Status of the ZDC EM-Calorimeter Prototype with Cosmic Ray

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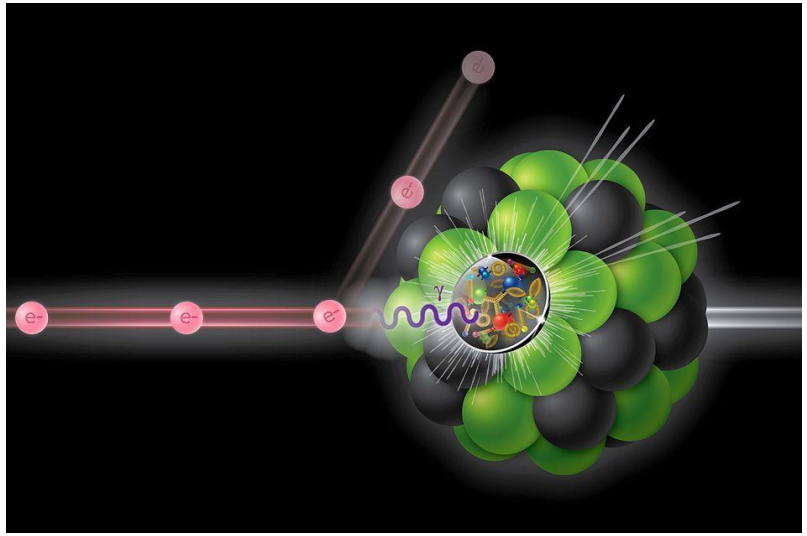
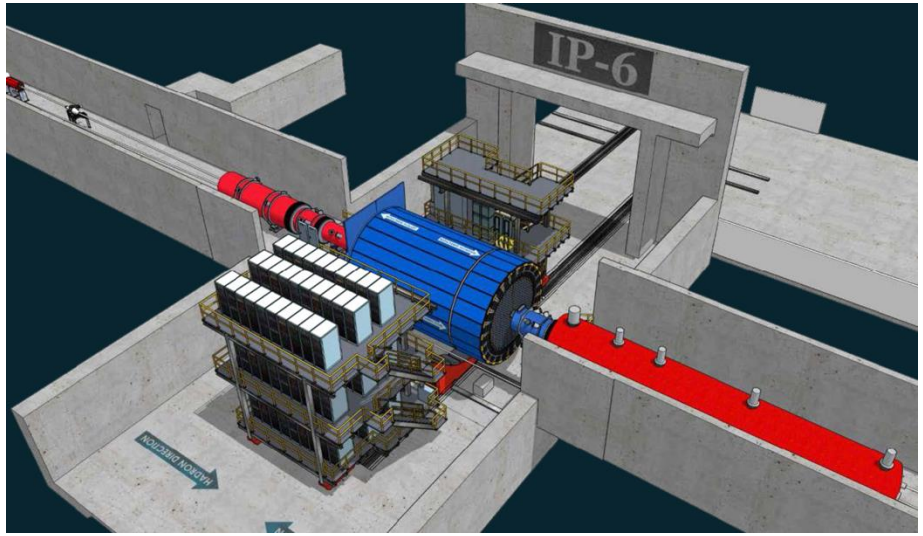
Motivation

- The **Electron-Ion Collider (EIC)** includes the **Electron-Proton/Ion Collider (ePIC)** experiment which is the first detector to study properties of nuclear matter and the role of gluons in the strong force.
- The **Zero-Degree Calorimeter (ZDC)** at the ePIC helps measure the production of particles from electron-ion collisions.



Electron-Ion Collision



ePIC Detector

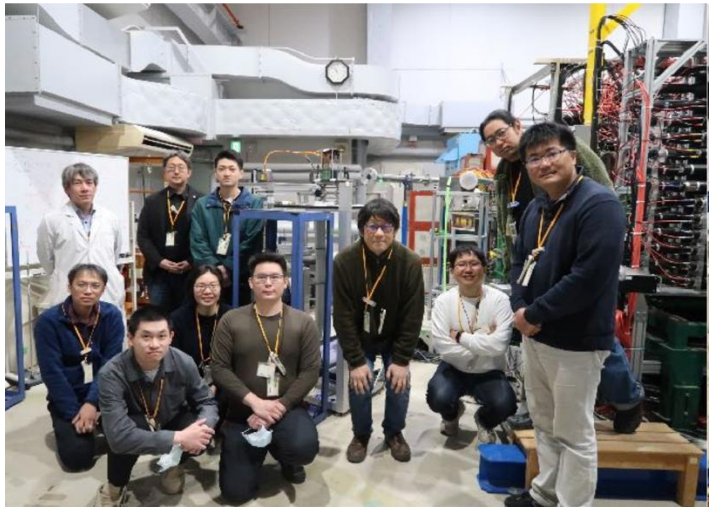
Introduction & Goal

Introduction

- The detector is an **EM-Calorimeter** which can catch charge particles and get their energy.
- There is a beam test with positrons (e^+) at the ELPH, Tohoku University, February 2024. (Beam energy: $47.18 \sim 823.26 MeV$)
- The beam test showed a severe nonlinear gain in the SiPM.

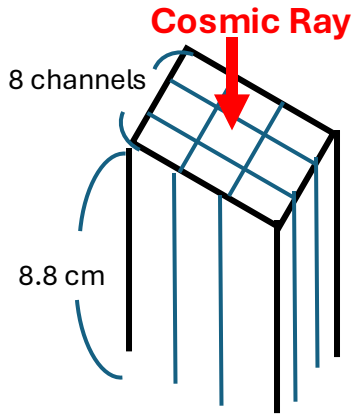
Goal

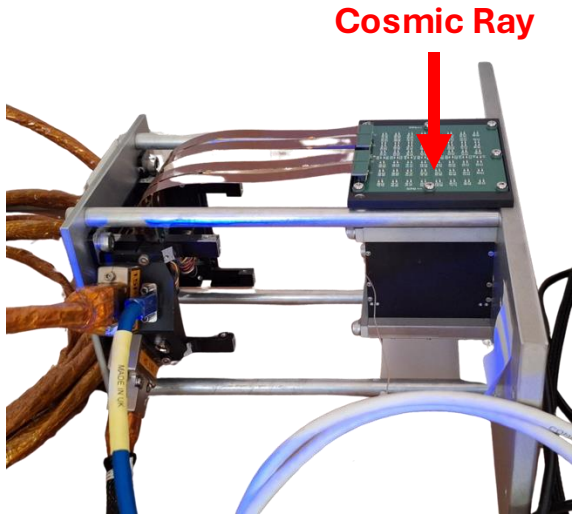
- Use cosmic rays as the source to measure the cosmic MIP.
  (Cosmic muon energy $\approx 4 GeV$)
- Check whether the ADC saturation and SiPM nonlinear behavior.



Setup

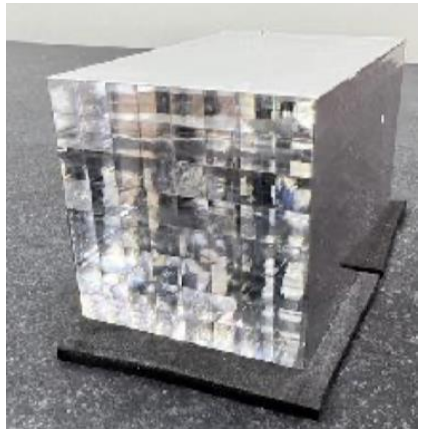
- The ZDC EM-Calorimeter prototype is composed of 8x8 LYSO crystal and SiPM.
- Setting:
  - Location: On the 10 floor
  - Power Supply: 5.07V
  - HV Value: Both 4E (ROCA ROCB)
  - VF Value (Trigger Value): D2 (200)
- Events per week: ≈ 2,000,000





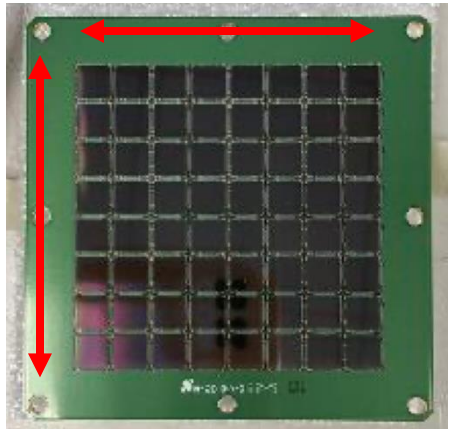
ZDC EM-Calorimeter

Each: $7.12 \times 7.12 \times 88.3 mm^3$



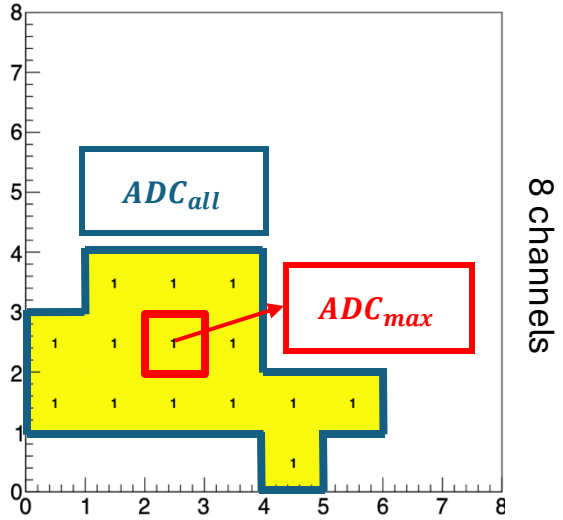
LYSO crystal

$56.96\ mm$



SiPM

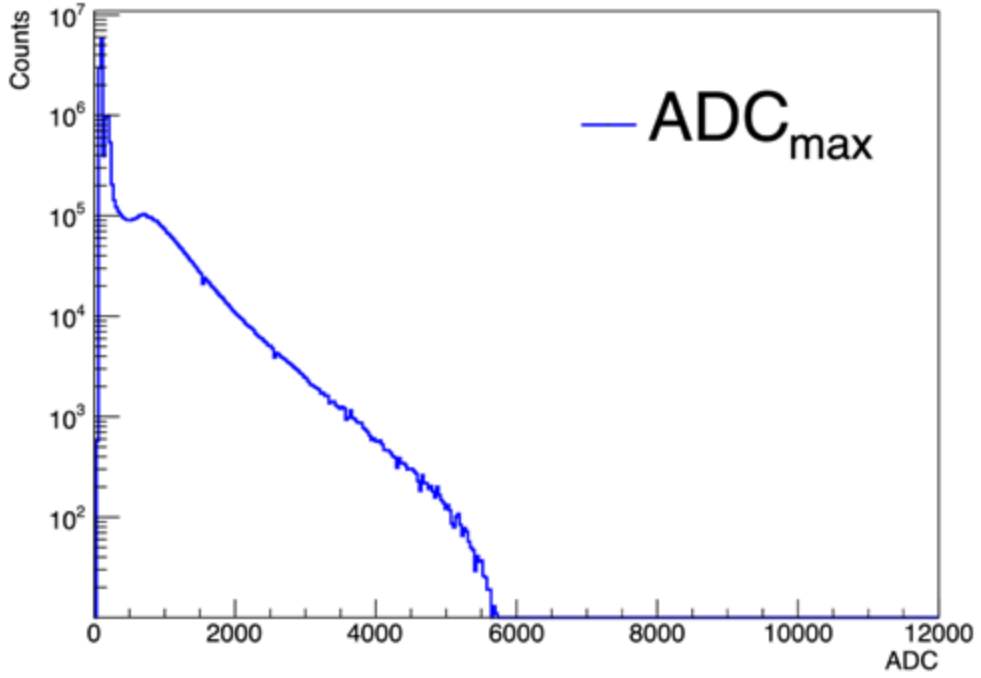
8 channels



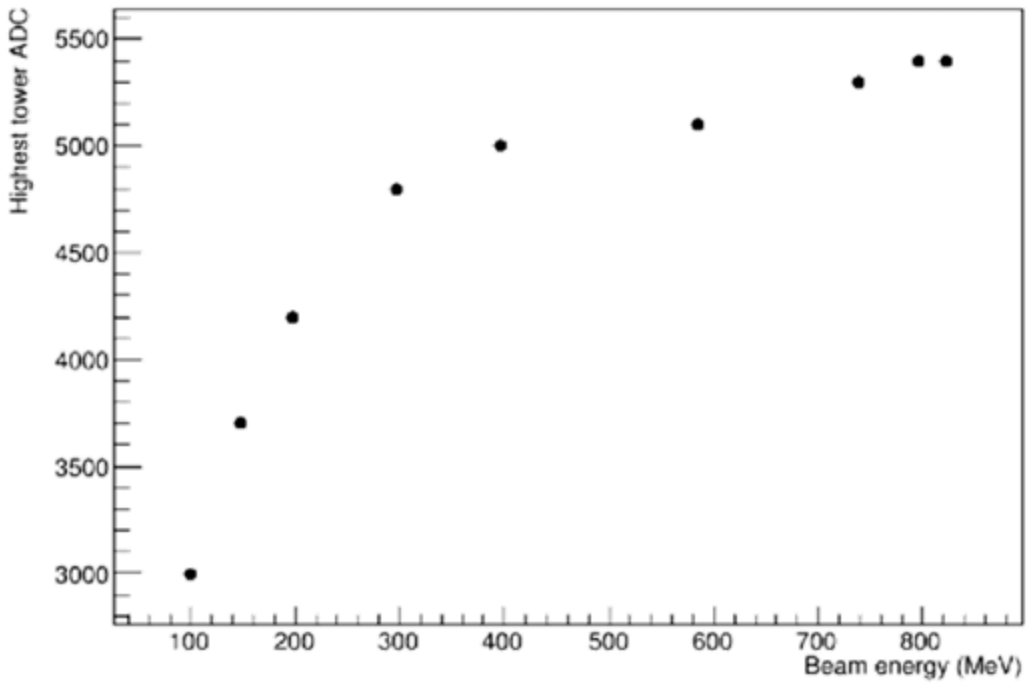
Result – ADC_{max} spectrum

- ADC don't have saturation. → The maximum ADC value is 11000.
- There have a slope change at **5000ADC~6000ADC** in $\mathbf{ADC_{max}}$.
  → The SiPM will have serious nonlinear behavior.

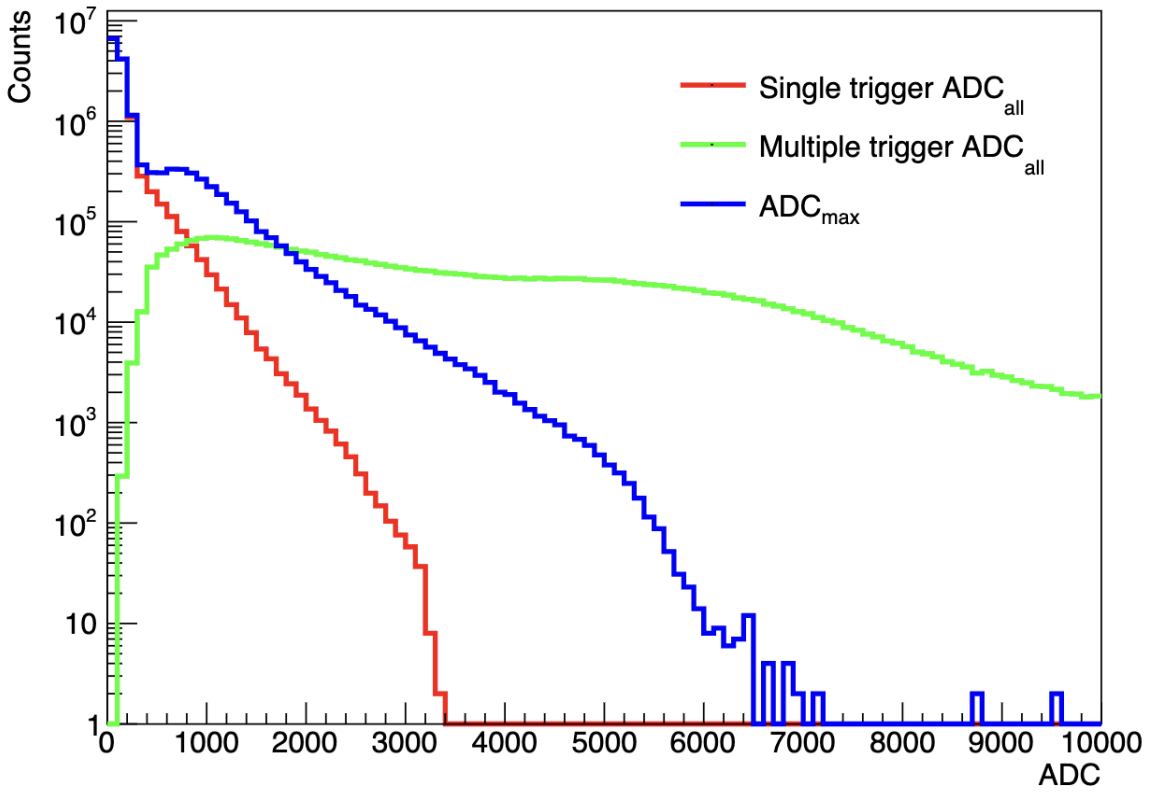
15,500,000 events (bins: 500)



Beam test result

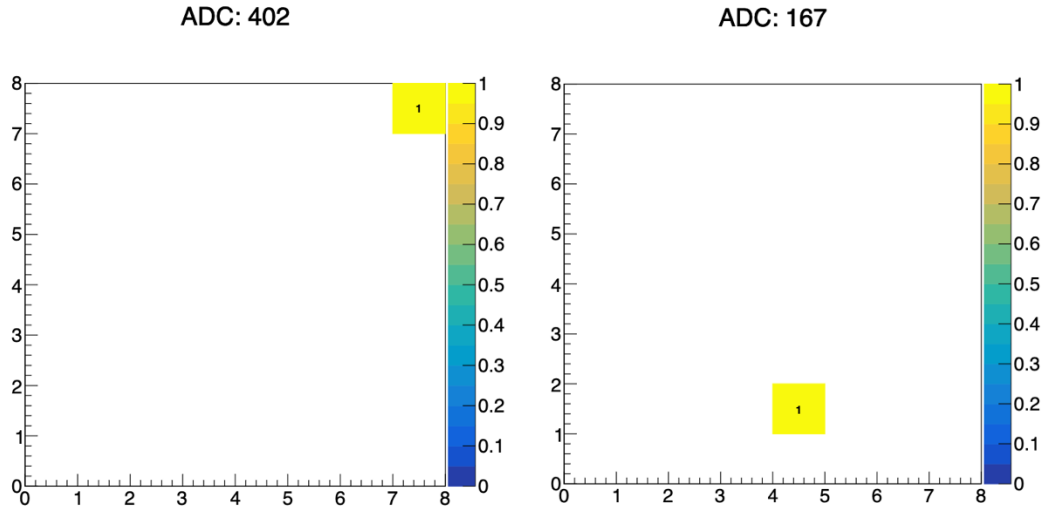


Result - Single Hit Selection



- Select the event only have “single trigger”.
- There don’t have any peak in the single hit spectrum.

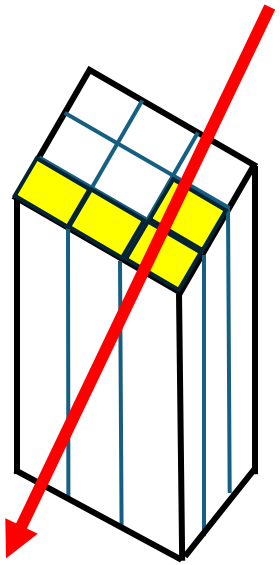
Single trigger event



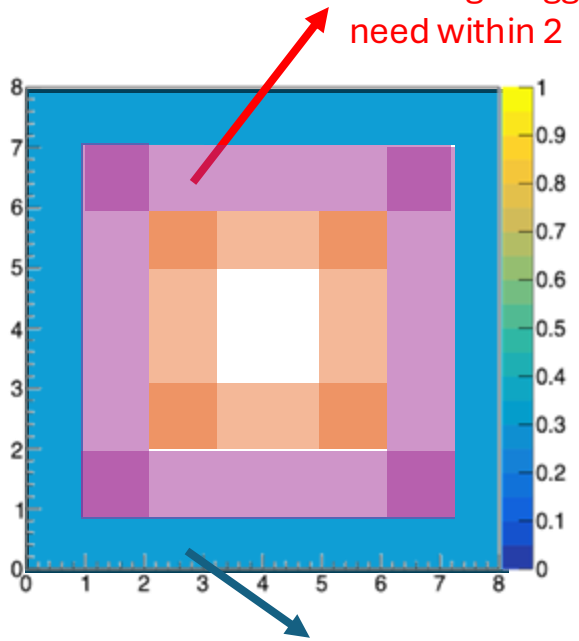
Result - Line Selection

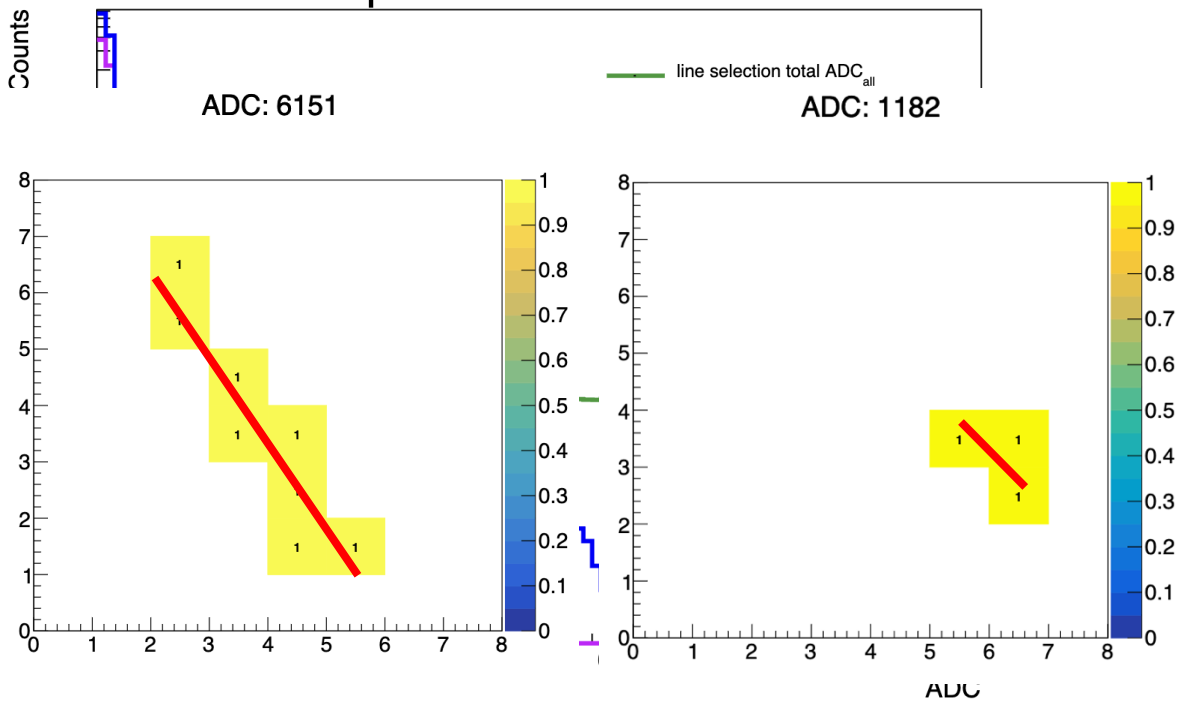
1. Select the event without outer ring.
   → Ensure event penetrate the whole detector.
2. One of second ring edge trigger is within 2.
   → Select the event is the line.

- There have a cut at peak at 6000 ADC just one ADC_{all} curve.
- Hard to judge where is the cosmic MIP and the incident point.



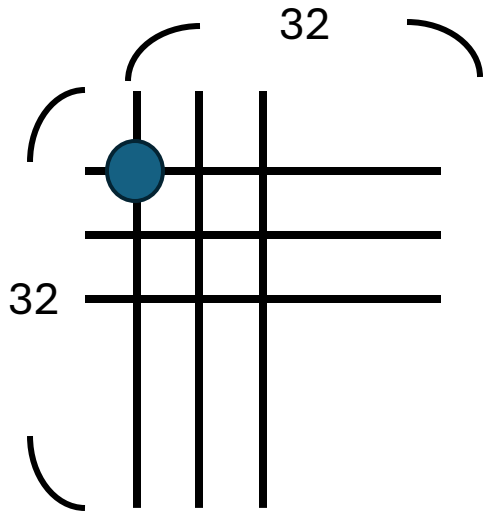
Cosmic Muon

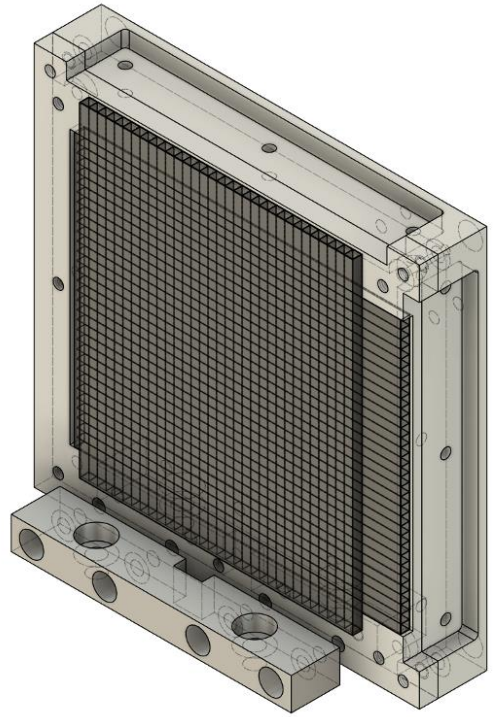




To Do List

- Add the position detector to improve the resolution and get the exact cosmic muon incident point.
- Compare data with the simulation to help analysis.
- TAKE MORE DATA!





Position detector

Summary

- **Goal**
  - Use the cosmic ray as the source to measure the characteristic of ZDC EM- Calorimeter.
  - Check for nonlinear behavior in the SiPM and saturation in the ADC.
- **$\mathbf{ADC_{max}}$ spectrum**
  - There have a slope change at 5000ADC~6000ADC in $\mathrm{ADC}_{\mathrm{max}}$.
  - ADC don’t have the saturation, but SiPM have nonlinear behavior.
- **Single Hit Selection**
  - There don’t have any peak in the single hit curve.
- **Line Selection**
  - There is a flat peak at 6000 ADC in the $\mathrm{ADC}_{\mathrm{all}}$.
- **TO DO List**
  - Add the position detector to get the exact cosmic muon incident point.
  - Compare data with the simulation.
  - TAKE MORE DATA!

Backup

Comparison of Various Crystals

	X_0	LY (ph/MeV)	T dep. of LY (%/K)	Decay time (ns)	λ_{em} nm
$PbWO_4$ (CMS)	0.89 cm	200	-1.98	5 (73%) 14 (23%) 110 (4%)	420
LYSO	1.14 cm	30,000 (market standard)	-0.28	36	420
GAGG	1.59 cm	40,000 – 60,000		50 – 150	520
SciGlass	2.4-2.8 cm	>100		22 – 400	440-460

Cosmic Ray

Primary cosmic ray

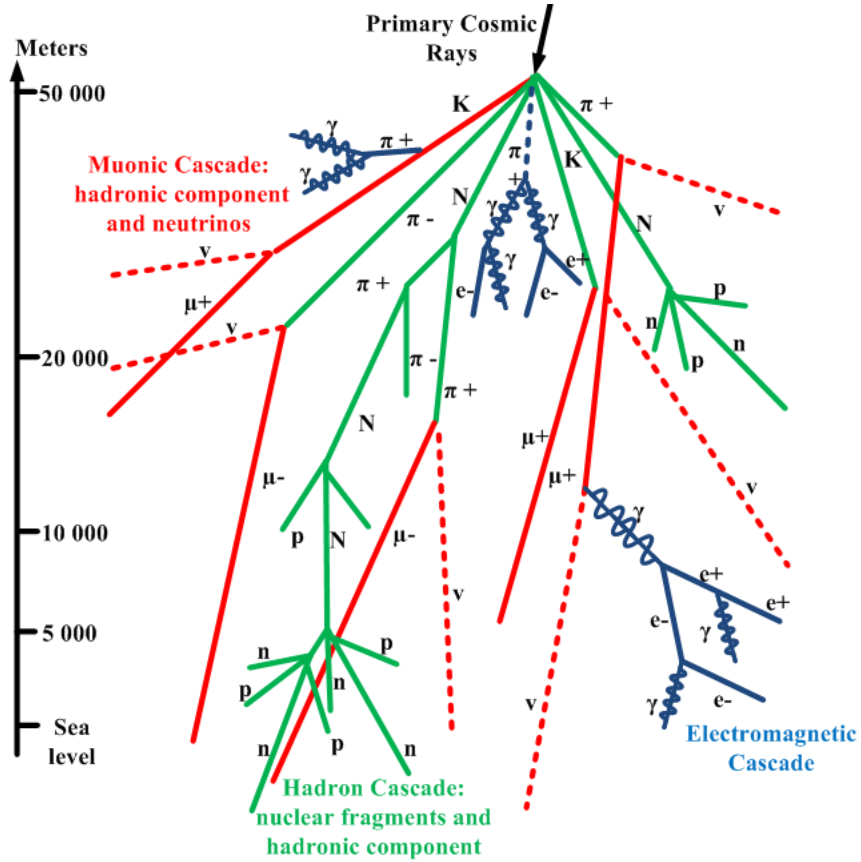
- Cosmic rays are produced by the sun and elsewhere in the galaxy.
- 95% are protons, 4% are helium nuclei.

Secondary cosmic ray

- High-energy particles and γ-rays collide with the atmosphere, producing a large number of secondary particles.
- The chain reaction is called “Air Shower”.

Around the sea level

- Muon are the most abundant charged particles at the sea level.

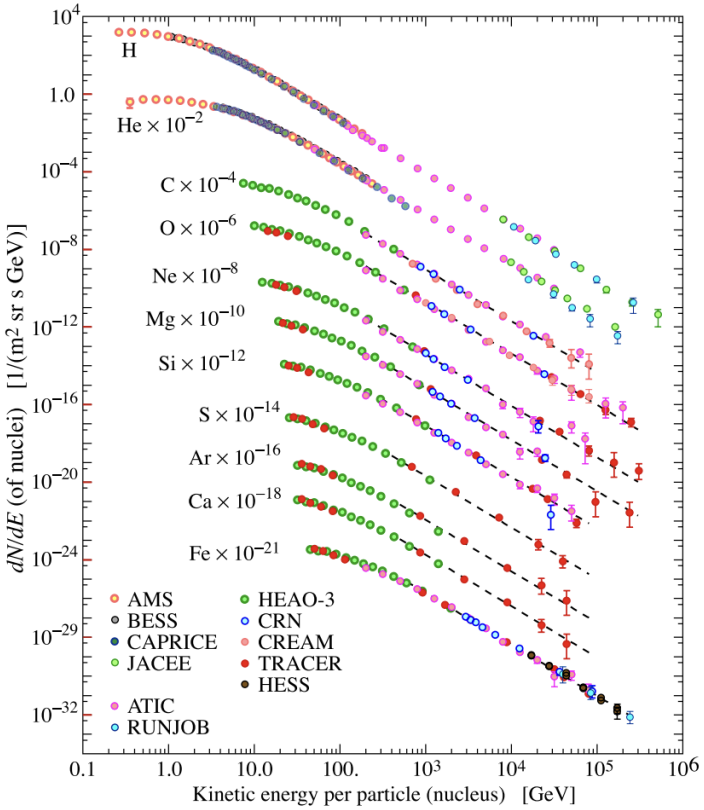


From: https://hal.archives-ouvertes.fr/tel-01191520

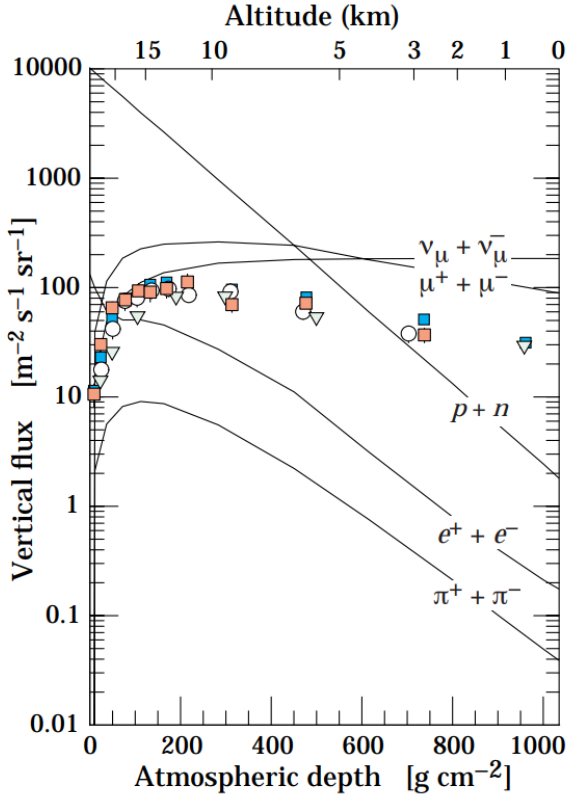
Cosmic Ray and Air Shower

- At the sea level, the muon flux is greater than other particle.

Primary cosmic ray



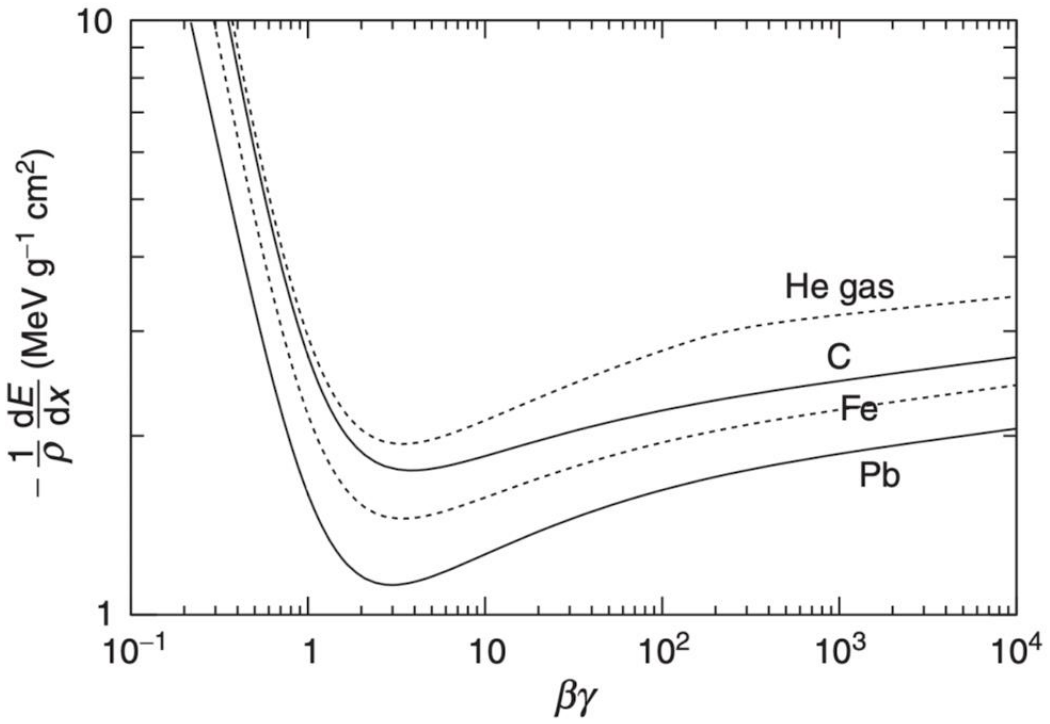
Flux-Atmospheric depth curve



From: http://pdg.lbl.gov/2013/reviews/rpp2013-rev-cosmic-rays.pdf

Minimum Ionizing Particle (MIP)

- When a charged particle has kinetic energy greater than twice its rest energy, it will lose the minimur energy as it passes through substances.
- The particle in $\beta\gamma \approx 3$ have the $-\frac{1}{\rho}\frac{dE}{dx} \approx 1\sim2$.



Bethe–Bloch equation:

$$\frac{1}{\rho}\frac{dE}{dx} \approx -\frac{4\pi\hbar^2 c^2 \alpha^2}{m_e v^2 m_u}\frac{Z}{A}\left\{\ln\left(\frac{2\beta^2\gamma^2 c^2 m_e}{I_e}\right) - \beta^2\right\}$$

Energy curve

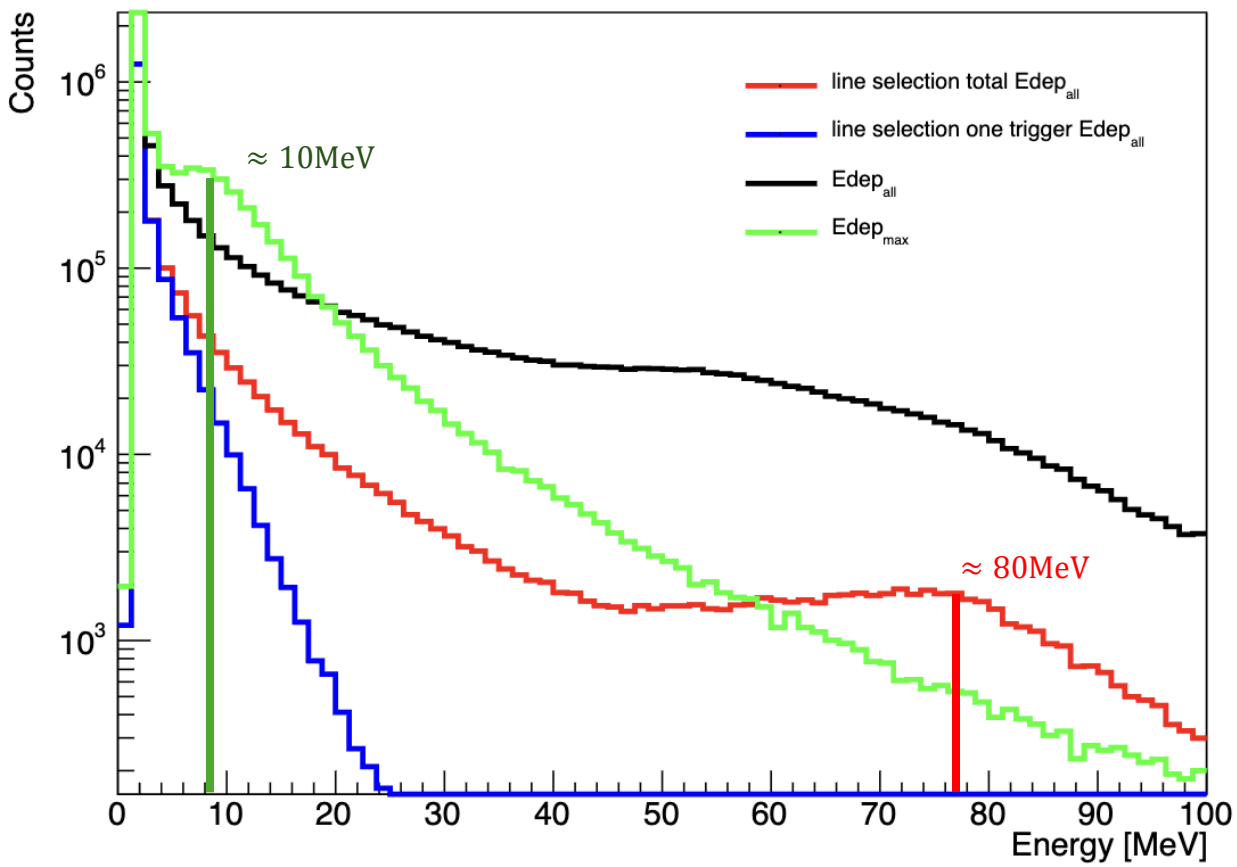
- The ADC - Edep change function need to be calibration.

Cosmic muon $\approx 4\text{GeV} \rightarrow \beta\gamma = 37.339$

$$\rightarrow \frac{1}{\rho}\frac{dE}{dx} \approx 1$$

Crystal: $LYSO(Lu^{1.8}Y.^{2}\ SiO^{5}:Ce)$

$$\rho = 7.1(g/cm^3)$$



- Zenith(one trigger):

$$8.8(cm) \cdot 1 \cdot 7.1 = 61.6(\text{MeV})$$

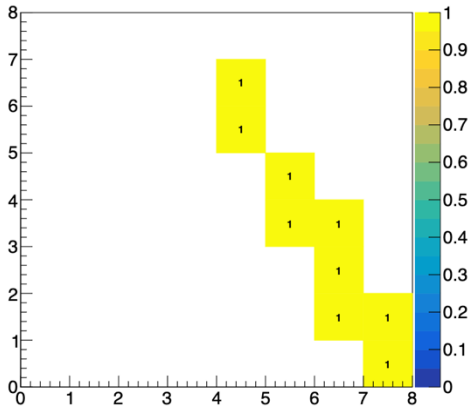
- Multiple trigger:

$$10.69(cm) \cdot 1 \cdot 7.1 = 75.96(\text{MeV})$$

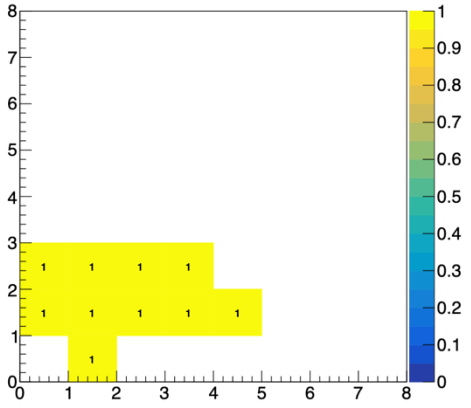
$$\sqrt{8.8^2 + 2(7.12 \cdot 6)^2}$$

Each event – ADC (Without selection)

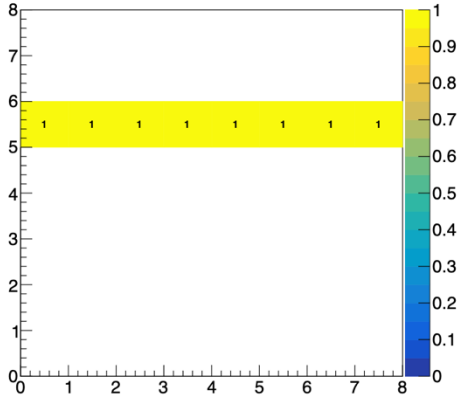
ADC: 6750



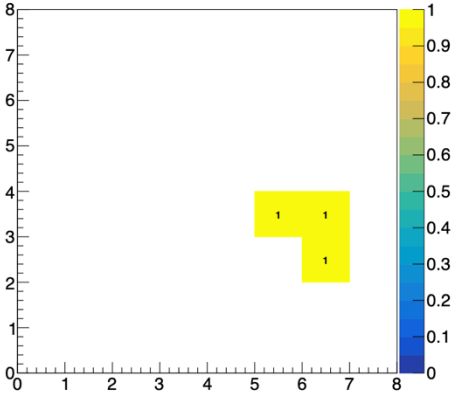
ADC: 9856



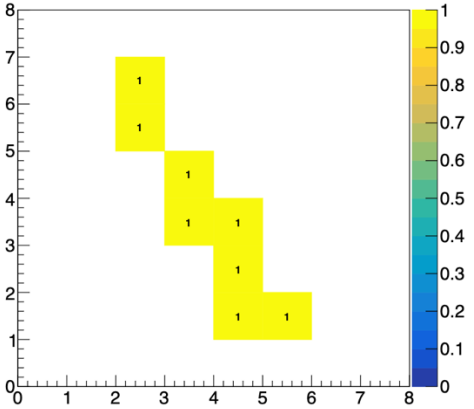
ADC: 6227



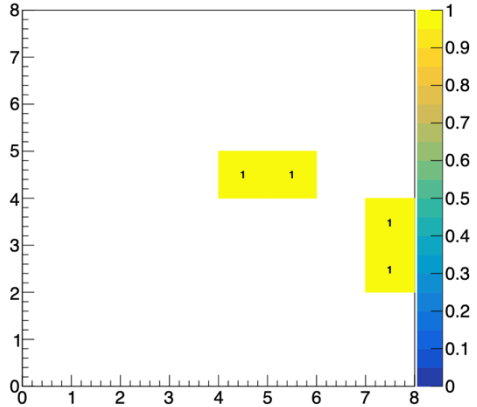
ADC: 1182



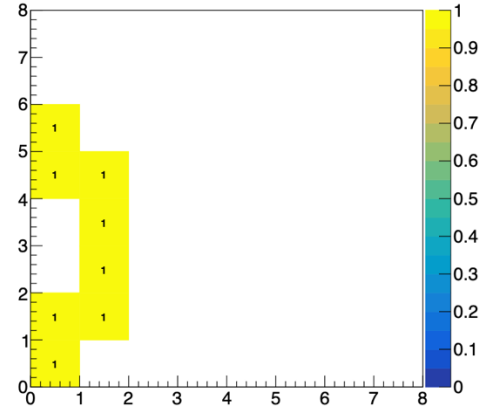
ADC: 6151



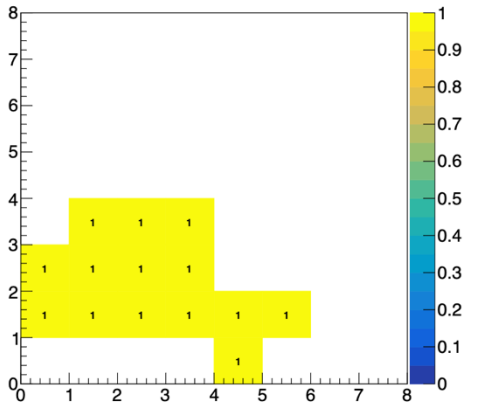
ADC: 2074



ADC: 6654

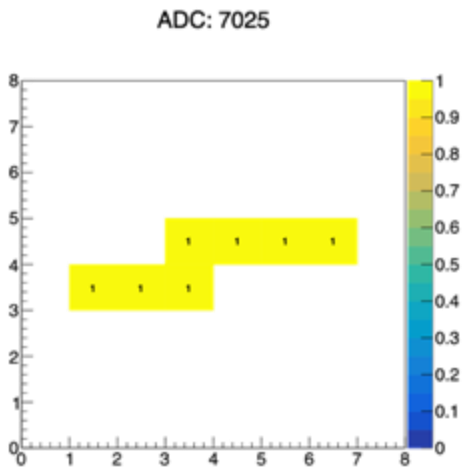


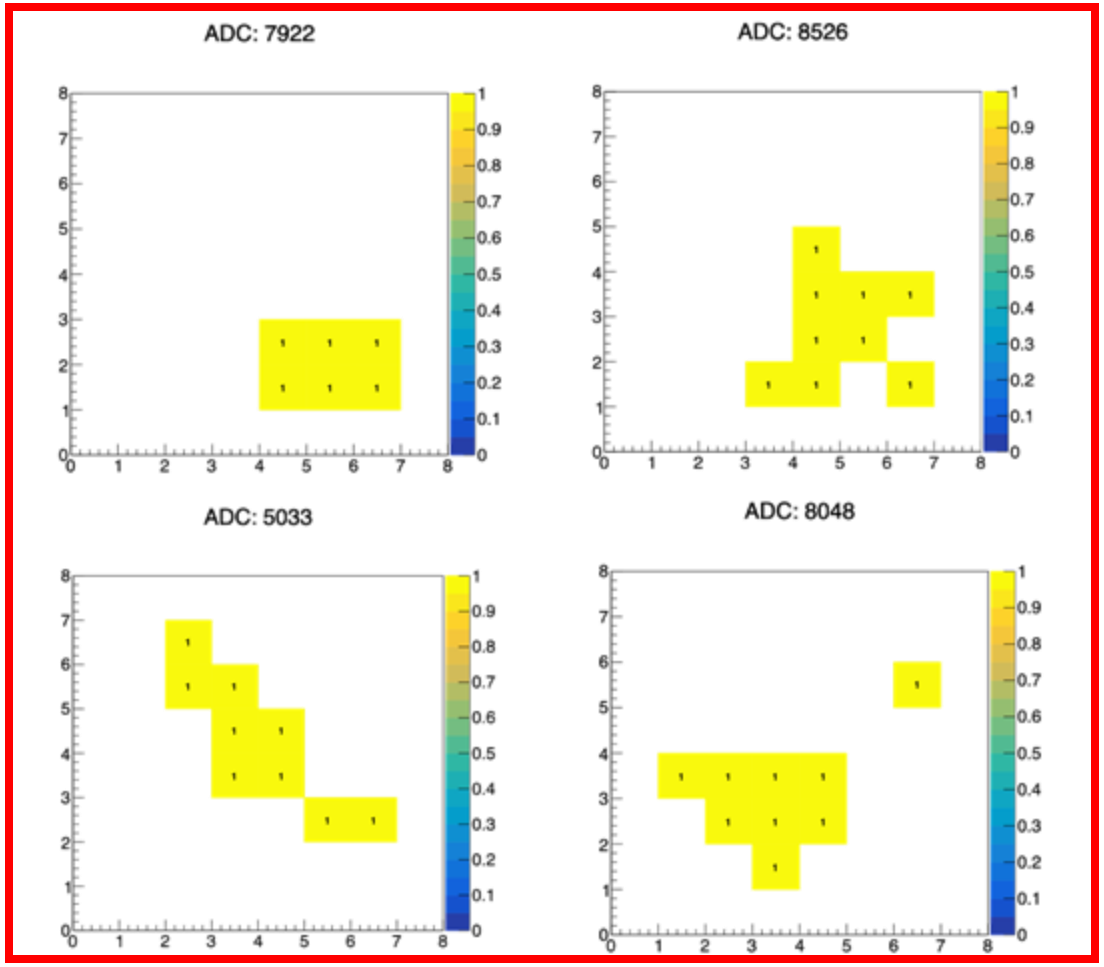
ADC: 11387

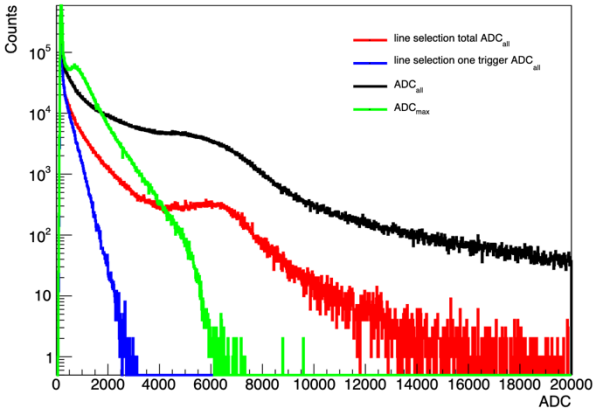


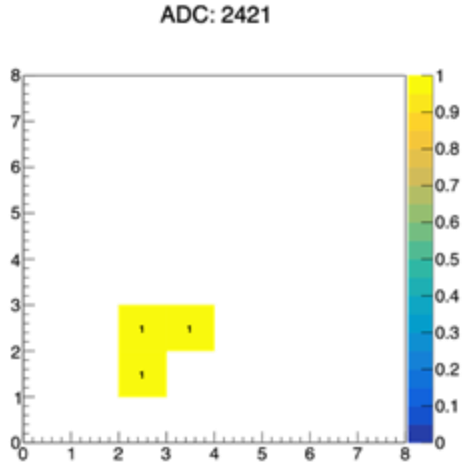
Each Event after Line Selection

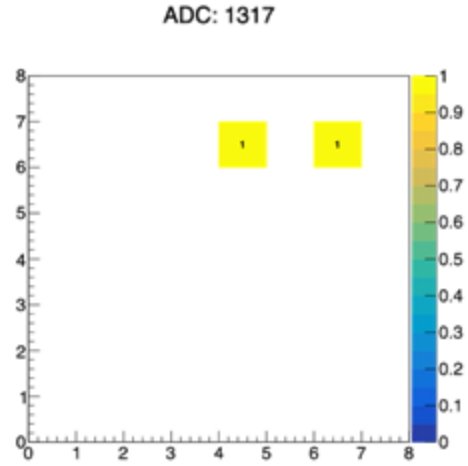
There have some events is the electron scatter not muon.



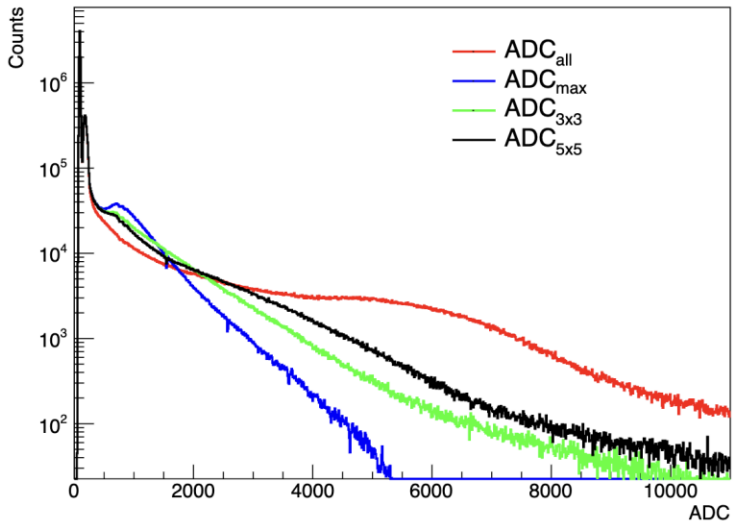


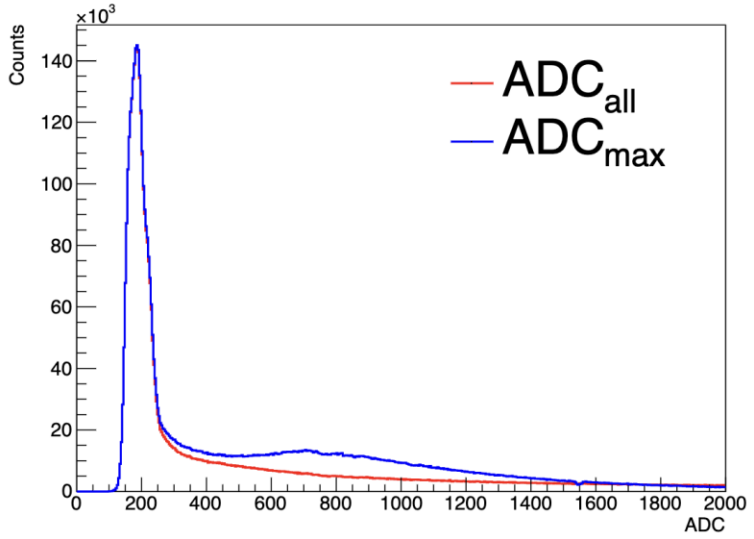


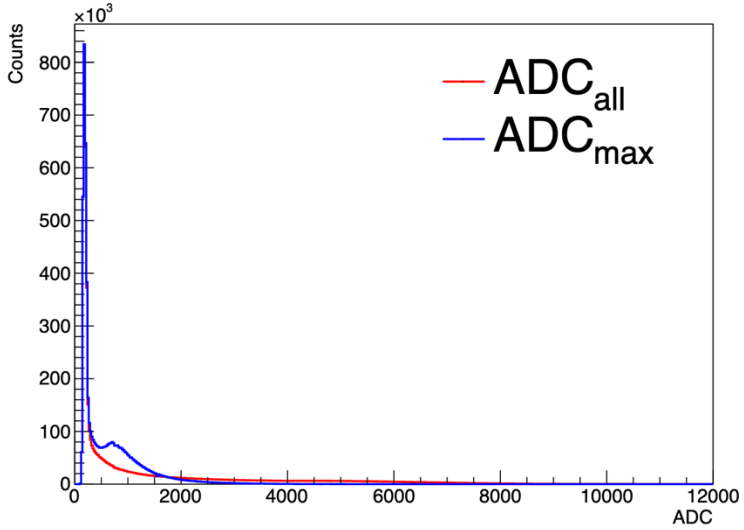




ADC spectrum zoom in & linear scale







ADC_{all} - trigger channels curve

The more channel is trigger, the ADC_{all} is larger.