Data-driven light response calibration in MicroBooNE

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MicroBooNE Collaboration

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The MicroBooNE detector

- MicroBooNE is a large scale Liquid Argon Time Projection Chamber (LArTPC):
  - Short Baseline Neutrino (SBN) program
  - taking data since 2015 - collected > 200,000 $\nu_\mu$ neutrino interactions
  - longest continuously running large scale LArTPC detector

- Primary physics goal:
  - investigate low energy (200-600 MeV) excess anomaly observed by the MiniBooNE experiment
Use of light in MicroBooNE

- In MicroBooNE scintillation light is used to establish the timing of interactions:
  - providing trigger information to the detector readout system
  - allowing interactions in time with the beam spill to be distinguished from background cosmic activity
- MicroBooNE located on the surface:
  - large cosmic background
Photon detection system

- Primary photon detection system: 32 8” Hamamatsu R5912-02 MOD PMTs + TPB coated wavelength-shifting acrylic plates
- PMT waveform recorded without threshold for 23.4 μs in coincidence with the beam trigger
- Sampling 64 MHz (15.625 ns ticks), 60 ns electronics shaper response

Calibrating the light response

- Routine calibrations are required to:
  - ensure the stability of the photon detection system and understand its behaviour over time
  - use physical quantities (PE) when analysing the data
- PMTs gains calibrated continuously during detector running
- Data-driven calibration of light response variations over time in terms of light yield in PE / MeV

1. MeV → γ
2. photon transport
3. γ → PE
PMT gain calibration

- PMT continuous gain calibrations have been implemented:
  - gains calculated by fitting response to SPE noise, ~200 kHz SPE noise rate
  - gain fluctuations over time caused by combination of temperature, operating voltage and intensity/frequency of incident light
Data sample for light yield calibration

- Light response over time studied using a sample of cathode-piercing cosmic muons:
  - data between Mar 2016 – Jul 2018
  - tracks distributed throughout entire detector
  - minimally dependent on light for reconstruction
Light yield calculation

- Metric for light yield: number of PE per cm track length (minimally ionising through-going muons)
- Tracks sorted into time bins with equal statistics (varying bin width), and PE/cm evaluated using truncated median of distribution
Light yield variation over time

- Investigated variation over time in total light yield summed across all PMTs
- Significant variation in MicroBooNE’s light response is observed
  - total decline of ~45%
- Can investigate for possible causes of decline in the data:
  - provide greater understanding of the physics behind the decline
  - enable development of a data-driven calibration for the variation over time
Region-of-detector-dependence-like effects in data
Region of detector dependence

- If the light yield decline is dependent on the region of the detector that the tracks are in, could indicate dependence on the PMTs or the read-out from them in particular parts of the detector

- Detector divided into 5 regions in beam direction (z) corresponding to each set of PMTs, tracks selected that are contained within each region and PE summed across corresponding PMTs
Region of detector dependence

- Decline in light yield is approximately uniform throughout the entire detector along the beam direction:
  - independent of region of detector and of particular sets PMTs
  - cause of decline affecting the whole detector
- Possible cause: degradation of TPB
  - would affect all PMTs at the ~same rate
  - however, would expect decline to be more uniform over time
Contamination-of-argon-like effects in data
Propagation distance dependence

- Sample binned by midpoint of tracks in drift direction (x)
- Range investigated limited geometrically, all tracks crossing cathode

- Small photon propagation distance dependence:
  - could indicate light being absorbed or scattered during propagation by some contaminant in the argon
Prompt vs late light

- Scintillation in argon has two components:
  - prompt light, $\tau \sim 6$ ns
  - late light, $\tau \sim 1.6$ μs

- Quenching of late light:
  - contaminants could quench the slow component of the scintillation light
  - effect in data: increase to the fraction of prompt light (100 ns) to total light (3 μs)
  - possible contaminants: N$_2$, O$_2$, H$_2$O
Prompt vs late light

- Fraction of prompt light to total light over time:
  - ~10% increase over period investigated
  - most rapid increase corresponds to most rapid light yield decline

- Potential quenching of slow component:
  - could indicate presence of impurities
  - amount insufficient to account for entire light yield decline, other factors such as absorption/scattering must also contribute

- Investigation into evolution of the average waveforms over time is on-going
Argon purity

- $\text{N}_2$, $\text{O}_2$ and $\text{H}_2\text{O}$ levels monitored continuously using gas analysers:
  - electron lifetime approximately constant; $\text{O}_2$ and $\text{H}_2\text{O}$ levels do not vary over time
  - $\text{N}_2$ monitoring system suggests level is very low and approximately constant over time
Summary

• In the process of developing a full data-driven calibration chain for the light response in MicroBooNE

• MicroBooNE light response observed to vary significantly over time:
  – declines by ~45% in the data sample investigated between 2016 and 2018
  – indications in data suggest decline caused by the introduction of a contaminant into the Argon
  – $N_2$, $O_2$ and $H_2O$ levels all monitored and steady over time
  – investigations into the nature of this contaminant are on-going

• MicroBooNE is the longest continuously running large scale LArTPC experiment and the understanding gained from it is directly useful for the SBN program and future detectors:
  – long term stability of the light response in LArTPC detectors
  – techniques for calibration of variations in light response over time
Back-up
Data sample

- Distribution of cathode piercing tracks in beam direction (z):
Data sample

- Distribution of cathode piercing tracks in drift direction (x):
Individual PMTs

- Tracks selected that are contained within $z = +/- 50cm$ of the centre of each PMT
- PMTs in each row compared to avoid bias due to tracks originating from top of detector
Individual PMTs

- Approximately uniform overall light yield decline of 40-50% for each individual PMT
- Some PMT-by-PMT fluctuations in rates, especially at early times, but overall trend ~uniform
Argon Purity

- Electron lifetime approx constant:
  - $O_2$, $H_2O$ levels constant
  - rapidly recovers from any periods of lower purity
  - note: values not space charge corrected