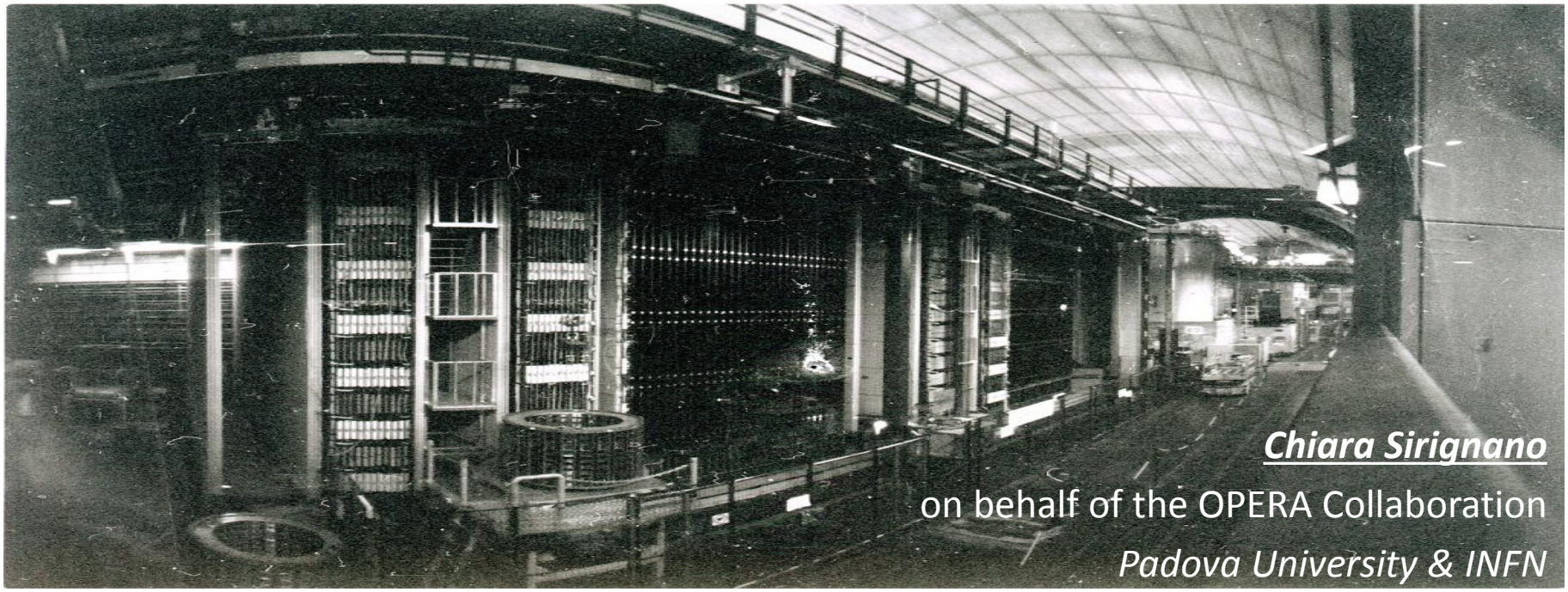
More results from the OPERA experiment

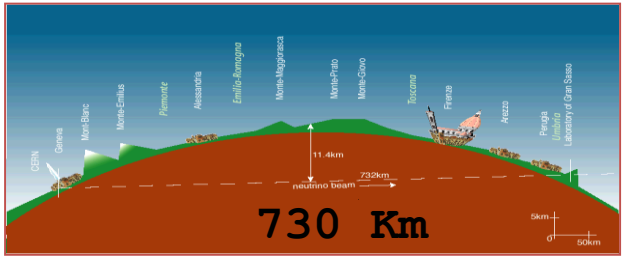


Chiara Sirignano

on behalf of the OPERA Collaboration

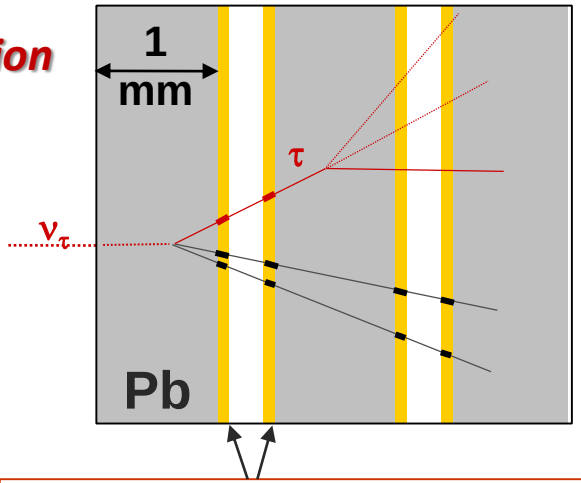
Padova University & INFN

Oscillation Project with Emulsion tRacking Apparatus

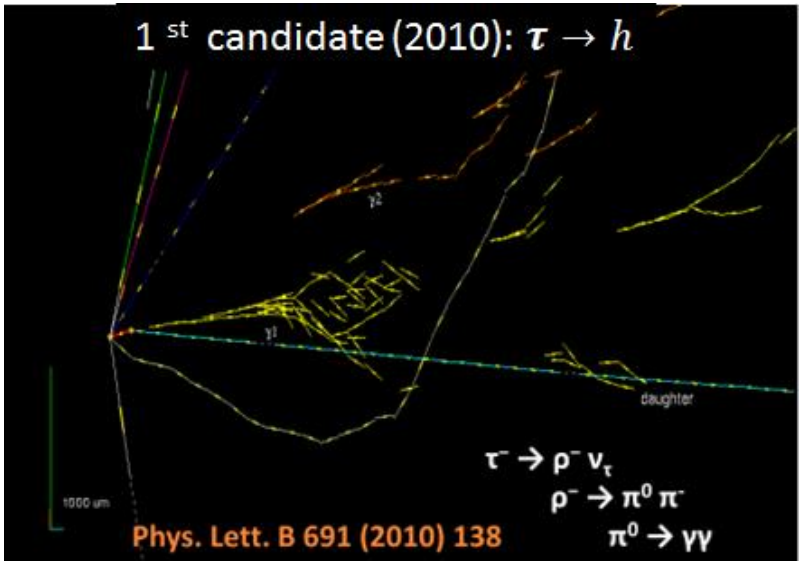


- Long baseline neutrino oscillation experiment
- ***CNGS*** quasi – pure wide band ν_μ beam
- <E> = 17 GeV optimized to maximize ν_τ CC interactions
- Nuclear emulsions + Lead (150 000 ECC bricks) "active target", allowing 3D particle reconstruction, sub-micron spatial resolution and high background rejection rate.
- More than 18 000 neutrino interactions collected in 5 years
- More than 7000 ν_μ interactions fully reconstructed and studied
- Detection of 5 ν_τ CC interaction by a full reconstruction of the primary vertex and observation of τ lepton decay topologies (***PRL*** 115 (2015) 121802)

Reconstruction



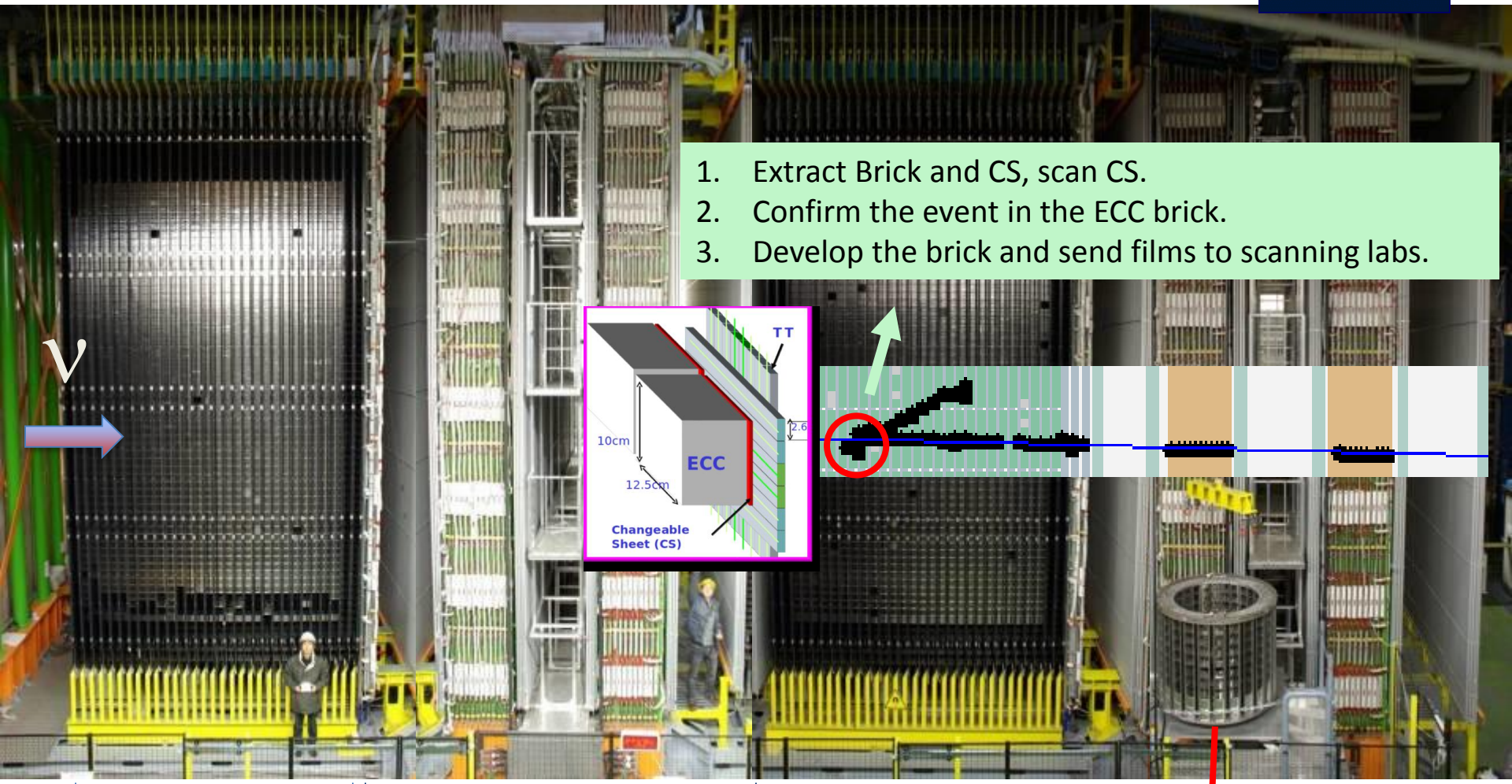
57 × 2 emulsion layers (42 μm thick)
poured on a 200 μm plastic base



SM1 SM2

OPERA

1. Extract Brick and CS, scan CS.
2. Confirm the event in the ECC brick.
3. Develop the brick and send films to scanning labs.

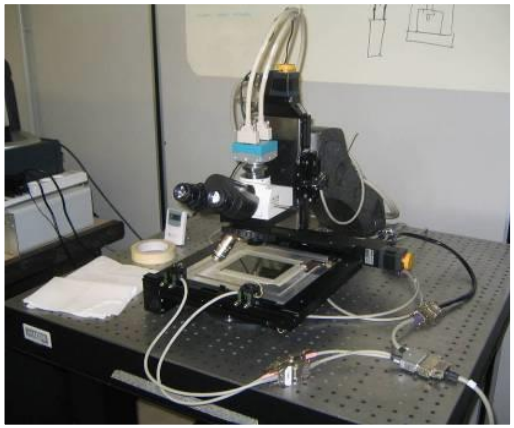


Target area : (ECC + CS + planes of scintillator strips)

~ 150.000 bricks
1.25 kt mass

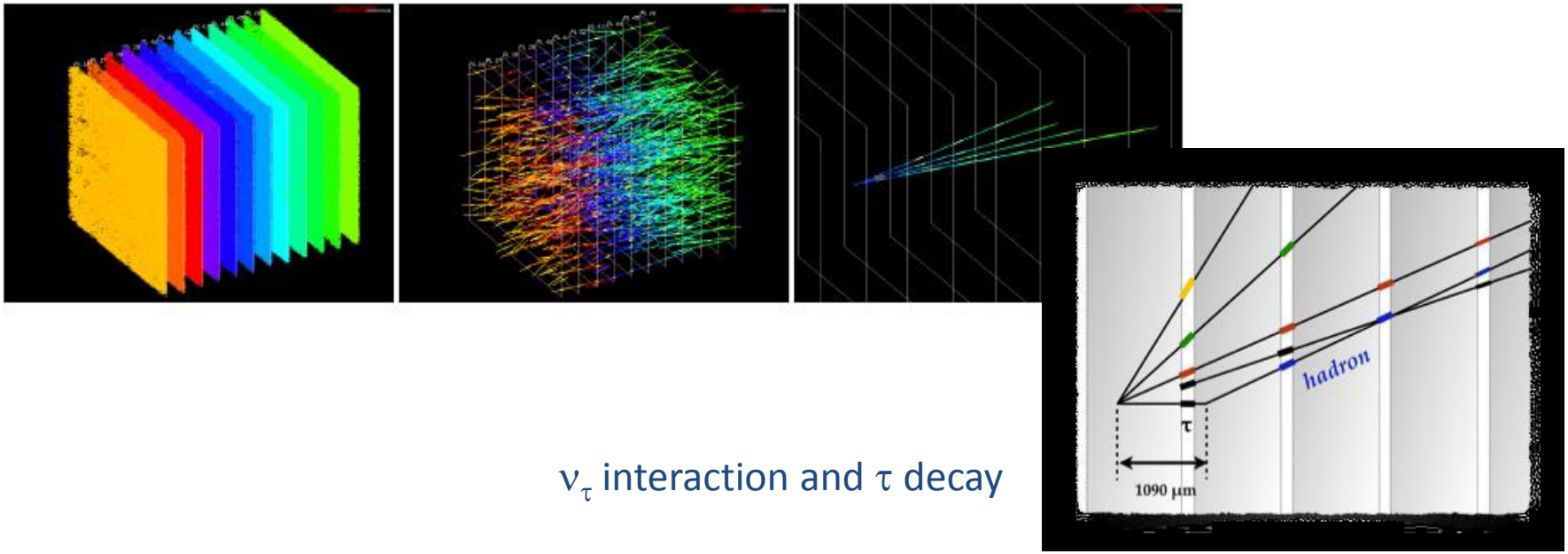
Muon spectrometer (Magnet+RPC+PT)

Brick Manipulator System



- New generation automatic emulsion scanning systems
- Scanning speed/system > 20cm^2/h
- Customized commercial optics and mechanics
- Customized DAQ & event reconstruction software
- ~ 0.3 μm spatial resolution
- ~ 2 mrad angular resolution
- ~ 95% detection efficiency on a single emulsion film

Neutrino interaction reconstruction chain



ν_τ interaction and τ decay

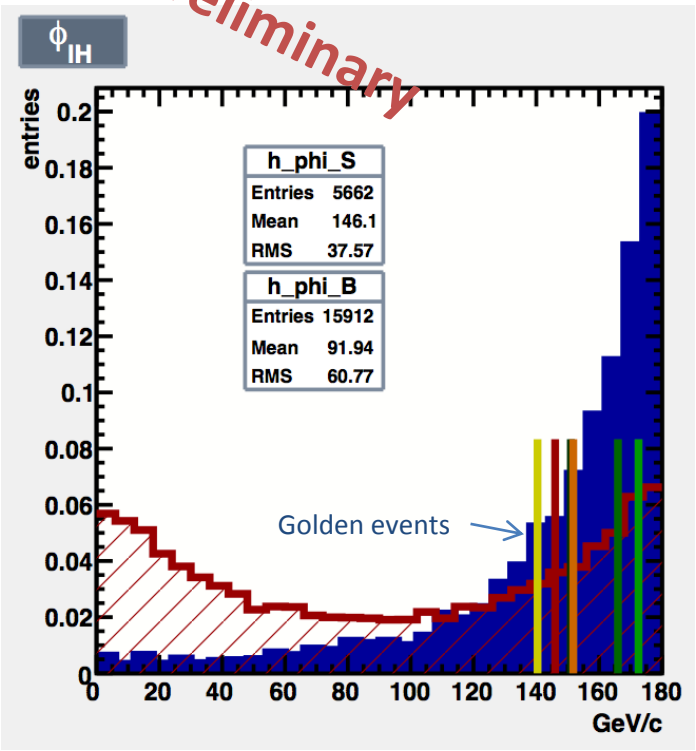
Events selection with looser kinematical cuts

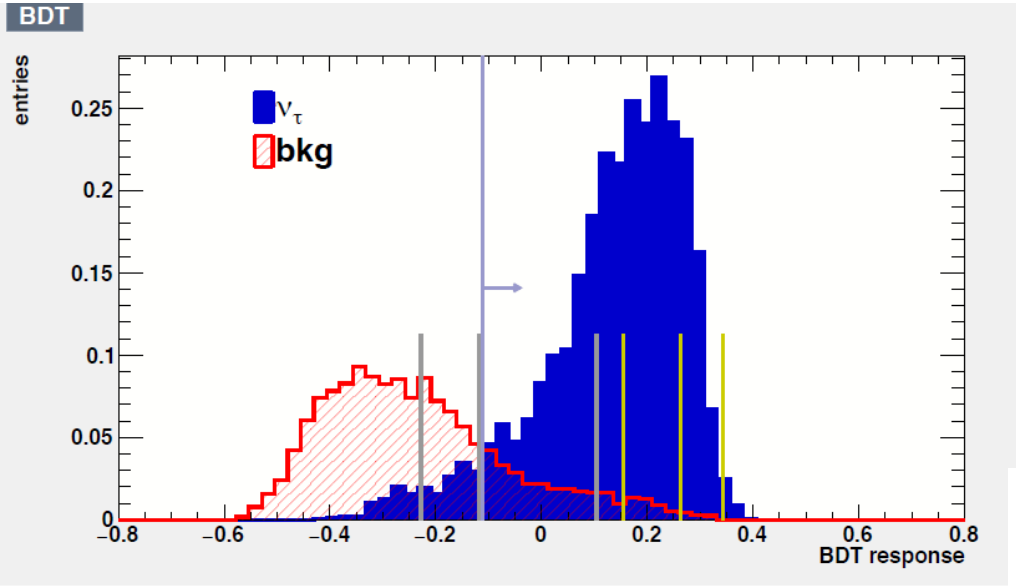
Selection criteria where modified to increase the statistics and multivariate analysis was applied to select new interesting events

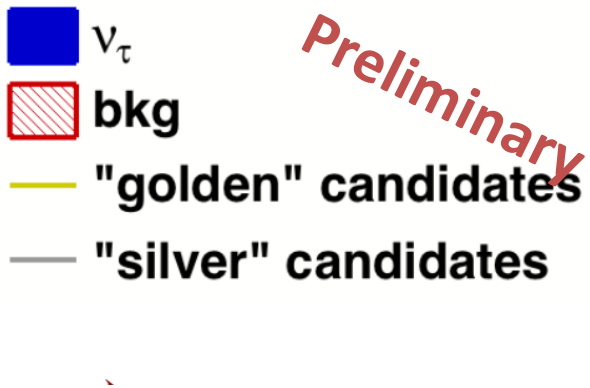
Variable	$\tau \to 1h$ OLD	$\tau \to 1h$ NEW	$\tau \to 3h$ OLD	$\tau \to 3h$ NEW	$\tau \to \mu$ OLD	$\tau \to \mu$ NEW	$\tau \to e$ OLD	$\tau \to e$ NEW
z_{dec} (μm)	$[44, 2600]$	<2600	<2600		$[44, 2600]$	<2600	<2600	
θ_{kink} (rad)	>0.02		<0.5	>0.02	>0.02		>0.02	
p_{2ry} (GeV/c)	>2	>1	>3	>1	$[1, 15]$		$[1, 15]$	>1
p^T_{2ry} (GeV/c)	$>0.6\,(0.3)$	>0.15	/		>0.25	>0.1	>0.1	
p^T_{miss} (GeV/c)	<1	/	<1	/	/		/	
ϕ_{lH} (rad)	$>\pi/2$	/	$>\pi/2$	/	/		/	
m, m_{min} (GeV/c^2)	/		$[0.5, 2]$	/	/		/	

- ✓ **5 more ν_τ candidates**
- ✓ **S/B reduced from 10 to 3**
- ✓ **Improvement in Δm^2_{23} measurement, the first ever in appearance mode**

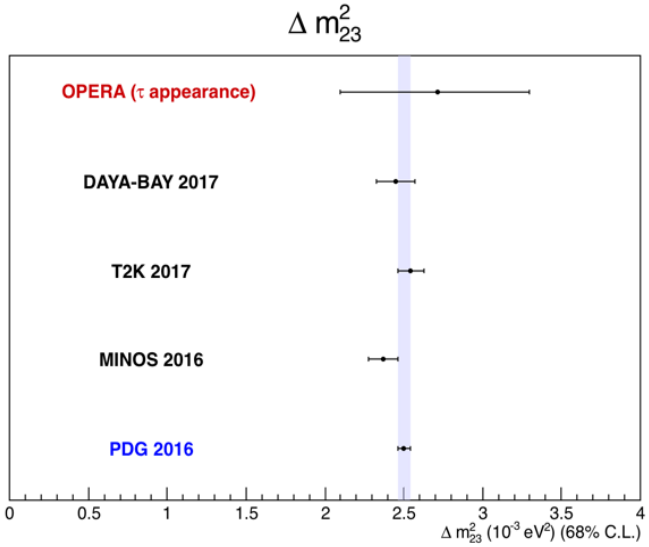
Channel	Expected Background				Expected Signal	Total
	Charm	Had. re-interaction	Large μ-scat.	Total		Expected
$\tau \to 1h$	0.15	1.28	–	1.43	2.96	4.39
$\tau \to 3h$	0.44	0.09	–	0.52	1.83	2.35
$\tau \to \mu$	0.008	–	0.02	0.03	1.15	1.18
$\tau \to e$	0.035	–	–	0.03	0.84	0.87
Total	0.63	1.37	0.02	2.0 ± 0.5	6.8 ± 1.4	8.8 ± 1.9







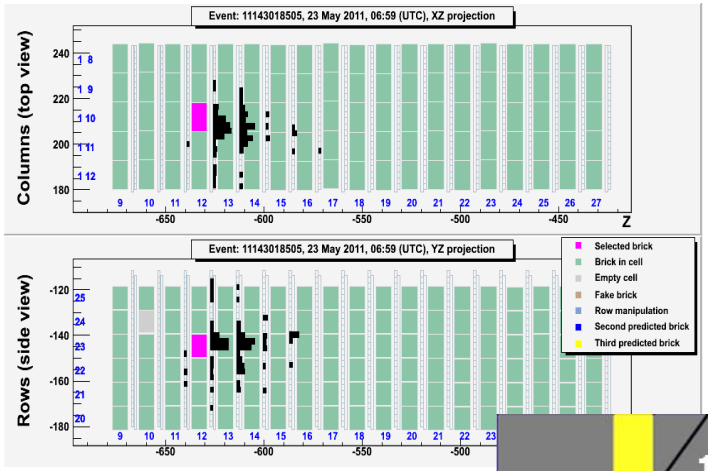
Expected Signal	Expected Background	Observed ν_τ	Δm^2_{23} (10^{-3} eV^2)
6.8	2.0	10	2.7 ± 0.6 68% C.L

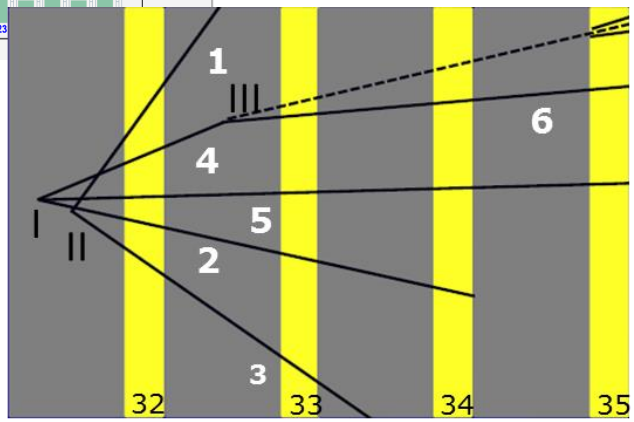


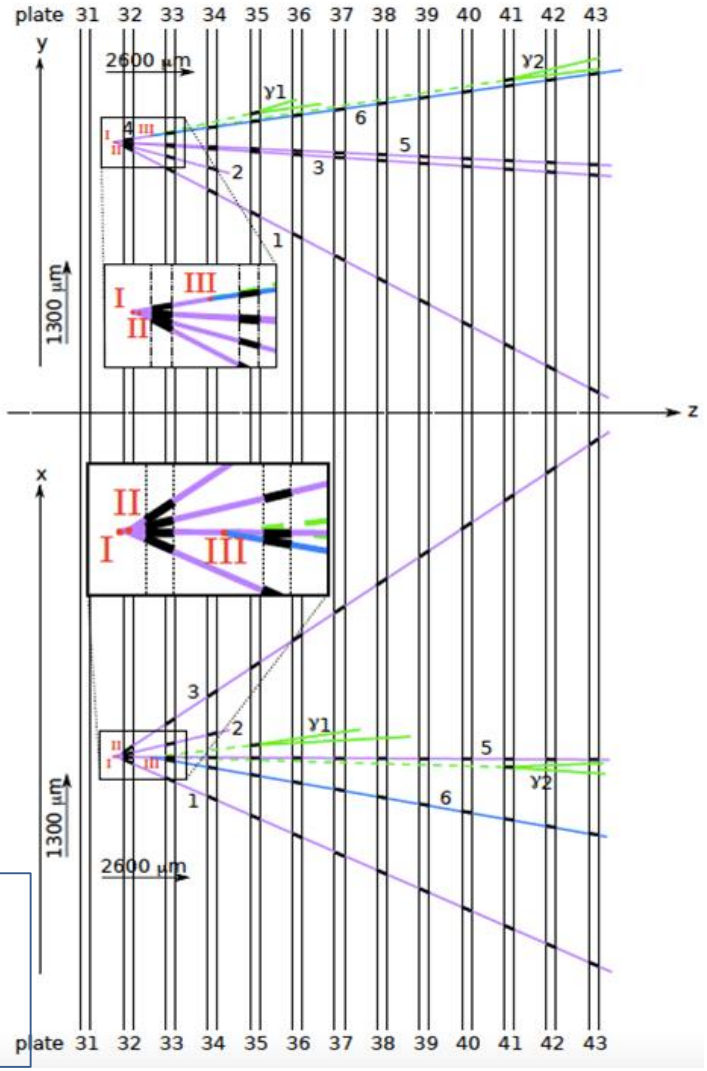
5.2 σ significance

Muon-less event 114301850

Zoom of the interaction region : pink brick selected







Two secondary vertices reconstructed in emulsion :

- **short two prong (F.L. = 103 μm)**
- **charged one prong (kink) (F.L.= 1174 μm, θ_k = 97mrad)**

Event interpretation

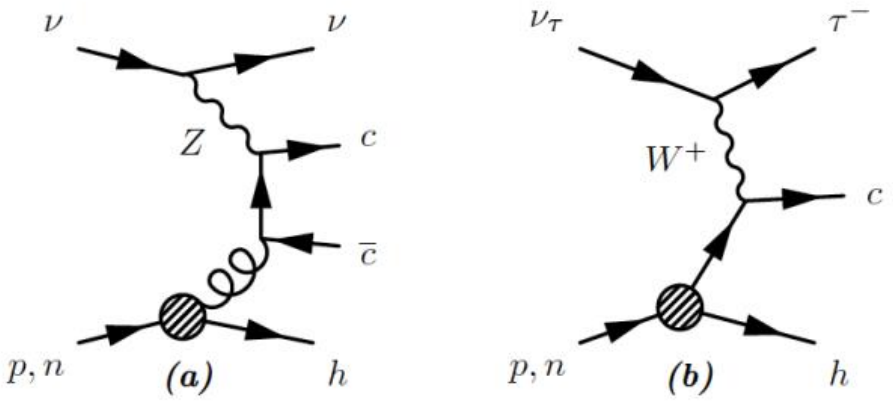
Two possible rare processes :

a) ν NC + $c\bar{c}$ (only 3 events in CHORUS)

b) ν_τ CC + charm (never observed)

and possible backgrounds :

- ν_τ CC + hadron interaction
- ν_μ CC + charm + hadron interaction
- ν_μ NC + 2 hadron interactions
- ν_μ CC + 2 hadron interactions

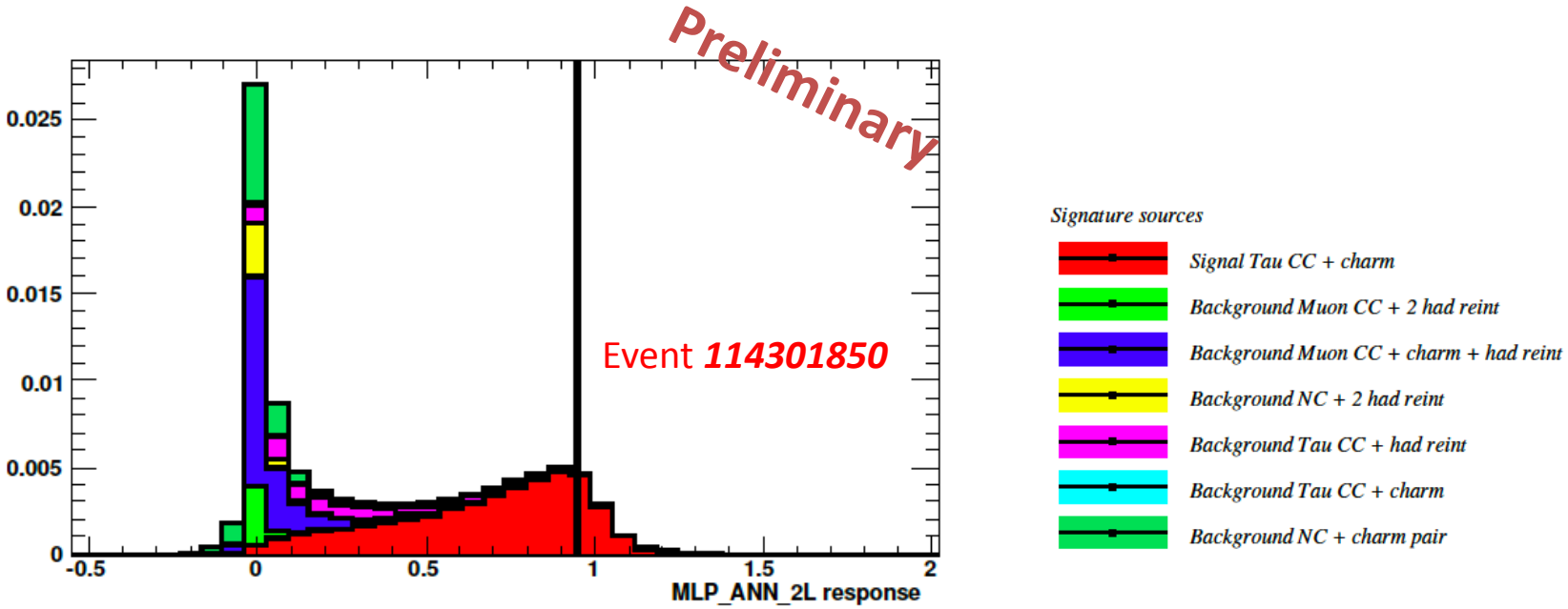


Preliminary

Sample	Expected events (10^{-3})
DIS ν_μ CC	4.0 ± 0.5
DIS ν_μ CC + charm	20.5 ± 0.5
DIS ν NC	3.8 ± 0.3
DIS ν NC + $c\bar{c}$ pair	12.59 ± 0.02
DIS ν_τ CC	9.0 ± 0.1
DIS ν_τ CC + charm	44.5 ± 0.1
Total	94.4

A complete simulation was performed, considering the observed topology and OPERA event location efficiencies, 0.1 events expected.

Event classification by multivariate analysis



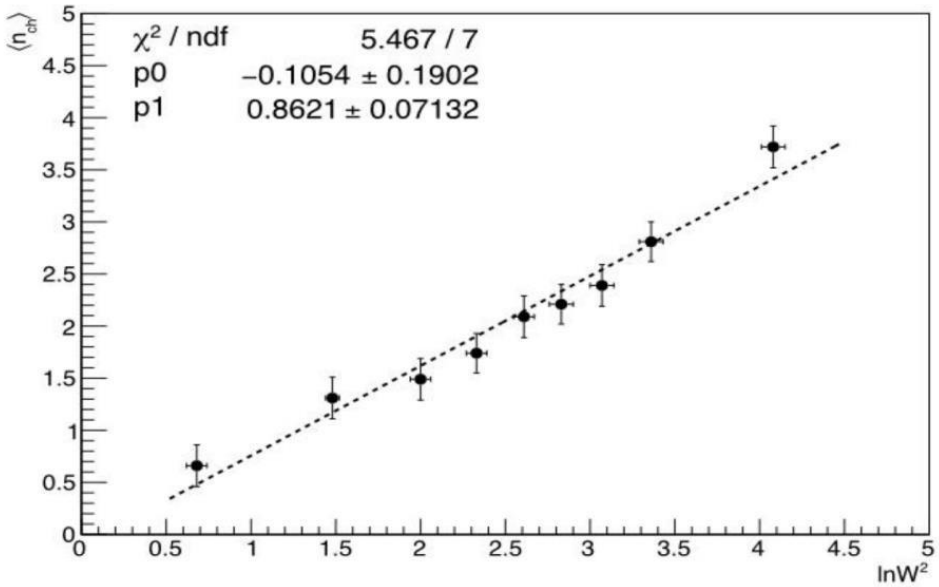
The event is classified as a tau neutrino interaction with charm production, never observed before !!

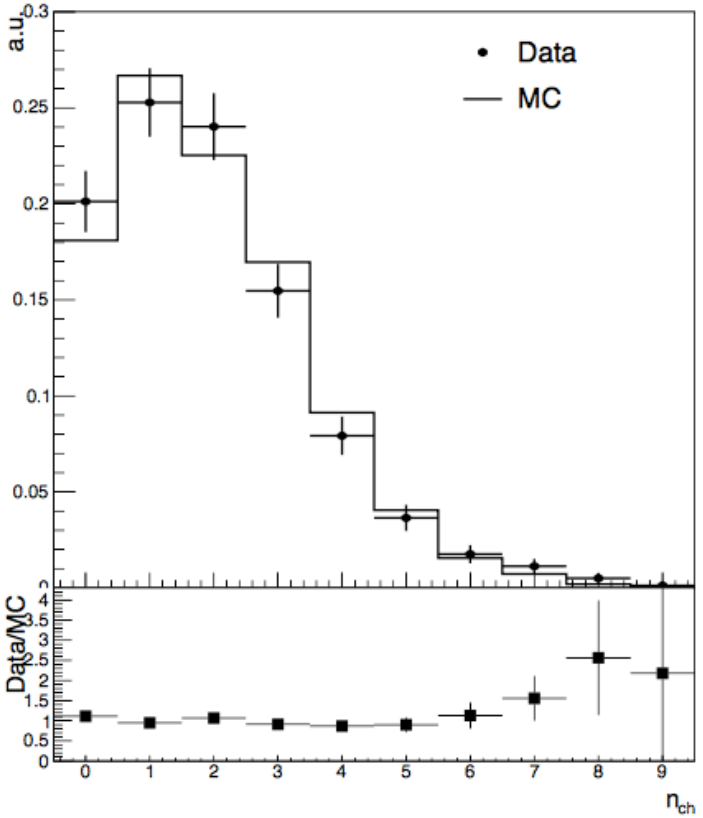
The significance evaluated with respect to the background only hypothesis is 3.5 σ

Multiplicity studies in neutrino-lead scattering

The average charged particles multiplicity at primary vertex was measured.

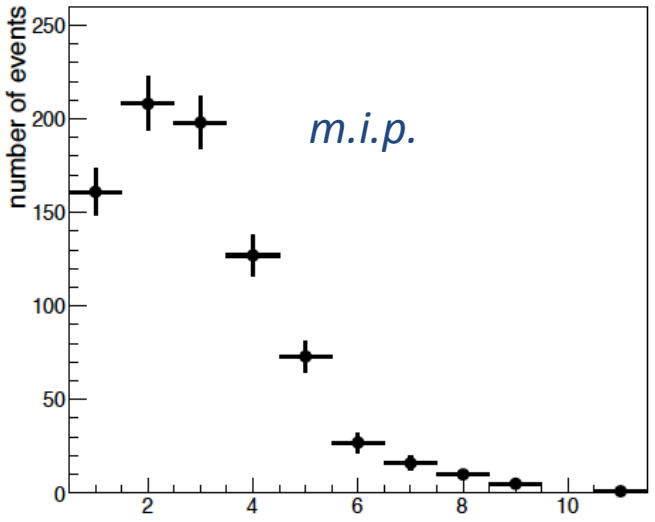
- ✓ Test for phenomenological and theoretical models
- ✓ Provides data to tune MC event generators.
- ✓ Test KNO Scaling

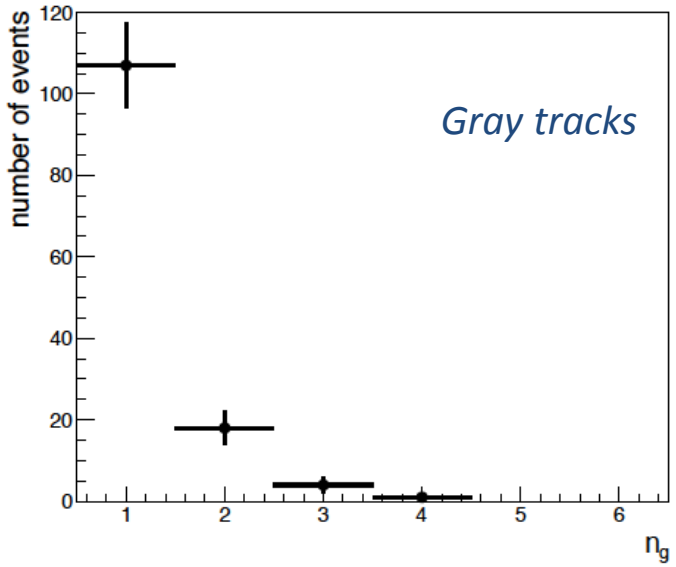


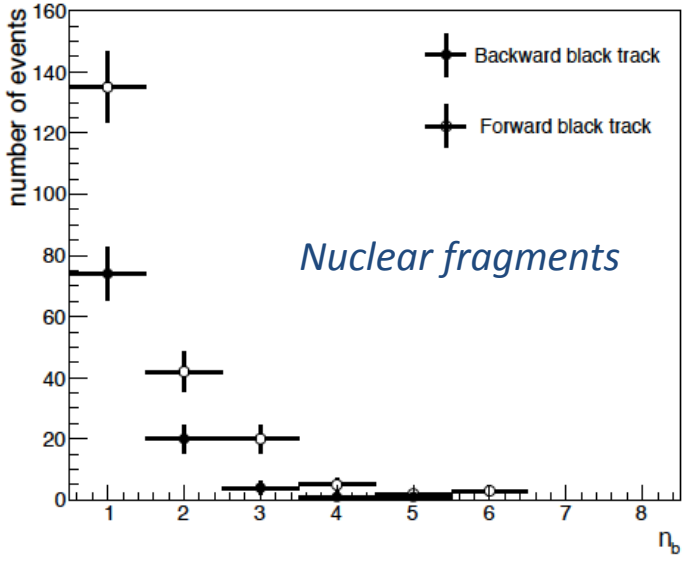


submitted to EPJC and arXiv (http://arxiv.org/abs/1706.07930)

The average charged particles multiplicity at primary vertex was measured also for different Ionization (N_{grains}/100 μm), this is peculiar in emulsion.

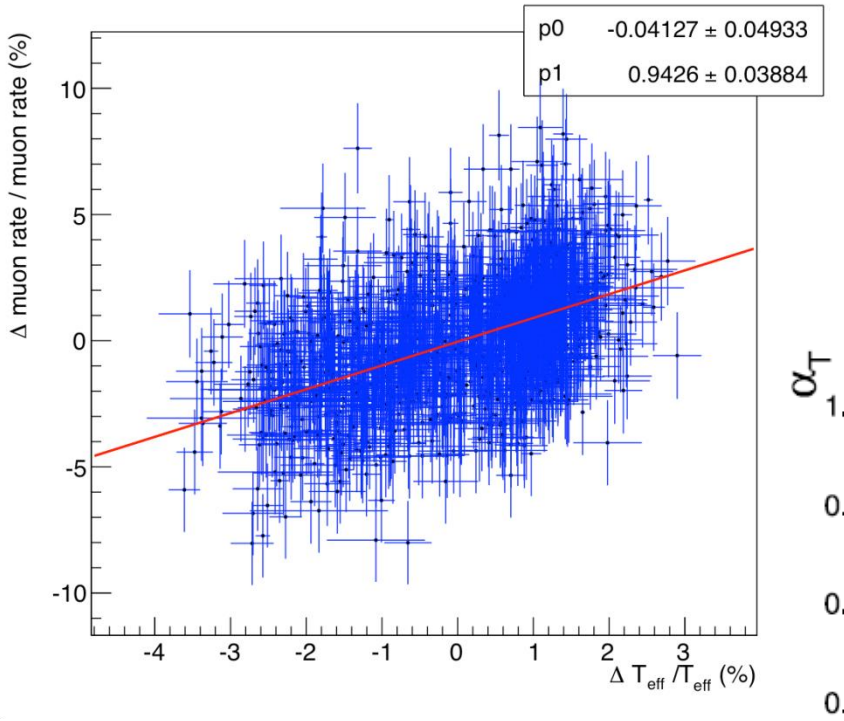






Cosmic-muons rate temperature dependance

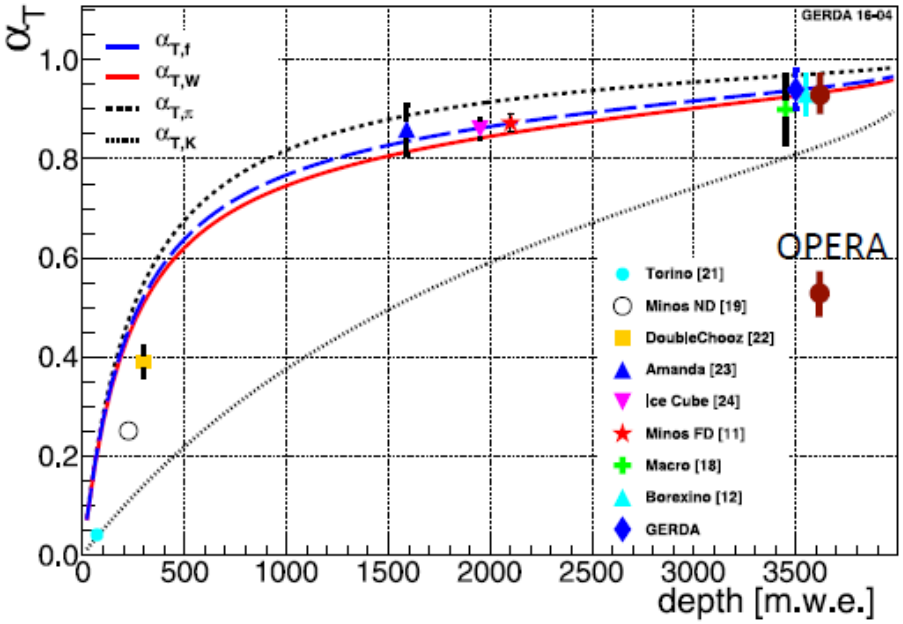
Atmospheric temperature increase affects the cosmic-muons rate



$$\frac{\Delta I_\mu}{I_\mu^0} = \alpha_T \frac{\Delta T_{\rm eff}}{T_{\rm eff}}$$

Preliminary

$$\alpha_T = 0.94 \pm 0.04$$



Thanks for the attention

28 institutions - 140 physicists

http://operaweb.lngs.infn.it

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