Recent results of the OPERA neutrino experiment

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Germany
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Israel
Technion Haifa

Italy
Bari
Bologna
LNF Frascati
L'Aquila,
LNGS
Naples
Padova
Rome
Salerno

Japan
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Toho
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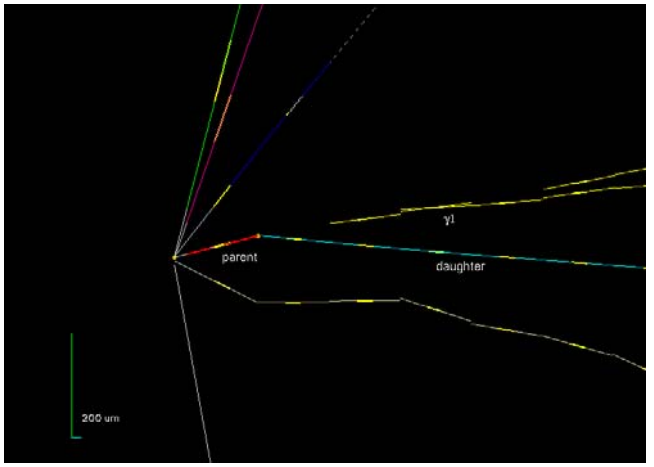
Nagoya
Utsunomiya

Korea
Jinju

Russia
INR RAS Moscow
LPI RAS Moscow
ITEP Moscow
SINP MSU Moscow
JINR Dubna

Switzerland
Bern

Turkey
METU Ankara



140 physicists, 28 institutions in 11 countries

Outline

- the OPERA experiment
- status of data taking and analysis
- Oscillation physics results

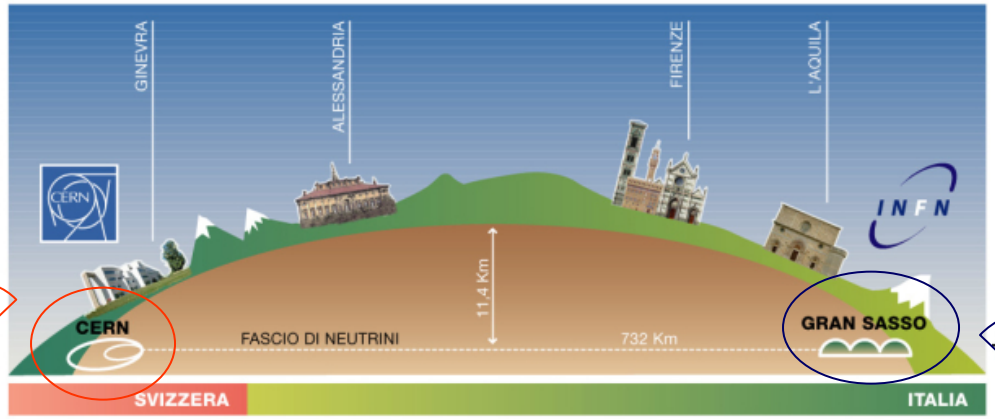
The Oscillation Project with Emulsion tRacking Apparatus

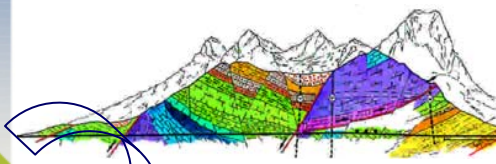
HEP 2013
Stockholm
18-24 July 2013

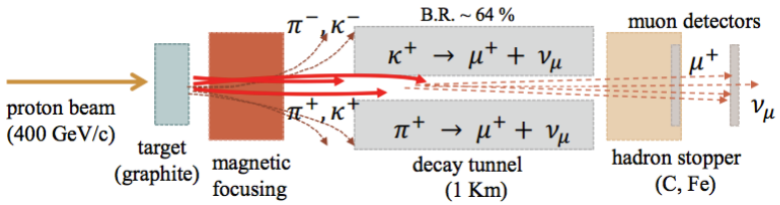
OPERA

Laboratori Nazionali del Gran Sasso (Italy)

- 1400 m rock overburden
- cosmic μ reduction ~ 10^6 (1μ /m^2/h)
- low radioactivity rock

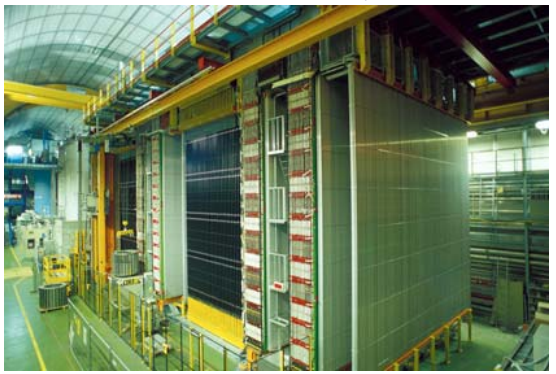






Cern Neutrinos to Gran Sasso beam

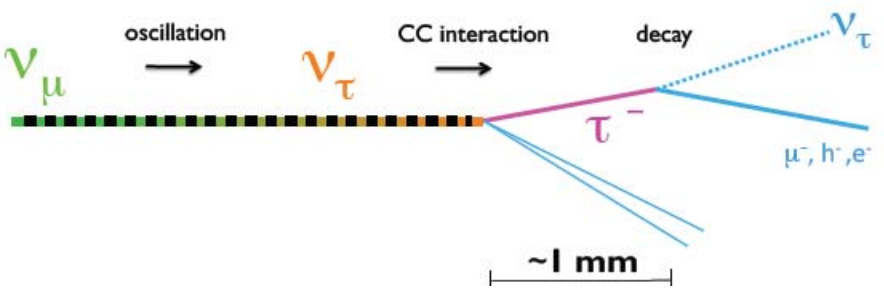
732 km



Hybrid OPERA detector
- large target mass (1.25 kton)
- submicron resolution

Direct observation of ν_τ appearance from ν_μ oscillation at atmospheric scale

The ν_τ detection principle



τ decay channel	B.R. (%)
$\tau \rightarrow \mu$	17.7
$\tau \rightarrow e$	17.8
$\tau \rightarrow h$	49.5
$\tau \rightarrow 3h$	15.0

Based on event-by-event separation of ν_τ CC interactions from dominant ν_μ interactions by direct observation of τ lepton decay.

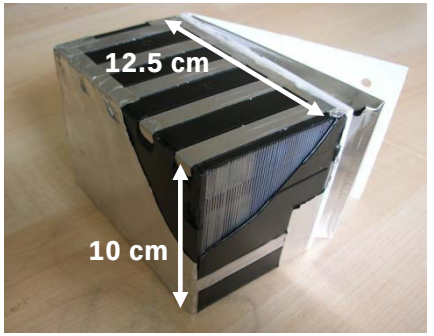
Requirements:

- Large target mass
- Micrometric resolution to observe τ decay *kink*

→ Nuclear emulsions

- High muon identification efficiency to reduce charm background; event region pre-selection

→Electronic detectors



Target segmented into basic units called bricks.
Brick: sandwich of 57 emulsion films interleaved with 1mm-thick lead plates

Total target mass ~ 1.25 kt
(about 150000 bricks)

The OPERA detector@LNGS

Veto (RPC)

High precision tracker
- drift tubes

Dipole magnet
- 1.53 *T*
- RPC planes

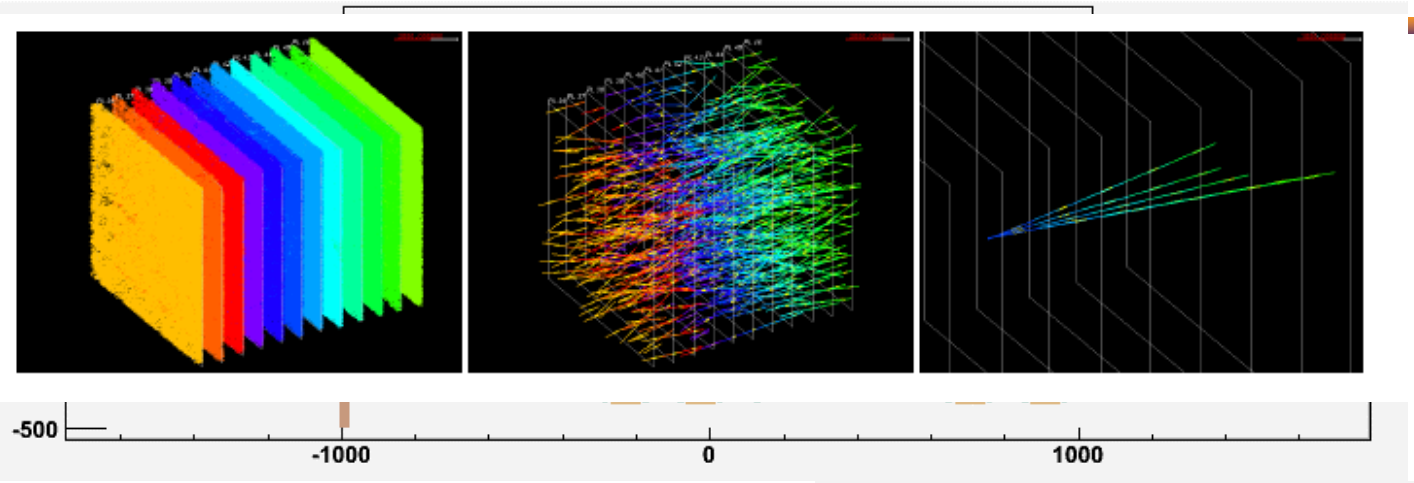
muon spectrometer (8×10 m^2)

Brick walls + Target Tracker (6.7m)^2

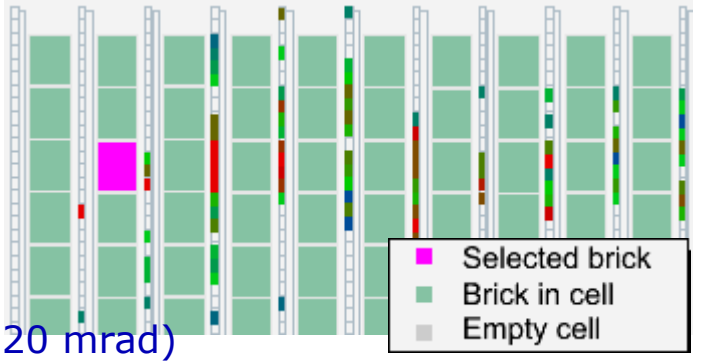
- target/SM: ~75000 *bricks*
  (Pb – nuclear emulsions)
  Mass/SM 0.625 kt
- Target tracker : 31 doublets XY
  (256 plastic scintillator strip + WLS fibres+ multi-anodes PMT) for trigger, brick selection and calorimetry

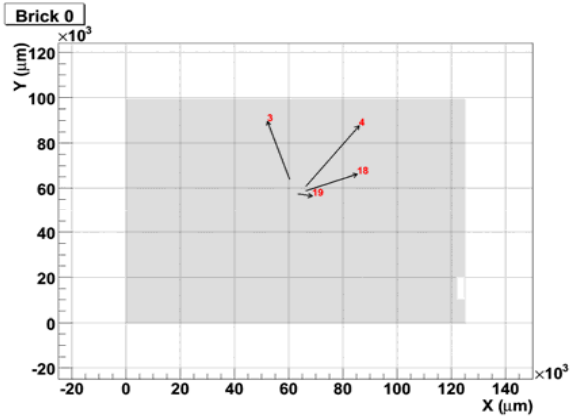
[Ref. JINST 4 (2009) P04018]

Event analysis in OPERA



- on-line analysis of electronic data
- brick finding algorithm for events 'on time' with the beam
- remove brick and scan CS: the interface between brick and TT ($\sigma_{pos} \approx 10$ mm, $\sigma_{\theta} \approx 20$ mrad)
- confirmation of the extracted brick
- development of the brick to be sent in a scanning Lab for '*CS to brick connection*' ($\sigma_{pos} \approx 70$ μm, $\sigma_{\theta} \approx 8$ mrad), event location, decay search studies, etc ..



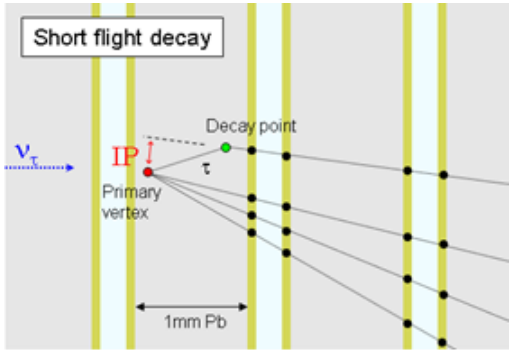


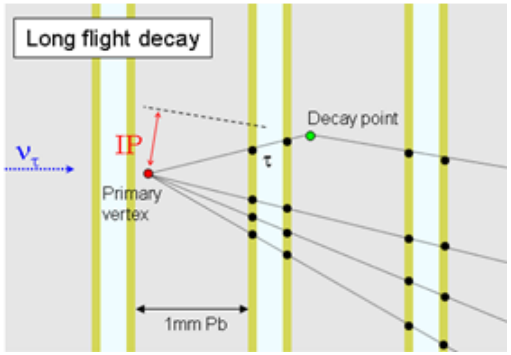
[2009 JINST 4 P04018]

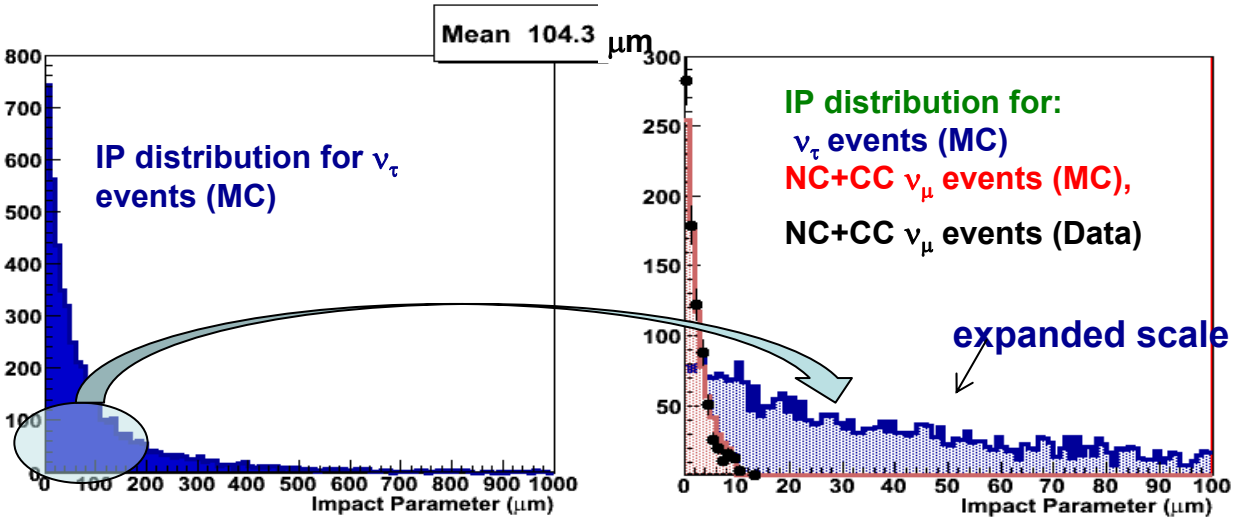
Decay search

Decay search procedure based on
- impact parameter (IP) evaluation
- small kink angle search
- extra-tracks search

- Momentum measurement by multiple Coulomb scattering
- E.m. shower detection and energy measurement
- Detection of highly-ionizing nuclear fragments



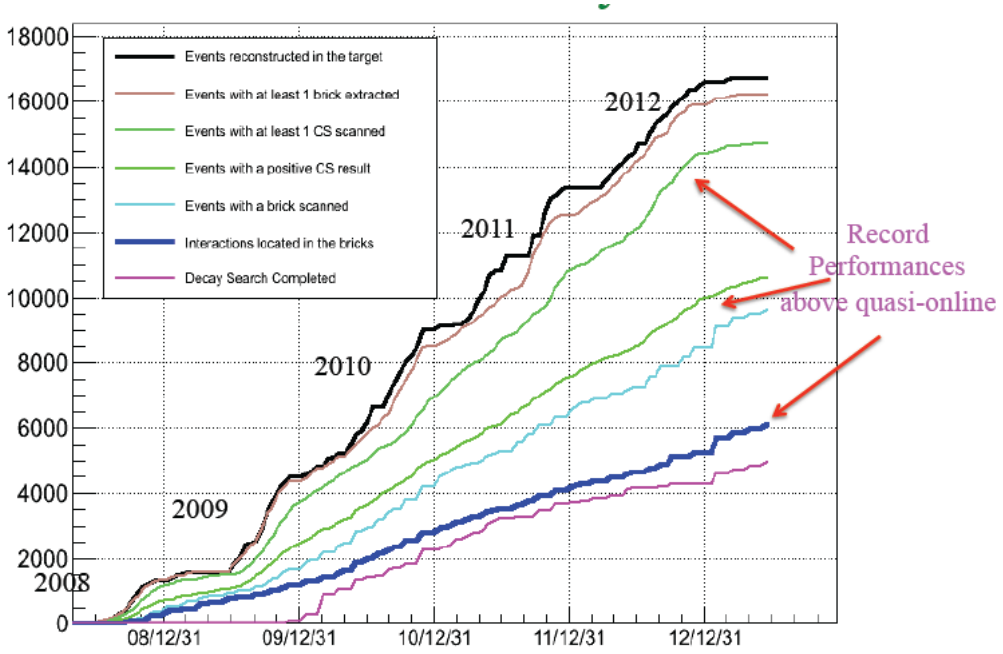


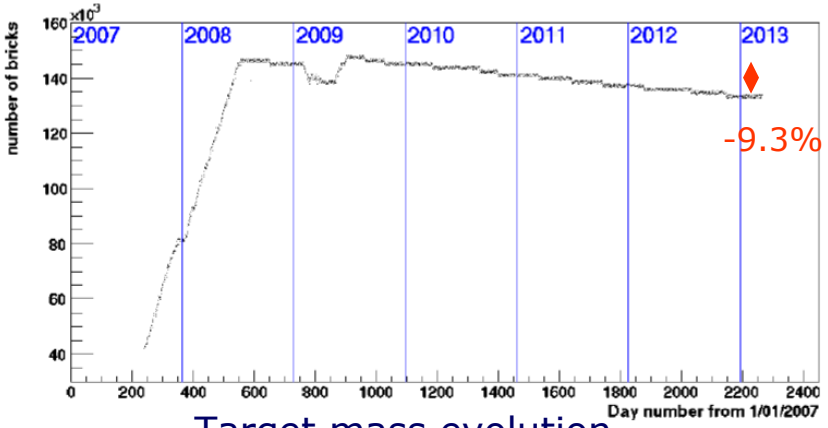


Status of data analysis

* nominal value: 4.5 10^{19} pot

year	beam days	# p.o.t.*
2008	123	1.74 x 10^{19}
2009	155	3.53 x 10^{19}
2010	187	4.09 x 10^{19}
2011	243	4.75 x 10^{19}
2012	257	3.86 x 10^{19}
tot	965	17.97 x 10^{19}



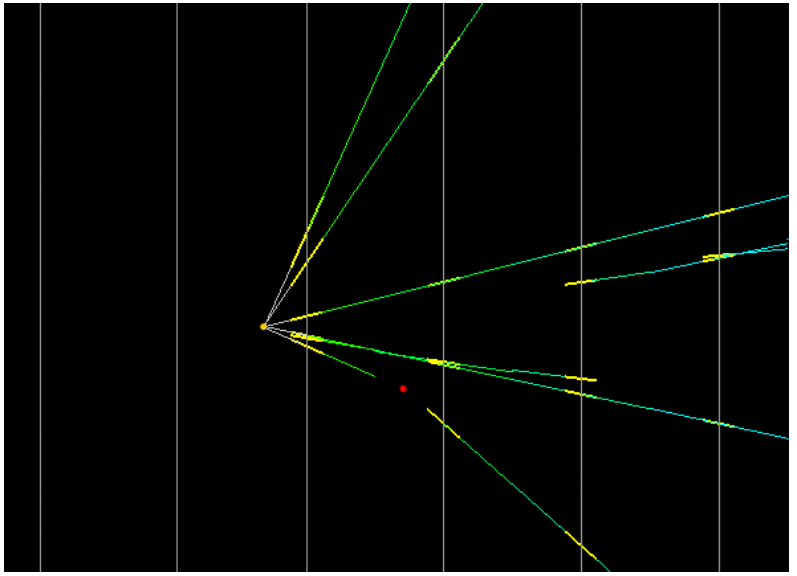


Target mass evolution

Located neutrino interactions	6067
Fully analysed events	4969
ν_τ candidate events	3

$\nu_\mu \rightarrow \nu_\tau$ oscillation search

control sample

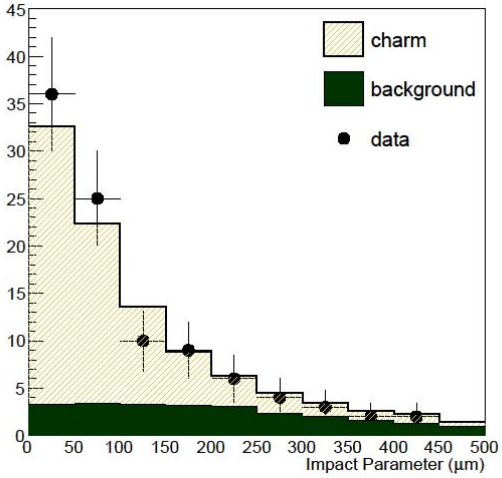


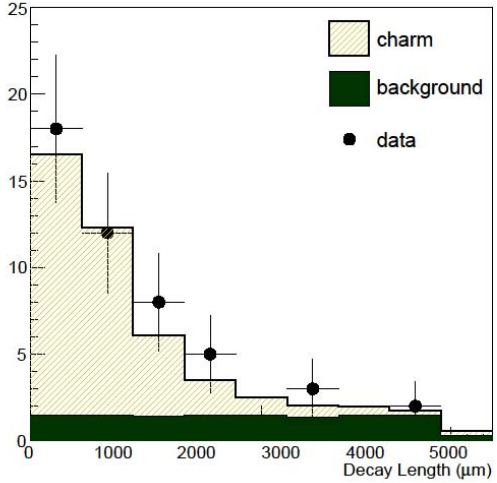
Charm decay topologies analogous to τ :
reference sample for the decay finding efficiency

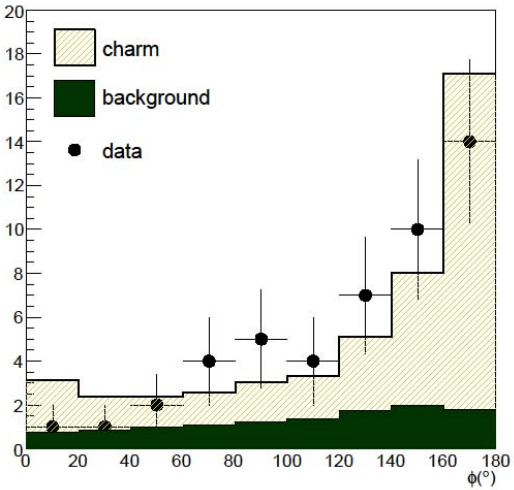
2008 → 2010 data sample

Expected events: 55 ± 5
Observed events: 50

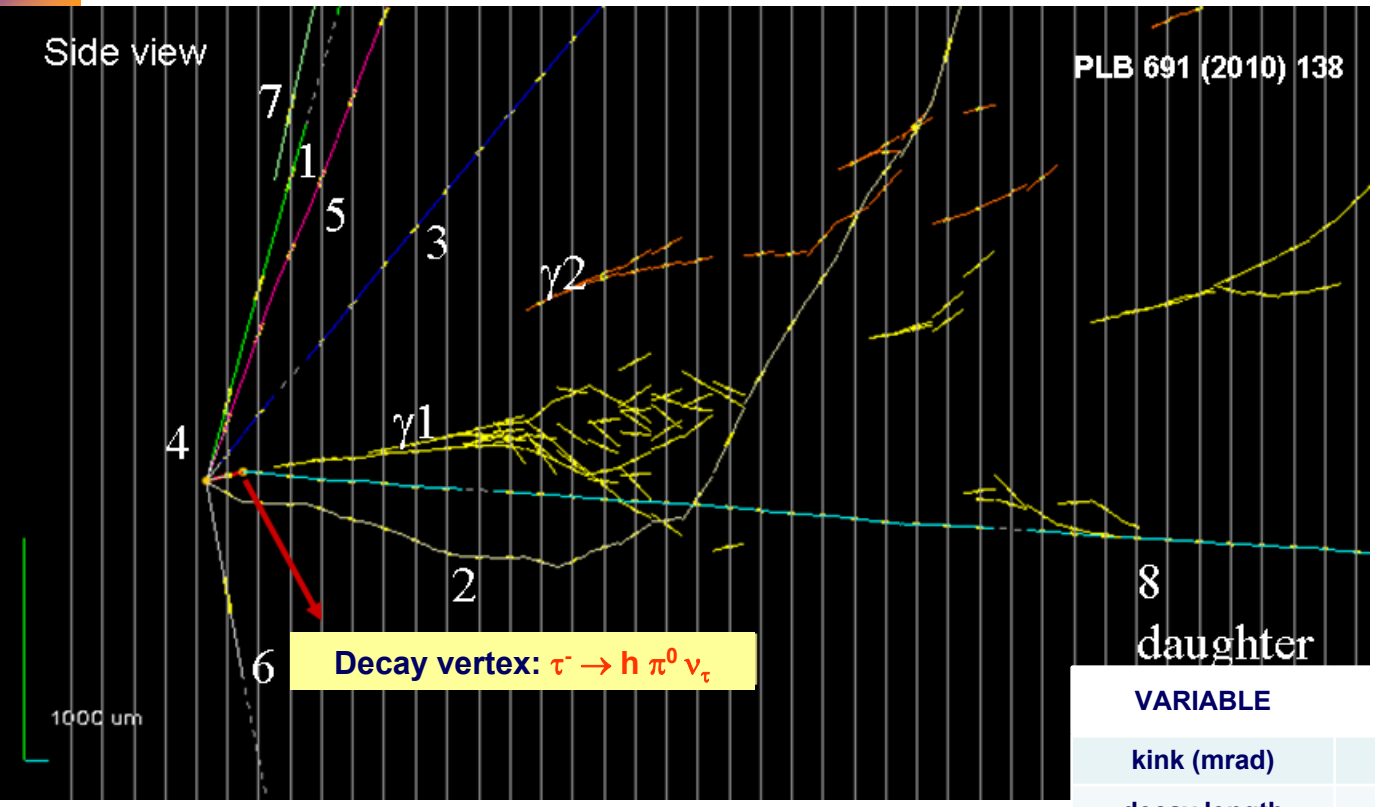
Kolmogorov test ≥ .99

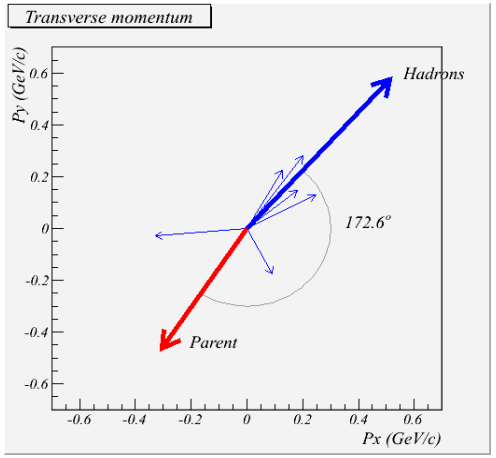






The first ν_τ "appearance" candidate

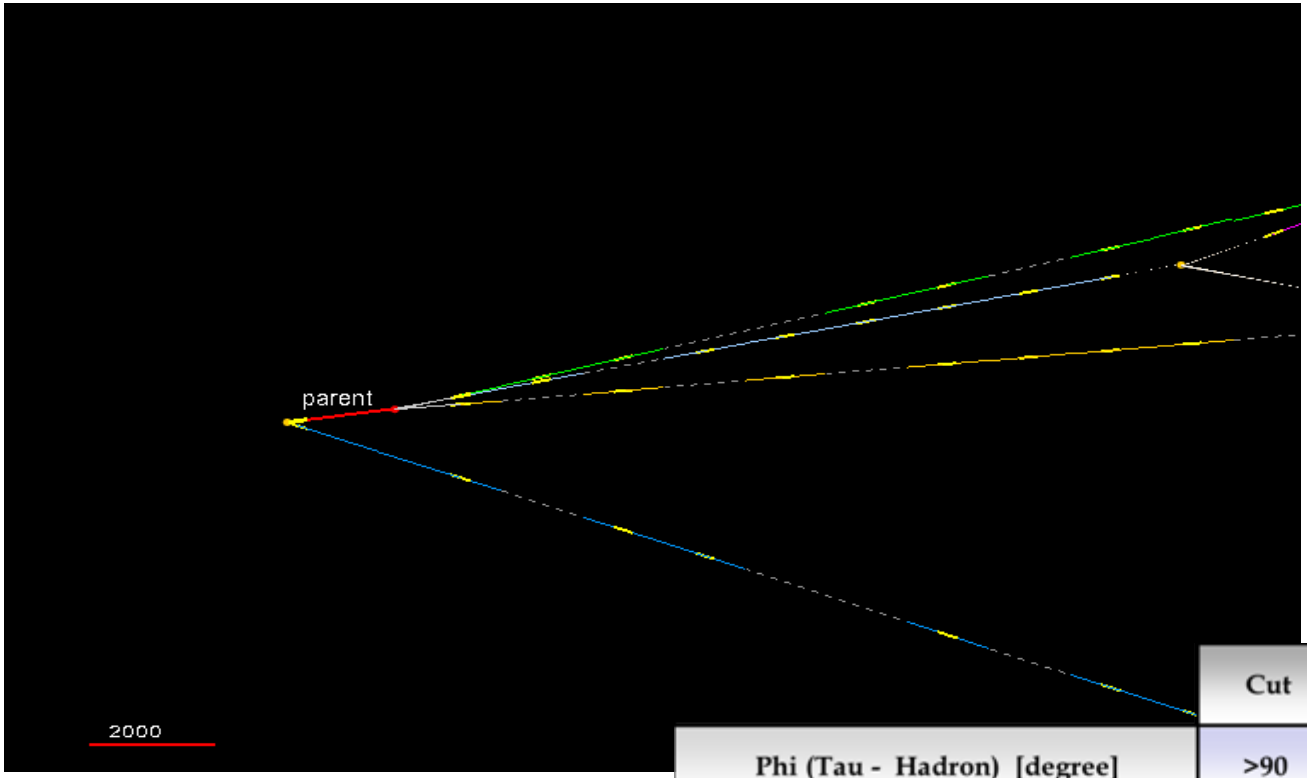




VARIABLE	AVERAGE	Selection criteria
kink (mrad)	41 ± 2	>20
decay length (μm)	1335 ± 35	within 2 lead plates
P daughter (GeV/c)	$12\ ^{+6}_{-3}$	>2
Pt (MeV/c)	$470\ ^{+230}_{-120}$	>300 (γ attached)
missing Pt (MeV/c)	$570\ ^{+320}_{-170}$	<1000
ϕ (deg)	173 ± 2	>90

2008-2009 decay searched data, released in 2010
(Phys. Lett. B (2010) 138)

The second ν_τ candidate



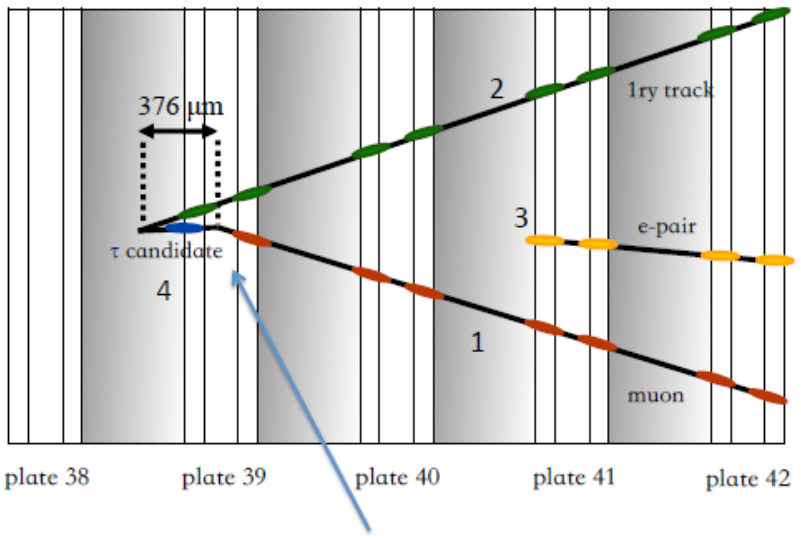
Cut	Value	Error
Phi (Tau - Hadron) [degree]	>90	167.8	± 1.1
average kink angle [mrad]	< 500	87.4	± 1.5
Total momentum at 2ry vtx [GeV/c]	> 3.0	8.4	± 1.7
Min Invariant mass [GeV/c²]	0.5 < < 2.0	0.96	± 0.13
Invariant mass [GeV/c²]	0.5 < < 2.0	0.80	± 0.12
Transverse Momentum at 1ry vtx [GeV/c]	< 1.0	0.31	± 0.11

All tracks were identified as hadrons

Event satisfies criteria for

$\tau^- \rightarrow h^+ h^- h^- \nu_\tau$

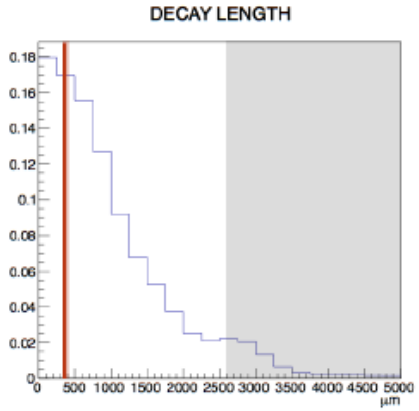
The third ν_τ candidate

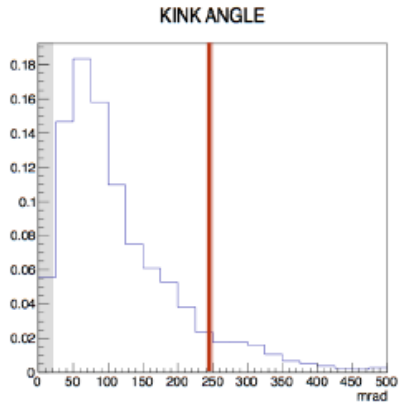


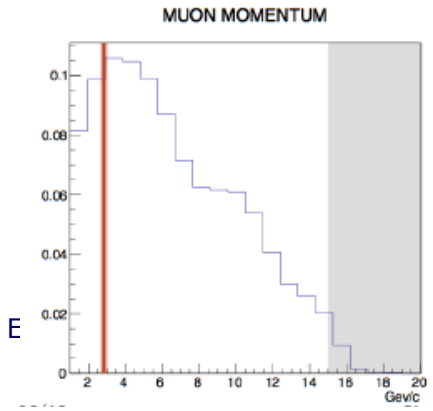
Decay in the plastic base

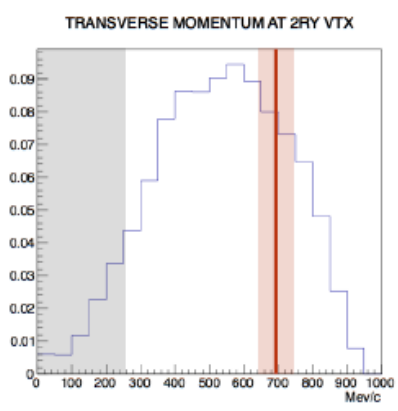
VARIABLE	AVERAGE
Kink angle (mrad)	245 ± 5
decay length (μm)	376 ± 10
Pμ (GeV/c)	2.8±0.2
Pt (MeV/c)	690±50
ϕ (degrees)	154.5 ± 1.5

All cuts passed: τ → μ candidate









$\nu_\mu \rightarrow \nu_\tau$ oscillation search

summary status

Extended sample		
	Signal	Background
$\tau \rightarrow$ h	0.66	0.045
$\tau \rightarrow$ 3h	0.51	0.090
$\tau \rightarrow \mu$	0.56	0.026
$\tau \rightarrow$ e	0.49	0.065
total	2.22	**0.23**

3 observed events in the $\tau \rightarrow$ h, $\tau \rightarrow$ 3h and $\tau \rightarrow \mu$ channels

Probability to be explained as a background = 7 x 10^{-4}

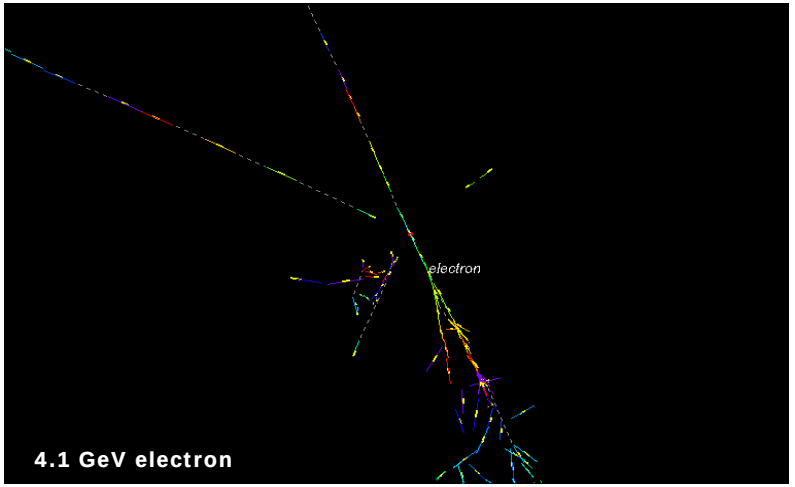
This corresponds to 3.2 σ significance of non-null observation
(3.5 σ significance with a likelihood approach)

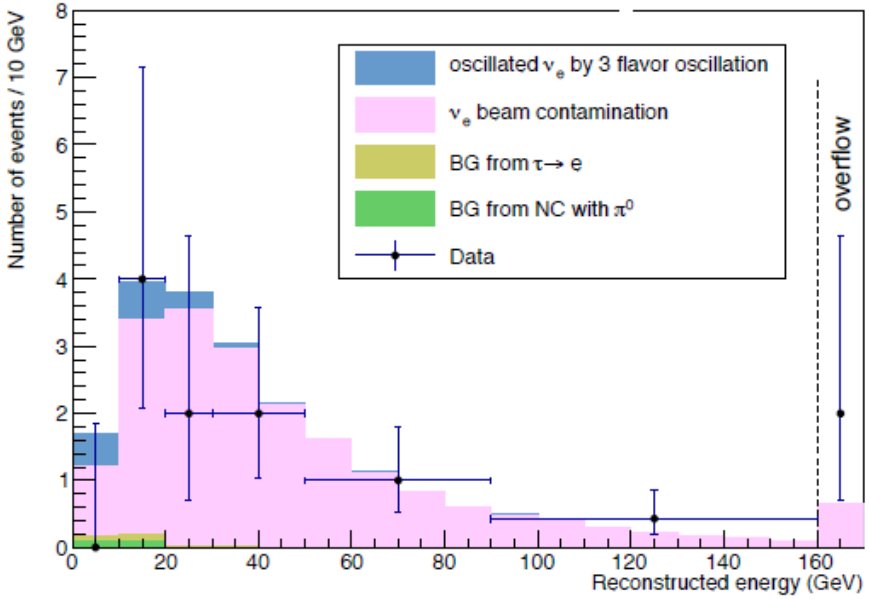
$\nu_\mu \rightarrow \nu_e$ oscillation search (I)

32 electron neutrino interactions reconstructed in the analysed sample

2008-2009 data sample:

19 electron neutrino candidates observed





Observation compatible with background-only hypothesis

19.8±2.8 (syst) events

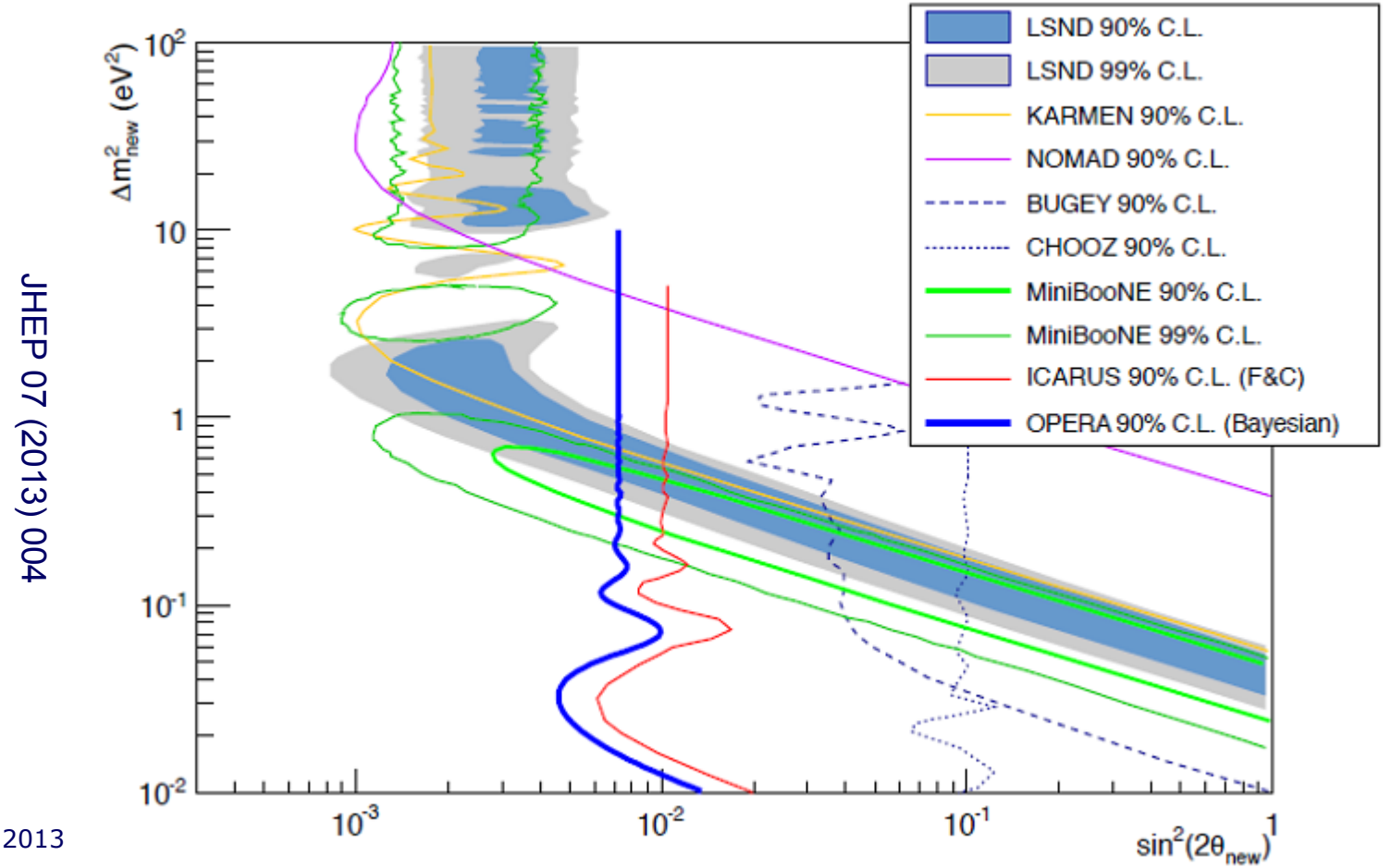
Energy cut to increase S/N

4 observed events wrt 4.6 expected

$\sin^2(2\theta_{13}) < 0.44$ (90% C.L.)

$\nu_\mu \rightarrow \nu_e$ oscillation search (II)

Search for non-standard oscillations at large Δm^2 values



Conclusions

- OPERA successfully ran on the CNGS neutrino beam from 2008 to December 2012

- 17.97 10^{19} pot collected (about 80% of the nominal value 22.5 10^{19} pot)

- $\nu_\mu \rightarrow \nu_\tau$ analysis:

  - three tau candidate events found up to now
    3.2 σ significance with simple counting method
    3.5 σ significance with likelihood approach

  - analysis on going: some more interesting events are under investigation

- $\nu_\mu \rightarrow \nu_e$ analysis:

  19 events observed (4 events with E_{rec}<20GeV)
  19.8±2.8 events expected (4.6 with E_{rec}<20GeV)
  → bounds set in the large Δm^2 region

  Larger statistics expected