The Liquid Argon in a Testbeam (LArIAT) Experiment

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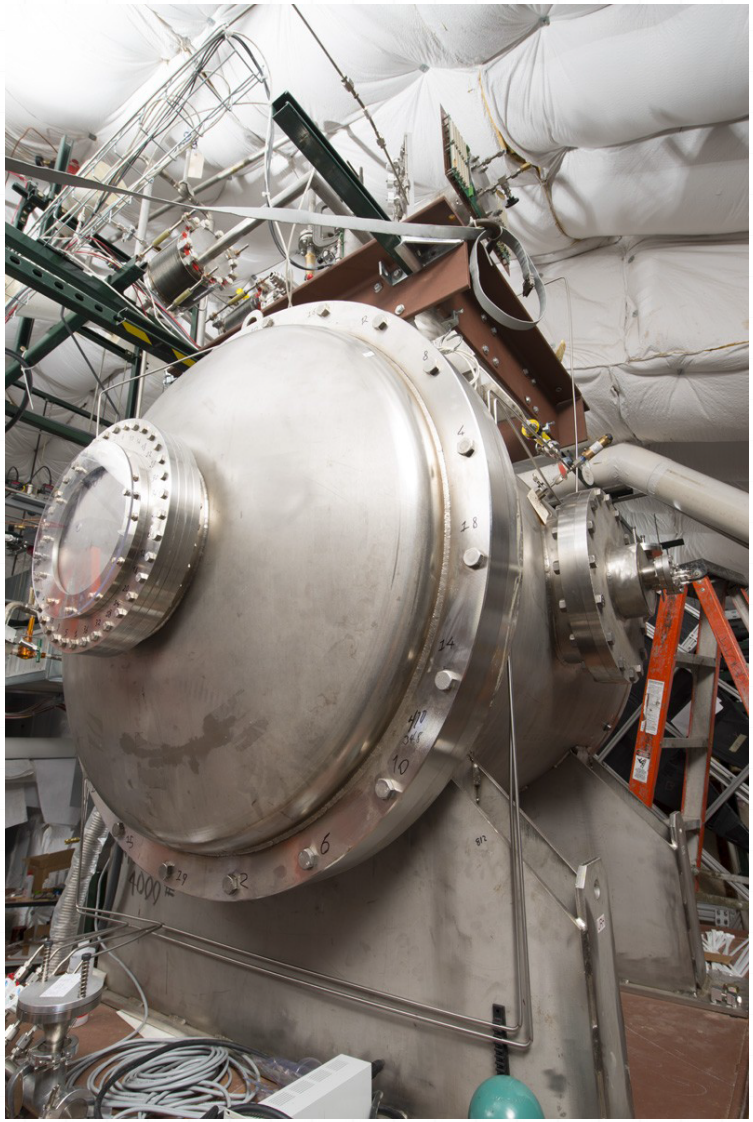
on behalf of LArIAT Collaboration

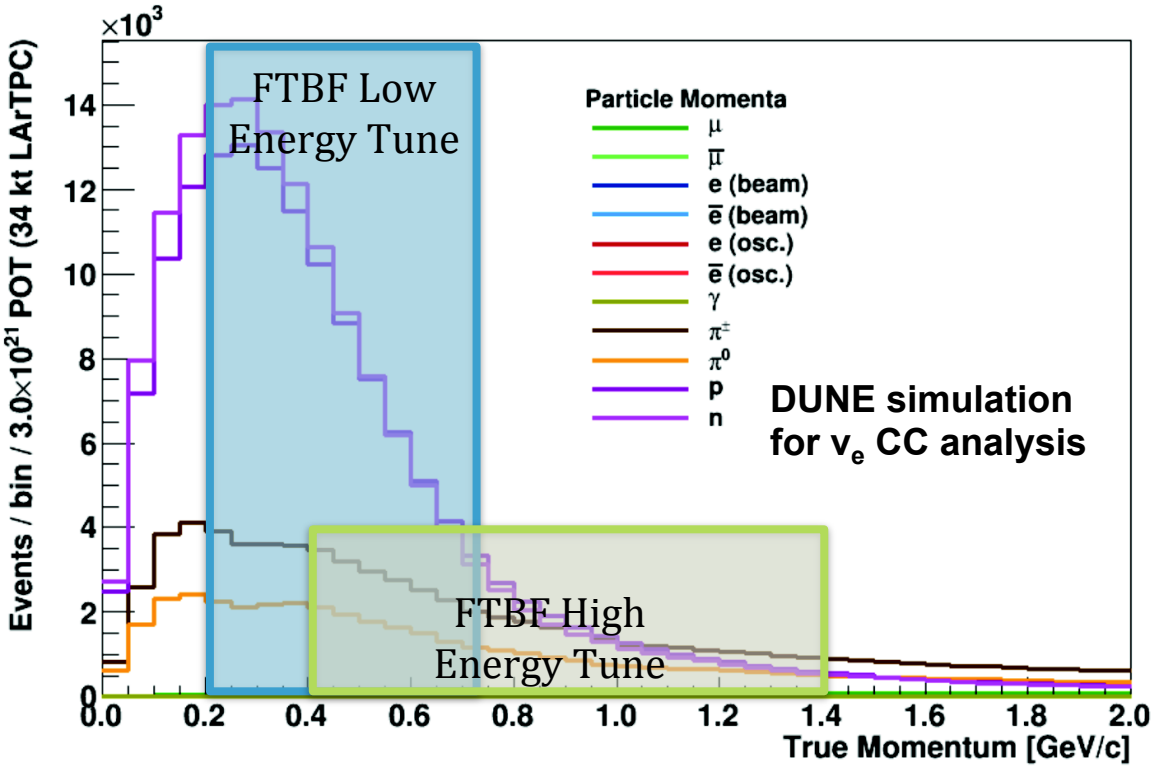
What's LArIAT?

- ✓ **Liquid Argon In A Testbeam**, is a 170 liters LAr TPC deployed in a beam of known charged particles.
- ✓ It's executing a comprehensive program designed to characterize LAr TPC performance in the energy range relevant to the forthcoming neutrino experiments.
- ✓ Hardware R&D, tune hadron-nucleus interaction models and neutrino generators, study reconstruction systematics and calorimetry in LAr TPC.



Motivation : needs of ν -experiments

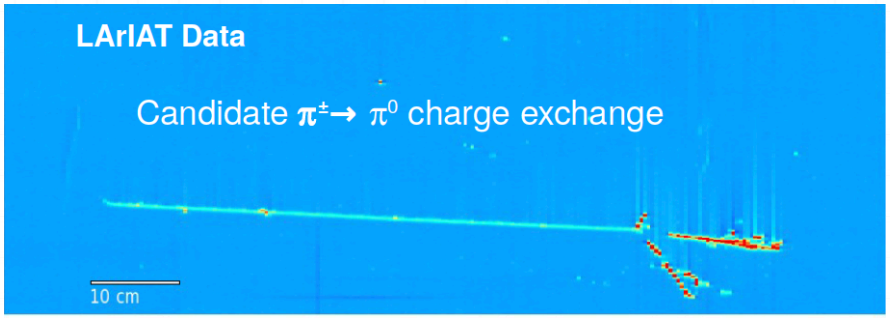
- ✓ A LAr TPC in the Fermilab Test Beam Facility is well suited to study charged particles in the energy range relevant to both the short-baseline (ICARUS, uBooNE, SBND) and long-baseline (DUNE) experiments.

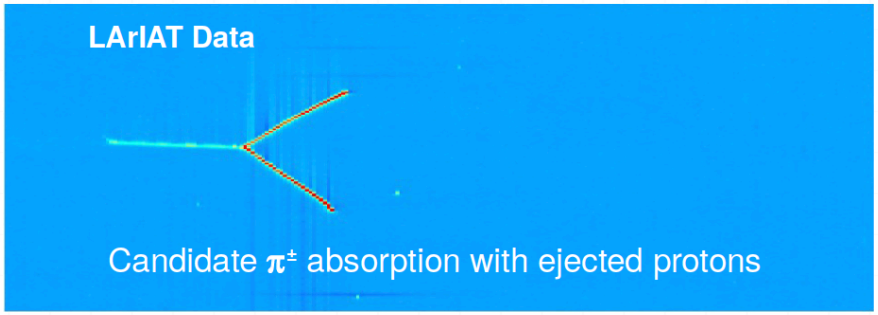


Physics goals

✓ π-Ar interaction cross sections:

- many π are produced in ν interactions with nuclei for ν energies of a few GeV;
- π – Ar cross section is a systematic in ν experiments.

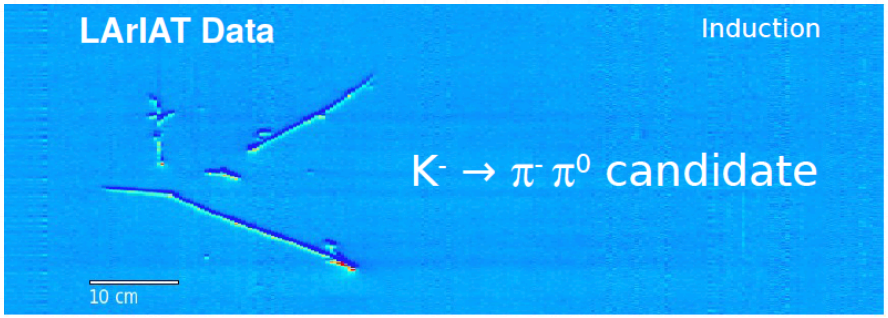


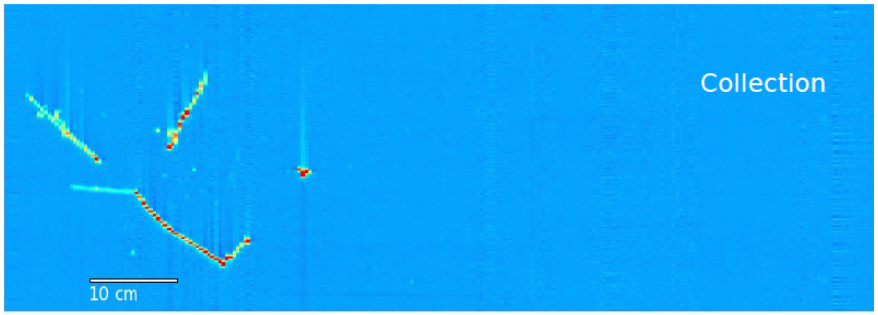


Physics goals

- ✓ π-Ar interaction cross sections.
- ✓ K-Ar interaction cross sections:

- physics beyond SM;
- relevant to proton decay searches in LArTPC ($p \rightarrow K^{+} + \overline{\nu}$).

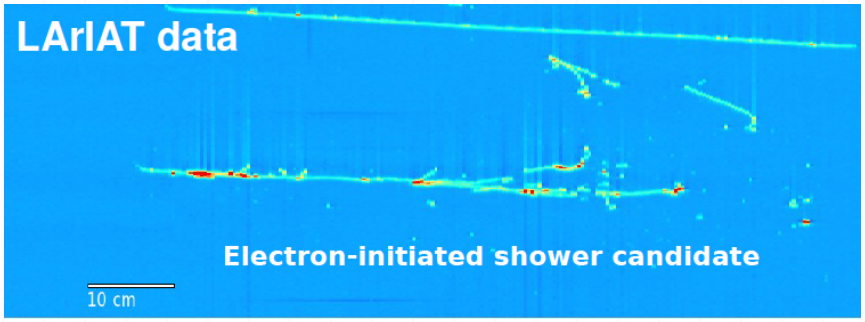


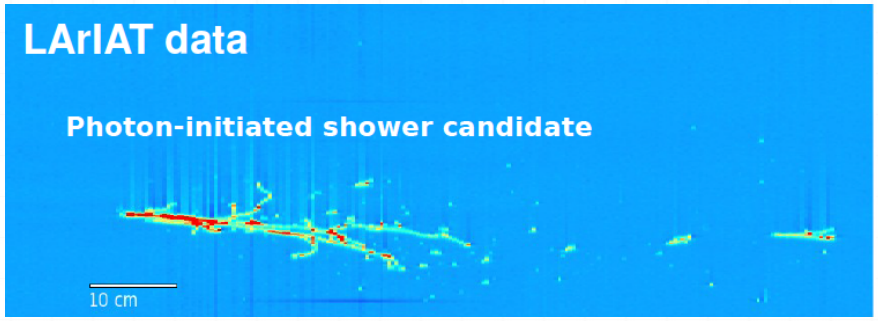


Physics goals

- ✓ π-Ar interaction cross sections.
- ✓ K-Ar interaction cross sections.
- ✓ e/γ shower identification:

- ν_e CC identification.

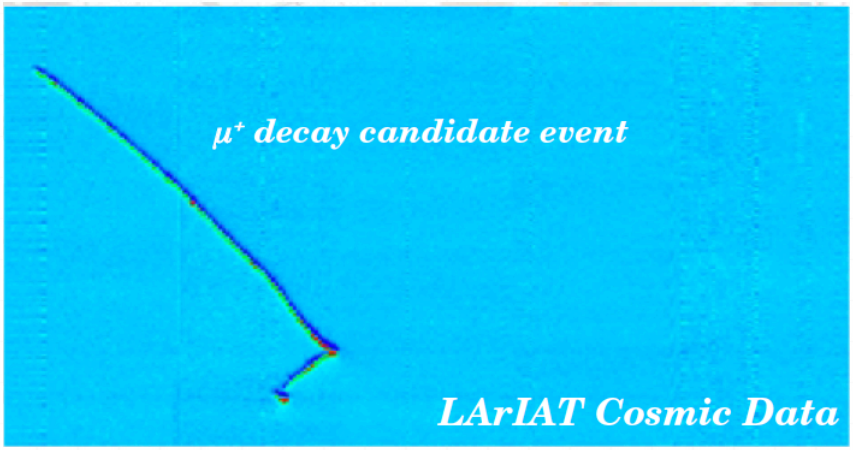


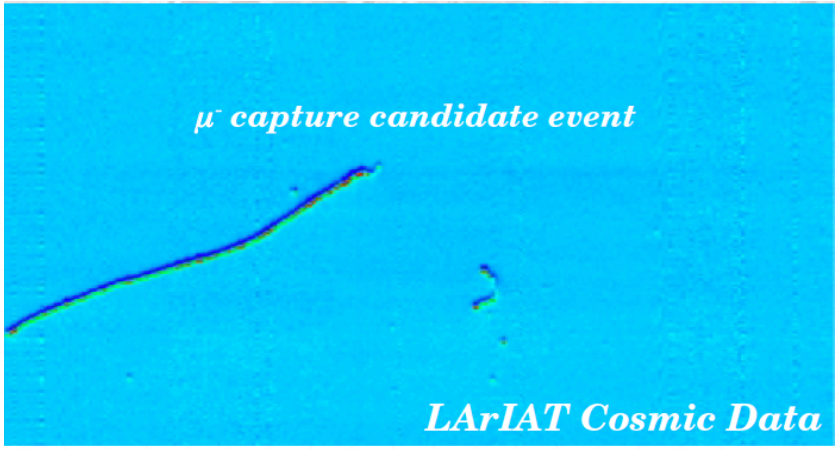


Physics goals

- ✓ π-Ar interaction cross sections.
- ✓ K-Ar interaction cross sections.
- ✓ e/γ shower identification.
- ✓ μ sign determination using topology:

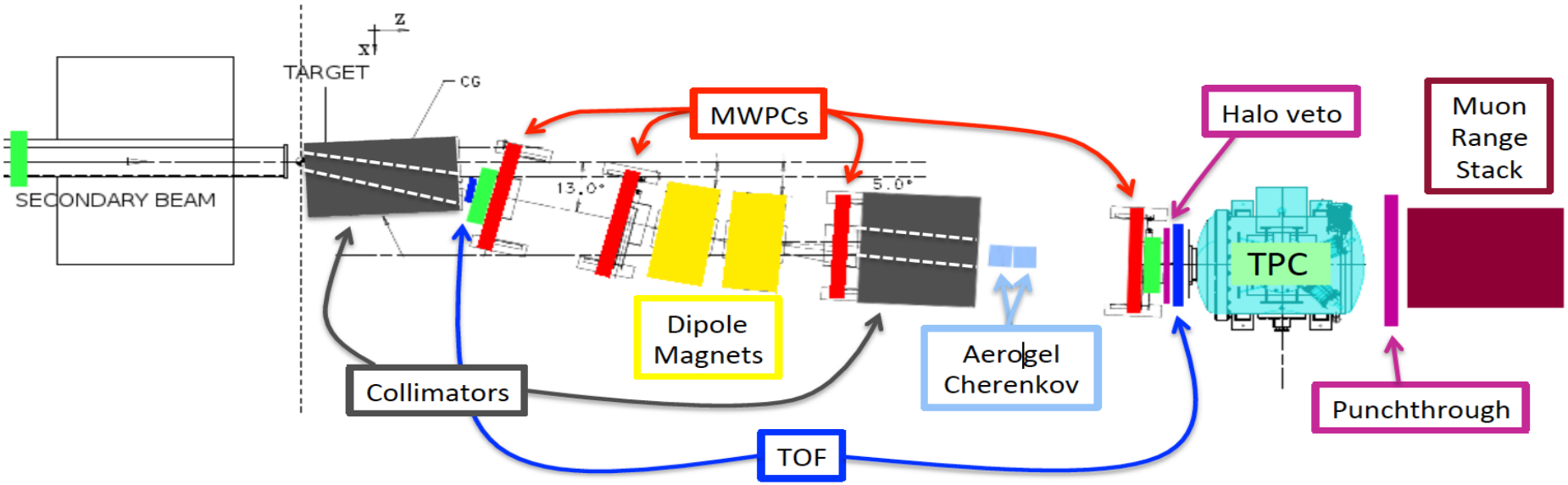
- μ^- undergo both capture on nuclei (76%) and decay (24%);
- μ^+ undergo decay (100%).
- possibility for distinguishing neutrinos from anti-neutrinos statistically.





Experiment overview

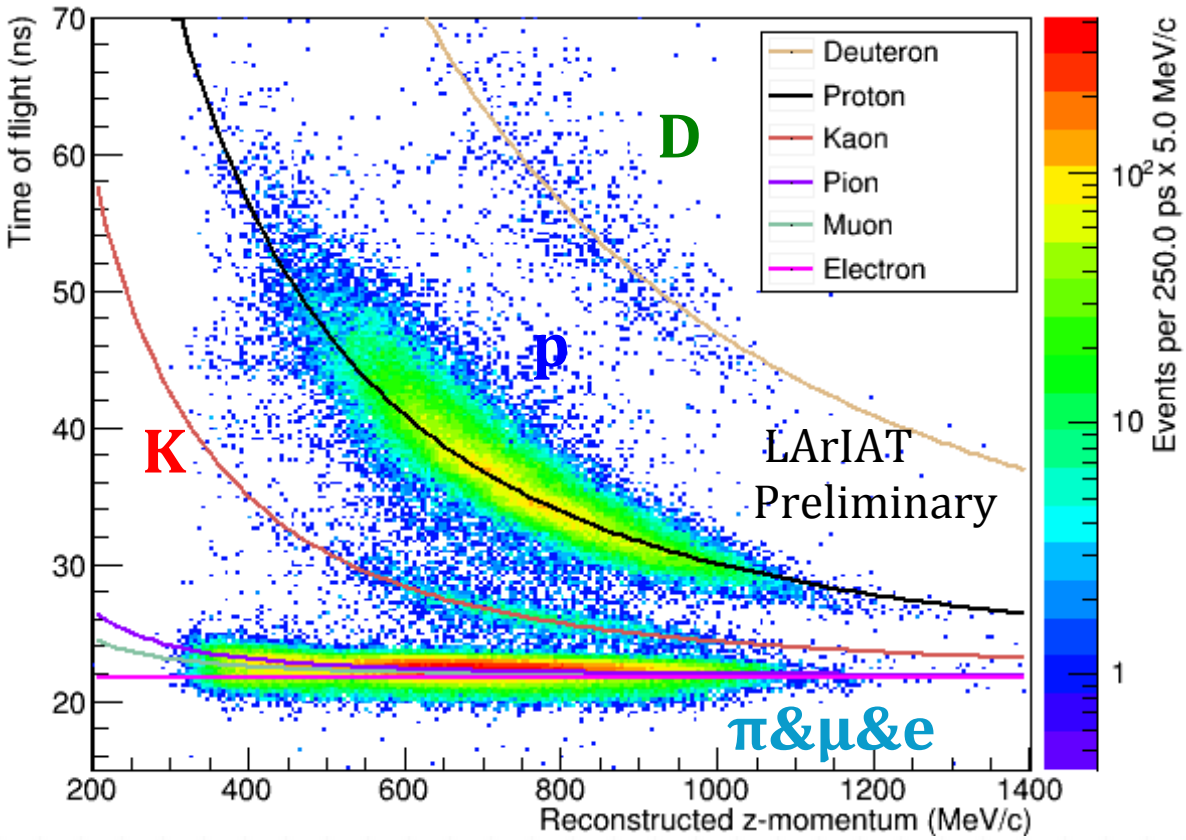
LArIAT Beamline



Test beam detectors

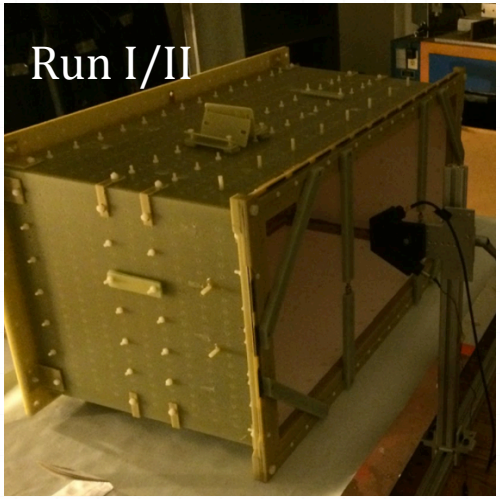
- ✓ MWPCs and TOF information make possible a particle identification.

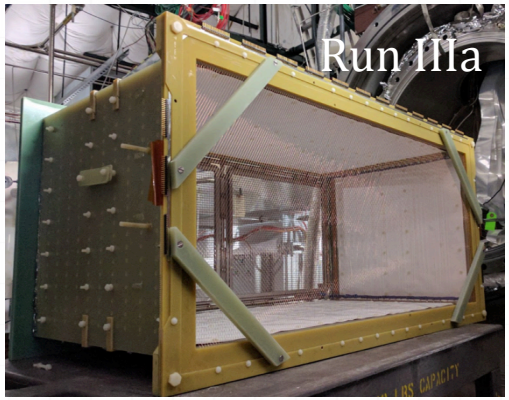
- ✓ Particle ID and momentum determination are performed before the particle enters TPC!

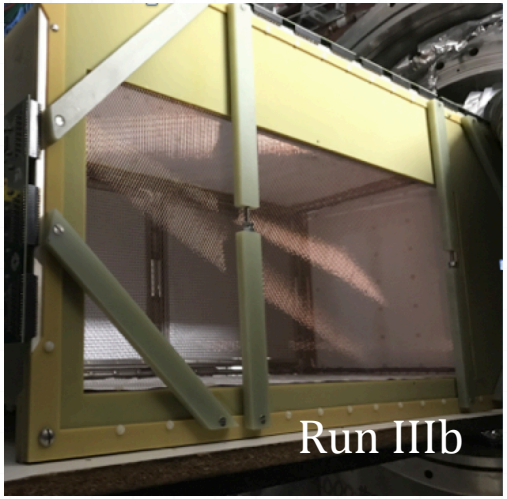


TPC

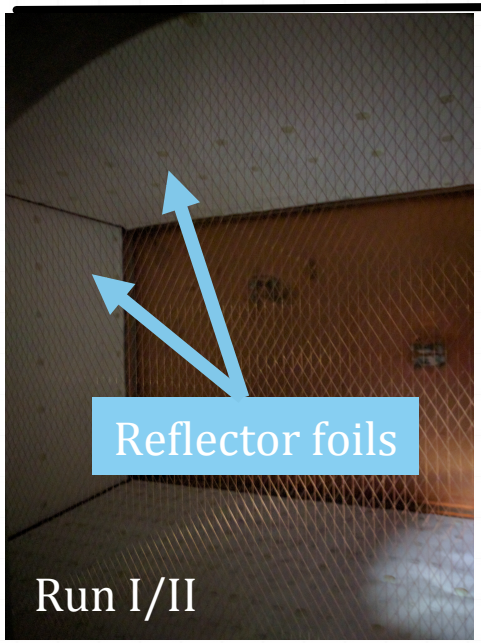
- ✓ LArIAT uses the refurbished ArgoNeuT TPC
  - 90 x 47 x 40 cm^3.
  - 2 Readout planes.
  - Drift field ~500 V/cm.
- ✓ LArIAT uses MicroBooNE preamplifying ASICs on custom motherboards.
  - Signal-to-noise – 70:1.
- ✓ Three Runs:
  - Run I/II: 4 mm wire pith;
  - Run IIIa : 5 mm wire pitch;
  - Run IIIb : 3 mm wire pitch.

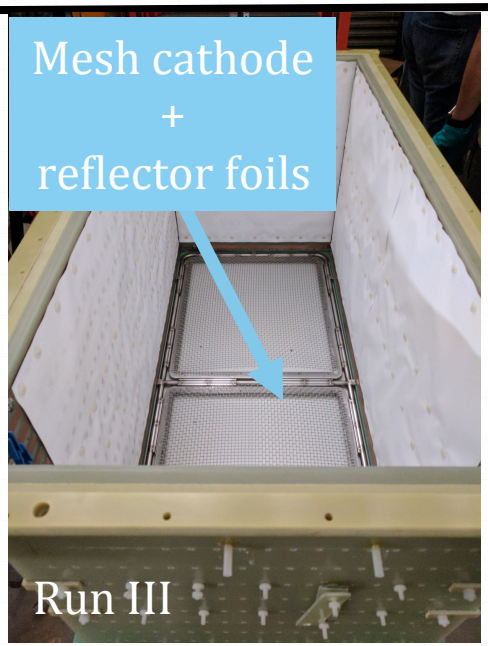




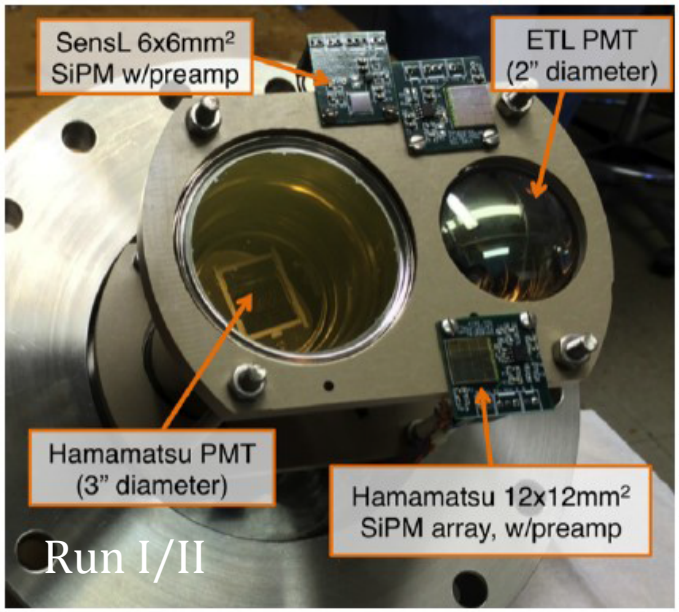


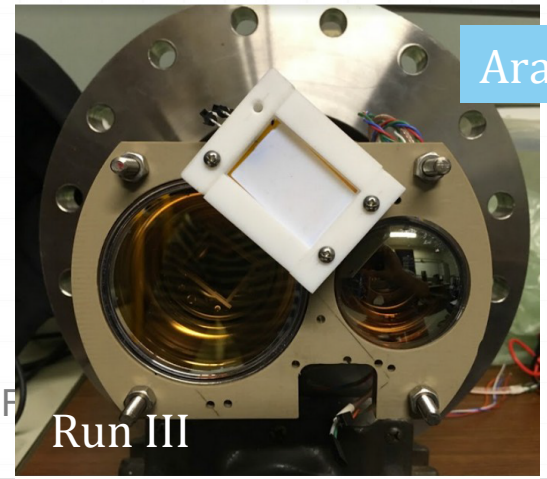
Light collection System

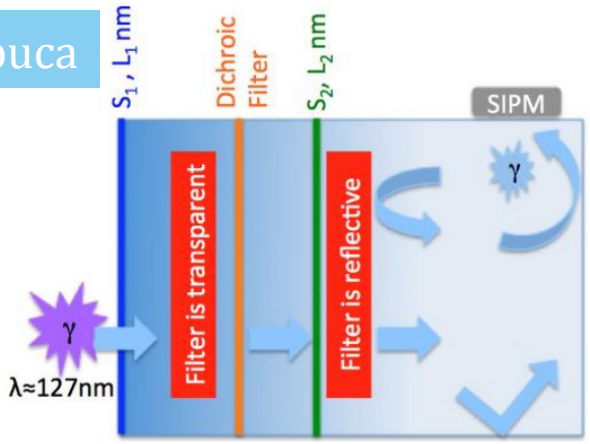




- ✓ Wavelength shifting (evaporated) reflector foils to shift the scintillation light into the visible spectrum.
- ✓ In Run III reflector foils also over the cathode.
- ✓ Arapuca light trap: use dichroic filters + 2 WLS. The readout 1 SiPM, with a much larger active surface.



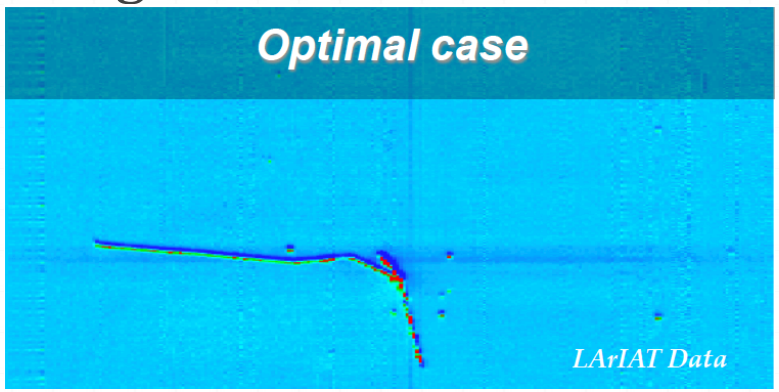


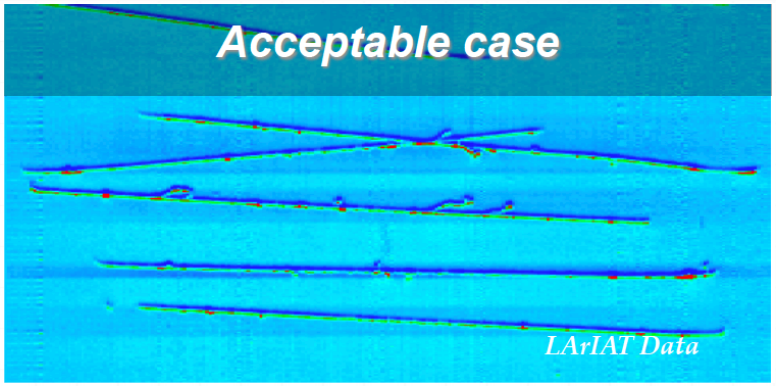


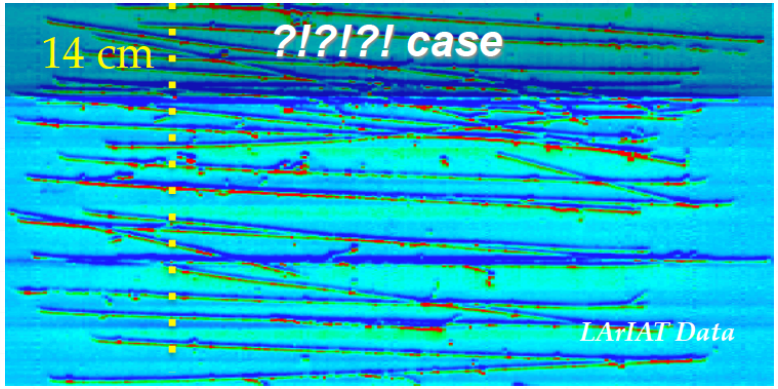
Cross-section calculation

Event Selection

- ✓ We reject events with more than 4 tracks in the first 14 cm of the TPC to minimize reconstruction issues and beamline-TPC ambiguous matches.



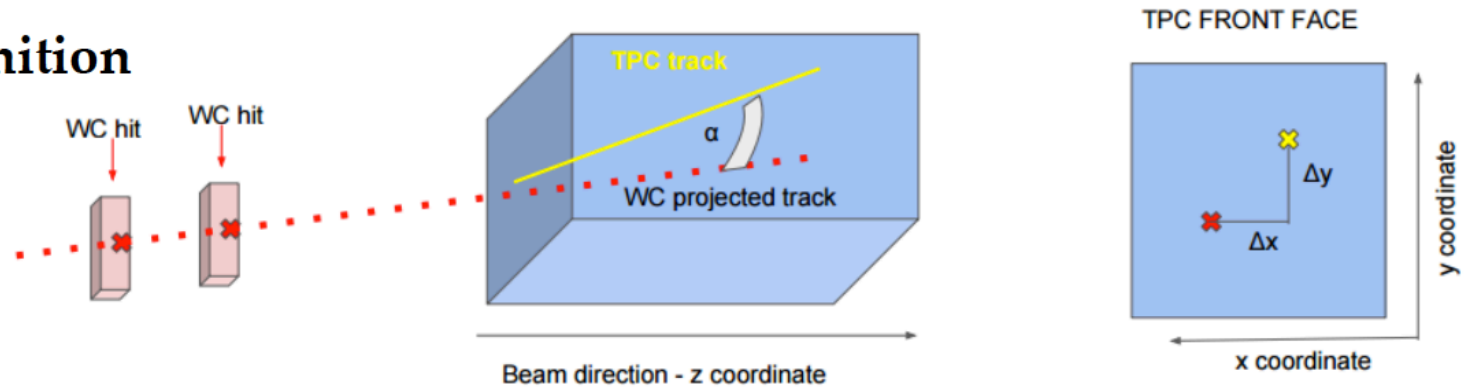




Event Selection

- ✓ A successful matching requires one reconstructed TPC track in the first 2 cm of the TPC length and only one WC – TPC track pair with low ΔX, ΔY and α values.

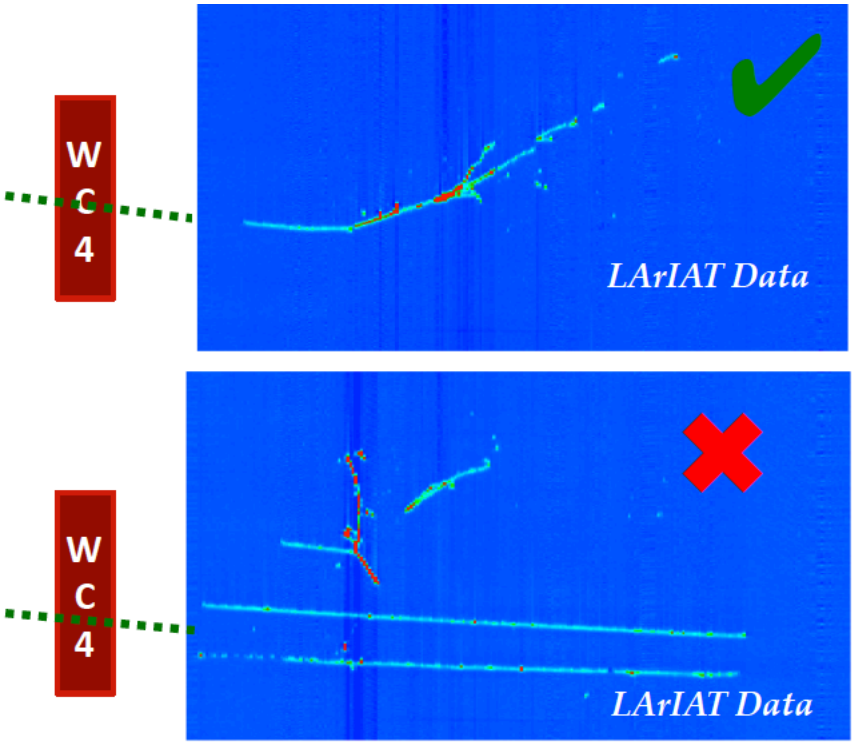
Match definition



-4 cm $< \Delta X <$ 6cm
-5 cm $< \Delta Y <$ 5 cm
$\alpha < 10^{o}$

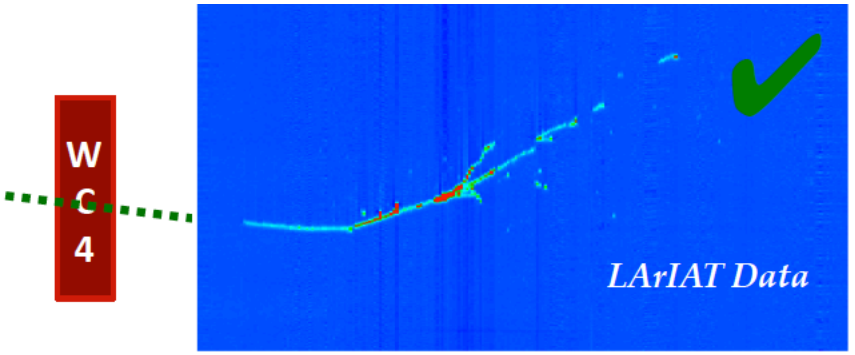
Event Selection

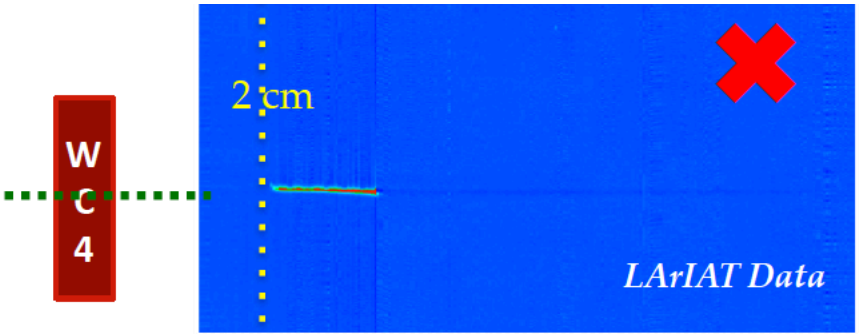
- ✓ We keep only events with a single beamline and TPC match: if more than 1 TPC track matches the WC track, the event is rejected.

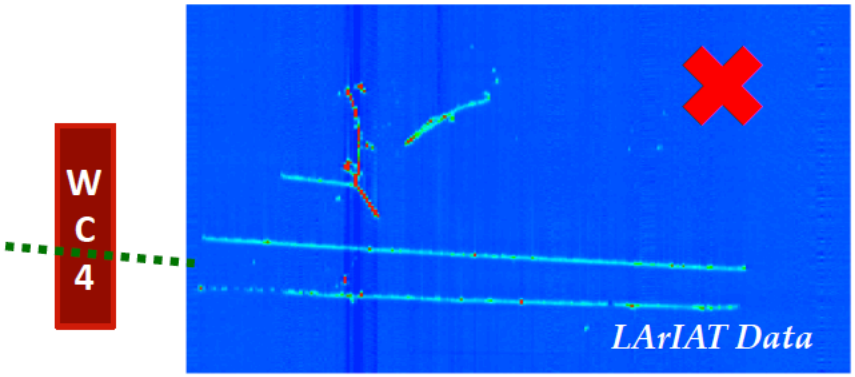


Event Selection

- ✓ We keep only events with a single beamline and TPC match: if more than 1 TPC track matches the WC track, the event is rejected.
- ✓ Events are also rejected if the TPC track starts more than 2 cm from the front face of the TPC.

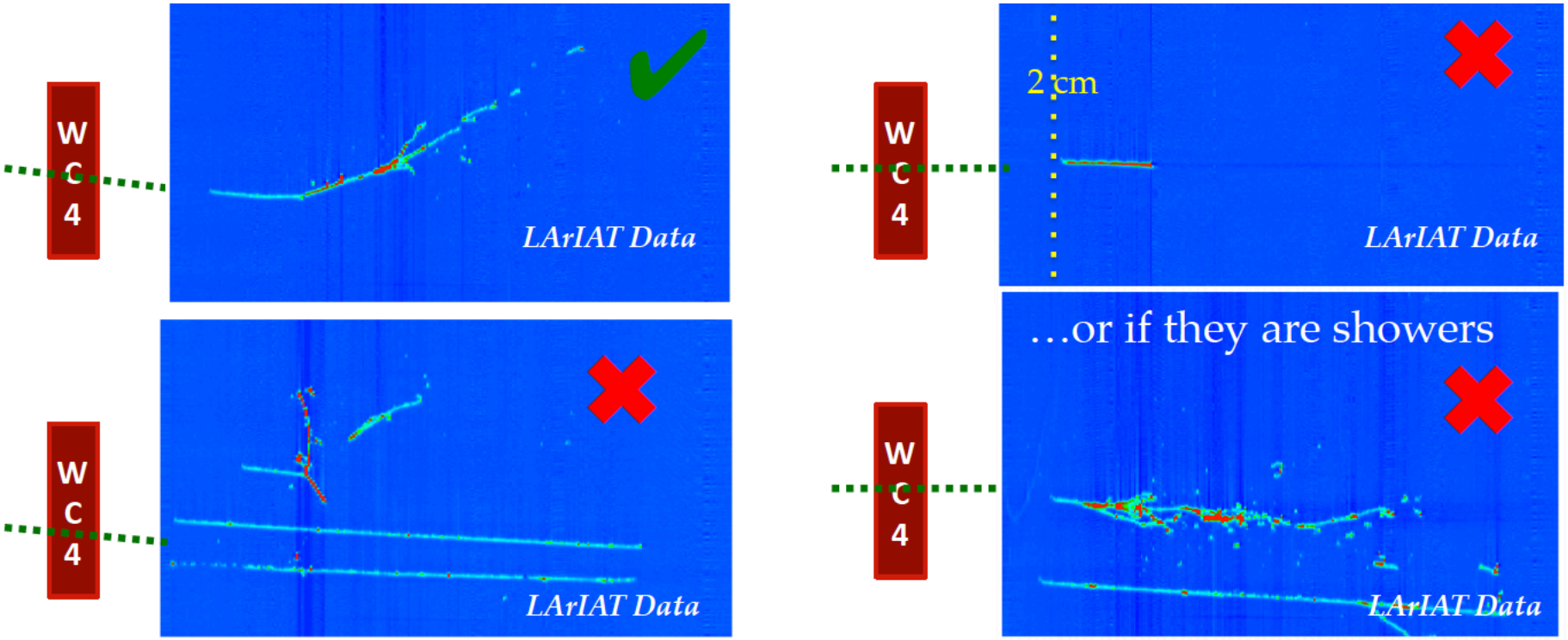






Event Selection

- ✓ We keep only events with a single beamline and TPC match: if more than 1 TPC track matches the WC track, the event is rejected.
- ✓ Events are also rejected if the TPC track starts more than 2 cm from the front face of the TPC or if they are showers.



Interaction probability

- We use the momentum measured by the WC to calculate the candidate initial kinetic energy K_i as

$$K_I = \sqrt{p^2 + m^2} - m - E_{Flat}$$

- E_{Flat} is the energy loss due to material upstream of the TPC (argon, steel, beamline detectors).

- The K_n at point n of the TPC track is calculated by subtracting the track deposited energy from the K_I at the TPC front face.

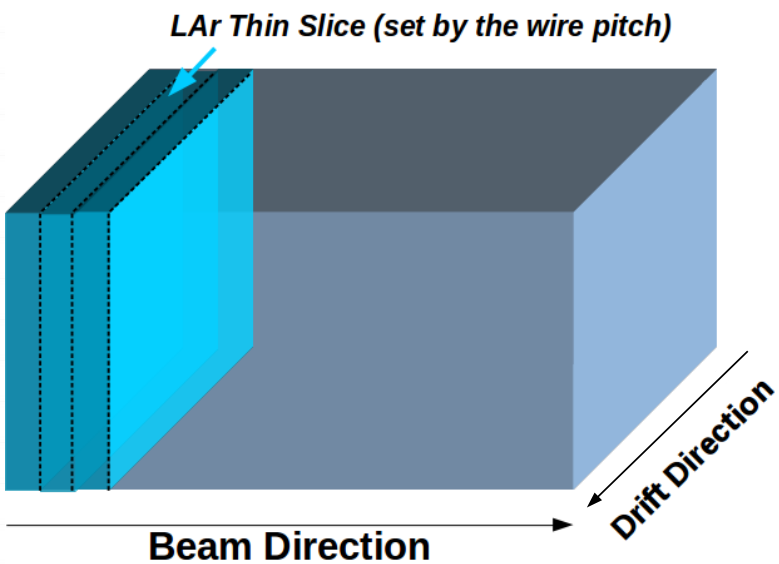
$$K_n = K_I - \sum_{i=1}^{n} \left(\frac{dE}{dx} \right)_i \times \delta X$$

Thin sliced method

- We divide the LAr volume in thin slabs and measure the probability of interacting in a slab δX as the ratio of the number of interacting particles to the number of incident particles.

$$\frac{N_{Interacting}}{N_{Incident}} = P_{Inter} = 1 - P_{Surv} = 1 - e^{-\sigma_{TOT}\rho\delta X} \approx 1 - (1 - \sigma_{TOT}\rho\delta X + \ldots)$$

$$\sigma_{TOT} \approx \frac{1}{\rho X} P_{Inter} = \frac{1}{\rho X} \frac{N_{Interacting}}{N_{Incident}}$$

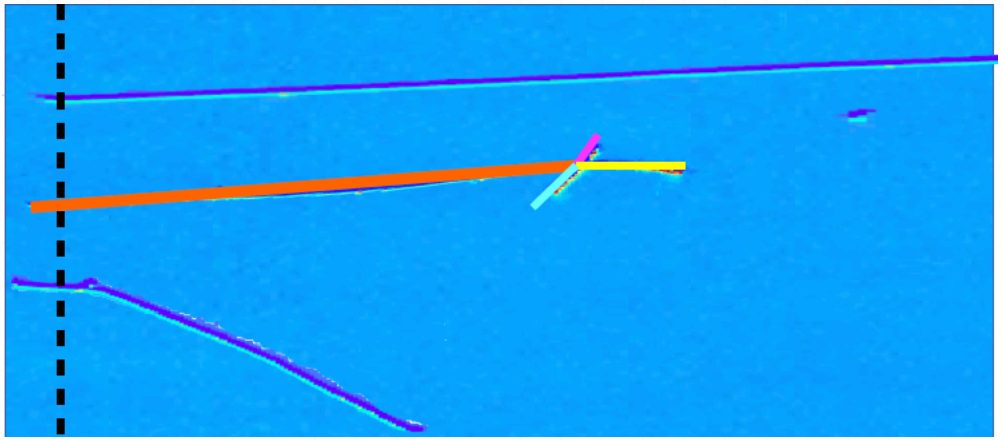


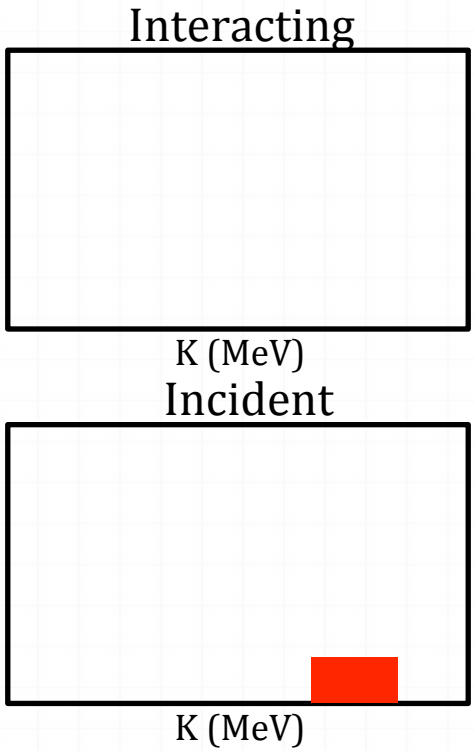
Thin sliced method

- ✓ The slice represents the distance between each 3D point in the track .
- ✓ Is the slice the end of the track ?

NO: Calculate the kinetic energy at this point and fill the "incident" histogram.

$$K_{Slice} = K_I - \sum_{i=1}^{n} \left(\frac{dE}{dx} \right)_i \times \delta X$$





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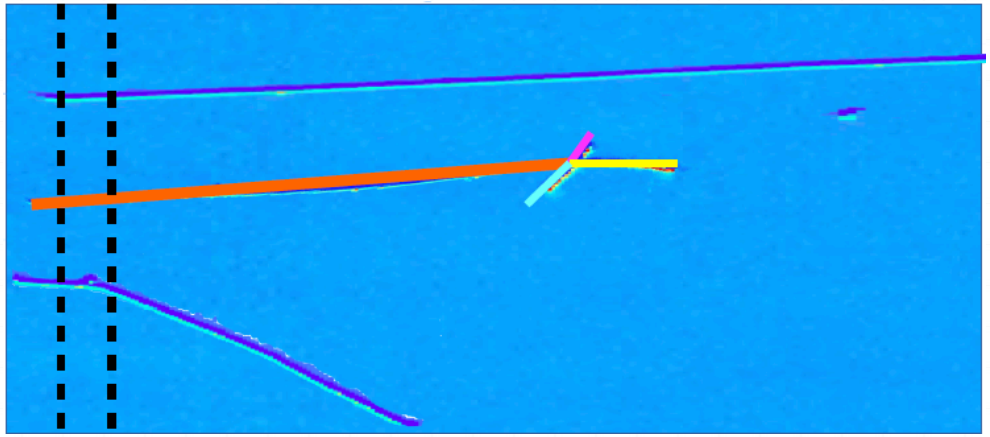

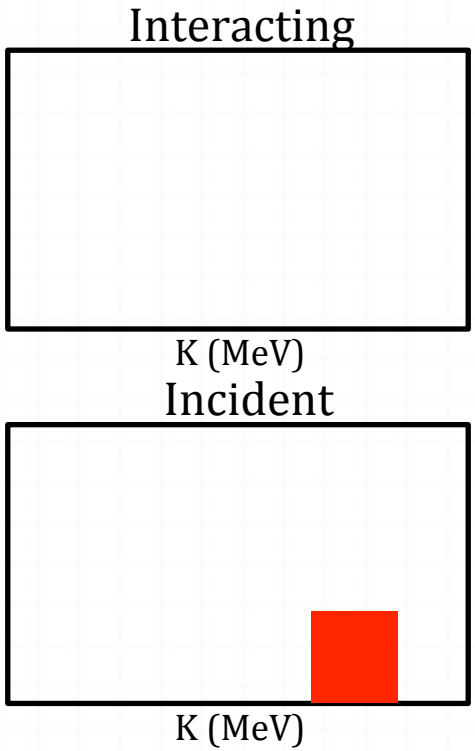

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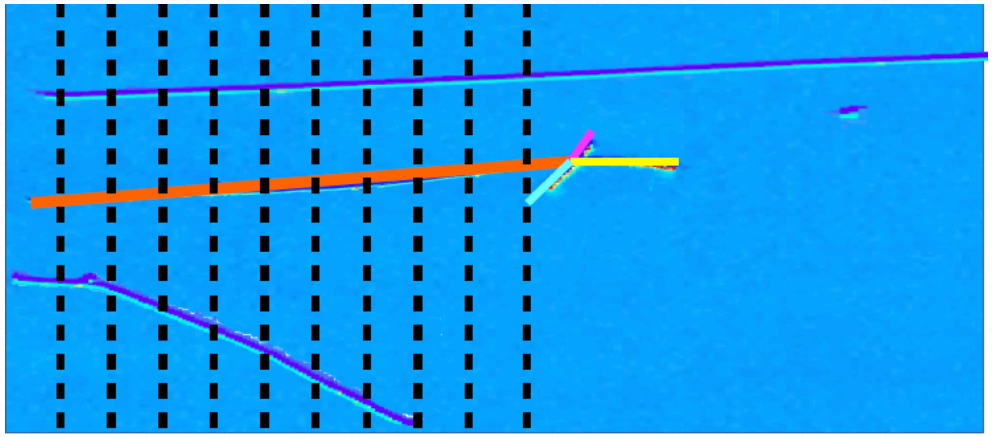
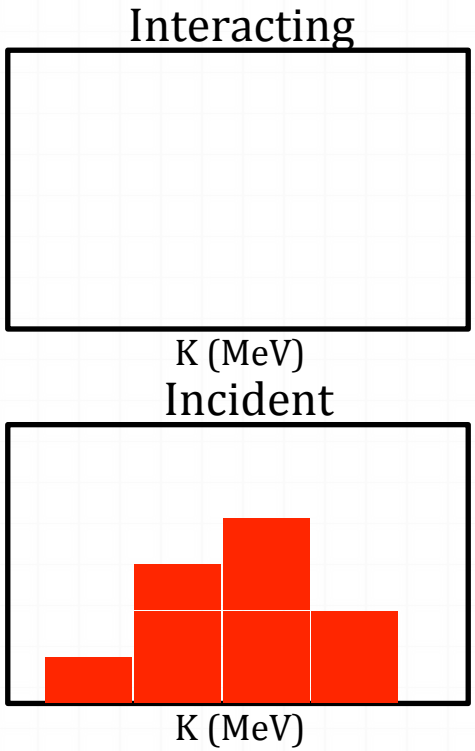


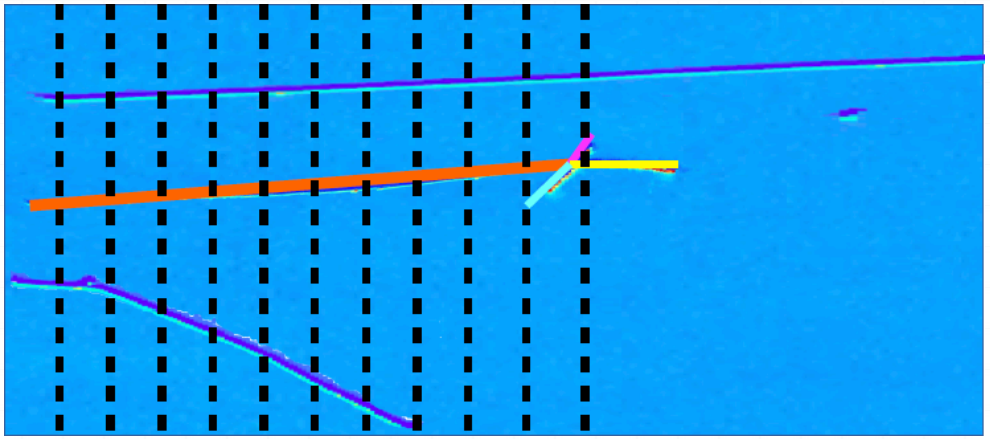


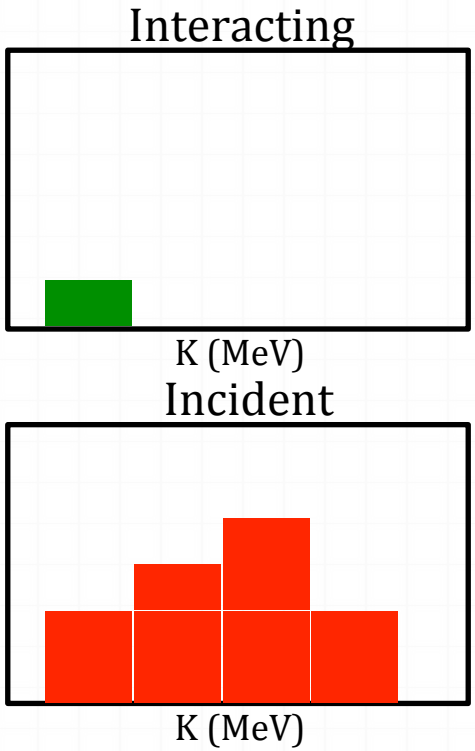
Thin sliced method

- ✓The slice represents the distance between each 3D point in the track .
- ✓Is the slice the end of the track ?

YES: Calculate the kinetic energy at this point and fill the "interacting" and the "incident" histograms.

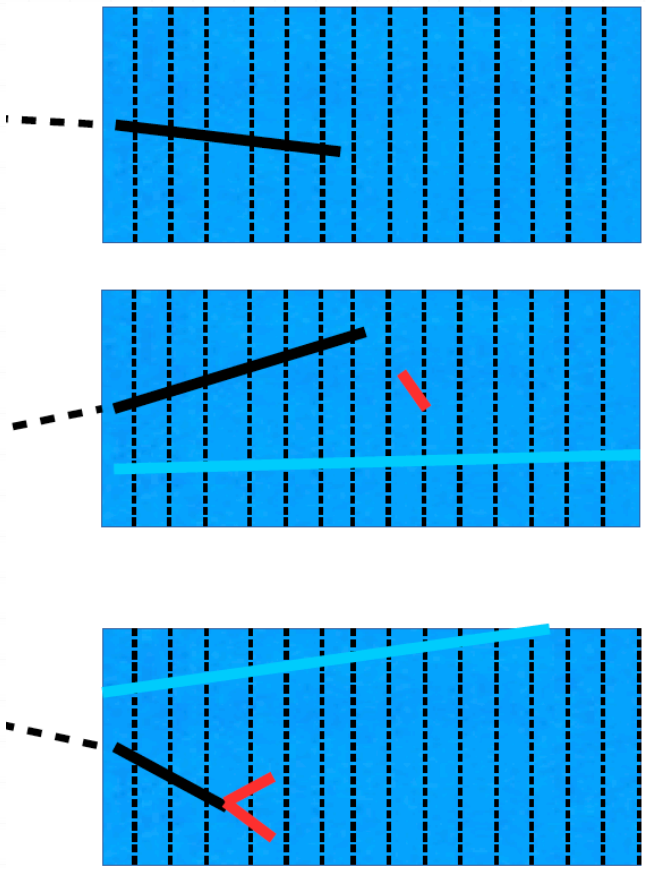
$$K_{Slice} = K_I - \sum_{i=1}^{n} \left(\frac{dE}{dx} \right)_i \times \delta X$$

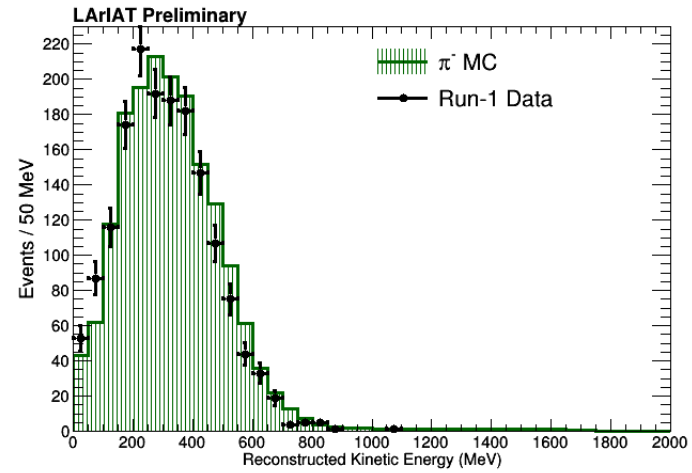


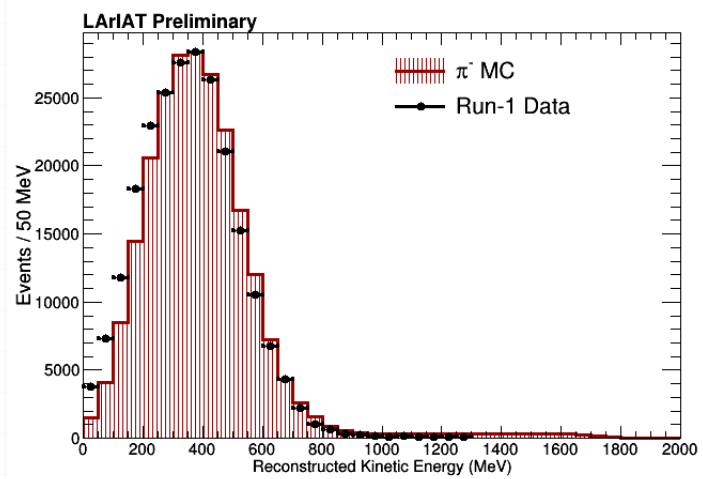


Thin sliced method

- ✓ Repeat for each WC to TPC matched track, disregarding any other activity occurring in the detector.

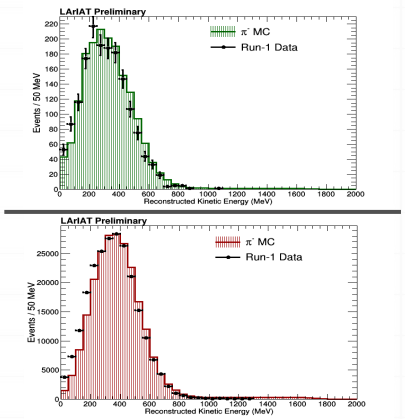




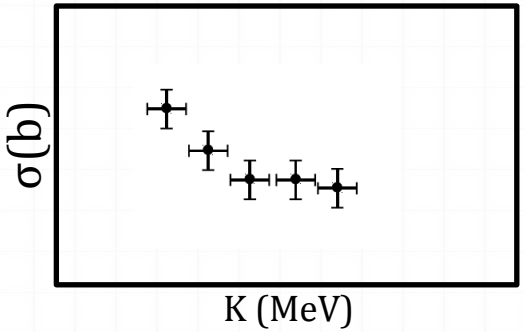


Cross - section calculation

- ✓ Finally we take the ratio of the two histograms and calculate the cross section.



$$= \frac{1}{nX}$$



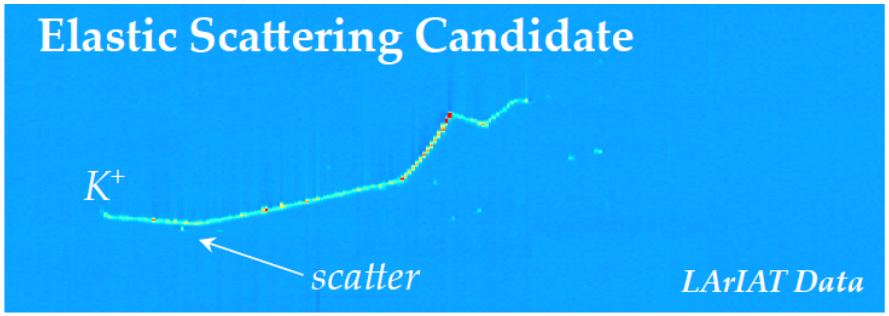
- ✓ Two particle species are under study:
  - Kaons
  - Pions

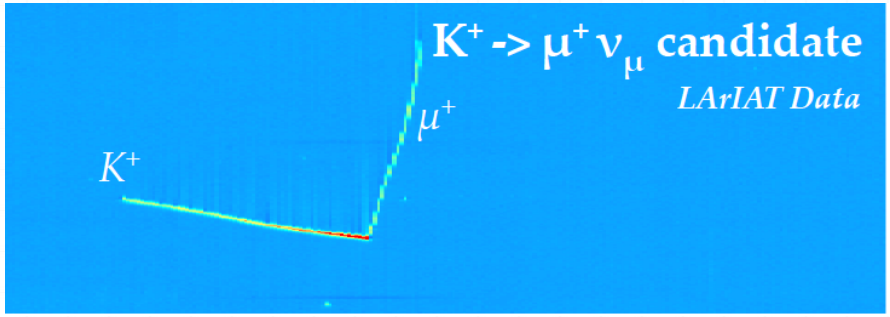
Kaons

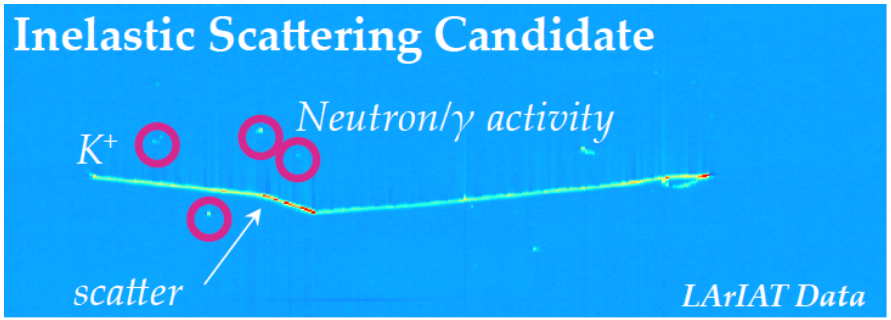
Total cross-section and background

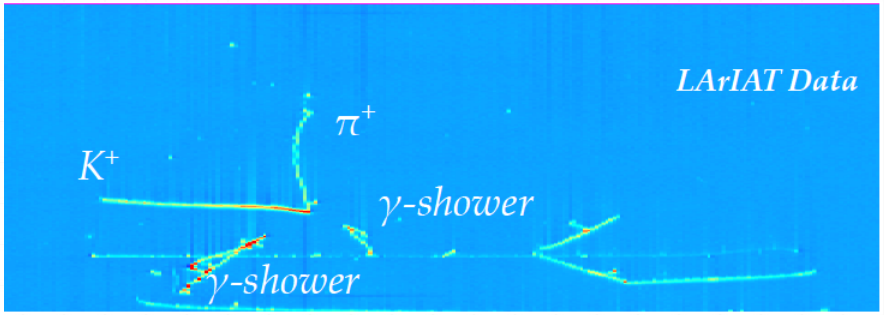
$$\sigma_{TOT} = \sigma_{Elastic} + \sigma_{Inelastic}$$

Kaon decay



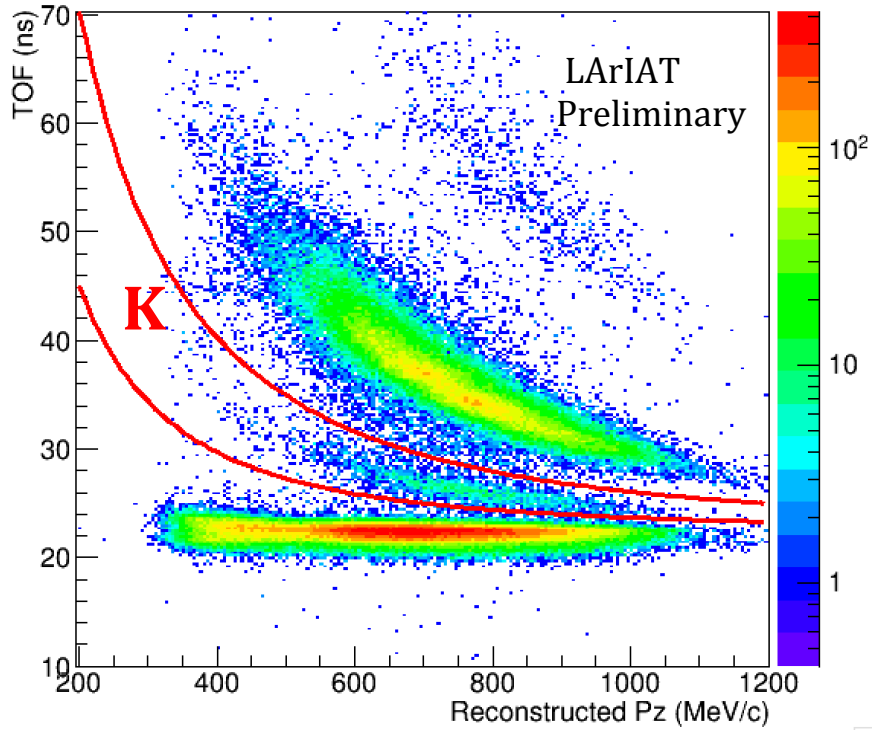


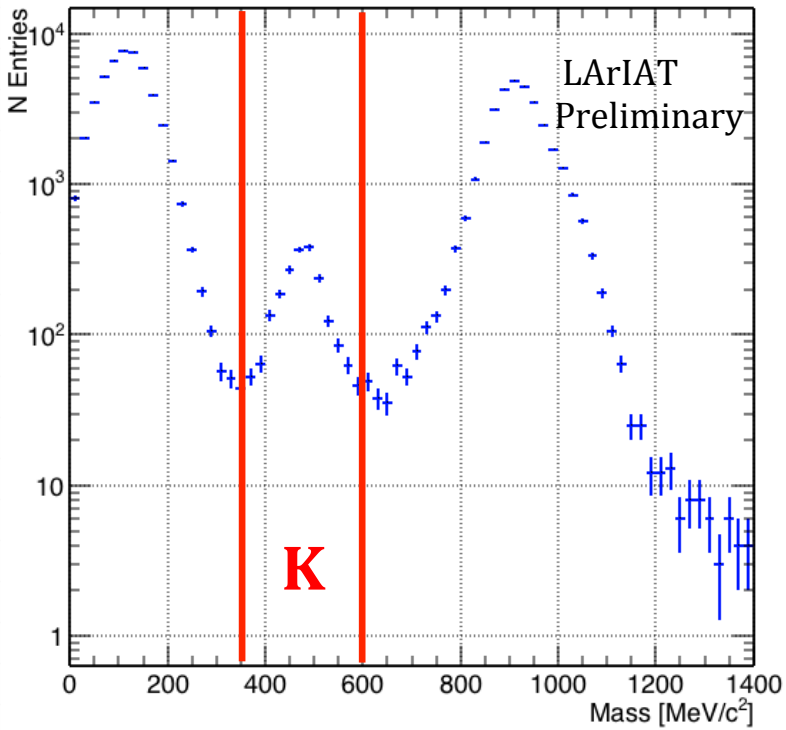




Event selection

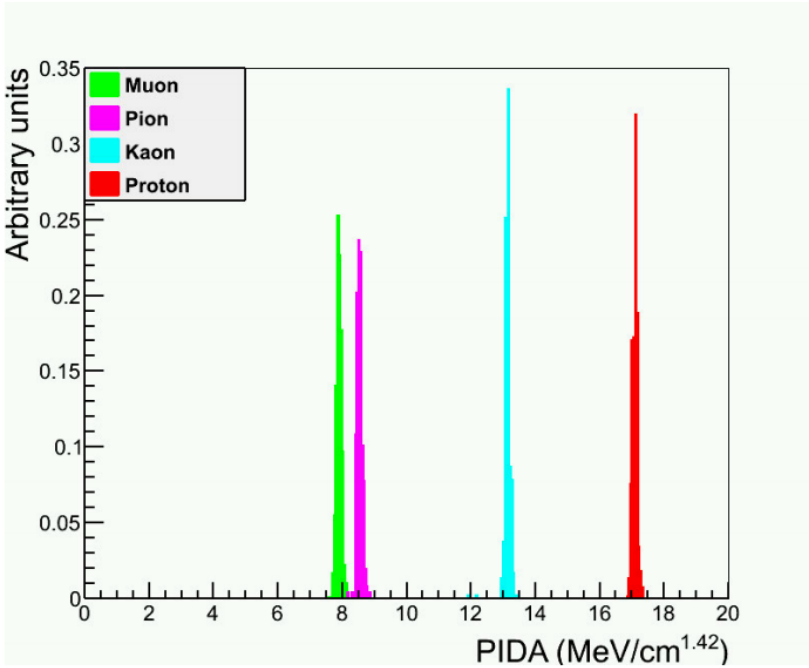
- ✓ Preliminary selection : 340 MeV/c^2 < Mass < 600 MeV/c^2;
- ✓ ~ 2000 Kaon candidates in the final sample (Run II only).

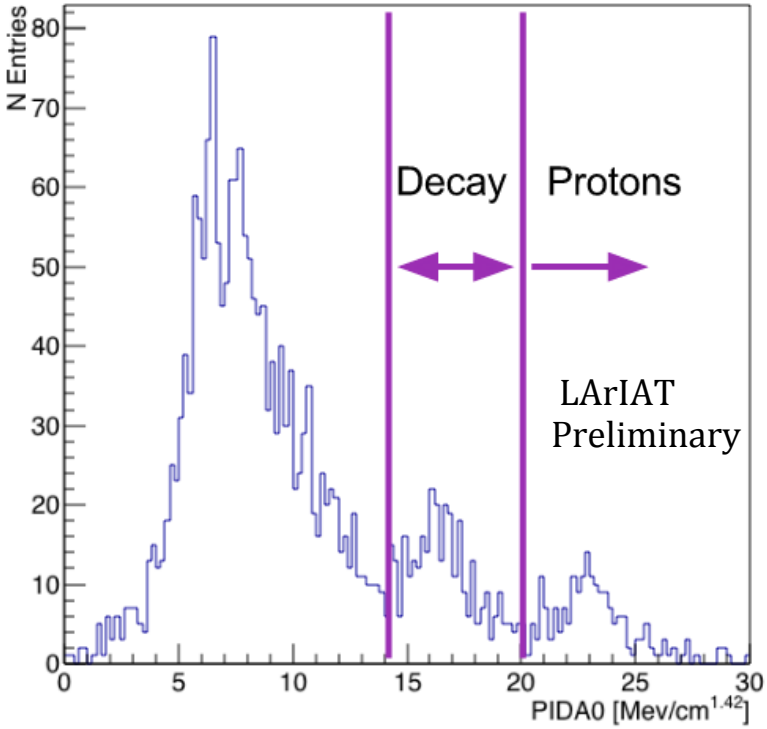




Kaon decay

- ✓ Since most of the Kaons decay at rest, the presence of a Bragg peak can be used to discriminate between decay and hadronic interaction.
- ✓ Particle IDentification Algorithm (PIDA) is a LArTPC based technique developed by ArgoNeuT (ArgoNeut Coll., JINST 8 2013 P08005), that parameterizes the Bethe-Bloch energy deposition curve.

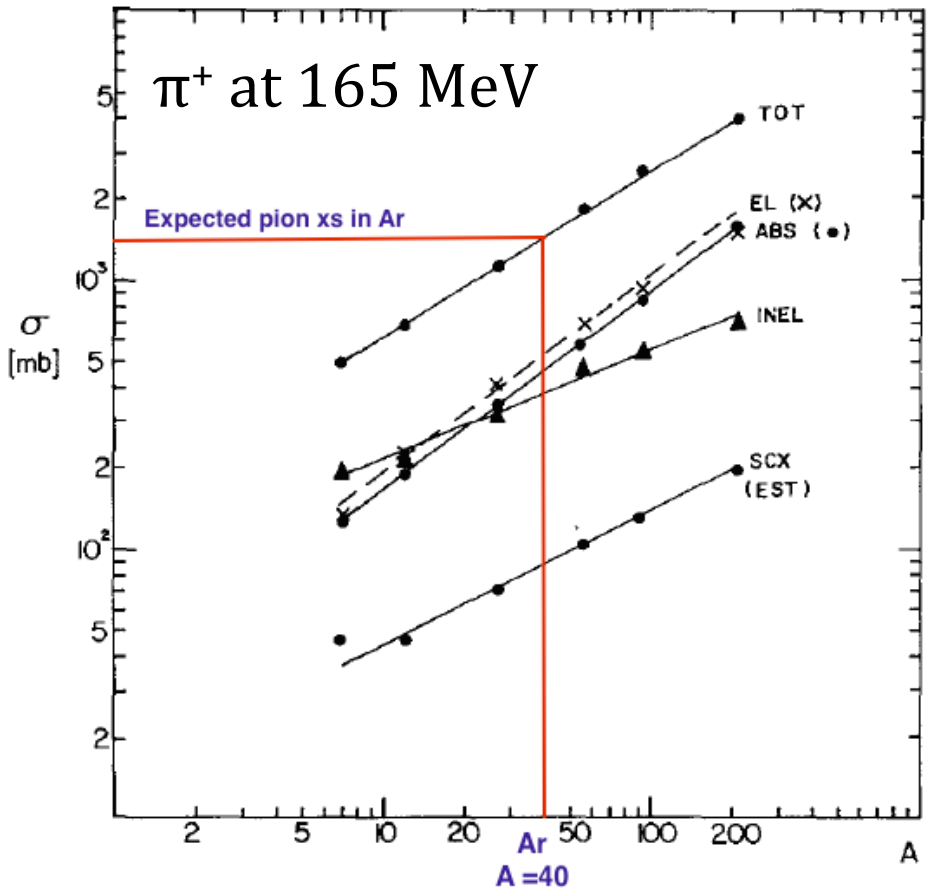




Pions

Total cross-section

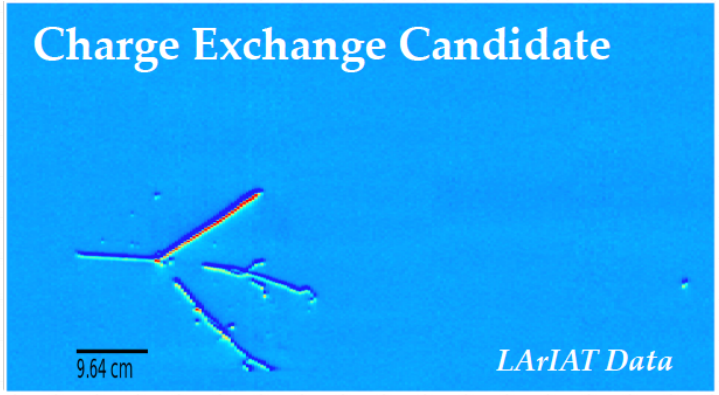
D. Ashery et al. Phys. Rev. C23, 2173 (1981)

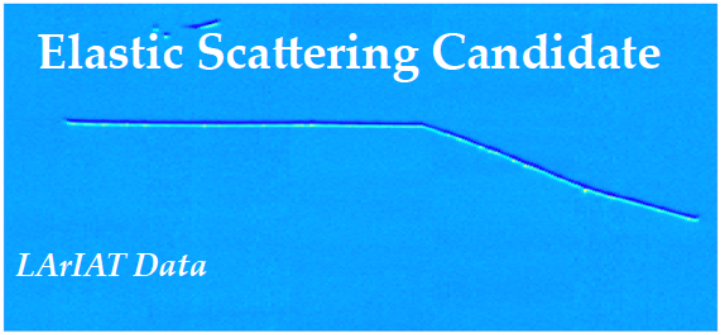


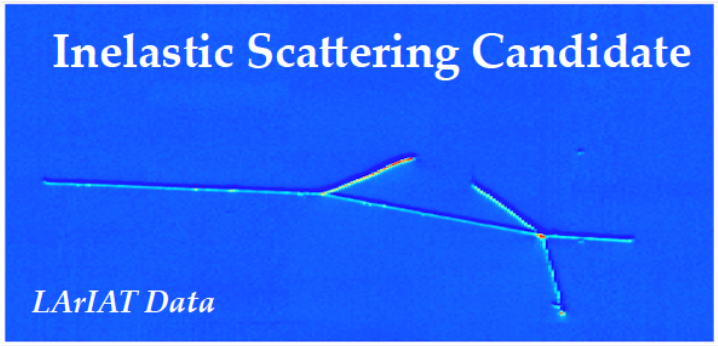
- ✓ No measurement for π cross section in liquid argon before LArIAT.
- ✓ Predictions come from interpolation between lighter and heavier nuclei.

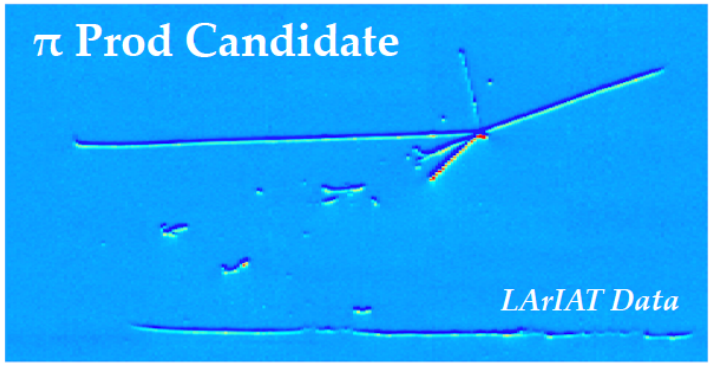
Total cross-section

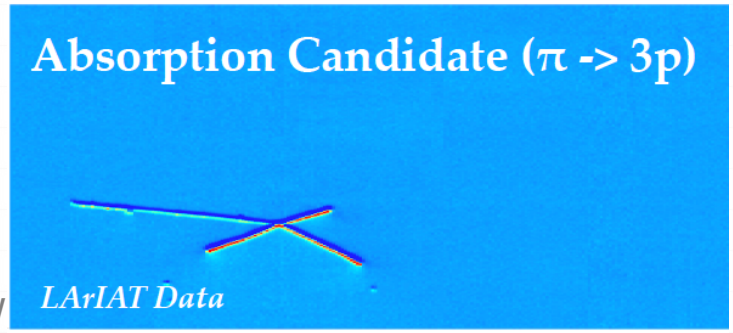
$$\sigma_{TOT} = \sigma_{Elastic} + \sigma_{Inelastic} + \sigma_{Ch-exc} + \sigma_{Absorb} + \sigma_{\pi-prod}$$





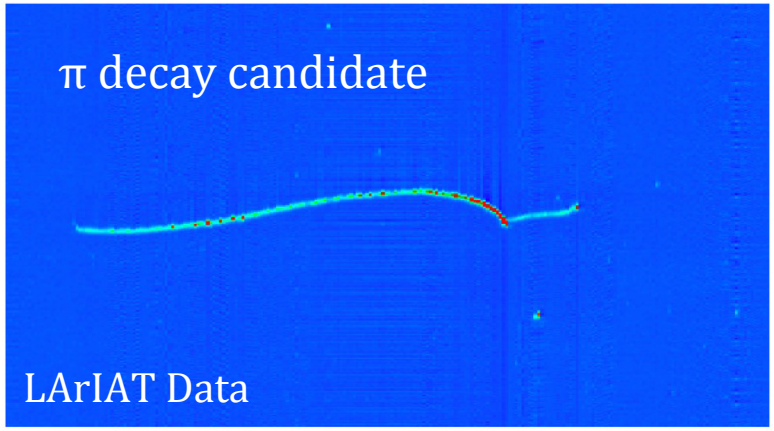


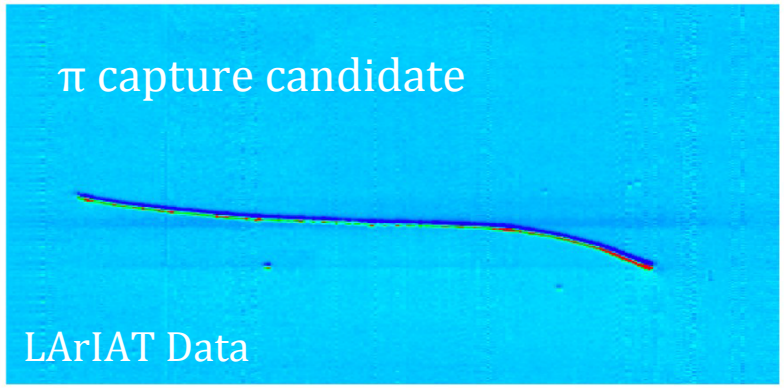


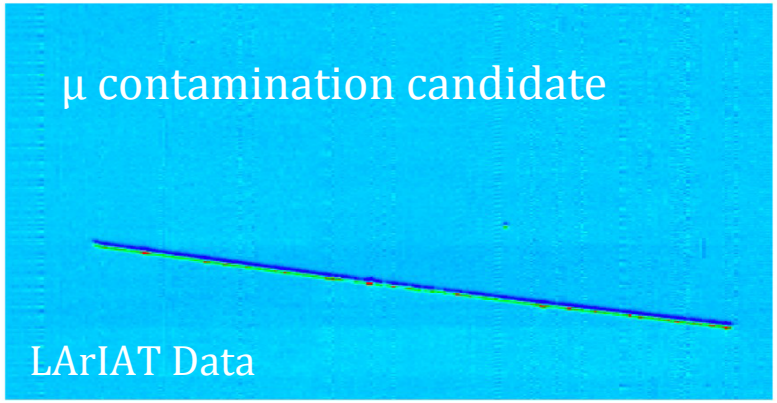


Background contamination

✓ Background process are currently included in the analysis: they will be estimated and excluded.





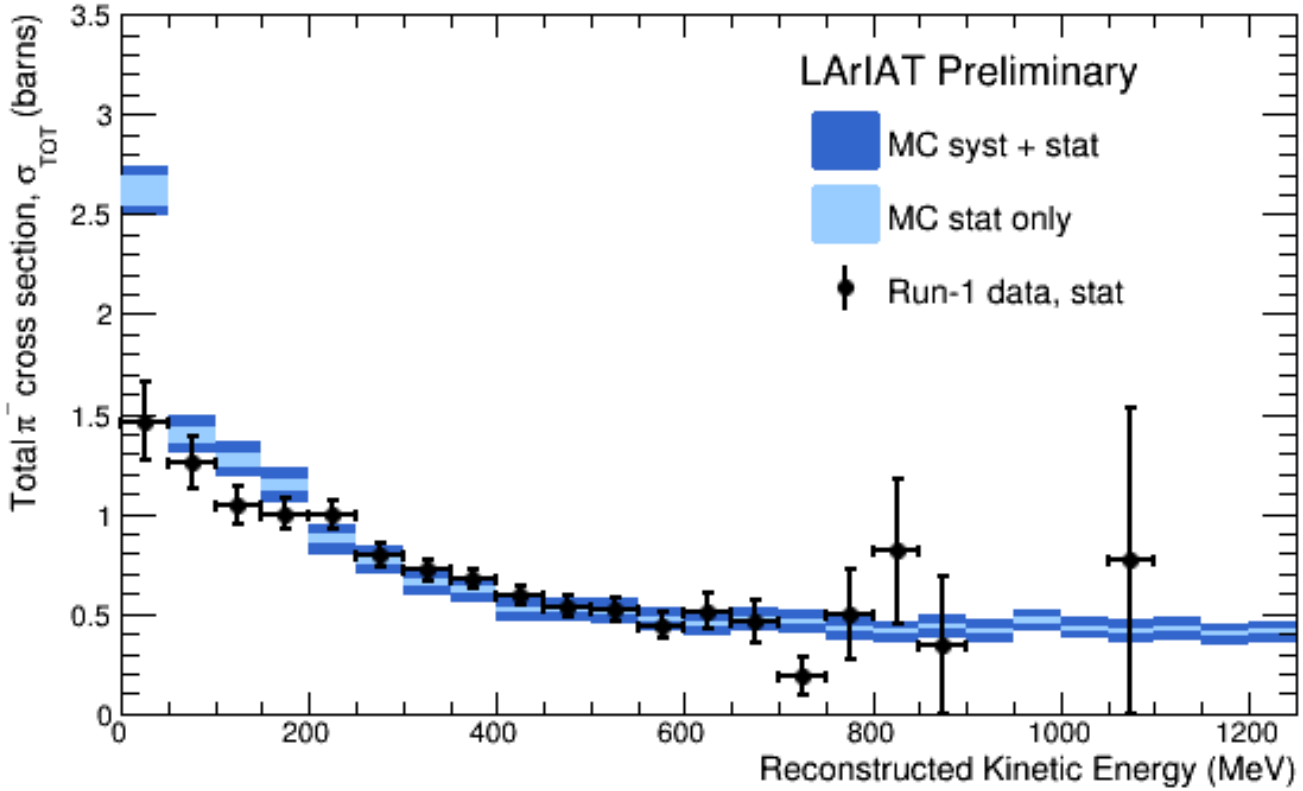


Event reduction table

Event Sample	Number of events
Data sample	32,064
π/μ/e ID by beamline	15,448
Requiring an upstream TPC track within z < 2cm	14,330
< 4 tracks in z < 14 cm	9,281
WC/TPC track matching	2,864
Shower rejection filter	2,290

	π	e	γ	μ	K
Beam composition before cuts	48.4%	40.9%	8.5%	2.2%	0.035%
Selection efficiency	74.5%	3.6%	0.9%	90.0%	70.7%

Pion-Ar Cross Section



✓ Systematic considered:

- dE/dx calibration : 5%
- E loss prior to the TPC: 3.5%
- through going μ: 3%
- WC momentum uncertainty: 3%

Conclusion

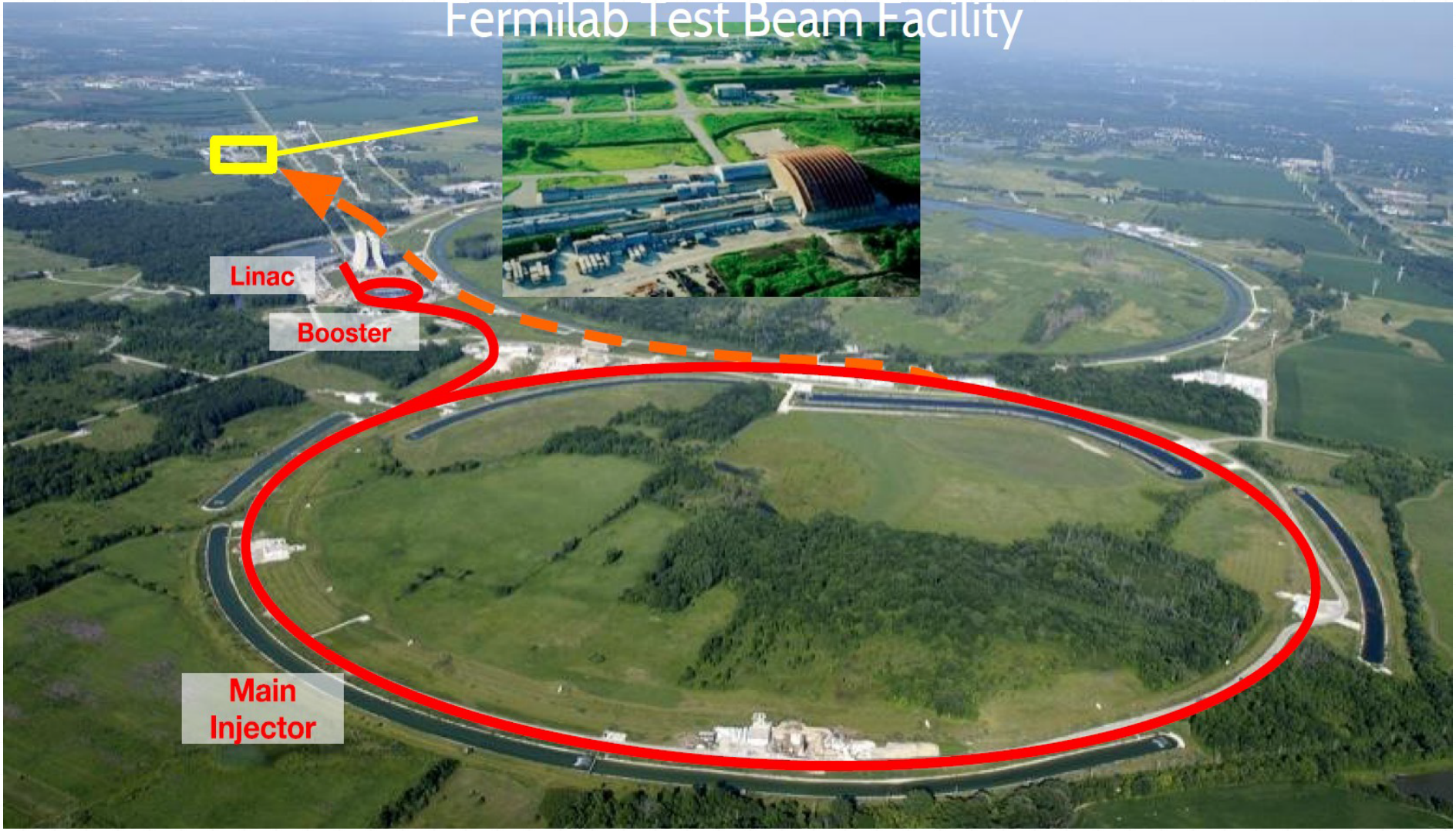
- ✓ Total Pion cross section on liquid argon never before measured!

- ✓ Work on:
  - kaon cross section;
  - assessment of systematic uncertainties;
  - improvement of the energy corrections;

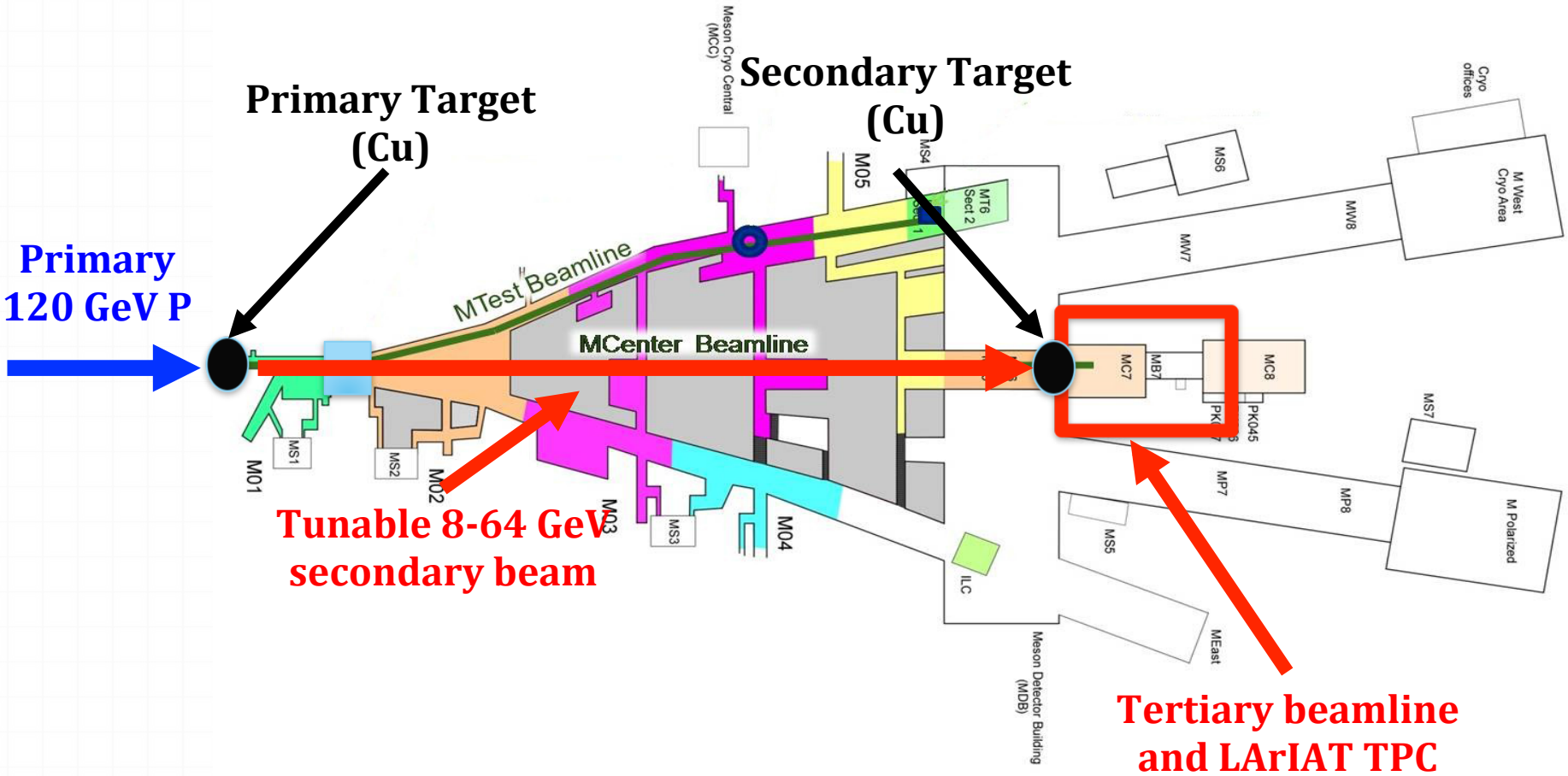
- ✓ First results in:
  - identification of pion and kaon hadronic interactions in LAr;
  - automatic reconstruction of pion and kaon events.

Back up

LArIAT Primary Beamline



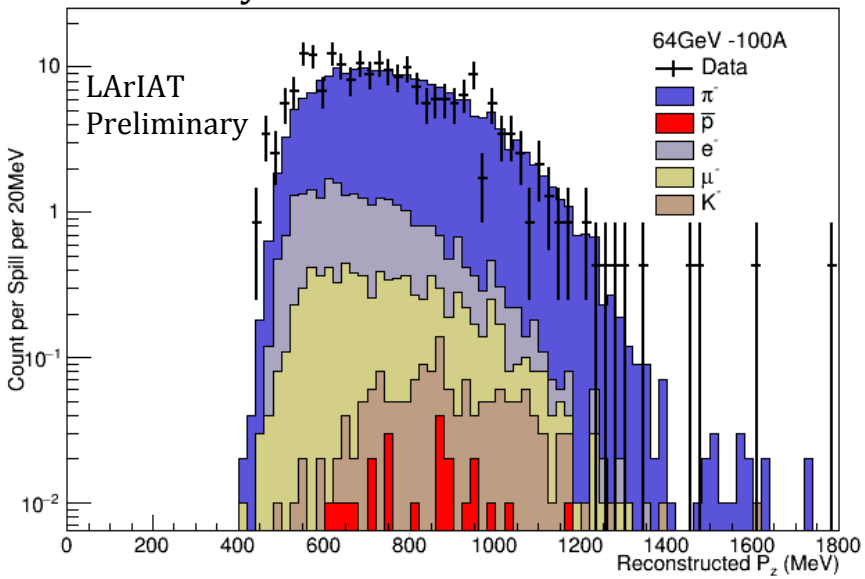
LArIAT Secondary Beamline

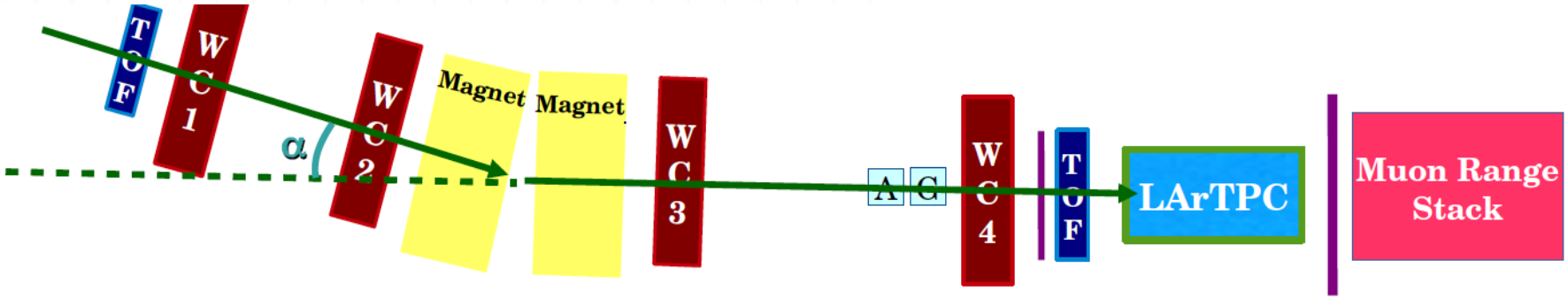


MWPCs and bending magnets

- ✓ MWPCs + bending magnets allow to reconstruct particles momentum before entering the LArTPC.
- ✓ WC pairs used to define particle tracks before and after the magnets.
- ✓ The angle α between the two tracks determines the momentum reconstruction.
- ✓ Charged particle beam~200 - 1400 MeV/c.

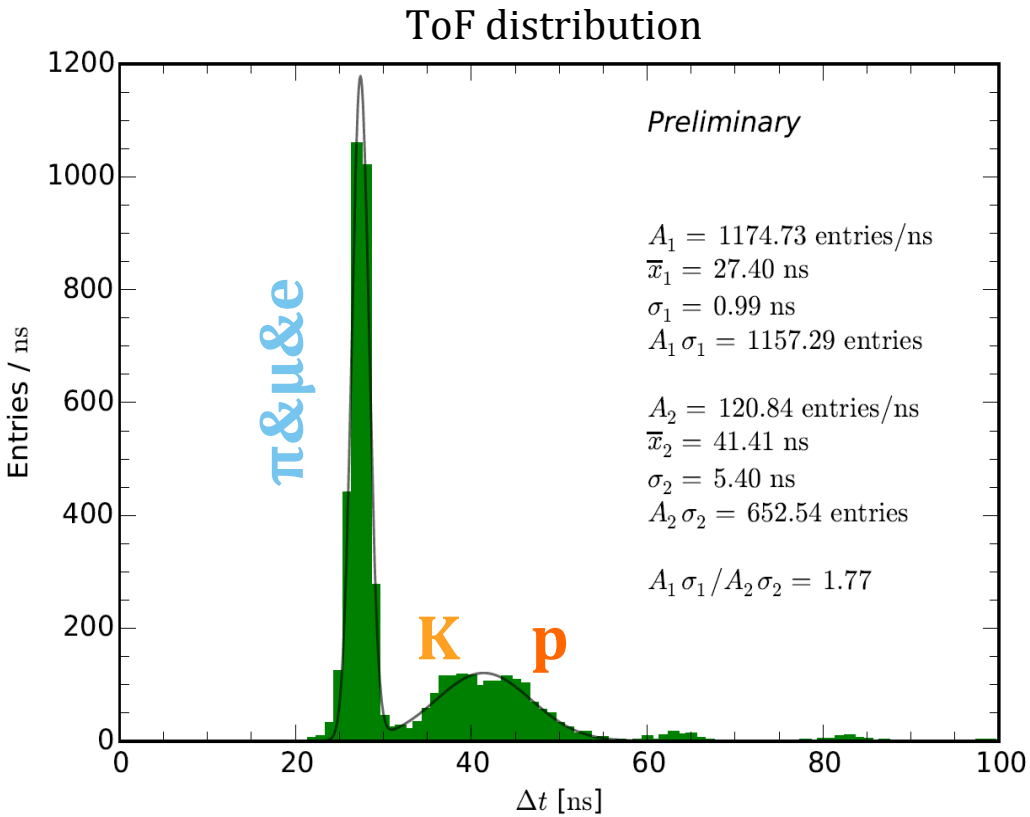
Tertiary Beam Particles Momentum





Time Of Flight detectors

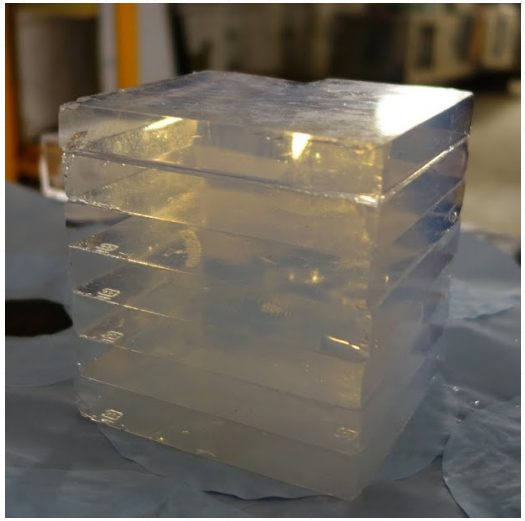
- ✓ 2 scintillator counters with 1 ns sampling provides TOF.
- ✓ Work done on hit time determination and hit matching between the two scintillators allowed us to improve the TOF resolution to less than one ns.
- ✓ The development of a new pulse fitting algorithm is currently underway:
  - Use the shape of the pulse to improve the time resolution.
  - Use tracking chambers to find impact point on scintillators.

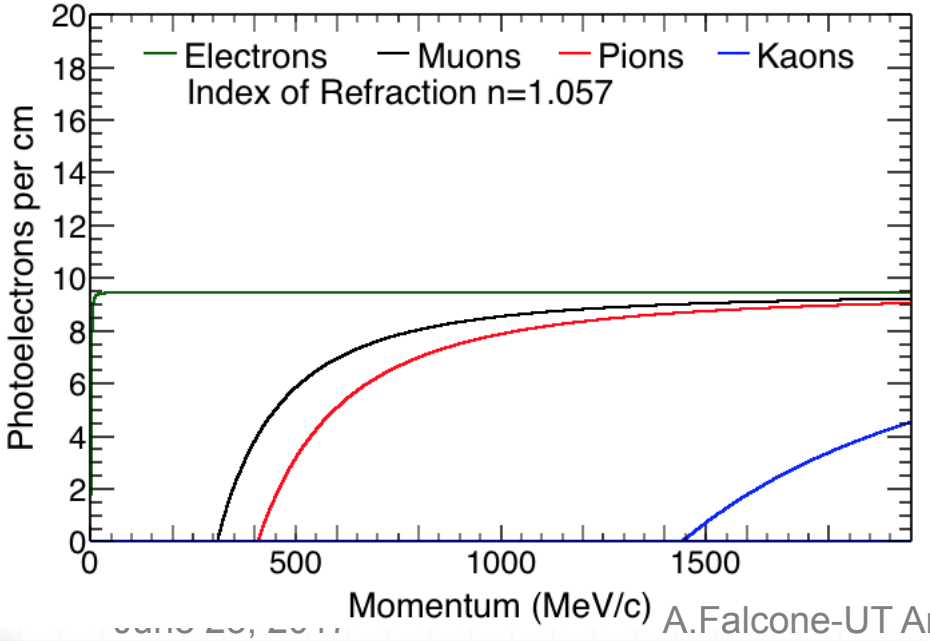


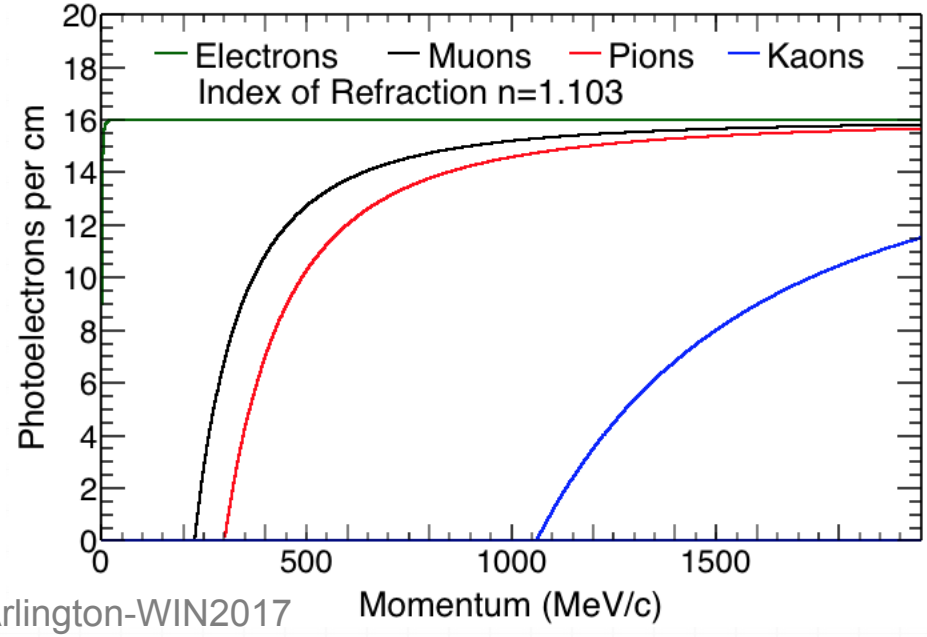
AeroGel

- Aerogel threshold Cherenkov detector in the LArIAT beam line is to separate muons and pions in a momentum range, where muons emit Cherenkov radiation while pions do not.

p (MeV/c)	n = 1.103	n = 1.057
200 - 300	eμπ	eμπ
300 - 400	eμπ	eμπ

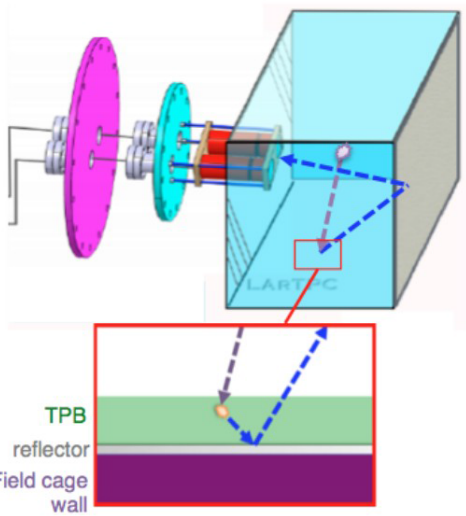


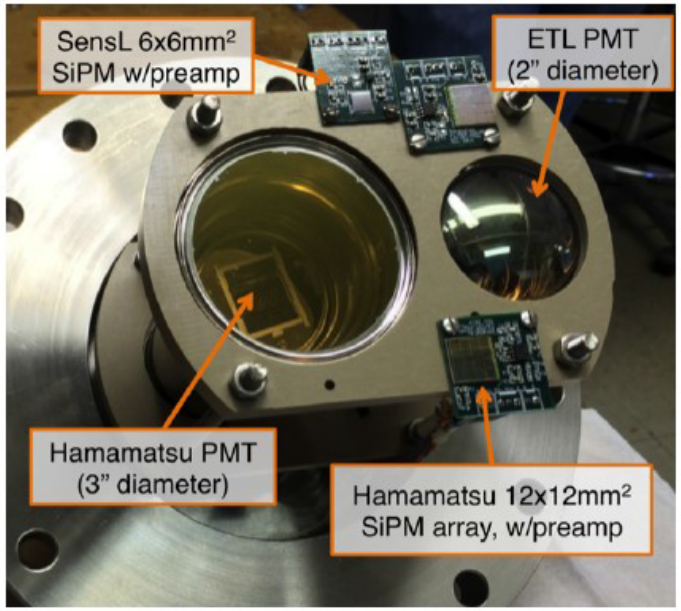


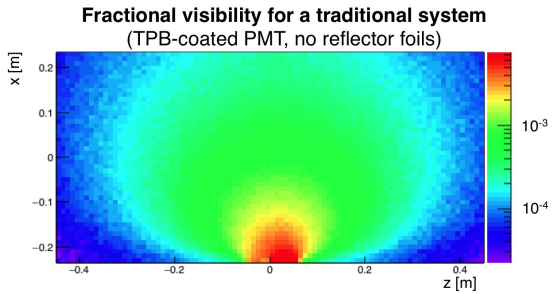


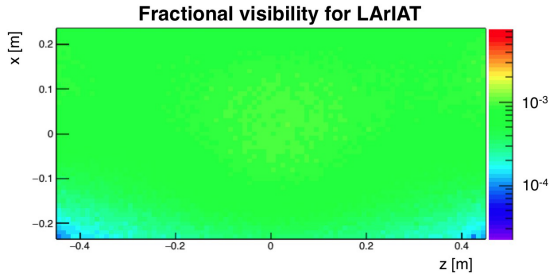
Light collection System

Reflector-based solution (LArIAT)



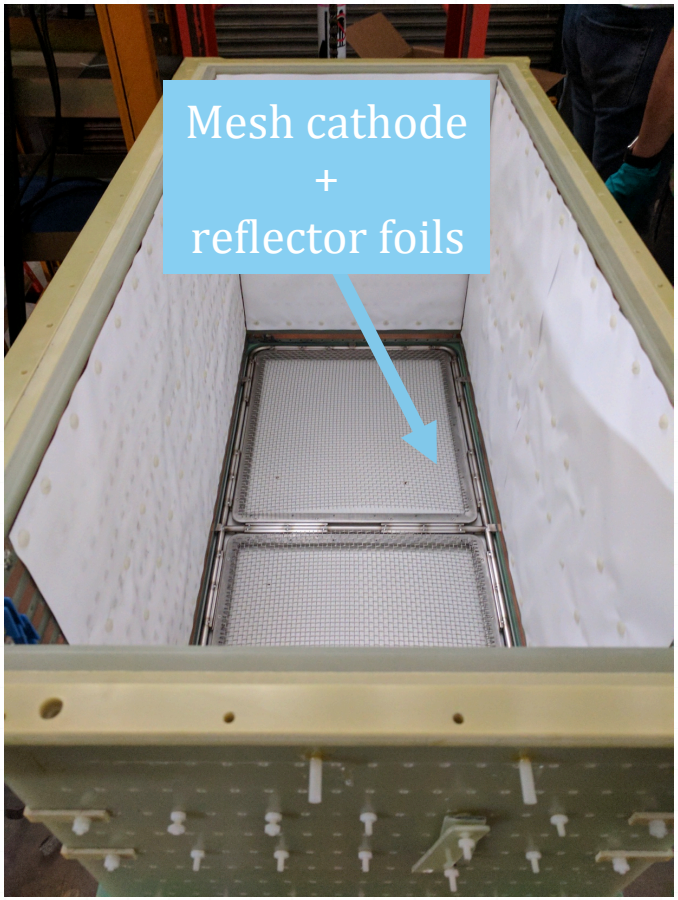


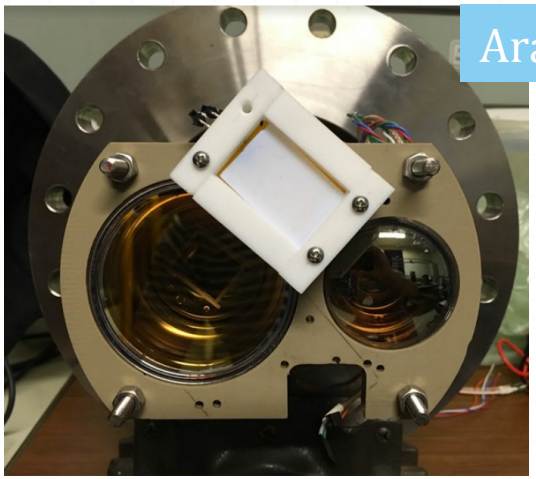


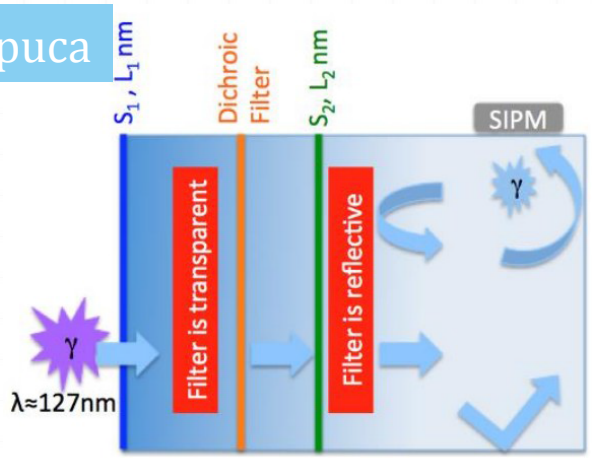


- ✓ Wavelength shifting (evaporated) reflector foils to shift the scintillation light into the visible spectrum.
- ✓ R&D for ν experiments, technique borrow from dark matter experiments.
- ✓ Higher and more uniform light yield.

Light collection System

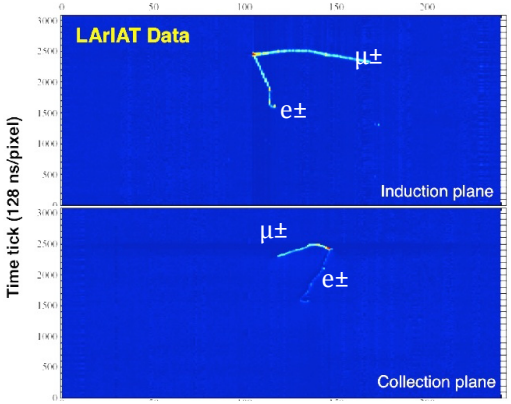


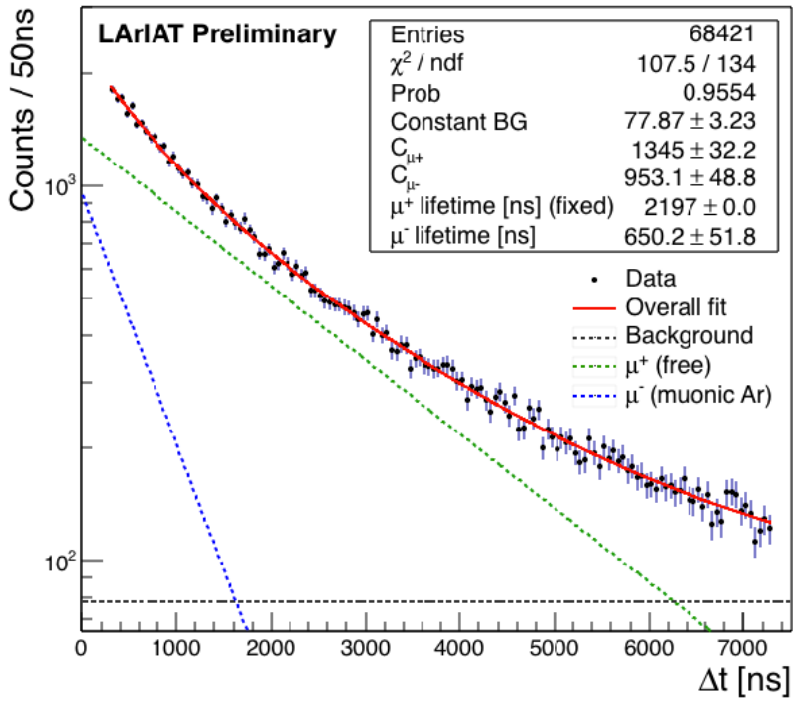




- ✓ Reflector foils now also over the cathode: improved light yield and collection uniformity.
- ✓ Arapuca light trap: use dichroic filters + 2 WLS. The readout 1 SiPM, with a much larger active surface.

Measure with light : Michel electron





- Michel electrons can be used for energy calibration, PID of stopping $\mu^{\pm}$.
- Stopping $\mu^{\pm}$ can decay to electron with τ_{free} = 2.2μs, but μ^- can also be captured by Ar nucleus with competing time constant τ_{capt}:

$$1/\tau_{\mu^-} = 1/\tau_{free} + 1/\tau_{capt}$$

$\tau_{\mu-}$ = 650 ± 52 ns from fit

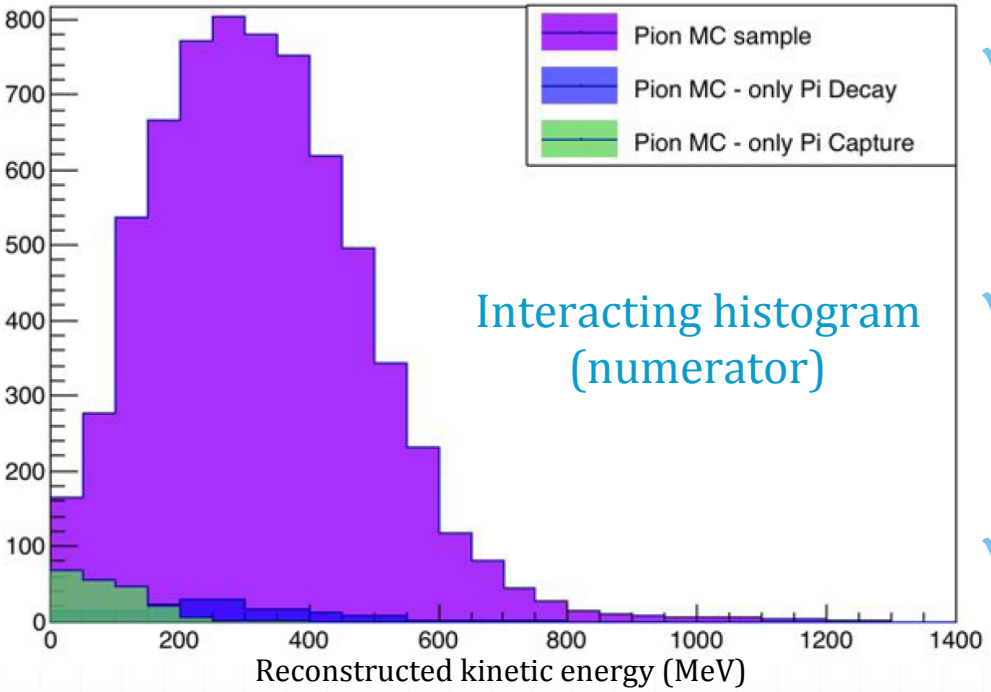
τ_{free} = 2197 ns (fixed)

τ_{capt} = 918 ± 109 ns

- Early results agree with recent measurement[1] (854 ± 13 ns) and theory prediction[2] (851 ns).

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

Background contamination



- ✓ ~ 9% π-capture and 2% π-decay in the interacting sample.
- ✓ ~ 34% crossing particles (π/μ) and 66% interacting particles in the TPC.
- ✓ ~10% muon contamination uniformly distributed (not shown here)