First results from the OPERA experiment

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on behalf of the **OPERA** collaboration

Rencontres de Moriond: Electroweak interactions and Unified theories
La Thuile, March 7-14 2009

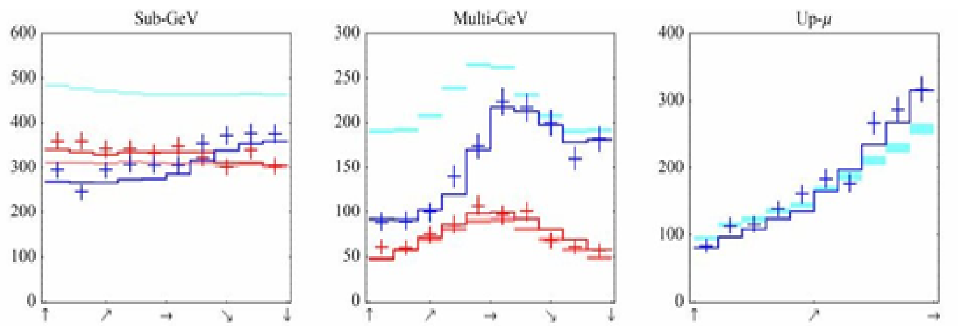
OutLine

- OPERA Physics motivation
- CNGS
- Experimental signature
- The OPERA Detector
- Physics Potential
- The OPERA way …
- Nuclear emulsion fast automatic scanning
- Preliminary results from the first physics runs

37 INSTITUTIONS ~ 160 PHYSICISTS

Annecy, Lyon, Strasbourg
Hamburg, Münster, Rostock
IRB Zagreb
L'Aquila, Bari, Bologna, Napoli, Padova, Roma, Salerno, LNF, LNGS
Aichi, Toho, Kobe, Nagoya,Utsunomiya
METU Ankara
Technion Haifa
Bern, ETH Zurich
Jinju
Sofia
JINR,INR-RAS,ITEP, LPI-RAS,SINP-MSU,Obninsk
IHE Bruxelles

OPERA Physics motivation



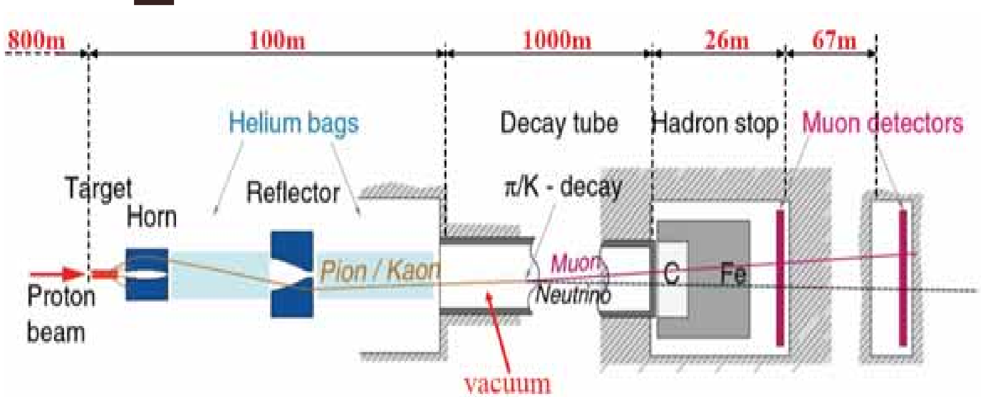
- SK (1998): atmospheric neutrino anomaly interpretable as $\nu_\mu \rightarrow \nu_\tau$ oscillation
- CHOOZ: no $\nu_\mu \rightarrow \nu_e$ oscillation
- SK oscillation signal confirmed by K2K and MINOS

Direct observation of ν_τ appearance still missing

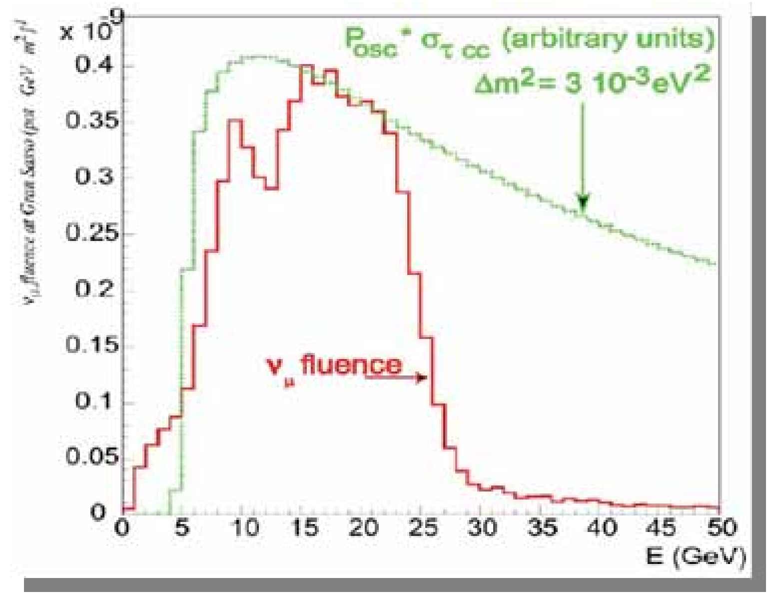
OPERA

(**O**scillation **P**roject with **E**mulsion t**R**acking **A**pparatus) is a long baseline neutrino oscillation experiment aiming at the direct observation of the $\boldsymbol{\nu_\tau}$ **appearance** through the $\boldsymbol{\nu_\tau}$ CC interaction with the target mass, in an initially pure $\boldsymbol{\nu_\mu}$ accelerator produced beam .

Cern-Neutrino-to-Gran-Sasso



400 GeV protons on graphite target. Secondary produced particles (π^+ and K^+) are focused in a 1 km decay tunnel producing an intense ν_μ beam with $< E > \sim 17$ GeV/c



$<E(\nu_\mu)>$	17 GeV
L	730 km
L/E	43 Km/GeV
$(\nu_e + \bar{\nu}_e)/\nu_\mu$	0.87%
$\bar{\nu}_\mu / \nu_\mu$	4%
ν_τ prompt	negligible

With the nominal proton intensity (4.5×10^{19} pot/y), 200 days/y of data taking and a target mass of 1.3 kton, the number of produced events is:

$\sim 25400\ \nu_\mu$ CC+NC

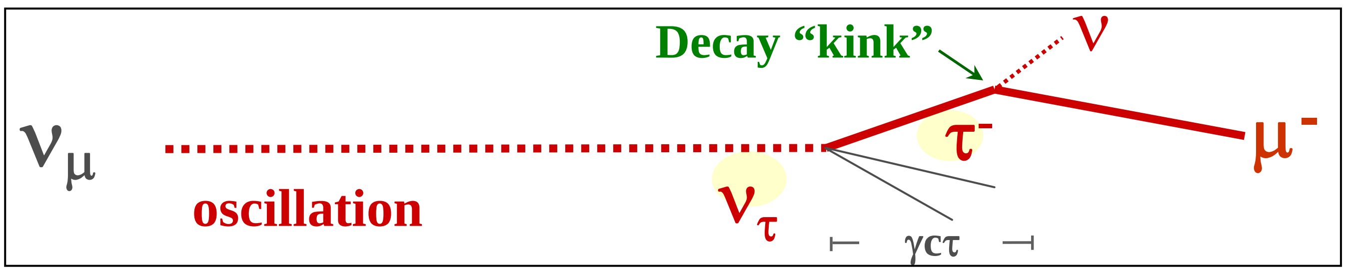
$\sim 169\ \nu_e + \bar{\nu}_e$ CC

Δm^2 (eV^2)	Nb of ν_τ CC α $(\Delta m^2)^2$
2.5×10^{-3}	125

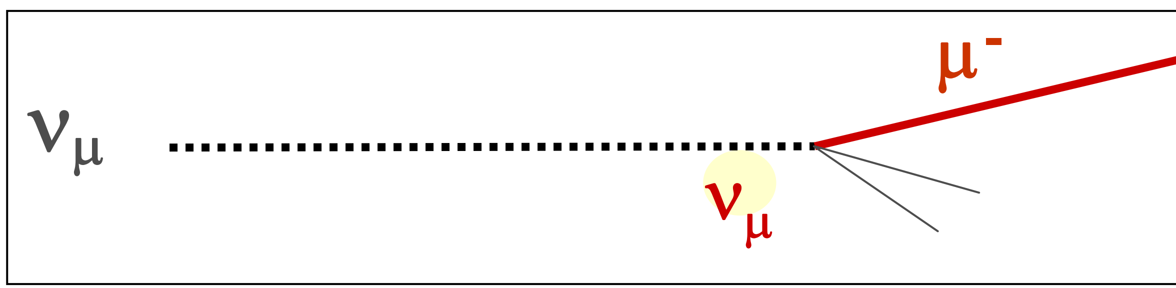
Experimental signature: ν_τ appearance

$\nu_\mu \Rightarrow$ (oscillation) CC interaction $\nu_\tau + N \to \tau^- + X$

$$\tau^- \to \begin{cases} \mu^- \ \nu_\tau \ \bar{\nu}_\mu & \text{B. R.} \sim 17\% \\ h^- \ \nu_\tau \ n(\pi^o) & \text{B. R.} \sim 50\% \\ e^- \ \nu_\tau \ \bar{\nu}_e & \text{B. R.} \sim 18\% \\ \pi^+ \pi^- \pi^- \ \nu_\tau \ n(\pi^o) & \text{B. R.} \sim 14\% \end{cases}$$



$c\tau \sim 87\ \mu m$



- Target mass O(kton)
  (low ν interaction cross-section)
- High granularity detector
  (τ decay detection, background rejection)

<u>lead – nuclear emulsion target segmented into basic units called *bricks*</u>

OPERA Detector: target section

BRICK:

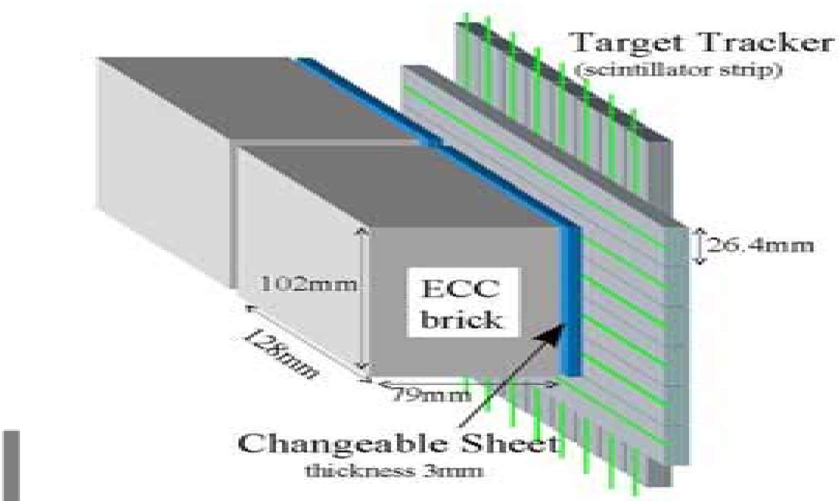
57 emulsion films (300 μm) + 56 lead sheets (1 mm)

- $10.3 \times 12.8 \times 8.2\ cm^3$, 8.6 Kg, 10 X_0
- Changeable Sheet (CS) doublet: 2 more films glued to the downstream face of each brick
- 150000 bricks produced and installed into the target
- 53 walls → ~2850 bricks/wall

  → target mass ~ 1.3 kton

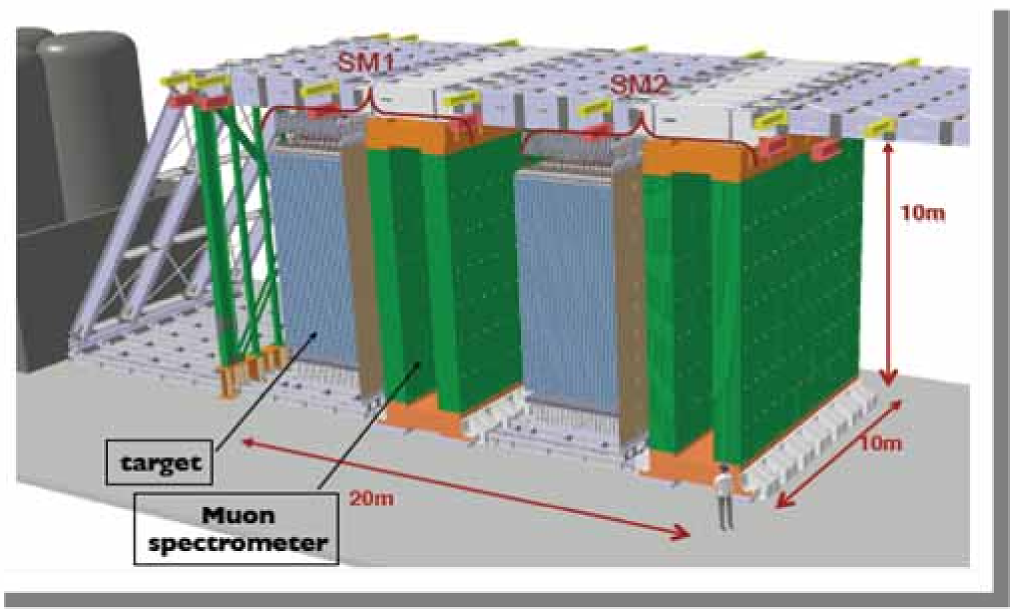
OPERA Detector

Each brick wall is followed by a plane of plastic scintillator strips oriented in X-Y direction and coupled by WLS optical fibres to PMTs.



Target Trackers (TT) are conceived to provide:

- Neutrino interaction trigger
- Brick localization



Spectrometers:

- Muon ID, momentum and charge measurement
- Track measurements are performed by RPC planes inserted in the magnet yoke (1.5 T field) and by drift tubes planes to add more precision

Physics potential

Full mixing, 5 years run, 4.5×10^{19} pot / year and target mass = 1.3 kton

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

Expected background:

- Charmed particles produced in ν_μ CC and NC interaction
- Hadron re-interactions in lead
- Large angle scattering: muons produced in ν_μ CC events
- π^0 misidentification

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

OPERA how to

- ***Trigger*** + select "on time" event with CNGS
- Electronic detectors information are processed by a software reconstruction program (***brick finding*** algorithm) that selects the brick with the highest probability to contain the neutrino interaction vertex
- The brick is removed by the ***Brick Manipulation System (BMS)*** and exposed to ***(frontal) X-rays*** to ensure a common reference system between CSd and brick
- The CSd is separated from the brick, developed and analysed in one of the two ***CS Scanning Stations***, located in Europe (LNGS) and in Japan (Nagoya)
- If any track related to the event is found in the CSd, the brick is exposed to ***(lateral) X-rays*** beam and to ***cosmic rays*** for films alignment. The brick is disassembled and the emulsion films are ***developed*** and sent to one of the scanning labs
- Tracks found in the CSd are searched for in the most downstream film of the brick and followed towards the interaction vertex (***scan-back*** procedure)
- A ***volume scan*** around the neutrino interaction point is performed and the neutrino vertex is located

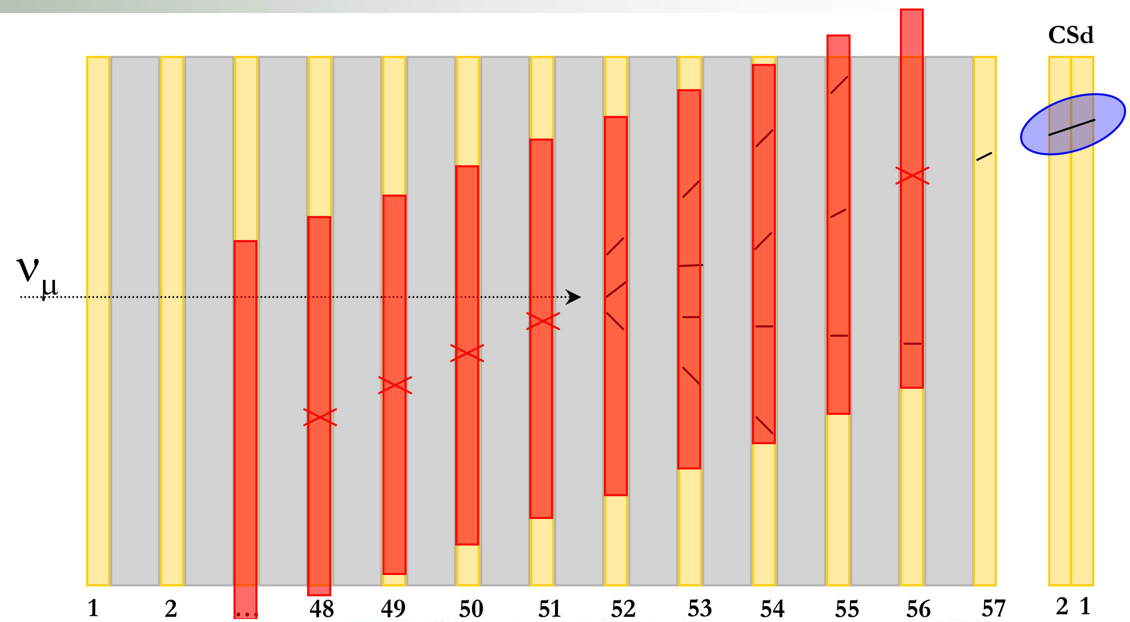
Emulsion Scanning

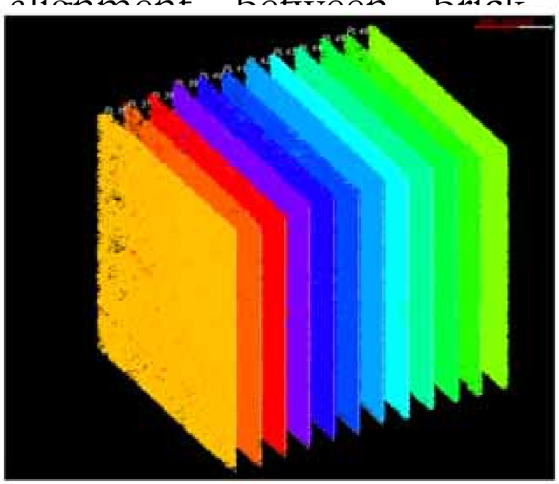
European Scanning System (ESS)

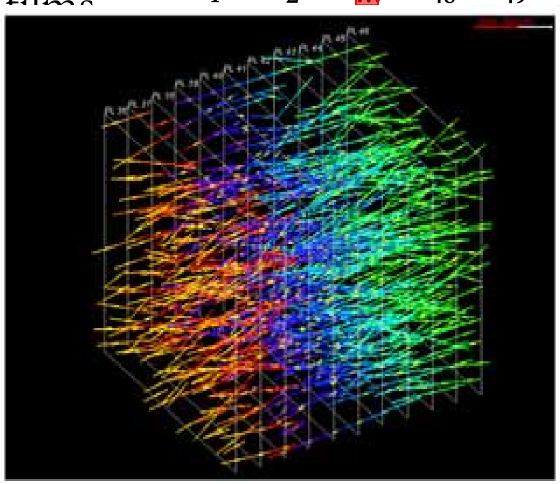
S-UTS (Japan)

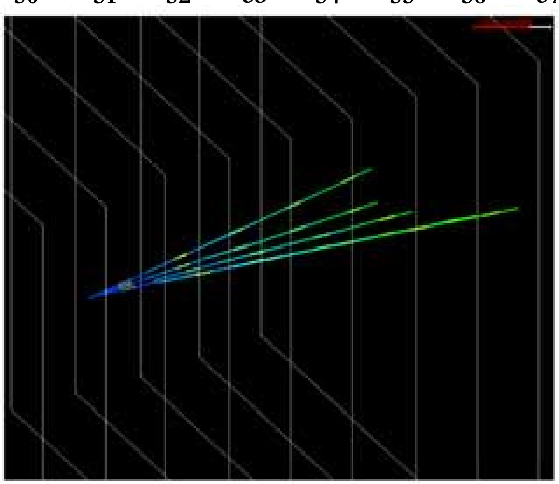
Event reconstruction

- **CSd general scan:**
  - ✓ 50 cm² around TT prediction
  - ✓ looking for tracks in all the available angular range (typically ±400 mrad)
  - ✓ alignment between emulsion films performed using X – ray marks (10μm accuracy)
- **Scan back:**
  - ✓ alignment between brick films
  pe
  (2
  - ✓
- **Vol**
  - ✓
  de
  - ✓





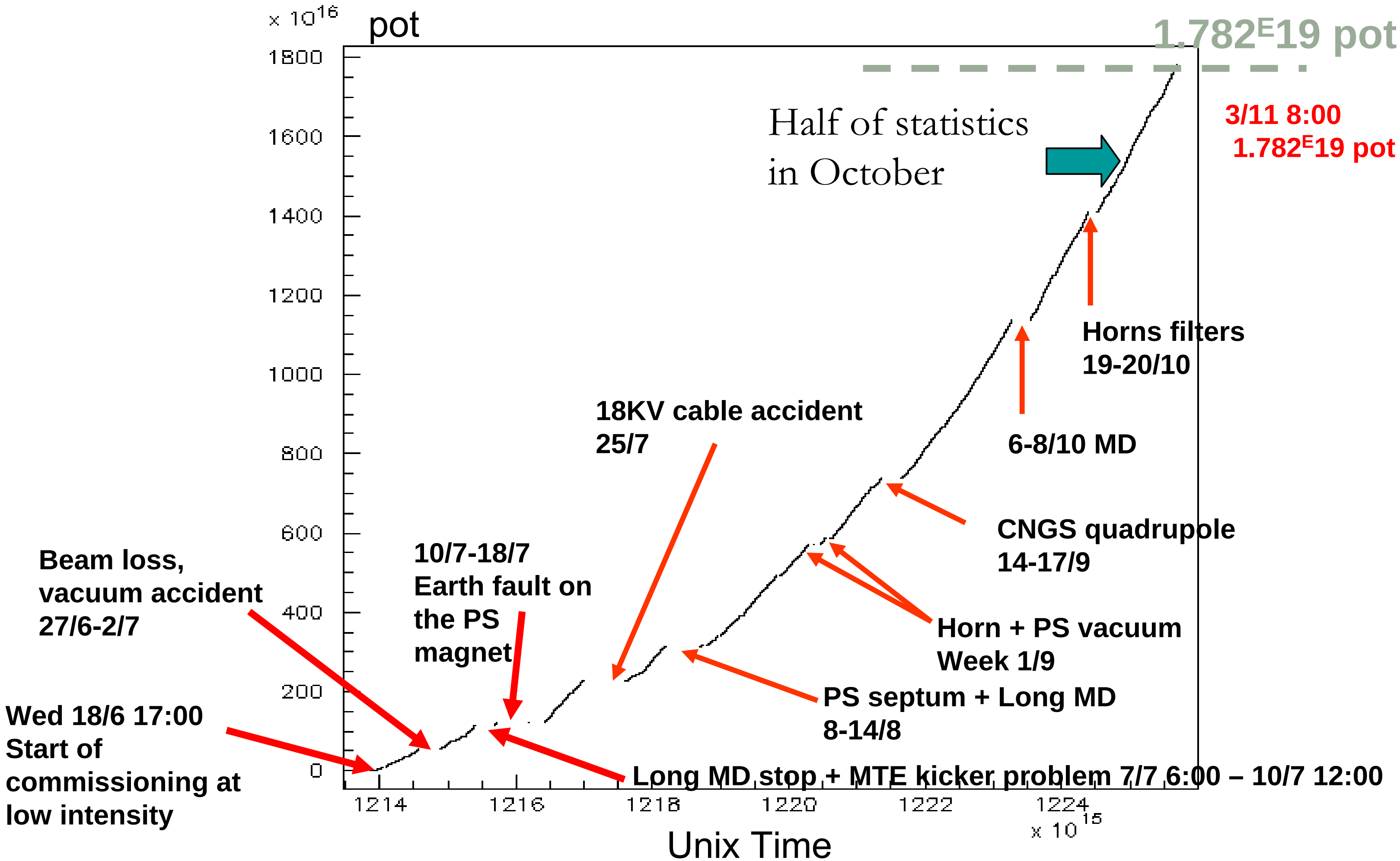




OPERA runs

- **2006**: short commissioning run
- **2007** (24th September - 20th October):
  - ✓ 0.082 x 10^{19} pot (i.e 1.8 x 10^{13} protons/extraction)
  - ✓ ~ 3.6 effective nominal days running (32±6 interactions in the bricks expected)
  - ✓ 38 interactions in the target
- **2008** (June 18th-November 3rd):
  - ✓ 1.782 x 10^{19} pot
  - ✓ 10100 events on time with the CNGS
  - ✓ ~1700 interactions in the bricks
  - ✓ 0.7 τ events expected

2008 Run


x 10^16
pot
1.782^E19 pot
1800
1600
1400
1200
1000
800
600
400
200
0
1214
1216
1218
1220
1222
1224
x 10^15
Unix Time
Half of statistics in October
3/11 8:00
1.782^E19 pot
Horns filters 19-20/10
6-8/10 MD
18KV cable accident 25/7
CNGS quadrupole 14-17/9
Horn + PS vacuum Week 1/9
PS septum + Long MD 8-14/8
10/7-18/7 Earth fault on the PS magnet
Beam loss, vacuum accident 27/6-2/7
Wed 18/6 17:00 Start of commissioning at low intensity
Long MD stop + MTE kicker problem 7/7 6:00 – 10/7 12:00

2008 Run: vertex location summary

Event analysis @ 2009, March 10th

	NC	CC	Total
Vertices located in the brick	72	412	484
Events in dead material	1	10	11

Estimation of the upper and lower limit in the event location on a data subsample:

	NC	CC	Total
Scanning started	74	388	462
CS to brick connected	67	368	435
Vertices located in the brick	43	293	336
Tracks passing through the brick	8	23	31
Events in dead material	1	7	8

Upper limit
NC: ~ 91%
CC: ~ 95%

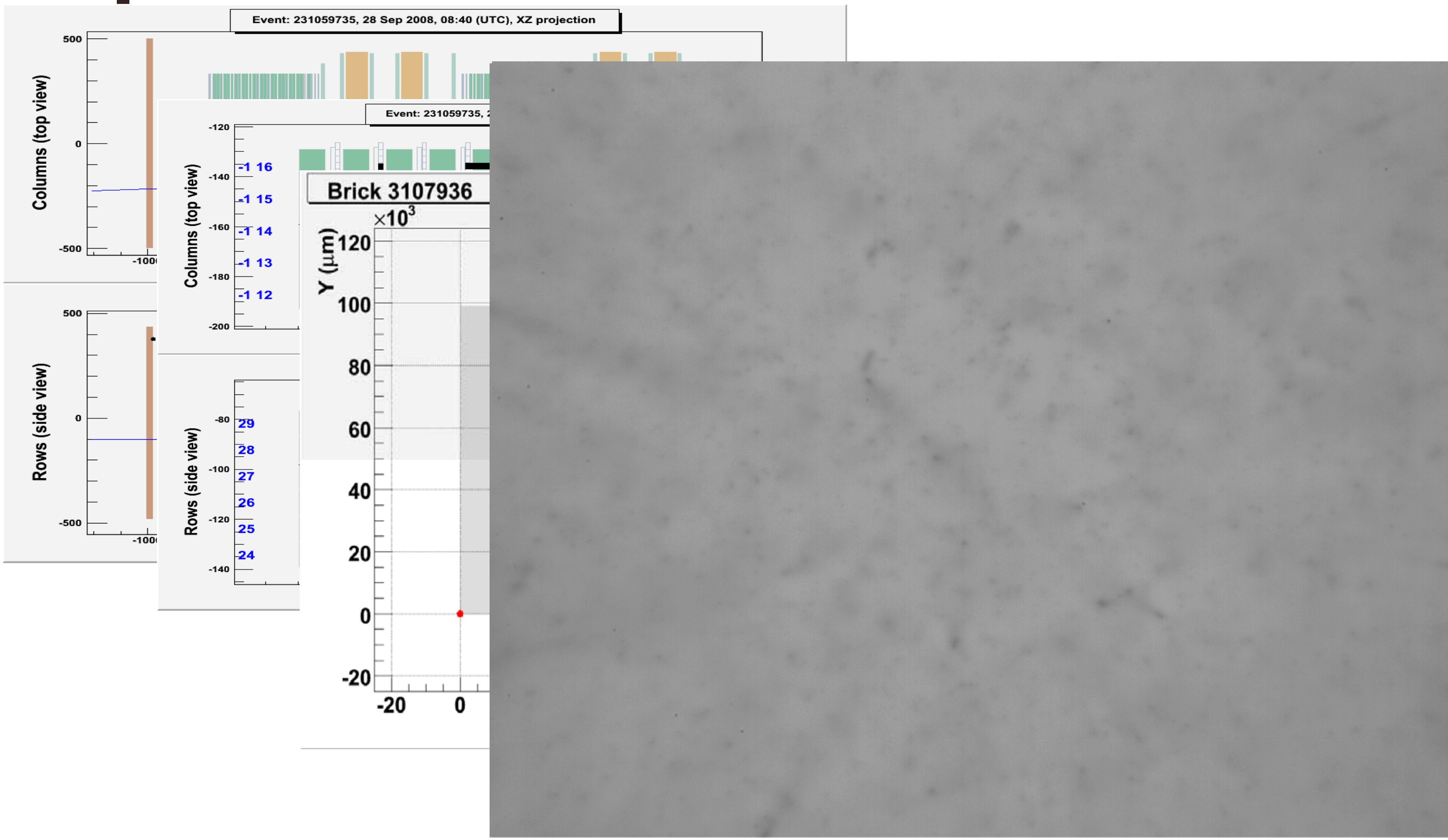
PRELIMINARY

Lower limit
NC: ~ 66%
CC: ~ 82%

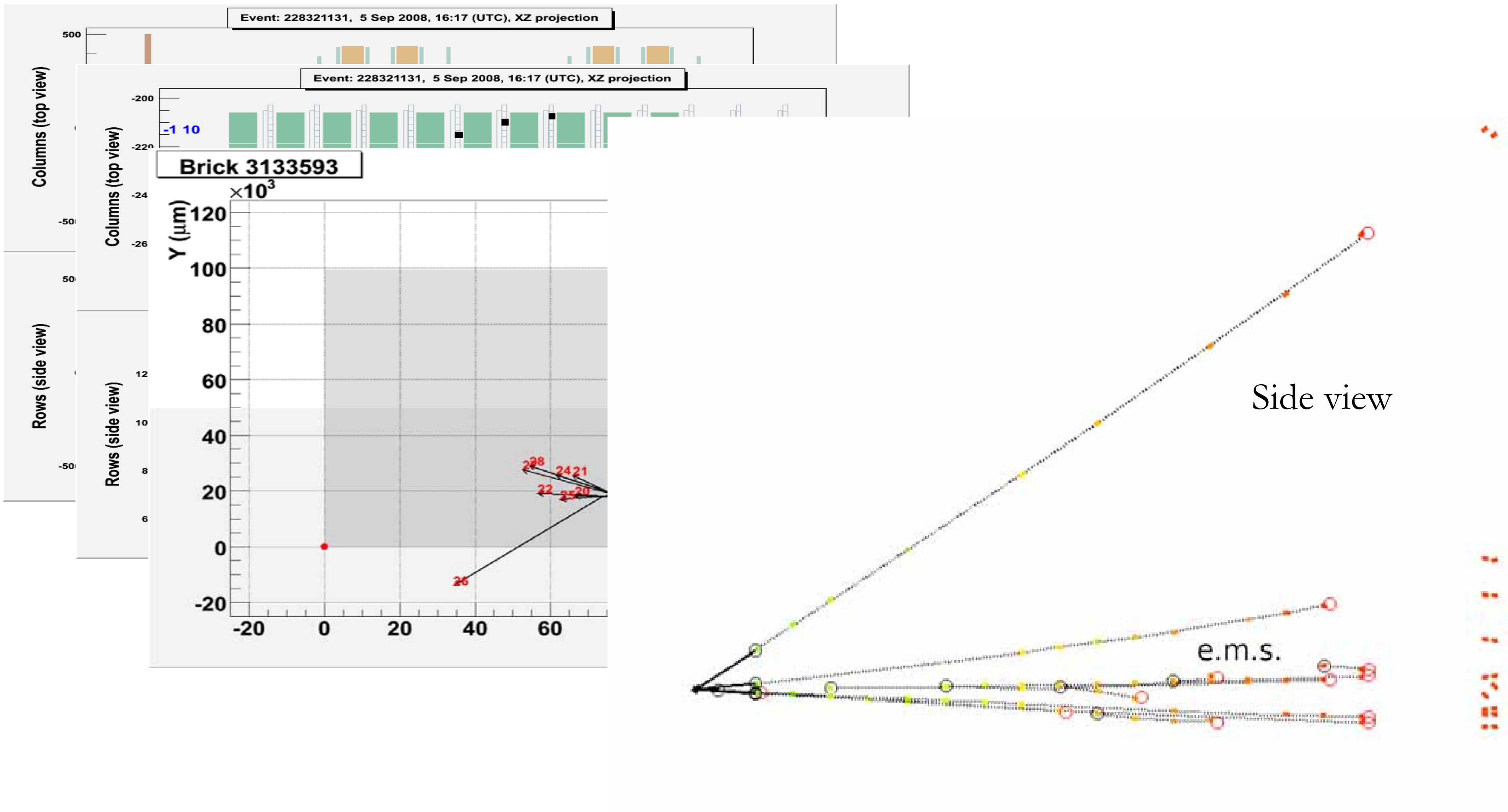
Dead material
8/336 ~ 2%

And now …let's open the box!

Vertex in emulsion

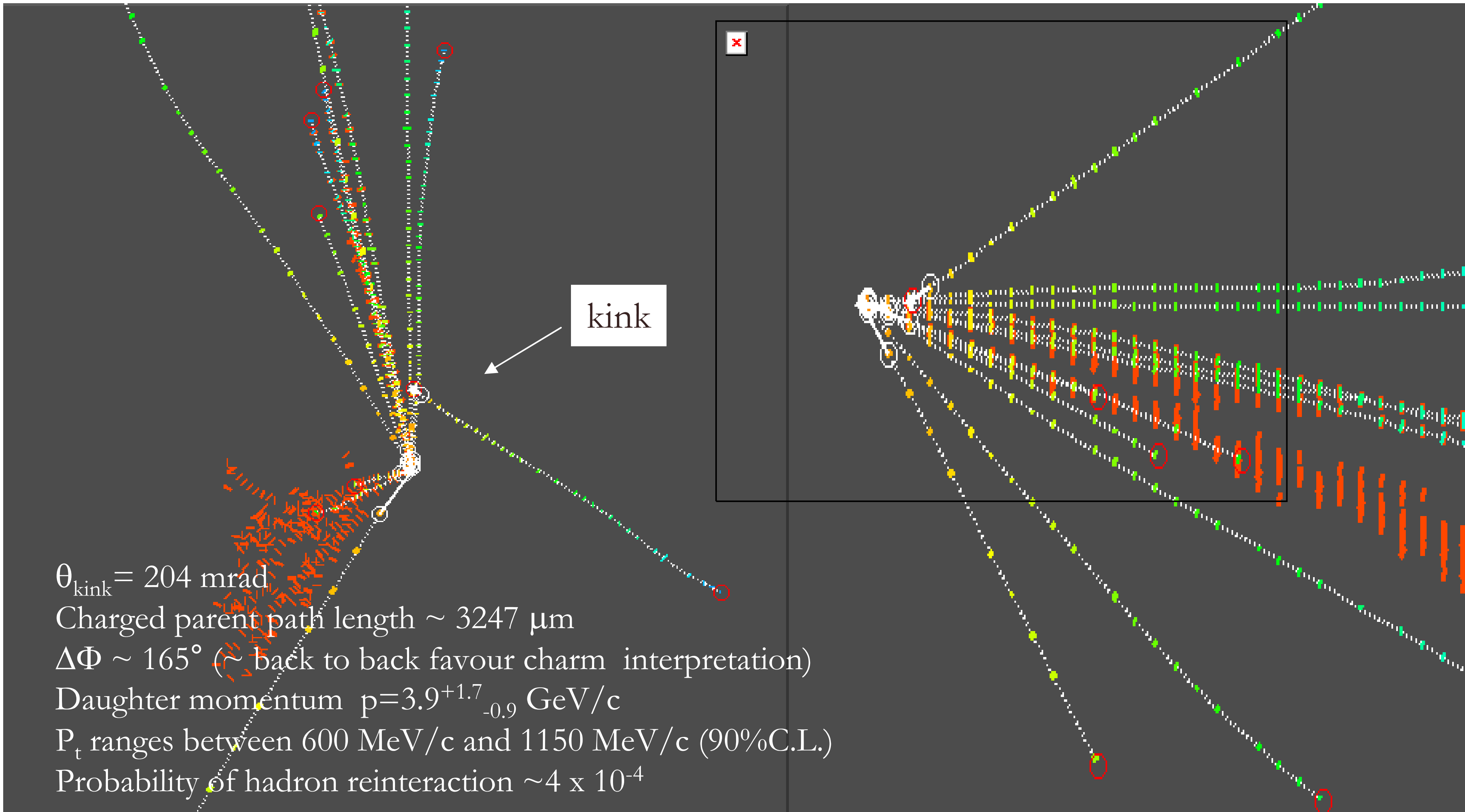


NC event



Event: 228321131, 5 Sep 2008, 16:17 (UTC), XZ projection
Columns (top view)
Rows (side view)
Brick 3133593
Y (µm)
Side view
e.m.s.

Charm 1(2007 Run)



θ_{kink}= 204 mrad

Charged parent path length ~ 3247 μm

$\Delta\Phi$ ~ 165° (~ back to back favour charm interpretation)

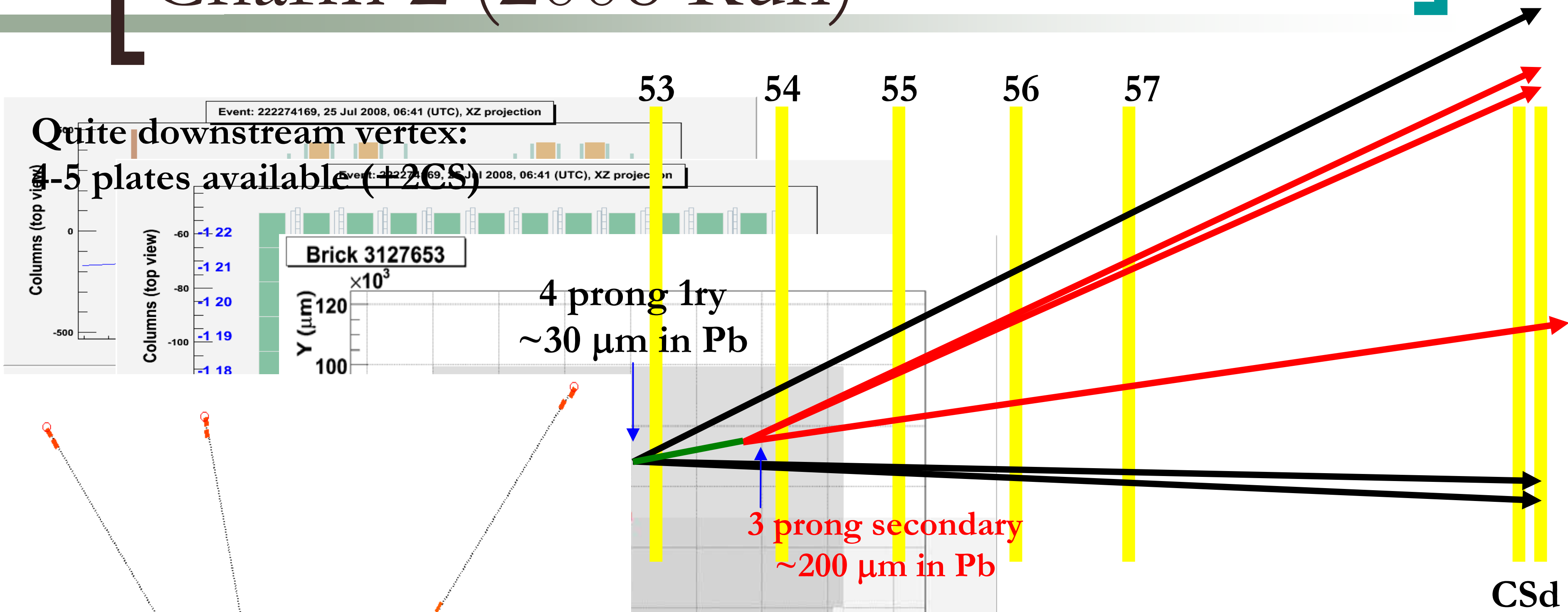
Daughter momentum $p=3.9^{+1.7}_{-0.9}$ GeV/c

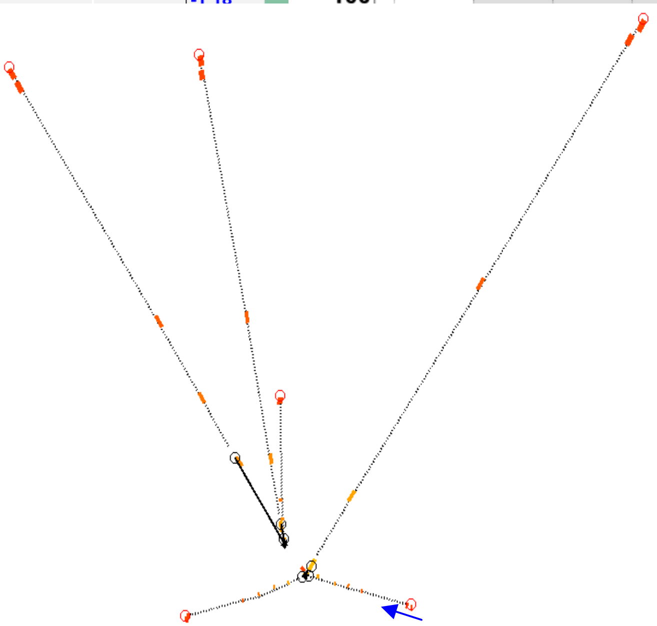
P_t ranges between 600 MeV/c and 1150 MeV/c (90%C.L.)

Probability of hadron reinteraction ~4 x 10^{-4}

Charm 2 (2008 Run)

Quite downstream vertex:
4-5 plates available (+2CS)





Charged parent path length ~ 1150 µm
ΔΦ ~ 150° (~ back to back favour charm interpretation)
$p_1=2.4^{+1.3}_{-0.6}$ $p_2=1.3^{+0.4}_{-0.3}$ $p_3=1.2^{+1.7}_{-0.4}$ GeV/c (evaluated by using multiple coulomb scattering and extracting downstream brick)
Probability of hadron reinteraction ~10^{-6}

Conclusions

- The OPERA detector is completed and it is now massive with 1.3 kton of lead-emulsion target
- Emulsion scanning laboratories and infrastructures are operational
- 2008 Run: from June 18th to November 3rd
  - Partial recovery of the beam after a rather problematic start: 1.78×10^{19} pot instead of 2.2×10^{19} p.o.t.
  - ~1700 events recorded… analysis is on-going
  - sample to fine tune OPERA analysis and to estimate efficiencies and background
- Expectations for 2009 (Start May 21th - End November 23rd):
  - 166 days
  - 2.4×10^{13} pot/extraction ⇨ 3.5×10^{19} pot ⇨ ~3500 events

Looking forward to see… the first τ event!!!