Study of the Inclusive Hadronic Kaon-Argon Cross Section

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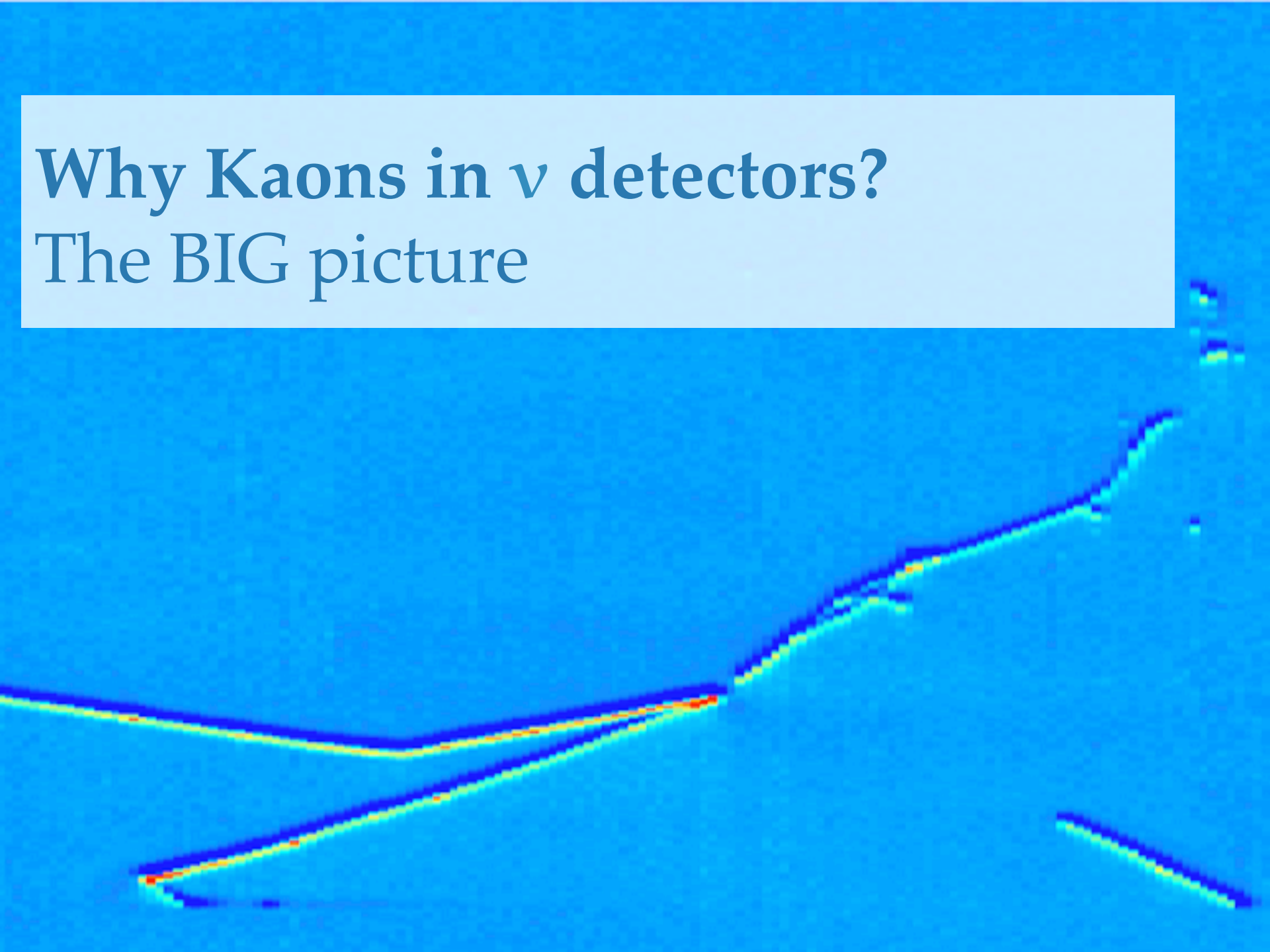
Fermilab – August, 2nd

DPF 2017

Why Kaons in ν detectors?

The BIG picture



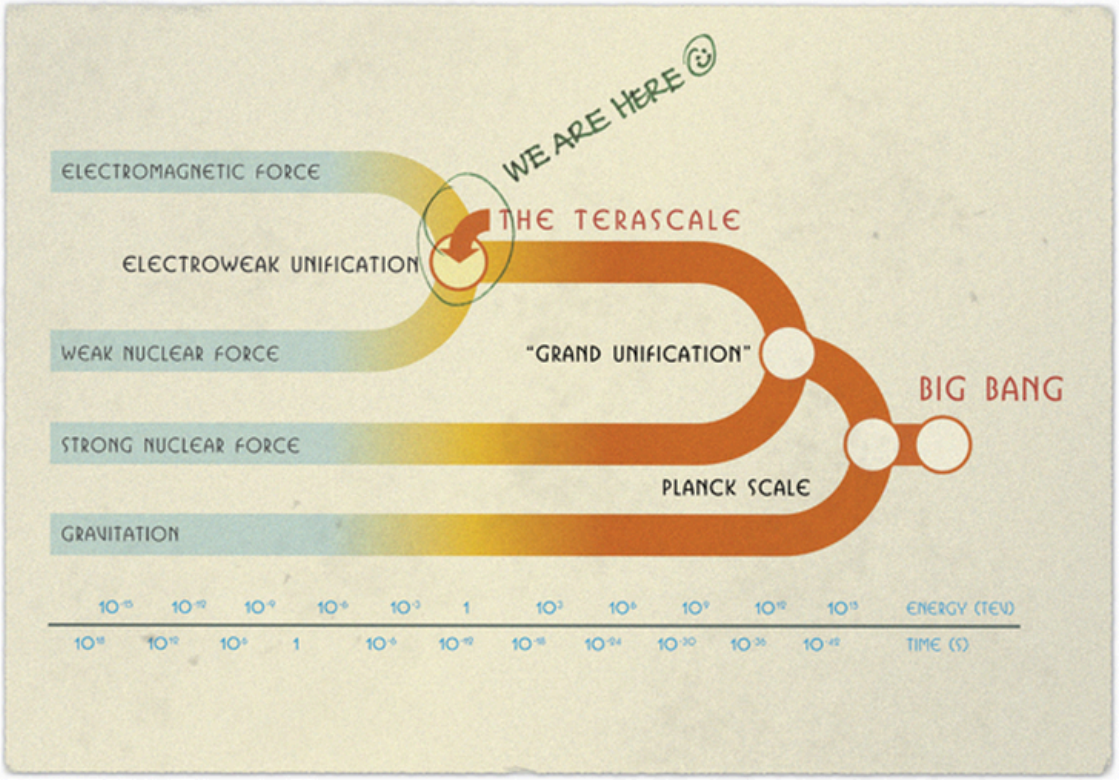
Nucleon Decay Searches

The detection of even one nucleon decay event would be a **direct evidence** of **physics BSM**, opening a window on GUTs exploration.

Every interaction in the **SM conserves baryon number**.

Proton (or bound neutron) **decay** can occur only as a **violation of baryon number** and it's predicted by almost every GUT.

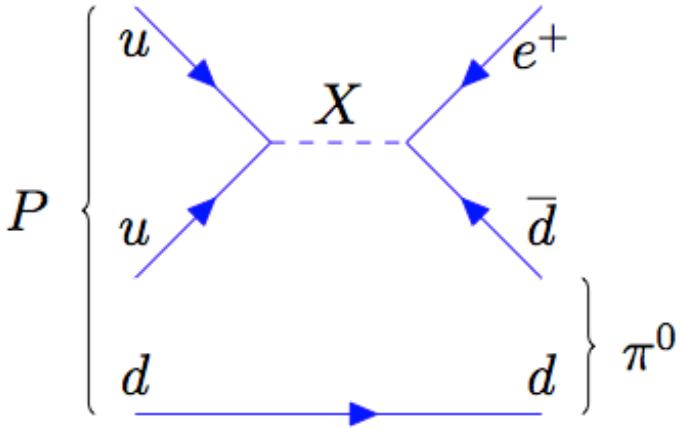
(So does $N\bar{N}$ oscillation… see Will's talk next)



Golden Modes

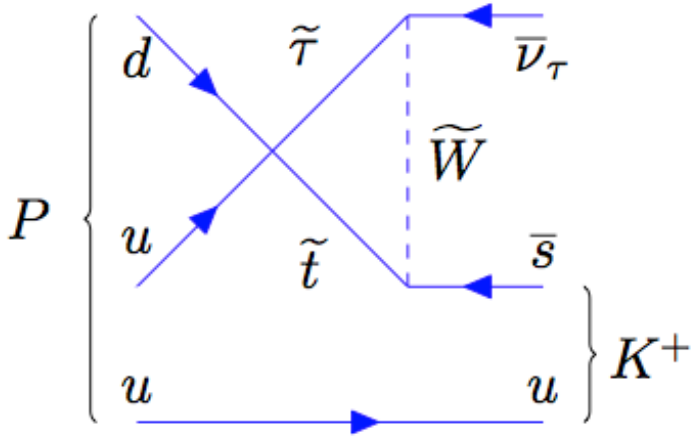
$p \rightarrow e^+\pi^0$

$\tau/B_{p\rightarrow e\pi 0} > 1.6 \times 10^{34}$ yr



$p \rightarrow K^+ \bar{\nu}$

$\tau/B_{p\rightarrow K+\nu} > 5.9 \times 10^{33}$ yr



arXiv:1307.7335 PhysRevD.95.012004 PhysRevD.90.072005

Ingredients for Nucleon Decay Detection

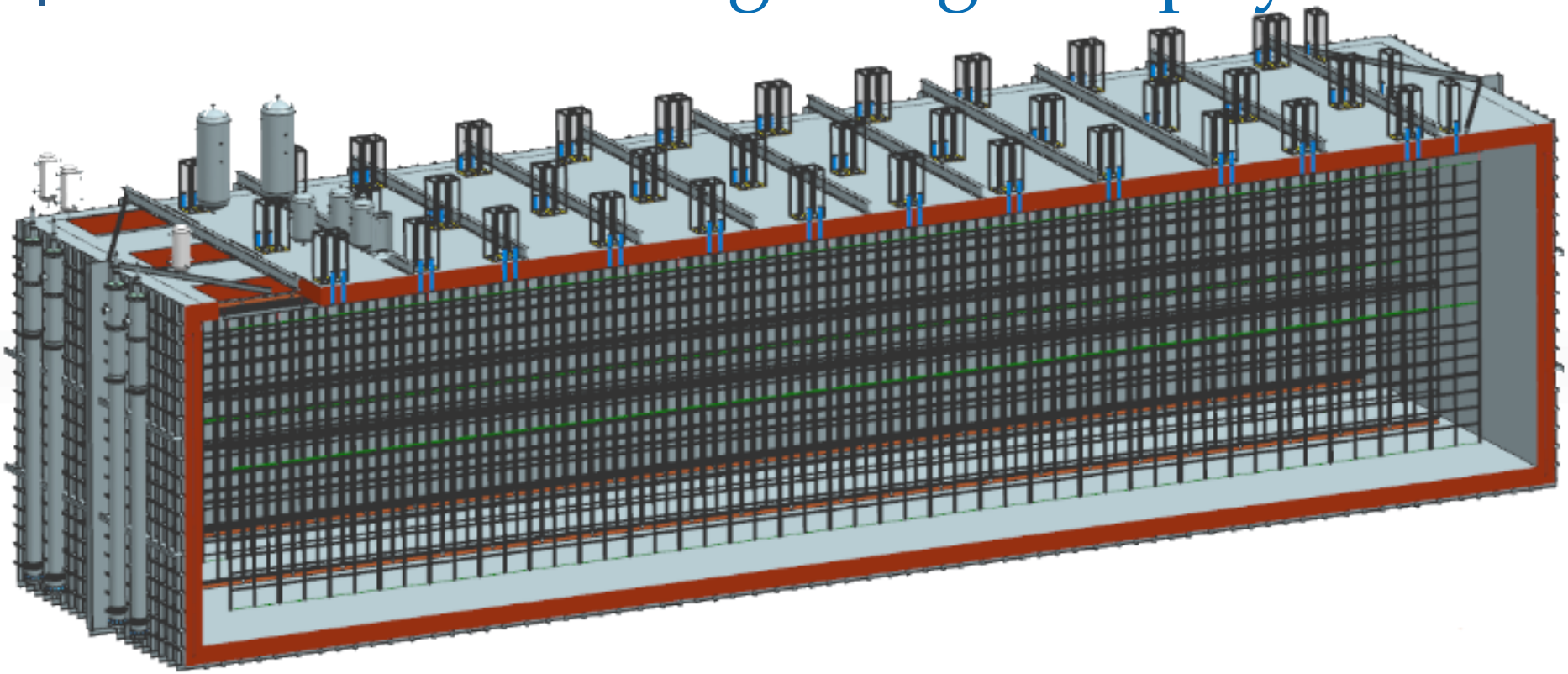
Lots of nucleons

Lots of time

Low background

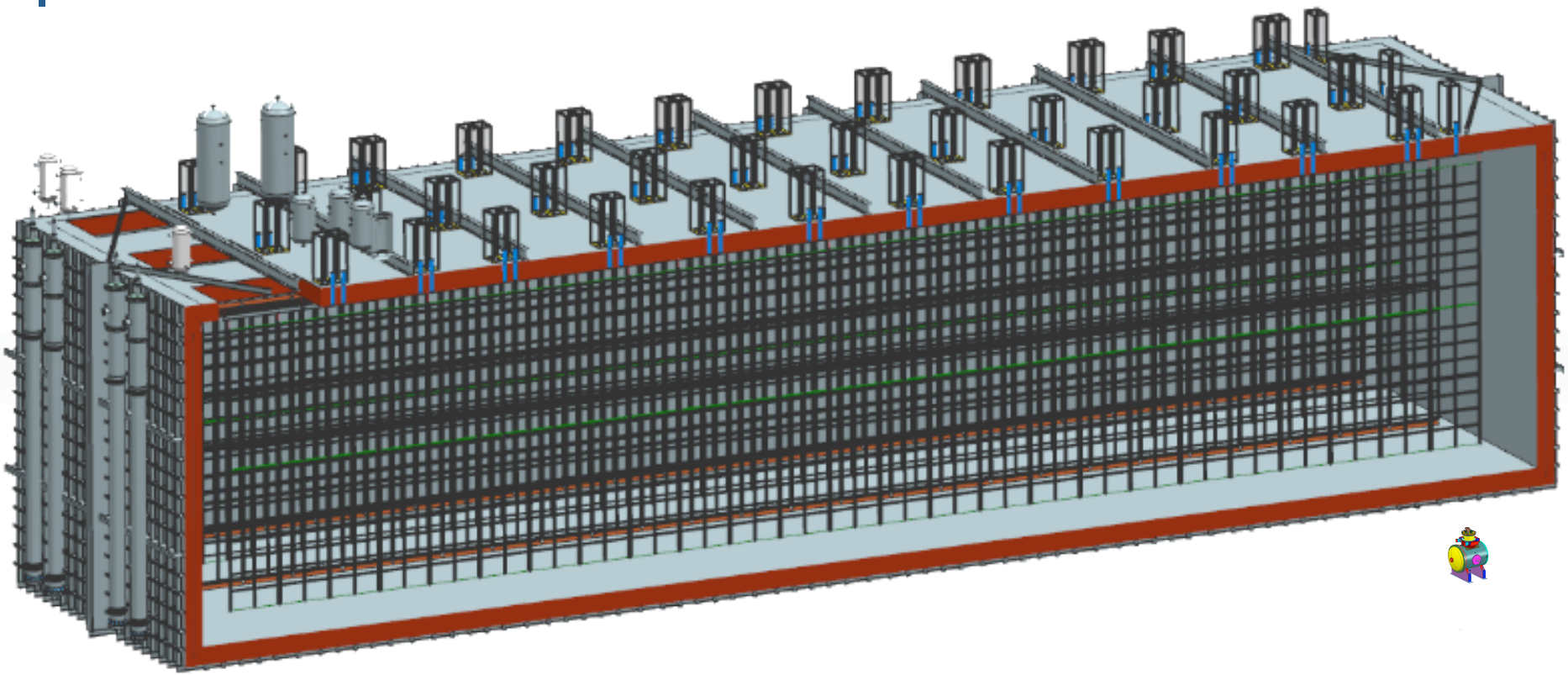
Excellent signal efficiency

DUNE: the next big thing in ν physics



One 10kT DUNE LArTPC Module (18 m x 19 m x 66 m)

DUNE + LArIAT



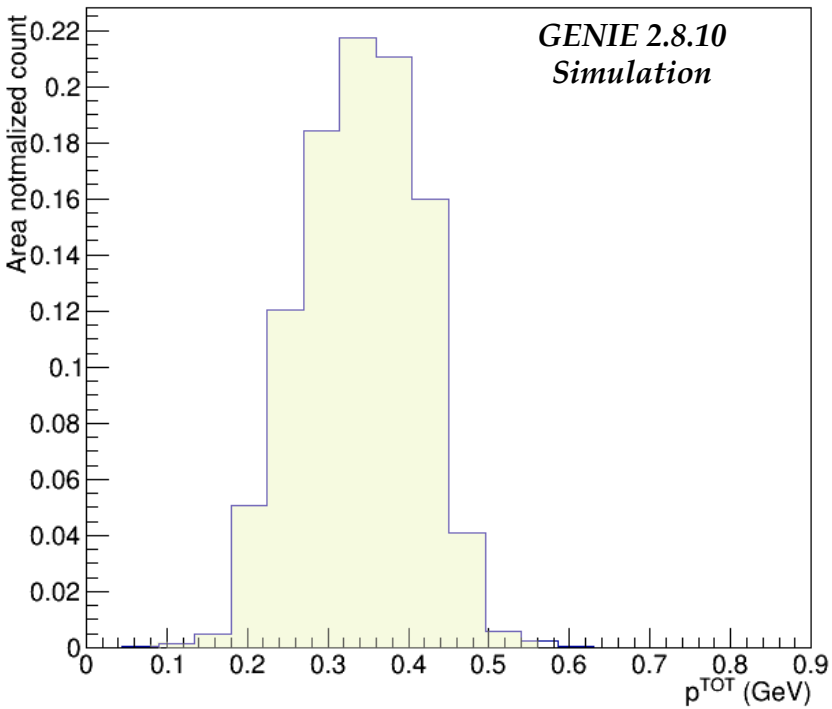
The LArIAT Cryostat (0.25 tons)
(0.4 m x 0.47 m x 0.9 m)

- Yes, we are small (we're sensitive to $\tau/B = 10^{21}$ at best).

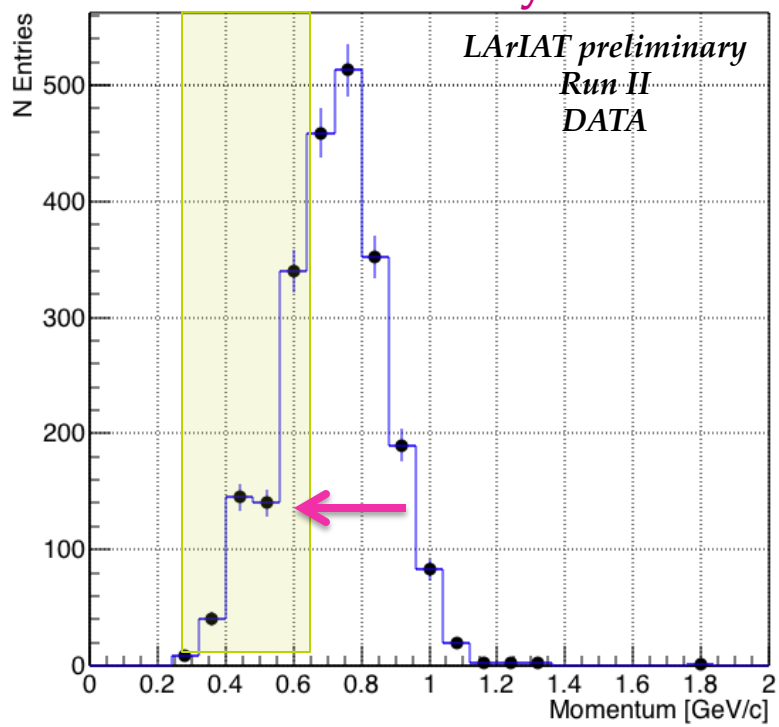
Why LArIAT is the best (place to study Kaons)

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

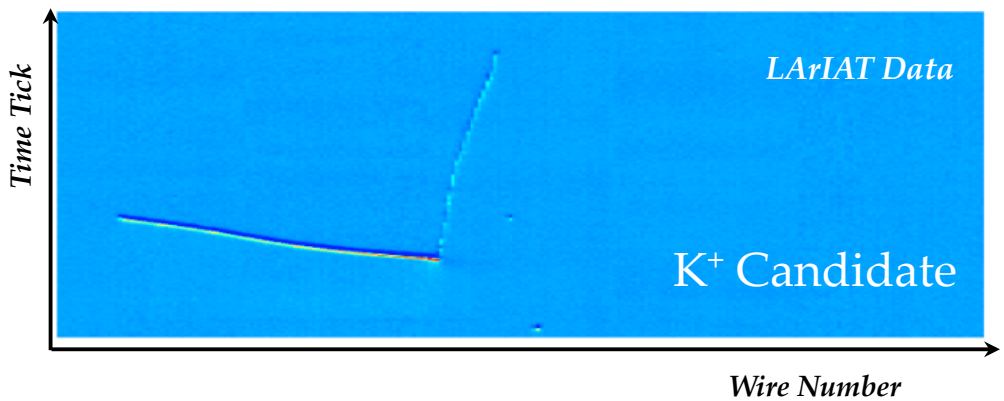


Kaon Initial Momentum in LArIAT tertiary beam

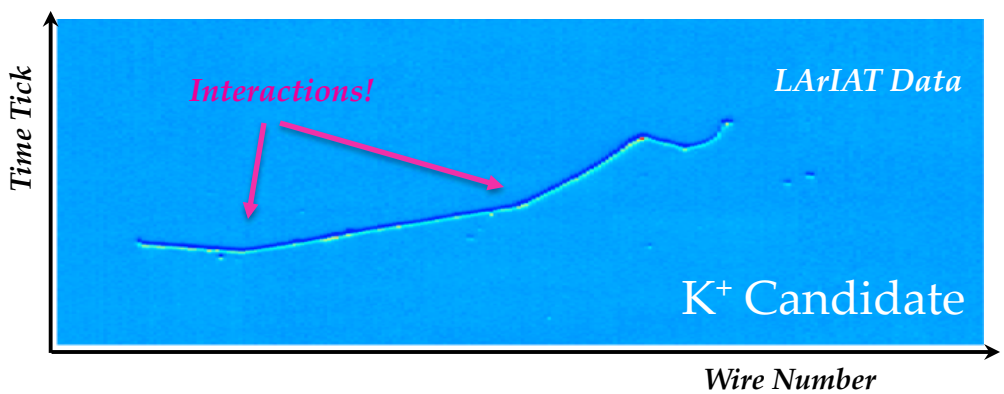


Why LArIAT is the best (place to study Kaons)

We currently have the biggest sample of identified kaons in LAr: **~ 2000 events**.

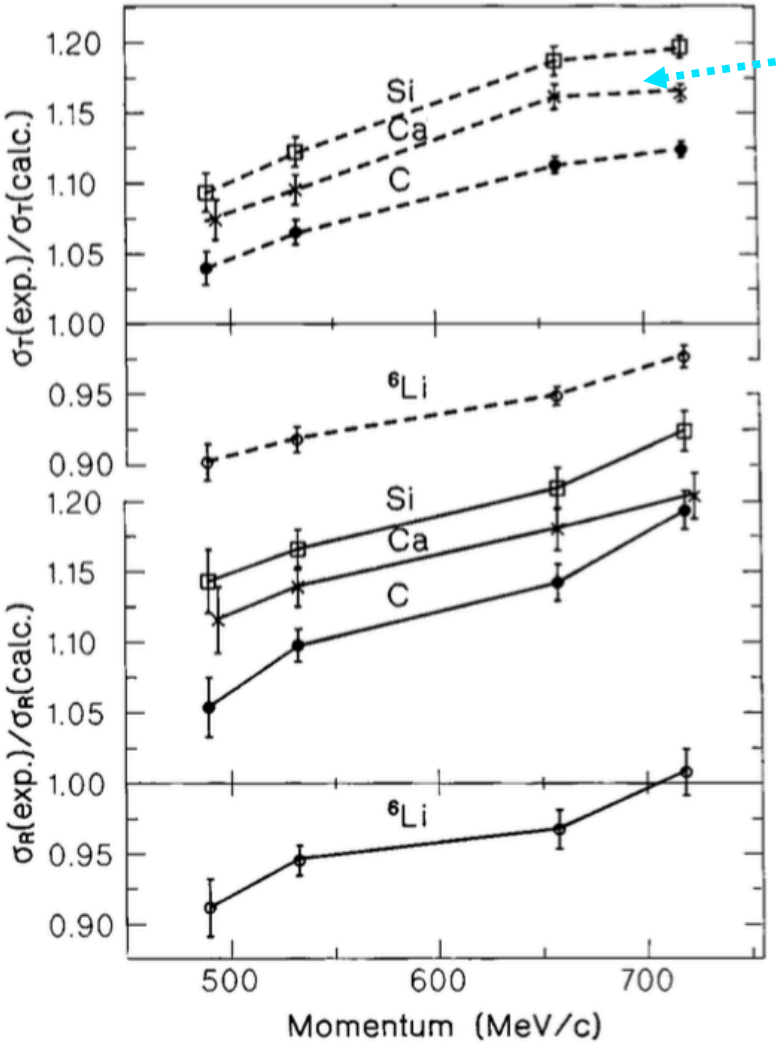


Develop kaon identification algorithms on LAr real DATA (see Dan Smith's poster!)



Improve K simulation in Ar used for proton decay signal simulation thanks to the **inclusive hadronic XS measurement**.

Review of (Very Little) Literature on K



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**.

The intrinsic value of this measurement lays in the exploration of the interaction between nuclei and strange light mesons.

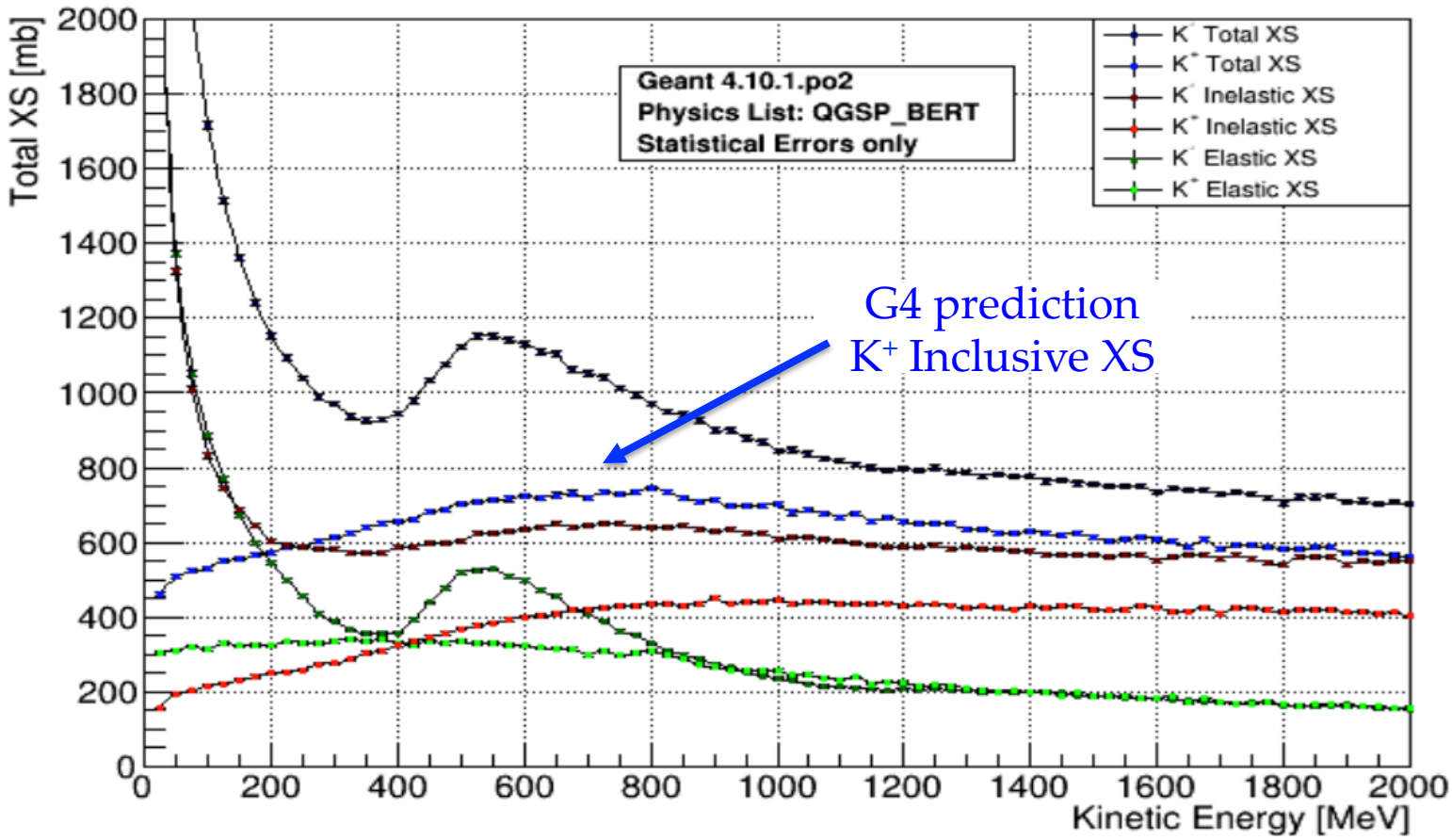
The first LArIAT study concentrates on K^+ cross section, given its relevance to proton decay searches in DUNE.

$p \rightarrow K^+ \bar{\nu}$ Golden channel for pdk in LAr.

Status of the Geant4 Process Simulation

Kaon Cross Section in Geant4: no experimental data for Ar.

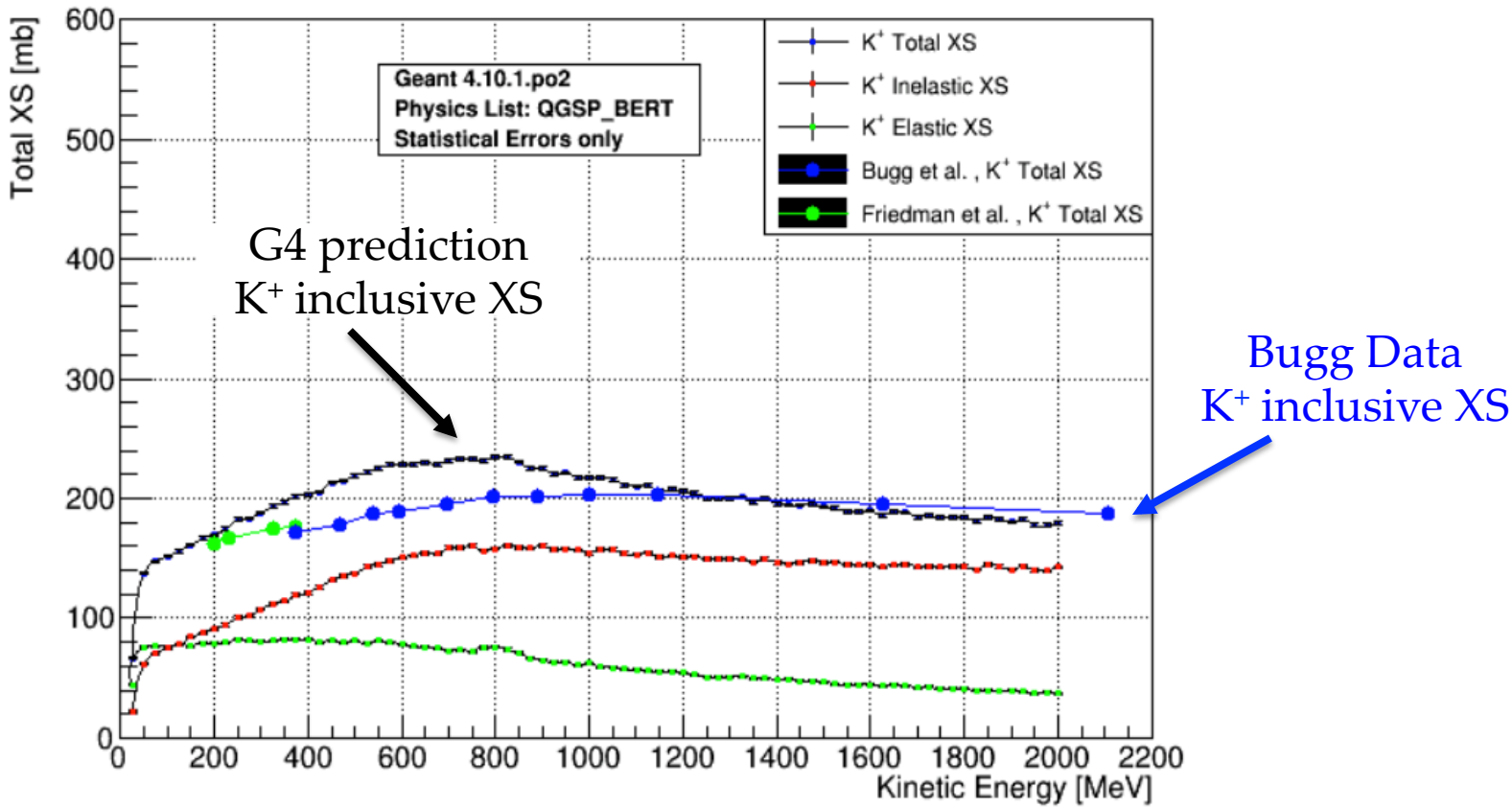
G4 predictions for Ar: K^+ and K^-



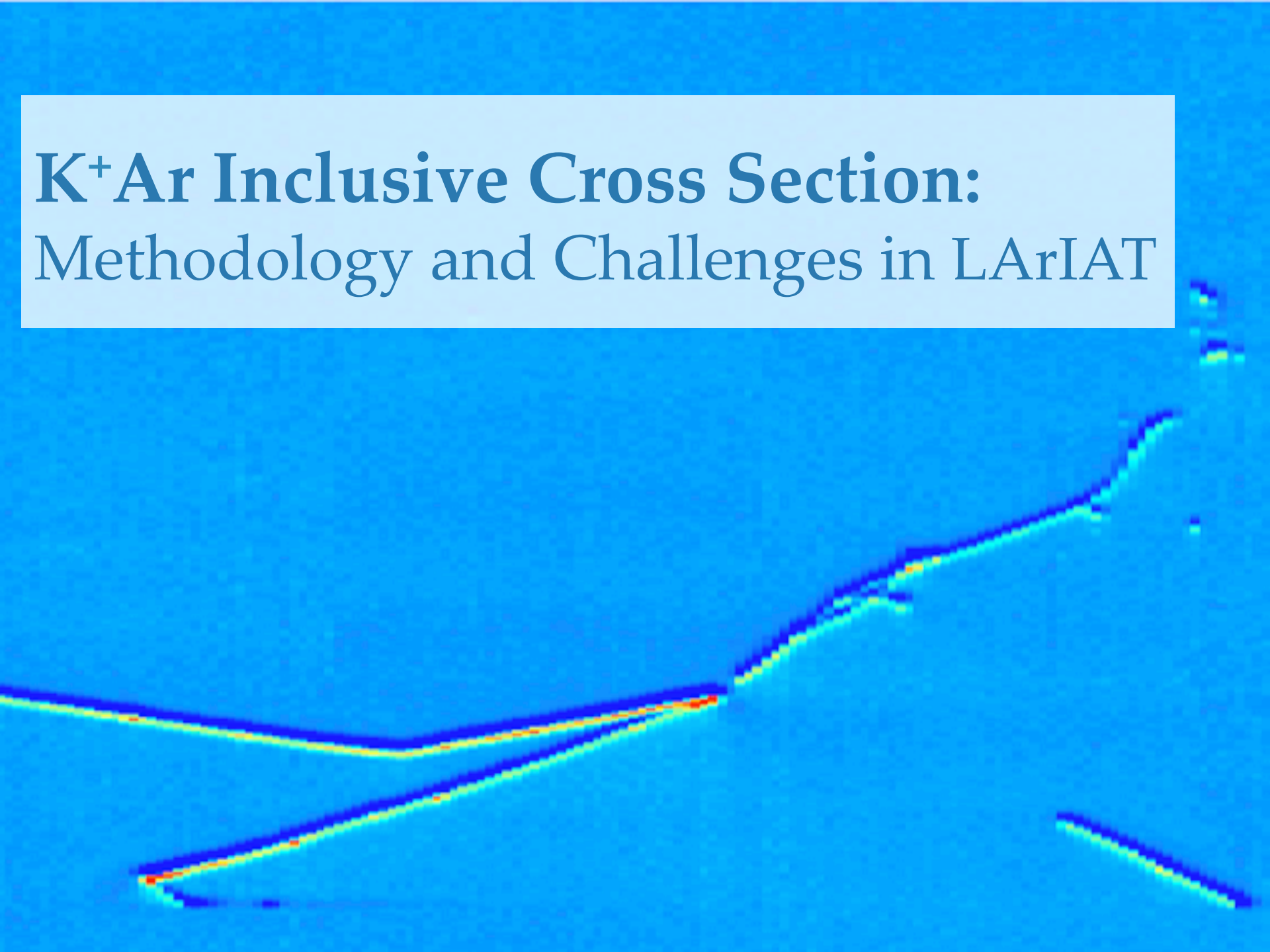
Status of the Geant4 Process Simulation

G4 Kaon Cross Section for Carbon matches poorly the data.

G4 predictions for C: K^+



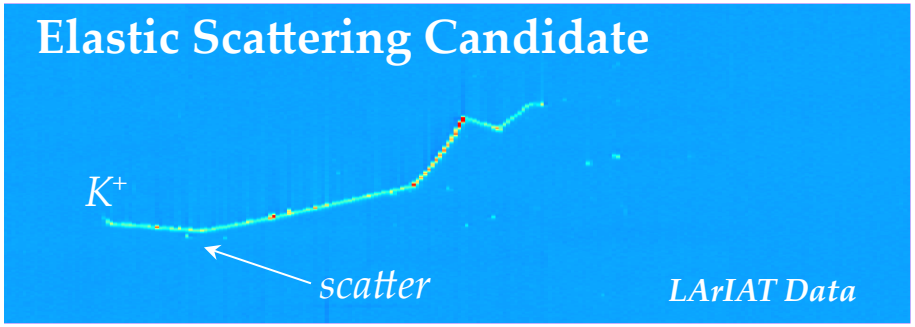
K^+Ar Inclusive Cross Section:
Methodology and Challenges in LArIAT

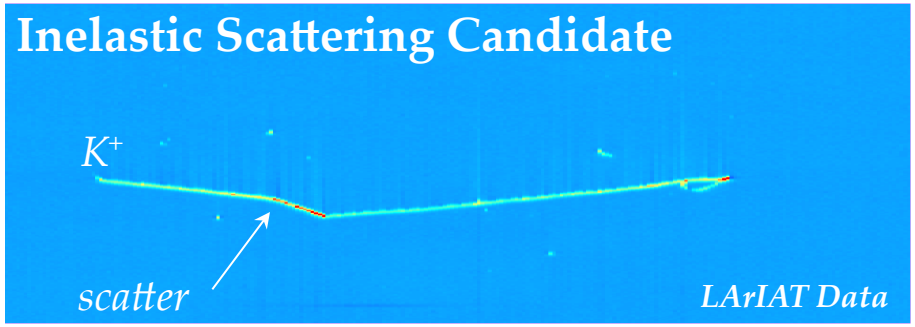


Signal and Background topologies

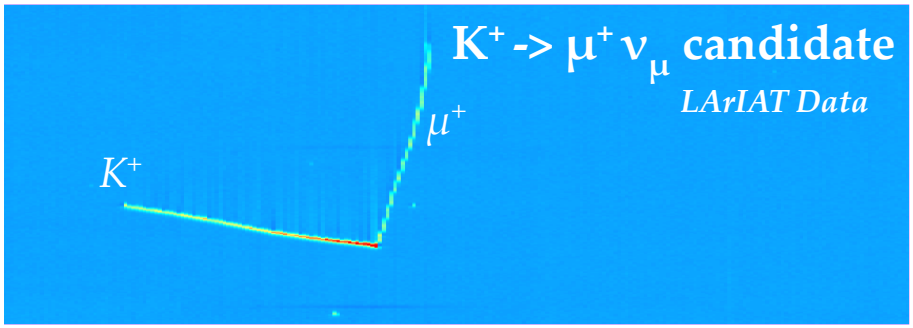
Signal: **All Hadronic Interactions**

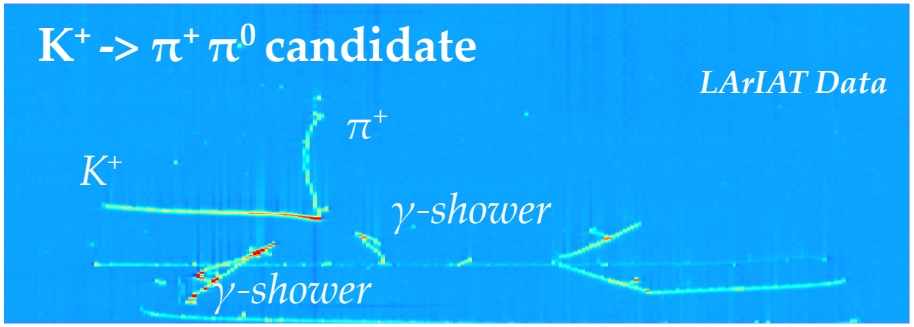
$\sigma_{Tot} = \sigma_{Elastic} + \sigma_{Reaction}$





Backgrounds: **Kaon Decay ; Coulomb Scattering**





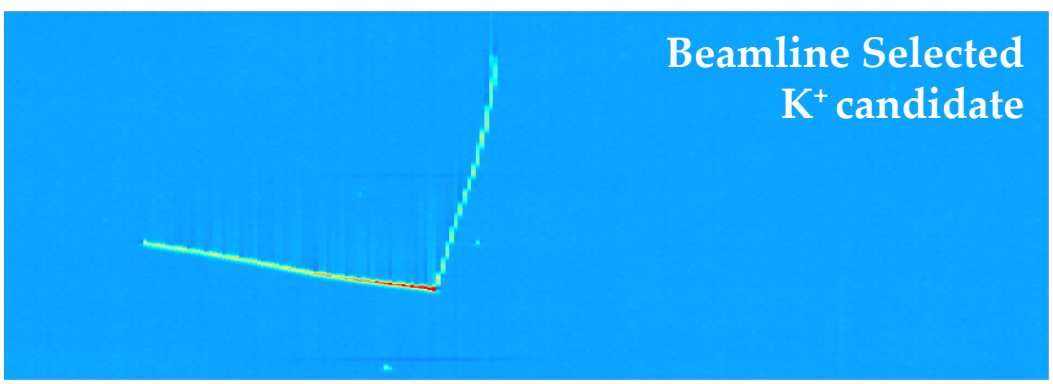
Analysis strategy: basics

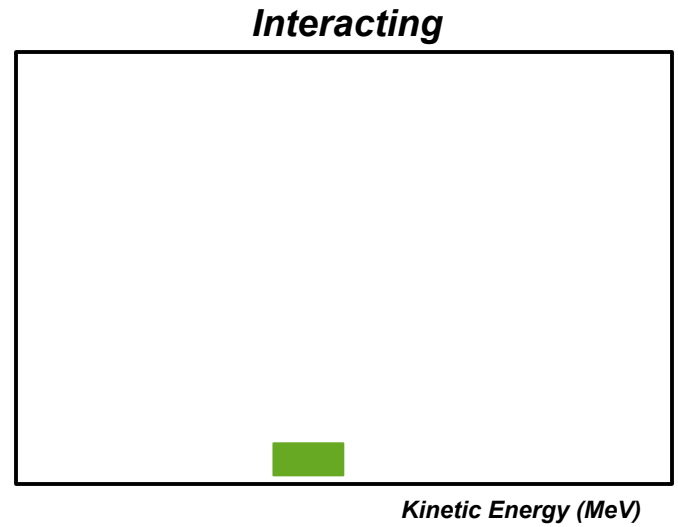
1. Identify Kaons in the beamline
2. Apply the thin slice method

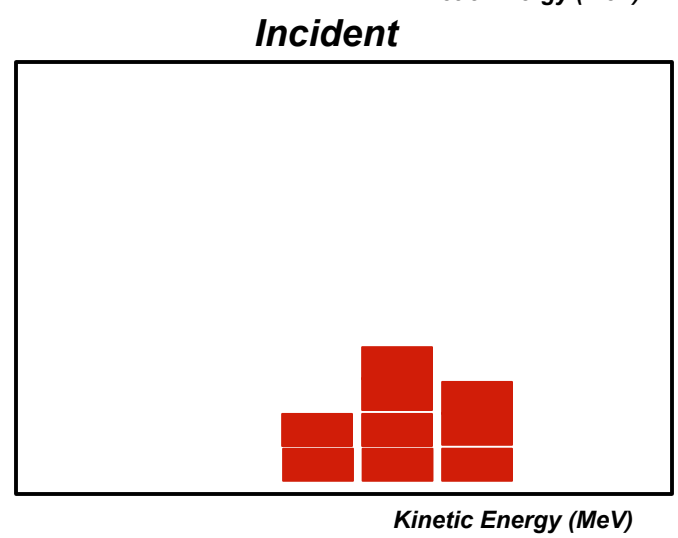
- The slice represents the distance between each 3D point in the track
- For each slice we ask:
  "Is this **the end** of the track?"

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

$$KE_{Slab} = KE_I - \sum_{i=0}^{n} \left(\frac{dE}{dX}\right)_i \times \delta X_i$$







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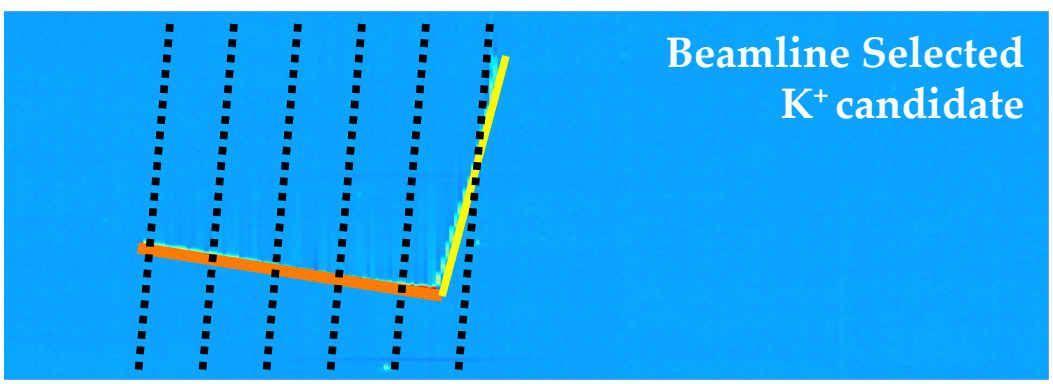
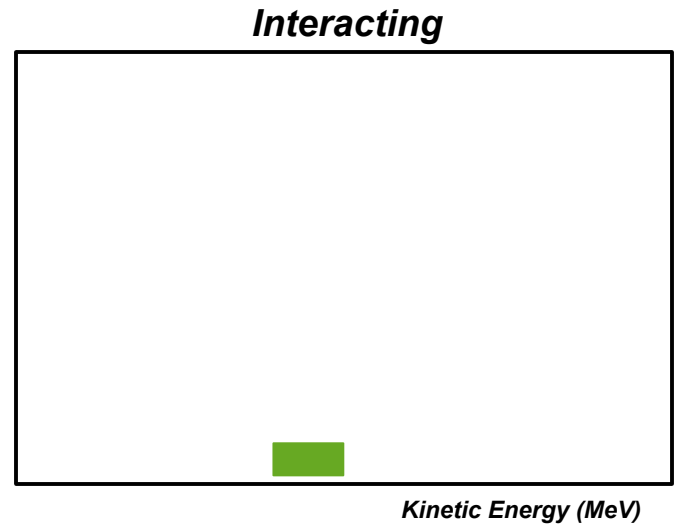
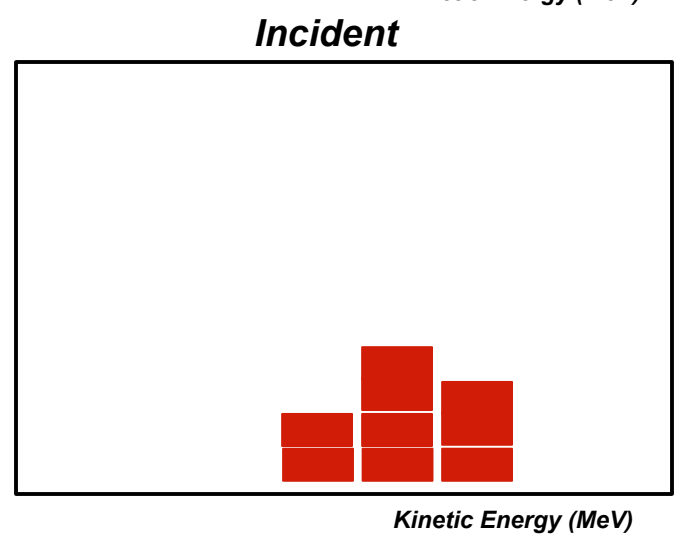




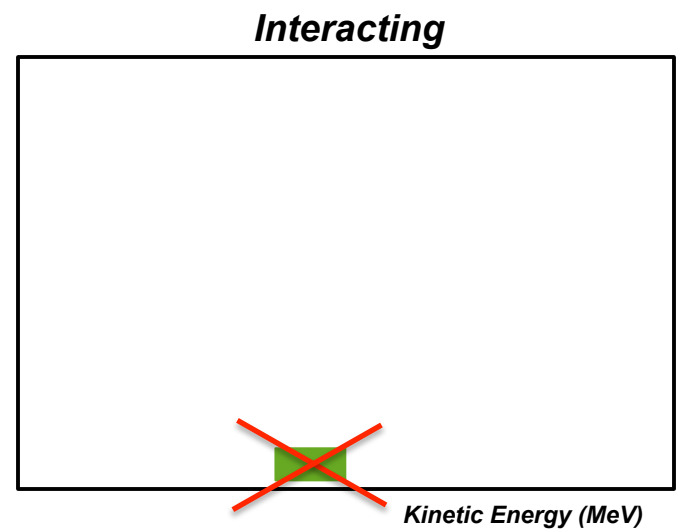


Analysis strategy: exception!

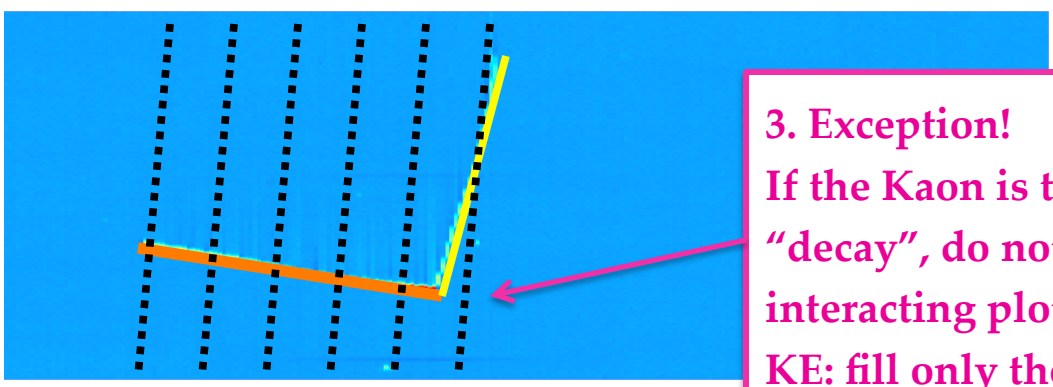
1. Identify Kaons in the beamline
2. Apply the thin slice method

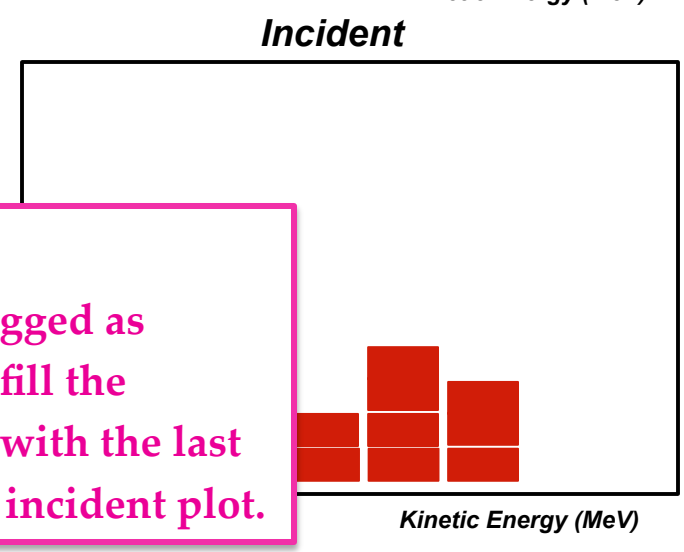
- The slice represents the distance between each 3D point in the track
- For each slice we ask: "Is this **the end** of the track?"

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



$$KE_{Slab} = KE_I - \sum_{i=0}^{n} \left(\frac{dE}{dX}\right)_i \times \delta X_i$$



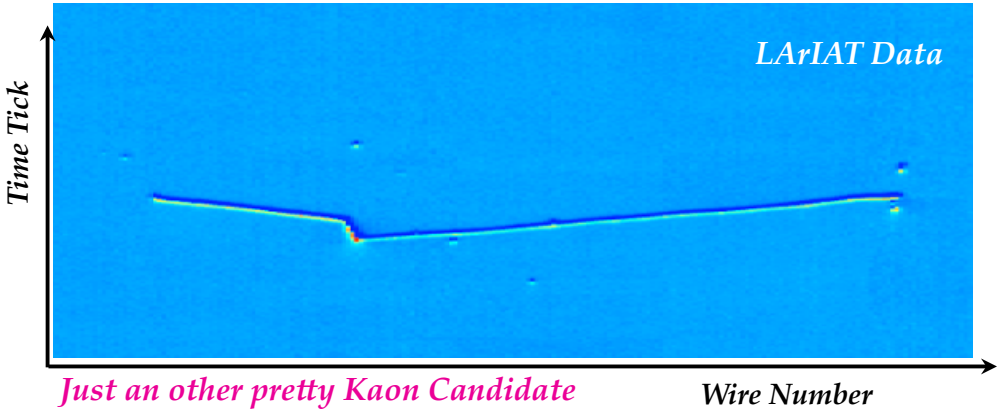


3. Exception!
If the Kaon is tagged as "decay", do not fill the interacting plot with the last KE: fill only the incident plot.

Key elements for the K^+-Ar XS

In order to measure the **Kaon Cross Section**, we need to :

- Identify kaons in the beamline
- Study the contamination in the kaon sample
- Study the loss in dead material between beamline and TPC
- Assess basics reconstruction:
  Tracking & Calorimetry
- Tag kaon decay slices
- Identify signal
  interactions



Just an other pretty Kaon Candidate

Find Kaons in the beamline!

We preselect the data using 3 filters:

– Time Stamp Filter (removes cosmic evts)

– Beamline Reconstruction:

TOF and a WC Track exists
and the mass is positive

– Mass Filter:

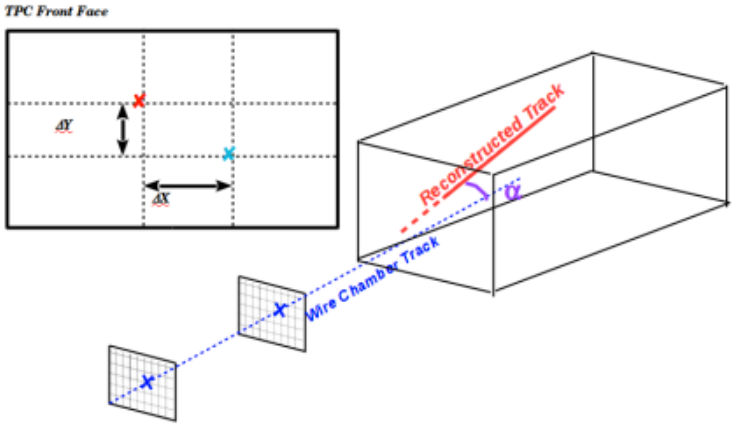
mass consistent with K:
350 MeV/c^2 < mass < 650 MeV/c^2

- Pile Up and TPC quality track Filter

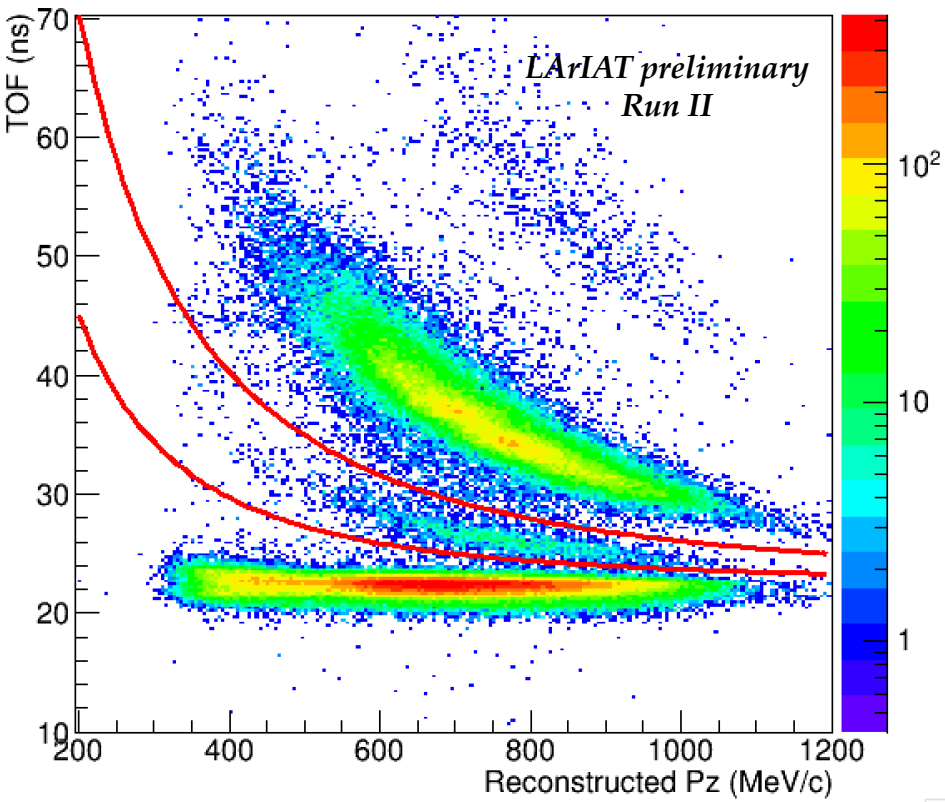
- Beamline – TPC match Filter:

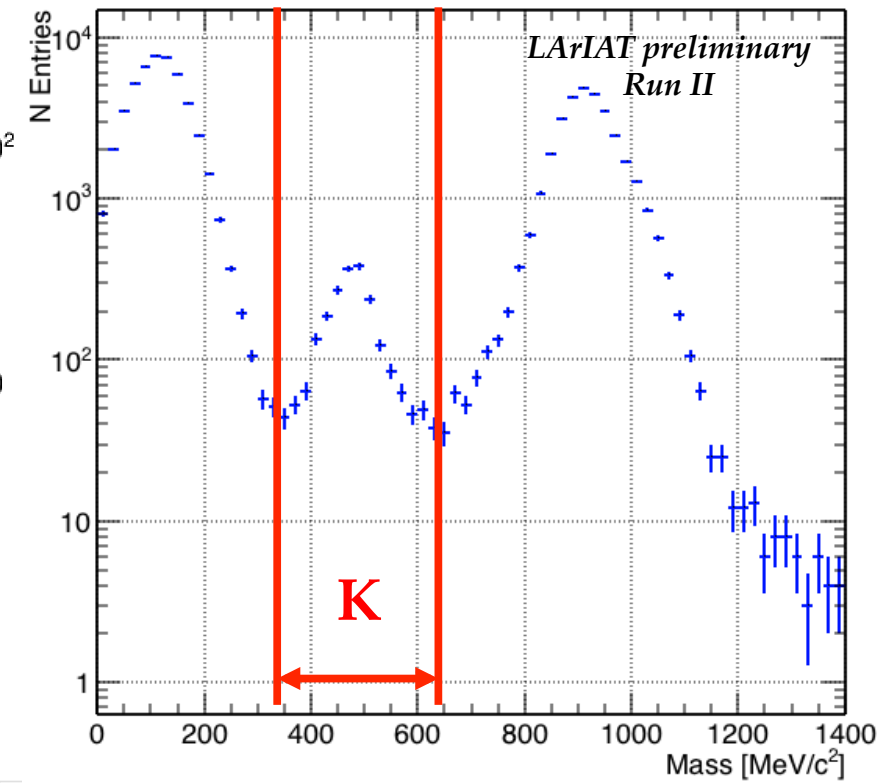
Require the best match between the
WC track and the TPC track
Δx, Δy and α

Stage	Number of Events
Run II Positive Polarity Data	~4000000
Time Stamp	1555402
Beamline Reconstruction	188060
Mass Filter	4289
WC to TPC match	1986



Find Kaons in the beamline!



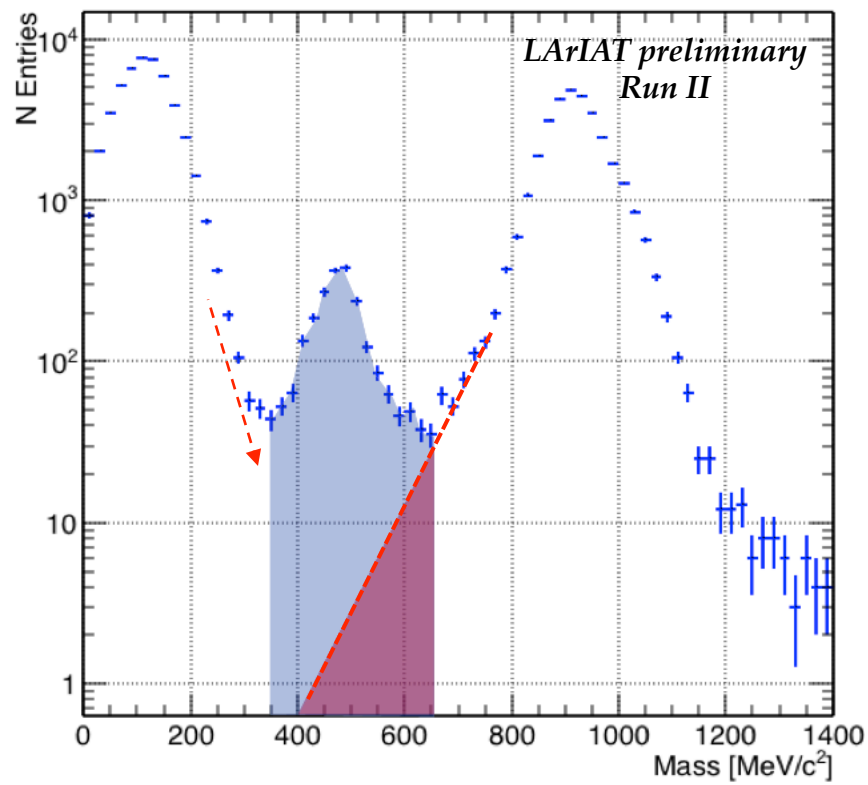


$$m = \frac{p}{c}\sqrt{(\frac{c * TOF}{\ell})^2 - 1}$$

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.

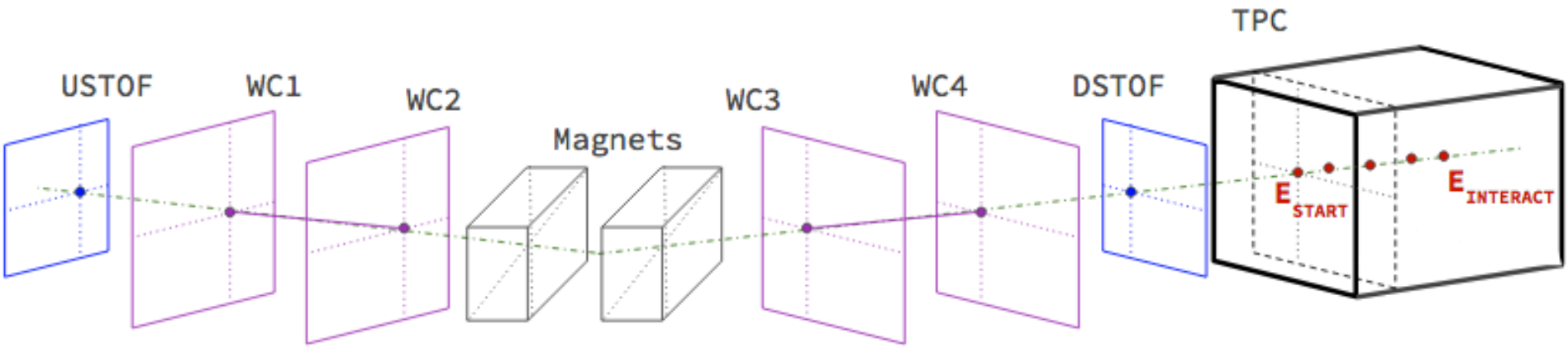


With 12 iterations of the fit we find:

High Mass Contamination = 4.9 ± 2.9 %
Low Mass Contamination = 2.6 ± 1.0 %

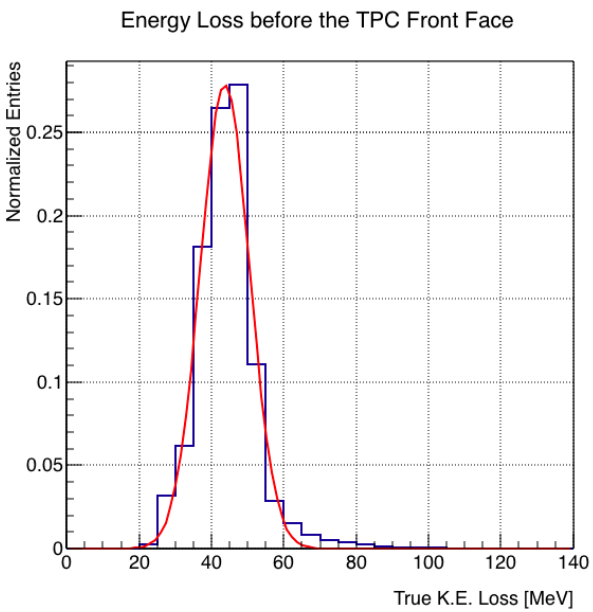
We will use the beamline MC to understand the fractional composition of the low mass peak and simulate contaminants accordingly.

Key element: Loss Before TPC



Truth study:
Average energy loss before the TPC Front Face = 44 ± 7 MeV.

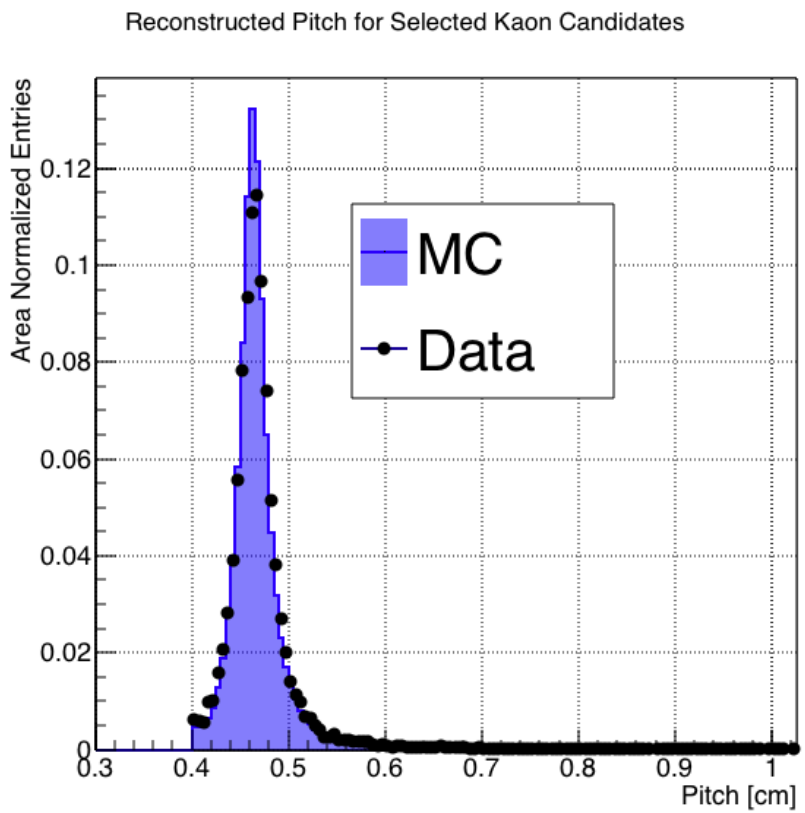
33 % of Kaons in the beamline interact or decay before getting to TPC.

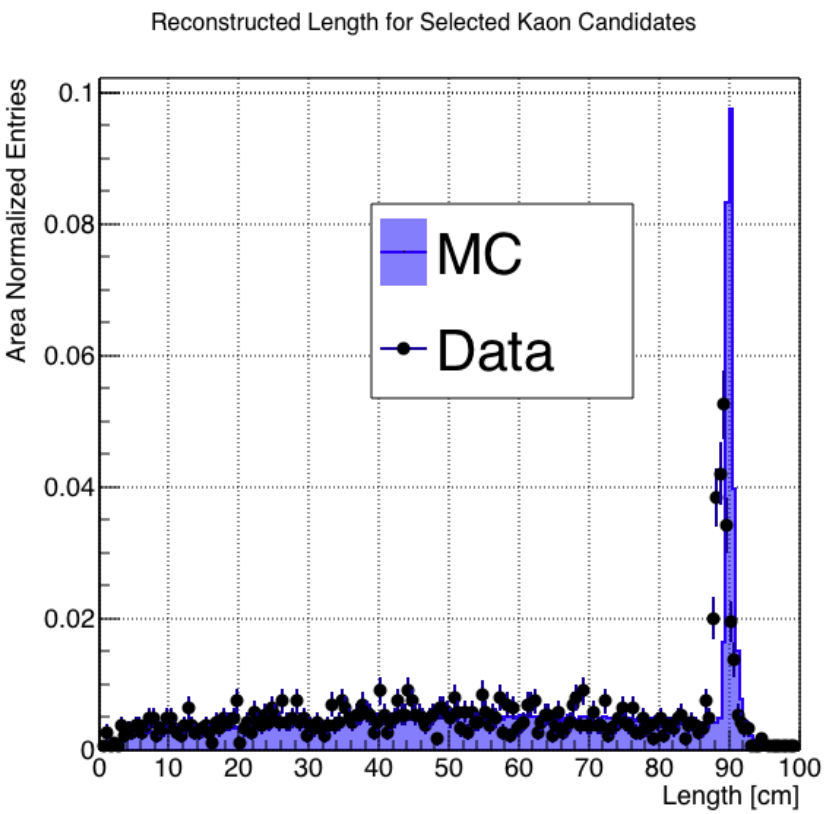


Basic Reconstruction: Tracking

Track Pitch and Track Length.

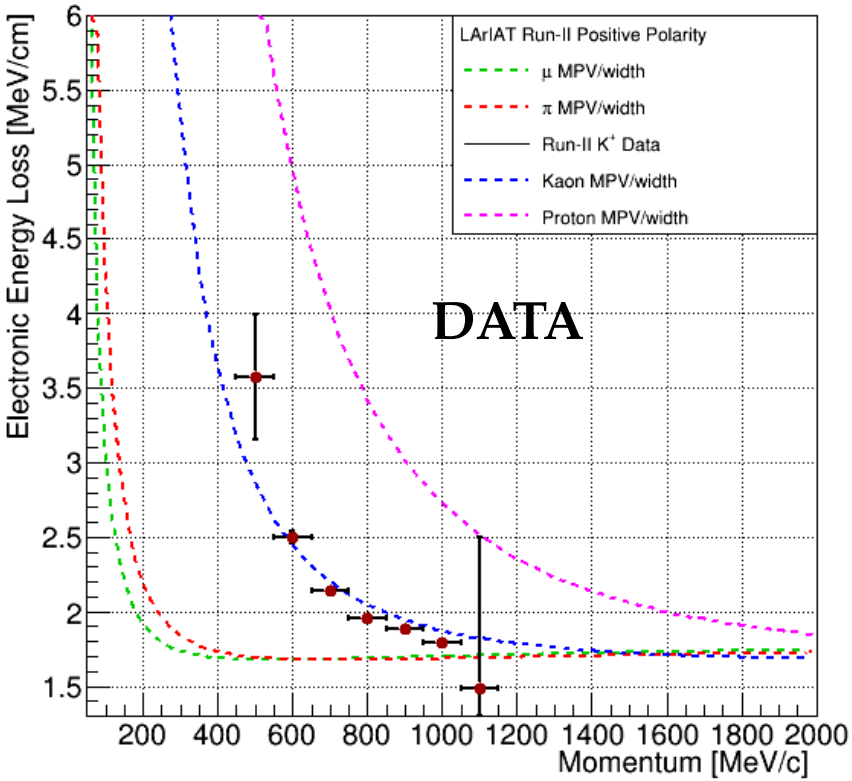
Data and MC comparison, area normalized.

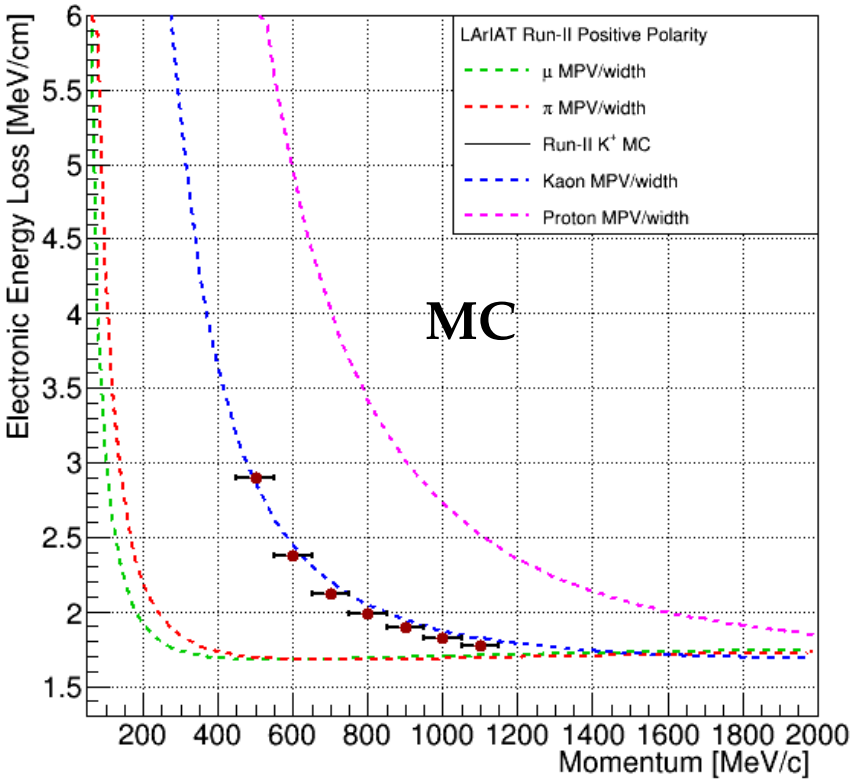




Basic Reconstruction: Calorimetry

dE/dX Vs Momentum. Data and MC.
Data has been tuned using a π+ sample.
Kaon MC has been tuned on the theoretical curves.



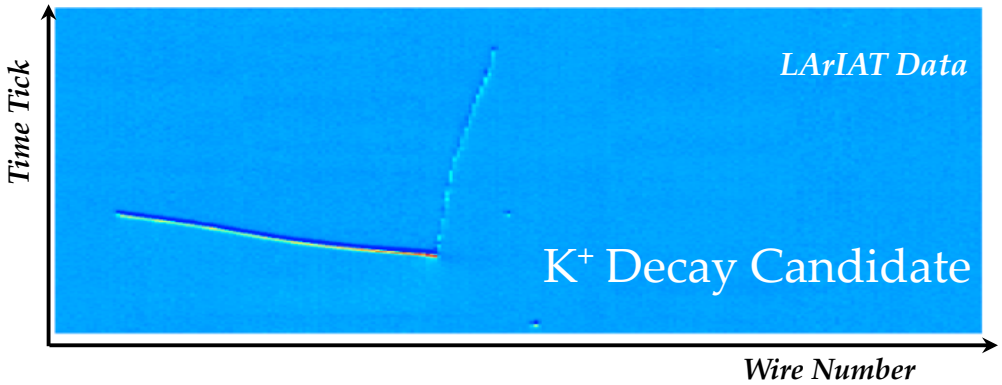


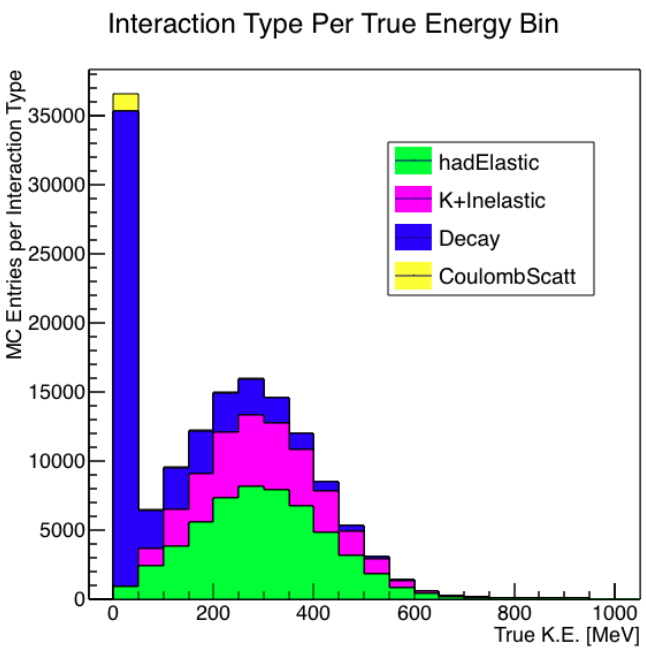
Key element: Tag K Decay Slices

Kaon decay proceeds by the **weak interaction**.

The endpoint of a decaying kaon could be **misidentified as a single strong interaction**.

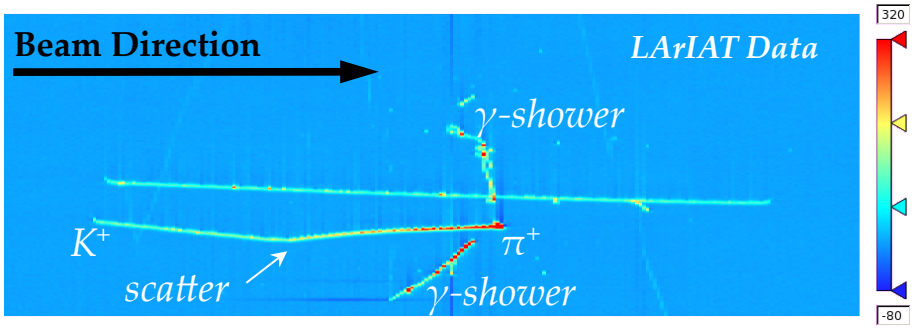
For kaon **decay at rest**, we can use the presence of a **Bragg peak** to tag the end point as non-interacting.
The development of the tools to tag **kaon decay in flight** is ongoing.



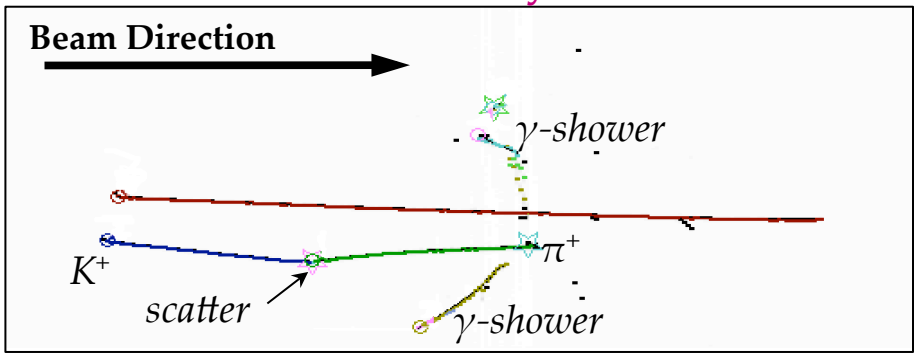


Key element: Identify Signal Interaction

LArIAT Data Preliminary K⁺ Candidate



LArIAT Data Preliminary Reconstruction



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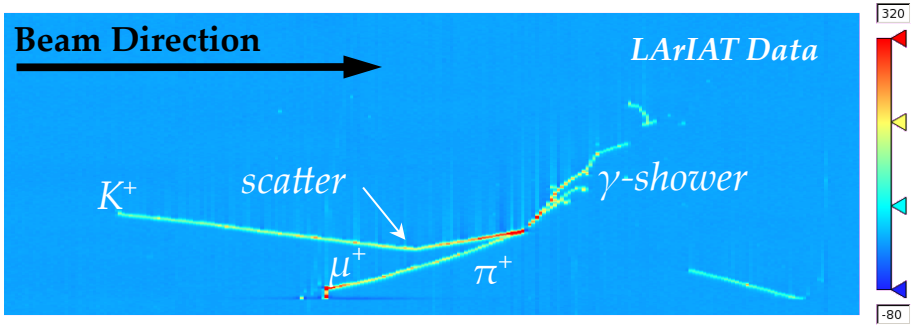
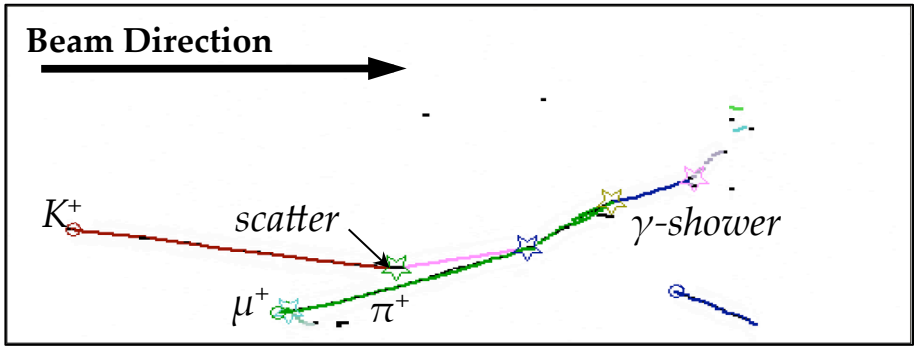


LArIAT Data Preliminary Reconstruction



Conclusions

In order to measure the **Kaon Cross Section**, we need to :

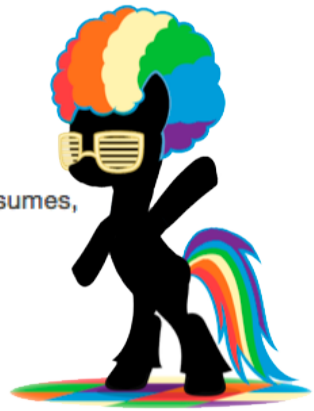
- Identify kaons in the beamline ✓
- Study the contamination in the kaon sample ✓
- Study the loss in dead material ✓
- Assess basics reconstruction:
  Tracking & Calorimetry (ongoing)
- Tag kaon decay slices (ongoing)
- Identify signal interactions ✓

Stay tuned…. The XS is coming soon!!!

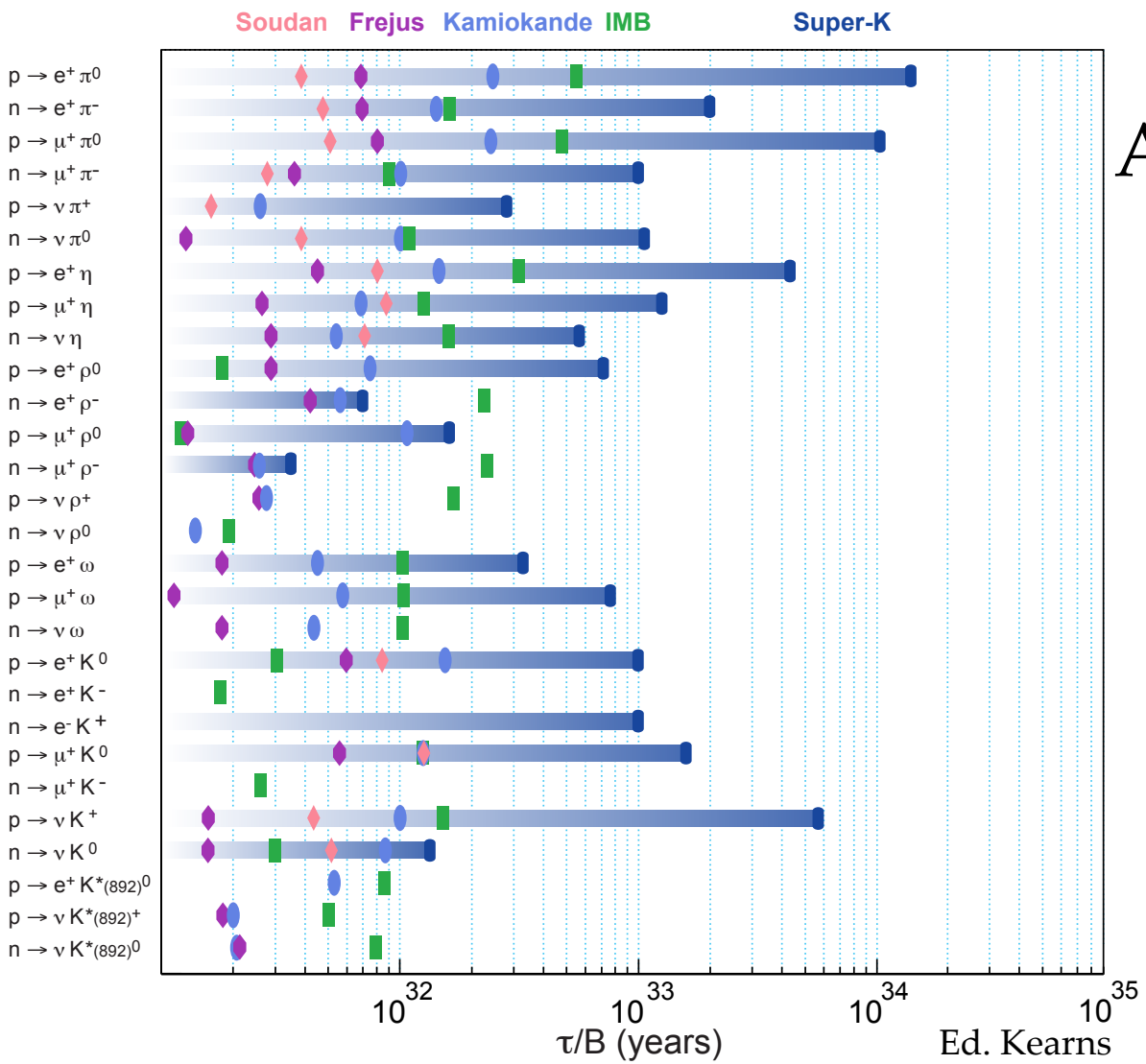
The LArIAT Collaboration

THANKS!!!!

- **Federal University of ABC, Brazil (UFABC)** Célio A. Moura, Laura Paulucci
- **Federal University of Alfenas, Brazil (UNIFAL-MG)** Gustavo Valdiviesso
- **Boston U.** Flor de Maria Blaszczyk, Rob Carey, Bruno Gelli, Marina Guzzo, Dan Gastler, Ed Kearns, Ryan Linehan, Daniel Smith, Silvia Zhang
- **U. Campinas, Brazil (UNICAMP)** Carlos Escobar, Ernesto Kemp, Ana Amelia B. Machado, Mônica Nunes, Lucas Mendes Santos, Ettore Segreto, Thales Vieira
- **U. Chicago** Ryan Bouabid, Will Foreman, Johnny Ho, Dave Schmitz
- **U. Cincinnati** Randy Johnson, Jason St. John
- **Fermilab** Roberto Acciarri, Michael Backfish, William Badgett, Bruce Baller, Raquel Castillo Fernandez, Flavio Cavanna (also INFN, Italy), Alan Hahn, Doug Jensen, Hans Jostlein, Mike Kirby, Tom Kobilarcik, Paweł Kryczyński (also Institute of Nuclear Physics, Polish Academy of Sciences), Sarah Lockwitz, Alberto Marchionni, Irene Nutini, Ornella Palamara (also INFN, Italy), Jon Paley, Jennifer Raaf†, Brian Rebel, Mark Ross-Lonergan (also Durham U), Michelle Stancari, Tingjun Yang, Sam Zeller, James Zhu (also UC Berkeley)
- **Federal University of Goiás, Brazil (UFG)** Tapasi Ghosh, Ricardo A. Gomes, Ohana Rodrigues
- **Istituto Nazionale di Fisica Nucleare, Italy (INFN)** Flavio Cavanna (also Fermilab), Ornella Palamara (also Fermilab)
- **KEK** Eito Iwai, Takasumi Maruyama
- **Louisiana State University** Justin Hugon, William Metcalf, Andrew Olivier, Martin Tzanov
- **U. Manchester, UK** Justin Evans, Diego Garcia-Gamez, Pawel Guzowski, Colton Hill, Andrzej Szelc
- **Michigan State University** Carl Bromberg, Dan Edmunds, Dean Shooltz
- **U. Minnesota, Duluth** Rik Gran, Alec Habig, Miranda Elkins
- **National Centre for Nuclear Research (NCBJ), Poland** Robert Sulej, Dorota Stefan
- **Syracuse University** Jessica Esquivel, Pip Hamilton, Greg Pulliam, Mitch Soderberg
- **U. Texas, Arlington** Jonathan Asaadi†, Animesh Chatterjee, Andrea Falcone, Amir Farbin, Ilker Parmaksiz, Dalton Sessumes, Sepideh Shahsavarani, Zachary Williams, Jae Yu
- **U. Texas, Austin** Will Flanagan, Karol Lang, Dung Phan, Brandon Soubasis (also Texas State University)
- **University College London** Anna Holin, Ryan Nichol
- **William & Mary** Mike Kordosky, Matthew Stephens
- **Yale University** Corey Adams, Bonnie Fleming, Elena Gramellini, Xiao Luo



Experimental Limits on τ_P



Ed. Kearns

At 0 background

$\tau/B = M \times T \times \varepsilon$

Mass

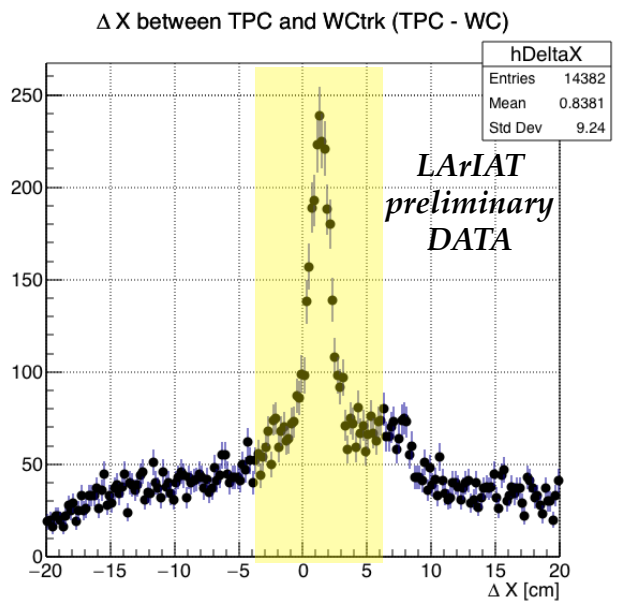
Exposure

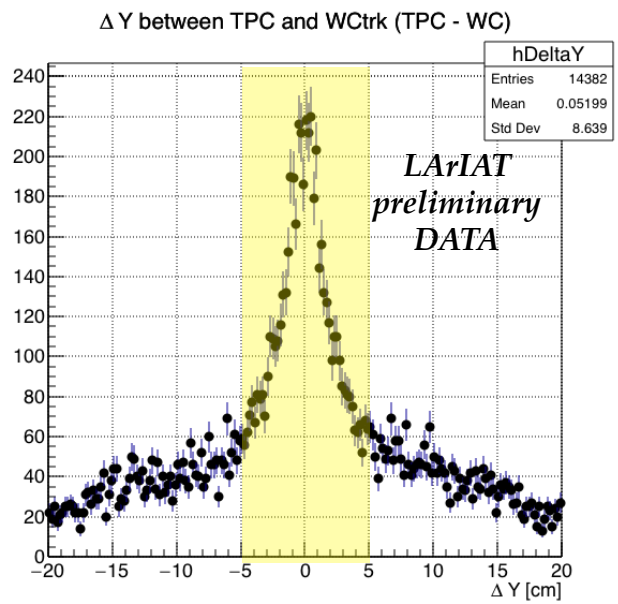
Signal efficiency

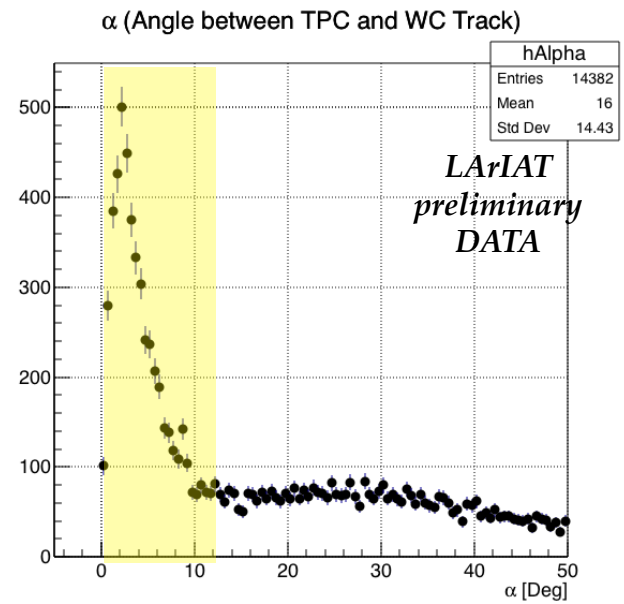
1. Find Kaons: WC2TPC Δx, Δy and α

Plot the distribution of WC2TPC match before the cuts are applied.
Selection:
Δx and Δy within ± 5 cm from the peak
$\alpha < 10^{o}$

Still to be optimized

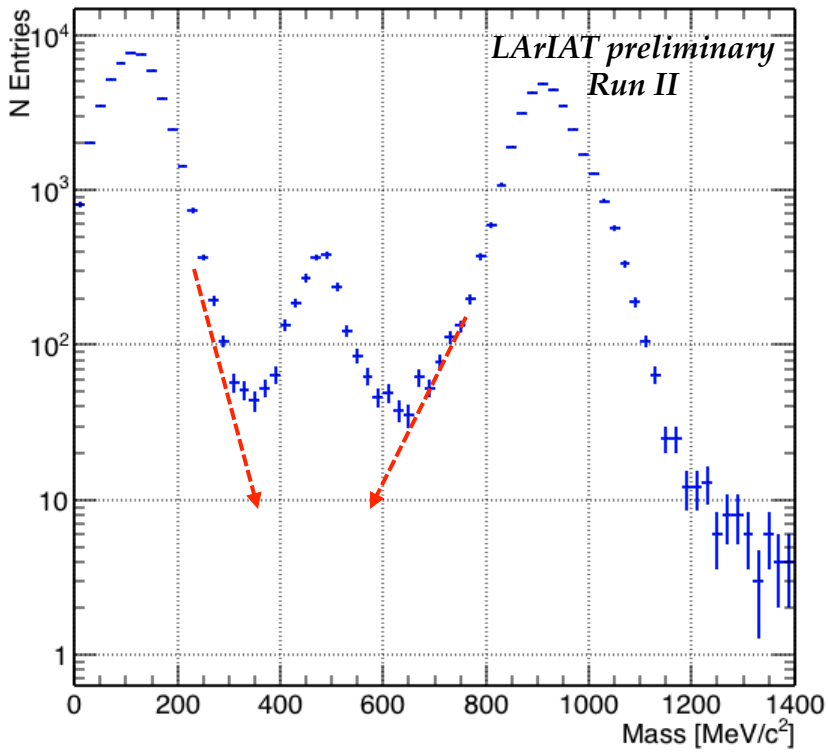






Contamination

Data Driven method from beamline mass distribution.
The basic idea is to **estimate the bleed over** from high and low mass peaks under the kaon peak.
The catch is that we **don't know** the **shape** of those tails!



1) Choose an arbitrary function
2) Fit in tail range
3) Extend the fit function under the kaon peak
4) Integrate the between 350-650 MeV/c^2
5) Integrate the mass histogram in the same range
6) Take the ratio between the 2 integrals
7) Repeat for several fit shapes and tail ranges

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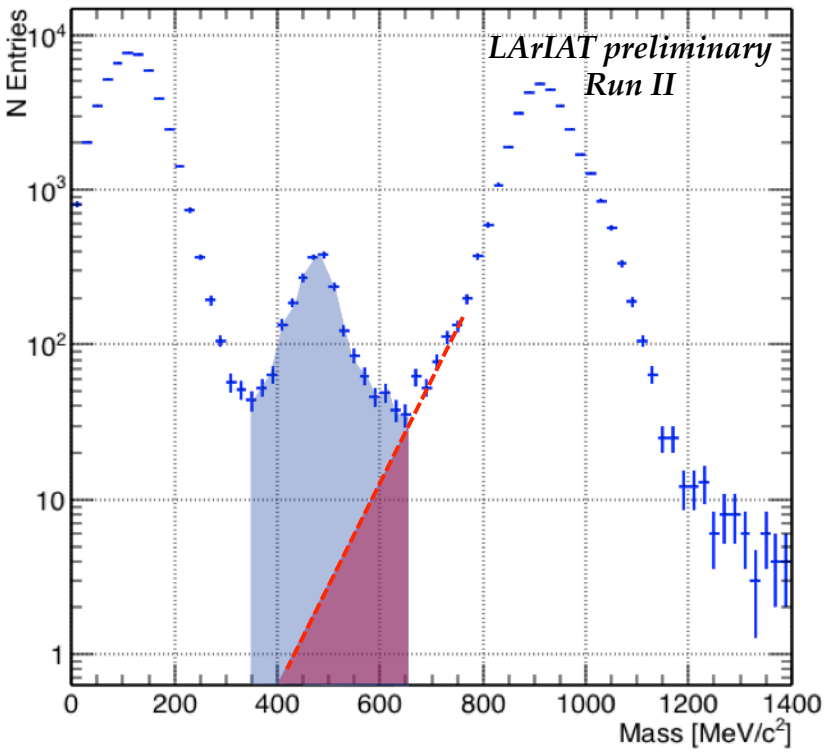

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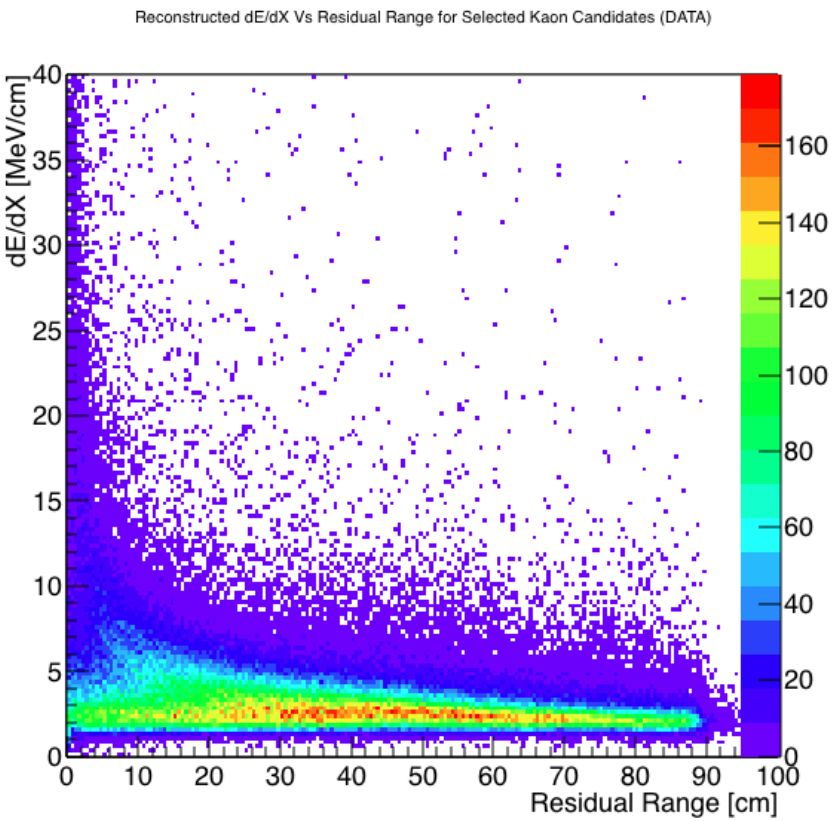
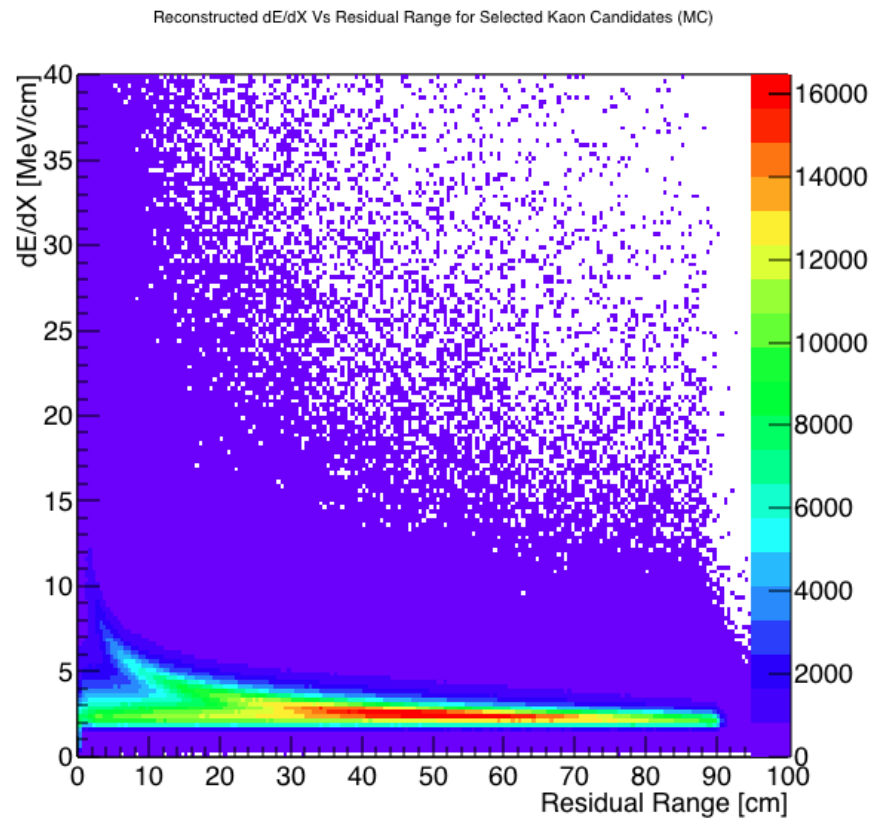
Basic Reconstruction: Calorimetry

dE/dX Vs Residual Range. Data and MC.
Improvement of noise simulation is ongoing.