NOW 2008
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Recent results from the OPERA experiment

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on behalf of the OPERA collaboration


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OPERA is an international collaboration made of ~ 200 physicists from 36 institutions and 13 countries.
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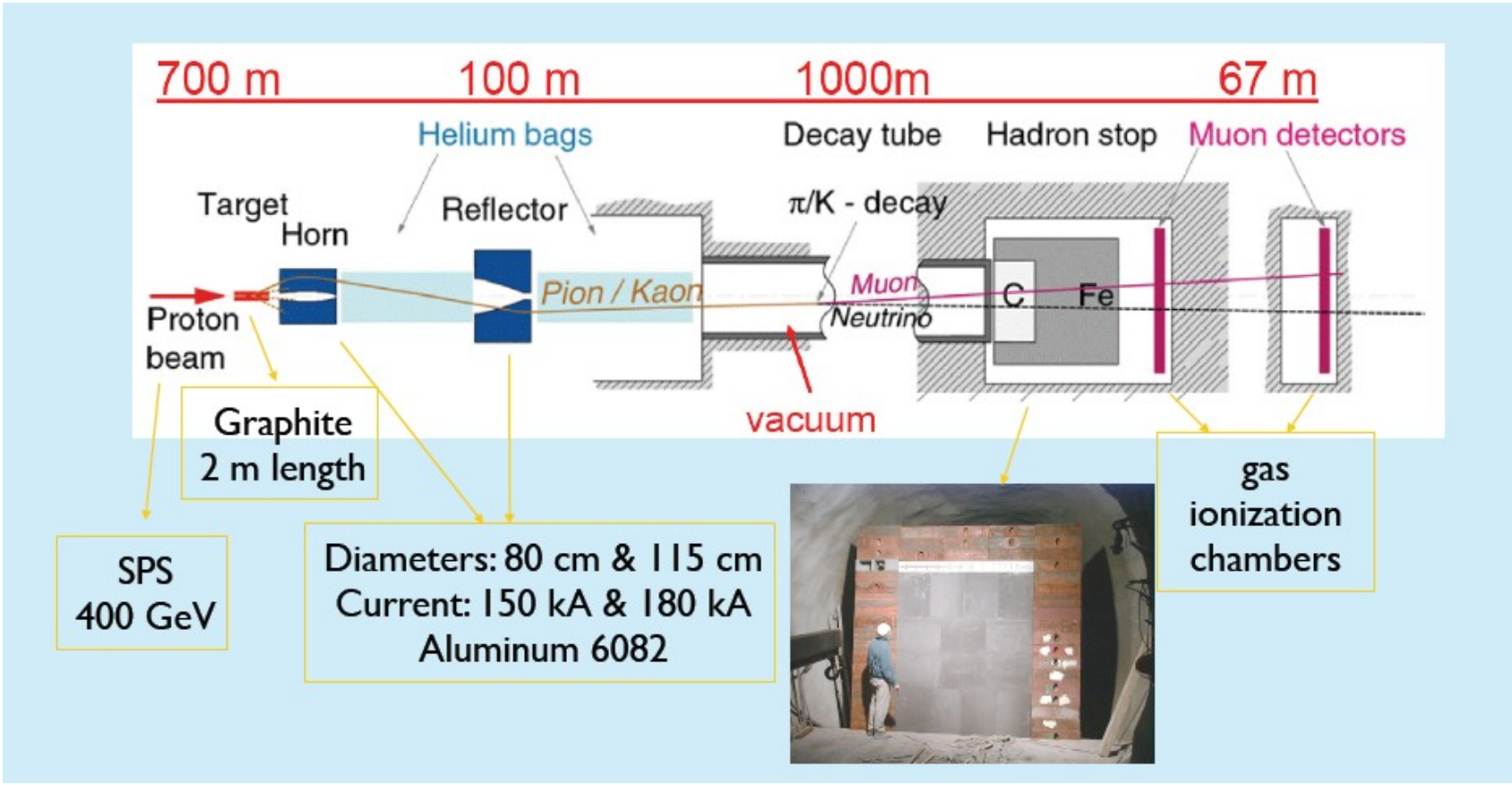
The OPERA experiment

- OPERA (Oscillation Project with Emulsion tRacking Apparatus) is a long baseline neutrino oscillation experiment
- The goal of the experiment is to directly measure for the first time neutrino oscillation in an appearance mode
- Using an almost pure ν_μ beam, the $\nu_\mu \rightarrow \nu_\tau$ transition is detected by observing the τ lepton decay, induced after a neutrino-lead CC interaction
- τ lepton decay is observed by means of Emulsion Cloud Chambers
- The detector is located on the CNGS (CERN to Gran Sasso) beam line at a distance from the neutrino source of 730 km

The CNGS beam



- The CNGS is a conventional neutrino beam: 400 GeV/c protons from the CERN SPS hit a graphite target producing pions and kaons which decay in flight and produce neutrinos

The CNGS beam

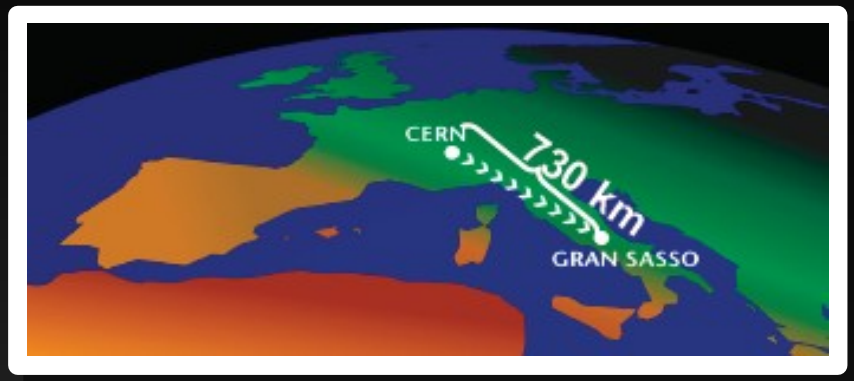
- The beam is optimized for ν_τ appearance in the atmospheric oscillation region. The present best fit is now:

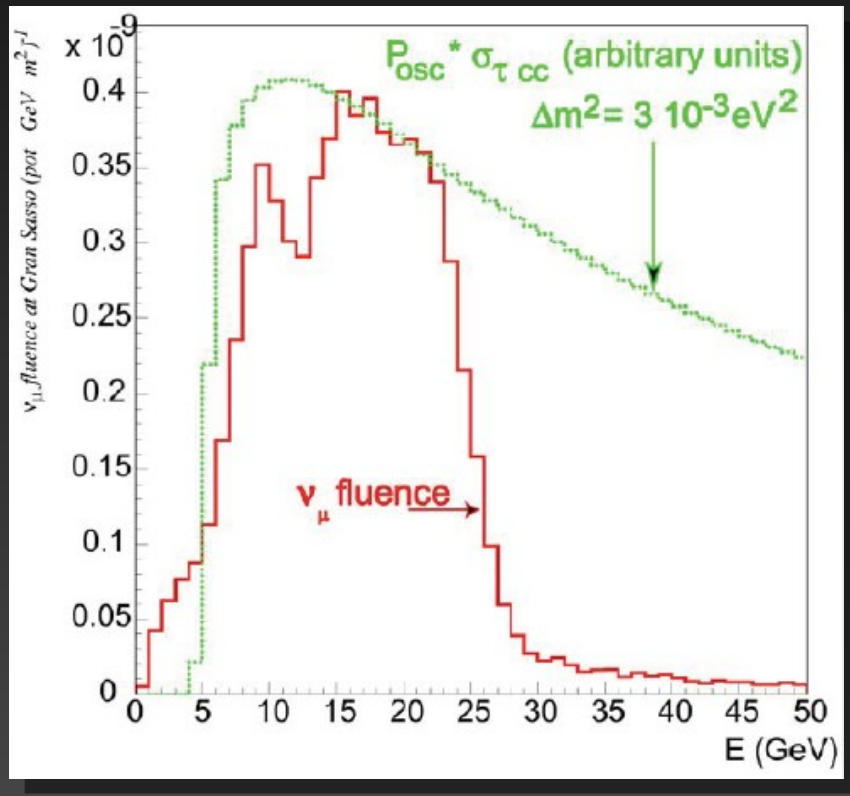
  $\Delta m_{23}^2 = (2.43 \pm 0.13) \times 10^{-3}\ eV^2$

  $\sin^2 2\theta_{23} = 1.0$

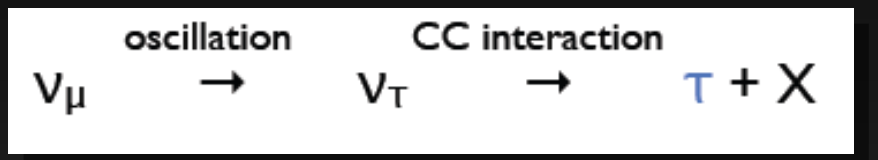
- Although the maximum of oscillation probability at 730 km is at about 1.5 GeV, we need to take into account the ν_τ CC cross section and the production threshold of 3.5 GeV

$<E_{\nu\mu}>$	17 GeV
$(\nu_e + \overline{\nu}_e)/\nu_\mu$	0.87%
$\overline{\nu}_\mu/\nu_\mu$	2.1%
ν_τ prompt	negligible
p.o.t./year	4.5×10^{19}
ν_μ CC/kton/year	~2900
ν_τ CC/kton/year	~16

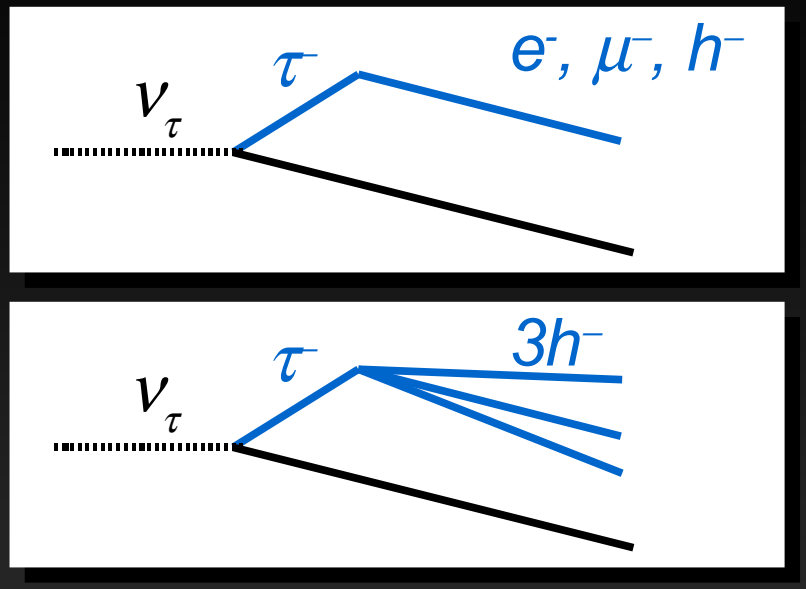




Detection principle



τ decay
(~10^{-13} s ; cτ~87 μm)



$\tau \rightarrow e$ (17.8%)
$\tau \rightarrow \mu$ (17.4%)
$\tau \rightarrow h$ (49.5%)

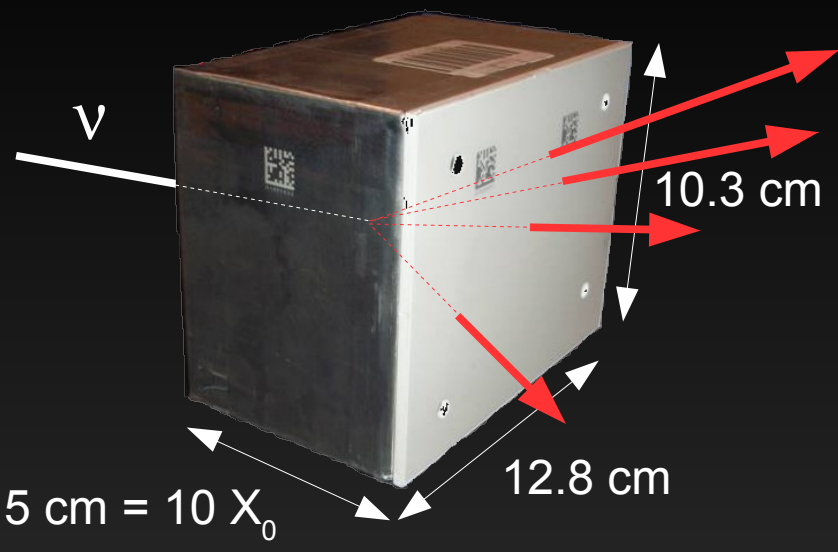
$\tau \rightarrow 3h$ (15.2%)

- The detection of the τ lepton requires an identification of a "kink" or "trident" topology
- The detector must fulfill the following requests:
  1. Large mass due to small CC cross section (lead target)
  2. Micrometric and milliradian resolution to observe the kink (photographic emulsions)
  3. Select neutrino interactions (electronic detectors)
  4. Identify muons and their charge to reduce charm background (electronic detectors)

An hybrid detector (emulsions + electronic detectors) like OPERA fulfills all these requirements

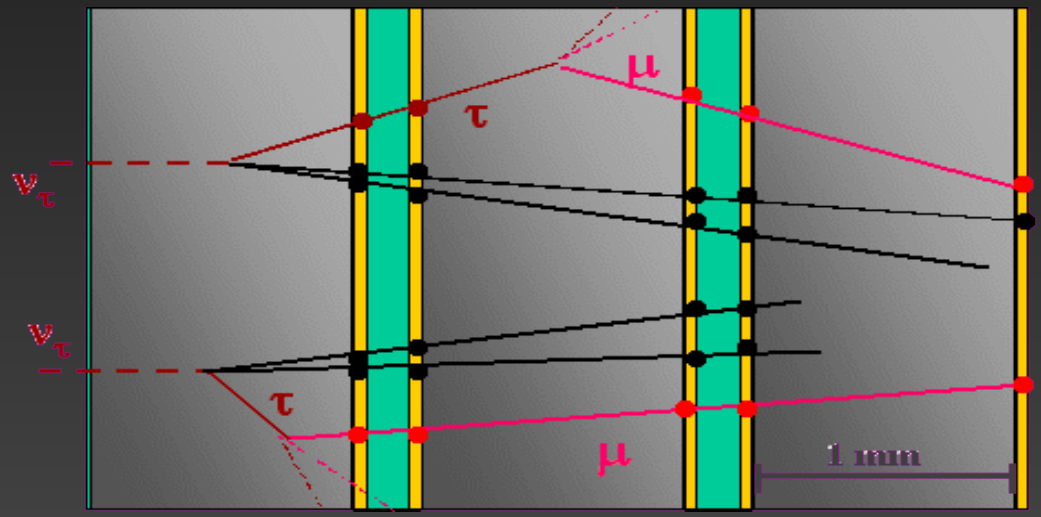
τ identification

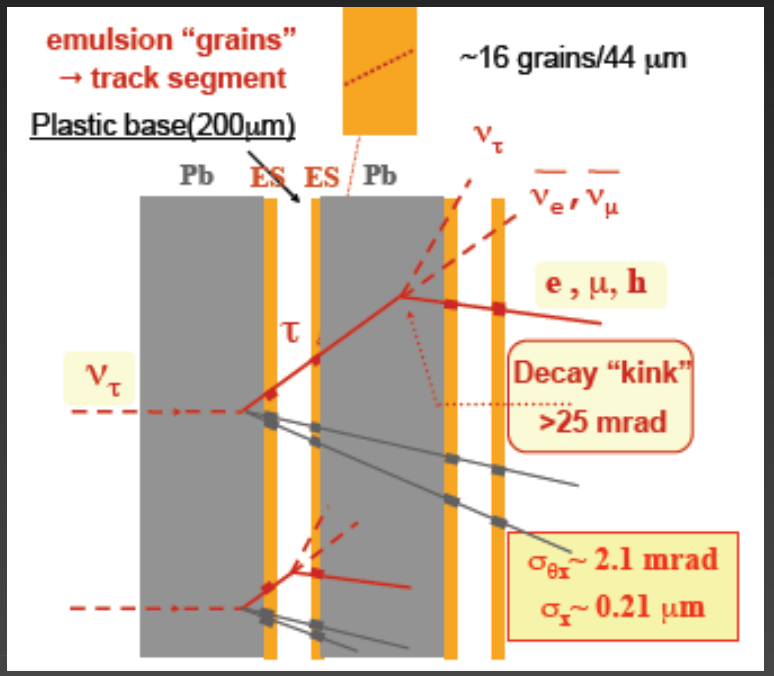
- The target is divided in about 152000 ECC's (Emulsion Cloud Chamber), so called "bricks". Each brick weights 8.3 kg
- One brick is made by a sandwich of:
  - 56 (1mm) Pb sheets
  - 57 (300μm) FUJI emulsion layers
  - 2 (300μm) changeable sheets



Long decay

Short decay





Expected signal and background

Full mixing after 5 years run at 4.5×10^{19} pot / year

Efficiency before τ identification: $\varepsilon_{trigger} \times \varepsilon_{brick} \times \varepsilon_{geom} \times \varepsilon_{vertex\ location}$

99% x 80% x 94% x 90%

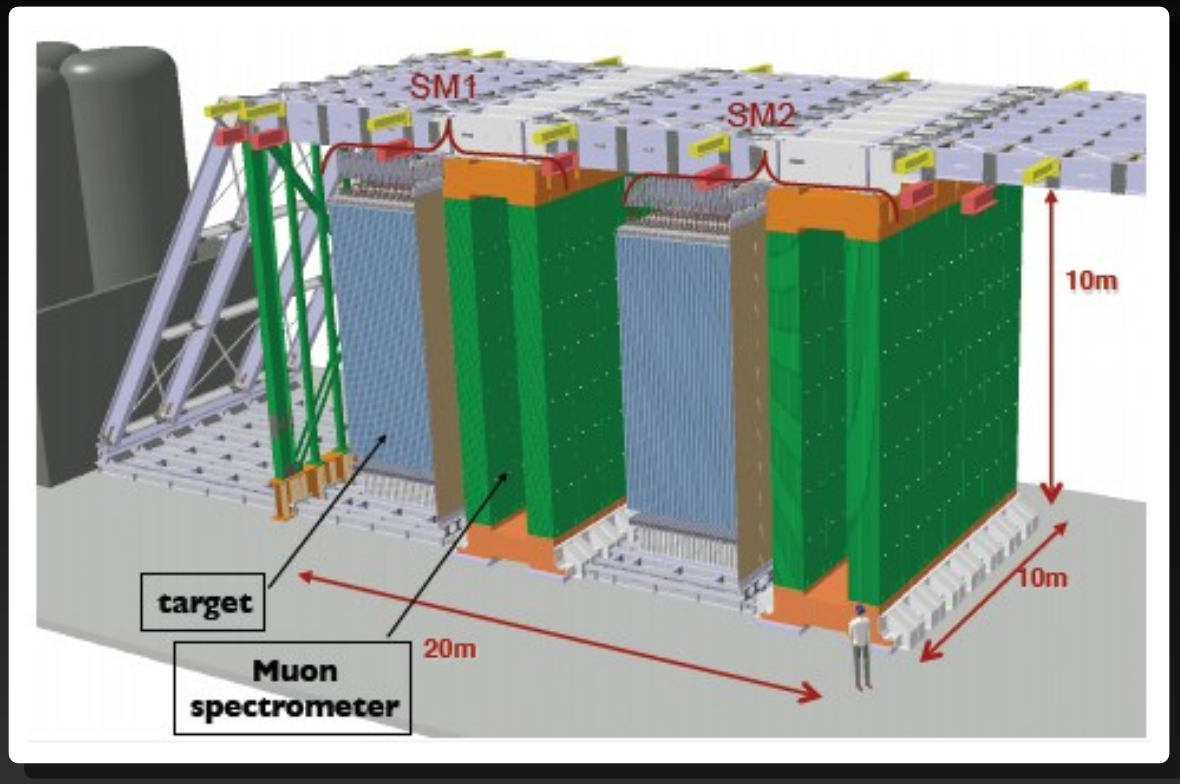
τ decay channels	ε(%)	BR(%)	Signal $\Delta m^2 = 2.5 \times 10^{-3}$ eV^2	Signal $\Delta m^2 = 3.0 \times 10^{-3}$ eV^2	Background
$\tau \rightarrow \mu$	17.5	17.7	2.9	4.2	0.17
$\tau \rightarrow e$	20.8	17.8	3.5	5.0	0.17
$\tau \rightarrow h$	5.8	49.5	3.1	4.4	0.24
$\tau \rightarrow 3h$	6.3	15	0.9	1.3	0.17
ALL	$\varepsilon \times BR = 10.6\%$		**10.4**	**14.9**	**0.75**

Background sources:

- **Charm production and decays**
- **Hadron re-interactions in lead**
- **Large-angle muon scattering in lead**

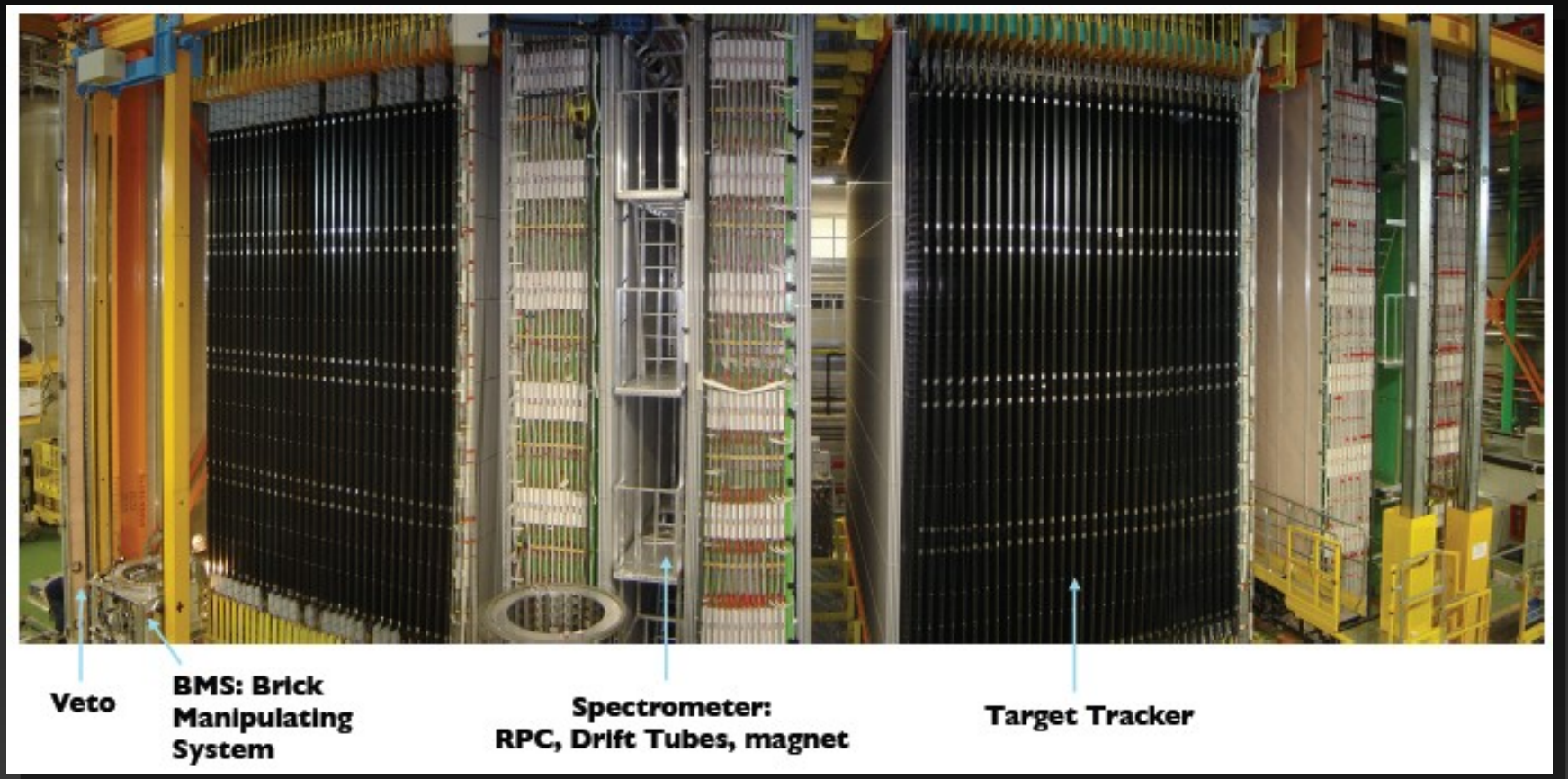
Occur if primary muon is not detected and possible wrong charge measurement of secondary muon. **Muon ID is very crucial issue for the experiment!**

The OPERA detector design



- The detector is located in the hall C at LNGS (Laboratori Nazionali Gran Sasso)
- The total target mass is 1.35 kton
- Each spectrometer consists of 22 RPC planes in magnetic field (1.5 T) and 6 Drift Tubes planes, to identify muons and measure charge and momentum
- Each target consists of 27 lead-emulsion brick walls alternated to scintillator planes to select the brick containing the neutrino interaction.

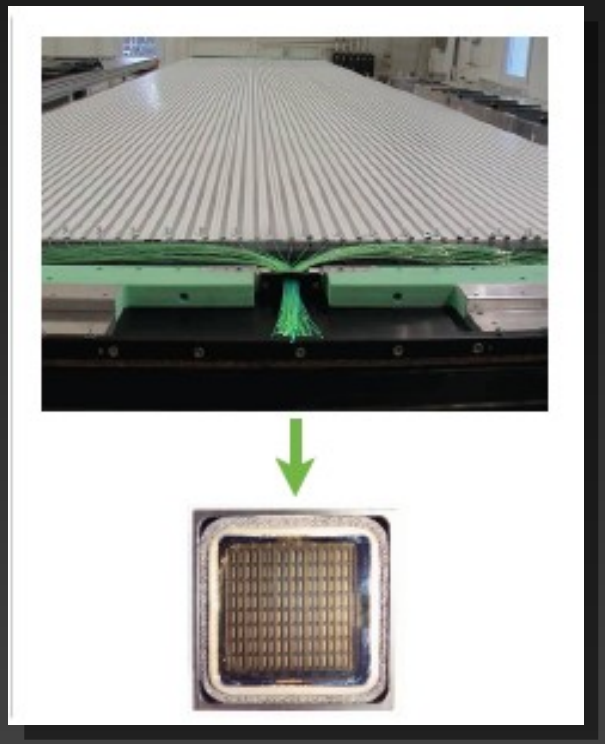
The OPERA detector today



- **Electronic fully instrumented and tested**

Target tracker

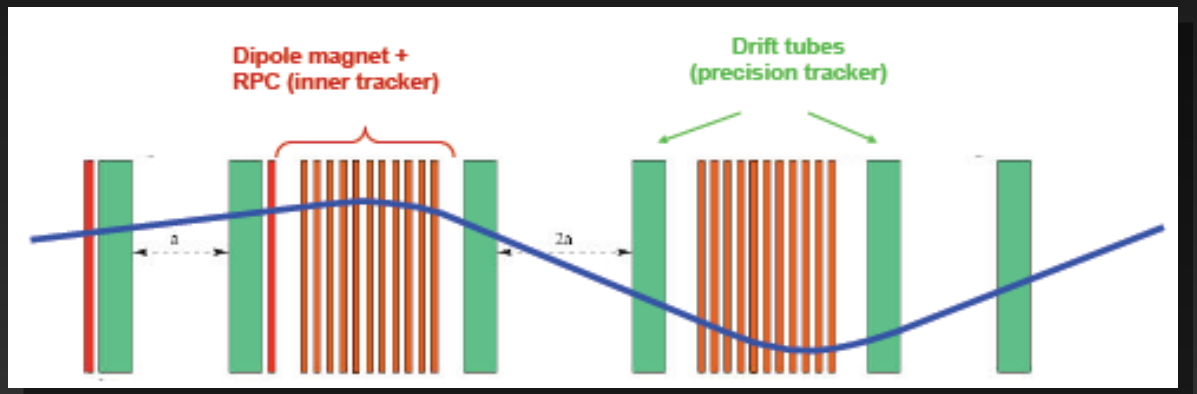
- The main goals of the target tracker are the trigger on the neutrino events and the identification of the brick to be extracted and then analysed
- It is made of plastic scintillator strips, each with a wavelength shifting fibre
- The fibres are connected in groups of 64 to multi-anode Hamamatsu PMTs at both ends



# p.e. per mip (2.15 MeV)	> 5
Detection efficiency	99%
Brick finding efficiency	80%

Spectrometer

- The goal of the spectrometer is the momentum measurement and charge discrimination
- In particular it is used to measure and identify muons, in order to reduce charm background
- It is made by inner tracker (RPC planes) and precision tracker (Drift Tubes) in a 1.5 T magnetic field



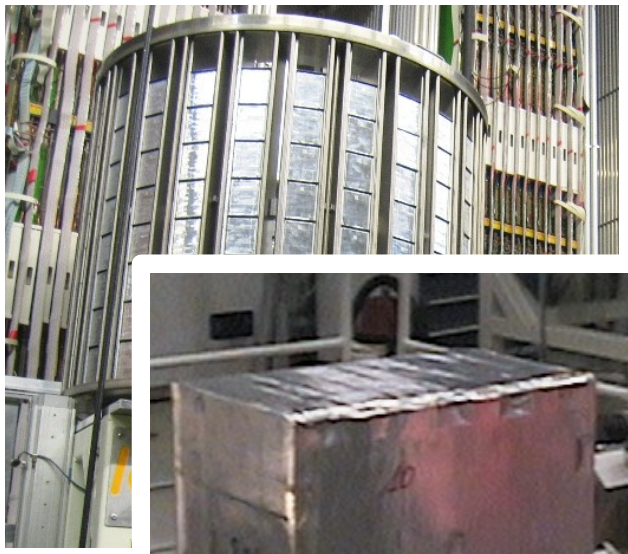
ε miss charge	0.1%-0.3%
Δp/p (<50 GeV/c)	~ 20%
μ ID (with TT)	~ 95%

Brick target

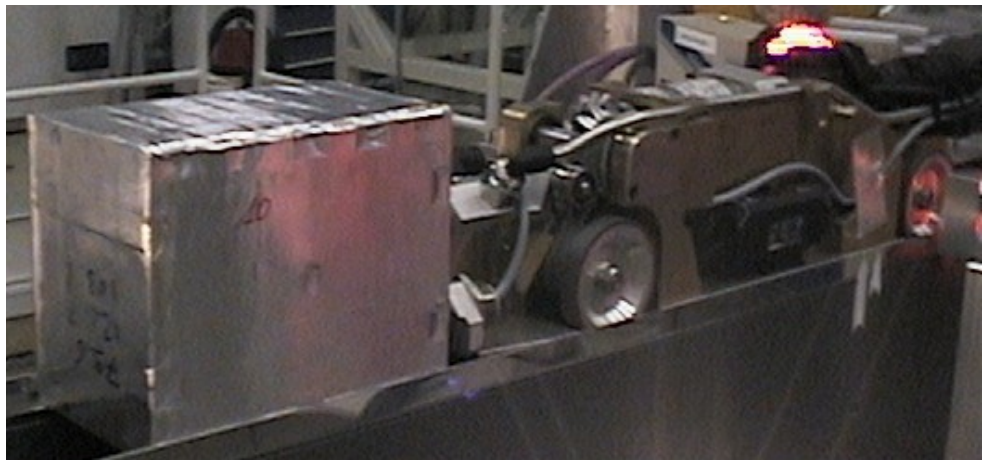
- Brick filling is finished in July 2008:
- 146621 bricks ~ 8 millions of nuclear emulsions
- 5000 bricks more will be added at the end of 2008 once additional lead will be delivered

The filling of the target

Brick assemble machine



Brick manipulating system

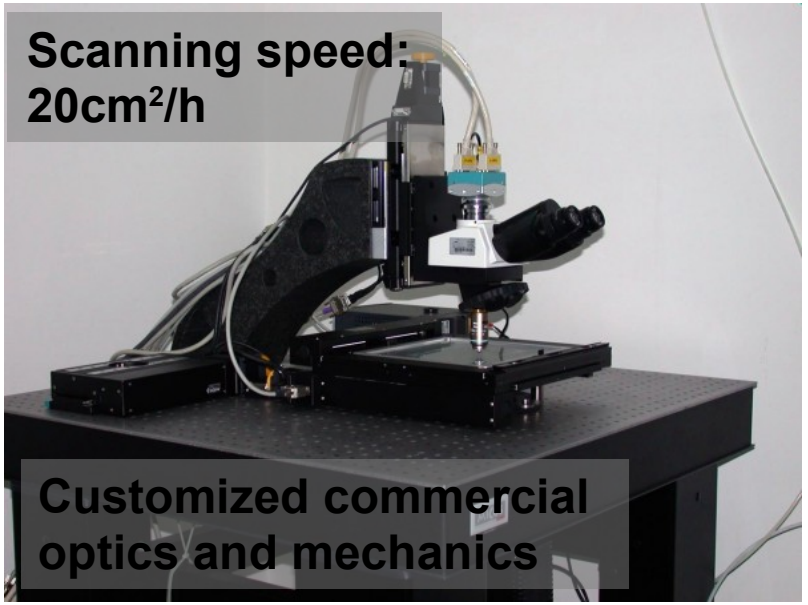


The automated microscopes

OFF-LINE DATA TAKING

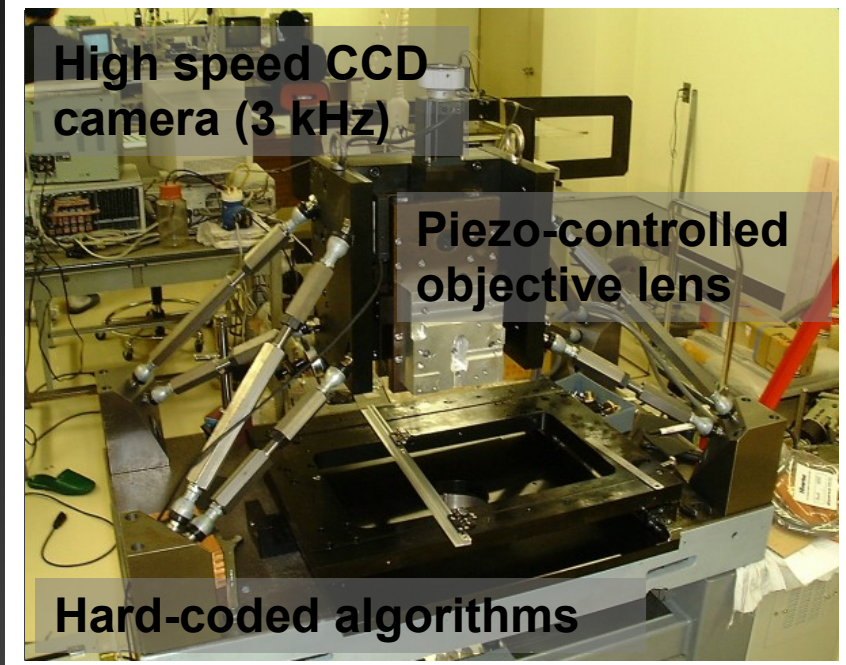
~30 bricks will be daily extracted from the target and analyzed by using high-speed automated systems. Scanning labs are ready with ~40 microscopes available, shared in Japan and Europe

European scanning system



asynchronous DAQ software

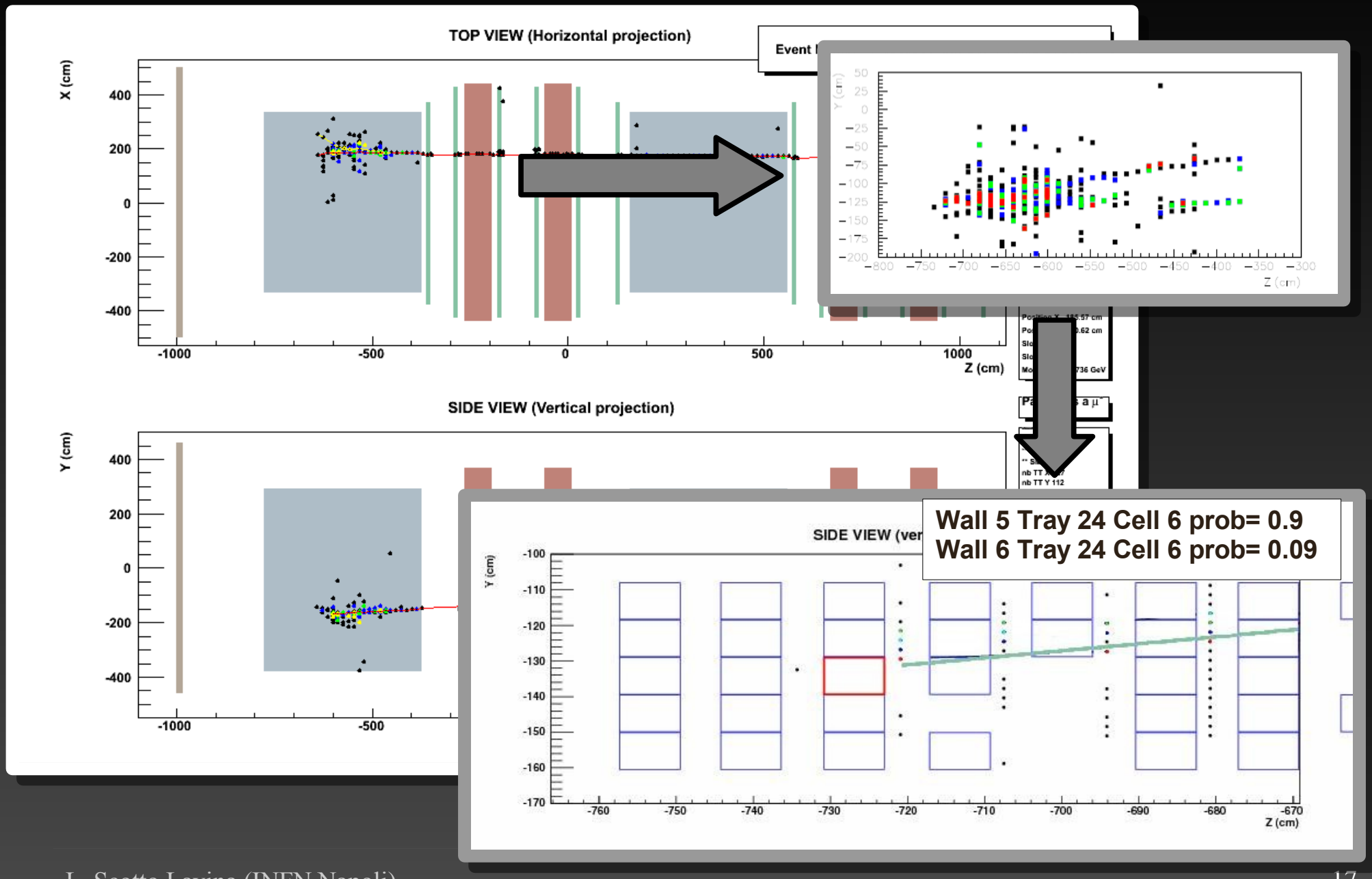
S-UTS (Japan)



OPERA working chain

1. Trigger on event “on time” with CNGS and selection of the brick using electronic detectors information (brick finding algorithm)
2. Brick removed by BMS (brick manipulating system)
3. The emulsion interfaces (CS) are separated from the brick, developed and a connection with respect to the electronic predictions is searched for in one of the two Scanning Stations, located in Europe (LNGS) and in Japan (Nagoya)
4. If any track is found in the CS, the brick is exposed to X-rays beam and to cosmic rays for sheets alignment
5. The brick is disassembled and the emulsion films are developed and sent to one of the scanning labs
6. The selected scanning lab acquire the brick, looking for the particles previously found in the CS and follow them until the neutrino interaction is found
7. A volume scan around the neutrino interaction is performed and the neutrino vertex is confirmed
8. The scanning lab stores the informations about the brick in a local database. Informations are then copied in one of the two synchronized central databases
9. The events are analyzed off-line and tau is searched, by accessing to the database

Brick finding



2007 Run

- The 2007 Run lasted from 24th September till 20th October: the goals were to finish the commissioning and to start the first OPERA physics run
- Unfortunately, because of failure of the electronic controls of the ventilation system, the integrated time of the physics run was only of about 5 days
- In these 5 days, the CNGS worked at 70% of the nominal power (1.58x1017 p.o.t./day) for a total number of p.o.t. of 8.24×10^{17}
- However, in the 2007 run we had 38 ν interactions in the target
- Although the statistic is not high enough for efficiency studies, we were able to test the full chain on real events: from brick finding, extraction, to the final film developing and scanning analysis
- The whole working chain was successfully tested!

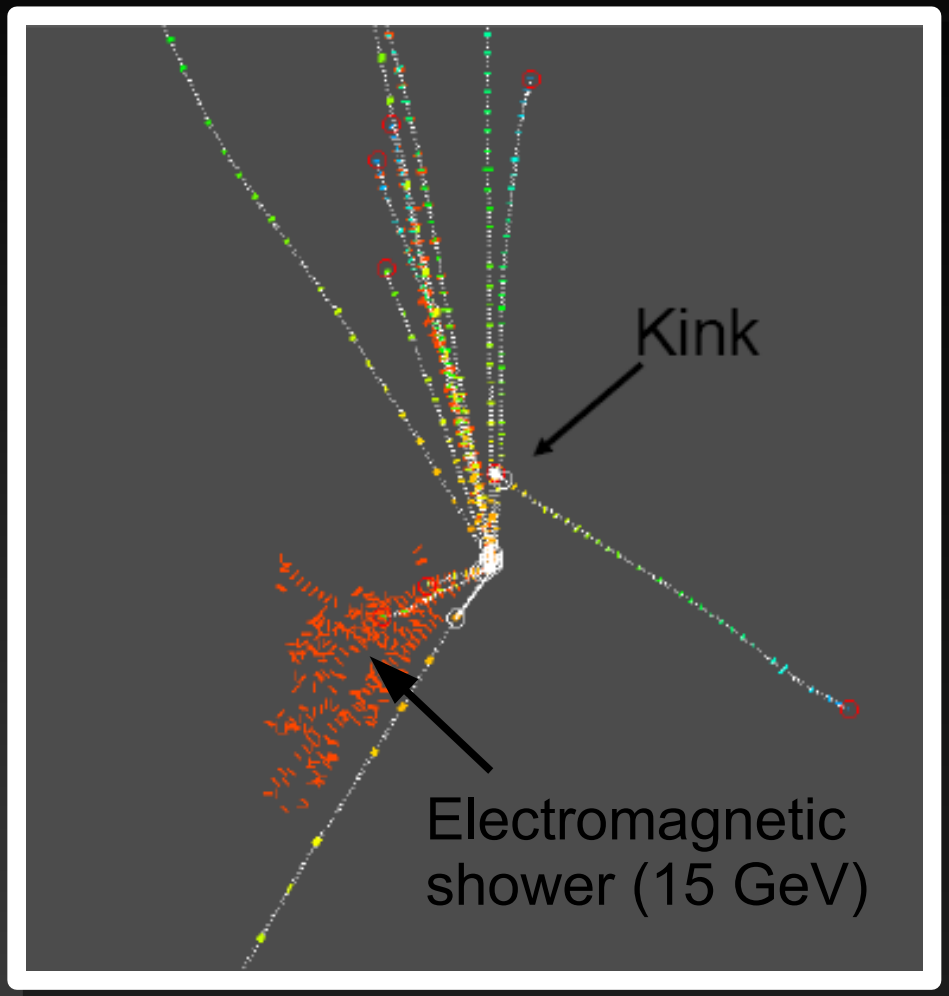
2007 Run

- We expect 32±6 interaction events in bricks, divided in 75% CC and 25% NC
- We found 38 events, divided in 29 CC (76%) and 9 NC (24%)
- The 38 events were shared in Europe (19) and Japan (19)
- Here is reported the status of the European bricks:

All events	19
Events confirmed in the Csd	18
Events not confirmed in the Csd	1
Events located in the bricks	15
Interactions in dead material	2
Analysis in progress	1

Muon passed between two bricks

2007 Run: a charm candidate !



Trk	TX	TY	IP	Momentum(GeV)	Comment
1	0.005	0.036	3.30	$1.7^{+0.5}_{-0.3}$	
2	0.005	0.139	1.01	-	parent
3	0.002	0.064	6.64	>20.0	SB
4	-0.021	0.064	7.15	$2.1^{+0.7}_{-0.4}$	SB
5	-0.029	0.046	2.83	>8.4	SB
6	-0.031	0.064	7.32	$2.4^{+0.8}_{-0.5}$	SB
7	-0.076	0.068	4.19	$1.8^{+1.6}_{-0.6}$	SB
8	-0.089	0.141	6.88	$2.5^{+1.4}_{-0.7}$	
9	-0.183	0.106	5.39	$0.7^{+0.2}_{-0.1}$	
10	-0.297	-0.143	19.17	$0.7^{+0.3}_{-0.1}$	
11	-0.067	0.008	7.26	$3.5^{+3.6}_{-1.2}$	e-pair
12	-0.069	0.005	16.80	$2.0^{+3.1}_{-0.8}$	e-pair

Secondary Vertex

Daughter momentum = $3.9^{+1.7}_{-0.9}$

θ kink = 0.204 rad

Flight length = 3247 μm

P_t = 796 MeV

P_t^{MIN} = 606 MeV (90% C.L.)

2008 Run

OPERA is taking data now!

- **Started since June 18th, will end on November 10th**
- **Almost 20 weeks of beam are provided for the OPERA experiment**
- **Expected beam performance for the 2008 run:**

Number of days	123
Efficiency	80%
Intensity (p.o.t./extraction)	2×10^{13}
Cycles per super cycle	3
Super cycle duration	48s (50%) + 42s (50%)
Integrated p.o.t.	2.28×10^{19}
Interactions rate (per week)	~120

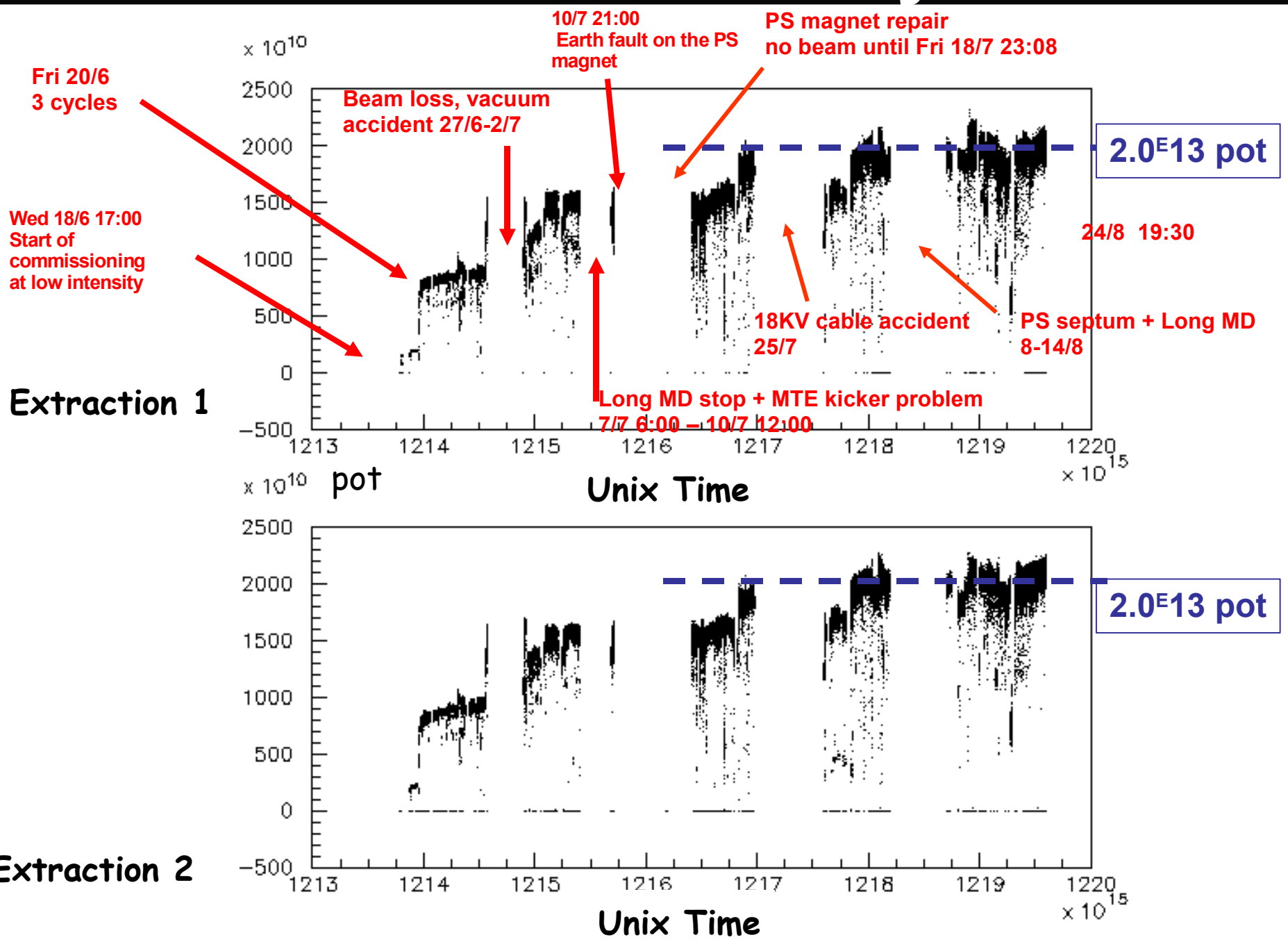
- **Expected interactions are:**

~ 2200 ν_μ interactions

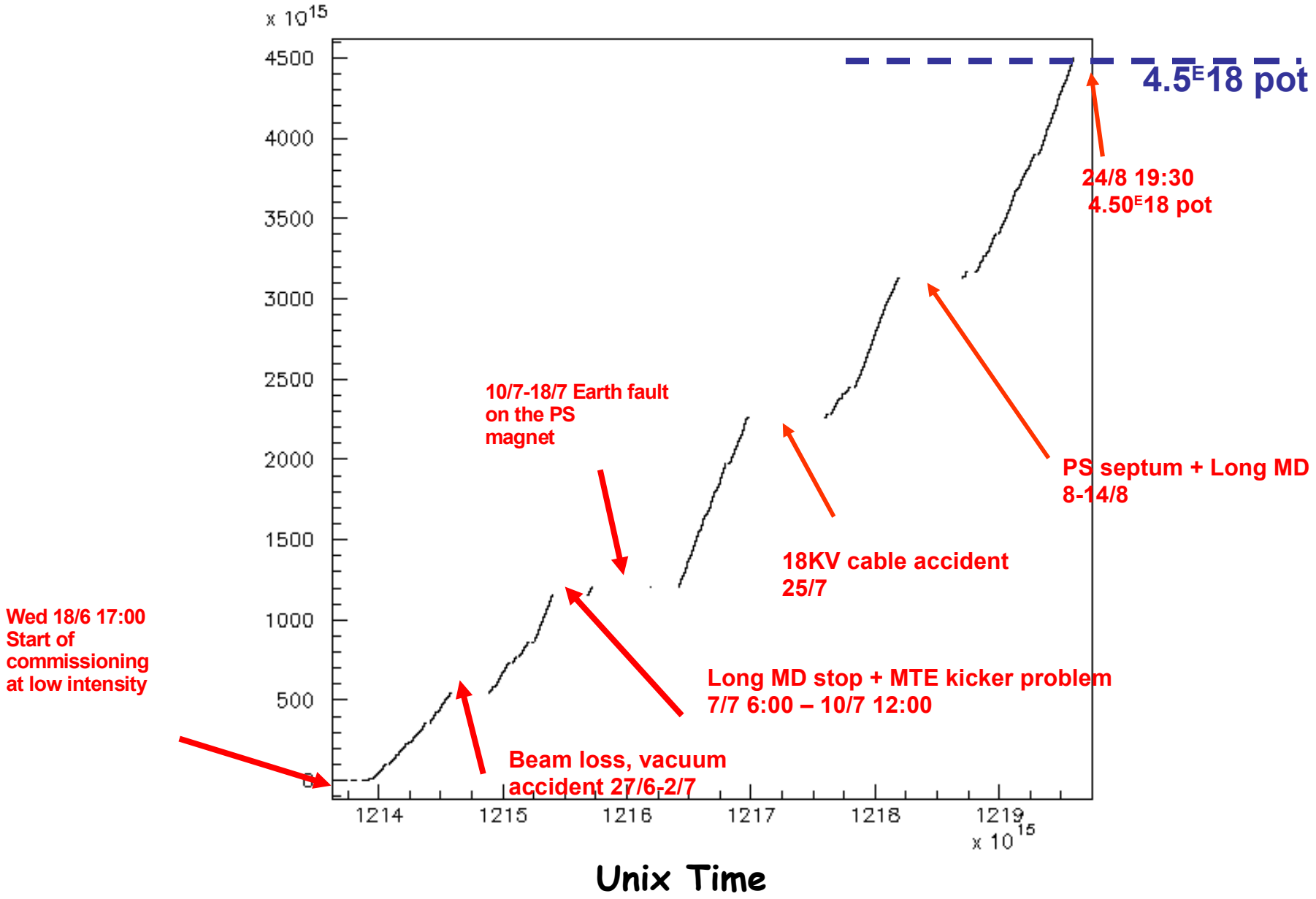
~ 10 ν_τ CC $\rightarrow$ 1 event considering efficiency

Observation of the 1st τ event ?

CNGS intensity



CNGS integrated intensity



Status of the neutrino beam

Updated on Sunday August 24th

4 major accidents:

- **Time freeze in SPS supercycle, hole in SPS magnet**
- **Replacement of PS magnet with short circuit**
- **Electrical problem of 18KV "Electricitè de France" power cable**
- **PS: broken electrostatic septum of CT extraction**

	Expected performance for the 2008 run	Expected on August 24th	Status on August 24th
Number of days	123	61	61
Integrated p.o.t.	2.28×10^{19}	1.13×10^{19}	4.5×10^{18}

50% of the run over

39.6% of expected p.o.t. delivered for this period

Detected interactions

Updated on Sunday August 24th

The expected number of interactions in the bricks with the present integrated flux (4.5×10^{18} p.o.t.) is:

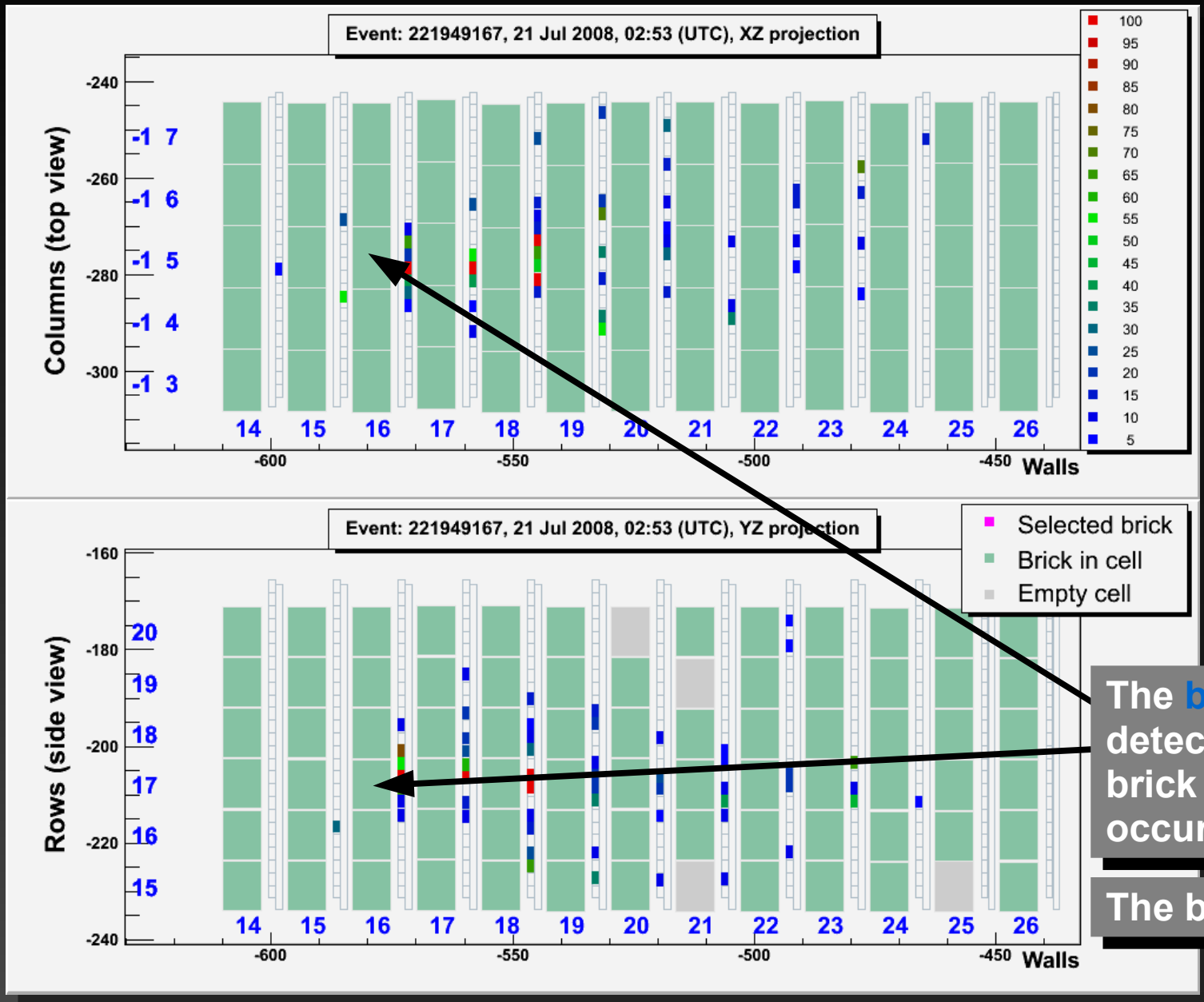
$N_{bricks} = 434 \pm 21$

Status of the OPERA detector:

Recorded on-time events: 2558
Candidate interactions in the bricks: 399, consistent with the expected value

The bricks confirmed by the two scanning stations (CS analysis) are weekly sent to the scanning laboratories

2008 Run: one example of NC event



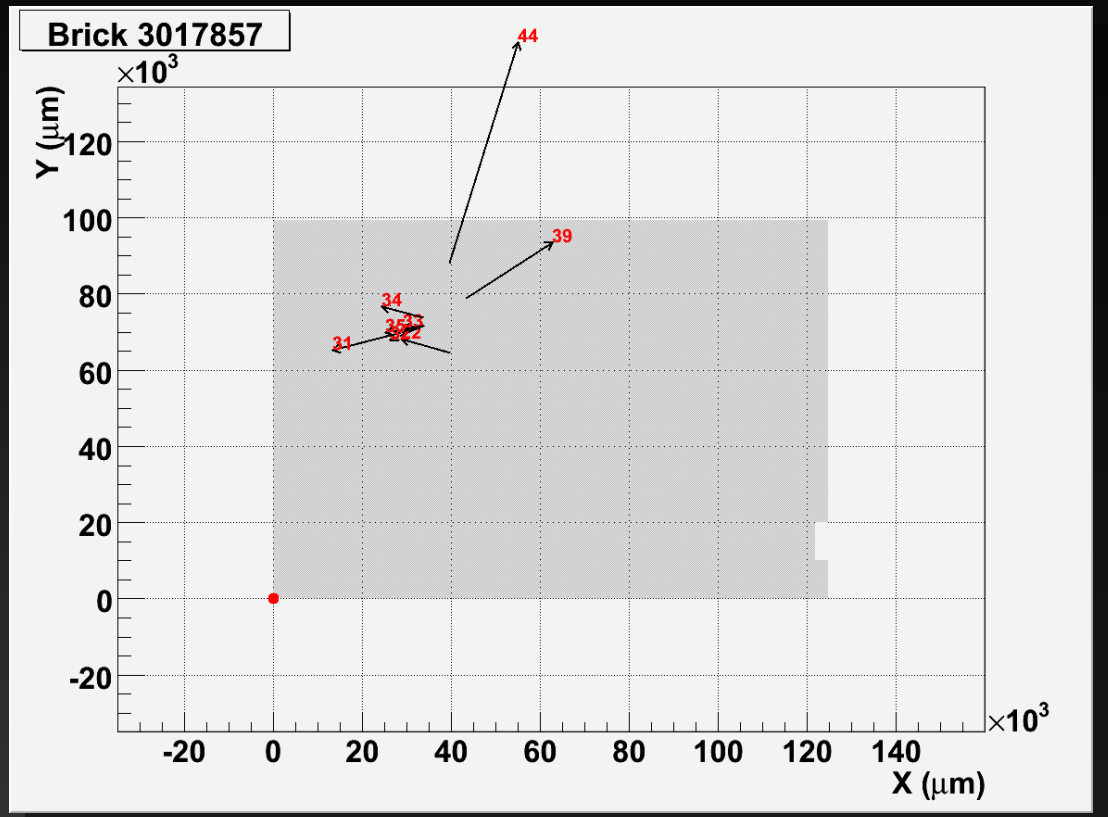
The **brick finding algorithm** detects the most probable brick where the interaction occurred

The brick is then extracted

CS analysis by the Scanning Station

The Scanning Station scans the whole surface of the two emulsion interfaces (CS) and selecting particle tracks found in both plates

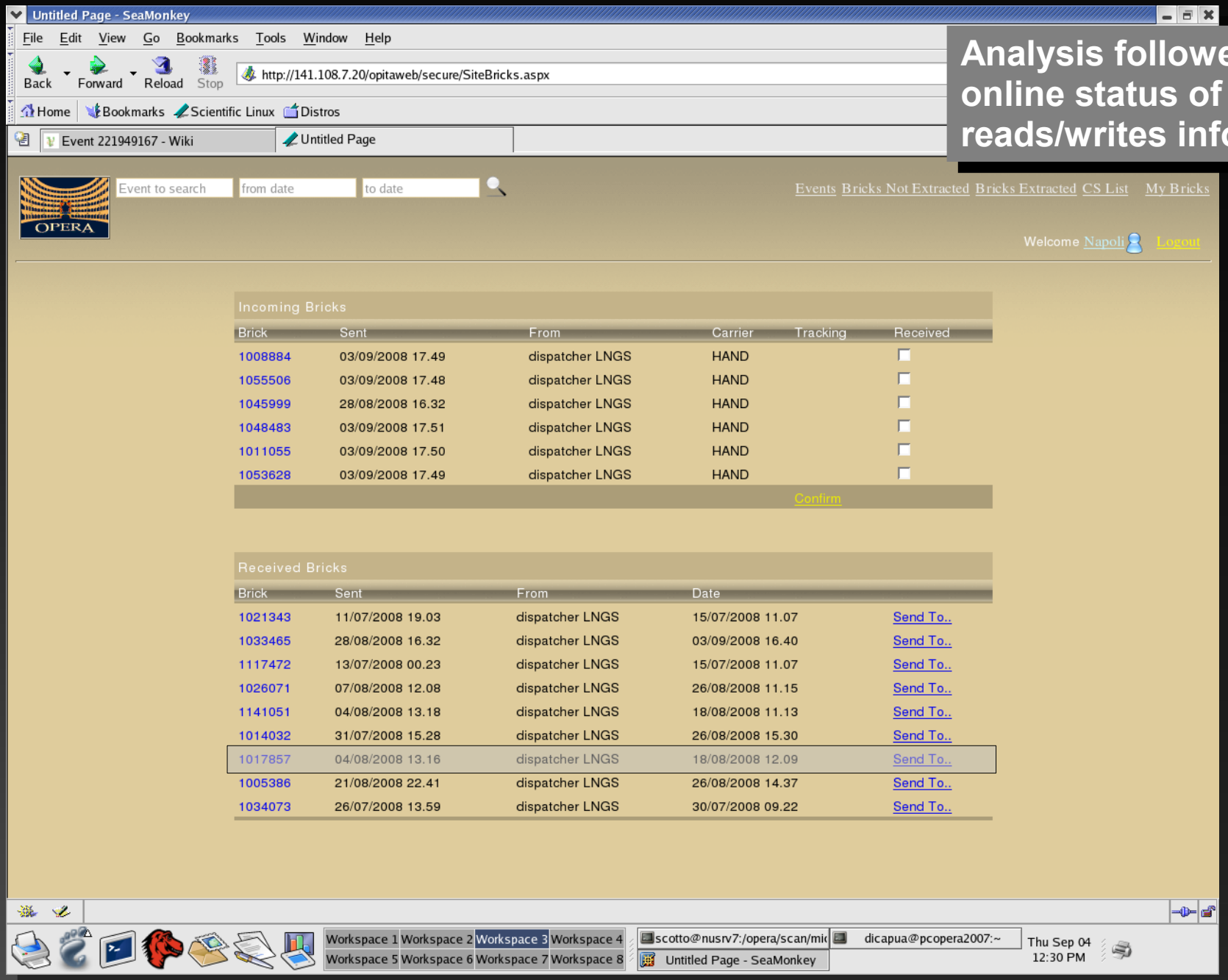
ID	TX	TY	Found	RES (X)	RES (Y)	RES (TX)	RES (TY)
22	-0.0978	0.0317	yes	118.3	68.6	-0.050	-0.001
31	-0.200	-0.0562	yes	-285.6	66.4	0.039	-0.002
32	-0.0704	-0.0342	yes	-27.9	101.5	0.000	0.005
33	-0.0476	-0.0036	yes	-18.0	82.3	-0.009	0.029
34	-0.0921	0.0287	yes	-41.4	130.9	-0.009	0.007
35	-0.0857	-0.019	yes	-42.5	128.0	-0.028	0.016
39	0.1949	0.1490	yes	50.4	188.9	0.006	0.003
44	0.1493	0.5692	no	-	-	-	-



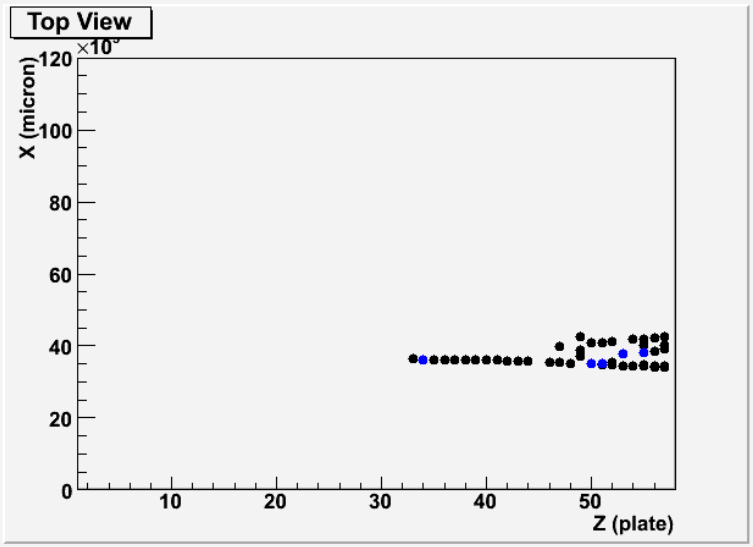
CS result validates the brick, which is then sent to the developing facility

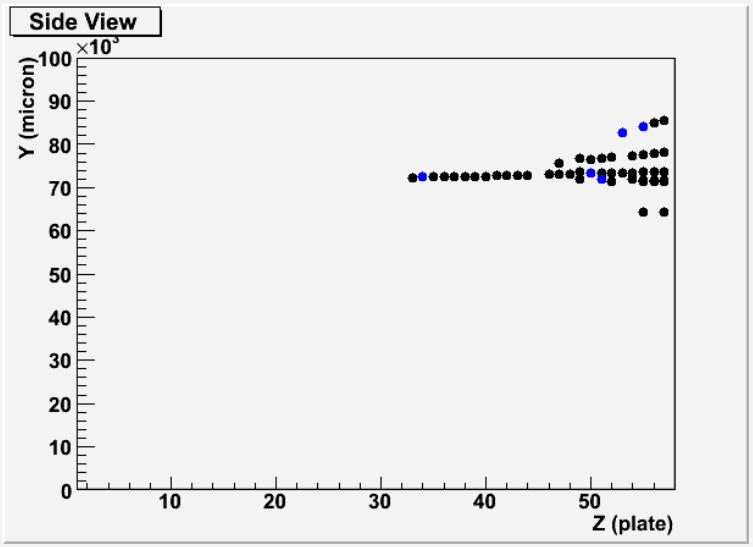
Delivery to one laboratory

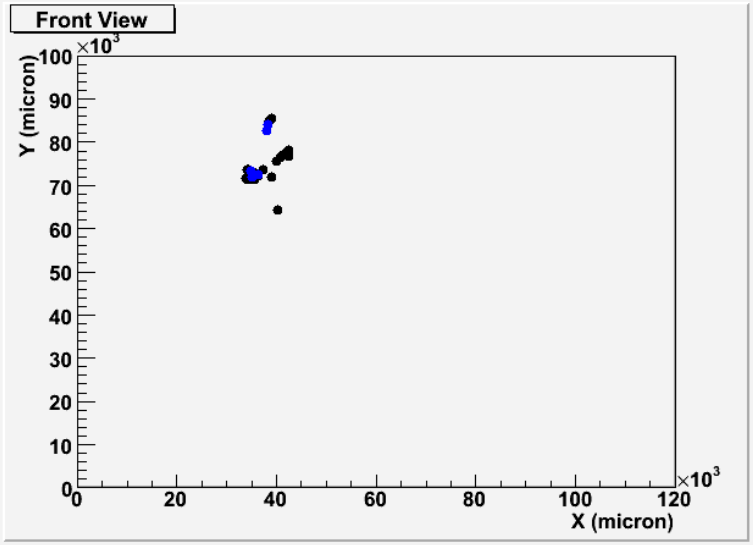
Analysis follower:
online status of bricks
reads/writes informations to DB



Location of the neutrino interaction in emulsion





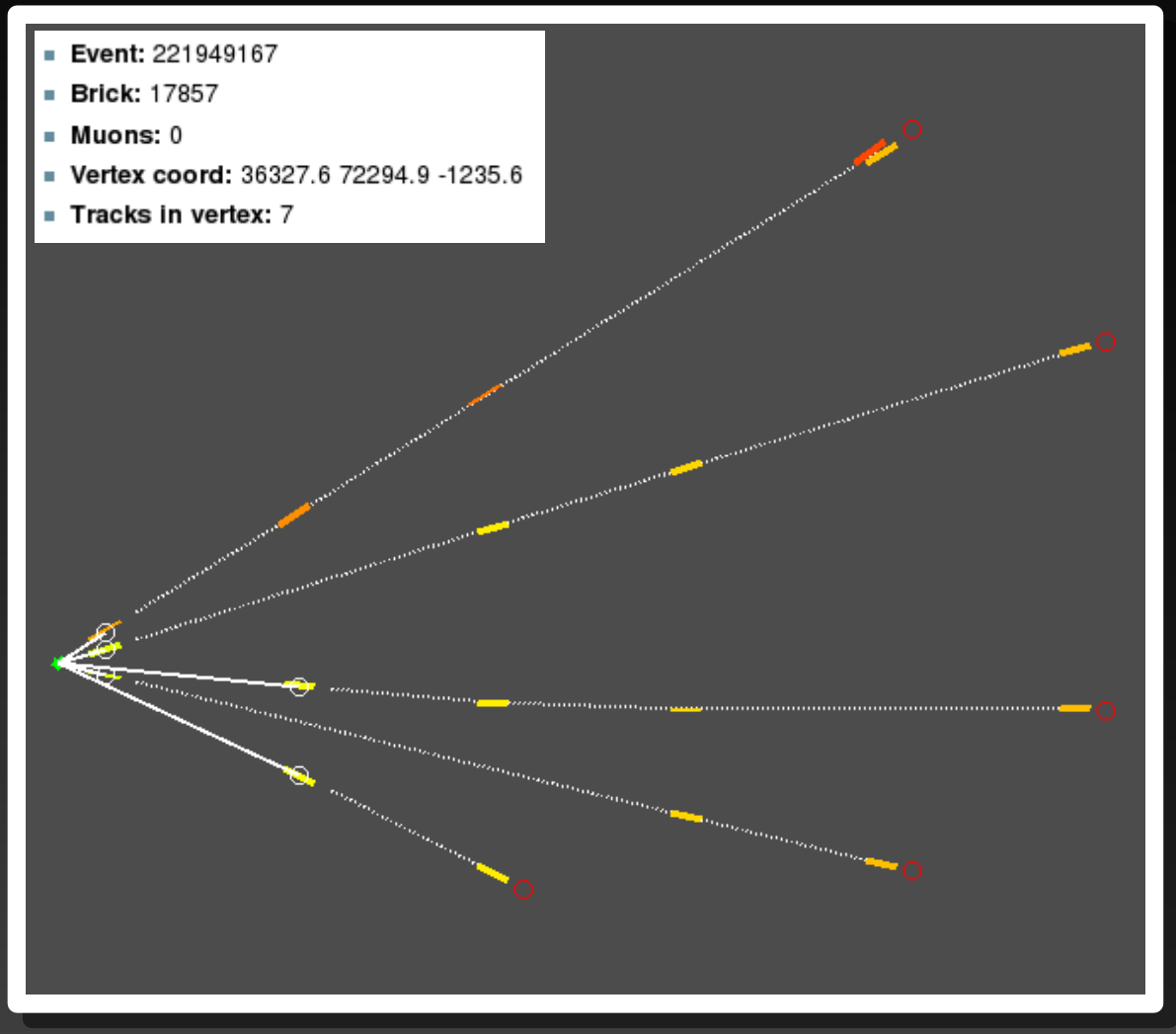


Predictions from the CS are followed back in the brick, looking for the position where the neutrino interaction occurred

Vertex reconstruction

Reconstructed track parameters at vertex

ID	TX	TY	Impact
1	0.175	0.166	8.7
2	0.058	-0.034	5.3
3	-0.011	0.070	4.1
4	-0.030	-0.022	5.9
5	-0.058	-0.029	2.6
6	-0.025	0.021	2.1
7	-0.187	-0.069	31.8



The vertex is confirmed and all raw data are stored into the DB

Conclusions

- The OPERA detector is essentially completed and it is now massive with 1.3 kton of lead-emulsion target
- Emulsion scanning laboratories and infrastructures are operational
- In 2007: first CNGS neutrino run:
  - Test and tuning of electronic detectors, brick finding algorithms and scanning strategy
  - Validation of reconstruction software and analysis tools
  - 38 neutrino events collected
  - The concept of the OPERA detector has been successfully validated!
- Now: run 2008 started since June 18th, 123 days of data taking
  - Expected 2.28x10^{19} p.o.t. and 1 ν_τ interaction
  - So far, collected 4.5x10^{18} p.o.t.