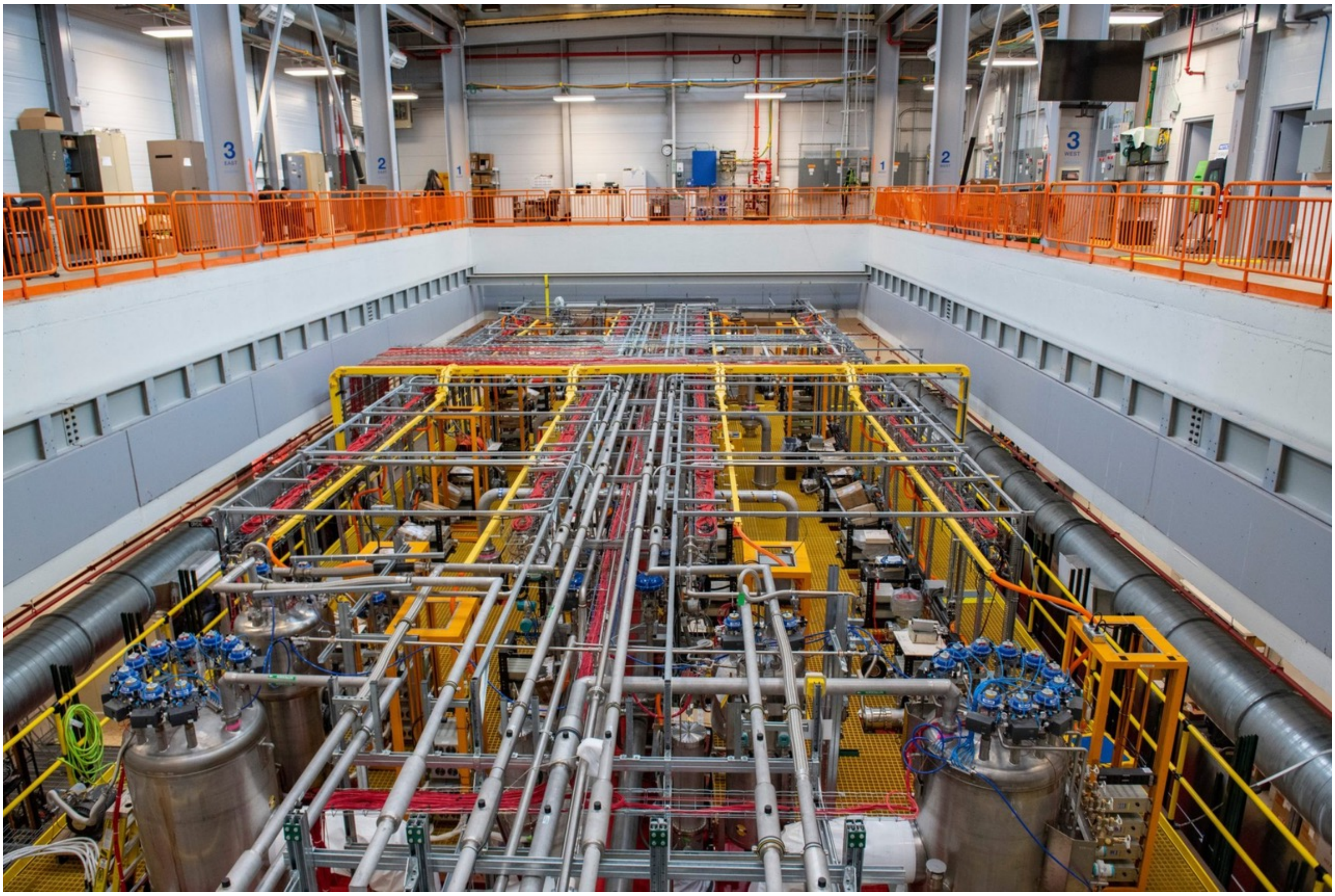
NEUTRINOS: THE FIRST ICARUS RESULTS AT FERMILAB

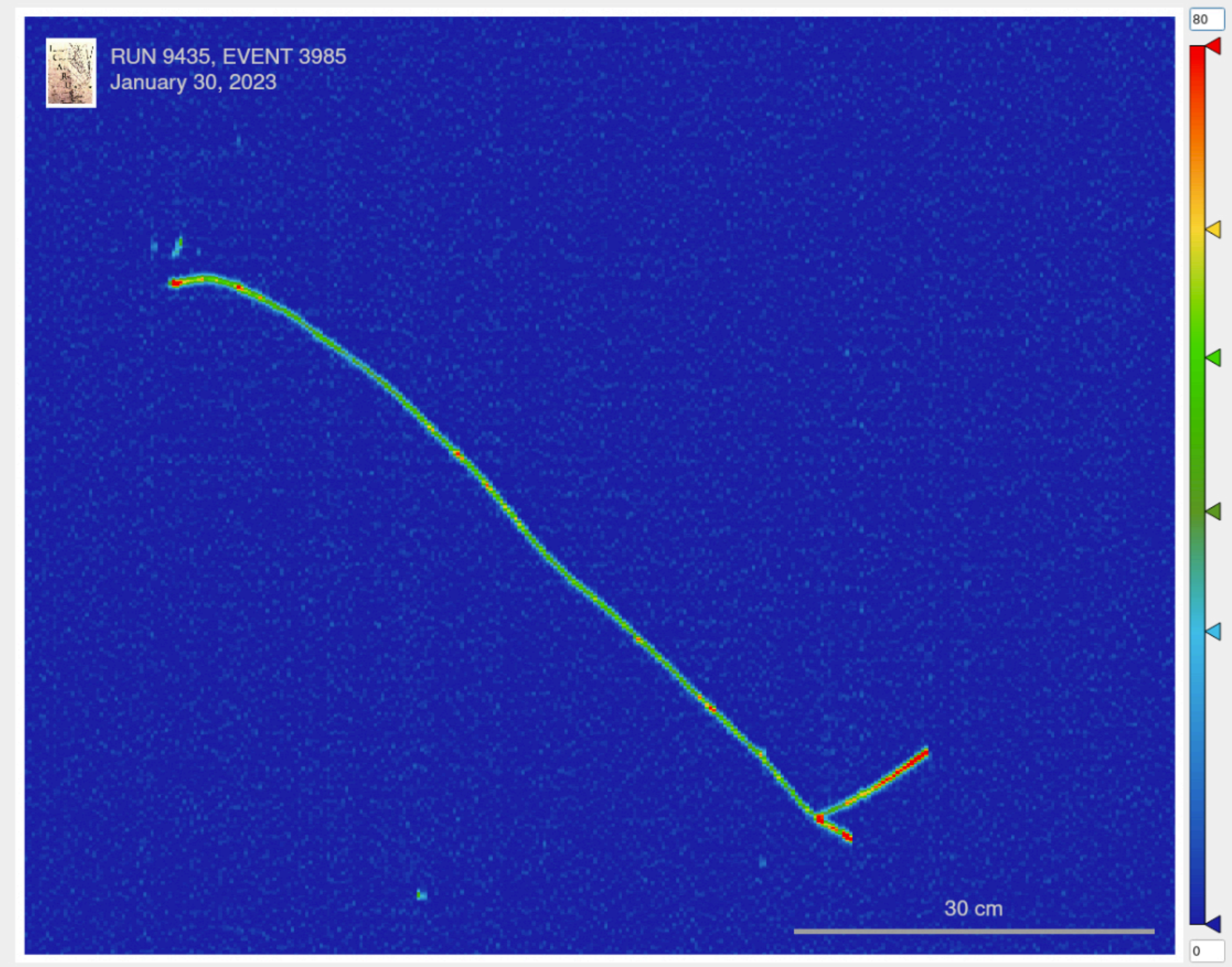
30 March 2026

The Collaboration of the ICARUS (Imaging Cosmic And Rare Underground Signals) experiment, led by Nobel Prize winner Carlo Rubbia, has presented the first results on neutrino oscillations in the Booster Neutrino Beam at Fermilab, in the United States, searching for a possible disappearance of muon neutrinos. The results are described in a scientific article made available on the ArXiv platform and submitted to the journal *Physical Review D* for publication. The analysis is based on data collected by ICARUS in the period 2022–2023, corresponding to about 2.05×10^{20} protons on target, and represents the first search for neutrino oscillations carried out by the ICARUS experiment since it has been operating at Fermilab.

ICARUS is a time projection chamber detector containing 760 tonnes of ultra-pure liquid argon, capable of visualising and reconstructing, with millimetre precision, the position of neutrino events by measuring the time taken by the signals produced by their interaction to reach the readout electrodes. After carrying out important research at the INFN Gran Sasso National Laboratories, and being upgraded at CERN, ICARUS has been taking data at Fermilab since 2020 as the farthest detector within the Short Baseline Neutrino (SBN) programme in the search for the “sterile neutrino”. It is currently the largest detector of this type in the world operating on a neutrino beam. Its distinctive features include the three-dimensional reconstruction of particle tracks with millimetre-scale resolution, the calorimetric measurement of the energy of electrons, muons and hadrons, and an excellent ability to distinguish between electrons and photons, which is fundamental for the identification of electron neutrinos.



L'immagine mostra una panoramica del grande rivelatore ad argon liquido ICARUS



L’immagine mostra l'interazione di un neutrino in argon liquido con la produzione di un muone e due protoni, registrata da ICARUS. La scala dei colori indica il deposito di energia di ciascuna particella

The analysis is based on the selection of events characterised by the presence of a muon, at least one proton and no pions, carried out using two automatic and independent event reconstruction approaches: Pandora and SPINE, the latter entirely based on artificial intelligence techniques. The two approaches achieved identification efficiencies for the possible signal of 48% and 78%, and purities of 82% and 91%, respectively. A thorough treatment of systematic uncertainties made it possible to accurately evaluate the neutrino flux of the Booster Neutrino Beam, neutrino interactions in liquid argon and the detector’s performance.

The ICARUS Collaboration observed no statistically significant evidence of muon neutrino disappearance in the energy spectrum of charged-current interactions. Exclusion curves were therefore derived at a 90% confidence level. In practice, these curves indicate which values of certain characteristic physical parameters – the difference between the squares of the masses of the neutrinos involved and the amplitude of the oscillation probability of muon neutrinos – are not compatible with the observed data. The contour of the experimental results obtained by the experiment lies almost entirely within the expected sensitivity region, within about one and a half standard deviations, thus in good agreement with expectations.

Despite the limitations inherent in a muon neutrino disappearance analysis conducted with a single detector, these first results represent a fundamental milestone for the Short-Baseline Neutrino programme. They demonstrate the high quality of the data collected with ICARUS and the full suitability of the detector for precision physics analyses, as well as the maturity of the software tools for event selection, statistical analysis and detector simulation.

The results obtained, together with joint operation with the near detector SBND – exposed to the same neutrino beam but at a shorter distance from the source – pave the way for a robust and internationally competitive two-detector combined analysis. The success of this measurement demonstrates the validity and experimental effectiveness of the liquid argon technique that underpins the future DUNE experiment.