ZDC HC update

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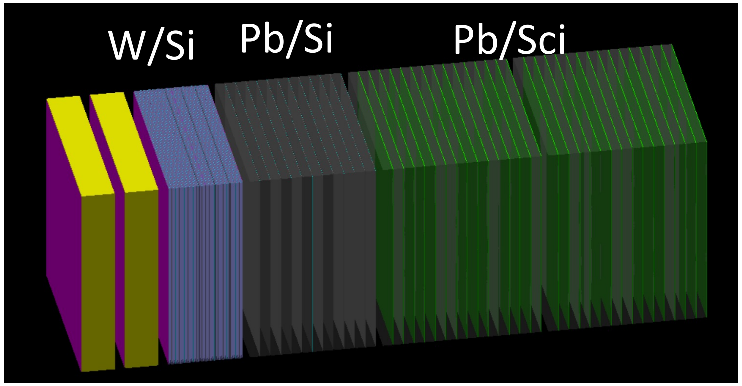
26/July/2021

Quick estimation of neutron reconstruction factors



The designed ZDC consists of (crystal and) 3 types of sampling calorimeters.

- Energy reconstruction for neutrons is not simple.

➔ Estimation of factors to convert
deposited energy [MeV] → reconstruction energy [GeV]

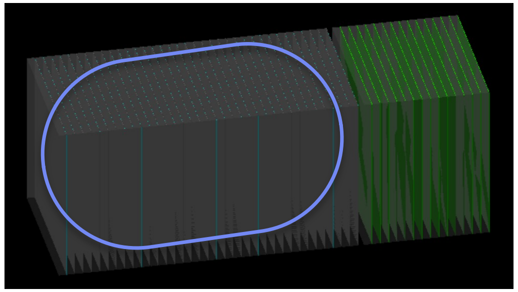
- Estimation is done by two methods:
  - Step-by-step estimation
  - Fit
- Check energy resolution and energy leakage.

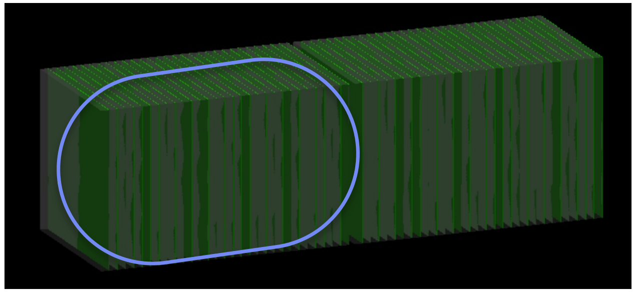
Note:
We are still at designing of the ZDC

- Aim is to obtain reasonable factors but not the best factors.
- This is to understand any feature of the designed ZDC.

First step for HC

- For each of Pb/Si and Pb/Sci parts, the number of layers is increased, and **neutrons** are shot using the **particle gun**.





- Events with no energy leak in Z direction are **considered as fully measured** in the detector part and analysed for estimation of the sampling fraction.
  - Ignoring the energy leak in x or y direction.

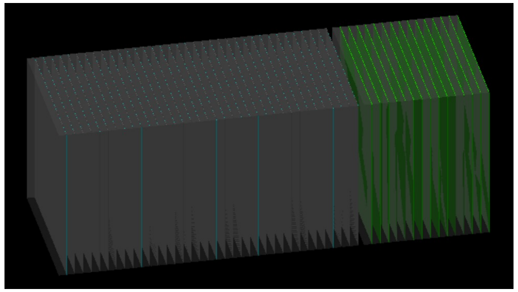
Neutron samples

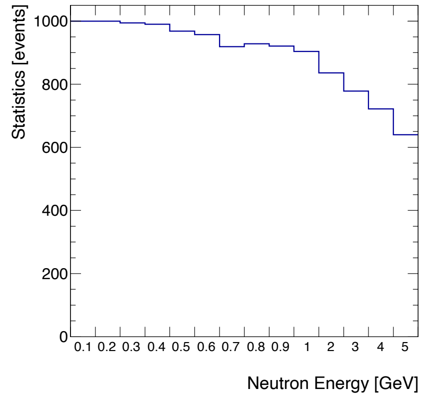
- 0.1 – 1 GeV with a step of 0.1 GeV
- 1 – 5 GeV with a step of 1 GeV

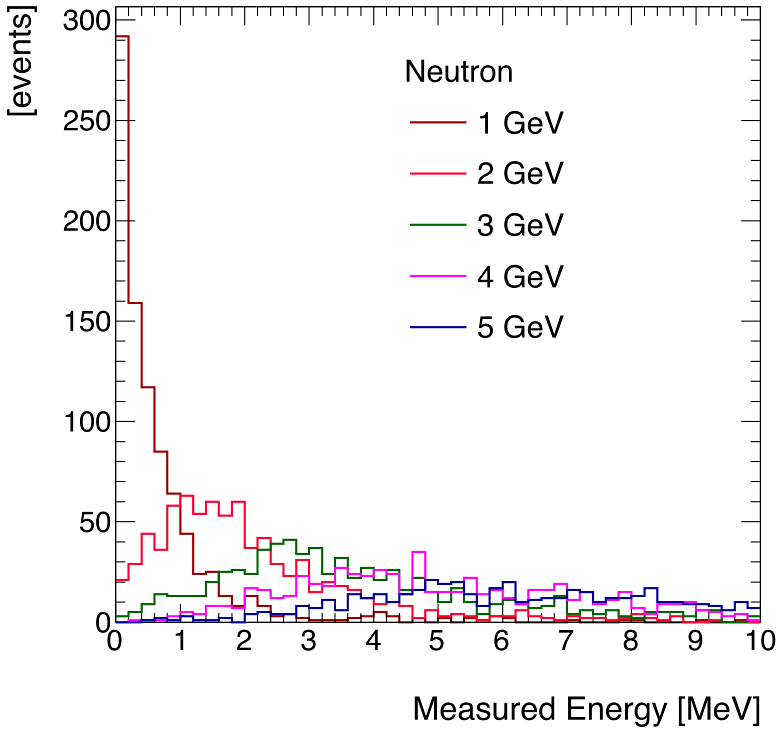
1000 events for each energy, shot on the center of the layer.

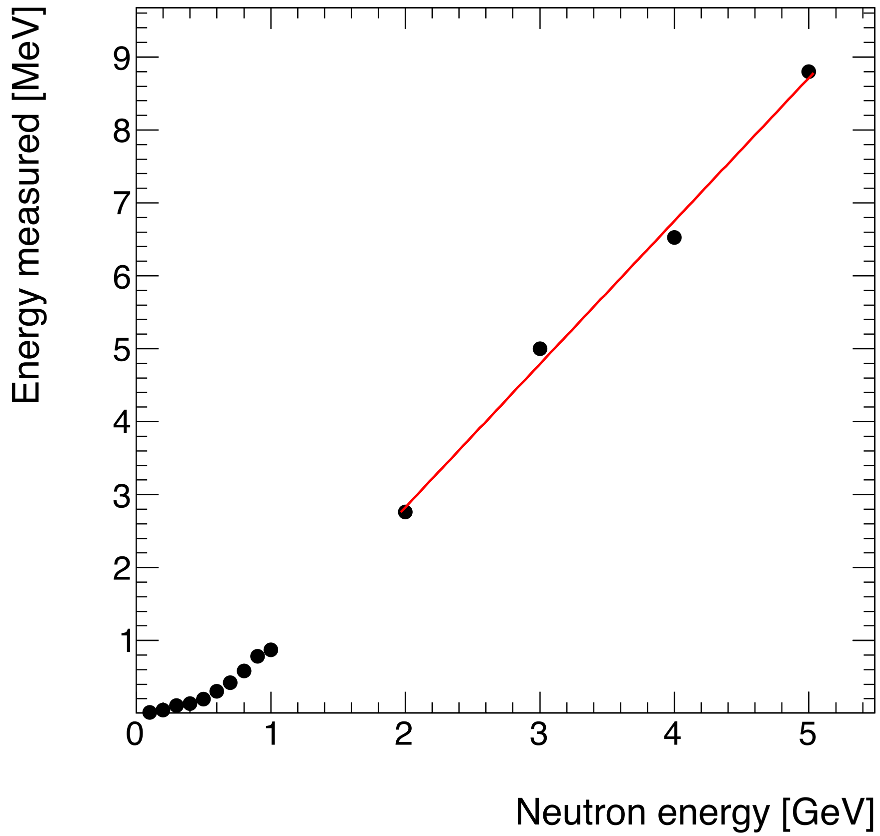
Pb/Si layers

12 layers (2 λ_I) → 36 layers (6 λ_I)





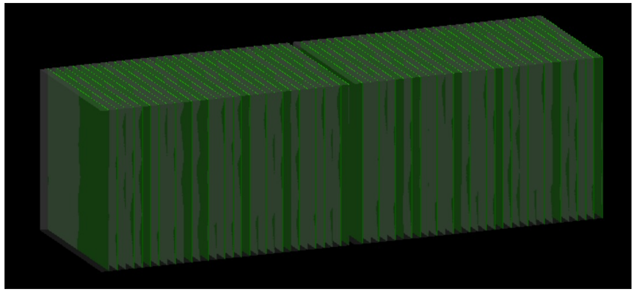


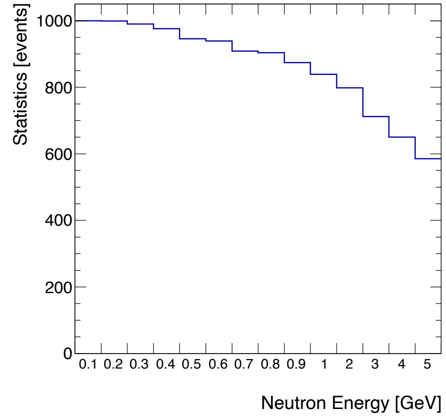


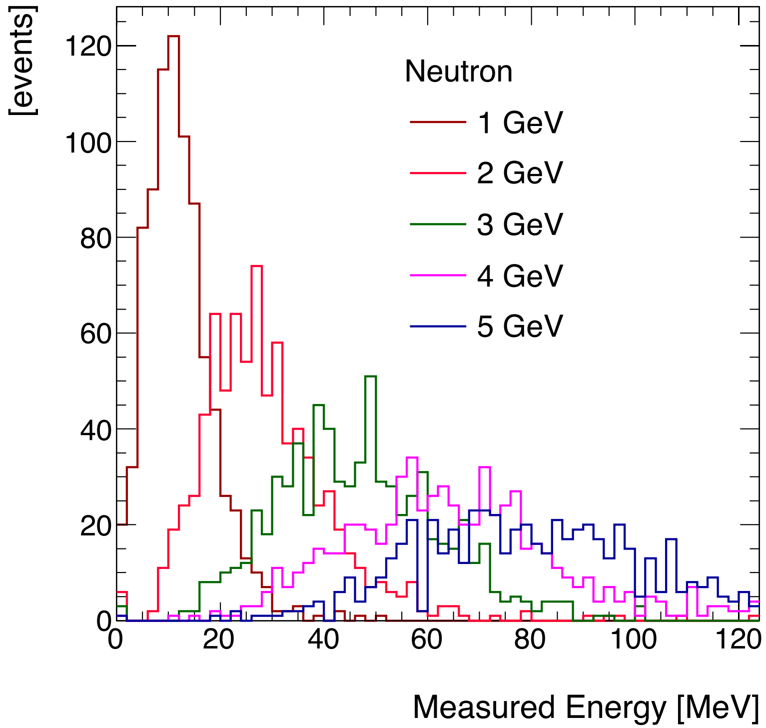
- Fit result: Meas [MeV] = 2*N[GeV] -1.1

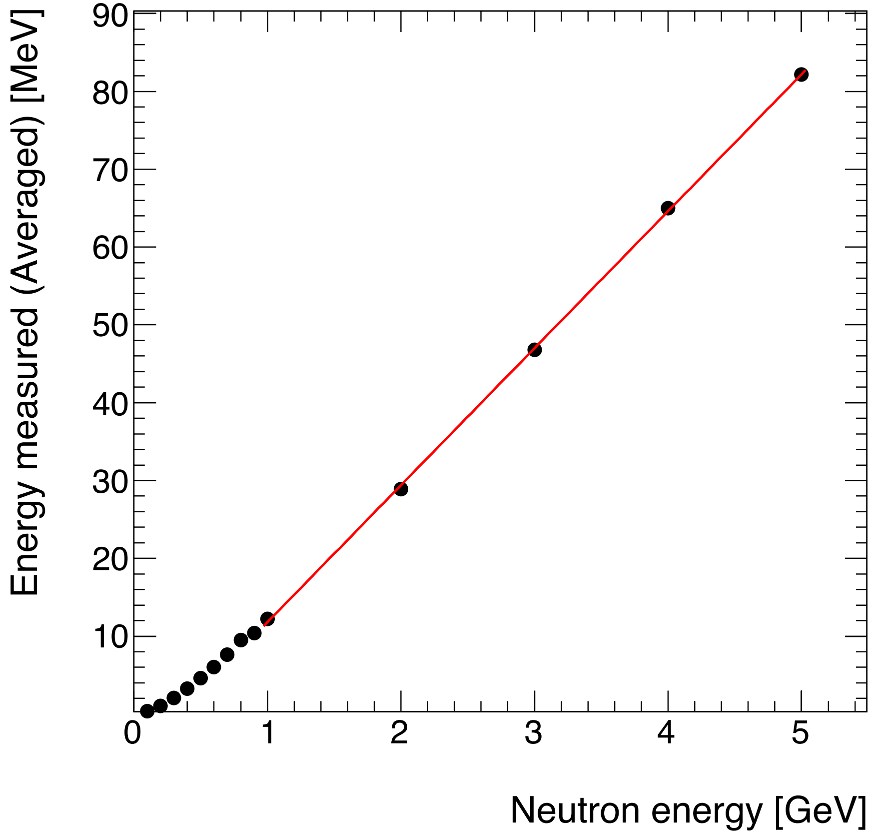
Pb/Sci layers

15 layers (2.5 λ_I) → 30 layers (5 λ_I)



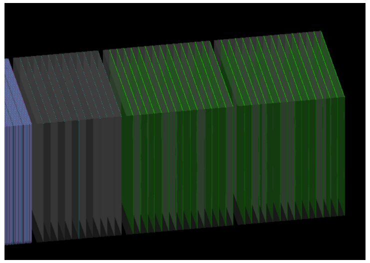






- Fit result: Meas [MeV] = 18*N[GeV] -5.8

Check of reconstruction

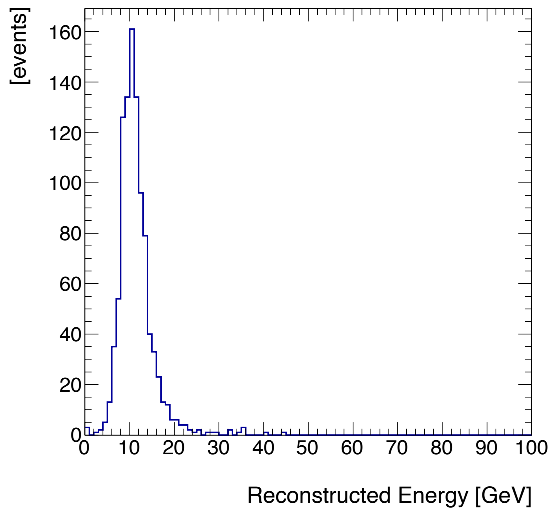


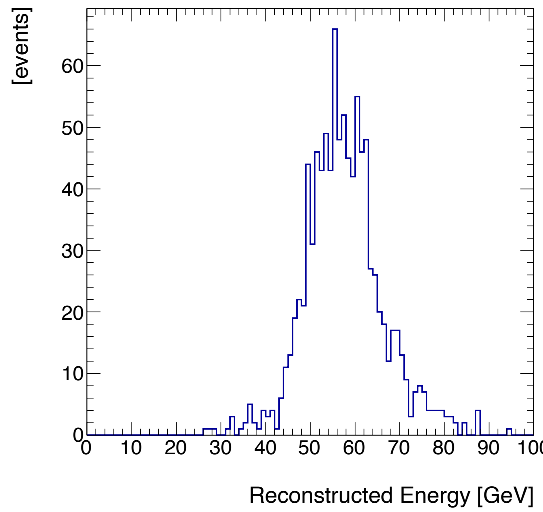
- Combine Pb/SI and Pb/Sci layers and see E=10 GeV and 50 GeV neutrons

- From fit result

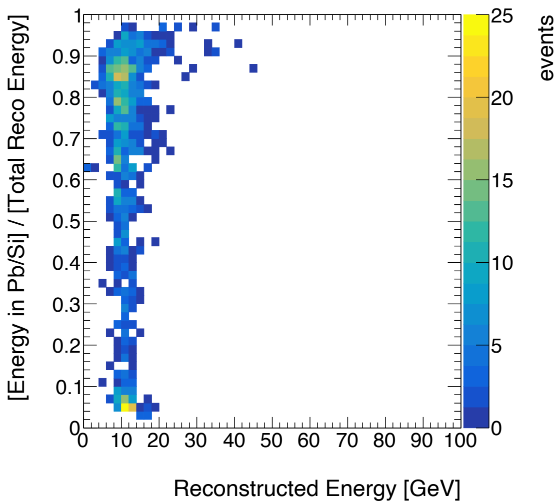
E_{SI} [GeV]= (Meas. [MeV] + 1.1)/2.

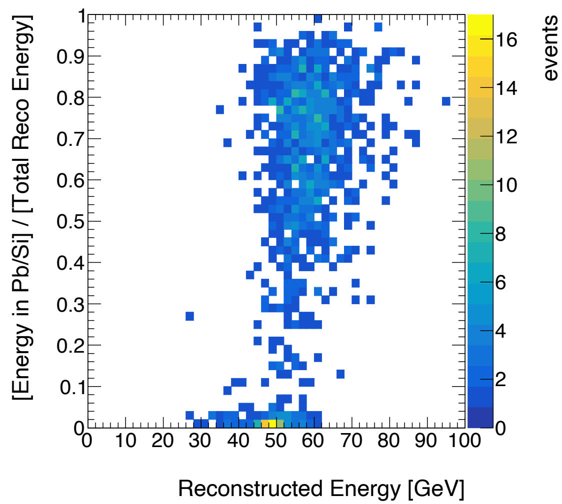
E_{sci} [GeV]= (Meas. [MeV]+5.8)/18





- Work for 10 GeV neutrons, but not good for 50 GeV neutrons.
- It seems energy in Pb/Si layers show shifts.
    - Events with all energy measured in Pb/Sci have peak at 50 GeV.



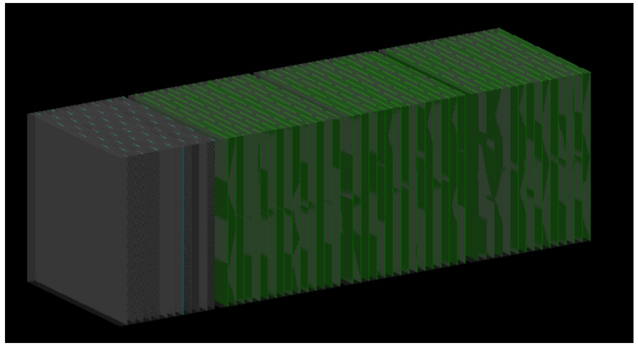


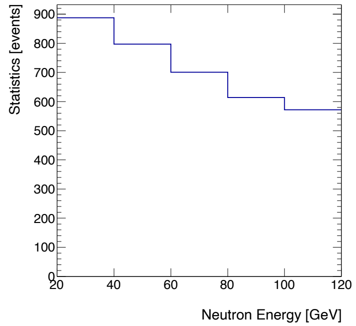
Revise Pb/Si reco with higher energy neutrons

Reconstruction of Pb/Sci seems to be OK.

→ Revise the Pb/SI energy reconstruction function.

- Added another box of Pb/Sci layers.
- Shot 20-100 GeV neutrons, 1000 events for each.
- Analysed events with no energy deposits at the very last 5 scintillator layers.





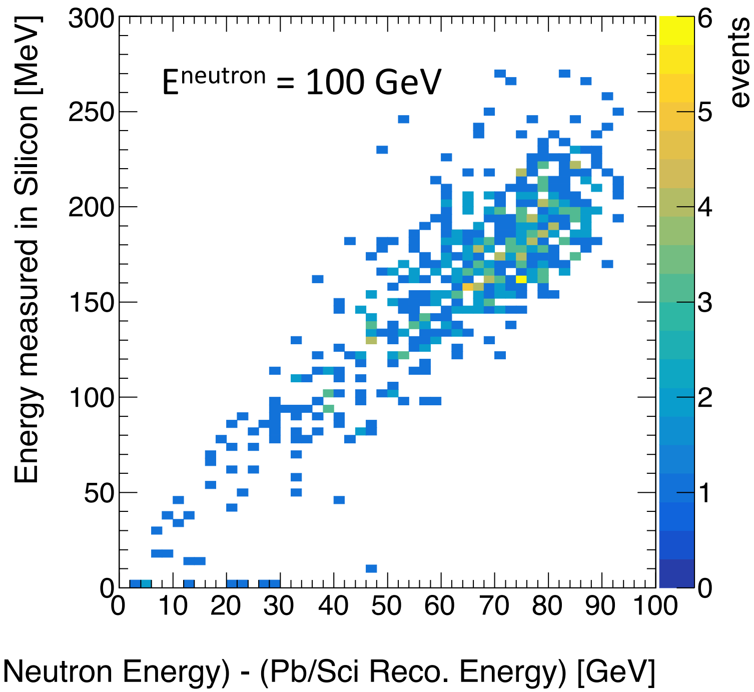
- Energy in Pb/Sci is reconstructed by:

  E_{sci}^{Reco} [GeV]= (Meas. [MeV]+5.8)/18

  (determined from low energy neutrons.)

Good correlation between

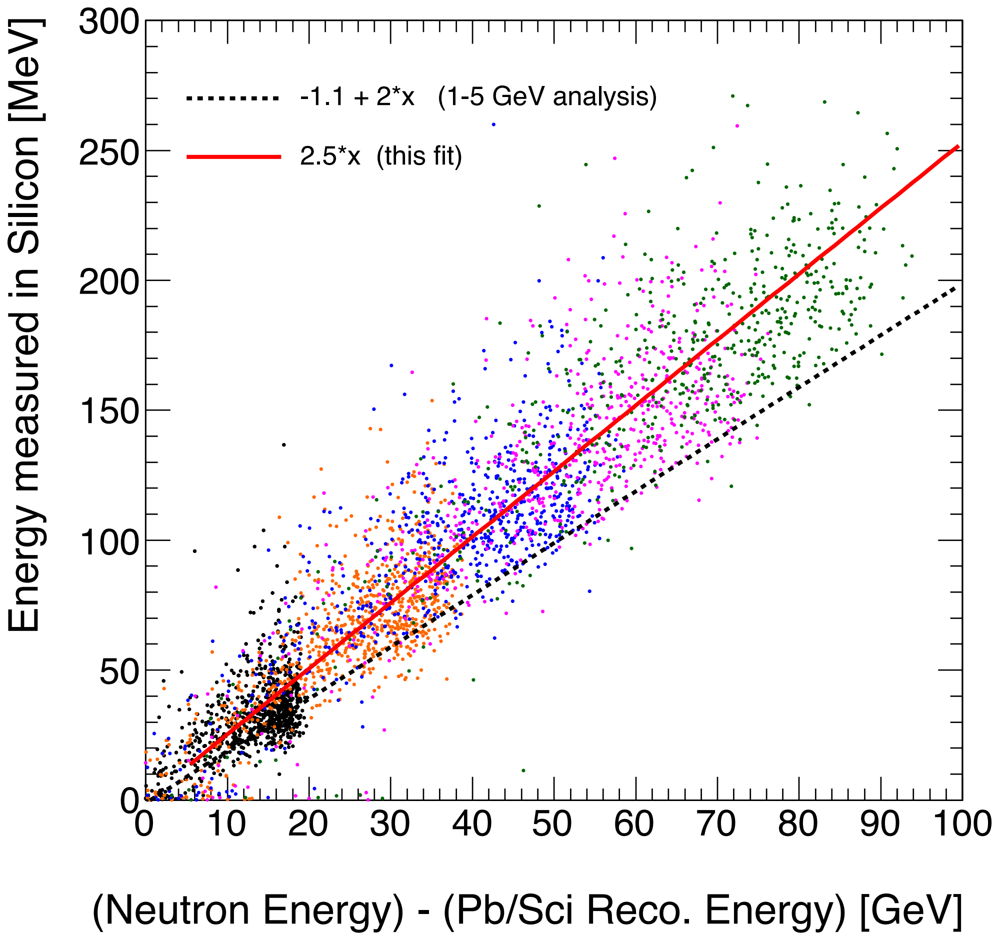
- the energy deposited in Silicon layers
- $[E^{neutron} - E_{sci}^{Reco}]$



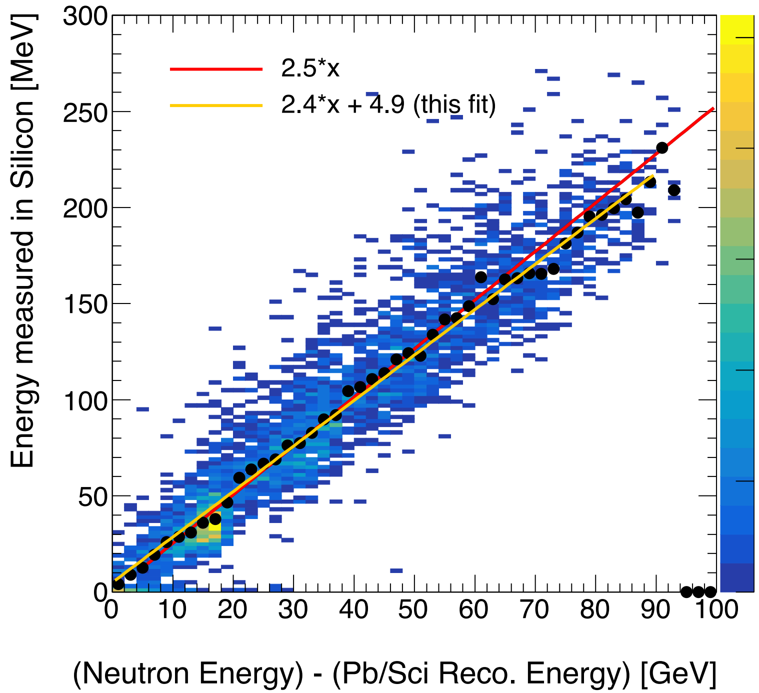
Revising Pb/Si layers

- Fit with a limitation of offset <=0
  → SI [MeV] = 2.5*E [GeV]

Samples:
E^N = 20 GeV, 40 GeV, 60 GeV, 80 GeV, 100 GeV



Another fit with allowing positive offset
→ SI [MeV] = 2.4* E [GeV] + 4.9



● : mean in a limited range around a peak in each x bin.

— : fit on them.

Reconstructed Energy (Hadron Calo. only)

- Using:

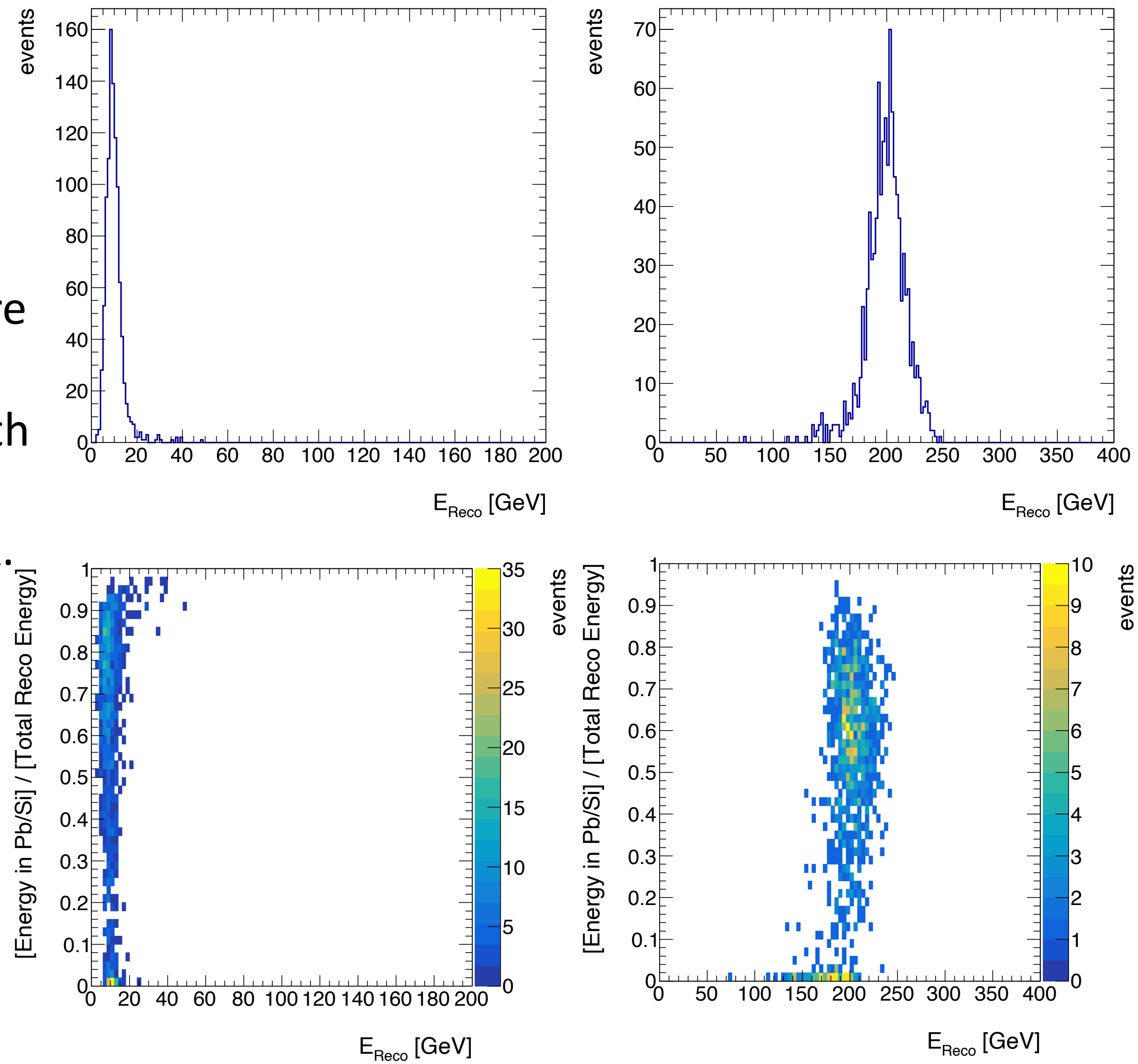
E_{SI} [GeV]= Meas. [MeV] /2.5

E_{sci} [GeV]= (Meas. [MeV]+5.8)/18

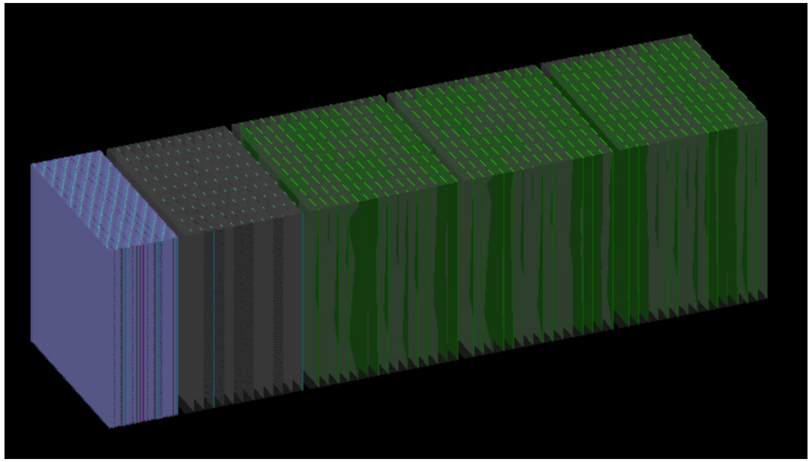
- 10 GeV and 200 GeV samples are not in the fit.
    - Sample includes events with energy in the last 5 layers.
      i.e. may have energy leak.

- Good for 200 GeV neutrons.
  Not bad for 10 GeV neutrons.

Next step:
Add EM calorimeters



Add W/Si layers

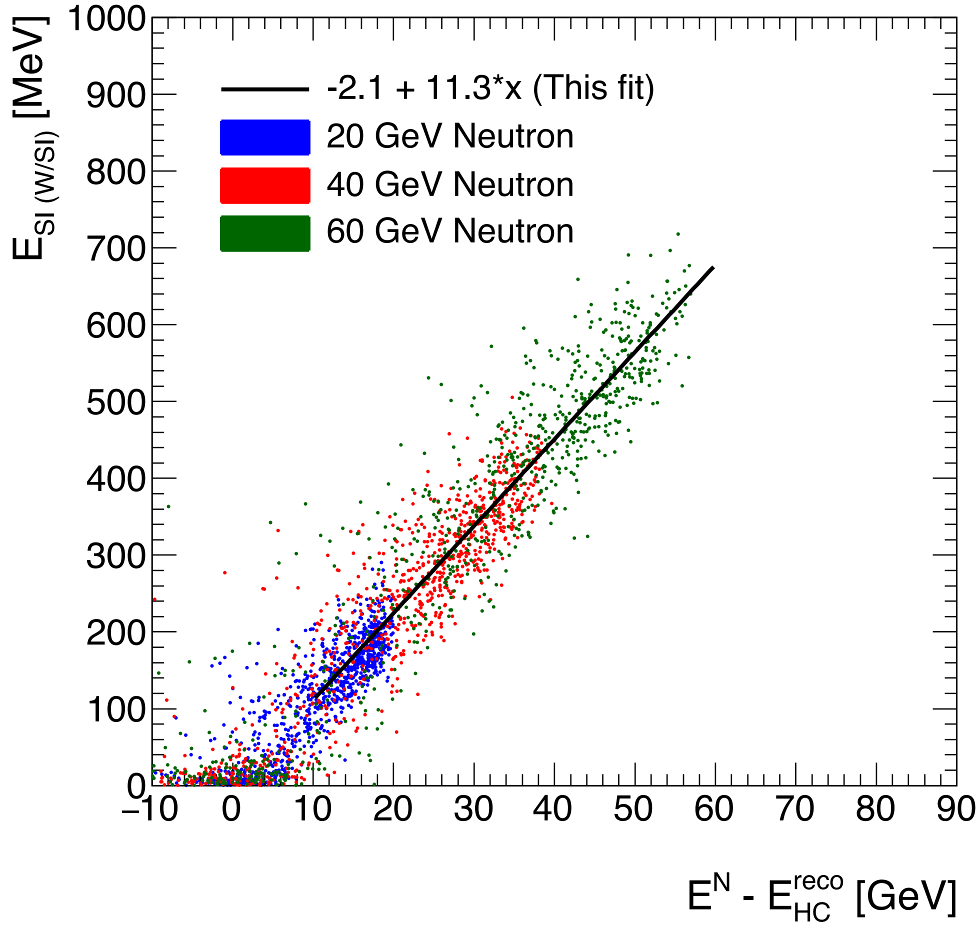


- Study W/Si layers using a similar method.
  - W/SI layers + Hadron calorimeter (HC), with additional Pb/Sci box.
  - Shot 20-60 GeV neutrons, 1000 events for each.
  - Analysed events with no energy deposits at the very last 5 Sci. layers.
  - Comparison of
    - Energy in Si layers of W/SI
    - Energy in HC

    → Shows linear correlation.

  Fit gives

  SI [MeV] = -2.1 + 11.3 *E [GeV]



Reconstructed Energy (W/SI + HC)

- Using:

$E_{W/SI}$ [GeV]= (Meas. [MeV]+2.1) /11.3

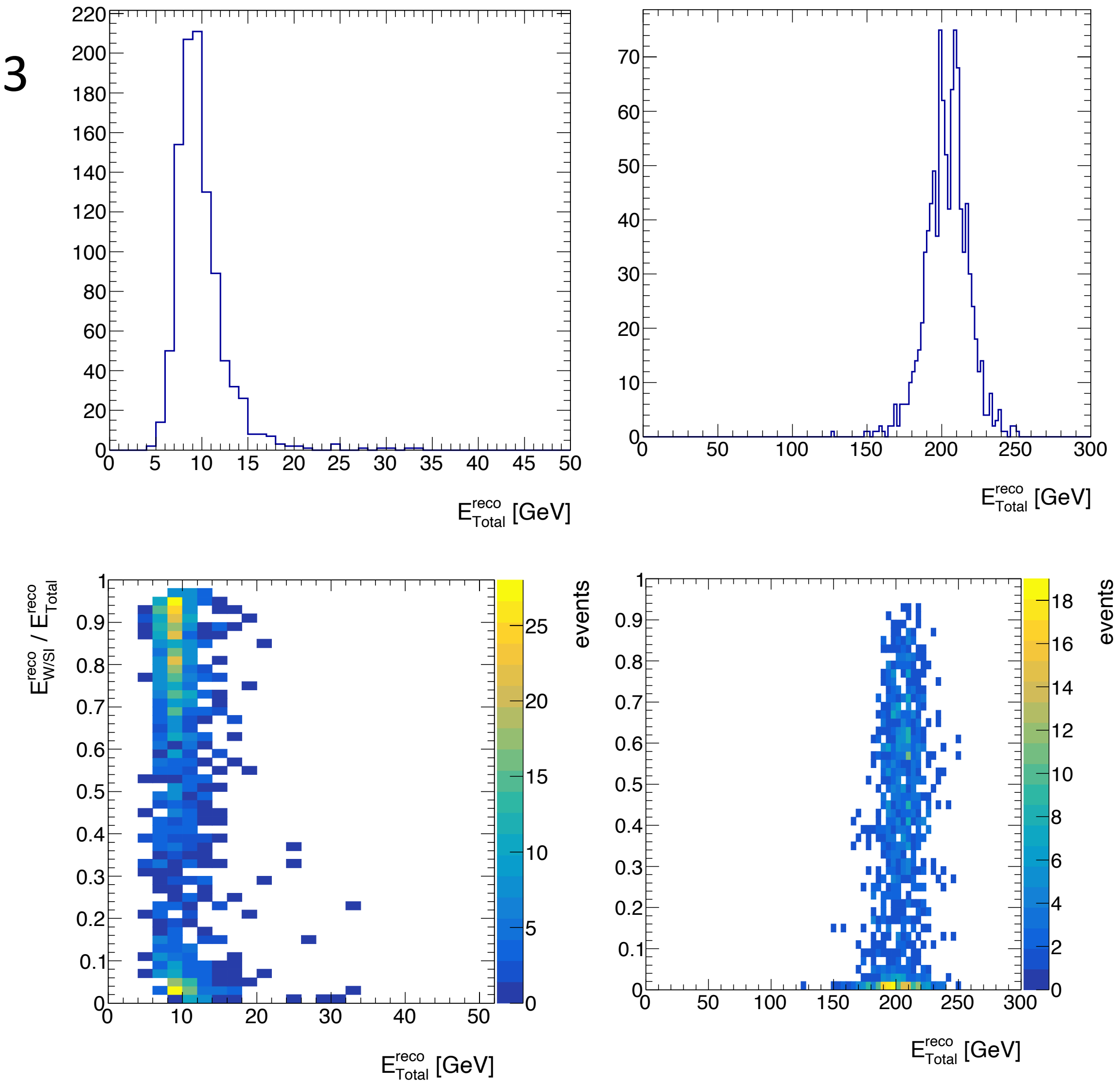
$E_{Pb/SI}$ [GeV]= Meas. [MeV] /2.5

E_{sci} [GeV]= (Meas. [MeV]+5.8)/18

- 10 GeV and 200 GeV samples are not in the fit.
  - Sample includes events with energy in the last 5 layers.

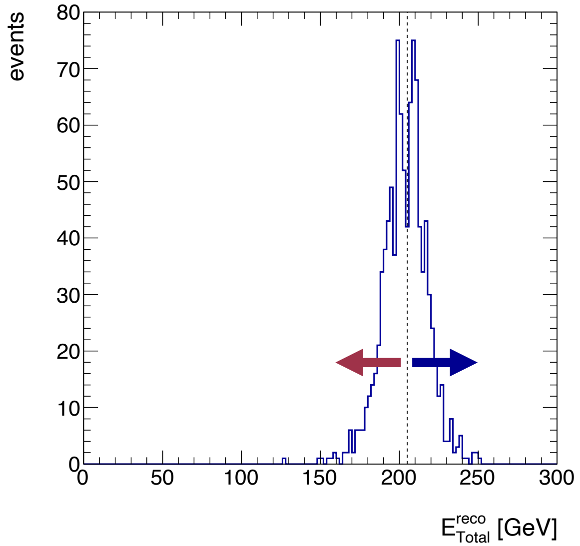
    i.e. may have energy leak.

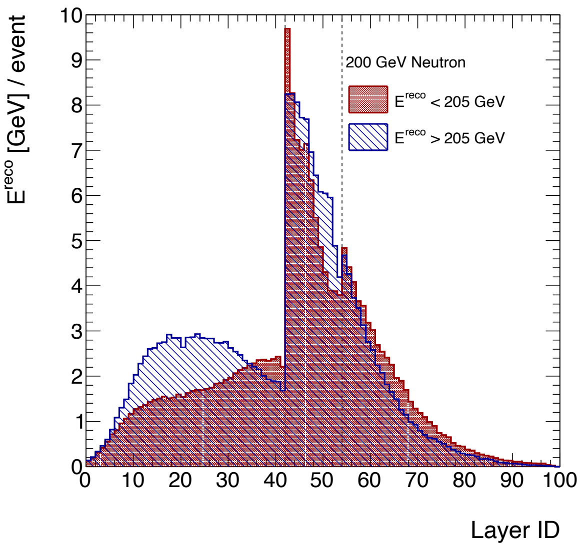
- Bias in 10 GeV sample.
- Double peak is seen in the 200 GeV sample.



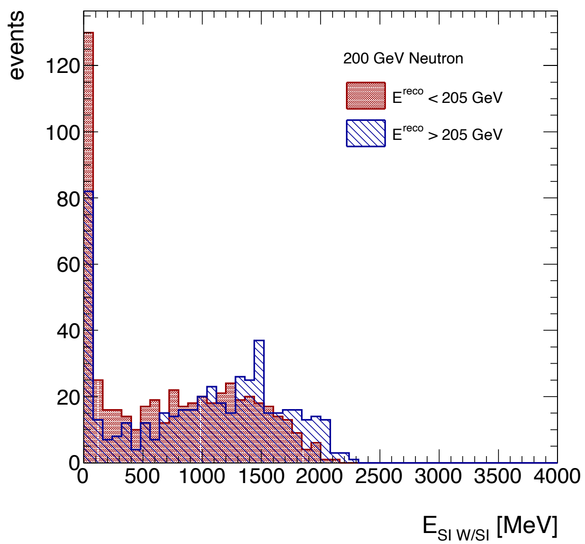
Check of the 200 GeV sample

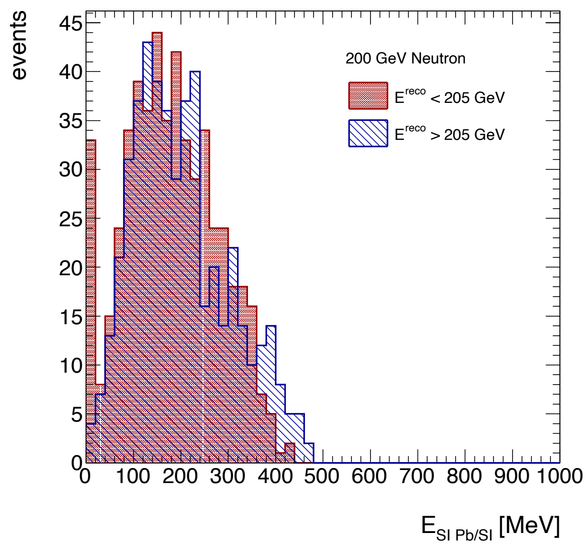
- Peaks seems to come from different shower development

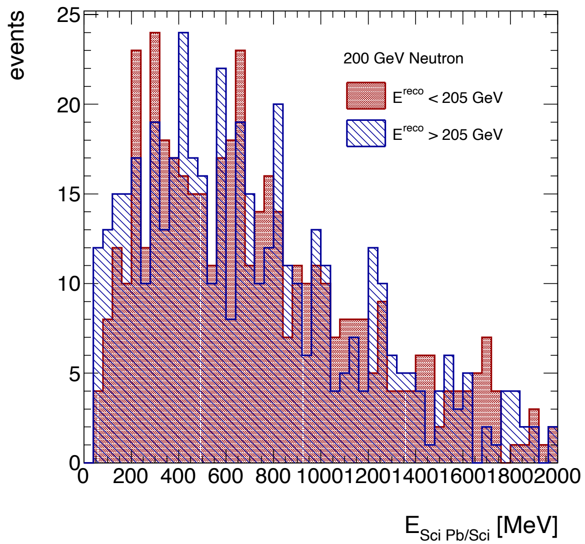




More energy in W/SI and Pb/SI seems to give higher total reconstructed energy.

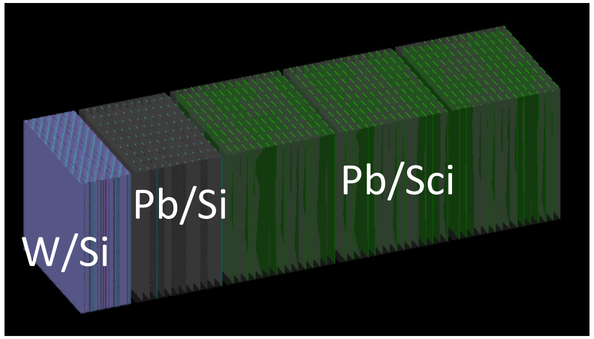






estimation by fit

Parameters from fit

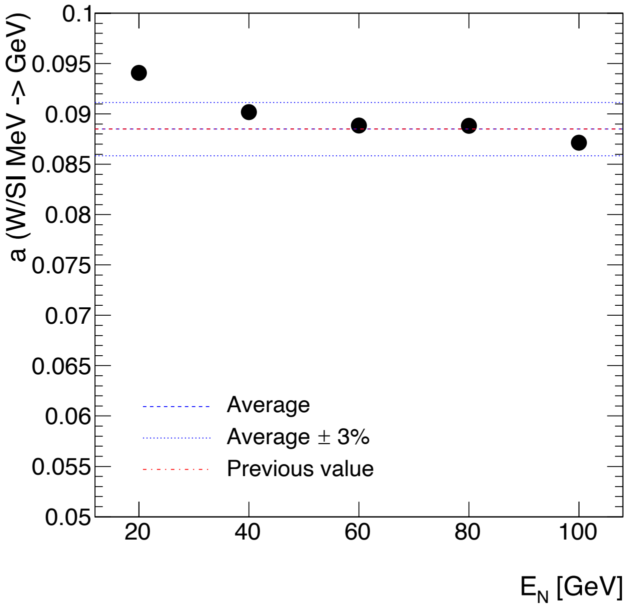


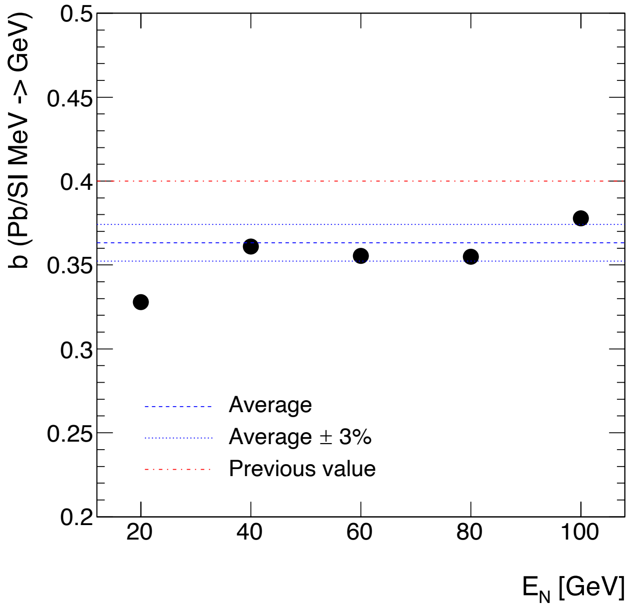
- The energy response in each detector looks quite linear.
- Extract parameters from fits:

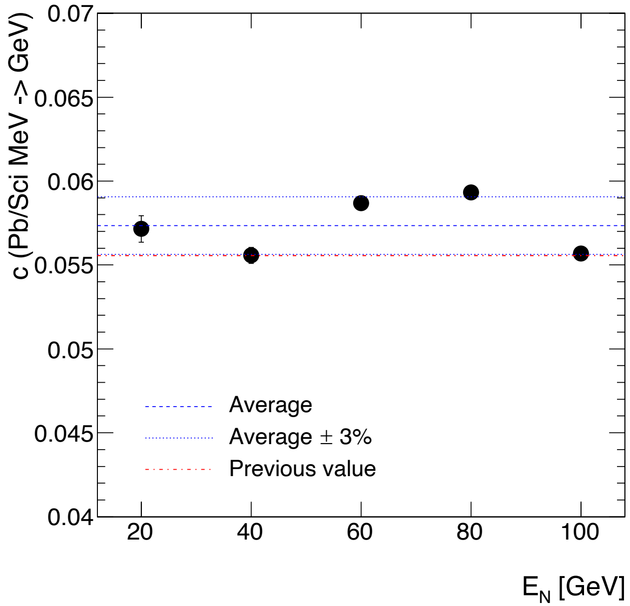
$$a \cdot E_{\mathrm{SI\ (W/SI)}} + b \cdot E_{\mathrm{SI\ (Pb/SI)}} + c \cdot E_{\mathrm{Sci}} = E_{\mathrm{N}}$$ (E_N = Neutron energy)

  Fit is done for each energy sample (E_N= 20, 40, 60, 80, 100 GeV)

- Events analysed have no energy deposits in the last 5 layers.





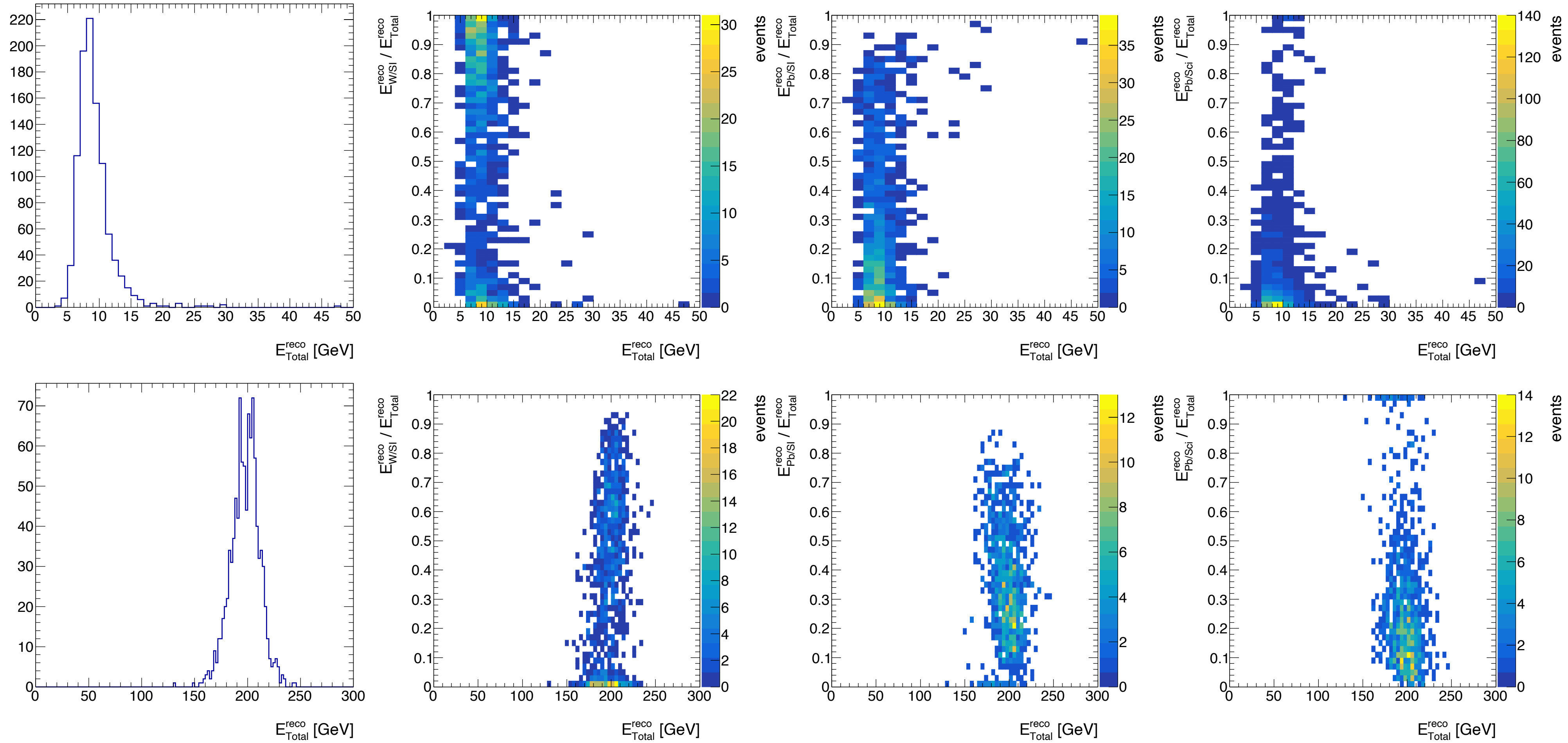


- Five fits give more-or-less consistent results.
- Parameter for Pb/SI has large correction from the previous estimation.
- Parameters for silicon shows a small sample-energy dependence.

estimation by fit

Reconstructed Energy

- Energy reconstruction for 10 GeV and 200 GeV neutrons, using the average value from the fits.
    - Still see the double peak, with bias in silicon layers

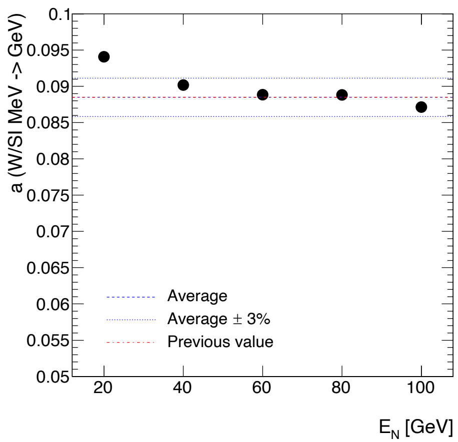


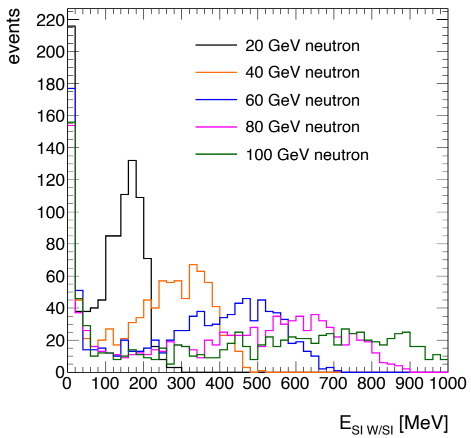
estimation by fit

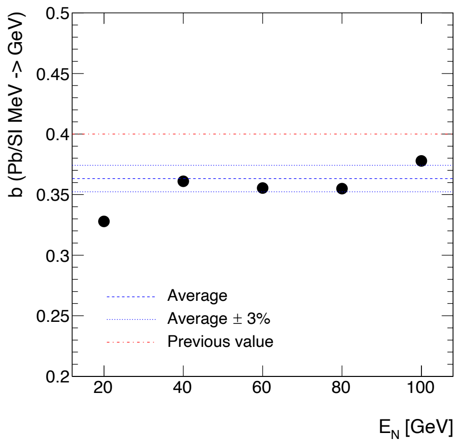
Energy dependent factors

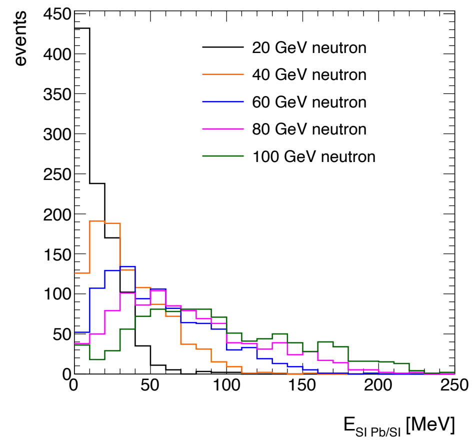
- Introduce energy dependence to the factors for silicon layers.
  - W/SI: Average * (1-0.008*(E_{SI}-500)/1000)
  - Pb/SI: Average * (1+0.04*(E_{SI}-50)/100)

  Made-up slopes by eye. Optimisation is needed in future.



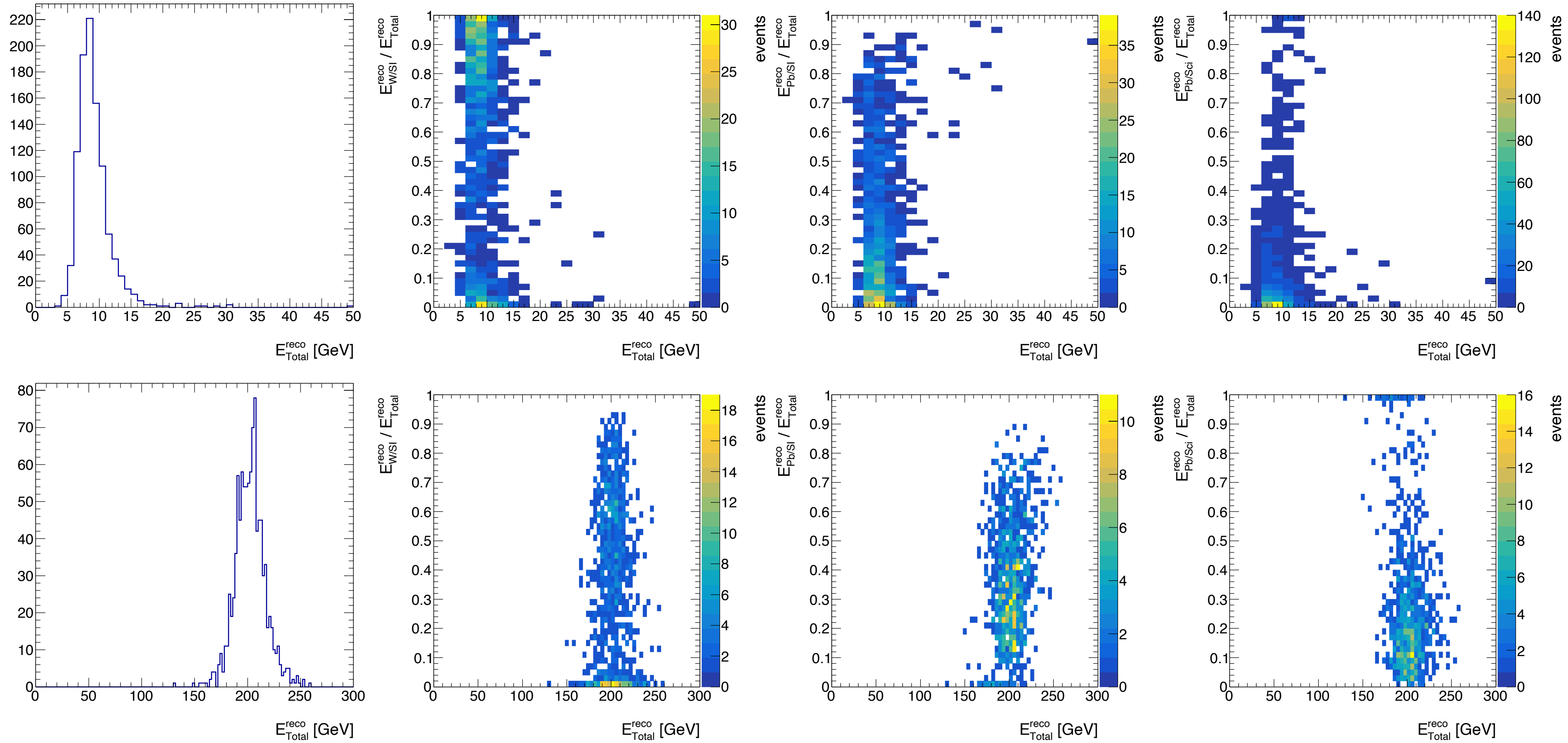






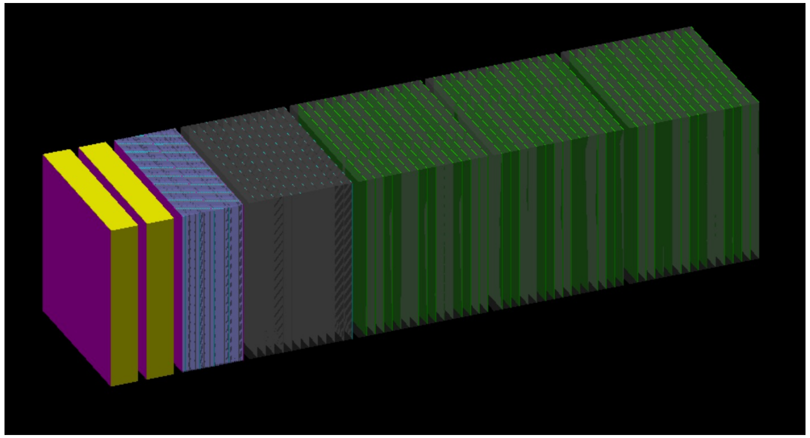
Energy dependent factors

- With energy dependence, reconstruction of 200 GeV neutron show less bias from silicon layers.

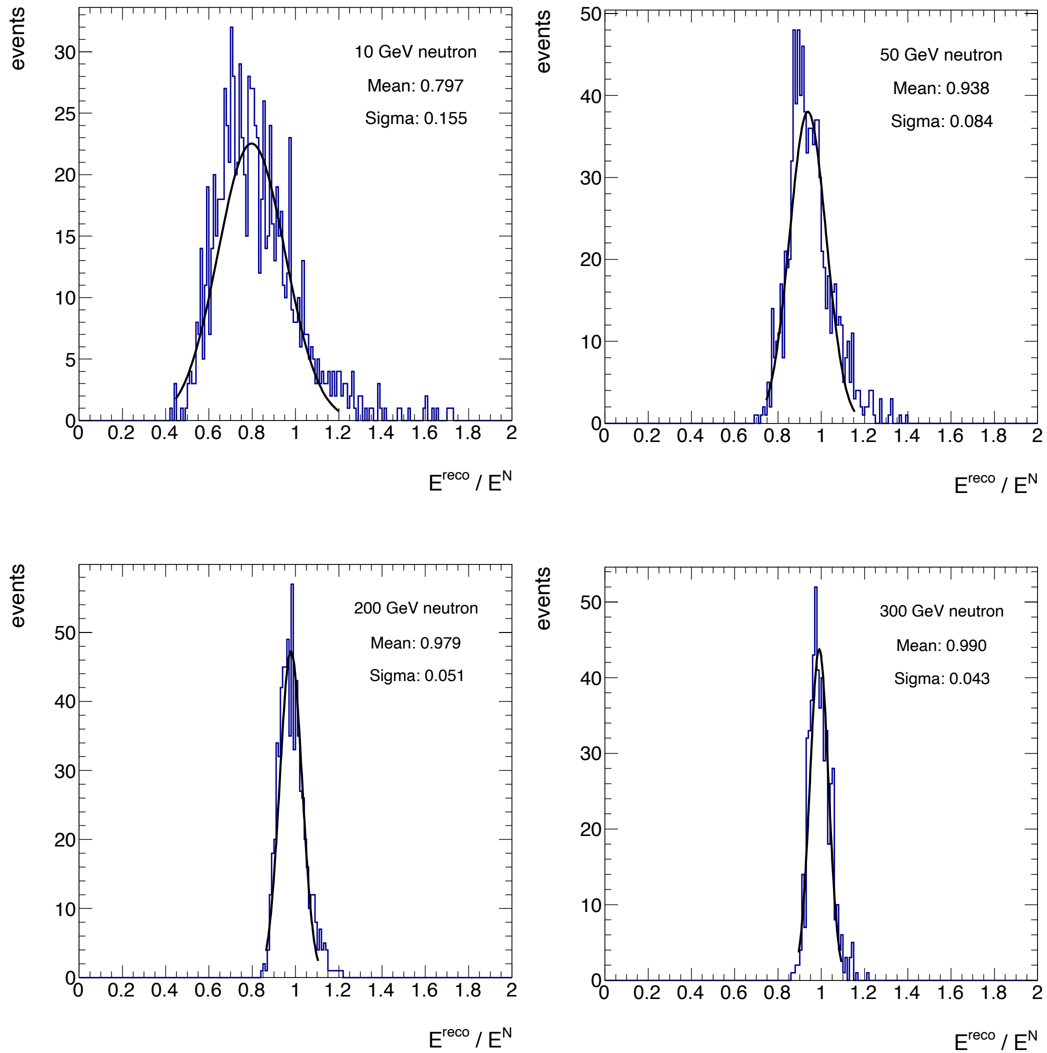


Energy reconstruction with Full Detector + additional Pb/Sci box

Finally add the crystal layers in front of the sampling calorimeters.



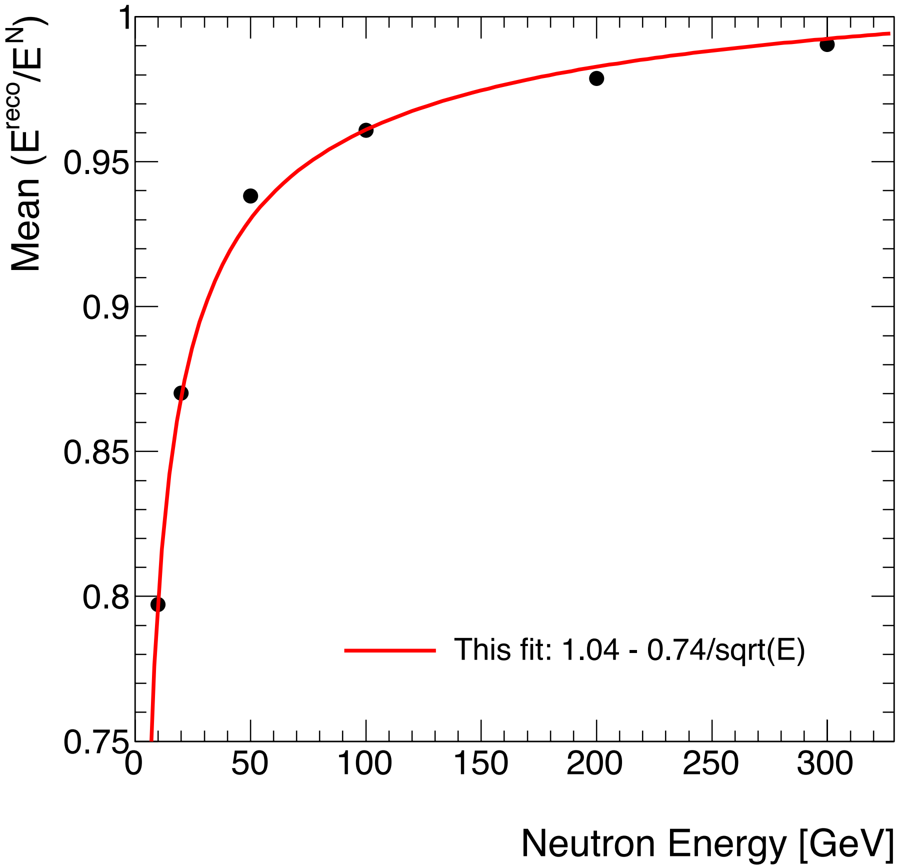
Energy in crystal is added without any scale factor.

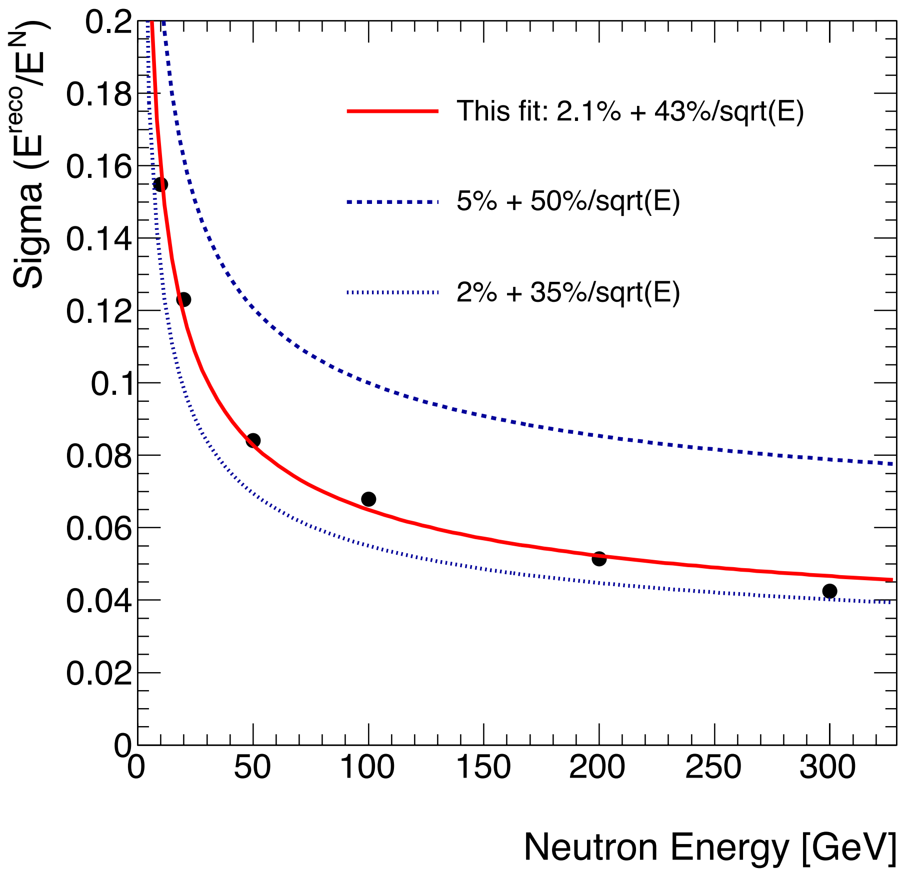


Fit results on the next page

Energy Reconstruction with Full Detector + additional Pb/Sci box

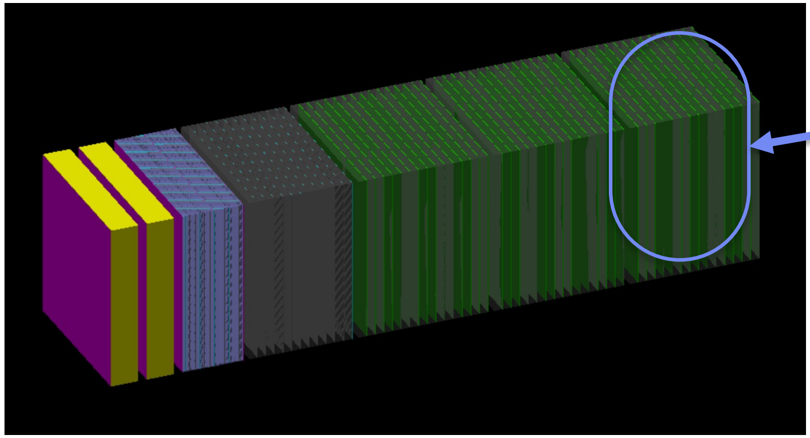
- Large bias is seen for lower energy neutrons.
- Resolution is already larger than the ideal value (35%/√E + 2%) in YR but smaller than the required value (50%/√E + 5%).



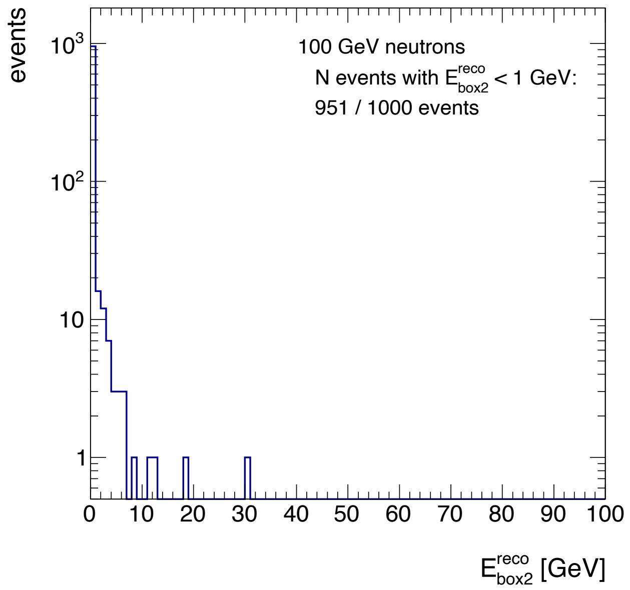


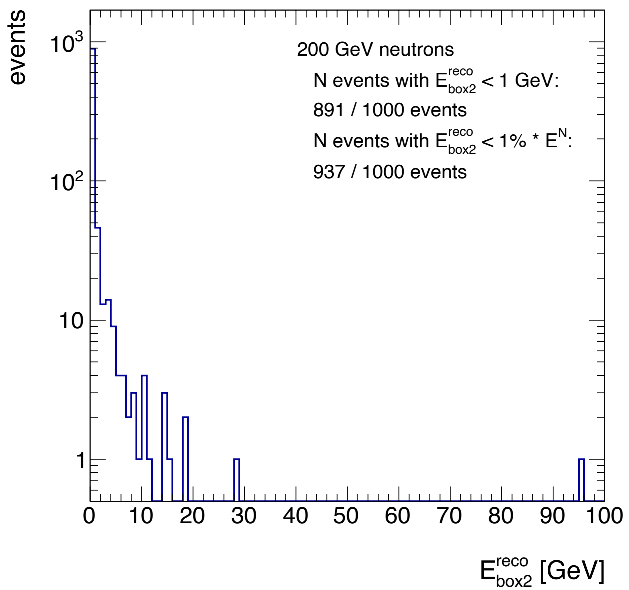
Energy leak

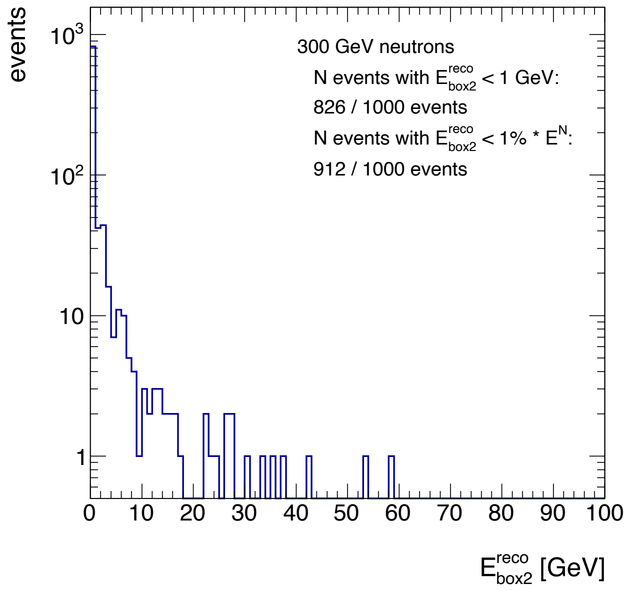
- The current design has two box of Pb/Sci instead of three.



Energy in the last box can be considered as energy leak.







> 1 % of energy leak for 5-10 % of events.

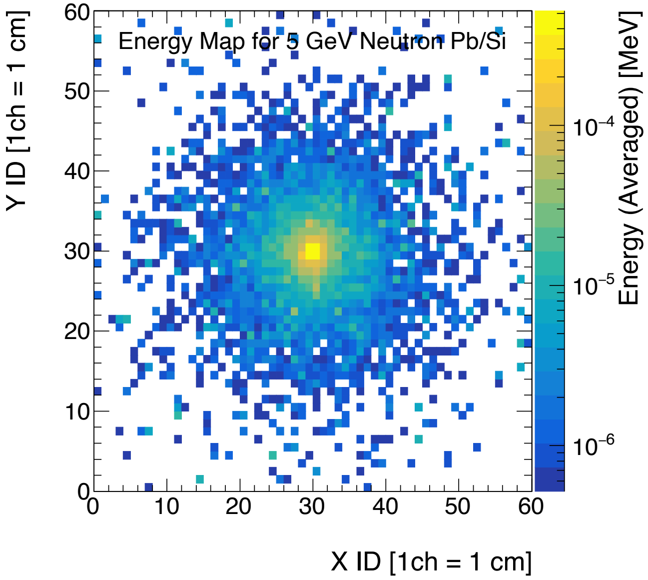
Summary

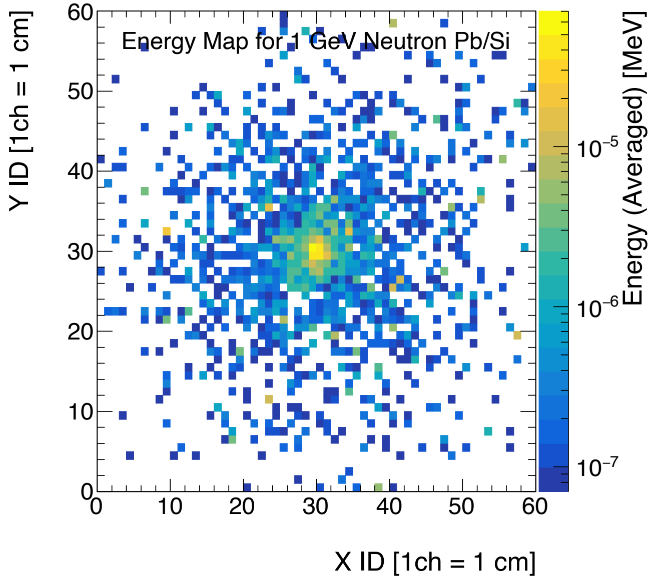
- Neutron reconstruction factors are estimated for the three sampling calorimeters.
  - Deposited energy in active material [MeV] → Reconstructed energy [GeV]
- Energy response looks quite linear in each calorimeter.
- A fit on [W/SI + Pb/SI + Pb/Sci] calorimeter energies gives

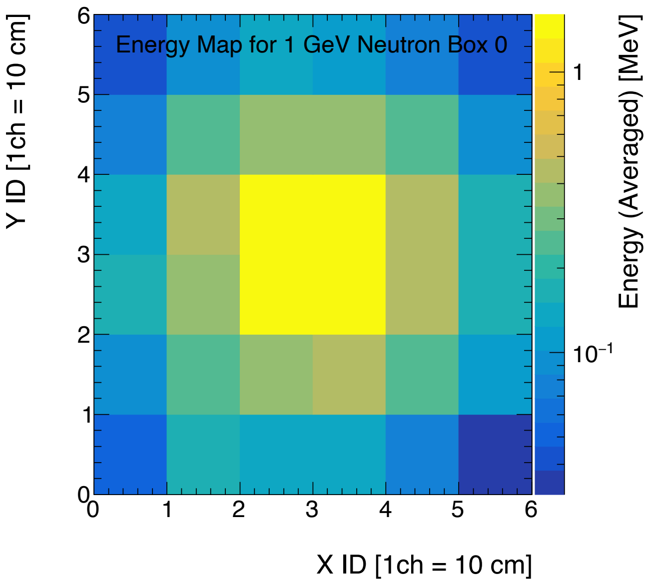
  W/SI: 0.0885 **Pb/SI**: 0.3632 **Pb/Sci**: 0.0575
  - It seems to be better to introduce energy dependence. Tentatively use:

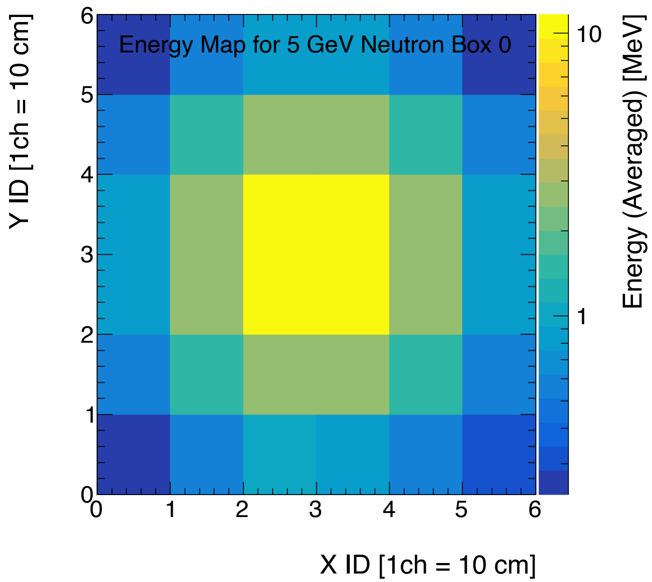
    W/SI: $(1-0.008*(E_{SI}-500)/1000)$ Pb/SI: $(1+0.04*(E_{SI}-50)/100)$
  - The factor for W/SI can easily introduce double-peak structure.
- With a full detector, reconstructed energy shows:
  - Large bias for lower energy neutrons.
  - Resolution worse than the ideal value but better than the required value.
- Energy leak is seen for > 10 % of 200 GeV neutrons.
  - >1 % energy leak for 5-10 % of events.

Modified HC: x-y map

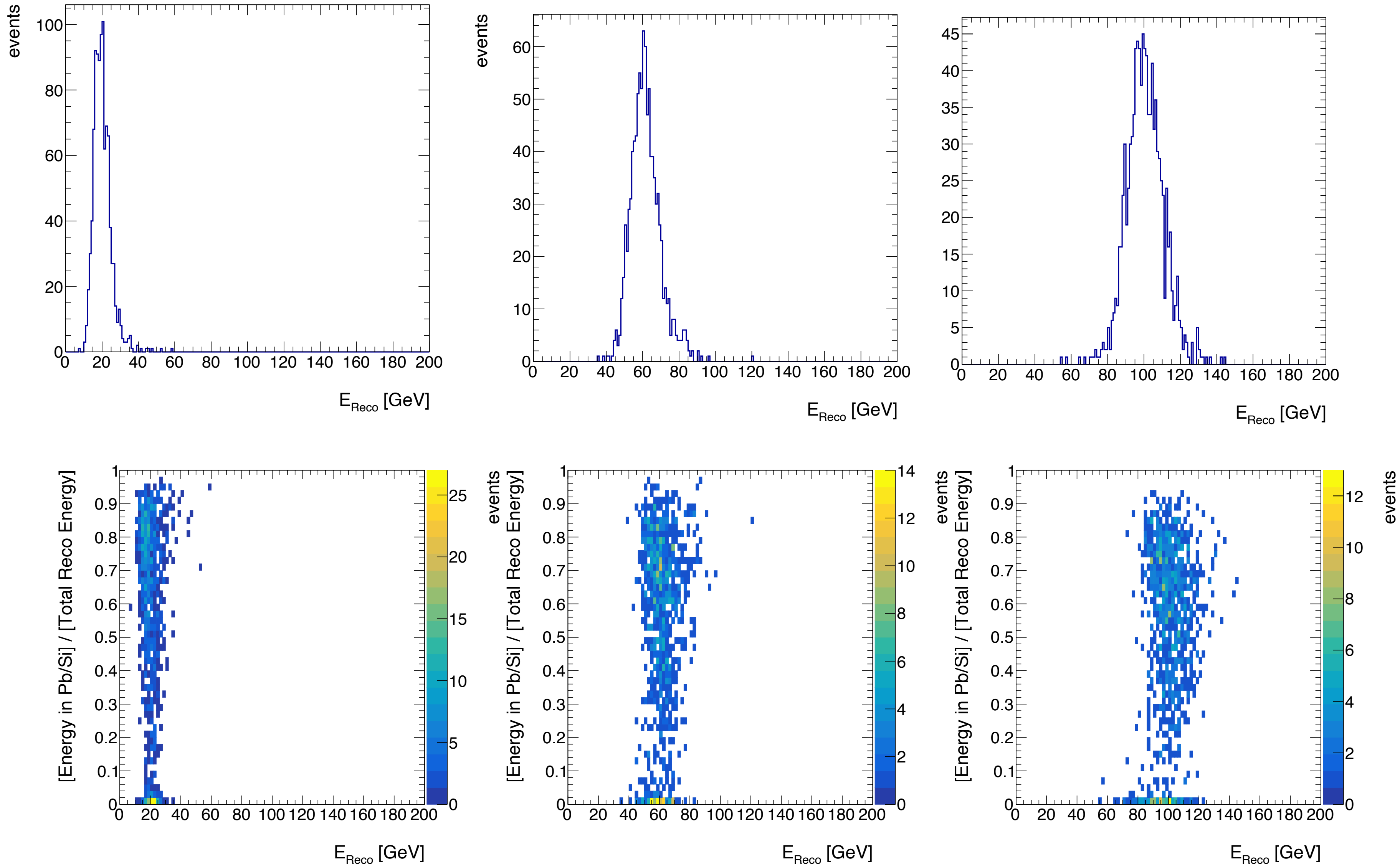








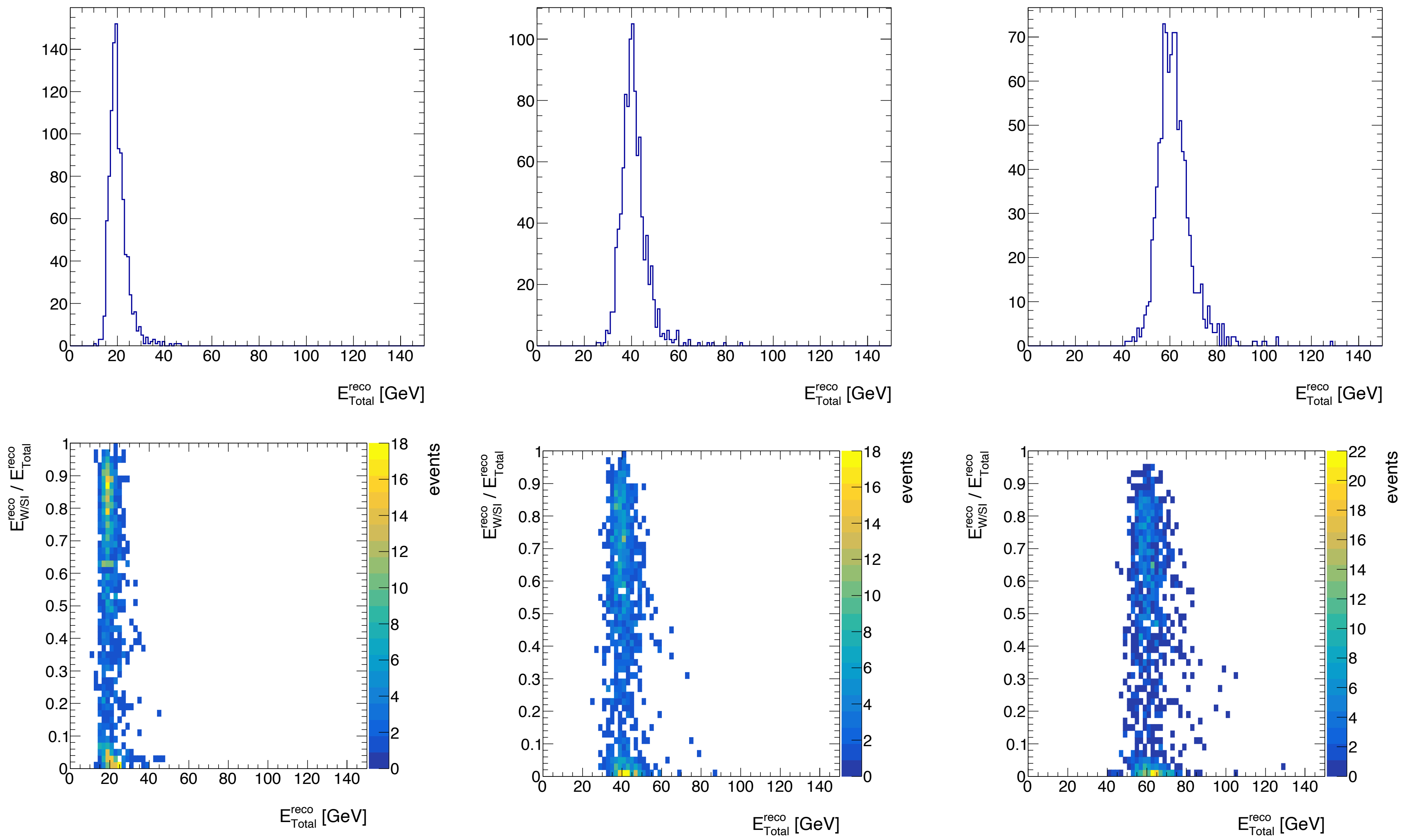
HC only: Reconstructed energy (backup)



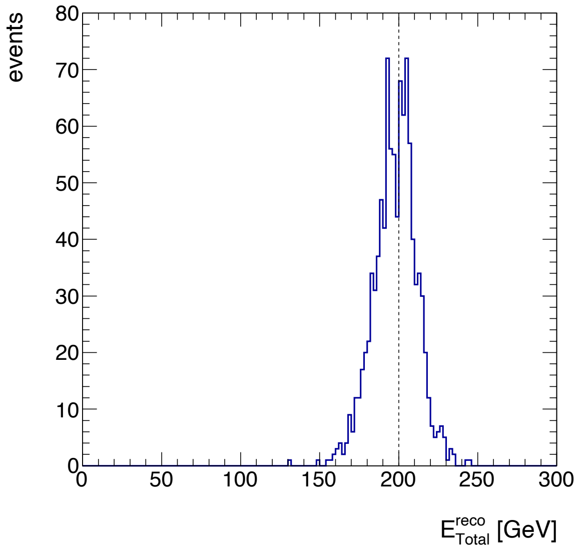
- Samples used in the extraction of the slope.

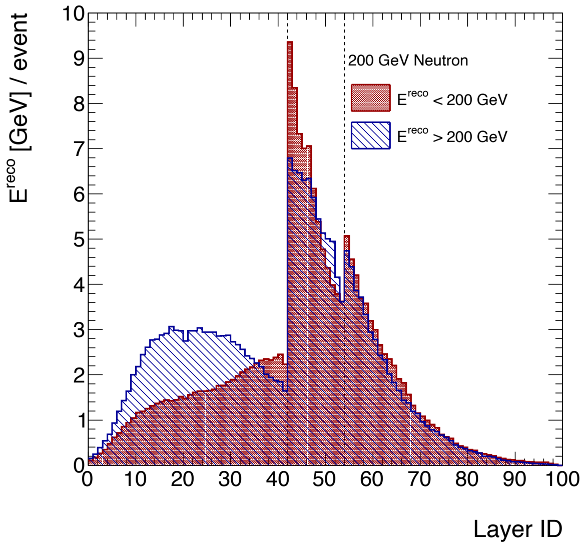
W/Si + HC: Reconstructed Energy (backup)

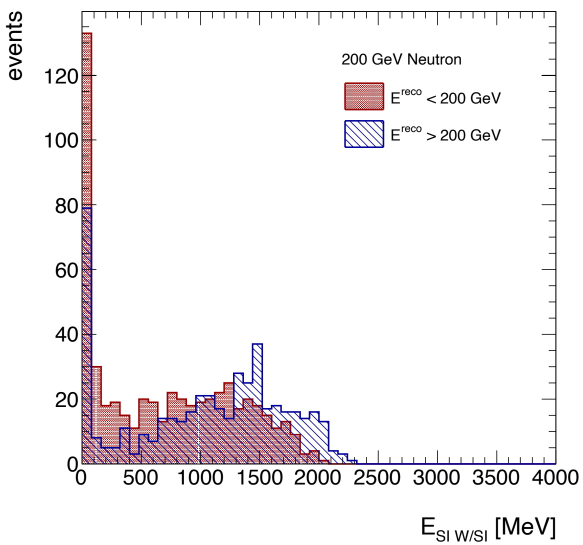
- Samples used in the extraction of slopes.

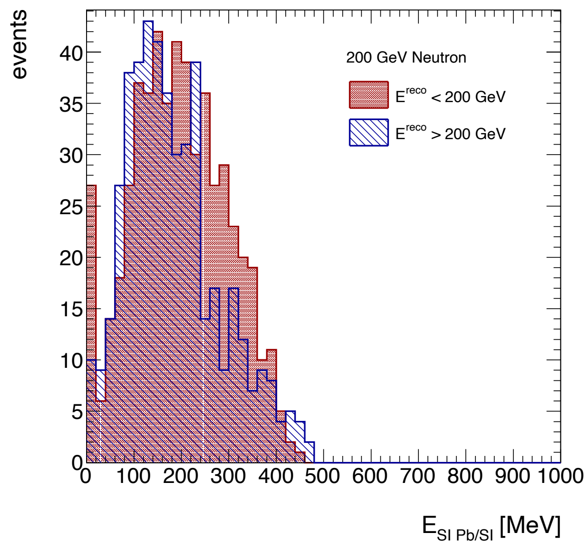


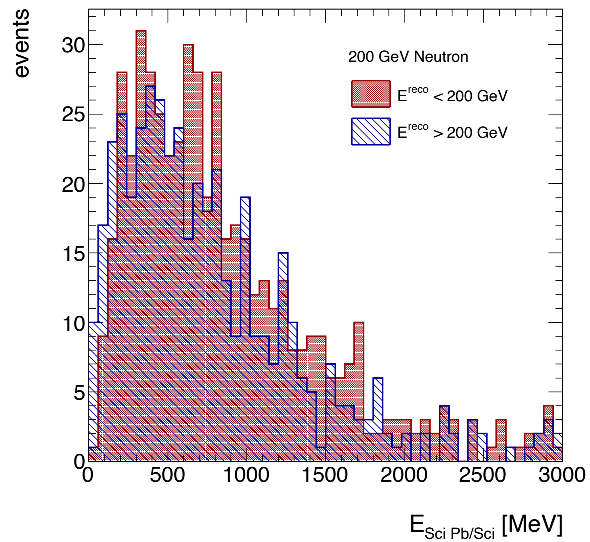
Check of the 200 GeV sample (Fit)





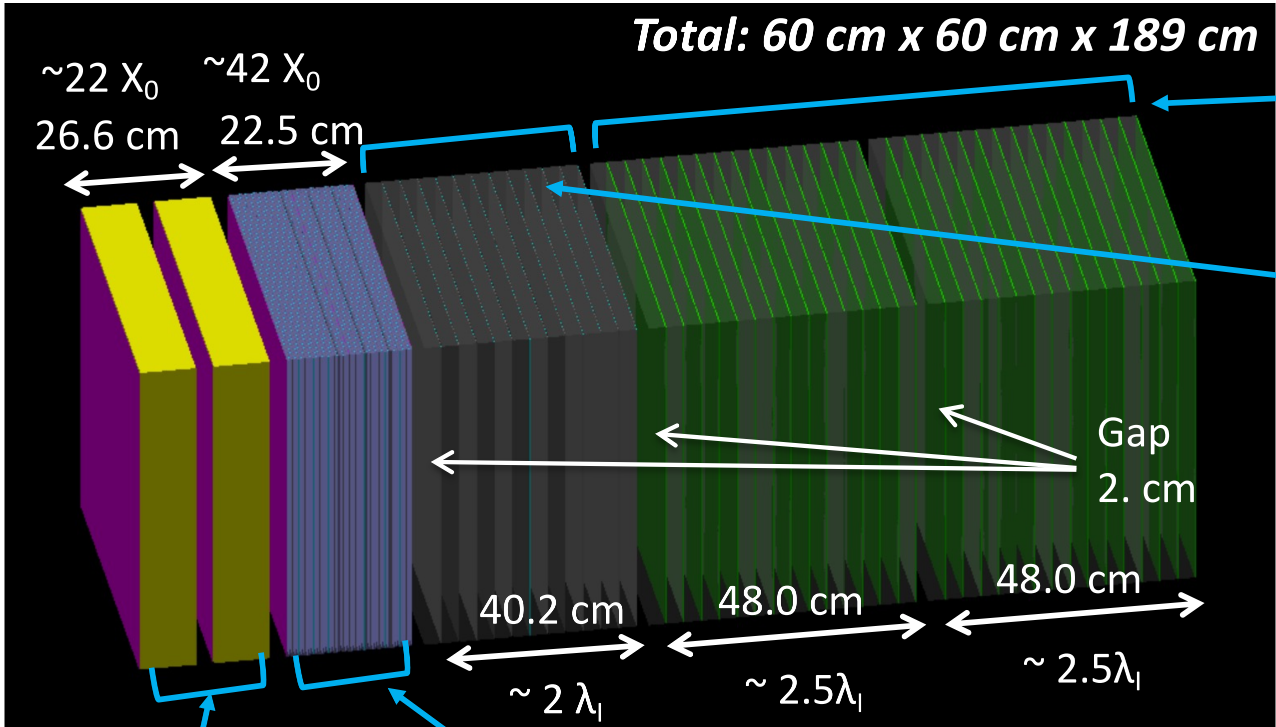






First ZDC design

Plots of energy deposition are in backup slides.



30 layers (15 layers x 2)

Pb 3cm Thickness
Scintilator
10 cm x 10 cm x 2 mm
Gap 0.0013 mm

12 layers

Pb 3cm Thickness
PET (Glue) 0.11 mm
Silicon
1 cm x 1 cm x 320 µm
PET (Glue, FPC) 0.41 mm
Gap 1. mm

2 layers

Silicon
3 mm x 3mm x 300 µm
PET (Glue, FPC) 0.39 mm
Gap 1.2mm
Crystal (PbWO4)
3cm x 3cm x 10 cm
Gap 3 cm

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

= Si + 2 x

20 layers

Tungsten 3.5 mm Thickness
PET (Glue) 0.11 mm
Silicon 1 cm x 1 cm x 320 µm
PET (Glue, FPC) 0.41 mm, Gap 1.mm

+

1 layer

Tungsten 3.5 mm Thickness
PET (Glue) 0.11 mm
Silicon 3 mm x 3mm x 300 µm
PET (Glue, FPC) 0.39 mm, Gap 1.2mm