Aspects on Neutrino (Mass-) and Mixing

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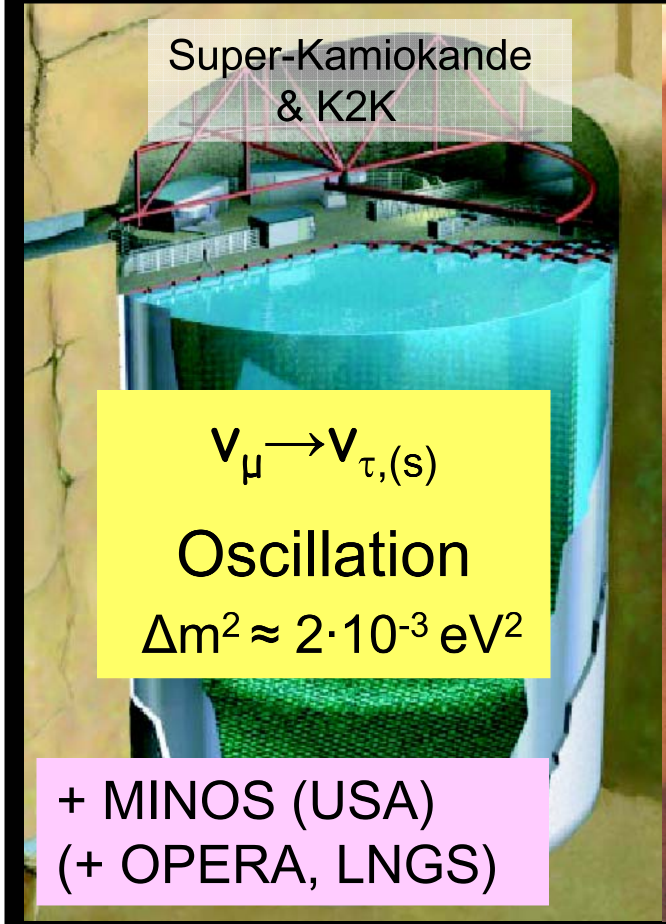
- Introduction: neutrino mass and mixing
- Neutrino Oscillation (I): mu – tau mixing
  - atmospheric neutrinos
  - present neutrino beam experiments:
    - MINOS (NuMi beam: Fermilab – Soudan Mine)
    - OPERA (CNGS beam: Cern – LNGS)
- Neutrino Oscillation (II): e – mu mixing
  - solar neutrino experiments
    - short review on past experiments (SNO)
    - Borexino
  - reactor experiment: KamLand
- Neutrino Oscillation (III): Future prospects (theta13 and CPV)
  - reactor experiments: Double Chooz and Daya Bay
  - off-axis (super)beams: T2K and NovA
  - neutrinofactory and beta beams
- Neutrino Oscillation (IV): Problems?
  - LSND / MiniBoone
  - GSI anomaly
  - NuTeV anomaly
- Nature of neutrino mass: Majorana or Dirac?
  - Double beta decay

Neutrino Oscillations have been observed → Add Neutrino Mass & Mixing to SM

JAPAN



Super-Kamiokande & K2K

$\nu_\mu \rightarrow \nu_{\tau,(s)}$

Oscillation

$\Delta m^2 \approx 2\cdot 10^{-3}\,\mathrm{eV}^2$

+ MINOS (USA)
(+ OPERA, LNGS)

atmospheric neutrinos
accelerator neutrinos

CANADA

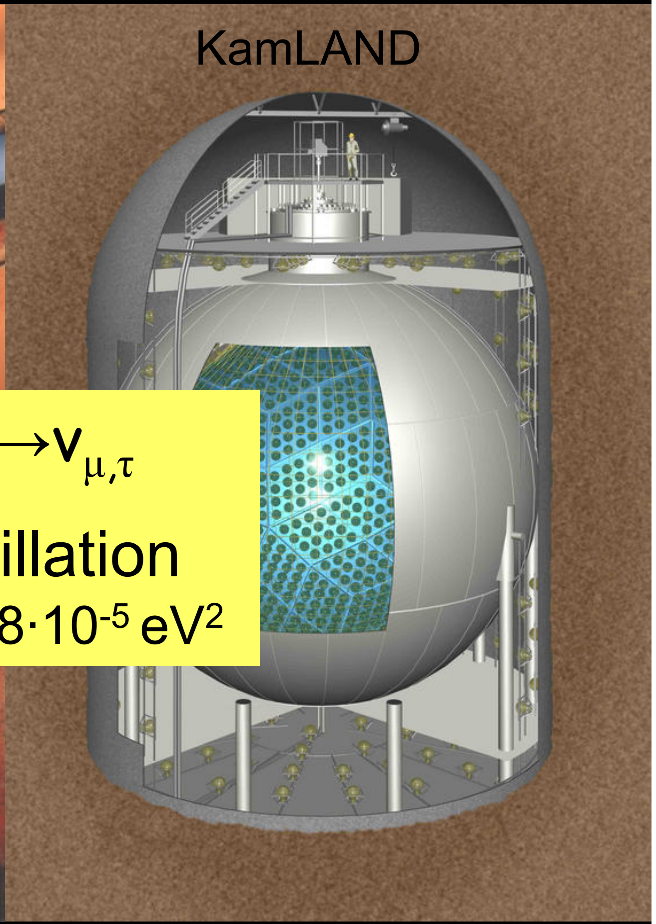
SNO

+Homestake (USA),
+Gallex/GNO (Italy),
+SAGE (Russia)
+SK

+ BOREXINO @ LNGS (Italy)

solar neutrinos

JAPAN



KamLAND

$\nu_e \rightarrow \nu_{\mu,\tau}$

Oscillation

$\Delta m^2 \approx 8\cdot 10^{-5}\,\mathrm{eV}^2$

reactor neutrinos

Quark-Mixing

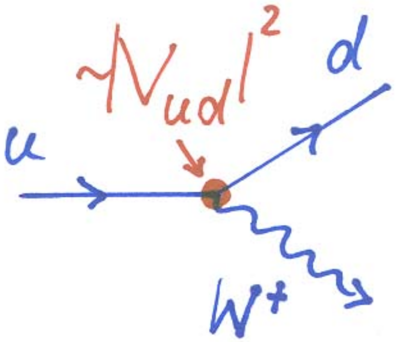
$$\begin{pmatrix} u \\ d' \end{pmatrix} \quad \begin{pmatrix} c \\ s' \end{pmatrix} \quad \begin{pmatrix} t \\ b' \end{pmatrix}$$

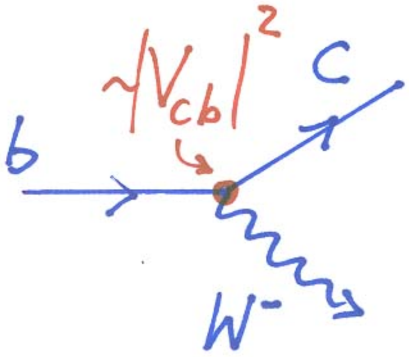
Cabbibo-Kobayashi-Maskawa (CKM) Matrix

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \boxed{\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}} \cdot \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

- 3 mixing angles
- 1 phase: $e^{i\delta}$
  CP-violation

BELLE,
BABAR,
CLEO,…
(BELLE2)





in precision measurement phase

Neutrino Mass and -Mixing

3 massive neutrinos: ν_1, ν_2, ν_3 with masses: m_1,m_2,m_3

flavor-Eigenstates ν_e,ν_μ,ν_τ ≠ mass-Eigenstates

neutrino mixing

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \cdot \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

example: $\left|\nu_e\right\rangle = U_{e1}\left|\nu_1\right\rangle + U_{e2}\left|\nu_2\right\rangle + U_{e3}\left|\nu_3\right\rangle$

Historical remark

- 1957-58: B. Pontecorvo proposed neutrino oscillations (because only ν_e was known, he thought of $\nu \leftrightarrow$ anti-ν)

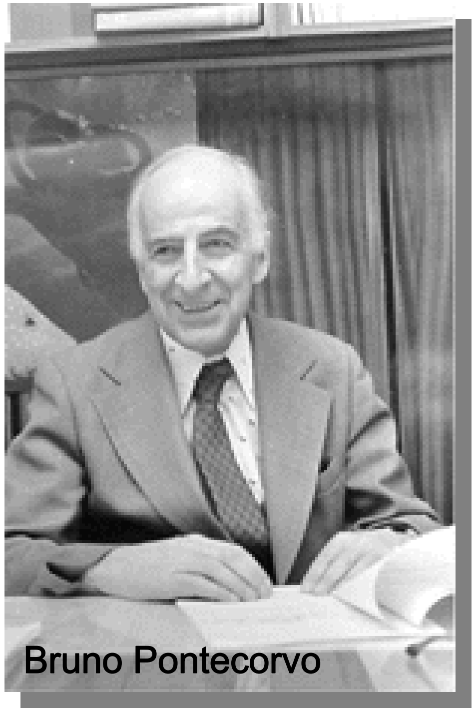
  B. Pontecorvo, JETP **6**, 429 (1957); B. Pontecorvo, JETP **7**, 172 (1958).

- 1962 Maki, Nakagawa, Sakata described the 2 flavor mixing and discussed neutrino flavour transition.

  Z.Maki, M. Nakagawa and S. Sakata, Prog. Theor. Phys. **28**, 870 (1962).

- 1967 full discussion of 2 flavor mixing, possibility of solar neutrino oscillations, question of sterile neutrinos by B. Pontecorvo.

  B. Pontecorvo, Zh. Eksp. Teor. Fiz. **53**, 1717 (1967), and JETP **26**, 984 (1968).



Bruno Pontecorvo

Therefore the neutrino mixing matrix is often called PMNS-Matrix

Parametrisation of Neutrino Mixing(I)

Pontecorvo-Maki-Nakagawa-Sakata (PMNS) Matrix:

- 3 mixing angles: θ_{12}, θ_{23}, θ_{13}
- 1 Dirac-phase (CP violating): δ

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

θ_{atm} θ_{13}, δ θ_{sol}

$\theta_{23} \approx 45^o$

$\theta_{13} < 13^o$, δ ?

$\theta_{12} \approx 33^o$

Parametrisation of Neutrino Mixing (II)

Pontecorvo-Maki-Nakagawa-Sakata (PMNS) Matrix:

- 3 Mixing angles: θ_{12}, θ_{23}, θ_{13}
- 1 Dirac-phase (CP violating): δ

But:

If neutrinos are Majorana particles two additional phases exist:

- 2 Majorana-Phases (CPV): α_1, α_2

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13}\boxed{e^{i\alpha_1}} & s_{13}e^{-i\delta}\boxed{e^{i\alpha_2}} \\ -s_{12}c_{23}-c_{12}s_{23}s_{13}e^{i\delta} & [c_{12}c_{23}-s_{12}s_{23}s_{13}e^{i\delta}]\boxed{e^{i\alpha_1}} & s_{23}c_{13}\boxed{e^{i\alpha_2}} \\ s_{12}s_{23}-c_{12}c_{23}s_{13}e^{i\delta} & [-c_{12}s_{23}-s_{12}c_{23}s_{13}e^{i\delta}]\boxed{e^{i\alpha_1}} & c_{23}c_{13}\boxed{e^{i\alpha_2}} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Leptons vs Quarks

Neutrinos

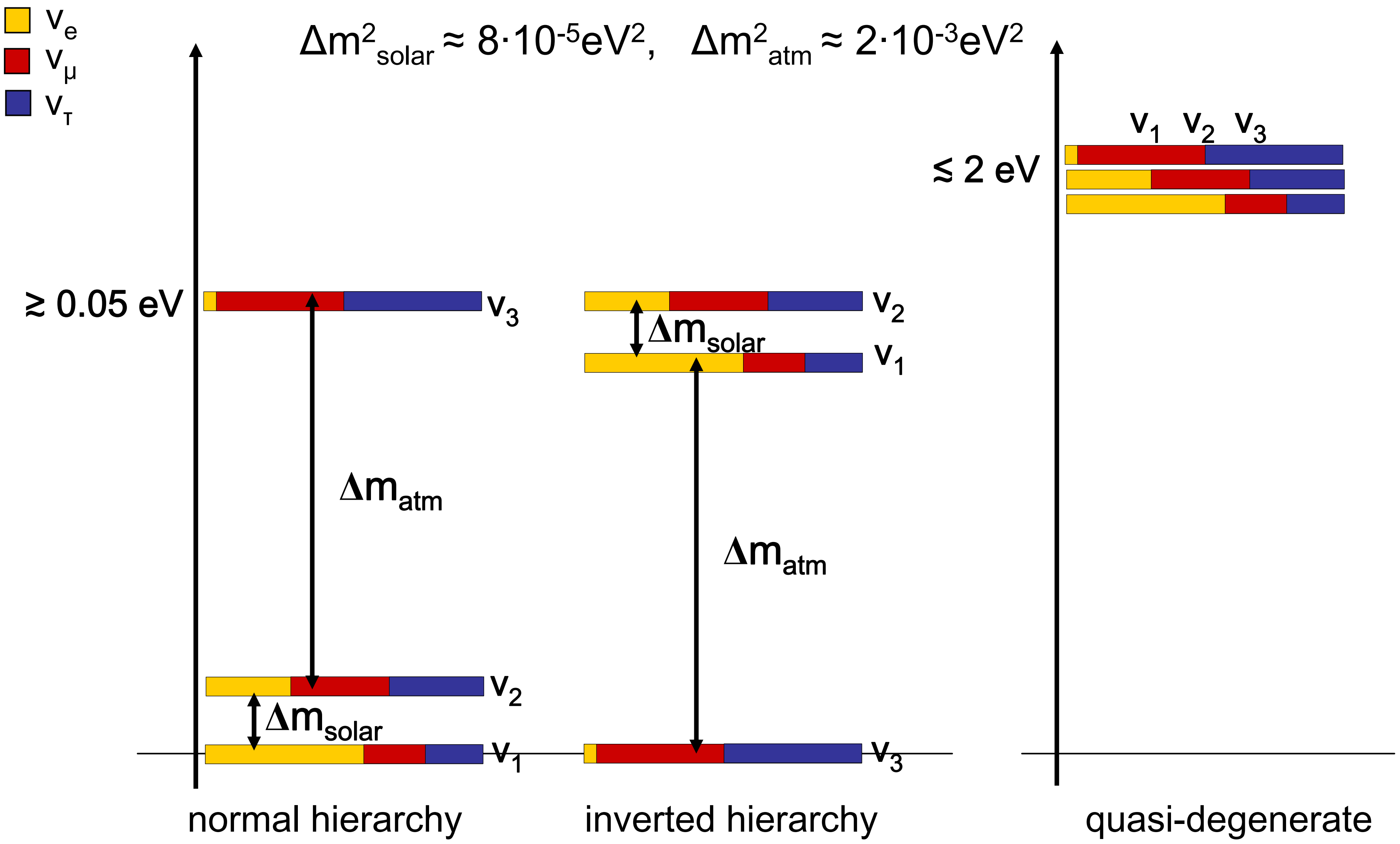
$$U_{MNSP} \sim \begin{pmatrix} 0.8 & 0.5 & ? \\ 0.4 & 0.6 & 0.7 \\ 0.4 & 0.6 & 0.7 \end{pmatrix}$$

Quarks

$$V_{CKM} \sim \begin{pmatrix} 1 & 0.2 & 0.005 \\ 0.2 & 1 & 0.04 \\ 0.005 & 0.04 & 1 \end{pmatrix}$$

What do we know about neutrino masses?

$\Delta m^2_{solar} \approx 8 \cdot 10^{-5} eV^2, \quad \Delta m^2_{atm} \approx 2 \cdot 10^{-3} eV^2$



Neutrino Mixing for 2 Flavors

$$\begin{pmatrix} \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} \cos\theta_{23} & \sin\theta_{23} \\ -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \begin{pmatrix} \nu_2 \\ \nu_3 \end{pmatrix}$$

$$|\nu_\mu\rangle = \cos\theta_{23}|\nu_2\rangle + \sin\theta_{23}|\nu_3\rangle$$

We have measured that $\theta_{23} \approx 45^o$:

$$|\nu_\mu\rangle = {}^1\!/\!_{\sqrt{2}}\left(|\nu_2\rangle + |\nu_3\rangle\right) \qquad |\nu_\tau\rangle = {}^1\!/\!_{\sqrt{2}}\left(-|\nu_2\rangle + |\nu_3\rangle\right)$$

General oscillation formula:

$$\boxed{\begin{aligned} P_{\nu_\alpha \to \nu_\beta} &= \delta_{\alpha\beta} - 4\sum_{i>j} \Re(U_{\alpha i}^{*} U_{\beta i} U_{\alpha j} U_{\beta j}^{*}) \sin^2\left(1.27\Delta m_{ij}^2 \frac{L}{E}\right) \\ &+ 2\sum_{i>j} \Im(U_{\alpha i}^{*} U_{\beta i} U_{\alpha j} U_{\beta j}^{*}) \sin\left(2.54\Delta m_{ij}^2 \frac{L}{E}\right) \end{aligned}}$$

$\Delta m_{ij}^2 \equiv m_i^2 - m_j^2 \text{ in eV}^2$

$L \text{ in km}$

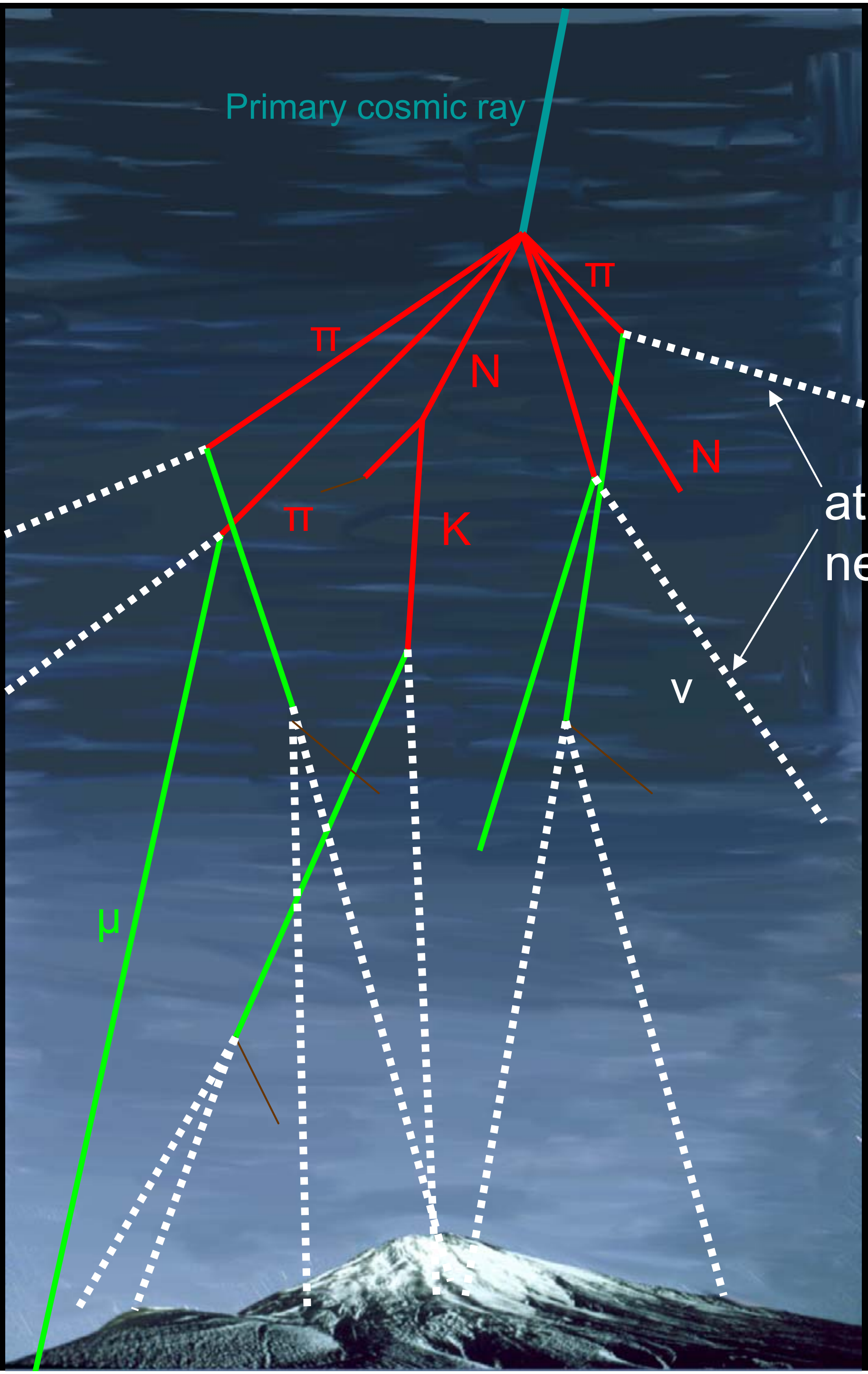
$E \text{ in GeV}$

Neutrino Oscillations (23)

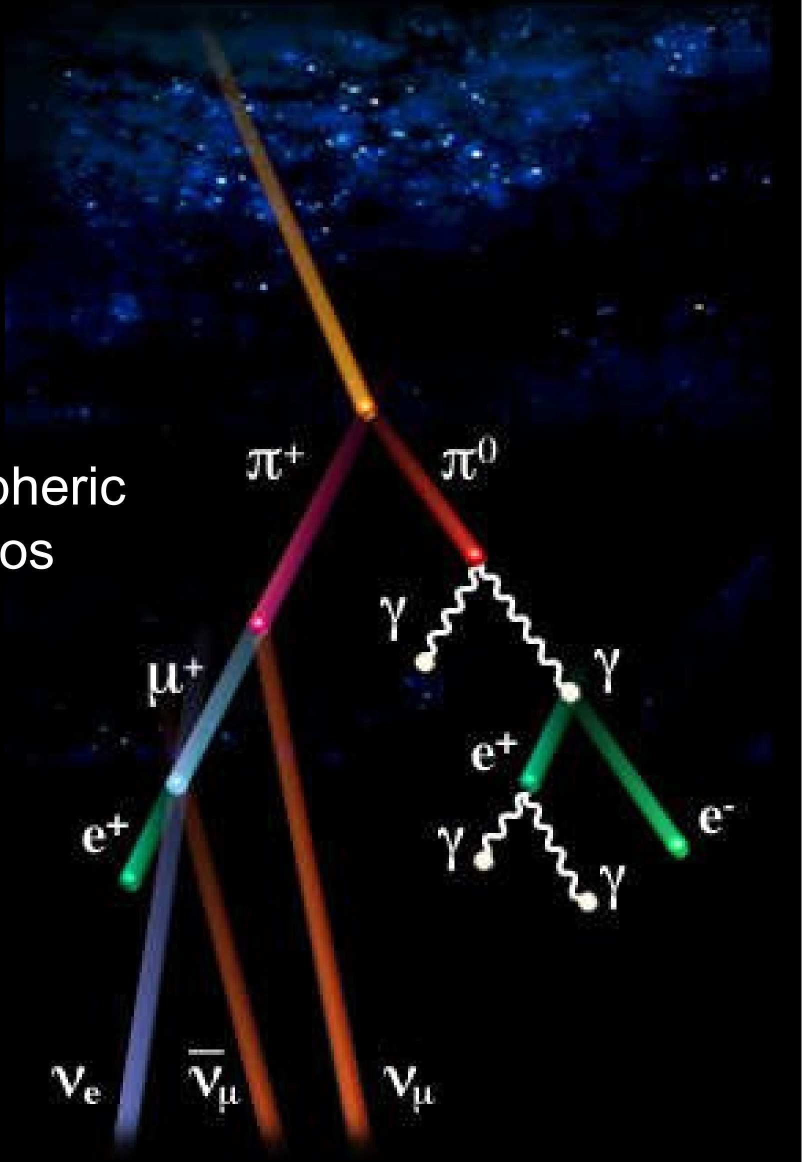
$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

$\nu_\mu \rightarrow \nu_\tau$ Oscillations

Atmospheric neutrinos & accelerator neutrinos

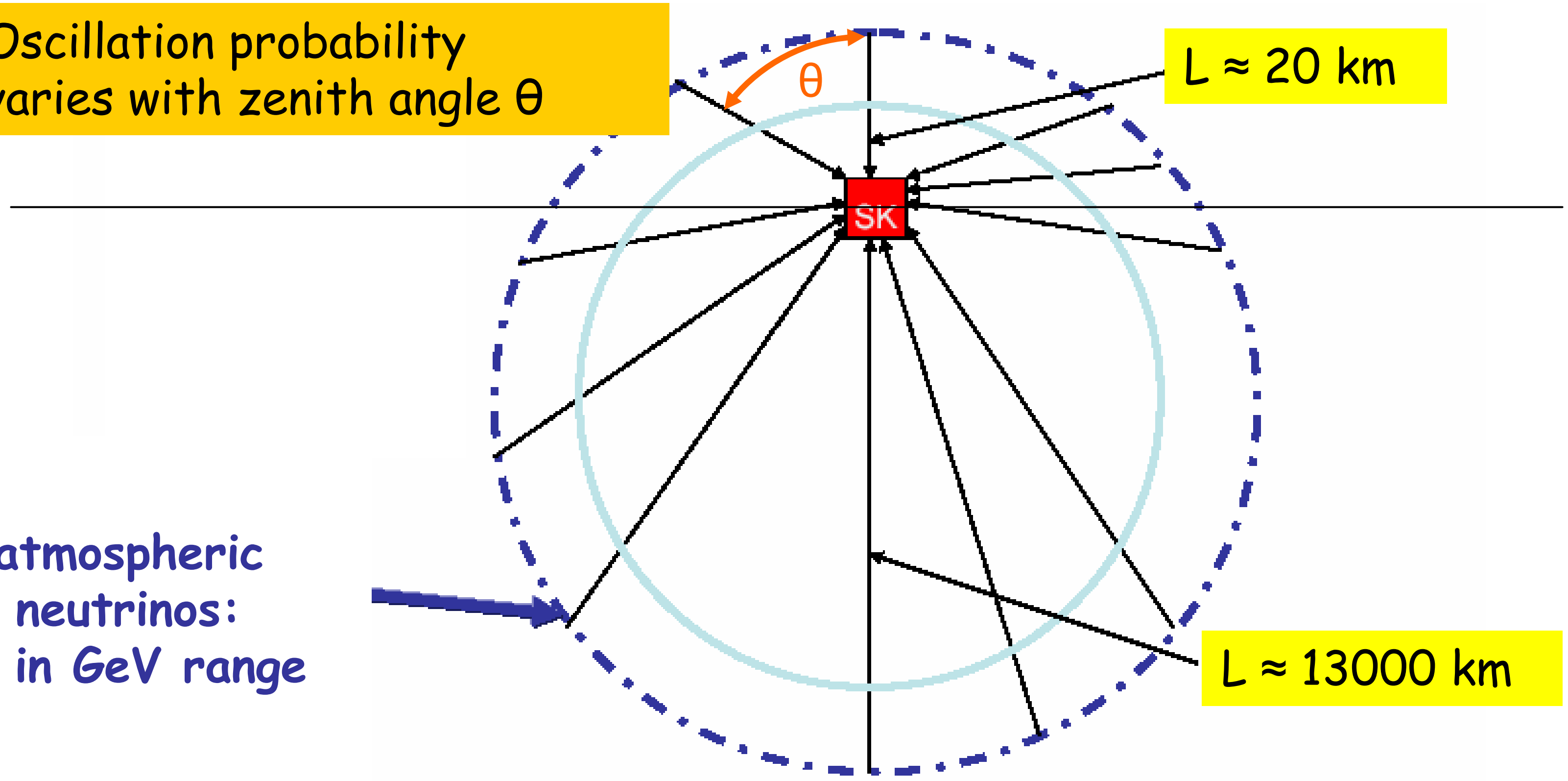


atmospheric neutrinos



$\#(\nu_\mu) / \#(\nu_e) \approx 2$

Oscillation of atmospheric neutrinos



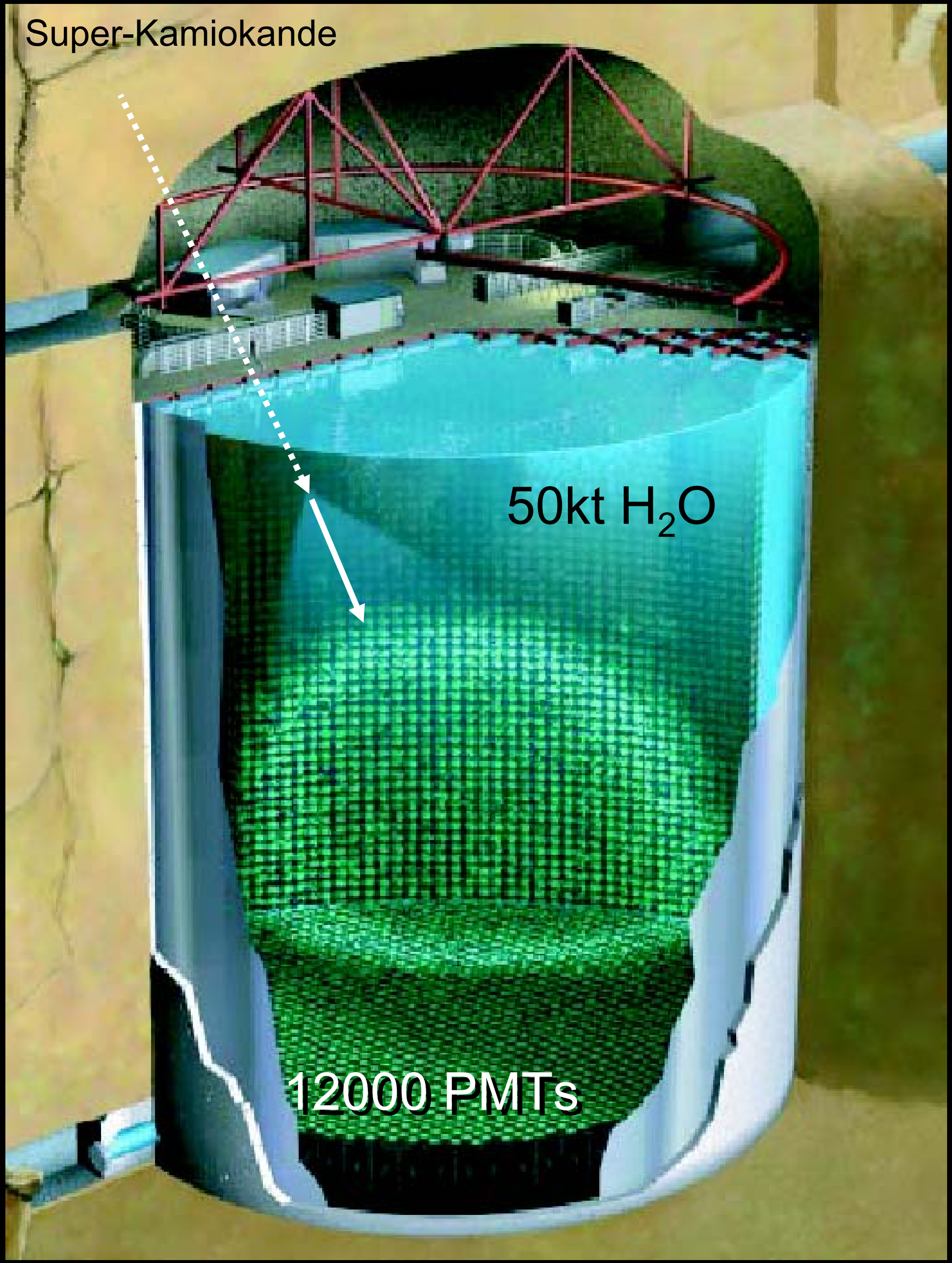
Oscillation probability
varies with zenith angle θ

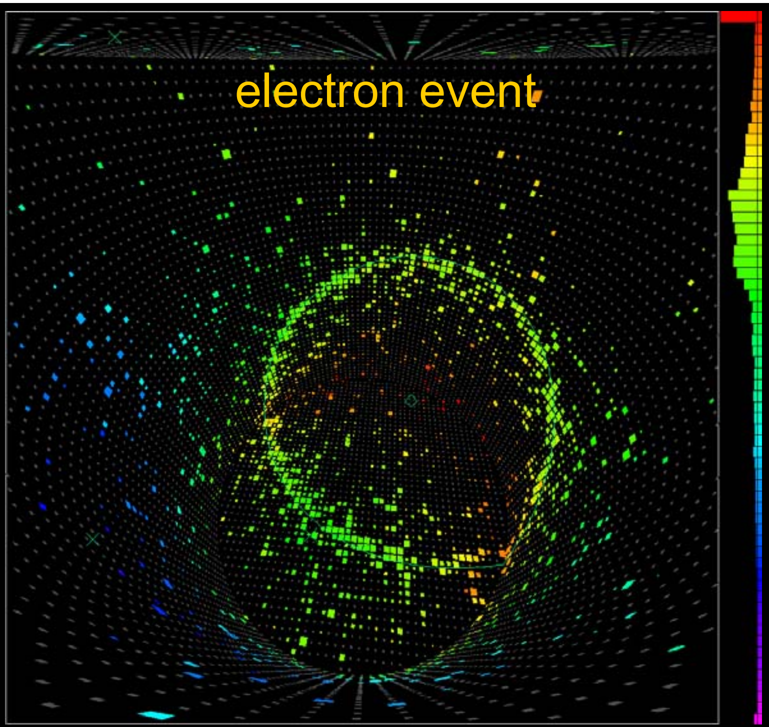
L ≈ 20 km

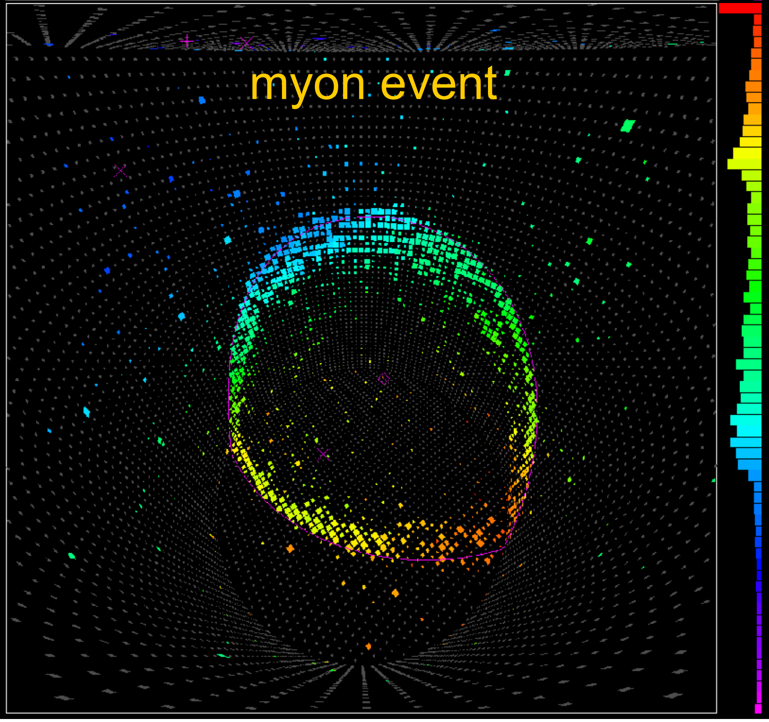
atmospheric neutrinos:
E_ν in GeV range

L ≈ 13000 km

$$P(\nu_\mu \rightarrow \nu_x) = \sin^2 2\theta_{atm} \sin^2\left(\frac{1.27 \Delta m^2_{atm}[\mathrm{eV}^2] L[\mathrm{km}]}{E_\nu[\mathrm{GeV}]} \right)$$

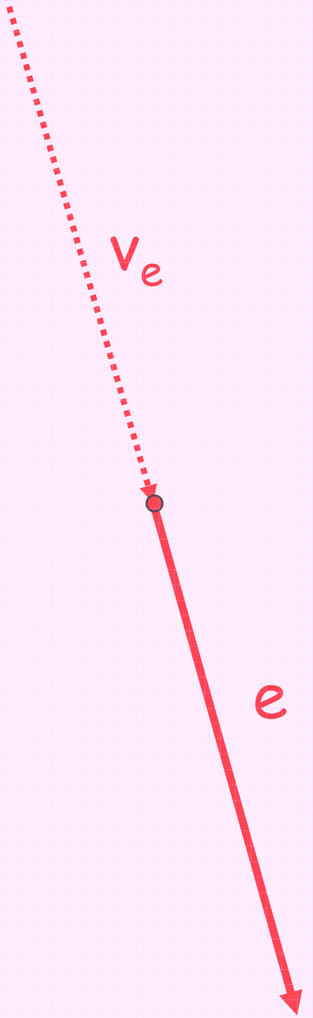

Super-Kamiokande
50kt H_2O
12000 PMTs

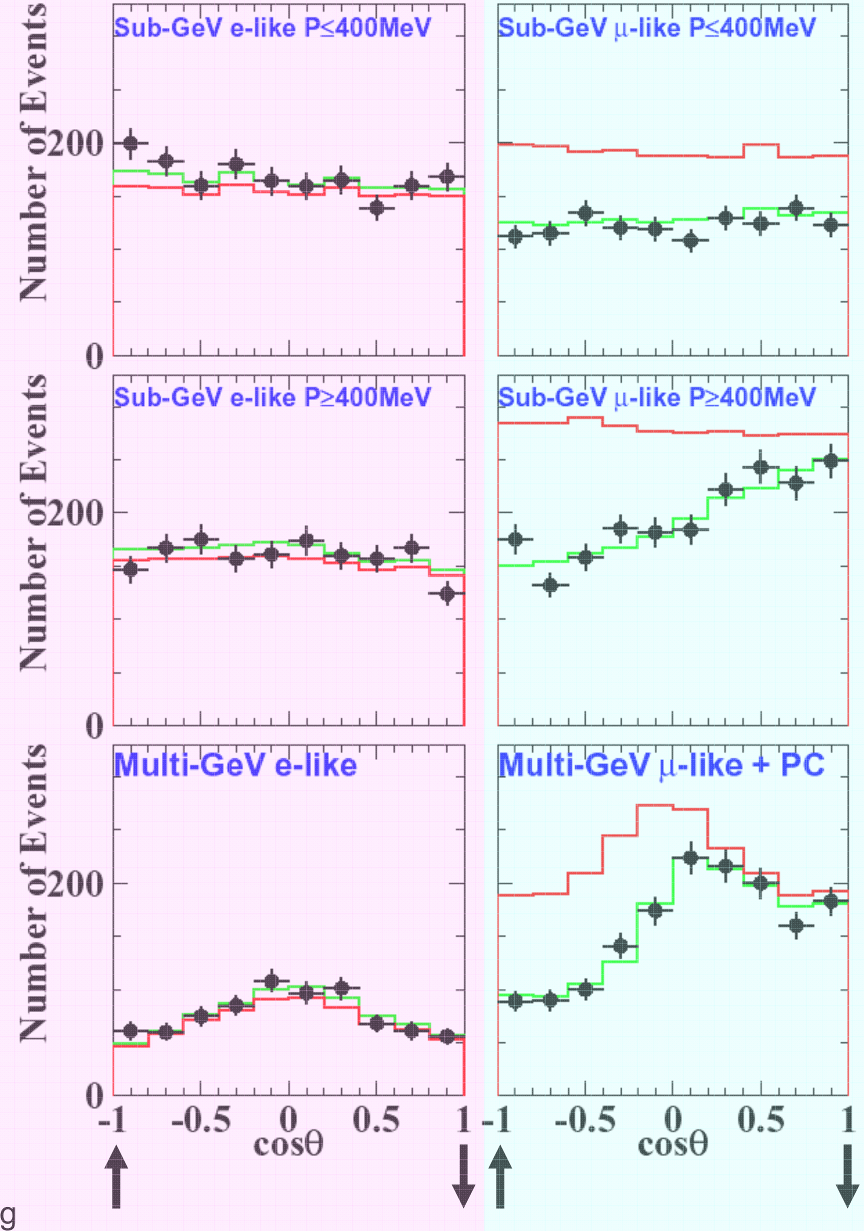

electron event


myon event

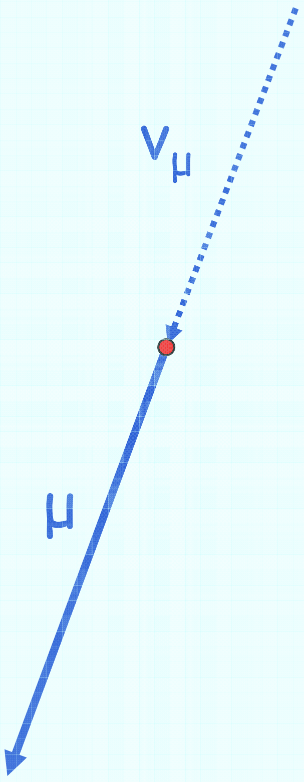
SuperK – atmospheric neutrinos

e–like events





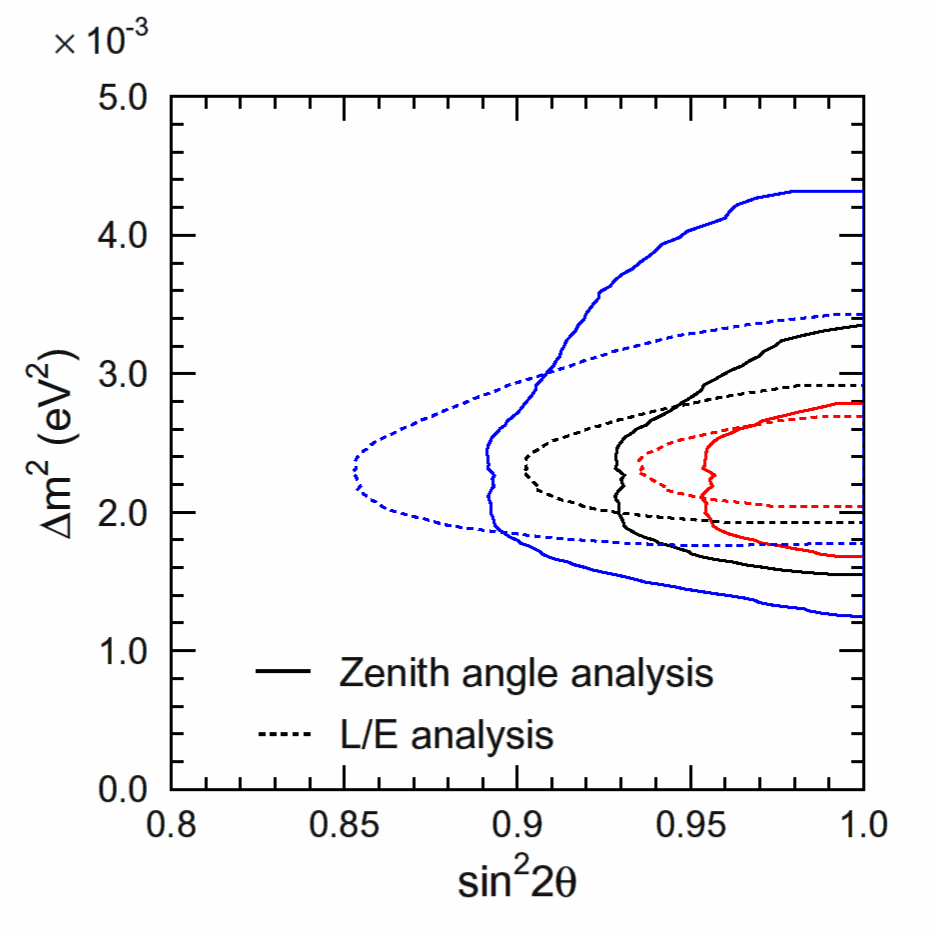
μ-like events



🟥 without oscillation
🟩 oscillation (best fit)
● data

SuperKamiokande

Atmospheric Neutrino Results

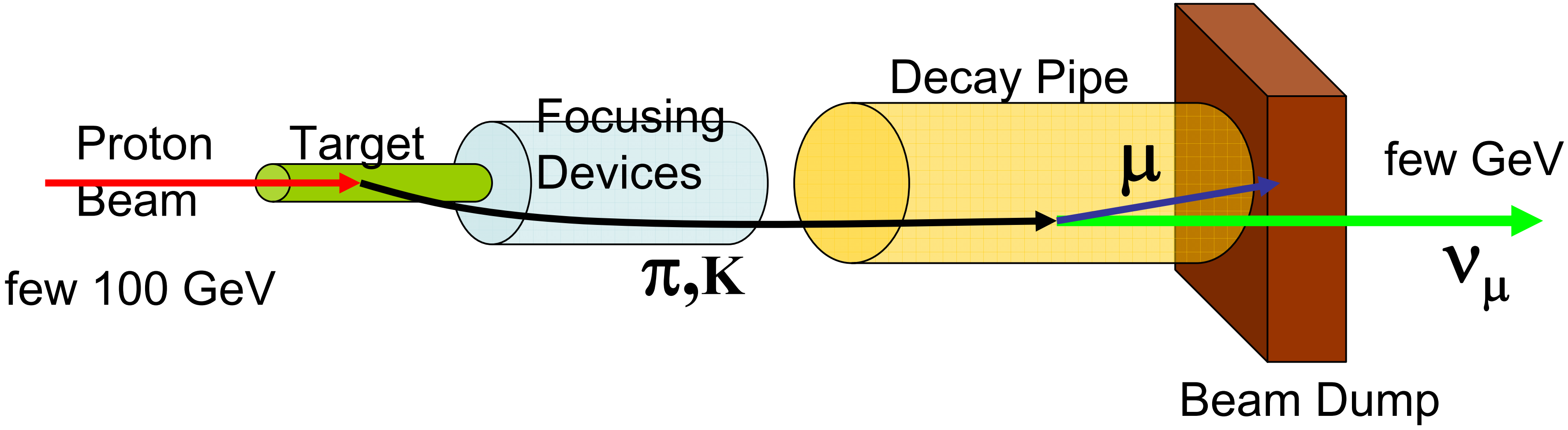


L/E Analysis
(PRL93 (2004) 101801),
Best Fit:
$\sin^2 2\theta = 1.02$
$|\Delta m^2| = 2.4 \times 10^{-3}$ eV^2

Full SK-I data set, 90% CL
(PRD71 (2005) 112005):

$\sin^2 2\theta > 0.92$
$1.5 \cdot 10^{-3}$ eV$^2 < \Delta m^2 < 3.4 \cdot 10^{-3}$ eV^2

Neutrino beams: Principle

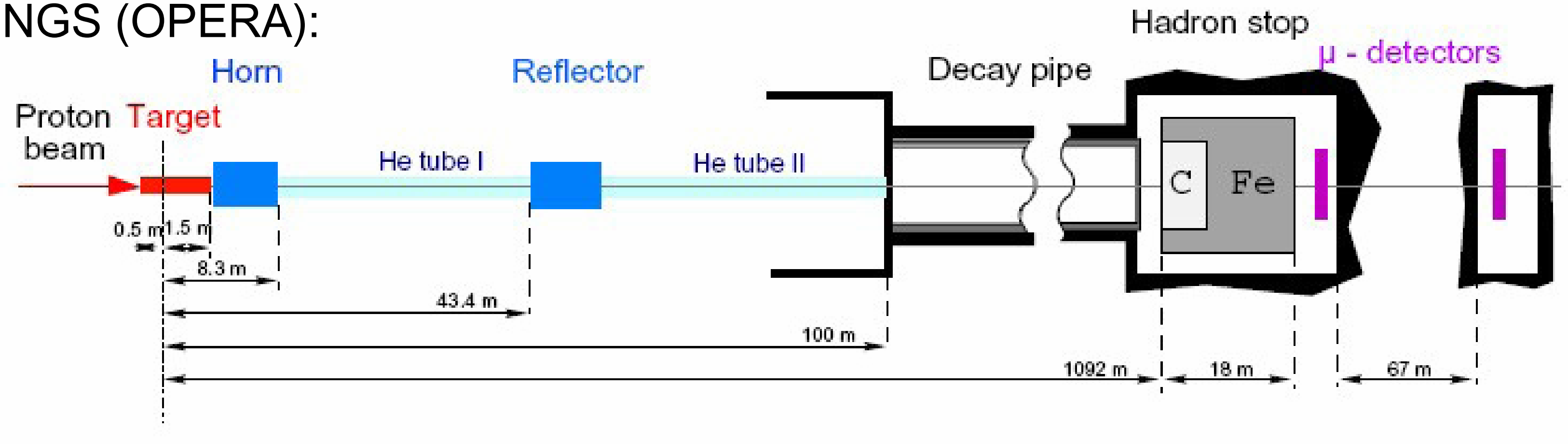


Beam composition (typical example):

- dominantly ν_μ
- contamination from $\bar{\nu}_\mu$ (≈6%), ν_e (≈0.7%), $\bar{\nu}_e$ (≈0.2%)
- $\nu_\tau \lesssim 10^{-6}$

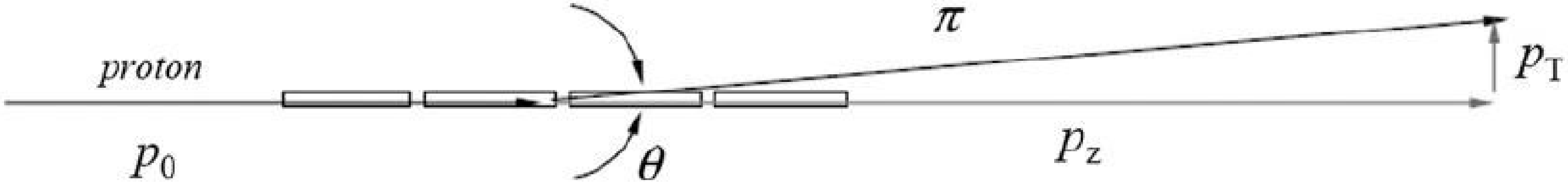
Technical Overview Conventional Neutrinobeams

CNGS (OPERA):



proton source	experiments	E_{proton}	pot/yr.	Power	E_ν
SPS	OPERA	400 GeV	$0.45*10^{20}$	0.12 MW	25 GeV
FNAL Main Injector	MINOS, NoνA	120 GeV	$2.5*10^{20}$	0.25 MW	3-17 GeV
J-PARC	T2K	40-50 GeV	$11*10^{20}$	0.75 MW	0.8 GeV

Neutrino Beam: Target



neutrino beamline	experiments	material	∅ [mm]	lenght [cm]
CNGS (SPS)	OPERA	graphite	4-5	200
NuMI (Fermilab)	MINOS, NoνA	graphite	6.4	90
J-PARC (KEK)	T2K	graphite	12-15	90
BoosterNeutrino	MiniBooNe	Be	10	60

Power can be up to 100GW!

CNGS Target

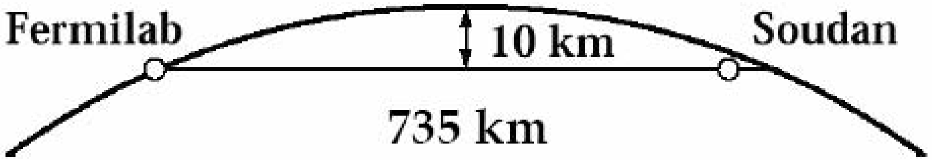
The MINOS Experiment

A large detector at Soudan

A smaller detector at Fermilab

Measure the beam and neutrino energy spectrum near the source

- See how it differs far away



Example of a disappearance measurement

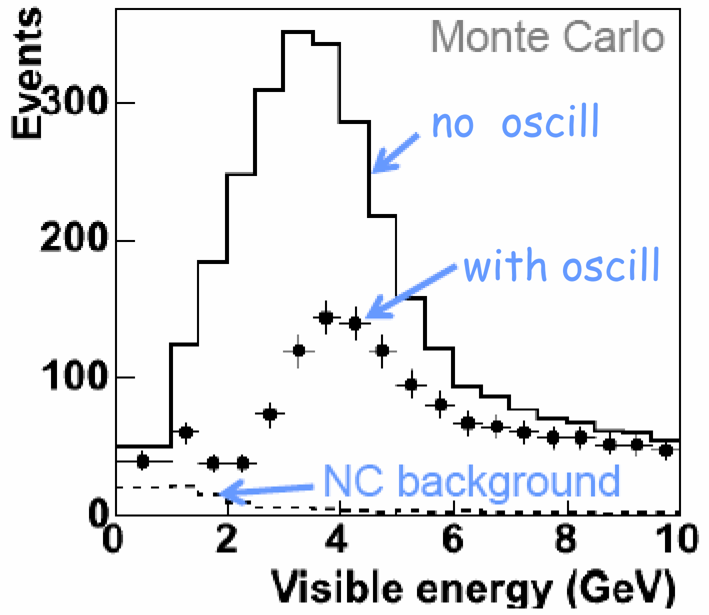
Look for a deficit of ν_μ events at a distance…

$$P(\nu_\mu \to \nu_\mu) = 1 - \underset{1}{\boxed{\sin^2 2\theta}}\,\sin^2(1.267\,\underset{2}{\boxed{\Delta m^2}}\,L/E)$$

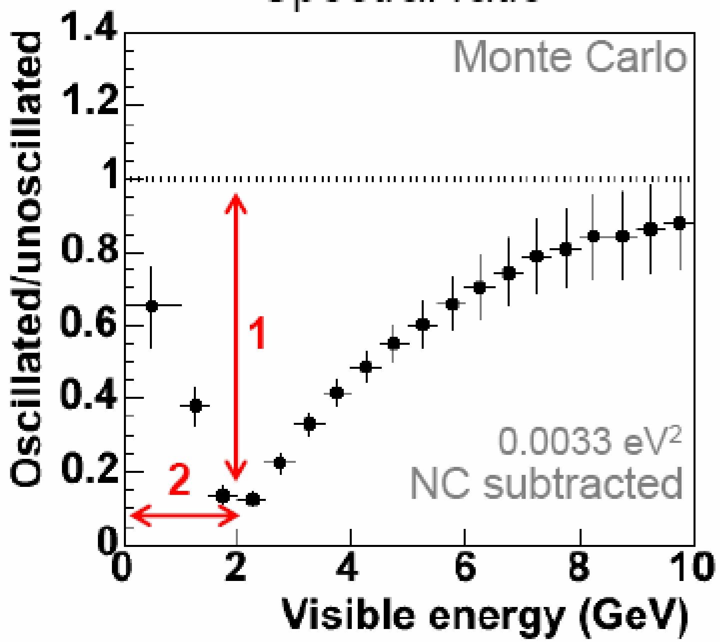
statistics!

energy resolution!

ν_μ spectrum



Spectral ratio

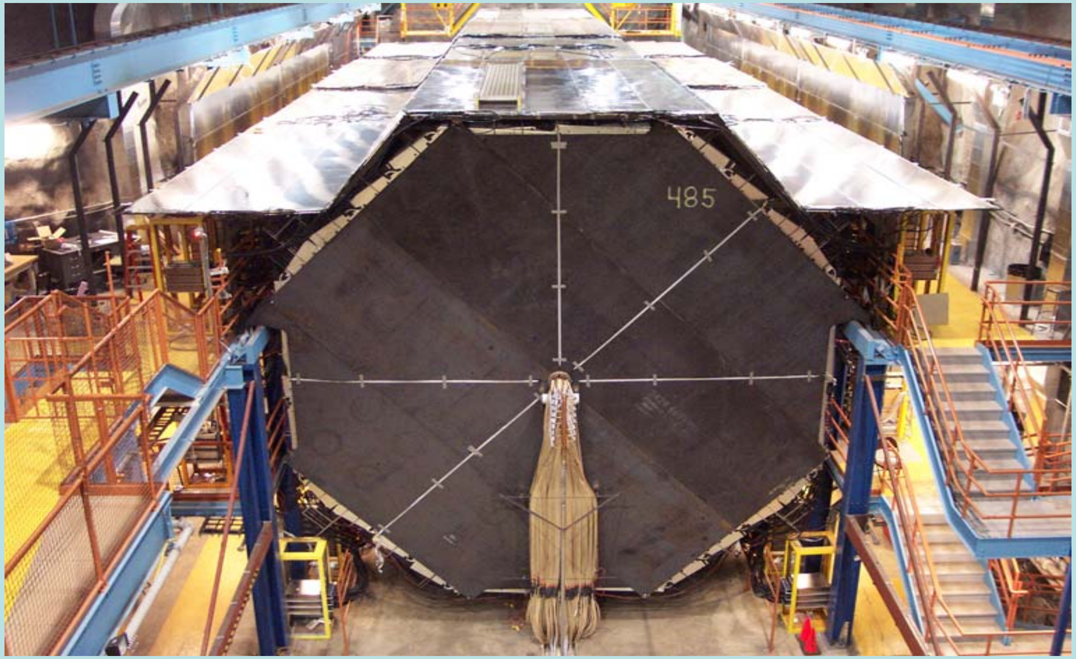


MINOS Detectors

Near Detector (Fermilab): 1km

1 kton, 4×5×15m
282 steel,
153 scintillator planes

Far Detector (Soudan Mine): 735km

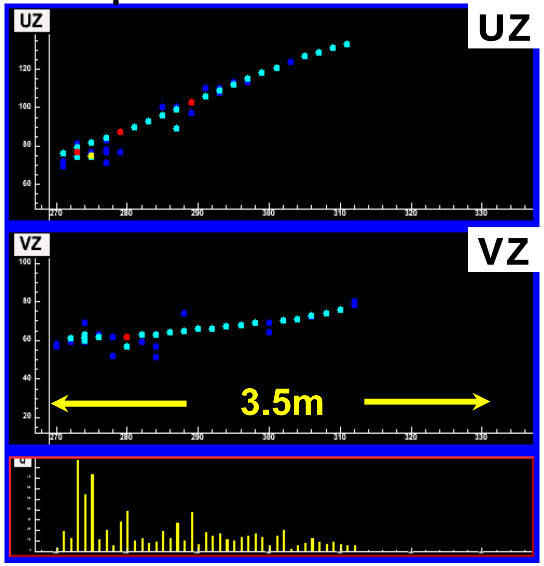


5.4 ktons, 8×8×30m
484 steel/scintillator planes

Event Topologies

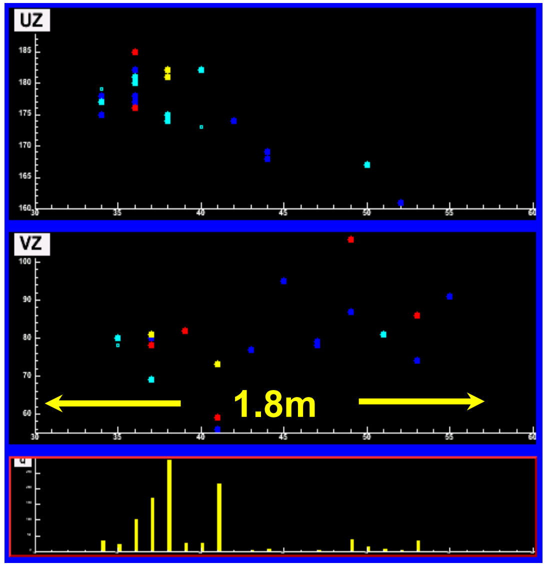
Monte Carlo

ν_μ CC Event



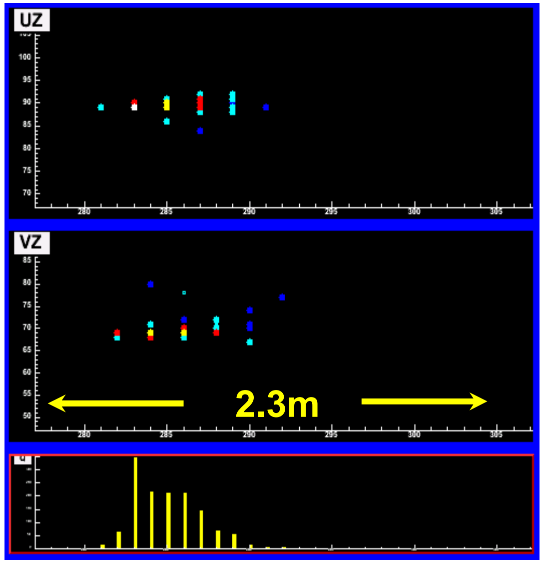
long μ track +
hadronic activity

NC Event



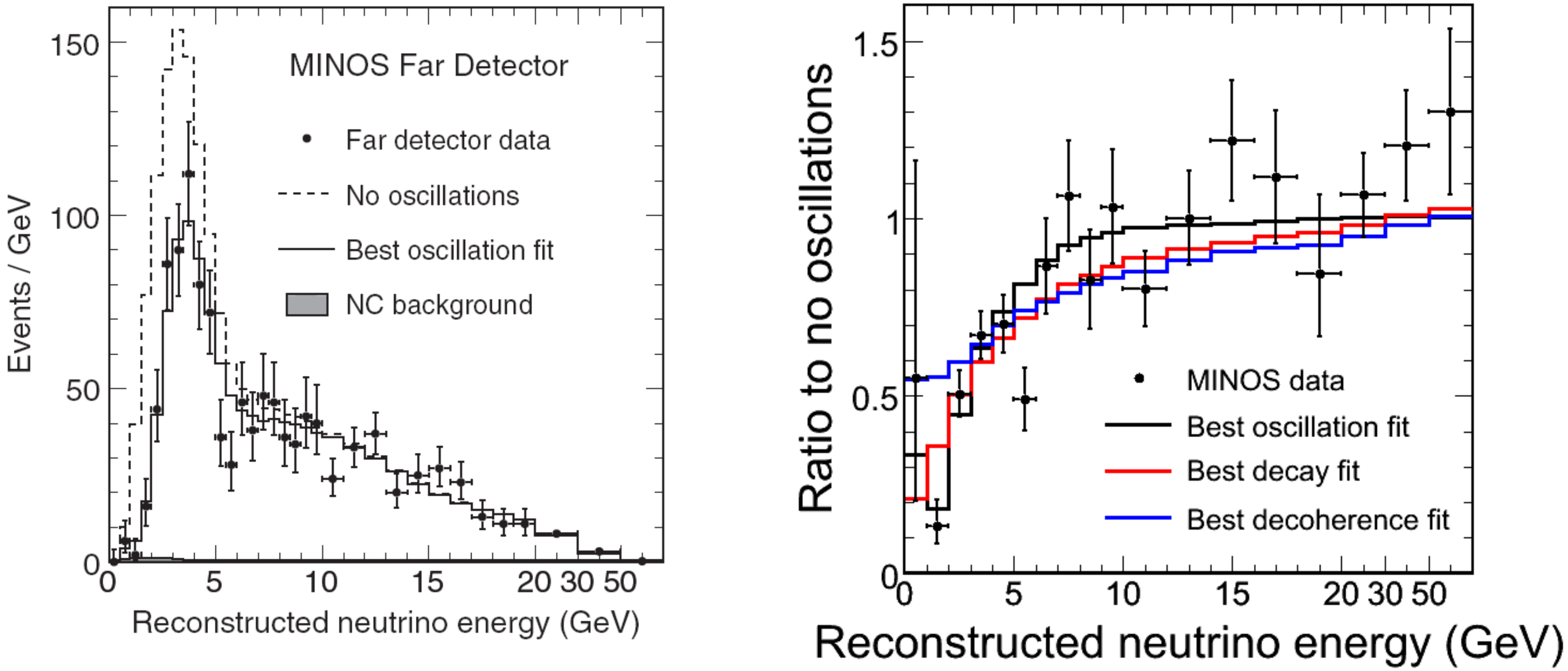
short event,
often diffuse

ν_e CC Event



short event,
typical EM shower
profile

MINOS Results: Fit to Oscillation Hypothesis



$$\left|\Delta m^2_{32}\right| = (2.43 \pm 0.13) \times 10^{-3}\,\mathrm{eV}^2 \quad (68\%\mathrm{CL})$$

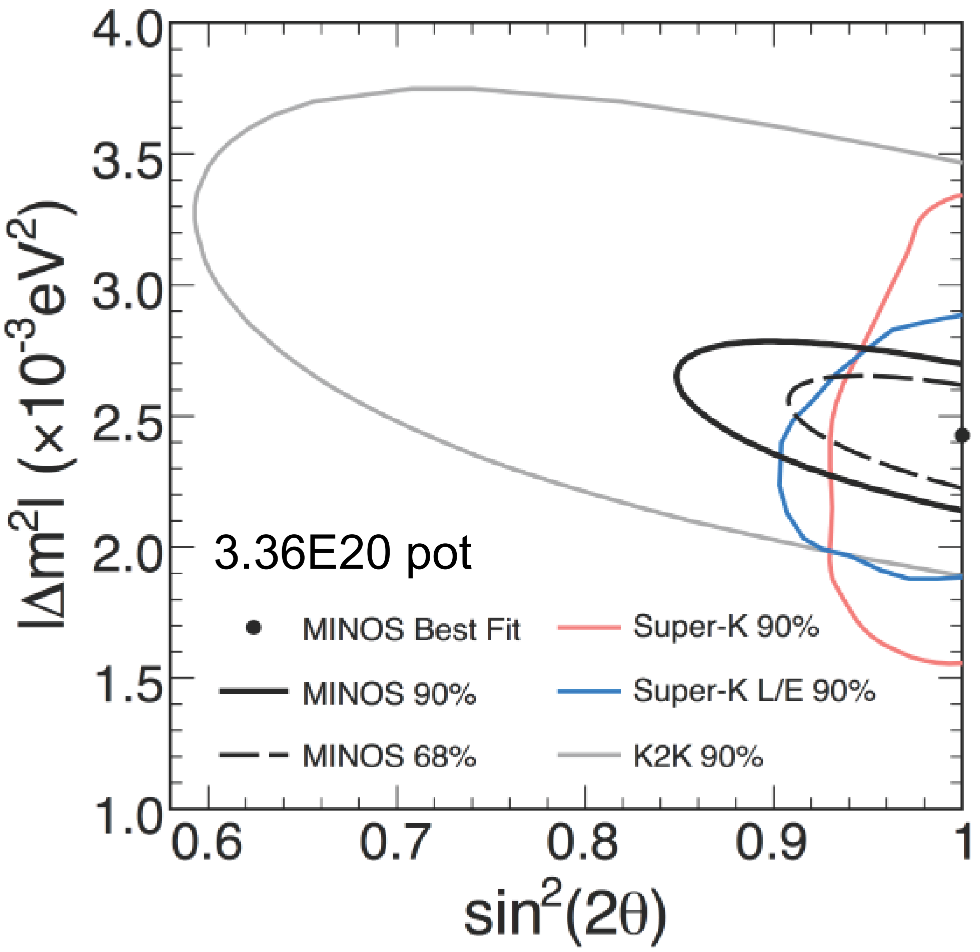
$$\sin^2 2\theta_{23} > 0.90 \qquad (90\%\mathrm{CL})$$

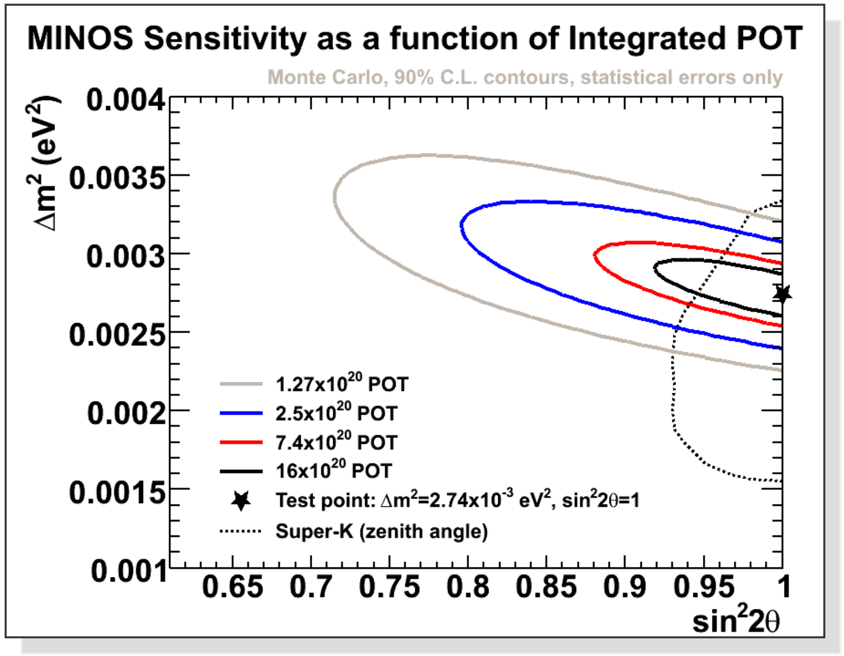
(best fit)

(for $3.36 \cdot 10^{20}$pot)

„Measurement of Neutrino Oscillations with the MINOS Detectors in the NuMI Beam“
MINOS Coll., Phys. Rev. Lett. 101, 131802 (2008)

MINOS: Allowed Regions (new)





MINOS: search for ν_e appearance

Why? This is one possibility to measure θ_{13} and δ_{CP} :

The Oscillation probability $P(\nu_\mu \rightarrow \nu_e)$ is approximately given by:

$$\begin{aligned} P(\nu_\mu \rightarrow \nu_e) \quad &\approx \quad \sin^2\theta_{23}\frac{\sin^2 2\theta_{13}}{(\hat{A}-1)^2}\sin^2((\hat{A}-1)\Delta) \\ &+\alpha\frac{\sin\delta_{CP}\cos\theta_{13}\sin 2\theta_{12}\sin 2\theta_{13}\sin 2\theta_{23}}{\hat{A}(1-\hat{A})}\sin(\Delta)\sin(\hat{A}\Delta)\sin((1-\hat{A})\Delta) \\ &+\alpha\frac{\cos\delta_{CP}\cos\theta_{13}\sin 2\theta_{12}\sin 2\theta_{13}\sin 2\theta_{23}}{\hat{A}(1-\hat{A})}\cos(\Delta)\sin(\hat{A}\Delta)\sin((1-\hat{A})\Delta) \\ &+\alpha^2\frac{\cos^2\theta_{23}\sin^2 2\theta_{12}}{\hat{A}^2}\sin^2(\hat{A}\Delta) \end{aligned}$$

with:

$\alpha = \Delta m_{21}^2 / \Delta m_{31}^2 << 1$

$\Delta = \Delta m_{31}^2 L / 4E$

matter dependent quantities :

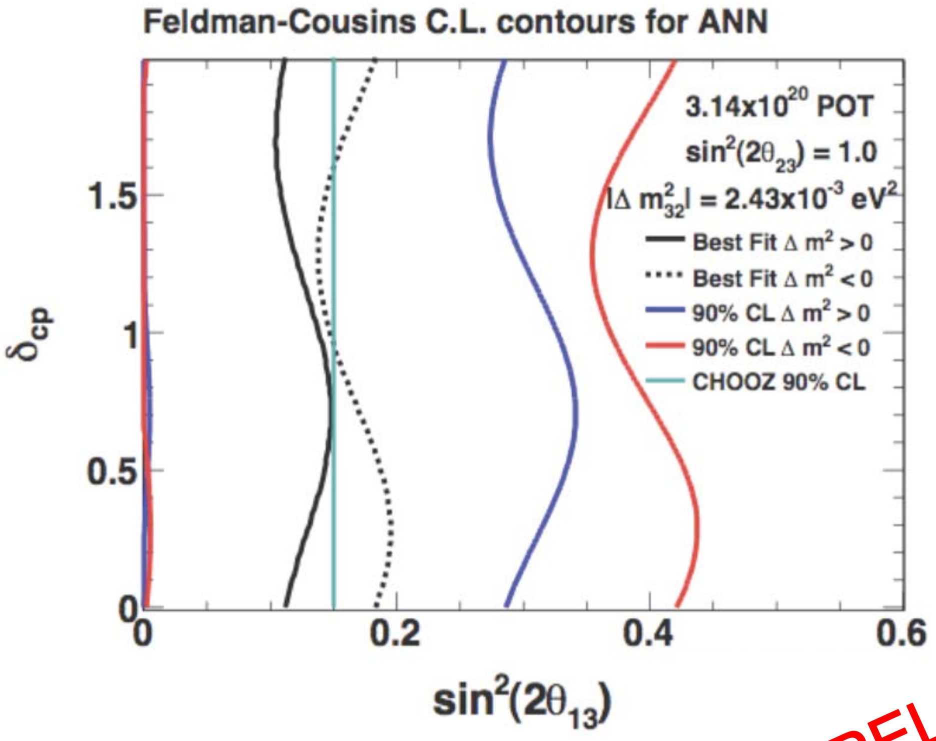
$\hat{A} = 2VE / \Delta m_{31}^2$

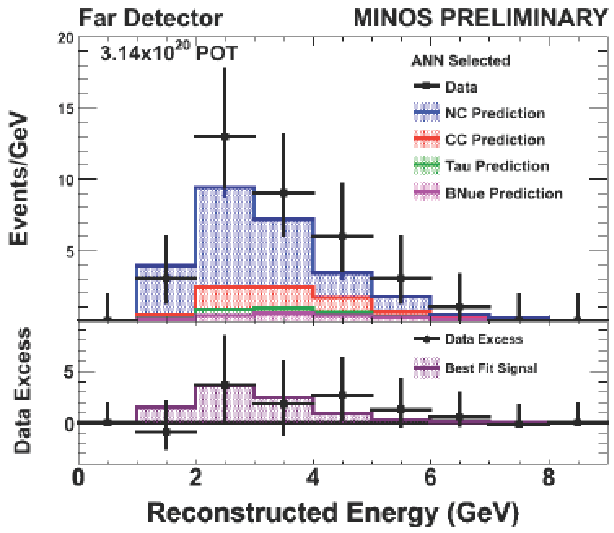
$V = \sqrt{2}G_F n_e$, with electron density n_e (assumed constant)

NEW! MINOS: ν_e appearance

35 events found in signal region, expected background: 27 ± 5(stat) ± 2(syst)

$\sin^2 2\theta_{13} < 0.29$ (90% CL) for $\delta_{CP} = 0$ and normal hierarchy



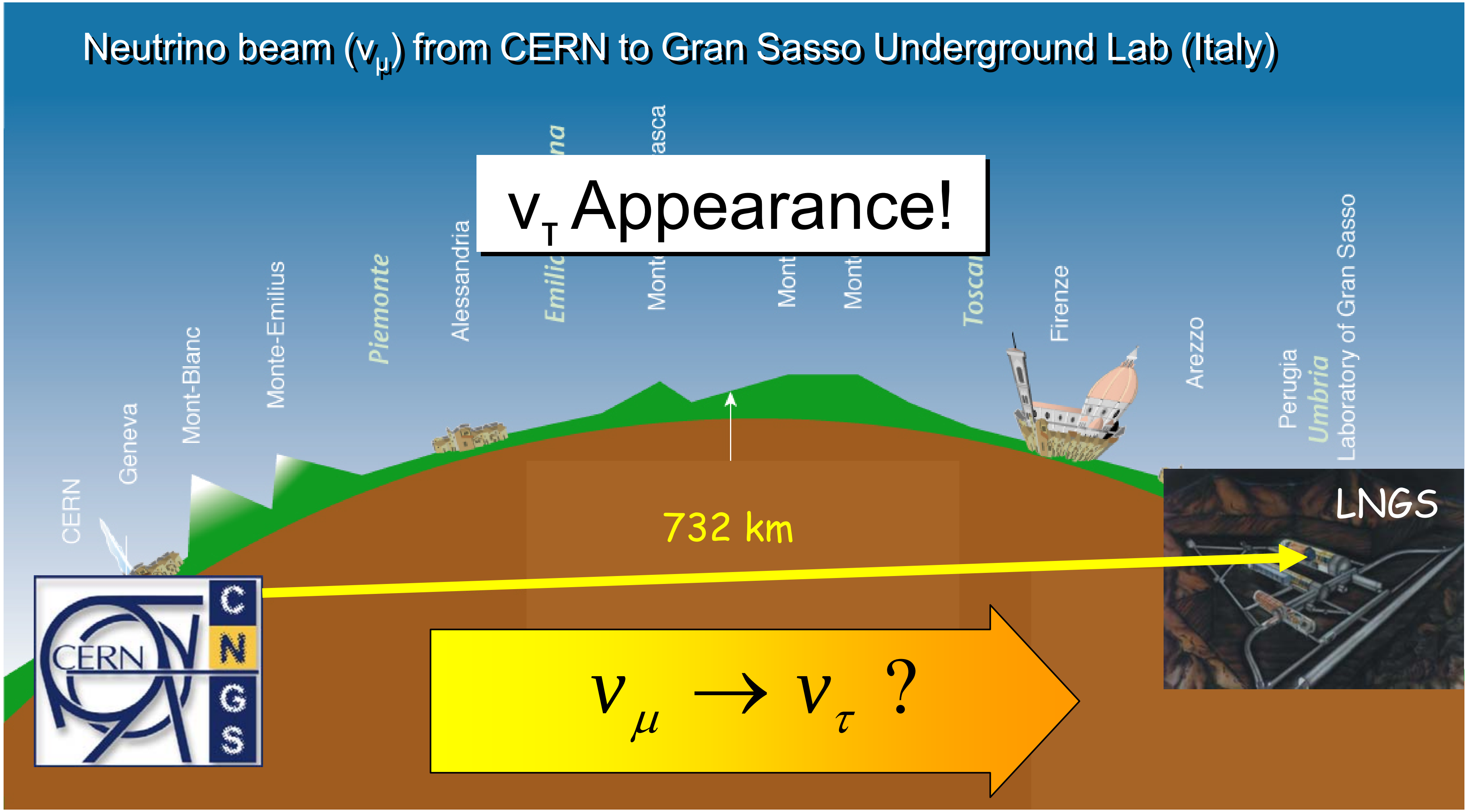


PRELIMINARY

From „Recent Results from the MINOS experiment", M. Diwan @ Neutrino Telescopes Venice March 2009, arXiv:0904.3706

OPERA:

Oscillation Project with Emulsion tRacking Apparatus



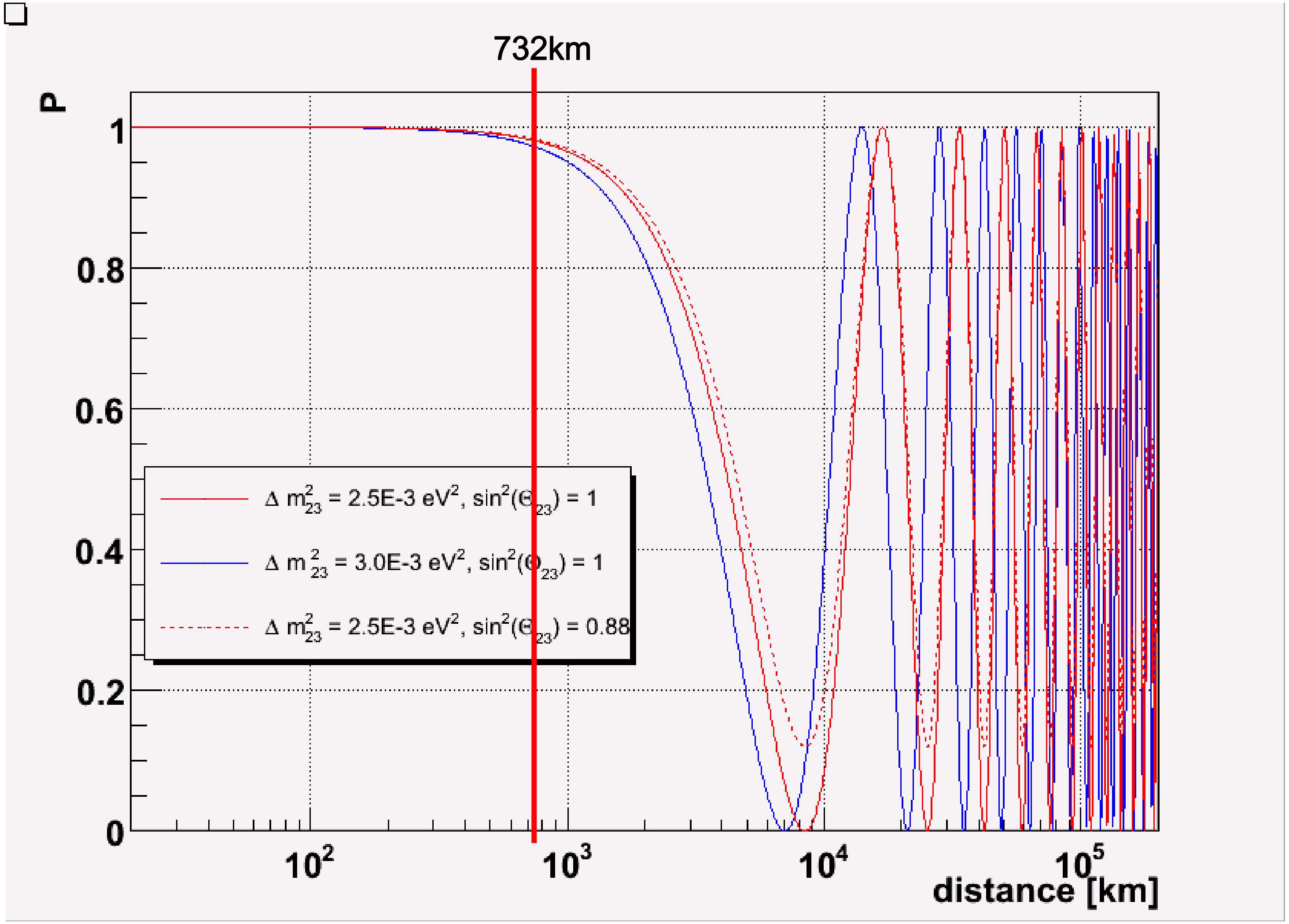
Neutrino beam (ν_μ) from CERN to Gran Sasso Underground Lab (Italy)

ν_τ Appearance!

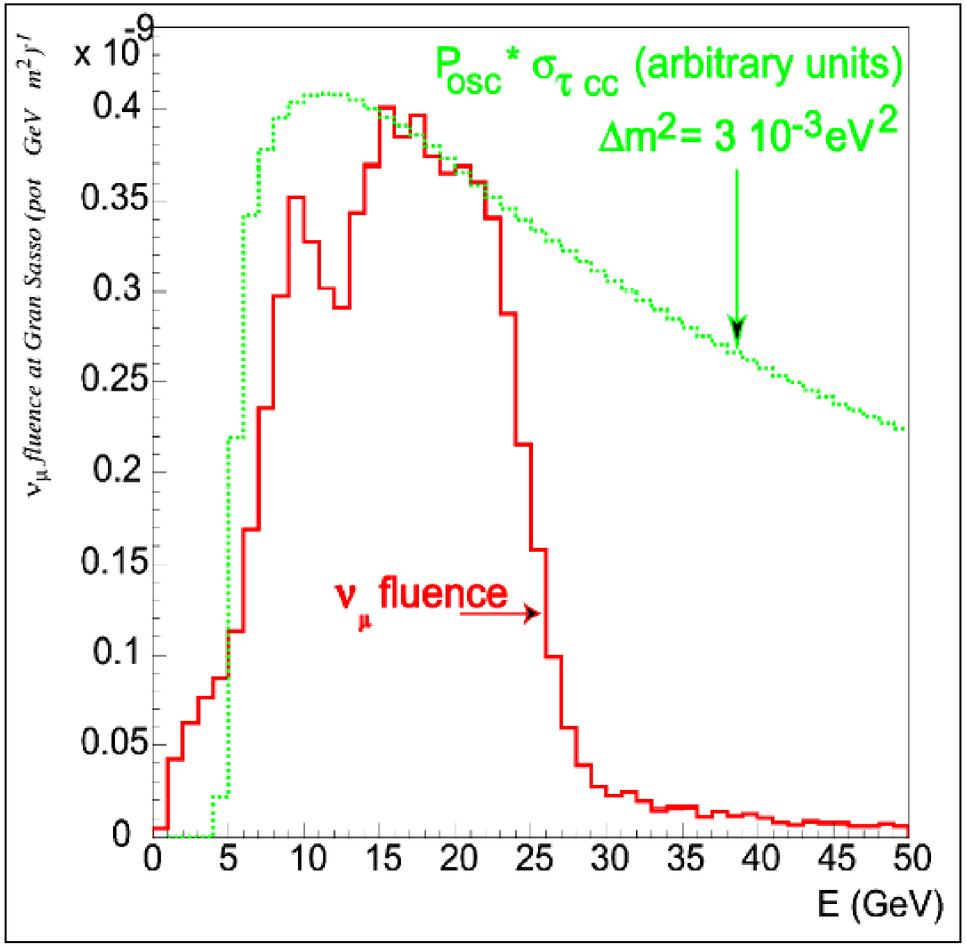
$$\nu_\mu \rightarrow \nu_\tau \; ?$$

first physics run: june-november 2008; run 2009: just started

survival probability of ν_μ for E_ν=17GeV



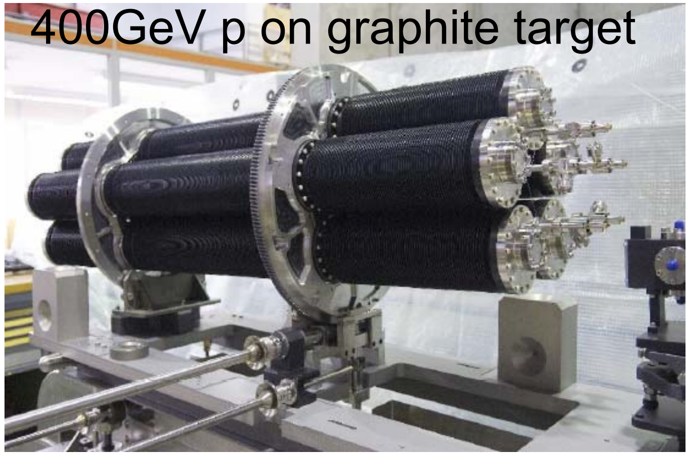
CNGS beam (“pure” ν_μ)



$$\langle E_\nu \rangle = 17\text{GeV}$$

$$\bar{\nu}_\mu / \nu_\mu = 4\%$$

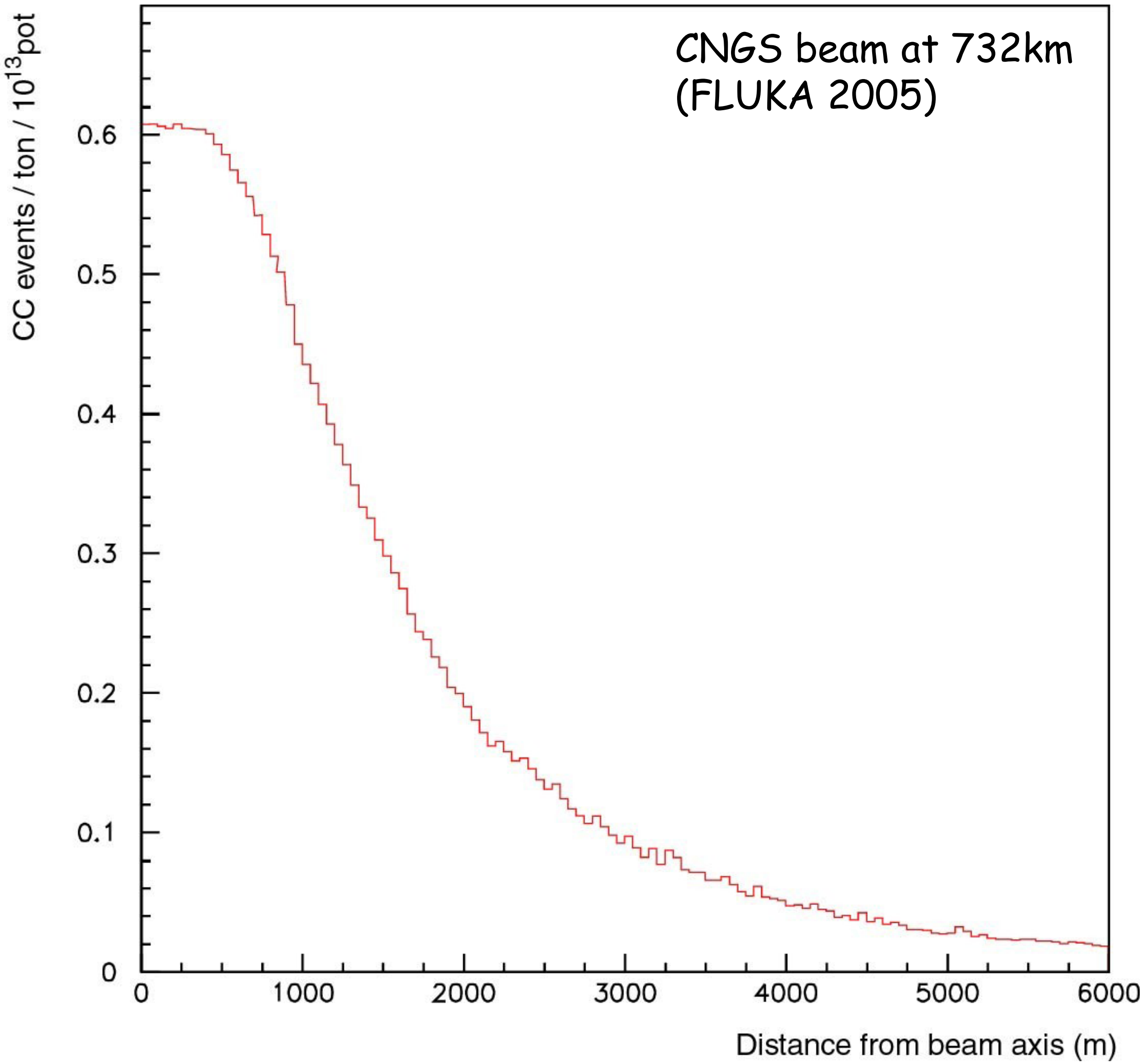
$$(\bar{\nu}_e + \nu_e) / \nu_\mu = 0.87\%$$



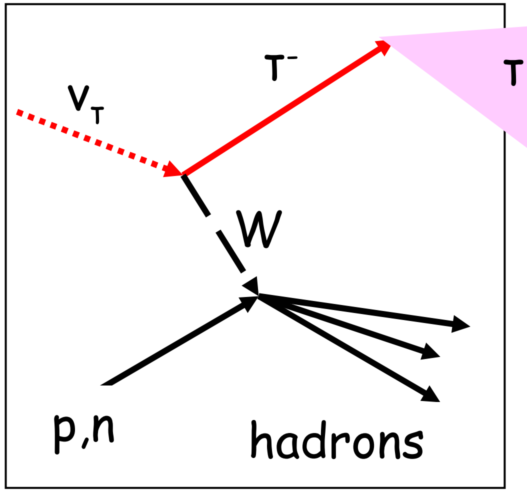
4.5·10^{19}pot/year

Total exposure expected: $22.5^{E}19$ pot

Profile of neutrino beam @ LNGS



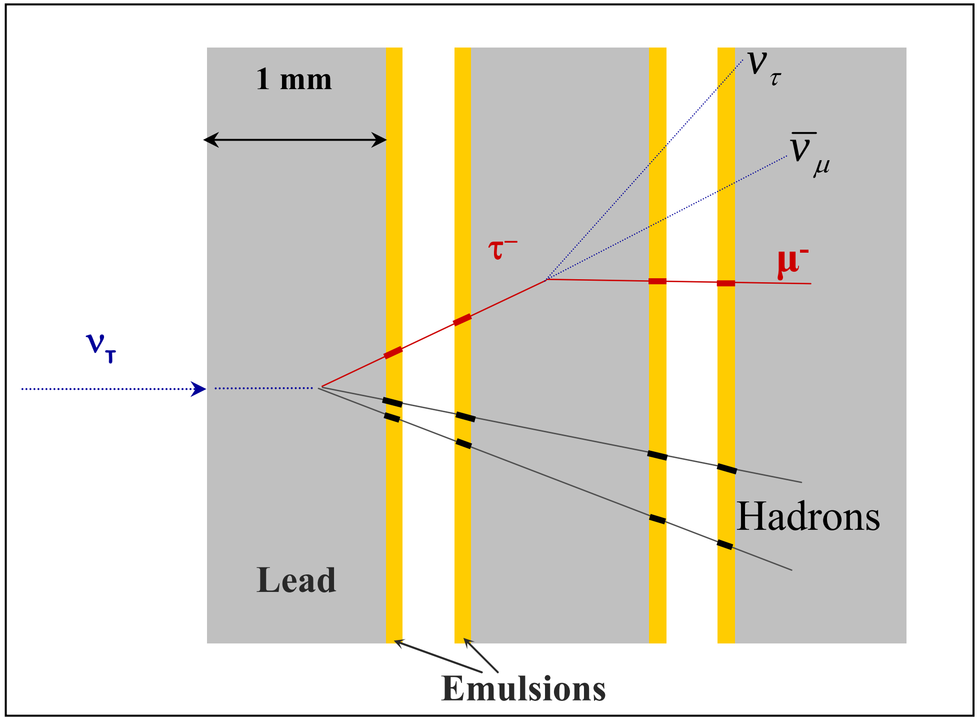
OPERA: ν_τ detection



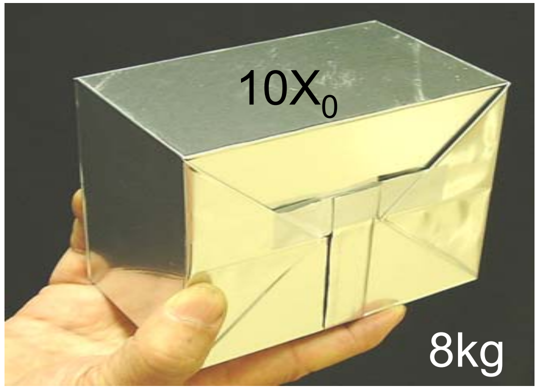
τ-decay:

$\tau^- \rightarrow \mu^- + \bar{\nu}_\mu + \nu_\tau$	17.4%	kink
$\tau^- \rightarrow e^- + \bar{\nu}_e + \nu_\tau$	17.8%	
$\tau^- \rightarrow \mathrm{hadron} + \nu_\tau$	49.5%	
$\tau^- \rightarrow \pi^-\pi^-\pi^+(n\pi^0) + \nu_\tau$	15.2%	trident

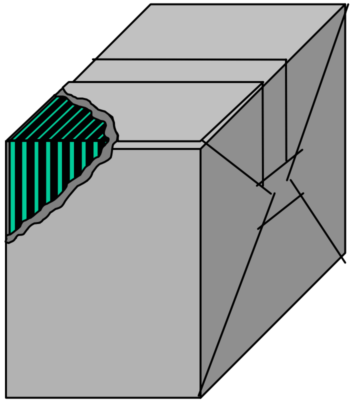
Typical topology of τ-decay:
“Kink” within 1mm from vertex



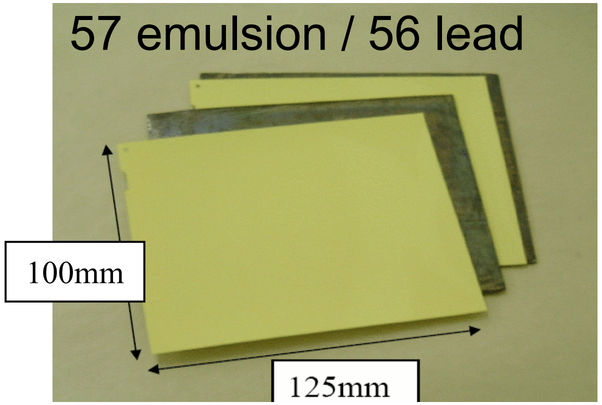
OPERA target: lead-emulsion-bricks



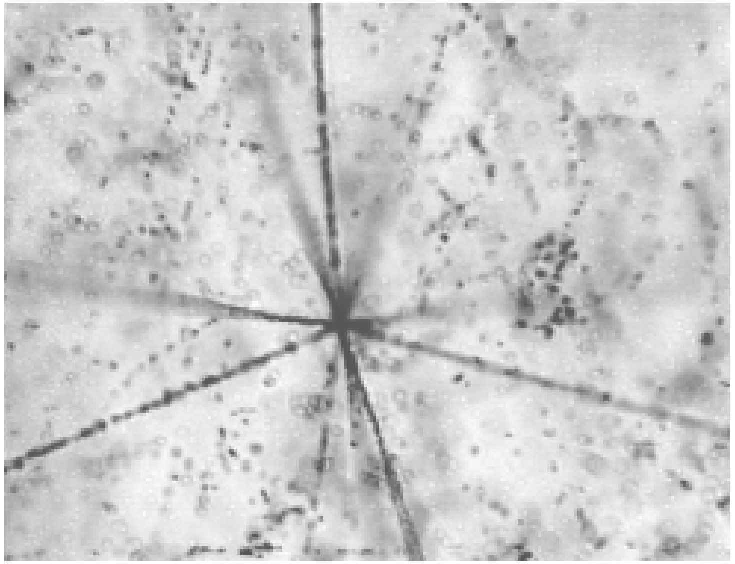
lead-emulsion-brick
(total ≈ 150000)



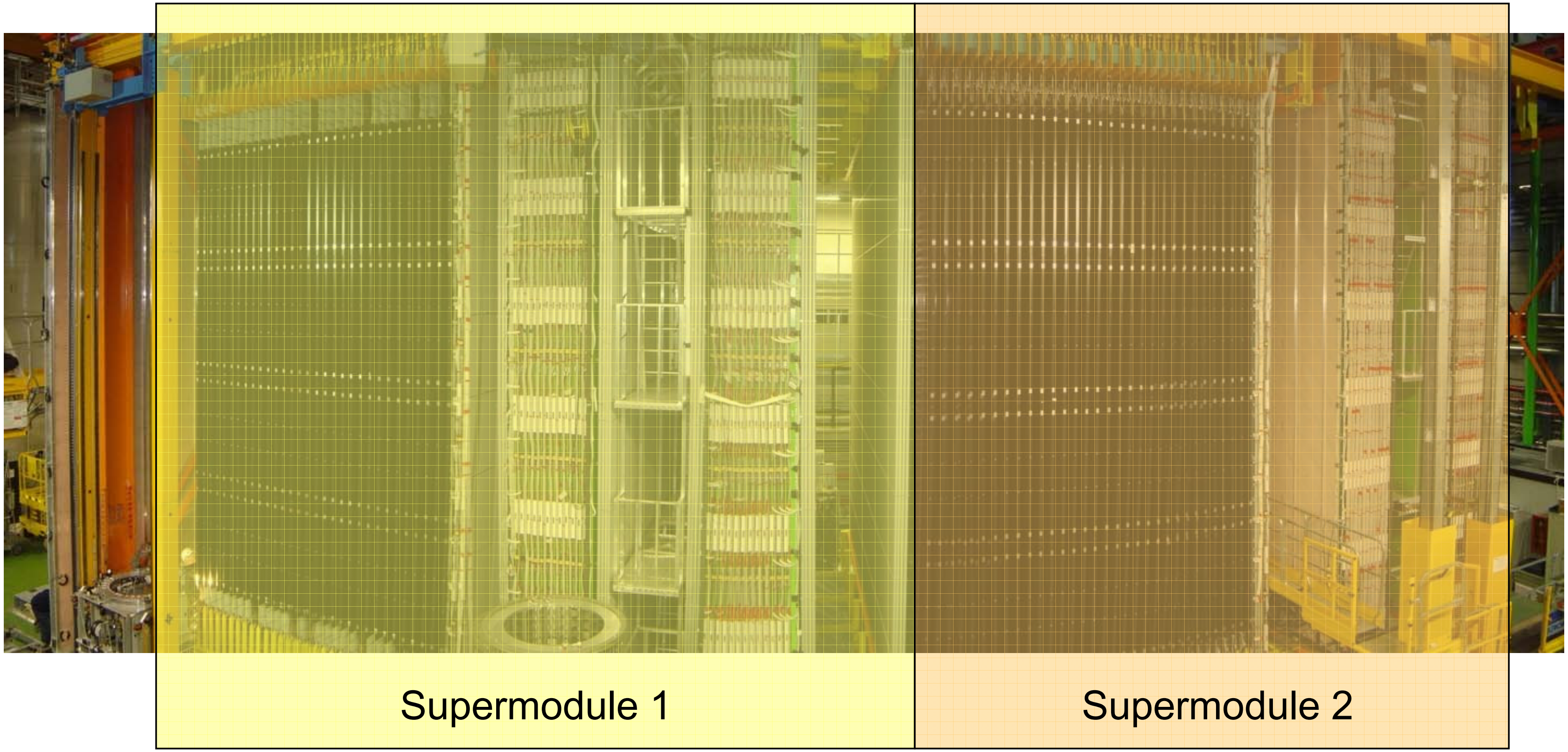
57 emulsion / 56 lead



target mass:
≈1.2 kton



OPERA - Detector



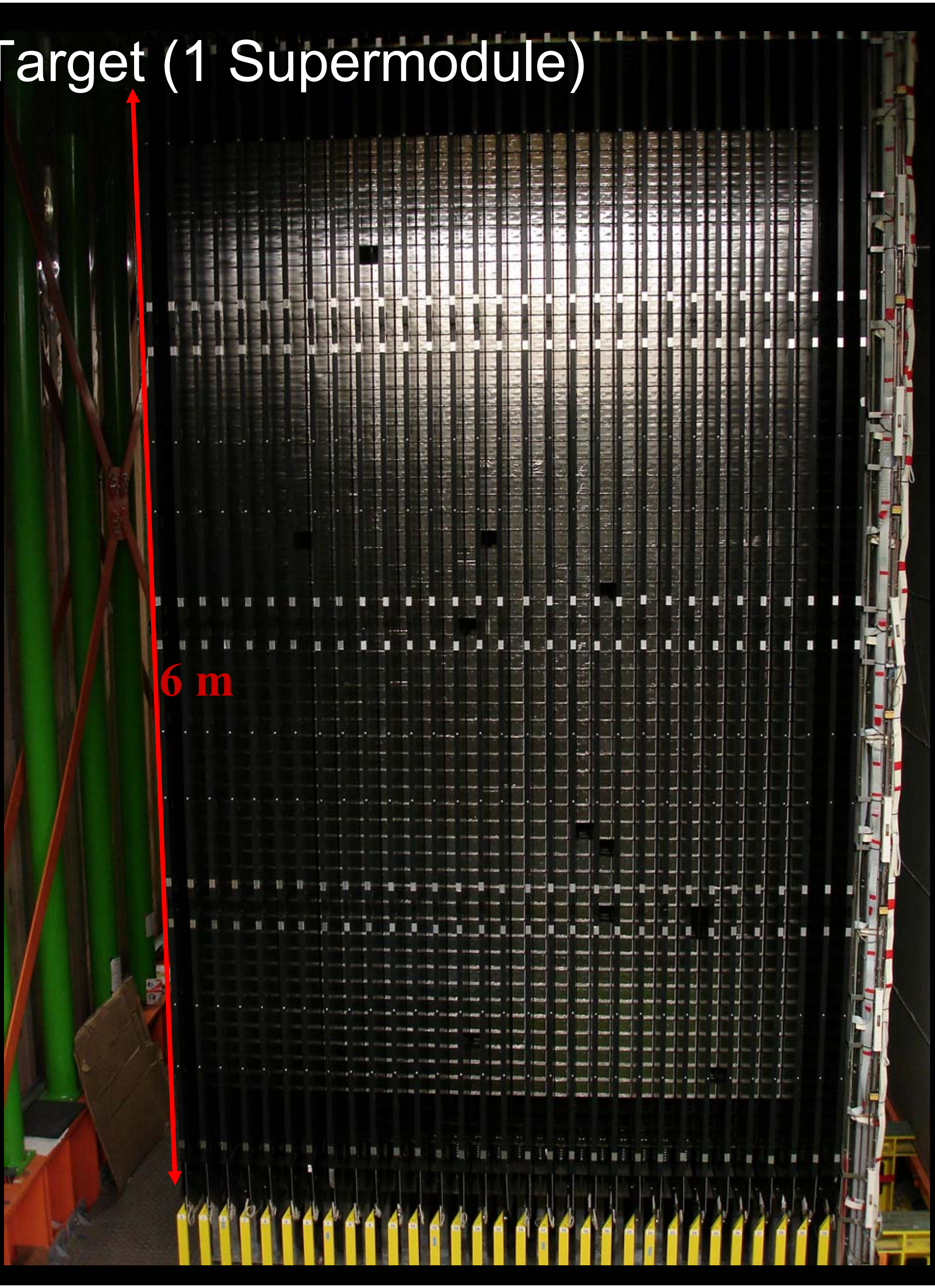
Supermodule 1

Supermodule 2

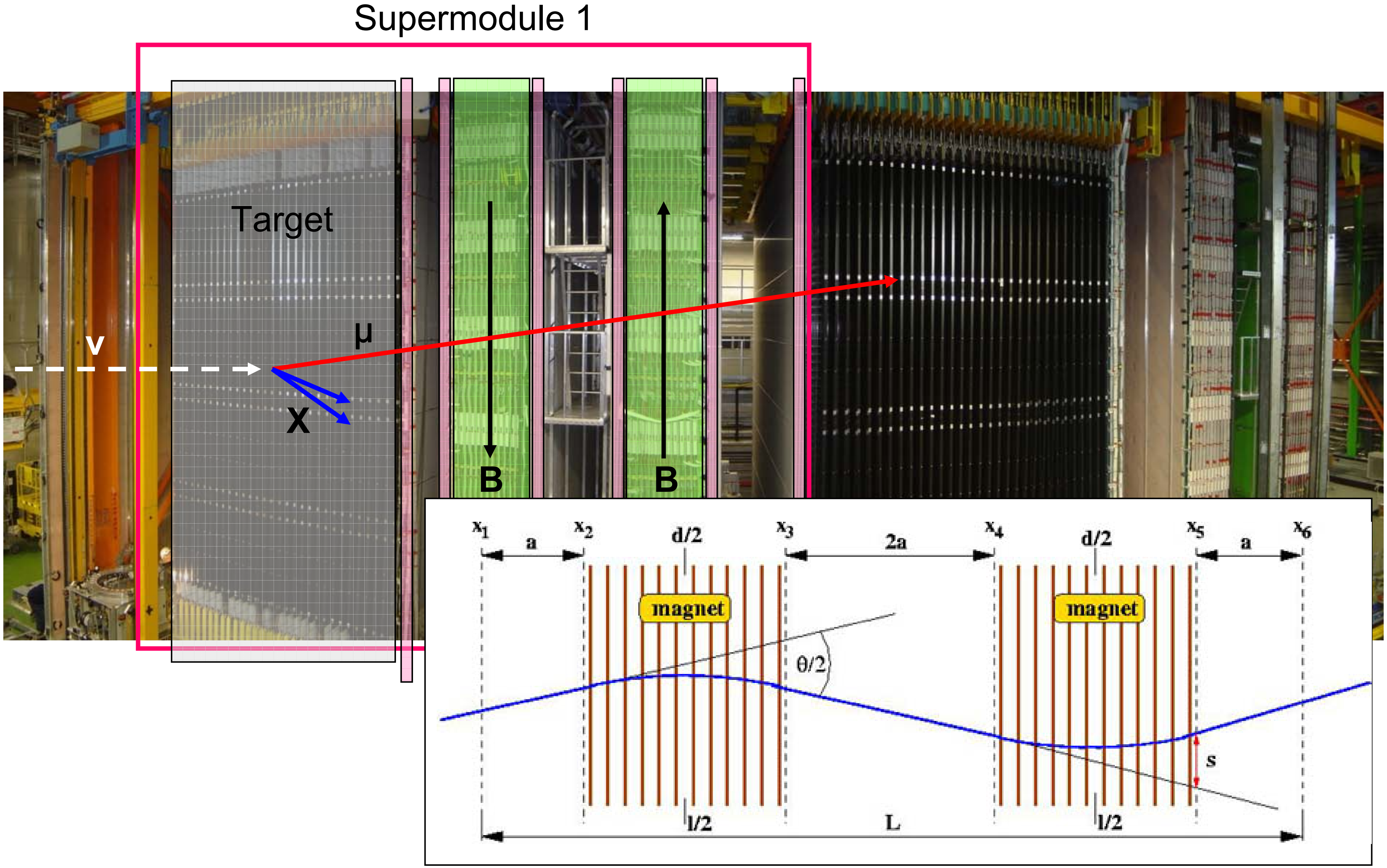
OPERA - Detector

Target Region:
- Target Tracker (Scintillator)
- Lead/Emulsion Bricks (75.000 per Supermodule)

The OPERA Target (1 Supermodule)

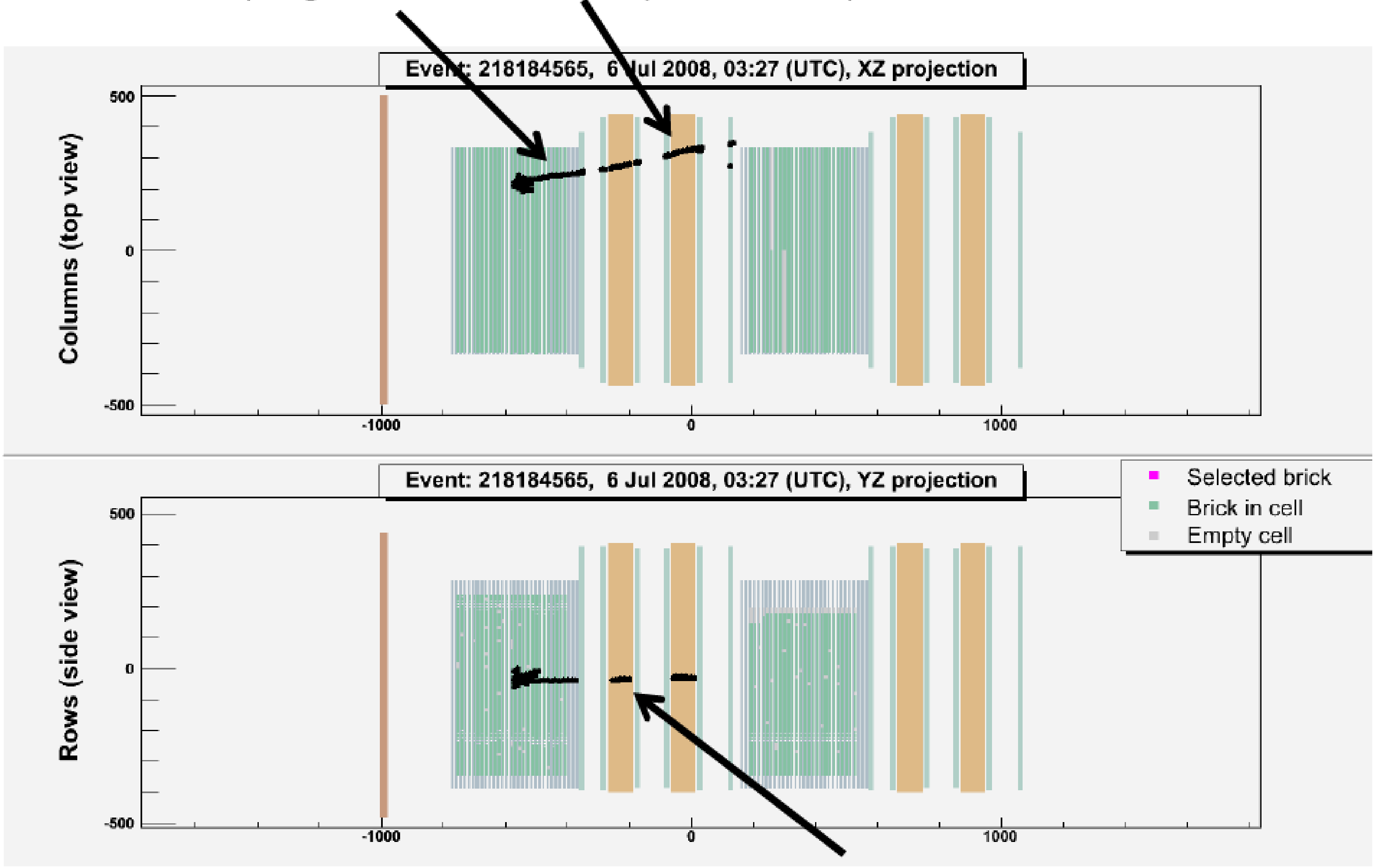


OPERA - Detector



Reconstruction (I): Myon-Spectrometer

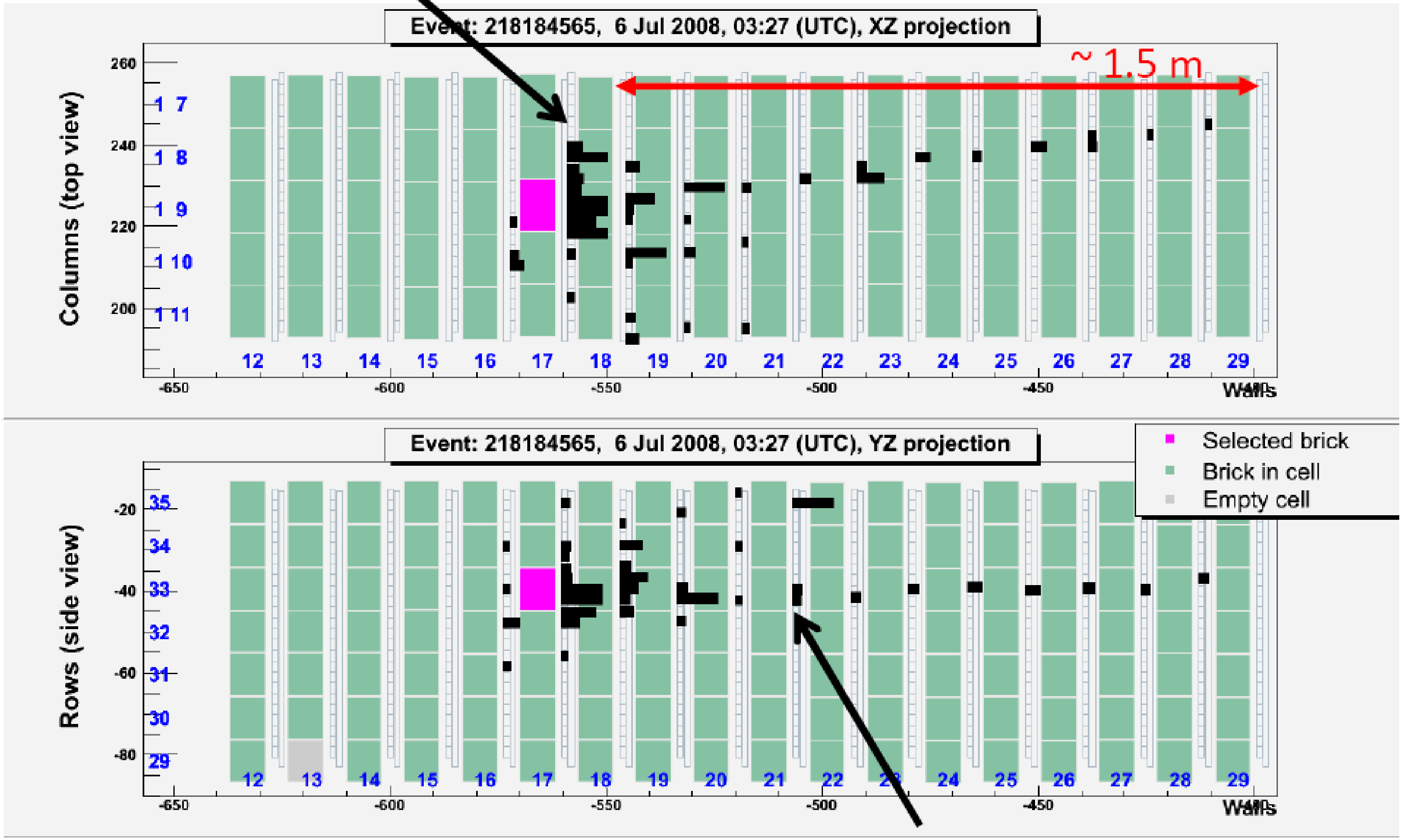
Electronic data (Target Tracker & Muon spectrometer)



Track identified as a muon (P=3.394 GeV/c)

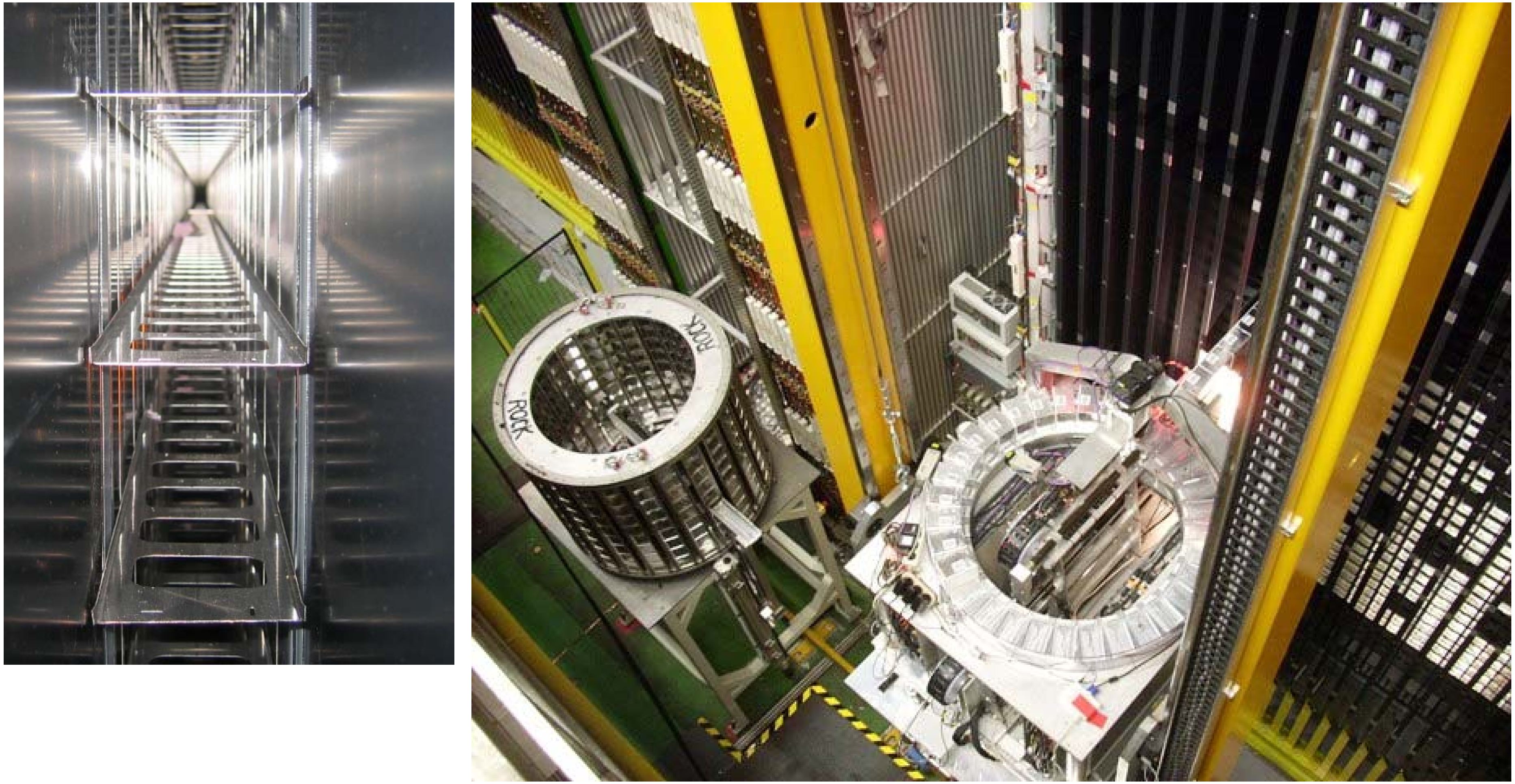
Rekonstruktion (II): Brick Finding

Electronic data (Target Tracker & Muon spectrometer)



Track identified as a muon (P=3.394 GeV/c)

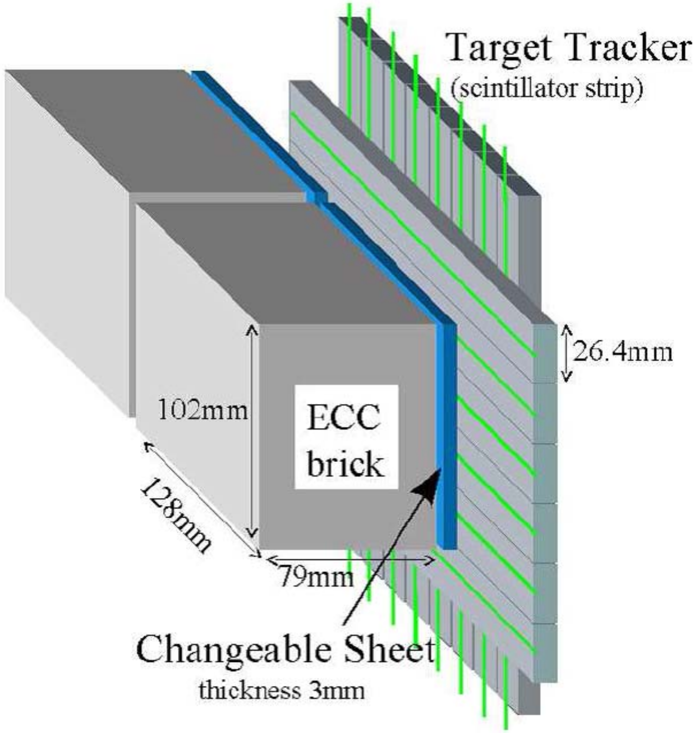
OPERA – Brick Manipulating System



≈30 bricks/day are extracted

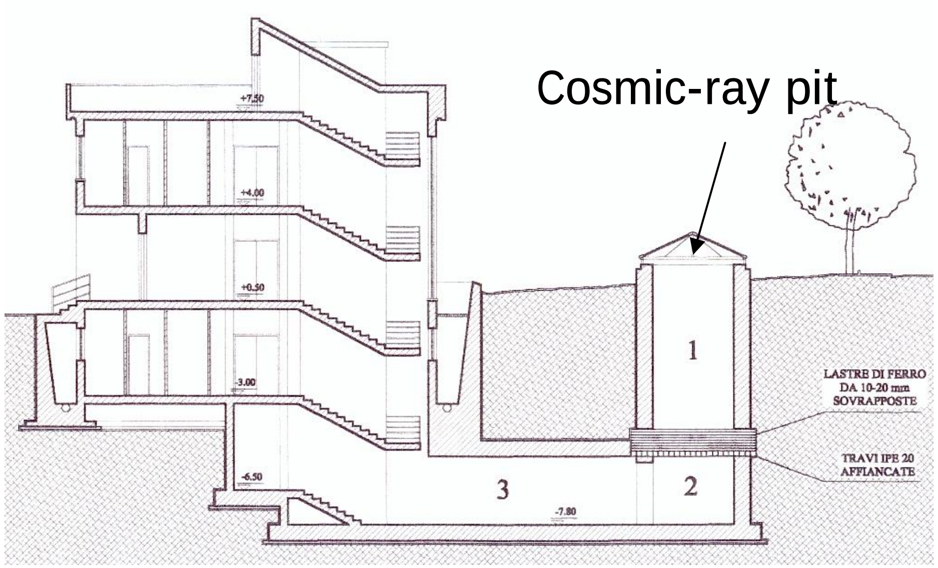
OPERA – Changeable Sheet (CS) Method

After extraction:
1.) First X-ray exposure of brick with CS
2.) CS is detached and developed underground
    brick is kept in shielding box (5cm iron)
3.) If track in CS is compatible with track reconstructed by electronic detectors:
    Second X-ray exposure of brick,
    brick brought to surface



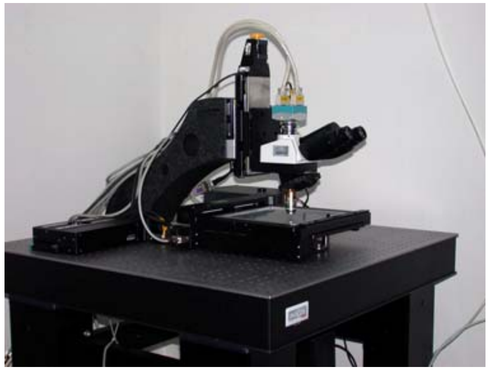
Emulsion Development @ LNGS

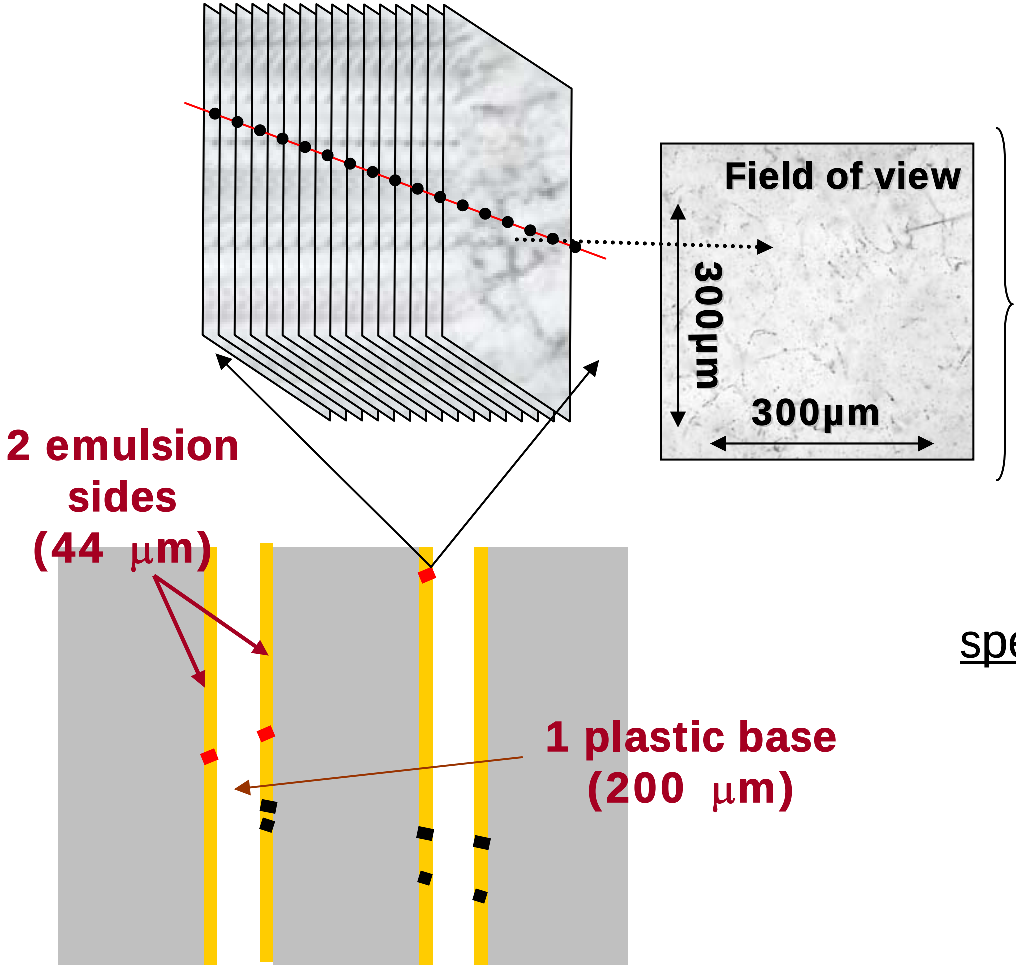
- Bricks brought to “cosmic ray pit” (@ surface), exposure 24h.
- Local alignment with cosmic myons (afterwards precision of 1-2µm).
- bricks are developed in 5 (6) automatic development lanes.
- 50 bricks/day can be developed (16h).


Cosmic-ray pit

Scanning

≈40 automatic microscopes
in scanning labs in Europe(ESS) and Japan(S-UTS)





16 tomographic images

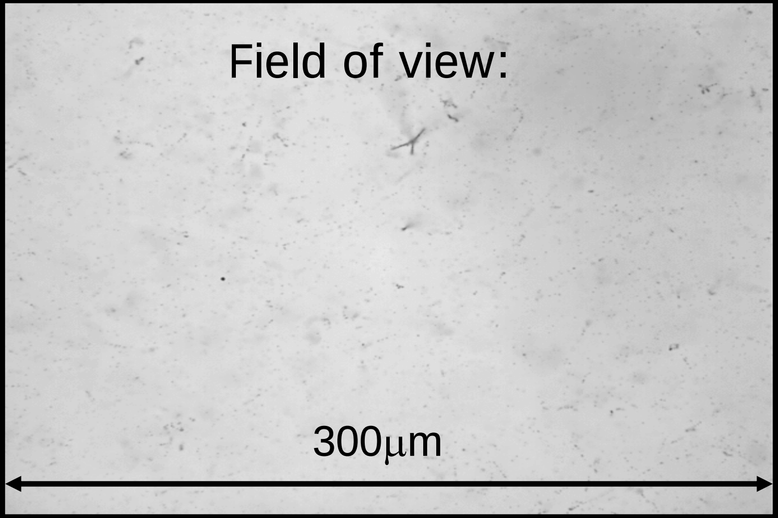
2D image processing

3D reconstruction of particle tracks

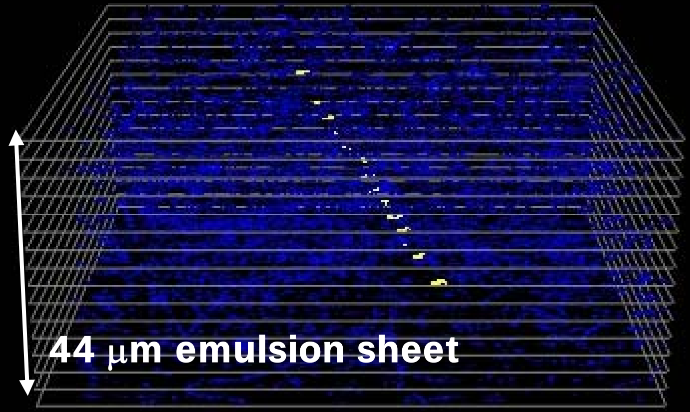
<u>speed</u> : 20cm²/hour/emulsion side

(1 emulsion sheet = 2 sides)

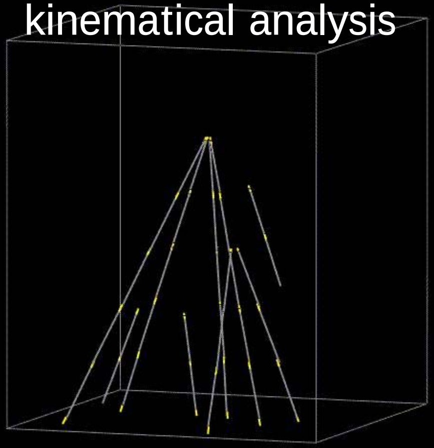
Scanning



2d image: 16 tomographic images



Vertex reconstruction & kinematical analysis



Expected Signal

Maximal mixing, run time of 5 years @ 4.5×10^{19} pot / year

channel	Reconstruction efficiency x BR %	Signal Δm^2_{23}=2.5 eV^2	Signal Δm^2_{23}=3.0 eV^2	Back-ground
$\tau \rightarrow \mu^-$	3.74	2.9	4.2	0.17
$\tau \rightarrow e^-$	3.08	3.5	5.0	0.17
$\tau \rightarrow$h-	3.19	3.1	4.4	0.24
$\tau \rightarrow$3h	1.05	0.9	1.3	0.17
Total	11.06	10.4	14.9	0.75

for OPERA with 1.35kt (75% of proposal)

Most important background processes:

- Charm production and decay
- Hadron re-interactions in lead
- Large angle myon scattering in lead

Overview expected events:

25000	ν interactions
120	ν_τ interactions
~10	identified ν_τ
<1	background

OPERA timetable

- May 2006: commissioning of electronic detector

- August 2006: first CNGS test beam (only electronic detector)

- October 2007: first physics pilot run (40% of the target)
  0.082^{E}19 pot, 38 events in bricks.

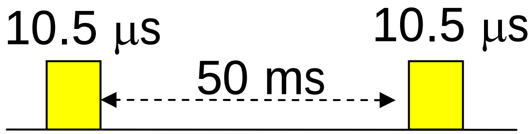
- July 2008: target complete
- June 2008 – november 2008: first OPERA beam period
  1.8^{E}19pot, 10100 on time events, 1700 bricks with events extracted.
  (26 charm events expected, 0.6 ν_τ expected)

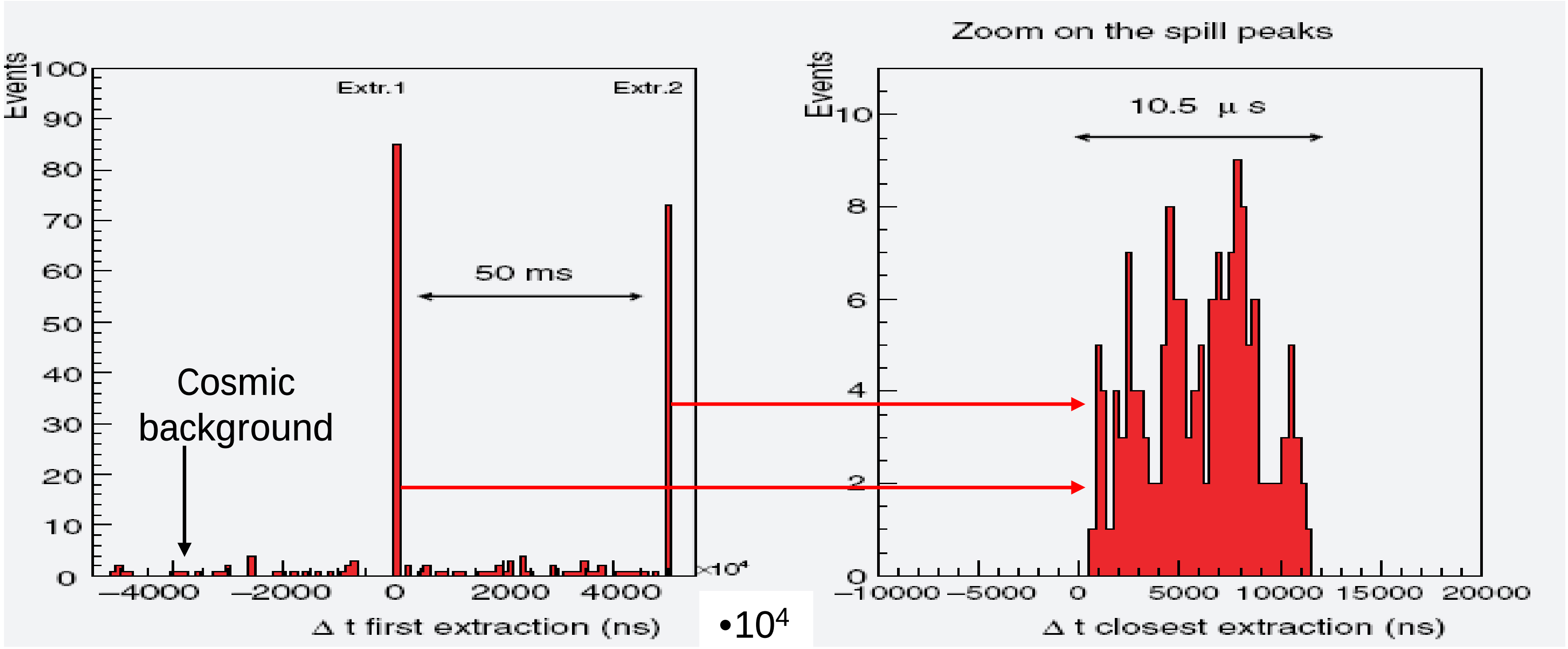
  OPERA collaboration: arXiv:0903.2973v1, accepted for publication in JINST.
  „The detection of neutrino interactions in the emulsion/lead target of the OPERA experiment“.

- New beam period started june 2009

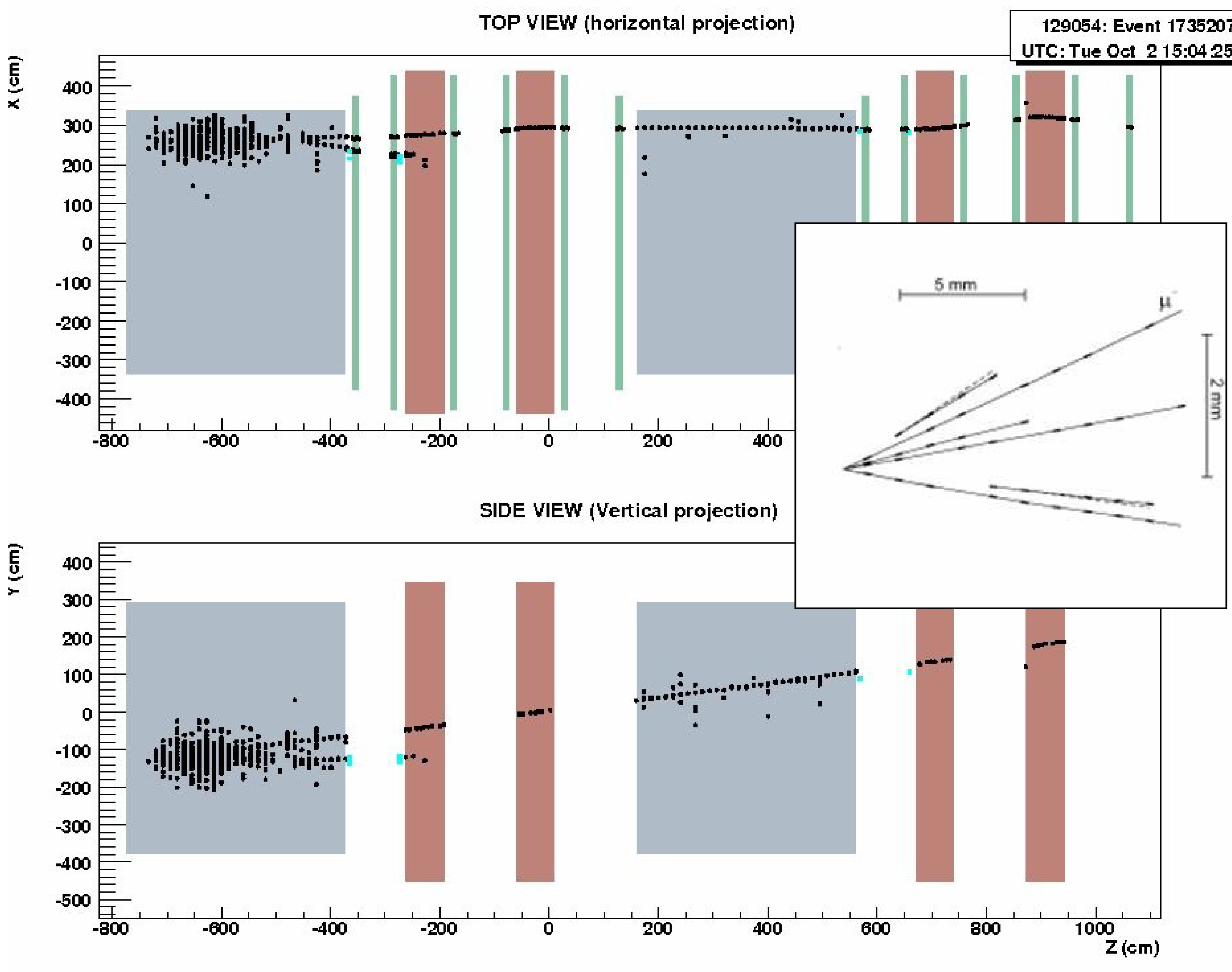
Time Synchronisation

- event selection using GPS timing information
- event timing agrees with CNGS time structure
- background $O(10^{-4})$
- accuracy 100nsec

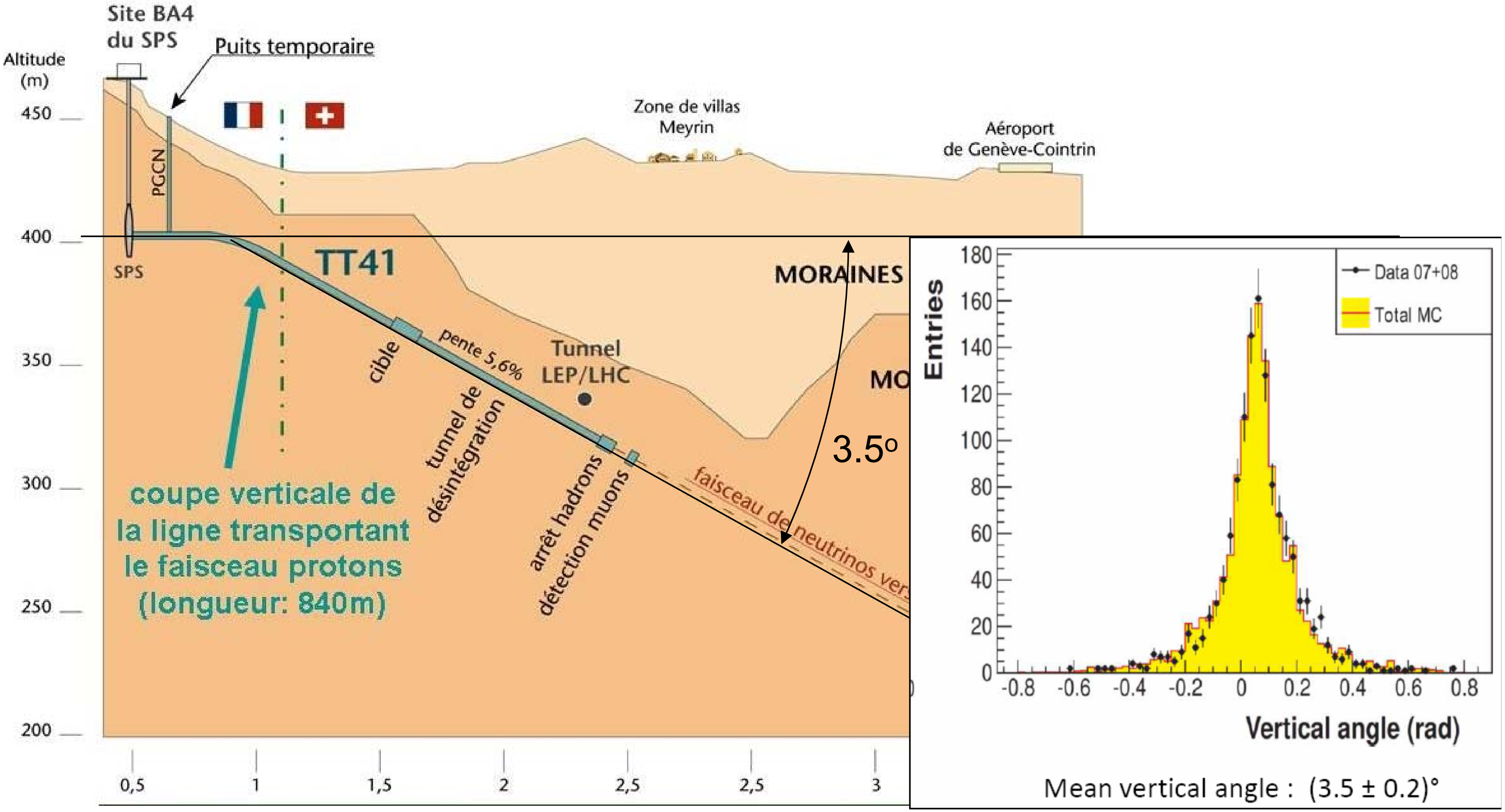




October 2007:
first OPERA-event in a brick observed

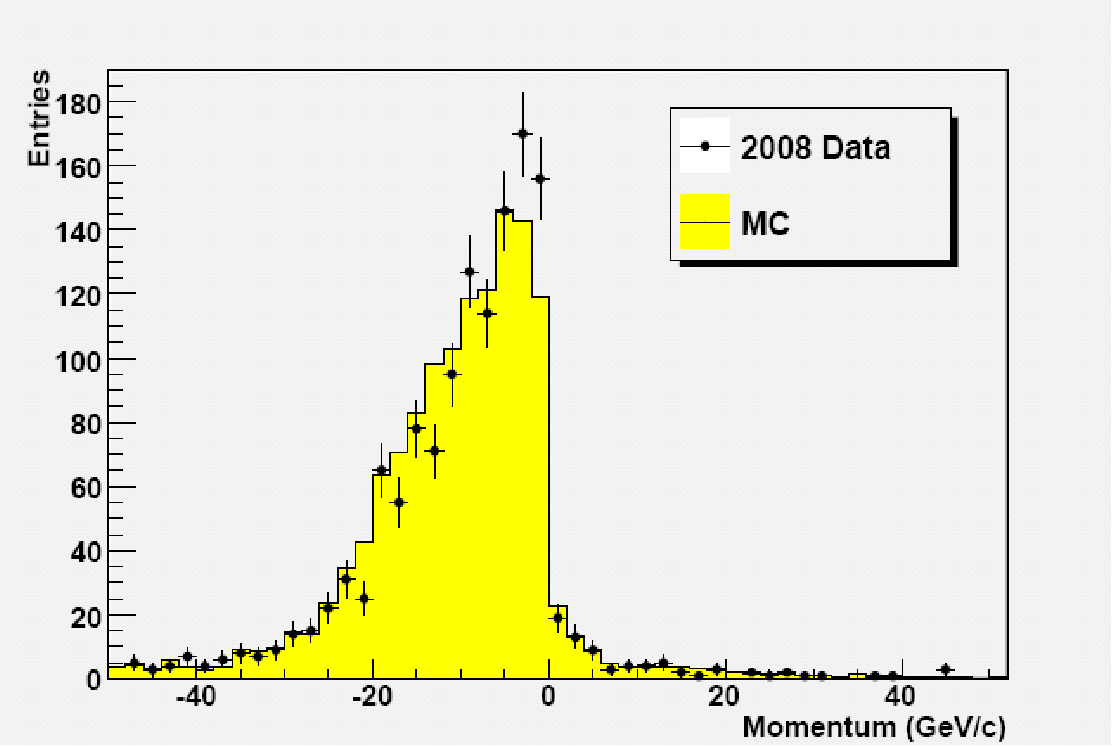


Direction of CNGS neutrino beam



Mean vertical angle : (3.5 ± 0.2)°

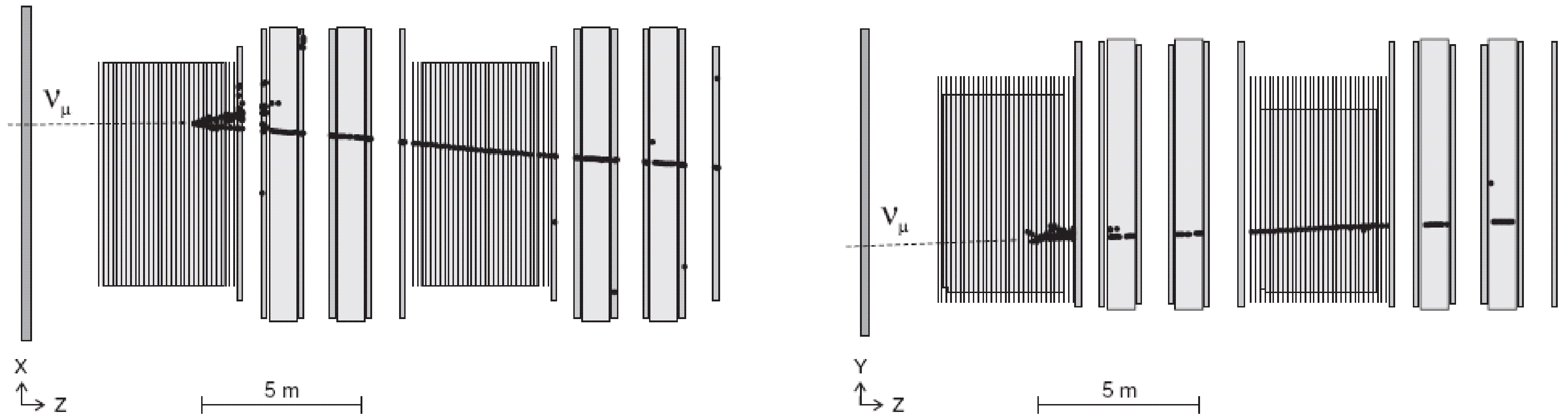
Reconstruction of μ momentum (electronic detector)

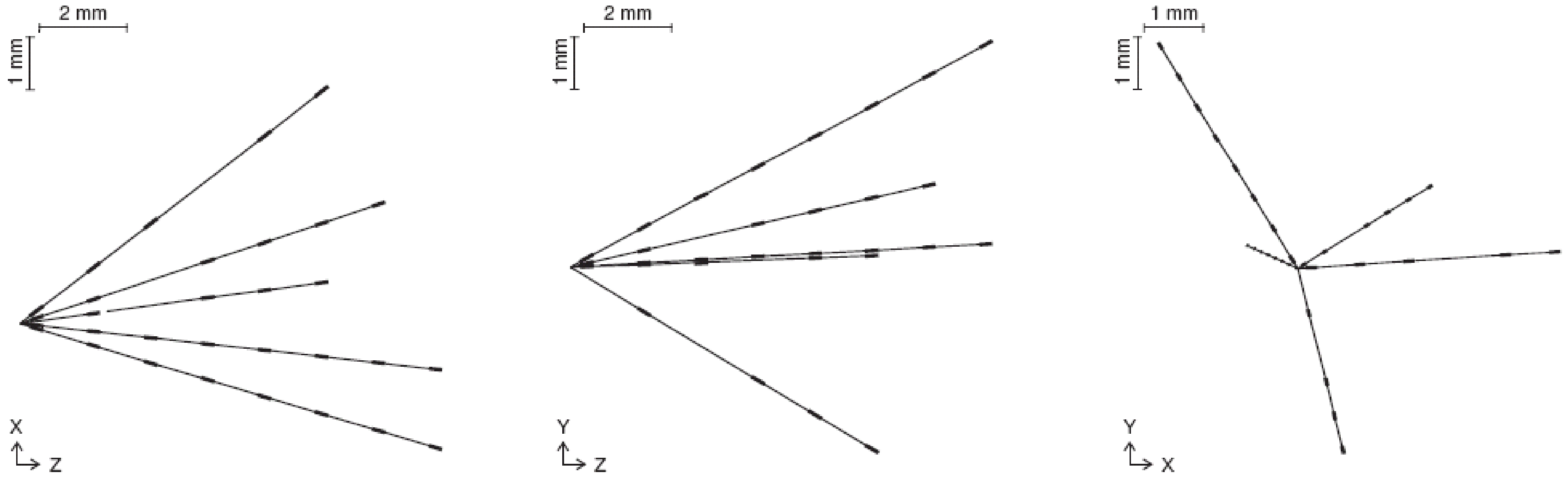


Status of Brick Analysis (March 09):

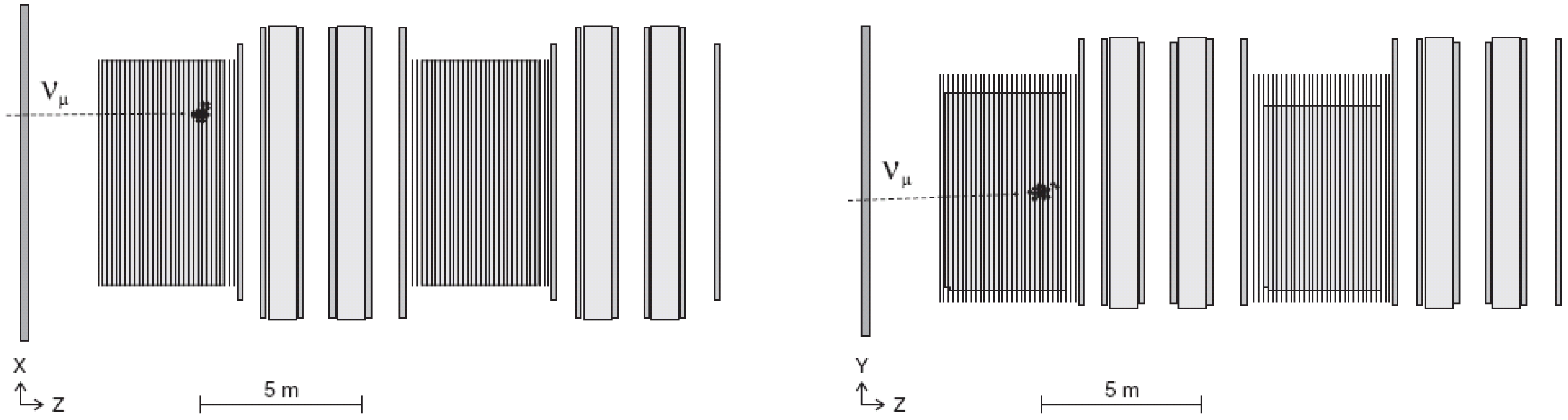
- 1700 bricks with events
- 754 bricks developped
- Events localised in 446 bricks
  (308 still waiting)
- Brick Finding Efficiency 70%, compatible with MC prediction
- Vertex Finding Efficiency:
  - CC events: 90%-95% (MC prediction 90%)
  - NC events: 74%-83% (MC prediction 80%)
- 2 charm candidates have been found
  (Using CHORUS measurements: 3 expected in this sample)

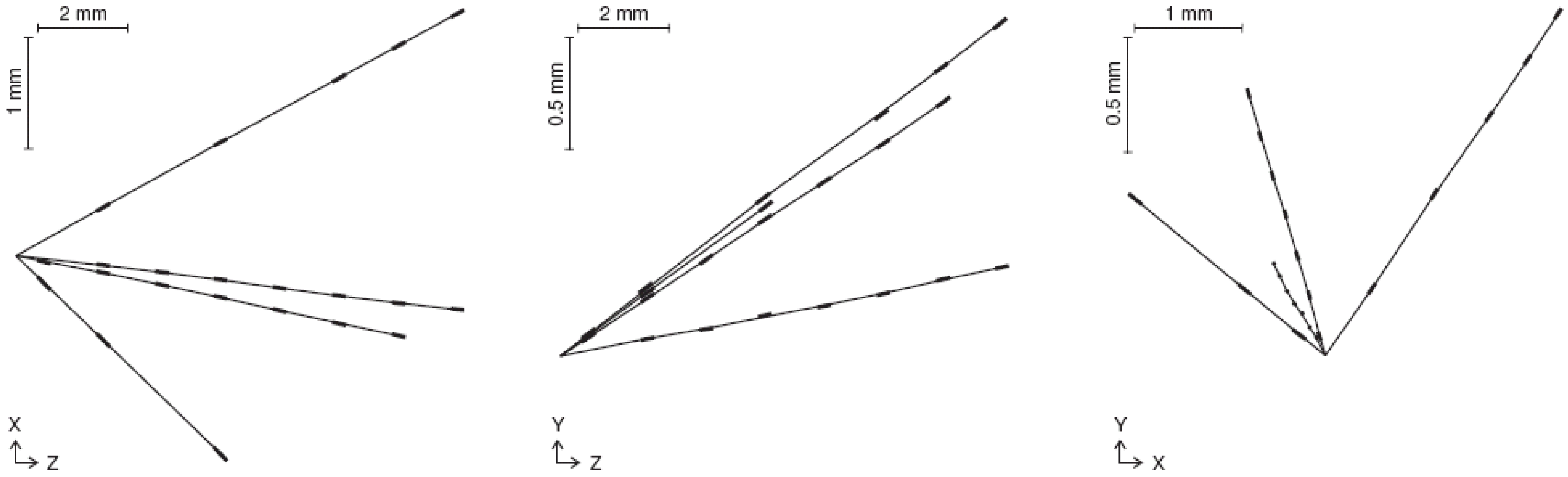
Example of real CC event:



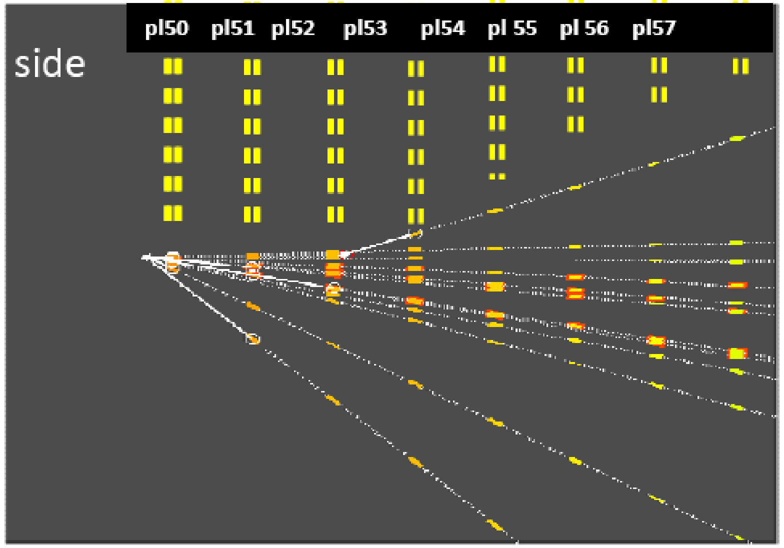


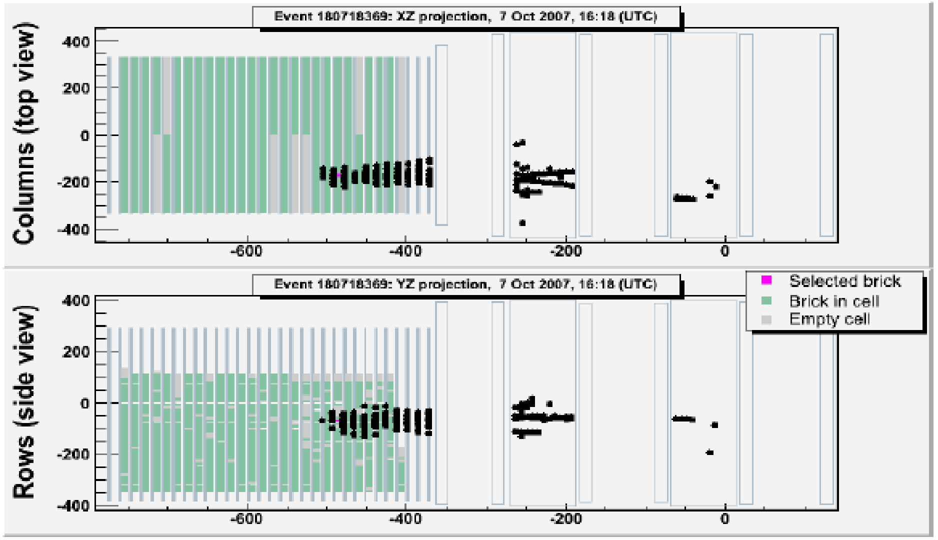
Example of real NC event:

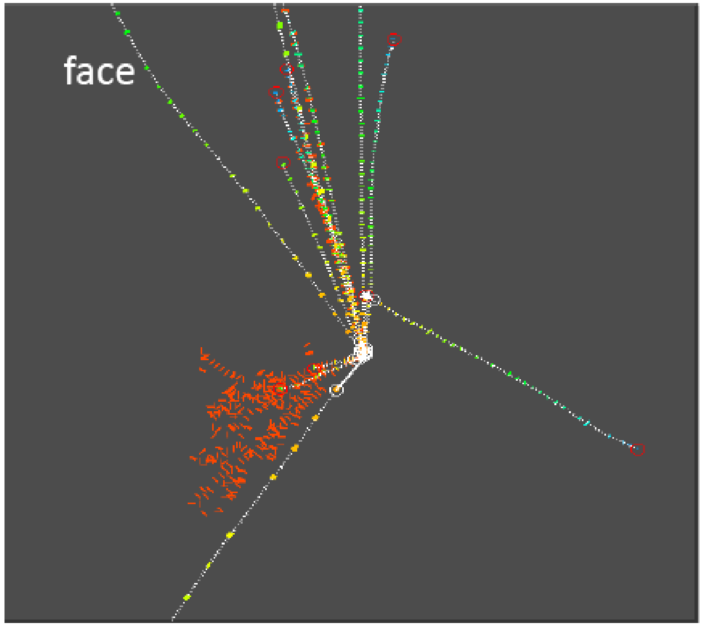




A Charm-Candidate







Clear kink topology
Two EM showers pointing to the vertex

Flight length	3247.2 µm
θ_{kink}	0.204 rad
$P_{daughter}$	3.9 (+1.7 -0.9) GeV
P_T	796 MeV

$4\mathrm{x}10^{-4}$ % probability for a hadron re-interaction to have a $P_T > 600$ MeV 7

OPERA summary:

- Detector (target) has been completed by July 2008
- First OPERA beam period june - november 2008:
  exposure: $1.8^{E}19$ pot, 1700 bricks with events extracted.
  Brick analysis is ongoing (≈ 450 vertices found by march09).
  First candidates for charm have been identified.
- Beam period 2009 just started (last week):
  $1.2^{E}18$ pot in first week.
  outlook: $3.5^{E}19$ pot from CNGS -> 3500 events in bricks expected,
  -> we may expect 2 v_τ candidates…

OPERA is awaiting the first ν_τ- candidate