

Status of ICARUS publications

ICARUS Collaboration Meeting

Fermilab (USA), October 16th 2024

A. Menegolli - University and INFN Pavia (Italy)

V. Paolone - University of Pittsburgh (USA)

Thanks a lot to all people providing information

[Link to SBN Committee Rules and Policies \(docdb 35334-v1\)](#)

ICARUS forthcoming technical notes and papers

- Data collected so far by ICARUS have been extensively analyzed in the last months to assess the performance of the TPC, PMT and CRT sub-detectors.
- A number of technical notes are now in preparation or already internally reviewed.
- Some technical works may be needed before the publication of papers focused on the data analysis and they have the priority (CRT, PMT timing, trigger).
- Today I will briefly introduce a few ICARUS activities which have been recently put into a technical note or which have been or are going to be submitted as technical notes or papers.

1. ICARUS cryogenics and purification systems

- Corresponding authors: M. Geynisman and C. Montanari (for the Cryogenics Group).
- Technical note submitted: [SBN Document 33913-v1](#)
- *“This paper describes the cryogenic and purification systems of the ICARUS T600 detector in its present implementation at the Fermi National Laboratory, Illinois, USA.”*
- Currently under internal review (L. Di Noto and A. Schukraft).
- Expected distribution to the Collaboration for review: end of 2024.

**Cryogenics and purification systems of the ICARUS T600 detector installation at Fermilab
FERMILAB-TM-2806-ND**

1. Authors and Institutions

Geynisman Michael^(a), Montanari Claudio^(a,c), Bremer Johan^(b), Chalfour Michel^(b), Doubnik Roza^(a), Fabre Caroline^(b), Nichols Trevor^(a), Pietropaolo Francesco^(b,d), Schwartz Frederick^(a), Vignoli Chiara^(a), Wilson Peter^(a), Zuckerbrot Michael^(a).

^(a) Fermi National Accelerator Laboratory, Batavia, IL 60510 United States

^(b) CERN, 1211 Geneva-23, Switzerland





^(c) Istituto Nazionale di Fisica Nucleare (INFN), Pavia, Italy

^(d) Istituto Nazionale di Fisica Nucleare (INFN), Padova, Italy

^(e) Istituto Nazionale di Fisica Nucleare (INFN), LNGS, Italy

2. Abstract

This paper describes the cryogenic and purification systems of the ICARUS T600 detector in its present implementation at the Fermi National Laboratory, Illinois, USA. The ICARUS T600 detector is made of four large Time Projection Chambers, installed in two separate containers of about 275 m³ each. The detector uses liquid argon both as target and as active media. For the correct operation of the detector, the liquid argon has to be kept in very stable thermal conditions and the contamination of electronegative impurities has to be consistently kept at the level of small fractions of parts per billion. The detector was previously operated in Italy, at the INFN Gran Sasso Underground laboratory, in a 4 years duration run on the CERN to LNGS Long Baseline Neutrino Beam. For its operation on the Booster and NuMI neutrino beams, at Fermilab, for the search of sterile neutrinos and measurements of neutrino-argon cross sections, the detector was moved from Gran Sasso to CERN for the upgrades required for operation at shallow depth with high intensity neutrino beams. The liquid argon containers, the thermal insulation and all the cryogenic equipment, have been completely re-designed and rebuild, following the schemes of the previous installation in Gran Sasso. The detector and all the equipment have been transported to Fermilab, where they have been installed, tested and recently put into operation. The work described in this paper has been conducted as a joint responsibility of CERN and Fermilab with the supervision provided by the Icarus Collaboration. Design, installation, testing, commissioning and operation is the result of a common effort of CERN, Fermilab and INFN Groups.

Technical Note	Internal Review	Collaboration Review	Submission to Journal
			

2. Design and Implementation of the CRT System

- Corresponding authors: M. Betancourt and L. Patrizii (for the CRT Working Group).
- CRT technical note was completed by the CRT working group. The note is intended for publication and was already internally reviewed by G.L Raselli and Thomas Coan.
- Collaboration review starting ~ today.
- An additional technical note, intended for internal ICARUS usage, will be written following the current one, to describe matching algorithms (CRT-PMT / CRT-TPC).

Design and Implementation of the Cosmic Ray Tagger System for the ICARUS detector at FNAL

A. Aduszkiewicz¹⁶, L. Bagby³, B. Behera^{*4}, P. Bernardini¹, S. Bertolucci², M. Betancourt³, H. Budd¹², T. Boone⁴, A. Campos¹⁴, D. Casazza⁵, V. Cicero², D. Cherdack¹⁶, T.E. Coan¹⁵, L. Degli Esposti², D. Di Ferdinando², L. Di Noto⁵, C. Guandalini², M. Guerzoni², A. Heggstuen⁴, C. Hilgenberg^{†4}, R. Howell¹², M. Iliescu⁶, G. Ingrassia², U. Kose⁷, G. Laurenti², C. Mariani¹⁴, N. Mauri², K.S. McFarland¹², E. Montagna², A. Montanari², N. Moggi², M. Murphy¹⁴, L. Pasqualini², V. Paolone¹³, L. Patrizii², G. Pellegrini², V. Pia², F. Poppi², M. Pozzato², A. Ruggeri², P. Sala⁸, P. Sapienza⁹, A. Schukraft³, G. Sirri², L. Stanco¹⁰, A. Surdo⁷, M. Tenti², V. Togo², N. Tosi², M. Vicenzi¹¹, R. J. Wilson⁴, and S. Zucchelli²

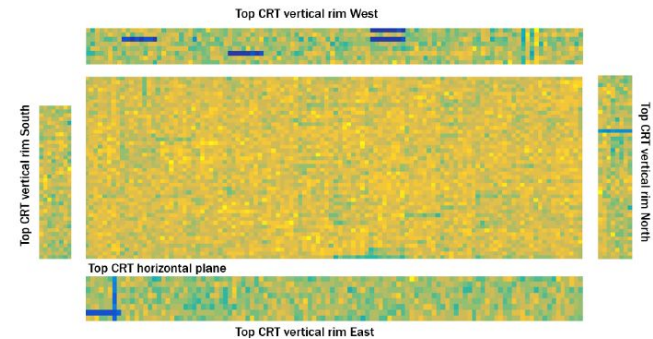


Figure 19: Distribution of the CRT Hits reconstructed in the different regions of the Top CRT. Blue regions correspond to malfunctioning channels.

Technical Note	Internal Review	Collaboration Review	Submission to Journal
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



3. Trigger system

- Corresponding authors: A. Guglielmi and G. Petrillo (for the Trigger Working group).
- A Trigger technical note is under development by the Trigger Working Group. The note is intended for publication and its draft is expected to be completed by the end of 2024.
- The note will cover the characterization of the trigger system deployed for the first ICARUS data taking for physics with BNB and NuMI neutrino beams (RUN1 and RUN2).

Operation of the Trigger System for the ICARUS Detector at Fermilab

Contents

1	Introduction	2
2	The ICARUS trigger system hardware setup	3
2.1	Accessing the proton accelerator signals	5
2.2	Readout of the PMT waveforms	6
2.3	Time synchronization	6
2.4	Acquiring data	8
3	Triggering possibilities	9
3.1	Trigger logic	9
3.2	Beam gates and trigger types	11
3.2.1	On-beam gates	11
3.2.2	Off-beam gates	11
3.2.3	Light-based triggers (Mj)	11
3.2.4	Calibration triggers	12
3.2.5	Trigger rates	12
4	Initial investigations of the ICARUS trigger efficiency	12
4.1	Data collected	12
4.2	Extracting the timing of the TPC tracks for efficiency measurements	12
4.2.1	Cathode-crossing tracks	13
4.2.2	Matching with the Cosmic Ray Tagger system	13
4.3	Trigger emulation	14
4.4	Analysis of the collected	15
4.5	Trigger efficiency measurements using cosmic rays	18
4.5.1	In-spill Trigger Efficiency	18
4.5.2	Out-of-spill Trigger Efficiency	20
4.5.3	Systematics on the trigger efficiency measurements	20
4.6	Additional trigger system implementation	21
5	Conclusions	21

Technical Note	Internal Review	Collaboration Review	Submission to Journal
			

4. MeVPrtl event generation





- Corresponding authors: J. Berger, A.Chatterjee, J. I. Crespo-Anadon, J. Dyer, R. Garrote, V. C. L. Nguyen, V. Paolone, L. Pelegrina-Gutierrez, G. Putnam
- Technical note submitted: [SBN Document 32019-v2](#)
- Ongoing ICARUS BSM analyses use MeVPrtl for Monte Carlo event generation, which has been developed by SBN collaborators for SBN.
- Modular structure accommodates searches with shared phenomenology, is configurable for any combination of **beam** (BNB/NuMI), **detector** (ICARUS/SBND), and **model** (currently Higgs Portal, Heavy Neutral Lepton, and Heavy QCD Axion).

MeVPrtl Event Generation

SBN Collaboration
Primary Authors:
J. Berger^a, J. I. Crespo-Anadón^b, J. Dyer^a, R. Garrote^b, V. C. L. Nguyen^c, V. Paolone^d, L. Pelegrina^e, and G. Putnam^f

^aColorado State University, Fort Collins, Colorado 80523, USA
^bCentro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT), Madrid E-28040, Spain
^cUniversity of Sheffield, Sheffield, UK
^dUniversity of Pittsburgh, Pittsburgh, PA, 15260, USA
^eUniversidad de Granada, Granada E-18071, Spain
^fEnrico Fermi Institute, University of Chicago, Chicago, IL, 60637, USA

The generator is located at:
<https://github.com/SBNSoftware/sbncode/tree/develop/sbncode/EventGenerator/MeVPrtl>

Technical Note	Internal Review	Collaboration Review	Submission to Journal
			

5. Prediction of NuMI electron and muon ν flux in ICARUS

- Corresponding authors: [A. Aduszkiewicz, D. Cherdack and A. Wood](#)
- First technical note submitted: [SBN Document 27384-v4](#)
- Flux at 5.75° off axis required detailed study.

Much work was done to:

- Put ICARUS in the NuMI coordinate system
 - Study: Had. Prod. (HP) chains for ICARUS ν 's
 - Evaluate the systematic uncertainties
 - Creating analysis data products and public plots
- Addendum to the technical note in preparation.

Prediction of NuMI electron and muon neutrino flux in ICARUS





D. Cherdack, A. Aduszkiewicz, A. Wood

Department of Physics, The University of Houston, Houston, Texas 77204, USA

August 30, 2023

Abstract

The NuMI neutrino flux prediction for ICARUS is extracted using Package to Predict the Flux (PPFX). Systematic effects on the flux due to modeling of the beamline and hadronic interactions are studied. Validity of the simulation's uncertainty characterization for high off-axis angles is evaluated, and potential avenues for improving the prediction and reducing the uncertainties are identified. The predicted electron and muon (anti-)neutrino flux for both forward and reverse horn operating modes is presented with its expected uncertainties. Covariance matrices were calculated and a principal component analysis (PCA) was performed to reduce statistical noise and remove degeneracies. The total uncertainty on the flux in the 0–20 GeV range of neutrino energy was found to be 11.5% (7.0%) for ν_μ (ν_e) incident on the ICARUS detector.

Technical Note	Internal Review	Collaboration Review	Submission to Journal
			

6. TPC energy scale calibration





- Corresponding author: G. Putnam
- Technical note submitted: [SBN Document 32501-v4](#)
- The paper reports on a combined measurement of electron-ion recombination in LAr and the electronics gain in the ICARUS.
- Paper draft internally reviewed (A. Fava, D. Naples, F. Pietropaolo).
- New draft submitted after Collaboration review: [SBN Document 33206-v4](#).
- Published into arXiv ([2407.12969](https://arxiv.org/abs/2407.12969)) and submitted to JINST.

PREPARED FOR SUBMISSION TO JINST

Angular dependent measurement of electron-ion recombination in liquid argon for ionization calorimetry in the ICARUS liquid argon time projection chamber

arXiv:2407.12969v2 [physics.ins-det] 9 Aug 2024

P. Abratenko²⁸ N. Abrego-Martinez⁴ A. Aduszkiewicz⁷ F. Akbar²³ L. Aliaga Soplin²⁷ M. Artero Pons¹⁷ J. Asaadi²⁷ W. F. Badgett⁶ B. Baibussinov¹⁷ B. Behera⁵ V. Bellini¹⁹ R. Benocci¹⁵ J. Berger⁵ S. Berkman⁶ S. Bertolucci⁸ M. Betancourt⁶ M. Bonesini¹⁵ T. Boone⁵ B. Bottino¹⁰ A. Braggiotti¹⁷ D. Brailsford²⁰ S. J. Brice⁶ V. Brio⁹ C. Brizzolari¹⁵ H. S. Budd²³ A. Campani¹⁰ A. Campos²⁹ D. Carber⁵ M. Carneiro¹ I. Caro Terrazas⁵ H. Carranza²⁷ F. Castillo Fernandez²⁷ A. Castro⁴ S. Centro¹⁷ G. Cerati⁶ A. Chatterjee²¹ D. Cherdack⁷ S. Cherubini¹³ N. Chitrasreemadam¹⁹ M. Cicerchia¹⁷ T. E. Coan²⁶ A. Cocco¹⁶ M. R. Convery²⁵ L. Cooper-Troendle²² S. Copello¹⁸ A. A. Dange²⁷ A. de Roeck² S. Di Domizio¹⁰ L. Di Noto¹⁰ C. Di Stefano¹³ D. Di Ferdinando⁸ M. Diwan¹ S. Dolan² L. Domine²⁵ S. Donati¹⁹ F. Drielsma²⁵ J. Dyer⁵ S. Dytman²² A. Falcone¹⁵ C. Farnese¹⁷ A. Fava⁶ A. Ferrari¹⁴ N. Gallice¹ F. G. Garcia²⁵ C. Gatto¹⁶ D. Gibin¹⁷ A. Gioiosa¹⁹ W. Gu¹ A. Guglielmi¹⁷ G. Gurung²⁷ H. Hausner⁶ A. Heggstuen⁵ B. Howard²⁶ R. Howell²³ I. Ingratta⁸ C. James⁶ W. Jang²⁷ Y.-J. Jwa²⁵ L. Kashur⁵ W. Ketchum⁶ J. S. Kim²³ D.-H. Koh²⁵ J. Larkin¹ Y. Li¹ C. Mariani²⁹ C. M. Marshall²³ S. Martynenko¹ N. Mauri⁸ K. S. McFarland²³ D. P. Méndez¹ A. Menegolli¹⁸ G. Meng¹⁷ O. G. Miranda⁴ A. Mogan⁵ N. Moggi⁸ E. Montagna⁸ C. Montanari³⁶ A. Montanari⁸ M. Mooney⁵ G. Moreno-Granados⁴ J. Mueller⁵ M. Murphy²⁹ D. Naples²² V. C. L. Nguyen²⁴ S. Palestini² M. Pallavicini¹⁰ V. Paolone²² R. Papaleo¹³ L. Pasqualini⁸ L. Patrizii⁸ L. Paudel³ G. Petrillo²⁵ C. Petta⁹ V. Pia⁸ F. Pietropaolo⁴² F. Poppi⁸ M. Pozzato⁸ G. Putnam³ X. Qian¹ A. Rappoldi¹⁸ G. L. Raselli¹⁸ S. Repetto¹⁰ F. Resnati² A. M. Ricci¹⁹ G. Riccobene¹³ E. Richards²² M. Rosenberg²⁸ M. Rossella¹⁸ P. Roy²⁹ C. Rubbia¹¹ M. Saad²² S. Saha²² P. Sala¹⁴ S. Samanta¹⁰ P. Sapienza¹³ A. Scaramelli¹⁸ A. Scarpelli¹ D. Schmitz³ A. Schukraft⁶ D. Senadheera²² S.-H. Seo⁶ F. Sergiampietri⁴² G. Sirri⁸ J. S. Smedley²³ J. Smith¹ L. Stanco¹⁷ J. Stewart¹ H. A. Tanaka²⁵ F. Tapia²⁷ M. Tenti⁸ K. Terao²⁵ F. Terranova¹⁵ V. Togo⁸ D. Torretta⁶ M. Tori¹⁵ F. Tortorici⁹ R. Triozzi¹⁷ Y.-T. Tsai²⁵ S. Tufanli² T. Usher²⁵ F. Varanini¹⁷ S. Ventura¹⁷ M. Vicenzi¹ C. Vignoli¹² B. Viren¹ Z. Williams²⁷ R. J. Wilson⁵ P. Wilson⁶ J. Wolfs²³ T. Wongjitrad²⁸ A. Wood⁷ E. Worcester¹ M. Worcester¹ M. Wospakrik⁶ H. Yu¹ J. Yu²⁷ A. Zani¹⁴ J. Zennaro⁶ J. Zettlemoyer⁶ C. Zhang¹ S. Zucchelli⁸

Technical Note	Internal Review	Collaboration Review	Submission to Journal
			

7. Tuning of TPC signal/noise simulation





- Corresponding authors: D. Carber, M. Mooney, J. Mueller, G. Putnam
- Technical note submitted: [SBN Document 35168-v2](#)
- Devoted to signal and noise calibration in the TPC (Charge scale equalization, Noise measurement and simulation, Signal shape measurement and simulation)
- Internal review completed (Xin Qian, London Cooper-Troendle, Francesco Pietropaolo)
- Published into arXiv ([2407.11925](#)) and submitted to JINST.

PREPARED FOR SUBMISSION TO JINST

Calibration and simulation of ionization signal and electronics noise in the ICARUS liquid argon time projection chamber

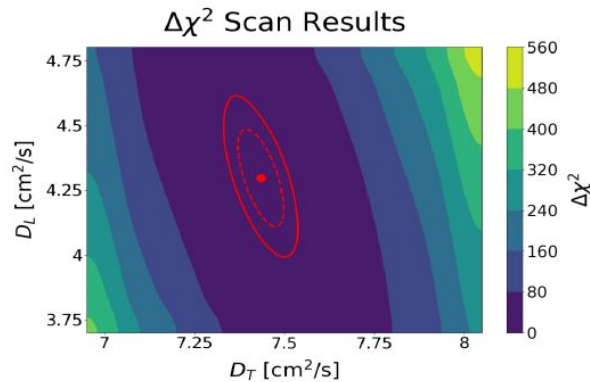
P. Abratenko²⁸ N. Abrego-Martinez⁴ A. Aduszkiewicz⁷ F. Akbar²³ L. Aliaga Soplin²⁷ M. Artero Pons¹⁷ J. Asaadi²⁷ W. F. Badgett⁶ B. Baibussinov¹⁷ B. Behera⁵ V. Bellini⁹ R. Benocci¹⁵ J. Berger³ S. Berkman⁶ S. Bertolucci⁸ M. Betancourt⁵ M. Bonesini¹⁵ T. Boone⁵ B. Bottino¹⁰ A. Braggiotti¹⁷ D. Brailsford²⁰ S. J. Brice⁶ V. Brio⁹ C. Brizzolari¹⁵ H. S. Budd²³ A. Campani¹⁰ A. Campos²⁹ D. Carber⁵ M. Carneiro¹ I. Caro Terrazas⁵ H. Carranza²⁷ F. Castillo Fernandez²⁷ A. Castro⁴ S. Centro¹⁷ G. Cerati⁶ A. Chatterjee²¹ D. Cherdack⁷ S. Cherubini¹³ N. Chitirasreemadam¹⁹ M. Cicerchia¹⁷ T. E. Coan²⁶ A. Cocco¹⁶ M. R. Convery²⁵ L. Cooper-Troendle²² S. Copello¹⁸ A. A. Dange²⁷ A. de Roeck² S. Di Domizio¹⁰ L. Di Noto¹⁰ C. Di Stefano¹³ D. Di Ferdinando⁸ M. Diwan¹ S. Dolan² L. Domine²⁵ S. Donati¹⁹ F. Drielsma²⁵ J. Dyer⁵ S. Dytman²² A. Falcone¹⁵ C. Farnese¹⁷ A. Fava⁶ A. Ferrari¹⁴ N. Gallice¹ F. G. Garcia²⁵ C. Gatto¹⁶ D. Gibin¹⁷ A. Gioiosa¹⁹ W. Gu¹ A. Guglielmi¹⁷ G. Gurung²⁷ H. Hausner⁶ A. Heggstuen⁵ B. Howard²⁶ R. Howell²³ I. Ingratta⁸ C. James⁶ W. Jang²⁷ Y.-J. Jwa²⁵ L. Kashur⁵ W. Ketchum⁶ J. S. Kim²³ D.-H. Koh²⁵ J. Larkin¹ Y. Li¹ C. Mariani²⁹ C. M. Marshall²³ S. Martynenko¹ N. Mauri¹ K. S. McFarland²³ D. P. Méndez¹ A. Menegolli¹⁸ G. Meng¹⁷ O. G. Miranda⁴ A. Mogan⁵ N. Moggi¹⁸ E. Montagna⁸ C. Montanari¹⁶ A. Montanari⁸ M. Mooney⁵ G. Moreno-Granados⁴ J. Mueller⁵ M. Murphy²⁹ D. Naples²² V. C. L. Nguyen²⁴ S. Palestini² M. Pallavicini¹⁰ V. Paolone²² R. Papaleo¹³ L. Pasqualini⁸ L. Patrizii⁸ L. Paudel⁵ G. Petrillo²⁵ C. Petta⁹ V. Pia⁸ F. Pietropaolo⁴² F. Poppi⁸ M. Pozzato⁸ G. Putnam³ X. Qian¹ A. Rappoldi¹⁸ G. L. Raselli¹⁸ S. Repetto¹⁰ F. Resnati² A. M. Ricci¹⁹ G. Riccobene¹³ E. Richards²² M. Rosenberg²⁸ M. Rossella¹⁸ P. Roy²⁹ C. Rubbia¹¹ M. Saad²² S. Saha²² P. Sala¹⁴ S. Samanta¹⁰ P. Sapienza¹³ A. Scaramelli¹⁸ A. Scarpelli¹ D. Schmitz³ A. Schukraft⁶ D. Senadheera²² S.-H. Seo⁶ F. Sergiampietri² G. Sirri⁸ J. S. Smedley²³ J. Smith¹ L. Stanco¹⁷ J. Stewart¹ H. A. Tanaka²⁵ F. Tapia²⁷ M. Tenti⁸ K. Terao²⁵ F. Terranova¹⁵ V. Togo⁸ D. Torretta⁶ M. Torti¹⁵ F. Tortorici⁹ R. Triozzi¹⁷ Y.-T. Tsai²⁵ S. Tufani² T. Usher²⁵ F. Varanini¹⁷ S. Ventura¹⁷ M. Vicenzi¹ C. Vignoli¹² B. Viren¹ Z. Williams²⁷ R. J. Wilson⁵ P. Wilson⁶ J. Wolfs²³ T. Wongjirad²⁸ A. Wood⁷ E. Worcester¹ M. Worcester¹ M. Wospakrik⁶ H. Yu¹ J. Yu²⁷ A. Zani¹⁴ J. Zennaro⁶ J. Zetlemoyer⁶ C. Zhang¹ S. Zucchelli⁸

arXiv:2407.11925v3 [hep-ex] 5 Aug 2024

Technical Note	Internal Review	Collaboration Review	Submission to Journal
			

8. Longitudinal and transverse electron diffusion

- Corresponding authors: A. Mogan, M. Mooney, S. Ruterbories
- Measurement of both longitudinal and transverse coefficients. Longitudinal is the first measurement in LAr at low field.



Measurement of the Transverse and Longitudinal Diffusion of Ionization Electrons in Liquid Argon with the ICARUS Detector

ICARUS Collaboration
 A. Mogan, M. Mooney, and S. Ruterbories
 Colorado State University,
 Fort Collins, CO 80523, USA

November 18, 2022

Abstract

Experiments in Liquid Argon Time Projection Chambers (LARTPCs) have shown that the smearing of signal waveforms by electron diffusion can have a significant impact on particle identification. Understanding and accounting for this diffusion can improve not only the identification process but also the accuracy of measurements in these detectors. Previous measurements have been found primarily for the longitudinal diffusion constant, but our novel method, which makes use of the relative change between near-anode and near-cathode data, allows the longitudinal and transverse diffusion constants (D_L and D_T , respectively) to be measured simultaneously. Using this method, we measure $D_L = 4.30^{+0.18}_{-0.15}$ cm²/s and $D_T = 7.44^{+0.06}_{-0.07}$ cm²/s in ICARUS operating at a drift electric field of roughly 493.8 V/cm. Our measurement of D_T is the first of its kind in an electric field below 1 kV/cm.

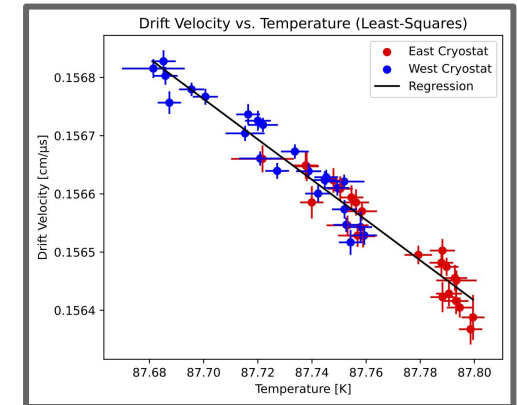
- Updated technical note to be submitted in November: present one is [SBN Document 28805](#)
- Internal review and submission to a journal within this calendar year.

Technical Note	Internal Review	Collaboration Review	Submission to Journal
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Other calibration works

9. DRIFT VELOCITY vs TEMPERATURE (Authors: Q. Blumenthal, M. Mooney)

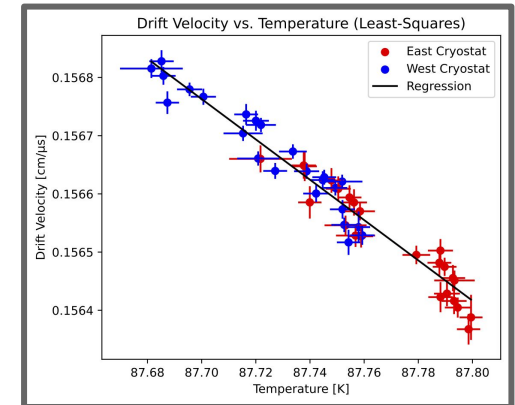
- Modeled drift velocity dependence on ullage temperature.
- Developed drift velocity model as a function of both temperature and electric field.
- Analysis is mature ([SBN Document 27465](#)), working on uncertainties.
- Technical note next week and draft paper will follow



Other calibration works

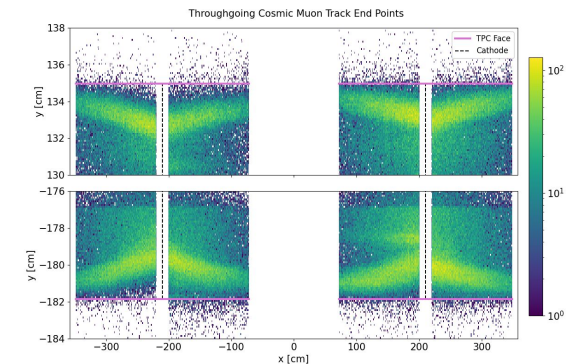
9. DRIFT VELOCITY vs TEMPERATURE (Authors: Q. Blumenthal, M. Mooney)

- Modeled drift velocity dependence on ullage temperature.
- Developed drift velocity model as a function of both temperature and electric field.
- Analysis is mature ([SBN Document 27465](#)), working on uncertainties.
- Technical note next week and draft paper will follow



10. SPACE CHARGE AND ELECTRIC FIELD DISTORTIONS (Author: L. Kashur)

- Transverse spatial offset maps have been created for all TPCs.
- Analysis is being finalized. Ready to review in mid 2024.
- Technical note by the end of calendar year and draft paper at the beginning of 2025.



11. Di-muon analysis





11. DI-MUON ANALYSIS (Corresponding author: G. Putnam)

- Search for a long-lived particle decaying to two muons in ICARUS with NuMI data.
- Technical note submitted [SBN document 34448](#)
- Paper draft internally reviewed by NuMI group and ESB, sent to the Collaboration for review.
- Ready to be put into arXiv and submitted to PRL

1 Search for a Hidden Sector Scalar from Kaon Decay in the Di-Muon Final State at
2 ICARUS

3 ICARUS Collaboration
4 (Dated: October 7, 2024)

We present a search for long-lived particles (LLPs) produced from kaon decay that decay to two muons inside the ICARUS neutrino detector. This channel would be a signal of hidden sector models that can address outstanding issues in particle physics such as the strong CP problem and the microphysical origin of dark matter. The search is performed with data collected in the Neutrinos at the Main Injector (NuMI) beam at Fermilab corresponding to 2.41×10^{20} protons-on-target. No new physics signal is observed, and we set world-leading limits on heavy QCD axions, as well as for the Higgs portal scalar among dedicated searches. Limits are also presented in a model-independent way applicable to any new physics model predicting the process $K \rightarrow \pi + S(\rightarrow \mu\mu)$, for a long-lived particle S . This result is the first search for new physics performed with the ICARUS detector at Fermilab. It paves the way for the future program of long-lived particle searches at ICARUS.

Technical Note	Internal Review	Collaboration Review	Submission to Journal
			

Other works in the streamline

12. NUMI-CC0PI XS ANALYSIS (Corresponding author: B. Howard, J. Kim et al.)

- First technical note internally reviewed and submitted [SBN document 34859](#)
- Muon-neutrino cross-section measurement with signal defined by events with no pions produced in the final state of the interaction.

Charged Current Mesonless Analysis with the off-axis NuMI beam at ICARUS

Bruce Howard, Jaesung Kim, Minerba Betancourt, Stephen Dolan,
Chris Marshall, Kevin McFarland, Guadalupe Moreno

February 14, 2024

Abstract

Due to its location, in addition to neutrinos produced by the Booster Neutrino Beam, ICARUS is also sensitive to those produced by the Neutrinos at the Main Injector (NuMI) beam. Given the off-axis angle from NuMI to ICARUS and the contribution to neutrino fluxes from both pion decays and kaon decays, NuMI neutrino interactions in ICARUS are measurable across a span of a few GeV in energy. Given the $\sim 2\text{-}3$ GeV first- and ~ 1 GeV second-oscillation maxima in the upcoming DUNE experiment, along with the potential for uncertainties related to neutrino interactions to be leading sources of systematic uncertainties in DUNE, interaction studies in these energy ranges with an Argon target are both valuable and complementary to studies of neutrino interactions using the Booster Beam as part of the SBN program. This technical note details a muon-neutrino cross-section measurement with signal defined by events with no pions produced in the final state of the interaction, thus targeting charged-current quasi-elastic-like signatures (CCQE-like). The measurement will be reported as a flux-averaged differential cross section as a function of a variety of kinematic variables, some of which exploit kinematic correlations between the outgoing muon and proton to maximise sensitivity to the poorly understood “nuclear effects” which can dominate systematic error budgets of oscillation measurements. This includes measurements of well-known observable that characterise the kinematic imbalance between the muon and proton on the plane transverse to the incoming neutrino.

Other works in the streamline

12. NUMI-CC0PI XS ANALYSIS (Corresponding author: B. Howard, J. Kim et al.)

- First technical note internally reviewed and submitted [SBN document 34859](#)
- Muon-neutrino cross-section measurement with signal defined by events with no pions produced in the final state of the interaction.

13. **NEW! Muon Neutrino reconstruction with Machine Learning - SPINE** (Corresponding author: J. Mueller)

- Technical note almost ready (next week)
- Intended to be submitted to Phys. Rev. D

[See J. Mueller's talk](#)

Charged Current Mesonless Analysis with the off-axis NuMI beam at ICARUS

Bruce Howard, Jaesung Kim, Minerba Betancourt, Stephen Dolan, Chris Marshall, Kevin McFarland, Guadalupe Moreno

February 14, 2024

Abstract

Due to its location, in addition to neutrinos produced by the Booster Neutrino Beam, ICARUS is also sensitive to those produced by the Neutrinos at the Main Injector (NuMI) beam. Given the off-axis angle from NuMI to ICARUS and the contribution to neutrino fluxes from both pion decays and kaon decays, NuMI neutrino interactions in ICARUS are measurable across a span of a few GeV in energy. Given the $\sim 2\text{-}3$ GeV first- and ~ 1 GeV second-oscillation maxima in the upcoming DUNE experiment, along with the potential for uncertainties related to neutrino interactions to be leading sources of systematic uncertainties in DUNE, interaction studies in these energy ranges with an Argon target are both valuable and complementary to studies of neutrino interactions using the Booster Beam as part of the SBN program. This technical note details a muon-neutrino cross-section measurement with signal defined by events with no pions produced in the final state of the interaction, thus targeting charged-current quasi-elastic-like signatures (CCQE-like). The measurement will be reported as a flux-averaged differential cross section as a function of a variety of kinematic variables, some of which exploit kinematic correlations between the outgoing muon and proton to maximise sensitivity to the poorly understood "nuclear effects" which can dominate systematic error budgets of oscillation measurements. This includes measurements of well-known observable that characterise the kinematic imbalance between the muon and proton on the plane transverse to the incoming neutrino.

Muon Neutrino Reconstruction with Machine-Learning Techniques at the ICARUS Detector

Justin Mueller

October 11, 2024

Abstract

The ICARUS T600 LArTPC detector successfully ran for three years at the underground LNGS laboratories, providing a first sensitive search for LSND-like anomalous electron neutrino appearance in the CNGS beam. After a significant overhauling at CERN, the T600 detector has been placed in its experimental hall at Fermilab, fully commissioned, and the first events observed with full detector readout. Regular data-taking began in May 2021 with neutrinos from the Booster Neutrino Beam (BNB) and neutrinos six degrees off-axis from the Neutrinos at the Main Injector (NuMI). Modern developments in machine learning have allowed for the development of an end-to-end machine-learning-based event reconstruction for ICARUS data. This reconstruction folds in 3D voxel-level feature extraction using sparse convolutional neural networks and particle clustering using graph neural networks to produce outputs suitable for physics analyses. The analysis presented here demonstrates a high-purity and high-efficiency selection of muon neutrino interactions in the BNB suitable for the physics goals of the ICARUS experiment and the Short-Baseline Neutrino Program.

Other works in the streamline

14. PMT TIMING PERFORMANCE (Main authors: S. Copello, M. Vicenzi)

- Should contain the methods and results allowing for the PMT time calibration with laser and cosmics and the overall time resolution of the PMT system in RUN1 and RUN2 (and maybe RUN3).

15. RECONSTRUCTION OF THE BNB/NUMI BUNCHED BEAM STRUCTURES (Main authors: A. Heggstuen, R. Triozzi, M. Vicenzi)

- Should contain the exploitation of bunched beams for neutrino selection

Perspectives for 2024 technical notes and publications

Work	Status	Authorship
Cryogenics and purification paper	Under internal review	Limited
CRT design, construction and performance	Ready for Collaboration review	Limited
Trigger performance	Technical note by the end of 2024	Full
MeVPrtl event generation	Technical note ready.	Limited
Prediction of NuMI electron and muon neutrino flux in ICARUS	Addendum note in preparation.	Limited
Energy scale calibration and angular dependence of Recombination	Submitted to JINST	Full
Tuning of TPC signal/noise simulation	Submitted to JINST	Full
Longitudinal and transverse electron diffusion	Technical note by the end of 2024	Full
Calibration of drift field distortion	Technical note by the end of 2024	Full
Drift velocity temperature dependence	Technical note almost ready	Full

Perspectives for 2024 technical notes and publications

Work	Status	Authorship
Di-muon event searches	Ready for submission to PRL	Full
CC0pi cross-section measurement	First technical note out	Full
Muon neutrino reconstruction with ML (SPINE)	Technical note almost ready	Full
PMT timing	First technical note by the end of 2024?	Full
Reconstruction of BNB/NUMI bunched structure	First technical note by the end of 2024?	Full

Perspectives for 2024 technical notes and publications

Work	Status	Authorship
Di-muon event searches	Ready for submission to a journal	Full
CC0pi cross-section measurement	First technical note out	Full
PMT timing	Technical note in later 2024	Full
Reconstruction of BNB/NUMI bunched structure	Technical note in later 2024	Full

A final remark: when a ICARUS technical note is put on docdb, please let the ESB aware of it!