



ILLINOIS INSTITUTE
OF TECHNOLOGY



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

FERMILAB-SLIDES-23-109-ND

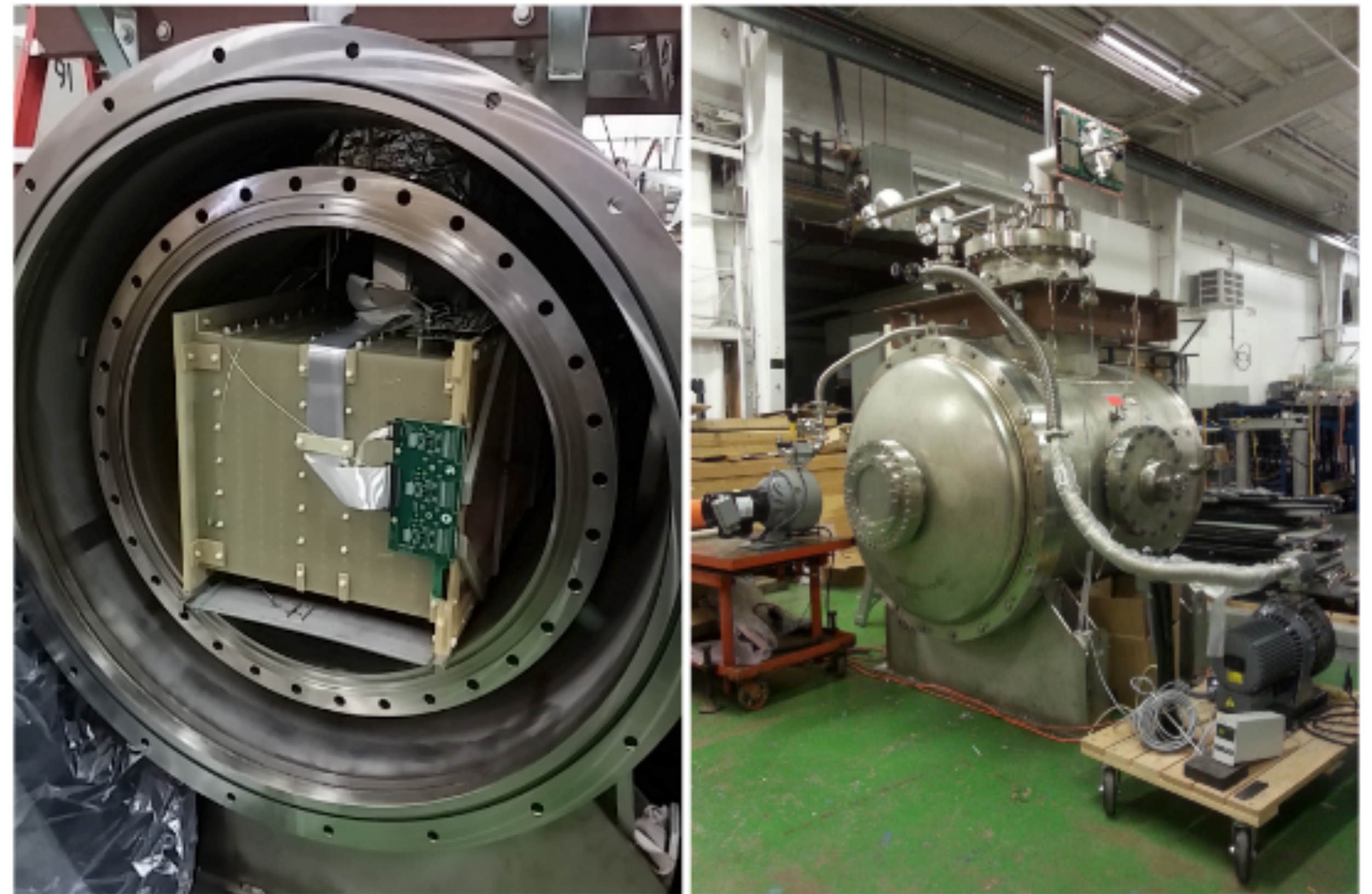
LArIAT

Liquid Argon In A Testbeam

An experiment to perform a precise calibration of LArTPC detectors.

LArIAT is not a neutrino detector, this detector focused in the study of charged particles that could emerge from neutrino argon interaction.

- When a charged particle passes through liquid argon, free electrons are produced
- Using an electric field, ionized electrons are drifted, signals are formed in 2 wire planes.
- 3D reconstruction is performed using information from the two planes, together with the drift time.



LArIAT cryostat with TPC, image from [LArIAT, JINST 15 \(2020\)](#).

Beamline

Momentum between
0.3 GeV/c to 1.4 GeV/c

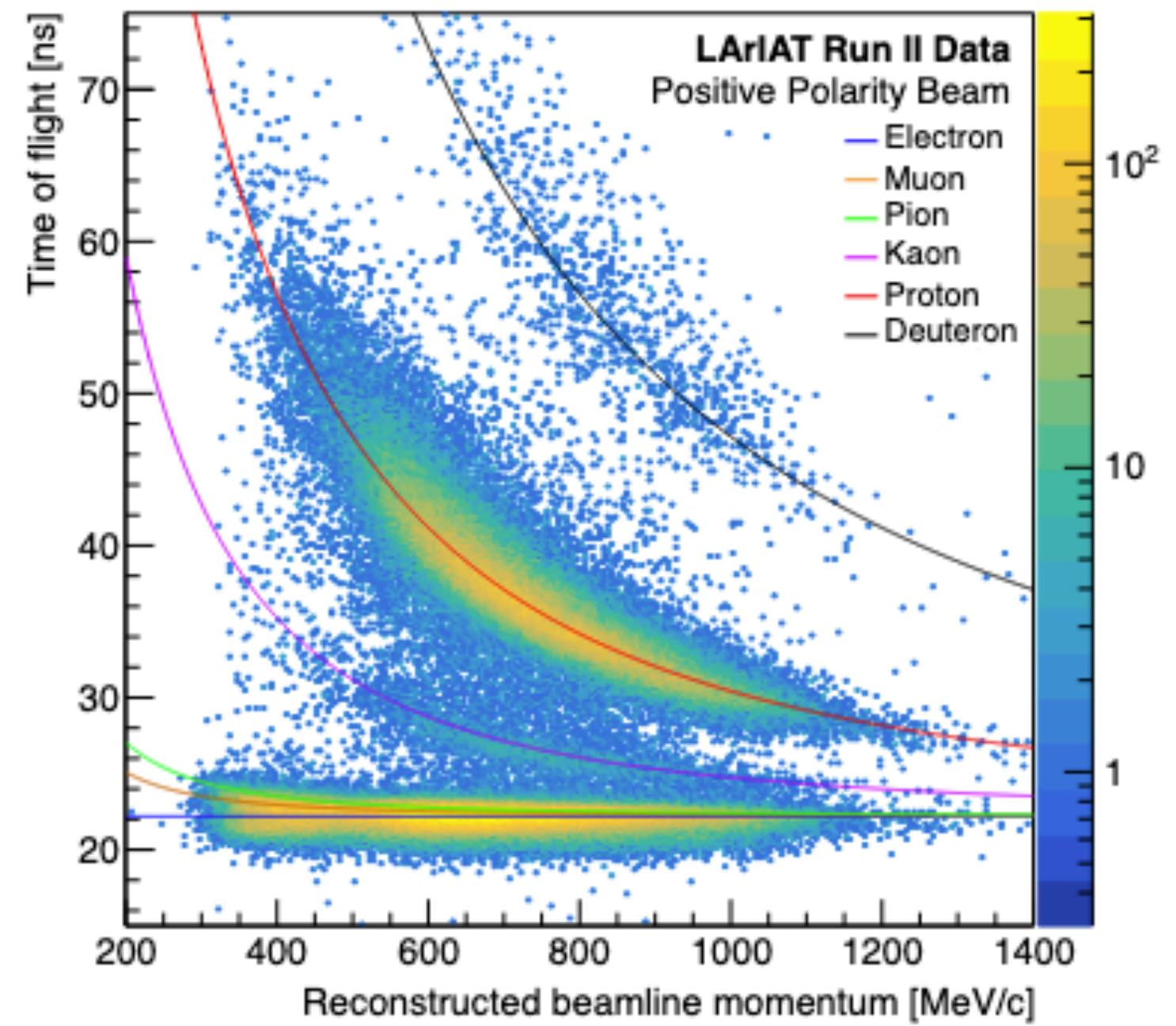
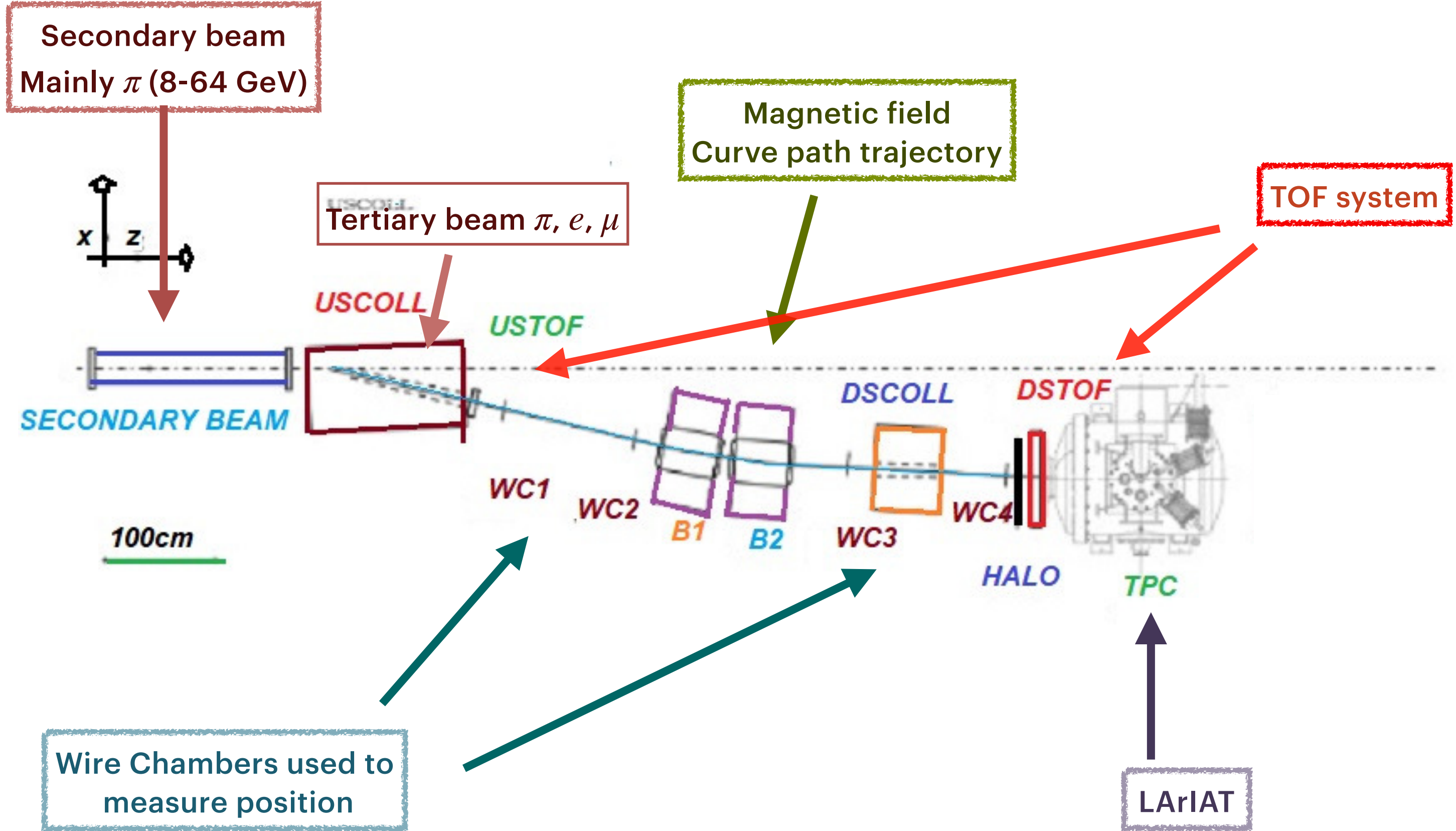


Image from LArIAT, JINST 15 (2020).

What is a Blip?

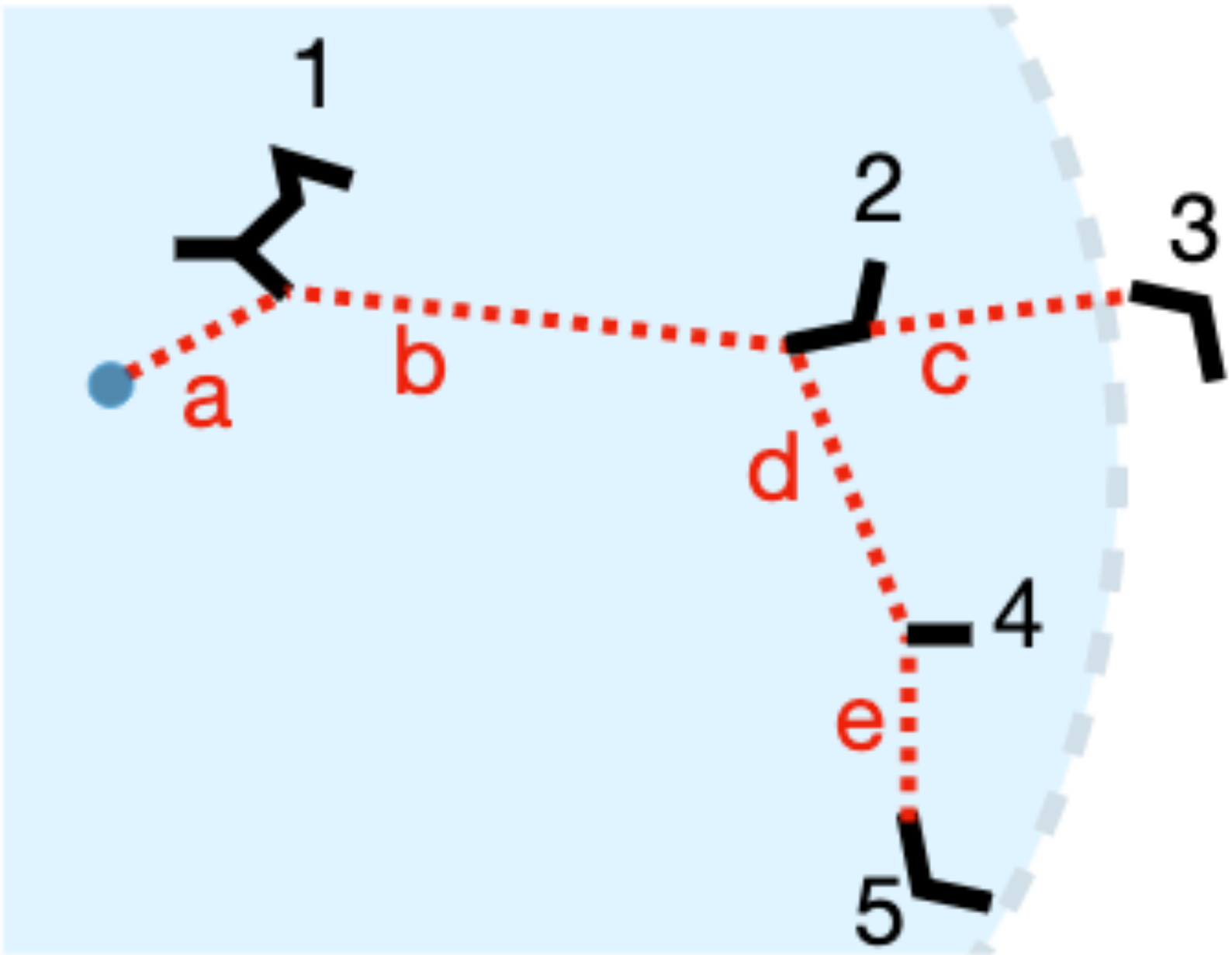
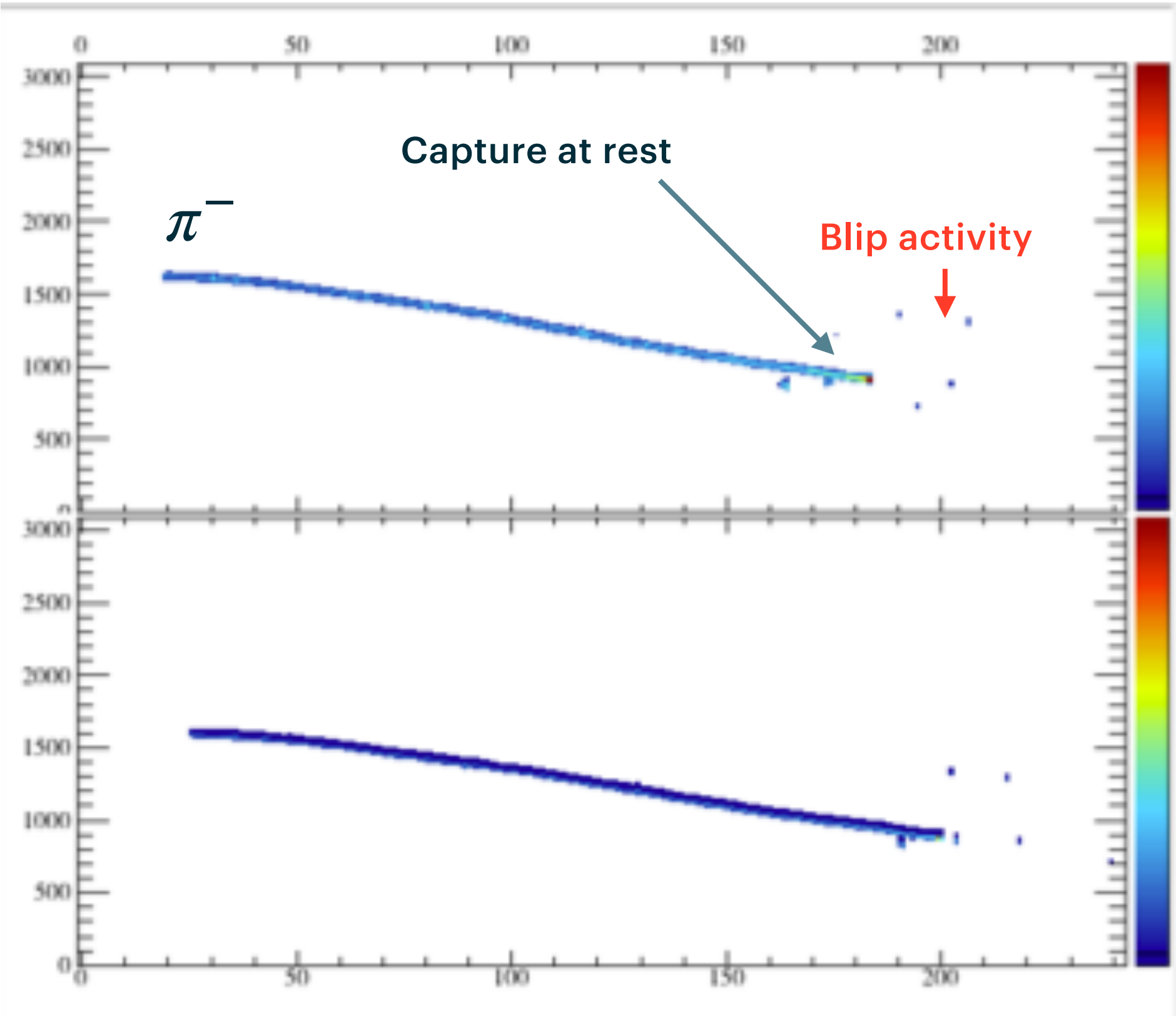
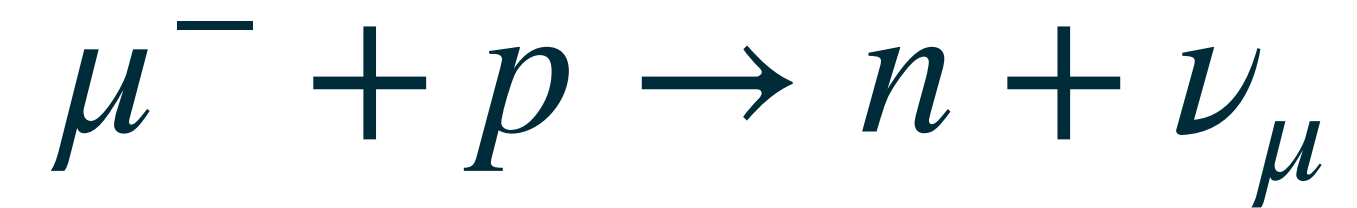


Image and table from [W. Castiglioni et al, PRD 102 \(2020\)](#)



LArIAT SIMULATION

Muon and pion Capture at rest



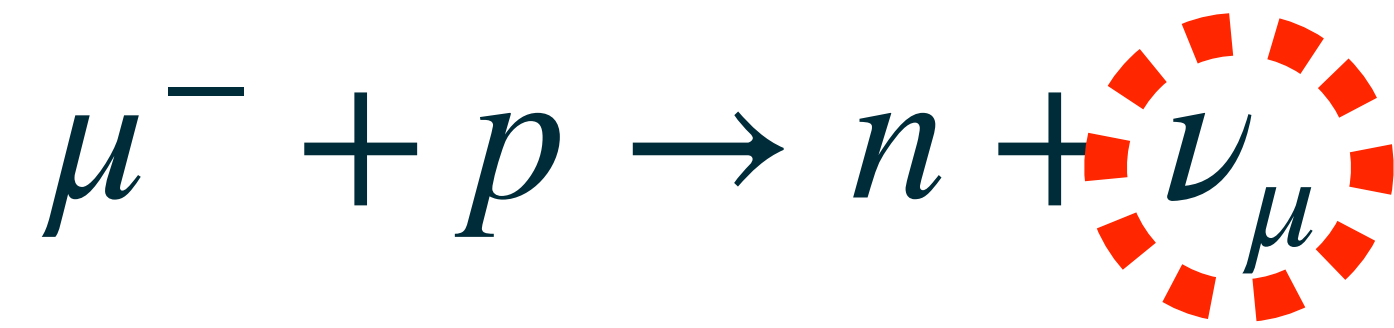
Muon capture at rest process



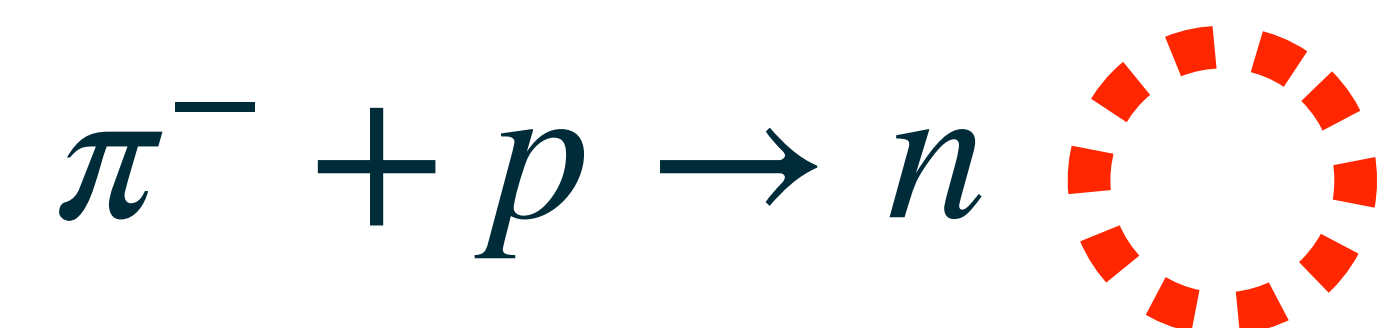
Pion capture at rest process

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

Muon and pion Capture at rest



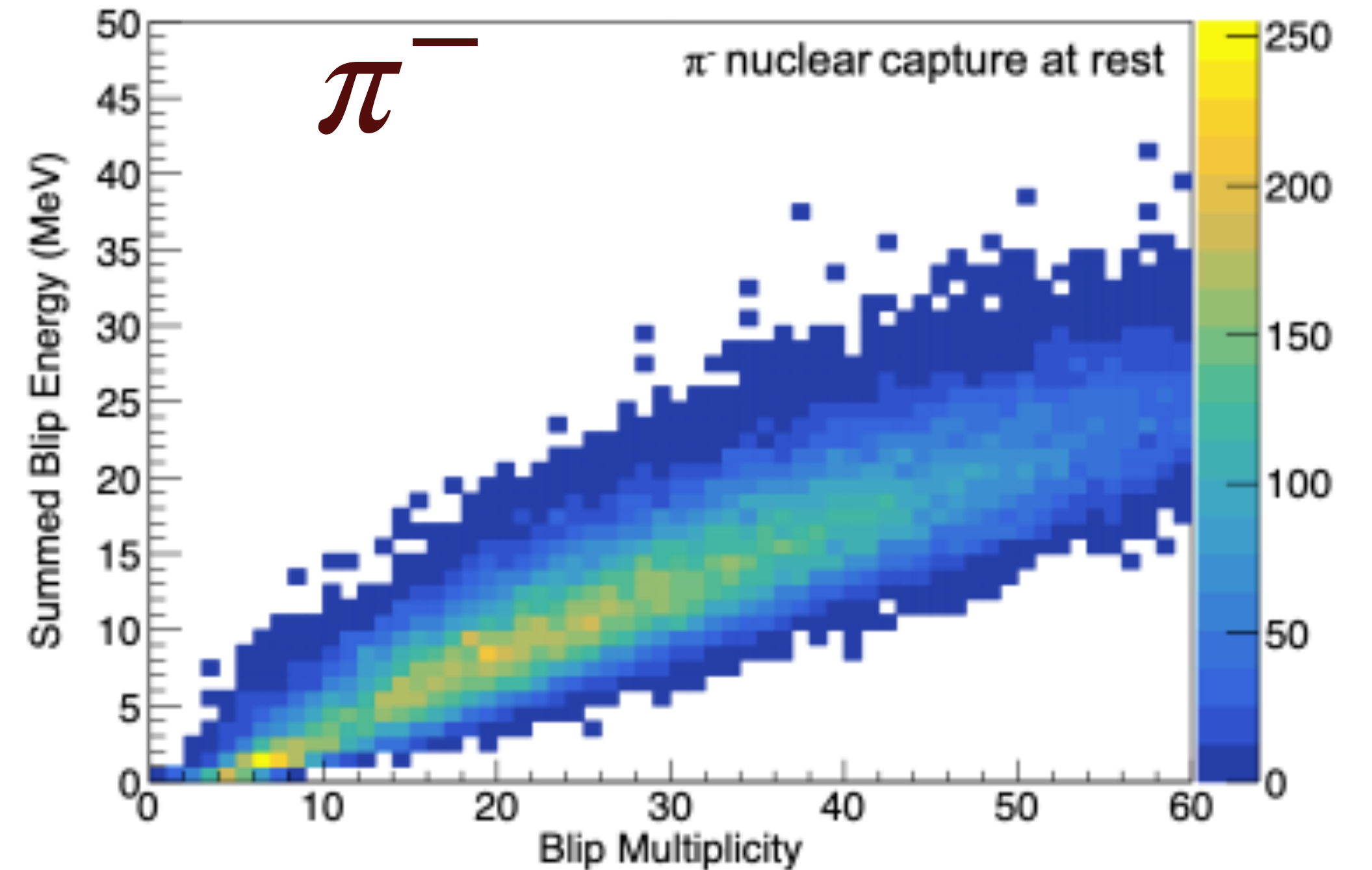
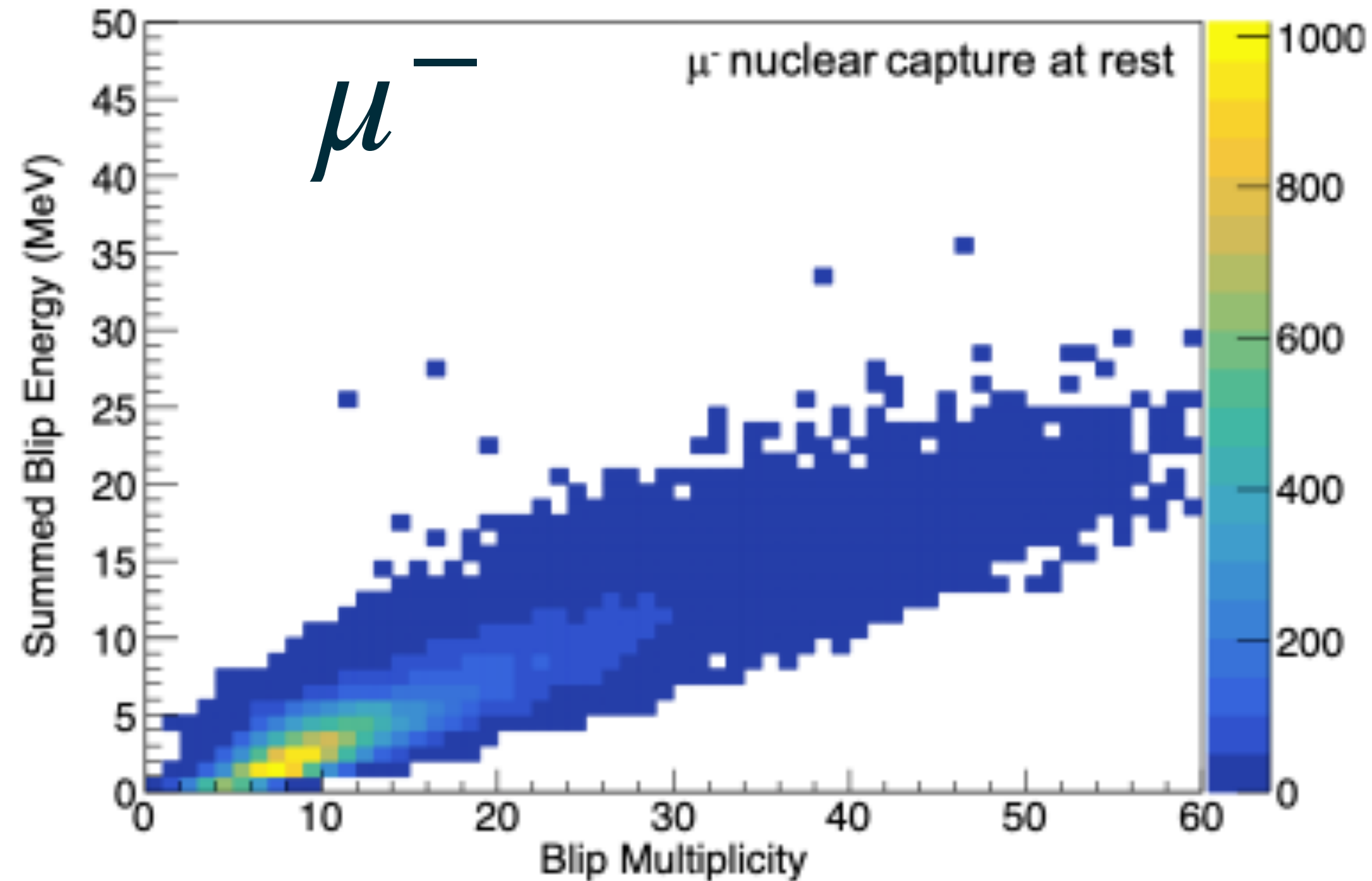
Muon capture at rest process



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

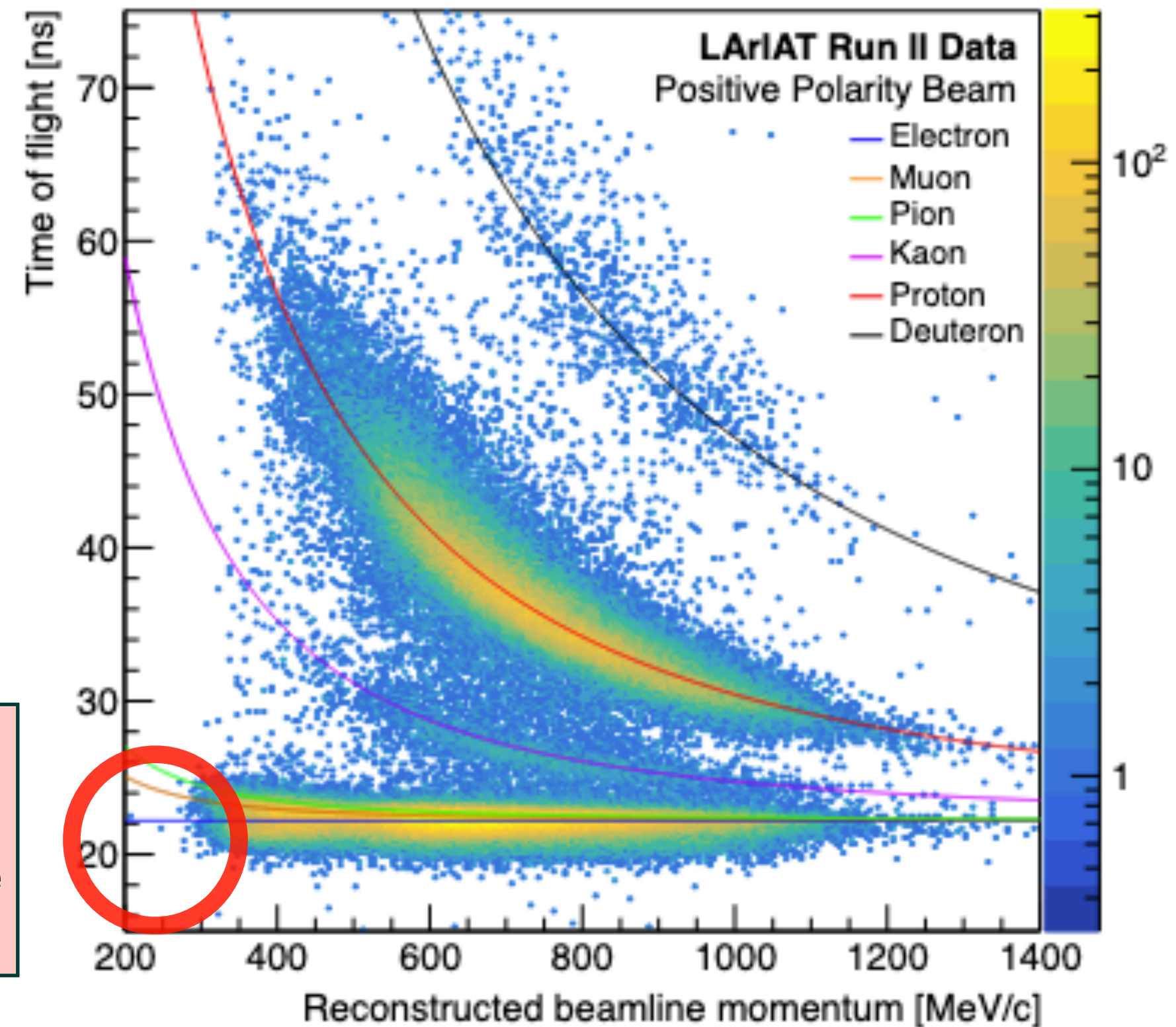
Muon and pion Capture at rest



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^-

Blip activity study

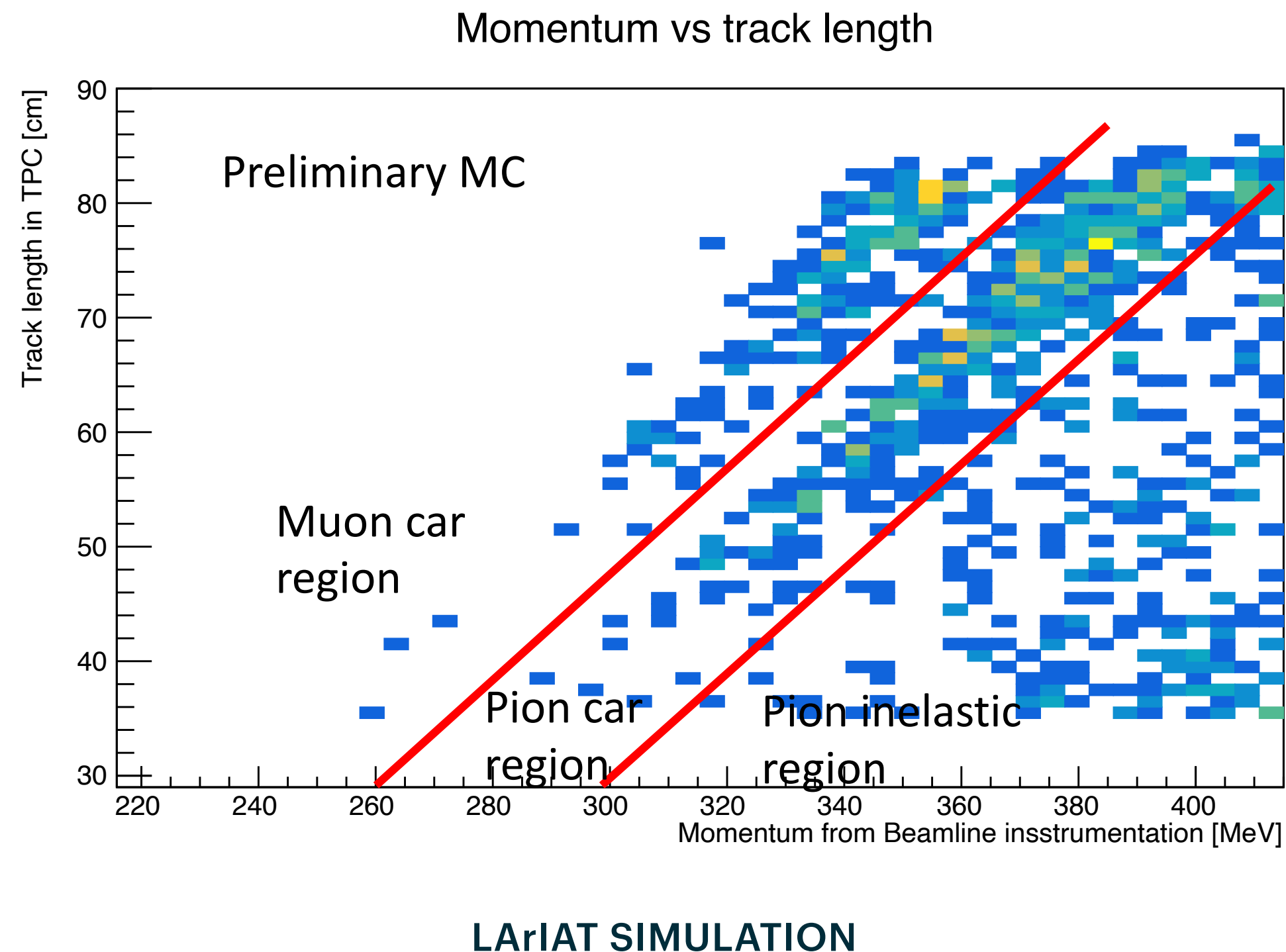


We want to use LArIAT because we have low energy needed for capture at rest

Image from [LArIAT, JINST 15 \(2020\)](#)

Studying blip activity for different particles will demonstrate if it is possible to do PID and sign determination for pions/muons

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



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

With a MC sample of 100k events in the -60A configuration, my final selection is made with

148 muon car events (91% purity)

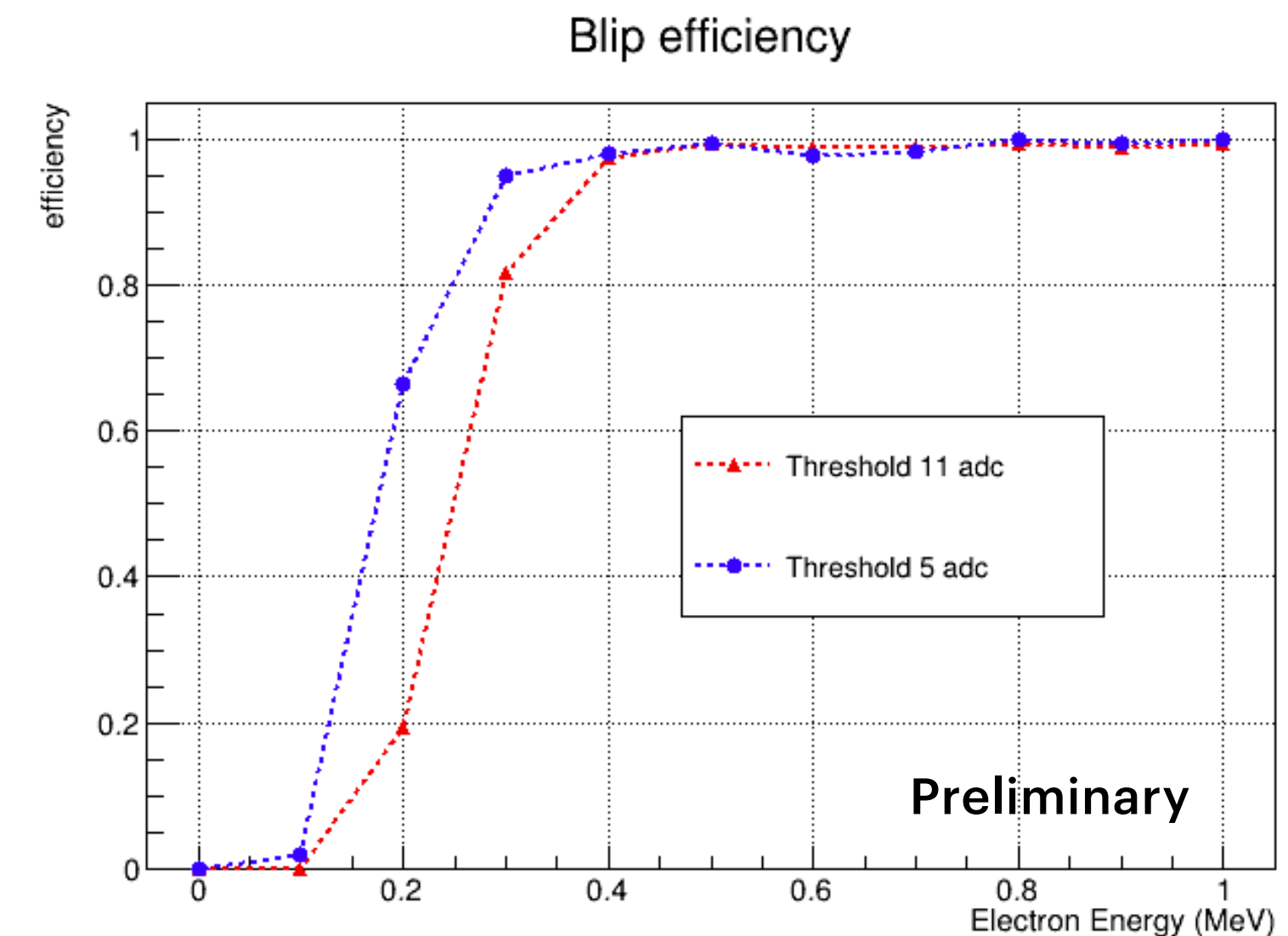
278 pion car events (84% purity)

Real Data has 65 muon car and 149 pion car candidates.

Blips in LArIAT (Blip Module)

We developed a Blip module to find matches (space and time) between planes to get blip information.

Studying the blip efficiency using single electrons in the TPC we found a configuration with lower thresholds where we have 60% detection efficiency for electrons of 200 KeV.



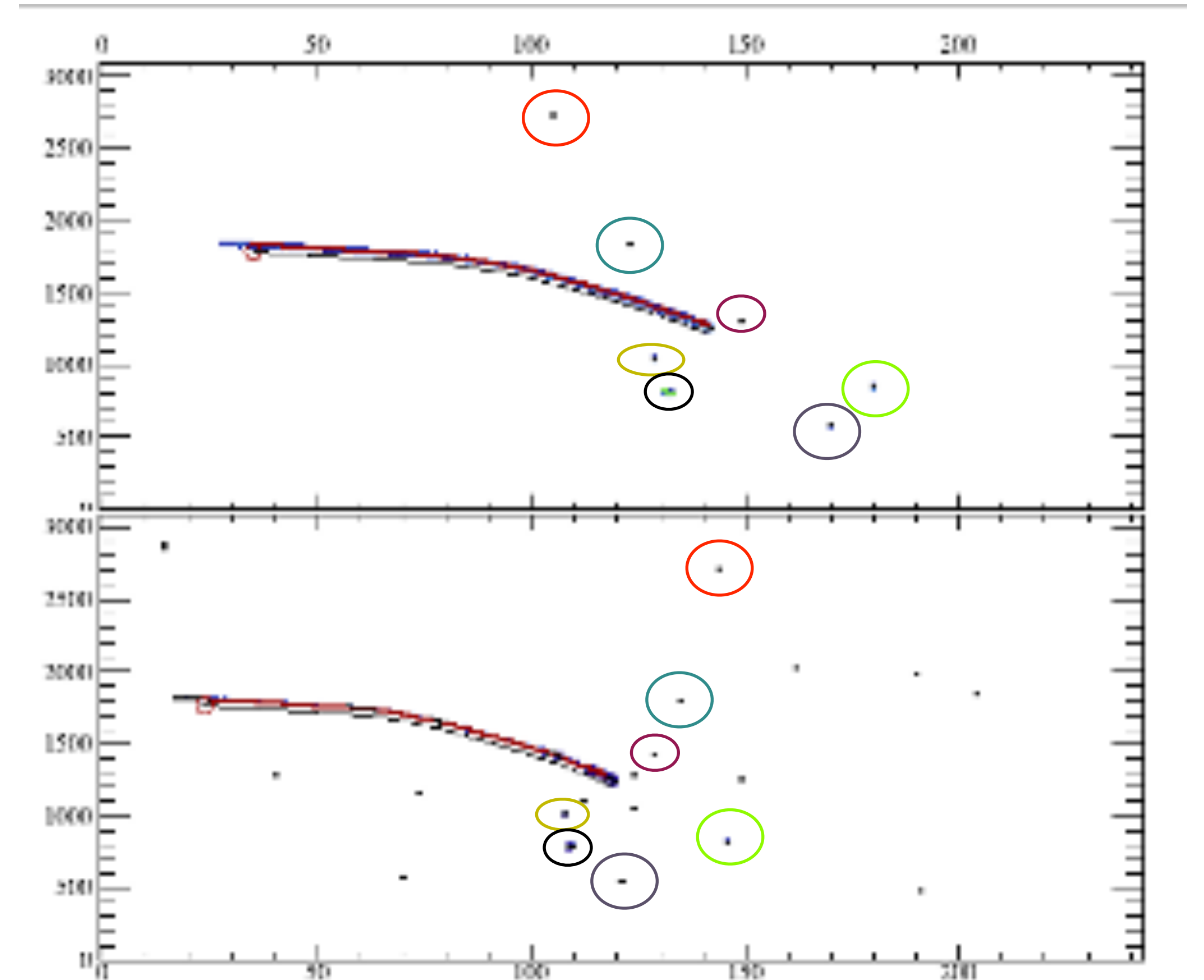
LArIAT SIMULATION,
Blip efficiency with default thresholds (11 ADC) and low thresholds (5 ADC)

Blips in LArIAT (Blip Module) example

We developed a Blip module to find matches (space and time) between planes to get blip information.

Example of an event with 7 blips matched (this blips match with truth information too)

LArIAT SIMULATION,
Activity in an event with 7 matched blips



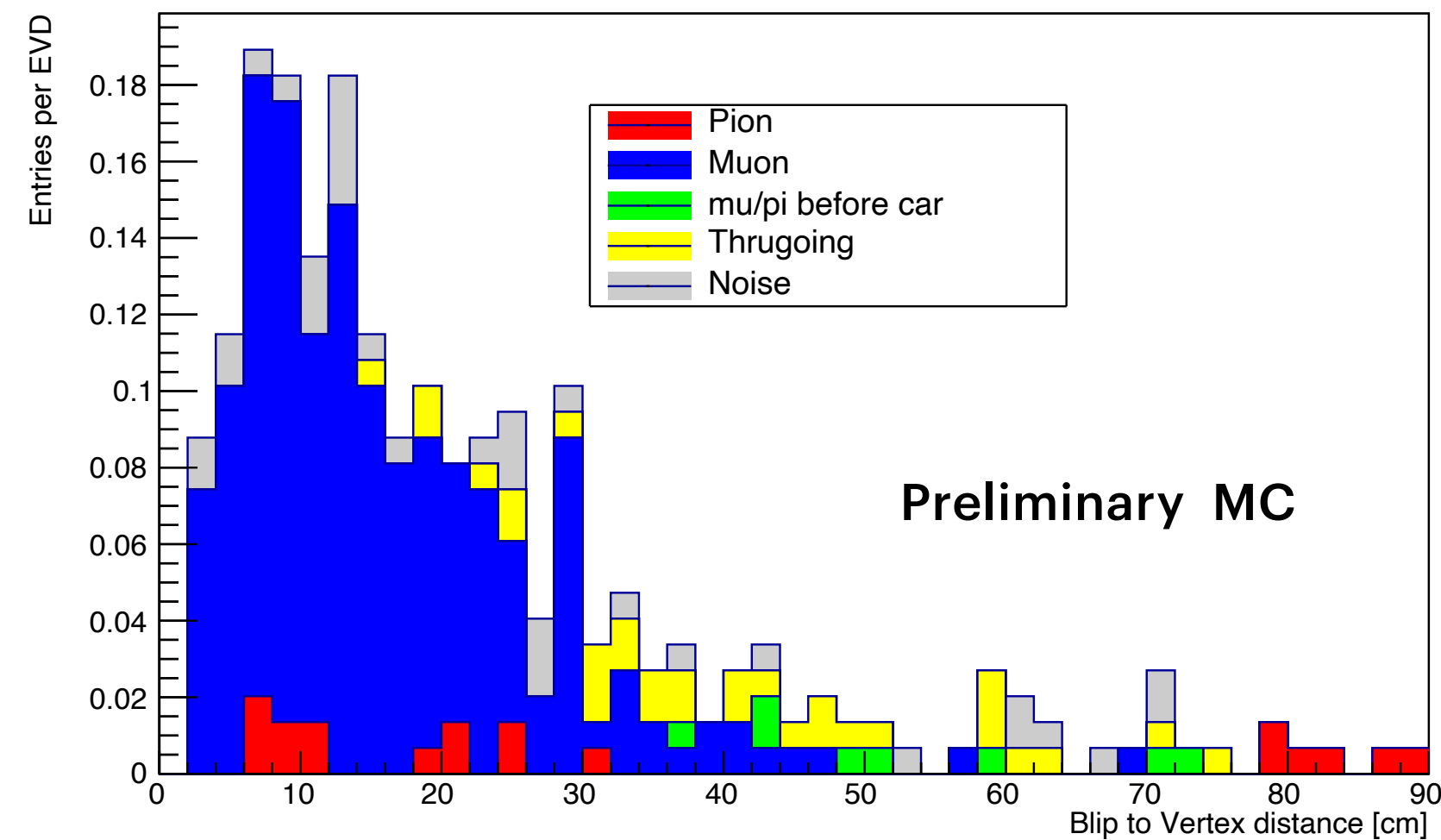
Blips in LArIAT, CAR MC samples

Preliminary	MuCAR region (MC)	PiCAR region (MC)
Events	148	278
# Blips	303	895
Blip multiplicity	2.05 ± 0.13	3.22 ± 0.14
Blip energy per EVD	1.24 ± 0.10	2.03 ± 0.11

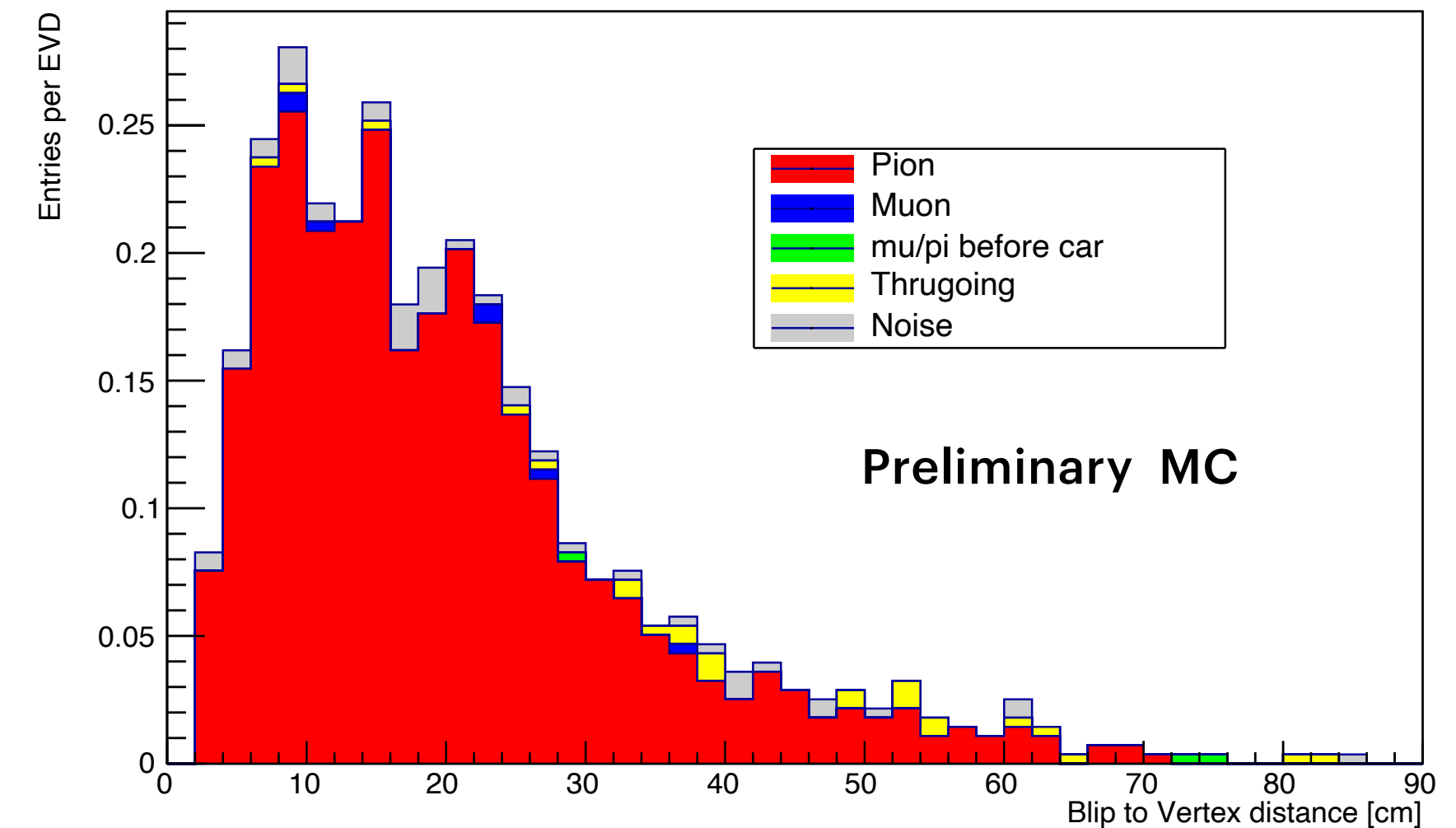
We see 1 more blip per EVD in the PiCAR region than MuCAR region
 For MC, PiCAR and muCAR blip multiplicities differ by 6.1 sigma

Blip activity for MuCAR and PiCAR regions with statistical errors

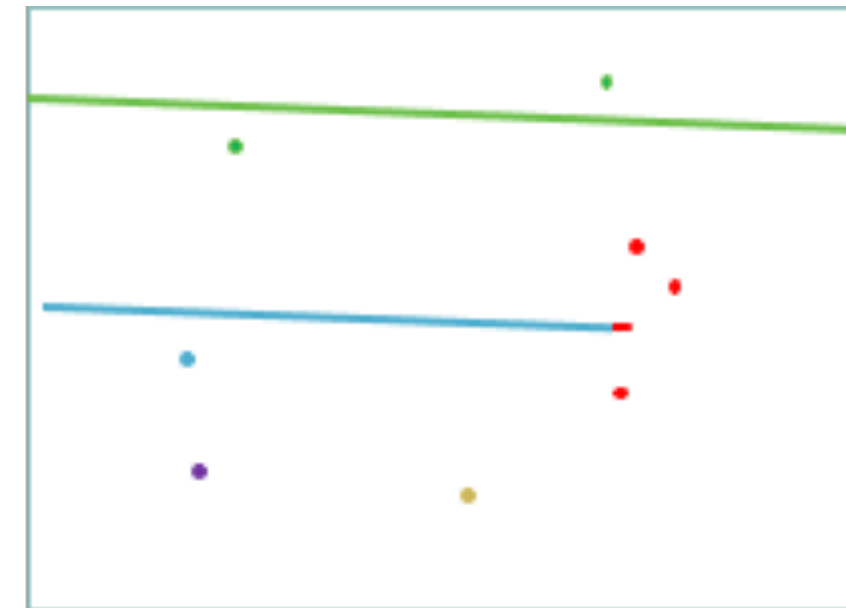
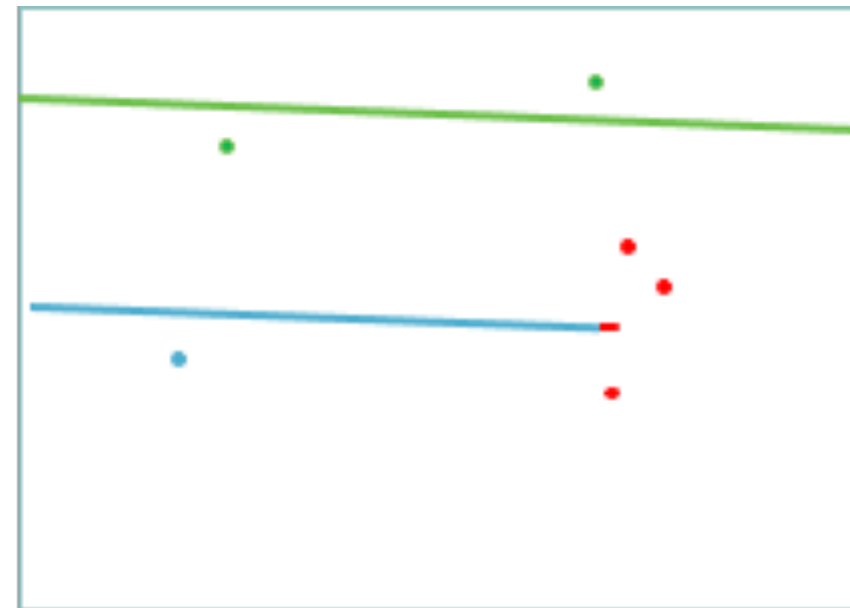
Muon CAR Region



Pion CAR Region



Blips in LArIAT, Data and MC background



MC is missing some sources of backgrounds we see in data

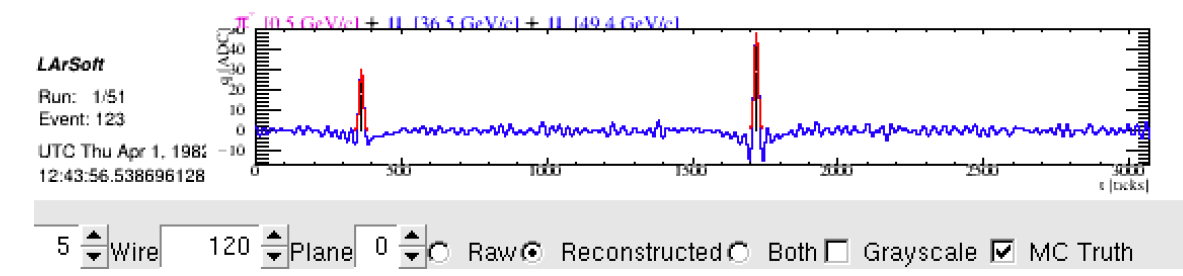
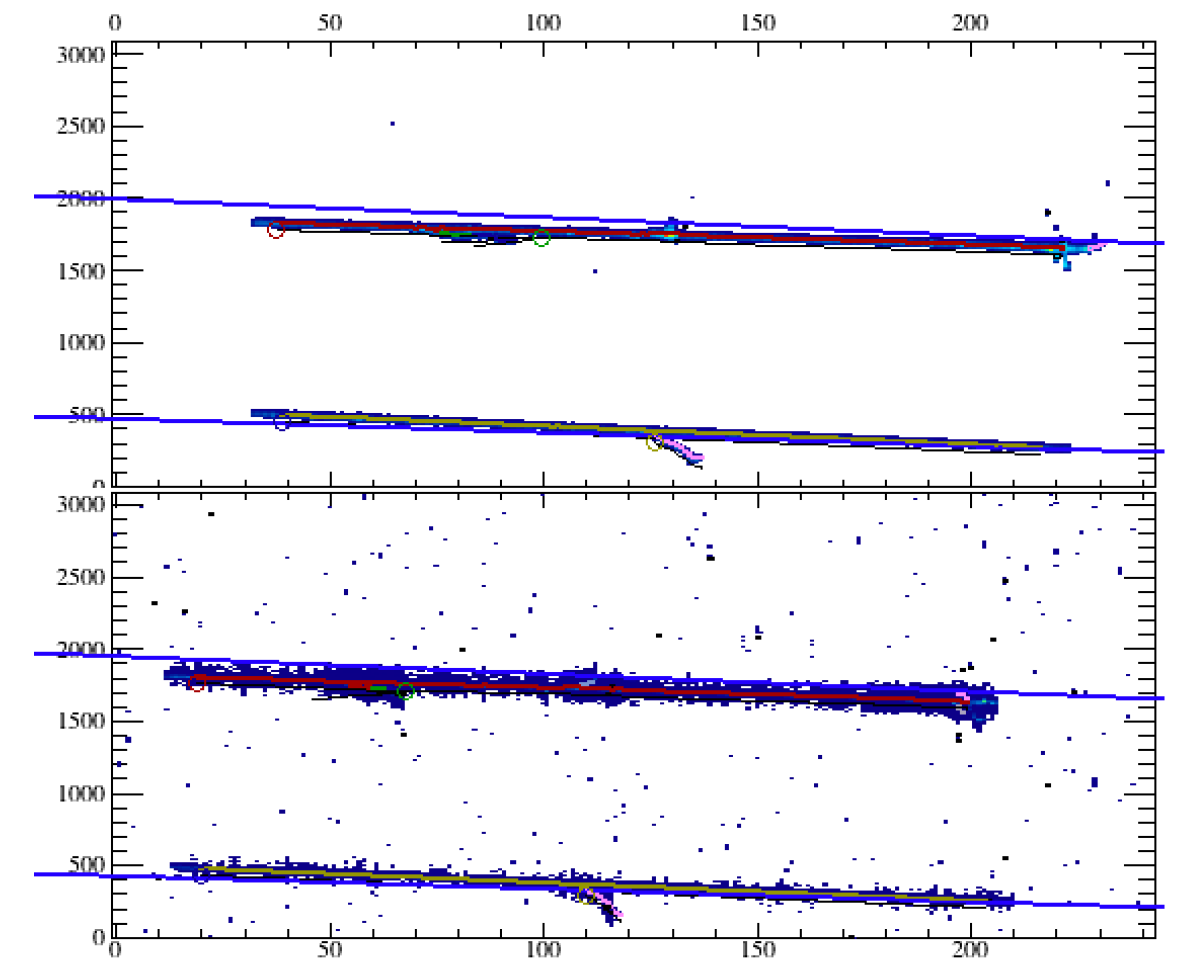
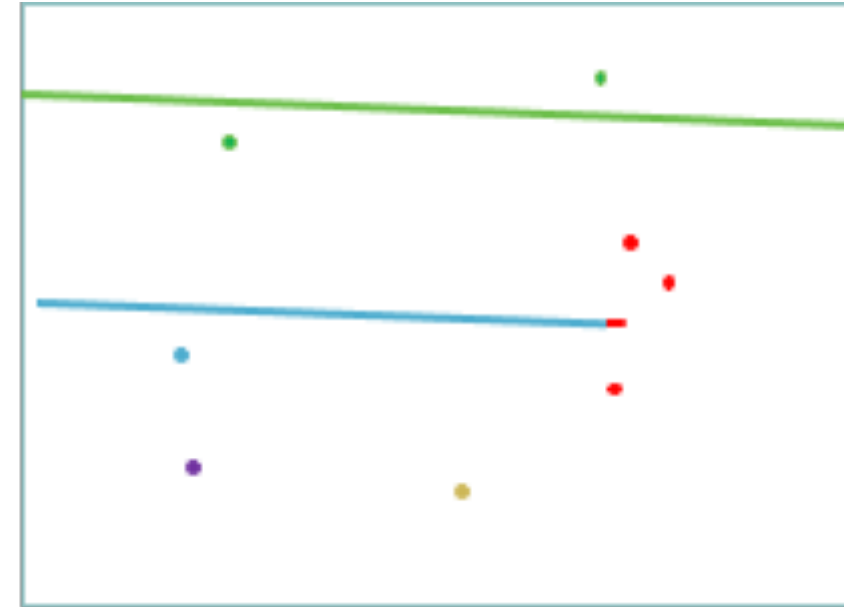
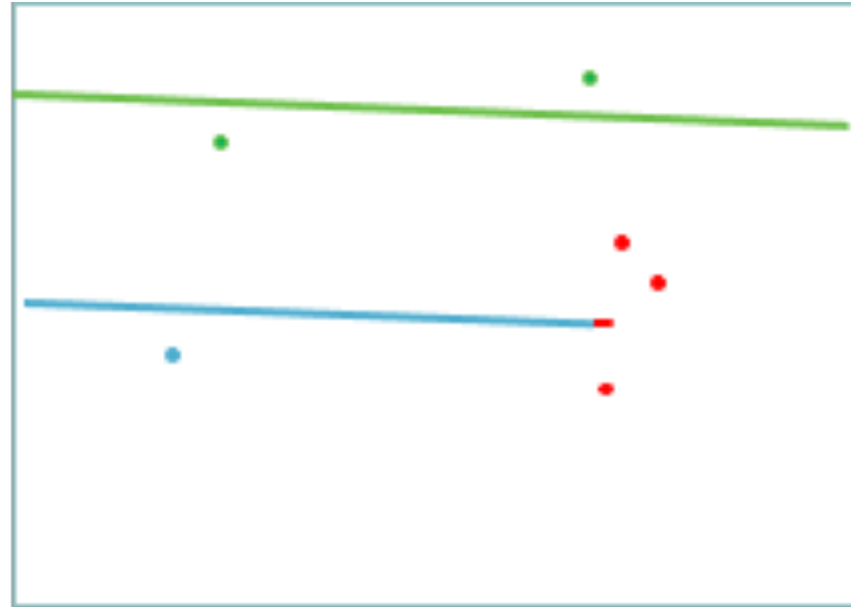
MC Blip

- 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 (pedestal, Ar39)

Blips in LArIAT, Data and MC background



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Thrugoing MC

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Thrugoing Data

Thrugoing muon event display

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

Summary and todo list

- A selection for Muon and Pion CAR particles were made with a high purity using beam line instrumentation.
- We developed a Blip analysis Module for LArIAT framework.
- We still need a bigger MC sample (working on that now).
- Check each event display
- Still need to get systematic errors, background subtraction.
- Get data blip information.

Thanks (Gracias)

BACKUP

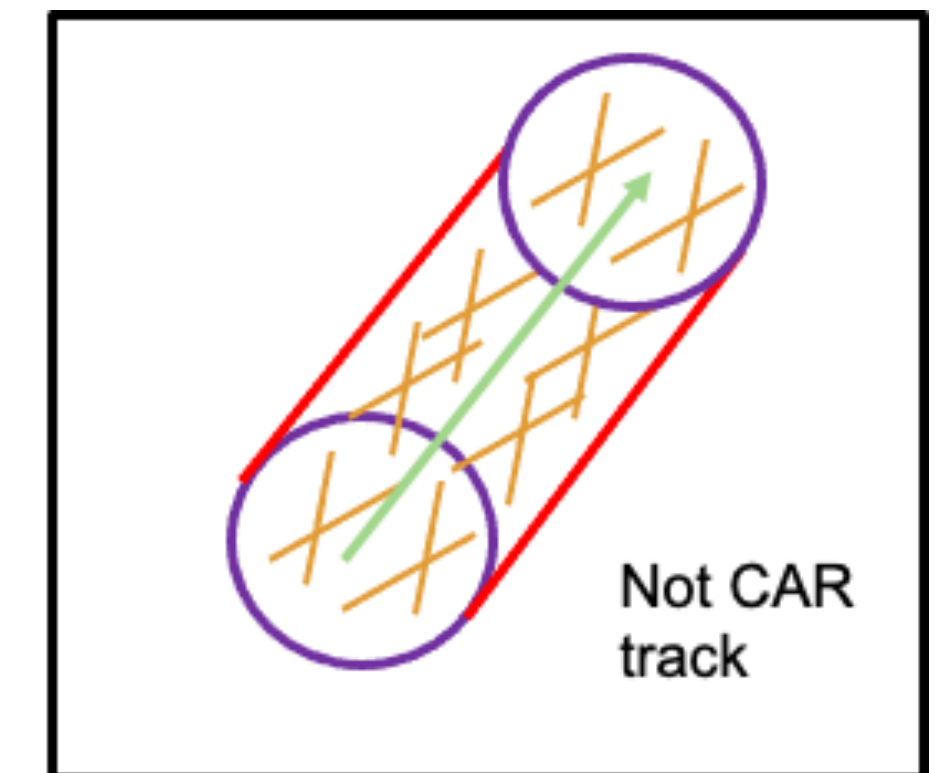
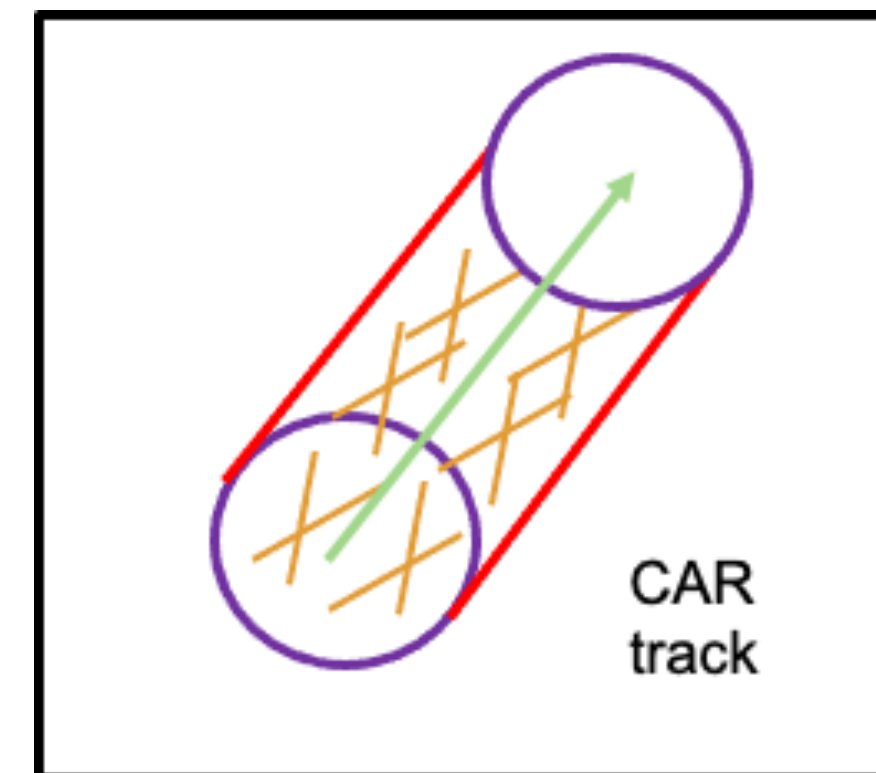
Cuts for track classification

- **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 > 2.5 MeV in the last 2 cm of the track.

Blips in LArIAT, cuts

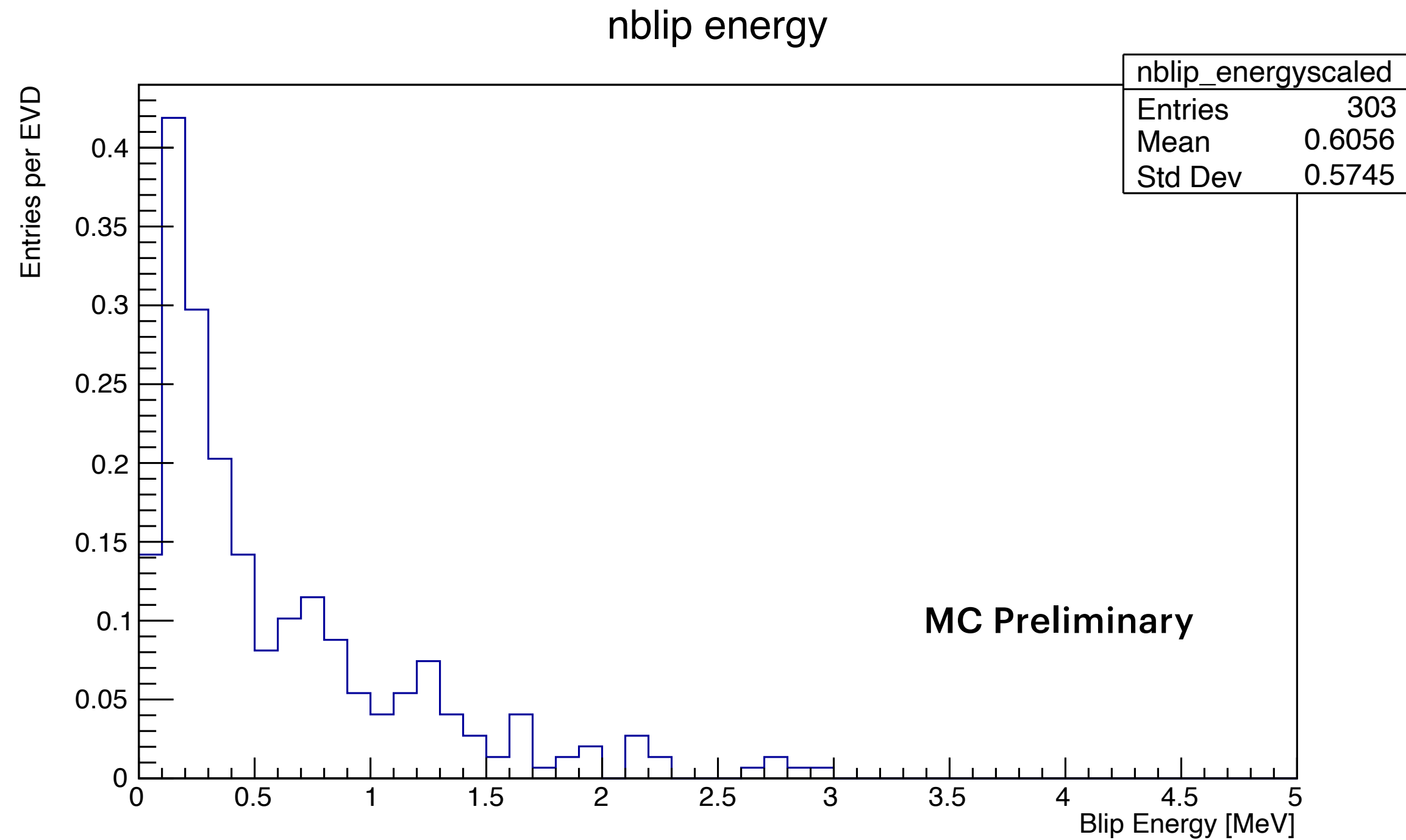
To keep blips produced by CAR process and remove background, we apply some cuts.

- Remove blips with a **distance from blip to track** smaller than 4.5 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)

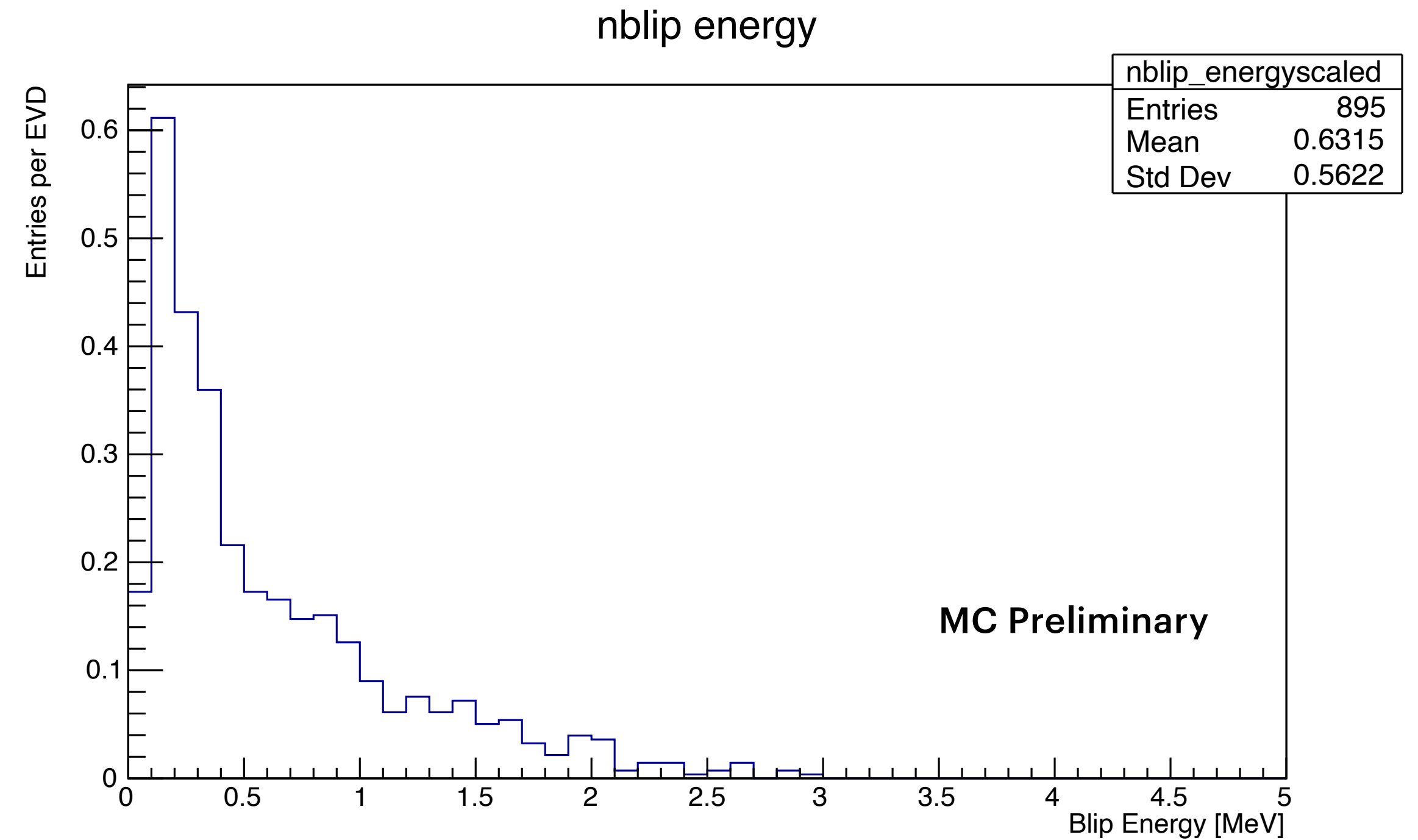


Cut diagram for car track and pileup tracks

Blip Energy for mucar and picar MC

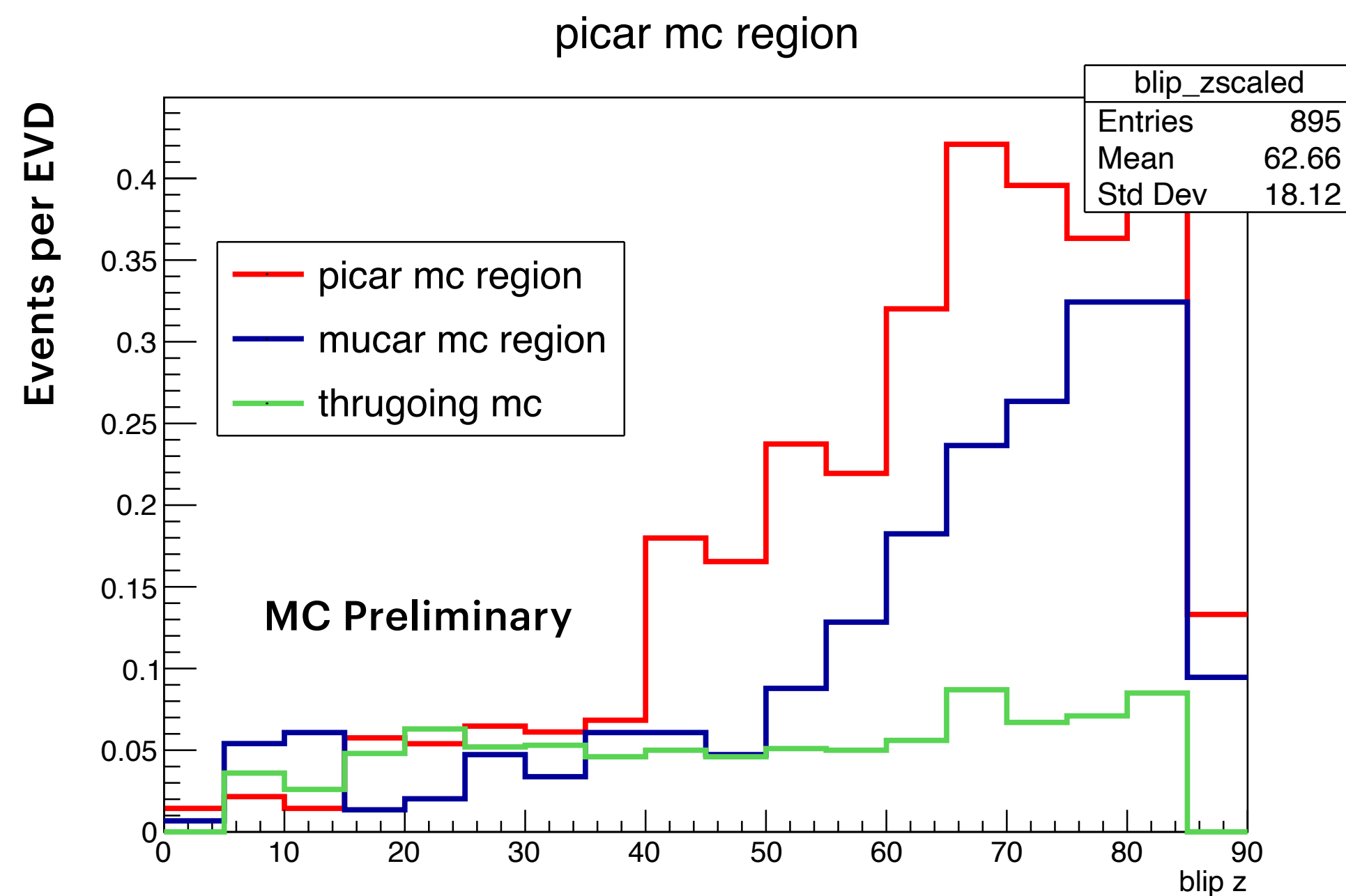


MC blip energy for mucar sample

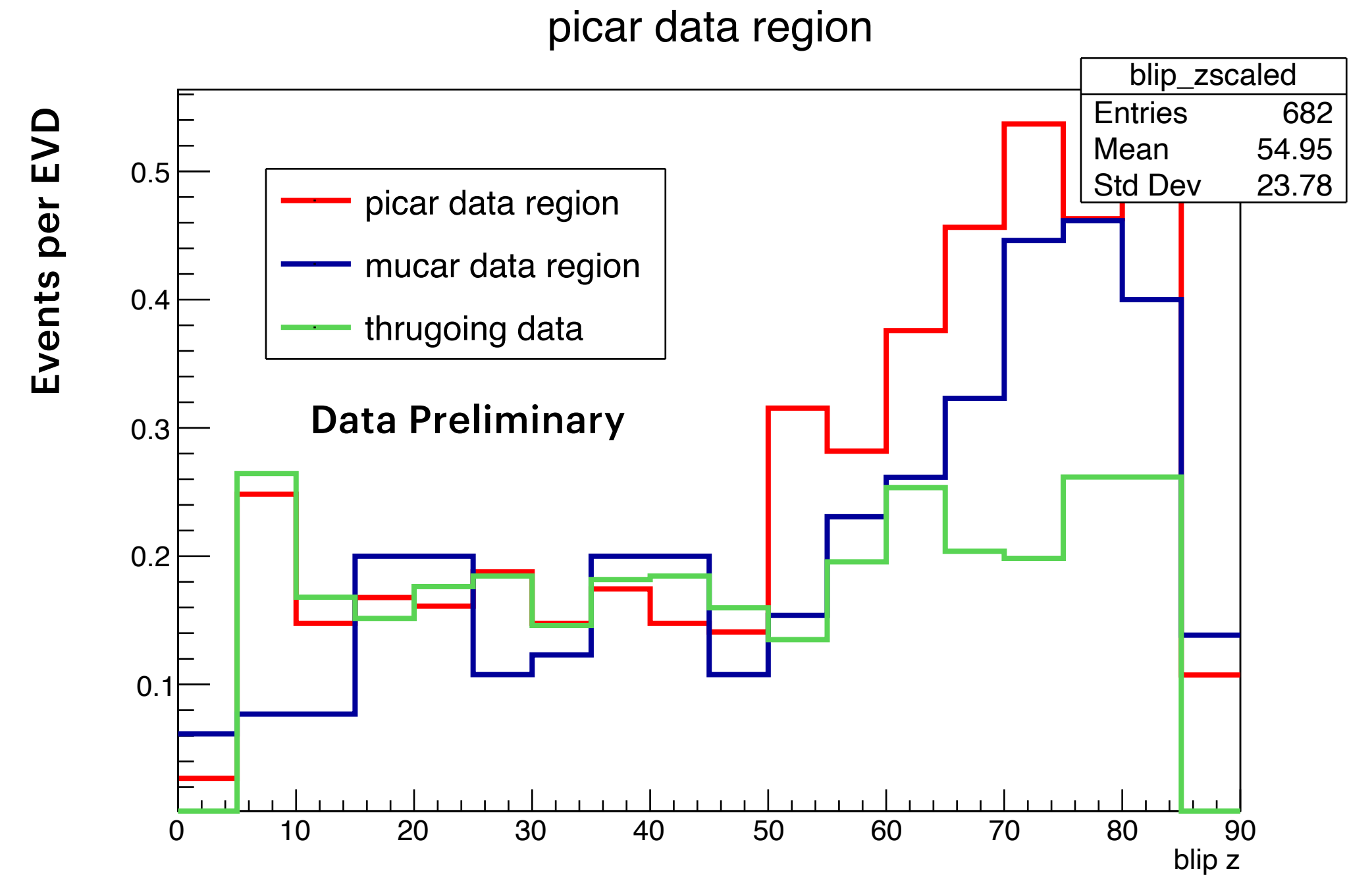


MC blip energy for picar sample

Thrugoing plots for choosing energy range

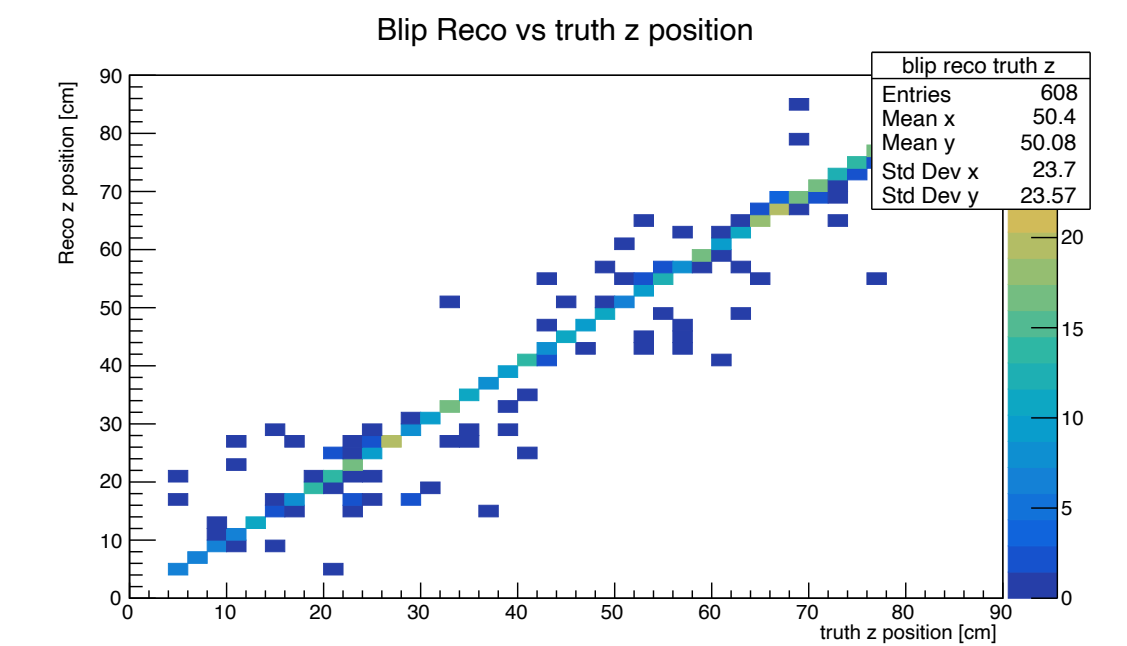
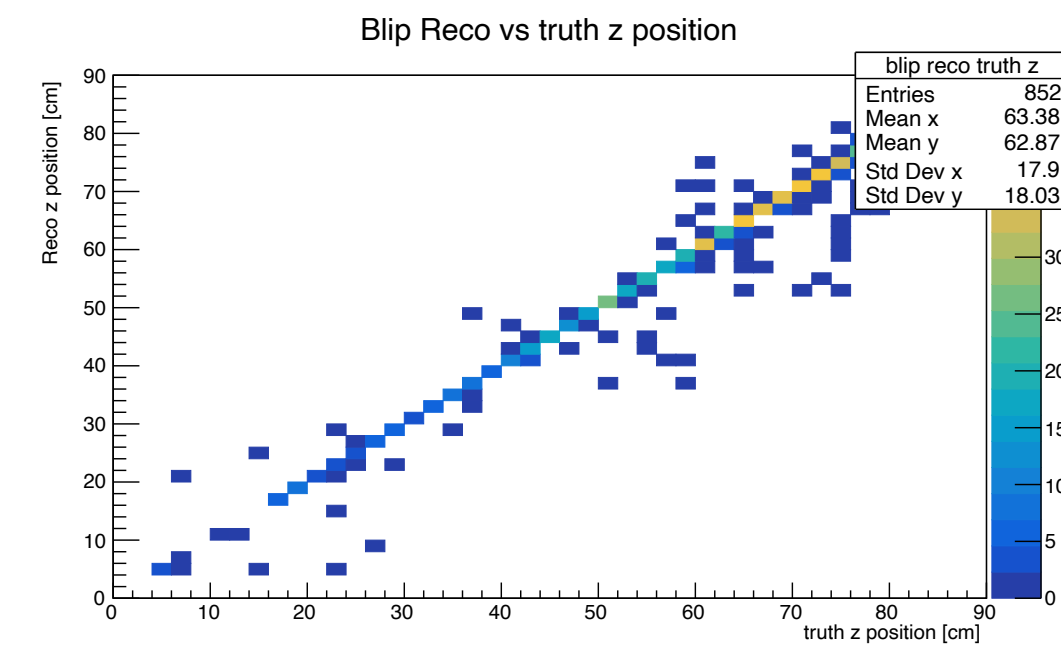
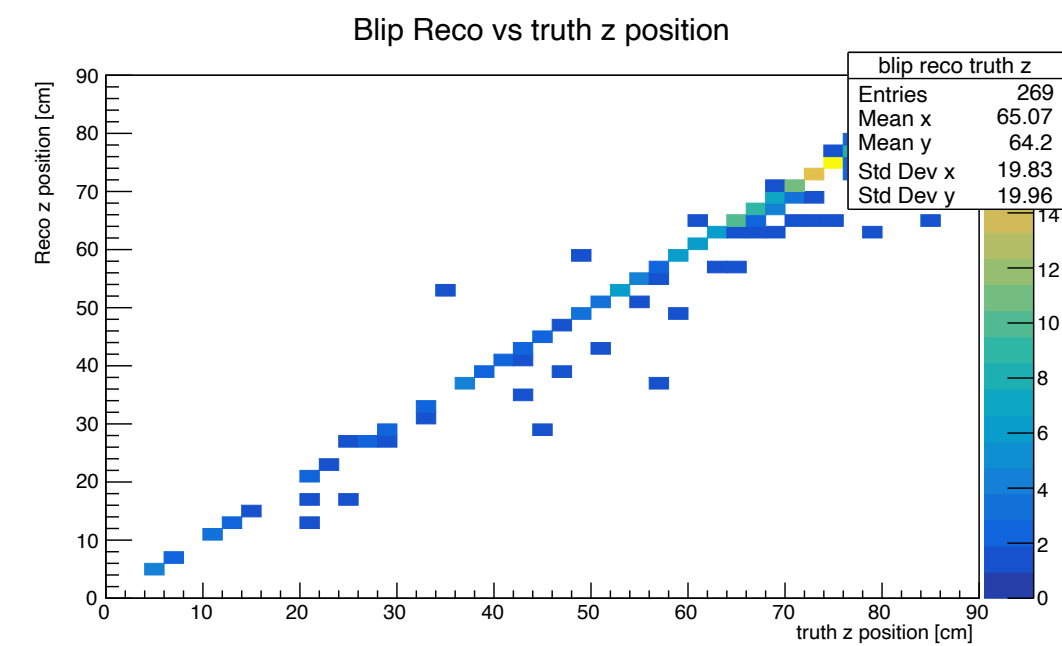
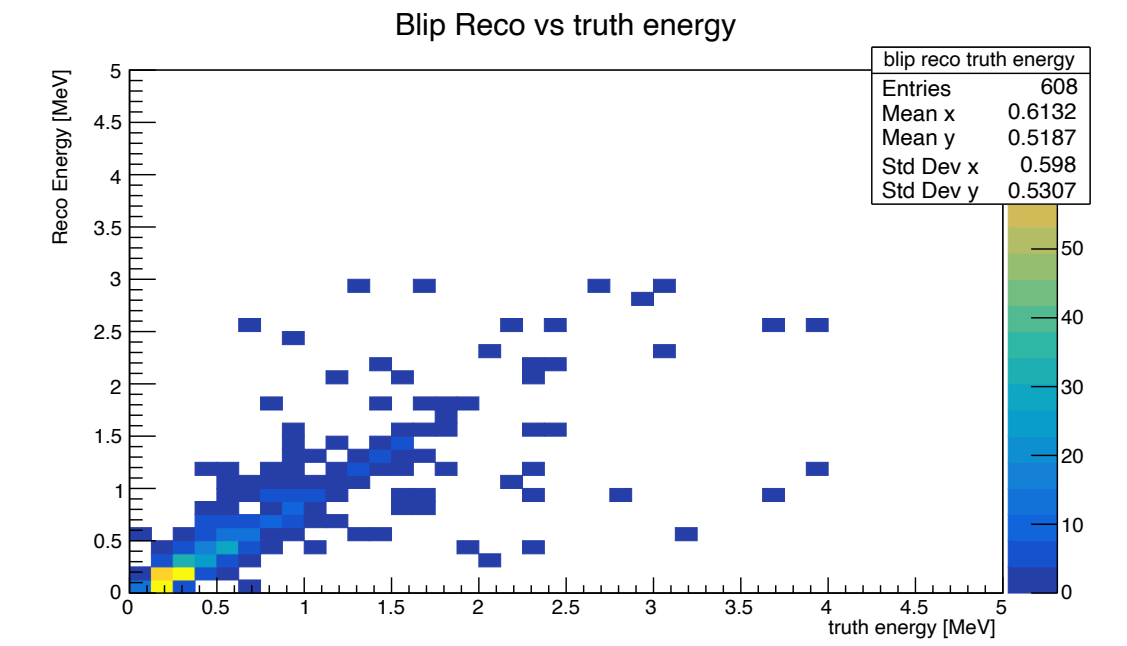
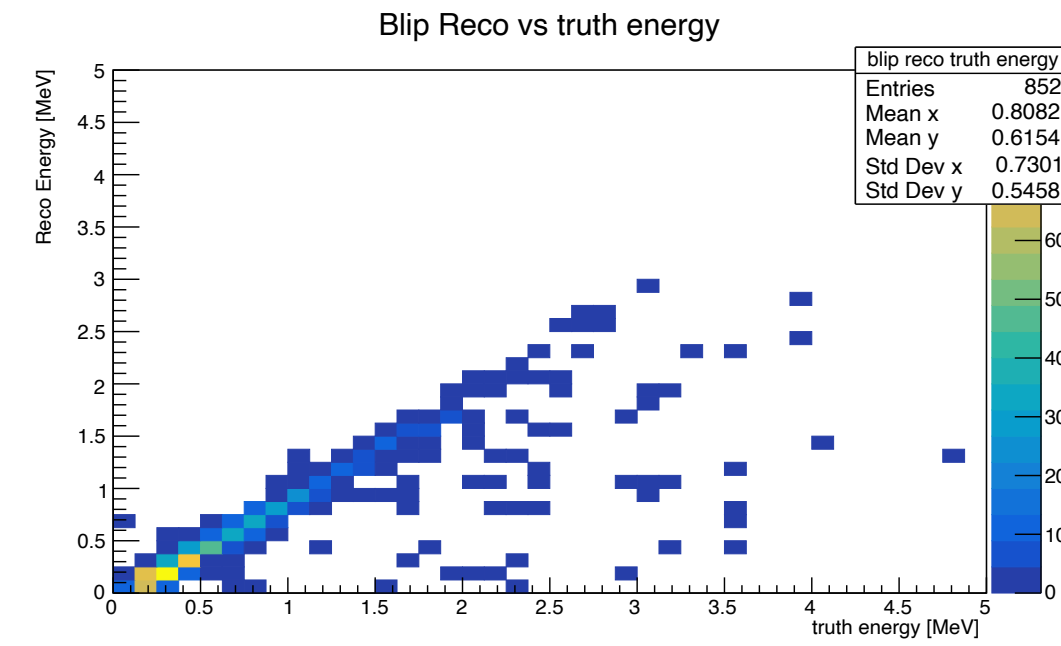
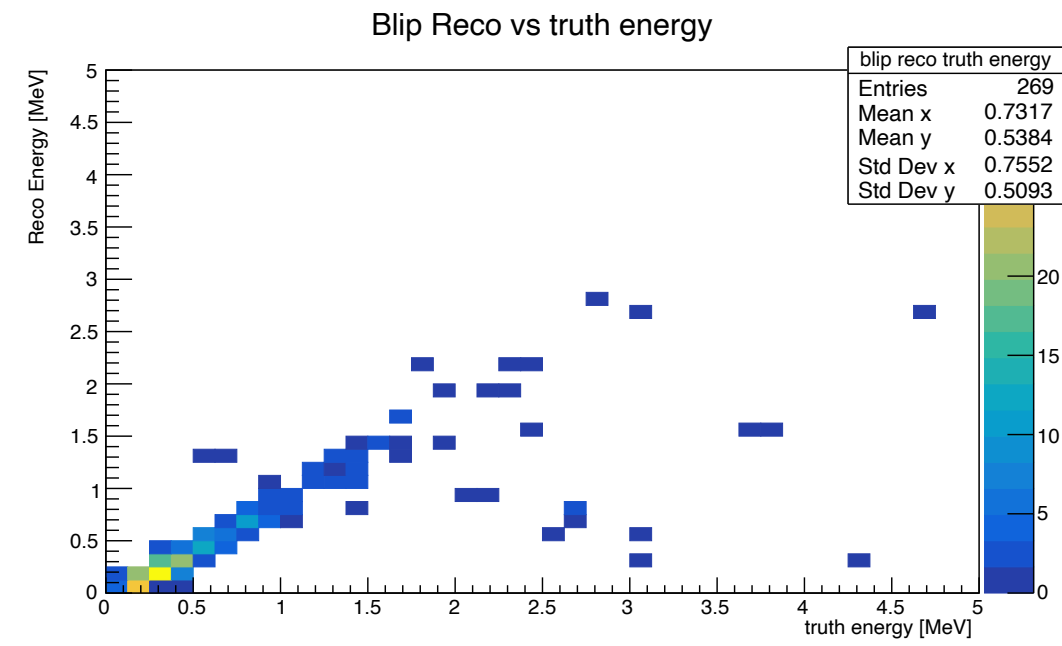


MC blip Z for MC sample



MC blip Z for real data

Truth vs reco energy and positions reconstruction for blips

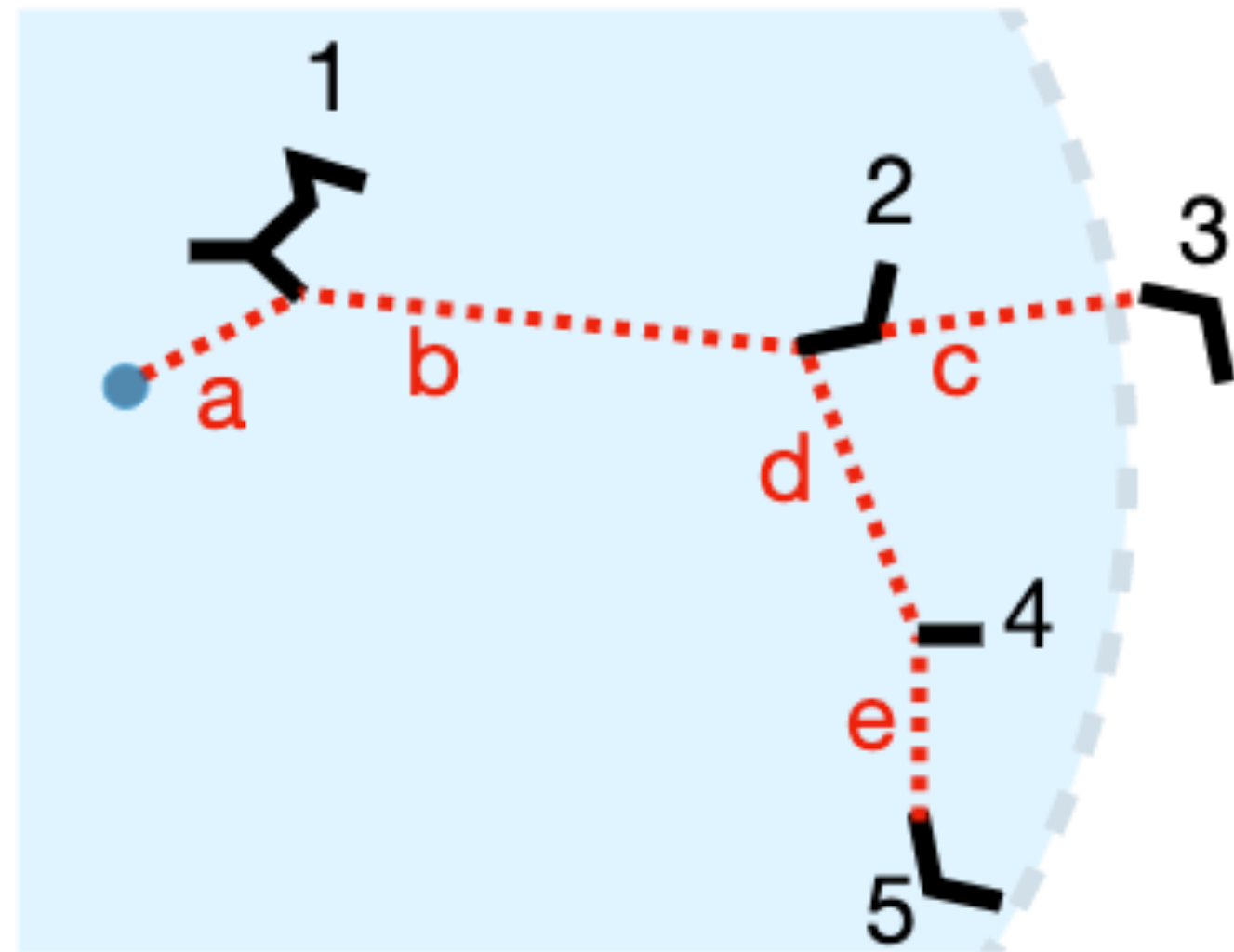


MC Mucar sample

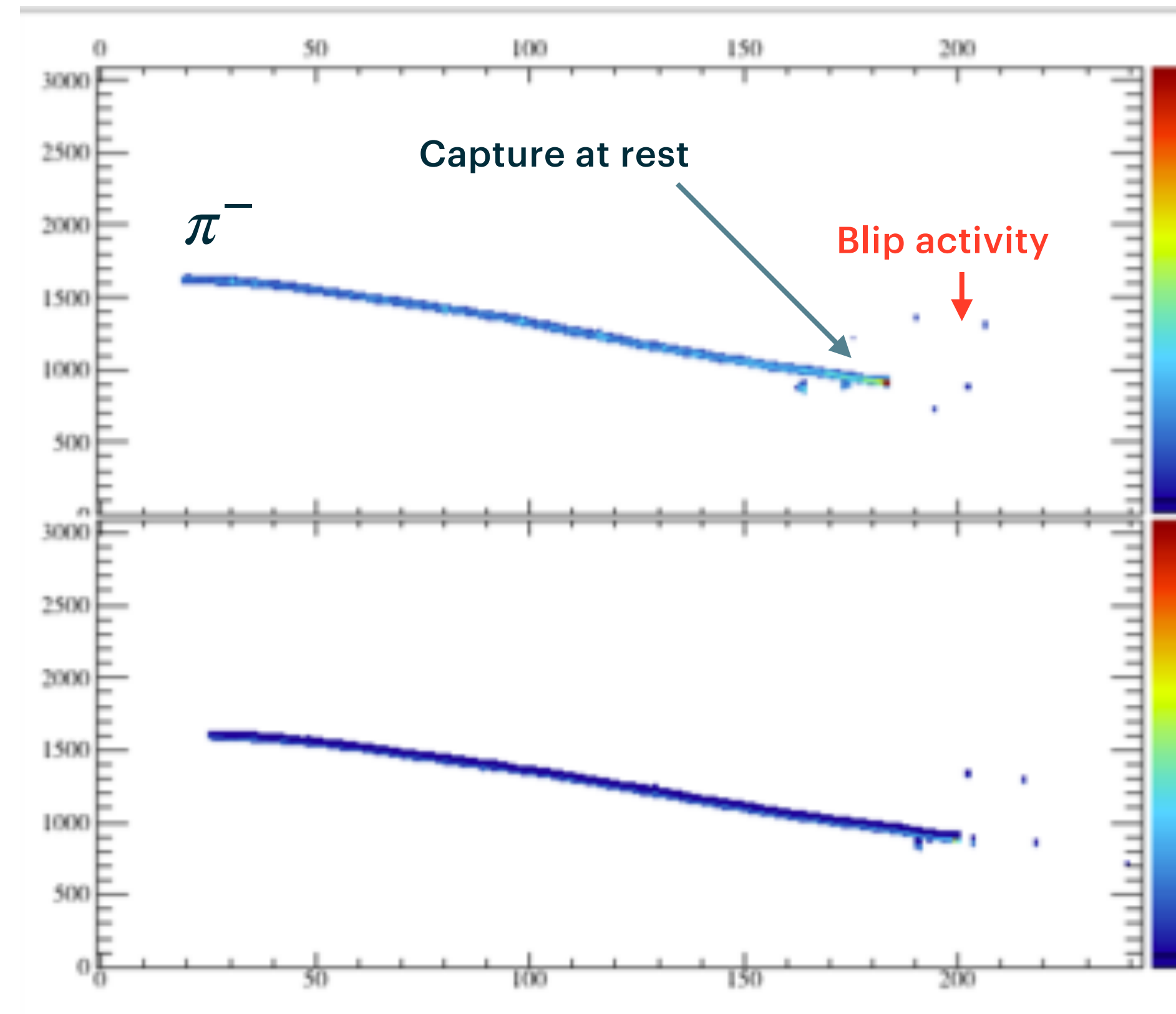
MC Picar sample

MC thruggoing sample

What is a Blip?



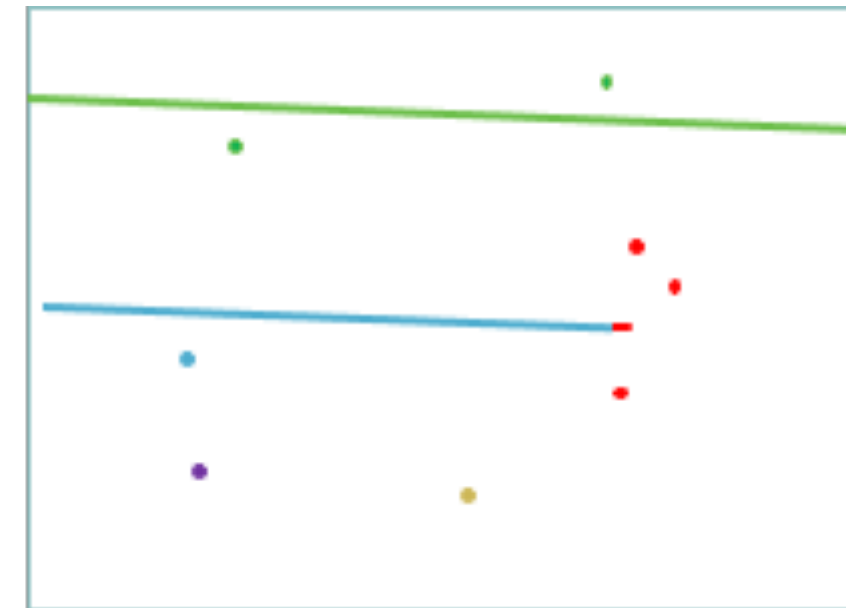
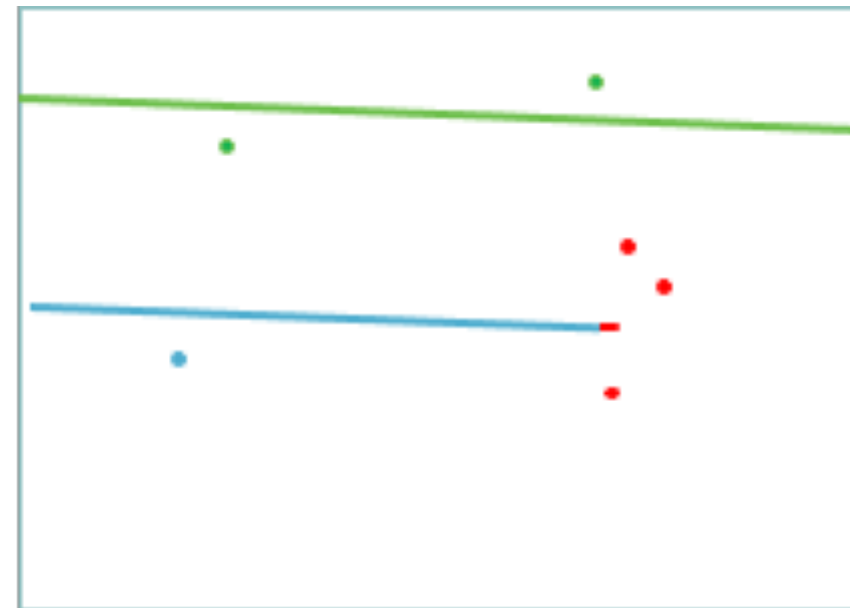
Item	Type	Creator Process	E_{start} (MeV)	E_{end} (MeV)	E_{blip} (MeV)
a	γ	Primary	3.00	3.00	-
1	$2 e^-$	Compton scatter	1.50	0	1.50
b	γ	Compton scatter	1.50	1.50	-
2	e^-	Compton scatter	1.00	0	0.75
c	γ	Bremsstrahlung	0.25	0.25	-
3	e^-	Photoelectric effect	0.25	0	0.25
d	γ	Compton scatter	0.50	0.50	-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



LArIAT SIMULATION

Image and table from [Benefits of MeV Reconstruction](#)

Blips in LArIAT, Data and MC background



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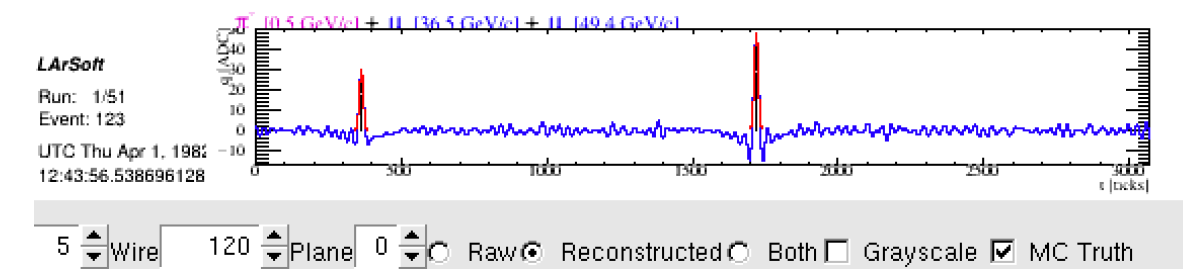
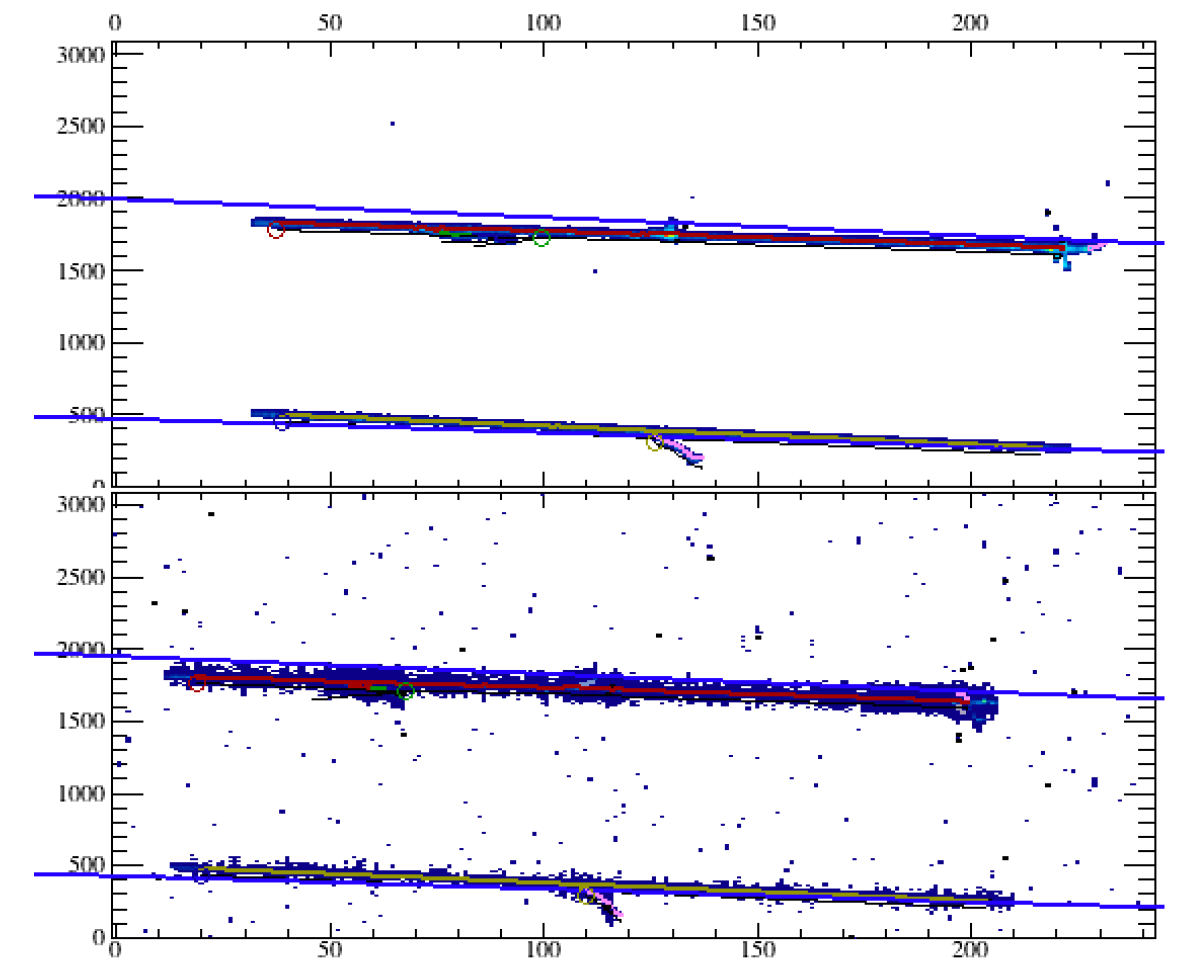
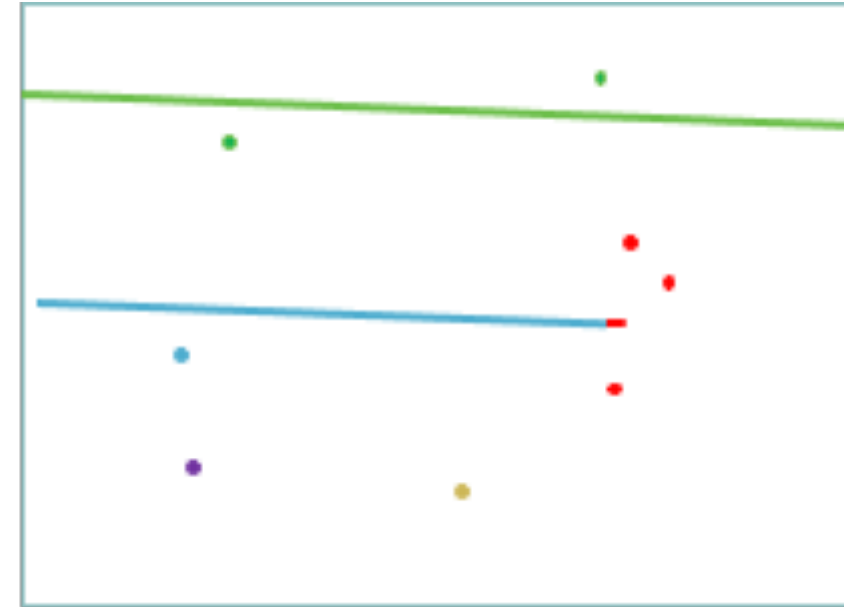
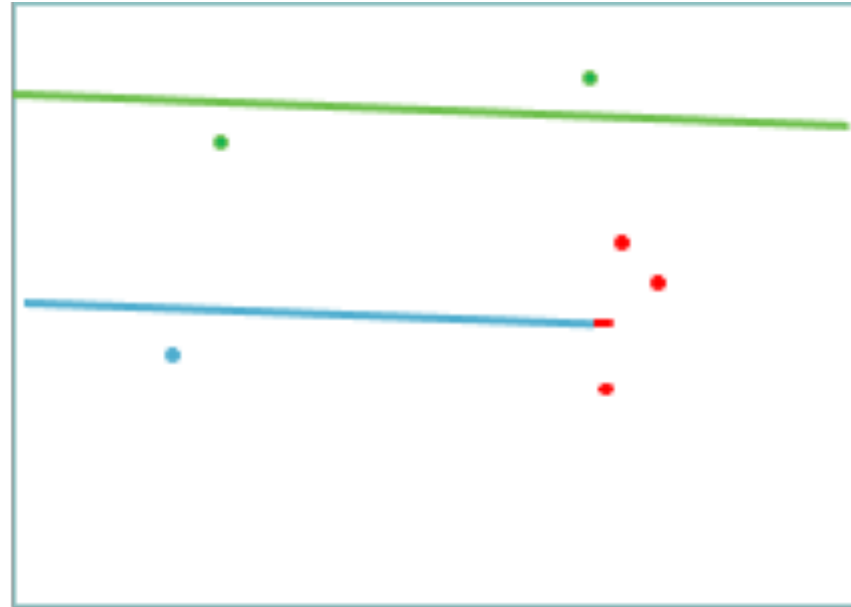
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Blips in LArIAT, Data and MC background



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Thrugoing MC

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Thrugoing Data

Thrugoing muon event display

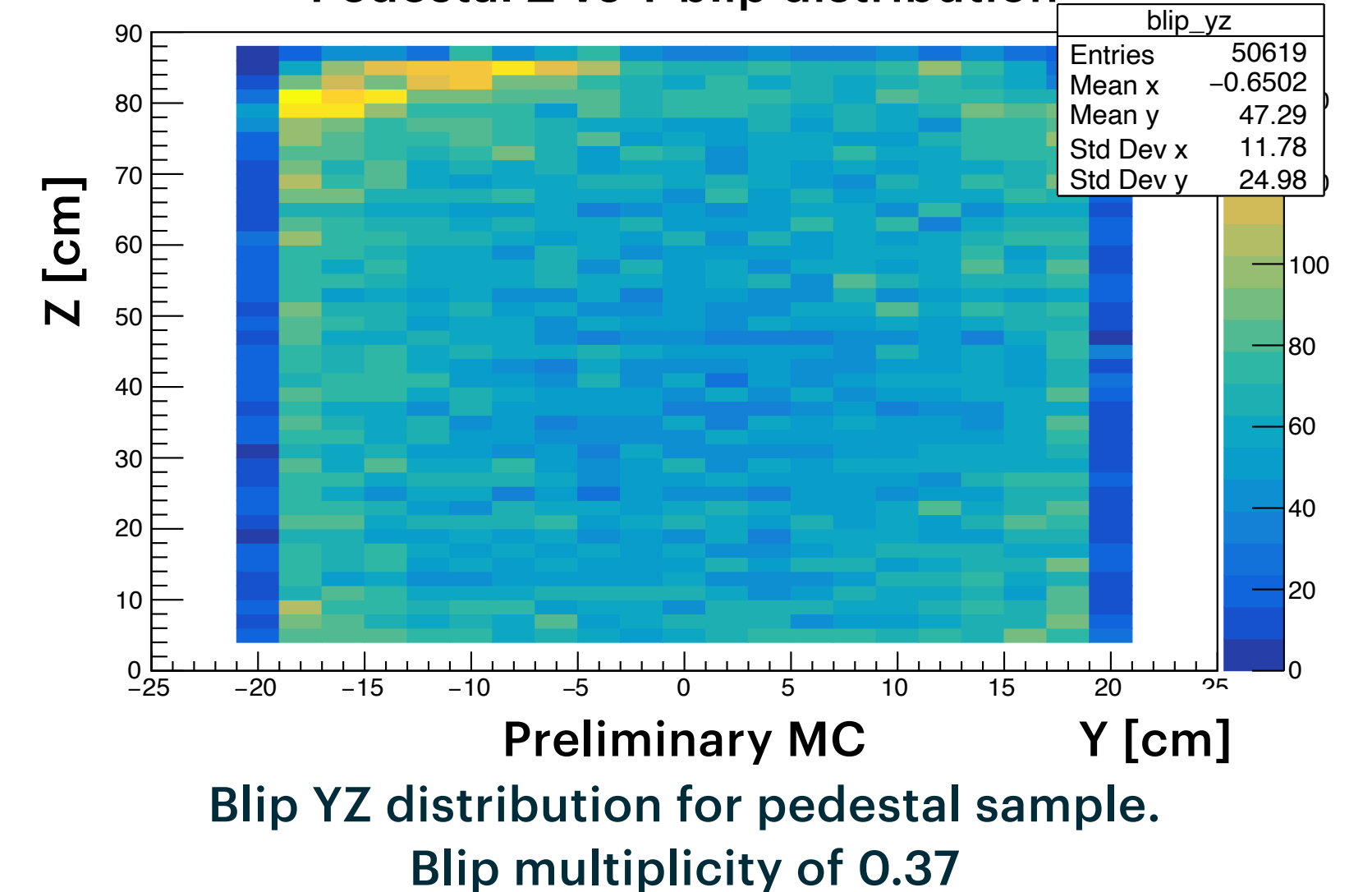
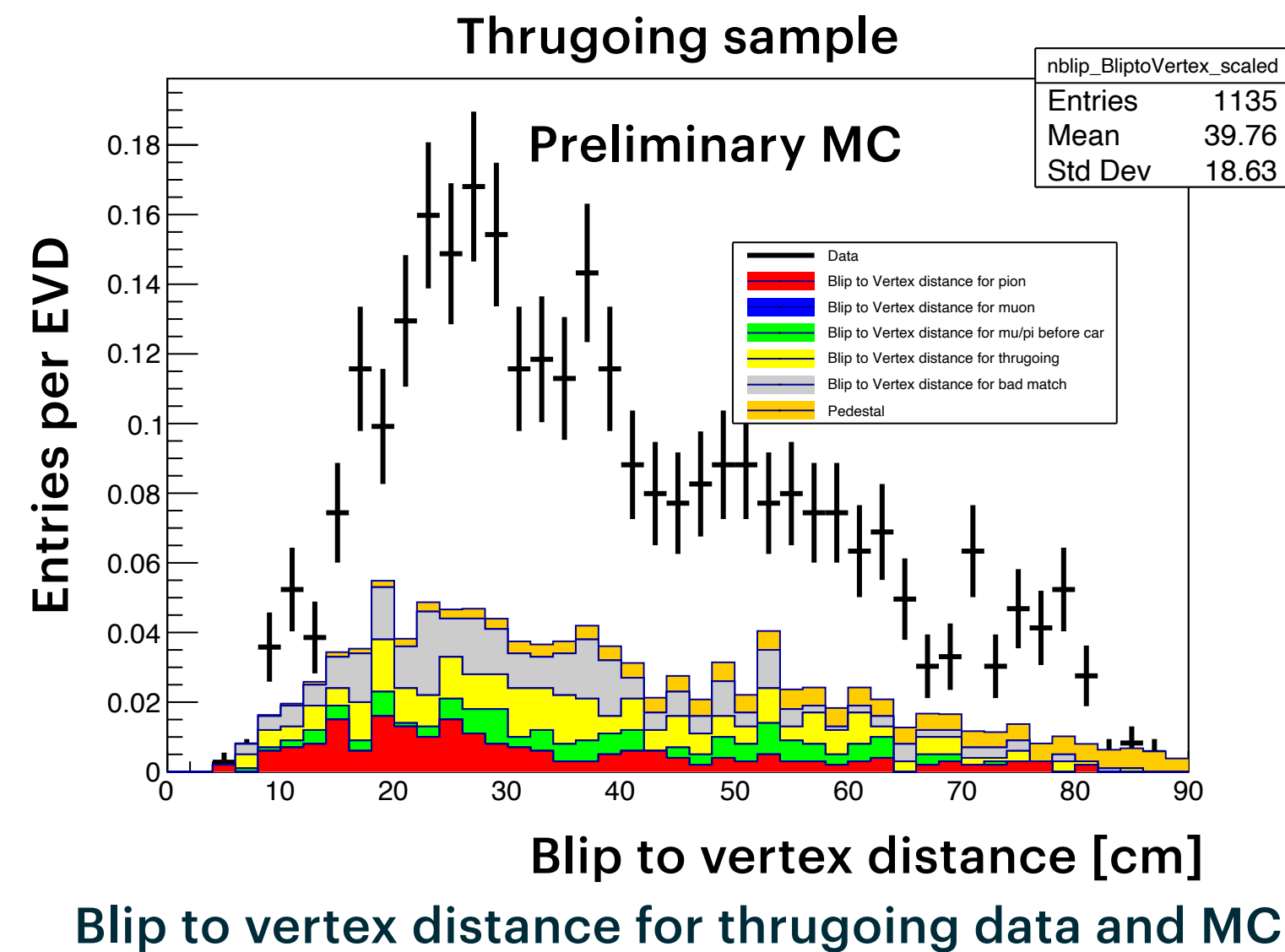
Our goal is to get a background subtraction, in this case the thrugoing sample includes all the background, so the idea is to use thrugoing MC for MC background and thrugoing data for data background

Blips in LArIAT, thru-going samples

	Thru-going MC	Thru-going 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

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

Blip activity for thru-going regions with statistical errors
Pedestal Z vs Y blip distribution



Blips in LArIAT, CAR MC samples after background subtraction

Preliminary	MuCAR region (MC)	PiCAR region (MC)
Blip multiplicity after background subtraction	1.16 ± 0.14	2.33 ± 0.15

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

Blip activity for MuCAR and PiCAR regions with statistical errors after background subtraction

MuCAR and PiCAR data analysis in progress