# 57th Annual Users Meeting (2024): Inspirations from P5

Tuesday, 9 July 2024 - Friday, 12 July 2024

Fermi National Accelerator Laboratory

# Book of Abstracts

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## Special Colloquium: From Inspirations to Futures

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## Efficiency Analysis of ML-Based Anomaly Detection Triggers for Emerging Jets

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Novel machine learning-based anomaly detection Level 1 (L1) triggers are currently under development at CMS, namely AXOL1TL and CICADA. The former employs a variational autoencoder, while the latter utilizes a convolutional autoencoder. These triggers aim to balance rate reduction with model independence, enabling the selection of potentially significant events that might be overlooked by traditional triggers relying on basic kinematic variable selections. Consequently, they have the potential to enhance signals indicative of physics beyond the Standard Model, such as those associated with emerging jets. Such signals are predicted by models featuring a composite dark sector where long-lived particles decay into Standard Model jets with displaced tracks and numerous vertices. This study evaluates the efficiency of these anomaly detection triggers in selecting events with emerging jets produced via the s-channel production of two dark quarks.

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## Test Beam Results of Planar Pixel Sensor for the CMS Phase 2 Inner Tracker Upgrade

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Results of the test beam measurements that characterize the performance of CMS Readout Chip (CROC) sensors to be used in the High Luminosity era of the Large Hadron Collider (HL-LHC) are presented. The HL-LHC peak instantaneous luminosity of $7.5 \times 10^{34}$ cm$^{-2}s^{-1}$ corresponds to an average of around 200 inelastic proton-proton collisions per beam-crossing every 25 ns. In order to efficiently reconstruct and track particles in these extreme and challenging conditions, the present CMS tracking detector will be completely replaced. The new tracking detector consists of an Inner Tracker closest to the beamline and an Outer Tracker surrounding it. These are populated with modules constructed of readout chips and silicon sensors. The test beam measurements of these modules are vital to understand the performance of the related technologies. Using a primary 120 GeV proton beam from the Main Injector at Fermilab, data was collected at the Fermilab Test Beam Facility (FTBF) using the silicon tracker telescope that provides a precision position measurement of the track impact point with less than 5 micron uncertainty. The proton beam was incident on a 1x2 planar CROC module with sensor developed by Hamamatsu. The sensor has 100x25 $\mu m^2$ standard pixels and also a smaller number of 225x25 $\mu m^2$ longer pixels at the boundary between the two ROCs. We present characterisation of these modules that includes pixel efficiency, resolution, cluster size and charge distributions.

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## FCC Update #2 (TBD)

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## Search For Low-Mass Quark-Antiquark Resonances Produced With an Initial State Photon at 13 TeV Using the CMS Detector

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We present a search for low-mass narrow $q\bar{q}$ resonances. This search uses data from LHC pp collisions at a center of mass of 13 TeV in Run 2, and corresponds to an integrated luminosity of 137 fb-1, currently using 10% of data. Utilizing full Run 2 data allows the use of a lower photon pT threshold trigger than a previous analysis performed with only 2016 data, allowing this analysis to be more sensitive to resonances in the low mass region. We require an initial state photon recoiling against the narrow resonance, leading to the resonance having a high transverse momentum. The high pT decay products of the resonance collimate and are reconstructed as a single large jet with an internal two-pronged substructure. A two-pronged dijet score based on the ParticleNet tagger is used to select jets with two-pronged substructure. The background is estimated via a data-driven method using a transfer factor between the distributions which fail and pass the two-pronged substructure requirement. The new physics signal is searched for as a narrow peak excess above the Standard Model backgrounds in the jet mass spectrum.

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## Fermilab Efforts in EDI & STEM

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## Predicting Missing Regions of Charged Particle Tracks Using a Sparse 3D Convolutional Neural Network

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This study explores the use of a Sparse 3D Convolutional Neural Network (ConvNet) to infer missing regions of charged particle tracks. Hits corresponding to energy depositions are voxelized into a three-dimensional (3D) grid for each track. Inactive regions within the tracks are replaced with a dense, rectangular 3D grid of voxels, ensuring consistent step sizes in X, Y, and Z directions. Voxels in these dense regions are initialized with an energy value of -1, indicating nonphysical energy or charge. The model is trained to predict which voxels should activate as part of the track and which should not. Results indicate that the model accurately predicts track voxels within ±1 unit in X, Y, or Z directions and effectively identifies non-track voxels, despite some overprediction. The approach shows promise in prediction of missing track regions with some accuracy.

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## Reconstruction of the BNB and NuMI Neutrino Bunch Structure with ICARUS

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ICARUS serves as the Far Detector of the Short Baseline Neutrino (SBN) program at Fermilab, sitting on-axis on the Booster Neutrino Beam (BNB) and 6° off-axis from the Neutrinos at the Main Injector (NuMI) beam. Neutrinos from both beams inherit the timing sub-structure of their parent proton spills, which is in turn derived from either the Booster's or the Main Injector's synchrotron acceleration. Since neutrino propagation introduces only a constant offset, their timing structure is preserved as they travel. Identifying this structure in data represents a powerful tool for selecting neutrino events and searching for physics beyond the Standard Model (BSM). This poster presents the preliminary reconstruction of the BNB and NuMI neutrino bunch structure with ICARUS data, exploiting only the precise timing of ICARUS optical readout system to both locate and assign a time to each interaction.

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## Performance analysis of phase 2 Tracker upgrade Ps Module before and after irradiation

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The Large Hadron Collider will undergo a luminosity upgrade targeting a peak instantaneous luminosity ranging from 5 up to $7.5\times10^{34}\text{cm}^{-2}\text{s}^{-1}$. The ambitious goal of the High Luminosity LHC is

to achieve a total of 3000-4000$fb^{-1}$ of proton-proton collisions at a center-of-mass energy of 14TeV. To cope with such challenging environmental conditions, the outer tracker of the CMS experiment will be upgraded using closely spaced silicon sensors (pixels and strips) to provide tracking information at the Level-1 trigger. A PS-Module, composed of both a pixel and a strip sensor, was tested at the Fermilab Test-Beam Facility to evaluate its ability to provide accurate tracking information, particle momentum discrimination capabilities and optimal performance at the irradiation levels expected after being exposed to the harsh conditions of the High Luminosity LHC. The results of the test and the comparison of the module performance before and after irradiation will be presented in this poster.

**Poster Session / 61**

# LDMX: The Light Dark Matter eXperiment

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The constituents of dark matter are still unknown, and the viable possibilities span a very large mass range. Specific scenarios for the origin of dark matter sharpen the focus to within about an MeV to 100 TeV. Most of the stable constituents of known matter have masses in this lower range, and a thermal origin for dark matter works in a simple and predictive manner in this mass range as well. If there is an interaction between light DM and ordinary matter, as there must be in the case of a thermal origin, then there necessarily is a production mechanism in accelerator-based experiments. The Light Dark Matter eXperiment (LDMX) is a planned electron-beam fixed-target missing-momentum experiment at SLAC that has unique sensitivity to light DM in the sub-GeV mass range. Although optimized for a missing momentum technique, LDMX is effectively a fully instrumented beam dump experiment, making it possible to search for visibly decaying signatures of dark sector particles. This would provide another outlet for LDMX to probe complementary regions of dark matter phase space for a variety of models. This contribution will give an overview of the theoretical motivation for LDMX, the main experimental challenges and how they are addressed, as well as projected sensitivities in comparison to other experiments.

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# Mu2e: Modeling Drift of Ionized Particles with ML

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The Mu2e experiment searches for charged lepton flavor violation through muon-to-electron conversion in the field of a nucleus. The signal is a monoenergetic electron with an energy of 104.97 MeV. Its momentum is reconstructed using information from drifting ionized particles. This project analyzes the drift of ionized particles with a deep neural network to help improve the momentum reconstruction process. The model yields a 20% improvement in resolution from a reference linear model.

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## High-throughput Custom Monitoring for the Mu2e TDAQ System

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In this project we are studying the application of programmable network hardware to provide a custom monitoring capability for the Mu2e Trigger and Data Acquisition System (TDAQ) system. The goal of the Mu2e experiment is to search for a charged-lepton flavor violating processes where a negative muon converts into an electron in the field of an aluminum nucleus. This experiment is intended to improve by four orders of magnitude the search sensitivity reached so far.

We have a working prototype of a system that provides high-throughput, custom monitoring for the Mu2e TDAQ system. The custom Mu2e network packet header format is parsed as it crosses the network switch. Parsing extracts bits that convey information about error states at read-out controllers (ROCs). This information is periodically relayed to the switch controller, which in turn alerts experiment operators.

Future work includes: (1) generalizing the prototype to support the detection of other error or performance conditions, and (2) runtime reconfiguration of the TDAQ system as a response to detecting such conditions. This reconfiguration would be used to mitigate error or performance conditions.

**Poster Session / 64**

## First Measurements of Differential Cross Sections In Kinematic Imbalance Variables With The MicroBooNE Detector

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Making high-precision measurements of neutrino oscillation parameters requires an unprecedented understanding of neutrino-nucleus scattering. In this presentation, we present the first muon neutrino charged current double-differential cross sections in kinematic imbalance variables. These variables characterize the imbalance in the plane transverse to an incoming neutrino. We use events with a single muon above 100 MeV/c, a single final state proton above 300 MeV/c, and no recorded final state pions. Thus, these variables act as a direct probe of nuclear effects such as final state interactions, Fermi motion, and multi-nucleon processes. We also present a complementary ongoing analysis using electron neutrinos. This channel is of the utmost importance for the extraction of neutrino oscillation parameters by making high-precision measurements. Our measurements allow us to constrain systematic uncertainties associated with neutrino oscillation results performed by near-future experiments of the Short Baseline Neutrino (SBN) program, as well as by future large-scale experiments like DUNE.

**Poster Session / 65**

## MLOps for Beam Controls

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Machine learning operations (MLOps) is the standardization and streamlining of the ML development lifecycle to address the challenges associated with large-scale machine learning applications. The full MLOps pipeline consists of open-source tools: DataHub, MinIO and MLflow. It is being used for dataset management and model development to handle changing data dependencies, varying business needs, reproducibility, and diverse teams working with differing tools and skills. To demonstrate the completion of an MLOps pipeline for particle accelerator operations, we are deploying a simple script that computes settings for the Booster's gradient magnet power supply. Once the demonstration is complete, we will develop and deploy ML-based optimization algorithms to improve Booster's overall efficiency. This MLOps pipeline opens the gate to systematically develop and deploy ML applications for accelerator controls and diagnostics.

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## The CMS Phase 2 Outer Tracker Analyzer of Test Outputs - POTATO!

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The Phase-2 upgrade of the Large Hadron Collider (LHC), also known as the High-Luminosity LHC (HL-LHC) is designed to achieve peak instantaneous luminosities which is about an order of magnitude higher than the nominal design value of $10^{34}\ cm^{-2}s^{-1}$ delivering a total of at least $3000 fb^{-1}$ data over 10 years of operation at $\sqrt{s}\ =\ 14\ TeV$. One crucial aspect of the CMS Phase-2 detector upgrade is the replacement of the existing tracking detector in order to deal with the extreme HL-LHC conditions, retaining and further expanding the physics performances achieved in the previous years. The outer part of the upgraded tracker (OT), will be equipped with over 13,000 macro Pixel-Strip (PS) and Strip-Strip (2S) modules! Module production is distributed across centers worldwide and necessitates coordinated efforts and standardized procedures. Along with production and assembly of the modules, Fermilab OT group is also working on a tool, Phase 2 Outer Tracker Analyzer of Test Outputs (POTATO) that will analyze, grade, upload and manage the large quantity of files to be stored in the centralized Database (DB). In this contribution a brief overview of the module testing and the power and dire need of POTATO to handle this large number of test outputs will be presented.

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## Constructing Data-Driven Predictions at the Far Detector for NOvA's Neutrino Oscillation Analysis

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NOvA, is a two-detector, long-baseline neutrino oscillation experiment located at Fermilab, Batavia, IL, USA. It is designed primarily to constrain neutrino oscillation parameters using $\nu_\mu$ ($\bar{\nu}_\mu$) disappearance and $\nu_e$ ($\bar{\nu}_e$) appearance data. The Neutrinos at Main Injector (NuMI) beamline at Fermilab provides a high purity 900 KW intense beam of neutrinos and anti-neutrinos to NOvA. The NOvA Near Detector, located 100m underground and 1km away from the beam source, observes the un-oscillated $\nu_\mu$ ($\bar{\nu}_\mu$) and beam $\nu_e$ ($\bar{\nu}_e$) event spectrum. The Far Detector, located in Ash River, MN, USA, is 809 km from the ND and records the oscillated $\nu_e$ ($\bar{\nu}_e$) and the un-oscillated $\nu_\mu$ ($\bar{\nu}_\mu$) event spectrum. NOvA uses a data-driven technique called extrapolation to predict the expected number of $\nu_\mu$ ($\bar{\nu}_\mu$) and $\nu_e$ ($\bar{\nu}_e$) events at the Far Detector using the Near Detector data. The use of data from a functionally equivalent Near Detector provides a powerful constraint on the systematic uncertainties in NOvA neutrino oscillation analyses. As NOvA continues to add data statistics, a robust constraint on systematics becomes more crucial for neutrino oscillation analysis. The details of the NOvA neutrino oscillation analysis framework and how it constrains dominant systematic uncertainties using the Near Detector data will be discussed in this poster.

**Poster Session / 68**

## Charged current single pion production on SBND

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The Short Baseline Neutrino (SBN) program at Fermilab is designed to provide precise measurements of neutrino oscillations using 3 Liquid Argon Time Projection Chambers (LArTPC) built along Fermilab's Booster Neutrino Beam (BNB). The Short Baseline Near Detector (SBND), located at only 110 m from the BNB target, will precisely characterize the neutrino flux before oscillations take place, thanks to its unprecedented neutrino interaction statistics.
Due to its proximity to the neutrino production target, the detector expects over a million neutrino interactions annually, which will open the possibility of exploring exclusive channels of neutrino interactions.
This poster will show SBND's capabilities of exploring Muon Neutrino Charged Current Single Pion production, for which previous measurements in Argon were limited by statistics. The poster will introduce the relevance of this process for neutrino Physics, the unique possibilities of SBND and a preliminary event selection using SBND's current reconstruction tools.

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## Population-level Dark Energy Constraints from Strong Gravitational Lensing using Simulation-Based Inference

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In this work, we present a scalable approach for inferring the dark energy equation-of-state parameter ($w$) from a population of strong gravitational lens images using Simulation-Based Inference (SBI). Strong gravitational lensing offers crucial insights into cosmology, but traditional Monte Carlo methods for cosmological inference are computationally prohibitive and inadequate for processing the thousands of lenses anticipated from future cosmic surveys. New tools for inference, such as SBI using Neural Ratio Estimation (NRE), address this challenge effectively. By training a machine learning model on simulated data of strong lenses, we can learn the likelihood-to-evidence ratio for robust inference. Our scalable approach enables more constrained population-level inference of $w$

compared to individual lens analysis, constraining $w$ to within $1\sigma$. Our model can be used to provide cosmological constraints from forthcoming strong lens surveys, such as the 4MOST Strong Lensing Spectroscopic Legacy Survey (4SLSLS), which is expected to observe 10,000 strong lenses.

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## Study of the Neutrino Magnetic Moment with the NOvA Near Detector

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Predicted by the Standard Model as theoretical, massless particles, neutrinos have been the subject of many experiments since their first detection. It is now experimentally confirmed that neutrinos do have mass necessitating an extension to the Standard Model. Such an extension allows for other surprising neutrino properties, such as a neutrino magnetic moment. While neutrinos are observed to be neutral and do not couple to photons at leading order, higher order expansion of the interaction allows for coupling to the photon to occur and gives rise to a neutrino magnetic moment through quantum loop effects. This is a useful property for studying the Dirac or Majorana nature of neutrinos, as the predicted value of the magnetic moment would differ. This talk focuses on an introduction to the neutrino magnetic moment as well as discusses the current status of work being done on NO$\nu$A utilizing the Near Detector to obtain an upper limit on the neutrino magnetic moment value.

**Poster Session / 72**

## Road to PROSPECT-II

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The Precision Reactor Oscillation and SPECTrum (PROSPECT) experiment is based in a segmented liquid scintillator antineutrino detector situated approximately 7 meters from the highly enriched High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory. Its main goal is to investigate short-baseline antineutrino oscillations.
The first phase of data collection, known as PROSPECT-I, was held from 2018 to 2019 and was used for several high-precision analyses, including multiple measurements of the $^{235}U$ antineutrino spectrum and searches for $eV$-scale sterile antineutrino oscillations.
The collaboration is now preparing for the second phase, PROSPECT-II, which features an upgraded detector design. This advancement will enhance sensitivity and statistical power, allowing for a broader range of analyses beyond those achieved in PROSPECT-I. As we transition into this new phase, new questions have arisen concerning background simulation and its potential differences from those conducted during the initial phase of the experiment. Moreover, it is essential to ascertain, through simulations, the positive effects that an improved detector could have on the study of oscillations. This information is crucial for justifying the proposed enhancements, and I will present all of this in the poster.

**Poster Session / 73**

## Demonstrating MeV-Scale Physics Capabilities of Large Neutrino LArTPCs with Ambient Blip Activity in MicroBooNE

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Large neutrino liquid argon time projection chamber (LArTPC) experiments can broaden their physics reach by incorporating isolated MeV-scale features present in their data. We use data from MicroBooNE, an 85-tonnes LArTPC exposed to Fermilab neutrino beams from 2015 until 2021, to demonstrate new calorimetric and particle discrimination capabilities for isolated ~O(1 MeV) energy depositions referred to as "blips". We observe concentrations of blips near fiberglass support struts along the TPC edge, with an energy spectrum indicative of specific gamma-ray decays. These and other blip sources are being used to validate calibrations in MicroBooNE's data by leveraging spectral features. This work further reports on the progress towards distinguishing between low-energy protons and electrons in large LArTPCs using cosmogenic data. The composition of proton-like blips selected using this new technique is being studied to evaluate the accuracy of cosmic ray flux models used in LArTPCs.

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## Industrial Applications via Novel Compact Electron Beam Accelerator

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Electron beam (e-beam) technology provides an efficient, safe and environmentally friendly way to drive chemical reactions. E-beam technology is used in a vast array of industries and common consumer products, with sales eclipsing $2B annually, providing an estimated added value to products of more than \$$500Beveryyearworldwide.

The main processes initiated by electron beam are polymer modification by crosslinking or scission, curing of coatings, decomposition of industrial effluents, or synthesis of new substances. Accelerator technology has applications in water and biosolids treatment, cargo scanning, material modification using electron beams, medical sterilization (X-ray and electron beam), industrial electron-beam driven chemistry, advanced manufacturing, environmental remediation and food sterilization. However, implementation of e-beam technology has been fairly slow due to general lack of knowledge of the technology. Also, applications of conventional e-beam accelerators currently available on the market are limited because they are not energy efficient, take up a large footprint and can be complicated to use and maintain.

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## Impact of HF-CRPA CCQE model on the latest NOvA results

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NOvA is a long-baseline neutrino experiment based at Fermilab, dedicated to measuring various neutrino oscillation parameters. Recently, the NOvA collaboration presented new results at NEUTRINO 2024. A significant enhancement in the modeling of charged-current quasielastic (CCQE) interactions has been achieved with the implementation of the Hartree-Fock (HF) mean-field model, incorporating continuum random phase approximation (CRPA) corrections. This HF-CRPA model offers substantial improvements in the low-energy region. In this presentation, I will discuss the impact of the HF-CRPA model on the latest three-flavor oscillation results of the NOvA experiment.

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## ML-based Reconstruction in a Pixelated LArTPC:

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The Deep Underground Neutrino Experiment (DUNE) will address open issues in neutrino physics such as the measurement of the CP-violating phase in neutrino oscillations and the neutrino mass ordering. The 2x2 demonstrator is a single-phase liquid argon time projection chamber (LArTPC), with four modules, operated as a prototype for the DUNE Liquid Argon Near Detector (ND-LAr). Each module in the 2x2 demonstrator is 0.67m x 0.67m x 1.8m. Based on the ArgonCube design concept, the 2x2 features a novel pixelated charge readout and advanced high-coverage photon detection system. Machine learning can be used to form a complete reconstruction pipeline for 2x2 events. This poster will describe the workings of a package under development called SPLINE and its current performance.

**Poster Session / 77**

## W+D Charm Jet Fragmentation

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Using ATLAS Run 2 data, proton-proton collisions at 13 TeV center of mass energy are analyzed to measure the properties of charmed particle fragmentation. The process $pp \to W \pm c$, where the c-quark fragments to a $^+$ hadron is used. Since quarks are not directly seen from the collision, a jet of particles containing the charmed hadron is used. This is accomplished by comparing the distribution of $z_T$, the ratio of the transverse momentum of the $^+$ to that of the track jet containing the hadron, to several Monte Carlo generators.

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## MuSTAR - An accelerator-driven subcritical reactor

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The Mu*STAR Nuclear Power Plant (NPP) is a transfor- mational and disruptive concept using advances in super- conducting accelerator technology to consume the fertile content in spent nuclear fuel (SNF) from light water reac- tors (LWRs) and to eliminte need for uranium enrichment.

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## Unveiling Sea Quark Dynamics: Measuring Sivers Asymmetry with Polarized Target at SpinQuest

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SpinQuest is a cutting-edge, high-luminosity Drell-Yan experiment utilizing polarized hydrogen and deuterium targets to measure the Sivers asymmetry for the light sea quarks in the nucleon. Detecting a nonzero Sivers asymmetry would provide clear evidence for nonzero orbital angular momentum of sea quarks. The Sivers asymmetry presents itself as an azimuthal asymmetry in the production of virtual photons via the Drell-Yan process, and SpinQuest will be able to measure this asymmetry using the existing SeaQuest dimuon spectrometer. In addition to making measurements sensitive to the sea quark Sivers function, we will also measure the azimuthal asymmetry in the production of $J/\psi$ particles, which is sensitive to the gluon Sivers function. Additionally, observing a sign change in the Sivers asymmetry between this measurement and future measurements at the Electron-Ion Collider would be a test of a fundamental prediction of Quantum Chromodynamics. In this poster we will review the physics and technology underpinning the experiment. This work was supported in part by US DOE grant DE-FG02-94ER40847.

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## Single and double differential charged current \bm{$\nu_\mu$}–Argon cross section without pions in the final state at MicroBooNE

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MicroBooNE, an 85-tonne liquid argon time projection chamber (LArTPC) detector is on-axis to the Booster Neutrino Beam (BNB) beamline facility at Fermi National Accelerator Laboratory. MicroBooNE is elucidating neutrino interactions with argon through cross-section measurements to refine interaction models and reduce uncertainties. In this poster, we present the status of the single and double multi-differential charged current (CC) cross section with zero pions in the final state (CC-$0\pi$) as a function of muon momentum ($0.1 < p_\mu < 2.0\,\mathrm{GeV/c}$) and the cosine of the muon angle ($-1 < \cos\theta_\mu < 1$). We present the details of the event selection and cross section extraction along with a set of tests using fake data to establish the robustness of the analysis methodology. We also discuss prospects for a future combined measurement with the Gd-$H_2O$ target at the ANNIE experiment, to explore MicroBooNE's proton multiplicity alongside ANNIE's neutron multiplicity.

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# A 3D field response simulation for pixelated charge readout in LArTPC

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The Deep Underground Neutrino Experiment (DUNE) is a next-generation long-baseline neutrino oscillation experiment. A critical component of the DUNE Near Detector (ND) is a Liquid Argon Time Projection Chamber (LArTPC), called ND-LAr. A novel pixelated charge readout technology, LArPix, has been developed for LArTPCs. We present a new 3D field response simulation for these pixelated anode designs used in the Module-0 Demonstrator, which is operated as a 600kg prototype for the DUNE ND-LAr. The field response model describes the electric currents induced in the anode planes when ionization electrons drift in the chamber. Field response is important for TPC readout simulation and charge reconstruction. In the prototype detector cosmic-ray run, evidence of LArPix retriggering by induced signal has been noticed. Thus, this field response simulation is also crucial in understanding electronic response and optimizing anode geometry to reduce the retrigger effect.

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# Calibrating LArPix for TinyTPC

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LArTPCs provide sensitivity to GeV signals, such as accelerator neutrinos and part of the supernova neutrino spectrum. TinyTPC is a LArTPC test stand for R&D of LAr doping to expand the reach of LArTPCs down to the 1-10 MeV range, which would substantially enhance the flagship analyses of experiments like DUNE, while enabling low energy analyses. We aim to dope LAr with Xe and photosensitive dopants to expand the LArTPC range by converting hard-to-detect scintillation light to efficiently-detected ionization charge. A critical element of the data analysis in TinyTPC is calibrating the readout. This poster will cover the calibration of TinyTPC, a pixelated liquid argon detector, where we find the distance a muon travels through each pixel. We then calculate the energy loss of muons traveling through the detector from cosmic data. We can reconstruct the path of the particles through the TPC using a density-based clustering algorithm designed to sort straight cosmic muon tracks from low energy radioactive decay curled paths and electronic noise.

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# TinyTPC: A Test Stand for LAr Doping

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TinyTPC is a small scale liquid-argon time projection chamber (LArTPC) featuring a pixelated readout system (LArPix) designed to improve the detection of charged particles. To enhance energy measurements at MeV scales, TinyTPC will study the impact of isobutylene, a photosensitive dopant that converts light to charge, and xenon, a wavelength shifter. This presentation will detail TinyTPC's commissioning, operation, data collection methodologies, noise levels, and upcoming tests involving isobutylene, xenon, and radioactive sources.

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## Doped LAr as a Platform for Low-Energy Physics

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LArTPCs are the technology of choice for many current and future neutrino experiments. Improving the performance of LArTPCs to signals with energies less than 10 MeV would substantially enhance the flagship analyses of experiments like DUNE, while potentially enabling the physics of solar neutrinos, dark matter searches, and neutrinoless double beta decay searches.
I outline the pathway and progress on R&D for photosensitive dopants, whose introduction into the LAr active medium has a potential to enable the detection of low-energy signals in large LArTPCs. This R&D program will demonstrate the feasibility and impacts of introducing doped LAr into current and future neutrino detectors at the kTon scale. I explain the impact of this technology on physics signals across energy ranges. I also introduce our ongoing tests of this technology in the TinyTPC test-stand at Fermilab.

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## Constraining Systematics for Future Sterile Neutrino Analysis at NOvA Experiment

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Equipped with detectors at both Fermilab in Illinois and Ash River in Minnesota, the NOvA experiment is designed to explore the complex properties of neutrinos, with a primary focus on the active three-flavor neutrino mixing phenomena. The experiment consists of two identical detectors: the Near Detector, situated 1 km underground at Fermilab, and the Far Detector, located 810 km away and 14 mrad off the beam axis in northern Minnesota. NOvA uses this significant distance to examine neutrino behaviour thoroughly.

Beyond investigating active neutrino mixing, NOvA also explores exotic oscillations, such as those involving sterile neutrinos. However, uncertainties in neutrino flux, cross-section, and detector systematics present significant challenges, making distinguishing genuine physics events from background noise difficult. This poster will discuss the approach to reduce the cross-section and flux systematics for the upcoming sterile neutrino analysis.

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## Status of ICARUS NuMI interaction cross-section analyses

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The ICARUS experiment, utilizing Liquid Argon Time Projection Chamber (LAr TPC) technology, has been installed at Fermilab, following its initial operation in Italy and subsequent refurbishment at CERN. ICARUS has successfully been taking physics data at Fermilab since June 2022. While the experiment's primary objective is to function as the far detector of the Short Baseline Neutrino program (SBN), searching for hints of physics beyond three-flavour PMNS neutrino oscillations, ICARUS also offers other diverse physics capabilities, including searches beyond the standard model and measurements of cross-sections. In addition to being exposed to the common Booster Neutrino (BNB) beamline of the SBN experiment, ICARUS receives neutrinos from the Main Injector (NuMI) beam. Due to the off-axis angle between NuMI and ICARUS, coupled with contributions from both pion and kaon decays to neutrino fluxes, interactions of NuMI neutrinos within ICARUS can be detected over a range of several GeV in energy. Measurements of these interactions present unqiue opportunities to infer neutrino interaction cross sections on an argon nuclear target within an energy range that overlaps both the SBN oscillation search and a significnat portion of the DUNE spectrum. This poster will summarize the current status of ICARUS' muon-neutrino cross-section measurements, highlighting our first analysis where the signal is defined by events with no pions produced in the final state of the interaction and correlations between an outgoing lepton and proton are measured.

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## Search for a Long-Lived ⊠⊠ Resonance at ICARUS in SBN

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The ICARUS detector in the SBN program at Fermilab is sensitive to "long-lived" new physics particles that would be produced in the Neutrinos at the Main Injector (NuMI) beam and decay inside the ICARUS liquid argon time projection chamber (LArTPC). We show results from a new analysis in ICARUS which searched for a long-lived particle produced in kaon decay which decays to two muons. The search is performed with an exposure of 2.41e20 protons on target in the NuMI beam. It is sensitive to new areas of parameter space for the Higgs portal scalar and an axion-like particle model. The sensitivity is also presented in a model-independent way applicable to any new physics model predicting the process $K \longrightarrow \pi + S(\longrightarrow \mu\mu)$, for a long-lived particle S. This 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.

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## Evaluating the Effects of Detector Modeling Uncertainties on Sterile Neutrino Oscillation Sensitivities with the ICARUS Detector

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The ICARUS T600 LArTPC detector was refurbished after an initial run at the underground LNGS labs and is currently taking data within its experimental hall at Fermilab after full commissioning. Regular data taking began in May 2021 with neutrinos from the Booster Neutrino Beam (BNB) and the Neutrinos at the Main Injector (NuMI) off-axis beam. As the far detector of the Short-Baseline Neutrino (SBN) Program, the ICARUS detector's capability in searching for both muon neutrino disappearance and electron neutrino appearance will allow for unprecedented sensitivity to light sterile neutrinos with eV-scale mass. The ultimate sensitivity of the detector to sterile neutrino oscillations depends on the understanding of the detector response and the uncertainties remaining after calibrating the detector model. This poster will review how detector-model-related uncertainties are quantified, evaluated and their impact on expected sterile neutrino oscillation sensitivities using the existing ICARUS data. The work pursued here is broadly applicable to other ICARUS analysis pathways such as neutrino-argon cross-sections and Beyond the Standard Model physics searches. It will finally discuss improvement pathways to reduce the systematic uncertainties to the level needed for the joint sterile neutrino oscillation analysis with the Short Baseline Near Detector (SBND) within the SBN Program.