FERMILAB-SLIDES-24-0059-V

DETECTION OF MEV-SCALE GAMMAS FROM PION/MUON NUCLEAR CAPTURE WITH THE LARIAT LIQUID ARGON TPC

This document was prepared by the LArIAT Collaboration using the resources of the Fermi National Accelerator Laboratory (Fermilab), a U.S. Department of Energy, Office of Science, Office of High Energy Physics HEP User Facility. Fermilab is managed by Fermi Research Alliance, LLC (FRA), acting under Contract No. DE-AC02-07CH11359.

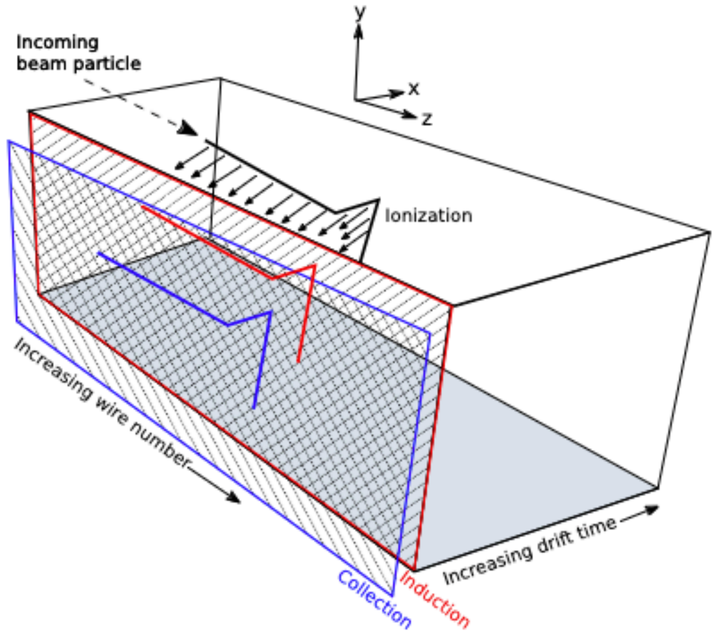
LArIAT

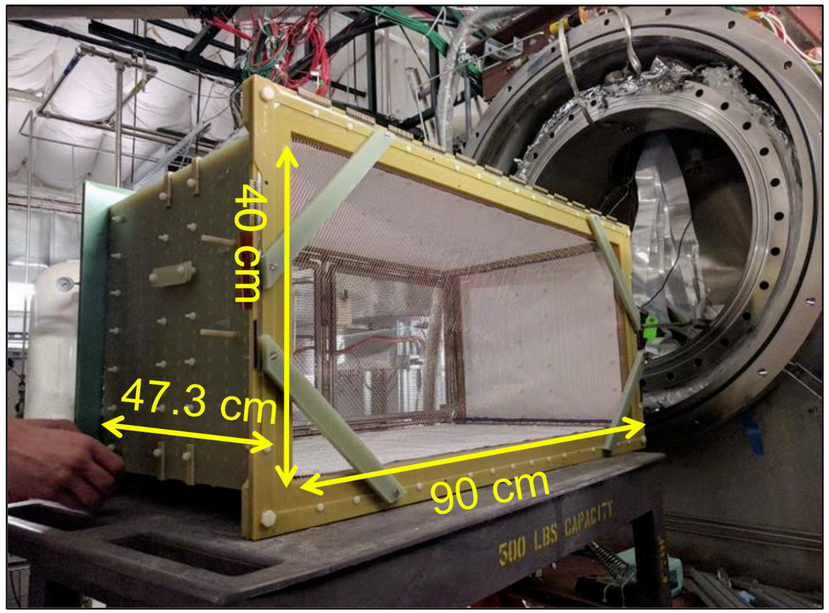
Liquid Argon In A Testbeam

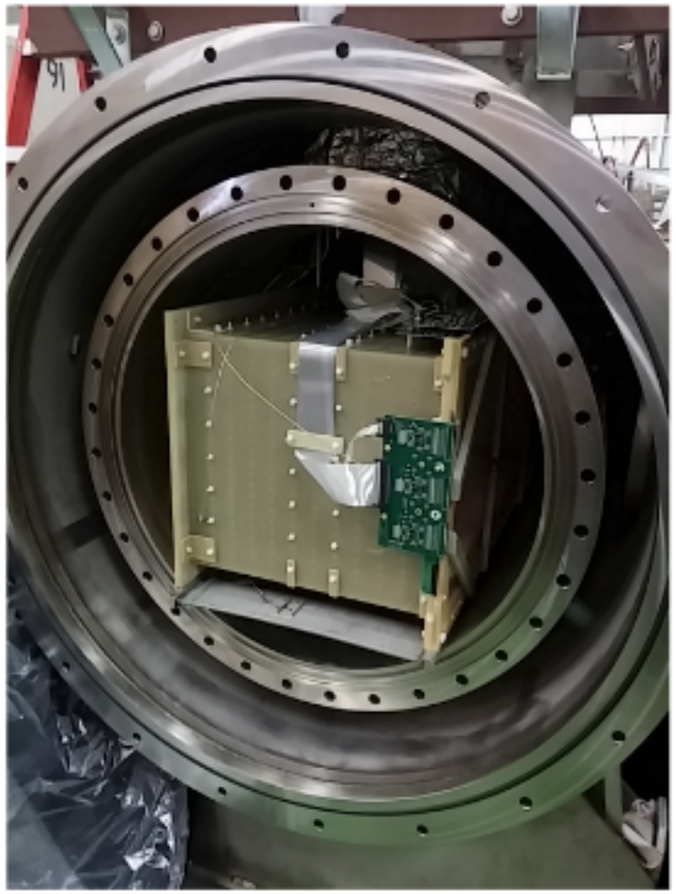
An experiment to perform a precise calibration of LArTPC detectors.

LArIAT is a LArTPC used to measure charged particles that could emerge from neutrino argon interactions, was the first LArTPC in a beam line.

- LArIAT took data from 2015 to 2017 at Fermilab.

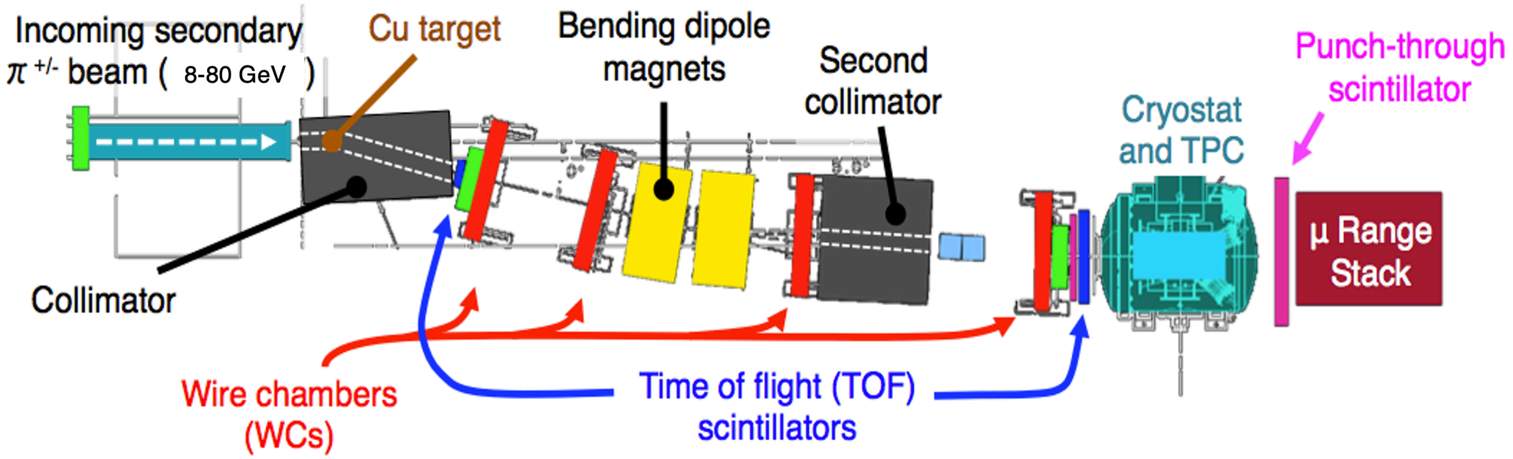






LArIAT cryostat with TPC, image from LArIAT, JINST 15 (2020).

Beamline



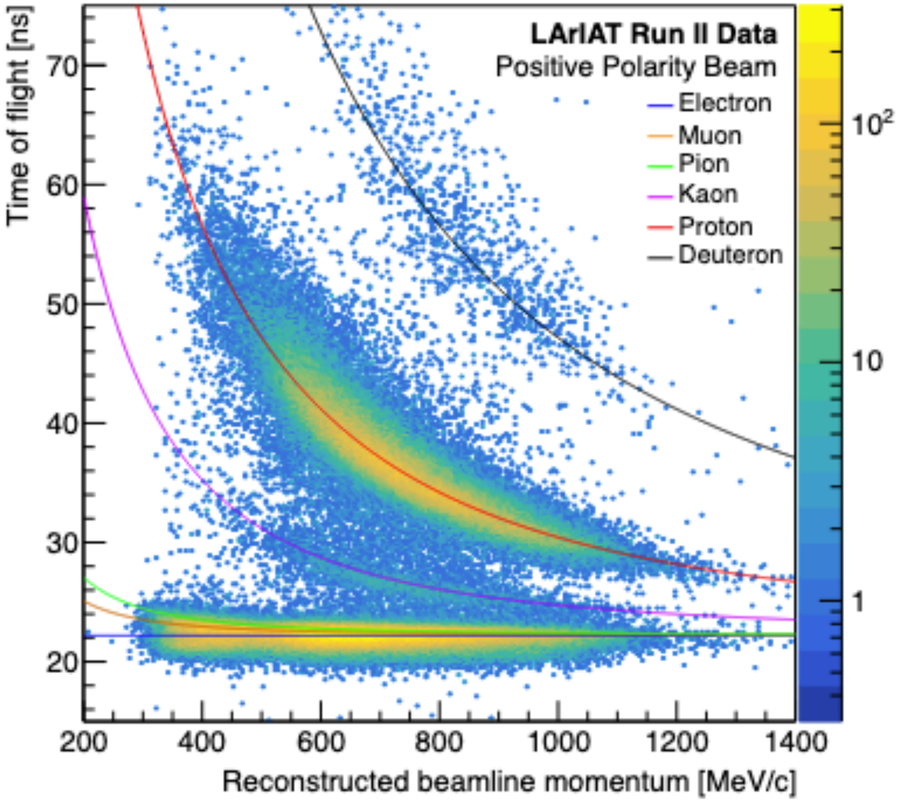


Image from LArIAT, JINST 15 (2020).

Muon and pion Capture at rest

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

Muon capture at rest process

$$\pi^- + p \rightarrow n$$

Pion capture at rest process

- Pions and muons captured at rest transfer different amounts of energy to nucleus

Muon and pion Capture at rest

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

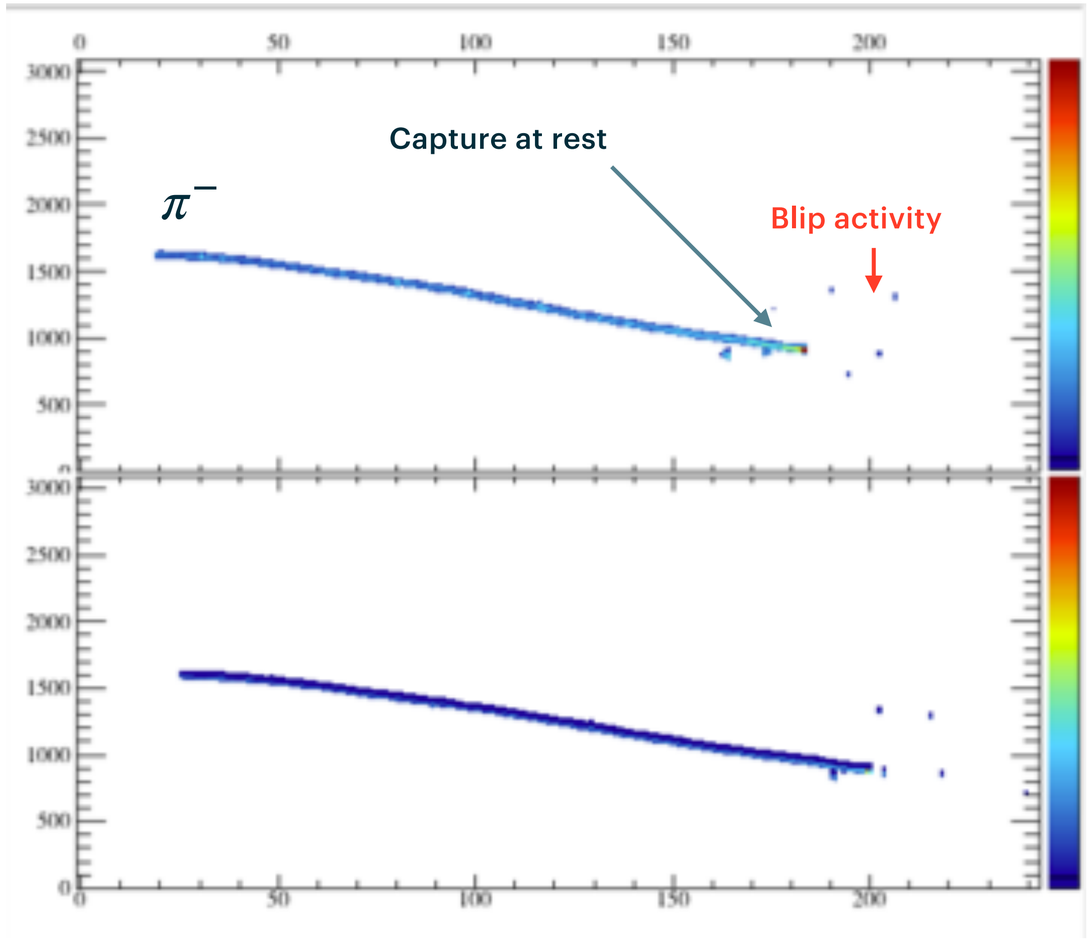
Muon capture at rest process

$$\pi^- + p \rightarrow n$$

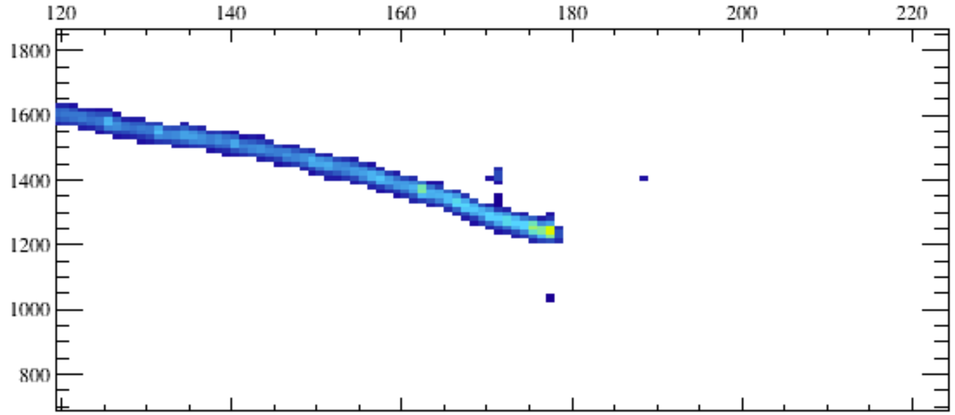
Pion capture at rest process

Pions transfer all energy to nucleus; muons transfer some energy to neutrinos
Blip activity for pion should be higher than muon

What is a Blip?



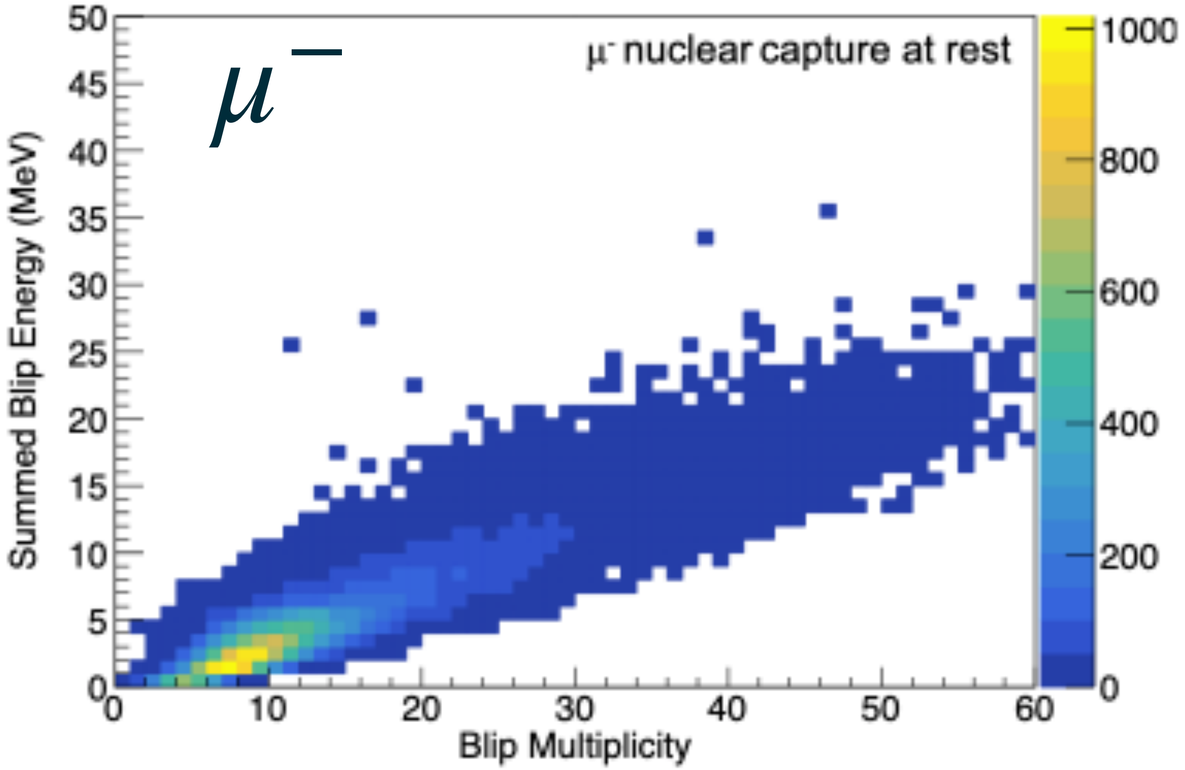
LArIAT SIMULATION



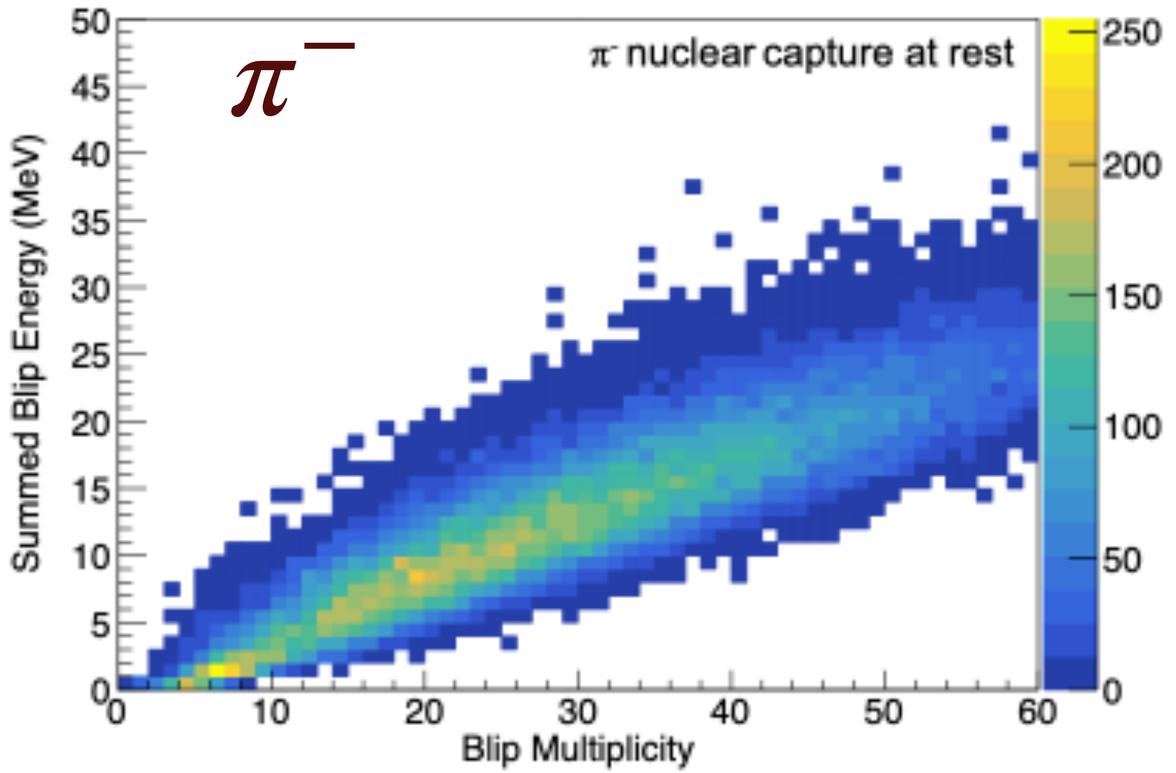
Blips are 1 to 2 signal wires big.

Muon and pion Capture at rest

Generic LAr simulation



Generic LAr simulation



Images from W. Castiglioni et al, PRD 102 (2020)

- For this generic LAr simulation, on average we have a higher blip multiplicity and summed blip energy for π^-
- Studying blip activity for different particles will demonstrate if it is possible to do PID and sign determination for pions/muons

Blip activity study

We want to use LArIAT because we have low energy needed for capture at rest

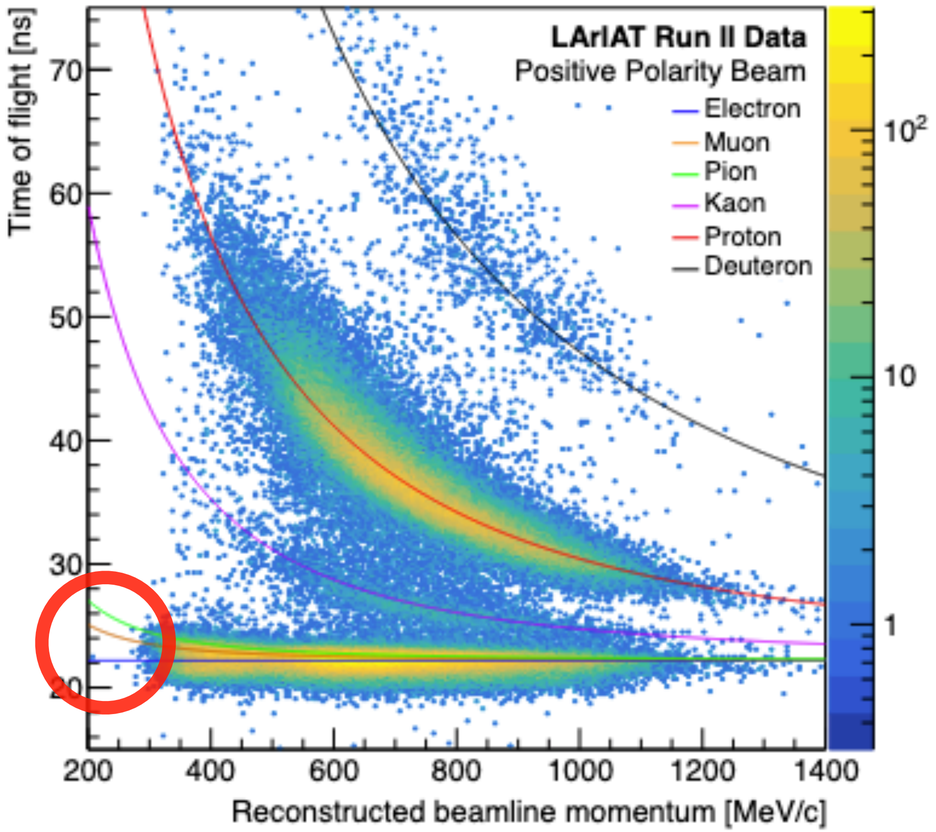
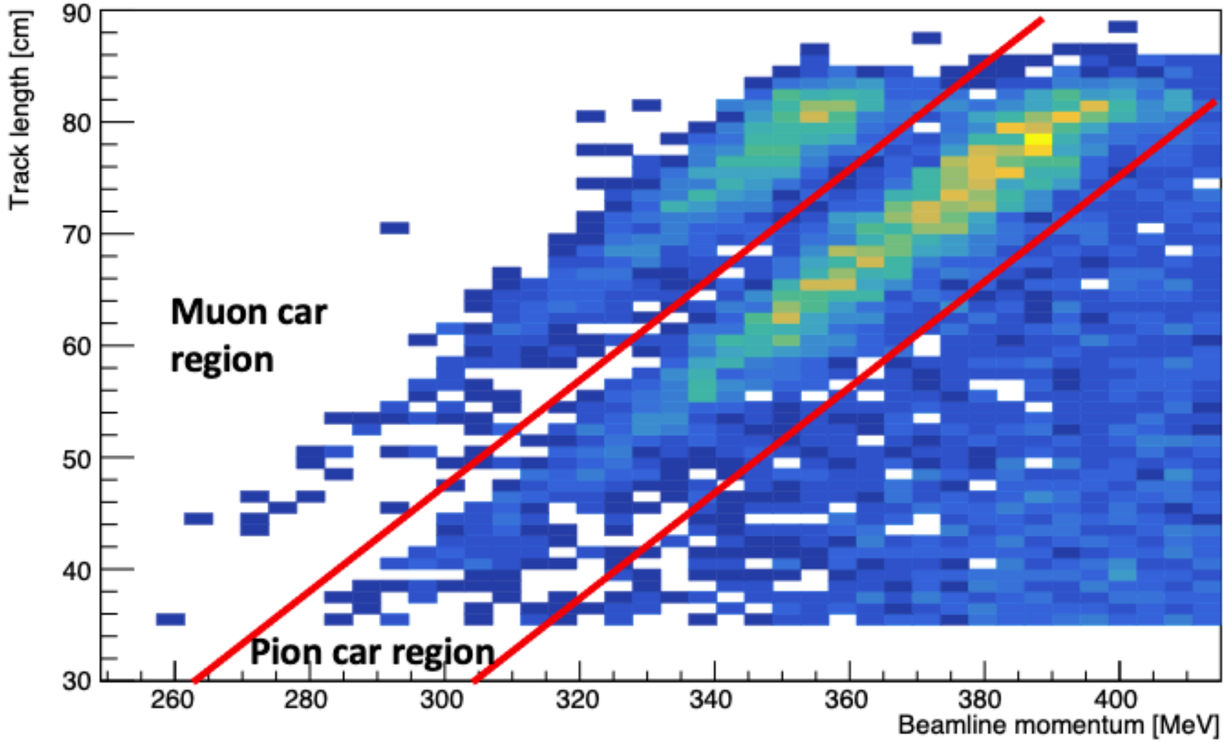


Image from LArIAT, JINST 15 (2020)

Mu- and pi- Capture At Rest (CAR) selection in LArIAT



LArIAT SIMULATION

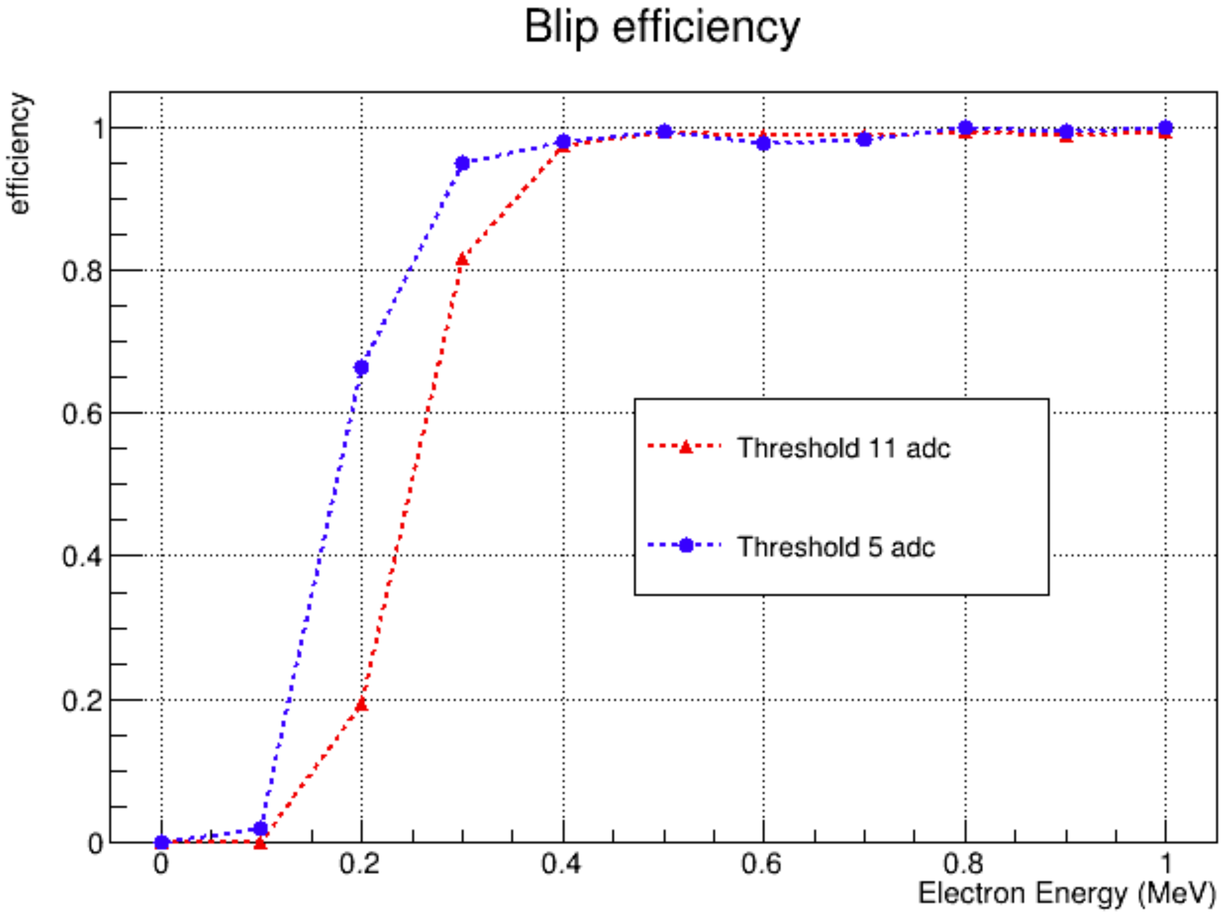
Using beam momentum and track stopping point inside of the TPC we separate stopping muons from stoping pions.

With a MC sample of 500k events in the -60A configuration, my final selection is made with

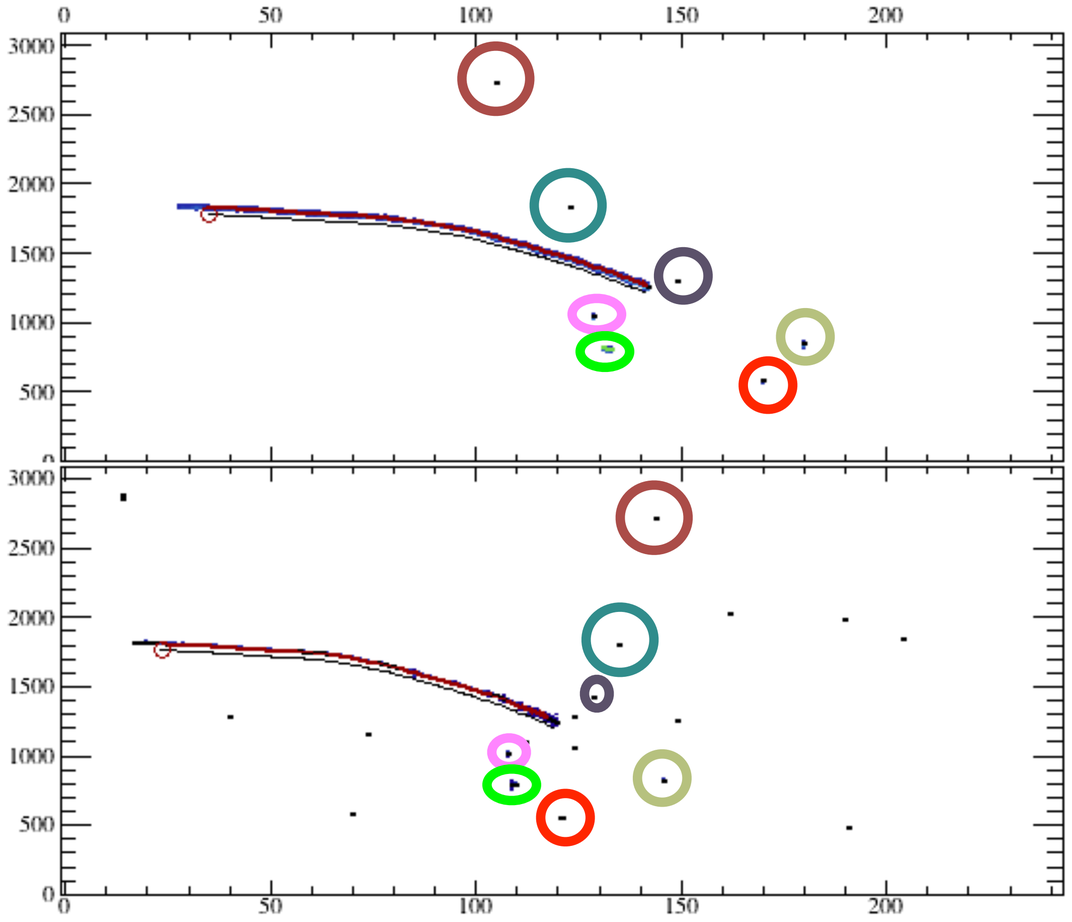
2177 muon car events (79% purity)
3877 pion car events (76% purity)

Real Data has 89 muon car and 211 pion car candidates.

Blip reconstruction in LArIAT

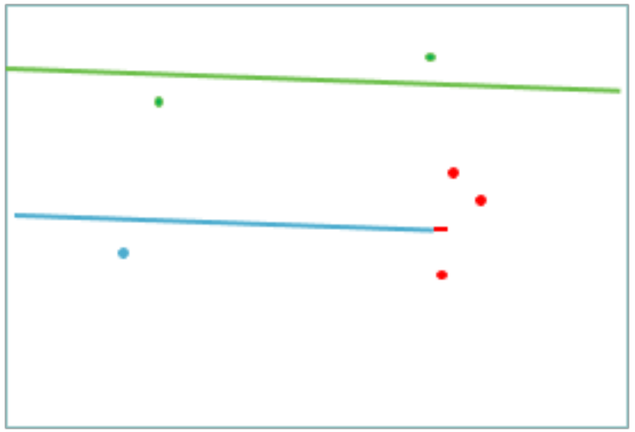


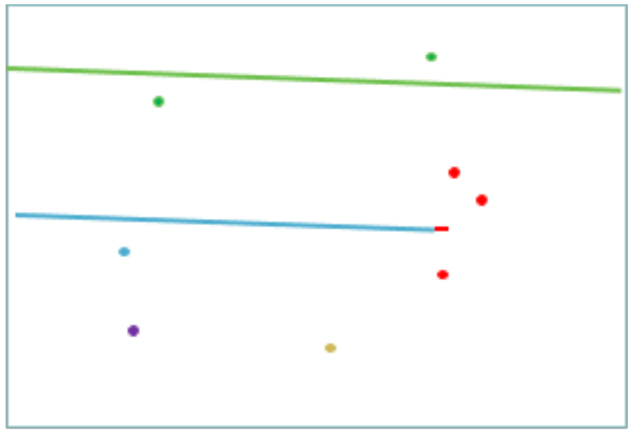
LArIAT SIMULATION,
Blip efficiency with default thresholds (11 ADC) and low thresholds (5 ADC)



LArIAT SIMULATION,
Activity in an event with 7 matched blips

Blips in LArIAT, Data and MC background





MC is missing some sources of backgrounds we see in data.

We are looking a way to subtract background.

MC Blip

- Blips produced by mu/pi car
- Blips produced by main track but not related to car process
- Blips produced by pileup muons

Data Blip

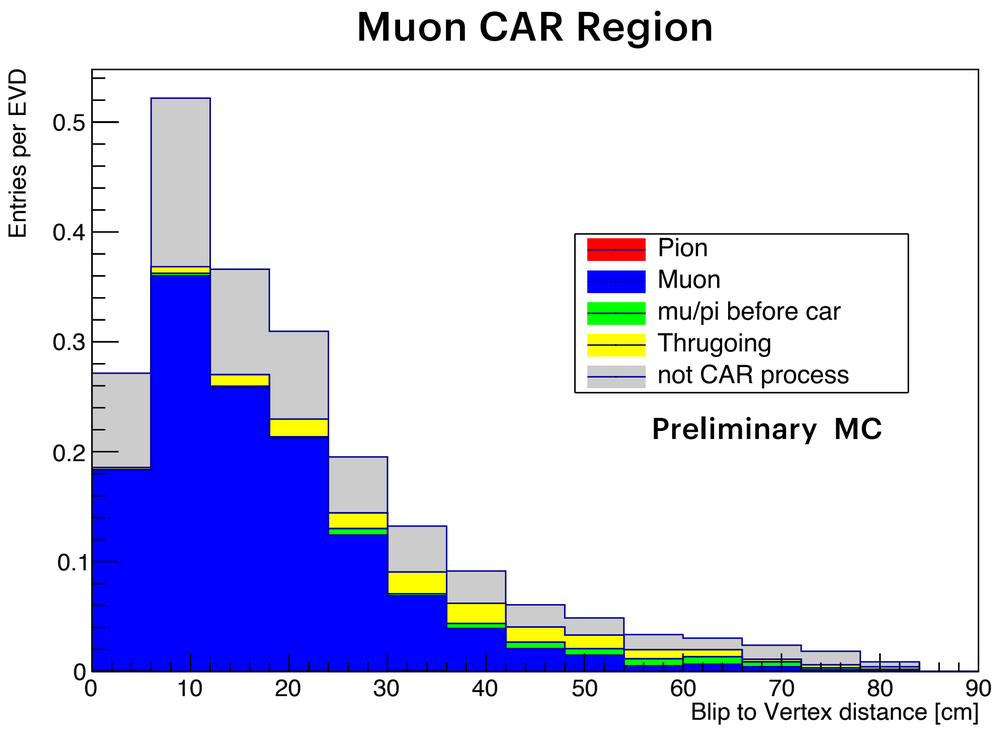
- Blips produced by mu/pi car
- Blips produced by main track but not related to car process
- Blips produced by pileup muons
- Blips produced by neutrons around the TPC
- Blips produced by nuclear activity (electronic noise, Ar39)

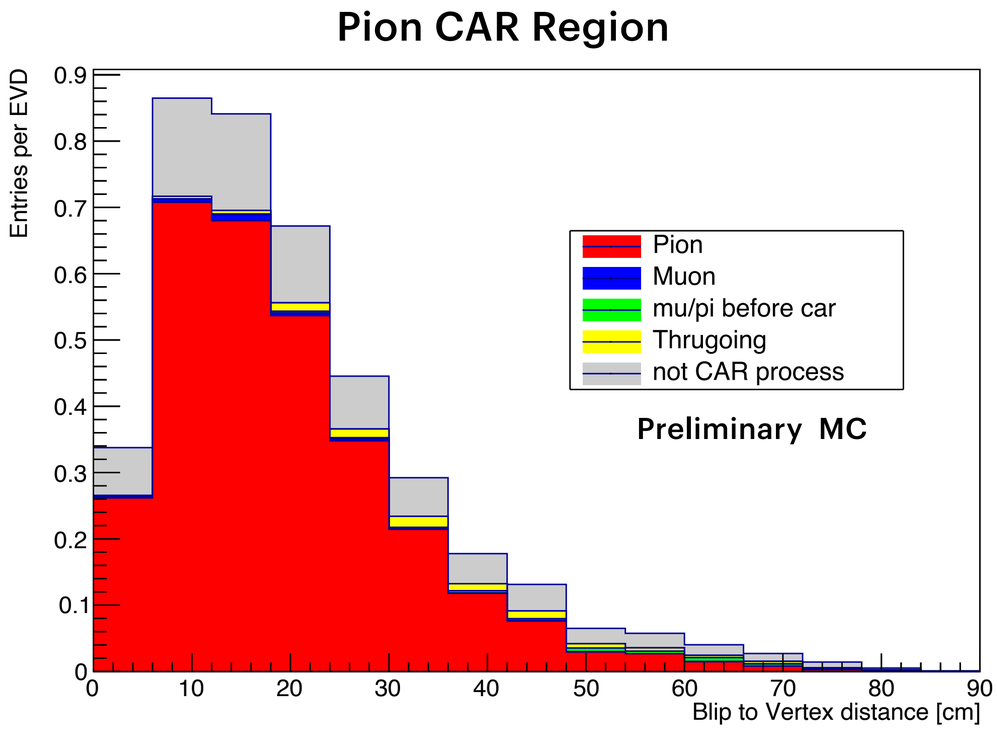
Blips in LArIAT, CAR MC samples

Preliminary	MuCAR region (MC)	PiCAR region (MC)
Events	2177	3877
Blip multiplicity	1.55 ± 0.03	2.80 ± 0.04

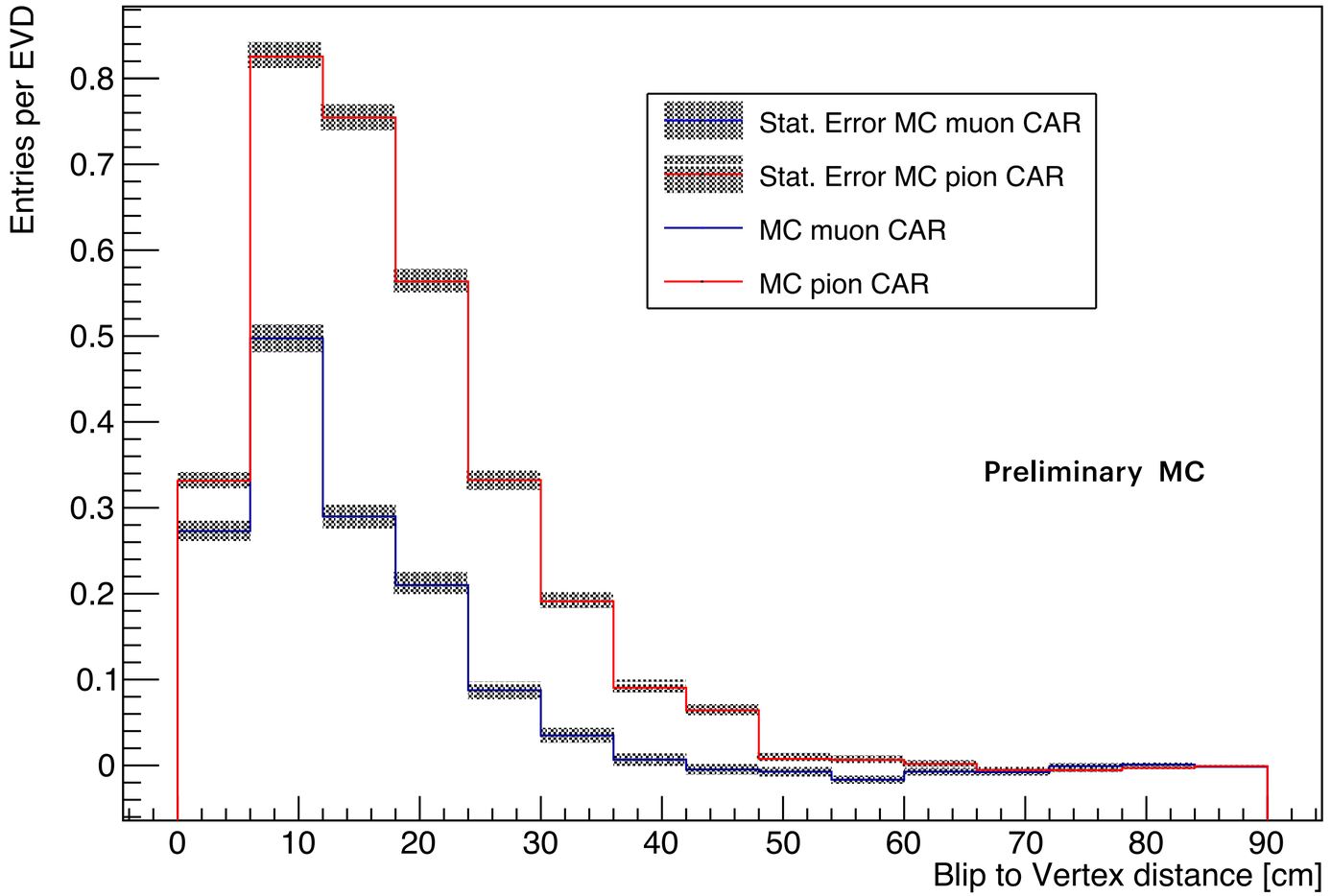
We see 1 more blip per EVD in the PiCAR region than MuCAR region

Blip activity for MuCAR and PiCAR regions with statistical errors





Blips in LArIAT, CAR MC samples after background subtraction



Blip activity for MuCAR and PiCAR regions with statistical errors

Summary

- A selection for Muon and Pion CAR particles were made with a high purity using beam line instrumentation and TPC reconstruction.
- We developed a Blip analysis Module for LArIAT framework.

In MC, we can distinguish the difference between muon CAR and pion CAR using blip information.

- Systematics and data analysis in progress.

Thanks

(Gracias)

BACKUP

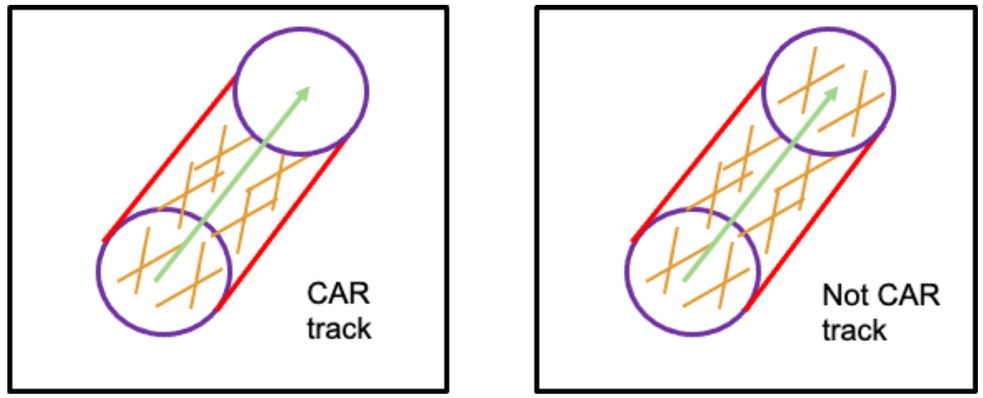
Cuts for track classification

- WC to TPC match: We are checking for at least 1 WC to TPC match.
- Cylinder cut: check for tracks in the front of the TPC that has a match with WC. After that a distance higher than 8 cm is requested between this track and all the other tracks of the event.
- Energy cut: remove events with wc track momentum > 415 MeV
- Signal cut: remove events with main track that finishes in the last 5 cm.
- dEdx; requirement of dEdx > 3.0 MeV in the last 2 cm of the track.

Blips in LArIAT, cuts

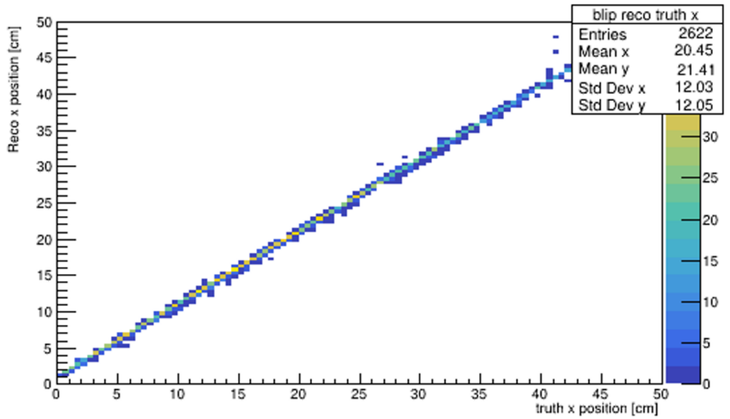
To keep blips produced by CAR process and remove background, we apply some cuts.

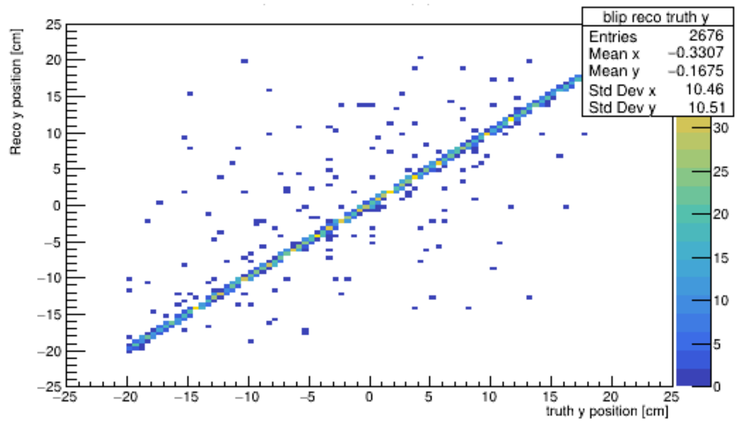
- Remove blips with a distance from blip to track smaller than 2.0 cm (top right diagram)
- Remove blips inside a sphere on the beginning and end of the track for not car tracks (bottom right)
- Remove Blips inside a sphere on the beginning of the track and keep everything at the end of car tracks (bottom left)

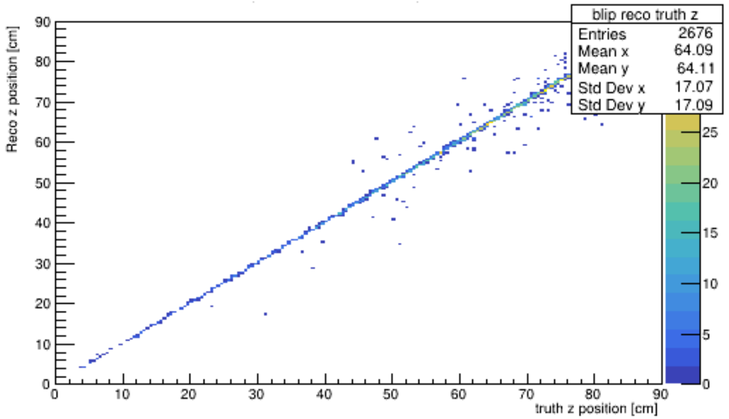


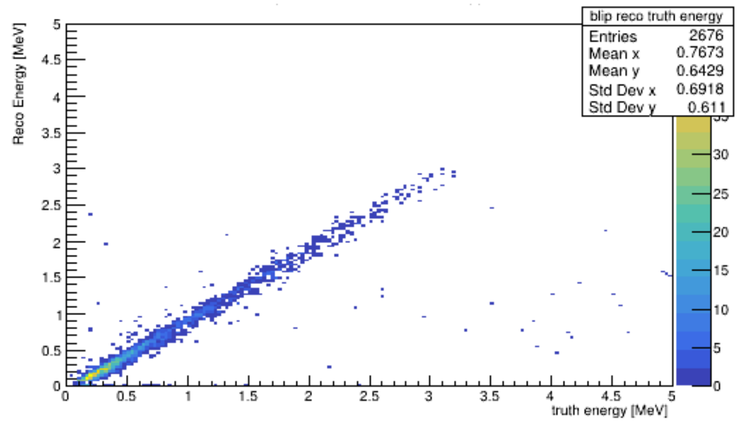
Cut diagram for car track and pileup tracks

Truth vs reco energy and positions reconstruction for blips



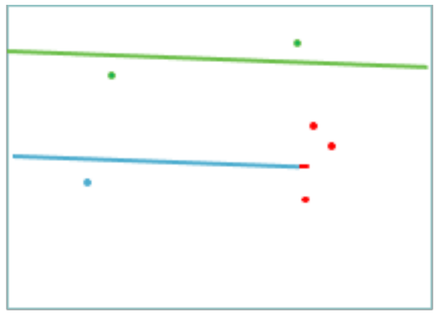


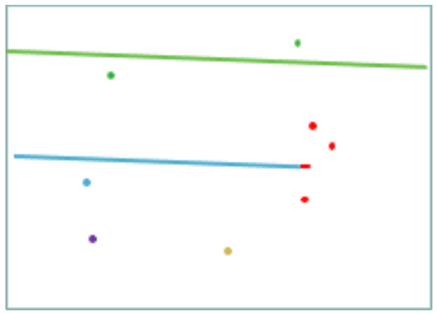


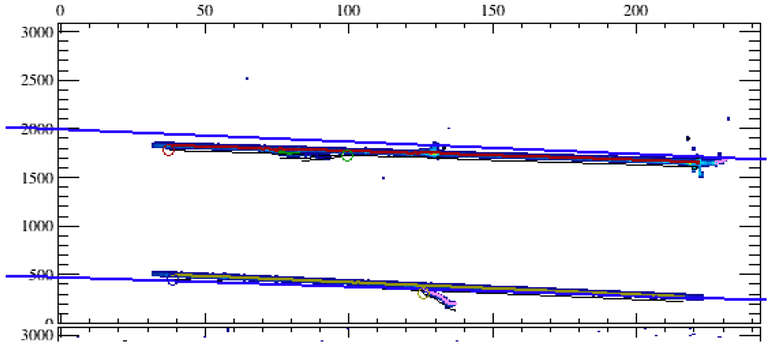


MC Picar sample, Blip Reco - truth X, Y, Z and energy

Blips in LArIAT, Data and MC background







Thrugoing muon event display

MC Blip

- Blips produced by mu/pi car
- Blips produced by main track but not related to car process
- Blips produced by pileup muons

Thrugoing MC

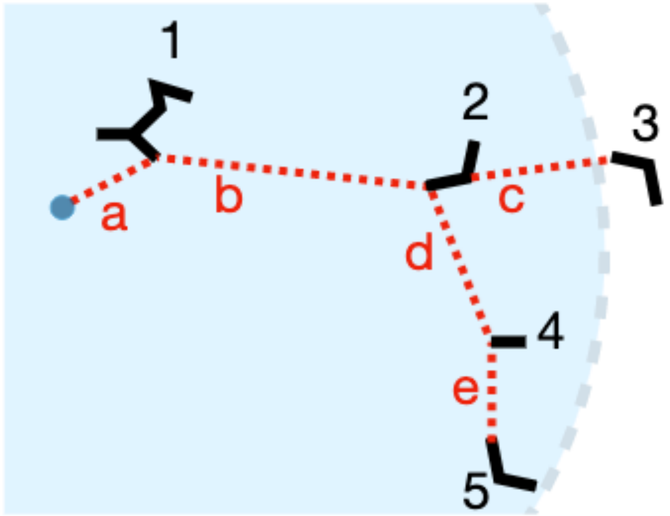
Data Blip

- Blips produced by mu/pi car
- Blips produced by main track but not related to car process
- Blips produced by pileup muons
- Blips produced by neutrons around the TPC
- Blips produced by nuclear activity (pedestal, Ar39)

Thrugoing Data

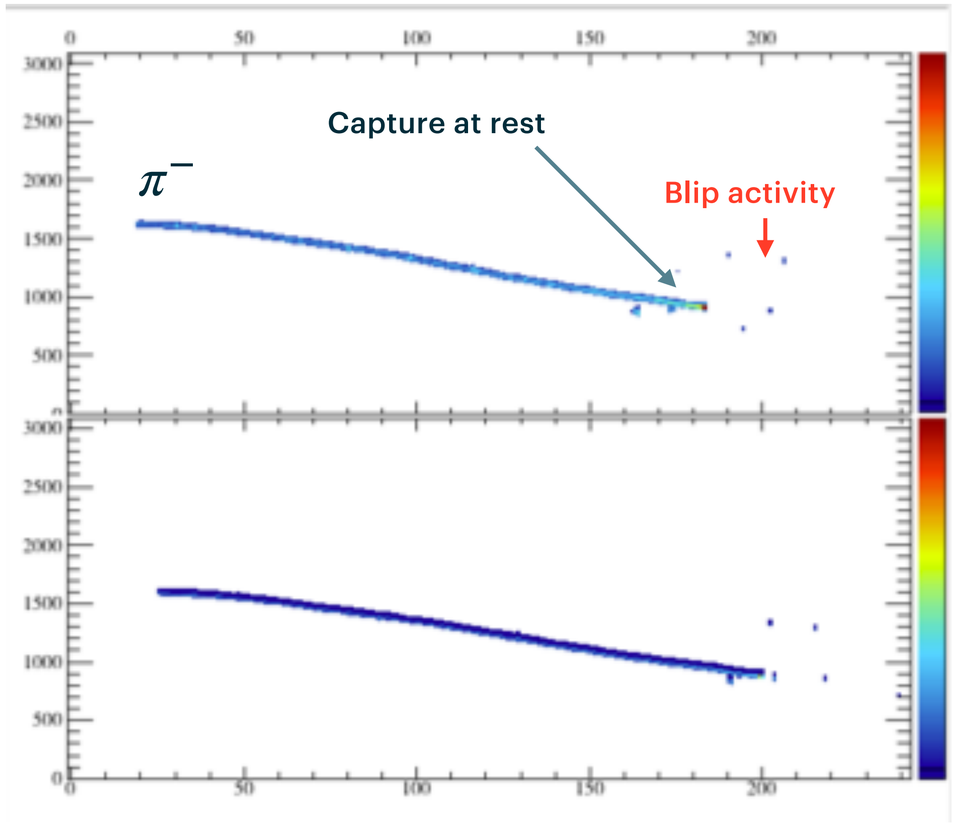
Our goal is to get a background subtraction, in this case the thrugoing sample includes all the background, so the idea is to use thrugoing MC for MC background and thrugoing data for data background

What is a Blip?



Item	Type	Creator Process	E_{start} (MeV)	E_{end} (MeV)	E_{blip} (MeV)
a	γ	Primary	3.00	3.00	-
1	2 e^-	Compton scatter	1.50	0	1.50
b	γ	Compton scatter	1.50	1.50	-
2	e^-	Compton scatter	1.00	0	0.75
c	γ	Bremsstrahlung	0.25	0.25	-
3	e^-	Photoelectric effect	0.25	0	0.25
d	γ	Compton scatter	0.50	0.50	-
4	e^-	Compton scatter	0.05	0	-
e	γ	Compton scatter	0.45	0.45	-
5	e^-	Photoelectric effect	0.45	0	0.45

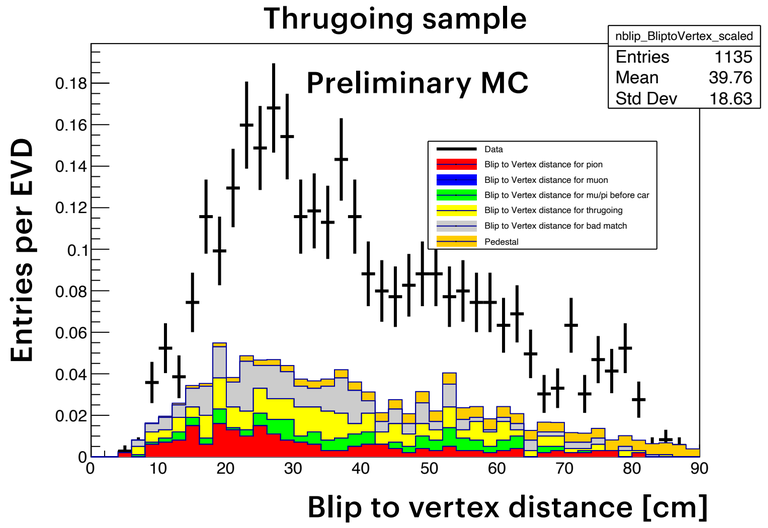
Image and table from Benefits of MeV Reconstruction



LArIAT SIMULATION

Blips in LArIAT, thrugoing samples

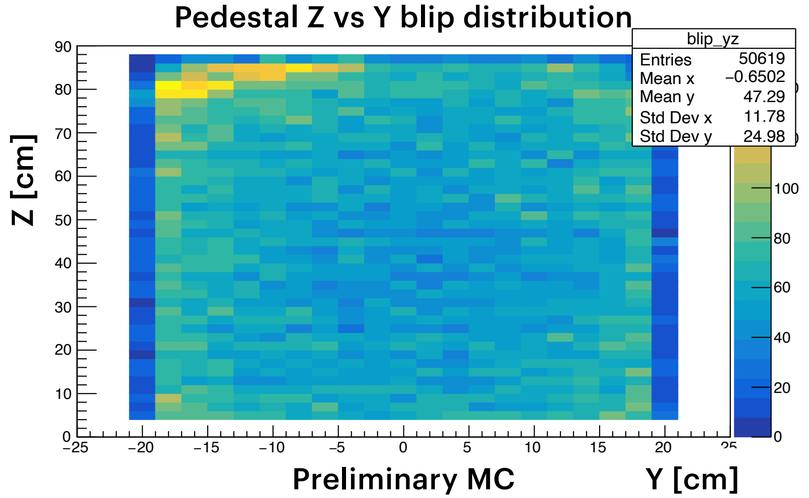
	Thrugoing MC	Thrugoing Data
Events	1000	363
# Blips	887	1135
Blip multiplicity	0.89 ± 0.05	3.13 ± 0.14
Total energy per EVD	0.59 ± 0.03	2.04 ± 0.10



Blip to vertex distance for thrugoing data and MC

We see higher activity in Data than MC, neutrons around the TPC produced in the beamline

Blip activity for thrugoing regions with statistical errors



Blip YZ distribution for pedestal sample.
Blip multiplicity of 0.37