INTENSE : Commissioning and developments of ICARUS at FNAL

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INTENSE Midterm Review
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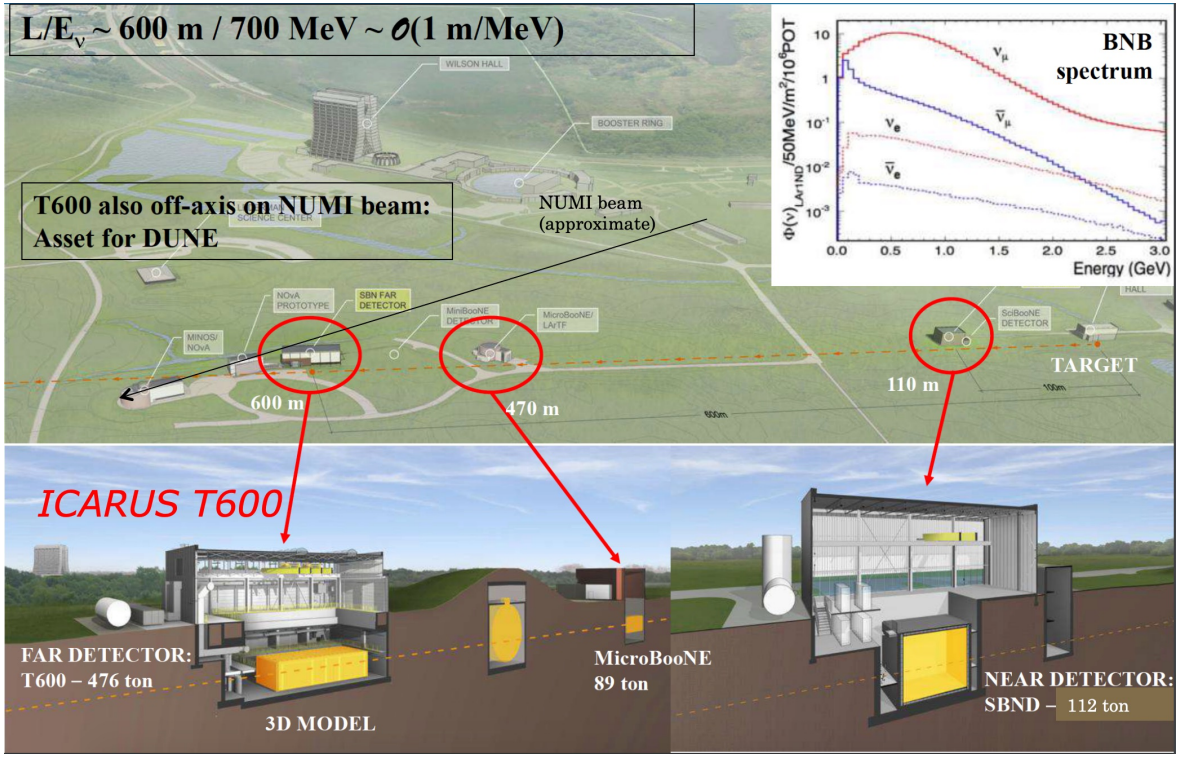
SBN at FNAL

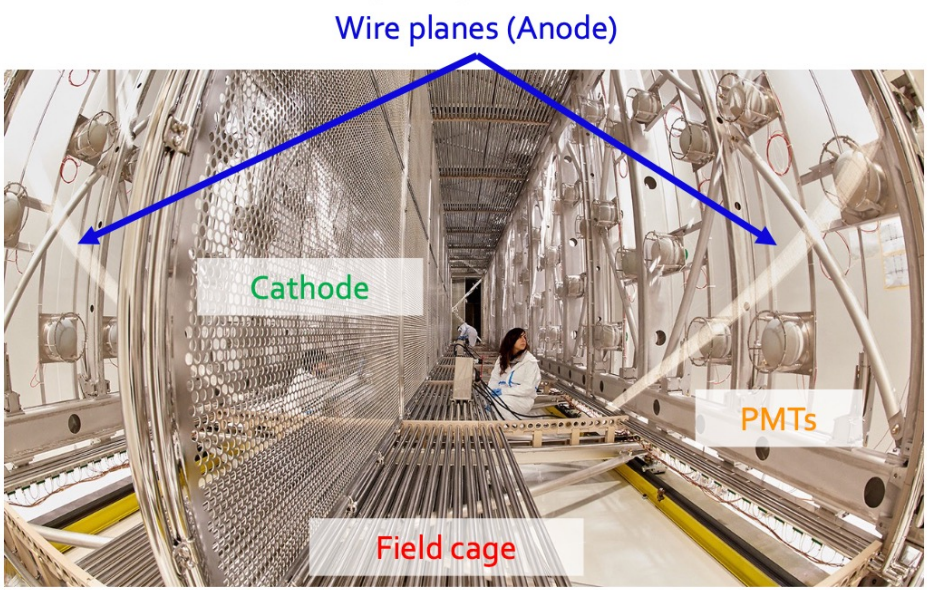
- The Short Baseline Neutrino experiment at FNAL has the goal to verify the possible existence of sterile neutrinos in the few eV^2 mass range
- This will be performed by searching for oscillations both in the $\nu\mu$ appearance and νe disappearance channels, comparing a near detector (SBND) and a far detector (ICARUS) along the Booster neutrino beamline
- Any difference between near and far detector neutrino spectra will be a sign of new physics!



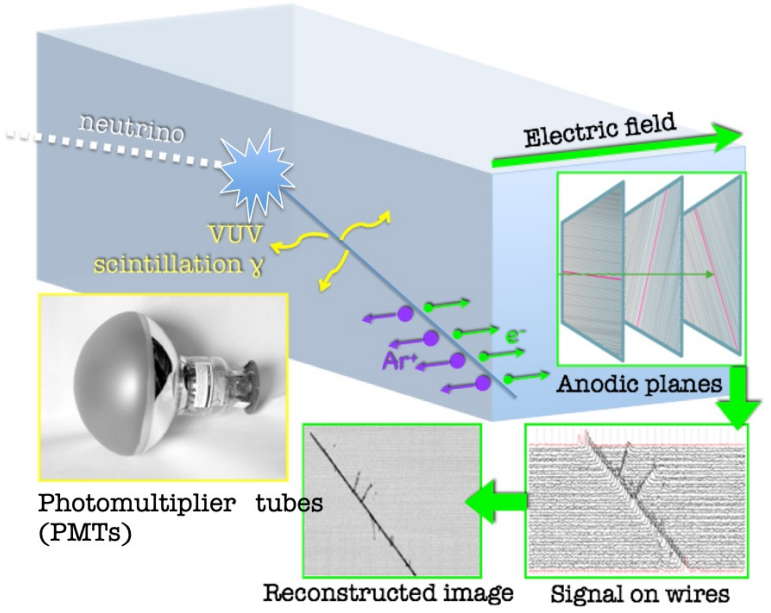
- Both near and far detector are liquid Argon time projection chambers (LAr-TPC). Ideal technology for neutrino physics: 3D reconstruction with ~mm spatial resolution, precise calorimetry for contained events, fast scintillation light

The ICARUS-T600 detector

- First large-scale LAr-TPC ever constructed. Its run at LNGS with CNGS neutrinos (2010-13) produced important limits on sterile neutrinos and proved the maturity of LAr-TPC technology for large neutrino experiments
- Total active mass ~476 t. 2 identical cryostats with central cathode; 1.5 m drift
- Charge produced by Ar ionization is read out by 3 wire planes (3mm wire pitch, 3mm distance between planes)
- LAr VUV scintillation light is read out by 360 PMTs (8" diameter), to provide fast signals for triggering and event localization
- The detector is surrounded by a Cosmic Ray Tagger (CRT) in order to tag incoming cosmic rays and reduce background to neutrino searches

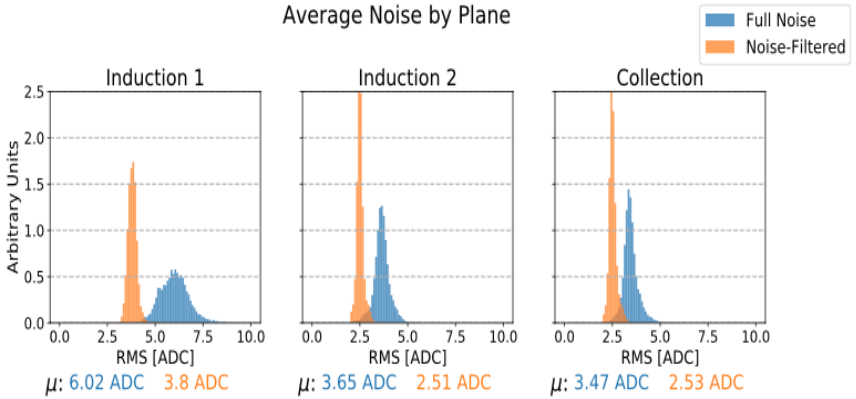


Inside ICARUS: internal view of one cryostat



ICARUS commissioning

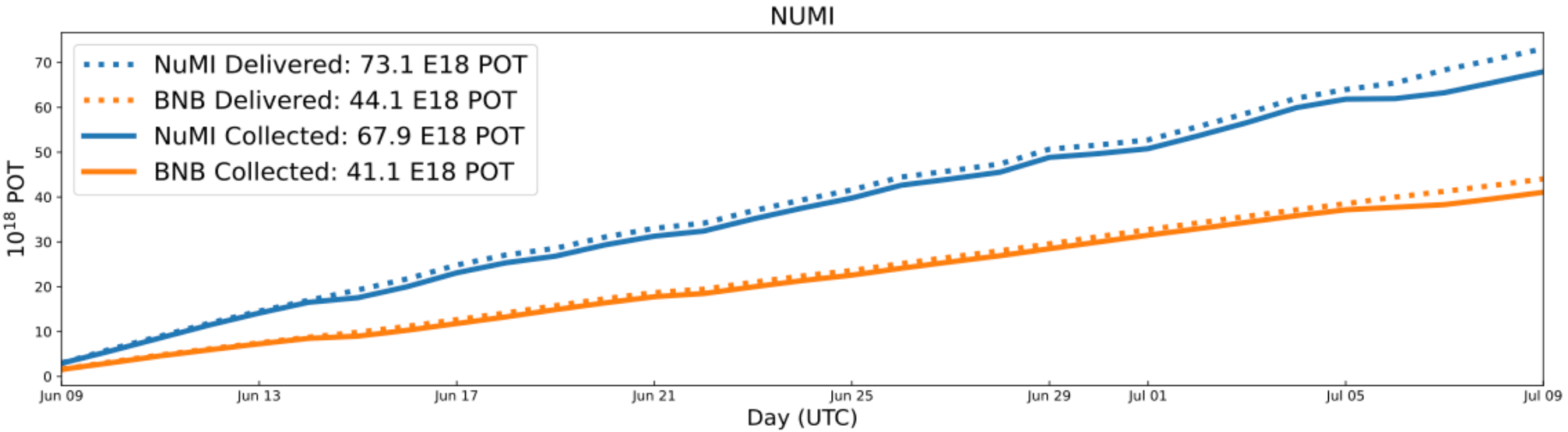
- The ICARUS detector was transported to FNAL in summer 2017 and deployed in the experimental building at FNAL in 2018.
- Filling with LAr took place in February-April 2020. Full commissioning and characterization of the TPC and PMT system lasted from 2020 to early 2022
- Installation of both side and top CRT was concluded by the end of 2021
- The last part of commissioning was the installation of a concrete overburden (~3m thickness) above the detector, in order to reduce cosmic ray rate by a factor ~2
- The overburden installation concluded on June 7, 2022, allowing to start physics data taking



I contributed to several tasks of commissioning. In particular I worked on TPC noise characterization and reduction

Run 1: the first physics run

- Run 1 officially began on June 9, 2022 and lasted until the beam summer shutdown at midnight on July 10
- ICARUS operated in physics mode, running in stable conditions mainly with beam majority trigger whenever at least one beam (NuMI or BNB) was available
- Testing and development activities were only performed during beam shutdowns
- Data acquisition was largely successful, with an average collection efficiency of ~93% for both BNB and NuMI beams
- Total collected beam amounts to ~6.8 10^{19} protons on target (POT) for NuMI and ~4.1 10^{19} POT for BNB



I coordinated this physics data acquisition, working on optimizing DAQ efficiency and developing tools for accouting delivered/collected POT and characterizing the detector performance

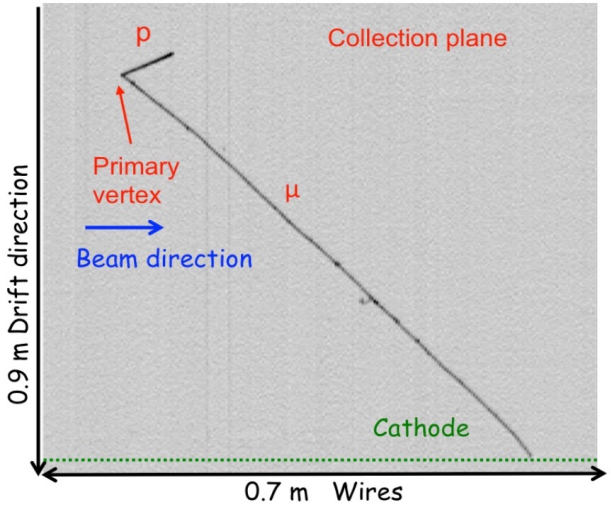
ICARUS developments during summer 2022

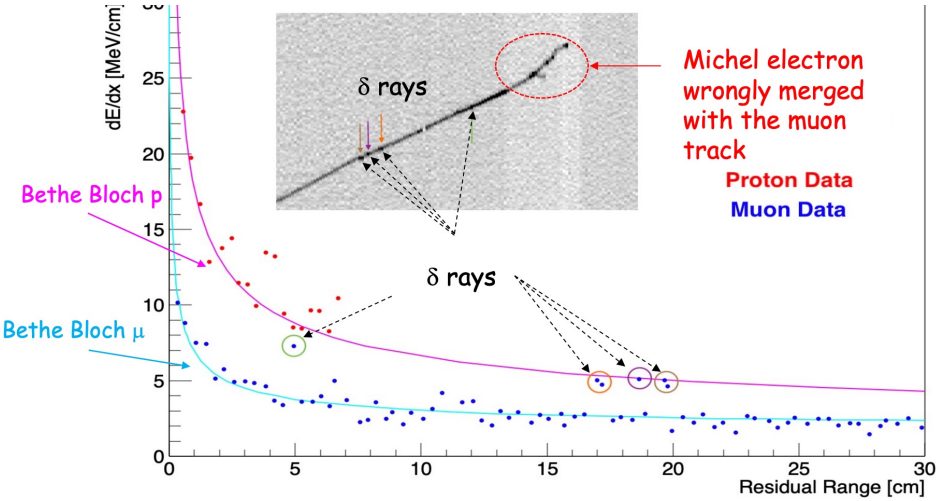
- Several developments of the ICARUS detector were planned for the beam shutdown, lasting from July 10 to ~mid October:
  - LAr filter regeneration, in order to guarantee adequate purity for high-quality data
  - Bottom CRT integration
  - Installation of PMT signal adders, in order to improve trigger efficiency
  - Improvement of the DAQ system, in order to run stably up to ~5 Hz
  - Calibration of wire plane transparency non-uniformities with cosmic ray runs
- A small fire happened in the cryogenic system in mid-September. Clean-up and replacement of damaged wiring took about a month. ICARUS is back to normal operational conditions
- Despite this delay, most of the planned work has been performed successfully
- ICARUS is ready for restarting physics operations (Run 2) very soon

I was part of the effort to characterize and solve DAQ problems and increase the DAQ rate.
I coordinated the cosmic calibration campaign and took part in the corresponding analysis
I took part in the clean-up and restoration of the TPC after the fire

ICARUS reconstruction and analysis

- The reconstruction of ICARUS event is based on "hits" (over-threshold energy depositions on single wires) which are then clustered in 2D and 3D tracks or showers
- This allows a full reconstruction of the direction and energy/momentum of each contained particle (non-contained muon momentum can be measured via MCS)
- Particle identification can be obtained from the relation between dE/dx and residual range





I focused on several reconstruction and analysis tasks:

- *Development of hit-finding algorithms*
- *Muon momentum measurement via multiple scattering*
- *Improvements in track reconstruction*
- *Event-by-event POT characterization*