Analysis Status of ZDC ECal

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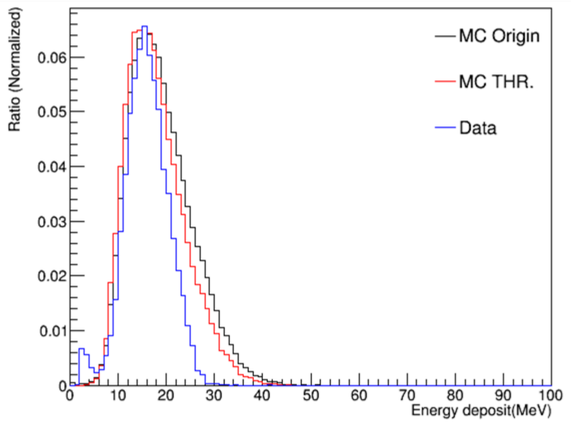
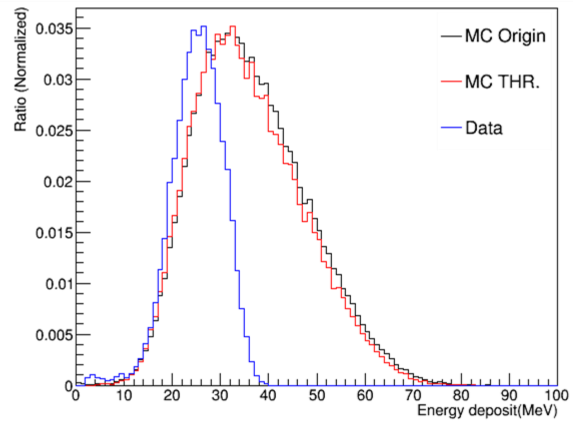
Data Analysis

Reminder :Inconsistency between Data and MC

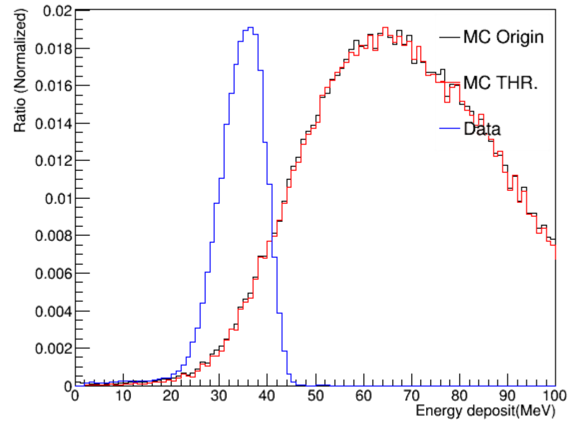
47MeV

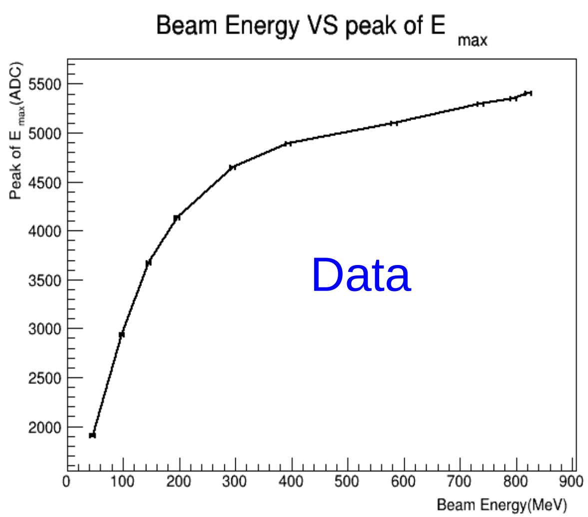


98MeV



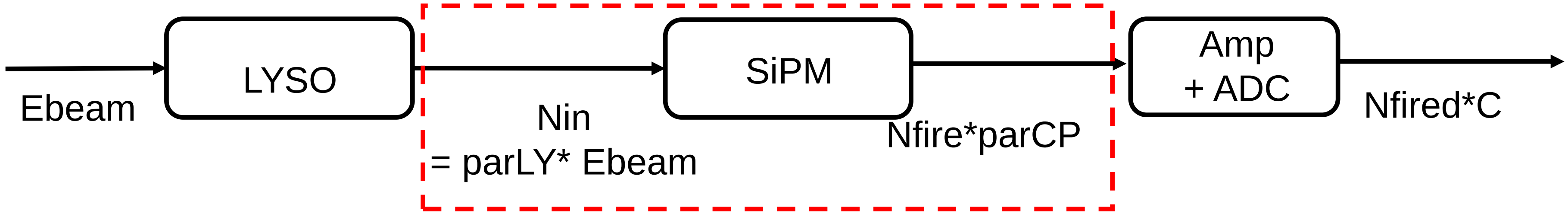
198MeV

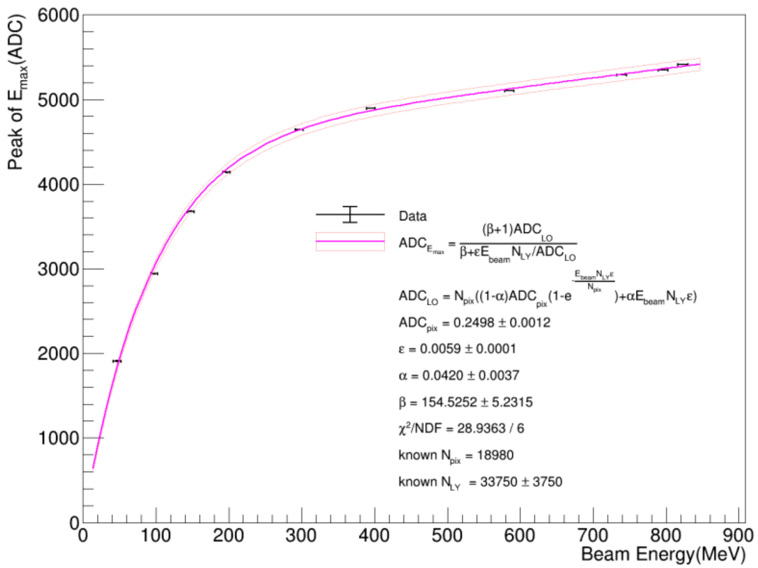




- MC simulation here only simulate LYSO crystal.
- Inconsistency between data and MC is caused by SiPM which is not simulated.

Reminder : Fit Data to Extract the Parameters of SiPM Behavior





$$ADC_{Emax} = \frac{(\beta+1)ADC_{LO}}{\beta + \varepsilon N_{in}/ADC_{LO}}$$

$$ADC_{LO} = N_{pix}[(1-\alpha)ADC_{pix}(1-exp\left(\frac{\varepsilon N_{in}}{N_{pix}}\right) + \alpha\varepsilon N_{in}]$$

ADC_{pix} = 0.2498 ± 0.0012

ε = 0.0059 ± 0.0001 Photon detection efficiency of SiPM

α = 0.0420 ± 0.0038 average charge contribution of remaining photons

β = 154.5352 ± 5.2206 charge contributiondecrease as the increase of Nphoton

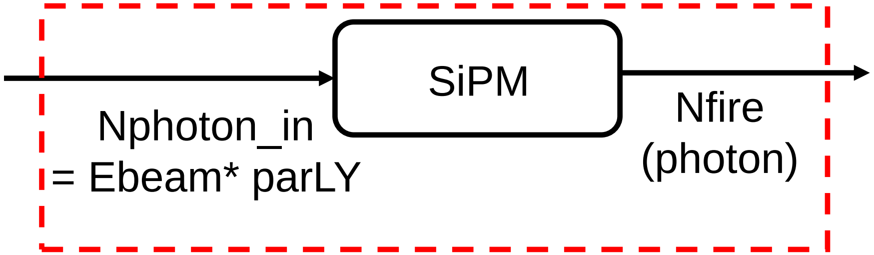
χ^2/NDF = 28.9377 / 6

known N_{pix} = 18980 Num. pixel of SiPM (fix)

known N_{LY} = 33750 ± 3750 Light yield of SiPM (fix)

- MC is progressing but not ready yet for SiPM simulation.
- Currently we **apply the fitting results to LYSO simulation**.

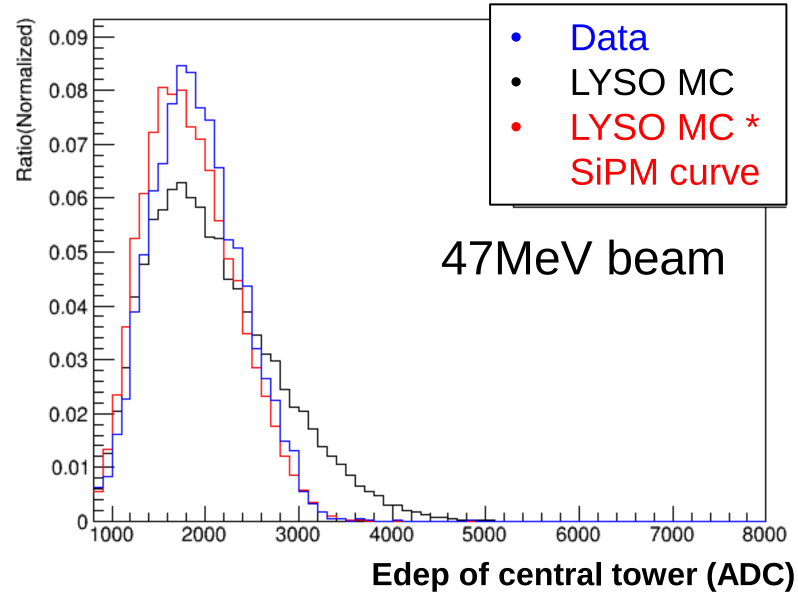
Data VS MC
Applying SiPM Behavior Curve

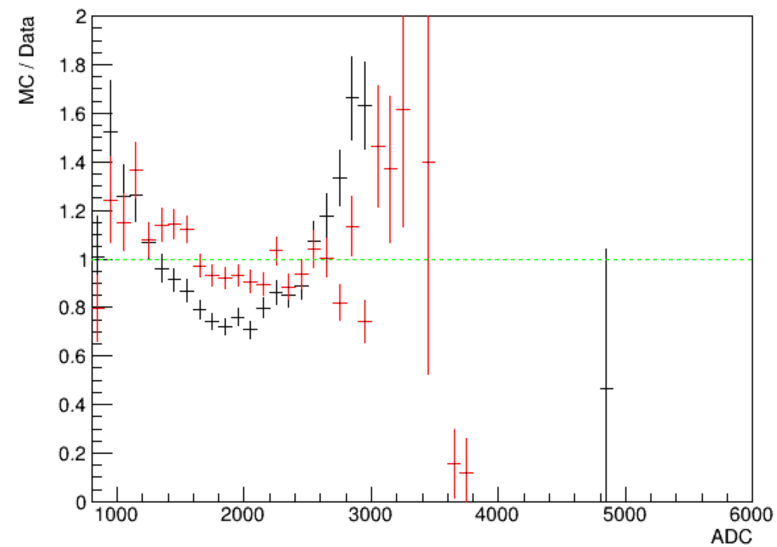


$$ADC_{Emax} = \frac{(\beta + 1)ADC_{LO}}{\beta + \varepsilon N_{in} * 0.37/ADC_{LO}}$$

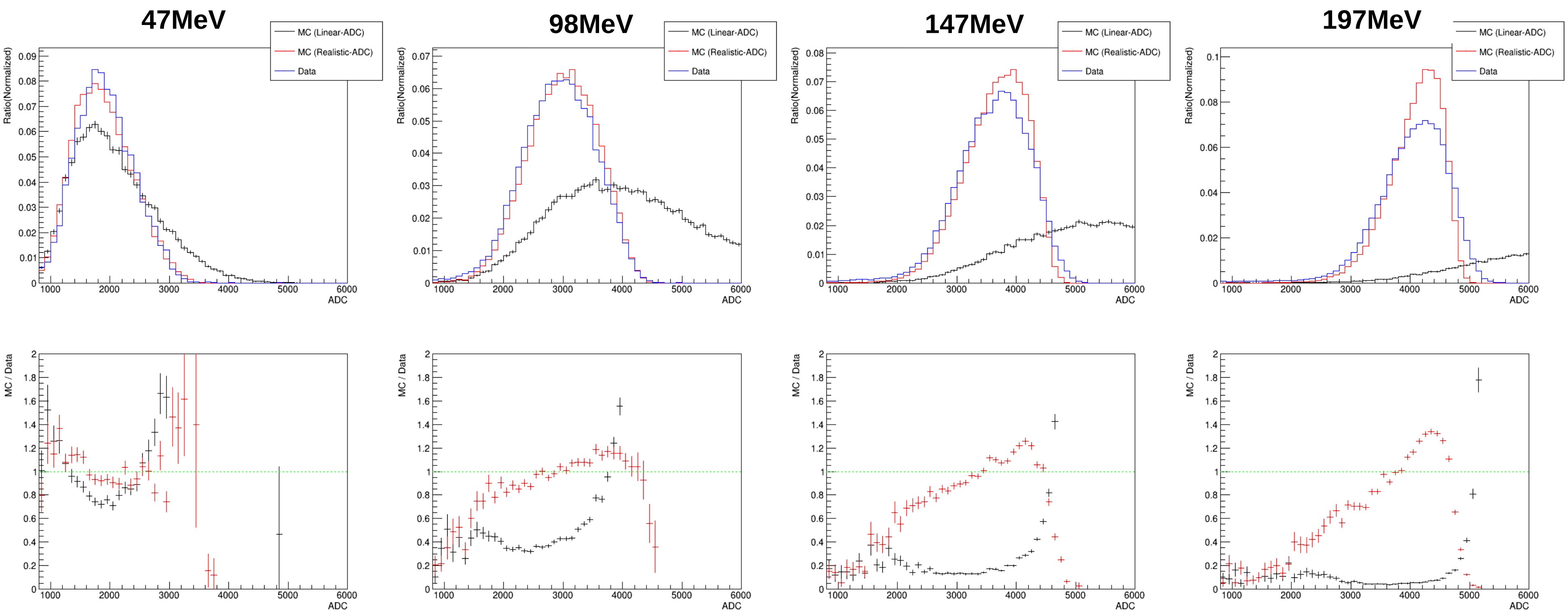
$$ADC_{LO} = N_{pix}[(1-\alpha)ADC_{pix}(1 - exp\left(\frac{\varepsilon N_{in} * 0.37}{N_{pix}}\right) + \alpha\varepsilon N_{in} * 0.37]$$

- MC is not ready yet for SiPM simulation. Currently we **apply the fitting results to MC output of LYSO simulation**.
- To well describe data, an extract factor has to be applied : $0.37 * N_{in}$.





Data VS MC
Applying SiPM Behavior Curve



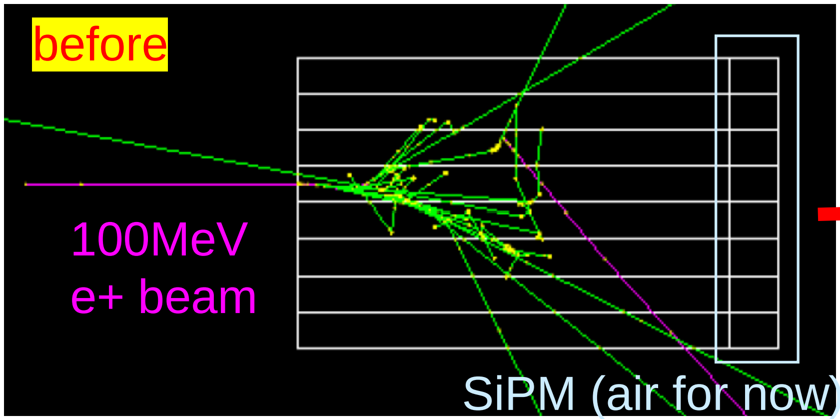
- Data
- LYSO MC
- LYSO MC * SiPM curve

- After applying SiPM curve, the consistency between data and MC is much improved.
- The consistency is worse in higher energy beam.
- Problem could come from LYSO simulation, we will change from energy dump to optical photons.

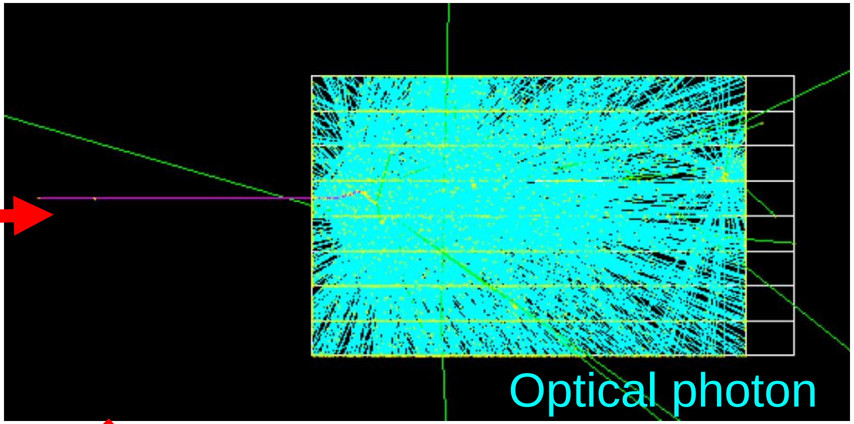
MC Simulation

MC Implementation of LYSO Crystal

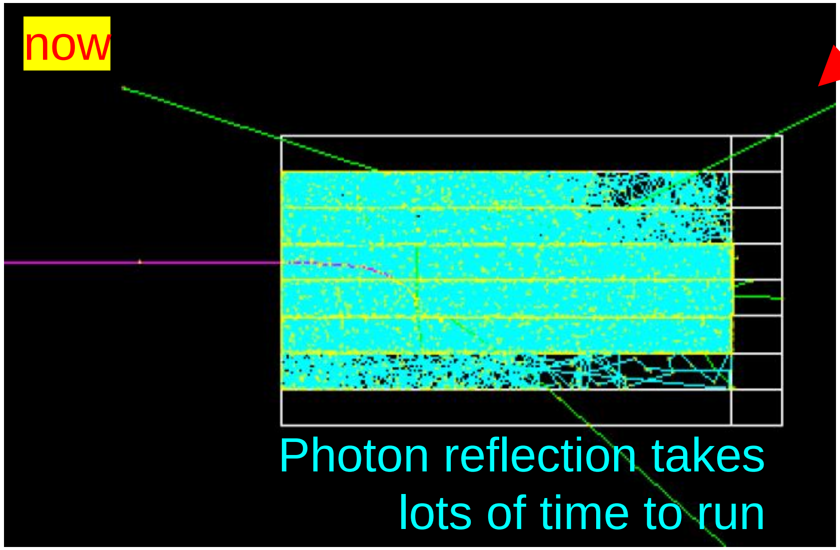
Only LYSO



LYSO + MPT(w/ Birk's)



LYSO + MPT(w/ Birk's) + Reflection Surface



- Positron/Beam(purple)
- Electron(yellow)
- Gamma (green)
- Optical photon (cyan)
  - Scintillation
  - Cherenkov

We are now still working on have proper setting for LYSO.

Material Property Table of LYSO

TABLE II
DENSITY, ELEMENTAL COMPOSITION, AND OPTICAL PROPERTIES OF THE LYSO MATERIAL IMPLEMENTED IN THE GEANT4 *In-Silico* TEST PLATFORM

Density (g/cm^3)	Elemental Composition	Refractive Index	Optical Yield, Emission Spectrum, Absorption Length	Optical Decay Time Constants (ns)	Resolution Scale (at 511 keV)	Reference
7.4	$Lu_{1.9}Y_{0.1}Si_1O_5$ (0.5% Ce doping)	See Figure 15	30 Photons per eV, See Figure 15	Fast: 7.1 (7%) Slow: 33.3 (93%)	4.17	[47]

energy dependent

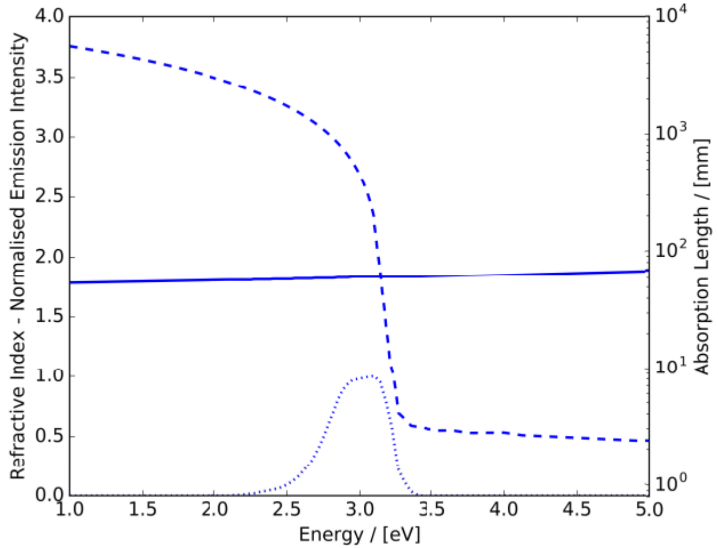


Fig. 15. LYSO scintillator crystal material refractive index (solid line), attenuation length (dashed line), and normalized scintillation photon emission intensity (dotted line) data sets implemented in the Geant4 *in-silico* test platform.

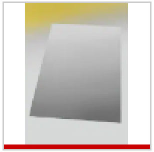
- Reference paper
  https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8876605
- Reference code
  https://github.com/JunhaoWang511/MLCsimulation/blob/master/src/MLCDetectorConstruction.cc

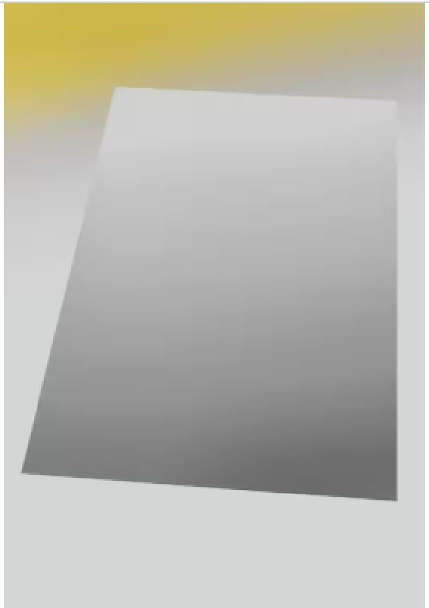
Reflection Surface : 3M ERS

3M™ Enhanced Specular Reflector Film (ESR)

3M ID B5005047091

Details   Typical Properties   Resources





Hover over image to zoom in

Product Description

3M™ Enhanced Specular Reflector Films (ESR) maximize the recycling efficiency of liquid crystal display backlights. 3M ESR is >98% reflective across the visible spectrum and contains no metal.

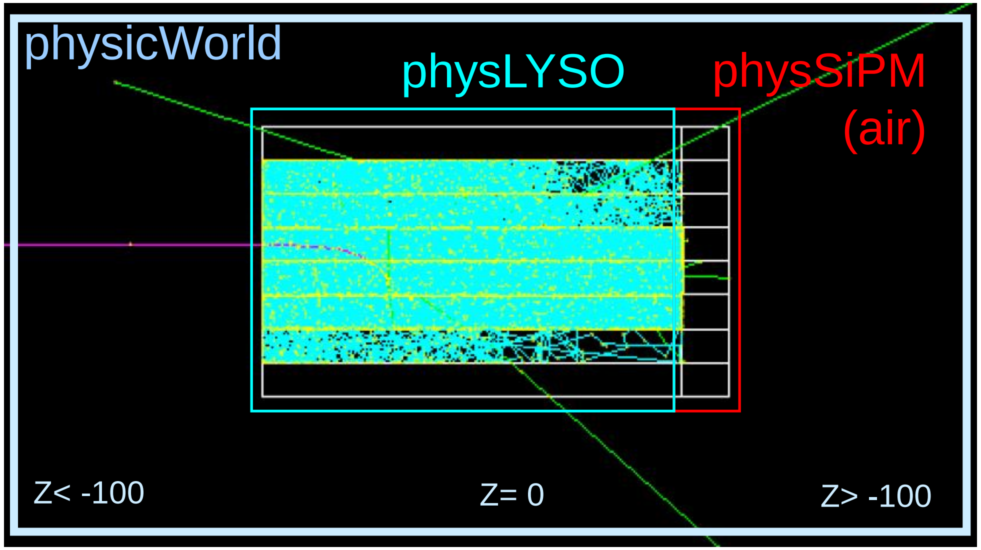
Construction/Performance

Product	3M ESR 65 Auto	3M ESR 80v2 Auto
Reflectivity (minimum)	98%	98%
Caliper (microns)	65 +/- 4	82 +/- 4
Halogen Free	Yes	Yes

Reflectivity = 0.98

https://www.3m.com/3M/en_US/p/d/b5005047091/

Tracking and Steps in MC



- Positron/Beam(purple)
- Electron(yellow)
- Gamma (green)
- Optical photon (cyan)
  - Scintillation
  - Cherenkov

```
*******************************************************************************************
* G4Track Information:   Particle = e+,   Track ID = 1,   Parent ID = 0
*******************************************************************************************

Step#    X(mm)    Y(mm)    Z(mm) KinE(MeV)  dE(MeV) StepLeng TrackLeng  NextVolume ProcName
    0        0        0     -100       0.5        0        0         0   physWorld initStep
    1   -0.592    -1.04    -77.1     0.497  0.00269       23        23   physWorld eIoni  ionization
    2    -1.25    -1.44    -44.1     0.491  0.00599     33.2      56.3    physLYSO Transportation  boundary

 Exiting from G4Scintillation::DoIt -- NumberOfSecondaries = 1
    3    -1.25    -1.44    -44.1     0.484  0.00718   0.0143      56.3    physLYSO msc Multiple Compton scattering
    :----- List of 2ndaries - #SpawnInStep=  1(Rest= 0,Along= 0,Post= 1), #SpawnTotal=  1 ---------------
    :      -1.25     -1.44     -44.1  2.83e-06      opticalphoton
    :----------------------------------------------------------------- EndOf2ndaries Info ---------------
```

msc 2ndary ➔ Generated scintillation optical photon ➔ assign to new track, Track ID = 2

```
*******************************************************************************************
* G4Track Information:   Particle = opticalphoton,   Track ID = 2,   Parent ID = 1
*******************************************************************************************

Step#      X(mm)      Y(mm)      Z(mm) KinE(MeV)  dE(MeV) StepLeng TrackLeng  NextVolume ProcName
    0      -1.25      -1.44      -44.1  2.83e-06         0        0         0    physLYSO initStep
    1       -1.9       3.56      -39.4  2.83e-06         0     6.95      6.95    physLYSO Transportation   boundary
    2       -1.9       3.56      -39.4  2.83e-06         0        0      6.95    physLYSO Transportation
    3      -3.56       1.97      -38.4  2.83e-06         0     2.49      9.44    physLYSO Transportation
    4      -3.56       1.97      -38.4  2.83e-06         0        0      9.44    physLYSO Transportation
    5     -0.036       3.56      -36.7  2.83e-06         0     4.22      13.7    physLYSO Transportation
    6     -0.036       3.56      -36.7  2.83e-06         0        0      13.7    physLYSO Transportation
    7      -1.52      -3.56      -39.5  2.83e-06         0     7.79      21.4    physLYSO Transportation
   55       3.16      -3.56      -36.7  2.83e-06         0    0.753       199    physLYSO Transportation
   56       3.16      -3.56      -36.7  2.83e-06         0        0       199    physLYSO Transportation
   57       2.66       3.56      -35.9  2.83e-06         0     7.19       206    physLYSO Transportation
   58       2.66       3.56      -35.9  2.83e-06         0        0       206    physLYSO Transportation
   59      -1.57      -3.56      -37.4  2.83e-06         0     8.43       214    physLYSO Transportation
   60      -1.57      -3.56      -37.4  2.83e-06         0        0       214    physLYSO Transportation
   61       2.15       3.56      -28.8  2.83e-06         0     11.8       226    physLYSO Transportation
   62       2.15       3.56      -28.8  2.83e-06         0        0       226    physLYSO Transportation
   63       1.25      0.849      -28.8  2.83e-06  2.83e-06     2.86       229    physLYSO OpAbsorption   absorbed
```

For optical photons : no energy dump during the transportation steps until it is absorbed.

```
*******************************************************************************************
* G4Track Information:   Particle = e+,   Track ID = 1,   Parent ID = 0
*******************************************************************************************

Step#    X(mm)    Y(mm)    Z(mm) KinE(MeV)  dE(MeV) StepLeng TrackLeng  NextVolume ProcName
    3    -1.25    -1.44    -44.1     0.484        0        0      56.3    physLYSO initStep

 Exiting from G4Cerenkov::DoIt -- NumberOfSecondaries = 1

 Exiting from G4Scintillation::DoIt -- NumberOfSecondaries = 1
    4    -1.23    -1.44    -44.1     0.463   0.0207   0.0154      56.3    physLYSO msc
    :----- List of 2ndaries - #SpawnInStep=  2(Rest= 0,Along= 0,Post= 2), #SpawnTotal=  2 -------------
    :      -1.24     -1.44     -44.1  2.92e-06      opticalphoton
    :      -1.23     -1.44     -44.1  2.94e-06      opticalphoton
    :------------------------------------------------------------------ EndOf2ndaries Info -------------

*******************************************************************************************
* G4Track Information:   Particle = opticalphoton,   Track ID = 4,   Parent ID = 1
*******************************************************************************************

Step#    X(mm)    Y(mm)    Z(mm) KinE(MeV)  dE(MeV) StepLeng TrackLeng  NextVolume ProcName
    0    -1.23    -1.44    -44.1  2.94e-06        0        0         0    physLYSO initStep
```

Optical photons are generated as positron passes through LYSO

```
****************************************************************************************************
* G4Track Information:   Particle = e+,   Track ID = 1,   Parent ID = 0
****************************************************************************************************

Step#    X(mm)    Y(mm)    Z(mm) KinE(MeV)  dE(MeV) StepLeng TrackLeng  NextVolume ProcName
   24    -1.26    -1.47    -44.1     0.104        0        0      56.7    physLYSO initStep
   25    -1.25    -1.46    -44.1       0.1  0.00376  0.00318      56.7    physLYSO Cerenkov
   26    -1.25    -1.46    -44.1    0.0987  0.00147  0.00119      56.7    physLYSO Cerenkov
   27    -1.25    -1.46    -44.1    0.0981 0.000591 0.000424      56.7    physLYSO Cerenkov
   28    -1.25    -1.46    -44.1    0.0981 3.17e-05 0.000119      56.7    physLYSO Cerenkov
   29    -1.25    -1.46    -44.1    0.0981 5.61e-05 0.000102      56.7    physLYSO Cerenkov
   30    -1.25    -1.46    -44.1     0.098 8.28e-05 7.36e-05      56.7    physLYSO Cerenkov
   31    -1.25    -1.46    -44.1     0.098        0 3.09e-05      56.7    physLYSO Cerenkov
   32    -1.25    -1.46    -44.1     0.098 2.26e-05 3.09e-05      56.7    physLYSO Cerenkov
   33    -1.25    -1.46    -44.1    0.0976 0.000399 1.92e-05      56.7    physLYSO Cerenkov
   34    -1.25    -1.46    -44.1         0   0.0976   0.0297      56.7    physLYSO eIoni
    :----- List of 2ndaries - #SpawnInStep=  8(Rest= 0,Along= 0,Post= 8), #SpawnTotal=  8 -------------
    :      -1.25     -1.46     -44.1   3.1e-06      opticalphoton
    :      -1.25     -1.46     -44.1  3.12e-06      opticalphoton
    :      -1.25     -1.46     -44.1  3.26e-06      opticalphoton
    :      -1.25     -1.46     -44.1  2.88e-06      opticalphoton
    :      -1.25     -1.46     -44.1  2.68e-06      opticalphoton
    :      -1.25     -1.46     -44.1  2.99e-06      opticalphoton
    :      -1.25     -1.46     -44.1  2.79e-06      opticalphoton
    :      -1.25     -1.46     -44.1   2.7e-06      opticalphoton
    :---------------------------------------------------------------- EndOf2ndaries Info ---------------
   35    -1.25    -1.46    -44.1         0        0        0      56.7    physLYSO Scintillation
    :----- List of 2ndaries - #SpawnInStep=  2(Rest= 2,Along= 0,Post= 0), #SpawnTotal= 10 -------------
    :      -1.25     -1.46     -44.1     0.511              gamma
    :      -1.25     -1.46     -44.1     0.511              gamma
    :---------------------------------------------------------------- EndOf2ndaries Info ---------------
```

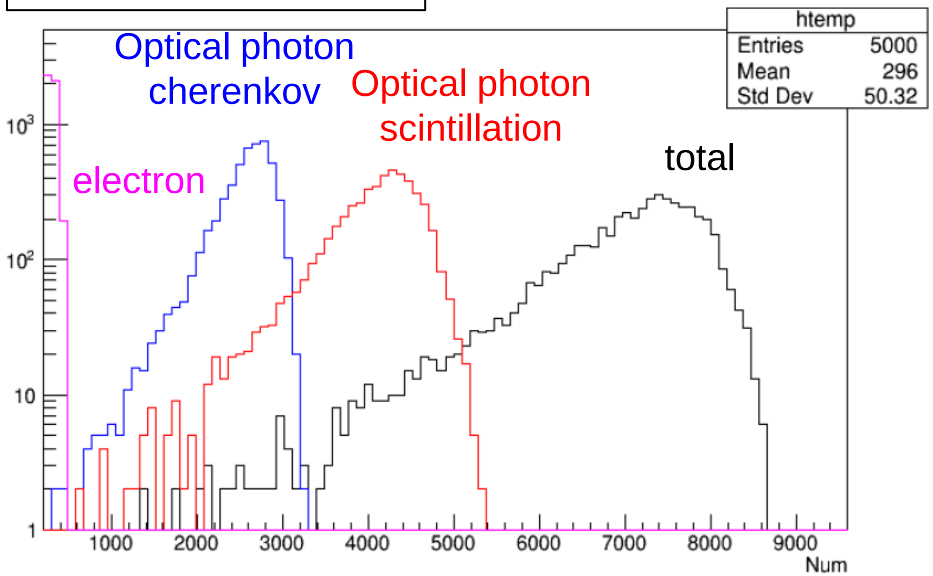
E dE

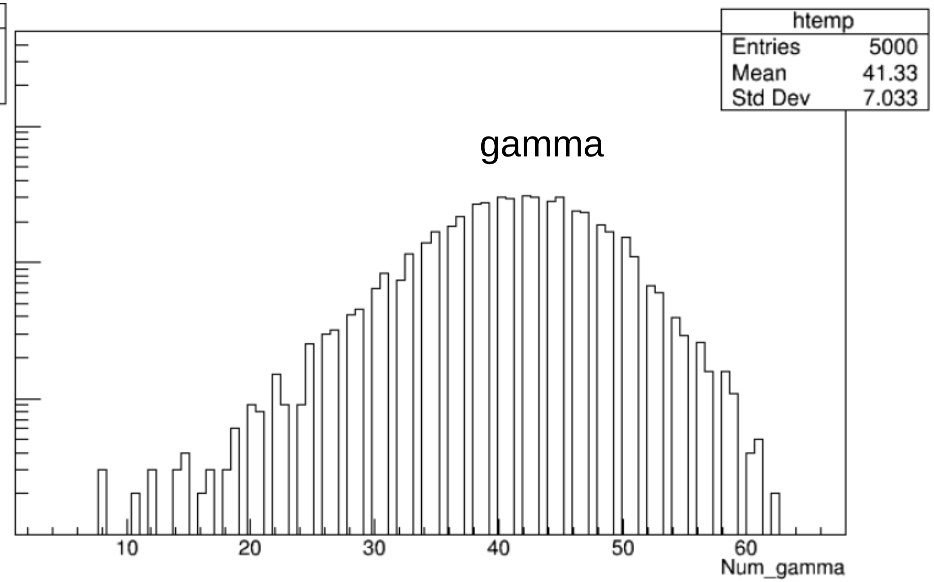
Scintillation generates extra energy doesn't come from beam = 0.511MeV (mass of electron)

Num. of Particles

100 MeV positron
LY = 50/MeV

N particles <u>per event</u>



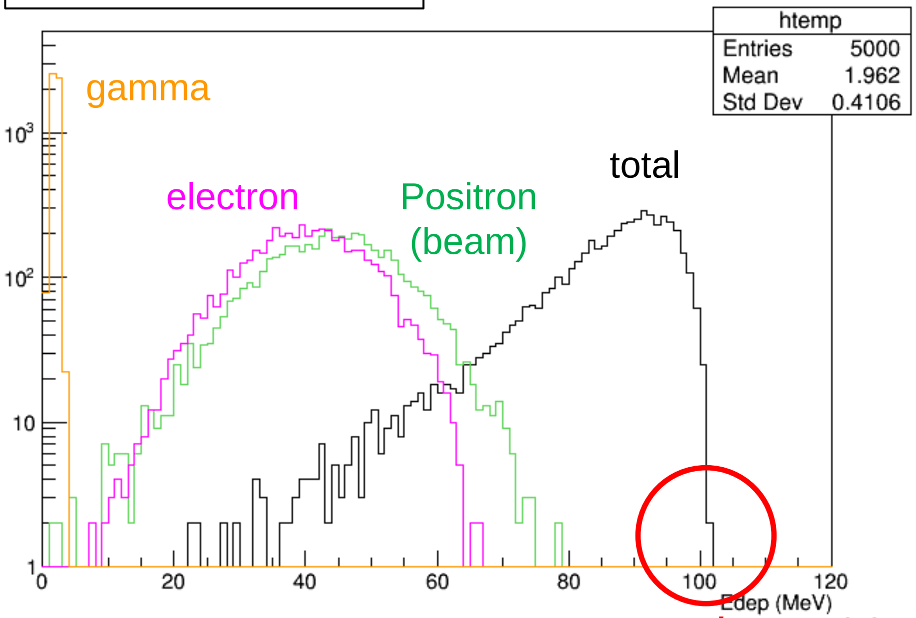


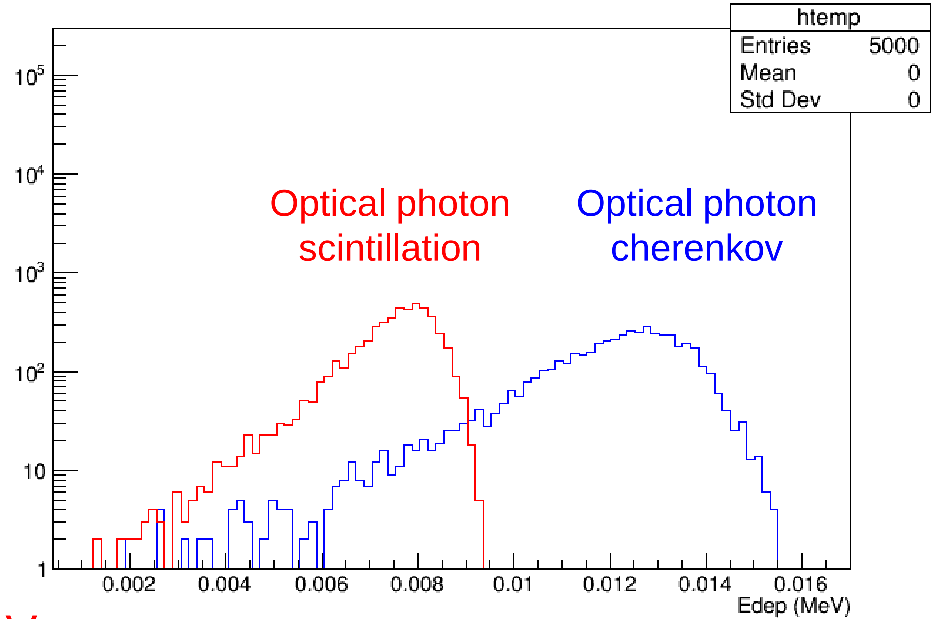
- Condition
  - 100MeV positron beams
  - Include MPT, Birk, reflection surface
  - 5k evts
  - **Exception : Light yield = 50/MeV, to reduce the running time (33000/MeV for LYSO).**
- Most generated particles are optical photons.

Energy Deposition

100 MeV positron
LY = 50/MeV

Energy deposition per event



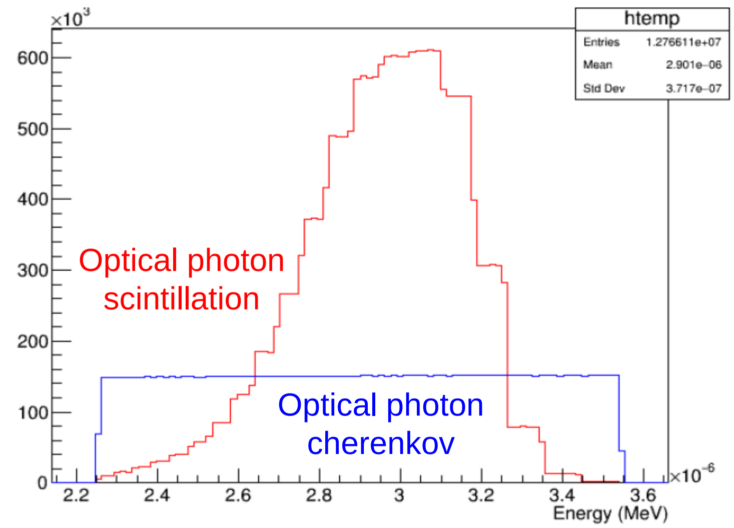


Edep>100MeV, gamma

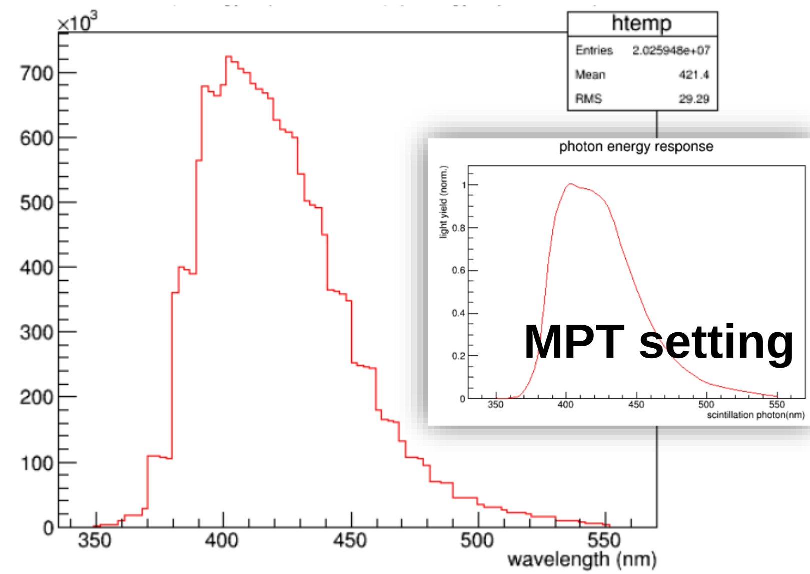
- Most energy are carried by beam and electron.
- Extra energy contribution from gamma.
- Optical photons carry very small amount of energy, ~0.01%.

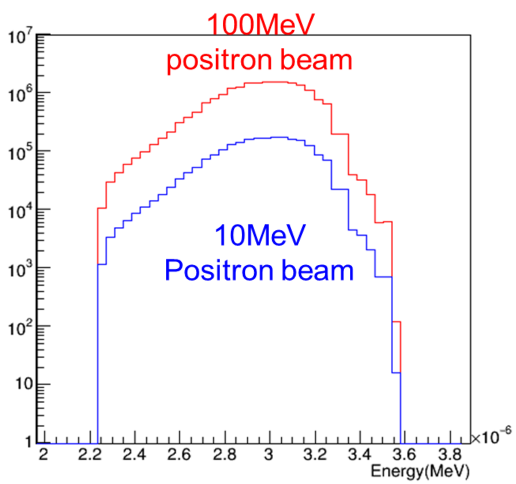
Optical Photons

100 MeV positron, LY = 50/MeV



$$\lambda(nm) = \frac{1240}{E(eV)}$$





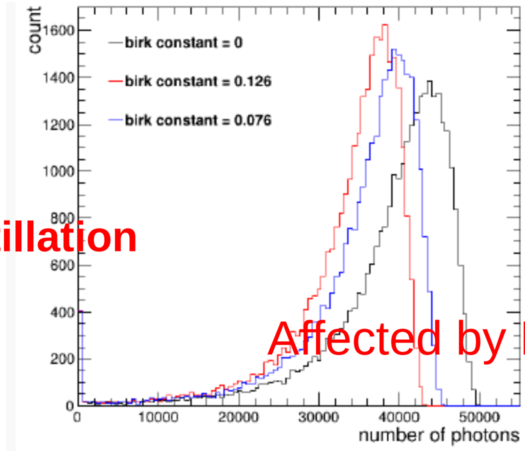
- Energy spectrum of scintillation photons is the same as the setup in MPT.
- Energy spectrum of Cherenkov photons is flat.
- Energy spectrum of optical photons doesn't change w/ the injected beam energy.
- Increase beam energy only increase number of scintillation photons and total energy deposition of scintillation photons, not their energy spectrum.

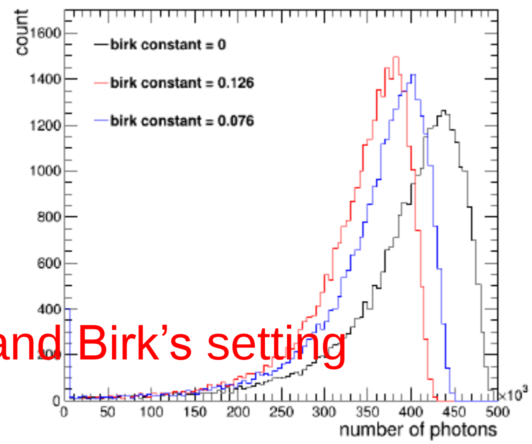
Effects of Light Yield Setting and Birk’s Law

100MeV positron

LY = 500 | **LY = 5000**

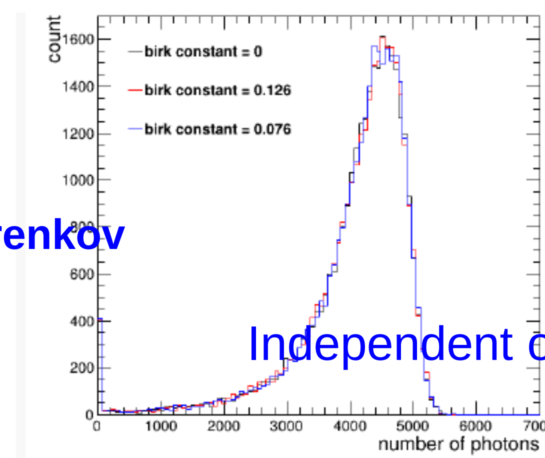
Scintillation

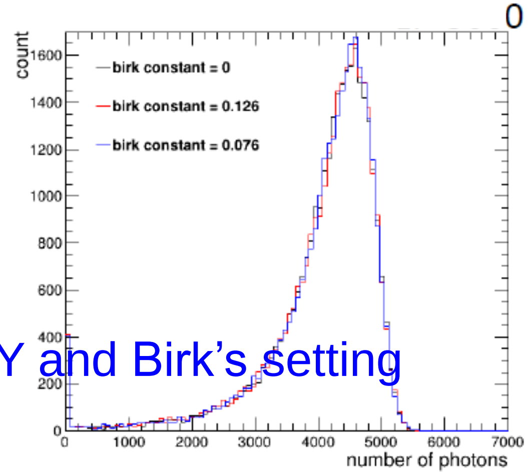




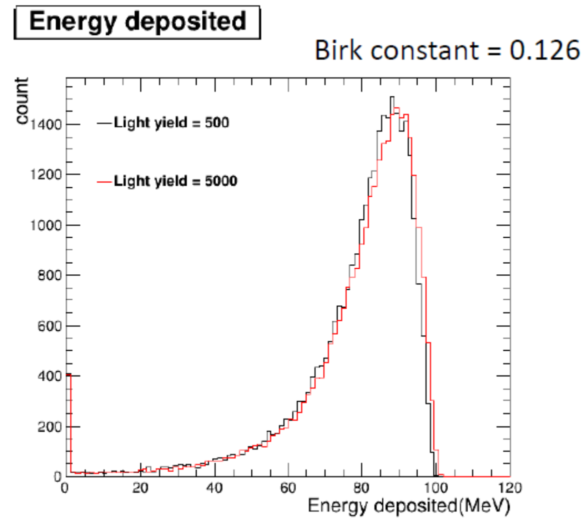
Affected by LY and Birk’s setting

Cherenkov





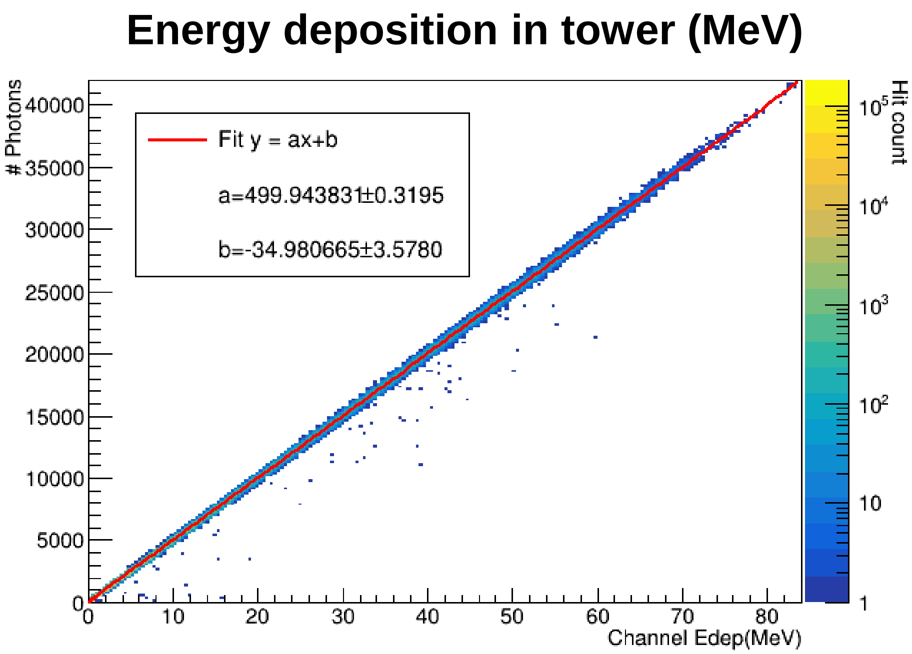
Independent of LY and Birk’s setting



- Total energy deposition in crystal doesn’t change w/ the setting of LY and Birk’s law.
- Currently we were still using the distribution of energy deposition of to fit data. We will switch to optical photons.

Energy and Optical Photons

100 MeV positron, LY = 500/MeV



- Energy deposition in crystal is linear with number of photons generated when E<100MeV.
- Will move to higher energy E = 800MeV and LY = 33,000/MeV.

Summary and To Do

- Data analysis : We apply LYSO simulation to SiPM behavior curve and compare data and MC. The consistency is more reasonable after applying SiPM curve. (LYSO simulation uses energy dump of all particles.)
- MC simulation : We implement MPT, Birk’s law, and reflection skin to LYSO simulation. We are able to access the information carried by optical photons.
- To do :

- Compare Data and MC using the distribution of number/energy of optical photons. Fine tune the setting of LY and Birk’s law might be required.
- Implement SiPM in MC.

Back up

Pearson Correlation

x_i are the **individual values** of one **variable** e.g. age

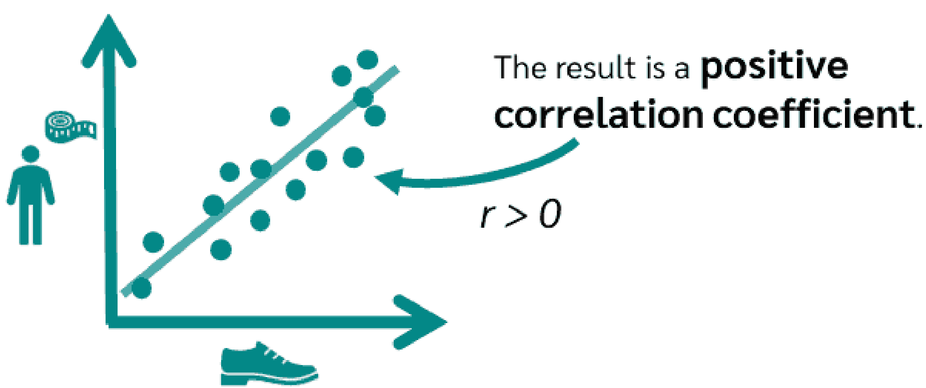
y_i are the **individual values** of the other **variable** e.g. salary

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}}$$

Where r is the Pearson correlation coefficient,

$\bar{x}$ and $\bar{y}$ are respectively the **mean values** of the two variables.

Amount of r	Strength of correlation
0.0 < 0.1	no correlation
0.1 < 0.3	low correlation
0.3 < 0.5	medium correlation
0.5 < 0.7	high correlation
0.7 < 1	very high correlation



Use Pearson correlation to fine tune ADC_{pix}, ε, α, β.

Fine Tune Fitting Parameters

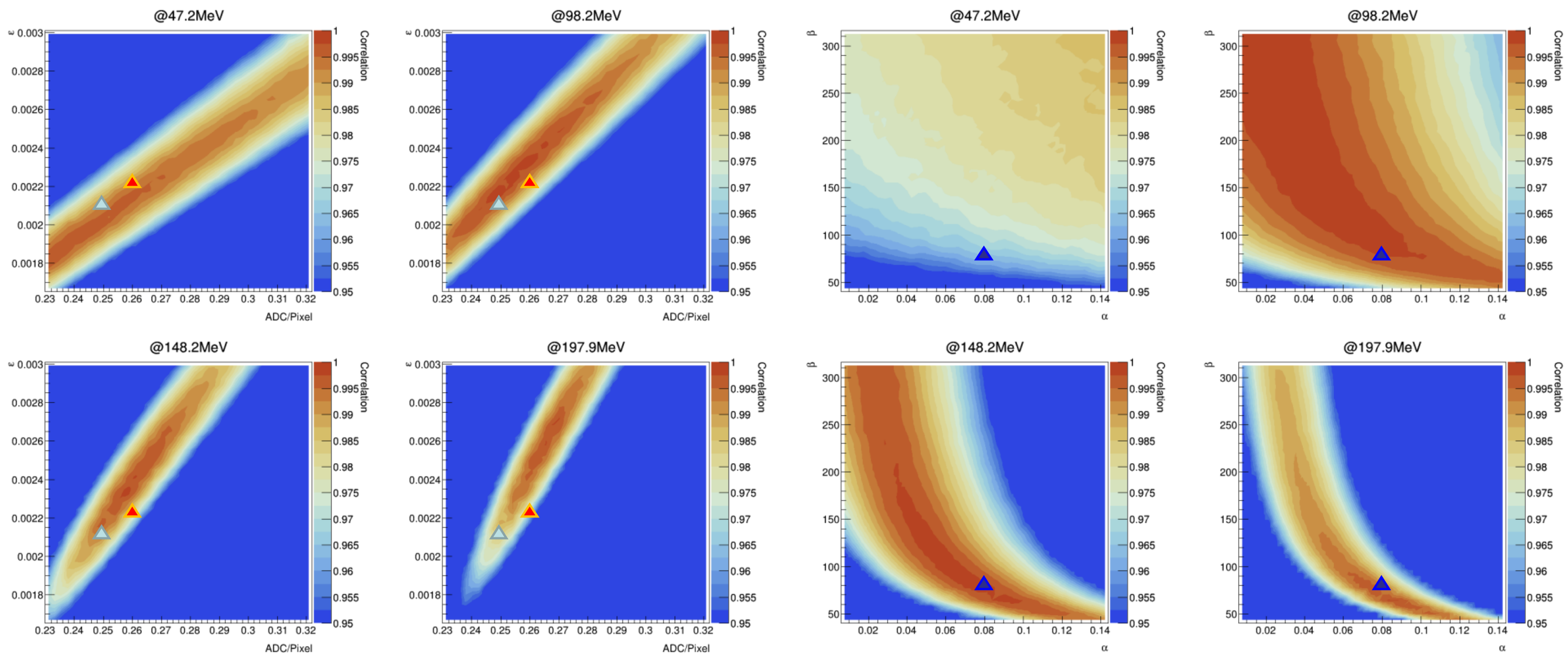
Fix α, β, tune ADC_{pix}, ε.

△ org

▲ chosen for ADC_{pix}, ε

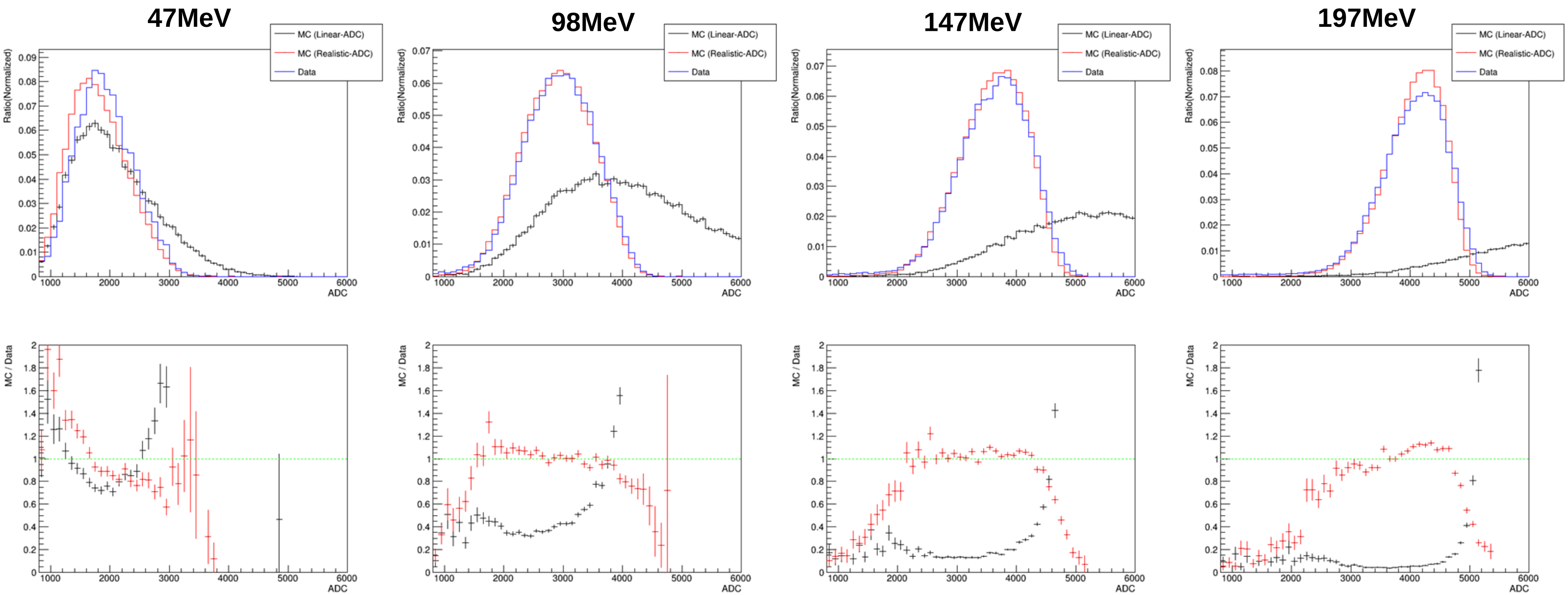
Fix ADC_{pix}, ε, tune α, β.

▲ chosen for α, β.



	ADC_{pixel}	$\boldsymbol{\varepsilon * C}$	$\boldsymbol{\alpha}$	$\boldsymbol{\beta}$
Org	0.2498	0.0021* 0.357	0.042	154.54
Fine tune	0.2500	0.0022* 0.373	0.080	80.00

Data VS MC
Applying SiPM Behavior Curve



- **Data**
- **LYSO MC**
- **LYSO MC * SiPM curve**

Better consistency with tuned parameters.