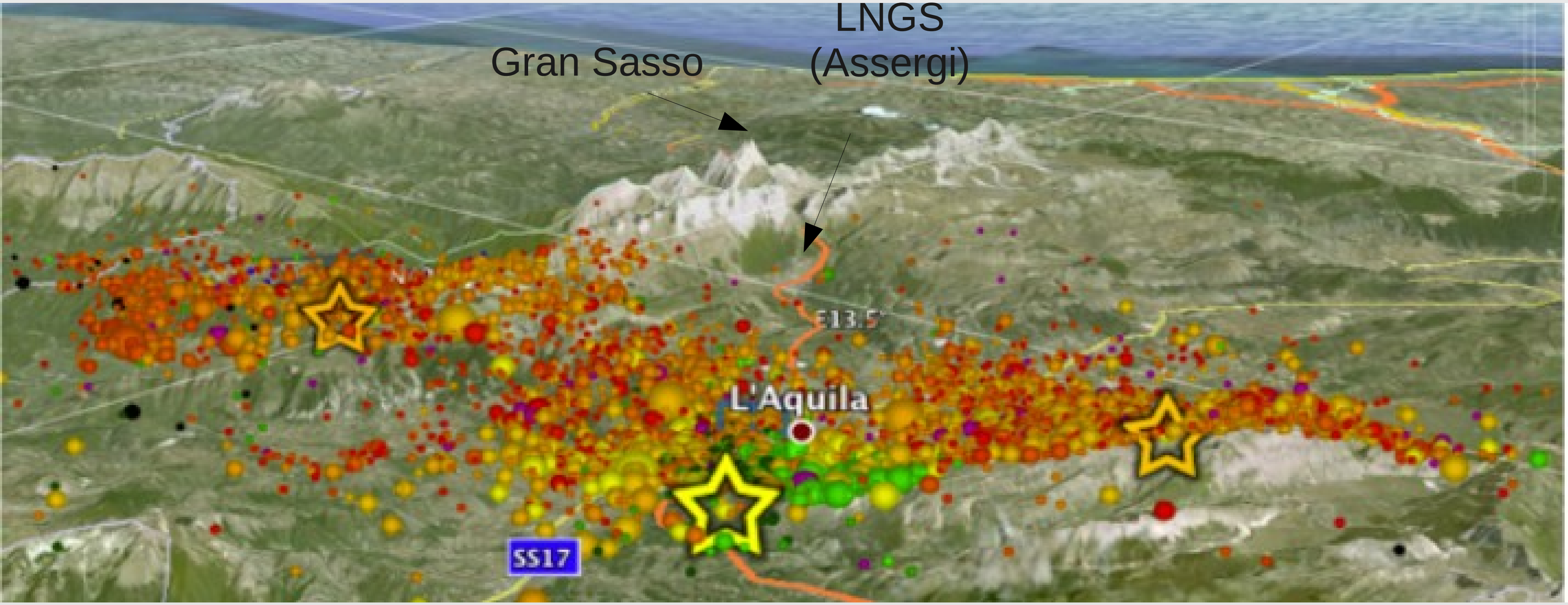
hadronic interaction probability ~ 10^{-6} (FLUKA)

The 6 April 2009 L'Aquila earthquake

interferogram



6.3 Richter, **298 people died**. Epicenter ~10 Km from LNGS. Thousands of aftershocks for weeks.



~4500 events

Earthquake impact

All people working at LNGS are safe but several people are homeless. (Severe damages at L'Aquila and various nearby villages).

No relevant infrastructural damages at LNGS or at the facilities underground (inspection two days after!). The detector looks in good condition. Some (rough) alignment measurements done do not show macroscopic problems. More refined checks are ongoing these days.

LNGS reopened on May 4 th (~ 1 month stop)

Main concern is about the manpower for running the experiments. INFN offered accomodations to cope with the emergency.

Start of 2009 CNGS run expected 14 may but at least two weeks of delay may be unavoidable.

Conclusions

- After a troublesome startup, CNGS has delivered a significant integrated intensity in 2008 (~$2*10^{19}$ p.o.t.). It represents the first real physics run for OPERA.
- The **construction of OPERA is over**; the subdetectors and the ancillary facilities are fully operative.
- Already after 4 months from the end of CNGS data taking, most of the analysis chain has been validated. A **crucial milestone** for this experiment.
- Plan to complete the last steps (vertex and kinematic analysis of the full sample) in a few months. **A lot of physics can be drawn from this sample**. Moreover, **7/10 of a tau** are waiting ☺
- The 6 April eathquake was a major drama for many people working at LNGS
- Impact on future activities seems less important that it could have been
- Perspectives for 2009 are good but not at the level of the design, yet (3.5 versus $4.5*10^{19}$ p.o.t. are expected this year). OPERA is a small fish in the storm of the LHC startup, but CERN confirmed recently its commitment in the LBL programme; at the same time, OPERA has the duty of **keeping pressure** on it for the success of the CNGS project.

Backup slides

Beam monitors

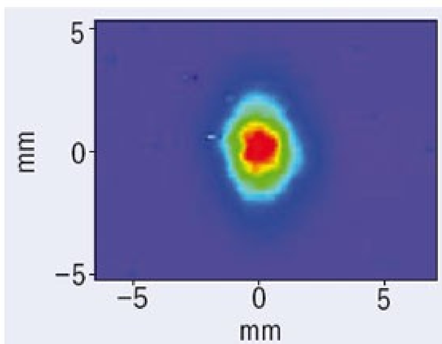
22+1 BPM (Beam Position Monitors)
button electrode monitors from LEP. tol ± 0.6 mm

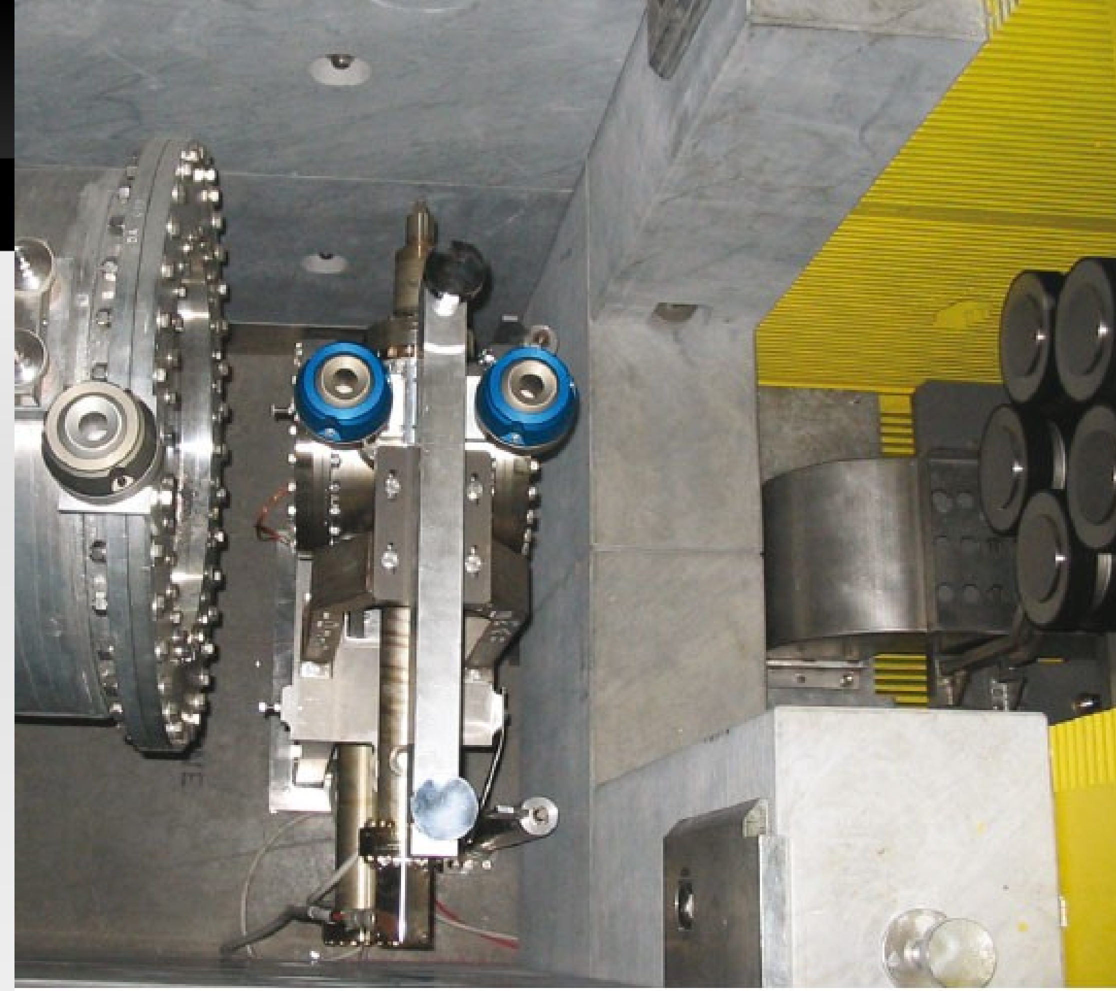
last BPM: tol ± 0.035 mm
strip-line coupler pick-up mechanically connected with target

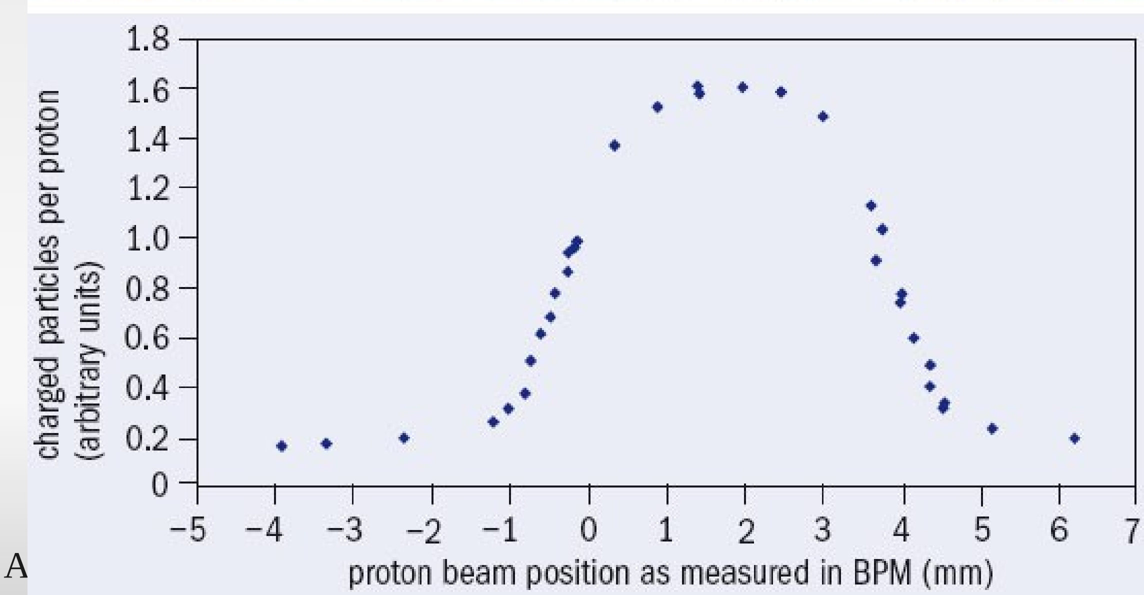
8 BPM (beam profile monitor)
OTR (optical transition radiation monitors)
75 µm C(high.int) 12 µm Ti (low int.)

2 BCT (beam current transformer):
beam intens. at start and end.

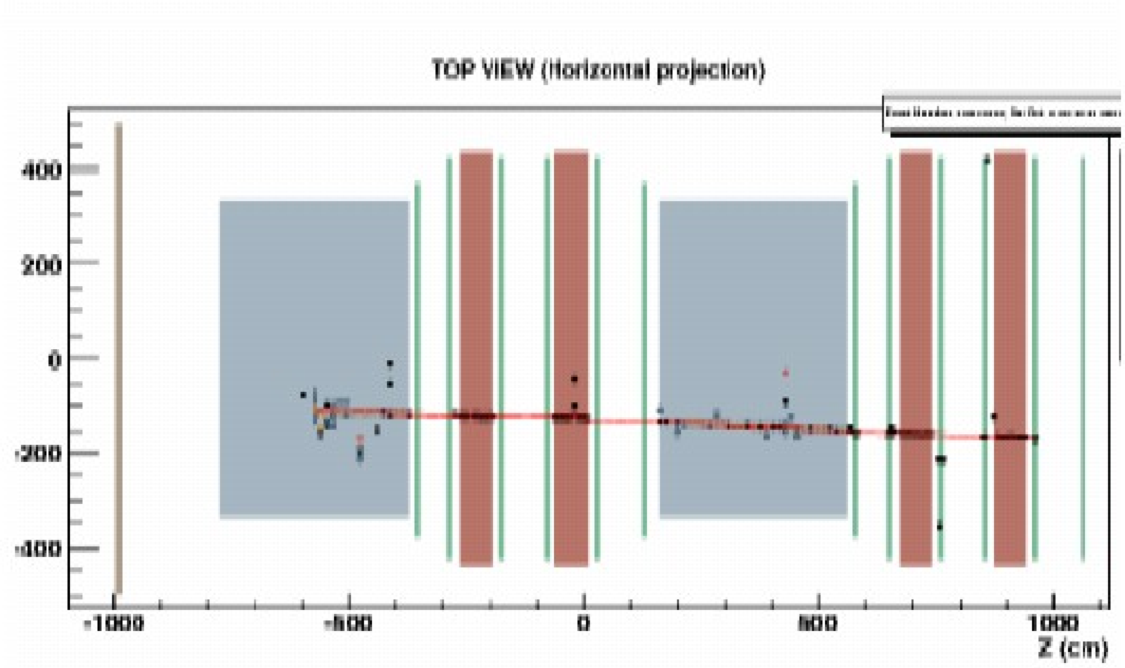
18 BML (beam loss monitor)
N_2 filled ioniz. chambers



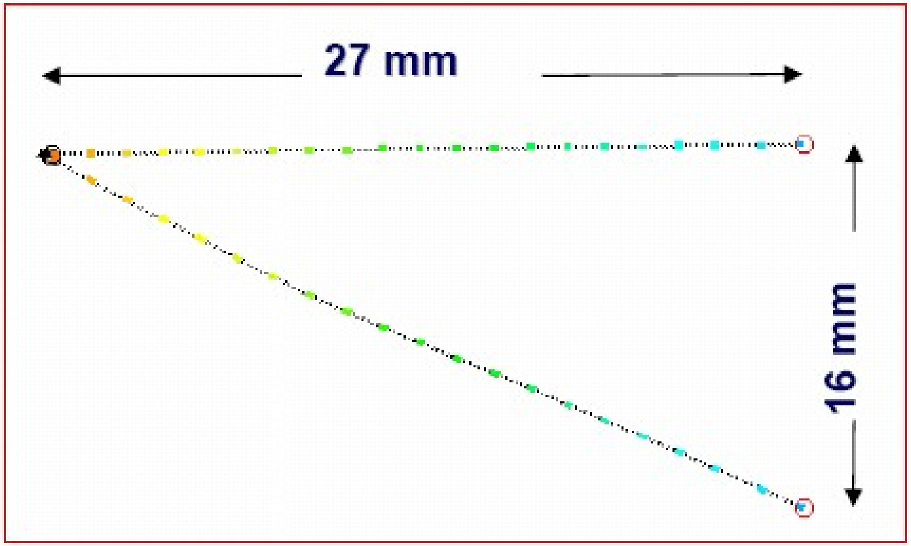


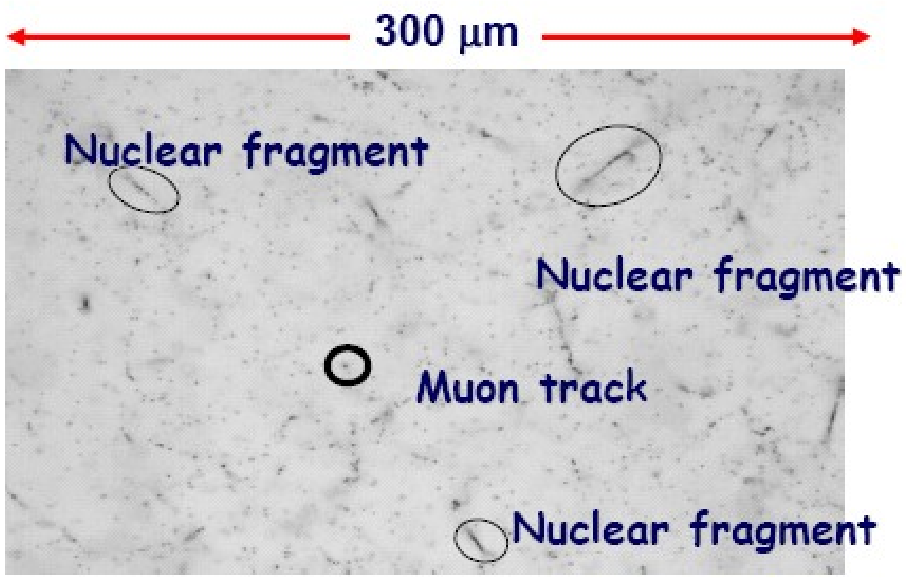


A ν_μ quasi-elastic CC interaction



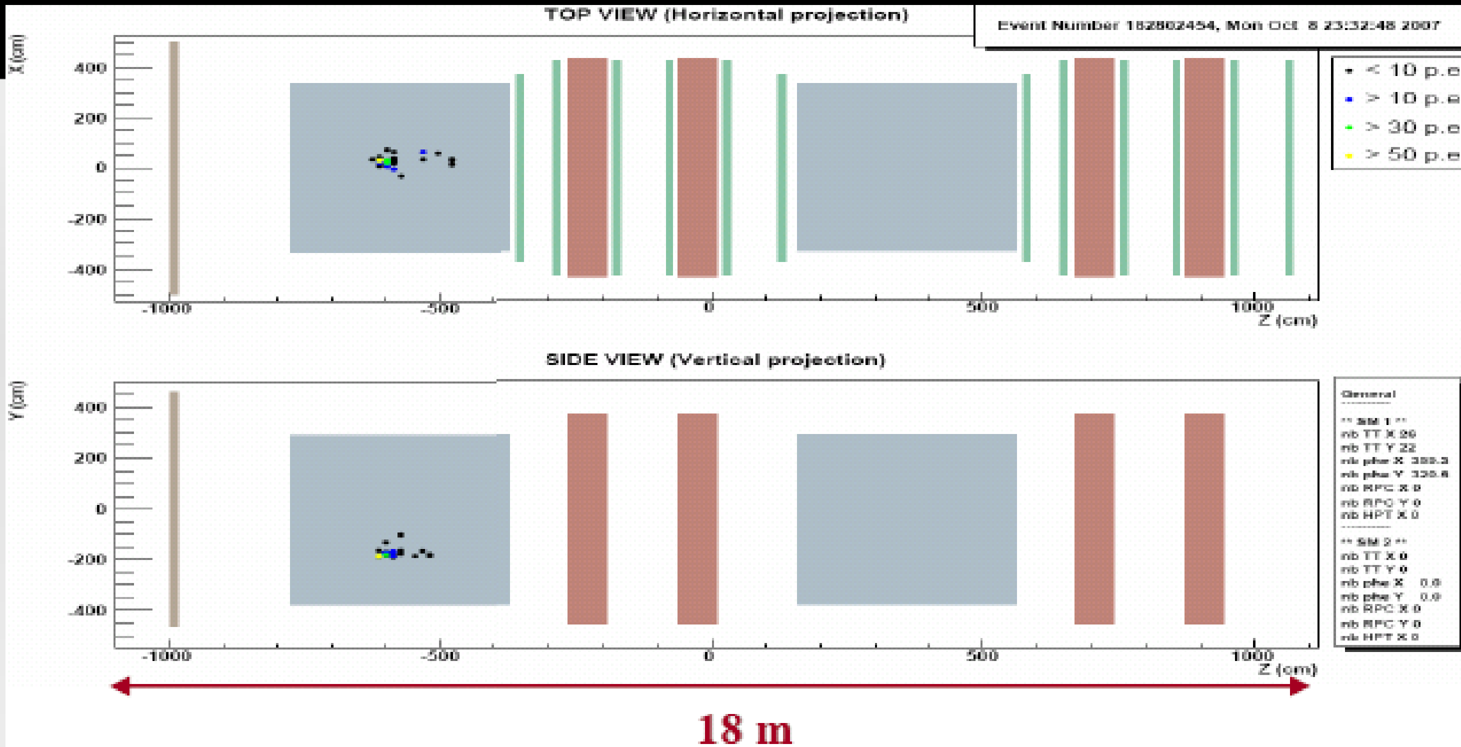
Event 179673325 QE-like topology



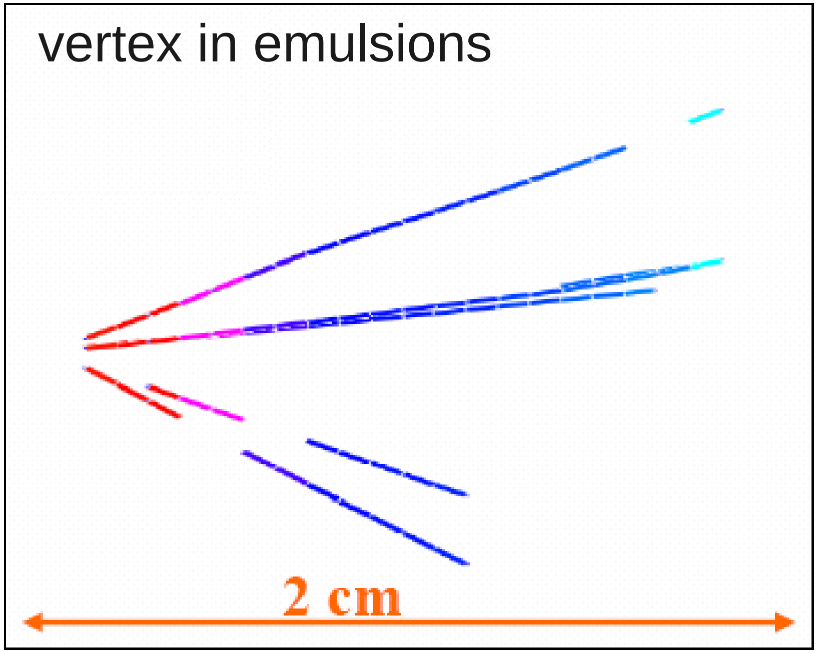


The visual inspection allows the observation of nuclear fragments and the classification of the event as DIS

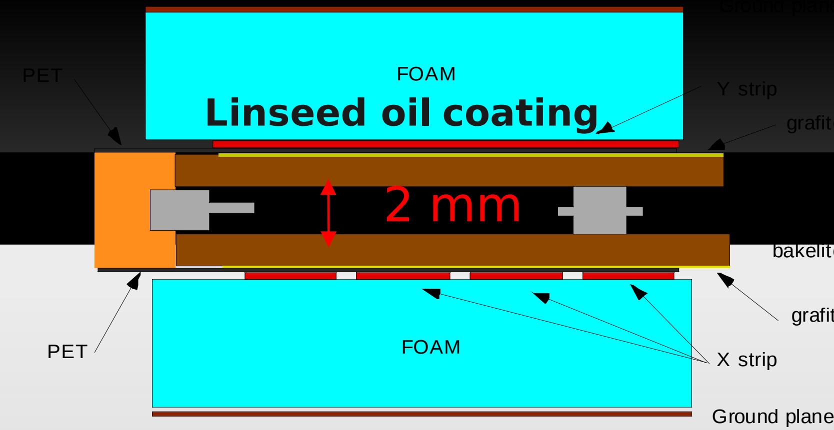
A ν_μ NC

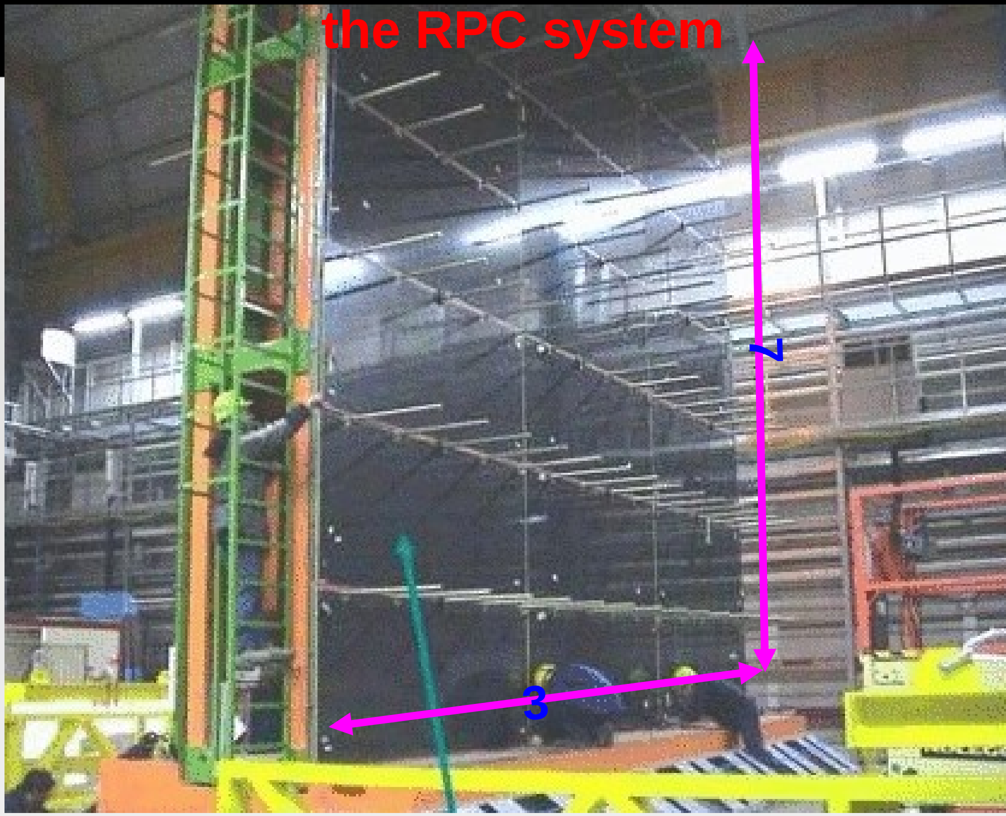


due to the lack of a clear vertex pointing high energy track ~> larger area to be scanned in Changeable Sheets

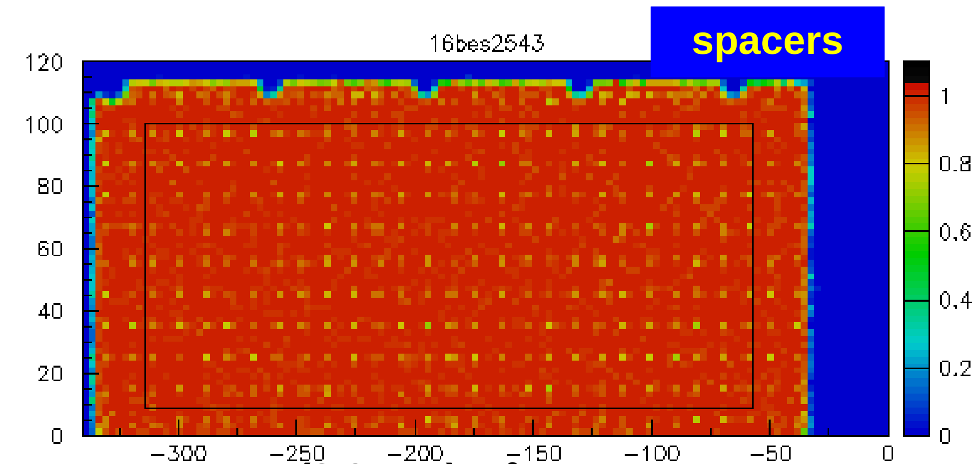


The inner trackers

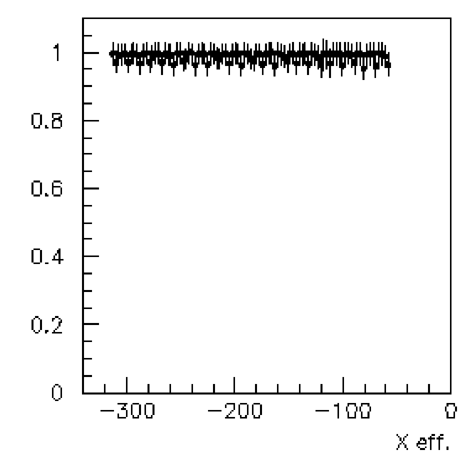


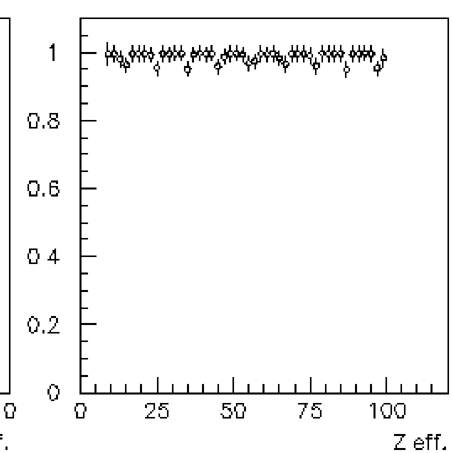


cosmic ray efficiency map for 1 chamber (at surface!)



- (2.9×1.1) m^2



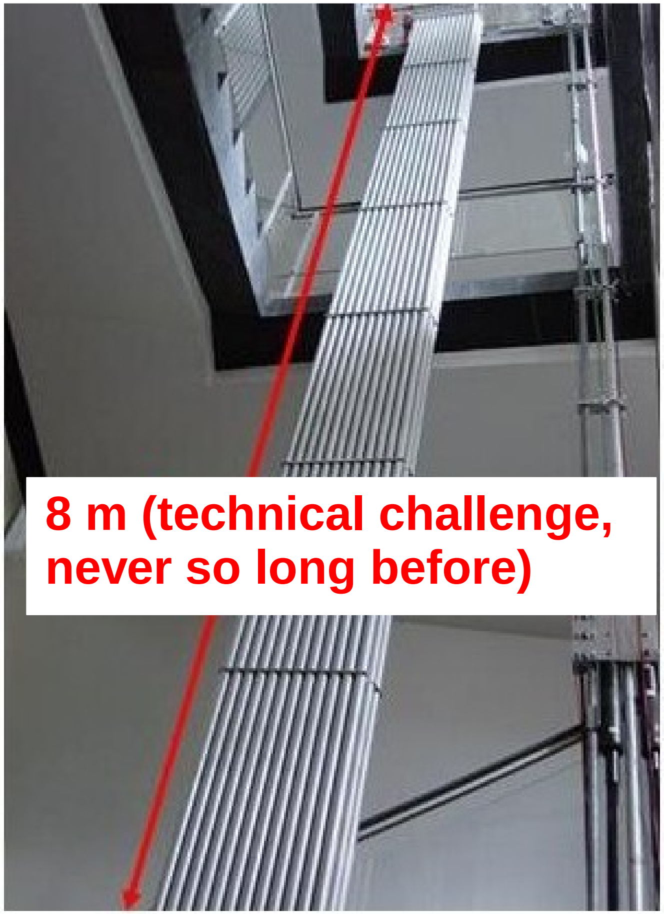


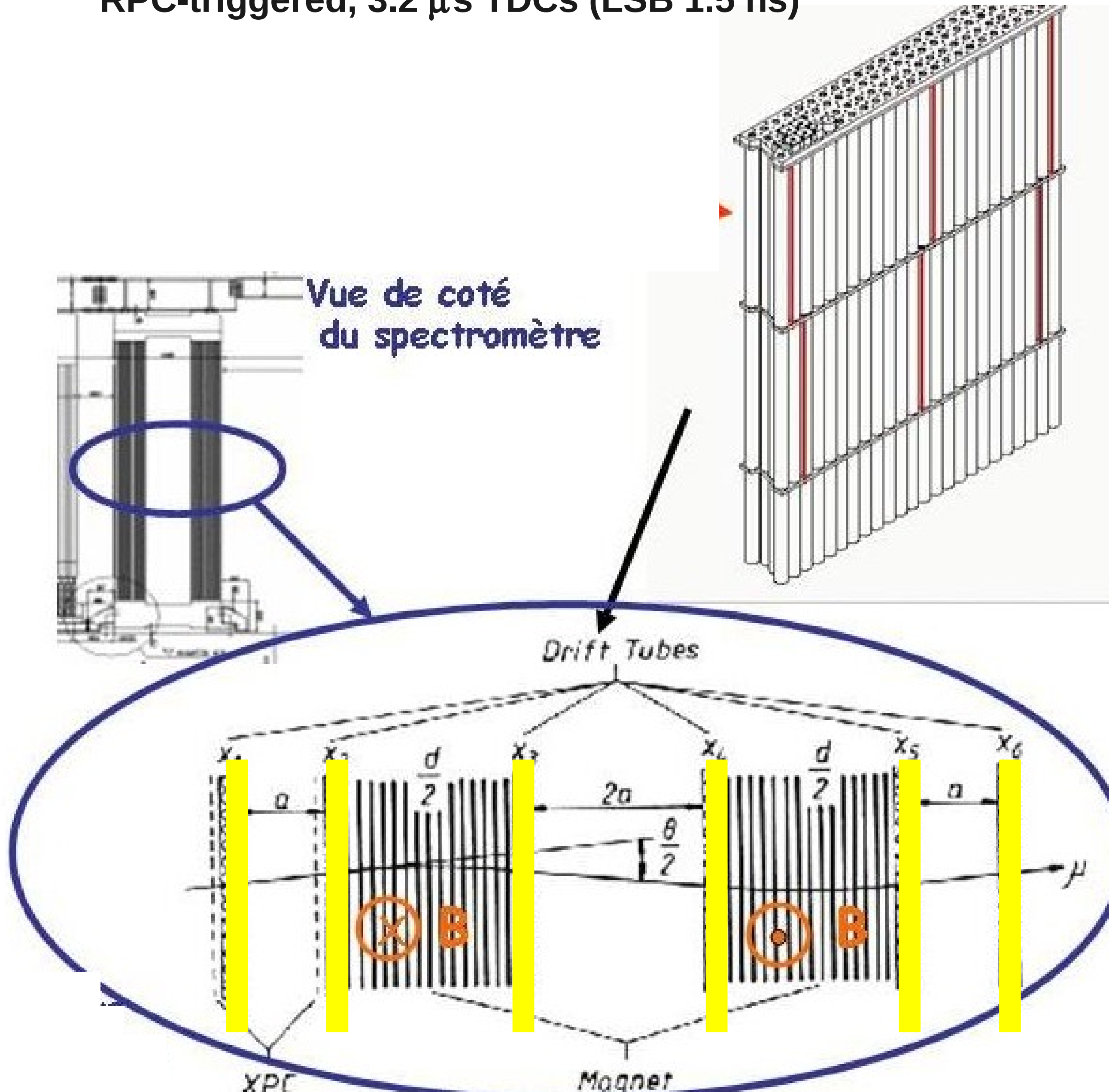
- 462 (Bakelite RPC) + 42 (XPC) x 2 ~ 1000
- tot. surface: 3326 m^2
- digital channels: ~ 27000
- strip pitches: 2.6, 3.5 cm (Vert, Hor)
- Front-End Boards: 468
- Controller Boards: 52
- Gas: 76%Ar+20%TFE+4%Iso+0.6%SF$_6$
- 8 kV/2mm

The precision trackers

38 mm diam. 8 m long tubes. 0.85 mm thick. 45 μm wire.
4 layers modules (staggered)
10.000 drift tubes
Ar/CO_2: 80/20% @ 1005±5 mbar (80 m^3 exchange 1m^3/h)
RPC-triggered, 3.2 μs TDCs (LSB 1.5 ns)

prototype in Hamburg

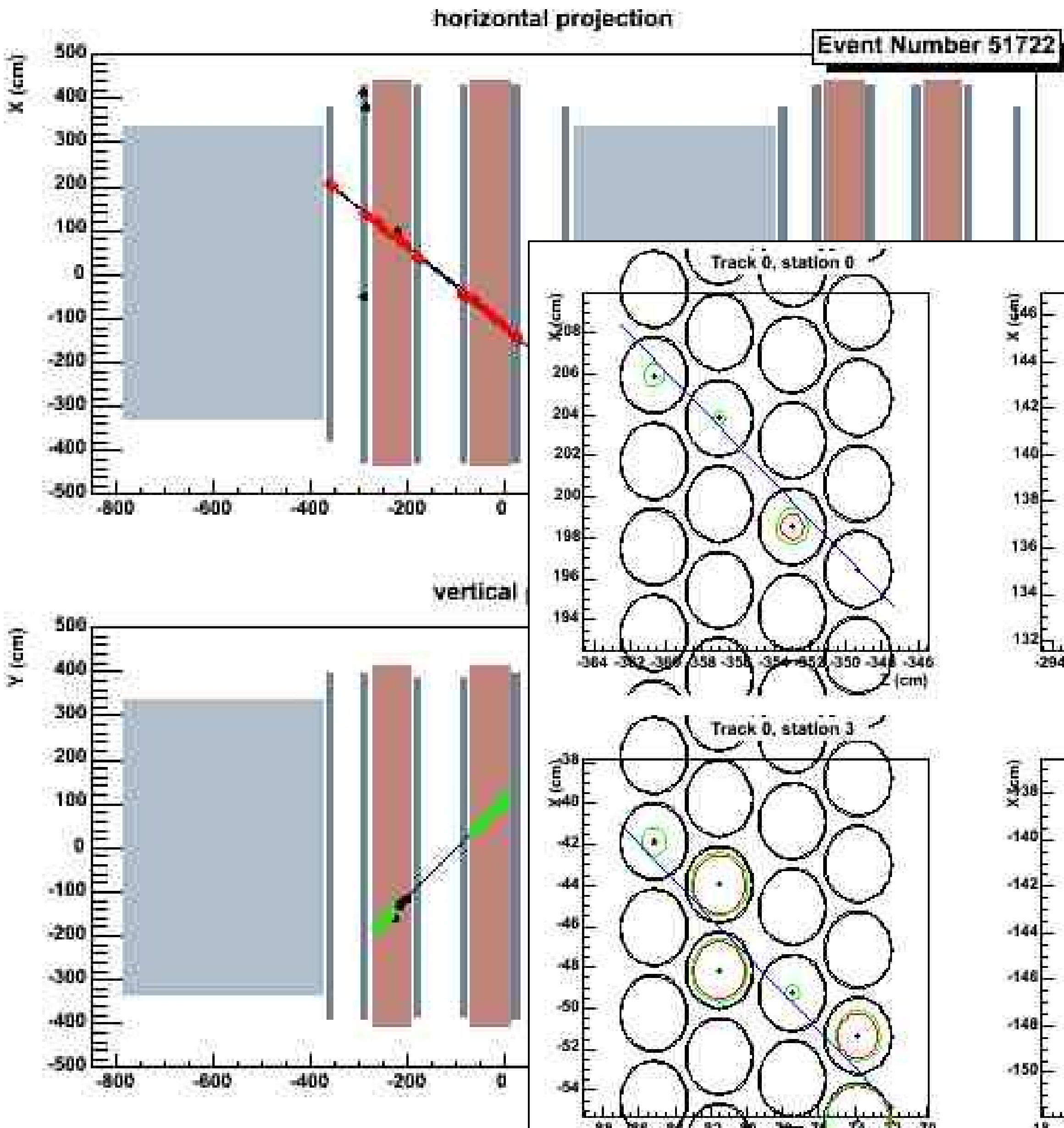




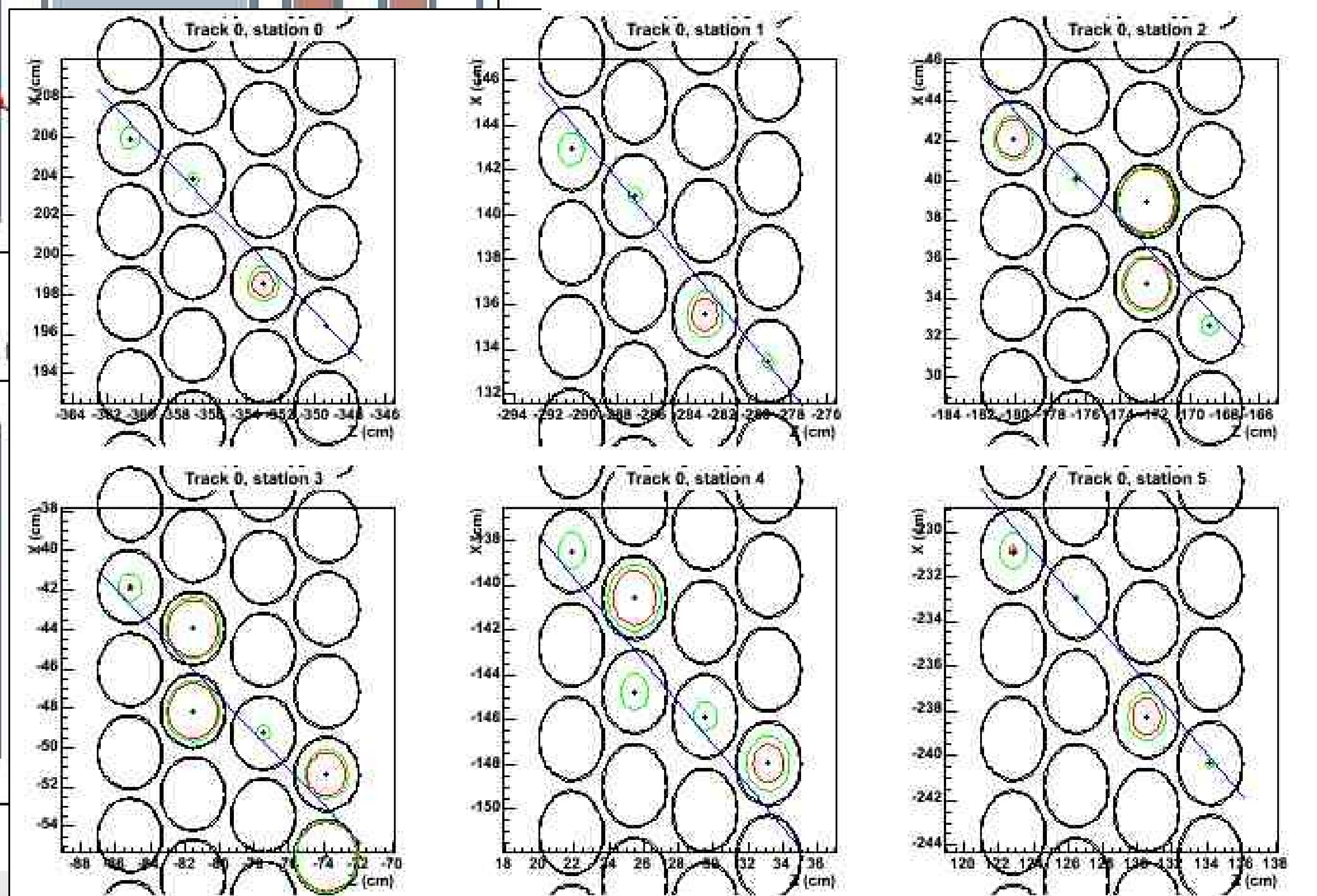
spatial resolution < 300 μm

single tube hit eff > 98%
+ correct r ~> 90%

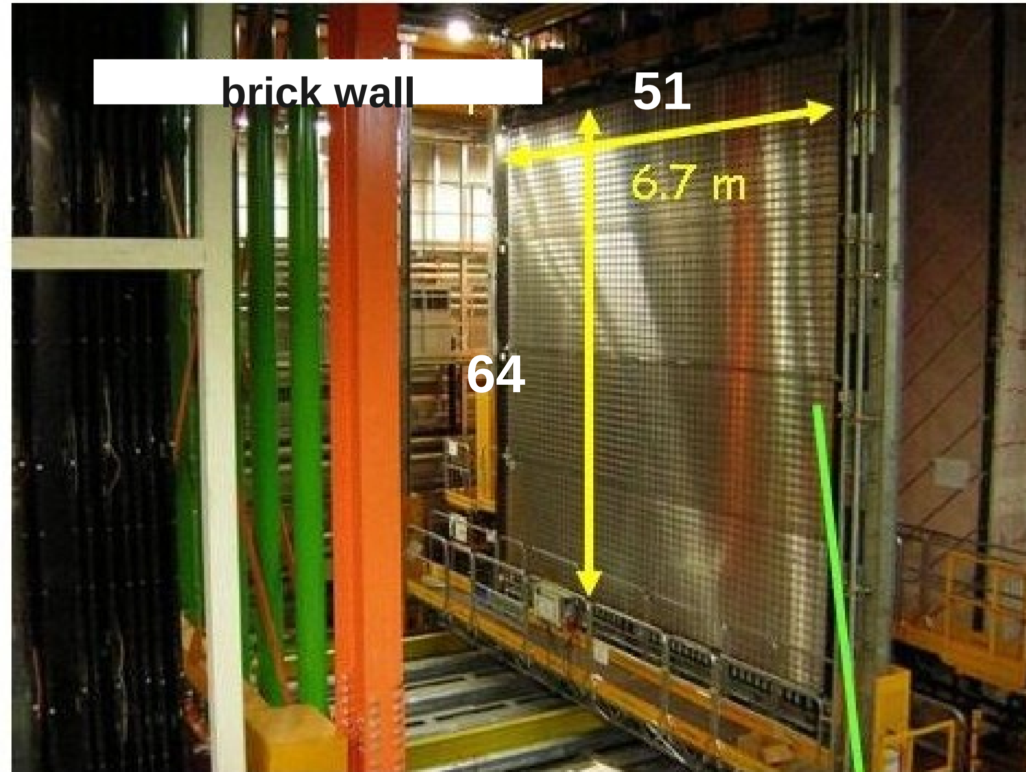
The precision trackers at work



A cosmic ray event crossing all the 6 stations (24 layers). Readout in the bending plane only



Target tracker plane photo-grammetry

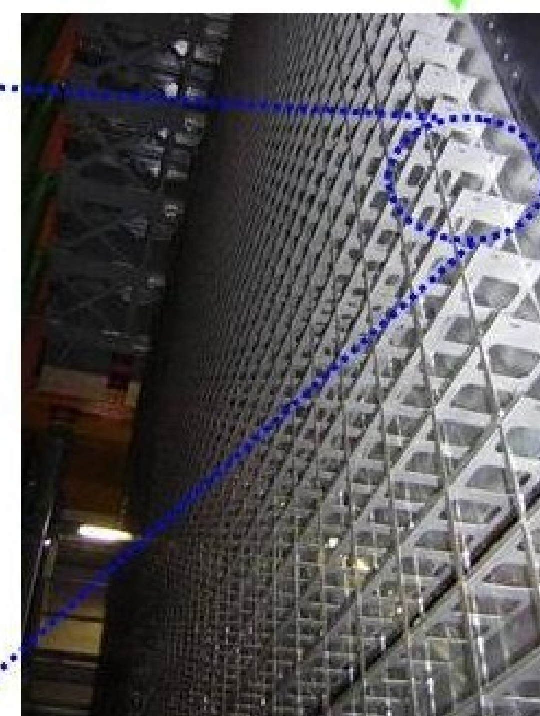


The target wall

51 x 64 bricks (27 tons)

light (0.5 % of weight)

robust structure



Radioactivity checks on lead

Needs of long-term (5-10 years) compatibility with the emulsions:

- low radioactivity
- no chemical reactions

$^{210}Pb \rightarrow {}^{206}Pb + \alpha\,(5.3\ \text{MeV}) + \beta\,(1.2\ \text{MeV})$

maximum tolerable rates: 20 α , 100 β /cm^2 /day

pure lead too soft to be laminated and cut precisely
→ add Calcium (0.03 to 0.07%) or Antimony (2.5%).

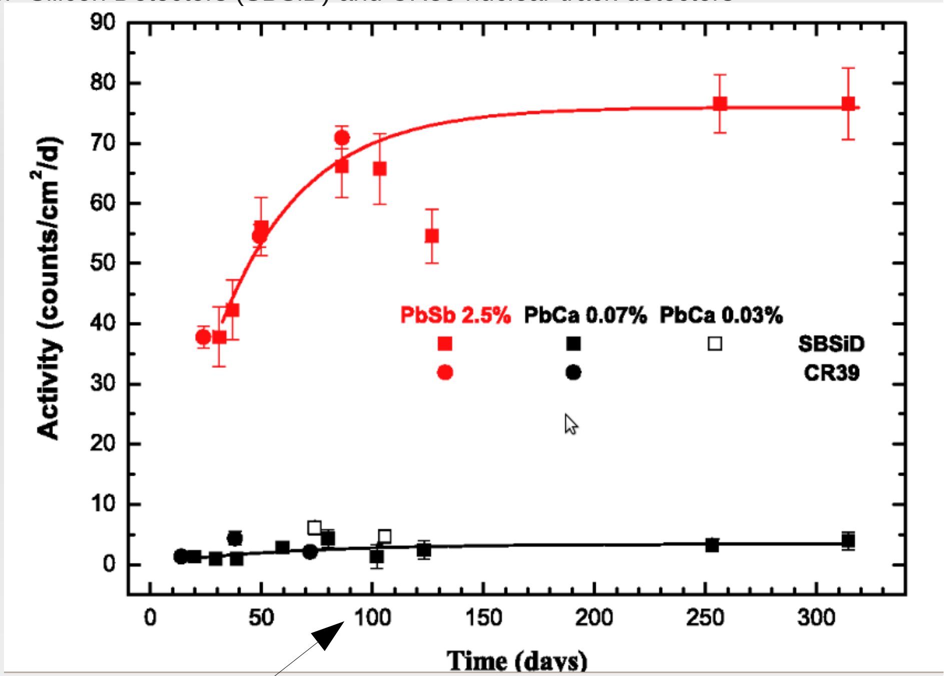
PbCa or PbSb alloys

- chemical long term compatibility tests (heating up to 40° C):
  - with vacuum packing PbCa produces an increas of random grains(fog), PbSb is safe.
  - with packing in air both safe (reduced concentration of poisoning gas) ← chosen

- α activity
  - much larger in PbSb plates than in PbCa (and increasing with time)

25 μ m long and 2.5 μ m thick All ~ same length:
emitted a t surface! 5.3 MeV:
migration to the surface of ^{210}Po (→ ^{210}Pb → ^{210}Po → ^{206}Pb).

Surface Barrier Silicon Detectors (SBSiD) and CR39 nuclear track detectors



The beam composition and radial profile at LNGS

$(\nu_e+\bar{\nu}_e)/\nu_\mu$	***0.9%***
$\bar{\nu}_\mu / \nu_\mu$	***4 %***
ν_τ ***prompt***	***negligible***

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

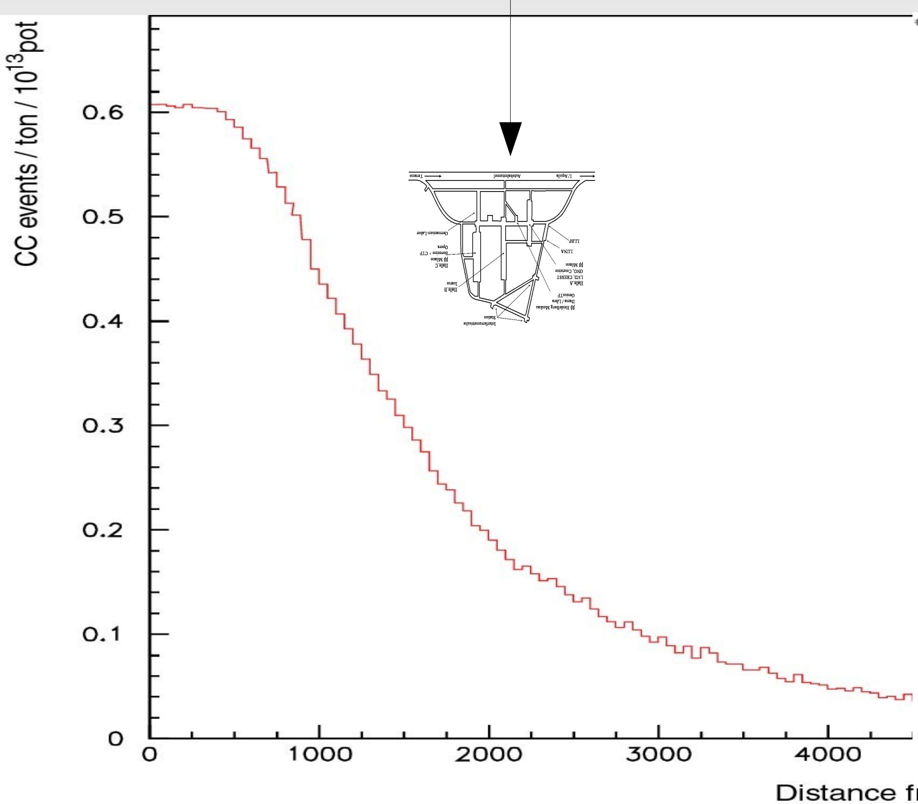
(from D_s)

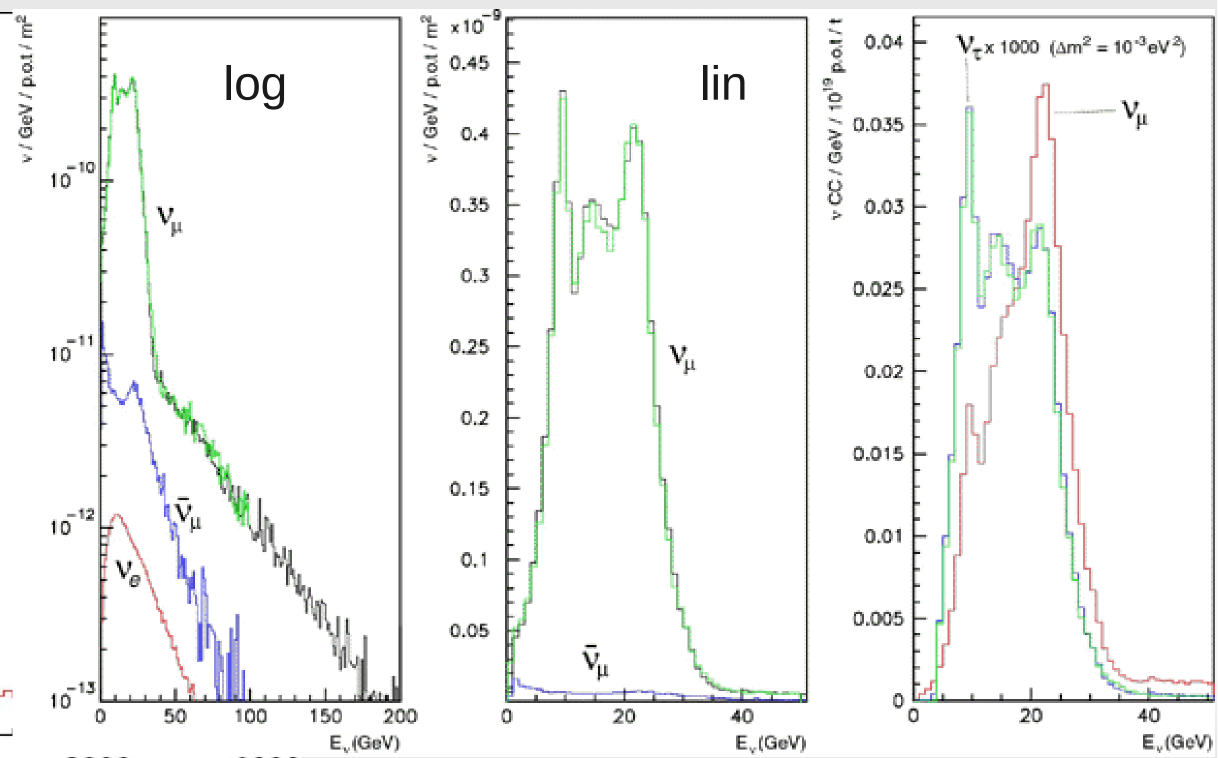
FLUKA based simulation

LNGS (approximately to scale)

fluxes

interactions



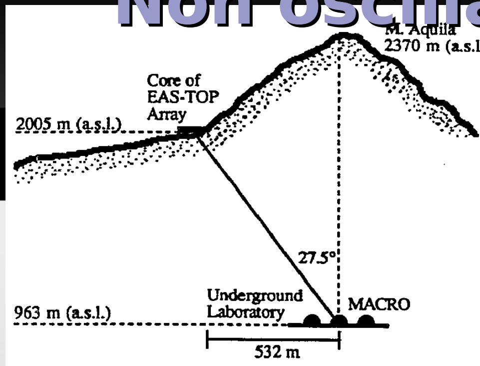


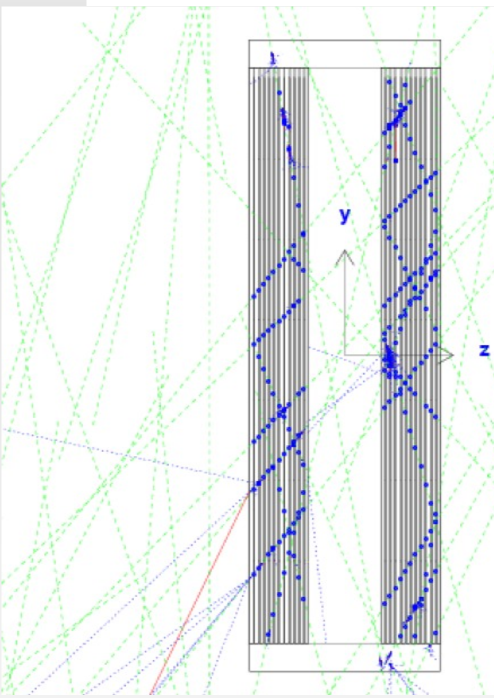
~2 Km

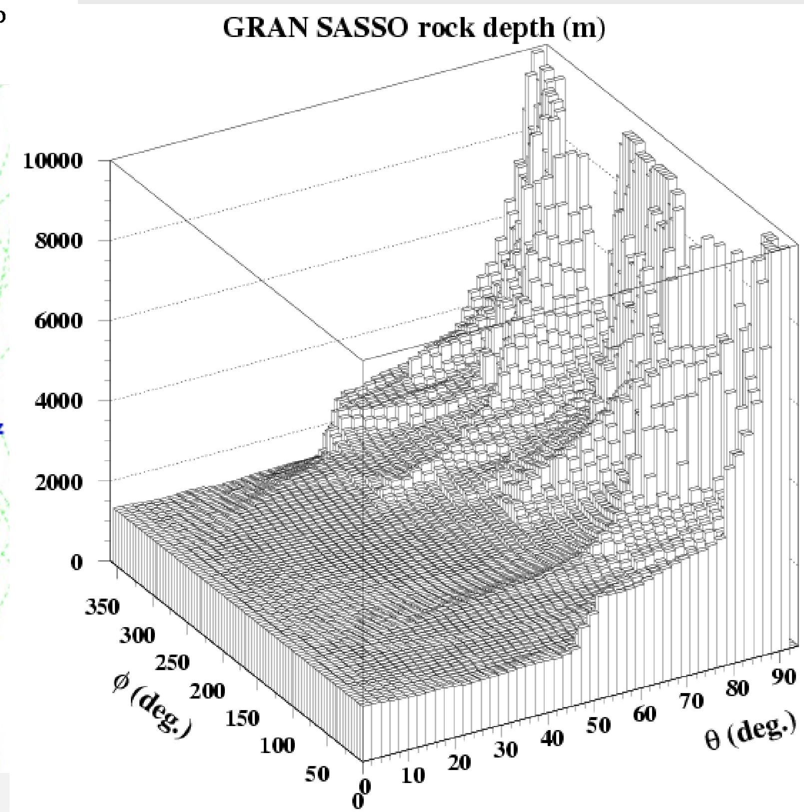
http://www.mi.infn.it/~psala/Icarus/cngs.html

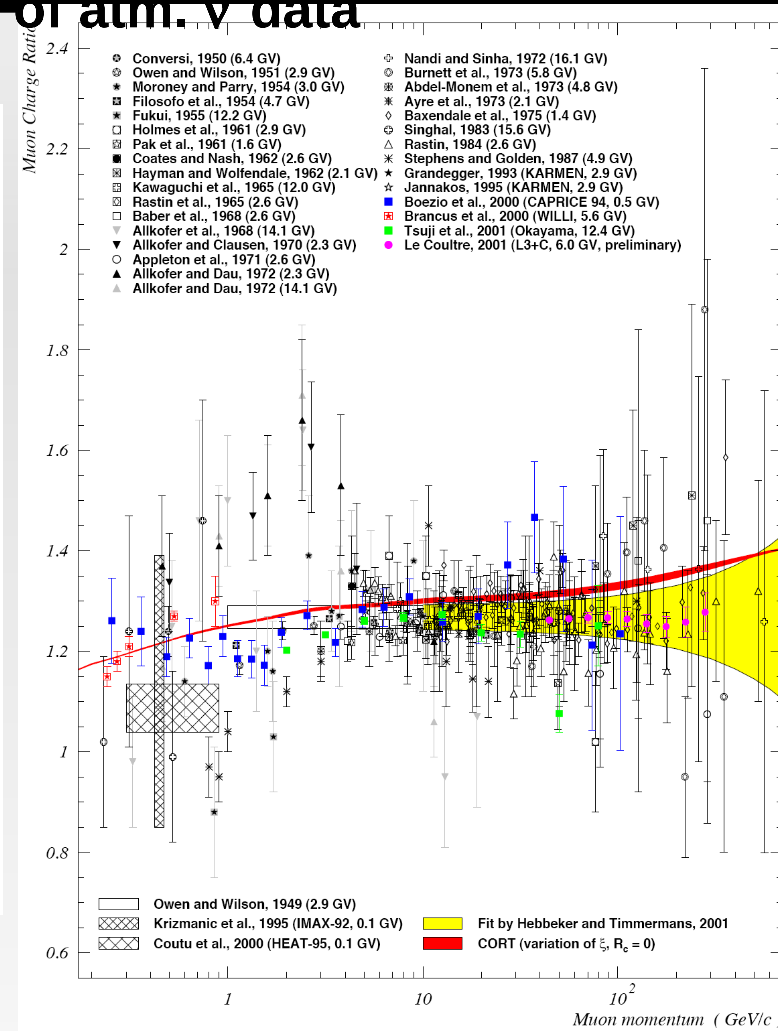
Non oscillation physics: high-E μ charge ratio – cosmic ray composition studies

– hor. muons: systematics of atm. ν data

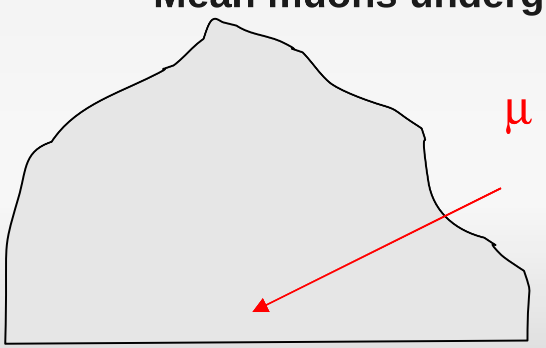








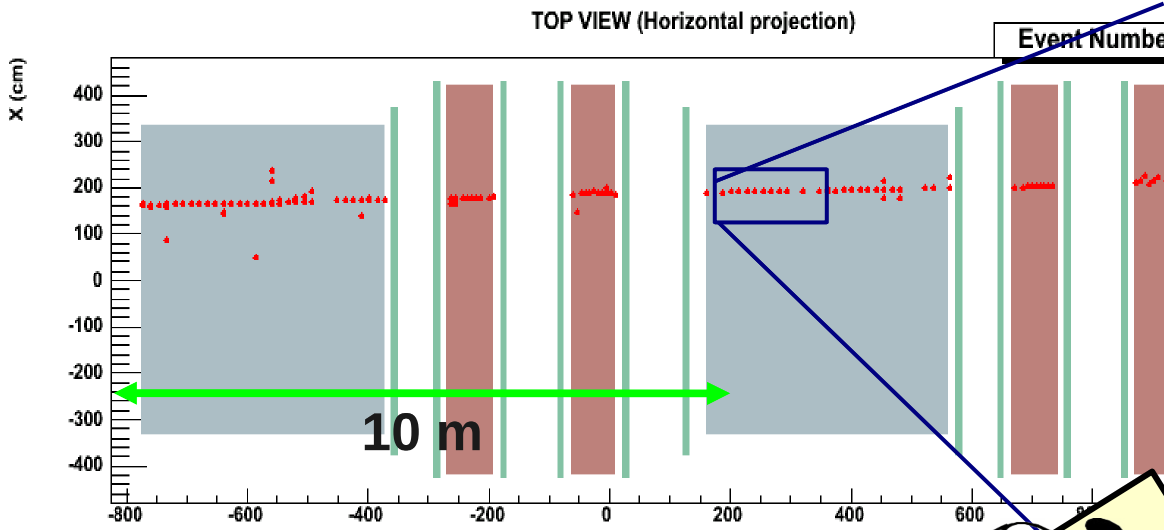
• Mean muons underground energy: 300 GeV

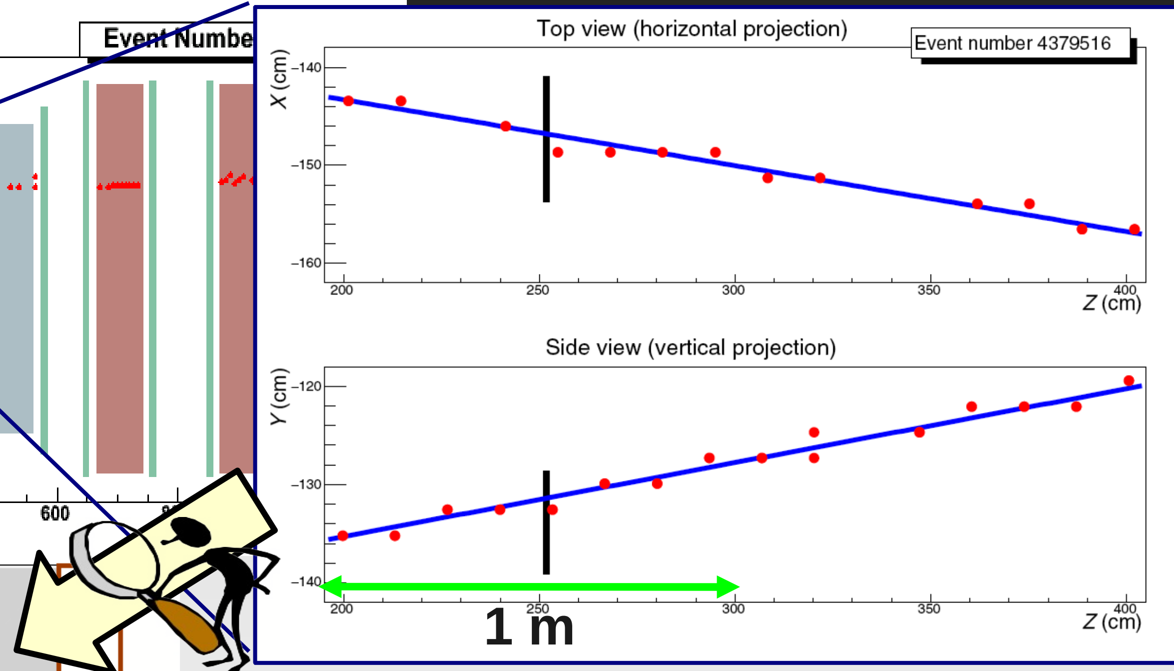


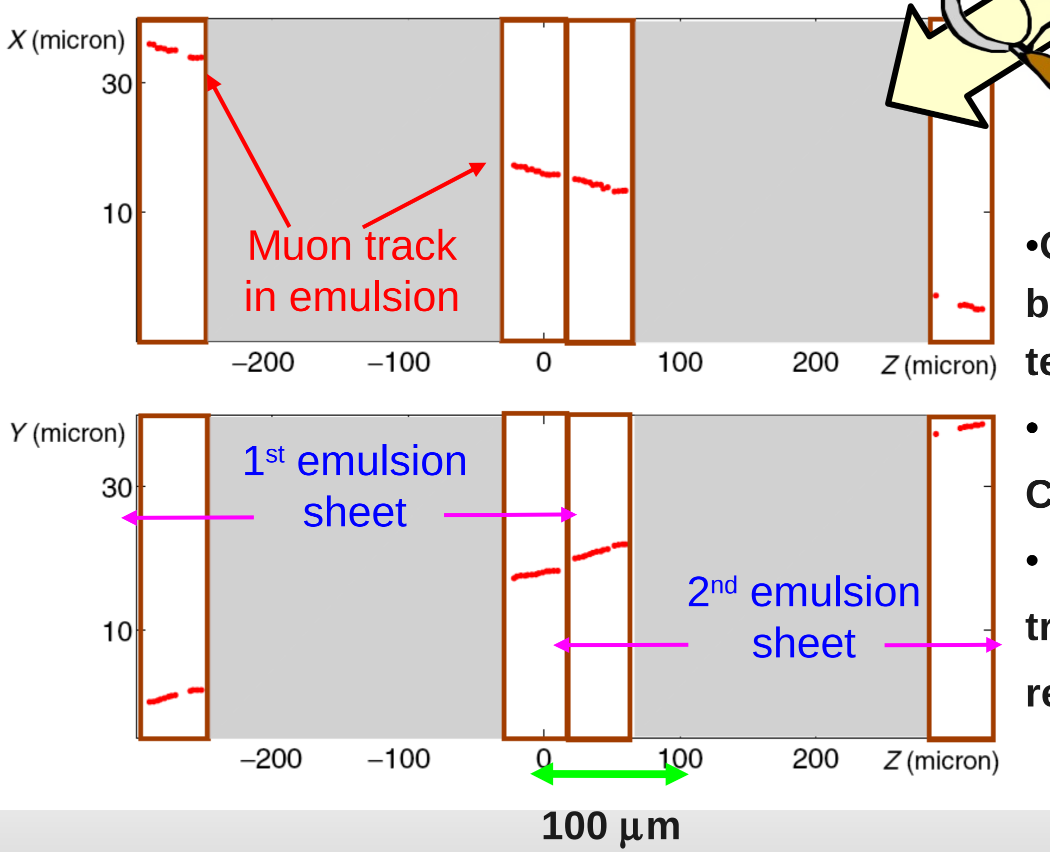
threshold energy at LNGS ~ 1 TeV

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

Target Tracker - CS connection

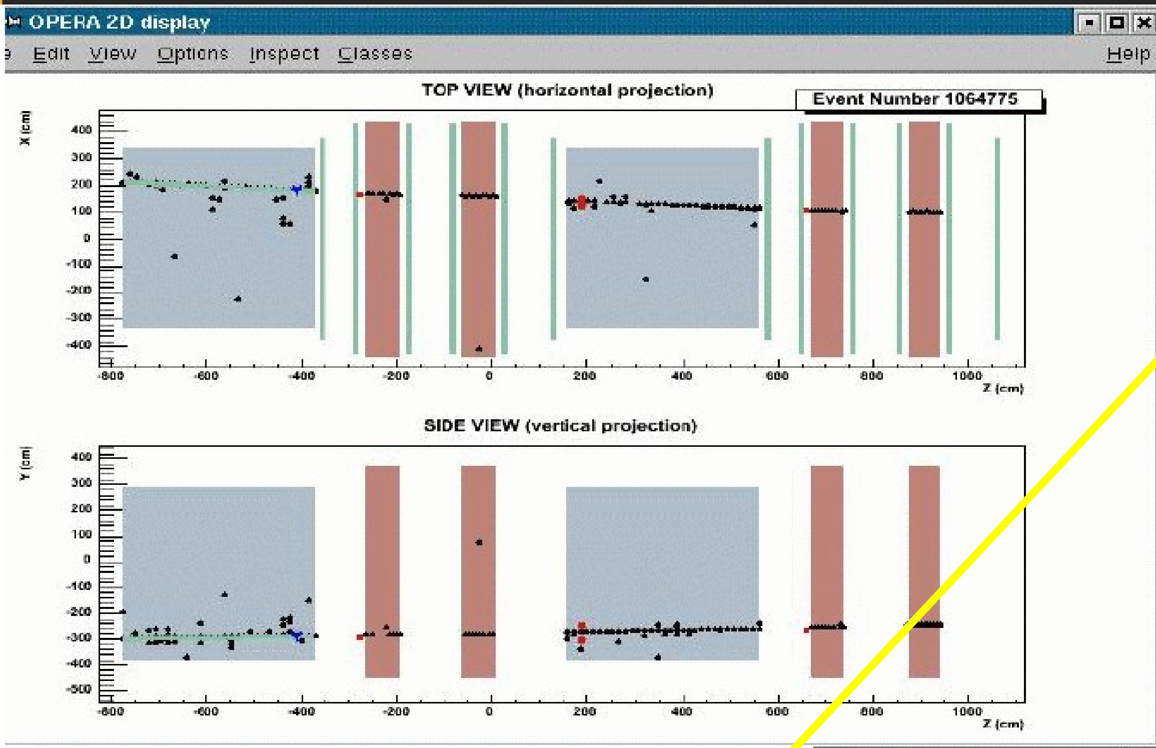






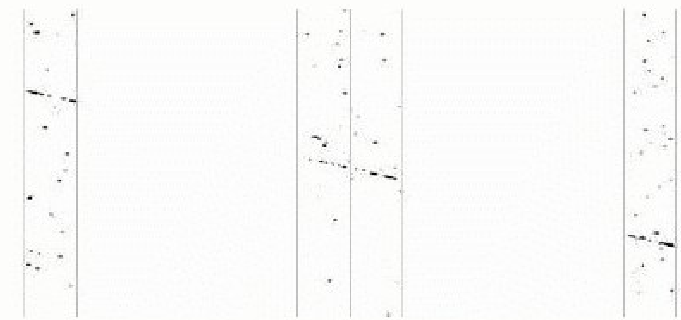
- One target wall partially instrumented with dummy bricks with real Changeable Sheet (CS) doublet to test the Target Tracker to Brick connection
- Muon tracks predicted by target tracker found in the CS doublets.
- Angular difference between prediction and found track <10 mrad, dominated by electronic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

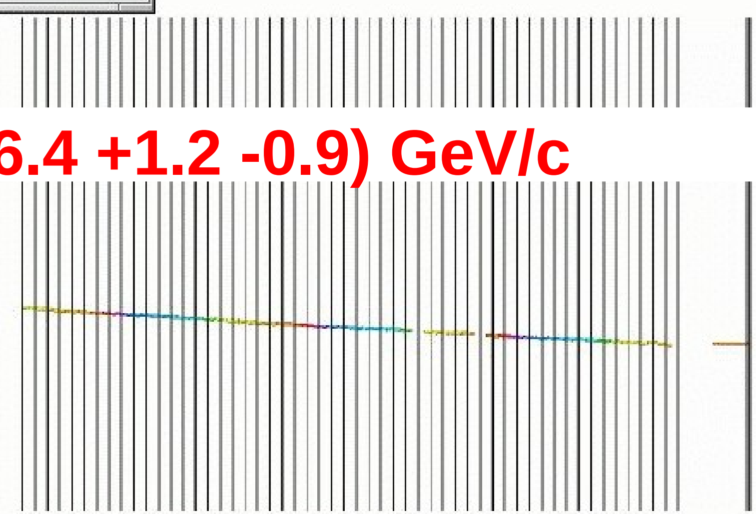
Momentum in the emulsions (Oct 06)



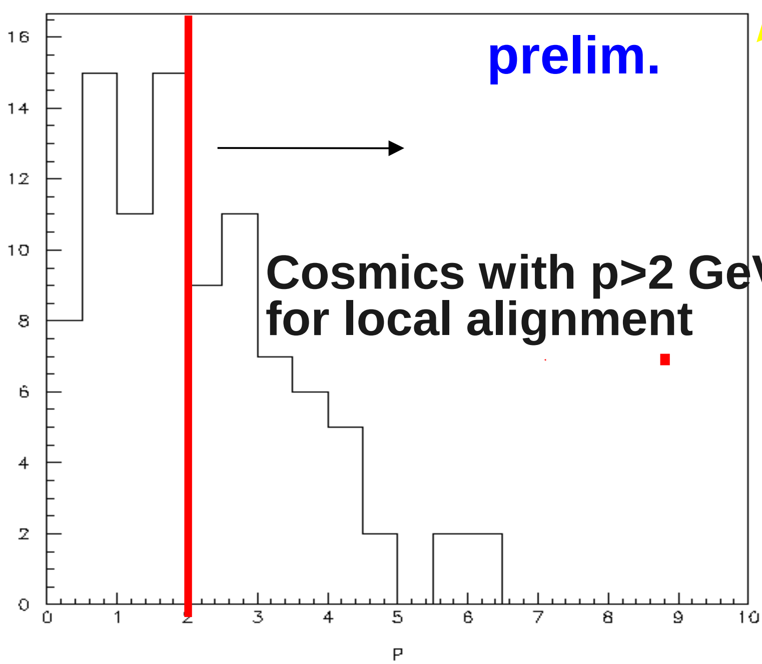
cosmics spectrum after surface exposure measured in emulsions with multiple scattering (angular method)

CS doublet





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



Cosmics with p>2 GeV/c used for local alignment

Tau channels and backgrounds

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

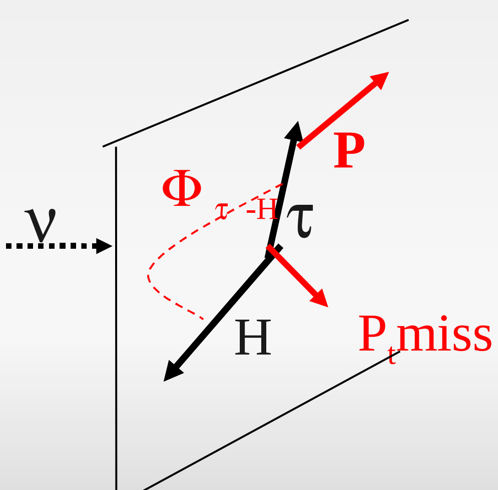
	signature	background
$\tau^- \rightarrow e^- \nu_\varepsilon \nu_\tau$	e.m. shower in the ECC	charm production in ν_μ CC with e- decay without primary μ identification
$\tau^- \rightarrow \mu^- \nu_\mu \nu_\tau$	μ ID (MS + Spectr.)	Large angle μ scattering
$\tau^- \rightarrow h^- \nu_\tau \; (n\pi^0)$	Events with a kink without muon or electron	charm production with hadronic decays + reinteractions

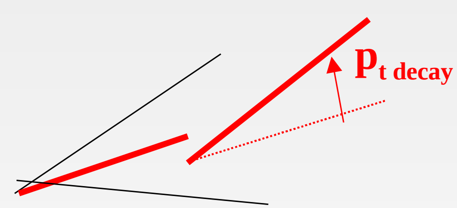
Dedicate kinematic analysis for each channel

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 $p_T^{@decay.vtx}$ (μ $_{channel}$) > 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/o γ) > 600 MeV (*) p_T^{miss} < 1 GeV ; $\Phi_{\tau-H} > \pi/2$	ν_μ NC bck suppressed (high p_T^{miss} low $\Phi_{\tau-H}$)

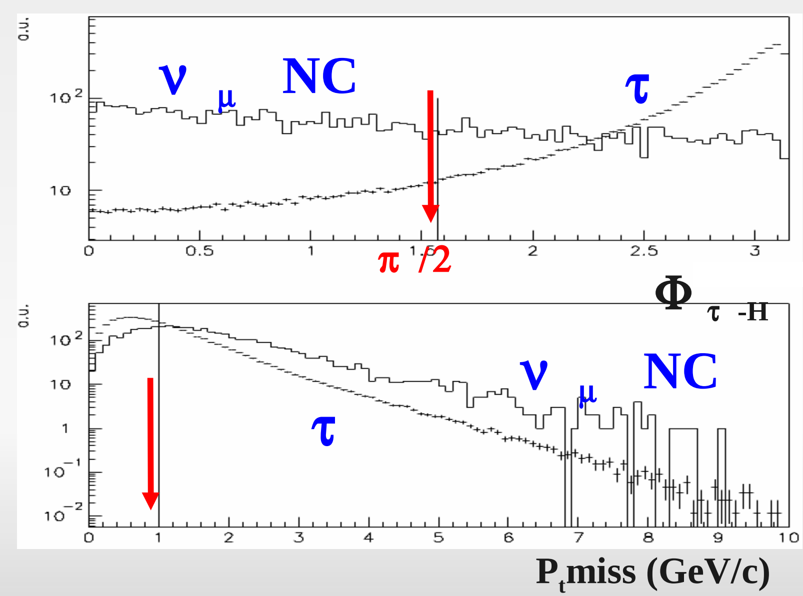
signal: τ & hadrons are *back-to-back*

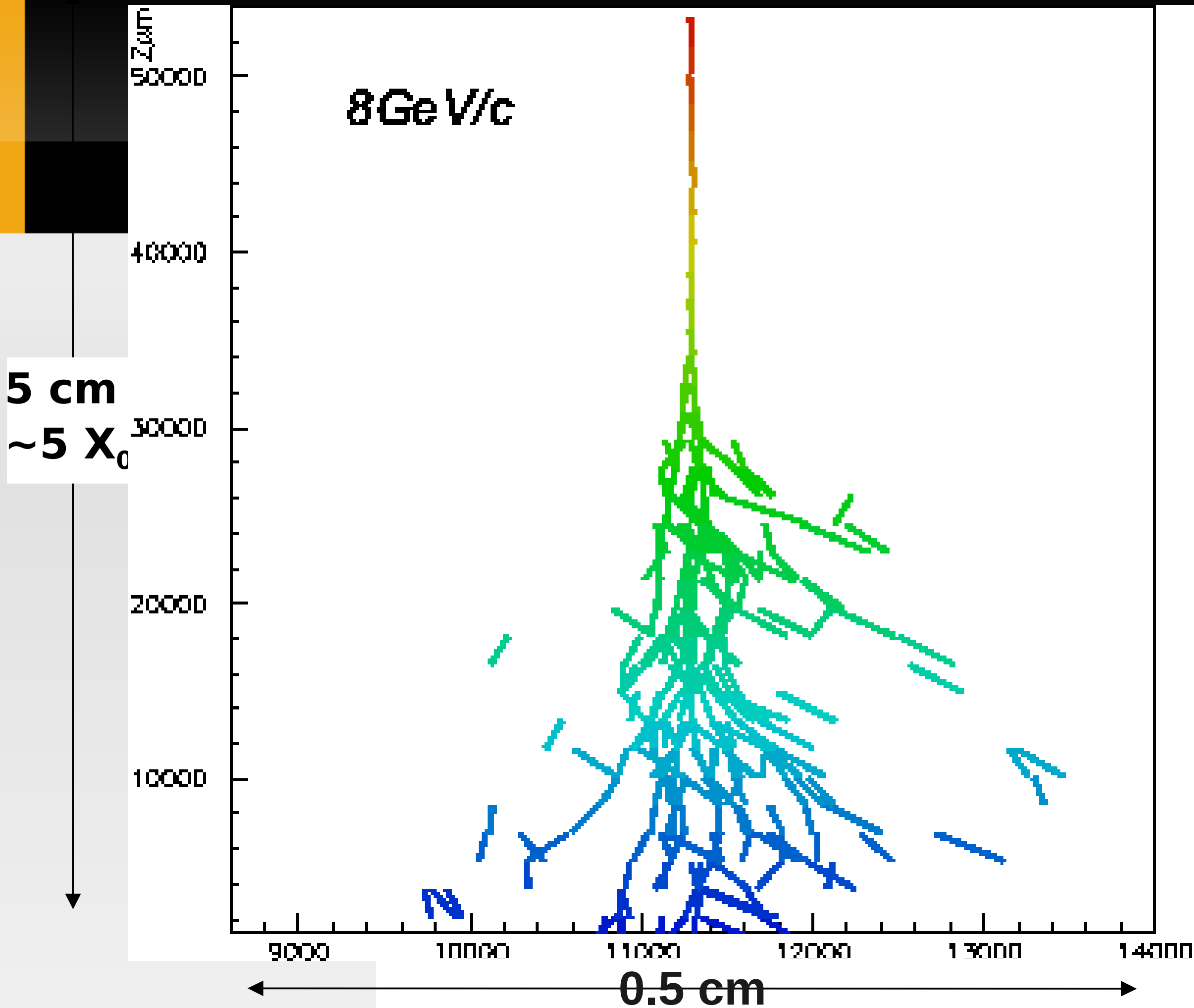


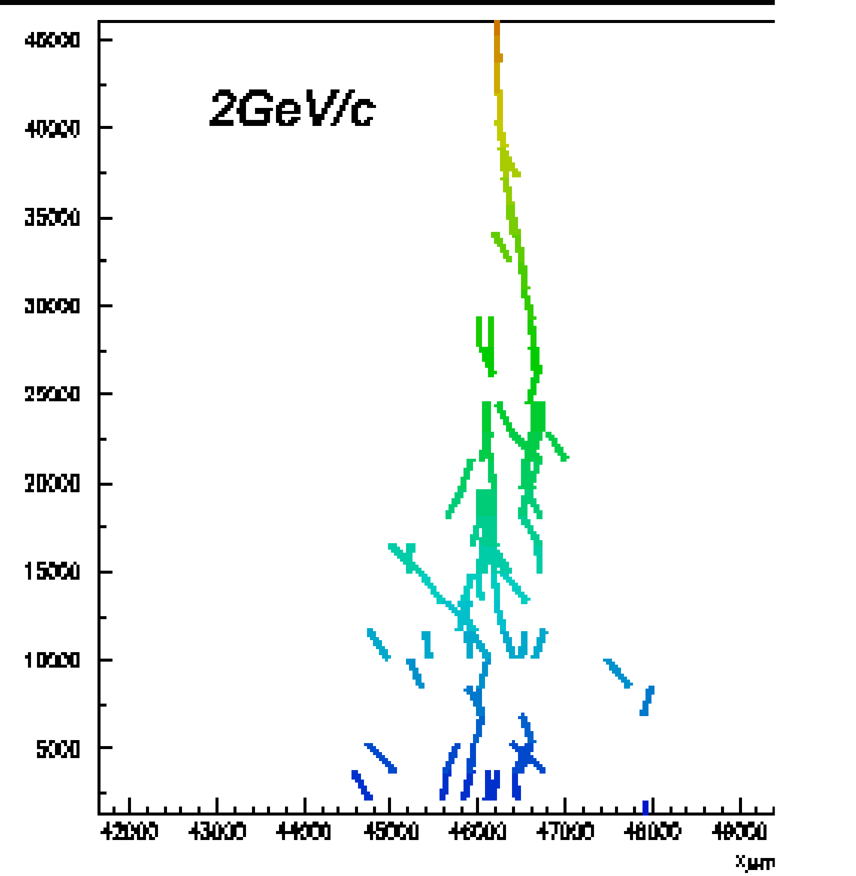


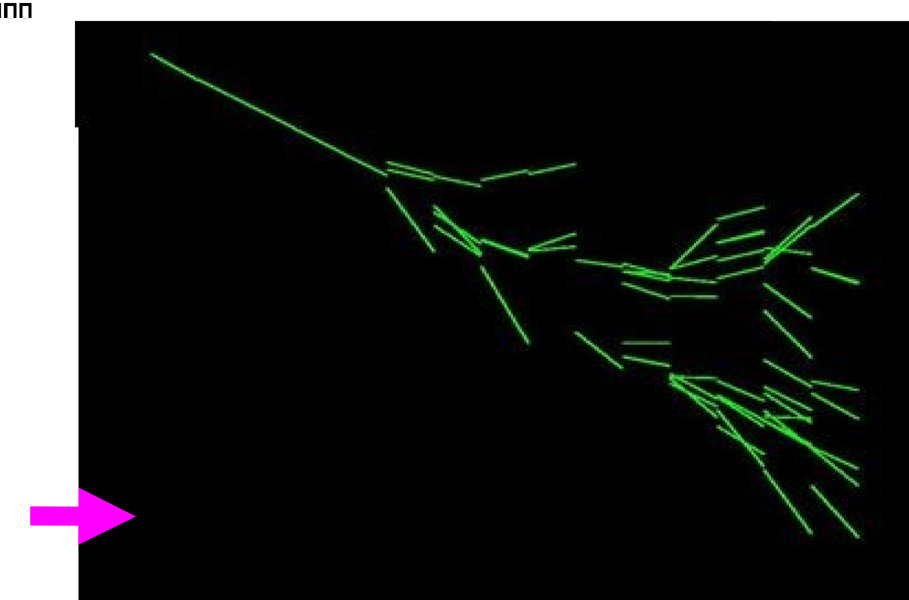
(*): due to low % of ν_μ NC evt with prompt γ.

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





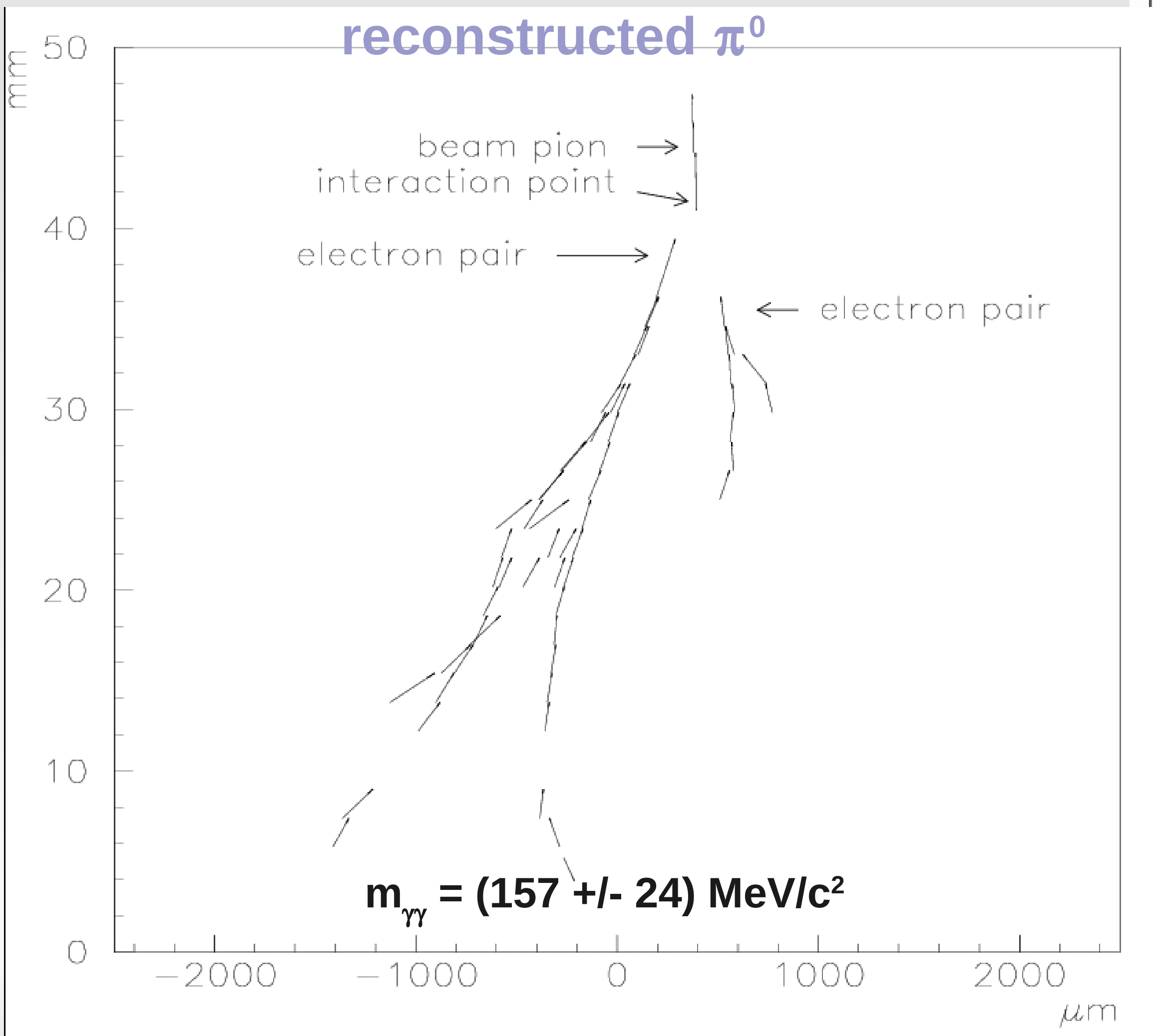




Electron identification in the ECC

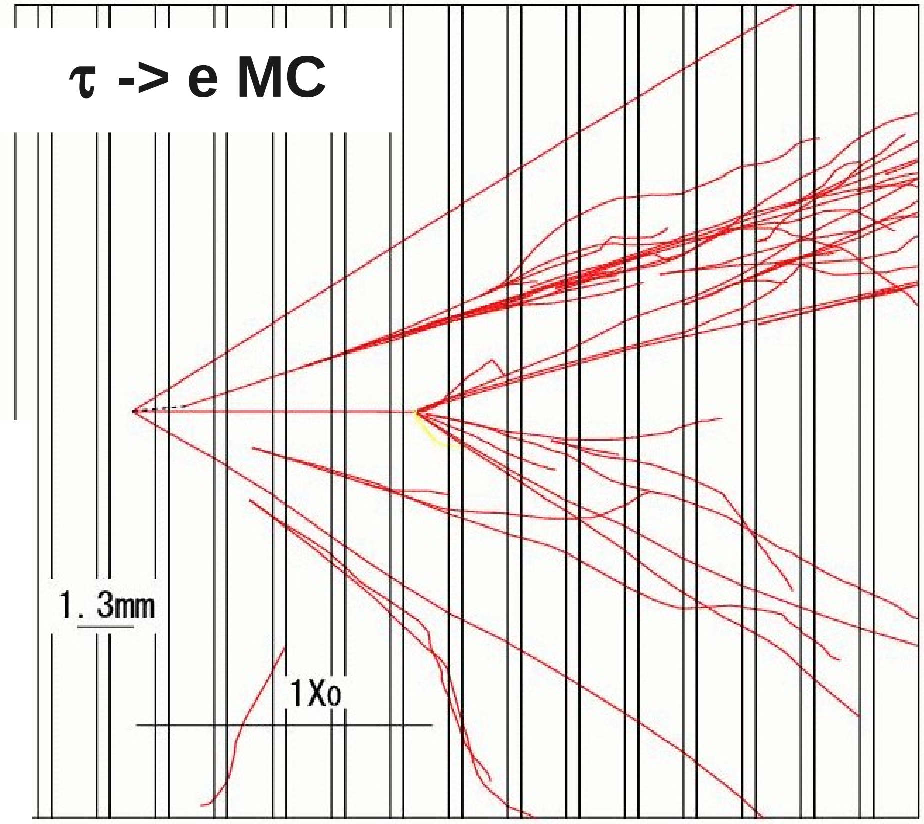
DESY 2003 e-test beam: 6 GeV

Electron identification



reconstructed π^0

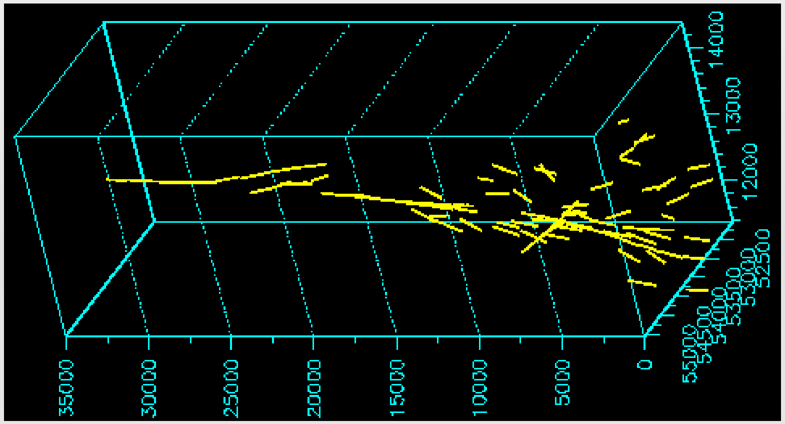
$m_{\gamma\gamma}$ = (157 +/- 24) MeV/c^2

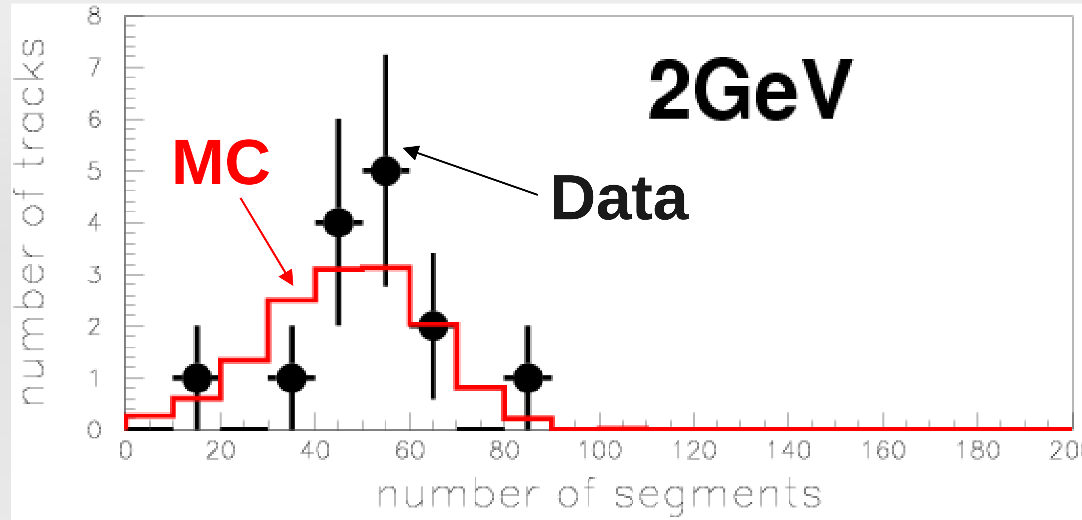


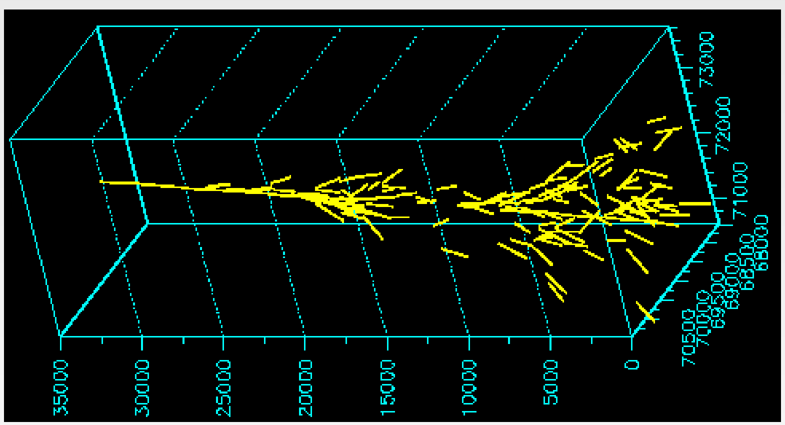
τ -> e MC

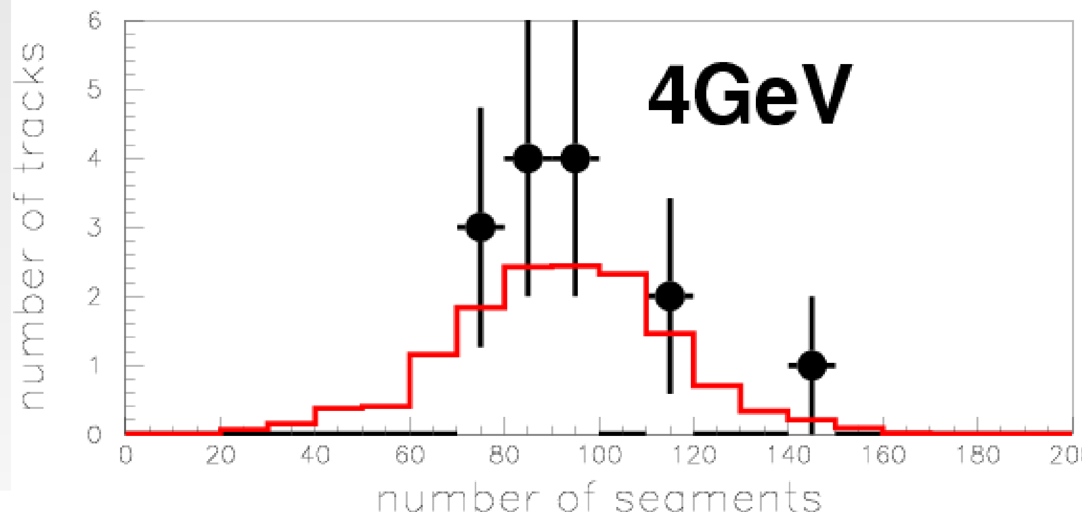
Electron energy measurement

Test exp. @ CERN









Energy determination by calorimetric method

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

@ a few GeV

dE/dx measurement

dE/dx ~ spatial density of grains

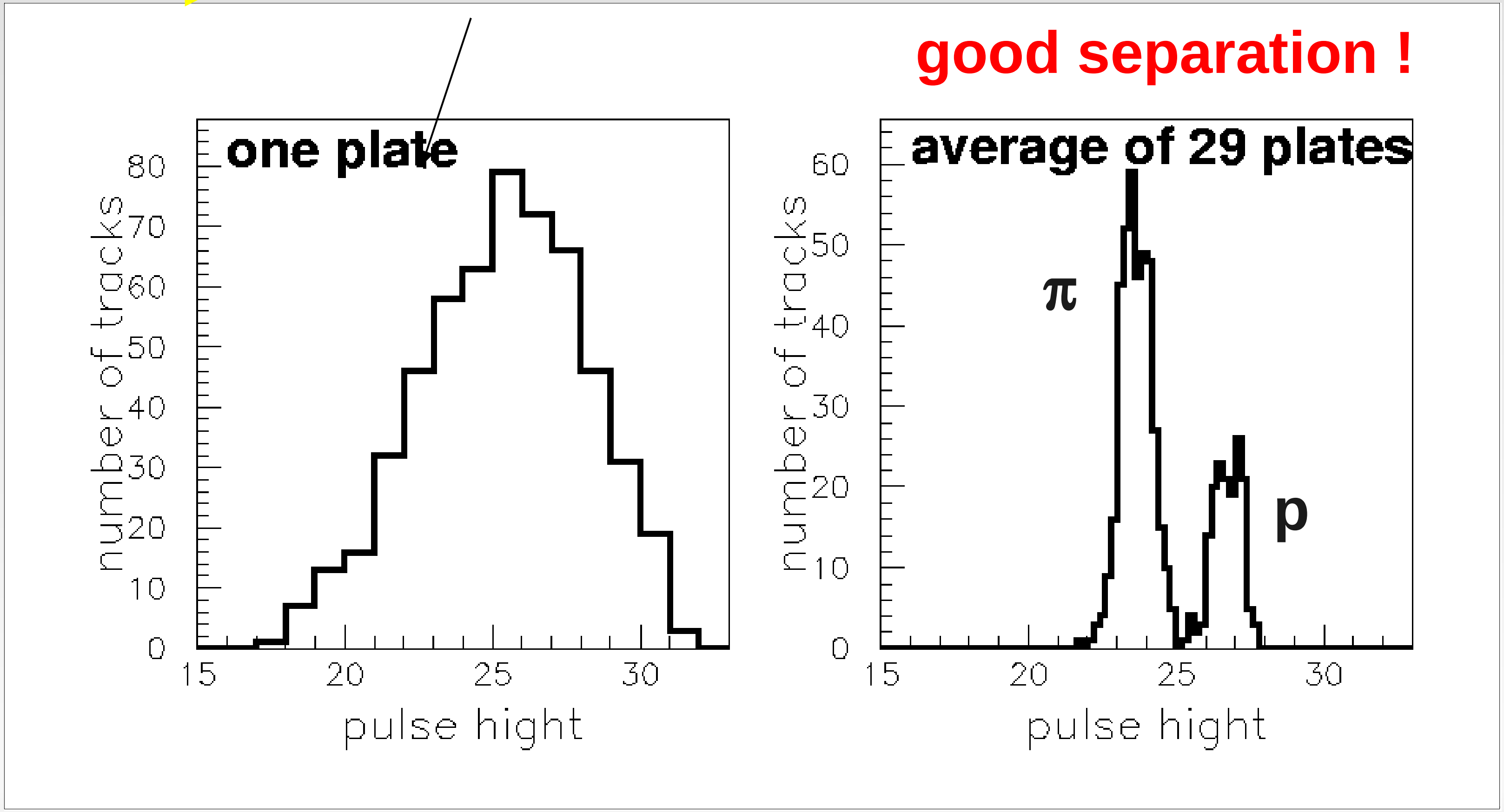
I := dE/dx = k / β^2 , E=Mβ^2/2

→ M ~ 4 I² x / k

δ M/M = 0.12

p = 1.2 GeV/c p, π^+ @ KEK/PS

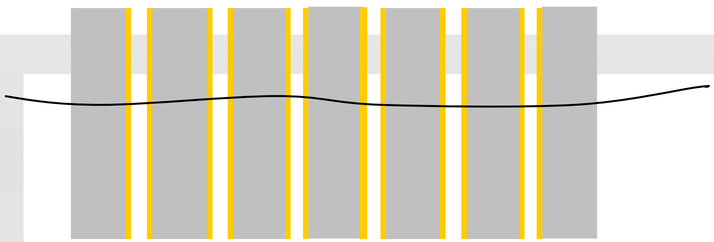
10 emulsions before stop point → δ M(π) = 16 MeV



N.I.M. A516 (2004) 436

Momentum by multiple scattering

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

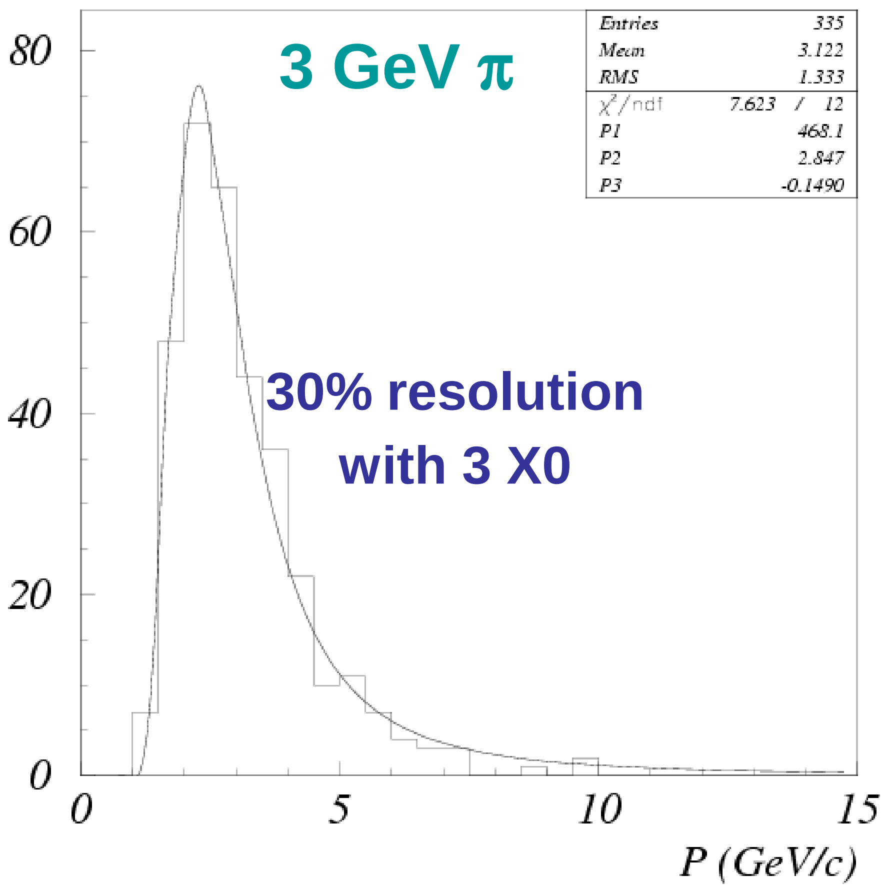


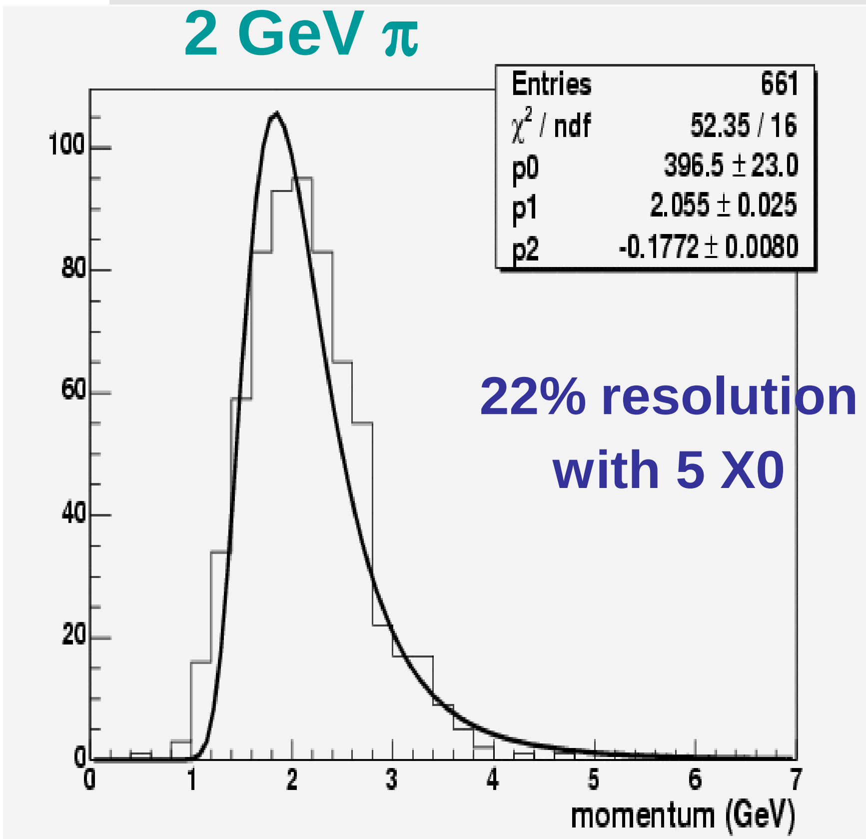
Angular method

based on angular difference btw adjacent base tracks

- not sensitive to relative shift but
- good parallelism of surfaces required

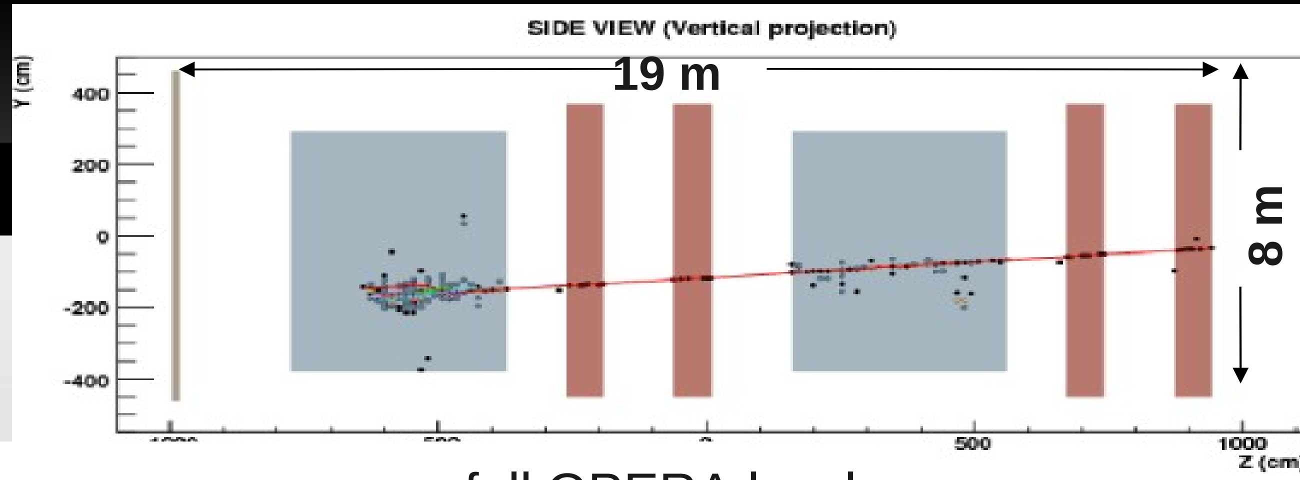
- **Coordinate method**
- based on displacements btw adjacent base tracks
- Longer lever arm (high p).
- Good local alignment required (cosmic ray exposure)





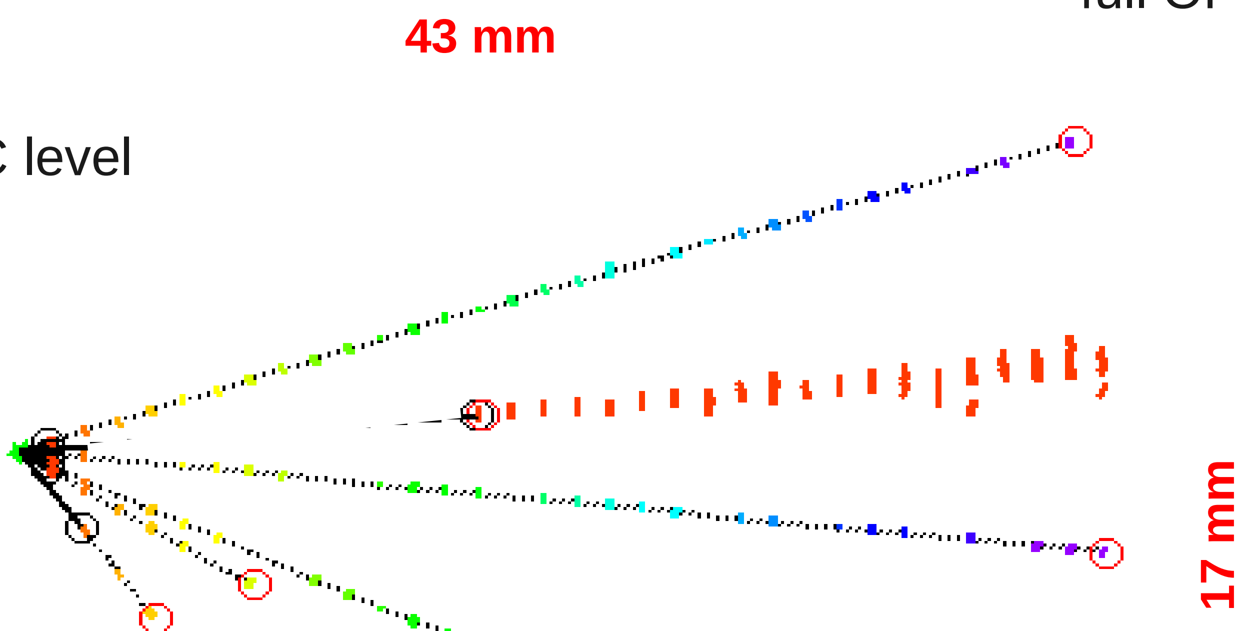
N.I.M. A512 (2003) 539

A ν_μ CC interaction



full OPERA level

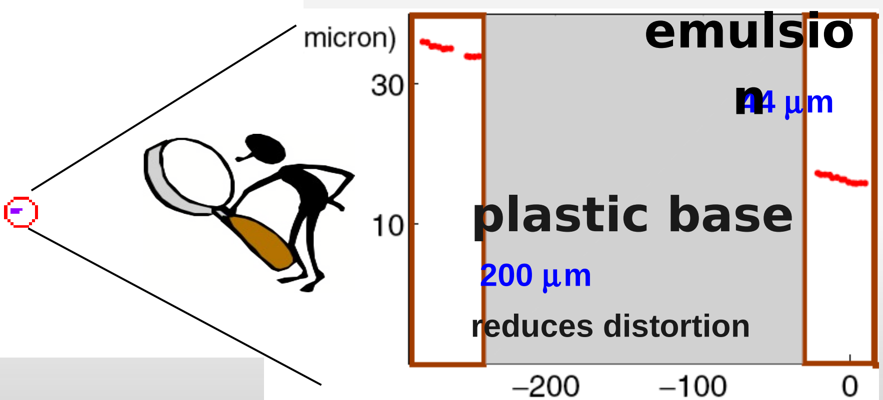
ECC level



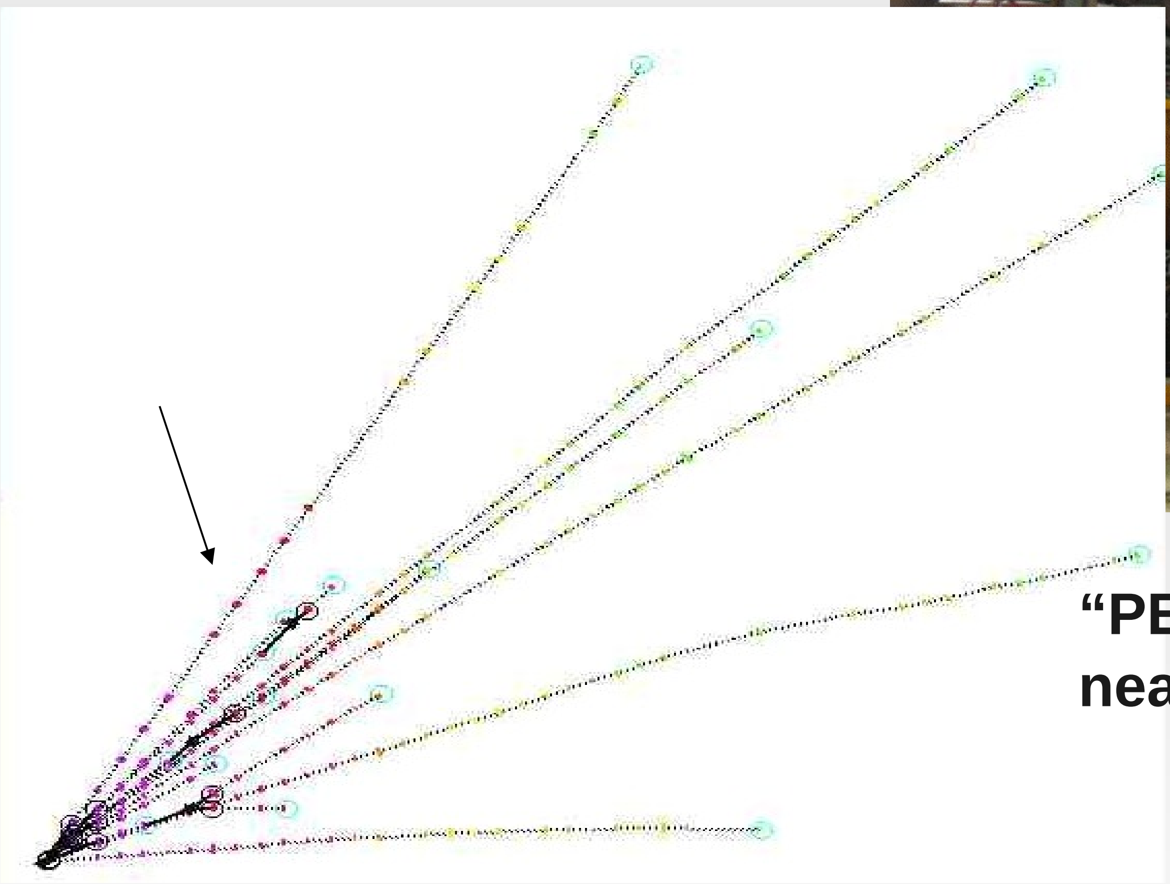
5 prongs with mean impact parameter 9 μ m

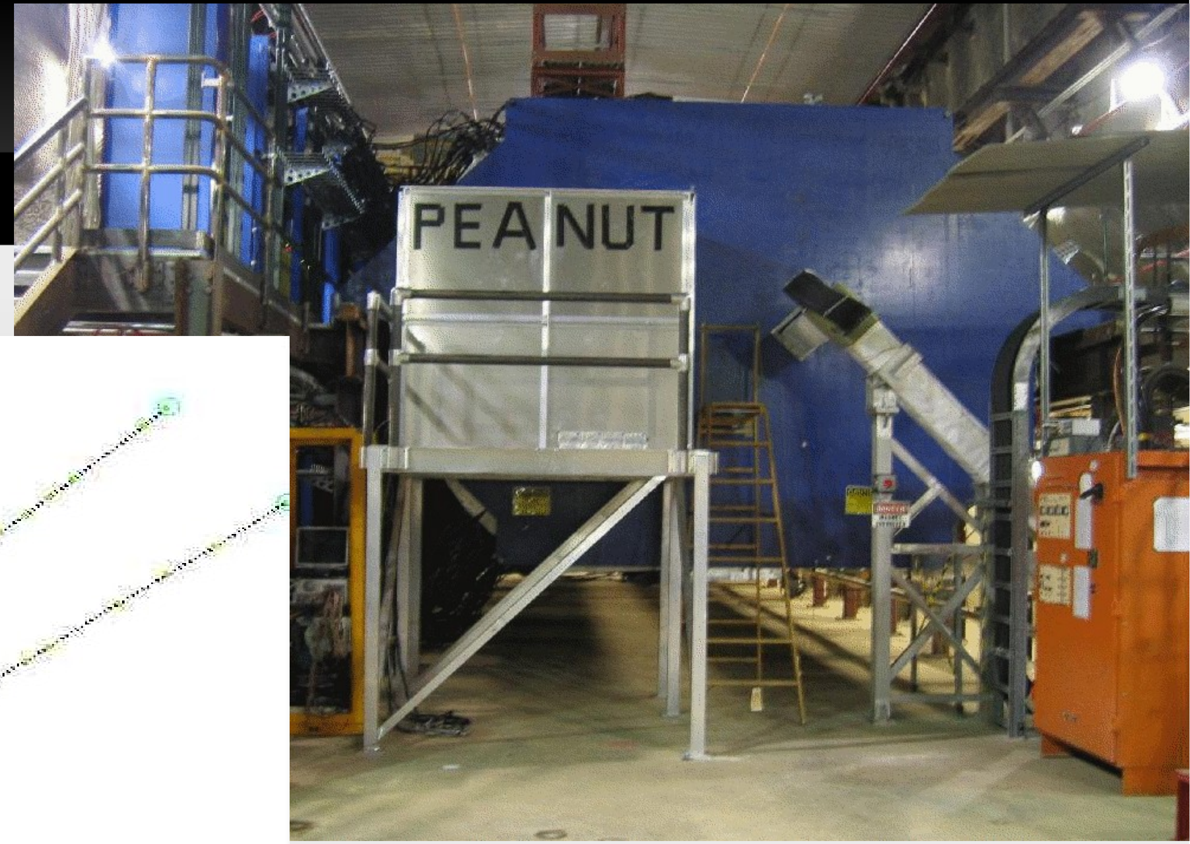
e.m. shower from γ conversion pointing to the vertex

•AgBr crystals diluted in a gelatine matrix



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

The 2007 run

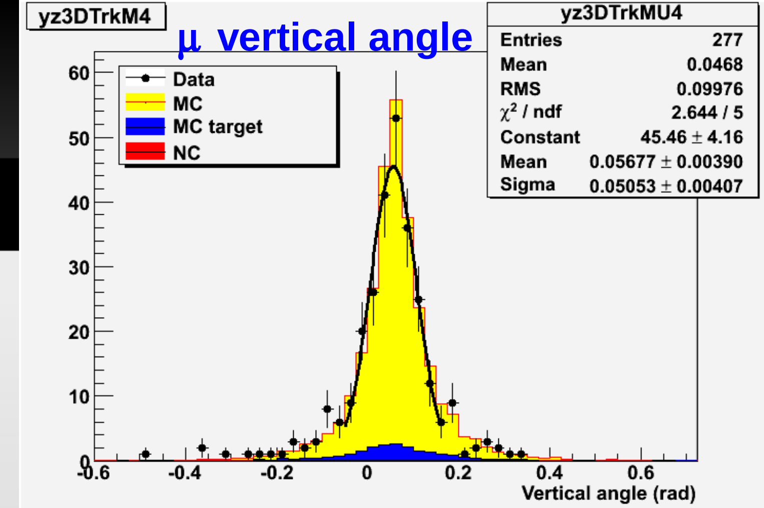
Short physics run (~40% target) **0.824*10^{18} pot**

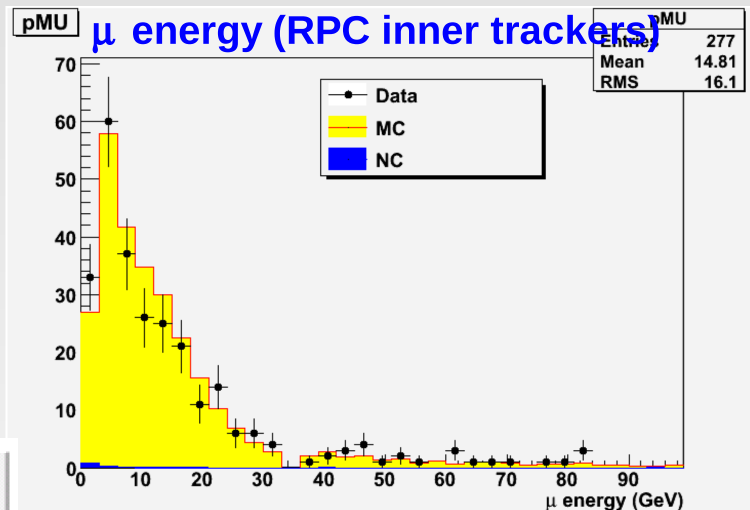
31.5 ± 6 expected events in bricks
38 events registered in the target
(29 CC-like and 9 NC-like)

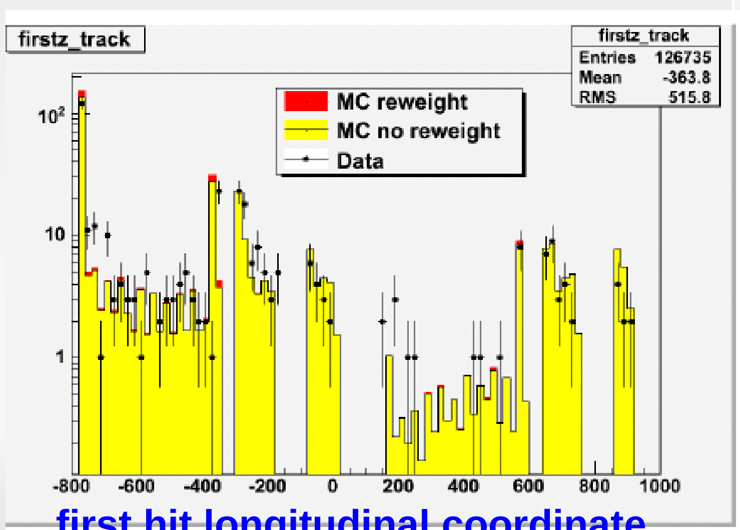
Out of target interactions (rock muons, vtx in the spectr.):
331 events passed the analysis cut
303 expected

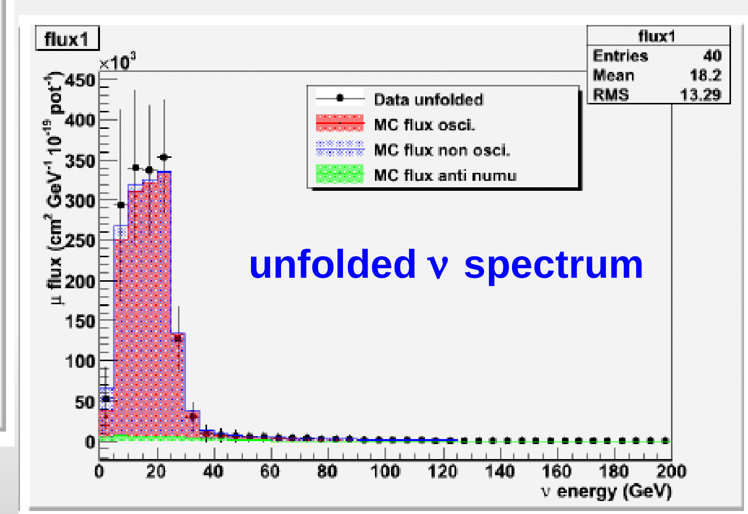
First test on real neutrino interactions for Brick handling, Film Processing, Scanning

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

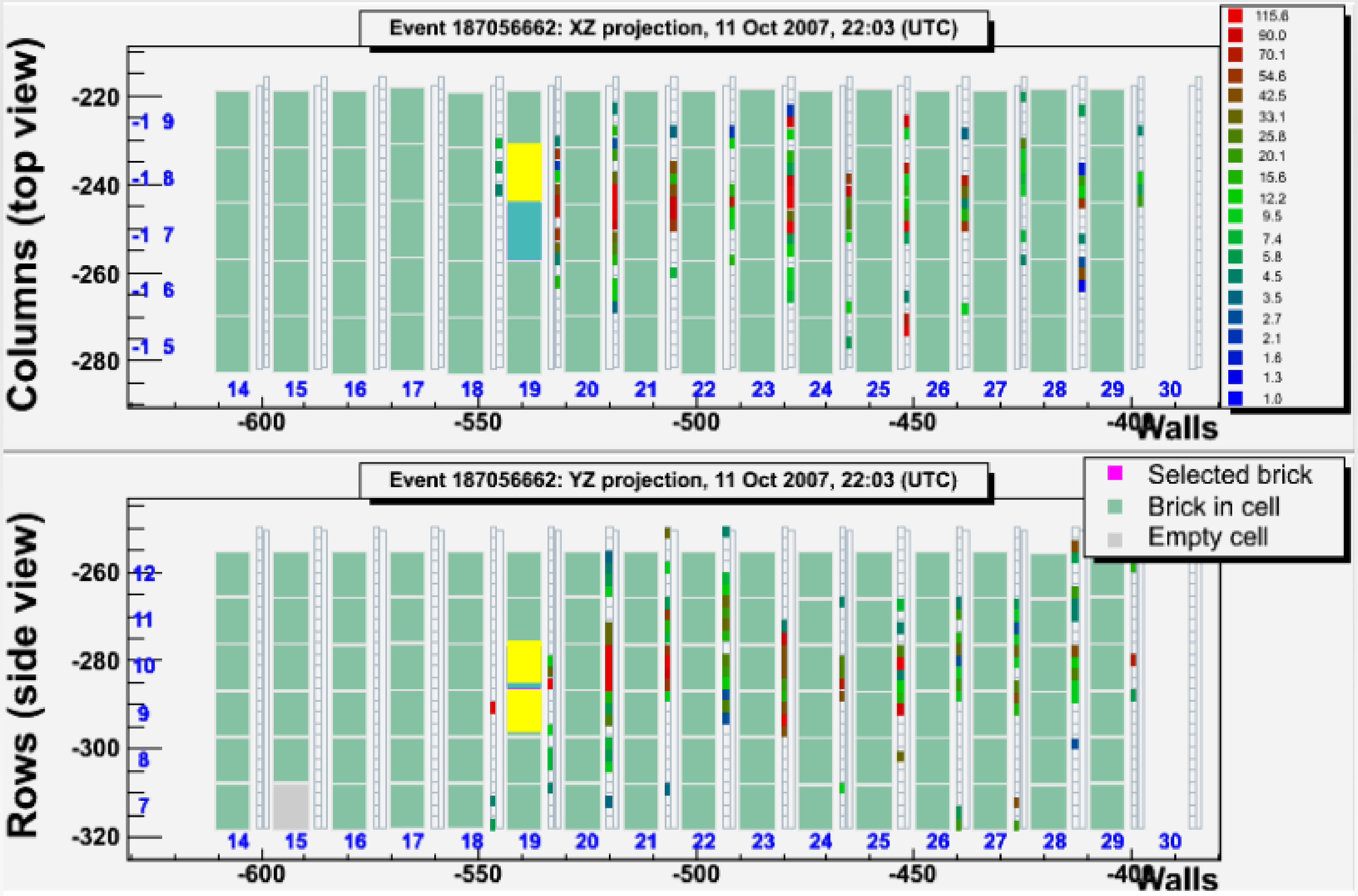








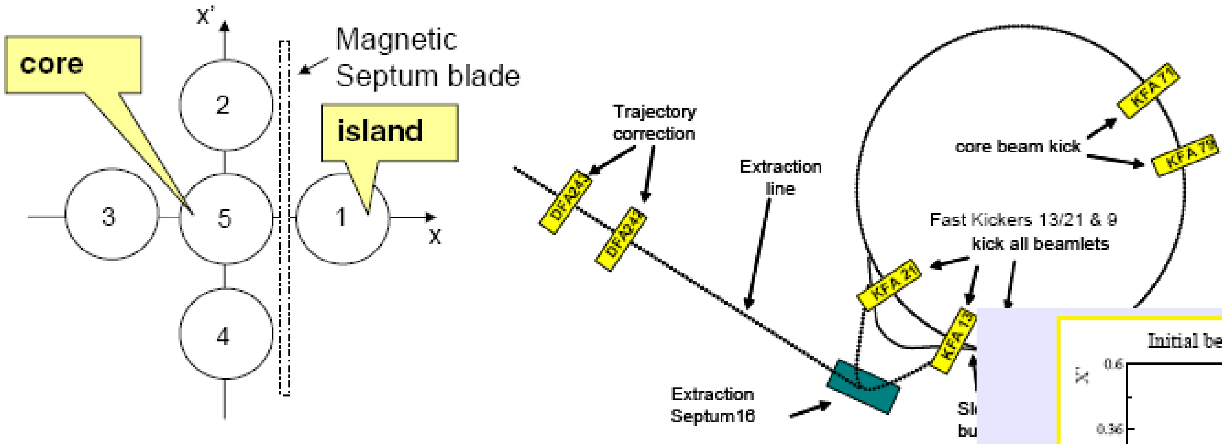
Brick finding



- 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

lti-turn extraction

Virtually loss-less

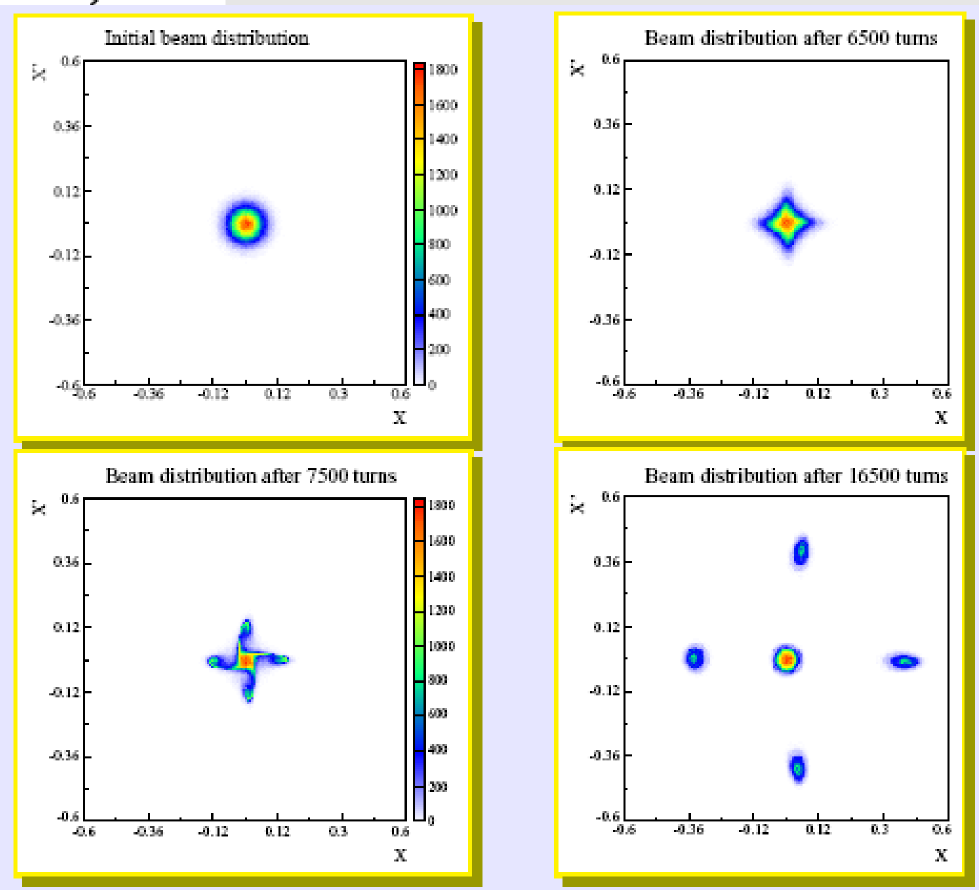


2001 First proposal (linked to 1.5 intensity increase for CNGS)

R&D and tests 2002-2004

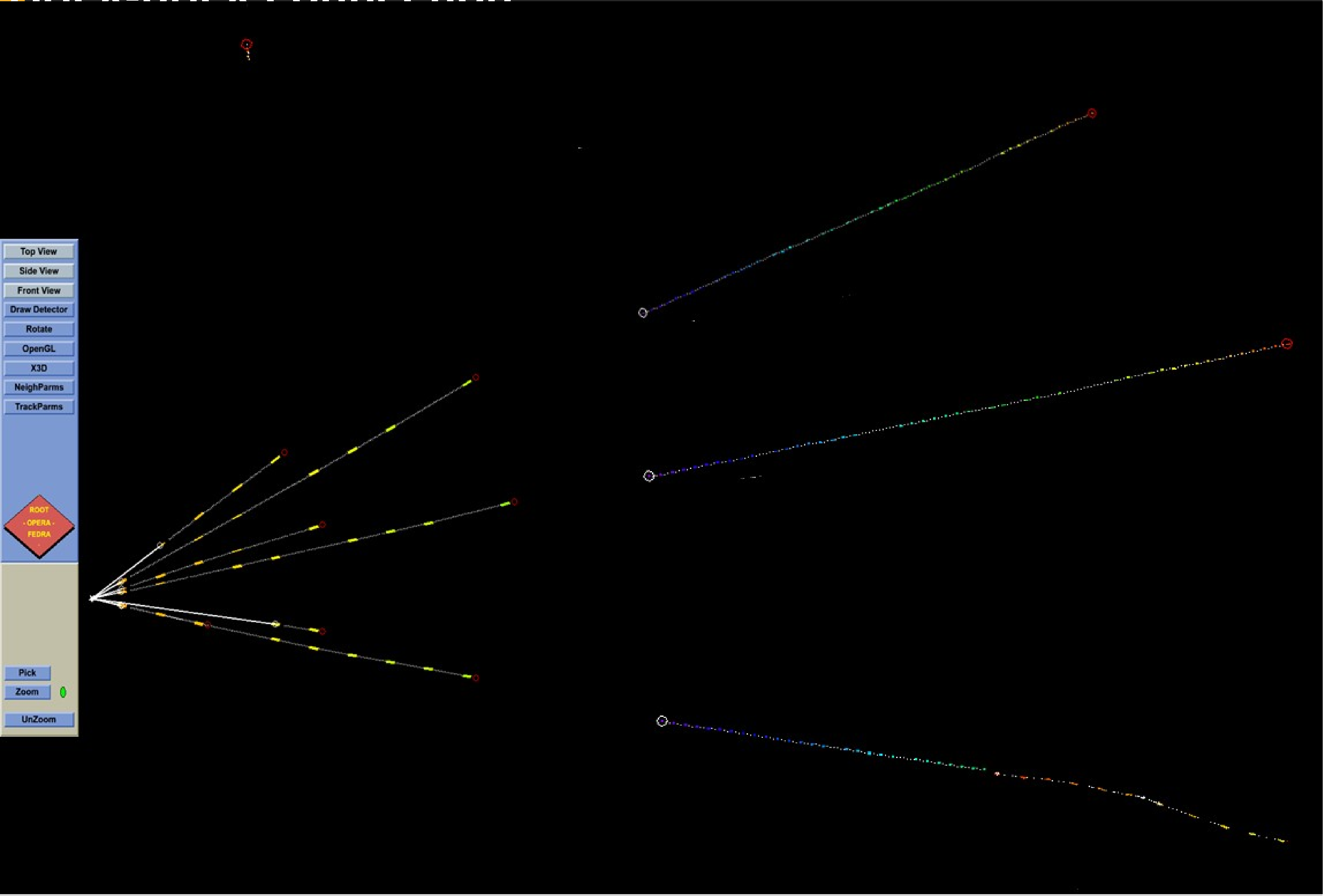
Implementation study group 2005

March 2006 TDR
October 2006 Project approved !



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

Brick-brick connection

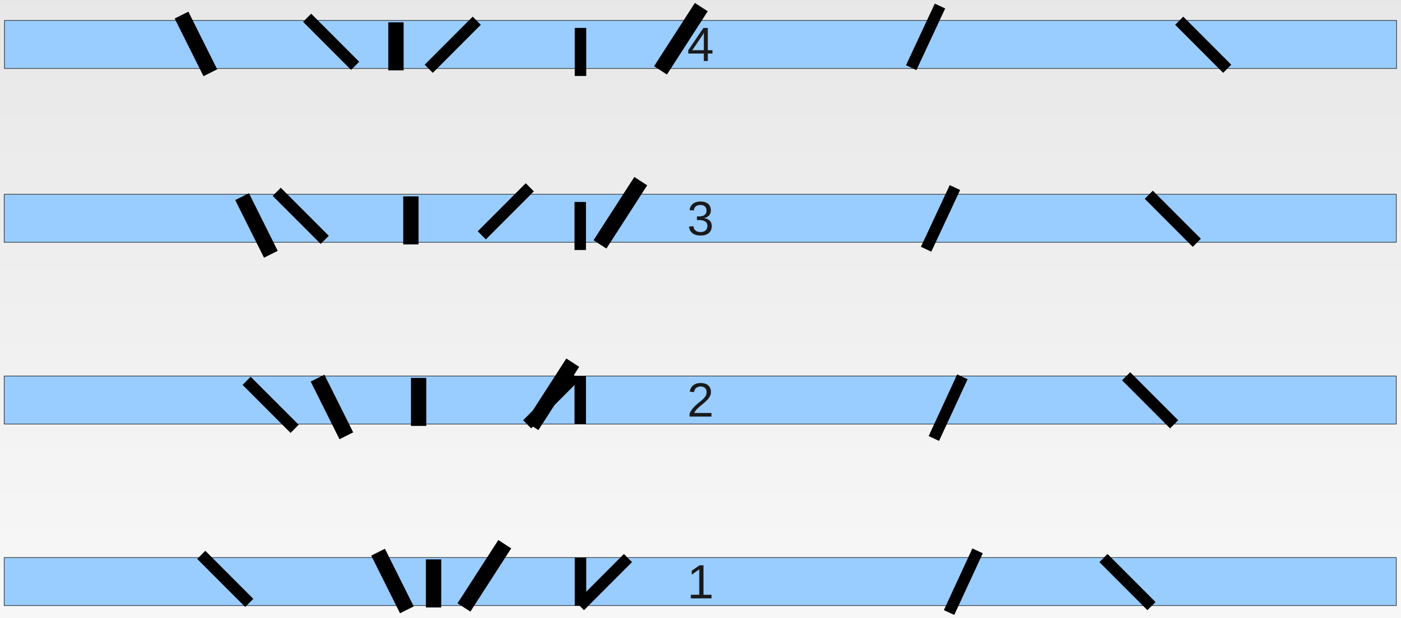


The BMS eyes

Pictures of a tray taken by the BMS vision system before (left) and after (right) insertion of bricks. The shadow of the tray visible on the brick surface is used to compute the distance of the brick with respect to the tray border.

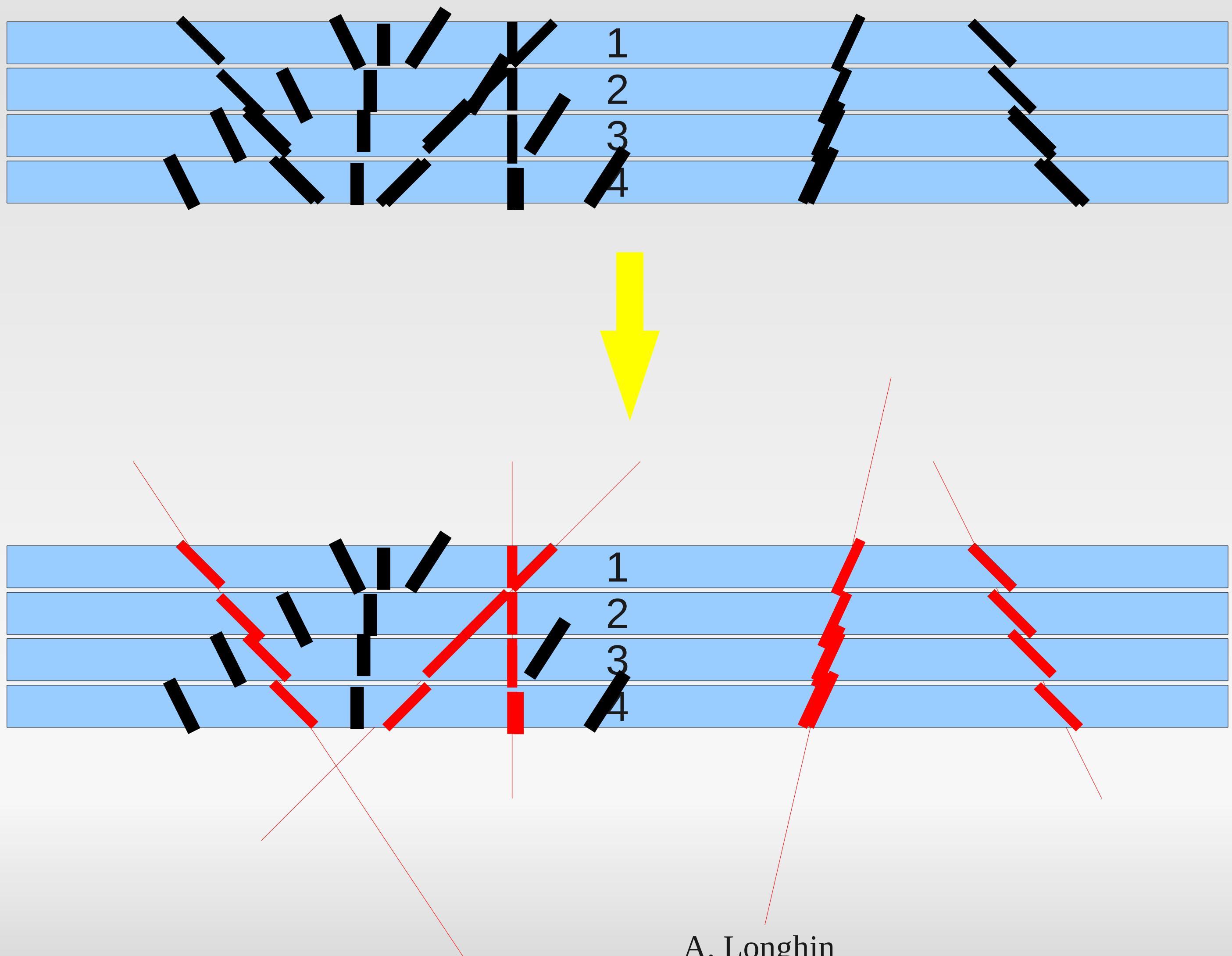
Virtual erasing I

Exposure order
Δz = 1.3 mm



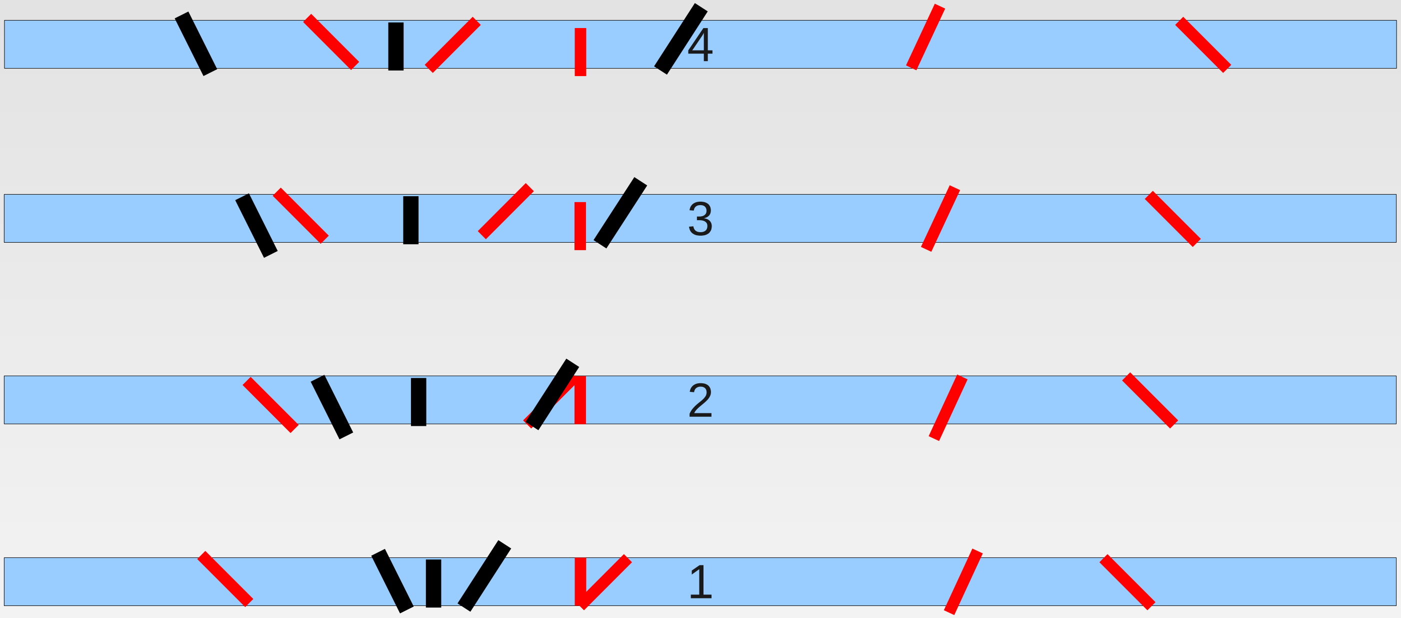
Virtual erasing II

transportation order
Δz = -0.3 mm



Virtual erasing III

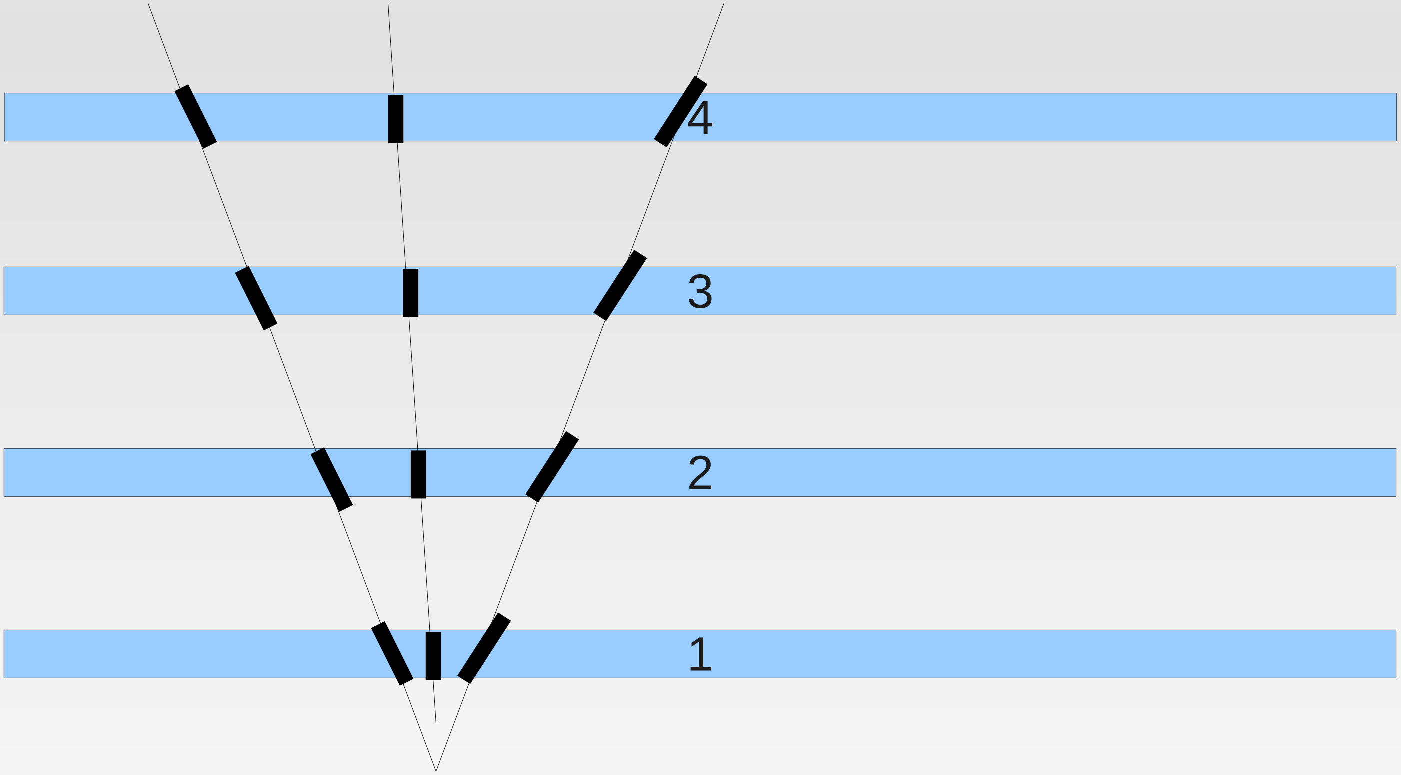
Exposure order
Δz = 1.3 mm



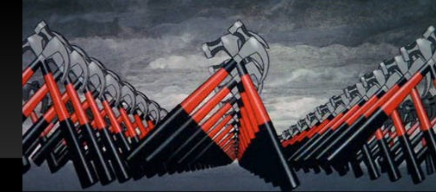
Base tracks which form ”volume tracks” in transportation alignment are tagged and excluded (”erased”)

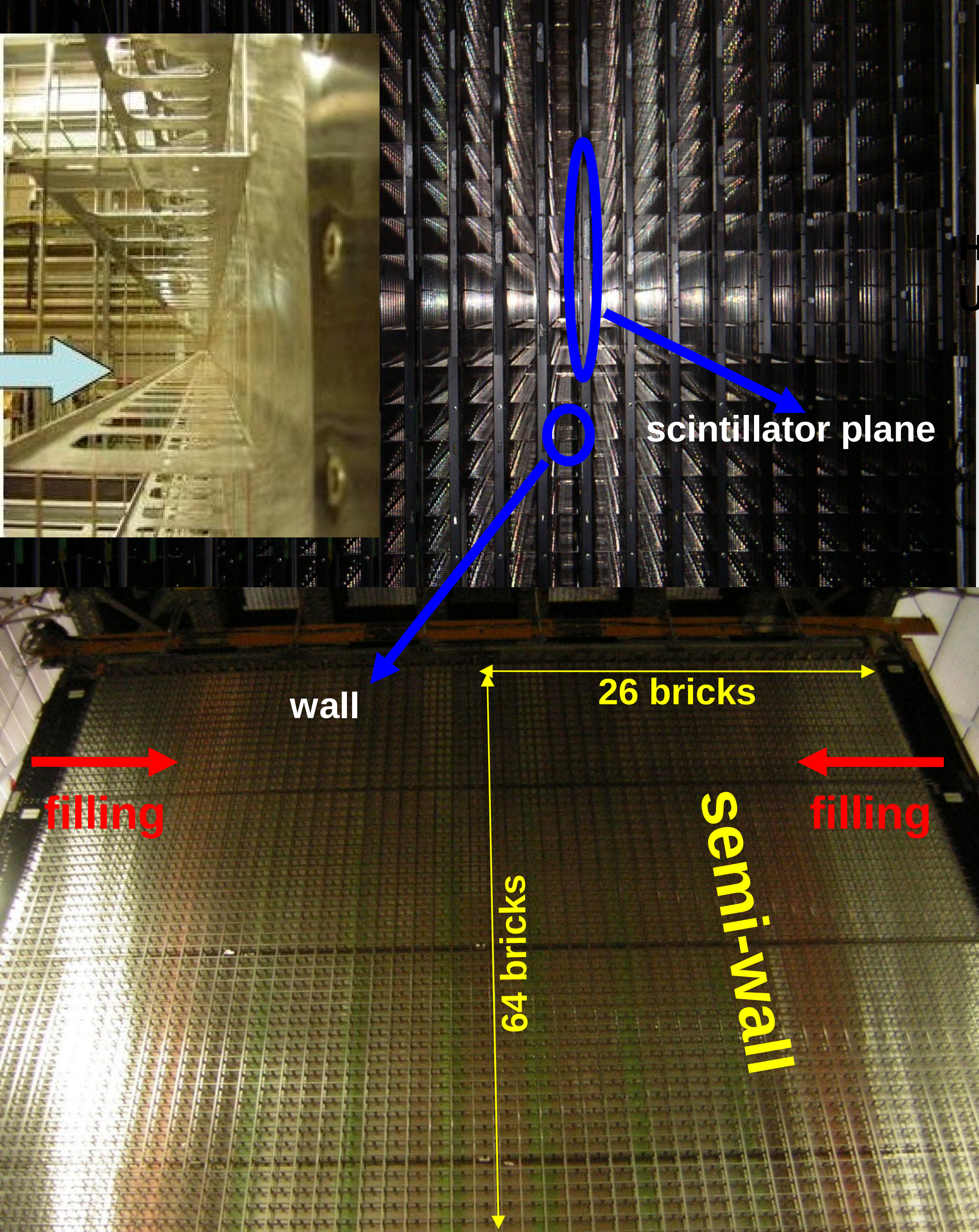
Virtual erasing IV

Exposure order
Δz = 1.3 mm



Bricks support structure: the “wall”





Tight mechanical tolerances for brick positioning accuracy and low mass to minimize interactions in passive target

Holds 3328 bricks ~ 28 ton

Ultra-light: 0.4% of bricks mass

- **Stainless steel vertical ribbons (0.8 x10 x 6780 mm)**
- **Laser-welded U-shaped trays (0.7mm)**
- **Spring tensioning system**

Achieved precisions:

- **construction *(w. mech. gauges)* (105.3 ± 0.1 / 82.6 ± 0.25 / 7330 ± 0.6) mm**
- **positioning *(measured during installation w. high. res photogrammetry)***
  - **vertical < 0.3 mm**
  - **transverse & longitudinal < 0.5 mm**
  - **planarity < 1 mm**

Development lab

Commercial up-to-date technologies
Chemical solutions are prepared by an industrial-type plant
fully automated up to 3000 films/day (~53 bricks)

6 parallel motorized chains connected to a series of tanks that contain the chemical solutions

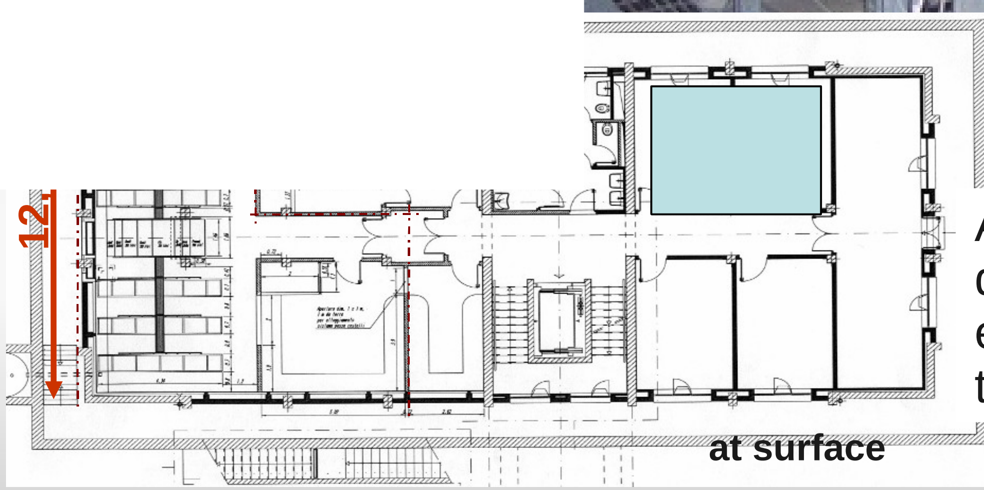
movable arms under PLCcontrol displace and insert the plate holders in/out of each tank at scheduled times

development/stopping/fixing/thickening/washing

each phase is from 5' →~20'
>= 1 brick per chain simultaneously

automatic exhaustion of chemical waste and insertion of fresh ones

~ 130 m^2



A smaller independent development facility exists underground for the changeable sheets