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LightFCP

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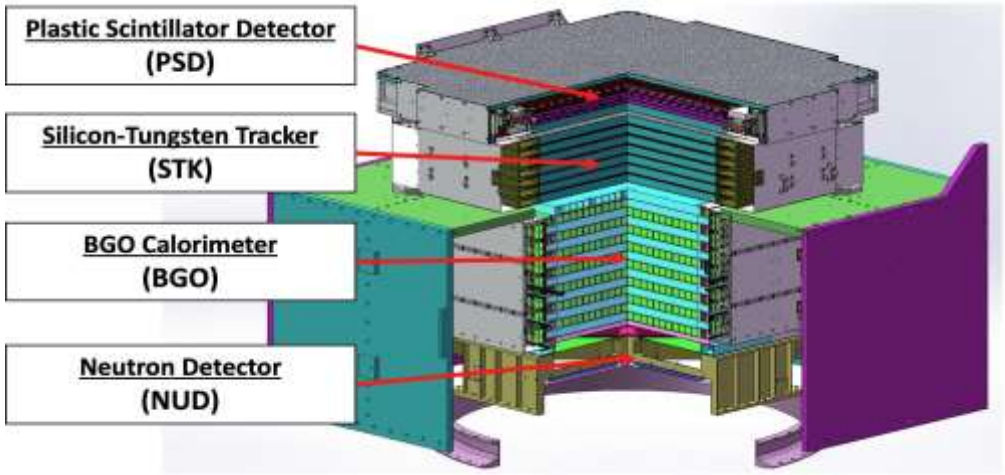
Motivation

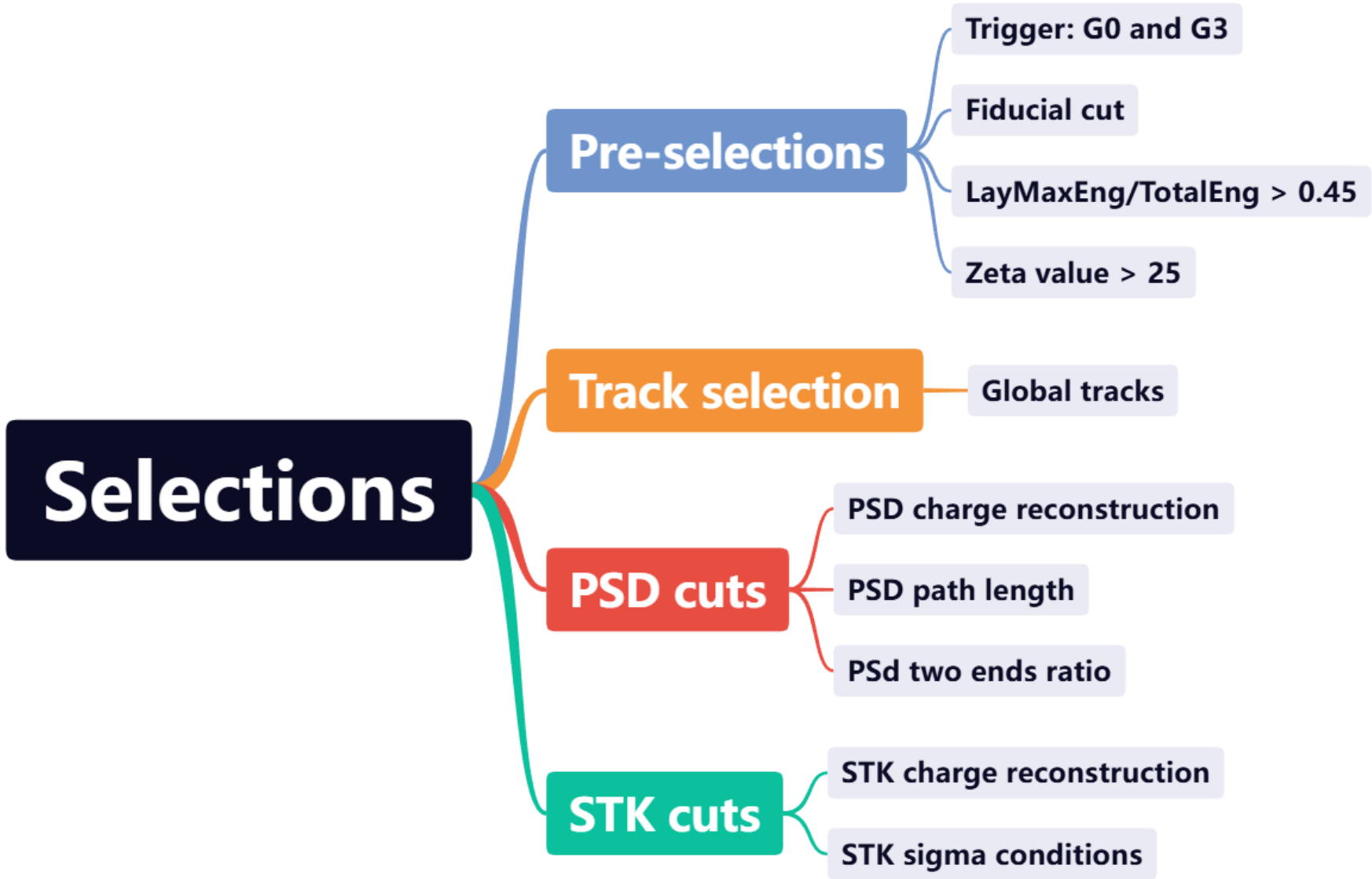
Some extensions of standard model predicted FCP maybe a type of massive lepton. There are some conclusions of FCP with DAMPE already.

But there is a lack of research on Light FCP, Light FCP would propagate like electron different from FCP. Bremsstrahlung is an important physical effect for LightFCP.

Methods

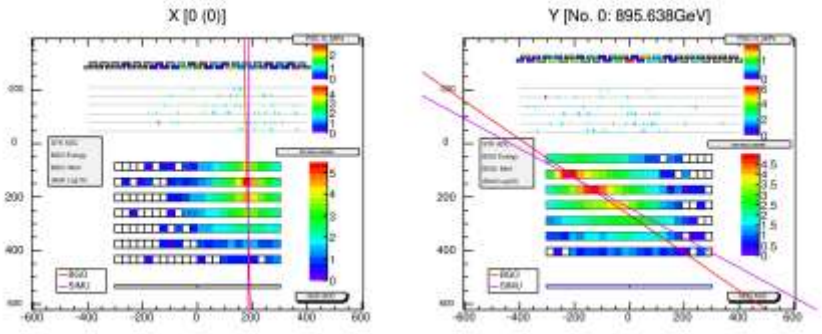
- **PSD:** Charge measurement.
- **STK:** Charge measurement and tracking.
- **BGO:** Energy measurement, tracking and shower profile.



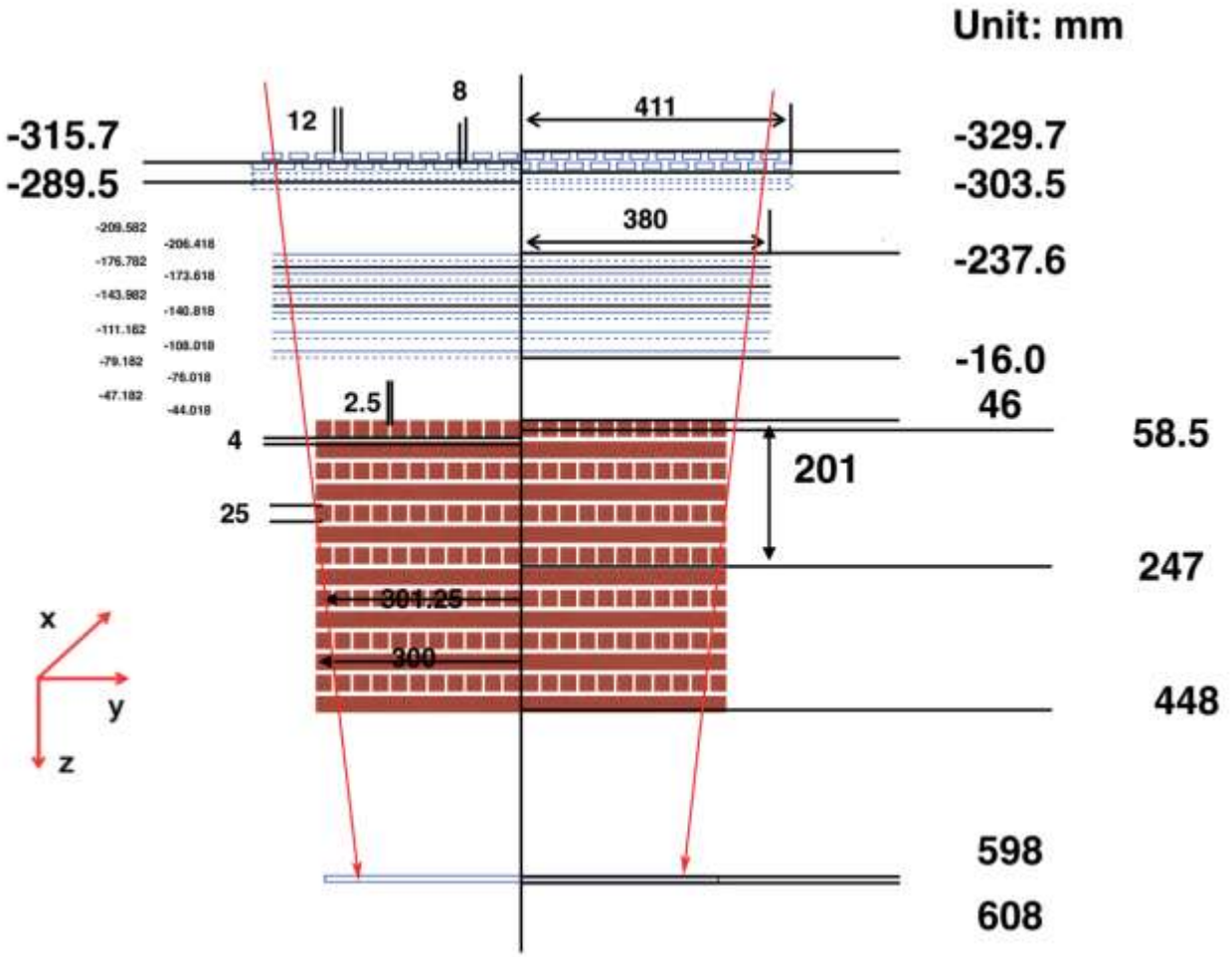

Selections
Pre-selections
Trigger: G0 and G3
Fiducial cut
LayMaxEng/TotalEng > 0.45
Zeta value > 25
Track selection
Global tracks
PSD cuts
PSD charge reconstruction
PSD path length
PSd two ends ratio
STK cuts
STK charge reconstruction
STK sigma conditions

Pre-selections

- **Trigger cut:** G0, G3.
- **Fiducial cut:** Constrain the positions of injection and ejection to maintain the event in the whole detector.
- **LayMaxEng/TotalEng>0.45:** Remove oblique events.
- **Zeta value >25:** Remove protons.



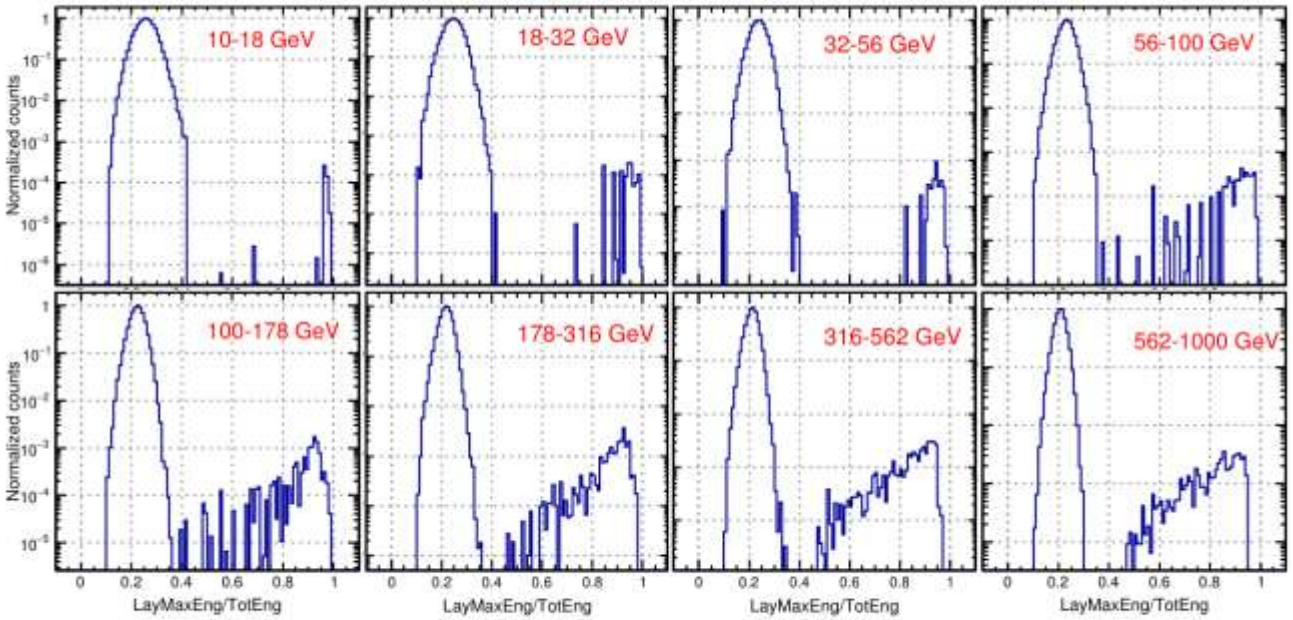
Oblique event sample



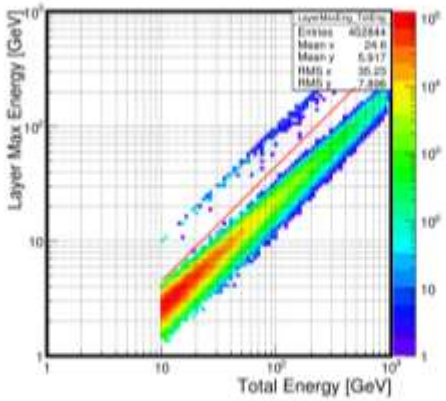
Pre-selections

LayMaxEng is the deposition energy of the maximum deposition energy layer in the 13-layer BGO detector. **TotalEng** is kinetic energy in simulation and total deposition energy in flight data.

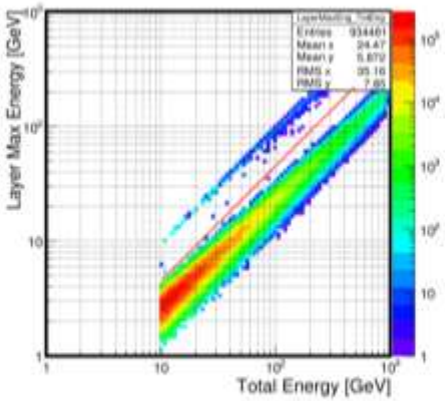
As shown in the figure, the oblique events meets condition: LayMaxEng/TotalEng > 0.45.



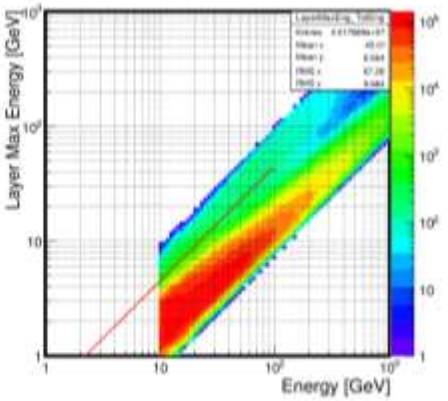
(a) MC LFCP for eight energy region



(d) MC LFCP

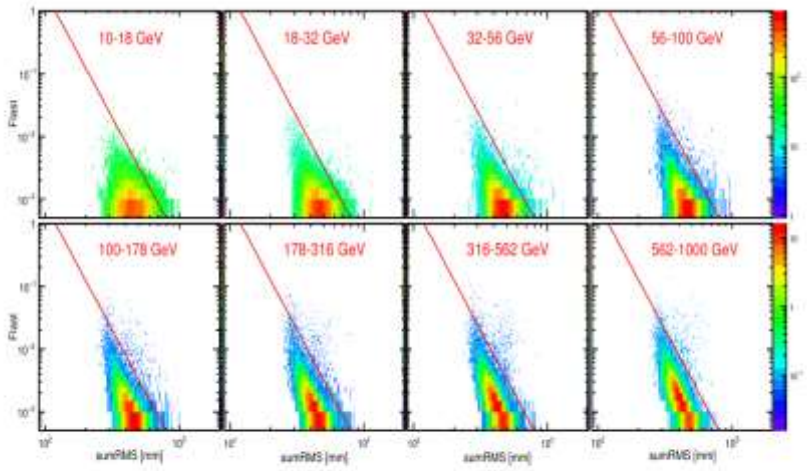


(e) MC Electron

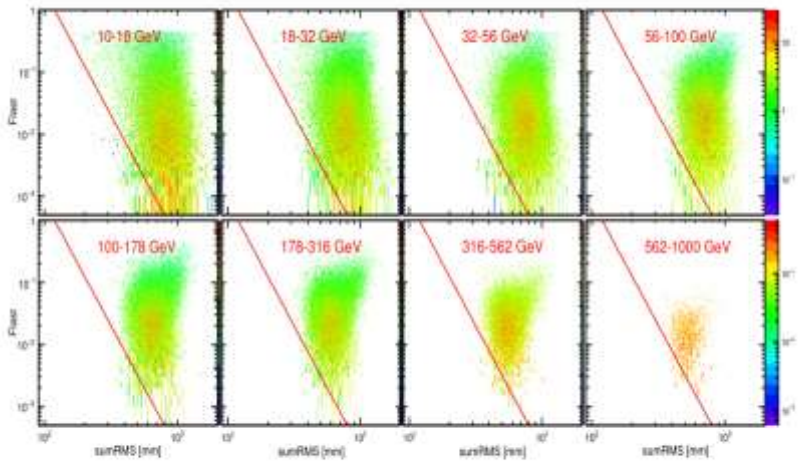


(f) Flight Data

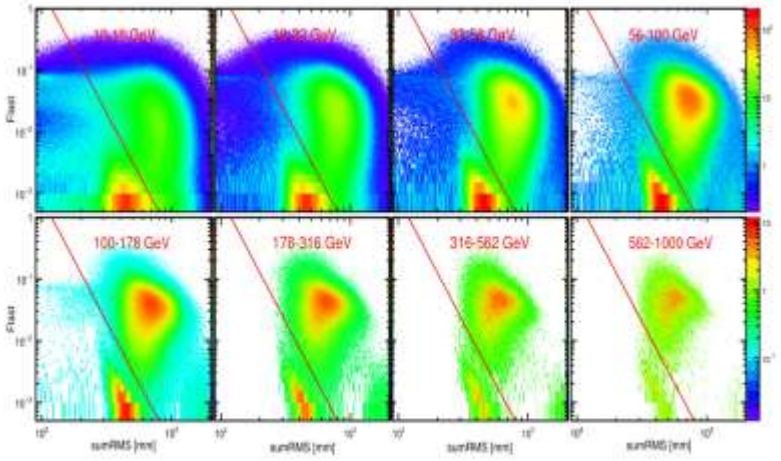
Pre-selections



(e) MC LFCP for eight energy region



(g) MC Proton for eight energy region



(h) Flight Data for eight energy region

Zeta value is defined by following equation: $\zeta = \frac{1}{8} \times 10^{-6} \times (sumRMS)^4 \times F_{last}$,

where **sumRMS** is the sum of the RMS of energy deposition in all 14 layers of BGO, and **Flast** is the fraction of energy deposited in the last BGO layer.

PSD cuts

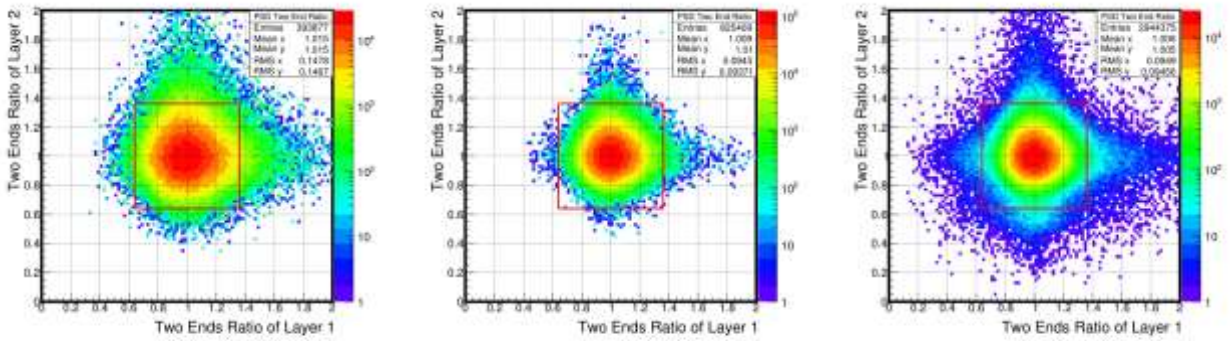
$$Q_{PSD} = (Q_0 + Q_1)/2$$

- **PSD charge:** Requiring that the charge of each PSD layer should be bigger than 0 e.

- **PSD path length:** The path length is required to be 10 mm.

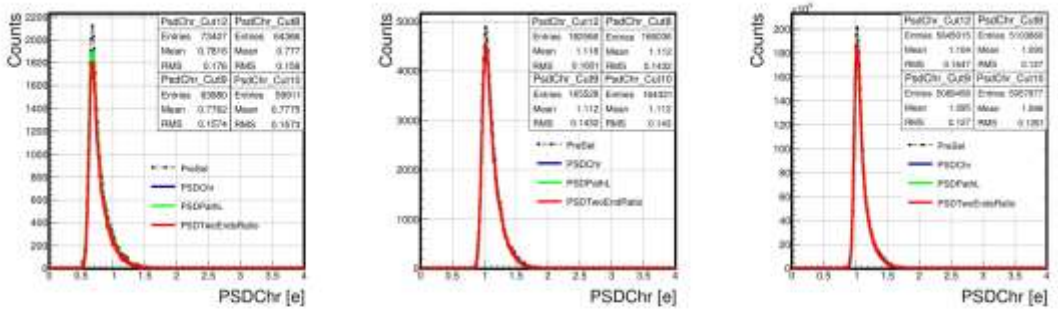
- **PSD two ends radio:** PSD adopts a two-end readout method. The two-end ratio of two layers must be inside of **[mean-3σ, mean+3σ]** if you want an relatively accurate result.

PSD two ends ratio

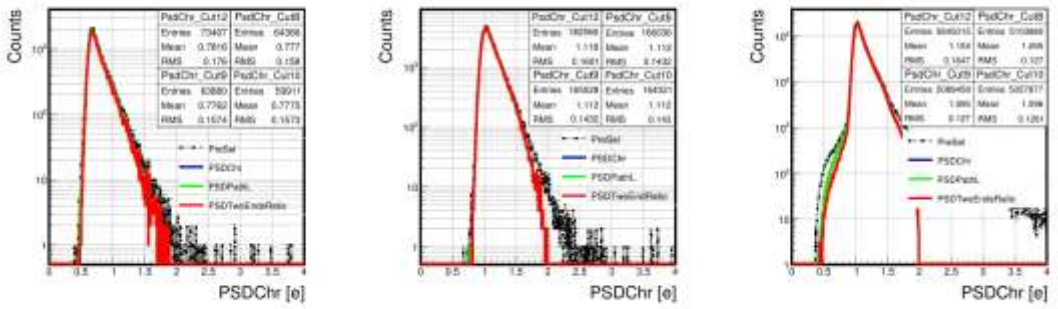


(a) MC LFCP (b) MC Electron (c) MC LFCP

PSD cuts flow



(a) MC LFCP Linear (b) MC Electron Linear (c) Flight Data Linear



(d) MC LFCP Log Scale (e) MC Electron Log Scale (f) Flight Data Log Scale

STK cuts

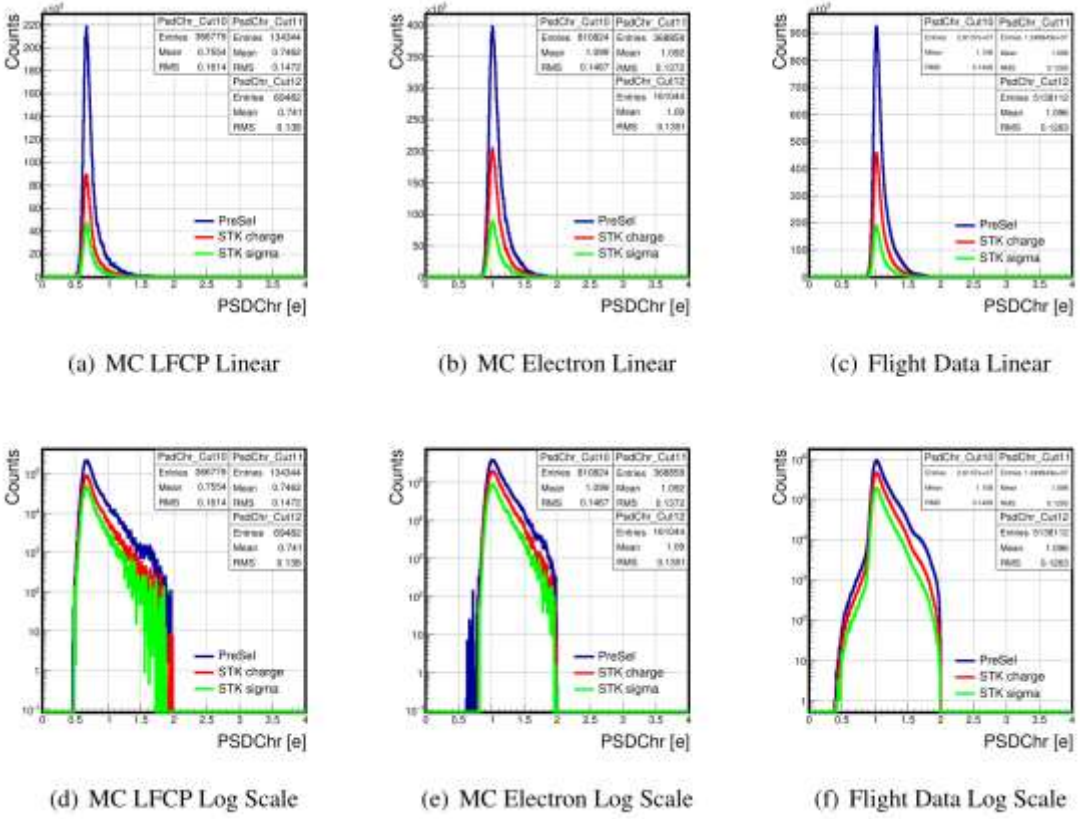
Due to the existence of tungsten plates, the charge signal of LFCP will involve many secondary particles.

To reduce the interference of secondary particles, the following restrictions are imposed on each sub-layer of the signal, and the standard deviation of the first four sub-layer signals is required to meet the conditions below.

- $ClusterEnergy \times \frac{6}{180} + NStrips < 6.$
- $\sigma < 15$ and $^{\sigma}/_{E_{ave}} < 1$

$$Q_{STK} = \frac{\sum_{i=1}^{N} Q_i}{N} \qquad \sigma = \sqrt{\frac{\sum_{i=1}^{N}(E_i - E_{ave})^2}{N}}$$

STK cuts flow

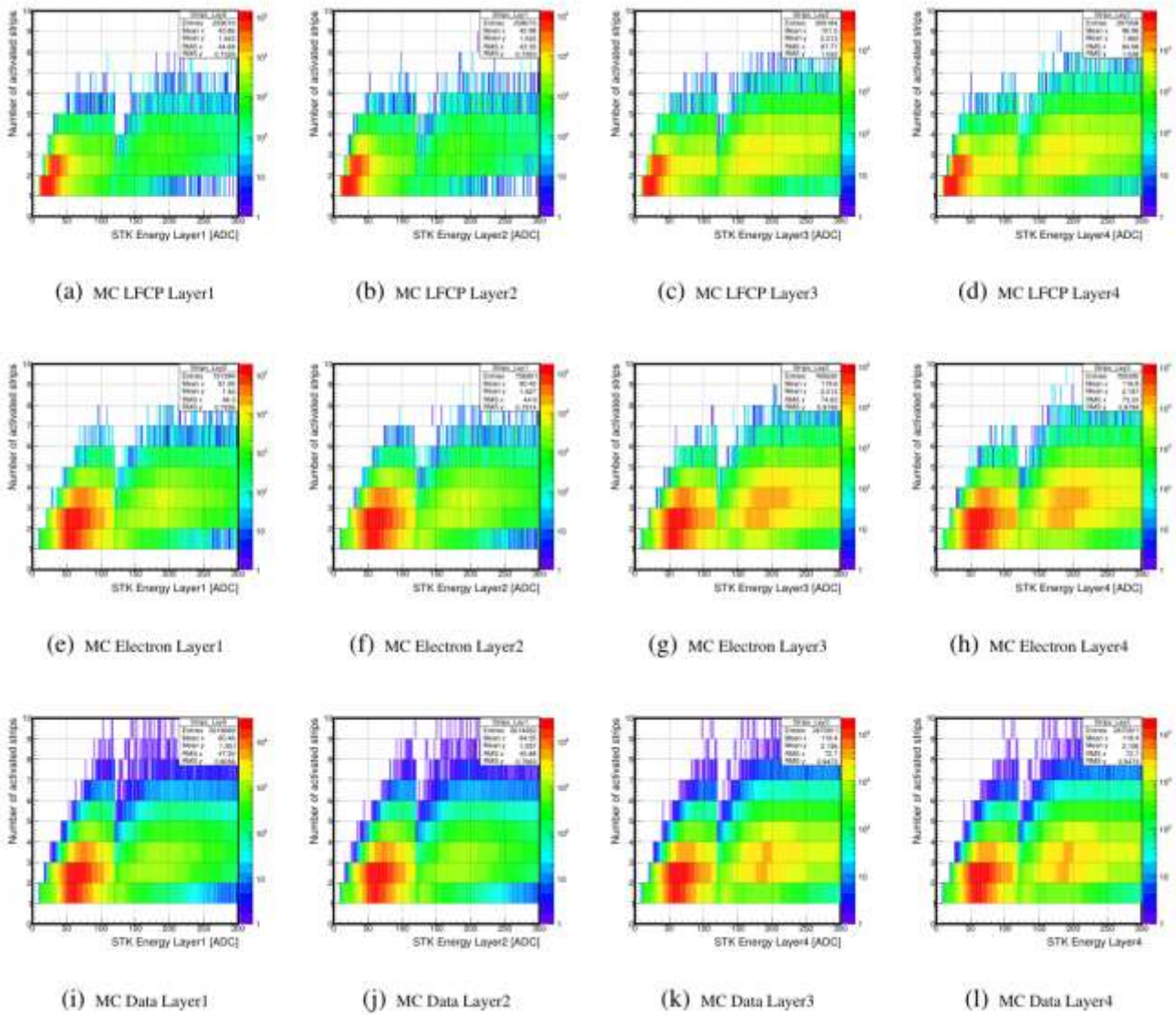


(a) MC LFCP Linear (b) MC Electron Linear (c) Flight Data Linear

(d) MC LFCP Log Scale (e) MC Electron Log Scale (f) Flight Data Log Scale

STK cuts

The distribution of STK strips under different layers and samples. Whose X-axis is the cluster energy of this certain layer and Y-axis represents the number of activated strips in this cluster.



(a) MC LFCP Layer1 (b) MC LFCP Layer2 (c) MC LFCP Layer3 (d) MC LFCP Layer4

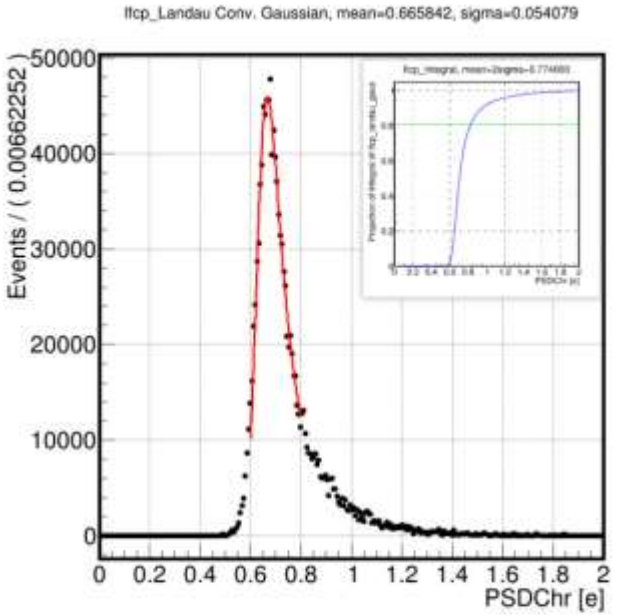
(e) MC Electron Layer1 (f) MC Electron Layer2 (g) MC Electron Layer3 (h) MC Electron Layer4

(i) MC Data Layer1 (j) MC Data Layer2 (k) MC Data Layer3 (l) MC Data Layer4

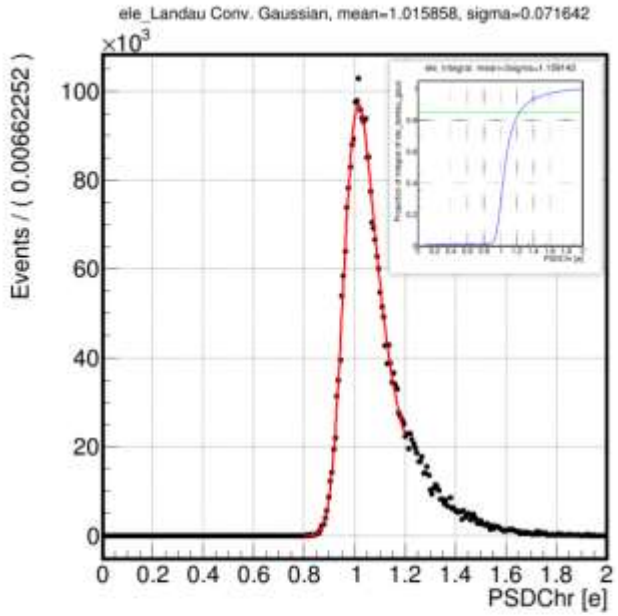
Charge region

The Landau convolution Gaussian function was used to fit the PSD charge spectrum and STK charge spectrum of LFCP and electrons respectively.

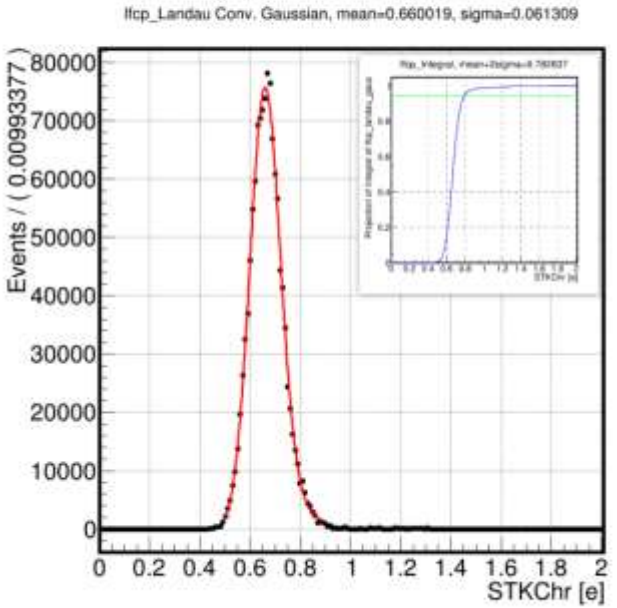
LFCP	Mean	Sigma	Mean+2Sigma
PSD	0.6658	0.0541	0.774
STK	0.6600	0.0613	0.783



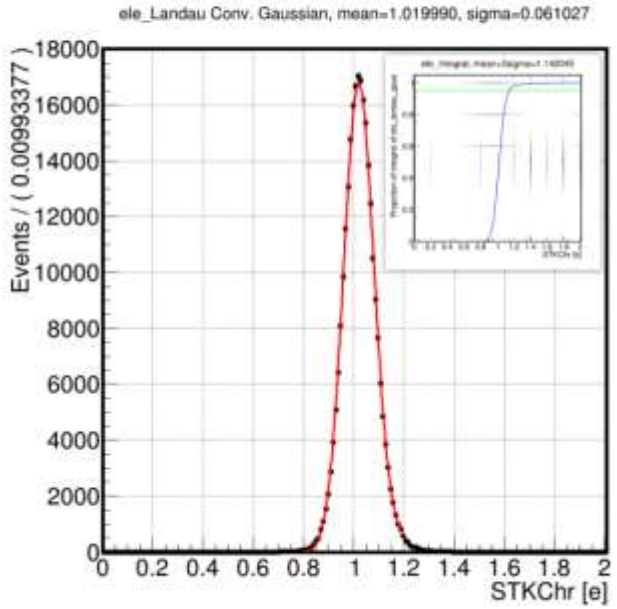
(a) MC LFCP



(b) MC Electron



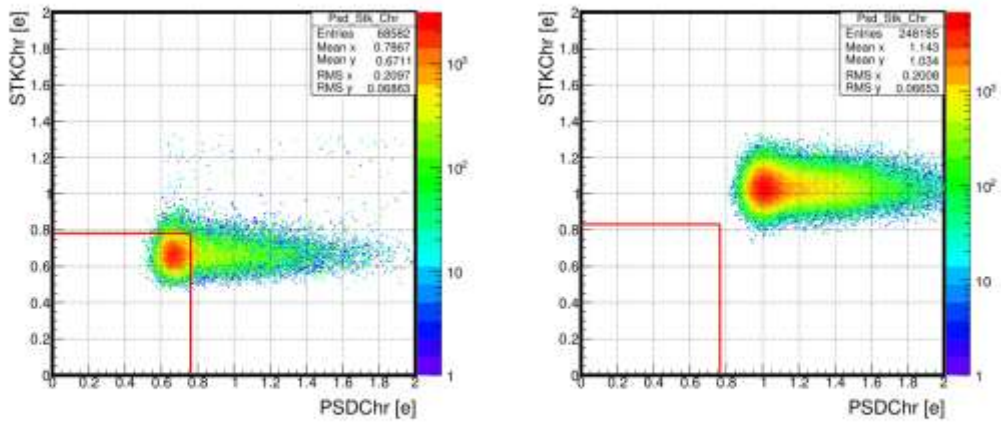
(c) MC LFCP



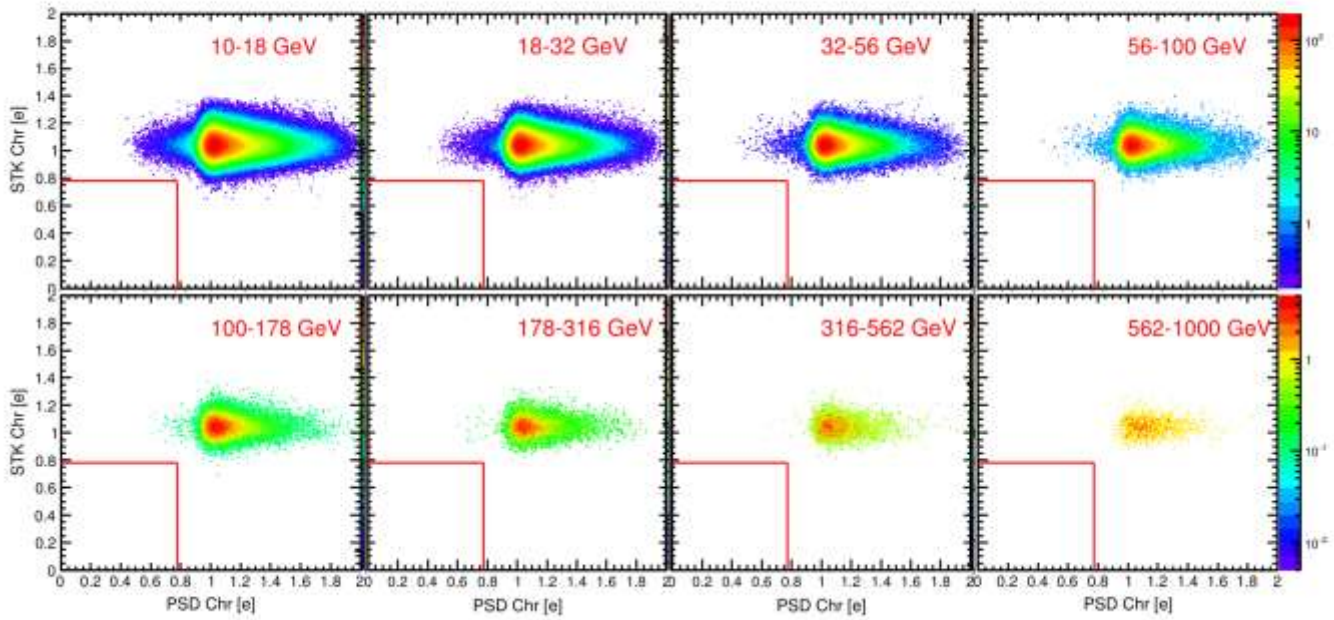
(d) MC Electron

Charge region

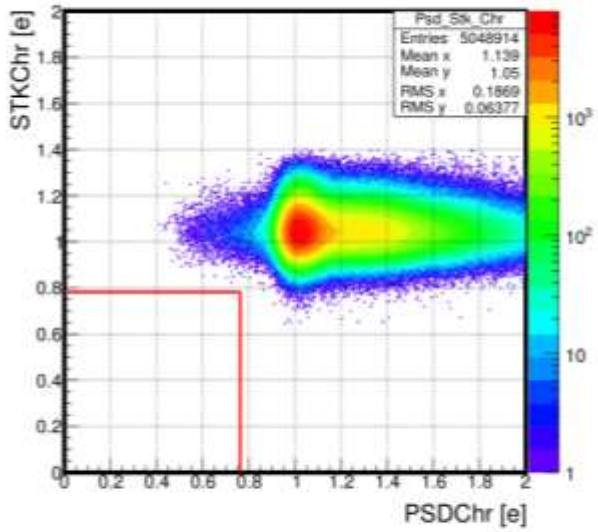
Based on the fitting results, get the PSD and STK signal region with mean+2sigma: **PSD charge < 0.774** and **STK charge < 0.783**. There is no cases were found in the signal area of the flight data. In the MC LFCP, the proportion of events within the signal region is about **57.61%**.



(a) MC LFCP (b) MC Electron



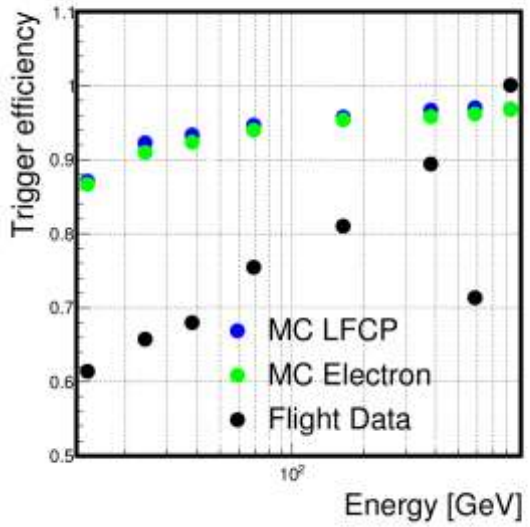
Flight Data for eight energy scale

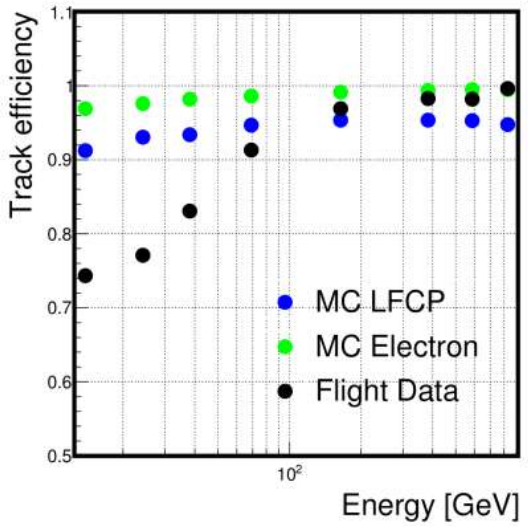


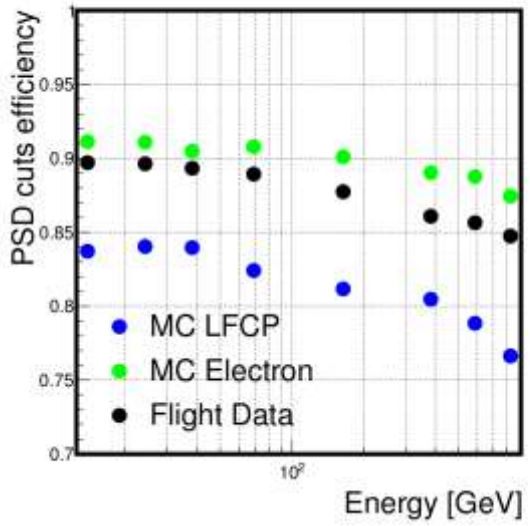
(c) Flight Data

Efficiency and systematics

$$\delta_{sel} = \frac{Eff_{data} - Eff_{MC\_electron}}{2 \times Eff_{MC\_electron}}$$







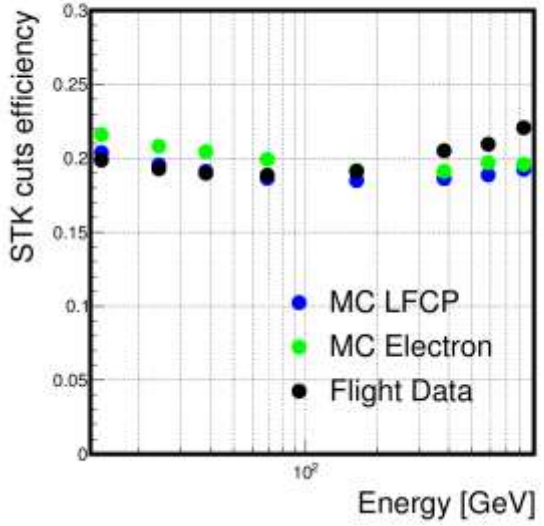
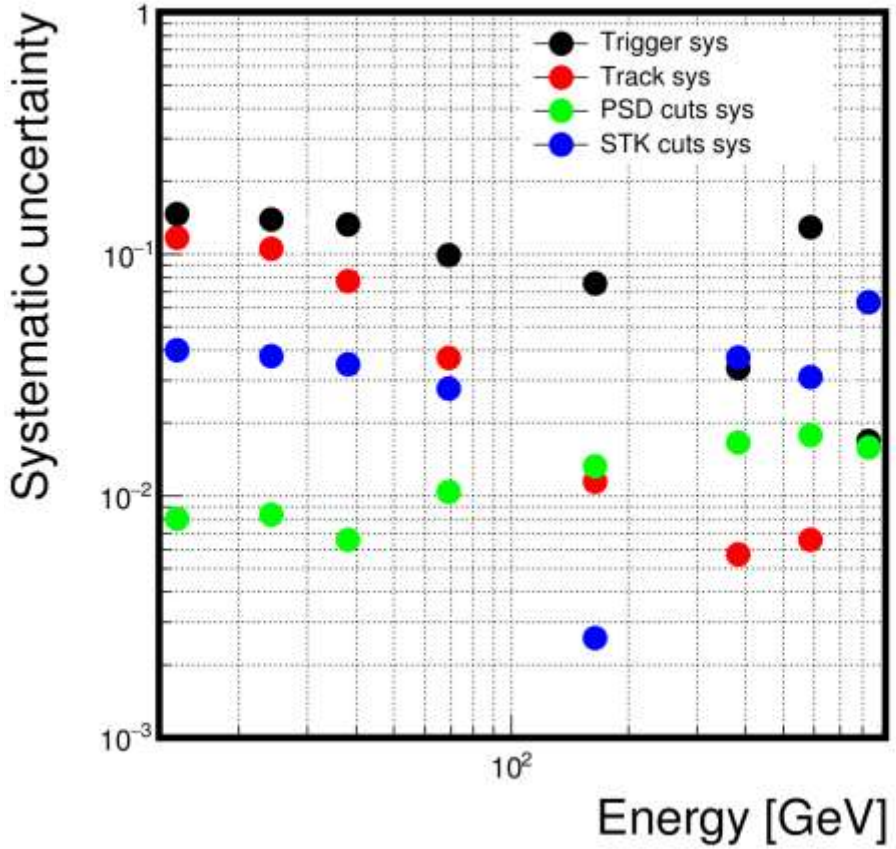


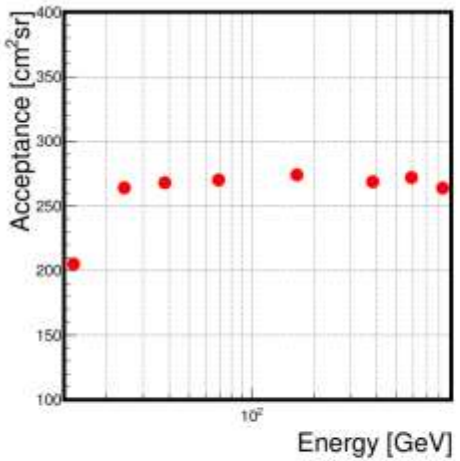
Table 1: Efficiency and systematic uncertainties

Item	MC LFCP (%)	MC Electron (%)	Flight Data (%)	Systematics (%)
Trigger efficiency	94.05	93.49	84.77	4.66
Track efficiency	94.08	98.55	89.80	4.44
PSD cuts efficiency	81.40	89.83	87.70	1.19
STK cuts efficiency	19.12	20.03	19.93	0.26

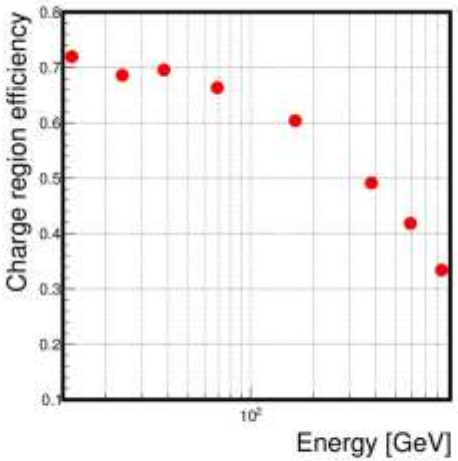


Results

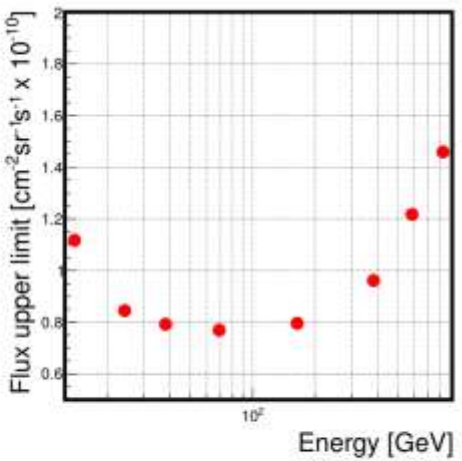
$$\Phi = \frac{N_{obs}}{T_{exp} A_{eff} \epsilon_{region} \epsilon_{trig} (1-\delta)}$$



(a) Acceptance



(b) Signal region efficiency



(c) Flux upper limit

The list following shows the meaning of parameters:

- Φ: The flux ($cm^{-2}sr^{-1}s^{-1}$) or flux upper limit (if no signal observed) of LFCP.
- N_{obs}: Observed events.
- T_{exp}: The total exposure time from run time. (about $2.1036 \times 10^8 s$ for 9 years with G3 trigger)
- A_{eff}: The effective acceptance ($cm^2 sr$), obtained from MC LFCP.
- ϵ_{region}: The efficiency of charge region for LFCP.
- ϵ_{trig}: The trigger efficiency for LFCP, obtained from LFCP.
- δ: It is systematic uncertainty of LFCP, $\delta = \sqrt{\delta_{trig}^2 + \delta_{trk}^2 + \delta_{PSD}^2 + \delta_{STK}^2}$.

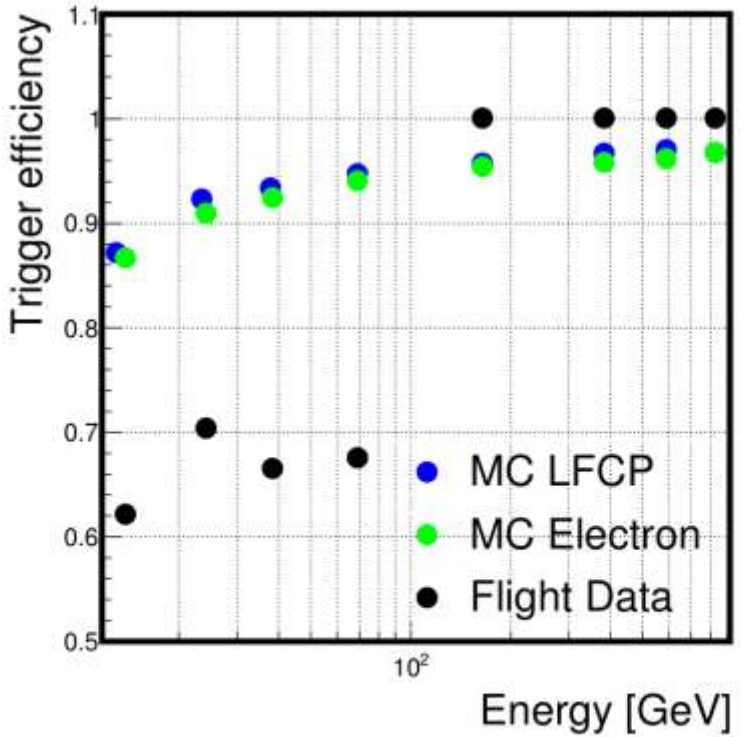
Backup

Trigger Efficiency

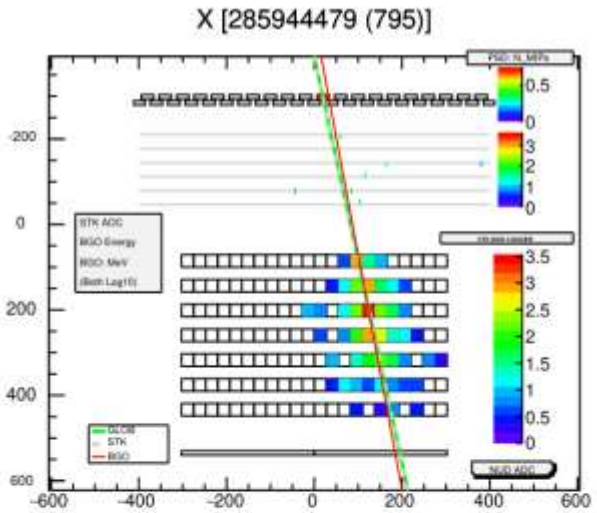
$$\epsilon_{G3} = \frac{N_{G3}}{(N_{G0} - N_{G0\&G3}) \times (N_{pre-scale}) + N_{G3}}$$

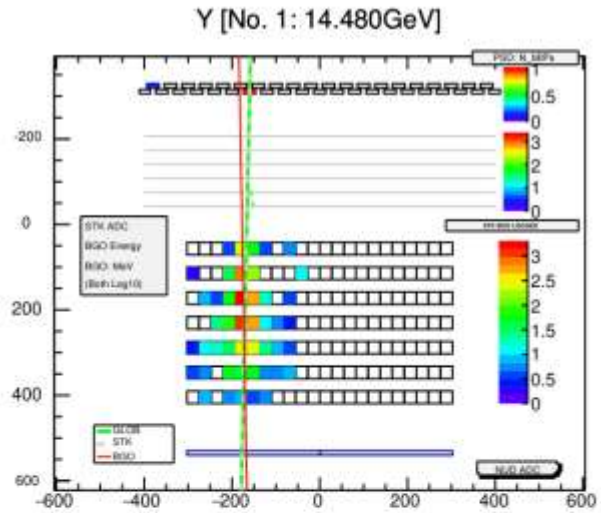
Flight Data 的 G3 触发效率低主要有两个原因：

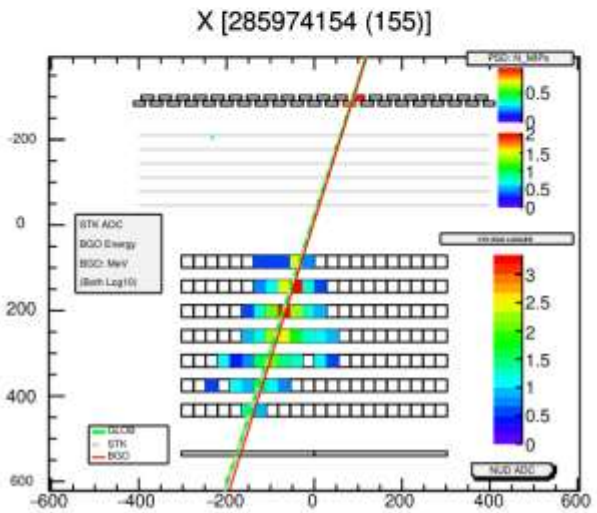
1. MIPs 事例的影响；
2. STK 电荷重建。

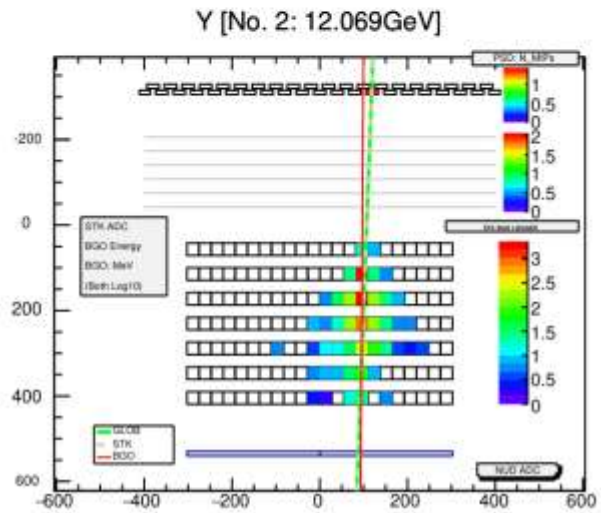


(a) Trigger efficiency



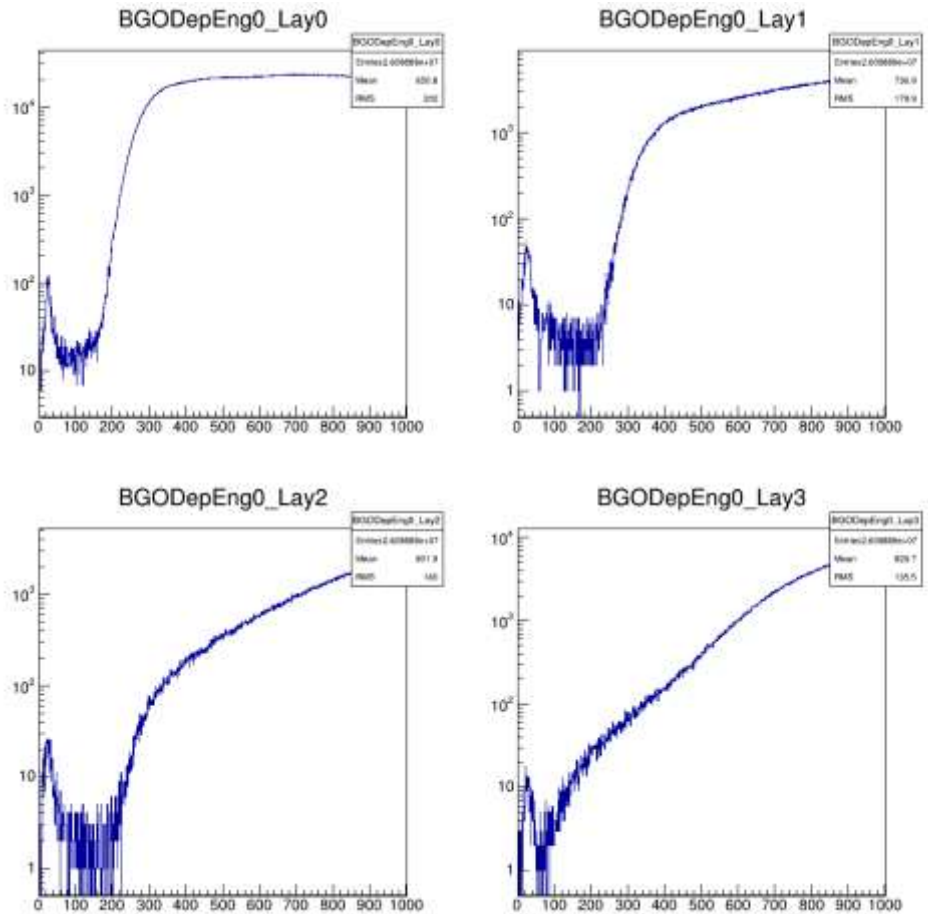


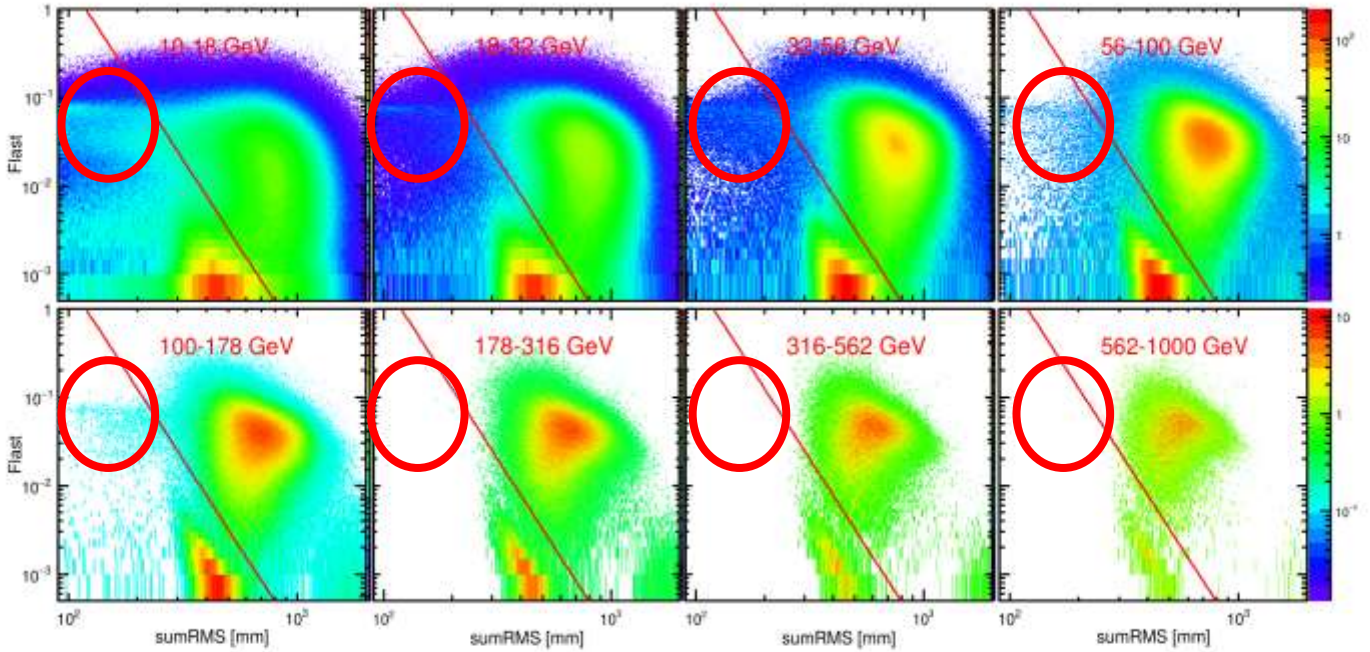




MIPs Events

红圈内 MIPs 事例随能量增加占比减少。



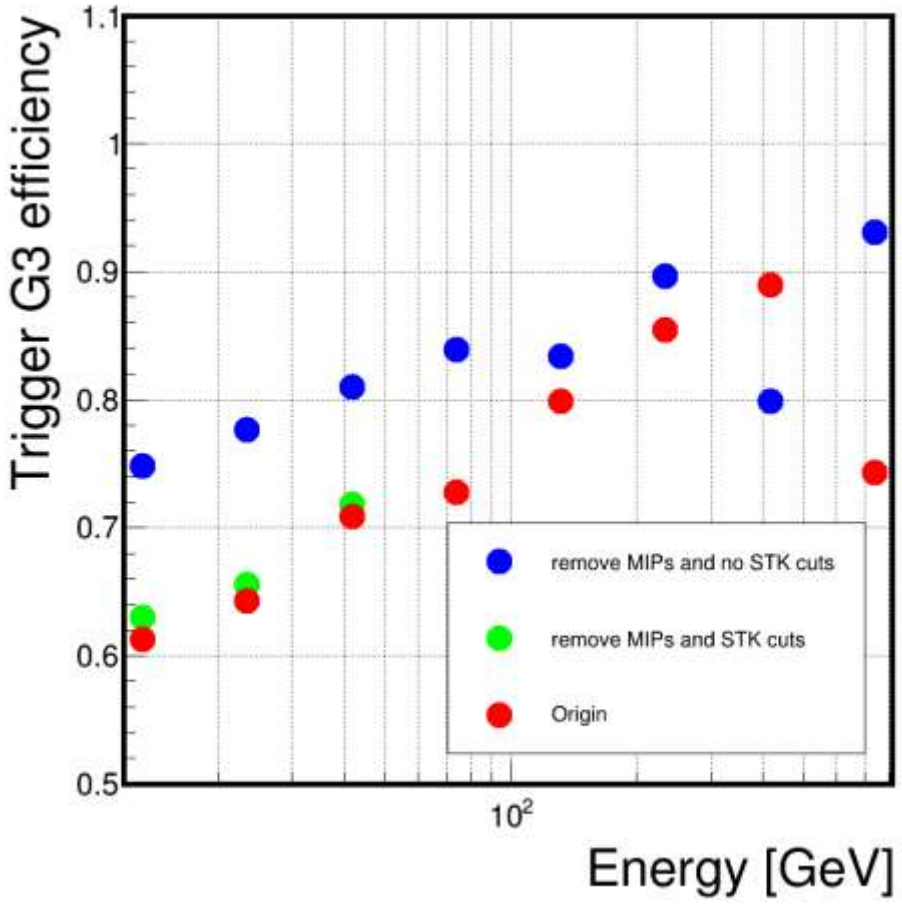


(h) Flight Data for eight energy region

Figure 3.3: Zeta value

STK Charge Reconstruction

STK 有效信号的筛选，人为把簇射过早的事例排除了，即留下更多MIPs事例。



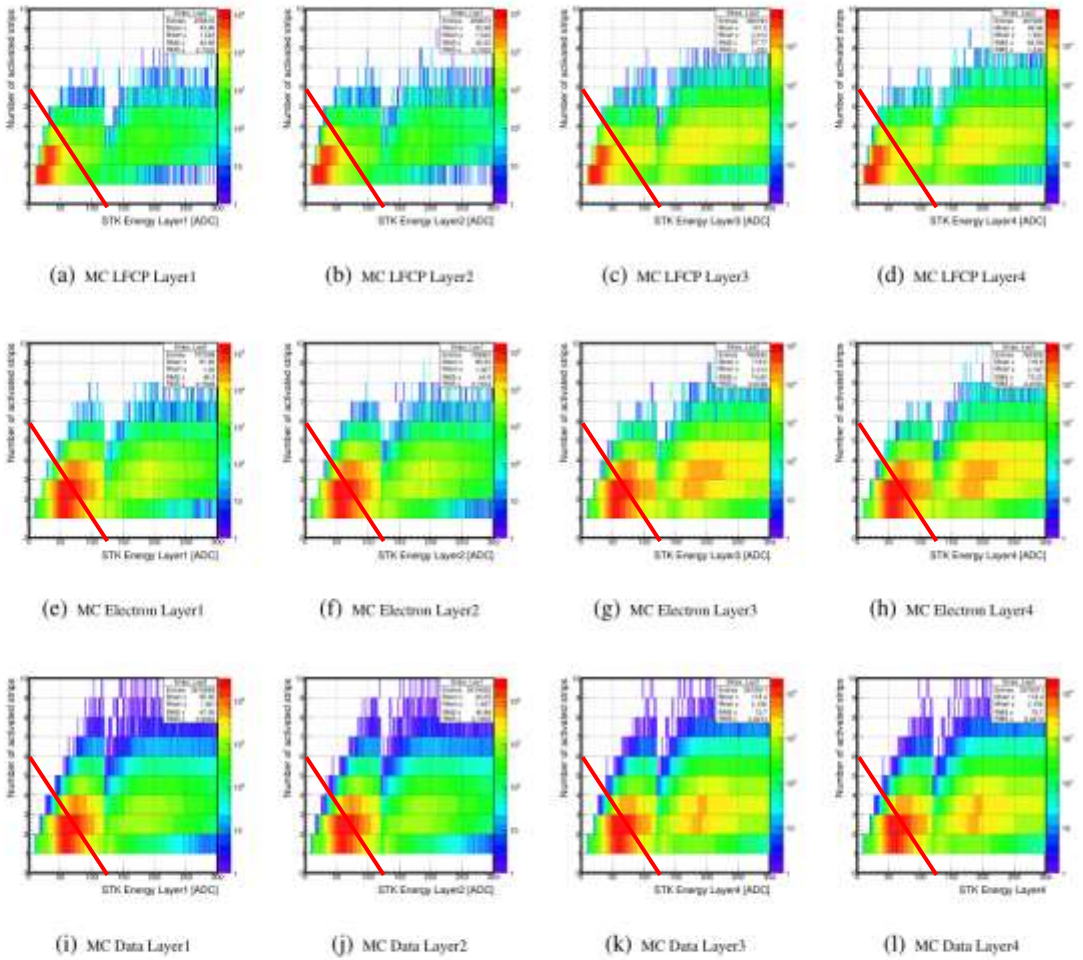
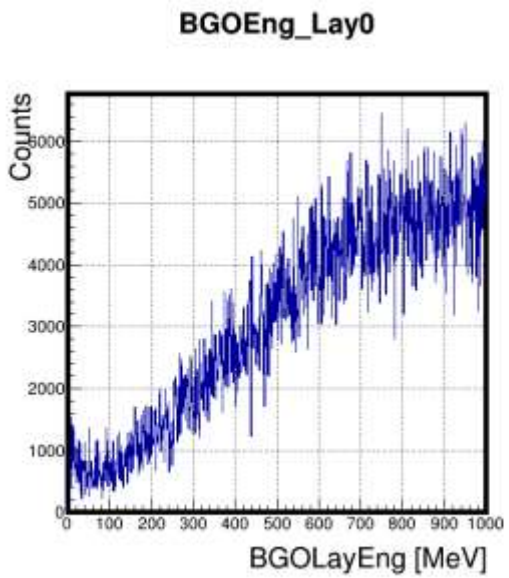
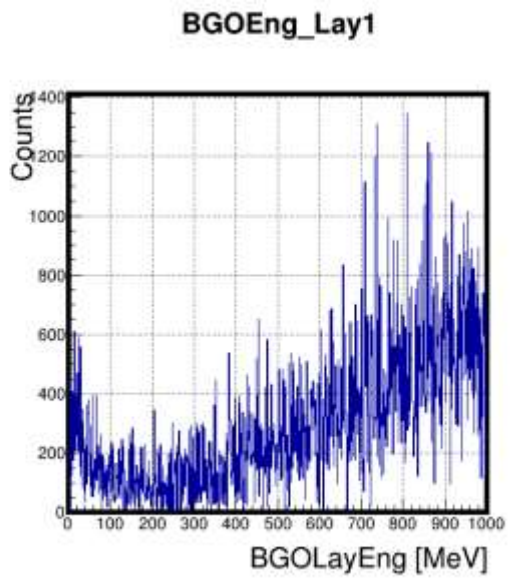


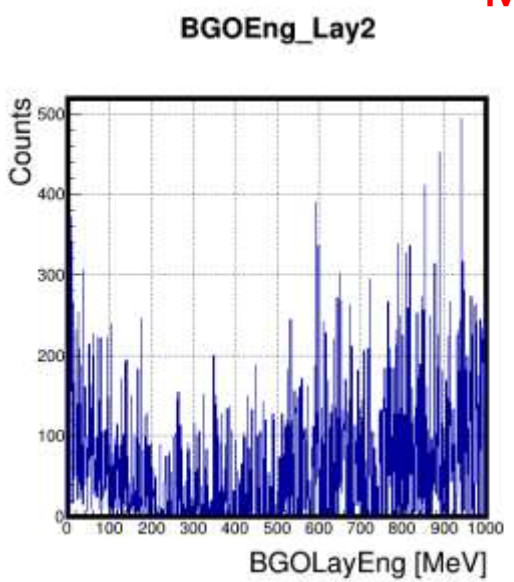
Figure 3.5: The distribution of STK strips under different layers and samples. Whose X-axis is the cluster energy of this certain layer and Y-axis represents the number of activated strips in this cluster.

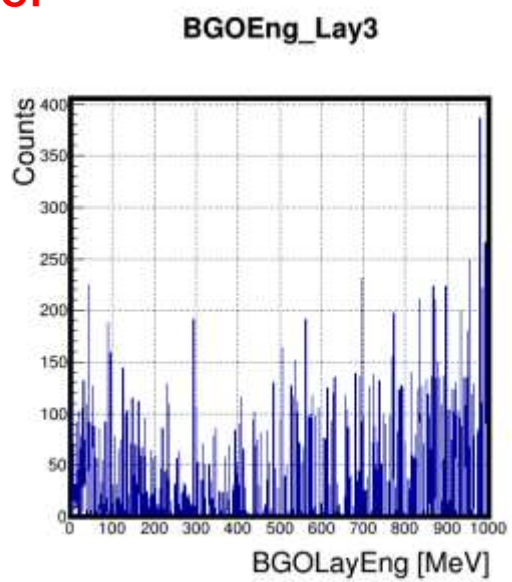
Shower cut

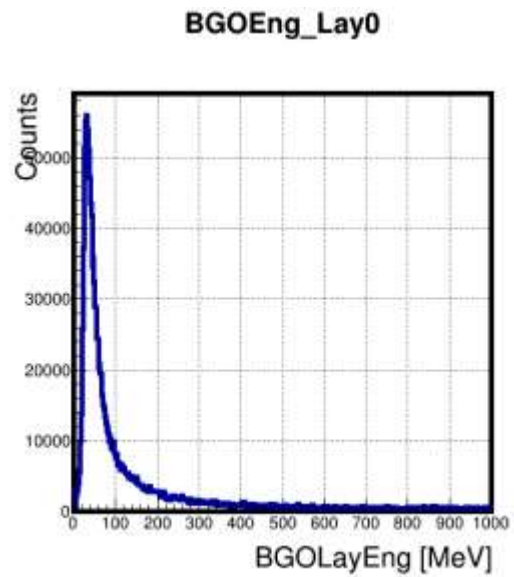


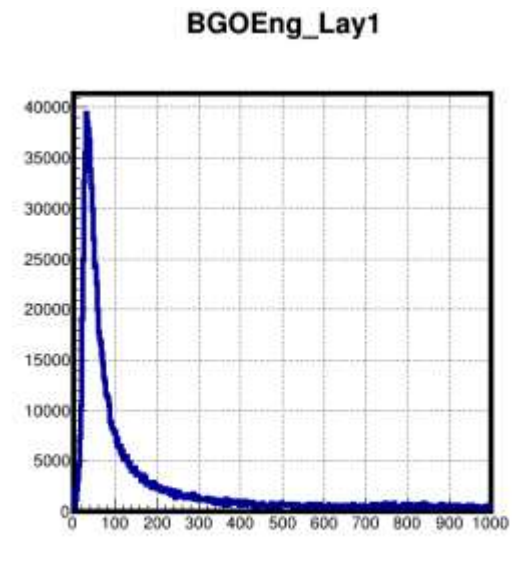


MC LFCP

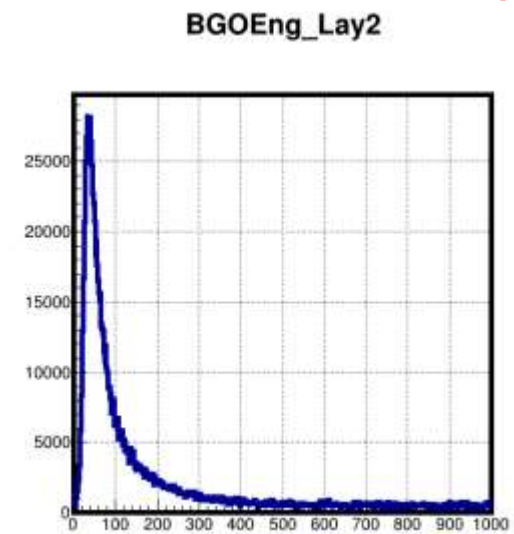


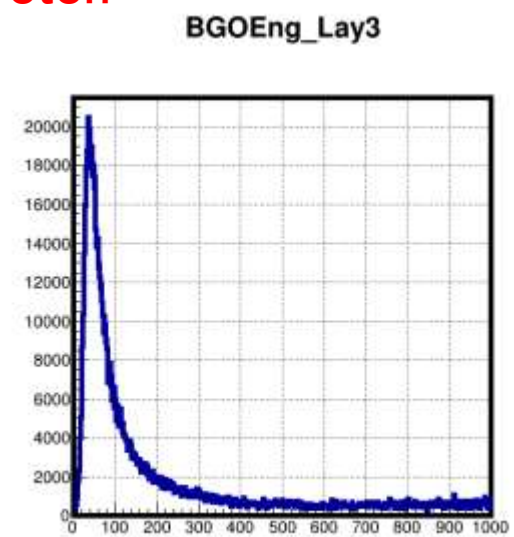






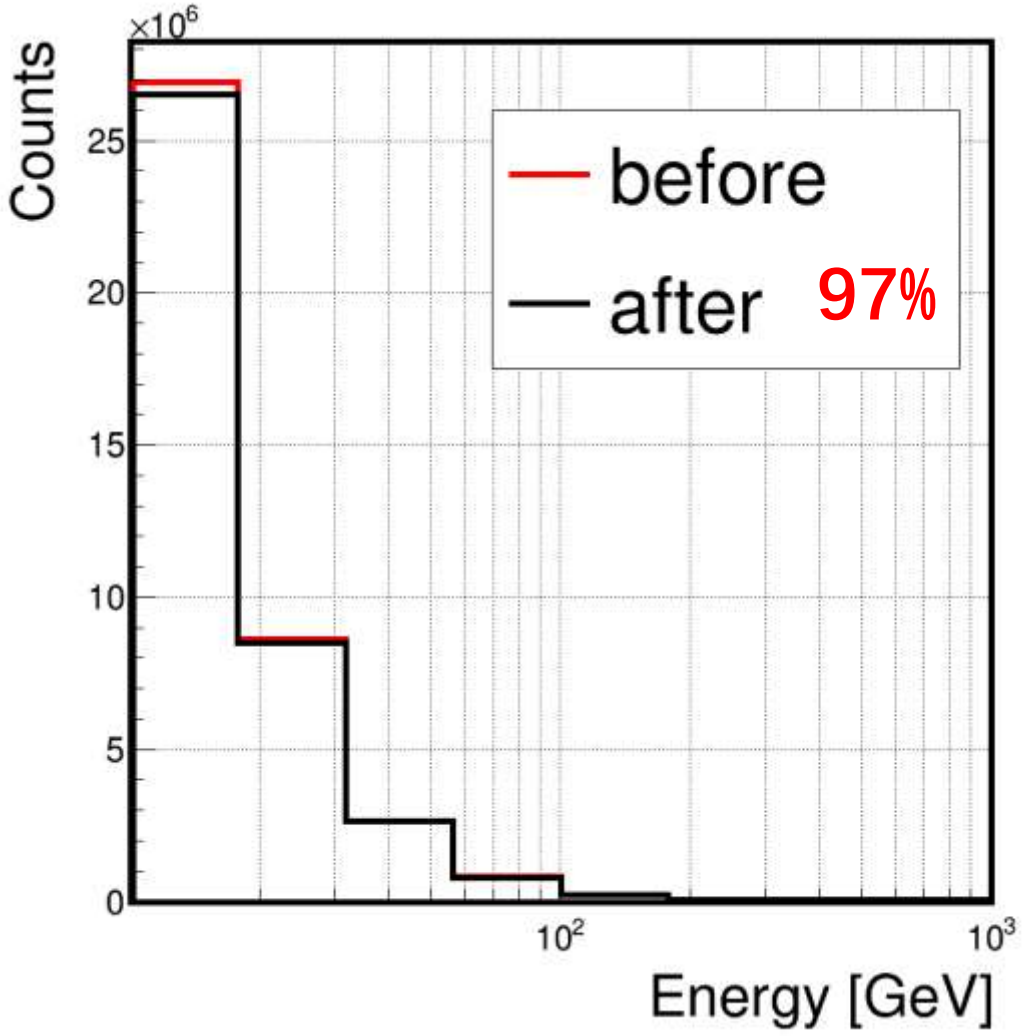
MC Proton

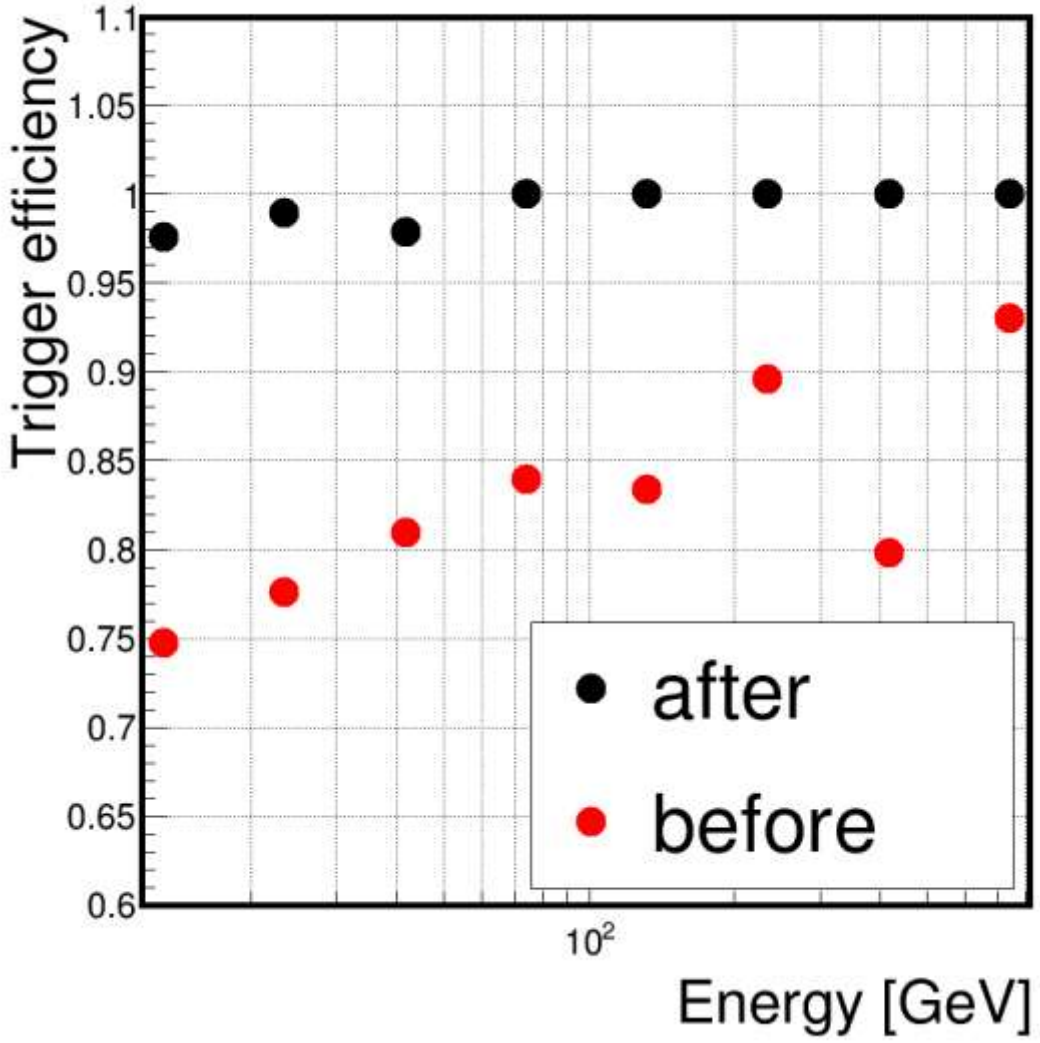




Shower cut

Max BGO deposit energy of the first three BGO layers should lower than 300 MeV.





Track Efficiency