Weekly report

Shima Shimizu

7/Oct./2021

My tasks

- **Study of ZDC energy reconstruction for photons: Today**
- Follow up the physics requirement to the ZDC – not yet
  - https://docs.google.com/spreadsheets/d/1IWYx5hFsKXEDIjQgLV5qOZPBfxDNbCMOgzwptTndtTE/edit#gid=0
- Preparation of ZDC reconstruction codes in Fun4All. – not yet
- **MC generation for the 2nd simulation campaign.**
  - Done: DJANGOH [ep, eD, eHe3] x [NC, CC] x [5x41, 10x100, 18x275(137,166)]
  - In discussion: PYTHIA photoproduction (Direct vs Resolved…?)
- **Analysis for CC cross section measurement**
  - Code development… Calorimeter clusters are at my hands, but no track matching.

Photon analysis for ZDC EMC optimization

Shima Shimizu (RIKEN/JSPS)

Forawrd/Backward meeting 8/Oct./2021

The first design

Si + 2 x { 20 layers + 1 layer }

- 20 layers:
  - **Tungsten** 3.5 mm Thickness
  - **Silicon** 1 cm x 1 cm x 320 μm
- 1 layer:
  - **Tungsten** 3.5 mm Thickness
  - **Silicon** 3 mm x 3mm x 300 μm

Si: 3 layers
Si: 40 layers
W: 42 layers

2 layers

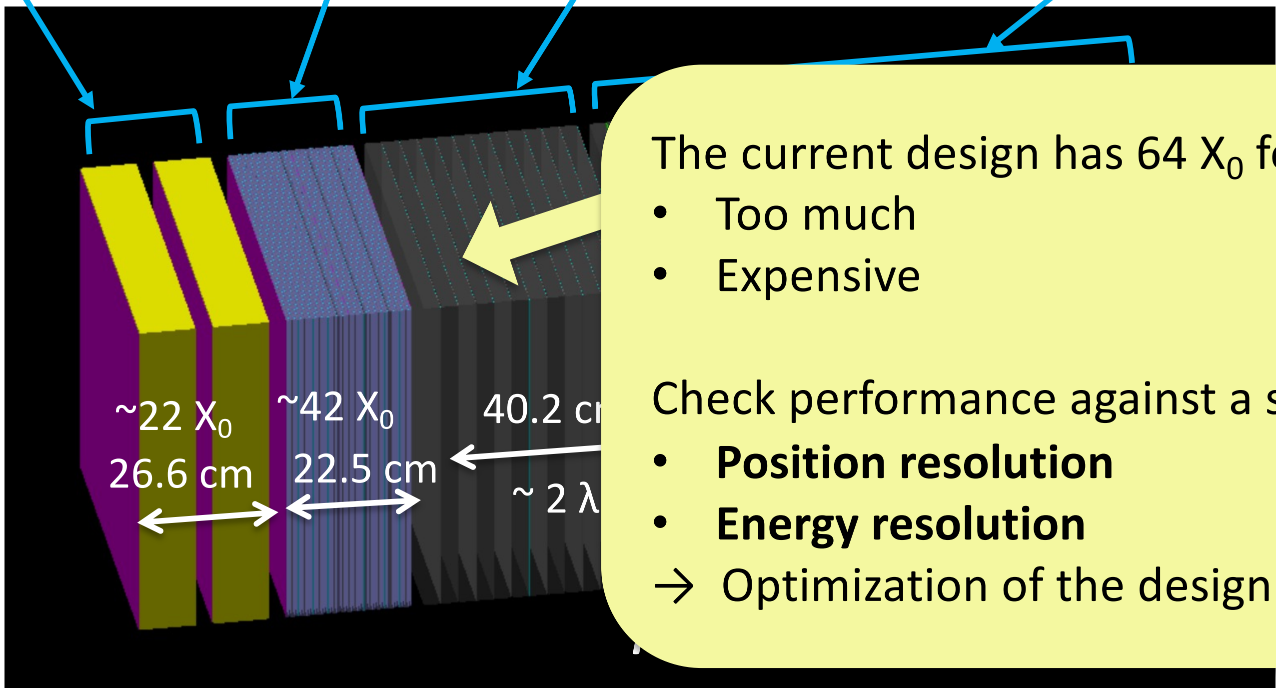
Silicon
3 mm x 3mm x 300 μm
Crystal (PbWO4)
3cm x 3cm x 10 cm

12 layers

Pb 3cm Thickness
Silicon
1 cm x 1 cm x 320 μm

30 layers (15 layers x 2)

Pb 3cm Thickness
Scintillator
10 cm x 10 cm x 2 mm



The current design has 64 X_0 for EM part.

- Too much
- Expensive

Check performance against a single photon:

- **Position resolution**
- **Energy resolution**

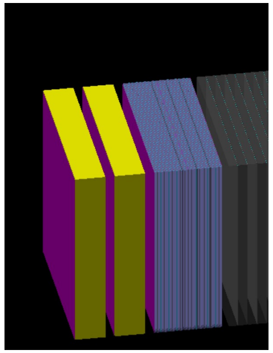
→ Optimization of the design.

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 (Λ decay) , neutron + 3 photons (Σ^0 decay)
    - Position resolution: 0.5-1mm
  - Energy resolution
    - $35\%/\sqrt{E}$

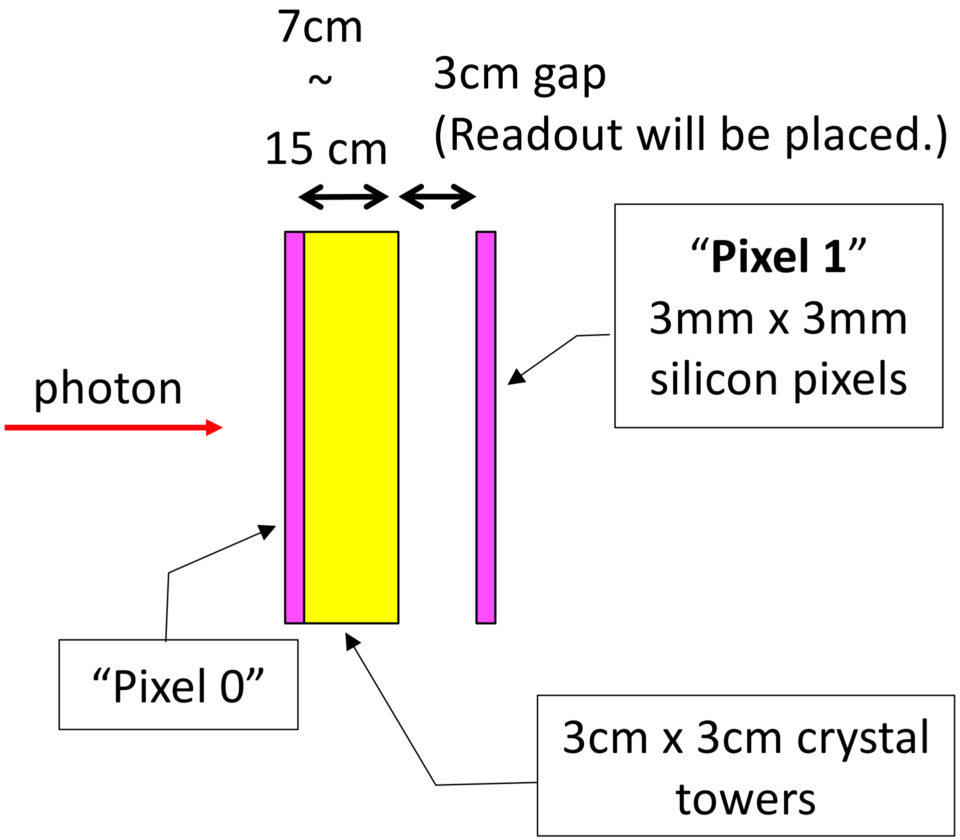
Position reconstruction



- Physics requirement:

  Position resolution of (0.5~) 1 mm

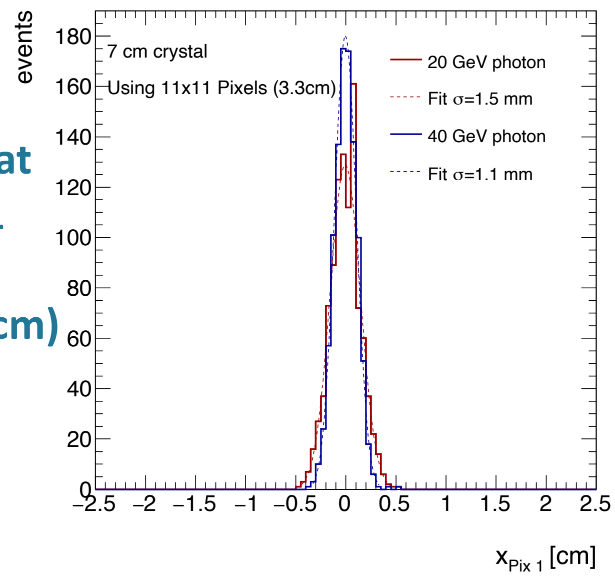
- Checked with three setups:
  - 7 cm (7.9X_0) thickness of Crystal
  - 10 cm (11 X_0) thickness of Crystal
  - 15 cm (16 X_0) thickness of Crystal
- Analysis:
  1. Photons are shot at the center of the plane (0,0).
  2. Reconstruct the photon position using the 1st crystal layers. Energy weighted mean of 3 x 3 towers → ($x_{Crystal}$, $y_{Crystal}$)
  3. Look into the pixel cells on the next layer, around ($x_{Crystal}$, $y_{Crystal}$).

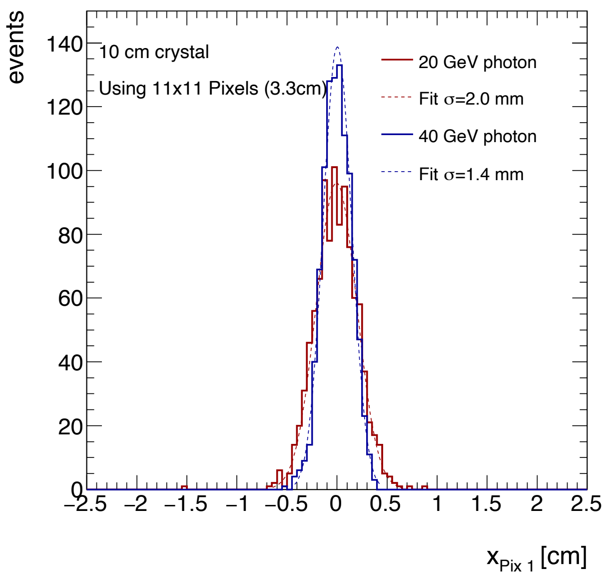


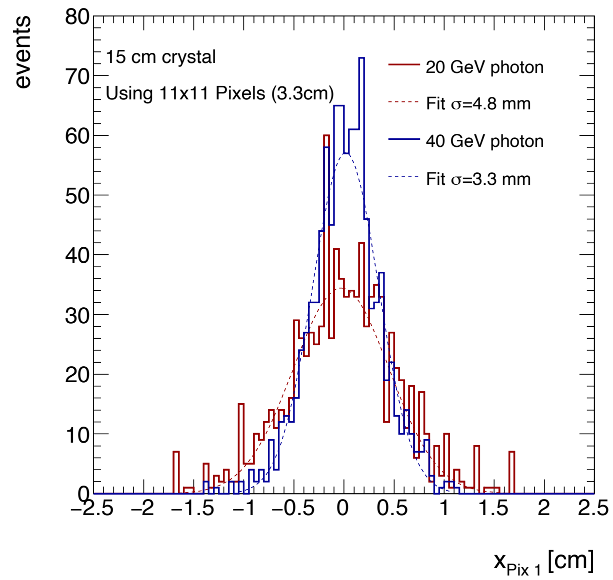
Photon position reconstruction on Pixel 1

7 cm crystal | **10 cm crystal** | **15 cm crystal**

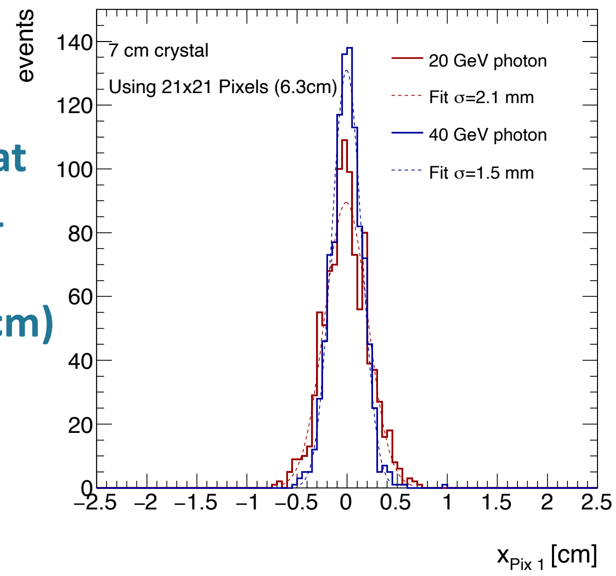
looking at 11 x 11 pixels (11 =3.3 cm)







looking at 21 x 21 pixels (21 =6.3 cm)



Best resolution: 1.1 mm

from:

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

- 20 GeV → 1.5 mm
- 10 cm thickness → 1.4 mm
- 6.3 cm square → 1.5 mm (21 x 21 chns)

➔ **Thinner crystal is preferred.**

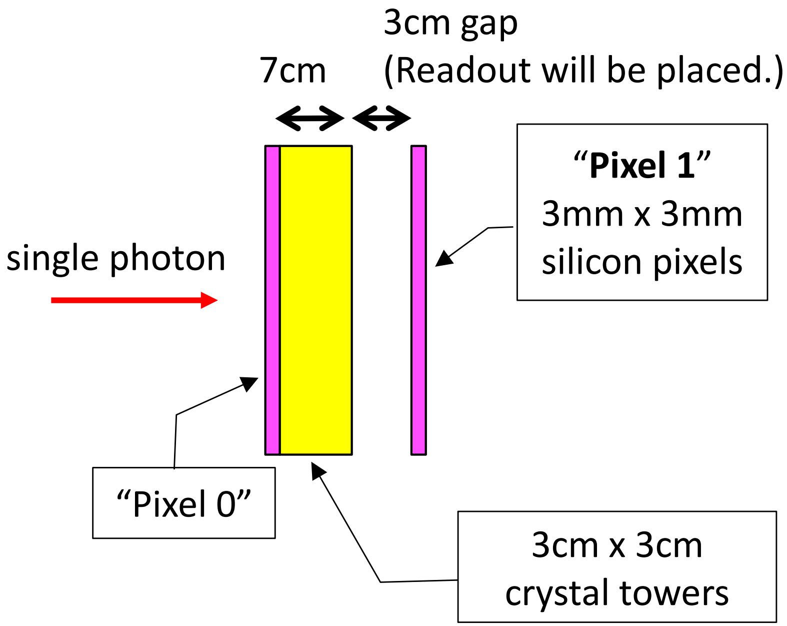
Energy reconstruction

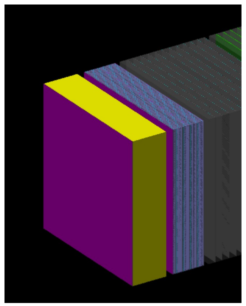
- Physics requirement:
  - 20 – 30 % energy resolution for O(100) MeV photons
  - 35%/√E energy resolution for O(10) GeV photons

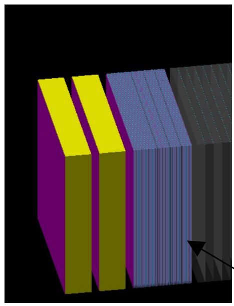
- Setup

  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

Energy reconstruction

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

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

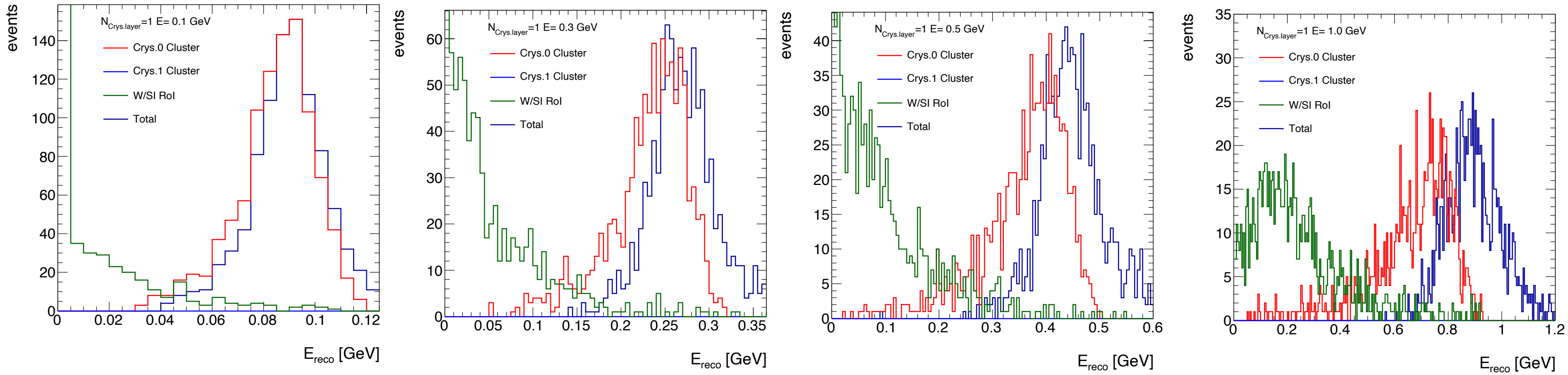
- 11x11 cells RoI is formed around (x, y) of Crystal 0 cluster. Energy deposit in RoI is taken.

W/SI

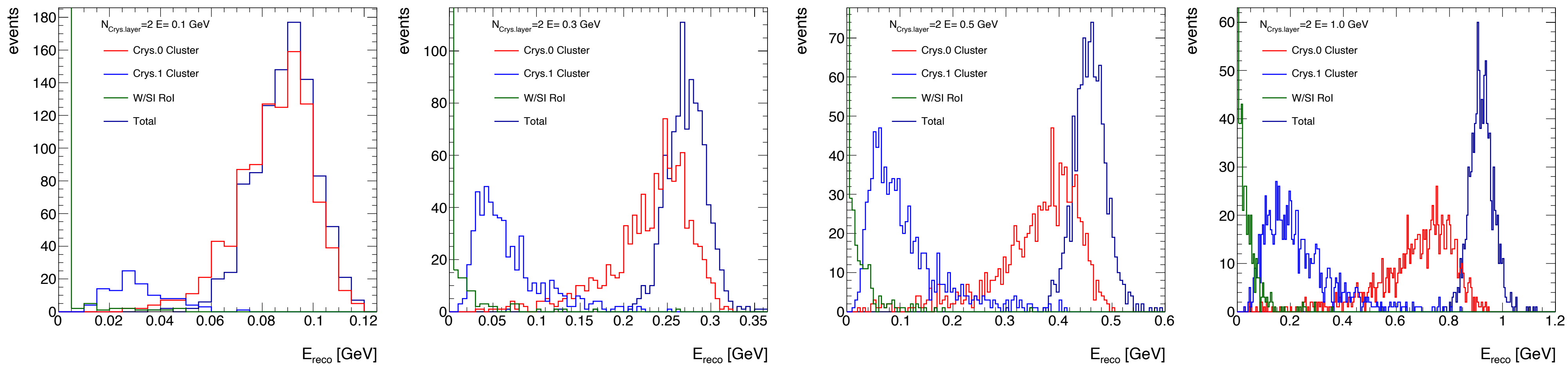
- 9cm x 9cm RoI is formed around (x, y) of Crystal 0 cluster.
  - "Reco." energy = 82.7 * Energy sum in RoI.

Reco energy (E=0.1 ~ 1 GeV)

Setup: 1 Crystal layer



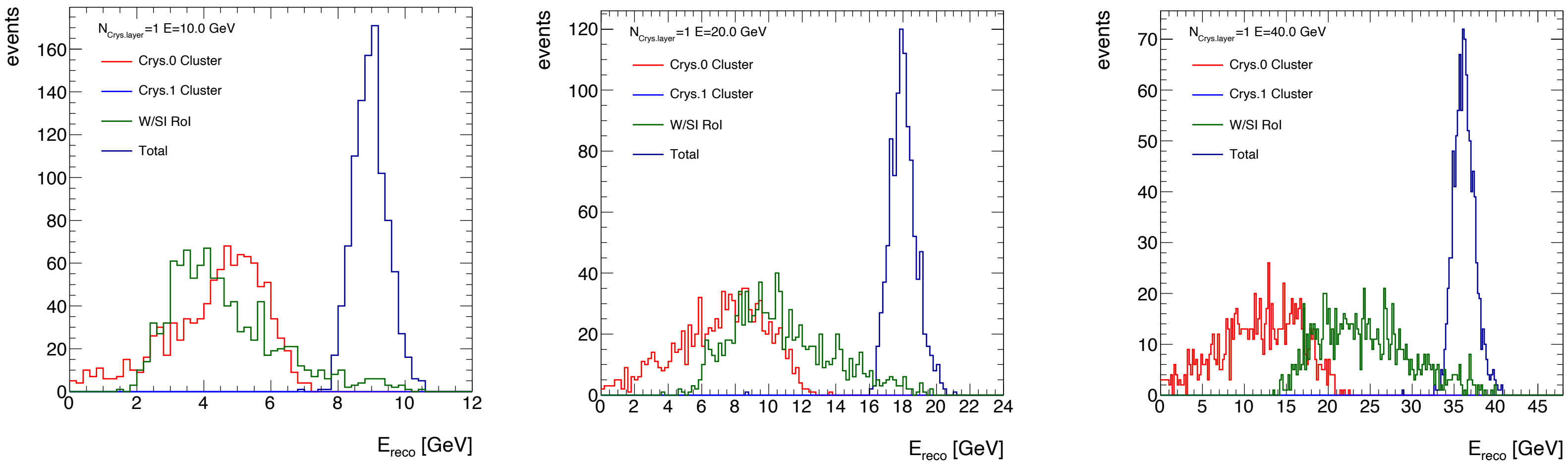
Setup: 2 Crystal layers



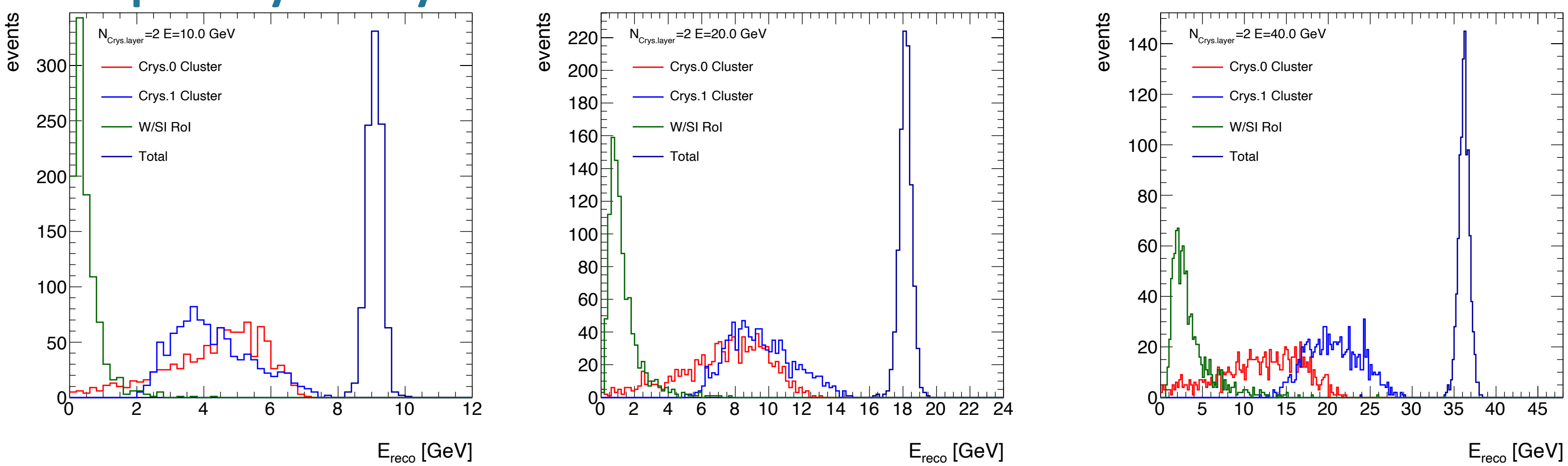
Most of the energy measured in 1st Crystal layer.

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

Setup: 1 Crystal layer



Setup: 2 Crystal layers

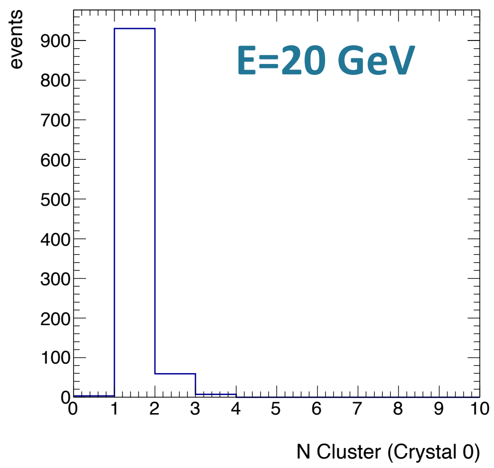


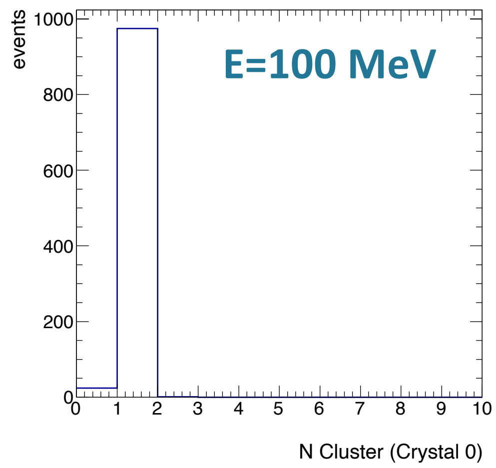
Half ~ less than half of the photon energy is measured in the 1st Crystal layer (Crystal 0).
All of the Crys.0, Crys.1, and W/SI contributes to the energy reconstruction for E>~10 GeV.

Some details… (more on backup)

- Clustering of Crystal tower
  - 15 MeV seed gives reasonable reconstruction efficiency for both 20 GeV and 100 MeV photons

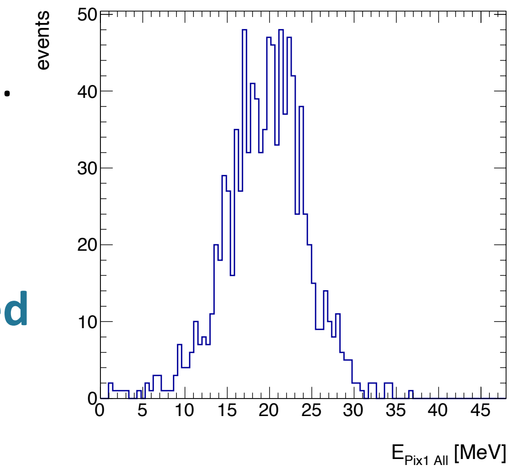
Number or clusters on the 1st Crystal layer (Crystal 0)





- Energy on Pix1
  - Pix 1 is for position (and timing?) measurement.
  - ~0.1 % of photon energy is deposited on Pix1.

Energy deposited on Pix1 layer



E=20 GeV

Some details… (more on backup)

- W/SI energy reconstruction

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

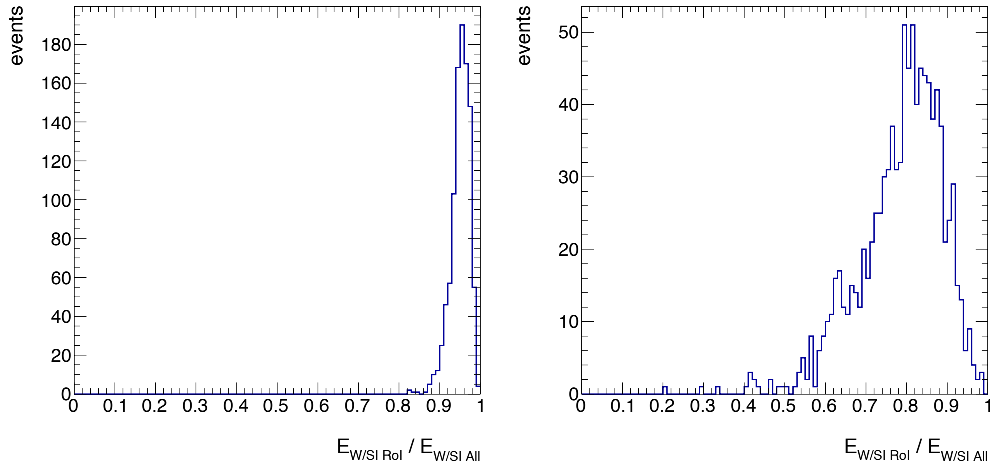
  - Scale factor 82.7 is obtained from direct shots of photons on W/SI layers

- W/SI RoI

  - RoI (9cm x 9cm) takes ~95% of energy for 1 Crystal setup, but 70~90% for 2 Crystals setup.

Fraction of RoI energy wrt all W/SI energy

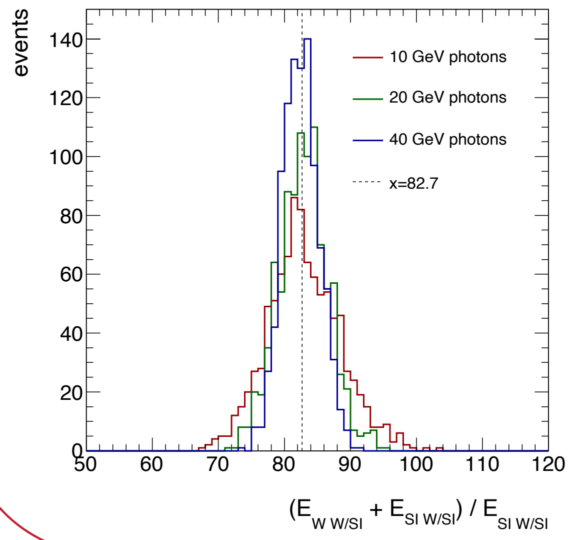
1 Crystal setup **2 Crystals setup**



Extraction of scale factor

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

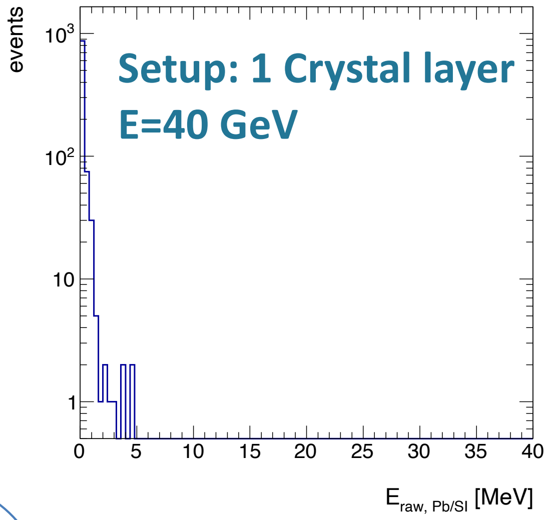
E=20 GeV photons

RoI energy correction may be needed in future.

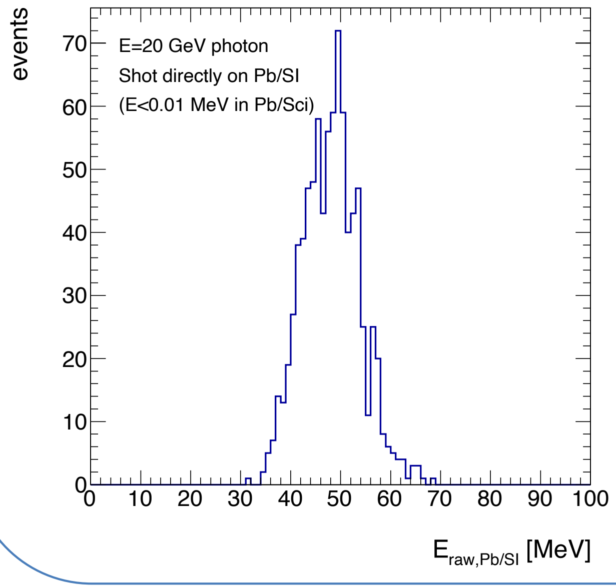
Energy leakage

- Energy in Pb/SI layer (HC part)
  - Not significant for most of the events, even for 40 GeV photons on 1 Crystal-layer setup.
  - Maximum 5 MeV in SI

    → corresponds to ~ 2 GeV * = 5% of E_γ



*Quick estimation of SF for Pb/SI



20 GeV photons are directly shot on Pb/SI

E_γ = 20 GeV <->

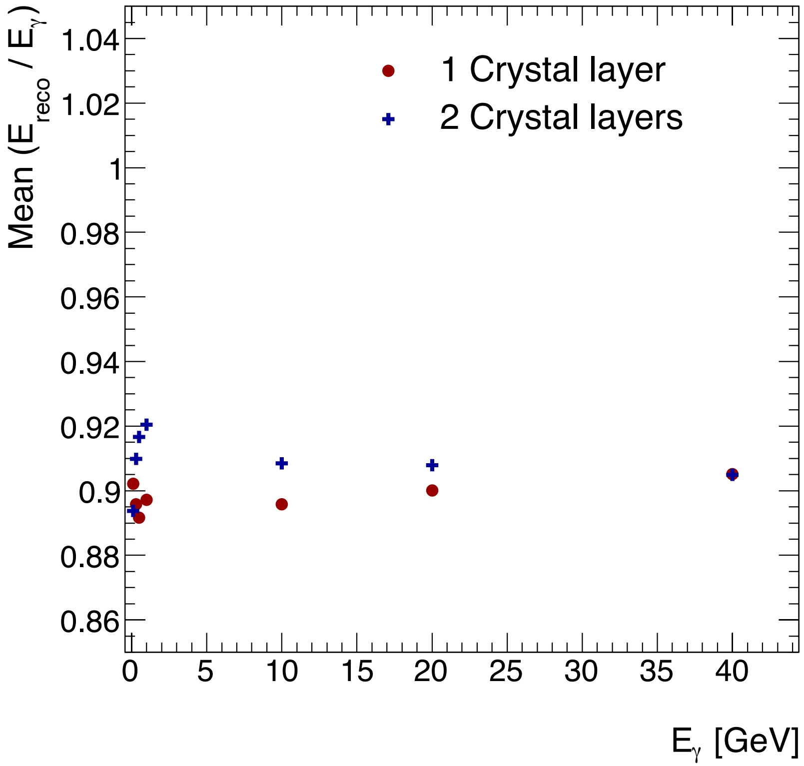
$E_{SI\ (Pb/SI)}$ ~ 50 MeV

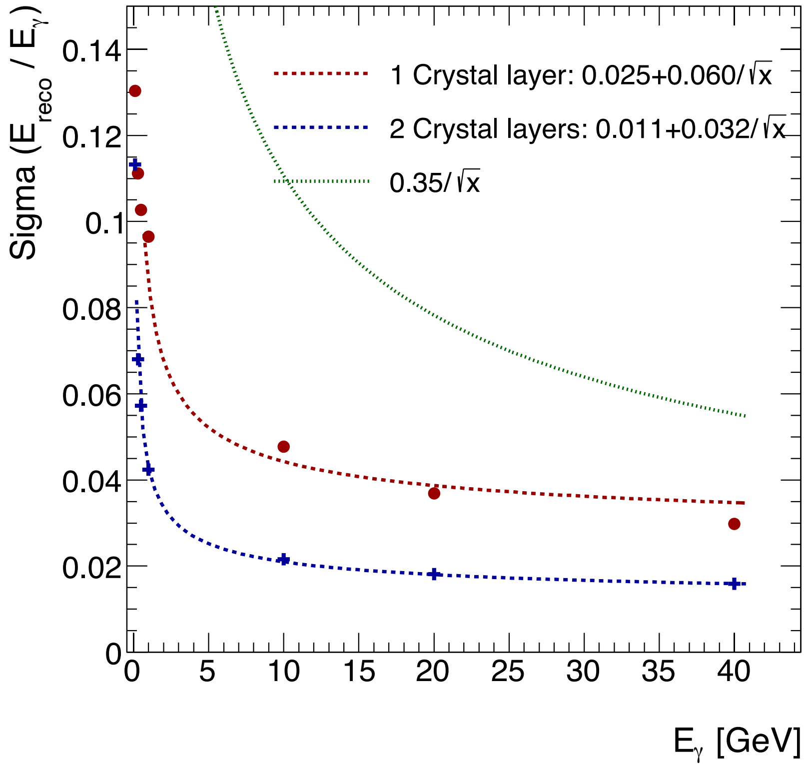
➔ SF ~ 400

Summary of energy reconstruction

$E_{Reco, total}$ / E_{γ} distributions are fitted.

(Note: No energy correction for RoI use (Crystal, Pix1, W/SI) and for energy leakage)





Both 1 Crystal and 2Crystals setups have better resolution than required.

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

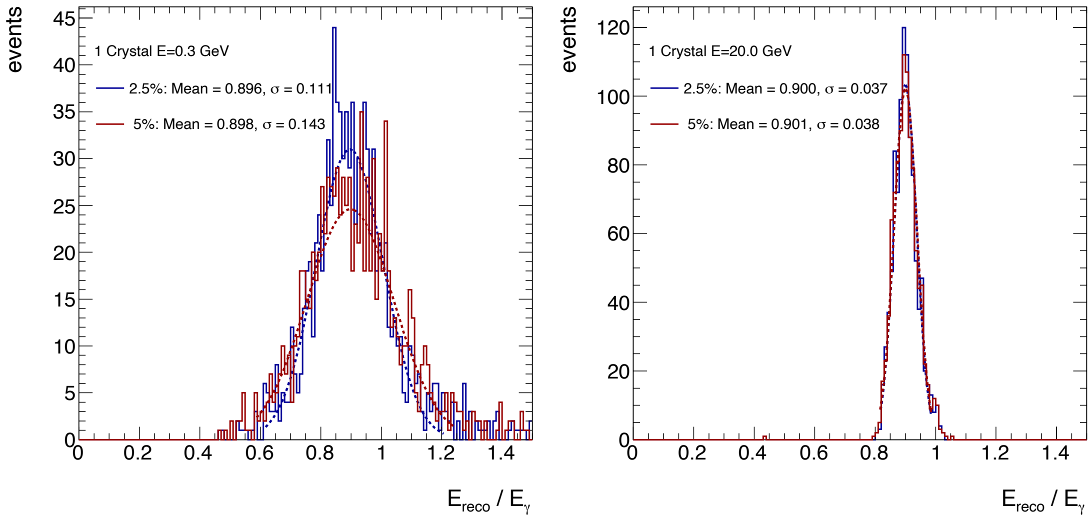
Impact of resolution of Crystal

- 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 $\frac{5\%}{\sqrt{E}} + 1\%$

1 Crystal setup

E = 300 MeV | E = 20 MeV



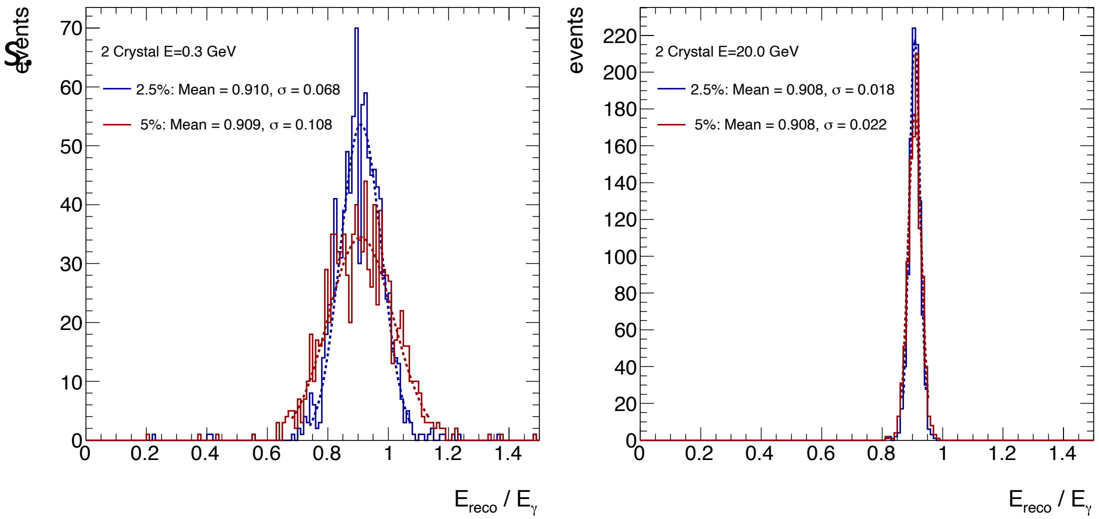
Doubled crystal resolution gives:

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

    1 Crystal: 0.037 → 0.038,

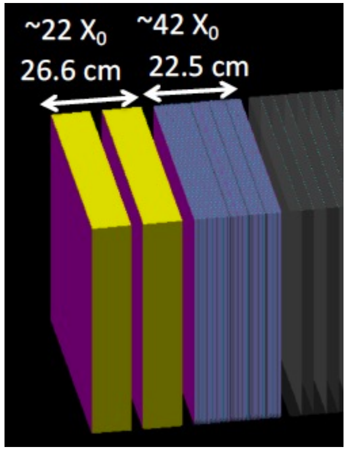
    2 Crystals: 0.018 → 0.022

2 Crystals setup



Summary

- Performance against single photons is studied.
  - Position resolution is 1.1mm/1.5mm for 40 /20 GeV photons, with 7 cm Crystal. Thicker crystals give worse resolution.
  - Energy resolution is well below the physics requirements, for both 1 Crystal and 2 Crystal setups.



Possible optimization:

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

To be considered:

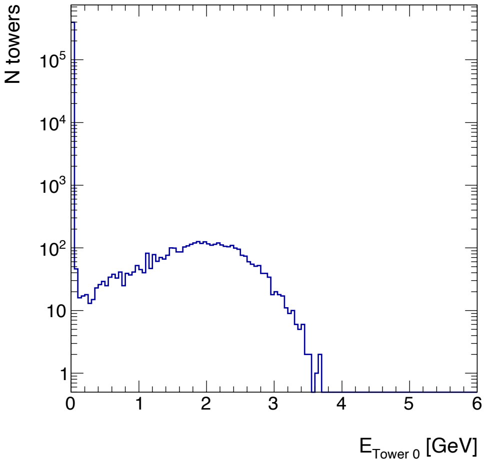
- Finer pixel silicon layer for better position resolution? (or further thinner crystal??)
- Replacement of silicon by scintillator at the outside of aperture?
- Reduced coverage of the crystal layer(s) from 60 cm x 60 cm?

Further study needed: radiation hardness, performance against multi-particles….

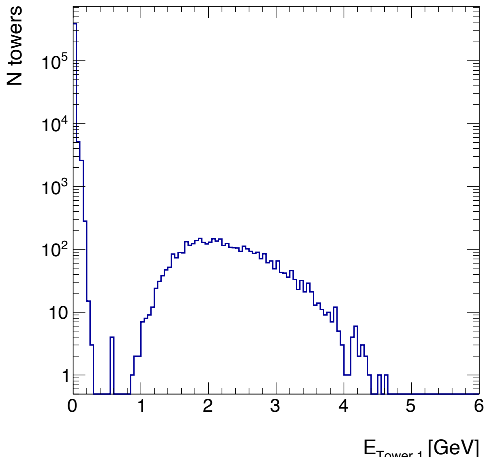
Backup

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

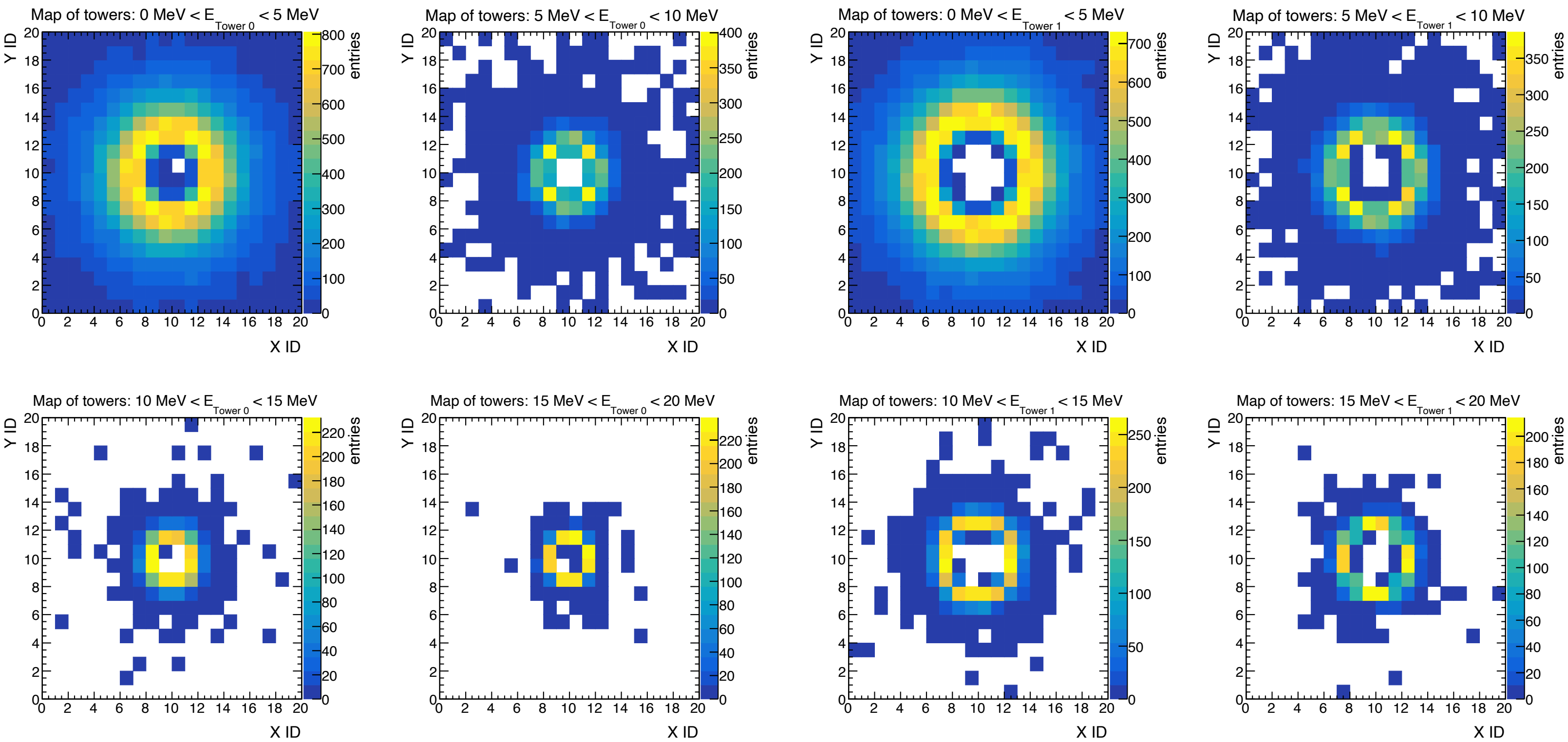
Crystal 0



Crystal 1

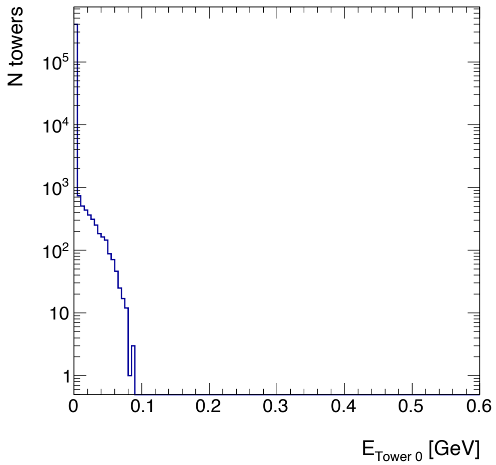


Lots of towers with small energies of < 150 MeV

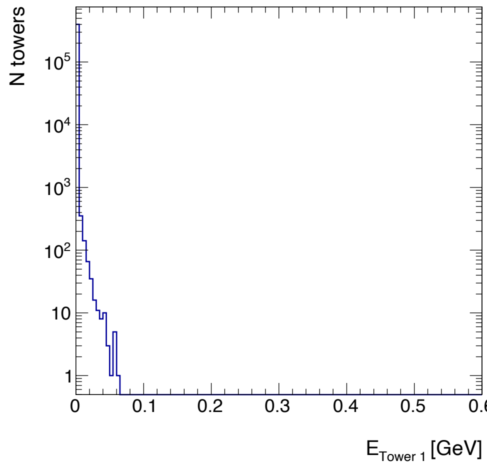


Requirement of 15 MeV will largely reduce their number.

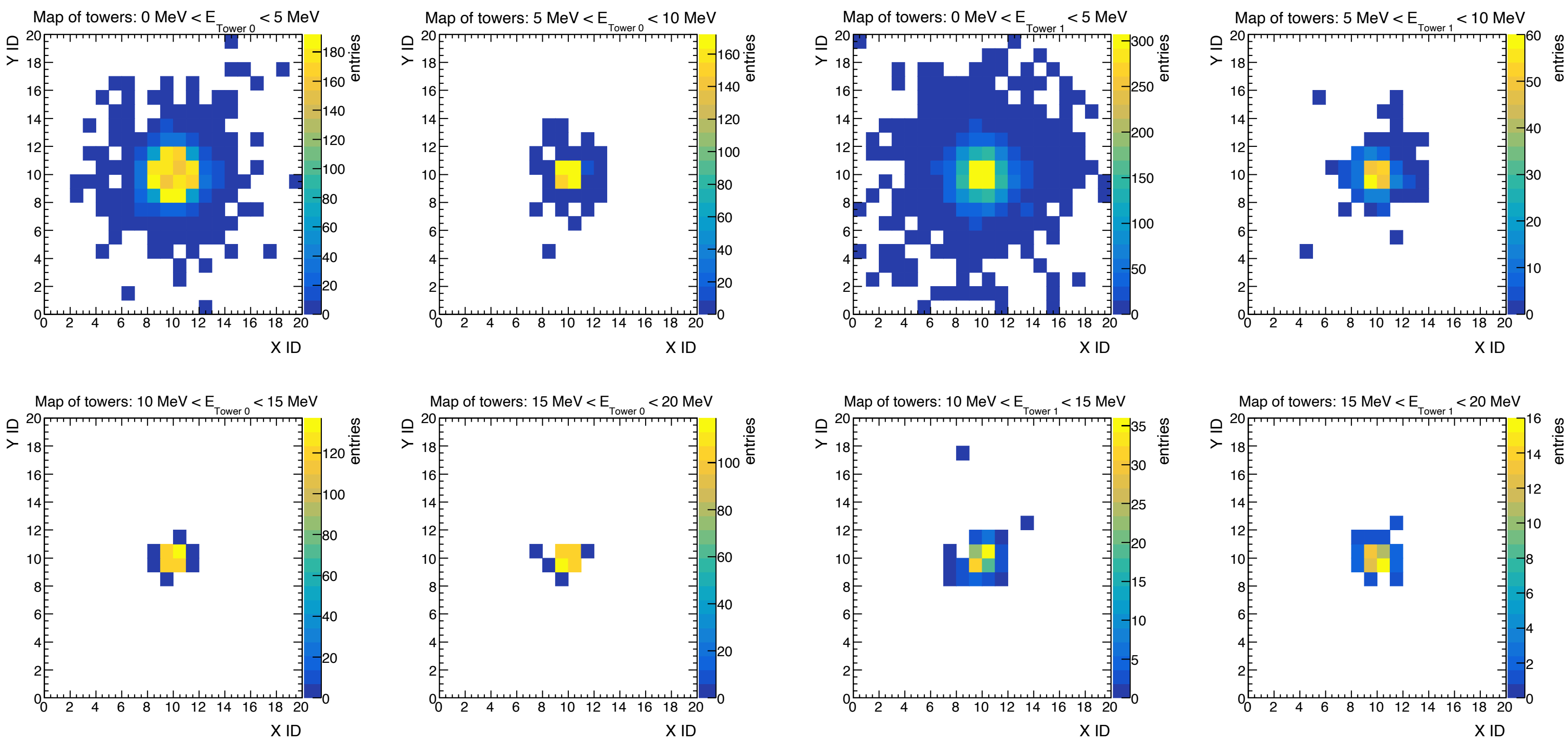
Tower Energy distribution (E = 100 MeV, 2 Crystals)



Crystal 0



Crystal 1

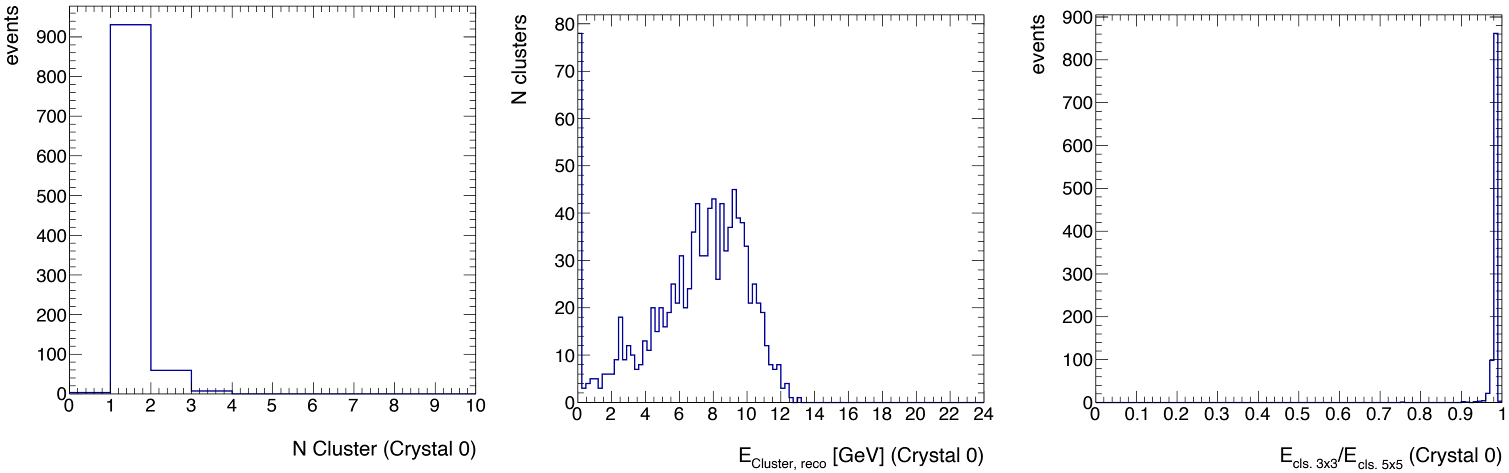


Towers with small energies are needed for energy reconstruction.

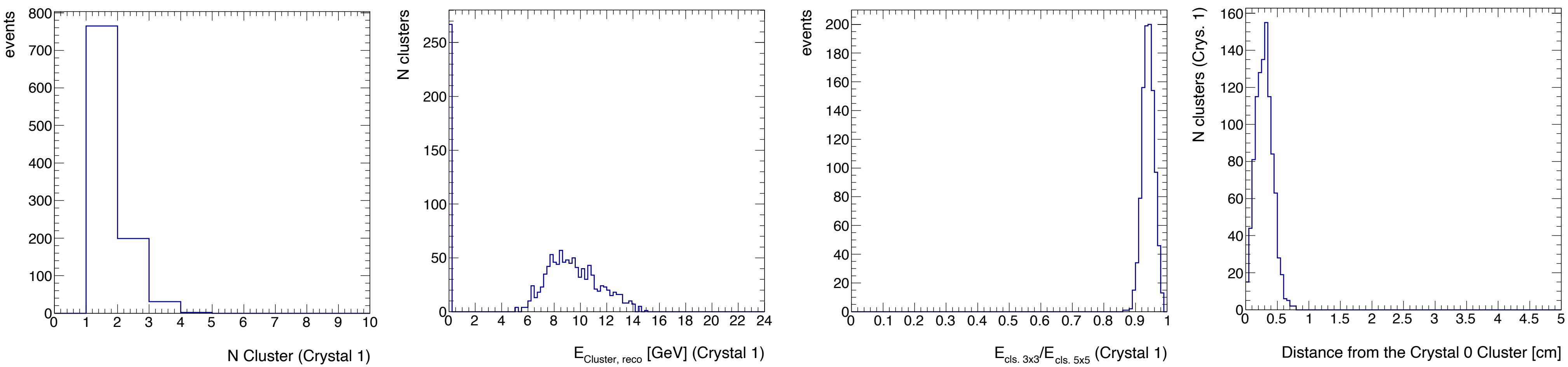
15 MeV requirement could be tight.

Cluster distribution (E=20GeV, 2 Crystals)

Crystal 0



Crystal 1

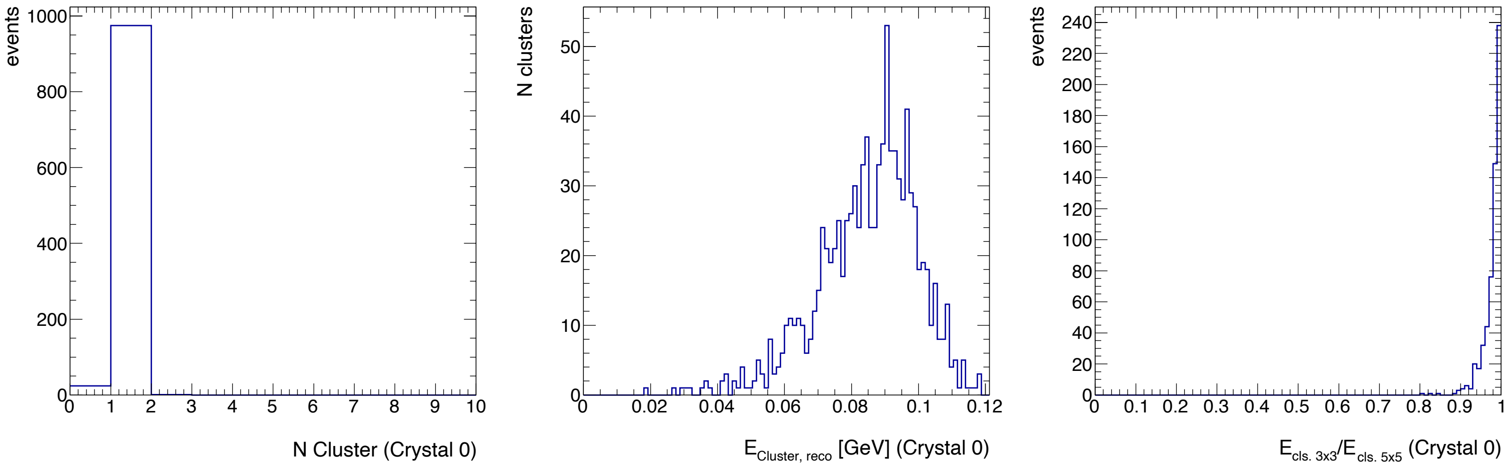


Number of clusters looks reasonable.

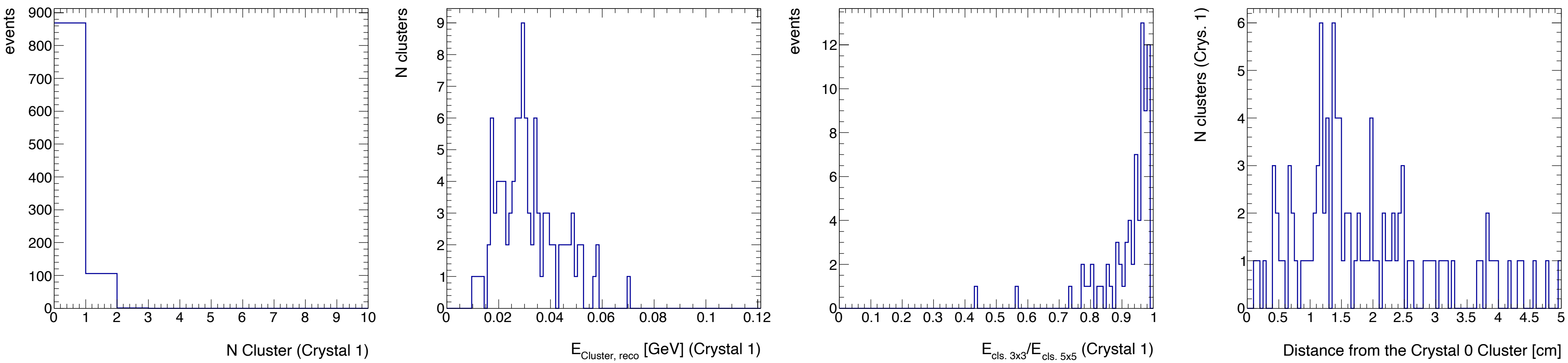
Use of 3x3 towers drops ~10% of energy on the 2nd Crystal layer (Crystal 1).

Cluster distribution (E=100MeV, 2 Crystals)

Crystal 0



Crystal 1



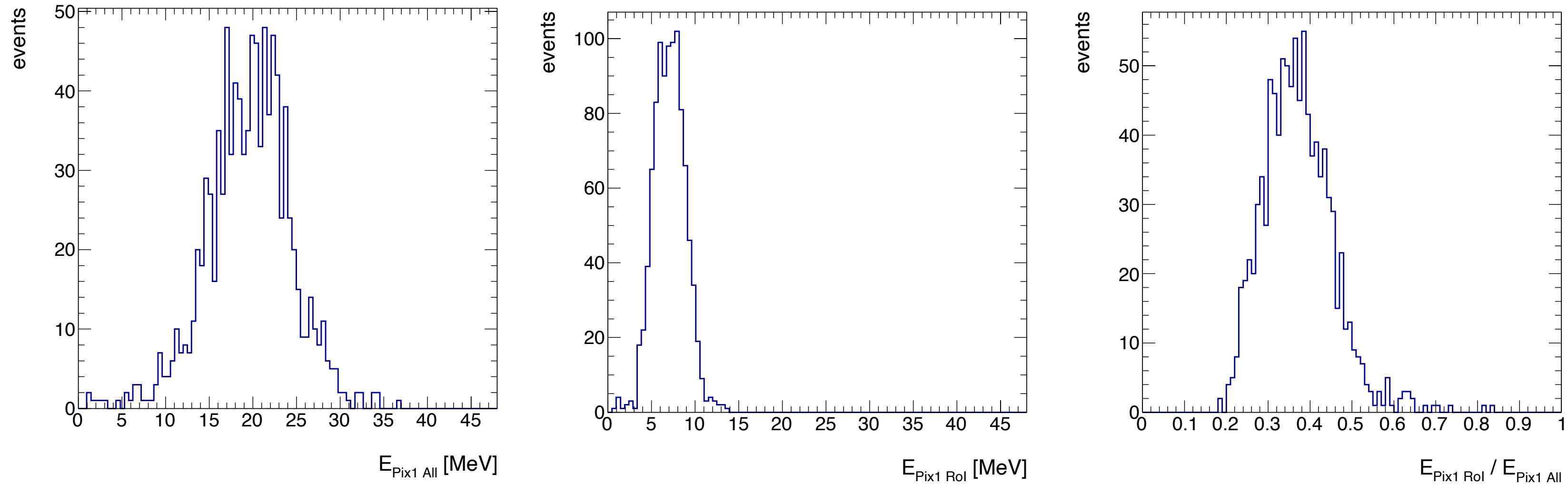
Cluster finding looks reasonable.

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

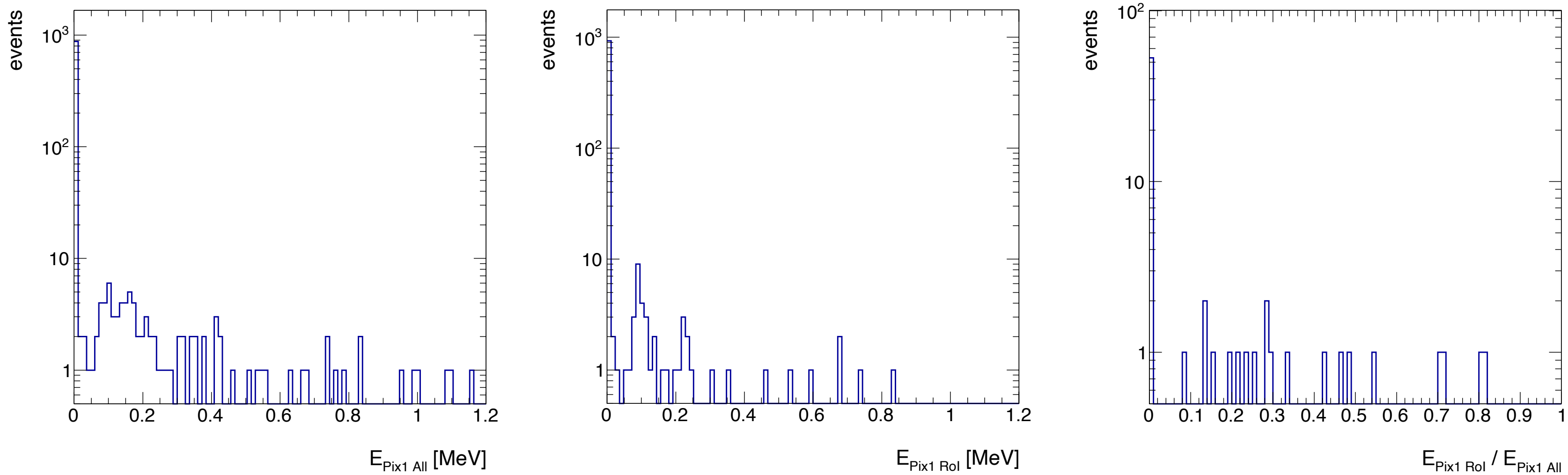
Energy on Pixel 1 layer

- 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



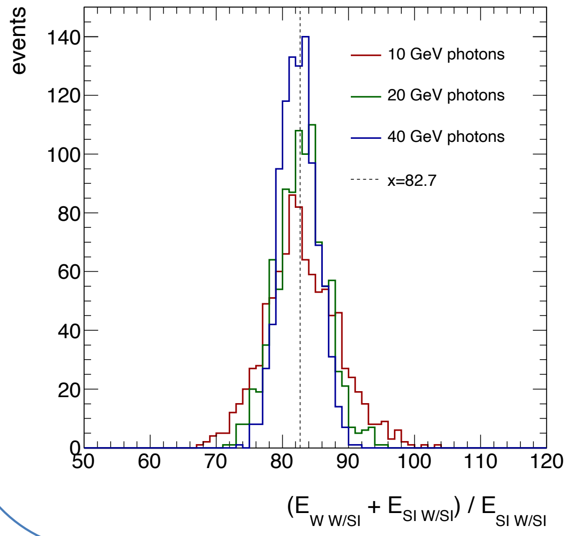
Energy in W/SI calorimeter

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

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.

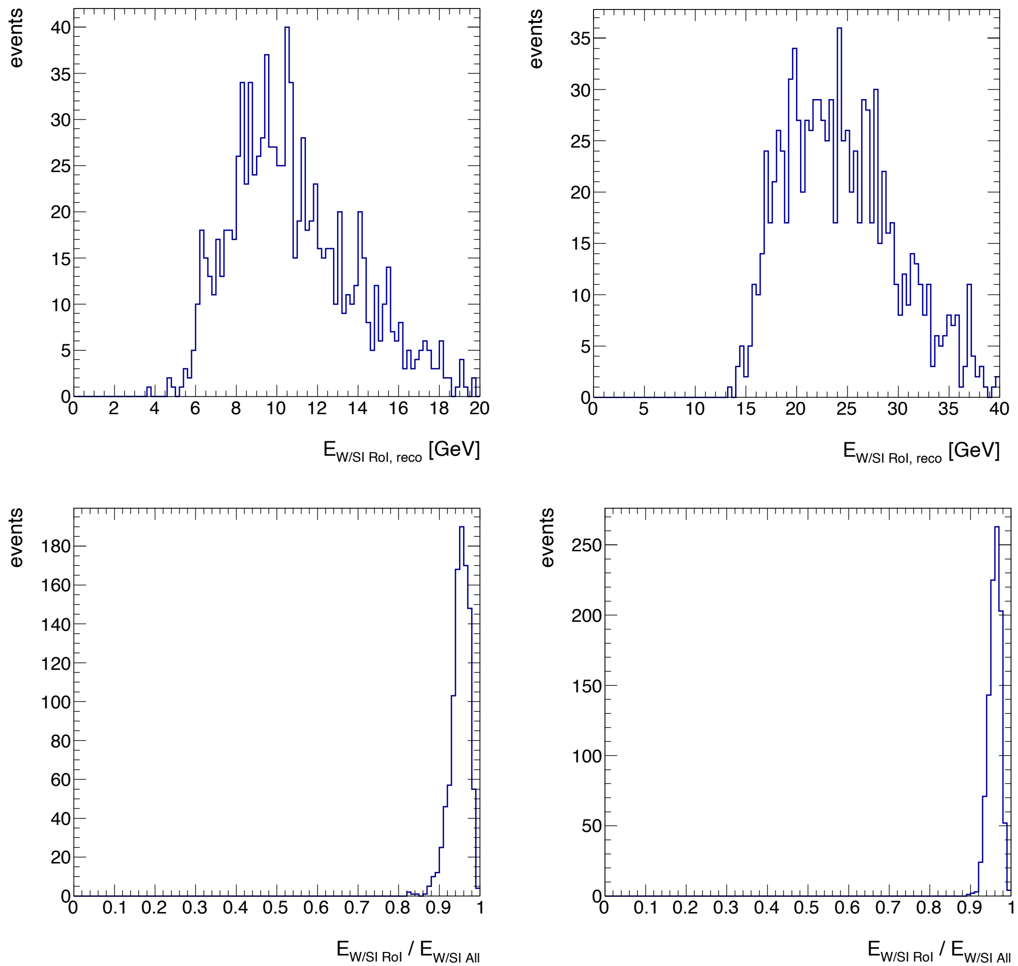


➔ SF = 82.7

Setting: 1 Crystal layer

E=20 GeV

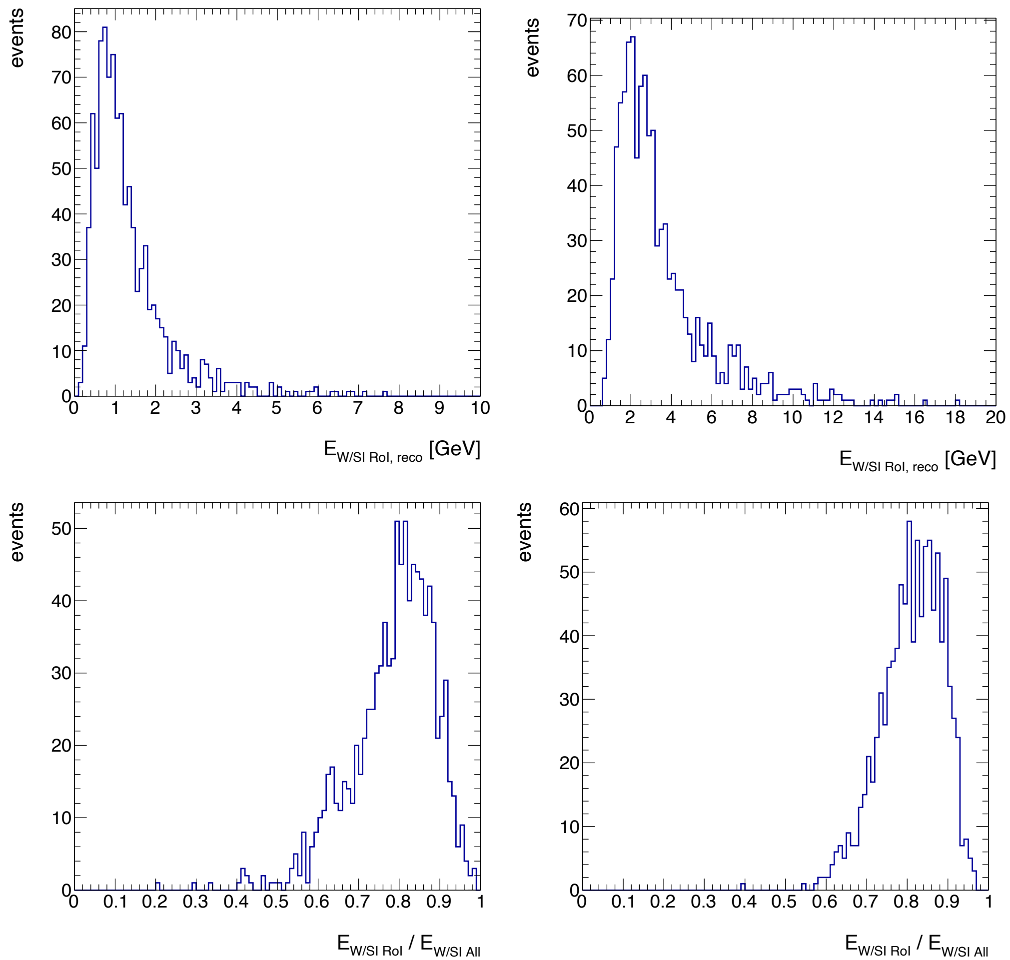
E=40 GeV



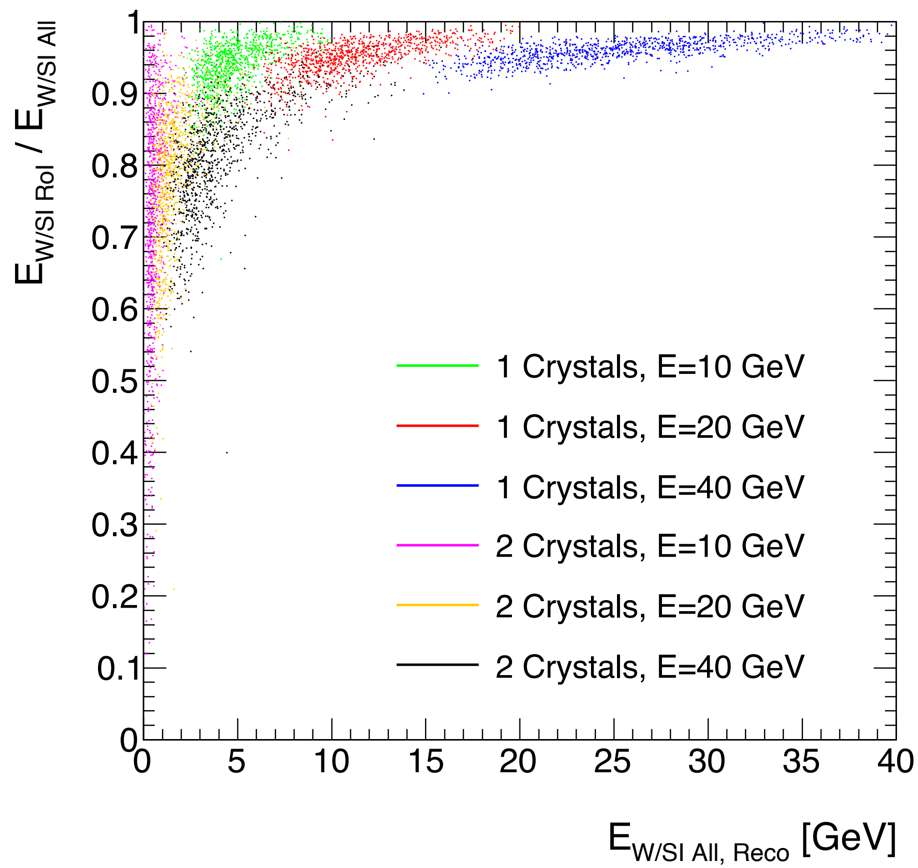
Energy in W/SI calorimeter

Setting: 2 Crystal layers

E=20 GeV E=40 GeV

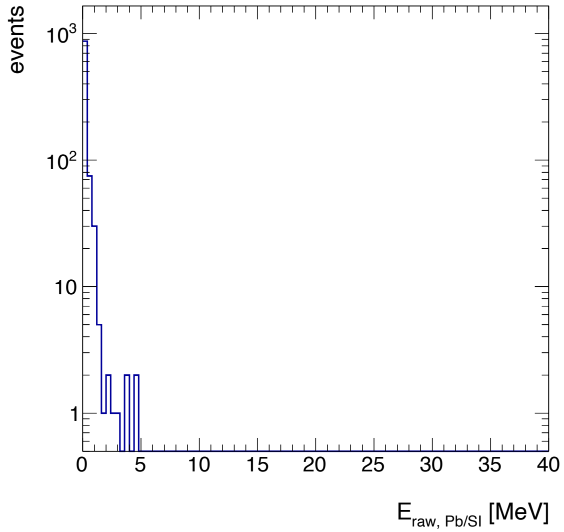


Correction for energy outside of RoI may be needed, but is not straightforward.



Energy in Pb/SI

1 Crystal layer E=40 GeV

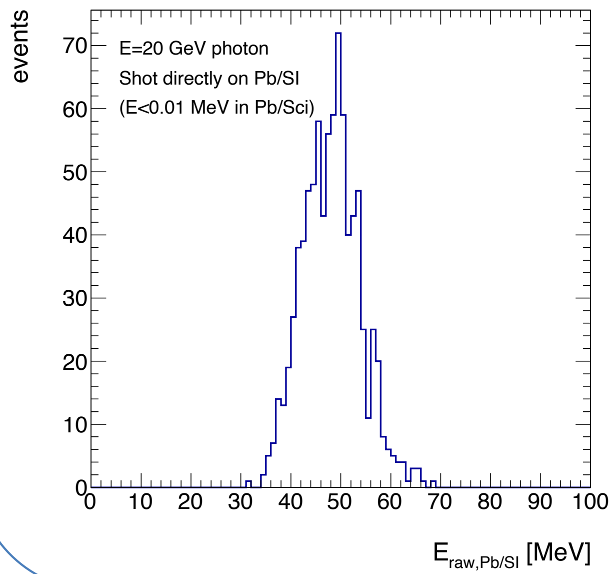


There is energy leakage to Pb/SI layers, but they are not significant for most of the events.

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

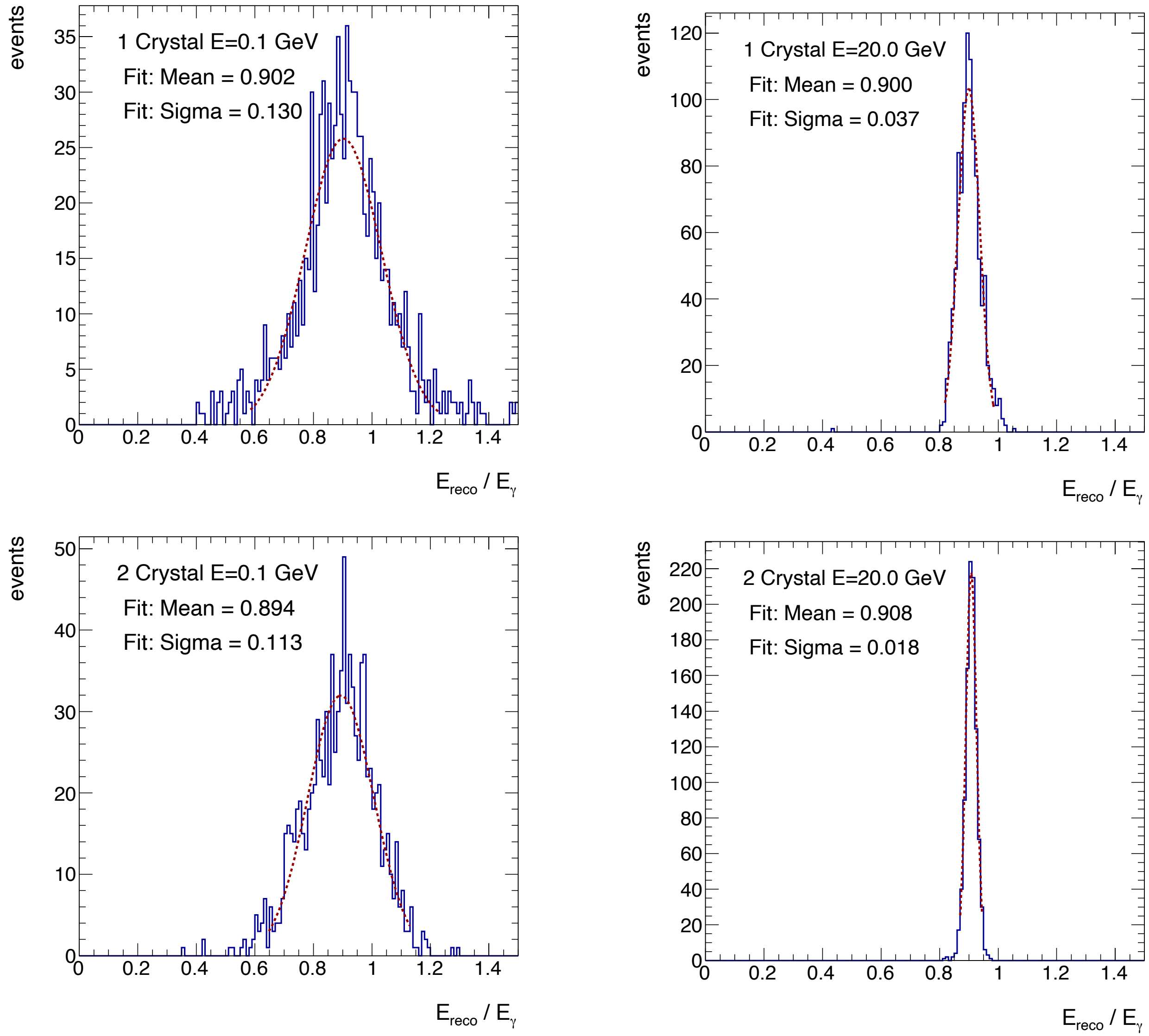
E_γ = 20 GeV <->

$E_{SI\ (Pb/SI)}$ ~ 50 MeV

➔ SF ~ 400

Reconstructed energy

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



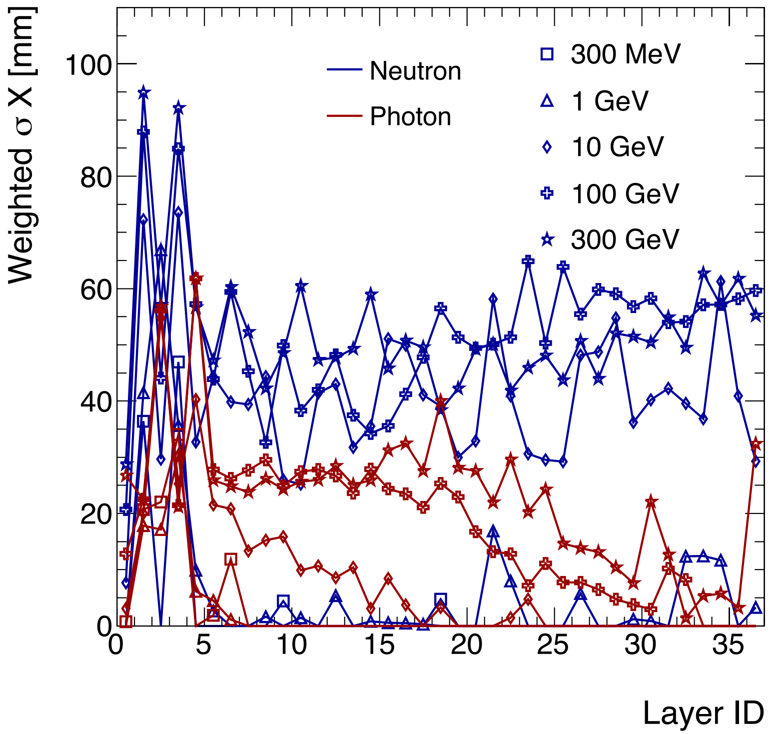
18/Aug. F/B mtg.

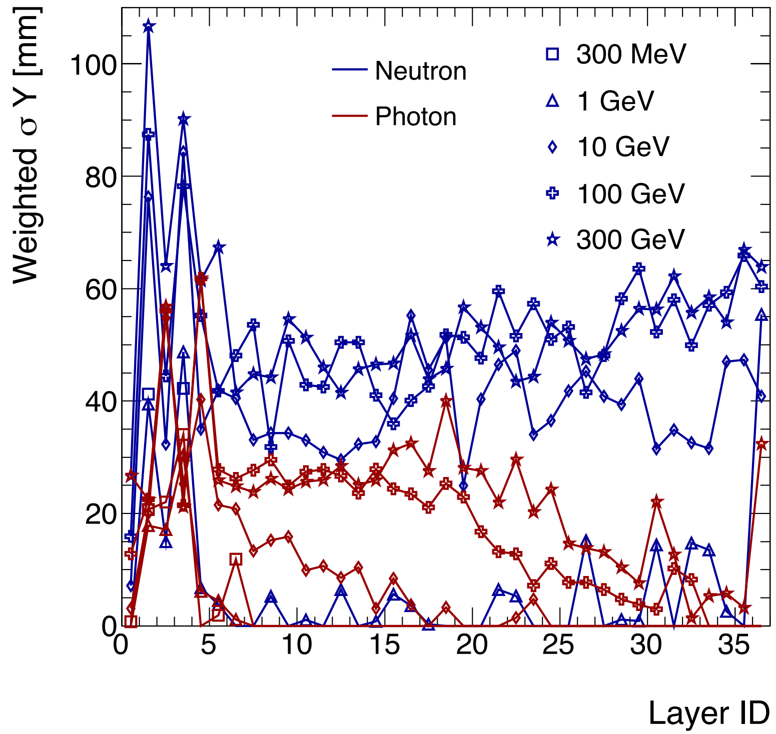
Transverse spread of energy deposits

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)