



# SEARCH FOR $\nu_\mu \rightarrow \nu_e$ OSCILLATION WITH THE OPERA EXPERIMENT



M. Tenti for the OPERA Collaboration

## OPERA Experiment

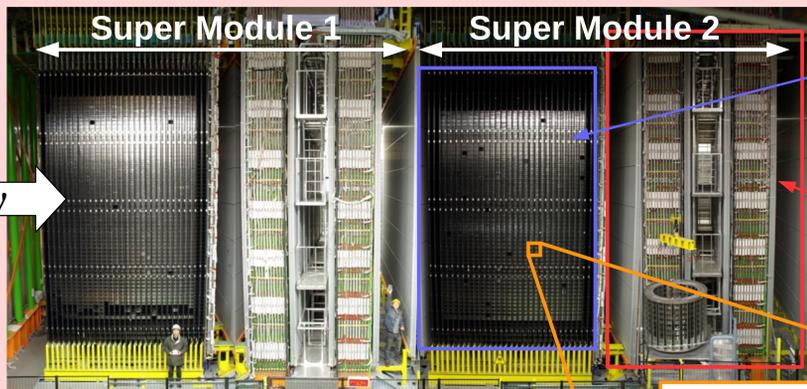
**Physics Goal:** detection of  $\nu$  oscillation in appearance mode in  $\nu_\mu \rightarrow \nu_\tau$  channel. [New J. Phys. 14 (2012) 033017]

**Basic Principle:** long baseline  $\nu_\mu$  beam (CNGS); beam energy to maximize  $\nu_\tau$  appearance and  $\nu_\tau$  CC interactions at the atmospheric neutrino scale  $\Delta m_{23}^2 \sim 10^{-3} \text{eV}^2$ .

**In Addition:** study of  $\nu_\mu \rightarrow \nu_e$  oscillation channel.

### CNGS Beam parameters

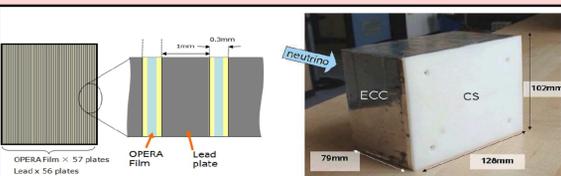
baseline	730 km
mean $\nu_\mu$ energy	17 GeV
p.o.t. 2008-2012	$18 \times 10^{19}$
<b>Beam Contamination (interaction rates in OPERA)</b>	
$(\nu_e + \bar{\nu}_e)/\nu_\mu$	$0.88\% + 0.05\%$
$\bar{\nu}_\mu/\nu_\mu$	2.1 %
$\nu_\tau$ prompt	negligible



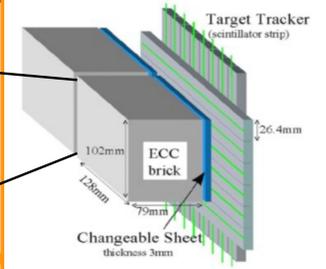
**Target**  
ECC brick walls + Scintillator strips

**Muon Spectrometer**  
RPC + drift tubes

**Basic OPERA module:** Emulsion Cloud Chamber (ECC)



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|---|--|
| <p><b>ECC Brick</b></p> <ul style="list-style-type: none"> <li>• 56 lead plates</li> <li>• 57 emulsion films</li> </ul> | <p><b>Changeable Sheets (CS)</b></p> <ul style="list-style-type: none"> <li>• 2 emulsion films glued downstream the brick</li> <li>• Interface between electronic detector and ECC bricks</li> </ul> |
|---|--|

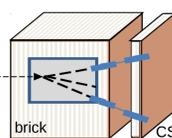
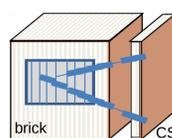
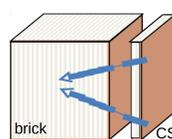
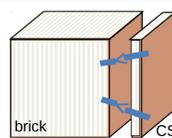
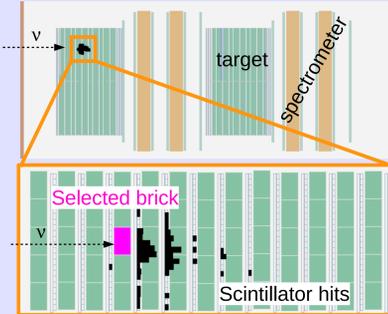


## Event Reconstruction

### Brick Finding

The **ECC brick** containing the neutrino interaction is **identified by electronic detectors** and removed from the OPERA apparatus.

**Electronic Detectors to CS Event Matching**  
CS are analyzed with automatic scanning microscopes looking for **event related tracks**.



### CS to ECC Brick Track Matching

The **CS tracks** are projected and searched for in the **downstream films** of the brick.

### Small-Area Scanning (backward)

The **matched tracks** are followed **backward** film by film up to their origins.

### Full Volume Scanning

A  $1 \text{ cm}^2 \times 15$  films **large volume** is scanned around the track origin.

### Event Analysis

**Tracks** in the scanned volume are reconstructed. **Vertices** and **decay** topologies are searched for.

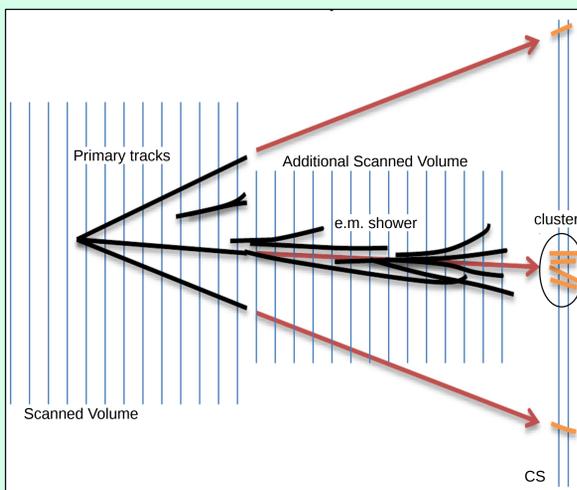
### @ Scanning Labs

## $\nu_e$ Search

The **identification of  $\nu_e$  CC interactions** is based on the detection of the associated electromagnetic shower.

**Scanned volume do not fully contain an electromagnetic shower** originated from a primary electron.

A **dedicated procedure** is defined using an additional scanning.



### $\nu_e$ Search Procedure

1. Tracks belonging to primary vertex are extrapolated to the CS where a **cluster of CS tracks** with similar angle (within 150 mrad) is searched for.
2. A cluster of 3 or more tracks is a **hint of electromagnetic shower**.
3. An **additional volume** is scanned along the primary track for **shower identification and reconstruction**.
4. If a shower is found, the primary track is **visually inspected** in the first two emulsion films to confirm that the track is a **single particle** and not an electron pair.

The averaged  $\nu_e$  detection efficiency is  $\epsilon_{\text{det}} = (53 \pm 5)\%$

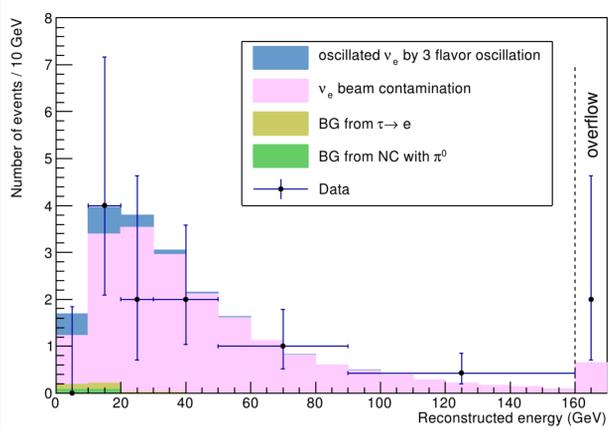
## Results

### Data Sample

The analyzed data sample corresponds to **2008 and 2009 runs** ( $5.25 \times 10^{19}$  pot).

**Observed** : 19 candidate  $\nu_e$  events.

**Expected** :  $19.8 \pm 2.8$  events from background and beam contamination.



### Standard Analysis

After a **cut on the reconstructed energy** ( $E < 20$  GeV, optimized for  $\theta_{13}$  sensitivity):

4 events are selected while 4.6 are expected.

The number of observed events is **compatible with the non-oscillation hypothesis**.

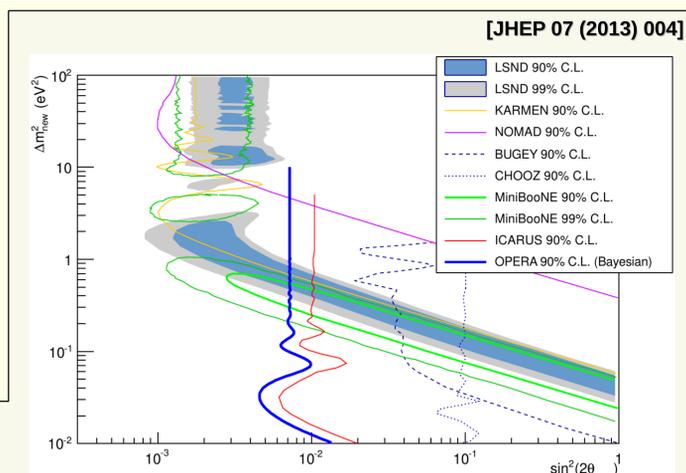
**Upper limit:**  $\sin^2 2\theta_{23} < 0.44$  (90% C.L.).

### Non-Standard Analysis (3+1)

Study of **non-standard  $\nu_\mu \rightarrow \nu_e$  oscillations**, as reported by **LSND** and **MiniBooNE** experiments.

After a **cut on the reconstructed energy** ( $E < 30$  GeV, optimized for sensitivity):

6 events are selected while 9.4 are expected.



The **exclusion plot** on  $\Delta m_{\text{new}}^2 - \sin^2 2\theta_{\text{new}}$  plane is obtained using the two flavor formula.

**Upper limit on  $\sin^2 2\theta_{\text{new}}$  at large  $\Delta m_{\text{new}}^2$  (90% C.L.):**  
 $5.0 \times 10^{-3}$  [Feldman & Cousins]  
 $7.2 \times 10^{-3}$  [Bayes]