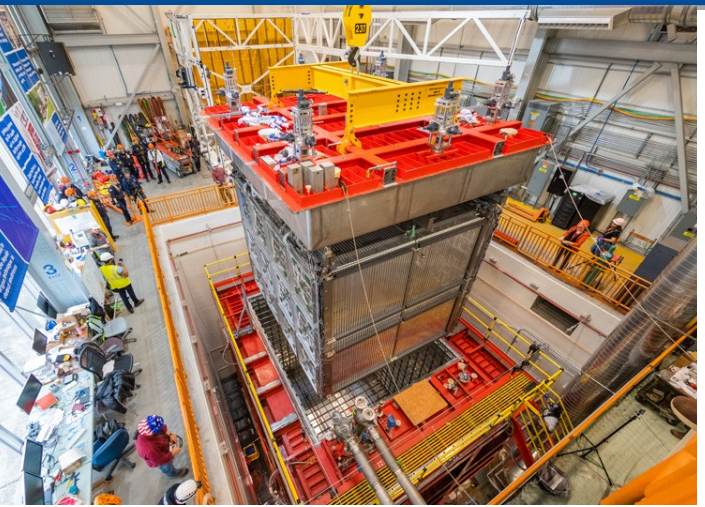
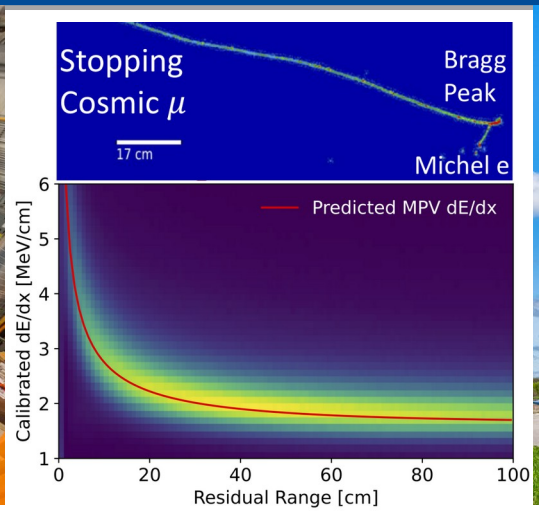




SBND Calibration Plan

Mike Mooney (Colorado State University)

SBND Operations Readiness Review

February 21-22, 2024

Colorado State University

SHORT-BASELINE NEAR DETECTOR SBND

Introduction

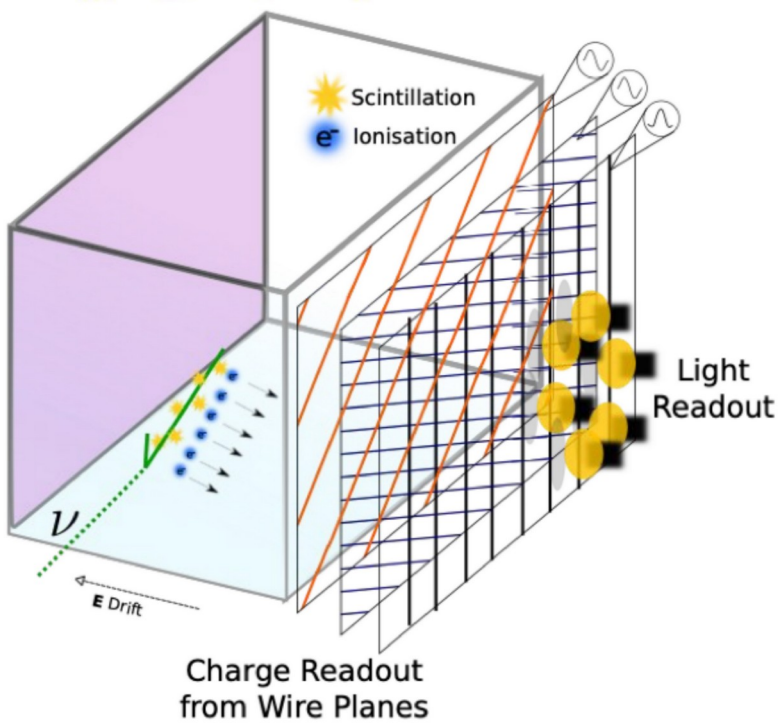
- This talk presents the SBND calibration plan, addressing following ORR charge questions:
  - (ORR Charge Q3) Is there a well-understood run plan for the remainder of FY24, consistent with the planned accelerator schedule and performance, with adequate resources for efficient/safe running of experiment?
  - (ORR Charge Q4) Are there well-developed plans for data processing and analysis?
  - (ORR Charge Q5) Are there clear goals set for reporting and publishing the results from the experiment in a timely fashion?
- Who am I: co-convener of SBND and ICARUS Calibration Working Groups, former MicroBooNE Run Coordinator during first neutrino beam data-taking (2015–2016)

Calibrations Toward First Physics

- Must plan on doing following “well”:
  - Particle identification (PID) for muons/pions vs. protons
  - Energy measurements of muons/protons (by range, multiple Coulomb scattering, calorimetry)
  - Measure angles of muons/protons
  - Estimation of trigger efficiencies

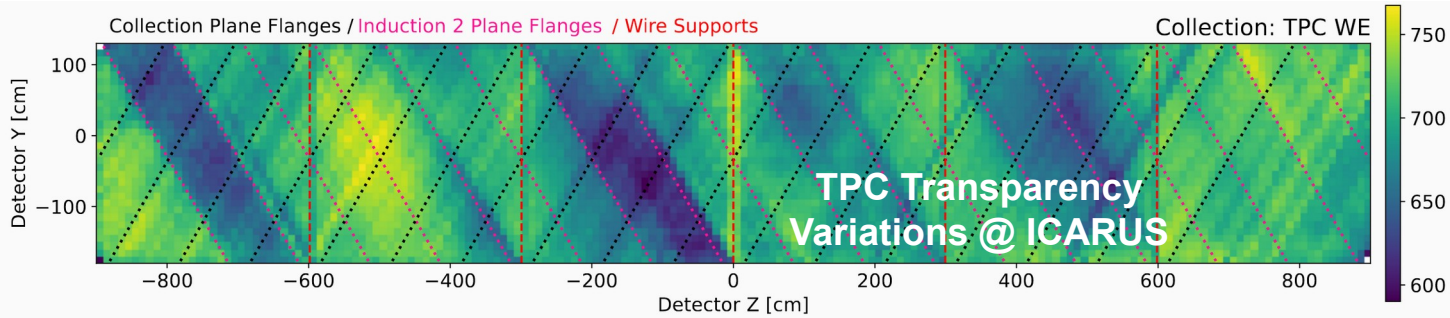
Specific Detector Calibrations of Interest

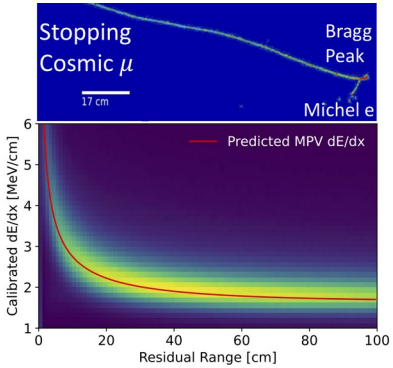
- Calibrations motivated by considerations on previous slide:
  - TPC energy scale – including gain, non-uniformity and angle-based corrections, electron lifetime, validation of recombination and wire signal shape
  - E field distortions such as space charge effects
  - PDS gain, timing, light yield
  - CRT gain, timing
- All of these calibrations should be achievable **by end of this summer** with current plan



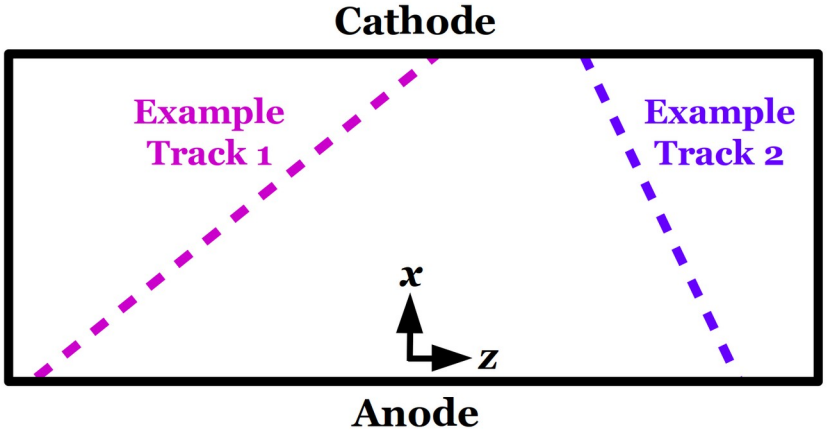
Lessons Learned from MicroBooNE, ICARUS, ProtoDUNE-SP

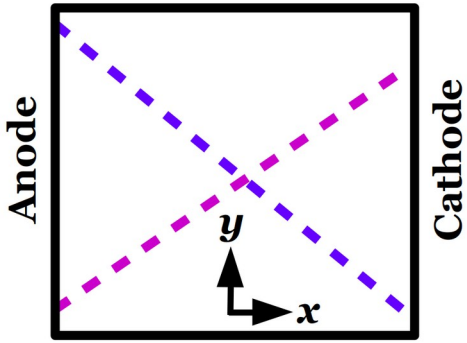
- Biggest lesson from previous LArTPC experiments: significantly leverage **cosmic muon data** while probing **diverse set of particle species** (e.g. protons, photons from neutral pions)
  - Make sure to take enough data in case of unexpected issues (see below), store on disk for fast access
  - Also very useful to have charge injection (pulser) for TPC electronics calibrations (gain, shaping time)
- Calibration plan at SBND largely focuses on comprehensive use of cosmic muons
  - Anode-cathode-crossing muons → utilize for **drift-dependent measurements** (e.g. electron lifetime)
  - Known dE/dx vs. residual range for stopping muons → **pin down charge scale**

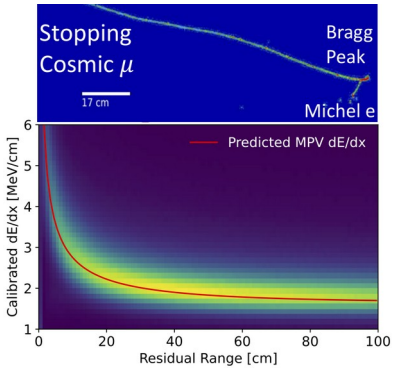




Details of Cosmic Muon Track Selection







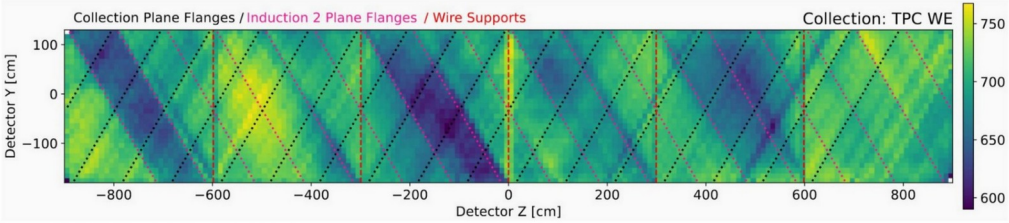
- Obtain sample of “anode-cathode-crossing tracks” by selecting tracks with maximum drift time consistent with charge traveling from cathode to anode
  - Can select with either prompt nearline 2D reconstruction (used by commissioning team) or precise offline 3D reconstruction (used for final calibrations and physics measurements)
- Also pick out stopping muons by selecting tracks with “Bragg peak” at end of track
- t_0 tag comes from TPC alone by **matching tracks from two drift volumes across cathode**

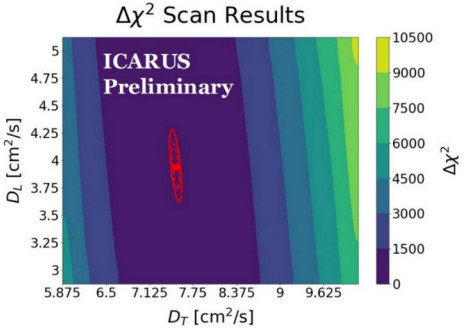
Calibration Workflow

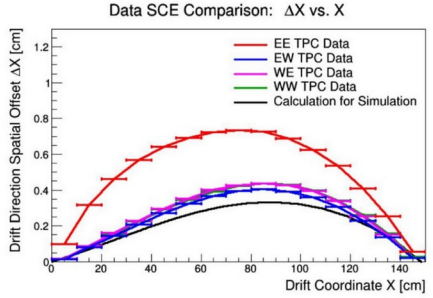
ORR Charge Q3/Q4

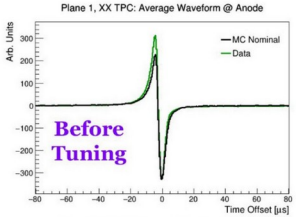
- Current calibration workflow in use for both SBND and ICARUS for majority of calibrations:
  - Procure sample of anode-cathode-crossing muons and stopping muons (see previous slide)
  - Store associated track/hit/waveform information in compact **calibration ntuple** (flat ROOT ntuple)
  - Produce calibration ntuples with standard reprocessing of data and MC production
    - Includes off-beam triggers, w/ O(100k) events during commissioning and O(1M) over Summer 2024
  - Also take pulser data to study TPC electronics response; procure protons, neutral pions, Michels, etc.
- Benefits of using calibration ntuples for calibrations:
  - Same scheme at both ICARUS and SBND, ensuring **uniformity of calibration approach across both detectors** (toward eventual SBN-wide measurements) and potential sharing of human resources, tools
  - Simple file format allows even new students to get involved meaningfully in calibration program (no need for LArSoft expertise, simply exposure to ROOT/C++/Python)
  - Small size of calibration ntuples allows **millions of events to be stored on disk** (tens of TB)

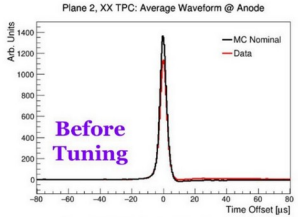
Use of Calibration Ntuples @ ICARUS

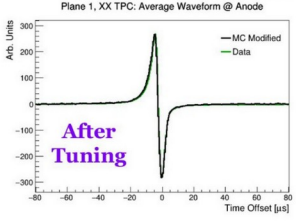


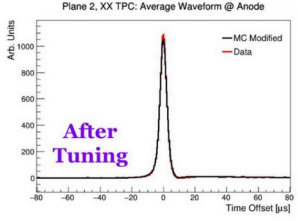


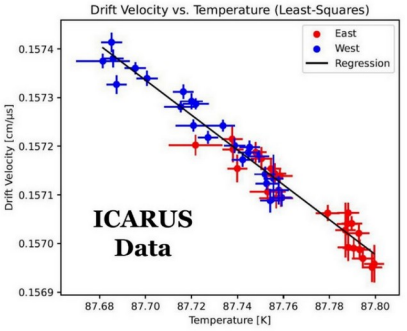


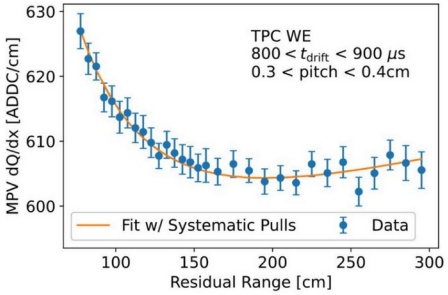






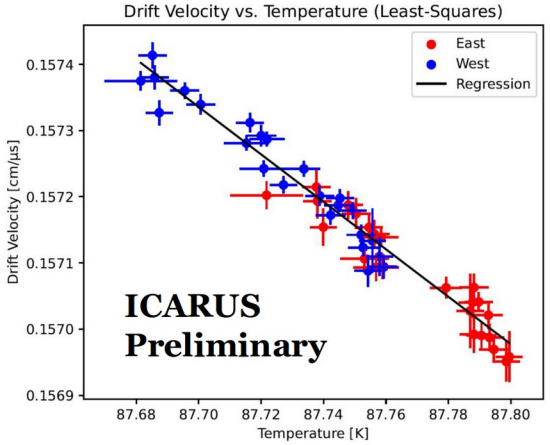


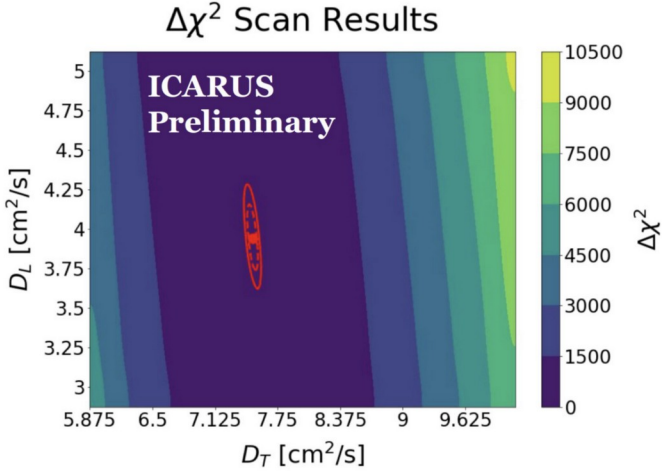




A lot of work has been carried out at ICARUS using the SBN-wide calibration ntuples workflow – experience/tools will be **essential** in getting early SBND calibration results!

LAr Property Measurements from ICARUS





- Hit ground running at SBND by updating simulation w/ ICARUS LAr property measurements:
  - Temperature dependence of ionization drift velocity at ~500 V/cm
  - Longitudinal/transverse diffusion measurements at ~500 V/cm
  - Track angle dependence of electron-ion recombination (studied using stopping protons) at ~500 V/cm
- **Improve upon LAr property measurements at SBND** during first year of data-taking

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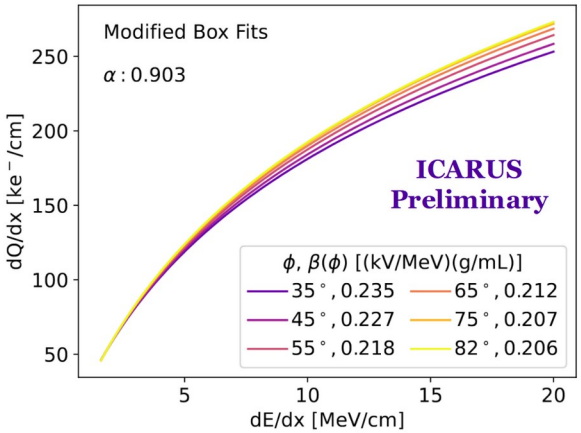

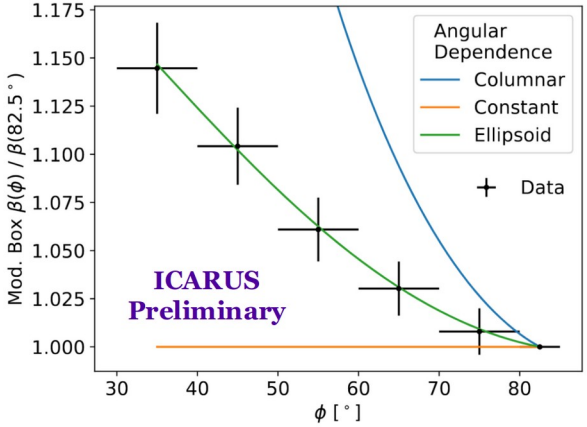

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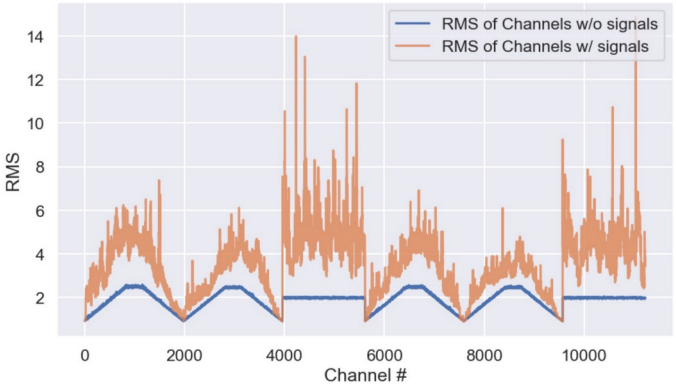
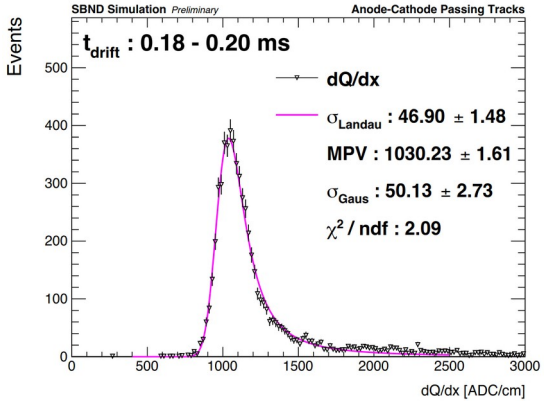
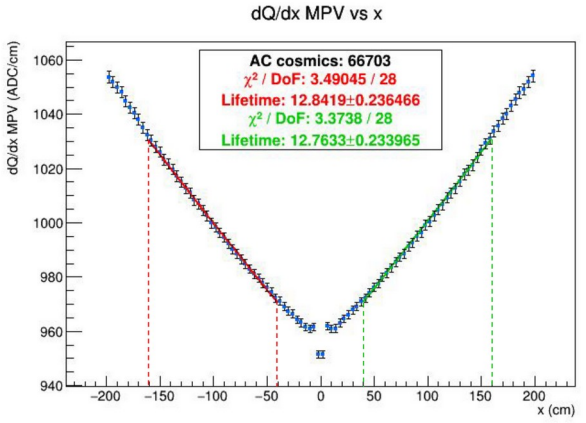
First SBND Calibration Studies w/ MC







- **SBND has already started a significant calibration effort**, including studies making use of calibration ntuples, via use of Monte Carlo simulation
  - First slide: TPC noise characterization (left), muon dQ/dx Landau x Gaussian fit (center), electron lifetime measurement (right)
  - Second slide: measurement of space charge effects in drift direction (left), recombination measurement using both muons and protons (center), single photoelectron amplitude measurement for PMTs (right)

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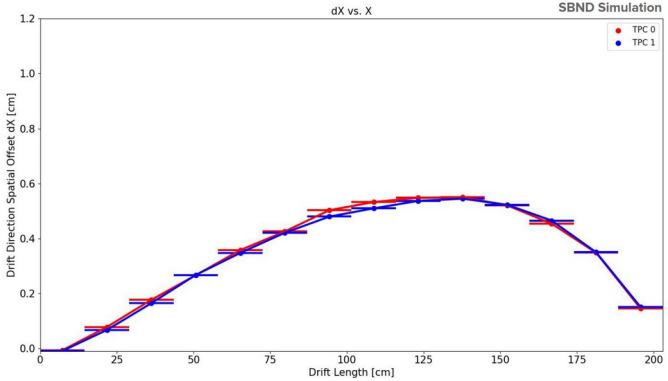

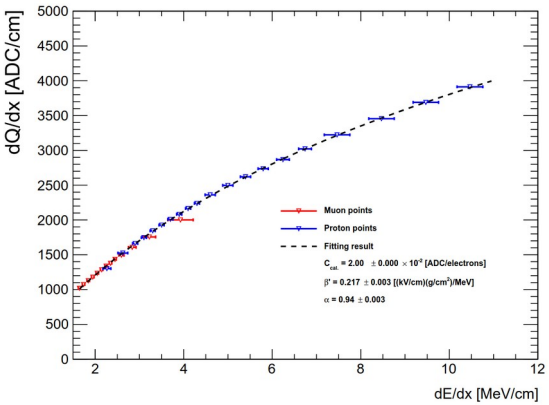

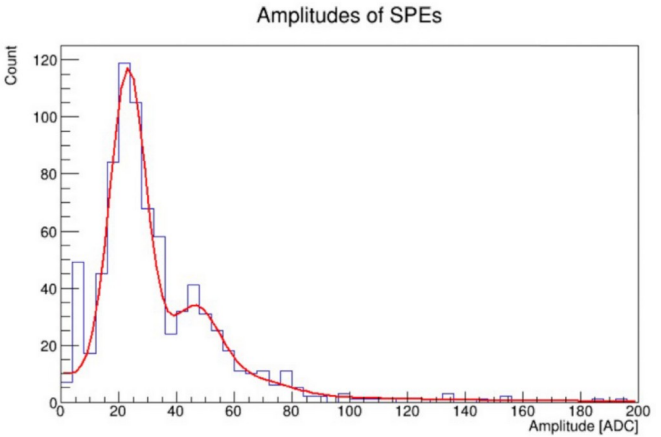

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SBND Calibration Task List

ORR Charge Q4

- In preparation for first data-taking, have been preparing list of calibration tasks and assigning tasks to collaborators
  - Robust amount of people involved in effort, including graduate students, postdocs, and scientists
  - Broad involvement across collaboration in terms of expertise (different detector subsystems)
  - Broad Involvement across collaboration in terms of (many) different institutions
- Coordinating discussions in SBND Calibration Working Group Meetings (weekly)
  - Co-conveners: Mike Mooney, Linyan Wan
  - A lot of progress already (see previous slides)

Workforce Training for SBND Calibrations

ORR Charge Q4

- Have been preparing the workforce for SBND calibrations through a couple of workshops
  - First one hosted in UK at University of Sheffield (see above)
  - Another one planned in the US at Fermilab sometime in March or April
- Hands-on tutorials/examples exist for students/postdocs to get ramped up to speed quickly
- One-on-one mentoring from Mike Mooney and Linyan Wan on various calibration projects

Interfaces w/ Commissioning

- Some overlap between commissioning and first calibration goals for experiment
  - Commissioning goal: ensure SBND detector is ready to collect physics-quality data
  - Calibration goal: ensure we are ready to analyze first physics-quality data toward producing first SBND results
- Commissioning team and Calibration Working Group are closely coordinating to make sure that first detector calibrations can emerge while detector is successfully commissioned
  - Techniques used for prompt 2D reconstruction approach for commissioning can be translated to full 3D reconstruction for final calibrations, and vice versa
  - Overlap in personnel between commissioning and calibration efforts
    - Includes transition plan from commissioning to calibration for some people

Interfaces w/ Detector Monitoring

ORR Charge Q3

- Calibration ntuples used for SBND calibrations can also be used in nearline/offline monitoring of detector → *complementary* to online monitoring
  - Relevant for things that can not be addressed easily with online monitoring, e.g. 3D effects (like E field distortions due to space charge effects) that require full track reconstruction
  - In short-term, calibration effort will check quantities of interest (e.g. transverse spatial offsets of cosmic muon track end points near detector edges) regularly to check for unexpected changes in detector condition
  - Long-term plan is to have *semi-automated workflow* that updates reference plots (stored on a webpage, for instance)
- Also planning use of calibration ntuples in CI Validation / offline data quality monitoring (DQM)
  - Effort started already for ICARUS, can easily extend to SBND

Summary

- Addressed following ORR charge questions in this presentation:
  - (ORR Charge Q3) Is there a well-understood run plan for the remainder of FY24, consistent with the planned accelerator schedule and performance, with adequate resources for efficient/safe running of experiment?
    - Planned data-taking including off-beam triggers will provide *plenty of cosmic muons for calibrations*, with minimal interference to commissioning effort and while aiding detector monitoring
  - (ORR Charge Q4) Are there well-developed plans for data processing and analysis?
    - *A full team* of students, postdocs, and scientists have been assembled/trained to carry out many needed calibration tasks, with calibration workflow in place and *already being exercised*
  - (ORR Charge Q5) Are there clear goals set for reporting and publishing the results from the experiment in a timely fashion?
    - First calibrations should be ready by end of summer (to be reported in a *SBND detector performance paper* on a similar timeline), enabling SBND to produce first public physics results *promptly*