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Analysis of test beam data

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Outline

- Beam test
- Calibration
  - Pedestal
  - Gain ratio
  - MIP
- Performance
  - Selection and PID
  - Linearity and energy resolution

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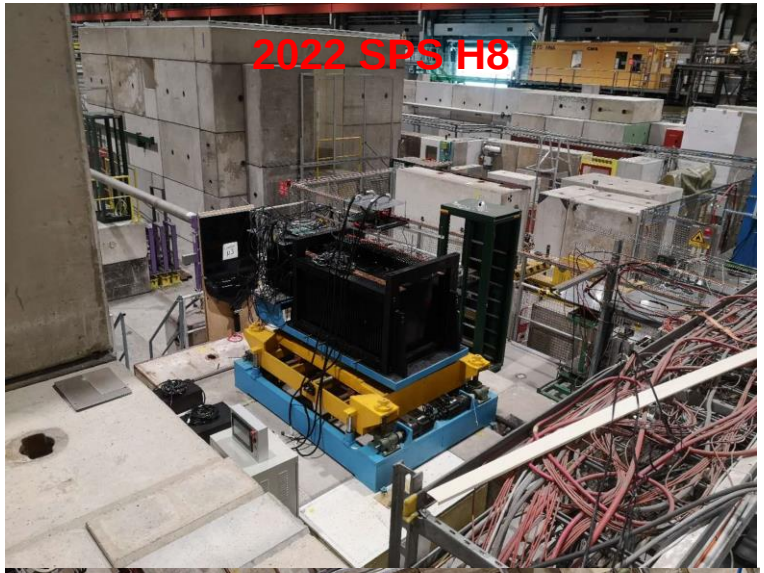
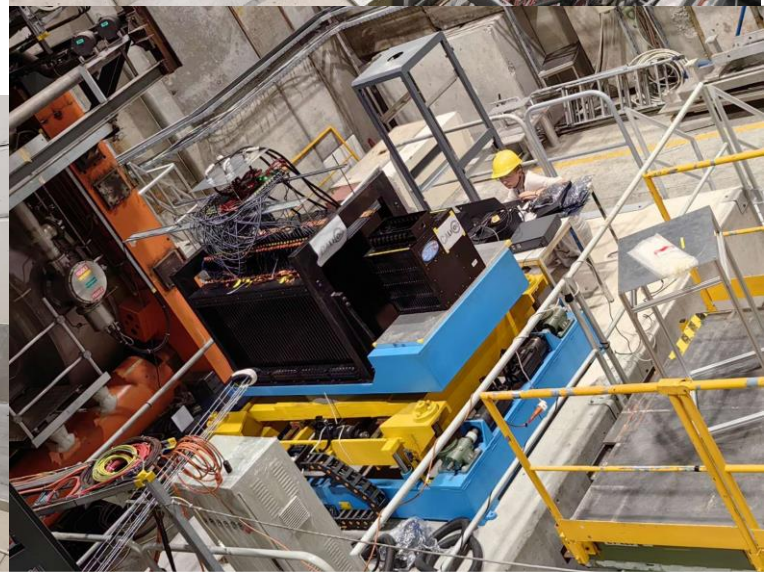
Beam test

- 3 beam tests has been done
  - 2022 October in SPS
  - 2023 May in SPS and PS
- Data
  - Electronic calibration data
  - Muon scanning
  - $\pi^{\pm}\ and\ e^{\pm}$



2023 PS T9



2023 SPS H2

Outline

- Beam test
- Calibration
  - Pedestal
  - Gain ratio
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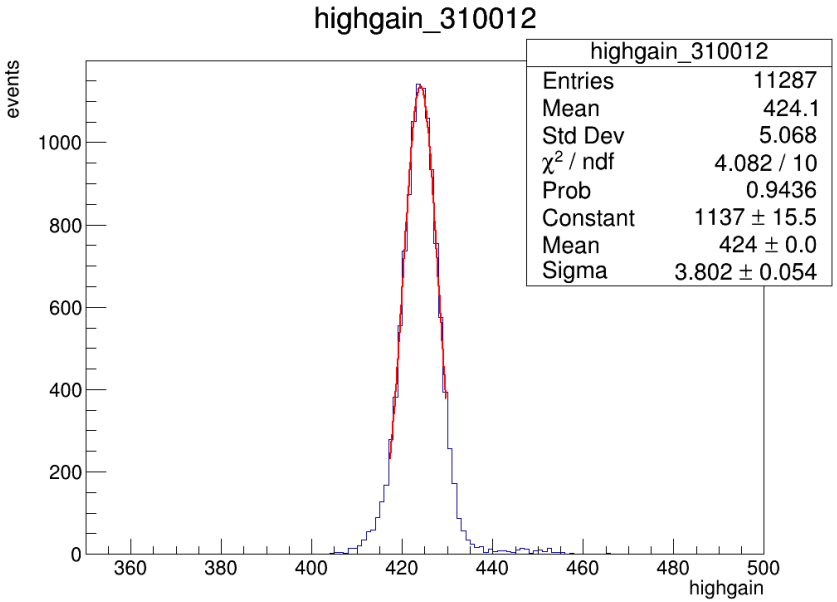
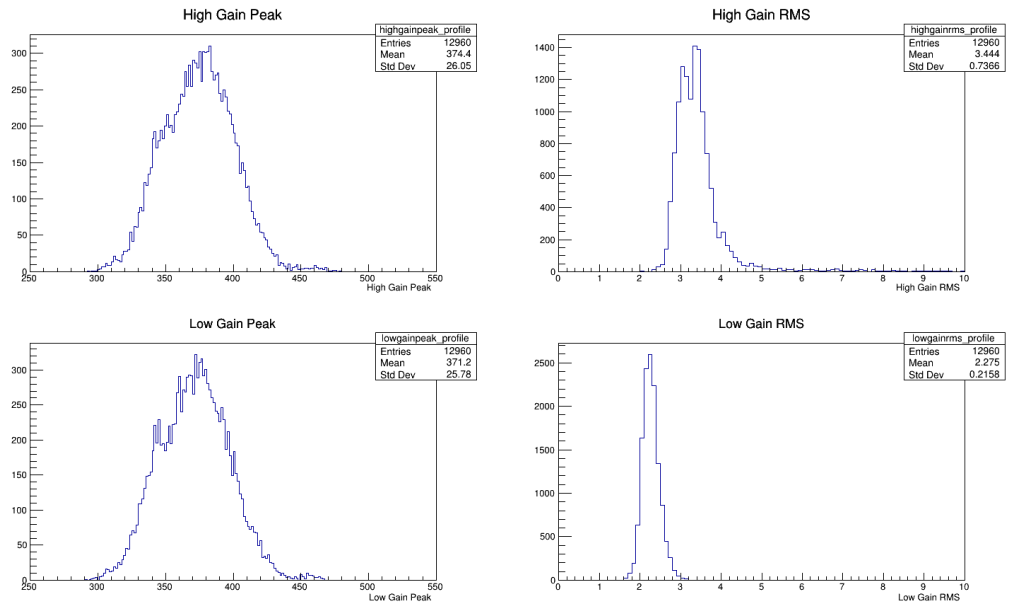
Pedestal

- Calibration file: an external forced trigger is used to generate this file
- The pedestal of each channel is analyzed



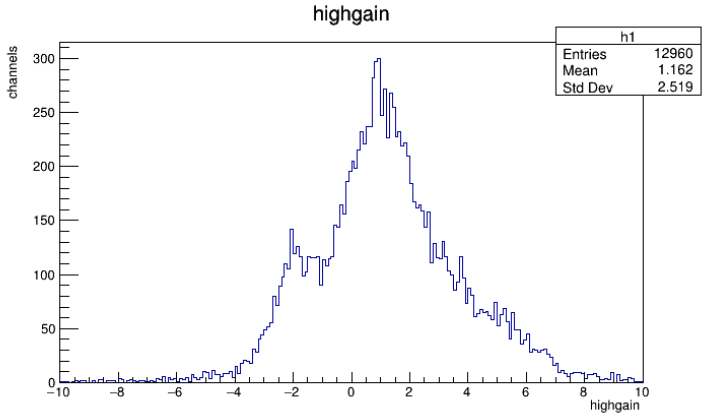
Pedestal distribution of a single channel

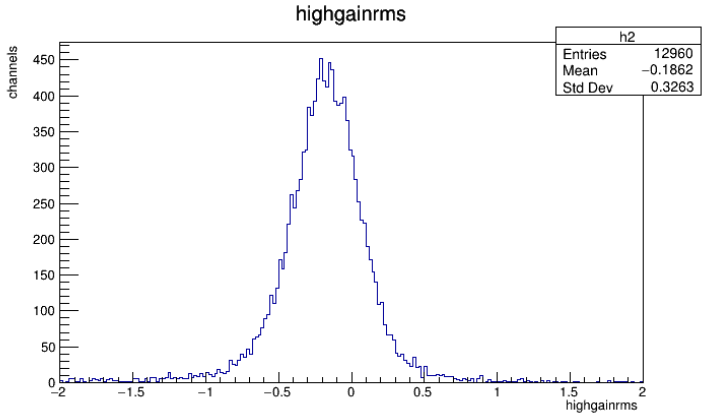


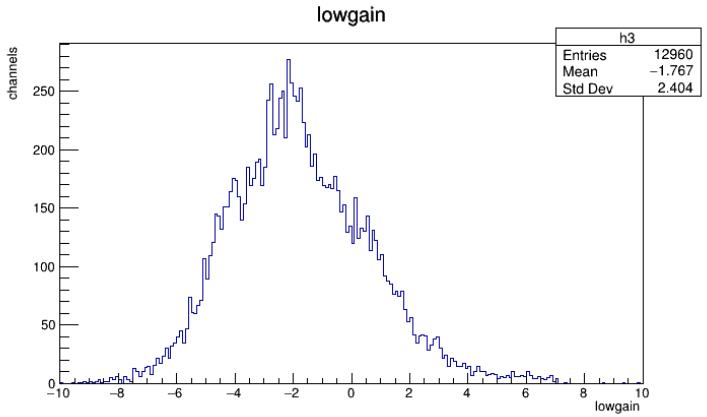
Fitting result of all channels

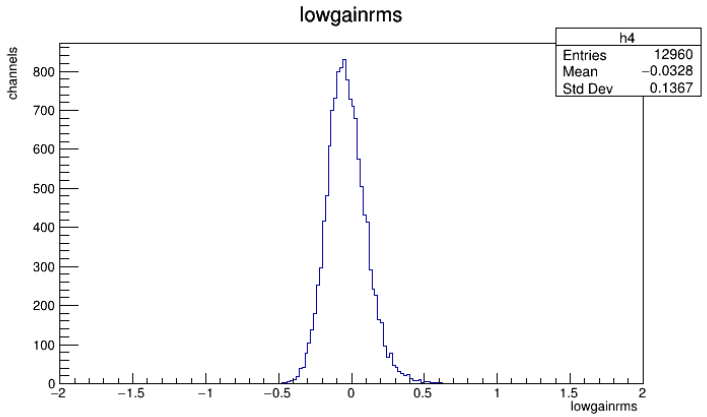
Pedestal

- The difference between pedestal of 2022 and 2023 is small



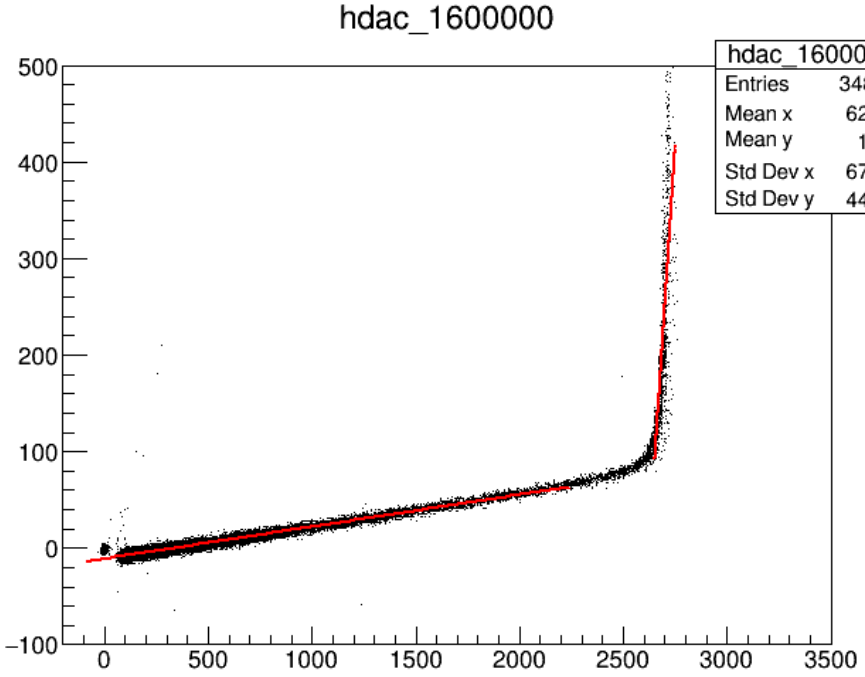




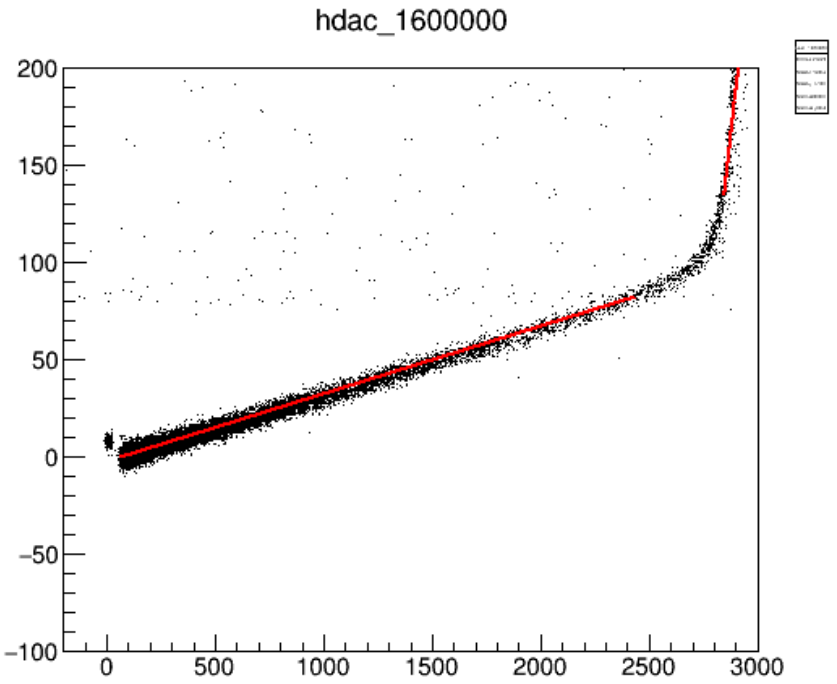


Gain ratio

- The gain ratio of the high/low gain is calibrated from pion beam data
- The saturation point is fitted as a parameter for each channel



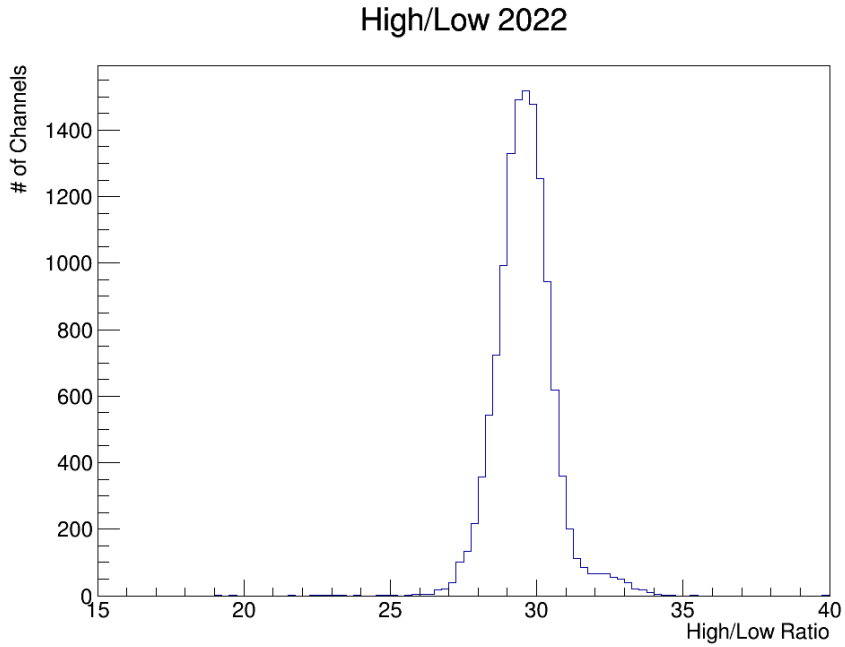
Calibration result of 2022



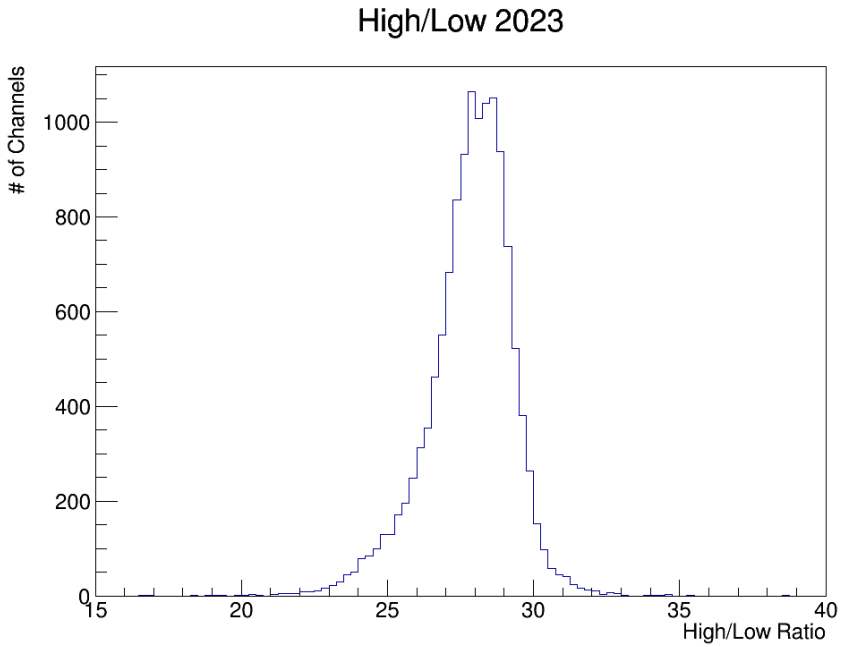
Calibration result of 2023

Gain ratio

- Each channel level is fitted and the parameter is stored



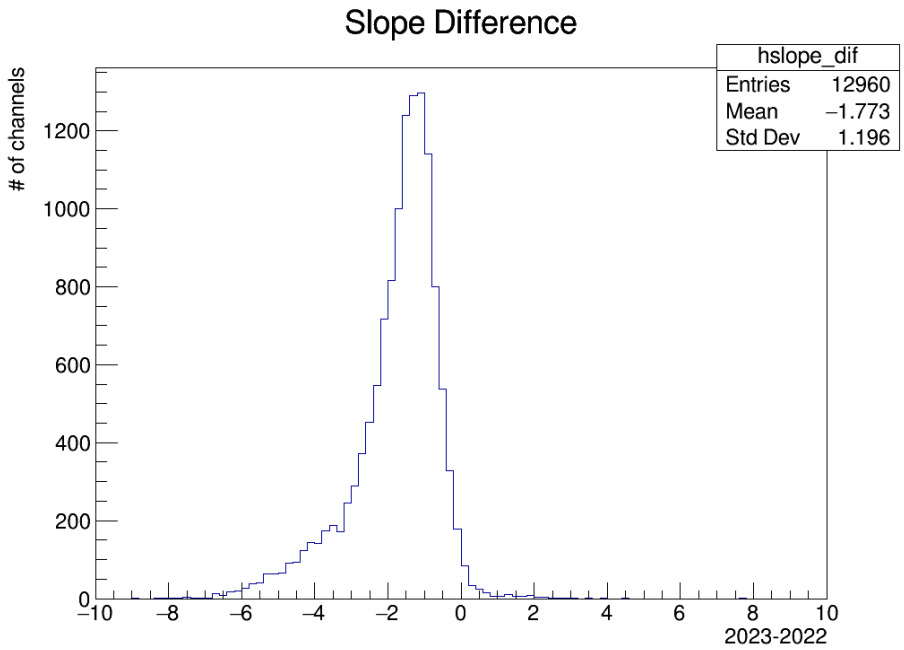
Calibration result of 2022

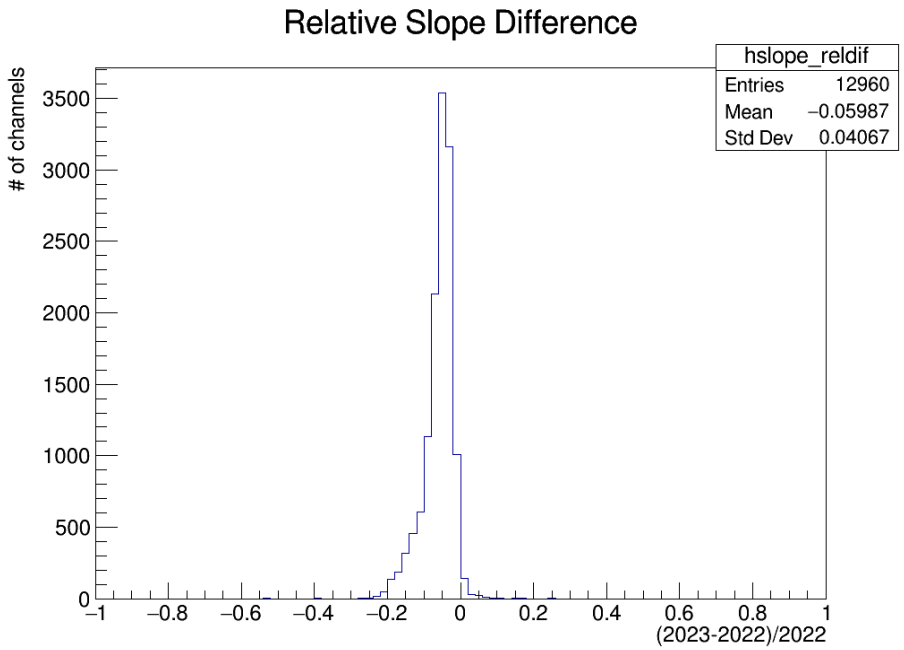


Calibration result of 2023

Gain ratio

- The result of 2022 and 2023 has small differences, this parameter is stable

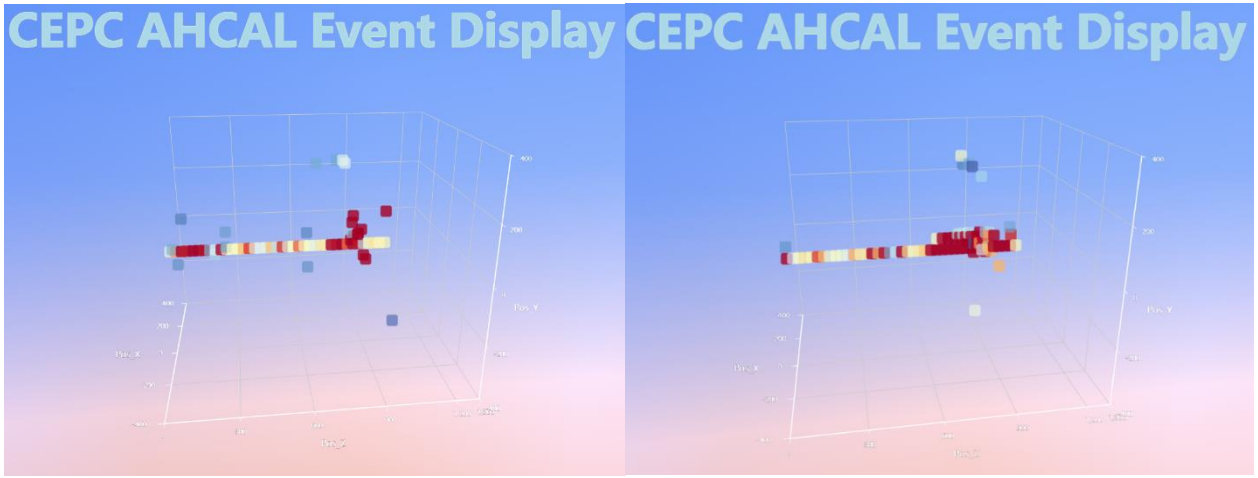




Difference on the gain ratio slope:2023-2022

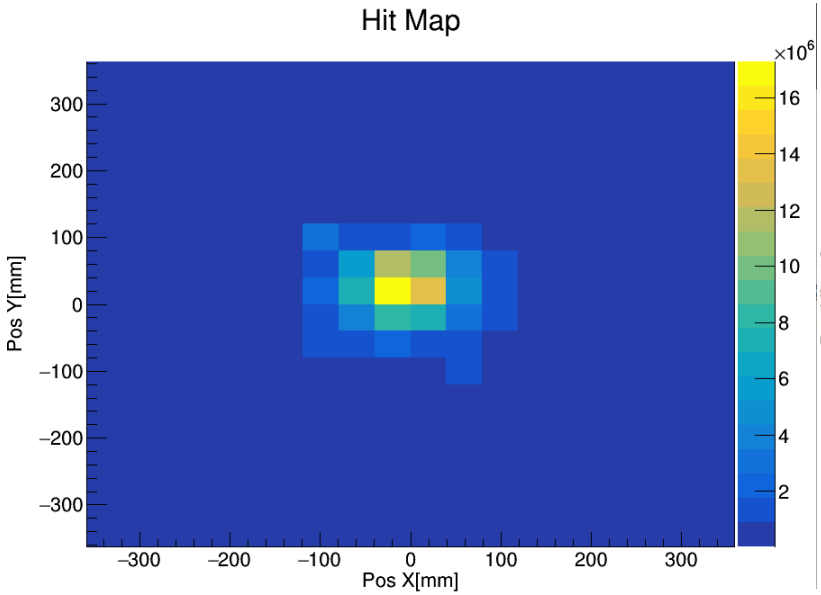
MIP Calibration

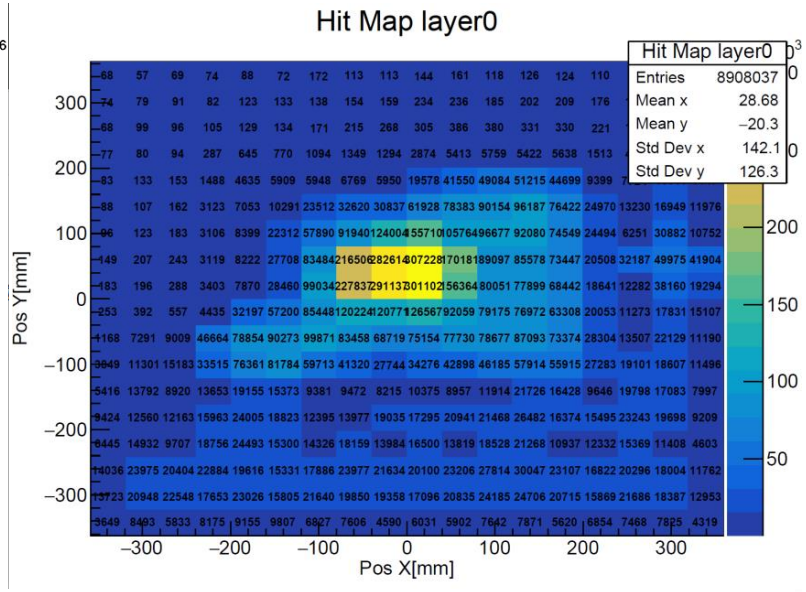
- Combined muon data
  - Different energy:100,108 and 160GeV
  - Different position
  - Different configuration
    - ECAL+HCAL and HCAL alone
    - Auto gain and normal gain



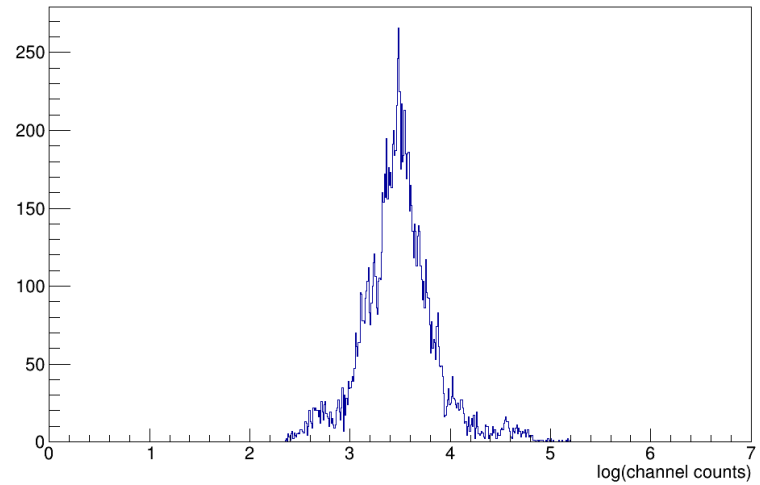
MIP Calibration

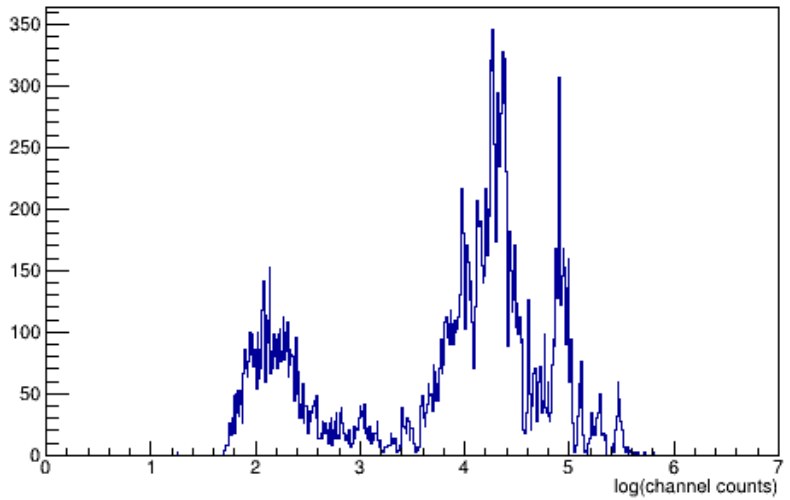
- Statistics overview





Hit map 2022 and 2023

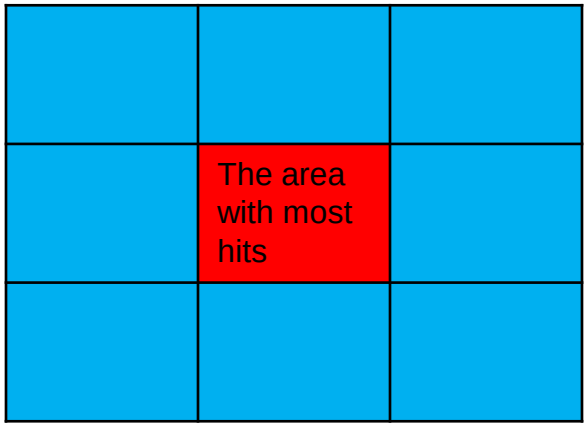


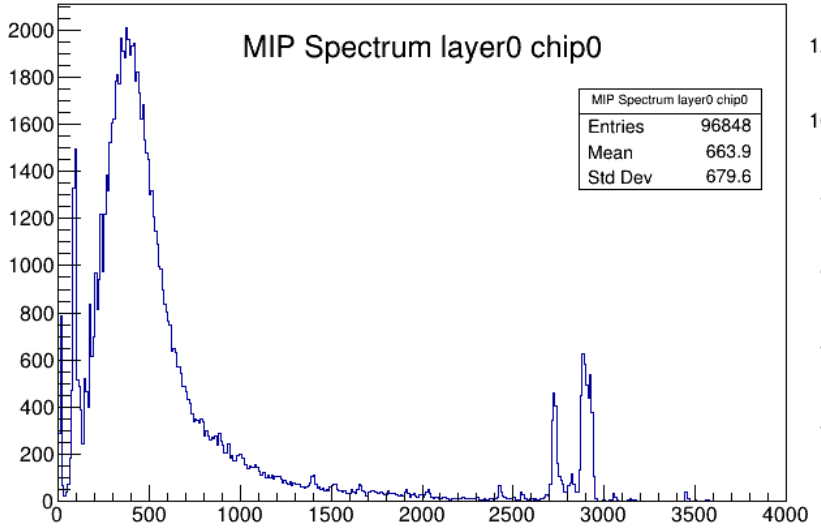


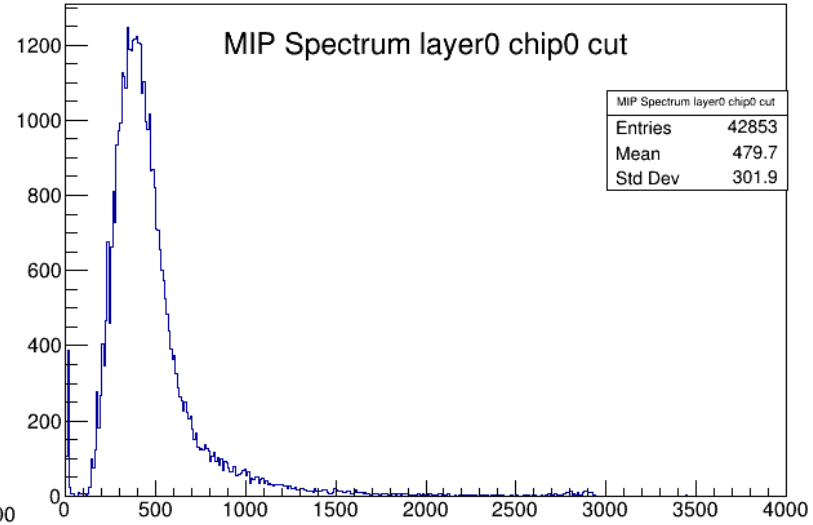
Logged Channel counts

MIP Calibration

- Selection criteria
  - Shower rejection
    - Max layer hit <5
  - Position Selection
    - Select hits in the most area



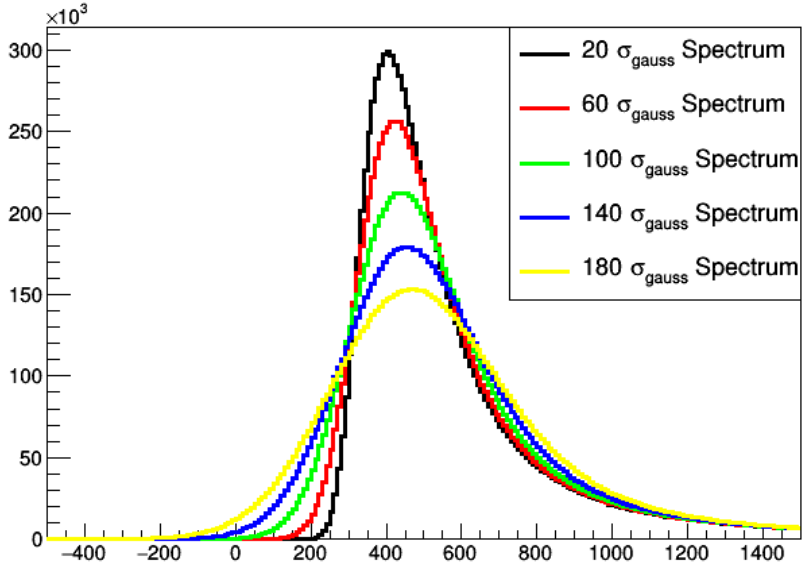


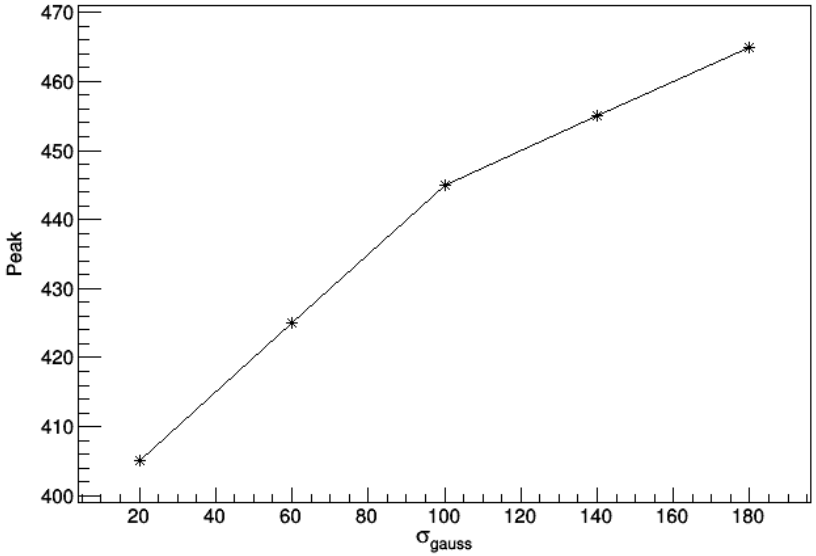


MIP Spectrum before and after Selection

MIP Calibration

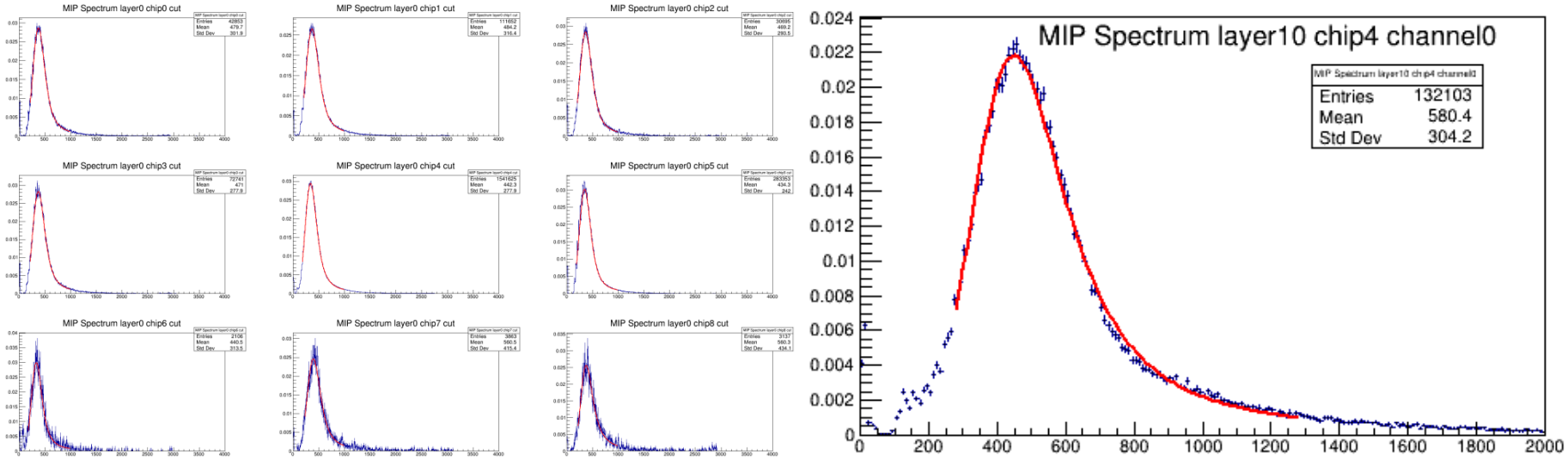
- The landau-gauss function is studied
  - The peak value is not only determined by the MPV but also determined by the σ_{gauss}





MIP Calibration

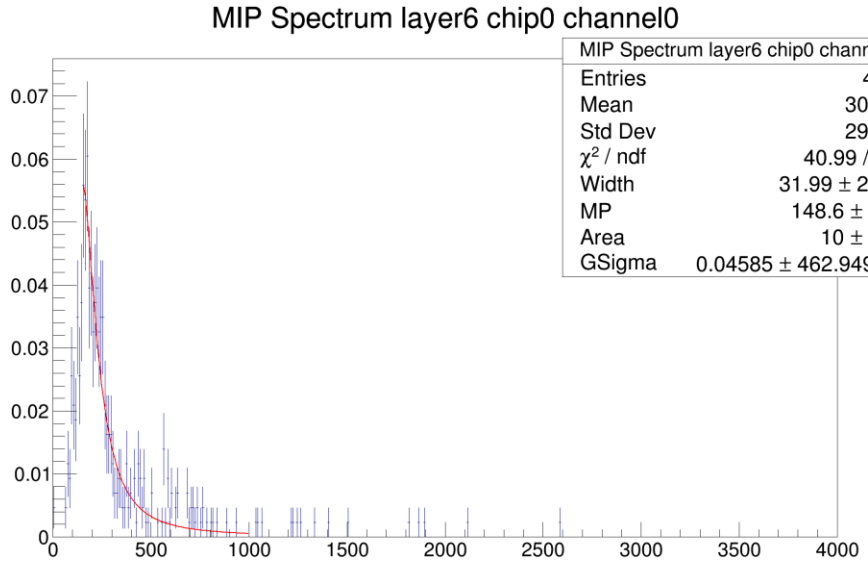
- The fitting is first done for each chip, then each channel is fitted
- All chips have good fitting for 2023 data



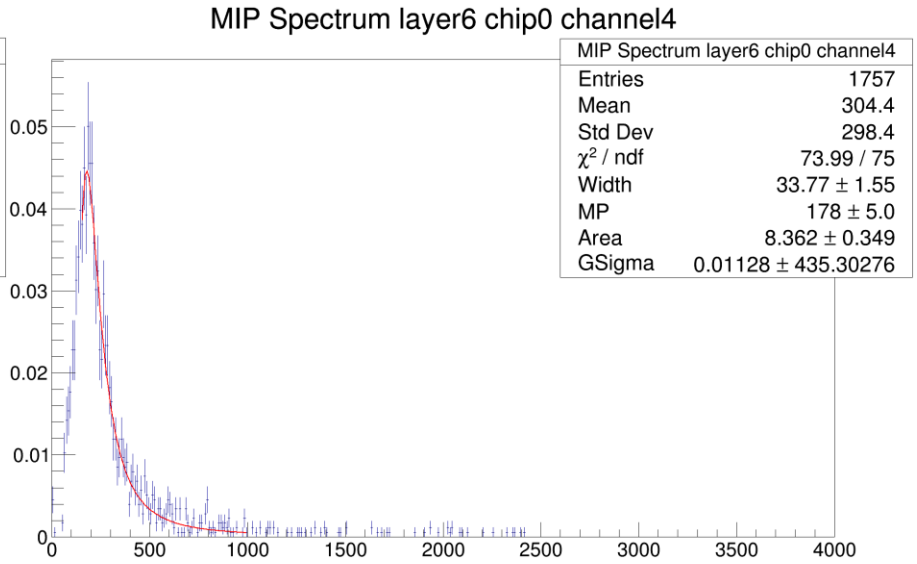
MIP Spectrum Fitting: chip and channel

MIP Calibration

- Good channels will be tagged as 1
- Some channels fail the fitting
  - Bad chip: tagged as -1
  - Inadequate statistics: tagged as -2
  - Bad fitting: tagged as -3

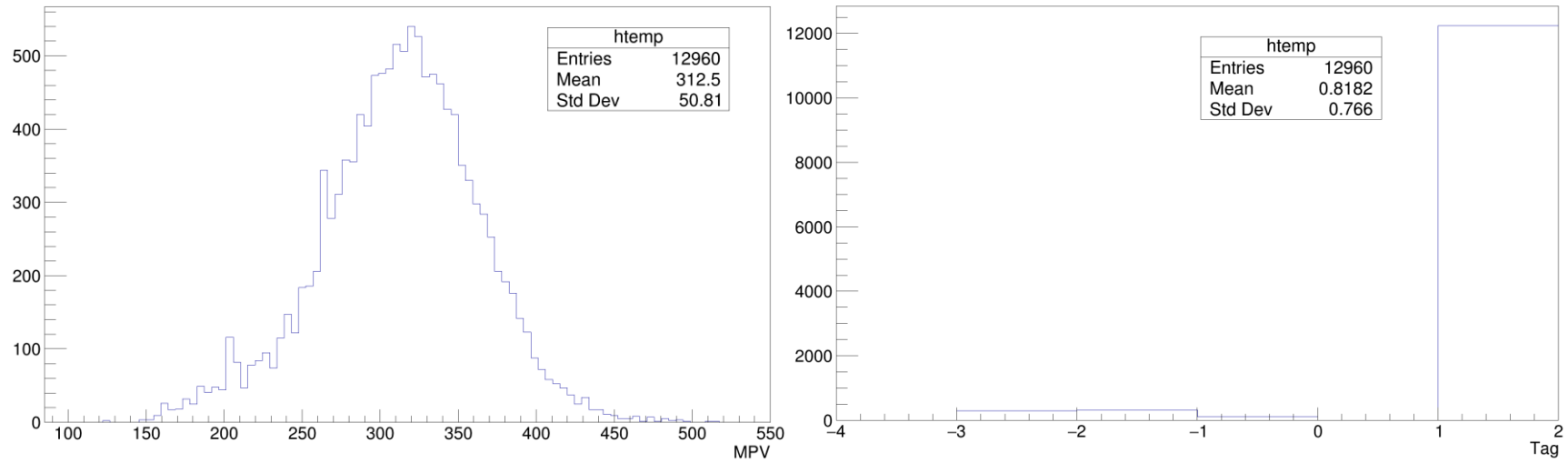


Inadequate statistics

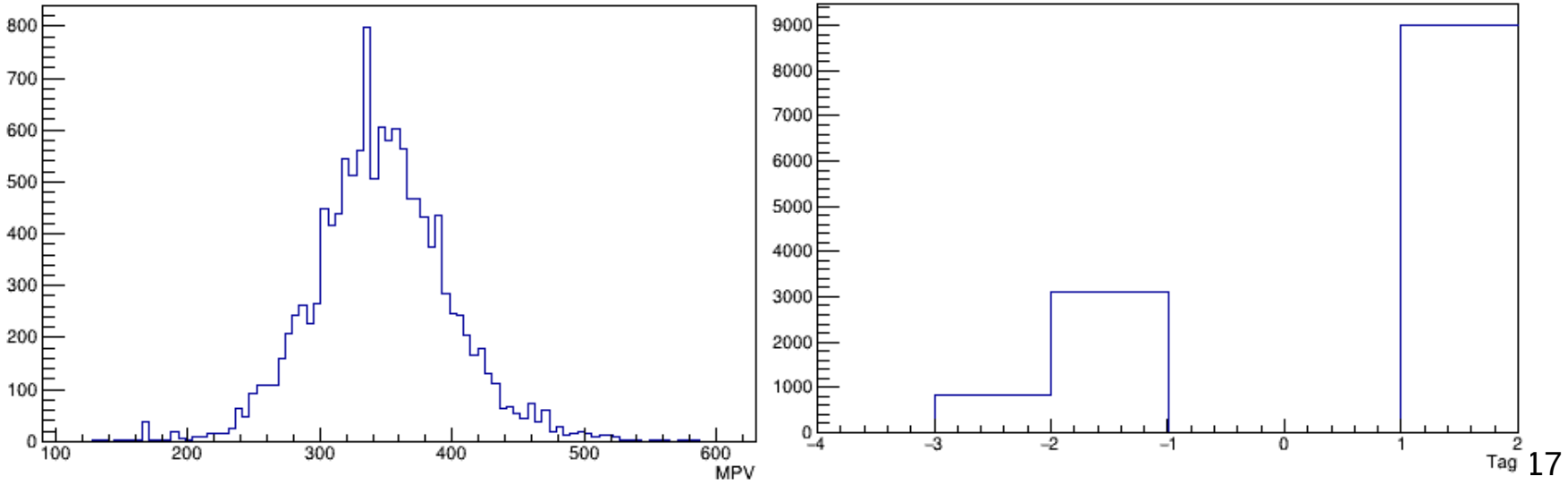


bad fitting

MIP Calibration



fitting result 2022:MPV and fitting tags



fitting result 2023:MPV and fitting tags

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- Beam test
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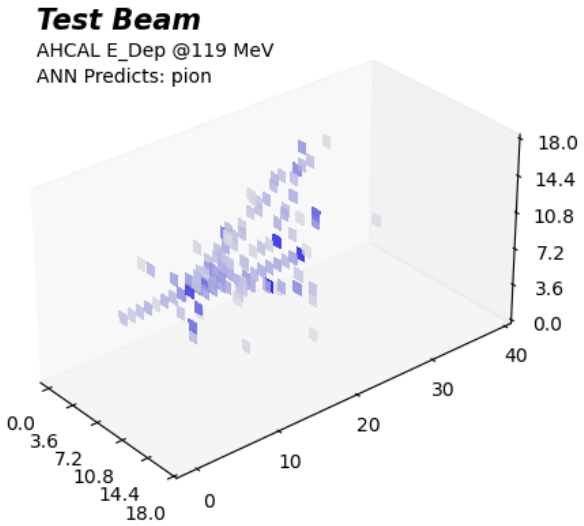
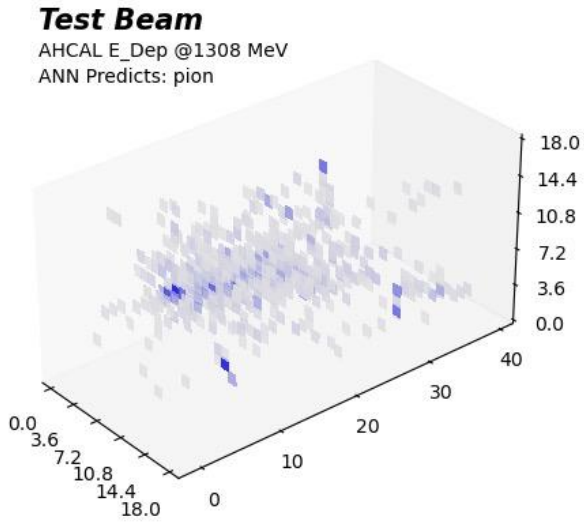
- Performance
  - Selection and PID
  - Linearity and energy resolution

Selection and PID

- HCAL alone pi- data taken in 2023 SPS is used to see the basic performance of HCAL
- Pi- energy from 10 to 80 GeV is analyzed
- Pi- MC is also generated for analysis

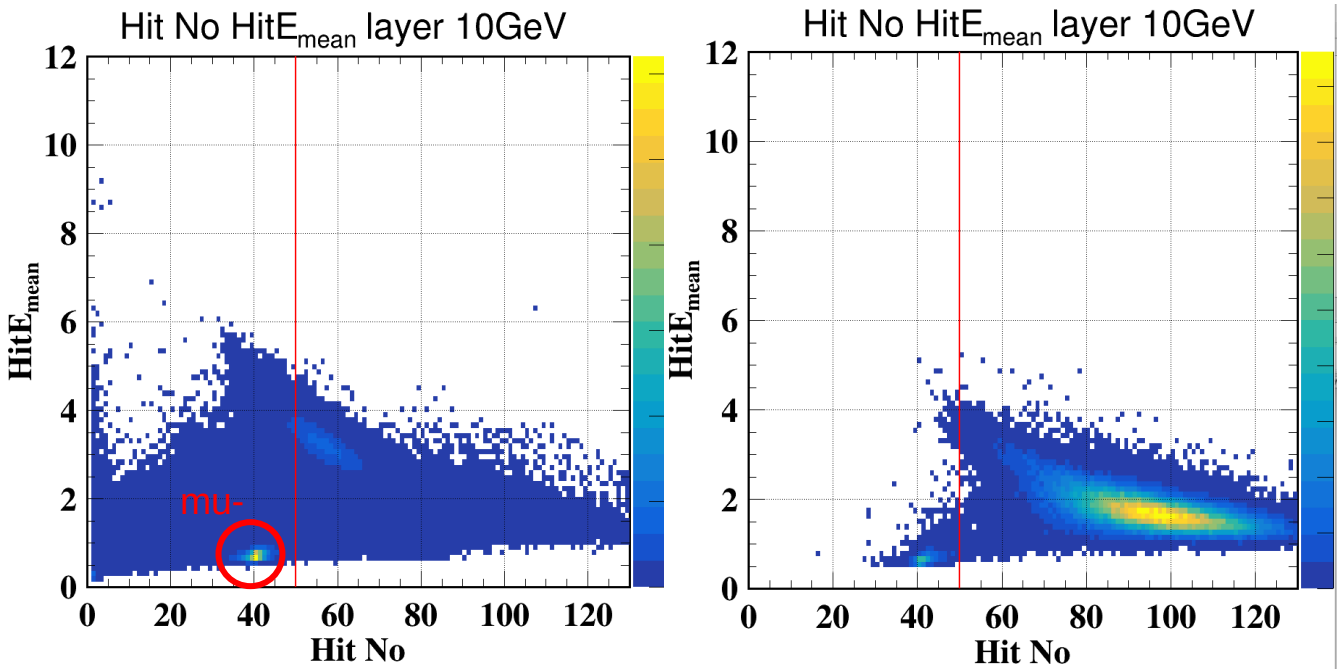




event display: 10GeV and 80 GeV pi-

Selection and PID

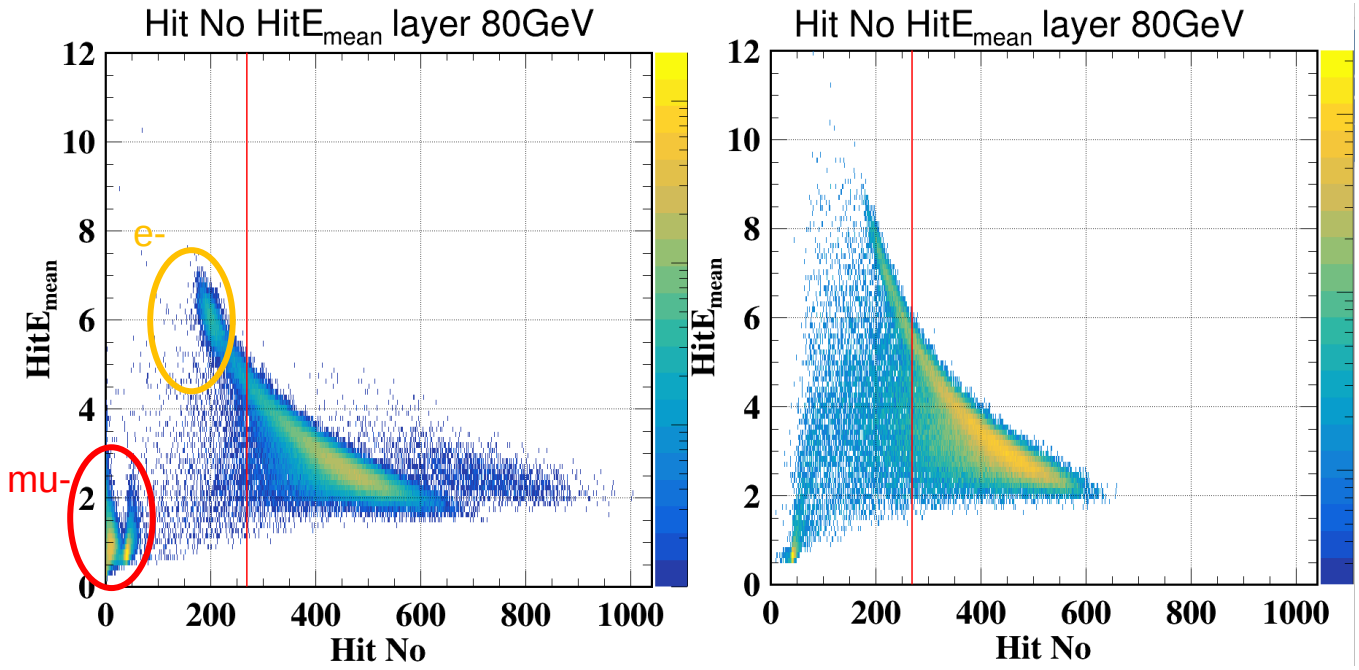
- Leakage cut is applied to pion data and MC
  - Start layer
    - The first layer with more than 4hits is defined as the shower start layer
    - The start layer<5
  - Hit no
    - Different hit no cut is applied for different energy point



Hit No vs Hit E mean: 10GeV data and MC

Selection and PID

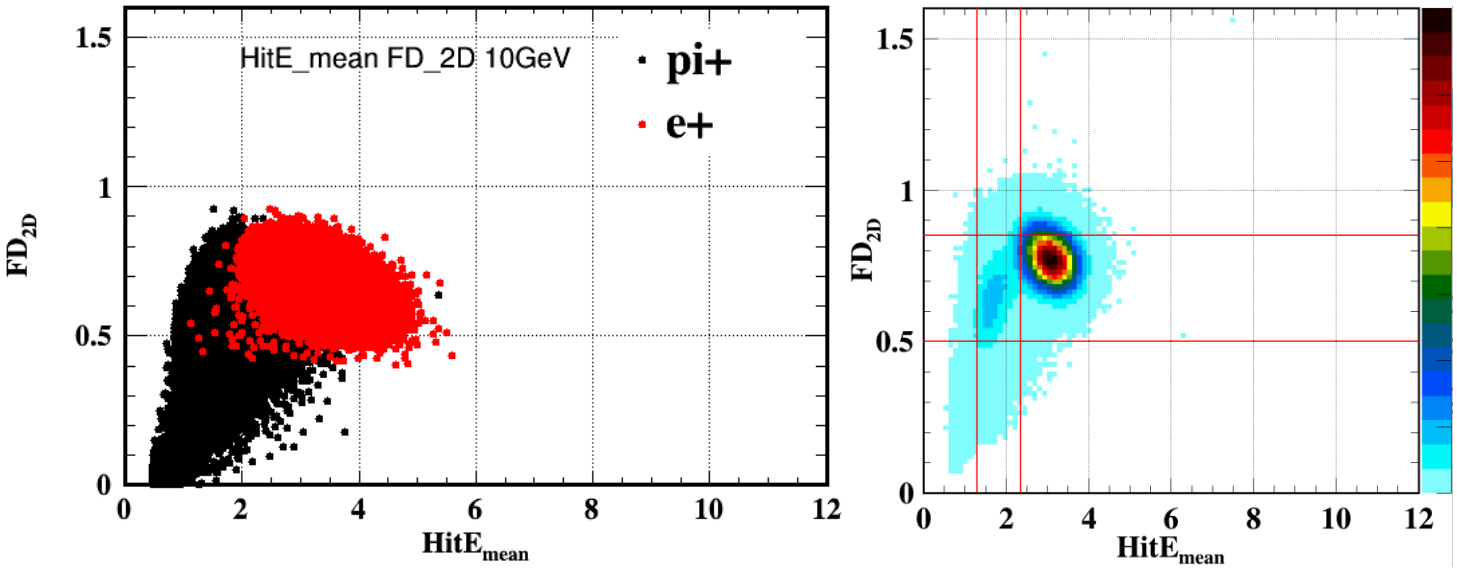
- The selection reject the muon or non-showered events
- In high energy point, e- is also cut by the selection



Hit No vs Hit E mean: 80GeV data and MC

Selection and PID

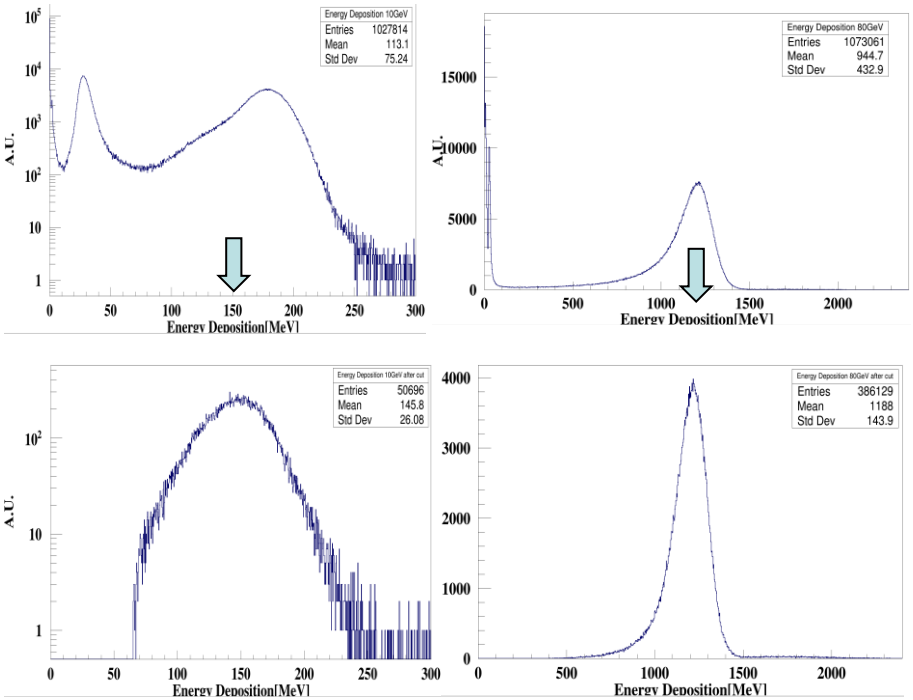
- PID
  - The beam purity is bad while energy < 30GeV
  - The PID cut using fractal dimension and mean of hit energy is applied to data of energy < 30GeV
  - Data of energy > 30GeV has no PID cut
  - This cut doesn't apply to the MC



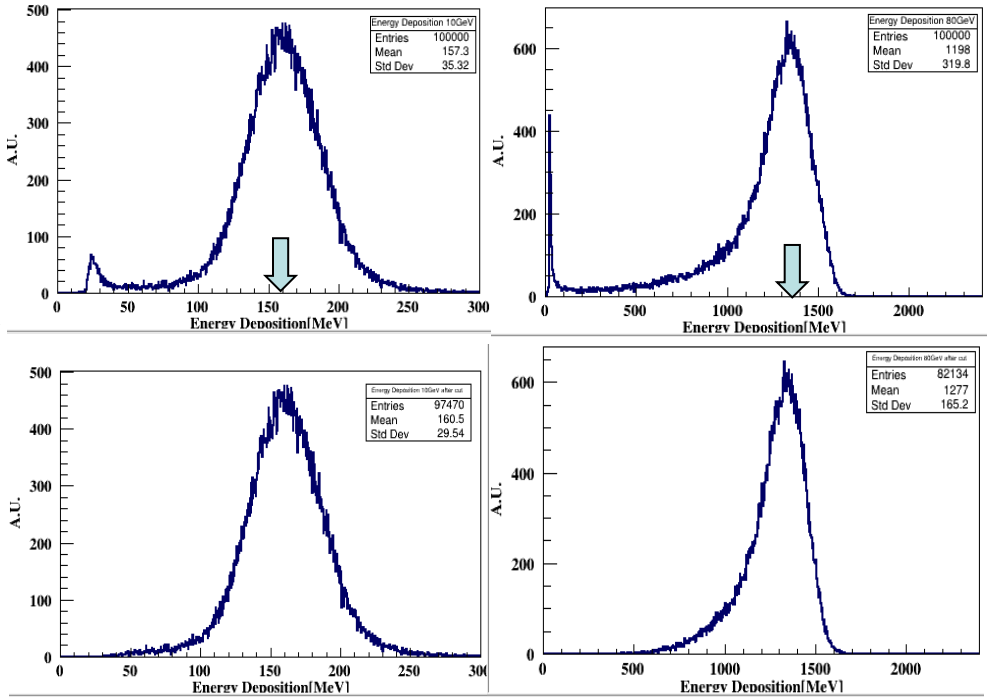
Hit E mean vs FD: MC and Data

Selection and PID

- The performance of selection
- Big disagreement is observed at low energy



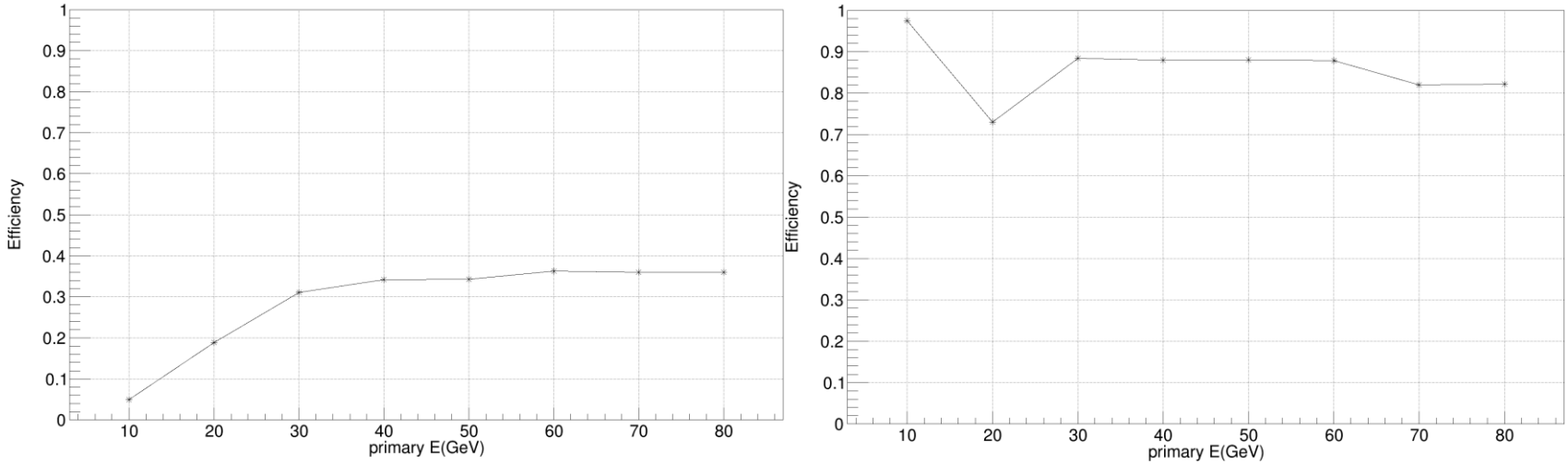
Data:10 and 80 GeV



MC:10 and 80 GeV

Selection and PID

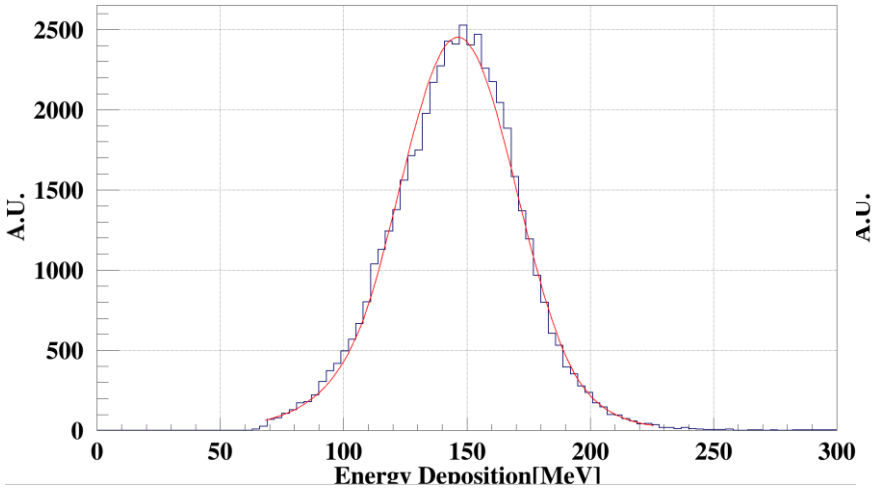
- Selection efficiency
  - The efficiency of MC is much high than efficiency of Data
  - The efficiency of MC is similar at different energy point while the efficiency of Data drops at low energy

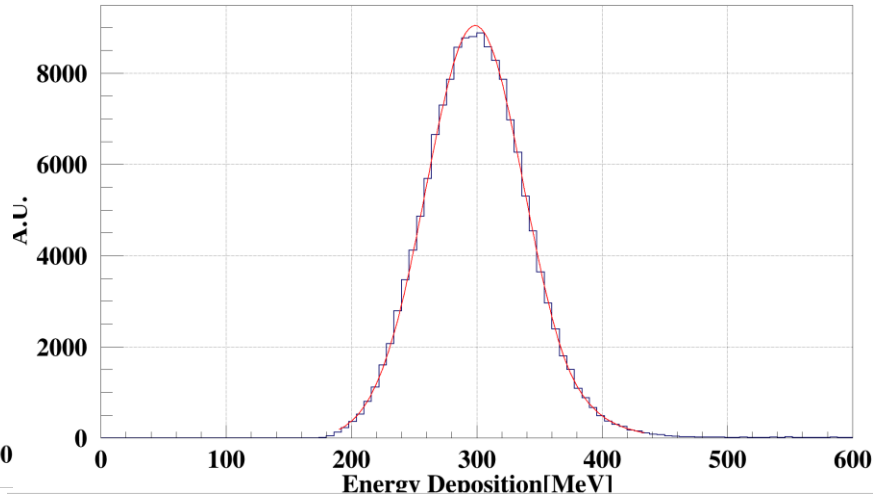


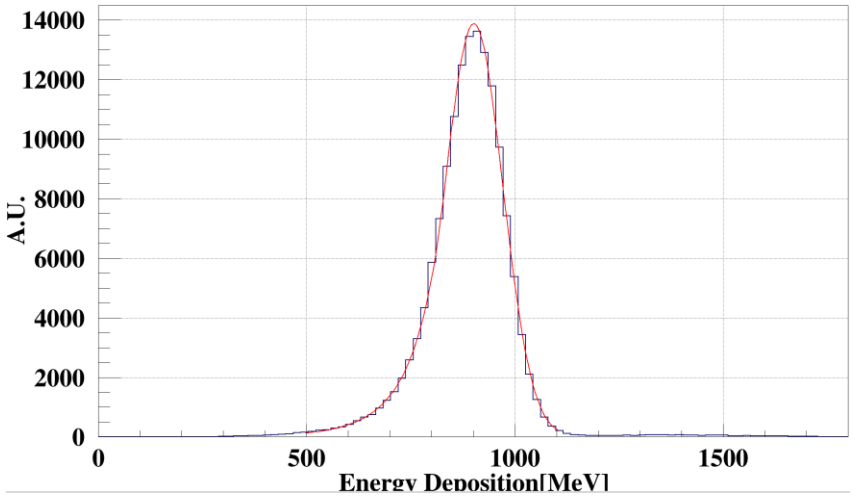
Overall selection efficiency: Data and MC

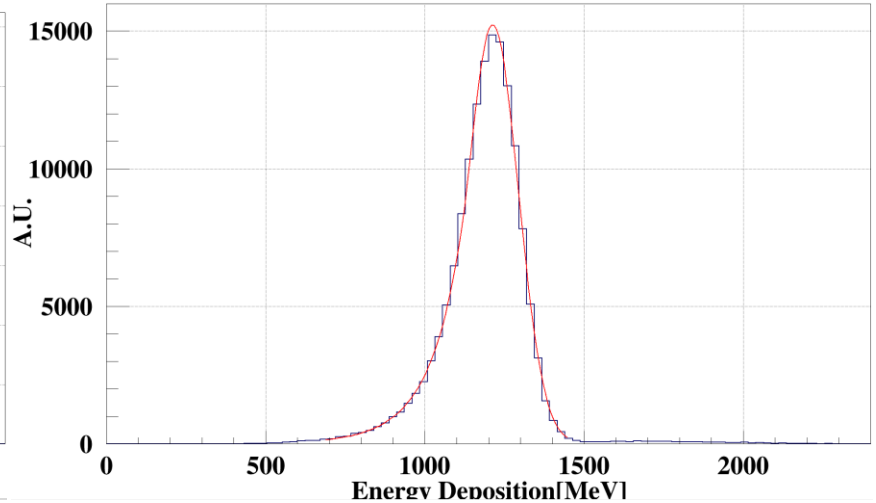
Linearity and energy resolution

- Crystal ball function is used for fitting





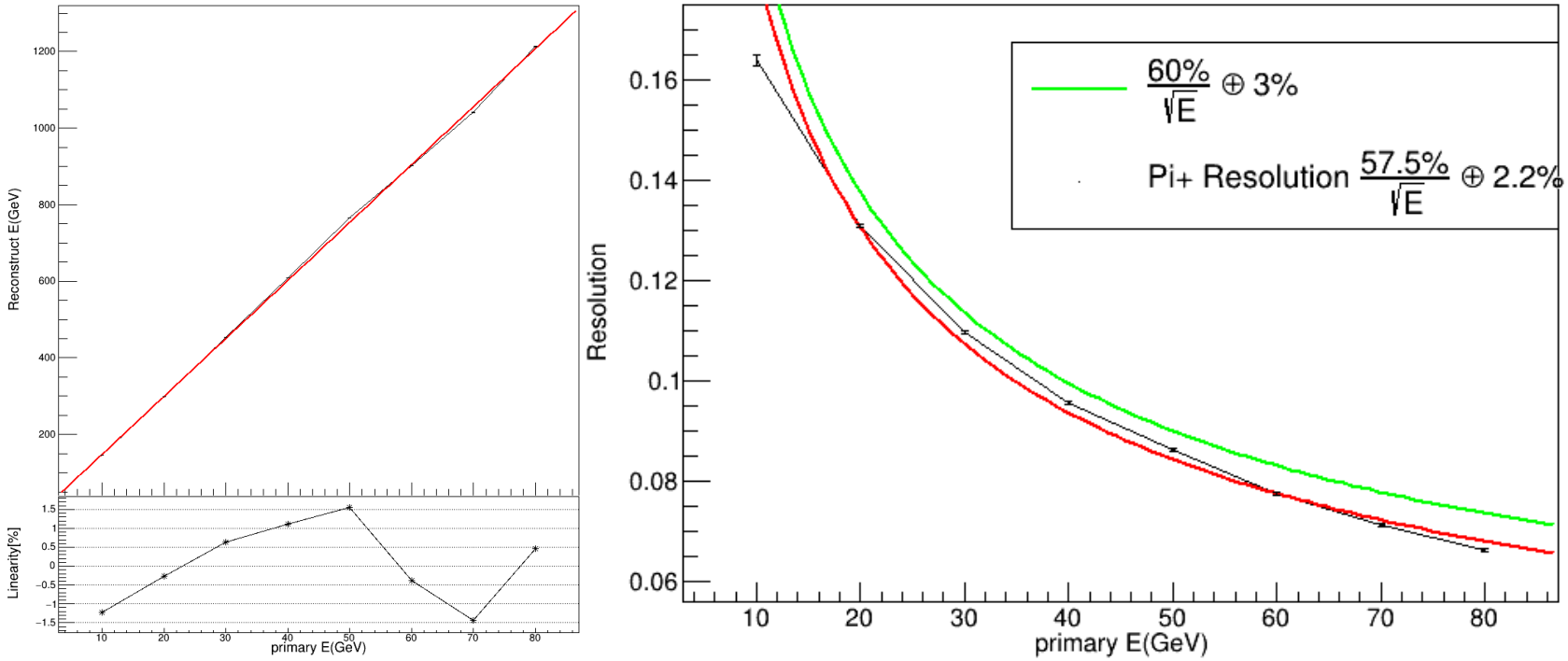




Energy deposition: 10,20,60,80GeV

Linearity and energy resolution

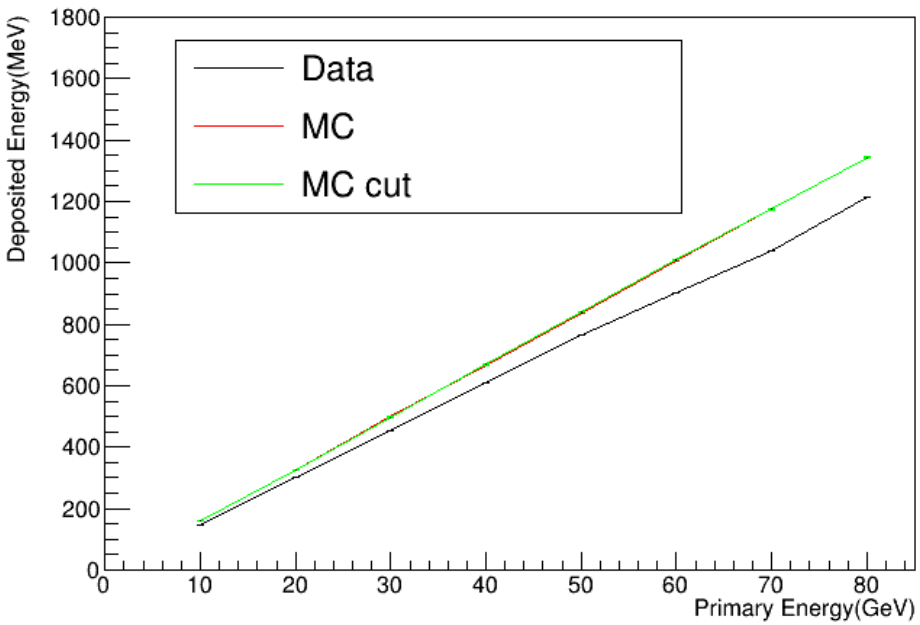
- The energy linearity is within $\pm 1.5\%$
- The energy resolution is $\frac{57.5\%}{\sqrt{E}} \oplus 2.2\%$

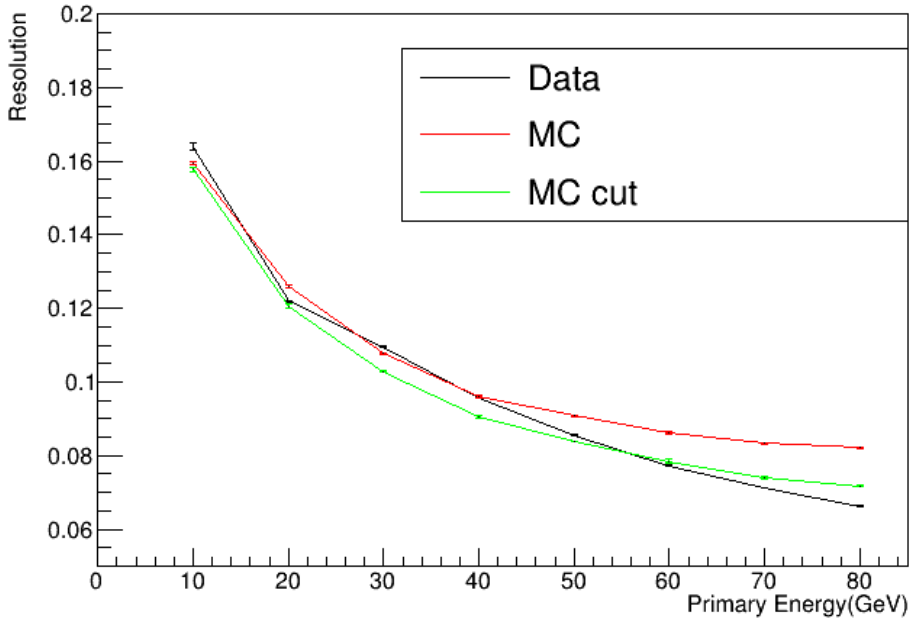


Energy linearity and resolution

Linearity and energy resolution

- There is still obvious difference between Data and MC





Energy linearity and resolution

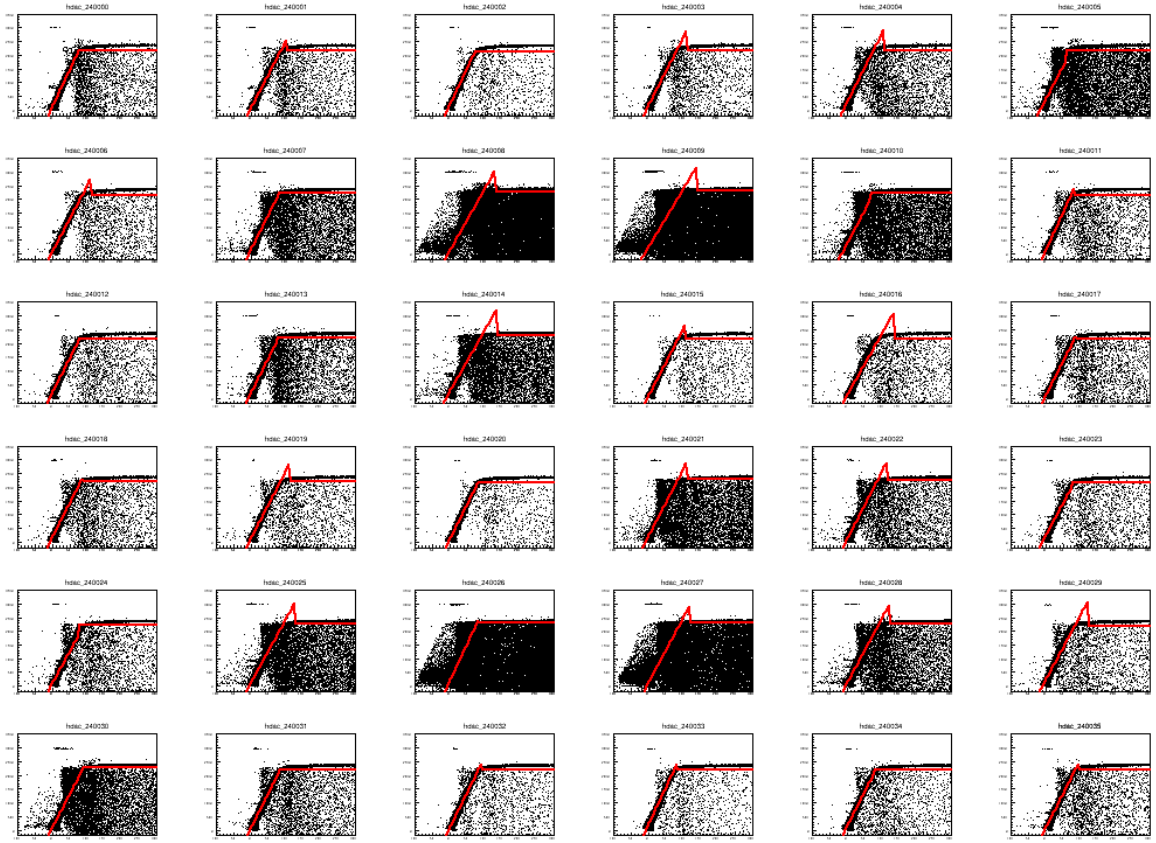
Summary and plan

- Summary
  - With the calibration done so far, the HCAL prototype reaches a energy linearity within $\pm 1.5\%$ and a energy resolution of $\frac{57.5\%}{\sqrt{E}} \oplus 2.2\%$
- Plan
  - Improve the performance with better calibration
  - MC and data agreement
    - Electron and muon first
    - Hadron may not easy

Back up

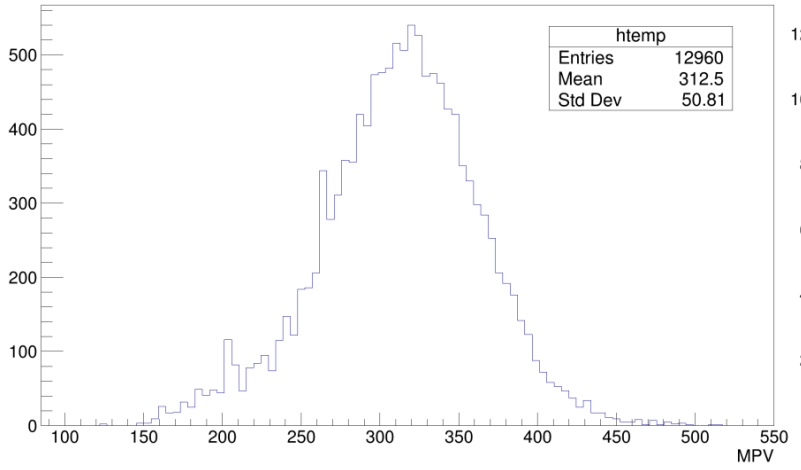
Gain ratio

- Some channels have abnormal performance
- Abnormal channel is recorded and a typical value of gain ratio and platform is set as the parameter of this channel

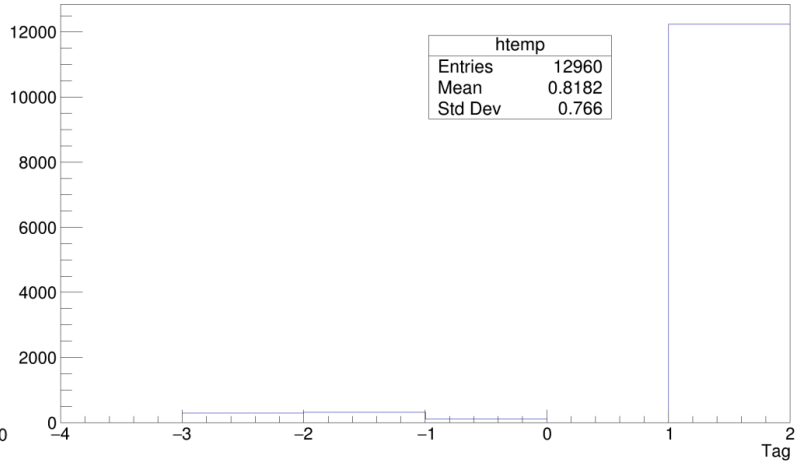


Channel selection

- Selection Criteria
  - $\mathrm{Entries} > 700$
  - $\chi^2/NDF < 20$
  - 200<MPV<400 || $|MPV_{channel} - MPV_{chip}|$<80
  - 20<Landau Width<100
  - 10<Gauss Sigma<150
- Channels fail the selection will use chip MPV
- Tag: 1 for normal; -1 for abnormal chips; -2 for inadequate statistics; -3 for abnormal fitting



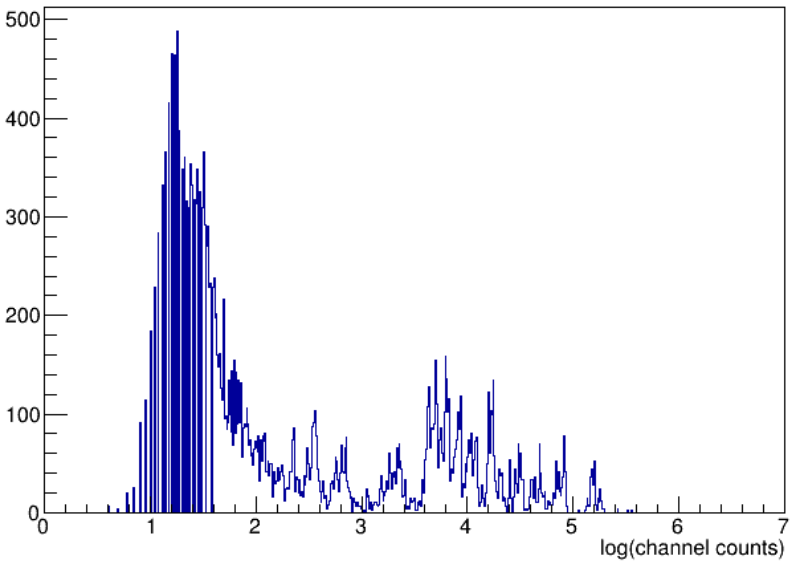
MPV



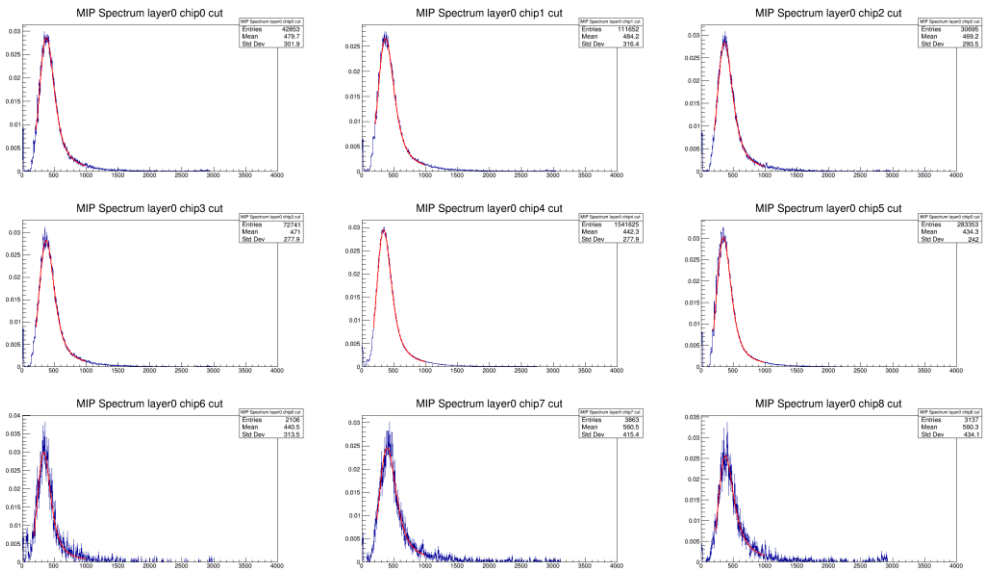
Tag

normal gain

- Good quality but low statistics
  - Many channels below 100 entries
  - Good fitting in chip level



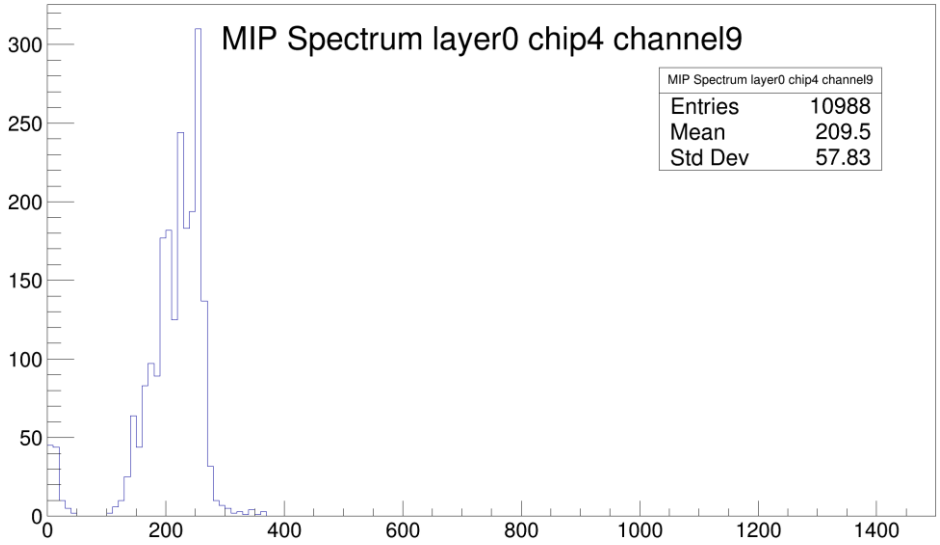
Channel statistics



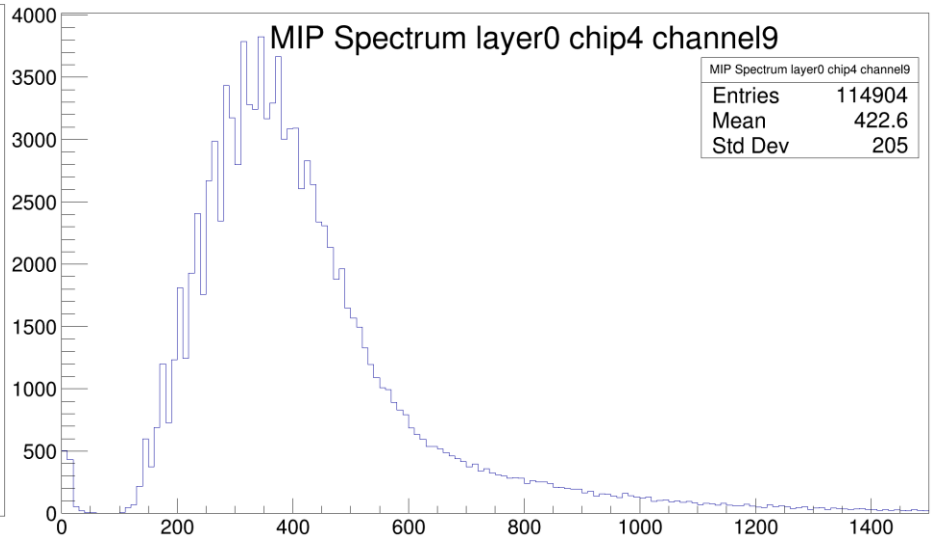
Chip level fitting

Auto-gain

- 280 threshold are first used but found out this threshold is too low
- 350 threshold is then used



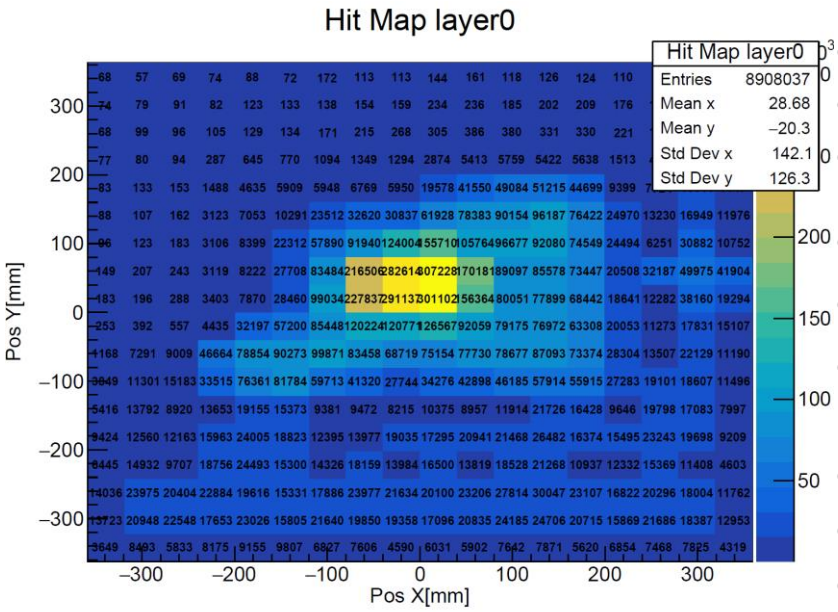
280 threshold



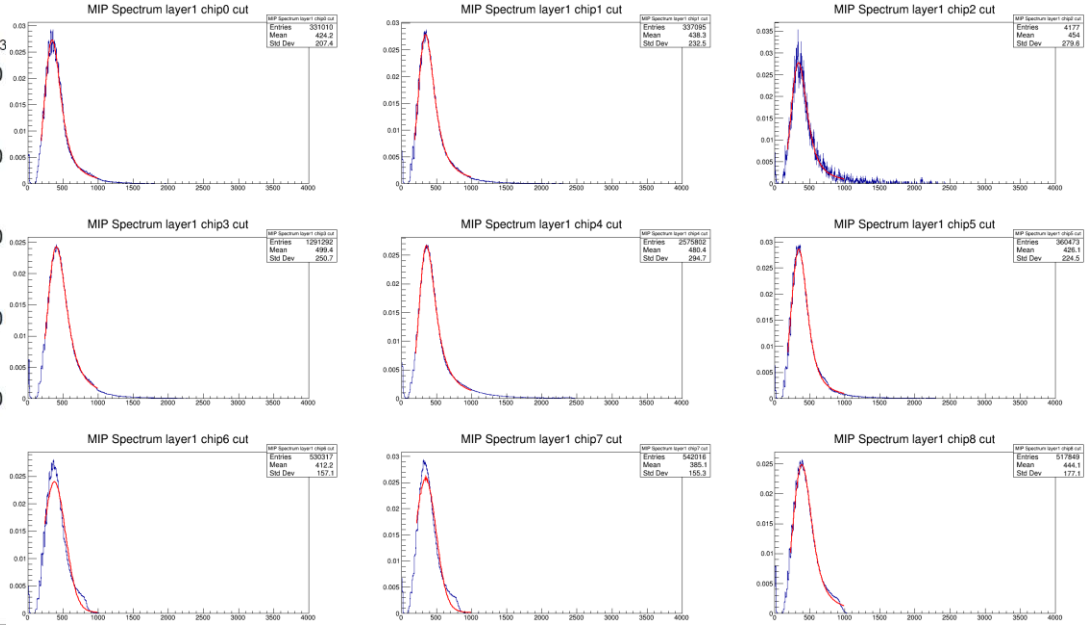
350 threshold

Auto gain

- 350 threshold
  - Top left area lack statistics because that area is covered by data of 280 threshold
  - The fitting result of auto gain is not good



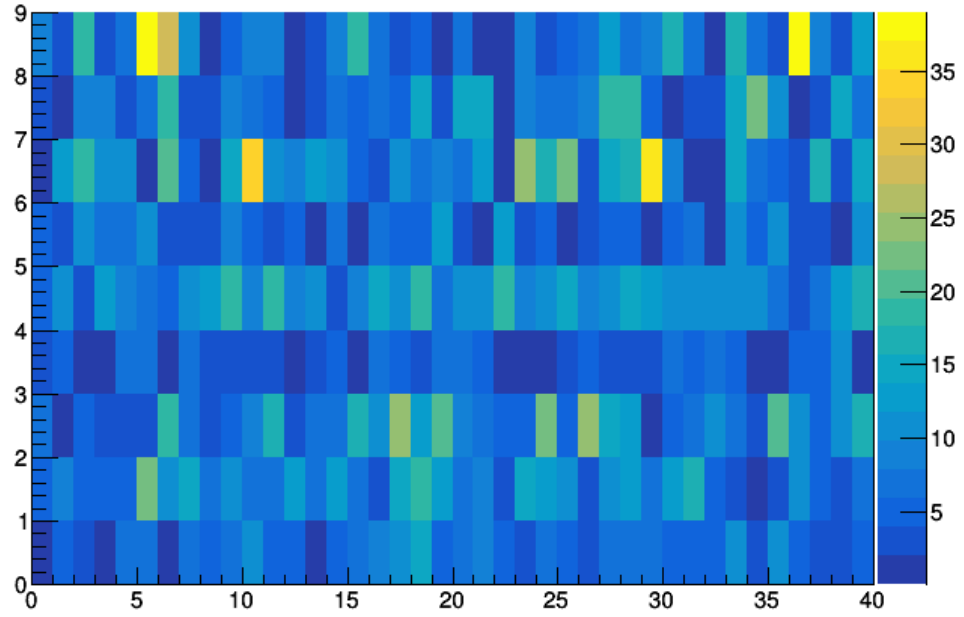
Hit Map layer0



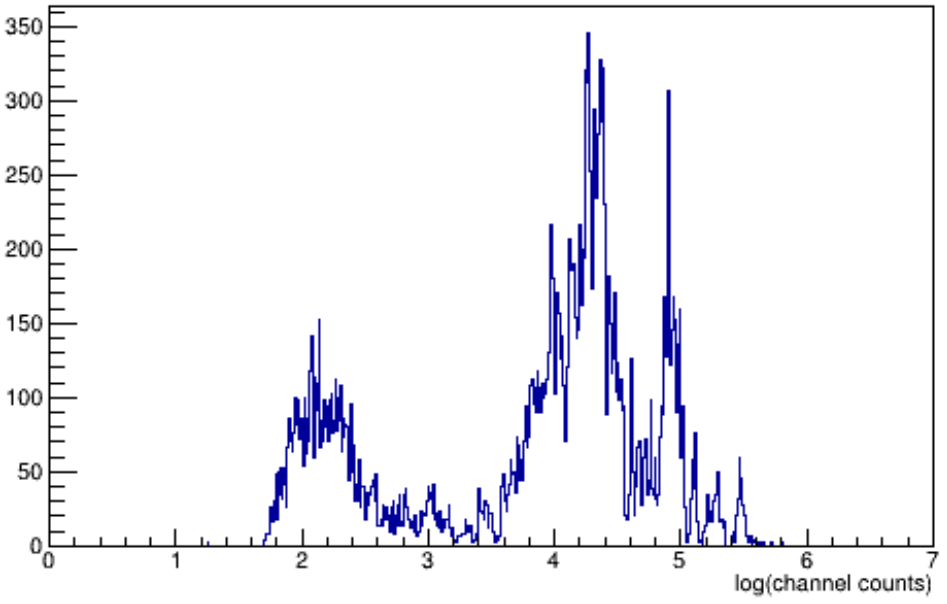
Fitting on chip level

Normal and auto

- The MPVs of normal gain and auto gain have small difference
- The data of normal gain and auto gain is combined for MIP calibration



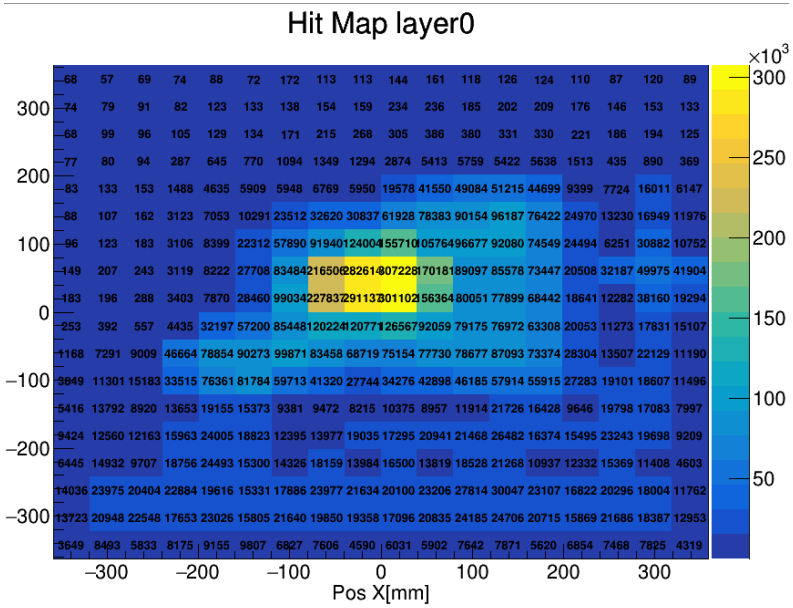
MPV difference between auto and normal gain



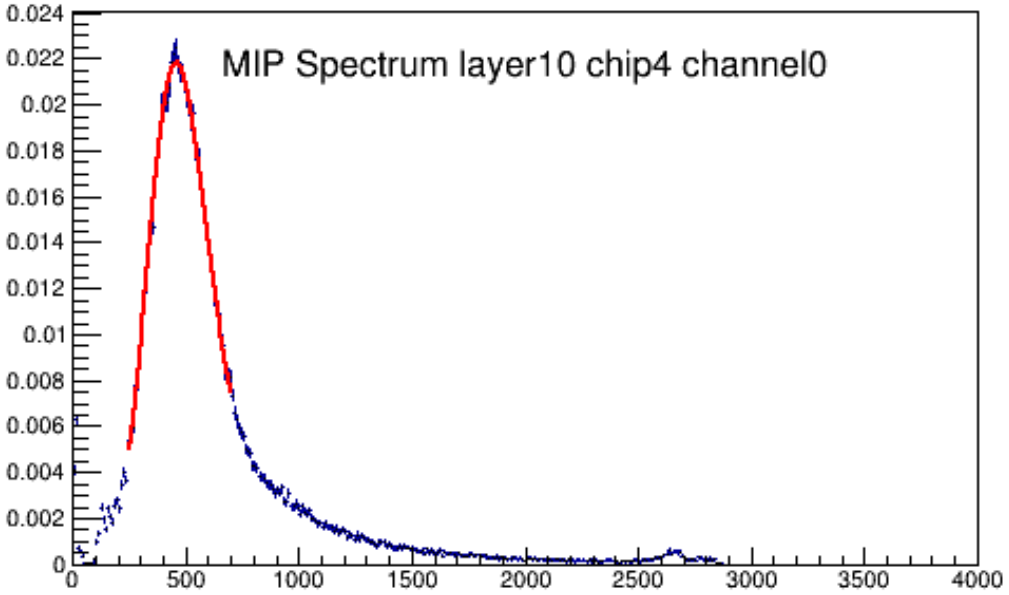
Channel statistics

Combined data

- The combined data still lacks statistics on the top left area
- The fitting is good if the statistics is enough



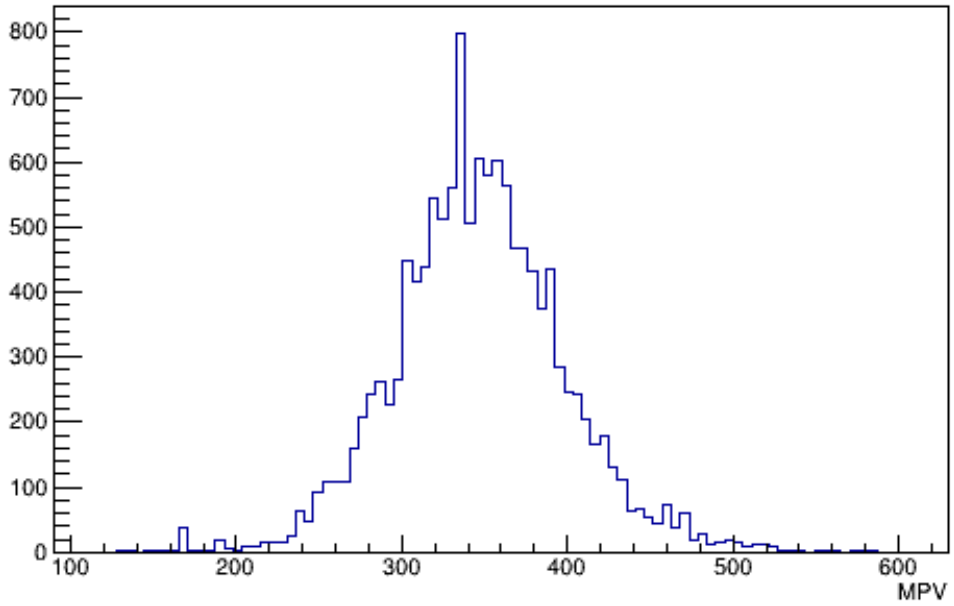
Hit Map layer0



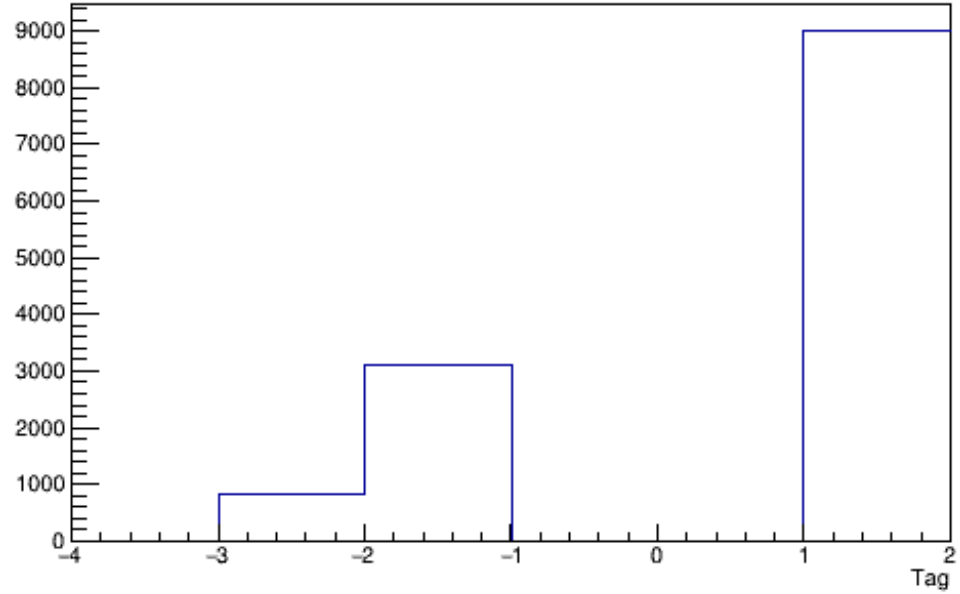
MIP Spectrum of a single channel

MIP Calibration 2023

- The 1st version of MIP calibration file is analyzed from normal and auto combined data
- About 3000 channels still lacks statistics



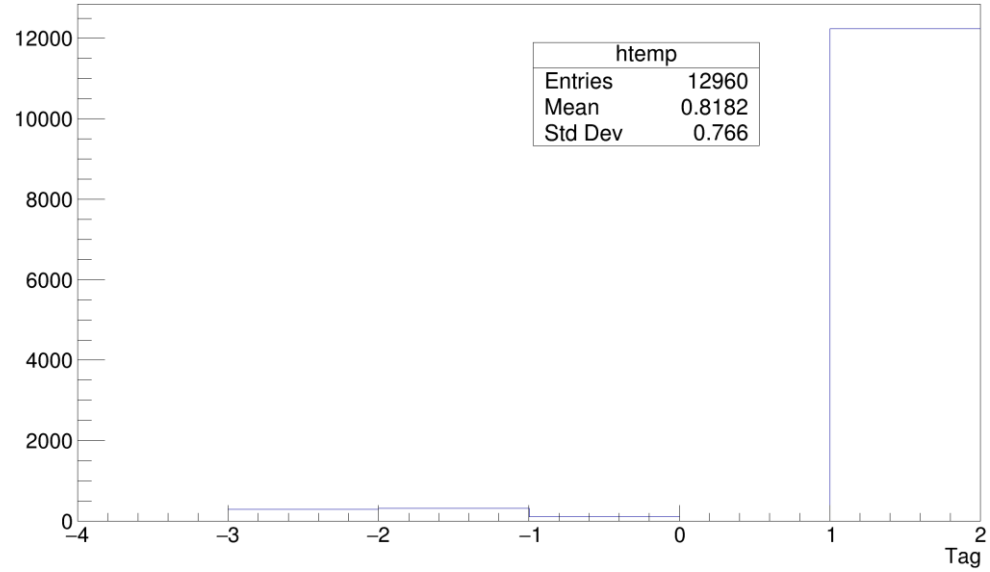
MPV of all channels



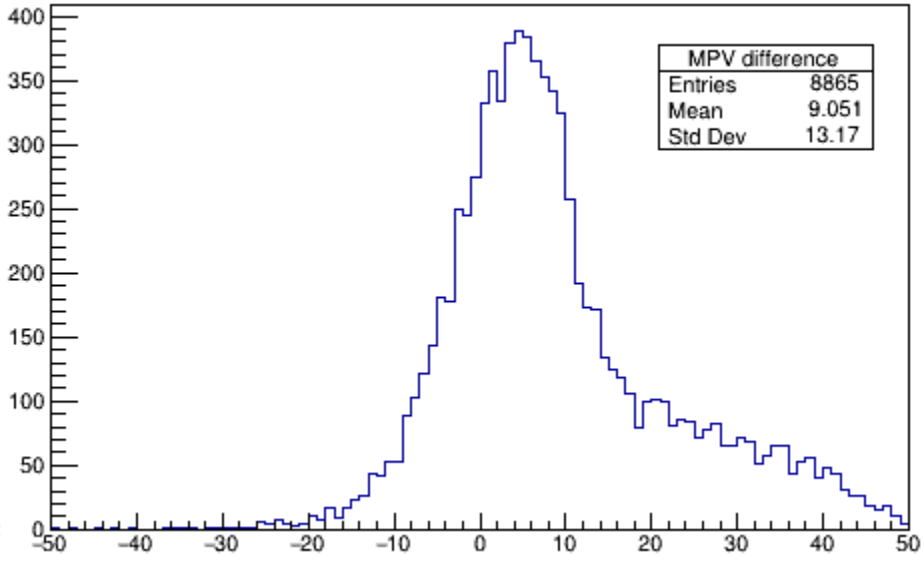
1 for good channel,-1 for low statistics,-2 for bad fitting

Comparison with 2022

- More channels were well calibrated with 2022 data
- The MPV of 2023 are mostly larger than the MPV of 2022

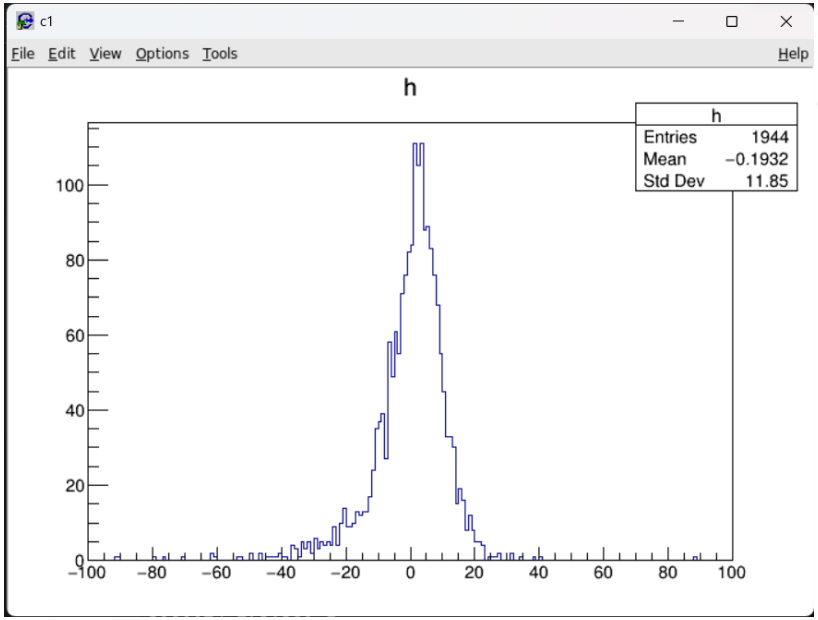


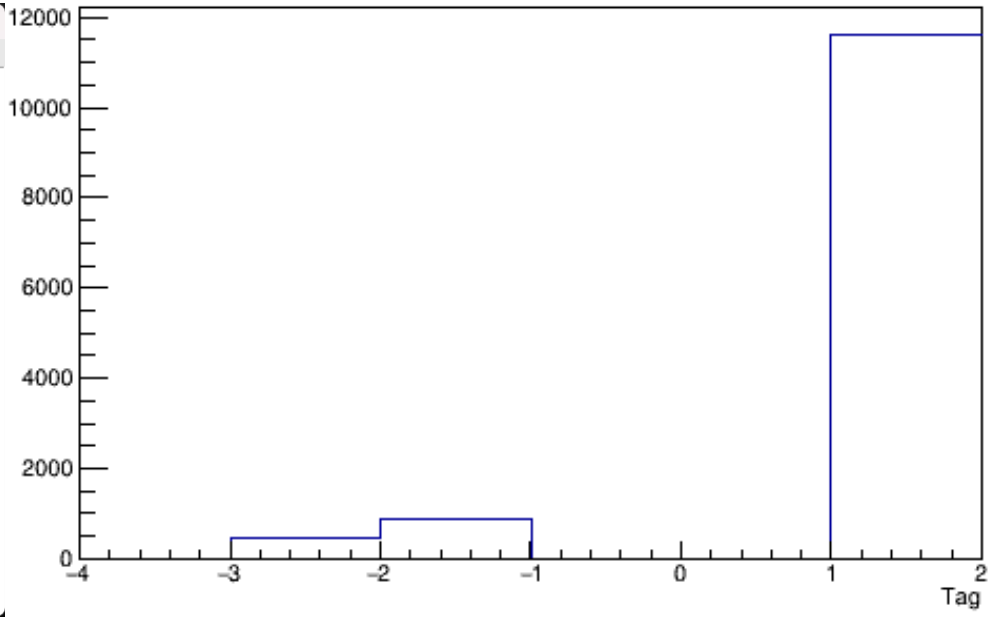
Calibration status of 2022



MPV difference :2023 - 2022

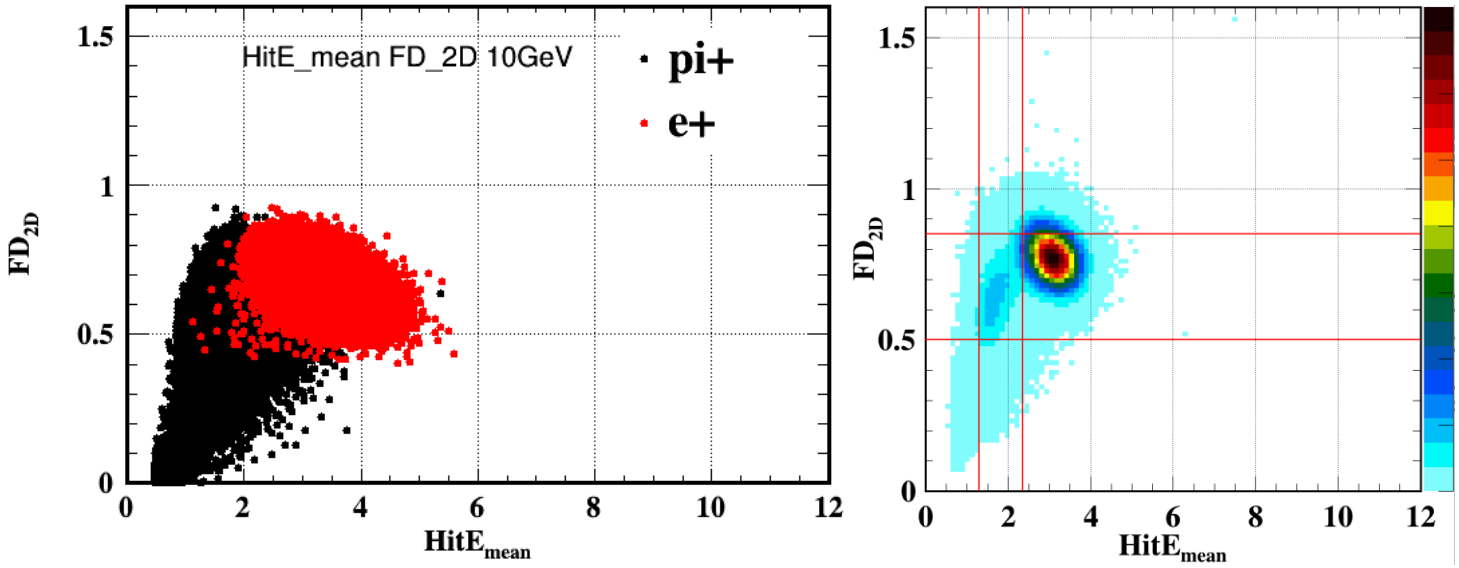
- merge


c1
File Edit View Options Tools Help
h
h
Entries 1944
Mean −0.1932
Std Dev 11.85
100
80
60
40
20
0
−100 −80 −60 −40 −20 0 20 40 60 80 100


12000
10000
8000
6000
4000
2000
0
−4 −3 −2 −1 0 1 2
Tag

Selection and PID

- PID
  - The beam purity is bad while energy < 30GeV
  - The PID cut using fractal dimension and mean of hit energy is applied to data of energy < 30GeV
  - Data of energy > 30GeV has no PID cut



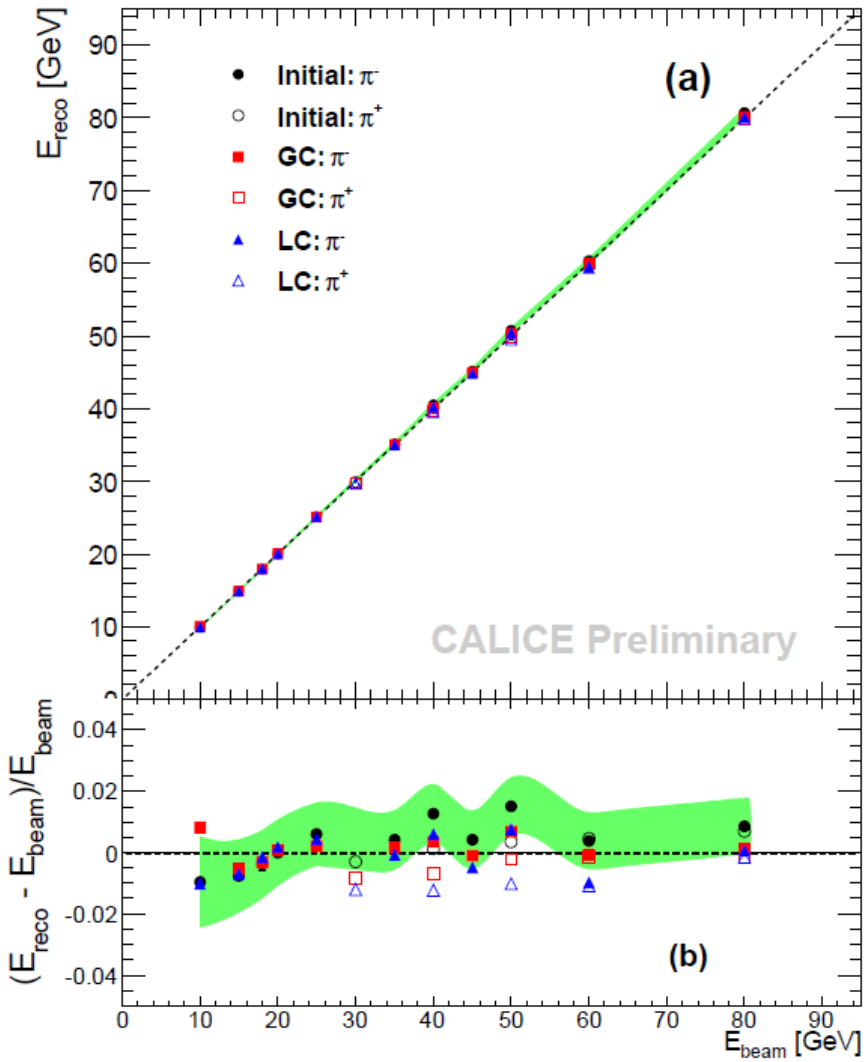
Hit E mean vs FD: MC and Data

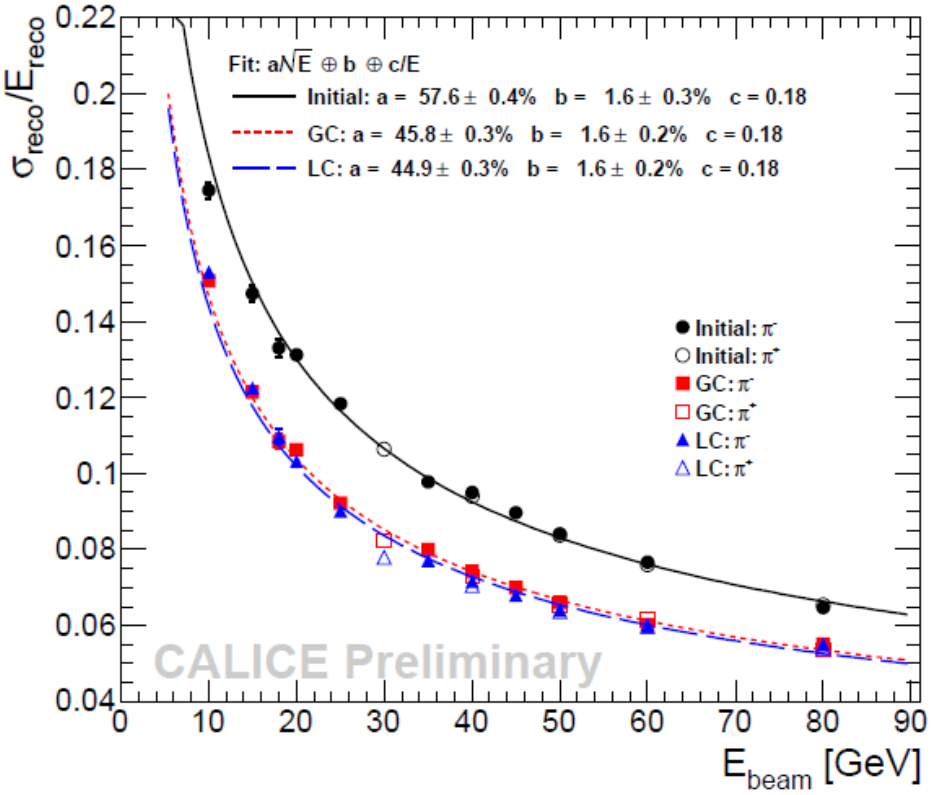
CALICE efficiency

particle type	beam energy [GeV]	all pions	selected pions
π^-	10	440208	84706
π^-	15	127554	24997
π^-	18	52880	10492
π^-	20	342798	67093
π^-	25	201243	39631
π^-	35	272987	54126
π^-	40	472345	93301
π^-	45	325092	63547
π^-	50	304023	59076
π^-	60	647090	121588
π^-	80	741440	139248
π^+	30	155210	30884
π^+	40	307177	60595
π^+	50	159414	30843
π^+	60	449273	86947
π^+	80	272441	52442

Table 1. Summary of the data samples. The total number of pions is the number of events classified as pions, after rejection of empty, noisy and double particle events, and the application of muon rejection and particle identification cuts. The number of selected pions are the events with an identified shower start in the first five layers of the AHCAL, which are used in the present analysis. For most energies, several run periods at different temperatures are combined to maximise statistics.

CALICE AHCAL





Linearity and energy resolution

- Leakage cut has no visible influence on the linearity