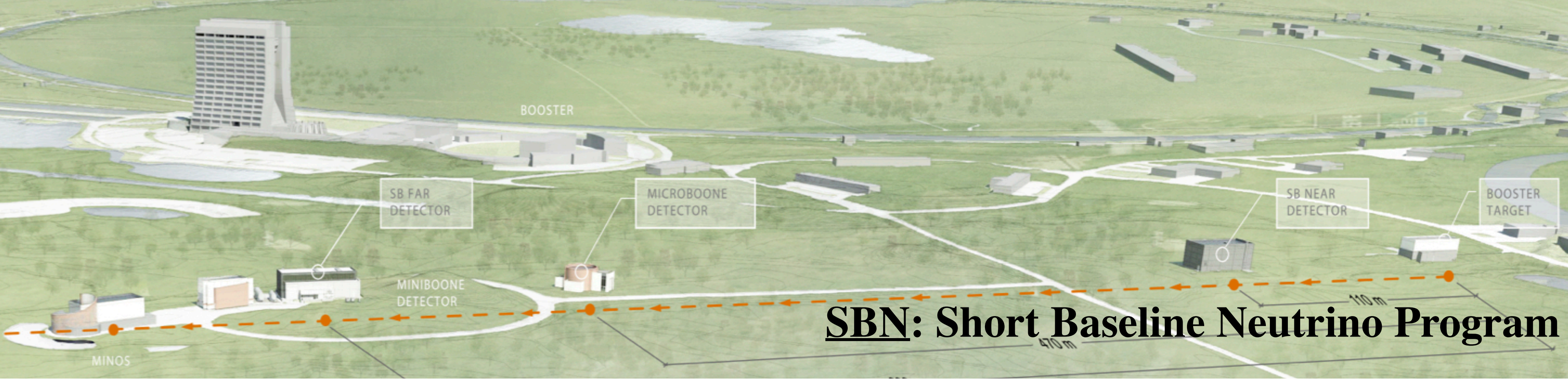
LArIAT: Liquid Argon in A Testbeam

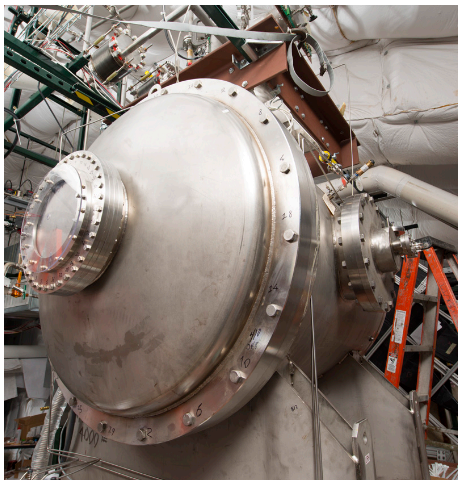
Status of (π^-,Ar) and (K^+,Ar) Total Hadronic Cross Sections

Elena Gramellini
Fermilab

NuInt 2018, October 18th



SBN: Short Baseline Neutrino Program

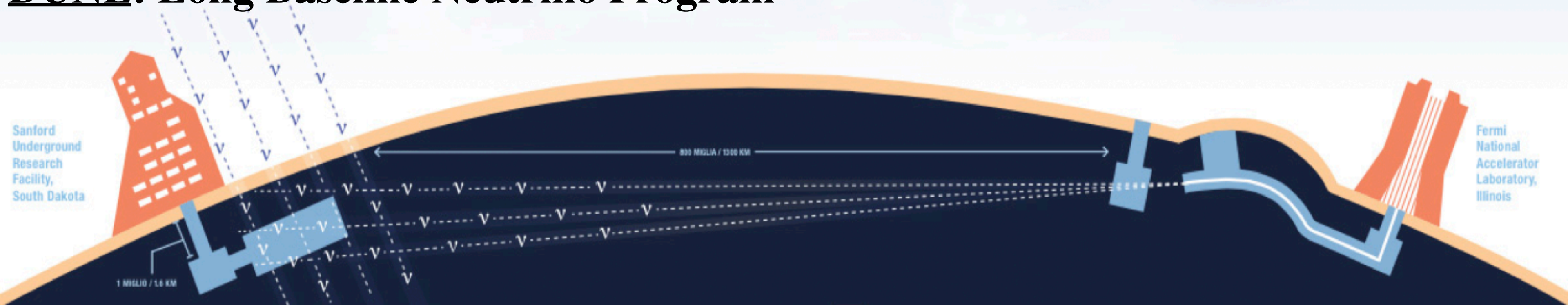


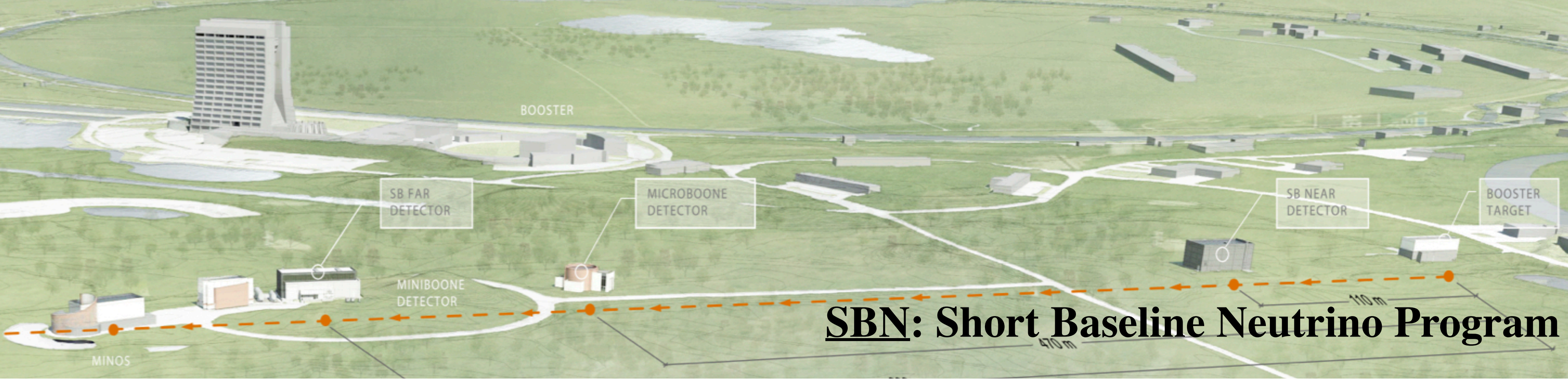
LArIAT: Liquid Argon In A Testbeam

LArIAT is a 170 liters LArTPC deployed in a beam of known charged particles in the energy region relevant to SBN & DUNE

Goal: characterize LArTPC performances for particles up to 1 GeV by measuring quantities key to ν physics in LAr

DUNE: Long Baseline Neutrino Program





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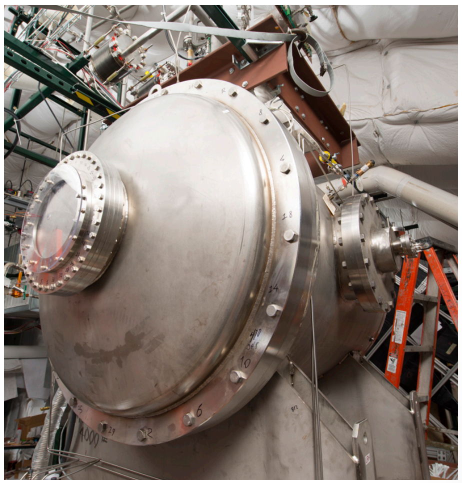


LArIAT: Liquid Argon In A Testbeam

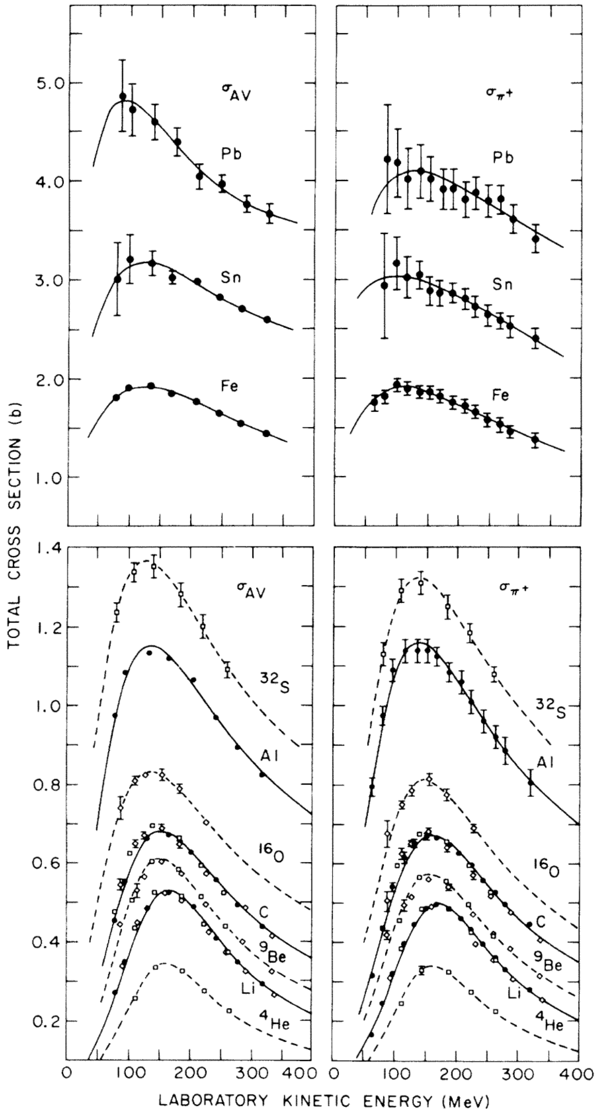
LArIAT is a 170 liters LArTPC deployed in a beam of known charged particles in the energy region relevant to SBN & DUNE

Goal: ch … 1
GeV by …

(π⁻,Ar) , (K⁺,Ar)
Total interaction cross sections
Never measured before

DUNE: Long Baseline Neutrino P…

π Cross Section in the Grand Scheme



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

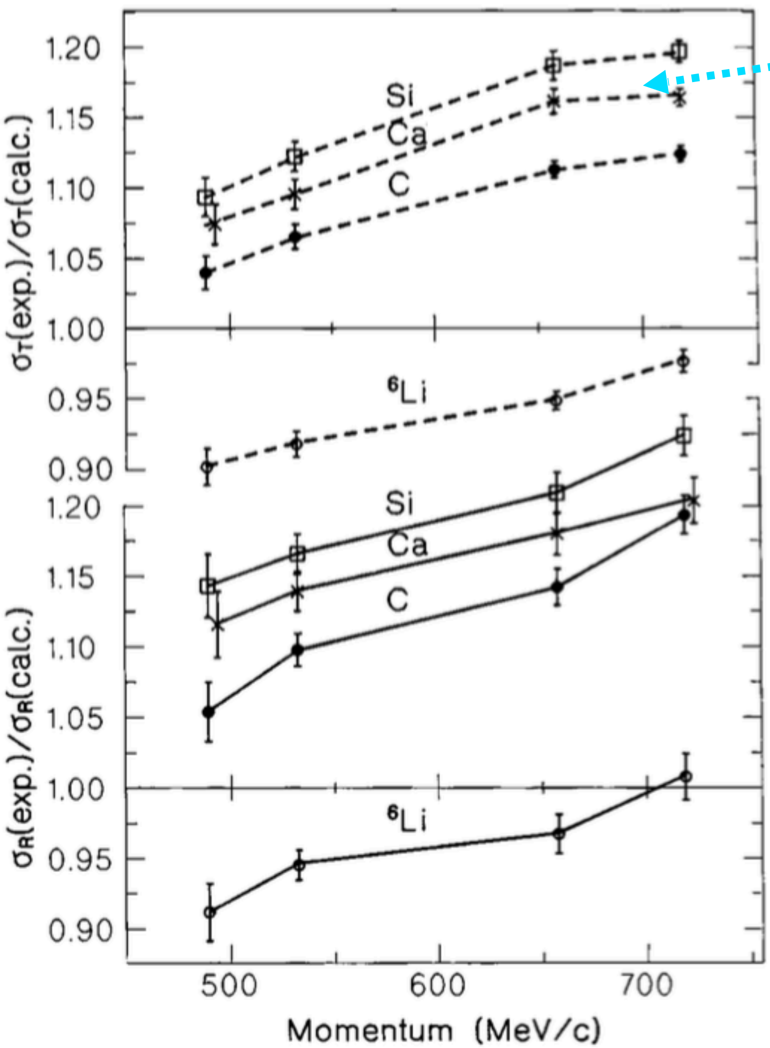
Pion Cross section:

In the energy range of **100-500 MeV**, pion interactions are dominated by **Δ resonances**, and the π-Ar cross section is boosted… the topology of ν events gets complicated!

Geant4 uses interpolation from lighter-heavier nuclei

The shape of the delta resonance **changes** as a function of the **mass number**

K Cross Section in the Grand Scheme



E. Friedman et al. Phys. Rev., C55:1304–1311, 1997

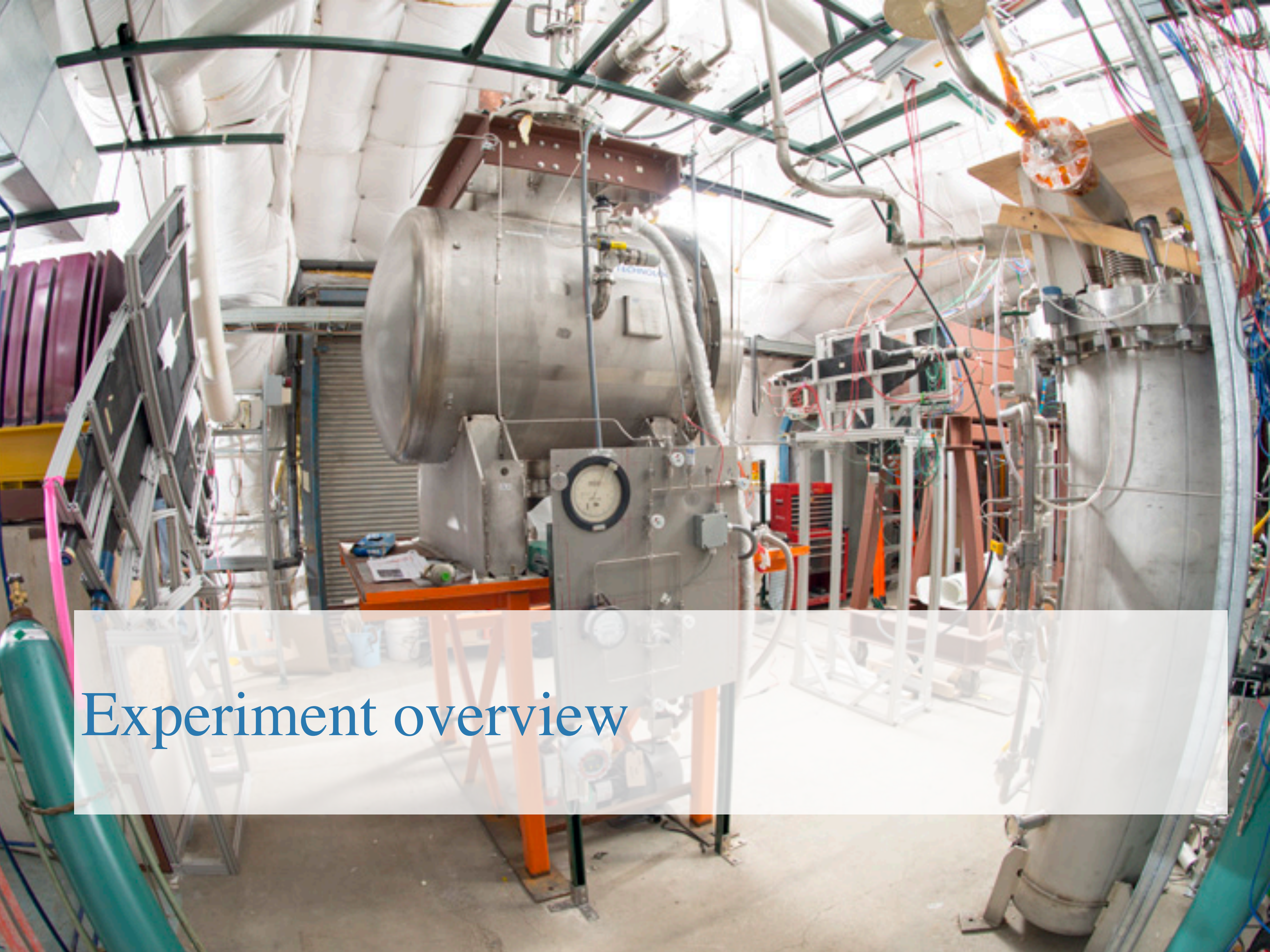
K – Ar cross section expected to lay in between the Ca and Si ones

Kaon cross section has been never measured on argon before, and **scarcely measured on other nuclei**

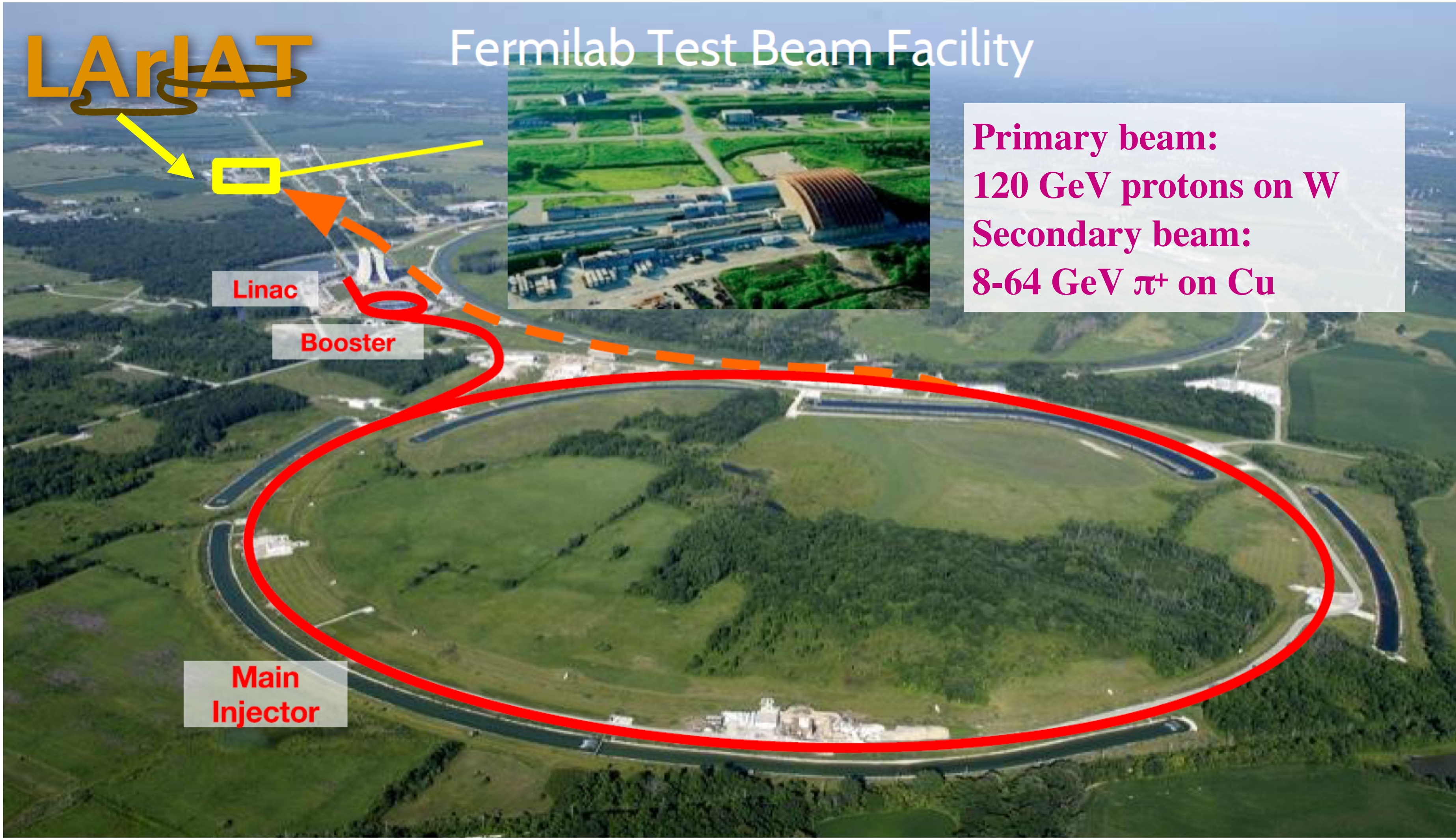
Geant4 uses interpolation from lighter-heavier nuclei

The first LArIAT study concentrates on K^+ cross section, given its relevance to proton decay searches in DUNE

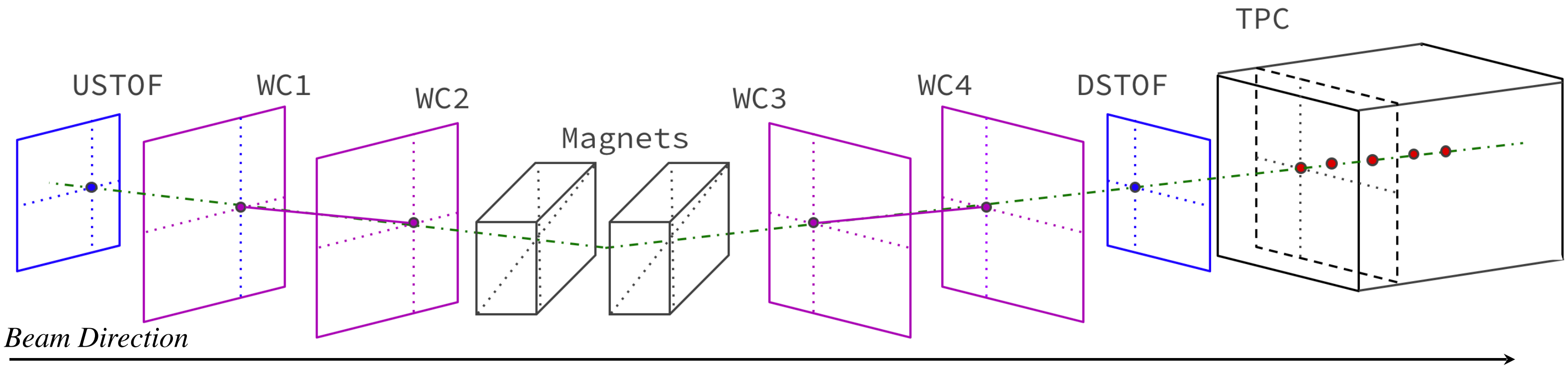
Experiment overview



The proton path



Tertiary Beamline: upstream TPC

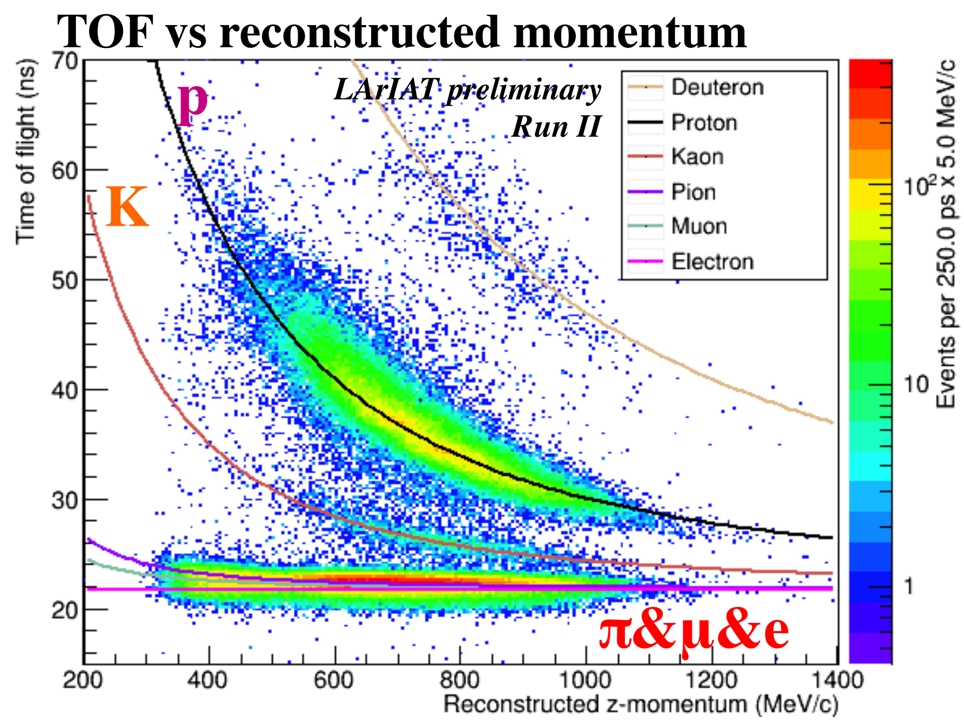


Two magnet polarities:
select **+ve** or **-ve** particles

Two magnet current intensities:
low & **high** energy beam

WC + Magnets: spectrometer
TOF: 2 scintillators counters

TOF + Spectrometer
p/**K**/**π&μ&e** discrimination



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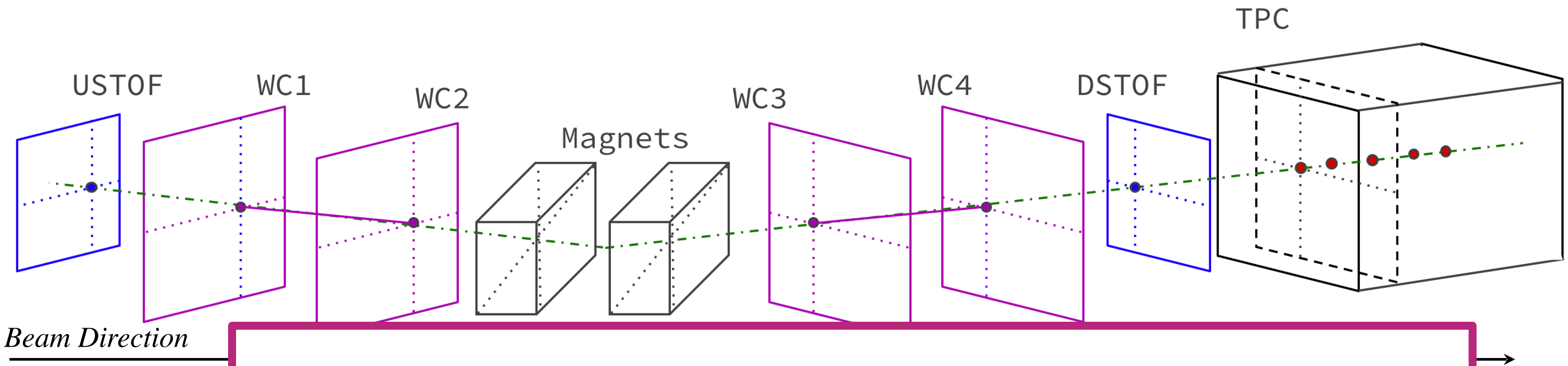


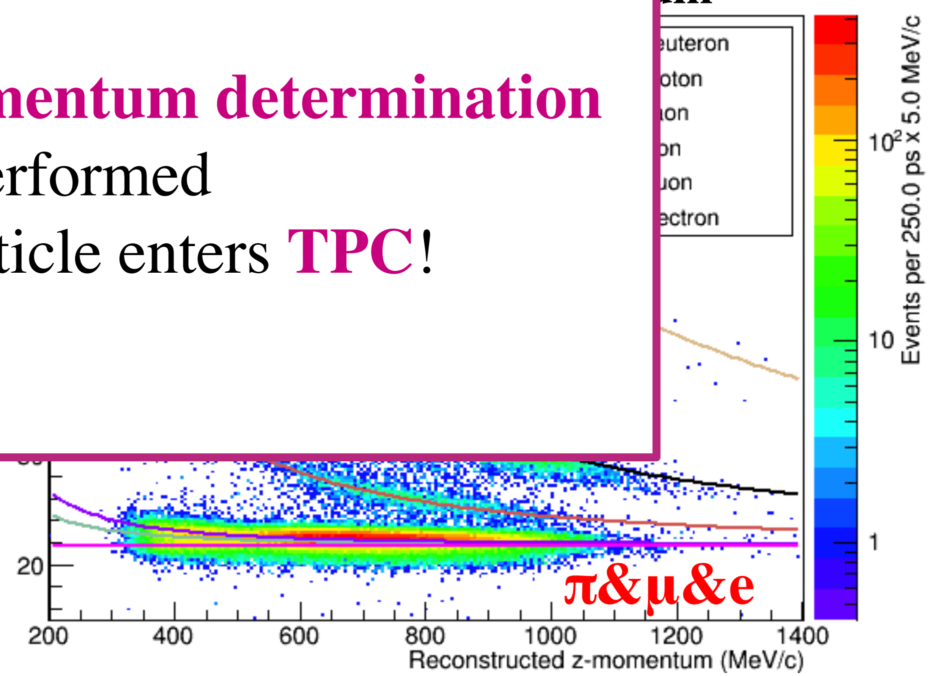
Particle ID and momentum determination are performed before the particle enters TPC!

Two magn
select +ve

Two magn
low & higl

WC + Mag
TOF: 2 scintillators counters

um

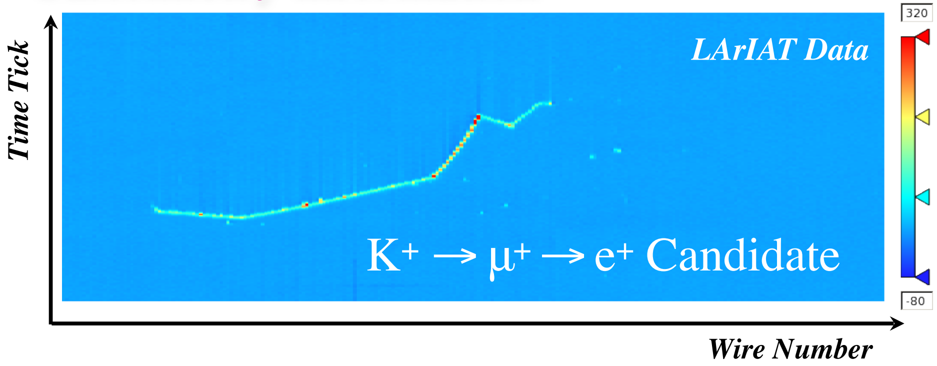


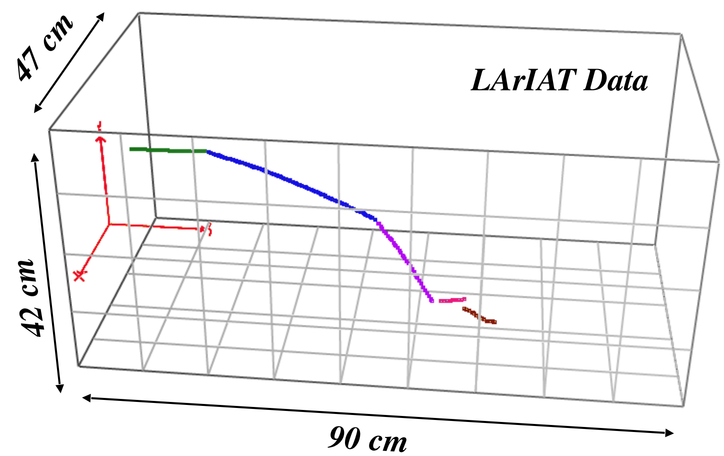
TOF + Spectrometer
p/K/π&μ&e discrimination

Inside LArIAT's hall: TPC+downstream

LArTPC Key Features

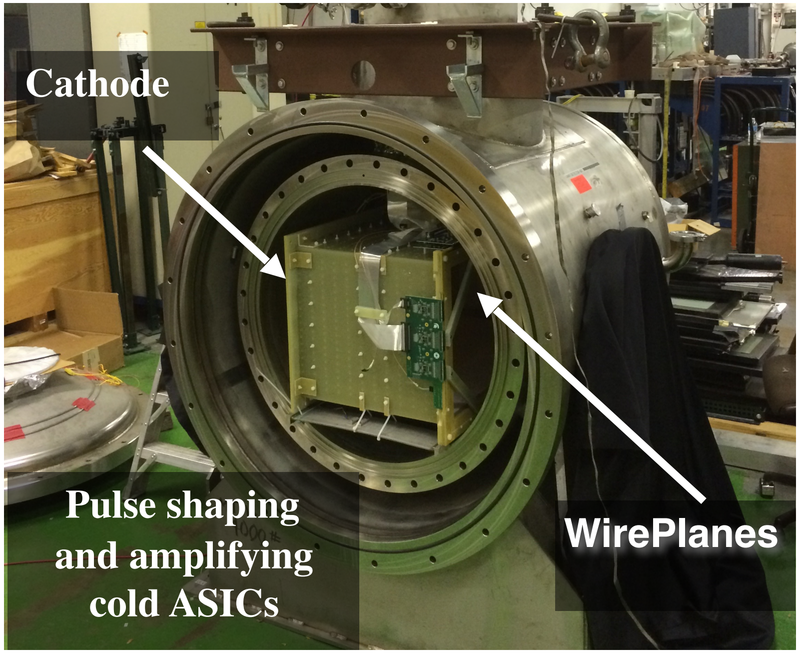
3D imaging with mm space resolution
Calorimetry information

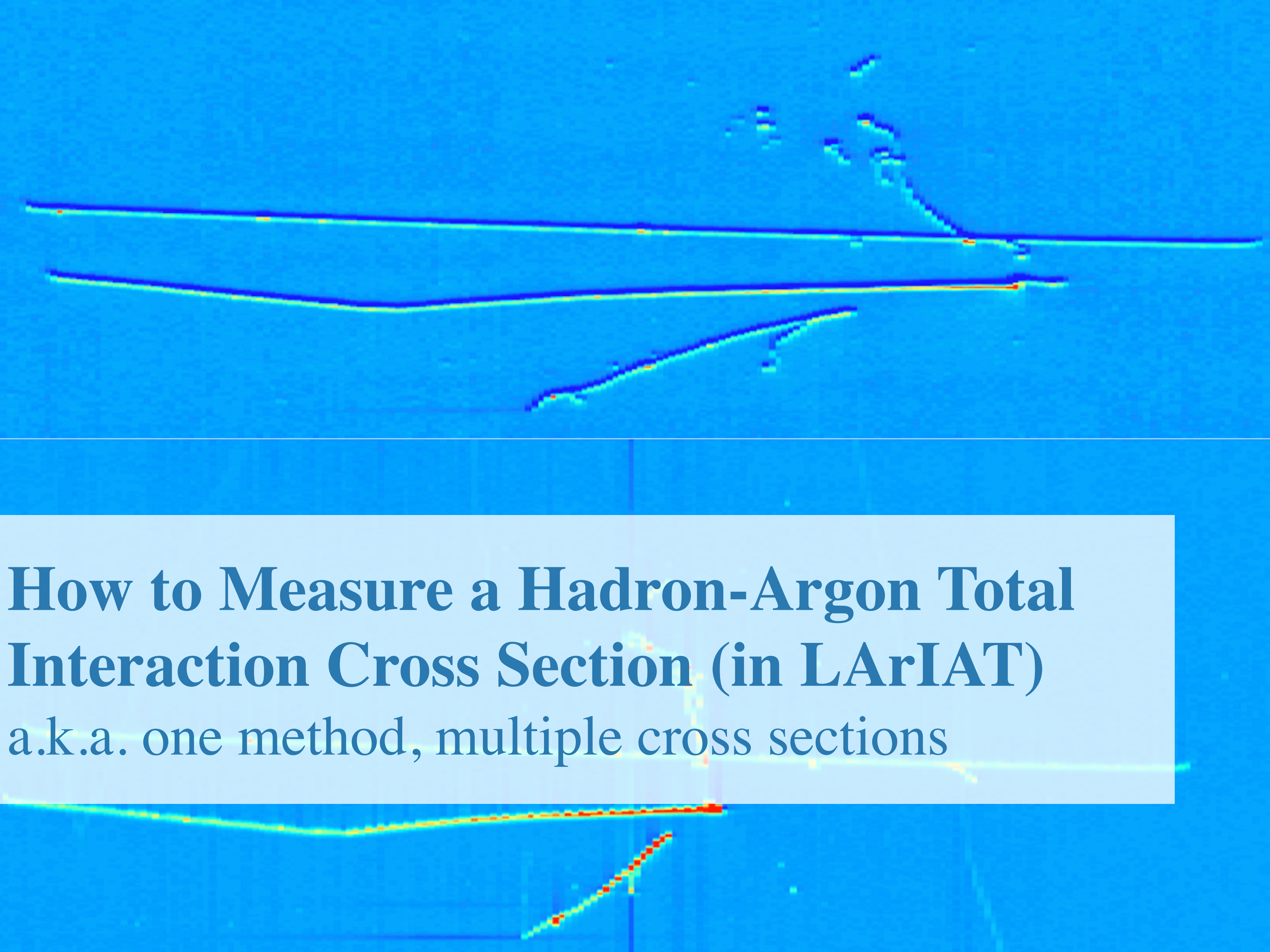




LArIAT: refurbished ArgoNeuT TPC
Signal pre-amplification in cold

Signal-to-noise
(MIP pulse height / pedestal RMS)
Run-2: ~70:1 (ArgoNeuT ~15:1)





How to Measure a Hadron-Argon Total Interaction Cross Section (in LArIAT)

a.k.a. one method, multiple cross sections

LArIAT XS analyses in 4 simple steps:

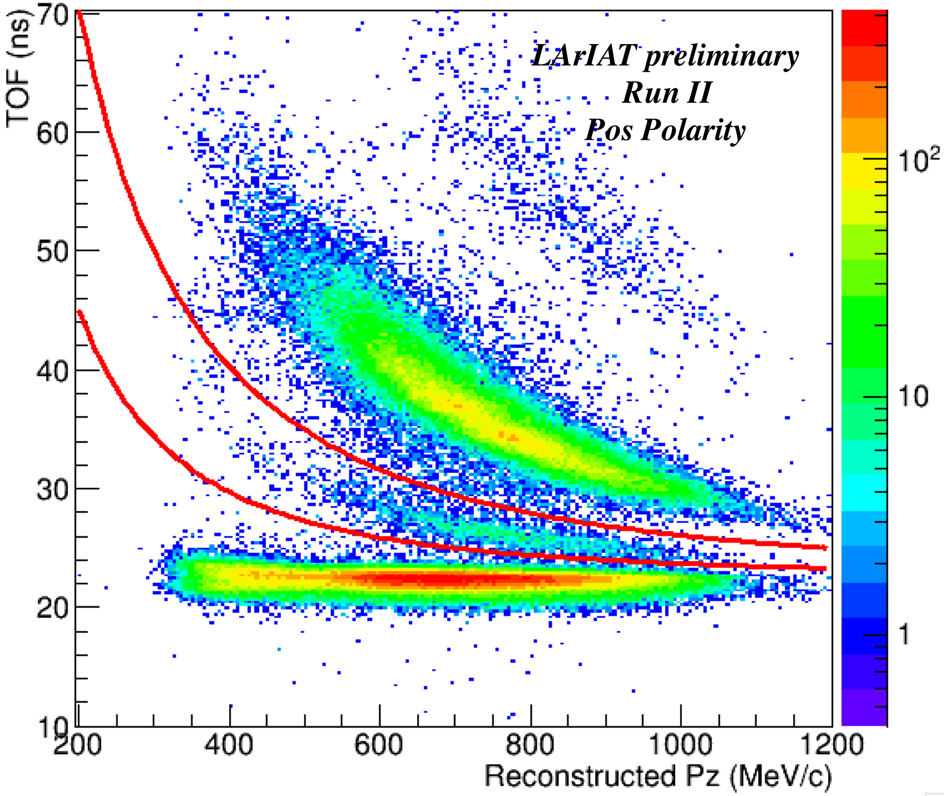
1) Select the right particles in the beamline

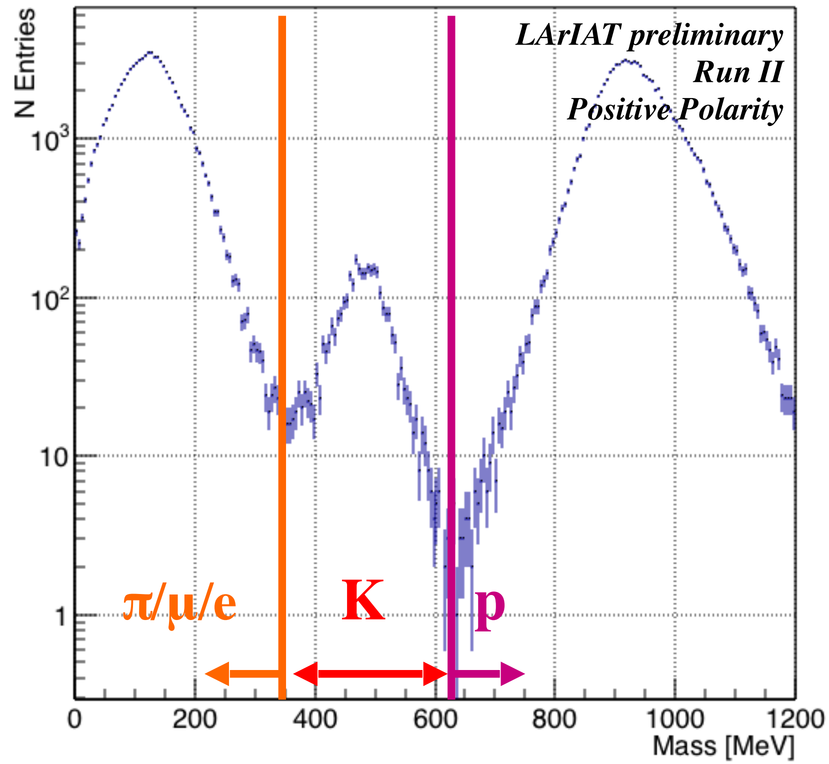
2) Beamline-TPC Handshake

3) Apply the “thin slice method”

4) Correct for Backgrounds and Reco effects

1) Select the right particles in beamline





$$m = \frac{p}{c}\sqrt{(\frac{c * TOF}{\ell})^2 - 1}$$

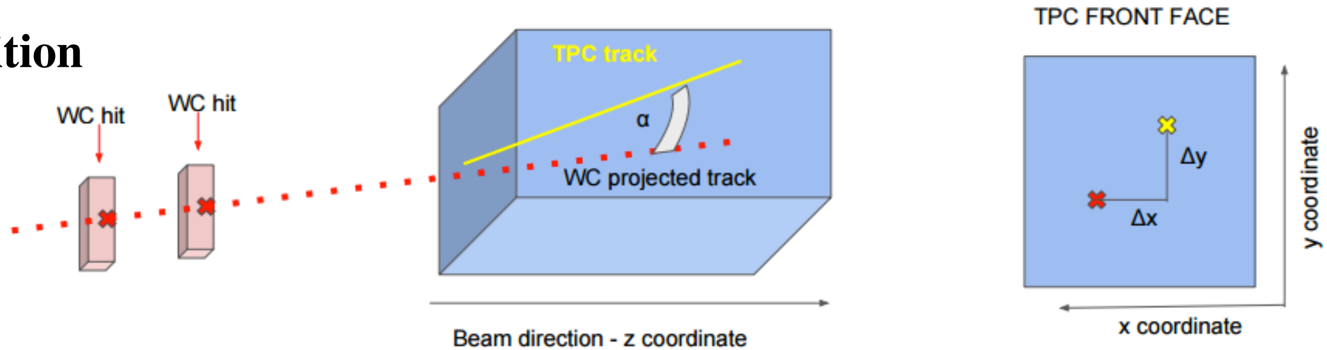
Keep

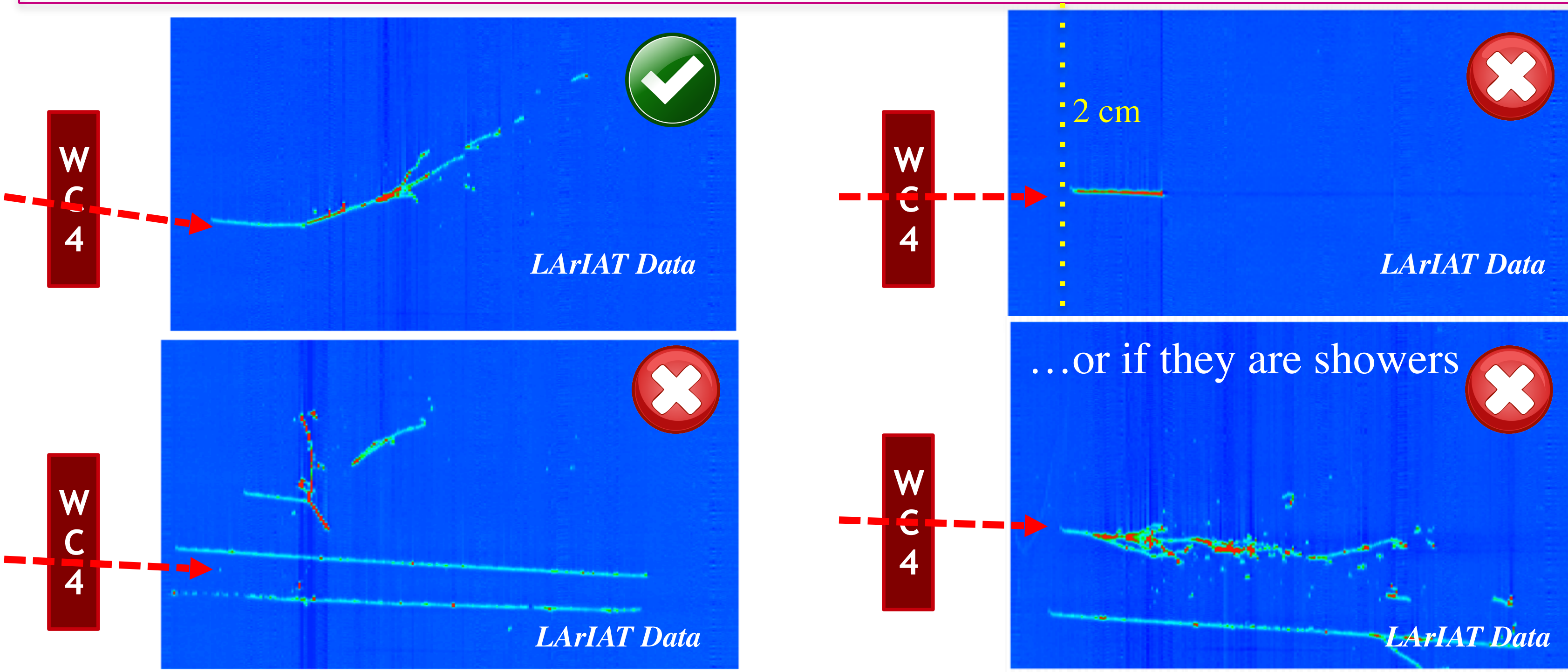
π: Mass < 350 MeV/c²

K: 350 MeV/c² < Mass < 650 MeV/c²

2) Beamline-TPC handshake

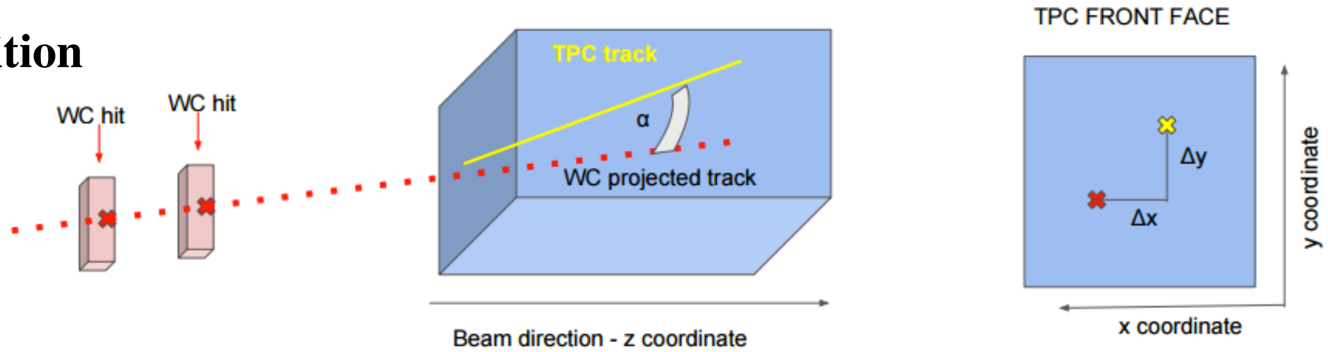
Match definition





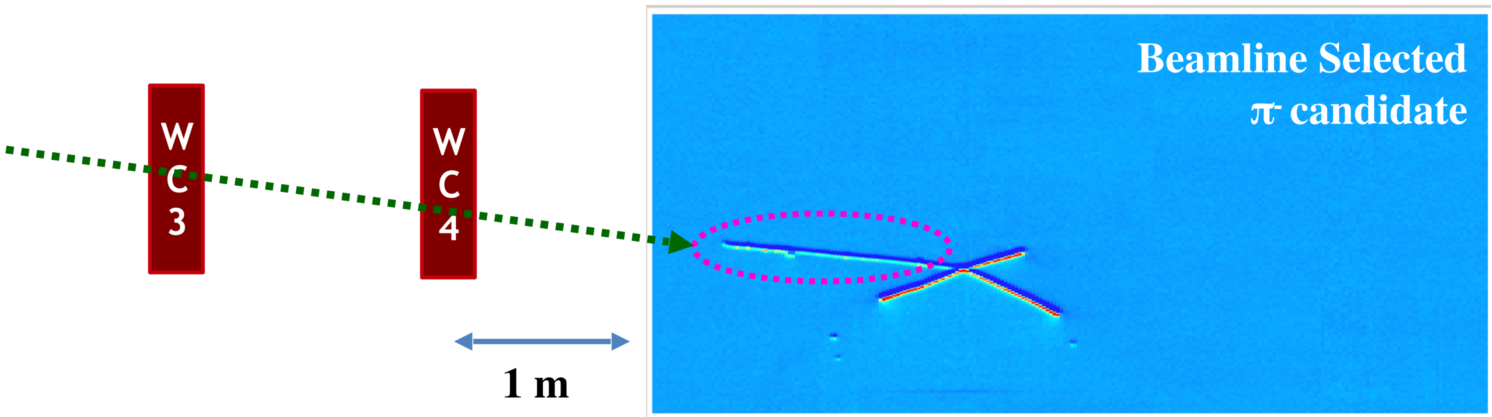
2) Beamline-TPC handshake

Match definition



	Run-II Neg Pol	Run-II Pos Pol
1. Events Reconstructed in Beamline	158396	260810
2. Events with Plausible Trajectory	147468	240954
3. Beamline $\pi^-/\mu^-/e^-$ Candidate	138481	N.A.
4. Beamline K^+ Candidate	N.A	2837
5. Events Surviving Pile Up Filter	108929	2389
6. Events with WC2TPC Match	41757	1081
7. Events Surviving Shower Filter	40841	N.A.
8. Available Events For Cross Section	40841	1081

Beamline candidates: what do we know?

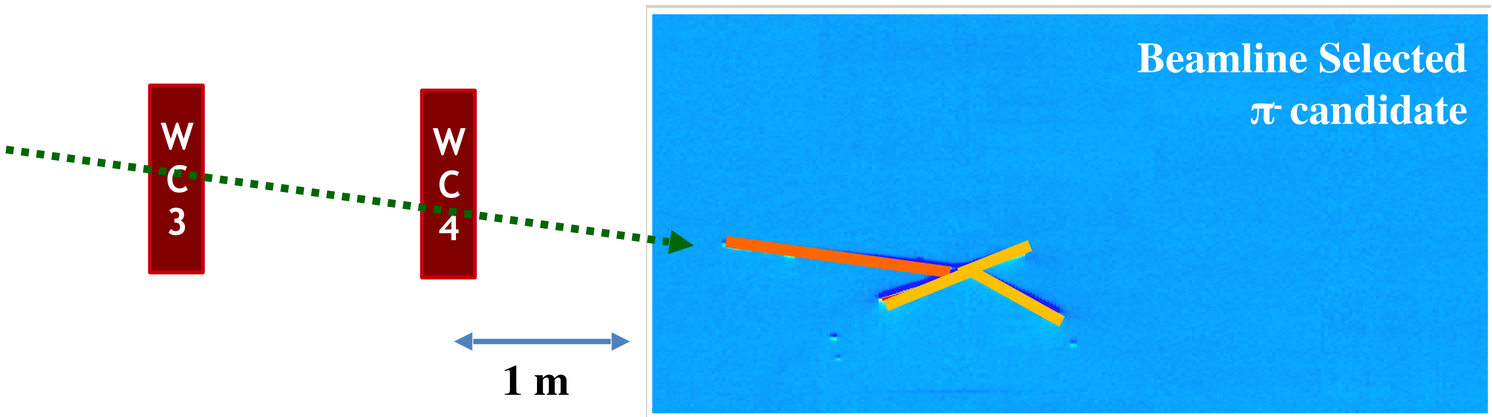


We use the **momentum measured by the WC** to calculate the candidate's initial kinetic energy as

$$E^{\text{kin}}_{\text{Front Face}} = \sqrt{p^2_{Beam} + m^2_{Beam}} - m_{Beam} - E_{Loss}$$

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

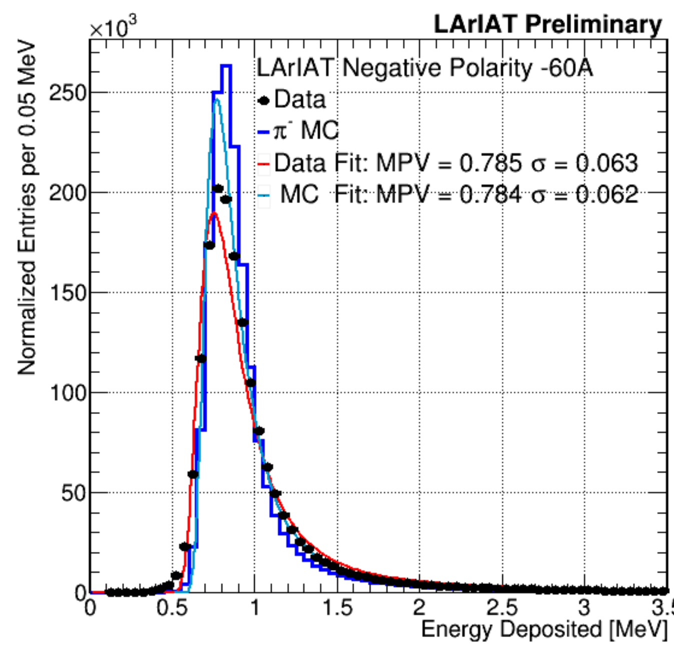
Beamline candidates: what do we know?



The **K.E.** at **each point** of the TPC track is calculated by subtracting the **track deposited energy** from the K.E. at the TPC front face.

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

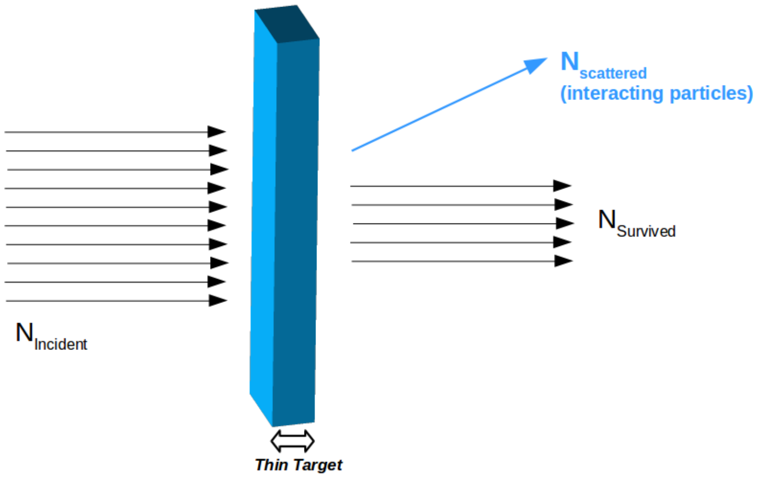
This key point of our measurement is enabled by the extraordinary tracking and calorimetry features of LArTPCs



3) TSM: a new spin on an old technique

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

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



σ_{Tot} = cross section per Ar,

n = Ar density

δX = depth of the slice,

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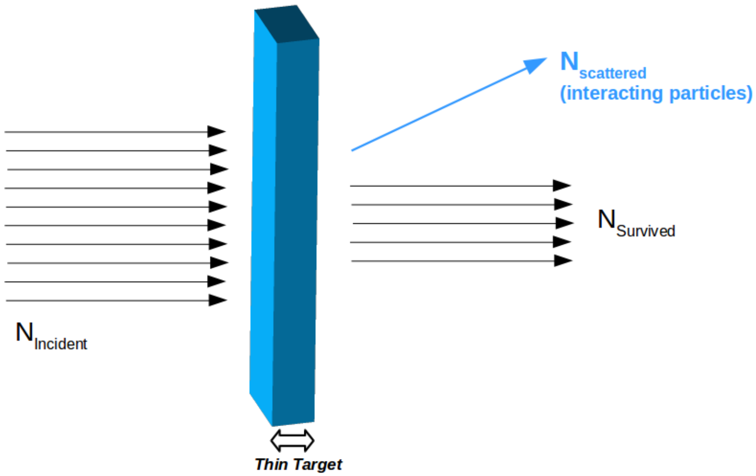
THIN

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



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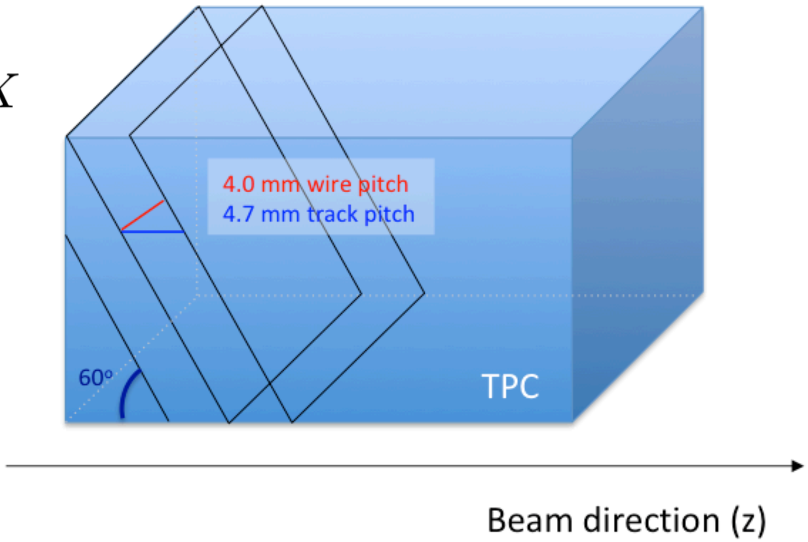


We treat the **wire-to-wire spacing** as a **series of "thin-slice"** targets, since we know the energy of the particle incident to each slice.

Each thin slice is an independent experiment

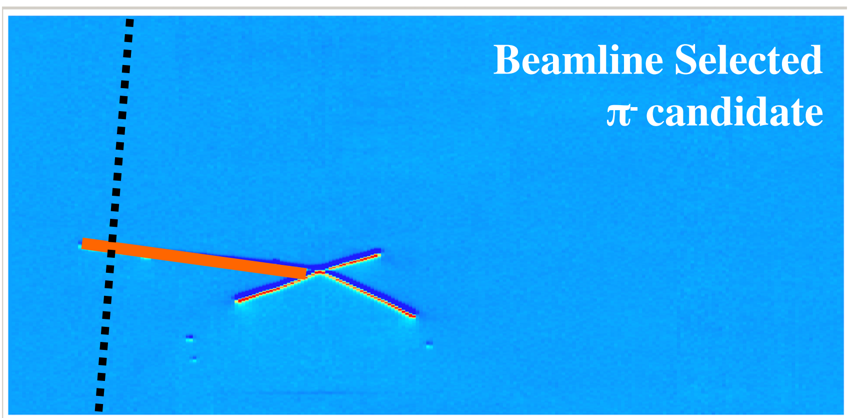
N_{Incident}, $N_{\text{Interacting}}$ calculation

We follow the TPC track slice by slice

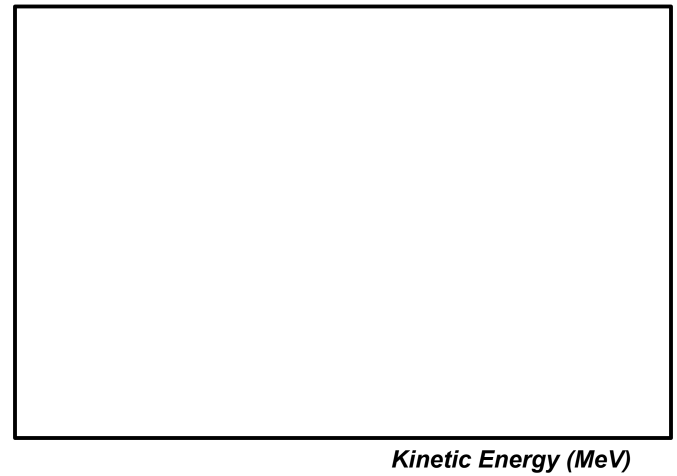
- The slice represents the distance between each 3D point in the track
- For each slice we ask:
  "Is this **the end** of the track?"

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

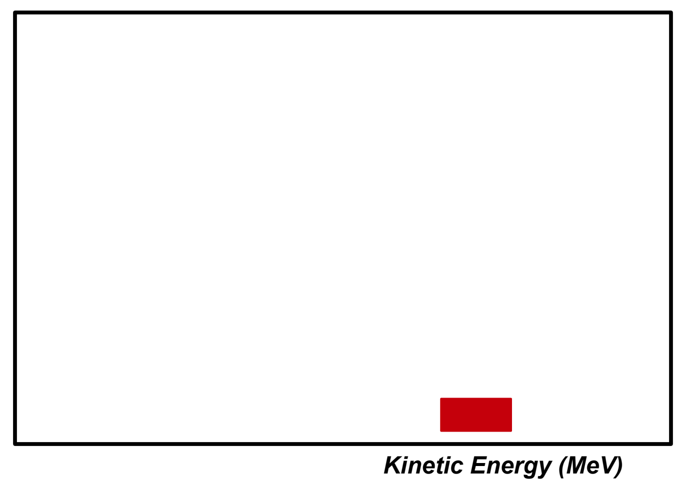
$$E_j^{\text{kin}} = E_{\text{Front Face}}^{\text{kin}} - \sum_{j<i} E_{\text{dep i}}$$



Interacting



Incident



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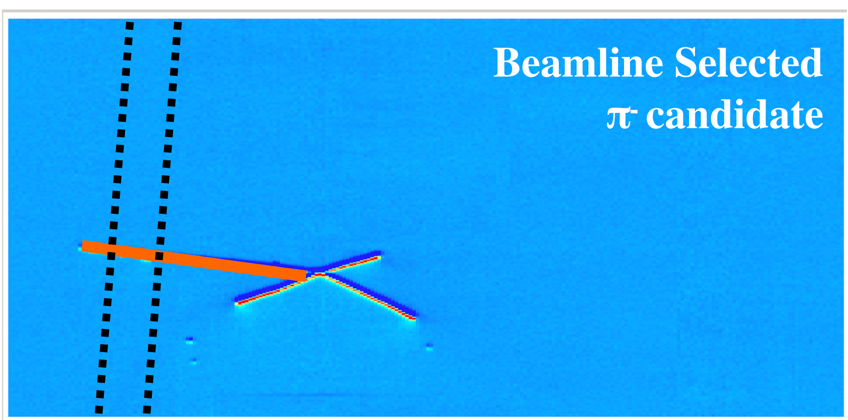

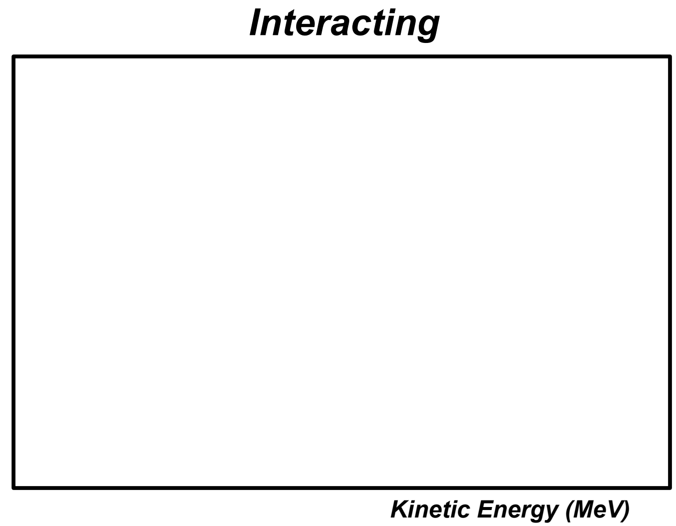

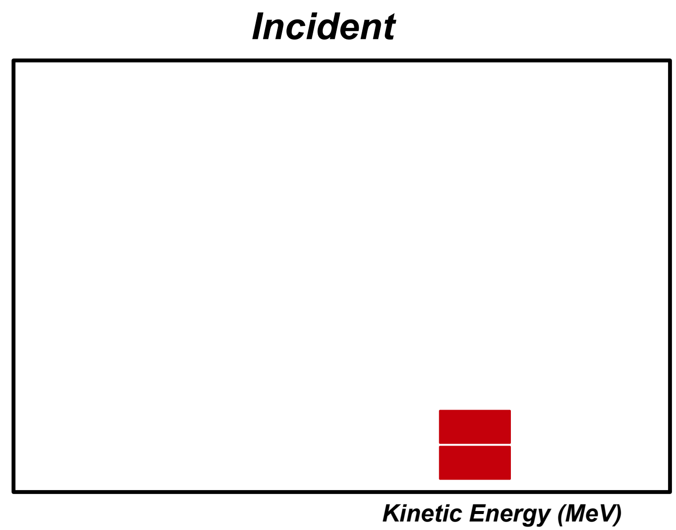

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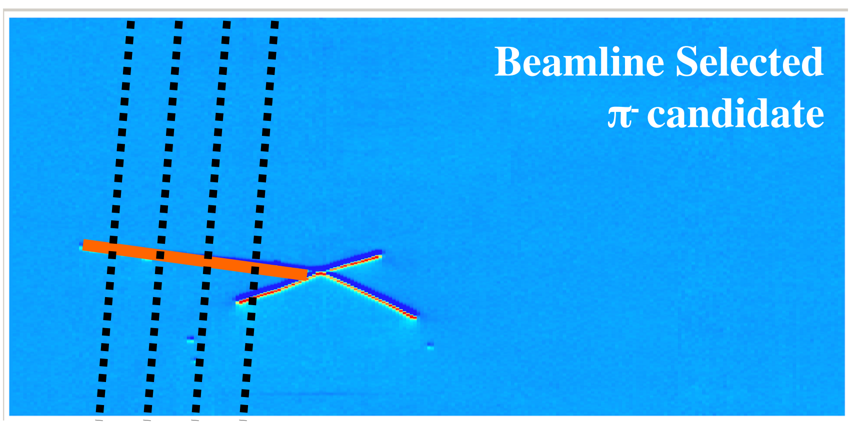
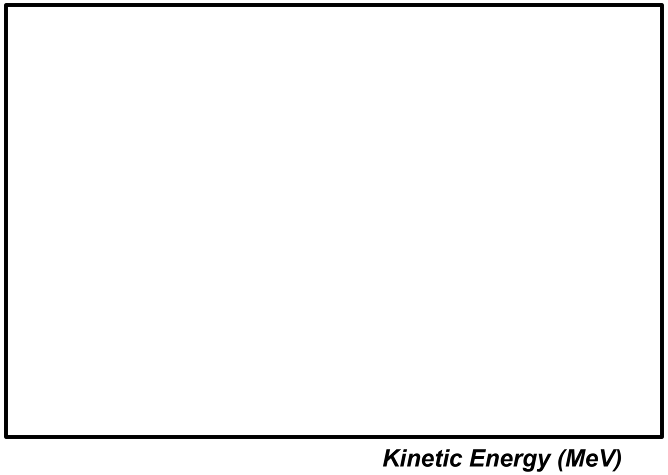
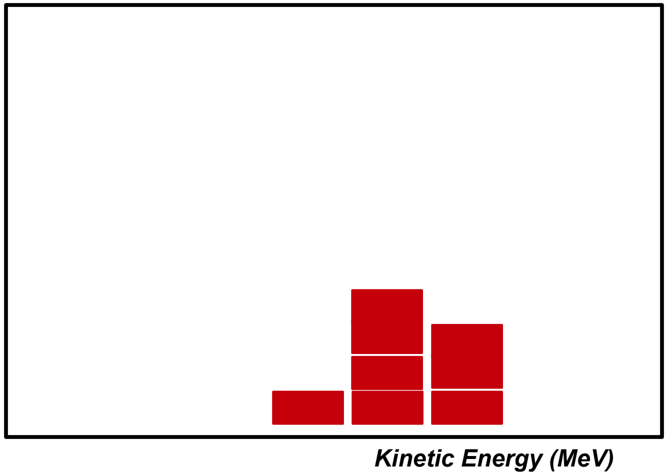


Interacting



Incident



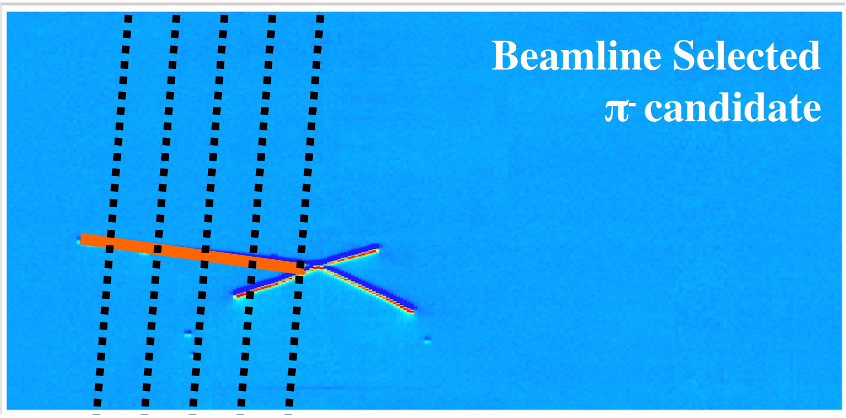
N_{Incident} , $N_{\text{Interacting}}$ calculation

We follow the TPC track slice by slice

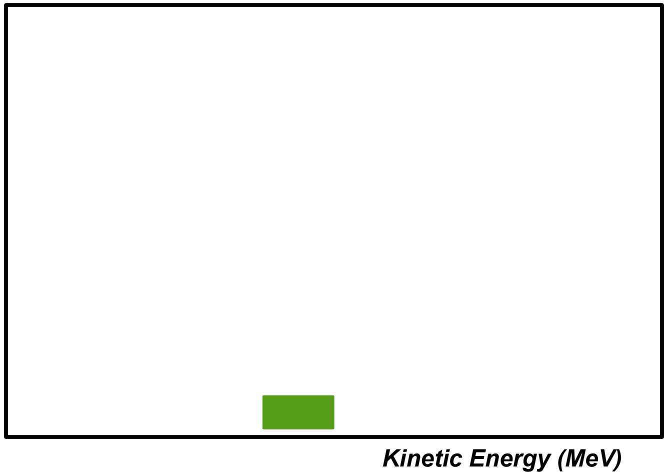
- The slice represents the distance between each 3D point in the track
- For each slice we ask:
  "Is this **the end** of the track?"

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

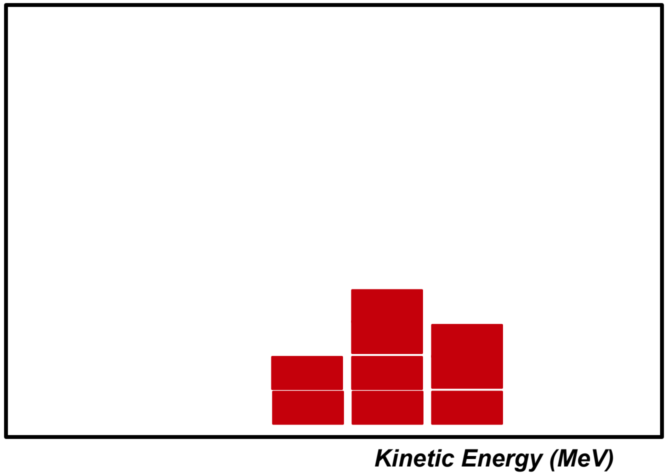
$$E_j^{\text{kin}} = E_{\text{Front Face}}^{\text{kin}} - \sum_{j<i} E_{\text{dep i}}$$



Interacting



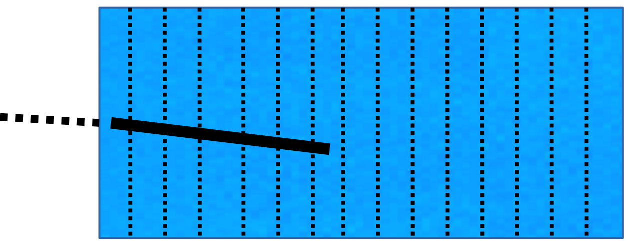
Incident



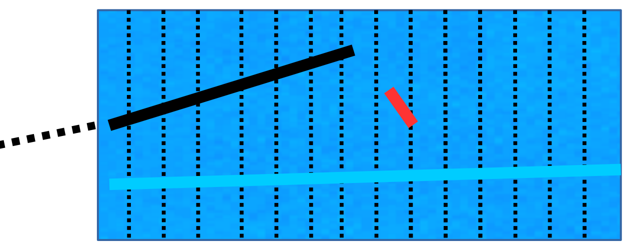
$N_{Incident}$, $N_{Interacting}$ calculation

Repeat for each WC to TPC matched track

- We disregard any other activity occurring in the detector

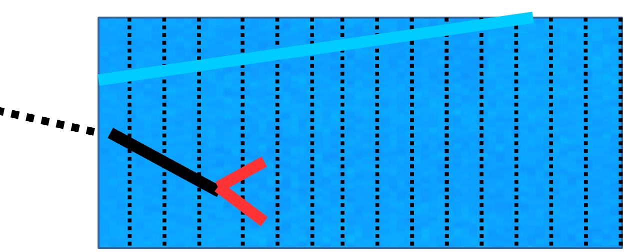


✔ The black track is followed

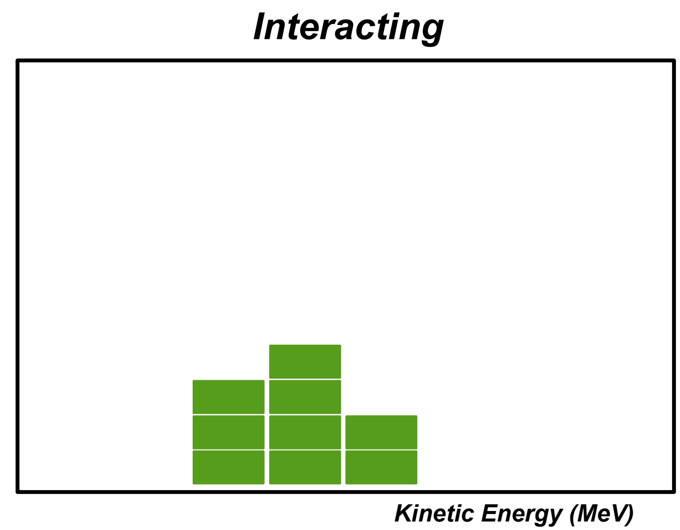


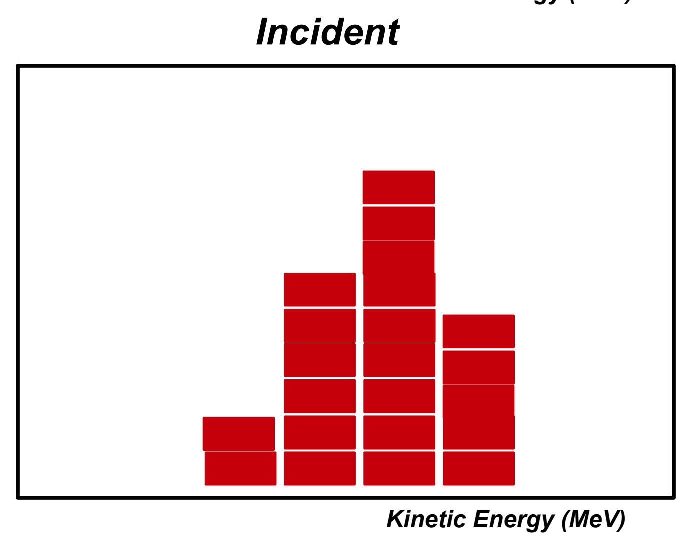
✖ The light blue track is not matched to WC

✖ The red stub is ignored



✖ The red tracks do not belong to the original track

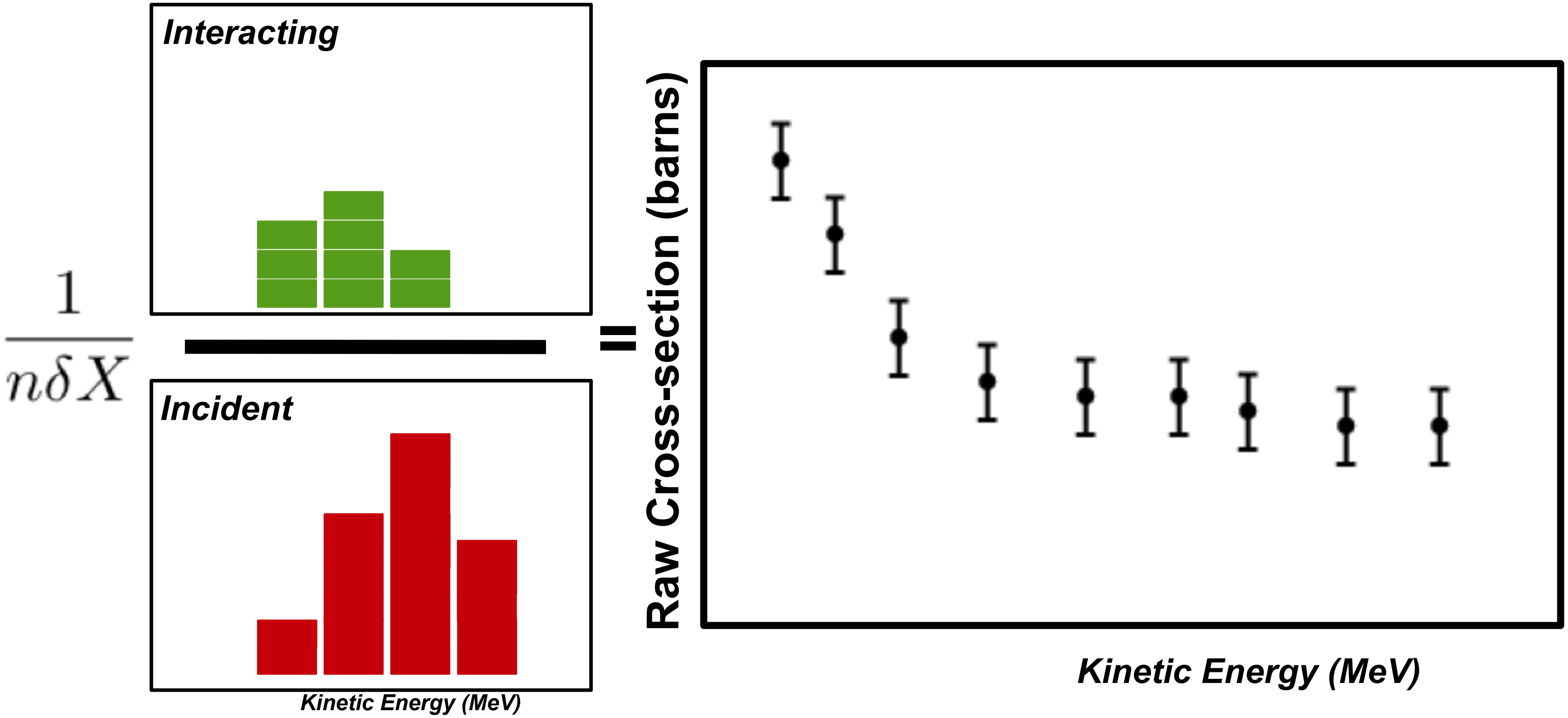




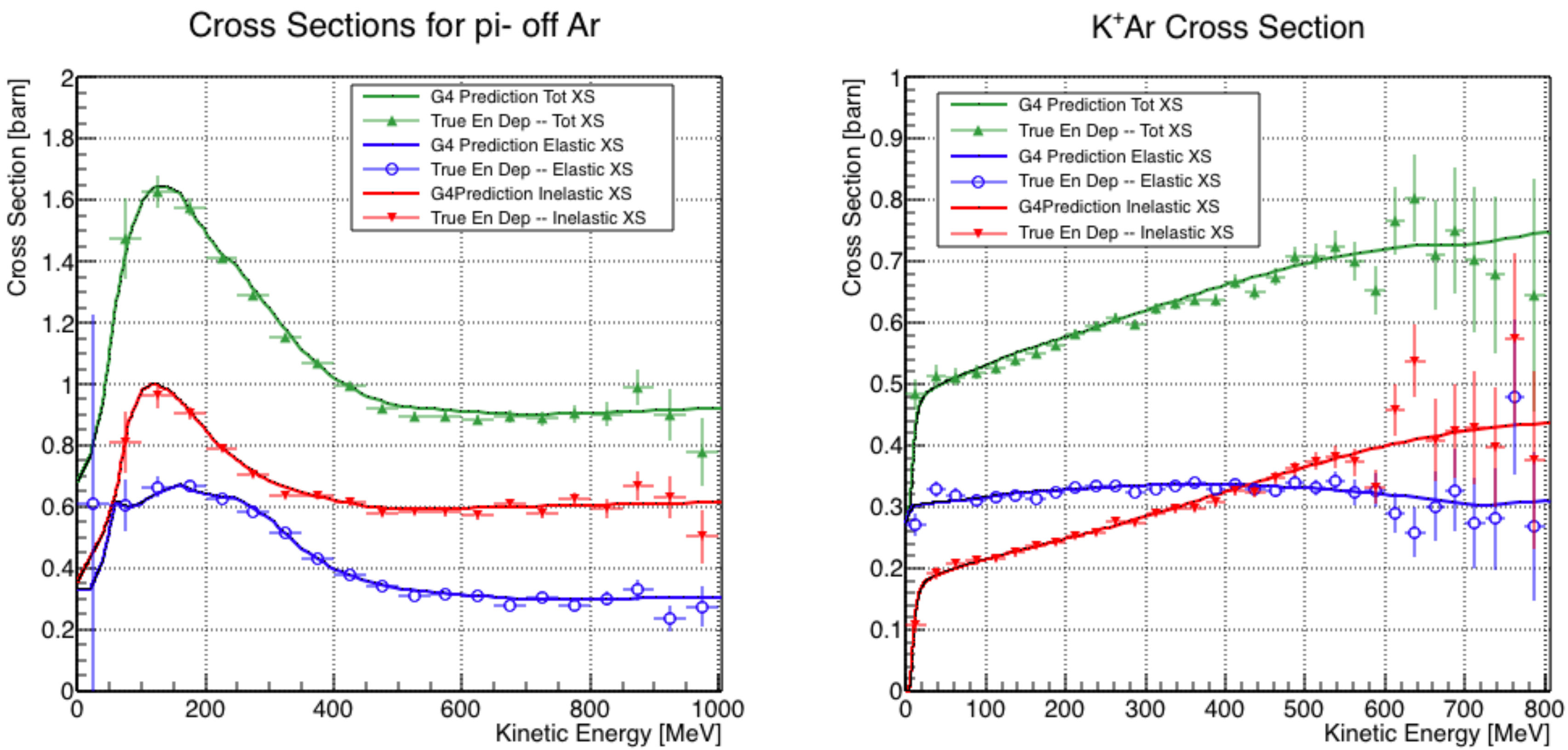
3) Thin-slice method

We take **the ratio** of the **two histograms** and calculate the **raw cross section**

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



Truth Quantities Check



As expected, the thin slice method applied on true MC quantities **recovers** the underlying XS distributions

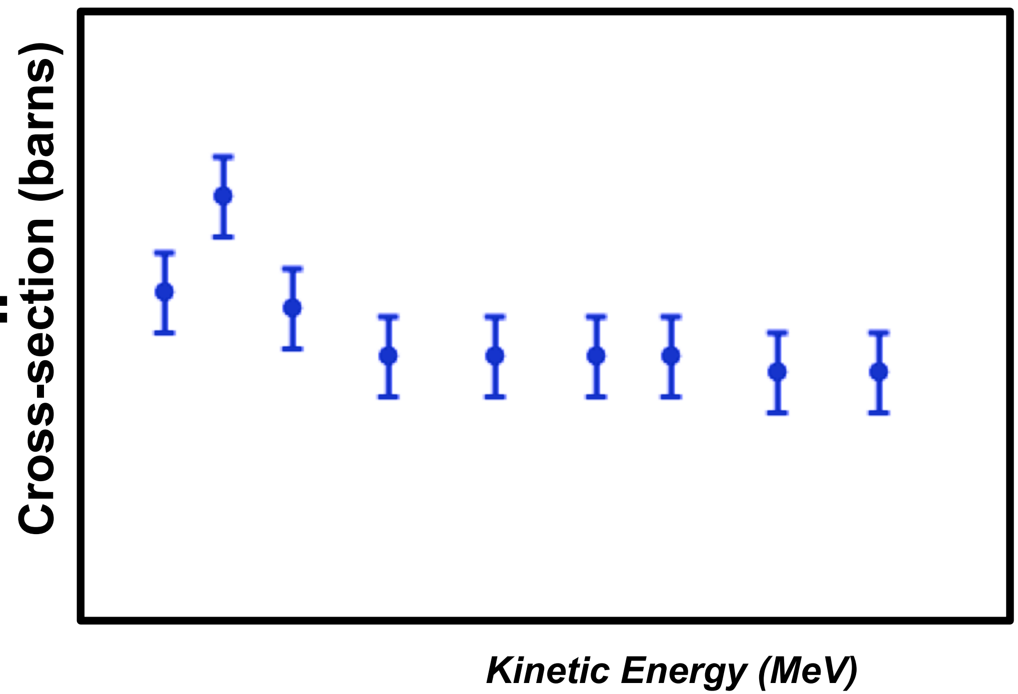
4) Correct for Background and Reco

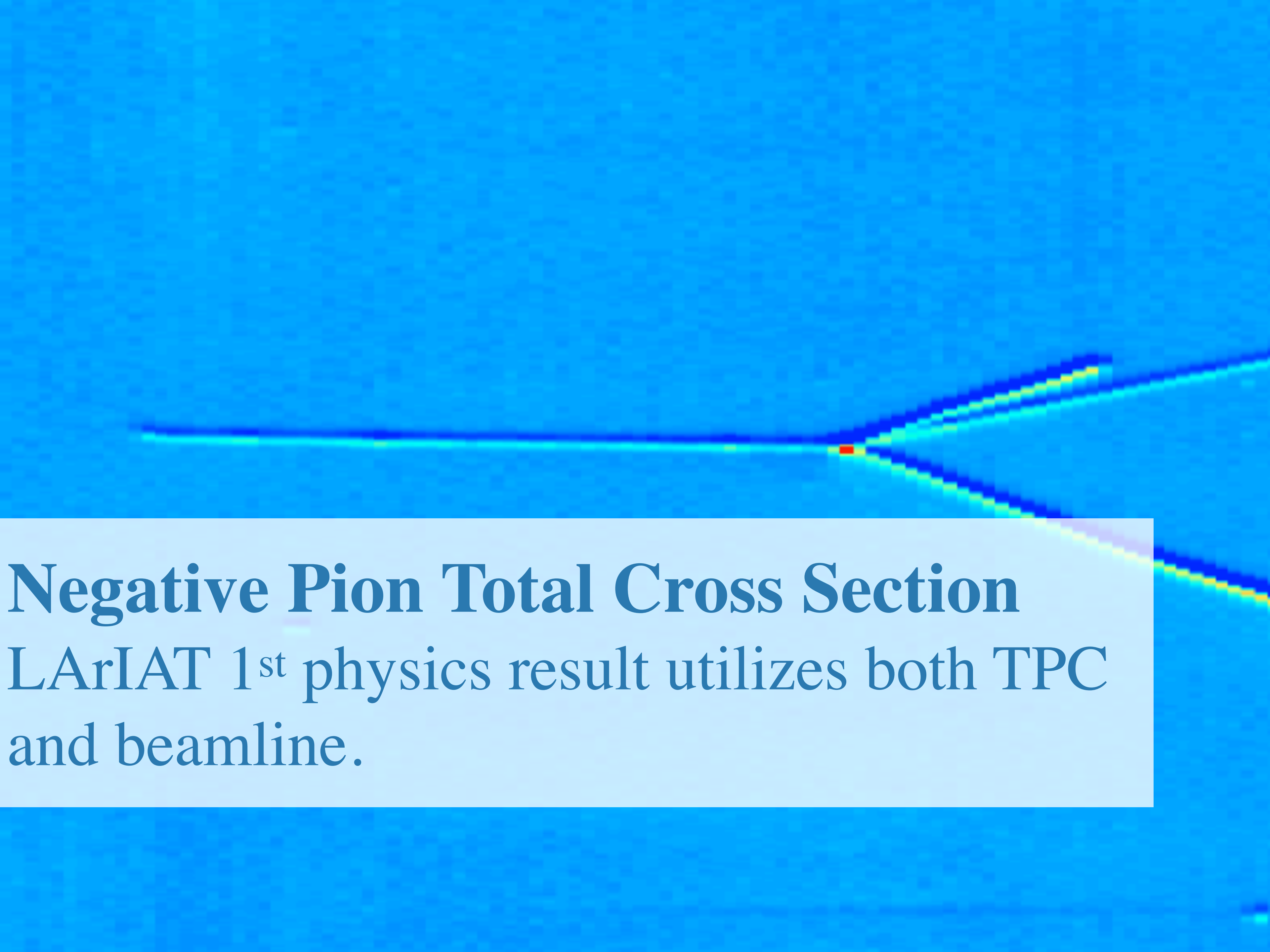
We evaluate the **background** and the **reconstruction** effects on the interacting and incident distributions **separately**

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

$\frac{1}{n\delta X}$

=



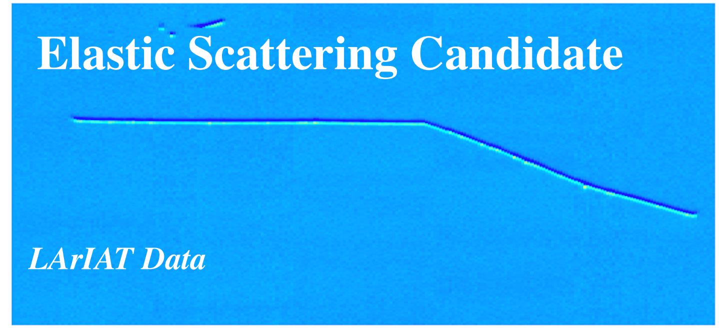


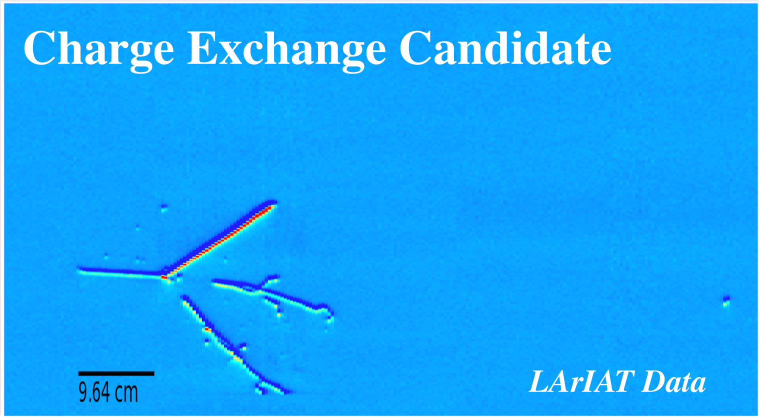
Negative Pion Total Cross Section

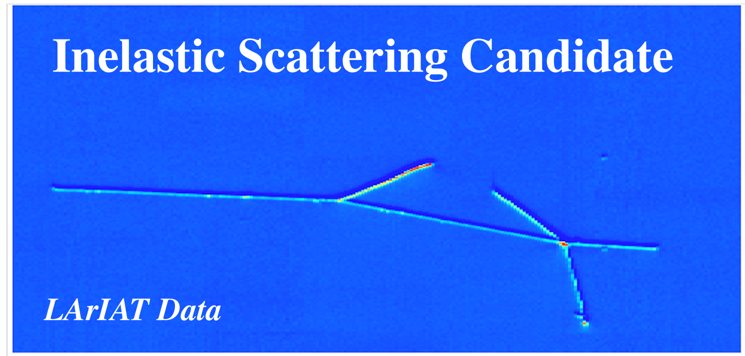
LArIAT 1st physics result utilizes both TPC and beamline.

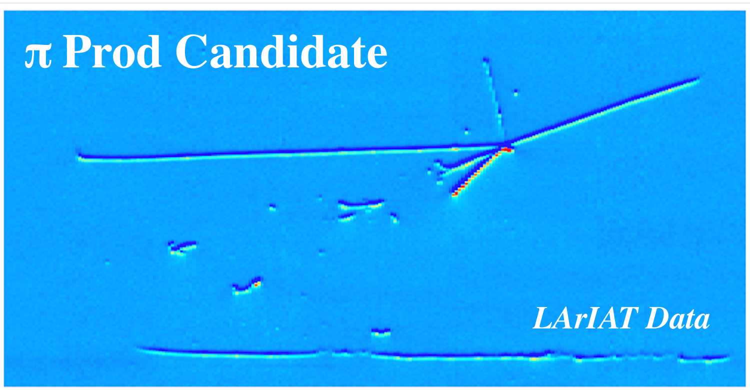
Signal Topologies

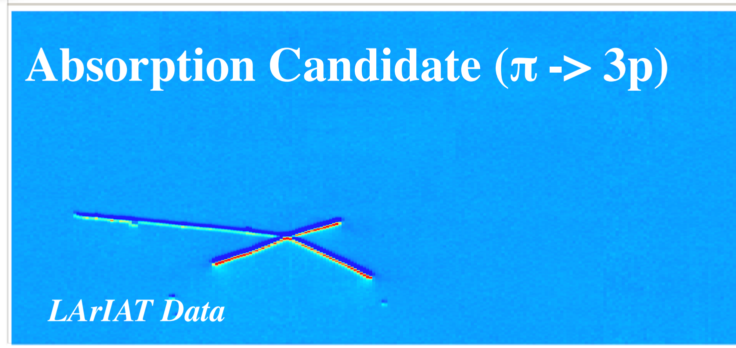
$$\sigma_{Tot} = \sigma_{elastic} + \sigma_{inelastic} + \sigma_{abs} + \sigma_{charge\ xc} + \sigma_{\pi\text{-}prod}$$



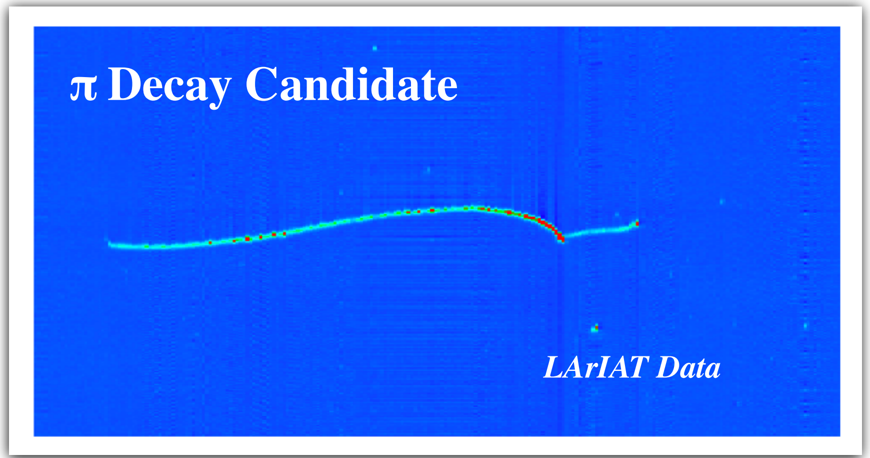


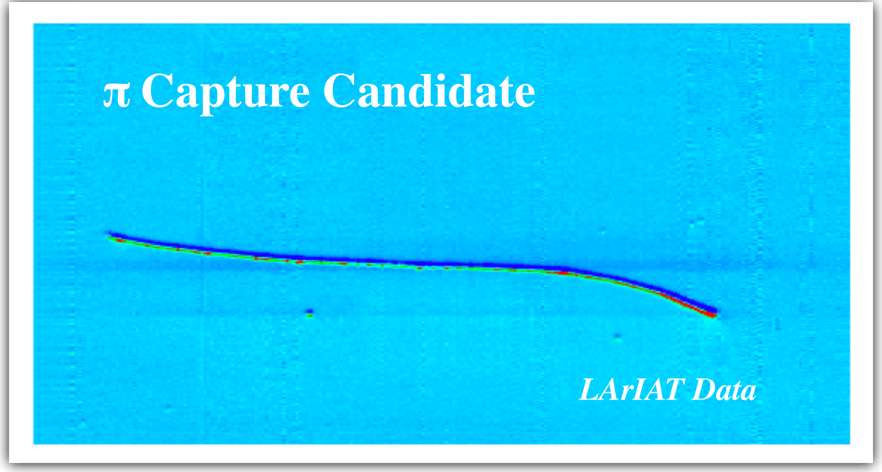






Intrinsic and Beamline Backgrounds



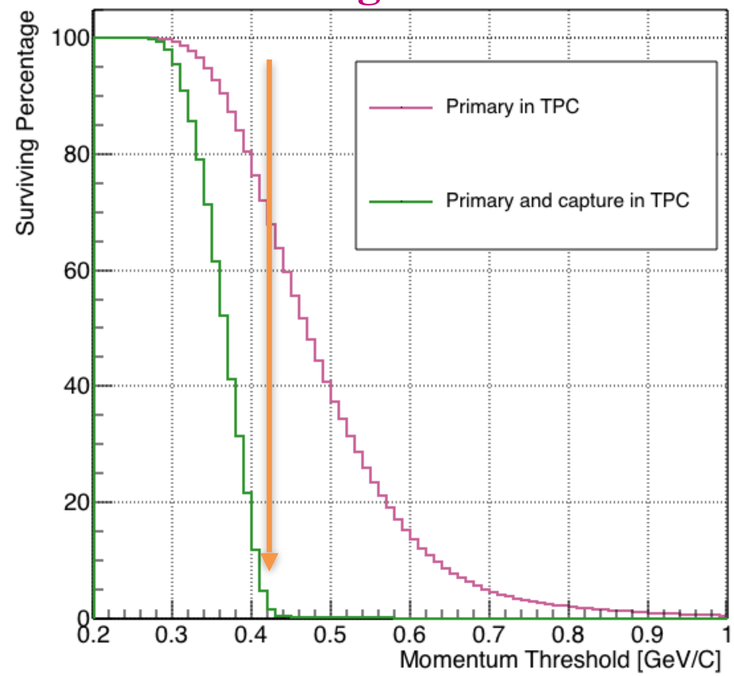


\+ residual electrons & muons

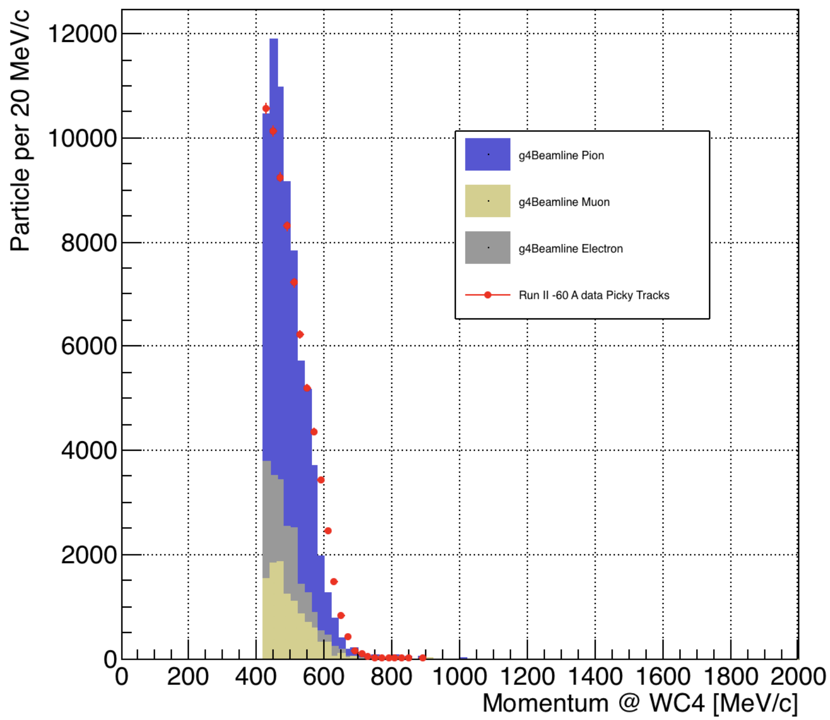
Intrinsic and Beamline Backgrounds

π-Capture and π-Decay occur mainly at rest: select particles with high incoming momentum.

Surviving Event Ratio



Beam Composition: Low Energy



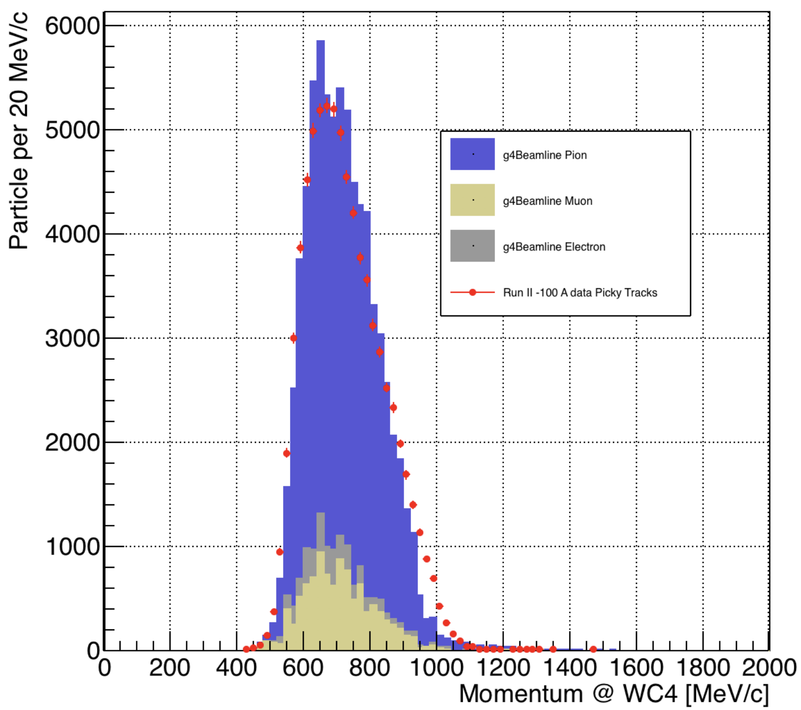
Assess beam composition and simulate contaminants

	Low E Beam	High E Beam
G4Pions	70.9 %	82.3 %
G4Muons	14.6 %	13.5 %
G4Electrons	14.5 %	4.2 %

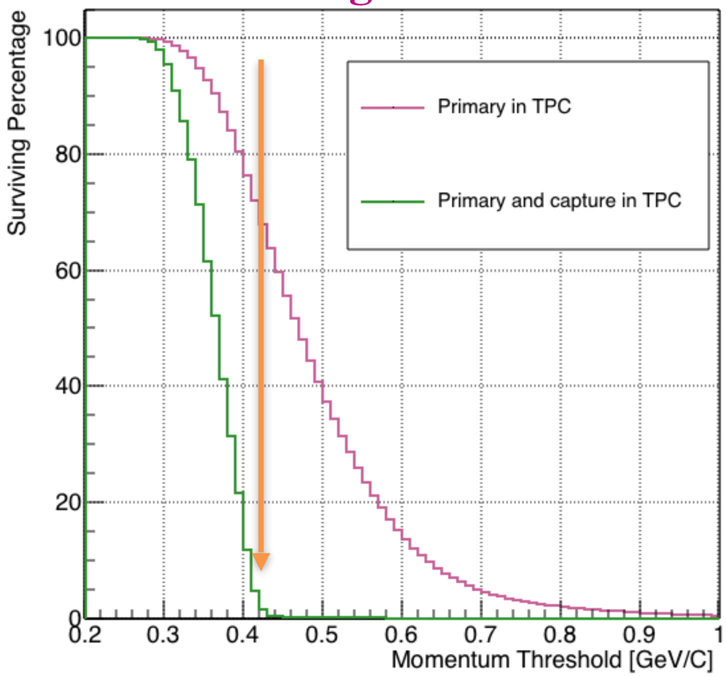
Intrinsic and Beamline Backgrounds

π-Capture and π-Decay occur mainly at rest: select particles with high incoming momentum.

Beam Composition: High Energy



Surviving Event Ratio



Assess beam composition and simulate contaminants

	Low E Beam	High E Beam
G4Pions	70.9 %	82.3 %
G4Muons	14.6 %	13.5 %
G4Electrons	14.5 %	4.2 %

XS Formula

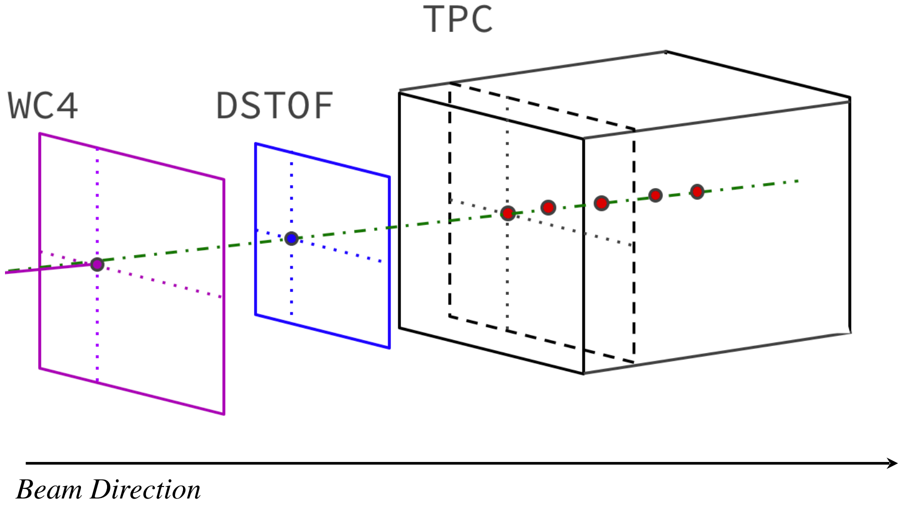
$$\sigma_{TOT}^{\pi^-}(E_i) = \frac{1}{n\ \delta X} \frac{\epsilon^{\text{Inc}}(E_i)\ \ C_{\text{Int}}^{\pi MC}(E_i)\ \ N_{\text{Int}}^{\text{TOT}}(E_i)}{\epsilon^{\text{Int}}(E_i)\ \ C_{\text{Inc}}^{\pi MC}(E_i)\ \ N_{\text{Inc}}^{\text{TOT}}(E_i)}$$

XS Formula: how well do we know E_i ?

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

$$E_{\text{slice j}} = \sqrt{p^2_{Beam} + m^2_{Beam}} - m_{Beam} - E_{Loss} - E_{\text{dep FF-j}}$$

$$\delta E_{\text{slice j}} = \sqrt{\delta p^2_{Beam} + \delta E^2_{Loss} + \delta E^2_{\text{dep FF-j}}}$$



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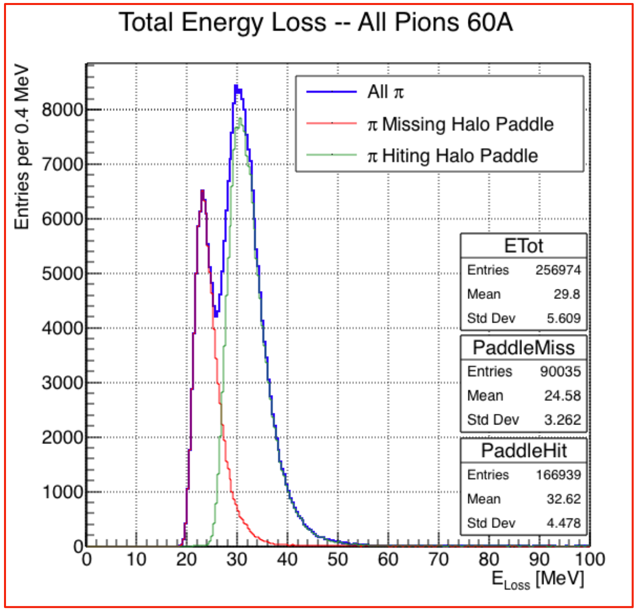
$$\sigma^{\pi^-}_{TOT}(E_i) = \frac{1}{n\ \delta X} \frac{\epsilon^{\text{Inc}}(E_i)\ C^{\pi MC}_{\text{Int}}(E_i)\ N^{\text{TOT}}_{\text{Int}}(E_i)}{\epsilon^{\text{Int}}(E_i)\ C^{\pi MC}_{\text{Inc}}(E_i)\ N^{\text{TOT}}_{\text{Inc}}(E_i)}$$

$$E_{\text{slice j}} = \sqrt{p^2_{Beam} + m^2_{Beam}} - m_{Beam} - E_{Loss} - E_{\text{dep FF-j}}$$

$$\delta E_{\text{slice j}} = \sqrt{\delta p^2_{Beam} + \delta E^2_{Loss} + \delta E^2_{\text{dep FF-j}}}$$

6 MeV

2% p_{Beam}



XS Formula: how well do we know E_i ?

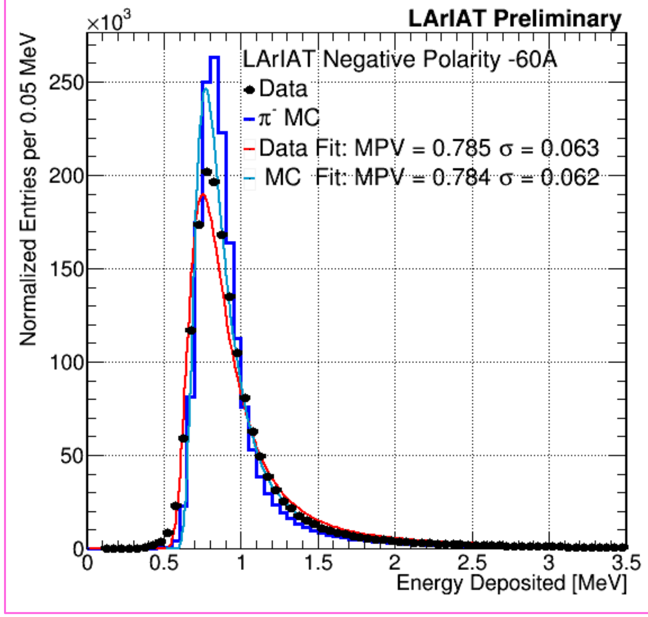
$$\sigma^{\pi^-}_{TOT}(E_i) = \frac{1}{n\ \delta X} \frac{\epsilon^{\rm Inc}(E_i)\ C^{\pi MC}_{\rm Int}(E_i)\ N^{\rm TOT}_{\rm Int}(E_i)}{\epsilon^{\rm Int}(E_i)\ C^{\pi MC}_{\rm Inc}(E_i)\ N^{\rm TOT}_{\rm Inc}(E_i)}$$

$$E_{\text{slice j}} = \sqrt{p^2_{Beam} + m^2_{Beam}} - m_{Beam} - E_{Loss} - E_{\text{dep FF-j}}$$

$$\delta E_{\text{slice j}} = \sqrt{\delta p^2_{Beam} + \delta E^2_{Loss} + \delta E^2_{\text{dep FF-j}}}$$

$$E_{\text{dep FF-j}} = \sum_{j<s} E_{\text{dep s}}$$

$$\delta E_{\text{dep FF-j}} = (j-1)\delta E_{\text{dep s}}$$



XS Formula: how well do we know E_i ?

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

$$E_{\text{slice j}} = \sqrt{p^2_{Beam} + m^2_{Beam}} - m_{Beam} - E_{Loss} - E_{\text{dep FF-j}}$$

$$\delta E_{\text{slice j}} = \sqrt{\delta p^2_{Beam} + \delta E^2_{Loss} + \delta E^2_{\text{dep FF-j}}}$$

Propagation to the cross section

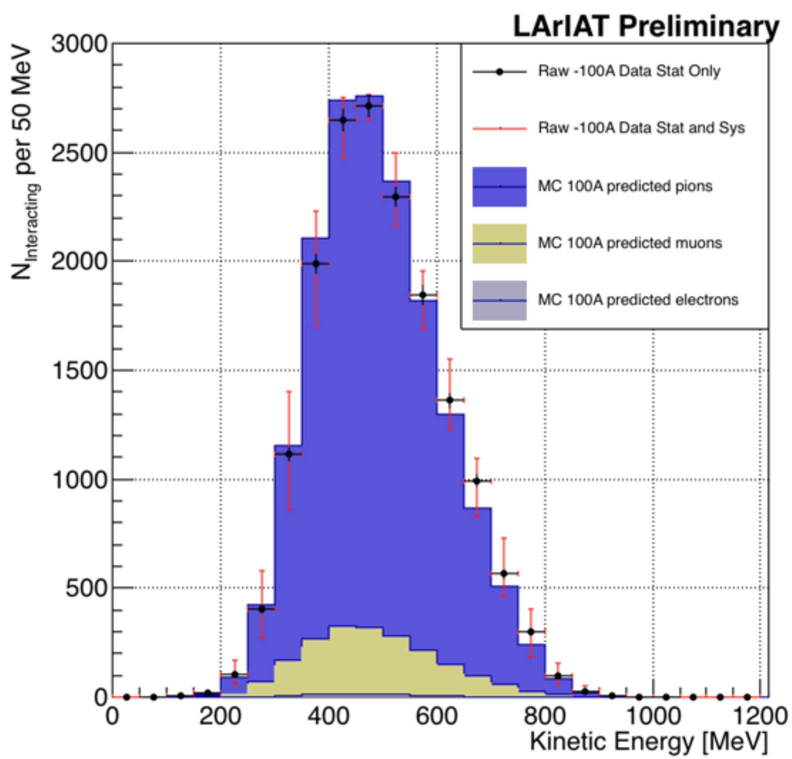
Calculate Interacting and Incident Plots for 3 cases:

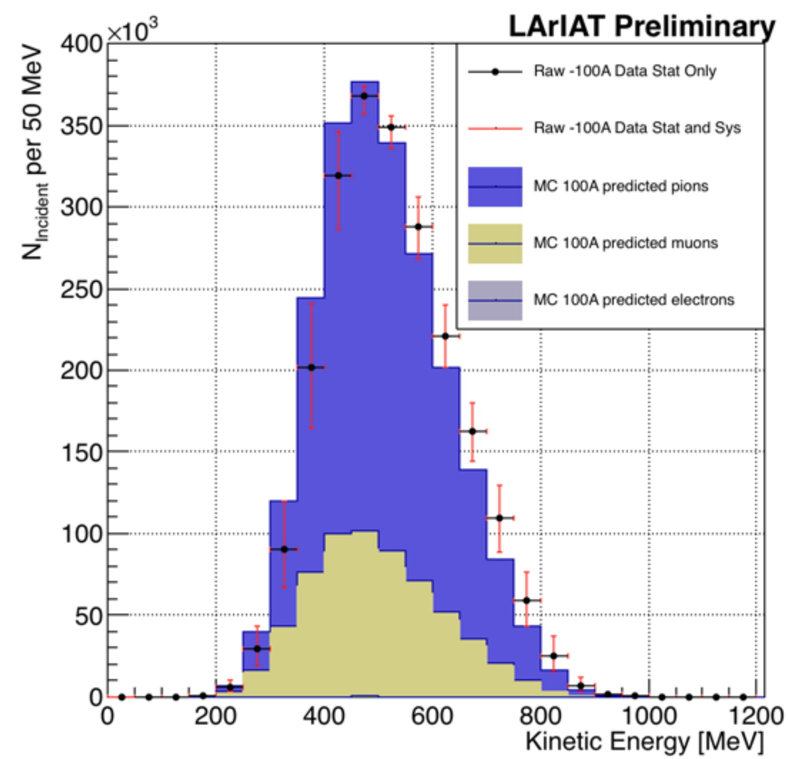
E_i, $E_i + \delta E$, $E_i - \delta E$

take ratio separately: 100% correlation

XS Formula: Raw Count

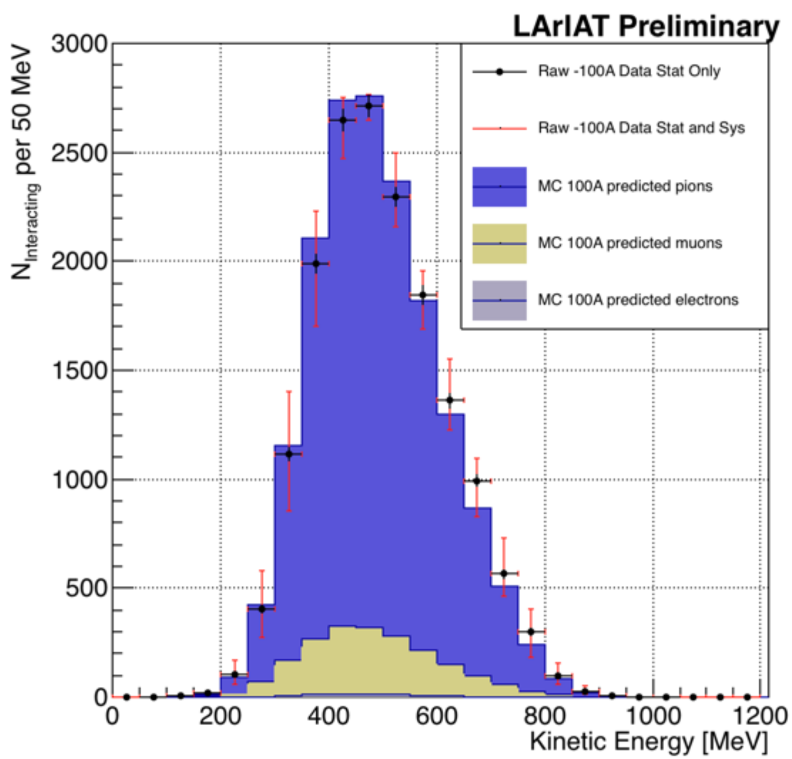
$$\sigma^{\pi^-}_{TOT}(E_i) = \frac{1}{n\ \delta X} \frac{\epsilon^{\text{Inc}}(E_i)\ \ C^{\pi MC}_{\text{Int}}(E_i)\ \ N^{\text{TOT}}_{\text{Int}}(E_i)}{\epsilon^{\text{Int}}(E_i)\ \ C^{\pi MC}_{\text{Inc}}(E_i)\ \ N^{\text{TOT}}_{\text{Inc}}(E_i)}$$





XS Formula: Background Subtraction

$$\sigma_{TOT}^{\pi^-}(E_i) = \frac{1}{n\ \delta X} \frac{\epsilon^{\text{Inc}}(E_i)}{\epsilon^{\text{Int}}(E_i)} \frac{C_{\text{Int}}^{\pi MC}(E_i)}{C_{\text{Inc}}^{\pi MC}(E_i)} \frac{N_{\text{Int}}^{\text{TOT}}(E_i)}{N_{\text{Inc}}^{\text{TOT}}(E_i)}$$



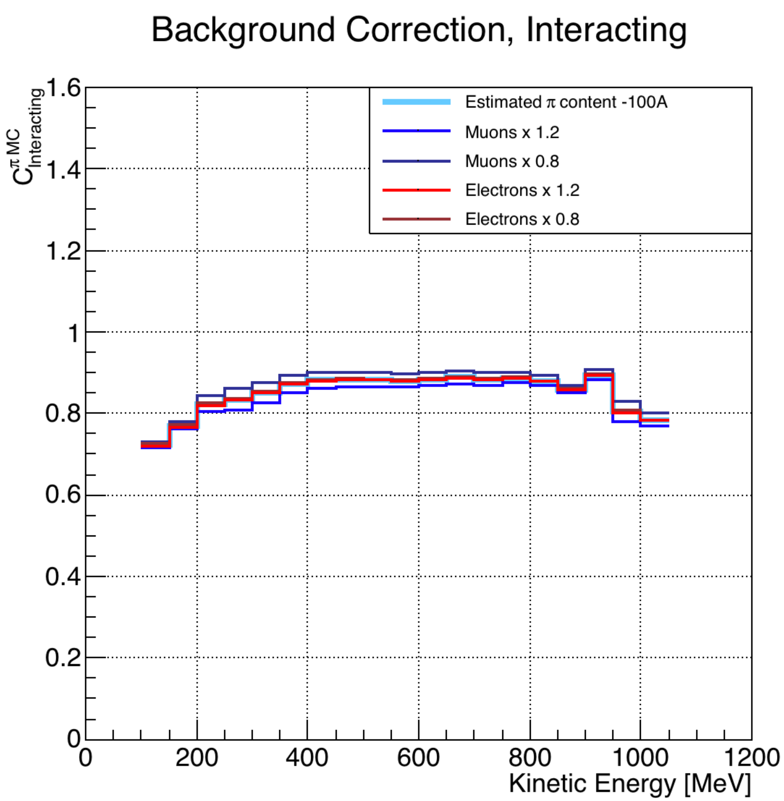
A.k.a. Pion Content

$$C_{\text{Int}}^{\pi\ \text{MC}}(E_i) = \frac{N_{\text{Int}}^{\pi\ \text{MC}}(E_i)}{N_{\text{Int}}^{\text{TOT MC}}(E_i)} = \frac{N_{\text{Int}}^{\text{TOT MC}}(E_i) - B_{\text{Int}}^{\text{TOT MC}}(E_i)}{N_{\text{Int}}^{\text{TOT MC}}(E_i)}$$

$$C_{\text{Inc}}^{\pi\ \text{MC}}(E_i) = \frac{N_{\text{Inc}}^{\pi\ \text{MC}}(E_i)}{N_{\text{Inc}}^{\text{TOT MC}}(E_i)} = \frac{N_{\text{Inc}}^{\text{TOT MC}}(E_i) - B_{\text{Inc}}^{\text{TOT MC}}(E_i)}{N_{\text{Inc}}^{\text{TOT MC}}(E_i)}$$

XS Formula: Background Subtraction

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



Beam composition

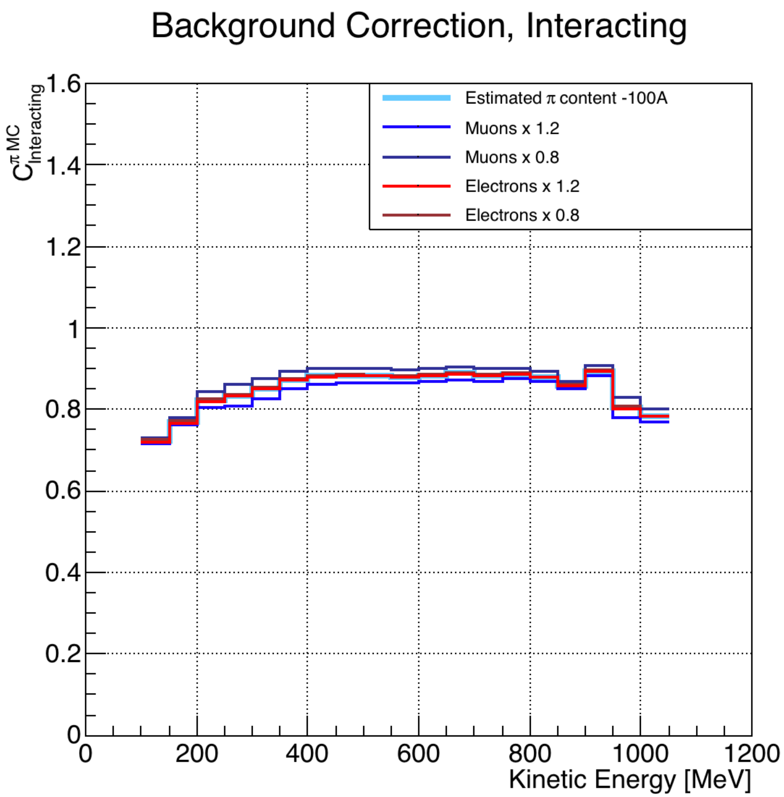
	Low E Beam	High E Beam
G4Pions	70.9 %	82.3 %
G4Muons	14.6 %	13.5 %
G4Electrons	14.5 %	4.2 %

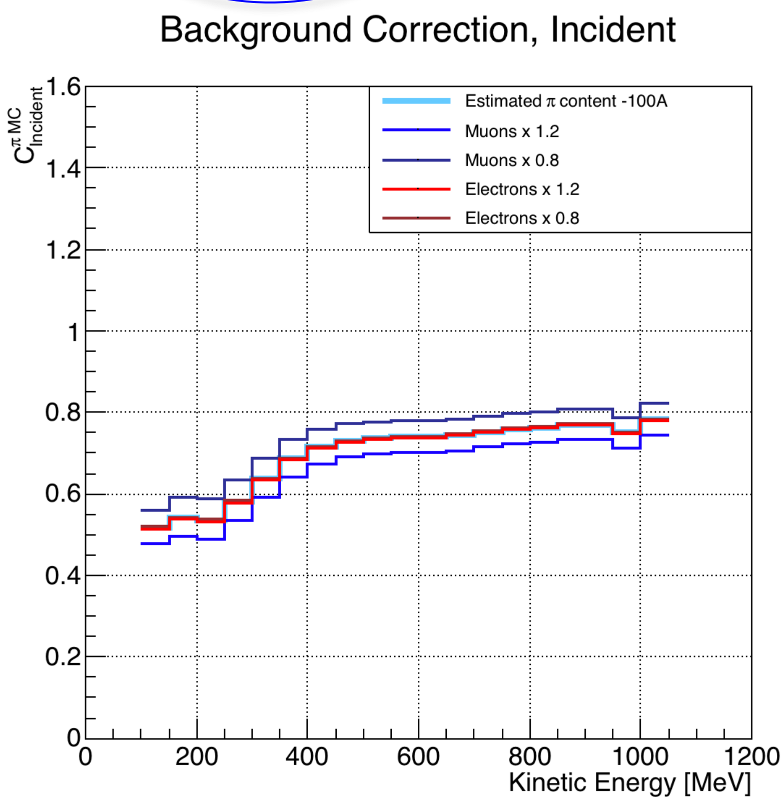
+/-20% variation in electron

+/-20% variation in muon

XS Formula: Background Subtraction

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

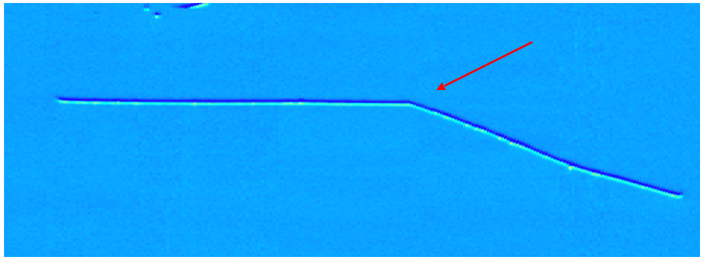




XS Formula: Reconstruction Effects

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

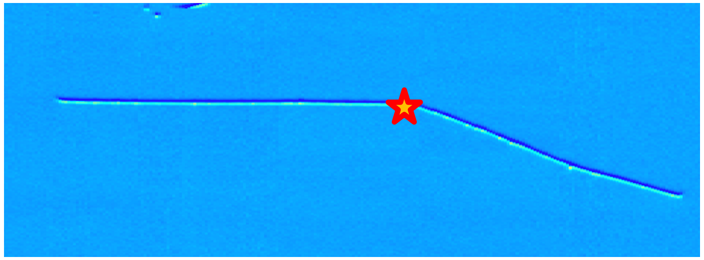
Interaction



XS Formula: Reconstruction Effects

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

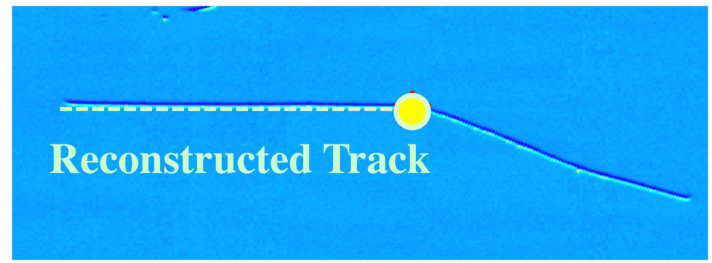
Interaction



XS Formula: Reconstruction Effects

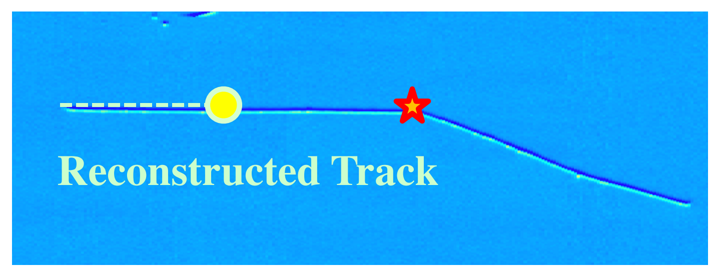
$$\sigma_{TOT}^{\pi^-}(E_i) = \frac{1}{n\ \delta X} \frac{\epsilon^{\mathrm{Inc}}(E_i)\ C^{\pi MC}_{\mathrm{Int}}(E_i)\ N^{\mathrm{TOT}}_{\mathrm{Int}}(E_i)}{\epsilon^{\mathrm{Int}}(E_i)\ C^{\pi MC}_{\mathrm{Inc}}(E_i)\ N^{\mathrm{TOT}}_{\mathrm{Inc}}(E_i)}$$

Correct Interaction ID



Missed Interaction

Early Stop

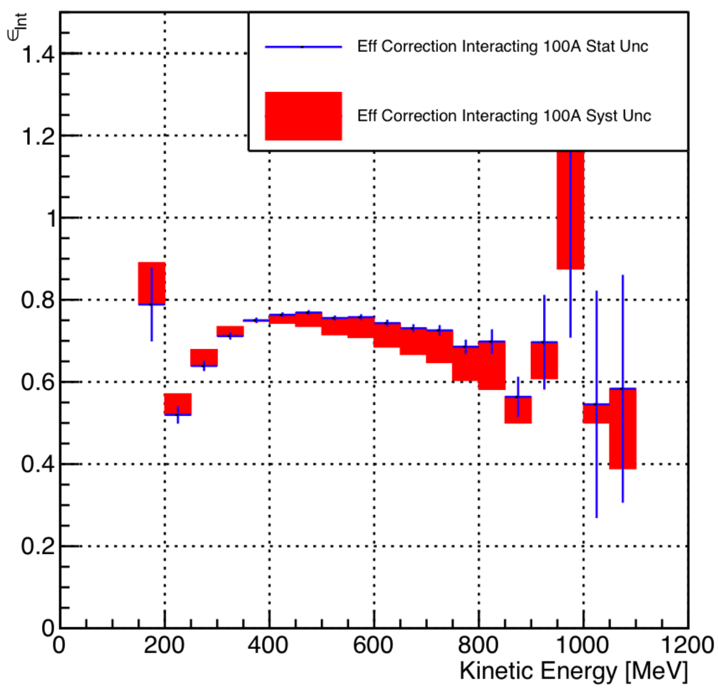


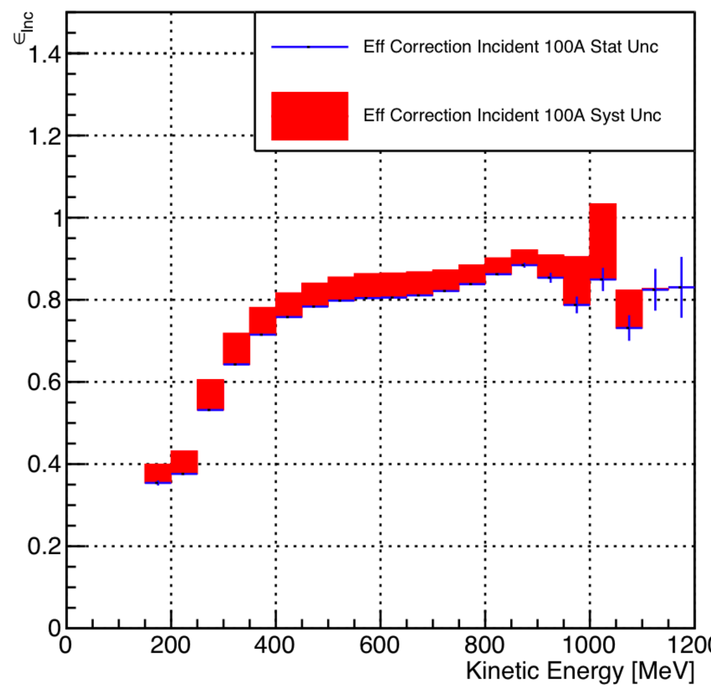
No sensitivity for angles < 5 deg

XS Formula: Reconstruction Effects

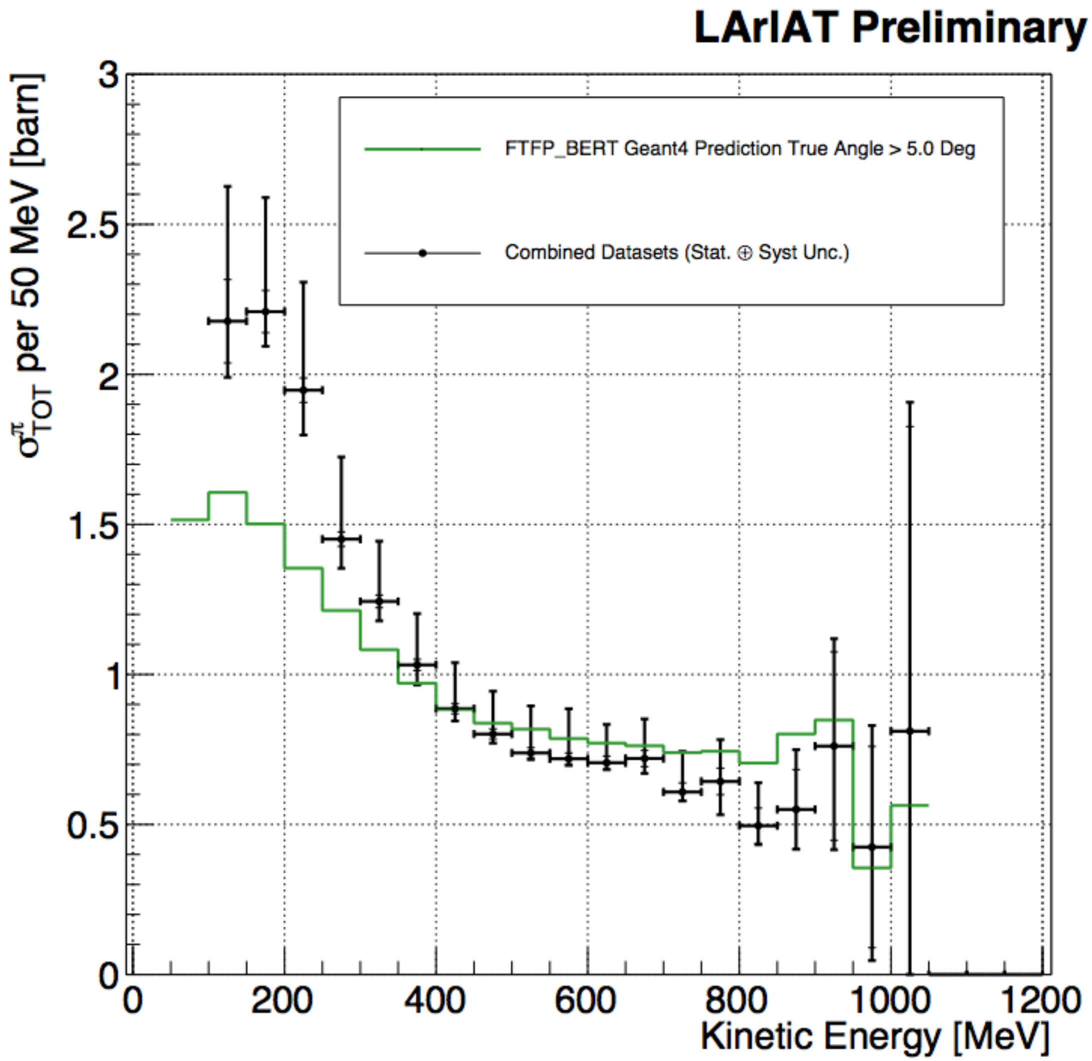
$$\sigma^{\pi^-}_{TOT}(E_i) = \frac{1}{n\ \delta X} \frac{\epsilon^{\rm Inc}(E_i)\ C^{\pi\ MC}_{\rm Int}(E_i)\ N^{\rm TOT}_{\rm Int}(E_i)}{\epsilon^{\rm Int}(E_i)\ C^{\pi\ MC}_{\rm Inc}(E_i)\ N^{\rm TOT}_{\rm Inc}(E_i)}$$

$$\epsilon_i^{\rm Int} = \frac{N^{\rm Reco\ MC\ \pi}_{\rm Int,i}}{N^{\rm True\ MC\ \pi}_{\rm Int,i}} \qquad \epsilon_i^{\rm Inc} = \frac{N^{\rm Reco\ MC\ \pi}_{\rm Inc,i}}{N^{\rm True\ MC\ \pi}_{\rm Inc,i}}$$



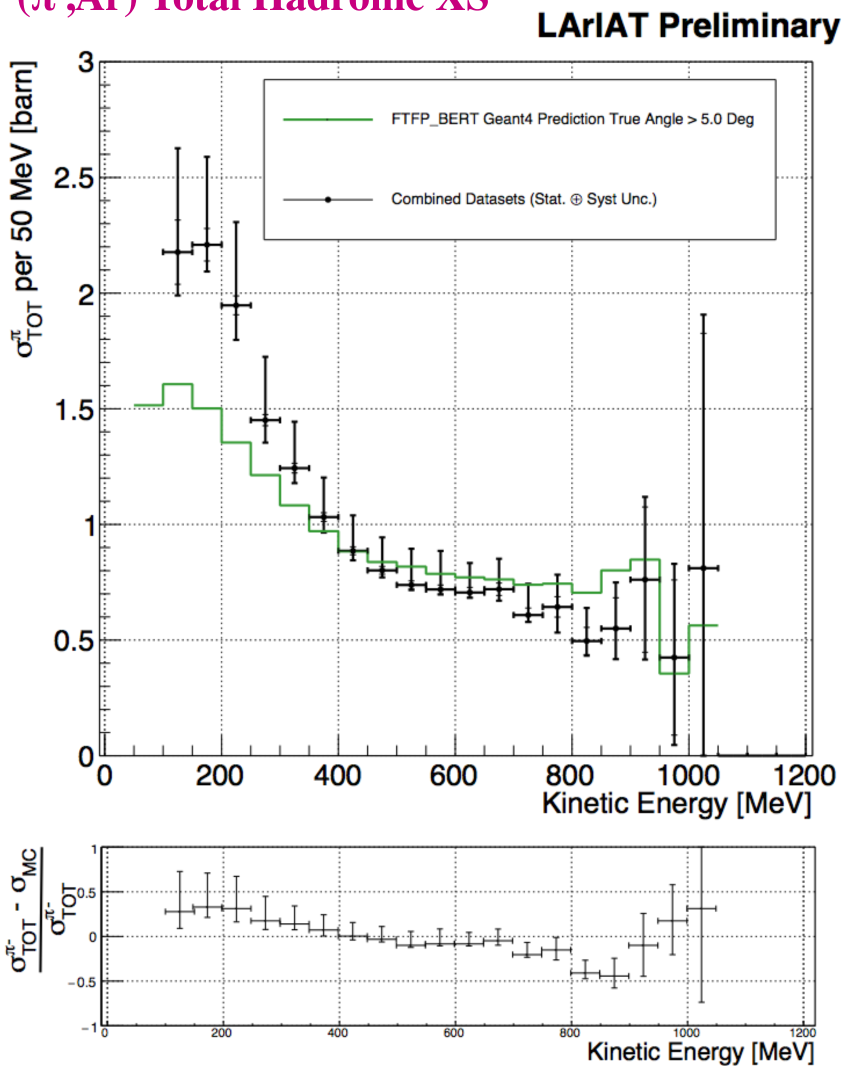


Cross Section Measurement



Conclusions & Prospects: (π-,Ar) XS

(π-,Ar) Total Hadronic XS



The **π- total hadronic cross section** has been measured for the **first time on Argon** in the 100-1050 MeV kinetic energy range.

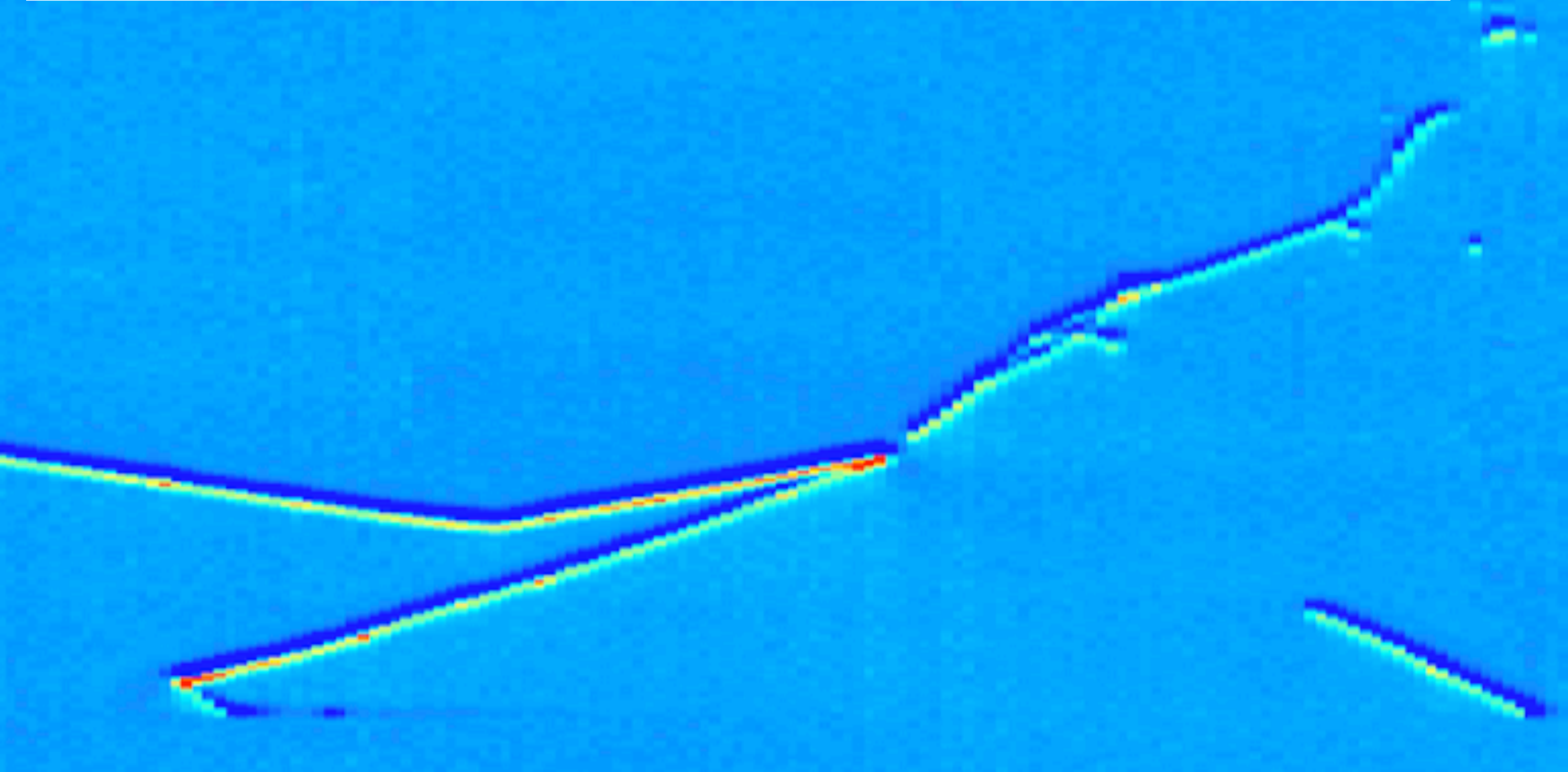
With the exception of the highest KE bins, the uncertainty is mostly dominated by the **systematics**.

Agreement with Geant4 FTFP_BERT predictions outside the Δ peak.
Hint to a shape difference, ground for exciting developments.

Possible updates: improve statistics & background removal from data

K^+ Total Cross Section

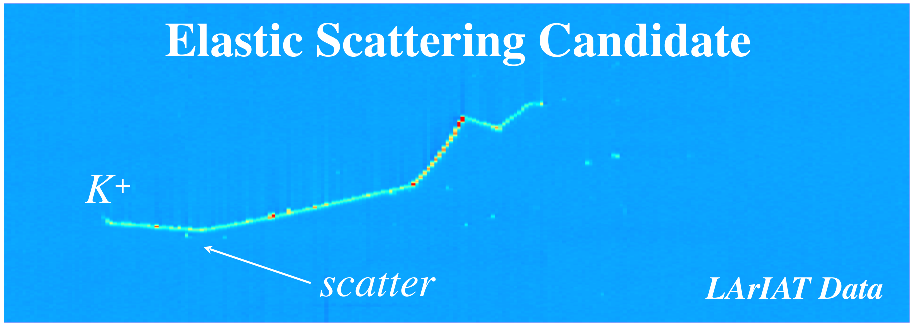
LArIAT's first glance at Kaons in Argon.

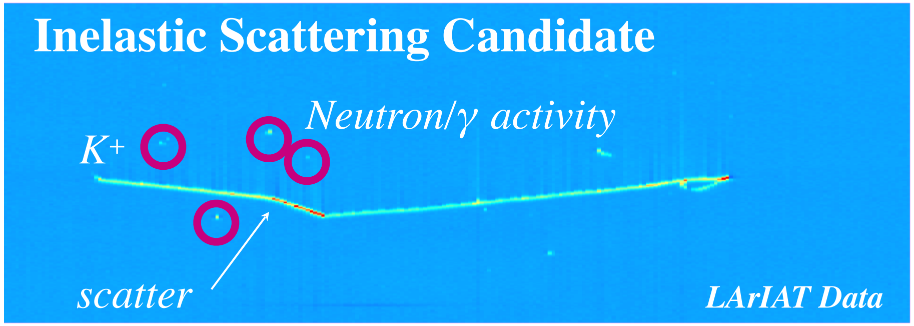


Signal & Background Topologies

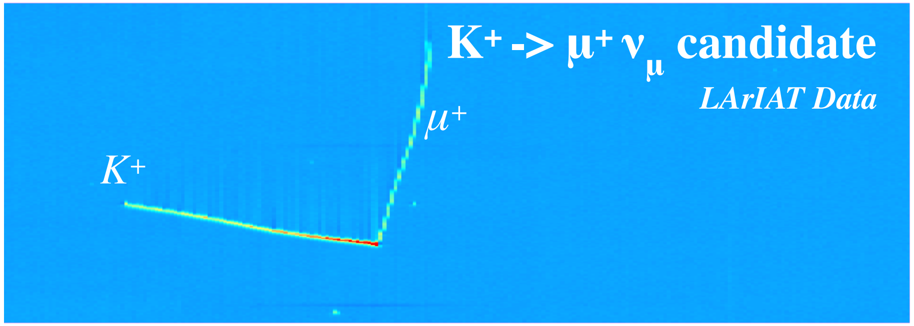
Signal: **All Hadronic Interactions**

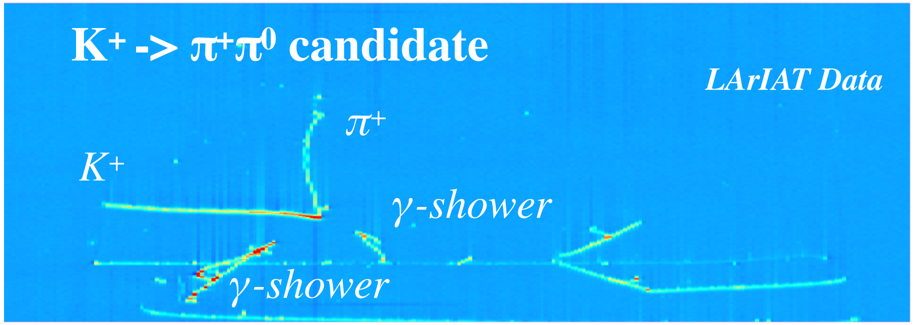
$$\sigma_{Tot} = \sigma_{Elastic} + \sigma_{Reaction}$$





Backgrounds: **Kaon Decay**





(K+,Ar) Cross Section

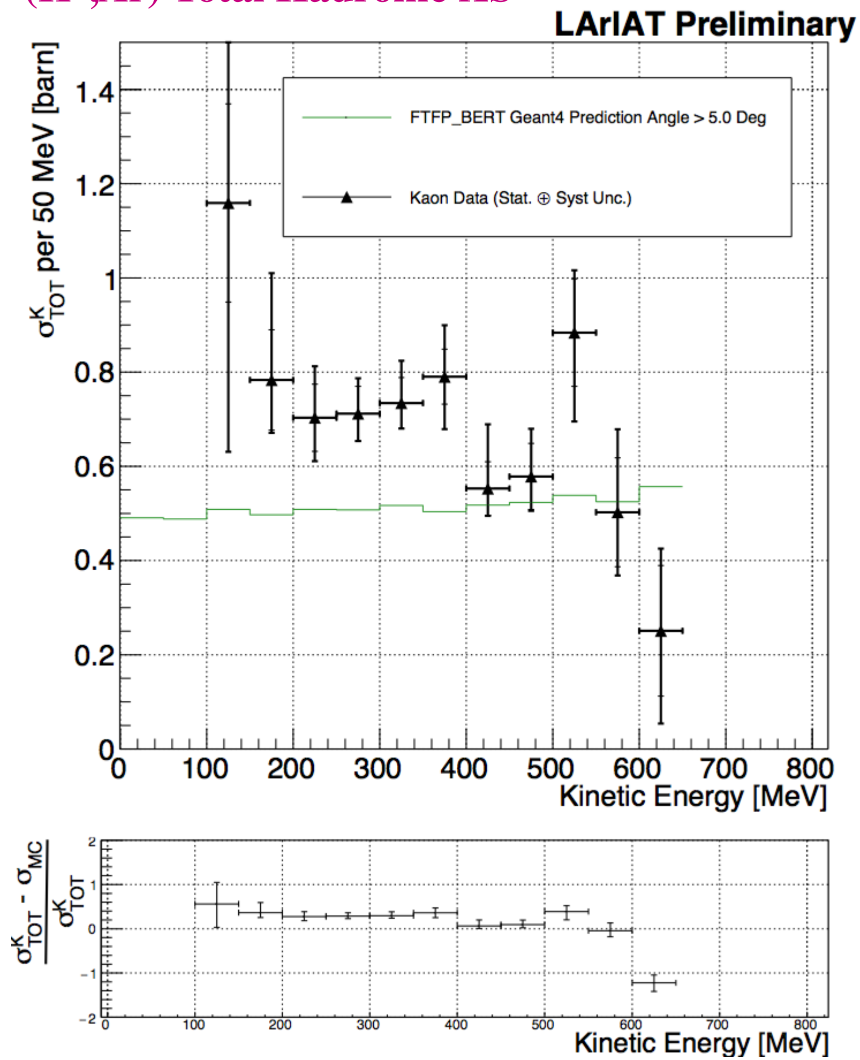
1081 Kaon Candidates for XS:
the uncertainty is mostly dominated by **statistics**.

Data driven assessment of beamline contamination:
0.2 ± 0.5 % from protons
5 ± 2 % from π/μ/e

Statistical removal of decay in flight.
Systematics: energy and tracking reconstruction.

The **K^+ total hadronic cross section** has been measured for the **first time on Argon** in the 100-650 MeV kinetic energy range.

(K+,Ar) Total Hadronic XS



Coming soon from LArIAT

Total Hadron-Ar interaction cross sections: (π^-,Ar) , (K^+,Ar)

Total Hadron-Ar interaction cross sections: (π^+,Ar), (K^-,Ar)

Exclusive channels: Pion absorption & charge exchange, p inelastic

Anti-proton characterization

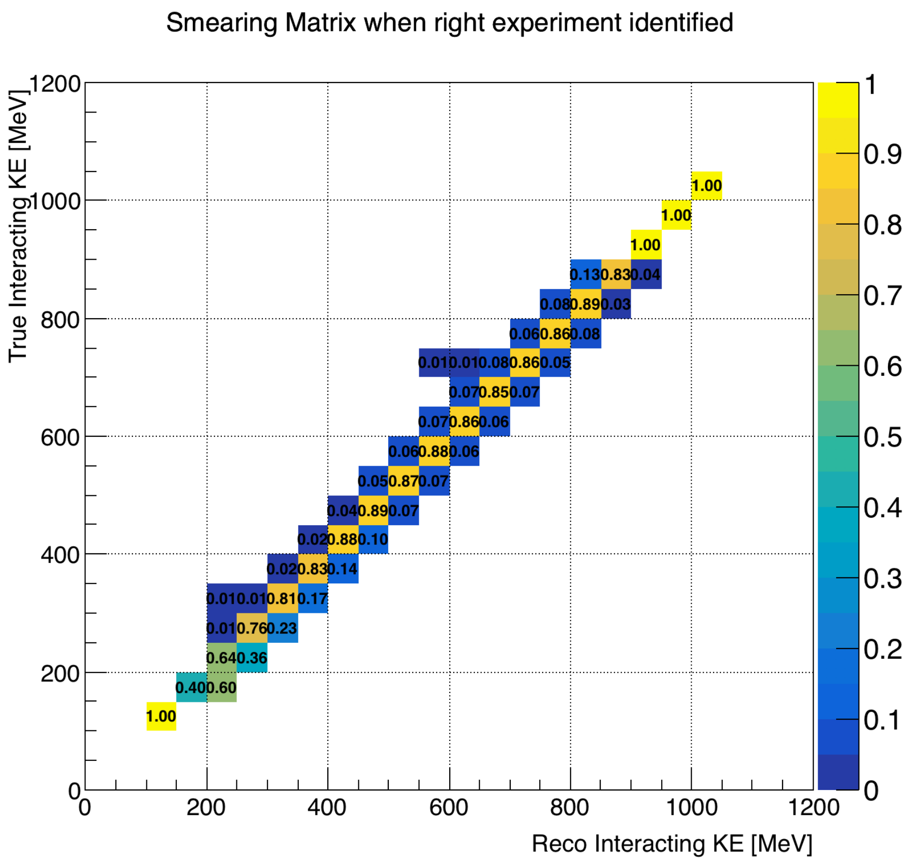
Light-augmented calorimetry

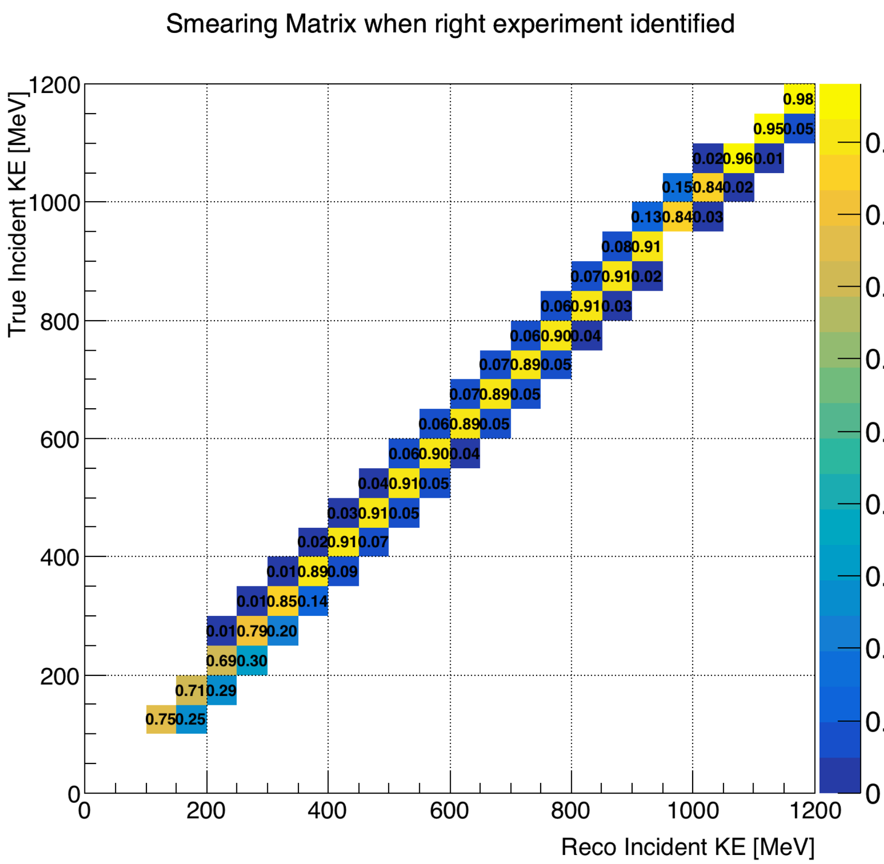
THANKS!!!

BACKUP

Pion smearing matrices

High Energy Beam Negative Pion

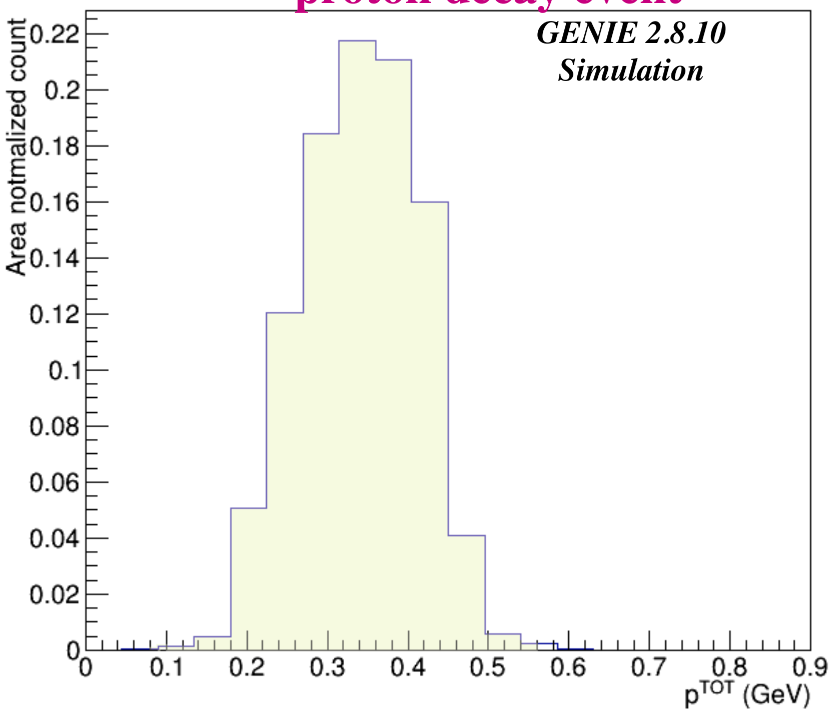




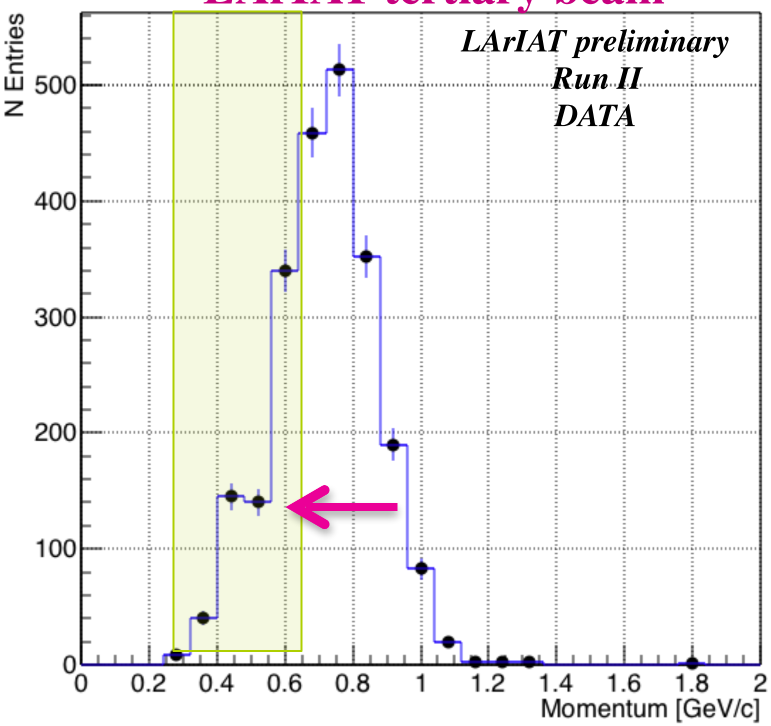
Why LArIAT is the best (place to study Kaons)

The momentum distribution for Kaons in the LArIAT TPC **overlaps** completely with the momentum spectrum expected for the Kaon on a proton decay event.

GENIE simulation of p_K for proton decay event



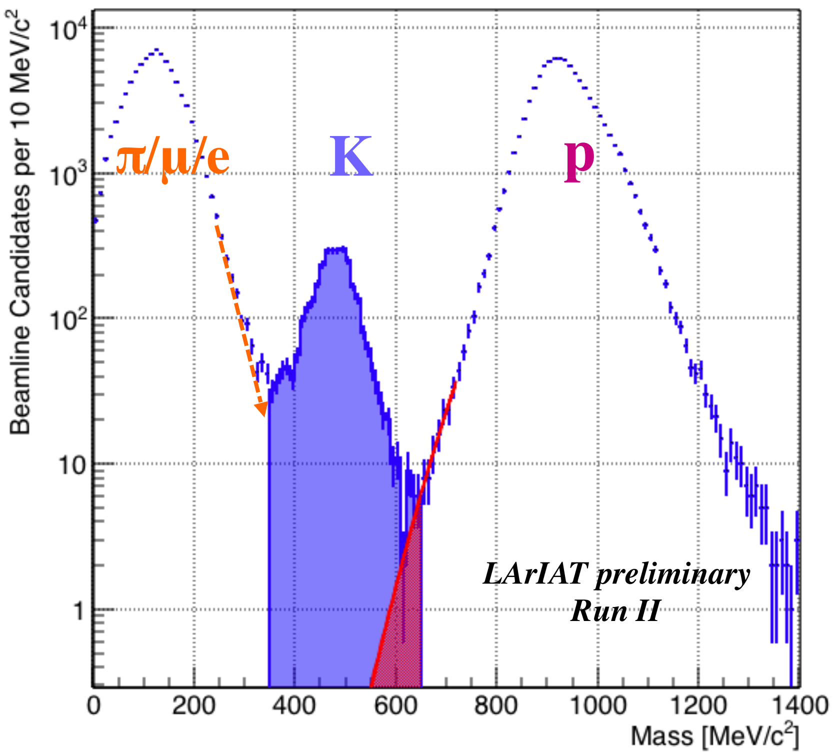
Kaon Initial Momentum in LArIAT tertiary beam



Beamline Contamination

Data Driven method from beamline mass distribution.
We **estimate the bleed over** from high and low mass peaks under the kaon peak.

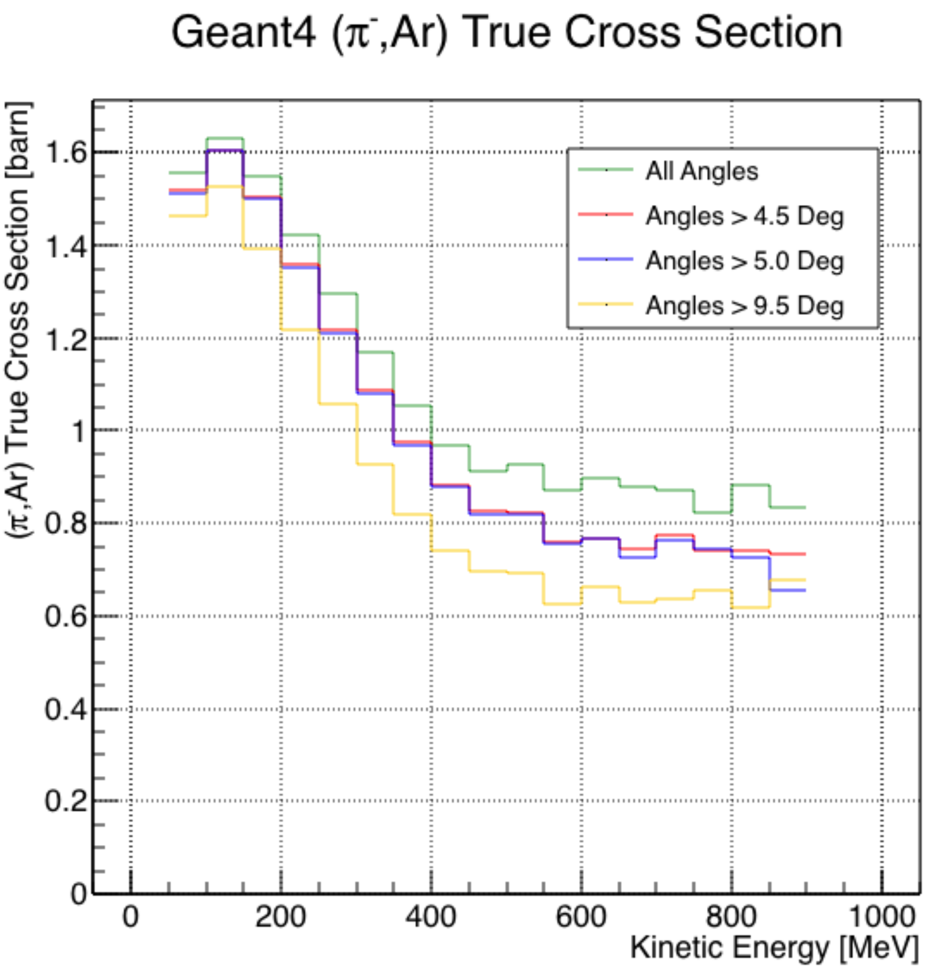
Issue: we **don't know** the **shape** of those tails: iterative fit method.

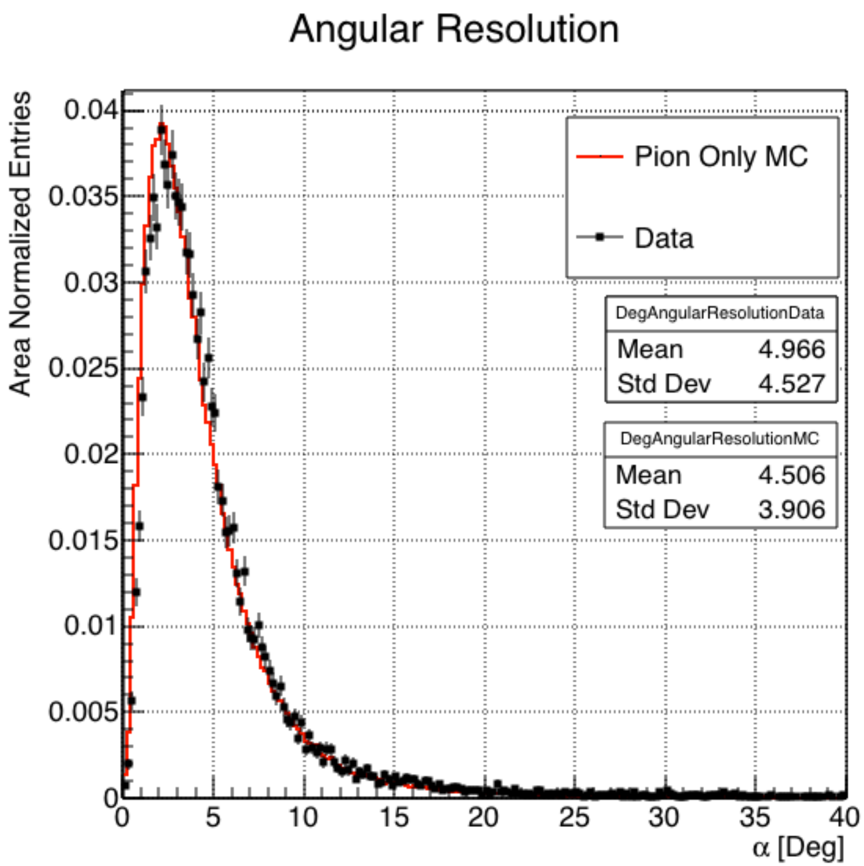


With 12 iterations of the fit we find:

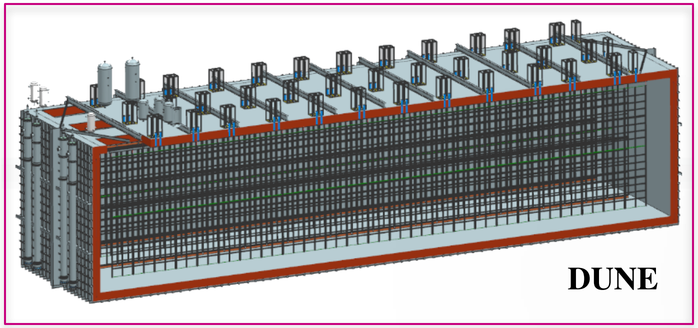
High Mass Contamination = 0.2 ± 0.5 %
Low Mass Contamination = 5 ± 2 %

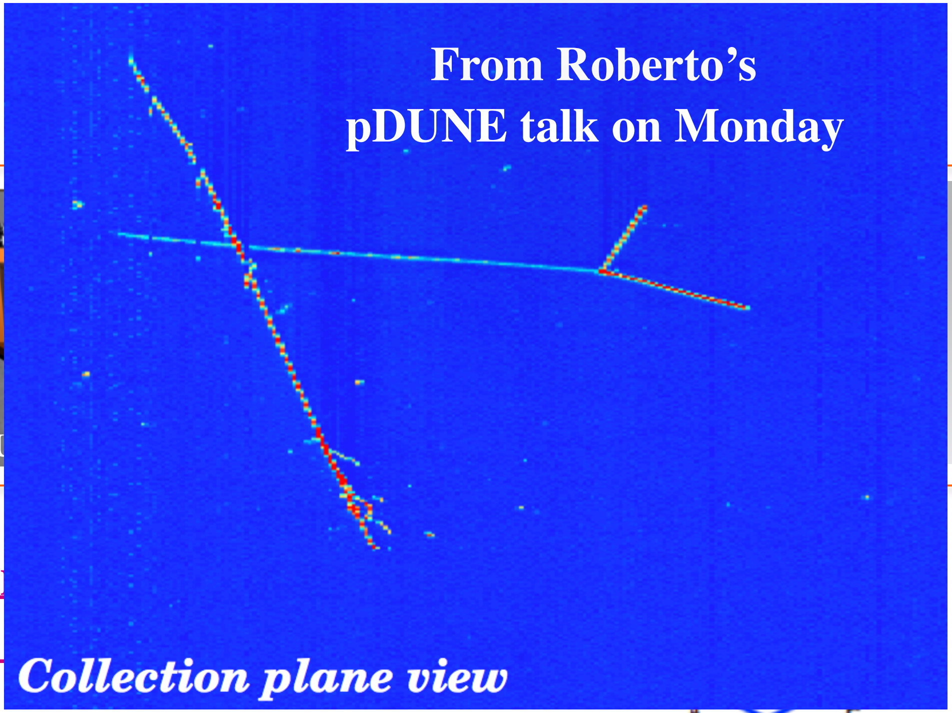
What angles are invisible to us?



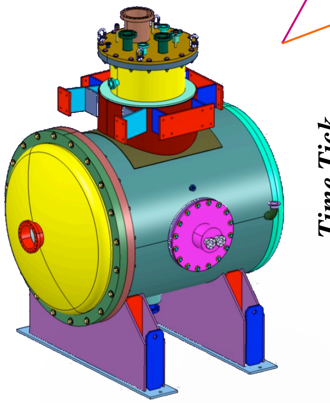


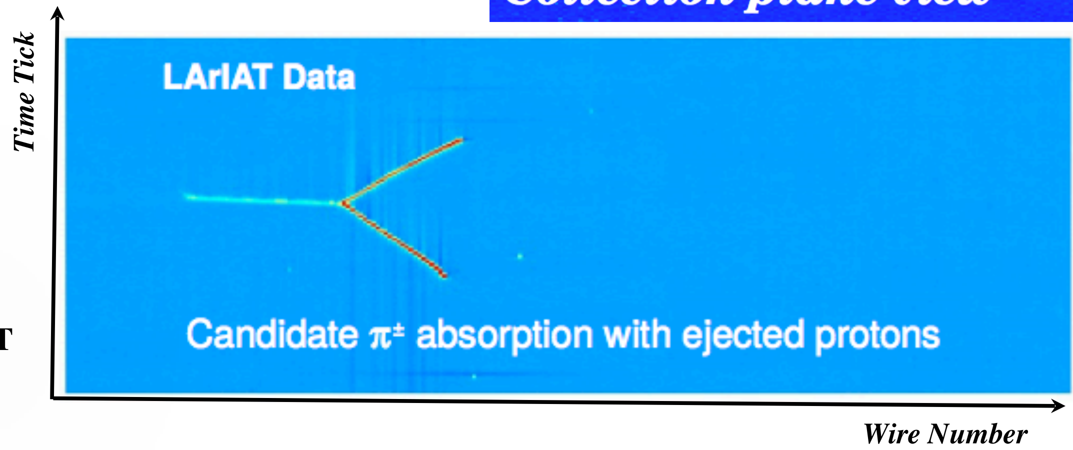
LArIAT's Goals

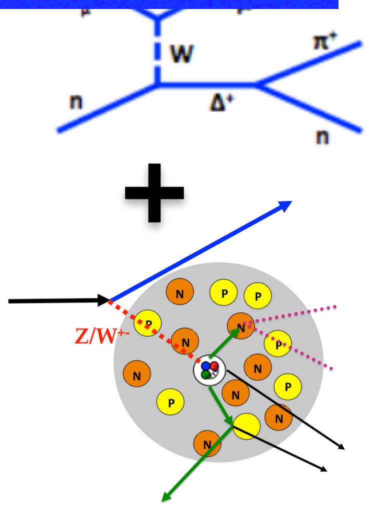




Hadron-Ar i
(π^-,Ar)







Inside LArIAT's hall: MWPCs