LArIAT in ~10 (+2) Minutes!

Vincent Basque,
on behalf of the LArIAT collaboration

What is LArIAT?

- **LArIAT is a Liquid Argon Time Projection Chamber…**

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- You might think: **Great… yet another LArTPC** to detect neutrino interactions talk…

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- **Not quite!**

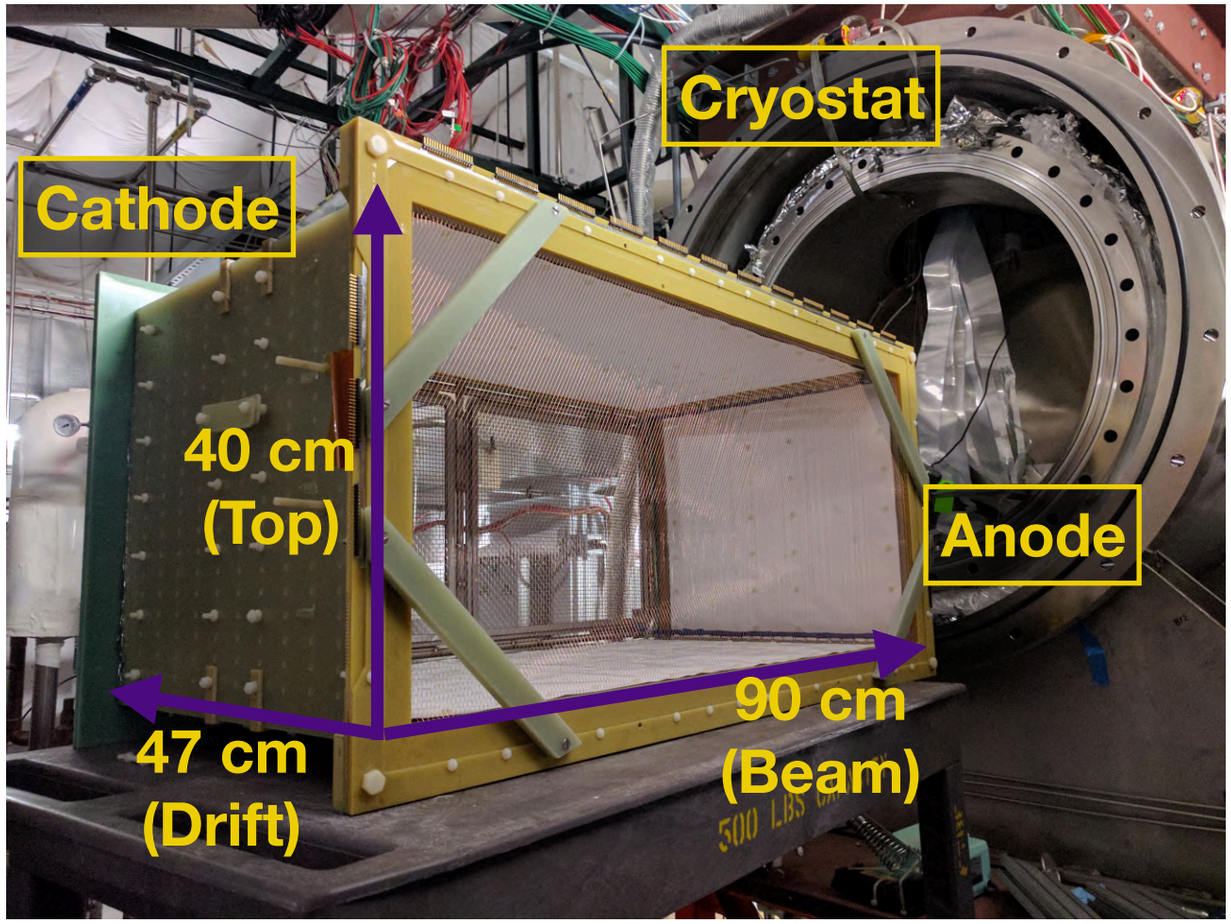
What is LArIAT?

- LArIAT is a Liquid Argon Time Projection Chamber…
- You might think: Great… yet another LArTPC to detect neutrino interactions talk…
- Not quite!
- LArIAT actually stands for **L**iquid **Ar**gon **I**n **A** **T**est beam!
- This means LArIAT is **not looking for neutrino interactions**… at least not directly from a neutrino beam.

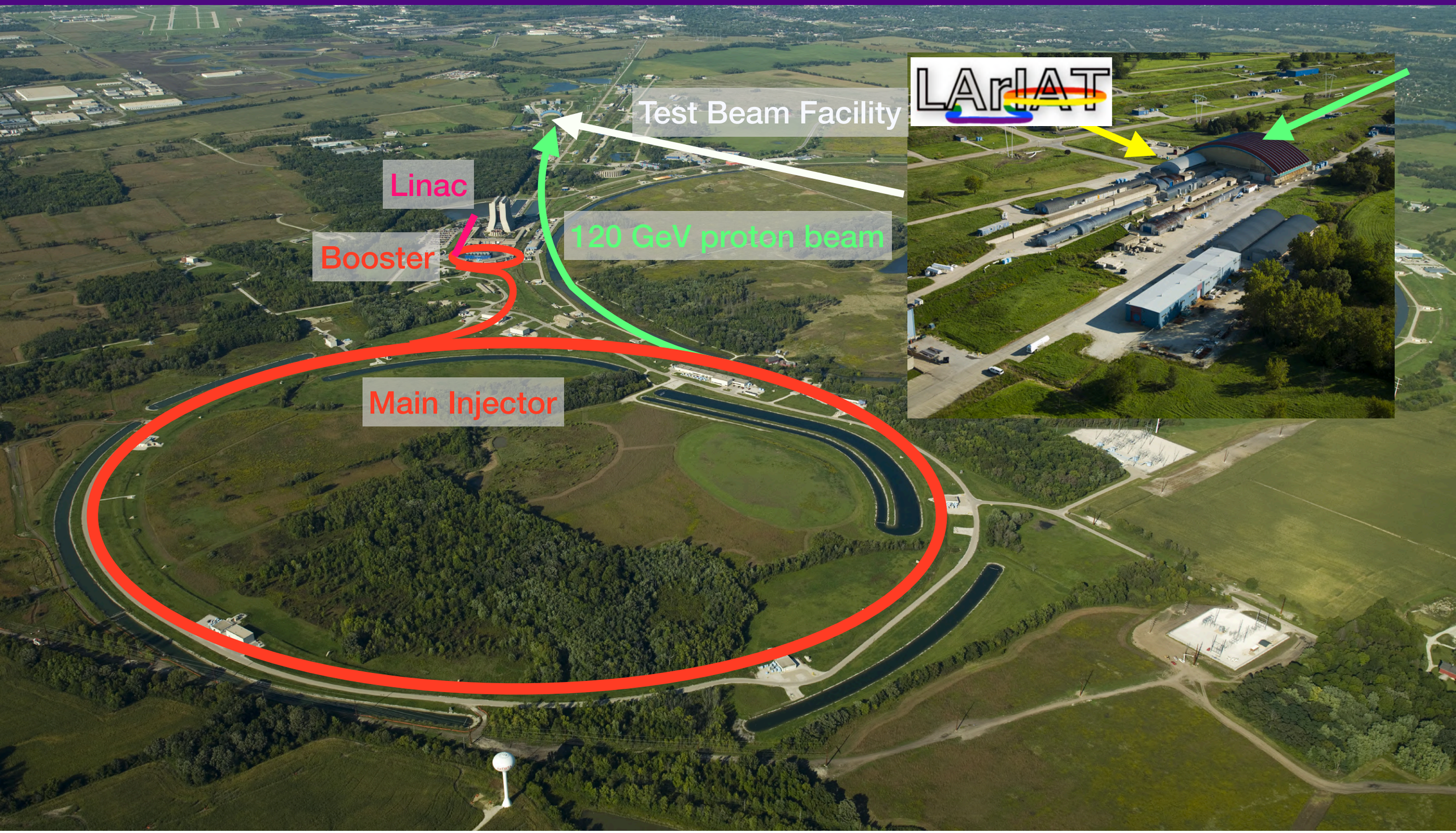
What is LArIAT?

LArIAT is a Liquid Argon Time Projection Chamber In a Test beam …

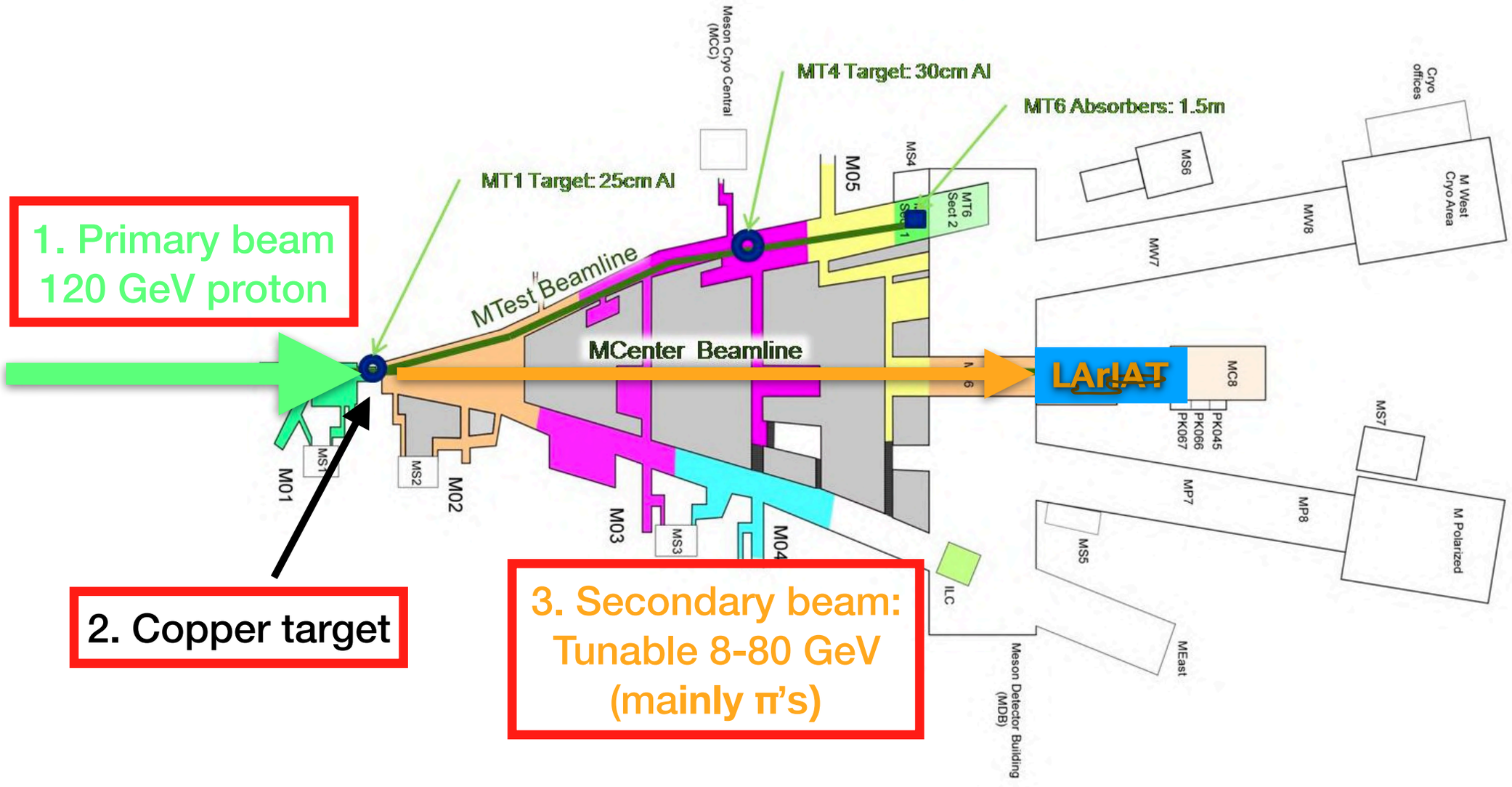
- Relatively small (0.24-ton LArTPC).
- Test beam -> beam of known charged particles.
- Series of auxiliary detectors to ID particles and their momenta.
- Program includes physics and R&D goals. Results will greatly contribute in the success of “not-so-future” LArTPCs (SBN-program, DUNE).



Proton Beam to Test Beam Facility

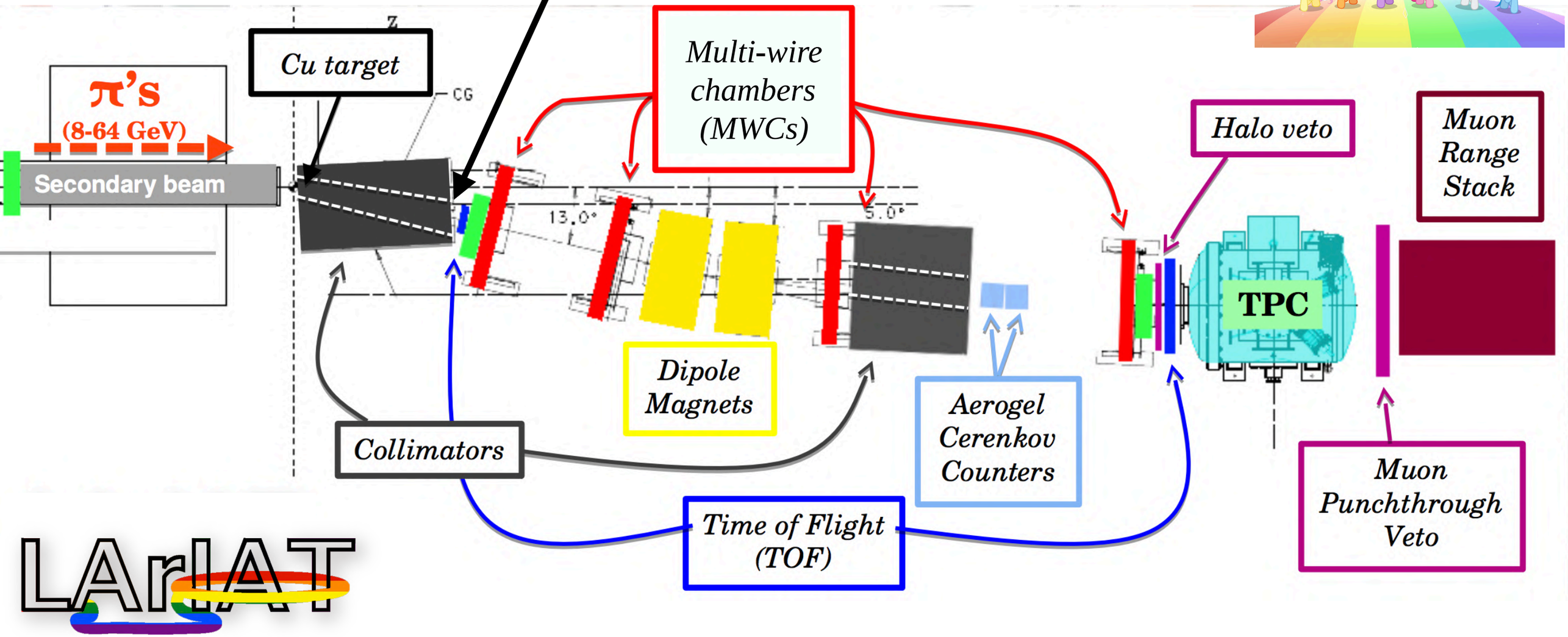


What happens to the *p* beam?



Secondary -> Tertiary

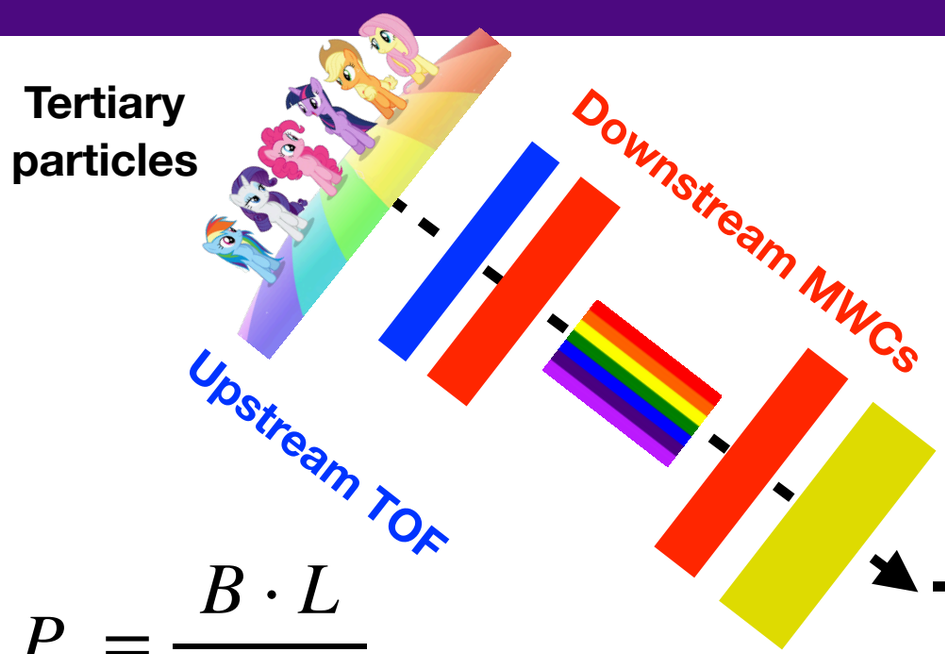
$$\pi \xrightarrow{\text{Cu}} e + \mu + \pi + K + p + d$$



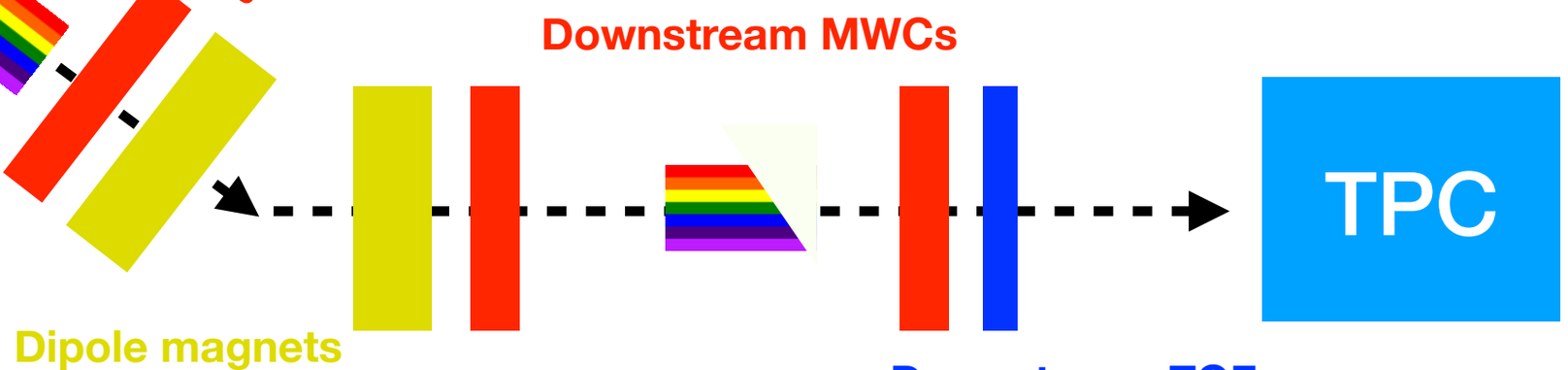
LArIAT

All of this allows particle identification before entering the TPC!
Main feature of a test beam of charged particles -> We know what we are getting!

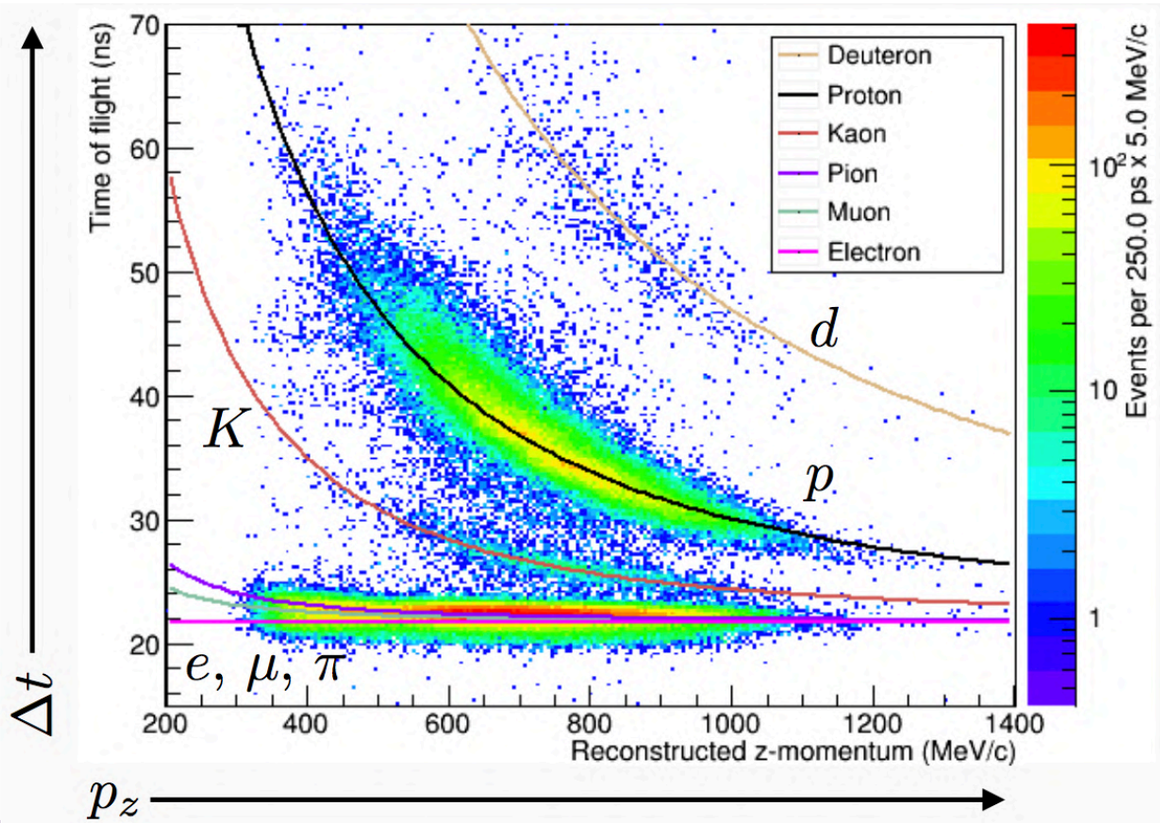
Wire Chambers + TOF = PID

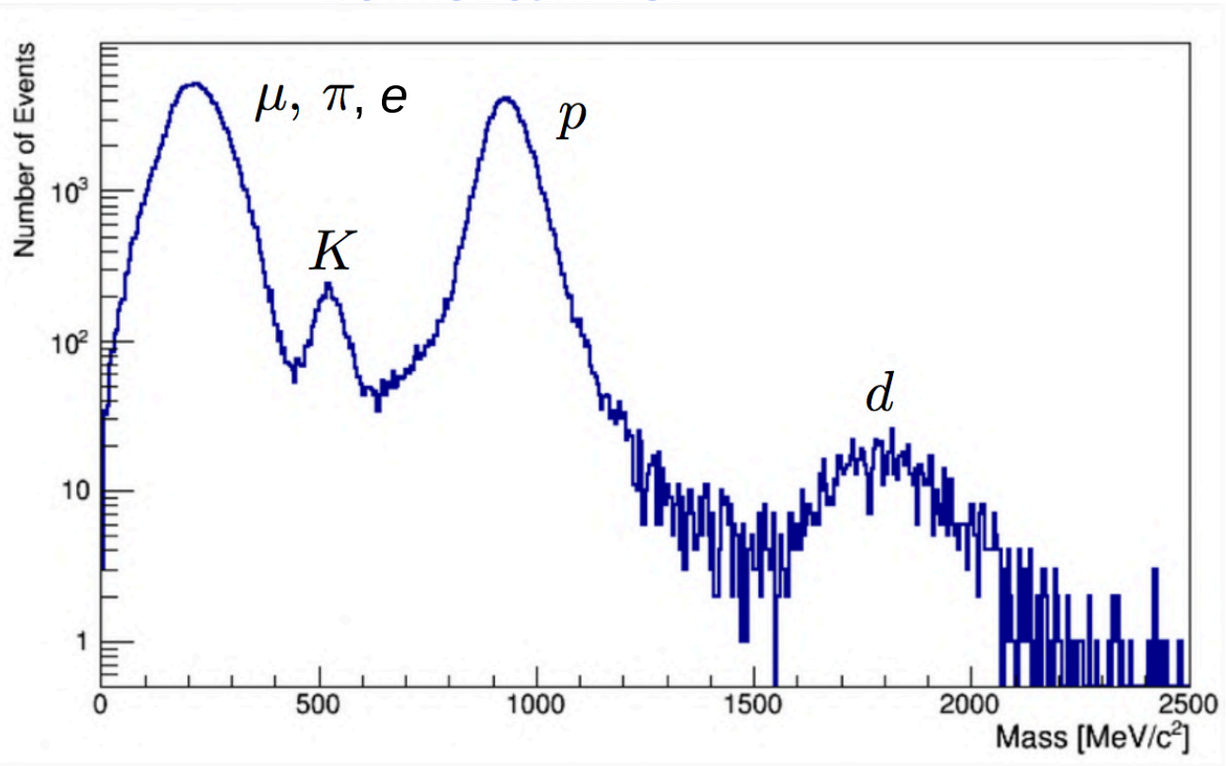


- **TOF -> provides time (Δt) through a "clock"**
- **MWCs -> pairs provide trajectory**
- **Momentum (p_z) -> trajectory + magnets (B-field)**



$$P_z = \frac{B \cdot L}{3.3 \cdot \theta}$$

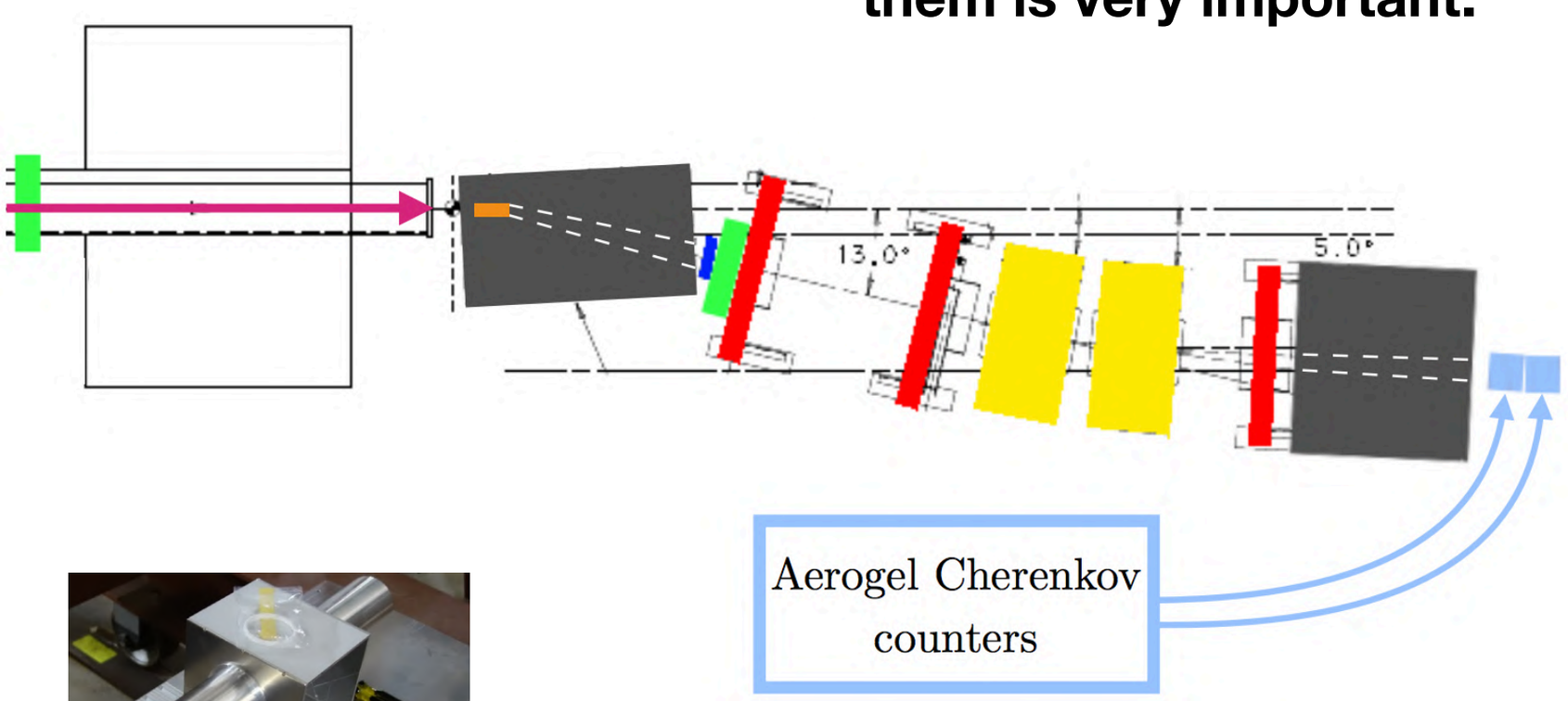


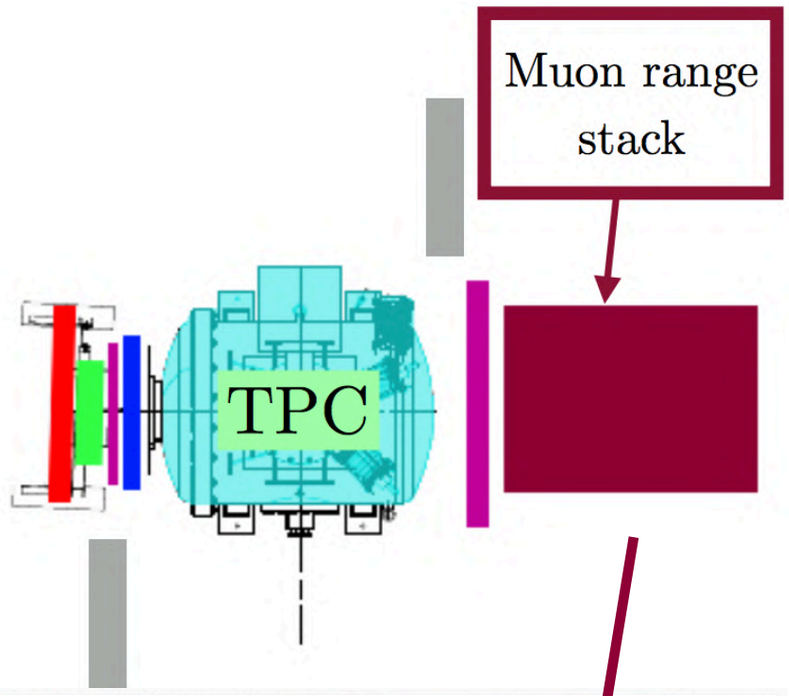


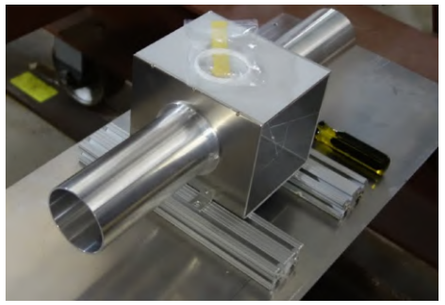
$$m = \frac{p_z}{c}\sqrt{\left(\frac{c\Delta t}{L}\right)^2 - 1}$$

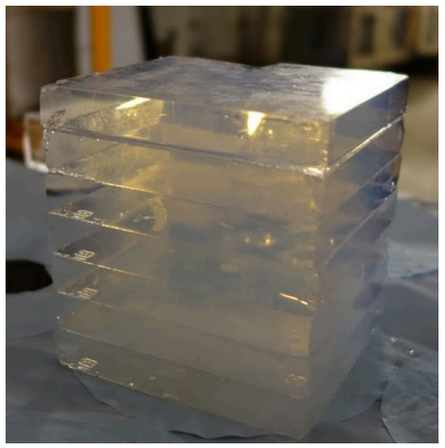
μ & π separation

Muons and Pions look quite similar in LArTPCs. Being able to discriminate between them is very important.



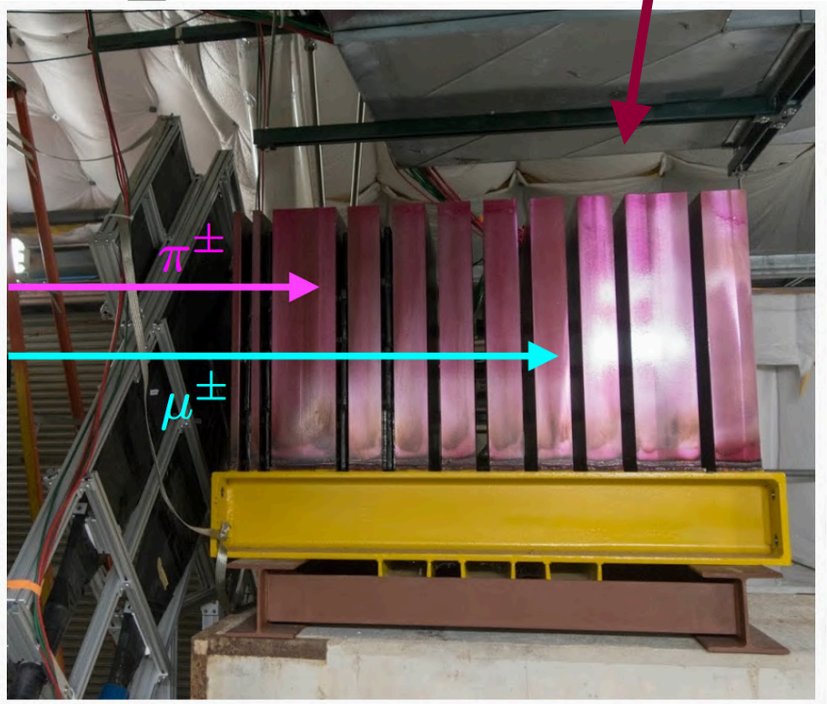




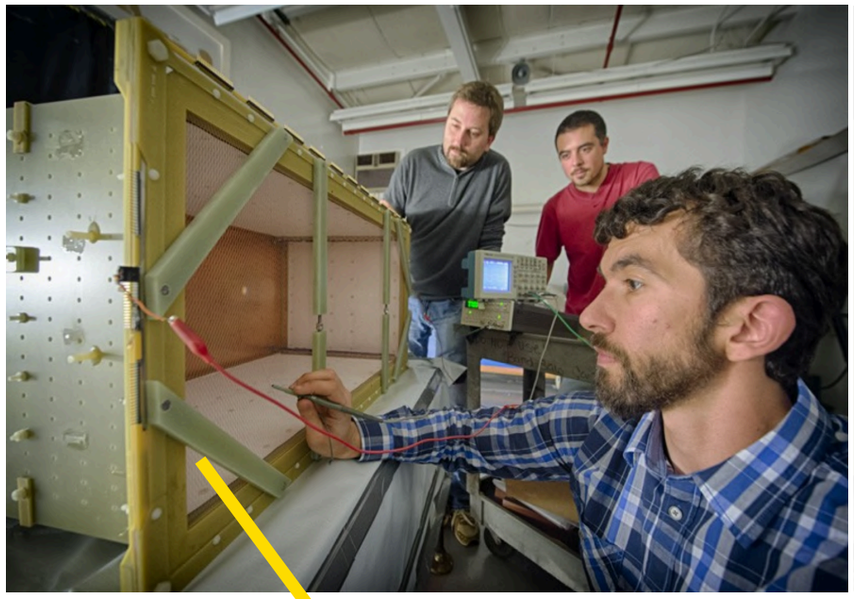


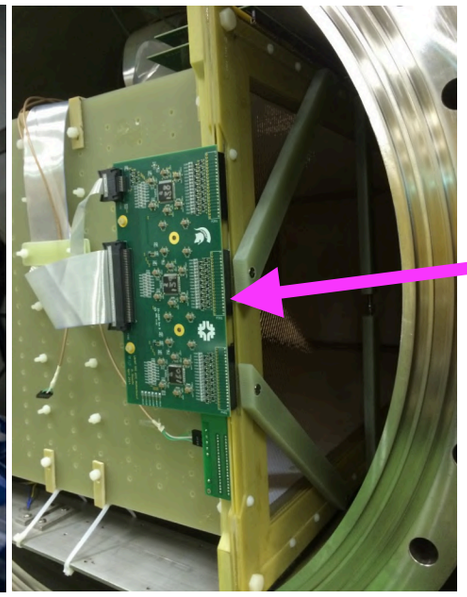
Effective for TPC-contained μ/π (low) energies

p_z (MeV/c)	n = 1.11	n = 1.057
200 - 300	μ π	μ π
300 -400	μ π	μ π

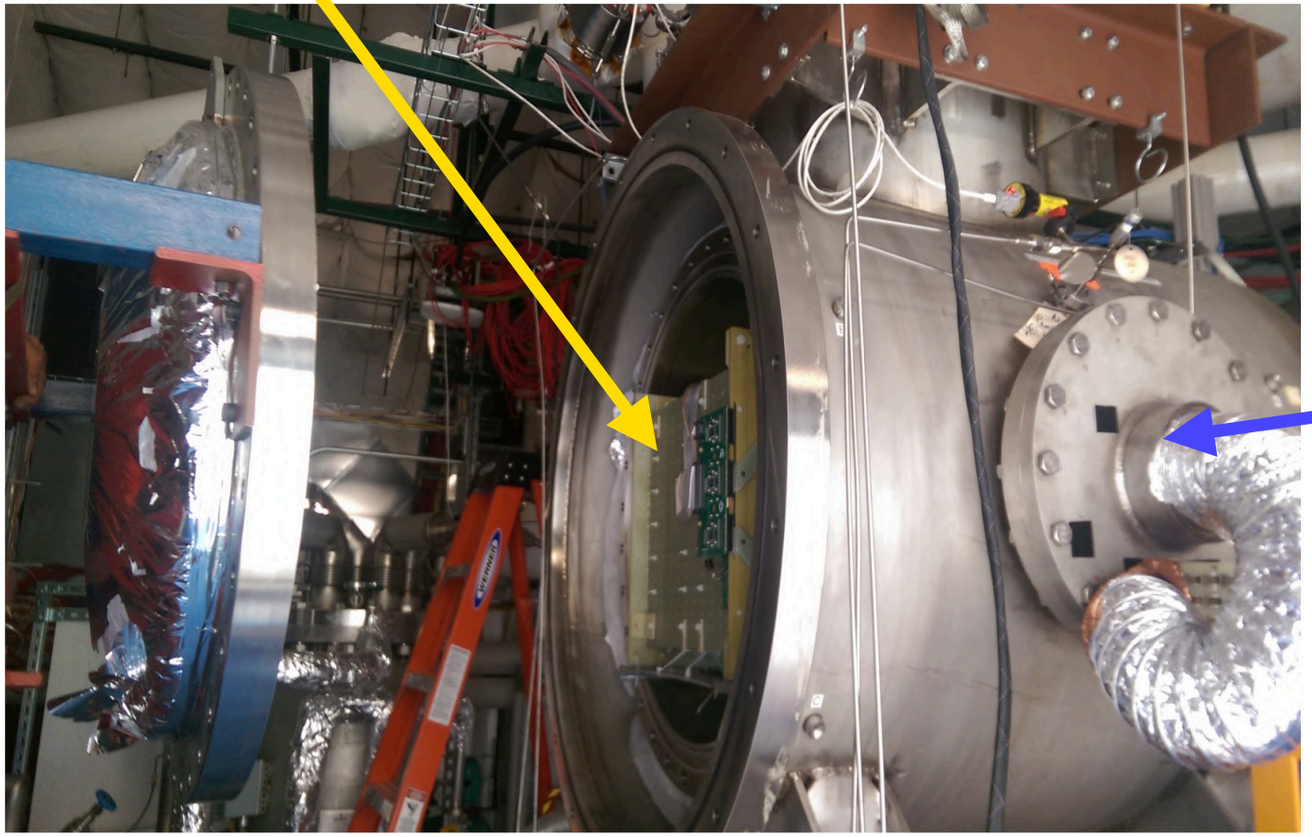


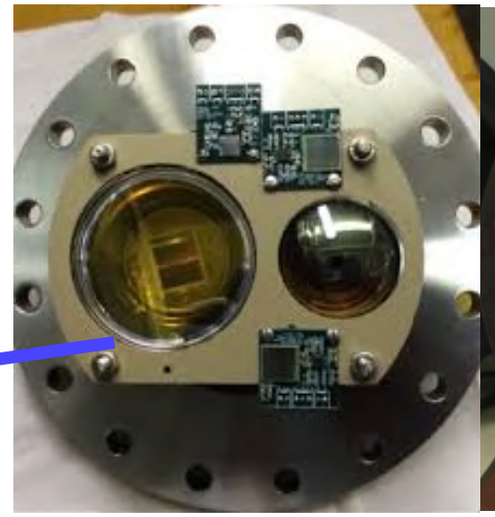
What goes in the Cryostat?

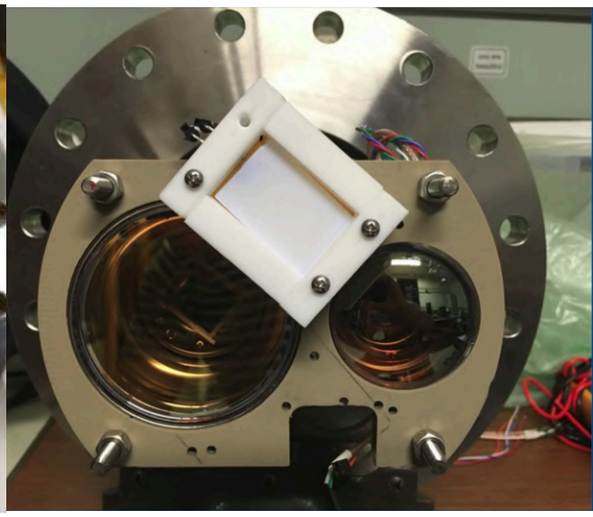




- Cold electronics (pulse shaping and amplifying): ~70:1 S/N during Run II





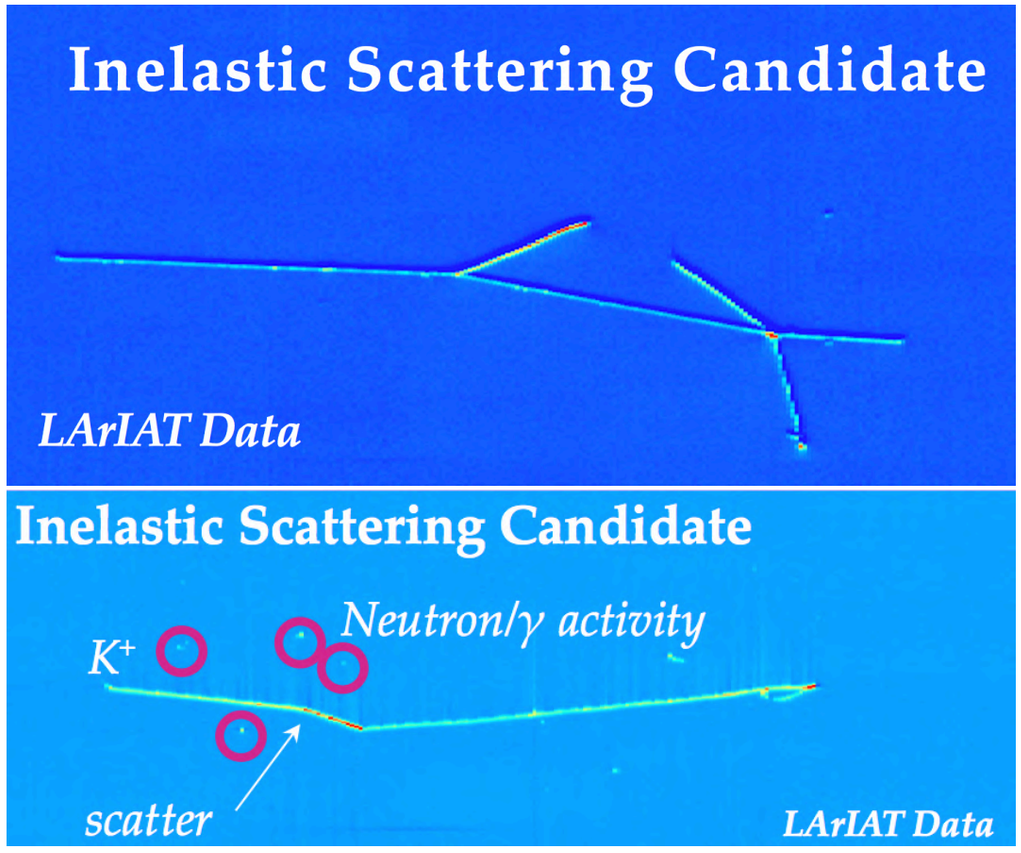


- Scintillation light readout:
  - PMTs/SiPMs (Run I and II)
  - PMTs/ARAPUCA (Run III)

Physics and R&D with LArIAT

Main physics program:

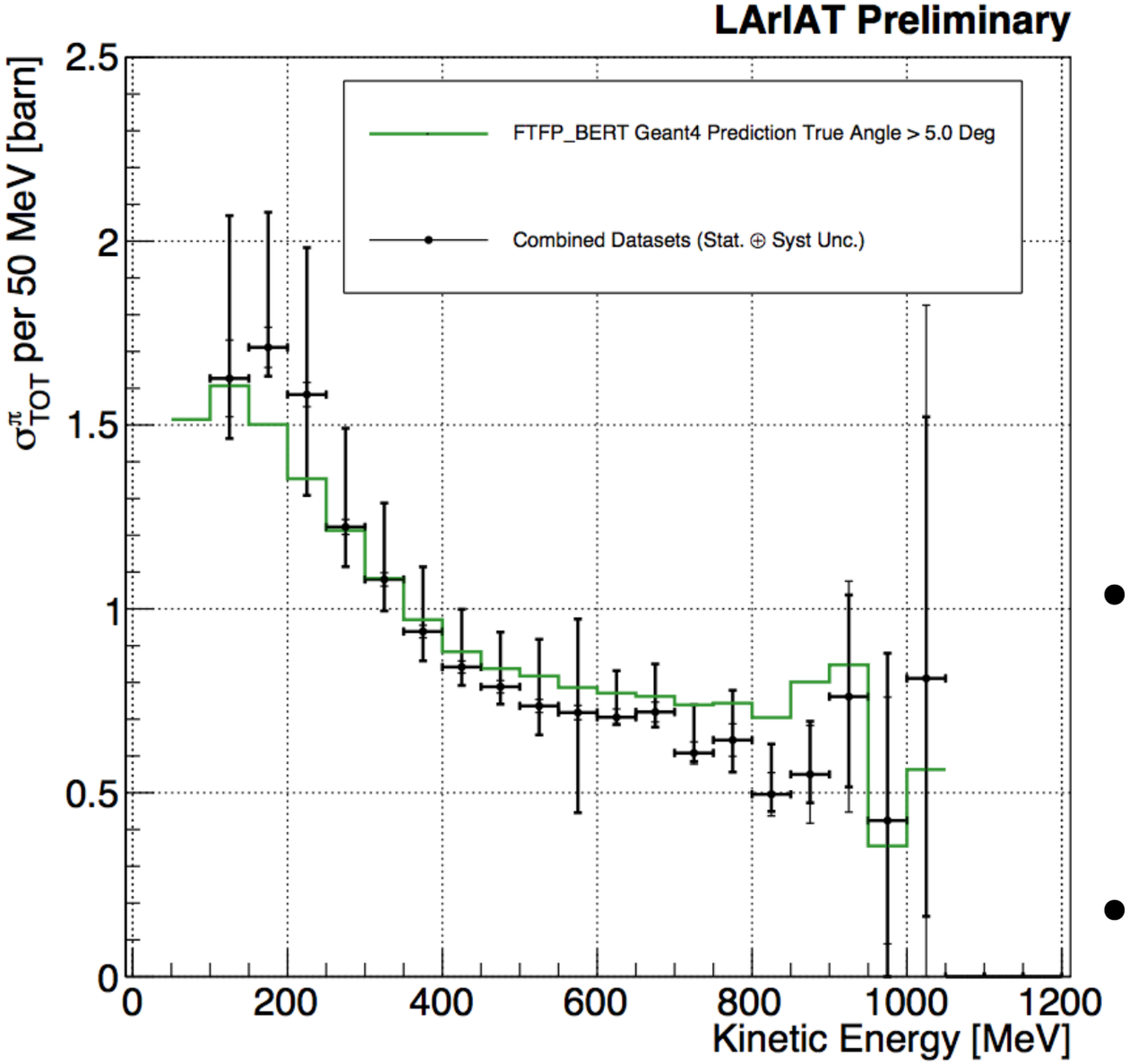
- Cross-section with hadrons:
  - Pions on argon
  - Kaons on argon
  - p on argon

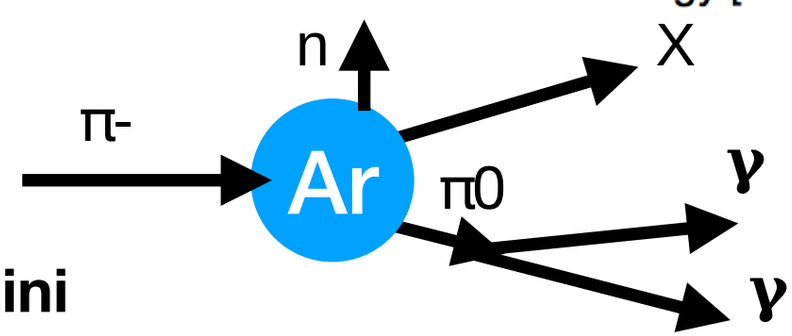


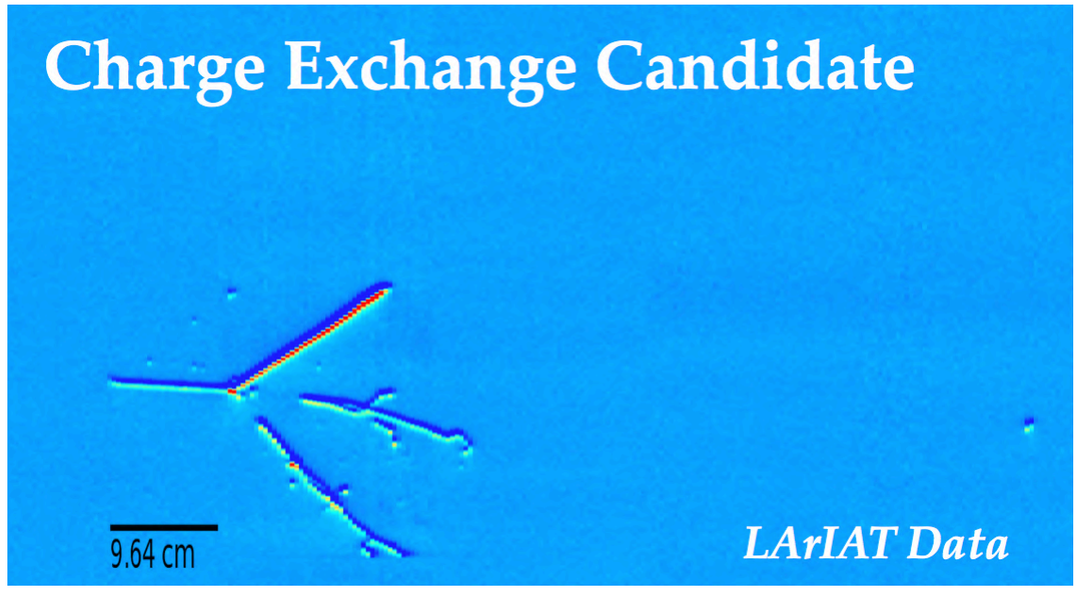
R&D work:

- Distinction between electron vs photon initiated electromagnetic showers.
- Scintillation light yield and ionisation charge deposition relationship.
- Calorimetric calibration with tertiary beam particles (same that emerge from neutrino interactions).
- Anti-proton analysis in liquid argon.

Pion- Cross-Section



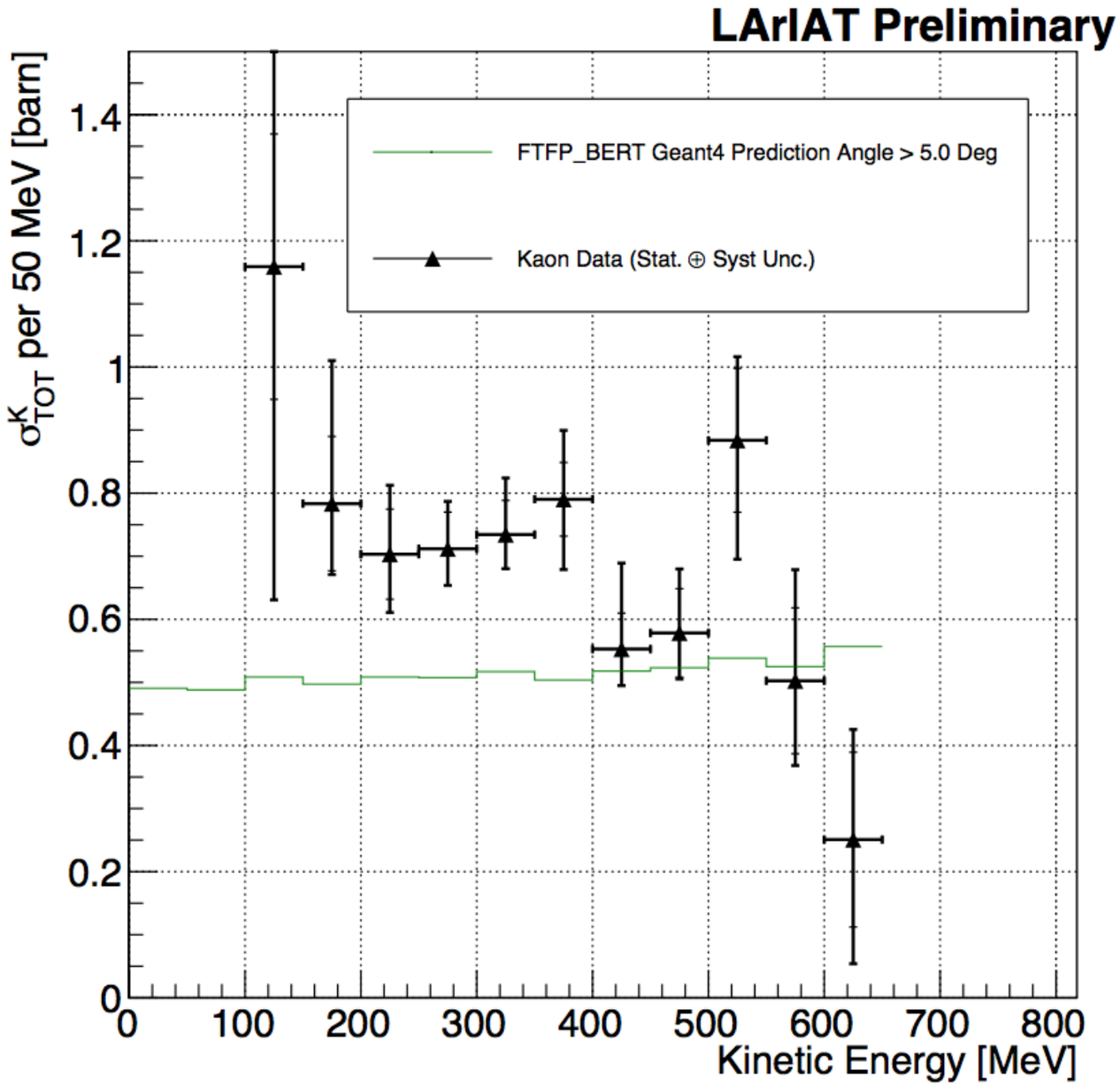


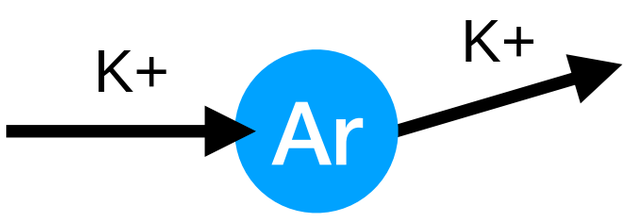


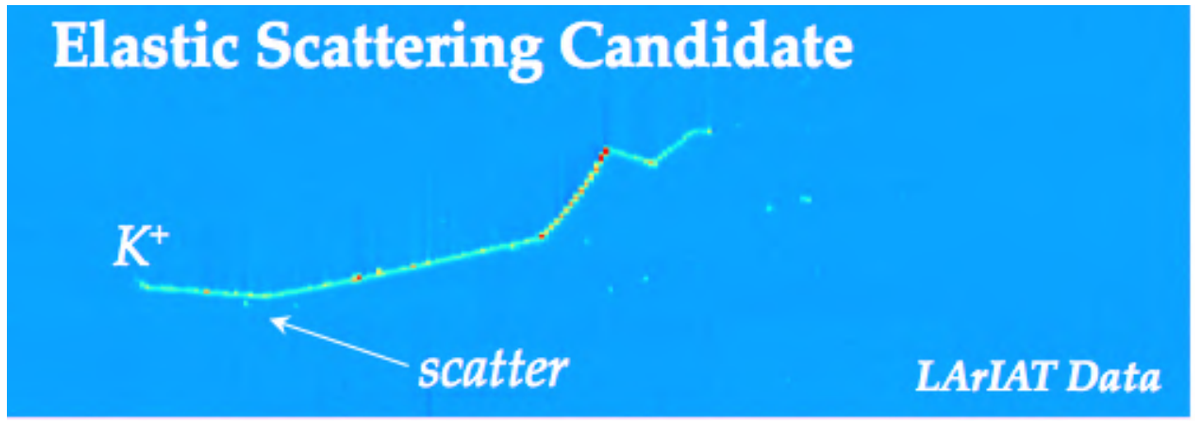
- First pion- total cross-section on liquid argon in energy range measurement!
- Uncertainty dominated by systematics (removal of background interactions - e.g. decay, capture).
- Hint of discrepancy but overall good agreement with prediction.

E. Gramellini

Kaon$^+$ Cross-Section





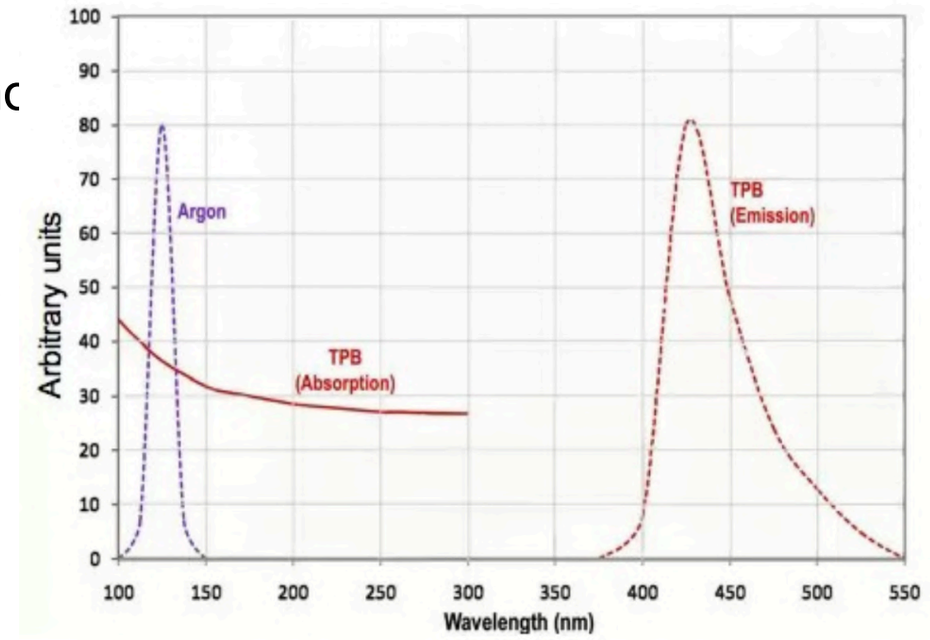


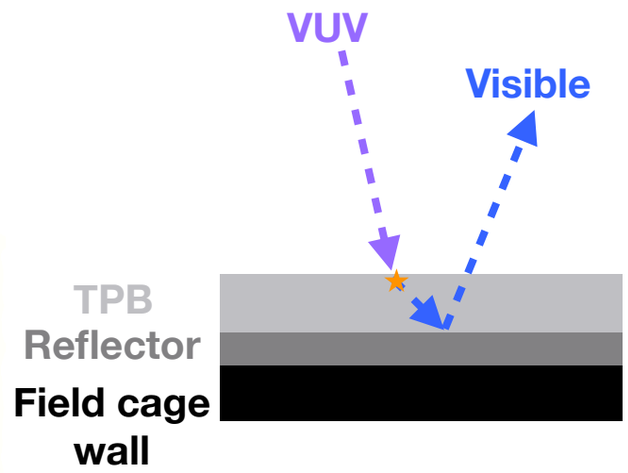
- First kaon$^+$ total cross-section on liquid argon in energy range measurement!
- Low statistics sample (stats error dominates over systematics here).
- General tension with prediction can help K model tuning.

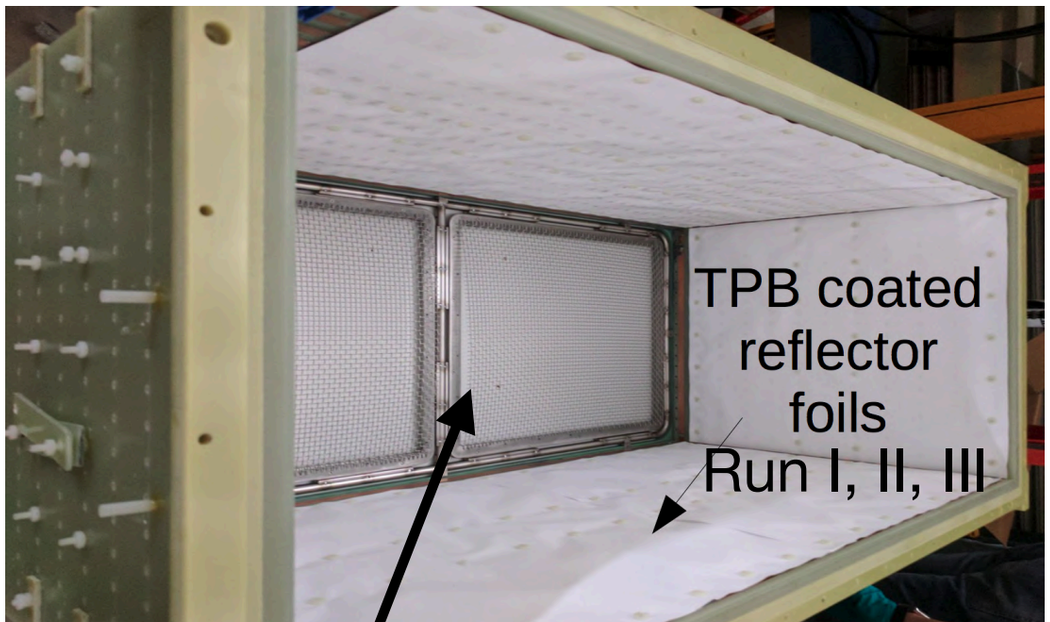
E. Gramellini

Improving Light Collection Efficiency

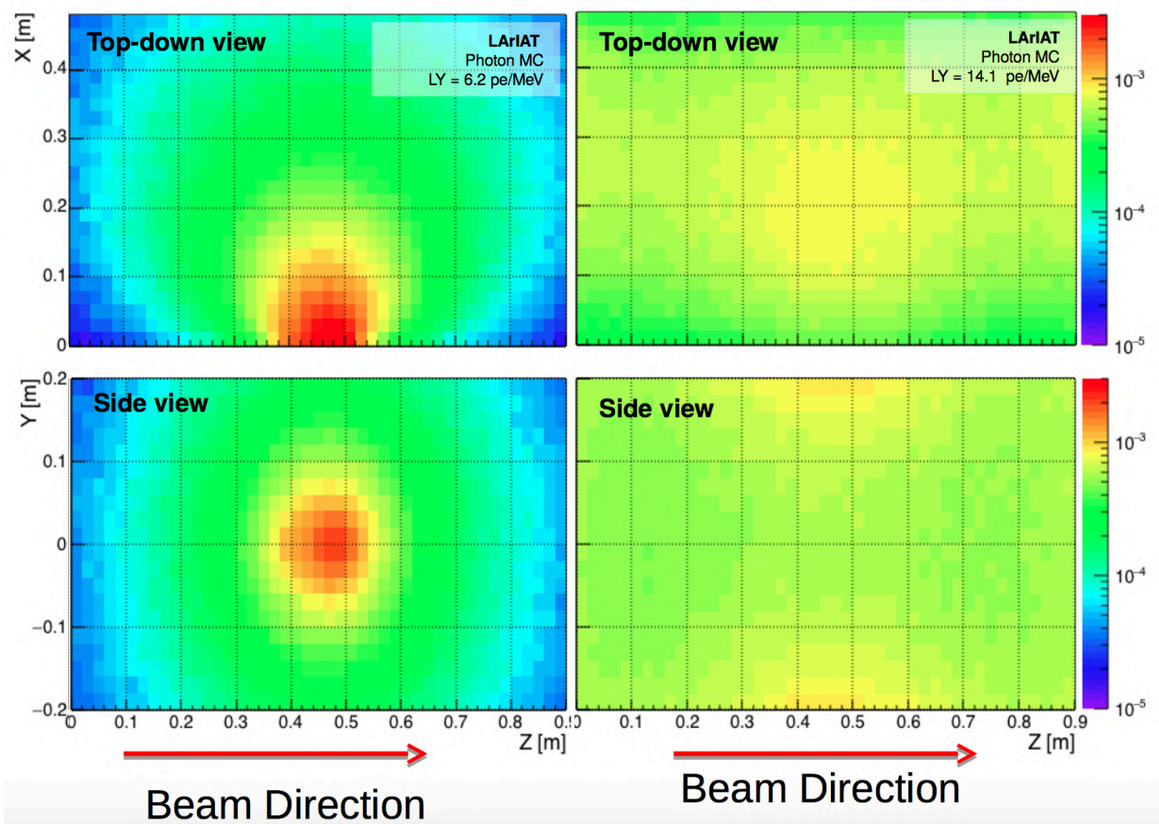
- LAr scintillates at 128-nm vacuum ultra-violet (VUV). Most light detectors are blinc to this light.
- Using a Wavelength-shifter such as tetra phenyl butadiene (TPB) will shift the scintillation to the visible spectrum.
- Advantages -> improved light yield and uniformity across the detector.
- This enables improvements to calorimetry and triggering done by the light.





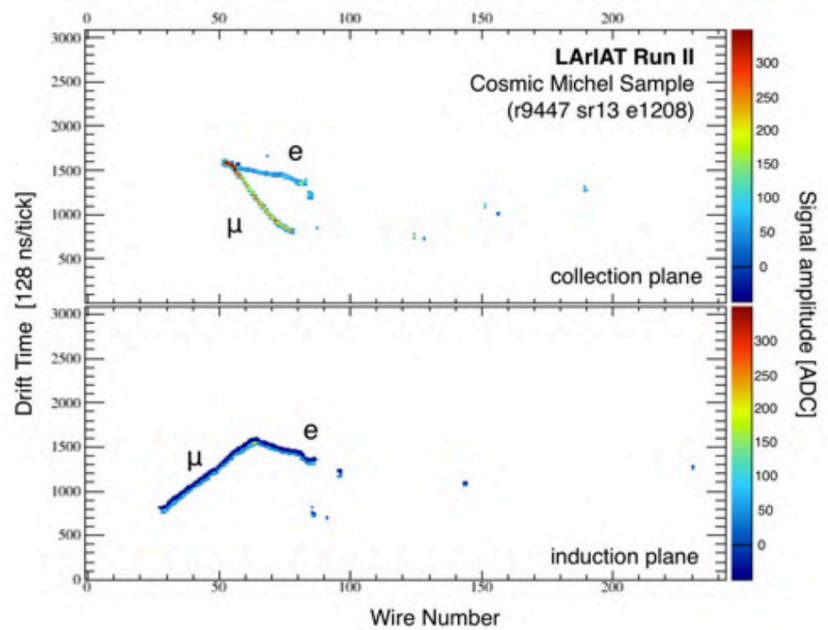


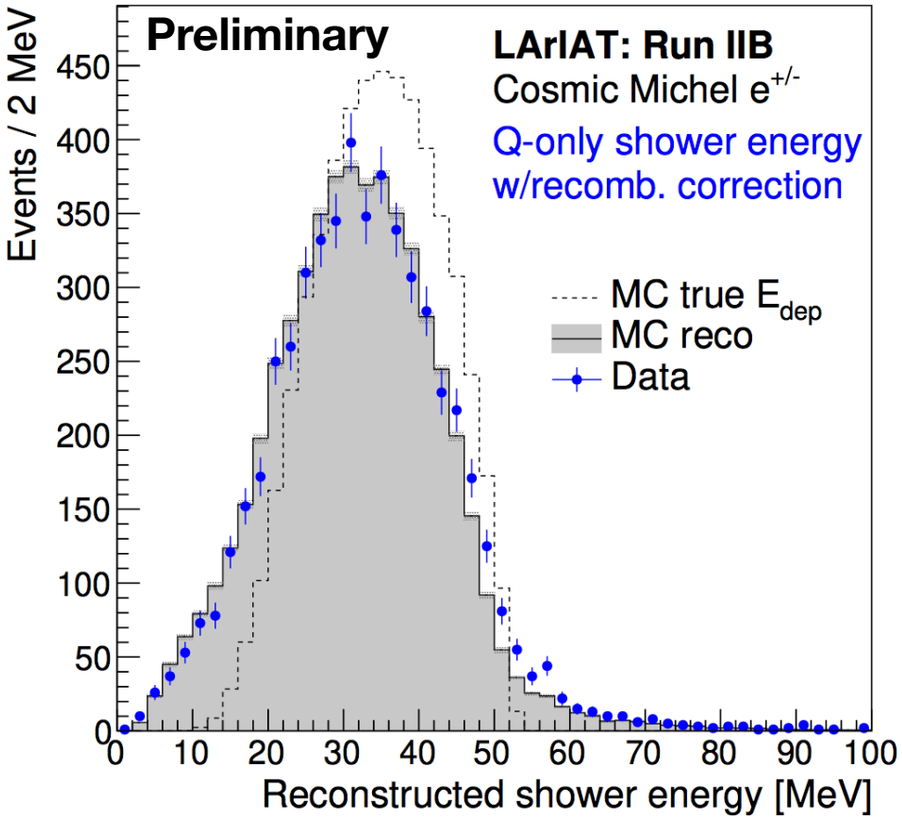
Cathode mesh + foil à la SBND (Run III)



What can we do with all this light?

- Michel electrons are very low energy electrons emitted by stopping muons.
- Michel e's are triggered using the light detection system. Being able to see more light can improve on their reconstruction.
- This shows an analysis of reconstructing cosmic Michel electrons only using charge and recombination corrections (Q) vs using a combination of charge and light (L) signals.



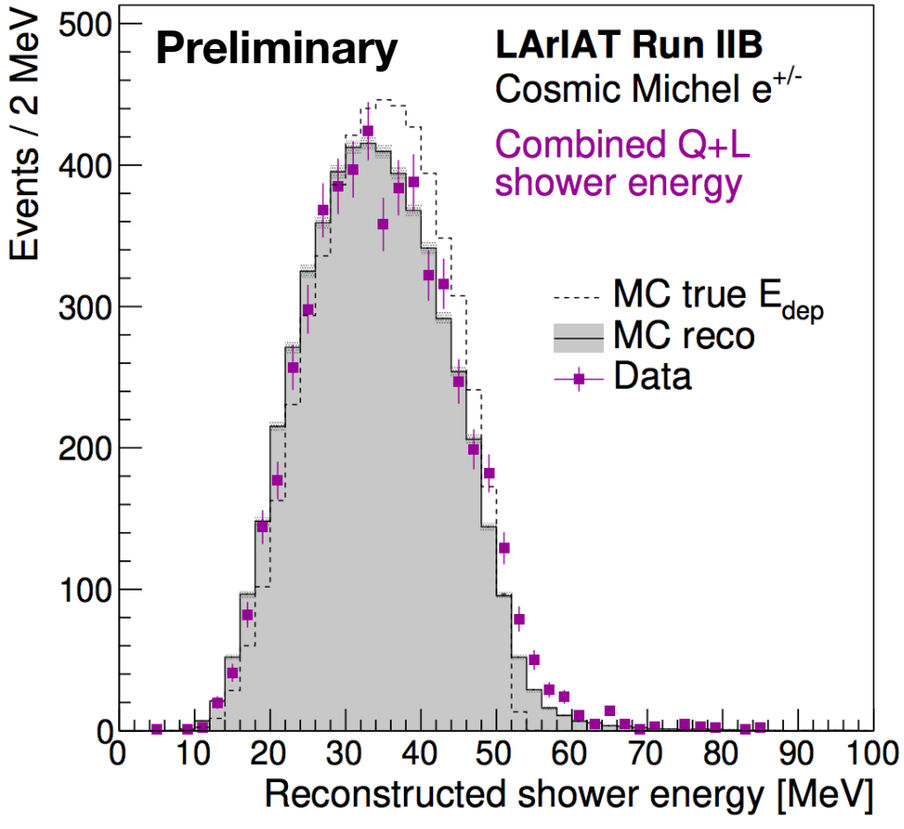


(a) 'Q-only' energy spectrum

Low-E tail in Q-only mitigated in Q+L. Information lost by only looking at Q is partially recovered with L.

Better MC-true and MC-reco agreement!

W. Foreman



(b) 'Q+L' energy spectrum

In the end…

- LArIAT may be small in size but certainly is full of interesting and important physics:
  - First total inclusive hadron-argon cross-section measurements in pion- and kaon+ in energy range.
  - Combining scintillation light and ionisation channels for energy reconstruction measurements (e.g. cosmic Michel electrons) by using the power of the wavelength-shifting reflective foils.
  - Development of particle ID and testing LArTPCs R&D.
- Stay tuned for exciting new results!

All valuable for short and long baseline experiments!

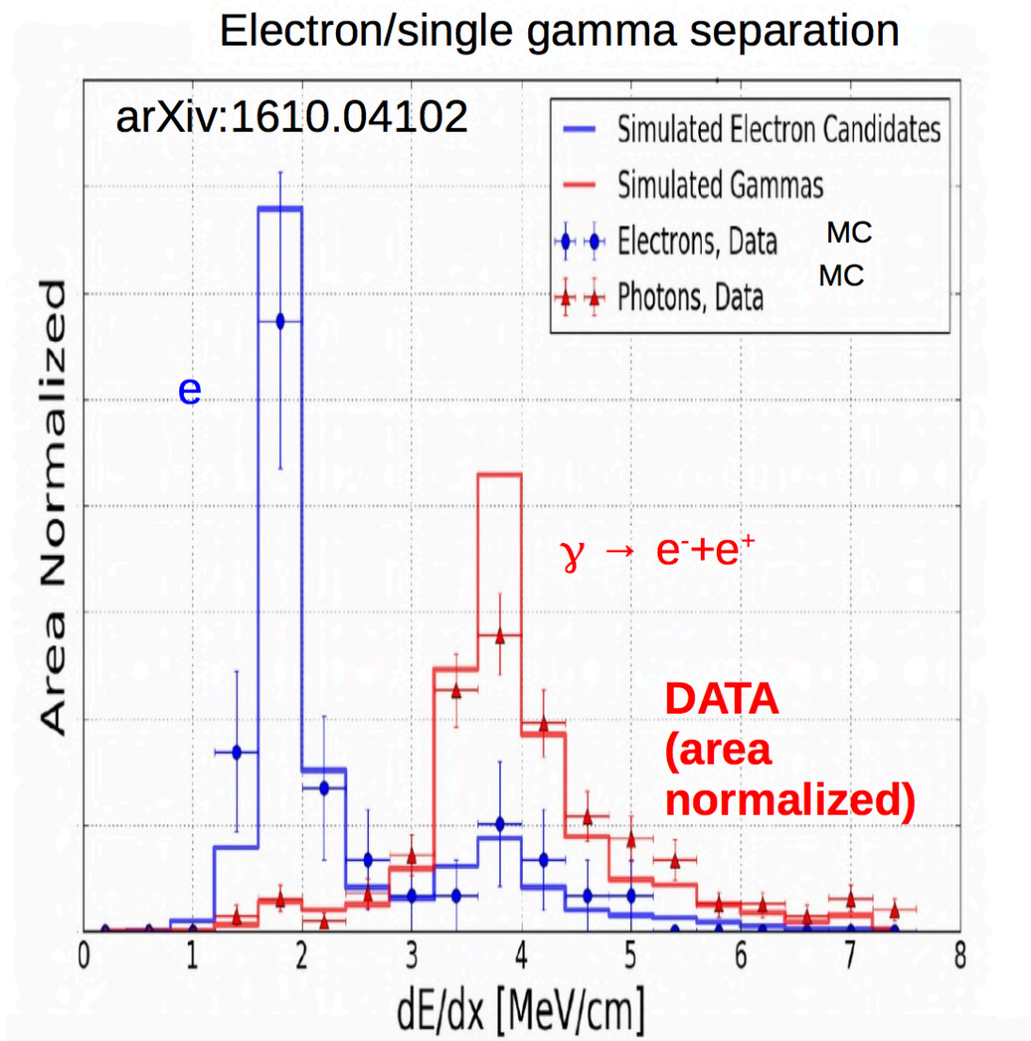
Thank you!

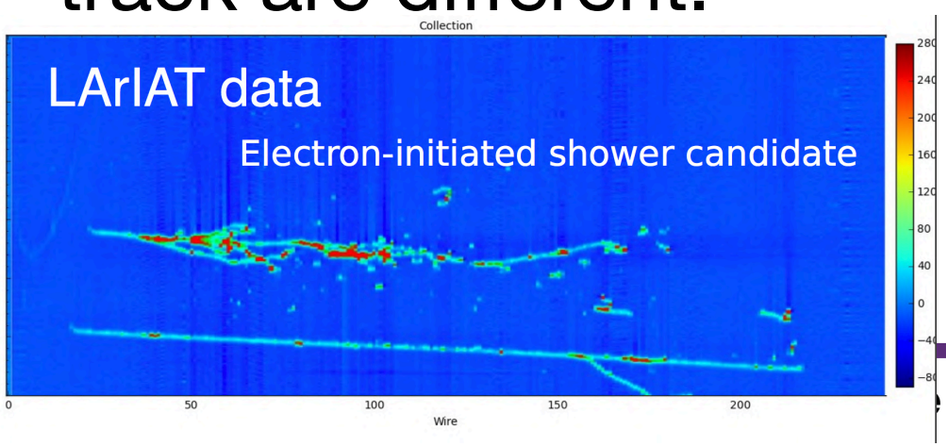
Backup

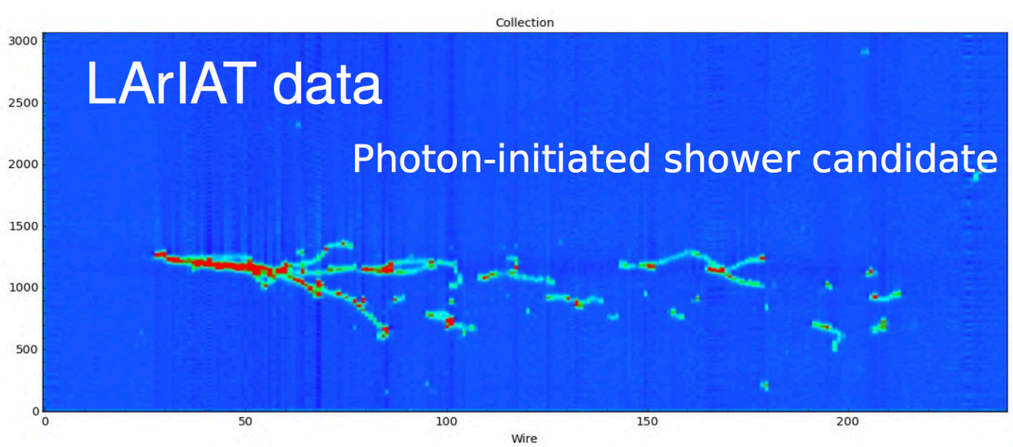
electron/gamma

- ArgoNeuT e/gamma separation. LArIAT will have more POT and possibly better distinction. Also working on some machine learning (CNN) methods.

- Gap between interaction point and also energy deposited at the start of the track are different.







Thin Slice Method

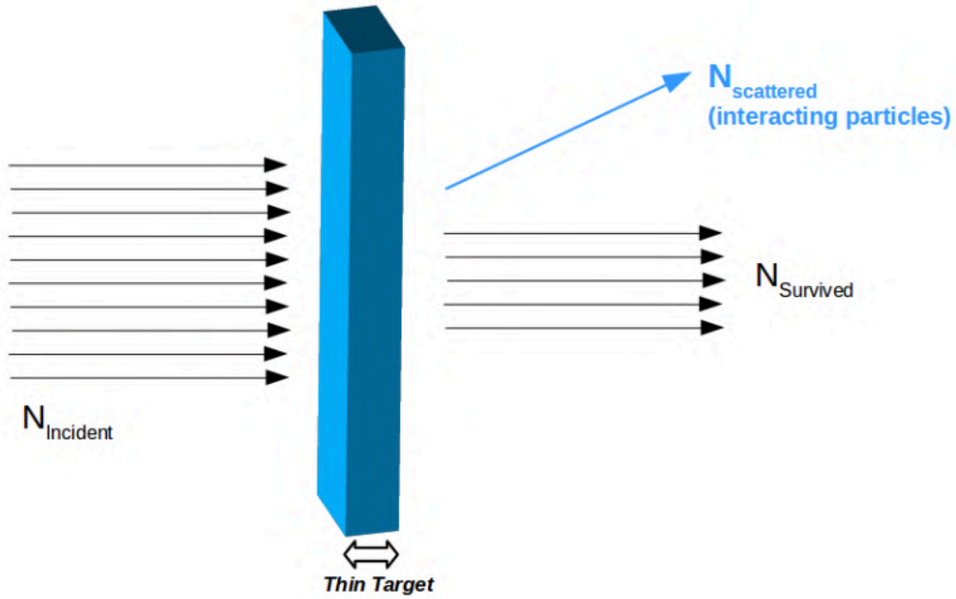
The particle **interaction probability** through a **thin slice** of Ar

$$P_{\mathrm{Int}} = \frac{N_{\mathrm{Int}}}{N_{\mathrm{Inc}}} = 1 - e^{-\sigma_{\mathrm{TOT}}\, \mathrm{n}\, \delta X}$$

σ_{Tot} = cross section per Ar,
n = Ar number density,
δX = depth of the slice

THIN

$$\sigma_{\mathrm{TOT}}(E) \sim \frac{1}{\mathrm{n}\, \delta X} \frac{N_{\mathrm{Int}}}{N_{\mathrm{Inc}}}$$



We treat the **wire-to-wire spacing** as a **series of "thin-slice"** targets, since we know the energy of the particle incident to each slice.

Each thin slice is an independent experiment

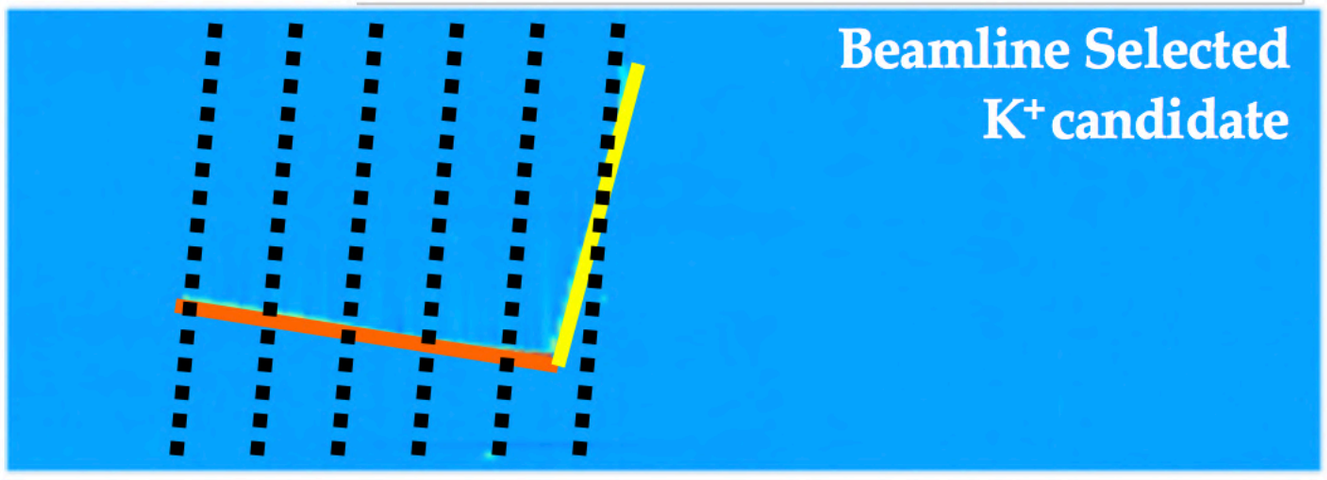
Thin Slice Method

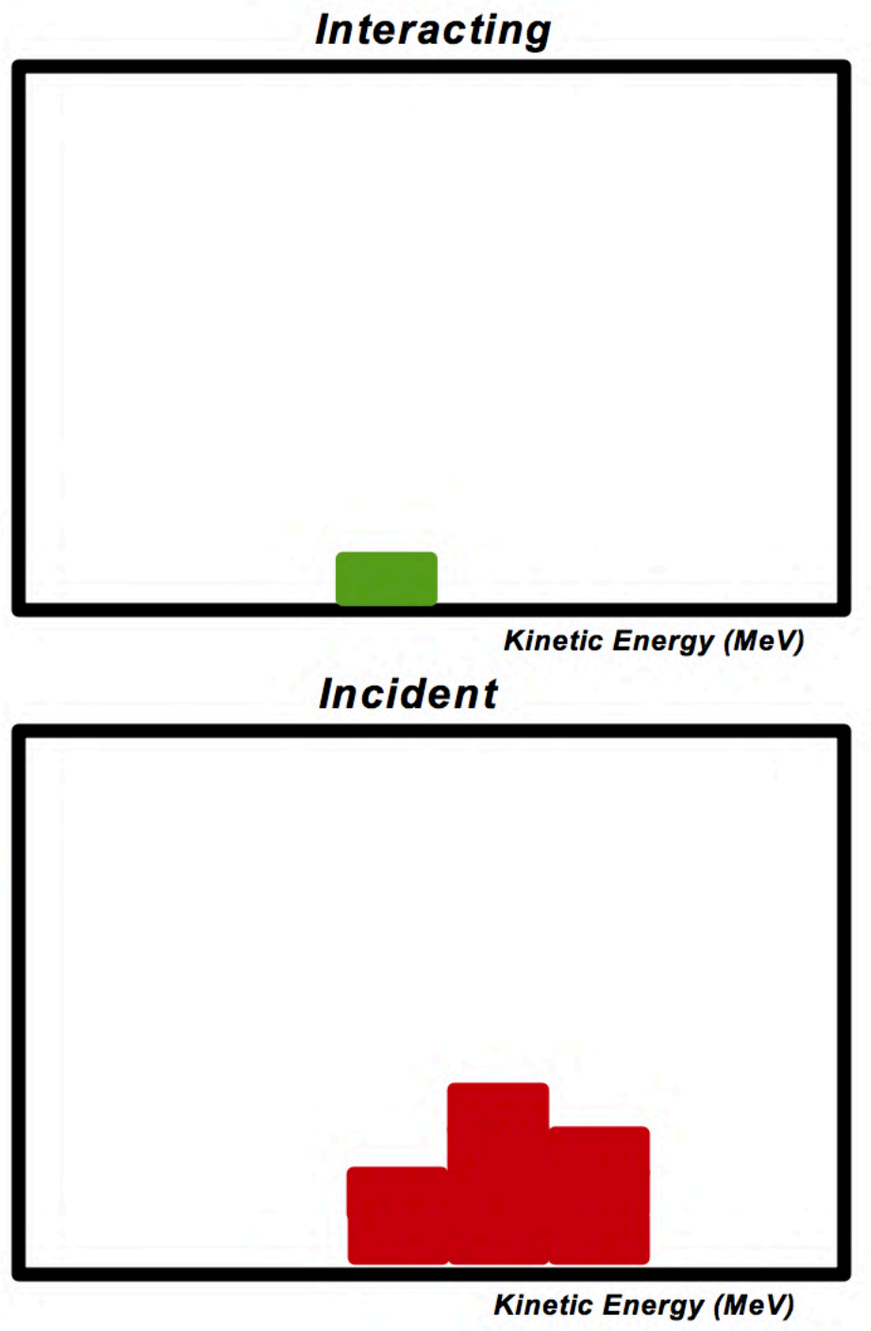
We follow the TPC track slice by slice

- The slice represents the distance between each 3D point in the track
- For each slice we ask: "Is this **the end** of the track?"

YES! Calculate the KE at this point and fill both the "**interacting**" and "**incident**" histograms

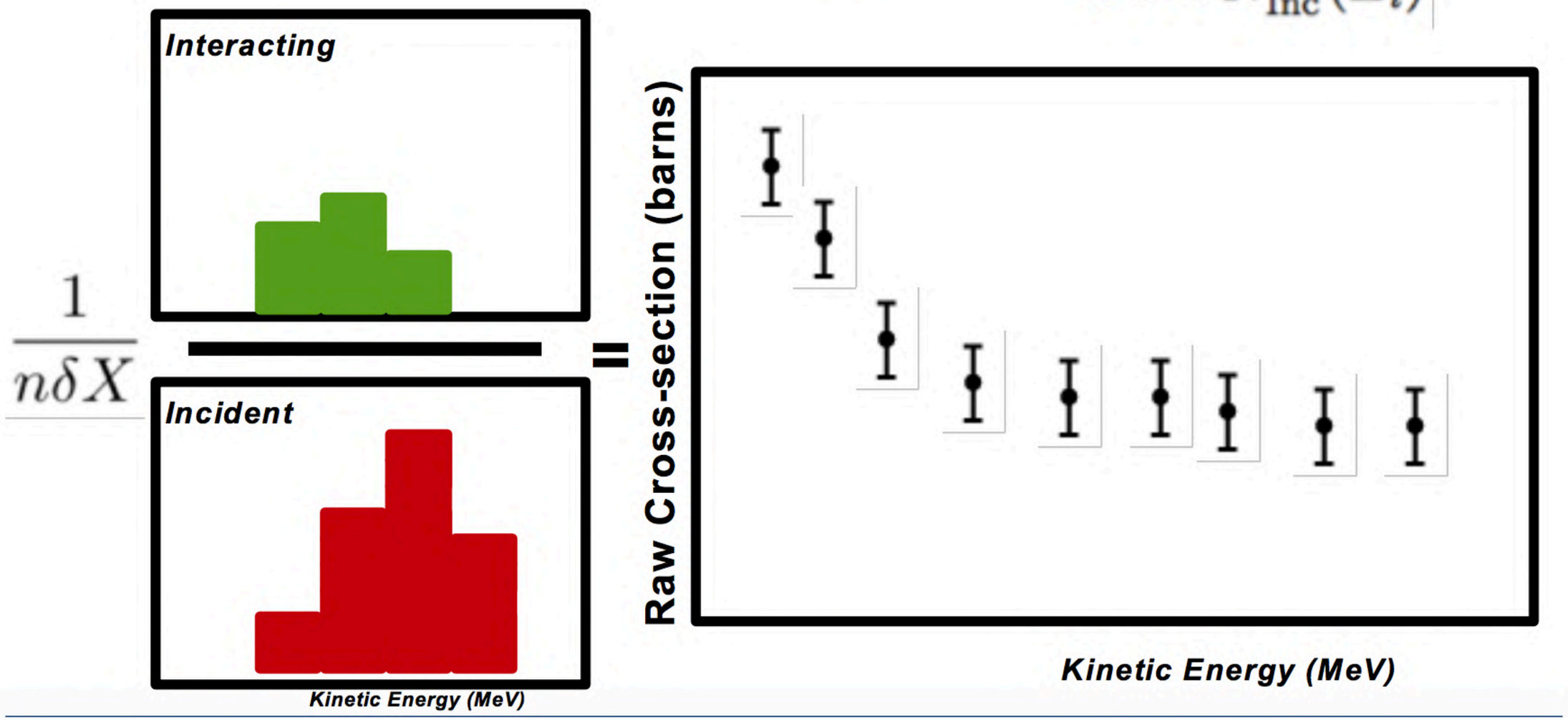
$$E_j^{\text{kin}} = E_{\text{Front Face}}^{\text{kin}} - \sum_{j<i} E_{\text{dep i}}$$





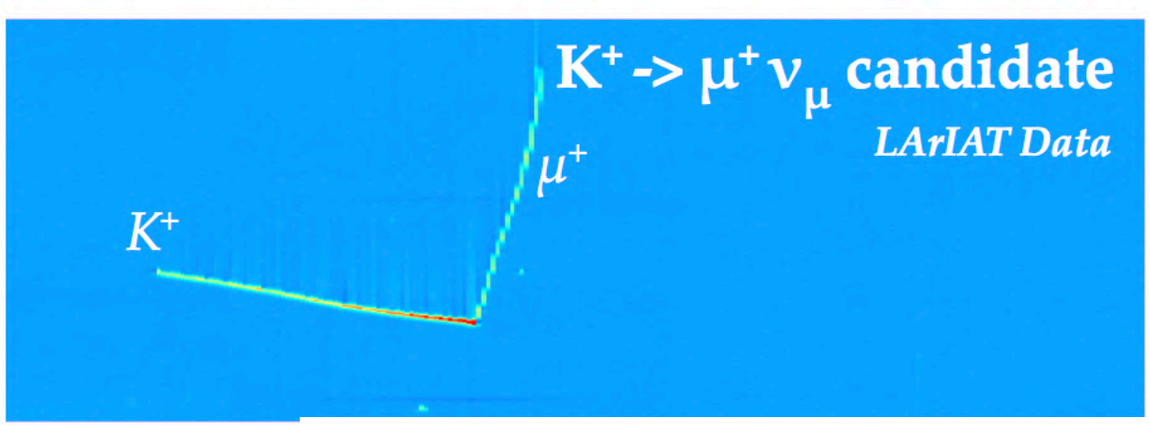
Thin Slice Method

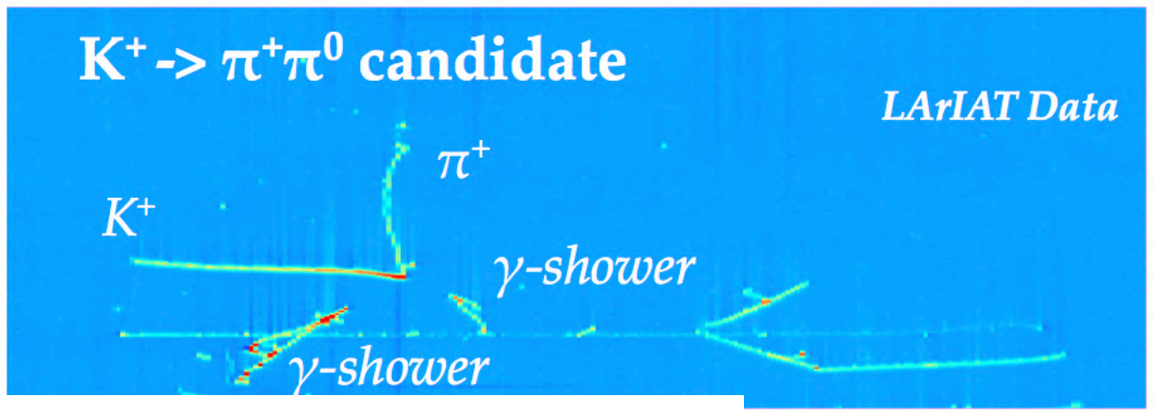
$$\sigma^{\pi^-}_{TOT}(E_i) = \frac{1}{n\,\delta X}\frac{N^{\pi^-}_{\text{Int}}(E_i)}{N^{\pi^-}_{\text{Inc}}(E_i)}$$

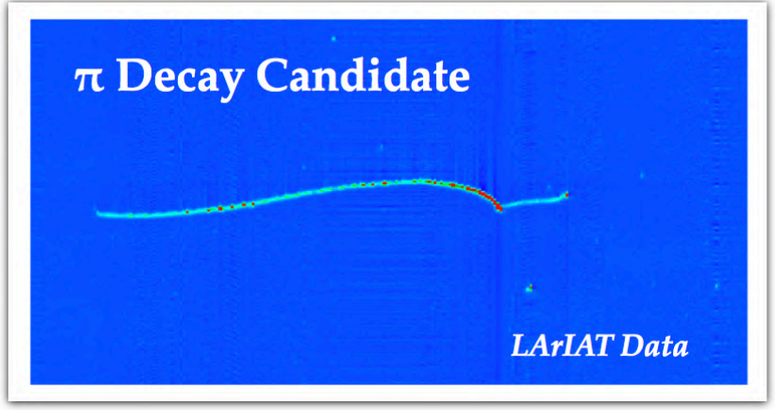


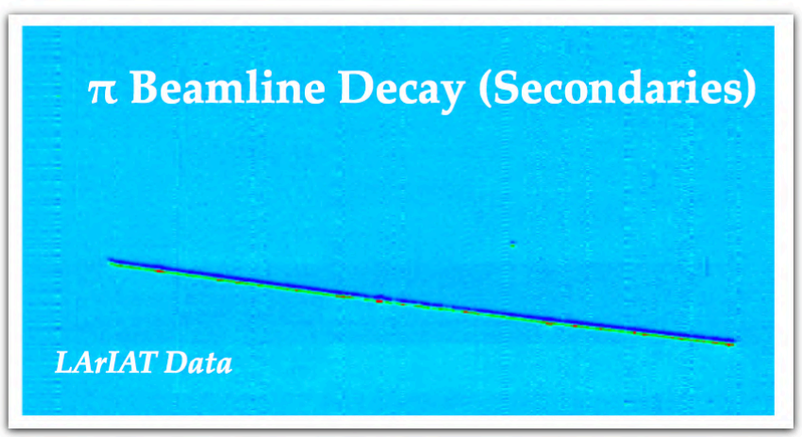
Backgrounds

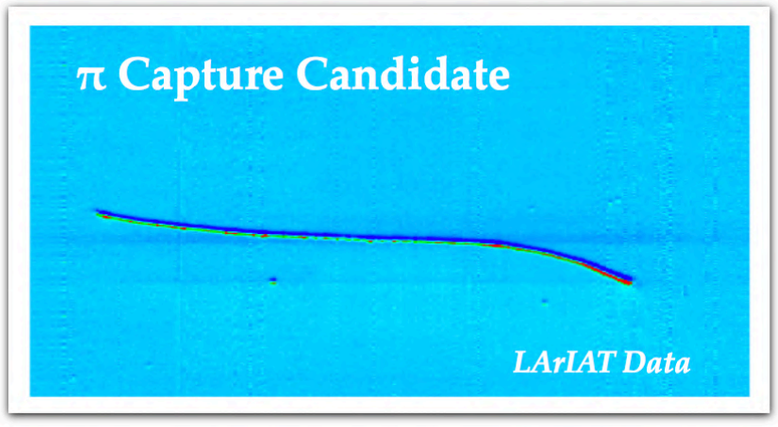
Backgrounds: **Kaon Decay, Secondaries**











+ residual electrons & muons

Nuclear Physics is messy

Incoming ν:

Flavor unknown

Energy unknown

Outgoing lepton:

CC: charged lepton

NC: neutral lepton

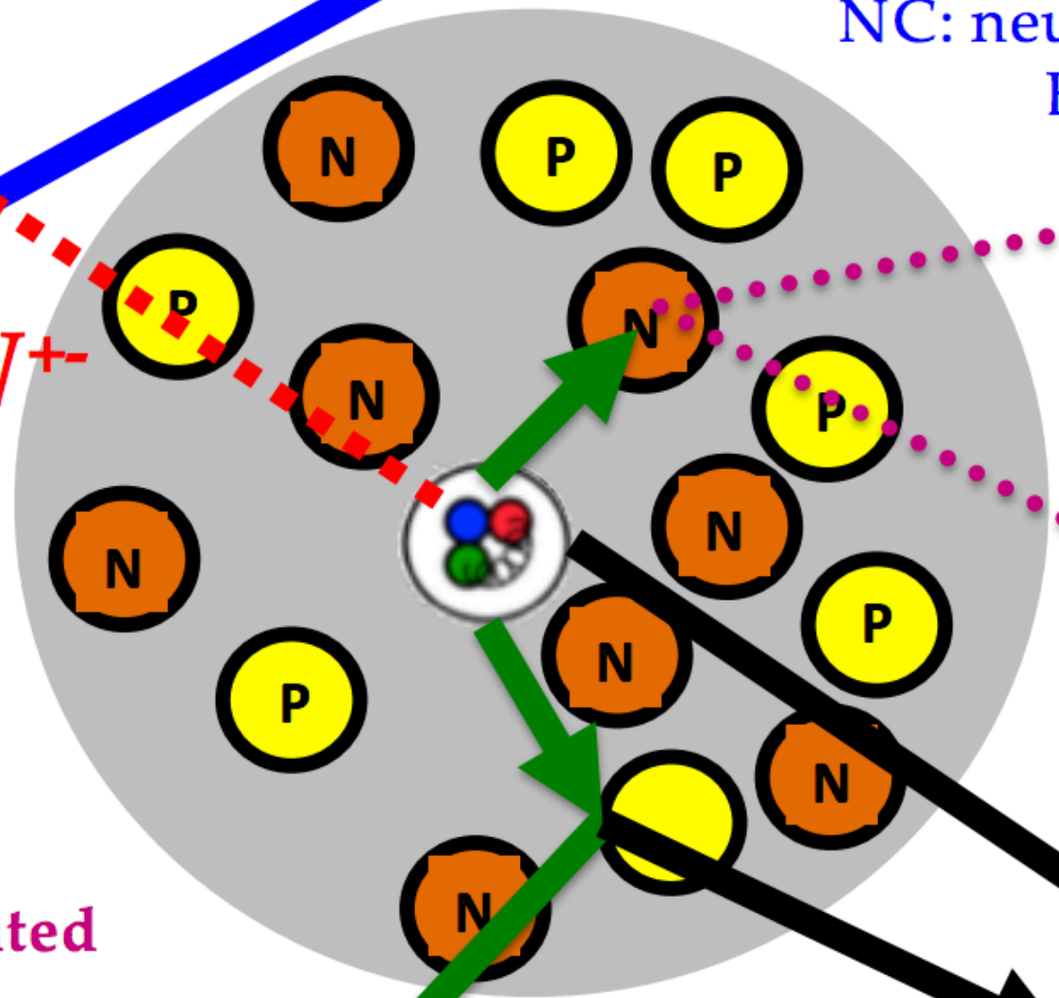
Energy: measure

Z/W+-

Mesons:

Final State Interactions

Energy? Identity?



Credit: Mike Kordosky

Need a **very well calibrated detector technology** able to characterize the ν interaction with the nucleus

Outgoing nucleons:

Visible?

Energy?