DETECTOR PHYSICS WITH MICROBOONE

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ON BEHALF OF THE MICROBOONE COLLABORATION

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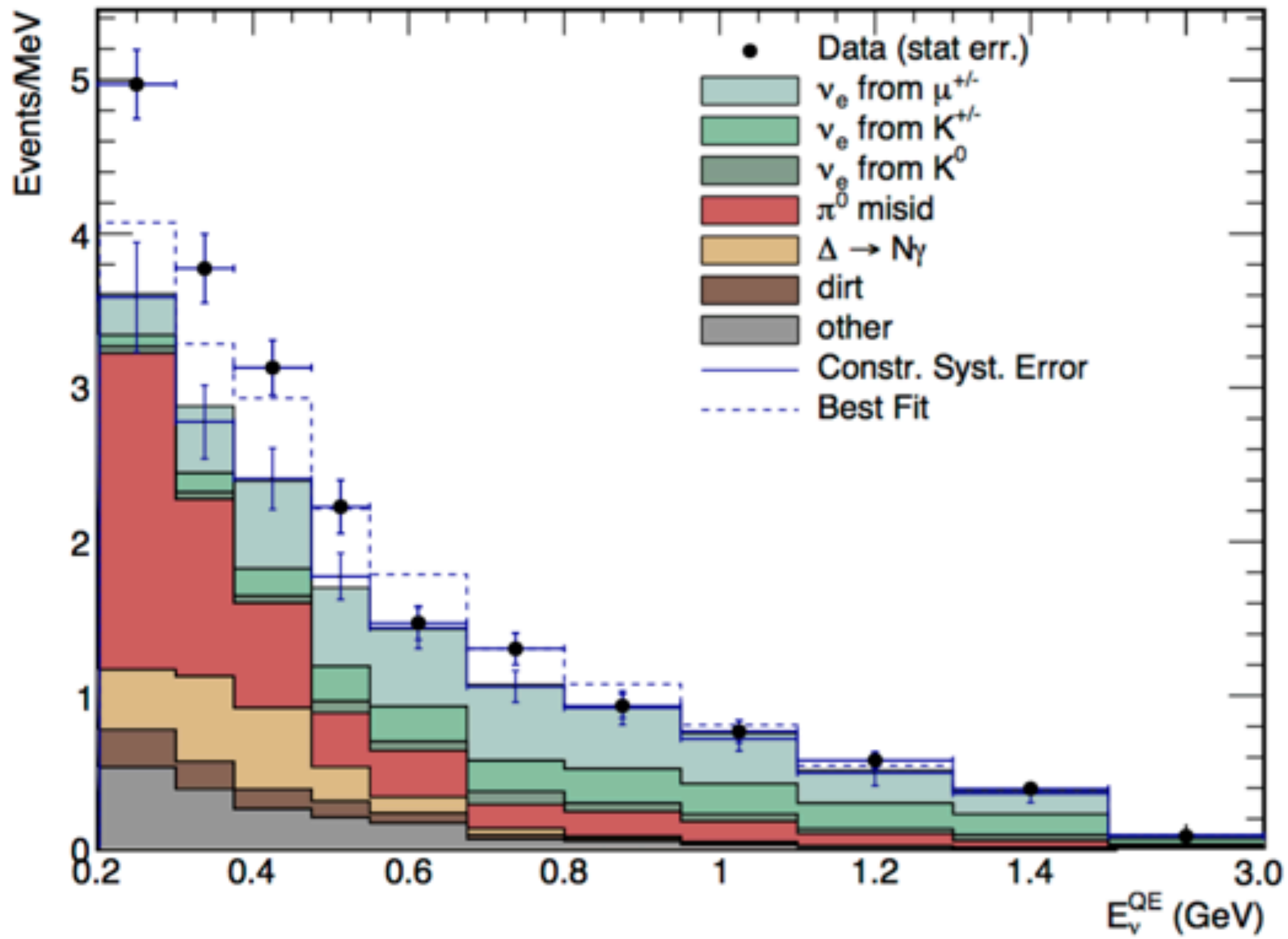
6 August 2019

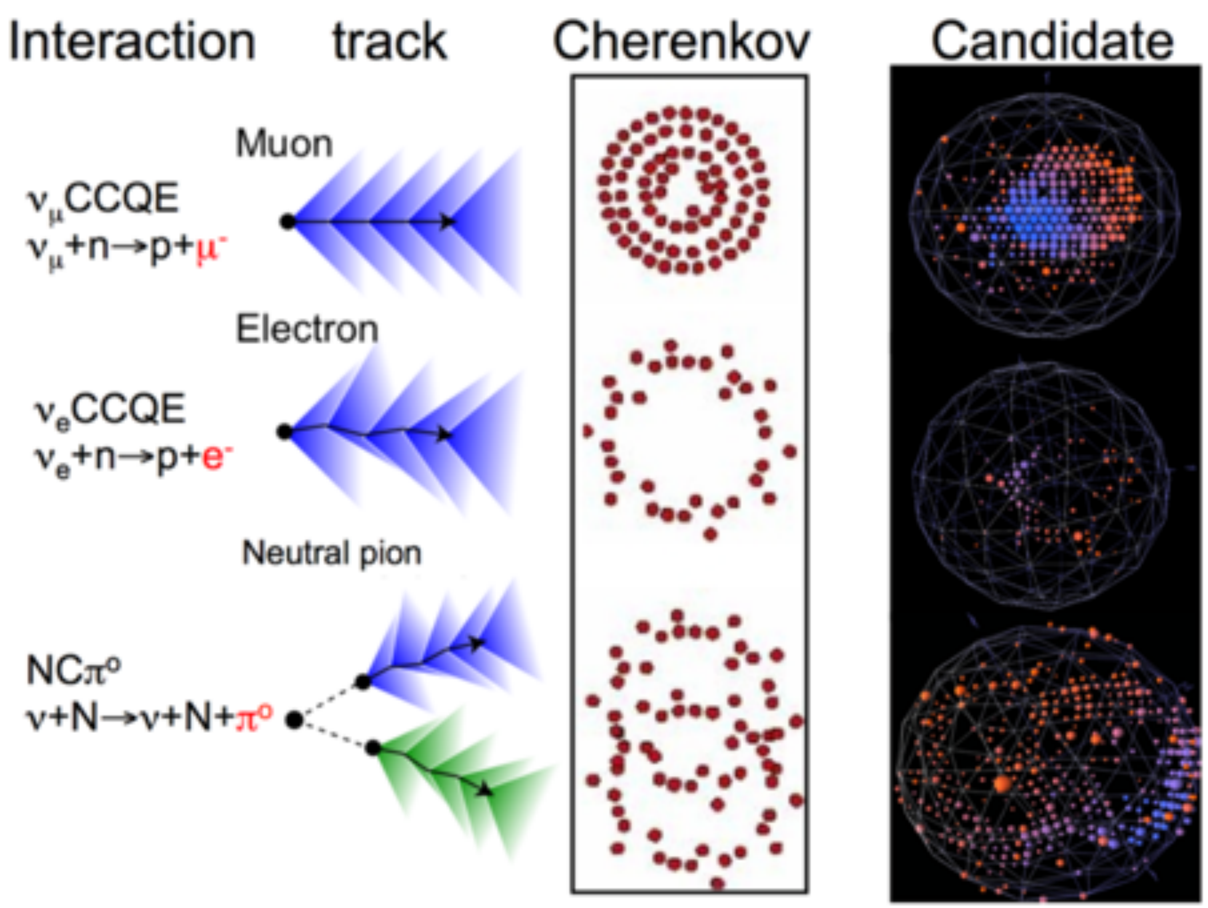
The MiniBooNE "Low Energy Excess"

- MiniBooNE result
  - 4.6σ excess of νe-like events in the 200-700 MeV region
  - hint at BSM physics
  - main BG: γ mis-ID

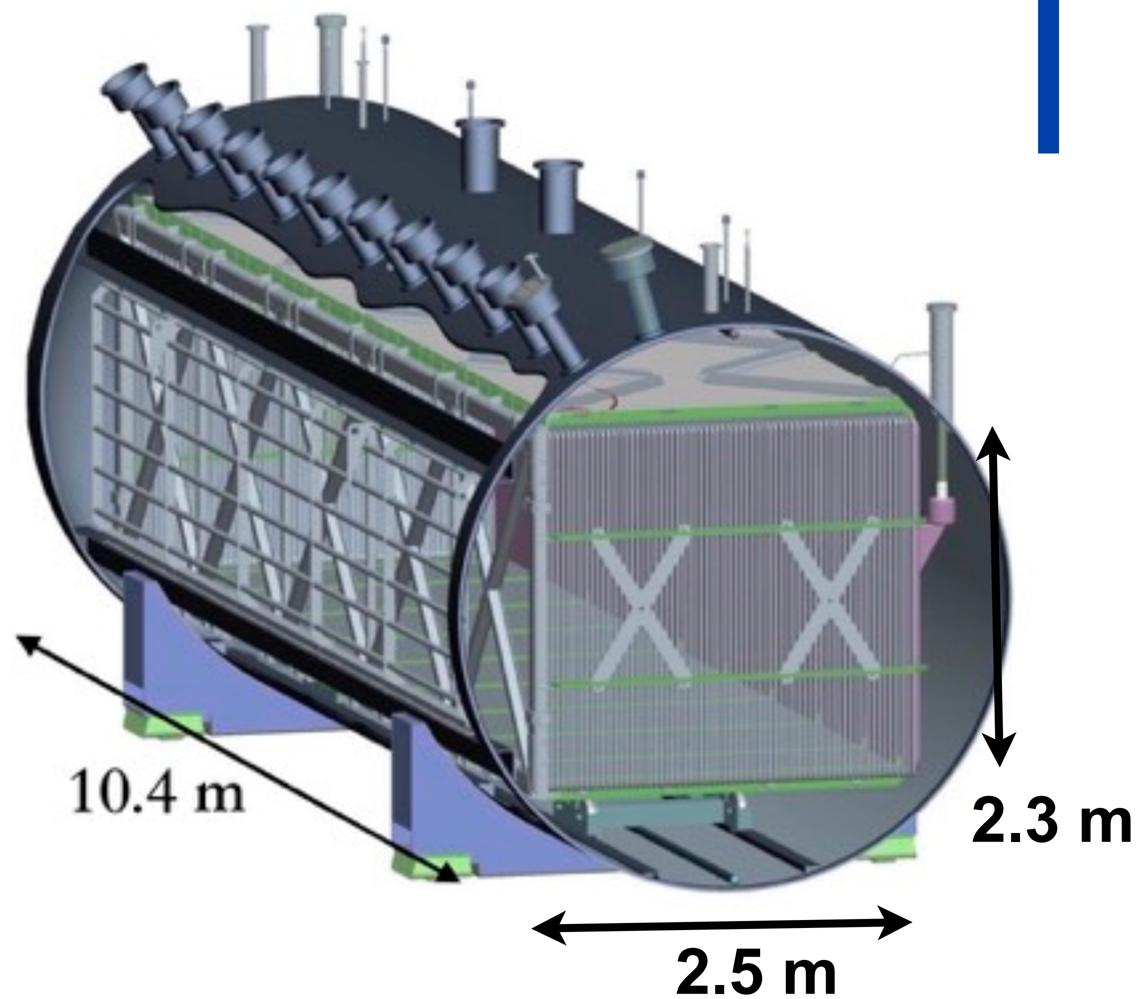
Phys. Rev. Lett. 121, 221801 (2018)



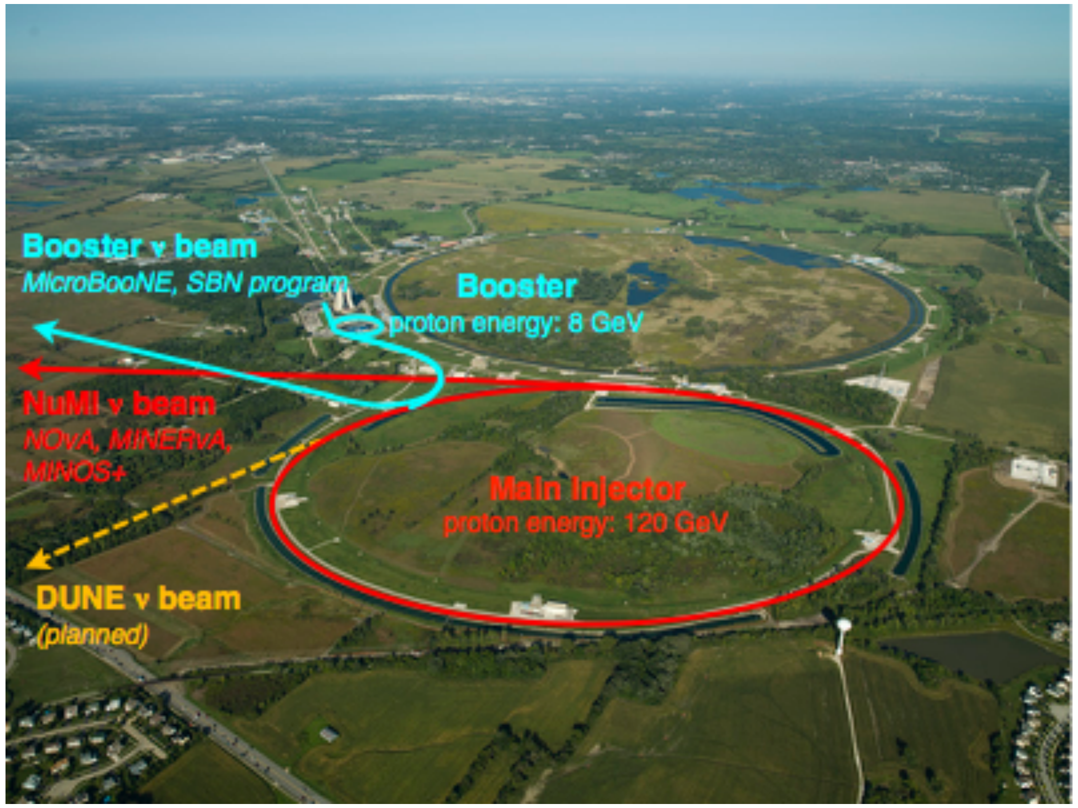
Cherenkov detector:
e/γ disambiguation impossible



The MicroBooNE Experiment

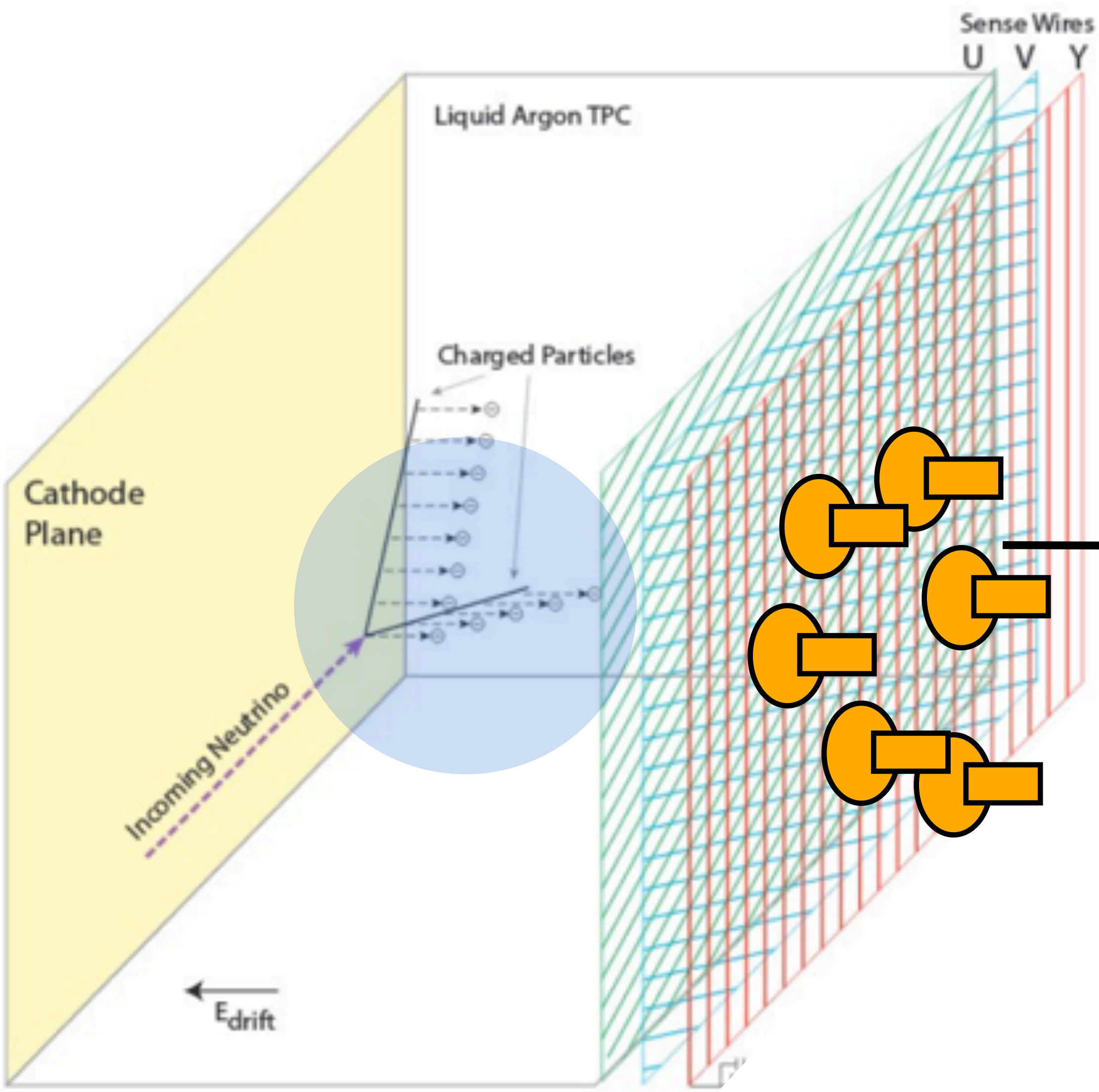


- Aim to investigate the MiniBooNE LEE & probe for evidence of neutrino oscillation at $\Delta m^2 \sim 1.1$ eV
- Using the same BNB beam
- Liquid Argon Time Projection Chamber (LArTPC) technology
  - excellent spatial resolution: detached shower distinguishable
  - good calorimetry: ***dE/dx*** e/γ
- Surface detector: CRs are a challenge
  - can reject using ***scintillation light***
- Understanding & calibrating detector response is crucial

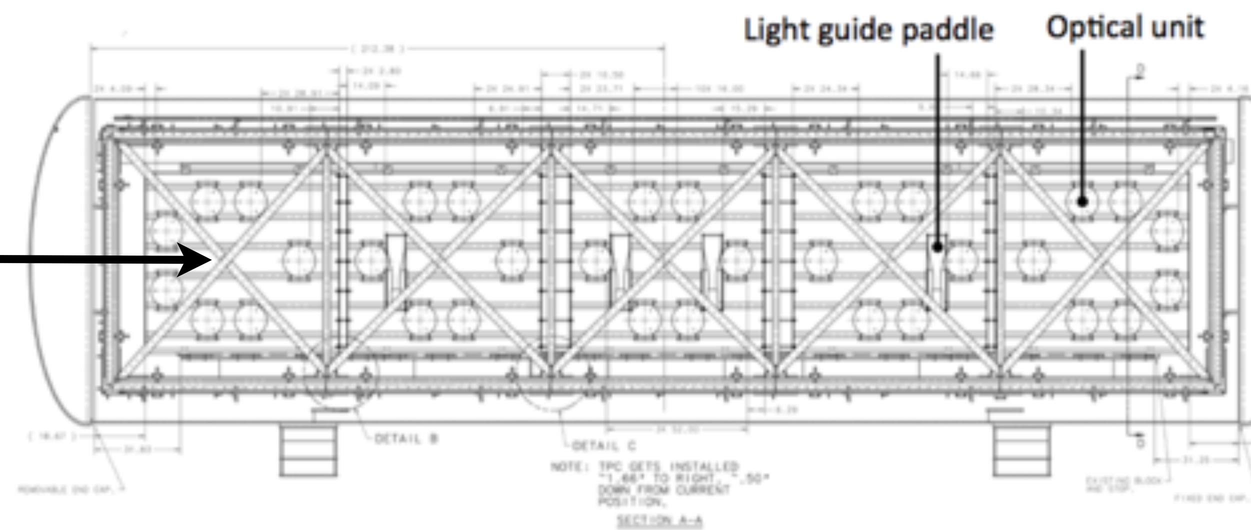


Working Principle Of LArTPCs

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

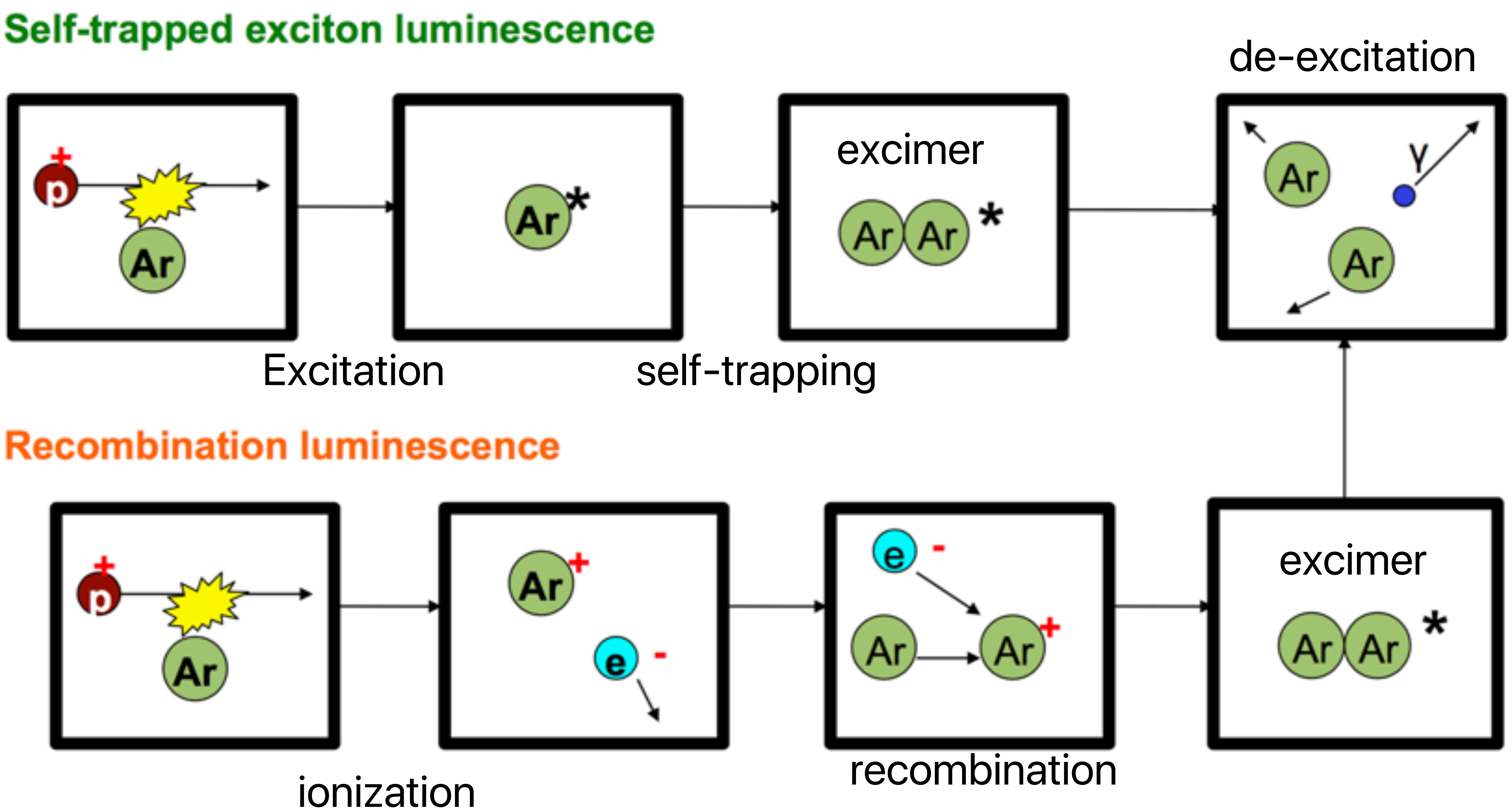


Light collection system records LAr scintillation



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

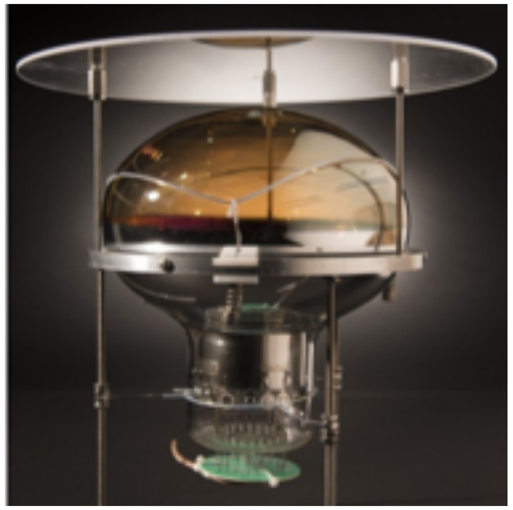


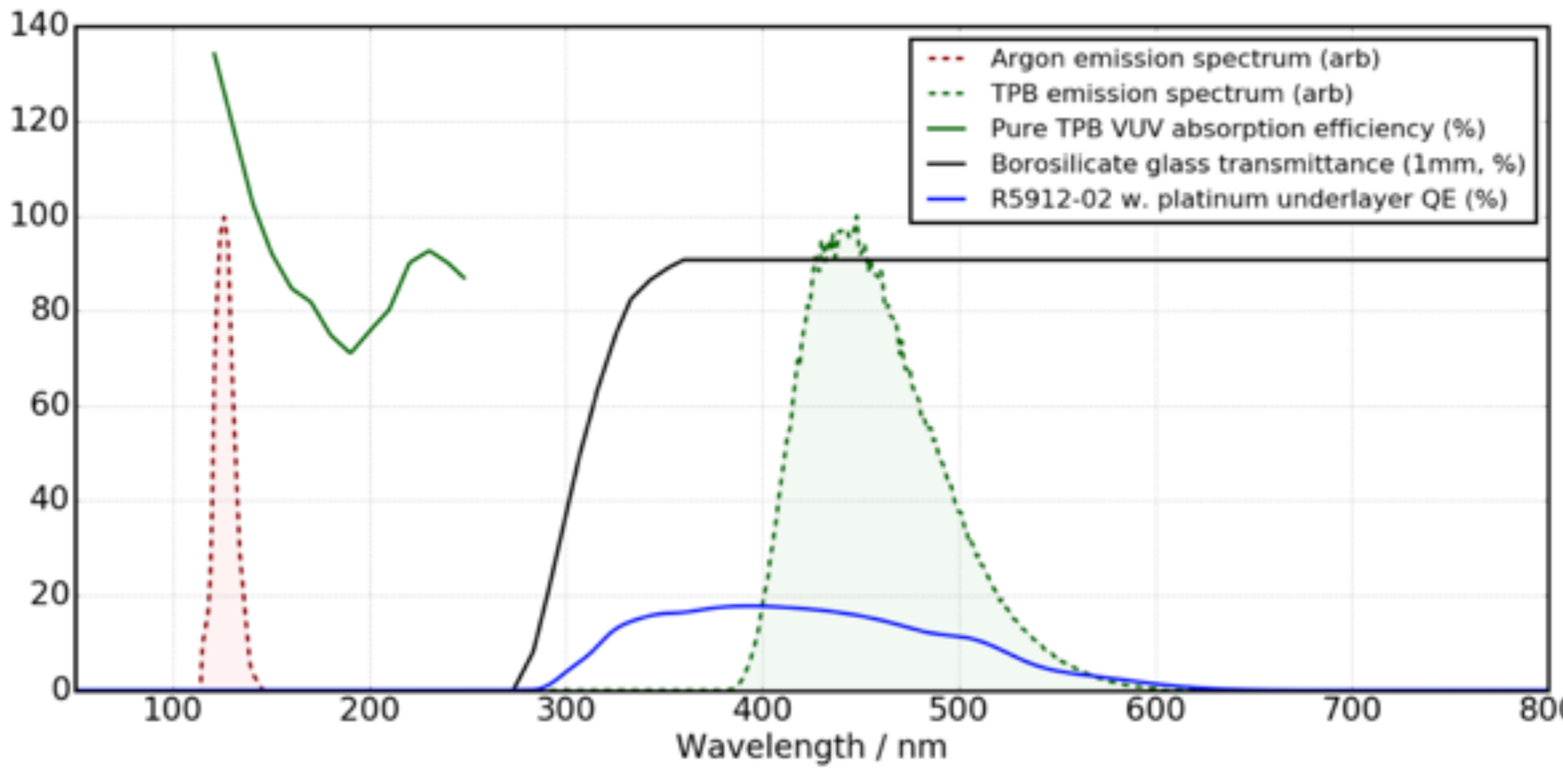
Illustrations by Ben Jones

Light Collection System Of MicroBooNE

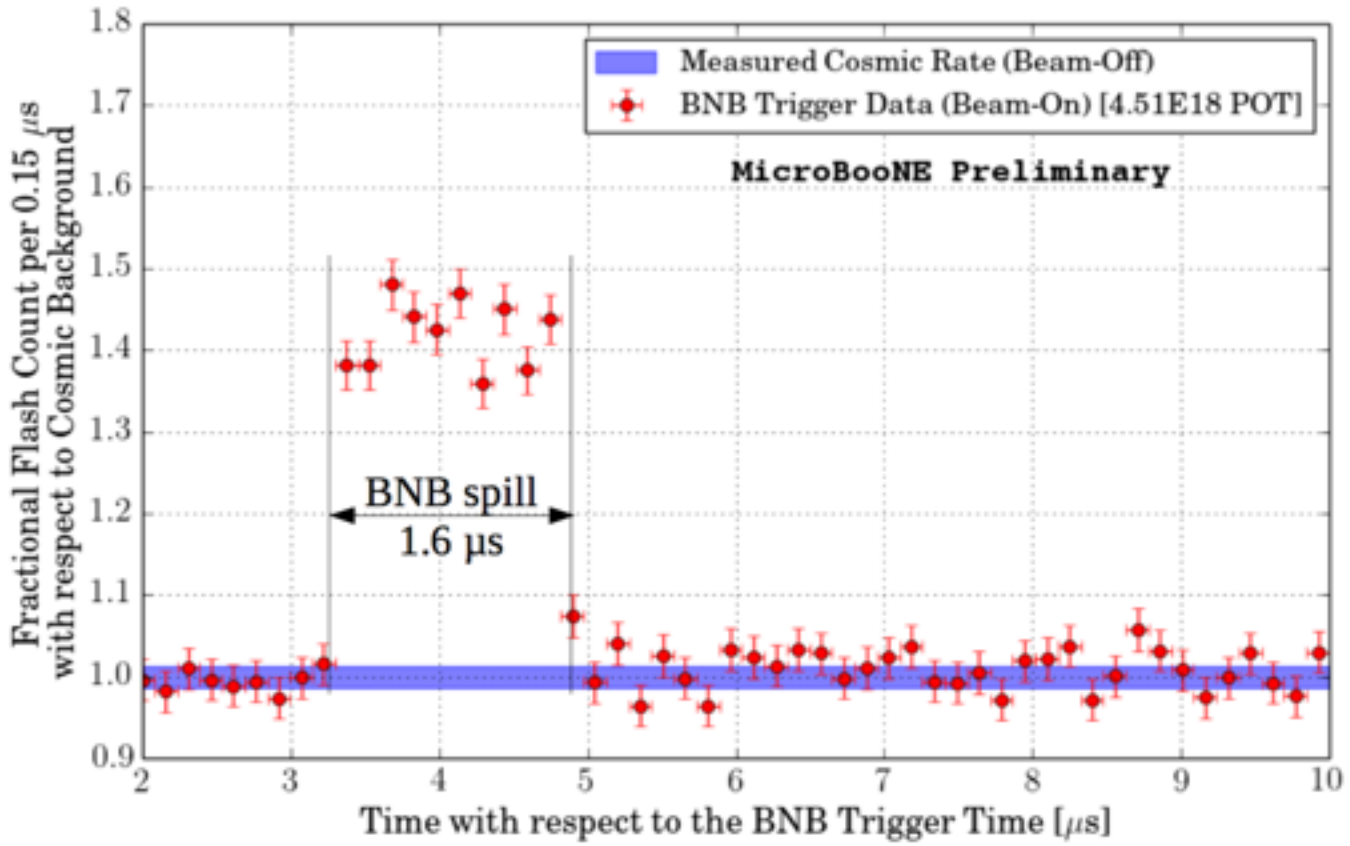
- 32 x 8 in PMTs (Hamamatsu) behind TPB-coated acrylic plates
- 5 rosettes on frame behind TPC readout wire planes
- Role of TPB: shift LAr scintillation wavelength to 430 nm (in PMT sensitive region)
- PMT analog signals-> splitters->preamp & shaper (60ns)->digitized at 64MHz
- Optical readout
  - unbiased, 1500 samples (23.4 us) coincident with beam spill

TPB-coated plate





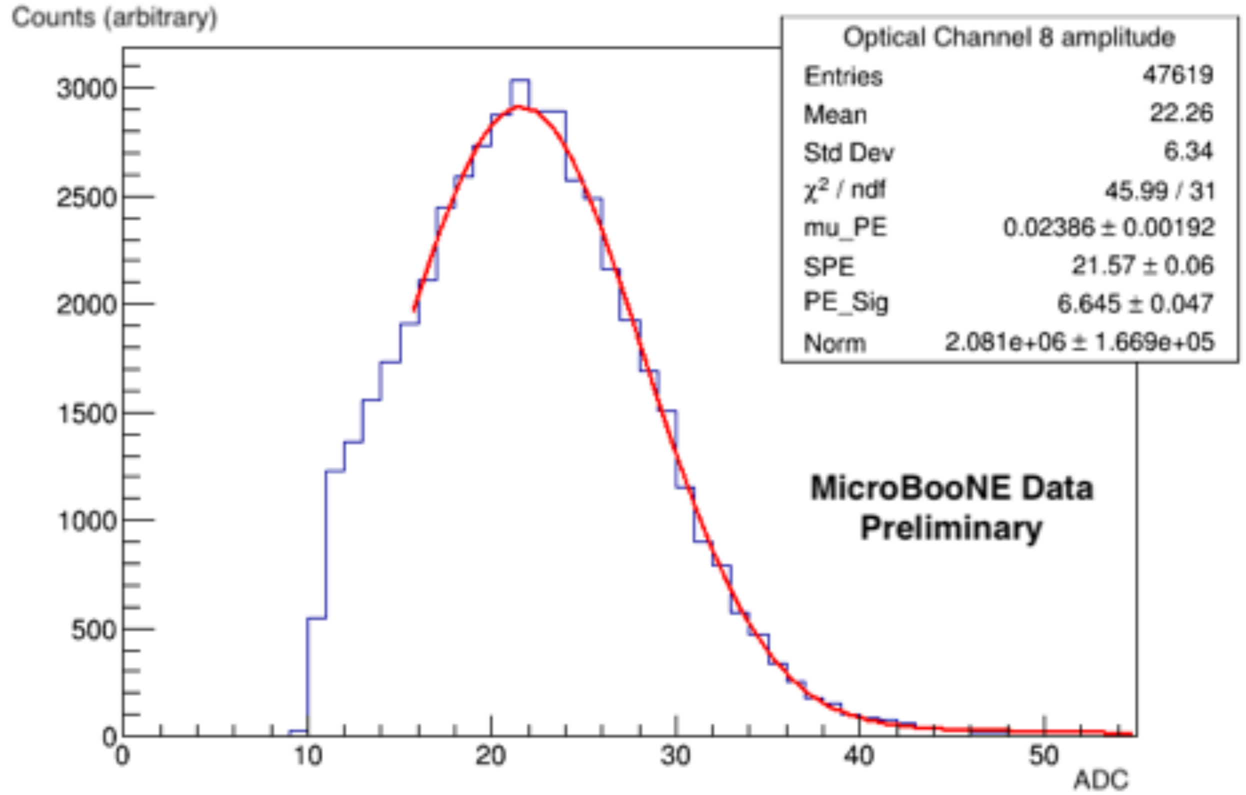
Uses Of Light In LArTPCs

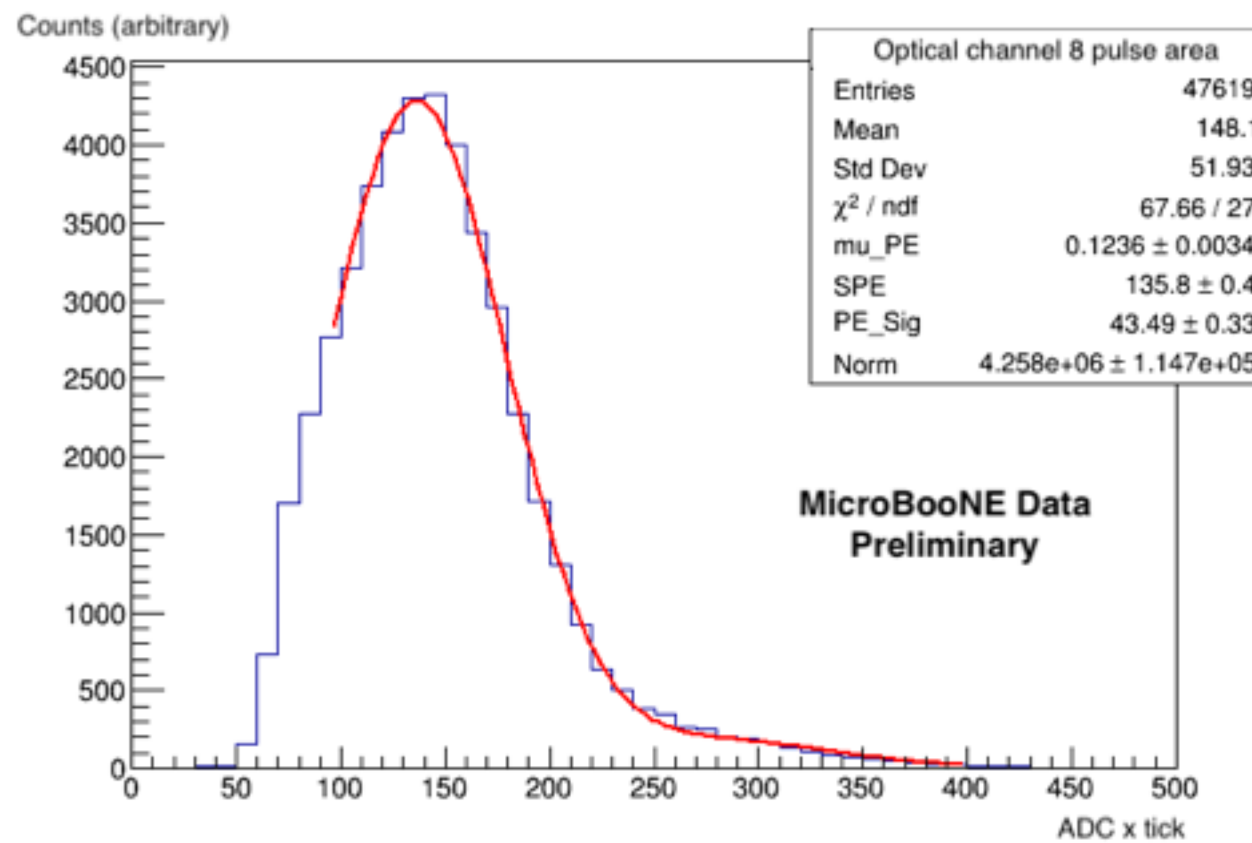


- Trigger
  - most beam spills empty, only cosmics
  - require PMT activity in time with beam=> drop trigger rate by factor x50
- Absolute drift coordinate
- ***Flash-matching*** (match TPC energy deposit to light data)
  - optical flash: collection of light coincident in time on all PMTs; corresponds to a single interaction in TPC
  - light hypothesis: model of how much light we expect
  - reject TPC activity not consistent with beam-window flash
- Stable & well-understood light response is crucial

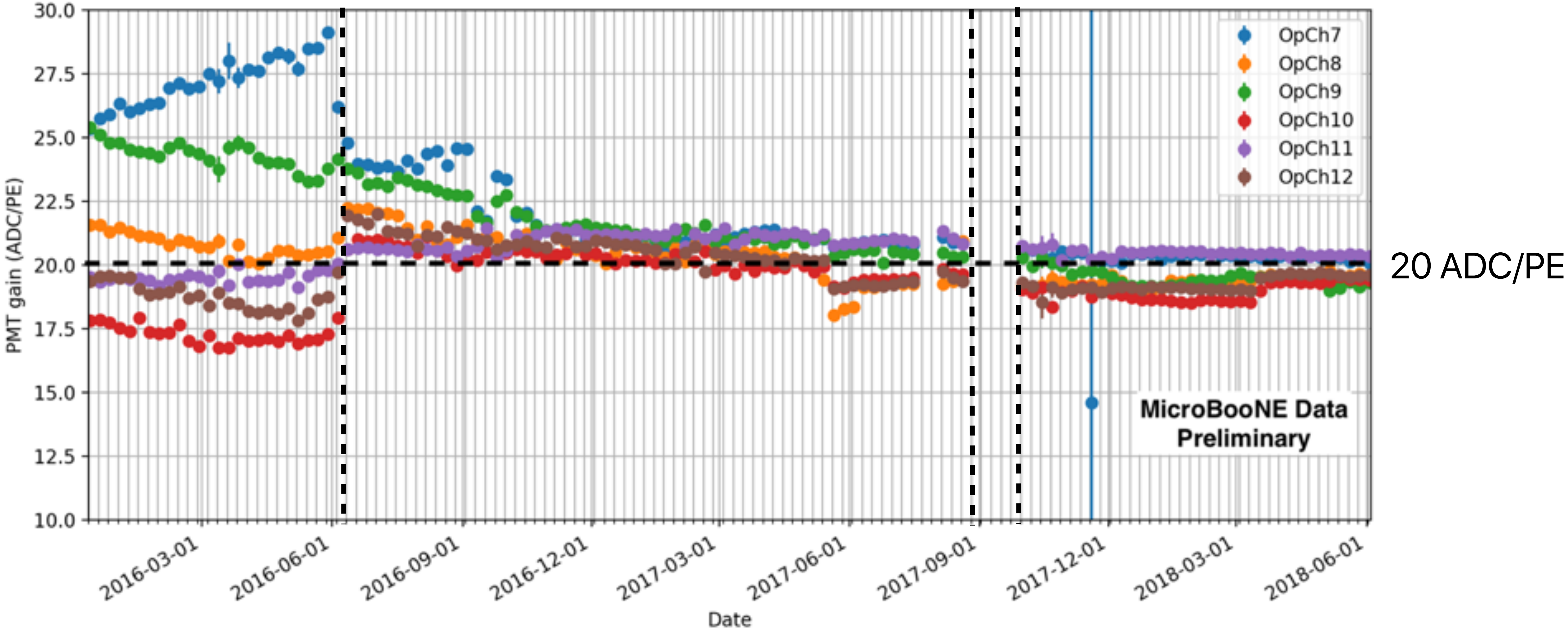
PMT Gain Measurements With SPE Pulses

- 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





Gain Measurements Over Dec 2015 - June 2018

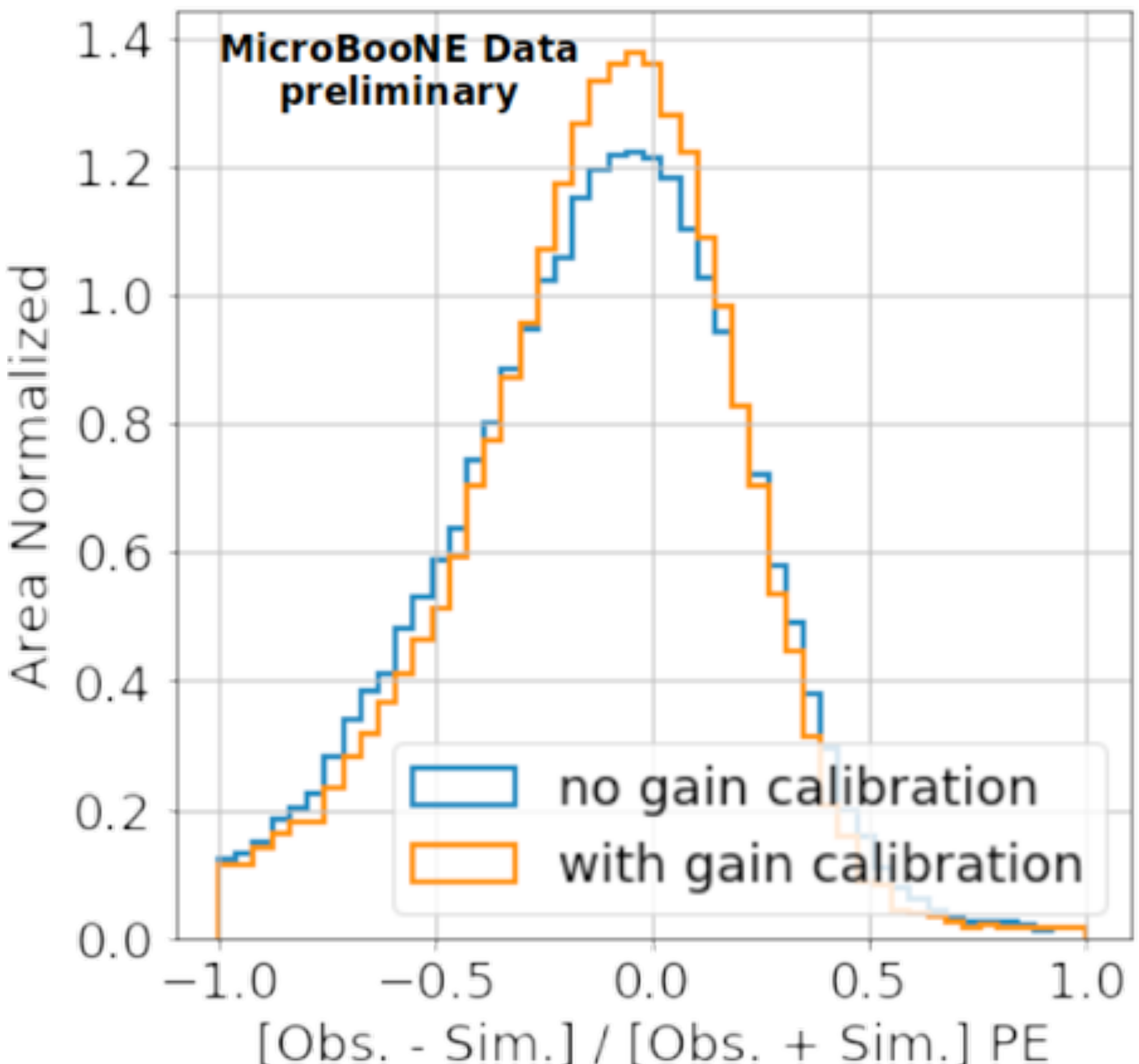


- Operations procedure change at end of Run 1
  - adjusted PMT gains to smaller range (goal: mean 20 ADC/PE)
  - implemented gain stability checks
  - HV adjustments after PMT power-off if gain deviated
- During summer shutdown 2017 exchanged HV modules
  - improved stability for all channels, very stable since

PMT Gain Calibration Performance

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

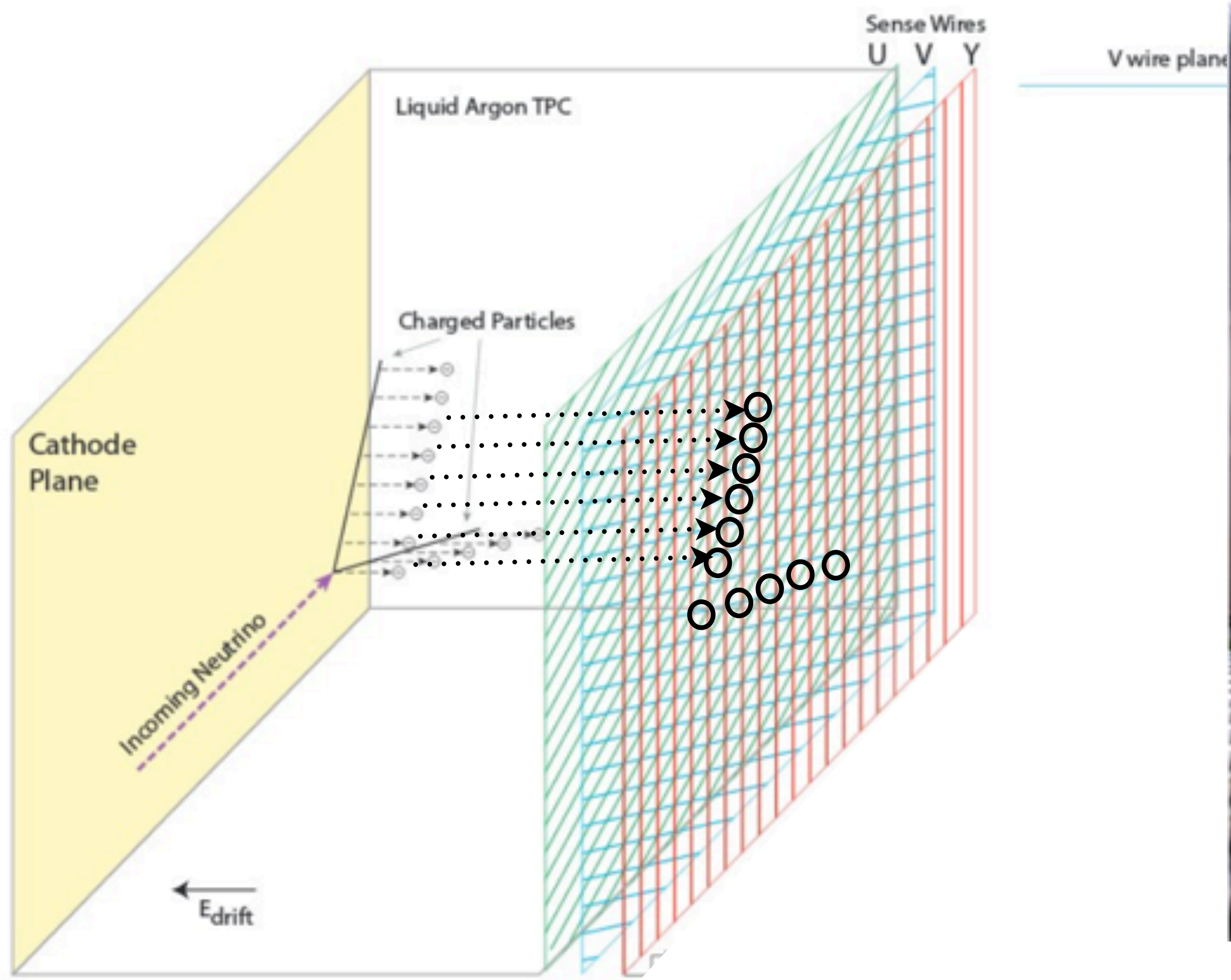
Residual of observed and simulated optical flash PE (Flash PE in 30-200 PE range)

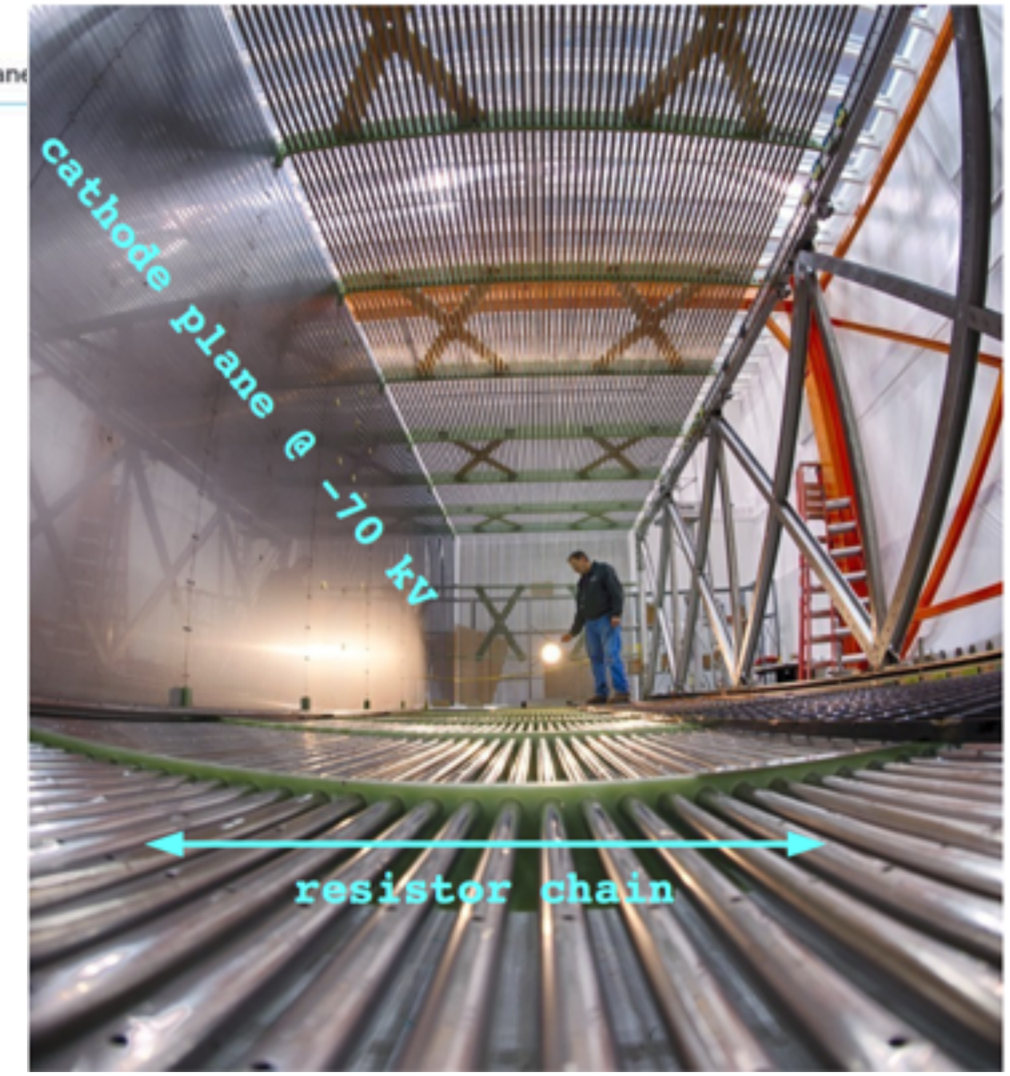


Working Principle Of LArTPCs

- 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

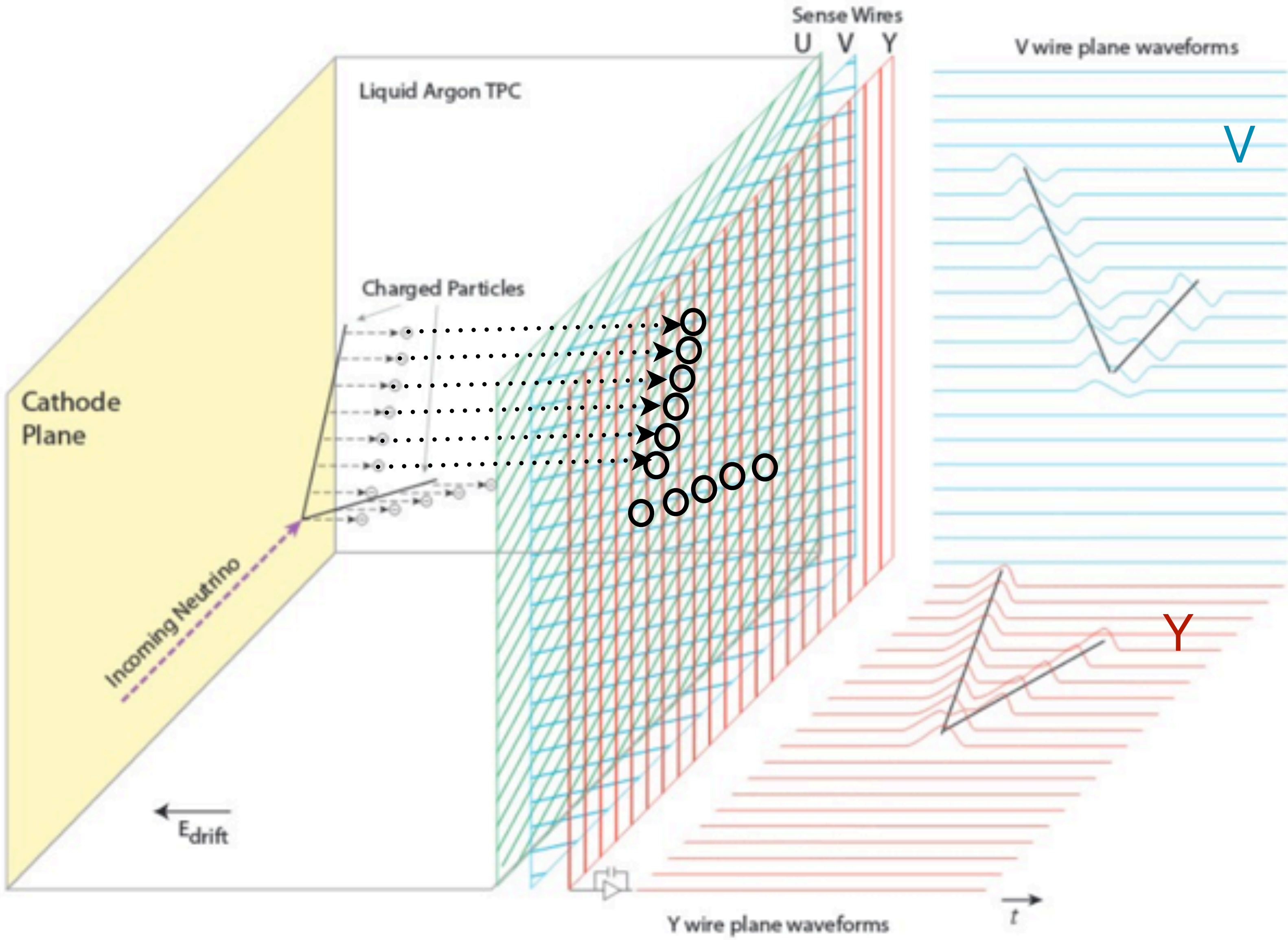




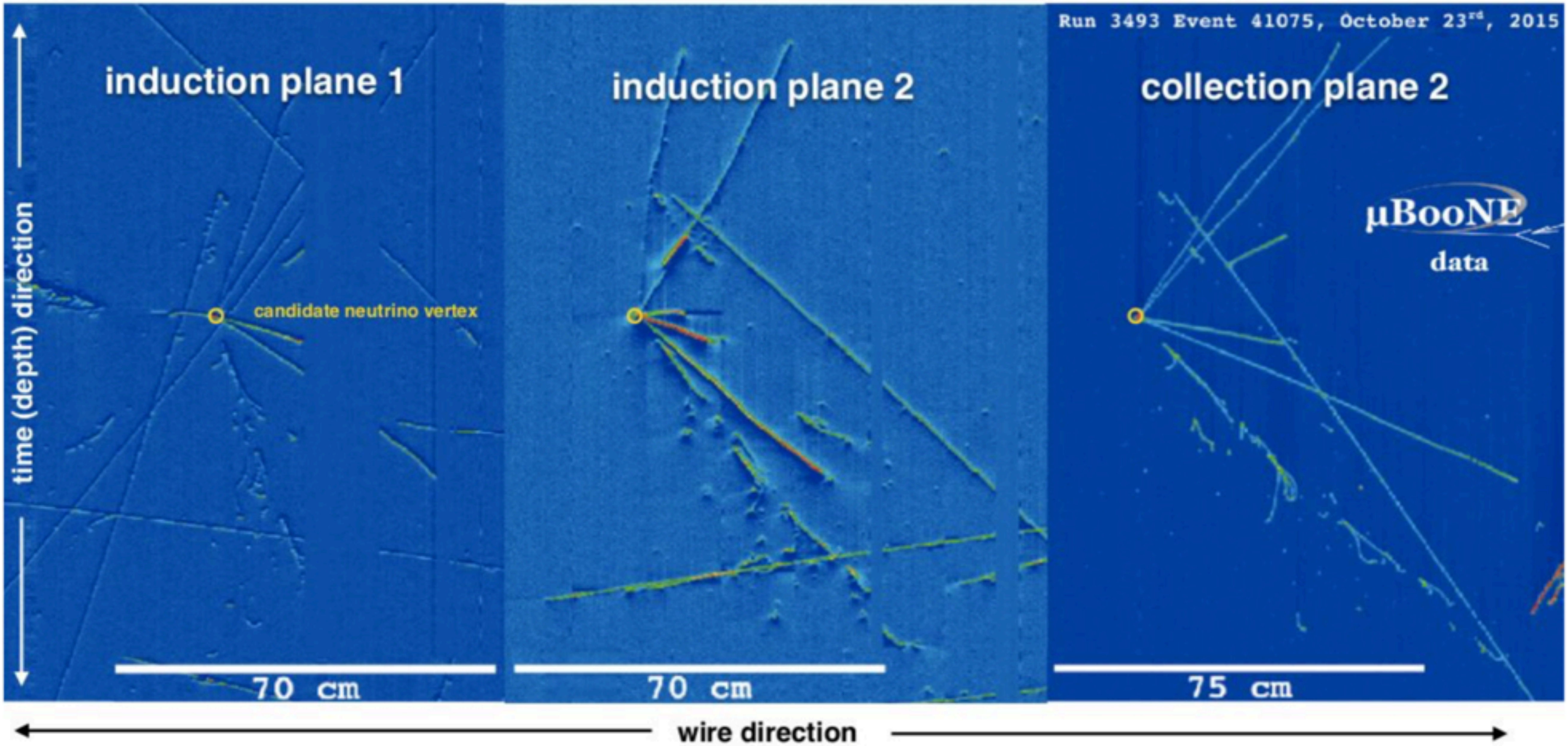
Picture courtesy of David Caratelli

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

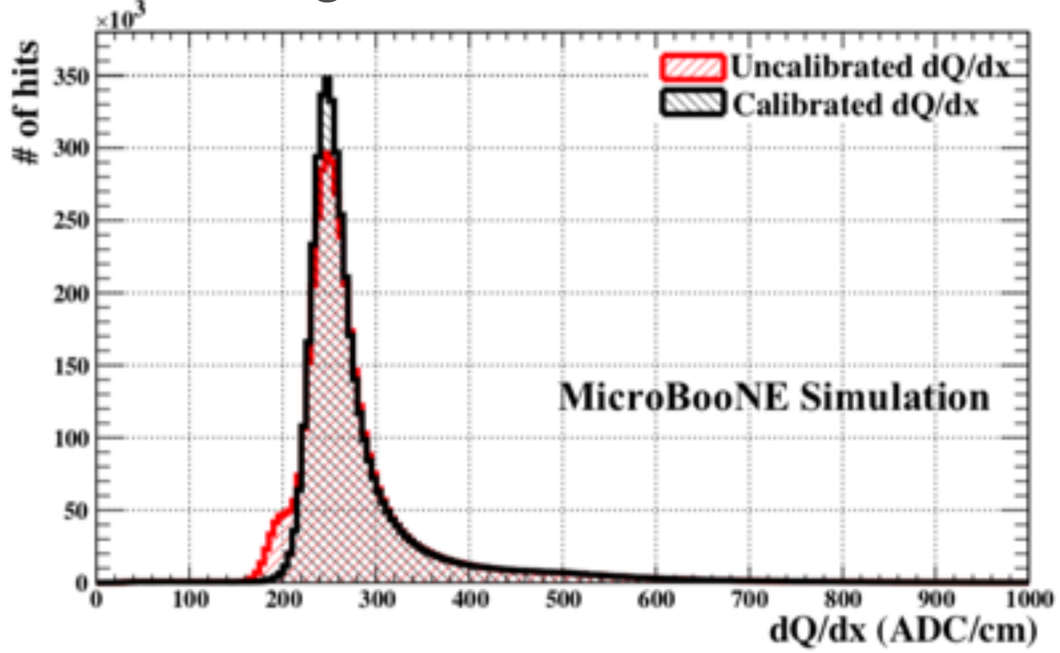


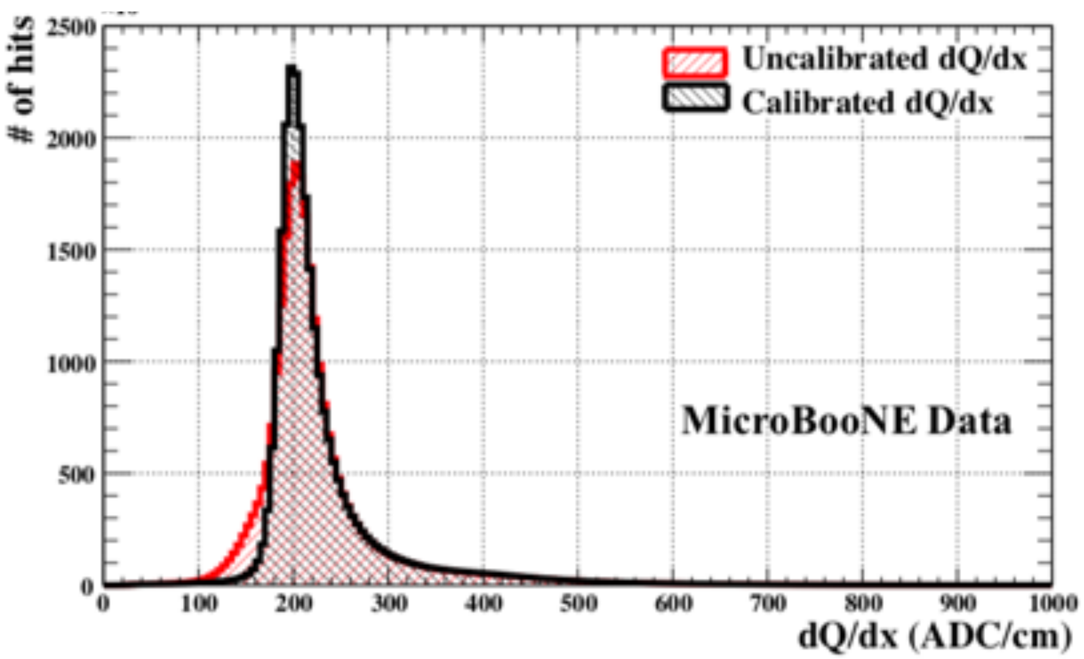
Characterizing And Calibrating TPC Response

- Pioneering work by MicroBooNE in multiple areas
  - noise filtering
  - wire response modeling (dynamic induced current effect)
  - signal deconvolution
  - space charge effects (SCE) and E-field calibrations
    - data-driven correction maps with UV laser and CR data
- Charge and energy calibration with crossing muons and protons

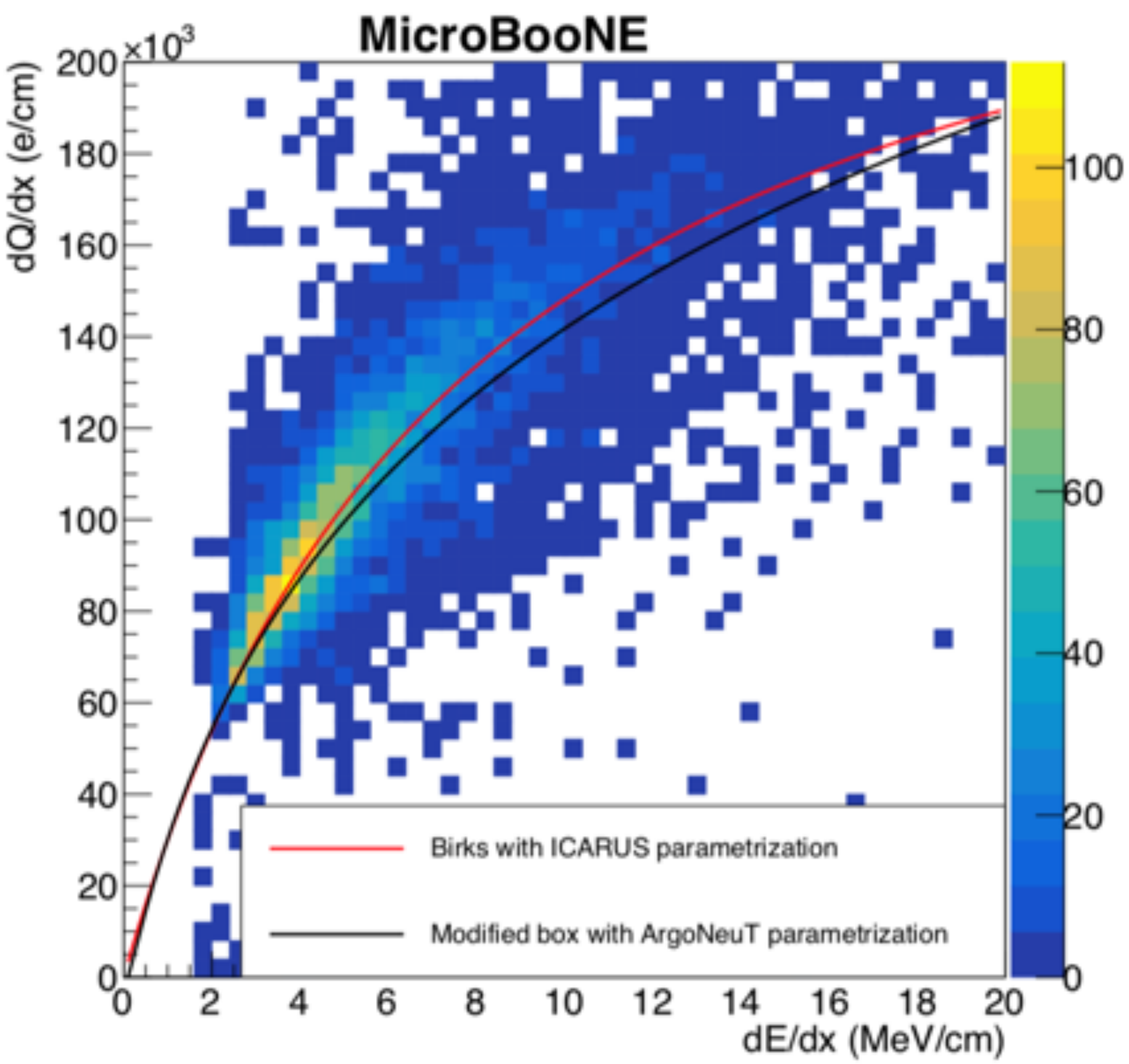
Characterizing And Calibrating TPC Response

- 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 ν-induced protons



arXiv: 1907.11736, submitted to JINST

Summary

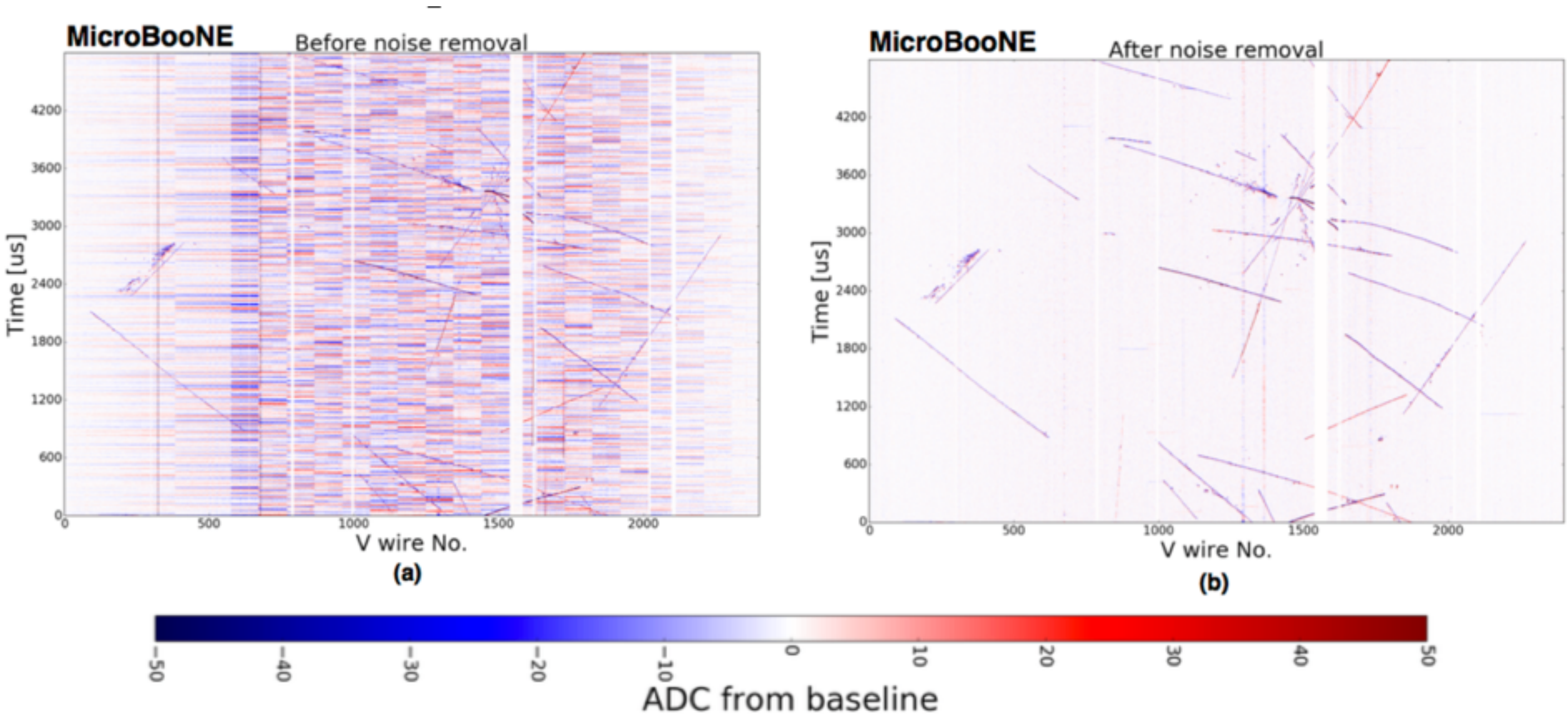
- MicroBooNE is a LArTPC aimed at probing the LEE observed by MiniBooNE
- LArTPC technology
  - excellent spatial resolution & good calorimetry: e/gamma separation
  - however long readout (& surface detector): cosmic ray BG challenging
- MicroBooNE: pioneer in many areas of TPC response study & calibration
- Using light data in MicroBooNE: powerful CR rejection
  - trigger
  - matching TPC activity to light
- Stability of light response crucial
  - successfully calibrated PMT gain fluctuations
  - remaining light instability studies underway

Backup slides

Characterizing And Calibrating TPC Response

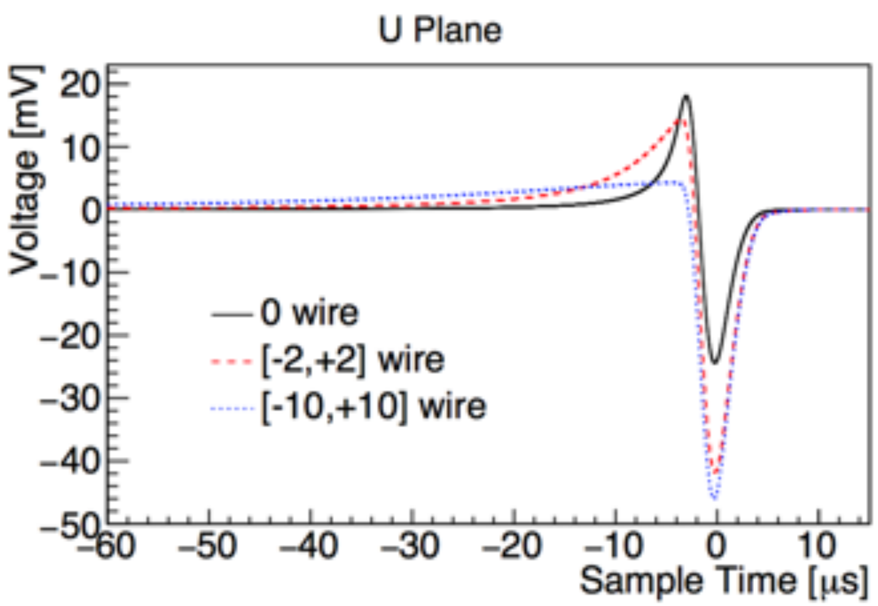
- Pioneering work by MicroBooNE in
  - noise filtering

Final S/N after noise filtering is ~40 on collection plane!
arXiv:1705.07341

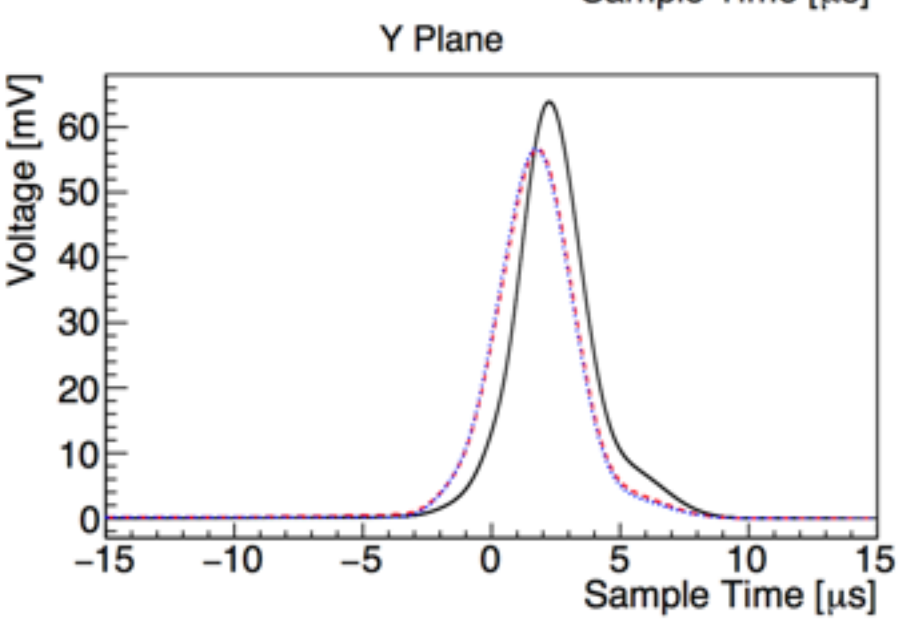


Characterizing And Calibrating TPC Response

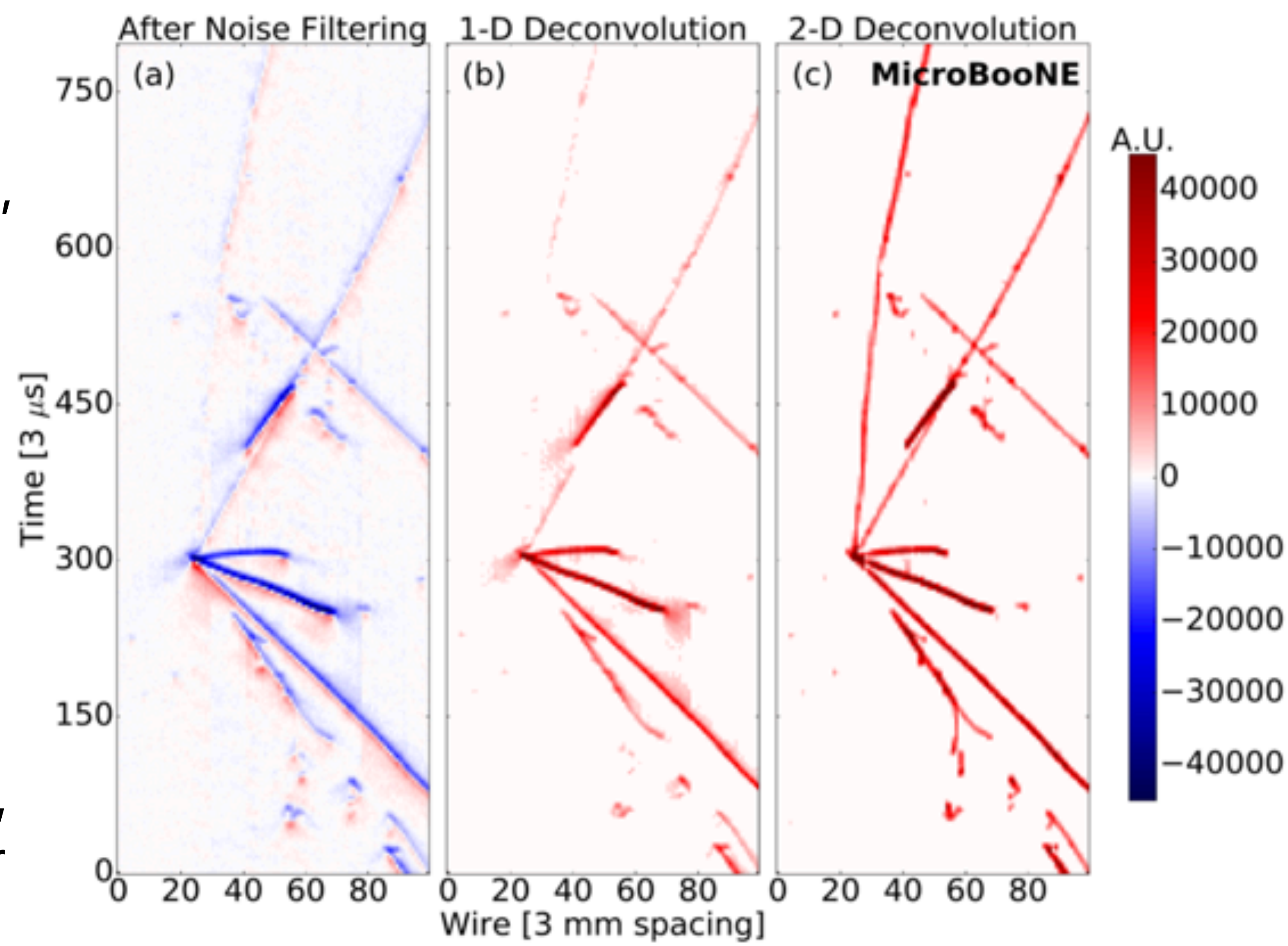
- Pioneering work by MicroBooNE in
  - noise filtering
  - wire response modeling (dynamic induced current ***DIC*** effect)
  - signal deconvolution



U: small, bipolar



Y: large, unipolar



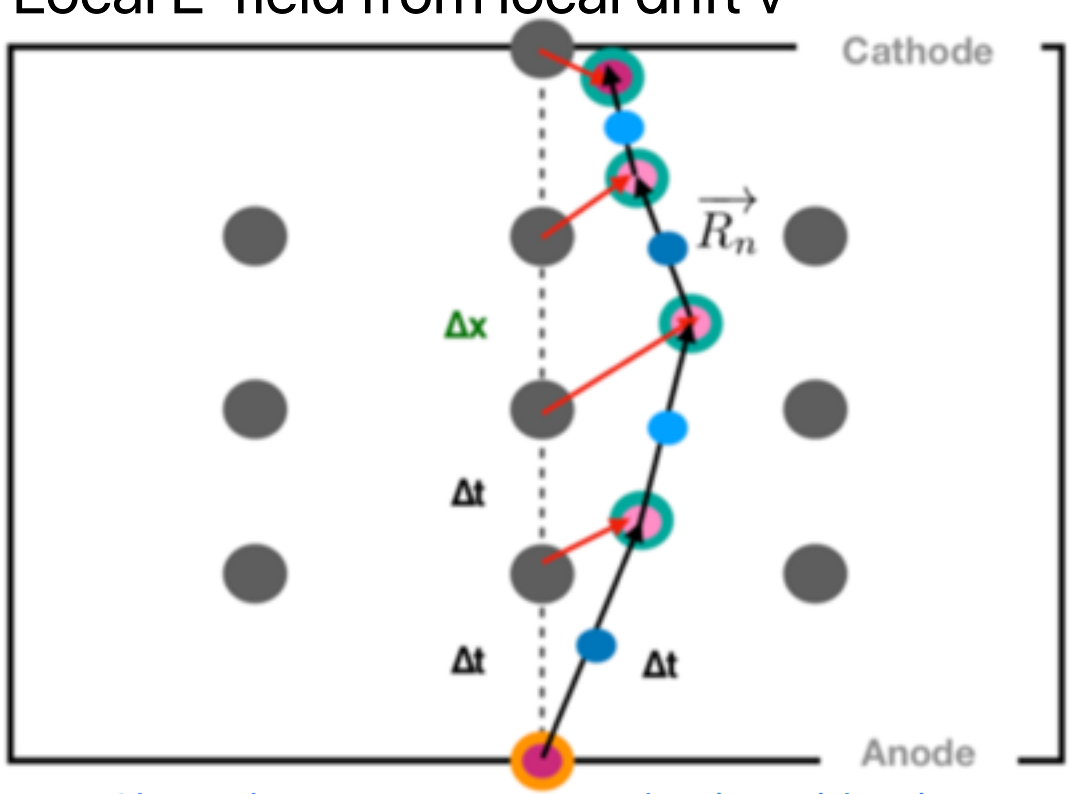
JINST 13 (2018) no07, P07006

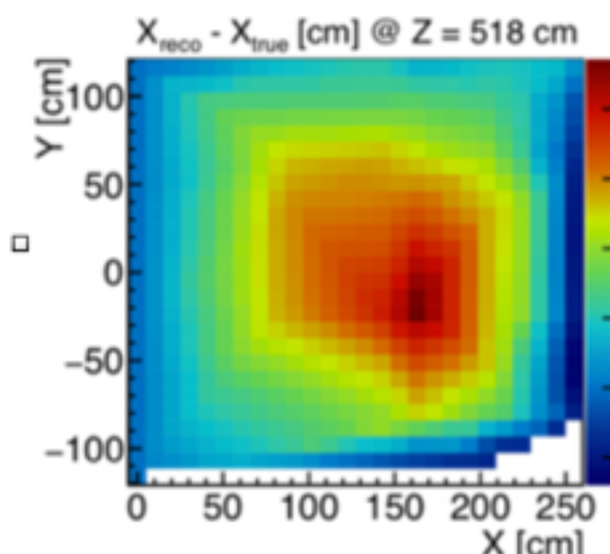
Characterizing And Calibrating TPC Response

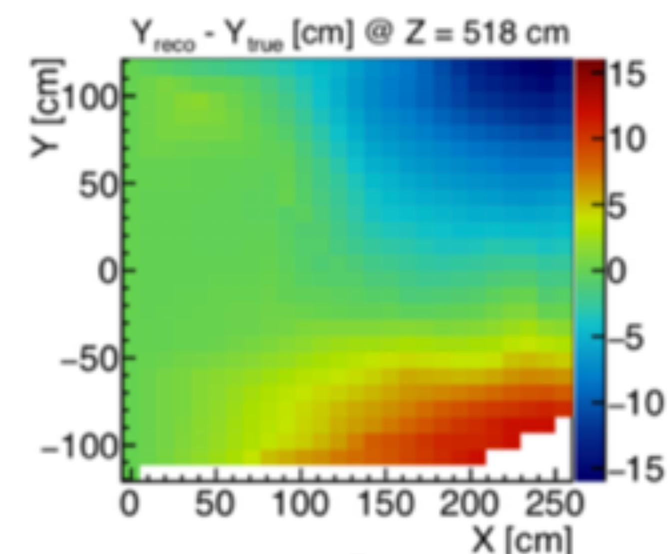
- Large CR flux & E field lower than design: lots of slow-moving Ar ions
  - distortion in E field
  - space charge effects (***SCE***):
    - spatial distortion of drift e^- => tracks/showers appear "bended"
- Pioneering data-driven SCE/E-field correction maps
  - cosmic rays
  - laser UV system

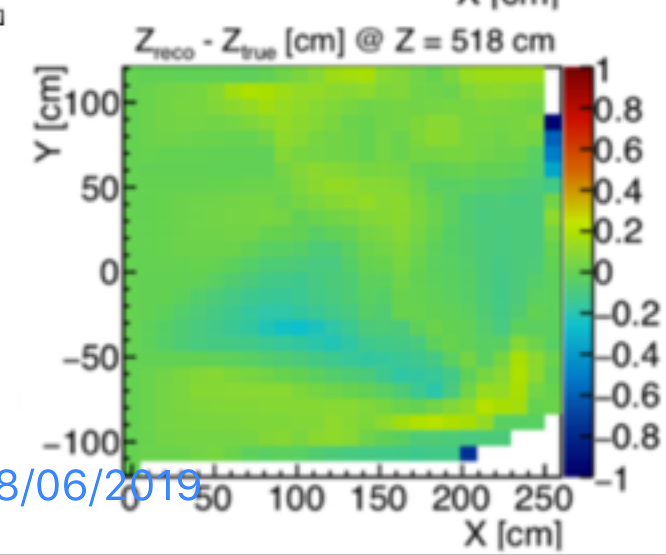
MICROBOONE-NOTE-1055-PUB

Local E-field from local drift v









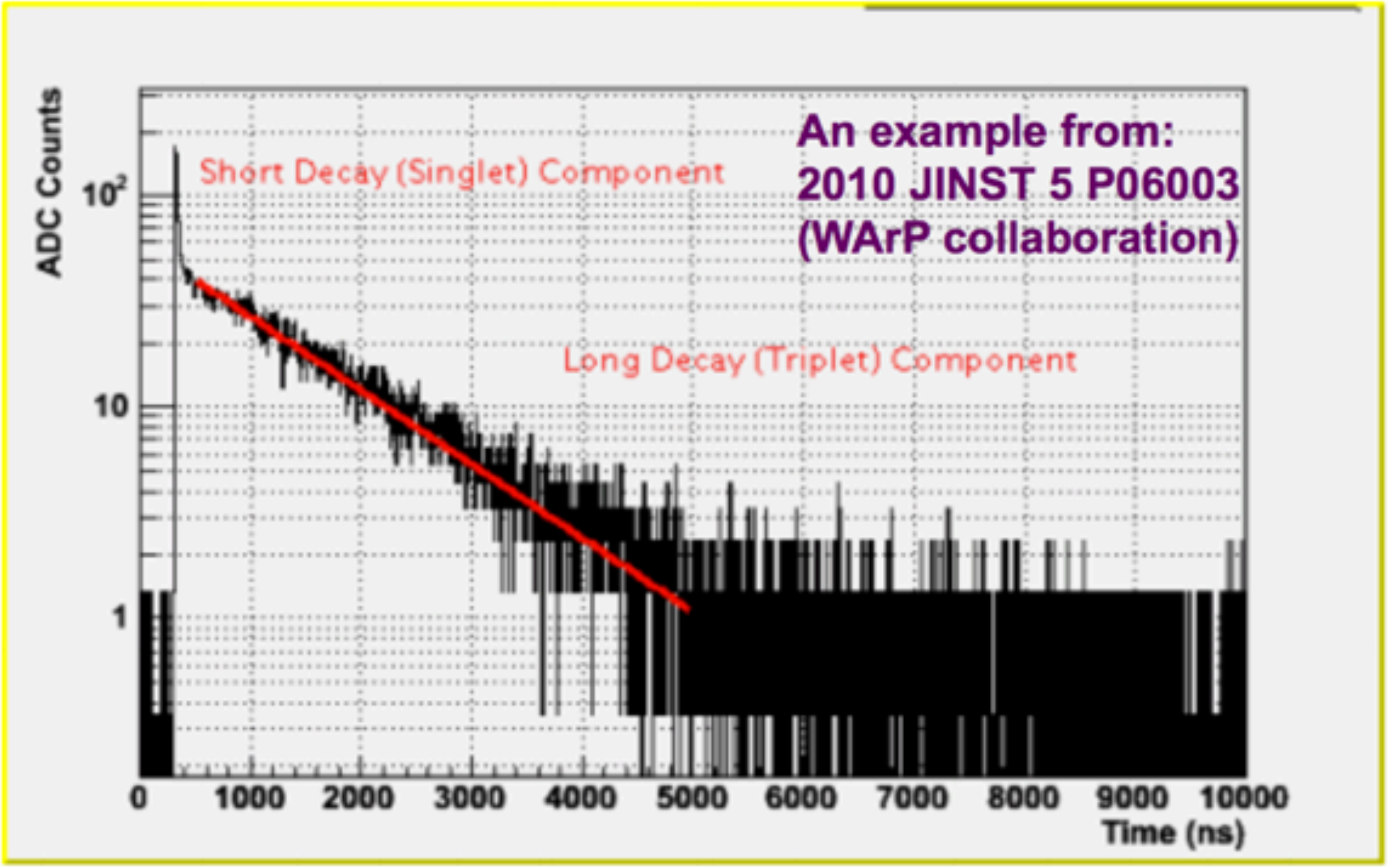
Maps from UV laser data

LAr Scintillation

- Excited states (excimers): Ar_2^+ core with bound electron
  - singlet state Σ_u^1
  - triplet state Σ_u^3

LAr is transparent to its scintillation!

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



prompt:late light ratio is dE/dx dependent

~25:75 for MIP

This can in theory be used for PID

PMT Gain Measurements With SPE Pulses

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