PROCEEDINGS OF SCIENCE
ONLINE ICRC 2021
THE ASTROPARTICLE PHYSICS CONFERENCE
Berlin | Germany
37th International Cosmic Ray Conference
12–23 July 2021

ICARUS: new voyage to sterile neutrino search in the Short Baseline Program

Umut Kose[a,*] **on behalf of the ICARUS Collaboration**
(a complete list of authors can be found at the end of the proceedings)

[a] *European Organization for Nuclear Research (CERN), 1211 Geneva 23, Switzerland*
E-mail: `umut.kose@cern.ch`

The ICARUS collaboration operated the 760-ton T600 detector in a successful three-year physics run at the underground LNGS laboratories studying neutrino oscillations with the CNGS neutrino beam from CERN, and searching for atmospheric neutrino interactions. ICARUS performed a sensitive search for LSND-like anomalous ν_e appearance in the CNGS beam, which contributed to the constraints on the allowed parameters to a narrow region around $\Delta m^2 = 1\ eV^2$, where all the experimental results can be coherently accommodated at 90% C.L. After a significant overhaul at CERN, the T600 detector has been installed at Fermilab. In 2020 cryogenic commissioning began with detector cool down, liquid Argon filling and recirculation. ICARUS has started operations and is presently in its commissioning phase with the aim of collecting its first neutrino events from the Booster Neutrino Beam and the NuMI off-axis beam. The main goal of the first year of ICARUS data taking will then be the definitive verification of the recent claim by NEUTRINO-4 short baseline reactor experiment both in the ν_μ channel with the BNB and in the ν_e with NuMI. After the first year of operations, ICARUS will commence its search for evidence of a sterile neutrino jointly with the SBND near detector, within the Short Baseline Neutrino (SBN) program. The ICARUS exposure to the NuMI beam will also give the possibility for other physics studies such as light dark matter searches and neutrino-Argon cross section measurements. The proposed contribution addresses ICARUS achievements, its status and plans for the new run at Fermilab and the ongoing developments of the analysis tools needed to fulfill its physics program.

37th International Cosmic Ray Conference (ICRC 2021)
July 12th – 23rd, 2021
Online – Berlin, Germany

---

[*] Presenter

1. Introduction

The Liquid Argon (LAr) Time Projection Chamber (TPC) is a continuously-sensitive and self-triggering detector, characterized by high granularity and spatial resolution, providing 3D imaging of tracks of charged particles, through the collection of ionization electrons drifting in highly-purified LAr. Moreover, the associated scintillation light in LAr provides a fast timing and triggering information. In addition, it is potentially scalable to huge masses (several kton). First proposed by C. Rubbia in 1977 [1], this detection technique allows to study neutrino interactions and to search for rare and new physics phenomenon.

After many years of R&D studies with prototypes of increasing in size, the ICARUS collaboration has pioneered and developed the LAr-TPC concept. This effort has been culminated in the successful assembly and operation of the ICARUS T600 with a total mass of 760 tons at Laboratori Nazionali del Gran Sasso underground laboratory, LNGS, to study neutrinos from CNGS beam and cosmics.

The ICARUS T600 detector consists of a large cryostat split into two identical, adjacent modules with an internal dimensions of $3.6\times3.9\times19.6$ m^3, which are filled with an active mass of 460 tons of ultrapure liquid argon. Each module is equipped with two TPCs made of three parallel wire planes, 3 mm apart, the first with horizontal wires and the other two at $\pm60^\circ$ from the horizontal direction. By appropriate voltage biasing, the first two planes facing toward the drift region, called induction planes, provide signals in a non-destructive way, and the charge is collected in the last wire plane, called collection view. The two TPCs in each module are separated by a common cathode, and the maximum drift distance is about 1.5 m, equivalent to $\sim$ 1 ms drift time for the nominal electric drift field of 500 V/cm. Each module is equipped with 8-inch diameter Hamamatsu R5912-MOD photomultiplier tubes (PMTs) placed outside of the anode planes, and used to detect the prompt LAr scintillation light for the purpose of event triggering and absolute timestamp of the event. A thorough description of the detector can be found in [2].

2. ICARUS at LNGS

The ICARUS detector took data for about 3 years at LNGS, exposed to the CERN Neutrino to Gran Sasso (CNGS) beam in the energy range of 10-30 GeV, collecting about 3000 neutrino events corresponding to 8.6×10^{19} protons on target (pot) and to cosmic rays, with recording efficiency exceeding $\sim$ 93%. Through accumulated events, the high level performances and the physical potentialities of LAr-TPC technique have been demonstrated: the achievement of high efficient electron/gamma separation and the remarkable particle identification capability by exploiting the measurement of dE/dx versus range [3]. This unique feature of LAr-TPC is an asset for efficient identification of ν_e Charged Current (CC) events while rejecting the Neutral Current (NC) backgrounds. Moreover the momentum of escaping muons has been measured by studying the multiple Coulomb scattering (MCS) along the muon track providing an average resolution $\Delta p/p \sim 15\%$ in 0.4 to 4 GeV/c energy range, which is relevant to to the next generation neutrino experiments [4].

From the technological point of view, an average electron lifetime better than 7 ms and a maximum value of 16 ms which translates into an impurity concentration lower than 20 parts per trillions of O_2 equivalent are achieved by adapting LAr purification system based on comercial

Hydrosorb/Oxysorb^{TM} filters [5]. This result demonstrates the effectiveness of single phase LAr-TPC detectors paving the way towards the construction of new generation of multi-kton sized detector with even longer drift distances.

Thanks to the tiny intrinsic ν_e and $\bar{\nu}_e$ (below 1%) compared to the ν_μ component in the CNGS neutrino beam, ICARUS could perform a sensitive search for a possible ν_e excess related to the short baseline anomalies. ICARUS analyzed 2650 CNGS neutrino interaction from 7.9×10^{19} pot sample. No excess was observed [6]. ICARUS could constrain the allowed region parameters to a narrow region around $sin^2 2\theta_{new} \sim 0.005$ and $\Delta m^2_{new} \sim 0.5\ e\mathrm{V}^2$ at 90% CL which definitely deserves further investigations.

3. Short Baseline Neutrino program at Fermilab

The anomalies at the short baseline with L/E~ 1m/MeV, across very different neutrino sources and energy ranges, cannot be explained in the standard three flavour picture. These anomalies could be described by the oscillation of an additional sterile neutrino state with a mass splitting of the order of $\sim 1\ e\mathrm{V}^2$ and small mixing angle. Moreover, the global fit of short baseline neutrino oscillation data in the framework of mixing schemes with one or more sterile neutrinos indicates strong tension between appearance and disappearance short-baseline neutrino oscillation experiments [7].

The Short Baseline Neutrino (SBN) [8] program is being developed at Fermilab in order to provide a definitive clarification to the sterile neutrino puzzle. The SBN program is exploiting three LAr-TPC detectors located at different location from the target along the Booster Neutrino Beam (BNB, average E_ν ~800 MeV): SBND acting as *near detector*, with 112 tons active volume, at 110 m from the target, MicroBooNE as *intermediate detector*, with 89 tons active volume, at 470 m, and ICARUS as *far detector*, with 476 tons active volume, at 600 m. The used detection technique provides an unambiguous identification of the neutrino interactions, the measurement of their energy and a strong mitigation of the possible sources of background. In addition, the multi-detector configuration allows simultaneous observation of neutrino interaction at difference distances, by independently measuring both ν_e appearance and ν_μ disappearance oscillation channels. The oscillation signal will be identified by observing any variation on the spectra at the different detectors.

The experimental condition in SBN is more challenging with respect to the deep underground conditions of the LNGS laboratory. Given the relatively shallow depth of the detector, protected only by a 3 m concrete overburden, the continuous flux of cosmic ray particles crossing active volumes introduces a constant background falsely identified as part of the event of interest. About 11 cosmic muons are expected to cross detector randomly in each drift time window and be superimposed to every neutrino interactions. In addition photons associated to cosmic muons could represent a serious source of background to ν_e appearance searches, since electrons produced in LAr via Compton scattering or by the pair production process can mimic a genuine ν_eCC interaction. In order to effectively identify the events associated to the neutrino beam and handle the expected cosmic background, a threshold of 100 MeV of deposited energy, a time resolution of the order of ~1 ns and a high granularity are required.

In order to prepare the detector to its new journey at the SBN, the ICARUS T600 detector has been transported to CERN in December 2014 for a significant overhauling process in order to

Figure 1: Left: ICARUS TPC module, PMTs can ben seen behind the wire planes; Middle: ICARUS cryostats installation at Fermilab; Right: ICARUS detector after complete installations

introduce new technological developments while maintaining the already achieved performances.

4. ICARUS overhauling

ICARUS overhauling activities took place at CERN in the framework of CERN Neutrino Platform: new cold vessels and a purely passive insulation were installed; the cathode panels were flattened, reducing the non-planarity to a few mm; the cryogenics and LAr purification system were refurbished; an improved scintillation light detection system was installed; a new, fast, higher performance readout electronic was developed.

The ICARUS overhauling process has been concluded in June 2017 with the installation of the TPC modules into newly constructed cold vessels. The two modules have been transported to Fermilab and safely arrived at the far site of the SBN program on July 2017. Modules were placed inside the warm vessel in August 2018, Figure 1-middle. Installation of the TPC and PMT feed-through flanges and connectivity tests were completed in February 2019. The detector installation has been completed at the beginning of 2020 (Figure 1-right) and between February and April the detector filled with liquid argon and gas recirculation have been activated in order to purify the argon.

4.1 ICARUS photon detection system

The new light collection system [9] exploits 360 new 8" Hamamatsu R5912-MOD photomultipliers, installed behind the TPC wire planes (90 PMTs in each TPC, see Figure 1-left) to detect the prompt argon scintillation light, at vacuum ultraviolet, $\lambda = 128$ nm. Each PMT's outer surface is coated with Tetra-Phenyl Butadiene (TPB)-a wavelength shifter that converts argon scintillation light into photons in the visible wavelength. This light is produced instantaneously at the charged particle entry into active LAr volume or at the production of charged particles from any type of interactions in the LAr volume. It will allow to precisely identify the time of occurrence (t0) of any ionizing event in the ICARUS TPCs, determine the rough event topology for selection purposes and generate a trigger signal for read-out. The PMTs gain equalization and timing are performed by 405 nm laser pulses flashing the PMTs via a fiber system.

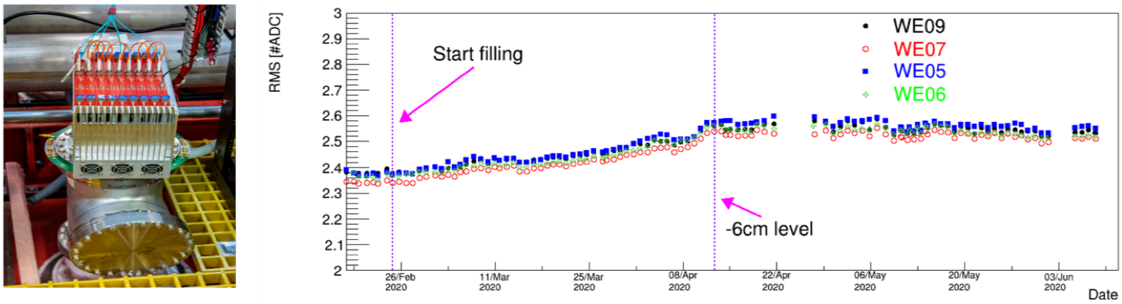

Figure 2: Left: A mini-crate populated by the nine readout electronic boards mounted on a feed-through flange, Right: Variation of the noise level during the filling with liquid argon (1 ADC~550 electrons). The noise has been measured in one of the TPC read-out electronics mini-crates and has been evaluated removing the coherent noise component, common to each group of 32 channels.

The new system provides sensitivity to low energy events (100 MeV), good spatial resolution (50 cm) and ~1 ns timing resolution, allowing to effectively identify the events associated to neutrino beams and to measure the time of the occurrence of each cosmic interaction crossing the detector.

4.2 Readout electronics

The new readout electronics designed for the ICARUS-T600 for shallow depth operation at Fermilab improves the performance of the system and drastically reduces costs and volume by using new, more advanced components [10]. This includes a new design of the analogue front-end, a serial 12 bit ADC system (one per channel) and serial bus architecture with optical links for Gigabit/s data transmission. The new analogue front-end adopts a ~1.5 μs fast signal shaping time to match the electron transit time in the wire spacing, prevents the signal undershoot as well as reducing the low frequency noise while maintaining a same or better S/N ratio. New readout system allows in unprecedented image sharpness of the events, with a better hit signal separation even in crowded and complex events like electromagnetic showers, both in collection and induction views. In addition, the full 400 ns synchronous signal sampling on the whole detector allows to slightly improve the resolution on the muon momentum by multiple Columb scattering, MCS.

Finally, a new compact "*mini crate*" mounted onto the feed-through flange designed to hold nine electronics boards, serving 576 channels, for the transmission of the TPC wire signals, Figure 2-left. During the liquid argon filling period ten mini-crates for the TPC readout electronics have been continuously recorded to monitor the noise conditions. As shown in Figure 2-right, a steady increase of the noise level has been observed, in agreement with the expected variation of the wire capacitance due to the increase of the level of liquid argon inside the TPC.

4.3 Cosmic Ray Tagger system

As discussed in section 3, due to the shallow depth of the detectors' location at SBN, they are continuously exposed to a flux of background cosmic ray particles. A high energy cosmic ray muon crossing the reconstructed volume can be misidentified as part of the neutrino interaction. In order to mitigate this problem, ICARUS detector is being surrounded by an external (total area of ~1000 m^2 and coverage > 95%), nearly 4π segmented Cosmic Ray tagging system composed by 3 subsystems:

Bottom, Side and Top CRT systems; each made of two layers of plastic scintillators with 98% of detector coverage. The bottom and side CRT modules were recovered from Double CHOOZ and MINOS, respectively. Both subsystems were installed and activated. Top CRT modules are newly constructed and the installation of the system will start in summer 2021, the whole system will be ready for first BNB neutrino run. This system will provide important information in particular on incident cosmic or beam induced muons by detecting the particles and measuring their crossing time and coordinates relative to events internal to the TPC. With a few ns resolution to be provided by the system will allow to measure the direction of incoming and outgoing particle via time of flight.

In addition, 3 m of concrete overburden directly above the pits will be placed right after Top CRT installation. This shielding will absorb more than 99% of the photon and hadron content of cosmic-ray showers hitting the experimental hall. The shielding and CRT will provide a powerful combination for cosmic-ray background mitigation that is essential to the physics goals of SBN.

5. BNB and NuMI beam: Run0

ICARUS can detect neutrinos from the two neutrino beams produced at Fermilab. The detector is exposed to on-axis flux from the BNB beam [11], at 600 m from target with an energy spectrum peaking at around 800 MeV, and to the 6° off-axis flux of neutrinos from the NuMI beam, at about 800 m from the target [12]. Neutrino beam data have been taken regularly since the end of March 2021 with minimum bias trigger, i.e. recording every beam spill. The collected data is being analyzed and used for tuning the event reconstruction software tool. In total 27.8$\times 10^{18}$ pot from Booster and 52$\times 10^{18}$ pot from NUMI are collected. After the summer shutdown, the first physics run will start in October 2021.

Exposed to both the BNB and NuMI neutrino beams at Fermilab, the ICARUS detector has recorded the first muon and electron neutrinos, demonstrating the high-level detection capabilities of the liquid-argon time projection chamber technique: Figure 3-left shows the first BNB ν_μCC quasi-elastic interaction recorded in ICARUS. Figure 3-middle shows a NuMI ν_μCC interaction. The use of additional views allows for recognizing the presence of two distinct electromagnetic showers pointing to the primary vertex as well as secondary interaction with gamma pointing to that. In this specific event a pion-muon-electron decay chain is also visible. Figure 3-right shows NuMI ν_eCC interaction. At the time of the collection BNB event, the electron lifetime was at the level of 1.2 ms while for NuMI sample shown above is 3.2 ms.

6. Initial physics search: The NEUTRINO-4 sterile neutrino puzzle

The claim of the observation of sterile neutrinos in the reactor Neutrino-4 experiment [13] shows an oscillatory pattern with a characteristic period of 1.4 m for E = 4 MeV neutrino energy and best fit parameters $\Delta m^2 = 7.25\ e\mathrm{V}^2$ and $sin^2 2\theta = 0.26$. The principle of muon-electron universality predicts equality between the ν_e and ν_μ mass matrix, so the ICARUS experiment could provide a definitive verification of Neutrino-4 result with sensitive disappearance tests in both ν_μ and ν_e channels.

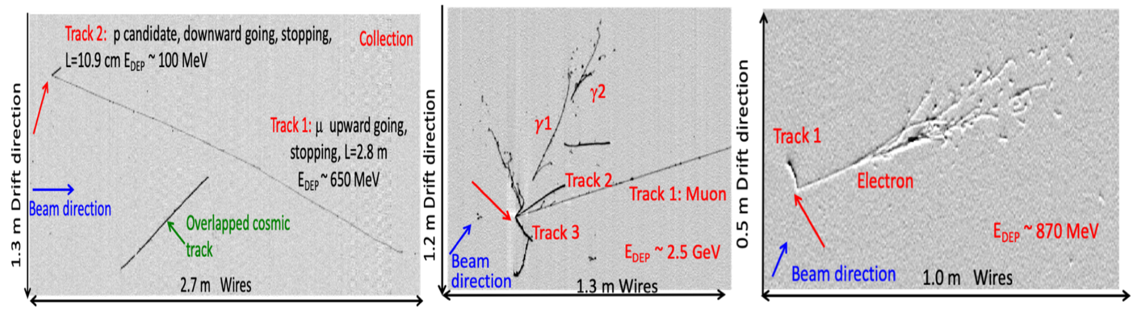

Figure 3: Left: BNB ν_μCC Quasielastic event; Middle: NuMI ν_μCC event; Right:NuMI ν_eCC event

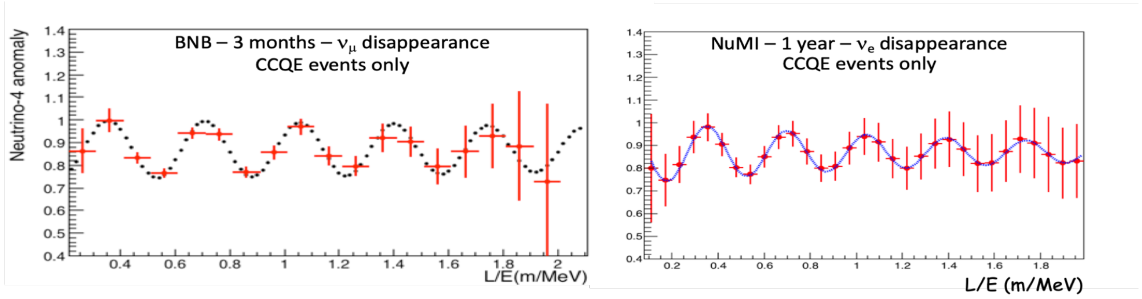

Figure 4: Left: Survival ν_μ oscillation probability for Neutrino-4 anomaly (black) for the best fit (Δm^2_{N4} = 7.25 eV^2, $sin^2 2\theta_{N4}$ = 0.26), and expected corresponding ICARUS measurement for 3 months of BNB (red). Right: Survival ν_e oscillation probability for Neutrino-4 anomaly (black) for the best fit (Δm^2_{N4} = 7.25 eV^2, $sin^2 2\theta_{N4}$ = 0.26), and expected corresponding ICARUS measurement for 1 year of NuMI (red)

By using contained ν_μCC QE interaction with a condition of muon length exceeding 50 m for better muon identification and considering the detector energy resolution of 3% together with the current knowledge of the BNB neutrino flux, ICARUS can observe the Neutrino-4 L/E oscillation-like signal as a function of the neutrino energy, averaged over the 50 m of pion decay tunnel. Figure 4-left shows the survival oscillation probability in the presence of the Neutrino-4 anomaly, considering ~ 11500 ν_μCC events collected in 3 months of data taking at BNB. On the other hand, in the NuMI beam the primary source of the neutrinos at ICARUS are the kaons decaying close to the target, leading much larger contribution of the ν_e signal. By considering one year of data taking at NuMI, we expect to collect ~ 5200 ν_eCC interactions. In presence of the Neutrino-4 anamoly, the same modulation can be observed in NuMI data as well, Figure 4-right. A detailed discussion can be found in [14].

7. Conclusions

The ICARUS detector performed a successful three-years of neutrino run at LNGS, representing the state of the art of LAr-TPC technique and it marks a major milestone in the practical realization of future LAr detectors for neutrino physics and for the search of rare events. After an extensive overhauling phase at CERN, ICARUS detector has been transported to Fermilab to starts its new journey on sterile neutrino search as a far detector of the Short Baseline Neutrino program.

PoS(ICRC2021)1071

Installation of the detector was completed at the beginning of 2020. Both the detector and the cryogenic systems are running very steadily since then.

ICARUS is now exposed to both the BNB and 6°-off axis NuMI neutrino beams at Fermilab, and data are collected steadily with the full PMT and TPC systems, since March 2021. The collected data will allow to tune the event reconstruction software tools. The first physics run will start in October 2021.

References

[1] C. Rubbia, The Liquid Argon Time Projection Chamber: A New Concept for Neutrino Detector, CERN-EP/77-08 1977

[2] M. Antonello et al., (ICARUS Collaboration), Design, construction and tests of the ICARUS T600 detector, Nucl. Instrum. Methods Phys. Res. A 527 (2004) 329–410.

[3] M. Antonello et al., (ICARUS Collaboration), Precise 3D track reconstruction algorithm for the ICARUS T600 liquid argon time projection chamber detector, Advances in High Energy Physics 2013, 2013, 2013, 26082

[4] M. Antonello et al., (ICARUS Collaboration), Muon momentum measurement in ICARUS T600 LArTPC via multiple scattering in few-GeV range, JINST 2017, 12, P04010.

[5] M. Antonello et al., (ICARUS Collaboration), Operation and performance of the ICARUS T600 cryogenic plant at Gran Sasso underground Laboratory, JINST 2015, 10, 12004.

[6] M. Antonello et al., (ICARUS Collaboration), Experimental search for the "LSND anomaly" with the ICARUS detector in the CNGS neutrino beam, Eur. Phys. J. C 2013, 73, 2345.

[7] C. Giunti, T. Lasserre, eV-Scale Sterile Neutrinos, Ann. Rev. Nucl. Part. Sci. 2019, 69, 163-190.

[8] R. Acciarri et al. A Proposal for a Three Detector Short-Baseline Neutrino Oscillation Program in the Fermilab Booster Neutrino Beam, arXiv:1503.01520 (2015).

[9] B. Ali-Mohammadzadeh et al. Design and implementation of the new scintillation light detection system of ICARUS T600, JINST 2020, 15, T10007.

[10] L. Bagby et al., New read-out electronics for ICARUS-T600 liquid Argon TPC. Description, simulation and tests of the new front-end and ADC system, JINST 2018, 13, P12007.

[11] A. A. Aguilar-Arevalo et al. (MiniBooNE Collaboration), Neutrino flux prediction at MiniBooNE, Phys. Rev. D 79, 072002

[12] P. Adamson et al., The NuMI Neutrino beam, Nucl. Instrum. Meth. A 806 (2016) 279-306.

[13] A. Serebrov, Analysis of the Results of the Neutrino-4 Experiment on the Search for the Sterile Neutrino and Comparison with Results of Other Experiments, JETP Lett. 112 (2020) 4.

[14] C. Rubbia, Experimental searches of neutrino anomalies, talk given in NEUTEL 2021: https://agenda.infn.it/event/24250/contributions/127395/

Full Authors List: ICARUS Collaboration

P. Abratenko[24], A. Aduszkiewicz[7], F. Akbar[20], J. Asaadi[23], M. Babicz[2], W.F. Badgett[6], L.F. Bagby[6], B. Behera[5], V. Bellini[9], O. Beltramello[2], R. Benocci[15], J. Berger[5], S. Berkman[6], S. Bertolucci[8], M. Betancourt[6], S. Biagi[13], K. Biery[6], M. Bonesini[15], T. Boone[5], B. Bottino[10], A. Braggiotti[17], J. Bremer[2], S. Brice[6], C. Brizzolari[15], J. Brown[6], H. Budd[20], M. Carneiro[1], H. Carranza[23], D. Casazza[10], A. Castro[3], S. Centro[17], G. Cerati[6], M. Chalifour[2], A. Chatterjee[19], D. Cherdack[7], S. Cherubini[13], T. Coan[22] A. Cocco[16], M.R. Convery[21], S. Copello[10], A. De Roeck[2], L. Di Noto[10], C. Di Stefano[13], M. Diwan[1], S. Dolan[2], L. Domine[21], R. Doubnik[6], F. Drielsma[21], J. Dyer[5], S. Dytman[19], V. Fabbri[8], C. Fabre[2], A. Falcone[15], C. Farnese[17], A. Fava[6], A. Ferrari[14], F. Ferraro[10], N. Gallice[14], F. Garcia[21], M. Geynisman[6], D. Gibin[17], B. Gomez Cortes[19], W. Gu[1], M. Guerzoni[8], A. Guglielmi[17], S. Hahn[6], A. Heggestuen[5], C. Hilgenberg[5], B. Howard[6], R. Howell[20], J. Hrivnak[2], C. James[6], W. Jang[23], W. Ketchum[6], D.H. Koh[21], U. Kose[2], J. Larkin[1], G. Laurenti[8], G. Lukhanin[6], C. Marshall[20], S. Martynenko[1], N. Mauri[8], A. Mazzacane[6], K.S. McFarlan[20], D.P. Mendez[1], A. Menegolli[1]8, G. Meng[17], O.G. Miranda[3], D. Mladenov[2], N. Moggi[8], C. Montanari[6],[b], A. Montanari[8], M. Mooney[5], G. Moreno Granados[3], J. Mueller[5], D. Naples[19], M. Nessi[2], T. Nichols[6], S. Palestini[2], M. Pallavicini[10], V. Paolone[19], R. Papaleo[13], L. Pasqualini[8], L. Patrizii[8], G. Petrillo[21], C. Petta[9], V. Pia[8], F. Pietropaolo[2],[a], F. Poppi[8], M. Pozzato[8], A. Prosser[6], G. Putnam[4], X. Qian[1], A. Rappoldi[1]8, G.L. Raselli[1]8, R. Rechenmacher[6], F. Resnati[2], G. Riccobene[13], L. Rice[19], A. Rigamonti[2], M. Rosenberg[19], M. Rossella[1]8, C. Rubbia[11], P. Sala[14], P. Sapienza[13], G. Savage[6], A. Scaramelli[1]8, A. Scarpelli[1], D. Schmitz[4], A. Schukraft[6], F. Sergiampietri[2], G. Sirri[8], J. Smedley[20], A. Soha[6], M. Spanu[15], L. Stanco[17], J. Stewart[1], H. Su[19], N.B. Suarez[19], C. Sutera[9], H. Tanaka[21], M. Tenti[8], K. Terao[21], F. Terranova[15], D. Torretta[6], M. Torti[15], F. Tortorici[9], Y.T. Tsai[21], S. Tufanli[2], T. Usher[21], F. Varanini[17], S. Ventura[17], C. Vignoli[12], M. Vincenzi[10], B. Viren[1], D. Warner[5], Z. Williams[23], R.J. Wilson[5], P. Wilson[6], J. Wolfs[20], T. Wongjirad[24], A. Wood[7], E. Worcester[1], M. Worcester[1], M. Wospakrik[6], H. Yu[1], J. Yu[23], A. Zani[14], J. Zennamo[6], J. Zettlemoyer[6], C. Zhang[1], S. Zucchelli[8], M. Zuckerbrot[6]

[1]Brookhaven National Laboratory, USA. [2]CERN, Switzerland. [3]Centro de Investigacion y de Estudios Avanzados del IPN, Mexico. [4]University of Chicago, USA. [5]Colorado State University, USA. [6]Fermi National Accelerator Laboratory, USA. [7]University of Houston, USA. [8]INFN Sezione di Bologna and University, Bologna, Italy. [9]INFN Sezione di Catania and University, Catania, Italy. [10]INFN Sezione di Genova and University, Genova, Italy. [11]INFN GSSI, L'Aquila, Italy. [12]INFN LNGS, Assergi (AQ), Italy. [13]INFN LNS, Catania, Italy. [14]INFN Sezione di Milano, Milano, Italy. [15]INFN Sezione di Milano Bicocca, Milano, Italy. [16]INFN Sezione di Napoli, Napoli, Italy. [17]INFN Sezione di Padova and University, Padova, Italy. [18]INFN Sezione di Pavia and University, Pavia, Italy. [19]University of Pittsburgh, USA. [20]University of Rochester, USA. [21]SLAC National Accelerator Laboratory, USA. [22]Southern Methodist University, USA. [23]University of Texas at Arlington, USA. [24]Tufts University, USA. [a]CERN, on leave of absence from Padova. [b]Fermilab, on leave of absence from Pavia.