ePIC pECal software implementation

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Outline

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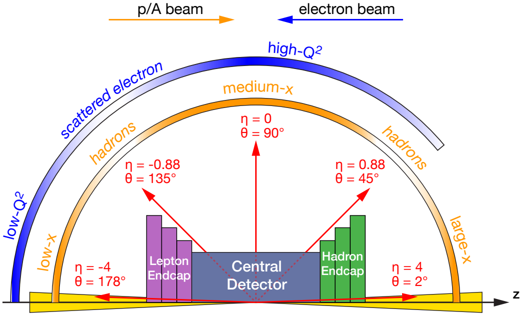
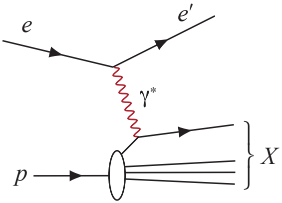
1. Physics requirements
2. Mixture tower structure
3. ePIC simulation campaign
4. $\pi^0 \to \gamma\gamma$ separation
5. DD4hep fiber implementation
6. Future plan

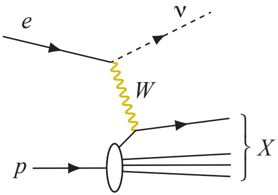
EIC physics

- Red particles are measured.
- Lepton endcap is important to reconstruct the kinematics of the scattered electron.
- Hadron endcap is important to measure hadrons in SIDIS and exclusive DIS.

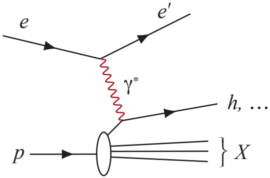




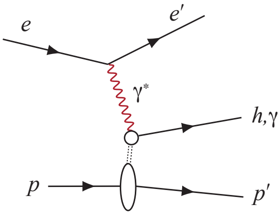
NC DIS: $e + p/\mathrm{A} \longrightarrow e' + X$



CC DIS: $e + p/\mathrm{A} \longrightarrow \nu + X$



SIDIS:
$e + p/\mathrm{A} \longrightarrow e' + h^{\pm,0} + X$



Exclusive DIS: $e + p/\mathrm{A} \longrightarrow e' + p'/A' + \gamma/h^{\pm,0}/VM$

Electron Proton Ion Collider (ePIC) Detector

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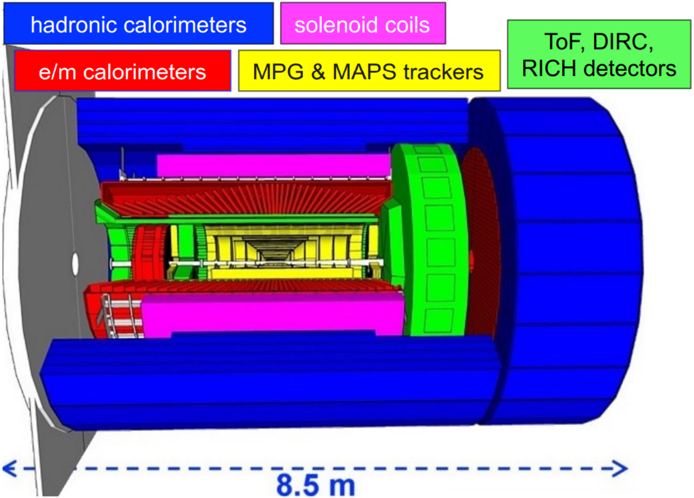
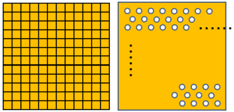
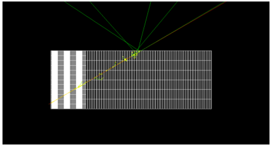


Comparison of ECal designs

- Homogeneous ECal at electron-going direction:
  - Reconstruct the scattered electron at the backward region.
  - Excellent energy resolution $[(2\text{–}7)\%/\sqrt{E} + (1\text{–}3)\%]$.
- Sampling ECal at proton-going direction:
  - Measure photons and hadrons at the forward region.
  - Good energy resolution $[(10\text{–}12)\%/\sqrt{E} + (1\text{–}3)\%]$.
- Two designs of sampling ECal: W/ScFi (upper) and Shashlyc (lower).
- pECal: W/ScFi *vs* Shashlyc:
  - Both have good energy resolution.
  - W/ScFi has e/h ratio closer to 1.
  - W/ScFi has smaller radiation length.
- W/ScFi pECal:
  - Beehive with fibers of radius 0.235 mm.
  - Absorber: 97% Tungsten + 3% polystyrene.
  - Fiber: 100% polystyrene.
- Readout will use SiPM.



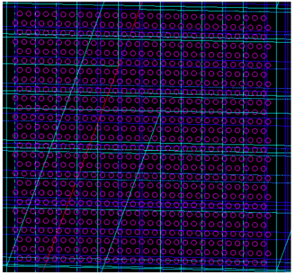
Shashlyk (front) W/ScFi (front)



Shashlyk (side)

Mixture tower configurations

Slides from Zhiwan



Fibers distributed inside one tower

	geometry fraction	material mass fraction
Absorber	78%	97% Tungsten+ 3% polystyrene
Fiber	22%	100% polystyrene

- **W/ScFi structure: 24 x 24 towers of 2.5 cm*2.5cm**
  - **796 Fibers placed in each tower, r = 0.235 mm.**
- **Mixture structure: 24 x 24 towers of 2.5 cm*2.5cm**
  - **Mixture material at same composition as W/ScFi**
- **Total material density to be 10.15 g/cm^3 (from experiment)**

```
// Get materials
G4Material* defaultMaterial = G4Material::GetMaterial("Galactic");
G4Material* gapMaterial2 =G4Material::GetMaterial("G4_POLYSTYRENE");
G4Material* absorberMaterial2= G4Material::GetMaterial("G4_Fe");

G4double a=183.85*g/mole;
G4Element* elW=new G4Element("Tungsten","W",74.,a);

  G4Material* EMCal_abs_mat=new G4Material("EMCal_fiber_mat", 10.15*g/cm3,2);
  EMCal_abs_mat->AddElement(elW, 94.8*perCent);
  EMCal_abs_mat->AddMaterial(gapMaterial2, 5.2*perCent);
```

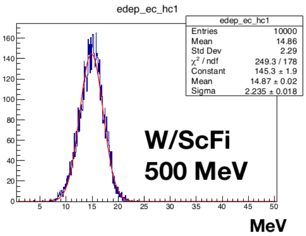
	mass fraction
Tungsten	94.8%
Polystyrene	5.2%

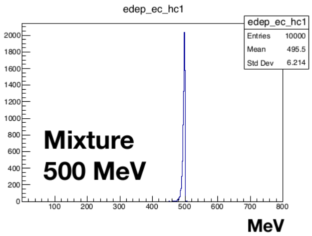
- **Next step: reconstructed the energy from this mixture tower configuration**

Sampling fraction for fibers

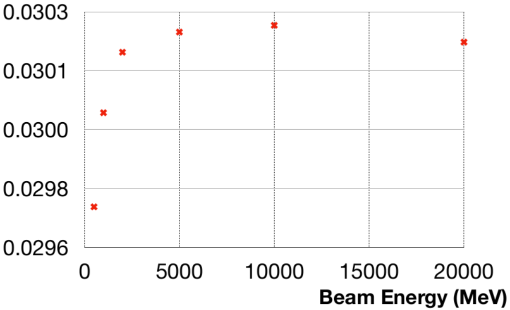
Slides from Zhiwan

- **Get the mean value of energy deposition for W/ScFi, and plot it out with respect to 6 beam energies.**
- **We have roughly 0.03 (at a 1% difference)**



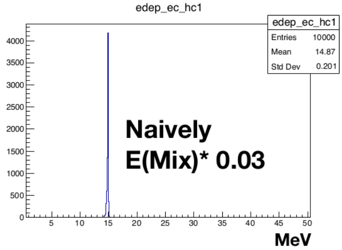


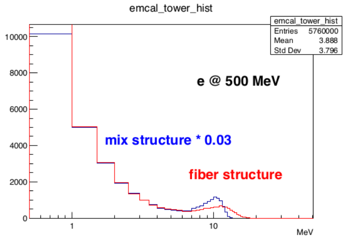
Beam Energy (MeV)	Energy in fibers(mean)	fraction
500	14.86	0.02972
1000	30.0	0.03000
2000	60.36	0.03018
5000	151.2	0.03024
10000	302.6	0.03026
20000	604.1	0.03021



Smearing procedure

Slides from Zhiwan





- **Smearing process is required to help get the correct energy resolution**

$$Gaus(E) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(E-\mu)^2}{2\sigma^2}}$$

  - **Mean** $\mu = \quad 0.03E$
  - **Sigma** $\sigma = \quad E\sqrt{a^2/E + b^2}$
  - **a = 0.1, b = 0.0015**

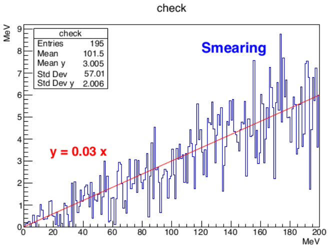
```
double threshold = 6.1;

double reco(double E0)
{
double E = E0;
if(E0 < threshold) return 0;
else{
double a = 0.1;
double b = 0.;
double sigma =  E* TMath::Sqrt(a*a/E +b*b) ;
double random = gRandom->Gaus(E*0.03,sigma);
E = random;
return E;
}
}
```

- **Code on the right**
  - **The parameter a and b is determined by fiber structure study**

Purpose:

- **Reproduce the fluctuation from Gaussian random**
- **keeps the mean ~ 0.03 E_0**



ePIC simulation campaign

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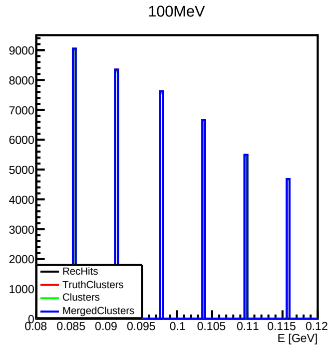
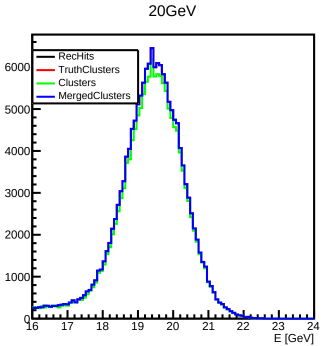
- Use single photon input data at different energies.
- DD4hep uses mixture tower structure.
- EICRecon scales the energy to 3% and smears the energy.
- Digitization: 14 bits and 3 GeV range. 1 bit corresponds to $\sim$6 MeV (3% energy is deposited).
- Tested energy deposits after EICrecon for sum of all hits energy, truth cluster energy, island cluster energy, and merged island cluster energy (merging clusters from the same truth particle).

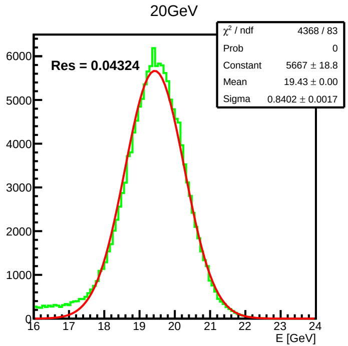
Clusters energy: single photon input



Energy deposit at low energy

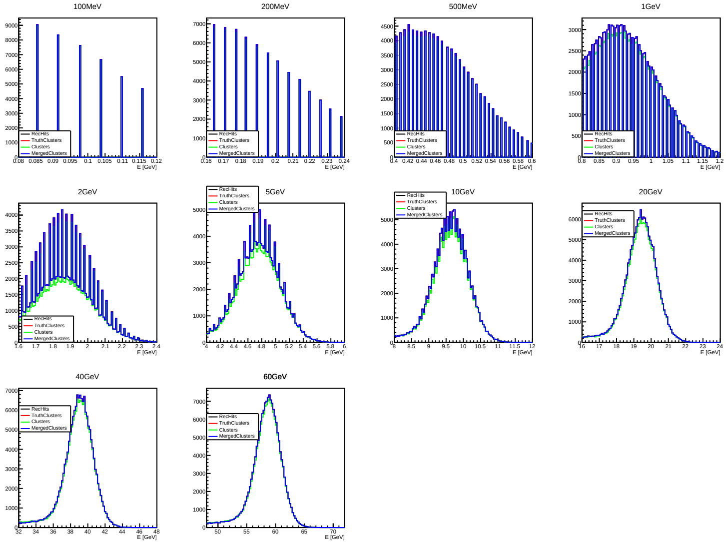


Energy deposit at high energy

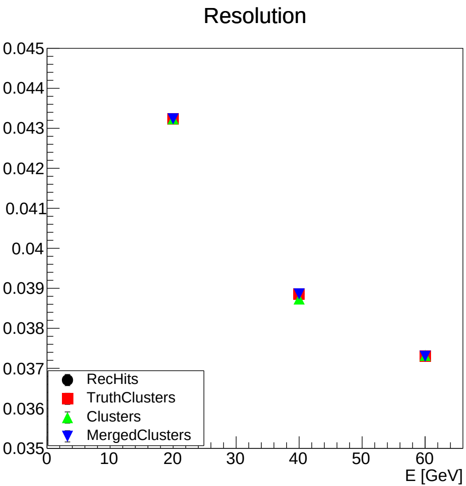


Island cluster energy resolution

Clusters energy: single photon input



Clusters energy resolution



Photon energy resolution

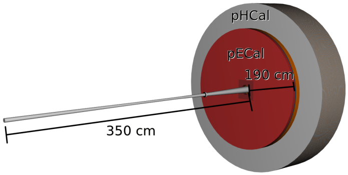
	Fiber energy resolution	Reconstructed 1	Ratio	Reconstructed 2	Ratio
		a = 0.1, b = 0.0015		a = 0.1, b = 0.0014	
500 MeV	0.1503	0.1560	**1.0379**	0.1557	**1.0360**
1 GeV	0.1163	0.1113	**0.9569**	0.1112	**0.9564**
2 GeV	0.0851	0.0812	**0.9539**	0.0797	**0.9363**
5 GeV	0.0570	0.0574	**1.0068**	0.0562	**0.9855**
10 GeV	0.0473	0.0452	**0.9568**	0.0441	**0.9332**
20 GeV	0.0391	0.0382	**0.9772**	0.0367	**0.9399**
30 GeV	0.0323	0.0352	**1.0896**	0.0335	**1.0390**
40 GeV	0.0313	0.0332	**1.0599**	0.0315	**1.0075**
50 GeV	0.0283	0.0323	**1.1381**	0.0306	**1.0783**

Electron energy resolution from Geant4

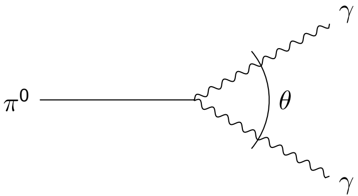
Summary for ePIC simulation campaign

- The energy responses look reasonable for high energy but low energy suffers from digitization.
- The energy resolutions are consistent with previous Geant4 simulations.
- Truth, island, and merged clustering algorithms work as expected for single particle input.

$\pi^0 \to \gamma\gamma$ separation



- "Usual" criteria: $\pi^0 \to \gamma\gamma$ distinguished if photons are separated by one tower size.
- pECal: 2.5×2.5 cm at z = 350 cm.
- $\theta_{min} = \frac{2.5\ cm}{350\ cm} = 0.007 \Rightarrow E_{\pi^0} = 38\ GeV$.



$$\theta_{min} = \frac{2m_{\pi^0}}{E_{\pi^0}}$$

Shower profile *vs* neural networks

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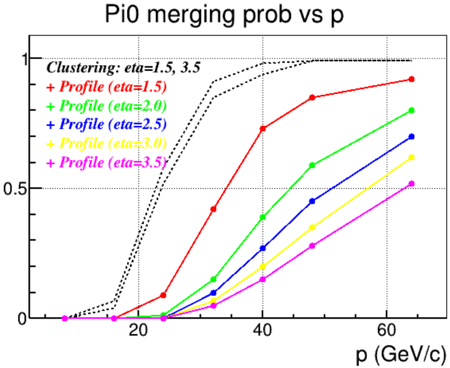
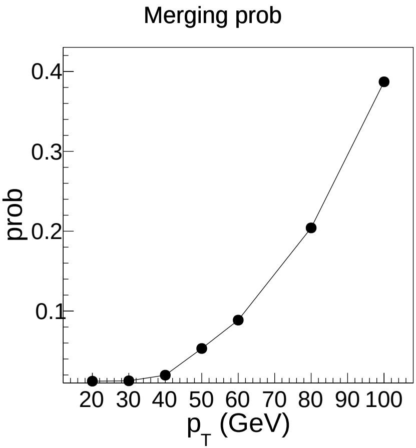
- Shower profile: $\chi^2 = \sum_i \left(\frac{E_i^{meas} - E_i^{pred}}{\sigma_i} \right)^2$
- EIC YR Fig. 11.46: pECal with granularity $\sim$0.008 (2.5×2.5 cm^2 at z=3m).



- Neural networks input ($\eta = 2$): 5×5 central tower energies; pECal x and y positions.



Summary of π^0 decay photon separation

- Neural networks can largely improve the π^0 decay photon separation.
- Reduce merging rate from 75% in a shower profile analysis to 10% at 60 GeV.
- By including the xy position of the shower, one NN can handle all ϕ positions.
- Future study to use one NN to handle all η and ϕ positions.

DD4hep fiber implementation

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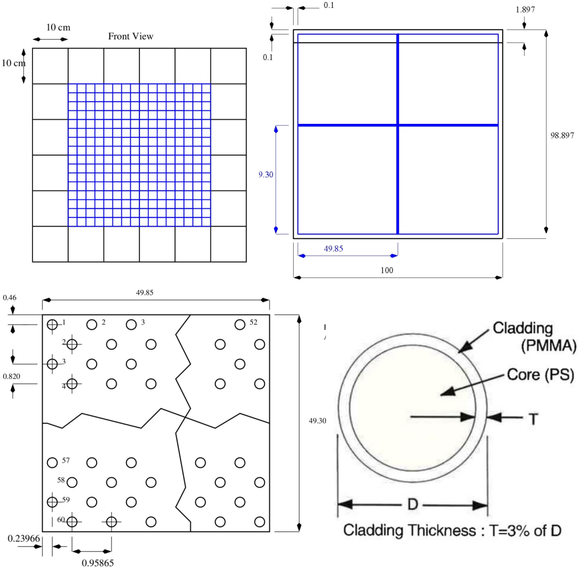
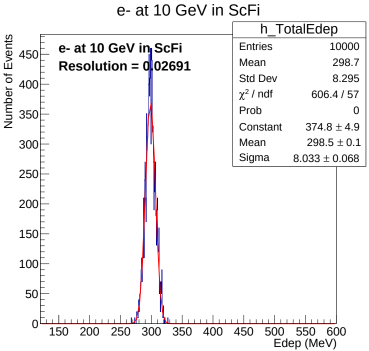
- Problem: pECal with fibers uses $\sim$6 GB memory in DD4hep and will use more memory when other detectors are included.
- Reason: storing *PlacementPath–VolumeID* mapping in *m_geo.g4Paths* uses large memory.
- Solution: group fibers in each module as a single readout channel.
- Result: reduce memory usage to $<$700 MB, which is the same as that without fibers.
- Method I: Change DD4hep to let it only store the *VolumeID* for each module instead of each fiber.
  - Pros: Easy to build fibers.
  - Cons: Need to change DD4hep code.
- Method II: Set the whole module as a sensitive detector and cover the insensitive areas by daughter radiators.
  - Pros: No need to change DD4hep code.
  - Cons: More coding to build the fibers.

pEcal (old) geometry

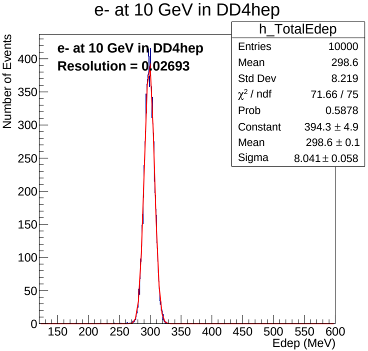
- Fiber implementation with this old geometry.
- Upper left: pECal front view.
- Upper right: One block of 2x2 towers.
- Lower left: pECal fiber layer in one block.
- Lower right: pECal fiber cladding.



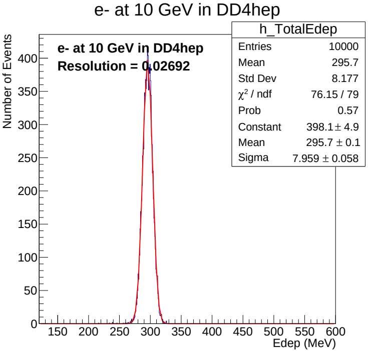
Consistency check in fiber implementation



Geant4



Method I (hacking DD4hep)



Method II (covering non-fiber)

Consistent with Geant4, though Method II is slightly different possibly due to the voxelization of Geant4.

Summary for DD4hep fiber implementation

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- These tests were done for an old geometry.
- Method I has exact agreement between DD4hep and Geant4 but needs to modify DD4hep code.
- Method II will slightly change the results but there is no need to change the DD4hep code. This method will be used for the updated geometry.

Future plan

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- Study the required length for pECal.
- Study the SiPM response.
- Study pECal performance in standalone Geant4 simulations with fiber structure.
- Implement fiber structure in DD4hep for updated geometry.