Photon analysis with 7 cm thick Crystal

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Pick-up from physics requirements

I still need to look in details in

https://docs.google.com/spreadsheets/d/1IWYx5hFsKXEDIjQgLV5qOZPBfxDNbCMOgzwptTndtTE/edit#gid=0

but pickups are:

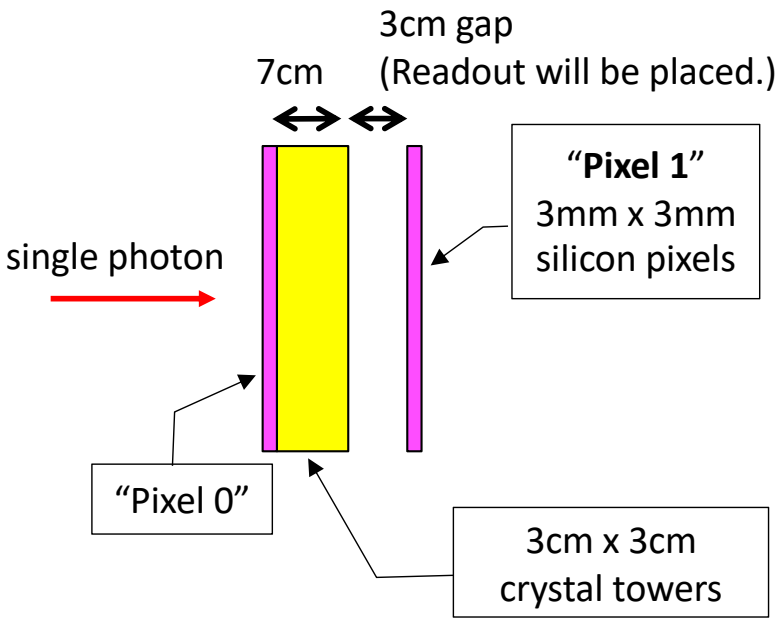
- Tag O(100) MeV photons
  - >90 % efficiency
  - Energy resolution 20-30%
- Tag 20-40 GeV photons
  - 2 photons from pi0
    - Nominal distance of 2 photons: 14 cm. Position resolution: 2 cm
  - neutron + 2 photons, neutron + 3 photons
    - Position resolution: 0.5-1mm
  - Energy resolution
    - 35%/√E

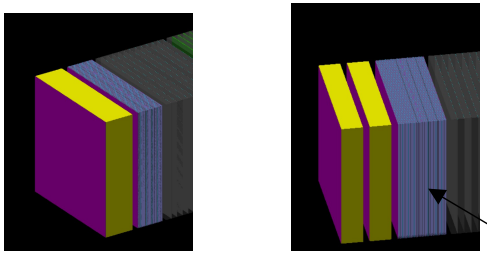
Setup

EM calorimeter:

- 1 or 2 layers of 7 cm crystal
- 22 layers of W/SI

with Silicon Pixel layers inserted.





W/SI layers

- 3.5 mm Tungsten plate
- Silicon
  Pad layer: 1 cm x 1 cm x 320 μm (20 layers)
  Pixel layer: 3mm x 3mm x 300 μm

Note: Open issues/topics (not for today)

- 7 cm thickness may worsen the resolution due to less photons, but thicker crystal worsen the position resolution.
  - Currently estimated as: 1.1 mm for 40 GeV photons. ← not enough.
- Material of crystal.
- Possible replacement of Silicon by Scintillator for the region outside of aperture.

Energy reconstruction

Crystal

- Clustering of EM crystal towers
  - Take a tower with E_{tower}> 15 MeV as a seed tower.
  - 3x3 towers with a seed as the center → cluster
  - Cluster raw energy is $\sum_{3\times3} E_{\text{tower}}$
  - Cluster raw energy is smeared based on $\frac{2.5\%}{\sqrt{E}} + 1\%$ → "Reco." cluster energy
- On the 1st crystal layer (Crystal 0), a cluster with the highest energy is taken.
- On the 2nd crystal layer (Crystal 1), a cluster close to the cluster on the Crystal 0 is taken.

Pixel 1

- 11x11 cells RoI is formed around (x, y) of Crystal 0 cluster. Energy deposit in RoI is taken.

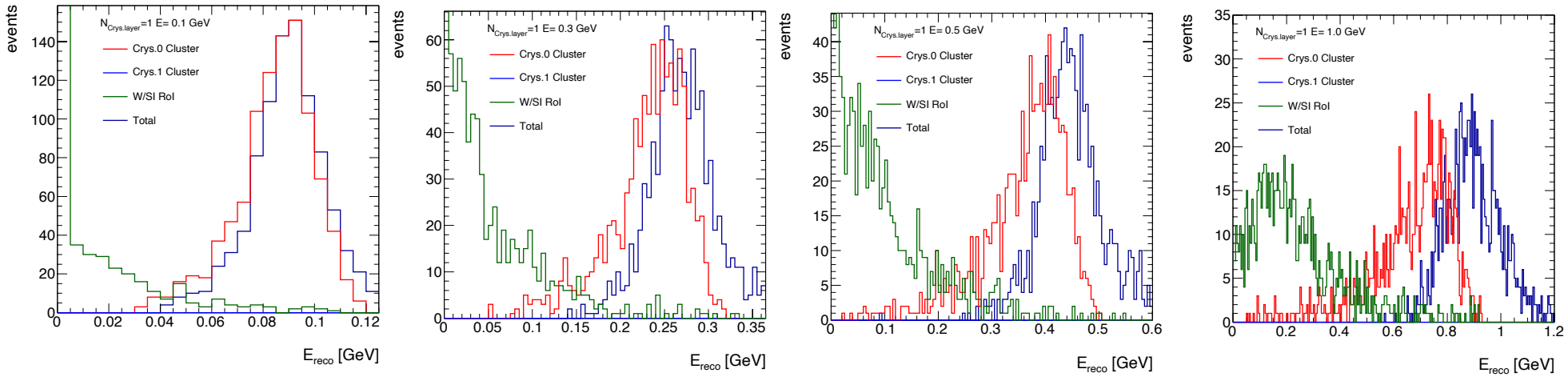
W/SI

- 9cm x 9cm RoI is formed around (x,y) of Crystal 0 cluster.
  - "Reco." energy = 82.7 * Energy sum in RoI.

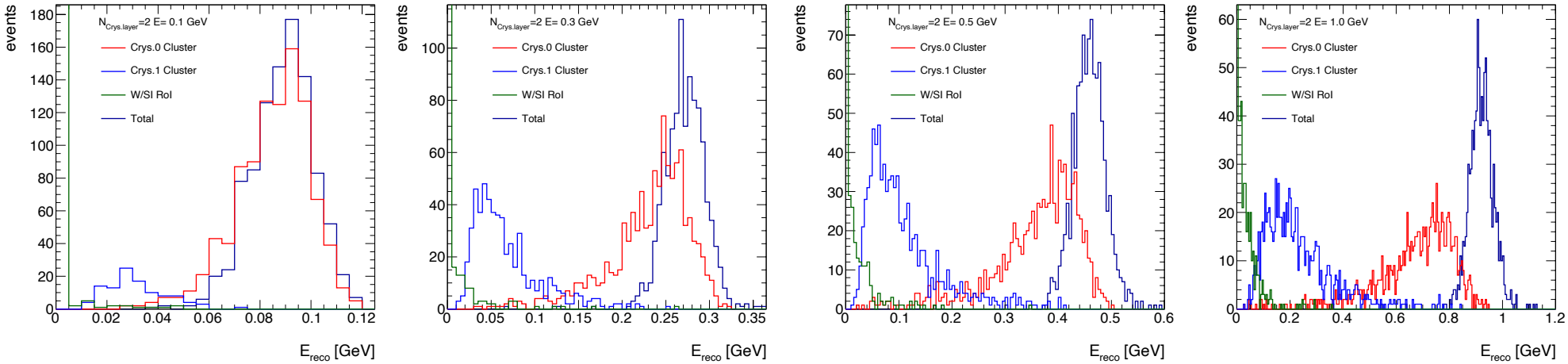
→ $\mathbf{E_{Reco,\ total} = E_{Reco,\ crys.0} + E_{Reco,\ crys.1} + E_{Pix1} + E_{reco,\ W/SI}}$

Reco energy (E=0.1 ~ 1 GeV)

1 Crystal layer



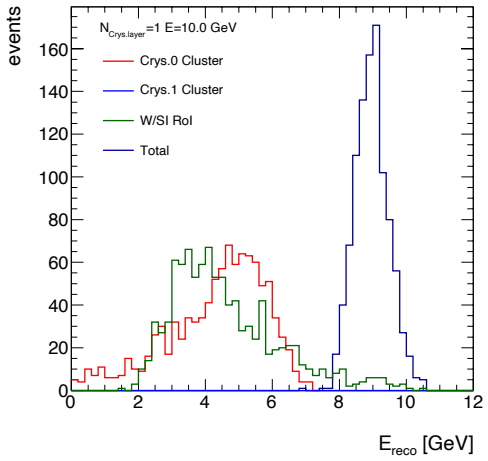
2 Crystal layers

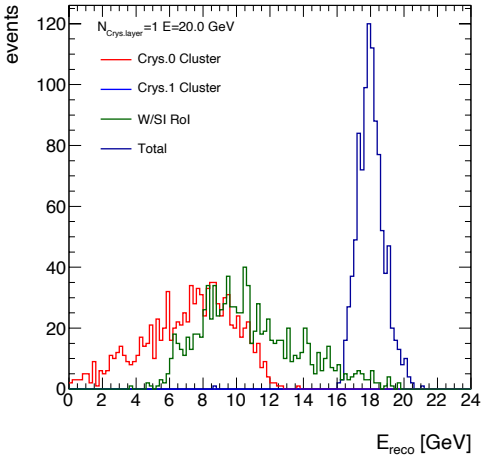


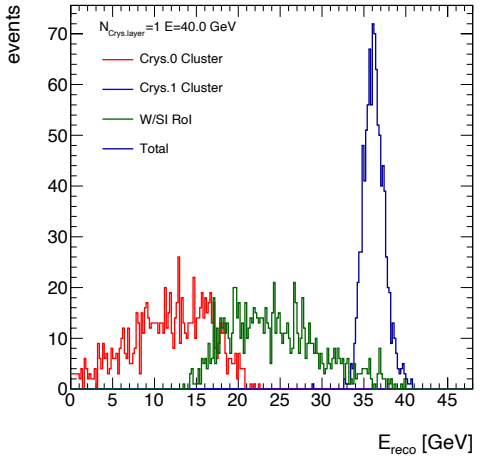
Most of the energy measured in 1st Crystal layer.

Reco energy (E=10, 20, 40 GeV)

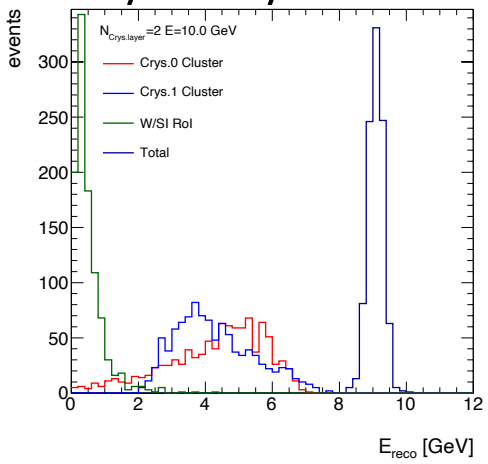
1 Crystal layer

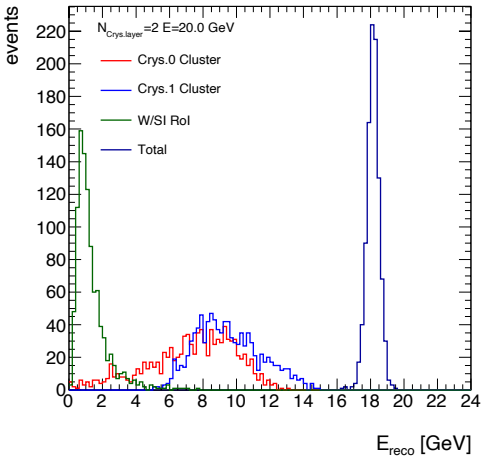


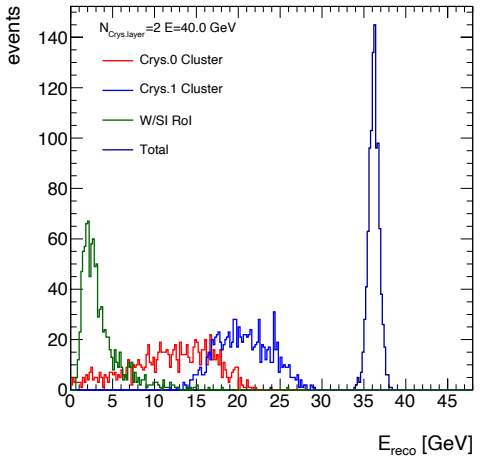




2 Crystal layers

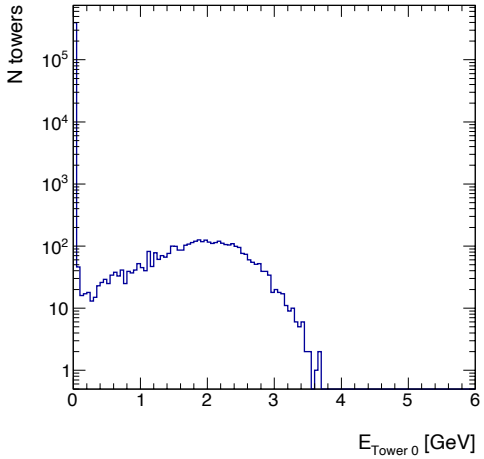




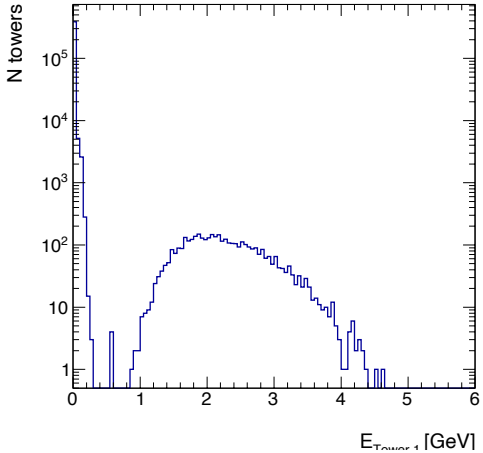


Half ~ less than half of the photon energy is measured in the 1st Crystal layer (Crystal 0).
All of the Crys.0, Crys.1, and W/SI contributes to the energy reconstruction for E>~10 GeV.

Tower energy distribution (E=20 GeV, 2 Crystals)

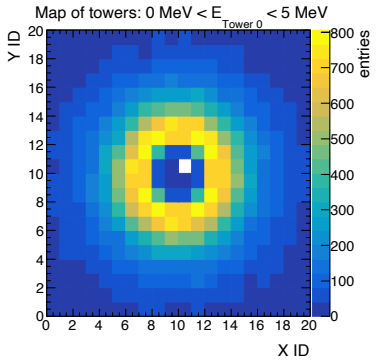


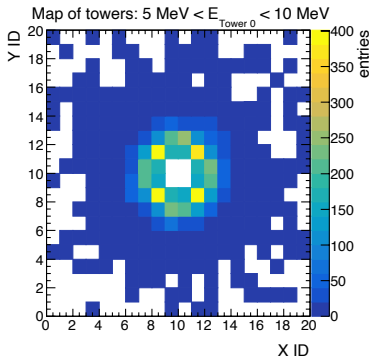
Crystal 0

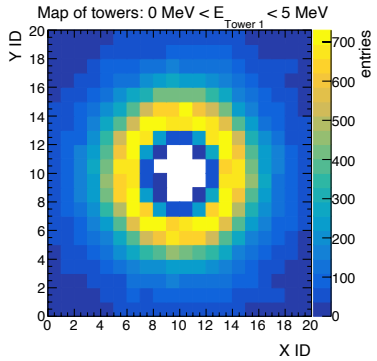


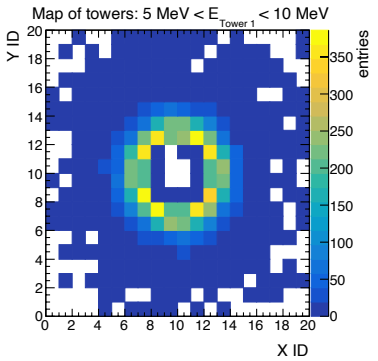
Crystal 1

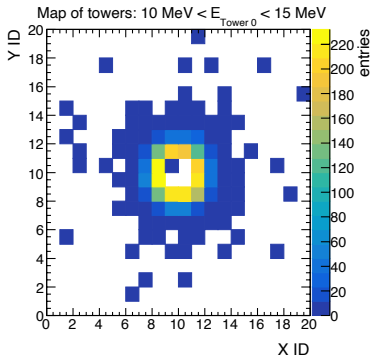
Lots of towers with small energies of < 150 MeV

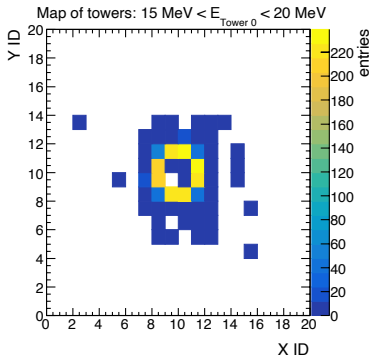


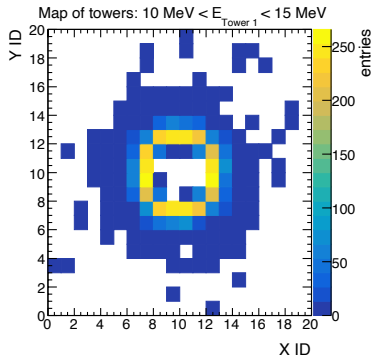


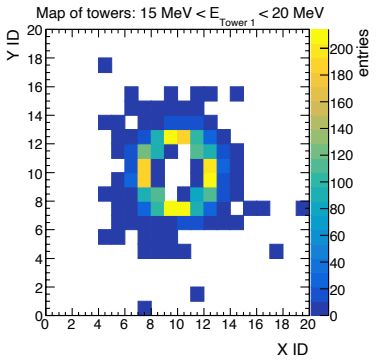






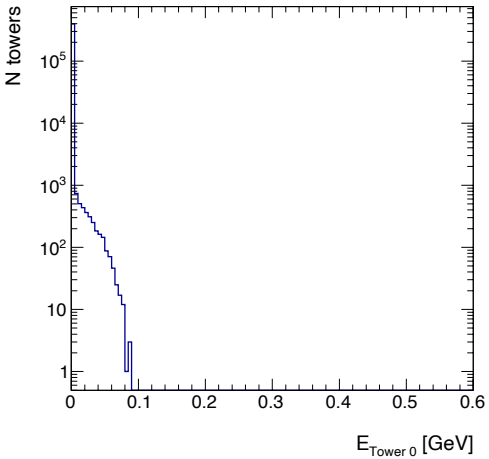




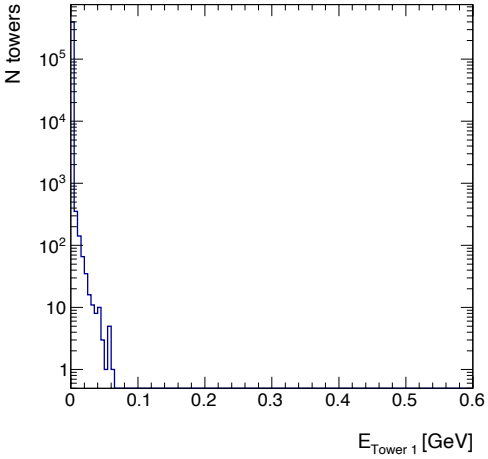


Requirement of 15 MeV will largely reduce their number.

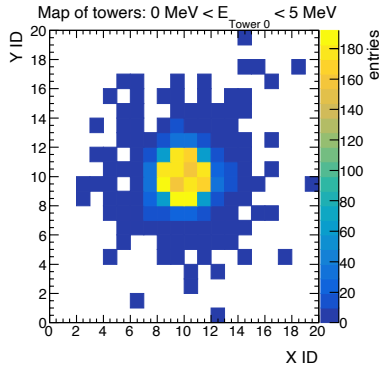
Tower Energy distribution (E = 100 MeV, 2 Crystals)

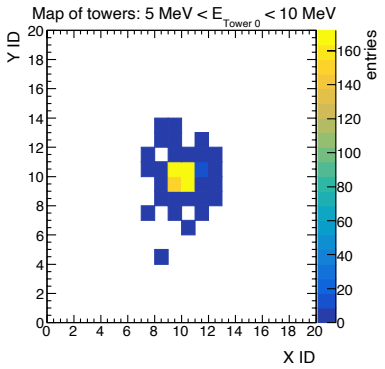


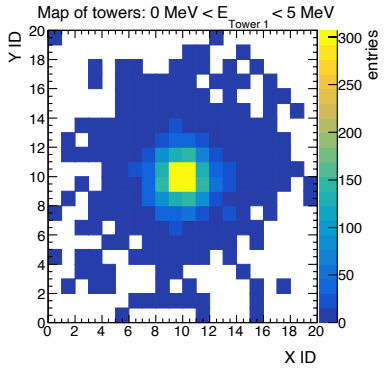
Crystal 0

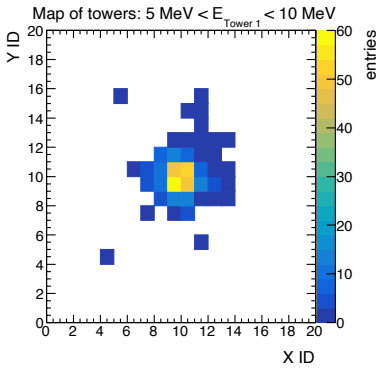


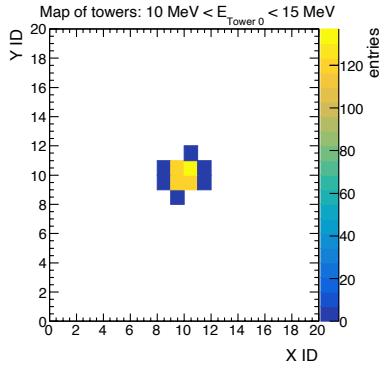
Crystal 1

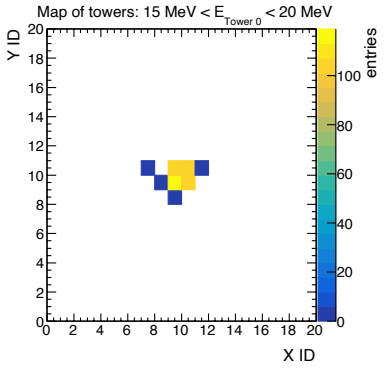


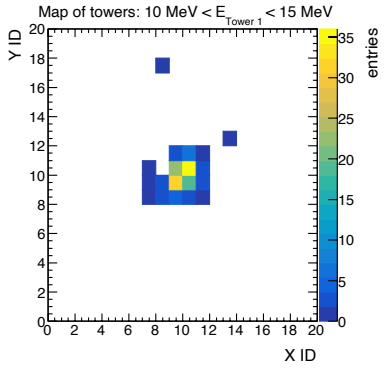


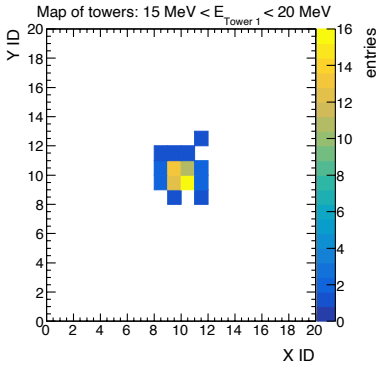










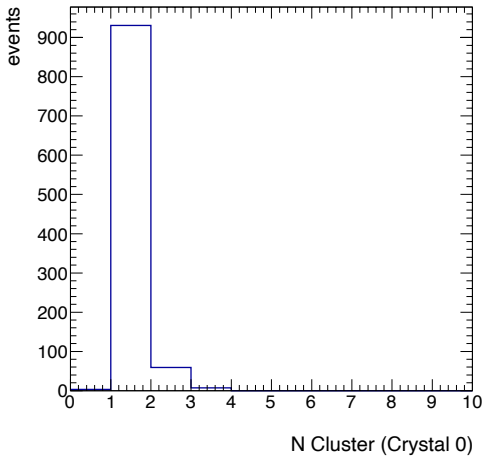


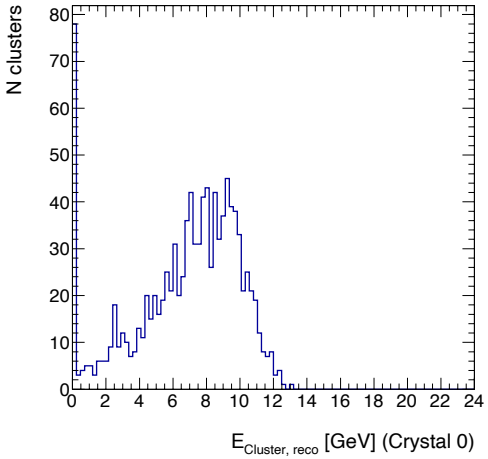
Towers with small energies are needed for energy reconstruction.

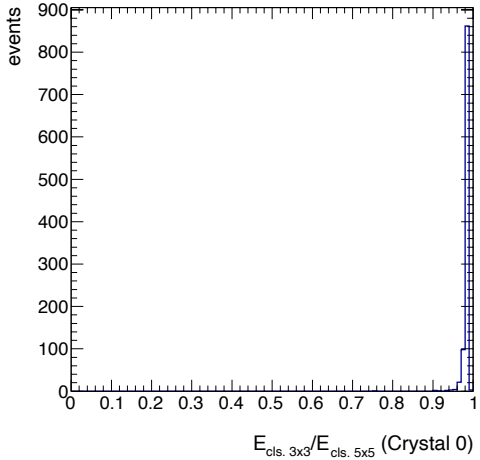
15 MeV requirement could be tight.

Cluster distribution (E=20GeV, 2 Crystals)

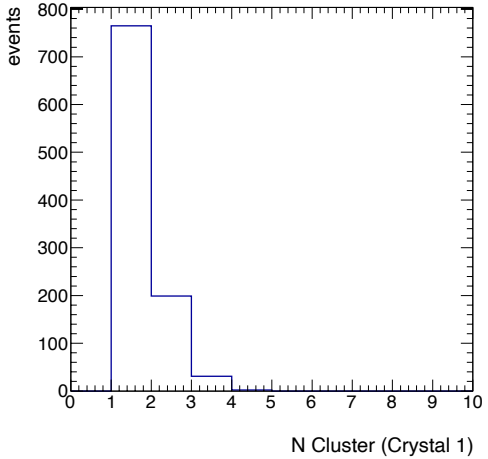
Crystal 0

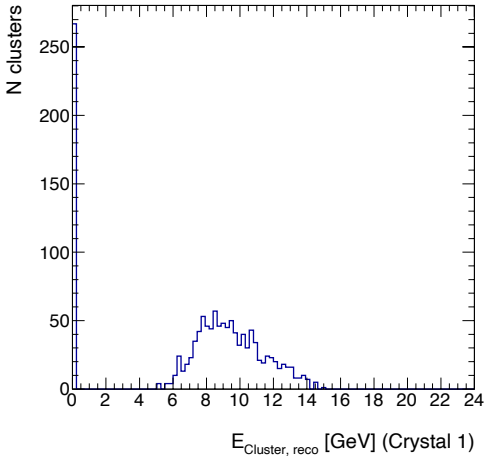


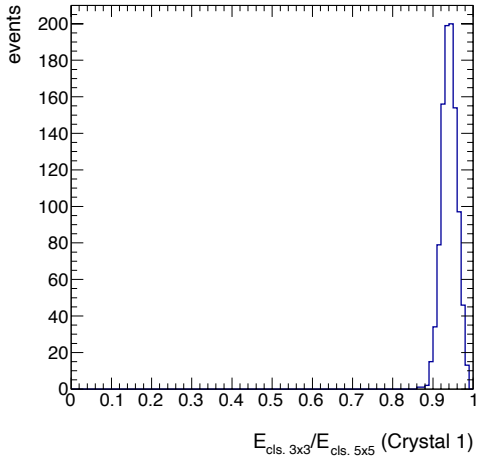


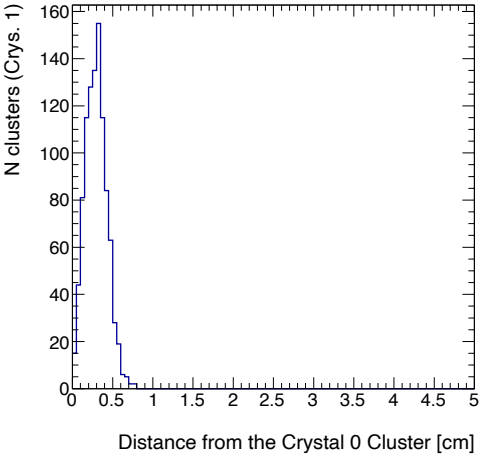


Crystal 1







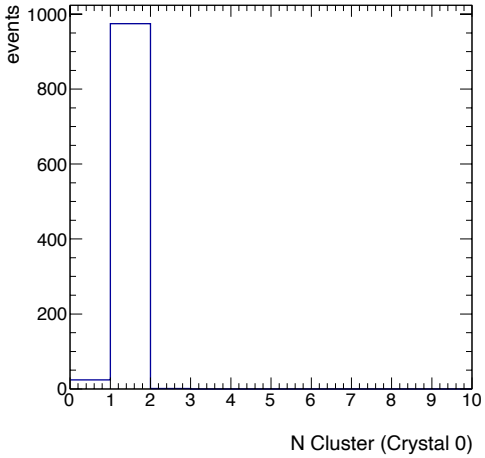


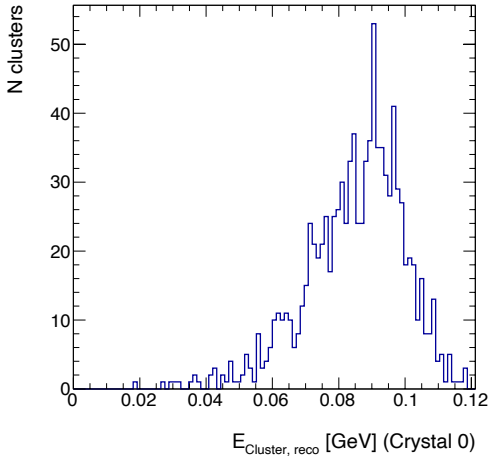
Number of clusters looks reasonable.

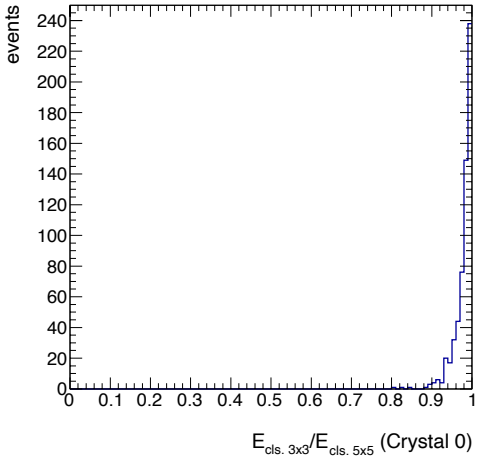
Use of 3x3 towers drops ~10% of energy on the 2nd Crystal layer (Crystal 1).

Cluster distribution (E=100MeV, 2 Crystals)

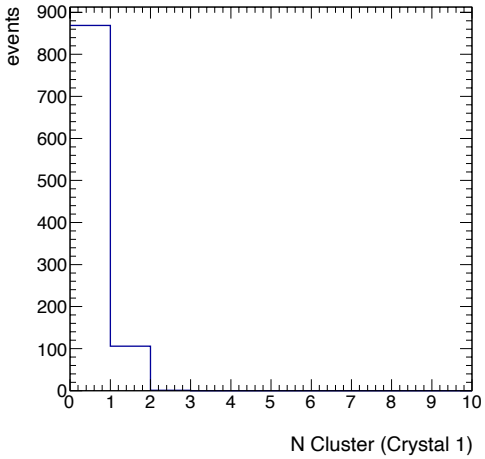
Crystal 0

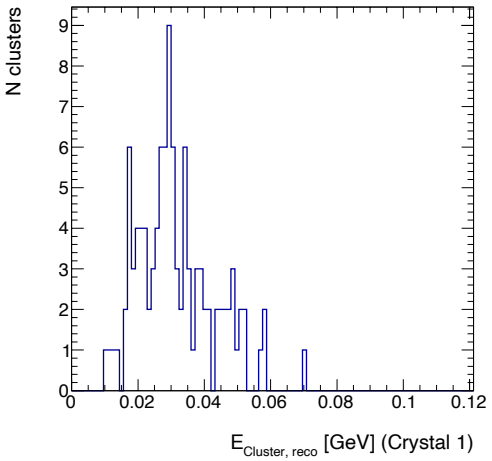


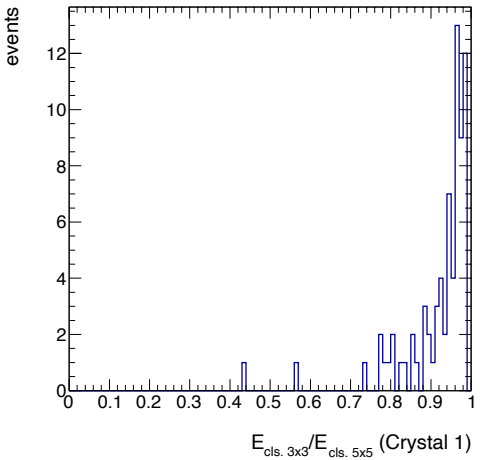


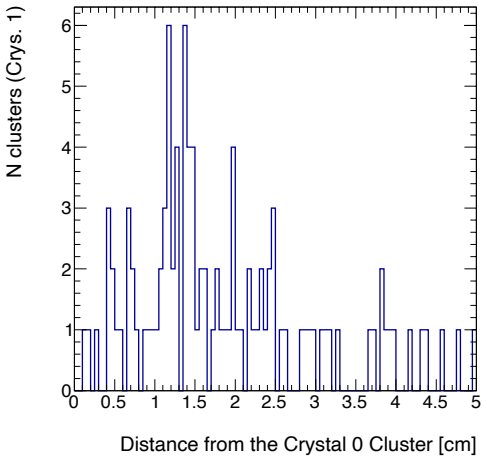


Crystal 1









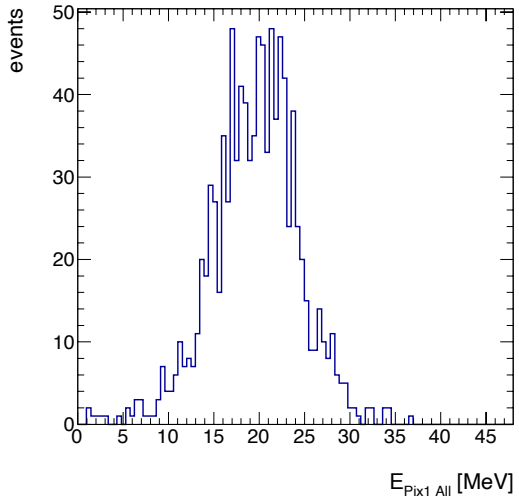
Cluster finding looks reasonable.

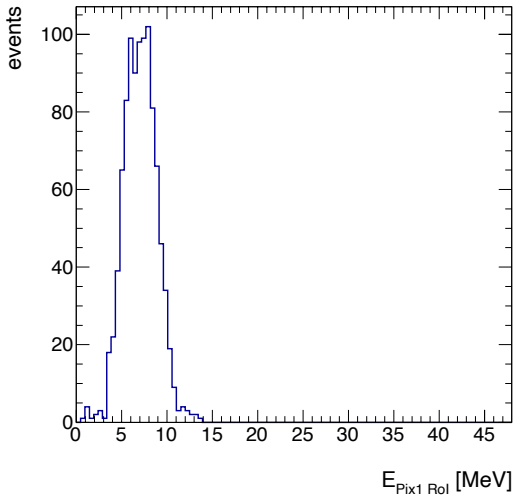
Almost no cluster on the 2nd Crystal layer, but the most of the energy is on the 1st cluster.

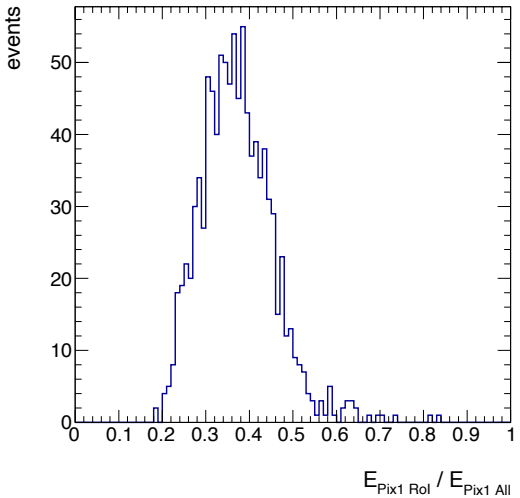
Energy on Pixel 1 layer

- RoI = 11 ch x 11 ch (3.3cm x 3.3 cm)
- RoI is mostly for position measurement.
- ~0.1% of photon energy is deposited on Pix 1.

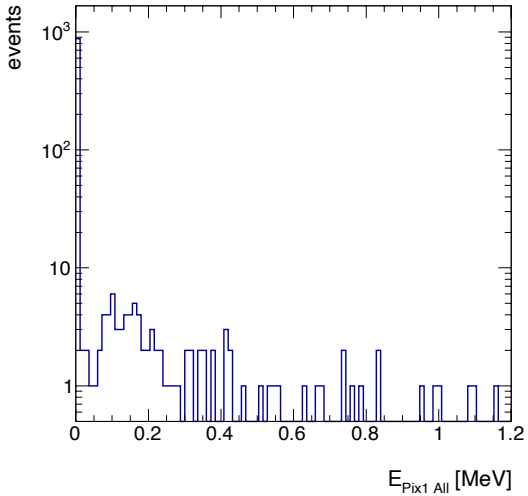
E=20 GeV

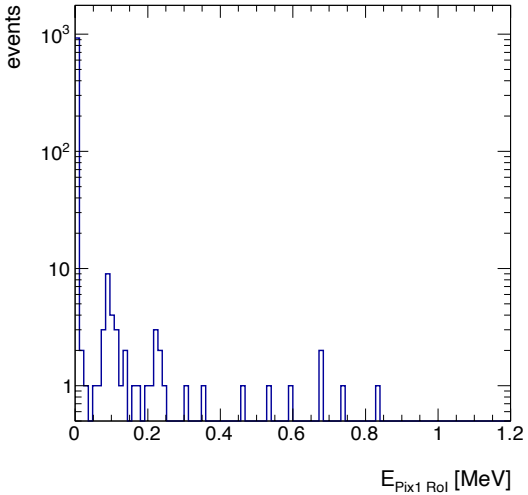


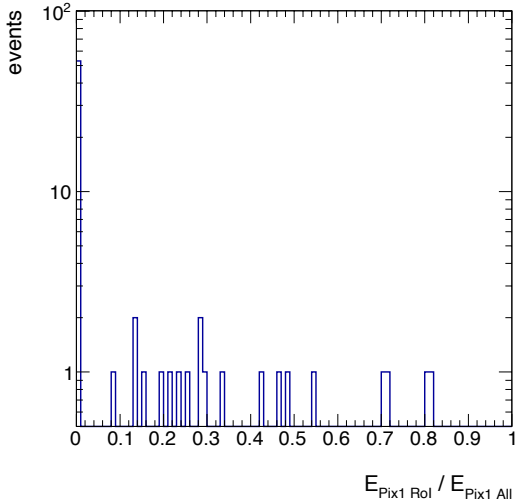




E=100 MeV







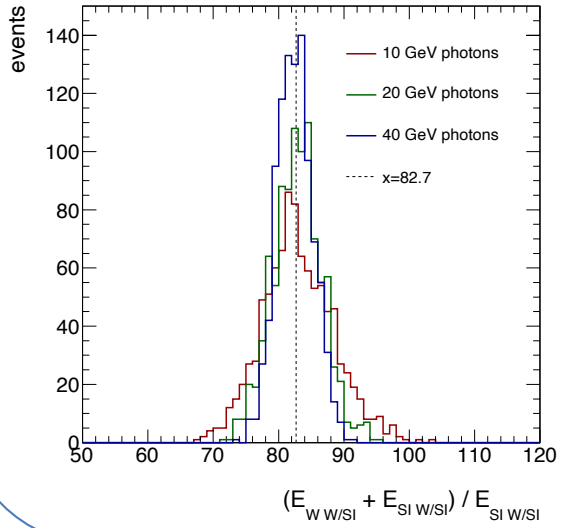
Energy in W/SI calorimeter

$E_{W/SI\ Reco} = E_{W/SI\ RoI,\ raw} \times 82.7$

Reminder:

Shot 10 - 40 GeV photons directly on W/SI layers (No crystal)

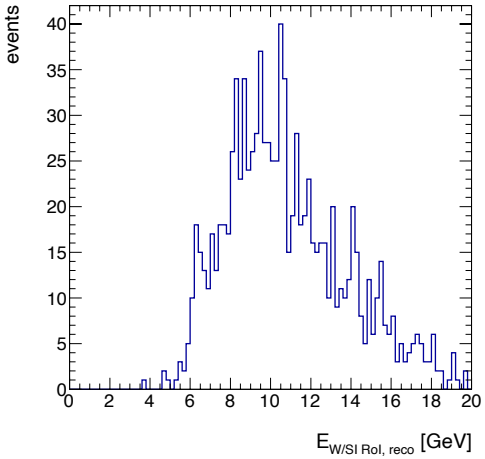
Events with $E_{Abs.\ (W+PET)} + E_{SI} > 99\%$ of beam energy are analysed.

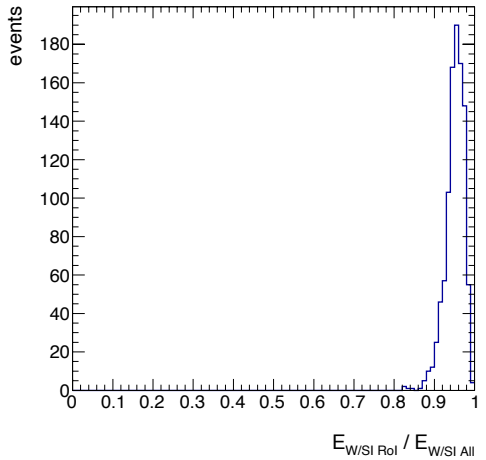


➔ SF = 82.7

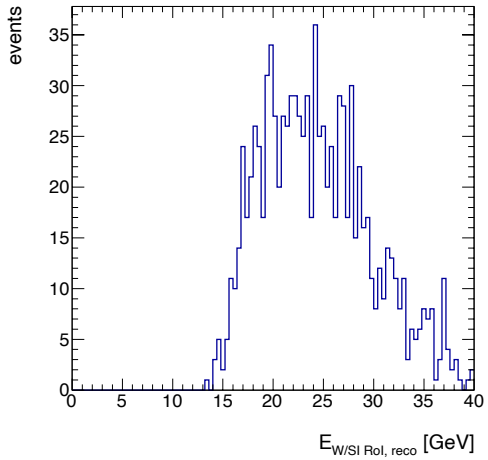
Setting: 1 Crystal layer

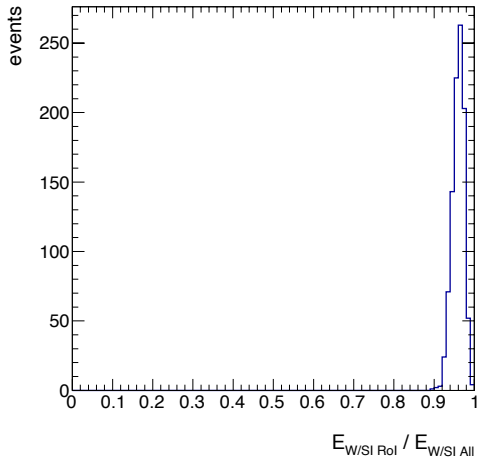
E=20 GeV





E=40 GeV

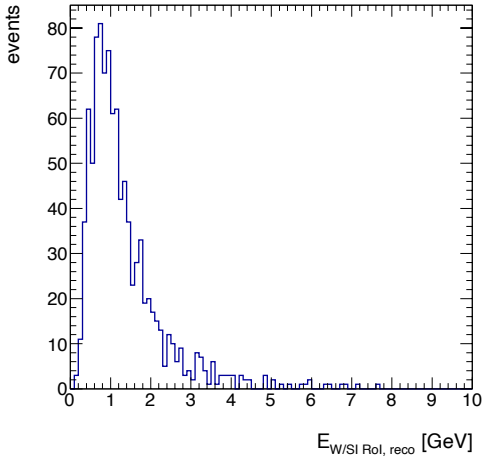




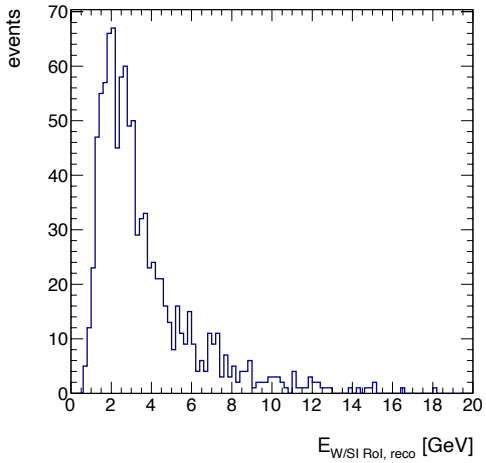
Energy in W/SI calorimeter

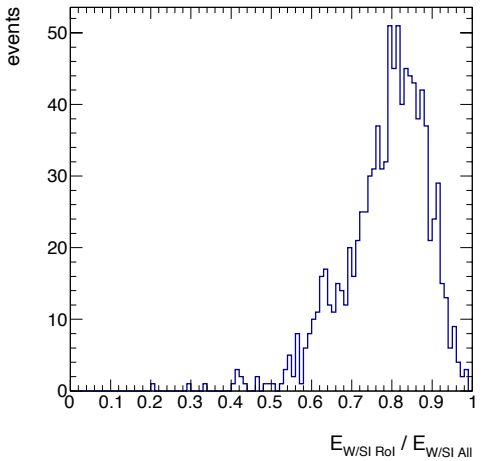
Setting: 2 Crystal layers

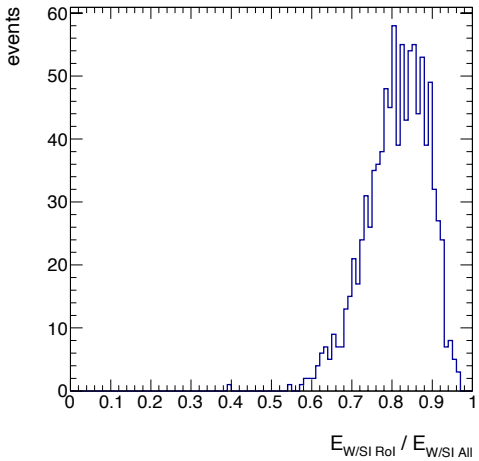
E=20 GeV



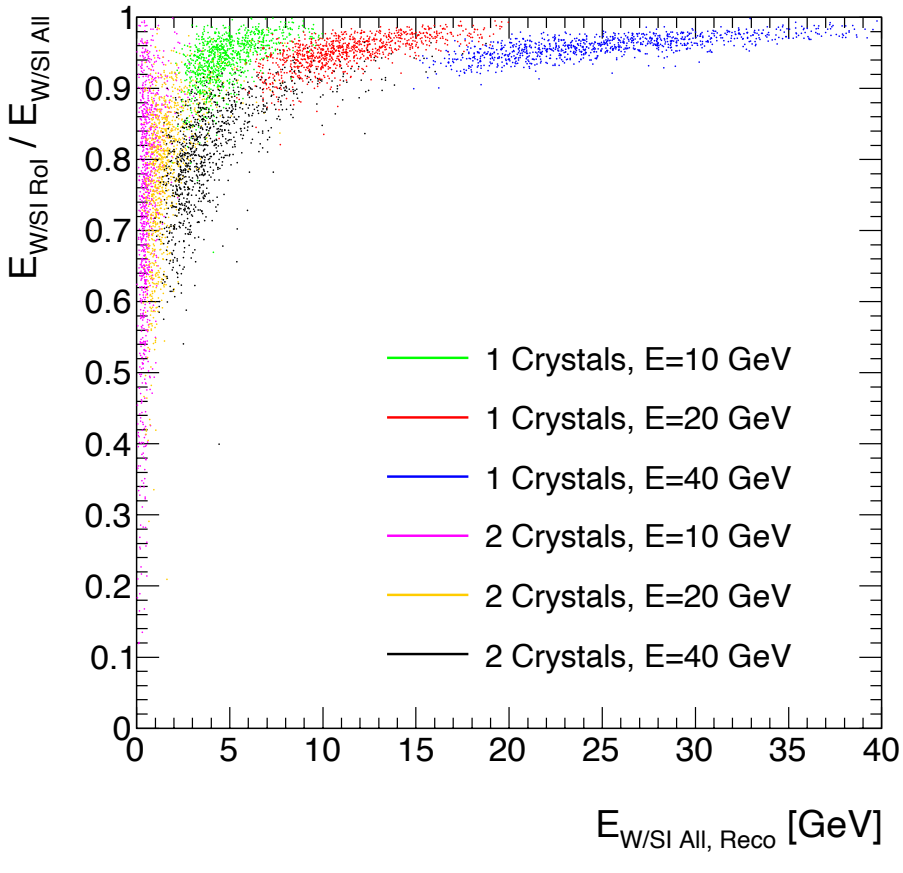
E=40 GeV





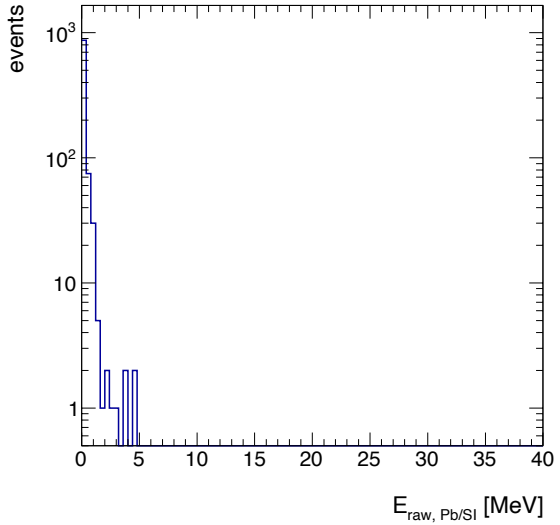


Correction for energy outside of RoI may be needed, but is not straightforward.



Energy in Pb/SI

1 Crystal layer E=40 GeV

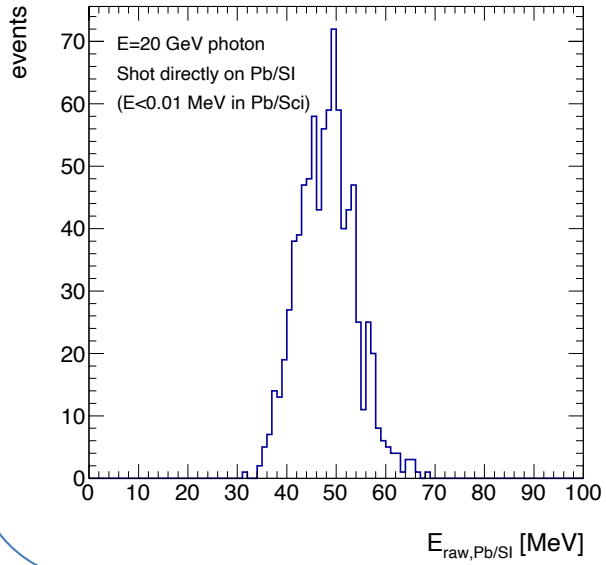


There is energy leakage to Pb/SI layers, but they are not significant for most of the events.

For events with leakage:

- 5 MeV corresponds to ~ 2 GeV* = 5% of E_γ

*Quick estimation of SF for Pb/SI



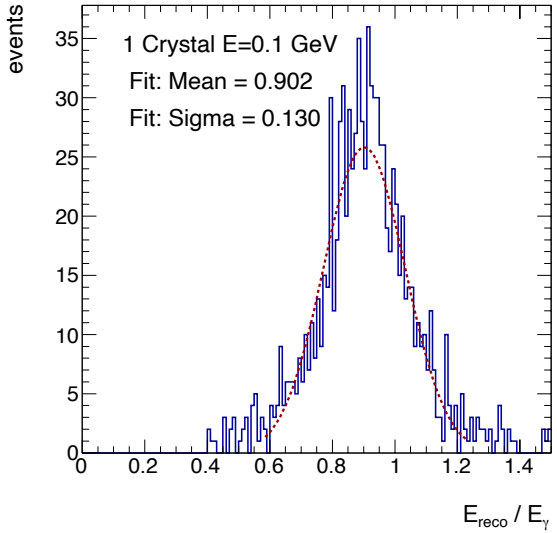
20 GeV photons directly shot on Pb/SI

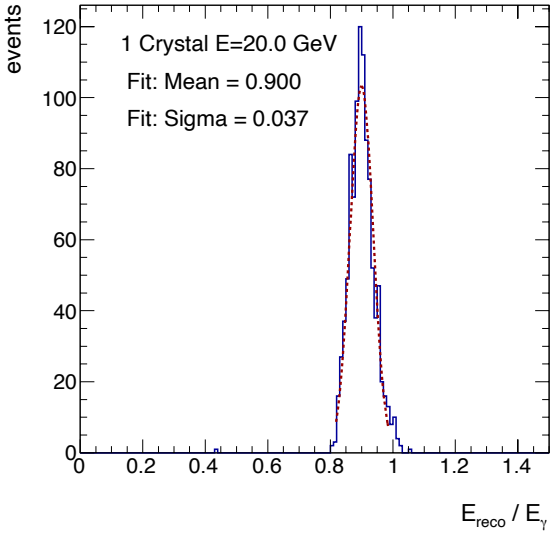
E_γ = 20 GeV <->
$E_{SI\ (Pb/SI)}$ ~ 50 MeV

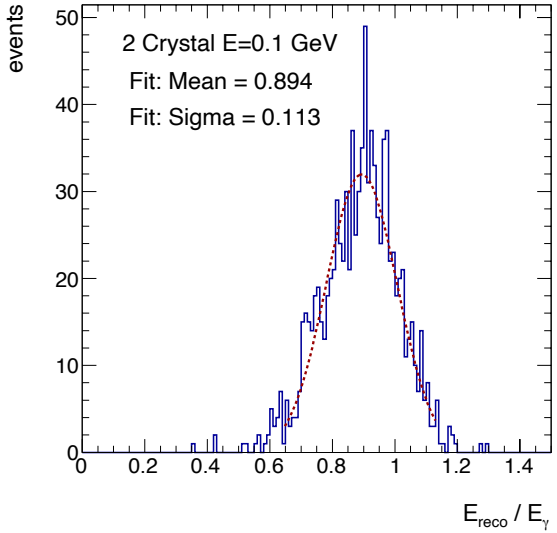
➔ SF ~ 400

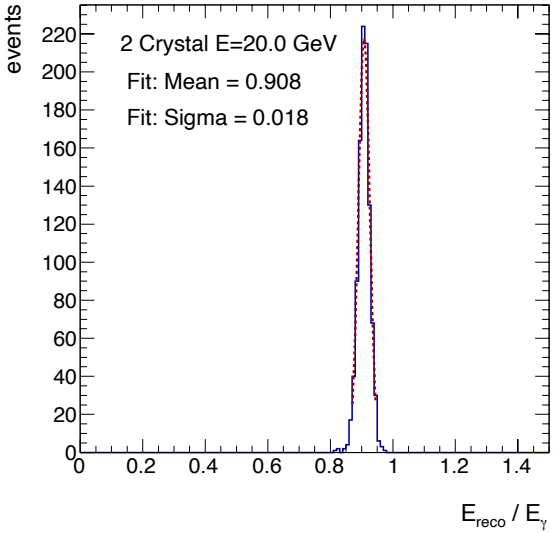
Reconstructed energy

- Fit on each E_{reco} / E_{photon} distribution

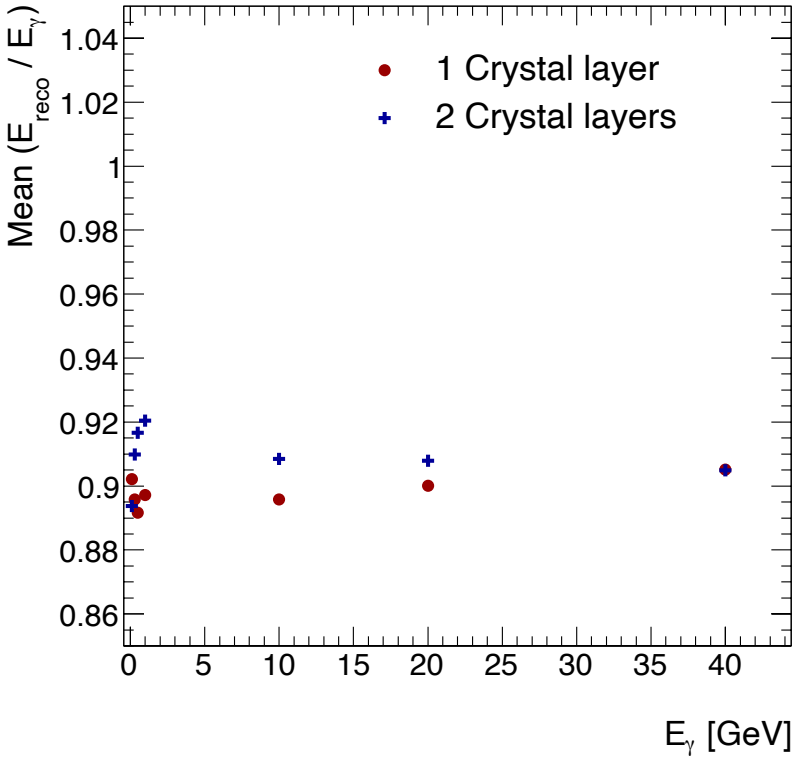


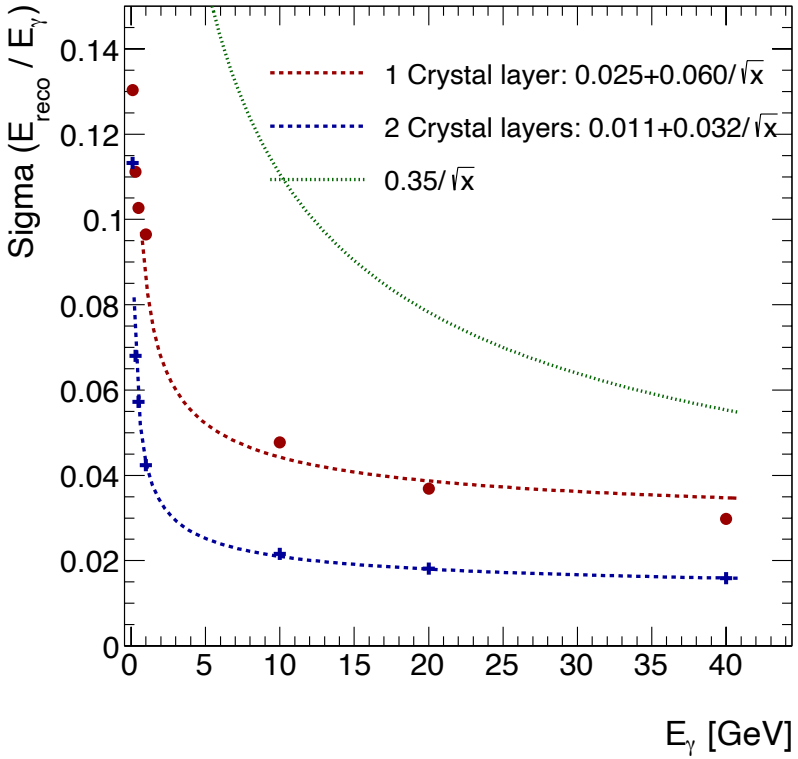






Summary of fit results





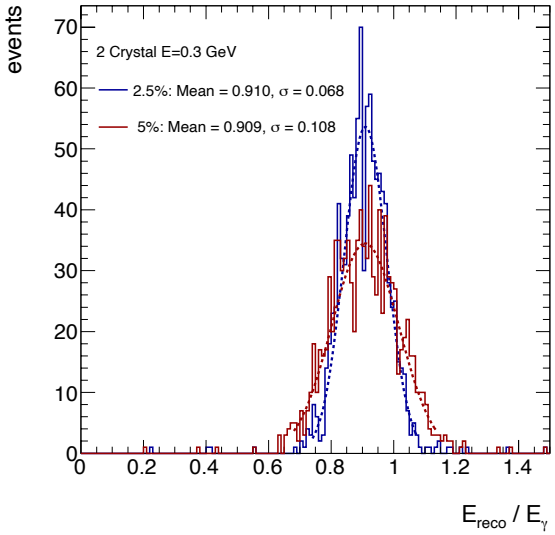
Both cases have better resolution than required.

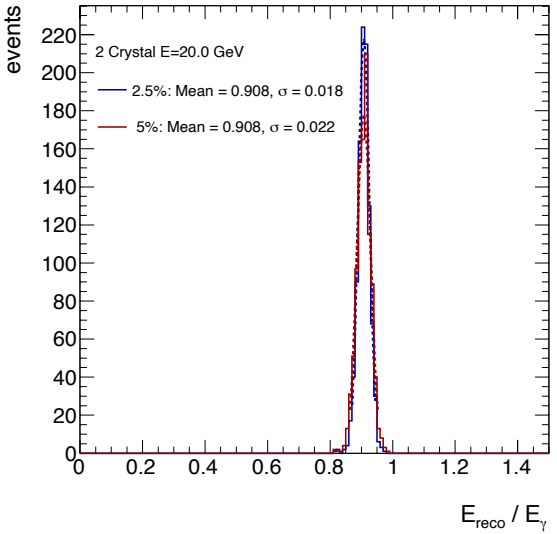
- 1 Crystal layer will double the size of resolution, but still better than required.

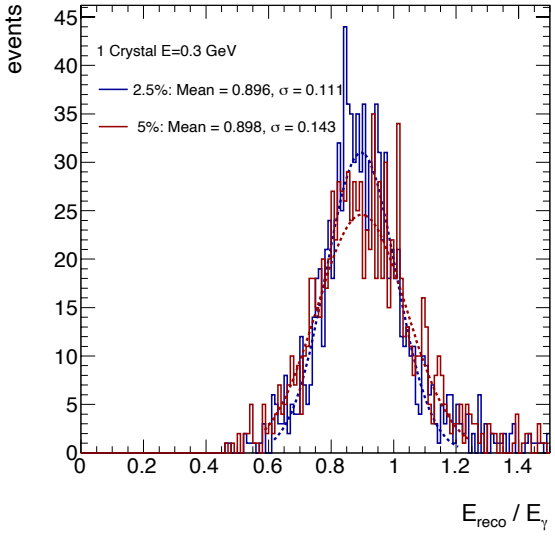
Impact of resolution of Crystal

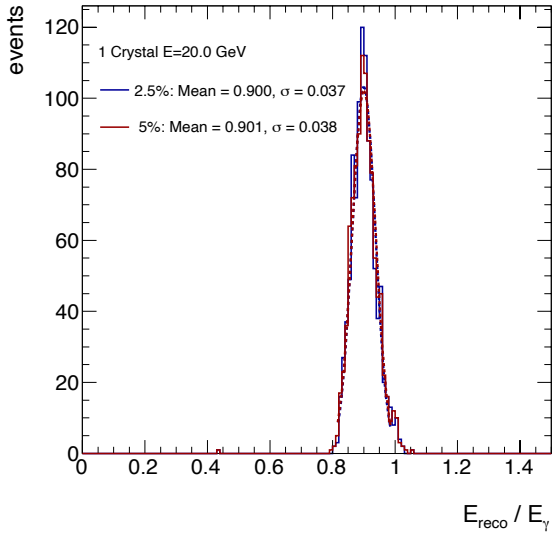
- The current setting includes:
  - No readout system
  - Resolution of crystal is assumed as $\frac{2.5\%}{\sqrt{E}} + 1\%$.
    ← Based on CMS and PANDA: ~20 cm crystals

→ Compared to $\frac{5\%}{\sqrt{E}} + 1\%$





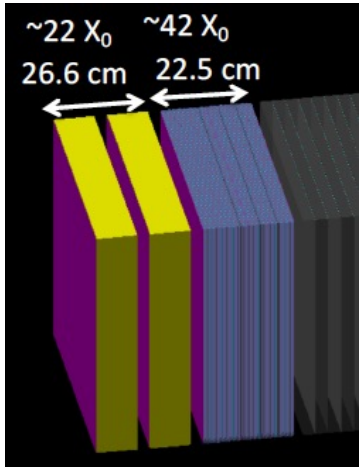




Doubled resolution gives:

- Less impact on 1 Crystal than 2 Crystals.
- In any case, the impact is not large.
  - Low E_γ: still less than 0.2
  - 20 GeV: difference is minor.

Summary and outlook



- Current design in Fun4All:
  - 10 cm Crystal x 2
  - 42 layers of W/SI
  - SI layers: 3 mm x 3mm pixel layers or 1cm x 1cm pad layers.
- Estimation done as:
  - Photon energy resolution is well below physics requirement.
  - With 7 cm Crystal, position resolution is 1.1 / 1.5 mm for 40 /20 GeV photons.

    ← larger than physics requirement.

➔

- 7 cm crystal is preferred to 10 cm.
- W/SI layers can be reduced to 22 layers from 42 layers.

  * 6 cm reduction in Crystal + 11 cm reduction in W/SI = 17 cm reduction.
- Better to think of finer pixel silicon layer for better position resolution?

Backup

Photon position reconstruction on Pixel 1

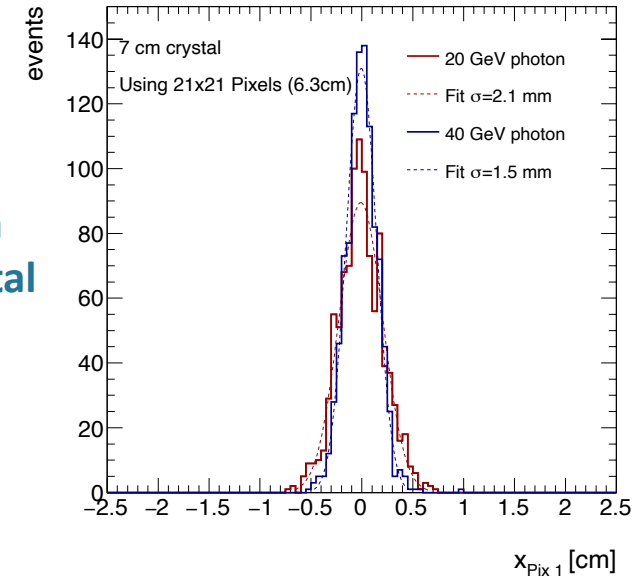
Best resolution: 1.1 mm

for

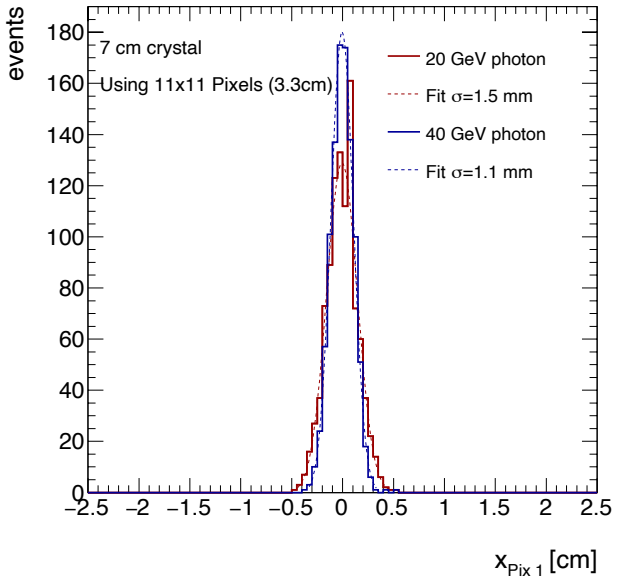
- 40 GeV photon.
- 7 cm thickness.
- in 3.3 cm square.
  (11 x 11 chns)

7 cm crystal

looking at 21 x 21 pixels

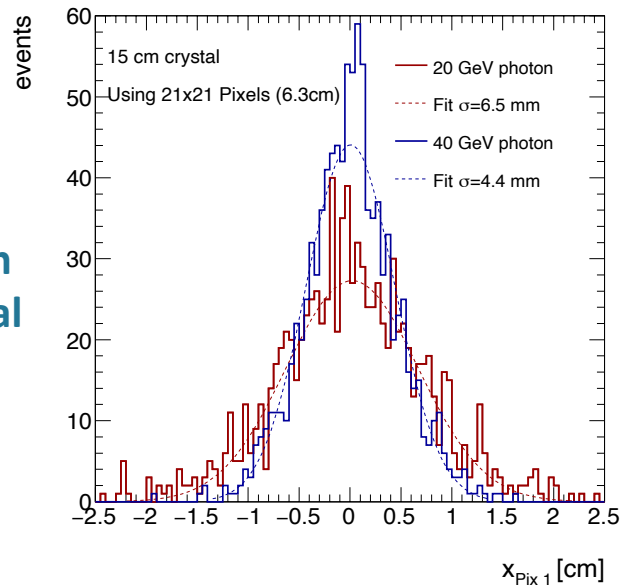


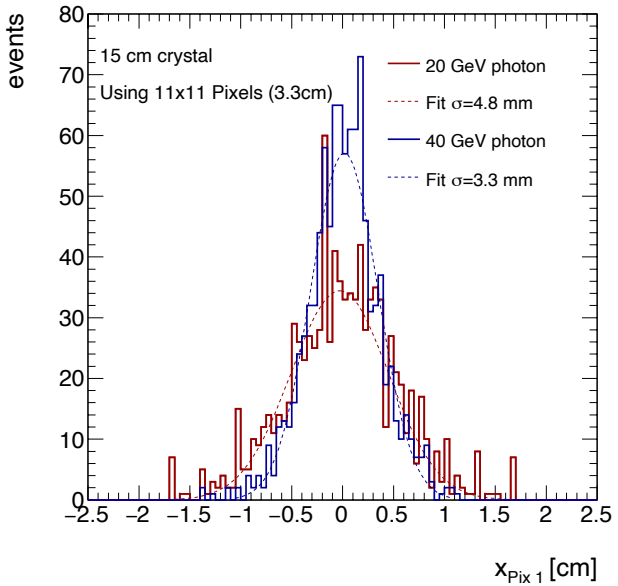
looking at 11 x 11 pixels



- 20 GeV → 1.5 mm
- 15 cm thickness → 3.3 mm
- 6.3 cm square → 1.5 mm
  (21 x 21 chns)

15 cm crystal



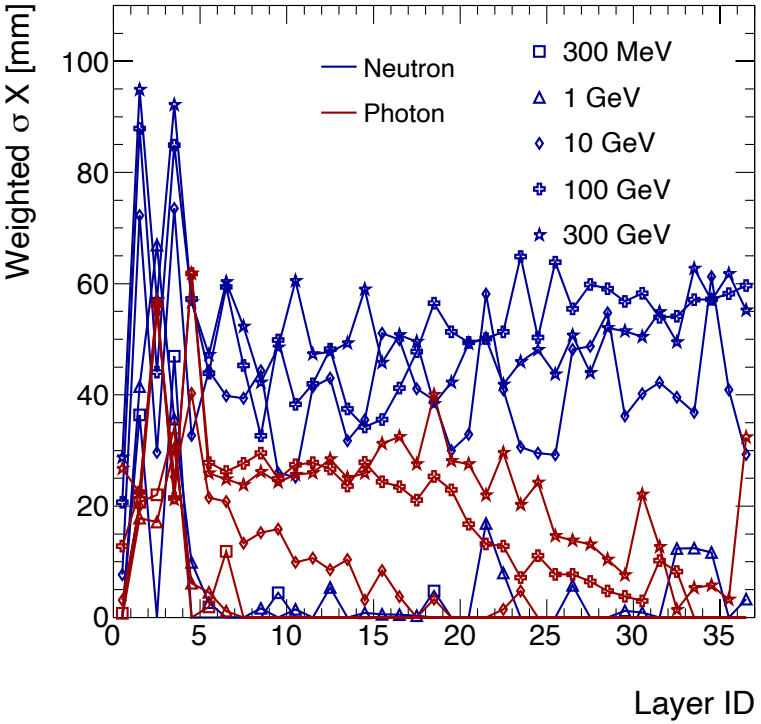


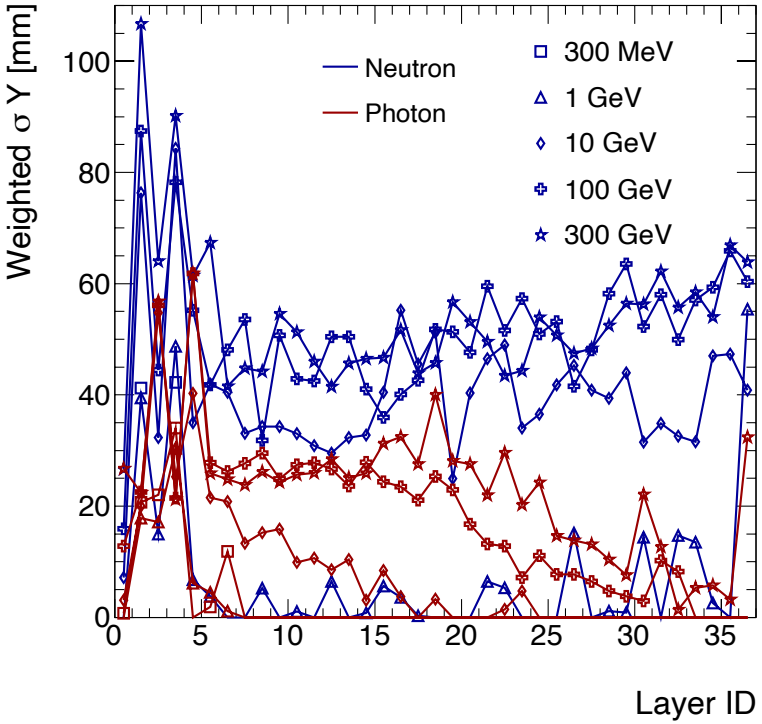
Transverse spread of energy deposits

with 7 cm x 2 Crystals

- Energy weighted sigma are checked.

$$\sigma = \sqrt{\frac{\sum E_i(x_i-\bar{x})^2}{\sum E_i}} = \sqrt{\left|\frac{\sum E_i x_i^2}{\sum E_i} - \bar{x}^2\right|}, \text{ where } \bar{x} = \frac{\sum E_i x_i}{\sum E_i}$$





- First 5 layers will be looked in details later.
- Difference of shower width is visible in Si/W layers (Layer ID > 5).
- Photon shower is fading around Layer ID 20-30.

Cluster distribution (E=300 MeV)