1. Introduction

The ICARUS-T600 detector, with about 500 ton of sensitive mass, is the largest LAr TPC ever constructed representing the state of the art for this detection technology. ICARUS concluded in June 2013 a very successful, long duration run with the T600 detector at the LNGS underground laboratory taking data both with both the CNGS neutrino beam and cosmic rays. The successful, continuous, long-term operation of the ICARUS T600 detector has conclusively demonstrated that the single phase LAr-TPC \cite{1,2} is the leading technology for the future short and long baseline accelerator driven neutrino physics. This achievement was made possible by the long and continuing efforts of the ICARUS Collaboration and by the support of INFN, which allowed bringing the LAr TPC technology to full maturity.

Relevant physics and technical results were achieved during the three years long run at CNGS, demonstrating the excellent detection performance as tracking device with \~1 mm$^3$ spatial resolution and as homogenous calorimeter measuring the total energy with excellent accuracy for contained events. The detector demonstrated remarkable features in e/$\gamma$ separation and particle identification exploiting the measurement of dE/dx vs. range. The capabilities to reconstruct the neutrino interaction vertex, to identify and measure e.m. showers generated by primary electrons and to accurately measure invariant mass of photon pairs allow to reject to unprecedented level NC background in the study of $\nu_\mu \rightarrow \nu_e$ transitions. Momentum of non-contained muons can be determined via multiple Coulomb scattering with $\Delta p/p \sim 15\%$ in the 0.4–4 GeV/c range.

The solutions adopted for the argon recirculation and purification systems in ICARUS have permitted to reach an extremely low electronegative impurity content in LAr as required to drift the free electrons created by ionizing particles with very small attenuation. A content less than 20 parts per trillion of O$_2$-equivalent contamination corresponding to a free electron lifetime exceeding 16 ms has been measured in the T600 \cite{P2}. This represents a milestone for
any future project involving higher mass scales LAr-TPCs where electron drift paths of several meters are required.

ICARUS performed a sensitive search for $\nu_e$ excess related to a LSND-like anomaly on the $\nu_\mu$ CNGS beam ($\sim 1\%$ intrinsic $\nu_e$ contamination, $L/E_{\nu} \sim 36.5$ m/MeV) providing the limit on the oscillation probability $P(\nu_\mu \to \nu_e) \leq 3.85 \times 10^{-3}$ at 90\% CL with the $7.23 \times 10^{19}$ pot analyzed event sample, as presented at Neutrino 2014 and to the CXIV meeting of SPSC [5]. The ICARUS result [3][4] indicates a very narrow region of the parameter space ($\Delta m^2 \approx 0.5$ eV$^2$, $\sin^2 2\theta \approx 0.005$) where all experimental results can be accommodated at 90\% CL, calling for an ultimate experiment to investigate the neutrino anomalies observed at accelerators, nuclear reactors and with radioactive sources used in the calibration of solar neutrino experiments.

The processing and analysis of the collected data at LNGS with CNGS beam and cosmic rays is progressing. Presently about 92\% of the total collected CNGS sample has been scanned, filtered and reconstructed and is now available for the further steps in the analysis. Updates of the analyzed statistics of CNGS interactions and of cosmic events are presented as well as the observation of extremely high value of the ionization electrons lifetime, and progress in the validation of the Coulomb multiple scattering algorithm for measuring muon momentum. Data reconstruction improvement

The next step will be an experiment [P4.] at the $\sim 0.8$ GeV FNAL Booster neutrino beam, proposed in the framework of the Short Baseline Neutrino Oscillation Program (SBN) at Fermilab as the definitive answer to the “sterile neutrino puzzle”. Three LAr-TPC detectors, i.e. SBND (82 ton active mass), MicroBooNE (89 ton) and ICARUS-T600 (476 ton) will be installed at 100 m, 470 m and 600 m from target respectively. The neutrino oscillations are searched for comparing the measured neutrino spectra at the far sites with the un-oscillated ones at the near site. The common Conceptual Design Report “A Proposal for a Three Detector Short-Baseline Neutrino Oscillation Program in the Fermilab Booster Neutrino Beam”, submitted to the FNAL-PAC in January 2015, underwent level 1 approval. At the same time ICARUS will also collect a large sample of $\nu_e$ CC events with the NUMI Off-Axis beam peaked at $\sim 2$ GeV, which will be an asset for the future long base-line LBNF project.

INFN and CERN have signed a Memorandum of Understanding for the WA104 project [7] at CERN dedicated to overhauling the T600 detector before its installation in the Booster neutrino beam at FNAL in 2017. The activity at CERN officially started after the arrival of the T600 detectors from LNGS and after the placement of the first T600 unit in the clean room, in December 2014. The overhauling activities on the first T600 unit are now proceeding timely and very efficiently, within the common INFN and CERN effort.

Six new US institutions ((Los Alamos National Laboratory, Colorado State University, SLAC, Univ. of Pittsburg, FNAL and Argonne National Laboratory organized as ICAR-US teams) have recently joined the ICARUS Collaboration to participate in the WA104/ICARUS overhauling phase as well as in the subsequent SBN experimental program at FNAL.

2. Update of the analyzed statistics of CNGS interactions in the T600

The CNGS data processing has been almost completed, bringing the total statistics to $7.93 \times 10^{19}$ pot out of the total $8.6 \times 10^{19}$ pot delivered by CERN and collected by the ICARUS detector during the 2010-2012 runs. In particular $\sim 0.94 \times 10^{19}$ pot, affected by a mismatch
between the trigger source information and the event tagging system, were recovered with an ad-hoc procedure (70% efficiency).

In total 2650 CNGS neutrino interactions have been identified in the scanning fiducial volume, consistent within 6% with MC predictions for the corresponding exposure, representing the most complete dataset for carrying out the neutrino disappearance study. The stability of the detector performance with time has also been checked (Figure 1): about 3.4 neutrino interactions and about 12 beam related muons per $10^{17}$ pot were recorded on average.

![Figure 1: Number of all collected neutrino interactions inside the fiducial volume (blue) and rock muons (red, divided by 2), normalized by pot statistics and trigger and DAQ efficiency, as a function of run time for the 2011 (left) and 2012 run (right): each point refers to the average over $10^{18}$ pot and only statistical errors are quoted.](image)

In the recovered event sample the additional electron neutrino event shown in Figure 2 has been identified. Figure 3 shows the evolution of dE/dx, across Collection view wires, from a single m.i.p. to an e.m. shower for this event. The total observed 7 electron-like events are consistent with the 8.4 events expected from intrinsic beam $\nu_e$ component and standard oscillations in the total analyzed sample.
3. Update of the cosmic event study

The ICARUS T600 detector collected, apart from the CNGS beam events, also cosmic ray data with a total exposure of 0.73 kt year. First results from the analysis of cosmic muons have been presented in the ICARUS SPSC 2014 report. Since then the analysis continued, doubling the studied sample statistics. The well-known Teramo anomaly, which reflects the variation of the Gran Sasso massif profile along different directions, is visible in the real data.

The events collected with the cosmic ray trigger were analyzed also aiming at the study of atmospheric neutrinos interactions. According the Monte Carlo calculations about 200 atmospheric neutrino interactions are expected for 0.73 kt year exposure [6]. An automatic classification procedure has been implemented and complemented by careful visual scanning to reject the cosmic muons and select the atmospheric neutrino interactions.
The automatic procedure includes: the rejection of empty events with a 20 MeV threshold on the deposited energy, making of clusters from hits, the 3D track and vertex reconstruction, the rejection of cosmic muons. An algorithm for automatic search of an interaction vertex allowed discarding "one proton" (1 isolated track) and to identify "multi-prong" event topologies for further analysis based on visual scanning by requiring:
1. 25 consecutive hits are the minimum track length required to define a track;
2. An angle smaller than 175° is required between two tracks;
3. At least 35 % of the hits within 100 mm distance from the vertex has to be assigned to identified tracks;
4. The drift coordinates of the reconstructed interaction vertex in different views agree to better than 20 mm.

The performance of the automatic selection has been verified with MC atmospheric neutrino events. The results are presented in Table 1. Crossing cosmic muons are automatically rejected with 92.5% efficiency, whereas only 5% of the atmospheric neutrinos signal is lost. The identification efficiency of the multi-prong interactions of ~41% for \( \nu_\mu \) CC, ~52% for \( \nu_e \) CC and ~15% for NC has been determined with the Monte Carlo events. Overall 70 ± 8 atmospheric neutrino events with at least two charged particles are expected in the full T600 exposure.

**Table 1: Monte Carlo expectations for 0.73 kt year exposure after the selection criteria. 197 atmospheric neutrino interactions are expected.**

<table>
<thead>
<tr>
<th></th>
<th>CC ( \nu_e )</th>
<th>CC ( \nu_e )</th>
<th>NC ( \nu )</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>72 ± 8</td>
<td>55 ± 7</td>
<td>70 ± 8</td>
<td>197 ± 14</td>
</tr>
<tr>
<td>Empty (&lt; 20 MeV) /cosmic ( \mu )</td>
<td>10 ± 1</td>
<td>8 ± 1</td>
<td>45 ± 6</td>
<td>63 ± 8</td>
</tr>
<tr>
<td>Multi-prong ( \nu ) candidate</td>
<td>30 ± 4</td>
<td>29 ± 4</td>
<td>11 ± 1</td>
<td>70 ± 8</td>
</tr>
<tr>
<td>One prong ( \nu ) candidate</td>
<td>32 ± 4</td>
<td>18 ± 3</td>
<td>14 ± 2</td>
<td>64 ± 8</td>
</tr>
</tbody>
</table>

So far, only data corresponding to 20 days of data taking have been completely analyzed, including the final time consuming visual scanning stage. In this analyzed sample 1.0 ± 0.4 muon-like, 1.0 ± 0.4 electron-like and 0.4 ± 0.2 NC-like atmospheric neutrino events are expected. The recorded out of spill event sample corresponding to 76781 triggers was filtered resulting in 5402 multi-prong neutrino event candidates to be visually studied. We have observed: 2, 0, and 2 event candidates in each of these categories, respectively. It should be noted that a residual neutron background, which could affect the NC-like events has not been addressed requiring a deeper dedicated analysis. Figure 4 shows a muon-like atmospheric neutrino event identified in the analysis, with a 124 cm length muon track exiting the detector, a charged particle (p or \( \pi \)) and \( \pi^0 \). The measured deposited energy is about 440 MeV (no correction for quenching applied).
5. Observation of an extremely high electron lifetime

One of the most important issues in the LAr TPC detection technique is the extremely low level of electronegative impurities, which is required to transport ionization electron over macroscopic distances with small signal attenuation. The electron lifetime $\tau$ in the ICARUS T600 LAr TPC has been measured using the attenuation $\lambda = 1/\tau$ of the charge signal, produced by cosmic-ray muon tracks traversing the detector volume, as a function of the electron drift distance. The charge signal was measured in the Collection plane (see Figure 6) removing noisy channels for selected clean (i.e. without associated electromagnetic showers or long delta electrons) and sufficiently long muon tracks with $> 100$ wires and $> 94$ cm length along the drift coordinate. The muon tracks used to determine the electron lifetime are selected amongst the $\sim 3100$ through going cosmic rays per day collected by ICARUS T600 detector at LNGS. The truncation method described in details in [P2.] was applied to each track to mitigate the asymmetric Landau tail of the dE/dx. The LAr purity time evolution in the T600 East module is

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**Figure 4:** A muon-like atmospheric neutrino event candidate, $E_{\text{dep}} = 440$ MeV recorded by the ICARUS T600 detector. Collection (left) and Induction 2 views (right) are shown. Both the exiting muon and the hadronic tracks are clearly visible. Converting $\gamma$'s are also recognized.

**Figure 5:** A contained NC atmospheric neutrino event candidate, $E_{\text{dep}} = 245$ MeV clearly recognized in Collection (larger figure) and Induction 2 (small insert) views. Two charged particles emerge from the interaction vertex: a 63 cm long pion track (interacting and generating two protons) and a not identified 23 cm long not stopping particle.
shown in Figure 7. Each data point was obtained averaging over about 100 muon tracks collected in about half a day.

\[ \text{Figure 6: Example of a track used for purity measurement extending over 776 wires and 2060 t-samples.} \]

In April 2013 the ACD CRYO pump used during the first 2 years of data taking was replaced with a new Barber Nichols BNCP-32C-000 pump with an external motor similar to those used in the liquid nitrogen recirculation. The electron lifetime \( \tau \) decreased rapidly to values below 1 ms during the two week period of pump replacement. With the Barber Nichols pump installed, \( \tau \) started to increase very rapidly reaching the value of \( 16.1^{+1.3}_{-1.1} \) ms corresponding to 6% maximum signal attenuation for the 1.5 m maximum drift distance. It should be noticed that at the end of the ICARUS T600 data taking \( \tau \) was still rising. The obtained free electron lifetime greater than 15 ms corresponds to a mean attenuation length of about 25 meters and represents a milestone for the next generation of LAr TPC detectors.

The uniformity of the electron lifetime over the large ICARUS detector volume was also verified with the use of about 1000 almost vertical cosmic muon tracks traversing the East cryostat, reconstructed in three dimensions. For each muon the difference \( \delta \lambda \) between the track attenuation \( \lambda_T \) and the average attenuation \( \lambda \) in the corresponding cryostat and event time was computed. The average \( \delta \lambda \) is plotted in Figure 8 as a function of the longitudinal position along the detector, demonstrating the uniformity of the LAr purity.
Figure 7: Electron lifetime $\tau$ of the East module for the last part of the ICARUS data taking: in red full points the measurements with the new pump with external motor are shown. The dashed vertical lines represent the stops and restart of the LAr recirculation (during these periods gaseous Ar recirculation system continued to operate).

Figure 8: The measured variation of the level of impurities in the East cryostat along the longitudinal direction. Red circles refer to the left chamber, blue stars to the right one. The dashed lines are the linear fits in both chambers. The fit results are amply compatible with a uniform LAr purity across the length of the whole detector: slope for the left chamber $(8.8 \pm 90) \cdot 10^{-5}$ ms$^{-1}$m$^{-1}$, slope for the right chamber $(2.7 \pm 11) \cdot 10^{-4}$ ms$^{-1}$m$^{-1}$.
6. Muon momentum from multiple scattering.

The measurement of the muon momentum in $\nu_\mu$ charged current events exploits the Multiple Coulomb Scattering (MCS) method for muons escaping the detector. Dedicated algorithms have been developed and validated on a sample of muons produced in CNGS neutrino interactions in the upstream rock at LNGS, and stopping in the T600 fiducial volume. The momentum of stopping muons can be measured calorimetrically and compared with the one measured from MCS. For the present analysis 415 single muon events with minimum track length of 2.5 m produced in the CNGS $\nu_\mu$ interactions with the T600 upstream rock were selected. The distribution of this stopping muon sample as a function of kinetic energy, obtained from the calorimetric measurement, and track length is presented in Figure 9.

![Figure 9: The distribution of stopping muons analysed in this work, as a function of their kinetic energy (bottom axis) and corresponding muon length (top axis).](image)

The last meter of each muon track was not used for the MCS measurement, in order to avoid bias from the final, low-energy part of the track, where MCS deflections are extremely large. Outlier hits, originating mainly from $\delta$-rays, have been removed from the track; they were identified relying on their large energy deposition on wires and looking for deviation from a Kalman fit of the muon track.

The MCS measurement was performed on the muon track projection on the two-dimensional Collection plane. A detailed estimation of all measurement errors has been performed to disentangle the genuine MCS effects from the apparent track deflections due to positional uncertainty. The coordinates of each 2D point are given by the wire position and drift time, which is the main source of uncertainty of the hit position measurement. The single-hit contribution was estimated by measuring the dispersion of the drift coordinate with respect to a sufficiently short (three consecutive hits) part of the track, to minimize the MCS contribution. The average value of hit position uncertainty on the drift coordinate resulted ~0.7 mm. An additional uncertainty term derived from the not-complete synchronization of electronic boards, which received the trigger signal within a 400 ns interval.

The measurement of the RMS multiple scattering angle $\phi_{\text{MCS}}$ over a track segment $L$ allows to determine muon momentum $p$ according to the following formula, which describes the Gaussian part of the angle distribution (large values of scattering angle are not included):
The deflection angles between consecutive segments along the muon track were measured, and from their distribution muon momentum was extracted. The observed deflection angles contain, in addition to MCS, also contributions from the single point space resolution, and from the board to board synchronization, which are equal to ~2 mrad and ~1 mrad, respectively, and are momentum independent.

A muon momentum measurement can be extracted from the comparison between the observed angle deflections between segments and the ones expected both from position uncertainty and MCS. The value $p_{\text{MCS}}$ resulting from this procedure is compared with the calorimetric estimate $p_{\text{CAL}}$ in Figure 10.

![Figure 10](image)

**Figure 10:** The distribution of $p_{\text{MCS}}/p_{\text{CAL}}$ ratio for the stopping muon sample (left) and $p_{\text{MCS}}/p_{\text{CAL}}$ ratio vs. $p_{\text{CAL}}$ (right) for $L_m=4$ m. The width of the $p_{\text{MCS}}/p_{\text{CAL}}$ ratio distribution, as estimated by a Gaussian fit, is ~15%.

The measured MCS momentum $p_{\text{MCS}}$ is in agreement with the corresponding calorimetric measurement $p_{\text{CAL}}$. A momentum resolution $\Delta p/p \sim 15\%$ for the MCS measurement (using the first 4 meters of muon tracks) has been estimated from a Gaussian fit to the $p_{\text{MCS}}/p_{\text{CAL}}$ ratio distribution. For larger values of the muon momentum, $p_{\text{MCS}}/p_{\text{CAL}}$ decreases, depending on the track distance from the cathode (see Figure 11). This bias derives from the non-perfect planarity of the TPC cathode, as measured during the inspection of the T600, which took place at CERN after the detector decommissioning. Deviations from planarity up to ~2.5 cm and extending over a few meters, were measured.
The observed trend of $p_{MCS}/p_{CAL}$ ratio has been approximately reproduced by introducing in the Monte Carlo simulation a sinusoidal cathode deformation with amplitude of 2.5 cm and ~4m period. In the on-going T600 overhauling, a cathode with a planarity better than few millimeters will allow to remove this bias, extending the MCS muon momentum measurement to energies exceeding ~7 GeV.

The dependency of the momentum resolution both on true momentum $p_{CAL}$ and on the track length used in the MCS momentum determination is shown in Figure 11. As expected, $\Delta p/p$ strongly improves for larger track lengths, due to the increase in the segment statistics used in the momentum calculation, and for lower values of muon momentum. In the ~1 GeV/c region, which is of interest to future short and long baseline neutrino experiments, a resolution close to 11% can be achieved for a muon track length of 4 m. The details of the analysis will be the subject of a new publication that is presently under Collaboration review [P3.].

Figure 12: The dependency of momentum resolution on calorimetric muon momentum for several values of muon track lengths $L_\mu$ used in the MCS momentum measurement.
7. Future perspectives: sterile neutrino search at Fermilab BNB.

The proposed SBN experiment at FermiLab Booster neutrino beam (BNB) will investigate the presence of sterile neutrinos as hinted by neutrino anomalies observed at accelerator neutrino beams, nuclear reactors and radioactive Mega sources in solar neutrino experiments.

The experiment will likely clarify both LSND/MiniBooNE and Gallex/reactor anomalies by precisely and independently measuring both $\nu_e$ appearance and $\nu_\mu$ disappearance, mutually linked through the relation: $\sin^2(2\theta_{\nu e\mu}) = \frac{1}{2} \sin^2(2\theta_{\mu\mu}) \sin^2(2\theta_{ee})$. In absence of “anomalies”, the three detector signals should be a closer copy of each other for all experimental signatures. Accurate studies and simulations demonstrate the possibility to cover the LSND anomaly parameter region with a five sigma CL exploiting the three LAr-TPC detectors (Figure 13) within three years data taking.

The intrinsic $\nu_e$ events with a disappearance signal (if f.i. confirmed by nuclear reactor measurements) may result in the reduction of a superimposed appearance LSND $\nu_e$ signal. These two effects can be disentangled by changing the intrinsic $\nu_e$ beam contamination with different beam-line optics (horn focusing and decay tunnel length). In the framework of one additional sterile neutrino (3+1 model), the most relevant and solid result is LSND, where $\sin^2 2\theta_{\nu e\mu} = 4|U_{e4}|^2|U_{\mu4}|^2 \approx 1.5 \times 10^{-3}$. If LSND is confirmed, both $\nu_e$ and $\nu_\mu$ disappearance are present, since $\sin^2 2\theta_{ee} = 4|U_{e4}|^2 (1-|U_{e4}|^2)$ and $\sin^2 2\theta_{\mu\mu} = 4|U_{\mu4}|^2 (1-|U_{\mu4}|^2)$. Present claims from nuclear reactor experiments seem to indicate $\sin^2 2\theta_{ee} \approx 0.12$, $|U_{e4}|^2 = 0.03$, while much looser experimental hints are available in the muon disappearance channel. For $\Delta m^2 < 0.5$ eV$^2$ the $\nu_\mu$ disappearance effect at 600 m will be limited at the lowest $\nu$ energy bins 0.2-0.4 GeV. In order to enhance the effect, at a later stage one ICARUS T300 module may be moved to 1500 m distance from target (Figure 14).

![Figure 13: Left: Expected exposure sensitivity of $\nu_\mu \leftrightarrow \nu_e$ oscillations for 3 years - 6.6 $10^{20}$ pot BNB positive focusing (6 years for MicroBooNE); Right: SBN $\nu_\mu$ disappearance sensitivity.](image-url)
Figure 14: Expected $\nu_\mu$ disappearance for $\Delta m^2 \approx 0.44$ eV$^2$ and $\sin^2 \theta_{\mu\mu} \approx 0.1$ at 600 m (left) and 1500 m (right) from target.

At shallow depth detector installation at FNAL several uncorrelated cosmic rays will occur in T600 during the 1 ms drift window readout at each triggering event. This represents a new problem compared to underground operation at LNGS since, in order to reconstruct the true position of each track, it is necessary to associate precisely the related timing of each element of the TPC image with respect to the trigger time. Moreover the photons associated with cosmic $\mu$ represent a serious background for the $\nu_e$ appearance search, since electrons generated in LAr via Compton scattering/pair production can mimic a $\nu_e$ CC signal.

To strongly mitigate the cosmogenic background, all the c-ray particles entering the detector must be unambiguously identified. This can be achieved by implementing a Cosmic Rays Tagging around the LAr active volume providing an external timing of each track to be combined with the TPC reconstructed image. The adoption of a muon tagging system with 95% detection efficiency of single muon hit could ensure 99% efficiency in c-rays identification in T600, relying on double crossing of muons (only 15% are expected to stop in LAr).

The WA104/ICARUS program is now firmly established through the Memorandum of Understanding between CERN and INFN [7]. This project is devoted at improving the ICARUS T600 Liquid Argon Time Projection Chamber (LAr TPC) in order to prepare for its operation at shallow neutrino depths, on a two years time schedule to be completed by end of 2016. Overhauling activities on T600 have already started according to the MoU planning, introducing technology developments while maintaining the already achieved performance:

1. new cold vessels and new purely passive insulation;
2. maintenance and partial reconstruction of the cryogenics and purification systems;
3. substitution of the TPC cathodes with better planarity;
4. installation of an improved scintillation light collection system;
5. new faster, higher-performance read-out electronics.

In parallel, the muon tagging system will be designed and constructed and fully automatic tools for event reconstruction will be developed. In addition, the ongoing analysis of the data collected during the ICARUS-T600 underground operation at LNGS will be beneficial for future exploitation of the T600 in the SBN experiment.

On a longer time scale the overhauled ICARUS T600 detector could also provide a convenient near detector for the next long baseline at LBNF neutrino beam (DUNE).
7 Conclusions.

The successful, continuous, long-term operation of the ICARUS T600 detector, 760 tons of LAr, with CNGS neutrino beam has conclusively demonstrated that the single-phase LAr-TPC is the leading technology for the future short and long baseline accelerator driven neutrino experiments. This achievement was made possible by the long and continuing efforts of the ICARUS Collaboration and to the support of INFN, which allowed bringing the LAr TPC technology to full maturity.

Relevant physics and technical results were achieved during the three years data taking. Data analysis of recorded CNGS neutrino interactions and atmospheric neutrinos is still progressing. The sensitive search for $\nu_e$ excess related to a LSND-like anomaly indicates a very narrow region of the parameter space where all experimental results can be accommodated, calling for a definitive experiment to investigate the several observed neutrino anomalies.

As the next step the ICARUS-T600 detector will be exposed to the ~ 0.8 GeV FNAL Booster neutrino beam in the framework of the Short Baseline Neutrino Oscillation Program (SBN) at Fermilab as the definitive answer to the “sterile neutrino puzzle”. The neutrino oscillations are searched for comparing the measured neutrino spectra with the un-oscillated ones at the near site. ICARUS will also collect a large sample of $\nu_e$ CC events with the ~ 2 GeV NUMI Off-Axis beam, which will be an asset for the future long base-line LBNF project. The Conceptual Design Report submitted to the FNAL-PAC in January 2015, underwent level 1 approval.

INFN and CERN have signed a Memorandum of Understanding for the WA104 project at CERN dedicated to overhauling the T600 detector before its installation in the Booster neutrino beam at FNAL. The detector has been decommissioned and transported to CERN in December 2014. The overhauling activities are now proceeding timely and very efficiently, within the common INFN and CERN effort.

Six new US institutions have recently joined the ICARUS Collaboration to participate in the WA104/ICARUS overhauling phase as well as in the subsequent SBL experimental program at FNAL.

List of Publications Year 2014


[P2.] M. Antonello et al. (ICARUS Collaboration), Experimental observation of an extremely high lifetime with the ICARUS T600 LAr TPC, JINST, 9:P12006 (2014).


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