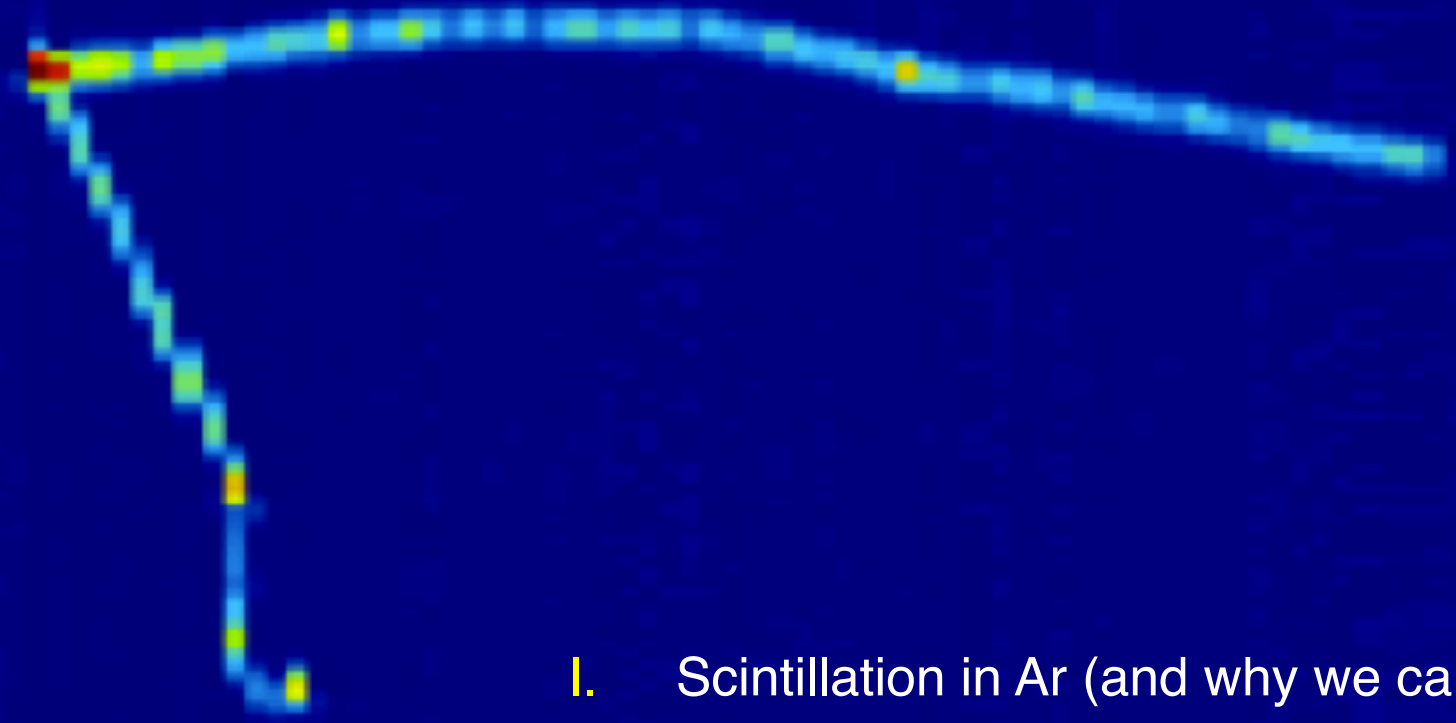
Studies of Michel Electrons in LArIAT

Will Foreman, University of Chicago

New Perspectives at Fermilab

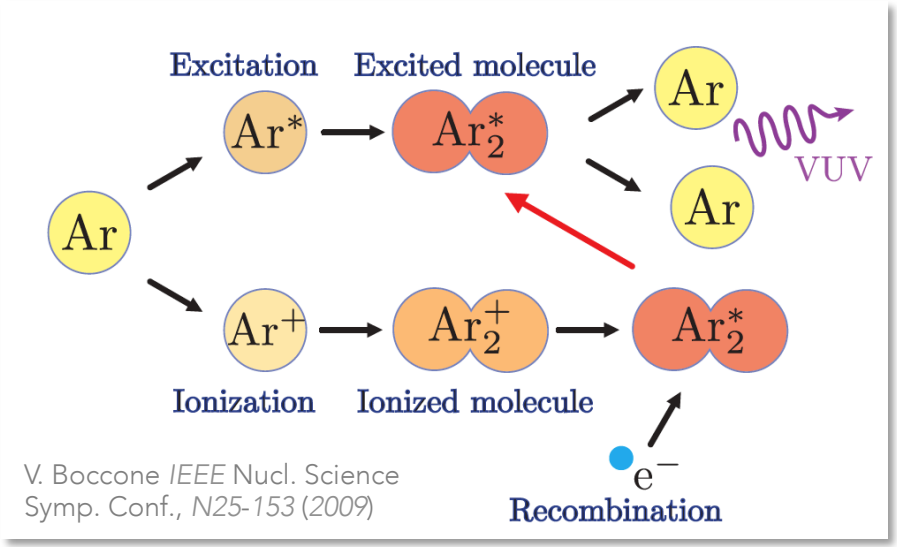
June 13-14, 2016



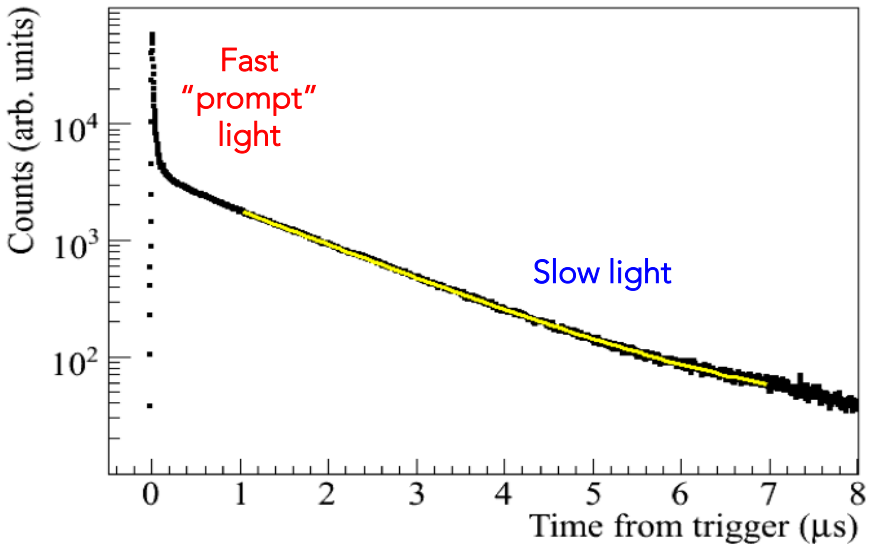
I. Scintillation in Ar (and why we care)
II. The LArIAT light collection system
III. Triggering on Michel electrons in LArIAT
IV. Preliminary analysis
V. Analysis plans and goals

Scintillation light in liquid argon

- LAr scintillates at 128 nm, with ~40k γ/MeV (at E = 0)
- Two components:
  - Fast (τ = 7ns)
  - Slow (τ = 1.6μs)
- **Typically used only to aid in event triggering**

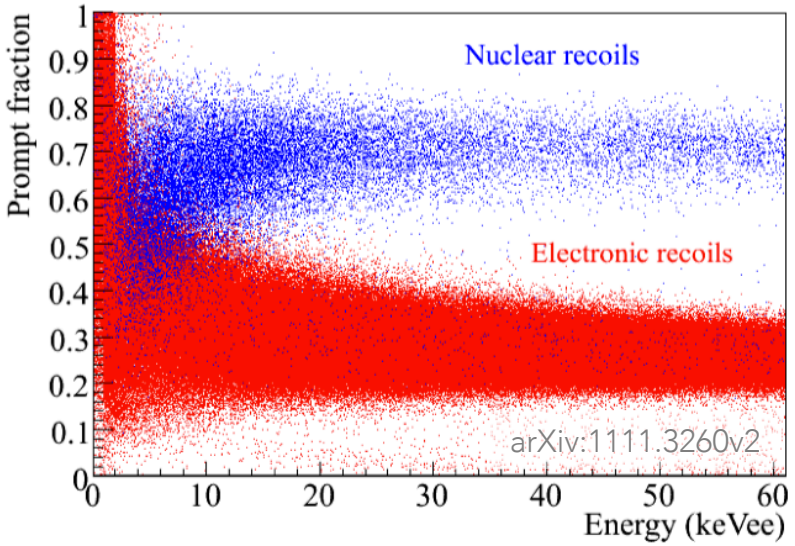


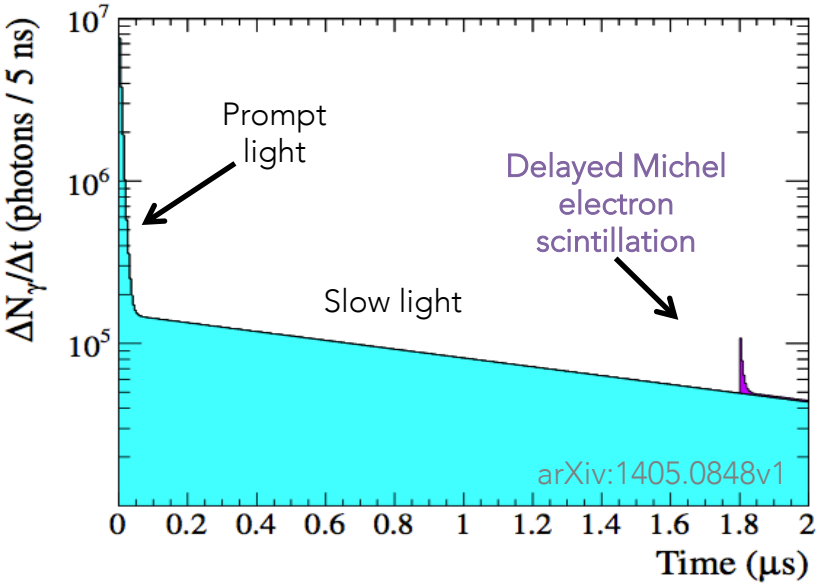
V. Boccone *IEEE* Nucl. Science Symp. Conf., *N25-153 (2009)*

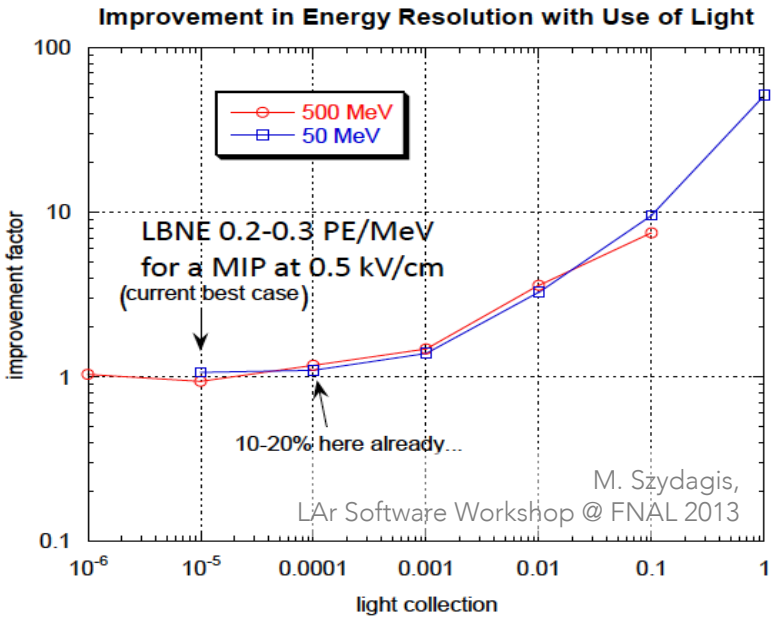


Potential physics benefits

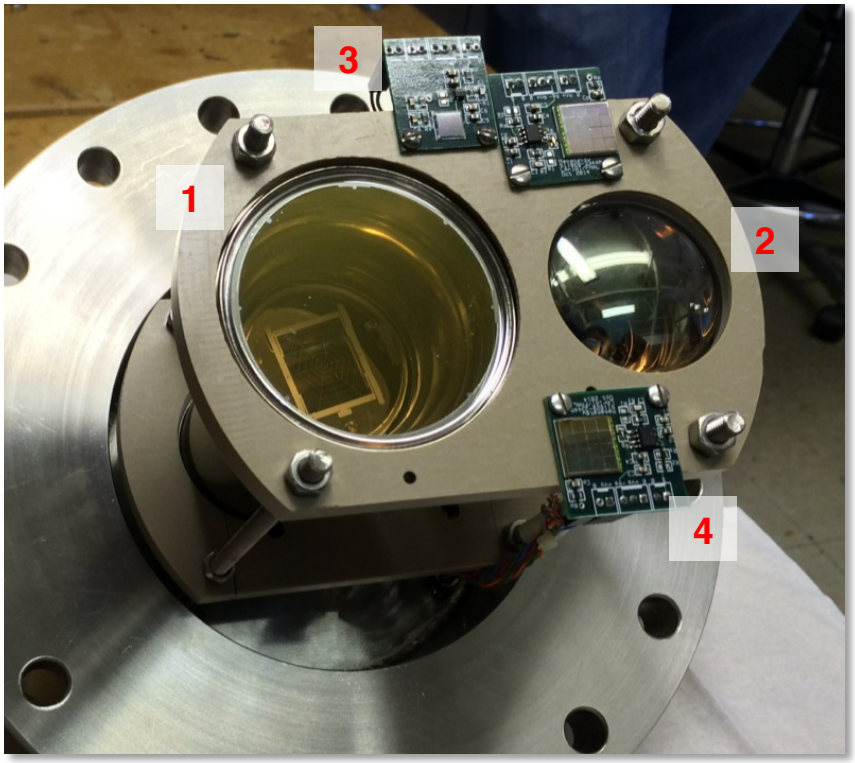
- Fast / slow component ratios dependent on ionization density → **PID**
- Light & charge complementary for Ar_2^+ recombination → **calorimetry**
- ID stopping μ from Michel decay time







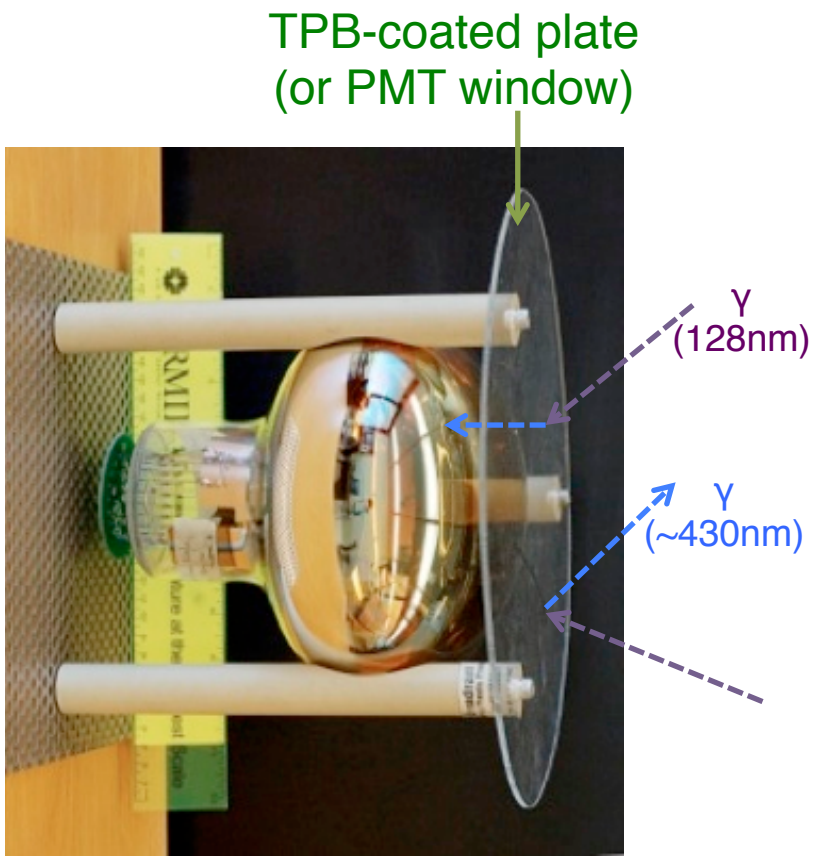
Light collection in LArIAT



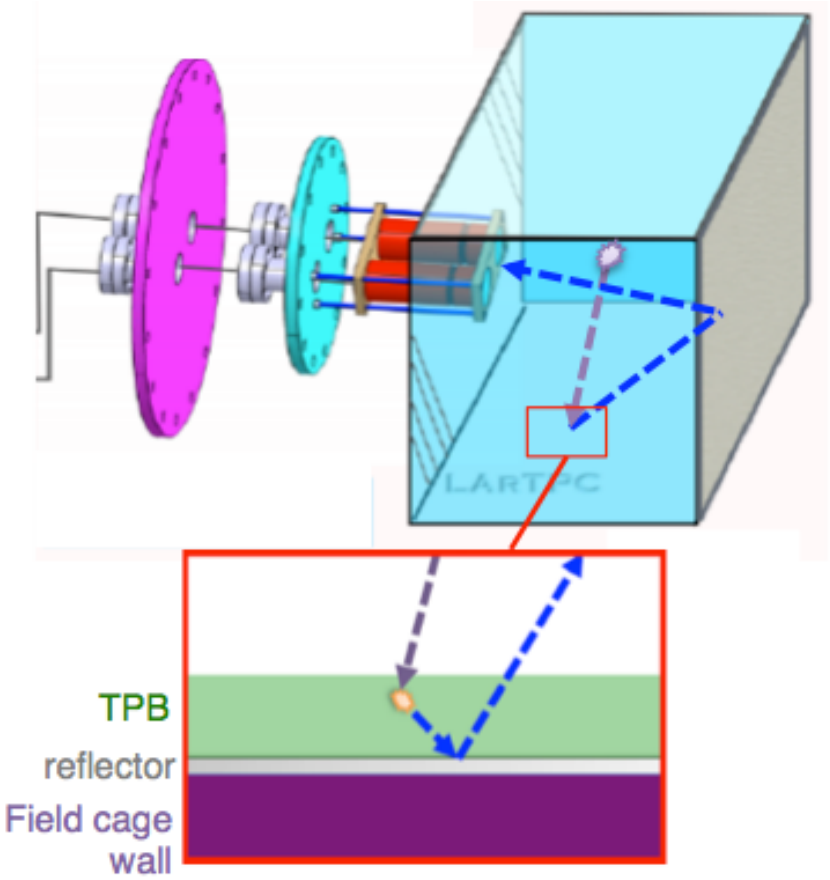
1. PMT: Hamamatsu R-11065 (3” diameter)
2. PMT: ETL D757KFL (2” diameter)
3. SiPM: SensL MicroFB-60035 w/preamp
4. SiPM: Hmm. S11828-3344M 4x4 array (*Run I*)
   SiPM: Hmm. VUV-sensitive (*Run IIa*)

Wavelength-shifting technique

Standard LArTPC approach (ie, ICARUS, MicroBooNE)

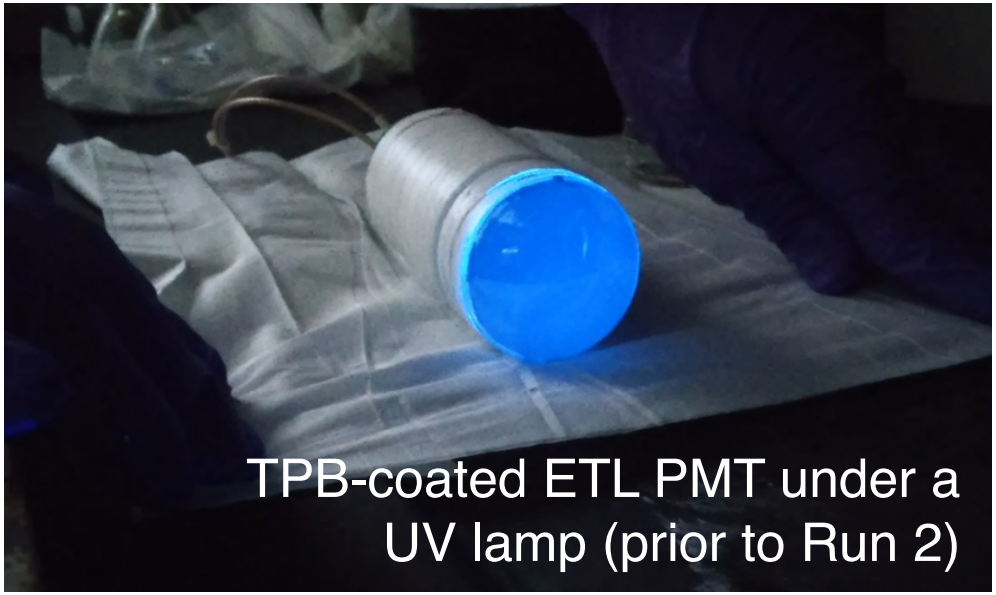


Reflector-based approach (LArIAT)

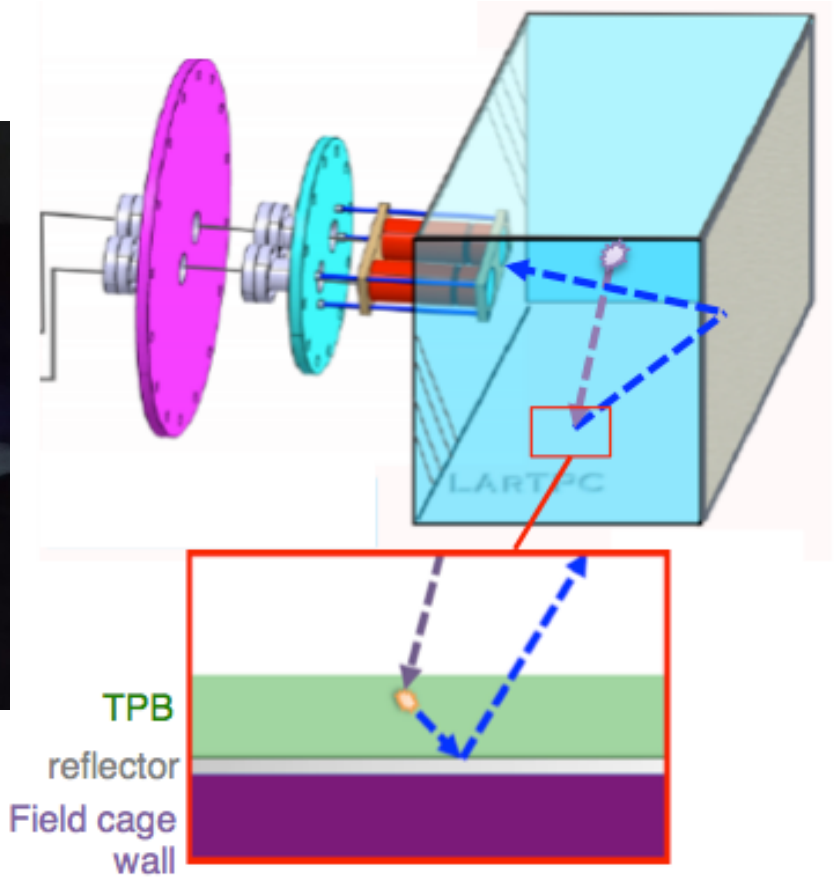


Wavelength-shifting technique

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

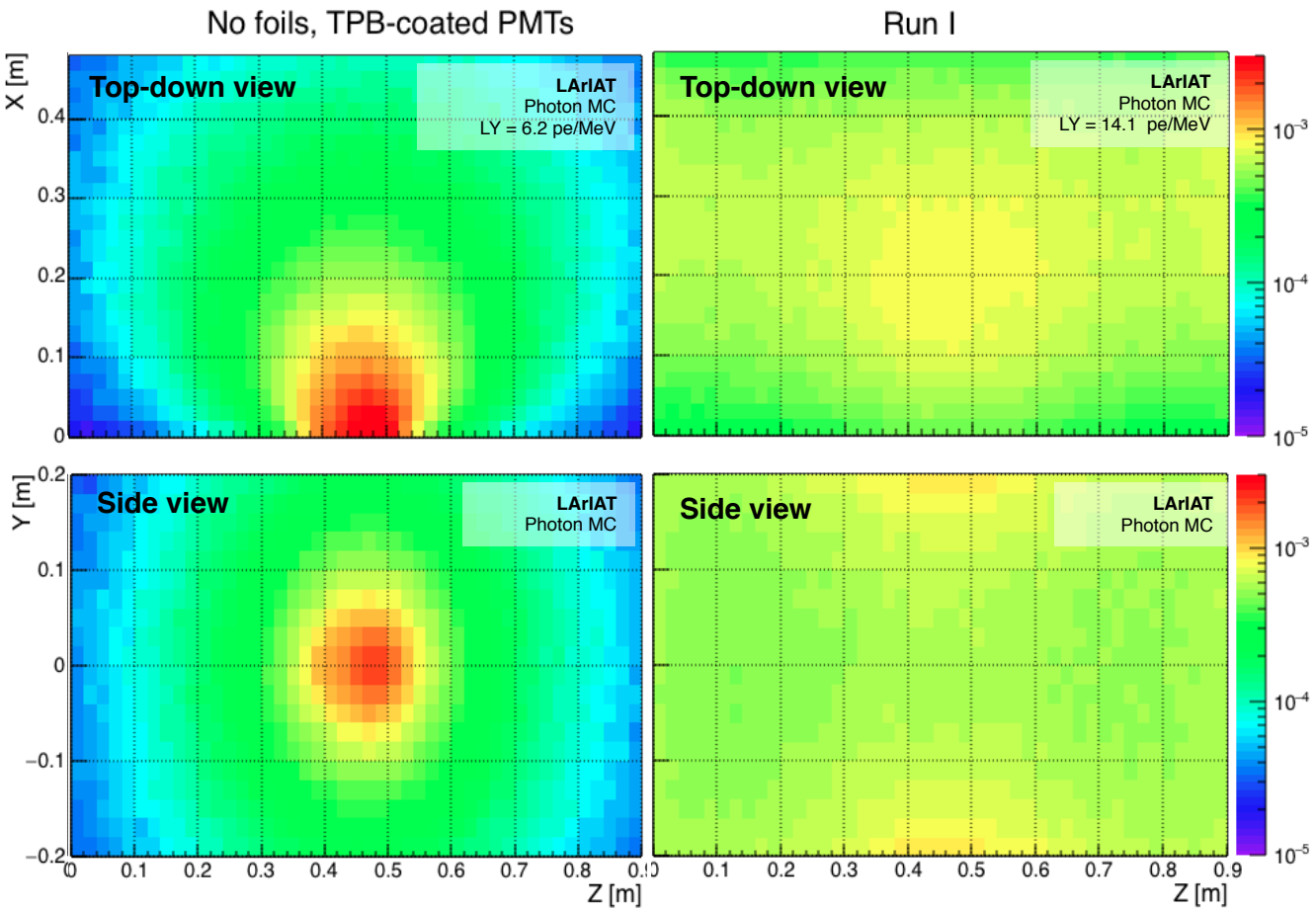


Reflector-based solution (LArIAT)



System visibility (from simulation)

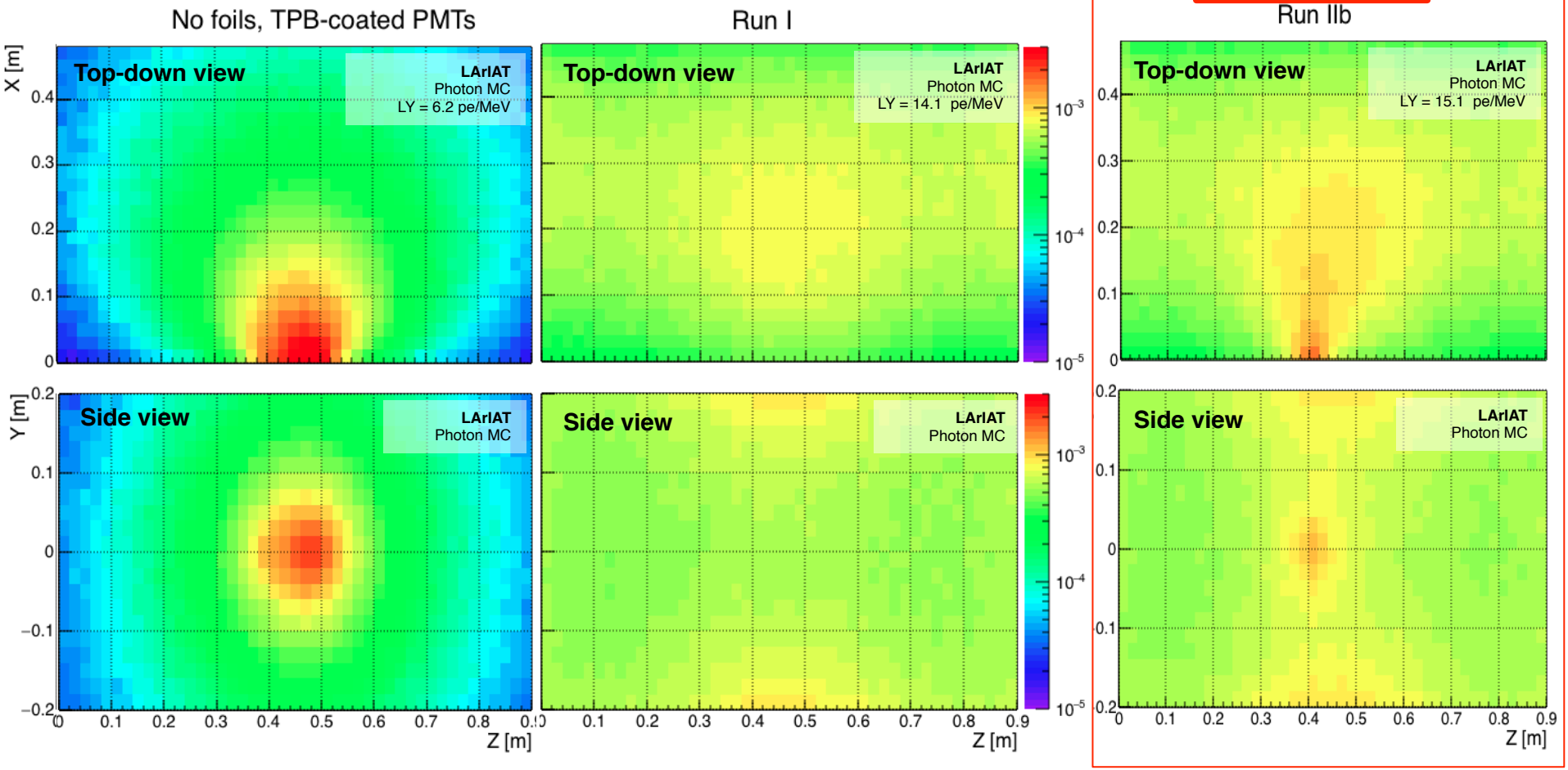
Fractional photon visibility for LArIAT Run I vs. a traditional setup



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

System visibility (from simulation)

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

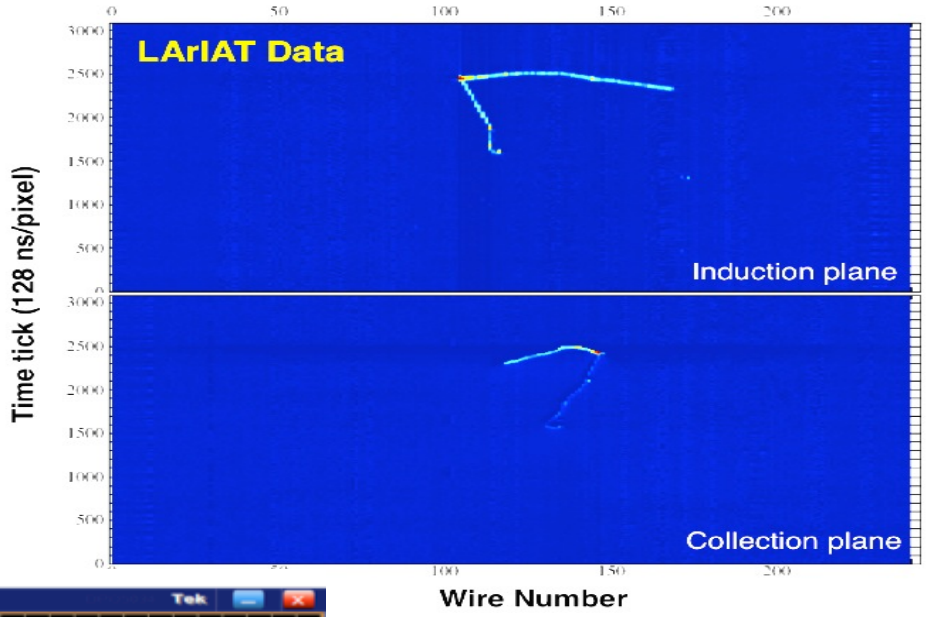


Triggering on Michel electrons in LArIAT

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

Useful for…

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

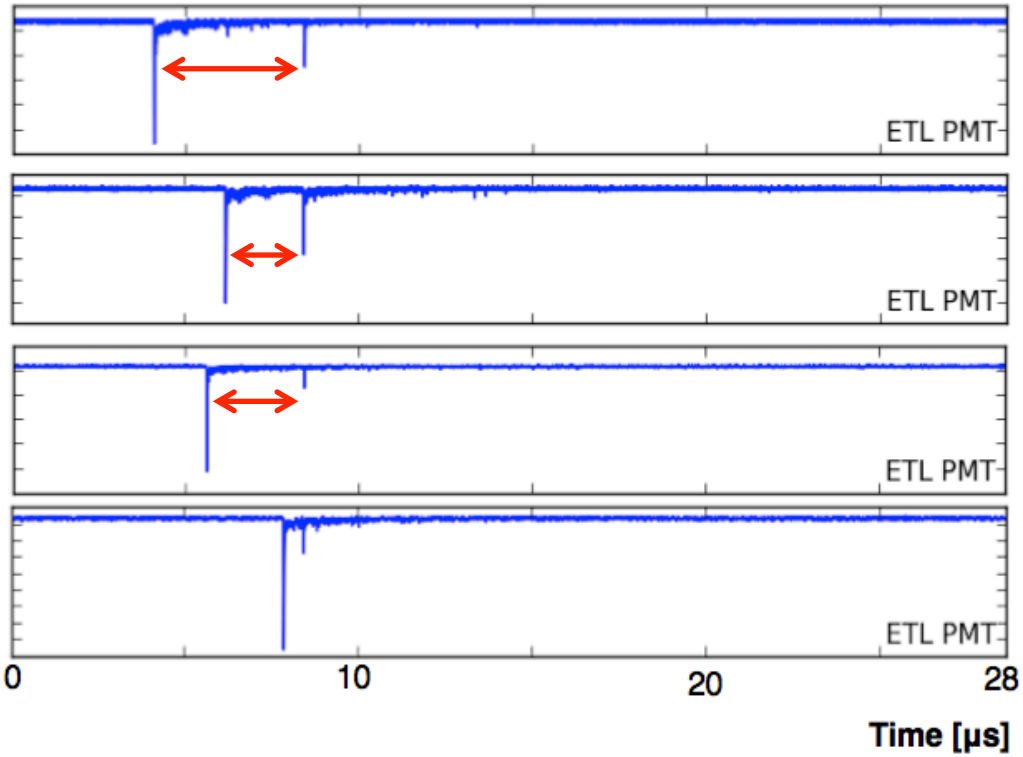


Real-time triggering on Michel e's from stopping cosmic μ's using light signals

Muon decay time

- Stopping $\mu^{+/-}$ can decay to electron with τ_{free} = 2.2μs
- … but μ^- can *also* be *captured* by Ar nucleus with competing time constant τ_c

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



Muon decay time

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- … but μ^- can *also* be *captured* by Ar nucleus with competing time constant τ_c

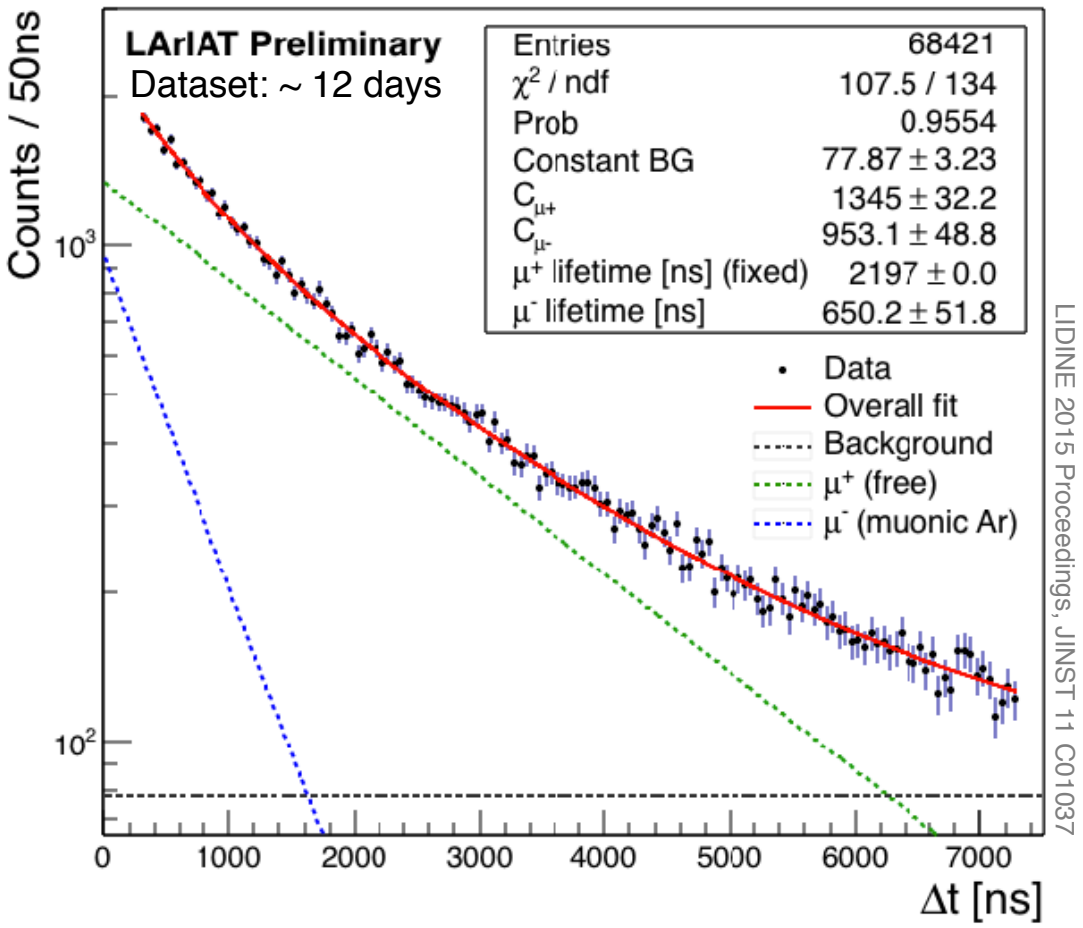
$$\tau_{\mu-} = \left(\frac{1}{\tau_c} + \frac{Q}{\tau_{free}} \right)^{-1}$$

650 ± 52 ns
(from fit result, preliminary)

918 ± 109 ns

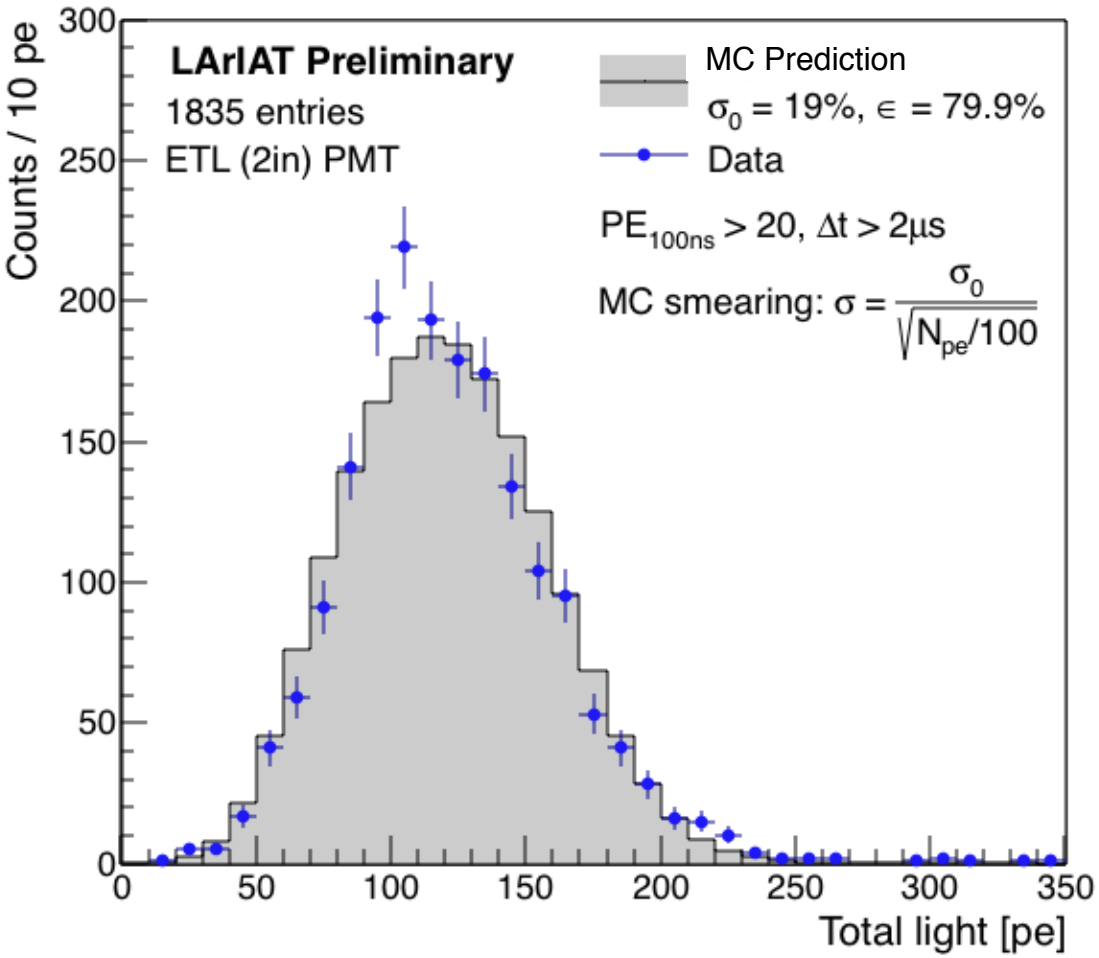
Early results agree w/ recent measurement[1] (854 ± 13 ns) and theory prediction[2] (851ns)

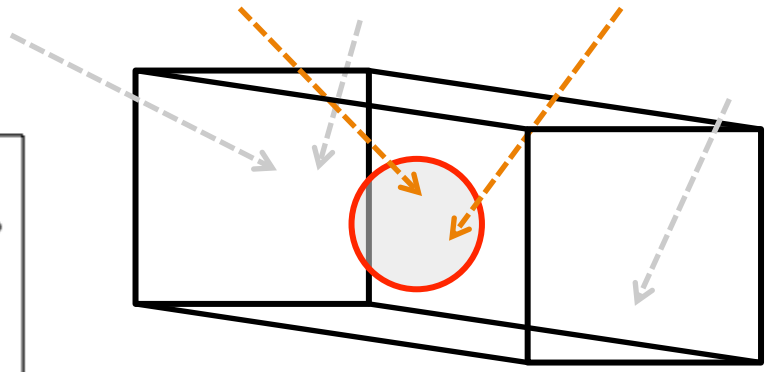
[1](Klinskih et al., 2008)
[2](Suzuki & Measday, 1987)



LIDINE 2015 Proceedings, JINST 11 C01037

Michel scintillation spectrum





Event selection:

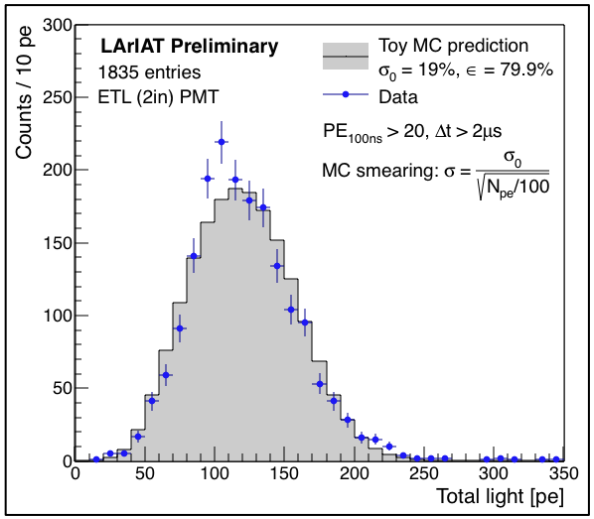
- Reconstructed μ endpoint < 15cm from TPC center
- $\Delta t > 2\mu s$

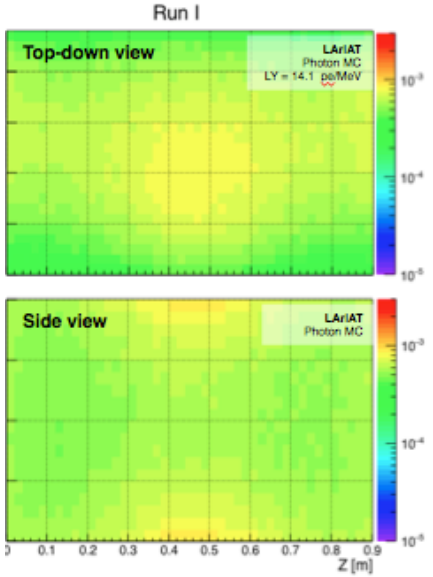
Data & MC (in development) are in approximate agreement

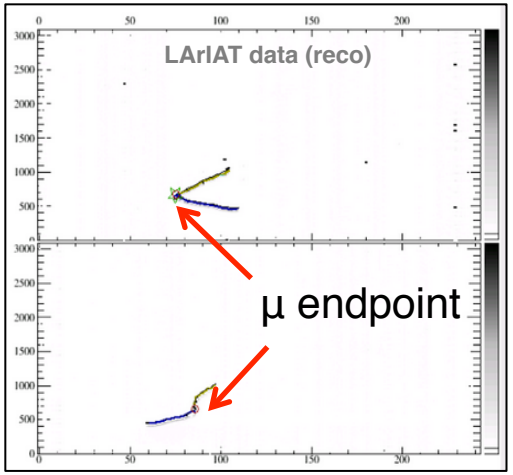
From this, we can estimate
ETL Light Yield = ~3 pe/MeV

GOAL: Scaling from **light** to **energy**

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

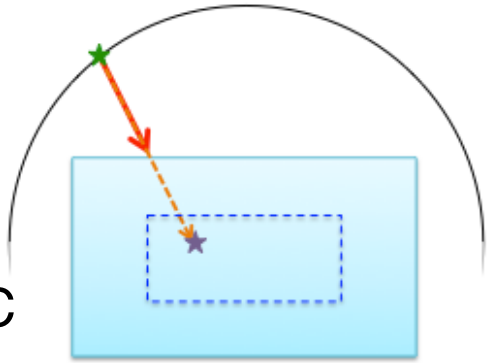


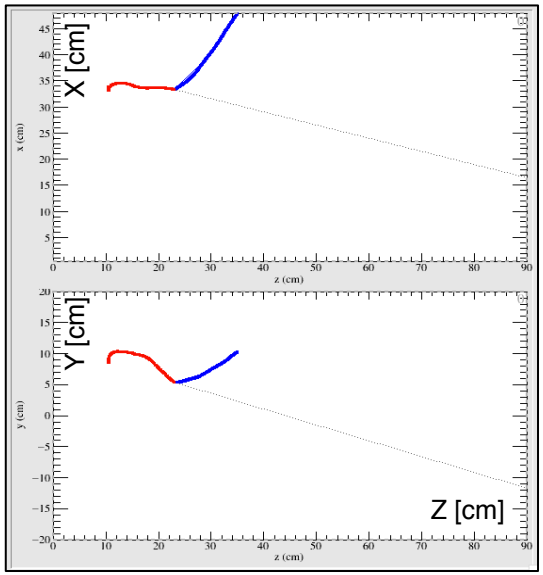


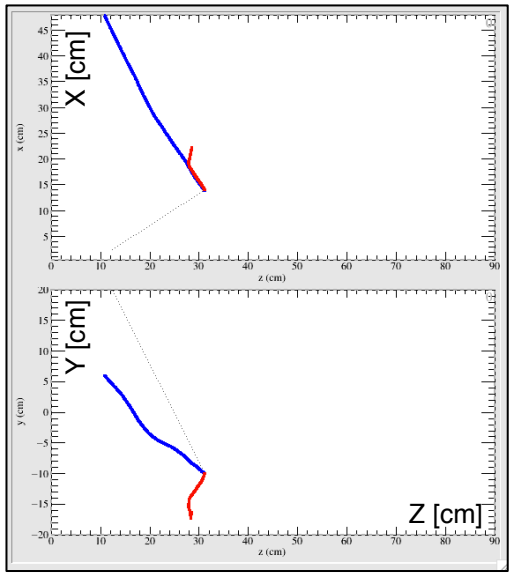


Monte Carlo studies

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

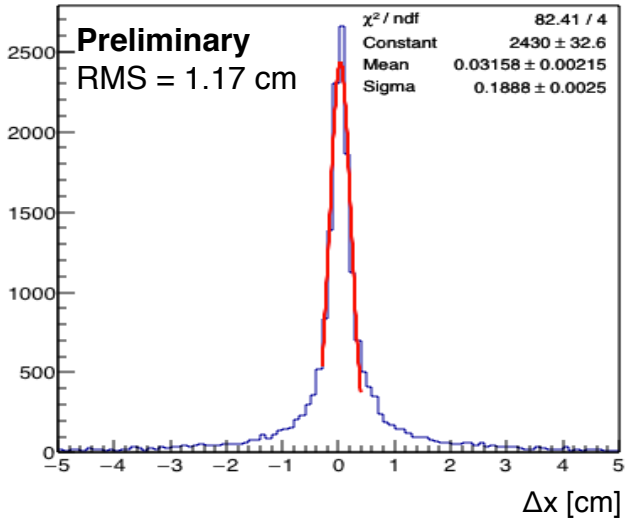






True MC particle trajectory examples

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***

Plans & Goals

- **Michel energy spectra** from
  - Scintillation light (from PMTs)
  - Charge (from TPC wires)
  - Charge + light *combined*

→ Data-driven energy calibration source for detector

Requires:

- ✧ Improved 3D $\mu^{+/-}$ track and $e^{+/-}$ shower reconstruction
- ✧ Accurate photon visibility map from full MC

- μ decay times → μ^--Ar capture rate, cosmic μ charge ratio

- Other studies enabled by abundant sample of low-E $e^{+/-}$ → dE/dx, low-energy shower reconstruction, scintillation-yield as function of E-field, etc…

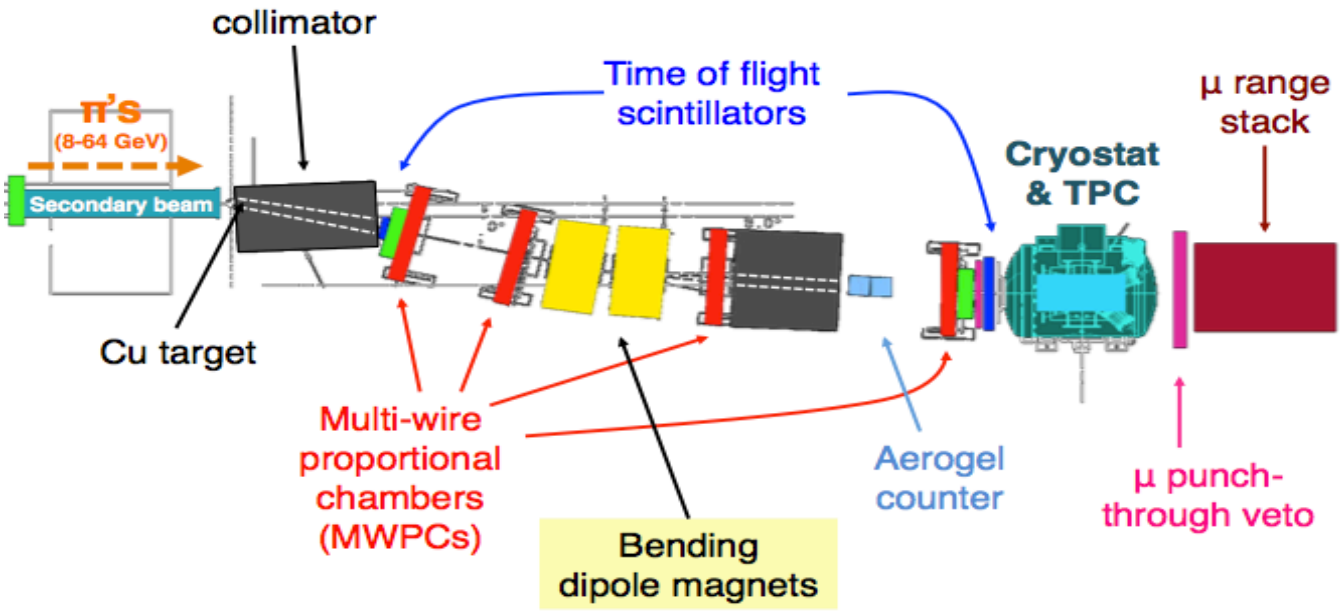
Conclusions

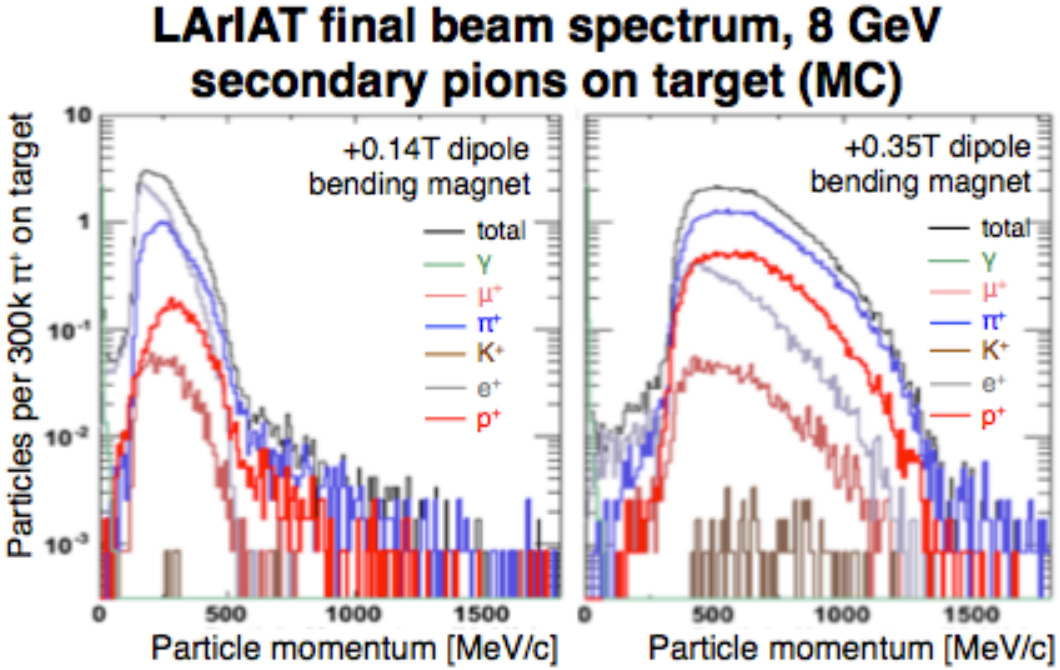
- Light has useful roles to play in LArTPCs (present + future)!
- Studies underway to demonstrate & explore many of these possibilities in LArIAT – stay tuned!

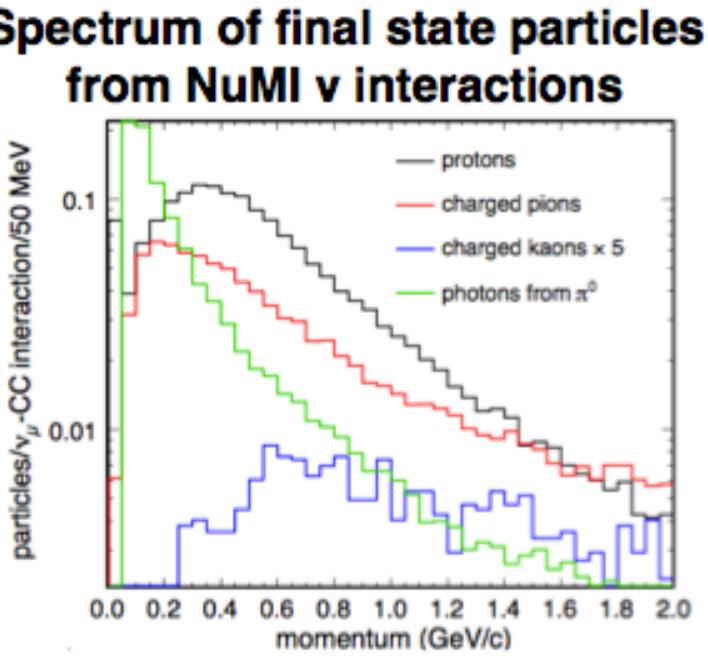
Thanks!

Backups

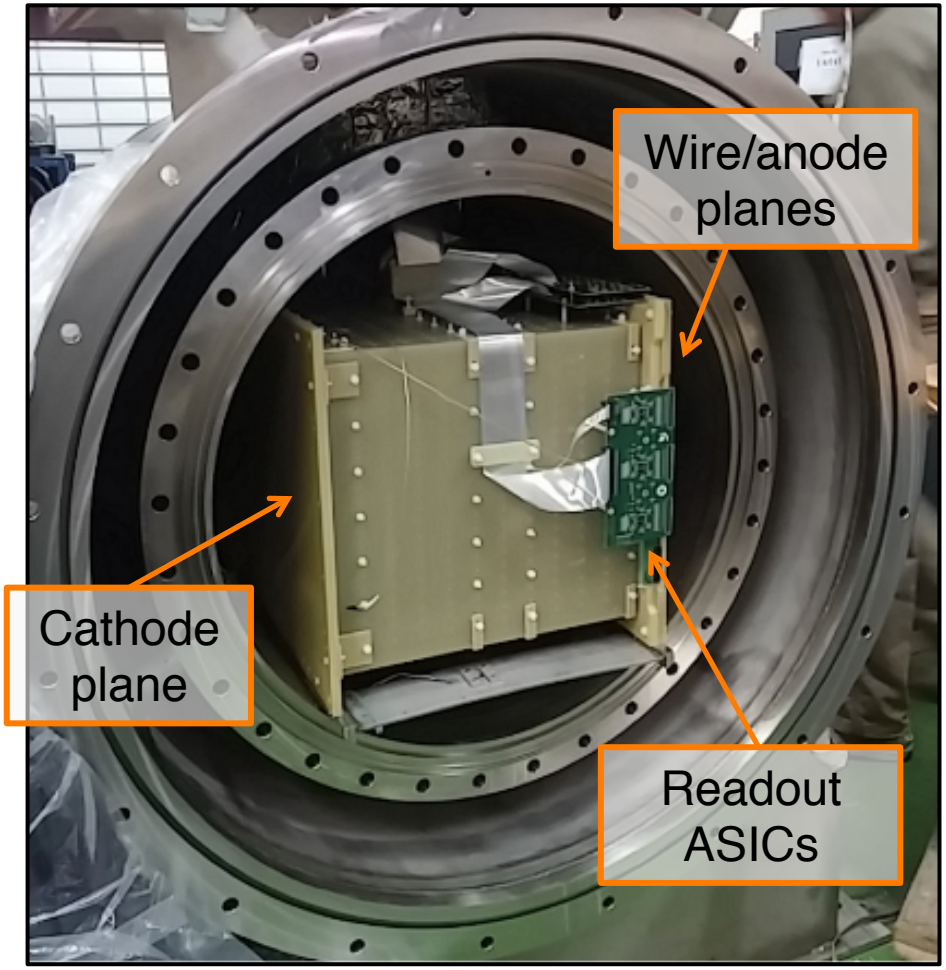
The LArIAT tertiary beamline



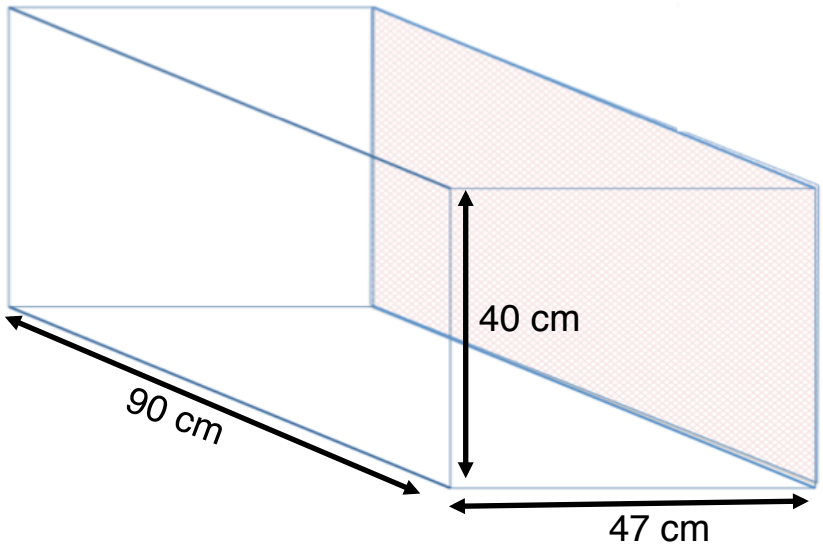




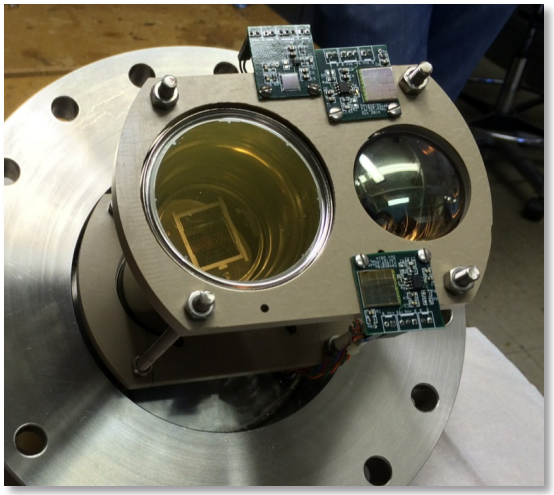
The LArIAT TPC



- **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.

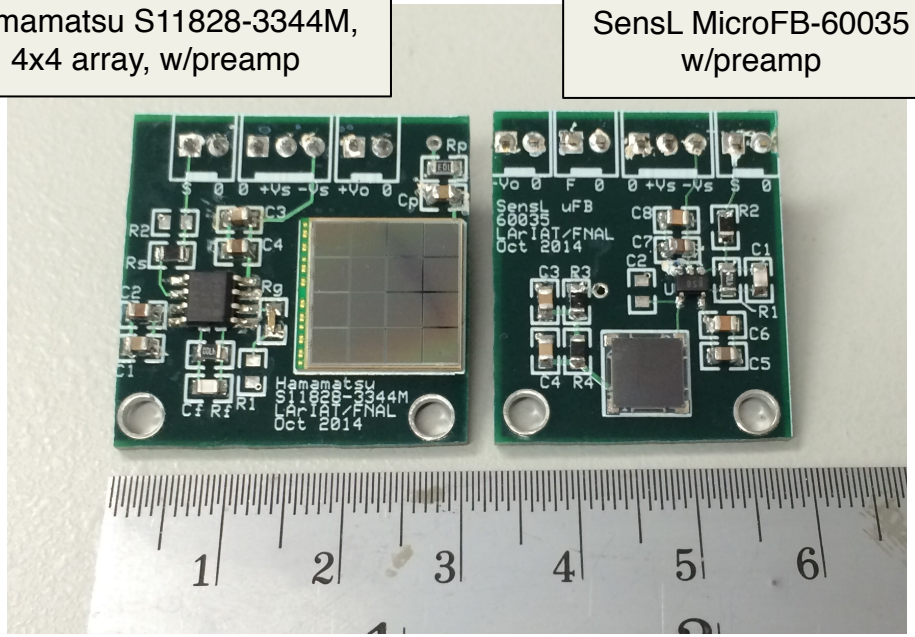
*VUV SiPM not shown

Hamamatsu PMT R-11065 (3” radius)

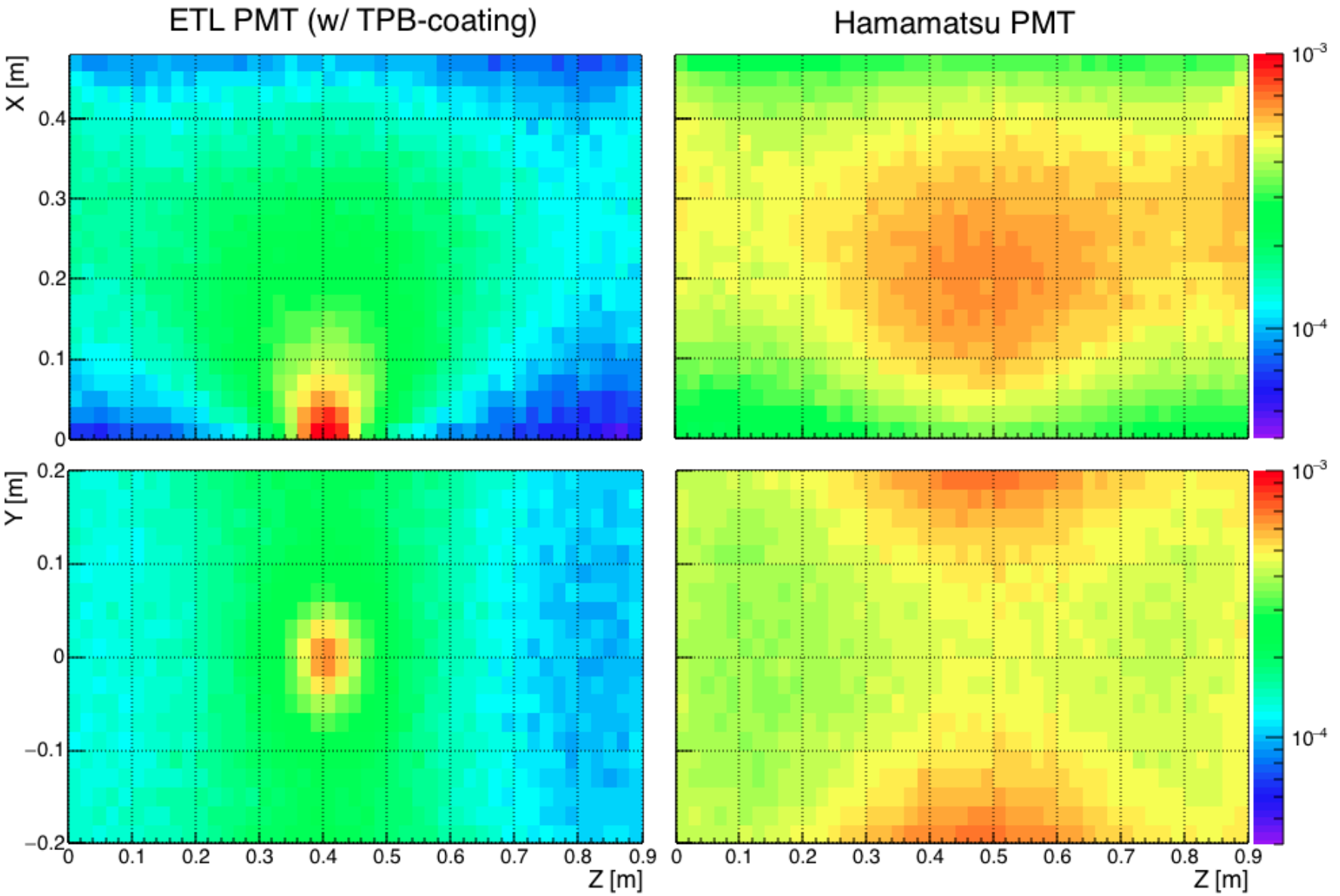
ETL PMT D757KFL (2” radius)

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

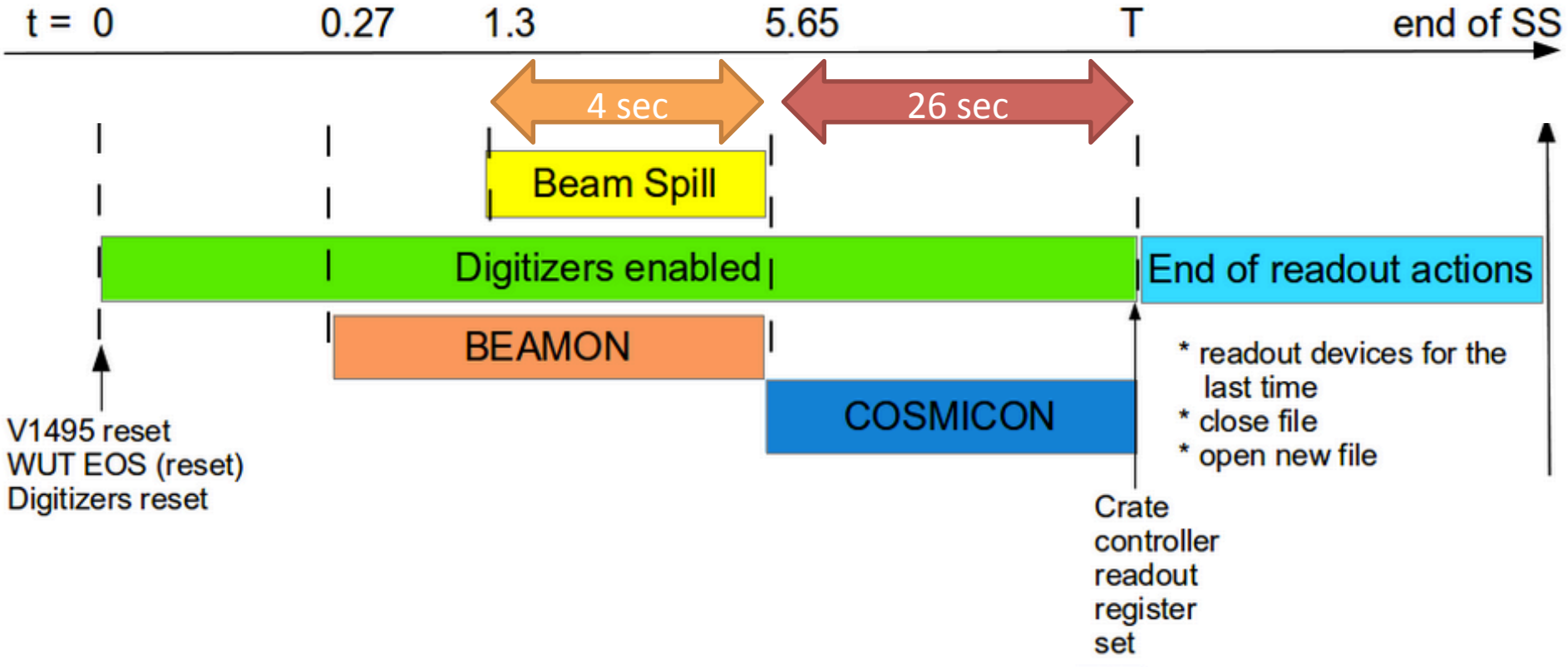
SensL MicroFB-60035 w/preamp



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

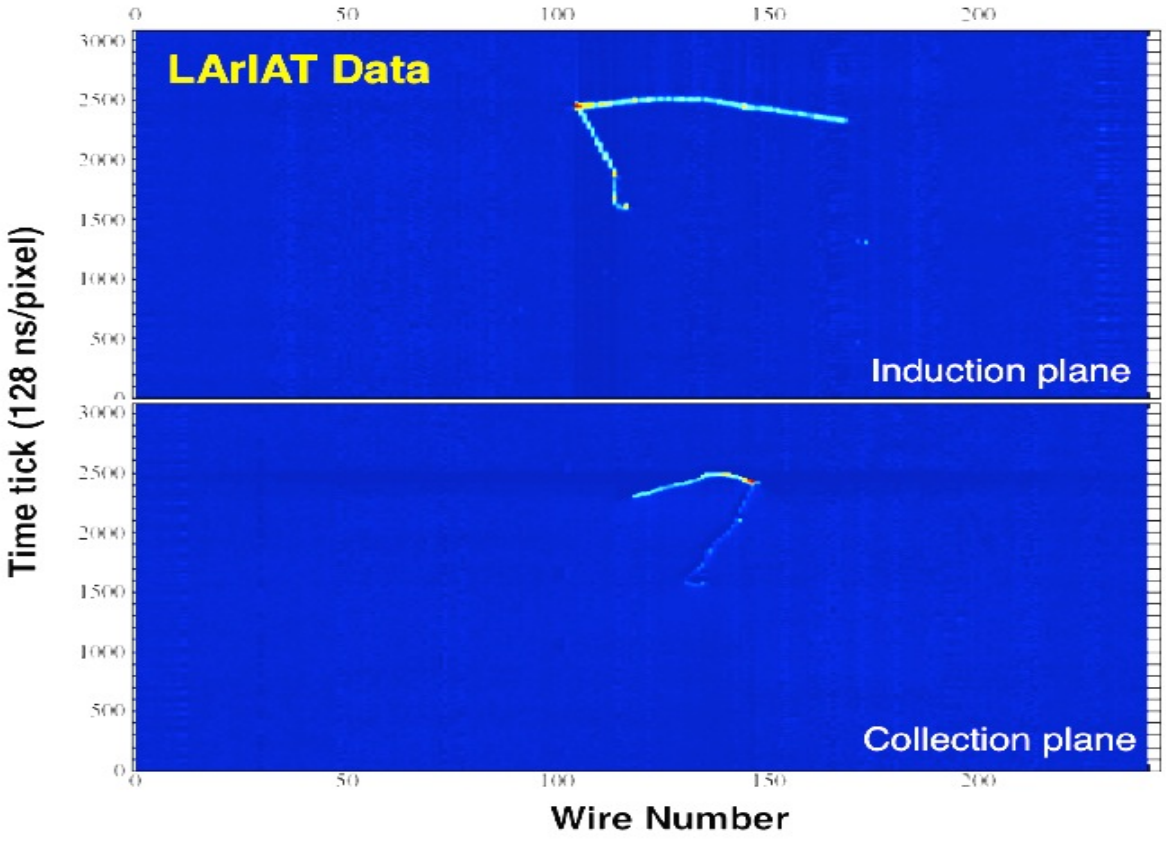


The LArIAT Supercycle



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

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)