The ICARUS T600 Detector as Far Detector within the SBN Program

Milind Diwan
Brookhaven National Laboratory
10/16/2019

15th Topical Seminar on Innovative Particle and Radiation Detectors (IPRD19), October 14-17, 2019 , Siena, Italy.

BROOKHAVEN
NATIONAL LABORATORY

Great gifts from Italy (other than cheese)

- ***Columbus, inventor of the modern notion: Ideas alone could be transformed into actions, even on a grand scale.***

- ***Galileo: Humble reasoning from a single individual is more important than the authority of thousands.***

- ***ICARUS: a detector for the rarest of physical phenomena.***

The ICARUS collaboration

full list of the Collaboration: https://icarus.fnal.gov/collaboration

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

Brookhaven (BNL)
Colorado State
FNAL
Houston
Pittsburgh
Rochester
SLAC
Southern Methodist Univ.
Texas (Arlington)

NP

EP-NU

Spokesperson: C. Rubbia, INFN GSSI

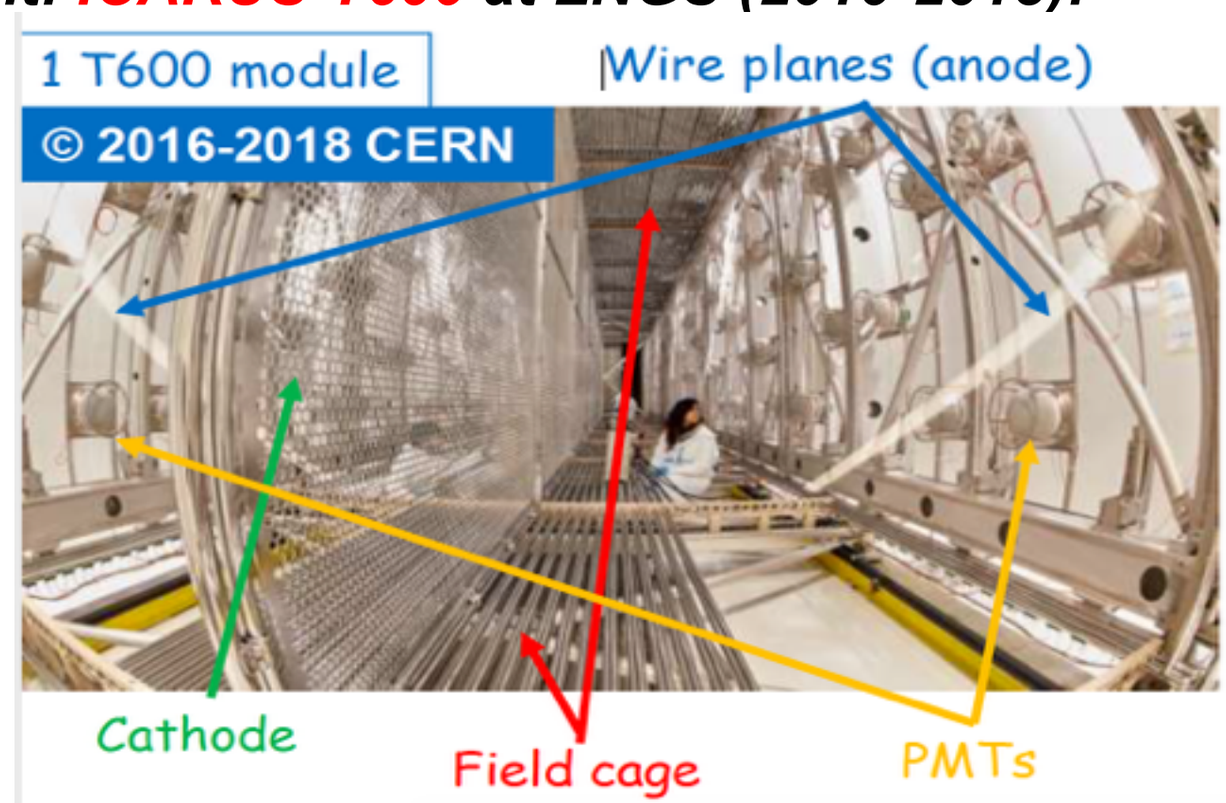
more than 90 collaboration members

International Partner

Many thanks for the major contributions to the Far Detector cryogenics and cosmic ray tagger from our partners at INFN-Bologna, INFN-Lecce, INFN-Milano, INFN-Napoli, INFN-Genoa, INFN-LNS.

Liquid Argon TPC: an "electronic bubble chamber"

- *LAr-TPCs: ideal detectors for neutrino physics and nucleon decay:*
  - *3D reconstruction with high (mm^3) spatial granularity.*
  - *Homogeneous, full-sampling calorimetry for contained particles.*
  - *Scintillation light can provide fast signals for timing/triggering.*
  - *Electrons can drift for several meters (if Argon is sufficiently pure).*
  - *LAr is dense and cheap: very large masses (ktons) are realistic.*
- ***First proposed by C. Rubbia in 1977: R&D at INFN and CERN resulted in first large-scale experiment: ICARUS-T600 at LNGS (2010-2013):***



- *ICARUS was exposed to CNGS beam and cosmics for 3 years, confirming expected performance and obtained important physics results.*
- *After proving the maturity of the LAr-TPC technique the technology was selected for large-scale installation by the LBNE collaboration in the US. This was turned into LBNF/DUNE international project.*

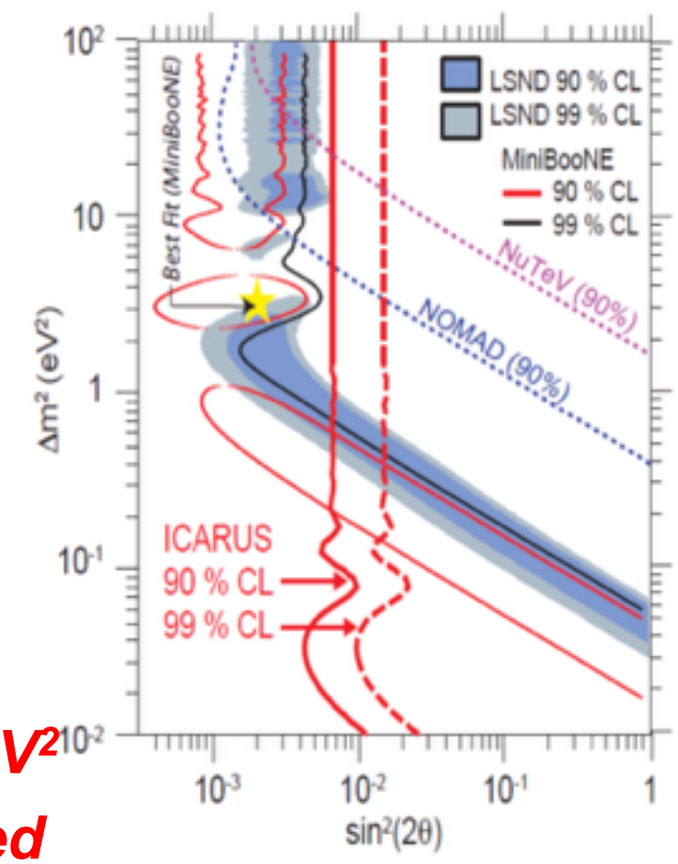
The LAr-TPC technology and ICAR*US-T600*

- ***ICARUS concluded in 2013 a successful 3 years long run in CNGS beam***
- ***An exceptionally LAr purity with only ~20 p.p.t. [O2] eq. of e-negative impurities; the measured e- lifetime >15 ms ensured few m drift path of ionization e- signal at 500 V/cm without attenuation*** ***2014 JINST 9 P12006***

➢ ***Demonstrated the LAr-TPC performance, especially in ν_e identification and π^o rejection in νμ−νe study;*** *EPJ C (2013) 73:2599 .*

➢ ***Performed a sensitive search for LSND-like anomaly through νe appearance in the CNGS beam***

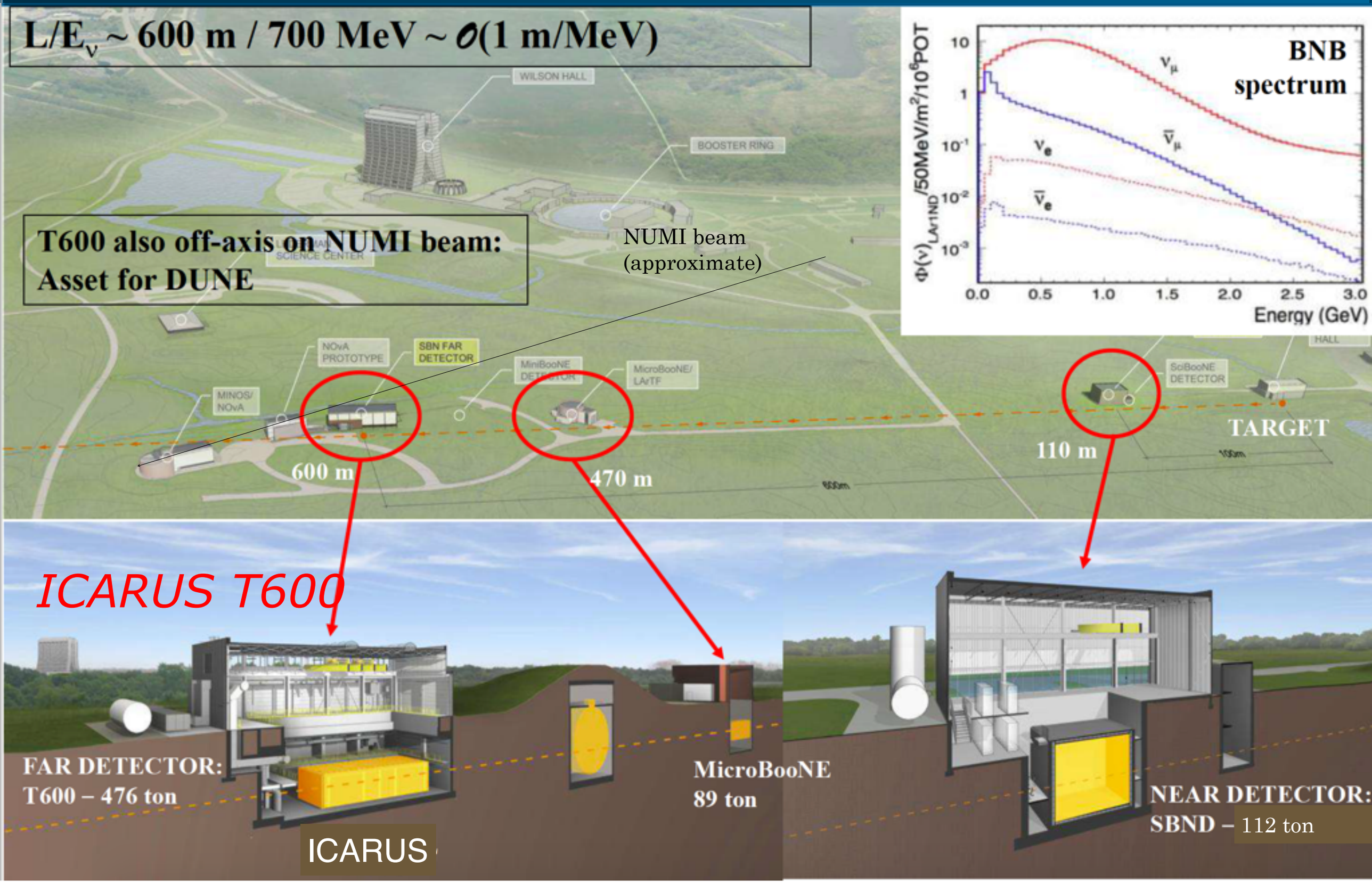
- ***7.9 10^{19} pots analyzed (2650 ν interactions);***
- ***7 νe events observed, ~74% estimated ν_e id. efficiency with negligible background from misidentification;***
- ***8.5±1.1 νe backgr expected mostly from intrinsic beam contamination.***



constraining LSND to a narrow region at $\sin^2 2\theta$ ~0.005, Δm^2<1 eV^2 where all experimental results can be coherently accommodated

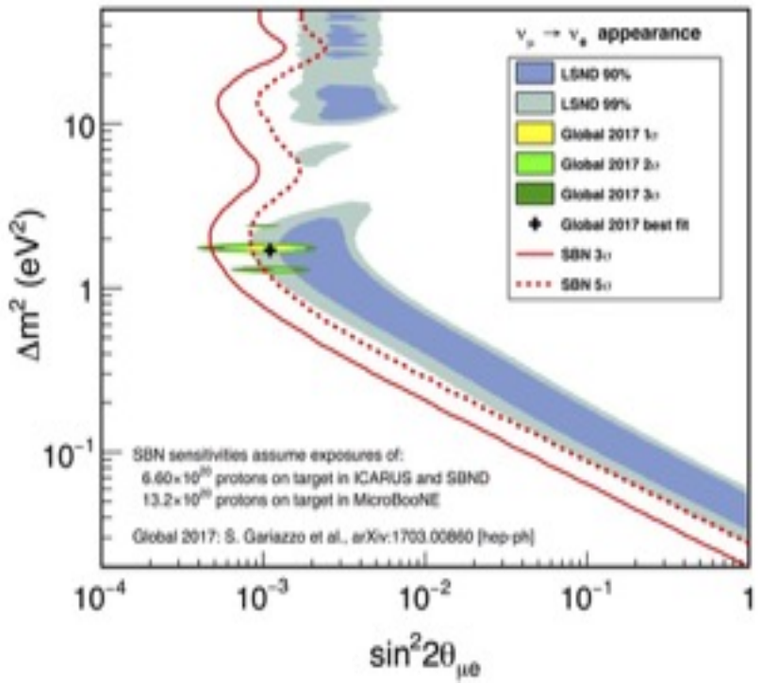
ICARUS success leads to next neutrino/astro-particle projects with multi-kt LAr-TPC DUNE and current SBN short base-line at FNAL with 3 LAr-TPCs (SBND, MicroBooNE, ICARUS) to investigate sterile vs

The SBN project

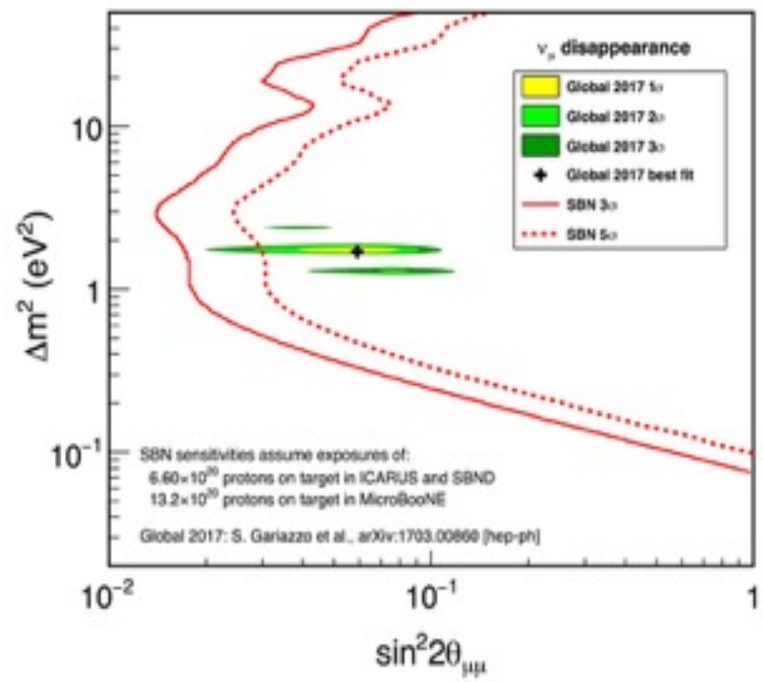


SBN Sterile neutrino search at FNAL Booster ν beamline

- ***We will precisely measure both ν_e appearance and ν_μ disappearance with a near and far detector using the same technology***



ν_e appearance: LSND 99% CL region covered at 5 σ level



3-5 σ ν_μ disapp. SBN sensitiv.

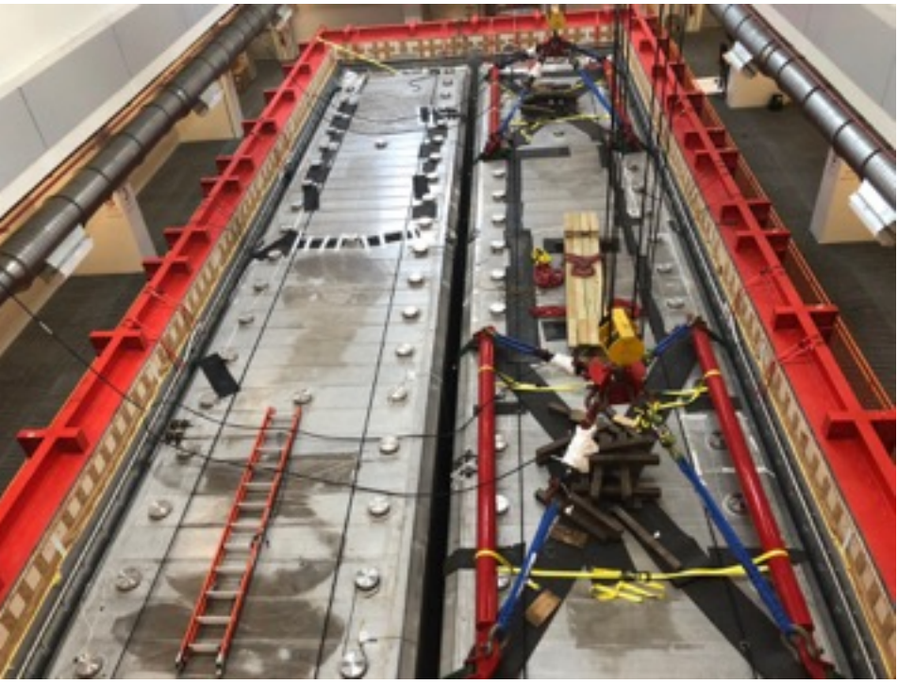
- ***Using the same detector technology for all the 3 detectors will greatly reduce the systematic errors: SBND (near detector) will provide the "initial" beam composition and spectrum.***
- ***The great ν_e identification capability of LAr-TPC will help reduce the NC background.***
- ***During SBN operations, ICARUS will also collect ~ 2 GeV neutrinos from NuMI (Neutrino Main Injector) Off-Axis beam. This will be an asset for the long-baseline project DUNE.***

ICARUS Upgrades for FNAL surface operations.

- ***Main challenge at FNAL: cosmic ray rate of 11 kHz at surface.***
- ***Beam conditions: 8 GeV protons, $5x10^{12}$ POT/spill 1.6 micro-sec at 5 Hz.***
- ***Neutrino event rate is 1 per 180 spills (similar rate from beam produced muons) (expected cosmics in spill ~ 1 cosmic/ 50 spills)***
- ***Upgrades to the detector to address this and other challenges***

  1. ***New cold vessels with purely passive insulation***
  2. ***New LAr cryogenics and purification plant***
  3. ***Extensive upgrade to PMT system with high granularity and ns time resolution.***
  4. ***Faster/high performance Trigger/DAQ/readout electronics system.***
  5. ***3 m concrete overburden to remove cosmic hadrons/gammas***
  6. ***External cosmic ray tagger to correlated muons with TPC events***

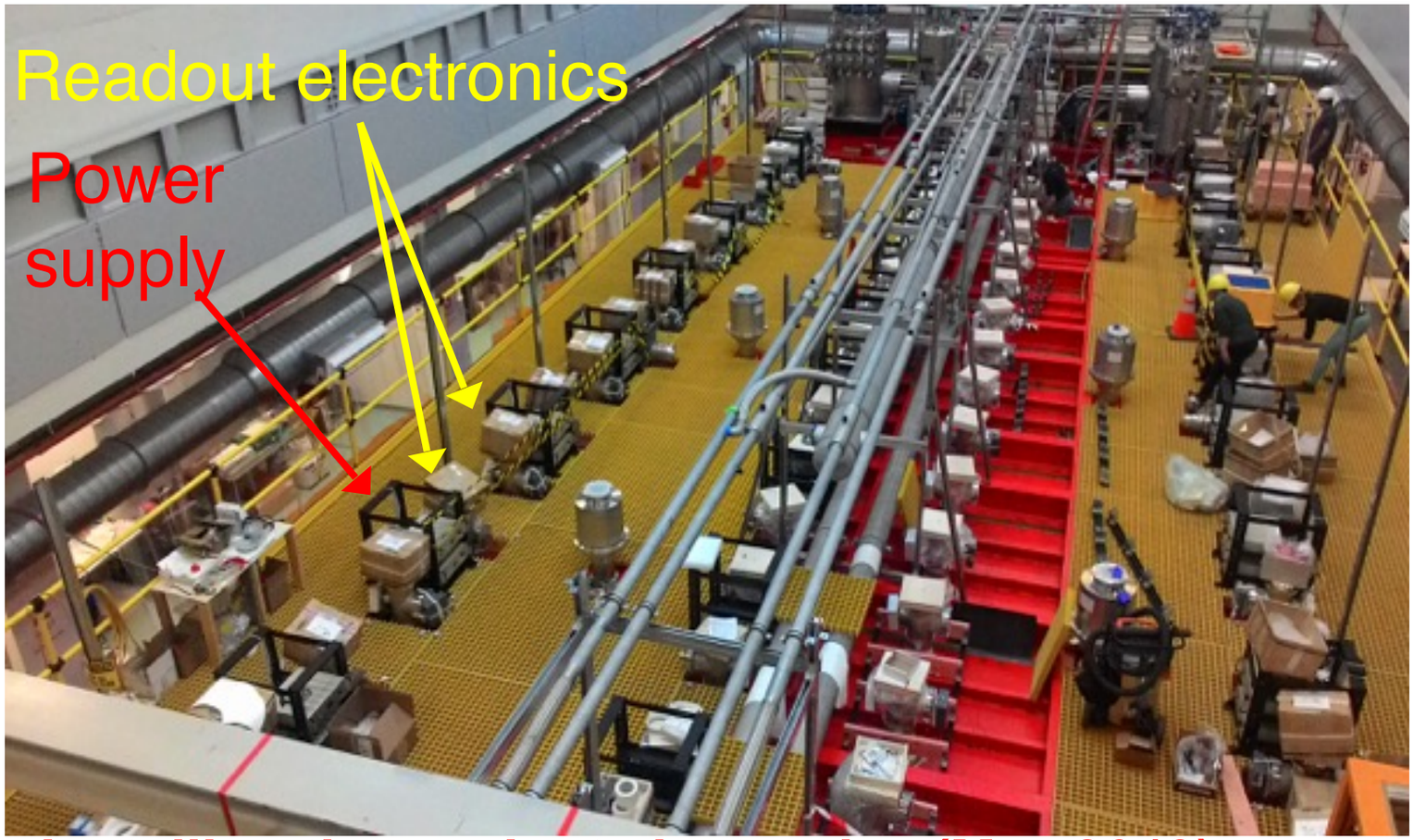
ICARUS installation @FNAL



Placement of ICARUS (August 2018)

Chimneys installation (October 2018)

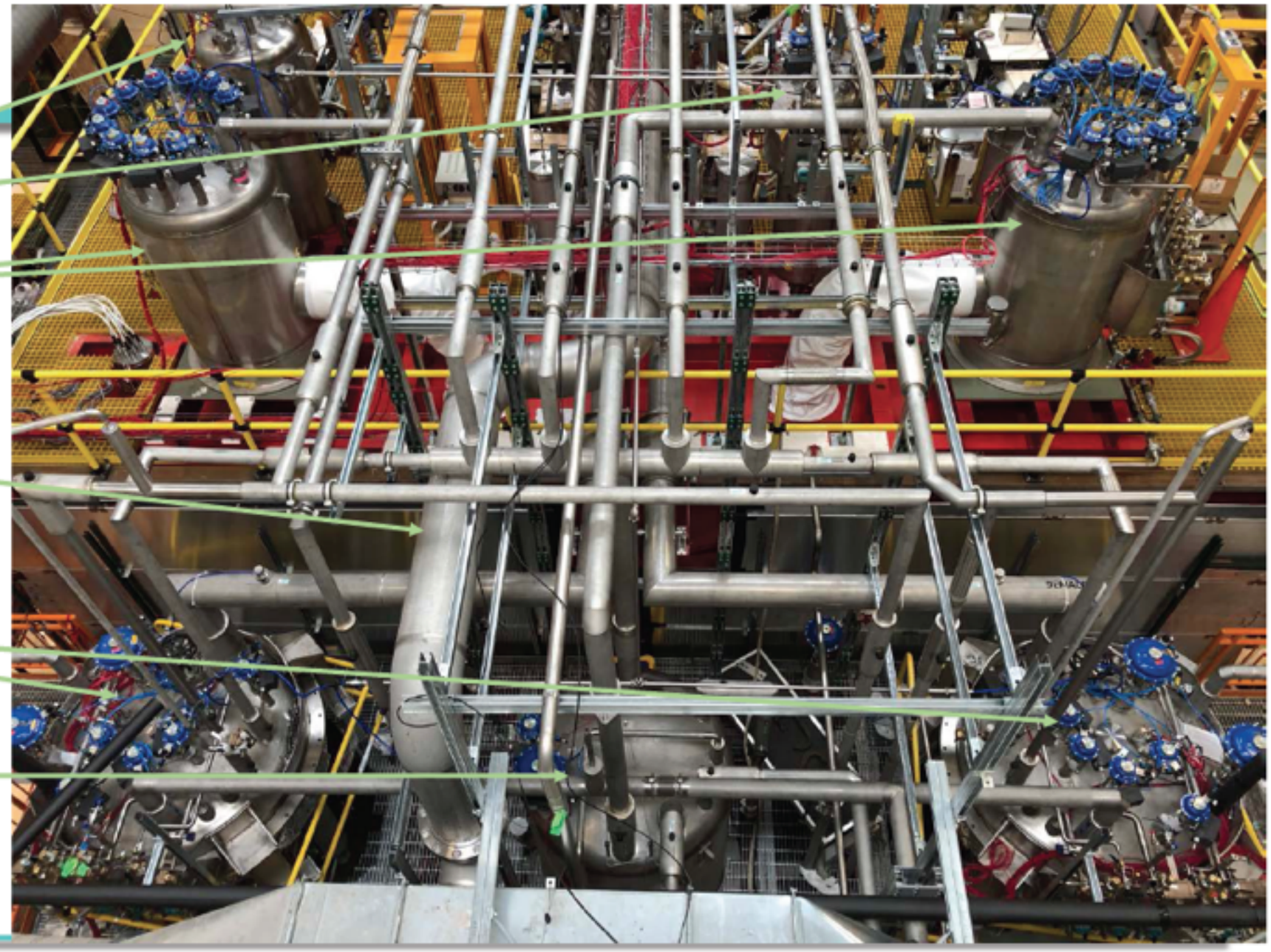
Feedthrough installation (December 2018)



Installing the readout electronics (May 2019)

Sep 2019

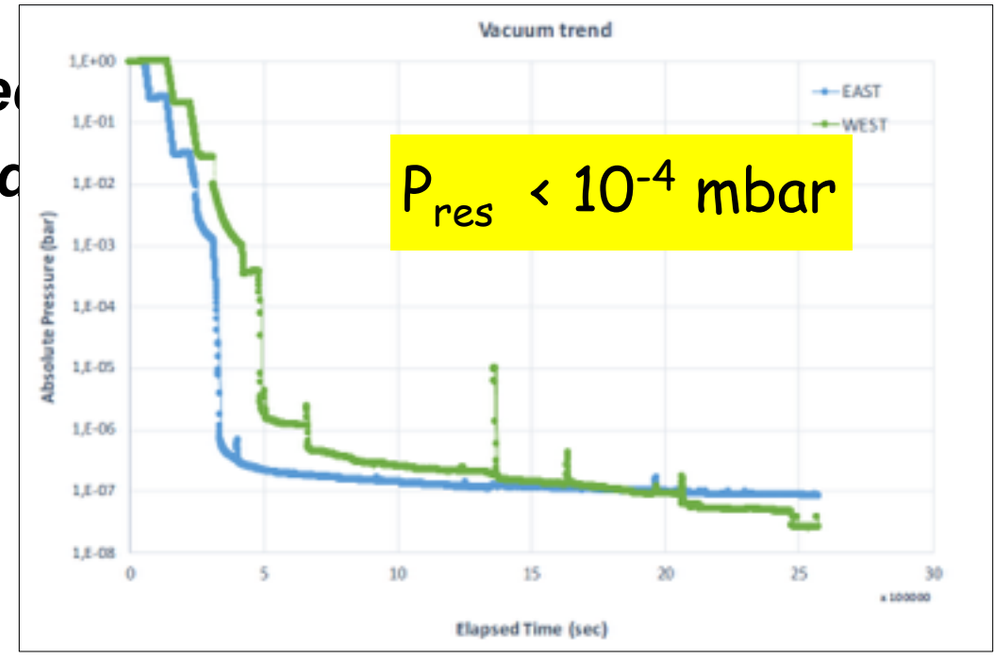
Cryogenic components

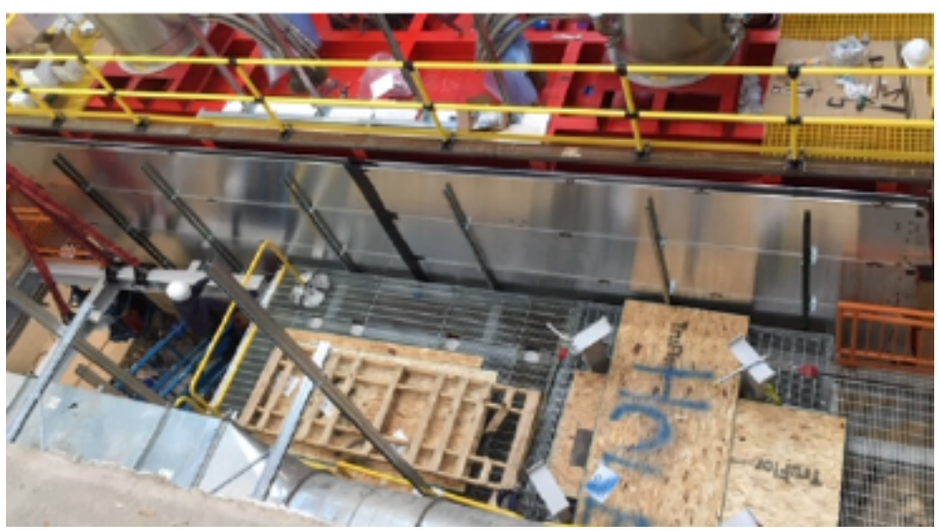


Cryogenic system has been considerably enhanced

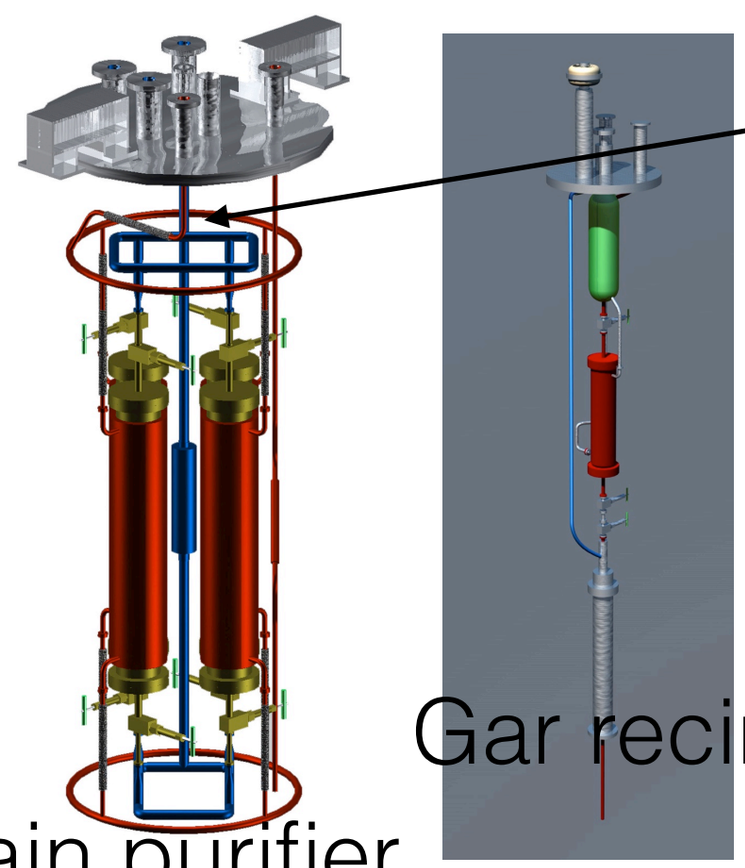
ICARUS installation at FNAL - status

- ***Top cold shields and top CRT support installe***
- ***Installation of proximity cryogenics completed***
- ***<u>ICARUS Vacuum phase started June 5th!</u>***
- ***<u>Cabling to DAQ is in progress.</u>***
- ***<u>wire connectivity checkout completed</u>***
- ***<u>PMT checkout completed</u>***





Side CRT installation



4 Filters in parallel
Single filter volume ≈ 17 lt
25% Hydrosorb
75% Oxysorb

Filter size ≈ 4.3 lt
100% Oxysorb

There is enough capability for the lifetime of the experiment

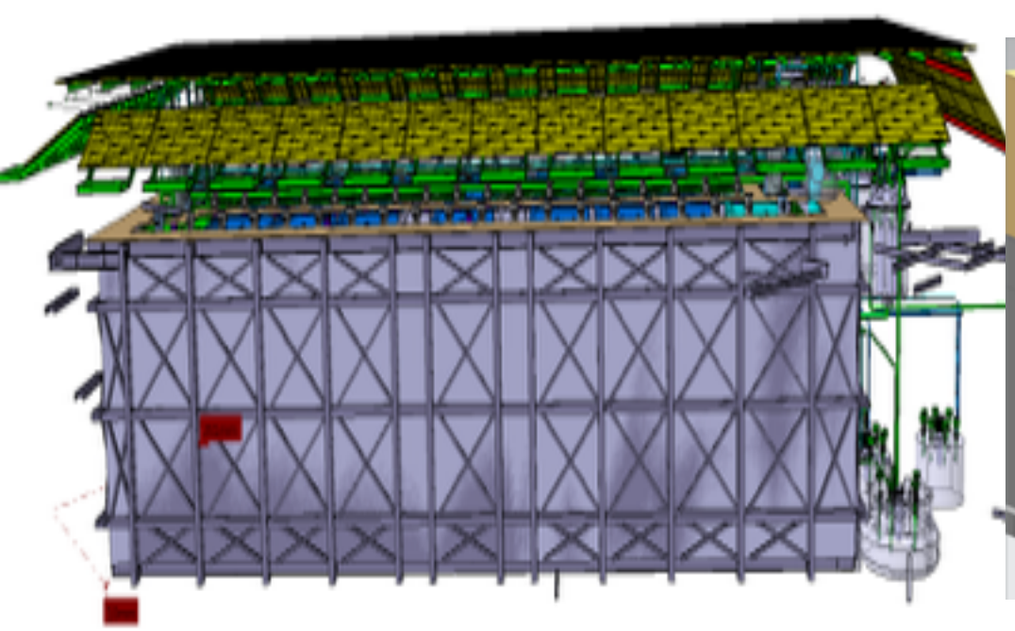
The Cosmic Ray Tagging system (CRT)

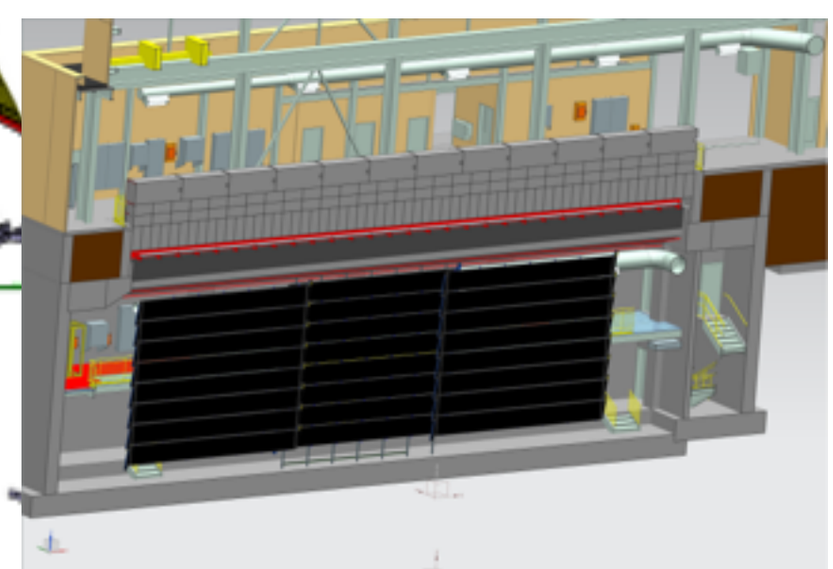
- ***Surrounds the cryostat with two layers of plastic scintillators: 1100 m²***
- ***Tags incident cosmic or beam-induced muons with high efficiency (95%)***
- ***spatial and timing coordinates of the track entry point.***
- ***Reconstructed CRT hits are matched to activity in the LAr volume.***
- ***Few ns time resolution provided signature of incoming versus outgoing***

TOP:
~ 400 m²: roof+angled parts
Will catch~80% cosmic ms
2 strip layers (X+Y)
SiPM readout

SIDES:
~ 500 m² on four sides
Old MINOS veto modules
parallel strips
SiPM readout

BOTTOM:
~ 200 m², already installed
D-Chooz veto modules
2 parallel layers
PMT readout

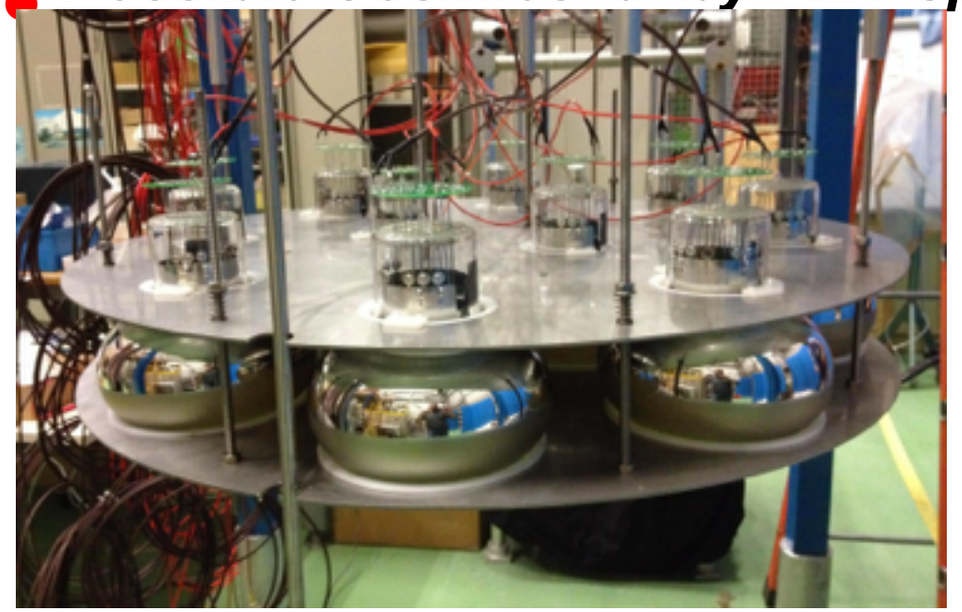


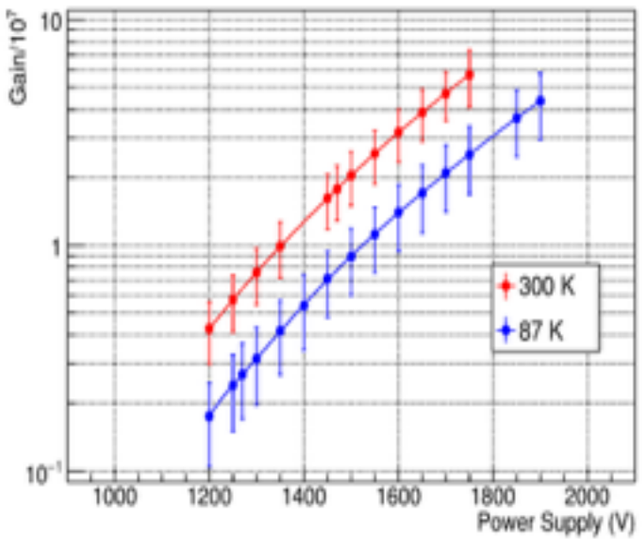


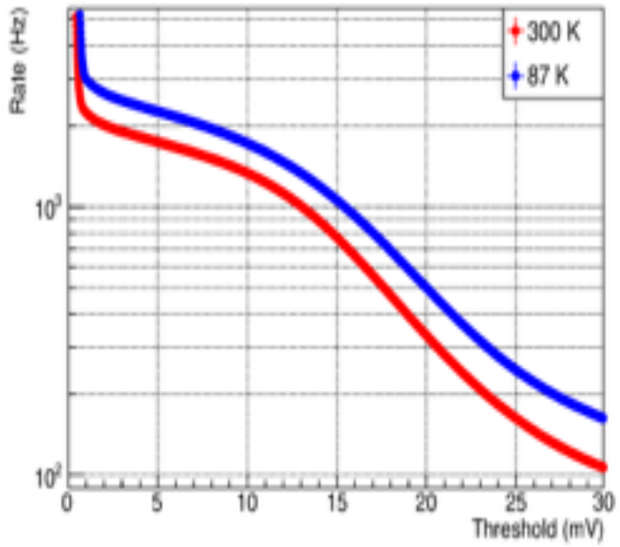
Upgrade of the light collection system

ICARUS@SBN exploits 180 PMTs per module (5% coverage, 15 phe/MeV) that provides: (8 inch - R5912-MOD from Hamamatsu with TPB coating)

- ***Sensitivity to low energy events (~ 100 MeV)***
- ***Good spatial resolution (≤ 50 cm)***
- ***≈ ns timing resolution***
- ***Possible Cosmics id. by PMT space/time pattern***







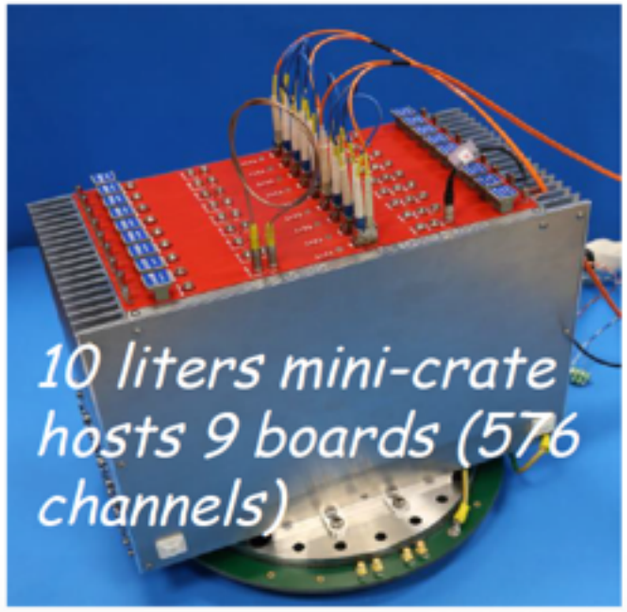
- **All PMTs tested at room temperature in a dedicated dark room at CERN, 60 PMTs tested in LAr.**
- **Campaign to test and commission the system along with the trigger has started at FNAL.**

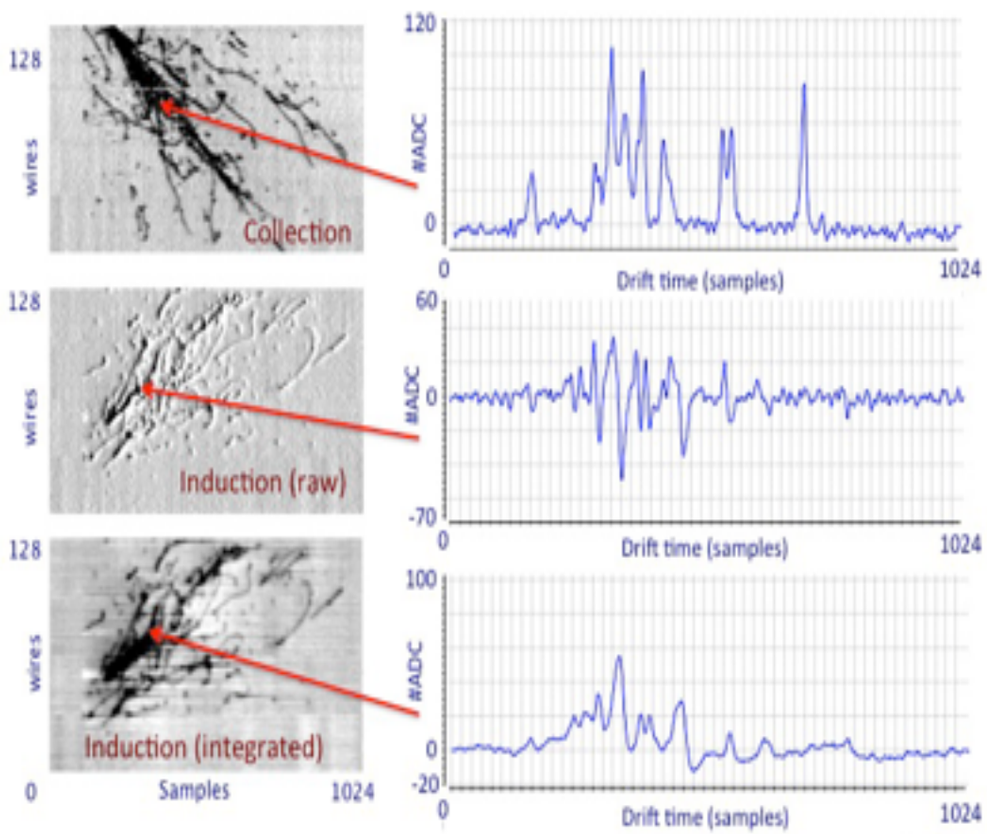
Please see poster about this R&D system *JINST 13 (2018) P10030*

Upgrade of the TPC read-out electronics

New TPC readout electronics

- ***Outside the cryostat***
- ***Serial 12-bit ADC, fully synchronous in the whole detector***
- ***CAEN A2795 64-chan modules.***
- ***More compact layout: both analog+digital electronics hosted on a single flange.***





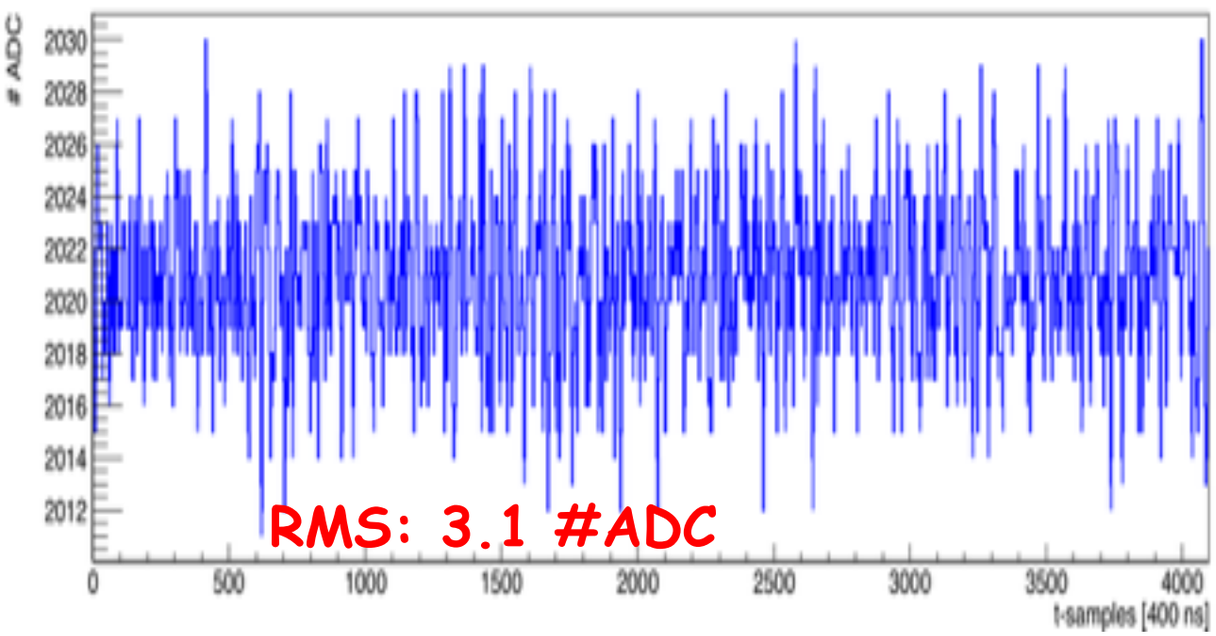
- Lower noise ~ 1200 e- equivalent (~20% S/N improvement w.r.t. LNGS electronics).
- Shorter shaping time (~ 1.5 μs for all planes) and drastic reduction of undershoot after large signals.
- Induction 2 signal keeps bipolar shape → allows calorimetric measurement in this plane, to improve ν_e identification efficiency by ~20%.

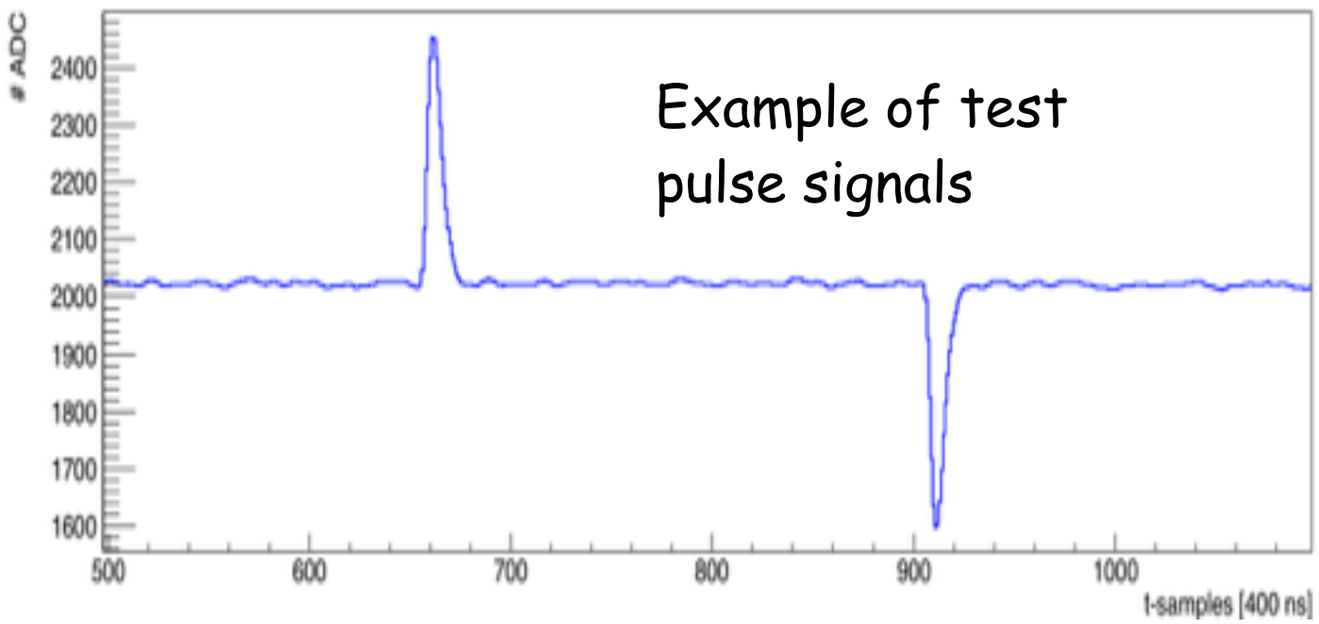
New electronics extensively tested on a 50-liter TPC@CERN

JINST 13 (2018) P12007

Recent tests on the readout electronics

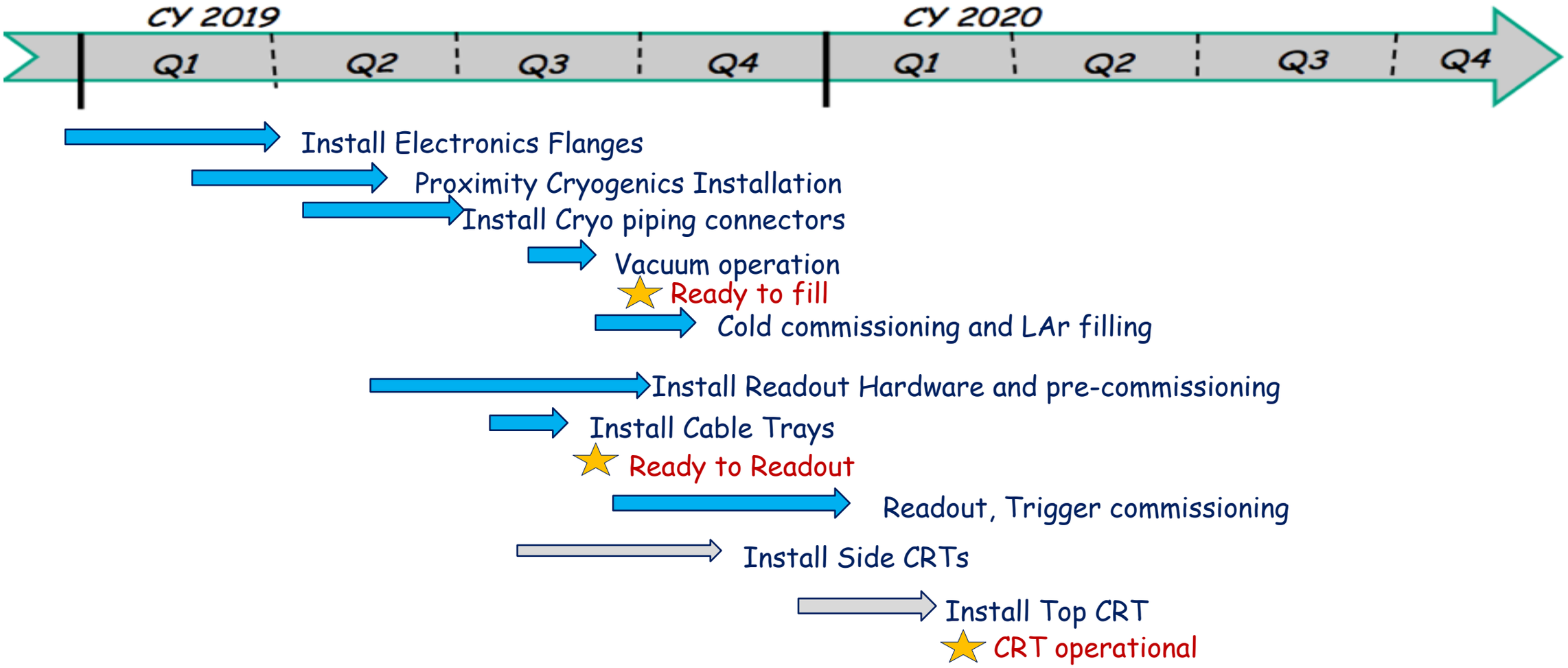
- ***All the feedthrough flanges and the mini-crates with the TPC wire read-out electronics (576 channels + optical links) has been installed.***
- ***A test of the full readout chain, from wires to DAQ, has been performed in April/May for all the mini-crates :***
  - ***Allowed to check readout and set baseline for future noise monitoring***
  - ***Noise measured on random triggers and test pulses***
  - ***Noise RMS ~1700 e-, (after proper grounding, shielding and filtering expectation is ~1200 e- as measured in CERN 50-liter setup)***





ICARUS at FNAL – plans and commissioning

- ***TPC/trigger electronics installation ongoing.***
- ***PMT electronics installation to be completed soon.***
- ***ICARUS expected to be ready to fill by end of this month***
- ***After cryogenics commissioning, cool down and filling, ICARUS T600 should be operational in the first quarter of calendar 2020.***
- ***Commissioning of CRT, DAQ, trigger and slow controls will follow.***
- ***Data-taking for physics is expected by spring of 2020.***



Conclusions

- The ICARUS-T600 proved that LAr-TPC technology is mature and ready for large-scale neutrino physics experiments.
- The SBN project at FNAL is expected to clarify the short baseline neutrino puzzle, by looking at both appearance and disappearance channels with three LAr-TPCs.
- After an extensive refurbishing, ICARUS is being installed as the SBN far detector at FNAL. ICARUS Data taking expected in 2020, near detector in 2021.
- ICARUS will see first neutrinos soon !