SciGlass: Performance Studies

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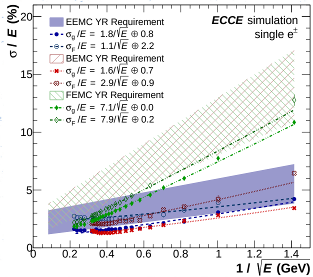
Review Charge: Simulation and Performance

- c. **Simulation studies**: already performed, ongoing and planned (with timelines); results from the simulations; particular care in (i) showing how realistic the parameters used in simulations are and (ii) reporting what is missing for a fully realistic simulation (backward, specific event categories, …)
- d. Does the simulation take into account the **realistic light collection uniformity, response of the selected photosensors and related FEE**?

3. **Performances**:
   Please use the official simulation framework. Please tag all software (sim., reco., and analysis) used in these studies.
   - a. Key plots to be shown:
     - i. Photon and electron energy resolution σ/E as a function of E (0-18GeV) at $|\eta|$=0, 0.5, 1. Consider a minimum energy of 50 MeV.
       1. For each point, please extract FWHM and percentage of gammas/electrons within a cut window of $|E/p-1| < 1x$ FWHM. Please provide the E/p lineshape in the backup material.
     - ii. Photon angular resolution (ϕ, η) as a function of E (0-18 GeV) at $|\eta|$=0, 0.5, 1
     - iii. Pion rejection as a function of p (0-18 GeV/c) at 95% e-efficiency at $|\eta|$=0, 0.5, 1
     - iv. Pion rejection versus e-efficiency at p = 1, 5, 10 GeV/c at $|\eta|$=0, 0.5, 1
     - v. Separation of gamma from π^0 decay: separation probability as a function of p at $|\eta|$=0, 0.5, 1
     - vi. Measured cluster energy response to E= 8 GeV single electron vs η & ϕ in the full acceptance
   - b. Comparison of the **present assessment of the detector performance compared with the YR requirements**?

Simulation studies

» **ECCE simulation** with PANDA-like geometry (Fun4All framework)



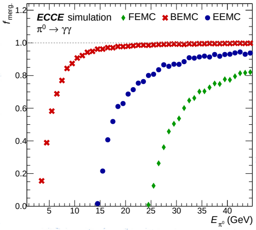


Figure 19: Fraction of neutral pions for which the showers from their decay photons are merged into a single cluster and can not be reconstructed using an invariant-mass-based approach for the different ECals.

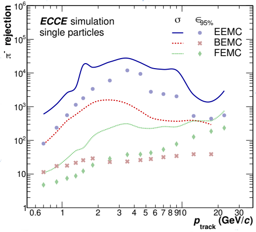


Figure 20: Pion rejection factor for the different ECals with $E/p > 1 - 1.6\sigma_e/E$ or based on a $\varepsilon_e \approx 95\%$ cut.

`https://arxiv.org/abs/2207.09437`

» **Standalone Geant4** with optical photon propagation for beam tests using specific photosensors (by Petr Stepanov)

» **Simulation for ePIC** (DD4hep-based)

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Simulation studies

- **ECCE simulation** with PANDA-like geometry (Fun4All framework)
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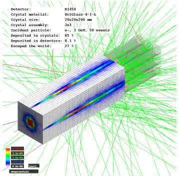

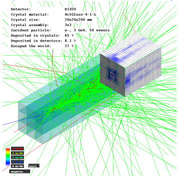

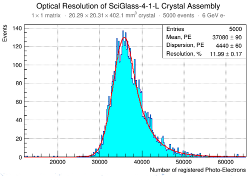

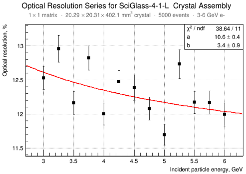

- **Simulation for ePIC** (DD4hep-based) Subject of this talk

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Simulation setup

- Single particle simulations
- Momentum direction sampled uniformly on a sphere
- Vertex at `(0, 0, 0)`
- ePIC 23.03.0 geometry (next slide)
- `FTFP_BERT` physics list
- Particle momenta are used in place of reconstructed charged track momenta
- Analysis cut: only consider towers with $E_{\text{tower}} > 50$ MeV

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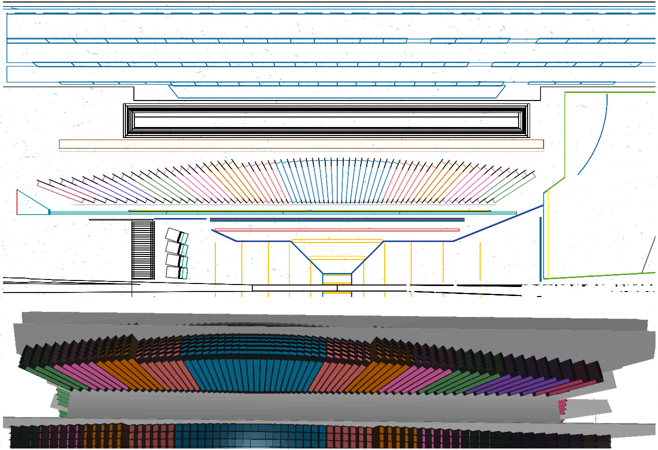
Simulation setup: SciGlass calorimeter geometry

Tower dimensions and placement implemented based on mechanical design



SciGlass lengths of 45.5 and 40 cm ($\approx$ 16.3 and 14.3 X_0)

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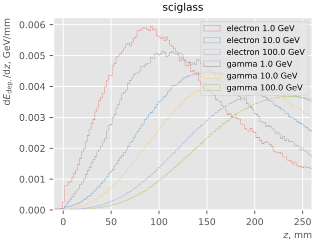
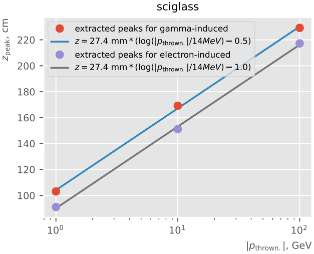
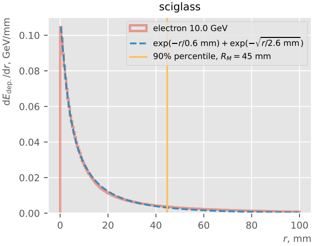
SciGlass material in Geant

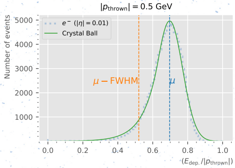
- Density $4.22\ \mathrm{g/cm^3}$
- Energy deposits corrected according to the Birks' law with $kB = 0.0333\ \mathrm{mm/MeV}$ (nominal for PbWO4 at CMS)
- Radiation length $X_0 \approx 2.8$ cm (via Rossi approximation)
- Molière radius $R_M \approx 4.5$ cm

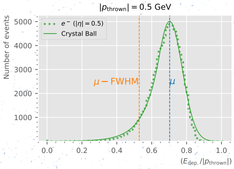


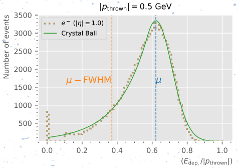


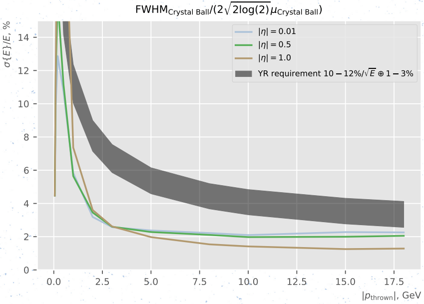


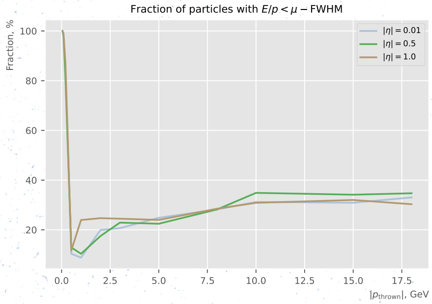
Energy resolution











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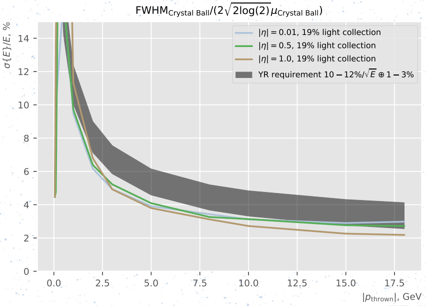
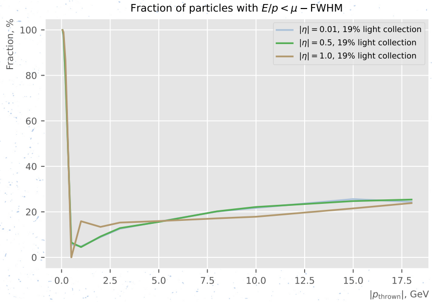
Energy resolution: digitization and readout

- Assuming Hamamatsu S14161-6050HS-04 (4×4 array of 6×6 mm 14331 channel MPPCs)
- PDE $\epsilon_Q \approx 50\%$ at SciGlass emission wavelength
- Light yield $\mathcal{L} \approx 3000\ \gamma/\text{MeV}$ ($10\times$ $PbWO_4$)
- Geometric light collection factor: $\epsilon_{LC} = N_{\text{packages}} \times (0.36\ \text{cm}^2)/(25\ \text{cm}^2) \approx N_{\text{packages}} \times 16\%$
- Pixel saturation and light collection fluctuates according to

$$P_{\text{pixel}} = 1 - \exp\left(-\frac{E_{\text{tower}} \times \mathcal{L} \times \epsilon_Q \times \epsilon_{LC}}{N_{\text{pixels}}}\right), \qquad N_{\text{photons}} \sim \text{Binomial}(N_{\text{pixels}}, P_{\text{pixel}})$$





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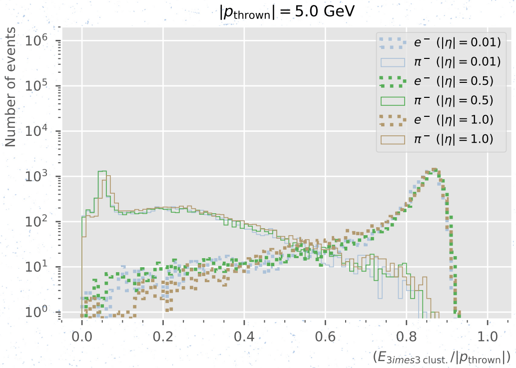
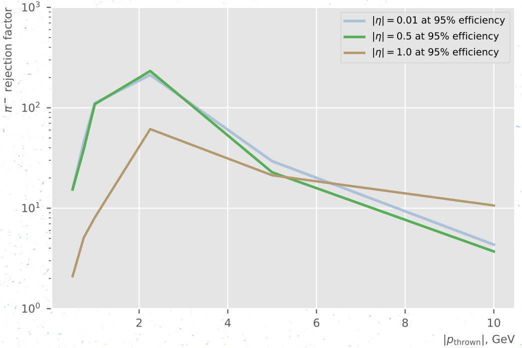
Pion rejection: η dependence

The E/p cut is used where E is a deposited energy sum in a 3×3 cluster, and p – true momentum.

$$\text{pion rej. factor} \equiv \frac{1}{\text{FPR}} = \frac{N(\pi^- \text{ thrown})}{N(\pi^- \text{ ID as } e^-)}, \qquad \text{electron eff.} \equiv \text{TPR} = \frac{N(e^- \text{ ID as } e^-)}{N(e^- \text{ thrown})}$$





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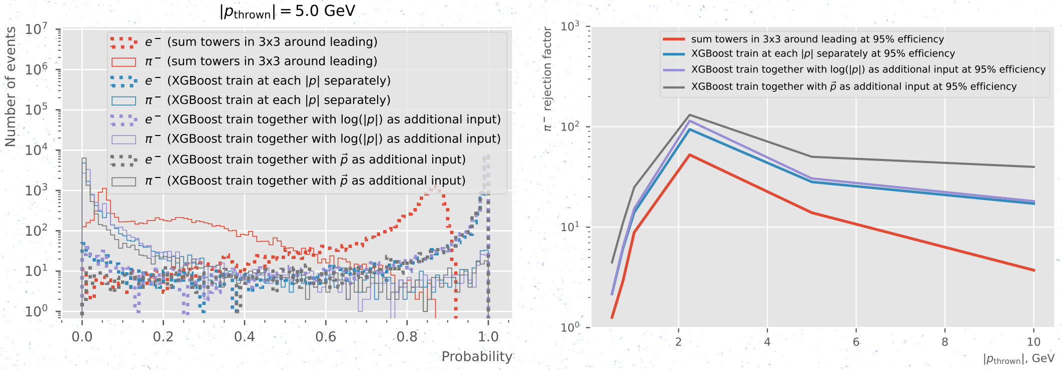
Pion rejection: ML

Boosted Decision Trees implementation in XGBoost used with default parameters.
ML input: 9 tower energies for 3x3 cluster, particle p_T, η and φ.



TODO: Also input the position of the 3x3 cluster in the calorimeter (improve ML)

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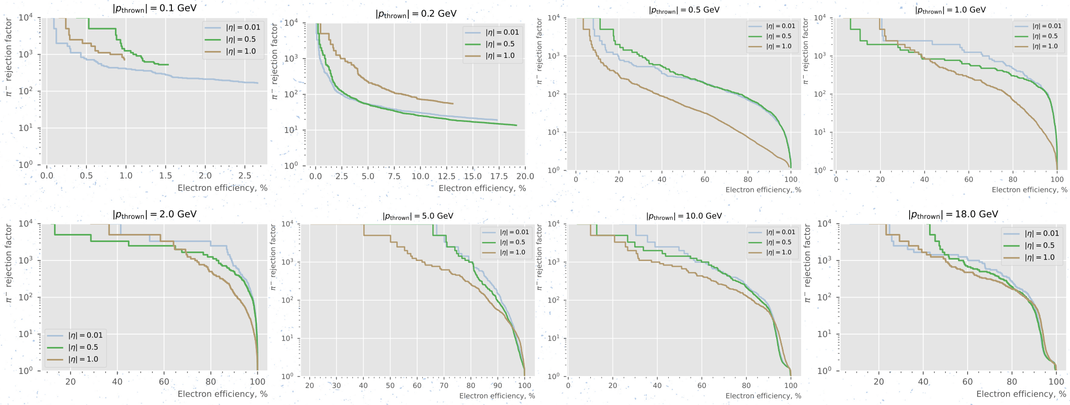
Pion rejection ROC: η dependence



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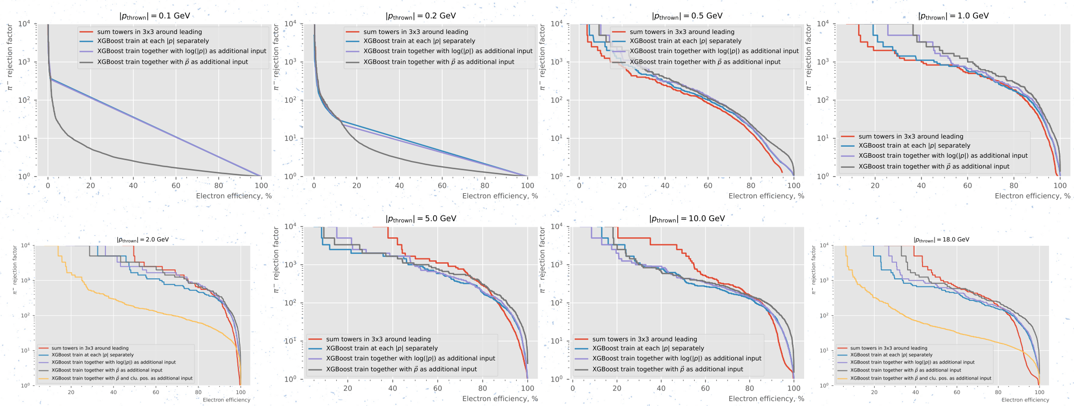
Pion rejection ROC: ML method



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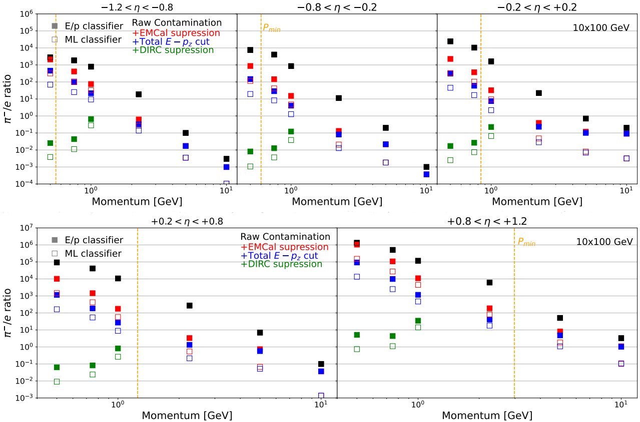
Pion rejection: π^- contamination in DIS

$$\left(\frac{N_{\pi-}}{N_{e-}}\right)_{\text{raw}}, \quad \frac{1}{\epsilon\cdot(\pi\ \text{rej.})}\left(\frac{N_{\pi-}}{N_{e-}}\right)_{\text{raw}}, \quad \frac{1}{\epsilon\cdot(\pi\ \text{rej.})}\left(\frac{N_{\pi-}}{N_{e-}}\right)_{E-p_Z\ \text{cut}}, \quad \frac{1}{\epsilon\cdot(\pi\ \text{rej.})\cdot\epsilon_{\text{DIRC}}\cdot(\pi\ \text{rej.}_{\text{DIRC}})}\left(\frac{N_{\pi-}}{N_{e-}}\right)_{E-p_Z\ \text{cut}}$$



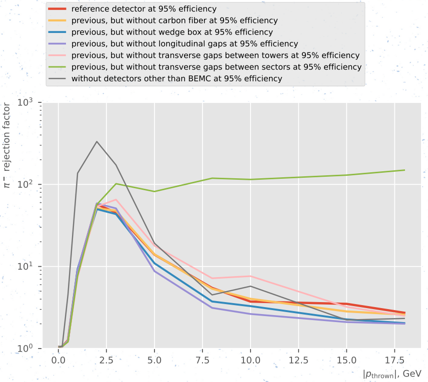
(Analysis by Claire Gwenlan, Tyler Kutz, Paul Newman, and Barak Schmookler)

The 90% purity requirement is not achieved at $\eta > 0.2$ by the current design

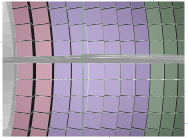
Pion rejection: detector design

» Longitudinal gaps are **not** projective in η

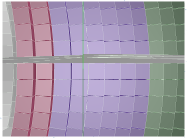
» Transverse gaps are projective in φ



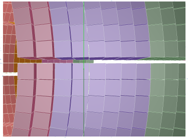
reference detector



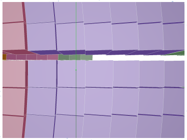
…without carbon fiber



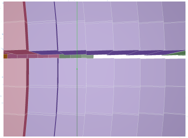
…without wedge box



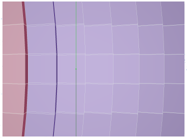
…without longitudinal gaps



…without tower gaps



…without sector gaps



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Pion rejection: detector design

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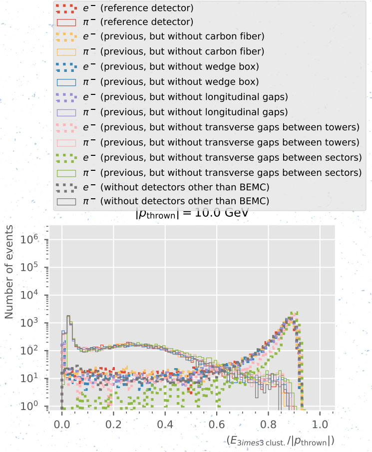
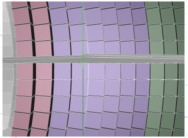
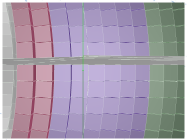


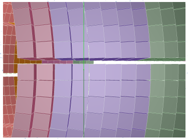
reference detector



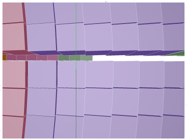
...without carbon fiber



...without wedge box



...without longitudinal gaps



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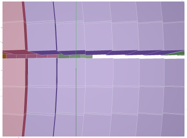
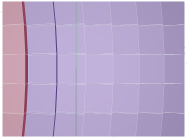


...without sector gaps



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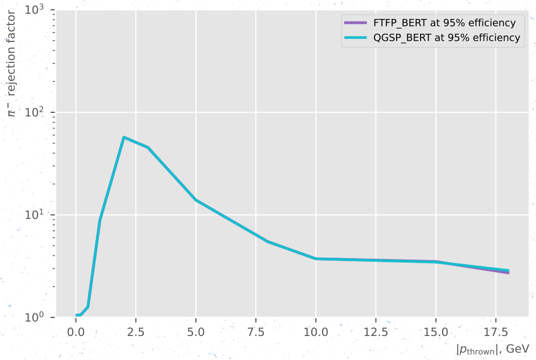
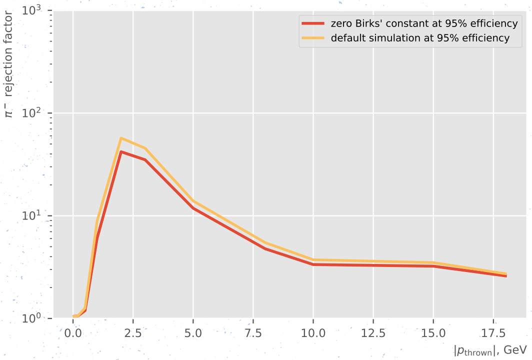
Systematics





e.g., Paper: Birks' scaling in EJ 299-33

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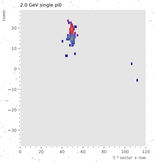
Island Clustering

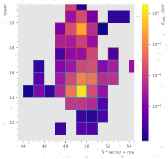
1. Pick connected "islands" of hits
2. Select islands with peak energy > threshold (50 MeV here)
3. In each island, find hits that are local maxima w.r.t. 4 neighbours
4. Select local maxima above a threshold (100 MeV here – yeah, should be 50)
5. For hit h calculate its distance d_{hm} to each local maxima hit m, the weight is

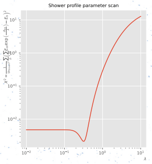
$$\omega_{hm} \sim E_m \exp\left(-\frac{d_{hm}}{\lambda}\right)$$

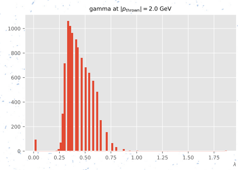
6. Fraction proportional to ω_{hm} of energy E_h is attributed to a subcluster m.

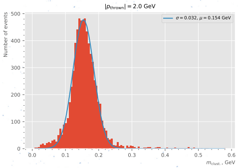
For each island calculate $\chi^2 = \sum_h \left(\sum_m E_m \exp\left(-\frac{d_{hm}}{\lambda}\right) - E_h\right)^2$, minimize χ^2 over λ





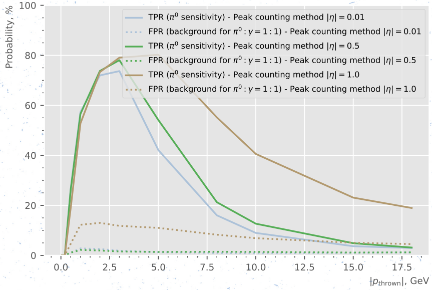


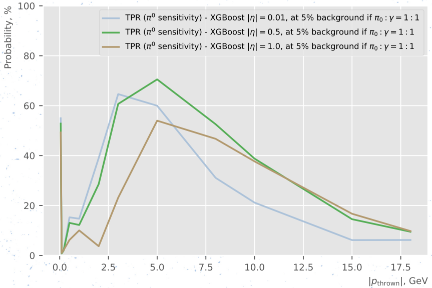




π^0/γ separation

$$\pi^0 \text{ sensitivity} \equiv \frac{N(\pi^0 \text{ identified as } \pi^0)}{N(\pi^0 \text{ produced a cluster})}, \qquad \gamma \text{ background} \equiv \frac{N(\gamma \text{ identified as } \pi^0)}{N(\gamma \text{ produced a cluster})}$$



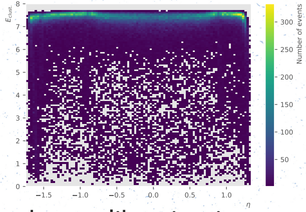


- Naive method based on counting local maxima
- ML classifier based on 5x5 cluster information (without tracking) – potential for recognizing elongation

Reconstructed cluster energy response

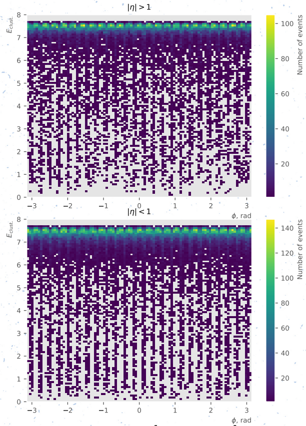
…to $E = 8$ GeV single electron vs η and φ in the full acceptance

$E_{\text{clust.}}$ vs η:



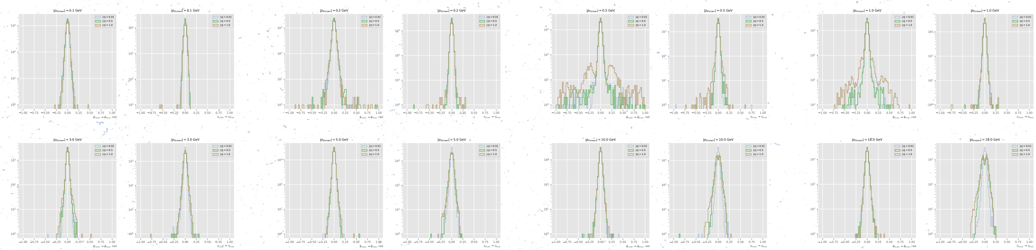
η-dependent calibration is expected.

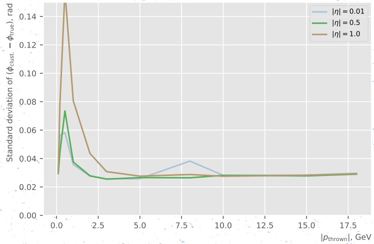
$E_{\text{clust.}}$ vs ϕ:

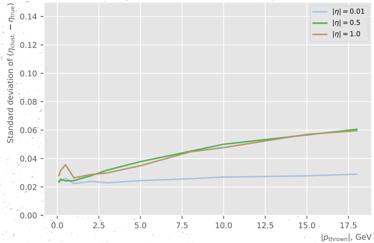


Wedge box structure has a dominant effect.

Angular resolution







The $\Delta\eta$ bifurcates at high momentum (shower deepens towards higher $|\eta|$?).

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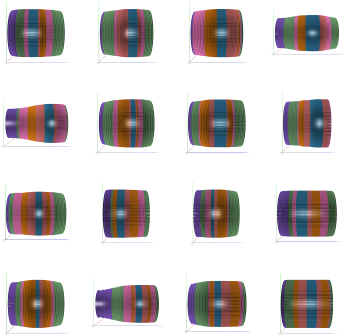
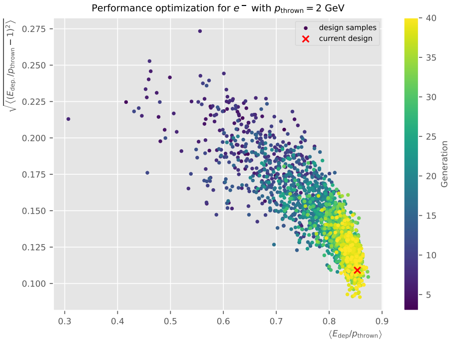
Further work: detector optimization

Tower placement and rotation in the mechanical design is not optimized using physics metics, yet!

Random samples in the design space:



Example toy optimization for 2 objectives (x,y-axes – measures for acceptance and resolution):



Both plots rely on longitudinal variations only. Other parameters to be included.

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Conclusion

- Energy resolution is well exceeding the YR requirement
- Requirements on pion rejection can be met after a change:
  - Removing/modifying wedge structure
  - Relaxing the requirement on 95% electron efficiency constraint
- Neutral pion separation was demonstrated using simple algorithms
- Further input from beam tests would be extremely valuable for constraining hadron interaction properties

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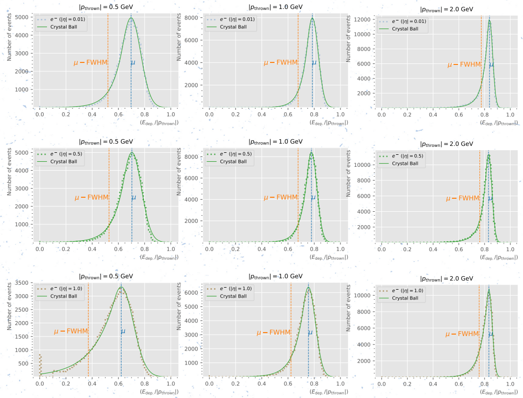
Backup

Yellow Report Requirements

η	Nomenclature			Electrons and Photons		
				Resolution	PID	min E
-3.5 to -3.0		Central Detector	Backward Detector		π suppression up to 1:1E-4	50 MeV
-3.0 to -2.5						50 MeV
-2.5 to -2.0				2%/√E(+1-3%)		50 MeV
-2.0 to -1.5				7%/√E(+1-3%)		50 MeV
-1.5 to -1.0				7%/√E(+1-3%)		50 MeV
-1.0 to -0.5			Barrel	(10-12)%/√E (+1-3%)		50 MeV
-0.5 to 0.0						50 MeV
0.0 to 0.5						50 MeV
0.5 to 1.0						50 MeV



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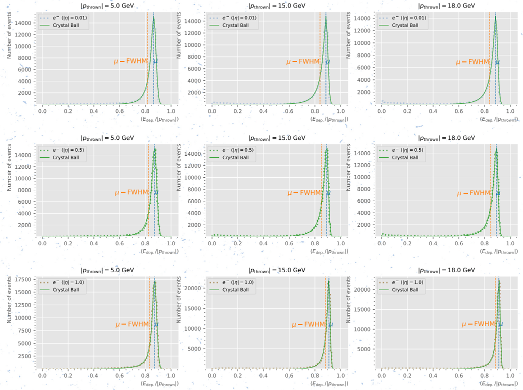
|p_thrown| = 5.0 GeV
|p_thrown| = 15.0 GeV
|p_thrown| = 18.0 GeV
e⁻ (|η| = 0.01)
e⁻ (|η| = 0.5)
e⁻ (|η| = 1.0)
Crystal Ball
μ − FWHM
μ
Number of events
(E_dep./|p_thrown|)