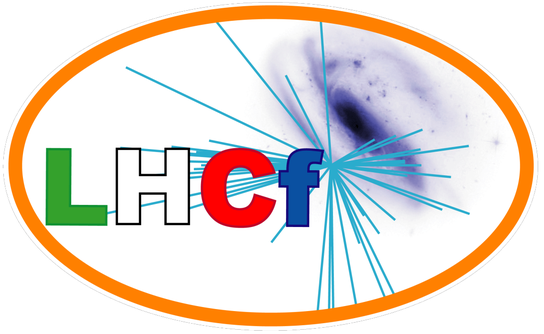
Energy Calibration for Arm1 detector



Yuga Kitagami

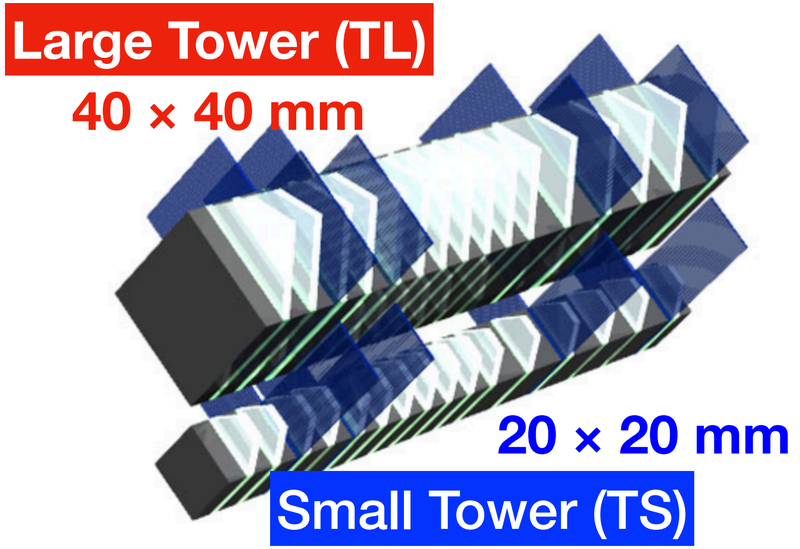
NAGOYA UNIVERSITY

LHCf Arm1 detector

Sampling calorimeter consisted by two towers

Layers in each tower

- Sampling layers ×16 (Gd_2SiO_5 (GSO) plates)
- Position sensitive layers×4 (GSO-bar hodoscopes)
- Tungsten plates (44 radiation length)



Reconstruction of incident energy

$$E_{rec} = F(\sum_i Q_i A_i \times C_i)$$

Q_i : ADC values

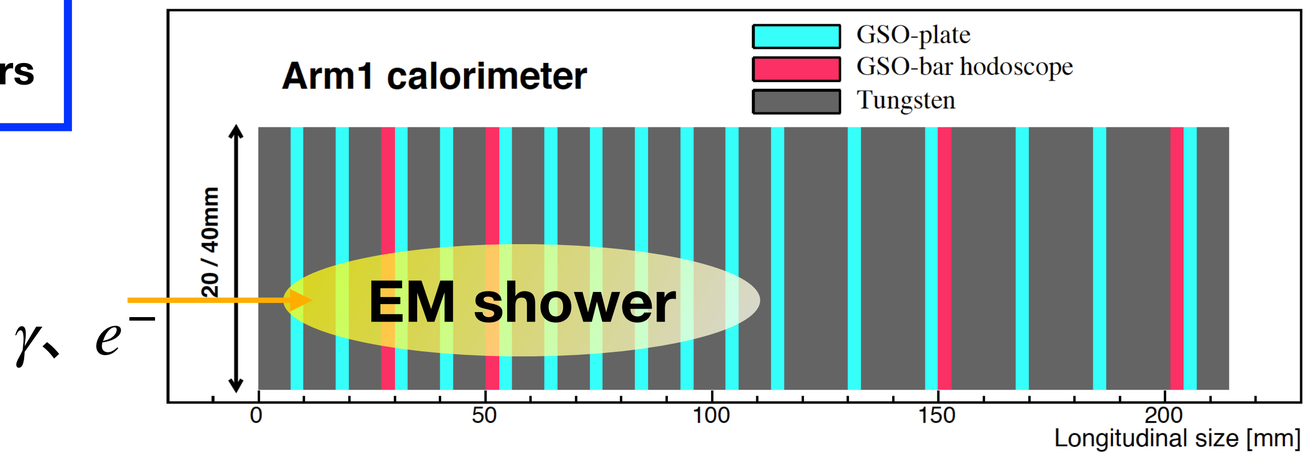
A_i : Conversion factors

C_i : Other correction factors

Resolution (200 GeV photons)

Energy resolution : 3%

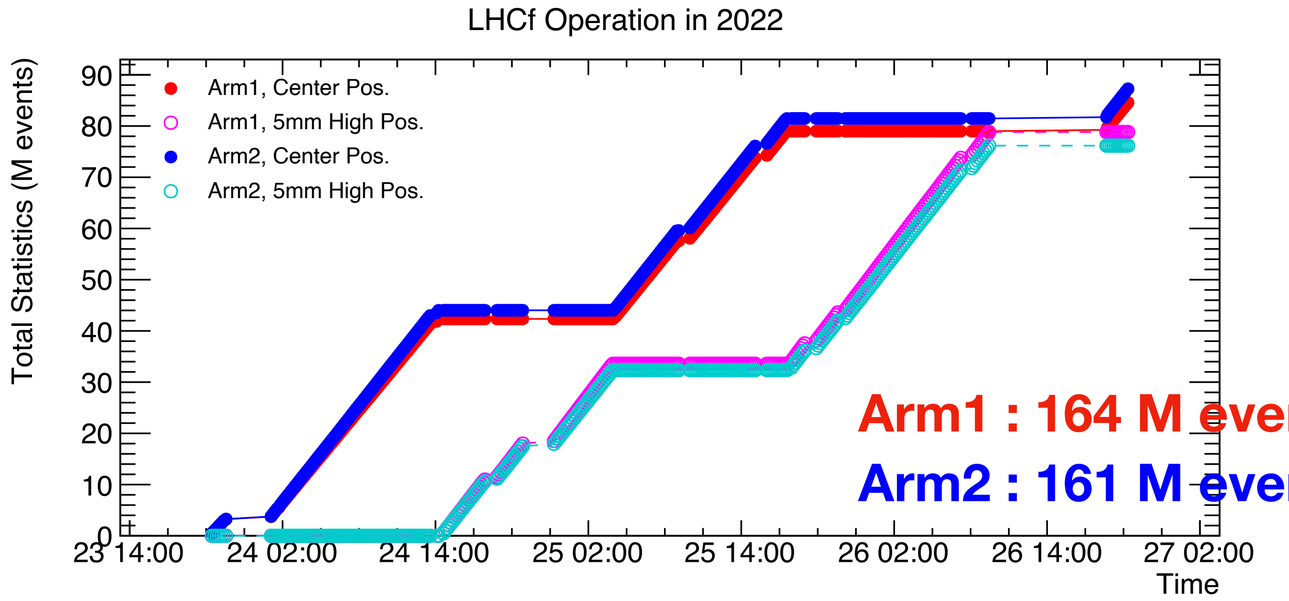
Position resolution : 0.2 mm



LHCf measurement in 2022 (pp $\sqrt{s}$=13.6 TeV)

2022/09/23 ~ 2022/09/26

We succeeded to obtained the high-statistics data.



Arm1 : 164 M events

Arm2 : 161 M events

π^0 **: 720k events**

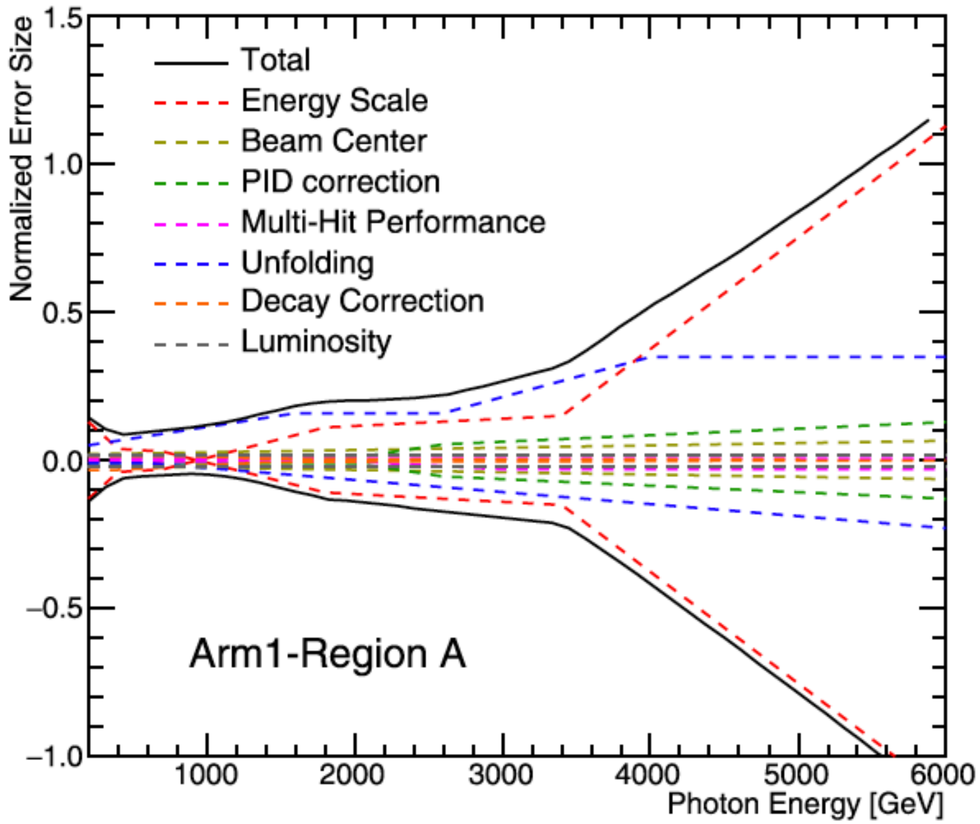
η **: 15k events**

(It is 10 times higher statistics than 2015 measurements)

It is possible for more precise analysis about the particles including strange quark (exp. η, K)

Systematic errors in LHCf measurements

Systematic errors on the production cross-section of photons in 2015 measurement



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Energy scale is the largest contribution to systematic errors of LHCf measurements.

⇨ **It is important to perform the energy calibration with high-precision.**

Energy calibration in 2015 was performed by using data obtained at SPS beam tests conducted before operation.

Breakdown of systematic errors of energy scale measured in Op2015.

Breakdown of systematic errors of energy scale	Error
Energy calibration	2.2%
Cable attenuation	0.5%
Gain Table	1.3%
HV stability	1.4%
Position dependency	1.4%
Others	0.7%

Effective components for calibration by beam test

Energy shift in each sampling layer between SPS2015 and SPS2021

Gain change was predicted due to the status of scintillators.

Compare the mean of ADC counts in each sampling layer and tower.

- **Layer 0-9 : By using 197.3 GeV/c electron beam.**
- **Layer 10-15 : using 350 GeV/c proton beam.**

Above 10% energy shift was found in some layers.

Conversion factor ratio between 2015 and 2021 (2021/2015)

layer	TS	TL
0	1.0	0.992
1	0.926	0.984
2	0.862	1.121
3	1.063	1.056
4	1.082	1.143
5	0.835	1.0
6	1.109	0.994
7	1.026	0.488
8	1.145	1.051
9	0.969	0.932
10	0.914	0.897
11	0.915	0.924
12	1.090	0.725
13	0.966	0.867
14	0.945	1.028
15	0.959	0.947

Thanks for Kondo san's work

Energy shift in each sampling layer between SPS2021 and SPS2022

I checked it same as comparing SPS2015 and SPS2021.

Energy shift is exist in some layers.

⇨ It is necessary to do energy calibration for LHC 2022 analysis.

Energy calibration was performed by comparing SPS2022 and MC.

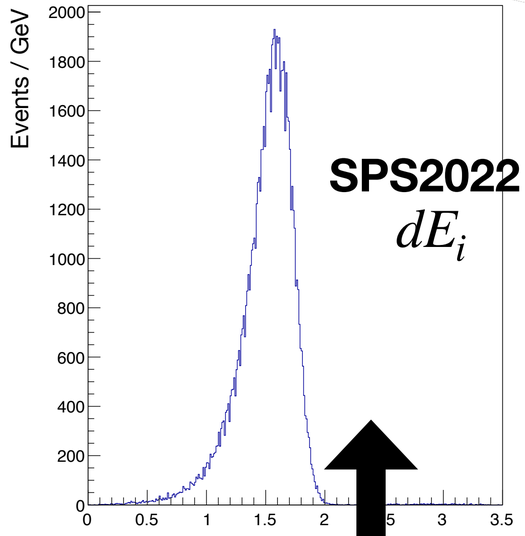
Conversion factor ratio between SPS2021 and SPS2022

Layer	TS	TL
0	1.263	1.264
1	1.148	1.108
2	1.059	1.049
3	0.986	1.016
4	0.979	0.990
5	1.016	1.033
6	0.991	1.070
7	0.993	0.982
8	0.957	0.969
9	1.106	1.108
10	1.084	1.053
11	1.102	1.035
12	1.013	1.044
13	1.069	1.090
14	0.988	1.149
15	1.041	1.068

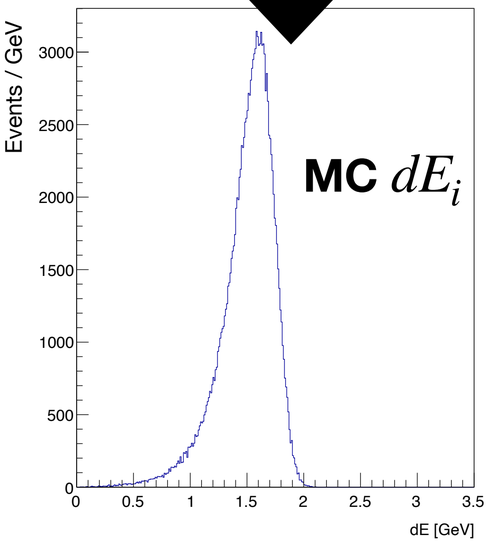
Energy calibration method by using SPS MC

Conversion factors were calculated by comparing the mean of energy deposit dE_i between data and MC as;

SPSMethod's A_i = **SPS2022's A_i** × $\dfrac{\bar{dE}_{i_{MC}}}{\bar{dE}_{i_{2022}}}$



Compare $\bar{dE}_i$

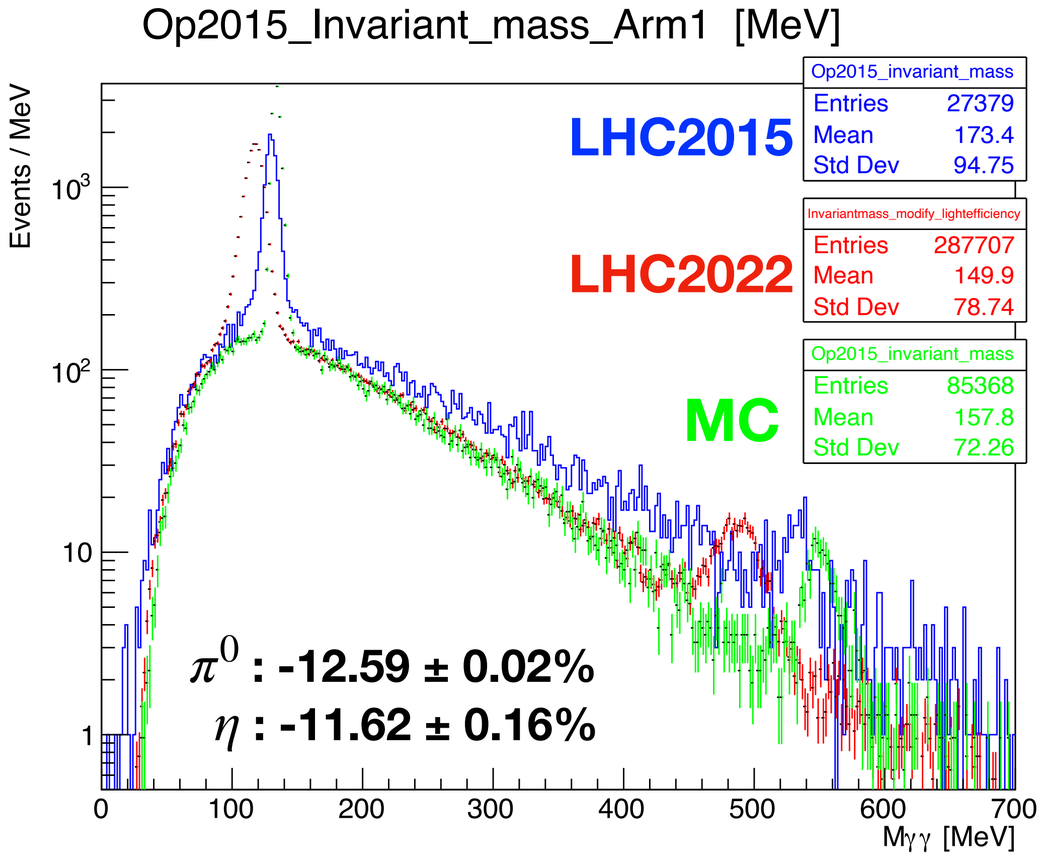


Only i = 0-8 were calibrated because EM showers developed at these range.

Energy calibration results by using SPS MC

Conversion factor A_i estimated by using MC

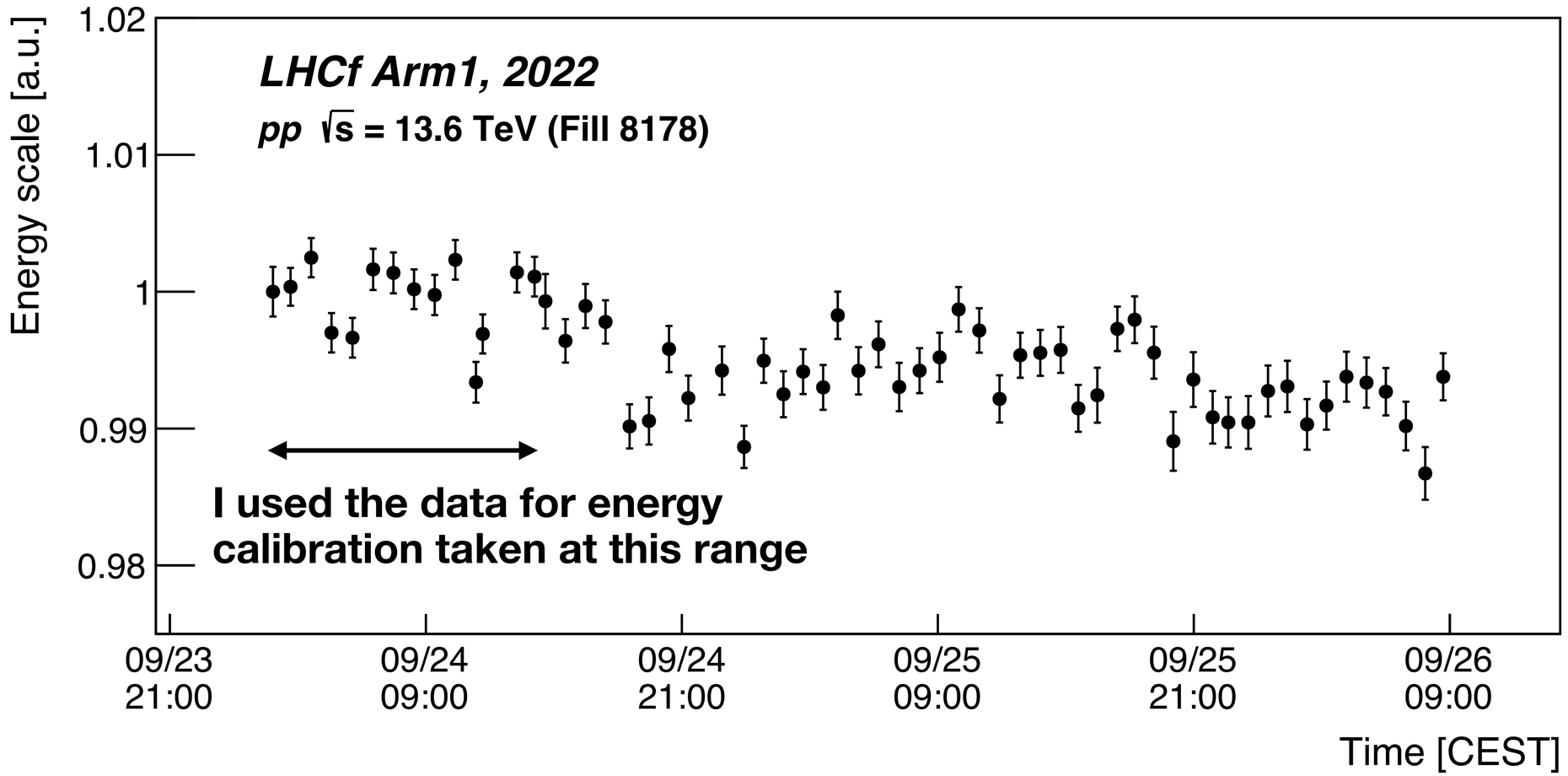
Layer	A_i (TS)	A_i (TL)
0	8475.88	7409.46
1	3982.63	5444.65
2	2310.76	7973.16
3	3957.44	6200.94
4	6218.76	6419.87
5	985.91	2932.55
6	6102.06	4155.47
7	5188.62	3287.77
8	4900.87	3703.72



Energy scale sifting about 11-13 % are found.

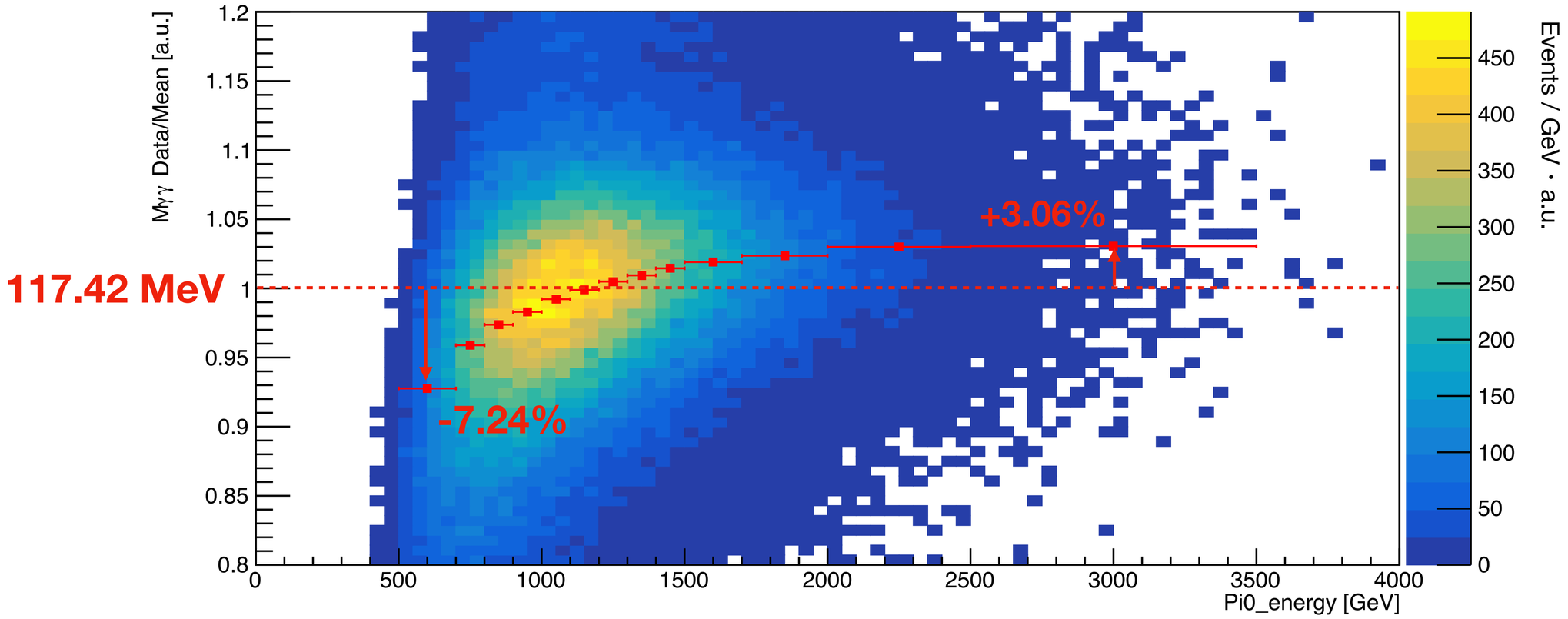
I checked the stability and energy dependency of energy scale.

Energy scale stability



Energy scale change in whole 2022 measurement is -0.7 (±0.1) %.
It is stable and little effect on the energy scale shift.

Energy dependency after energy calibration by using MC



Energy dependency is found.

But it does not explain -13% of energy scale shifting.

Energy calibration method by using LHC2022 data

High-statistical 2022 measurement data can be used for energy calibration.

I checked the energy scale in each layer to confirm if there are any strange layers by comparing dE_i of incident photons between LHC data and MC, following reconstructed energy (E_{rec}) of range;

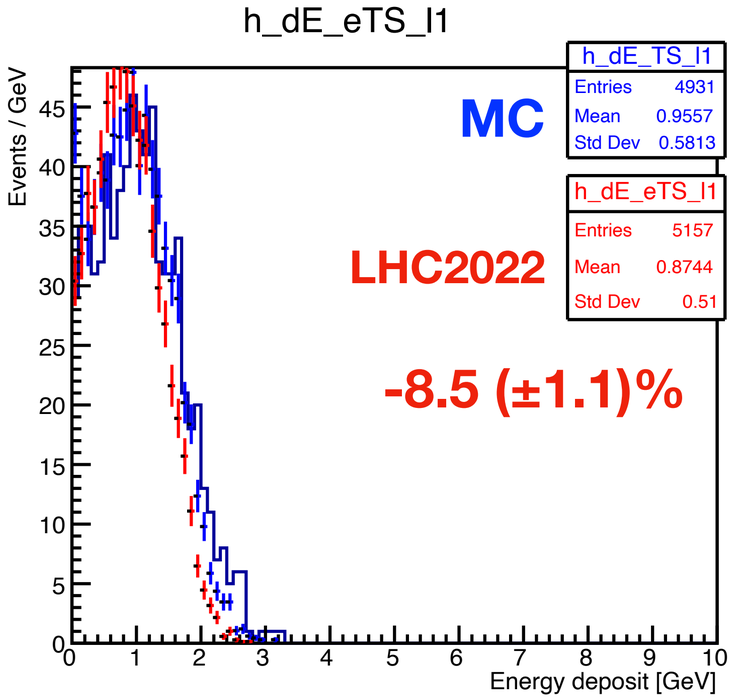
Patern	LHC2022 (GeV)	MC (GeV)
Patern 1	500 < E_{rec} < 550	573 < E_{rec} < 630
Patern 2	1000 < E_{rec} < 1100	1145 < E_{rec} < 1260

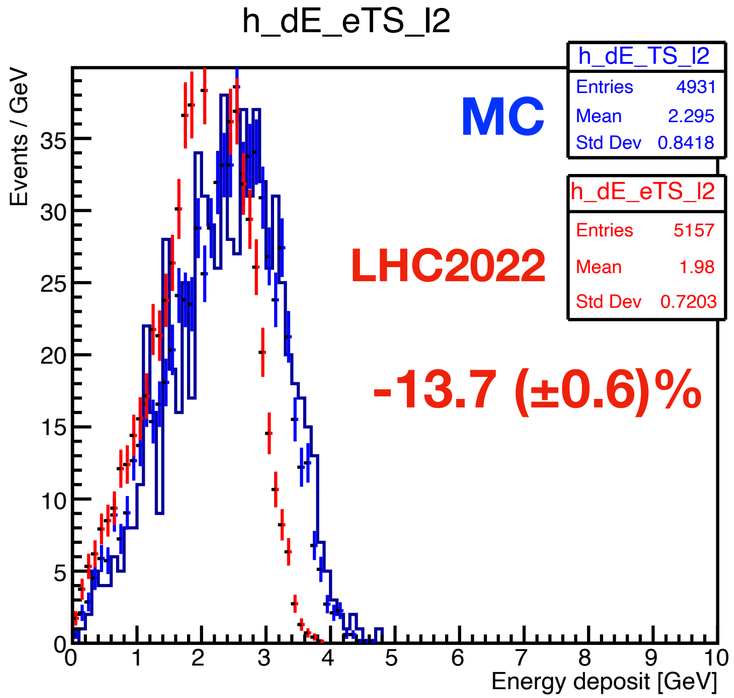
LHC2022 : E_{rec} **= 0.87*** E_{true}

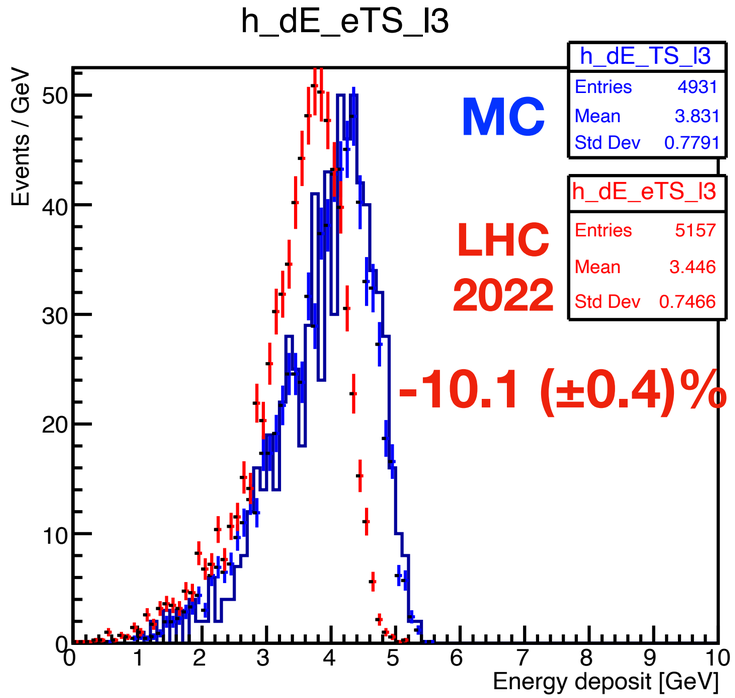
Energy calibration was performed by comparing the mean of dE at Patern 1.

Checking each sampling layer

Patern 1、TS, Layer 1~3

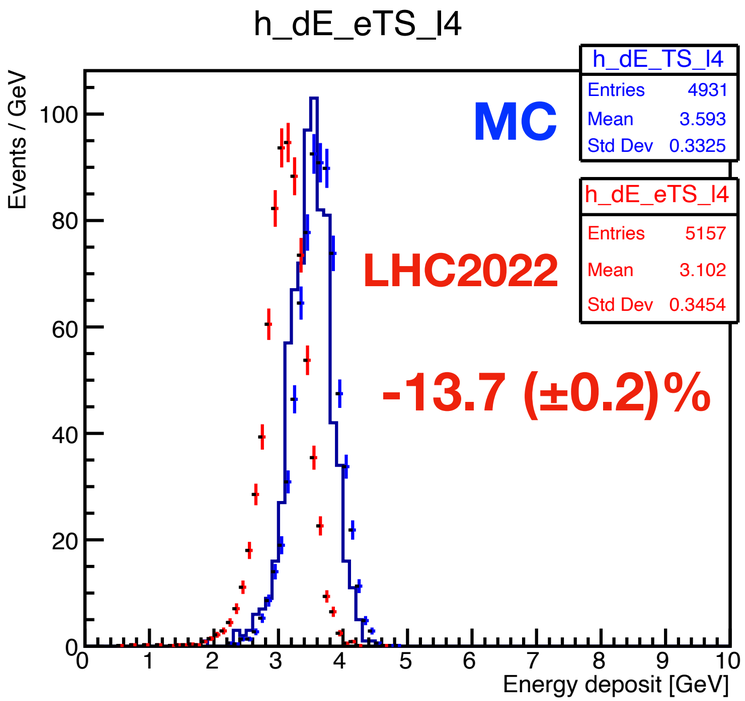


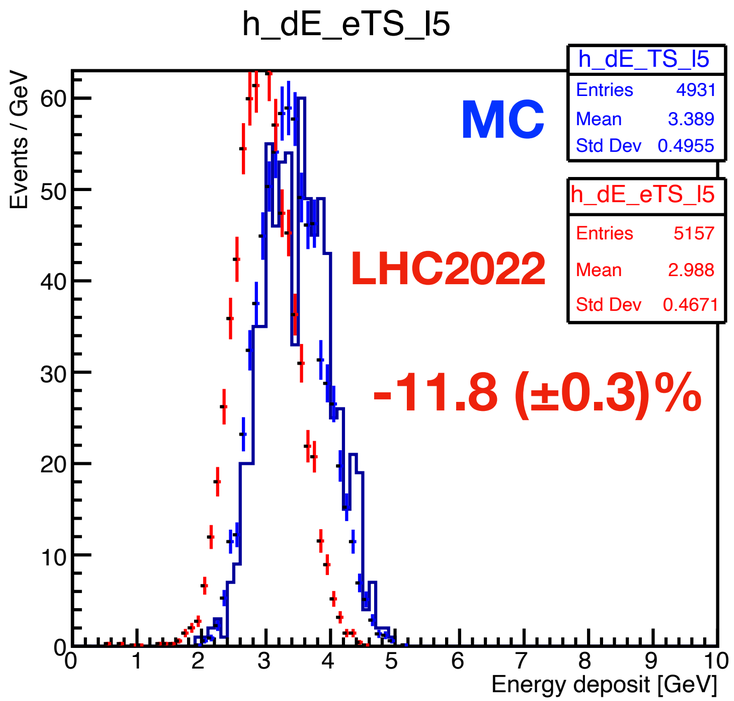


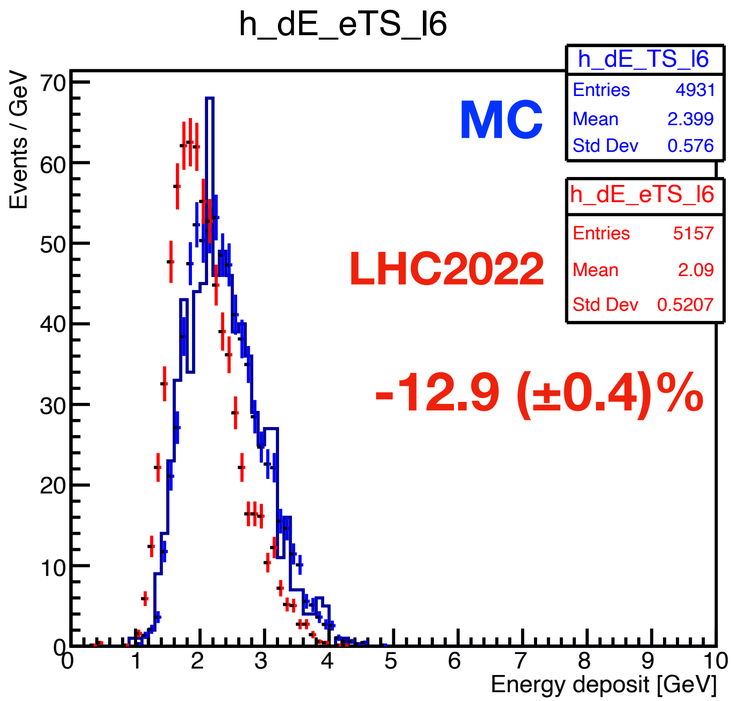


Checking each sampling layer

Patern 1、TS, Layer 4~6

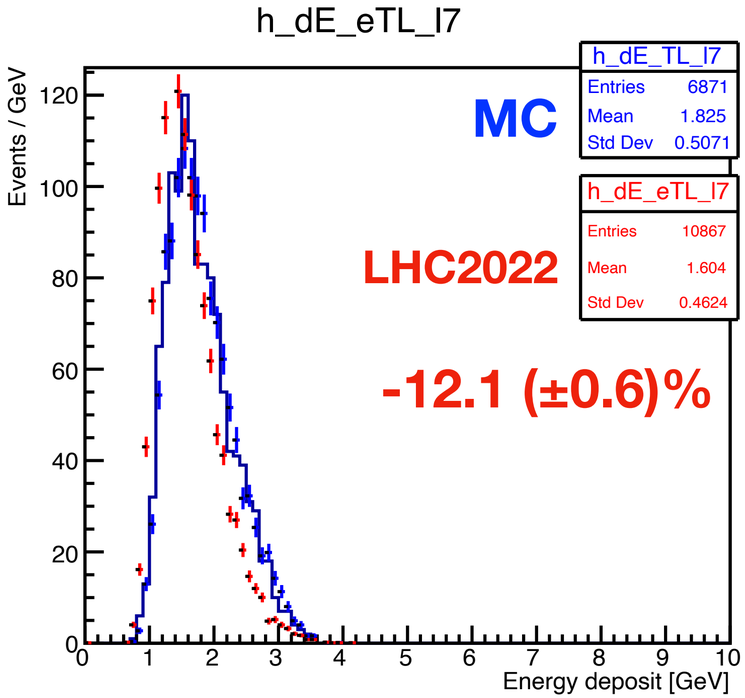


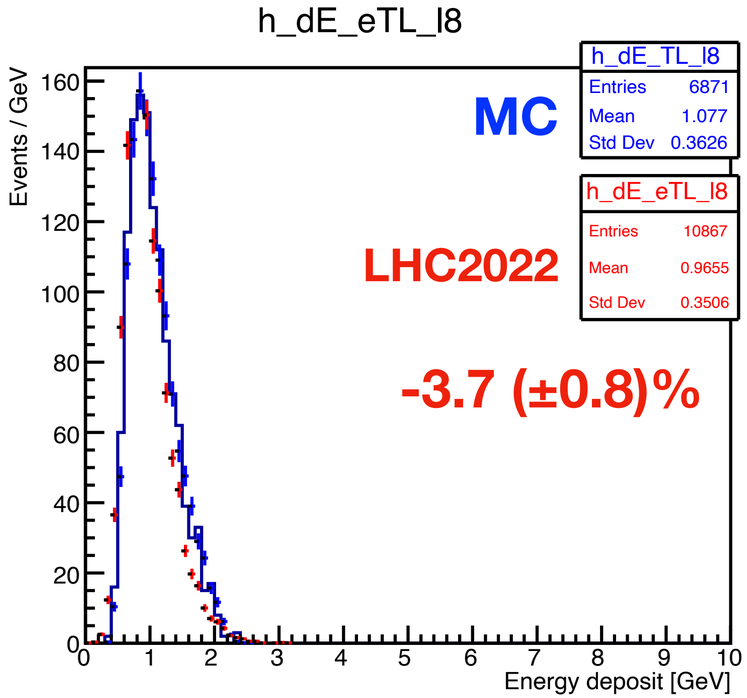


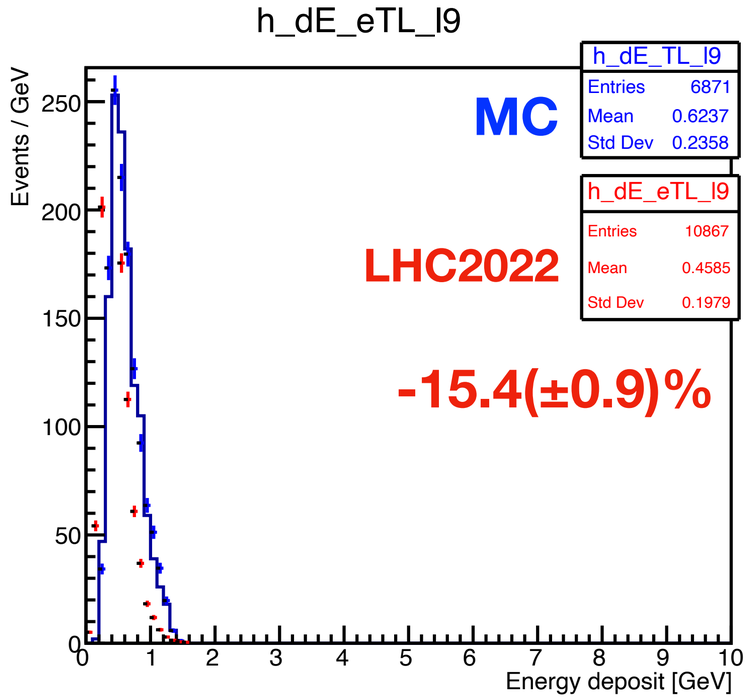


Checking each sampling layer

Patern 1、TS, Layer 7~9

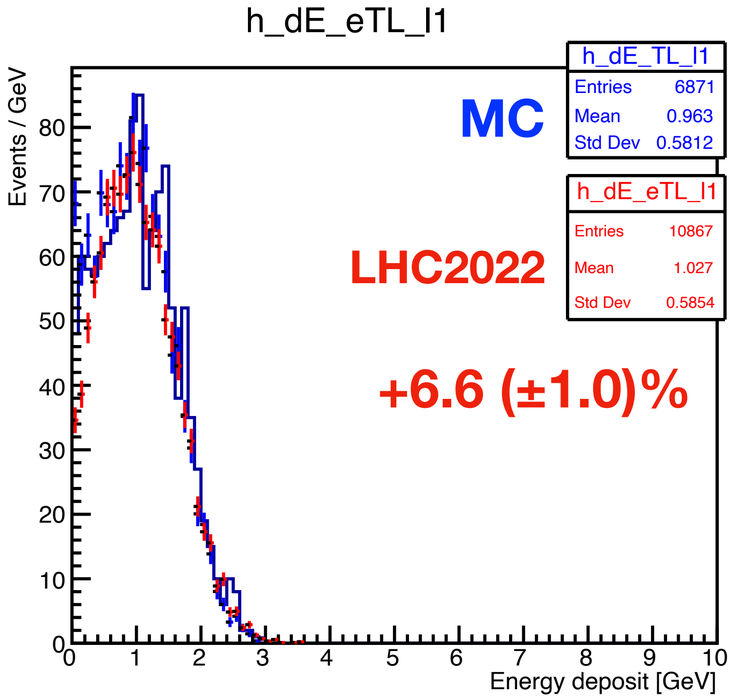


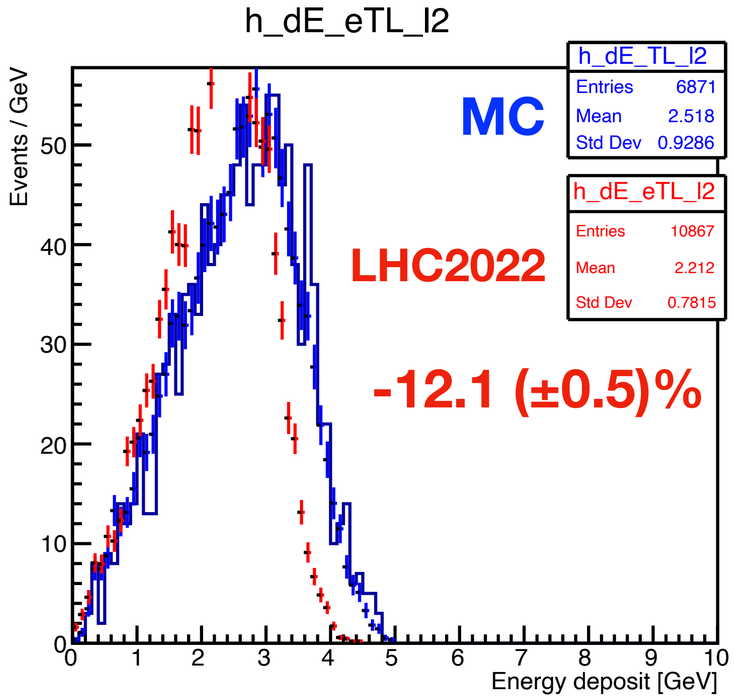


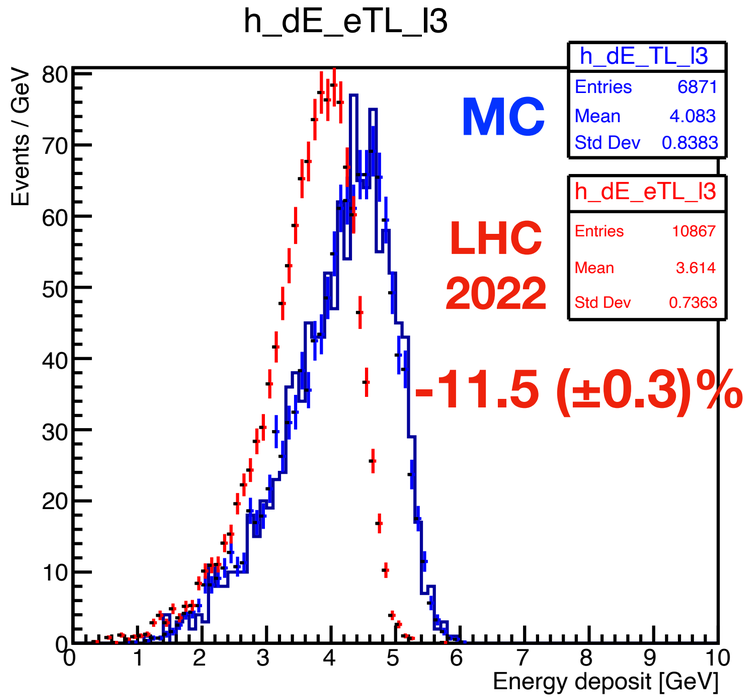


Checking each sampling layer

Patern 1、TL, Layer 1~3

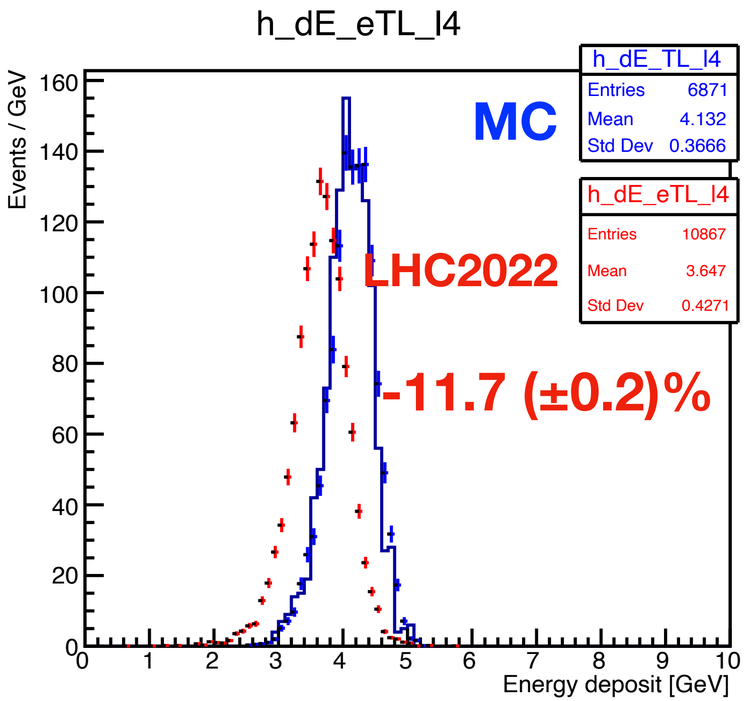


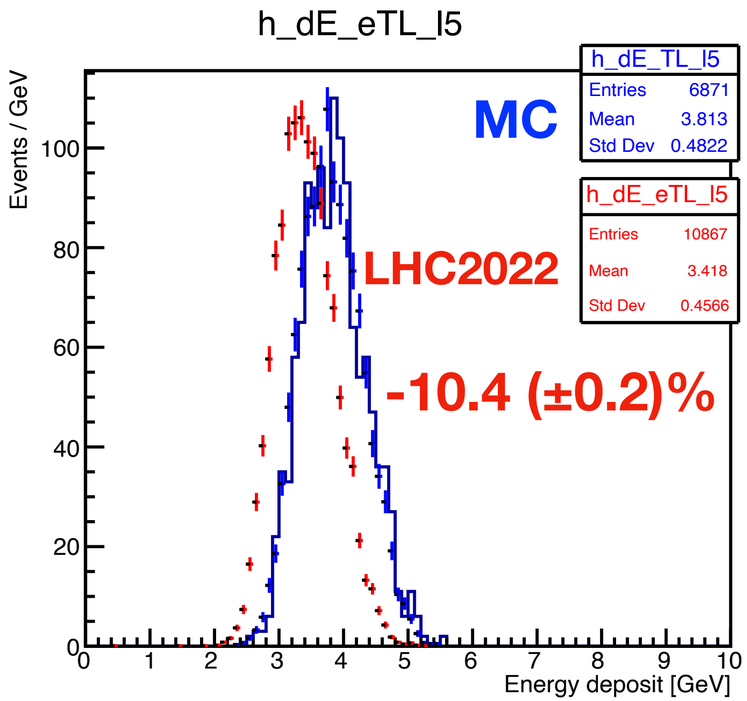


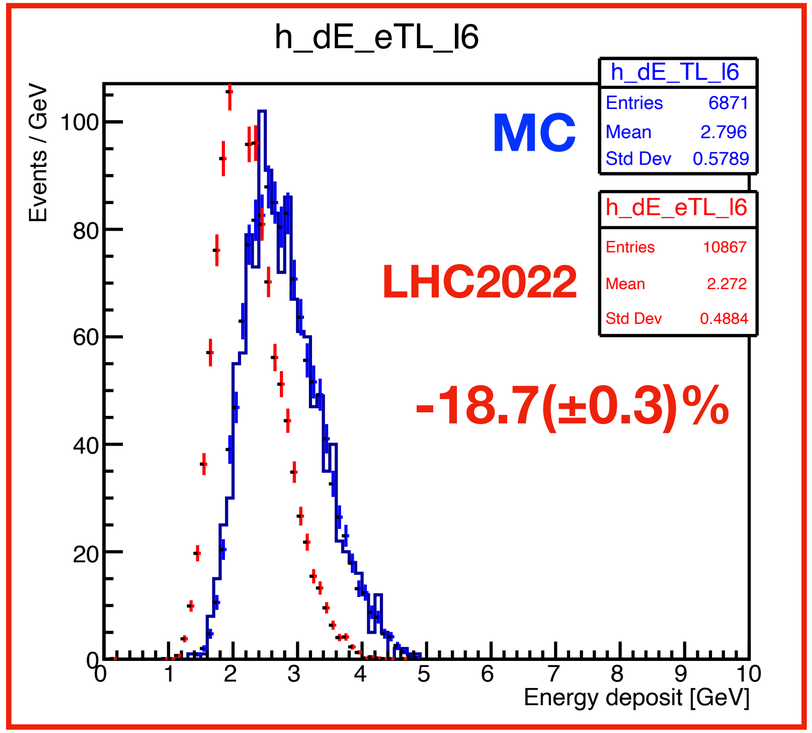


Checking each sampling layer

Patern 1、TL, Layer 4~6



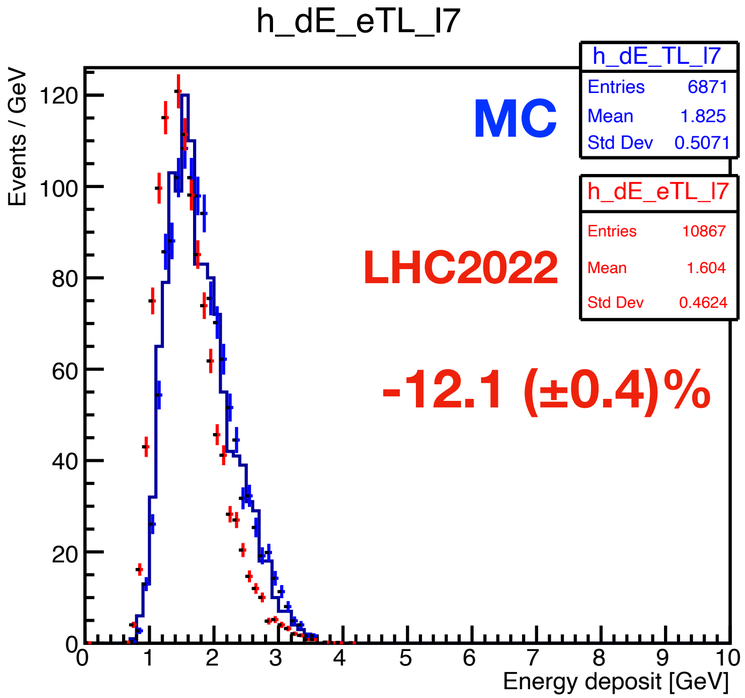


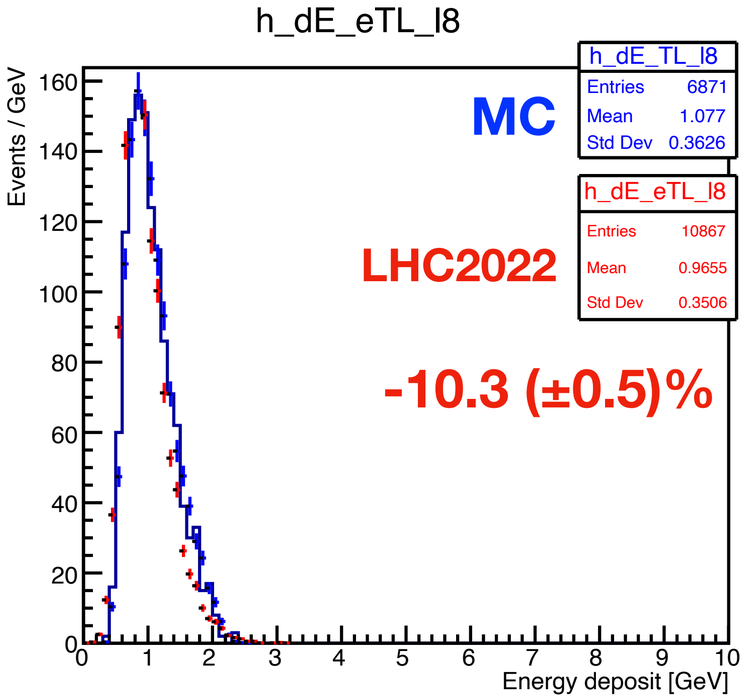


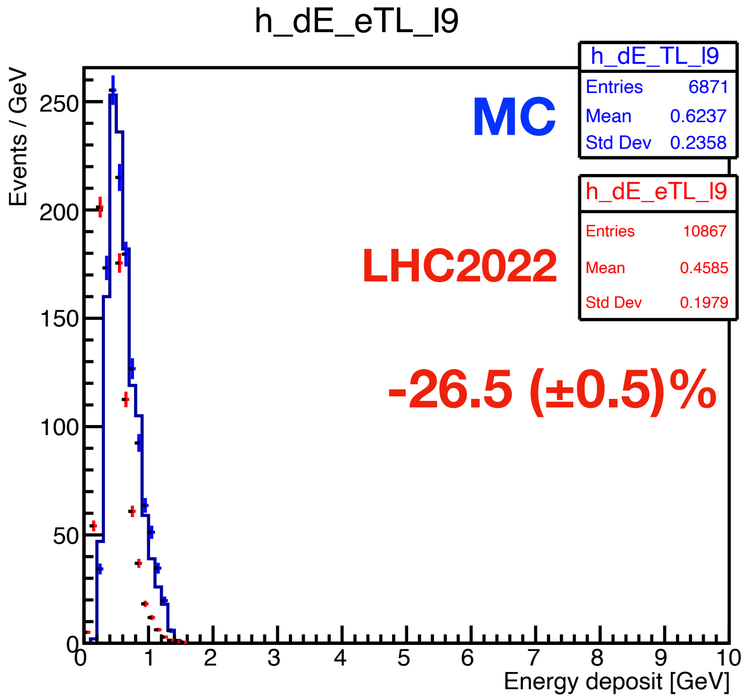
Big energy shift

Checking each sampling layer

Patern 1、TL, Layer 7~9

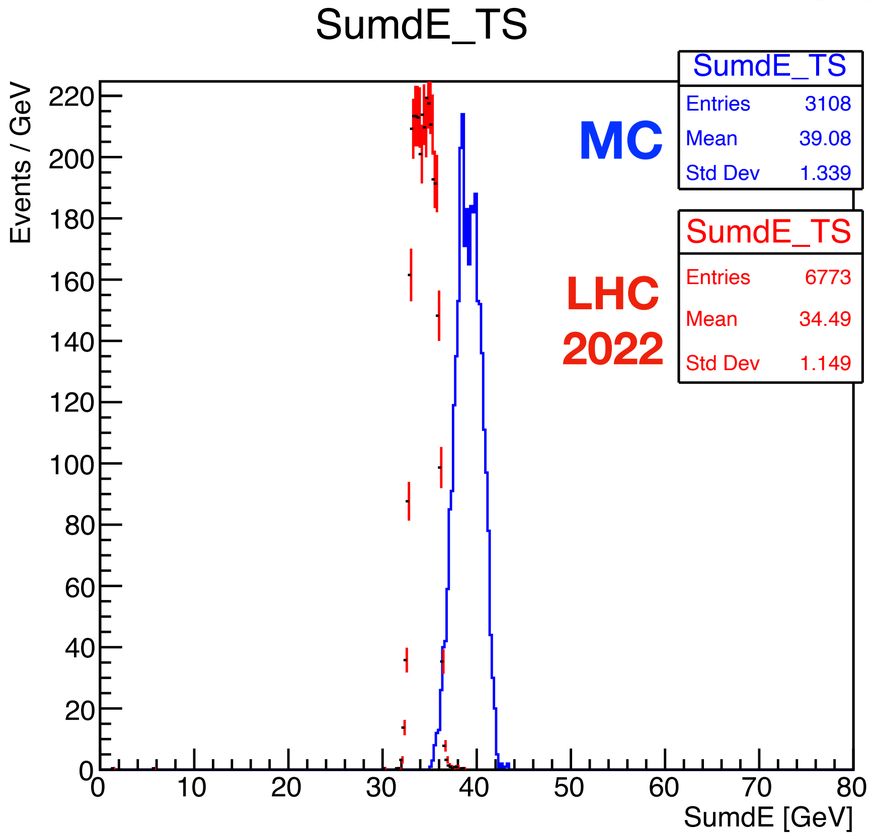


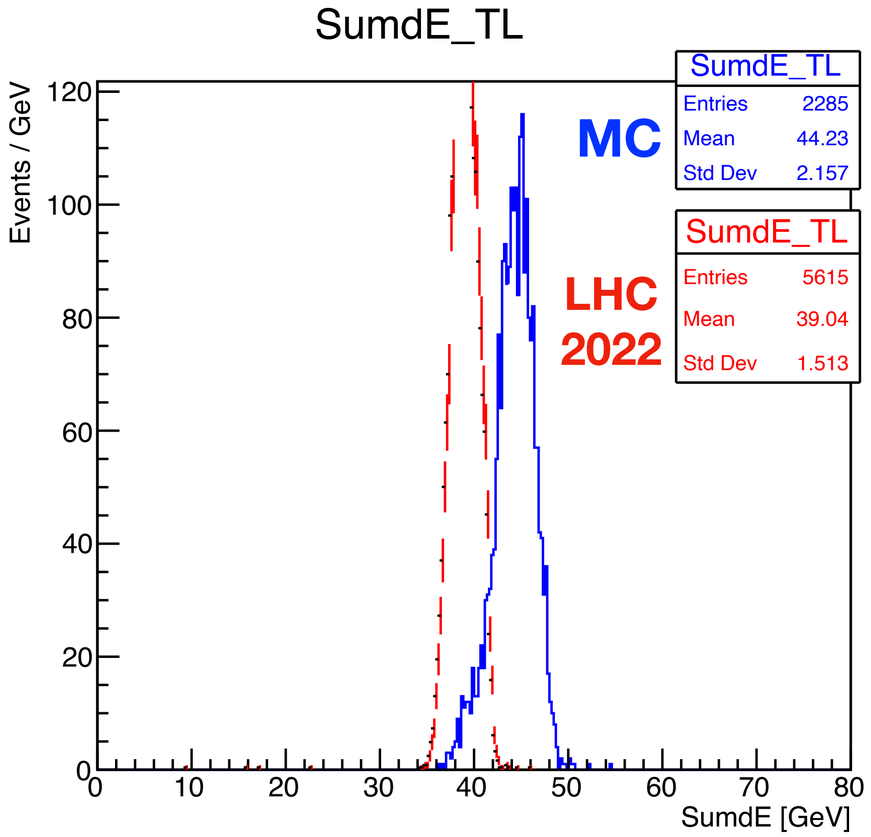




Checking SumdE

Patern 1



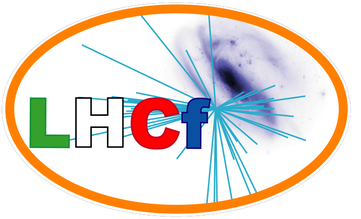


-12.9 (±0.1)%

-12.7 (±0.0)%

Consistent with energy scale shift

Overall of checking each sampling layer and SumdE



Patern 1

Layer	TS (%)	TL (%)
0	-8.5 ± 1.1	+6.6 ± 1.0
1	-13.7 ± 0.6	-12.1 ± 0.5
2	-10.1 ± 0.4	-11.5 ± 0.3
3	-13.7 ± 0.2	-11.7 ± 0.2
4	-11.8 ± 0.3	-10.4 ± 0.2
5	-12.9 ± 0.4	-18.7 ± 0.3
6	-12.1 ± 0.6	-12.1 ± 0.4
7	-3.7 ± 0.8	-10.3 ± 0.5
8	-15.4 ± 0.9	-26.5 ± 0.5
SumdE (LHC/MC)	-12.9 ± 0.1	-12.7 ± 0.0

Patern 2

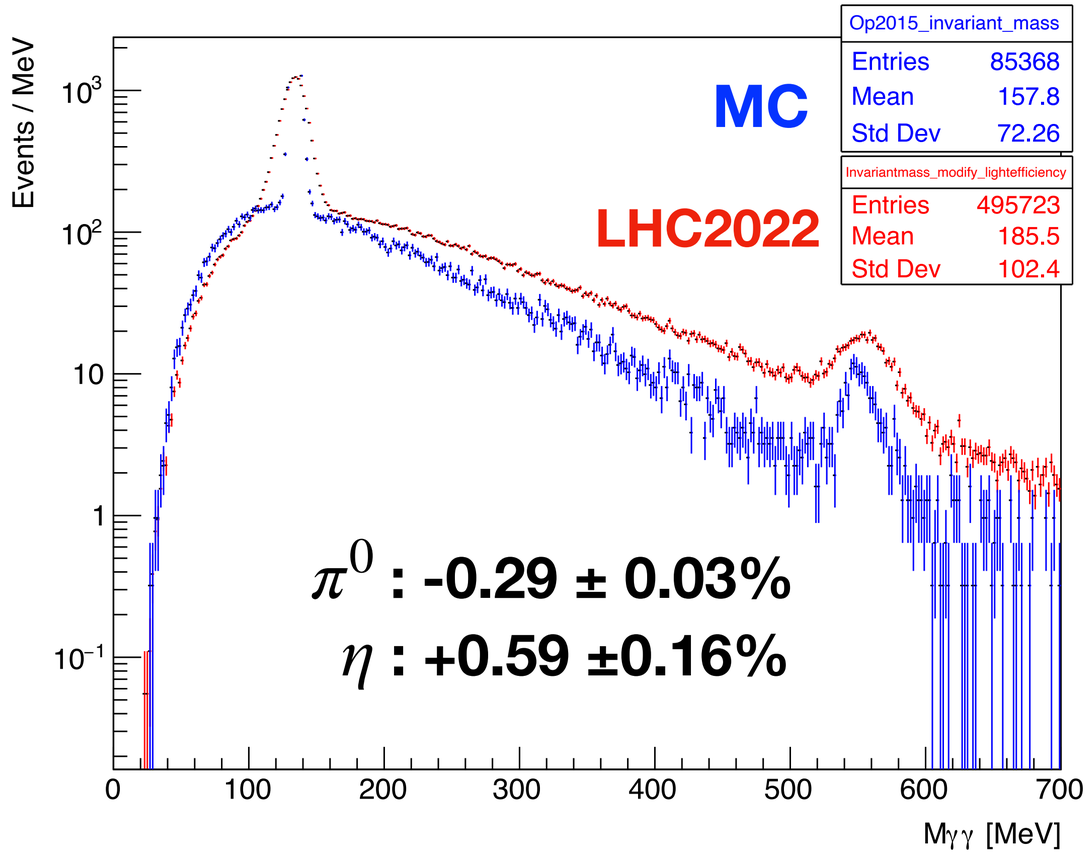
Layer	TS (%)	TL (%)
0	-1.9 ± 1.2	±0.0 ± 1.6
1	-11.9 ± 0.7	-12.5 ± 0.9
2	-9.1 ± 0.4	-10.9 ± 0.5
3	-14.3 ± 0.2	-11.4 ± 0.2
4	-11.2 ± 0.2	-10.0 ± 0.2
5	-14.7 ± 0.3	-18.0 ± 0.4
6	-15.3 ± 0.4	-11.7 ± 0.5
7	-9.7± 0.6	-10.4 ± 0.7
8	-24.8 ± 0.6	-24.6 ± 0.7
SumdE (LHC/MC)	-12.7 ± 0.1	12.7 ± 0.1

The 6th sampling layer in TL is strange. And the 8th layer in TS show the inconsistent result between the different energy change.

Checking the energy scale after energy calibration

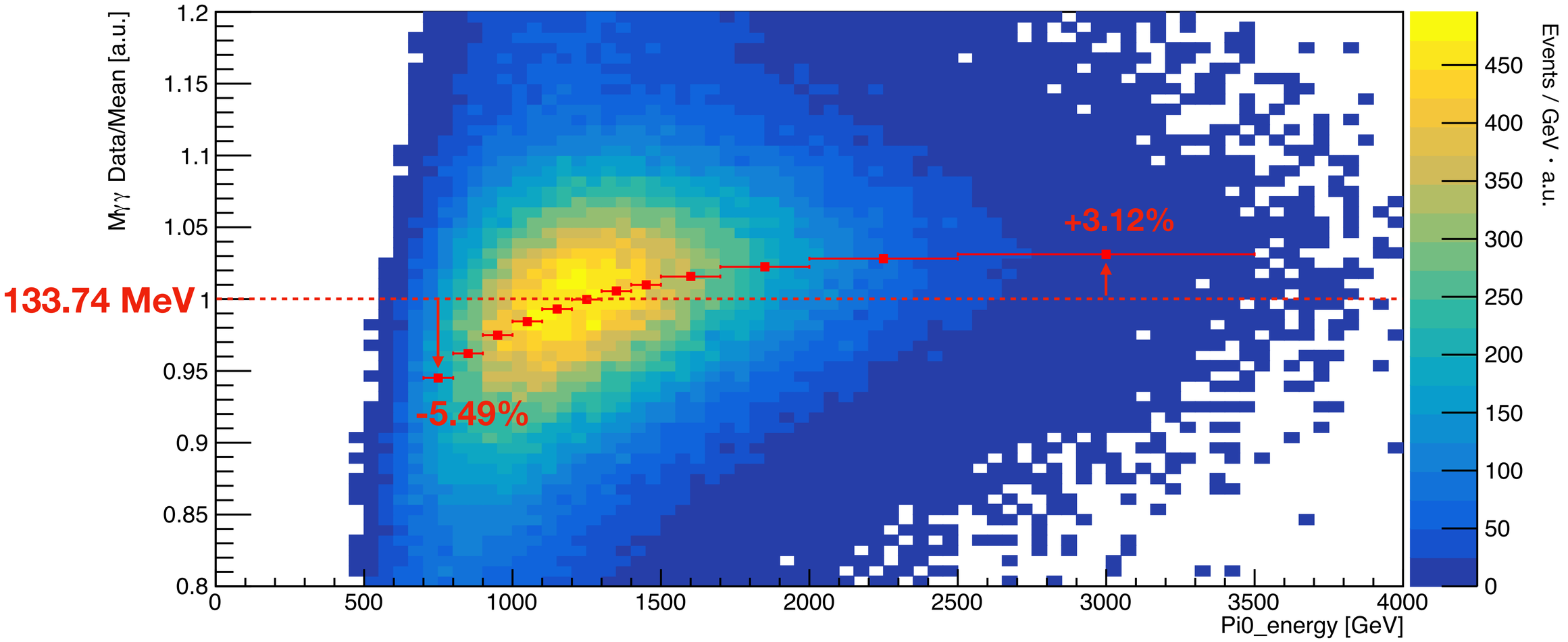
Conversion factor A_i estimated by using LHC2022 data

Layer	A_i (TS)	A_i (TL)
0	7754.93	7903.45
1	3436.03	4783.35
2	2078.17	7057.74
3	3417.10	5472.53
4	5483.74	5753.76
5	859.18	2382.84
6	5360.84	3652.39
7	4995.38	2947.59
8	4144.31	2722.53



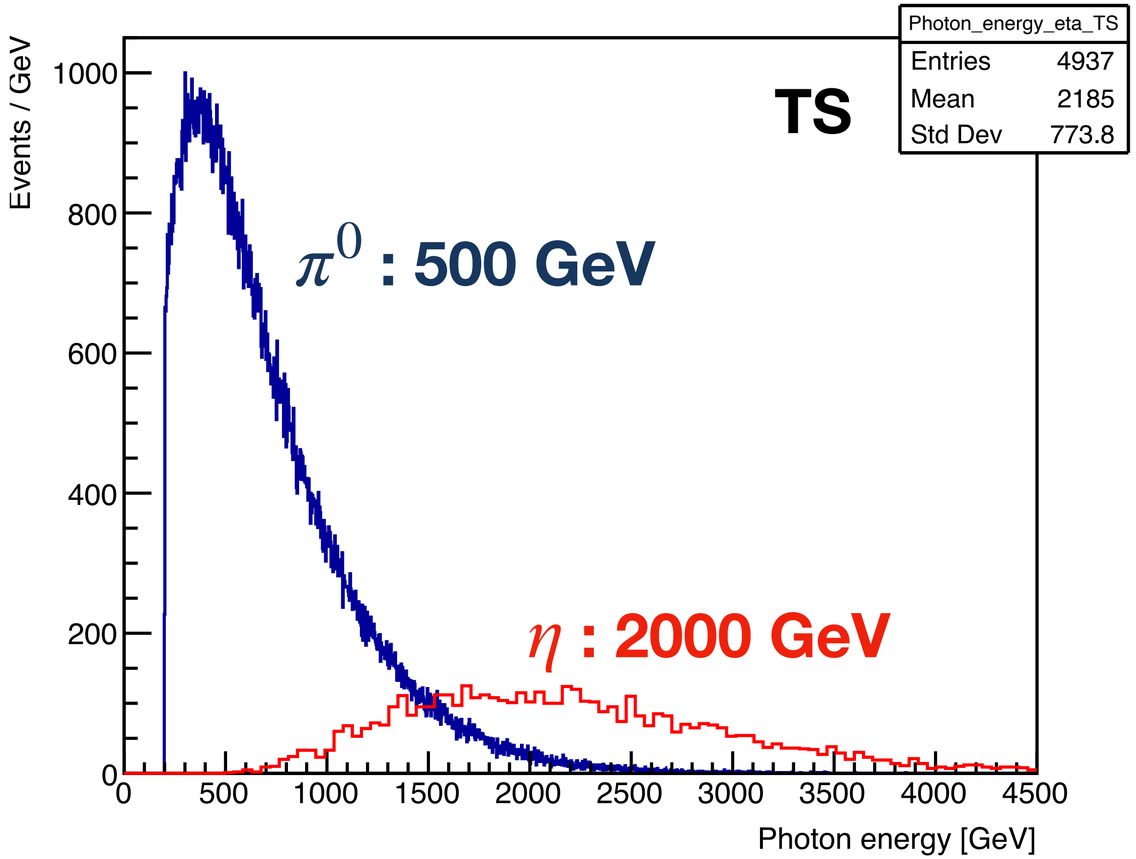
Confirmed energy scale of π^0 and η are consisted within 1%.

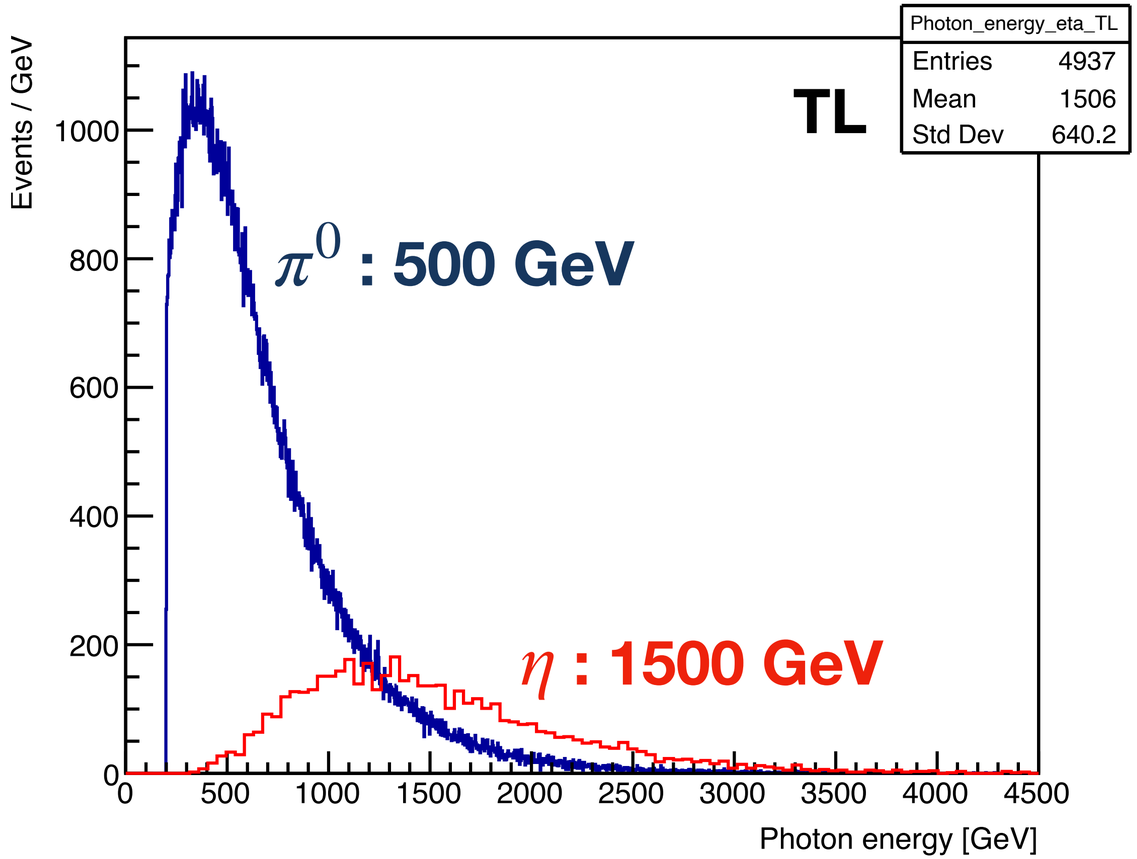
Energy dependency after energy calibration by using LHC data



Energy dependency is still nothing to change.

Energy range of photons derived from π^0 and η





Photons energy derived from η is 3~4 times higher than that of π^0.

Summary

- Energy calibration was done by using the LHC data.
  - Energy scale : π^0 -0.29±0.03 %
    η +0.59±0.16 %
- TL, layer 6 is a bit strange for energy scale.
- Energy dependency of energy scale is found.
  - Lower energy (< 1000 GeV) : -5.5% ~ -2.5%
    Higher energy (> 2500 GeV) : +3.1%
- Photons energy derived from η is 3~4 times higher than that of π^0.
- Energy calibration in layer 9-15 will be done by using 197.3 GeV/c electron beam data taken at detector rotating.

Back Up

Energy calibration method used so far

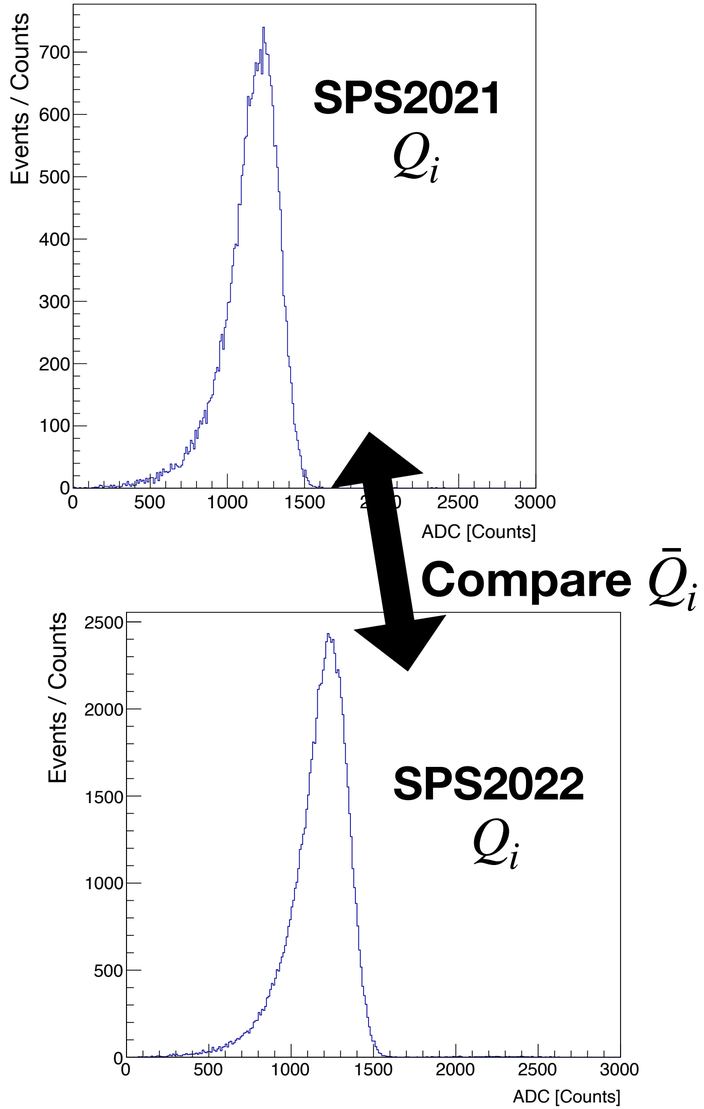
Conversion factor A_i are decided by SPS beam test.

$$\text{SPS2022's } A_i = \boxed{\text{SPS2015's } A_i \times \frac{\bar{Q}_{i2021}}{\bar{Q}_{i2015}}} \times \frac{\bar{Q}_{i2022}}{\bar{Q}_{i2021}}$$

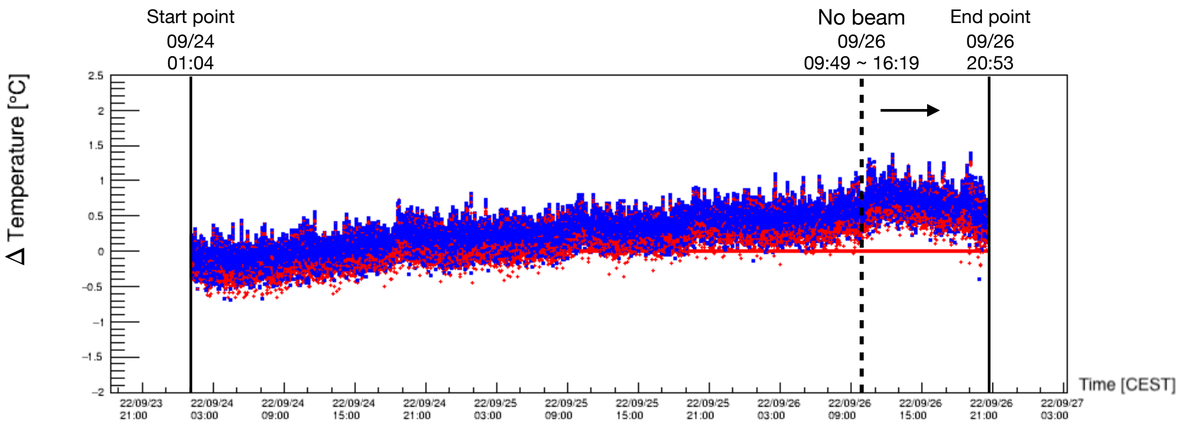
SPS2021's A_i

i = 0-9: used 197.3 GeV/c electron beam,

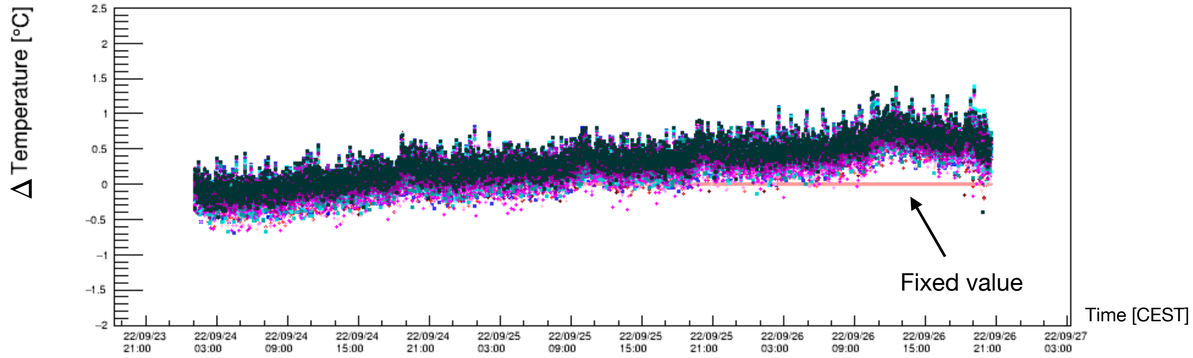
i = 10-15: used 350 GeV/c proton beam



LHC2022 Arm1 temperature stability



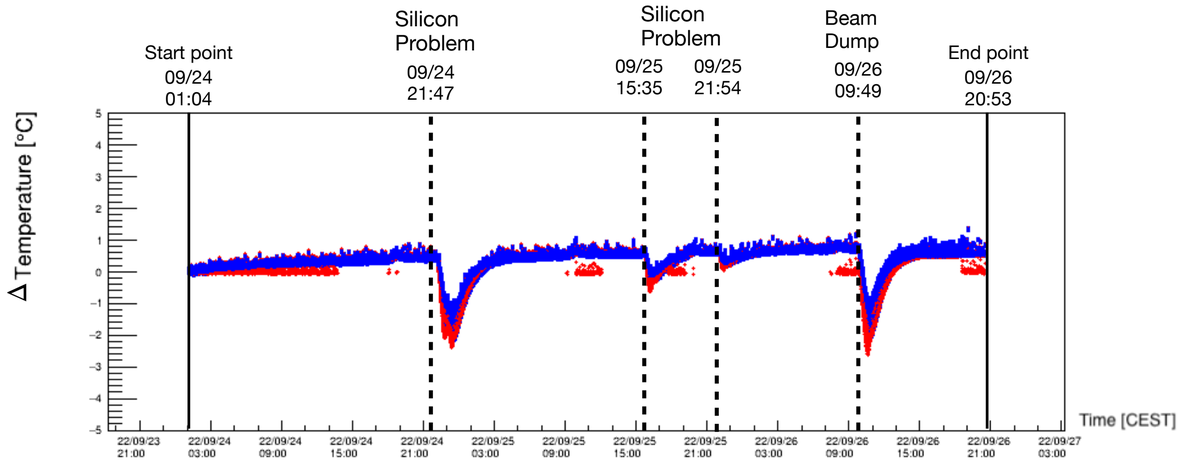
Arm1 TS0 Arm1 TL0 Arm1 TS1 Arm1 TL1 Arm1 TS2 Arm1 TL2
Arm1 TS3 Arm1 TL3 Arm1 TS4 Arm1 TL4 Arm1 TS5 Arm1 TL5
Arm1 TS6 Arm1 TL6 Arm1 TS7 Arm1 TL7 Arm1 TS8 Arm1 TL8
Arm1 TS9 Arm1 TL9 Arm1 TS10 Arm1 TL10 Arm1 TS11 Arm1 TL11
Arm1 TS12 Arm1 TL12 Arm1 TS13 Arm1 TL13 Arm1 TS14 Arm1 TL14
Arm1 TS15 Arm1 TL15



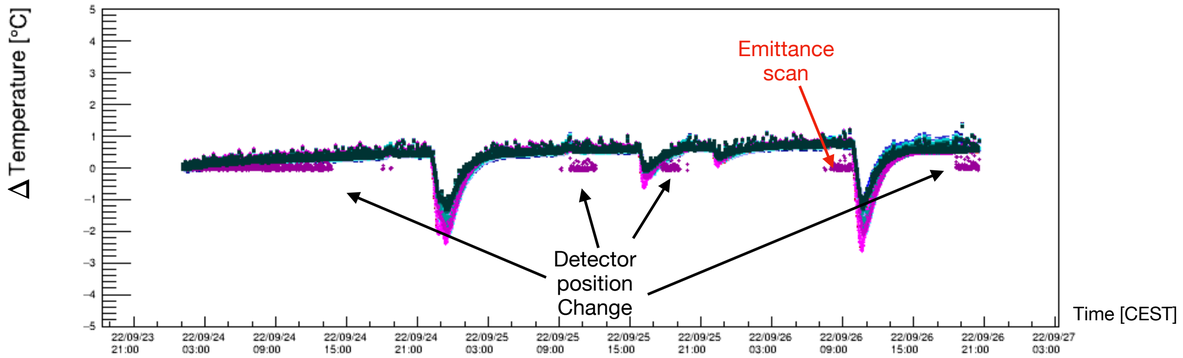
Arm1 TS0 Arm1 TL0 Arm1 TS1 Arm1 TL1 Arm1 TS2 Arm1 TL2
Arm1 TS3 Arm1 TL3 Arm1 TS4 Arm1 TL4 Arm1 TS5 Arm1 TL5
Arm1 TS6 Arm1 TL6 Arm1 TS7 Arm1 TL7 Arm1 TS8 Arm1 TL8
Arm1 TS9 Arm1 TL9 Arm1 TS10 Arm1 TL10 Arm1 TS11 Arm1 TL11
Arm1 TS12 Arm1 TL12 Arm1 TS13 Arm1 TL13 Arm1 TS14 Arm1 TL14
Arm1 TS15 Arm1 TL15

Temperature increased slightly 0.8 degree during the operation.

LHC2022 Arm1 temperature stability



·Arm2 TS0 ·Arm2 TL0 ·Arm2 TS1 ·Arm2 TL1 ·Arm2 TS2 ·Arm2 TL2
·Arm2 TS3 ·Arm2 TL3 ·Arm2 TS4 ·Arm2 TL4 ·Arm2 TS5 ·Arm2 TL5
·Arm2 TS6 ·Arm2 TL6 ·Arm2 TS7 ·Arm2 TL7 ·Arm2 TS8 ·Arm2 TL8
·Arm2 TS9 ·Arm2 TL9 ·Arm2 TS10 ·Arm2 TL10 ·Arm2 TS11 ·Arm2 TL11
·Arm2 TS12 ·Arm2 TL12 ·Arm2 TS13 ·Arm2 TL13 ·Arm2 TS14 ·Arm2 TL14
·Arm2 TS15 ·Arm2 TL15

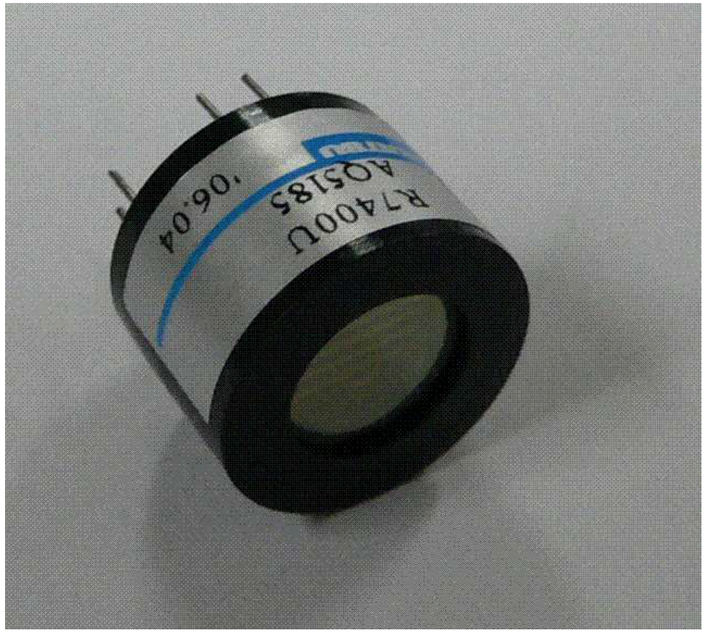


·Arm2 TS0 ·Arm2 TL0 ·Arm2 TS1 ·Arm2 TL1 ·Arm2 TS2 ·Arm2 TL2
·Arm2 TS3 ·Arm2 TL3 ·Arm2 TS4 ·Arm2 TL4 ·Arm2 TS5 ·Arm2 TL5
·Arm2 TS6 ·Arm2 TL6 ·Arm2 TS7 ·Arm2 TL7 ·Arm2 TS8 ·Arm2 TL8
·Arm2 TS9 ·Arm2 TL9 ·Arm2 TS10 ·Arm2 TL10 ·Arm2 TS11 ·Arm2 TL11
·Arm2 TS12 ·Arm2 TL12 ·Arm2 TS13 ·Arm2 TL13 ·Arm2 TS14 ·Arm2 TL14
·Arm2 TS15 ·Arm2 TL15

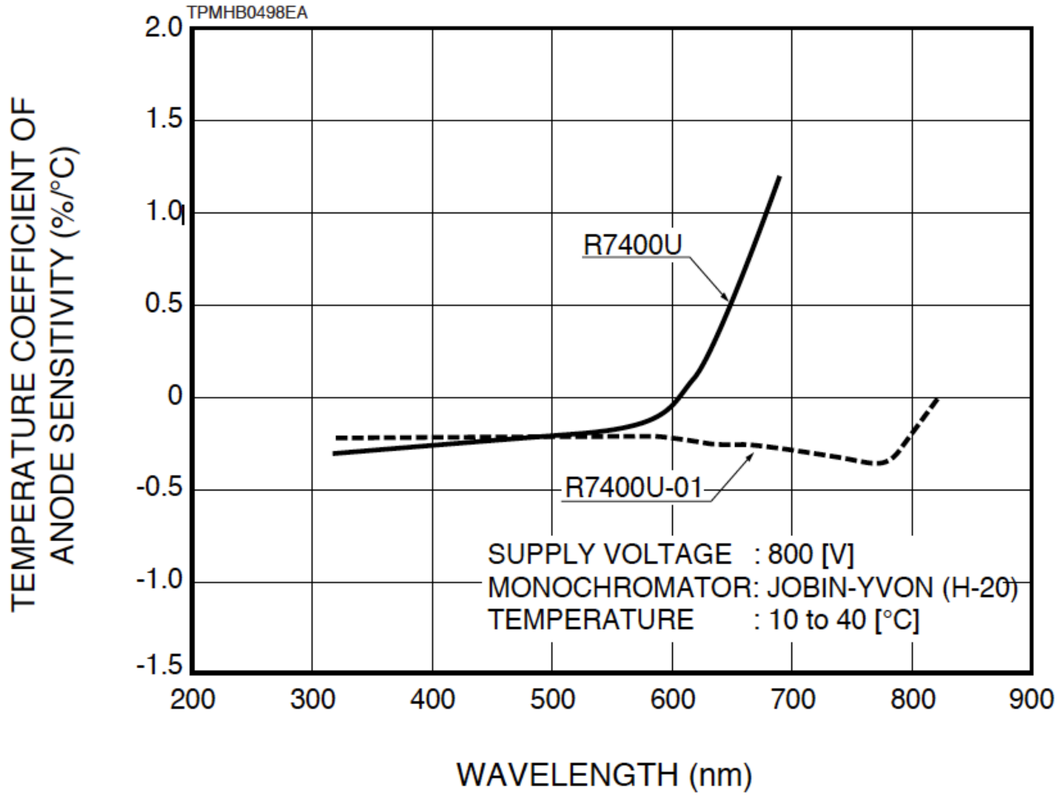
Temperature increased slightly 0.6 degree during the operation.

PMT used in LHCf measurement

R7400U are used in LHCf detectors

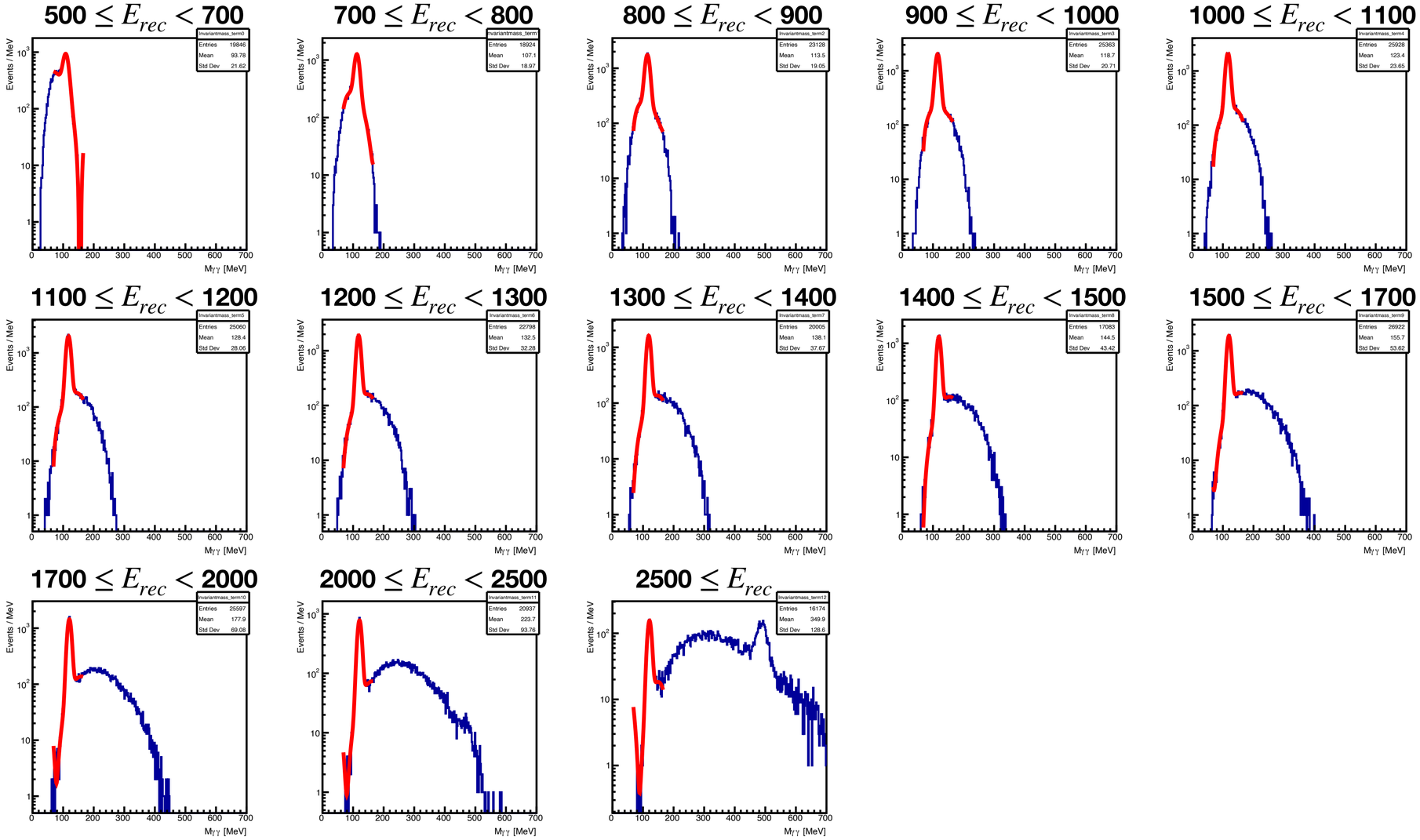


R7400U

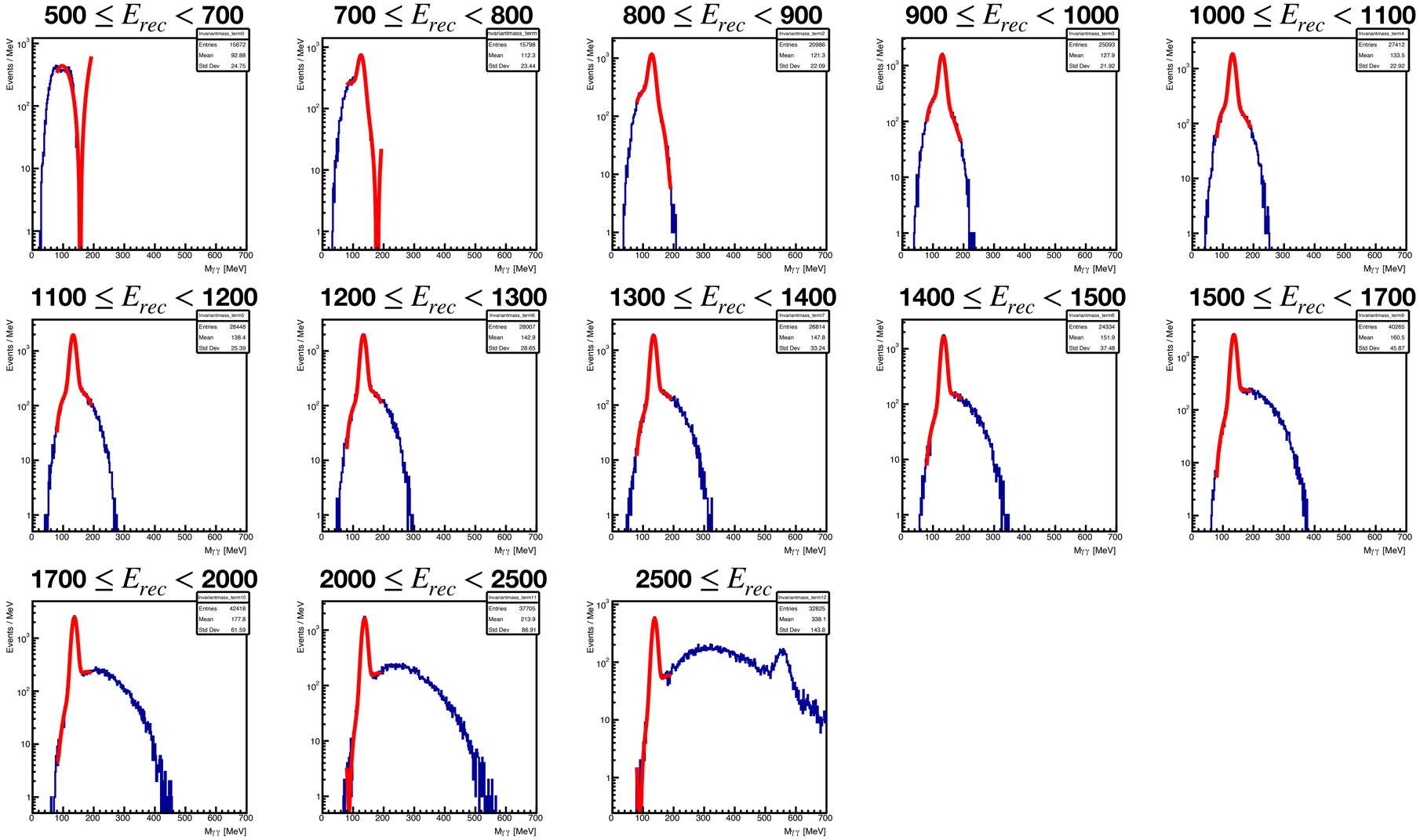


- -0.25% / ˚C in catalog
- -0.23% / ˚C by experimental data

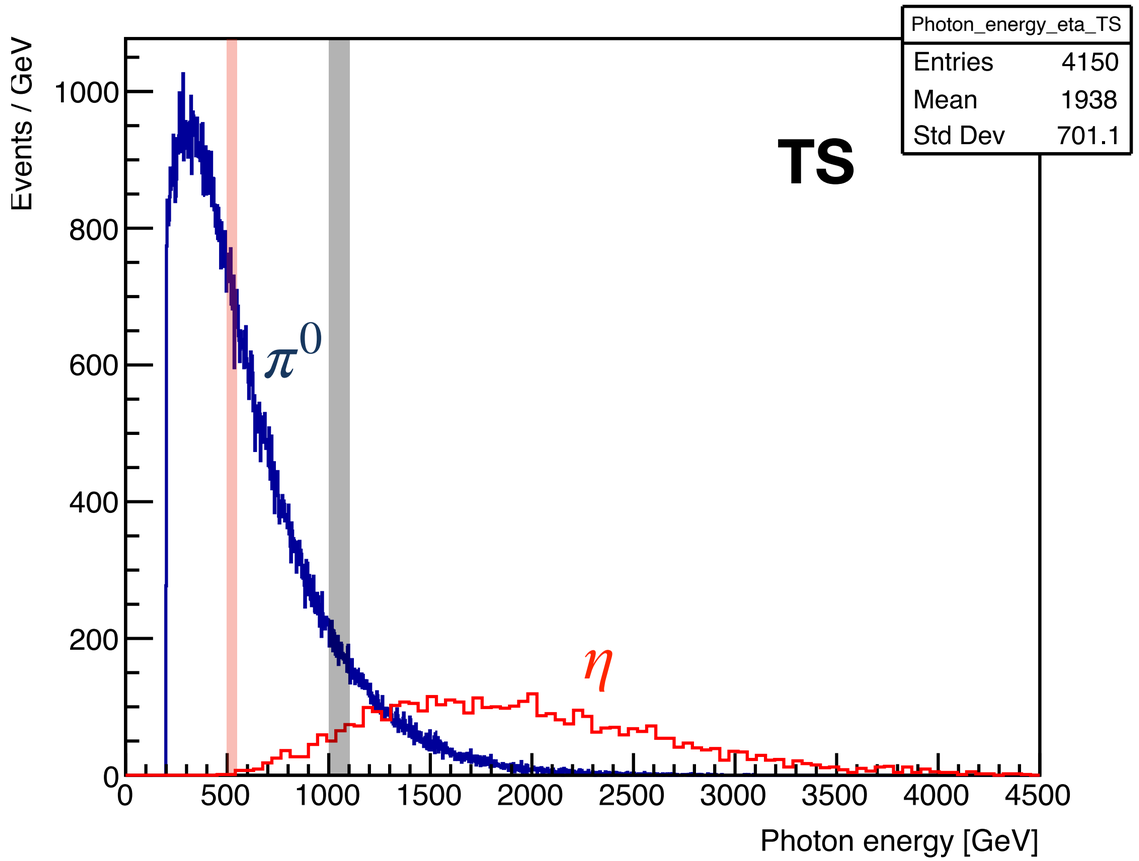
Energy dependency in each energy range before energy calibration

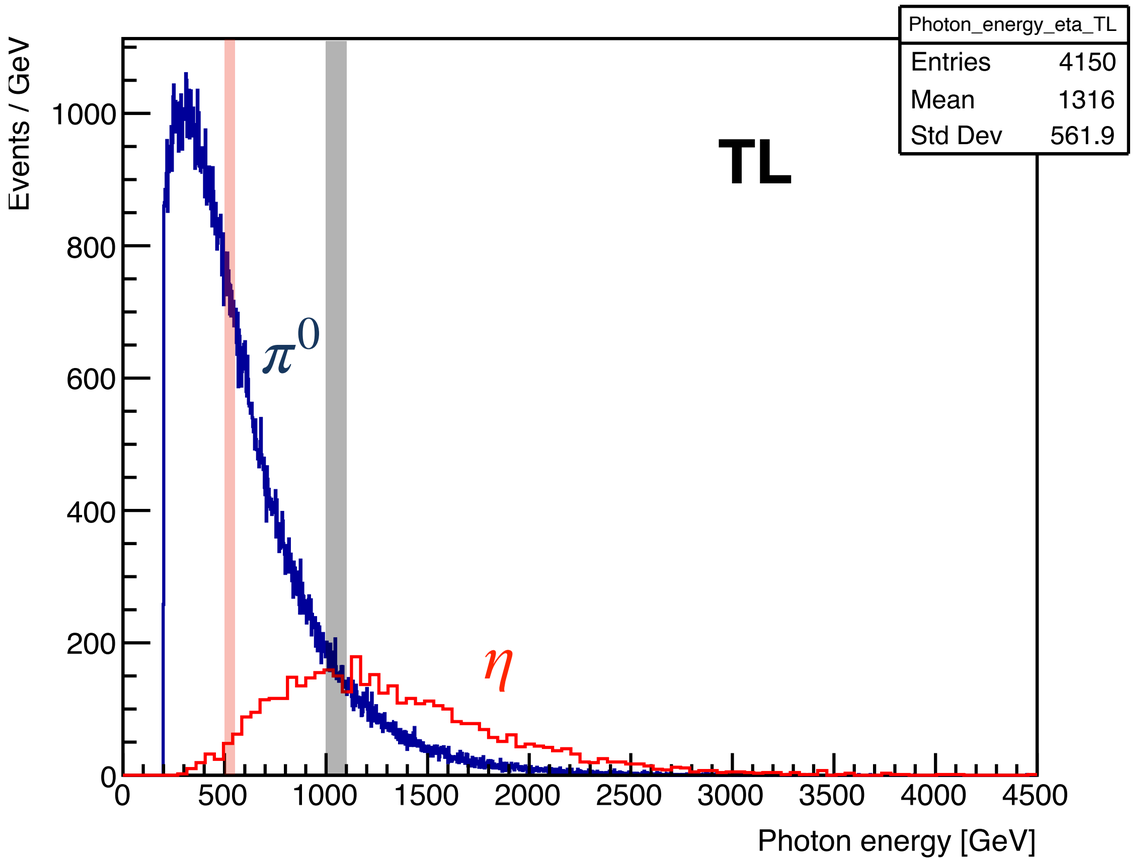


Energy dependency in each energy range after energy calibration



Energy range of photons (before energy calibration by LHC2022)





Patern 1

Patern 2

Patern 1

Patern 2