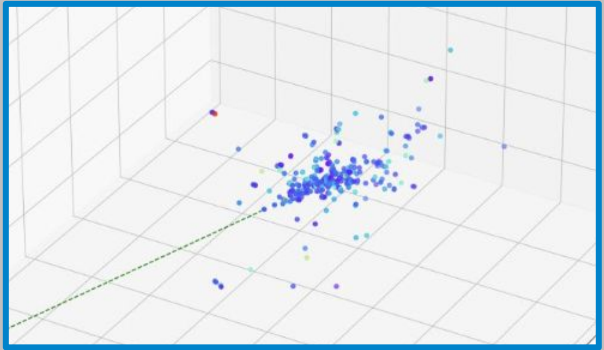
EIC Calorimetry WG Meeting

Imaging Calorimetry for Central EM Barrel



ANL EIC Calorimetry Team
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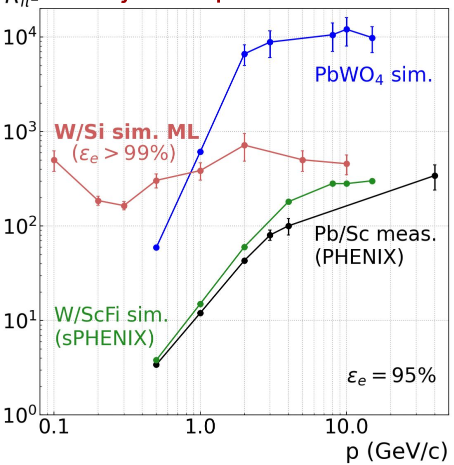
06/07/2021

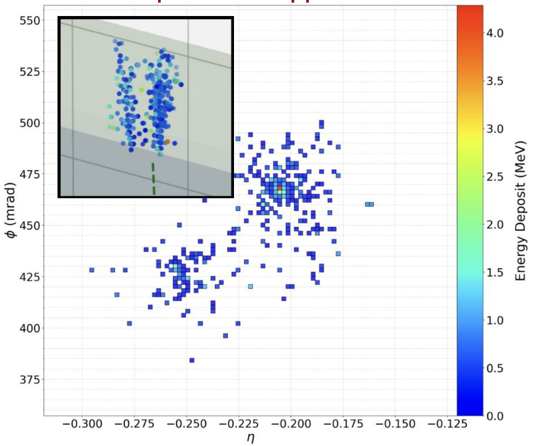
Imaging calorimeter based on monolithic silicon sensors

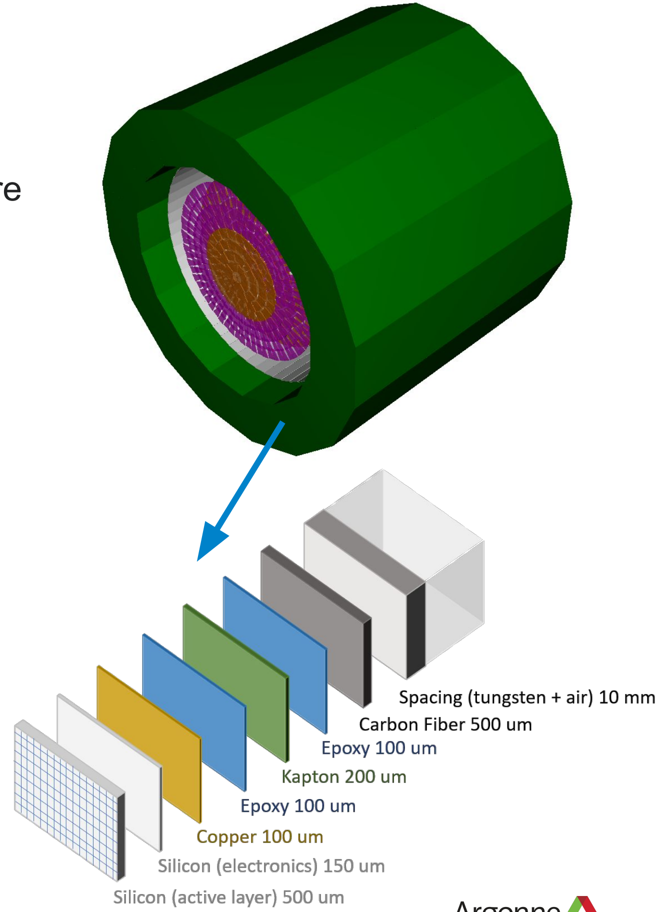
AstroPix (developed for NASA, off-the-shelf)
- Have no stringent power and cooling requirements (used in space)
- Energy resolution: 2% within dynamic range (20 keV ~ a few MeV)
- Time resolution: 50 ns

Ongoing design optimization using the simulation with IP6@EIC software framework with **AstroPix digitization, 3D clustering, ML algorithms,** …

Tests against YR benchmarks: separation, shower separation, spatial and energy resolutions

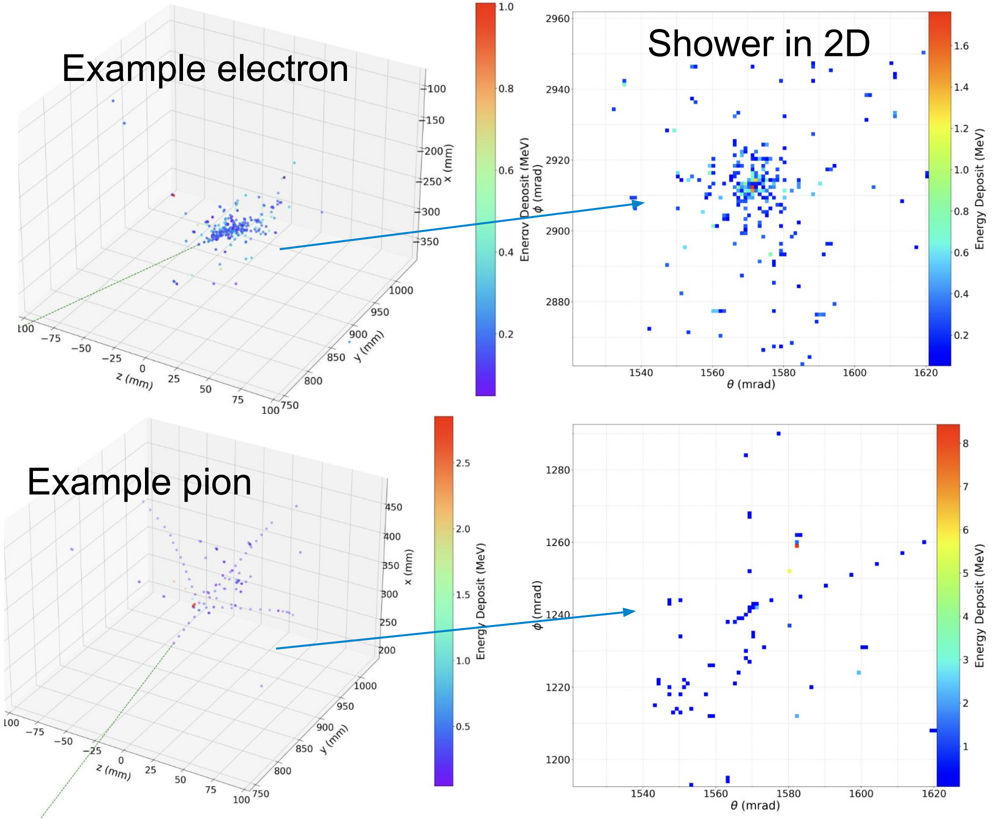






Electron/Pion separation

Shower profile analysis



ML Classification

Utilize hit information from every layer (3D)

20 × 20 × 3

Layers Hits Features (E, η, ϕ)

- Grid size for hits is [η:0.001, ϕ:0.001rad]
  - Raw hits grouped if within the same grid (energy sum)
- Sorted by energy
  - Drop lowest energies ones if there were more than 20 hits
  - Feature values normalized to [0, 1]
- Padded with zero
  - Fill (0,0,0) if less than 20 hits

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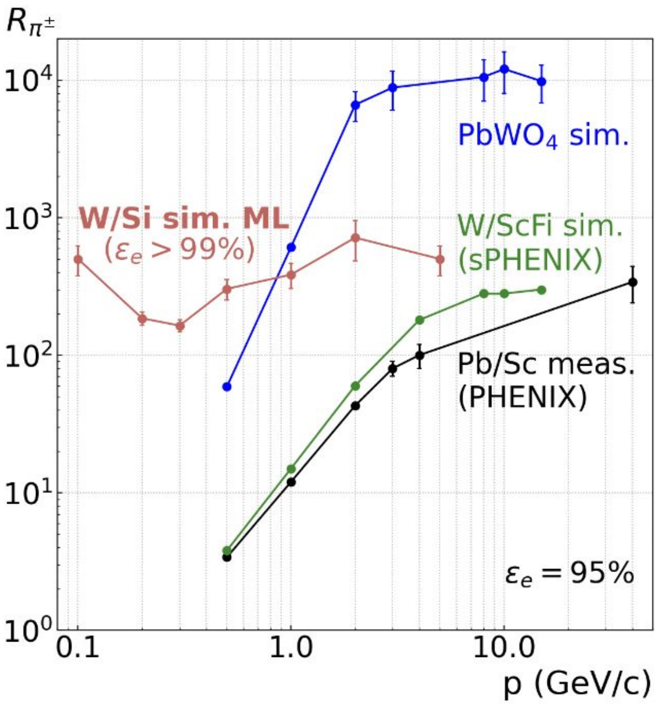

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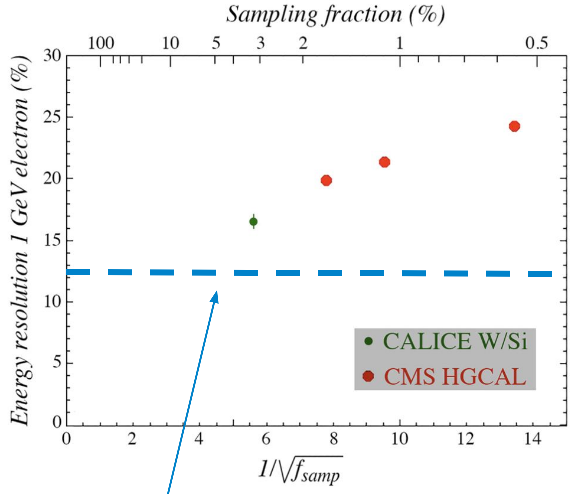
Energy Resolution for Si Calorimetry

$$\sigma/E = \alpha \oplus \beta/\sqrt{E} \oplus \gamma/E$$

- **Pathlength fluctuations -** important contribution to sampling fluctuations for scintillators with thin layers
- **Soft electrons** are an important component of the developing EM showers
- For **500 µm Si** the signal from shower electrons with energies larger than **330 keV** produced in Compton scattering or photoelectric effect **depends on the angle at which they traverse an active layer**
- **The larger the angle** with the shower axis, **the larger the contribution** of these particles to the signal

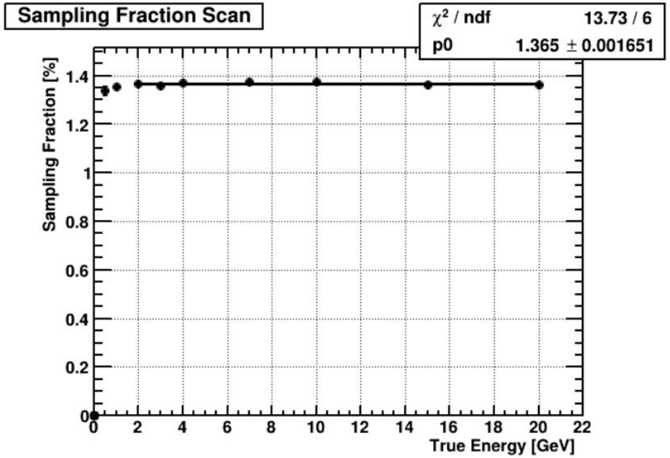
New Developments in Calorimetric Particle Detection, R. Wigmans, https://arxiv.org/abs/1807.03853



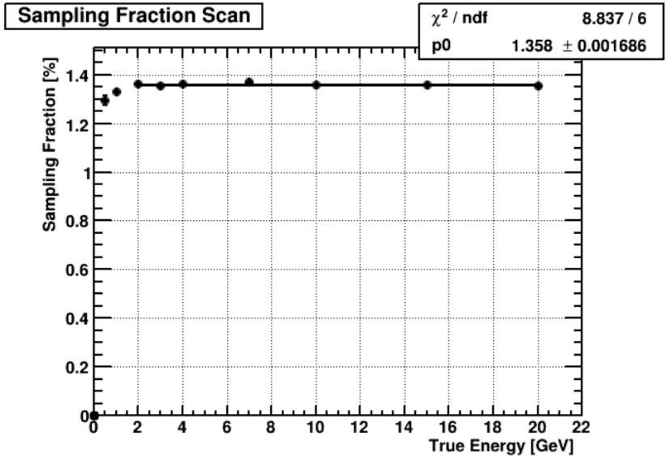
~12% from the $0.027\sqrt{(d/f_{sam})}$ dependence

Sampling Fraction and Energy Resolution

20 layers with 4 mm tungsten (~ 20 X_0)



Electrons



Photons

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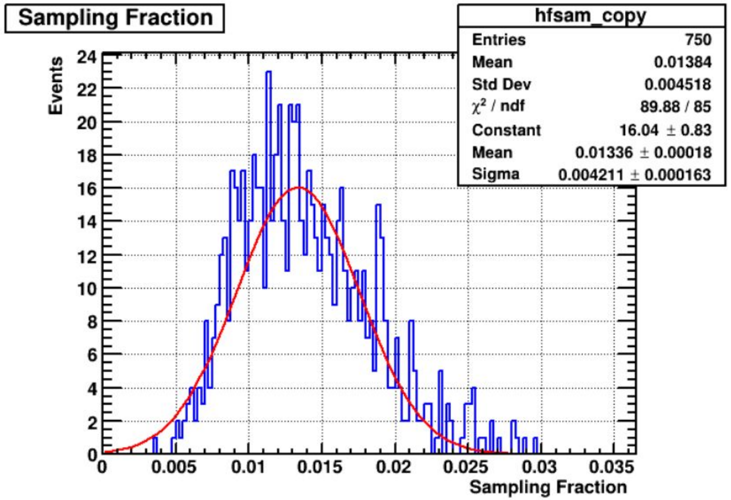

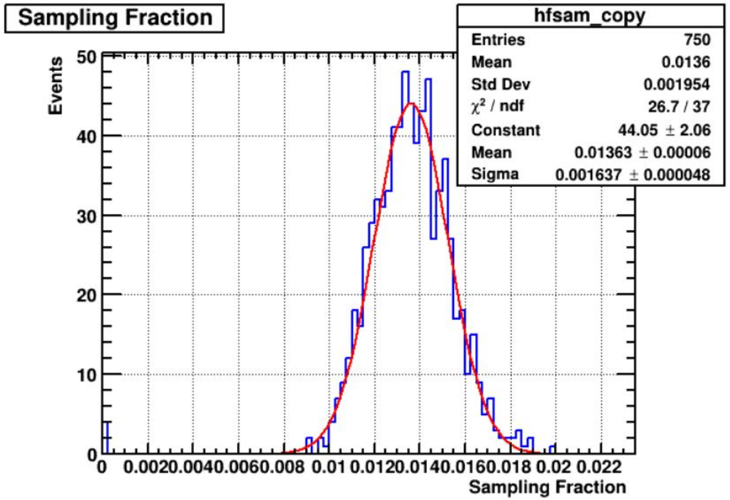

Electrons: Energy deposit for 0.5 GeV and 5 GeV electrons

Sampling Fraction and Energy Resolution

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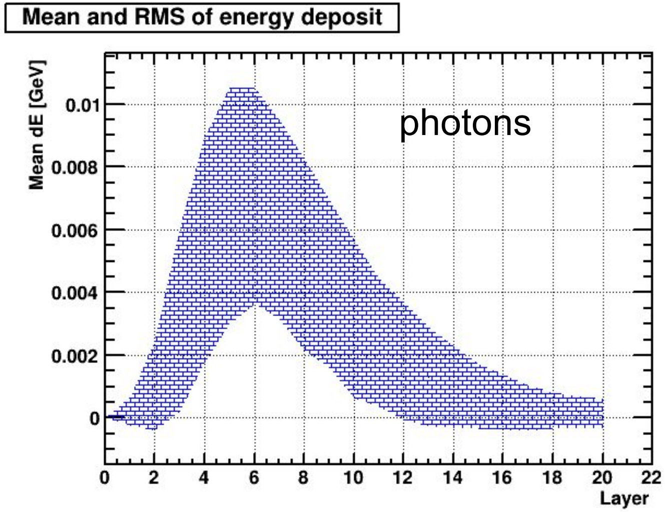

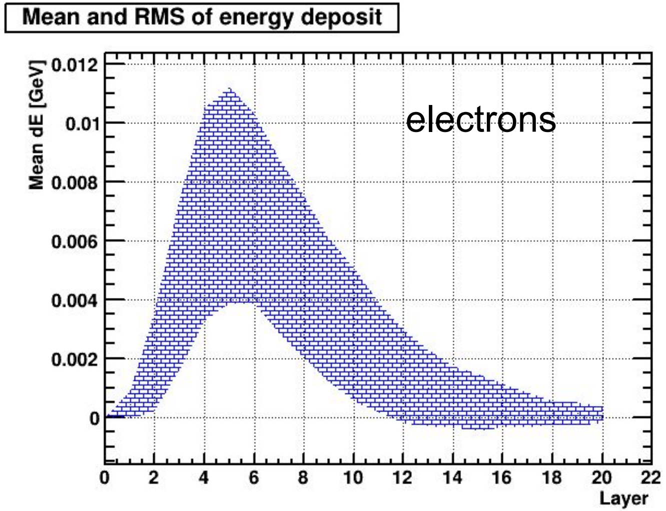

4 GeV photons (left) electrons (right) energy loss in active layers

Sampling Fraction and Energy Resolution

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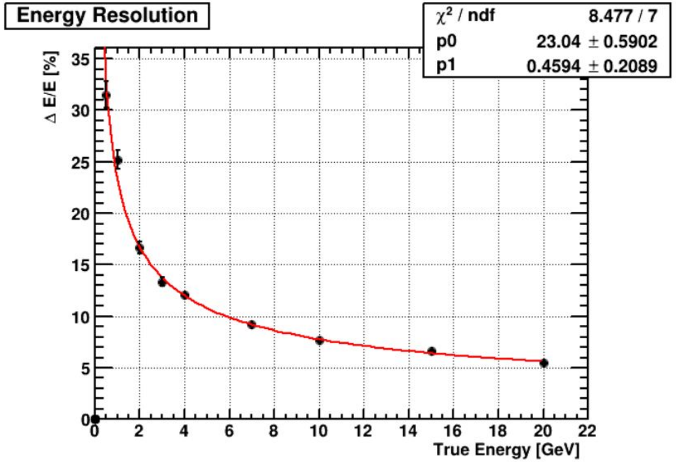
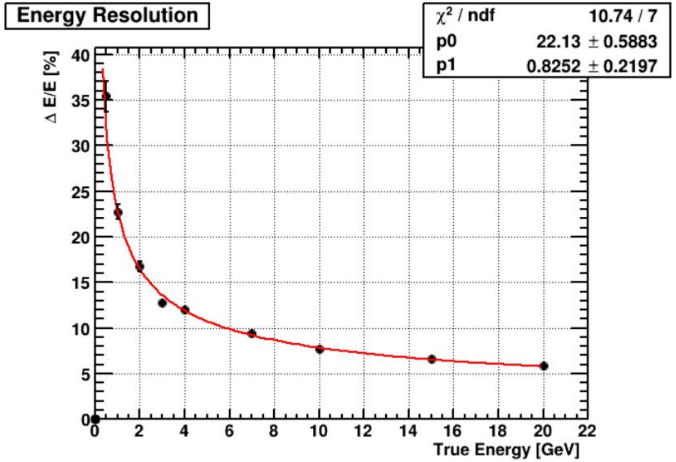


Electrons

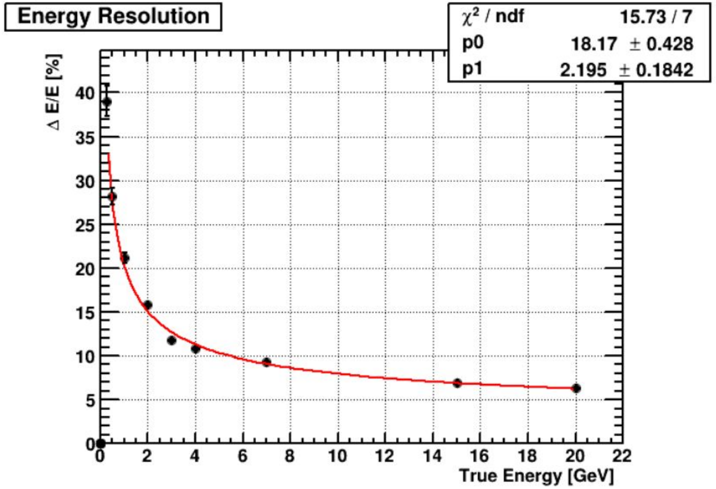


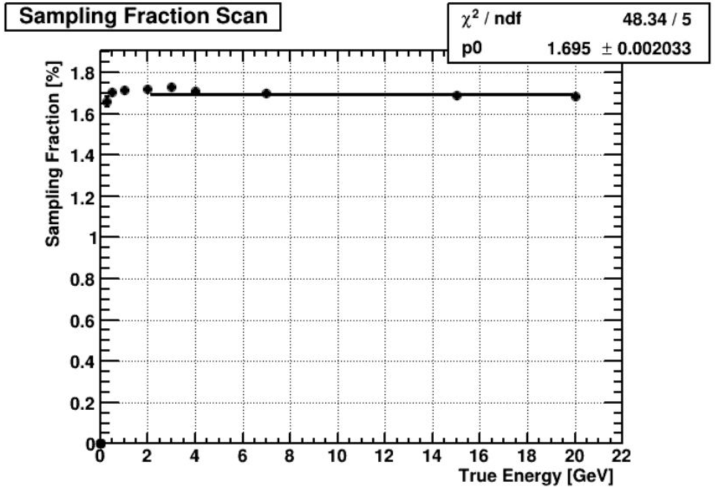
Photons

Sampling Fraction and Energy Resolution

20 layers with 3 mm tungsten (~ 17.5 X0)

photons





SiFi/W Calorimeter

Alternative to use instead of W layers

05/27/21 Concept for BEcal ATHENA. O.Tsai

- Replace solid tungsten layers with W-powder/ScFi 'active' layers – that will allow to tune energy resolution to desired value by choosing sampling fraction/frequency

- Technology vise making encapsulated W/ScFi with carbon skin should be very easy
- Thickness of WScFi layers can be as desired, i.e. may be thicker than $1X_0$
- Outer shell 0.5 mm SS, W/ScFi layers glued to shell creating compartments for sensor layers
- Sensor layers inserted from front side
- SiPM readout on the front side, cables utilities from sensor layers fanout from front side
- Support structure similar to STAR/sPHENIX, i.e. rails/bearings
- EM Modules inserted into solenoid from both sides. (like it was done in STAR barrel ecal)
- Number of pixels layers, thickness of WScFi layers had to be optimized
- Granularity in W/ScFi readout has to be optimized (phi and X/Y)

SiFi/W Calorimeter

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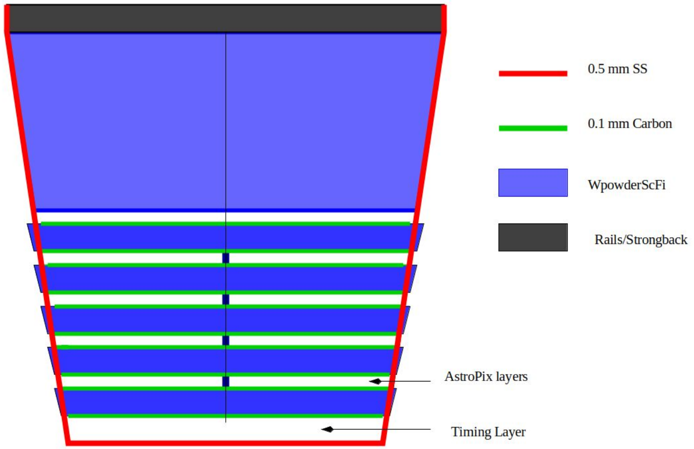
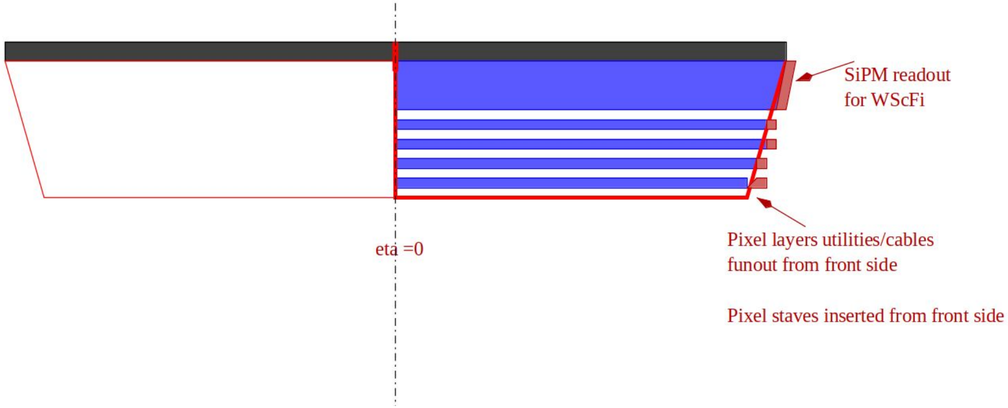




SiFi/W Calorimeter

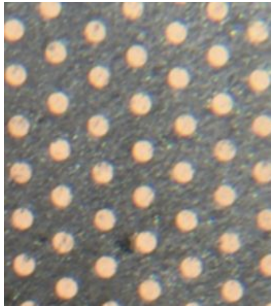
sPHENIX Calorimeter Parameters https://arxiv.org/pdf/1704.01461.pdf

Scintillating Fiber (Kuraray SCSF78) Diameter **0.47 mm**, spacing **1 mm** http://kuraraypsf.jp/psf/sf.html
Absorber Matrix of Tungsten powder and epoxy w/embedded scintillating fibers

- Whole SPACAL block ~10 g/cm^3 (~ half density of metallic tungsten)
- Tungsten powder: **11.25 g/cm^3**
- Sampling fraction for EM-showers ~ 2.3%
- Radiation length **X_0 ≈ 0.7-0.8 cm**

TABLE I
EMCAL BLOCK COMPONENT MATERIALS

Material	Property	Value
Tungsten powder	THP Technon 100 mesh	
	particle size	25-150 μm
	bulk density (solid)	$\geq$ 18.50 g/cm^3
	tap density (powder)	$\geq$ 11.25 g/cm^3
	purity	$\geq$ 95.4% W
	impurities ($\leq$ 5 percent)	Fe, Ni, O2, Co, Cr, Cu, Mo
Scintillating fiber	Kuraray SCSF78 (single cladding, blue)	
Epoxy	EPO-TEK 301	



Approximation in simulation:

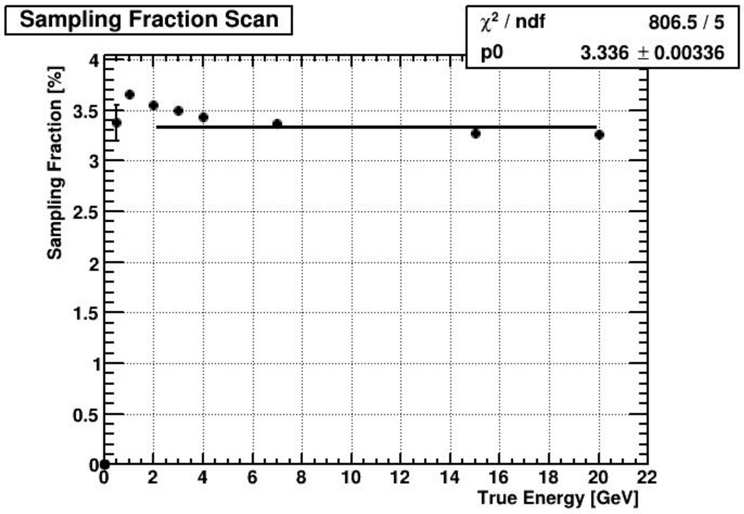
- W radiation length: 6.76 g/cm^2 (**~0.6 cm** for Tungsten powder: 11.25 g/cm^3)
- Approximation with layers: W - SiFi - W - SiFi - W - SiFi - W   1 - 0.45 - 2 - 0.45 - 2 - 0.45 - 1 [mm]
- This gives radiation length **X_0 ~ 0.735 cm per layer**

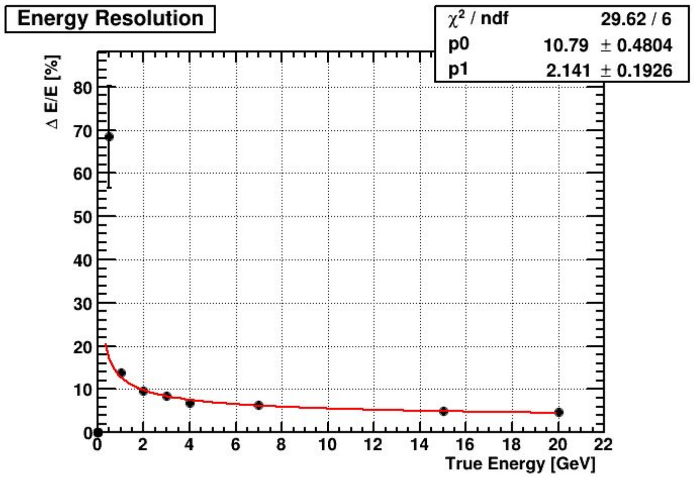
Hybrid Calorimeter

First rough simulations (see previous slide)

- 5 layers AstroPix + SiFi/W (~5 X_0)
- SiFi/W ~15 X_0
  - Only checking total energy losses in active layers (no reconstruction, digitization for SiFi/W layers) - Upper limit of resolution

electrons





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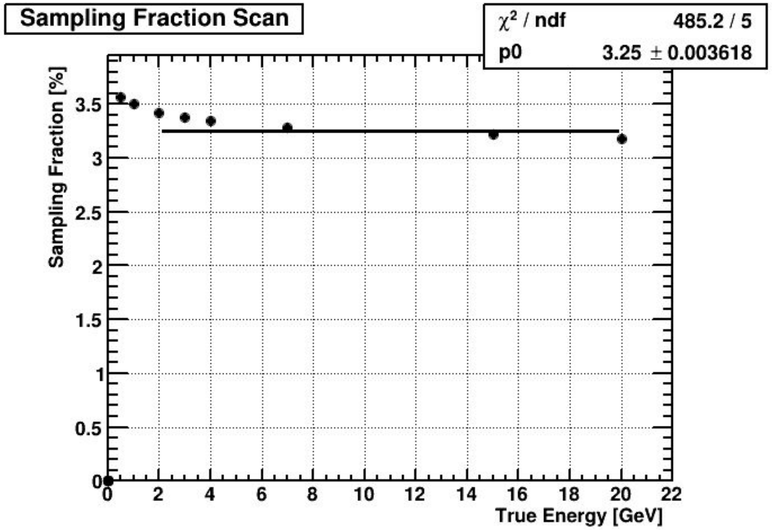
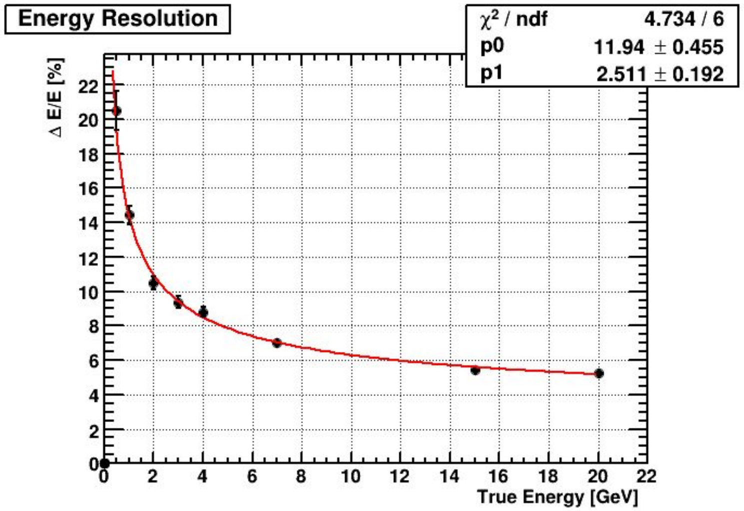


photons

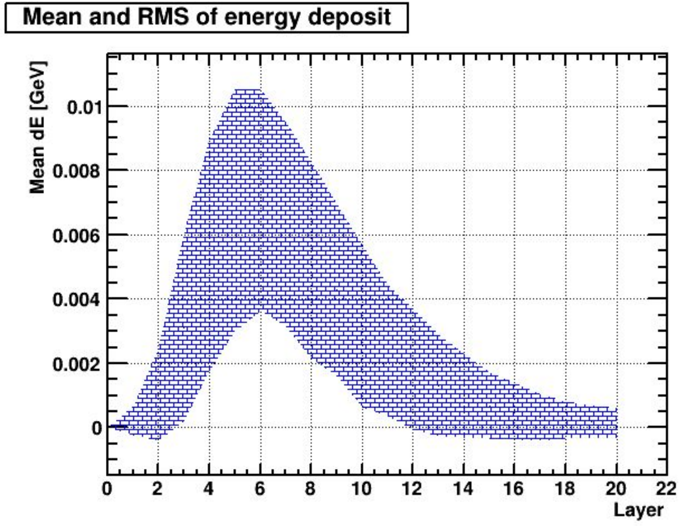


Hybrid Calorimeter

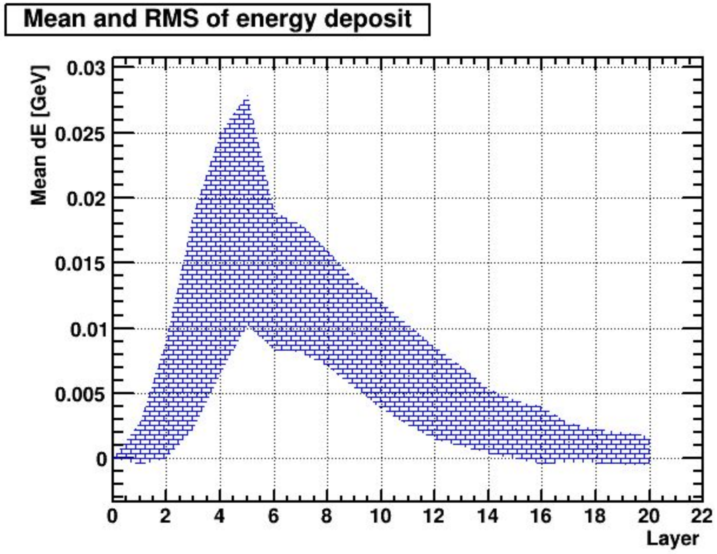
First rough simulations

4 GeV photons, energy deposited in active layers every X_0

Imaging Si Calo with 4mm W



Hybrid

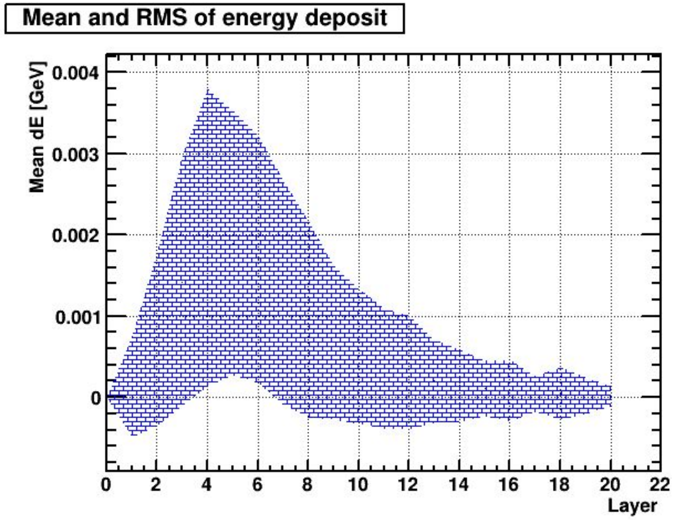


Hybrid Calorimeter

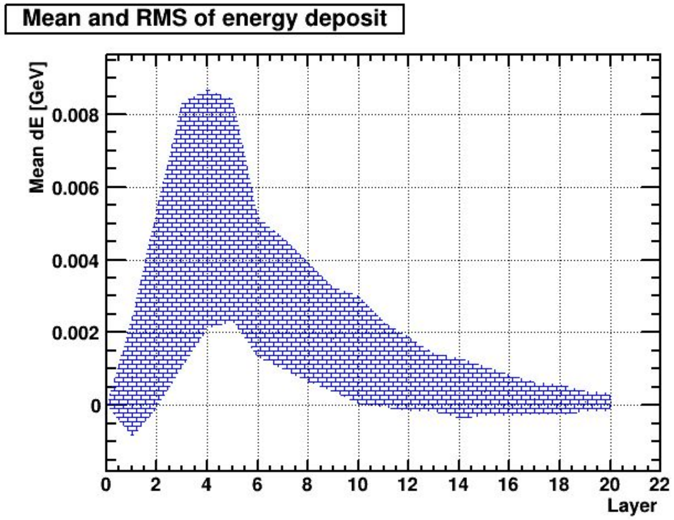
First rough simulations

1 GeV photons, energy deposited in active layers every X_0

Imaging Si Calo with 4mm W



Hybrid



Hybrid Solution

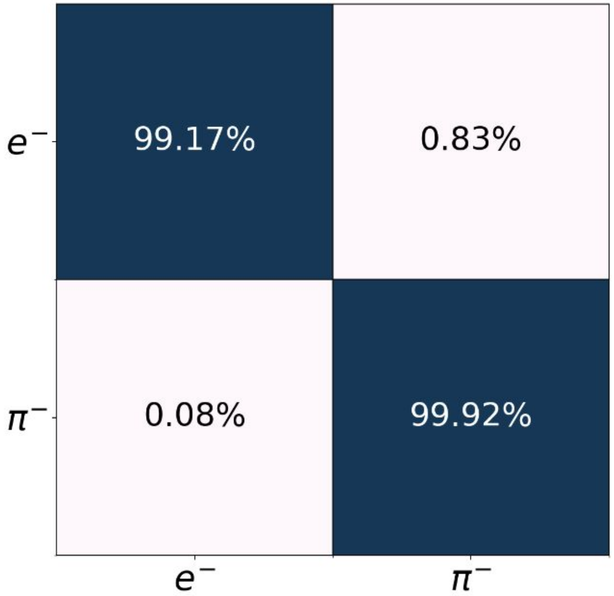
- Realistic readout and digitization in simulation (to test granularity)
- Optimization to flatten the sampling fraction
- We gain in energy resolution but what about the e/π resolution?
- Support structure for SiFi/W Calorimeter?
  - Support for imaging colorimeter (briefly) estimated with ANL engineering team

Backup

ML Classification – Charged Pions Rejection

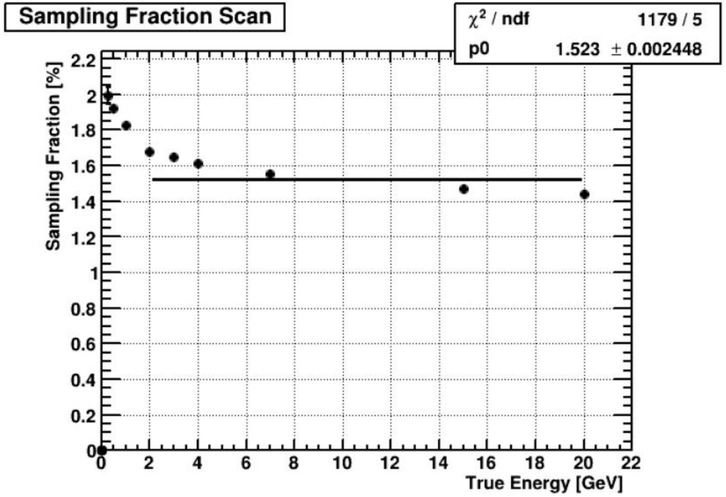
- 100k events, several momentum points
  - e^-, π^-
- Simple ML model implemented with tensorflow
  - 2 CNN layers with pooling
  - 2 Dropout layers
  - 2 Dense layers
- 80% data for training models
  - 10% for validation
  - 10% for test

Test dataset results (100 MeV)

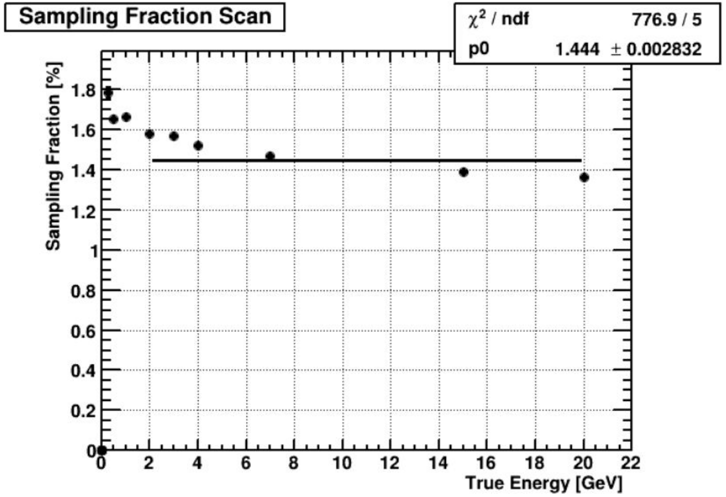


Sampling Fraction and Energy Resolution

5:5:10 layers with tungsten 2:3:5 mm



Electrons



Photons

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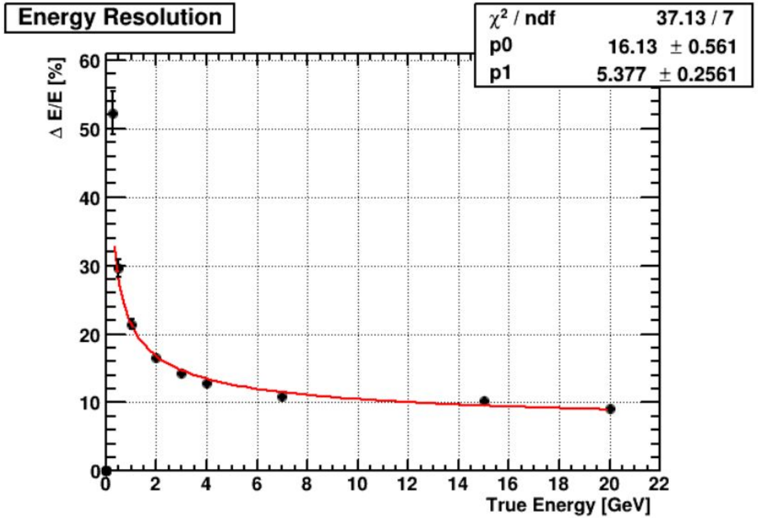

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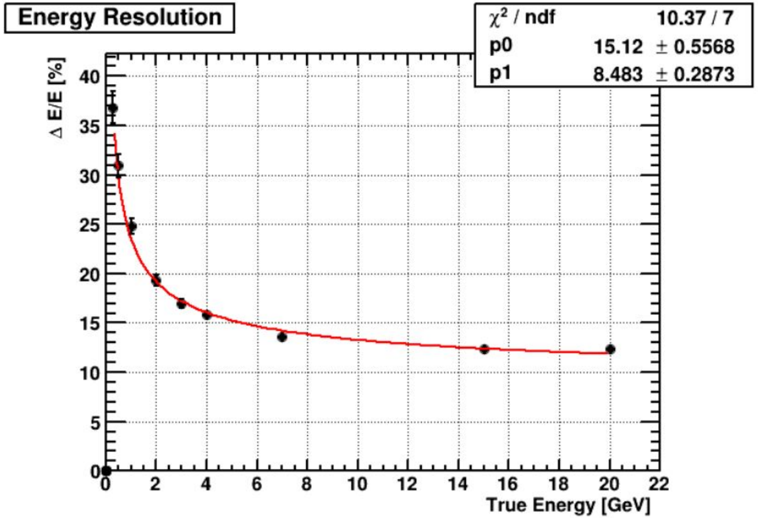
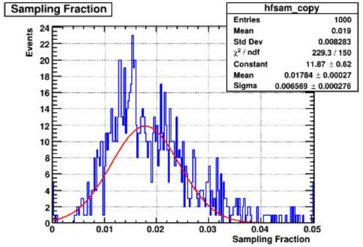


Photons

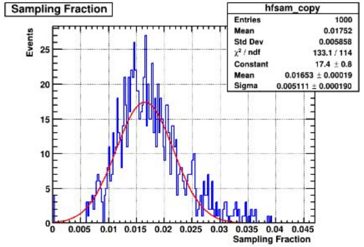
5:5:10 layers with tungsten 2:3:5 mm

photons

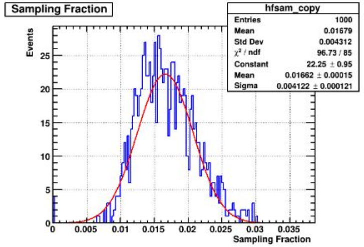
0.25 GeV



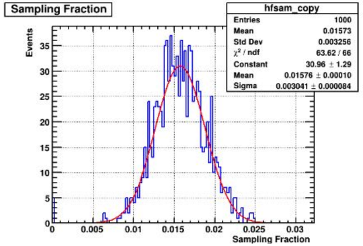
0.5 GeV



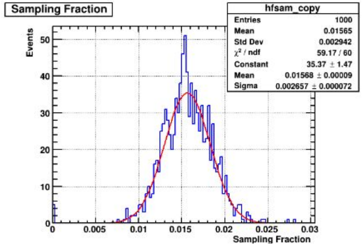
1 GeV



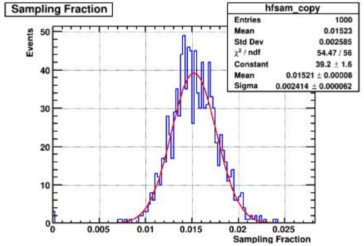
2 GeV



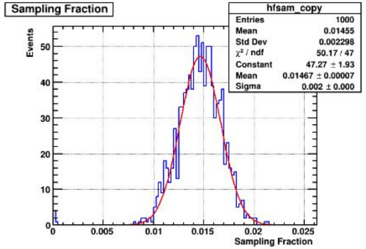
3 GeV



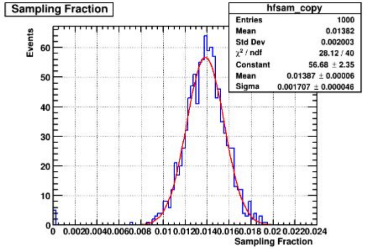
4 GeV



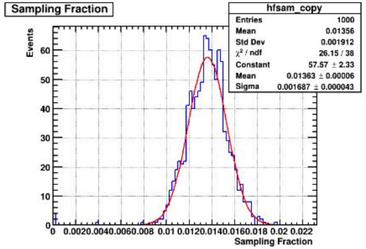
7 GeV



15 GeV

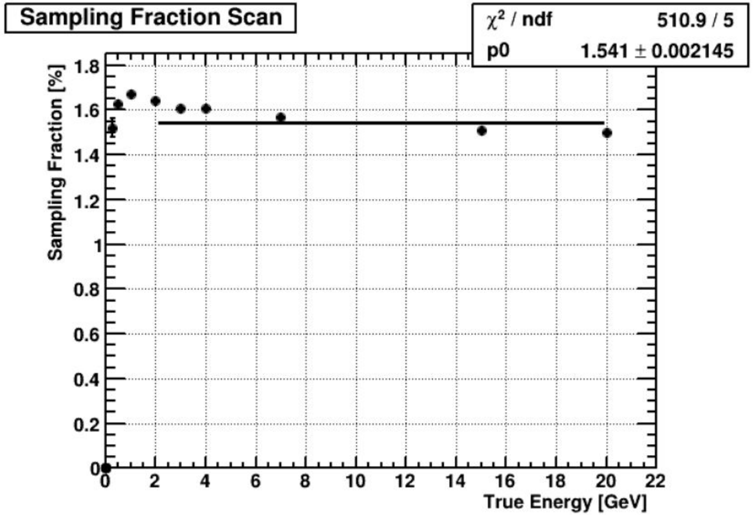


20 GeV

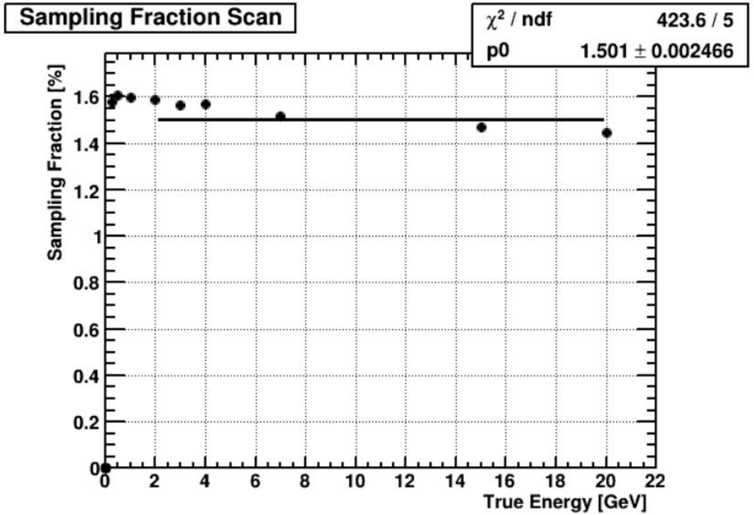


Sampling Fraction and Energy Resolution

10:10 layers with tungsten 3:5 mm



Electrons



Photons

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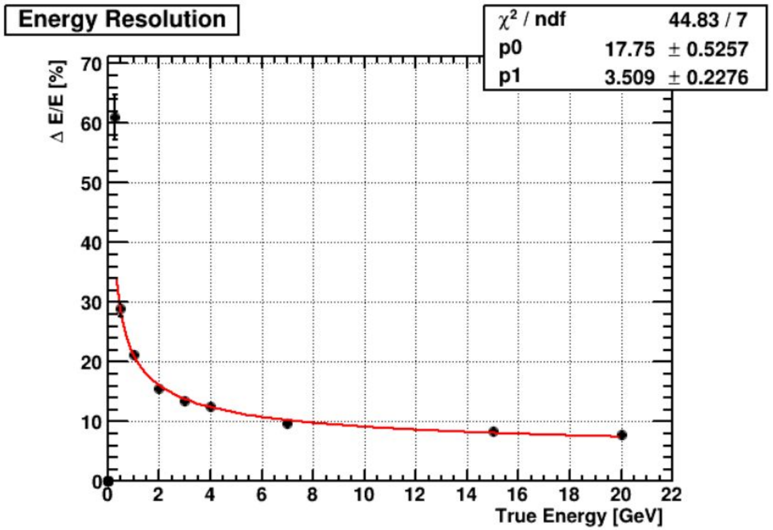
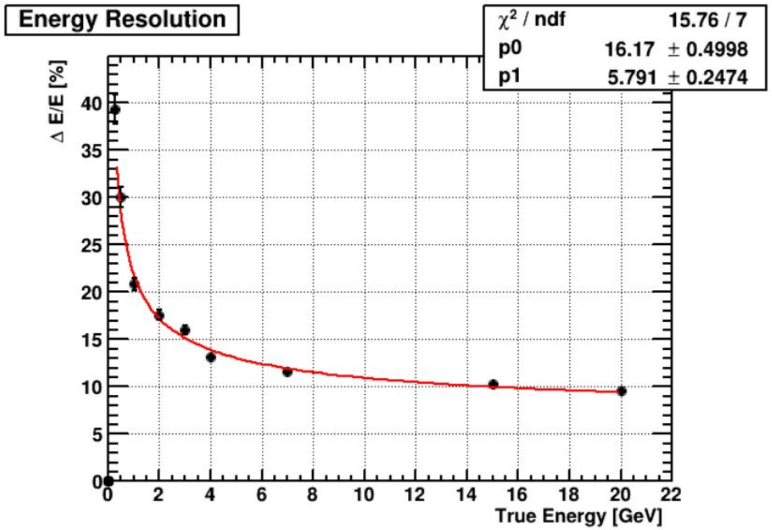


Electrons



Photons