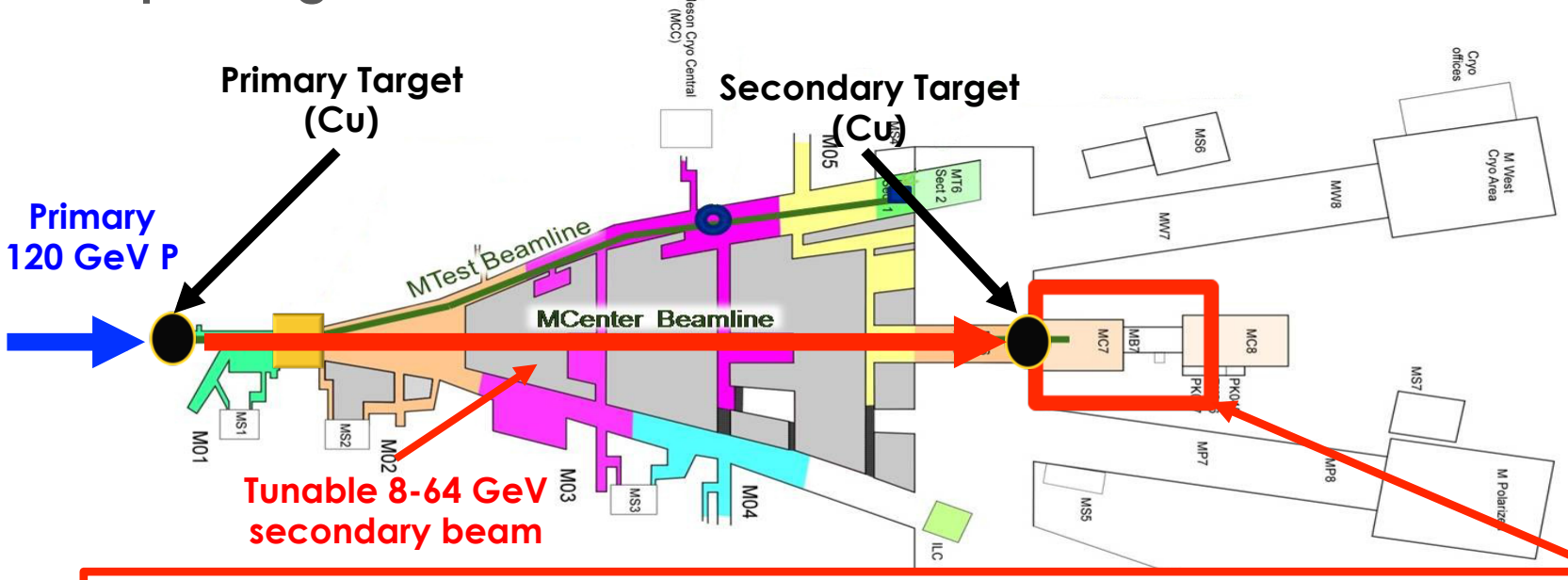
Inputs to LArIAT physics results

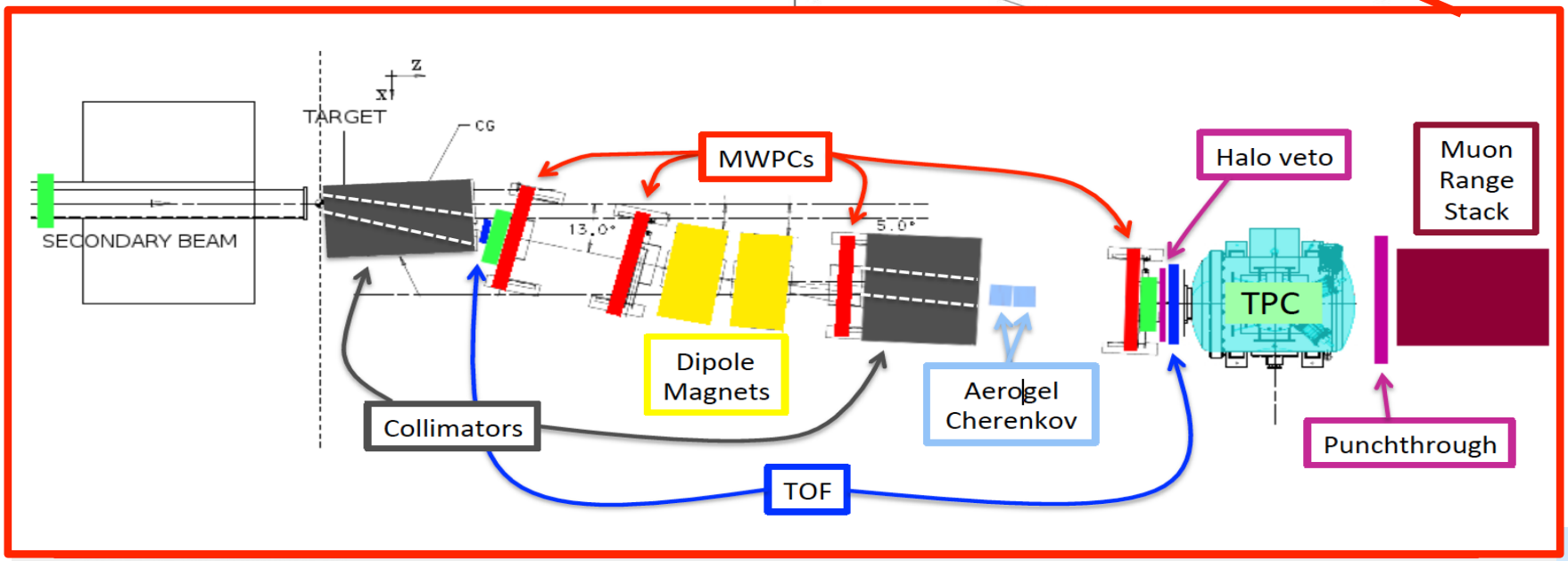
and lessons for broader LArTPC program

Andrea Falcone (UTA)
on behalf of LArIAT Coll.

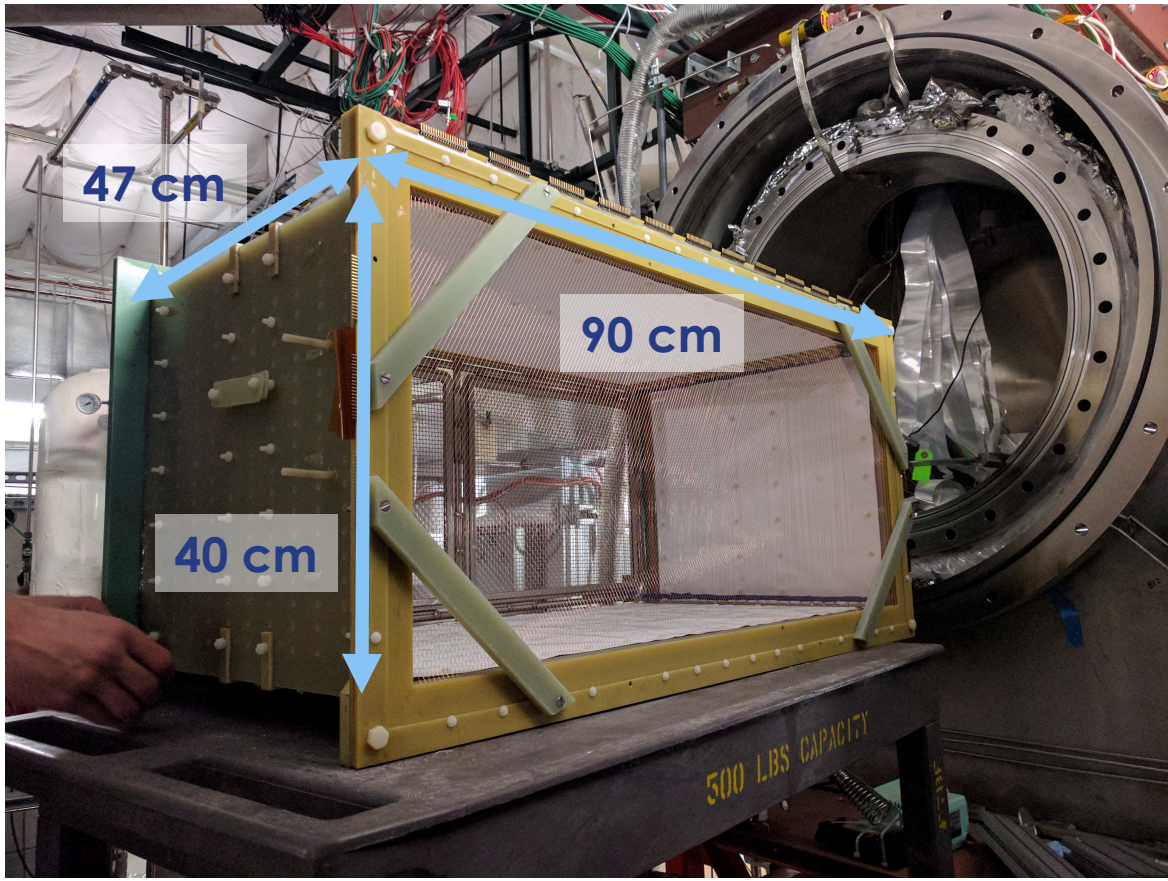
LArIAT

Liquid Argon In A Testbeam





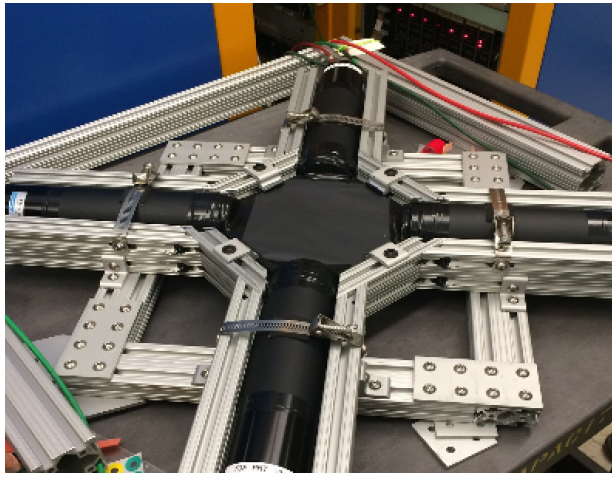
- **Liquid Argon In A Testbeam**
- Third run is ongoing.
- 200-1400 MeV/c charged particle beam momentum range:
  - Pions
  - Muons
  - Electrons
  - Kaons
  - Protons/Antiprotons
  - Deuterons



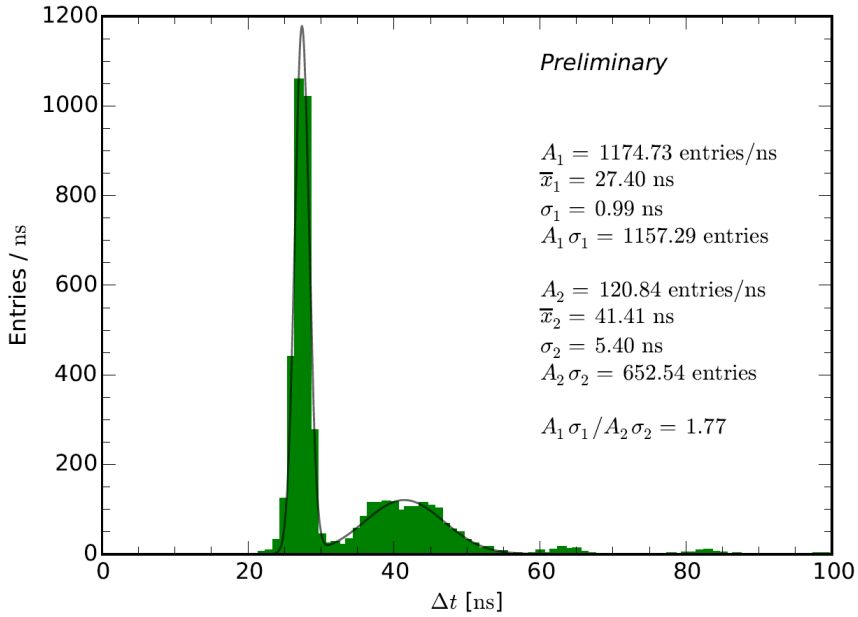
Testbeam detectors

Test beam detectors: TOF

- **2 scintillator counters** with 1 ns sampling provides TOF. Not very fast: impossible distinguish between light particles (e/ μ / π).
- 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, to bring our resolution down to the order **of few hundreds of ps**.
- Use the **shape of the pulse** to improve the time resolution.
- Use tracking chambers to find **impact point** on scintillators.



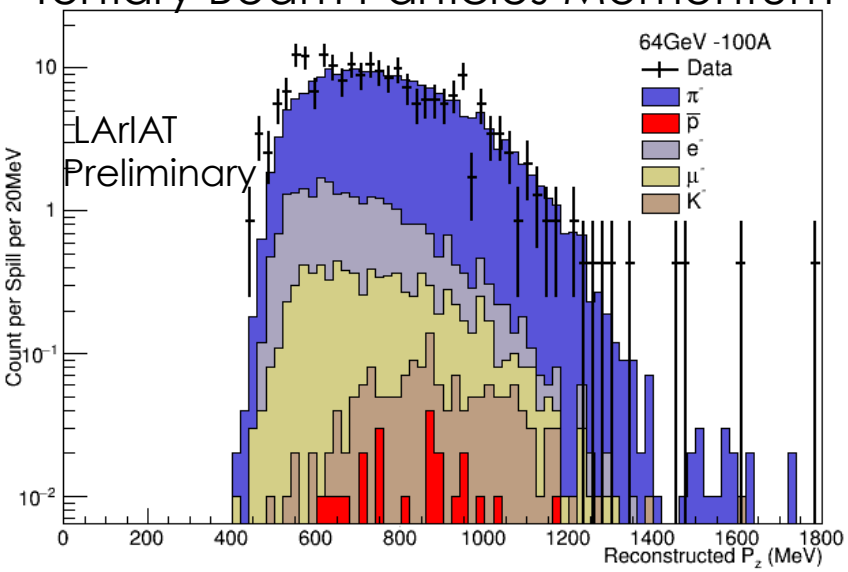
ToF distribution

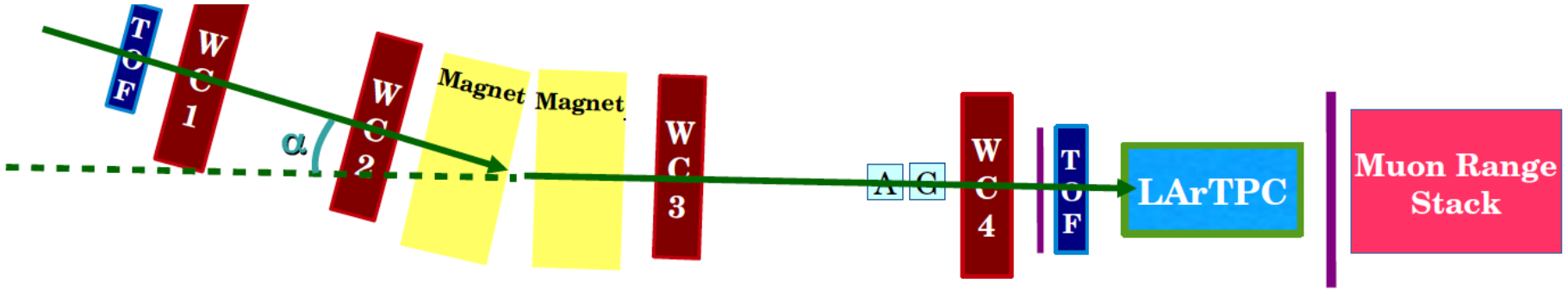


Test beam detectors: MWPCs

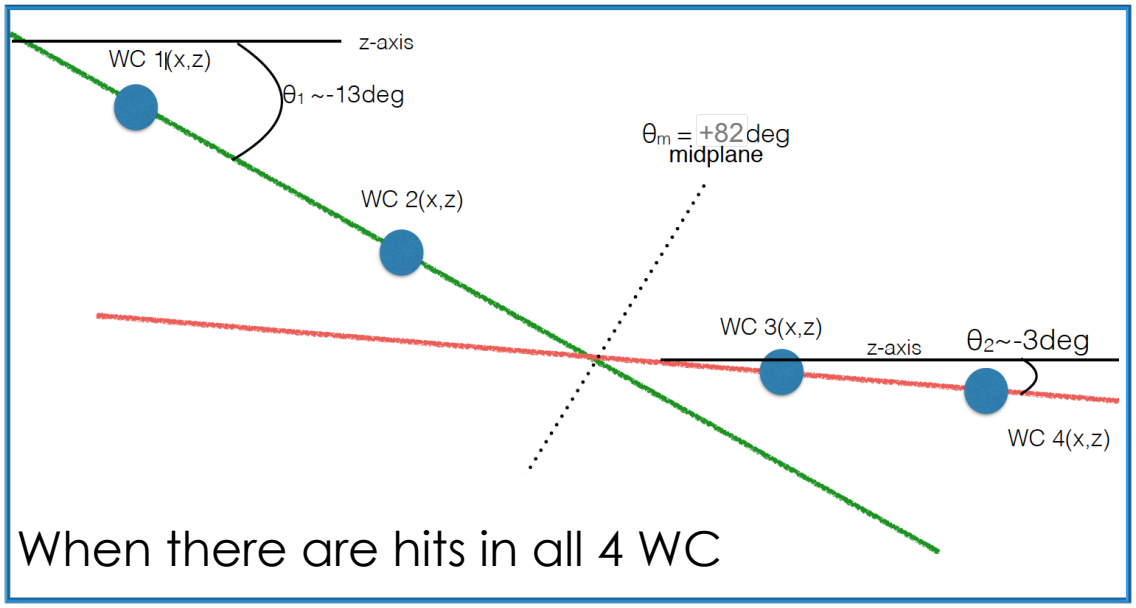
- MWPCs + bending magnets allow to **reconstruct particles momentum** before entering the LArTPC.
- WC pairs used to define particle tracks before and after the magnets.
- The angle α between the two tracks determines the momentum reconstruction.
- Momentum reconstruction possible even if information from one of the two **inner WCs is missing**.

Tertiary Beam Particles Momentum

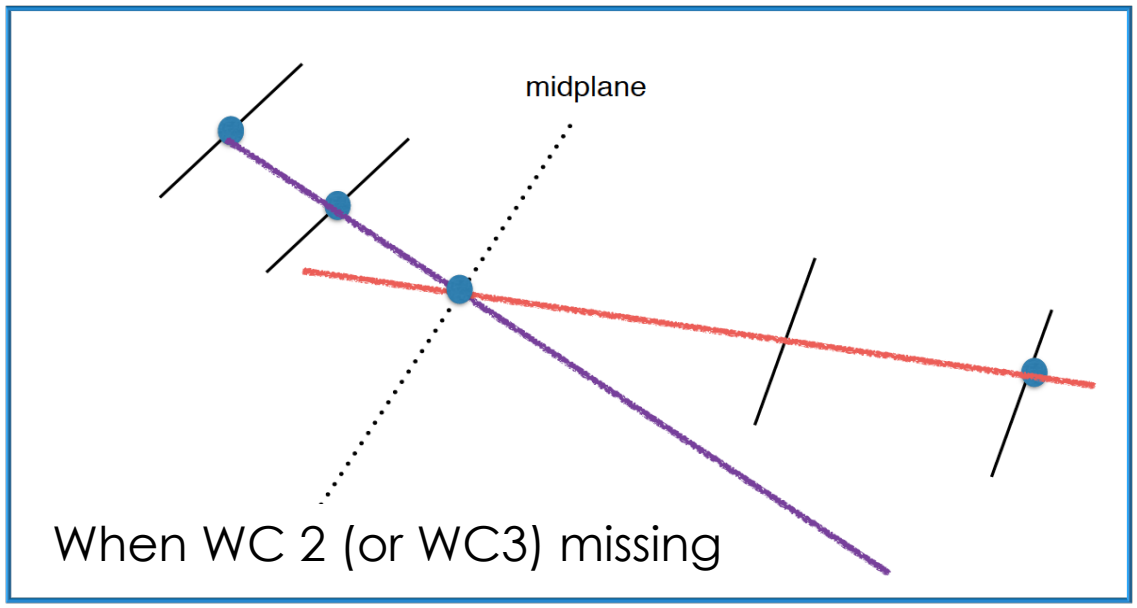




Test beam detectors: MWPCs



When there are hits in all 4 WC

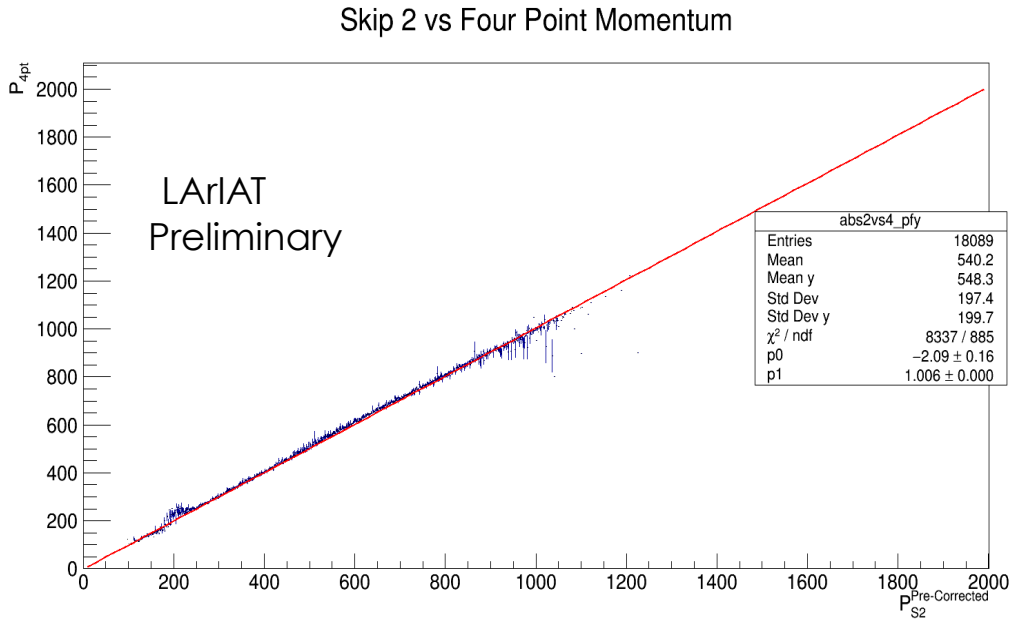


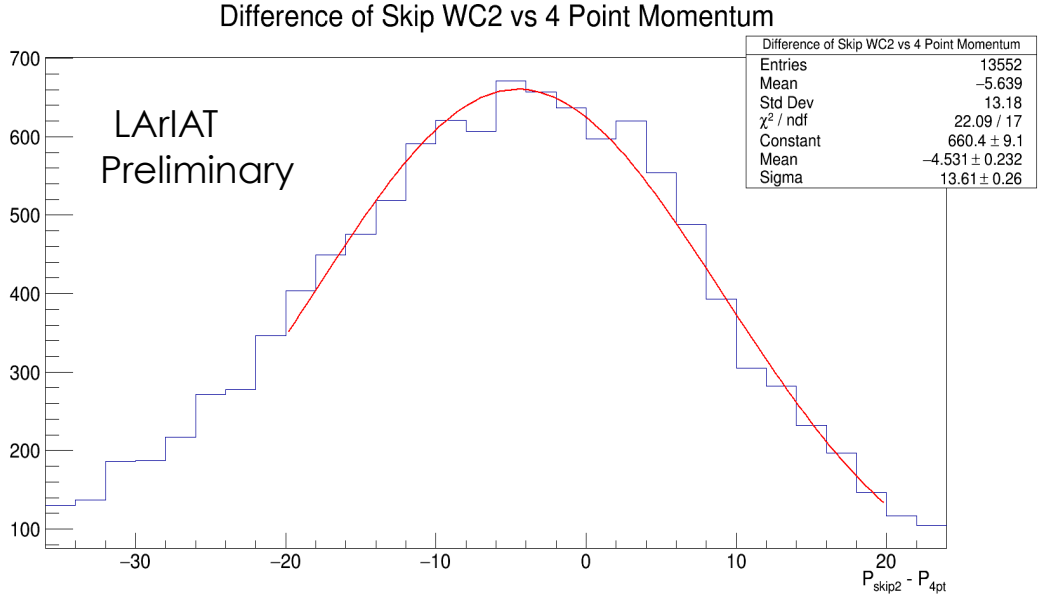
When WC 2 (or WC3) missing

- Looking beamline from the top.
- $$p \approx \frac{\int B\,dl}{\sin(\theta_2) - \sin(\theta_1)}$$
- By extrapolating the completed leg to its intersection with plane centered between the magnets (**midplane**), the fourth point to be used with the incomplete leg can be calculated.

Credit: (G. Pulliam, Syracuse U)

Test beam detectors: MWPCs



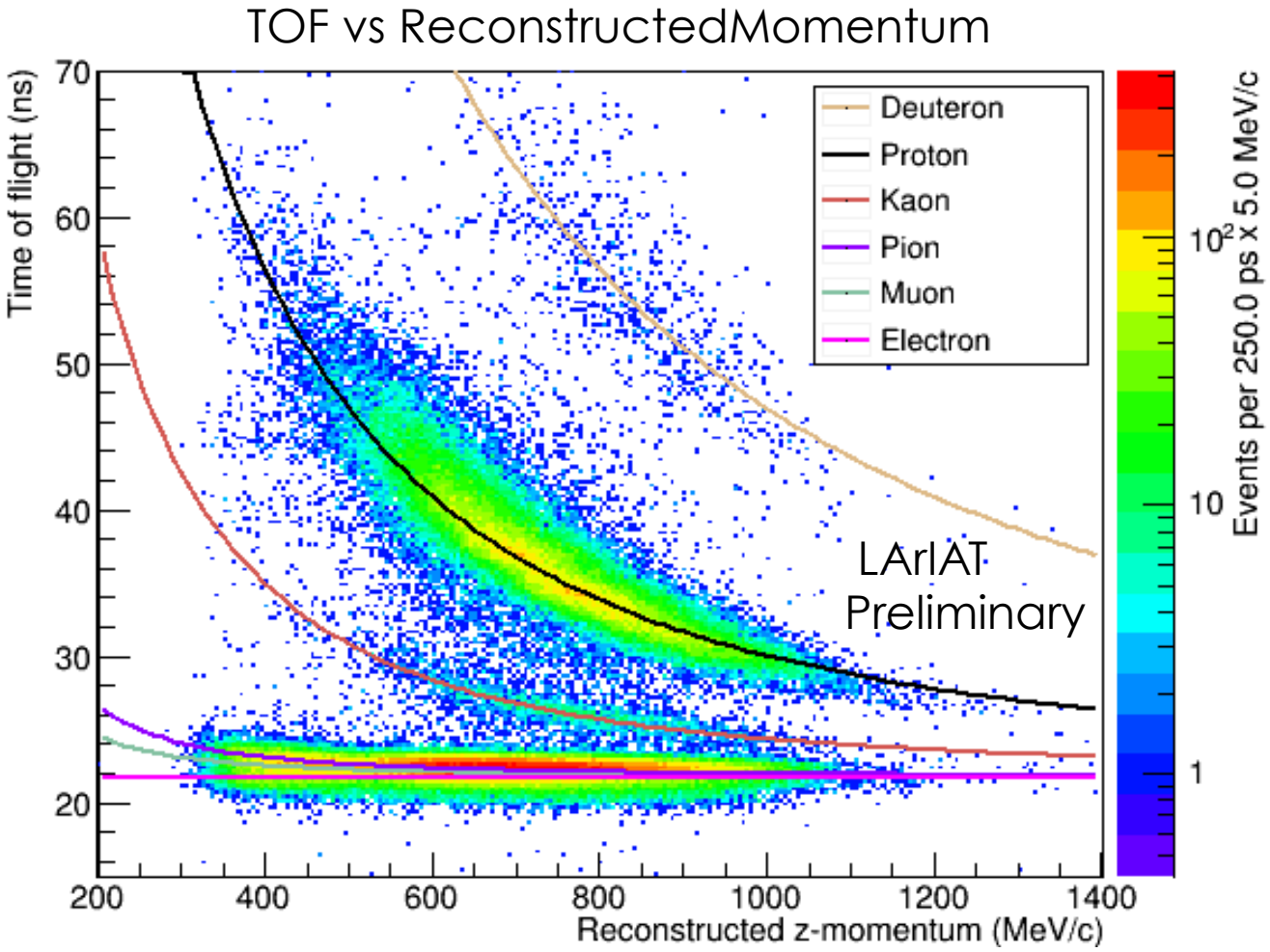


- To compute the introduced error, a comparison between **momentum calculated with all 4 WCs** data and **momentum obtained blinding WC2 (WC3)** is performed.
- Fit parameters provide a **correction scaling** a three point track to a four point track.
- Sigma from fit provides **uncertainty of momentum** of three point track relative to a four point track.

Credit: (G. Pulliam, Syracuse U)

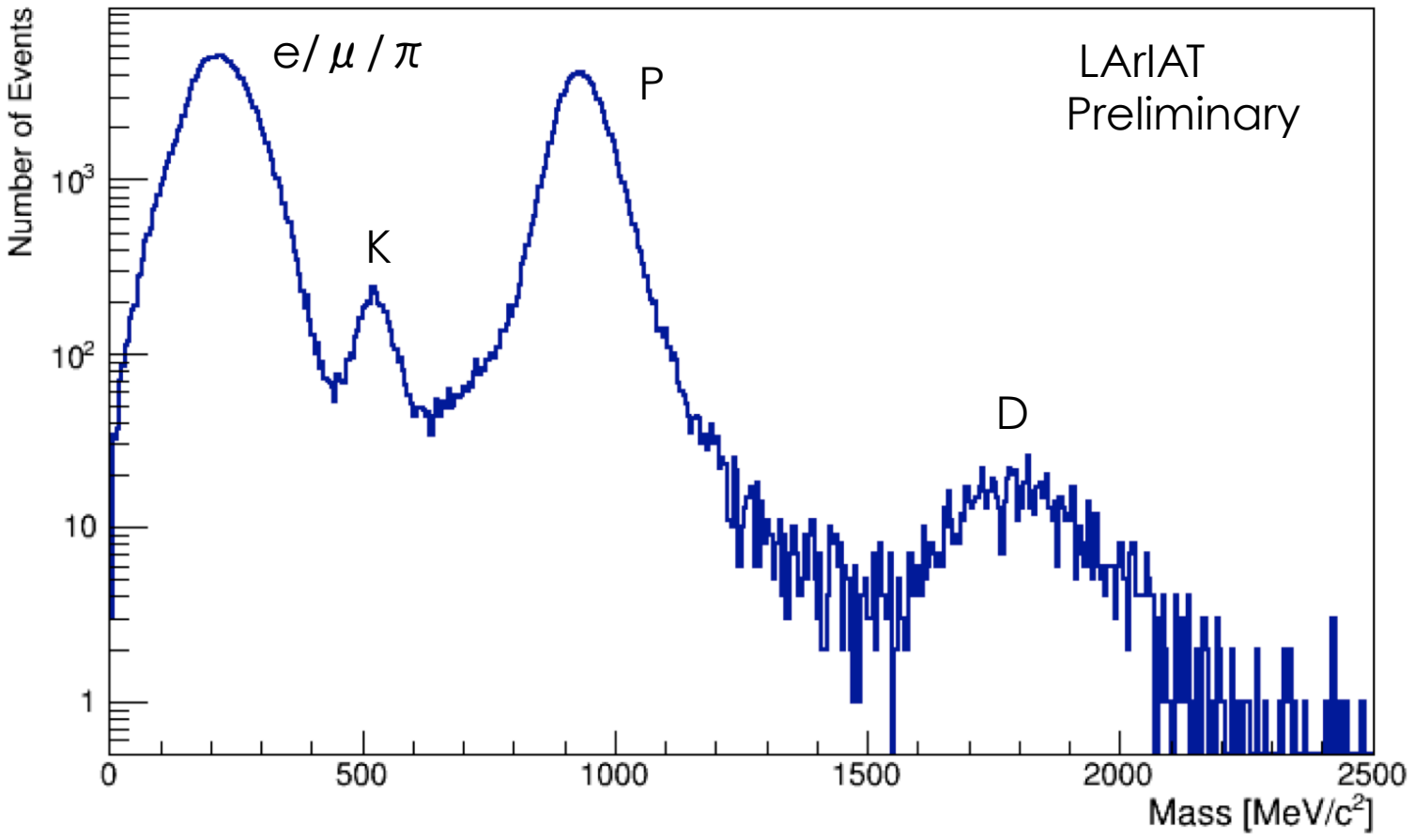
Test beam detectors: MWPCs and TOF

- MWPCs + TOF make possible a **particle selection**.



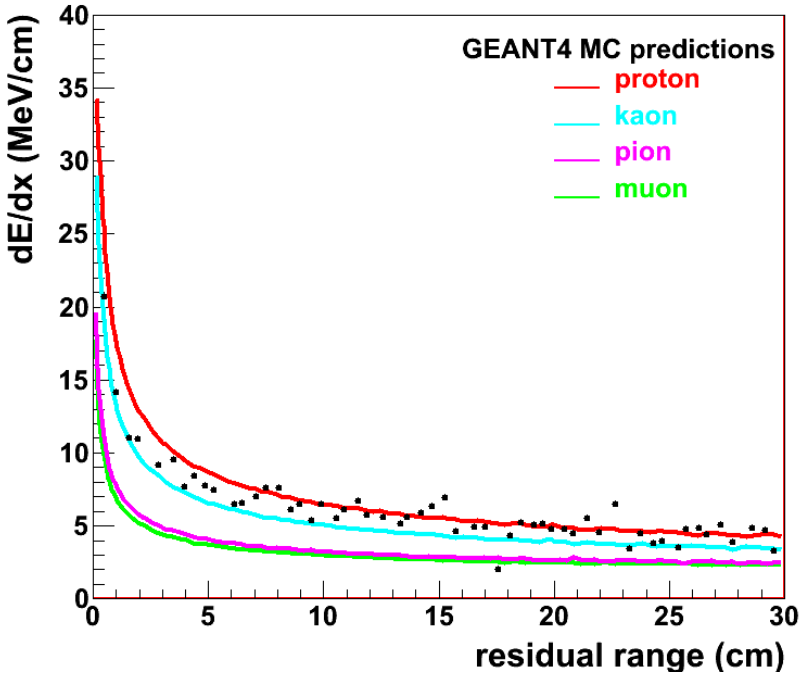
Test beam detectors: MWPCs and TOF

- MWPCs + TOF make possible a particle selection.
- The **mass** of the particles can be also retrieved: $m = \frac{p}{c}\sqrt{\left(\frac{ToF \times c}{l}\right)^2 - 1}$



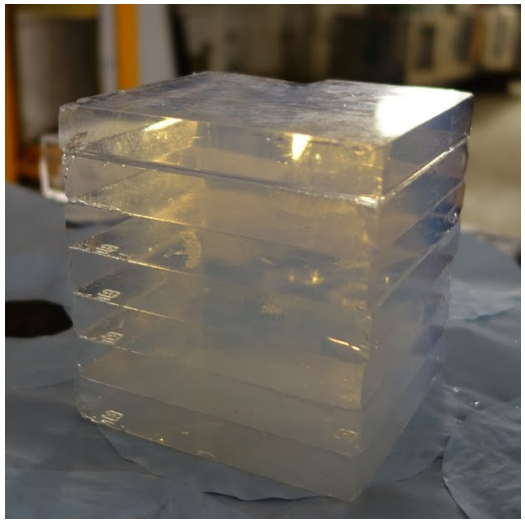
Test beam detectors: MWPCs and TOF

- MWPCs + TOF make possible a particle selection.
- The mass of the particles can be also retrieved.
- The capability of knowing the particle species allows the ability to evaluate both **particle reconstruction** and **particle ID algorithms** (work in progress… more in the following slides).

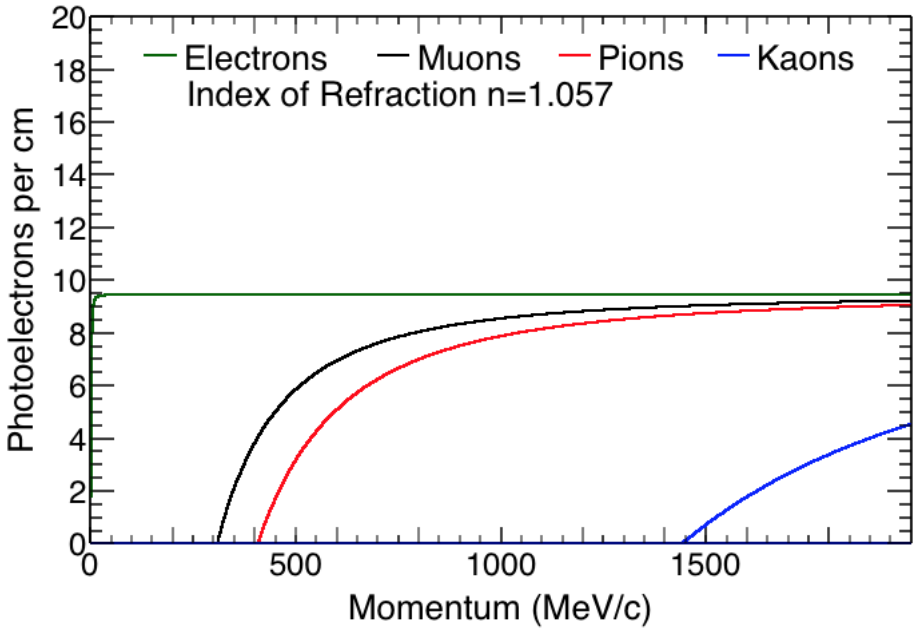


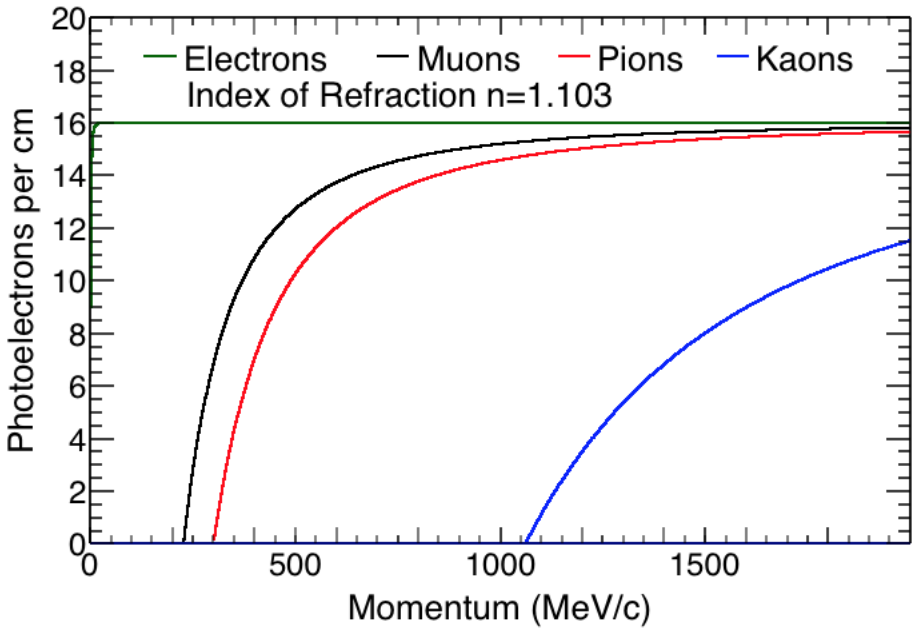
Test beam detectors: AeroGel

- 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	e μ π	e μ π
300 - 400	e μ π	e μ π



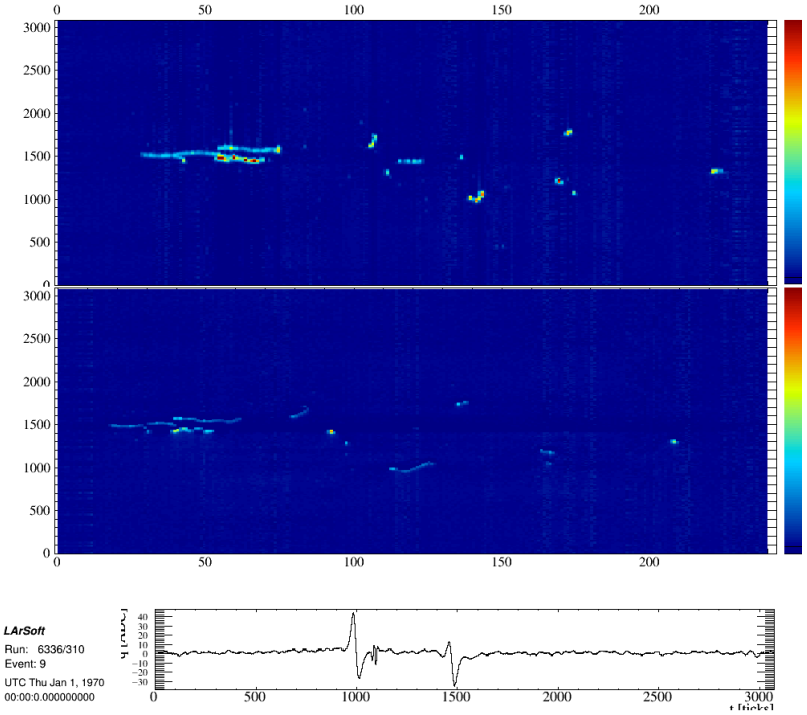


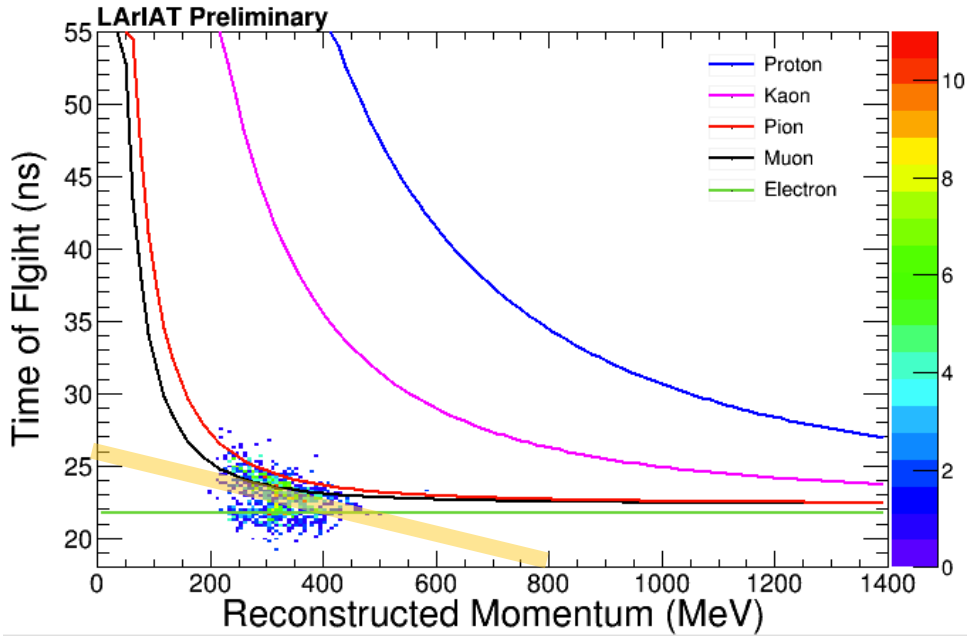
Credit: (B. Soubasis UT Austin)

Test beam detectors: AeroGel

- For momenta below 300 MeV/c, aerogel (n = 1.057) can also be used to **select or reject electrons,** one of largest backgrounds in pion cross section analysis.
- Study on small sample: **97.11± 0.007%** of the EM –Shower electron candidates below 300 MeV/c are identified by the aerogel counters.

Event Selection	# of Events
# of events	1034
AG electron event	767
EM shower event	589
Matched AG&EM shower	572

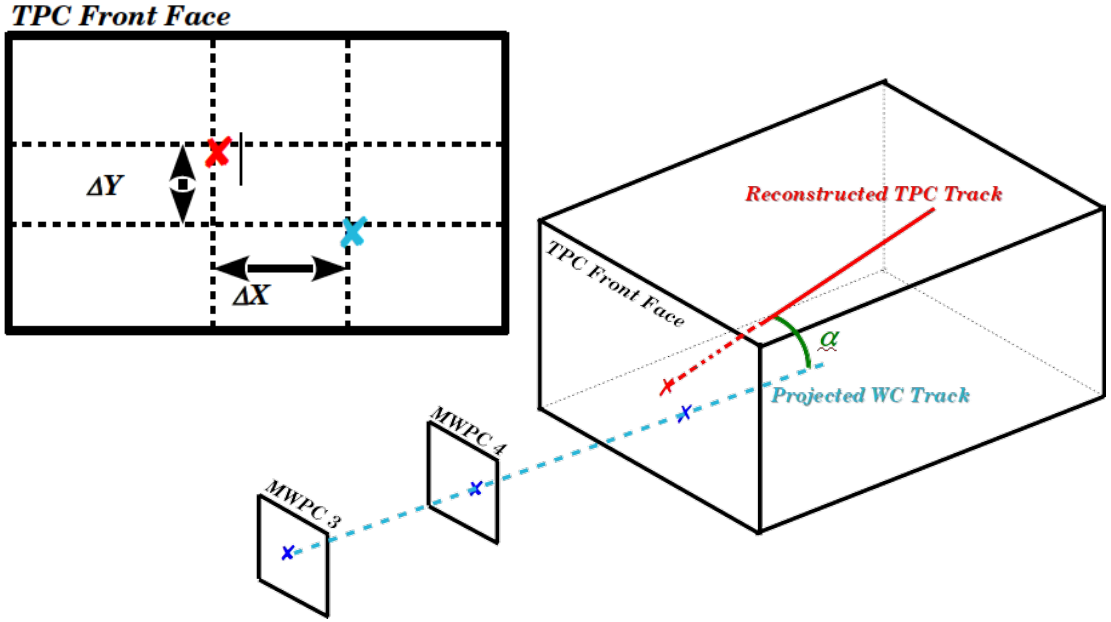


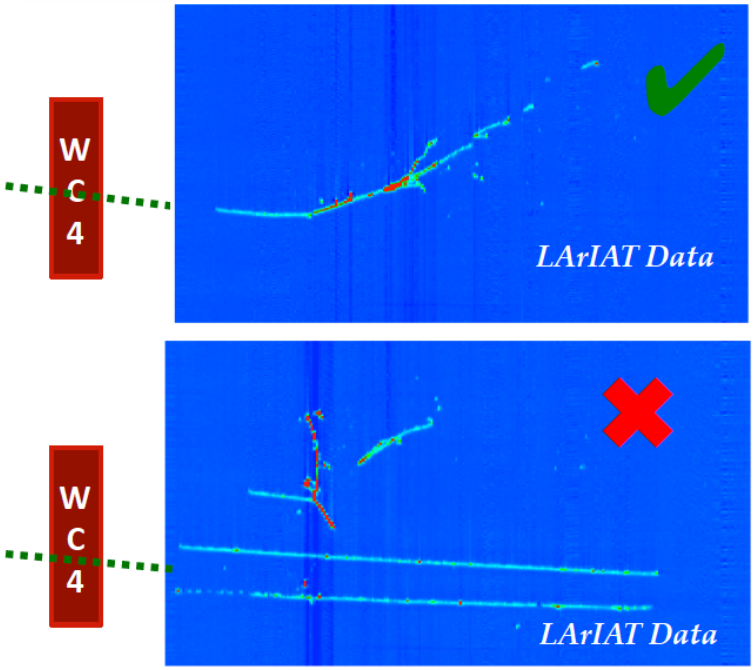


Credit: (B. Soubasis UT Austin)

From testbeam to TPC

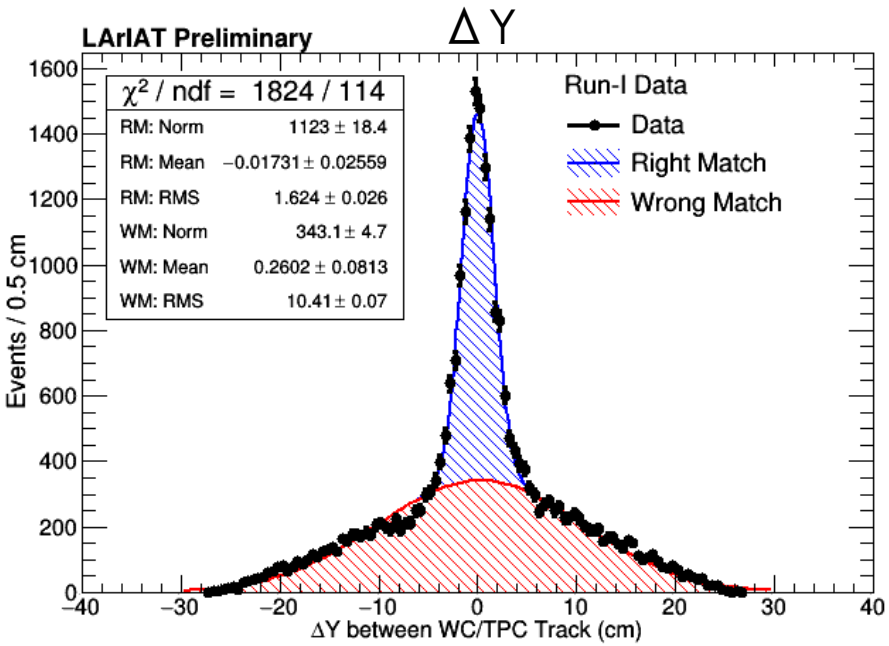
WCs – TPC tracks matching

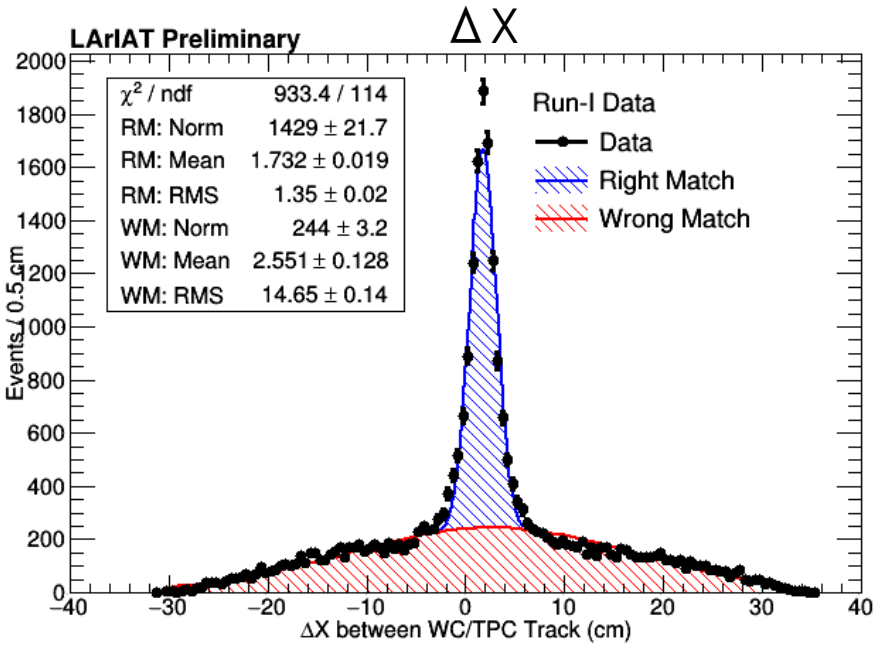




- Both beamline particle trajectory, as determined be the last two MWPCs, and the reconstructed TPC tracks are projected to the TPC front plane.
- Matching based on ΔX, ΔY and α.

WCs – TPC tracks matching





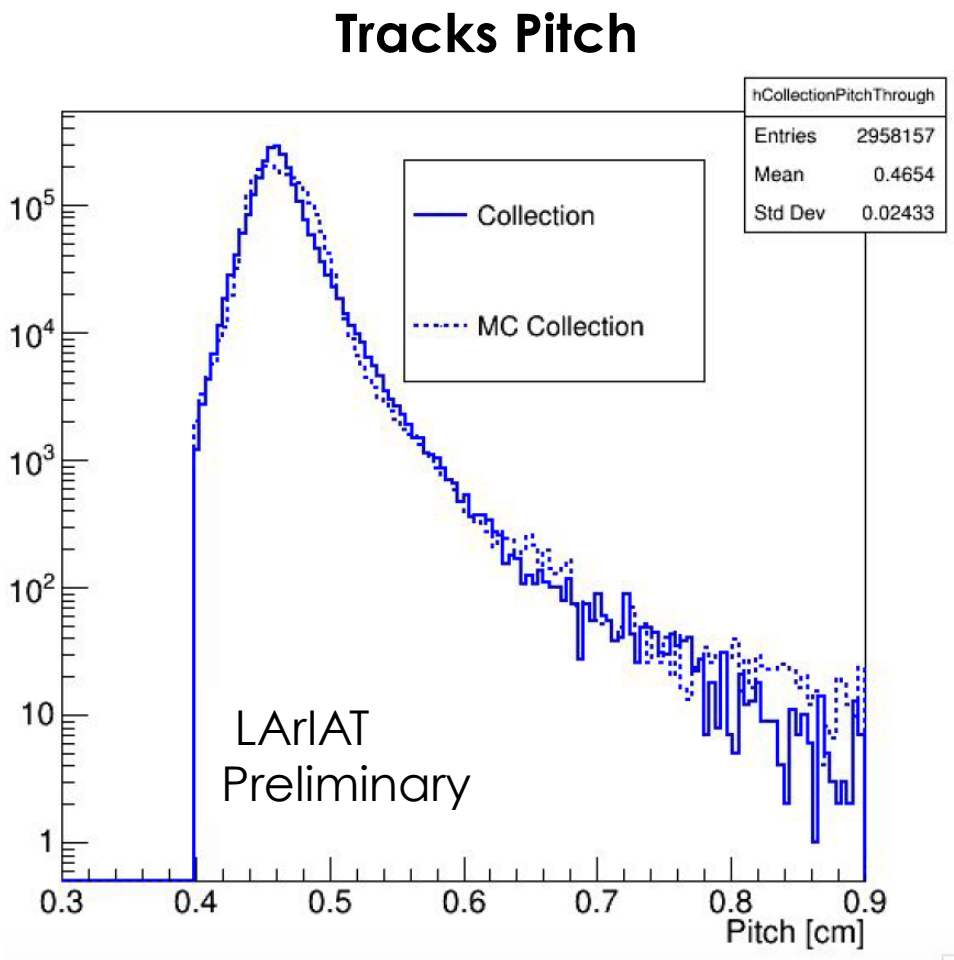
- A successful matching requires **only one reconstructed TPC track in the first 2 cm** of the TPC length and only one WC – TPC track pair with low ΔX, ΔY and α values.

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

- Asymmetry in ΔX is under study.

Beam Line MC

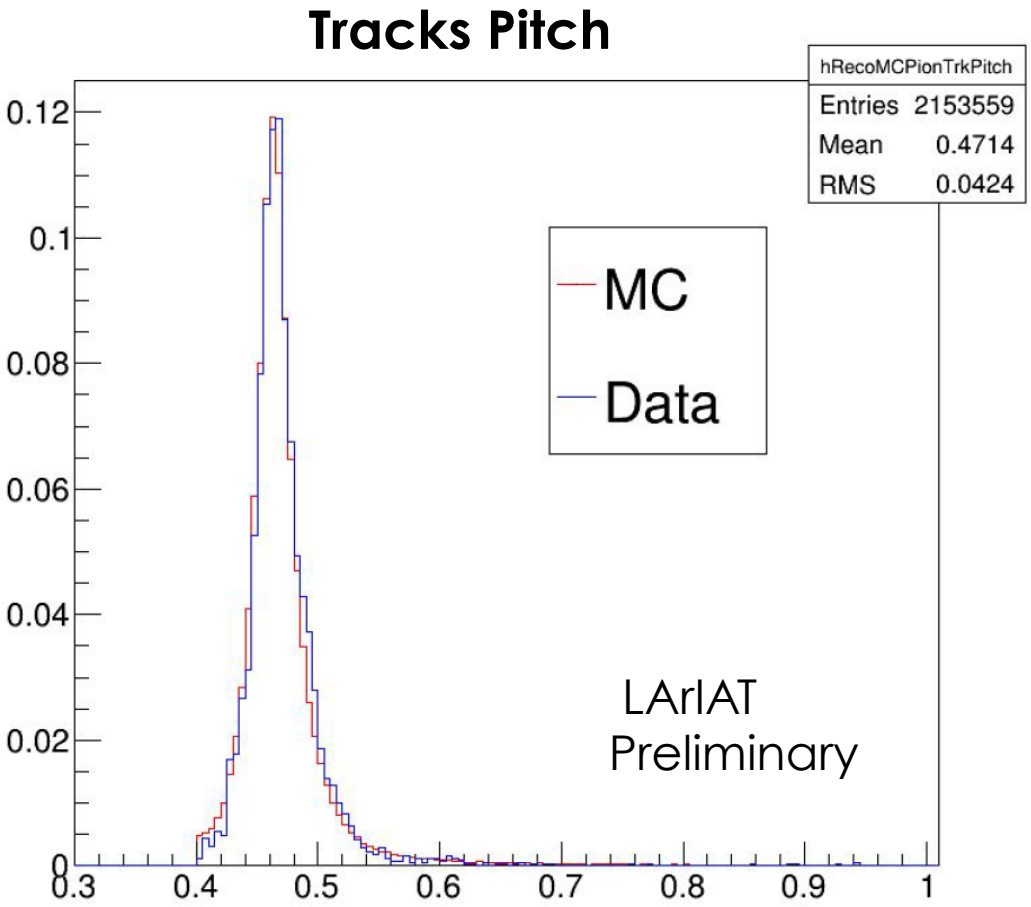
- Using a **non-realistic beam MC simulation** can lead to unexpected mis-matches between data and MC:
  - e.g. mis-match with the track pitch



- Using a simple beamline MC (flat momentum spectrum and Gaussian distributed spread in the angles) lead to a disagreement between MC reconstructed track pitch and data reconstructed track pitch.
  - e.g. Using LArSoft Single Particle Gun generator

Beam Line MC

- Using a **non-realistic beam MC simulation** can lead to unexpected mis-matches between data and MC:
  - Fixed when generating MC using the data derived beam momentum and angles (and their correlation)

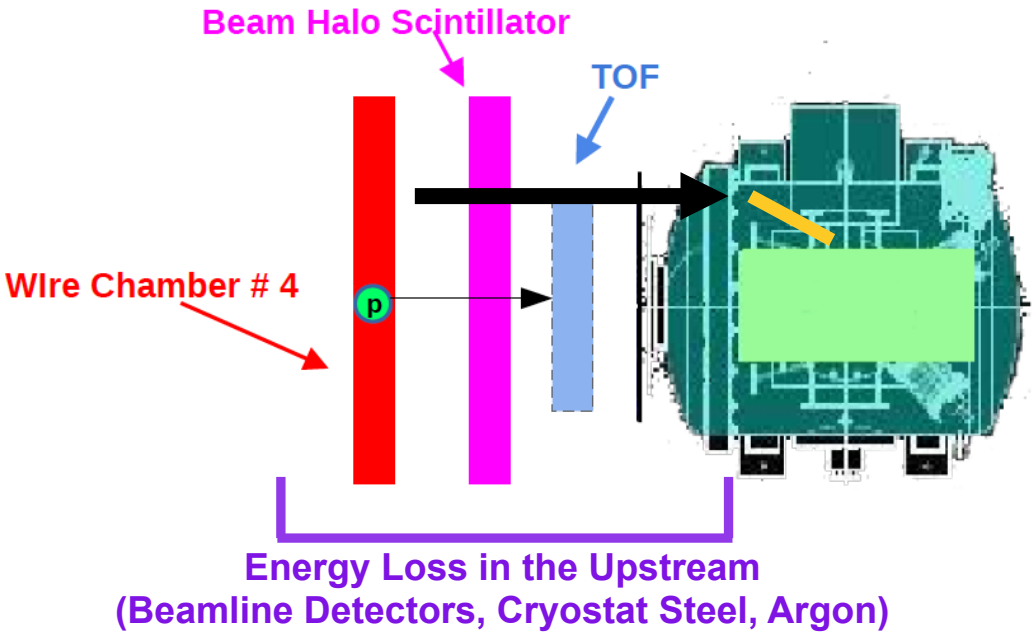


- MC with **realistic momentum** and angle spectrum.
- Momentum, angle and position **derived from data** and generated with the hit-or-miss method.

Credit: (E. Gramellini, Yale)

Energy loss

- The momentum of the incoming particle is calculated using the hits from the WCs. However, there is **material between WC4 and the TPC** which causes the particle to lose energy before entering the TPC (scintillator, steel, argon, G10, etc…).



$$E_{TPC} = \sqrt{p^2 + m^2} - m - E_{LOSS}$$

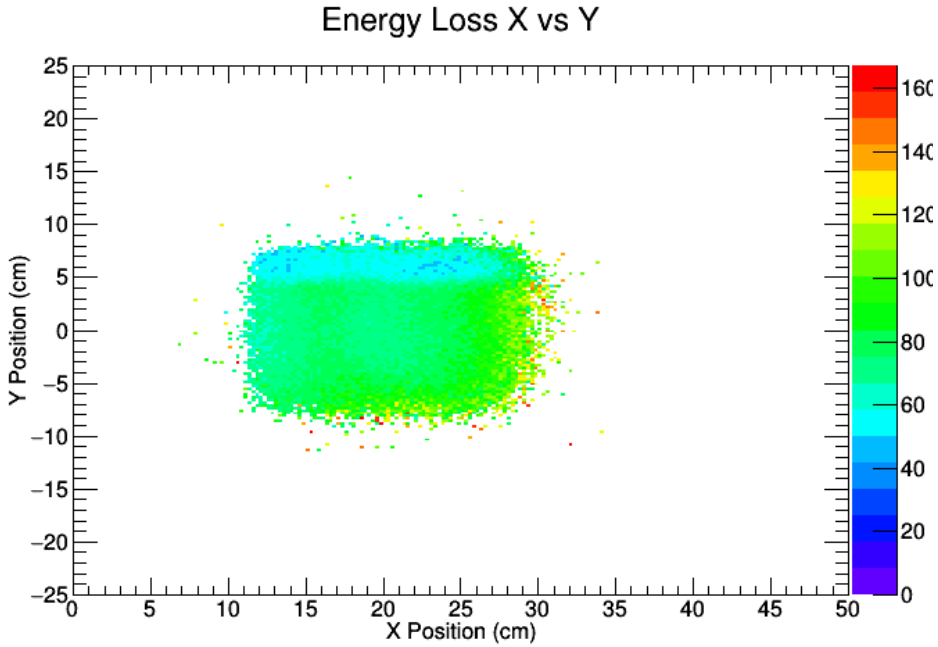
- E_{LOSS} has a **positional dependence** that has to be taken into account.

Energy loss

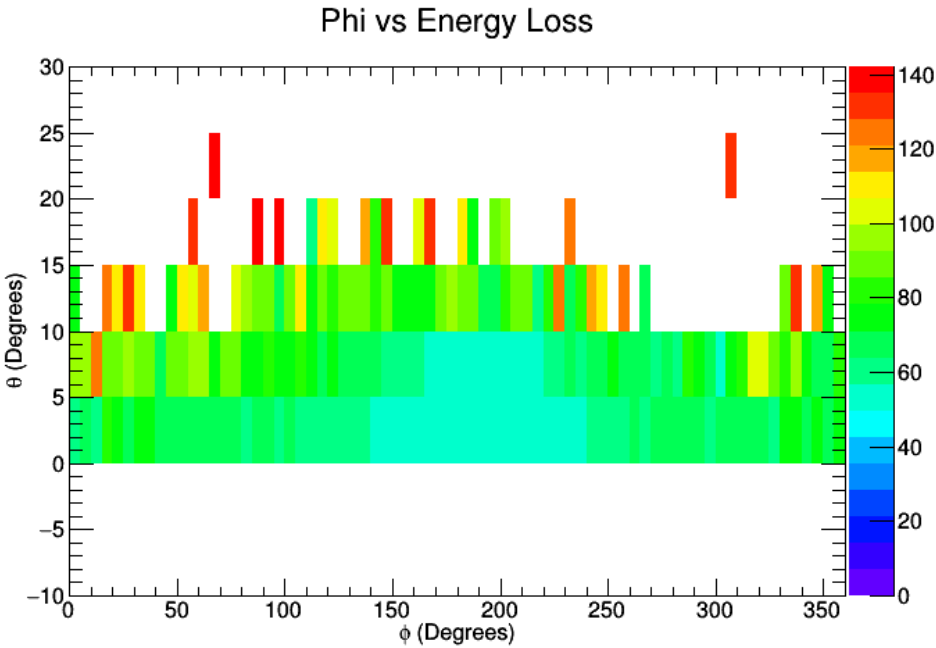
- **Proton** are being used to calibrate this positional dependence: if a proton stop inside the TPC without interacting, there is the measure of the energy the proton had.

- Proton, with initial momentum and angular dependence from data, are generated. Study is ongoing.

$$E_{LOSS}(X,Y,\theta,\varphi) = \sqrt{p^2 + m_P^2} - m_P - E_{TPC}$$



Initial position inside the TPC (X,Y)



Initial angle inside the TPC (θ ,φ)

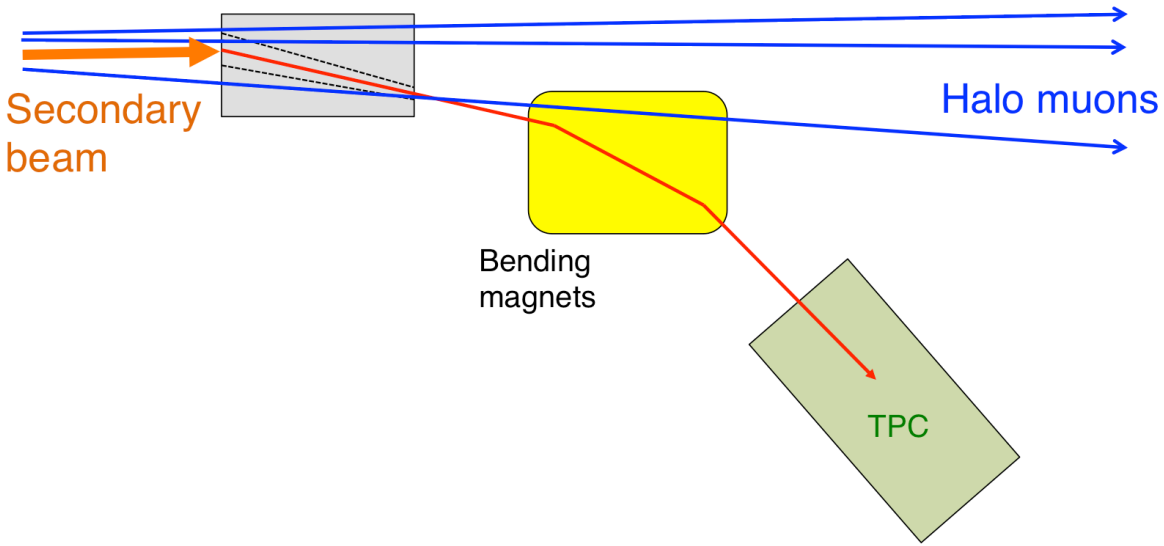
Credit: (J. Asaadi, UT Arlington)

Placement of the TPC

- In LArIAT, a problem is the TPC sees **stray halo muons** produced upstream (at the first secondary Cu target) which hugely limits the beam intensities.

- If we could have changed the **arrangement of our tertiary beamline** to minimize these secondary particles from appearing in the same spill as real beamline events, it would have improved LArIAT performance.

Ideal TPC Placement



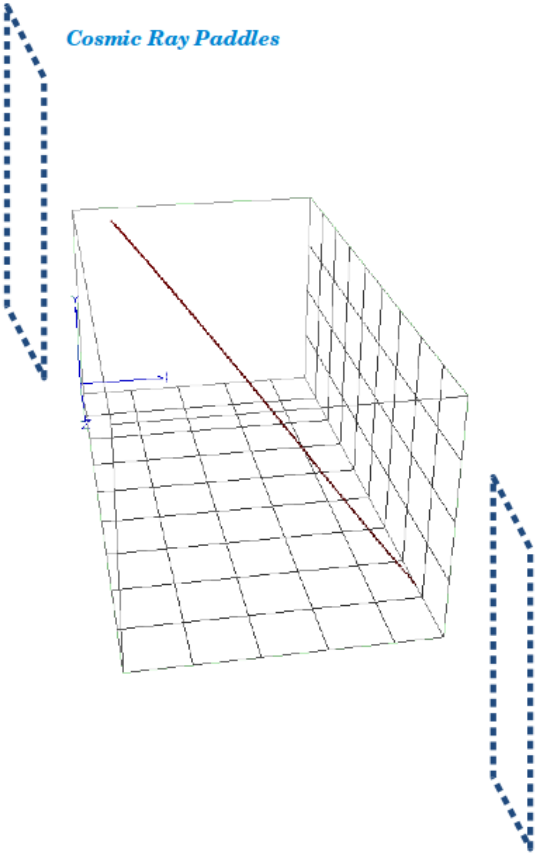
Lessons learned from beamline

- Design the beam line to avoid (as much as possible) the particle halo coming from the target.
- Position and momentum measurement as close as possible to the TPC begin.
- Less material than possible between the momentum measurement device and the begin of the TPC.
- Very realistic simulation of this material.
- It is fundamental to have a MC that realistically mimic the angle and momentum spectrum of the real beam.

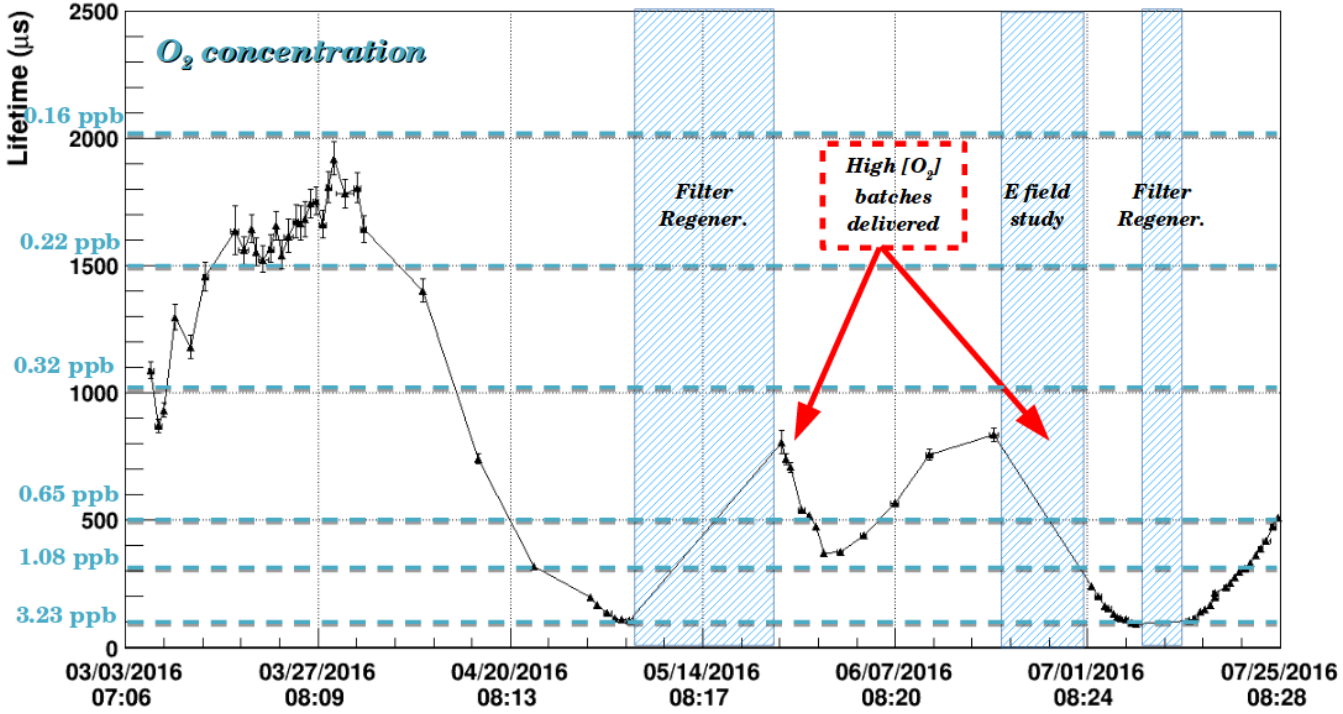
TPC

Argon Purity

- Cosmic Rays Paddles trigger cosmic muons (mip) that cross the entire drift field.
- They are used to determine the **electron lifetime** (i.e. O2-equivalent contamination), fitting the exponential decay trends of the amount of charge collected at the wire planes as a function of the drift time.



Electron lifetime achieved without LAr recirculation



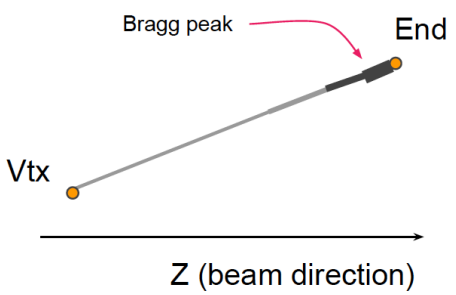
Particle ID

- LArIAT is a perfect place where **test particle ID algorithm** in LAr.
- In the evaluation of ID algorithm **MC True information can be substituted with beamline derived information**.
- Beamline derived information have an error, but the events are real, i.e. **take into account all possible effects and topologies**.

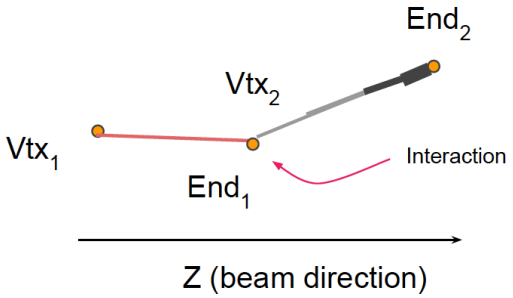
Particle ID

- At the moment, in LArSoft, are implemented some ID algorithm based on calorimetry, and in particular on the fit of **dE/dX vs Residual Range**, that should distinguish between different particles.

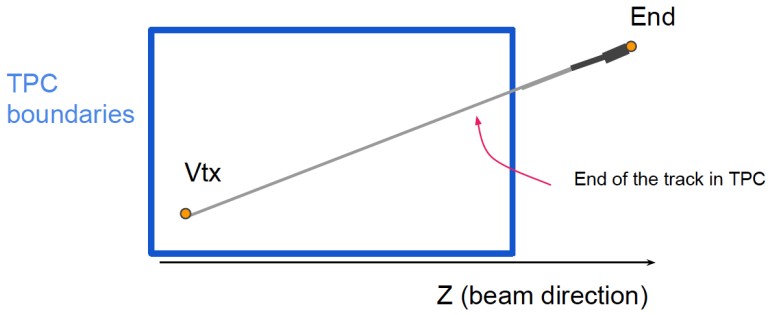
- They basically look for the Bragg peak at the end of a stopping track to determine the particle species. But …



No interaction: 1 Reco Track.
Bragg peak at the end of the track.



Interaction: 2 Reco Tracks.
Bragg peak at a different track

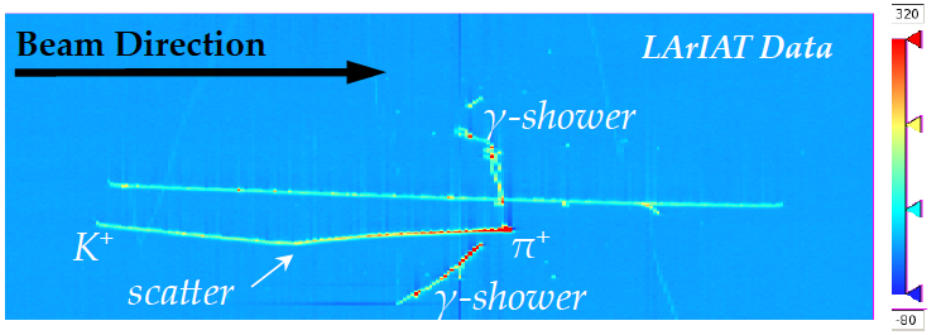


Bonus case: escaping particle

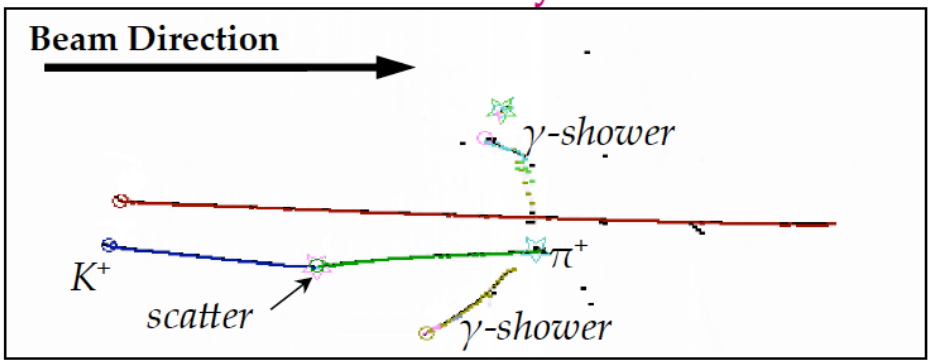
Credit: (E. Gramellini, Yale)

Particle ID

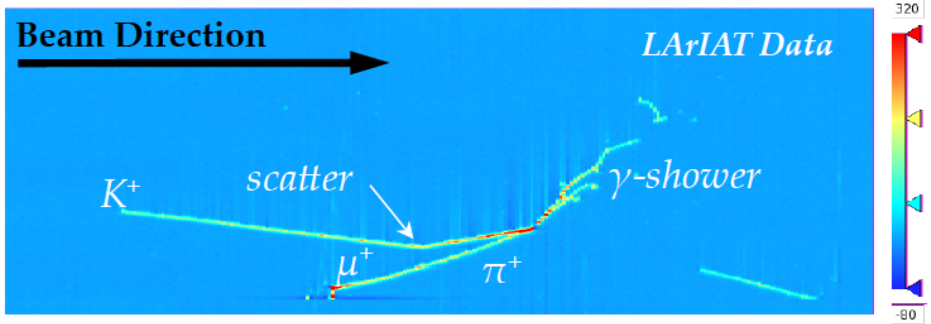
LArIAT Data Preliminary K^+ Candidate



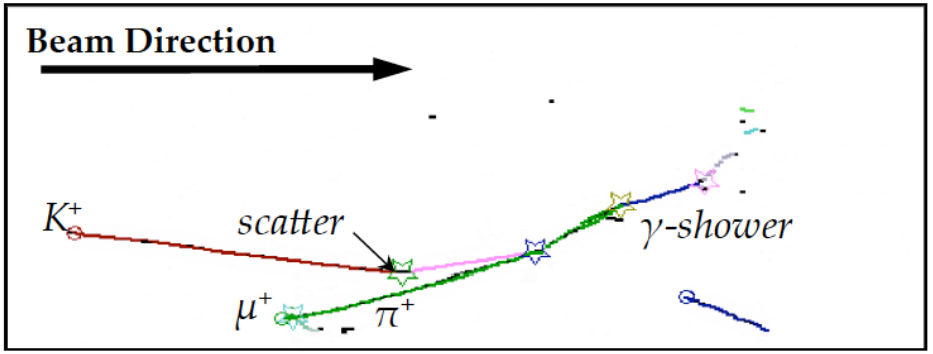
LArIAT Data Preliminary Reconstruction



LArIAT Data Preliminary K^+ Candidate



LArIAT Data Preliminary Reconstruction



- If these algorothms are used without taking into account topologies results can be disastrous.

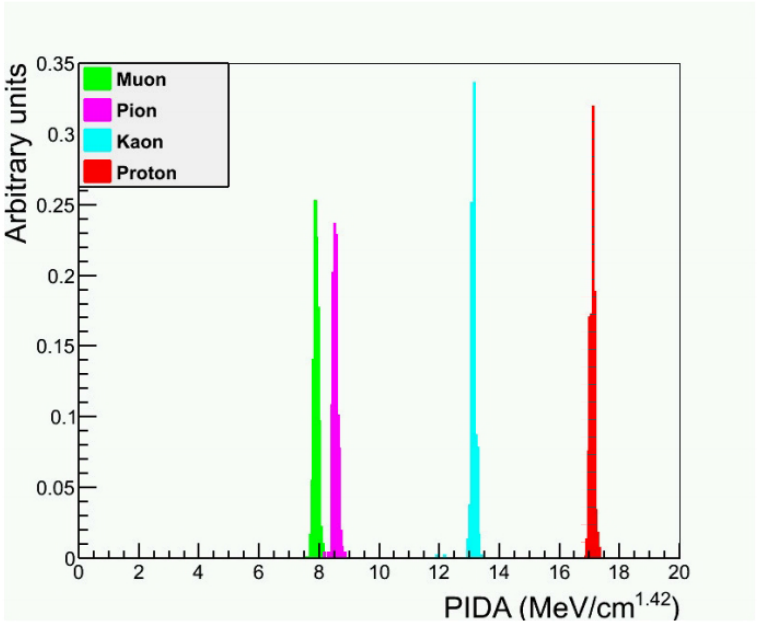
Credit: (E. Gramellini, Yale)

PIDA

- Particle IDentification Algorithm (**PIDA**) is a LArTPC based technique developed by ArgoNeuT.
- It parameterizes the BetheBlock energy deposition curve for **stopping particles** in terms of the residual range R and a parameter A, unique for each particle (the PIDA parameter).
- For each given track, A is calculated by averaging the value of dE/dx and R for each reconstructed point i of the track,

$$\frac{dE}{dx} \approx AR^{-0.42}$$

$$A = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{dE}{dx}\right)_{calo,i} R_i^{0.42}$$

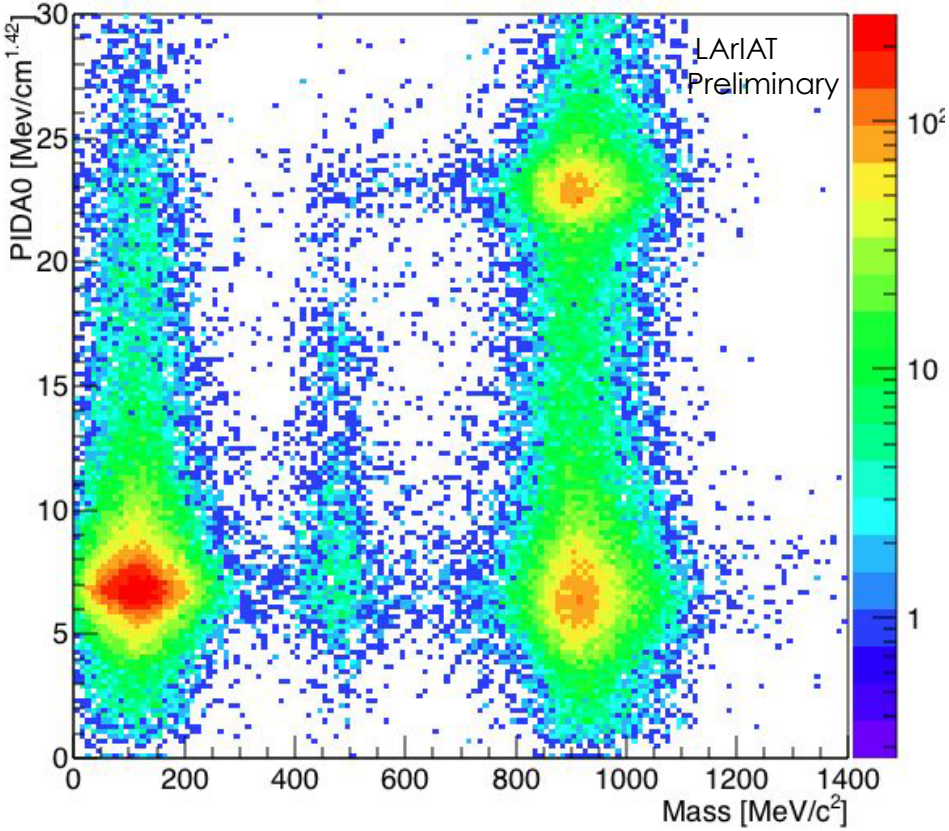


R. Acciarri et al. (ArgoNeuT Collaboration), JINST 8 (2013) P08005

PIDA

- PIDA as ID method works only for **stopping particles**.

PIDA vs mass

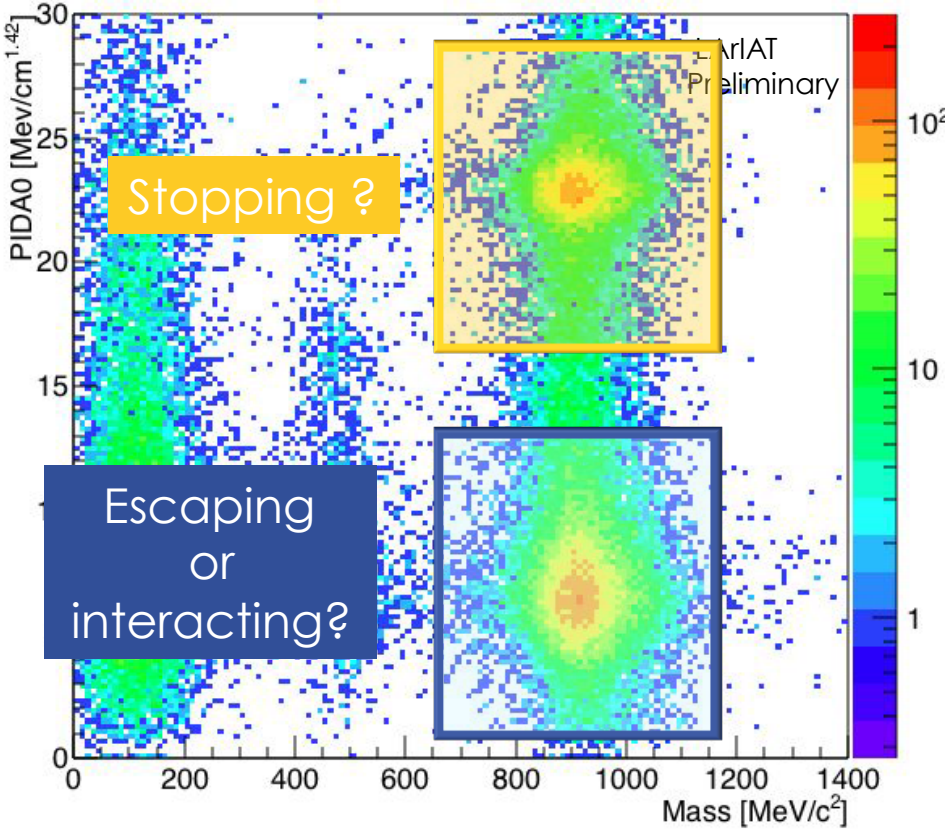


Credit: (E. Gramellini, Yale – D.Smith, U Boston)

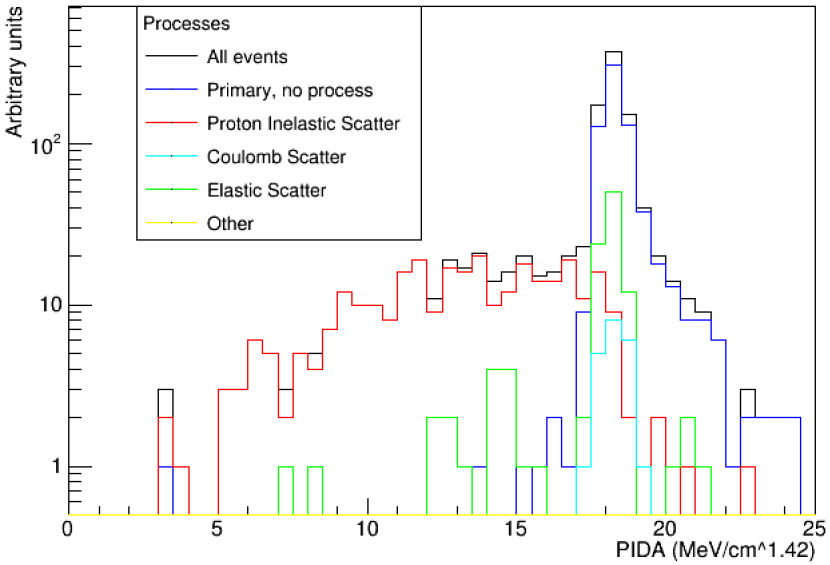
PIDA

- PIDA as ID method works only for **stopping particles**.
- Can be used to tag **interacting/decaying/escaping** particles!

PIDA vs mass



Proton MC



Credit: (E. Gramellini, Yale – D.Smith, U Boston)

Lessons learned from TPC

- It's very important to test ID algorithm on real data to take into account all possible effects.
- Knowing the cross section permits to compute how often the different topologies will appear.
- Good job, LArIAT …

Back up

Test beam detectors: MuRS

- Four layers of XY planes sandwiched between (pink) steel slabs.
- Each plane is composed by 4 scintillating bars connected to a PMT.
- Allows to discriminate π / μ exiting the cryostat.