Studies with the LArIAT Light Collection System

William Foreman

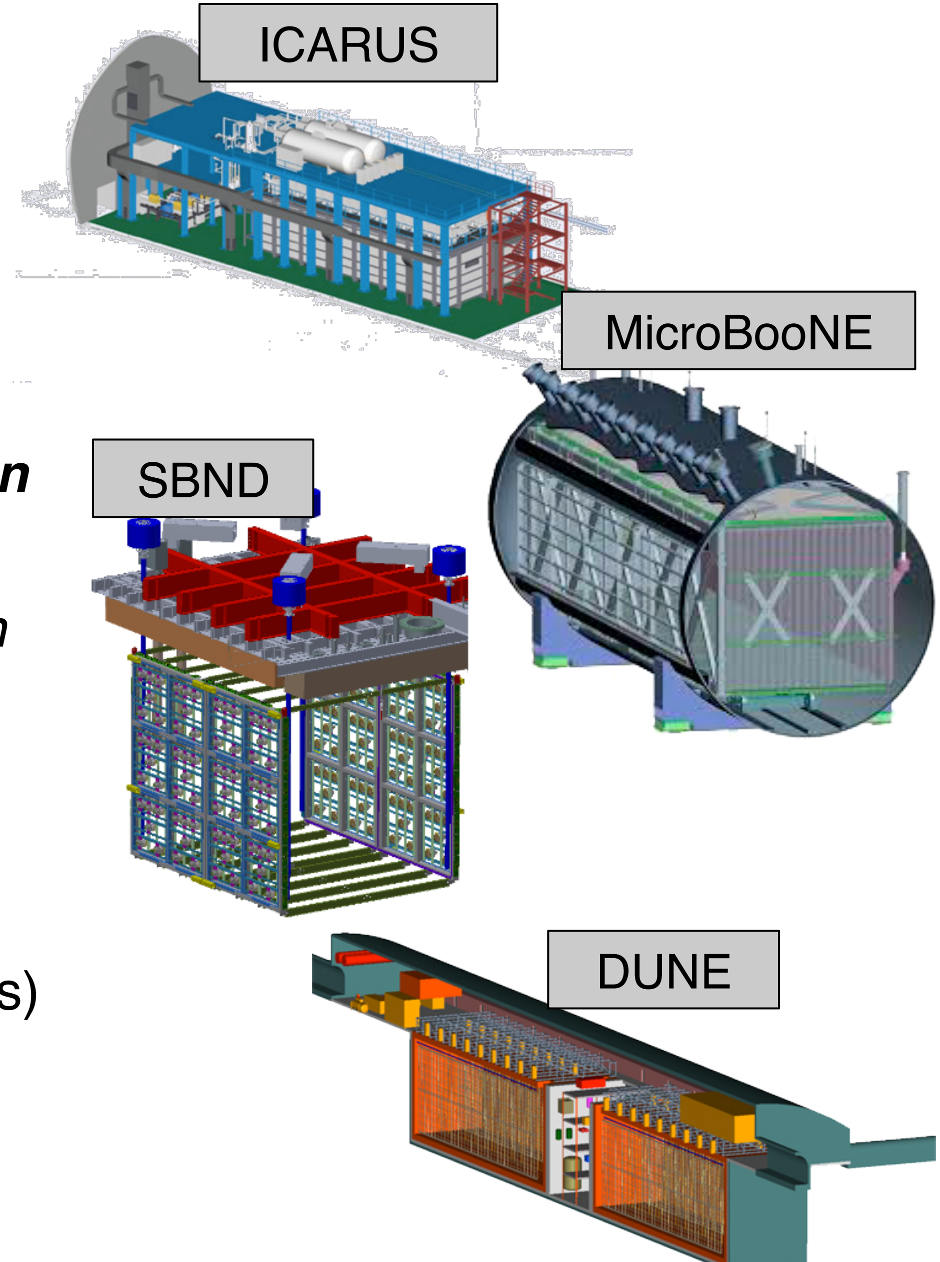
University of Chicago

International Conference on High Energy Physics

August 6, 2016

Light collection in LArTPC neutrino experiments

- Liquid Argon Time Projection Chambers (LArTPCs) poised to play major role in neutrino physics
  - Collect drifted e^- to reconstruct tracks in 3D
  - But, ***also detect LAr scintillation***
- Prompt timing: *much faster detection of light than drift electrons!*
- Typical uses of light:
  - Beam event triggering
  - Reject cosmics (surface detectors)
  - Interaction time T_0

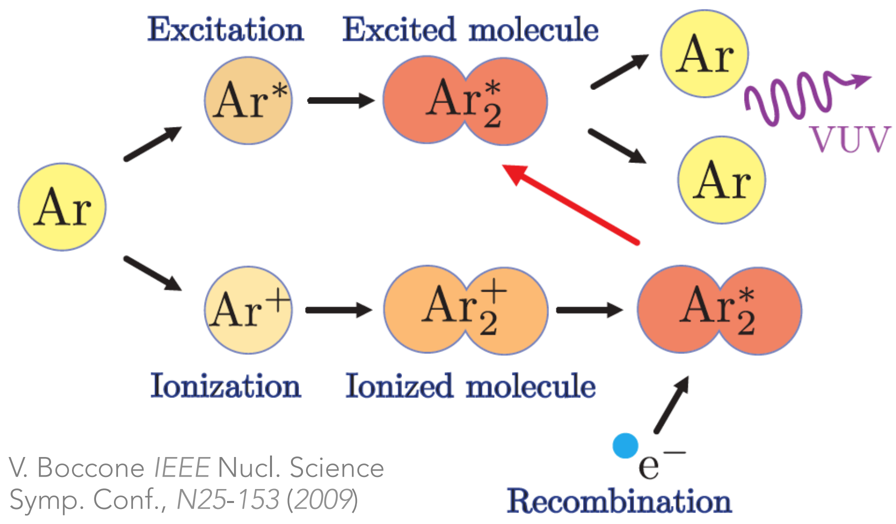


Scintillation in liquid argon

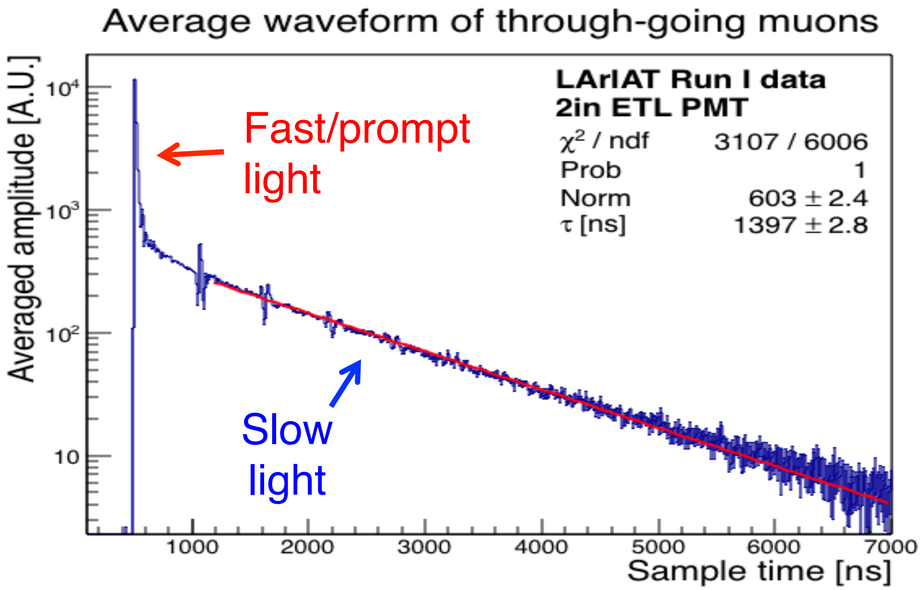
There's a wealth of information in this light!

- ~40k γ/MeV (at E = 0)
- Distinct time structure:
  - Fast / prompt (7ns)
  - Slow / late (1.5μs)

With high collection efficiencies, can exploit these characteristics to benefit physics analyses…



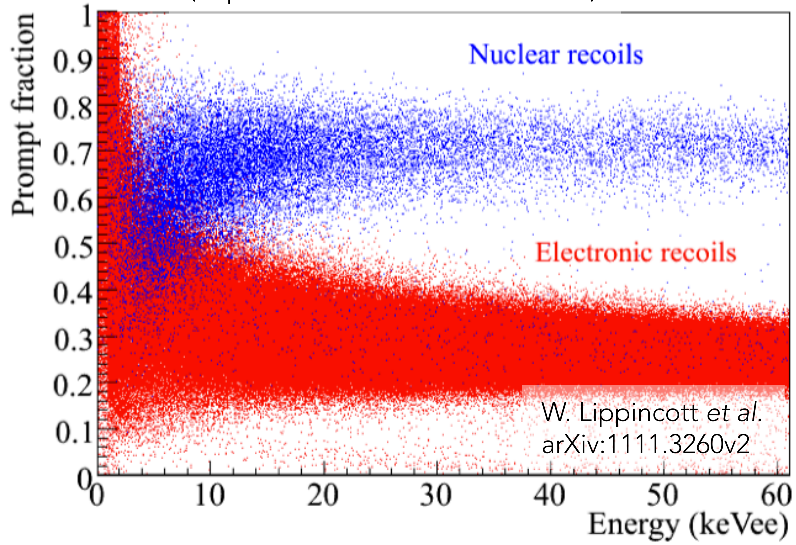
V. Boccone *IEEE* Nucl. Science Symp. Conf., *N25-153* (*2009*)

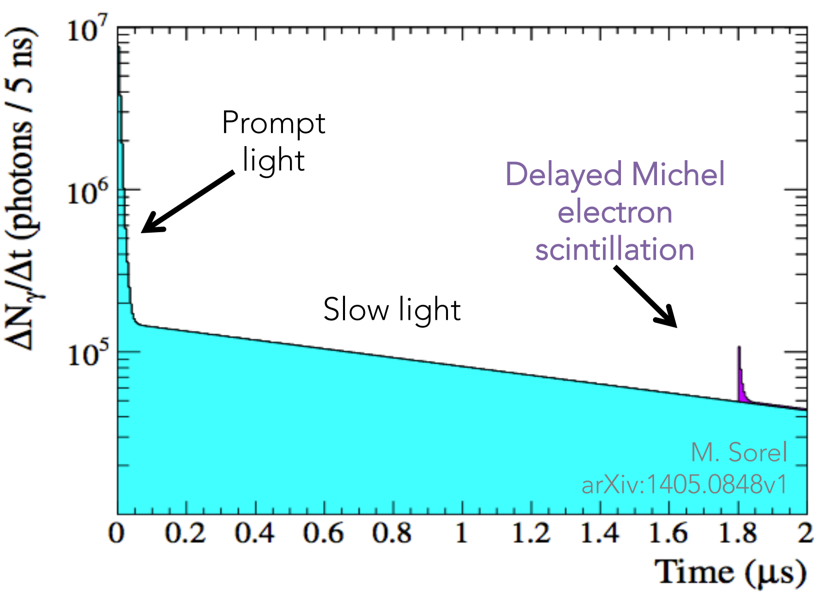


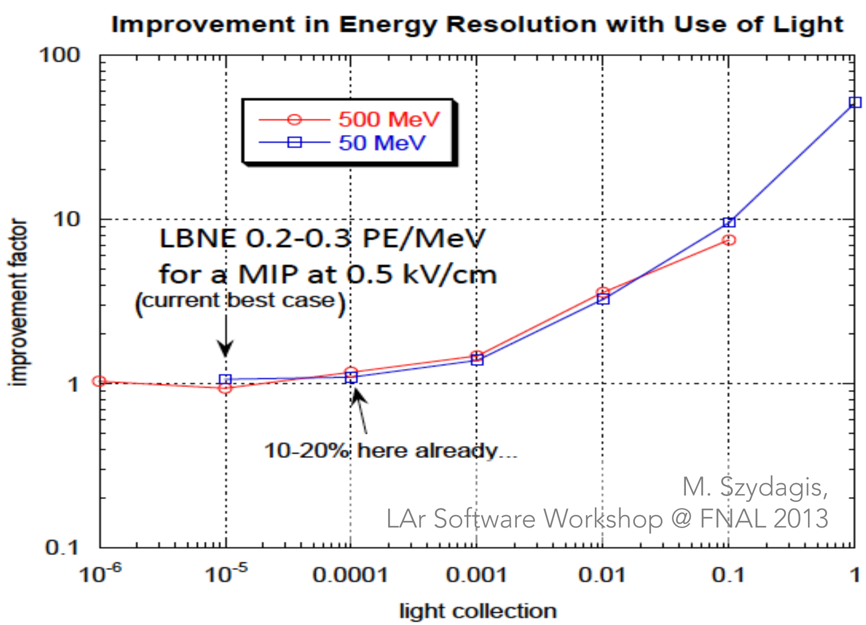
Potential physics benefits from enhanced photon collection

- Fast / slow component ratios dependent on ionization density → **PID**
- Light & charge complementary for Ar_2^+ recombination → **calorimetry**
- ID stopping μ from Michel decay time

PID in MicroCLEAN
(Liquid neon dark-matter detector)

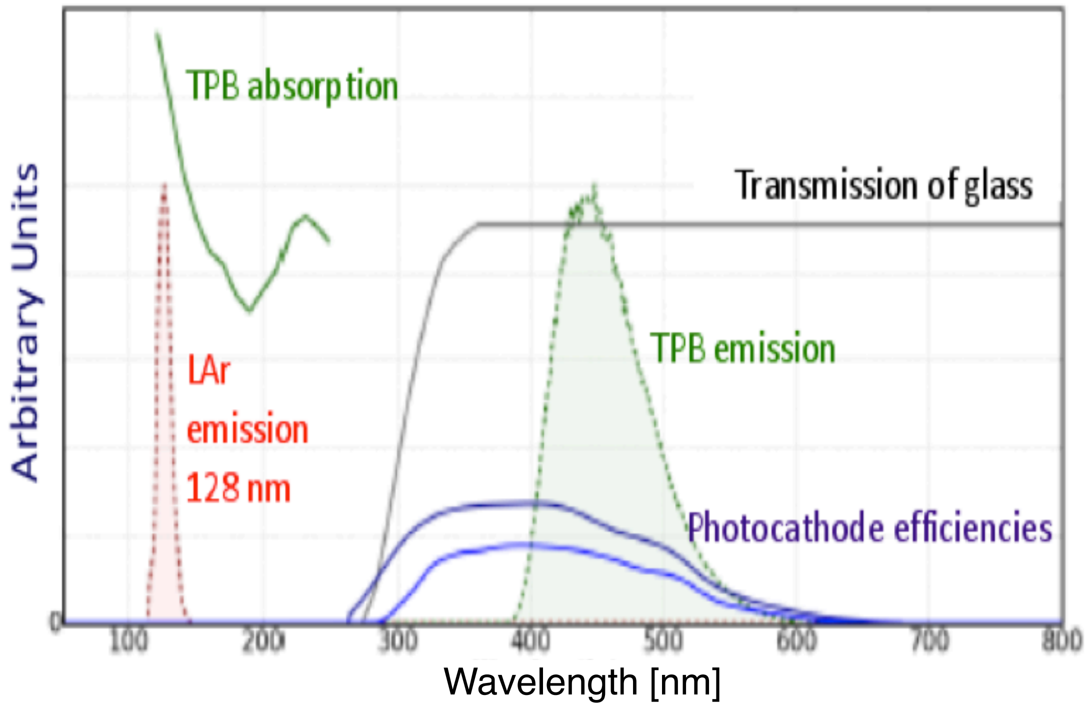




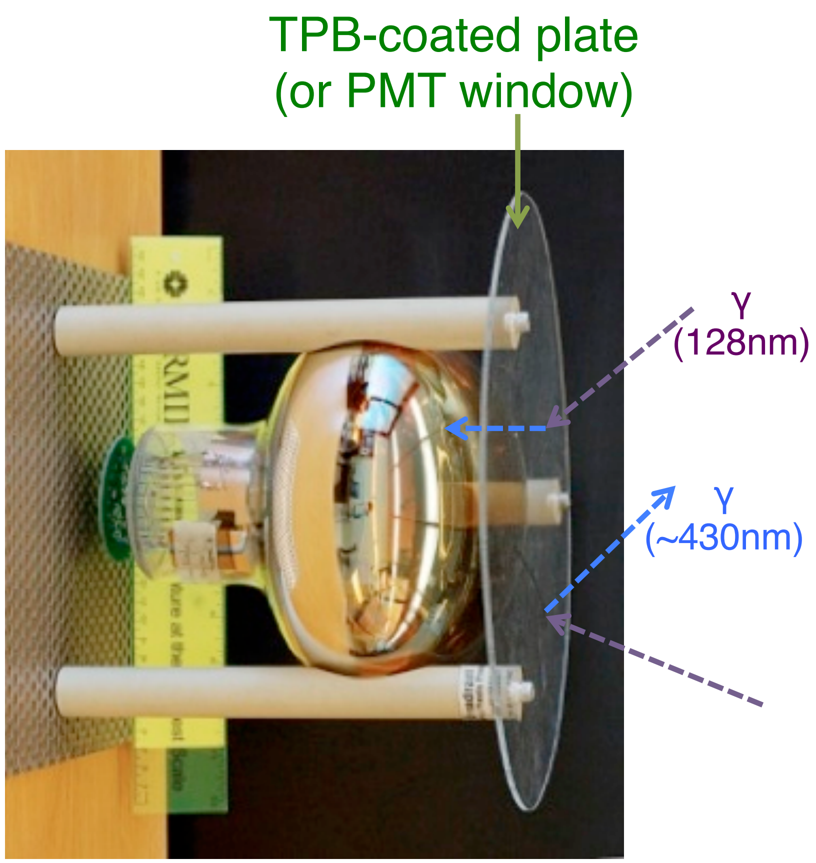


So how do we detect this light?

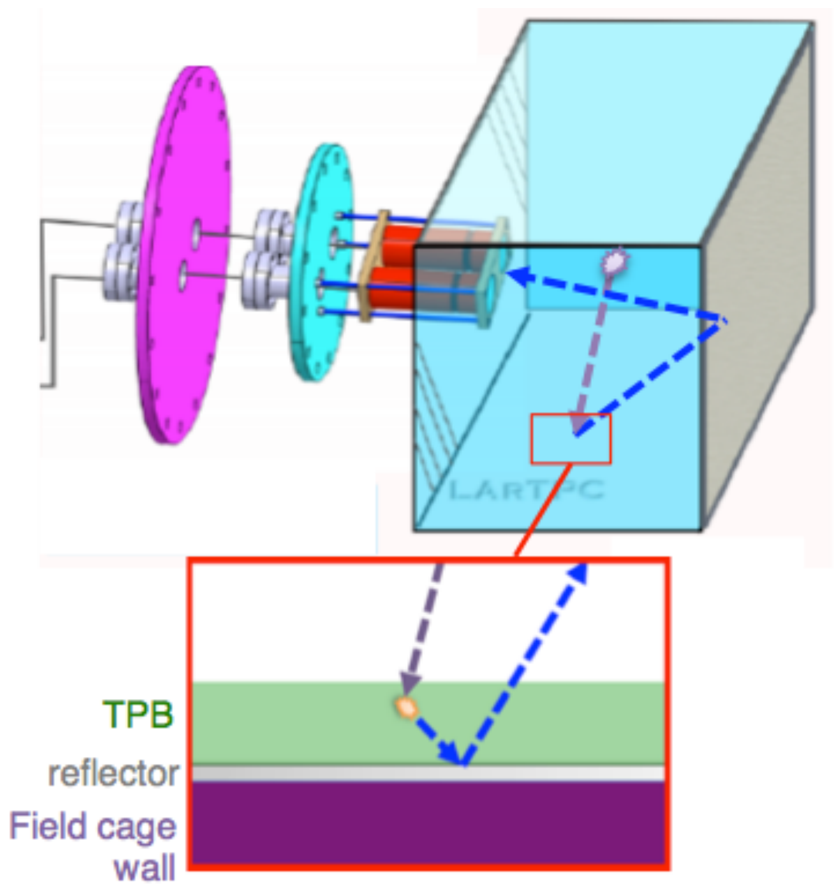
- LAr scintillates in the vacuum-ultraviolet (VUV, 128ns)
- Most PMTs/photodetectors *blind* to these photons
- Need to wavelength-shift to visible using a compound such as tetraphenyl-butadiene (TPB)



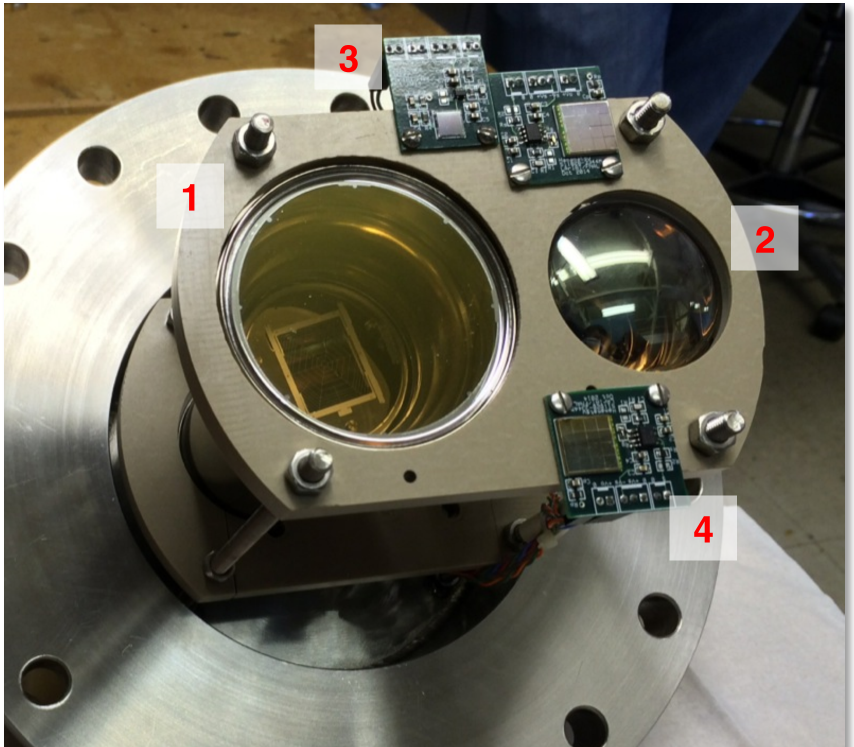
Standard LArTPC approach (ie, ICARUS, MicroBooNE)



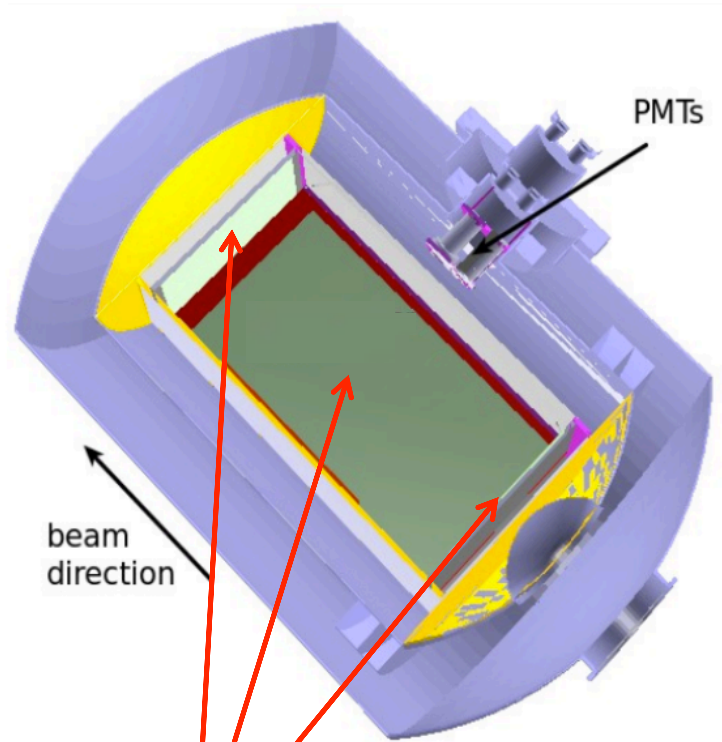
Reflector-based approach (LArIAT)



The LArIAT light detection system



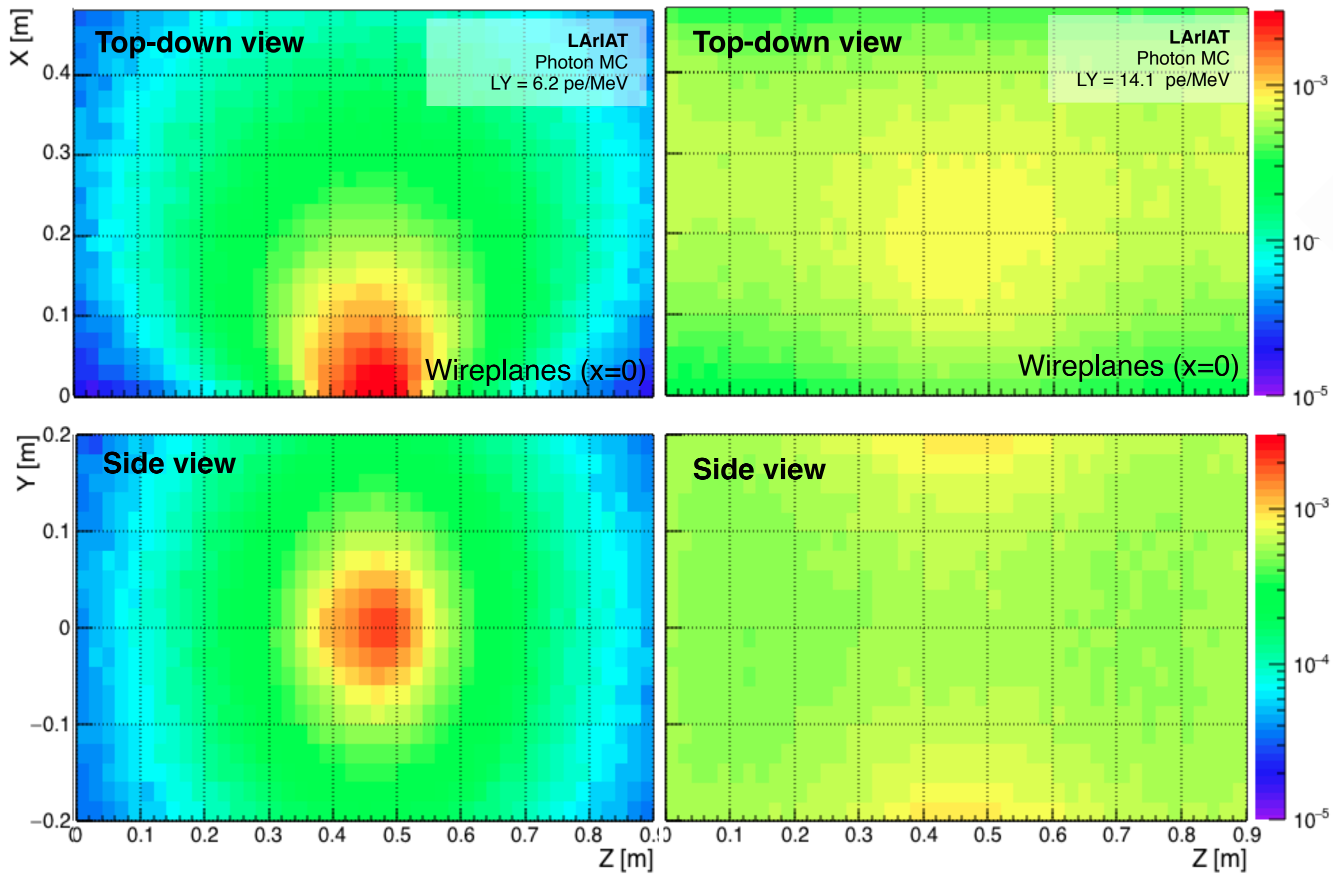
1. PMT: Hamamatsu R-11065 (3" diameter)
2. PMT: ETL D757KFL (2" diameter)
3. SiPM: SensL MicroFB-60035 w/preamp
4. SiPM: Hmm. S11828-3344M 4x4 array (*Run I*)
   SiPM: Hmm. VUV-sensitive (*Run II*)



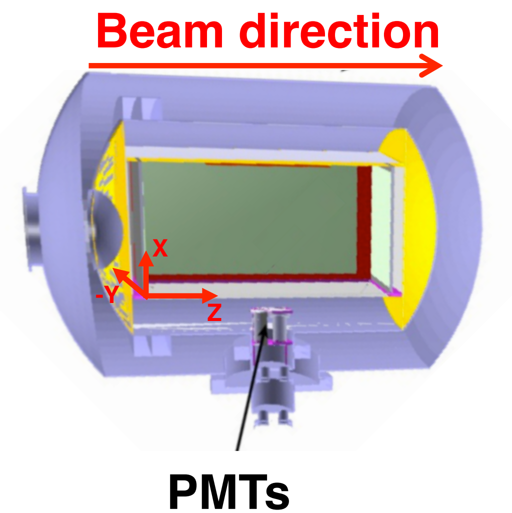
TPB-coated reflector foils on field cage walls

Fractional photon visibility for LArIAT vs. a standard setup

No foils, TPB-coated PMTs | LArIAT



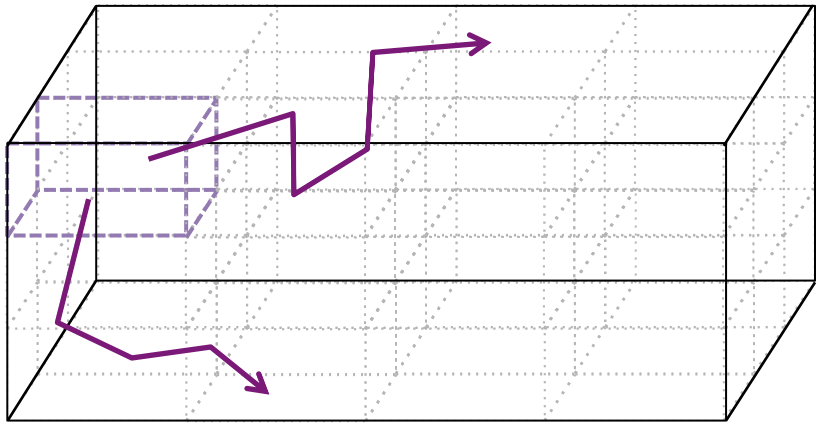
Beam direction | Beam direction



> 2x light & **more uniform visibility** compared to case with no foils and TPB-coated PMTs

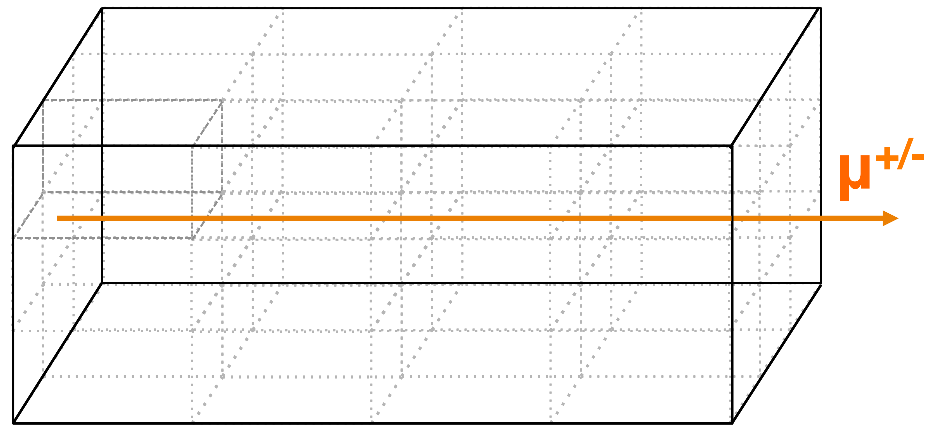
Voxel-based fast simulation

- Simulation of scintillation γ on event-by-event level is taxing! (~40k per MeV deposited in LAr)
- Instead, a "photon visibility library" is generated ahead of time
  - Detector divided into 3D voxels
  - Many VUV γ generated per voxel and propagated via Geant4
  - # reaching photodetectors used to calculate "visibility" of each voxel-PMT pair



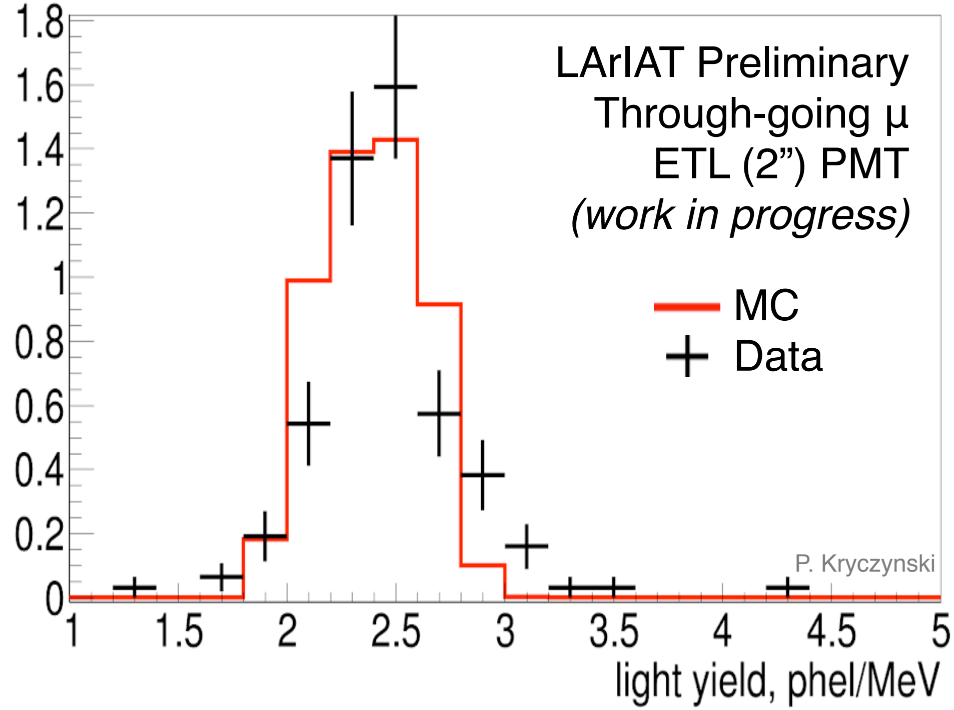
- In event MC, particle *energy loss* per voxel translated directly to #γ per PMT

Voxel-based fast simulation



- Validation using through-going muon tracks

- Agreement between preliminary **MC** and **data**

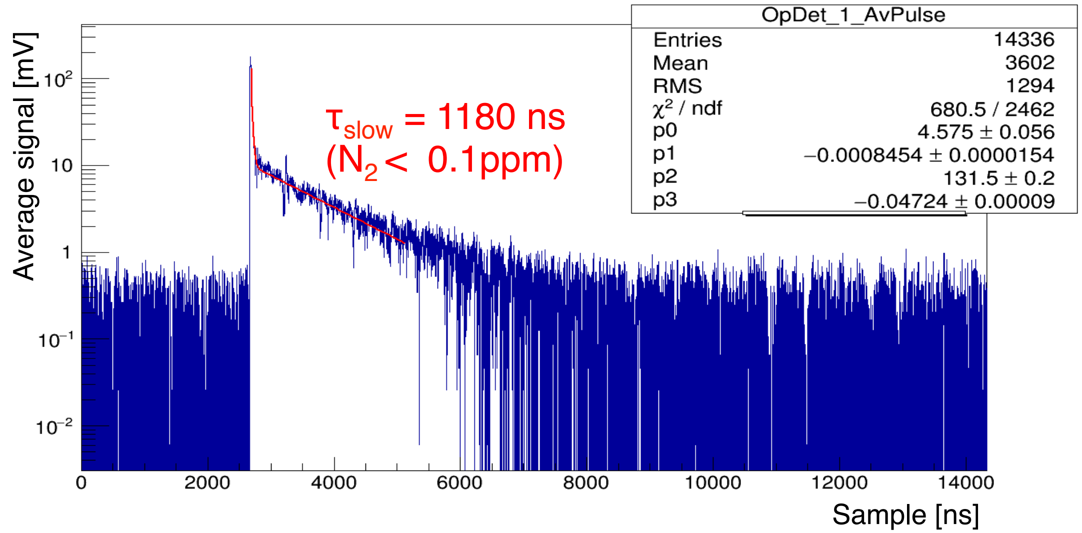


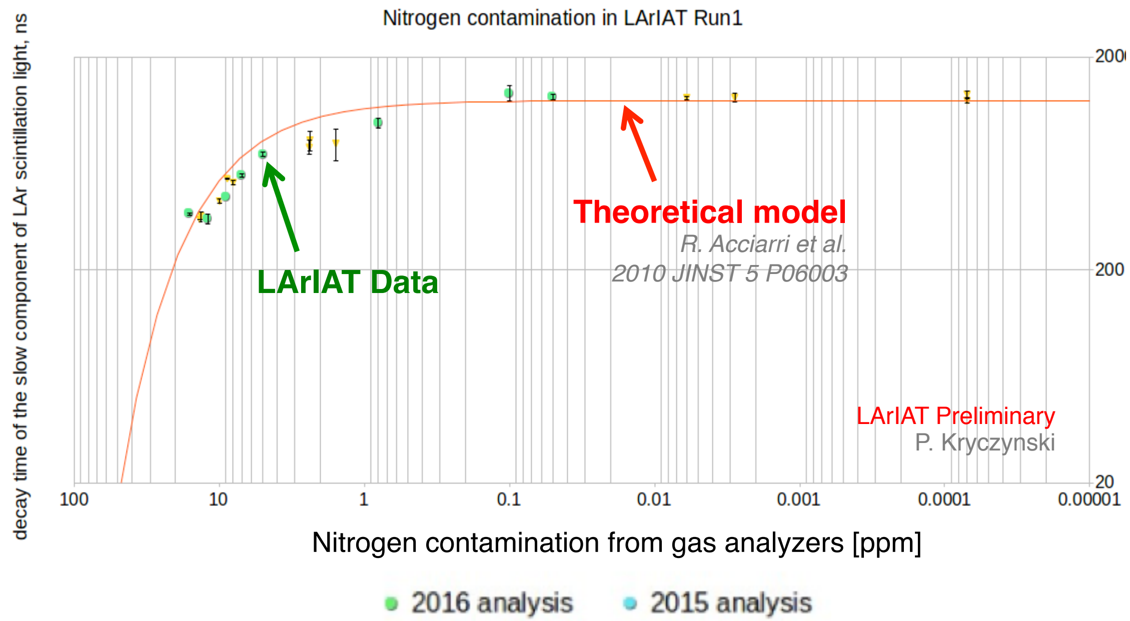
Ongoing Light-based Analyses

- N_2 contamination measurement
- Enhanced calorimetry using charge + light
- Triggering/PID and light-based reconstruction for stopping $\mu^{+/-} \rightarrow e^{+/-}$

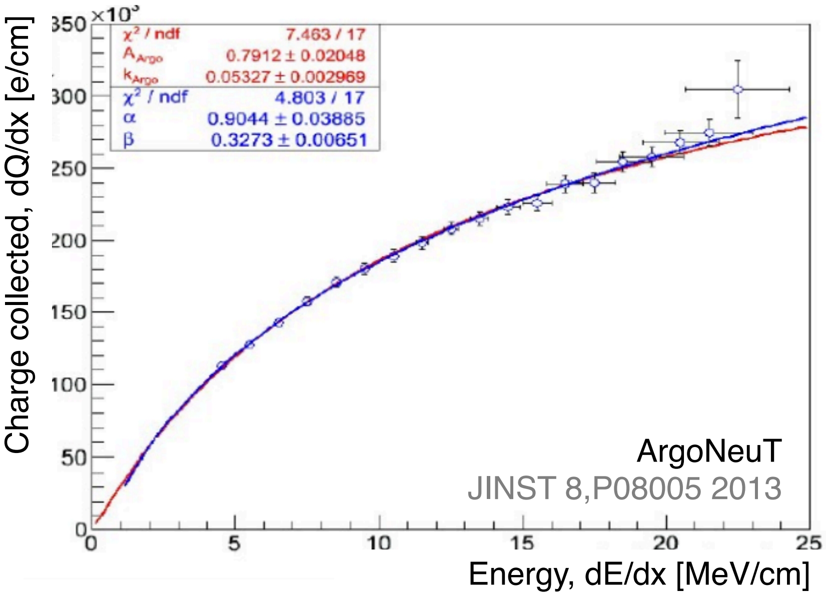
1. Nitrogen contamination

- N_2 in LAr suppresses scintillation light
- From fits to scintillation, can extract "slow" light time component and determine N_2 concentration
- Results agree with trend from model



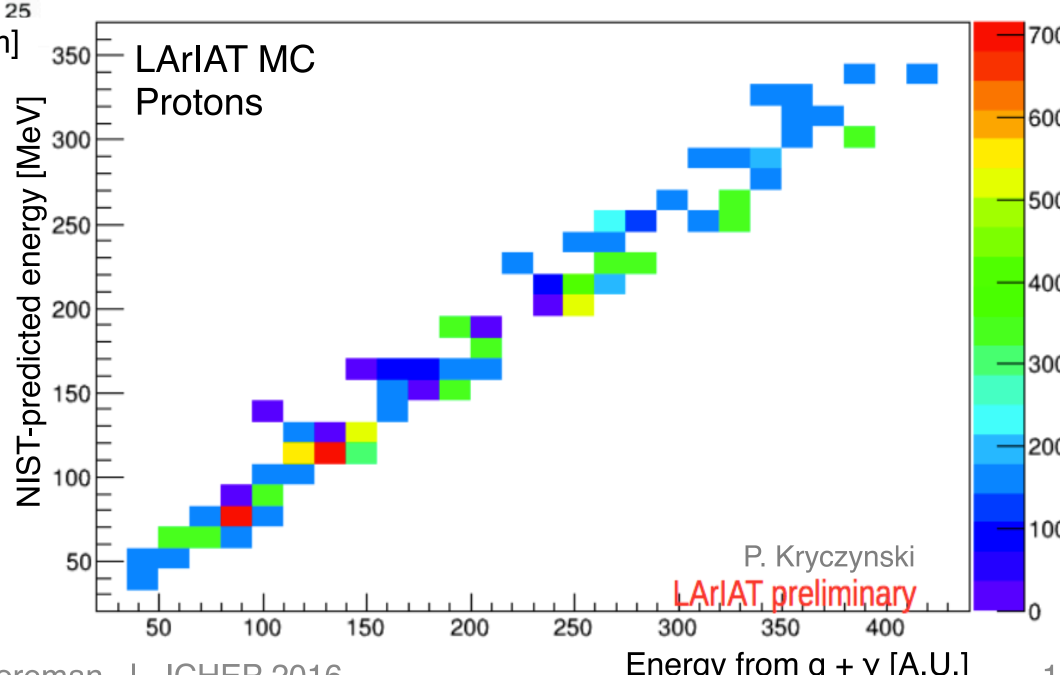


2. Calorimetry enhancement



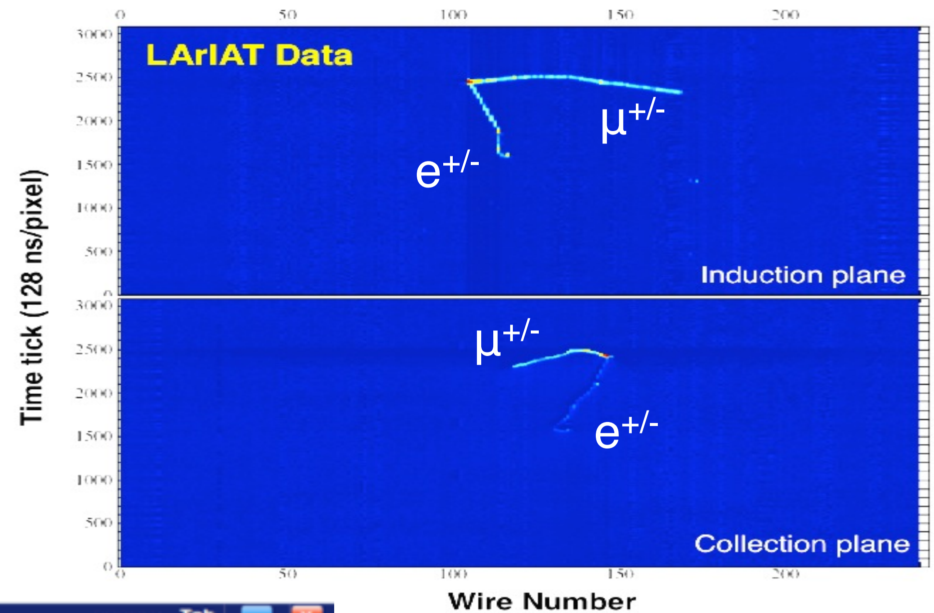
- $Ar^+ + e^-$ recombination leads to non-linearity between **energy deposited** & **charge collected**
- But recombination process produces light!

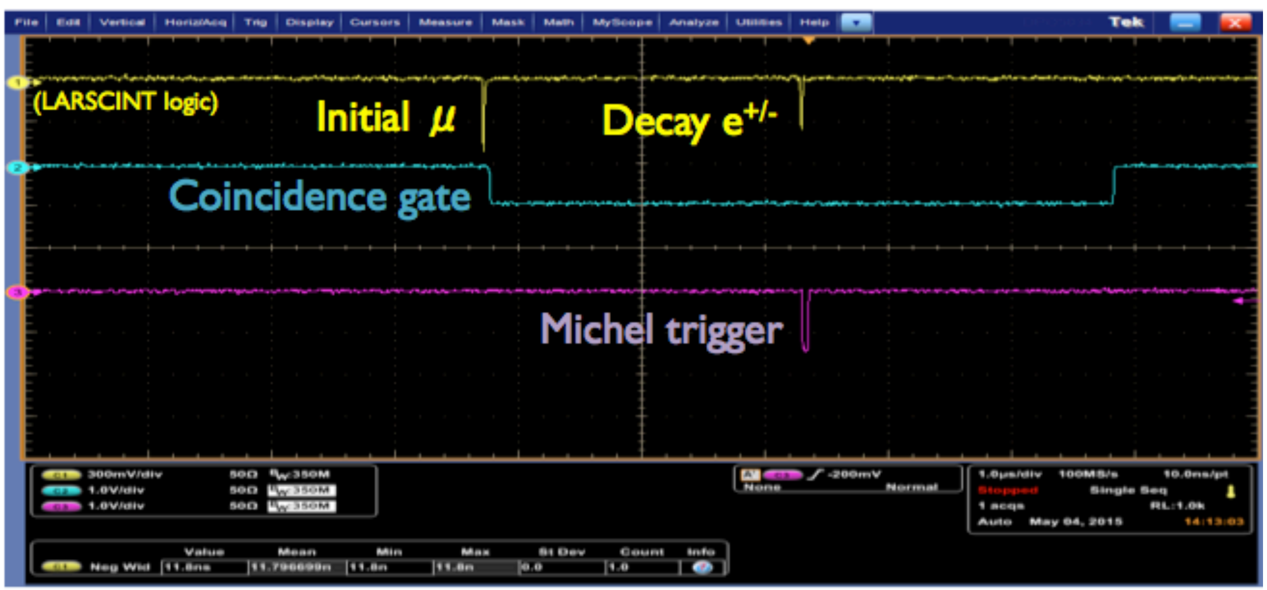
- Combining light (γ) + charge (q) may help restore this linearity
- Studies underway in LArIAT to investigate this possibility



$\mu^{+/-}$ (at rest) → $e^{+/-} + \nu_\mu + \overline{\nu}_e$

- Energy calibration
- PID of stopping $\mu^{+/-}$
- Training ground for shower reco, dE/dx measurements..





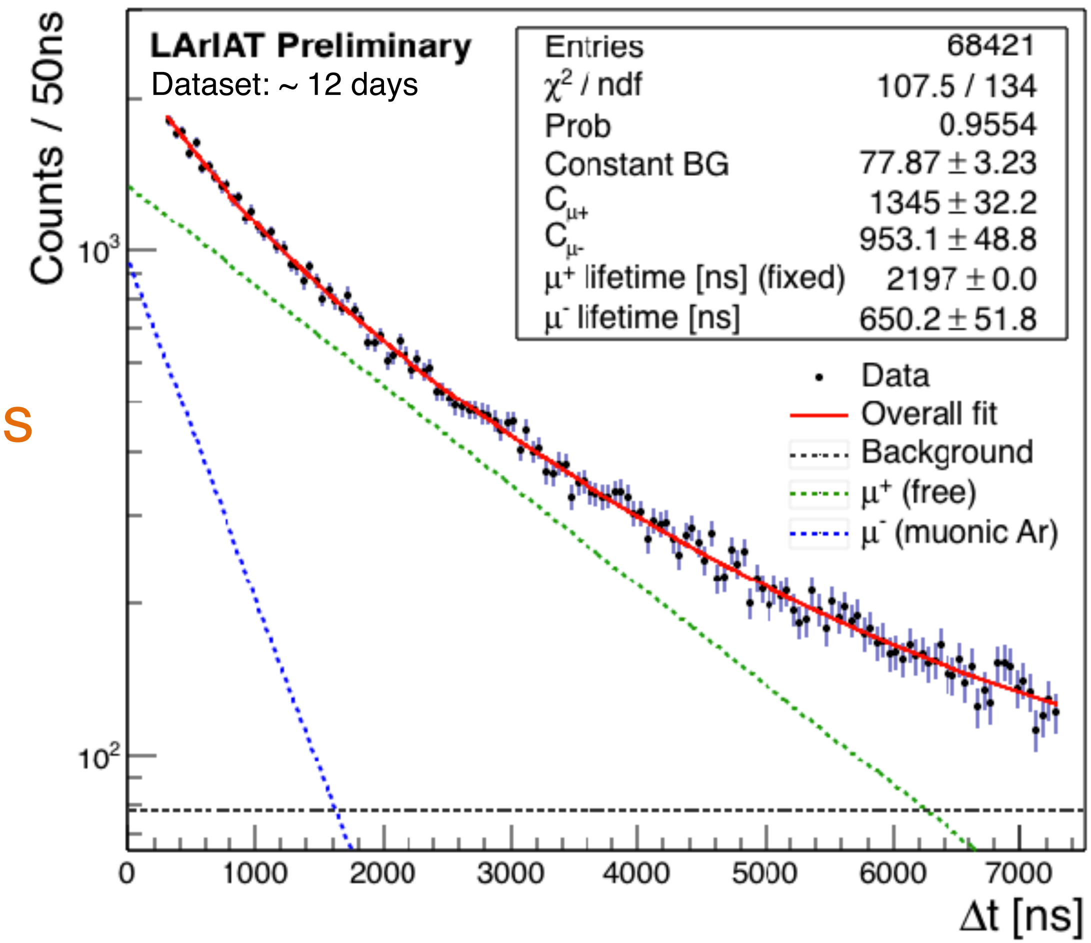
Real-time triggering on Michel e's from stopping cosmic μ's using **light signals**

3. Michel electrons: μ^- capture lifetime in Ar

$$\boxed{\tau_{\mu-}} = \left(\frac{1}{\tau_c} + \frac{Q}{\boxed{\tau_{free}}}\right)^{-1}$$

650 ± 52 ns
(from fit result, preliminary)

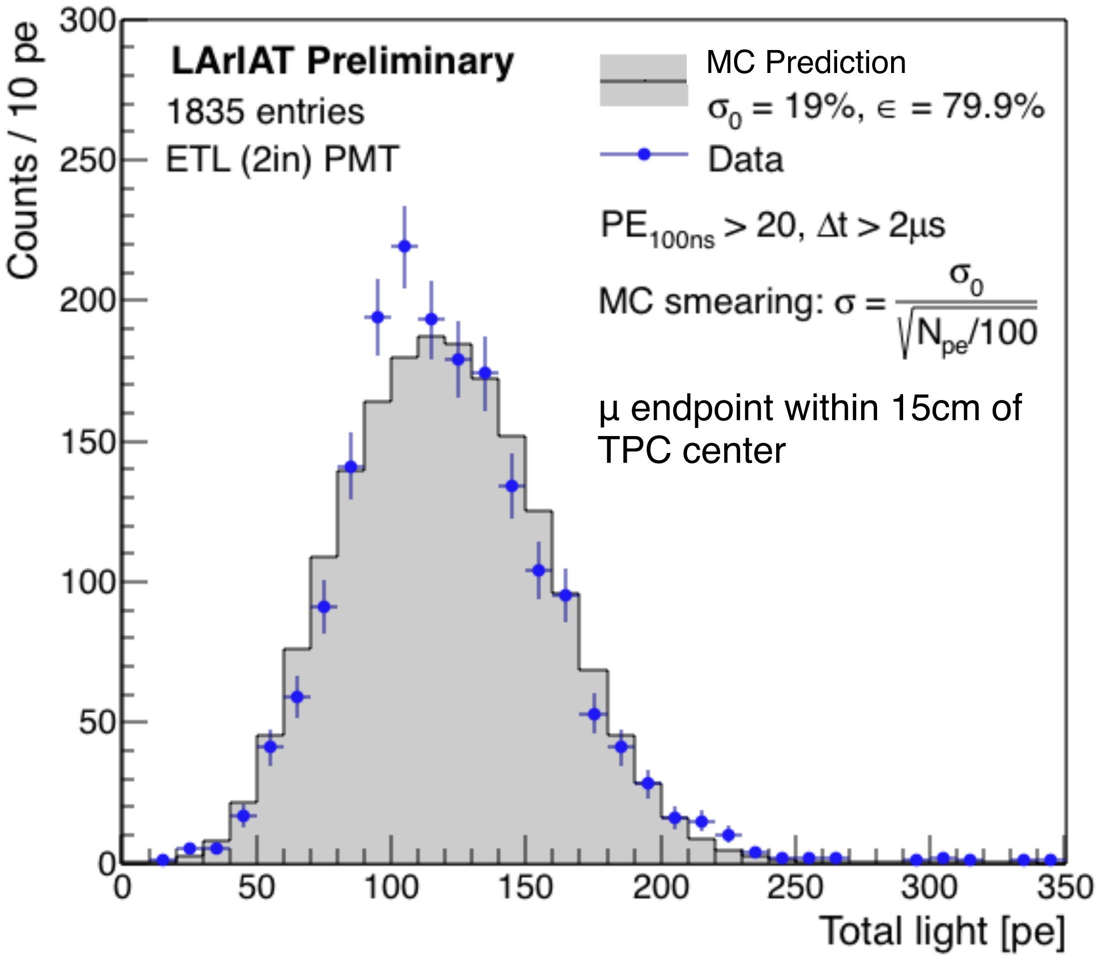
918 ± 109 ns



LIDINE 2015 Proceedings, JINST 11 C01037

Early results agree w/ recent measurement[1] (854 ± 13 ns) and theory prediction[2] (851ns)

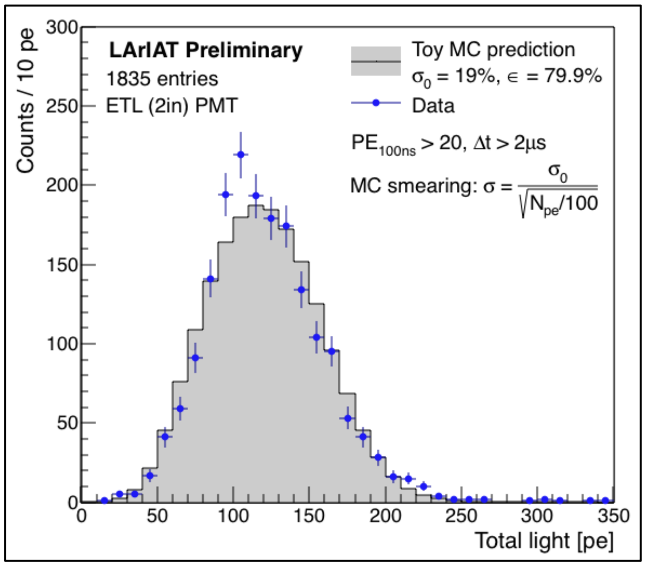
[1](Klinskih et al., 2008)
[2](Suzuki & Measday, 1987)

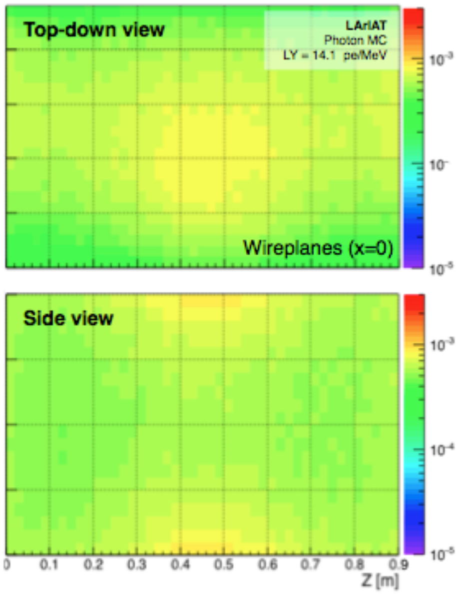


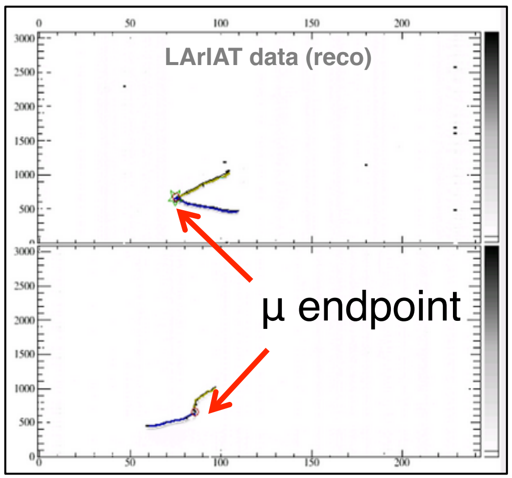
- Michel-candidate signals integrated to get PE spectrum
- Data in approximate agreement with preliminary MC
  - Gives confidence in MC-predicted LY: 2.4 pe/MeV for 2” ETL PMT (Run I) averaged over whole TPC

GOAL: Scaling from **light (γ)** to **energy (MeV)**

Raw PE spectrum + MC photon visibility (& γ/MeV yield) + Reconstructed $e^{+/-}$ position (or μ endpoint)



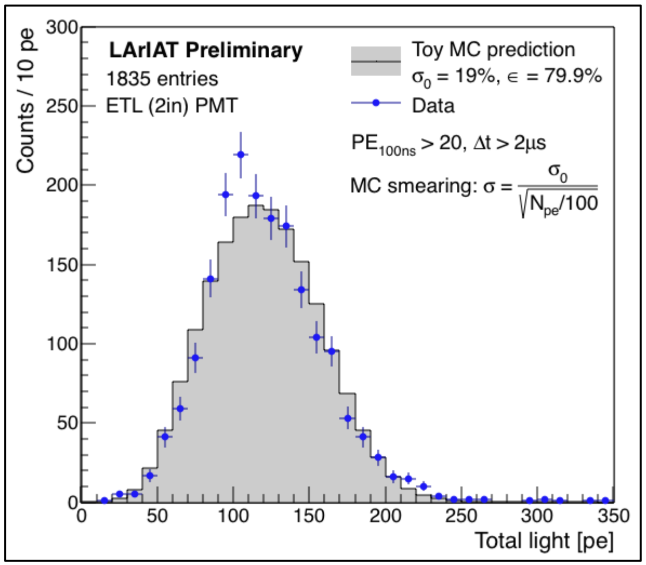


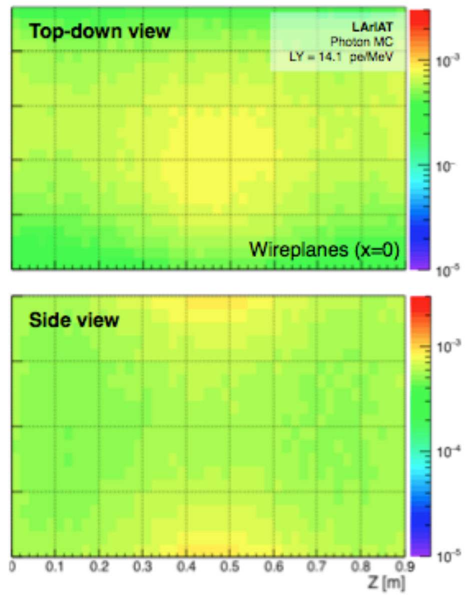


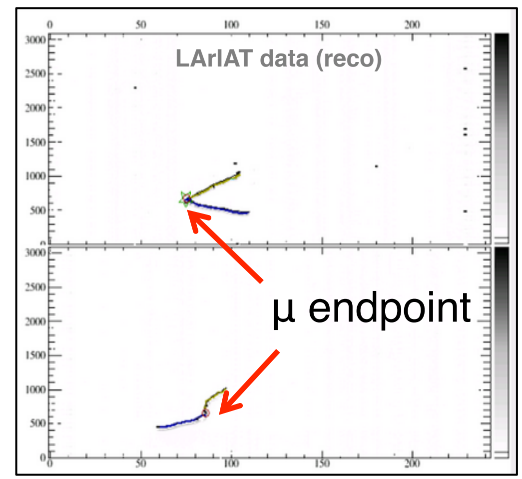
3. Michel electrons: scintillation energy spectrum

GOAL: Scaling from **light (γ)** to **energy (MeV)**

Raw PE spectrum + MC photon visibility (& γ/MeV yield) + Reconstructed $e^{+/-}$ position (or μ endpoint)



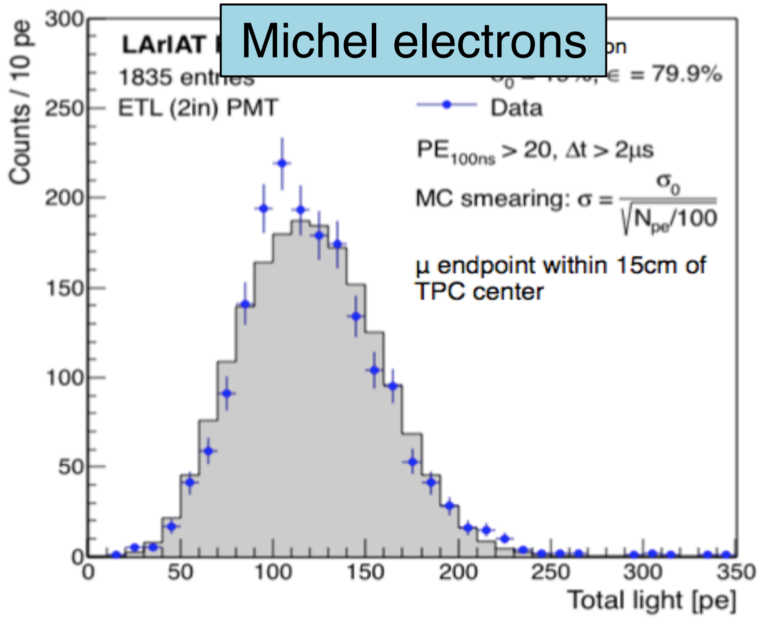


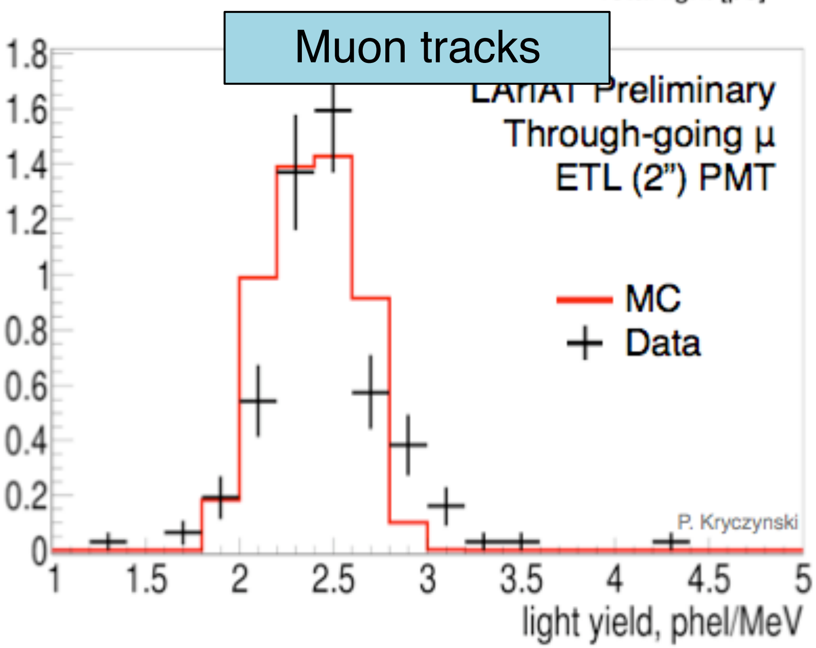


Compare reconstruction through scintillation vs. ionization

→ Can we improve energy resolution by combining them?

The takeaway

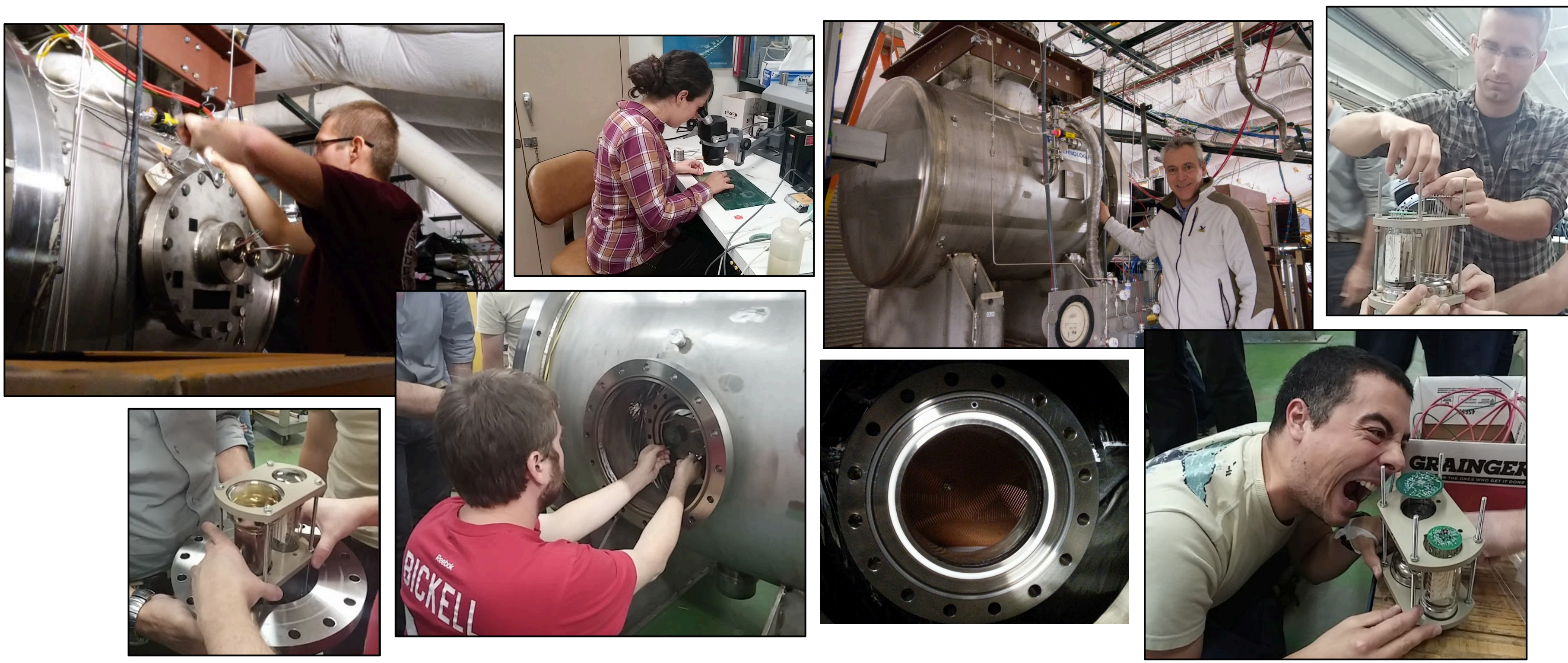




- Reflector-foil system in LArIAT yields 2.4 pe/MeV on a single 2-inch PMT!
- Data and MC agreement seen in two independent analyses

Conclusions

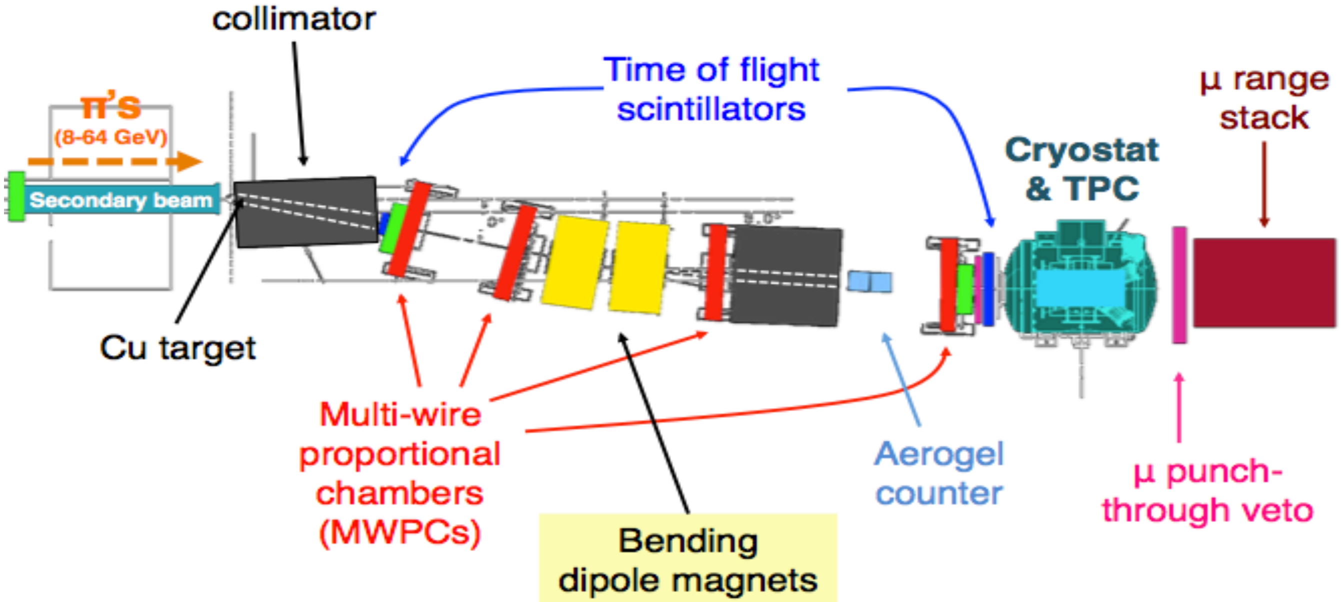
- Light has useful roles to play in LArTPCs (present + future)!
- Studies underway to demonstrate & explore many of these possibilities in LArIAT – stay tuned!



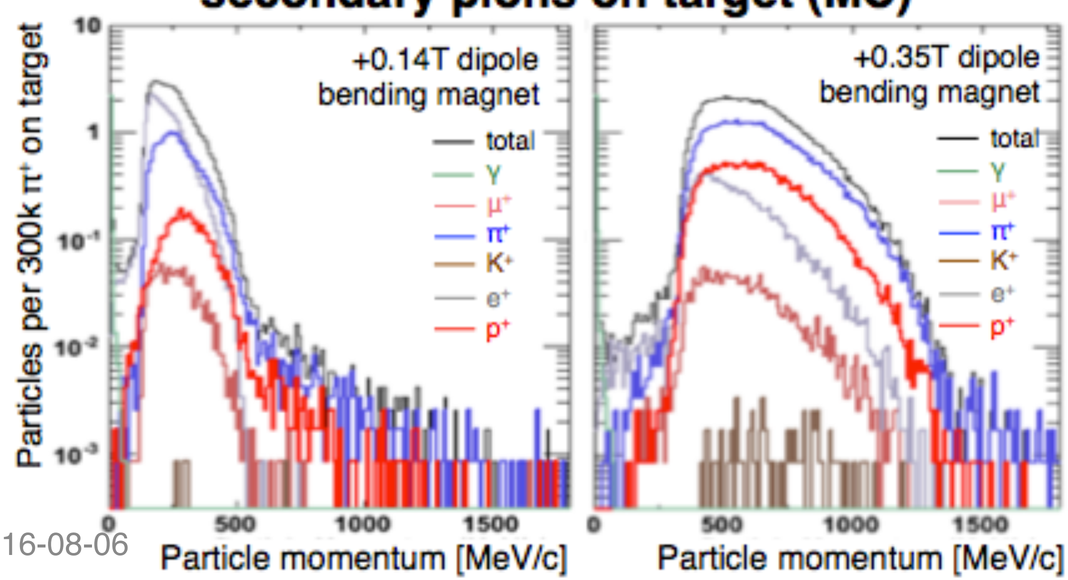
Thanks!

Backups

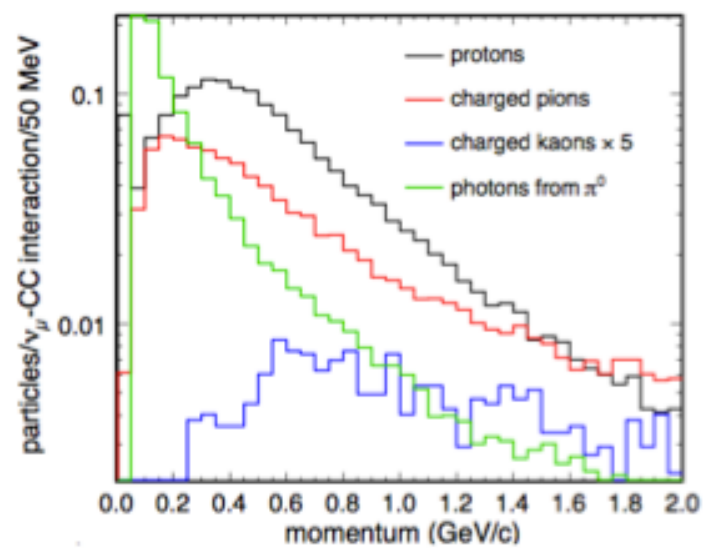
The LArIAT tertiary beamline



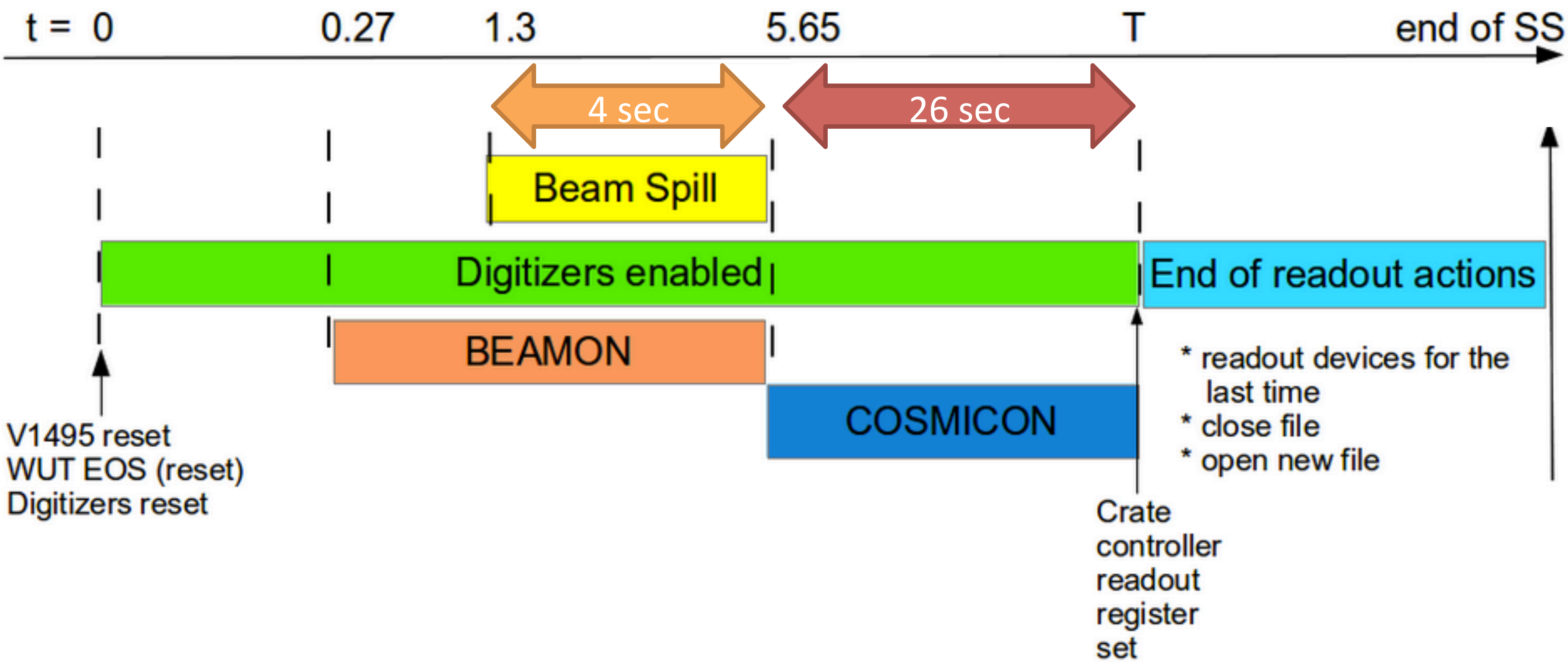
LArIAT final beam spectrum, 8 GeV secondary pions on target (MC)



Spectrum of final state particles from NuMI ν interactions

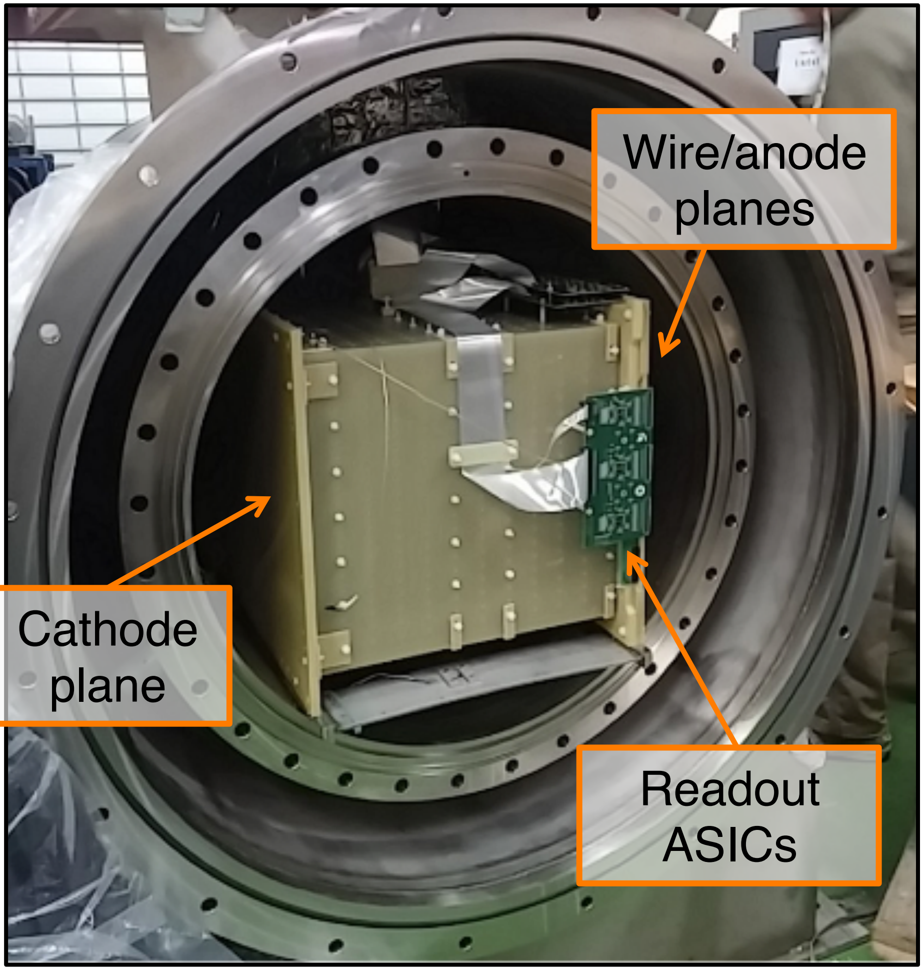


The LArIAT Supercycle

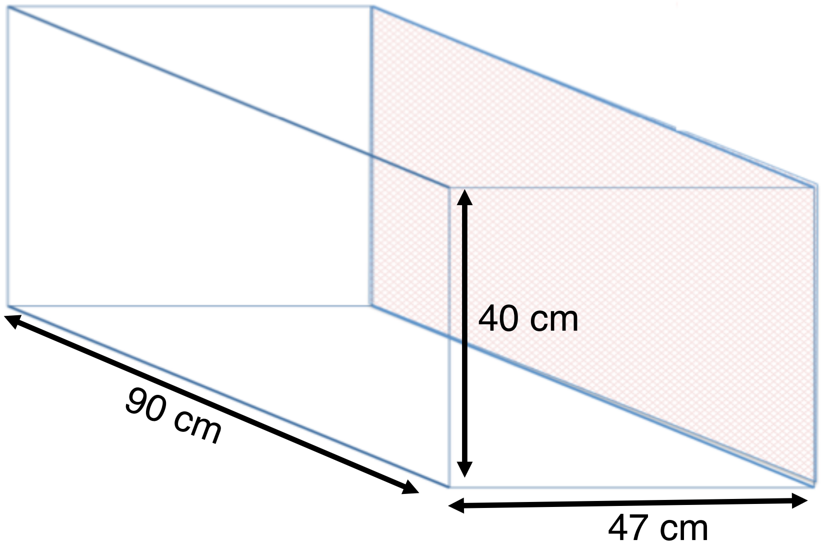


Spill supercycle = **4s beam + 24s cosmics & light-based Michel triggers**

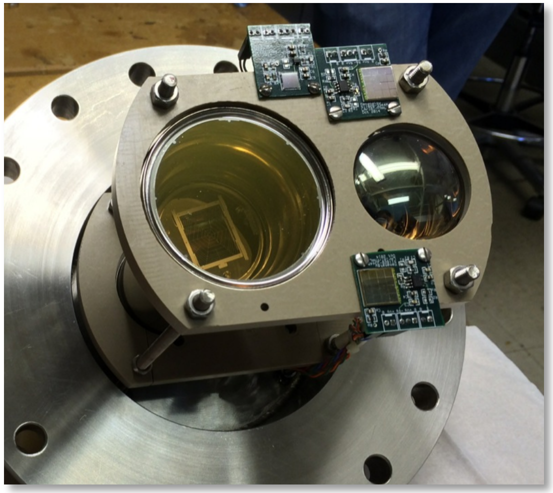
The LArIAT TPC



- **The time projection chamber**
  - Repurposed from ArgoNeuT
  - New wireplanes
    - 1 shield plane: 225 vertical wires
    - 2 readout planes: 240 wires each, +/-60^{o}, 4mm pitch
  - Drift field ~500 V/cm



The LArIAT light collection components



Two cryogenic PMTs

Three silicon photomultipliers (SiPMs)* on custom preamp boards.

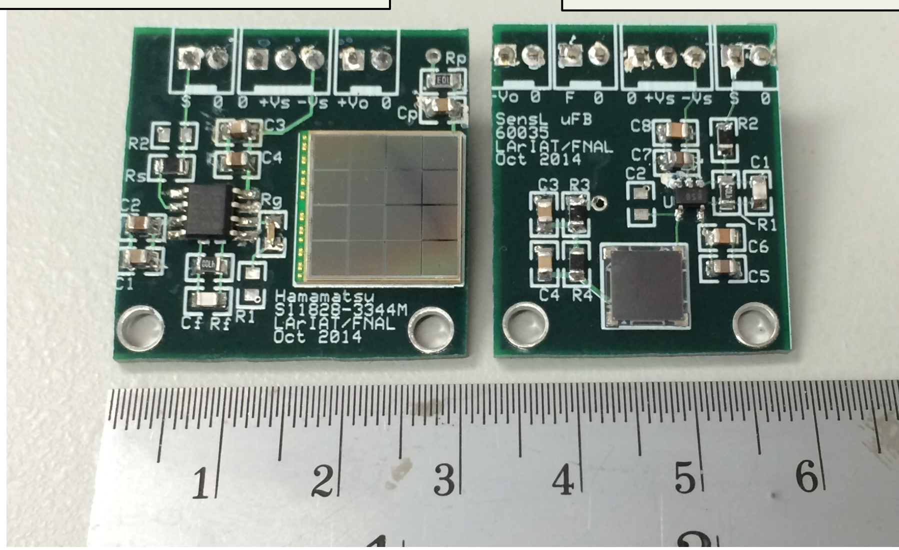
*VUV SiPM not shown

Hamamatsu PMT
R-11065
(3” diameter)

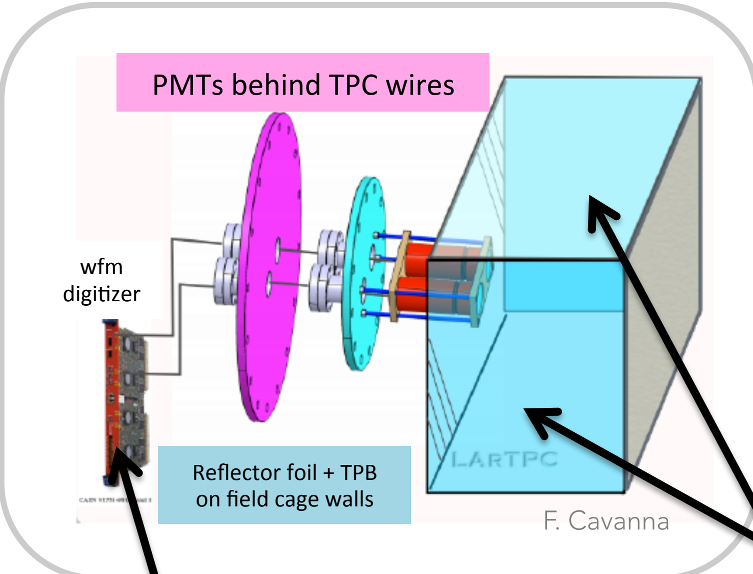
ETL PMT
D757KFL
(2” diameter)

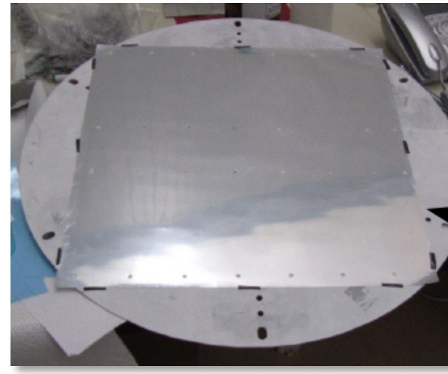
Hamamatsu S11828-3344M,
4x4 array, w/preamp

SensL MicroFB-60035
w/preamp



Digitization and reflector foils



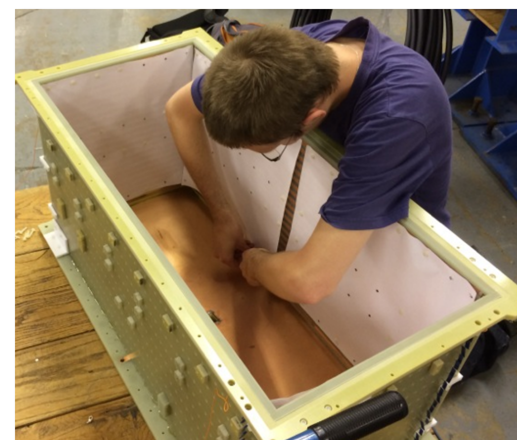


Reflector foil before/after TPB evaporation

Inner walls lined with **TPB reflector foil** to maximize light collection and *uniformity* compared to traditional LArTPCs

Signals digitized by **CAEN V1751** at 1GS/sec

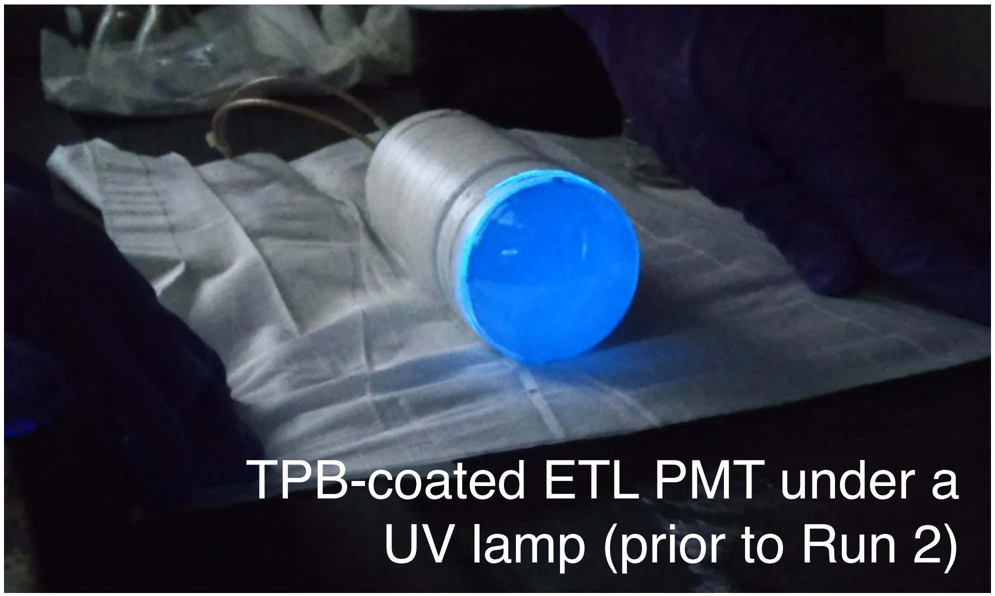
- Fast DAQ to optimize differentiation of fast & slow component (~7ns vs ~1.6μs)



Test-mount of mock foil masks onto LArIAT TPC.

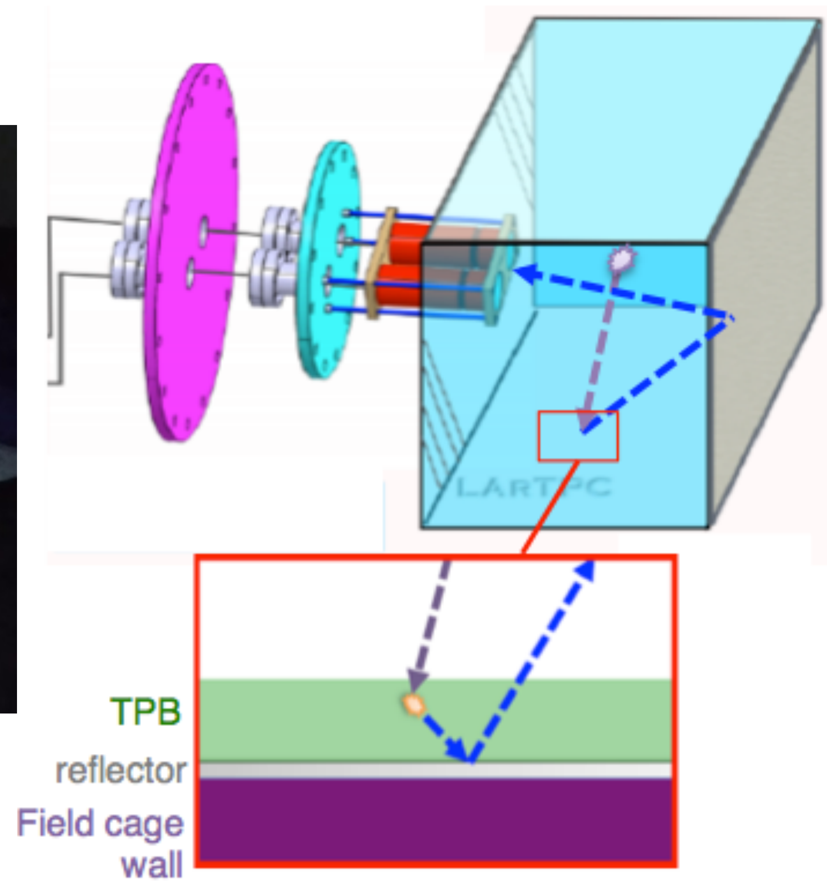
Wavelength-shifting technique

Experimented with a TPB-coated PMT as well during Run II

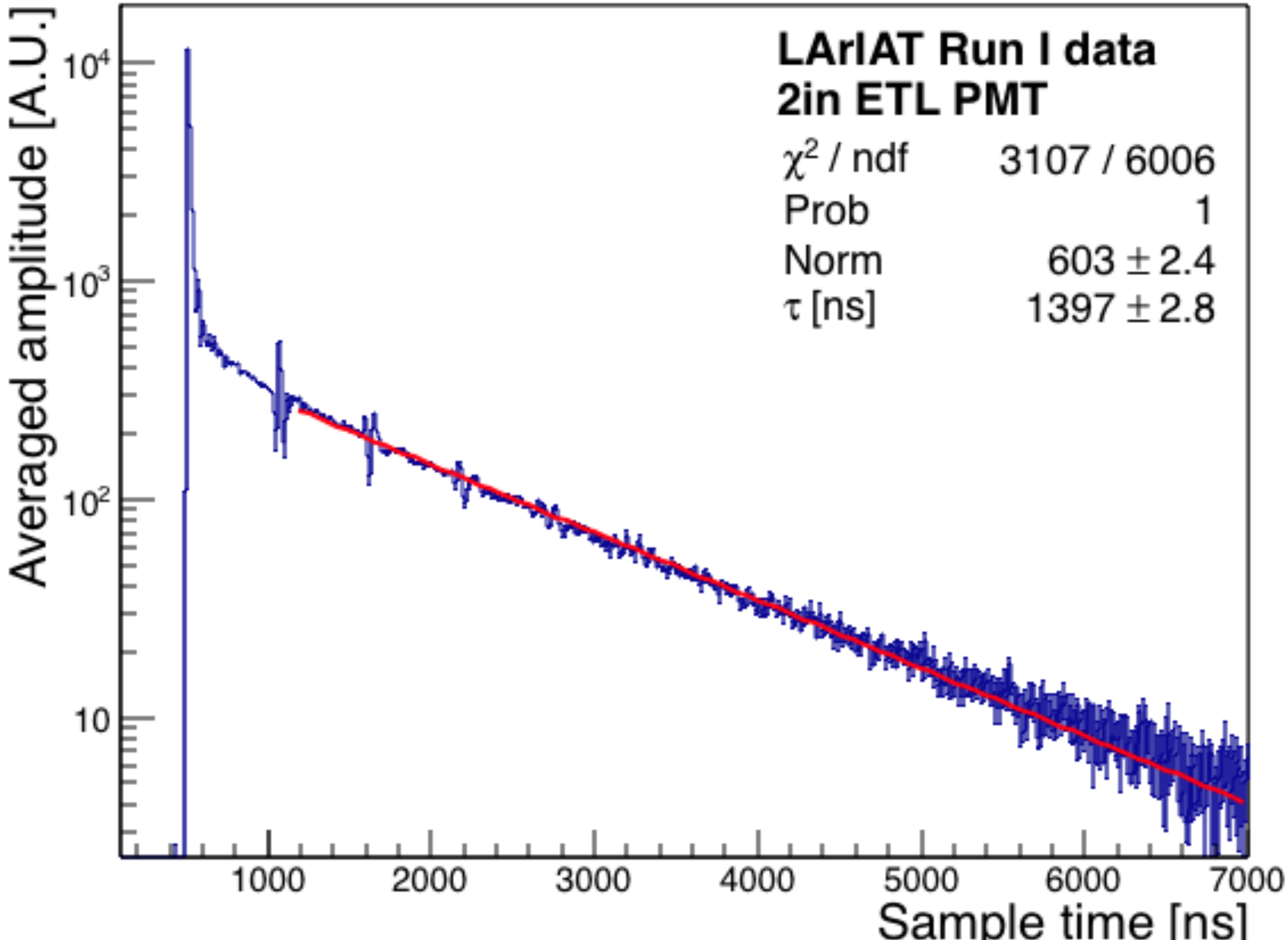


TPB-coated ETL PMT under a UV lamp (prior to Run 2)

Reflector-based solution (LArIAT)



Average waveform of through-going muons

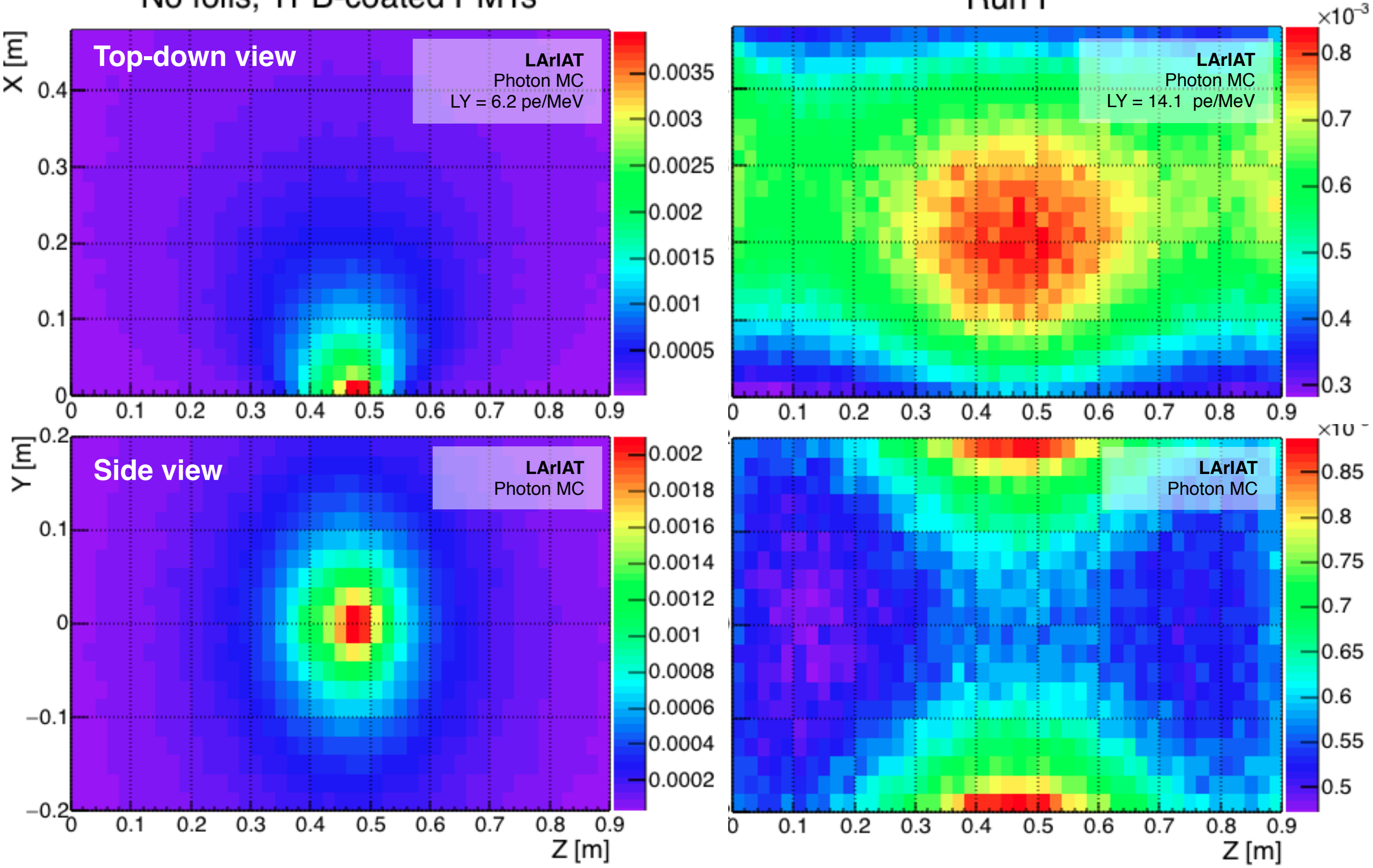


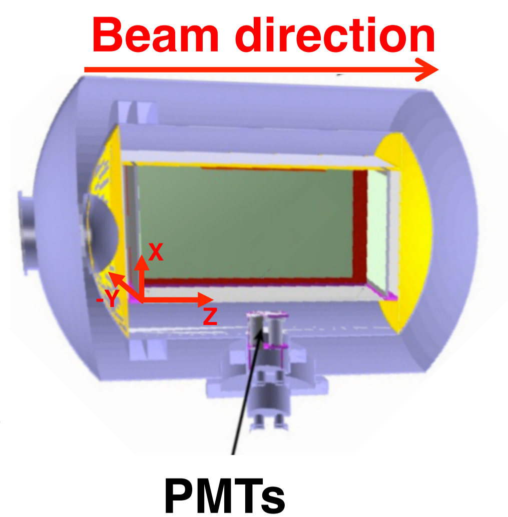
System visibility from simulation

Fractional photon visibility for LArIAT Run I vs. a traditional setup

No foils, TPB-coated PMTs

Run I

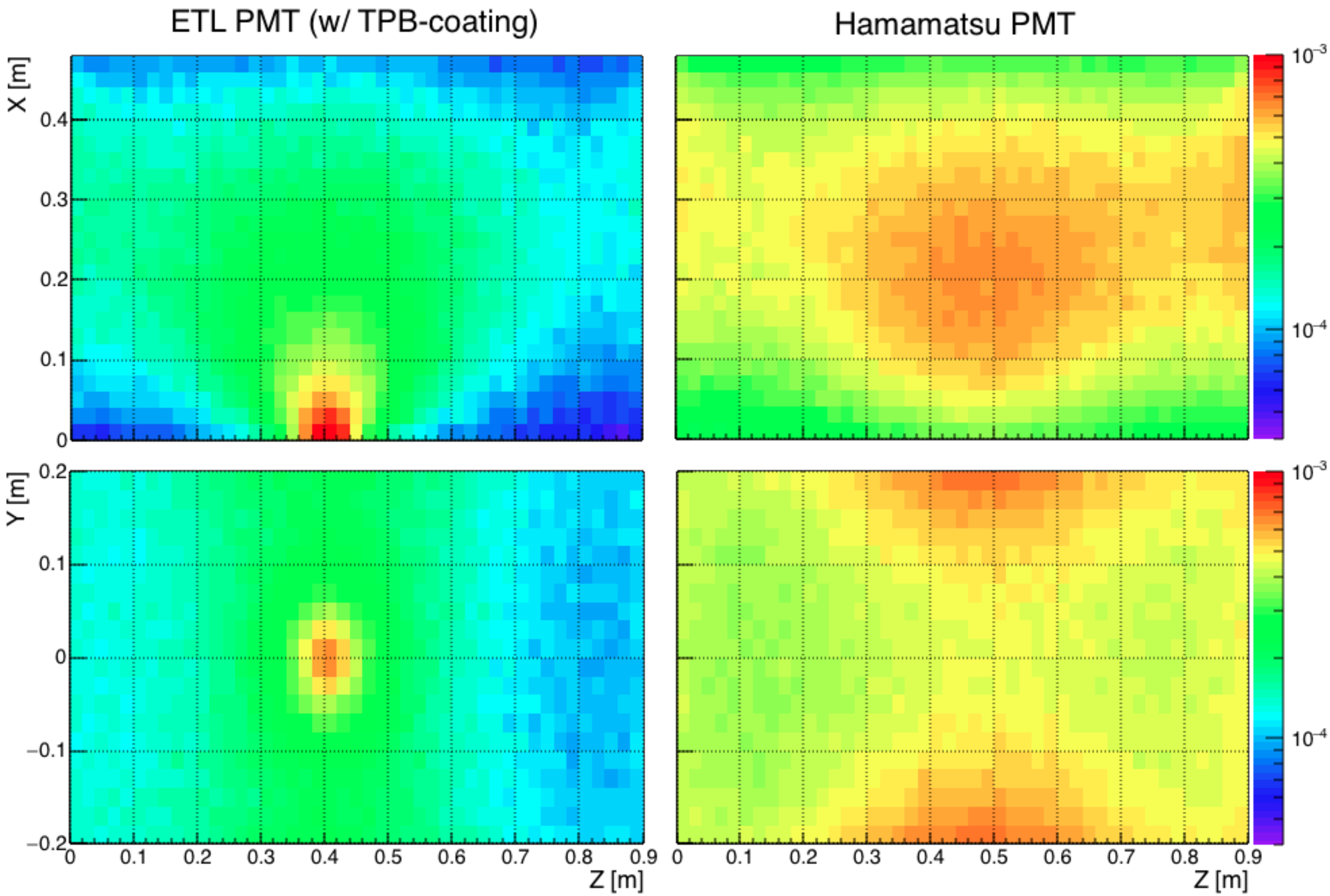




Beam direction

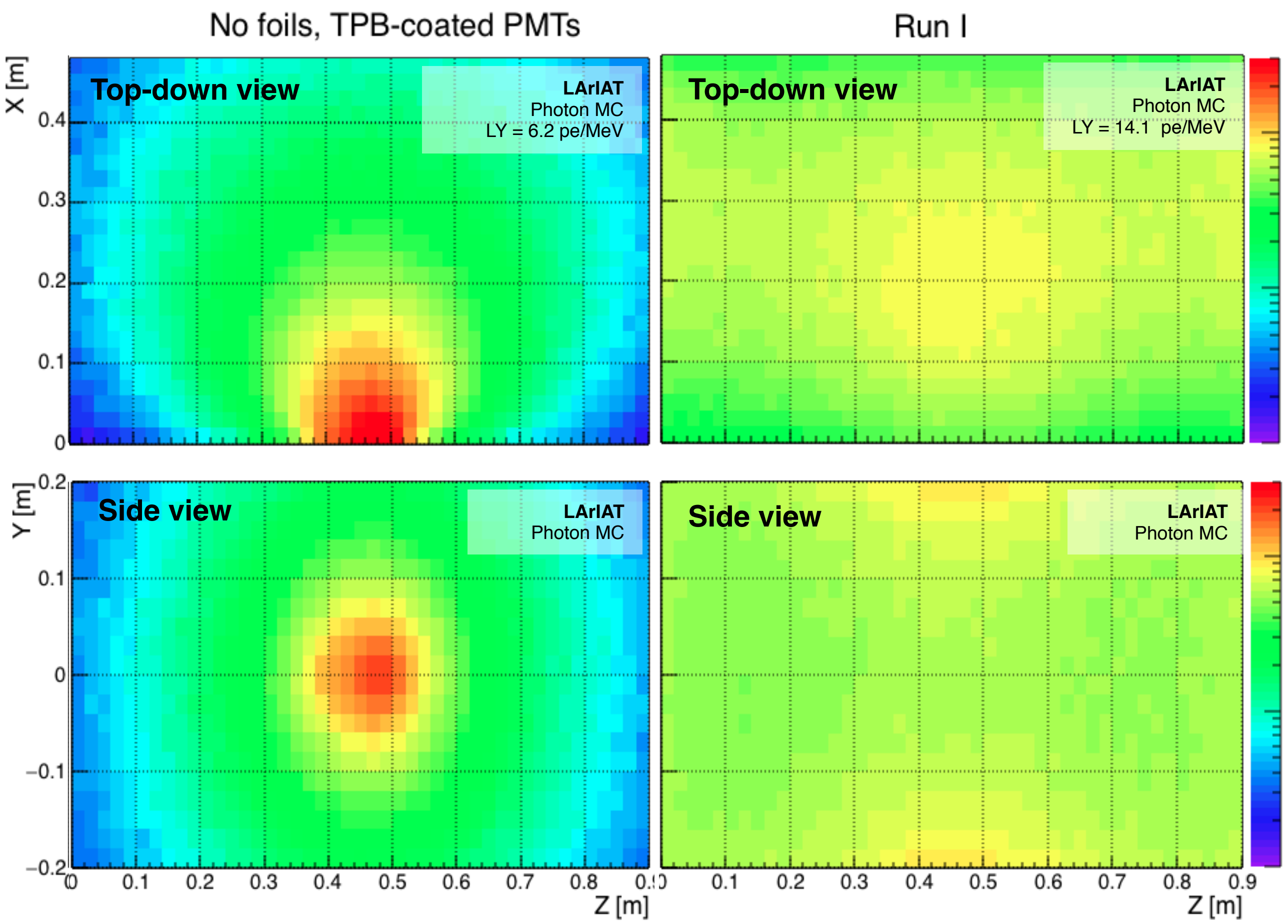
Beam direction

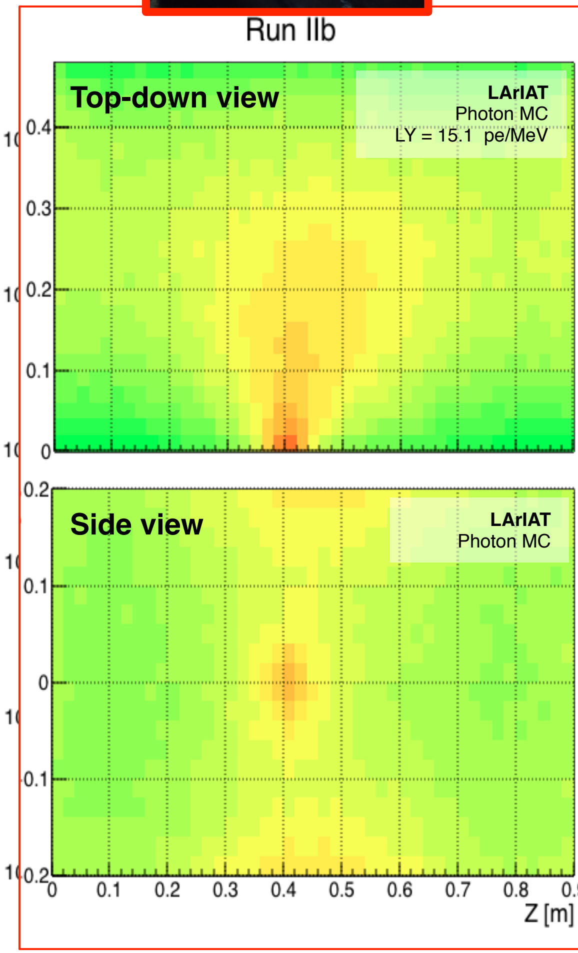
Fractional visibility per PMT for LArIAT Run IIa (toy photon propagation MC)



System visibility (from simulation)

Fractional photon visibility for LArIAT Run I vs. a traditional setup

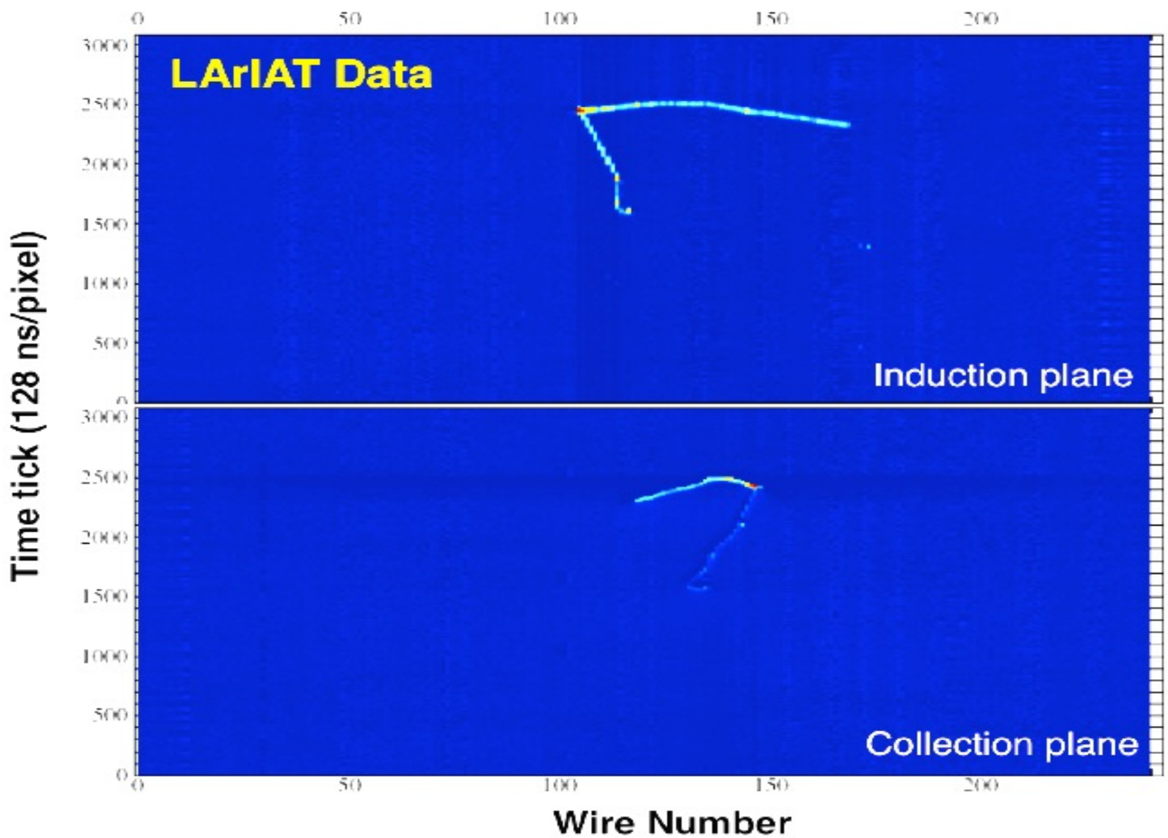




Beam direction

Beam direction

Data

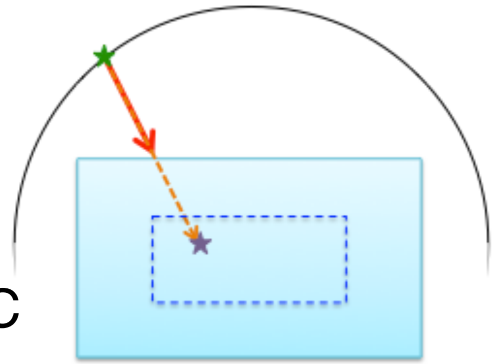


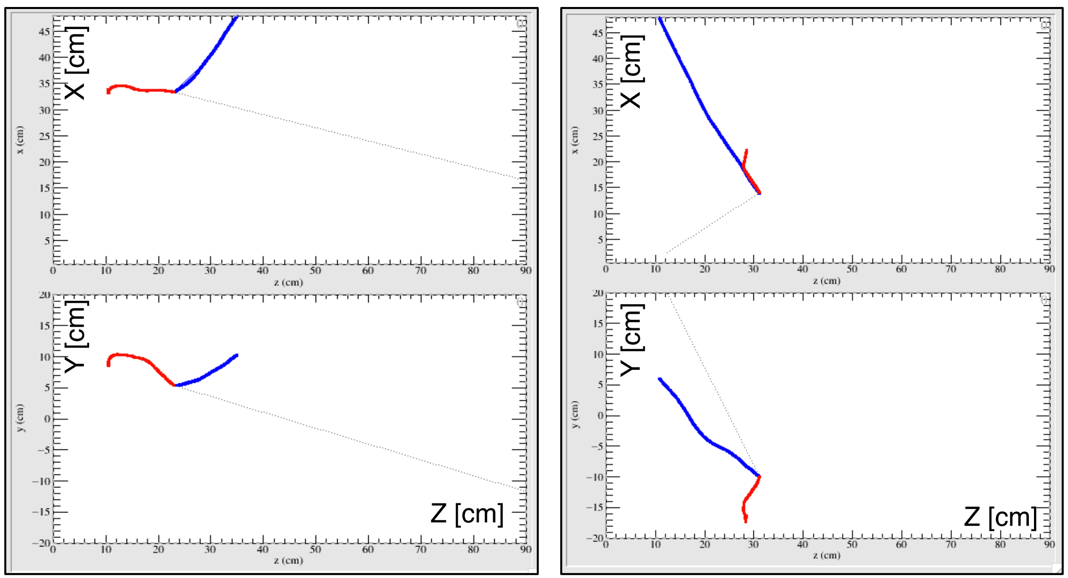
For initial analysis, using dataset obtained during a 12-day period in Run I

- *Only ETL PMT data used*
- ~4 days cumulative cosmic trigerring
- ~1 Hz collection rate
- ~ 100k analyzable Michel electrons (estimated)

Cosmic Muon Monte Carlo studies

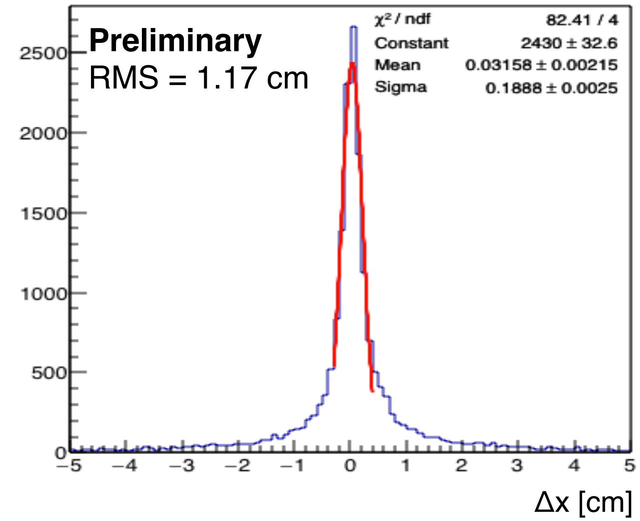
Simulated 100k μ^+ with p_0 = 200-500 MeV aimed toward center region of TPC





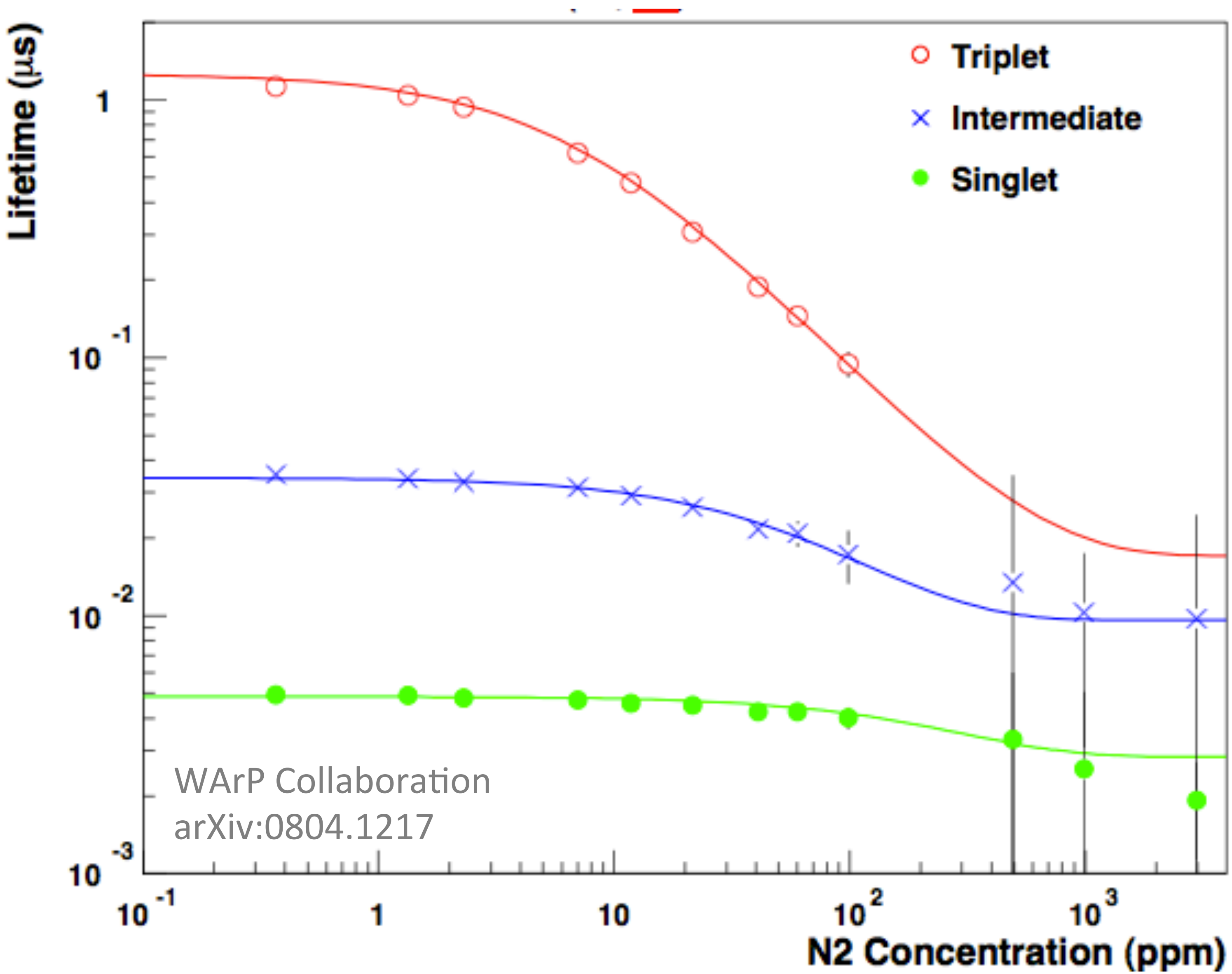
True MC particle trajectory examples

Stopping μ endpoint reco resolution in X (LArIAT MC)



- Good rate of identifying these events using simple topological track info alone (start/end point)
- More work to do in improving ***μ endpoint resolution***

N_2 vs slow scintillation lifetime



N_2 vs slow scintillation lifetime