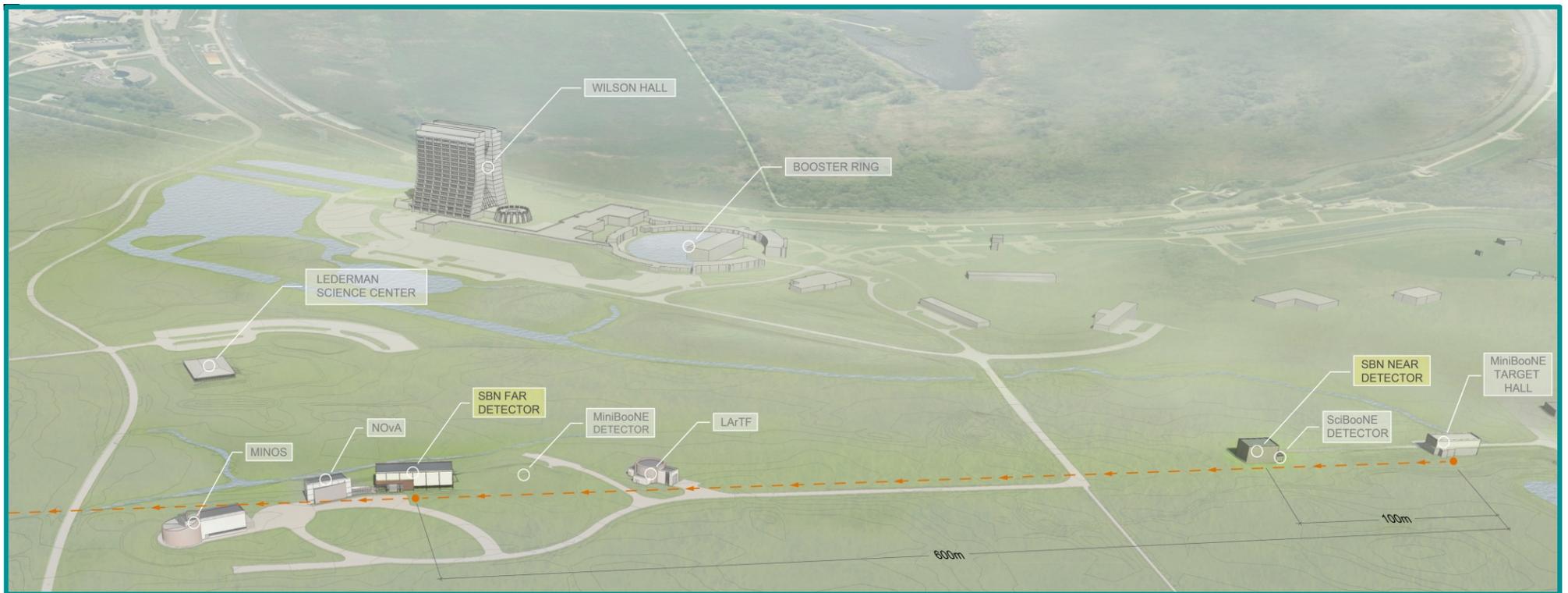


# ICARUS-SBN

Alla ricerca dei neutrini sterili

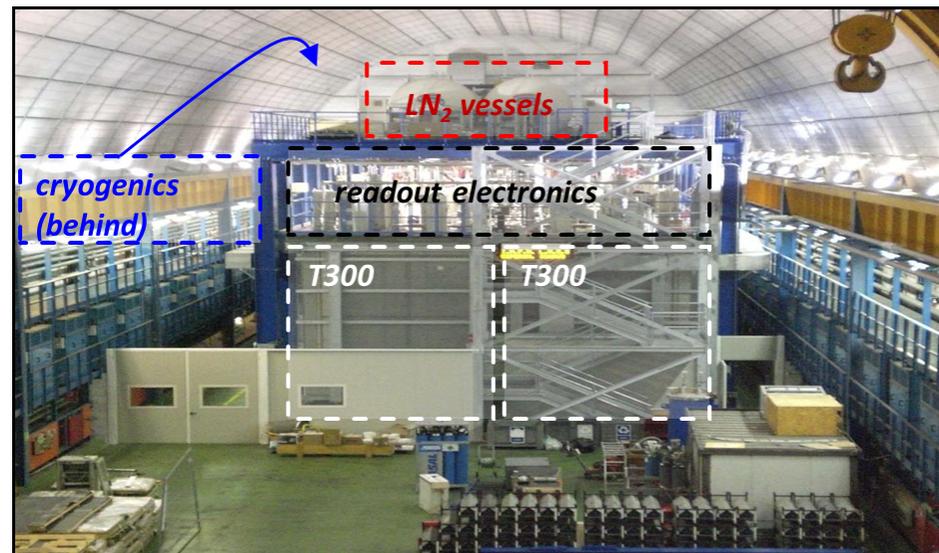
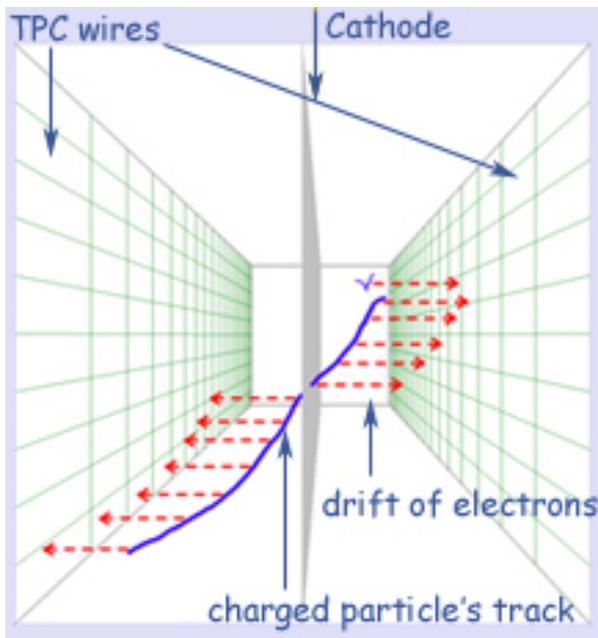


*Fabrizio Boffelli*

Dipartimento di Fisica  
Università di Pavia  
13 settembre 2018

ICARUS-T600 (**I**maging **C**osmic **A**nd **R**are **U**nderground **S**ignals) - T600 is a neutrino detector based on Liquid Argon Time Projection Chambers (Lar-TPC) technology: electrons produced at the passage of ionizing particles are carried out by an electric field towards reading wires spacing 3 mm. In this way we have a 3D tracks reconstruction and the measure of the particles' energy:

ICARUS-T600 in Hall B of  
INFN Gran Sasso Laboratories (2010-2013)



# ICARUS T600: the first large Liquid Argon TPC

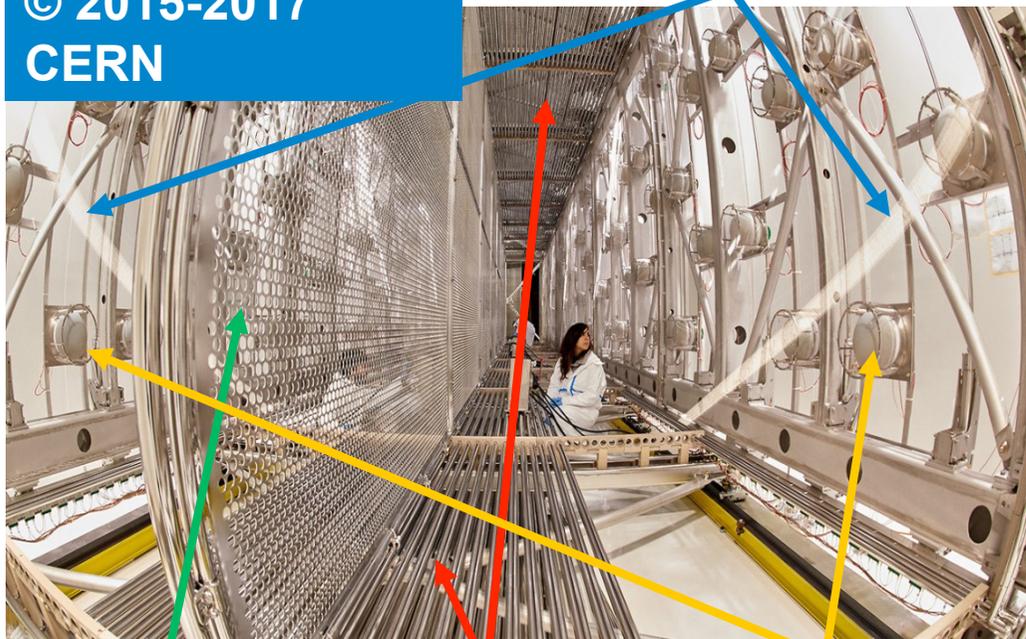
- ICARUS-T600 LAr TPC is a high granularity uniform self-triggering detector with 3D imaging and calorimetric capabilities, ideal for  $\nu$  physics. It allows to accurately reconstruct a wide variety of ionizing events with complex topology.
- Exposed to CNGS beam, ICARUS concluded in 2013 a very successful 3 years run at Gran Sasso INFN underground lab, collecting  $8.6 \times 10^{19}$  pot event statistics, with a detector live time  $>93\%$ , and cosmic ray events.

*Two identical modules: 760t total LAr mass / 476t active*

1 T600 module

© 2015-2017  
CERN

Wire planes (anode)



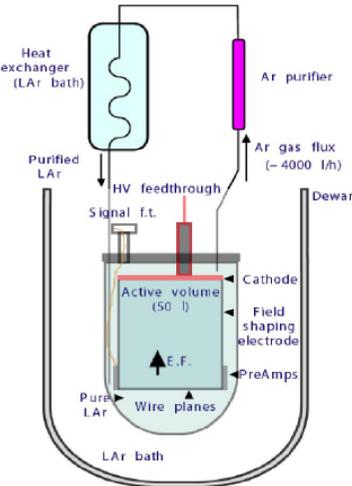
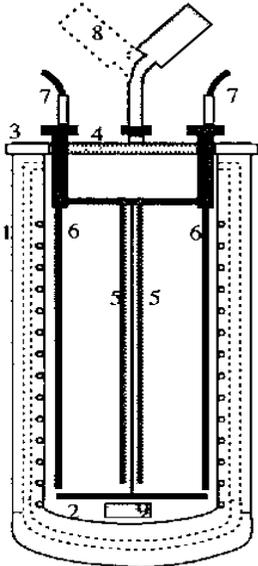
Cathode

Field cage

PMTs

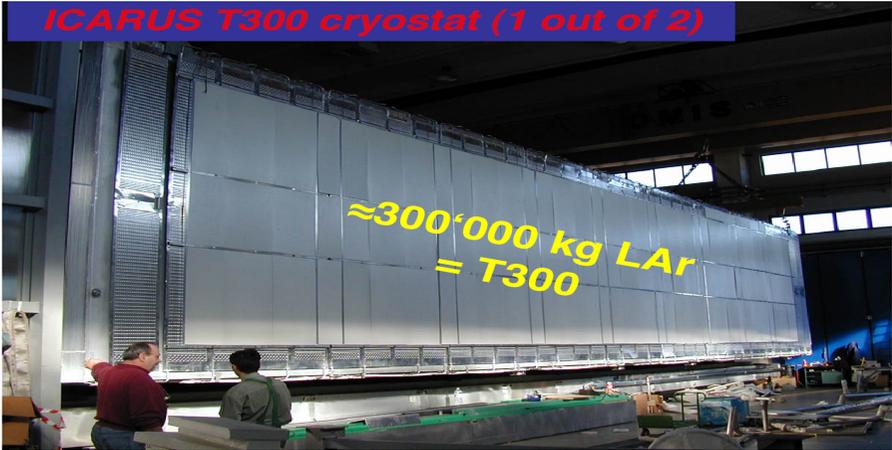
- 2 TPC's per module, with a common central cathode:  $E_{\text{Drift}} = 0.5 \text{ kV/cm}$ ,  $v_{\text{Drift}} \sim 1.6 \text{ mm}/\mu\text{s}$ , 1.5 m drift length;
- 3 "non-destructive" readout wire planes per TPC,  $\approx 54000$  wires at  $0^\circ, \pm 60^\circ$  w.r.t. horizontal: Induction 1, Induction 2 and Collection views;
- Ionization charge continuously read ( $0.4 \mu\text{s}$  sampling time);
- 74 8" PMT's, coated with TPB wls, for  $t_0$ , timing and triggering.

# ICARUS story

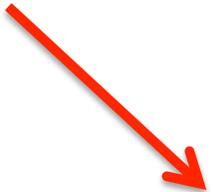


50 l LAr at CERN

A first step: ICARUS 3 ton



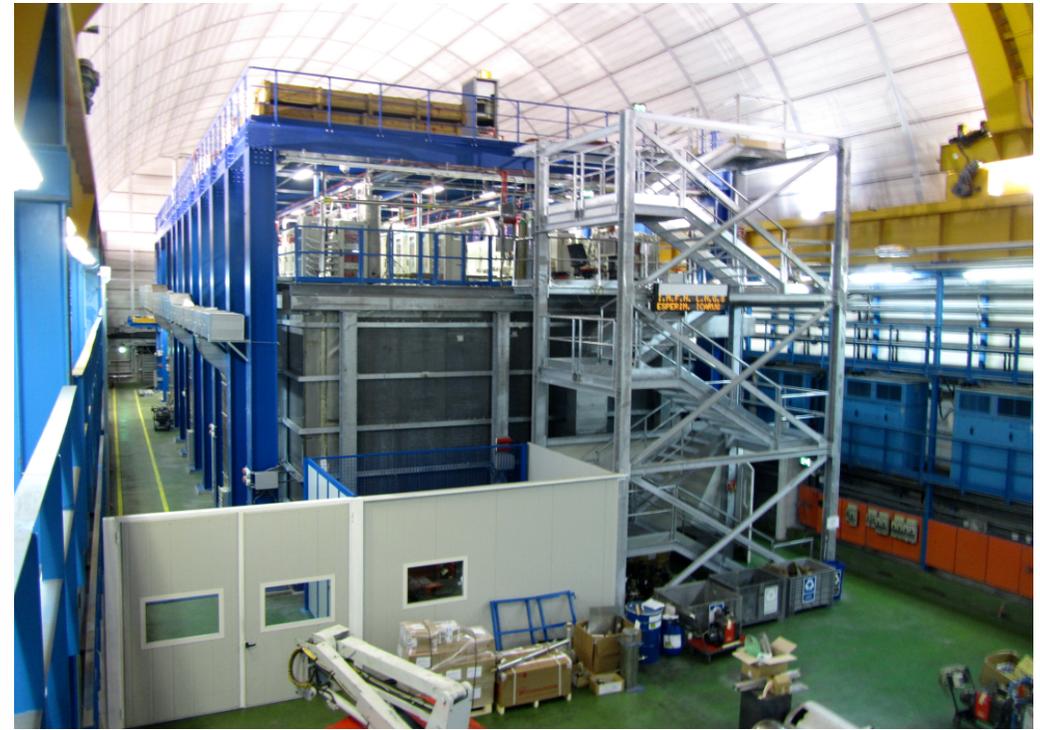
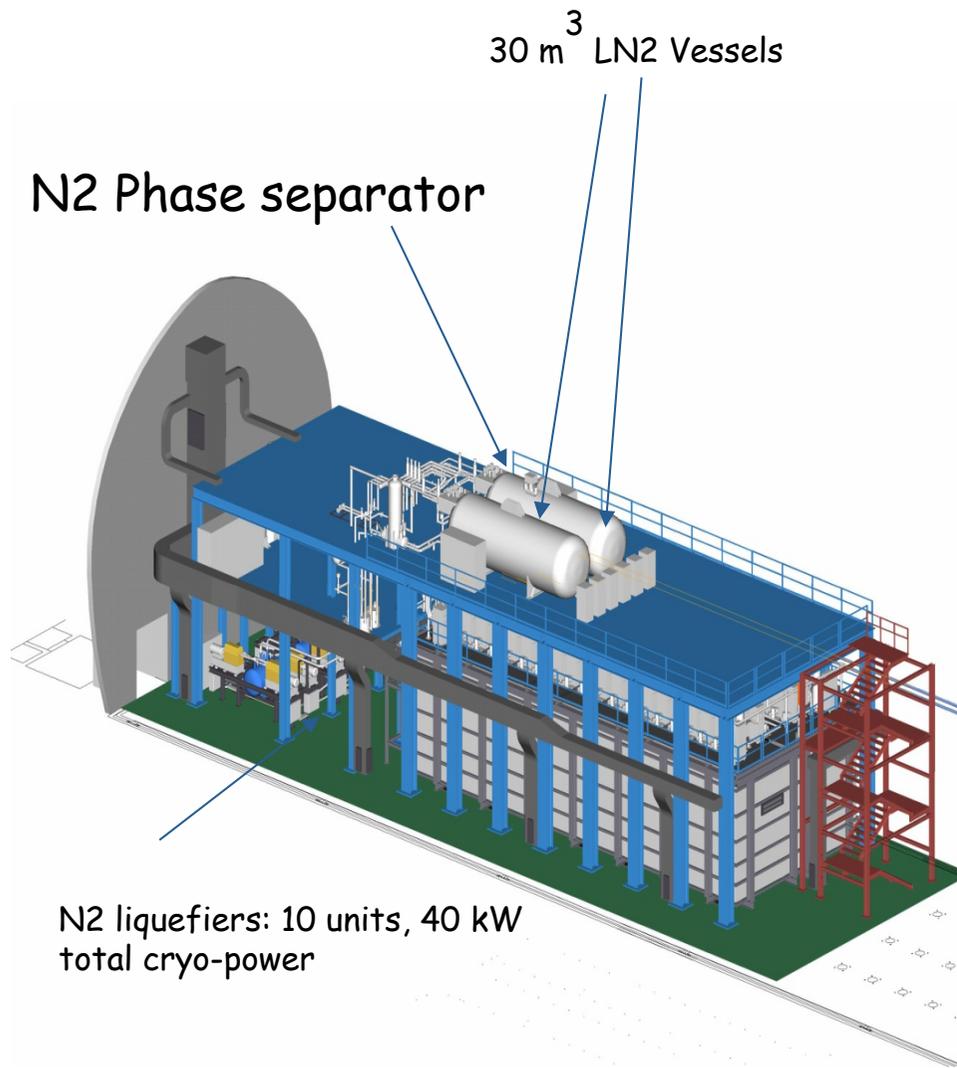
Semi-module T300 in INFN Laboratories @ Pavia, Via Ferrata (2001)



ICARUS 10 m<sup>3</sup> @ LNGS

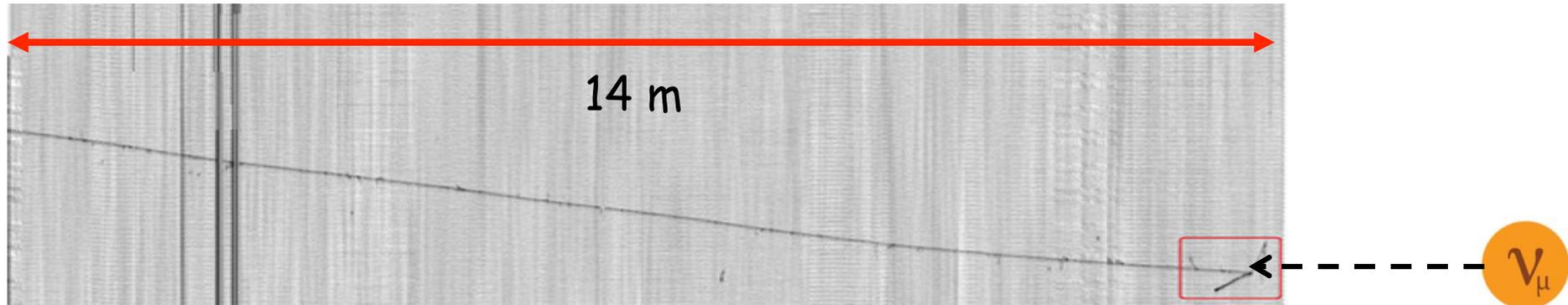


# ICARUS T600 at LNGS (2010-2013)

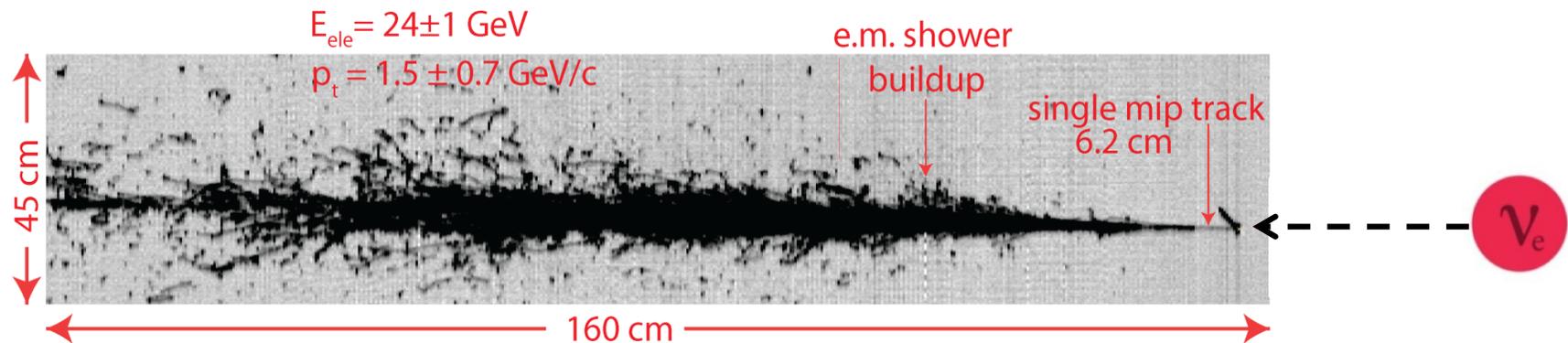


# ICARUS was employed for neutrino oscillation research:

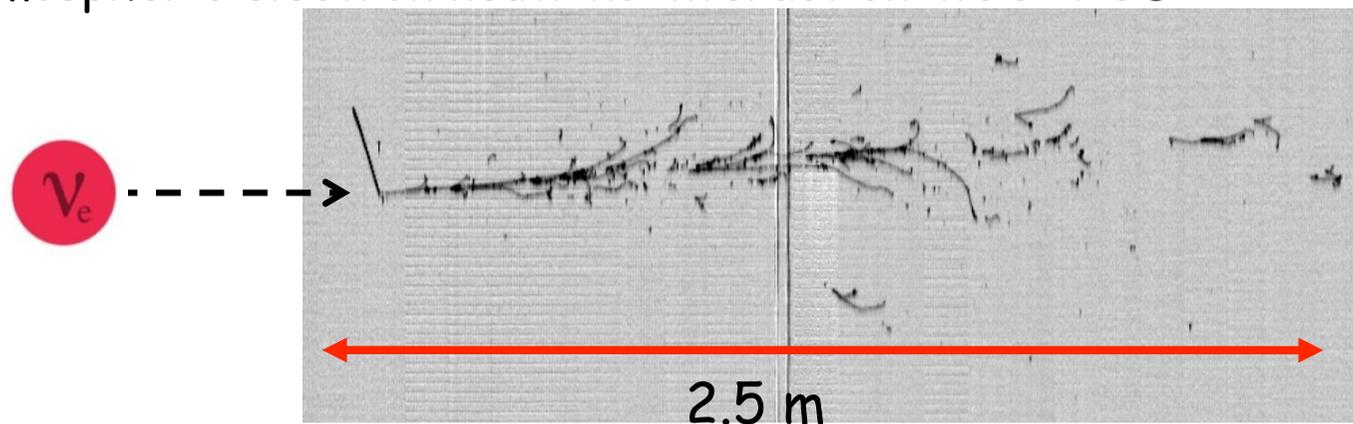
Muon neutrino interaction from CERN beam to Gran Sasso in ICARUS:



Electron neutrino interaction from CERN beam to Gran Sasso in ICARUS:

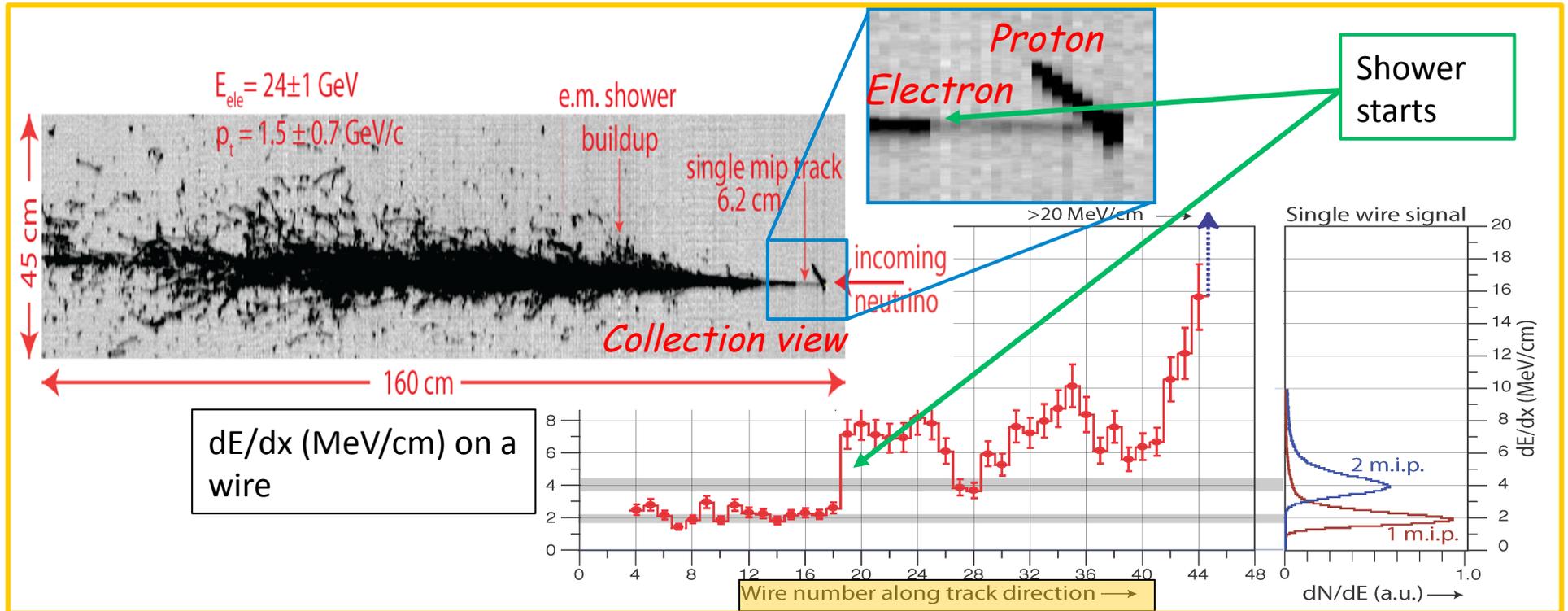


Atmospheric electron neutrino interaction in ICARUS:



# Particle identification in LAr TPC

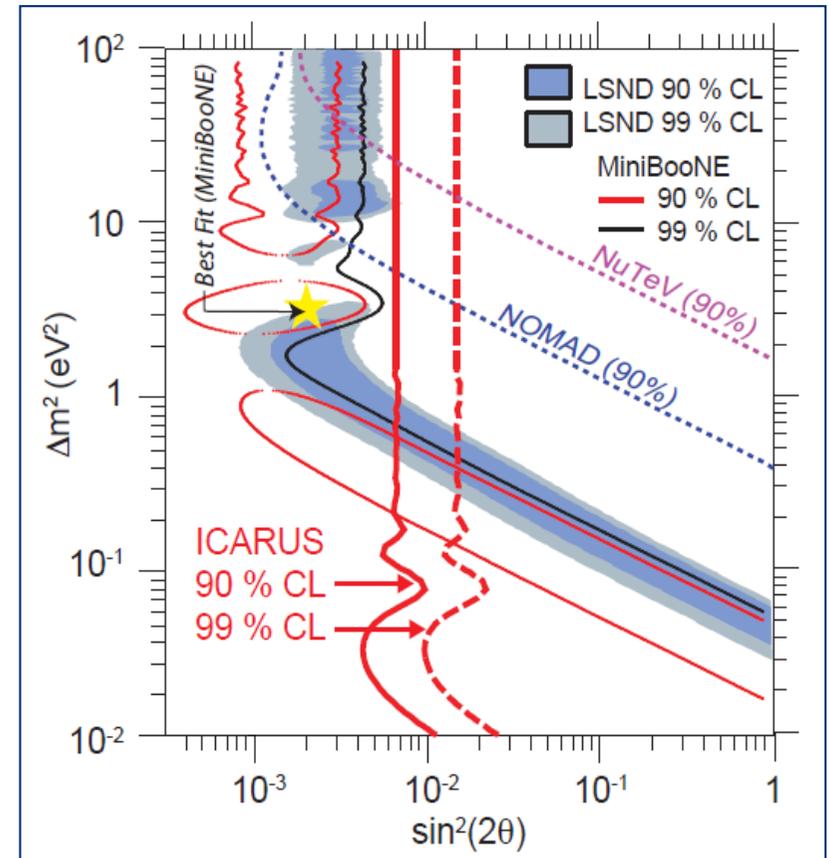
From signal of each wire we can measure charge density, proportional to ionization density, depending on particle type



# ICARUS LAr-TPC technology achievements

ICARUS run at LNGS allowed reaching several physics/technical results demonstrating the maturity of the LAr-TPC technology:

- An exceptionally low level  $\sim 20$  p.p.t.  $[O_2]$  eq. of electronegative impurities in LAr; the measured  $e^-$  lifetime  $\tau_{ele} > 15$  ms ensured few m long drift path of ionization  $e^-$  signal without attenuation;
- Demonstrated detector performance, especially in  $\nu_e$  identification and  $\pi^0$  bkg rejection in  $\nu_\mu \rightarrow \nu_e$  study to unprecedented level;
- Performed a sensitive search for LSND-like anomaly with CNGS beam, constraining the LSND window to narrow region at:  
 $\Delta m^2 < 1 \text{ eV}^2$ ,  $\sin^2 2\theta \sim 0.005$   
where all positive/ negative experimental results can be coherently accommodated at 90% C.L., confirmed by OPERA.



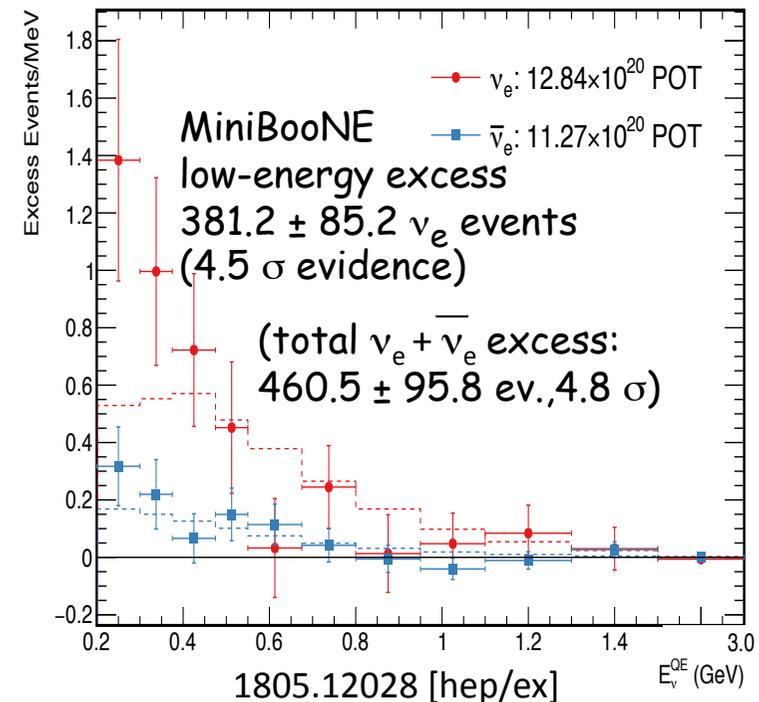
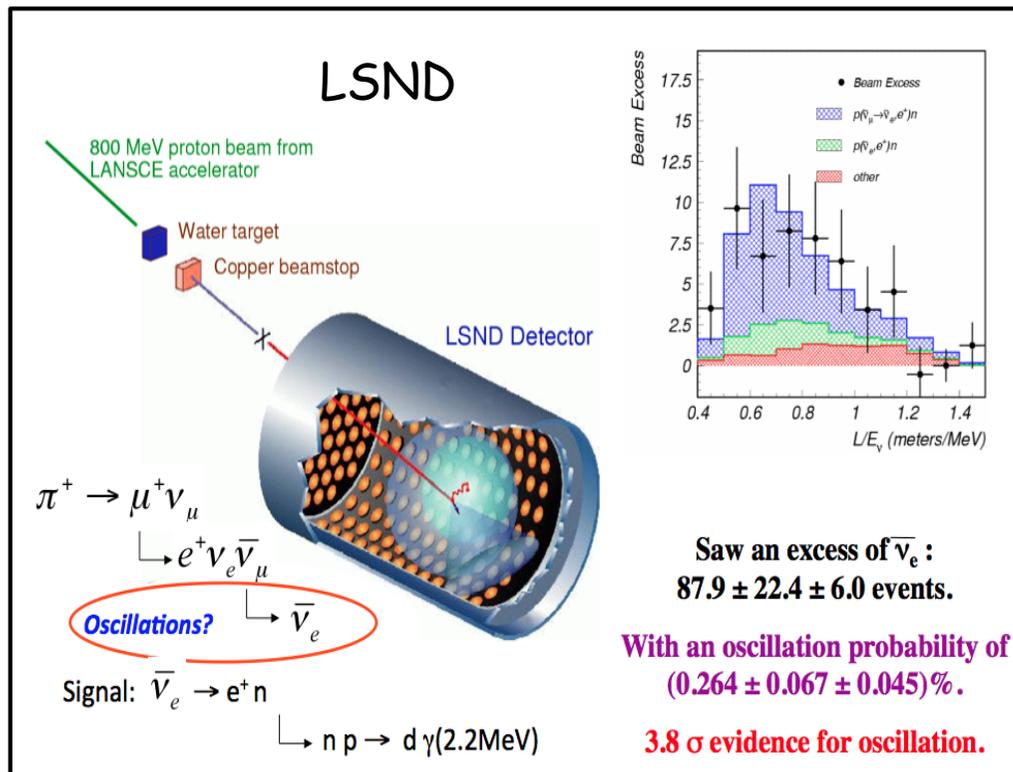
Eur. Phys. J. C (2013) 73:2599

Success of LAr-TPC technology with large impact on neutrino and astroparticle physics projects: SBN (Short Base-line Neutrino) program at FNAL with 3 LAr-TPC's.

# Sterile neutrino puzzle - I

Anomalies have been collected in last years in neutrino sector, despite the well-established 3-flavour mixing picture within Standard Model:

- **appearance of  $\nu_e$**  from  $\nu_\mu$  beams in accelerator experiments (LSND + MiniBooNE, combined evidence from new MiniBooNE results  $> 6\sigma$ );
- **disappearance of anti- $\nu_e$** , hinted by near-by nuclear reactor experiments (ratio observed/predicted event rates  $R = 0.938 \pm 0.024$ );
- **disappearance of  $\nu_e$** , hinted by solar  $\nu$  experiments during their calibration with Mega-Curie sources (SAGE, GALLEX,  $R = 0.84 \pm 0.05$ ).

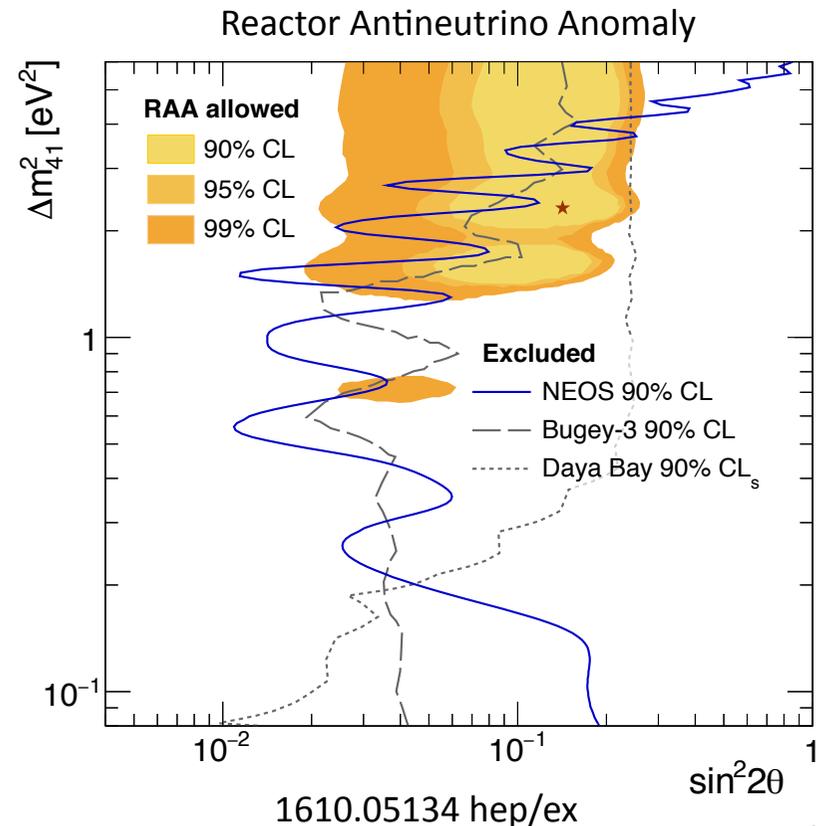


## Sterile neutrino puzzle - II

Results **hint to a new "sterile" flavor**, described by  $\Delta m^2 \sim eV^2$  and small mixing angle, driving oscillations at short distance:

- ICARUS constrained  $\Delta m^2_{new} \leq 1 eV^2$ , small mixing;
- Planck data and Big Bang cosmology point to at most one further flavor with  $m_{new} < 0.24 eV$ ;
- **No evidence of  $\nu_\mu$  disappearance** in MINOS and IceCube in 0.32-20 TeV;
- Recent reactor data (NEOS, DANSS) can be inserted in 3+1 frameworks supporting one sterile neutrino, but they are not conclusive.
- $\nu_e$  appearance results of accelerator-based experiments are in tension with mentioned  $\nu_\mu$  disappearance data.

**THE EXPERIMENTAL SCENARIO  
CALLS FOR A DEFINITIVE  
CLARIFICATION!**



# From Gran Sasso to Fermilab (passing through CERN...)



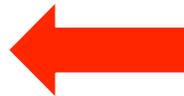
End 2014



Upgrade at CERN (2015-2017)

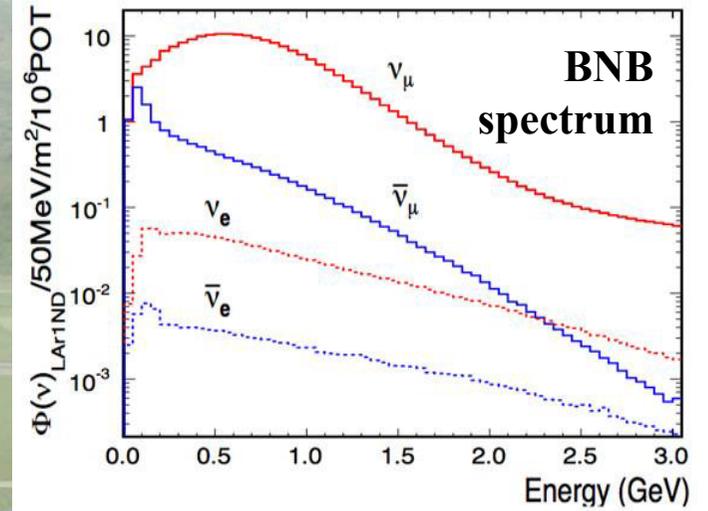


Fermilab: summer 2017!!!

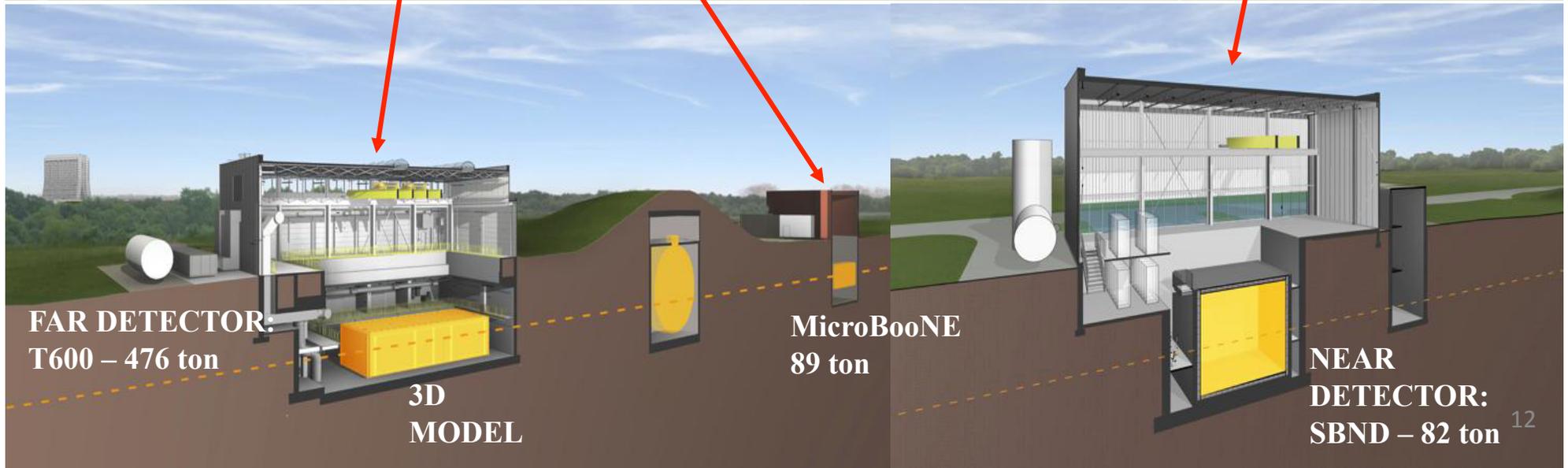
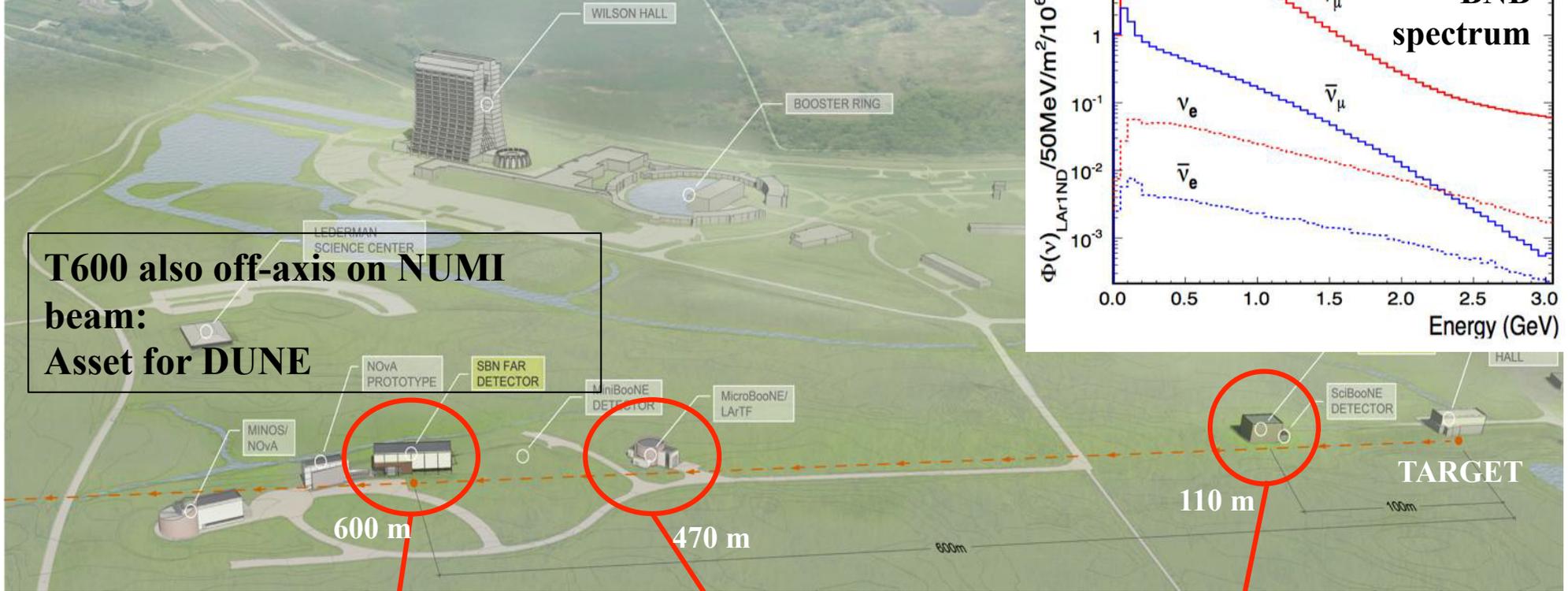


Together with two similar detectors, ICARUS T600 will take part in the Short-Baseline Neutrino project at the Booster Neutrino Beam at Fermilab, that has the goal to provide a definitive answer to the sterile neutrino puzzle by measuring both  $\nu_e$  appearance and  $\nu_\mu$  disappearance.

$$L/E_\nu \sim 600 \text{ m} / 700 \text{ MeV} \sim \mathcal{O}(1 \text{ m/MeV})$$



**T600 also off-axis on NUMI beam:  
Asset for DUNE**





June - July 2017  
from CERN to Fermilab  
Buon viaggio!

#IcarusTrip  
[IcarusTrip.fnal.gov](http://IcarusTrip.fnal.gov)



Denland

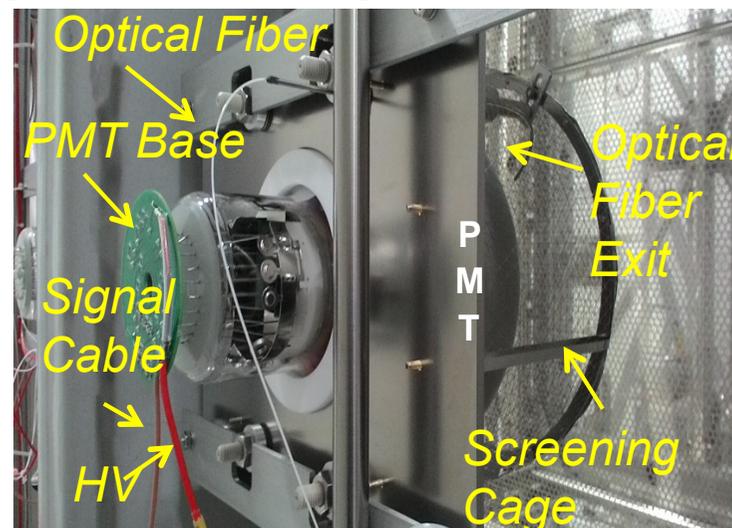
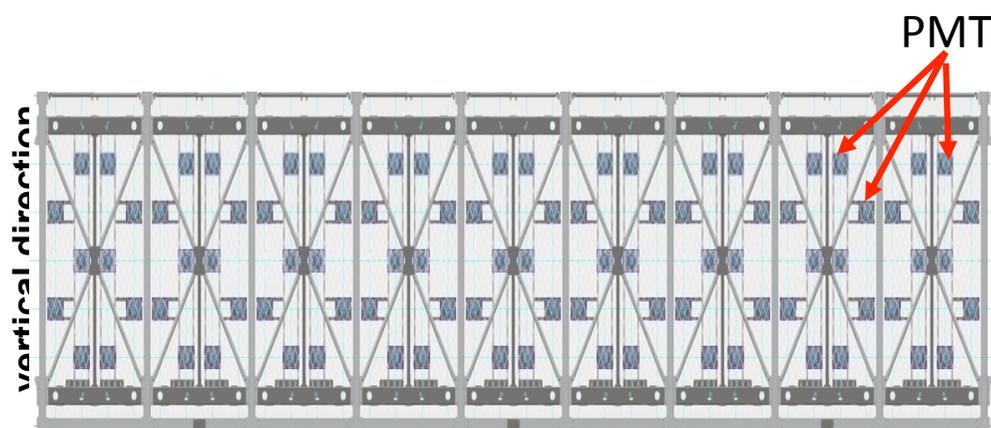
Sweden

Ireland  
United Kingdom  
Denmark  
Germany  
Poland  
Austria  
France

North Atlantic Ocean

# New PMTs – Pavia responsibility

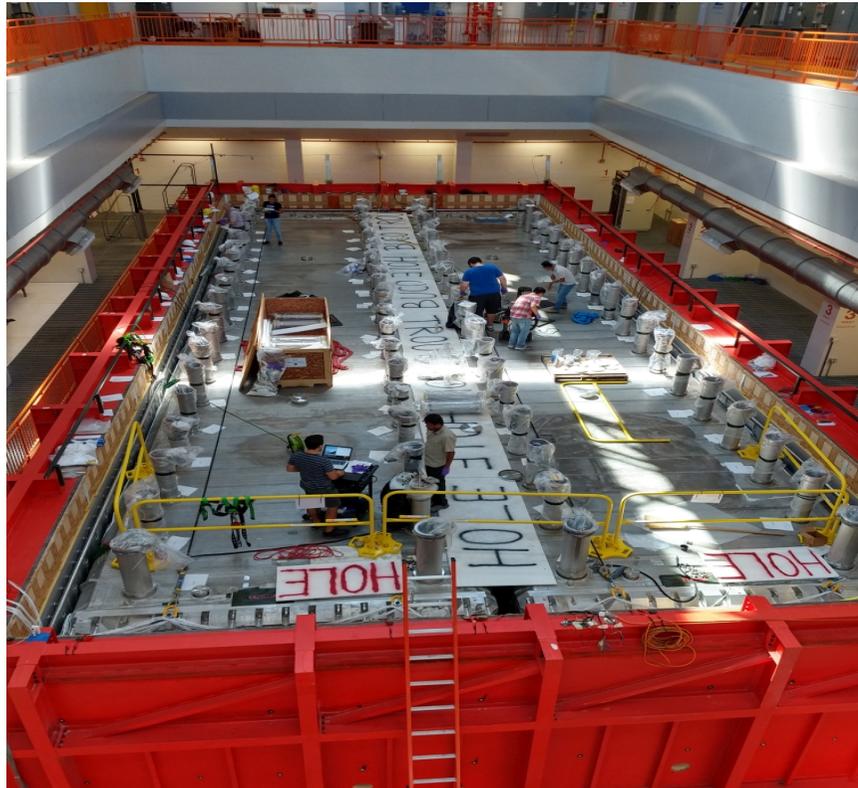
- 90 PMT's per TPC layout: 5% cathode coverage area, allowing to collect 15 phe/MeV deposited energy.



- Hamamatsu R5912-MOD (8", 10 dynodes) are rated for cryogenic temperature, as they feature a cathode with platinum under-layer.
- Each PMT is enclosed in a wire screening cage to prevent induction of PMT pulses on the facing TPC wires
- PMT sand blasted glass windows coated by  $\sim 200 \mu\text{g}/\text{cm}^2$  of Tetra-Phenyl-Butadiene (TPB) wavelength shifter to detect the  $\lambda = 128 \text{ nm}$  scintillation light in LAr.

*A clear cosmic  $\mu$ 's identification will be provided by neural networks ( $\sim 2\%$  expected residual misidentification).*

# Progress of installation



- Warm vessel bottom and side installed in 2017
- Cold shield bottom and side assembled in May 2018
- Detector installation August 2018
- Top shield and vessel installation early fall 2018
- Electronic installation in fall 2018
- Cryogenic installation fall - winter 2018



Dipartimento di Fisica  
Università di Pavia

# Cosa facciamo a Pavia per ICARUS?



ICARUS – PAVIA: *F. Boffelli, T. Cervi, A. Falcone,  
A. Menegolli, C. Montanari, P. Picchi, A. Rappoldi,  
G. Raselli, M. Rossella, A. Scaramelli*

- *C. Montanari: ICARUS Technical coordinator.*
- *G.L. Raselli: lead ICARUS PMT and trigger working group.*
- *A. Menegolli: co-lead ICARUS Editorial Board.*
- Completamento dell'analisi dei dati presi al Gran Sasso.
- Sviluppo del software per la simulazione e l'analisi dei dati al Fermilab.
- Realizzazione e installazione del sistema di rivelazione della luce di scintillazione mediante PMTs.
- Realizzazione e gestione del sistema di acquisizione dei segnali dei PMTs e del trigger.
- R&D di nuovi tipi di foto-rivelatori per applicazioni in criogenia.

## Present ICARUS Collaboration

*Brookhaven National Laboratory (BNL), USA*

*Colorado State University, USA*

*Fermi National Laboratory (FNAL), USA*

*University of Houston , USA*

*INFN Sez. di Catania and University, Catania, Italy*

*INFN GSSI, L'Aquila, Italy*

*INFN LNGS, Assergi (AQ), Italy*

*INFN Sez. di Milano Bicocca, Milano, Italy*

*INFN Sez. di Napoli, Napoli, Italy*

*INFN Sez. di Padova and University, Padova, Italy*

*INFN Sez. di Pavia and University, Pavia, Italy*

*Los Alamos National Laboratory (LANL), USA*

*University of Pittsburgh , USA*

*University of Rochester , USA*

*SLAC, Stanford, CA, USA*

*University of Texas (Arlington), USA*

*+CERN and others INFN groups involved in the  
SBN program*

*Spokesman: C. Rubbia , GSSI*

<http://icarus.lngs.infn.it/> (sito web di ICARUS con descrizione e referenze alle pubblicazioni).

<http://icarus.fnal.gov/> (sito web del progetto ICARUS al Fermilab).

<http://www.nu.to.infn.it/> (sito sempre aggiornato sulla fisica del neutrino).



**Thank you !**