



OPERA neutrino event subsamples @ CERN Open Data Portal

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Goals of the OPERA experiment

Since its discovery, the phenomenon of neutrino oscillations is being studied mostly in *disappearance* mode.

Observation of the *appearance* of oscillated neutrinos consistent with the disappearance results was also a very important issue.



Scientific Background on the Nobel Prize in Physics 2015

NEUTRINO OSCILLATIONS

Super-Kamiokande's oscillation results were later confirmed by the detectors MACRO [55] and Soudan [56], the long-baseline accelerator experiments K2K [57], MINOS [58] and T2K [59] and more recently also by the large neutrino telescopes ANTARES [60] and IceCube [61]. Appearance of tau-neutrinos in a muon-neutrino beam has been demonstrated on an event-by-event basis by the OPERA experiment in Gran Sasso, with a neutrino beam from CERN [62]. [PRL 115, 121802 (2015)]

The main goal:

the first *direct observation* of ν_τ appearance in a pure ν_μ beam through the detection of the short-lived τ leptons produced in ν_τ charged-current (CC) interactions.

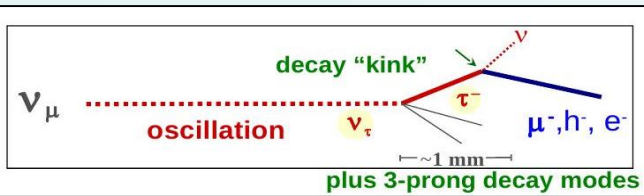
Expanded physics program:

– oscillation physics:

- $\nu_\mu \rightarrow \nu_e$ study
- sterile neutrino analysis

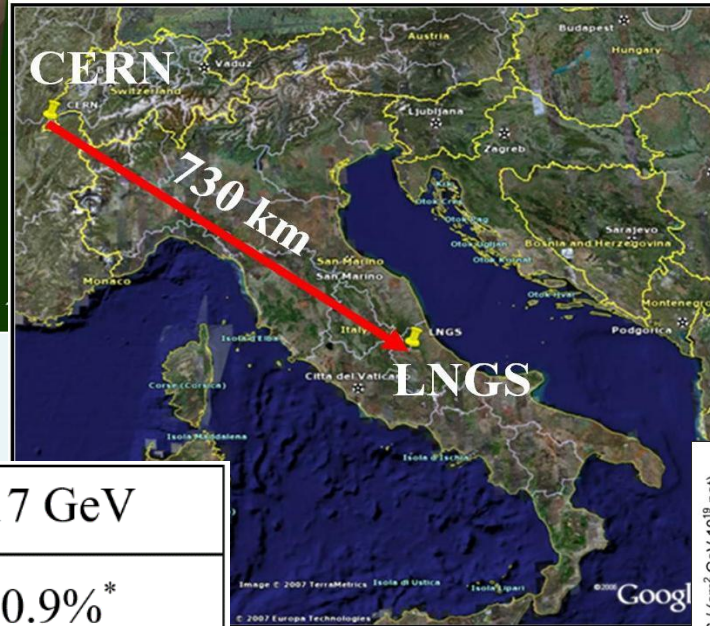
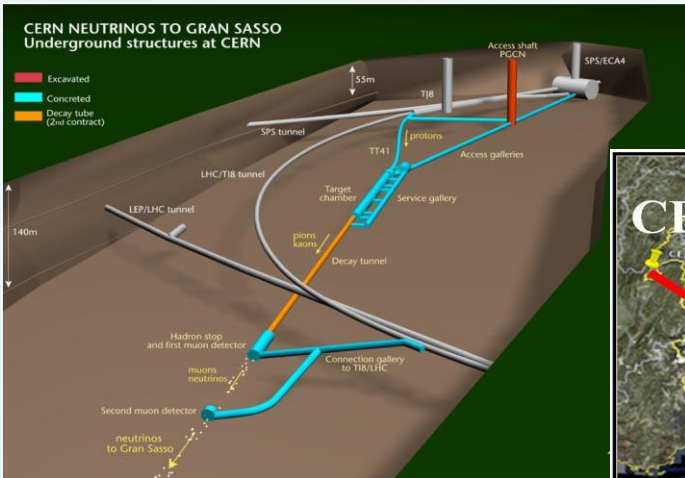
– non-oscillation physics:

- charged particle multiplicity analysis
- cosmic ray physics



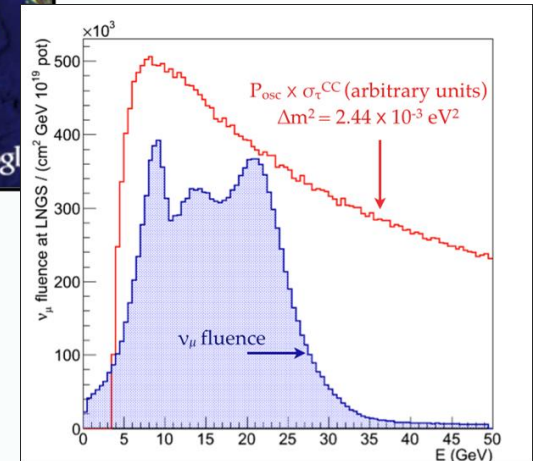
Channel	BR
$\tau^- \rightarrow e^- \nu_\tau \bar{\nu}_e$	17.8%
$\tau^- \rightarrow \mu^- \nu_\tau \bar{\nu}_\mu$	17.7%
$\tau^- \rightarrow h^- \nu_\tau (n\pi^0)$	49.5%
$\tau^- \rightarrow 3h \nu_\tau (n\pi^0)$	15.0%

CNGS neutrino beam



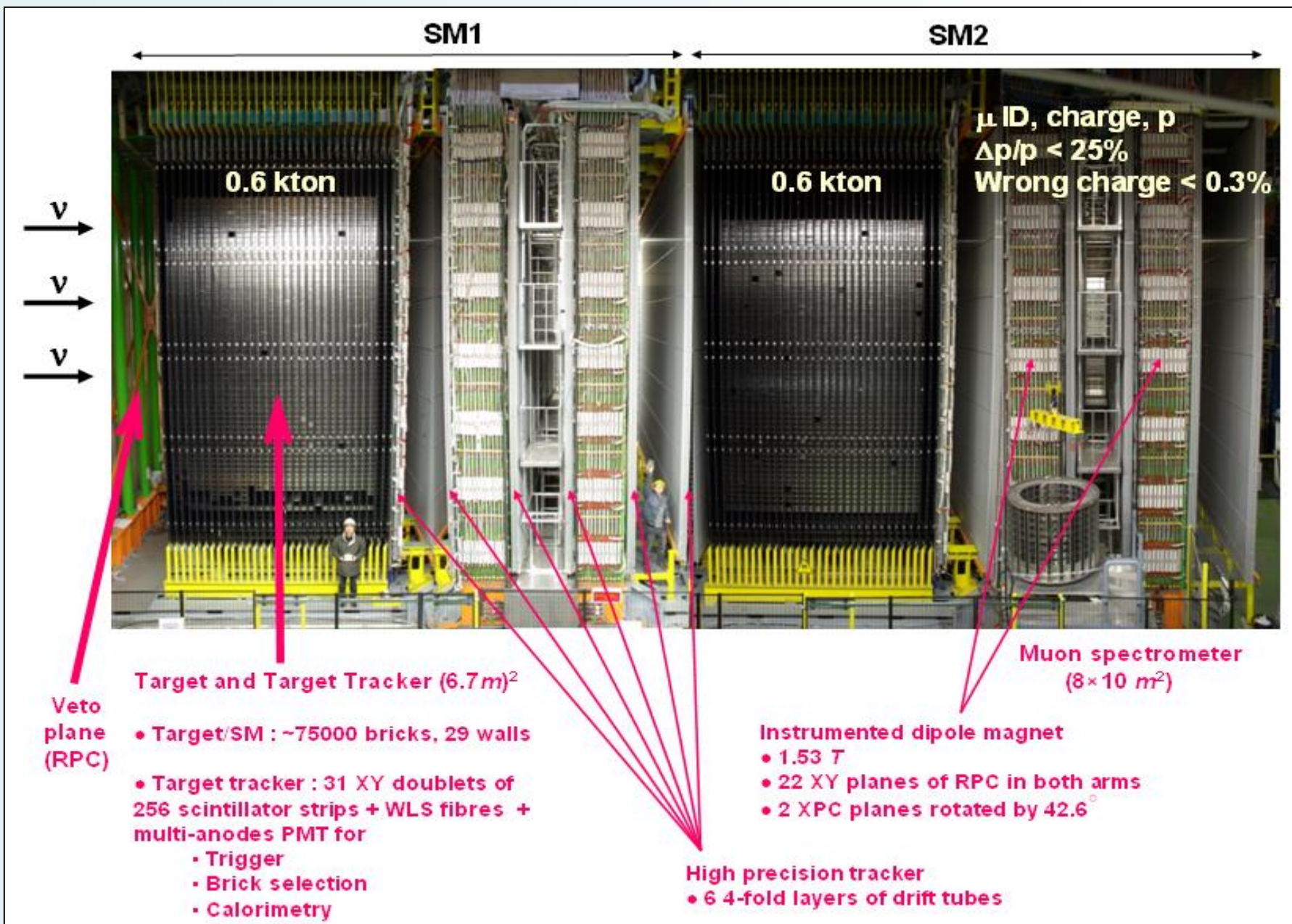
$\langle E_{\nu_\mu} \rangle$	17 GeV
$(\nu_e + \bar{\nu}_e)/\nu_\mu$	0.9%*
$\bar{\nu}_\mu/\nu_\mu$	2.0%*
ν_τ prompt	negligible

* interaction rate @ LNGS

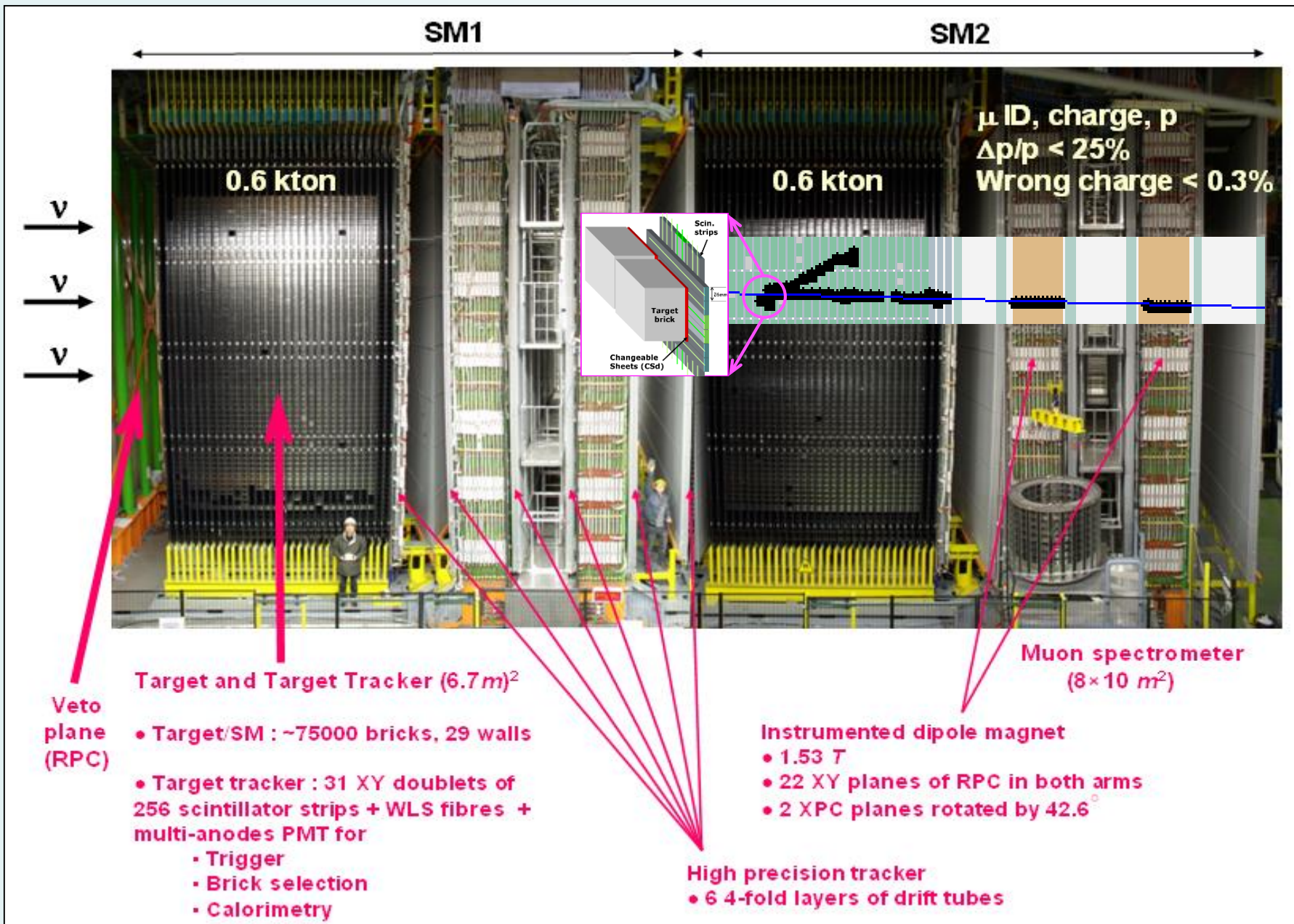


The beam was optimized to maximize the number of ν_τ CC interactions in the detector

OPERA hybrid detector



OPERA hybrid detector



CERN Open Data Portal

CERN Open Data Portal

opendata.cern.ch

Documentation

About

The CERN Open Data portal is the access point to a growing range of data produced through the research performed at CERN. It disseminates the preserved output from various research activities, including accompanying software and documentation which is needed to understand and analyse the data being shared.

The portal adheres to established global standards in data preservation and Open Science: the products are shared under open licenses; they are issued with a digital object identifier (DOI) to make them citable objects in the scientific discourse (see details below on how to do this).



22nd of May 2018: [release](#) of the first set of OPERA data samples.

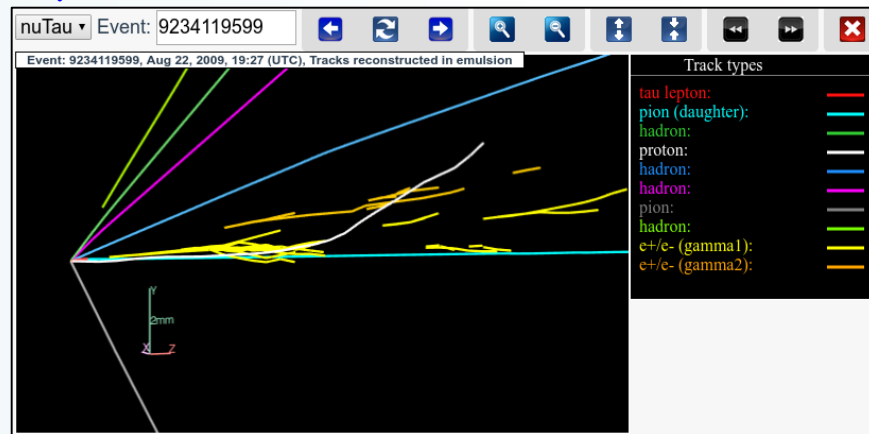
OPERA became the first non-LHC experiment presented in the portal.

ν_τ event sample

10 ν_τ -candidate events observed in the $\tau \rightarrow h$, $\tau \rightarrow 3h$, and $\tau \rightarrow \mu$ channels.

Results of a dedicated analysis, with a detailed classification of all particles produced in the neutrino interactions, has been presented.

ν_τ -candidate event reconstructed in the nuclear emulsions



Channel	Expected Background				Exp. Signal	Observed
	Charm	Had. re-interaction	Large μ -scat.	Total		
$\tau \rightarrow 1h$	0.15 ± 0.03	1.28 ± 0.38	—	1.43 ± 0.41	2.96 ± 0.59	6
$\tau \rightarrow 3h$	0.44 ± 0.09	0.09 ± 0.03	—	0.53 ± 0.12	1.83 ± 0.37	3
$\tau \rightarrow \mu$	0.008 ± 0.002	—	0.02 ± 0.008	0.03 ± 0.01	1.15 ± 0.23	1
$\tau \rightarrow e$	0.035 ± 0.007	—	—	0.03 ± 0.007	0.84 ± 0.17	0
Total	0.63 ± 0.13	1.37 ± 0.41	0.02 ± 0.008	2.0 ± 0.5	6.8 ± 1.4	10

* expectations for full mixing and $\Delta m_{32}^2 = 2.50 \times 10^{-3} eV^2$

Probability to be explained by background: 4×10^{-10}

This corresponds to 6.1σ significance of non-null observation

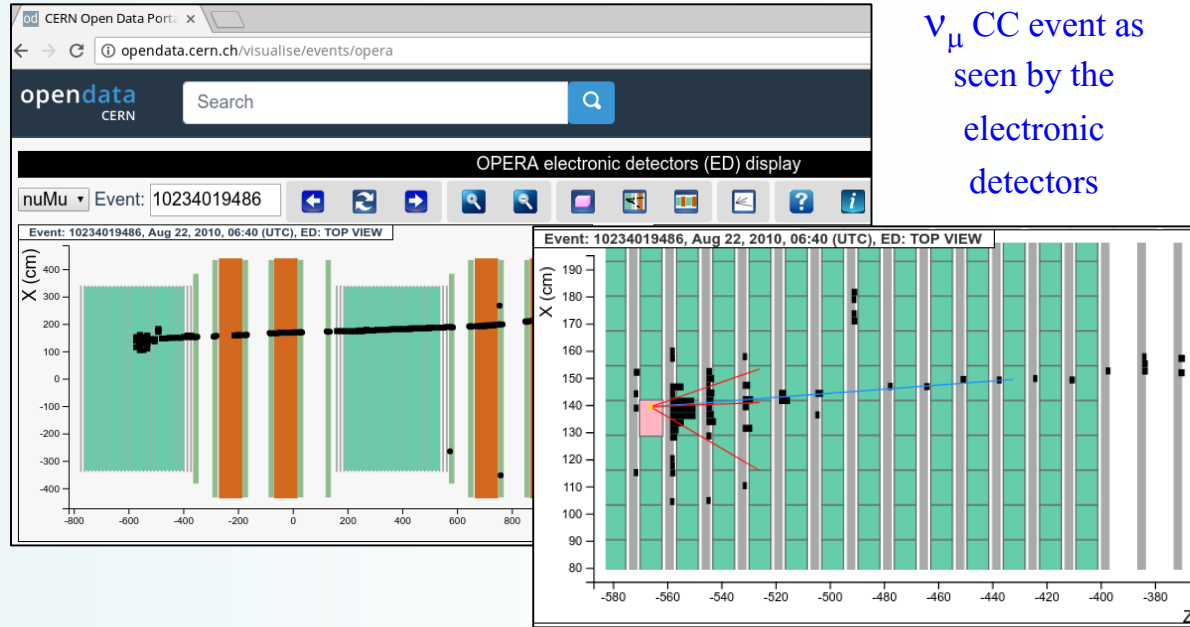
[PRL 120 (2018) 211801]

$\nu_{\mu} CC$ event sample

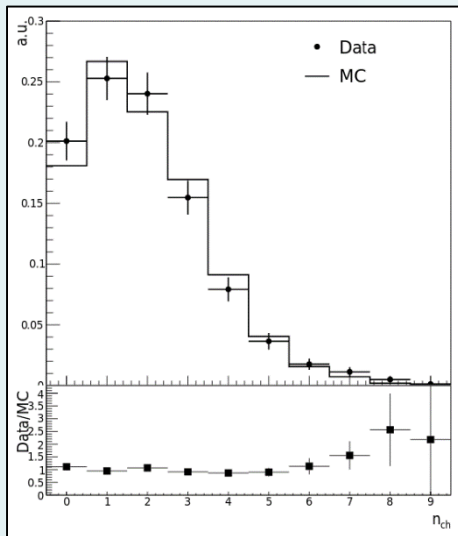
817 $\nu_{\mu} CC$ events where a muon was reconstructed in the final state.

The events were selected for study of charged hadron multiplicities in CC neutrino-lead interactions.

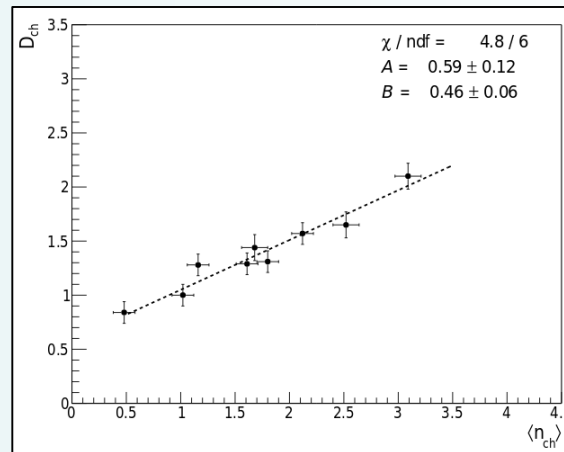
$\nu_{\mu} CC$ event as seen by the electronic detectors



Data-MC comparison of the charged hadron multiplicity



The charged hadrons multiplicity dispersion as a function of mean number of tracks



[Eur.Phys.J C78 (2018)
no.1, 62]

OPERA data for the two event samples

opendata.cern.ch/search?page=1&size=20&experiment=OPERA&file_type=zip

Filter by experiment

OPERA 4

Filter by year

2009-2012 2

2010-2012 2

Filter by file type

csv 831

pdf 2

zip 4

Electronic detector data for multiplicity studies

The dataset was extracted from the official OPERA data repository. It contains 817 muon neutrino interactions with the lead target where a muon was reconstructed in the final state. This happens in th...

[Dataset](#) [Derived](#) [OPERA](#)

Electronic detector data for tau neutrino appearance studies

This dataset was extracted from the official OPERA data repository and it contains all the data of the electronic detectors for the ten tau neutrino candidates, identified after an extensive analys...

[Dataset](#) [Derived](#) [OPERA](#)

Emulsion data for neutrino tau appearance studies

This dataset was extracted from the official OPERA data repository and it contains all the emulsion data information for the ten tau neutrino candidates, identified after an extensive analysis that...

[Dataset](#) [Derived](#) [OPERA](#)

Emulsion data for track multiplicity

The dataset was extracted from the official OPERA data repository. It contains 817 muon neutrino interactions with the lead target where a muon was reconstructed in the final state. This happens in th...

[Dataset](#) [Derived](#) [OPERA](#)

csv-file examples: electronic detector data for the two samples

11 csv-files* for each event: EventInfo.csv, RawTTHitsXZ.csv, RawTTHitsYZ.csv, FilteredTTHitsXZ.csv, FilteredTTHitsYZ.csv, RawRPCHitsXZ.csv, RawRPCHitsYZ.csv, FilteredRPCHitsXZ.csv, FilteredRPCHitsYZ.csv, RawDTHitsXZ.csv, FilteredDTHitsXZ.csv

Dataset Semantics (Description of the variables in the csv-files):

ampL:PMT amplitude measured from the "left" side of a scintillator strip (in photo-electrons)

ampR:PMT amplitude measured from the "right" side of a scintillator strip (in photo-electrons)

ampRec:PMT amplitude reconstructed from the "left" and "right" side amplitudes of a scintillator strip taking into account light attenuation in a WLS fiber (in photo-electrons)

clLength:cluster length (in cm)

driftDist:drift distance (in cm)

enHad:energy of a hadron jet (in GeV)

enNeu:energy of a neutrino (in GeV)

enVis:visible energy (in MeV)

evID:event Id (11-digit number)

muMom:momentum of a muon (in GeV/c)

posX:X position of a drift tube, RPC, Target Tracker hit in the OPERA detector system of reference (in cm)

posY:Y position of an RPC hit in the OPERA detector system of reference (in cm)

posZ :Z position of a drift tube, RPC, Target Tracker hit in the OPERA detector system of reference (in cm)

timestamp:event time in milliseconds since 01/01/1970

* [csv-file](#) is a delimited text file that uses a comma to separate values.

Summary & outlook

- *First two OPERA data subsamples* have been published on the CERN [Open Data Portal](#):

- the “tau appearance sample” (10 ν_τ candidate events),
- the “multiplicity sample” (817 ν_μ CC events).

- *Browser-based event display* has been developed and integrated to the portal for visualization of the published OPERA events.

- A dedicated paper with a detailed description of the two released data subsamples is almost ready to be applied for publication in the [Nature Scientific Data](#) journal.

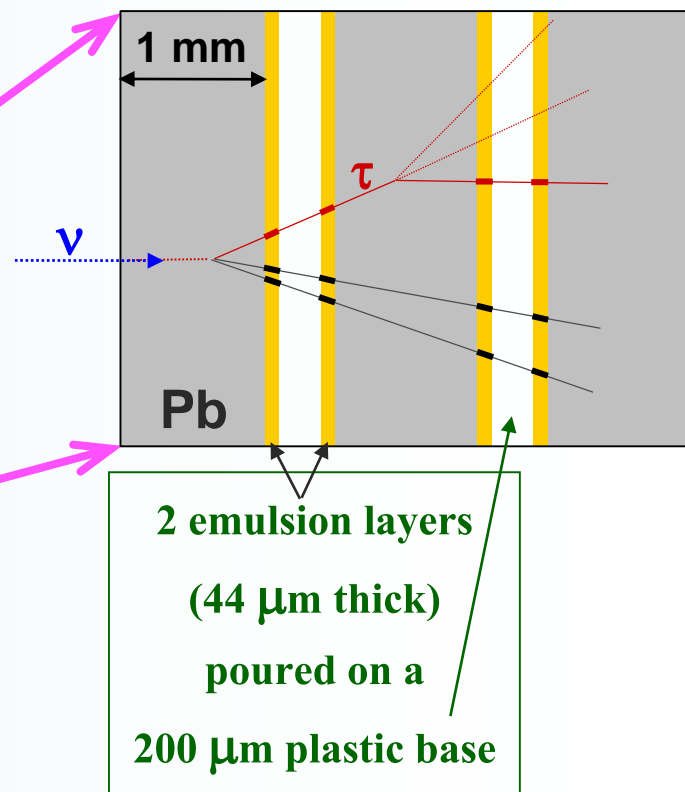
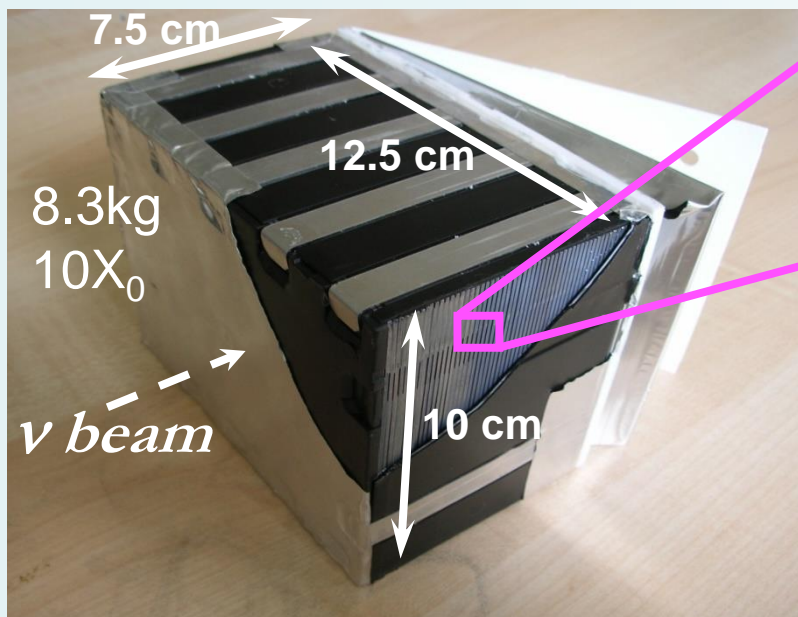
- More data subsamples (e.g., *ν_e sample, cosmic muon sample*) are planned to be released.

- Interactive tutorials (exercises for students, etc.) to be developed as well.

Backup slides

OPERA ECC brick

Basic unit of the OPERA detector was an *Emulsion Cloud Chamber* module (*ECC brick*): sandwich of **57** emulsion films interleaved with lead plates + a separate box with a removable pair of films (CSd)



The OPERA target

Number of bricks: $\sim 150'000$
Total mass: ~ 1.2 kton
Total film surface: $\sim 111'000$ m²

The ECC technique proved its efficiency and is going to be used in future experiments for ν_τ registration (**DsTau**, **SHiP**, ...) and even for directional dark matter search (**NEWSdm**).

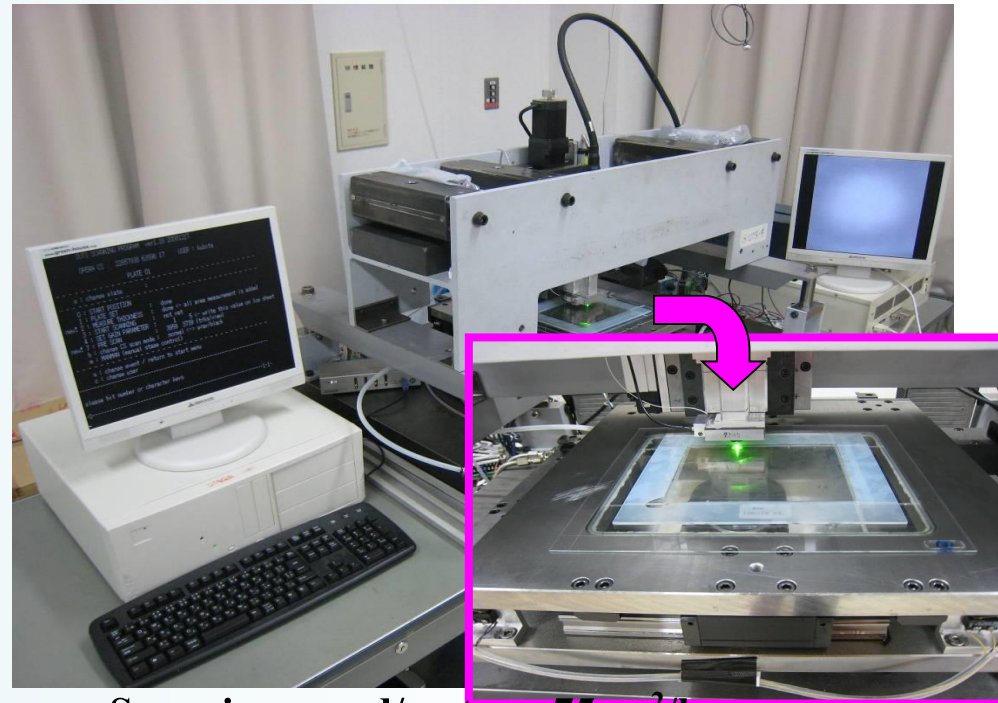
Emulsion scanning stations used in OPERA

EU: ESS (European Scanning System)



- Scanning speed/system: $20\text{cm}^2/\text{h}$
- Customized commercial optics and mechanics
- Asynchronous DAQ software

Japan: S-UTS (Super Ultra Track Selector)

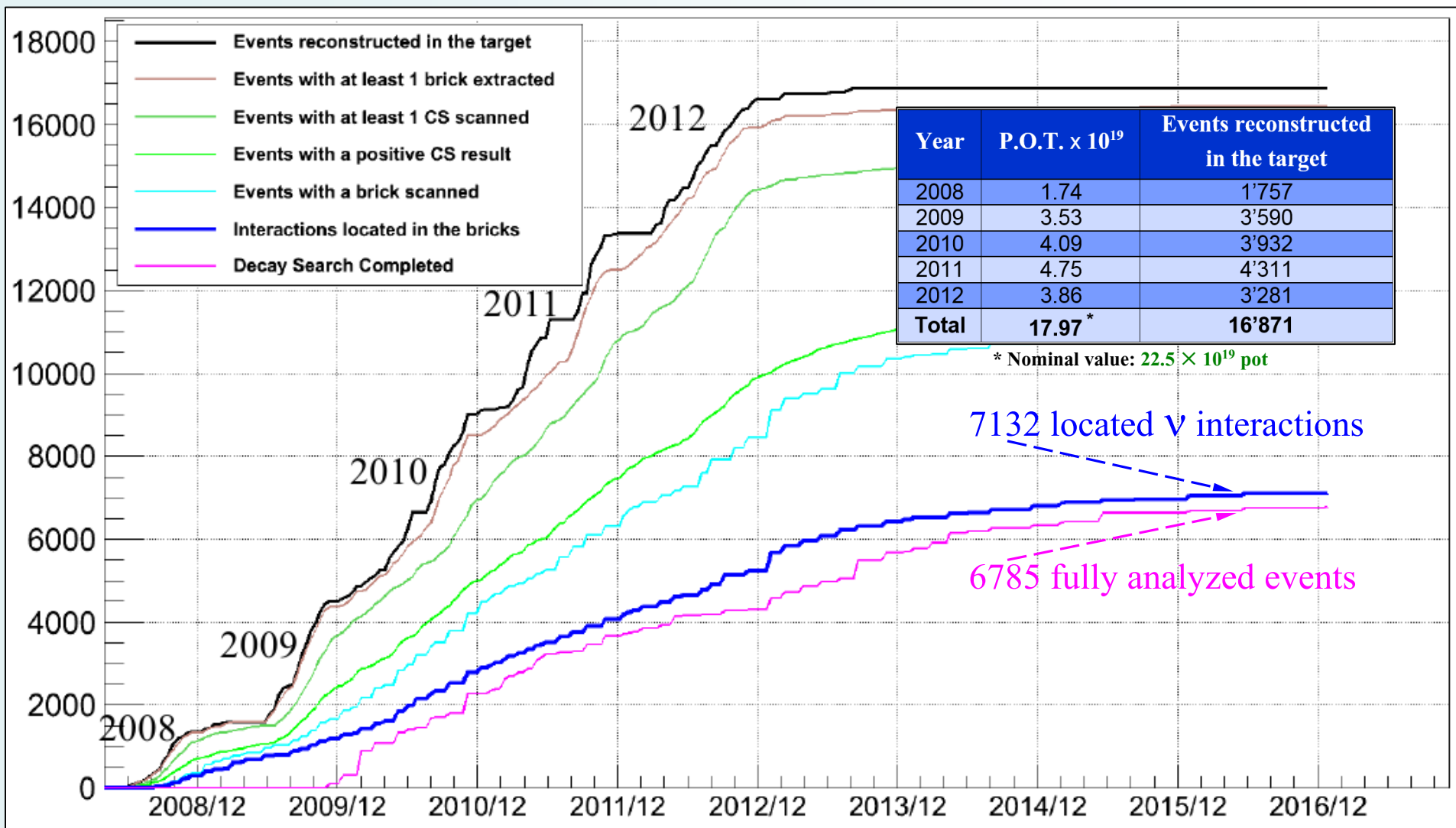


- Scanning speed/system: $75\text{cm}^2/\text{h}$
- High speed CCD camera, Piezo-controlled objective lens
- FPGA Hard-coded algorithms

Both systems demonstrated:

- $\sim 0.3\ \mu\text{m}$ spatial resolution
- $\sim 2\ \text{mrad}$ angular resolution
- $\sim 95\%$ base track detection efficiency

Status of data analysis



Discovery of ν_τ appearance in the CNGS beam (2015)

Channel	Expected background				Expected signal*	Observed
	Charm	Had. reinterac.	Large μ scat.	Total		
$\tau \rightarrow 1h$	0.017 ± 0.003	0.022 ± 0.006		0.04 ± 0.01	0.52 ± 0.10	3
$\tau \rightarrow 3h$	0.17 ± 0.03	0.003 ± 0.001		0.17 ± 0.03	0.73 ± 0.14	1
$\tau \rightarrow \mu$	0.004 ± 0.001		0.0002 ± 0.0001	0.004 ± 0.001	0.61 ± 0.12	1
$\tau \rightarrow e$	0.03 ± 0.01			0.03 ± 0.01	0.78 ± 0.16	0
Total	0.22 ± 0.04	0.02 ± 0.01	0.0002 ± 0.0001	0.25 ± 0.05	2.64 ± 0.53	5

* expectations for *full mixing* and $\Delta m_{32}^2 = 2.44 \times 10^{-3} \text{ eV}^2$

Observed in data: **5 events** in the $\tau \rightarrow h$, $\tau \rightarrow 3h$, and $\tau \rightarrow \mu$ channels

Probability to be explained by background: **1.1×10^{-7}**

This corresponds to **5.1σ** significance of non-null observation

[PRL 115 (2015) 121802]

Disclaimer for the OPERA open data

(from opendata.cern.ch/docs/about-opera)

- **The open data are released under the [Creative Commons CC0 waiver](#). Neither OPERA nor CERN endorse any works, scientific or otherwise, produced using these data.**
- **All released data samples will have a unique DOI that you are requested to cite in any applications or publications.**