Simulation studies of the pair spectrometer calorimeter for luminosity detector of ePIC experiment

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Content

Luminosity Detector - Introduction

- Performance of particle collider : Beam Energy & Luminosity

- Luminosity is the maximum no. of collisions that can be produced in the collider per cm^2 per sec.

Fig. Schematic diagram of two symmetric beam bunches colliding in interaction point [2].

$$L = f\, N^2 / 4\, \pi\sigma^2$$

N ~ # particles in the bunch, f ~ bunch crossing frequency & σ ~ transverse size of bunch

- Rate of any event during collision (R) = L · cross-section (σ_p) of the associated process.

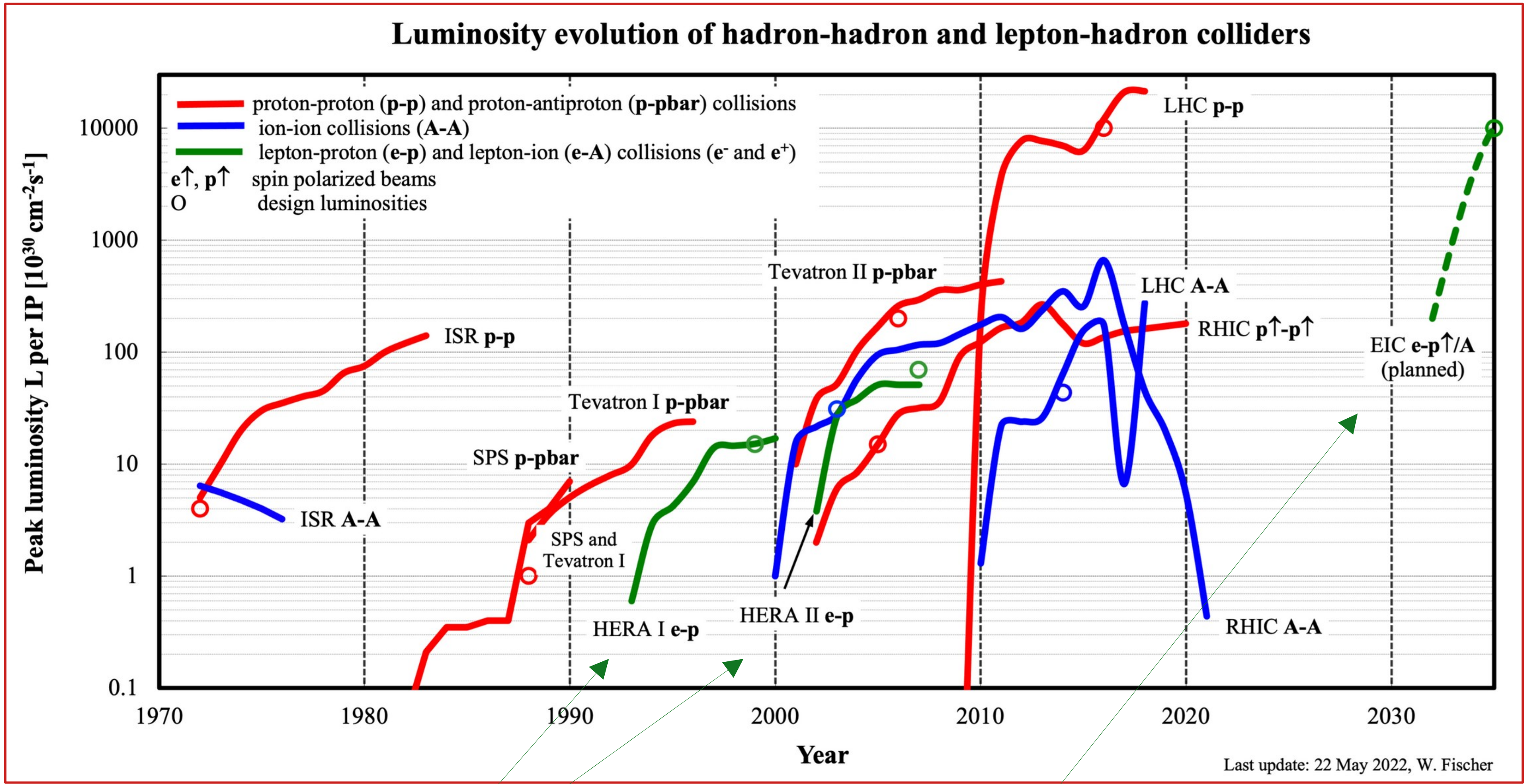
- Precise measurement of L = Precise measurement of σ_p

- High Luminosity to observe physics processes having low cross-section.

- At EIC, precision ~ 1% & High Luminosity ~ $10^{33\text{-}34}$ cm^{-2} s^{-1}

[2] https://www.lhc-closer.es/taking_a_closer_look_at_lhc/0.luminosity

Luminosity Detector – Past to Future



The Forerunner !

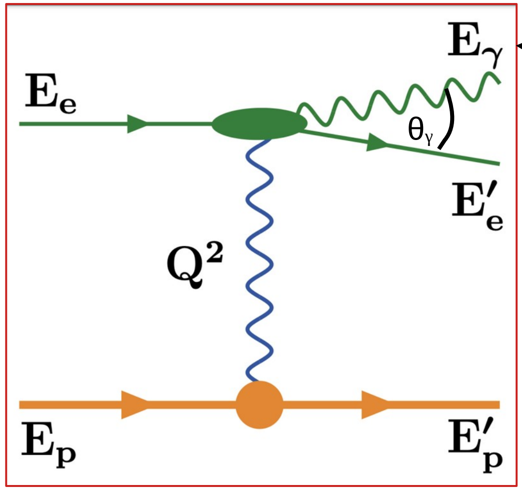
The Future !

[1] https://www.rhichome.bnl.gov/RHIC/Runs/

Luminosity Detector – Bremsstrahlung Process

- HERA (Forerunner of EIC) measured luminosity via Bremsstrahlung (BH) radiation.
- Radiation due to elastic scattering of electron near strong electric field (p / Nu).

E_e : Incoming e^- energy
E_p : Incoming p energy



E_e' : Outgoing e^- energy
E_p' : Outgoing p energy

1. High Rate ~ 4.7 MHz [2]

2. Precisely calculable cross-section from QED, Bethe-Heilter equation

$$L = R/\sigma_{BH}$$

[1] https://arxiv.org/pdf/2106.08993.pdf [2] http://www-library.desy.de/preparch/desy/1992/desy92-066.kek.pdf

Luminosity Detector – Major Background during measurement

1. Synchrotron Radiation

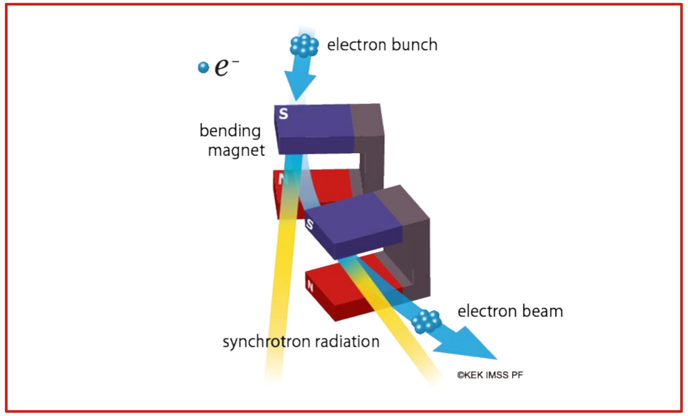


Fig. e- beam bending in dipole magnet, producing a fan (shown in yellow) of Synchrotron radiation (SR).

- High rate due to bending dipole magnets in vicinity of IP Like B2ER (0.2 T).
- A fan of SR photons is primarily along neg. z-axis along Lumi Detector.
- Low energy (~ 10-100 MeV) therefore mimics BH photons.
- Can be solved with proper estimation through dry runs/pilot bunches and with ZEUS (HERA) PS design of Lumi Detector.

2. Beam-Gas Interactions

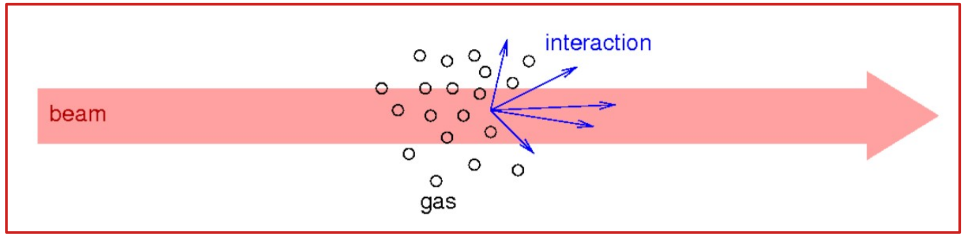
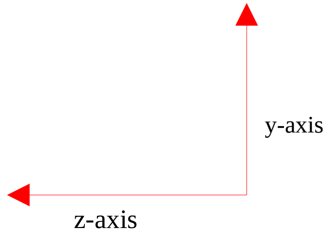


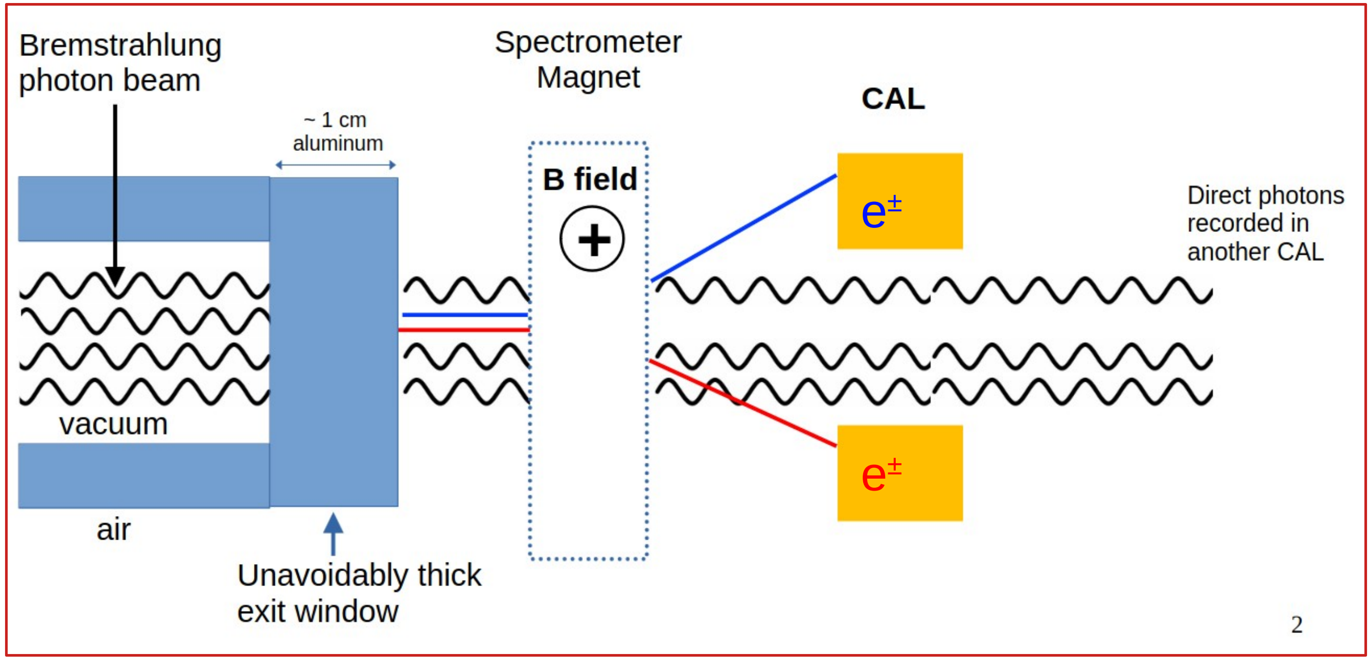
Fig. A beam of particle colliding with residual gas.

- Collision of e^- /p beam with residual gas in the beam pipe and/or IP.
- Firstly, e^- beam produces extra BH photons.
  - Lower rate than SR.
  - Can be taken care of with proper estimation through dry runs/pilot bunches.
- Proton beam will produce extra hadrons near the CAL region.
  - Can be taken care with thick shielding and identifying hadrons hit with CAL.

https://www.kek.jp/en/topics-en/20220623pf40year/

Luminosity Detector – ZEUS Design Problems





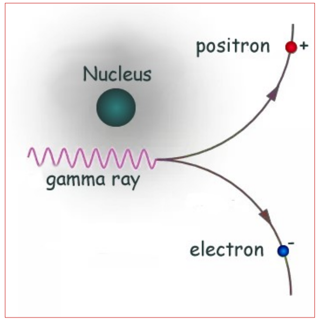


Fig. Pair Production [2]

Primary problem with ZEUS layout :

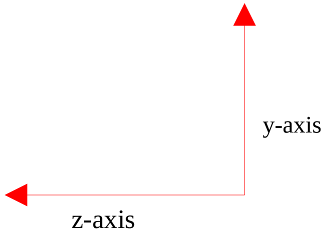
Thick γ exit window also acts as γ converter.

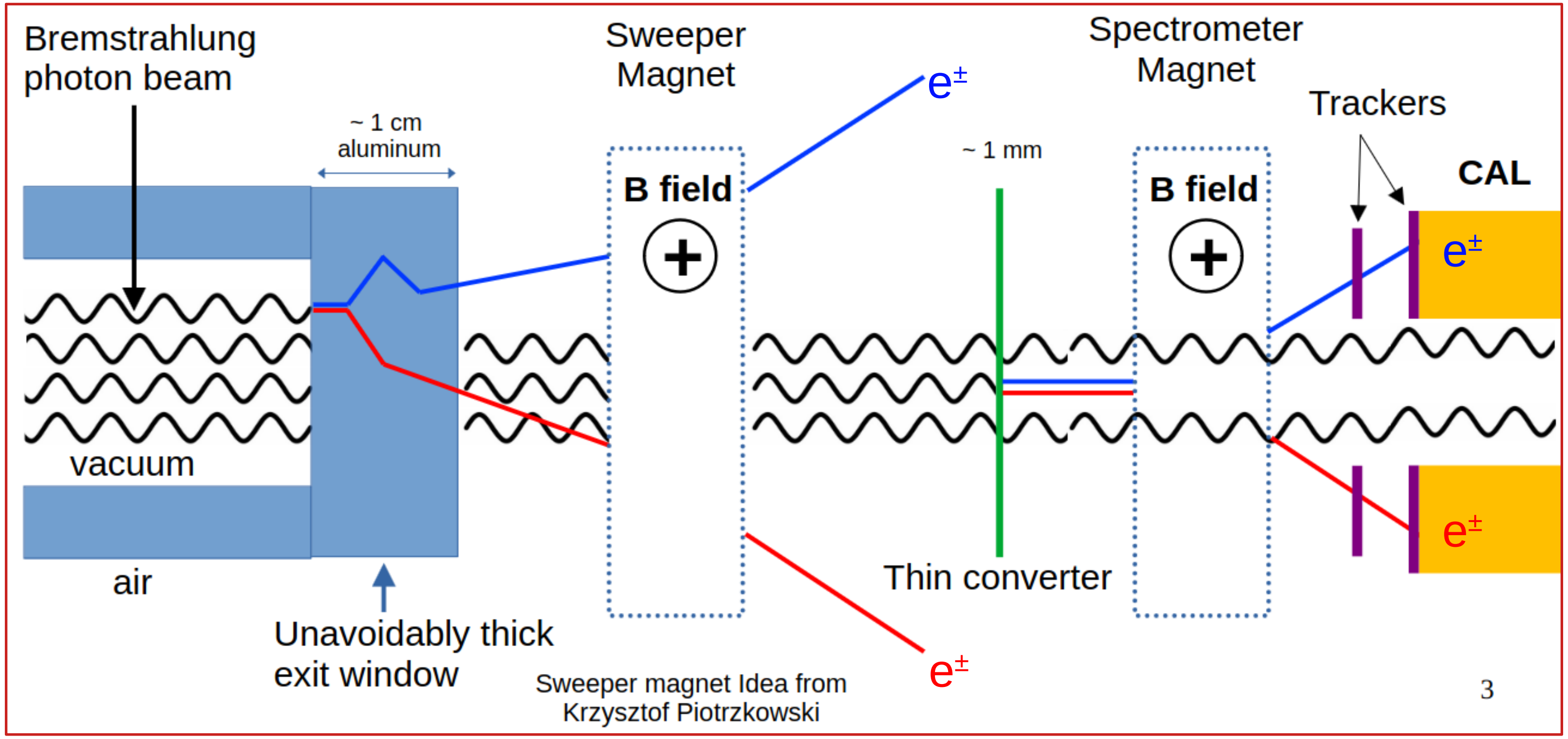
Multiple scattering of γs, Excessive pair converted γs, Huge Pile up at PS

Limits the Accuracy of Measurement

[2] https://www.cyberphysics.co.uk/topics/particle/pairproduction.html

Luminosity Detector – ePIC Design





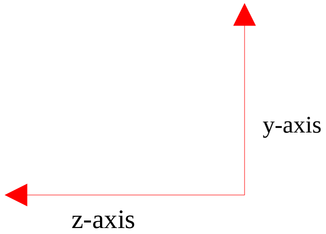
Primary advantage :

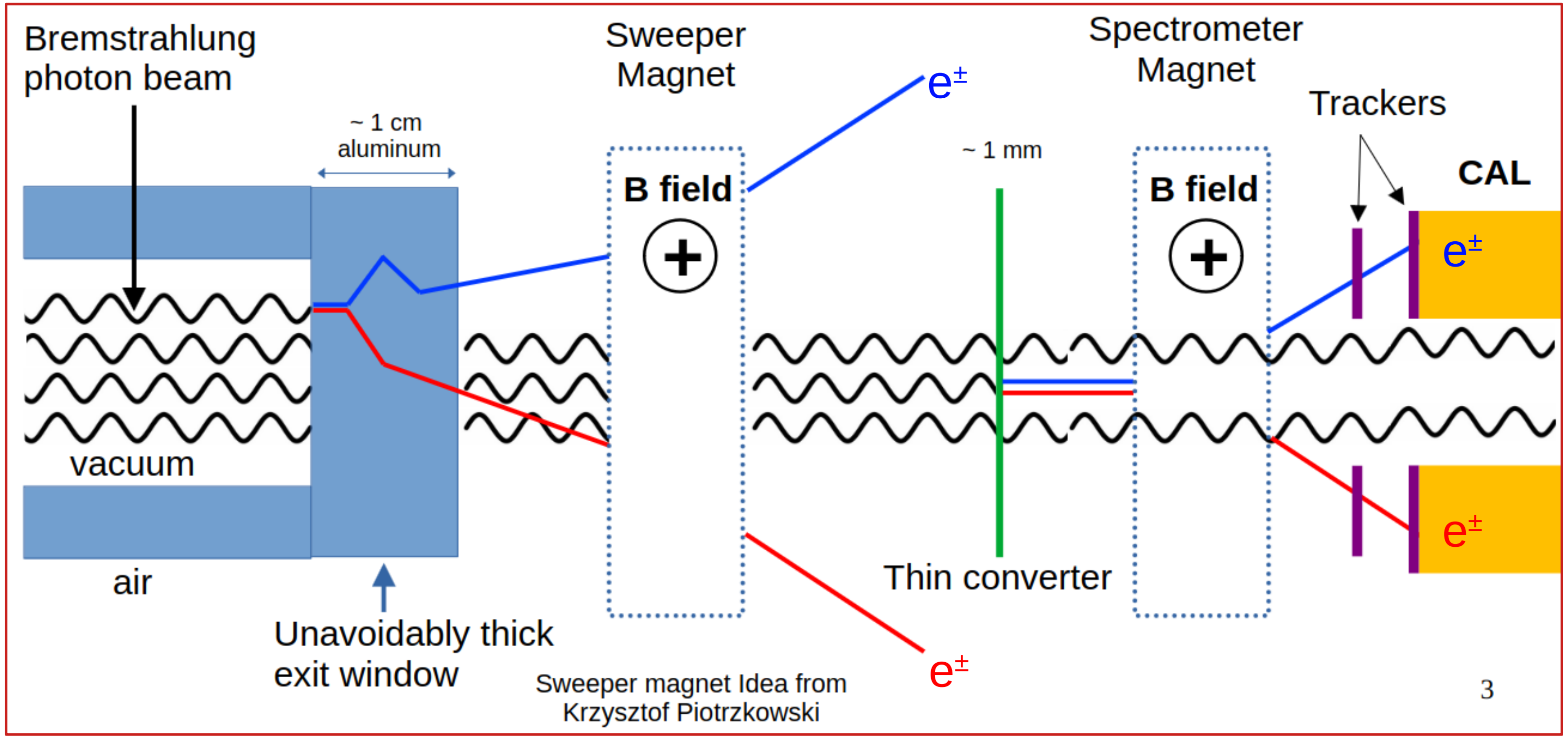
1. Thin BH γ converter

Control on pair produced $e^{\pm}$ reaching PS (event pileup Minimized)

Gain in the Accuracy of Measurement

Luminosity Detector – ePIC Design





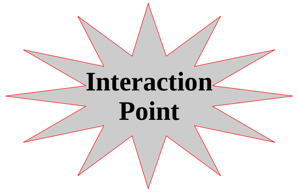
Primary advantage :

2. Addition of Trackers

Measure path of produced $e^{\pm}$ reaching PS

I. Profile of e^{-} beam
II. Acceptance correction

Luminosity Detector – Placement at far-backward region.



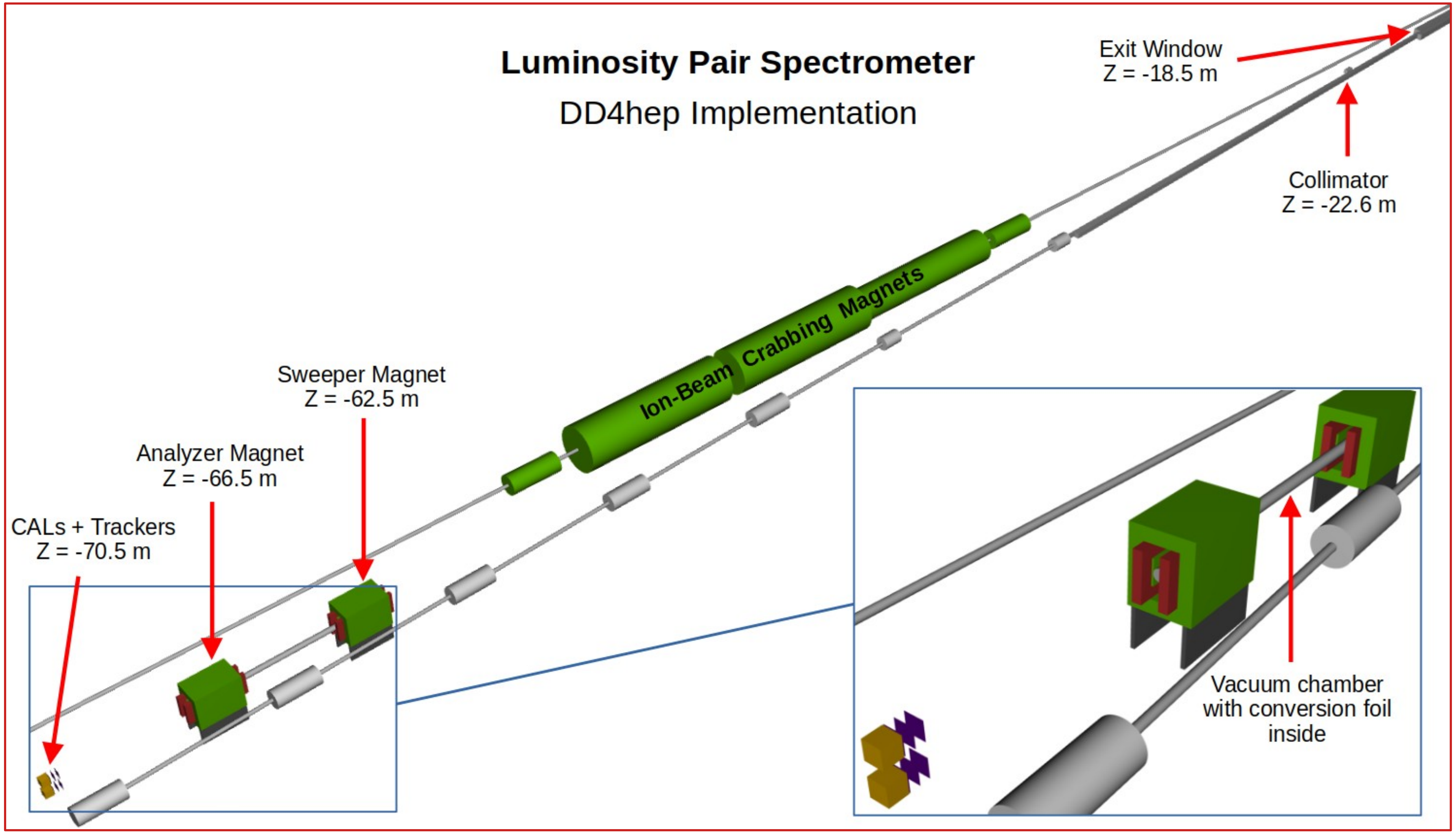


Fig. Current Epic Luminosity Detector design with e⁻ and p beam pipes and magnets built by Dhevan G., Aranya G. & Justin C. in DD4hep. The placement of different component not fixed, changes according to experimental needs.

https://arxiv.org/pdf/2106.08993.pdf

Pair Spectrometer – EM Calorimeter Type

Homogeneous Calorimeter

- Detector = absorber + active material

- good energy resolution
- limited spatial resolution
- Ex. Scintillator Crystals like $PbWO_4$

Sampling Calorimeter

- Detectors and absorber separated → only part of the energy is sampled.
- Absorber – Hard Material like Pb, W
- Active Part – Scintillating fibers, crystals
- good spatial resolution
- limited energy resolution
- Ex. Spaghetti CAL ~W-Scintillator fibers

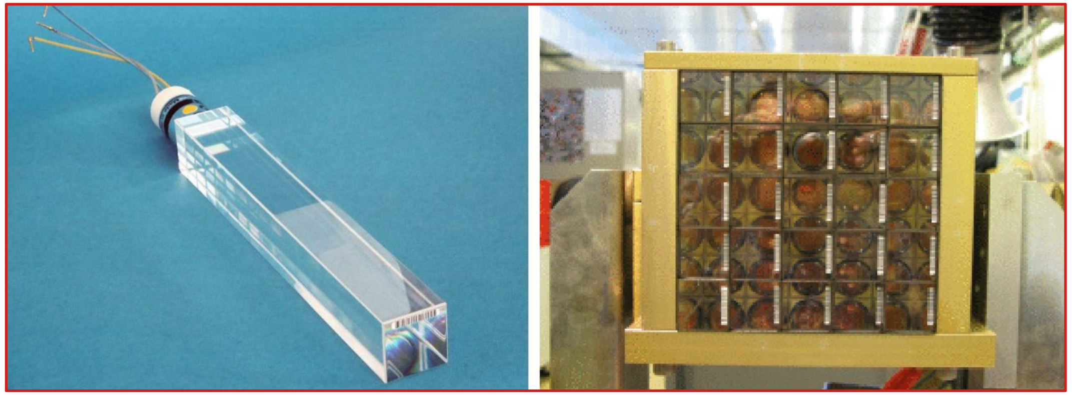


Fig. A picture of $PbWO_4$ crystals used in CMS experiment [1]

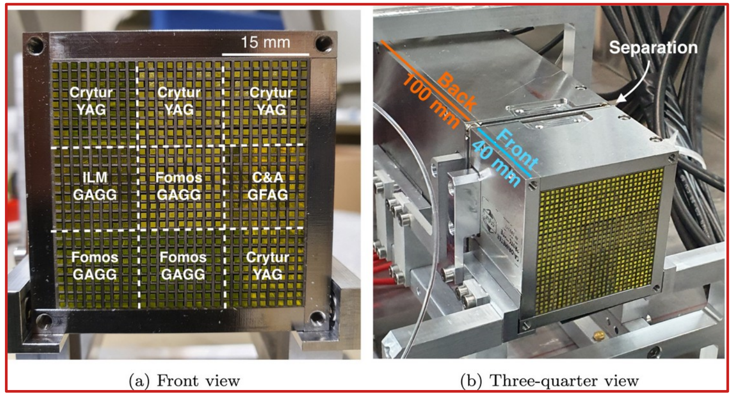


Fig. A picture of W-Scifi Calorimeter used in G2 muon Experiment

Fig. W-Scifi Detector used in Sphenix Exp.

Integration time > Bunch spacing in ePIC → Current Focus Spaghetti CAL !

[1] https://davec.web.cern.ch/Student-writeups/Rebecca-Falla-ClusteringEE.pdf

[2] https://doi.org/10.1016/j.nima.2022.167629

[3] https://www.bnl.gov/rhic/sphenix.php

W-Scifi – W to Scifi Volumetric Ratio

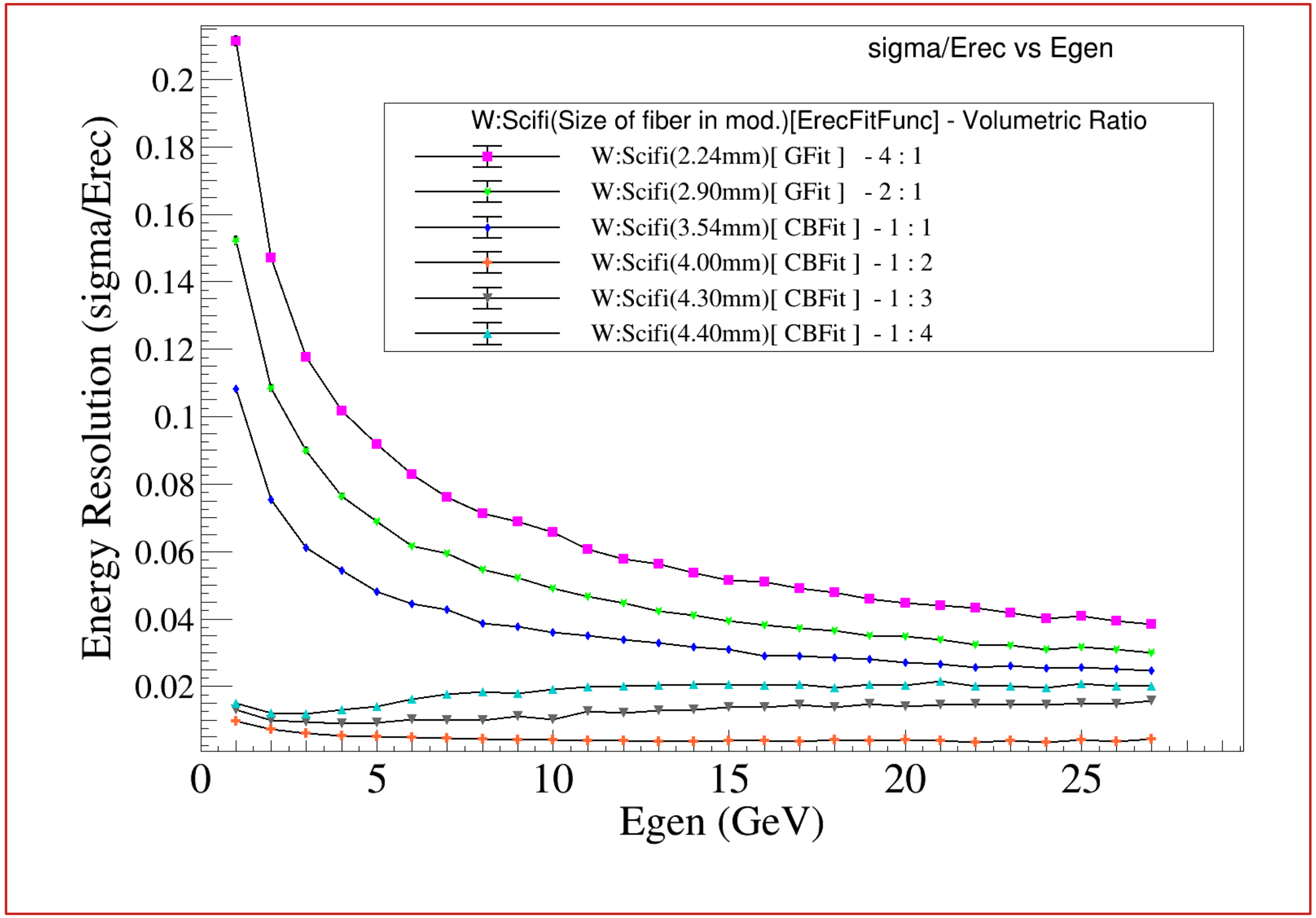


Fig. Electron resolution plot for different volumetric ratio of W and Scifi in CAL.

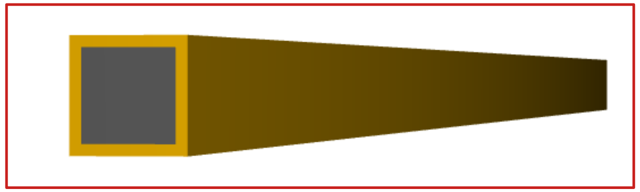


Fig. Single module 5x5x200 mm. Inner (gray) part Scifi with outer (golden) part W. Fiber Size can be changed to match the needed volumetric ratio of CAL

- e^- gun at center of CAL (0.0, 17.0, 6490) cm.
- 1 e^- @ event, 4000 Events
- Energy range : 1 – 28 GeV
- Gaussian/Crystal Ball fit to each energy histogram
- Sigma and Mean from fit function determines resolution value for each energy.

Better resolution when W:Scifi ~ 1:1

W-Scifi – Size of fiber

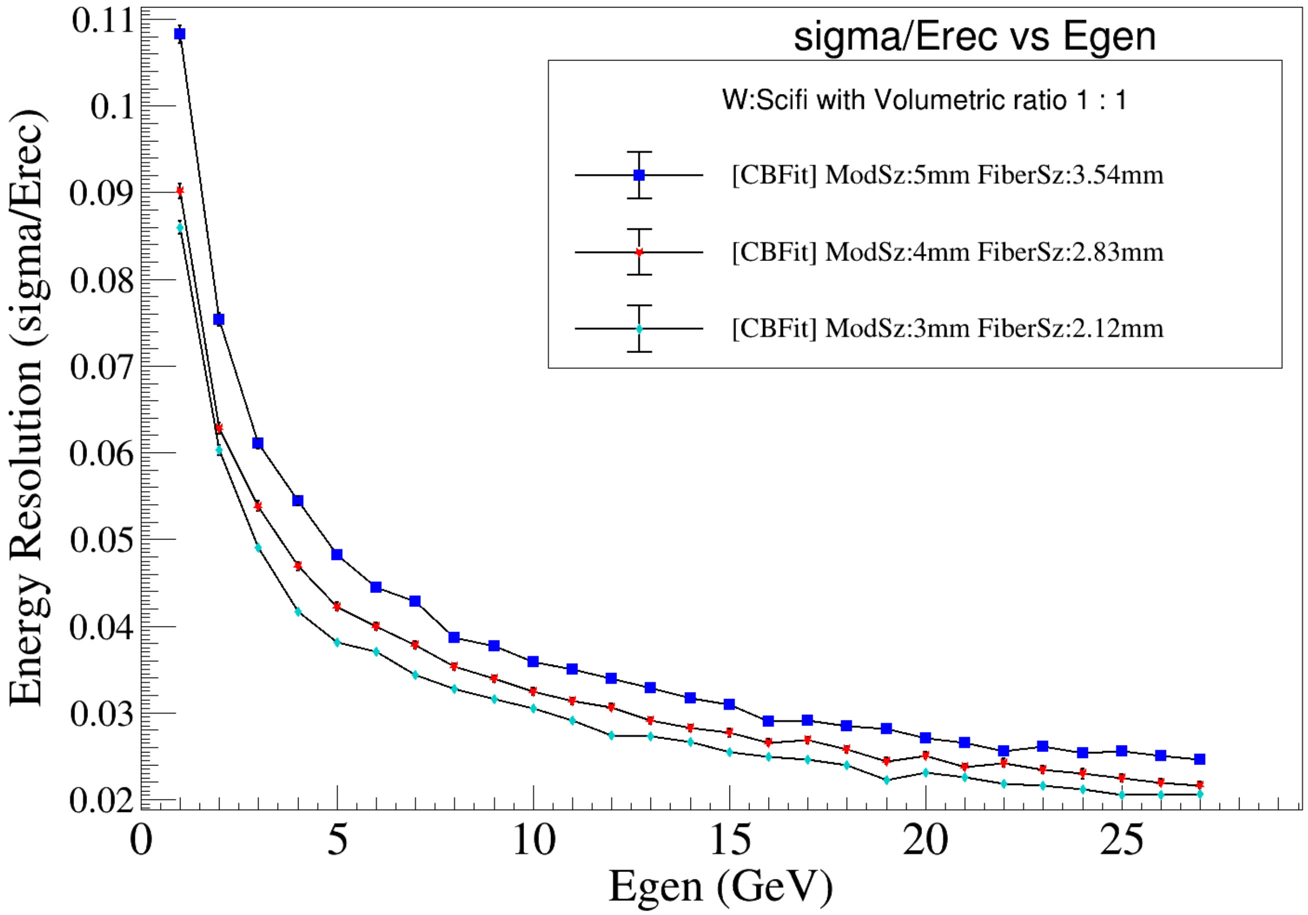


Fig. Energy resolution plot for different fiber size but same volumetric ratio of W and Scifi in CAL.

Moderately better resolution when fiber radii is smaller

W-SciFi CAL - Design

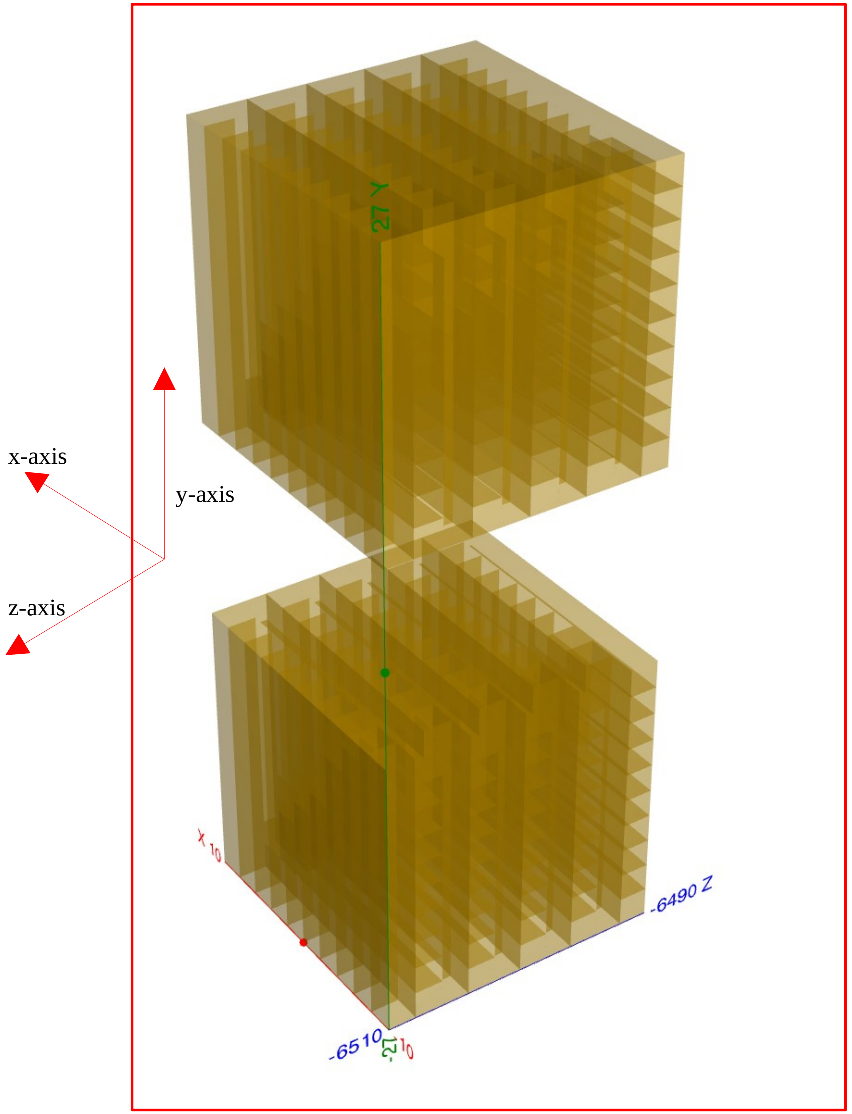


Fig. 2D W-SciFi calorimeter built by Aranya Giri in DD4hep

- Calorimeter size - 20 x 20 x 20 cm^3
- Alternating Layer of Y-rot and X-rot module
- Each Layer has 10 modules
- Module size - 2 x 2 x 20 cm^3
- Fiber Size - radius – 0.1 cm , height - 20 cm
- Fiber # in a module - 60
- W-Scifi Ratio - 1 : 1
- Fiber Holder
  - Material - Brass
  - thickness – 0.05 cm
  - 5 x Fiber Holders 5 cm apart
- 5 closest fibers are bundled to make a single readout channel.

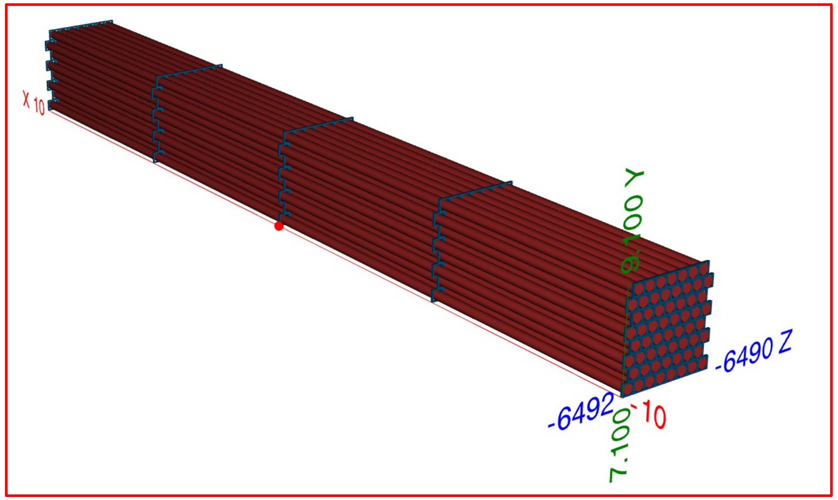


Fig. Each single W-Scifi module in CAL

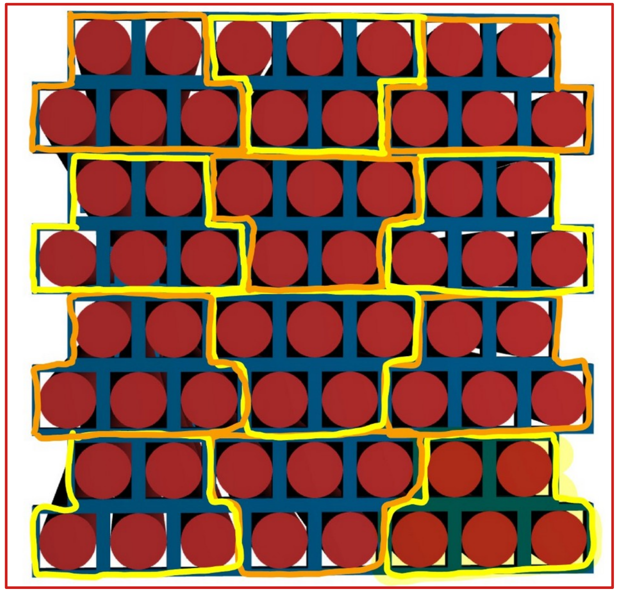


Fig. Representation of Scifi fiber bundles in each module

Inspiration of Design : [1] 10.1088/1742-6596/404/1/012023

W-Scifi – Resolution

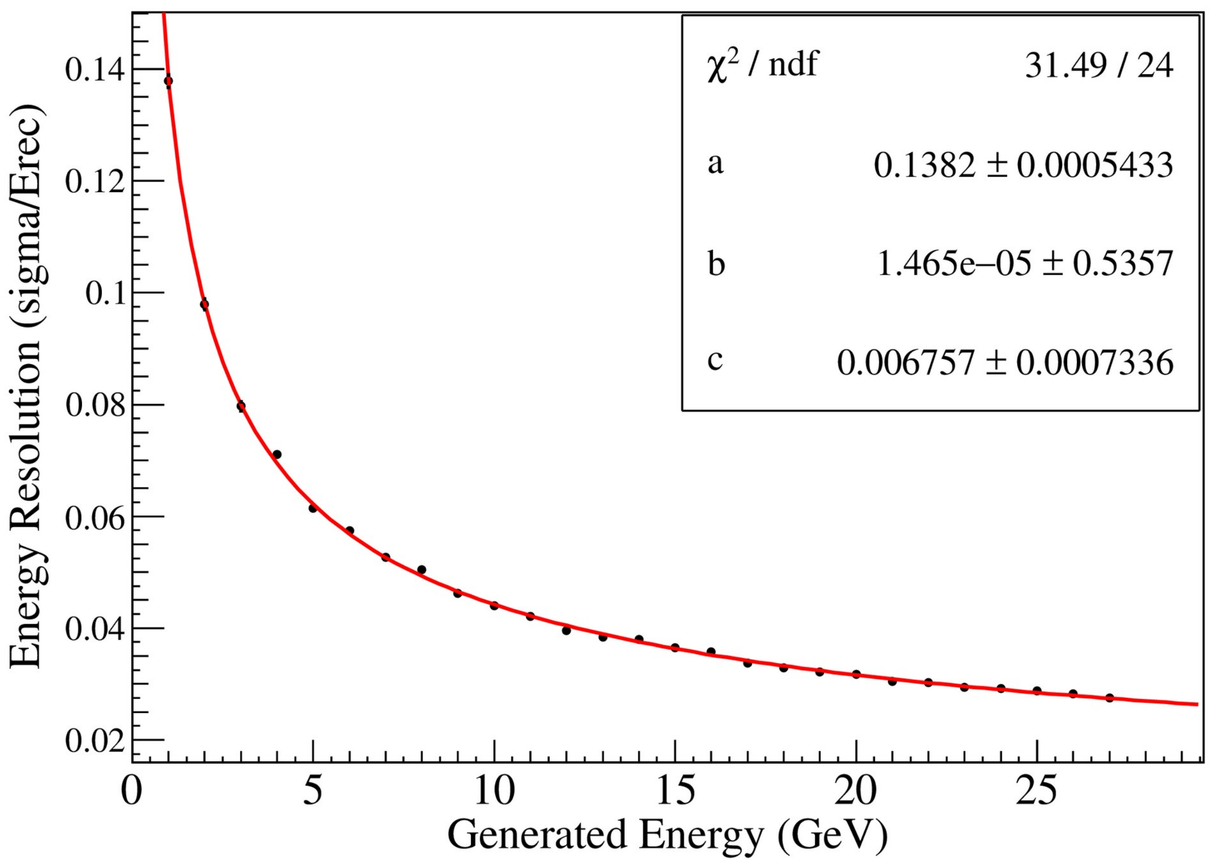


Fig. Energy resolution plot for current W-Scifi design.

- e^- gun at center of CAL (0.0, 17.0, 6490) cm.
- 1 e^- @ event, 4000 Events
- Energy range : 1 – 28 GeV
- Gaussian fit to each energy histogram
- Resolution Parameter
  - a. - 13.8%
  - b. - 0.01 MeV
  - c. - 0.7%

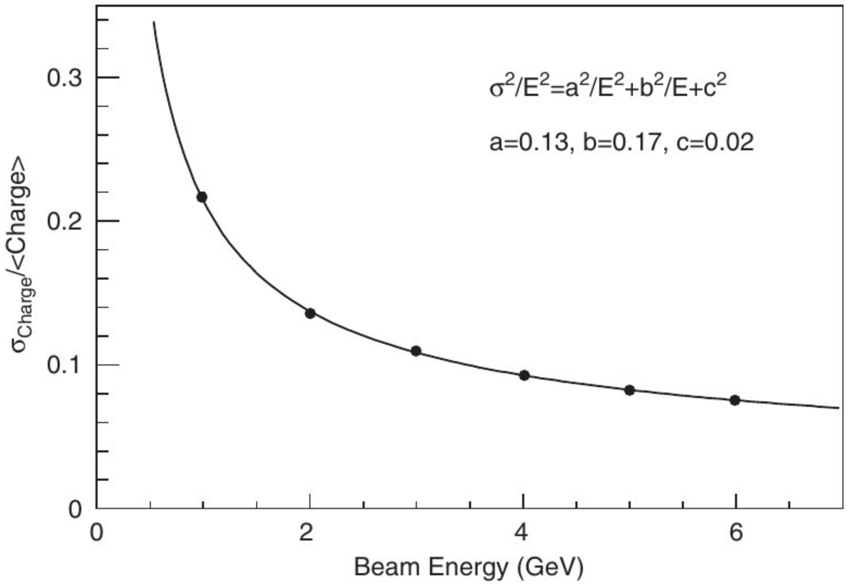


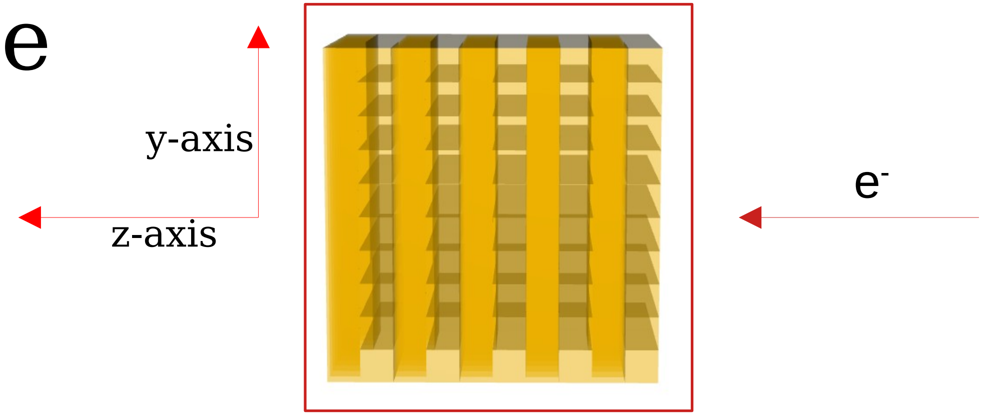
Fig. Energy resolution plot for segmented tungsten-scintillator sampling calorimeters at ZEUS experiment [2].

Resolution comparable with ZEUS Pair Spectrometer CAL.

[2] https://doi.org/10.1016/j.nima.2006.06.049

W-Scifi – Shower Energy Profile

- 10 GeV e⁻ shot at center of CAL.



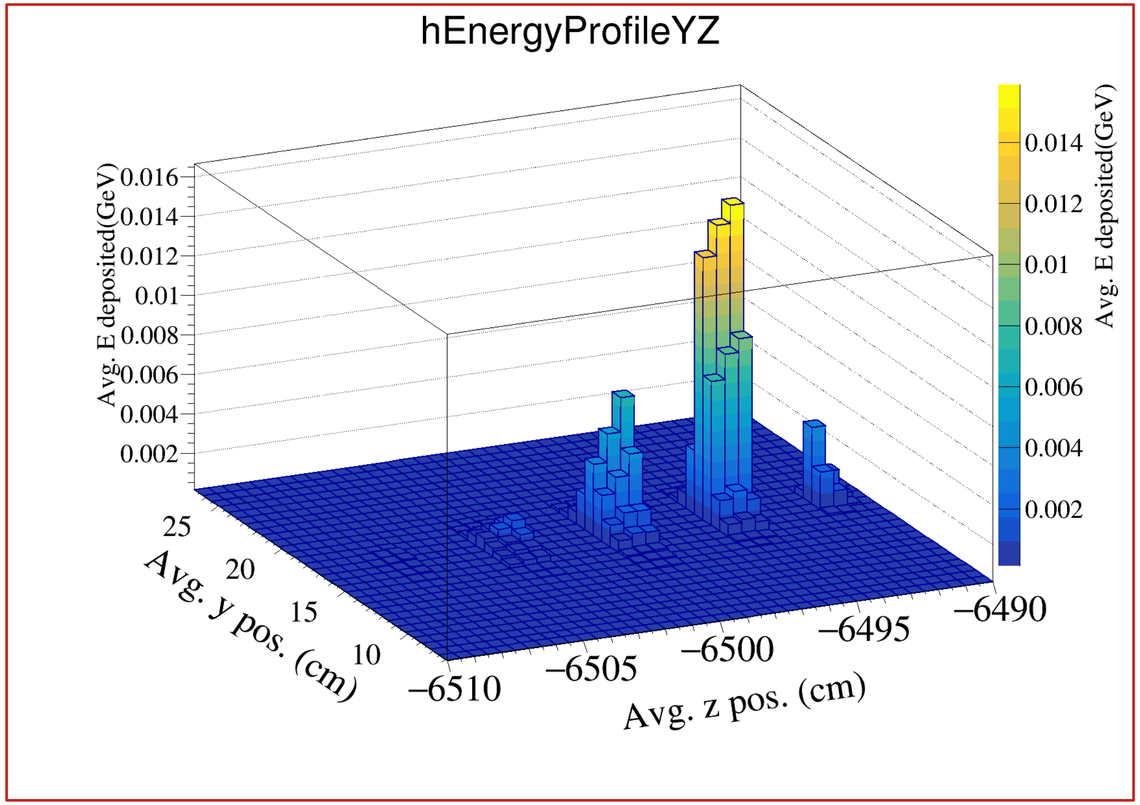


Fig. Shower energy profile in Y-rot layer

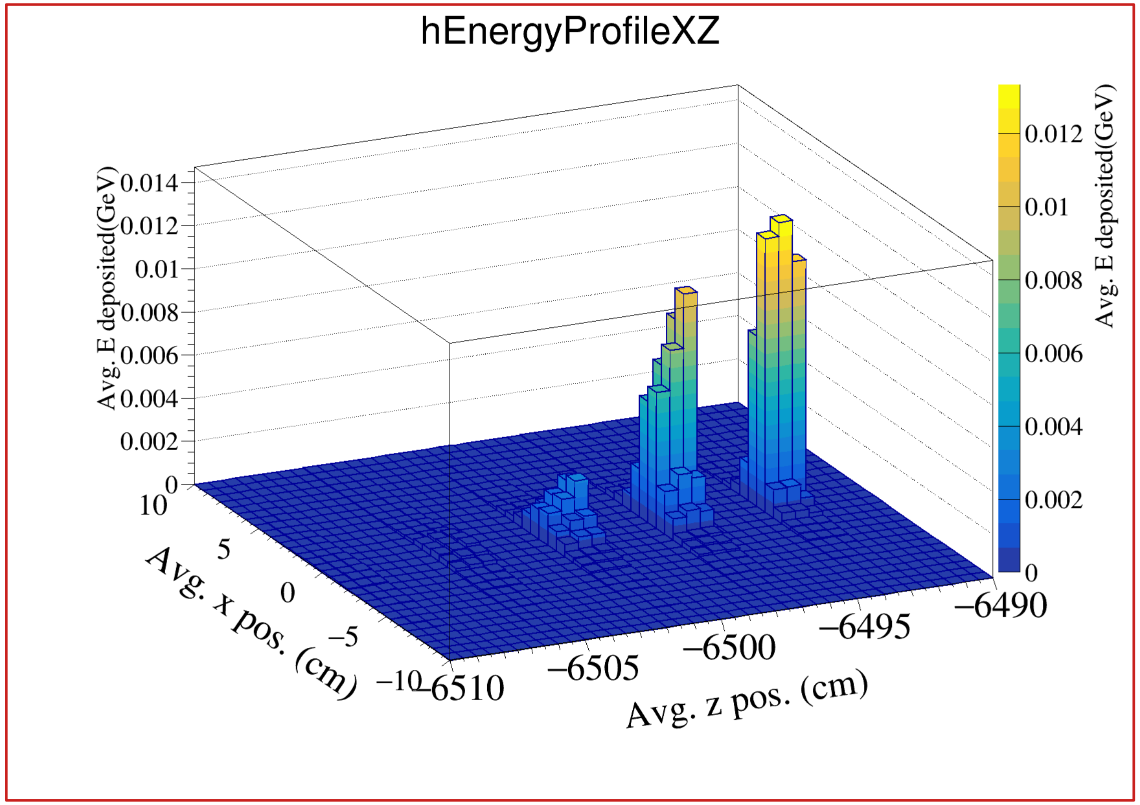


Fig. Shower energy profile in X-rot layer

W-Scifi – Shower profile for multiple hits

- Two 10 GeV e^- shot at center of CAL.
- Only 3cm vertical (along Y-axis) separation between them.

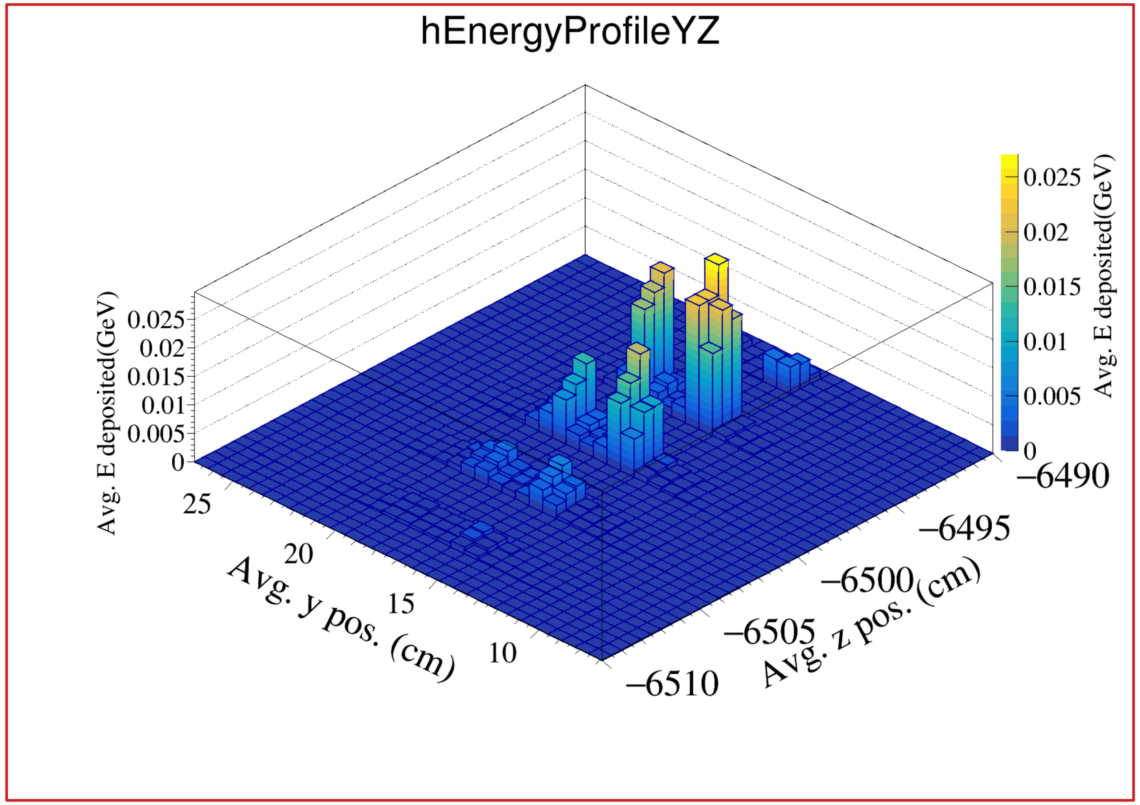


Fig. Shower energy profile in Y-rot layers for 2 electrons, 3cm separated along Y-axis

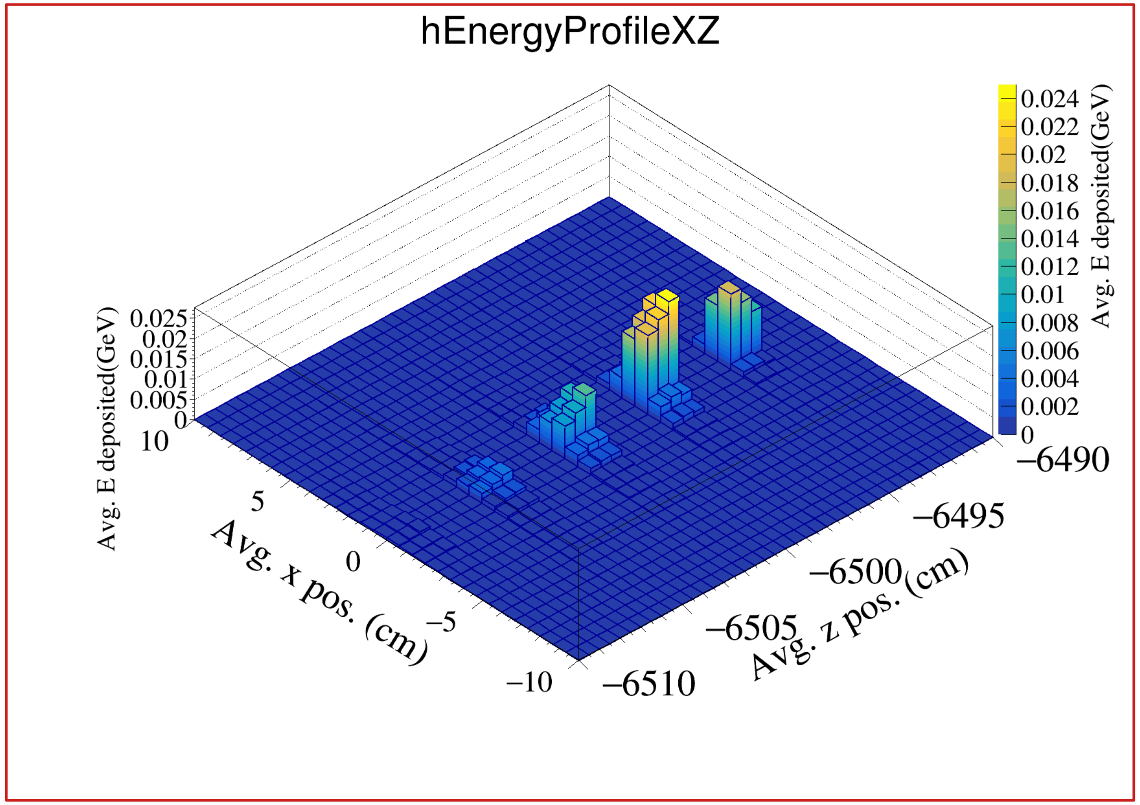


Fig. Shower energy profile in X-rot layers for 2 electrons, 3cm separated along Y-axis

Two separate peaks in Y-rot layers.

W-Scifi – Shower profile for multiple hits

- Two 10 GeV e⁻ shot at center of CAL.
- Only 3cm horizontal (along X-axis) separation between them.

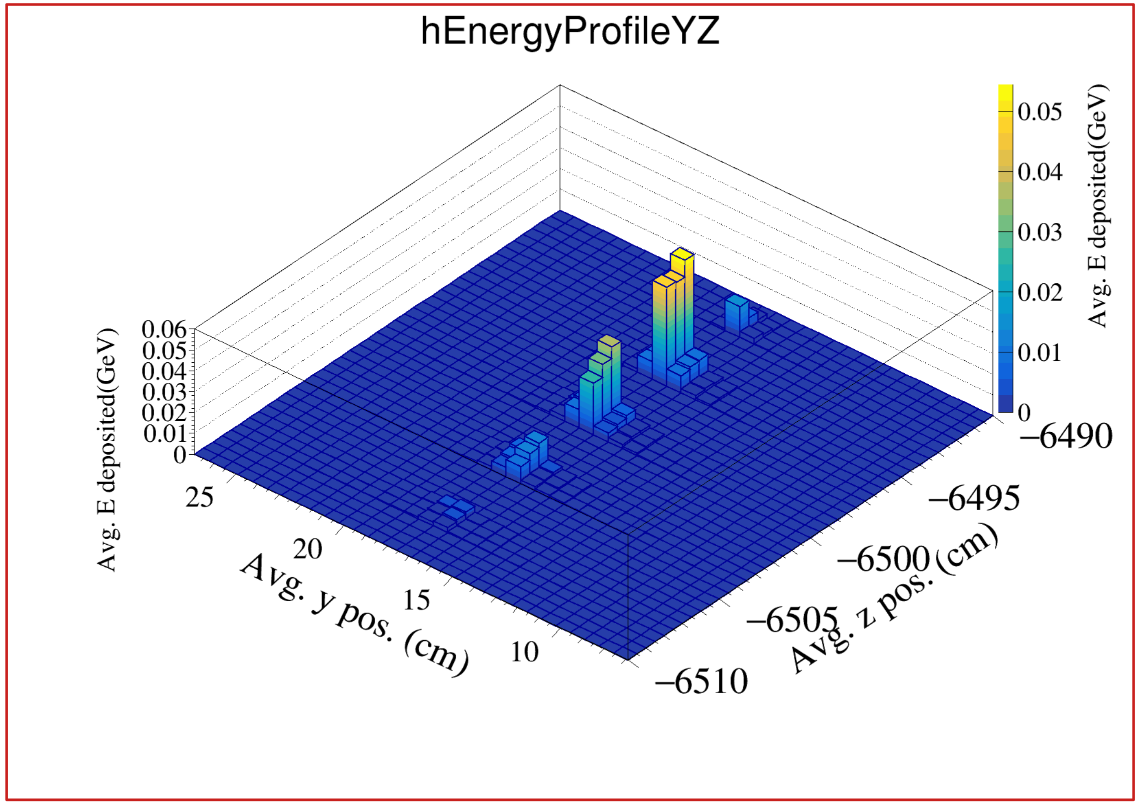


Fig. Shower energy profile in Y-rot layers for 2 electrons, 3cm separated along X-axis

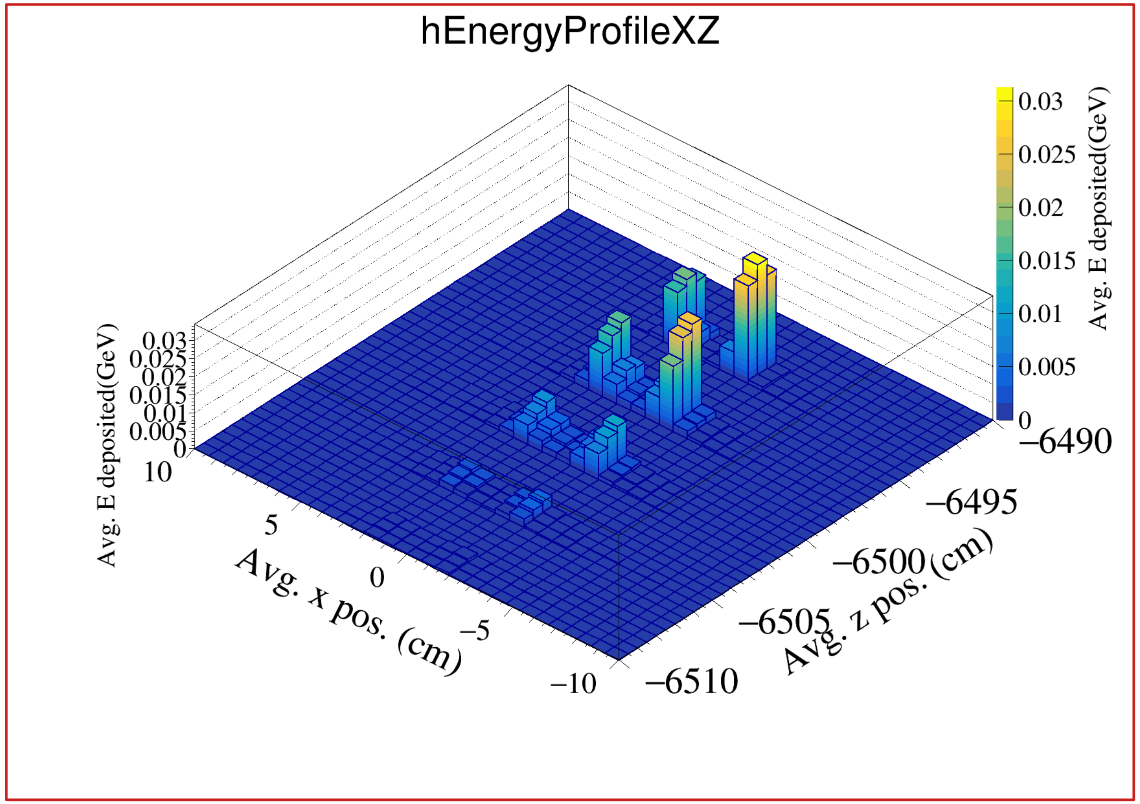


Fig. Shower energy profile in X-rot layers for 2 electrons, 3cm separated along X-axis

Two separate peaks in X-rot layers.

The Y-rot and X-rot combination will be used to measure pile-ups

W-Scifi – Shower profile for different particles

- 1 GeV electron , pion$^+$ and proton shot at center of CAL.

electron

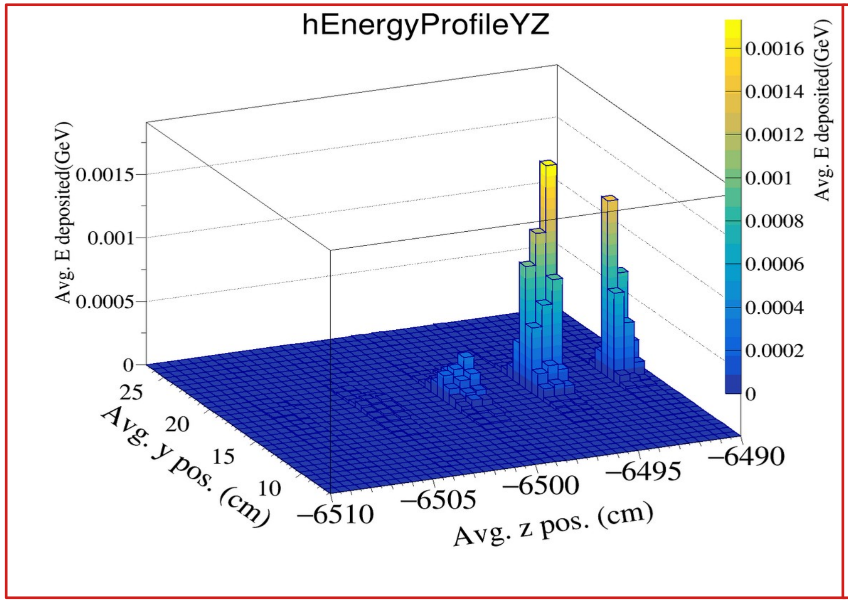


Fig. Electron shower energy profile in Y-rot layers

pion$^+$

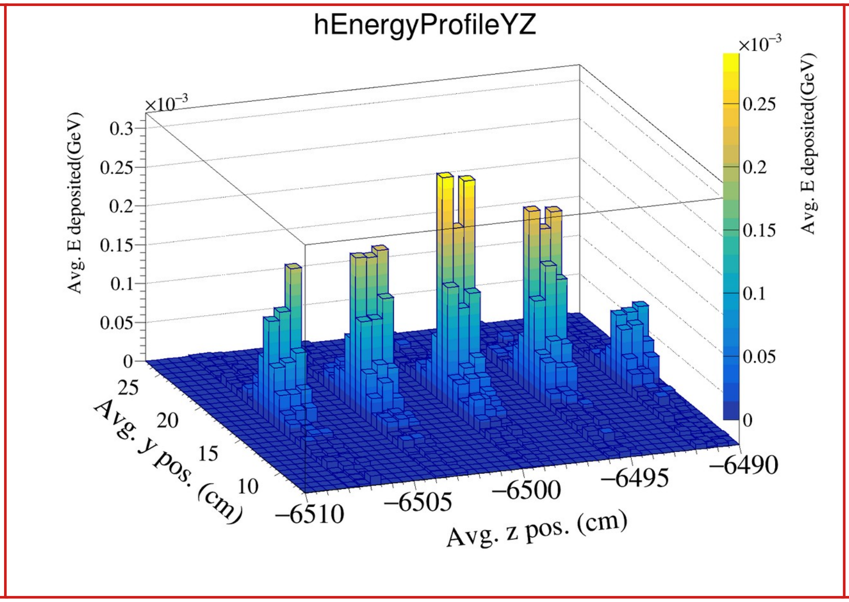


Fig. Pion shower energy profile in Y-rot layers

proton

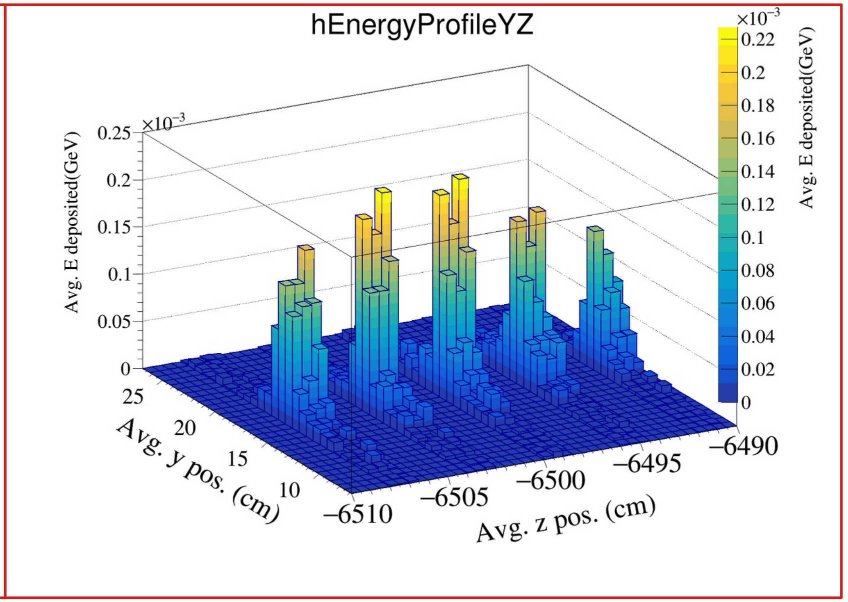


Fig. Proton shower energy profile in Y-rot layers

Irrespective of Y-rot or X-rot,

The energy profile along z-axis can be used to distinguish electron and hadrons (background particles)

End Note

- A new 2D W-Scifi Calorimeter is built in DD4hep for the luminosity detector.
- Different aspects like W to Scifi ratio and fiber size were studied.
- Energy resolution and EM shower energy profile were assessed for this design.

Next Steps

- Optimizing the design of 2D W-Scifi Calorimeter.
- Pile-up analysis will be rigorously studied with this new design.
- Estimate of background (like due to beam-gas) in the current location of Calorimeter.

Acknowledgment

- Prof. Rene Bellwied
- Dr. Dhevan Gangadharan
- ePIC far-backward Collaboration
- EHEP Group at UH

Thank You !!

Back Up

W-Scifi – Sampling Fraction

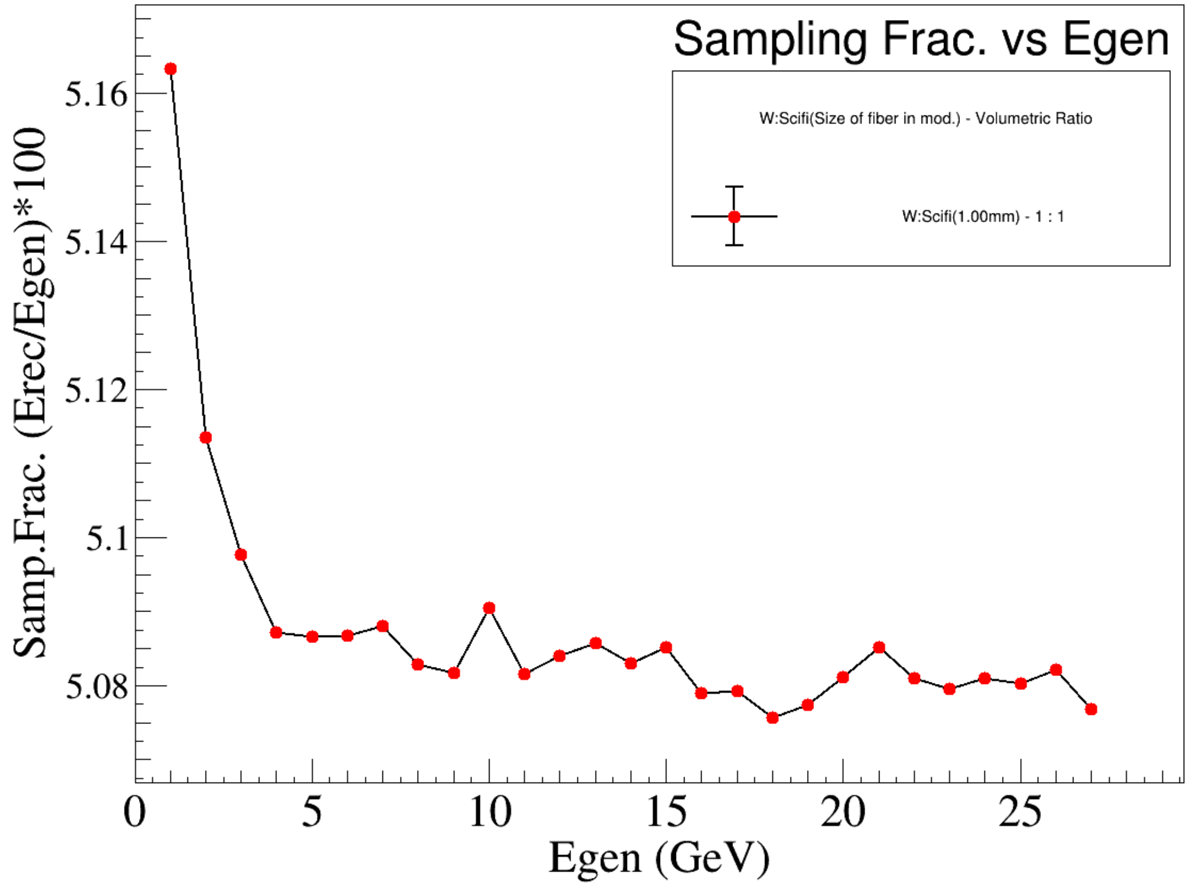
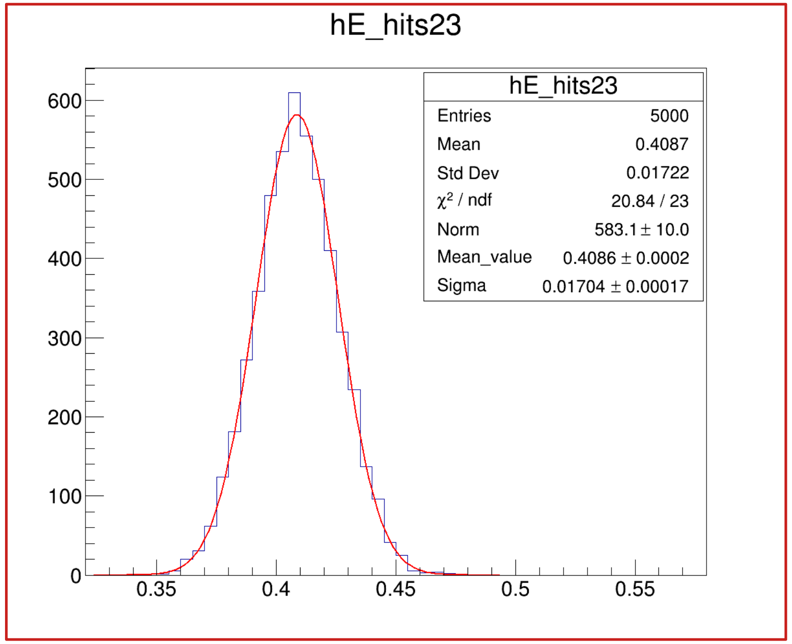


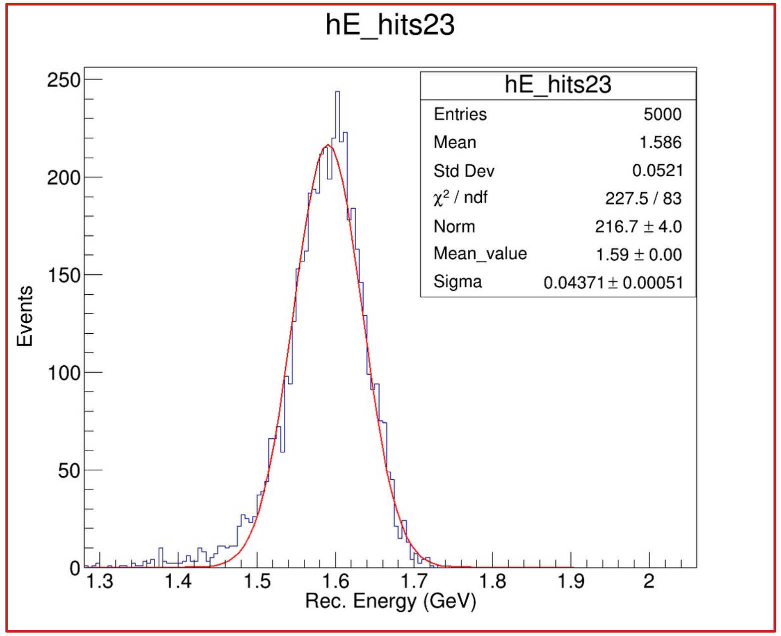
Fig. Sampling fraction vs Energy plot for current 2D W-Scifi design.

Sampling Fraction ~ 5.08% after 1.6% decrease in lowest energies

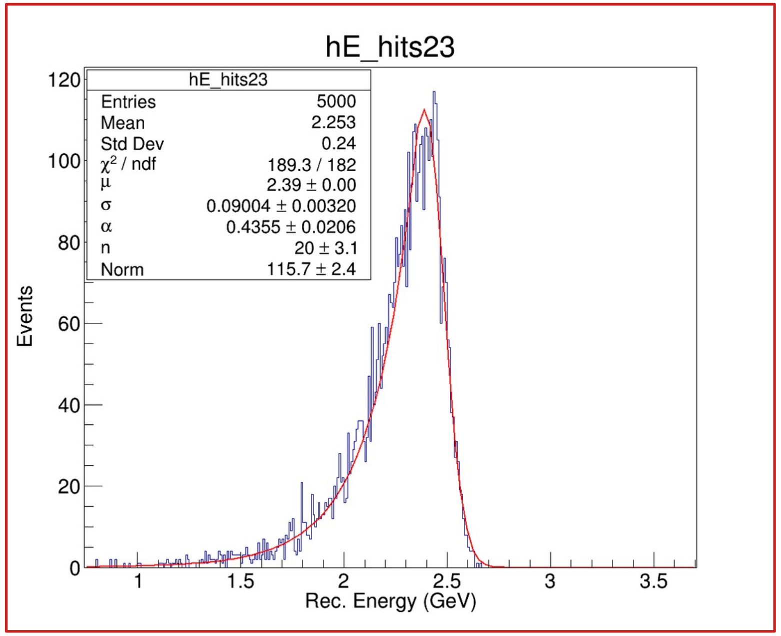
W-Scifi – W to Scifi Volumetric Ratio Fit Plots



W : Scifi - 4 : 1



W : Scifi - 1 : 1



W : Scifi - 1 : 2