Status and perspective of the ICARUS-T600 detector at the Fermilab Short-Baseline Neutrino Program*

Author: Francesco Poppi (INFN Bologna) on behalf of the ICARUS Collaboration.

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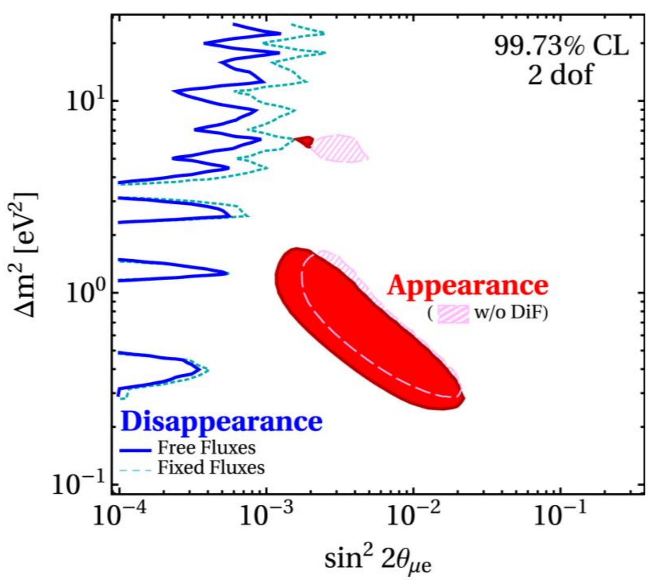
A collection of unexpected results were observed at an L/E ~ 1 km/GeV:

- $\bar{\nu}_e$ appearance in $\bar{\nu}_\mu$ beam (LSND);
- $\nu_e$disappearance using radioactive sources (SAGE and GALLEX experiments);
- $\bar{\nu}_e$ disappearance in nuclear reactor experiments.

These anomalies can be possibly explained by the existance of one or more sterile neutrinos with a Δm^2 of $\sim 1\ \mathrm{eV}^2$.
Several experiments investigated the light sterile hypothesis (e.g. MiniBooNE **[arXiv:1805.12028]** and MicroBooNE **[arXiv:2210.10216]**), but the results are not consistent and they show a clear tension when combining disappearance and appearance experiments.



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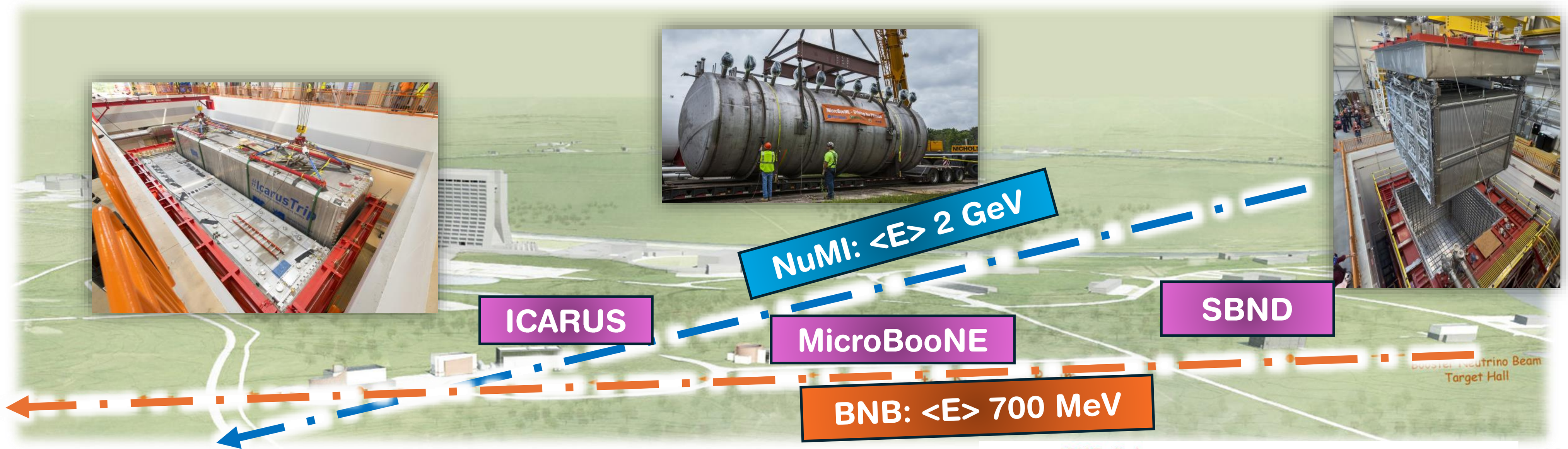
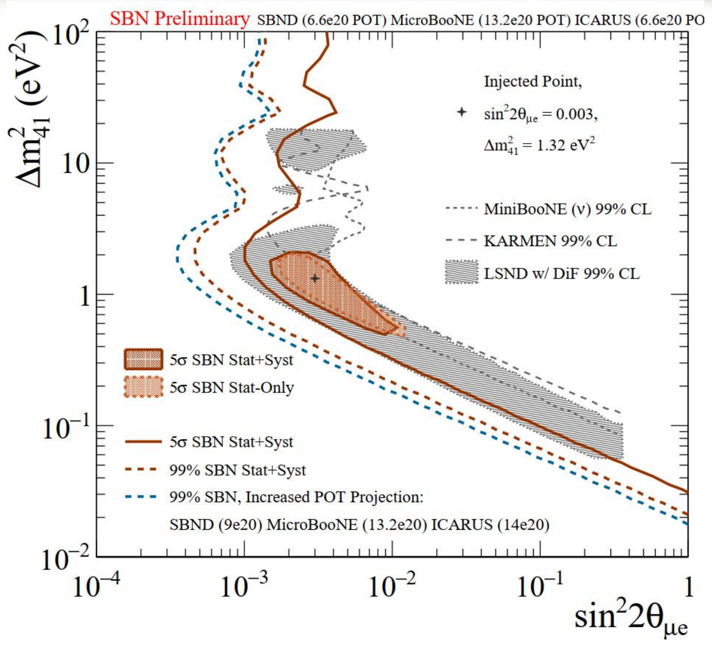
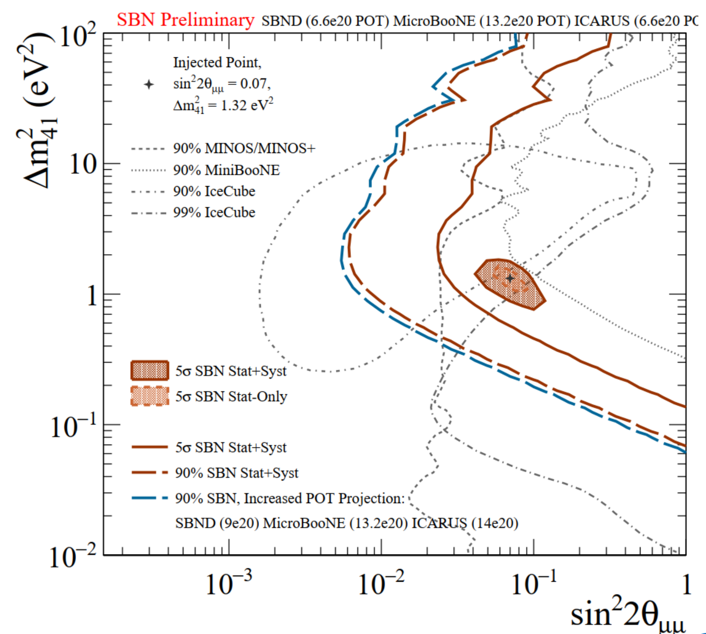


The SBN Program, consisting of a near (SBND) and far (ICARUS-T600) detectors along the Booster Neutrino Beam (BNB), will definitively solve the short-baseline anomalies, searching for sterile neutrino oscillations both in appearance and disappearance channels.
The use of the same Lar-TPC technology at the near and far detector greatly reduces the systematics (flux, cross-sections and detector response).
The SBN program will provide a defintive answer to the sterile neutrino puzzle testing with >5σ confidence level the values of the oscillation parameters suggested by the surviving anomalies.
Additionally, both detector have a rich phyics program besides the joint sterile neutrino search:

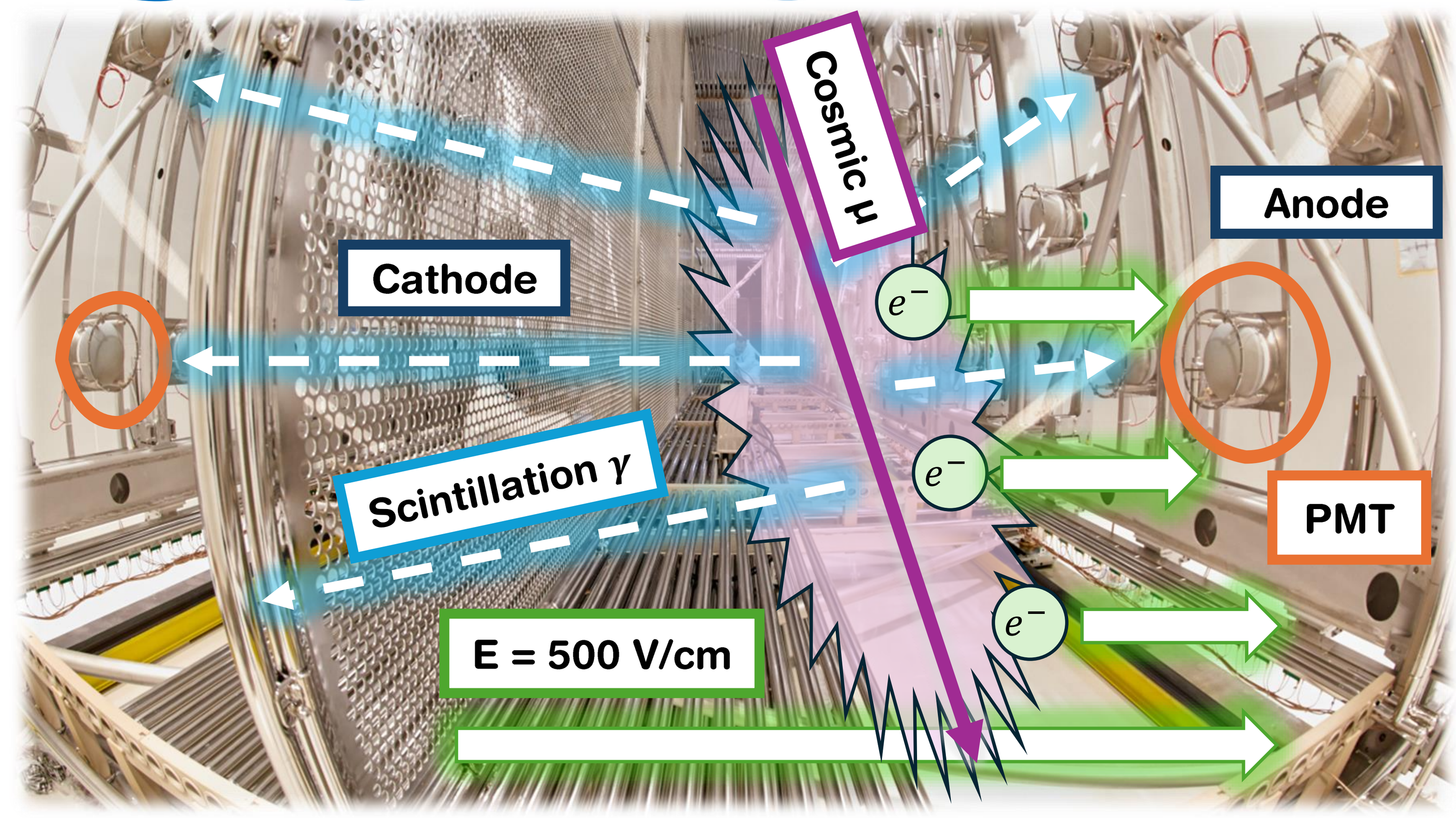
- measurement of $\nu - Ar$ interactions cross-sections in the DUNE energy range with an unprecedent statistics;
- Sub-GeV Dark Matter searchs and other BSM physics;
- ICARUS will also perform a stand-alone verification of one of the most recent neutrino anomalies reported by the Neutrino-4 experiment **[arXiv:2112.14856]**.



SBN Apprearance Sensitivity



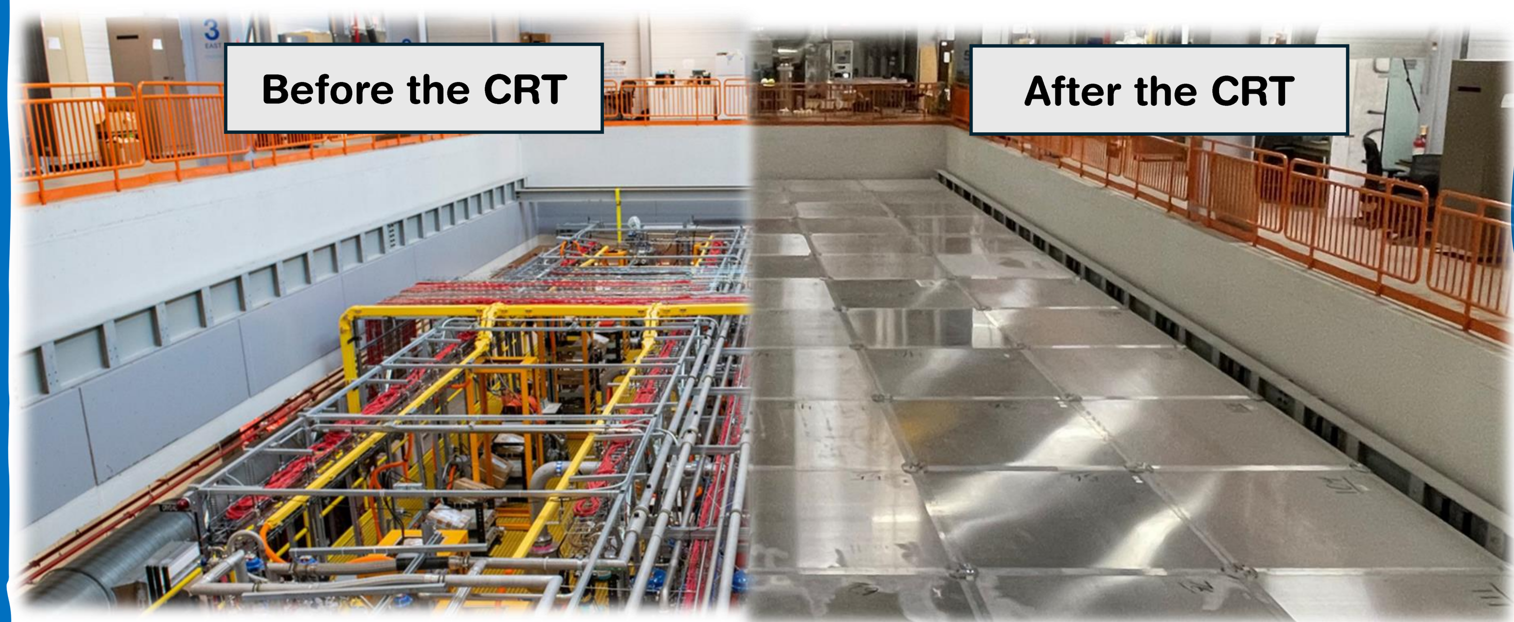
SBN Disappearance Sensitivity



ICARUS-T600 was the pioneer of the LAr-TPC technology. The detector is composed of two identical modules, each with two TPCs separated by a common cathode (1.5 m drift, $E_D = 500 V/cm$), for a maximum drift time of 0.96 ms. Each TPC is instrumented with three readout wire planes per TPC (two inductions and one collection), for a total of 54k wires at 0, +/- 60° with a 3 mm pitch. S/N ratio > 10 for MIP tracks in Induction 2 and Collection planes.
A total of 360 PMTs coated with TPB are installed behind the anode planes, in order to detect and trigger on the LAr scintillation light.
At Fermilab ICARUS is installed at shallow depth, thus exposed to a large flux of cosmic rays. If in time with the neutrino beam, a cosmic particle could determine an event trigger, and, eventually, it could mimic a neutrino interaction.
The expected rate of cosmics and neutrinos is:

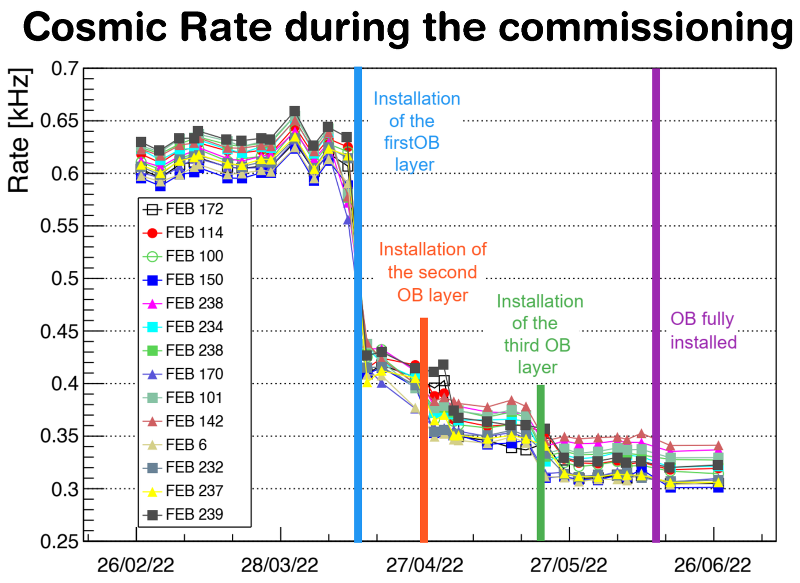
- 1 ν every 180 / 53 spills for BNB (1.6 μs) / NuMI (9.6 μs);
- 1 cosmic μ every 55 / 6 spills for BNB (1.6 μs) / NuMI (9.6 μs).

To suppress the cosmogenic background, a 3m concrete shield layes above the detector. The surviving cosmic rays are identified by an external 4π coverage Cosmic Ray Tagger (CRT) system.

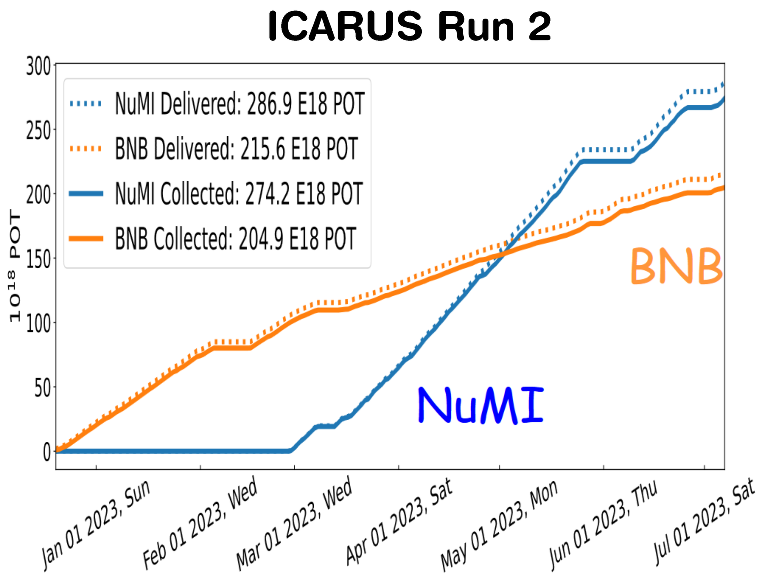


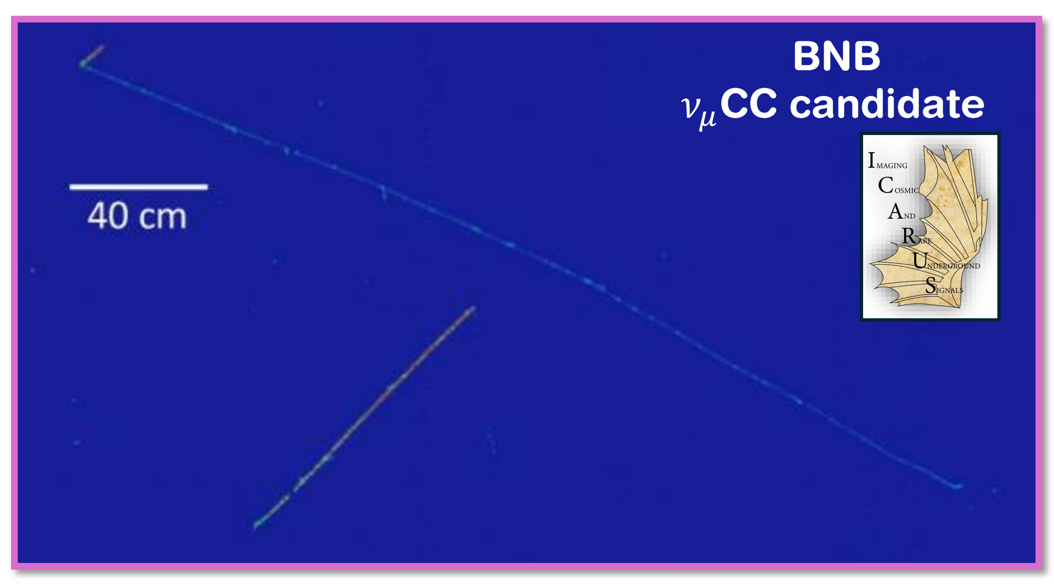
Following an overhauling at CERN, the ICARUS detector was shipped to Fermilab in summer 2017 and one year later it was installed in the detector hall. A newly designed cryogenic system was designed for the Fermilab operation and the detector began its commissioning phase in January 2020. The commissioning phase was concluded in June 2022, following the installation and commissioning of the CRT system and the deployment of the concrete shielding, and it set the start of the first ICARUS run (Run 1).
After the installation of the overburden, the cosmic rate effectively decreased to ~100 Hz/m^2 in agreement with the expected cosmic muon rate.
In the first 1 month-long run at Fermilab, ICARUS collected ~6.8 10^{19} Protons on target (POTs) for NuMI and ~4.1 10^{19} POTs for BNB.
During summer 2022 ICARUS started a long calibration campaign using cosmic rays and at the end of December 2022 Run 2 officialy started and it was concluded in July 2023.
Overall, including the combined statistics of Run 1 + Run 2 is of ~3.4 10^{20} POTs for NuMI and ~2.5 10^{20} POTs for BNB, corresponding to an extimated number of ~ 240k / ~ 408k neutrino interactions for BNB / NuMI.
Starting from spring 2024 ICARUS began the Run 3 data collection.

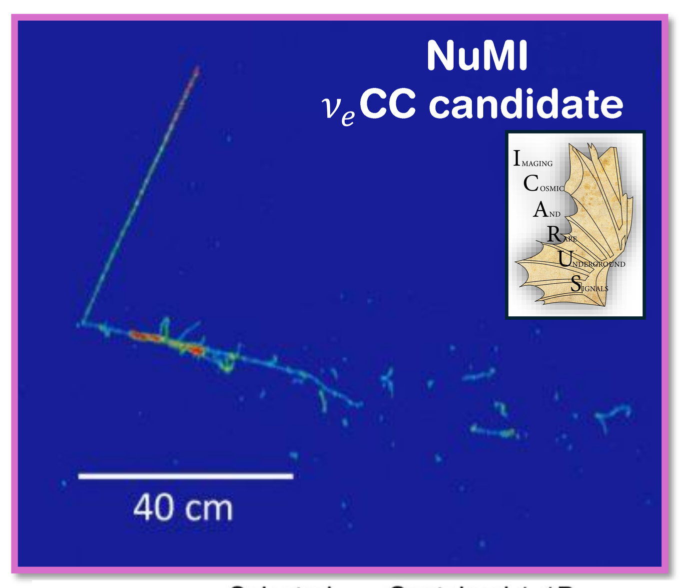
Cosmic Rate during the commissioning



ICARUS Run 2







Accurate measurements of the detector parameters (field response, electron recombination, diffusion and others) were performed to calibrate the calorimetric response and improve the particle identification.
ICARUS exploits automatic event selection by means both of a semi-analytical procedure using the Pandora reconstruction tools and using a Machine-Learning approach, these tools were validated with an event-scanning campaign
The first results are expected in 2024 and they will focus on BSM analysis, Cross-section measurements and an ICARUS-only oscillation analysis investigating the Neutrino-4-like claim. The first oscillation channel that ICARUS is focusing on is the ν_μ disappearance along the Booster Neutrino Beam selecting fully contained interactions with 1μ and 1/N protons in the final state.