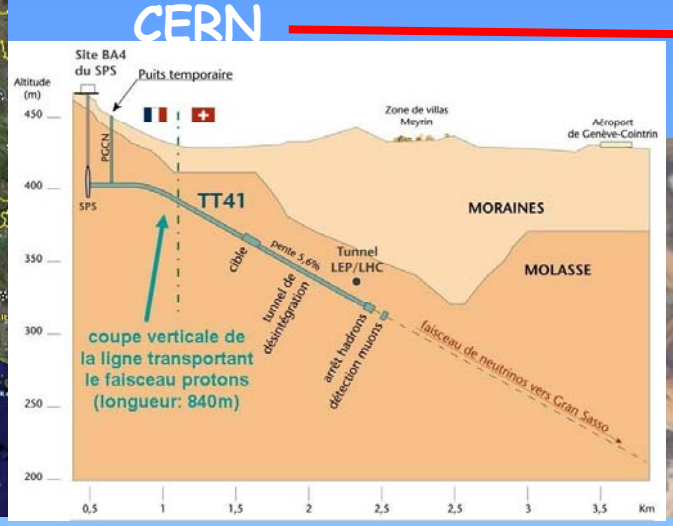
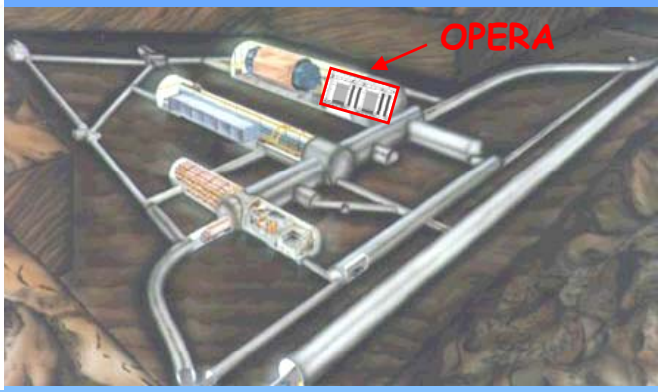




OPERA Status

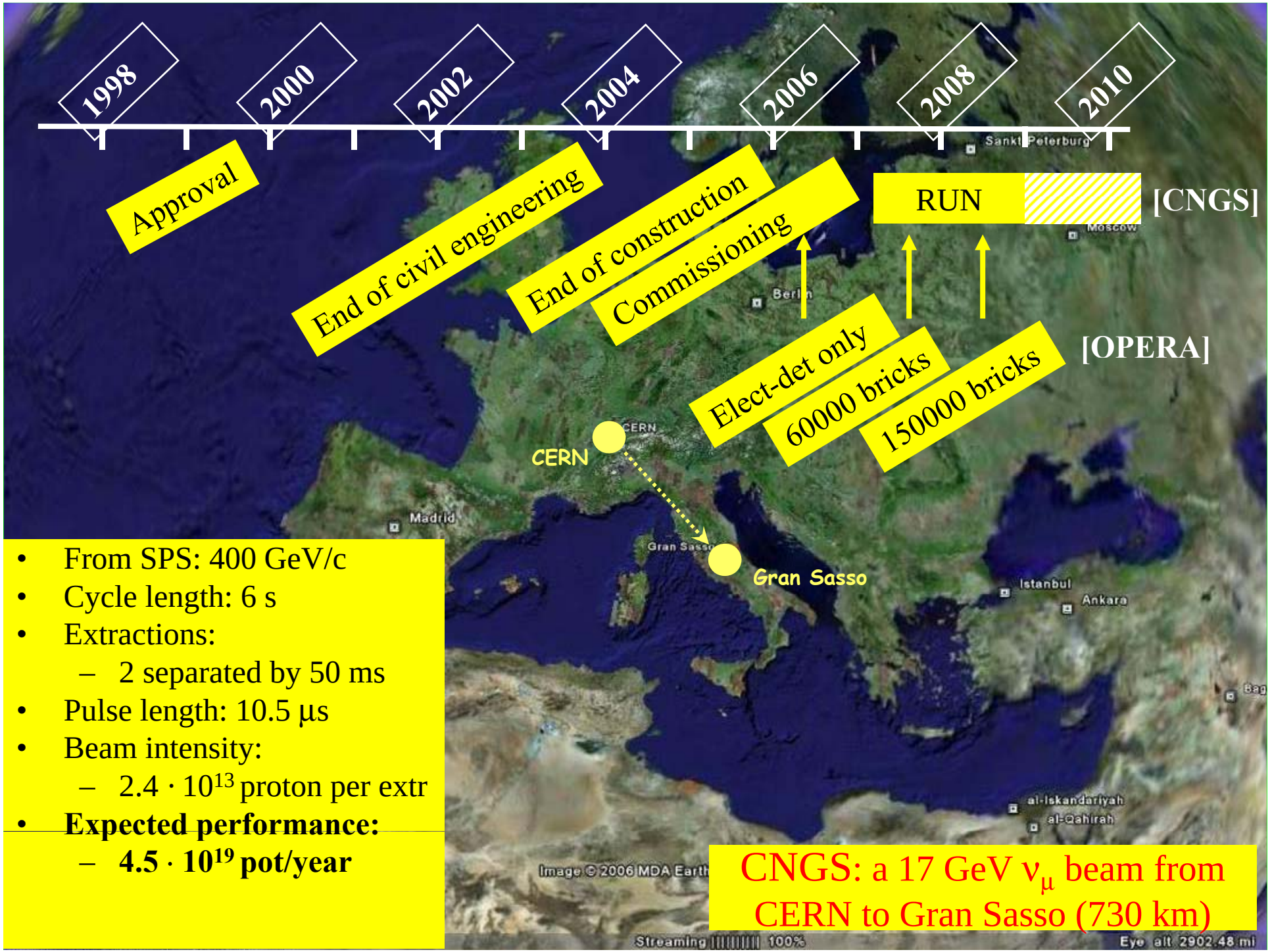
(yesterday – today: neutrino detection)

Luca Stanco – INFN Padova*

* on behalf of OPERA Collaboration

The experimental challenge of direct detection of TAU's appearance

- LongBaseLine experience in Europe (CNGS)
- "Modern" Nuclear Emulsion Technique (OPERA Detector)
- RUNS from 2006 to 2008,
  from DAQ to submicrometric measures:
  what we have learned, what we are learning
- Expectations for 2009 and 2010

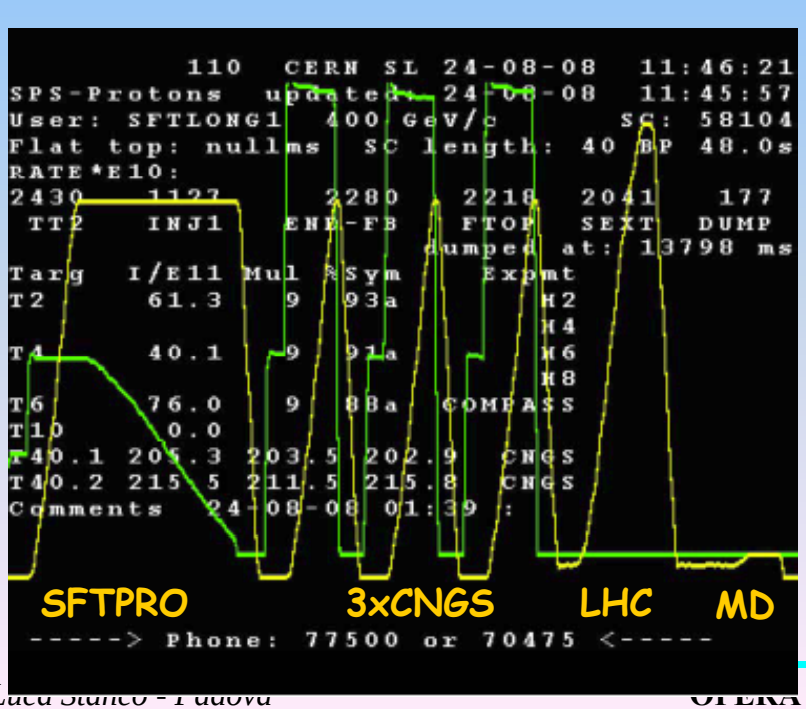


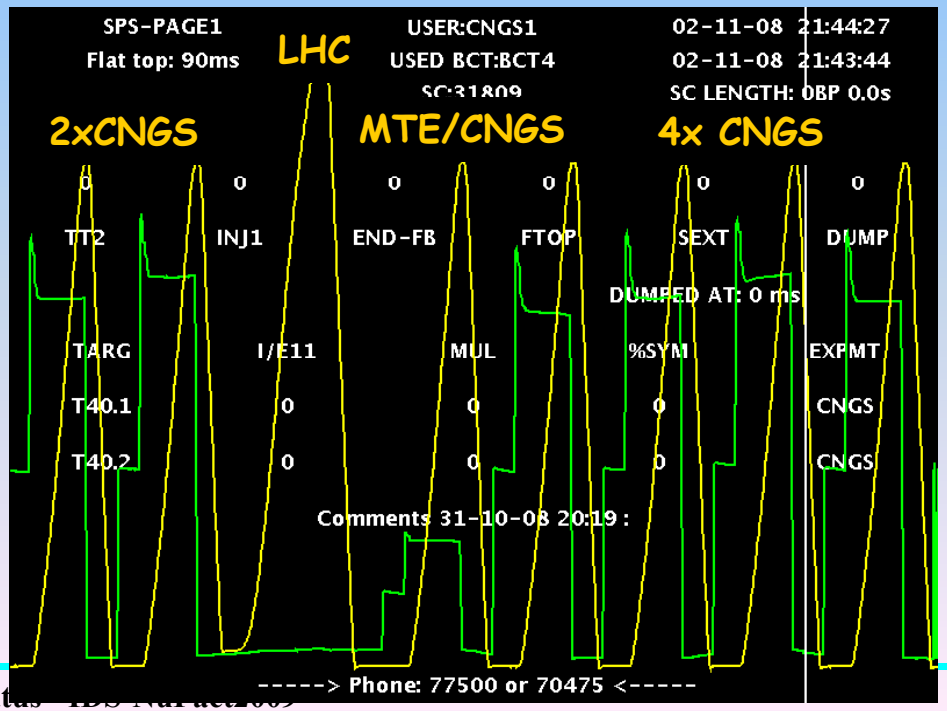
- From SPS: 400 GeV/c
- Cycle length: 6 s
- Extractions:
  - 2 separated by 50 ms
- Pulse length: 10.5 μs
- Beam intensity:
  - $2.4 \cdot 10^{13}$ proton per extr
- **Expected performance:**
  - **$4.5 \cdot 10^{19}$ pot/year**

CNGS: a 17 GeV ν_μ beam from CERN to Gran Sasso (730 km)

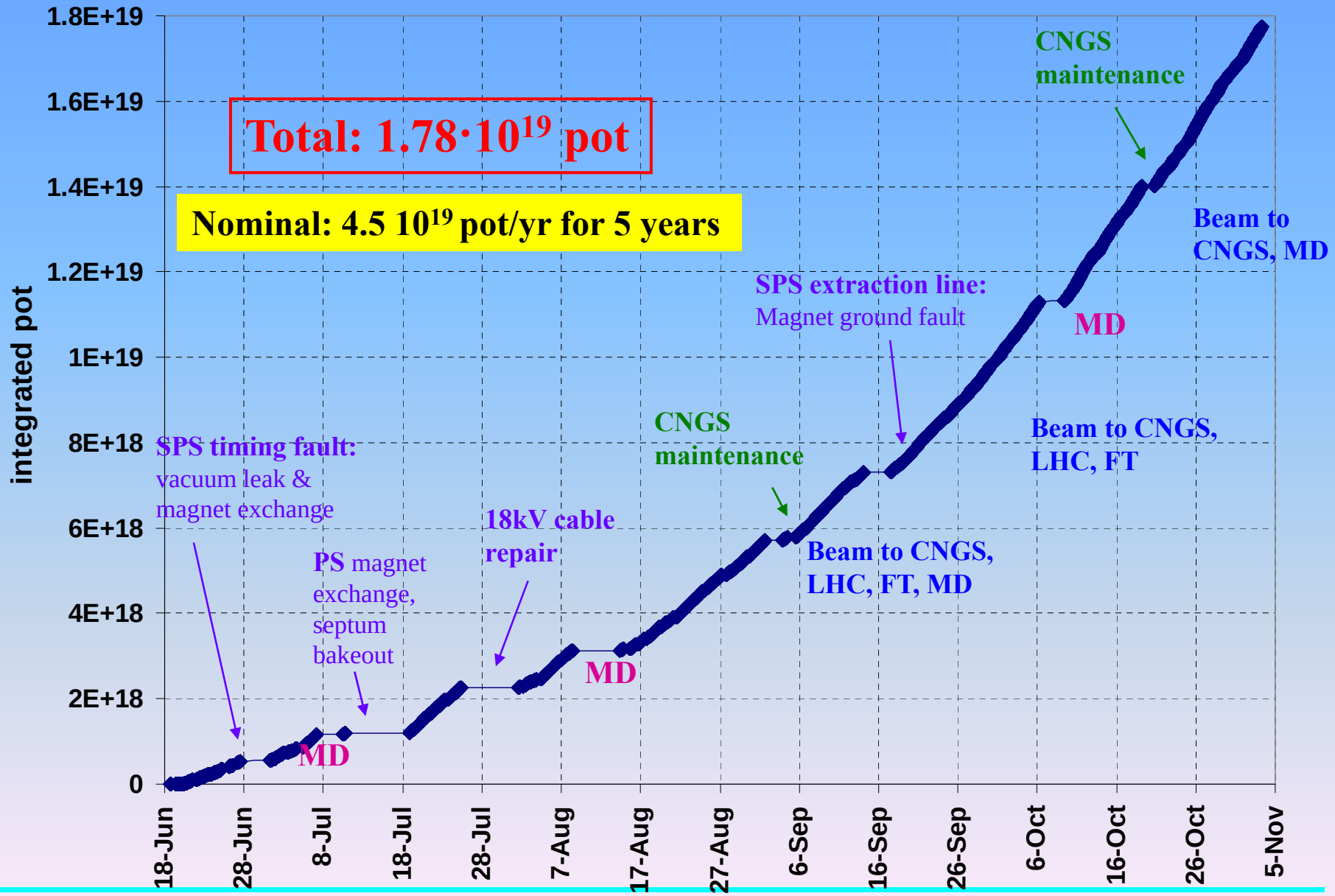
- 2006 Pilot run: after commissioning in Aug, no follow-up in October due to a problem in the cooling of one horn. Moreover, no bricks in OPERA
- 2007: Major problems in the radiation shielding of the ventilation system. Only $8 \cdot 10^{17}$ pot. Significant interventions during winter shutdown.
- 2008 OPERA fully operational (see below). Performance of the CERN injection complex poor at beginning but steadily improving.
- After the LHC accident, further increase of the integrated intensity for OPERA (duty cycle 37.5% →83%).

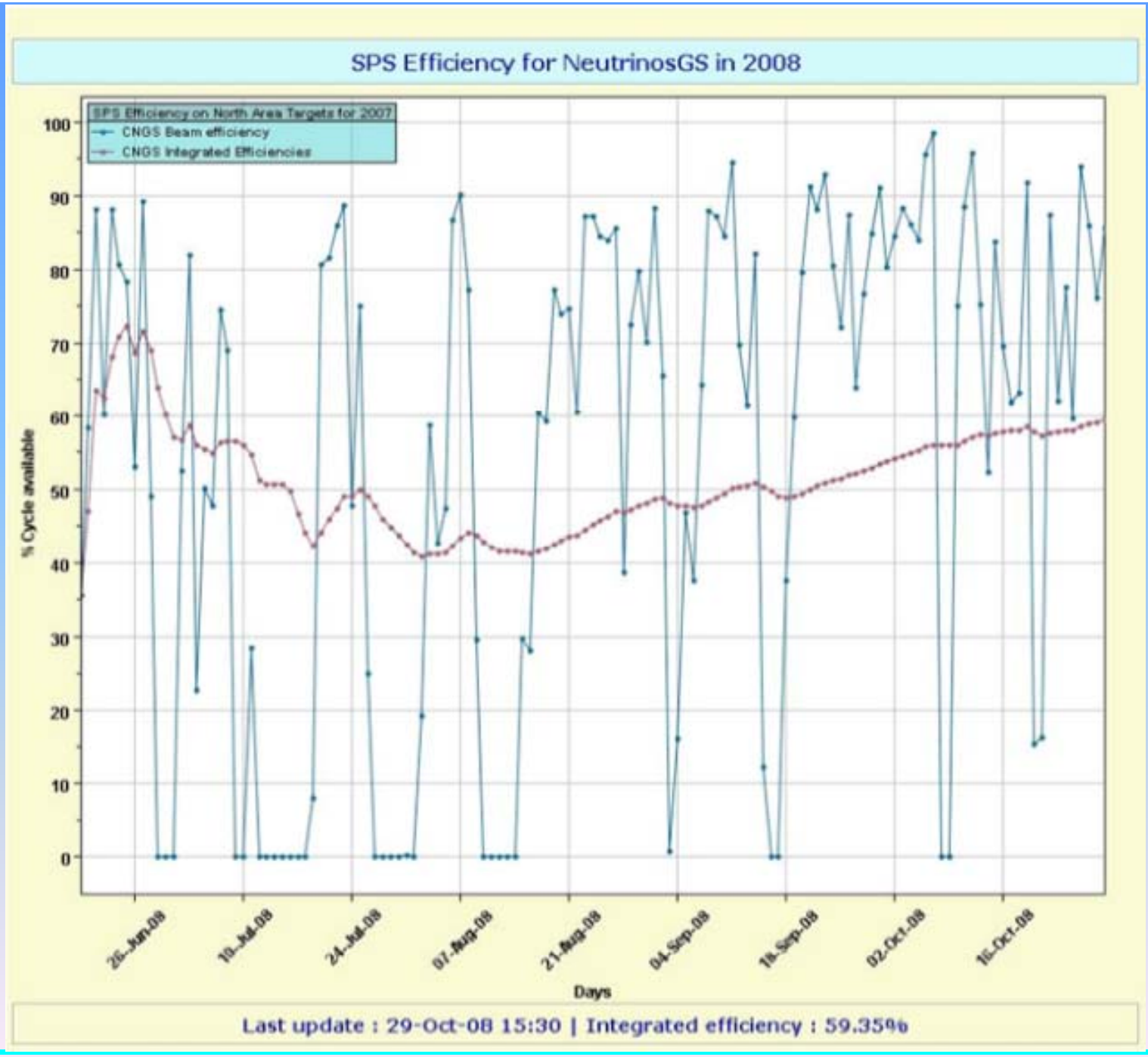
The 2008 run was the first long physics run for the CNGS





CNGS Run 2008: 18 June- 03 Nov 2008



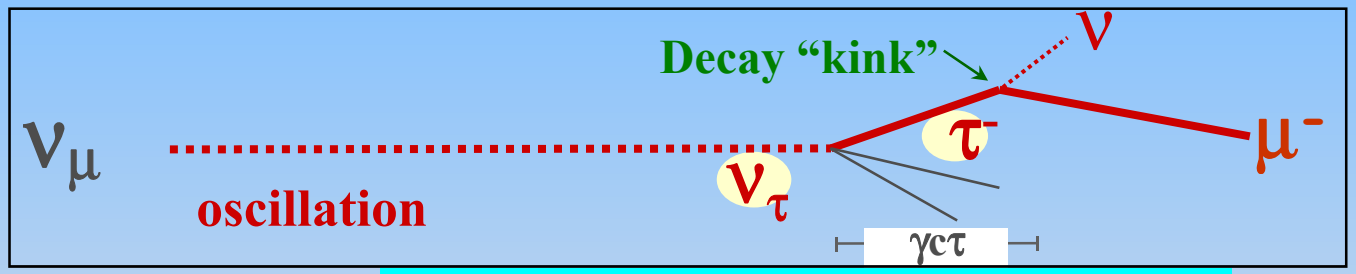

SPS Efficiency for NeutrinosGS in 2008
SPS Efficiency on North Area Targets for 2007
CNGS Beam efficiency
CNGS Integrated Efficiencies
% Cycle available
100
90
80
70
60
50
40
30
20
10
0
26-Jun-08
10-Jul-08
24-Jul-08
07-Aug-08
21-Aug-08
04-Sep-08
18-Sep-08
02-Oct-08
16-Oct-08
Days
Last update : 29-Oct-08 15:30 | Integrated efficiency : 59.35%

… for tau neutrino CC detection !

$\nu_\mu \xrightarrow[\text{oscillation}]{} \nu_\tau + N \xrightarrow{\text{CC interaction}} \tau^- + X$

$\tau^- \rightarrow$

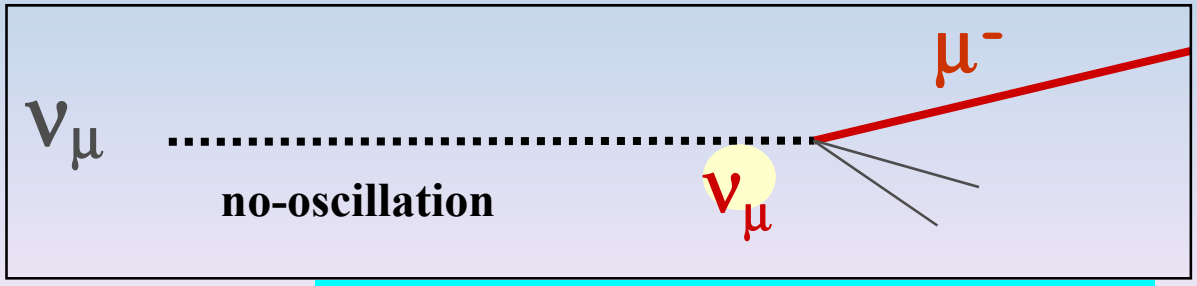
$\mu^- \ \nu_\tau \ \bar{\nu}_\mu$	B. R. ~ 17%
$h^- \ \nu_\tau \ n(\pi^o)$	B. R. ~ 50%
$e^- \ \nu_\tau \ \bar{\nu}_\varepsilon$	B. R. ~ 18%
$\pi^+ \pi^- \pi^- \ \nu_\tau \ n(\pi^o)$	B. R. ~ 14%



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

(≈ 600 μm of path)

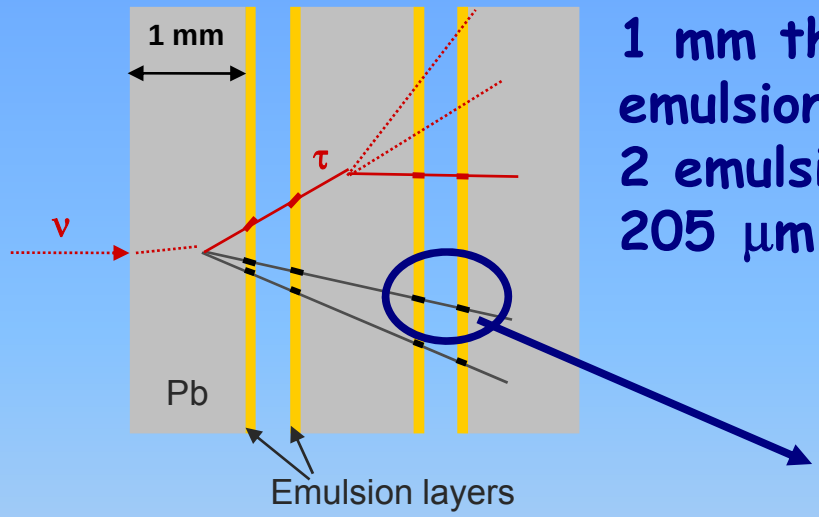
(with ≈ 35% of Non-Scaling QE and 65% DIS)



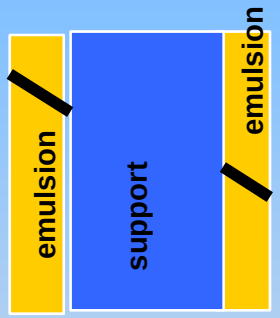
(with ≈ 11% of Non-Scaling QE and 89% DIS)

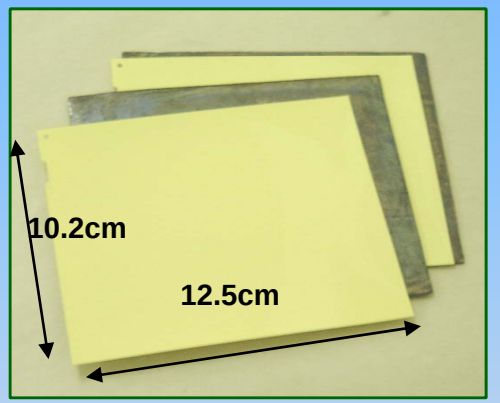
The OPERA principle

OPERA adopts the ECC concept (Emulsion Cloud Chamber):



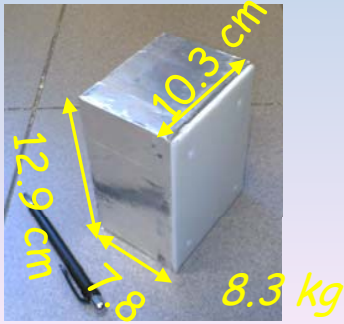
1 mm thick Pb layers interleaved with emulsions with 1 μm space resolution
2 emulsion layers (44 μm thick) poured on a 205 μm plastic base





Track reconstruction accuracy inside emulsion layers: $\Delta x \approx 1$ μm $\Delta\theta \approx 1$ mrad

"BRICK" arrangment:
- 57 emulsion sets
- 56 Pb layers

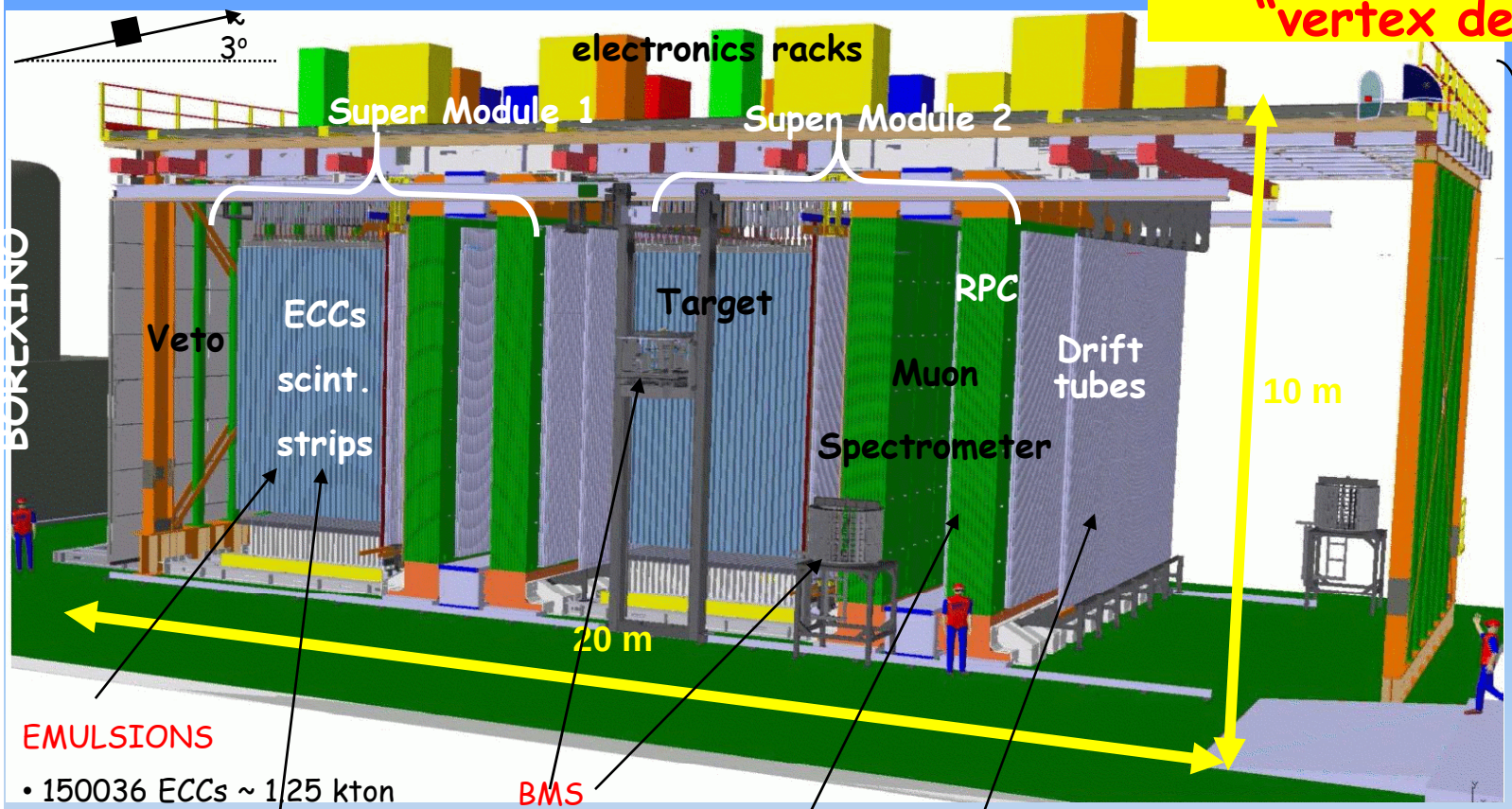


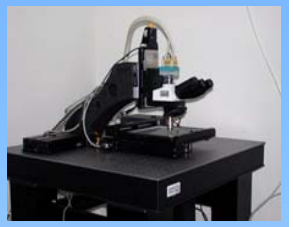
Plus 2 external emulsion sets for "interplay" with Electronics Data, arranged in a white plastic cover

CS

The OPERA detector

a quite large fine grained "vertex detector" !





EMULSIONS

• 150036 ECCs ~ 1.25 kton

BMS

Brick Manipulator system

TARGET TRACKERS

• 2 x 31 scintillator strips walls
• 256+256 X-Y strips/wall
• both-sides readout, WLS fiber
• 64-channel H7546 PMT
• 63488 channels
• ♦ ~ 0.8 cm (2.6 cm pitch)
• ε ≅ 99%
• rate ≅ 20 Hz/pixel @1 p.e.

INNER TRACKERS

• 990-ton Fe dipole magnets (B= 1.55 T) instrumented with
• 22 RPC planes (streamer mode)
• 3050 m² surface
• ♦ ~1.3 cm spatial resolution
• ε ≅ 96% (geometrical)

HIGH PRECISION TRACKERS

6 drift-tube layers/spectrometer
spatial resolution < 0.5 mm

+ several essential "off-site" ancillary facilities:

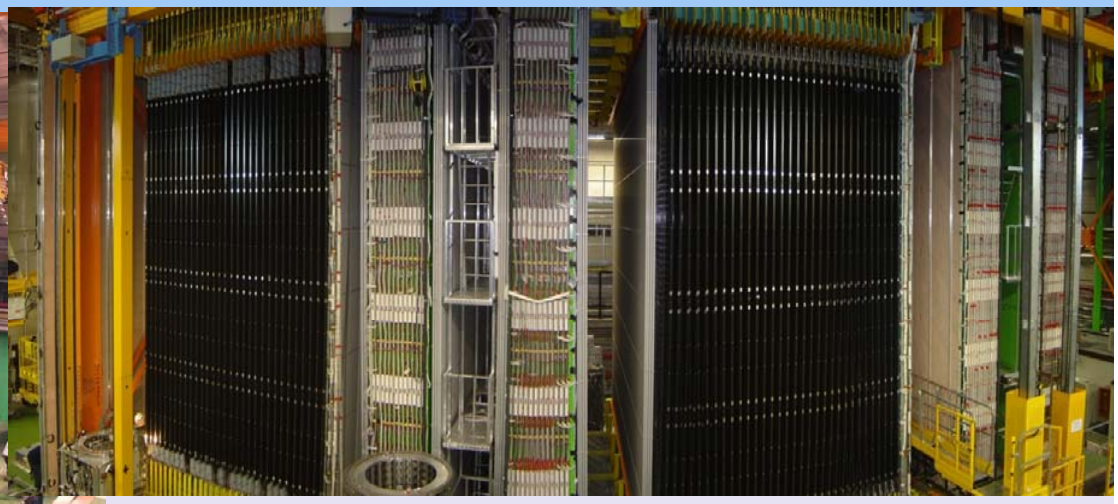
- **emulsion "refreshing",**
- **brick assembly/disassembly**
- **labelling**
- **automatic development**
- **scanning**

September 2003

... 2004

... 2005

... 2006



Installation completed with VETO and HPT before first half of 2007

10

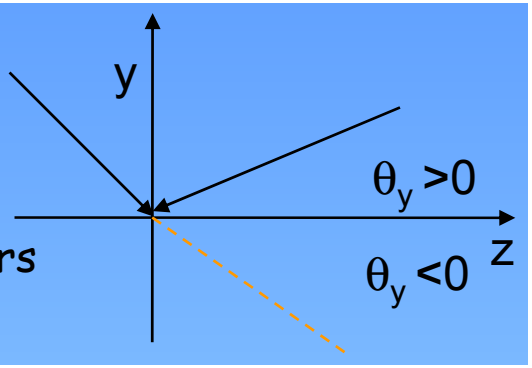
The OPERA 2006 run

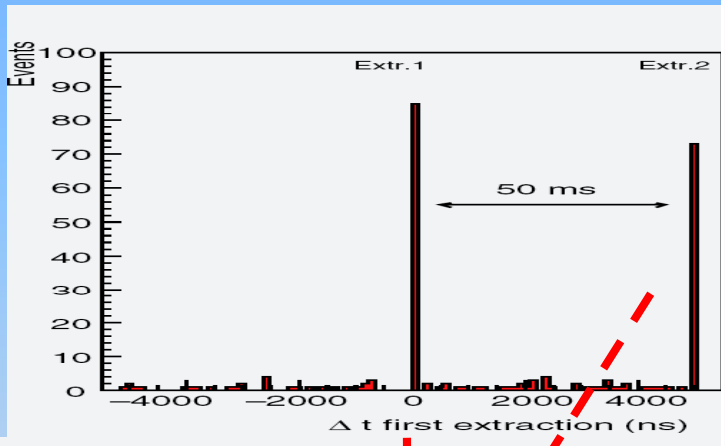
R. Acquafredda et al., New J. Phys. 8 (2006) 303

Aug 2006: technical run, **0.76*10^{18} pot** collected

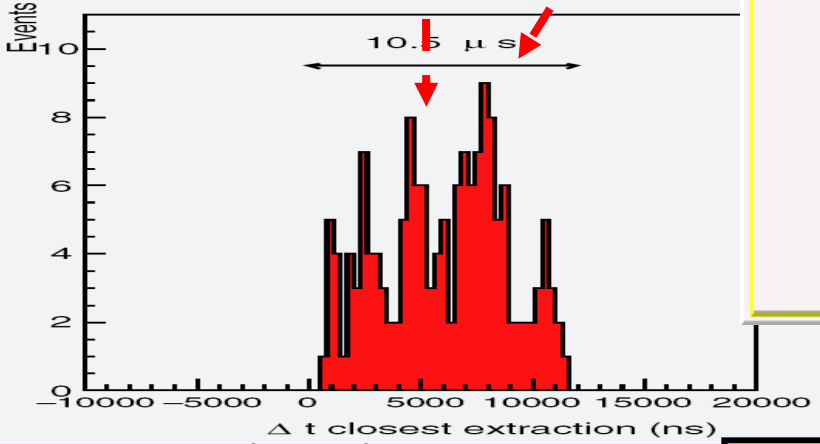
319 interactions in the rock, mechanical structure and spectrometers

GPS time correlated with CERN beam spill time



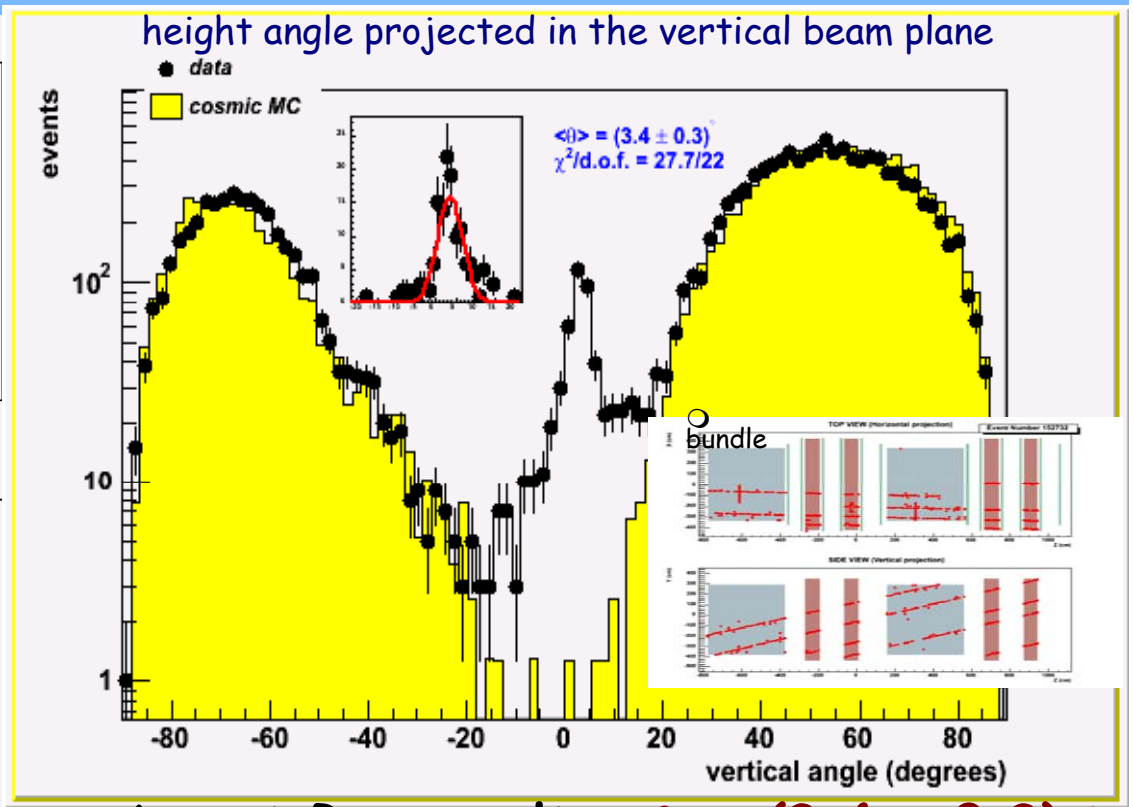


Zoom on the spill peaks



Extraction length = 10.5 μs

height angle projected in the vertical beam plane

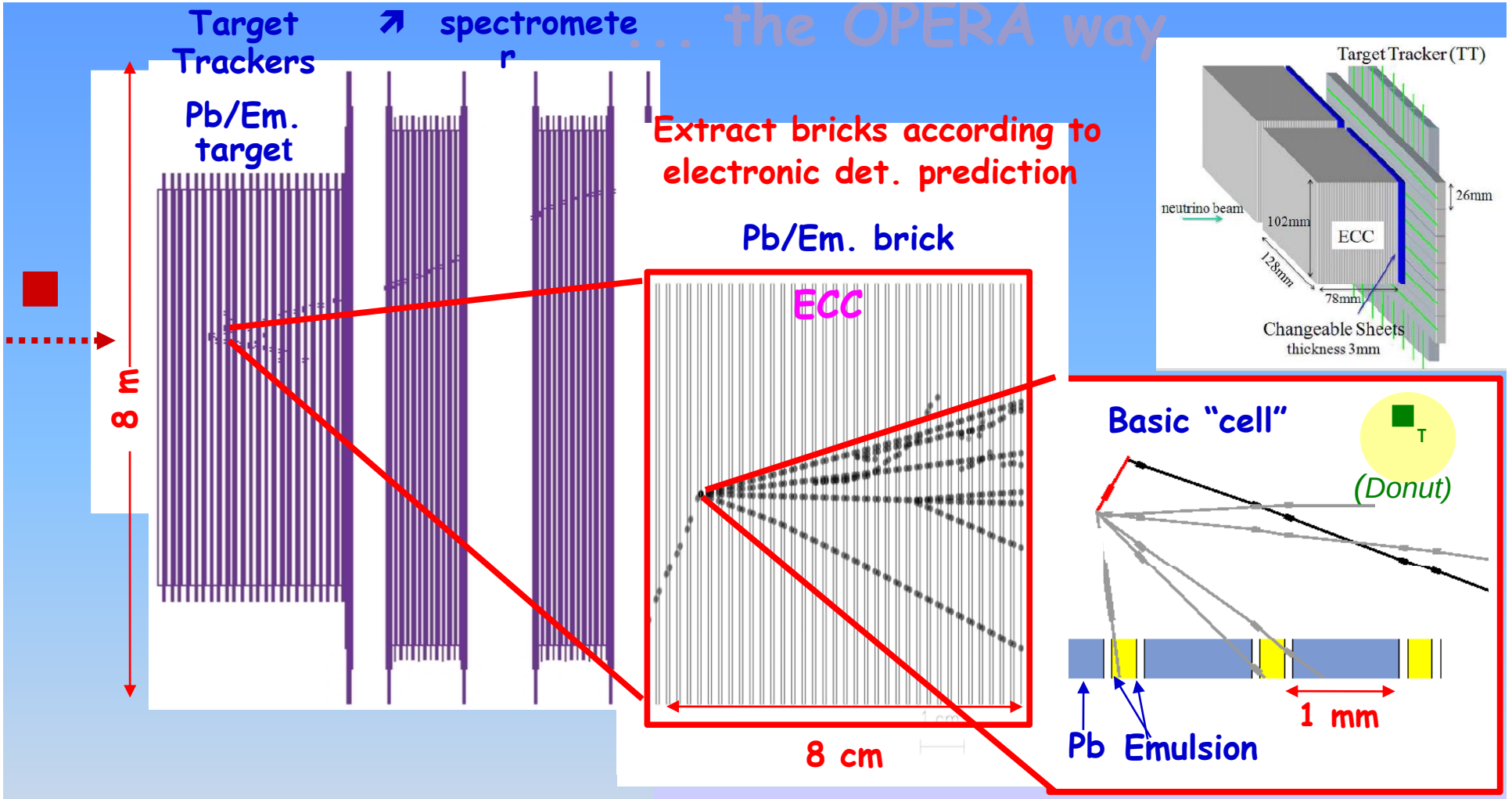


August Run result: <θ>= (3.4 ± 0.3) °

(statistically dominated)

MC: simulation from MACRO parametrization, ABSOLUTE normalization

... the OPERA way



Electronic detectors

detect ■ interaction, brick finding

↗ ID, Q and p : background suppression

Emulsion detectors:

modular structure of 150036 ECCs

mass industrial production with high standards

FAST-AUTOMATIC scanning

vertex search, decay search, e/↗ ID, event kinematics

The OPERA 2007 run

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

31.5 ± 6 expected events in bricks

38 events registered in the target

(29 CC-like and 9 NC-like)

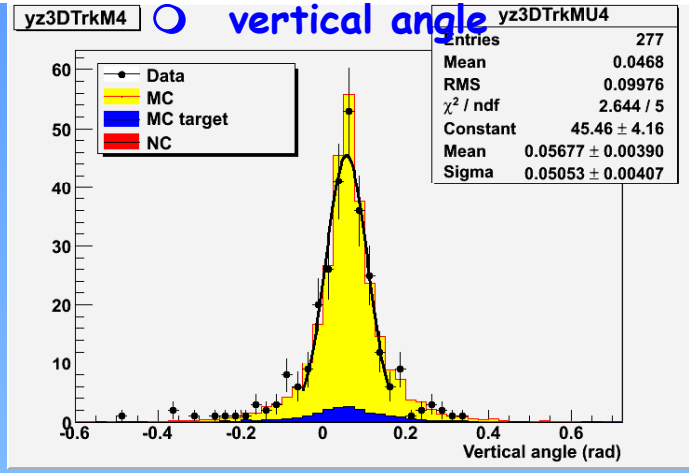
Out of target interactions (rock muons, vtx in the spec

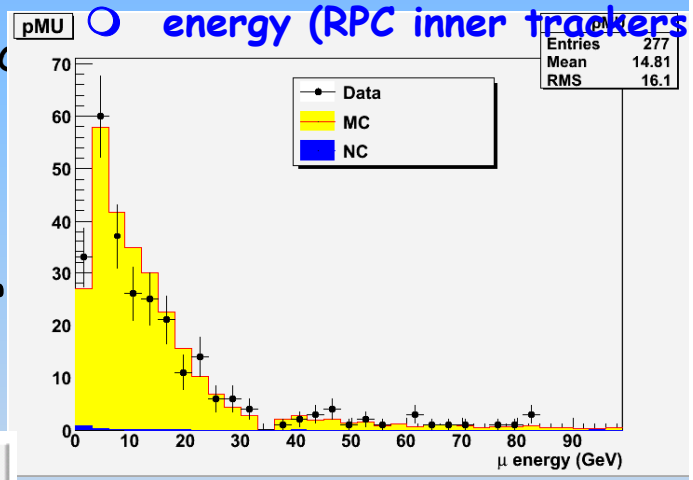
331 events passed the analysis cut

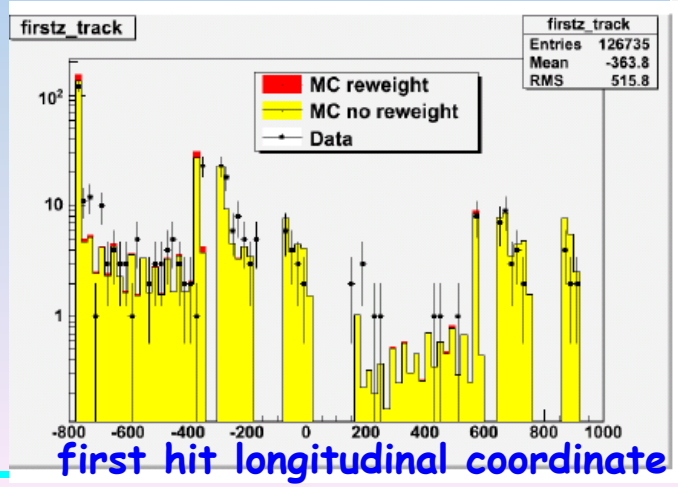
303 expected

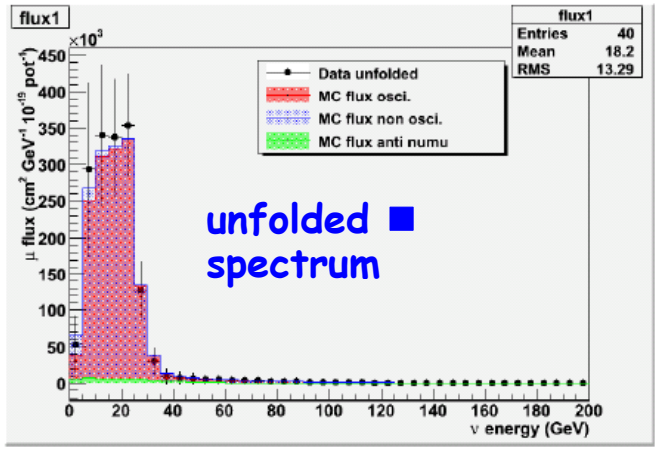
First test on real neutrino interactions for Brick handling, Film Processing, Scanning

Unfortunately statistics has been limited: ANALYSIS with 2008 RUN…









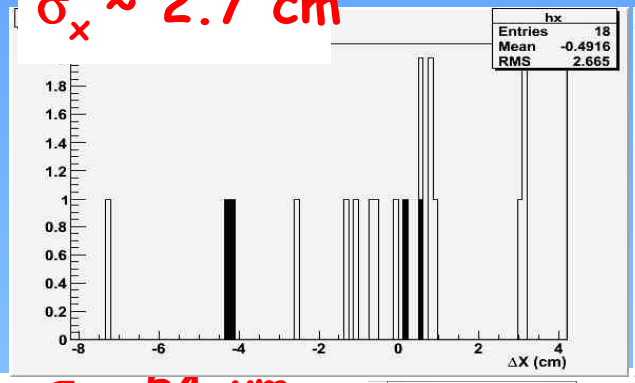
Interconnection between electronic counters and emulsions

physics events !

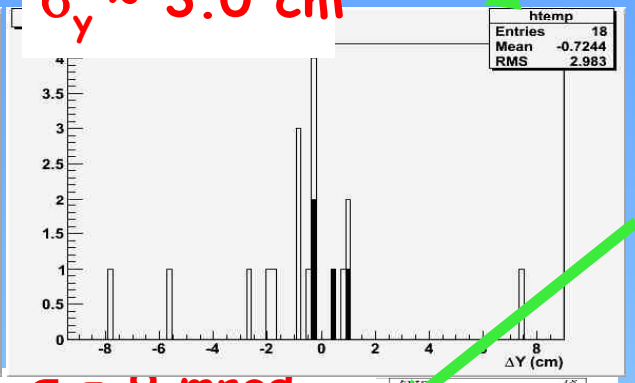
see also arXiv:0804.1985v1

leap of a factor 10000 in precision !

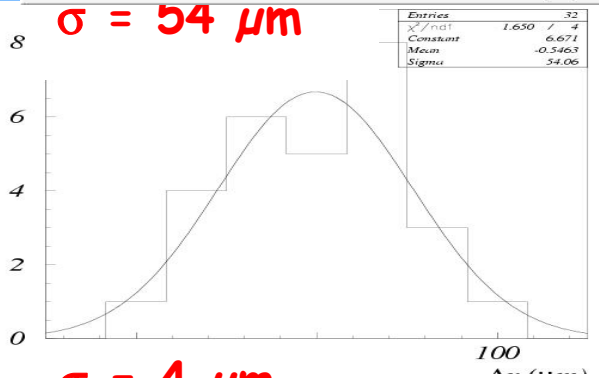
$\sigma_x \sim 2.7$ cm



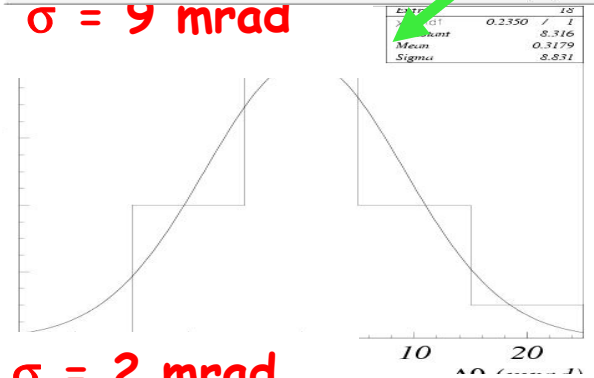
$\sigma_y \sim 3.0$ cm



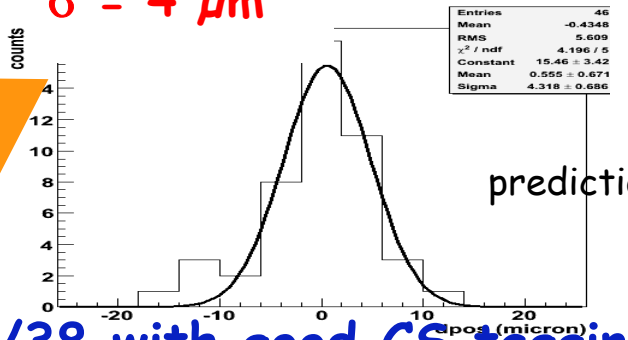
σ = 54 μm



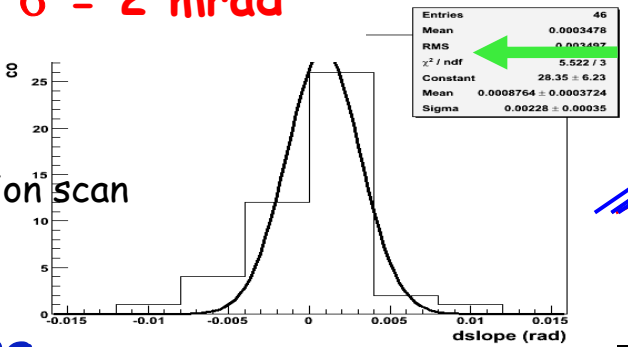
σ = 9 mrad



σ = 4 μm



σ = 2 mrad



prediction scan

36/38 with good CS tagging

Wall Finding: > 95%

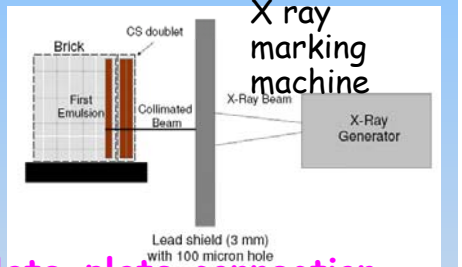
Brick Finding: (80 ± 7) %

Electronic-detector to CS

- position of bricks known from extensive alignment measurements + mechanical model of structure deformation

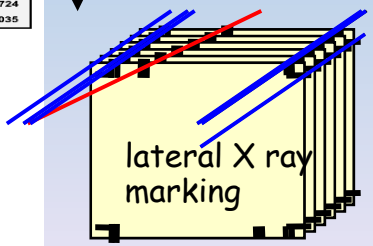
CS-brick connection

- marking with 4 X ray beams to fix CS-1st plate relative position.
- Also performed for all plates with thin lateral X beams to get fast alignment pattern to be used in tracks follow-down
- CS-CS align: Compton tracks.

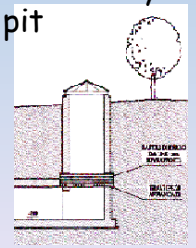


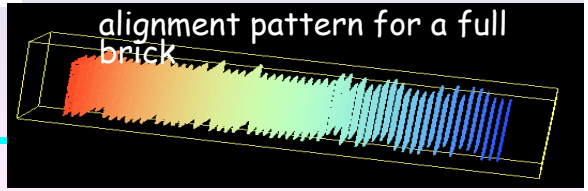
X ray marking machine

Plate-plate connection



cosmic ray pit

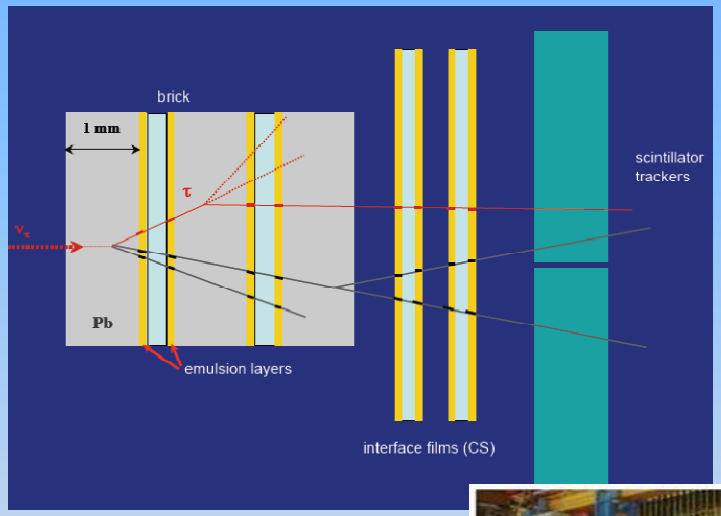


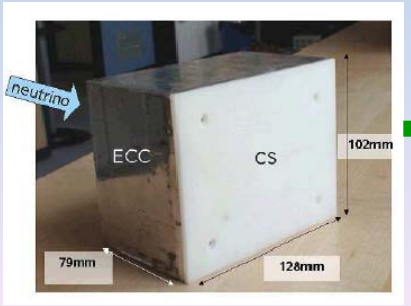


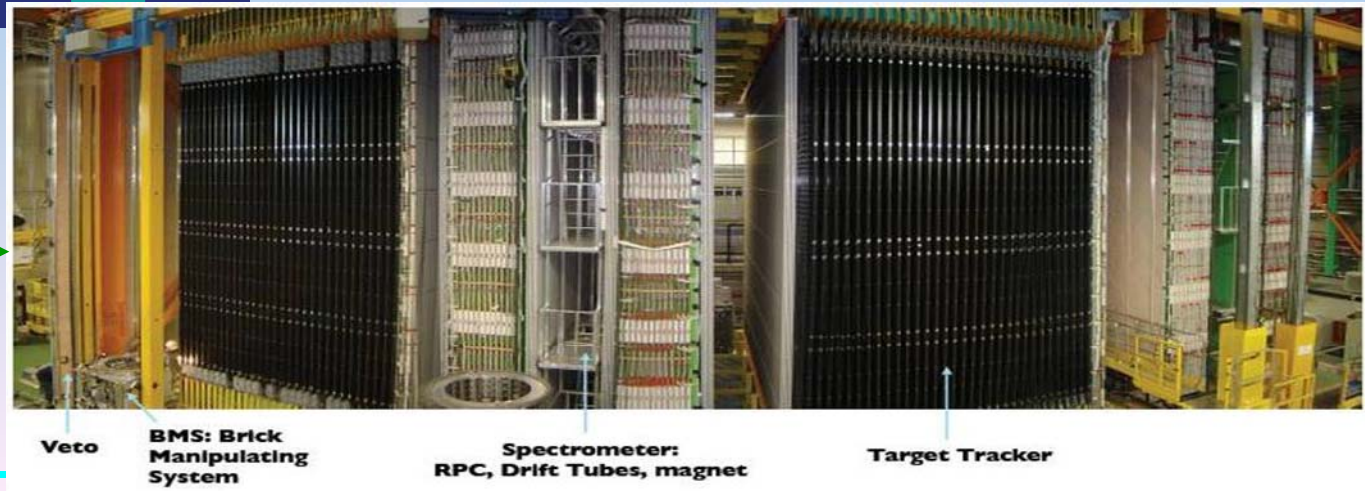
- cosmic rays used for local alignment. Exposure at surface done in a pit designed to suppress low-E component.

The completion of the OPERA construction(*)

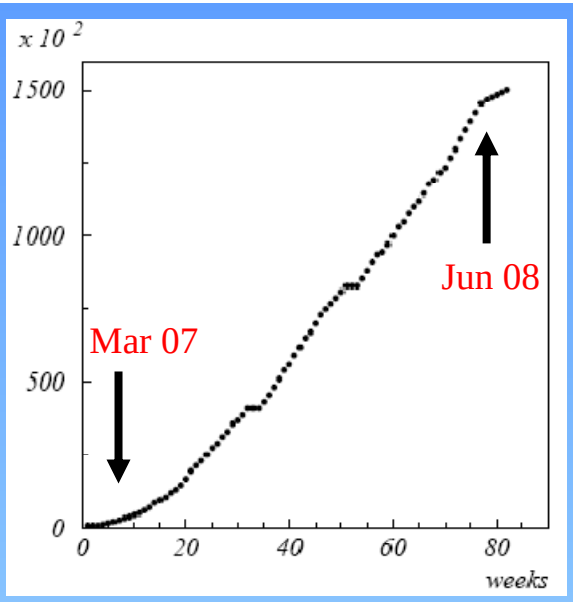
OPERA is based on the only proven technology (DONUT) to identify ν_τ on an event-by-event basis (nucl.emuls.&lead driven by real time detectors). It will be celebrated as a **major engineering achievement** since it brought such technology to an **immense size** (1.25 kton)





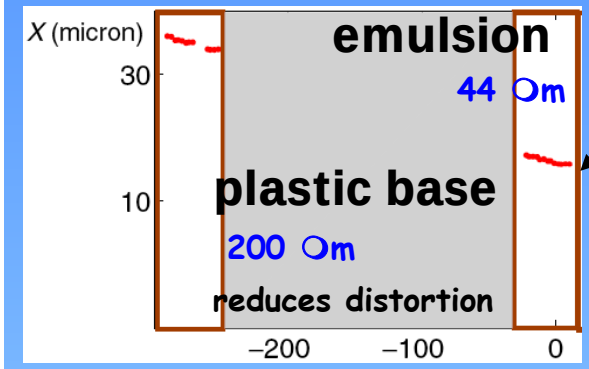


(*) R.Acquafredda et al., "The Opera experiment in the CERN to GS ν beam"; submitted to JINST

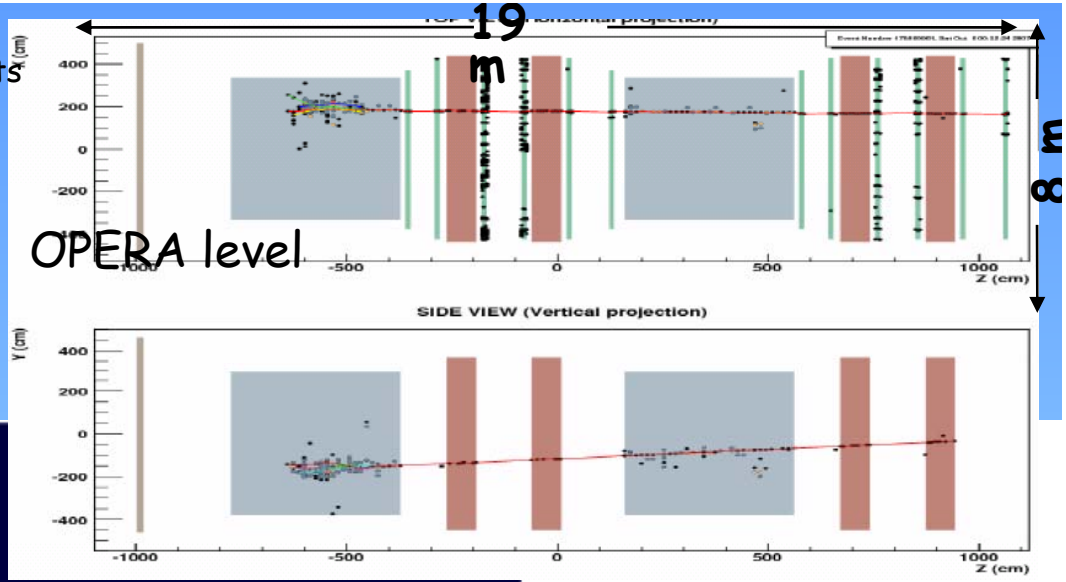


150036 brick have been produced and installed in the detector (1.25 kton mass)

OPERA is an **hybrid detector** built running in parallel with several ancillary facilities that - before 2008 – hadn't been validated at nominal speed, yet



~10 measurements per side



XY

A beautiful ν_μ CC

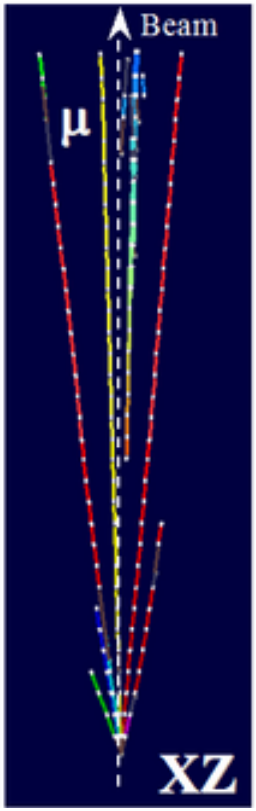
ECC level

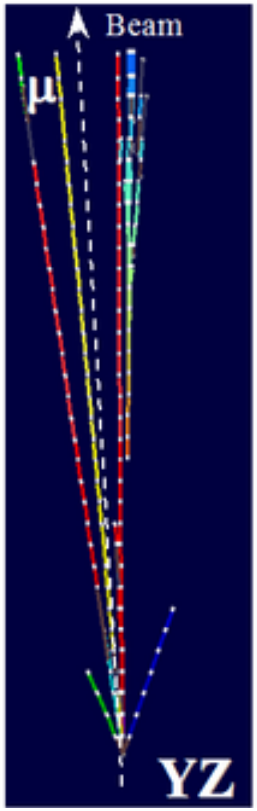
pair opening angle 10 mrad

E_{γ_0} = 157 MeV

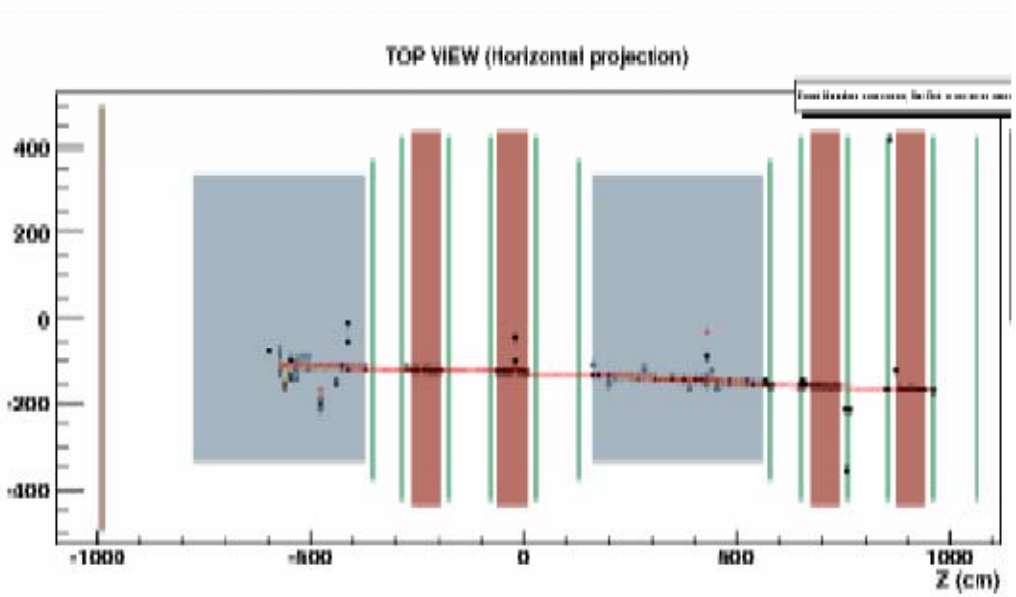
low p track

6 prongs

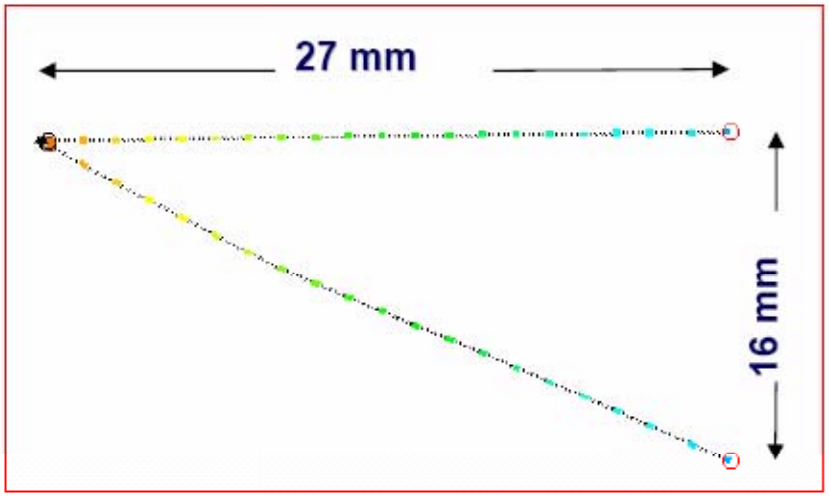


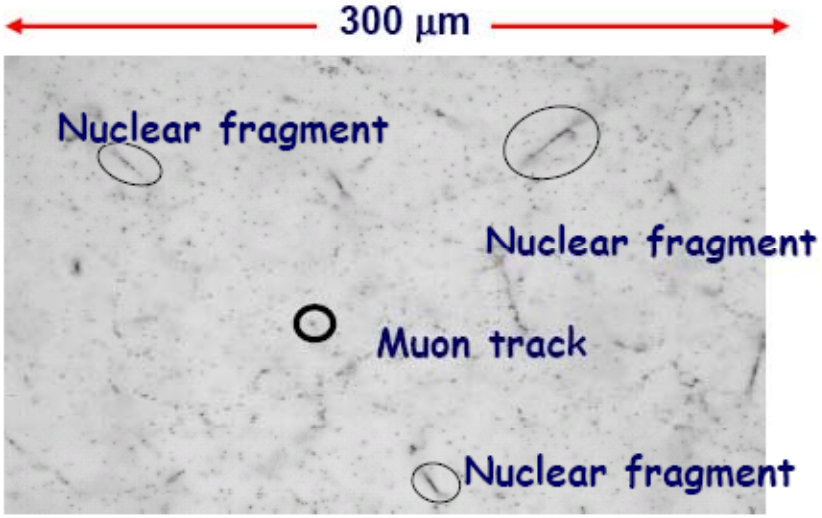


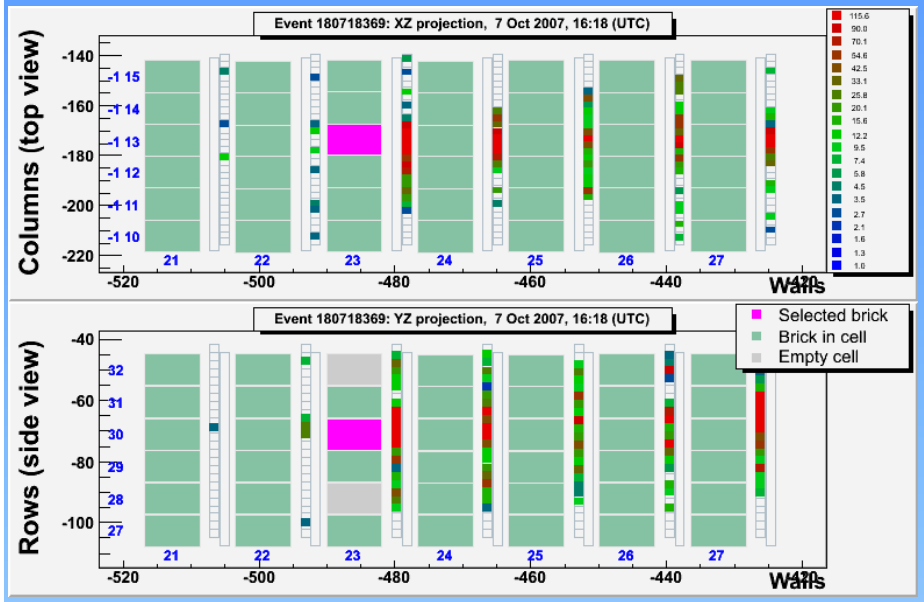
A ■ quasi-elastic CC interaction



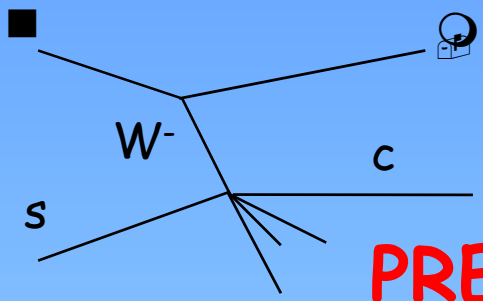
Event 179673325 QE-like topology



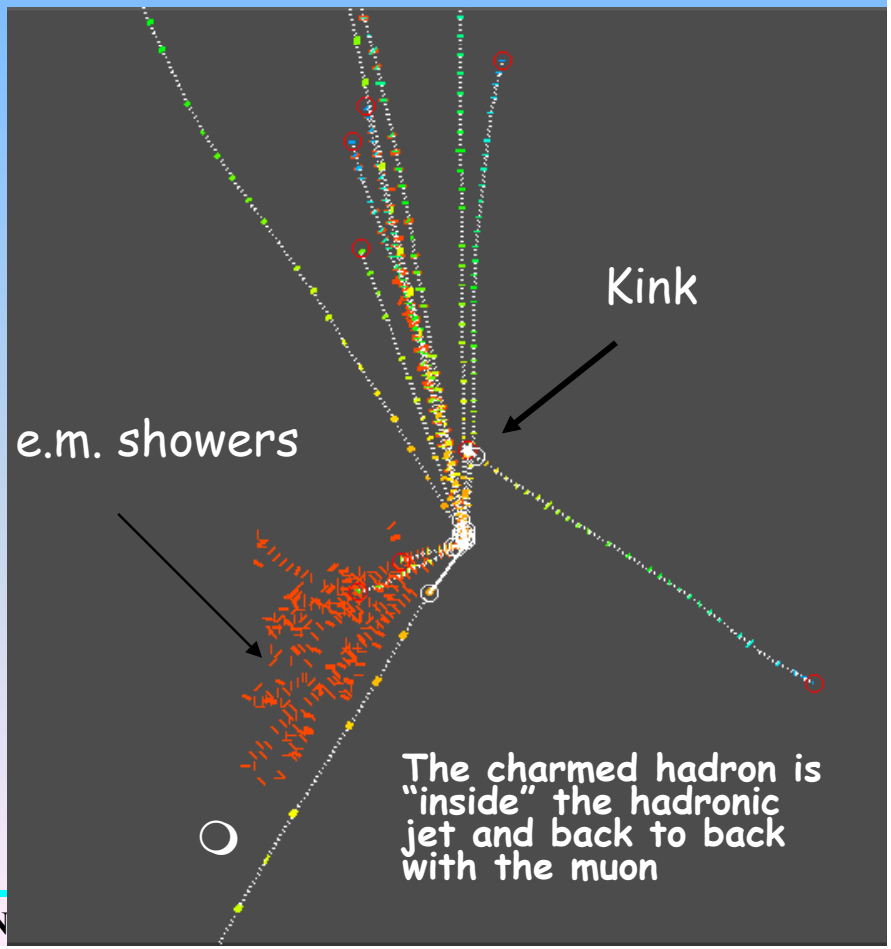




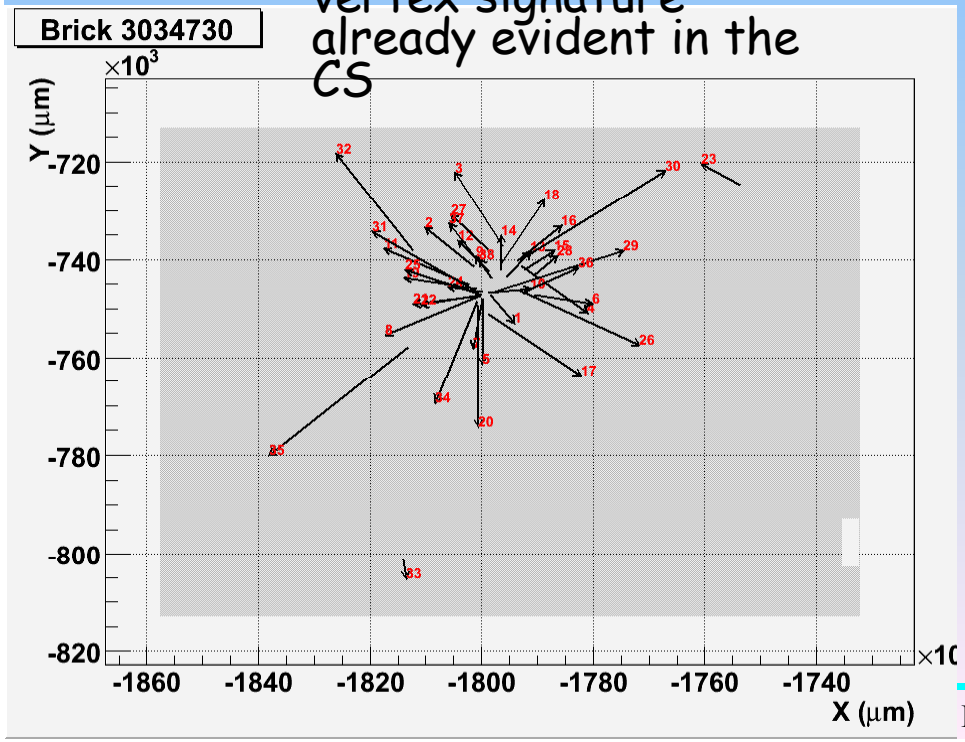
A charm candidate



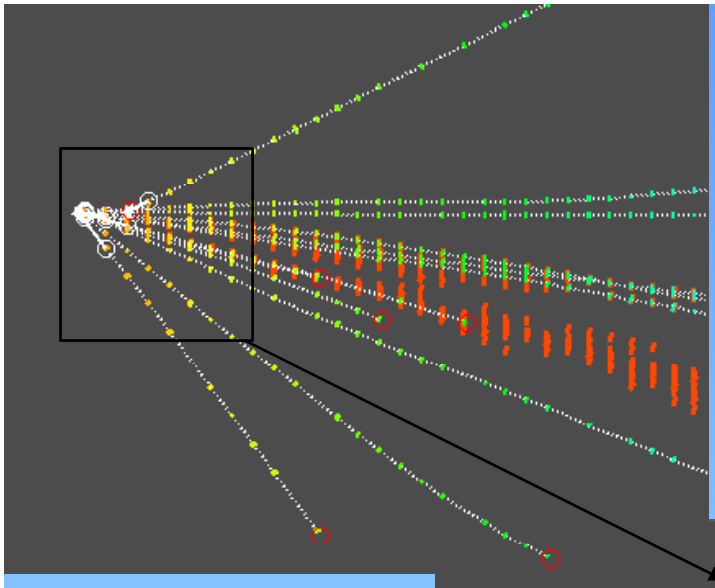
PRELIMINARY

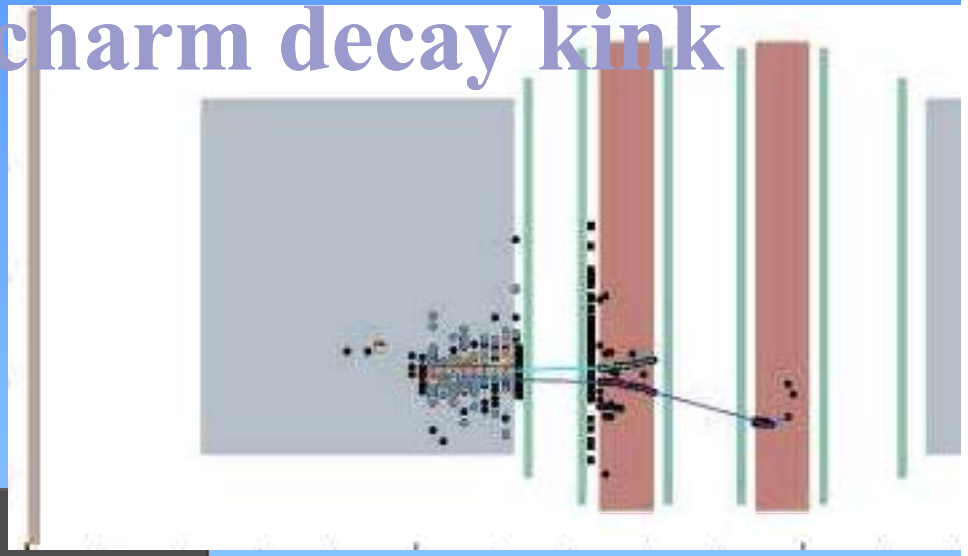


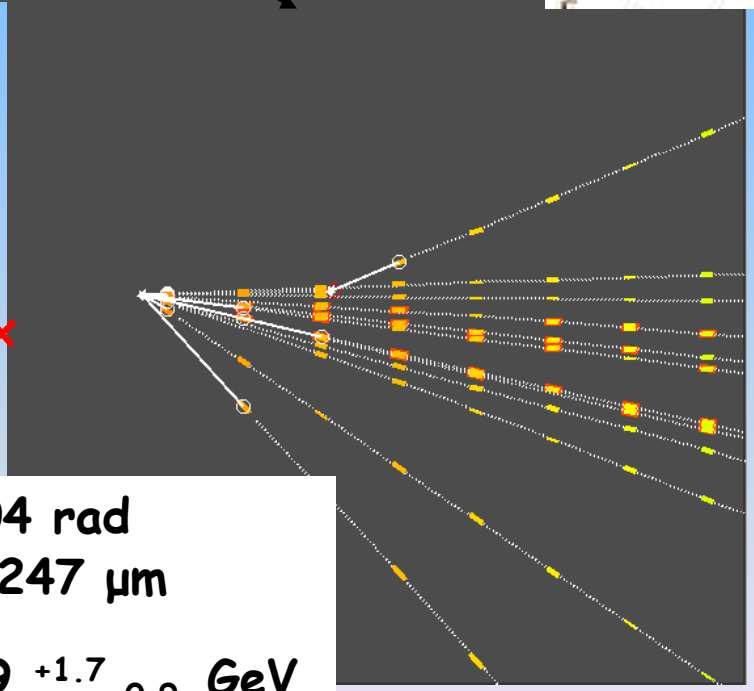
vertex signature already evident in the CS

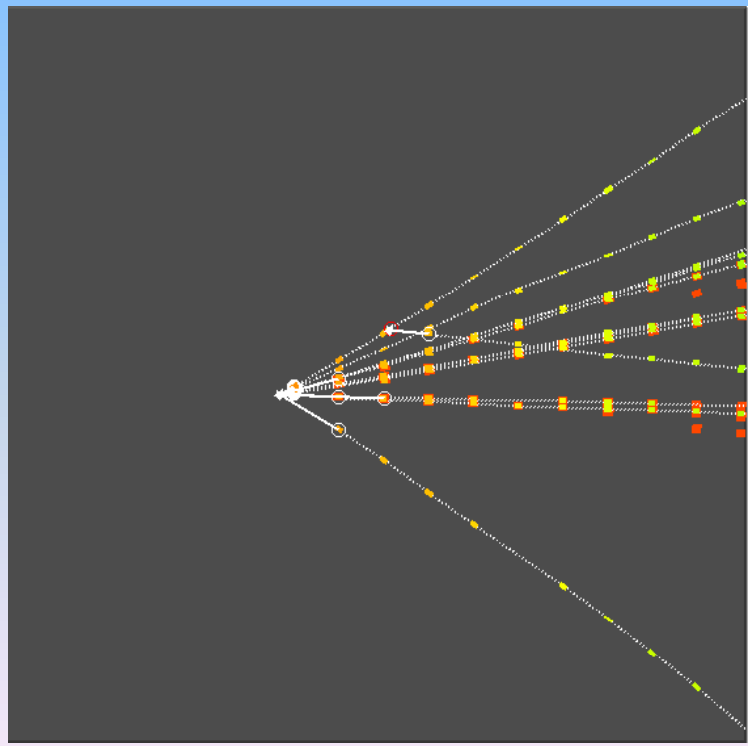


The charm decay kink







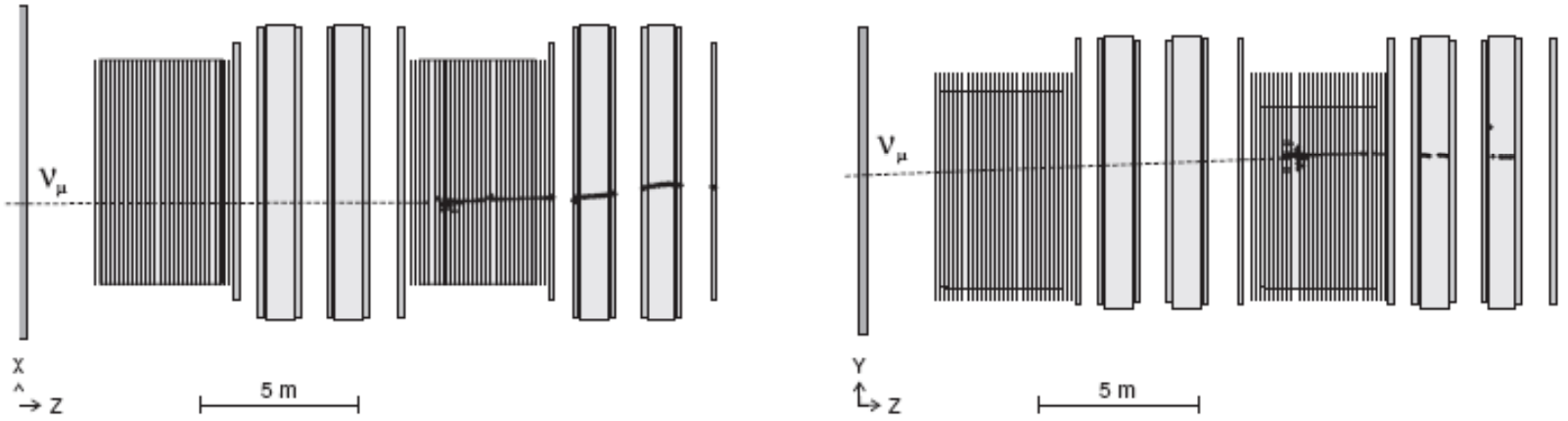


Secondary Vertex
(1 prong decay)

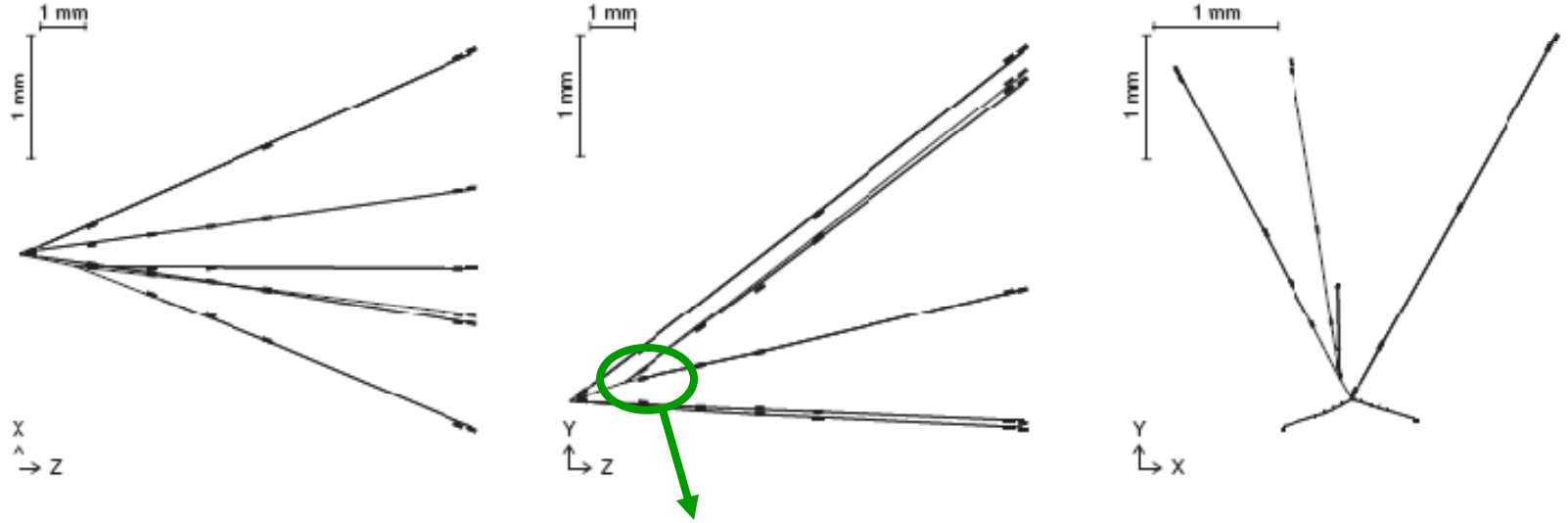
kink angle = 0.204 rad
Decay length = 3247 μm

p(daughter) = $3.9\ ^{+1.7}_{-0.9}$ GeV
p_t = 796 MeV
p_t^{MIN} = 606 MeV (90% C.L.)

2° Charm



$\Delta\phi \simeq 150°$



Three prongs

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

OPERA: tau physics search potential

Full mixing, 5 years run, 4.5×10^{19} pot / year and M_D =1.3 Kton
Efficiency before τ identification: $\varepsilon_{trigger} \times \varepsilon_{brick} \times \varepsilon_{geom} \times \varepsilon_{vertex\ location}$ = 99% x (≥70%) x 94% x 90%

τ decay channels	ε(%)	BR(%)	Signal $\Delta m^2 = 2.5 \times 10^{-3}$ eV²	Signal $\Delta m^2 = 3.0 \times 10^{-3}$ eV²	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	ε×BR=10.6%		**10.4**	**14.9**	**0.75**

Expected backgrounds:

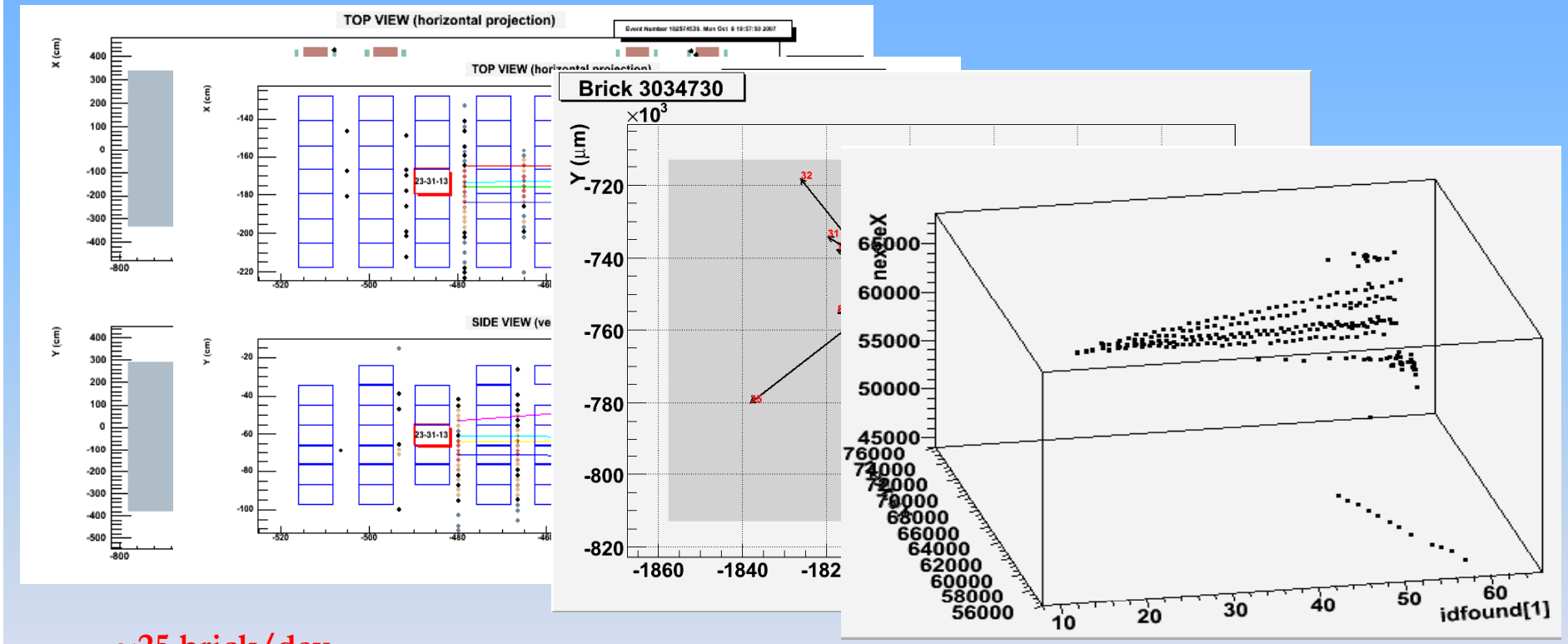
- Charmed particles produced in ν_μ CC and NC interaction
- Hadron reinteractions in lead
- Large angle μ scattering: muons produced in ν_μ CC events
- π^0 mis-identification
- …

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 path: from DAQ to Event Analysis

- ***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 ***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 ***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 sheets 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 (***scan-back***)
- A ***volume scan*** around the neutrino interaction is performed and the neutrino vertex is confirmed
- The scanning lab stores the information about the brick in a local ***database***. Information are then copied in one of the two synchronized central databases
- The events are analyzed ***off-line*** and tau is searched, by accessing to the database

OPERA automatic path along the run



~25 brick/day

~200 cm^2/event

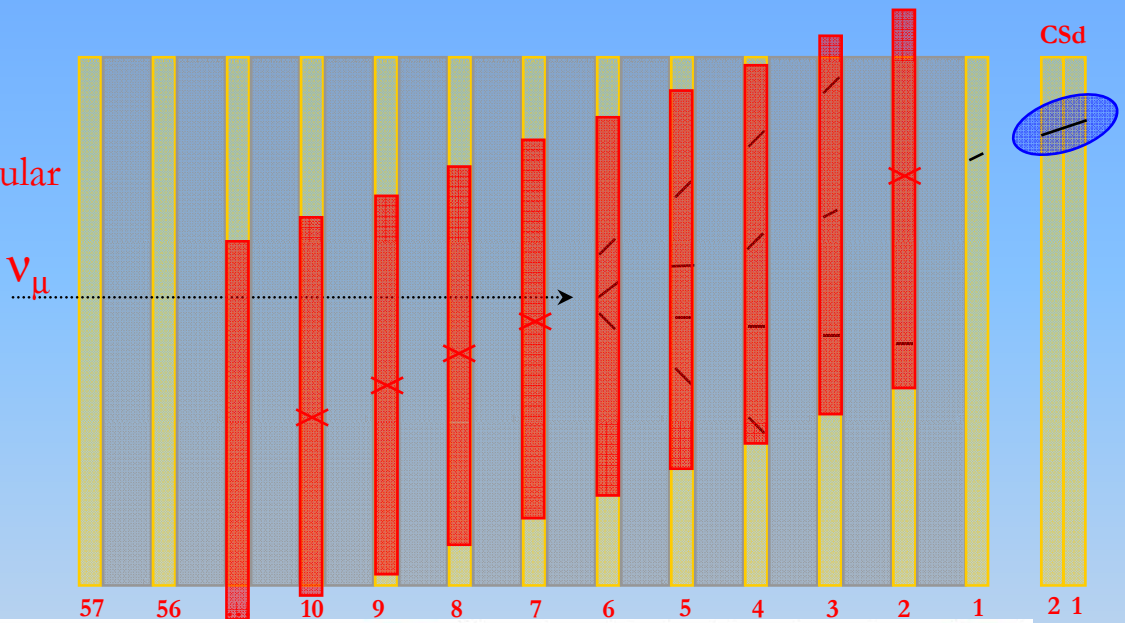
Nuclear emulsion are analysed with a new generation of high speed automatic systems:

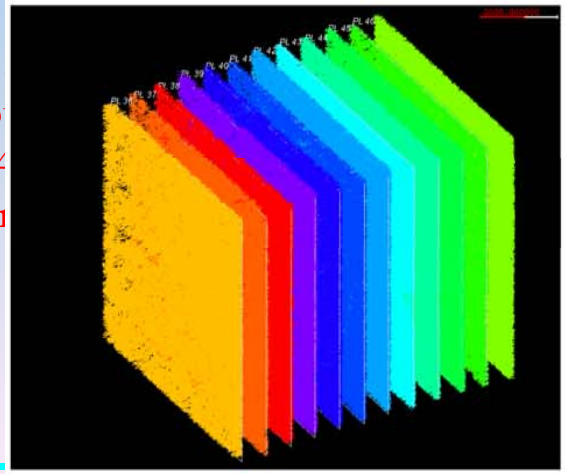
~40 microscopes currently available in Japan (S-UTS) and Europe (ESS)

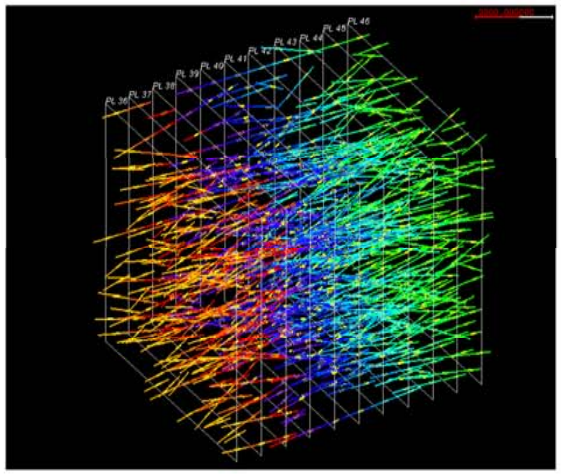
ALL THAT with a current scanning speed of 20 cm^2/h (ESS) to reach 100 cm^2/h (S-UTS)

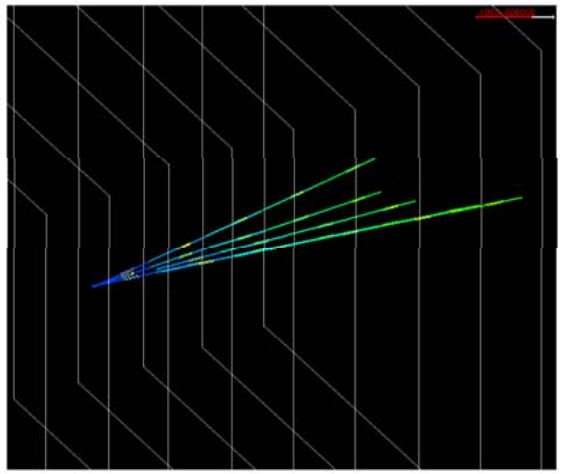
Event Reconstruction

- **CSd general scan**:
  - ✓ 50 cm^2 around TT prediction
  - ✓ looking for tracks in all the available angular range (typically ±400 mrad)
  - ✓ X –ray alignment (10μm accuracy)
  - ✓ tolerances 40 μm, 10 mrad (θ=0)
  - ✓ Compton alignment (1μm accuracy)
- **Scan back**:
  - ✓ alignment with lateral X-ray marks (12 μm accuracy)
  - ✓ definition of the stopping point
  - ✓
  - ✓
  - Co
  - 4
- **Volu**
  - ✓
  - ✓









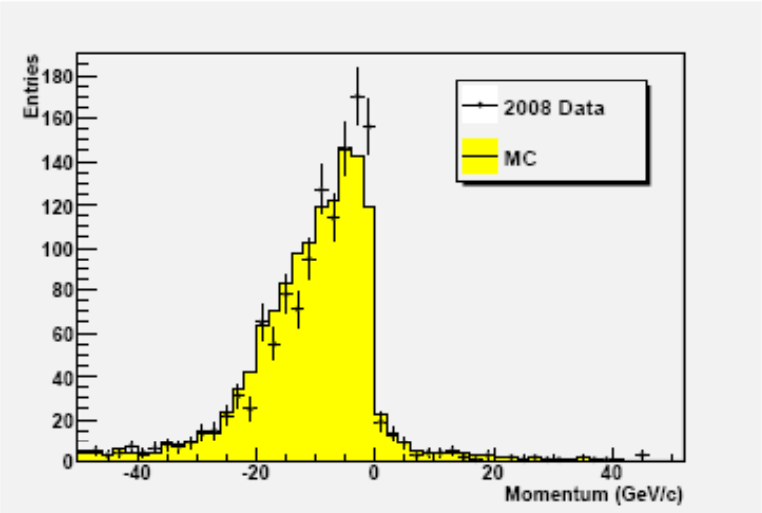
OPERA as a real-time detector

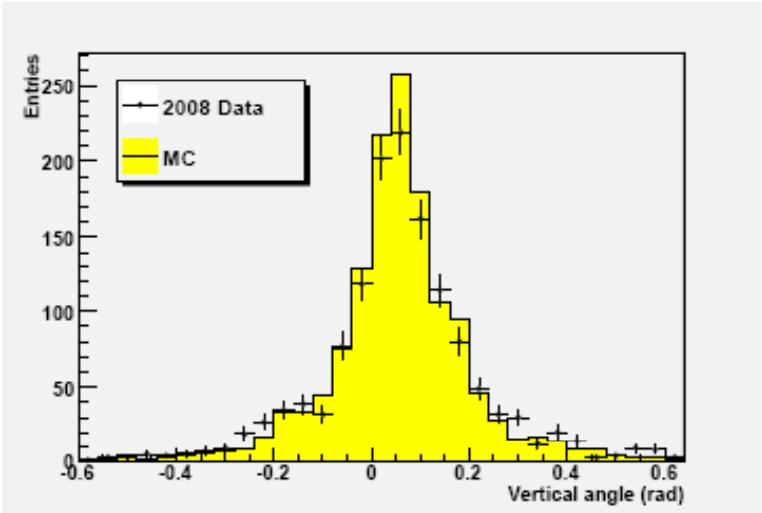
2008 RUN

- CNGS-LNGS syncronization: based on GPS. Present precision is 100 ns (can be improved up to 10 ns)
- DAQ livetime >99%. Overall livetime during CNGS 99%
- Collected events correlated with CNGS: 10122 on time (mainly in surrounding material) and 1663 in the target
- Direction and momentum reconstruction for CNGS event

OK [Negligible bkg from cosmics]

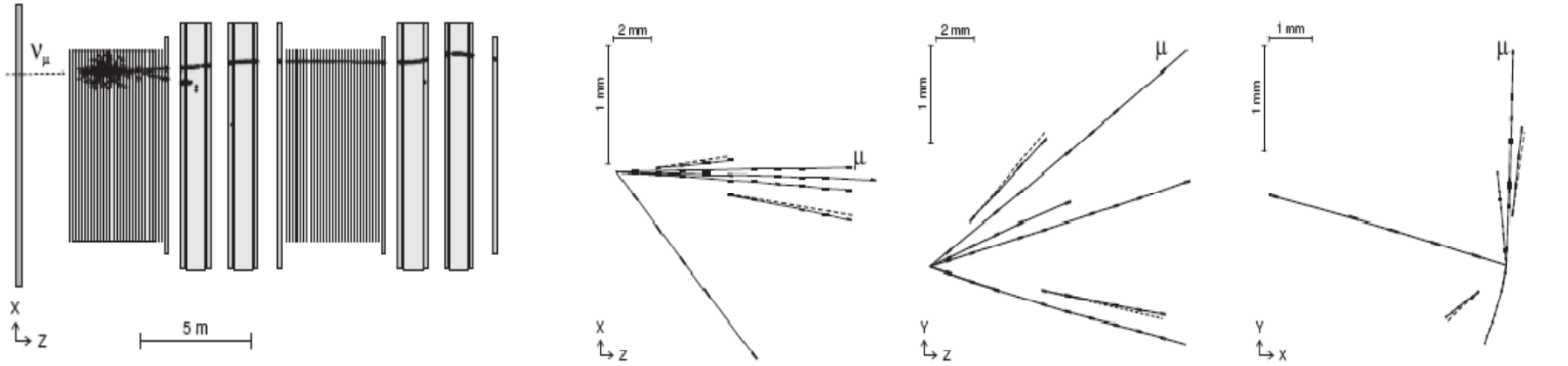
OK





OPERA as a hybrid detector

• Prediction of the brick where the interaction occurred	Part. validated (*)
• Alignment and development of the Changeable Sheets	Fully validated
• Scanning of the Changable Sheets	Fully validated
• Extraction of the Bricks at the rate of CNGS events	Fully validated
• Identification of the primary vertex	In progress (**)
• Kinematic reconstruction and decay search	In progress (**)



(*) Extr. of 1° brick nearly completed. 2° in progress.

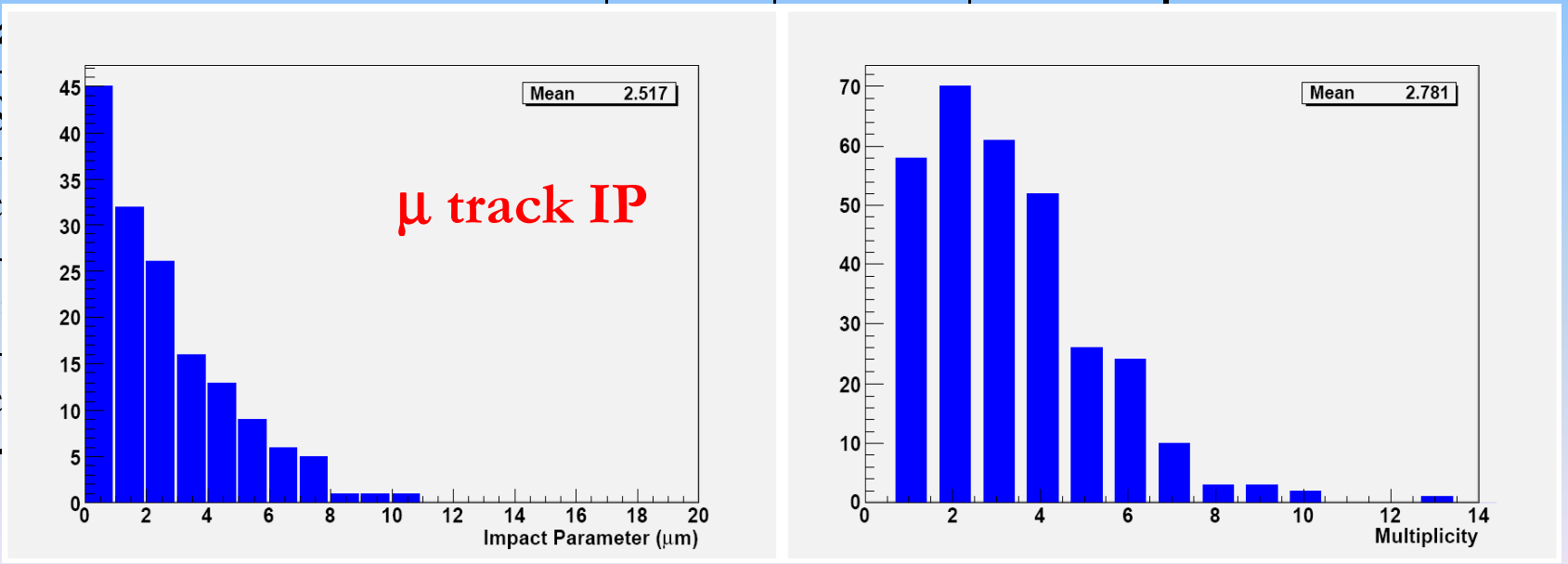
(**) First results below on a subsample of ≃400 events.

2008 Run: vertex location summary

Events analysis (European set only) @ March 5th 2009

	NC	CC	Total
Bricks assigned	83	441	524
Bricks received in the labs	78	394	472
Sc			
CS			
Ve			
Pa			
Ve			

For the time being event location with ONE brick extraction ≥ 70%

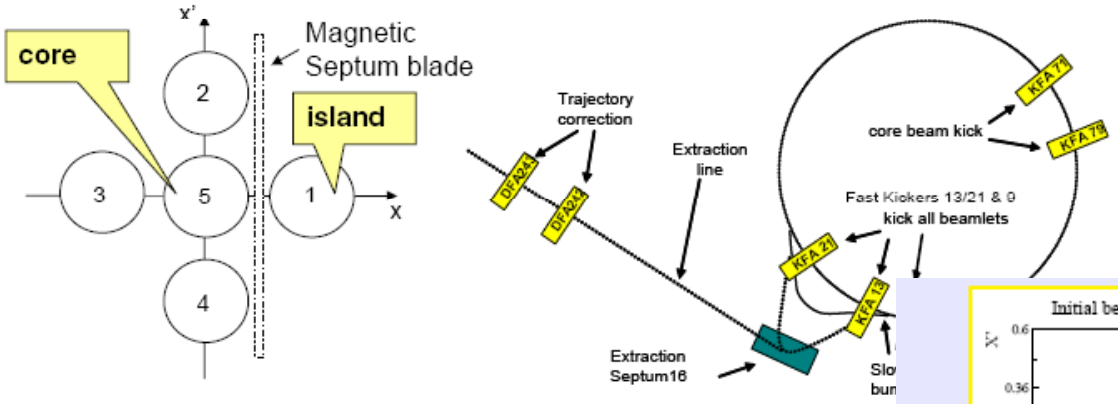


N. Agafonova et al., 19 March 2009, arXiv:0903.2973v1 [hep-ex]. submitted to JINST

- The beam is separated into a central beam and four islands by means of non-linear magnetic elements like sextupoles and octupoles.
- Each beamlet is ejected using fast kickers and a magnetic septum

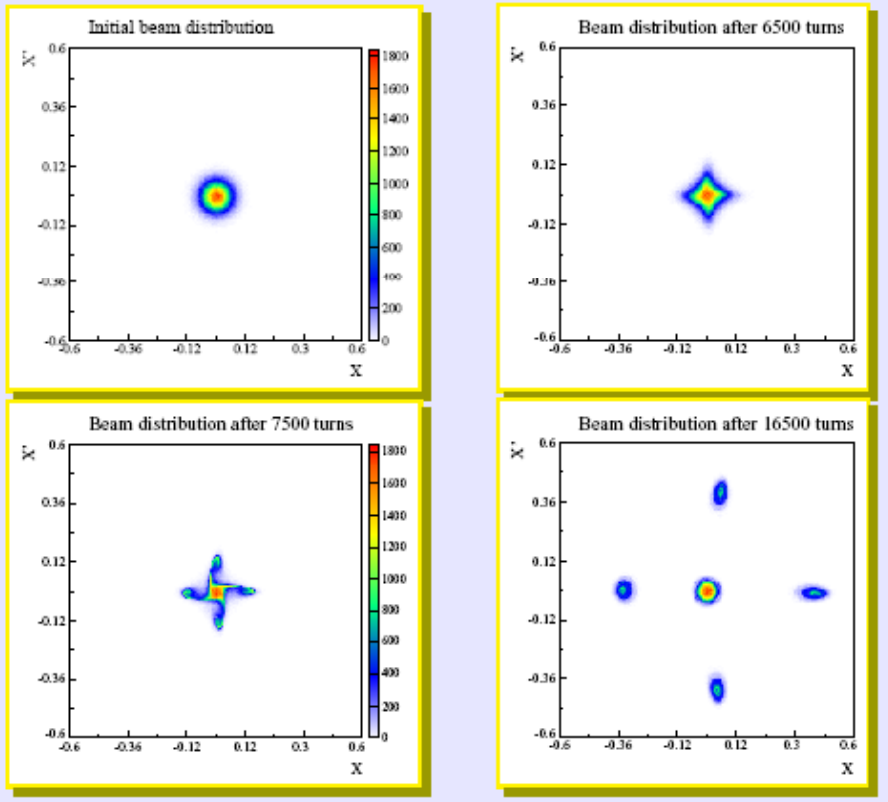
Multi-turn extraction

Virtually loss-less

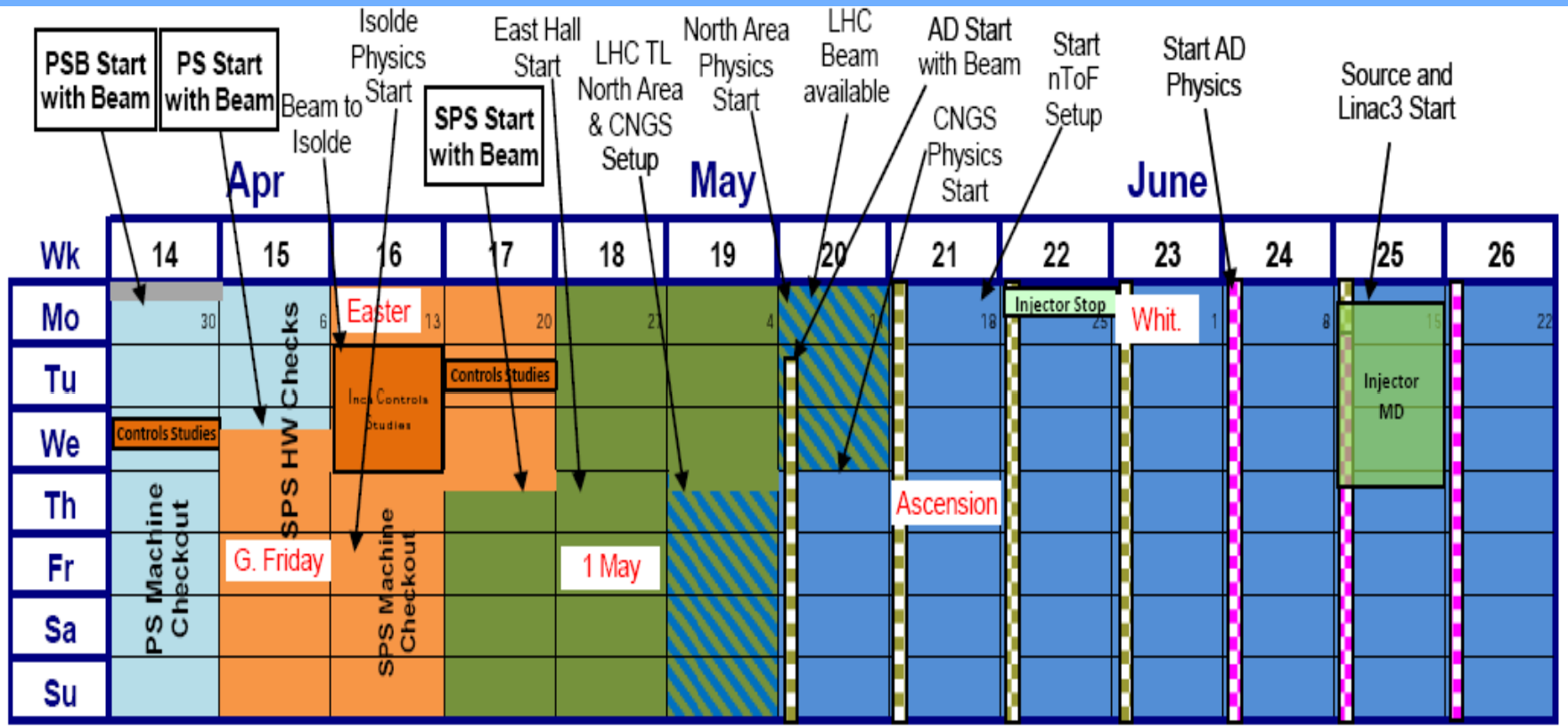


- 2001 first proposal (linked to 1.5 intensity increase for CNGS)
- R&D and test 2002-2004
- Implementation study group 2005
- March 2006 TDR
- October 2006 Project approved
- August 2008: First MTE obtained !
- …2009 ?? …

Important step for safe achievement of the goal of 22.5×10^{19} pot



SPS start-up CNGS beam for Physics RUN: 2009 May 21st



RUN 2009 expectations

173 days
48s supercycle
80% efficiency
$2.4^{E}13$ pot/extraction

→$3.6^{E}19$ pot
→3500 events of nu interactions

Efforts needed for improving this performance..

RUN 2010 expectations

→$4.5^{E}19$ pot
→450 nu interactions in OPERA bricks

ALL TOGETHER WE WOULD LIKE TO COLLECT $22.5^{E}19$ POT !!

With 2008-10 runs
we may be able to exclude
tau appearance with a
reasonable probability

OR

at a not so large probab.
to confirm tau appearance

Conclusions

OPERA challenges:

1) from cm to micron precisions
2) Intimate interplay of "standard" and "subtleties" technologies
3) Industrial activities not only at construction time but even heavier at analysis stage
4) Detector operativeness" will not last for years…

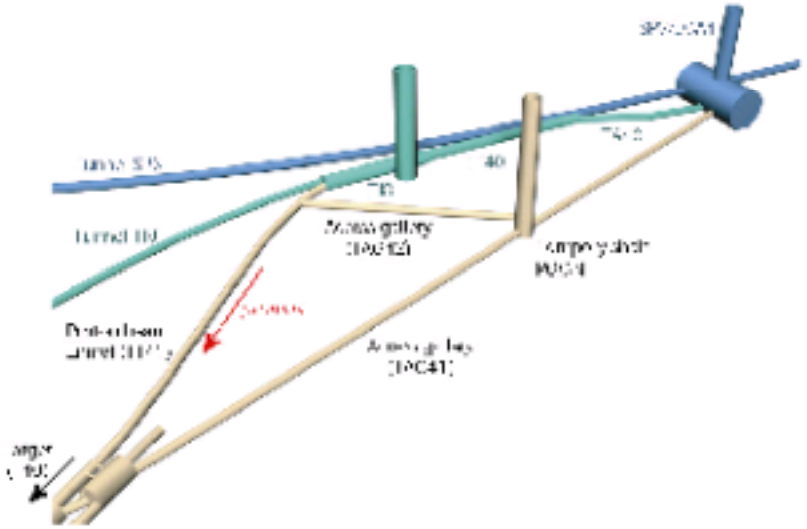
OPERA goals:

1) tau's evidence
2) tau's oscillation confirmation
3) Ancillary results on charm and cosmics
4) Confirm the unexpected !

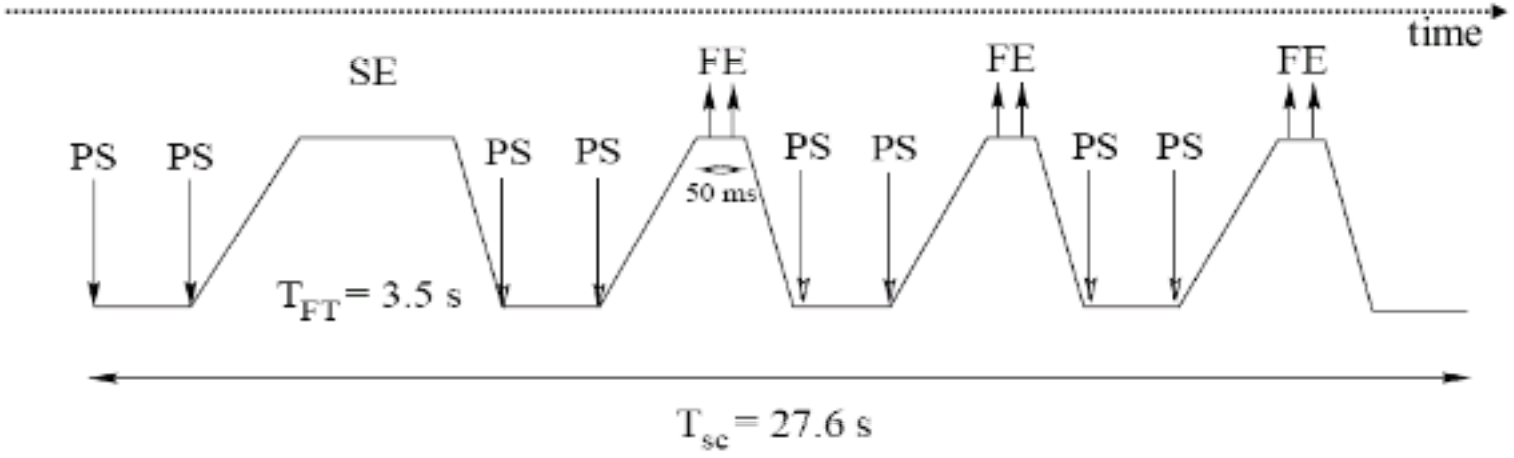
Good Physics Searches to everybody !

Backup Slides

CNGS beam @ CERN:



Proton extractions from SPS with 3 cycles of 6s each : 2 extractions of 10.5 μs, separated by 50 ms.

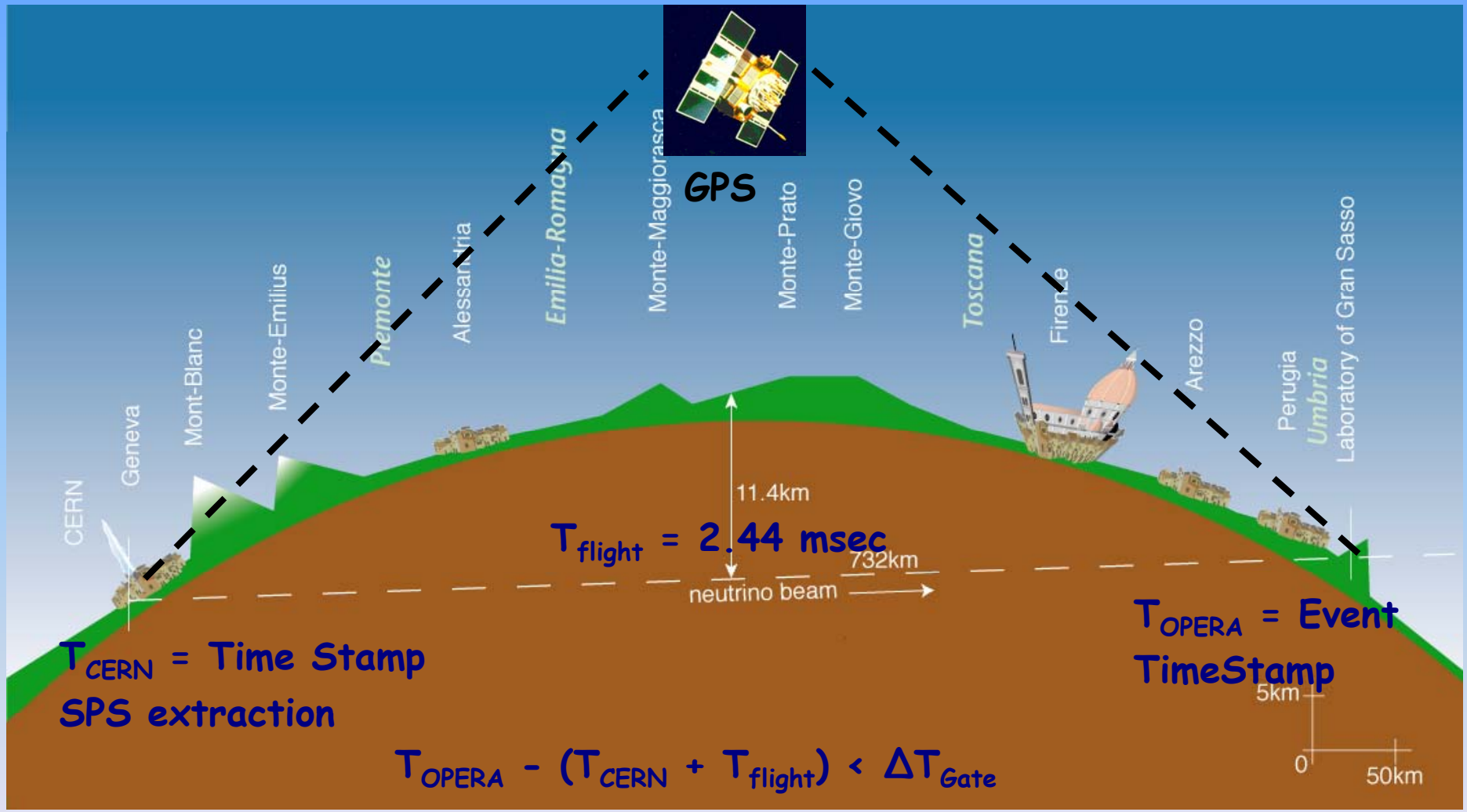


Beam event selection : $T_{OPERA} - (T_{SPS} + TOF) < T_{gate}$

~2.4ms ~1extraction

Nominal intensity : 4.5 10^{19} pot /yr, with **2.4 10^{13} pot/extraction (FE)**

Time selection of beam events



GPS Time Stamp resolution ~ 100 ns