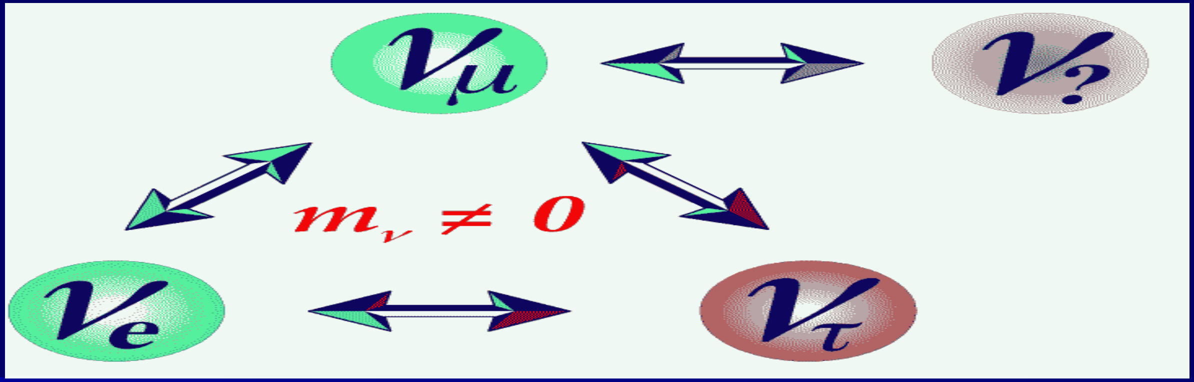
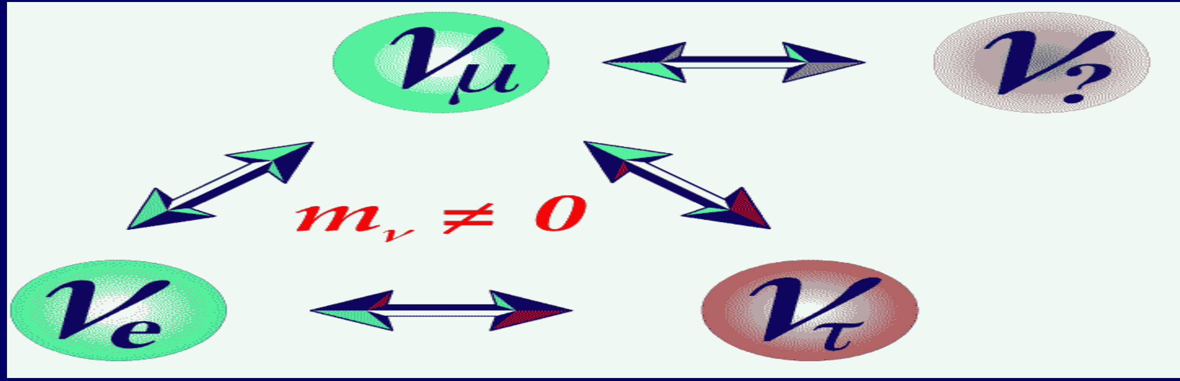


Oscillations ν sur faisceaux : d' OPERA aux expériences de 2nde génération

J.MARTEAU, IPNL-IN2P3, collaboration OPERA

Séminaire CPPM, 28 Avril 2008



1. Le projet CNGS1/OPERA
   - 1.1 Concepts & potentiels
   - 1.2 Le détecteur OPERA
   - 1.3 Data taking and analysis

2. Les premiers résultats du run de physique

3. Vers T2K et au-delà

Conclusions

1. The CNGS1/OPERA project

1.1 Concepts & physics potential

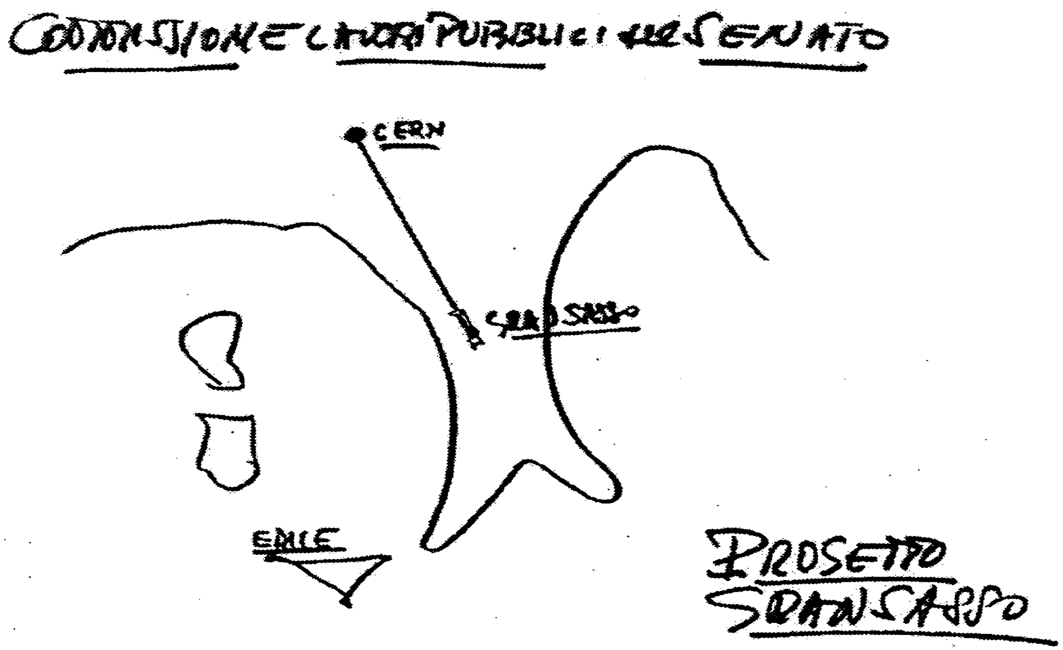
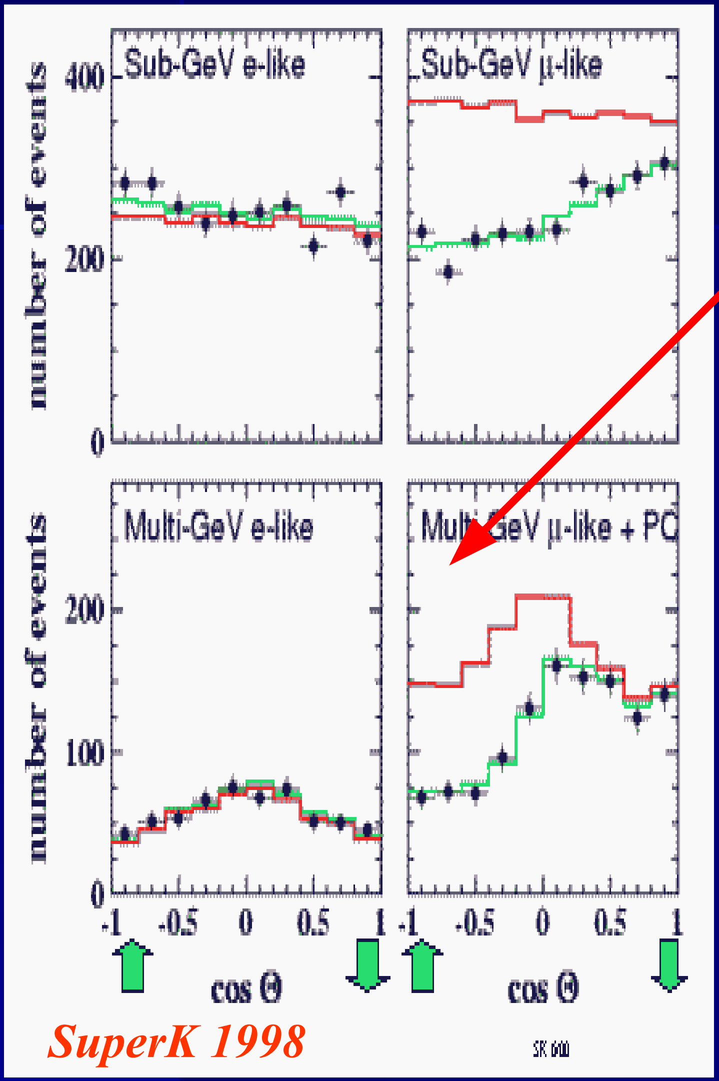
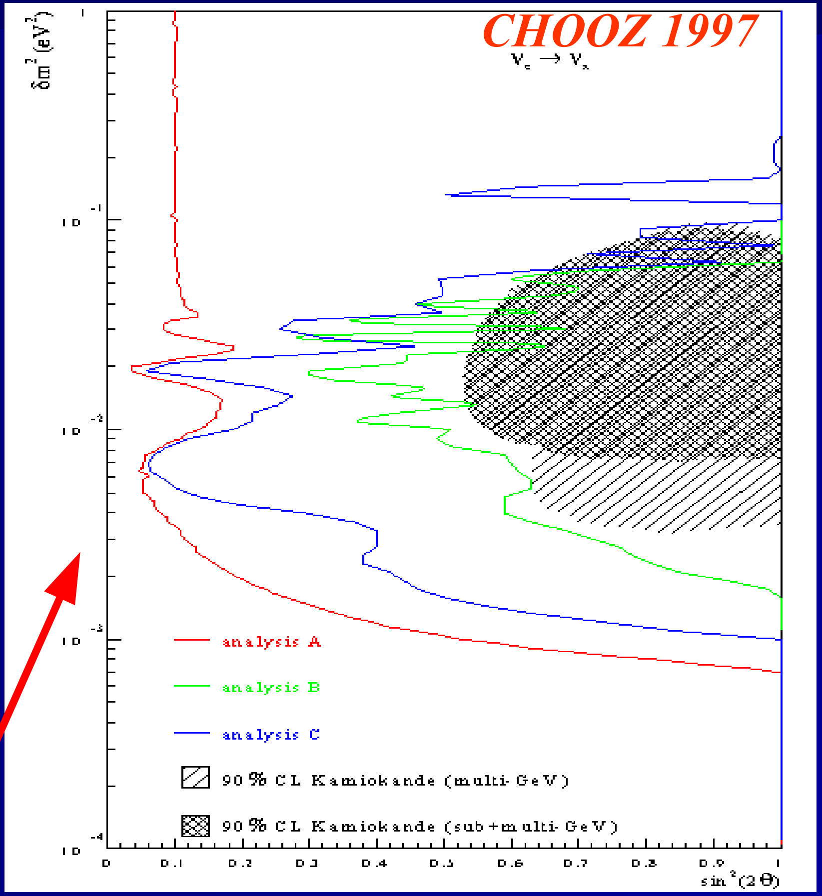


Figure 1.1.1: Sketch by A. Zichichi, 1979

The original motivations

From Kamiokande to SuperK:
Atmospheric neutrinos anomaly interpretable in terms of $\nu_\mu \rightarrow \nu_\tau$ oscillations





CHOOZ (reactor experiment)
no $\nu_e \rightarrow \nu_x$ oscillations $\Rightarrow$ $\Theta_{13} < 11°$

CERN Neutrino to Gran Sasso (CNGS)

- Search for ν_τ appearance in the CNGS ν_μ beam
- Validation of the $\nu_\mu \rightarrow \nu_\tau$ hypothesis
- in the "atmospheric" sector
- Secondary oscillations $\nu_\mu \rightarrow \nu_e$ search

CERN (730 km)

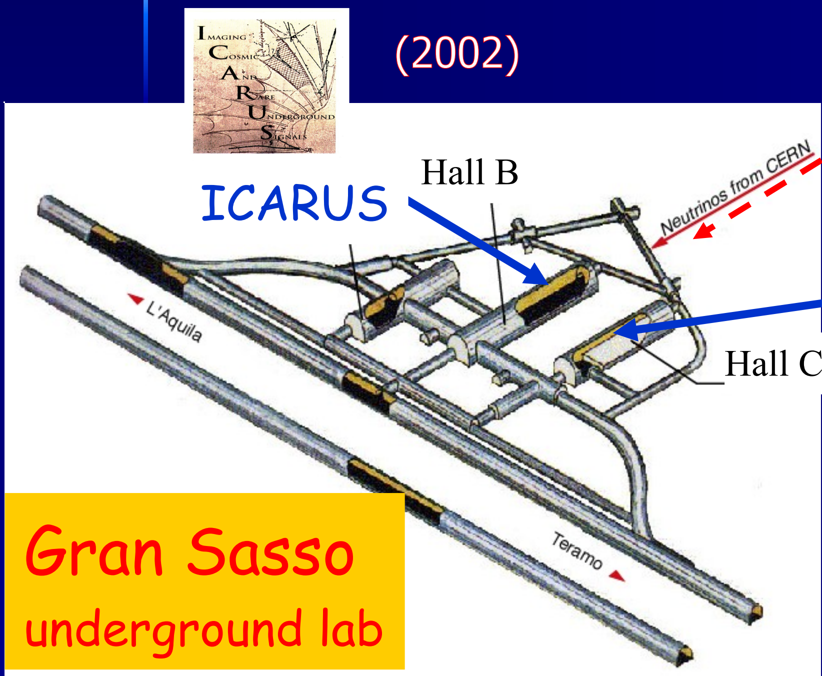
(1999)

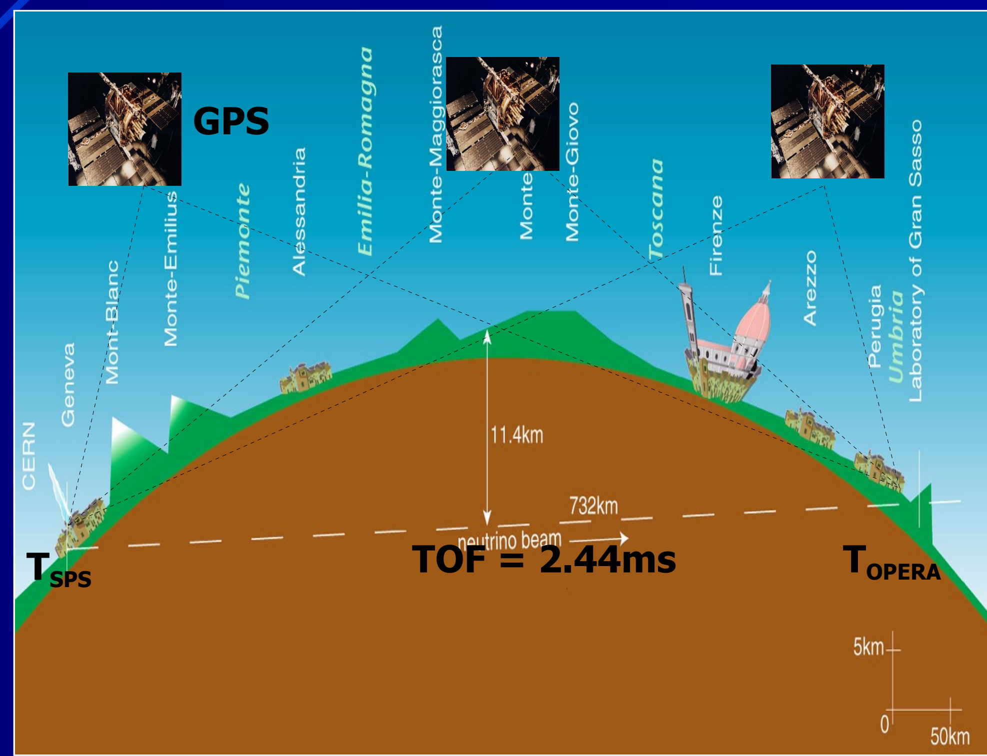
ν

(2002)

OPERA (CNGS1)

(2000)





The only direct measurement of flavour appearance

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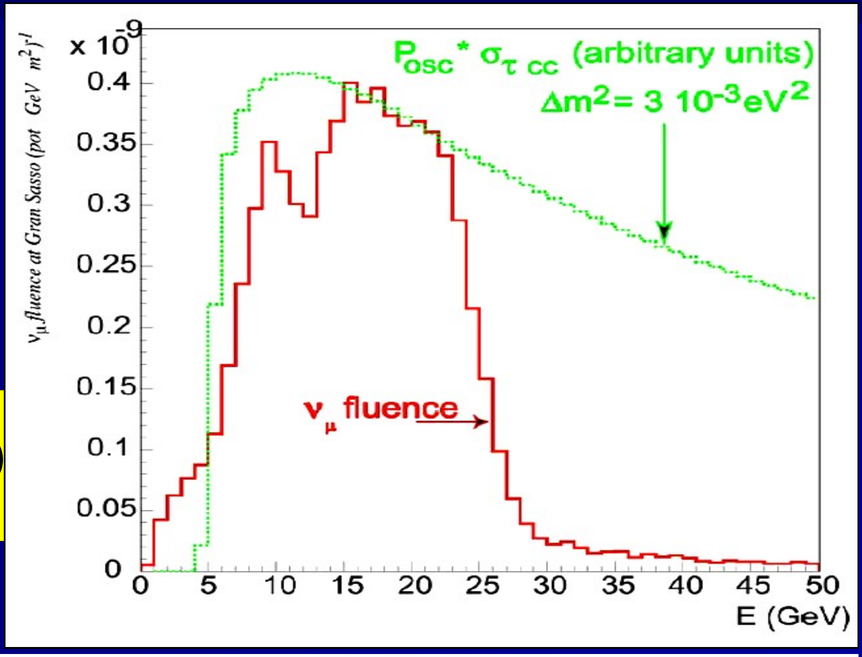
The CNGS beam

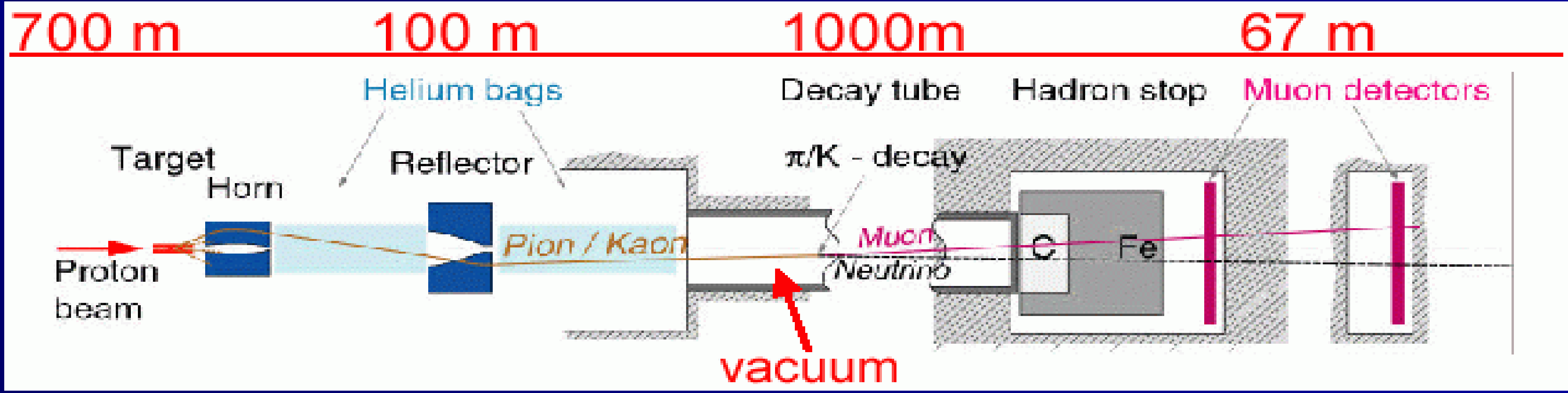
- CERN ν_μ beam optimized to study the ν_τ appearance by τ detection
- L=730km, mean $E_{\nu\mu}$=17GeV
- $(\nu_e+\bar{\nu}_e)/\nu_\mu$=0.68% ν_τ prompt negligible

(τ production optimized)

$$N_\tau = C \int_{3.5GeV}^{E_{max}} \Phi_\mu(E) P_{\mu\tau}(E) \sigma_\tau(E) dE$$

$$P_{\mu\tau} = \sin^2(2\theta)\sin^2(1.27\Delta m^2 \frac{L}{E})$$





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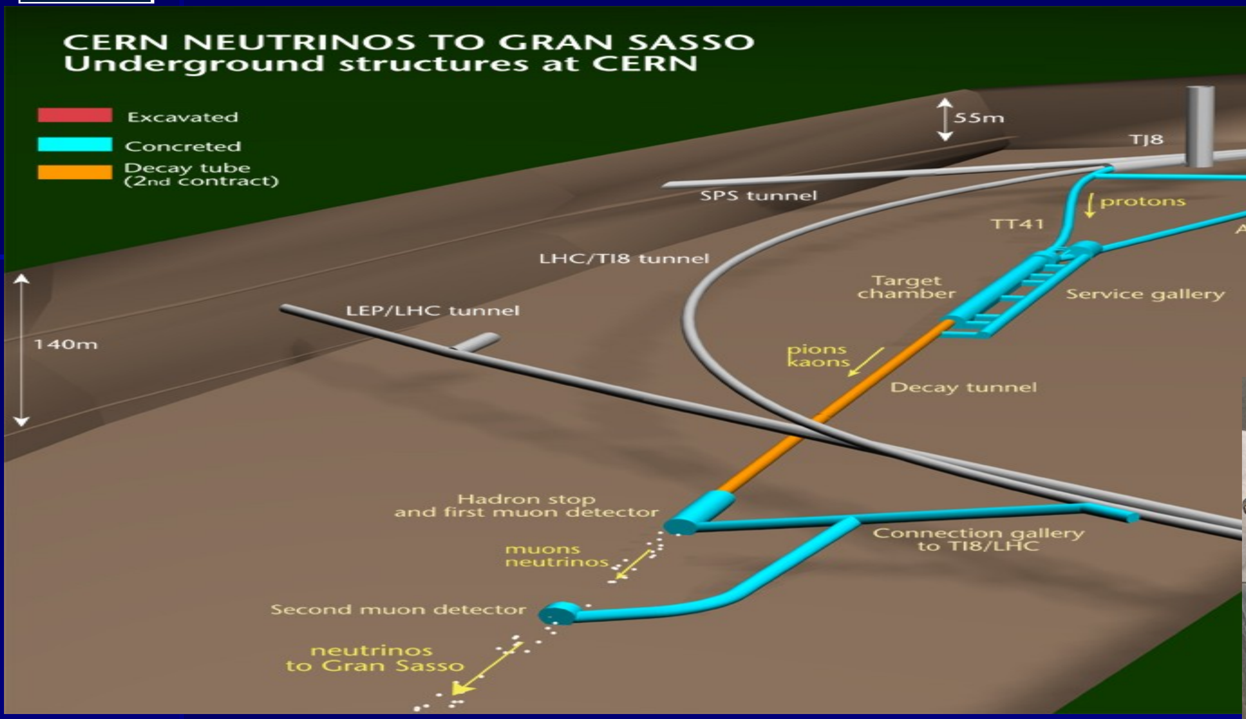
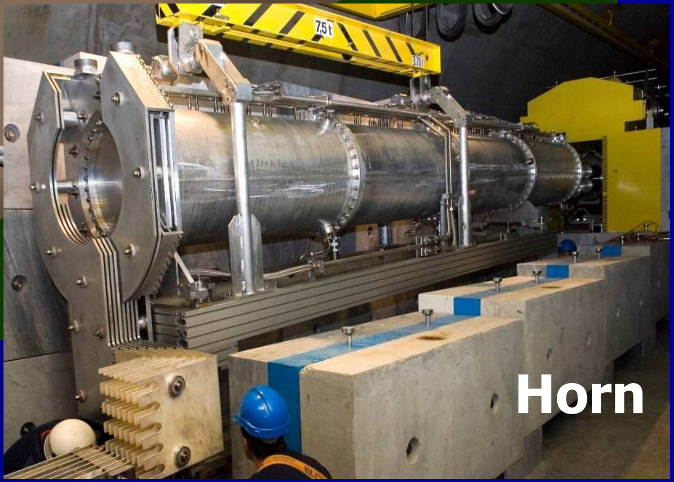
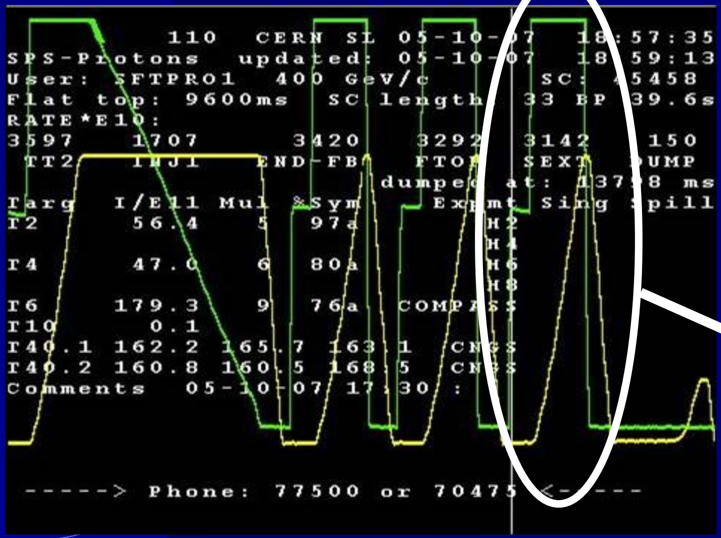
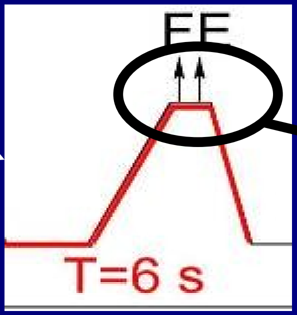
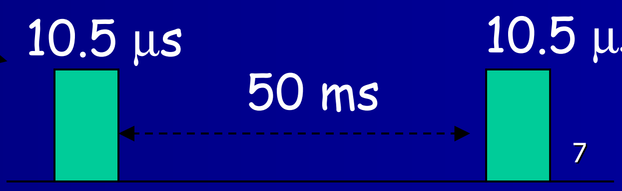
The CNGS beam



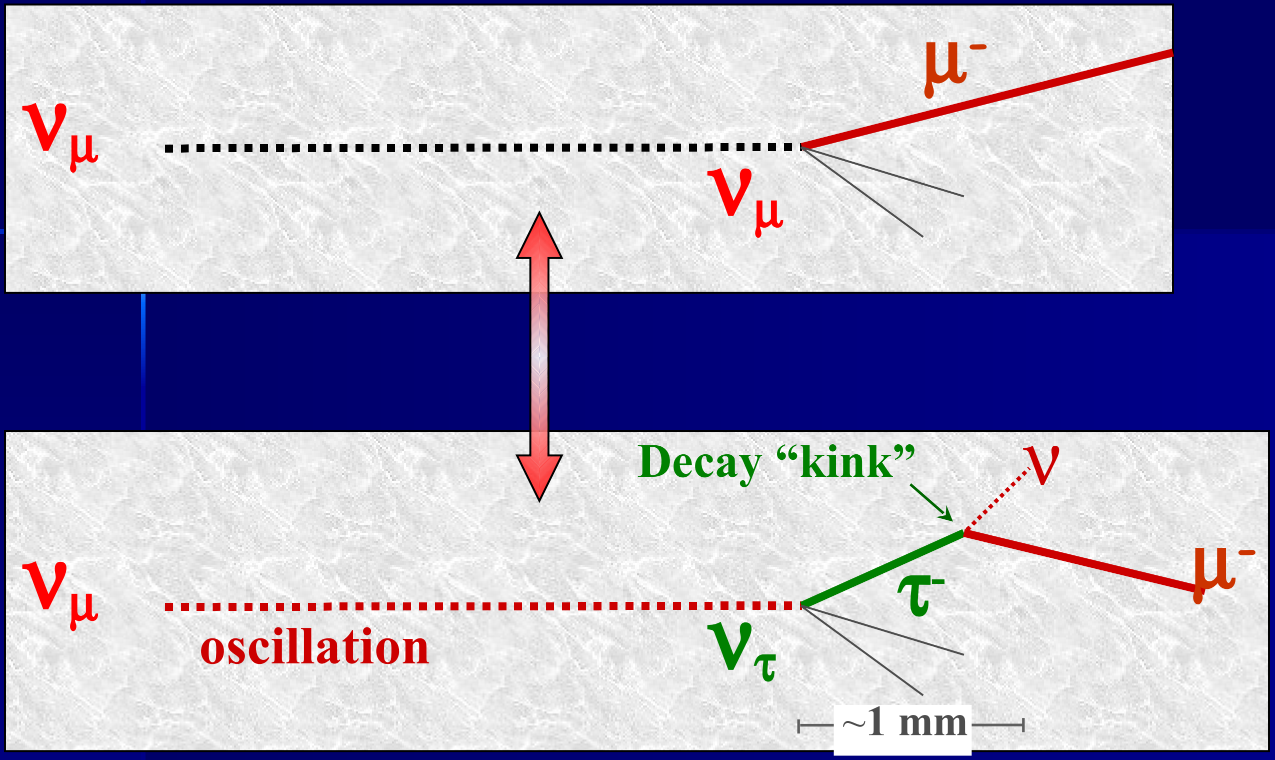


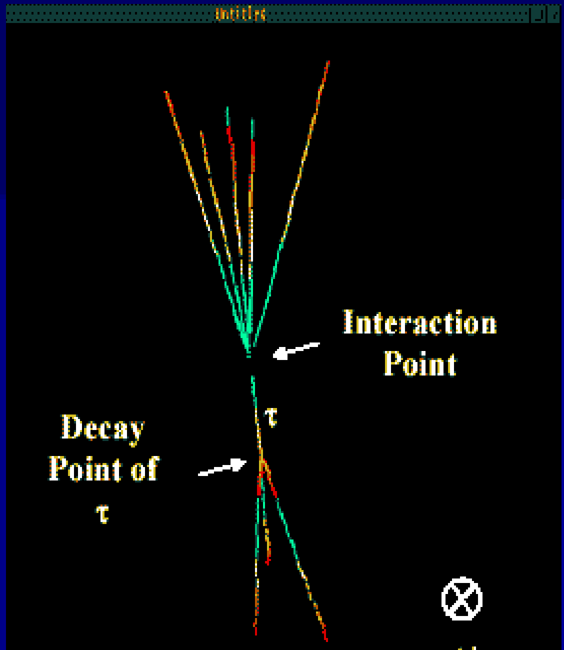






τ search : topological signature





DONUT ν_τ identification

2 contradictory requirements:
- Low X-section $\Rightarrow$ high mass
- High granularity
  - signal identification
  - background rejection

Target : 1350 tons, 5 years running

- **26 000 neutrino interactions**
- **~150 ν_τ interactions**
- **~15 identified ν_τ**
- **< 1 background event**

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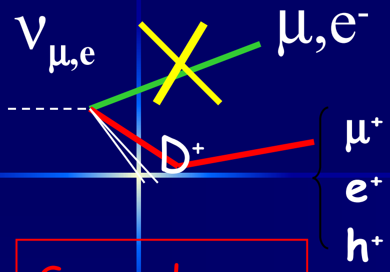
τ search : backgrounds

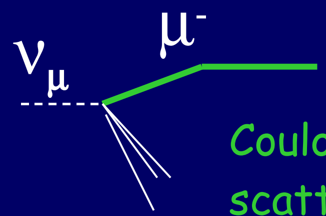


Primary lepton not identified

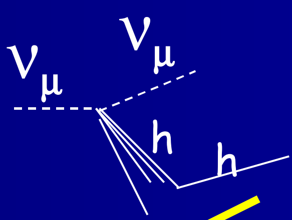
Charm production in CC, common to the 3 channels

Same decay topology as τ

<u>Good muon identification is fundamental</u>



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



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

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

Expected nbr of background events after 5 years running with nominal beam

τ search : sensitivity

τ^- decay channels	Signal ÷ Δm^2 (Full mixing)		Background
	2.5×10^{-3} (eV^2)	3.0×10^{-3} (eV^2)	
$\tau^- \rightarrow \mu^-$	2.9	4.2	0.17
$\tau^- \rightarrow e^-$	3.5	5.0	0.18
$\tau^- \rightarrow h^-$	3.1	4.4	0.23
$\tau^- \rightarrow 3h$	0.9	1.3	0.18
ALL	10.4	15.0	0.76

- 5 years CNGS data taking ($4.5\ 10^{19}$ pot/year)
- 1.35 ktons target mass

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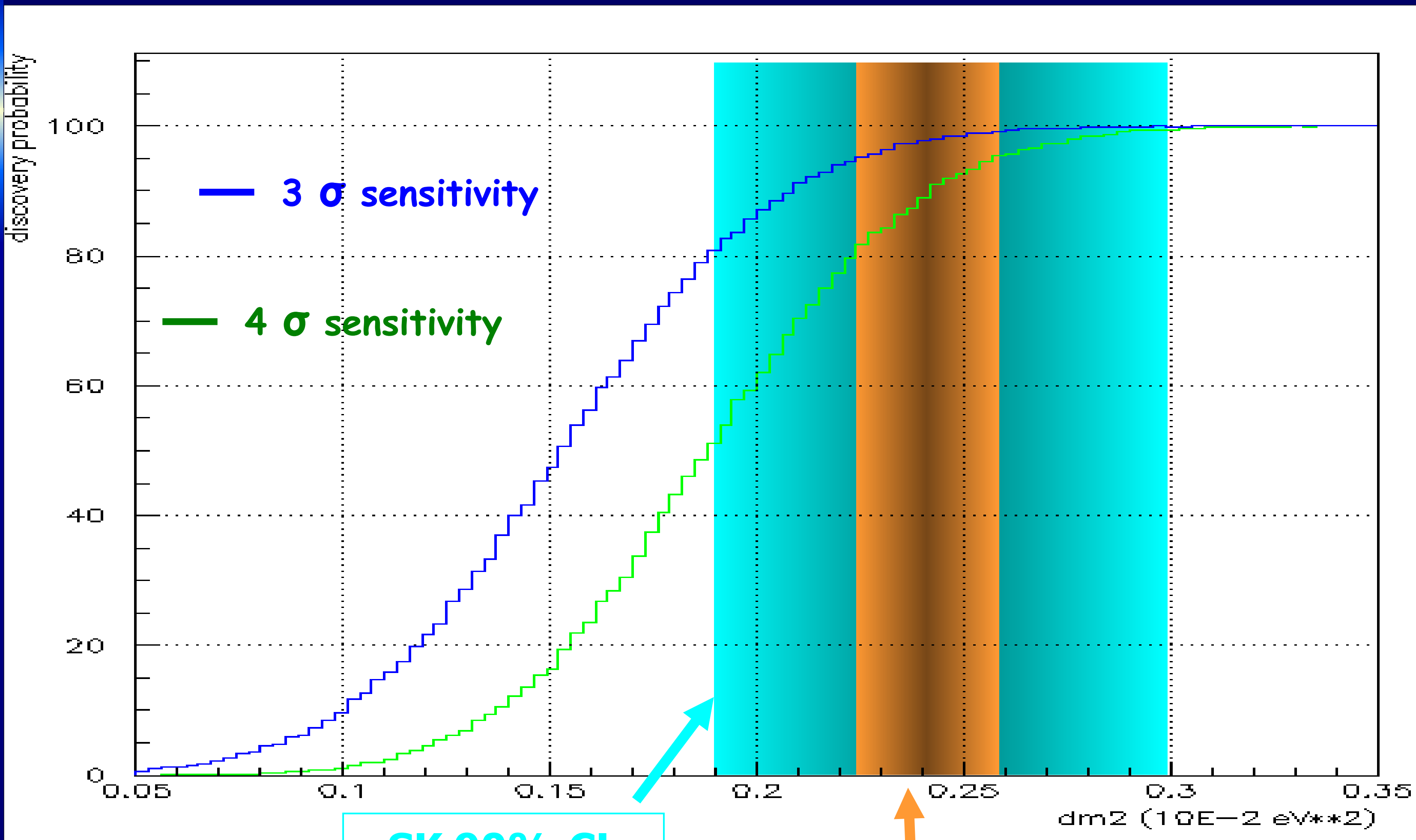
τ search : observation probability vs Δm^2



SK 90% CL
(L/E analysis)

Last MINOS
measurement

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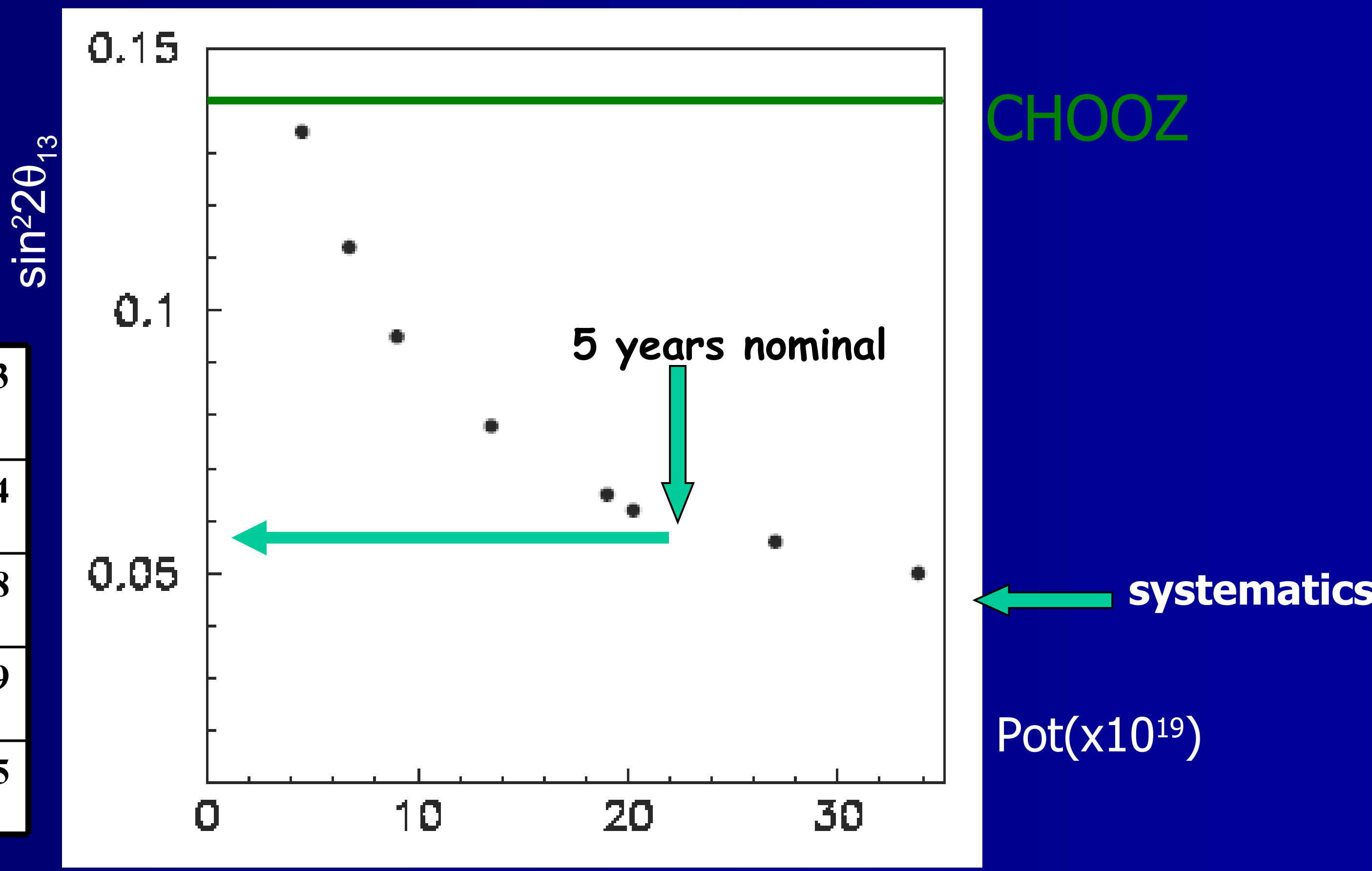
$\nu_\mu \rightarrow \nu_e$ search : physics potential

- Secondary oscillations $\nu_\mu \rightarrow \nu_e$ search
- Good e id. in the emulsions (NN analysis)
- Simultaneous fit on E_e, missing p_T and E_{vis} distributions

Nb of events (5 years running)

Signal @ CHOOZ limit	17.3
$\tau \rightarrow e$	3.4
ν_μCC	0.8
ν_μNC	3.9
ν_eCC beam	13.5



Assuming : $\theta_{23}=\pi/4$, $\Delta m^2_{23} = 2.5 \times 10^{-3}\ eV^2$

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1. The CNGS1/OPERA project

1.2 The OPERA detector

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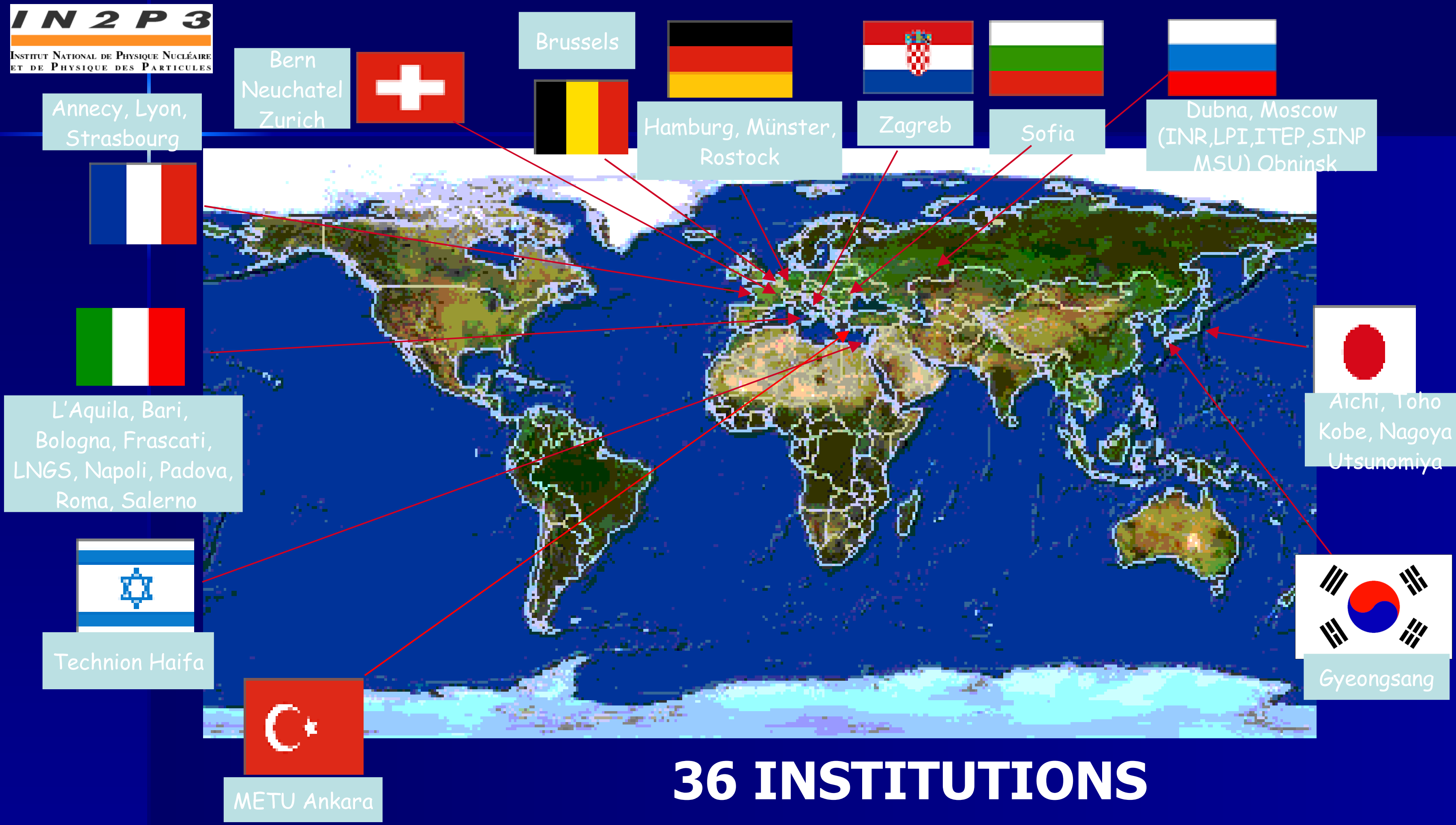
The OPERA collaboration

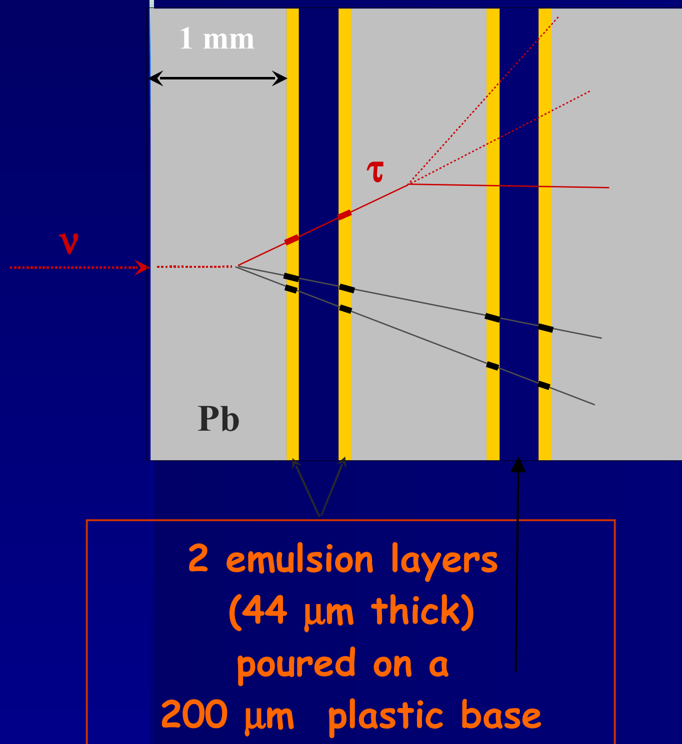


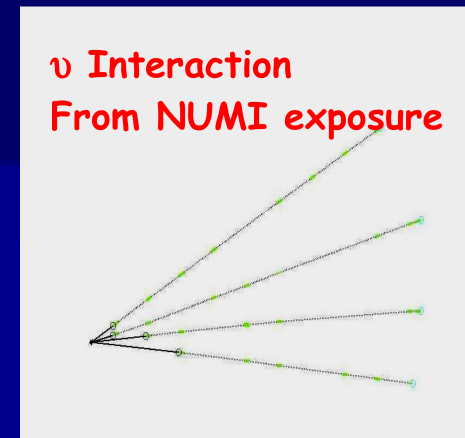
36 INSTITUTIONS

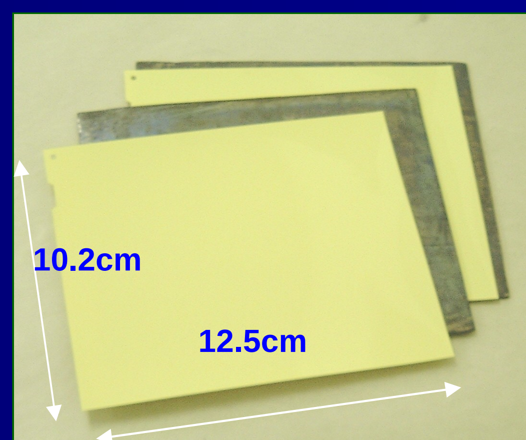
~200 PHYSICISTS

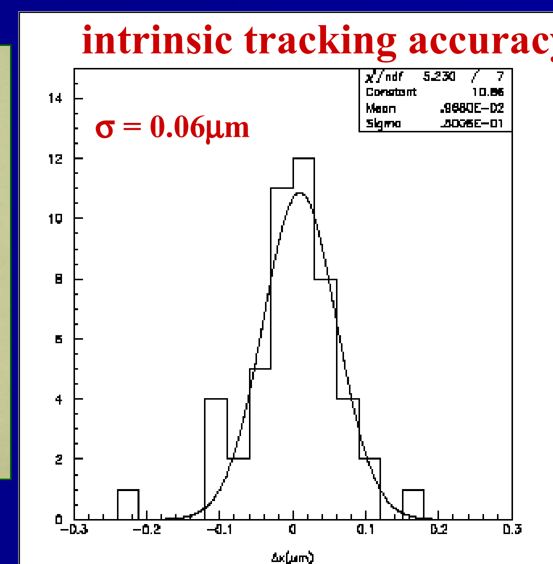
Nuclear emulsions technology

- "Emulsion Cloud Chamber" (DONUT)
- 56 Pb + 57 emulsions sheets
- Emulsions : spatial resolution
- Compact and modular structure
- CS doublet for event prediction









- ν interaction vertex search
- kink topology reconstruction
- MCS momenta measurement
- dE/dx e/π separation at low E
- e id. and e/γ E measurement

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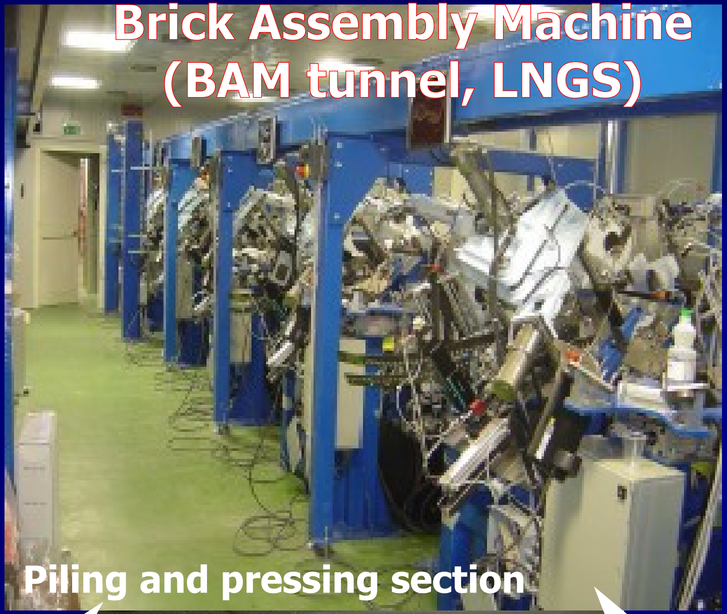
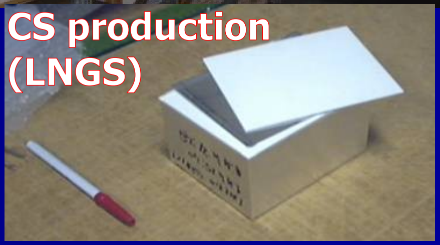
Bricks elements & production





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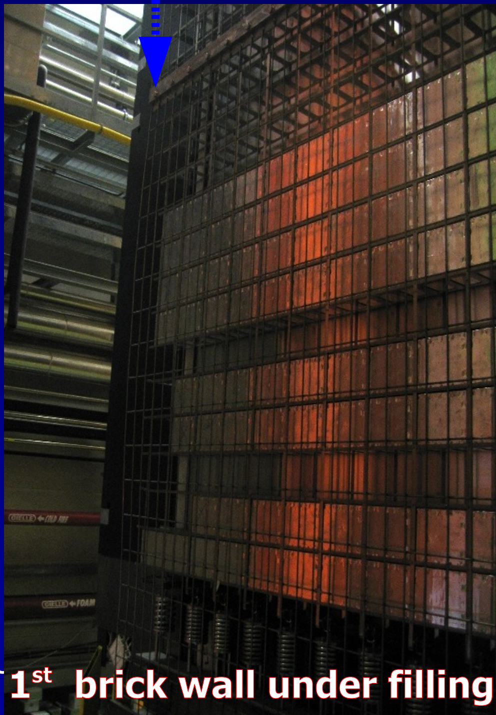
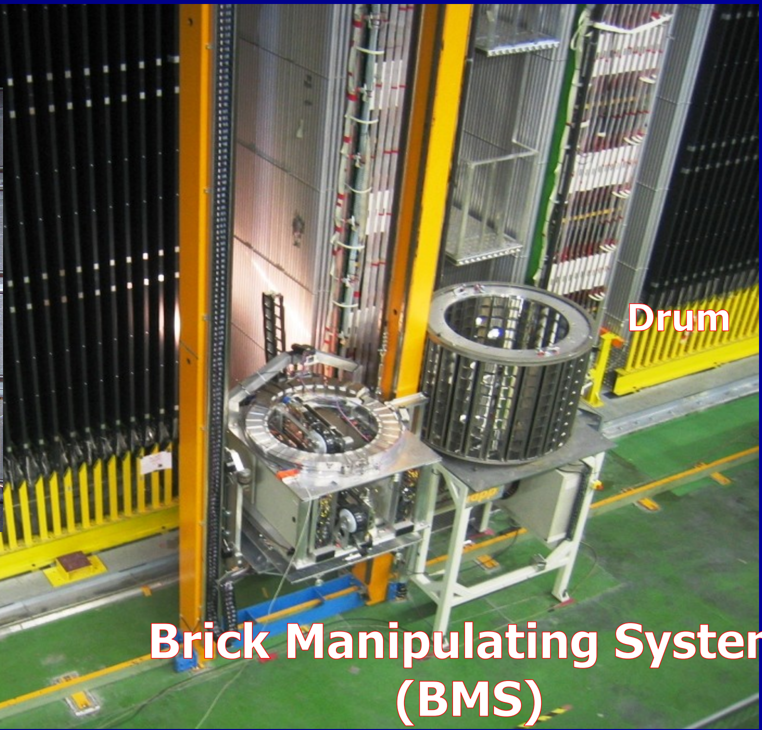
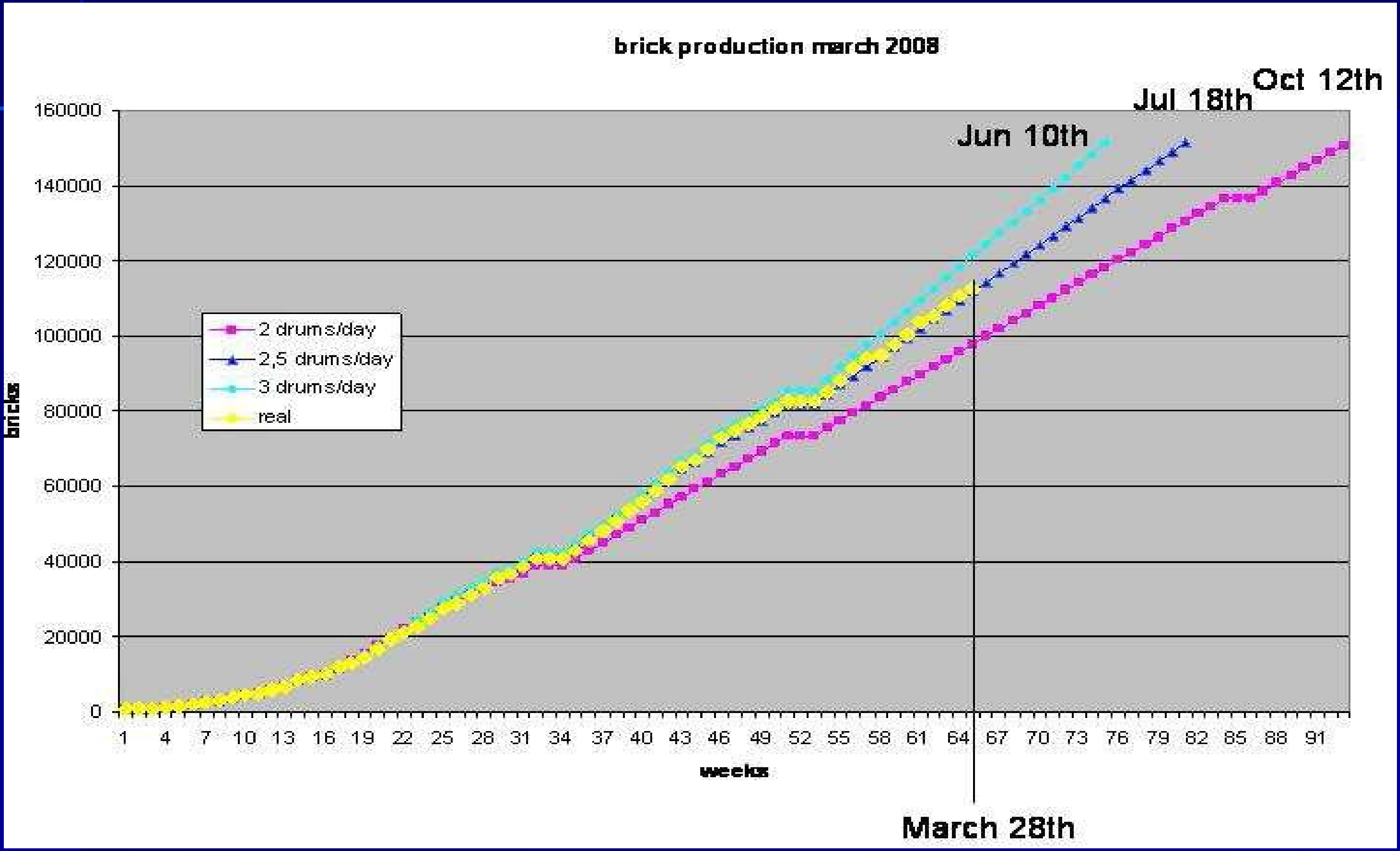
Bricks finding & manipulation

- With bricks one builds walls…





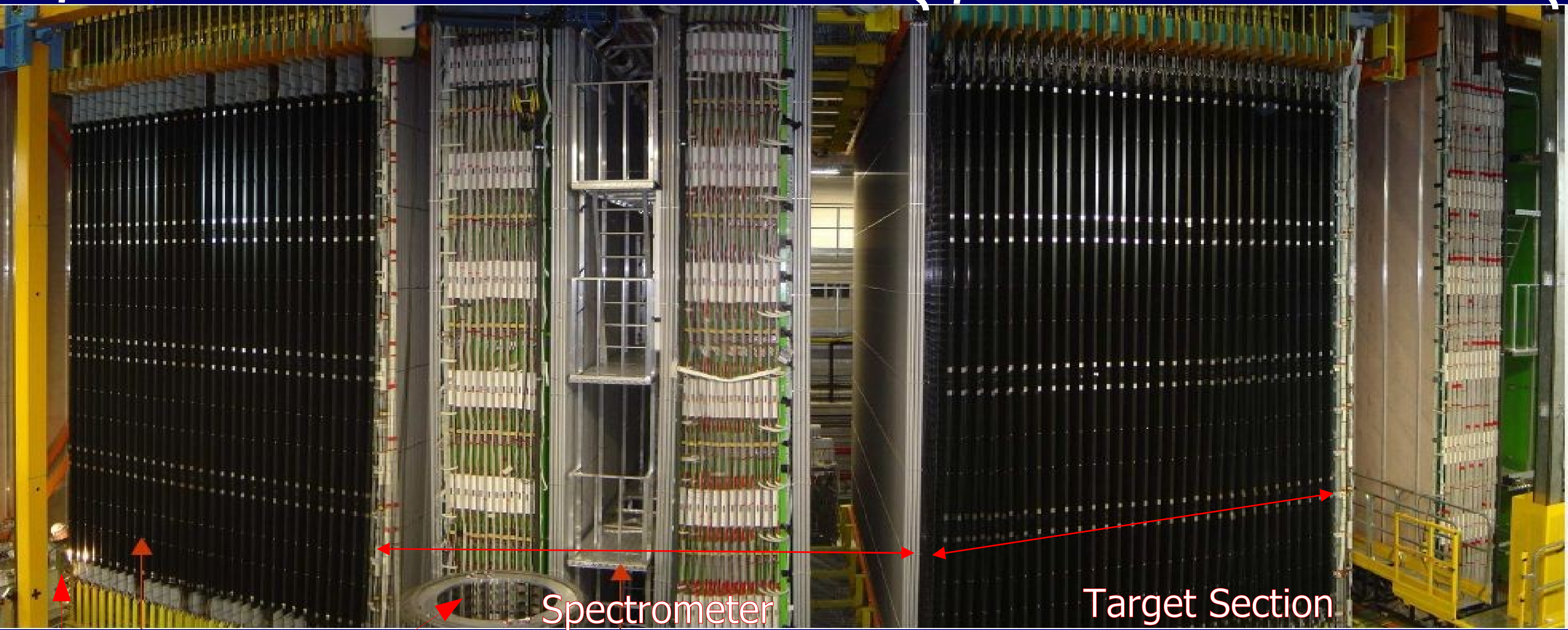
Bricks production status



The OPERA detector

1st SuperModule

2nd SM



Veto

Glass RPC,

~100m2

BMS

Spectrometer

- RPC-XPC, 3050m2
- HPT, 10080 7m tubes
- ~2ktons Fe
- Dipolar magnet 1.55T

Target Section

- brick walls (62 walls, 206000 bricks)
- scintillator target tracker (5900m2)

- T.T. : trigger, neutrino interactions localization (brick finding), kinematics
- Spectrometer : μ id., charge and momentum measurement
- Bricks : ν vertex id., decay kink search, kinematics, e/π sep., e/γ E meas.

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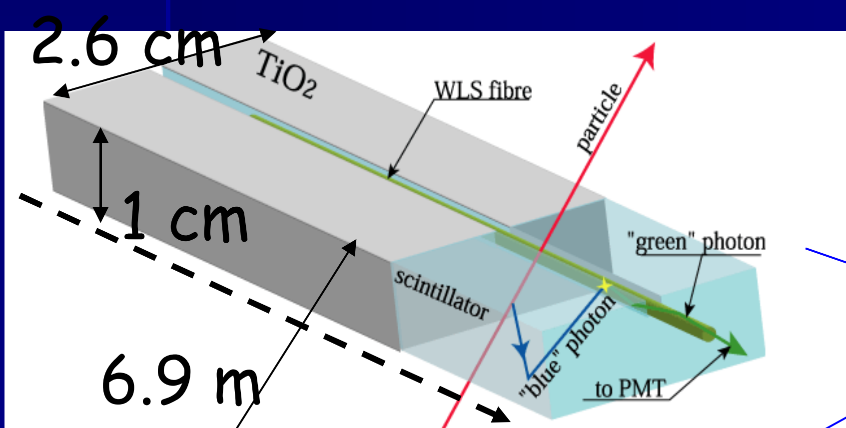
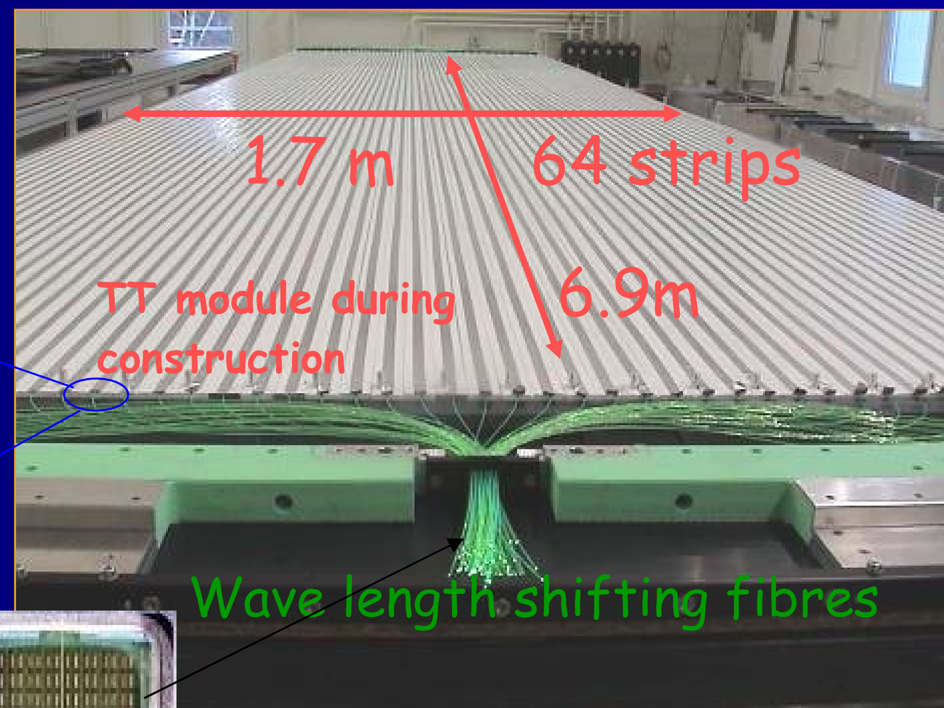
Target Traker modules components

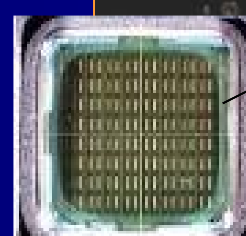
Goal : trigger and brick finding

- ✓ 62 XY planes
- ✓ 32256 scintillator strips 7m × 2.5cm × 1cm (AMCRYS-H, Kharkov)
- ✓ WLS Fibres 1mm diameter (Kuraray)
- ✓ MaPMT 64 channels (Hamamatsu) : 16 × 62 = 992 PMTs
- ✓ Dedicated autotriggerable F/E electronics (min. threshold = 1/5 p.e.)



Extruded plastic scintillator strip





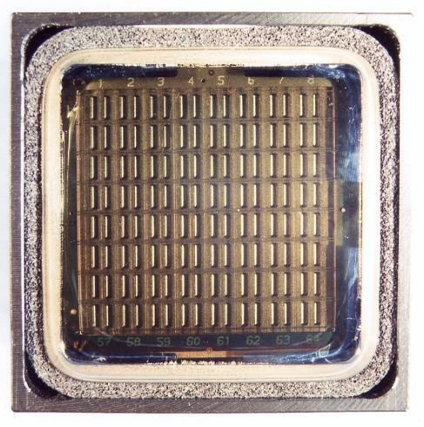
64 pixels Photomultiplier

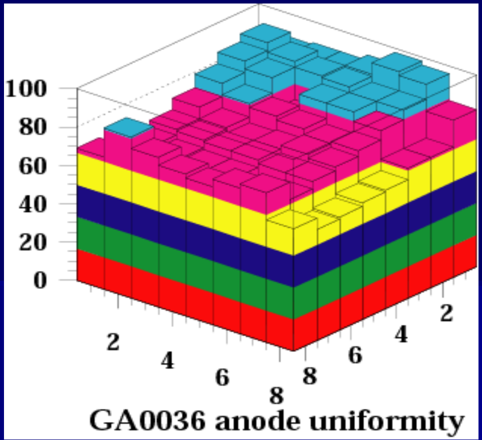
TT active readout

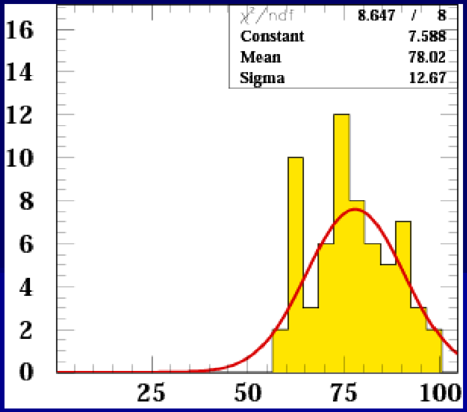
64 # MAPMT

(Hamamatsu)

3x3 cm^2

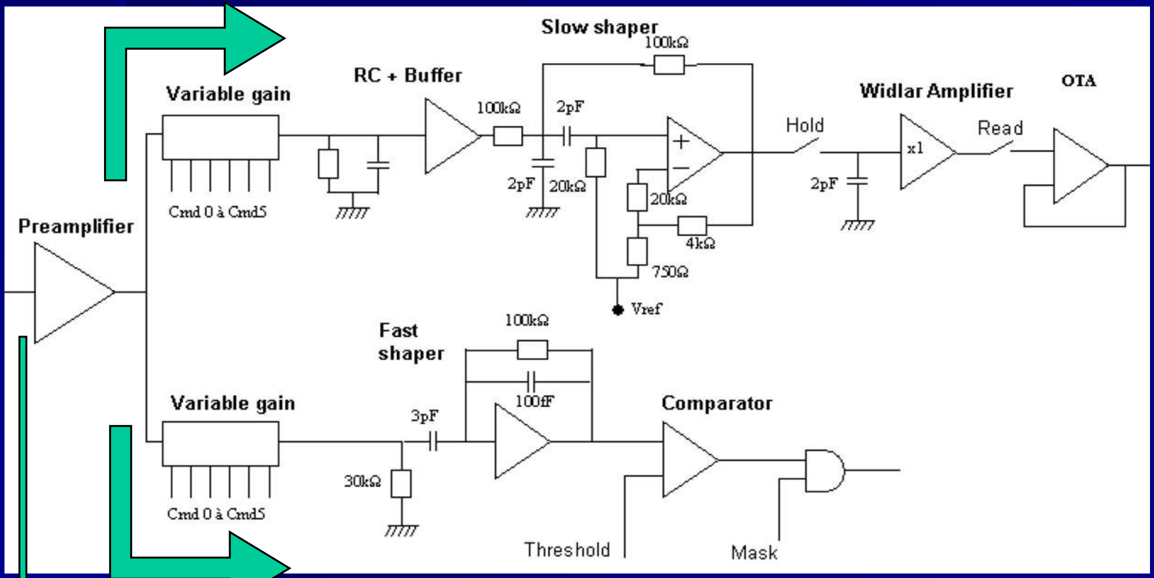


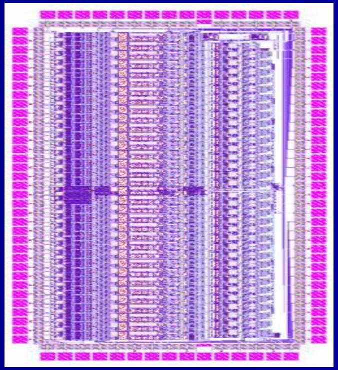




Front-End Chip: final

"slow" for charge measurement





- Technology: AMS BiCMOS 0.8 µm
- Chip area : 10 mm^2
- Package : QFP100
- Power consumption : 185 mW

"fast" for triggering

channel to channel gain adjustment (1:4 range)

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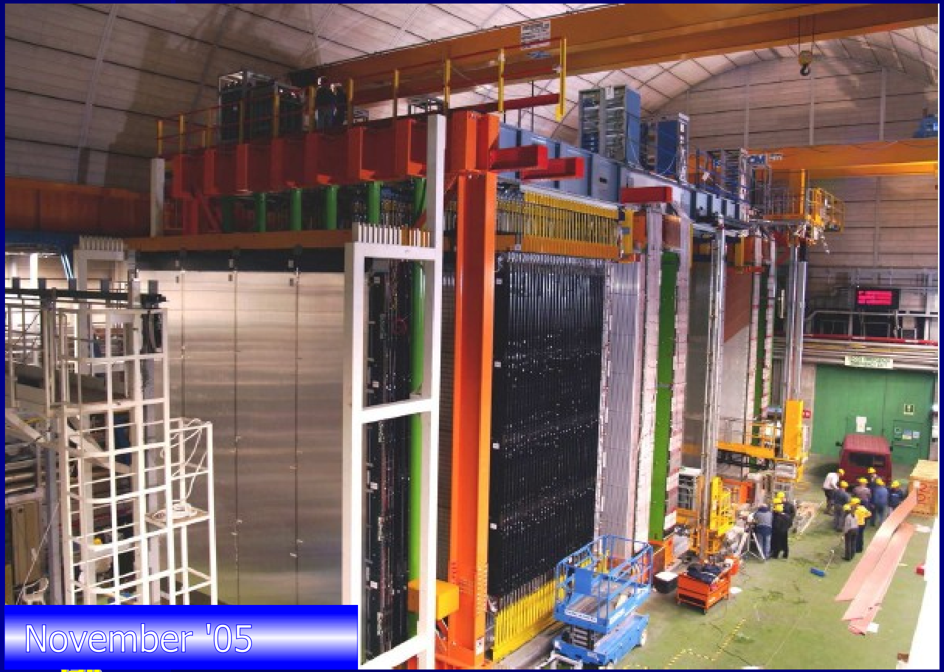
The OPERA detector construction

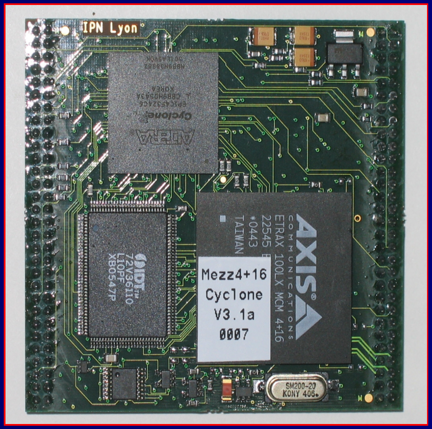
September '03


September '04

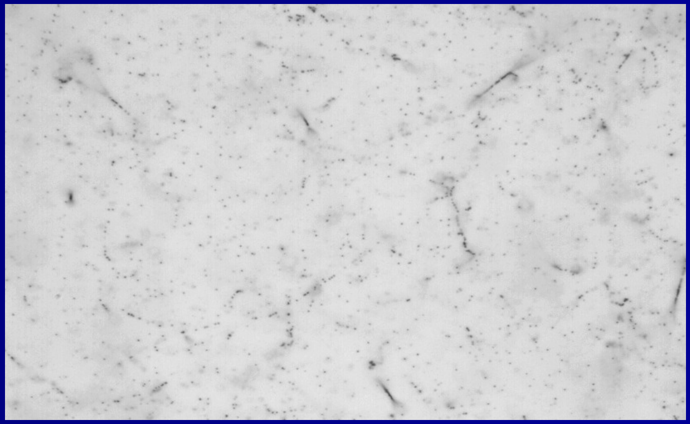

November '05

- Today : all electronic detectors commissioned and running since '06 except Veto (march '07) and HPT 2nd SM (1st half '07)
- General DAQ and GPS clock distribution running
- On-line software and DB schemes commissioned

2. Data taking and analysis



+



On-line electronic detectors

Offline emulsion analysis

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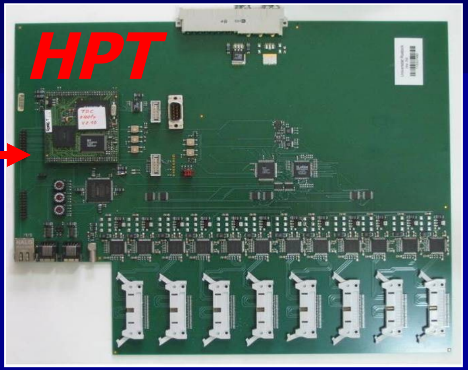
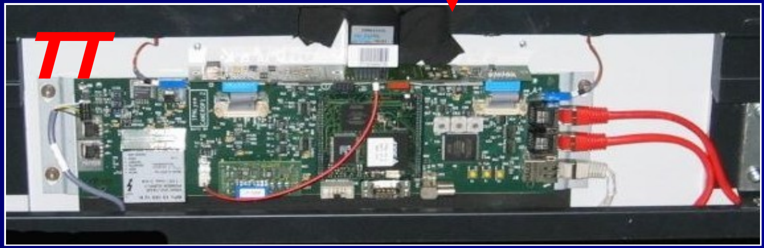
DAQ general features

➢ The distributed DAQ is based on Ethernet. Each sensor (1200) is seen as a node in a Gigabit standard network. The basic "element" of the system is a daughter board ("mezzanine") embedding FPGA, FIFO, μ–processor (AXIS)

R/O: RPC tracker



R/O: drift tubes



R/O: scintillator + WLS fibres + MaPMT

➢ The client/server protocol used relies on the CORBA standard implemented in C++ with interfaces into postgreSQL and Oracle database.

This software is completely object oriented and uses the Interface Description Language (IDL) to describe the distributed objects independantly of the programming language. InterORB protocols guarantee interoperability.

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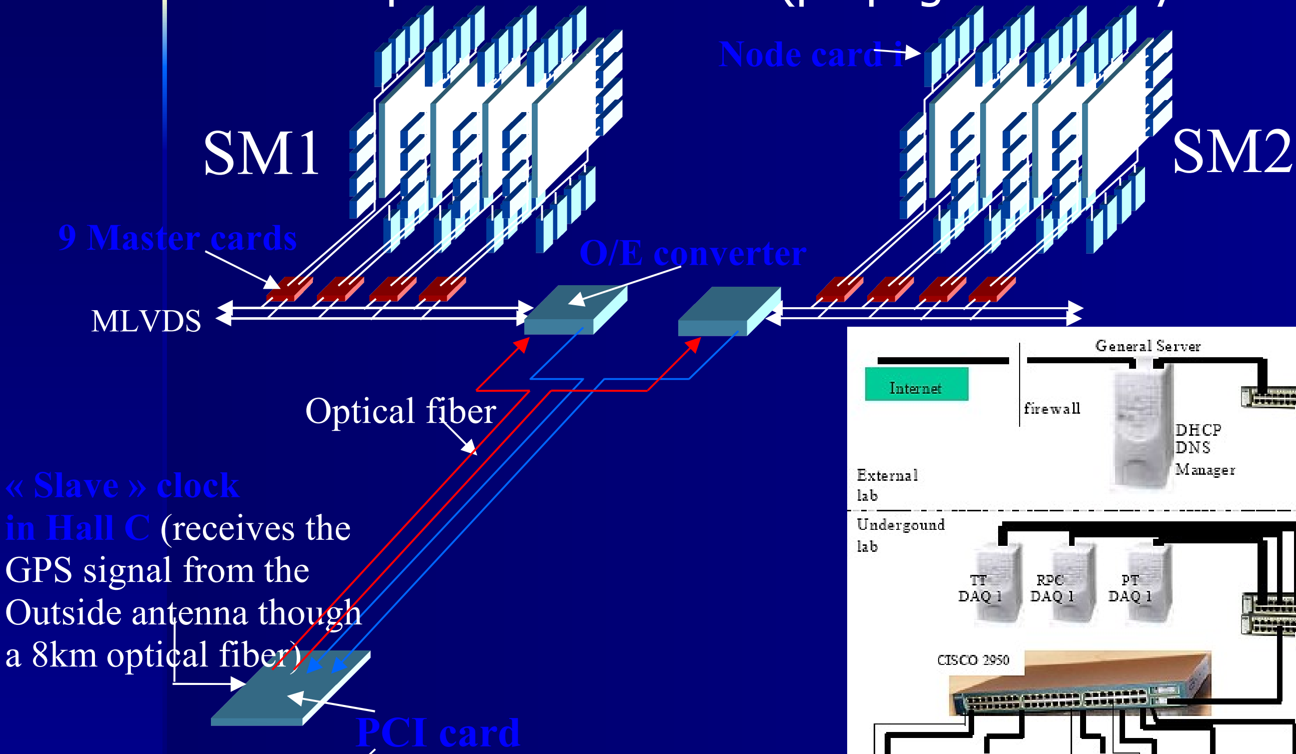
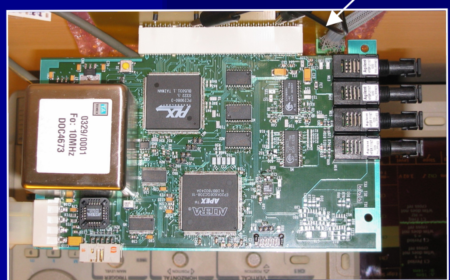
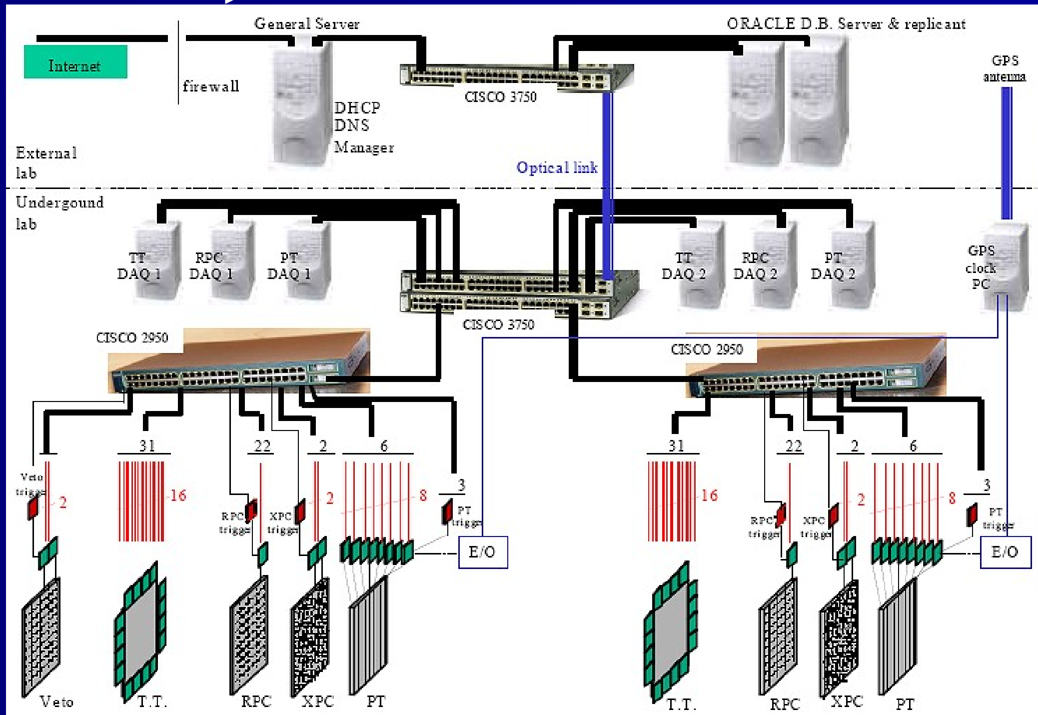
Clock distribution & network architecture

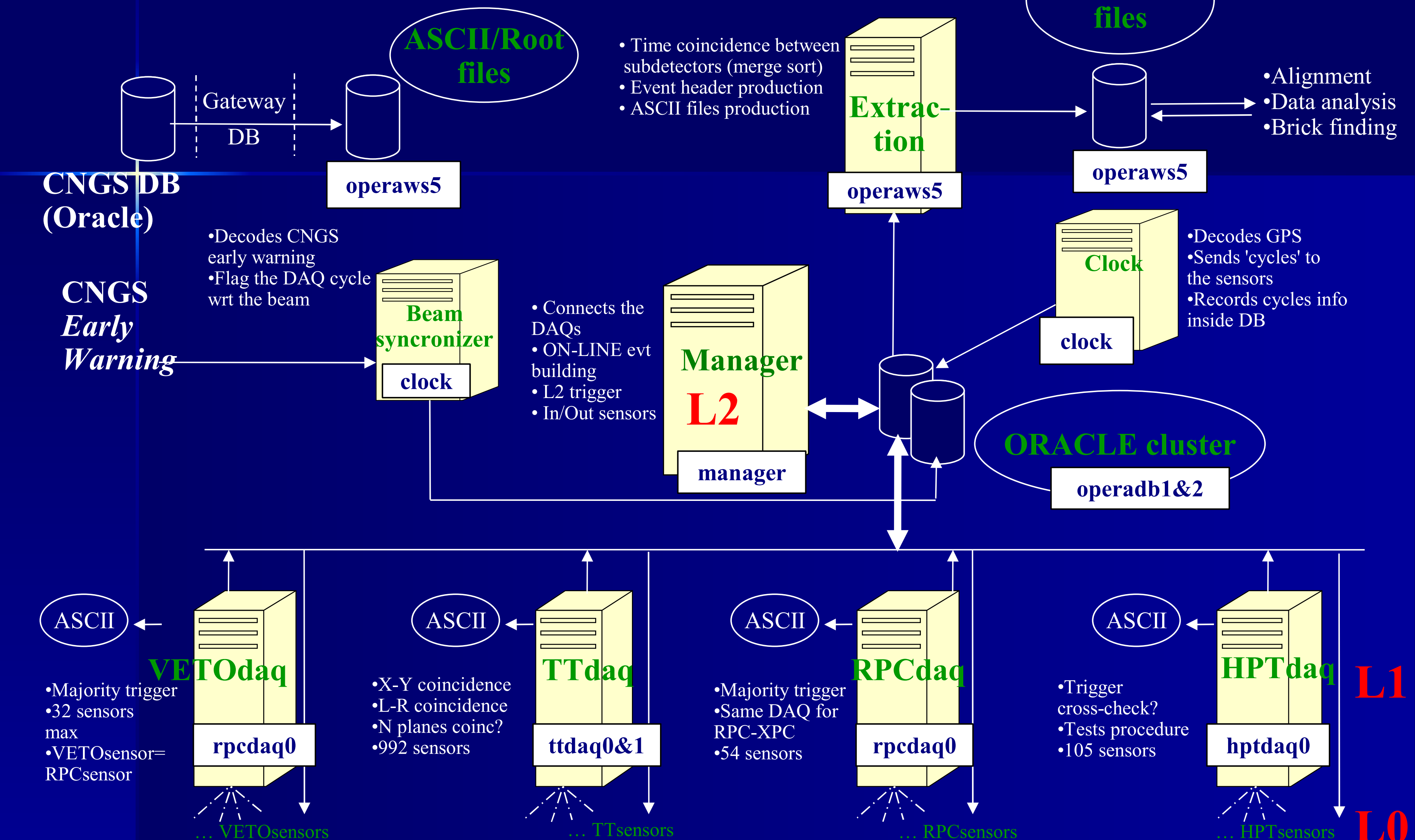
➢ Each individual node runs a local 100MHz clock generated via a common 20MHz clock send from a precise and stable oscillator. The oscillator is plugged onto a dedicated PCI board which locks the clock signal on the GPS and encode specific commands (propagation delay meas., reset, reboot etc).







On-line software



+operans (naming service); operanfs (sensor NFS); operaws2-3 (VNC servers)
+operaws1 (Root files production); opera (gw and general services)

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Event selection & brick finding

Data processing:

- data are continuously extracted from the DAQ data base
- all events are processed through the *OPREC* reconstruction package
- *In time* events are selected and stored on a dedicated file

Brick finding:

- all *in time* events are scanned visually and sorted by categories:
  - *in target* event CC or NC like (according to the muon id)
  - magnet interaction
  - rock muon
- *in target* events are analyzed through the *brick finding* package
  - each step of the reconstruction for the muon is checked manually
  - iterative process including;
    - neural network for the wall finding
    - hadronic shower parametrization
    - probability estimate for the vertex location in each brick
    - exact configuration and alignment of the target at the time of the event (BMM data base)
  - at the end the list of bricks is provided for each event

Brick extraction:

- Listed bricks are extracted by the BMS
- Extraction operations still performed in parallel with insertion

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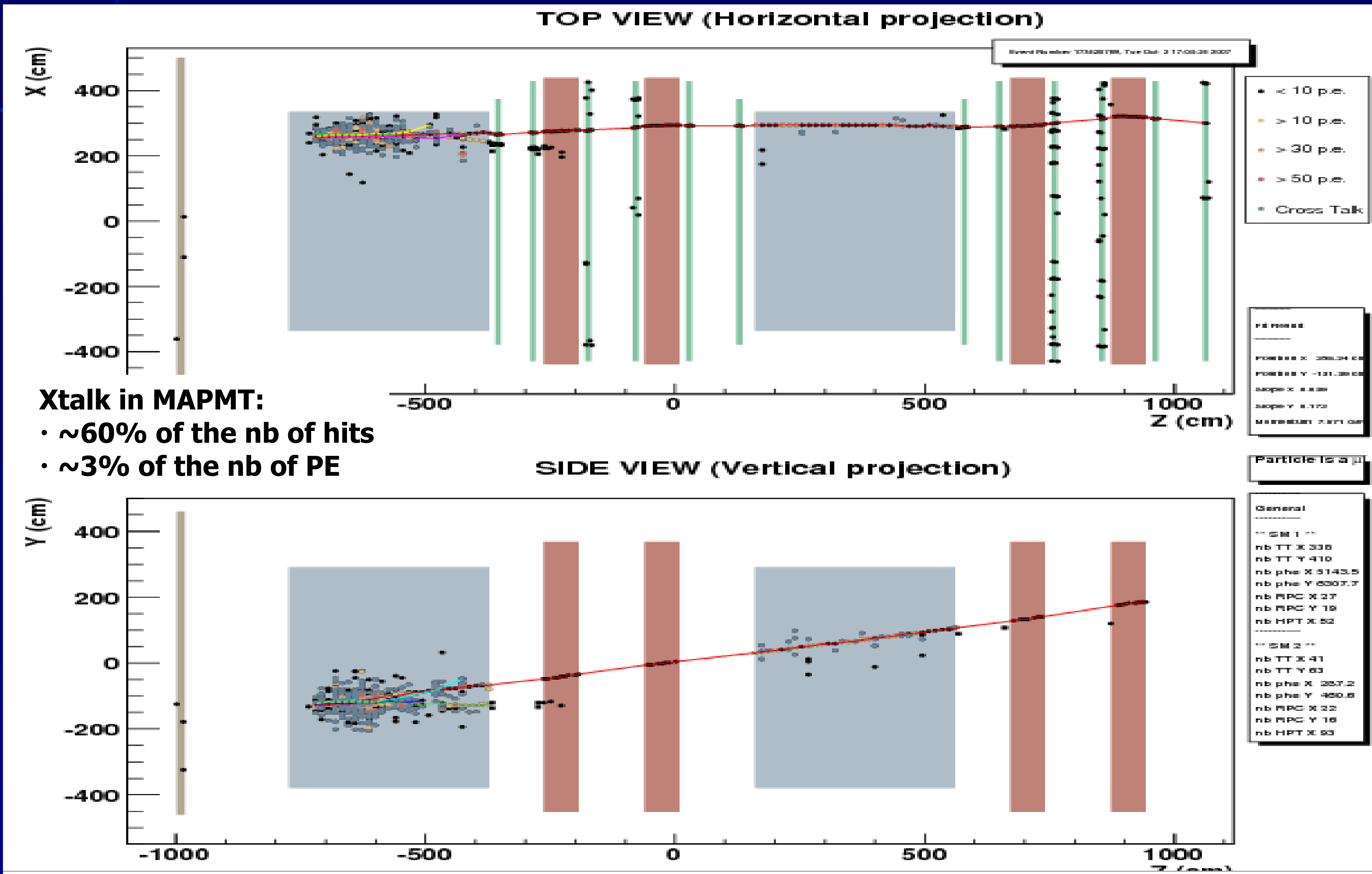
CC-like event processing : OPERA "baby"

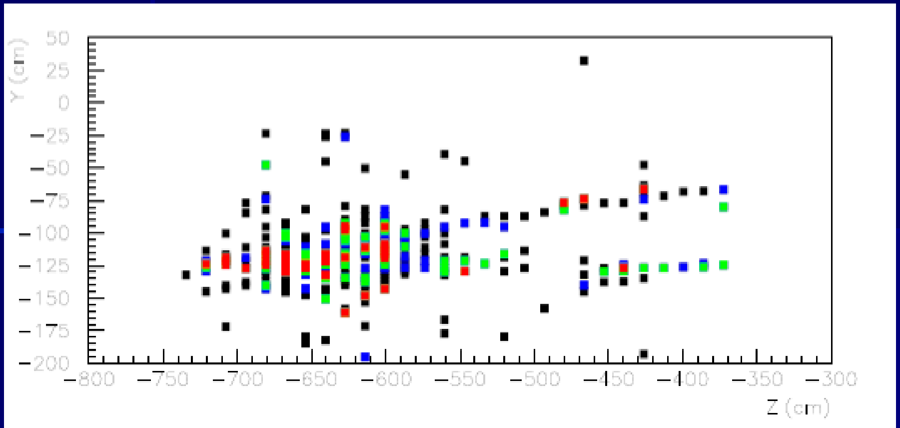
« Opera baby » P_μ : 7.87 GeV/c



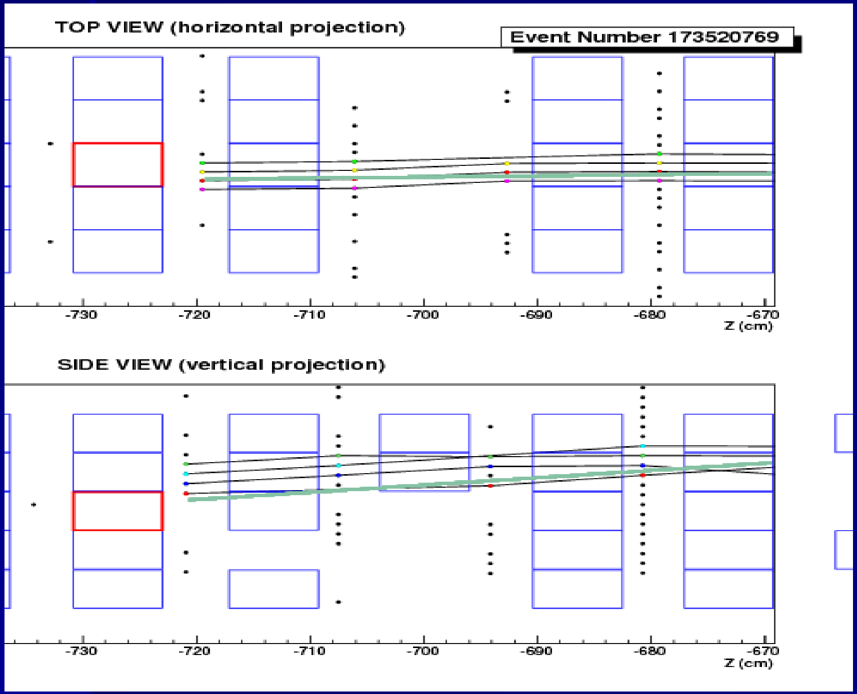
Xtalk in MAPMT:

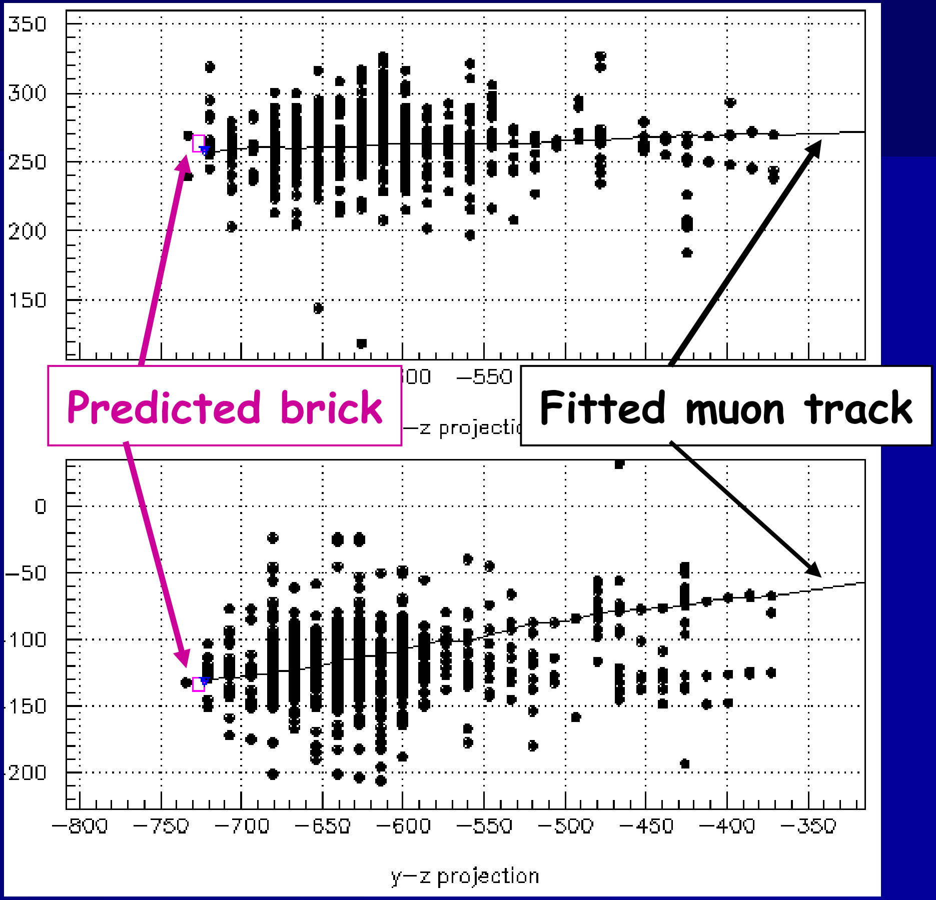
- **~60% of the nb of hits**
- **~3% of the nb of PE**

CC-like event processing : OPERA "baby"



11451 p.e. tot
1579 p.e. muon





Wall 5 Tray 24 Cell 6 prob= 0.9
Wall 6 Tray 24 Cell 6 prob= 0.09

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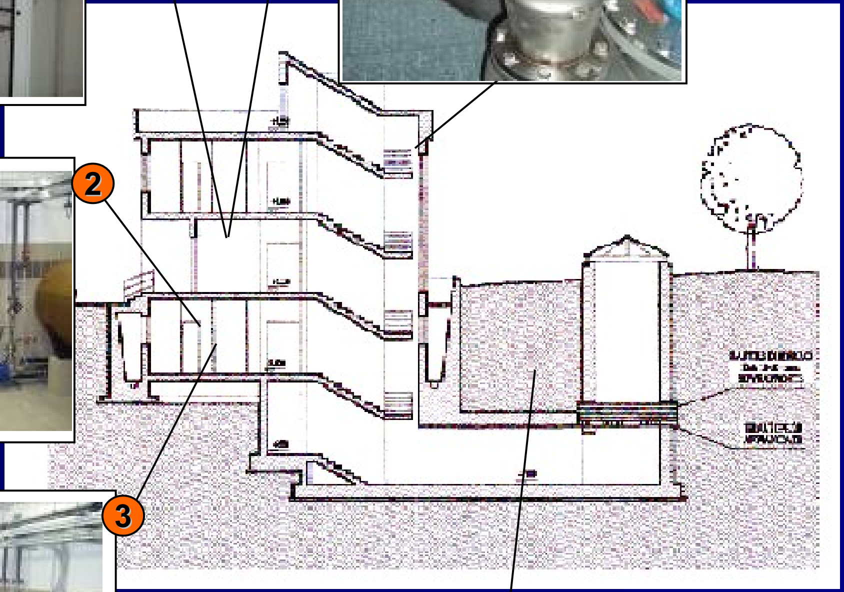
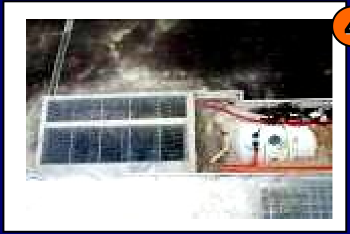
Processing : development lab at LNGS





- Main control unit powered, working 1
- Demi water ready, 20° C ok 2
- Filtered water available, 20° C ok 3
- Collection tanks secured 4
- A nice chemical Lab set aside (small operations, & quality check! : 5 thanks to LNGS Chemical Service)
- Big preparation tanks 6

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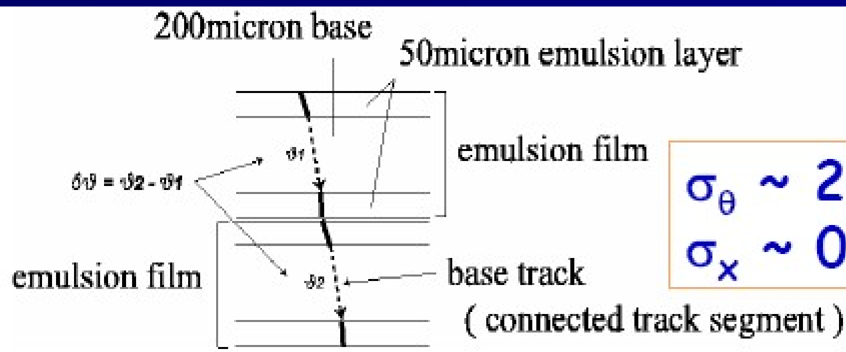
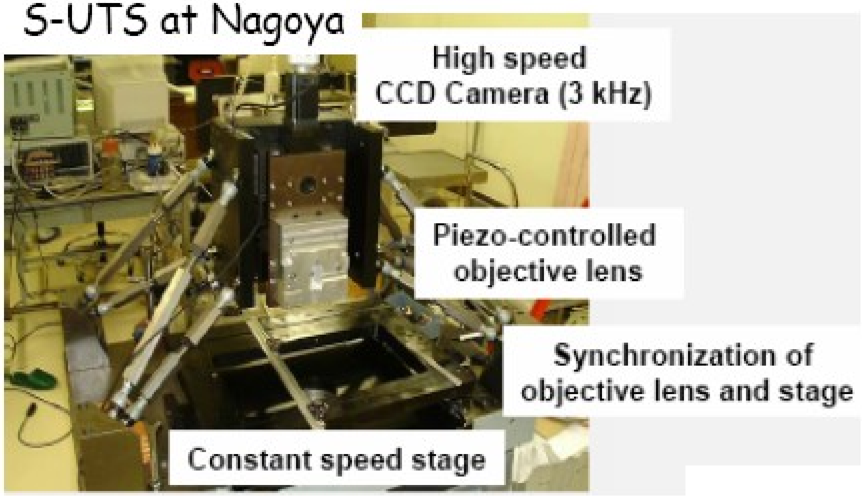
Off-line emulsion scanning

Two different systems (both operational) are running for scanning systems : "hard"-coded oriented (Japan) or "soft"-coded oriented (Europe).
Both systems are ready and working at more than 20cm^2/hour (10 required).



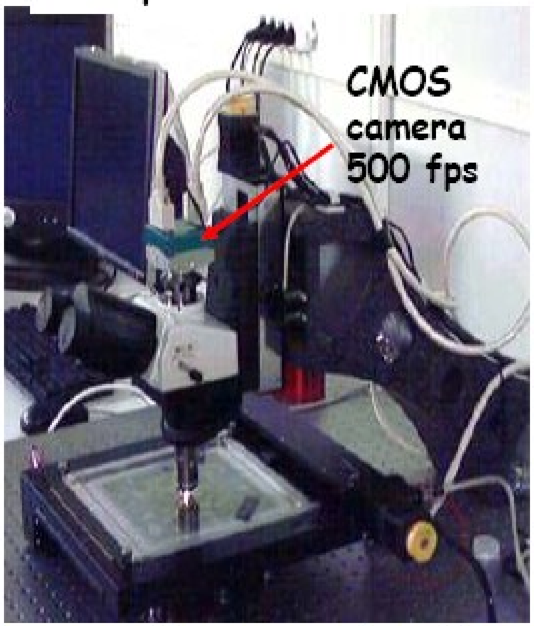
$\sigma_\theta \sim 2$mrad
$\sigma_x \sim 0.5\mu$m

S-UTS at Nagoya



Dedicated hardware
Hard coded algorithms

European station



Customized commercial products
Software algorithms

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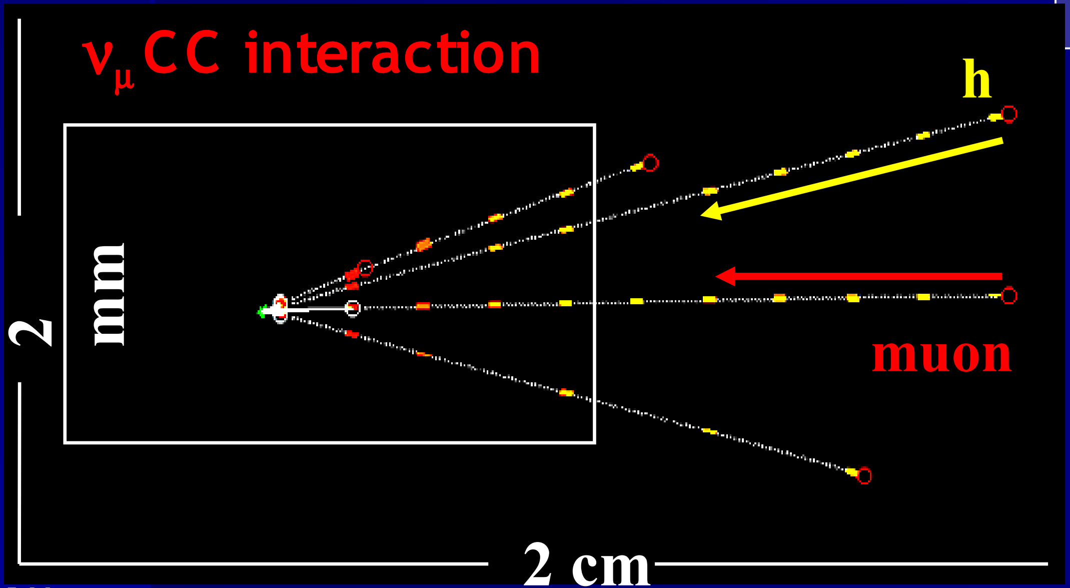
Scanning station overview

Emulsion scanning is performed in a fully automatic way.

About 40 microscopes are operational in the various OPERA scanning laboratories.

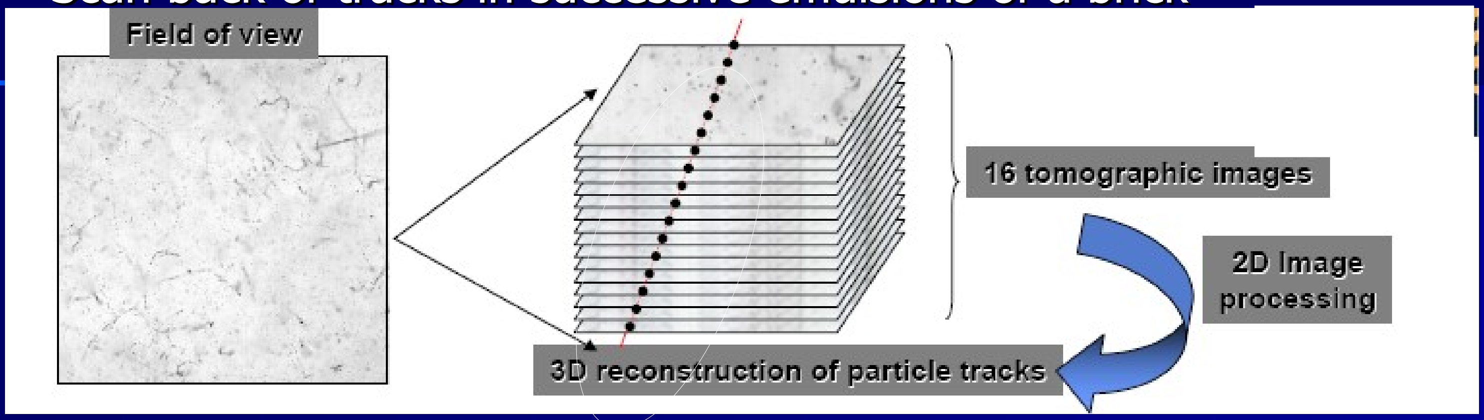
Bern emulsion scanning lab.



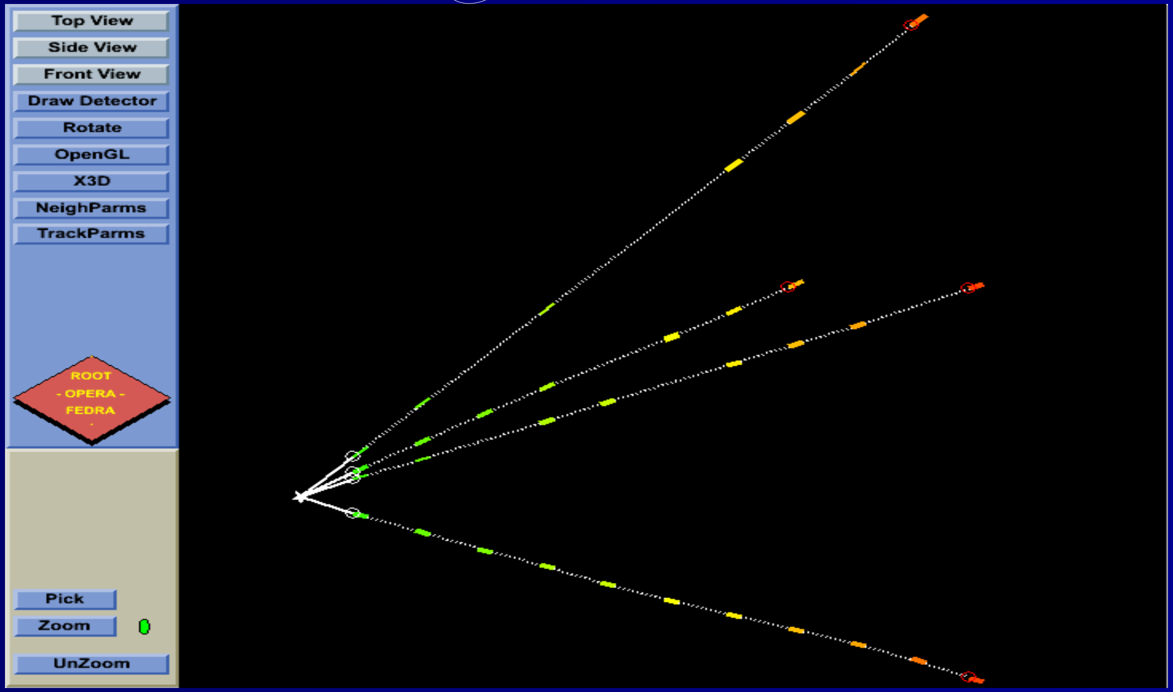
Predictions from electronic detectors are followed back inside the brick until tracks stop. Then a full scanning around neutrino interaction vertex is performed and the event topology and kinematics reconstructed.

Off-line emulsion scanning

- Tracks reconstruction by analysis of ~16 “slices” per emulsion
- Identification of “base”-tracks (both emulsion sheets)
- Scan back of tracks in successive emulsions of a brick



OPERA baby



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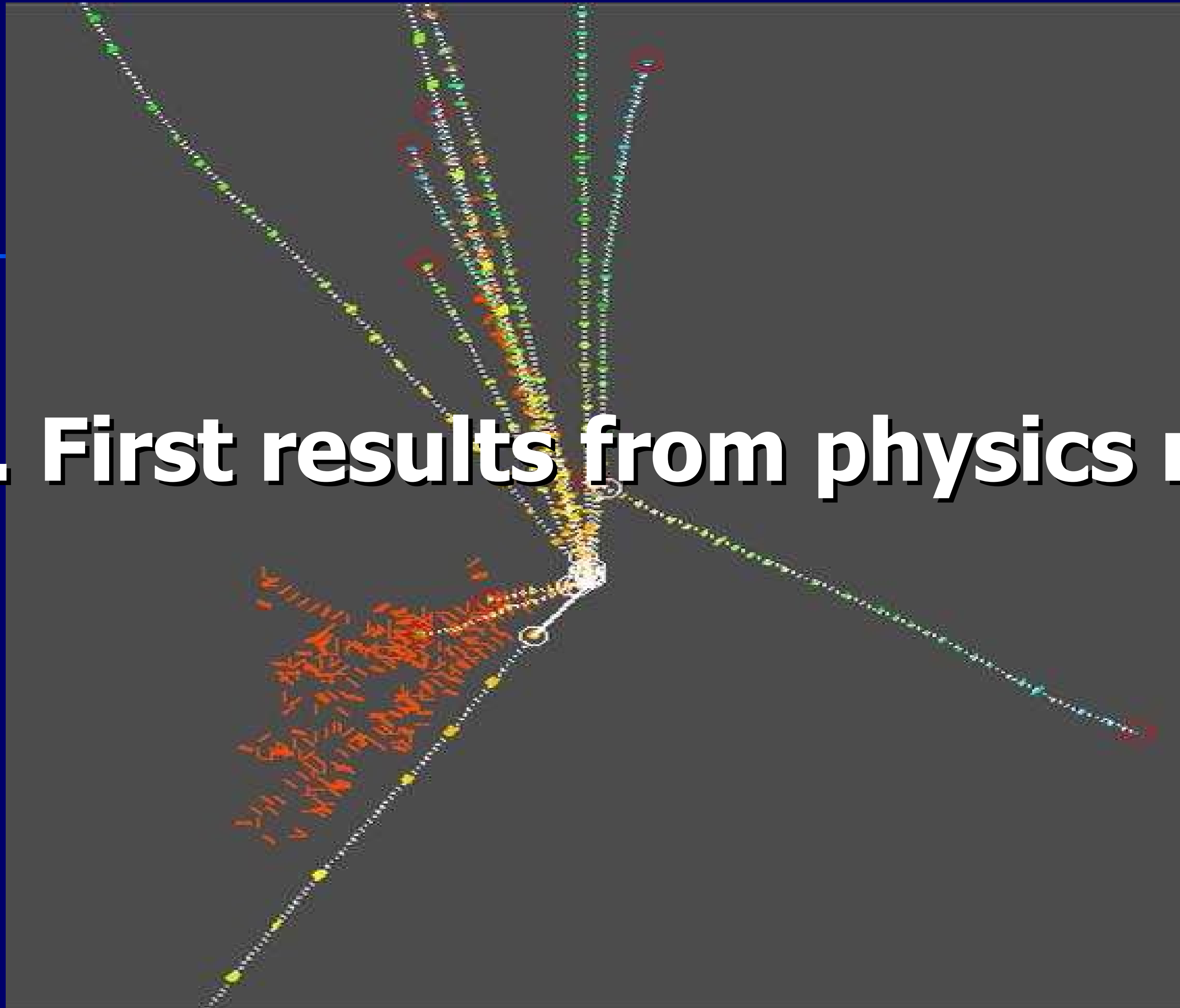

2. First results from physics run

3 runs : august & october '06, october '07

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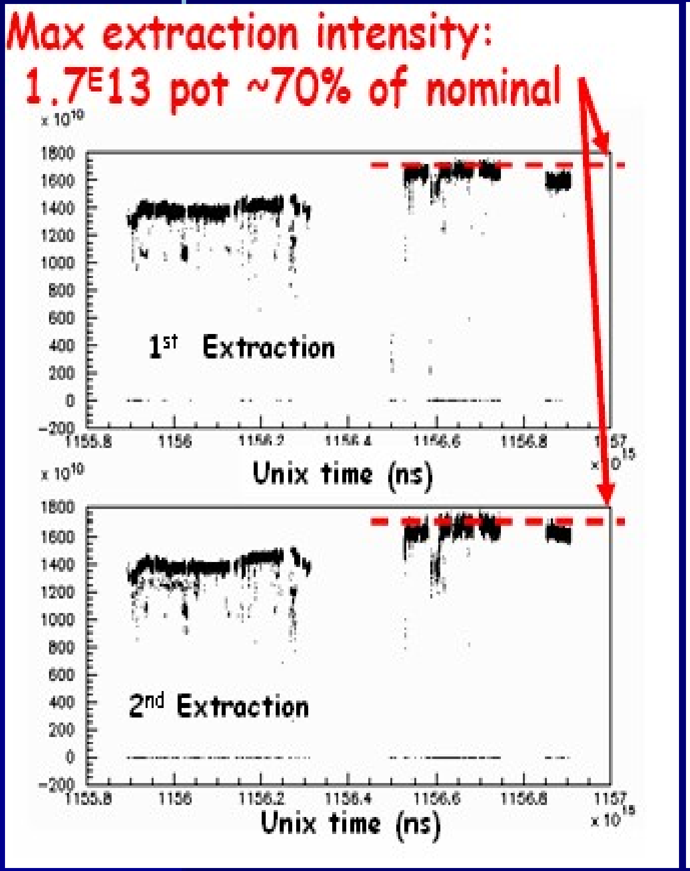
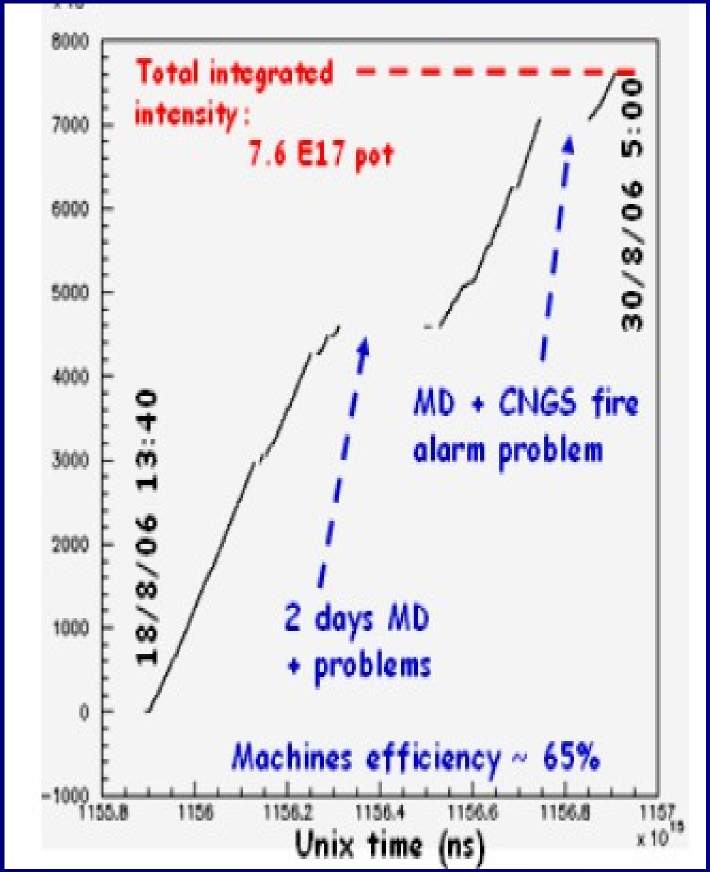
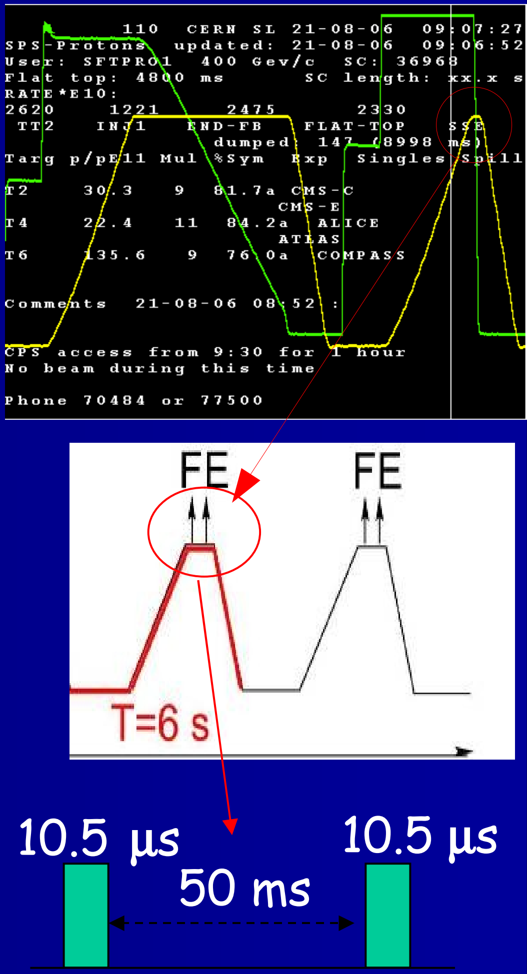
August '06 run

- 8.5 days of real beam operation (121 hours within 2 weeks of operation)
- Used for electronic detectors, DAQ, GPS commissioning and tests of CNGS-OPERA information exchange (gateway DB, early warning signal...)
- Beam side informations :







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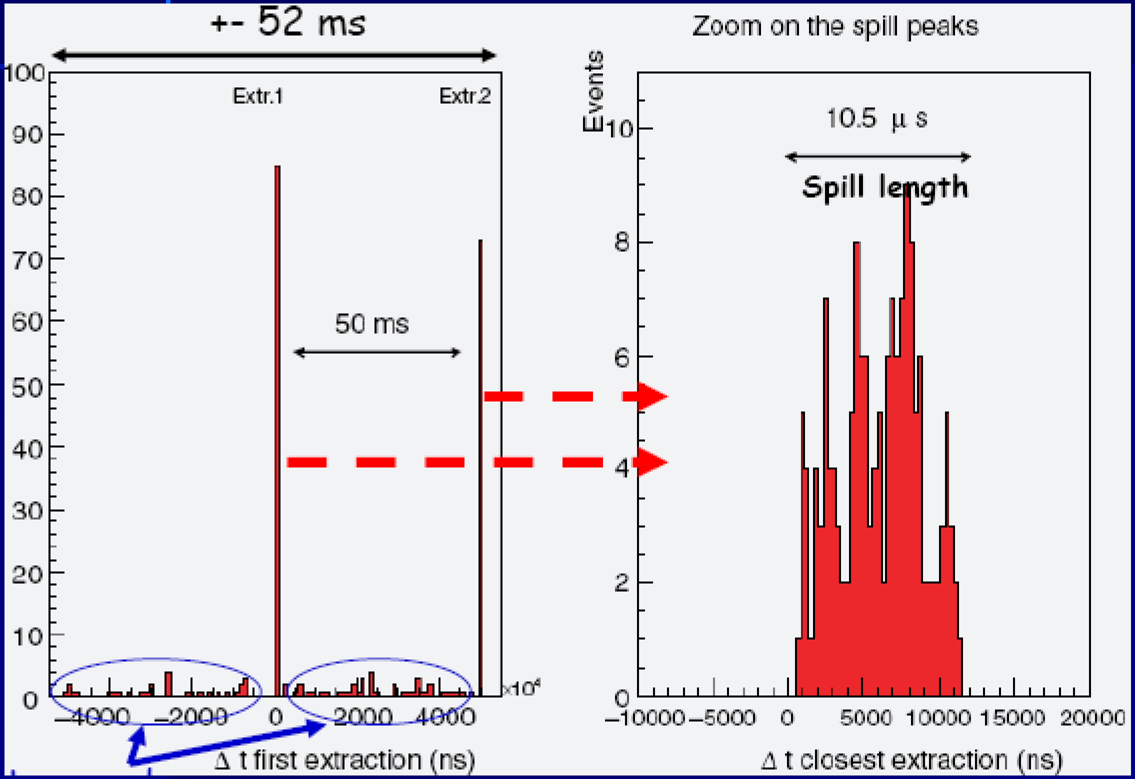
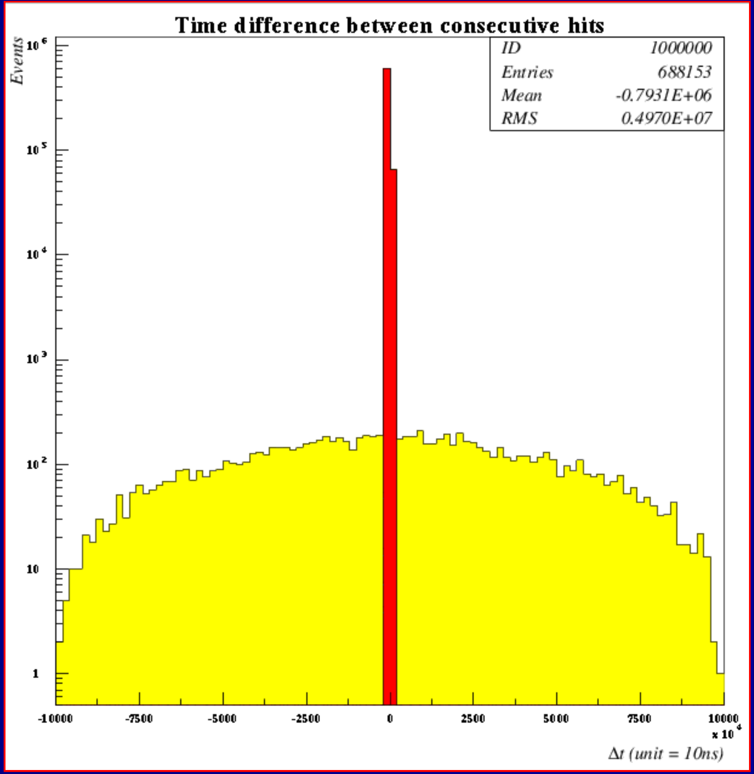
Timing issues

- Events selection from GPS time information : $T_{OPERA} - (T_{SPS} + TOF) < T_{GATE}$
- The events time distribution is peaked around the 2 extraction peaks times within negligible CR background (o(10^{-4}) in ~ms windows)



Cosmic rays bckd

- All hits : the consecutive times difference distribution shows a peak of width ~$T_{COINCIDENCE}$ (typ. 200ns)



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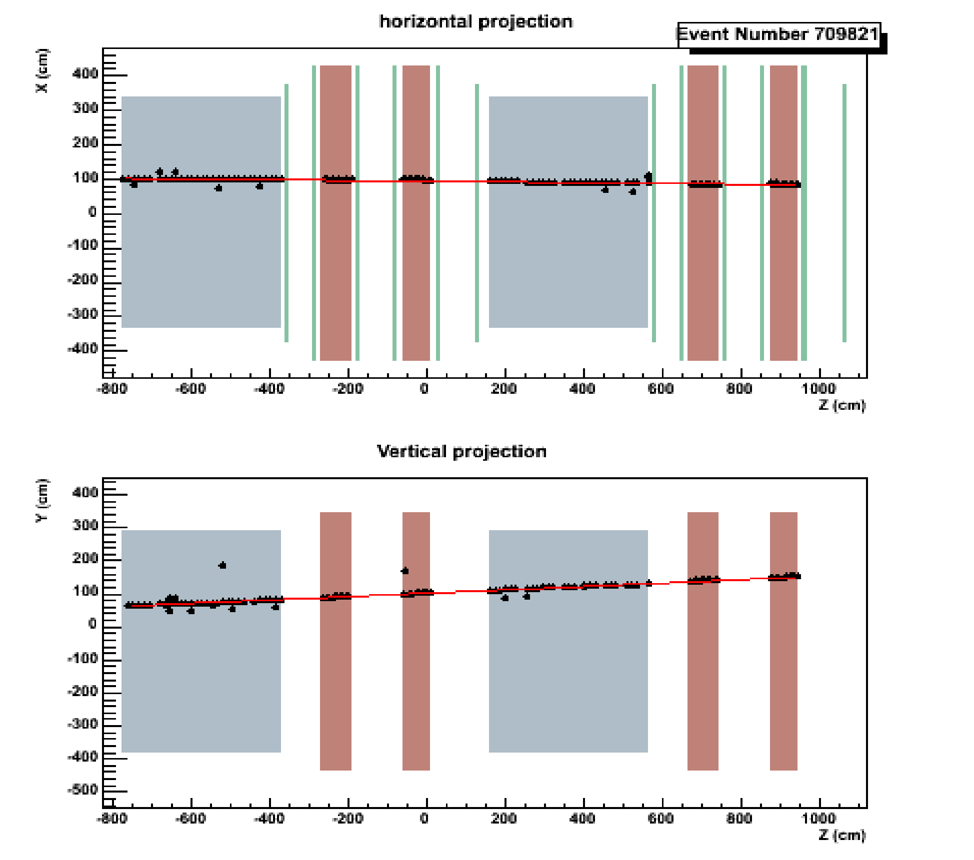
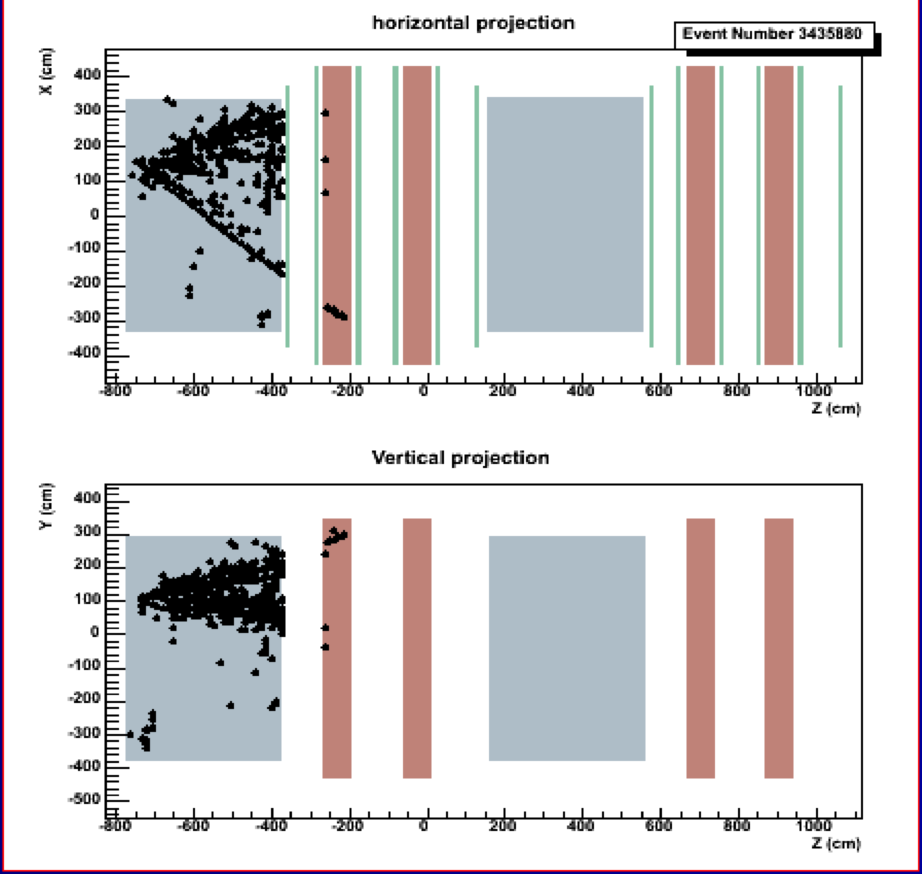
August '06 run

- Neutrino induced interactions : 319 detected altogether (in agreement with the predictions)
- ¾ muons coming from the rock, ¼ neutrino interactions in the detector

CC event originated from material in front of the detector





CC event originated in the detector's target material

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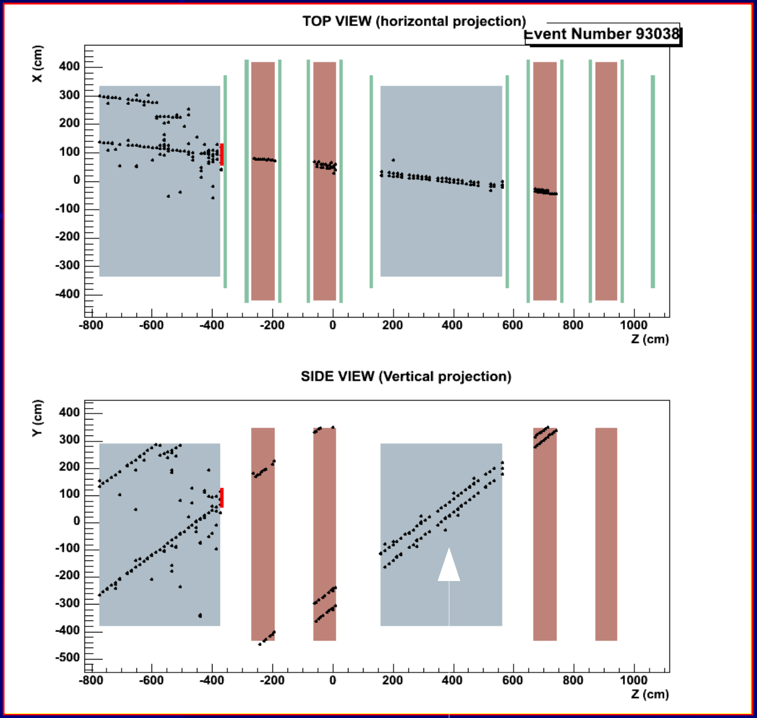
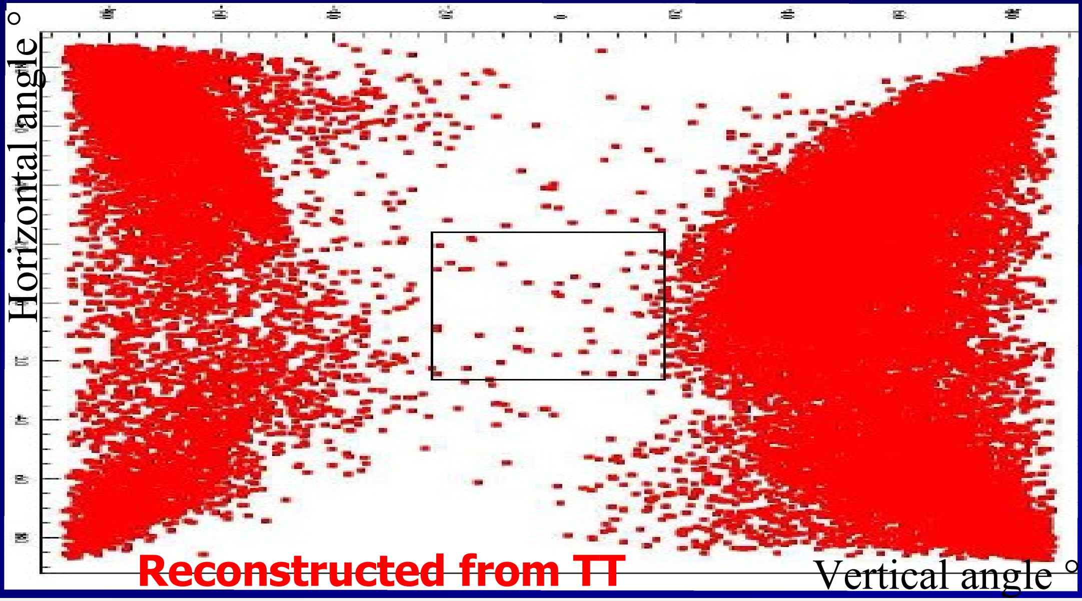
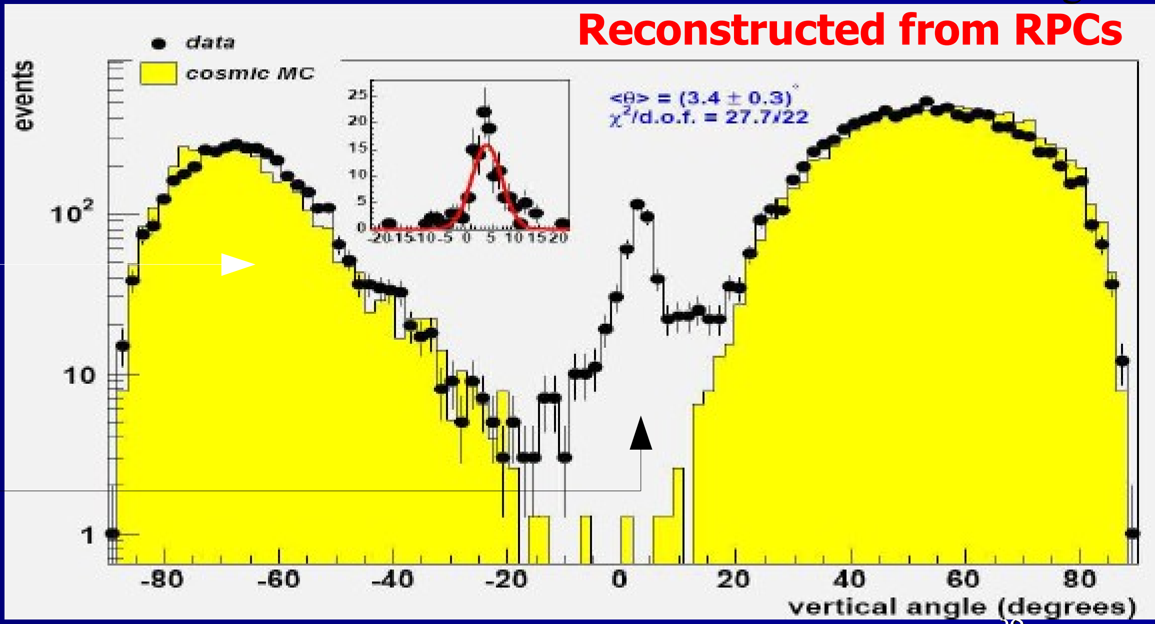
CNGS vs cosmics events







Cosmic rays induced events with a typical down-going topology

Beam events: ~horizontal tracks

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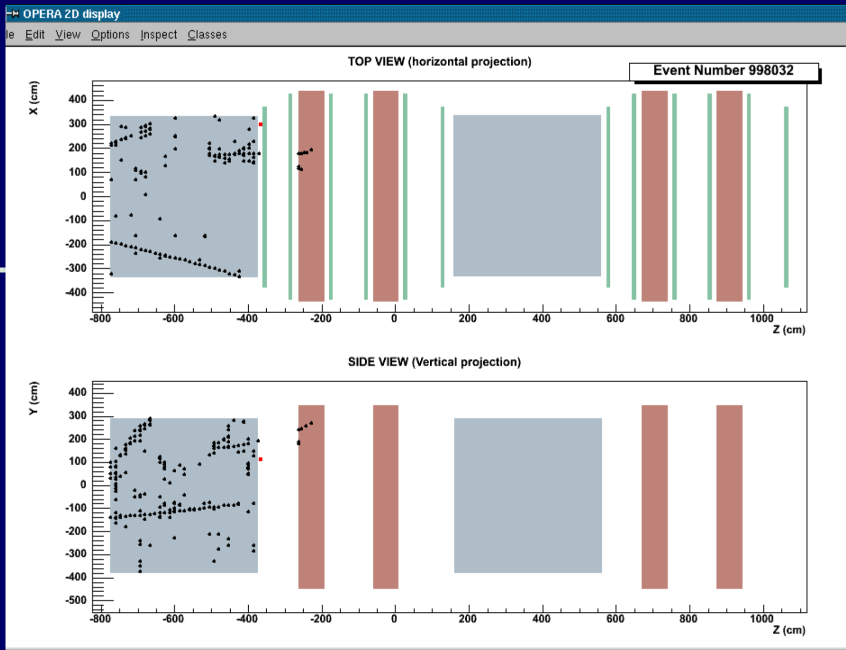
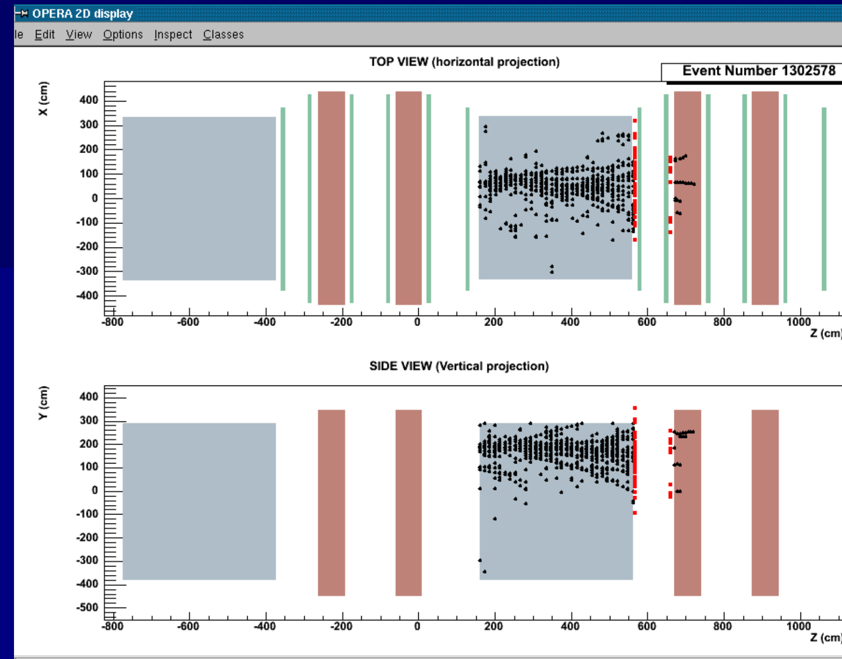
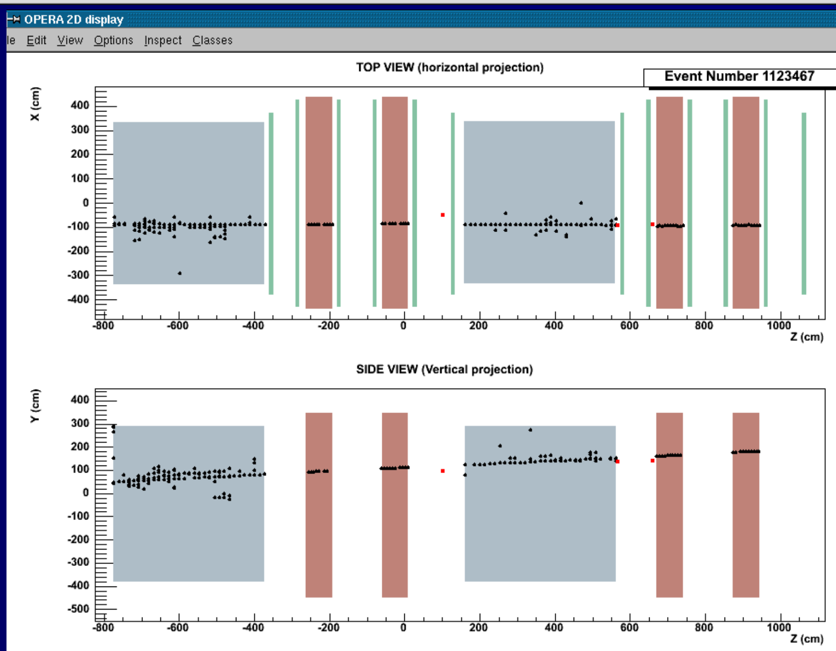
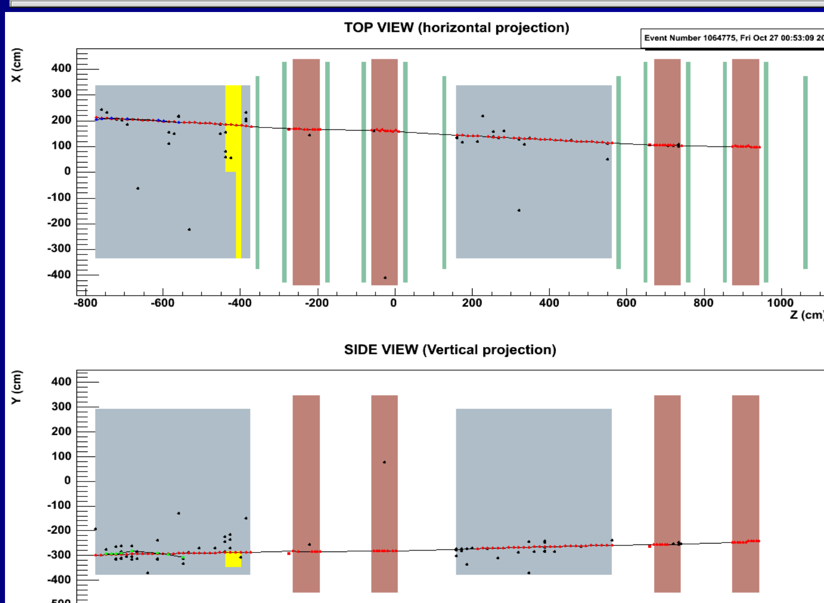
October '06 run









To be followed in the bricks...

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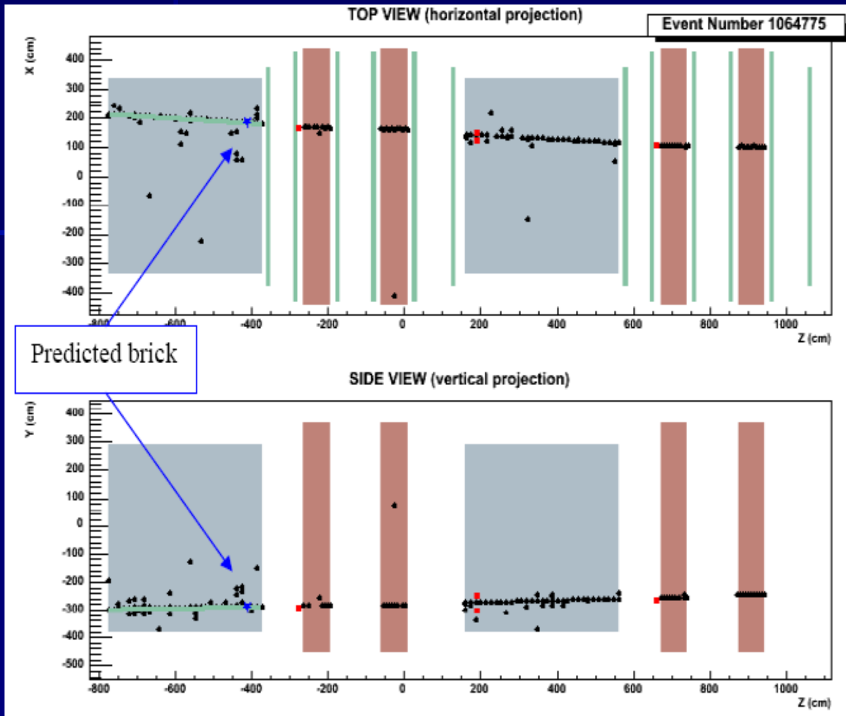
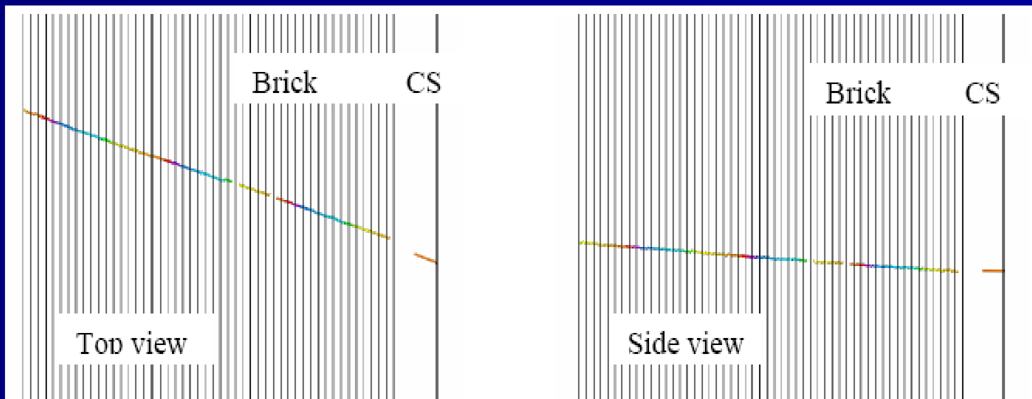
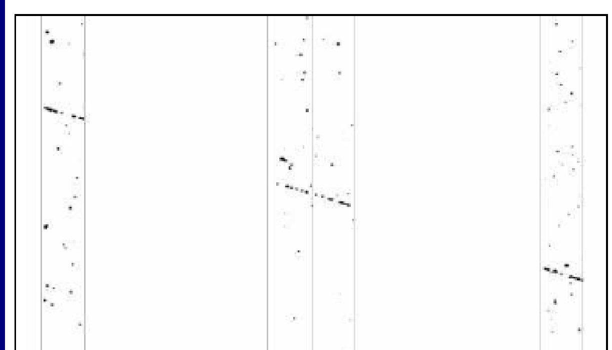
October '06 run

- Short run due to CNGS leak problem.
- 25 neutrino events collected.
- 1kbricks in the target (BAM pilot run)
- 1 brick crossing muon identified.
- Brick extracted from the wall.







Details of the CS scanning showing the reconstructed grains.

- Extrapolation from ED predictions to bricks validated for beam events.
- Under evaluation for cosmics.
- Requires additional run to tune at least the brick finding procedure

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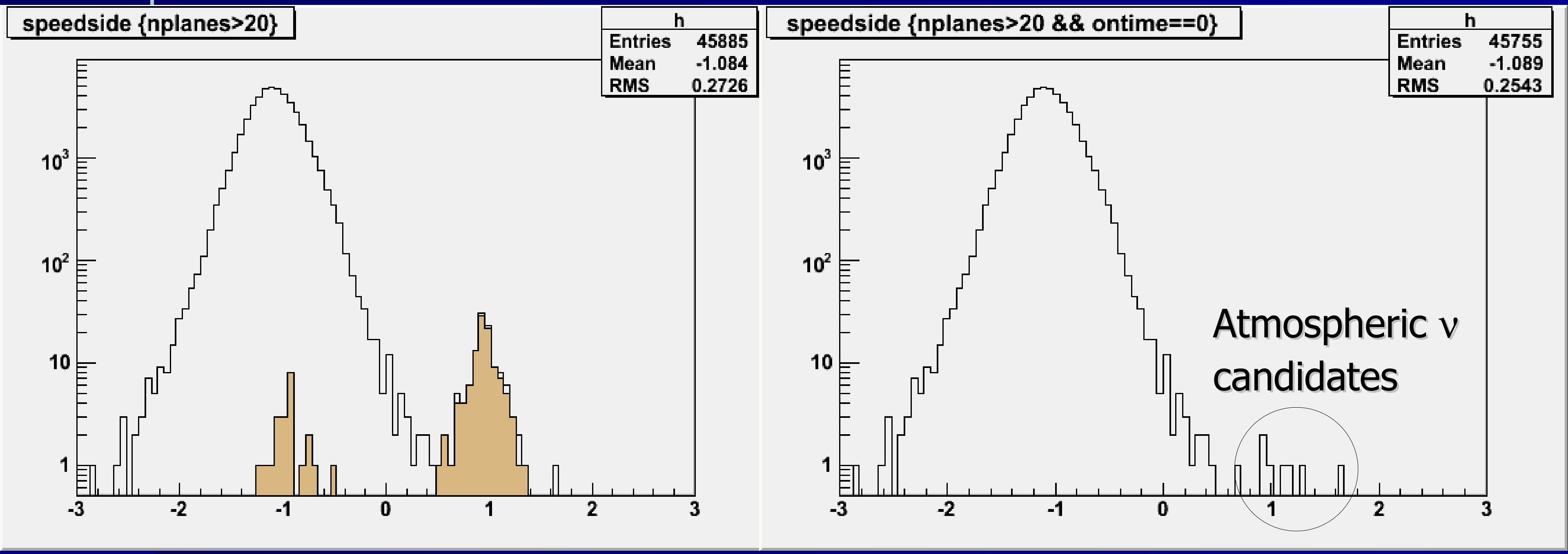
Cosmics analysis

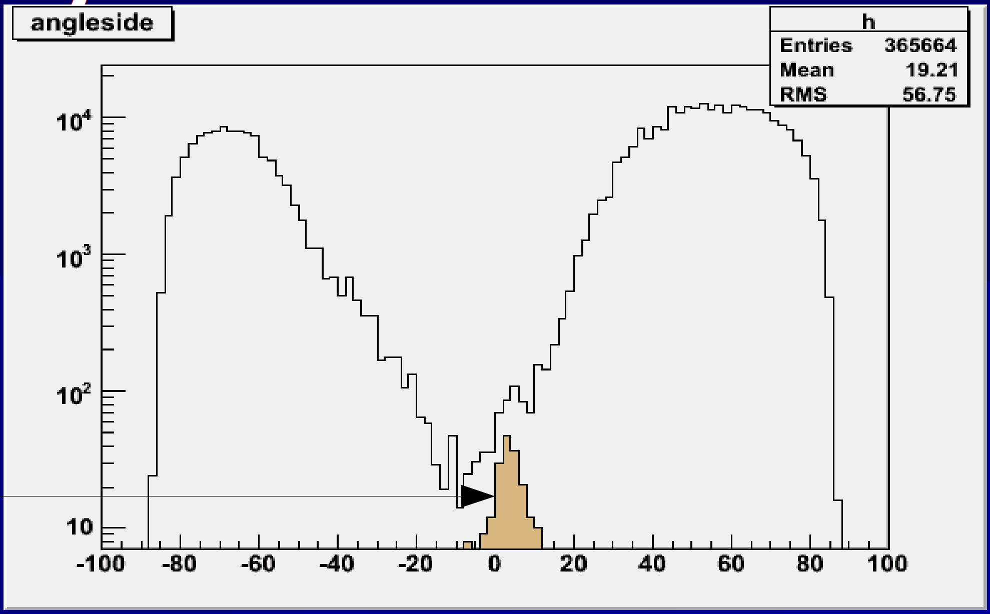
- TOF analysis to disentangle up/down-going particles
- 10ns timestamp accuracy
- Cuts on the event topology (track length in the detector)

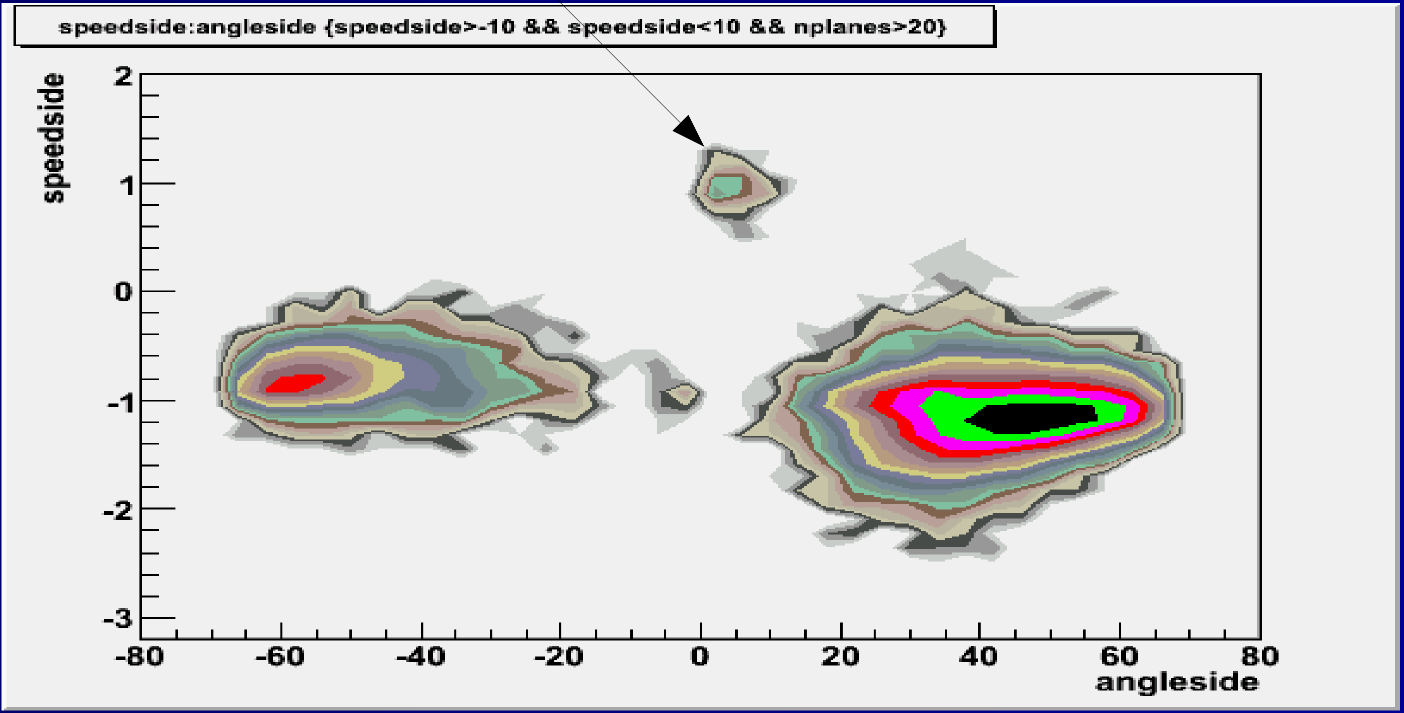


- 1/(β=v/c) distributions
- -1 : down-going particle / +1 : up-going particle
- Orange: on-time events (beam)
- ~250d data taking
- Data/full MC comparison under investigation

Cosmics analysis

- TOF vs angle scatter plot
- Beam events close to the horizontal direction





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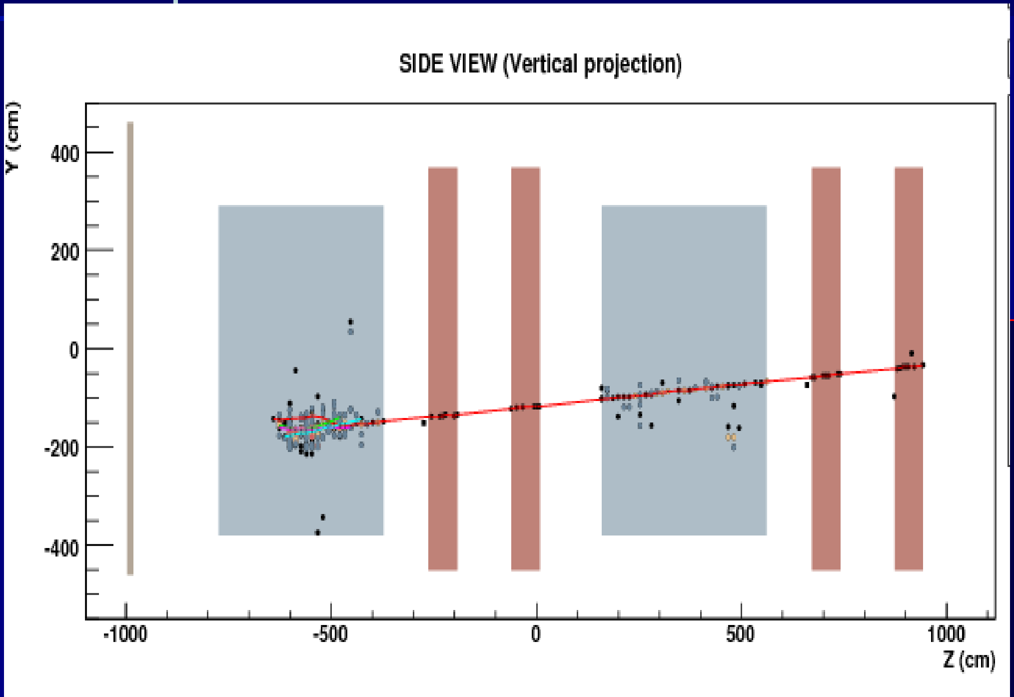
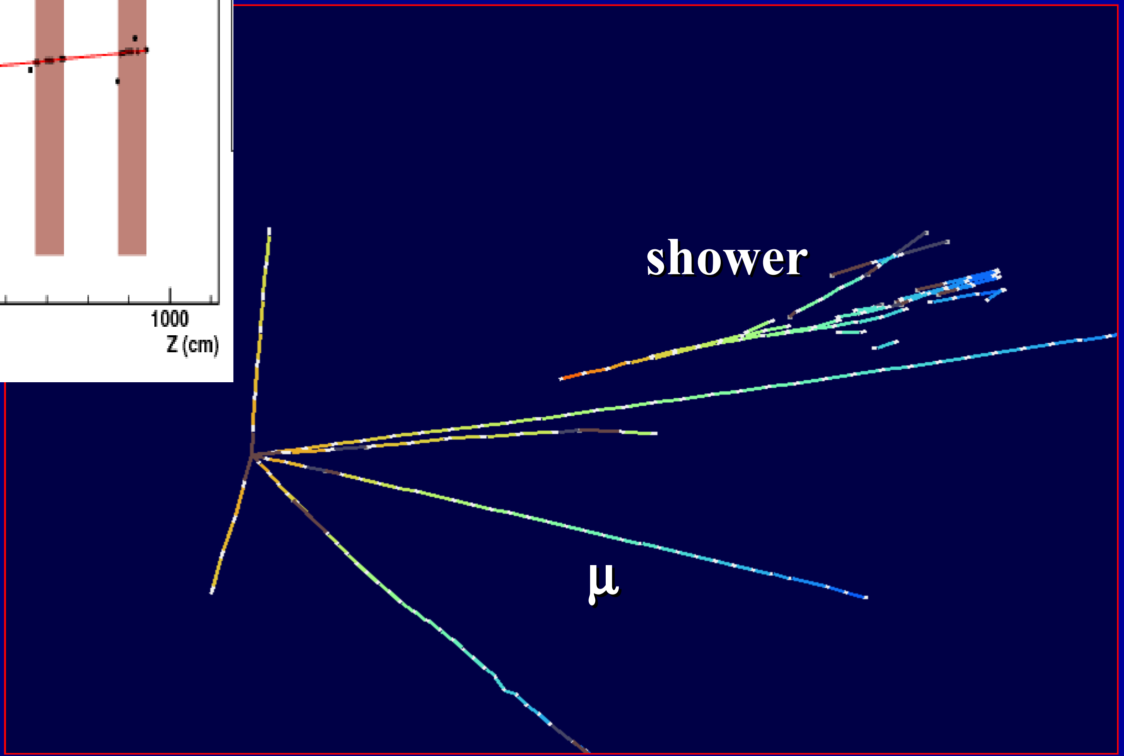
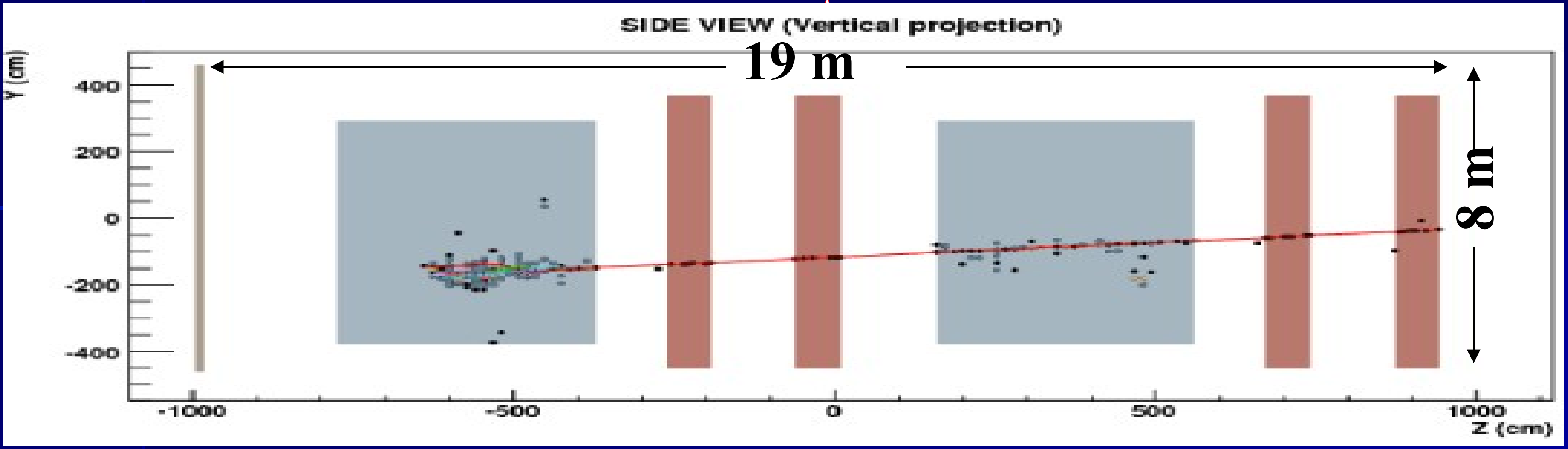
'07 physics run

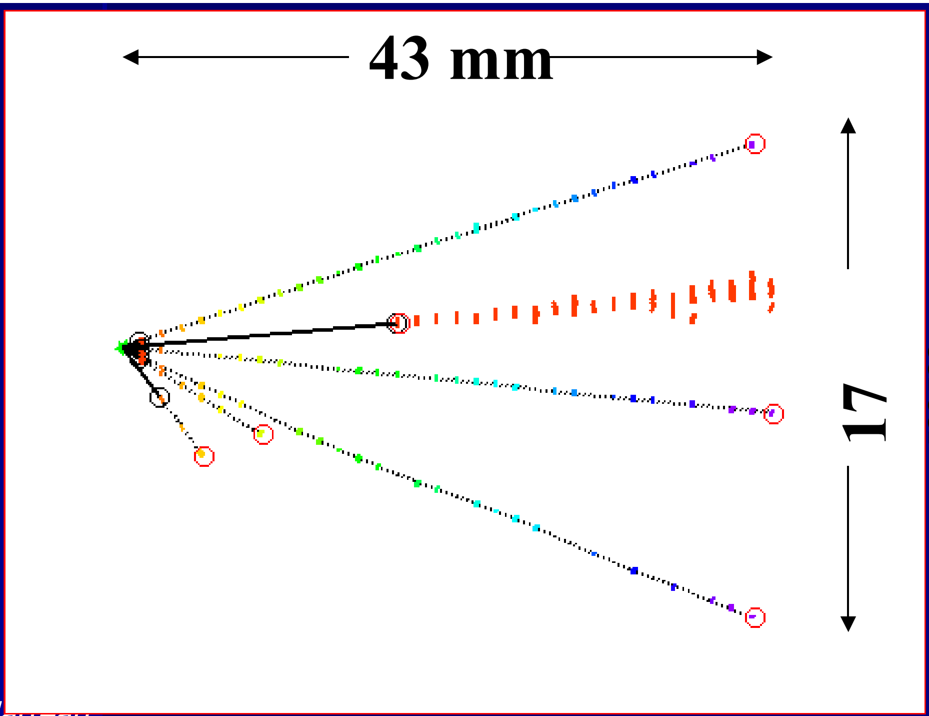
- Short run due to CNGS services electronics irradiation problems.
- 38 neutrino events collected in the OPERA target (1st SM) : 29 CC + 9 NC
- Bricks extractions + CS scanning for prediction confirmation + Scanning





Event 178969961 : ν_μCC interaction



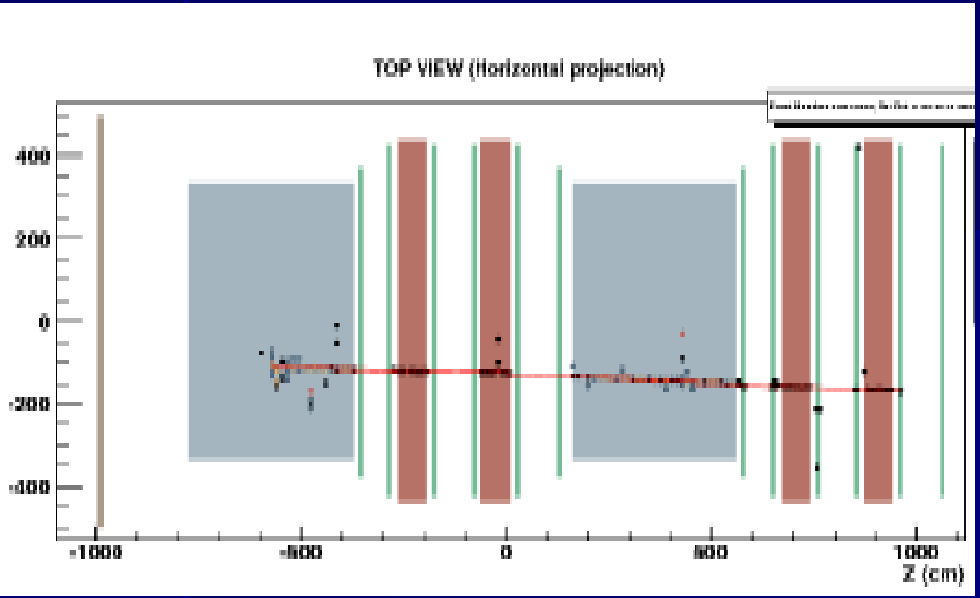


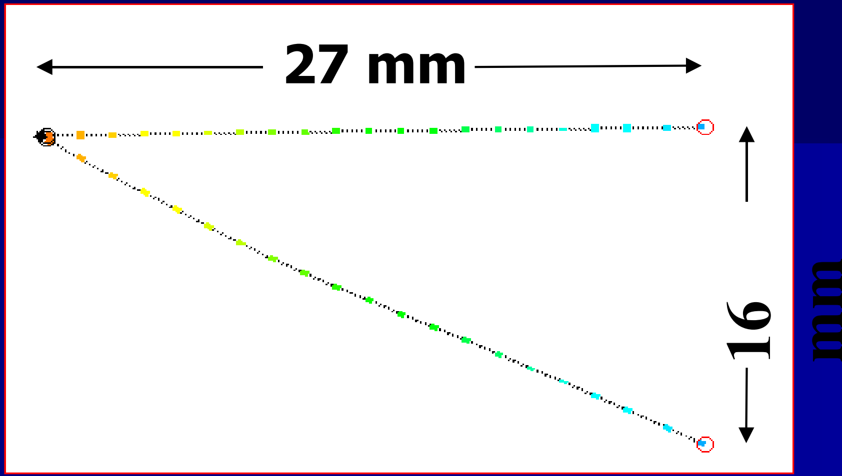
5 prongs associated to the neutrino interaction

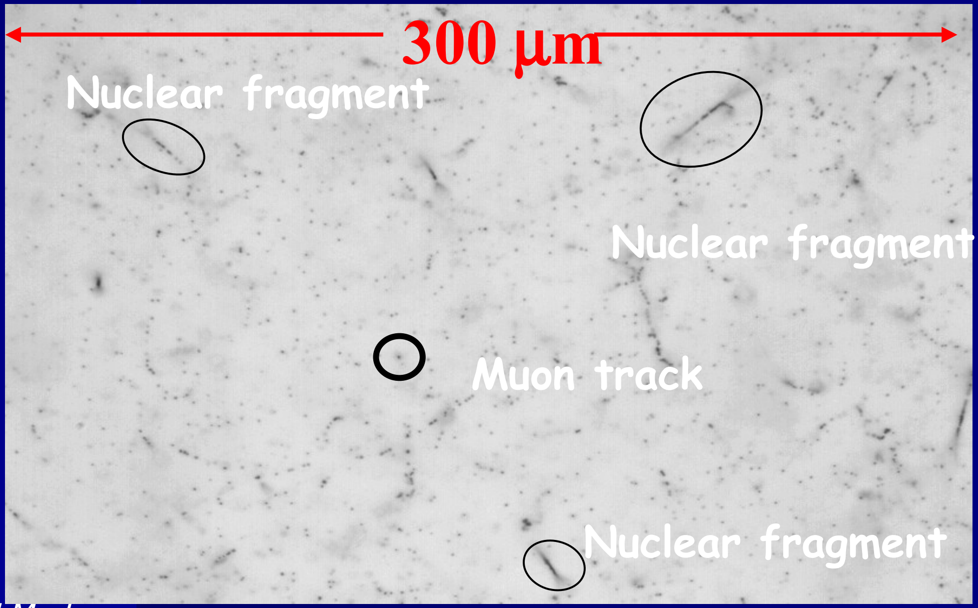
<IP> = 9 μm

Electromagnetic shower pointing to the vertex (γ conversion)

Event 179673325 : QE-like topology

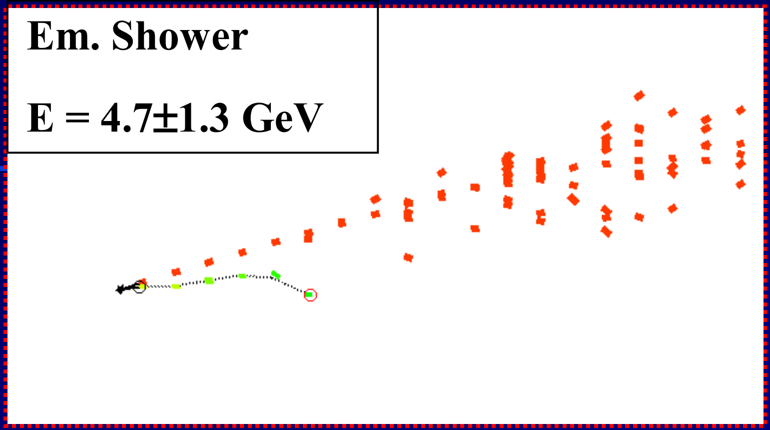


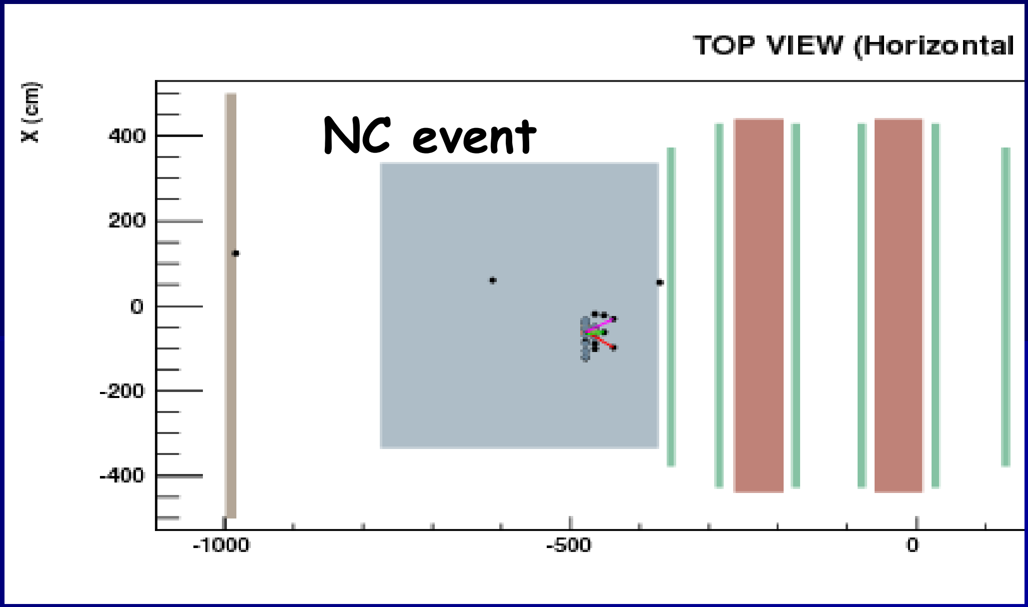


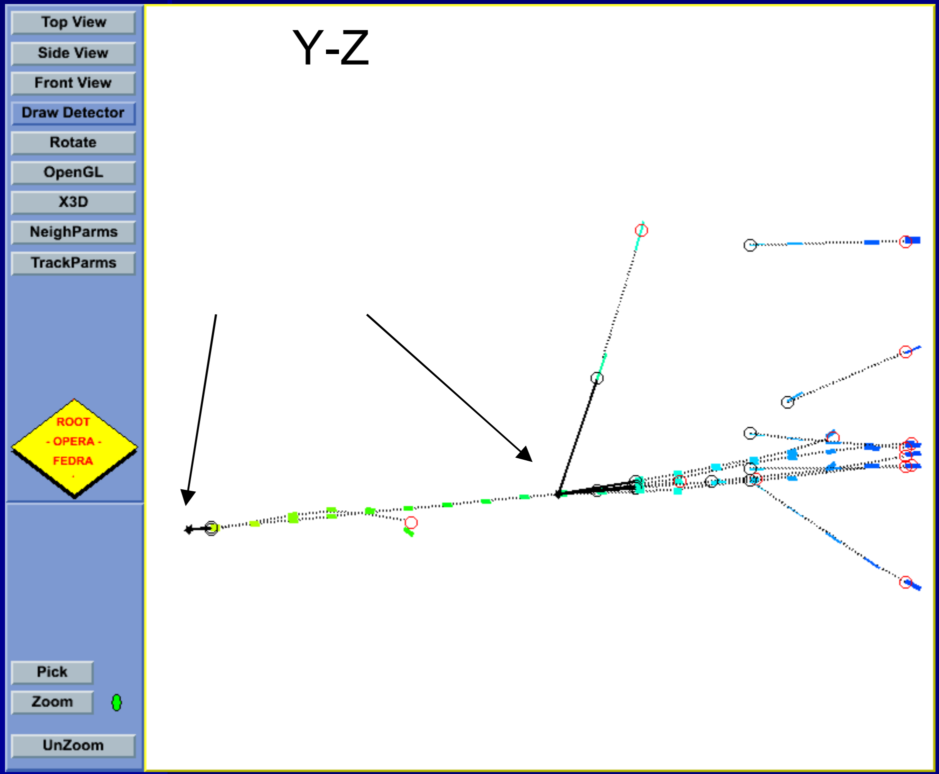


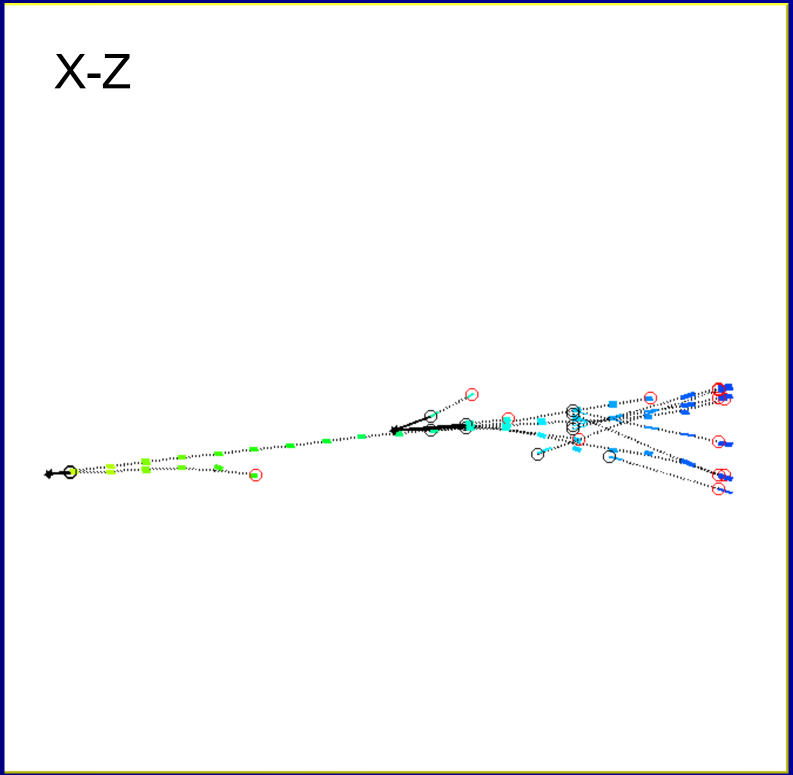
The visual inspection allow the observation of nuclear fragments and the classification of the event as DIS

Event 183545620

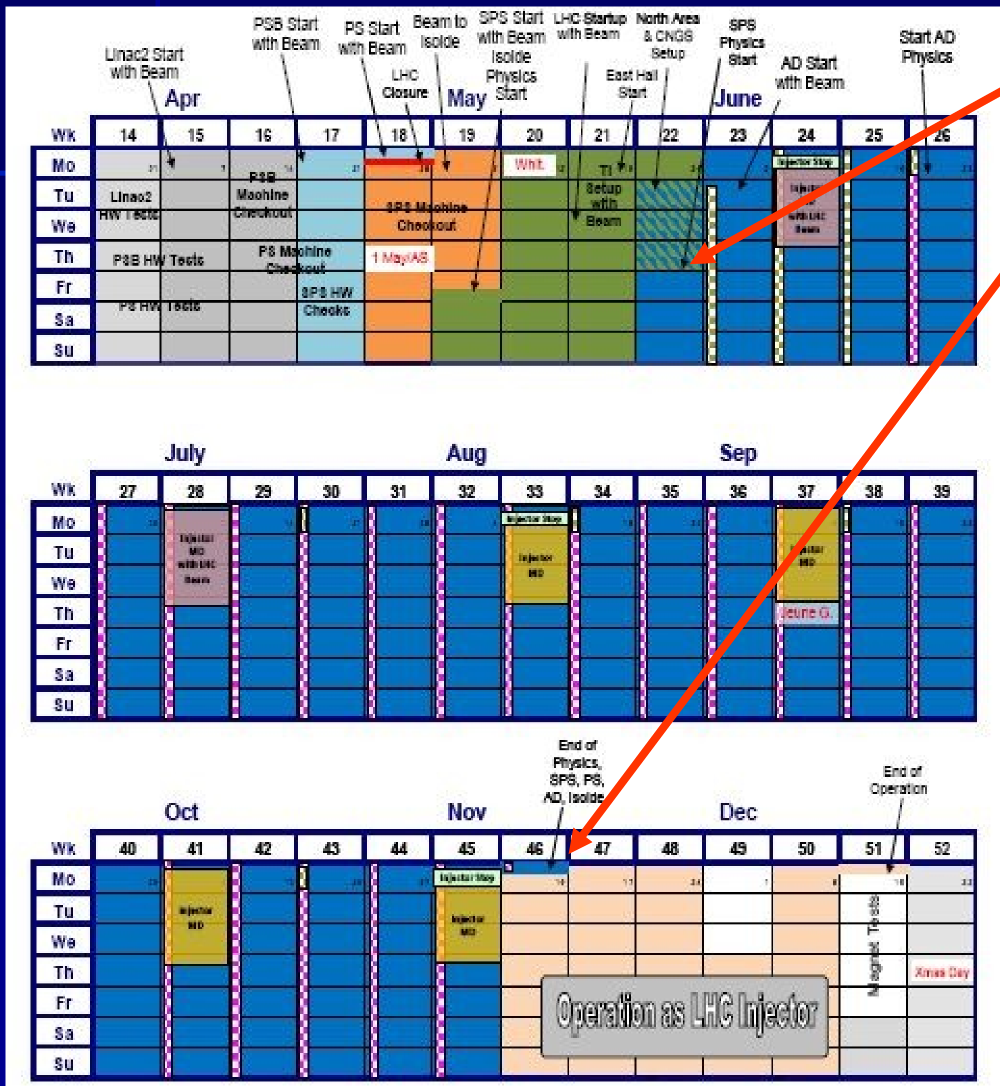








Perspectives on the CNGS : '08 physics run



Start: May 29th
End : Nov. 10th
147 days for the CNGS (200)

$3*10^{19}$ p.o.t ($4.5*10^{19}$)

Total number of interactions	3470
ν_μCC events	2610
ν_μNC events	780
$\nu_e/\bar{\nu}_e$ events	23
Charm decay	110
Tau candidate (@2.5 10^{-3} eV^2)	1.3

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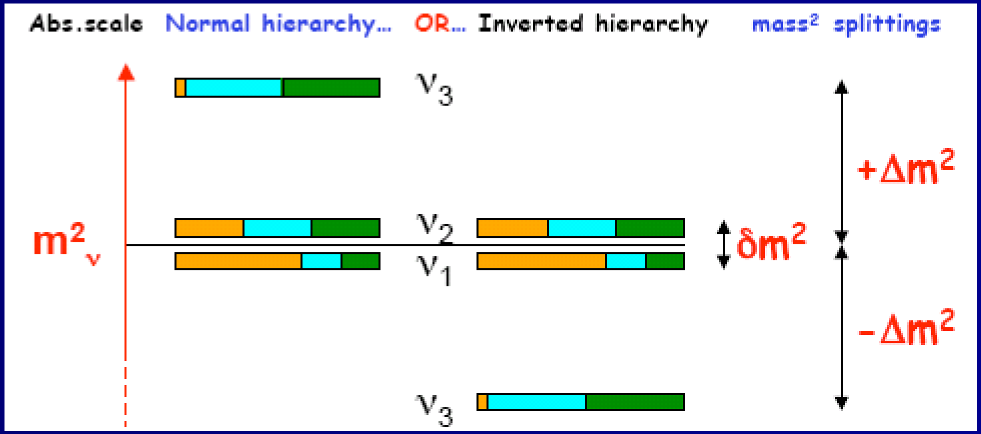
3. Vers T2K et au-delà

Future (2010–2020): θ_{13}, CP violation, sgn(Δm^2)

- Proof for ν_τ appearance in the atmospheric sector (OPERA)
- Precise measurement of Δm^2_{23} and θ_{23} → is θ_{23} exactly $\pi/4$? (MINOS, OPERA, T2K)
- Improve the accuracy on the solar parameters

- Measure θ_{13} (why θ_{12} and θ_{23} angles are large and θ_{13} seems very small or null ?)

•Determine if the mass hierarchy the same as for charged leptons (sign of Δm^2_{23}) throug MSW matter effects



•Absolute mass values (cosmology, double beta)

•Show CP violating effects (measure the phase δ in the mixing matrix)

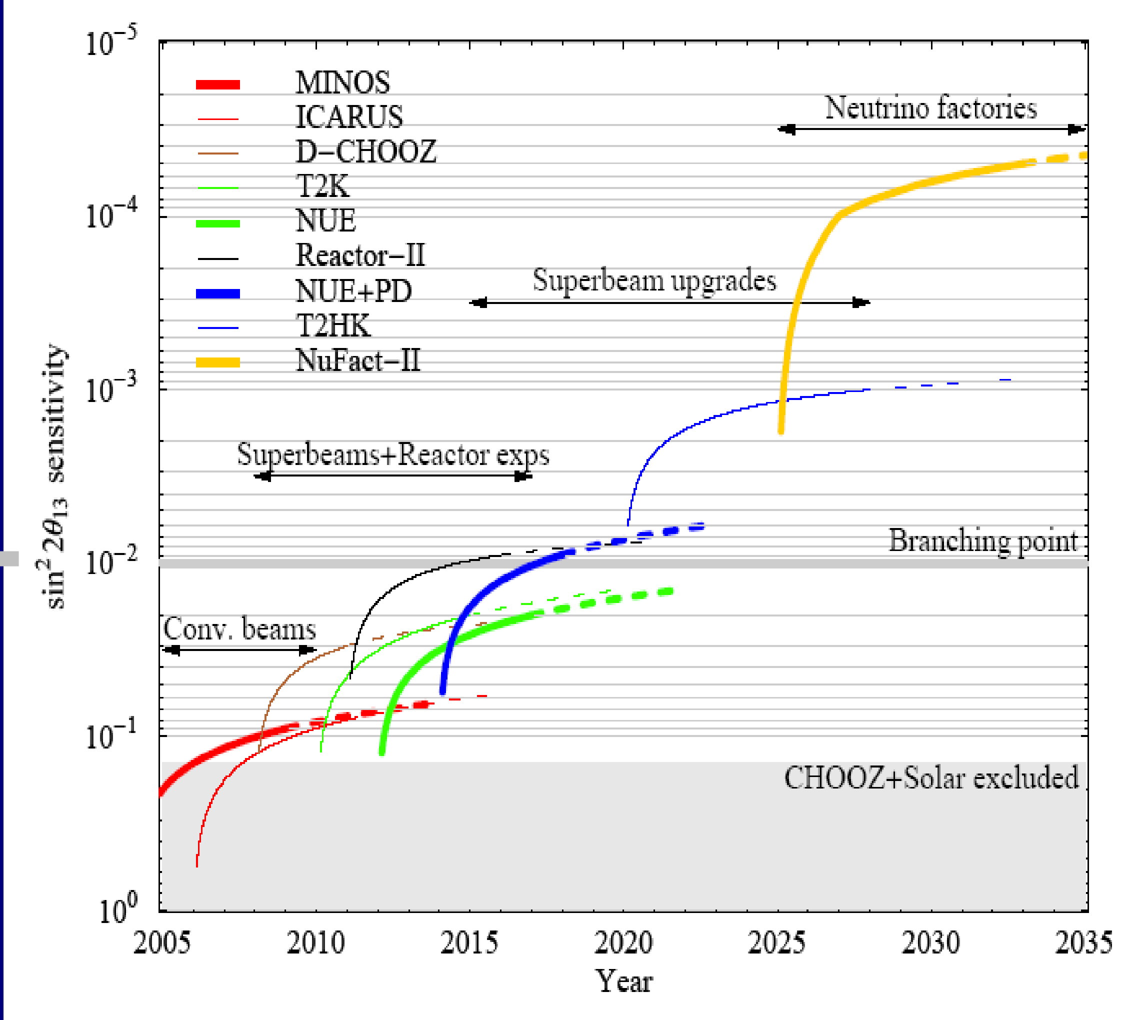
Future (2010–2020): branching point

$\sin^2 2\theta_{13} > 0.01$

- Conventional super ν_μ beam works
- Known beam technology
- Background highly nontrivial
- ν_ε beam contamination not negligible but tolerable
- Upgraded sensitivity with scenarios at the second maximum (T2KK) or high energy beam (Nova)

$\sin^2 2\theta_{13} < 0.01$

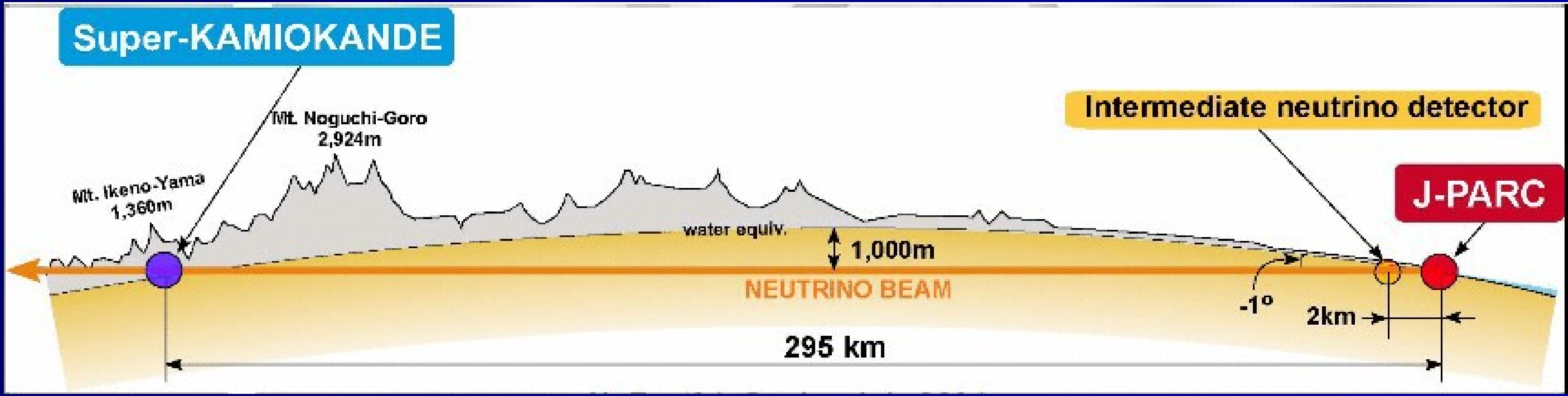
- **beta beam or**
- **neutrino factory required**



Branching point : things change at $\sin^2 2\theta_{13}$~0.01 : the priority is to set the scale of the effect ⇒ T2K

The 1st Super-Beam: T2K from Tokai to SK

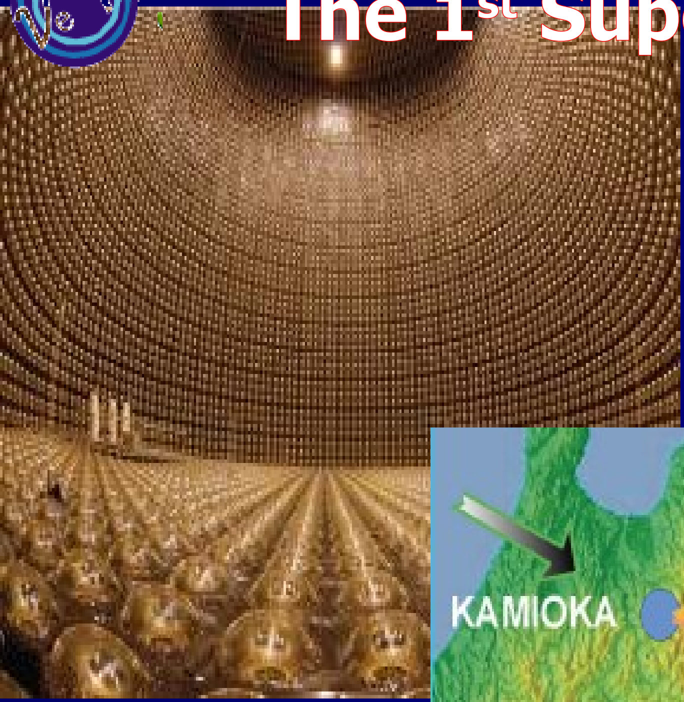
- Low energy neutrino beam (~0.6 GeV) from Tokai (JPARC multipurpose proton accelerator) to Super-Kamiokande by 2009.
- 0.75 MW from a 50 GeV proton synchrotron (neutrino beam two orders of magnitude more intense than in K2K)
- foreseen upgrades for CP violation search: 4 MW power and 1000 kton Hyper-K (2020?)

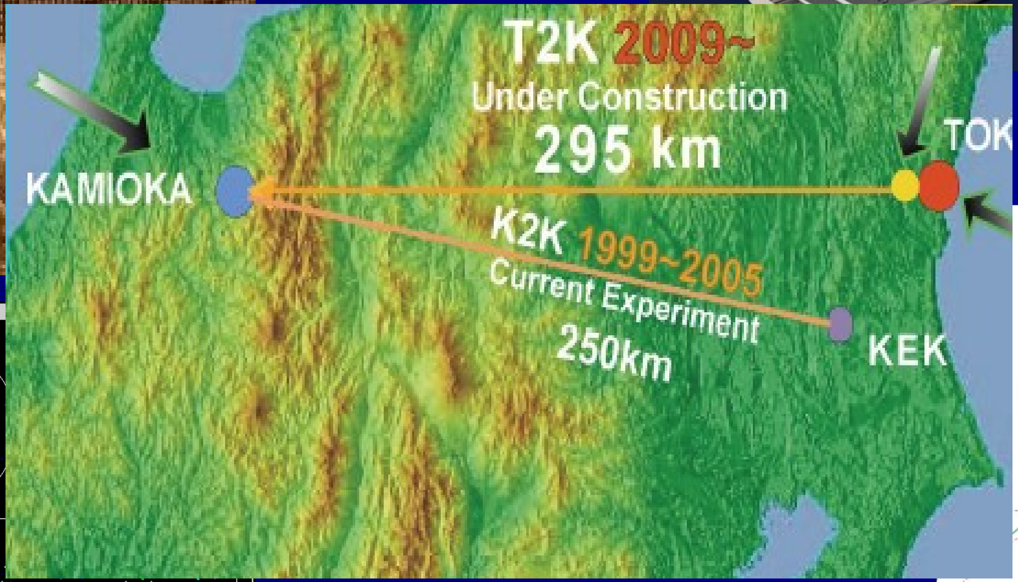


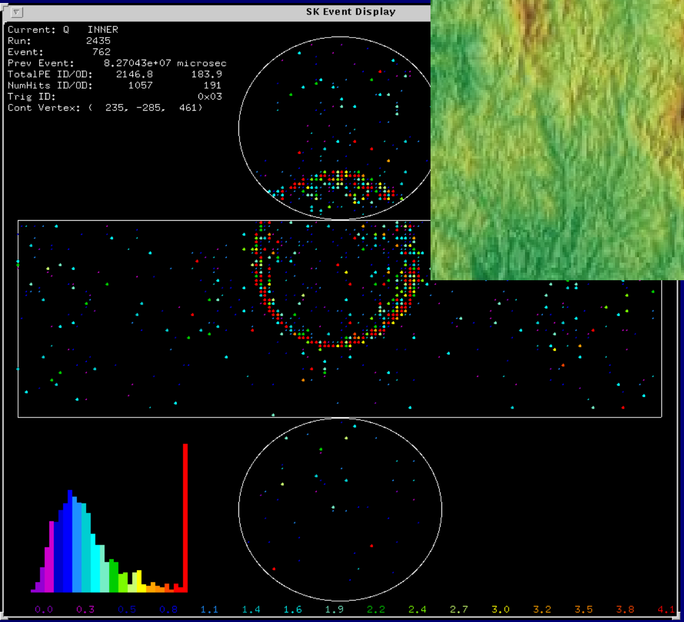
Physics objectives ...

- T2K will be the 1st 'next generation' physics programme
- Goal: precision measurements on the oscillation parameters
- Goal: discovery of (still) unknown phenomena (CP violation, neutrino intrinsic nature, neutrino mass hierarchy etc)

The 1st Super-Beam: T2K from Tokai to SK

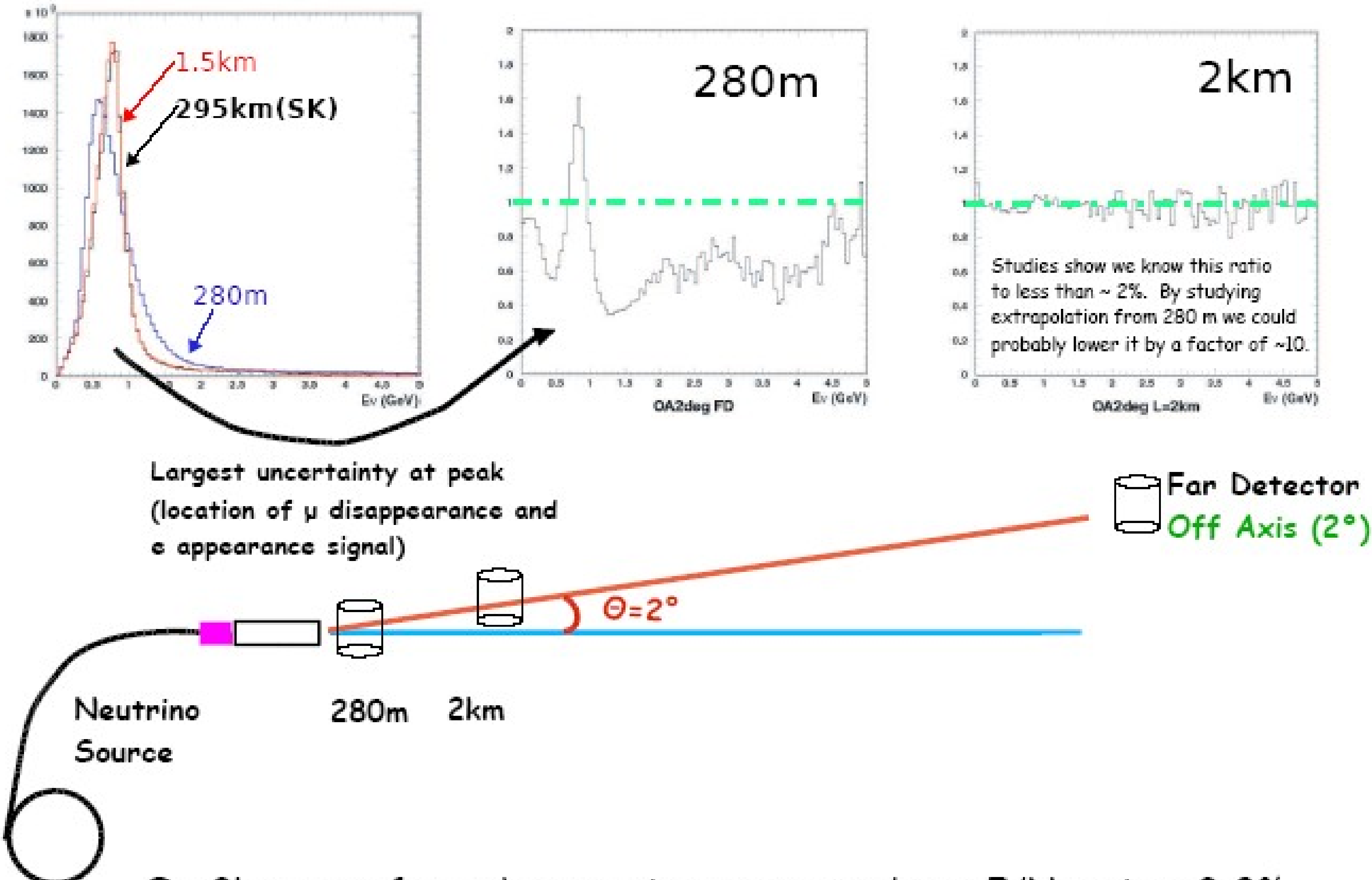






+LBL detector in Korea to measure at the second oscillation maximum ?

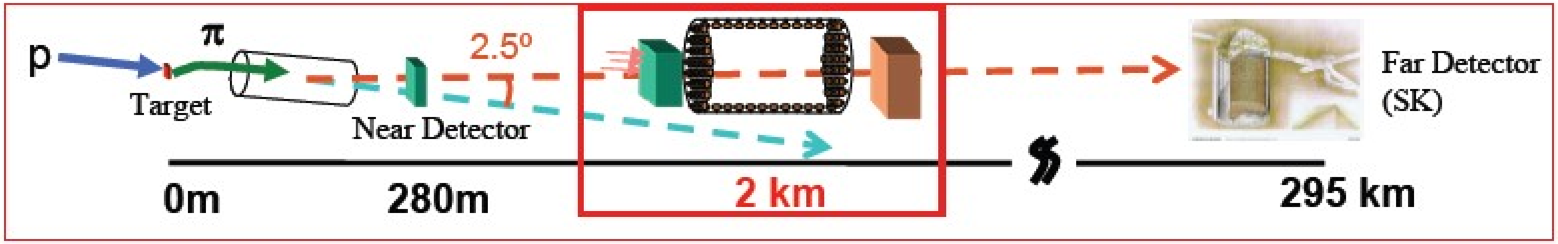
T2K : off-axis technology, near detector(s)



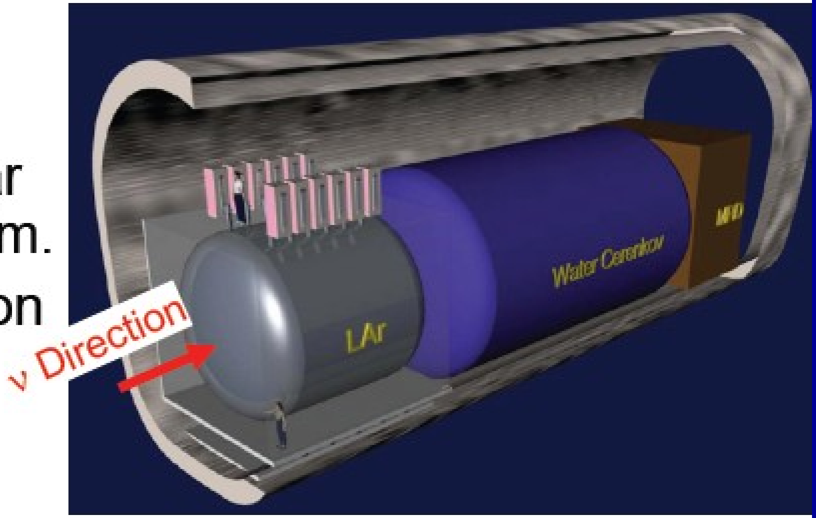
@ ~2km away from the neutrino source we know F/N ratio ~ 2-3%

LAr technology in T2K

Intermediate detector @ 2km

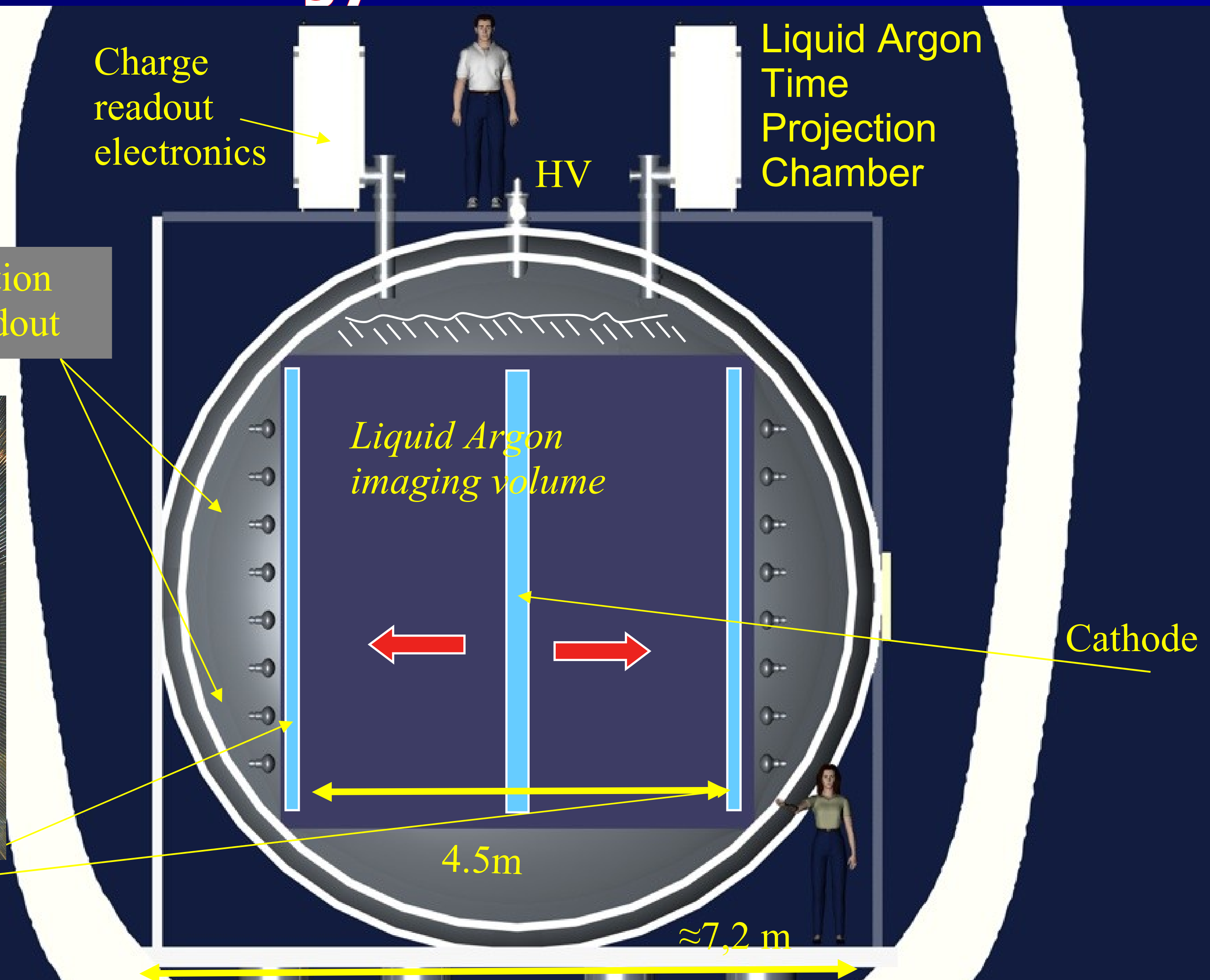


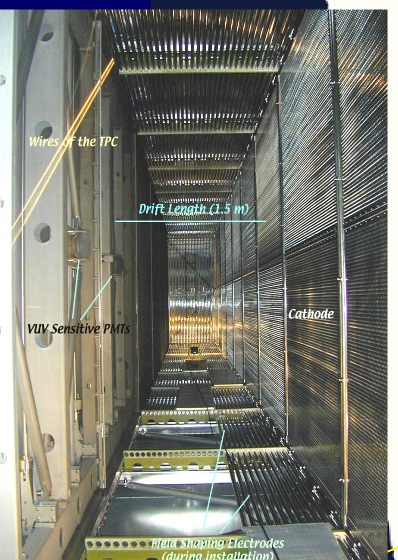
- E_ν spectrum @ 2km
  ~ E_ν spectrum @ SK w/o oscillation
  → Uncertainties from Far/Near ratio is smaller than ND@280m.
- Possible Detector configuration
  - Liquid Ar TPC
  - Water Cherenkov
    - Same target & ν reconstruction algorithm as SK
  - Muon Range Detector



Facilities for 2km is to be requested in Japan after the commissioning of J-PARC facilities.

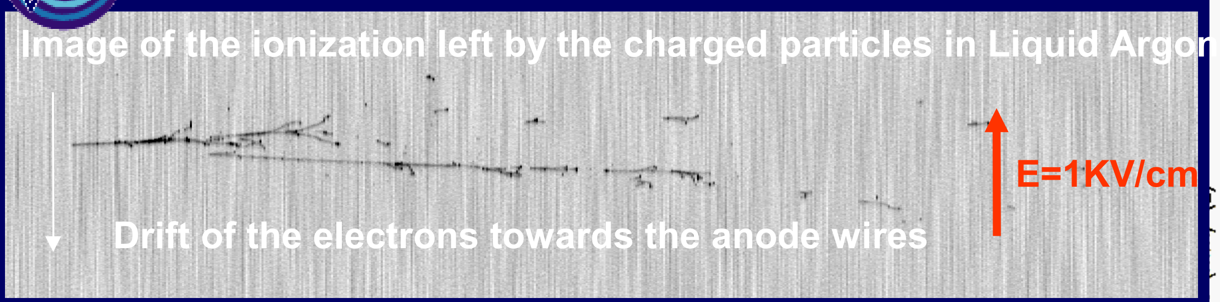
LAr technology in T2K

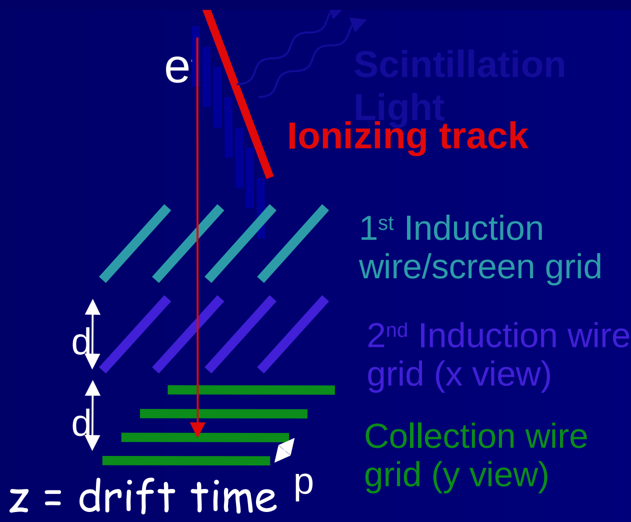




Liquid Argon … same time the target and the sensitive me… secondary particles produ… neutrino interactions

LAr technology in T2K

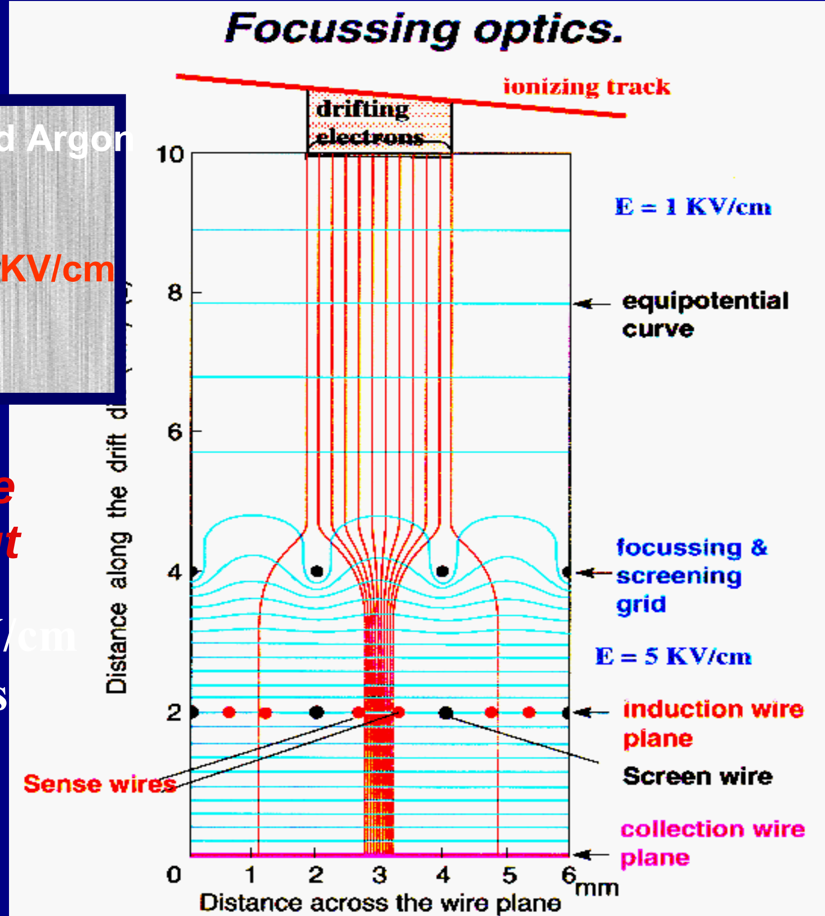




Non-destructive multiple readout

Drift Field: 1 kV/cm

Drift time ~ 3 ms



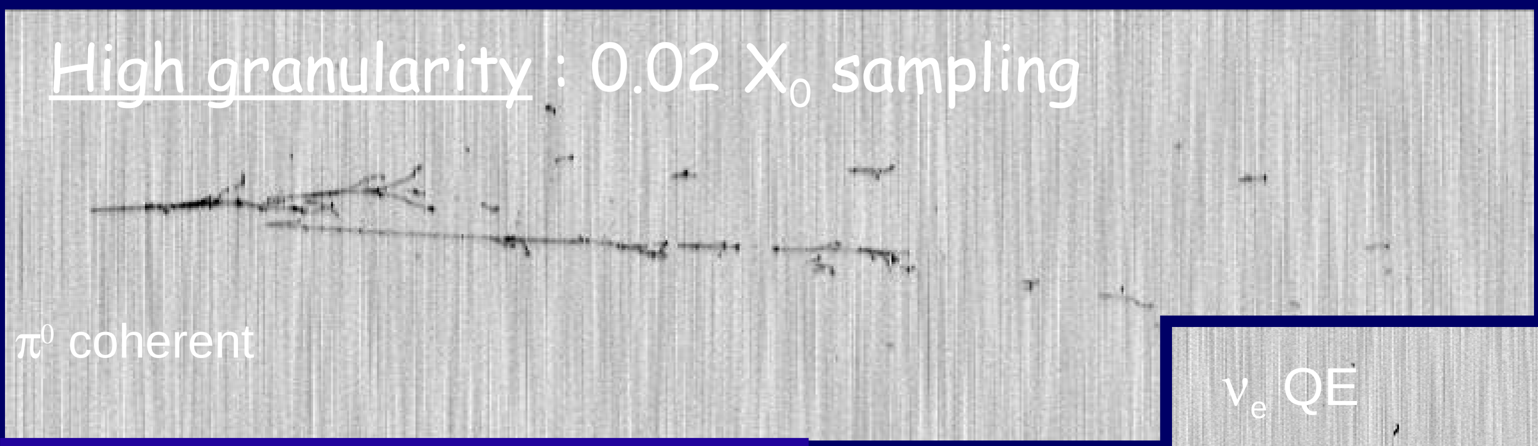
- Detection of primary ionization in LArgon: 1 m.i.p ~ 20000 electrons on 3 mm
- High resolution calorimetric measurement of e.m. and hadronic showers

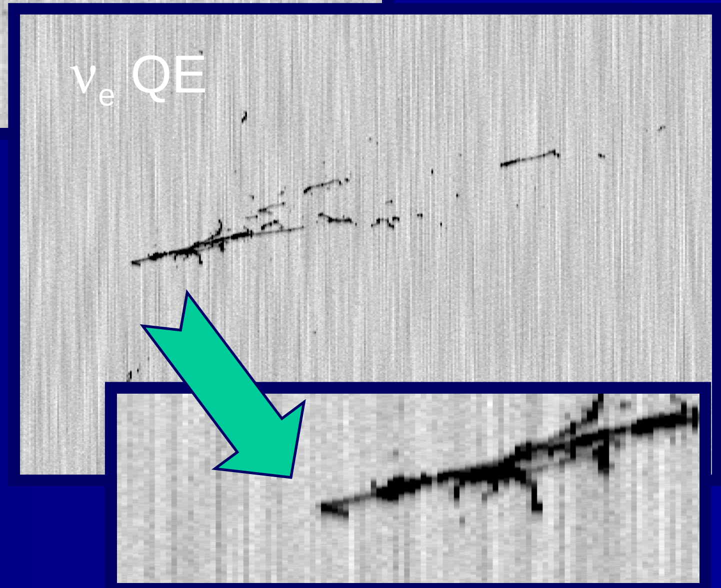
- PMs detecting UV scintillation ligth in Argon used to provide the t=0 signal of the event to measure the drift space
- Each wire is sampled with a 2.5 MHz flash ADC to measure the charge distribution along the drift (time)

→ 3D event reconstruction with ~ 1 mm space resolution

LAr technology in T2K

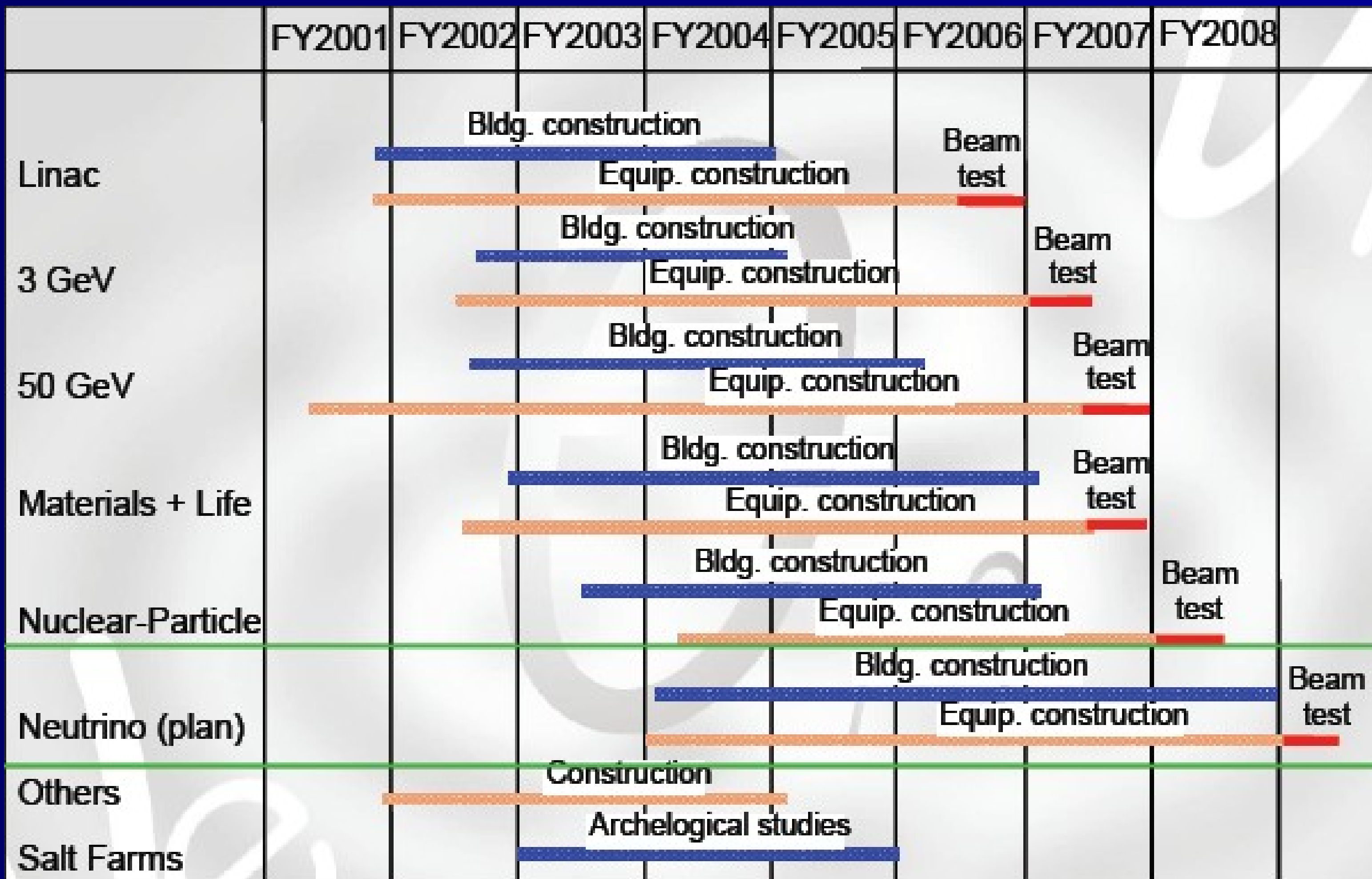
Tracking + Particle identification + Calorimetry
100 Ton mass easily feasible





ν_μ QE	ν_μ nQE	ν_eQE
120000/yr	70000/yr	3900/yr

Schedule


FY2001
FY2002
FY2003
FY2004
FY2005
FY2006
FY2007
FY2008
Linac
Bldg. construction
Equip. construction
Beam test
3 GeV
Bldg. construction
Equip. construction
Beam test
50 GeV
Bldg. construction
Equip. construction
Beam test
Materials + Life
Bldg. construction
Equip. construction
Beam test
Nuclear-Particle
Bldg. construction
Equip. construction
Beam test
Neutrino (plan)
Bldg. construction
Equip. construction
Beam test
Others
Construction
Salt Farms
Archelogical studies

Conclusions

The OPERA experiment has completed almost entirely the construction of all electronic detectors and faces the last (large) effort of brick production and insertion.

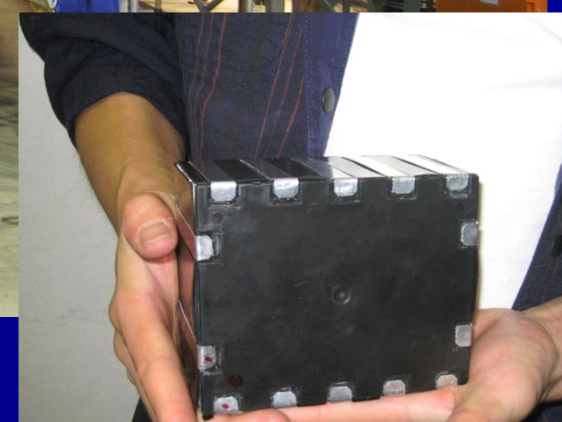
The data collection from electronic detectors and from the scanning systems have been validated.

Ready for the full oscillation physics in '08.

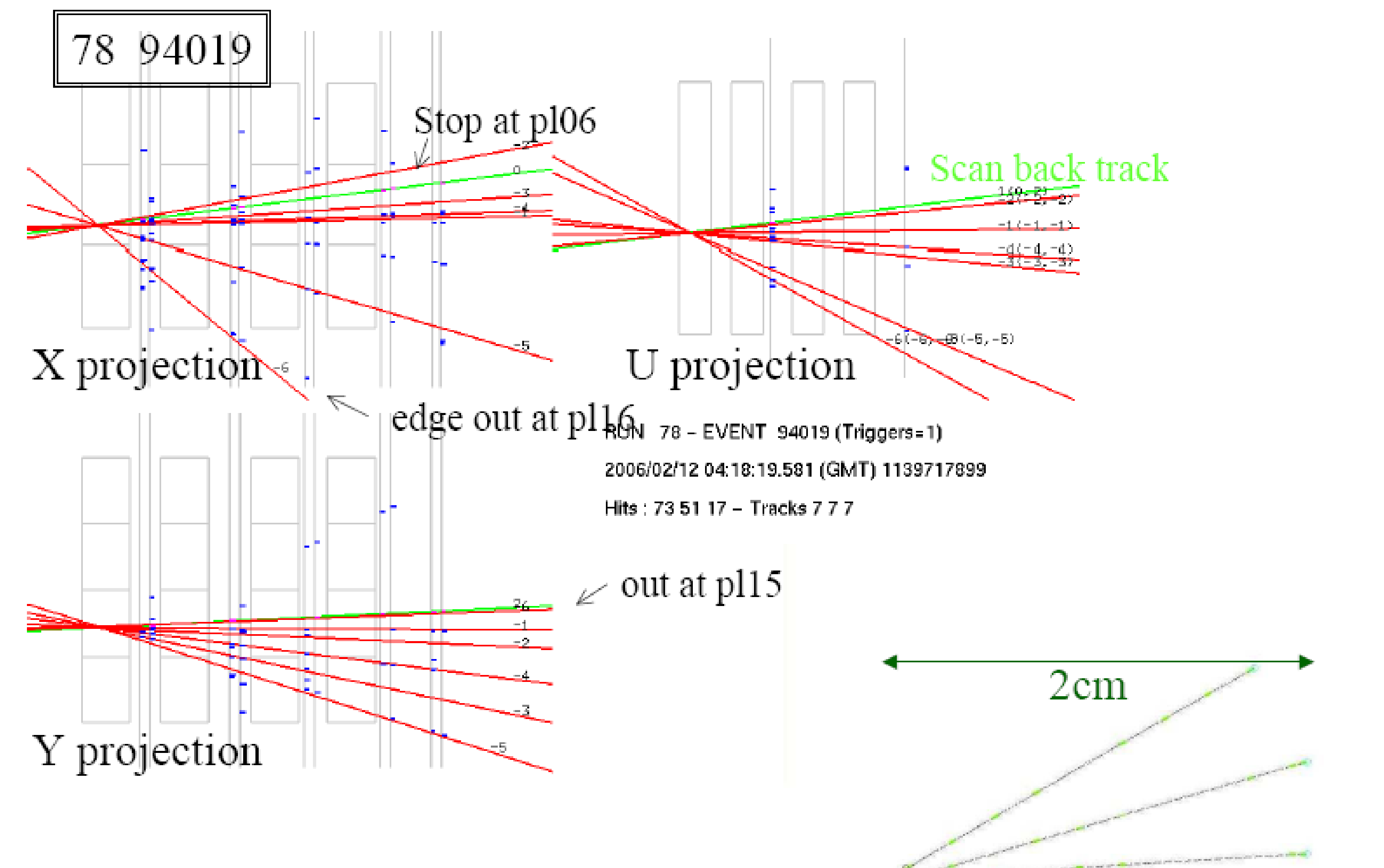
Future neutrino physics will be oriented after the T2K campaigns (phase-I/-II). Looking forward for the ultimate facilities (neutrino factories)

The end

Scanning rehearsal with bricks in NuMI beam : PEANUT



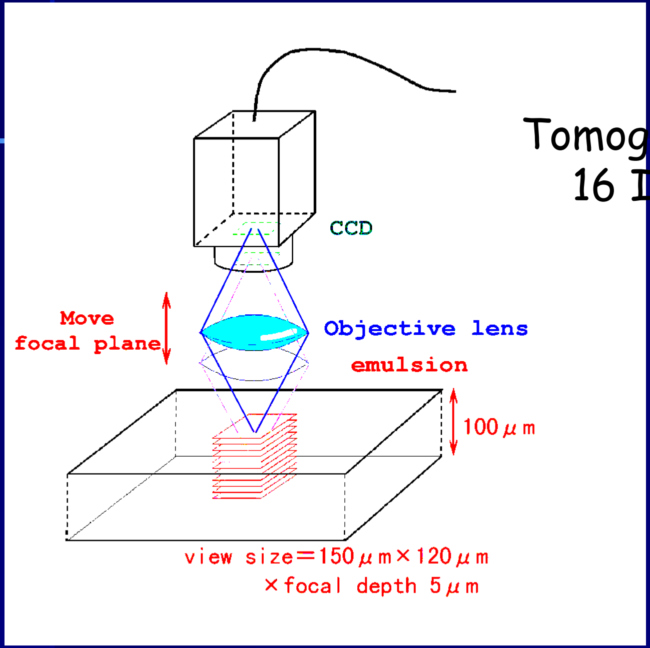
Scanning rehearsal with bricks in NuMI beam : PEANUT



neutrino interactions reconstructed by the SFT and in the emulsions

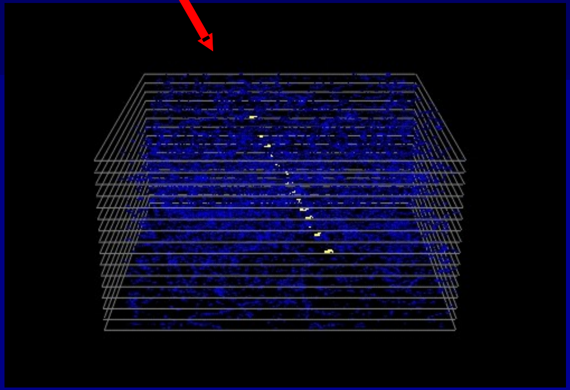
Scanning in Japan

Track Recognition by Track Selector

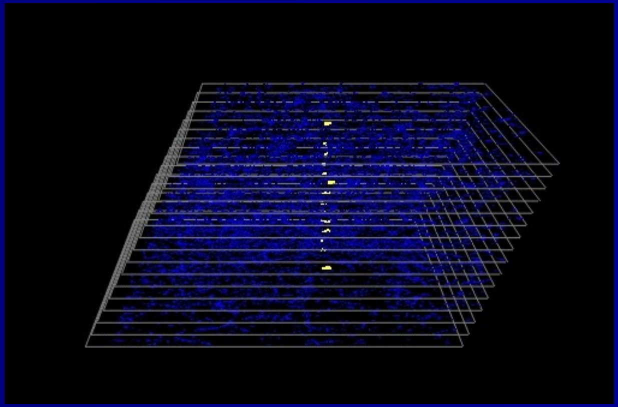


Tomographic
16 Images

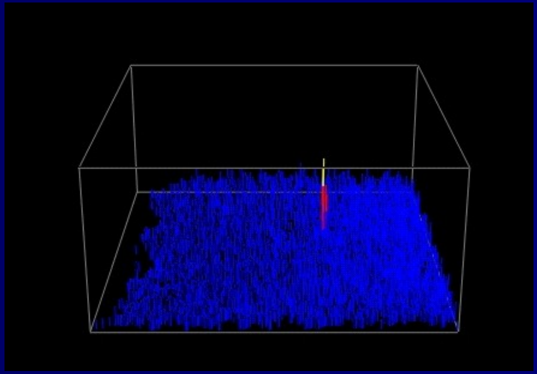
Penetrating Track



Give counter shift



Sum and
Discriminate



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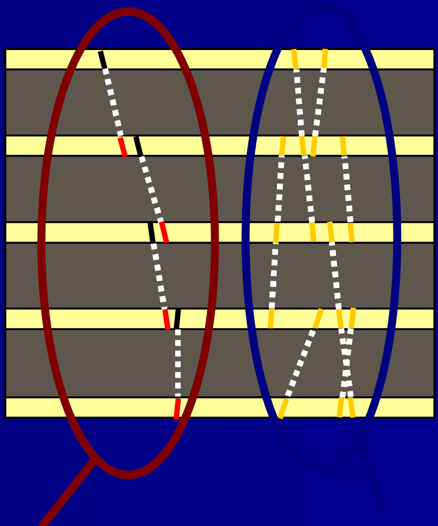
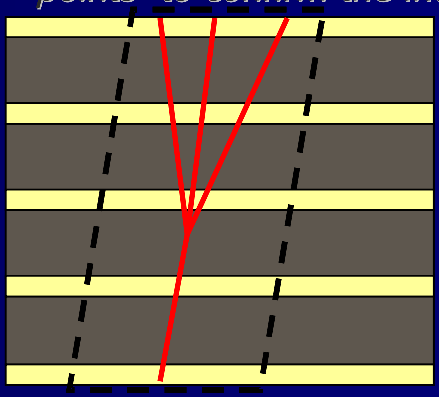
Vertex finding

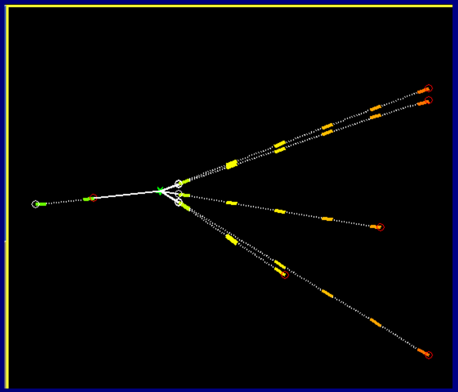
Scan-back strategy tested on 8 GeV/c pions to produce interactions

- *Scanback: measure tracks on downstream plate and follow back to interaction point*
  (realistic test of performance in OPERA)

- *TotalScan around track disappearance points to confirm the interaction*







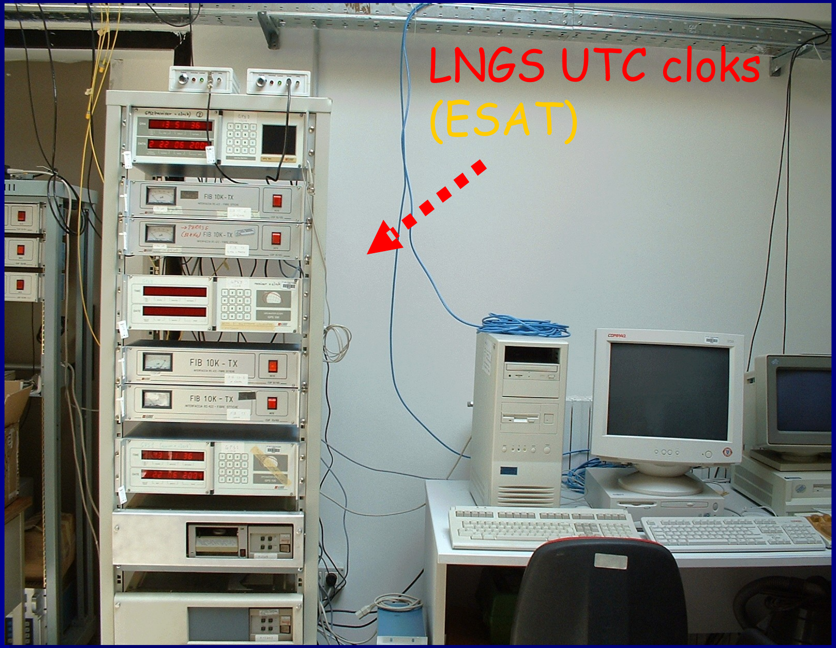
J.Marteau

CERN-LNGS UTC clocks intercalibration

For the neutrino spill syncronization both CERN and LNGS have a double unit (including a spare) UTC clock system, but from different manifacturers.
The CERN system was calibrated by the Swiss metrology institute METAS.

CERN and LNGS systems have comparable performance (<100 ns) and their single units are in both cases based on a GPS system + Rb clock.

One of the CERN UTC units was installed and running for one month in Gran Sasso in order to check for relative offsets and time stability of the two systems. Action was taken also to measure all the delays in the LNGS time distribution chain



CERN Symmetricom XL-DC unit installed at LNGS

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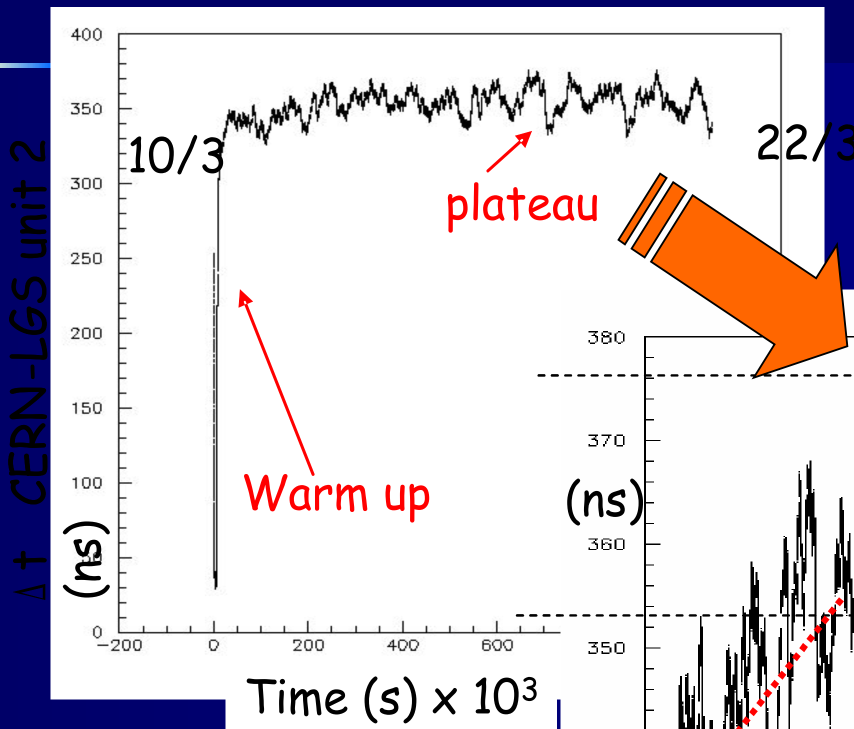
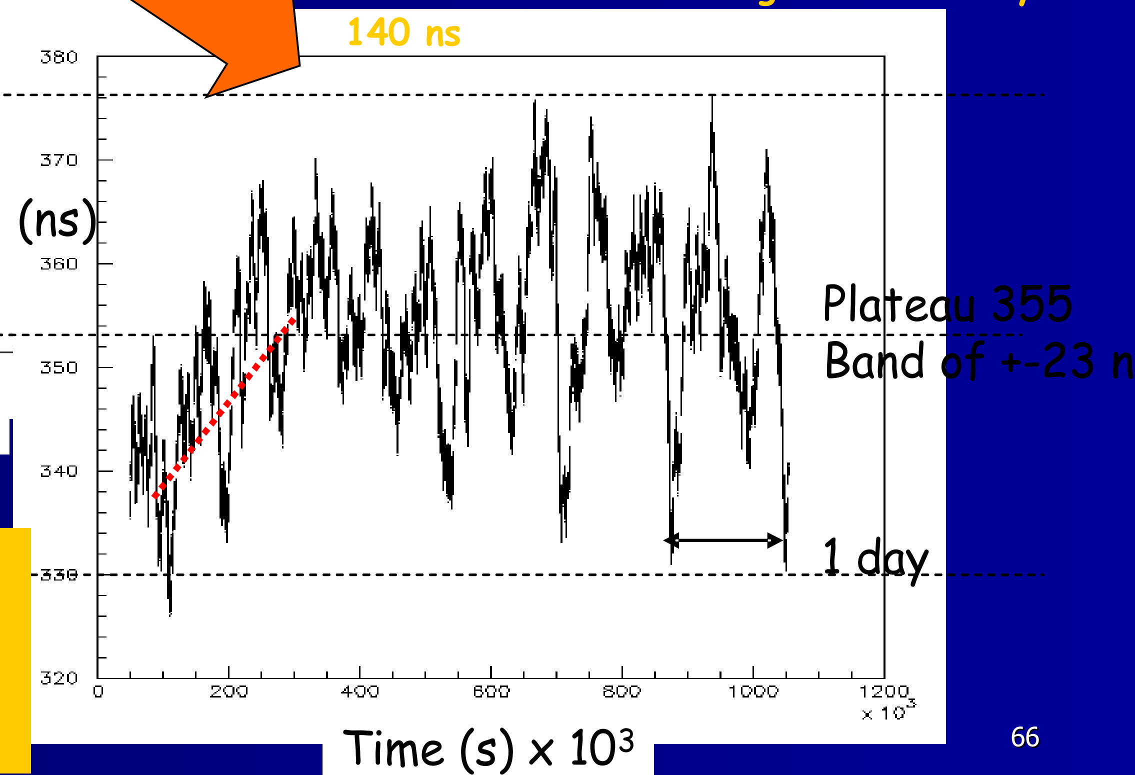
CERN-LNGS UTC clocks intercalibration

Time difference measured during 12 days with a time interval counter (300 ps accuracy)



It was measured an offset of about 350 ns due to the antenna cable delays of the LNGS units and mismatch in the geodesic reference system.
In addition it was measured that the two LNGS units differ among themselves by 140 ns



Correcting for the offsets the CERN and LNGS UTC systems were able to track each other within 20 ns

J.Marteau