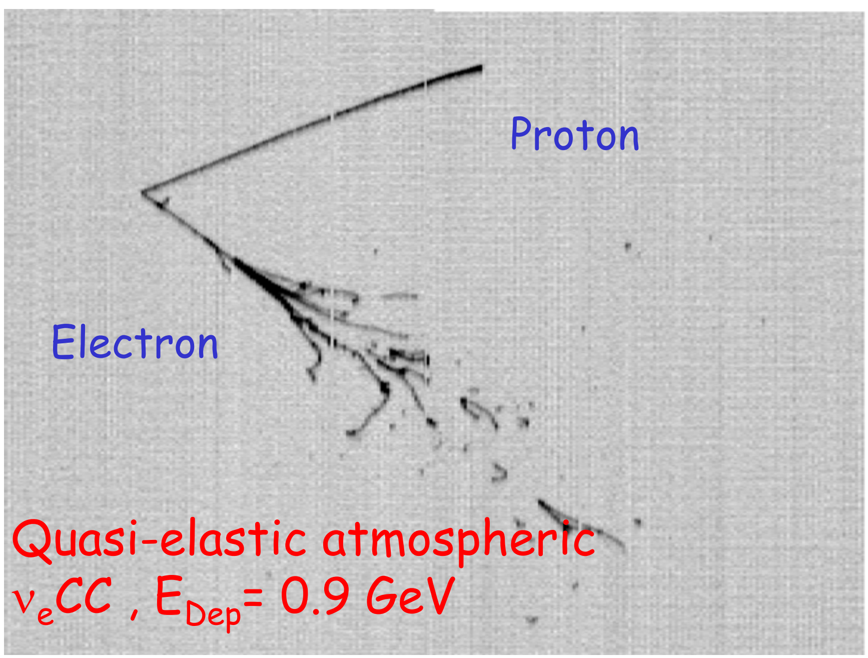
Sterile neutrino searches with the ICARUS detector

F. Tortorici, B. Ali-Mohammadzadeh, V. Bellini, C. Petta, C.M. Sutera
INFN and University of Catania
on behalf of the ICARUS Collaboration
https://icarus.fnal.gov/collaboration/

More than 100 scientists.
Spokesman: C. Rubbia (GSSI)



CNNP 2020, Capetown SA
27th February 2020

ITALY
Catania (INFN and Univ.)
GSSI
LNGS
INFN Milano Bicocca
INFN Napoli
Padova (INFN and Univ.)
Pavia (INFN and Univ.)

USA
Brookhaven (BNL)
Colorado State
FNAL
Houston
Pittsburgh
Rochester
SLAC
Southern Methodist University
Texas (Arlington)
Tufts University

CERN (Geneva)

MEXICO
CINVESTAV

https://www.facebook.com/IcarUSCollaboration/

What are we looking for in a neutrino detector?

Ultimately, two things:

- FLAVOR IDENTIFICATION:
  - ➢ Efficiency and purity in identifying νμCC vs. νeCC vs. νNC
  - ➢ Crucial for any νe appearance searches
  - ➢ The separation between electrons and photons is especially critical
  - ➢ This requires both a good granularity (much less than radiation length X_0) and a precise calorimetry (to measure dE/dx)
- LARGE MASS/EXPOSURE:
  - ➢ cross-sections are typically very small (~10^{-38} cm^2 at SBN energies)
  - ➢ Small, subdominant oscillation effects are often searched for (like at SBN) ->large statistics is needed
  - ➢ This implies both huge size and long continuous data-taking
  - ➢ A dense target material is needed

A Liquid Argon TPC (LArTPC) can combine such requirements

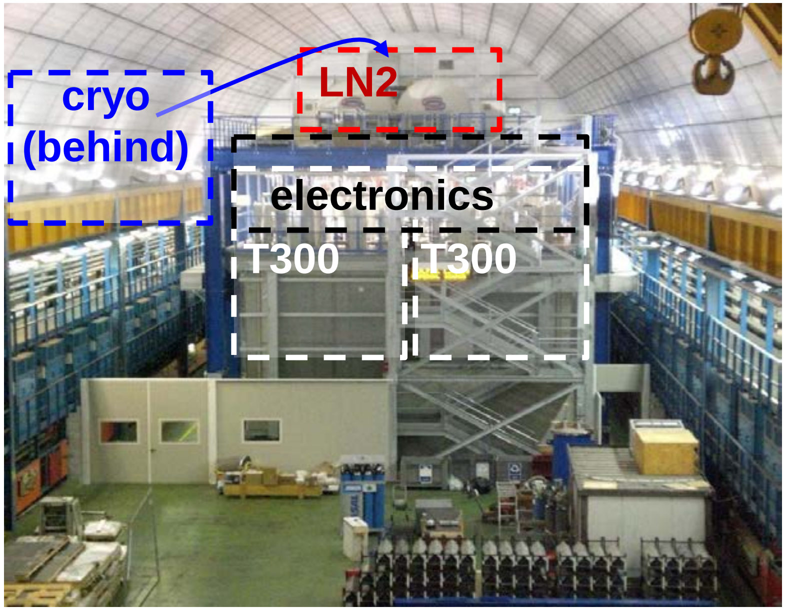
- Multiple wire planes allow 3D reconstruction with ~mm resolution
- Collection of drifting ionization electrons permits a precise calorimetry
- Scintillation light provides fast signals for triggering/timing purposes

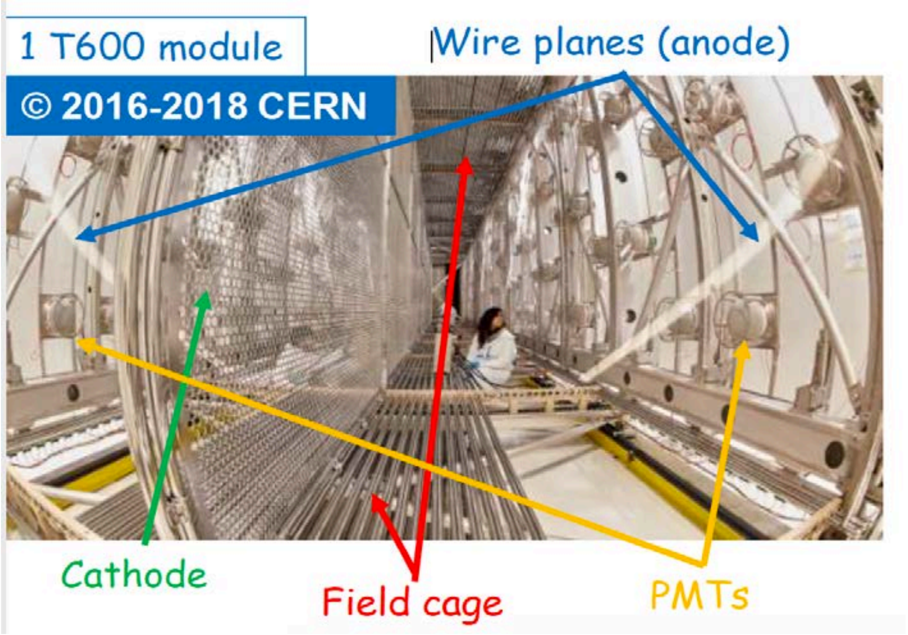
Only one major drawback: drift velocity is small (~1 mm/μs, drift time ~ ms)

Pile-up of cosmic rays can be a problem for surface operation.

ICARUS-T600 at LNGS

- 2 identical modules: each is 19.6x3.6x3.9 m^3, with active mass of 476 t (total 760 t)
- Drift distance 1.5 m and electric field 500 V/cm -> drift time ~ 1 ms
- 3 signal wire planes (2 Induction+Collection) with "non-destructive" wire readout
- Pitch and inter-plane distance both 3 mm; 400 ns sampling time; ~ 54000 total channels
- 74 (20+54) 8" PMTs with TPB wavelength-shifter coating



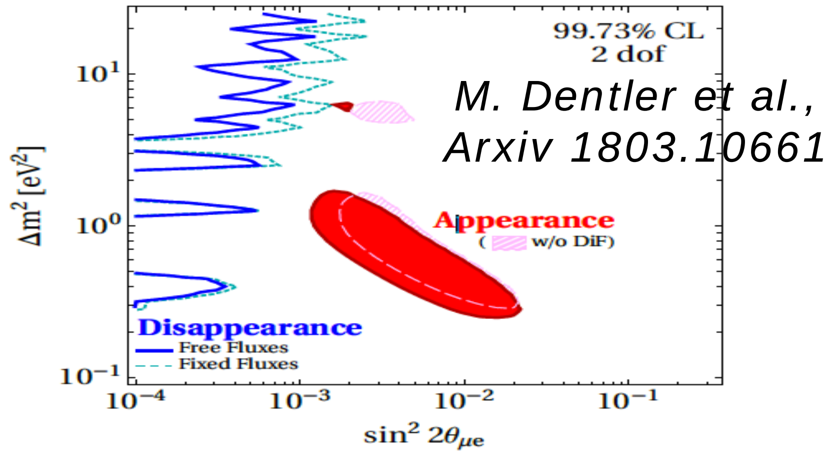


- ICARUS was exposed to CNGS beam and cosmics for 3 years (2010-2013)
- Run confirmed expected performance and obtained important Physics results
- It proved the maturity of the LAr-TPC technique for large-scale experiments

ICARUS paved the way to the next generation long-baseline project: DUNE

Perspectives for sterile neutrino physics

- The sterile neutrino scenario is far from understood and needs a definitive clarification
- Some "anomalies" from accelerators (LSND), reactor, neutrino sources, point out to flavor transitions in the $\Delta m^2 \sim 1$ eV^2 range
- However, no evidence of oscillations in $\nu\mu$ disappearance data (MINOS, IceCube)
- ICARUS, using CNGS beam, found that LSND allowed region is excluded – except small area around $\sin^2 2\theta \sim 0.005$, $\Delta m^2 < 1$eV^2 (Eur. Phys. J. C (2013) 73:2599)
  - 7.9 10^{19} pots (proton on target) analyzed (~2650 ν interactions)
- Tension between νe appearance and $\nu\mu$ disappearance results. Measuring both channels with the same experiment will help disentangle the physics scenario.



Combined analysis

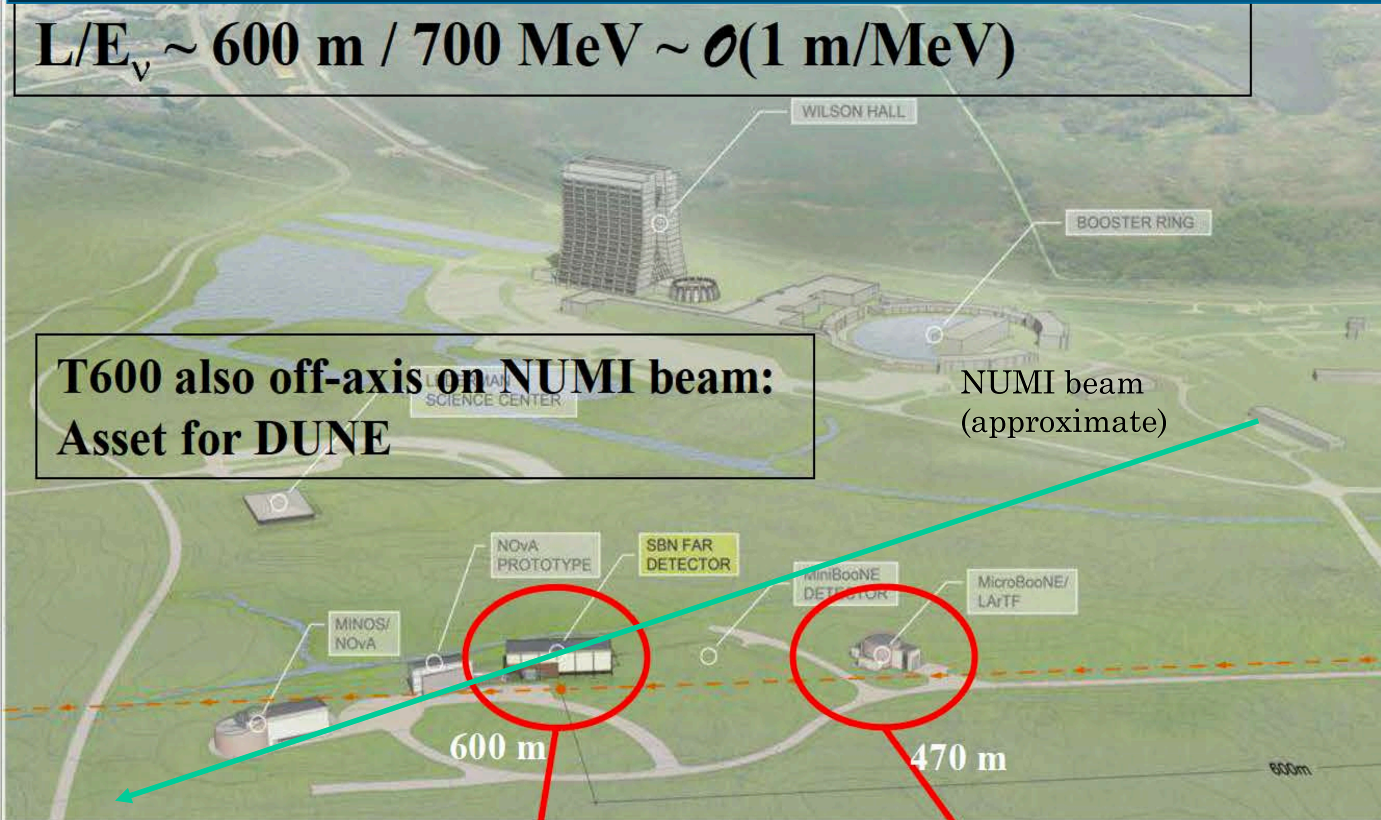
- A comparison between far/near detector is crucial for any accelerator experiment,
- with a better control of backgrounds and systematics.

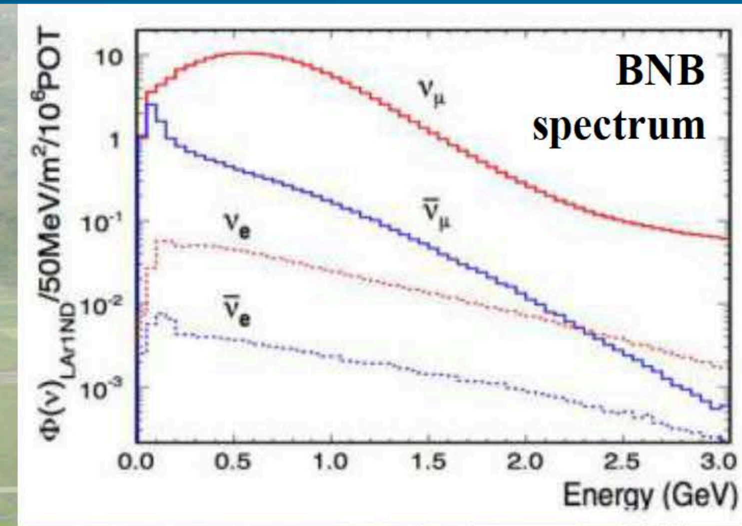
SBN satisfies these requirements: it could have a crucial role in solving the sterile neutrino puzzle! (and other goals: cross section measurements,...)

The SBN project (see proposal on arXiv: 1503.01520)

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

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





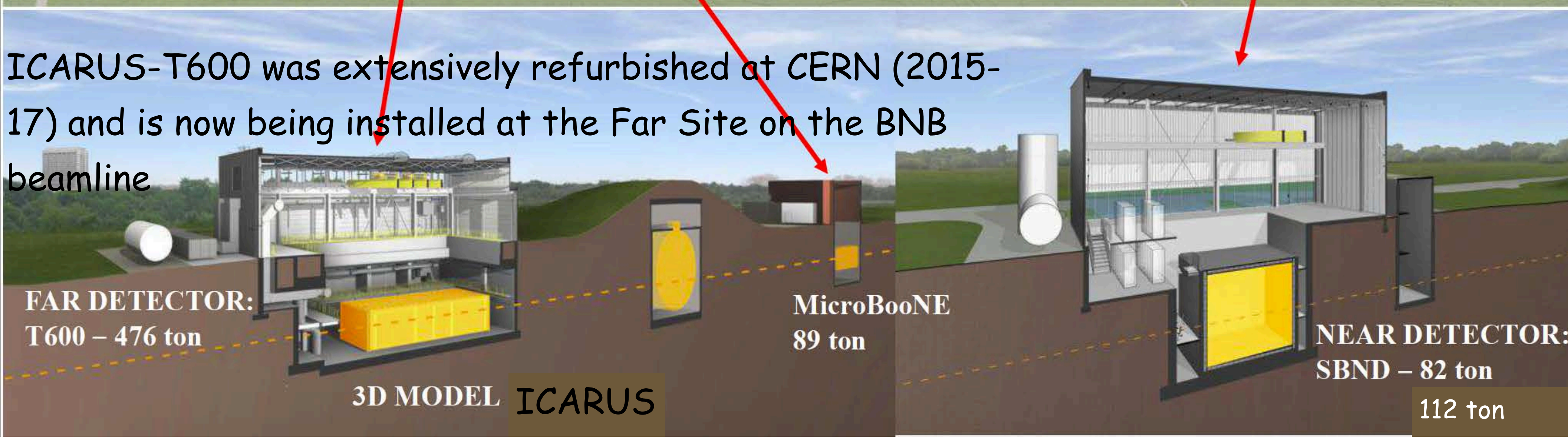
SciBooNE DETECTOR

TARGET

110 m

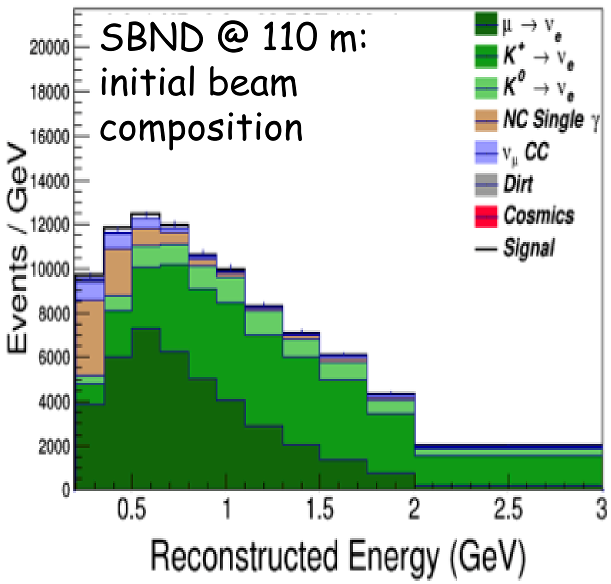
100m

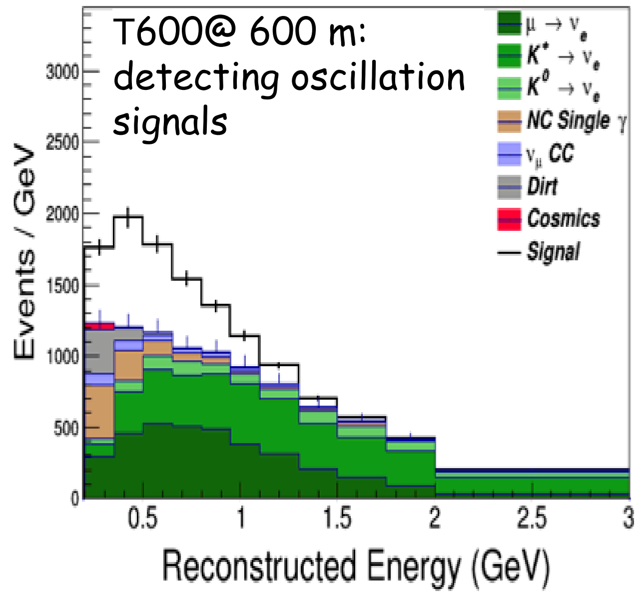
ICARUS-T600 was extensively refurbished at CERN (2015-17) and is now being installed at the Far Site on the BNB beamline



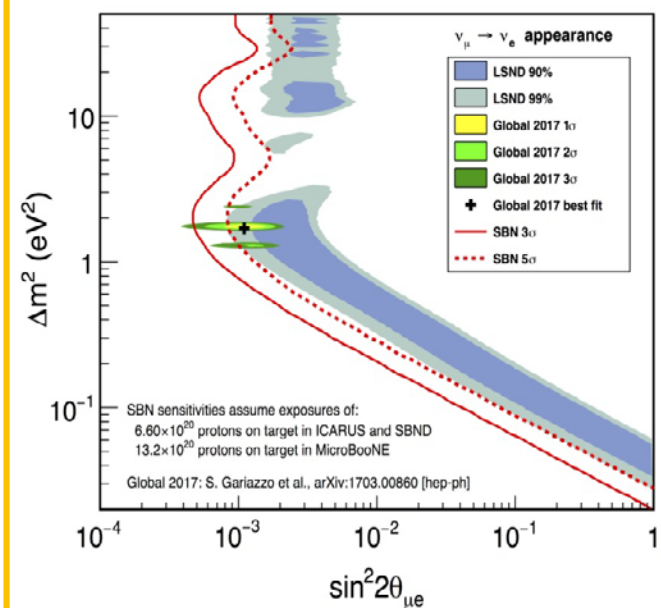
SBN spectra and sensitivities for 3 years (6.6 10^{20} pot)

νe spectra: $\sin^2 2\theta = 0.013$ $\Delta m^2 = 0.43$ eV^2 oscill. signal + background



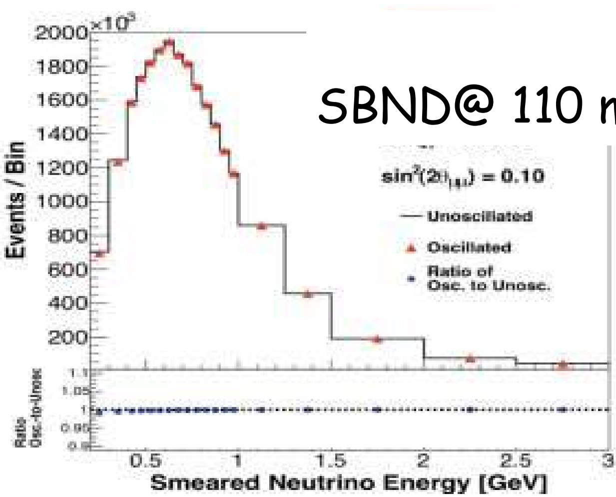


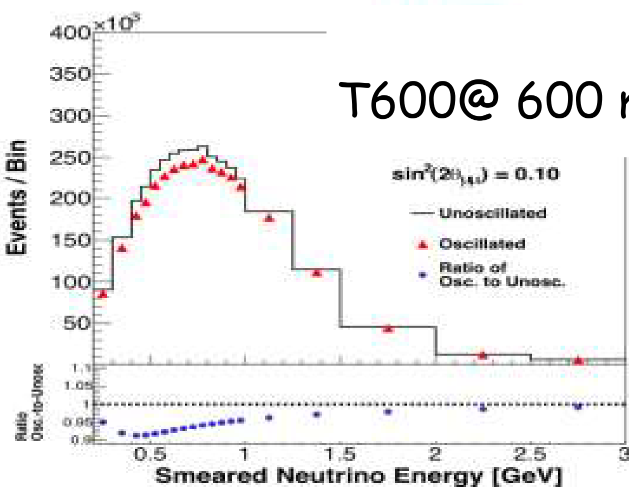
νe appearance: LSND 99% CL region covered at 5 σ



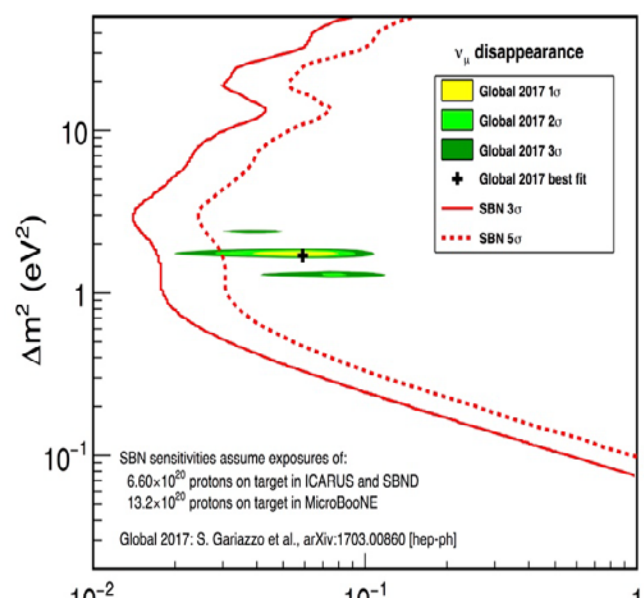
Same LAr-TPC technology: in absence of oscillations, spectra should be ~identical

νμ spectra: oscill. modulation $\sin^2 2\theta = 0.01$ $\Delta m^2 = 1.10$ eV^2





3-5 σ νμ disapp. sensitivity



A new experimental challenge: operating a LAr-TPC on surface

- ICARUS at FNAL is facing the challenging operation at shallow depth- 3 m concrete overburden only - requiring the recognition of O(10^6) ν interactions amongst >11 kHz of cosmic's:
  - 11 μ tracks will overlap each triggering event during 1 ms TPC drift readout;
  - furthermore associated γ's represent a serious background source for νe search since e's produced via Compton scatt./pair prod. can mimic νe CC.

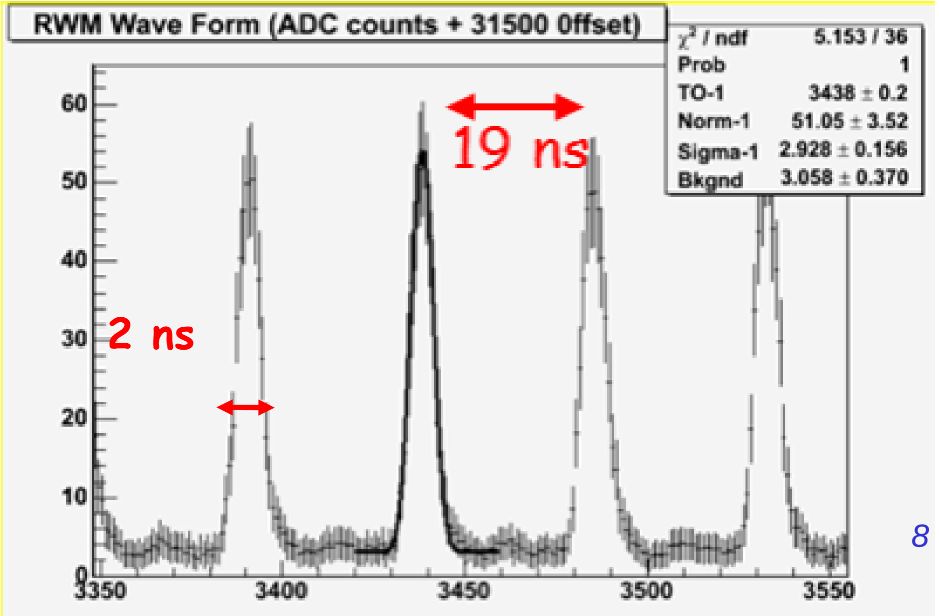
Rejecting cosmic induced background requires an external cosmic ray tagger for particles entering LAr-TPC and a much improved light detection system to associate the proper timing with each particle.

- ICARUS-T600 underwent an intensive overhauling at CERN in the Neutrino Platform framework before shipping to US.

  Several technology developments were introduced while maintaining the already achieved performance at LNGS run:
  - new cold vessels, with a purely passive insulation;
  - renovated LAr cryogenics/purification equipment;
  - upgrade of PMT system: higher granularity and ns time resolution;
  - new faster, higher-performance read-out electronics.

DAQ/Trigger system

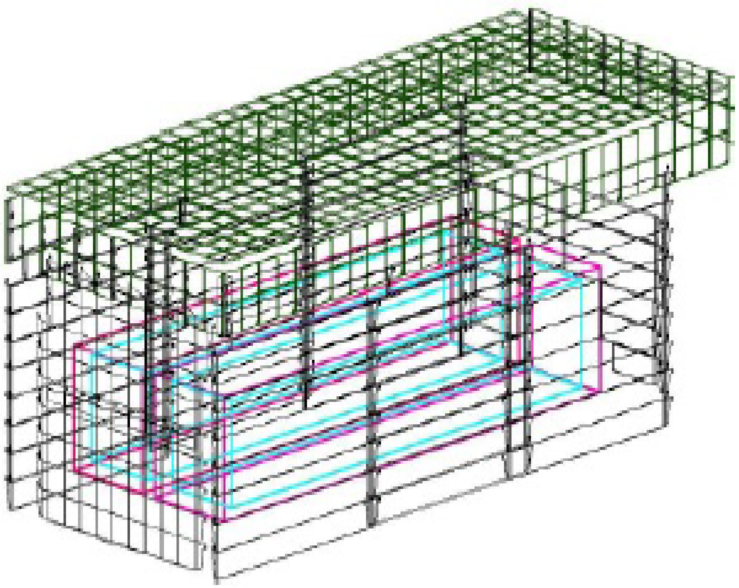
- ICARUS DAQ takes advantage of the architecture already deployed at LNGS, i.e. a waveform recording of TPC/PMT signals triggered by scintillation light in coincidence with proton beam extraction, ~50 ps synchronized by White Rabbit system.
- Expected ~ 0.25 Hz rate of in-spill physical events dominated by cosmic rays
  - ➢ BNB - 5×10^{12} pot/spill in ~1.6 μs, 5 Hz rate: ~1 ν/180 spill (0.03 Hz)
  - ➢ NuMI - 4×10^{13} pot/spill in ~8.6 μs, 0.5 Hz rate: ~1 ν/75 spill (0.02 Hz).
- 90 PMTs of each TPC are connected to fast digitizers to produce a set of LVDS signals in term of OR/AND of pairs of adjacent PMTs for majority logic.
  - PMT ns precision allows to exploit bunched structure of p-spill and particle time of flight with surrounding CRT to reject cosmic rays quasi on-line.



The Cosmic Ray Tagging system (CRT)

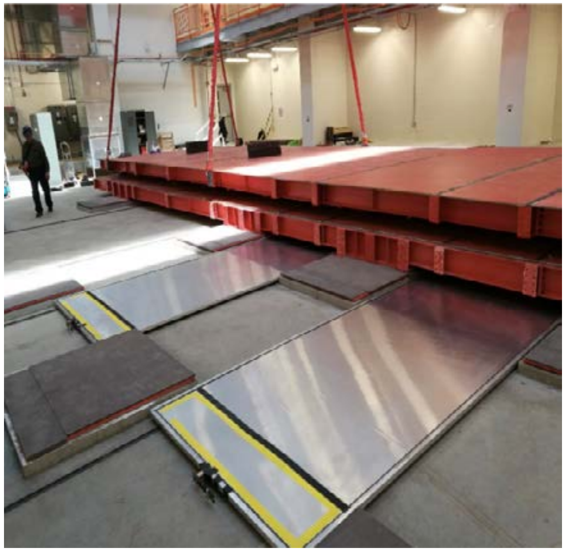
- CRT surrounds T600 cryostat with two layers of plastic scintillators (~1100 m^2)
- Tags incident cosmic/beam-induced μ's with >95 % efficiency, giving timing and spatial coordinates of entry point to be matched to activity in the LAr volume

TOP: *roof* + corners
catch~80% cosmic μ*'s,*
X+Y strip *layers + SiPM*



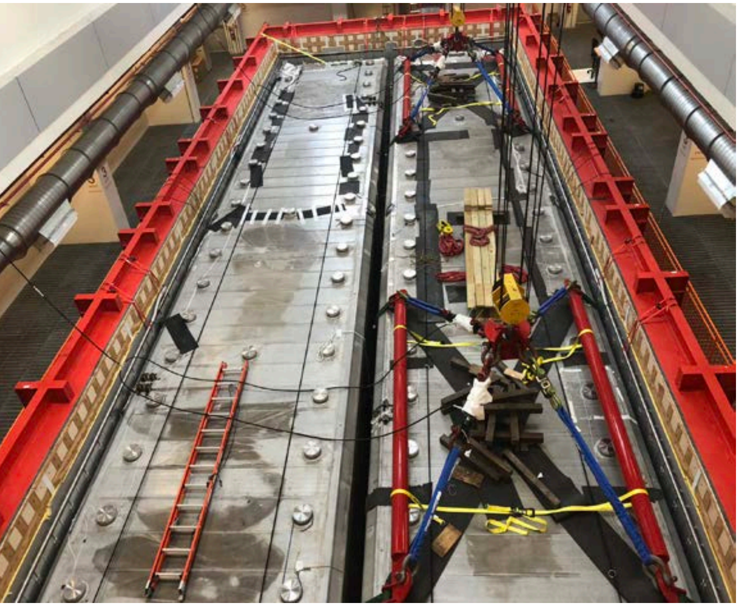
SIDES: on four sides
MINOS veto modules,
parallel strips + SiPM

BOTTOM: already installed
D-Chooz veto modules,
2 parallel layers + PMT



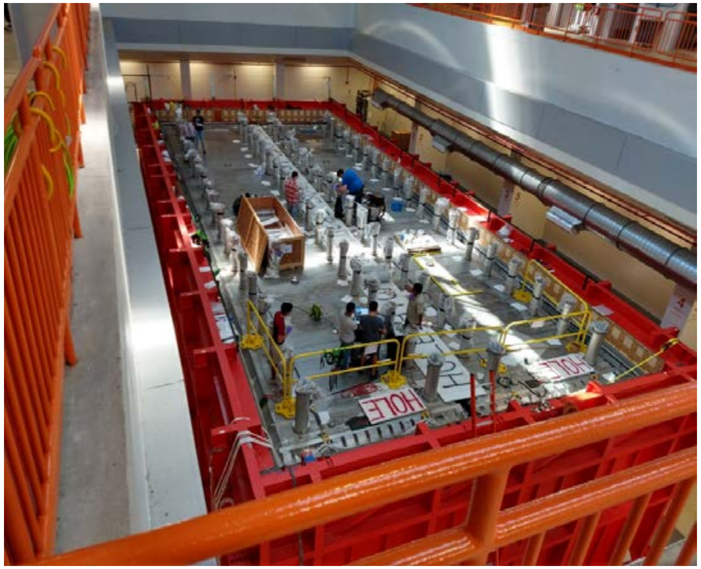
A few ns resolution required to discriminate the track direction of incoming/outgoing particle track by ToF (Time of Flight)

ICARUS installation at FNAL - status

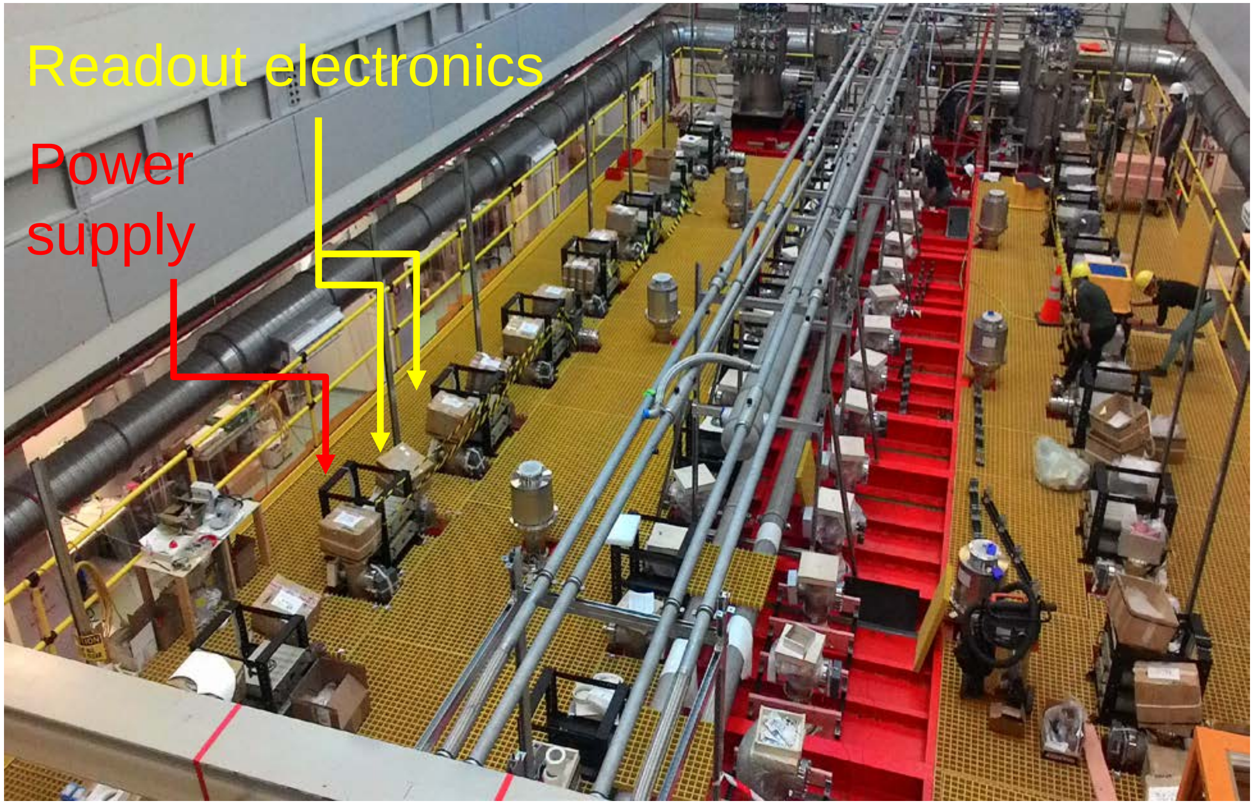


Placement of ICARUS (August 2018)

Chimneys installation (October 2018)



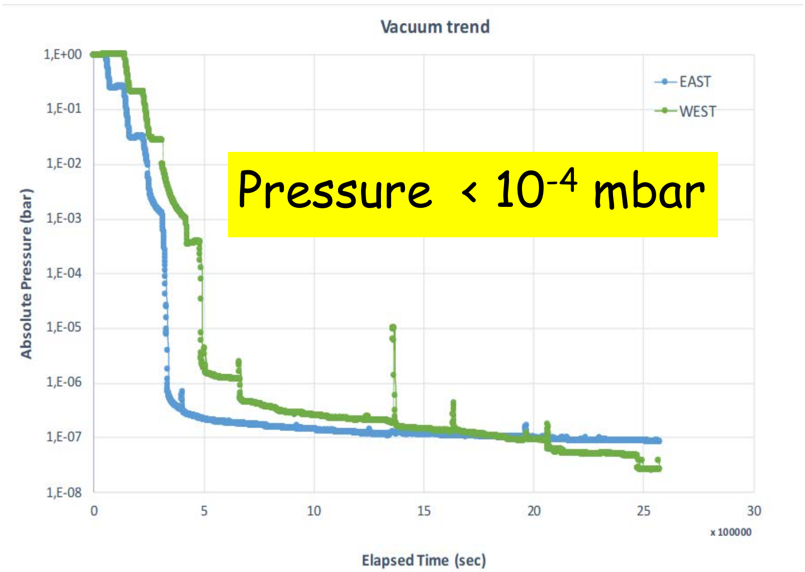
Feedthrough installation (December 2018)



Installing the readout electronics(May 2019)

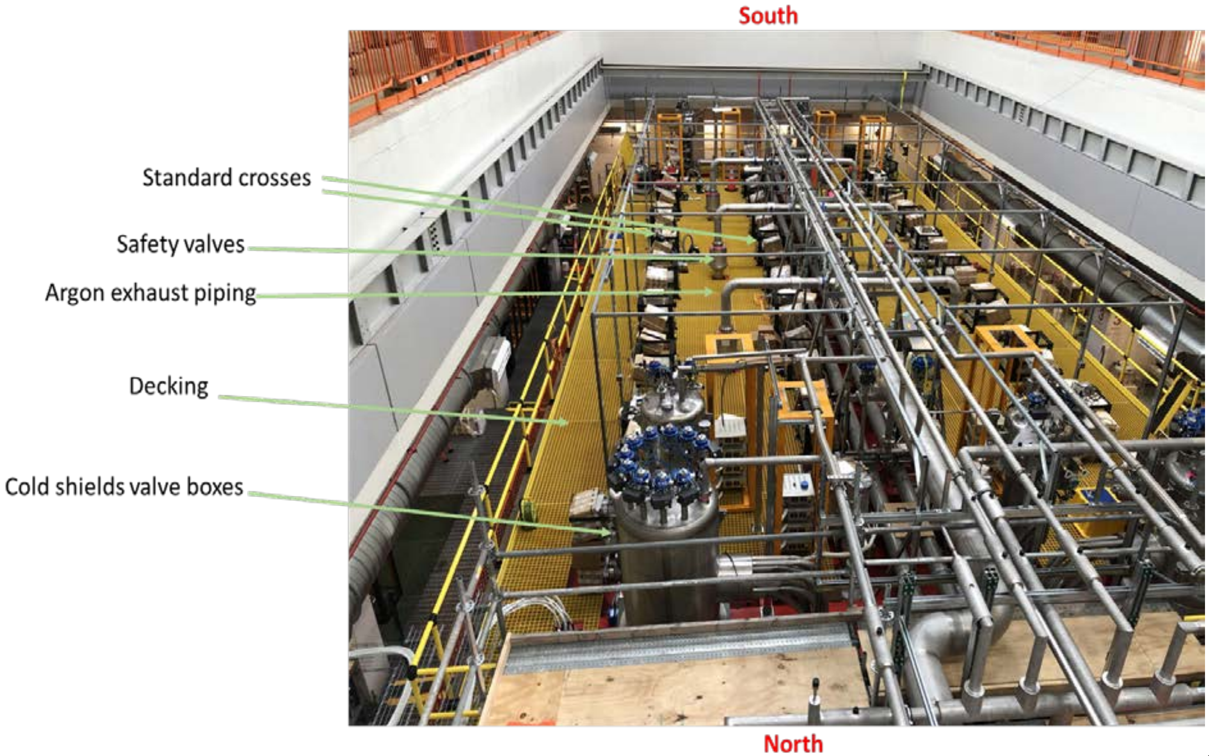
ICARUS installation at FNAL - status

- Top cold shields and top CRT support installed.
- Installation of proximity cryogenics completed.
- ICARUS Vacuum phase started June 5th , 2019.
- Cryogenics hardware installation and cabling is complete.
- Tests of cryogenic controls in progress.
- ODH system ready to operate.
- Side CRT installation also ongoing February 2020.



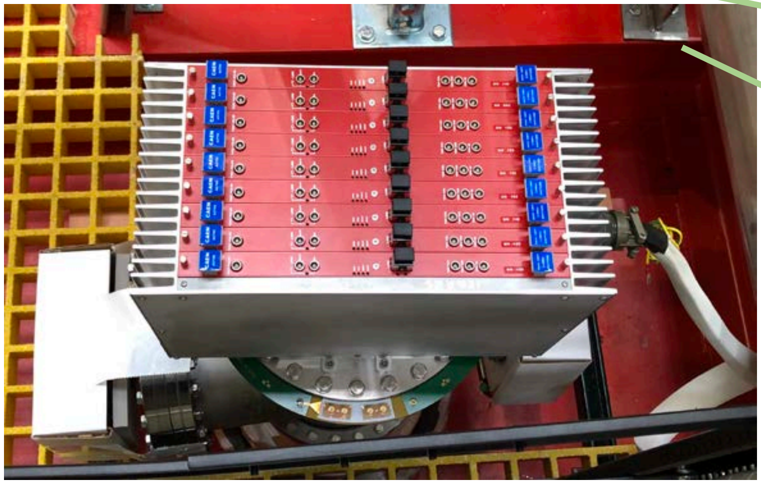
Connectivity test

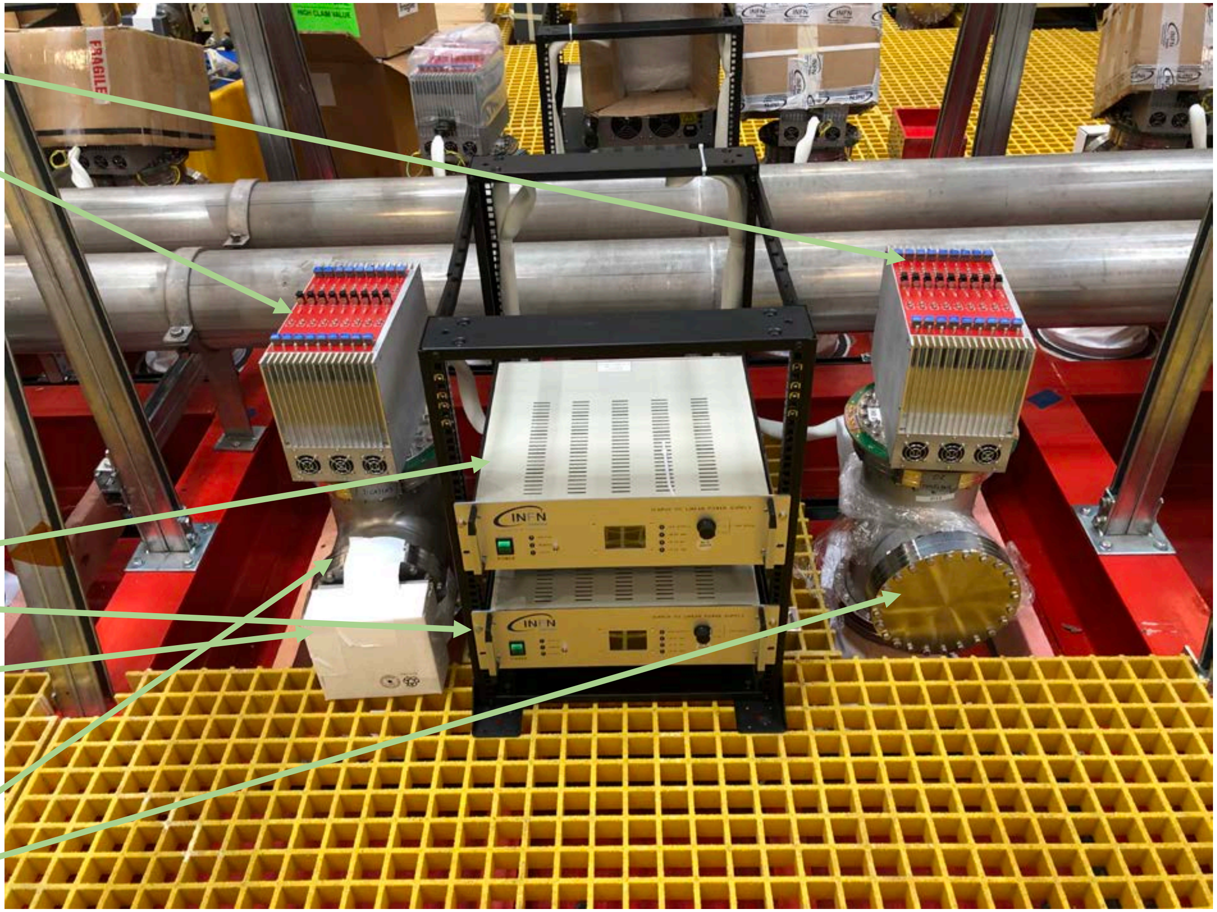
Side CRT installation



Wires Frontend Electronics

Minicrates with readout boards





Power supplies

Optical fibers feedthrough
(covered for protection)

Standard crosses

HV and signal feedthroughs for the PMT's are on the back side of the crosses

Argon venting

Venting pipe

Magnetic safety relief valve
(3 per cold vessel)

Roughing + Turbo vacuum
pump (3 per cold vessel)

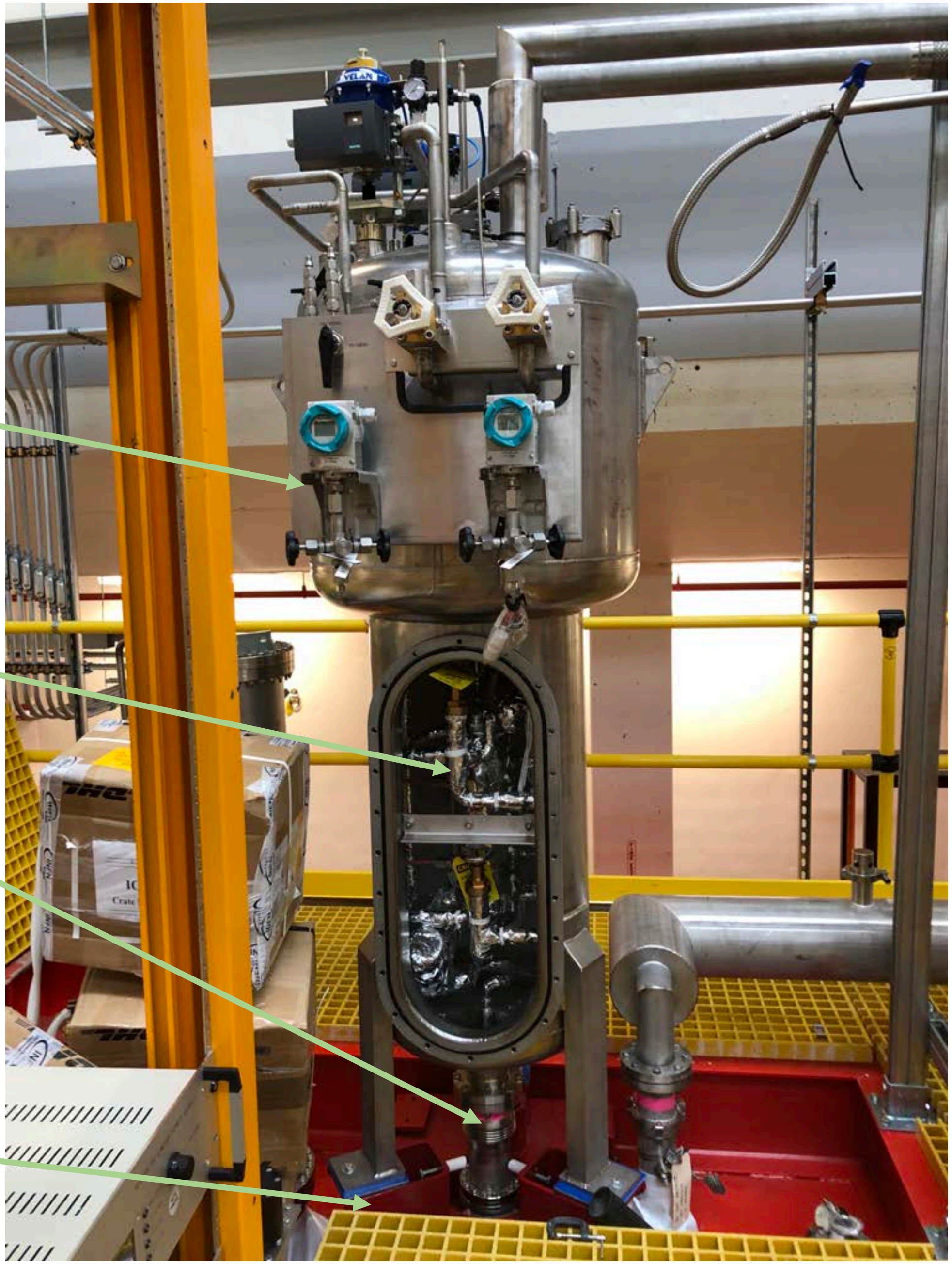
GAr recirculation unit (x4)

Argon re-condenser

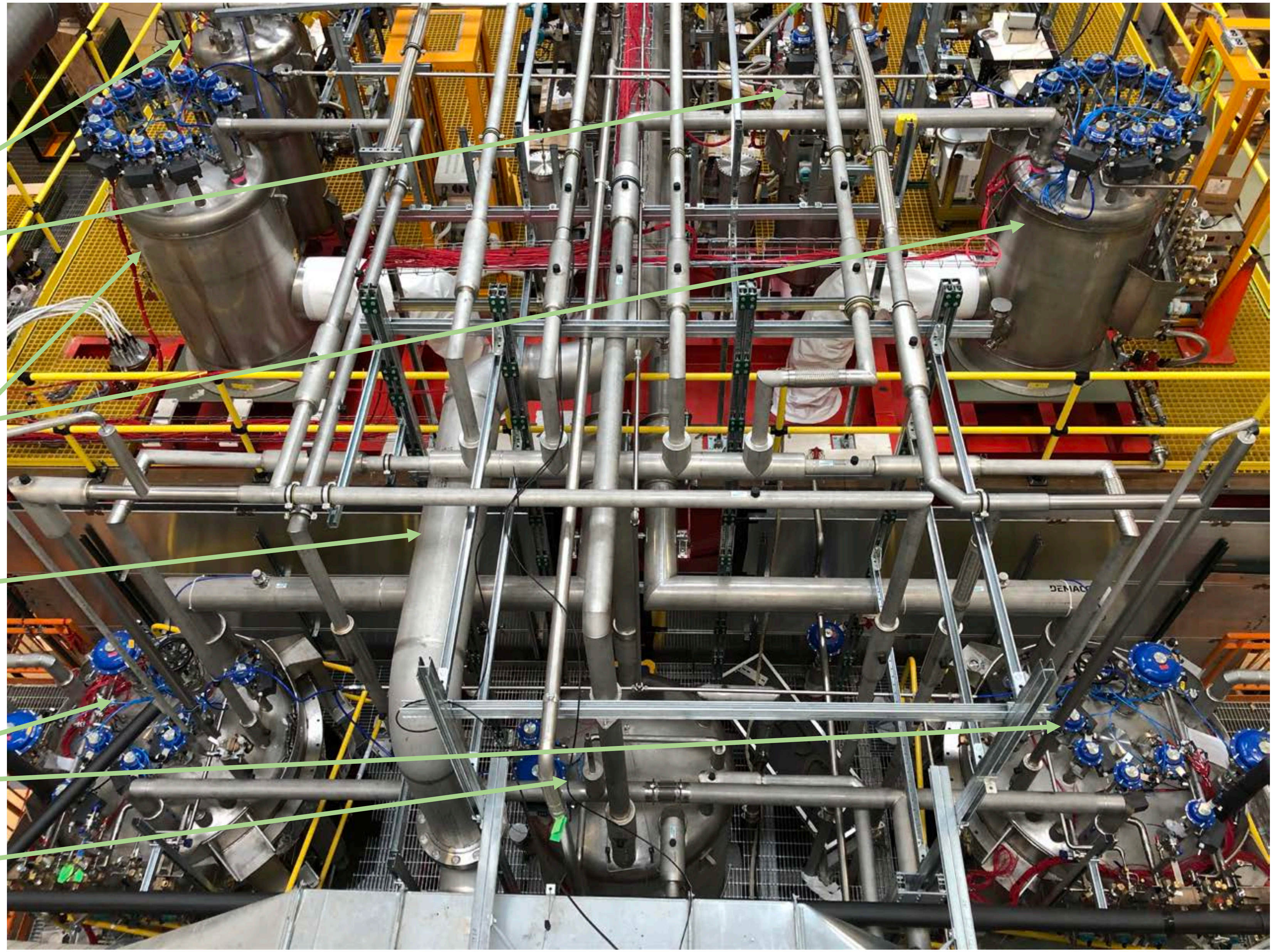
Purification filter (copper only)

Output

Sliding support (to allow displacement due to thermal contraction of the cold vessel)



Cryogenic components



GAr recirculation units

Cold shields valve boxes

Venting pipe

LAr filters

Nitrogen phase separator

North Side – Mezzanine level

Nitrogen phase separator

Lar purification unit (x2)

Side CRT modules

North Side – Bottom Level

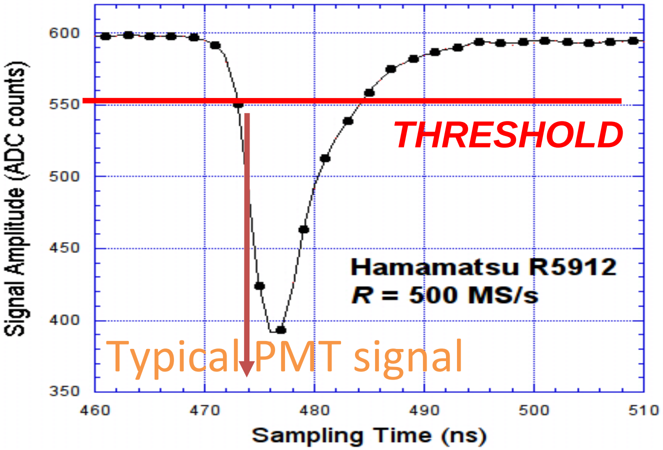
LAr purifier vacuum casing (lowered)

LN2 circulation pumps (x3)

LAr recirculation pump (x2)

INFN activities in ICARUS/SBN

- Besides the ICARUS overhauling activities already described, a number of Working Groups have been created.
- All INFN groups contribute to ICARUS major items, besides the installation and the commissioning.



➢ Padova: TPC electronics, trigger, software.
➢ Pavia: PMT, trigger, cryogenics, software.
➢ Milano Bicocca: PMT calibration with laser.
➢ Napoli: DAQ.
➢ LNGS: PMT.
➢ <u>Catania: PMT, Trigger, CRT, software</u>:

✓ Testing PMTs @ CERN (scintillation light for timing/triggering);

✓ Testing Light yield/efficiency of Side CRT's Optical Read-out Modules (ORM) @ FNAL.

✓ Development of GUI's for the Slow Control.

✓ MC event production @ FNAL;

✓ Procurement/installation of various parts of T600 & Side CRT @ FNAL.

PMT's activities before and after cooling down

- Before cooling down:
  - Test HV supply;
  - PMT calibration of PMTs with the final electronics;
  - Parameter settings (LVDS, baseline, threshold etc.);
  - Test of DAQ with both PMTs and TPC;
  - Set up of online monitoring of PMT DAQ system;
  - Discussion and preparation of a plan about calibration.
- After cooling down:
  - Activation of PMTs and check the correct functioning;
  - Perform a complete electronic check and debugging;
  - Perform a full calibration campaign;
  - Check of PMT DAQ system in view of data recording and trigger system activation;
  - Start calibration routines;
  - Perform the final calibration campaign with Laser, cosmic rays and random data.

ICARUS Slow Control Architecture at FNAL - status

Slow Control Architecture

Hardware and external data sources
- Power supplies
- GPS
- Cryogenics (IFIX)
- Beam
- Computer status
- DAQ status
- Environment

EPICS is the core software for SBN-FD, SBND, and microBoone.

EPICS

EPICS Extensions
- Control System Studio – user interfaces
- Archiver
- Alarm handler

SBN Tools
- Web displays
- Databases

Management: Geoff Savage

Conclusions

- ICARUS-T600 successful 3-year run at LNGS proved that LAr-TPC technology is mature and ready for large-scale neutrino physics experiments.
- ICARUS searched for possible LSND-like anomaly through νe appearance in the CNGS beam. No excess found, identifying a small allowed parameter region where sterile neutrinos have to be searched.
- The SBN project at FNAL will be able to clarify the sterile neutrino puzzle, by looking at both appearance and disappearance channels with three LAr-TPCs
- ICARUS is a crucial part of this effort, working in close collaboration with SBND. The analysis effort is common and very intense.
- ICARUS was extensively refurbished at CERN (2015-17) and is now being installed at the Far Site on the BNB beamline
- INFN Catania contributes on PMT's,Trigger, CRT, Slow Control and Software.
- The cooling down of the T600 ICARUS Far Detector is completed and the LAr filling just started on February 20th.
- The strong cooperative effort by INFN, CERN and FNAL will allow the end of commissioning by the end of March 2020, and then the data taking will start.

Thank you