Measurements of Pion and Muon Nuclear Capture at Rest on Argon in the LArIAT Test Beam Experiment

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FERMILAB-POSTER-24-0087-V.

Motivation

- DUNE (Deep Underground Neutrino Experiment) will be the largest neutrino LArTPC in the world.
- Identification of mu/pi would improve the understanding of BSM events, like decay of heavy neutral leptons with unusual topologies as final state with $\mu^+\mu^-/\pi^+\pi^-$ [2]. This is *difficult* using standard track-based dE/dx methods due to the similar masses and energy deposition profiles in argon.
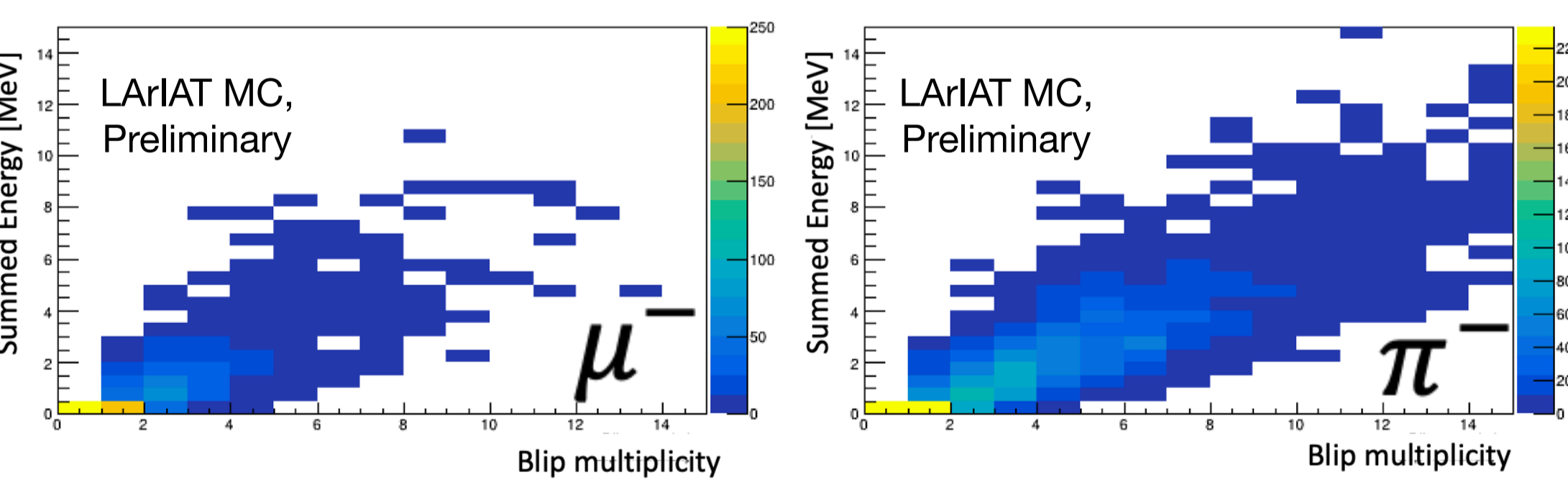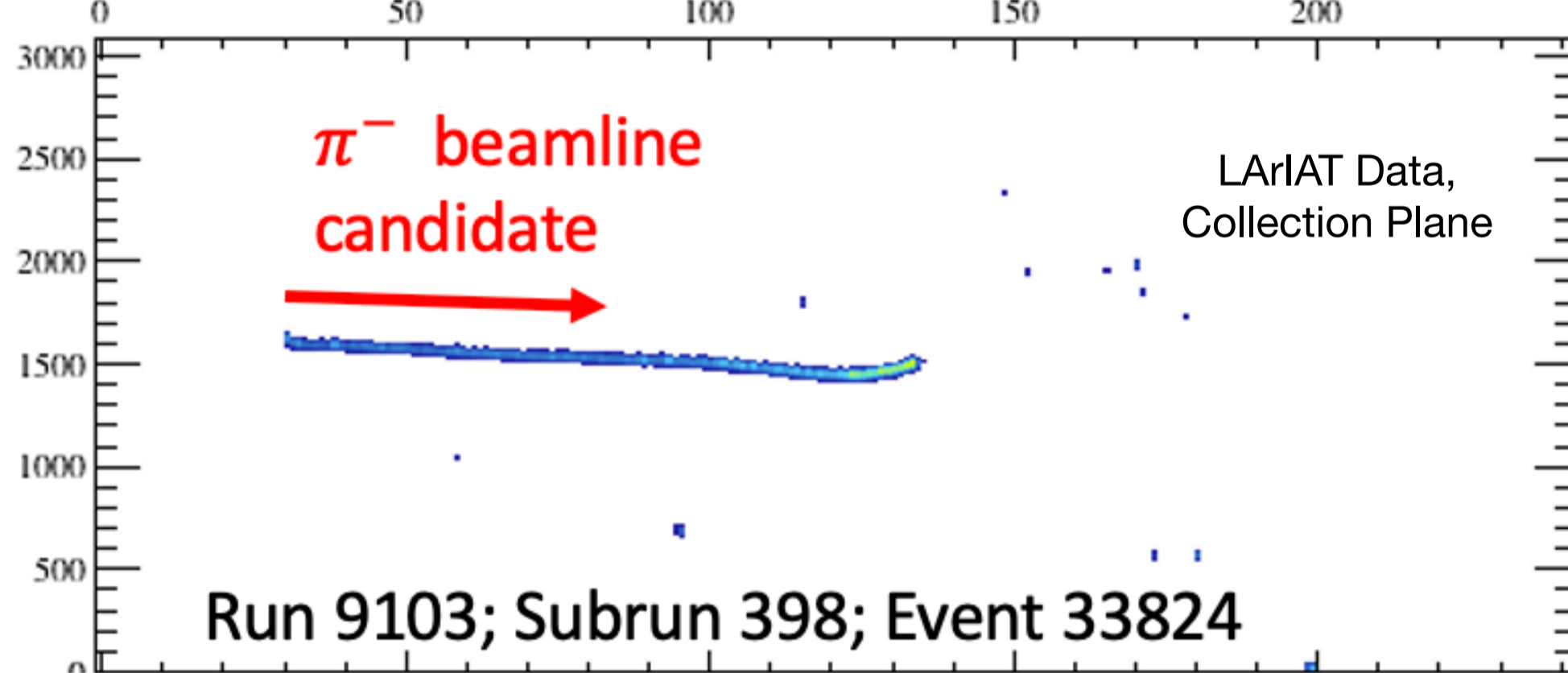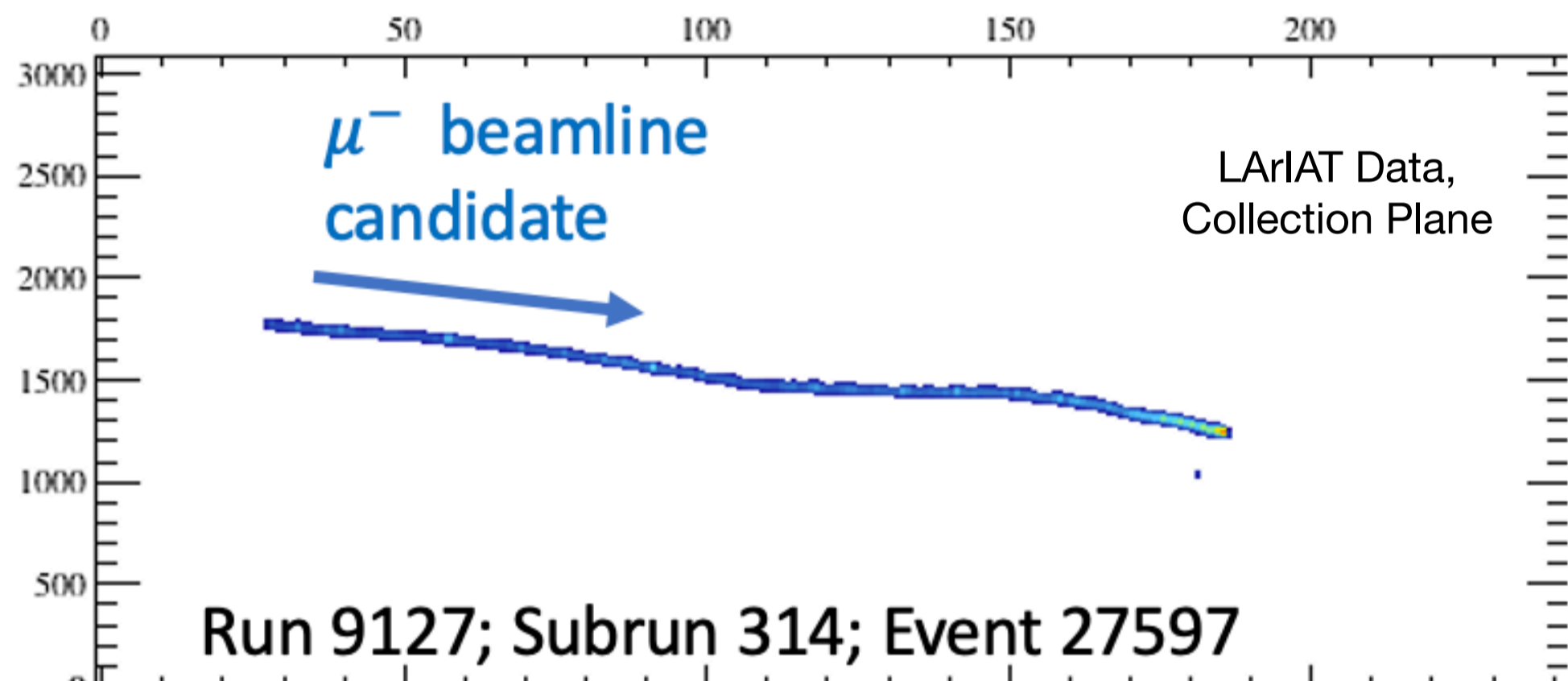
Missing energy !!!

$$\mu^- + p \rightarrow n + \nu_\mu \qquad\qquad \pi^- + p \rightarrow n$$

All energy to the nucleus !!!
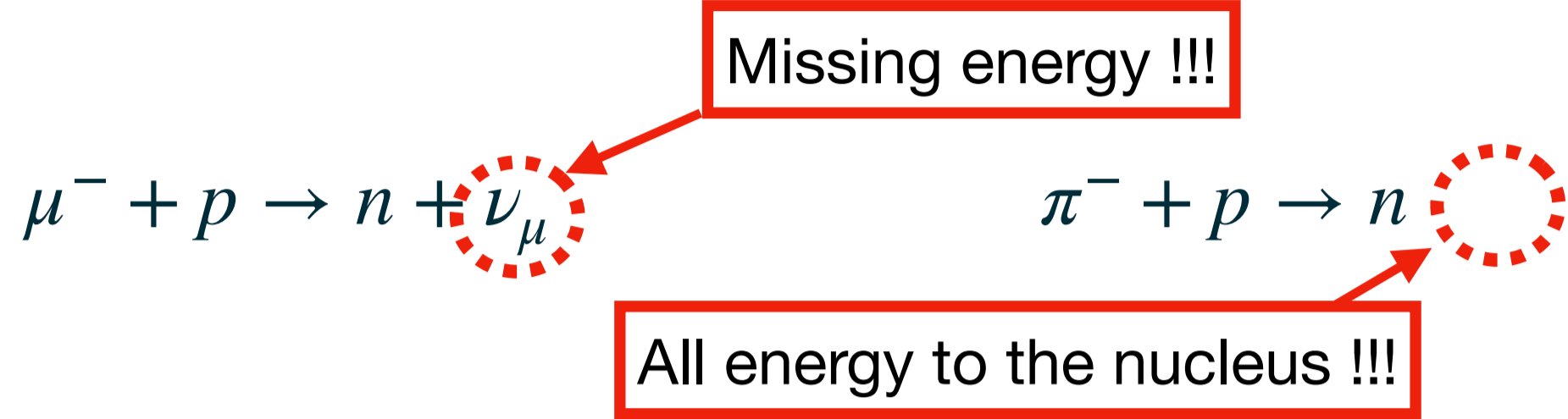
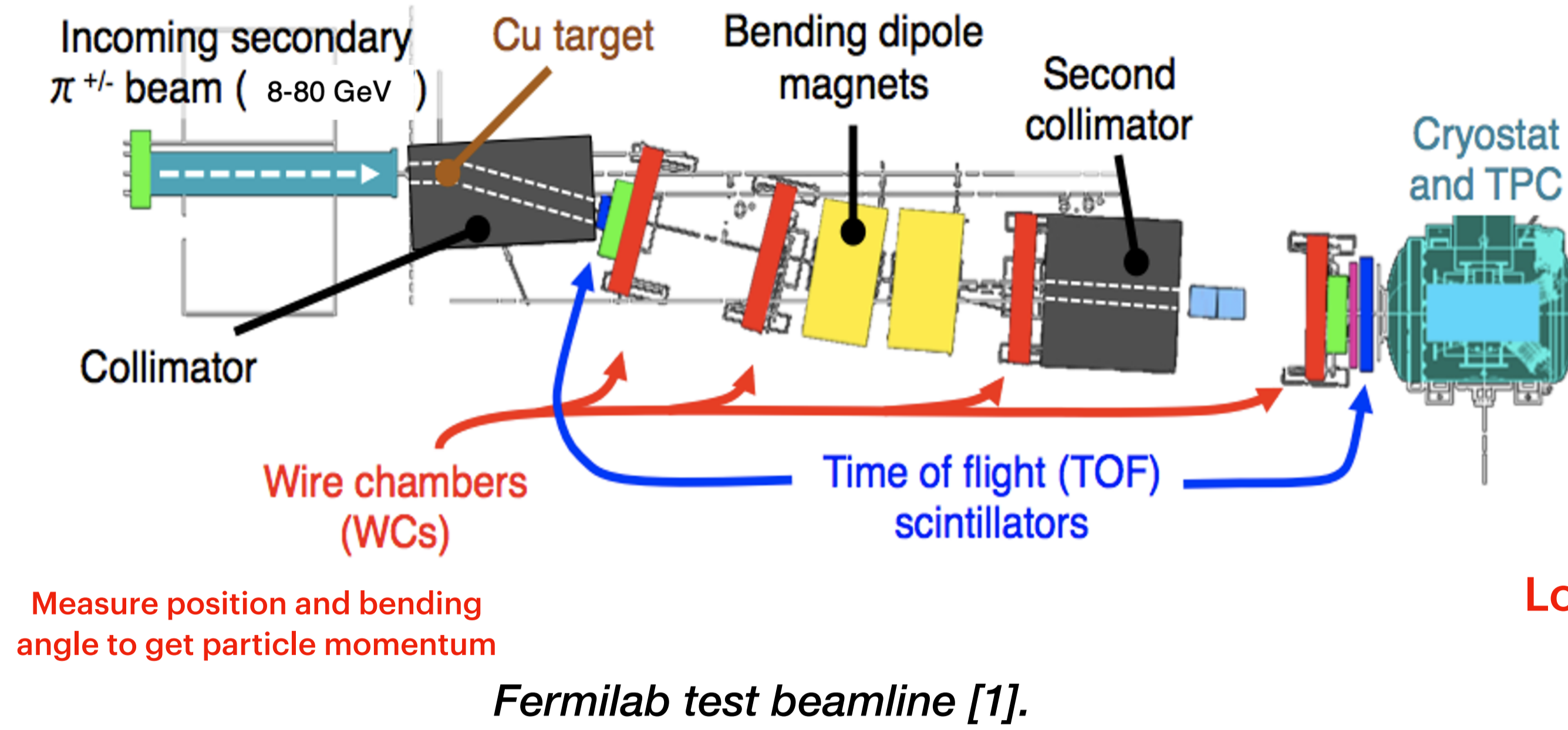| Muon capture at rest process	Pion capture at rest process

- Reconstruction of gammas from nuclear capture (Blips) can help with this!
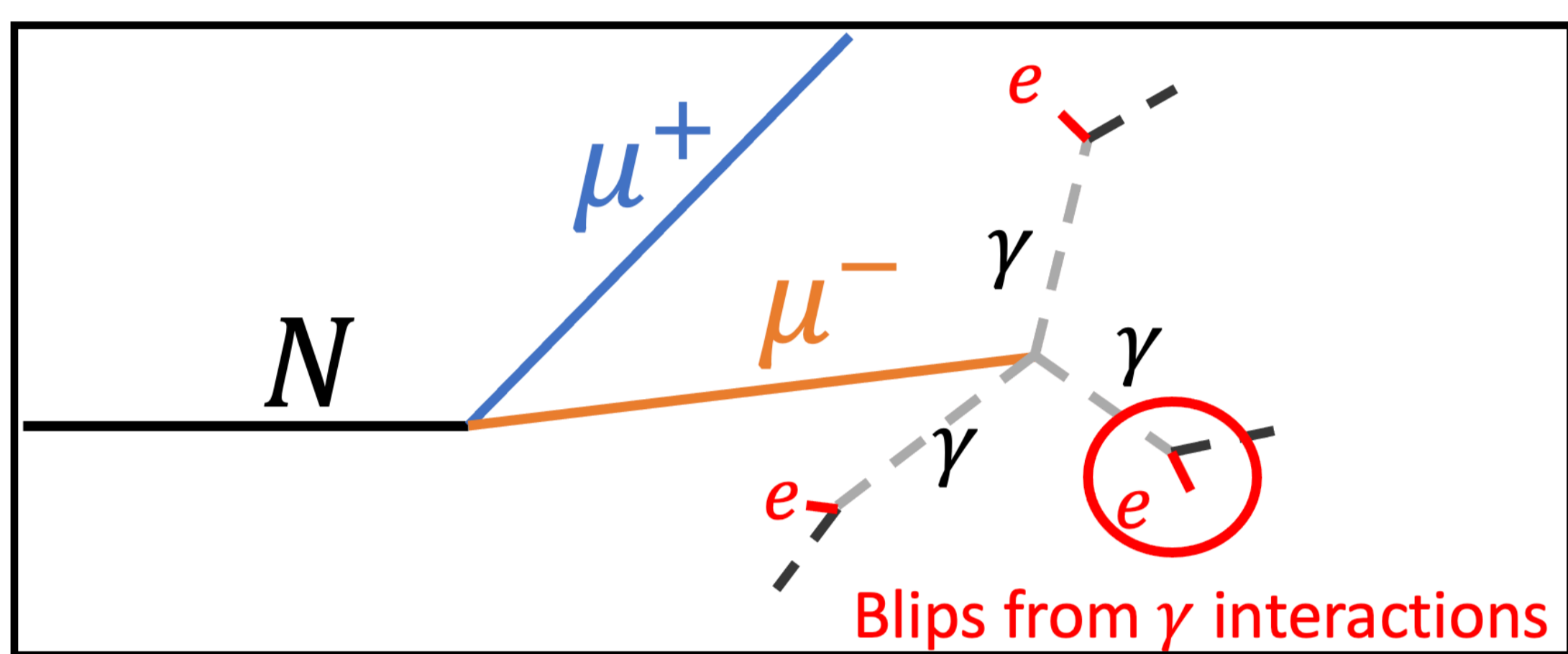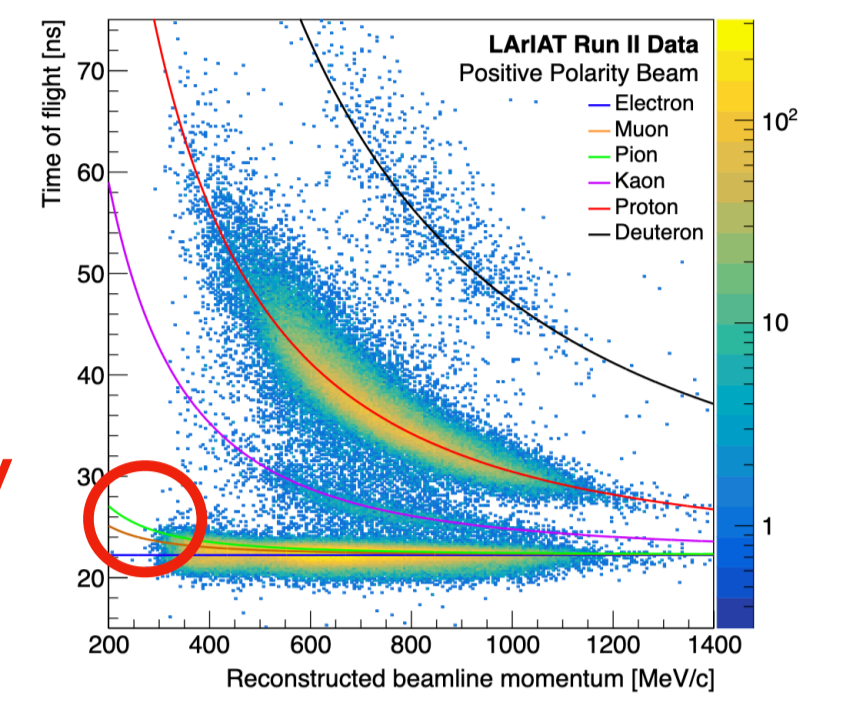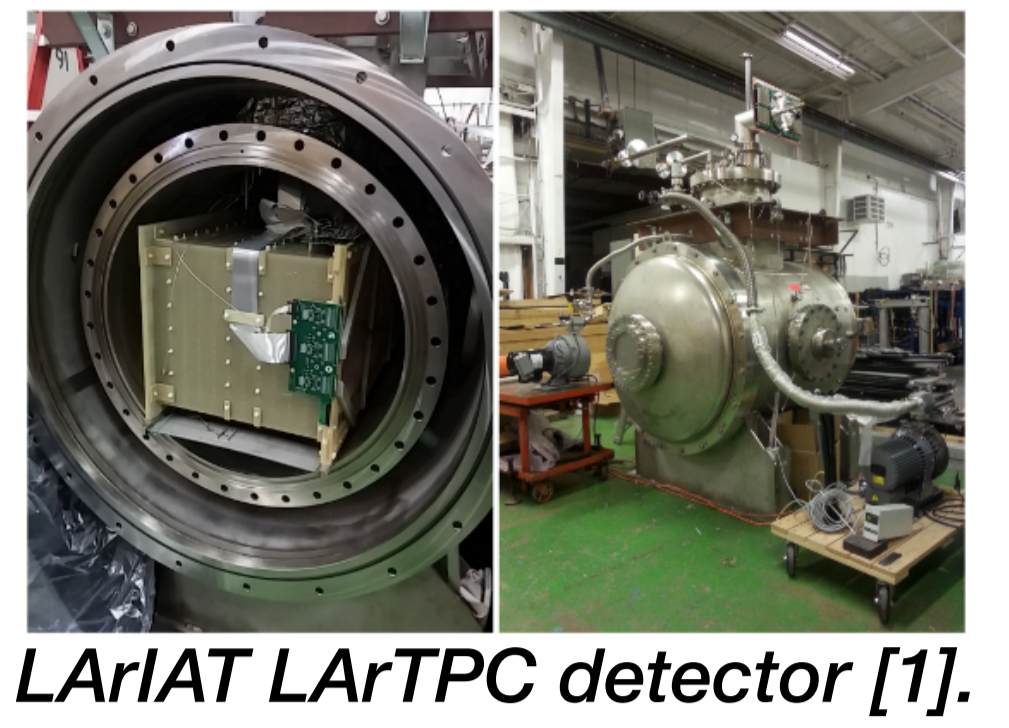

Unusual topologies $\mu^+\mu^-/\pi^+\pi^-$ for BSM. Gammas produced by muon/pion capture, these gammas produce electrons (Blips) from induced interactions.

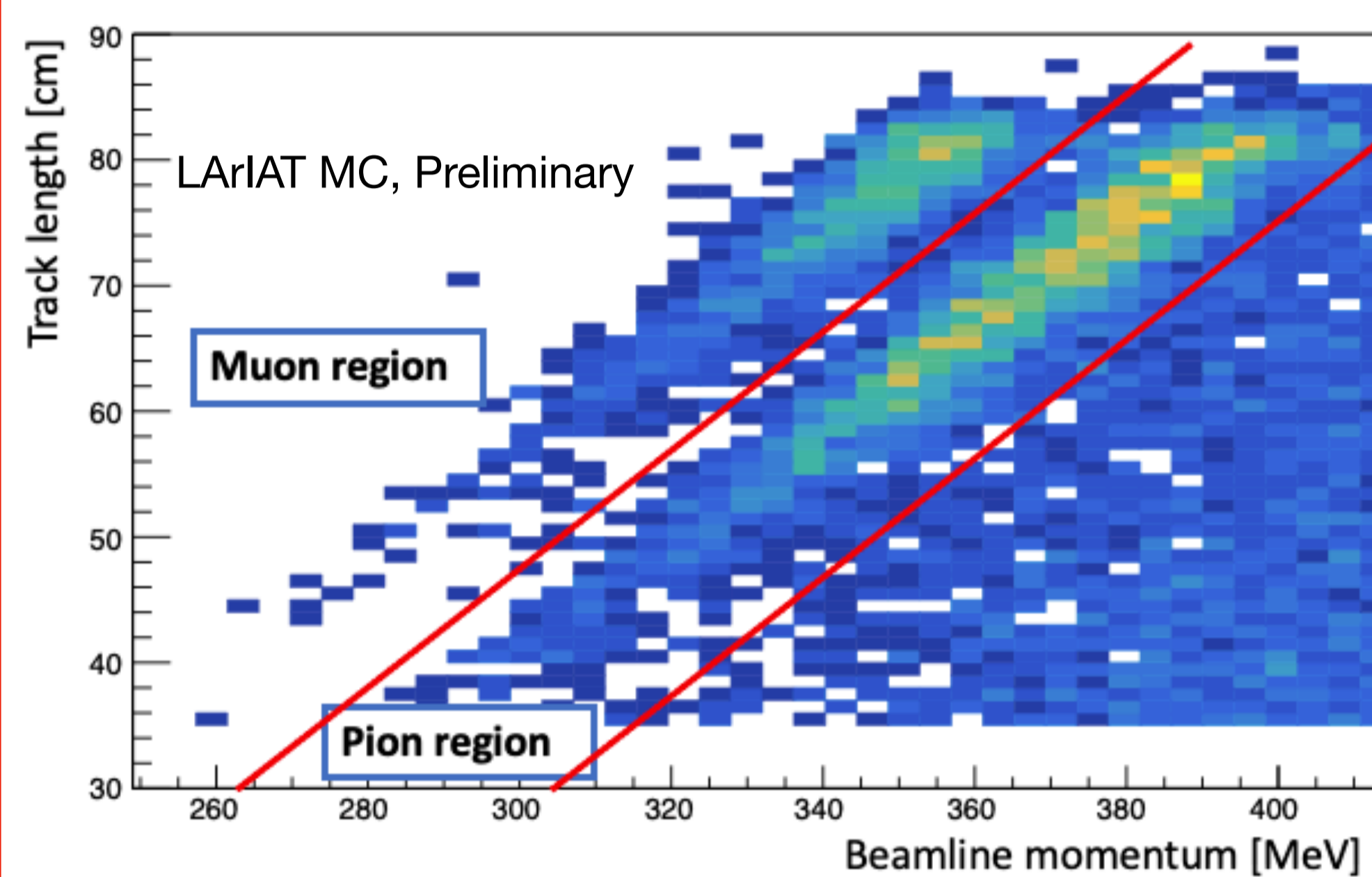μ^- beamline candidate — LArIAT Data, Collection Plane — Run 9127; Subrun 314; Event 27597

π^- beamline candidate — LArIAT Data, Collection Plane — Run 9103; Subrun 398; Event 33824

LArIAT MC, Preliminary

Why LArIAT?

LArIAT: Liquid Argon In A Testbeam

Incoming secondary $\pi^{+/-}$ beam (8-80 GeV) — Cu target — Bending dipole magnets — Second collimator — Cryostat and TPC — Collimator

Wire chambers (WCs) — Time of flight (TOF) scintillators

Measure position and bending angle to get particle momentum

Fermilab test beamline [1].

LArIAT LArTPC detector [1].

Low energy region

TOF vs reconstructed momentum [1].

Muon and Pion selection

LArIAT MC, Preliminary — Muon region — Pion region

Initial precuts on beam momentum, Bragg peak, start and end positions of the primary particle.
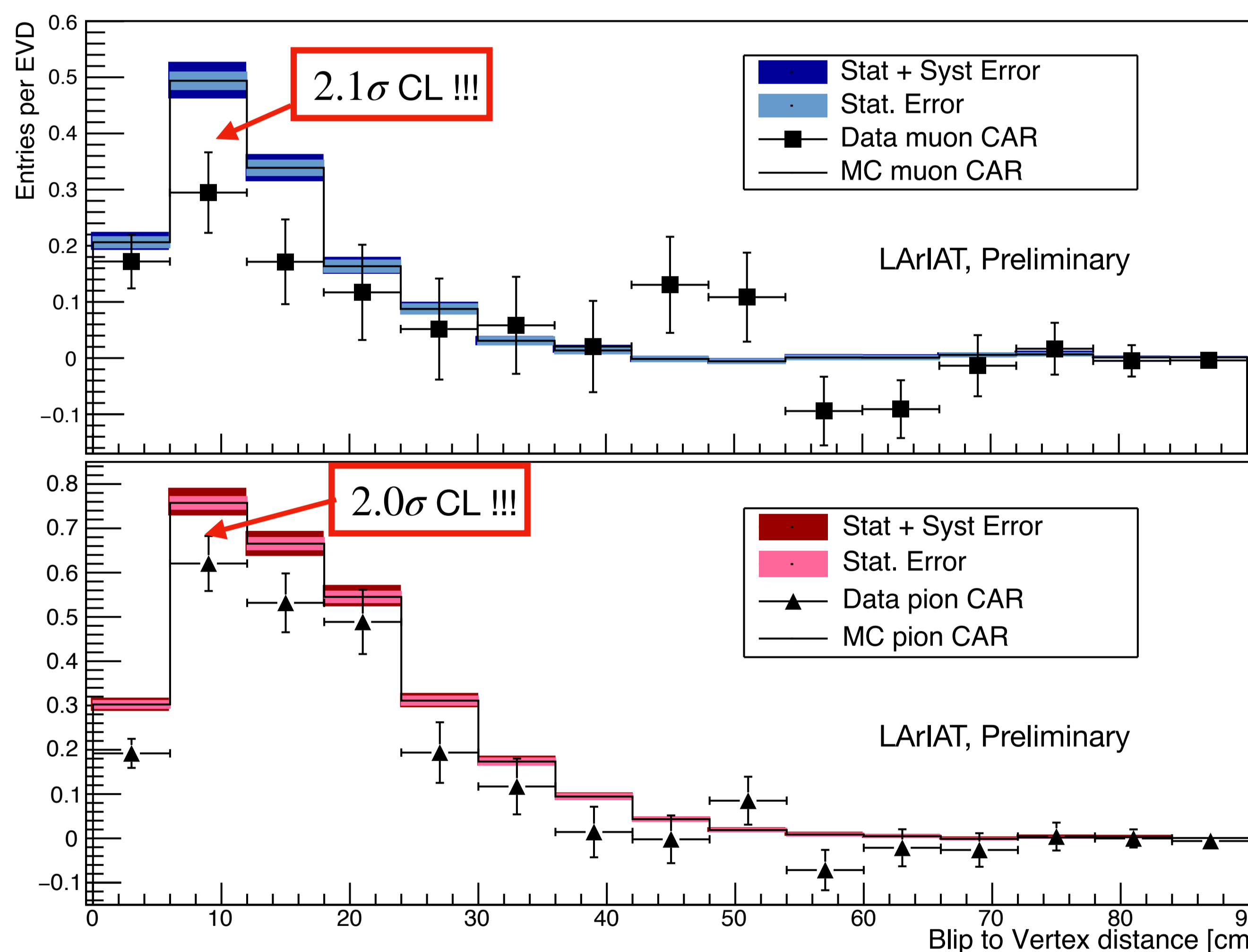
Using beam momentum and track stopping point inside of the TPC we separate stopping muons from stoping pions.

With a MC sample of 500k (G4 QGSP_Bert_HP Physics list) events a final selection of **2132 muon captured-at-rest events (79% purity)** **3931 pion captured-at-rest events (76% purity)**

*Data has 87 muon captured at rest and 209 pion captured at rest candidates.*

Data-MC comparison

2.1σ CL !!!

- Stat + Syst Error
- Stat. Error
- Data muon CAR
- MC muon CAR

LArIAT, Preliminary

2.0σ CL !!!

- Stat + Syst Error
- Stat. Error
- Data pion CAR
- MC pion CAR

LArIAT, Preliminary

Dataset	Blips per EVD
Muon Data	0.74 ± 0.19
Muon MC	1.22 ± 0.08

Dataset	Blips per EVD
Pion Data	1.86 ± 0.17
Pion MC	2.34 ± 0.09

Data based observations

- Data muon CAR
- Data pion CAR
- Data Thrugoing

LArIAT Data, Preliminary
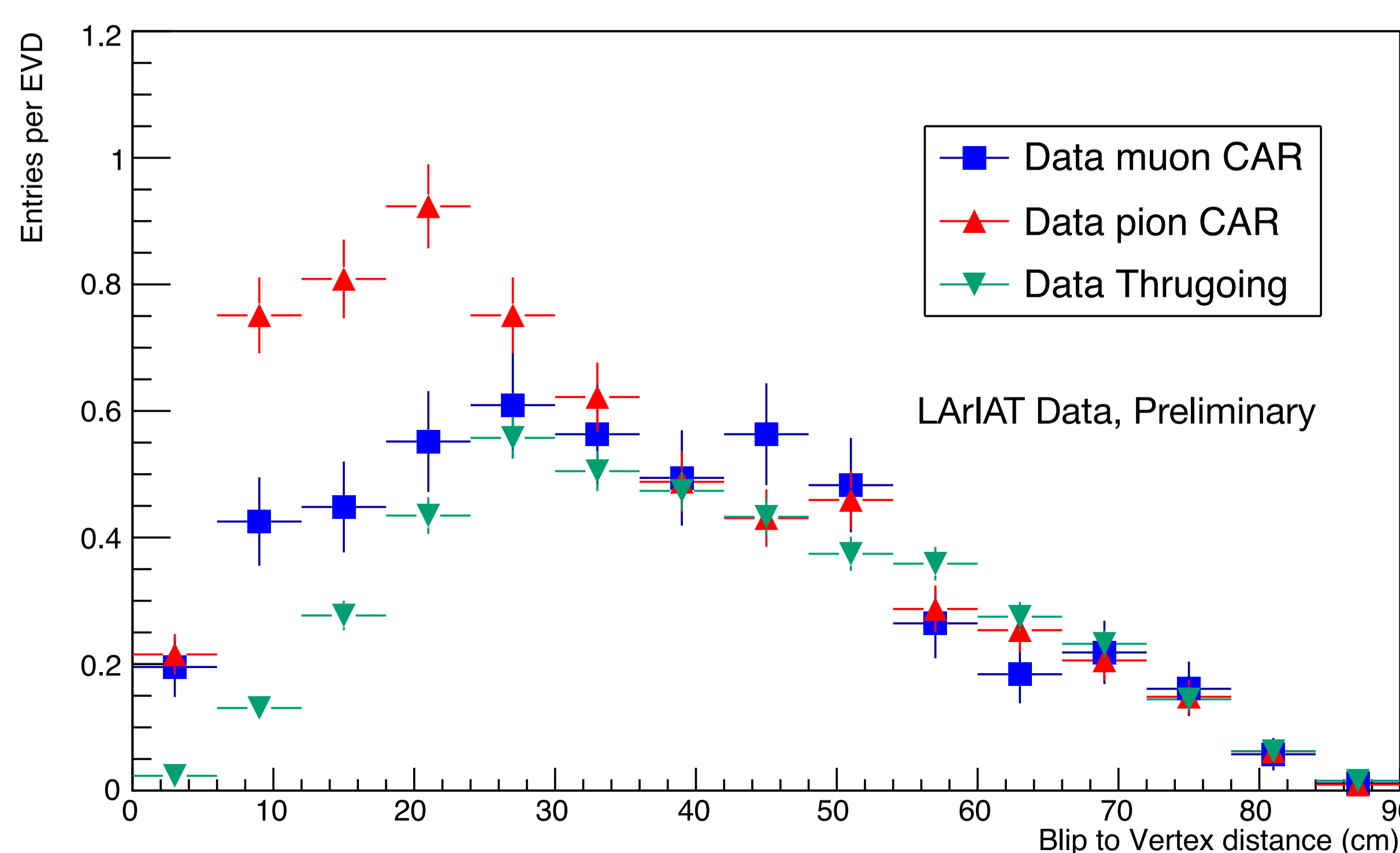
- Muon Captured at rest to through-going 4.2σ CL of statistical incompatibility
- Pion Captured at rest to through-going $\gg 5\sigma$ CL of statistical incompatibility
- Muon to pion captured at rest 3.6σ CL of statistical incompatibility

We have provided the first observation of the products of stopped pion and muon nuclear capture on argon, and have shown that capture products of the two particle types are clearly distinguishable from one another in neutrino LArTPC data
(arXiv.2408.05133)

References

[1] Acciarri, R. et al. (2020). The Liquid Argon In A Testbeam (LArIAT) experiment. Journal of Instrumentation, 15(04), P04026.
[2] Abratenko, P. et al. (2022). Search for long-lived heavy neutral leptons and Higgs portal scalars decaying in the MicroBooNE detector. American Physics Society, PhysRevD.106.092006

Acknowledgments