Michel electron studies using scintillation light in LArIAT

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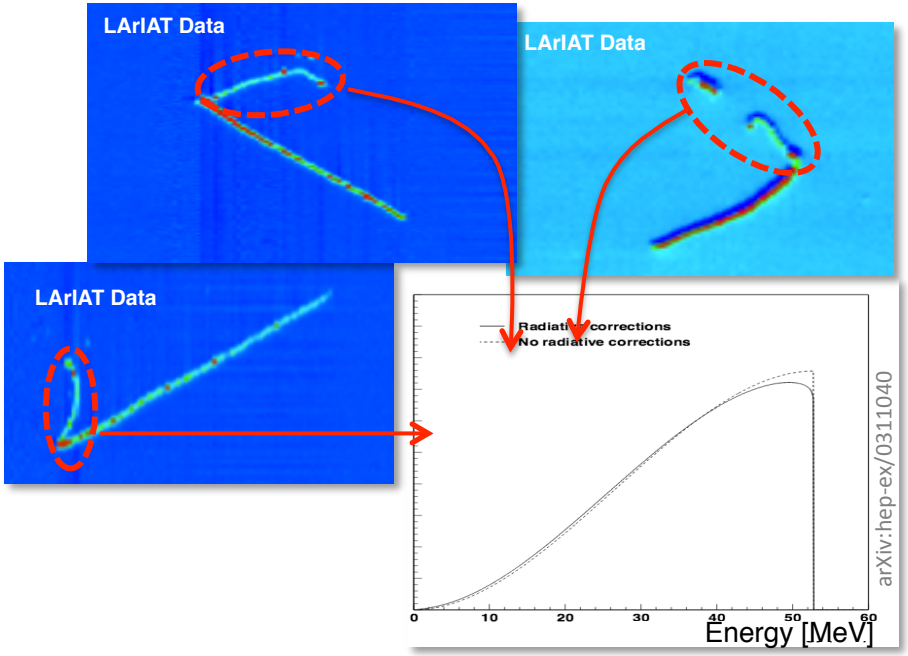
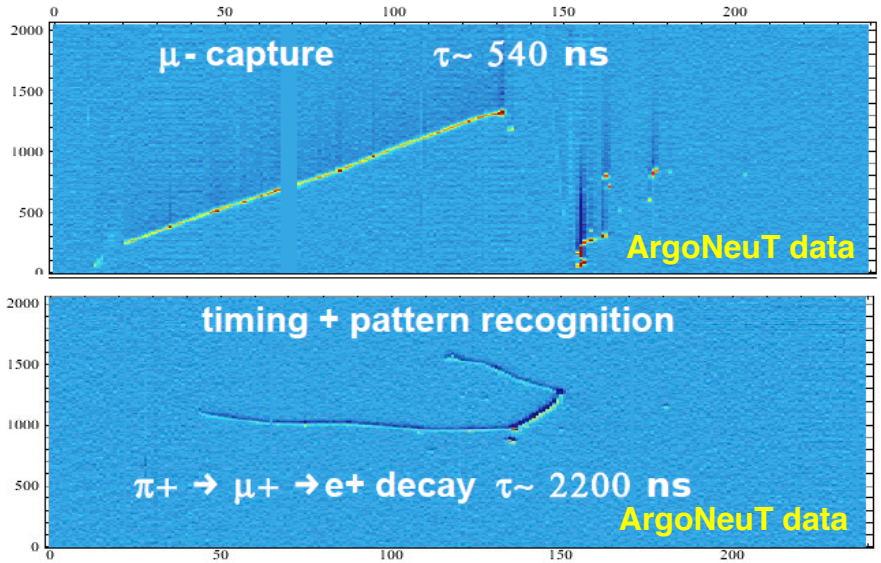
Why Michel electrons?

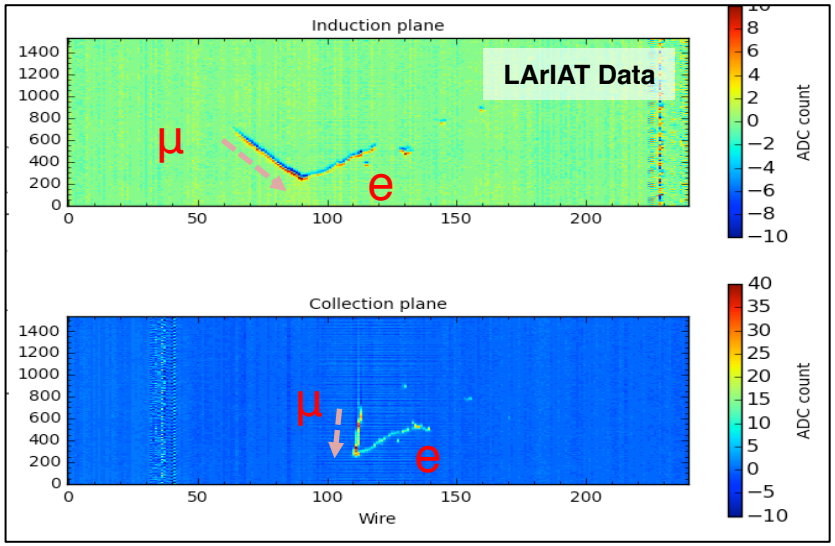
- Energy calibration source (both <u>TPC</u> *and* <u>photodetectors</u>)
- Measurement of μ^- capture probability in LAr
- Building and testing algorithms for finding stopping beam μ's
  - μ sign determination
- Source of low-E electrons

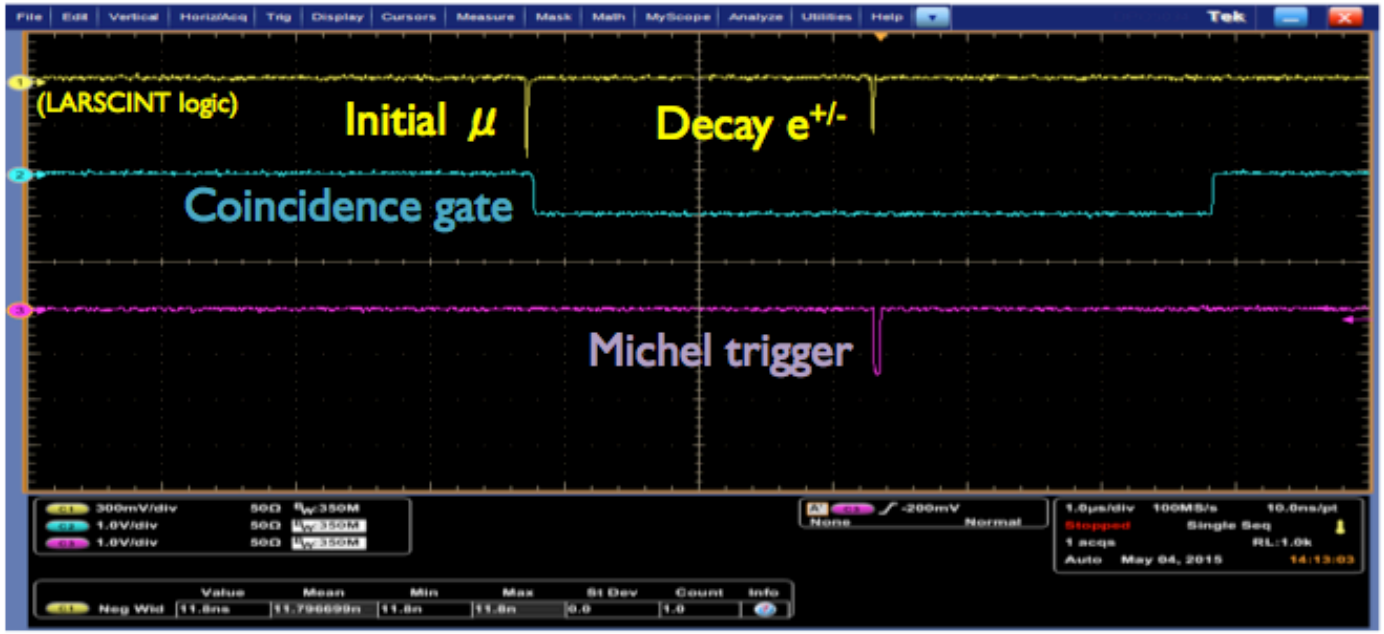




Triggering on Michels in LArIAT

- Light system in LArIAT allows for *real-time triggering* on Michel e's from stopping cosmic μ's
- In LArIAT, ~1Hz rate in cosmic gate (26s following beam spill)





Coincidence of these…

gives that

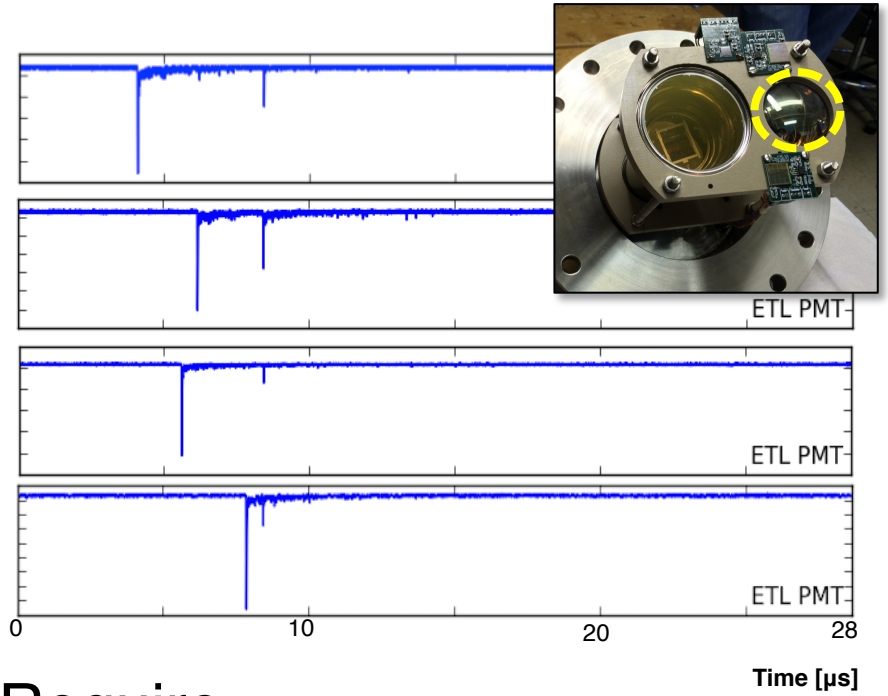
Collected data

June 2015

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

- For this analysis, using events obtained during a 12-day period
  - Optimal trigger configuration
- 14842 subruns (10.3 days cumulative)
- ~400k Michel triggers recorded in this timespan
- Estimated ~100k analyzable Michel electrons

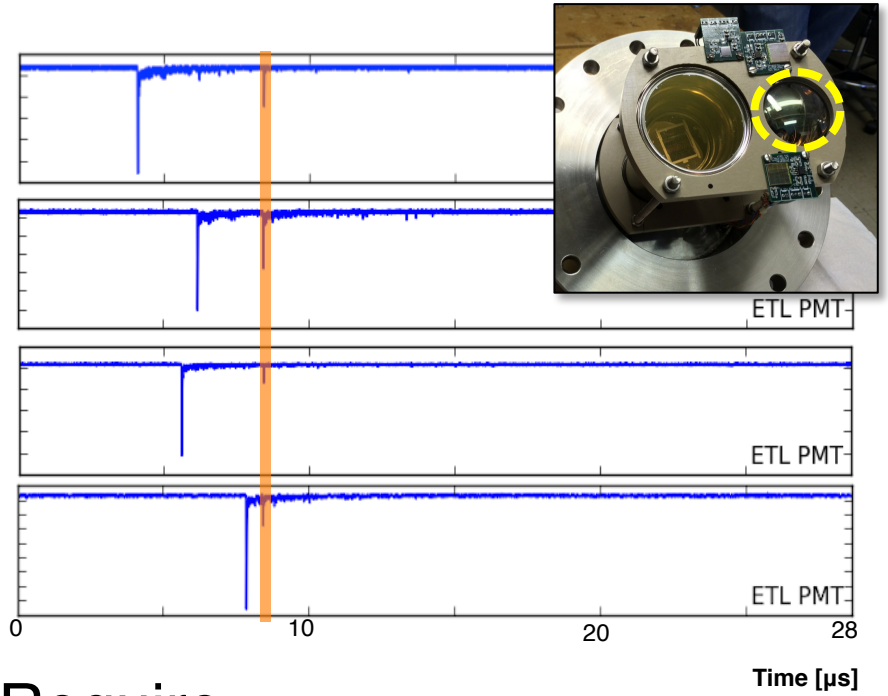
PMT waveform analysis

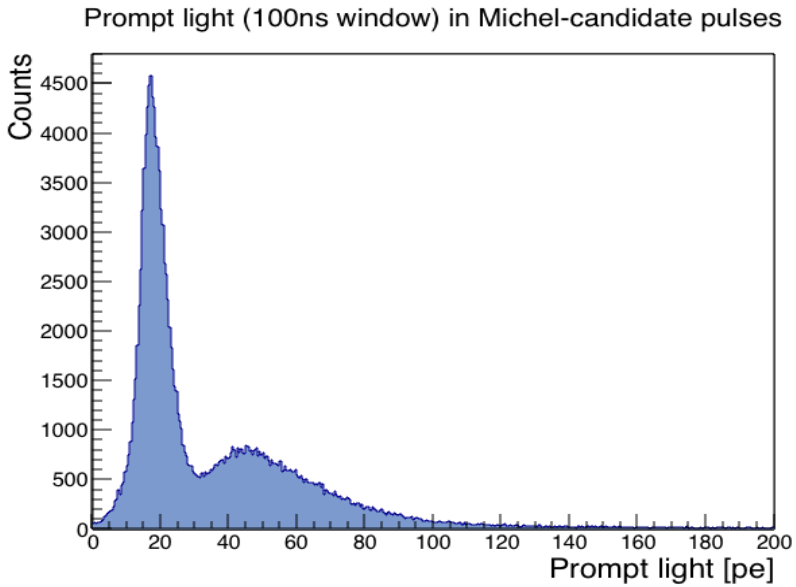


Require:

- Non beam event (<-BEAMON>)
- 2 optical hits in 2” ETL PMT

PMT waveform analysis

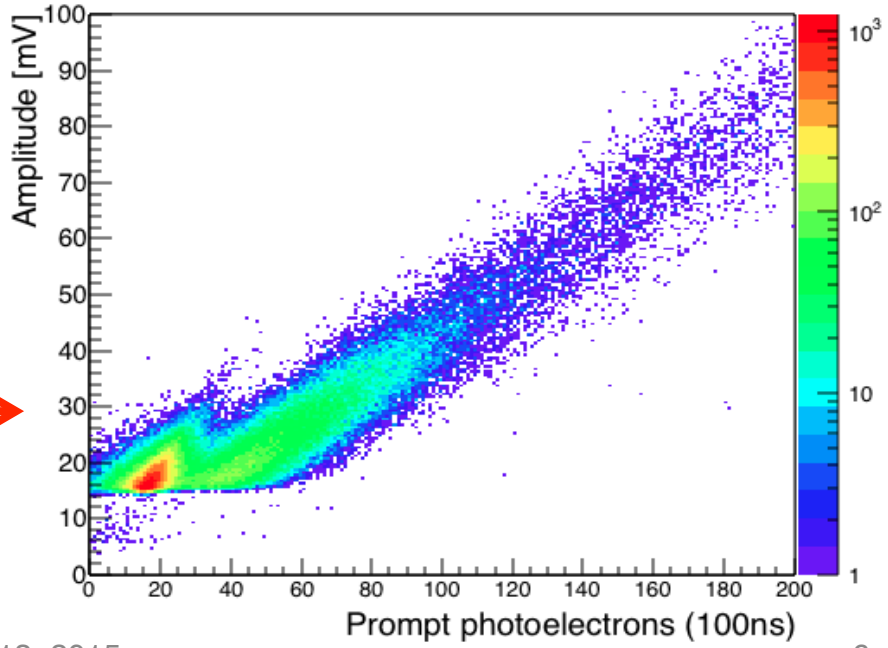




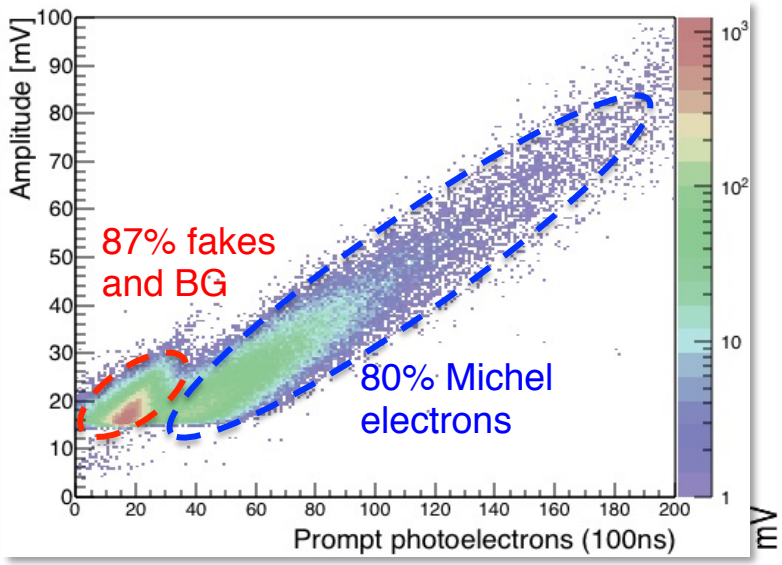
Require:

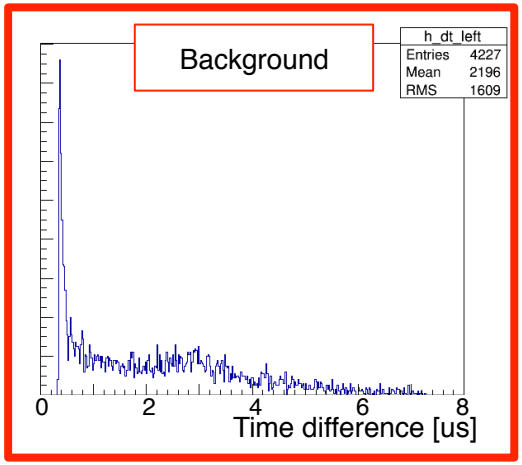
- Non beam event (<-BEAMON>)
- 2 optical hits in 2” ETL PMT

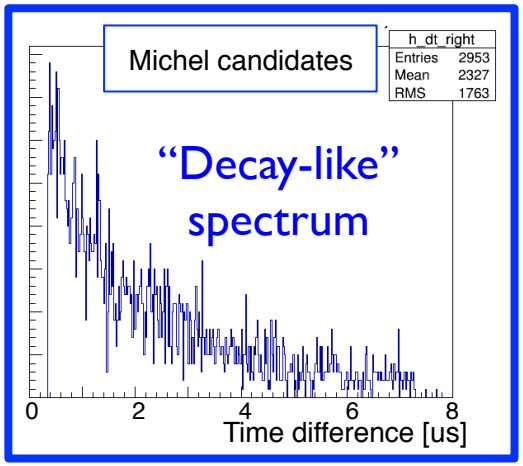
Optical hit finding and integration of 2nd (e-candidate) pulses in waveforms



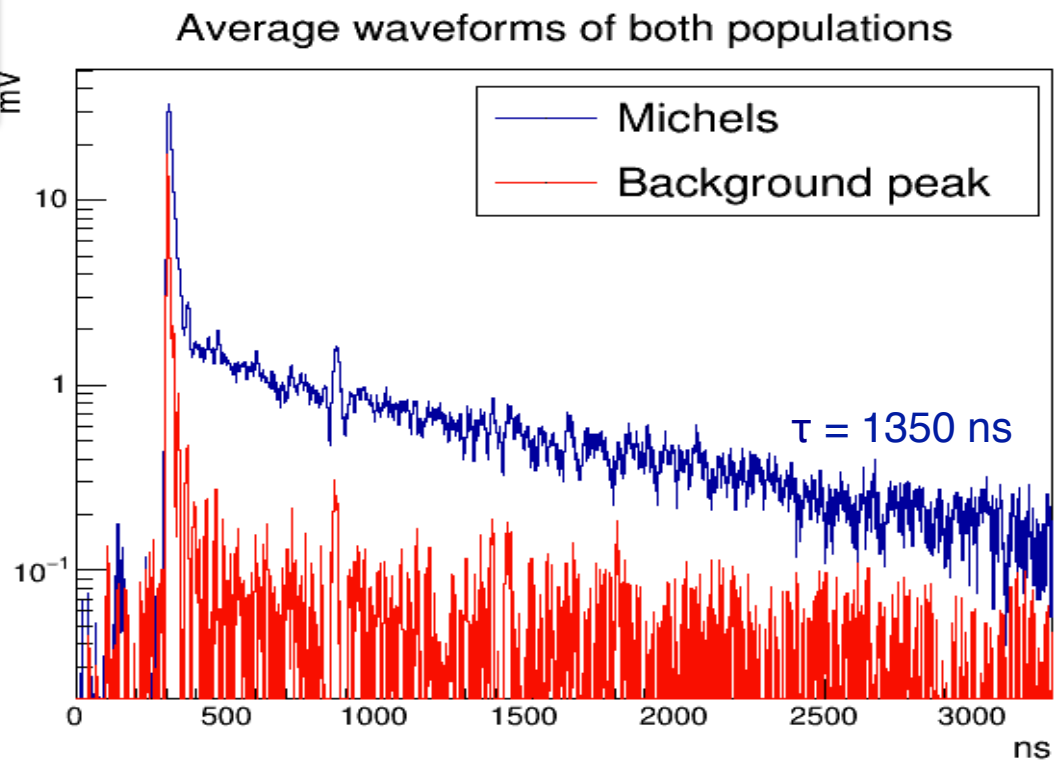
Comparing the two populations…







1. Visual inspection
2. Time spectrum
3. Average waveforms



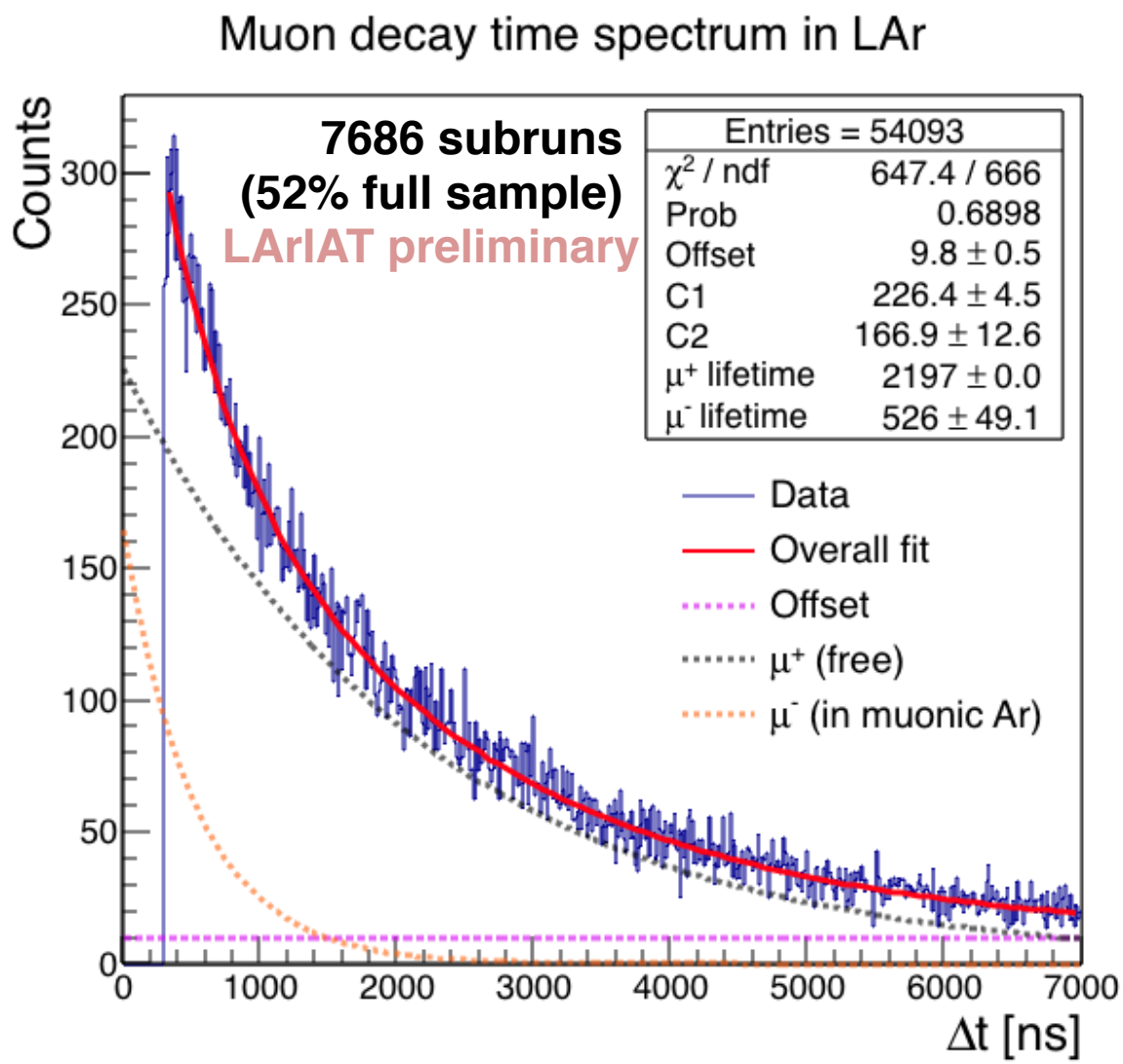
Stopping muon decay spectrum
(with background cut)

$$\frac{1}{\tau_{\mu^-}} = \frac{1}{\tau_{free}} + \frac{1}{\tau_{capture}}$$

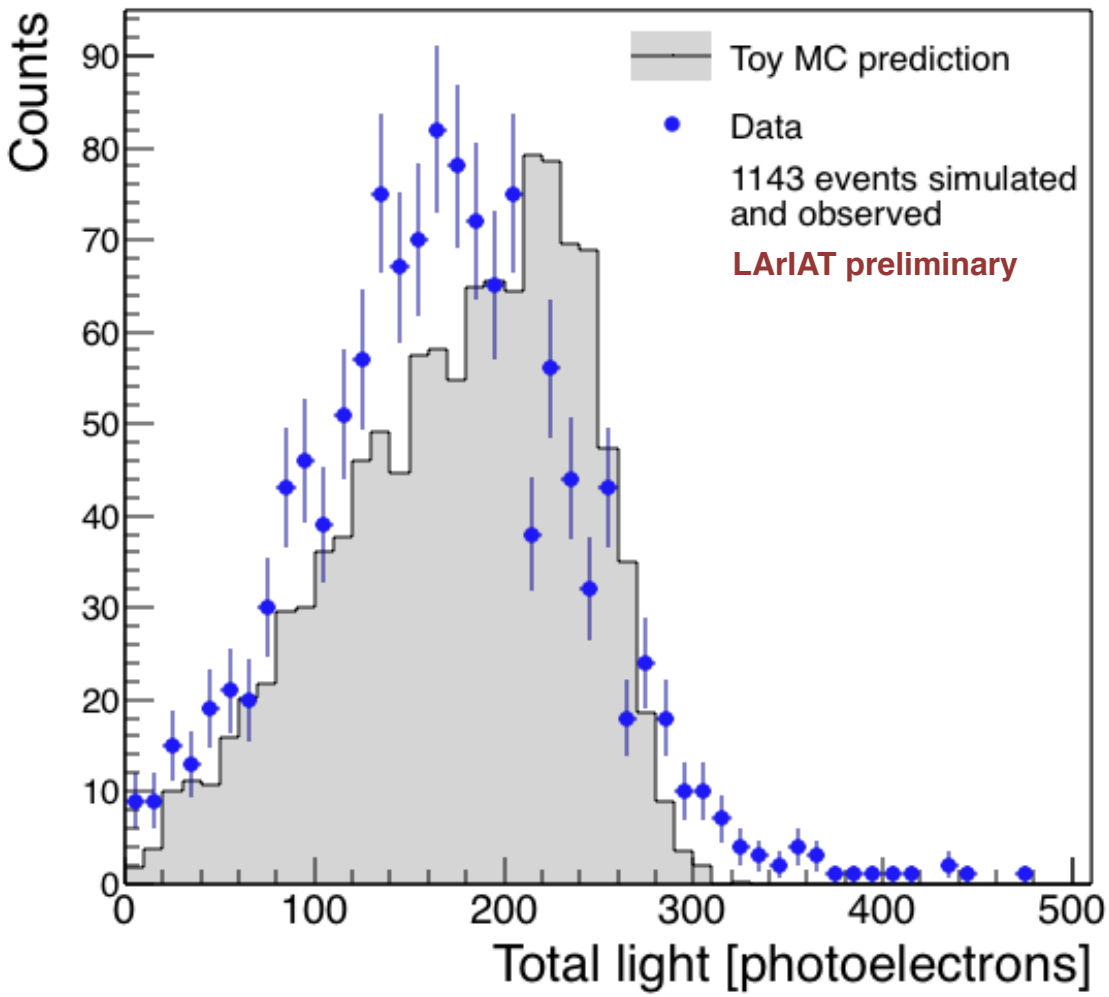
Fit shown here gives
τ_{μ^-} = 526(49) ns

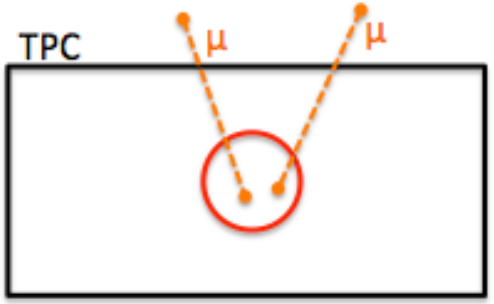
→ $\tau_{capture}$ = 692 ± 84ns
→ $P_{capture}$ = 76.1 ± 2.2%

Prev. measured values:
833±55 ns (Bertin et al, 1973)
709±56 ns (Carboni et al, 1980)



Limited region selection for LY estimation

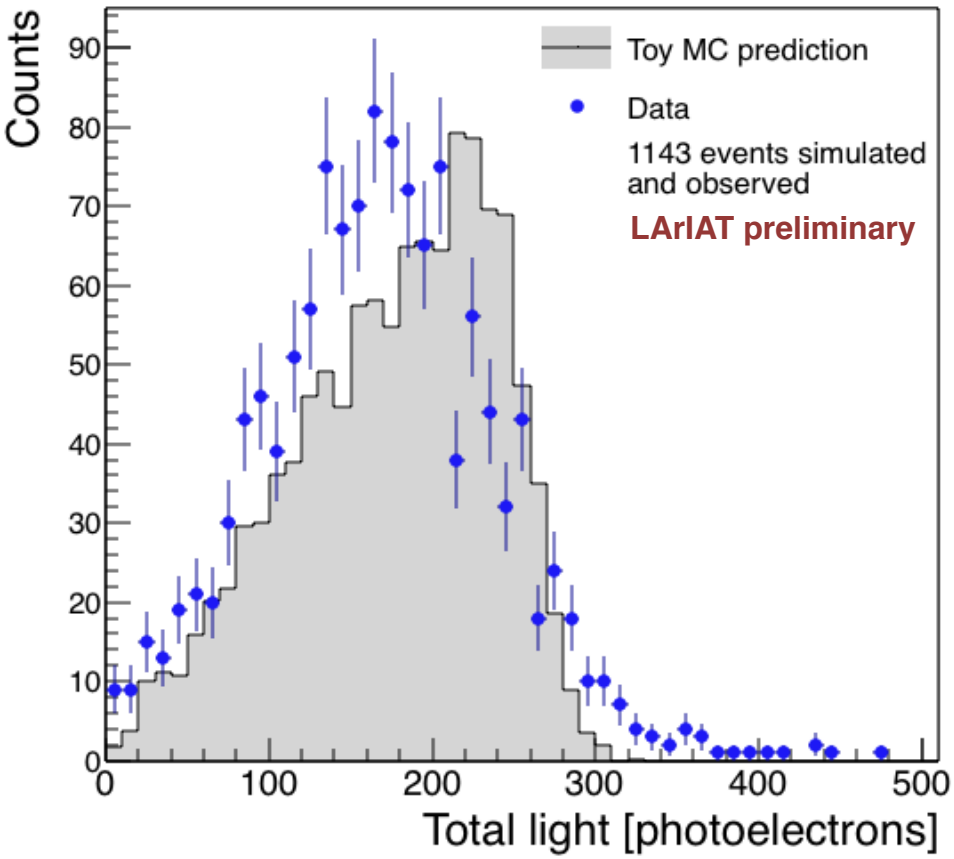




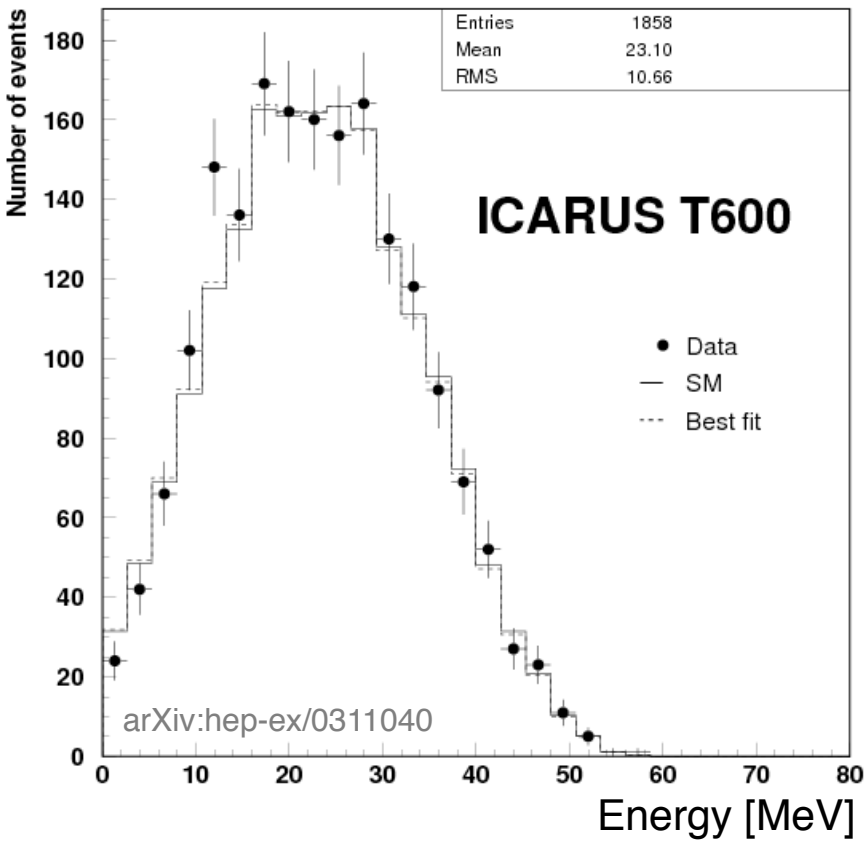
- Require μ stops in central region of TPC (sphere, r=10cm)
- Rough agreement with prediction
  - MC: 4.8 pe/MeV for 2" ETL PMT
  - Eye-balling the data: ~250 pe ÷ 53 MeV = ~4.7 pe/MeV

Comparison with ICARUS

Light signals

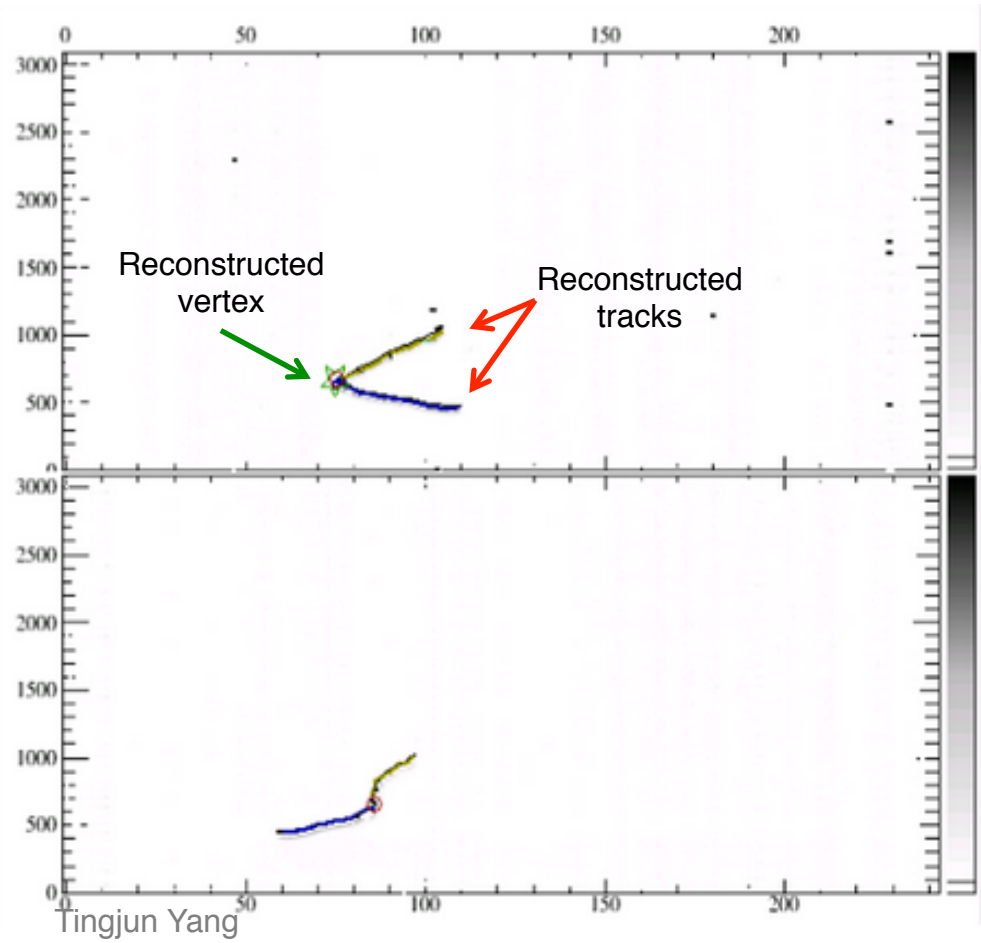


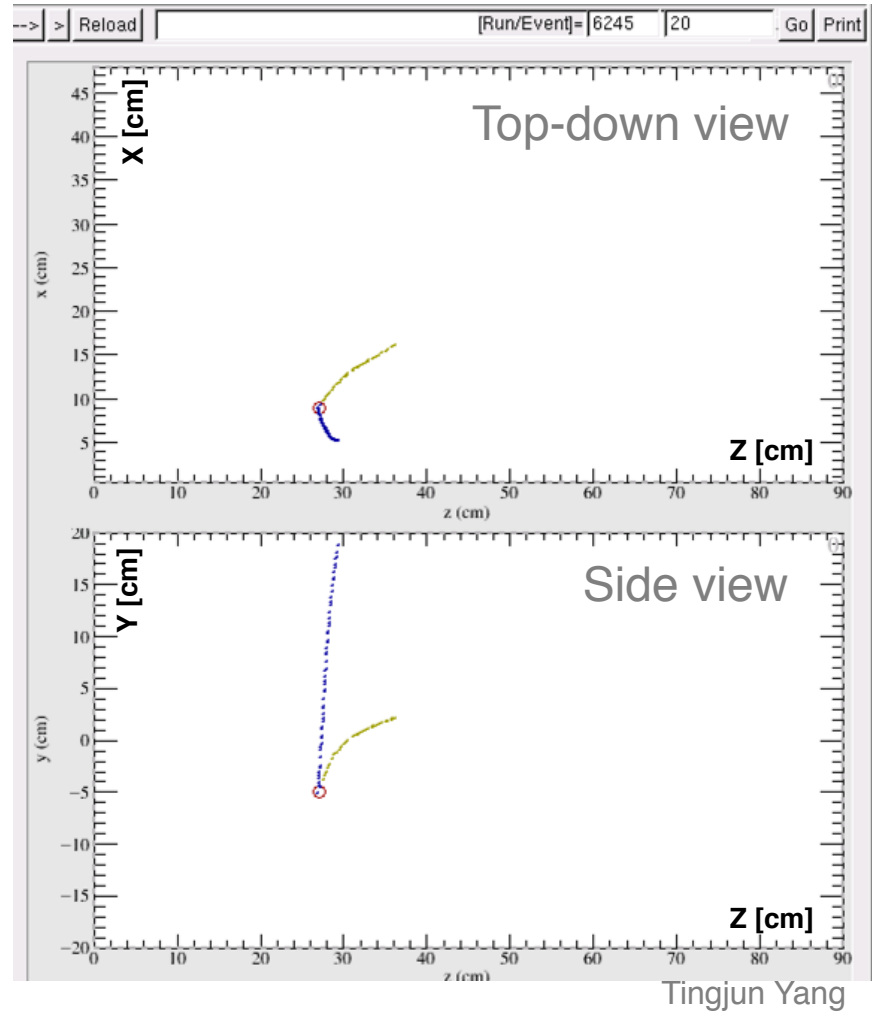
Ionization signals



NOT an apples-to-apples comparison, but worth noting the similar smearing…

Tracking and clustering



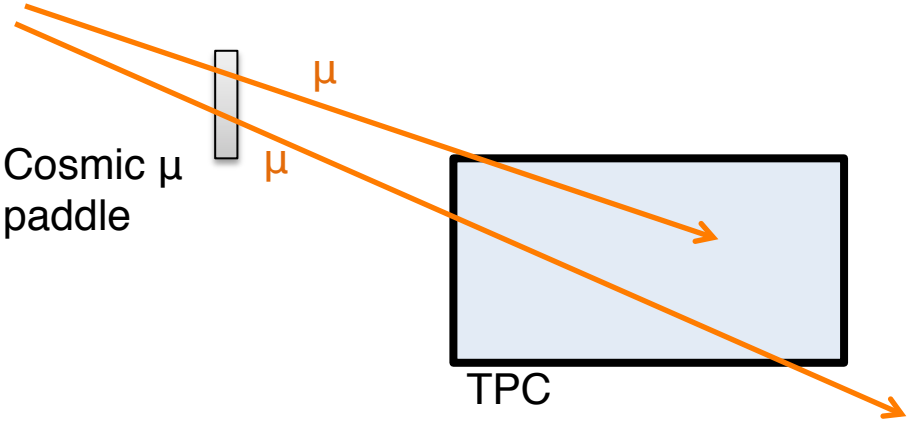


Beginning to optimize track/shower reconstruction of Michel events for measurement of energy spectrum

Improvements for Run II

- Repair base on Hamamatsu PMT
  - Coincidence of two PMTs will allow a more robust trigger

- Additional trigger using a μ "telescope" using existing cosmic paddles
  - Trigger on <COSMIC + LARSCINT> (~1Hz)
  - Catch both *through-going* and *stopping* muons without biasing selection toward Michel decays



Summary

- Analysis of Michel electron properties underway for for determination of light yield
- Potential for measurement of μ^- nuclear capture rate
- Beginning reconstruction and calorimetry of Michel electron "showers" through TPC ionization (→ absolute energy calibration)
- Paving the way toward in-depth μ sign determination studies using stopping beam μ's

Exploring new ways to enhance event selection, calorimetry, & $\mu^{+/-}$ decay tagging using PMT signals

Towards light-augmented calorimetry in LArIAT

Pawel Kryczynski Fermilab/IFJ PAN Krakow

LArIAT ORR 10/2015

Calorimetry in LArTPCs can be augmented by light

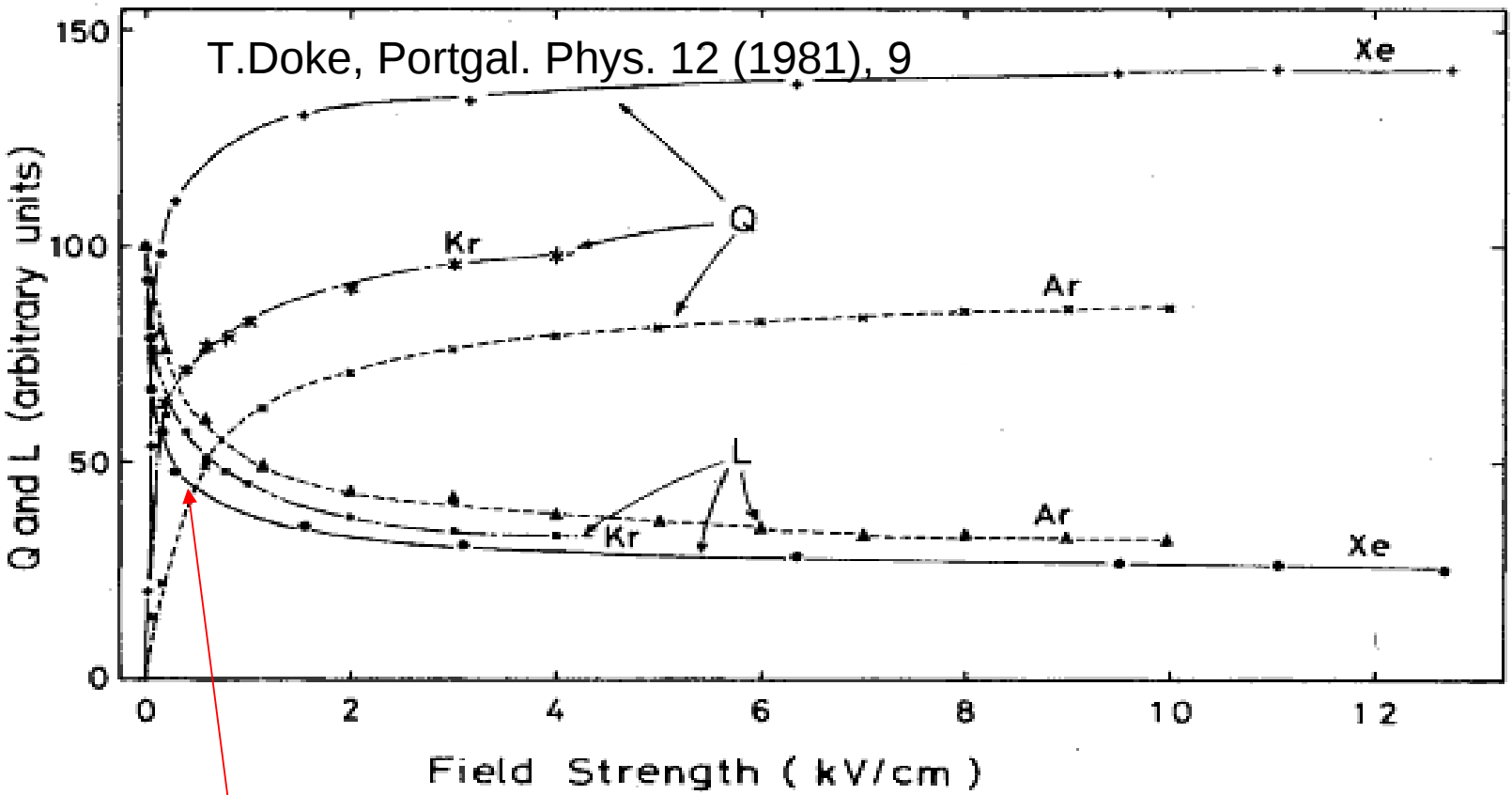
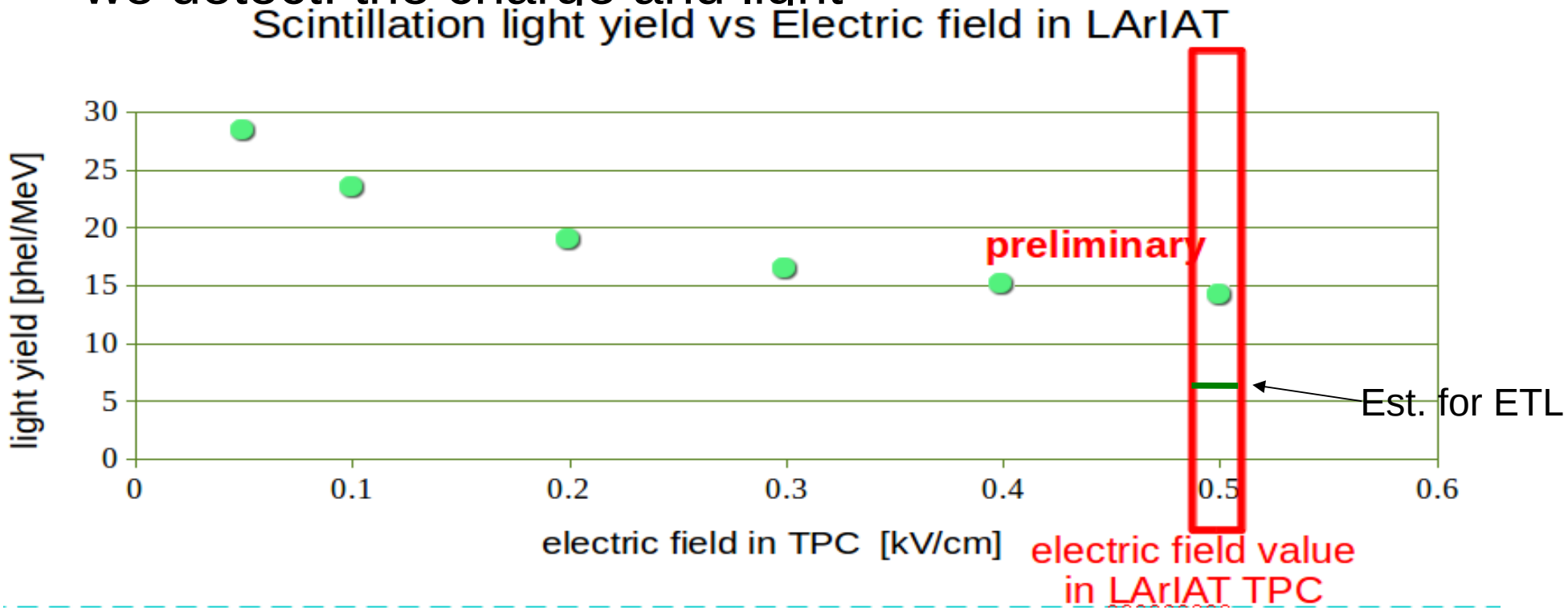


FIG. 2. Variation of relative luminescence intensity L and collected charge Q in liquid argon, krypton, and xenon vs applied-electric-field strength for 0.976- and 1.05-MeV electrons.

LArIAT default electric field value – still ~50% of zero-field scintillation expected – we should try to use it in calorimetry!

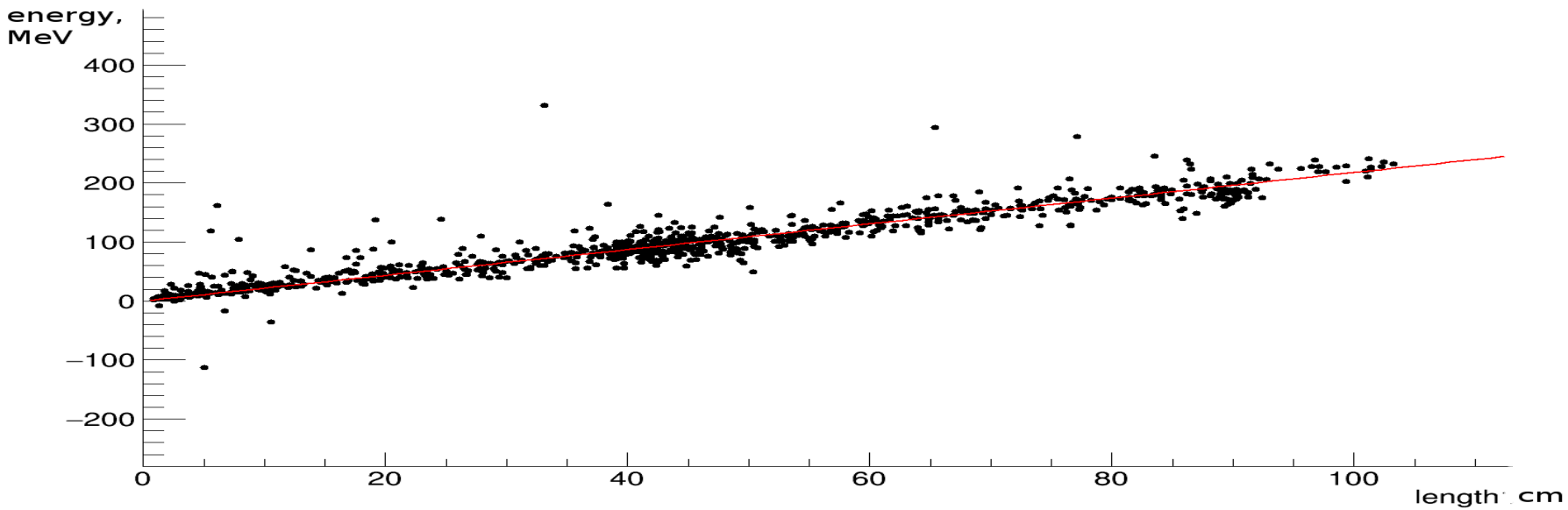
Light yield estimate

- In LArIAT we have high and uniform light yield
- We can use this feature for calorimetry
- Got input from MC simulations (for all photodets)
- Have to find correlation between two essential quantities we detect: the charge and light



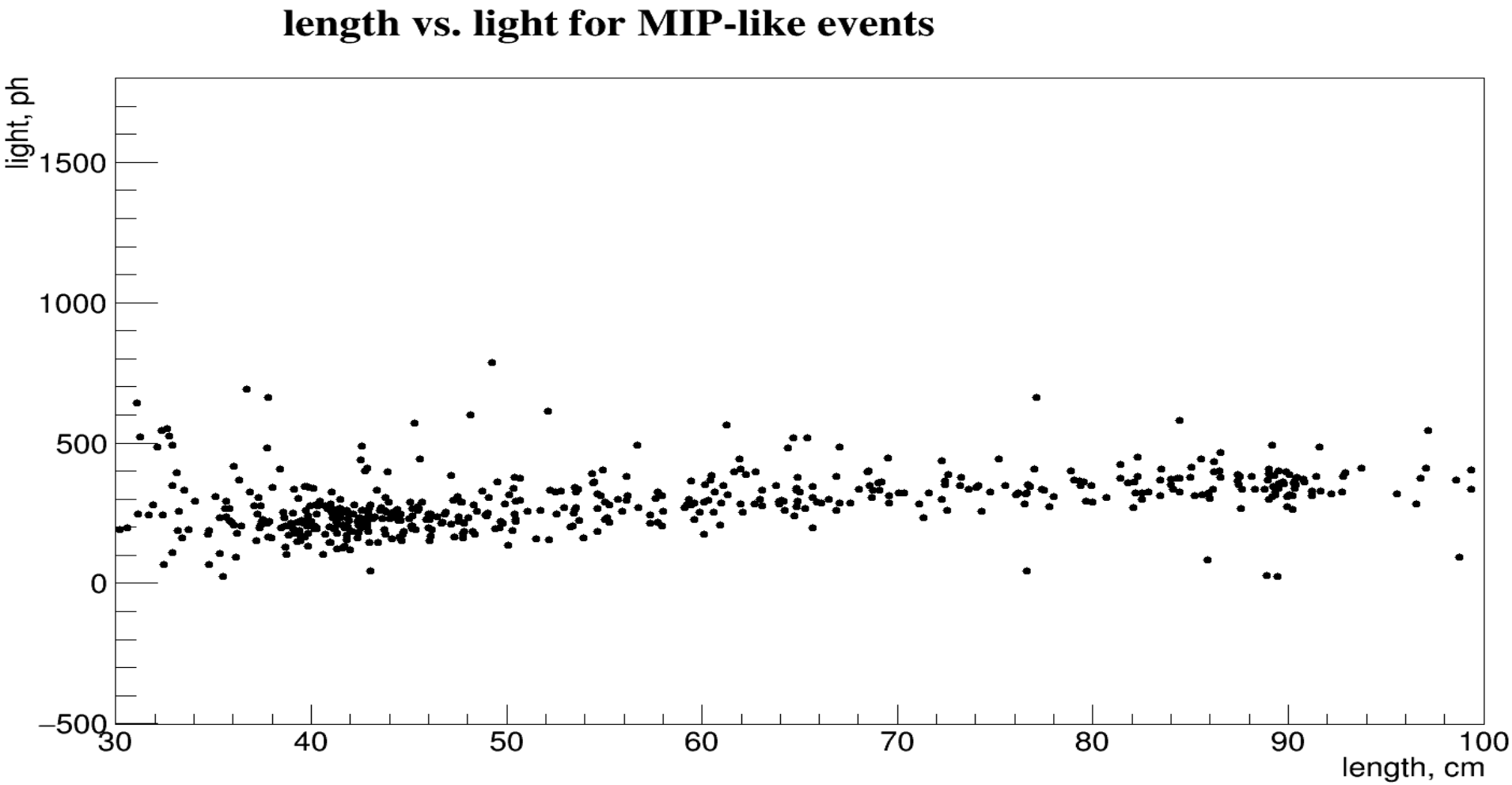
Charge-length correlation

- MIP-like particles sample passing through our TPC
- Energy well correlated with a reconstructed track length – next step is to correlate light likewise



Light – length correlation

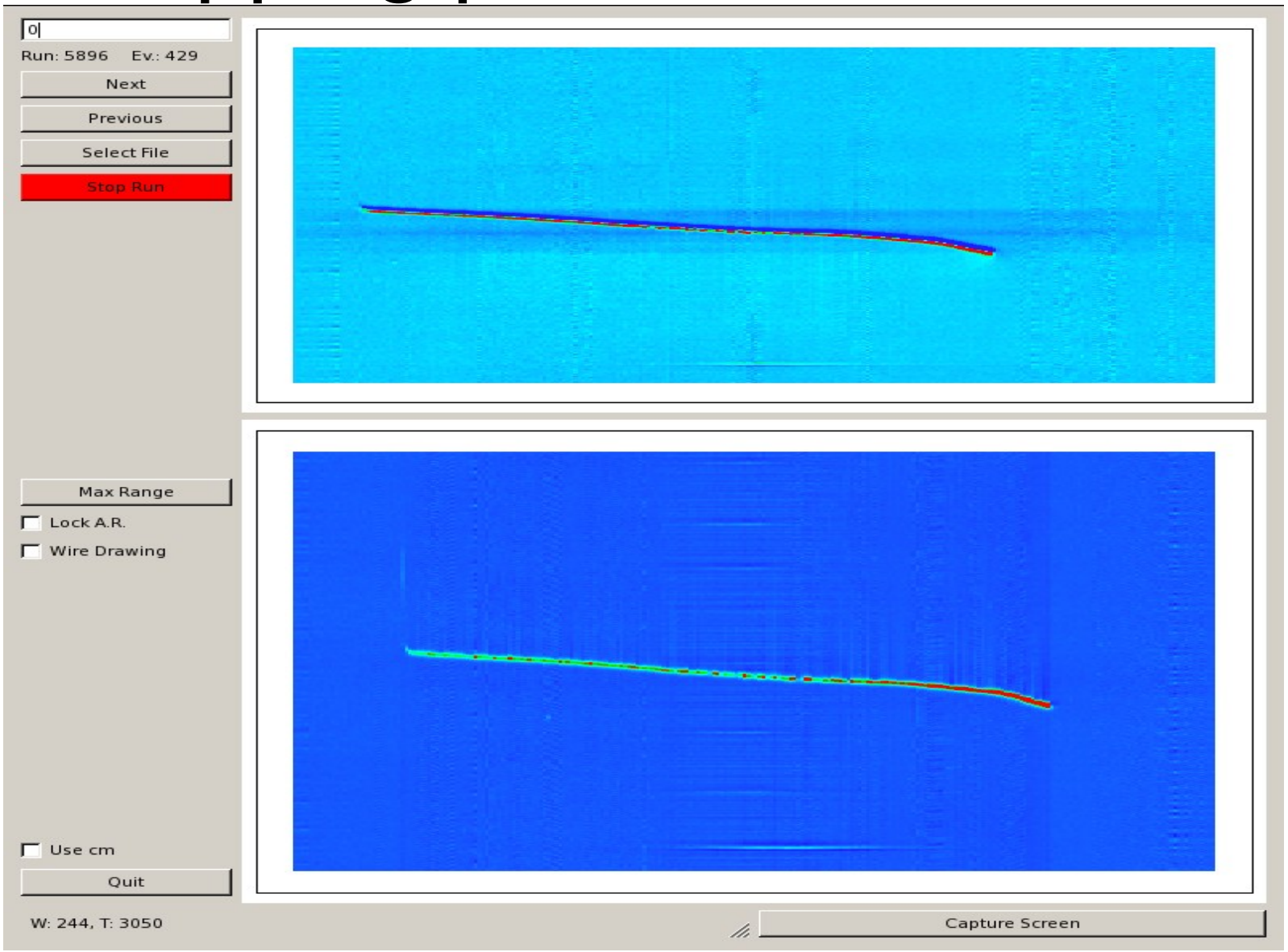
- Light is strongly correlated with a reconstructed track length



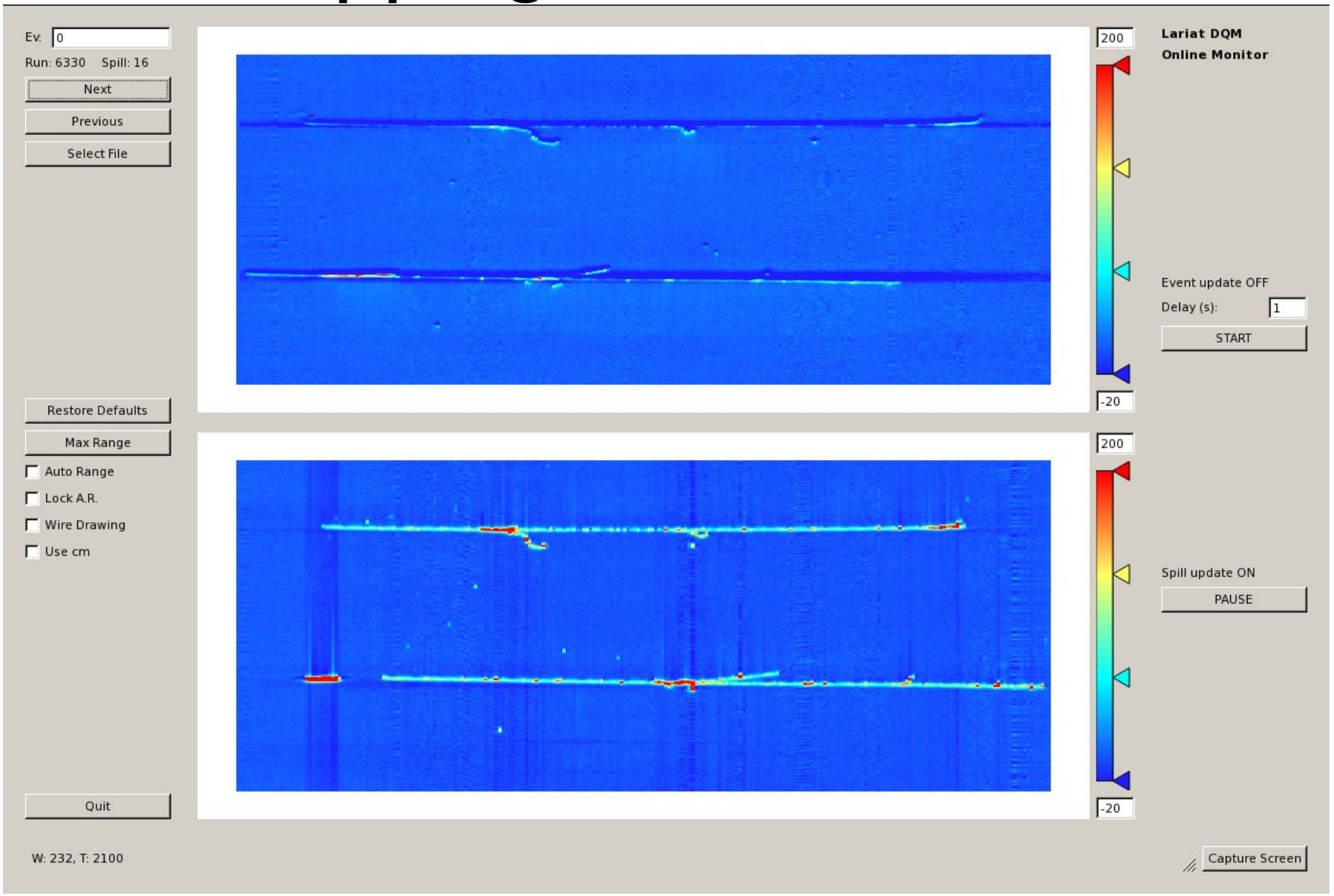
Proton and MIP-like samples study

- Selected a sample of proton-like particles stopping in the TPC and the MIP-like particles passing through it
  - Identification using beamline detectors - LArIAT unique feature and <u>essence of a technology calibration</u>!
  - For stopping proton-like population, selection confirmed by dE/dx based PID algorithm in TPC
  - Short tracks selected (less than ~35cm) for proton-like events and long (over 80cm) for crossing MIP-like ones

Stopping proton-like events



Stopping MIP-like events



Light vs. energy reconstructed from wires gives us light yield

Part of charge left by particle incoming in TPC is lost due to recombination

Deposit on wires is corrected wrt. electron lifetime

Using Box model or Birks Model recombination loss is compensated and charge is converted to ENERGY

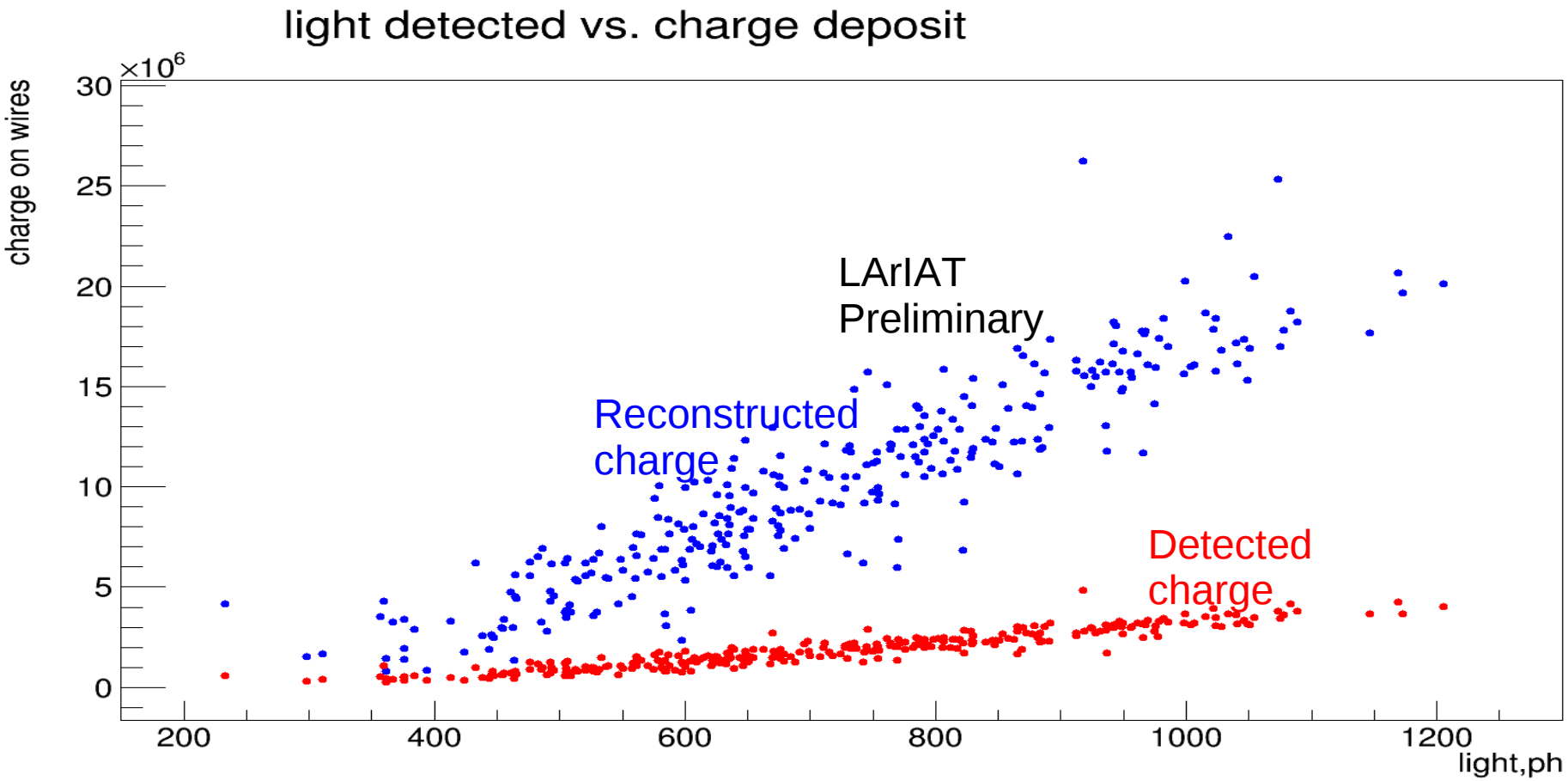
Can these two elements be merged to allow for model-independent calorimetry?

Light produced by incoming particle is detected by PMTs

Single electron calibration and Light yield
->ADCs converted into photoelectrons and then into ENERGY

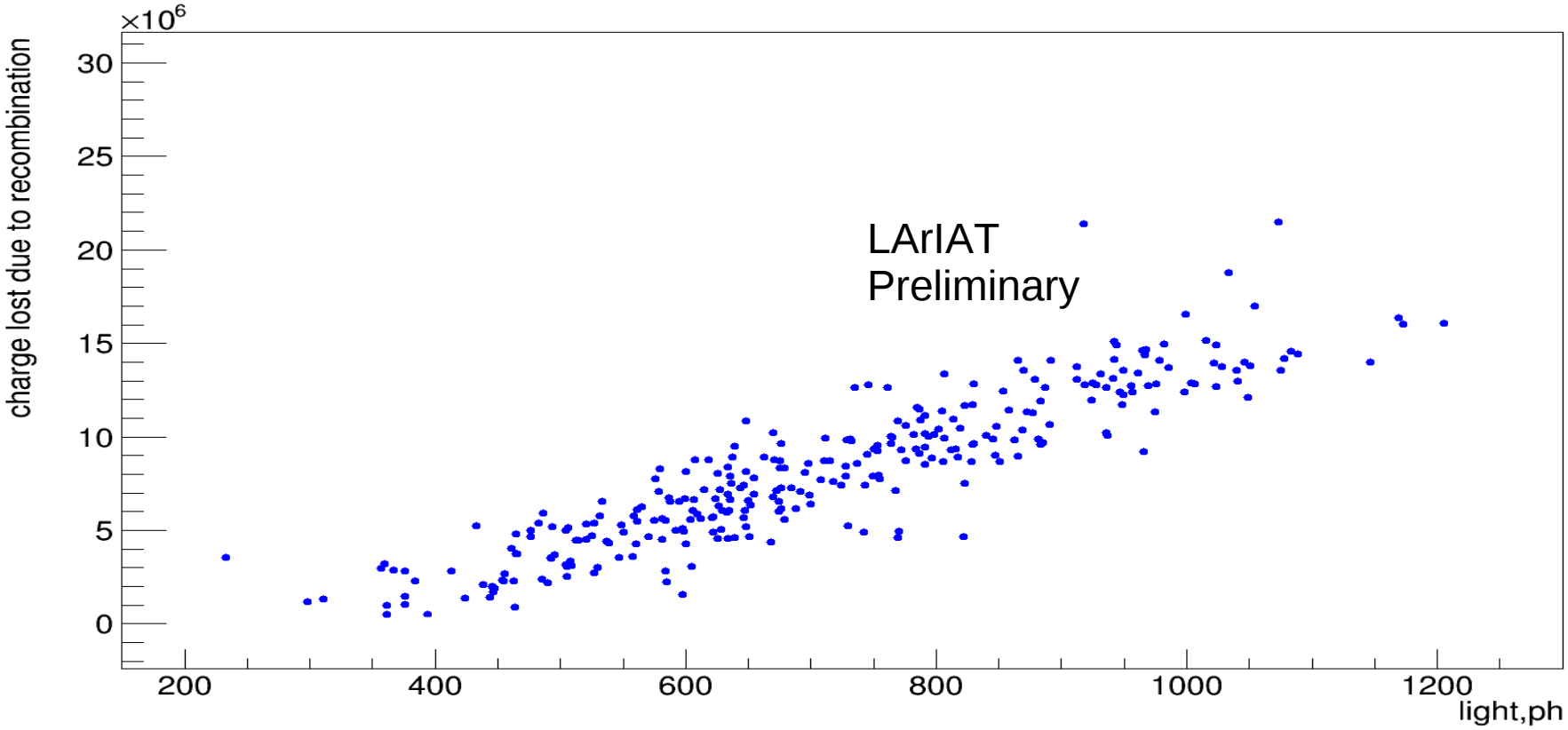
Light and charge deposit

- Comparison of charge on wires vs light for stopping proton-like events



Light and charge deposit

- Correlation of charge lost due to recombination vs light for stopping proton-like events



Thank you

Measurement of Pion-Argon Total Cross-sections at LArIAT

Animesh Chatterjee
University of Texas Arlington
LArIAT Operational Readiness Review
13-14 October, 2015

Outline

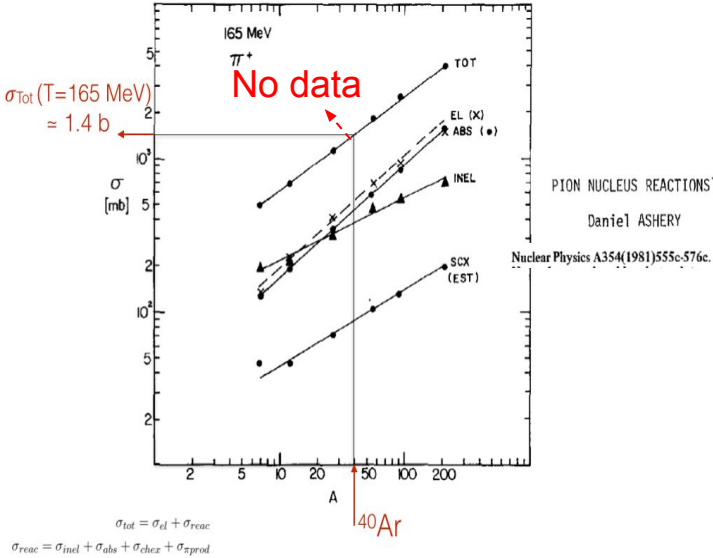
- Motivation
- Filtering, Reconstruction and selection of events
- Analysis method
- Preliminary Results
- Conclusion

Motivation

- Full Characterization of LArTPC technology has prime interest for Intensity Frontier Program in US.
- Pion is one of the most important final state particle in neutrino experiment

$$\nu_\mu + \mathrm{Ar} \Rightarrow \mu^- + \pi^+ + \mathrm{X}$$
$$\bar{\nu}_\mu + \mathrm{Ar} \Rightarrow \mu^+ + \pi^- + \mathrm{X}$$

- Identification of pion and precise measurement pion argon cross-section will reduce the uncertainty on the hadron interaction model.
- No existing data for pion argon cross-section, current MC codes use interaction models for Ar based on extrapolations from data with lighter and heavier elements.



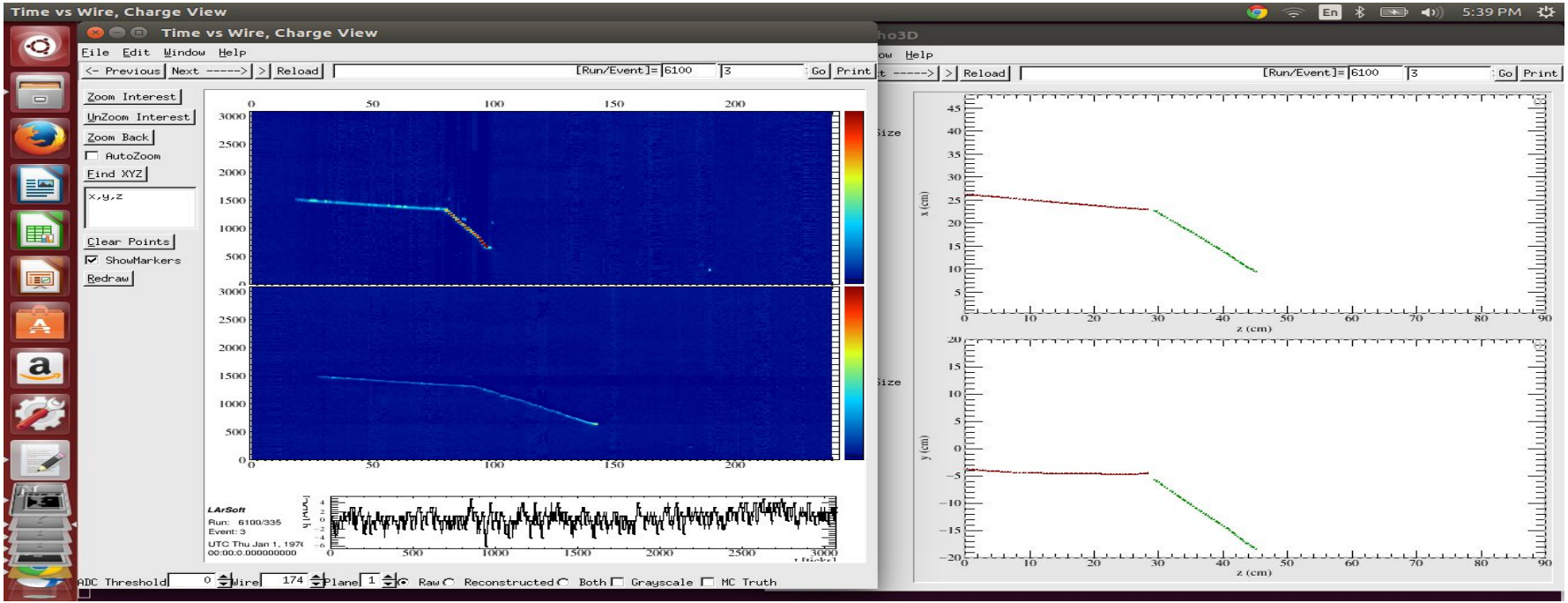
Decomposition of the pion nucleus total cross section into the contributions of the major reaction channels (ref. 17).

Raw data selected for the analysis

- To start we have taken small fraction(~ 10%) of negative pion data for the analysis .
- 60 A negative polarity data is chosen to get clean events.
- 6000 spills with an average of 20 events/spills

Quality events

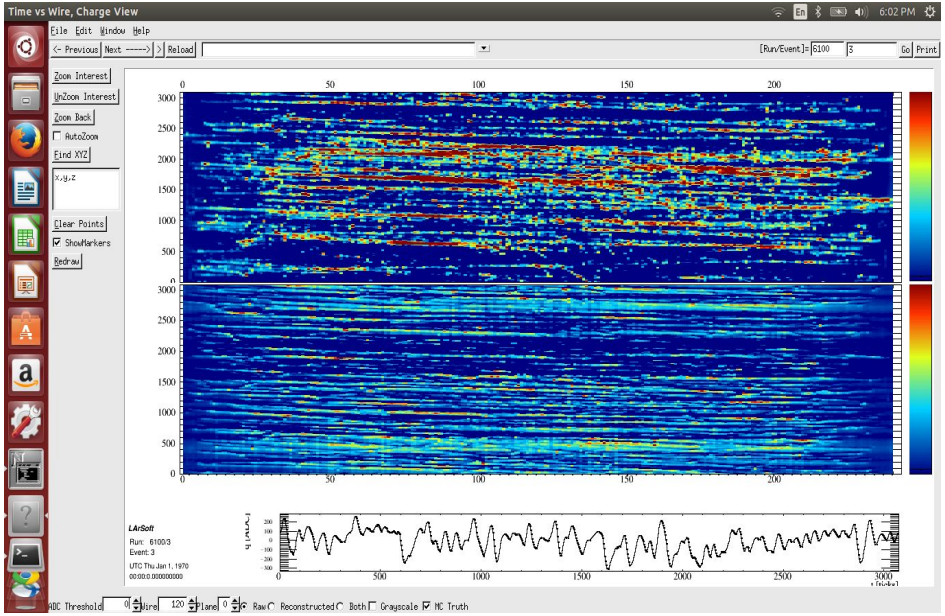
Quality events: events that we believe to contain pions and ones that allow us to associate initial energies with TPC tracks.



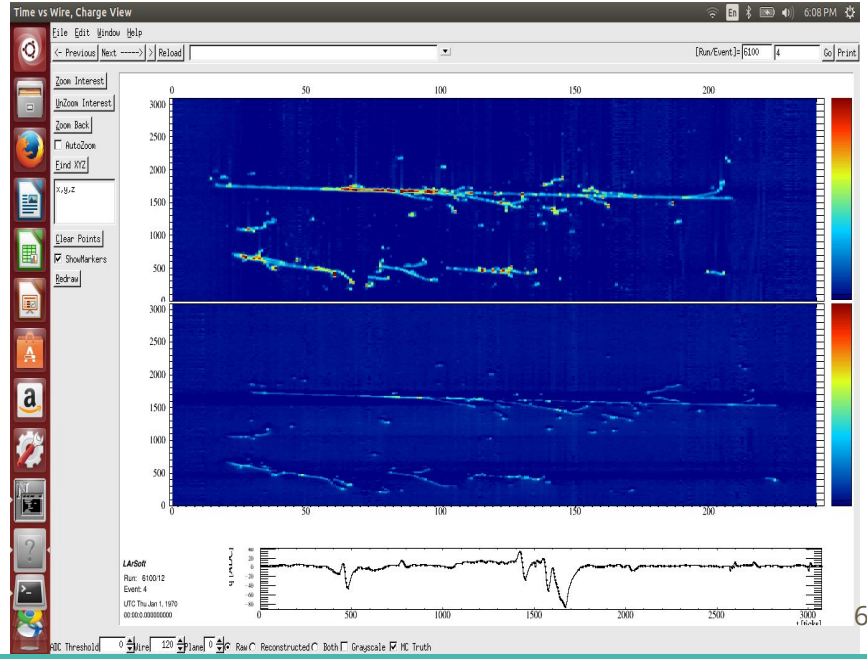
Selection of good quality events

How do we get good quality events from our test beam data?

PILEUP Events



Shower Events

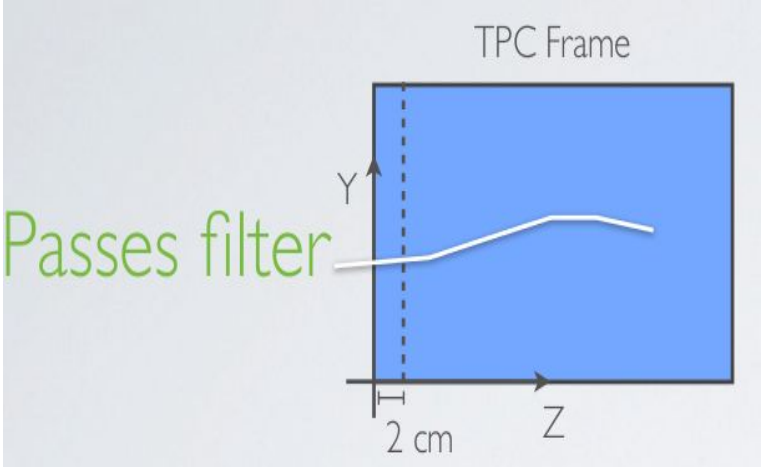


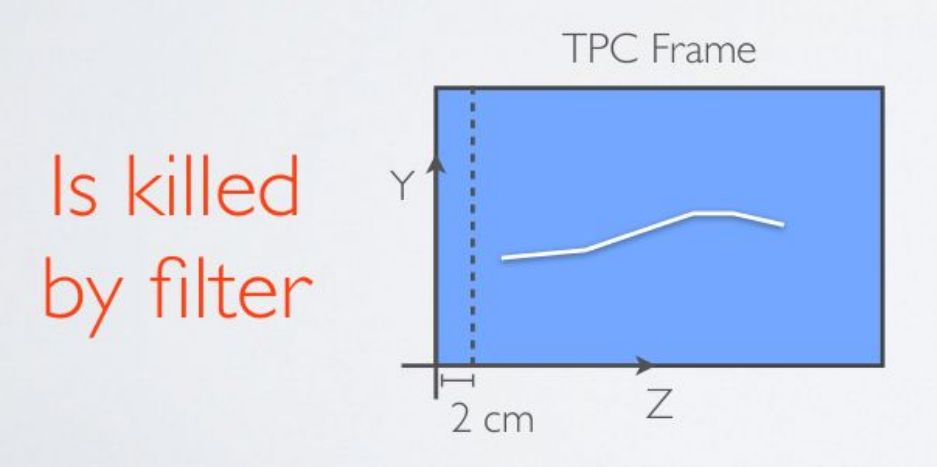
Framework of selection of events

- First filter : BEAMON and no PILEUP
- Beamline Reconstruction (WC tracks, TOF, PID)
- TPC Reconstruction (track reconstruction and calorimetric information)
- TPC primary selection
- TPC and WC track matching
- We have selected a pion to be interacting if the endpoint of the track lies within the fiducial volume, and energy at the end point is greater than 50 MeV.

TPC primary selection filter

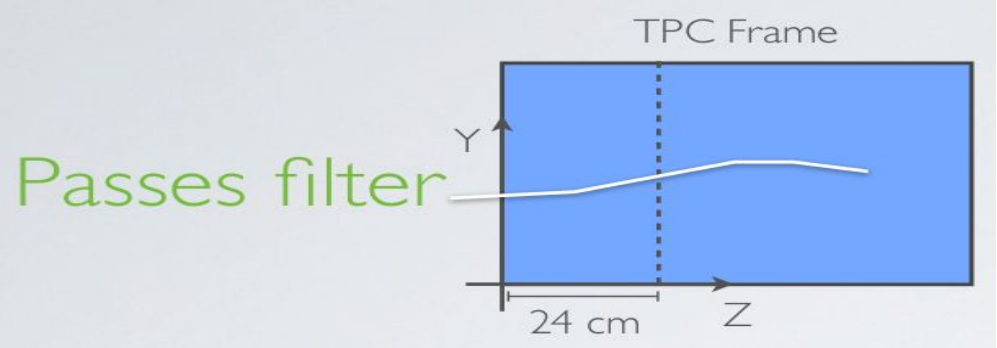
- First UPstream Zcut: The track must have a space point within 2 cm in Z of the UPstream face(ensures that we are looking at a primary from the beam).

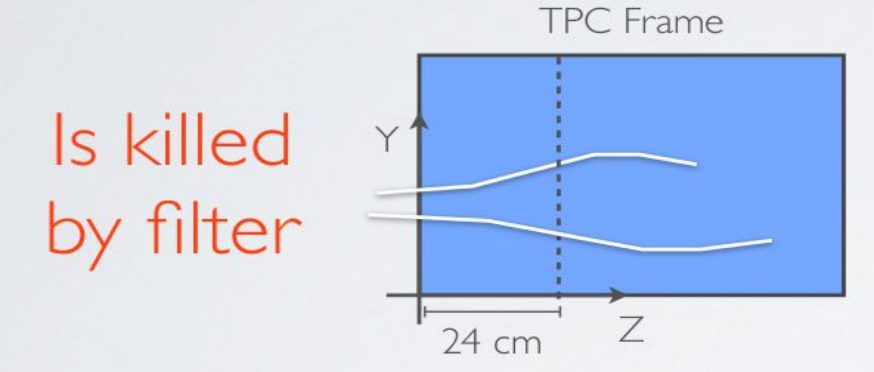


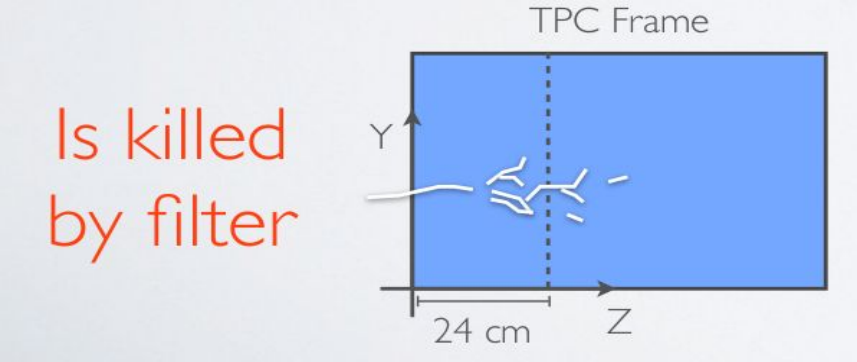


TPC primary selection filter

- Second Upstream Zcut: Must be 1 track within 24 cm in Z of the UPstream face (filter out showers from beam electron and multiple tracks)

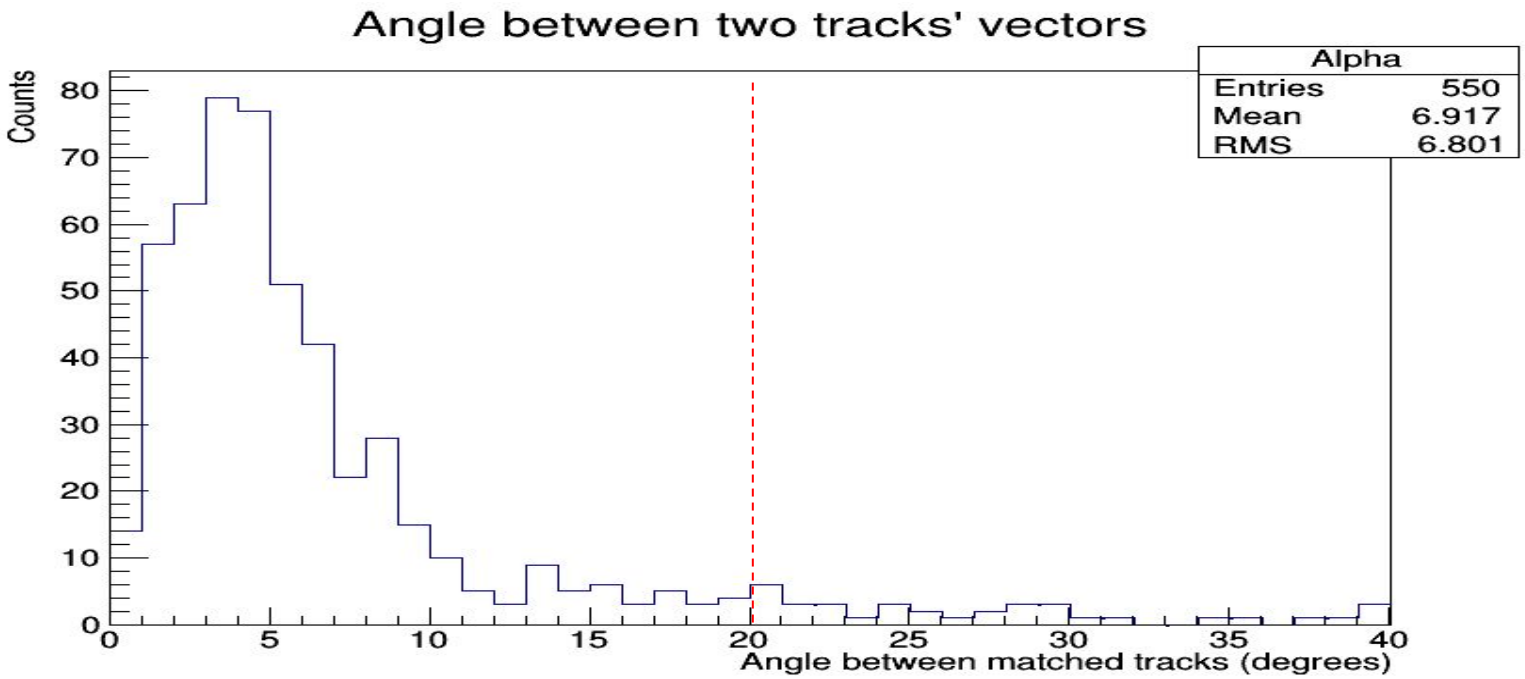






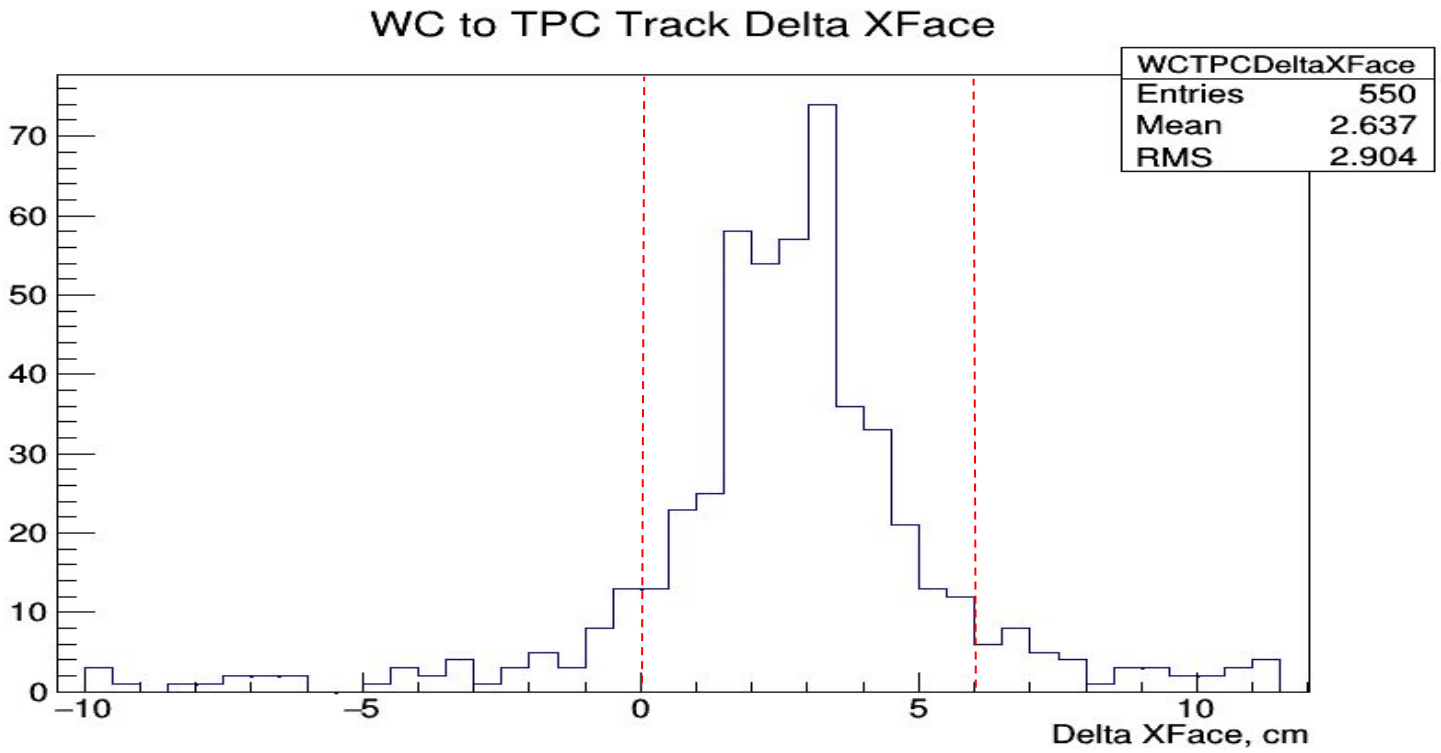
Track matching cuts

- Angle between WC track and TPC track direction at the US face < 20 deg.



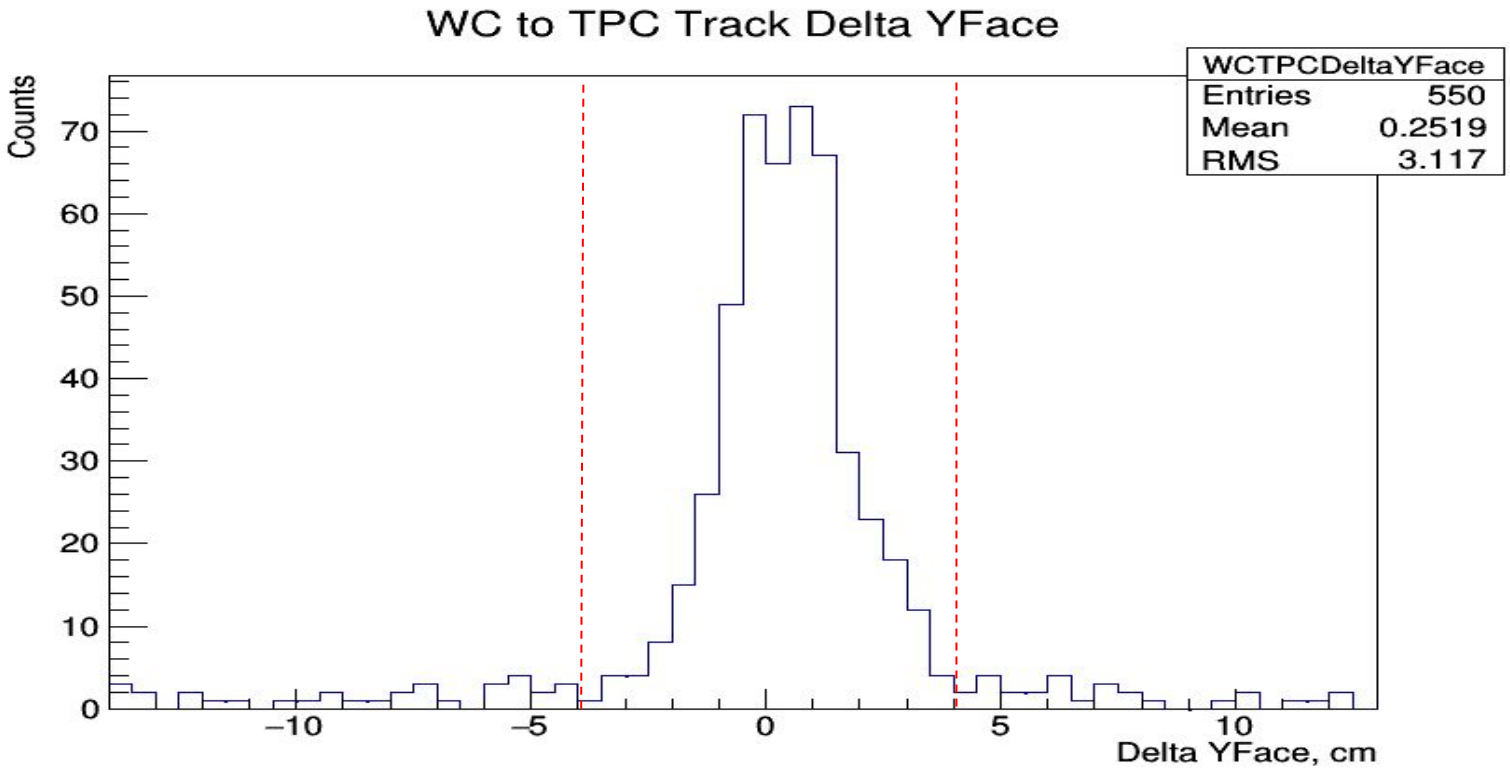
DeltaX cut

Delta X= (TPC Track X - WC Track X) = (0,+6)cm



DeltaY cut

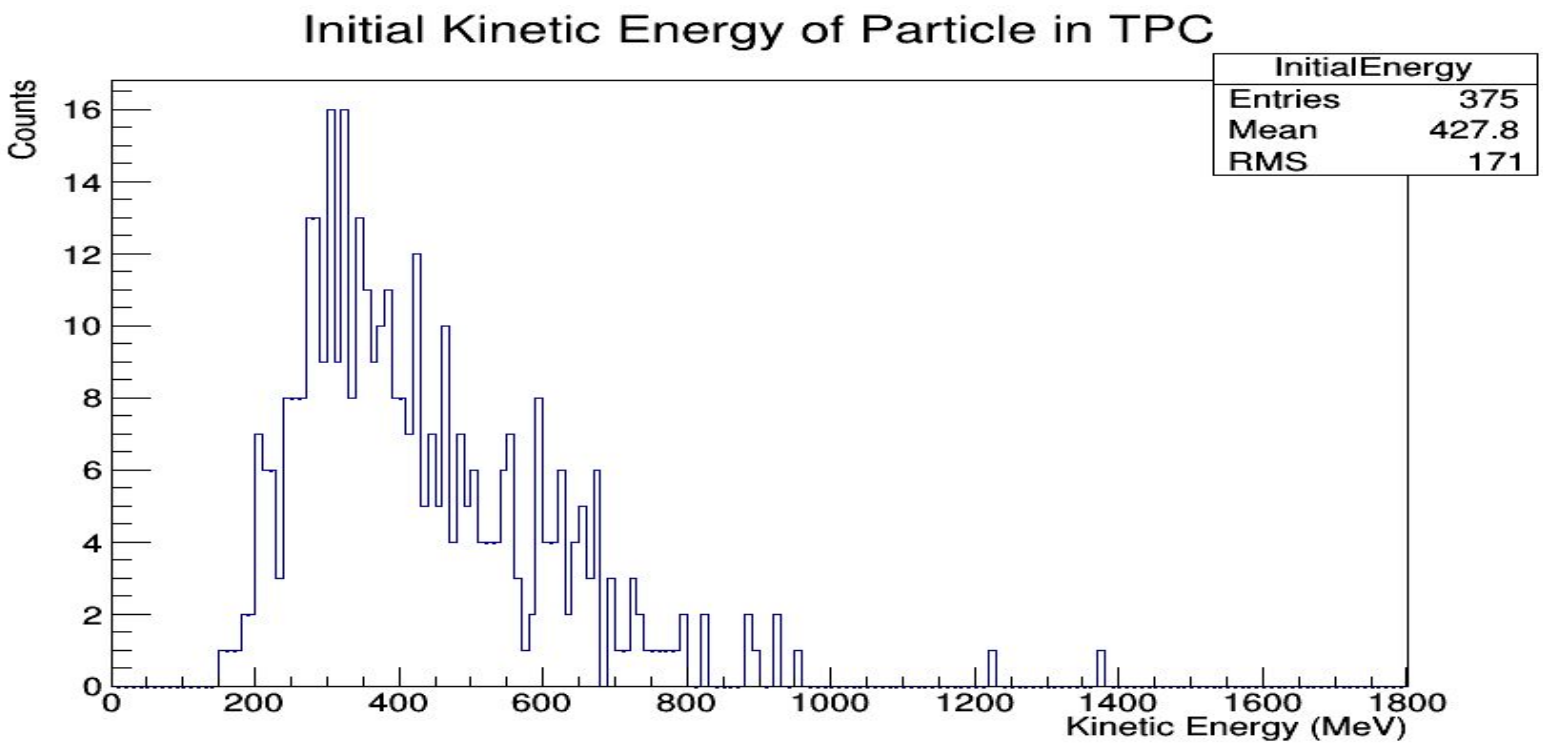
Delta Y= (TPC Track Y - WC Track Y) = (-4,+4)cm



Events after the cuts

Filter order	Filter type	Number of events	percentage
0	No Filter(BEAMON - no PILEUP)	13839	
1	WC track reconstruction	4455*(*3 times improvement is expected soon*)	32.19%
2	TPC track reconstruction	550	3.97%
3	Alpha	501	3.6%
5	DeltaY	440	3.17%
6	DeltaX	375	2.7%

Incident Energy distribution of pion at TPC

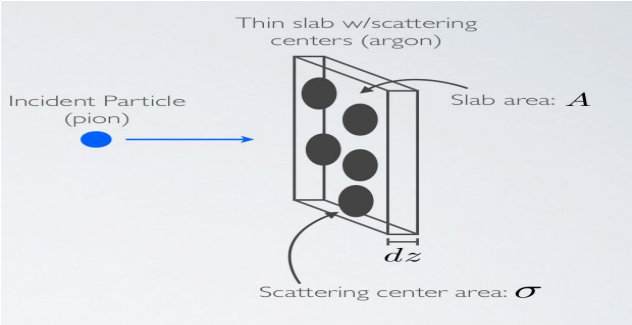


Cross-section analysis method

Total Pion-Argon cross-section:

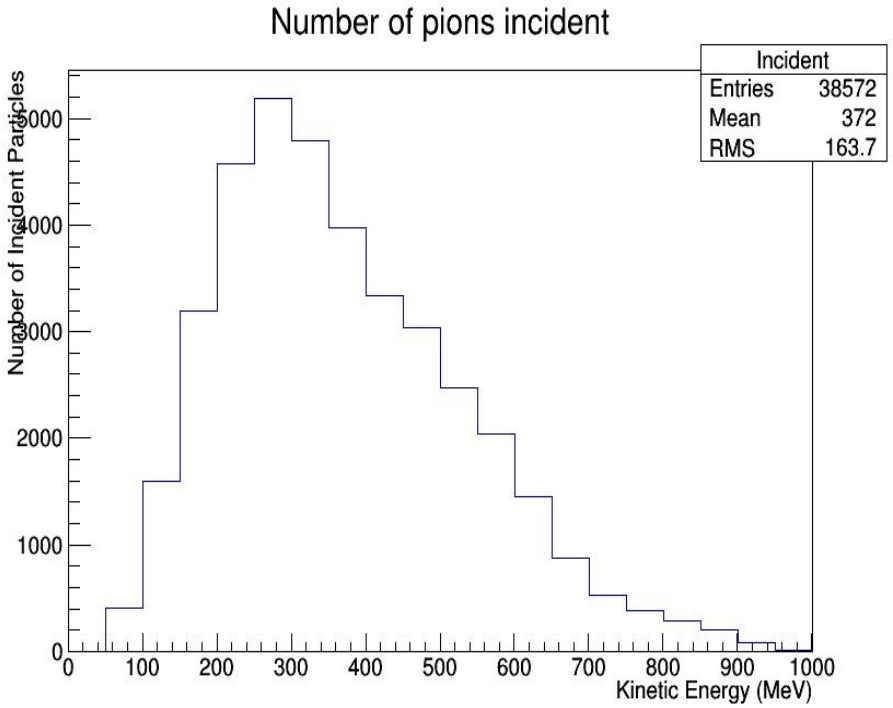
- "Many thin slabs method" for total cross-section measurement

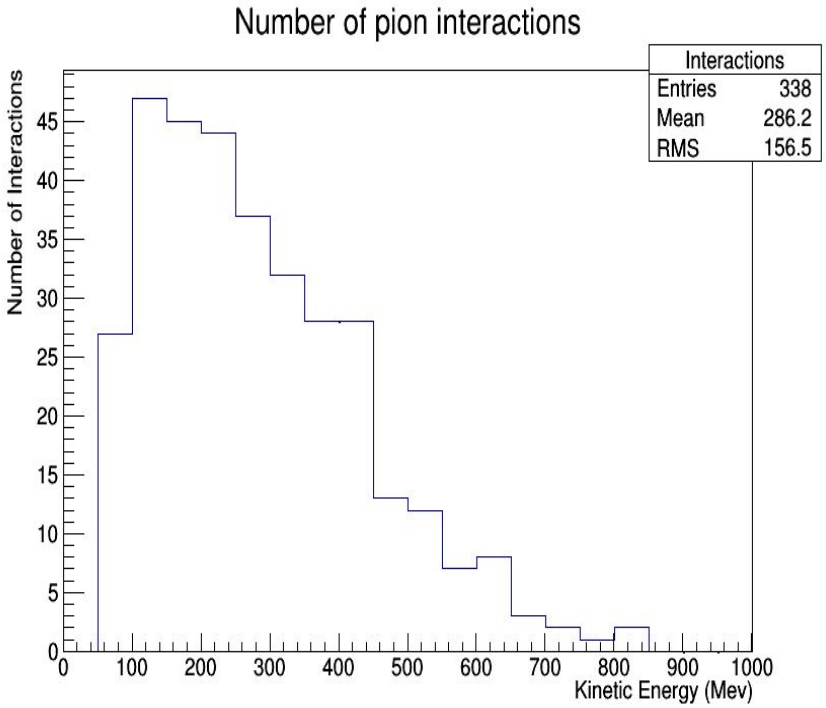
$$\sigma = \frac{N_s}{N_i} \frac{1}{n(dz)}$$



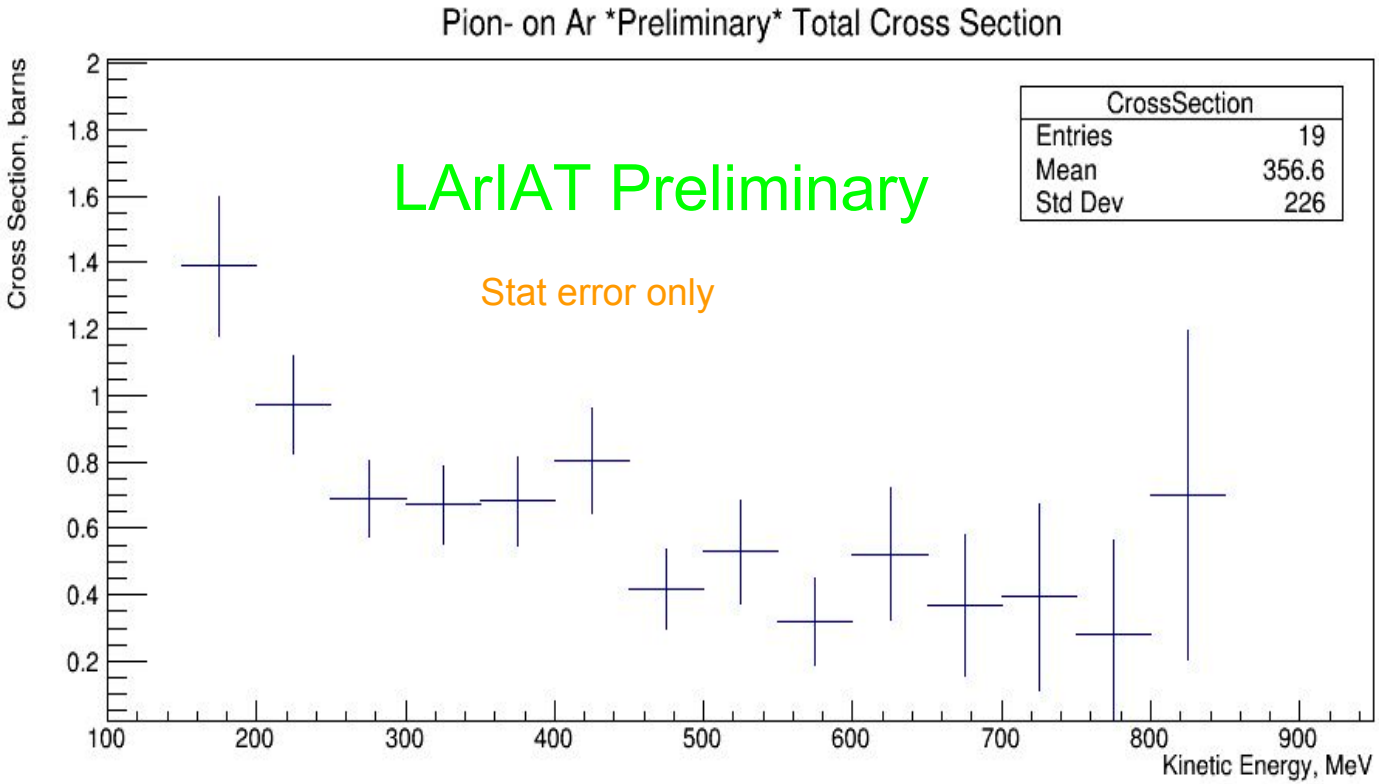
- n density of scatter centers in the target, n = $\frac{\rho N_A}{A}$
- dz fixed target thickness.
- The slabs follow track trajectory, slab width dz=4.725 mm (avg calo hit pitch distribution)

Number of incident and interacting pions

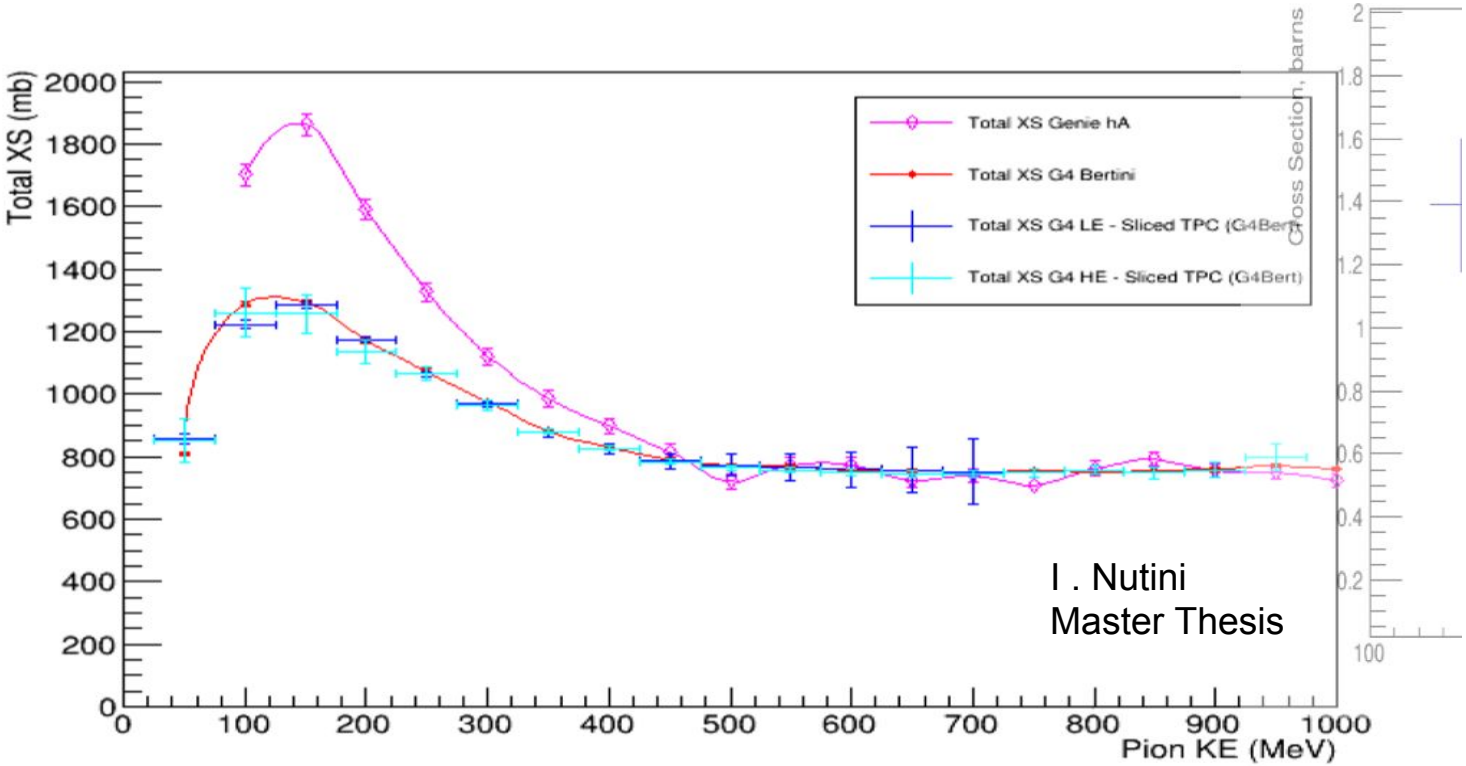




Pion -Argon total cross-sections (Preliminary)



Cross-sections (Monte Carlo)

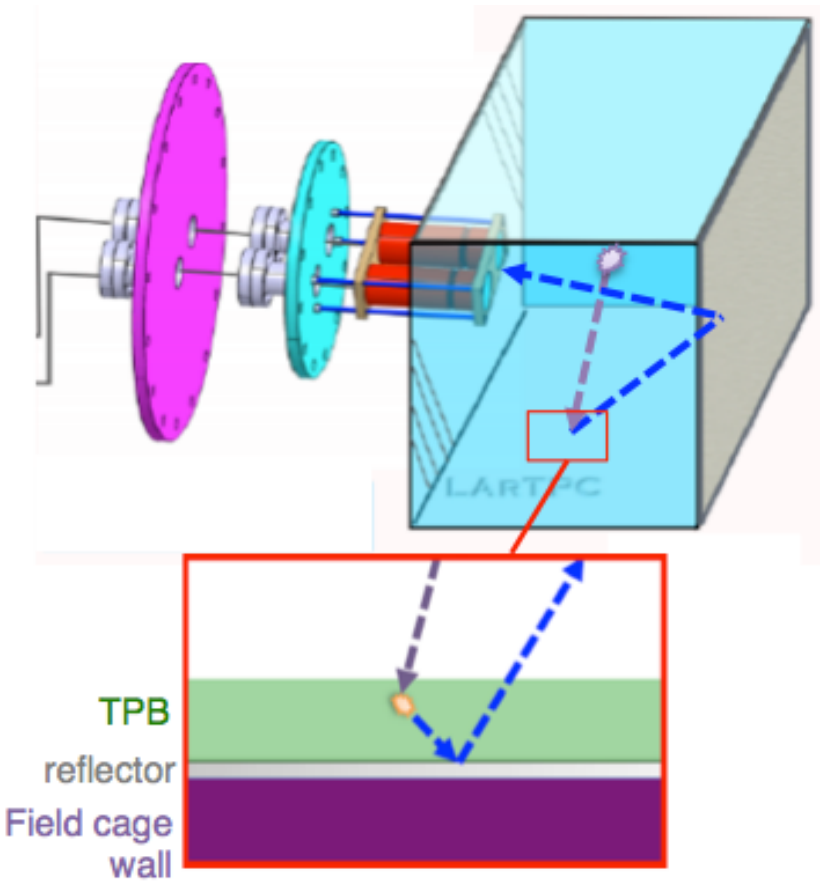


Conclusion

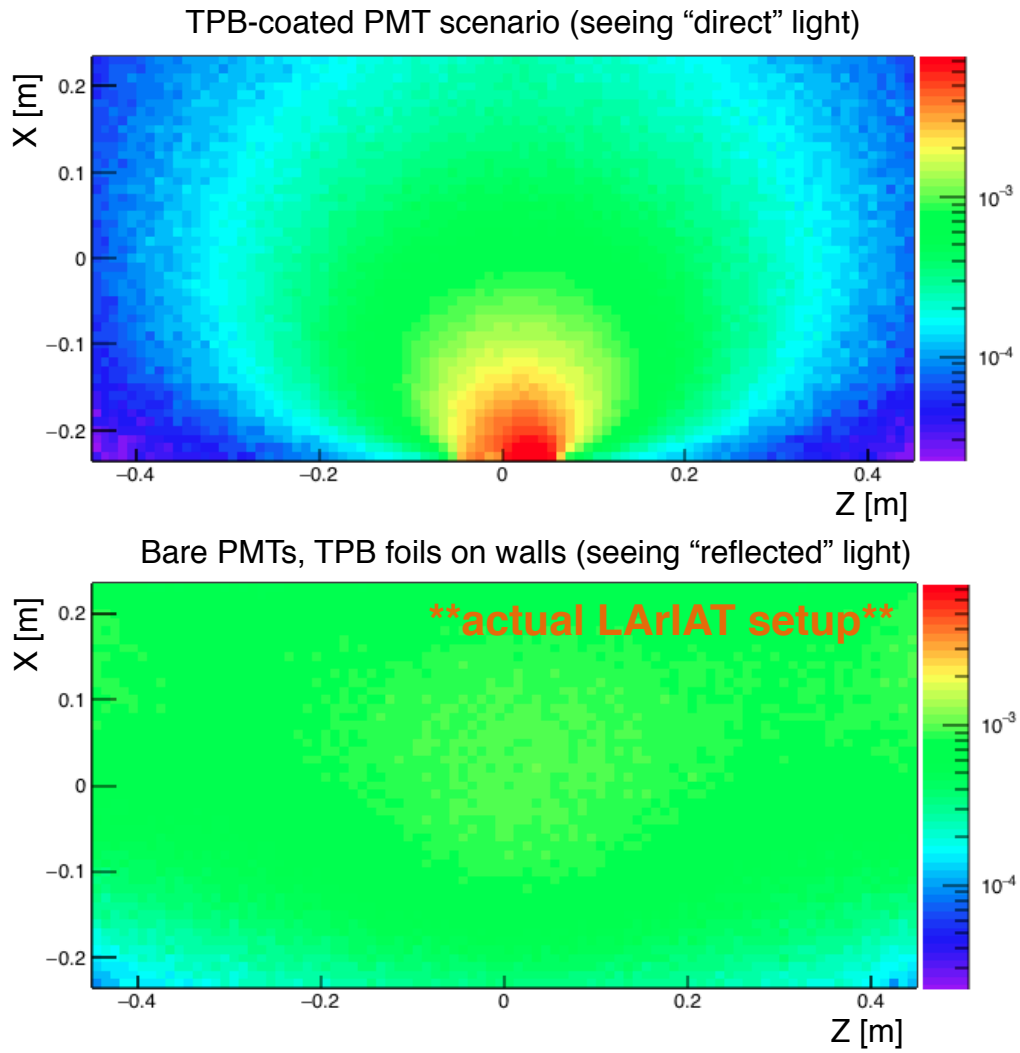
- Analysis framework is in good shape.
- In the process of improving -
  >WC track reconstruction ->
  tagging non interacting events
- We are going to process more data and will start analysing positive pion.
- Monte Carlo simulation work is in progress - -
  >Systematic uncertainties.

Backup slides (Michel studies)

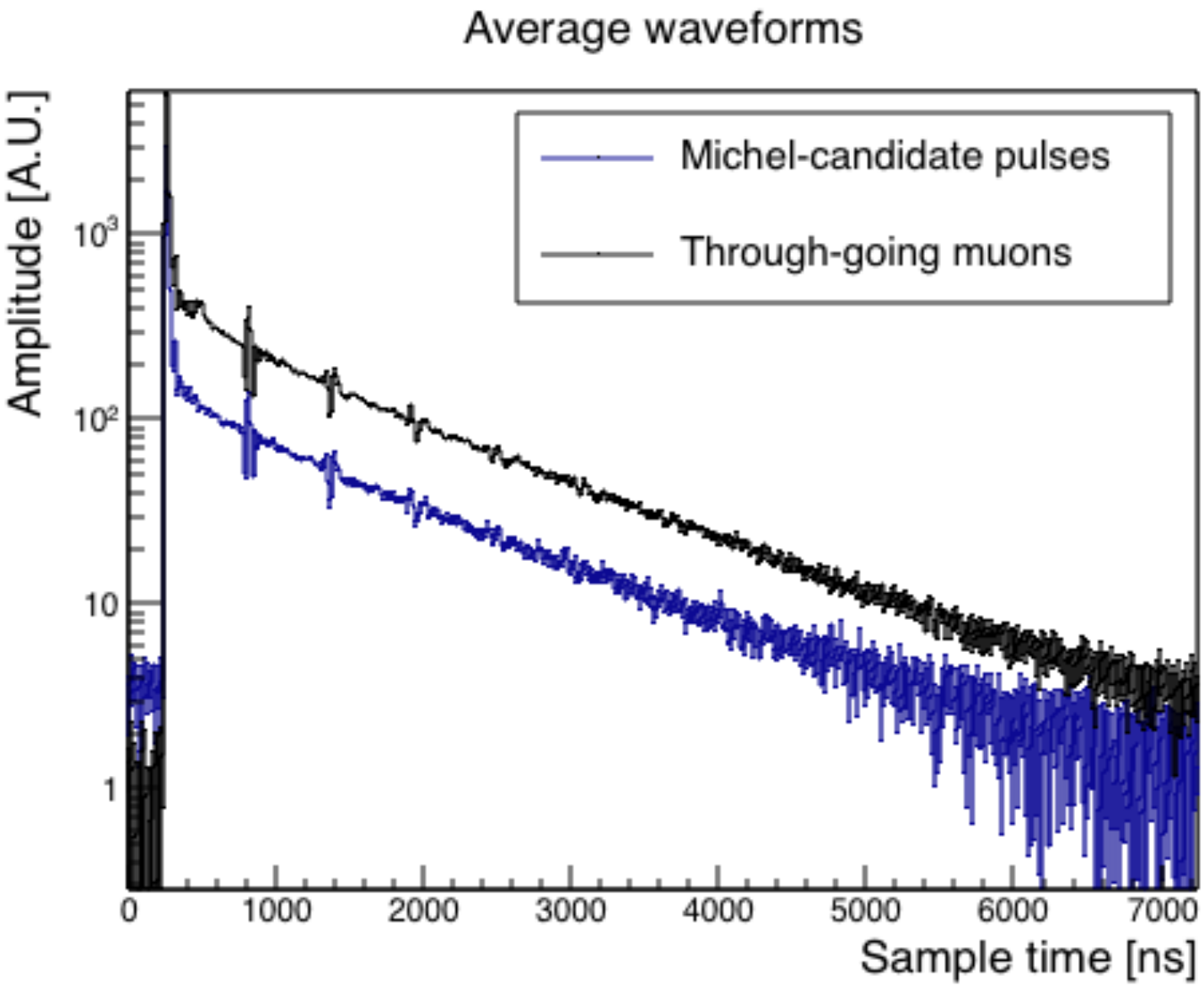
LArIAT's light collection system (recap!)



Fractional visibility map from MC (top-down view of LArIAT TPC)



Michel electrons vs. muons



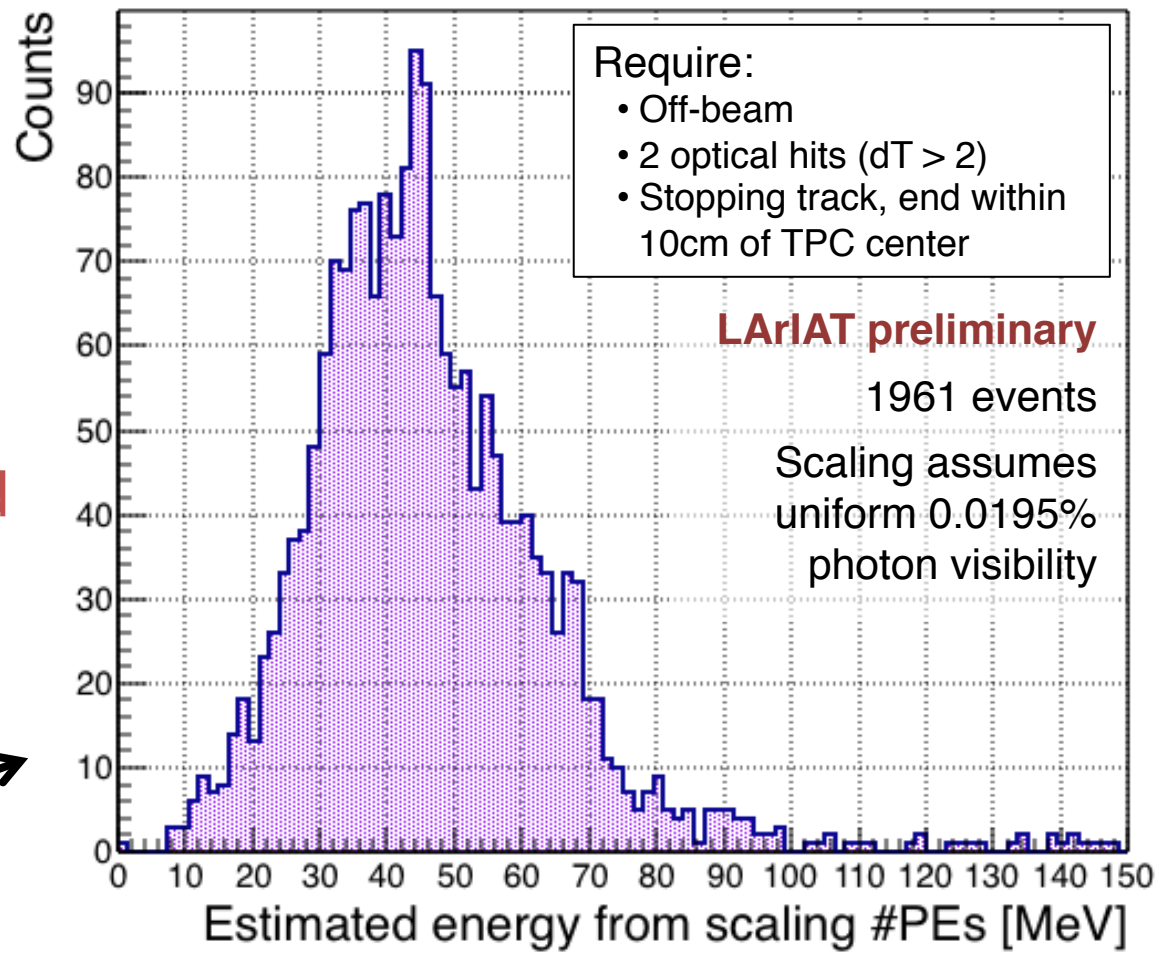
Preliminary light-to-energy calibration

Next step: use position of $e^{+/-}$ and scale light signal based on photon visibility at that point (from MC)

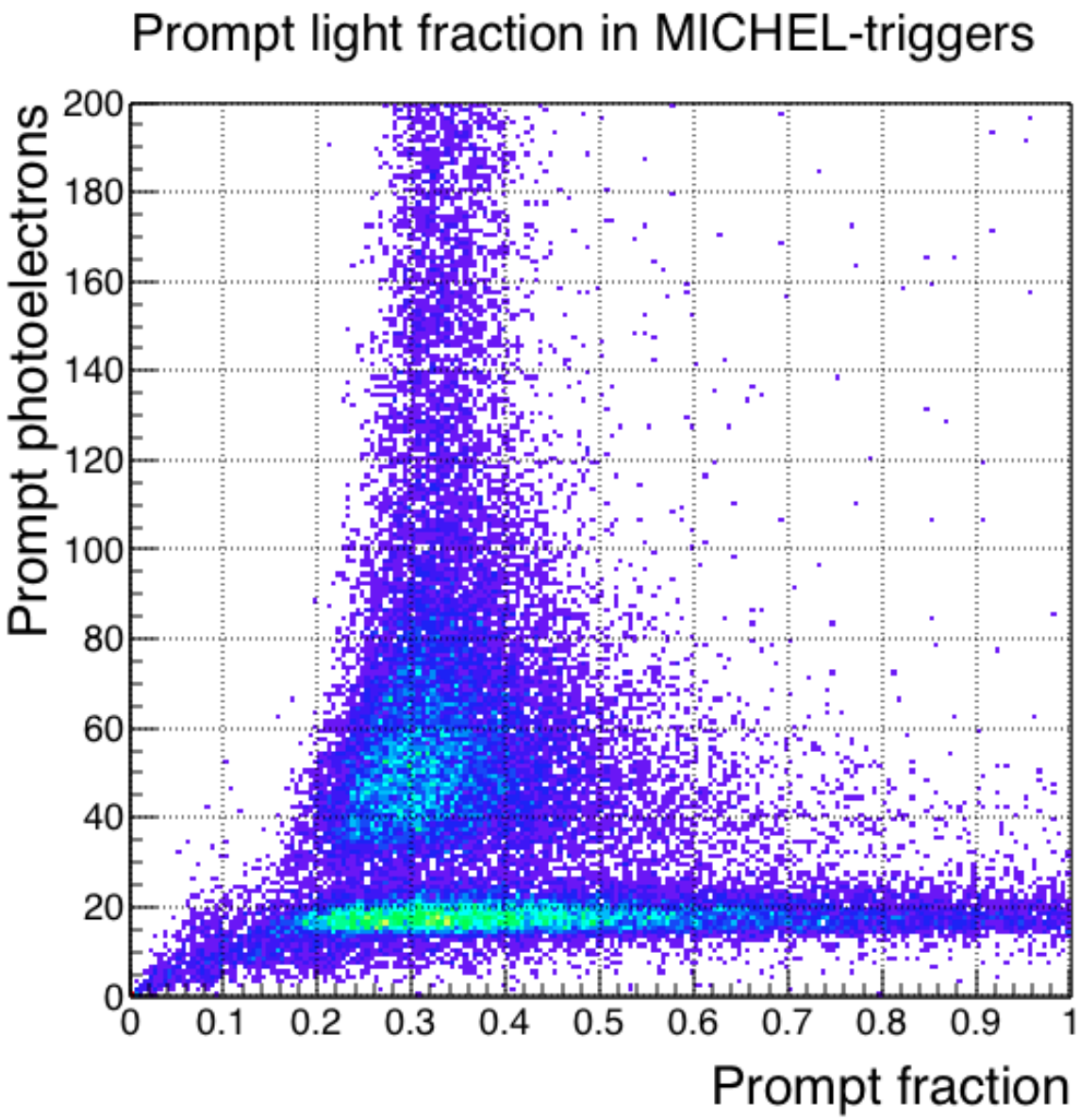
Requires more advanced 3D reconstruction (in progress)

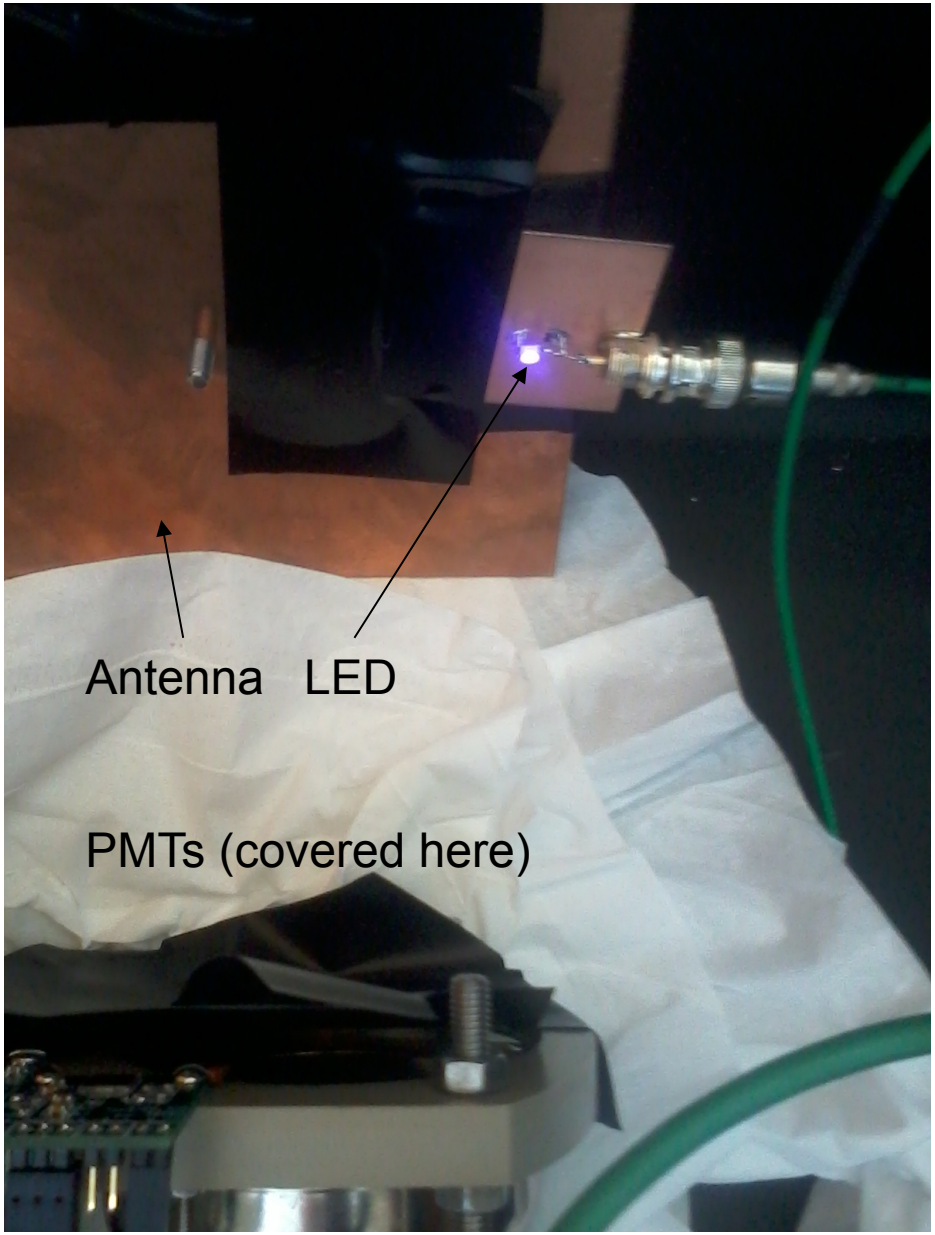
Preliminary result

- Assume uniform visibility, **no** position-dependence



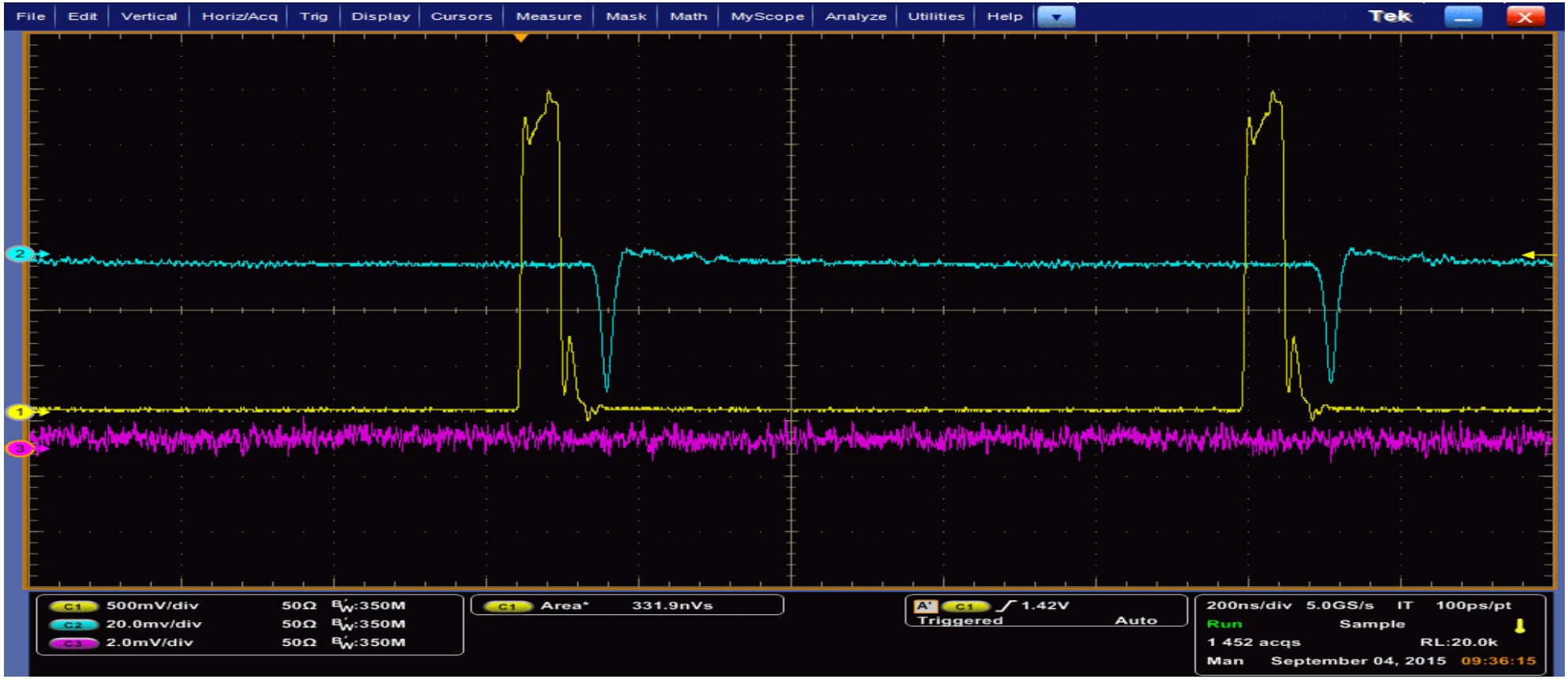
Preliminary PSD on MICHEL-triggers




Antenna
LED
PMTs (covered here)

Results for an old base

- Studies of the overshoot changing with growing light intensity (voltage on LED) without an antenna – also probably excluding possibility of cap. Coupling to plate as a source of such behavior



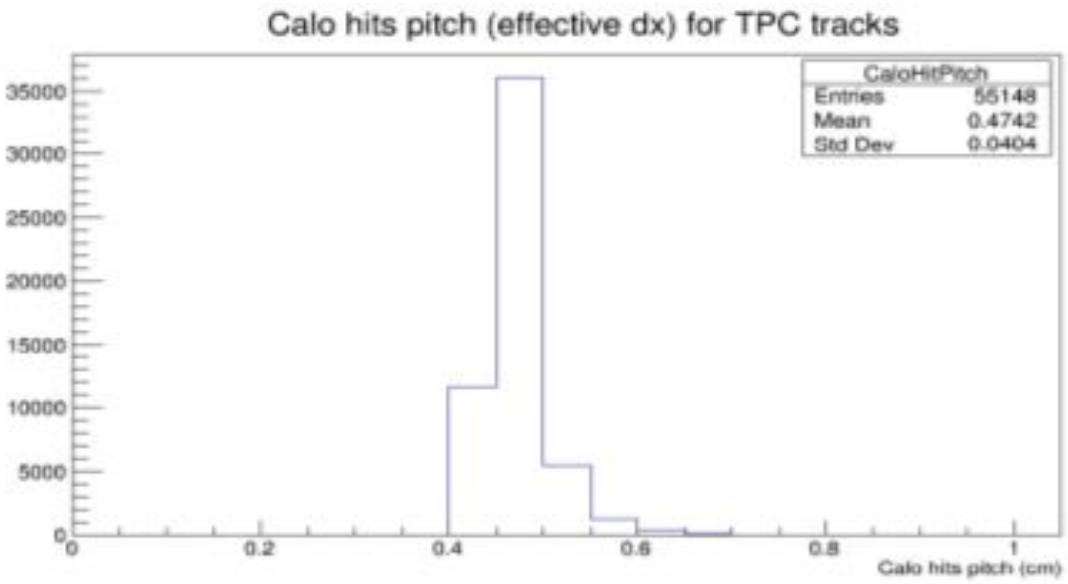
Results for an new base

- unipolar signal
- Small modulation on antenna – may also be a grounding problem (thanks, Will!)

Backup

Cross-section

Backup (calo hit)



$\longrightarrow$ Avg calo hit pitch $= 0.4725$ cm

Events after all cuts(table)