Updates on
Recent Activities in Taiwan

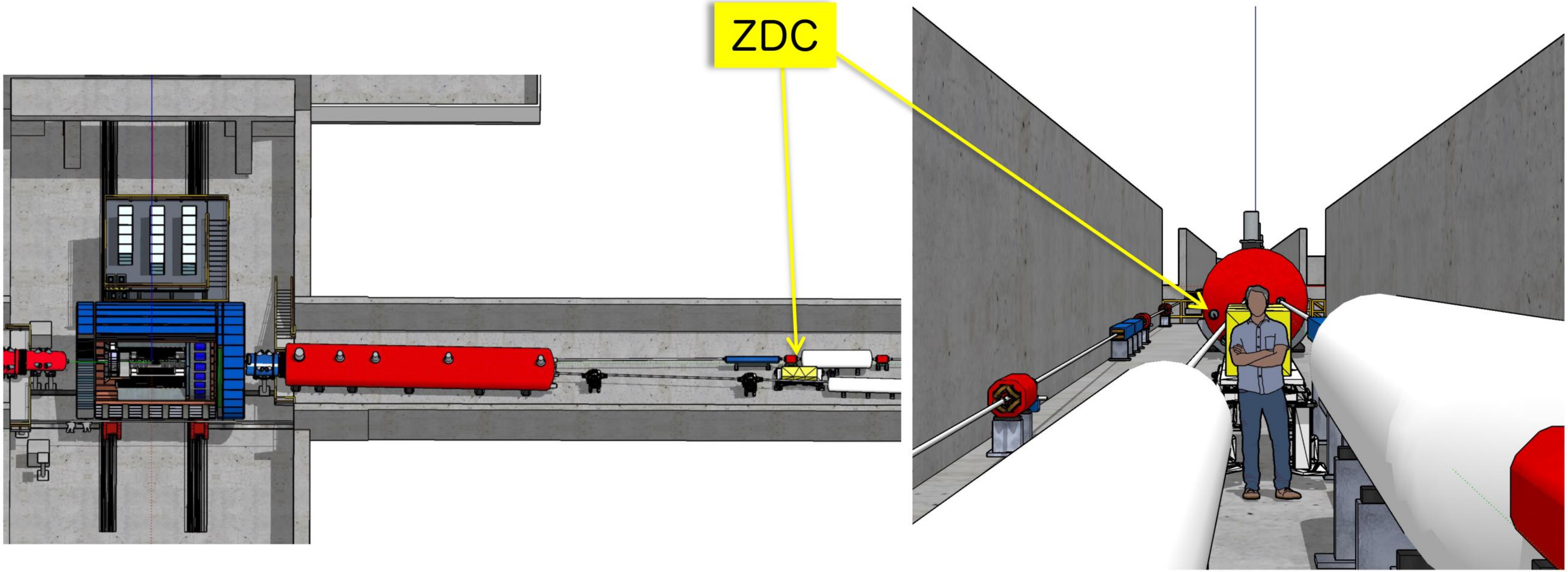
EIC Asian Meeting
July 13, 2023

Po-Ju Lin
Acadeima Sinca

Progresses on
the ZDC Monte Carlo Simulation

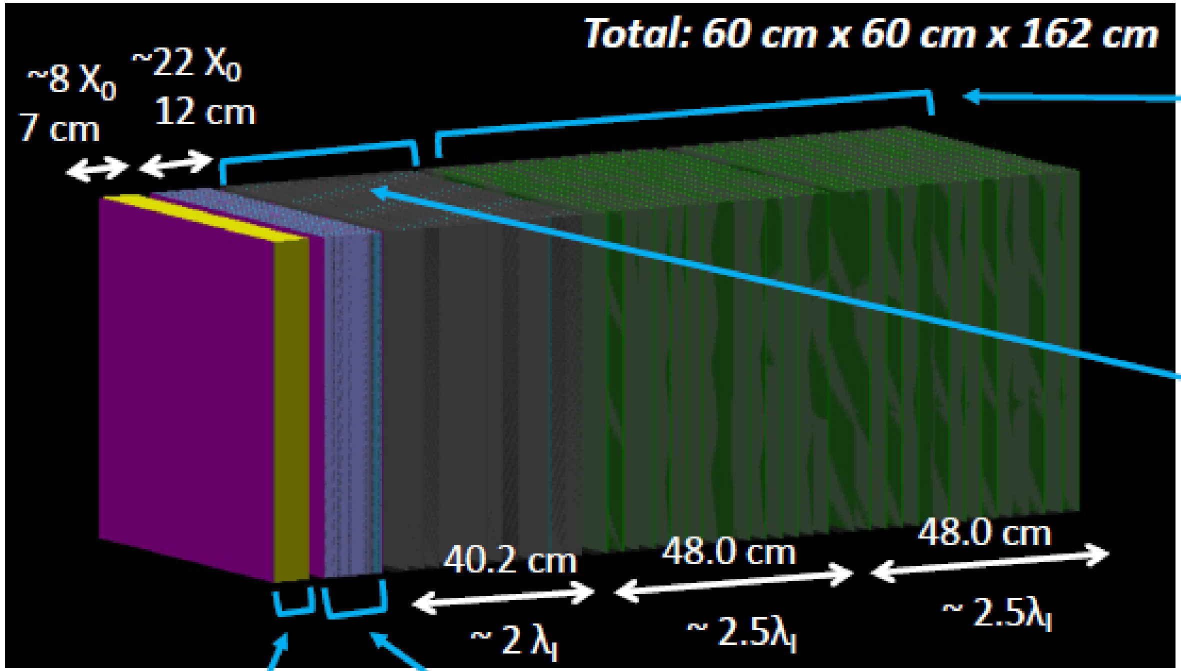
Zero Degree Calorimeter (ZDC)

A calorimeter for measuring photons and neutrons away from the interaction point.



ZDC Ver. 1

*note: space for readout may extend the longitudinal length.



15 layers x 2

- Pb 3cm thickness
- Scintillator 10 cm x 10 cm x 2 mm

12 layers

- Pb 3cm thickness
- Silicon pad layer 1 cm x 1 cm x 320 μm

1 layer

- Silicon pixel layer 3 mm x 3mm x 300 μm
- Crystal (PbWO4) 3cm x 3cm x 7 cm

Si: 3 layers
Si: 20 layers = Si + 2 x
W: 22 layers

10 layers

- Tungsten 3.5 mm thickness
- Silicon pad layer 1 cm x 1 cm x 320 μm

\+

1 layer

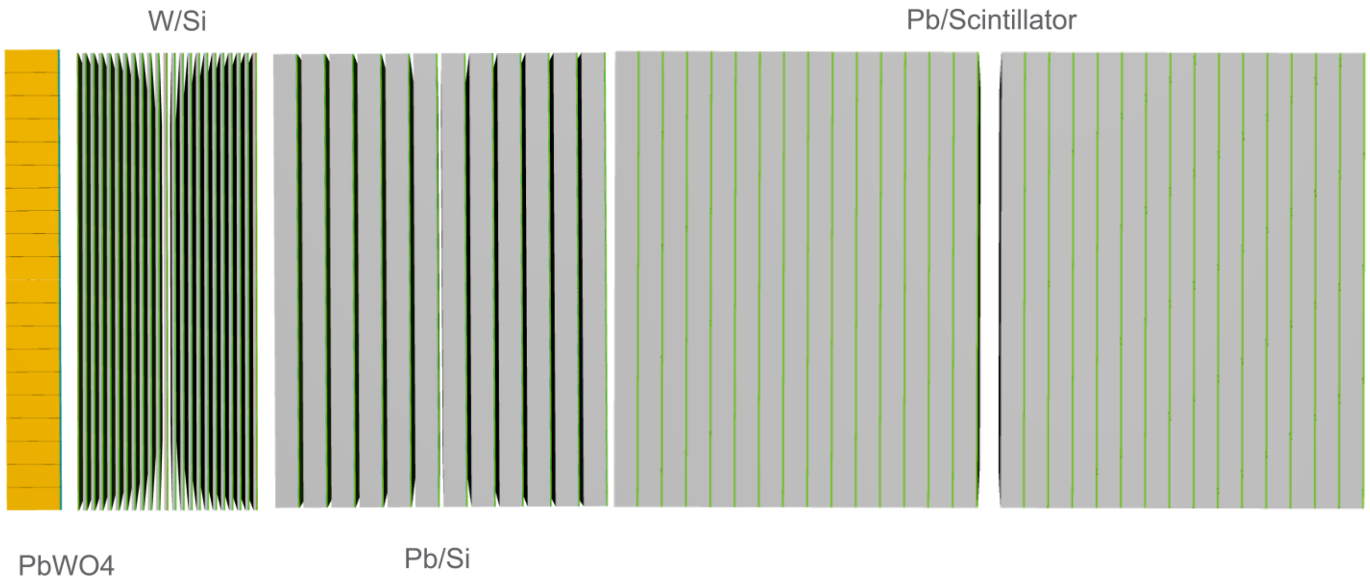
- Tungsten 3.5 mm thickness
- Silicon pixel layer 3 mm x 3mm x 300 μm

➢ Currently available for everyone one on the ePIC GitHub

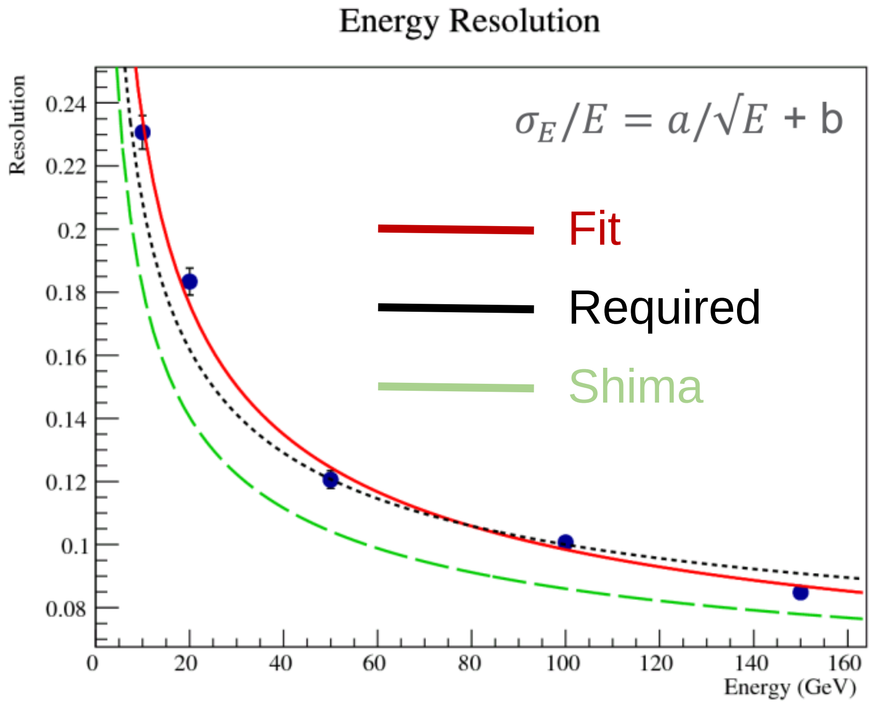
ZDC Ver. 1 – E Resolution

- Use particle gun to generate neutrons of different energy
  - Position at the front of ZDC, at angle along the ZDC center
  - Five different energy settings: (10, 20, 50, 100, 150) GeV
  - 1000 events for each setting
- Do calibration with linear fitter

$$E_{rec.} = c_1 E_{SiPix} + c_2 E_{Crystal} + c_3 E_{WSi} + c_4 E_{PbSi} + c_5 E_{PbScint} + b$$



- Same behavior confirmed by PNNL



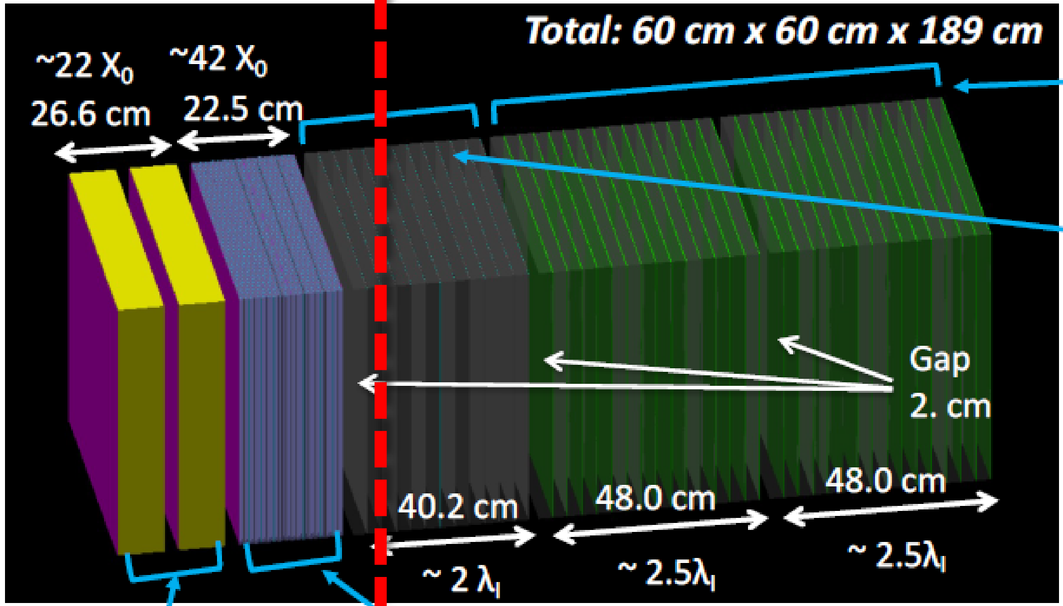
- Fit: $\frac{63\%}{\sqrt{E}} + 3.6\%$
- Required: $\frac{50\%}{\sqrt{E}} + 5\%$
- Shima: $\frac{44\%}{\sqrt{E}} + 4.2\%$

ZDC Ver. 0

Previous design studied by Shima

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

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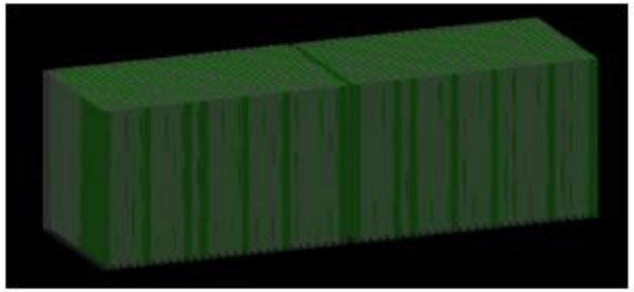
ZDC Ver. 0 - Check of Pb/Sci

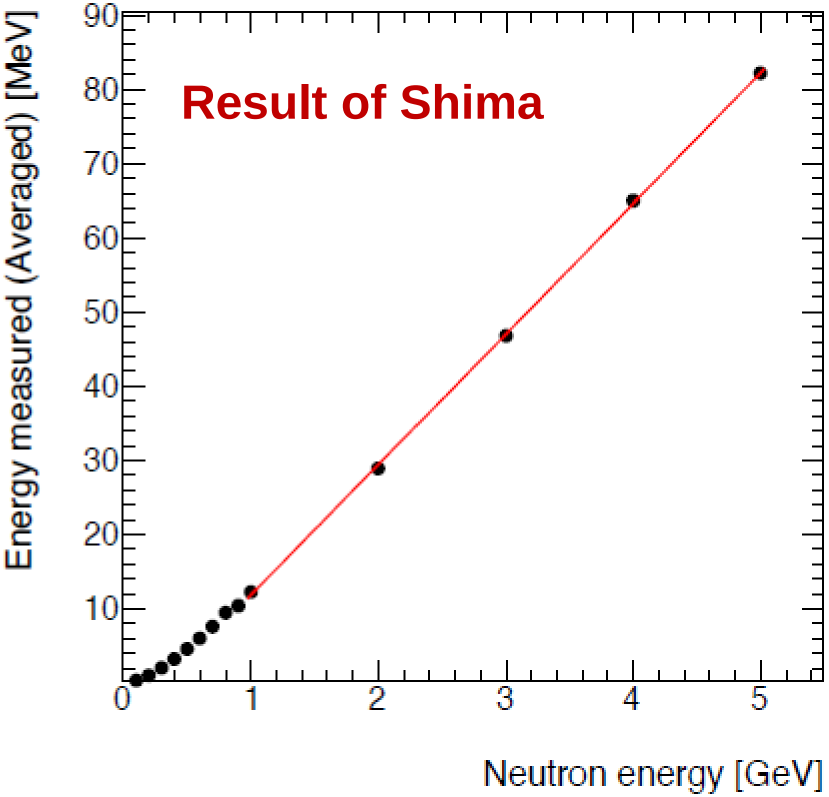
Neutron samples

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

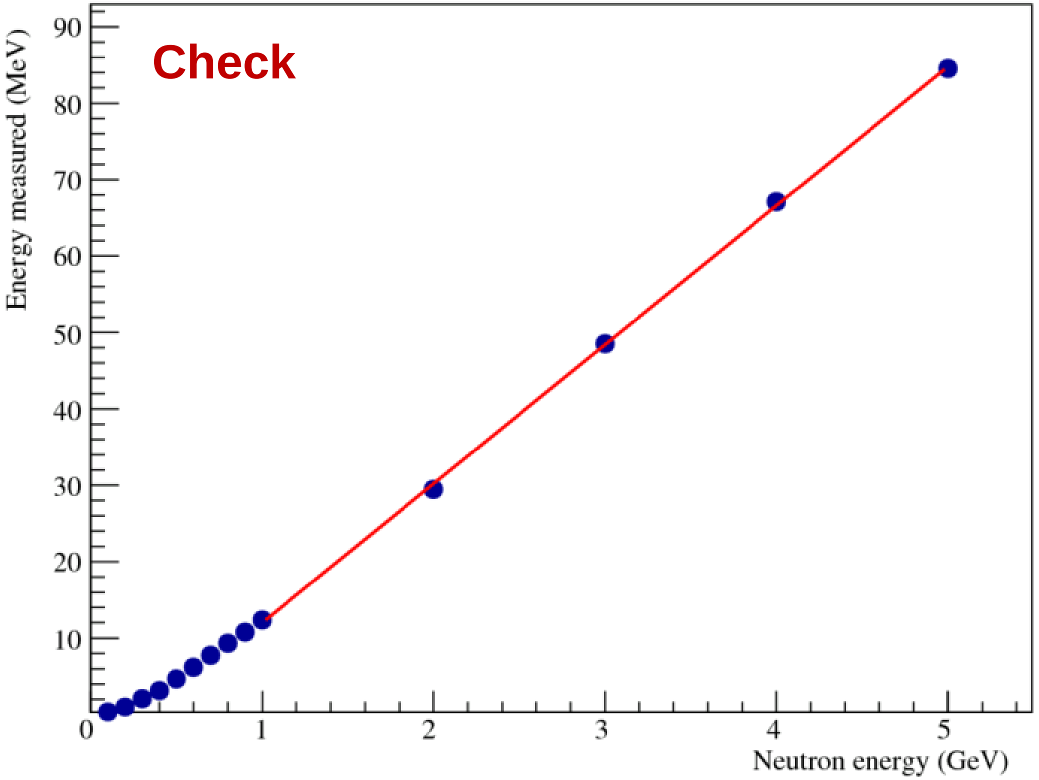
1000 events for each energy, shot on the center of the layer.



Pb/Sci ONLY, no other modules



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

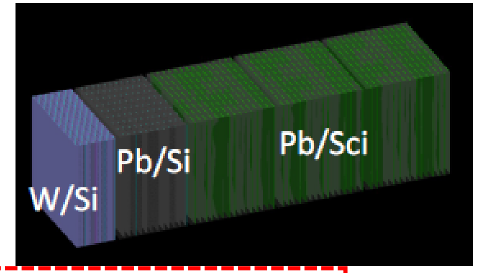


- Fit result: Meas [MeV] = $18.2(\pm 0.6) \times$ N [GeV] $-6.2(\pm 0.2)$

ZDC Ver. 0 - Check with 3 Modules

estimation by fit

Parameters from fit

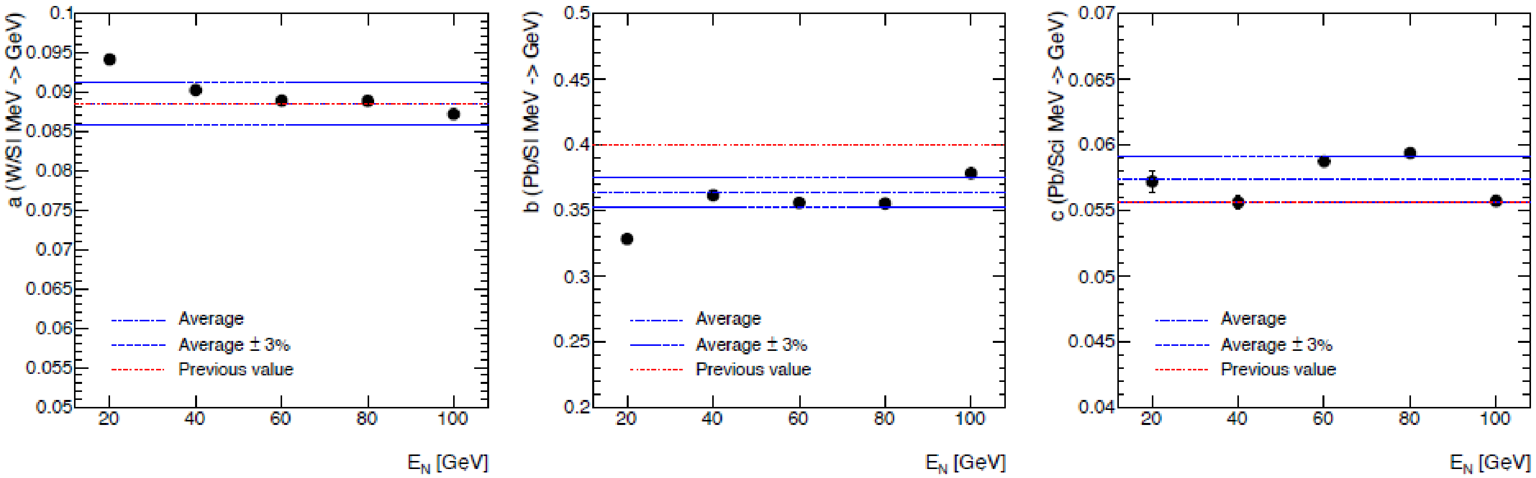


- The energy response in each detector looks quite linear.
- Extract parameters from fits:

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

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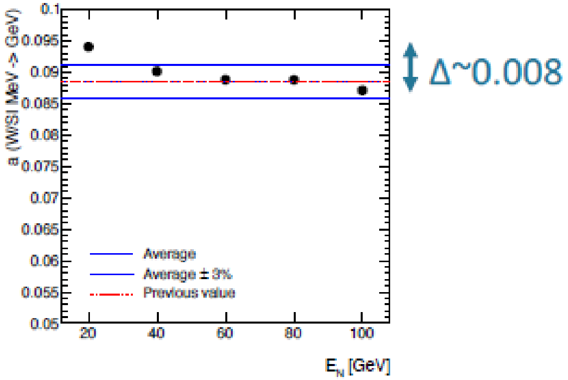
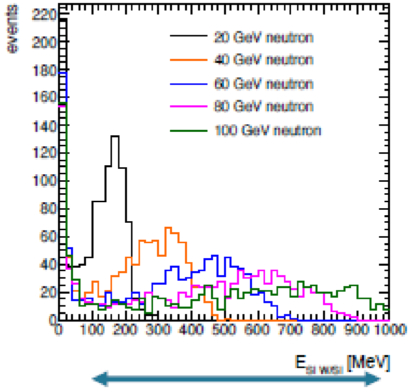
- W/SI: Average * (1-0.008*(E_{SI}-500)/1000)
- Pb/SI: Average * (1+0.04*(E_{SI}-50)/100)

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

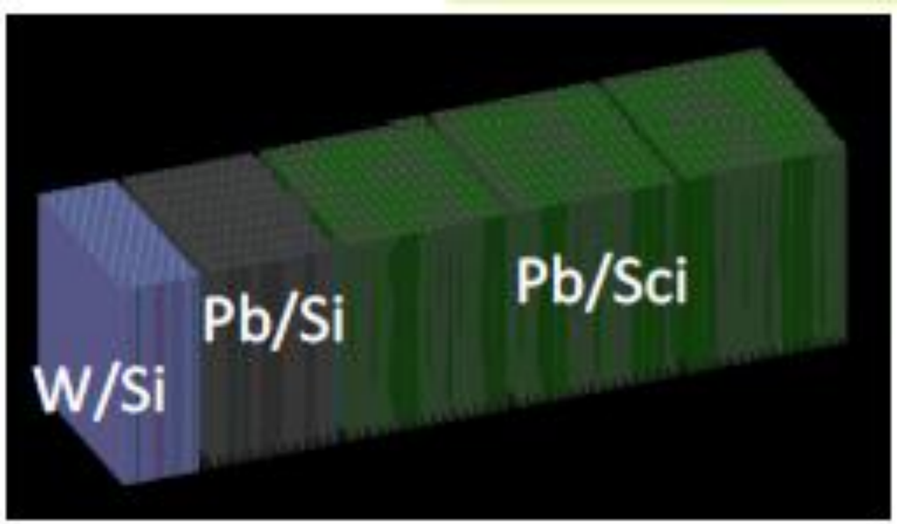




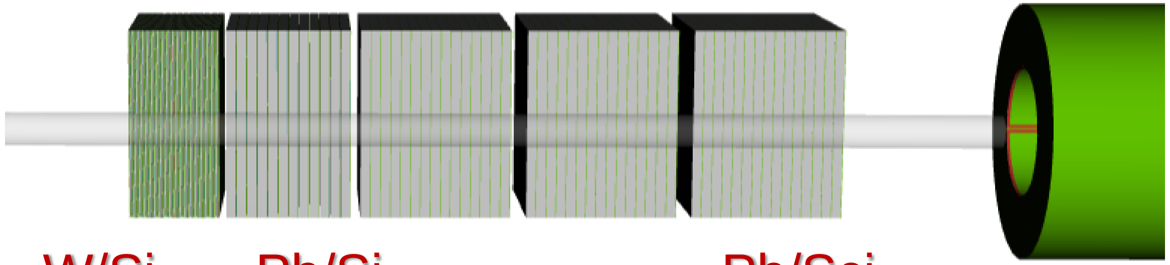
Leaver arm ~ 1000

ZDC Ver. 0 - Check with 3 Modules

Shima:



Implementation in DD4hep:

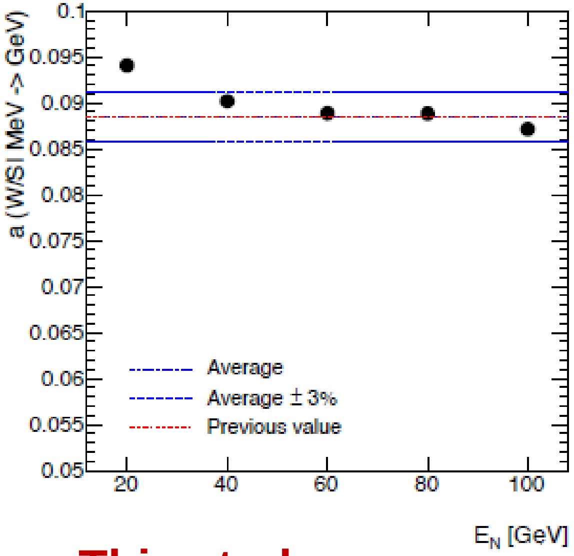


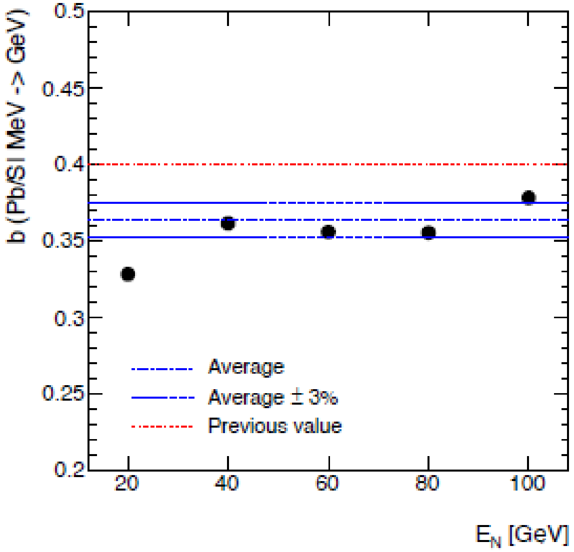
W/Si Pb/Si Pb/Sci

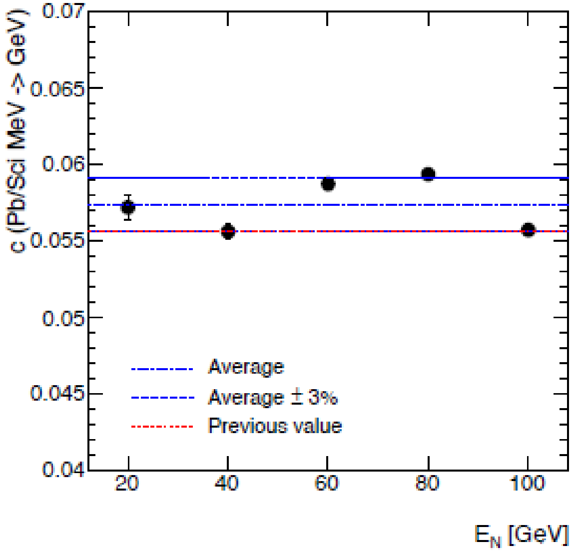
- Implementation of the 1st-version ZDC Geometry
  - Based on the slides that I have, should be similar enought, if not identical
- Try to reproduce the result of Shima with the first design.

ZDC Ver. 0 - Check with 3 Modules

Result of Shima

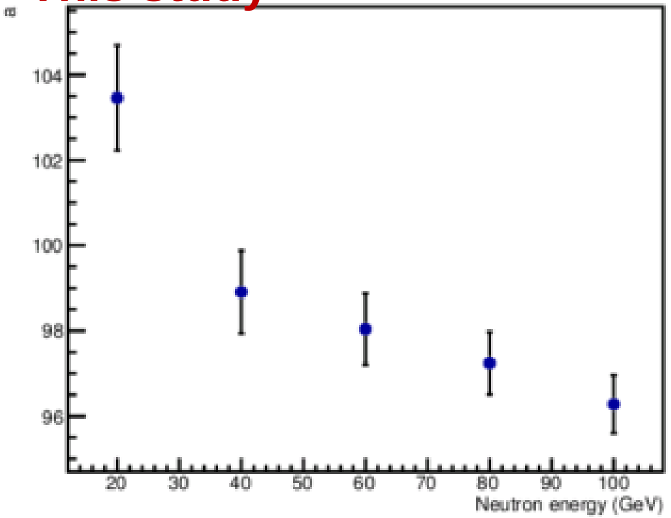


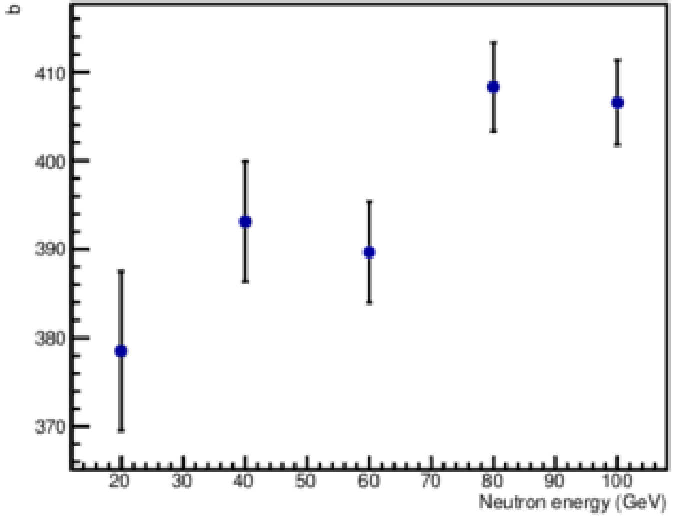


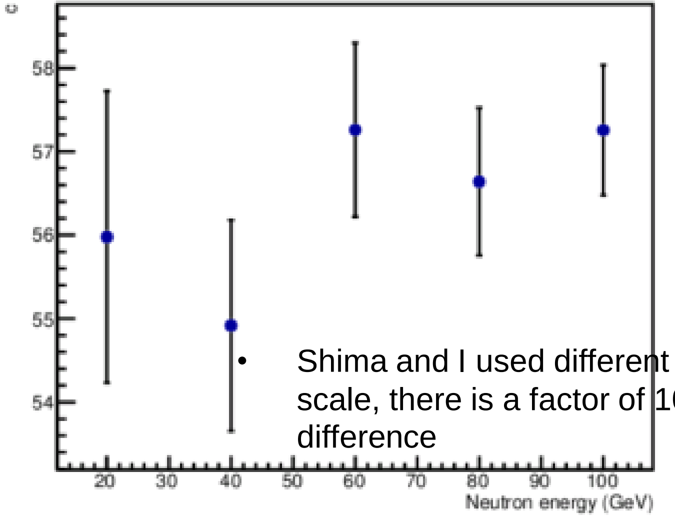


- Similar trend of energy dependence is obseved
- The parameters I have is larger than what Shima got

This study







- Shima and I used different energy scale, there is a factor of 1000 difference

ZDC Ver. 0 - Check with 3 Modules

Shima's parameterization:

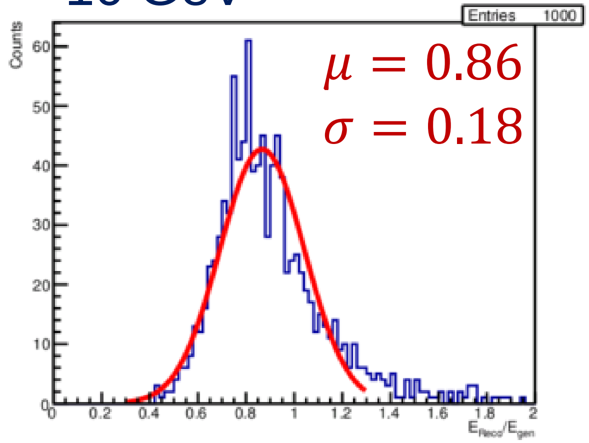
- W/SI: Average * (1-0.008*(E_{SI}-500)/1000)
- Pb/SI: Average * (1+0.04*(E_{SI}-50)/100)

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

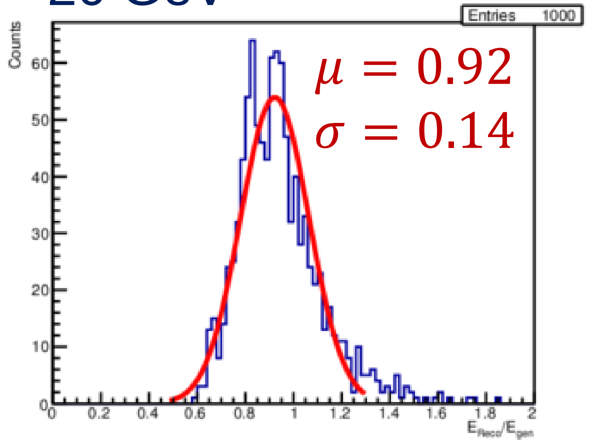
My parameterization:

- W/SI: 0.0988 * (1 - 0.007 * (E_{SI} - 500)/1000)
- Pb/SI: 0.3952 * (1 + 0.03 * (E_{SI} - 50)/100)

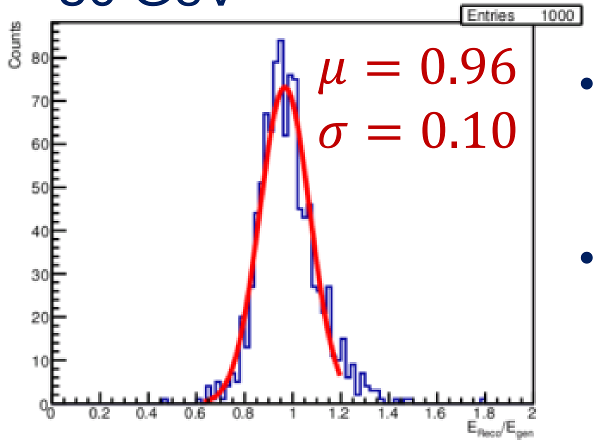
10 GeV



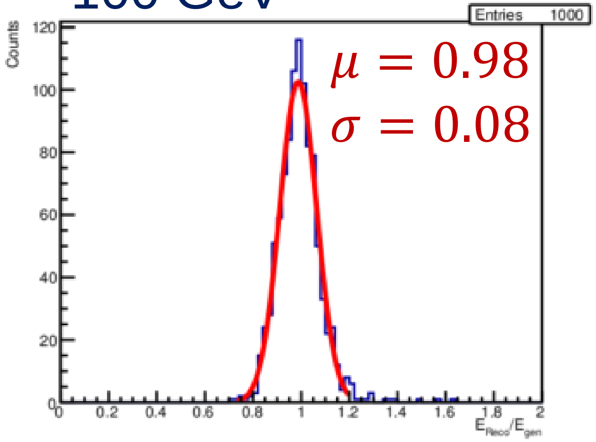
20 GeV



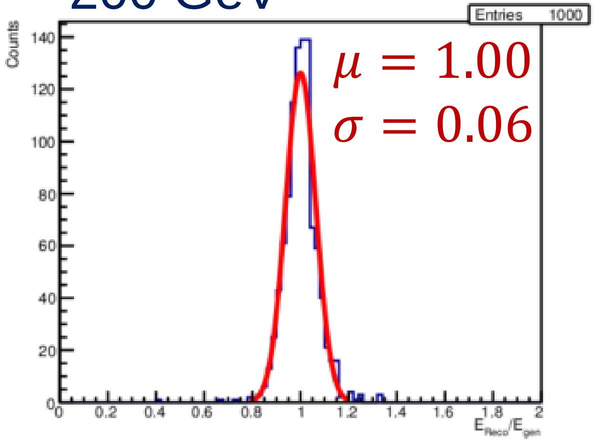
50 GeV



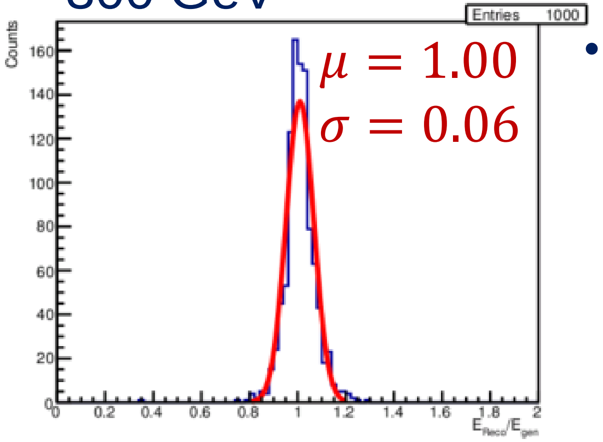
100 GeV



200 GeV

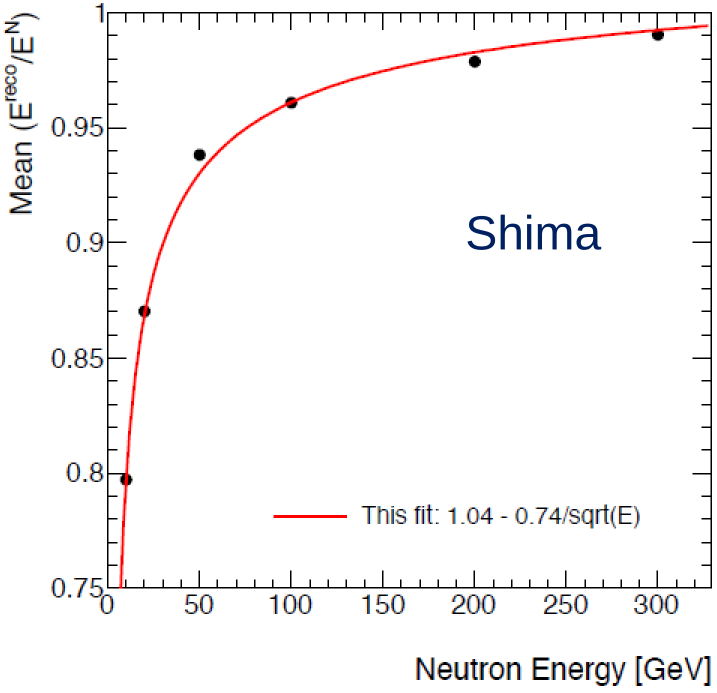


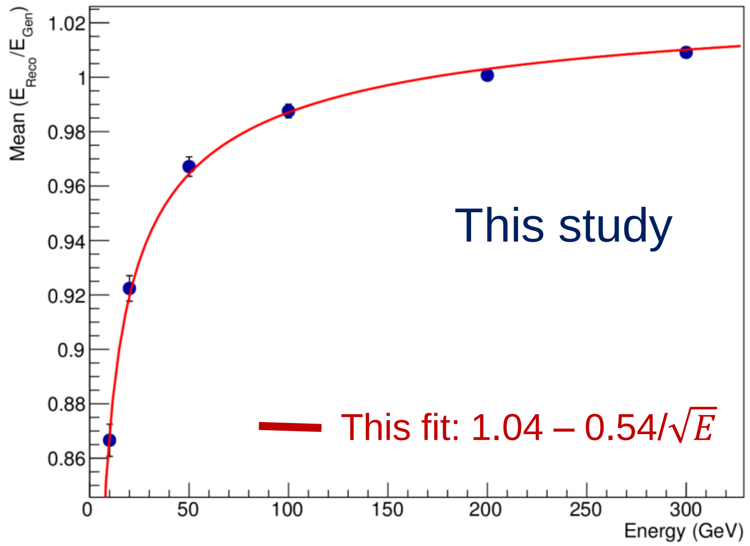
300 GeV

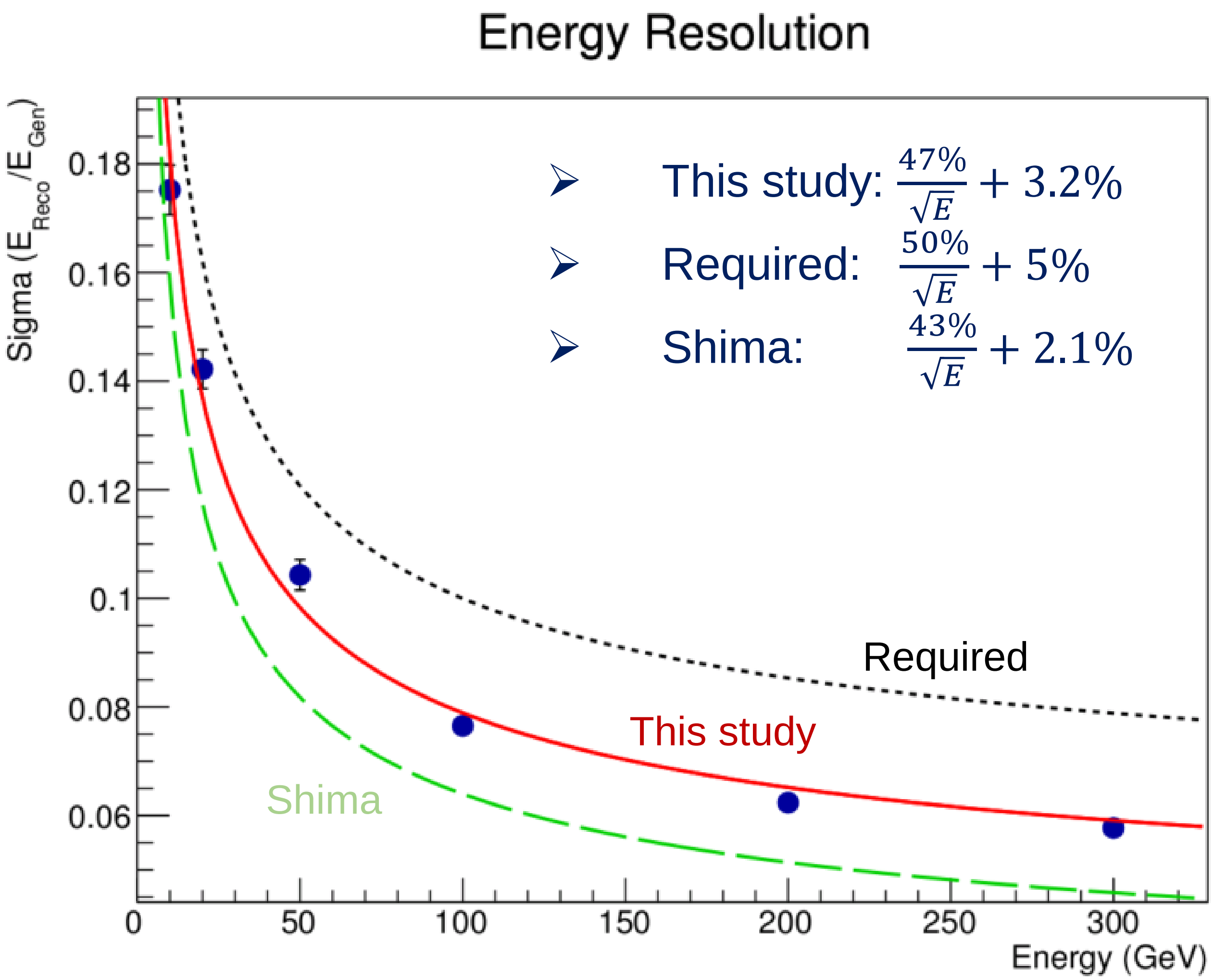


- Six energy settings (GeV): (10, 20, 50, 100, 200, 300)
- The energy deposited in the crystal is simply added to the calibrated energy from the other modules.
- Gaussian fit of E_{reco} / E_{Gen}

ZDC Ver. 0 - Check with 3 Modules







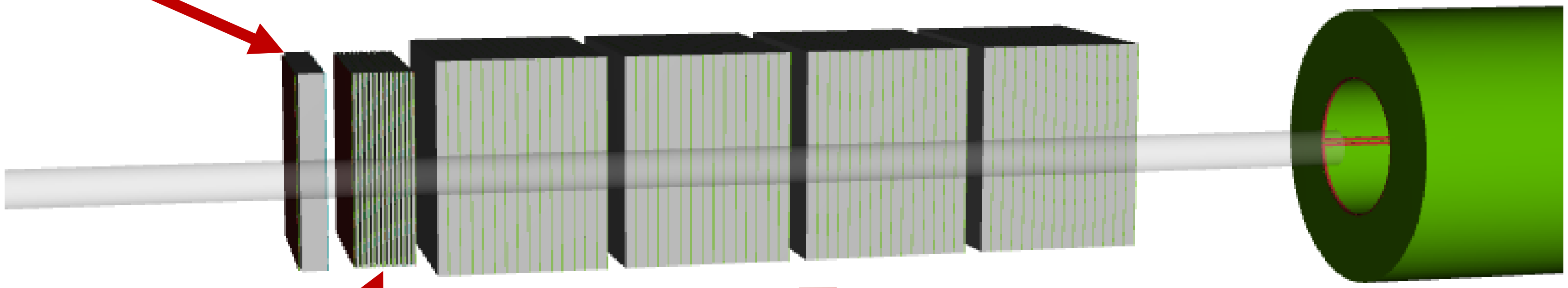
- Result not as good as what Shima had, but acceptable

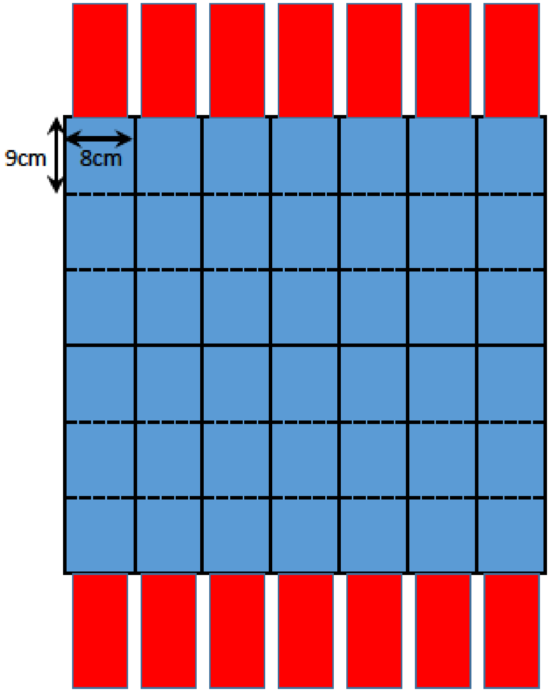
ZDC Ver. 2

➢ **More cost-effective design**

➢ 1st Silicon & crystal calorimeter:
- Smaller lateral dimension (x, y) = (56, 54) cm.

➢ Silicon Pixel lateral size (x, y) = (4, 3) mm



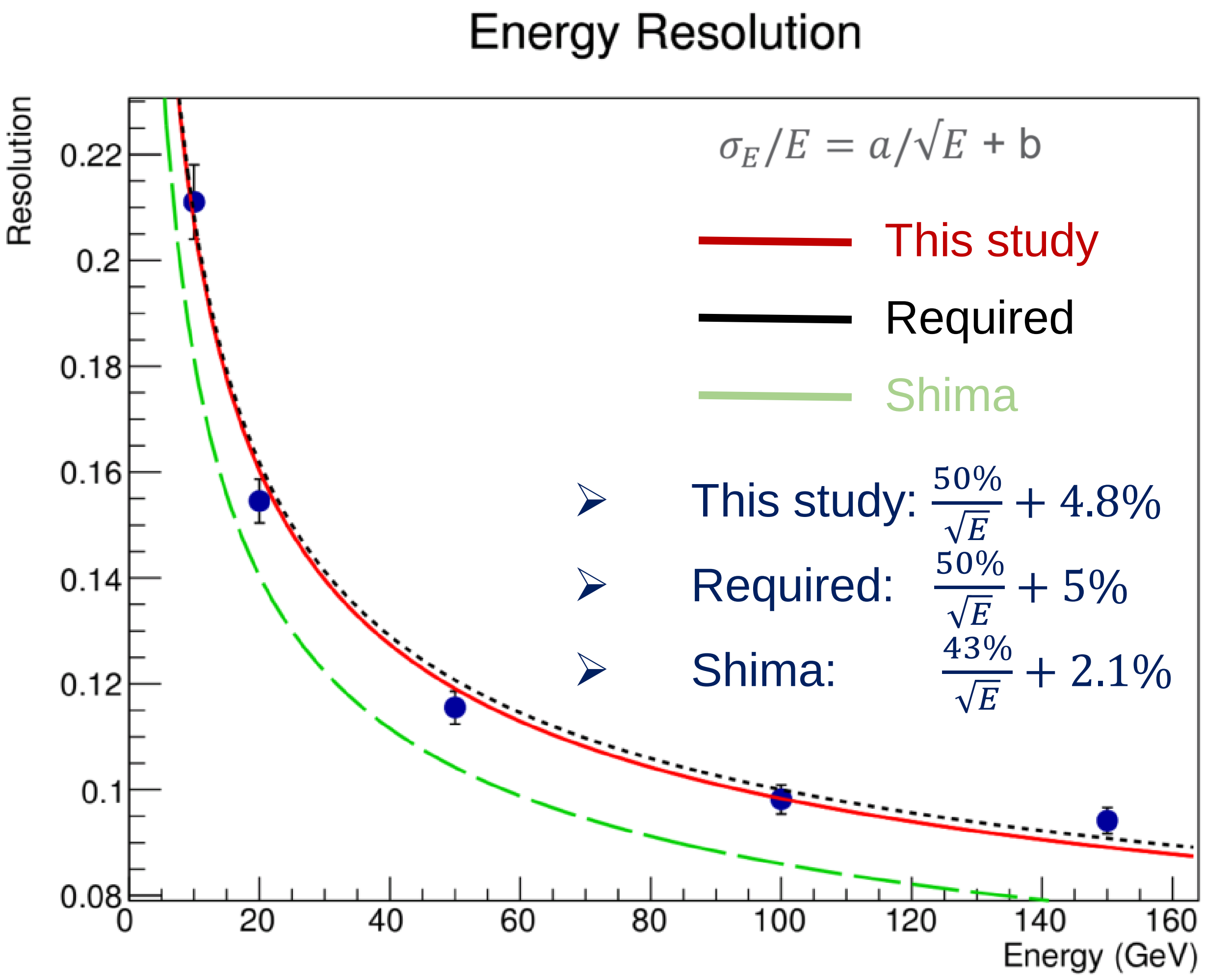


➢ W-Si imagine calorimeter
- Smaller lateral dimension (x, y) = (56, 54) cm.
- Smaller number of layers $1X_0 \times 22 \rightarrow 2X_0 \times 12$ layers

➢ Pb-Scintillator + fused silica
- Towers of 10cm x 10cm x 48cm, each module is 60cm x 60cm x 48cm
- 4 modules
- Not yet have the implementation of fused silica – only scintillator now

➢ Pb-Si modules removed

ZDC Ver. 2

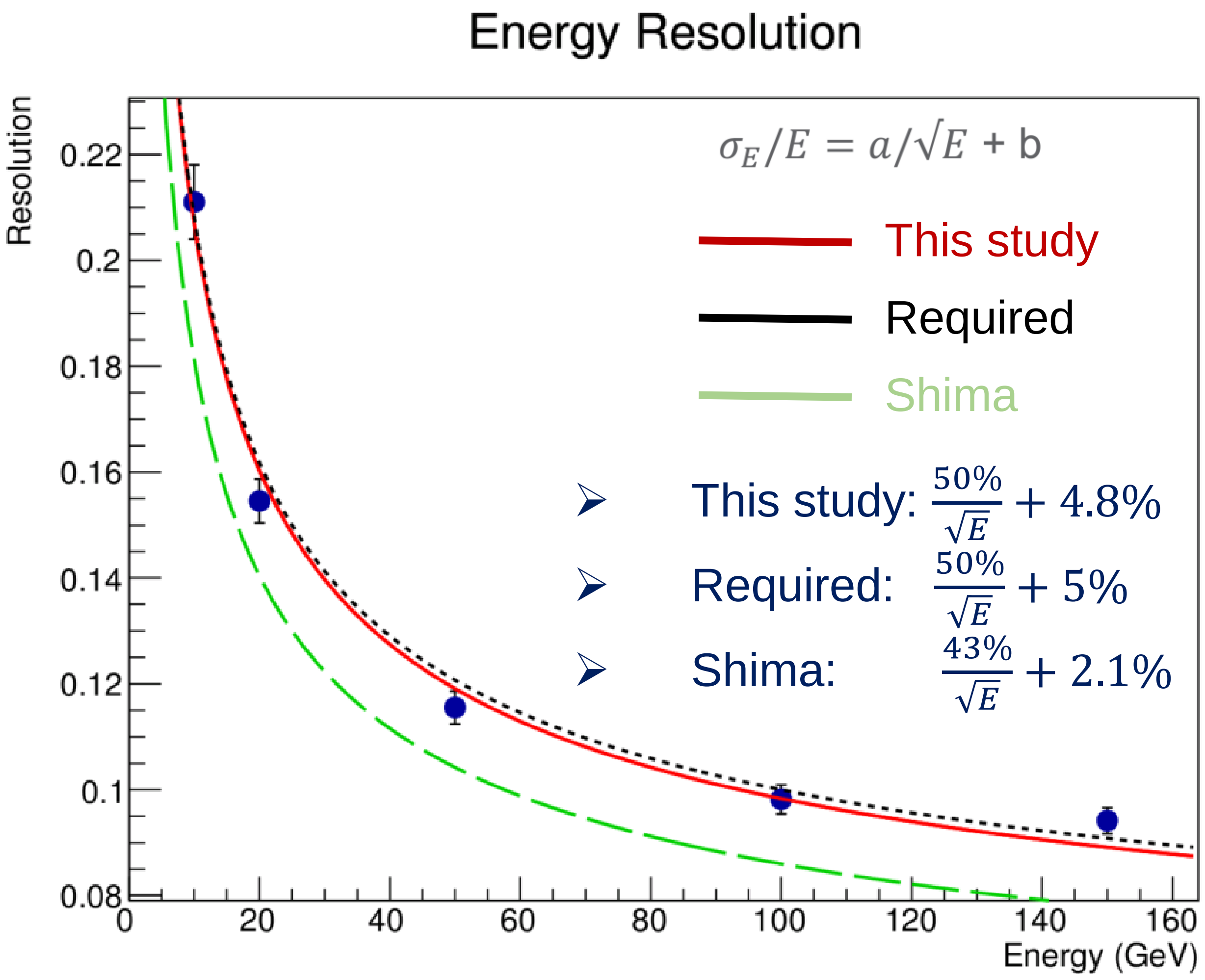


- Use particle gun to generate neutrons of different energy
  - Position at the front of ZDC, at angle along the ZDC center
  - Five different energy settings: (10, 20, 50, 100, 150) GeV
  - 1000 events for each setting
- Do calibration with linear fitter

$$E_{rec.} = c_1 E_{SiPix} + c_2 E_{Crystal} + c_3 E_{WSi} + c_4 E_{PbScint} + \mathrm{b}$$

ZDC Ver. 2

- Test suggested → modify the ratio of the thickness of Pb:Scinitllator to 4:1



DESY 87-041
FTUAM-EP-87-03
May 1987

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PERFORMANCE OF A COMPENSATING

LEAD-SCINTILLATOR HADRONIC CALORIMETER

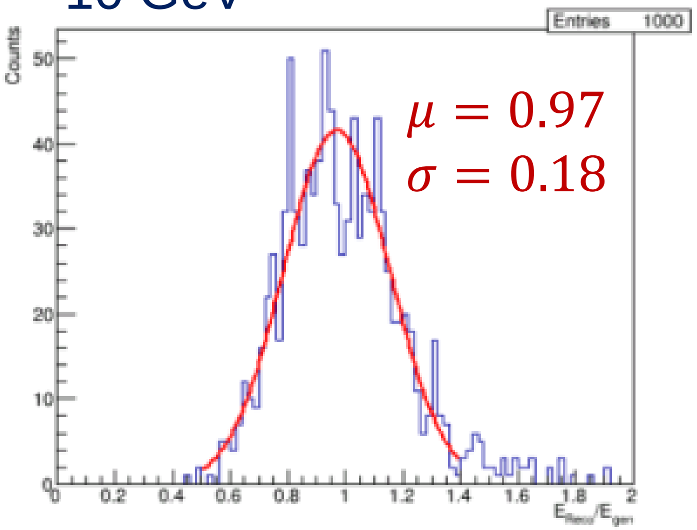
E.Bernardi[1], G.Drews[1], M.A.Garcia[2], R.Klanner[1], U.Kötz[1], G.Levman[3], M.Lomperski[4], D.Lüke[1], E.Ros[2], F.Selonke[1], H.Tiecke[5], M.Tsirou[4], W.Vogel[6]

Abstract

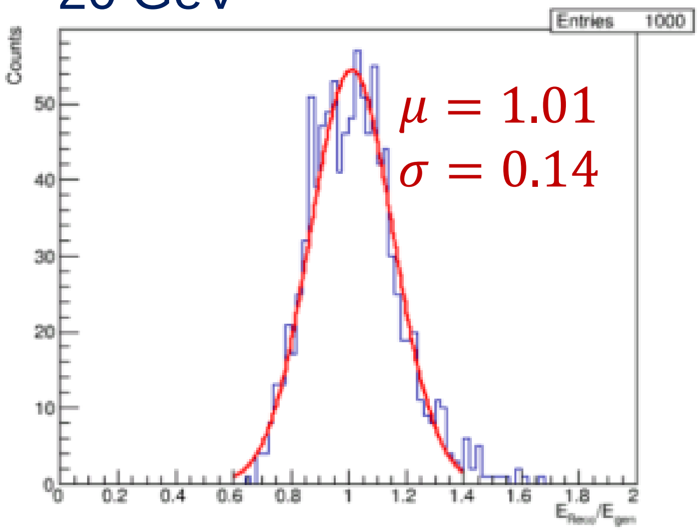
We have built a sandwich calorimeter consisting of 10 mm thick lead plates and 2.5 mm thick scintillator sheets. The thickness ratio between lead and scintillator was optimized to achieve a good energy resolution for hadrons. We have exposed this calorimeter to electrons, hadrons and muons in the energy range between 3 and 75 GeV, obtaining an average energy resolution of 23%/$\sqrt{E}$ for electrons and 44%/$\sqrt{E}$ for hadrons. For energies above 10 GeV and after leakage corrections, the ratio of electron response to hadron response is 1.05.

ZDC Ver. 2

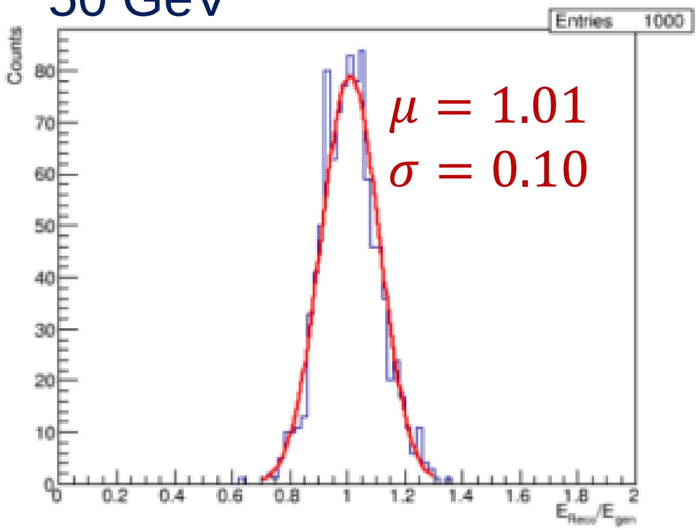
10 GeV



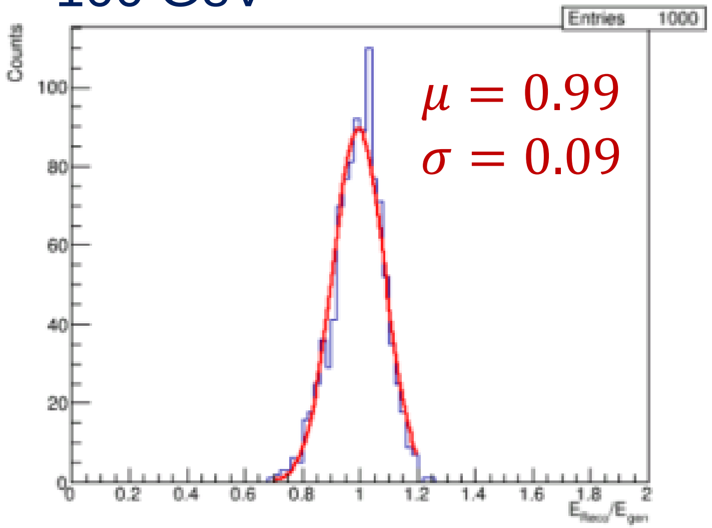
20 GeV



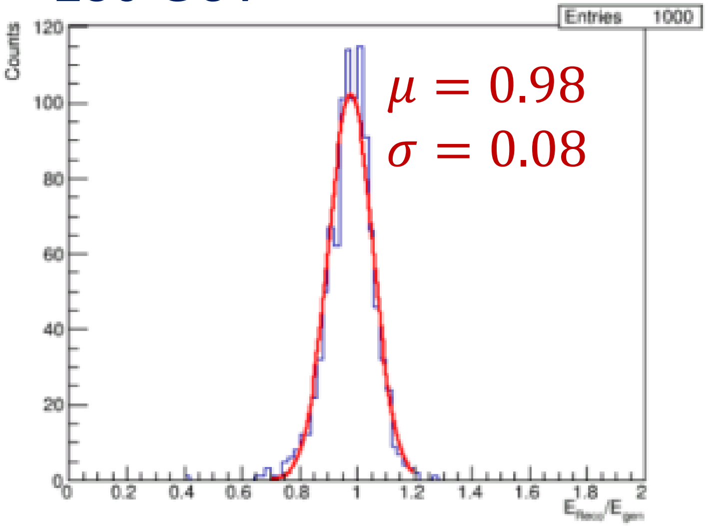
50 GeV



100 GeV



150 GeV

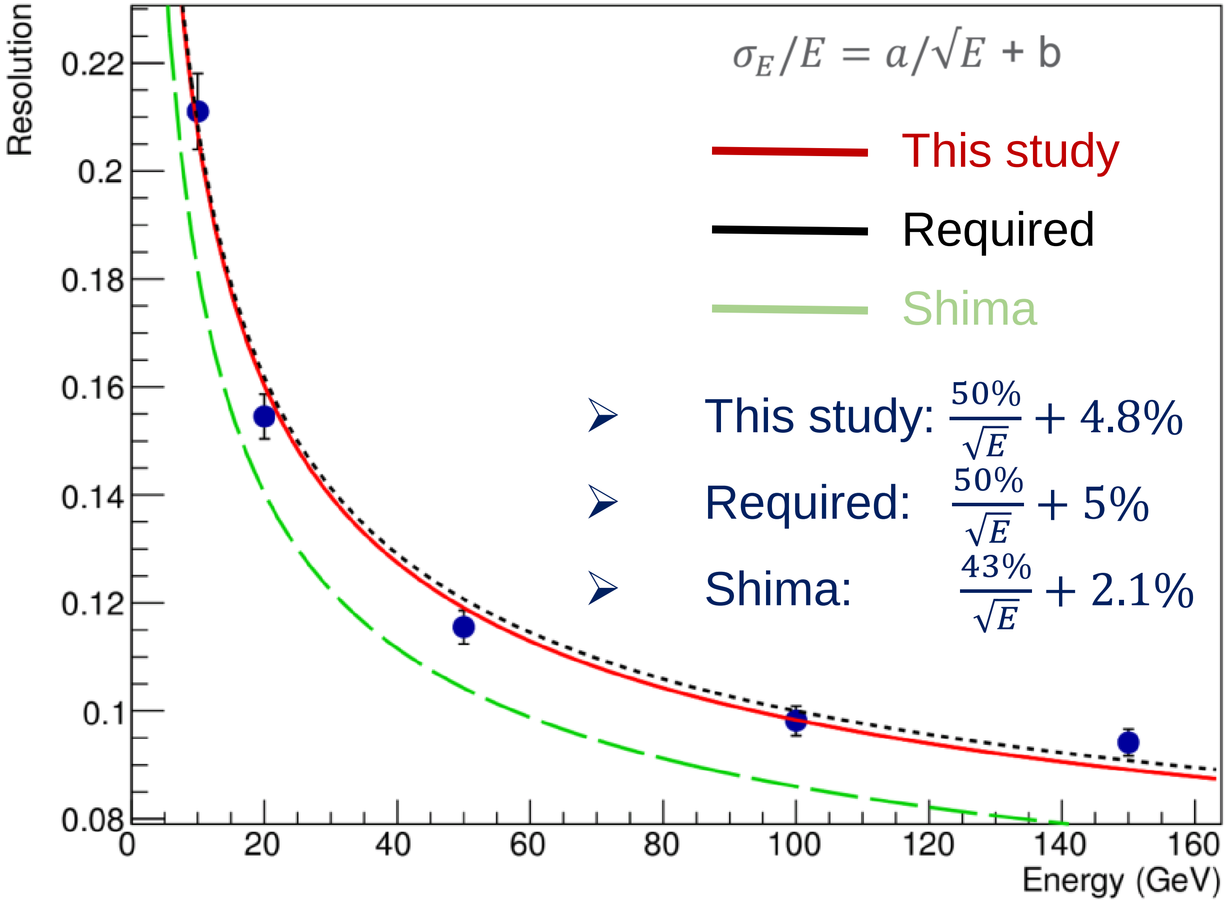


- Before:
  - Lead = 30 mm
  - Scintillator = 2 mm
- Now:
  - Lead = 25.6 mm
  - Scintillator = 6.4 mm

Each module contains 15 layers of Pb/Scintillators (480mm), unchanged.

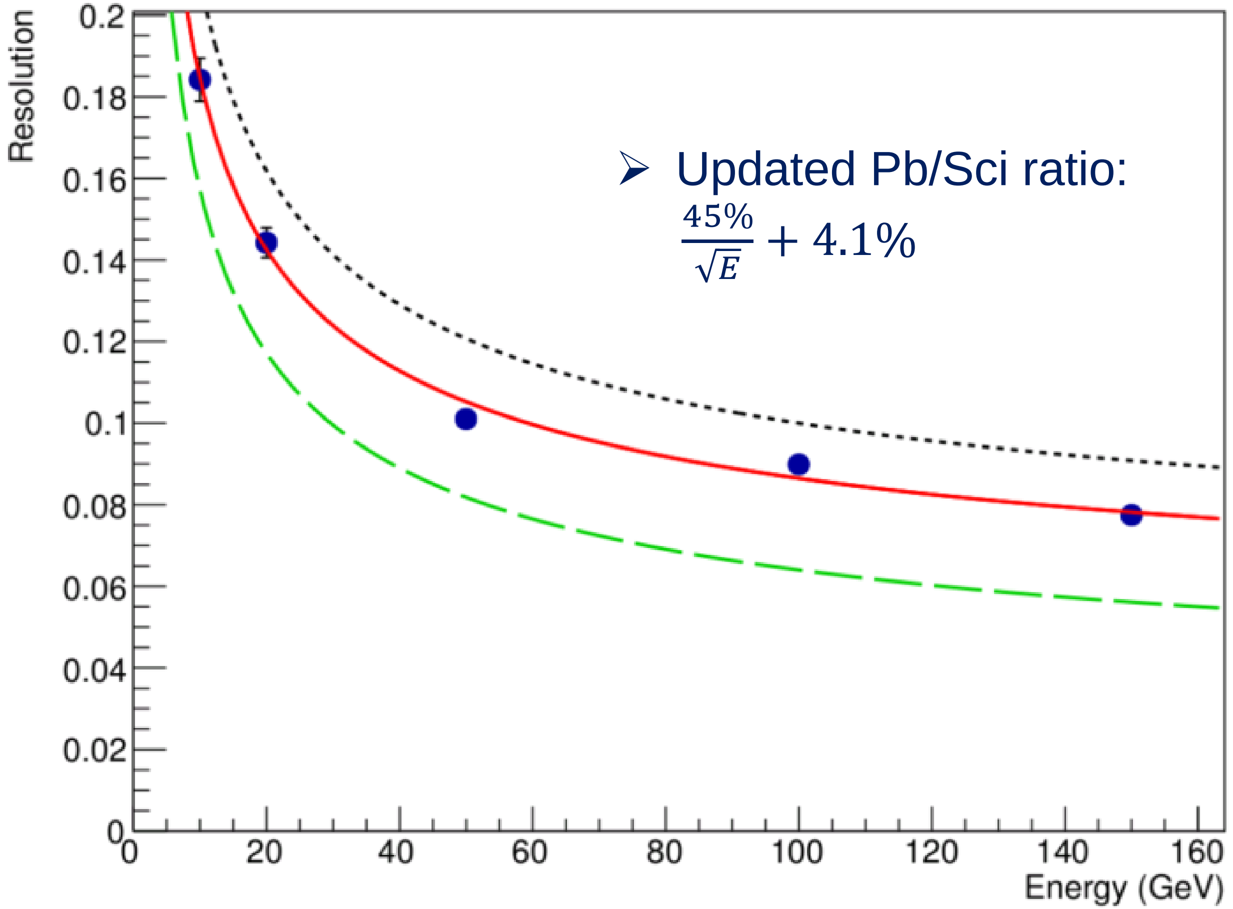
New ZDC Goemetry

Before



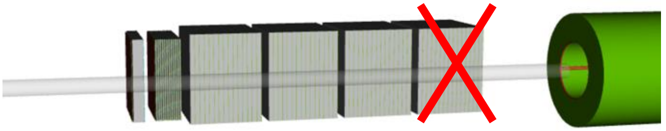
- This study: $\frac{50\%}{\sqrt{E}} + 4.8\%$
- Required: $\frac{50\%}{\sqrt{E}} + 5\%$
- Shima: $\frac{43\%}{\sqrt{E}} + 2.1\%$

Now

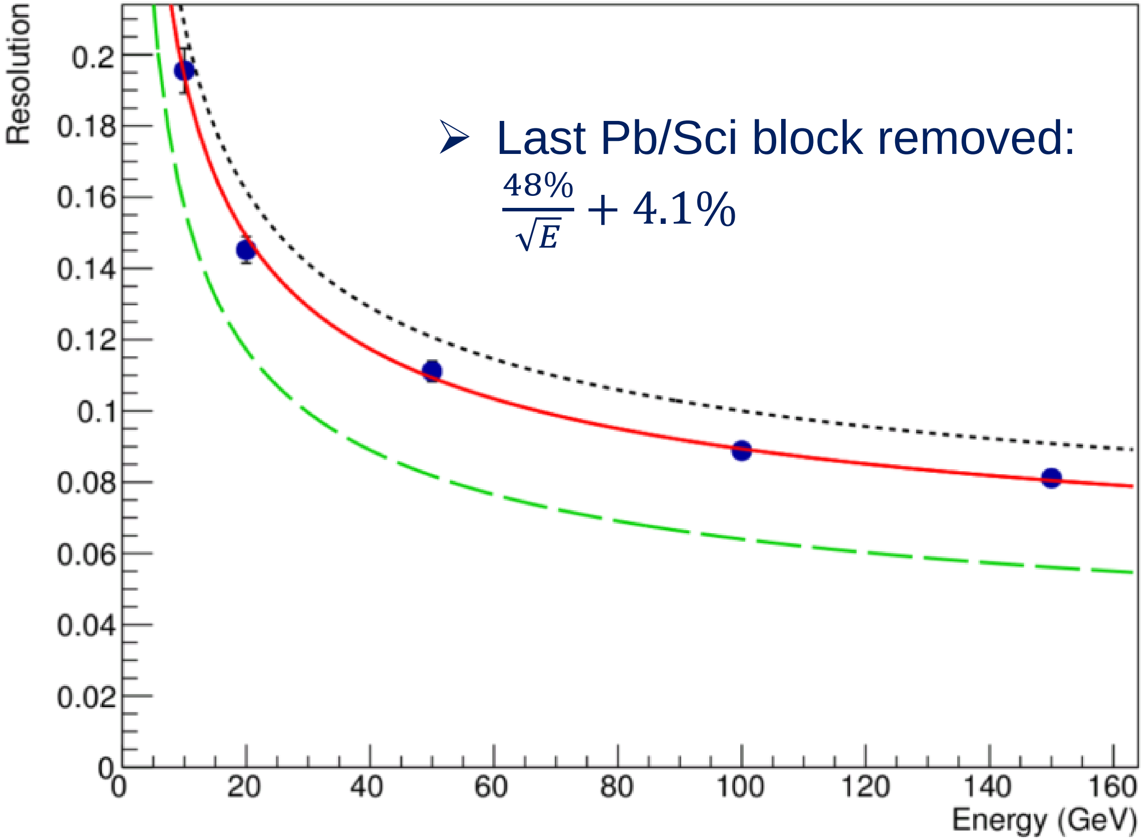


- Updated Pb/Sci ratio: $\frac{45\%}{\sqrt{E}} + 4.1\%$

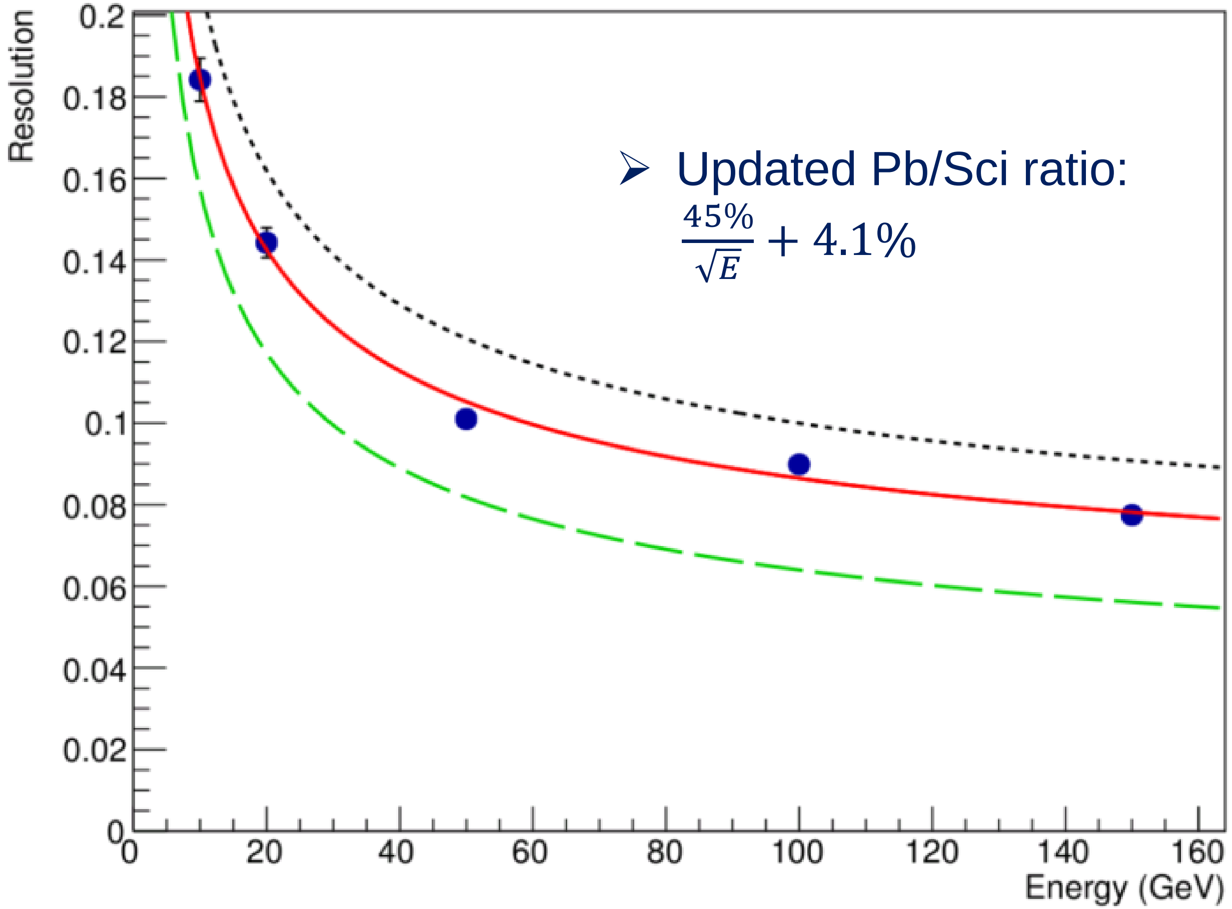
New ZDC Goemetry



Remove the last Pb/Sci block



Now



- ➢ Removing the last block deteriorates energy resolution
  → Still acceptable. Seeking for other possibilities.

Summary & Next Steps

- A series of resolution studies have been done for different ZDC designs
  - Previous observation of Shima has been confirmed using DD4hep
  - Reasonable energy resolution → optimization required

- Next Steps
  - Test of different ideas that within the size limit
  - Implementation of reconstruction
  - Position resolution
  - Shower development and the place for the imaging part of HCAL

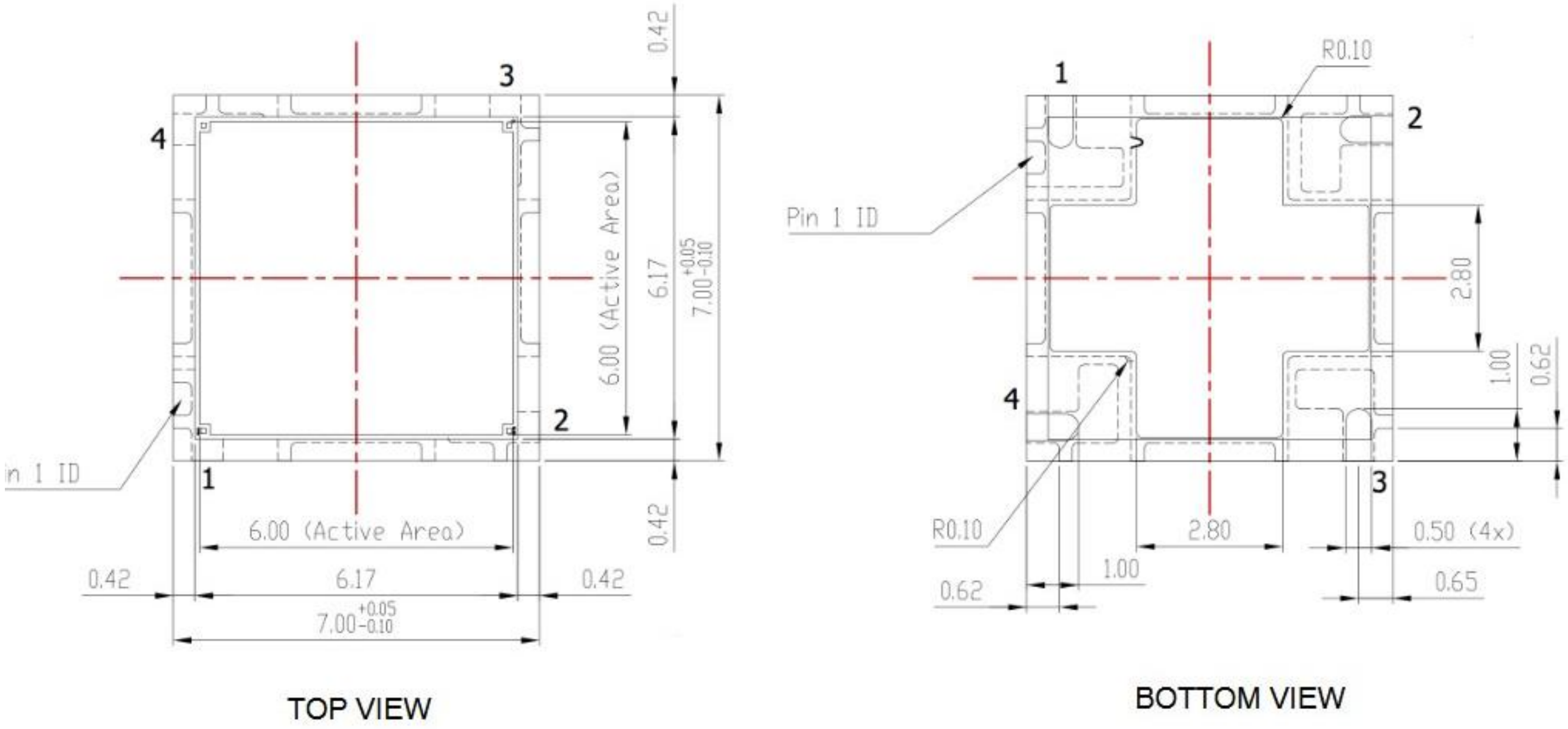
- New group expressing interest in ZDC simulation work:
  Group of Kentaro Kawade from Shinshu University

Status of constructing a ZDC EMCal for beam tests using LYSO crystals

Progress for the ZDC EMCal

- The fund for constructing an EMCal prototype for the ePIC ZDC using the LYSO crystals is in place
- The front-face cross-section of LYSO crystals was determined
- Standalone G4 simulation was set up and has been used to check detector performance

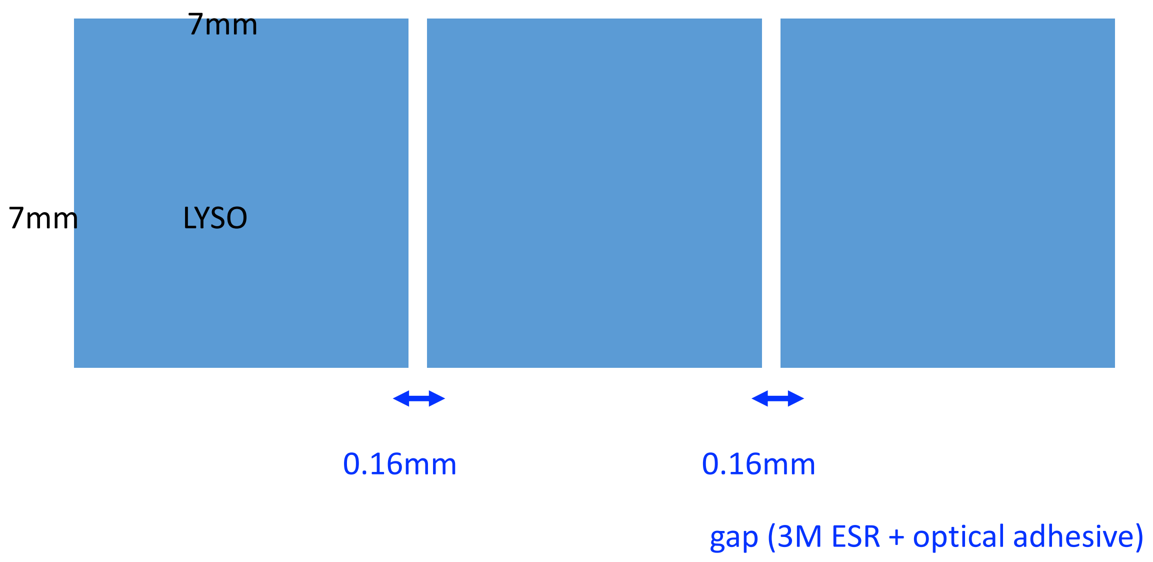
SiPM size



Active area: 6mm x 6mm
Total area: 7mm x 7mm
SiPMs are available at NCU

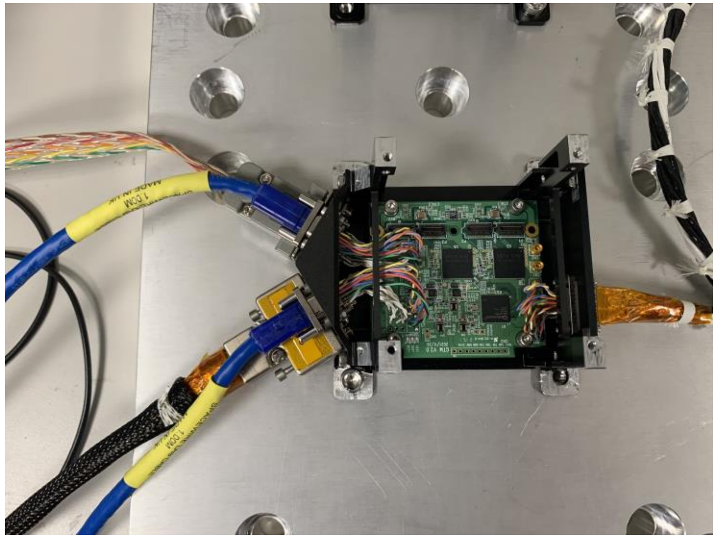
Front face cross-section of LYSO crystals

- thickness of 3M Enhanced Specular Reflector Film (ESR) and optical adhesive: 80µm



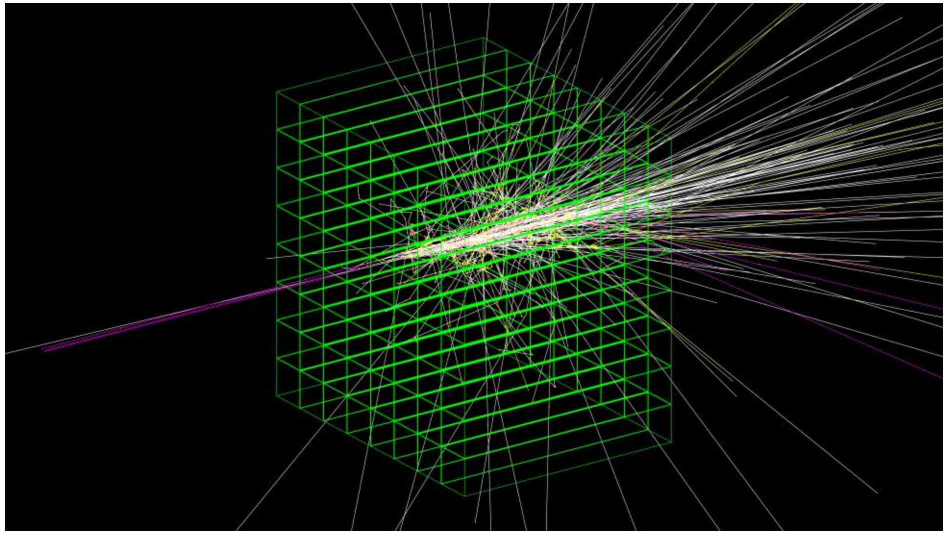
Readout

- The readout board was designed by Chih-Hsun Lin of Academia Sinica
- 128 channels
- Trigger:
  - self-triggered
  - can accept external timing signals → need to be studied
  - may take external triggers → need to be studied
- An adapter board is needed to fit our geometry, host the 8x8 SiPM array, and transmit signal from SiPMs to readout the board
  - will be designed after the LYSO crystals are ordered

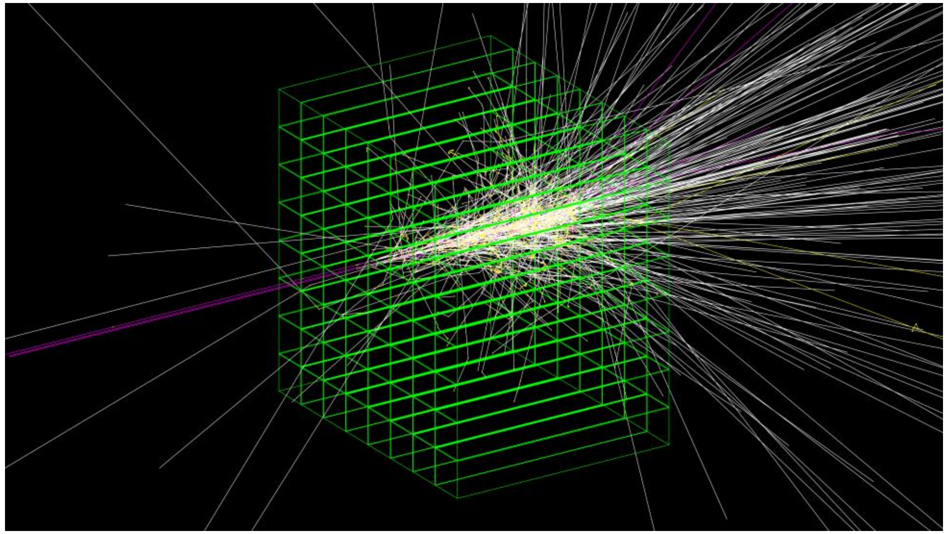


Event displays in Geant4

LYSO



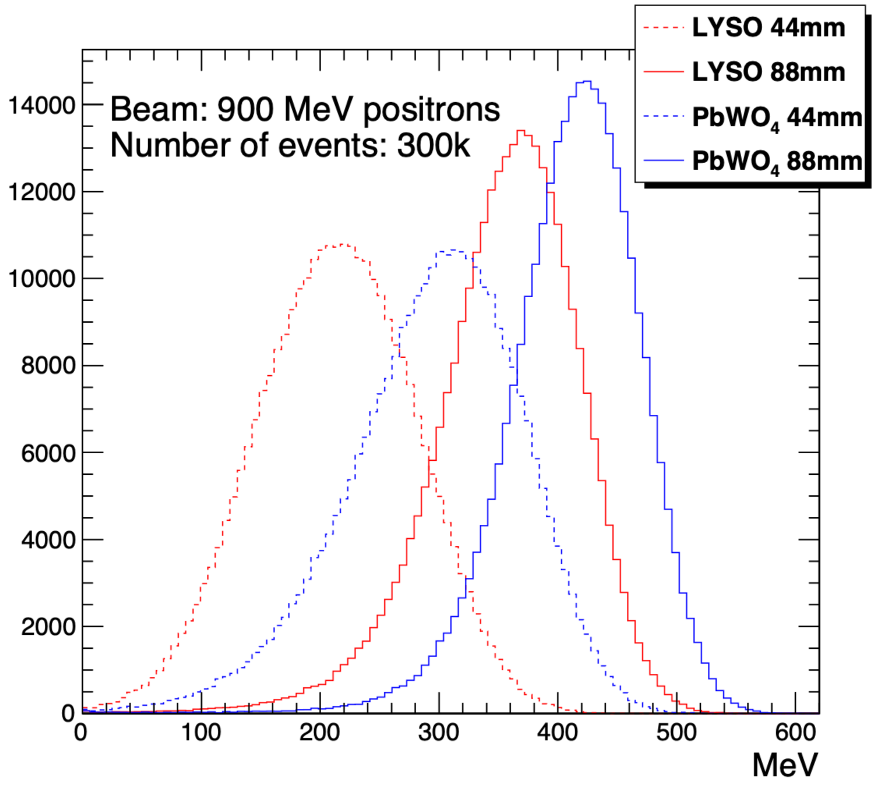
$PbWO_4$



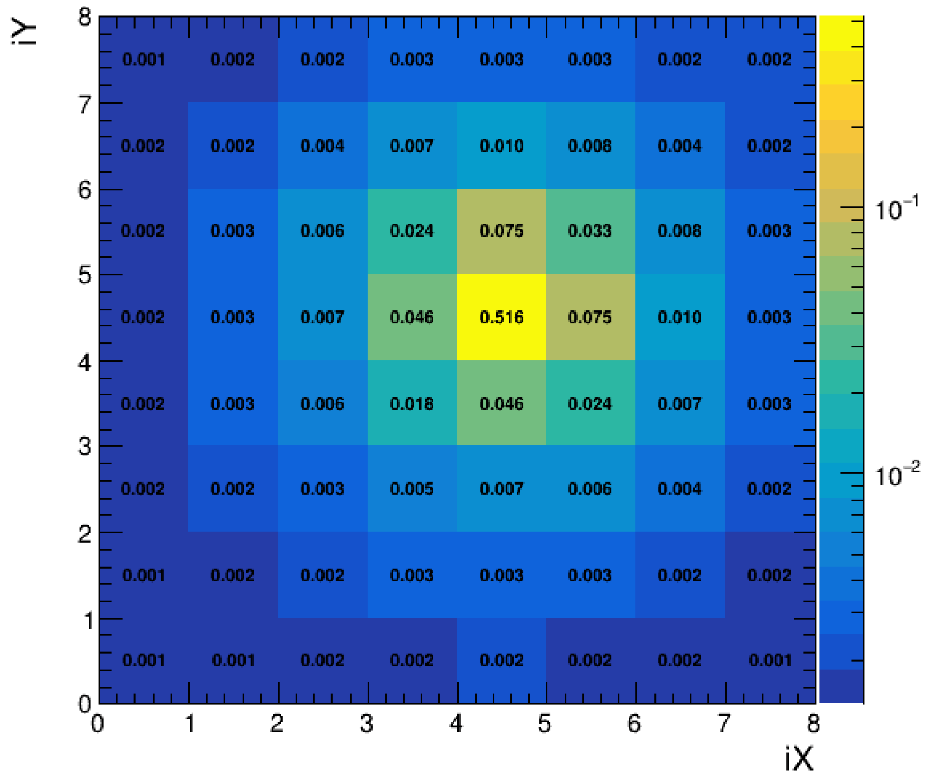
- Crystal dimension (front face):
  7mm x 7mm
- Crystal length: 88mm

- Crystal array: 8x8
- Beam: 900 MeV positrons

Energy deposit and shower profile



- Not really a fair comparison because $PbWO_4$ has a shorter radiation length
- Simulation needs to be redone with the exact $1X_0$ for $PbWO_4$

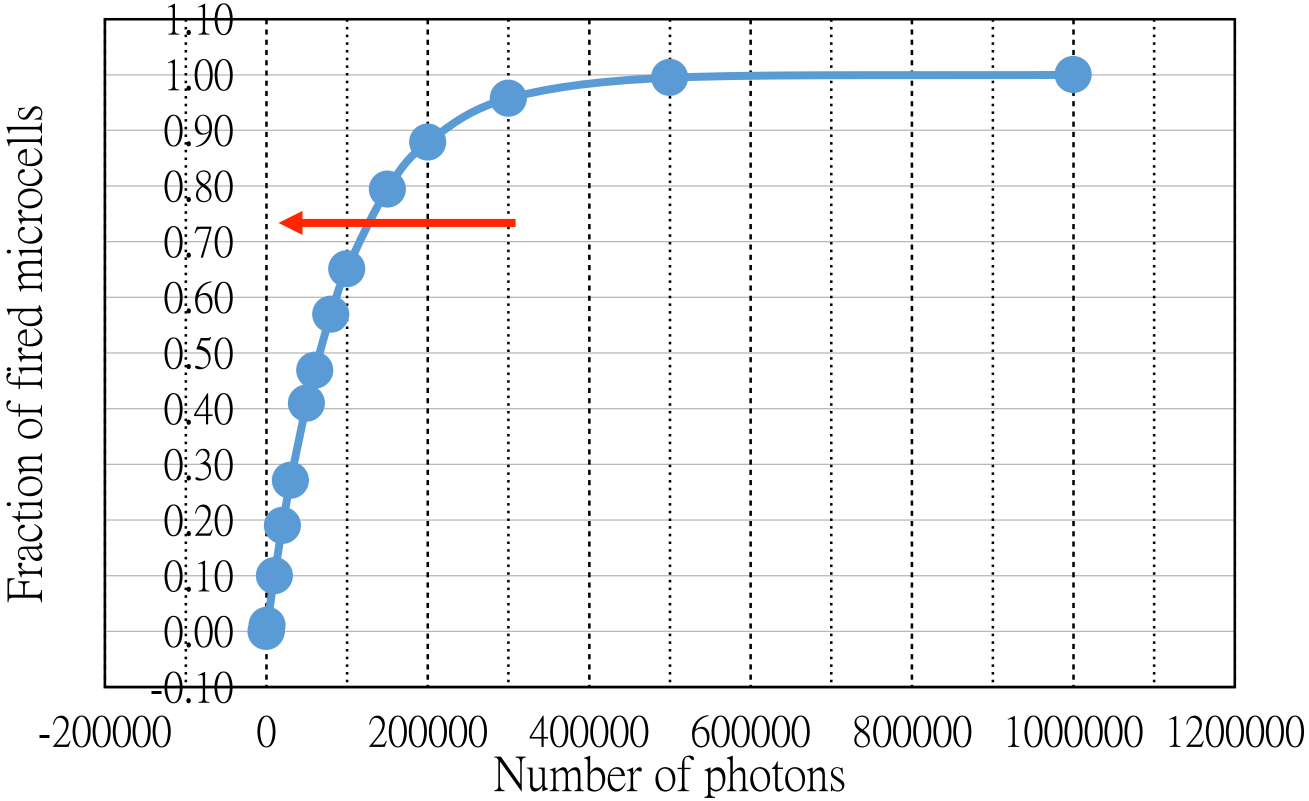


- 96% of energy is contained within the 5x5 array

Light yield estimation

- assuming light collection efficiency: 25% and photon detection efficiency: 20%
- length of crystal: 88mm
- LYSO: 500MeV x 40000 photons/MeV x 0.2 x 0.25
  = 1,000,000 photons
- $PbWO_4$: 500MeV x 200 photons/MeV x 0.2 x 0.25
  = 5000 photons

Fired microcells vs # of photons



- Need the fraction of fired microcells of a SiPM below 70% for a linear response

Saturation effect for the SiPM

- Based on the current estimation for 900 MeV positrons, we will have the saturation effect for the central crystal
- According to the discussion in the ePIC ZDC meeting, light collection efficiency may not be as high as 25%
  - need to be studied
- In addition, an optical filter can be added to suppress the light yield

Plans and timeline

- Place the order for the LYSO crystals
  - have been negotiating the price with the producer
- Design an adapter board for the SiPM array
- Construct and test the prototype with cosmic rays, lasers, and maybe low-energy proton beams in Taiwan
- Conduct beam tests in Japan

Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
order cystals	• design an adapter board • crystal production		construct the prototype	test with cosmic rays, lasers and proton beams			beam test at ELPF

Summary

- Constructing a prototype for ZDC EMCal using LYSO crystals is in progress
- An array of 8x8 crystals will be built with a front-face cross-section of 7mm × 7mm for a single crystal
- An adapter board will be designed to host the SiPM array
- Readout electronics are almost in place
- Plan to test this prototype with cosmic rays, lasers, and possibly low-energy proton beams in Taiwan between November 2023 and January 2024
- We target to have a beam test at ELPF in Japan in February 2024