THE MICROBOONE EXPERIMENT
RALITSA SHARANKOVA    TUFTS
ON BEHALF OF THE MICROBOONE COLLABORATION

ICHEP 2020
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The SBN Program At FNAL

- **Main physics goals**
  - Investigate the MiniBooNE “low energy excess” hinting at BSM
  - Neutrino x-section measurements towards DUNE
- **Detectors: Liquid Argon Time Projection Chamber (LArTPC) technology**
  - MicroBooNE (in operation since Dec 2015)
  - SBND (under construction) and ICARUS (commissioning)
- **Talks on MicroBooNE physics by** David Caratelli, Raquel Castillo Fernandez, Mark Ross-Lonergan, Pawel Guzowski, Wouter Van De Pontseele, Owen Goodwin
The MicroBooNE Experiment

- 89 ton LArTPC detector
- Excellent spatial resolution
- Good calorimetry: dE/dx
- Longest operating LArTPC experiment in US (since Oct 2015)
- Pioneering work in data processing, calibration, detector physics, reconstruction
Working Principle Of LArTPCs

- Charged particles ionize Ar
- Ionization e⁻ drift in electric field towards anode plane

E field: 273 V/cm
e⁻ drift: ~0.1 cm/μs
2.3 ms for full drift distance
Working Principle Of LArTPCs

- Charged particles ionize Ar
- Ionization e drift in electric field towards anode plane
- Signal read out by 8256 wires on 3 wire planes
Charge Signal Formation
Observing Light In MicroBooNE

- Charged particles ionize Ar
  - Produce isotropic UV scintillation light
  - Observed by photon detection system

Light collection system records LAr scintillation
Characterizing And Calibrating TPC Response

- Pioneering work by MicroBooNE in multiple areas
  - Noise filtering  \cite{JINST12P08003}
  - Wire response modeling (dynamic induced current effect)
  - Signal deconvolution  \cite{JINST13P07006,JINST13P07007}
  - Space charge effects (SCE) and E-field calibrations
    - data-driven correction maps with UV laser and cosmic ray data
- Charge and energy calibration with crossing muons and protons  \cite{JINST15P03022}

![Before noise removal](image1)

![After noise removal](image2)

**Signal deconvolution**

**dQ/dx with/without uniformity calibration**

\*Experiment 07/28/2020\*
Event Reconstruction Development

- Multiple independent reconstruction frameworks
  - Pandora: pattern recognition in 2D and 3D  \cite{Eur. Phys. J. C, 78:82, 2018}
  - Wire-Cell: tomographic imaging in 3D  \cite{MICROBOONE-NOTE-1083-PUB}
  - Deep Learning: combination of Convolutional Neural Networks and standard clustering/tracking
    - CNN for pixel labeling  \cite{PRD 99, 092001, 2019}
    - CNN for particle ID  \cite{MICROBOONE-NOTE-1081-PUB}
    - 3D tracking  \cite{FERMILAB-PUB-20-073-ND, arXiv:2002.09375}
- Software development being applied to SBND, ICARUS and DUNE
Talk Outline

- Measuring and calibrating Space Charge Effects (SCE)
- Calibrating PMT gain
Understanding Space Charge Effects

- Large CR flux & E field lower than design: lots of slow-moving Ar ions
- Space charge effects (SCE):
  - Spatial distortion of drift $e^-$ => tracks/showers appear “bent”
  - Local E-field distortions
- Pioneering data-driven SCE/E-field measurement & calibration
  - **Laser UV system**: tracks through multi photon ionization \textit{JINST} 15, P07010 (2020)
  - Cosmic rays
  - Complementary coverage

Muon track reconstructed entry/exit points
Near cathode points deviate from TPC boundary (dashed line) due to SCE
The Laser Calibration System

- Two systems: upstream and downstream, identical layout
- 266 nm UV laser injected into TPC through feedthroughs & system of mirrors
  - rotation of mirror inside cryostat allows for detector volume scan
SCE Calibration With Laser Tracks

- Spatial distortions estimated between reconstructed track and expected laser trajectory

Deviations in reconstructed position (central slice)
SCE Calibrations With Laser Data

- E-field distortion estimated from local drift velocity

![Graph showing drift speed vs. E-field (kV/cm)]

E-field deviation from nominal (central slice)

![Images showing deviation of E-field components (Ex, Ey, Ez) from nominal values at Z = 518 cm)]
Talk Outline

- Measuring and calibrating Space Charge Effects (SCE)
- Calibrating PMT gain
Light Collection System Of Microboone

- 32 x 8” PMTs (Hamamatsu) behind TPB-coated acrylic plates
- Role of TPB: shift LAr scintillation wavelength to 430 nm (in PMT sensitive region)
- PMT analog signals-> splitters->preamp & shaper (60ns)->digitized at 64MHz
- Optical readout: 23.4 us at 64MHz
Uses Of Light In LArTPCs

- Most beam spills empty, contain only cosmic rays
- Light data is an important handle for CR rejection
  - Trigger: require PMT activity in time with beam=> drop trigger rate by factor x50
  - Matching of TPC energy deposit to light data
    - Reject TPC activity not consistent with beam-window PMT data
- Stable & well-understood light response is crucial
  - PMT gain as well as LAr light yield can vary with time
  - Calibrating light response over full data taking period an important task
PMT Gain Calibration

- Early on saw up to 30% deviation in gains for some PMTs
  - implemented procedural changes to minimize instabilities end of Run1
  - data/MC calibration important to ensure stability
- First time measuring PMT gain evolution in LArTPC over prolonged operation
  - valuable lessons for future LArTPC experiments
  - helps isolate & investigate other sources of light instability
Summary

- MicroBooNE is a LArTPC experiment, part of the SBN program at FNAL
  - Probing the LEE observed by MiniBooNE
  - Measuring neutrino x-sections
- MicroBooNE: pioneer in TPC calibration, reconstruction and detector physics
- Novel SCE calibration using UV laser and cosmic ray data
  - Mitigate effect on reconstruction of positive ion collection due to high cosmic activity
- Light data in MicroBooNE: powerful tool for cosmic ray rejection
  - PMT gain and light yield calibrations ensure stable response & good data/MC agreement
Backup slides
The Miniboone Low Energy Excess (LEE)

- MiniBooNE experiment: measured BNB neutrinos with a liquid scintillator detector
  - 4.6σ excess of $\nu_e$-like events in the 200-700 MeV region
  - Hint at BSM physics
  - Main BG: $\gamma$ mis-ID


Cherenkov detector:
e/γ disambiguation impossible
Why LArTPC?

- Merits of noble gas TPCs:
  - Highly-granular (very good resolution)
  - \( e/\gamma \) differentiation using distance from vertex & \( dE/dx \)
Why LArTPC?

- Why Argon?
  - Abundant (1% of atmosphere)
  - Easily ionizable (~55,000 e/cm)
  - Pure Ar: high e mobility (long drift lengths)
  - High scintillation yield (~40,000 photons/MeV)
  - Transparent to its scintillation
  - Affordable

Scalable: good candidate for next-generation detectors (DUNE)
Characterizing And Calibrating TPC Response

- Pioneering work by MicroBooNE in noise filtering
  - Final S/N after noise filtering ~40 on collection plane

JINST 12, P08003 (2017)
Characterizing And Calibrating TPC Response

- Pioneering work by MicroBooNE in
  - Wire response modeling (dynamic induced current DIC effect)
  - Signal deconvolution

U: small, bipolar
Y: large, unipolar

JINST 13, P07006 & P07007 (2018)
Characterizing And Calibrating TPC Response

- Charge and energy calibration using crossing muons and protons
- $dQ/dx$ uniformity correction from crossing muons
- Recombination correction with modified box model
- Pure sample of $\nu$-induced protons

![Graphs showing $dQ/dx$ and $dE/dx$ distributions for MicroBooNE simulation and data.](image)
LAr Scintillation

- LAr: very bright scintillator (order of 10k photons/ MeV of deposited energy)
- Two main mechanisms of scintillation
- 128 nm UV photons released at de-excitation

Self-trapped exciton luminescence

Recombination luminescence

Illustrations by Ben Jones
LAr Scintillation

- Excited states (excimers): Ar$_2^+$ core with bound electron
  - singlet state $\Sigma_u^1$
  - triplet state $\Sigma_u^3$

LAr is transparent to its scintillation!

- At de-excitation both states emit a $128$ nm wavelength UV photon
  - single state: decay time $\sim 6$ ns (prompt/fast light)
  - triplet state: decay time $\sim 1600$ ns (late/slow light)

The prompt:late light ratio is dE/dx dependent

$\sim 25:75$ for MIP

This can in theory be used for PID
PMT gain knowledge necessary for proper light response measurement

Measured PE = photon flux x QE x photosensor gain x LY instability effects

PMT gain depends on
- temperature
- operating voltage
- frequency of incident light

PMT gain measurements in MicroBooNE
- ~200 kHz of SPE noise (origin unknown)
- measured with physics data over 1-week periods and stored in database
- collect O(1 PE) pulses
- multi-PE fit to pulse amplitude and area distributions
PMT Gain Calibration Performance

- Simulated PE: \( N_{\text{simPE}} = A/20 \) ADC (const gain simulated)
- Calibrated PE: \( N_{\text{recoPE}} = A/g_A \)
- Gain calibration minimizes PMT-to-PMT differences
  - can measure remaining light yield instabilities independently

Residual of observed and simulated optical flash PE
(Flash PE in 30-200 PE range)
PMT Gain Measurements With SPE Pulses

- Pure SPE case: pulse shape constant (for each PMT) so area and amplitude correlated
- Area & amplitude multi-PE fits independent, but measured gains are correlated
  - fitting procedure robust