EIC-ASIA
ZDC ECAL Test Beam Analysis

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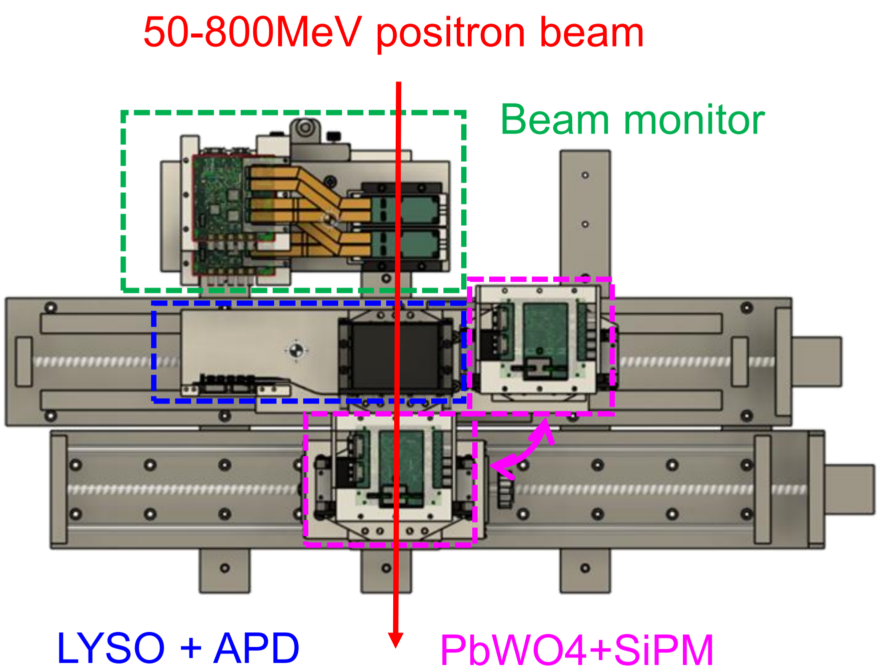
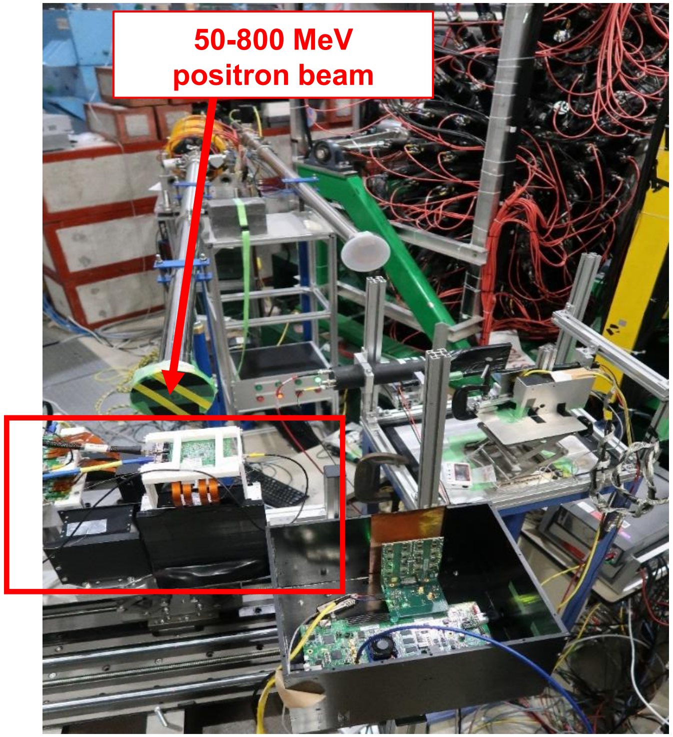
Review

Beam Test on 2025 Feb.

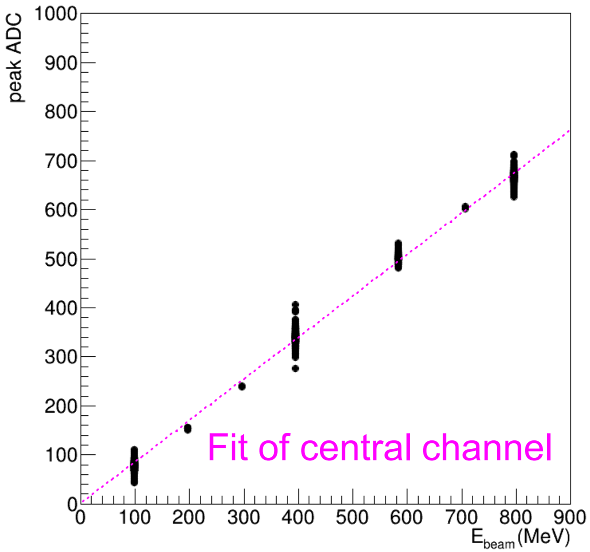
Detector	Crystal	Sensor	One crystal	Length	Array	Note
ZDC ECal 2nd LYSO + APD	**LYSO** Taiwan	**APD** C30739ECERH	1cm*1cm	6.6cm (6X0)	8x8	Crystal size is half Moliere radius
ZDC ECal 2nd PbWO4 + SiPM	**PbWO4** Czech	**SiPM** MICROFC-60035	2cm*2cm	5.3cm (6X0)	6x6	Two sensors for one crystal
Beam Monitor	**Plastic** Scintillator	**SiPM** MICROFC-10010	2mm*2mm	8cm	32ch in X 32ch in Y	Two sets 4 planes : 2X & 2Y



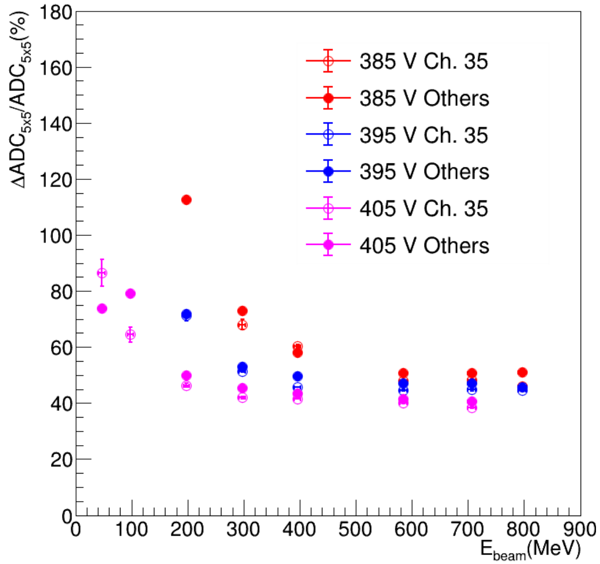


LYSO + APD

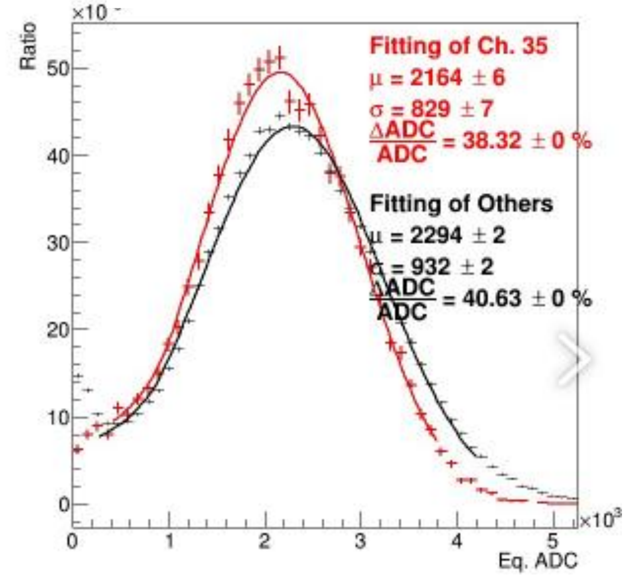
Gain Calibration



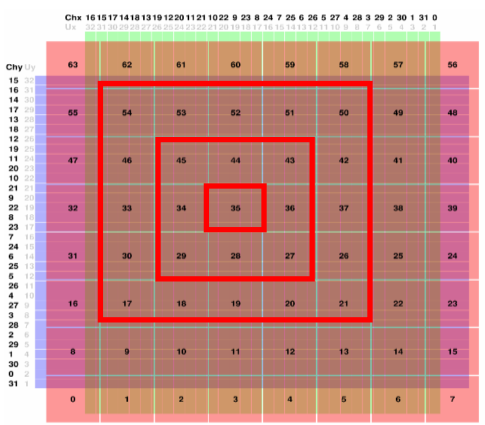
Energy resolution (E5x5)



E5x5 : 405V, 706MeV



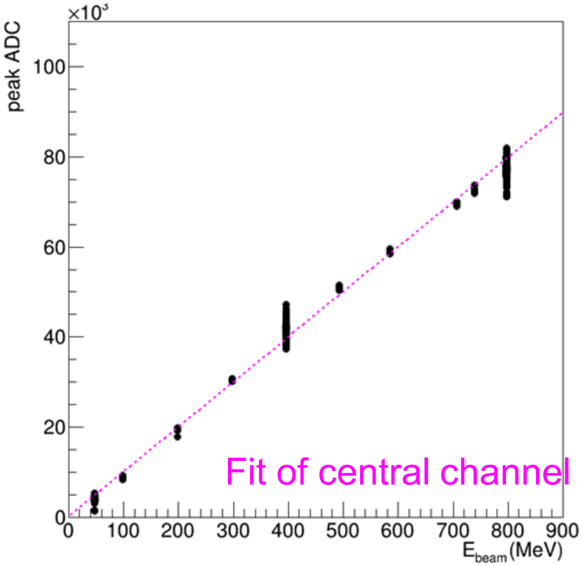
5x5 clustering (~5cm*5cm)



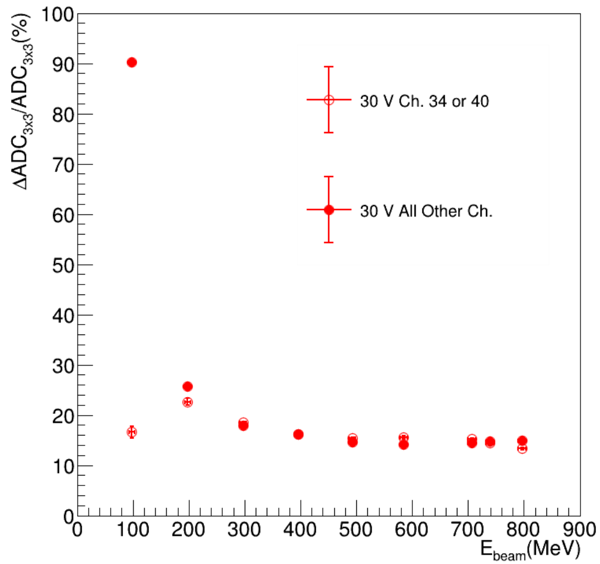
- Gain calibration is performed with 5*5 crystals.
- Preliminary results gave energy resolution for "LYSO + APD"~40% with 706MeV beam.

PbWO4 + SiPM

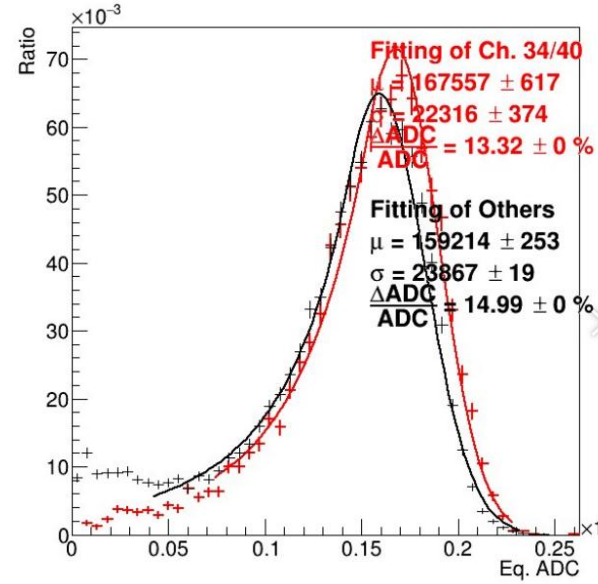
Emax after calibration



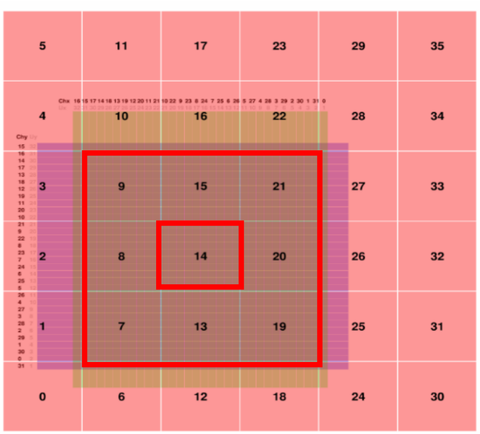
Energy resolution (E3x3)



706MeV beam



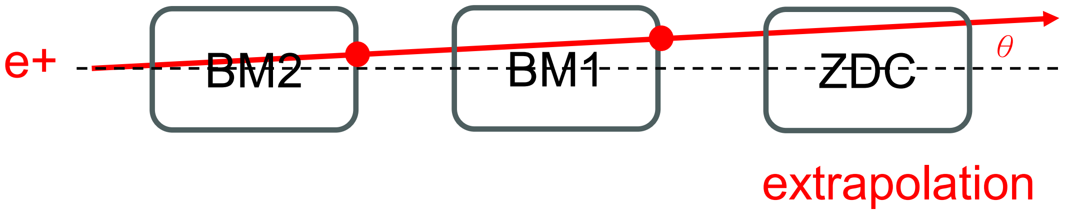
3x3 clustering (~6cm*6cm)

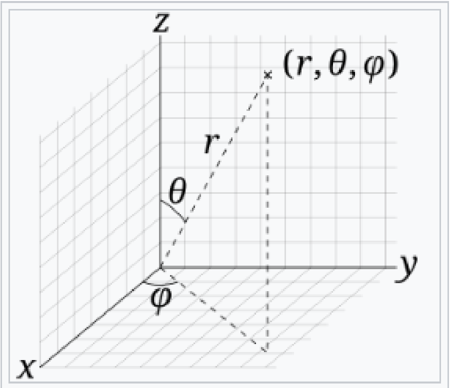


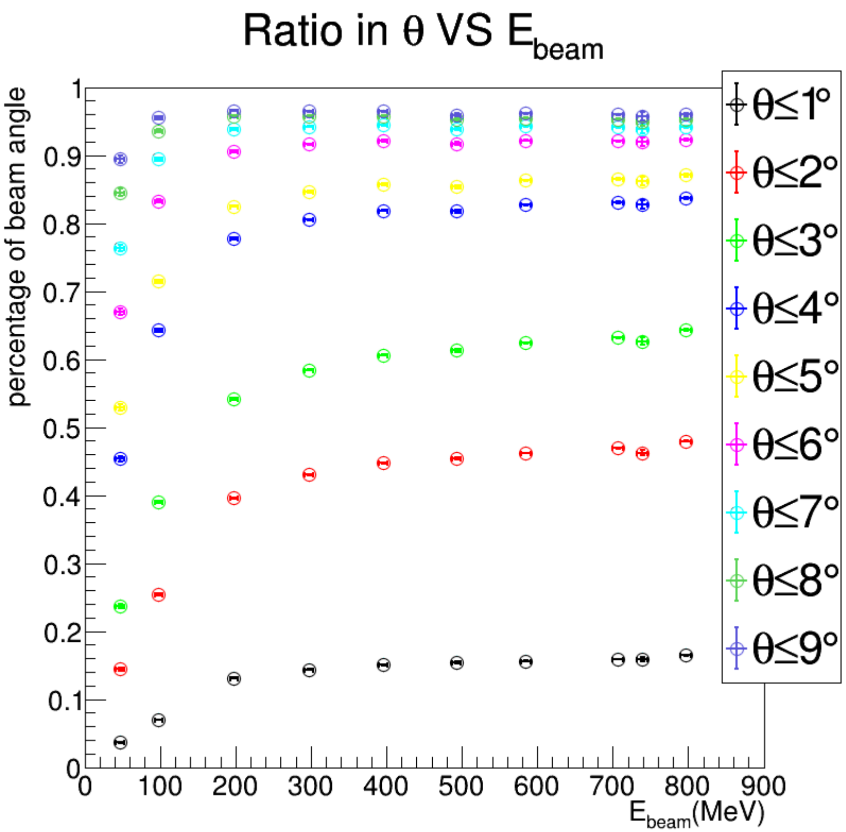
- Gain calibration is performed with 5*5 crystals.
- Preliminary results gave energy resolution for “PbWO4 + SiPM”~14% with 706MeV beam.

Apply Beam Selection

Beam Angle





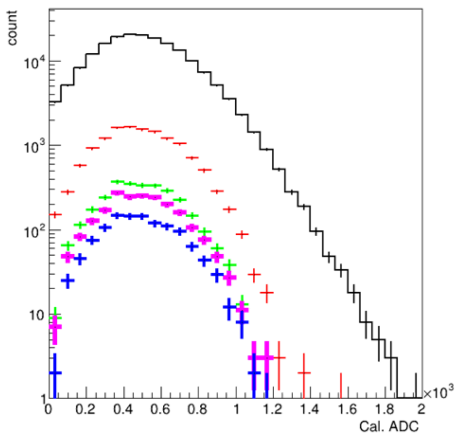


- Spherical coordinate : XY-surface is defined as the BM surface.
- theta = 0 degree = perpendicular to the surface of BM/ZDC.
- Only ~ 10% beam shoots straightly.
  - 40% beam < 2 degree
  - 80% beam < 4 degree
  - 90% beam < 6 degree

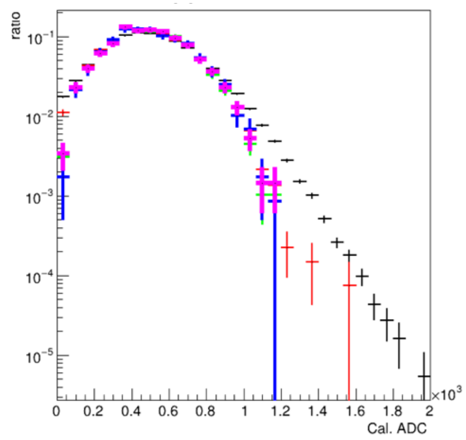
  (More studies later)

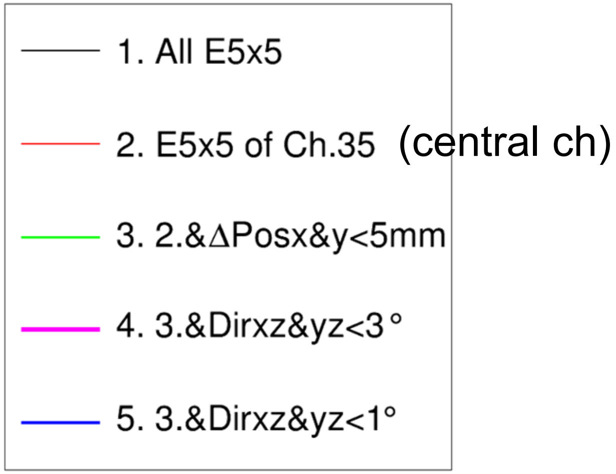
Energy resolution after Beam Selection
LYSO + APD

197 MeV, E5x5

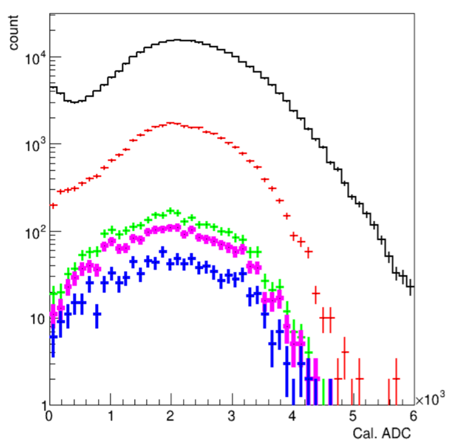


197 MeV, E5x5 (Norm)

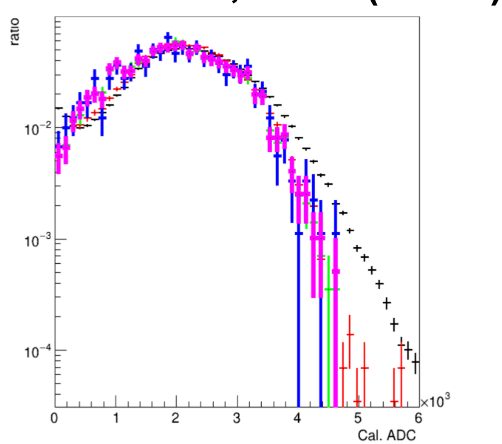




706 MeV, E5x5



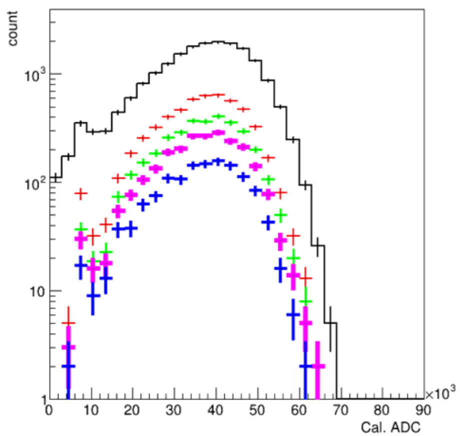
706 MeV, E5x5 (Norm)



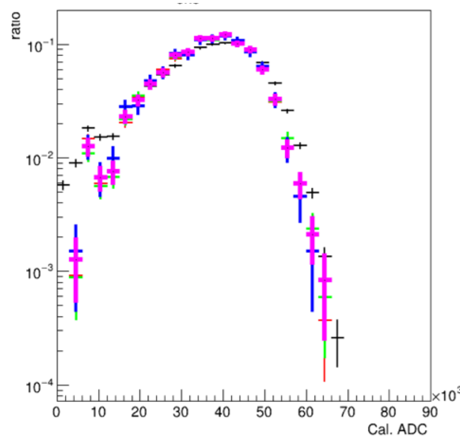
No obvious improvement after cuts/selections.

Energy resolution after Beam Selection
PbWO4 + SiPM

197 MeV, E5x5

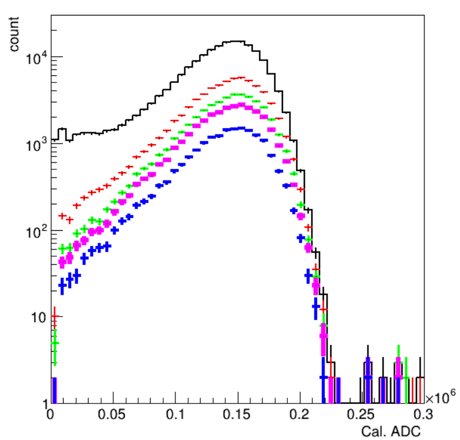


197 MeV, E5x5 (Norm)

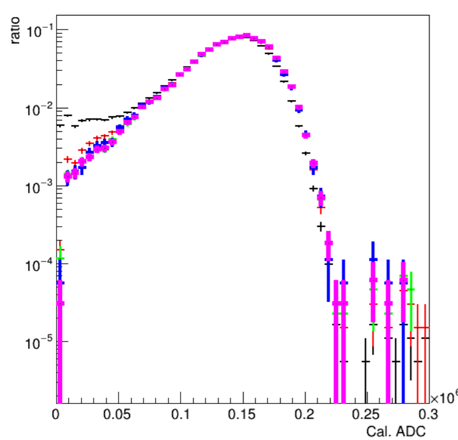


1. All E5x5
2. E5x5 of Ch.34 ∨40 (central ch)
3. 2.&ΔPosx&y<5mm
4. 3.&Dirxz&yz<3 °
5. 3.&Dirxz&yz<1°

706 MeV, E5x5



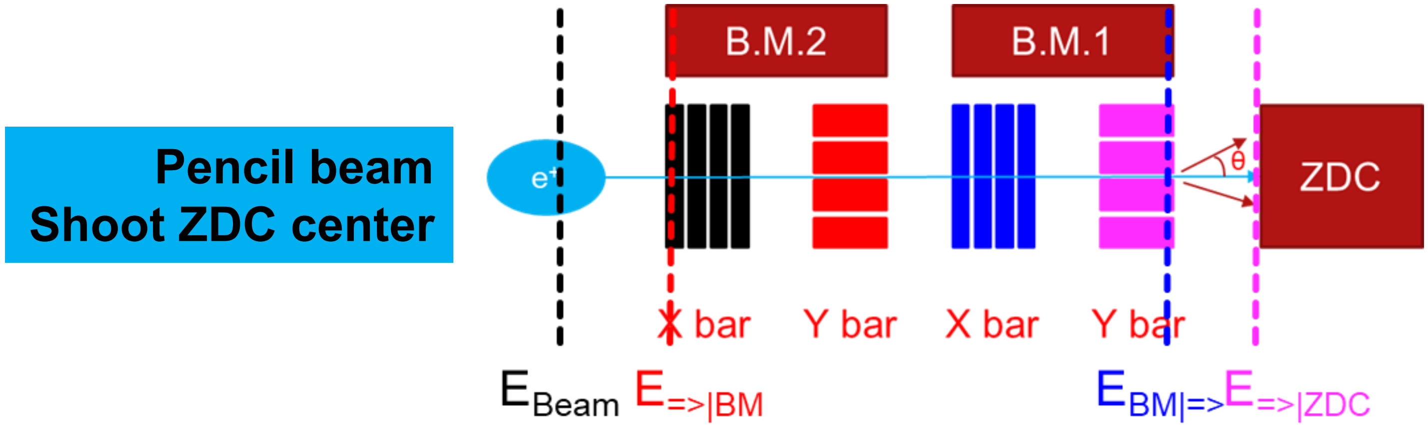
706 MeV, E5x5 (Norm)

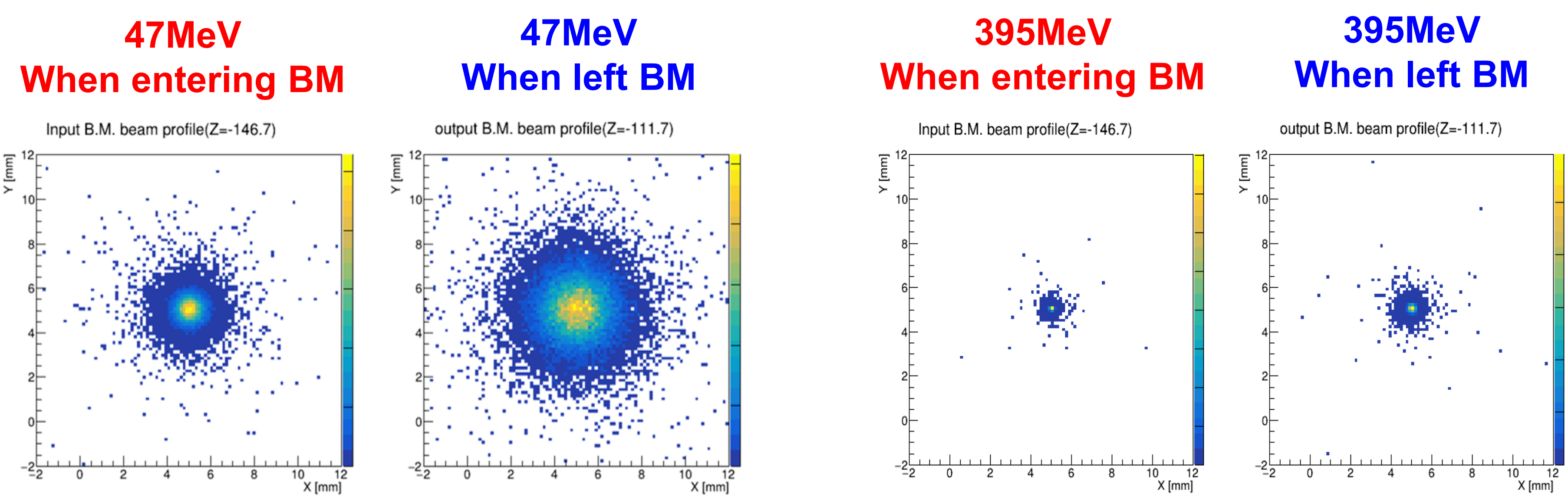


No obvious improvement after cuts/selections.

More Studies on Beam Angle

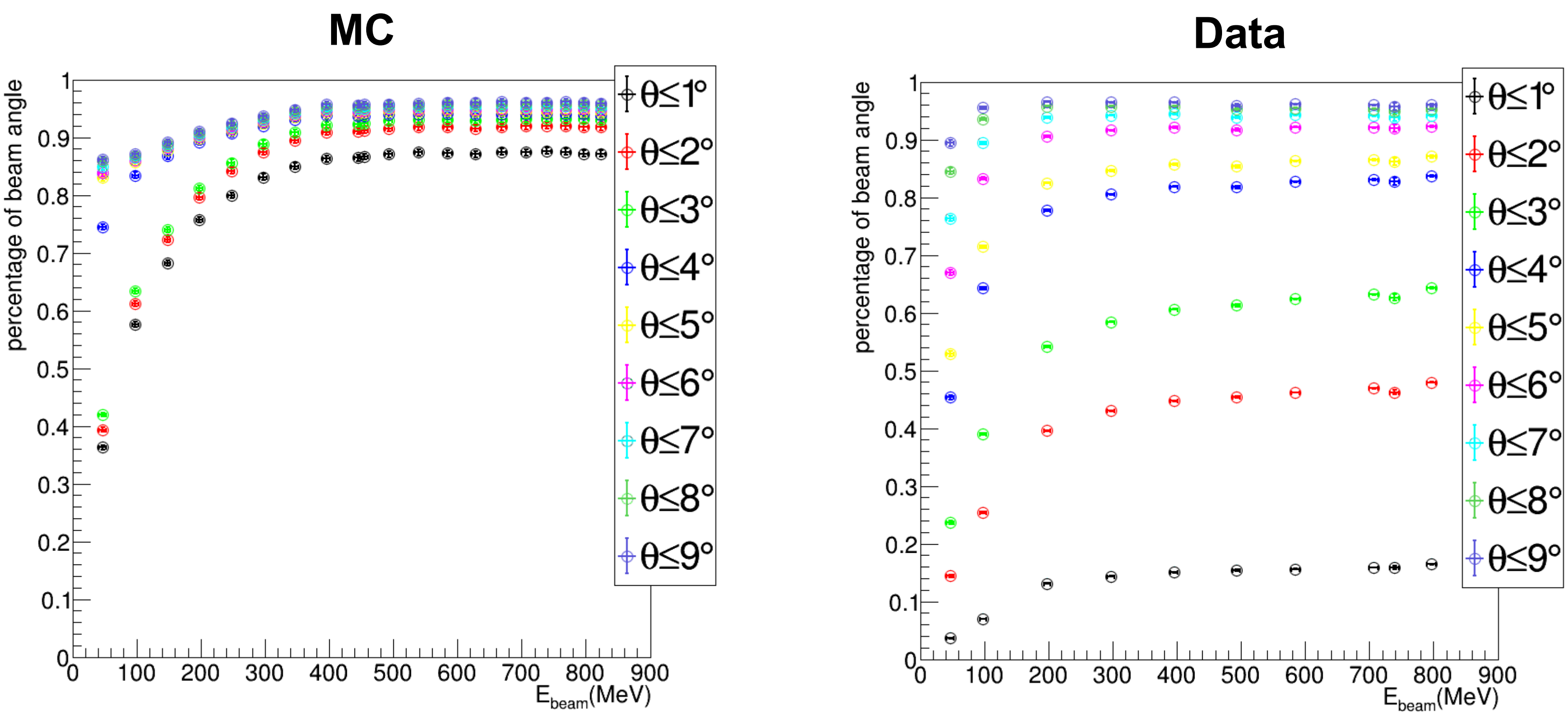
MC Simulation of Beam Profile





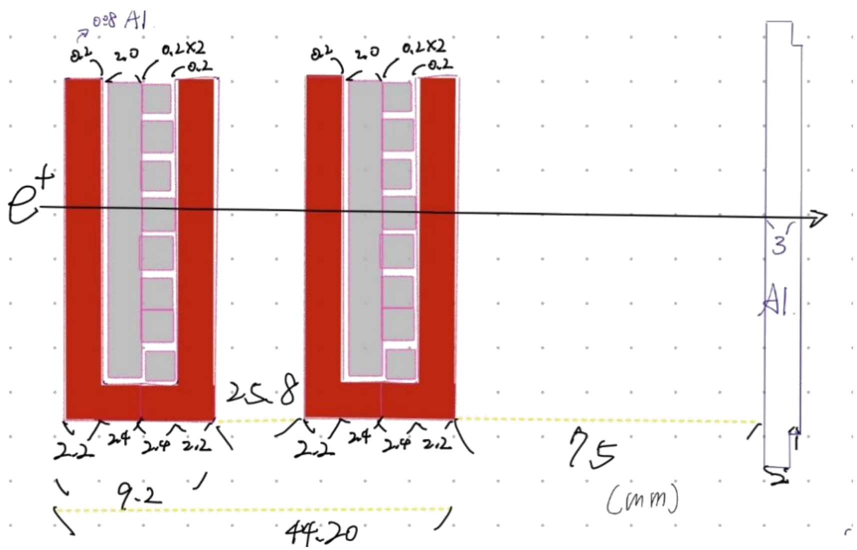
Wider spread for beam with smaller energy.

Beam Angle : Compare MC and Data



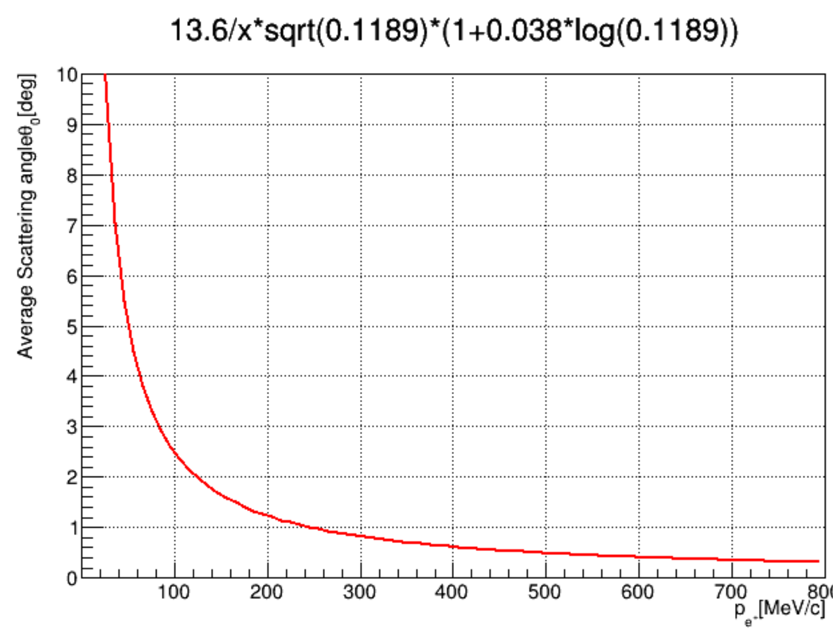
The beam angle is quite small MC. What we see from data should not be caused by the BM or the material in front of ZDC.

Calculation



material	X_0(mm)
Teflon($C^2F^4{}_n$)	155
Aluminum(Al)	88.9
Plastic Scintillator	424

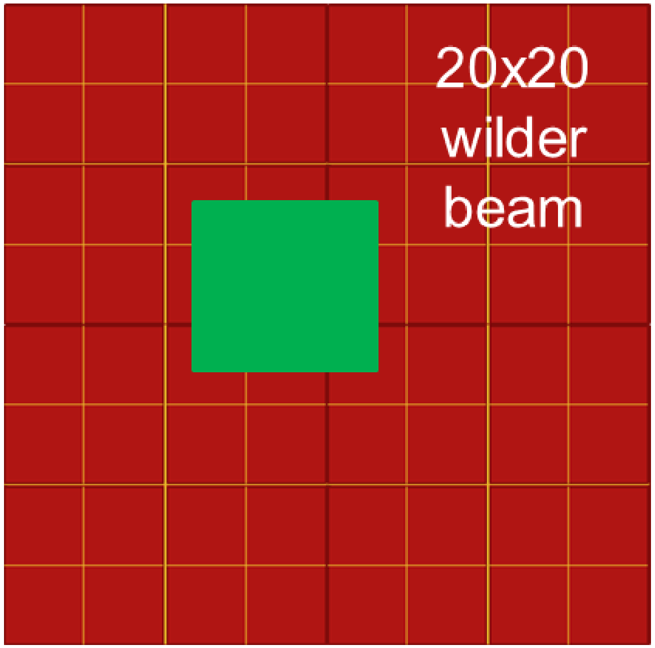
Material	Tef	AL	PS	AL	PS	AL	Tef	x2 B.M.	Shell-AL
Thickness (mm)	2.2	0.08	2.24	0.16	2.24	0.08	2.2	-	3
x/X_0	0.0142	0.0009	0.0053	0.0018	0.0053	0.0009	0.0142	Sum = 0.0852	0.0337

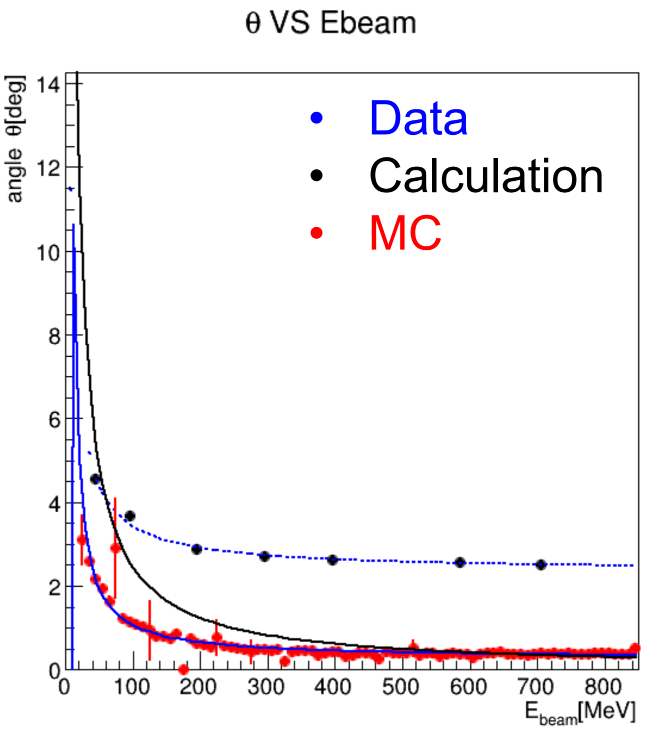


$$\frac{13.6MeV}{\beta p} Z \sqrt{\frac{x}{X_0}} \left(1 + 0.038 \ln \frac{x}{X0}\right)$$

Molière scattering formula : It describes the **root-mean-square (RMS) angular deflection due to multiple Coulomb scattering** of a charged particle traversing a material.

Compare Data, MC, and Calculation

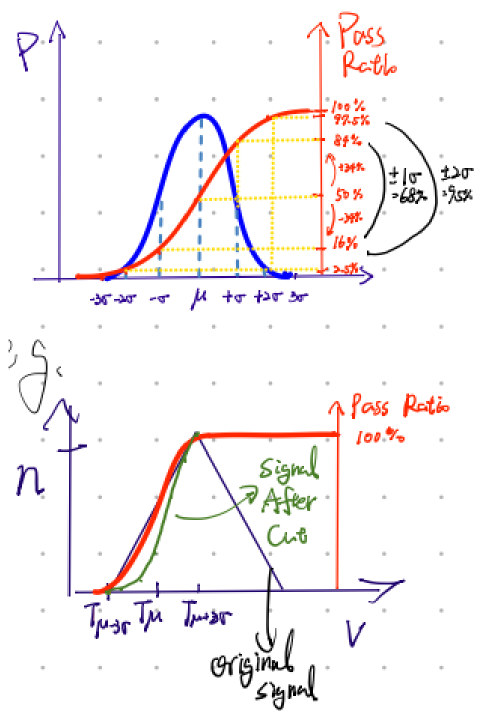




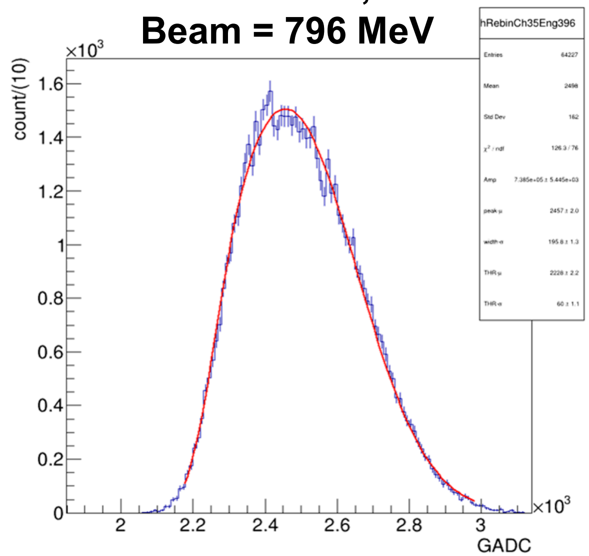
- Beam angle is larger in data compare to MC and calculation.
- Between MC and calculation, larger inconsistency for low energy beam less than 400MeV.
- We currently have no conclusion why we are seeing large beam angle in data.

More Studies on Gain Calibration

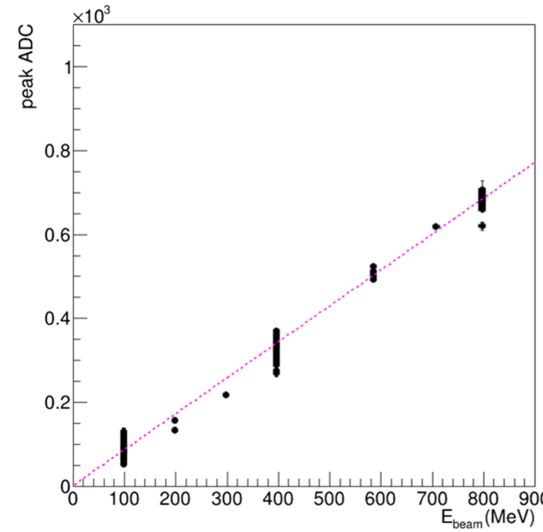
New Fitting Function



LYSO + APD,
HV=395V,
Beam = 796 MeV



Gain calibration
of 5*5 crystal

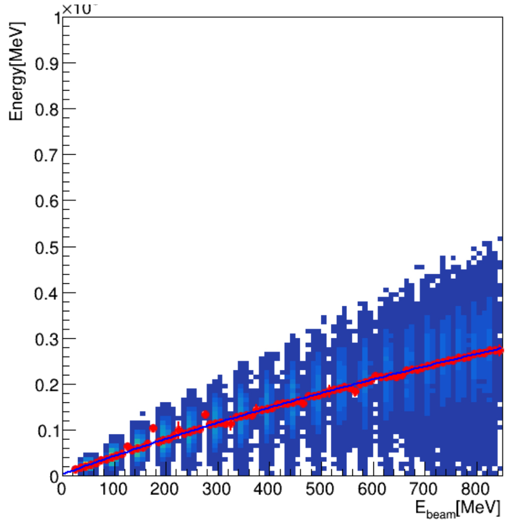


- **Fit ADC distribution**
- **Old method** : **Double-side crystal ball (ExpL*Gaus*ExpR).** Sometimes hard to fit when the distributions are very asymmetric.
- **New method : gaus* gaus_CDF**. The asymmetric distribution on the left-hand side is caused by the threshold cut of electronics. Fitting quality is better.

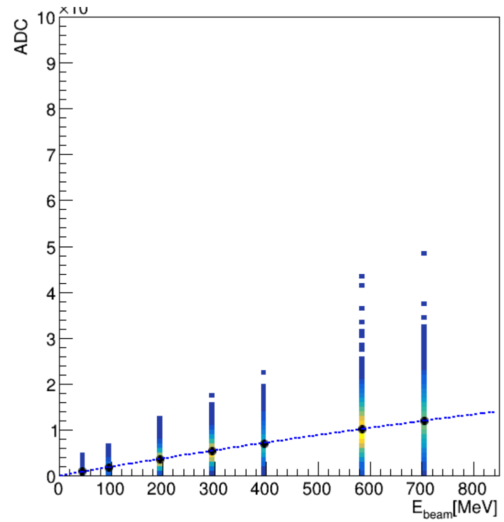
$$gaus\_CDF(x;\mu,\sigma) = \frac{1}{\sqrt{2\pi\sigma}}\int_{-\infty}^{x} e^{-\left(\frac{t-\mu}{\sigma}\right)^2/2}dx$$

ADC to Energy Mapping

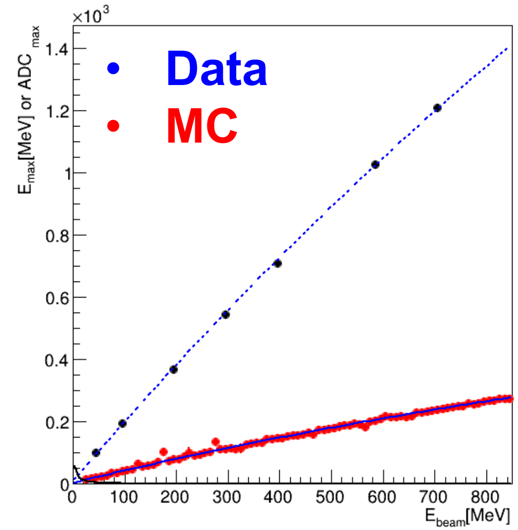
MC : E_{max} VS E_{beam}

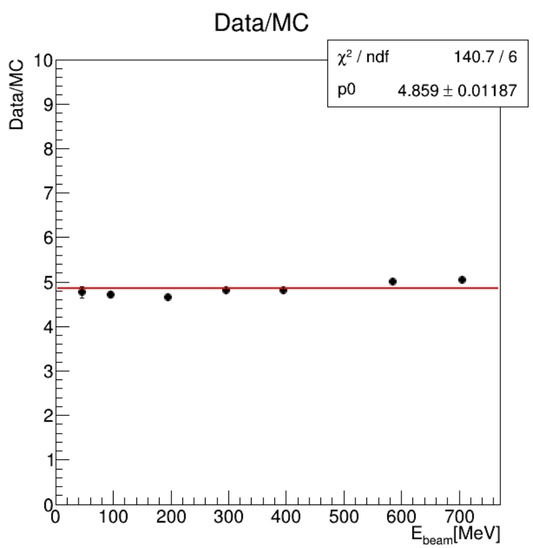


Data : ADC_{max} VS E_{beam}



MC VS Data





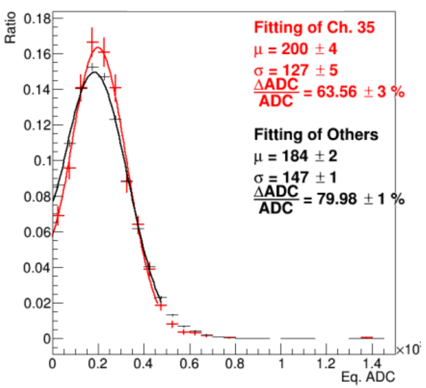
- **Example of LYSO + APD@ HV = 395V**
- **How to find ADC to energy mapping?**
- Data : ADC_{max} to E_{beam} relation ➔Eq#1
- MC : E_{max} to E_{beam} relation ➔Eq#2
- **From Eq#1 and Eq#2 ➔E_{max} and ADC_{max} relation (Under the assumption that data and MC are consistent in terms of the energy linearity.)**

APD + LYSO

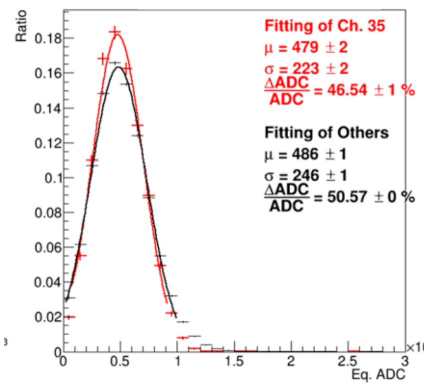
HV = 405V

Old fitting method (w/o energy to ADC mapping)

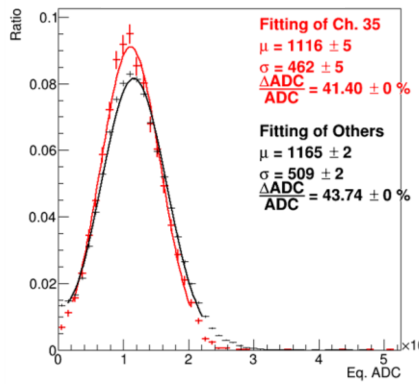
98 MeV



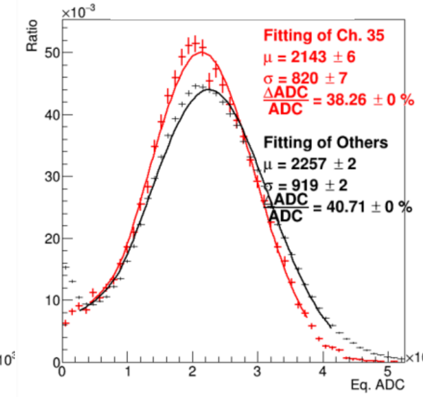
197 MeV



395 MeV

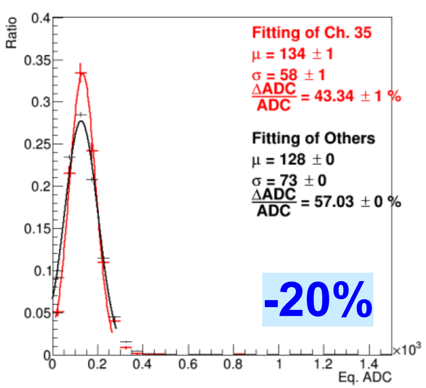


706 MeV

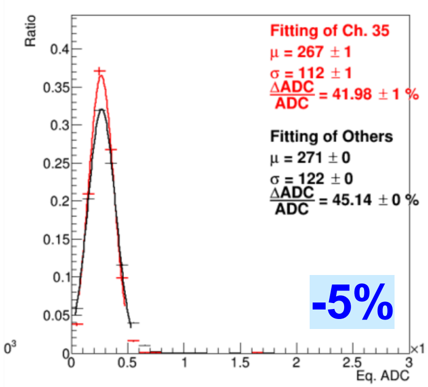


New fitting method (w/ energy to ADC mapping)

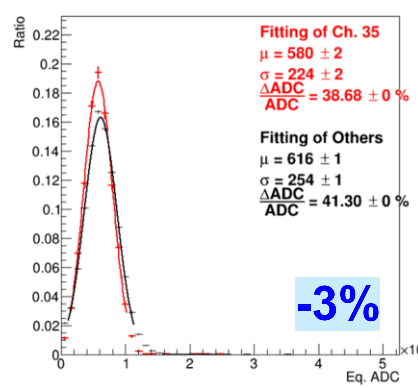
98 MeV



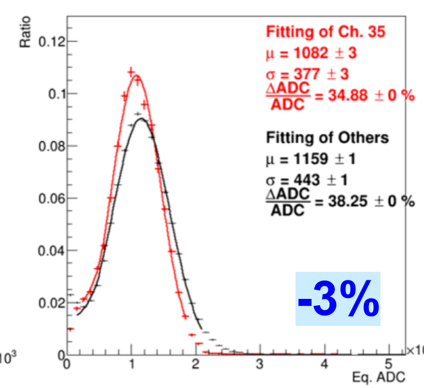
197 MeV



395 MeV



706 MeV



With the new gain calibration method, energy resolution improves, especially for low energy.

Summary and To Do

- We are working on improving the data analysis:
- **Beam cut:** not effective, still under investigation; unclear why the beam angle in data is so large.
- **Gain calibration method:** improved the energy resolution.
- **Next step:** practice linear energy regression with MC sample and apply to data.

Back up

Molière scattering formula

PDG

protons) and by Shen *et al.* [39] (relativistic pions, kaons, and protons).[7]

If we define

$$\theta_0 = \theta^{\rm rms}_{\rm plane} = \frac{1}{\sqrt{2}}\,\theta^{\rm rms}_{\rm space}\ , \tag{34.15}$$

then it is sufficient for many applications to use a Gaussian approximation for the central 98% of the projected angular distribution, with an rms width given by Lynch & Dahl [40]:

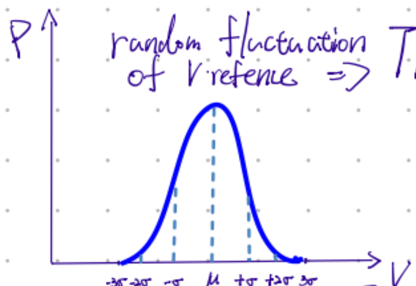
$$\begin{aligned}\theta_0 &= \frac{13.6\ \text{MeV}}{\beta c p}\, z\, \sqrt{\frac{x}{X_0}}\Big[1 + 0.088 \log_{10}(\frac{x\, z^2}{X_0 \beta^2})\Big] \\ &= \frac{13.6\ \text{MeV}}{\beta c p}\, z\, \sqrt{\frac{x}{X_0}}\Big[1 + 0.038 \ln(\frac{x\, z^2}{X_0 \beta^2})\Big]\end{aligned} \tag{34.16}$$

Here p, βc, and z are the momentum, speed, and charge number of the incident particle, and x/X_0 is the thickness of the scattering medium in radiation lengths (defined below). This takes into account the p and z dependence quite well at small Z, but for large Z and small x the β-dependence is not

It describes the **root-mean-square (RMS) angular deflection due to multiple Coulomb scattering** of a charged particle traversing a material.

Gaussian-CDF(Cumulative Distribution Function)

- Definition of f(x) CDF:
  - $\mathrm{CDF(x)} = \int_{-\infty}^{x} f(t)dt$
- CDF of Gaussian:
  - $Gaussian\ CDF(x;\mu,\sigma) = \frac{1}{\sqrt{2\pi\sigma}}\int_{-\infty}^{x} e^{-\left(\frac{t-\mu}{\sigma}\right)^2/2}dx\,, \mu = mean, \sigma = S.D.$

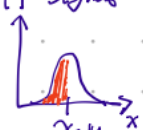


random fluctuation of V refence ⇒ Threshold 機率密度分佈 PDF函數

1. 代表一極短時間內的比較電壓為隨機對此高斯抽樣的結果

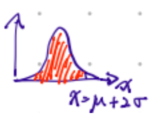
2. 由於大於比較電壓的訊號都可通過

eg1. if signal = x V = μ



此時紅色區域的機率和為 x=μ 時的通過率P~50%

eg2. if signal = μ+2σ



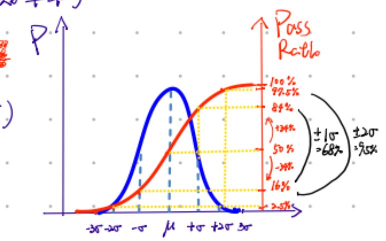
此時紅色面積(P)和 P⇒2σ⇒95%⇒97.5%

⇒ If signal = k ⇒ $P = \int_{\infty}^{k} gaus\left(\begin{smallmatrix}A=1\\ \mu=\mu\\ \sigma=\sigma\\ x\end{smallmatrix}\right)dx$

⇒ 也就是x≥k 的面積(機率和)

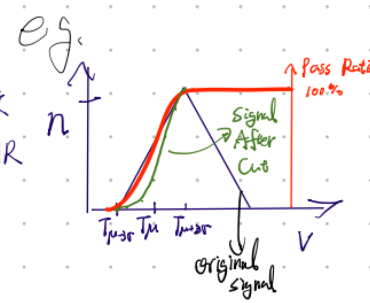
3. 因此THR對於訊號通過率的影響

⇒ 高斯的累計分佈函數 (CDF)

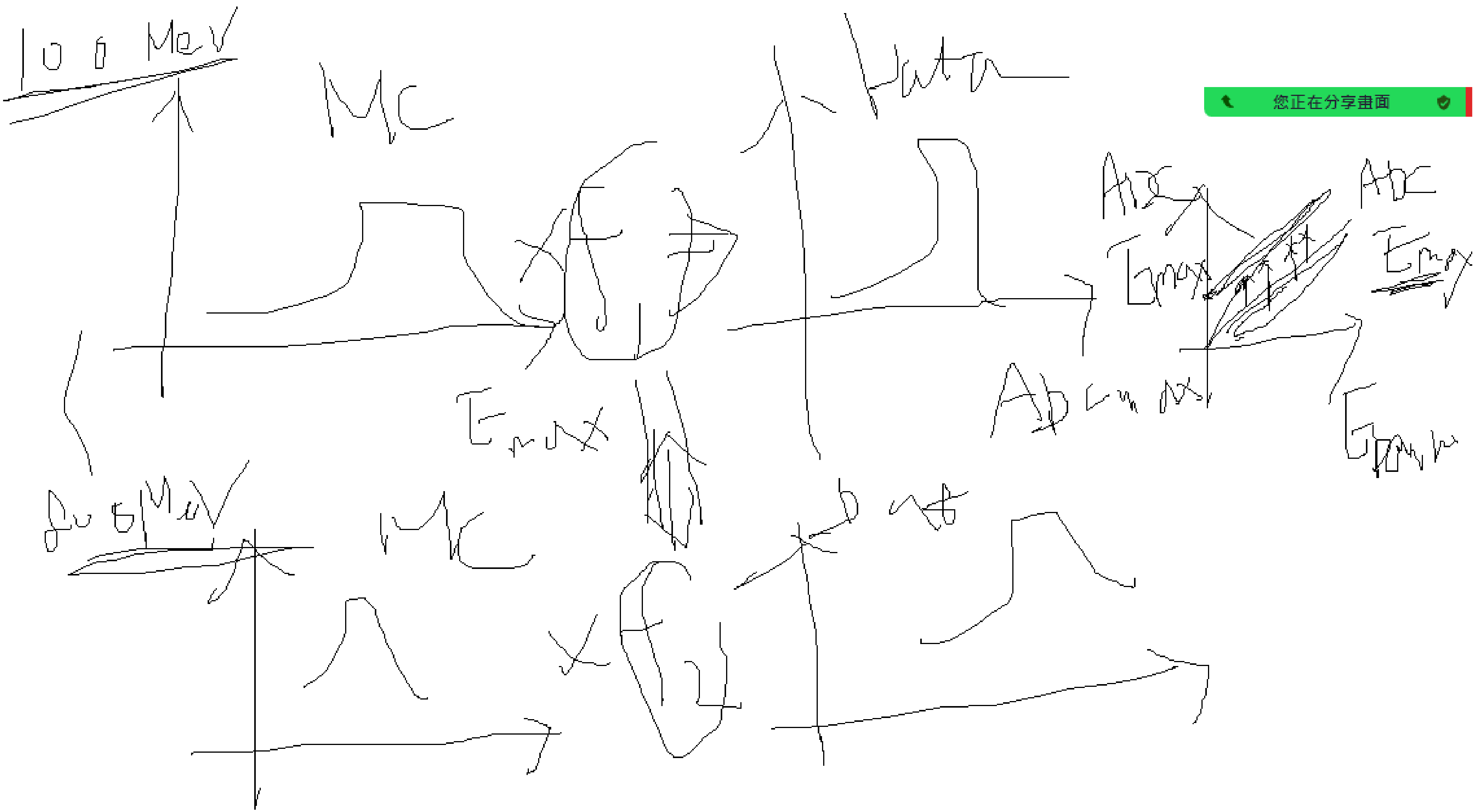


4. 由於這代表的是強度為 k 的訊號的通過率，因此只要把整個函數和一個訊號分佈相乘即得到 THR 對訊號分佈的影響

eg.

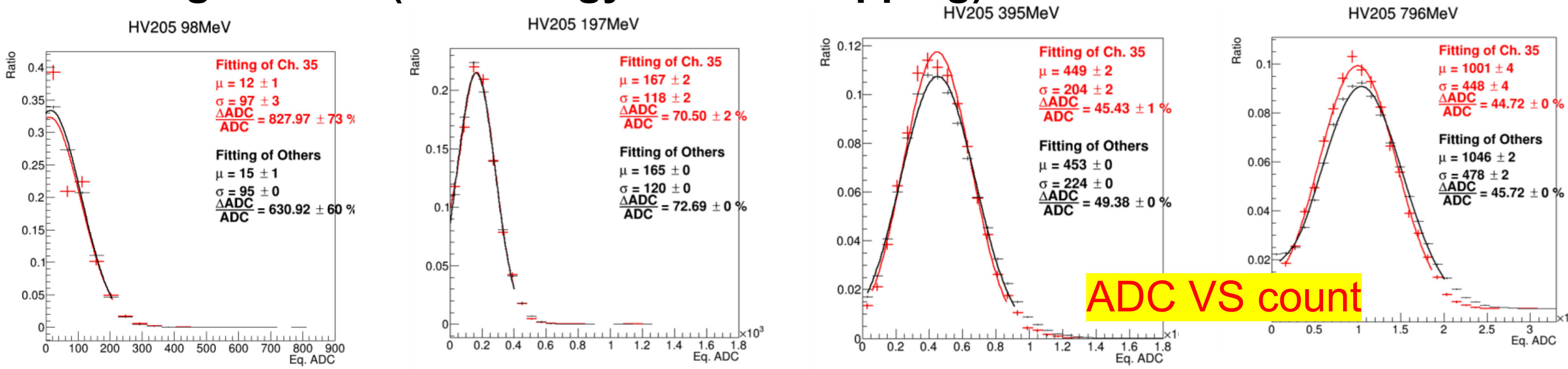


Varify Data and MC consistency
Emax, E3*3, E5*5

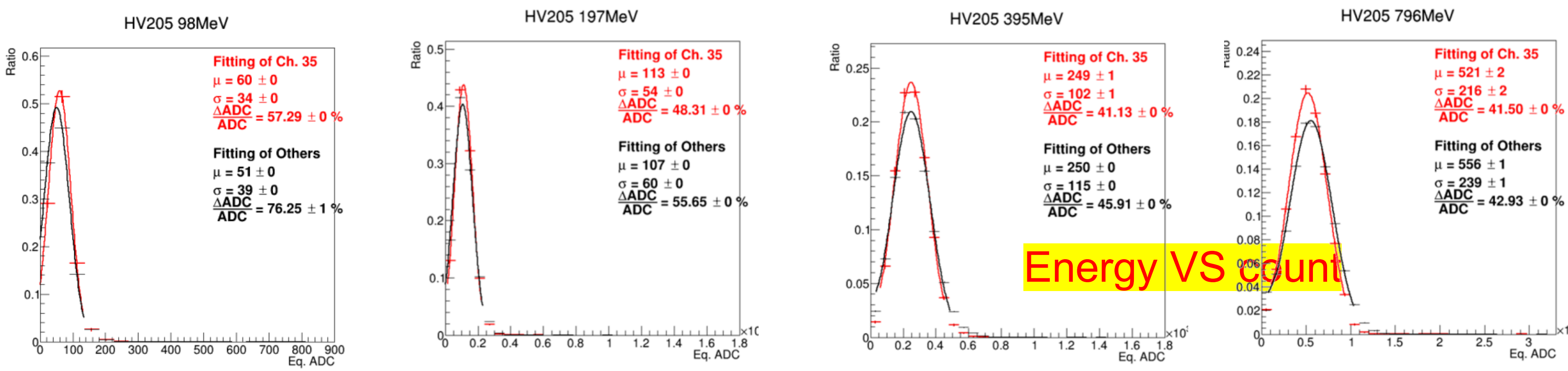


HV = 395V, APD + LYSO

Old fitting method (w/o energy to ADC mapping)



New fitting method (w/ energy to ADC mapping)



Energy resolution improves around 3%.