Photon-pi0 discrimination using ALLEGRO ECAL shower shape variables

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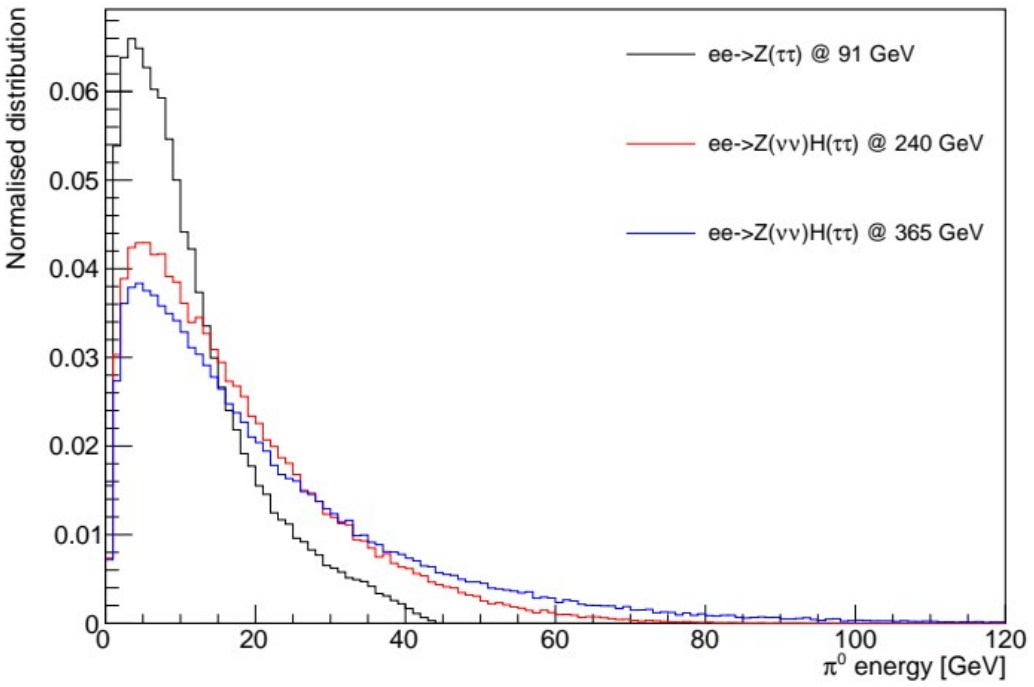
Motivations

- At FCC-ee, taus will be crucial to both EW precision measurement (tau polarisation with Z→tautau) and Higgs & BSM physics programs (ee→ZH, H→tautau). See Maria's talk for more details.
- High performance photon-pi0 separation is critical to the reconstruction of hadronic tau decay and non-tau background rejection.
- One needs to exploit the advantage of ALLEGRO high granularity ECAL in the performance of photon-pi0 separation using shower shape variables.

Preliminary results comparing different cross-talk and noise settings, as well as between SW clustering and topo-clustering, will be reported.

Pi0 energy distribution

- Collect truth level pi0 from all decay modes of tau (IDEA geometry)



The energy distribution peaks at around 5-10 GeV.

A higher center-of-mass energy leads to a longer tail.

It might be worth having a look at the photon energy distribution from the di-photon background.

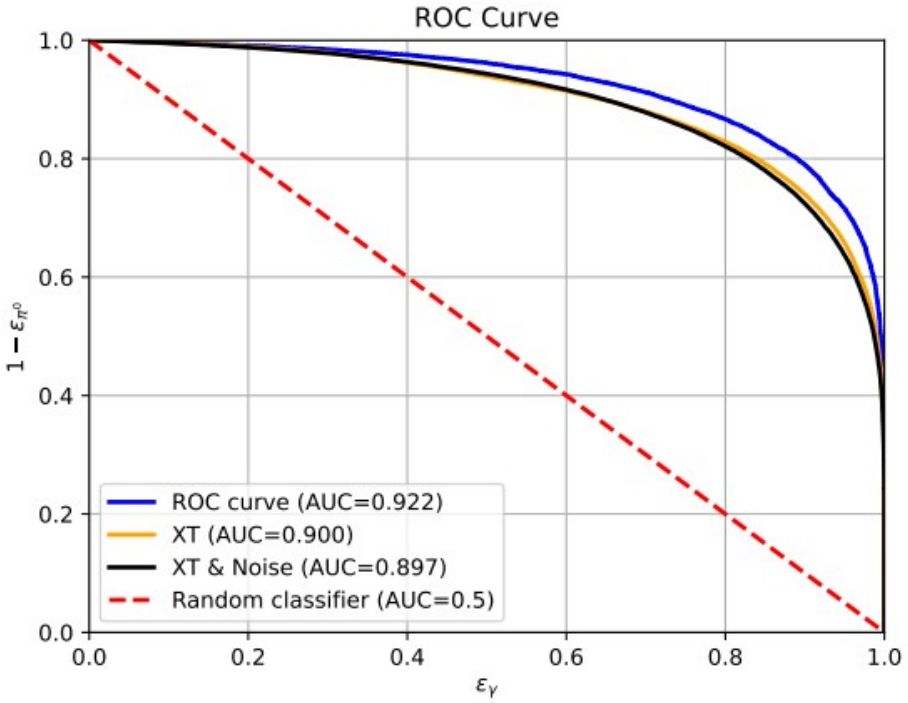
ALLEGRO full sim settings

- Particle gun: 100k photons and 100k pi0 with ALLEGRO v3 geometry. Energy range between [1, 100] GeV. Theta between [0.65, 2.49] rad.
- Photons and pions are reconstructed with the following settings for both SW clusters and topo clusters: (1) No cross-talk or noise (baseline), (2) With cross-talk but no noise, (3) With cross-talk and noise (1 sigma filter).
- 101 shower shape variables of the leading cluster in each reconstruction setting are saved for the study of photon-pi0 separation BDT training:

(1) The cluster mass
(2) The cluster energy
(3) E_fr_side_pm3_EMB_layer_*
(4) Energy fraction per layer
(5) Maximum cell energy per layer
(6) Delta_E_2ndmax_min_EMB_layer*
(7) Delta_E_2ndmax_min_vs_phi_EMB_layer*
(8) width_module_EMB_layer*
(9) width_theta_EMB_layer*
(10) Ratio_E_max_2ndmax_EMB_layer*
(11) Ratio_E_max_2ndmax_vs_phi_EMB_layer*

BDT training with SW clusters

- Applying the baseline training model to a simulation with cross-talk and noise leads to a degradation in photon-pi0 separation performance.



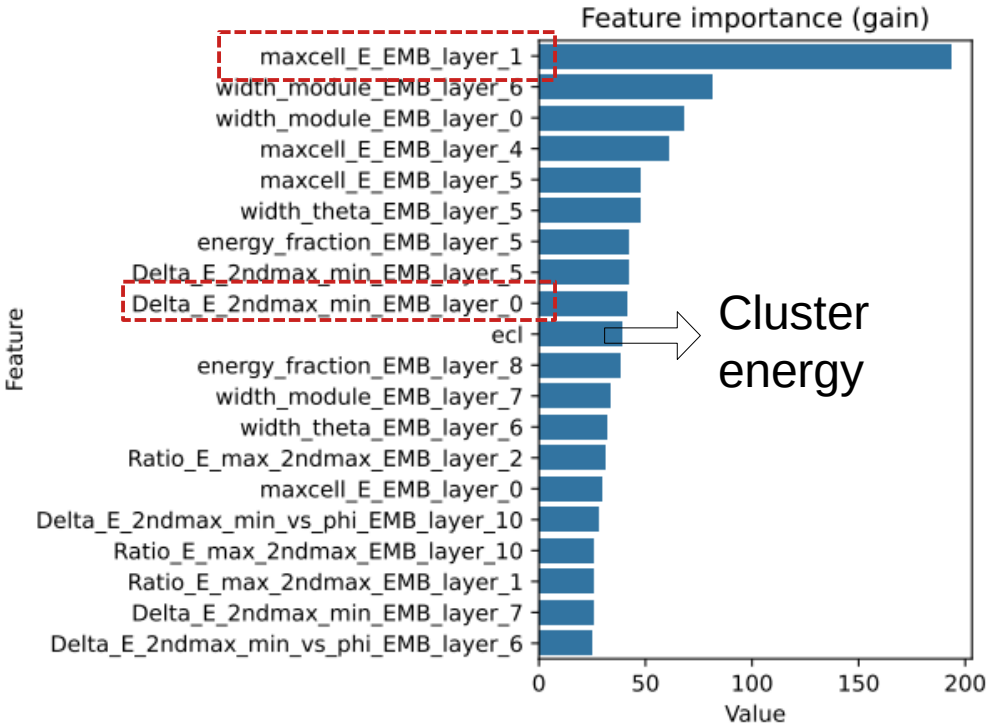
a. Blue curve:
Baseline training + baseline test data.

b. Alternative test dataset 1 (XT):
Baseline training model applied to a test dataset with cross-talk.

c. Alternative test dataset 2 (XT & Noise):
Baseline training model applied to a test dataset with both cross-talk and noise.

BDT training with SW clusters

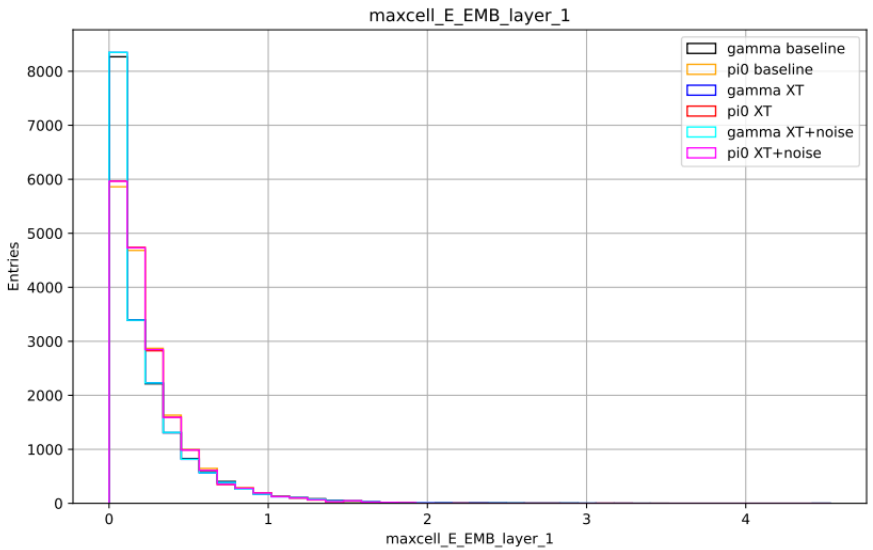
- Ranking of feature importance in the baseline training.



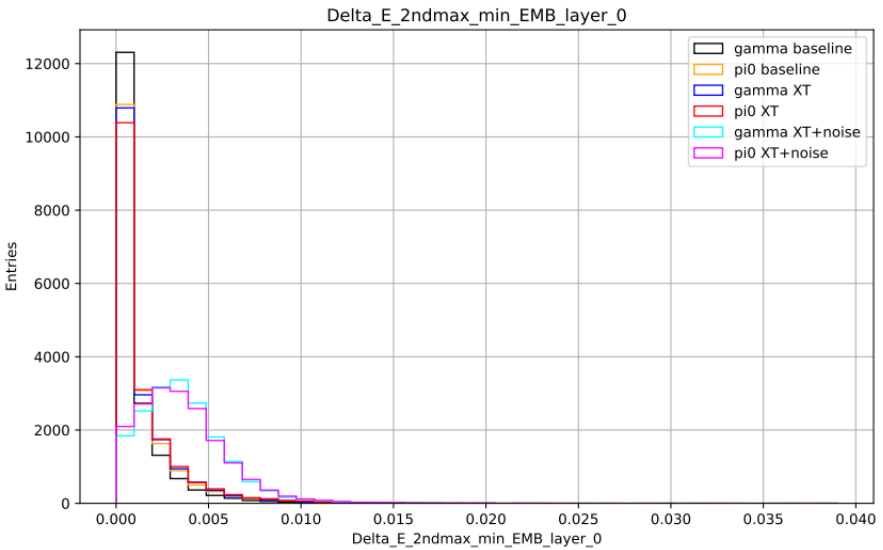
With the large energy range of [1, 100] GeV, the cluster mass doesn't seem to be one of the most important features.

BDT training with SW clusters

- Shower shape variables with some highest feature importance.



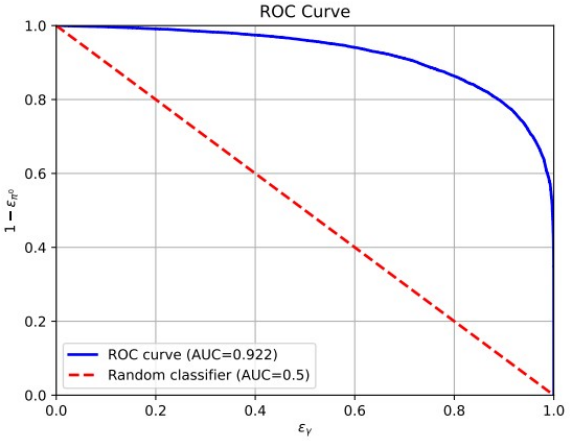
Maximum cell energy on layer 1



Energy difference of the 2nd highest cell wrt the local minimum between the 1st and the 2nd highest cells on theta direction (layer 0)

BDT training with SW clusters

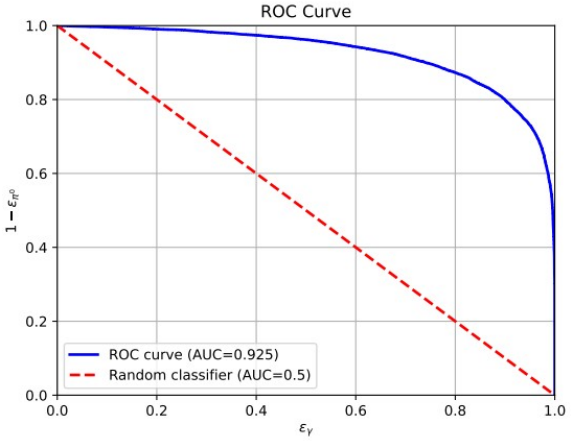
- The inclusion of cross-talk and noise in the input recovers the ROC-AUC.



Train & test with:

Baseline

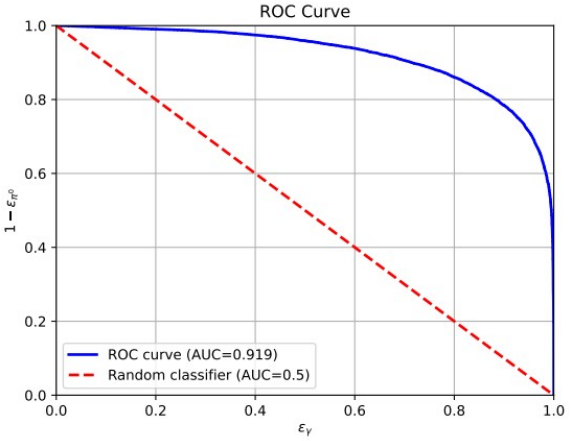
AUC=0.922



Train & test with:

Cross-talk

AUC=0.925



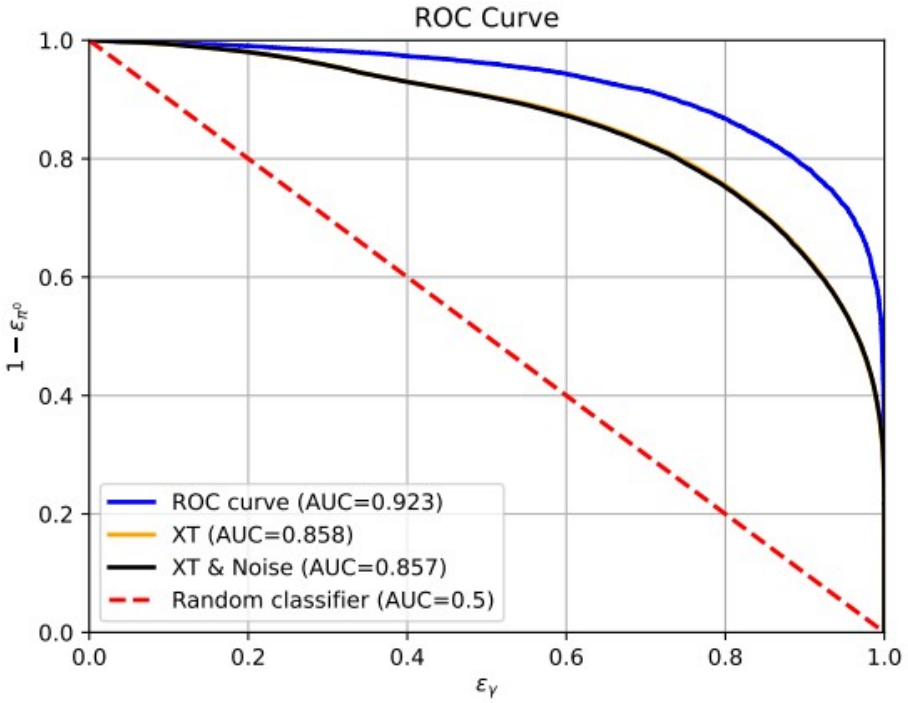
Train & test with:

Cross-talk & Noise

AUC=0.919

BDT training with **topo clusters**

- Applying the baseline model to datasets with cross talk and noise leads to an even larger degradation in photon-pi0 separation with topo clusters.



a. Blue curve:
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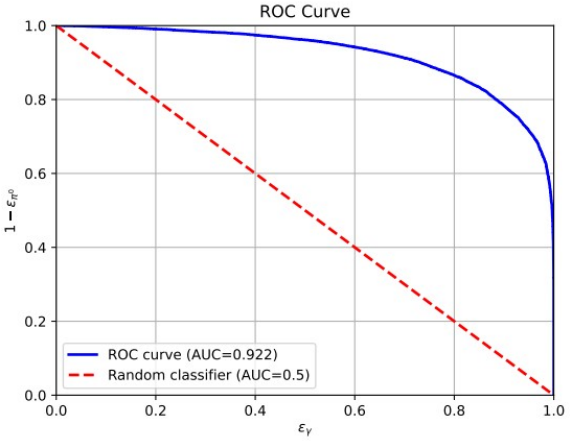
b. Alternative test dataset 1 (XT):
Baseline training model applied to a test dataset with cross-talk.

c. Alternative test dataset 2 (XT & Noise):
Baseline training model applied to a test dataset with both cross-talk and noise.

BDT training with **topo clusters**

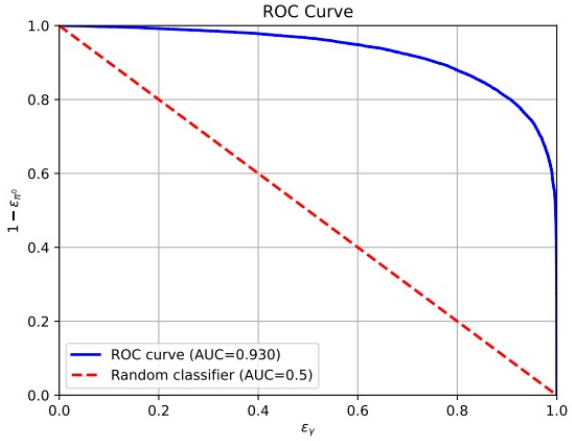
- The inclusion of cross-talk and noise in the input recovers the ROC-AUC.



Train & test with:

Baseline

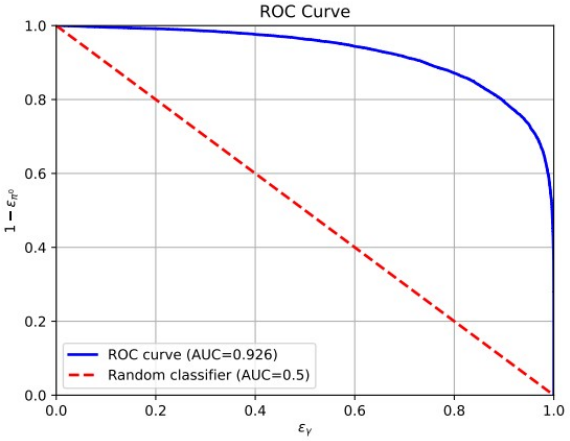
AUC=0.922



Train & test with:

Cross-talk

AUC=0.930



Train & test with:

Cross-talk & Noise

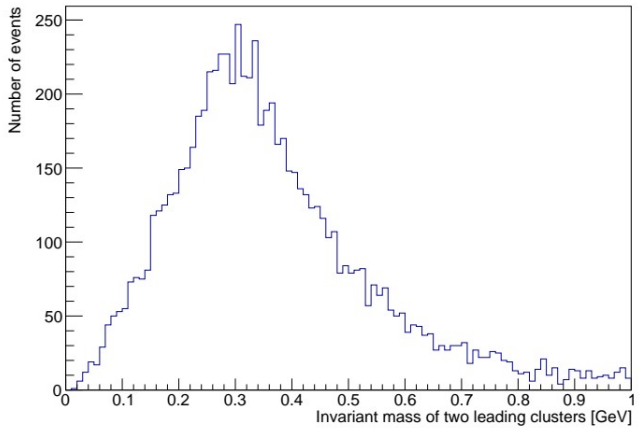
AUC=0.926

Discussions on the BDT training

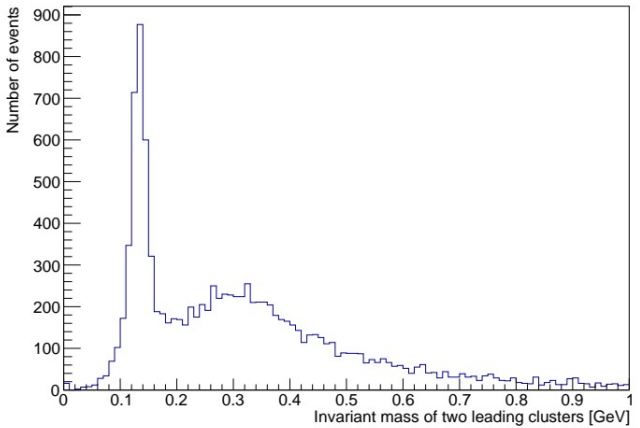
- Is a flat energy distribution of [1, 100] GeV optimised, or realistic enough, for the training of photon-pi0 separation?
- Should we use $Z \rightarrow$ tautau signal and di-photon background samples for the training, instead of relying on the particle gun?
- Once the photon-pi0 separation training is done, how do we implement the training model in the full simulation? Is it possible to propagate the BDT score of individual ECAL clusters to Pandora for pi0 identification, if such an interface exists?
- How much fraction of pi0 is reconstructed as two separate photon clusters and provided as input to the BDT training? (Study shown in the following slides.)

Pi0 reconstructed as two photon clusters

- Reuse the baseline photon and pi0 events produced for the BDT training.
- Energy & direction of the two leading clusters → Invariant mass~135 MeV?



Particle gun photons with energy in [1, 100] GeV (SW clusters).

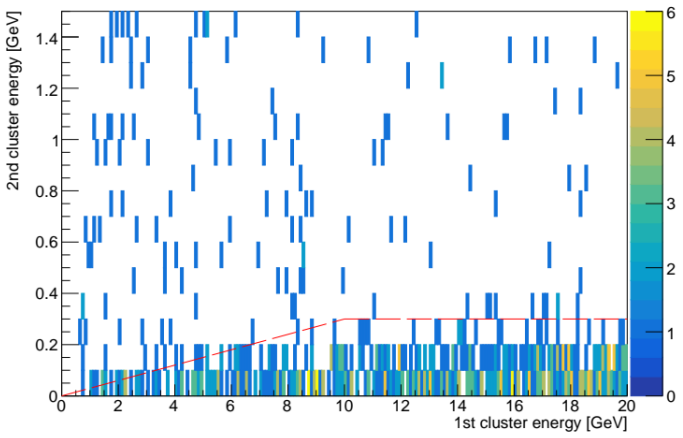


Particle gun pi0 with energy in [1, 100] GeV (SW clusters).

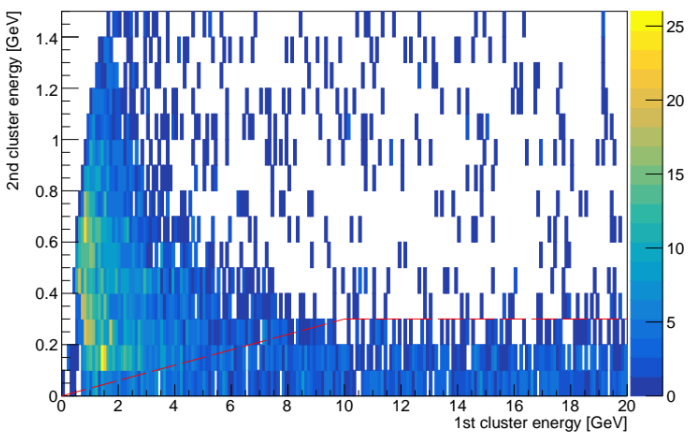
Some event selection is needed before the calculation of invariant mass.

Pi0 reconstructed as two photon clusters

- By comparing photons vs pi0, it looks like there is a band of events with very low sub-leading cluster energy (an artifact of clustering algorithm?).
- These events below the red line are excluded from the calculation of invariant mass.



Particle gun photons with energy in [1, 100] GeV (SW clusters).



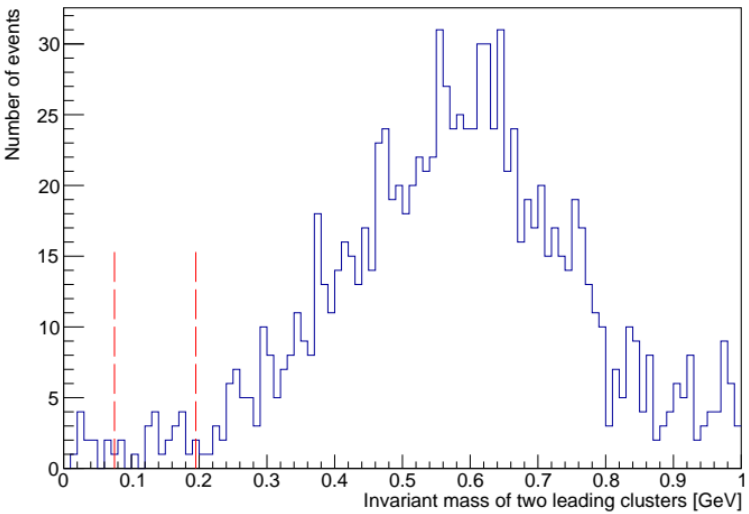
Particle gun pi0 with energy in [1, 100] GeV (SW clusters).

A low energy pi0 tends to be reconstructed as two separate photon clusters.

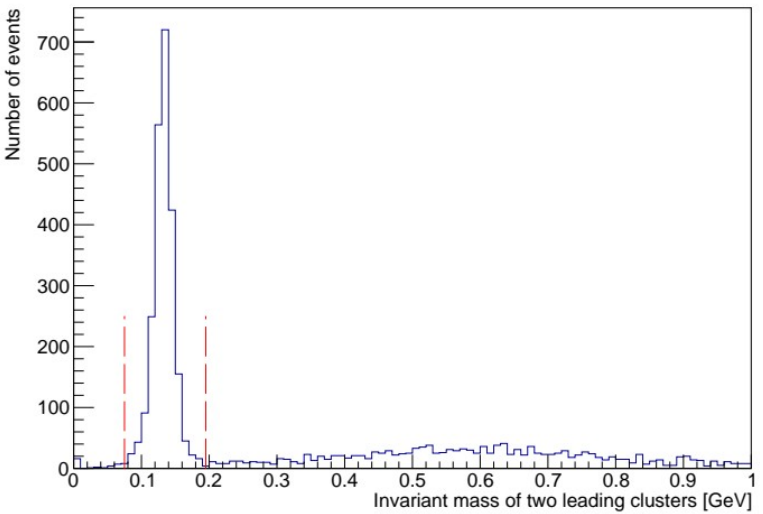
→ This might have a significant effect at the Z-pole.

Invariant mass distribution

- Reject events with small sub-leading cluster energy.
- Count number of events in the interval of 135 +/- 60 MeV.



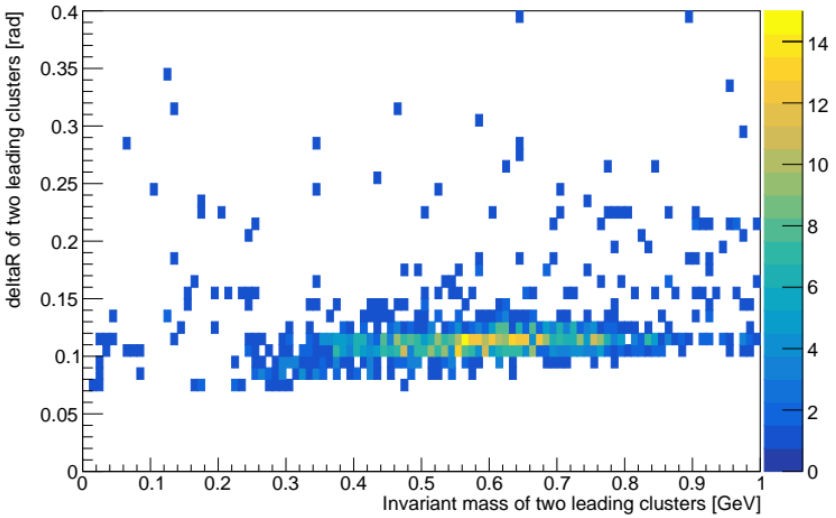
Particle gun photons with energy in [1, 100] GeV (SW clusters).
Fraction = 23/99992 = 0%



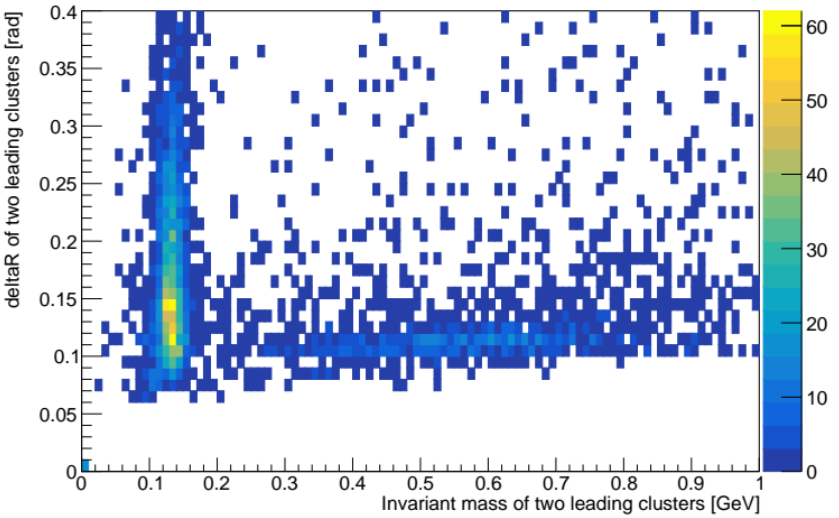
Particle gun pi0 with energy in [1, 100] GeV (SW clusters).
Fraction = 2359/99999 = 2.4%

DeltaR vs invariant mass

- Reject events with small sub-leading cluster energy.
- DeltaR = Sqrt(delta_phi * delta_phi + delta_theta * delta_theta)



Particle gun photons with energy in [1, 100] GeV (SW clusters).



Particle gun pi0 with energy in [1, 100] GeV (SW clusters).

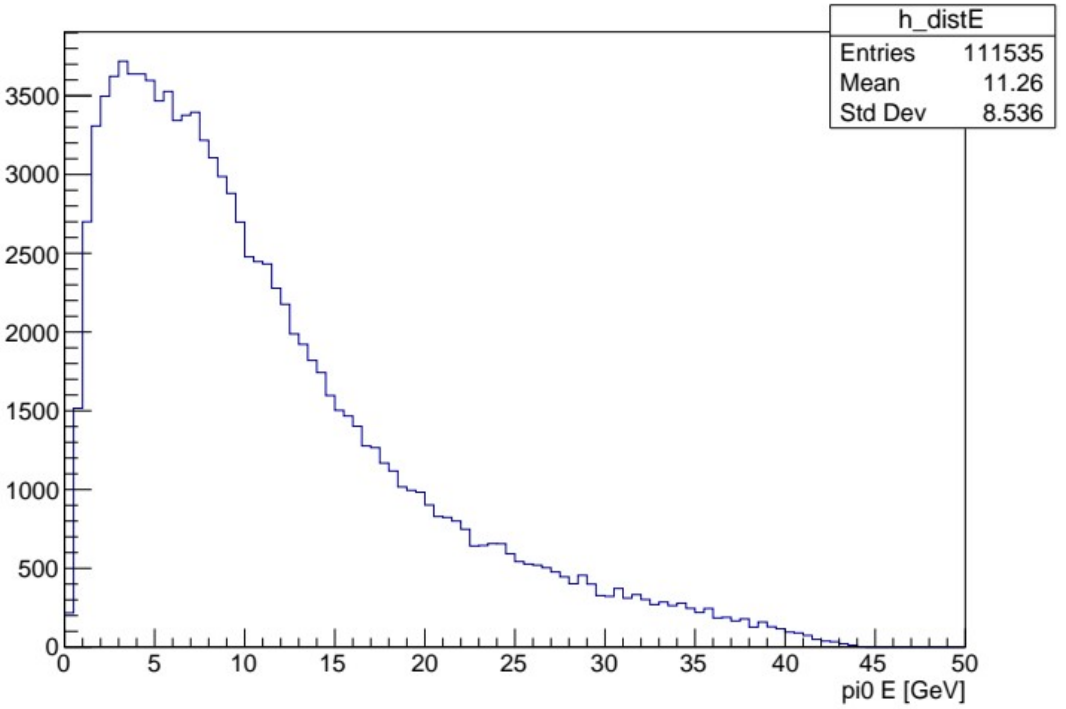
Summary

- Energy distributions of pi0 in the three most relevant physics processes are investigated. The energy spectrum peaks at around 5-10 GeV regardless of the center-of-mass energy.
- Photon-pi0 separation in ALLEGRO ECAL is studied with the addition of cross-talk and noise, using photons and pi0 in a wide energy range. Cross-talk and noise may have an impact on the BDT performance (2-7%), which can be restored by including the relevant effects in the model training.
- There is a possibility to improve the photon-pi0 separation by selecting events where the pi0 is reconstructed as two photon clusters, prior to the BDT training. The improvement might reach percent level, though depending on the exact rule of object reconstruction.

Backup

Pi0 energy distribution

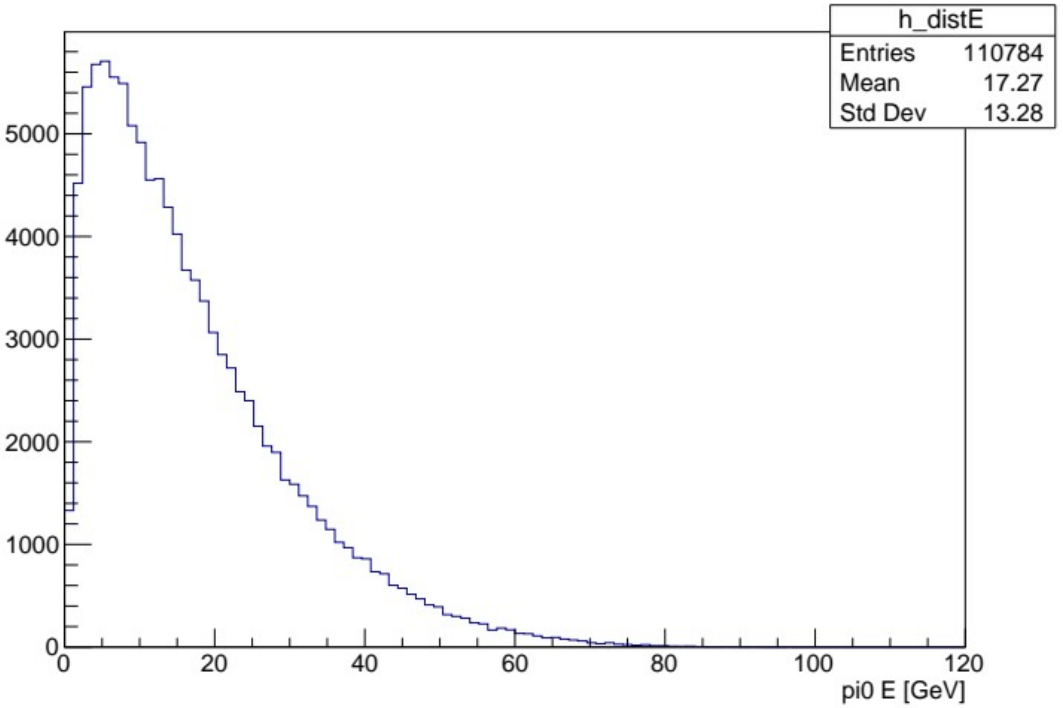
- ee → Z(tautau) @ 91 GeV



100k events were generated.
/eos/experiment/fcc/ee/generation/DelphesEvents/winter2023/IDEA/p8_ee_Ztautau_ecm91/events_111404736.root

Pi0 energy distribution

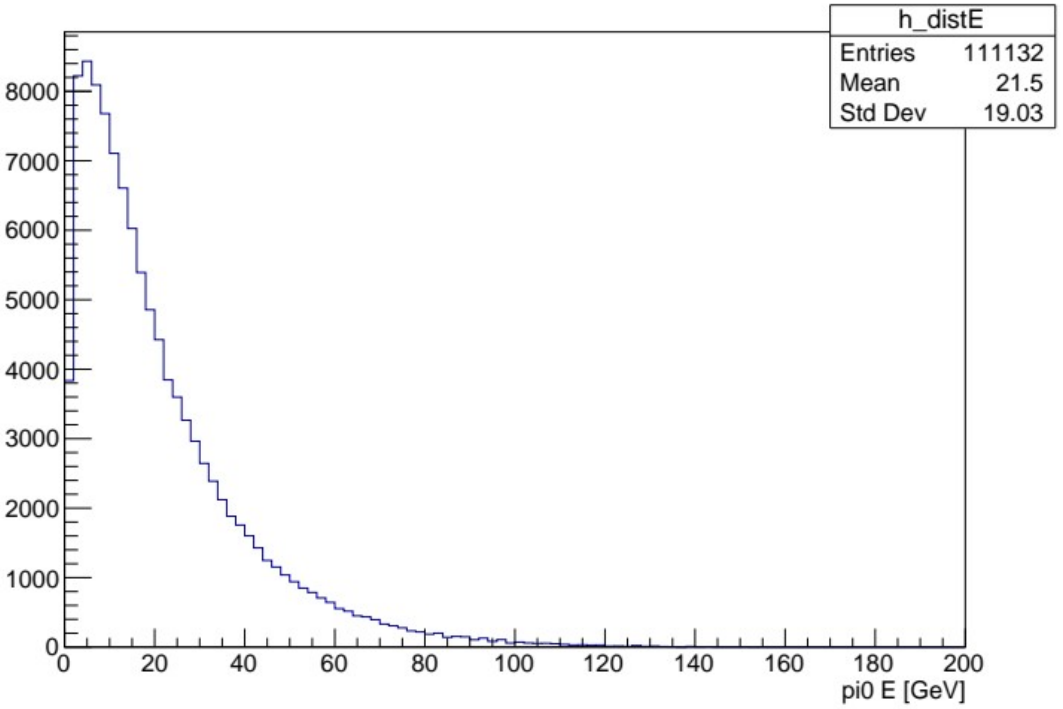
- ee → Z(vv)H(tautau) @ 240 GeV



100k events were generated.
/eos/experiment/fcc/ee/generation/DelphesEvents/winter2023/IDEA/wzp6_ee_nunuH_Htautau_ecm240/events_078984367.root

Pi0 energy distribution

- ee → Z(vv)H(tautau) @ 365 GeV



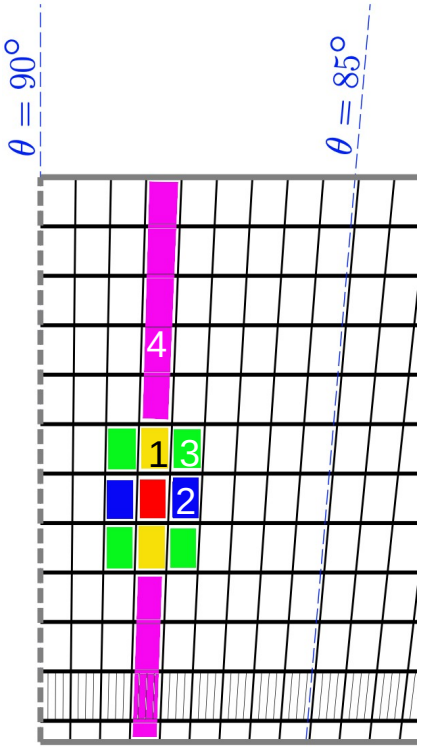
100k events were generated.
/eos/experiment/fcc/ee/generation/DelphesEvents/winter2023/IDEA/wzp6_ee_nunuH_Htautau_ecm365/events_112729784.root

Types of cross-talk neighbours

- 4 types of neighbours are considered*.

Type 1: Direct radial neighbours.
Type 2: Direct theta neighbours.
Type 3: Diagonal neighbours.
Type 4: Other cells in the theta tower.

Different cross-talk coefficients will be assigned to each type in the computation of cell energies.



*This study is done using the ALLEGRO v3 geometry with 11 radial layers.

Cross-talk coefficients

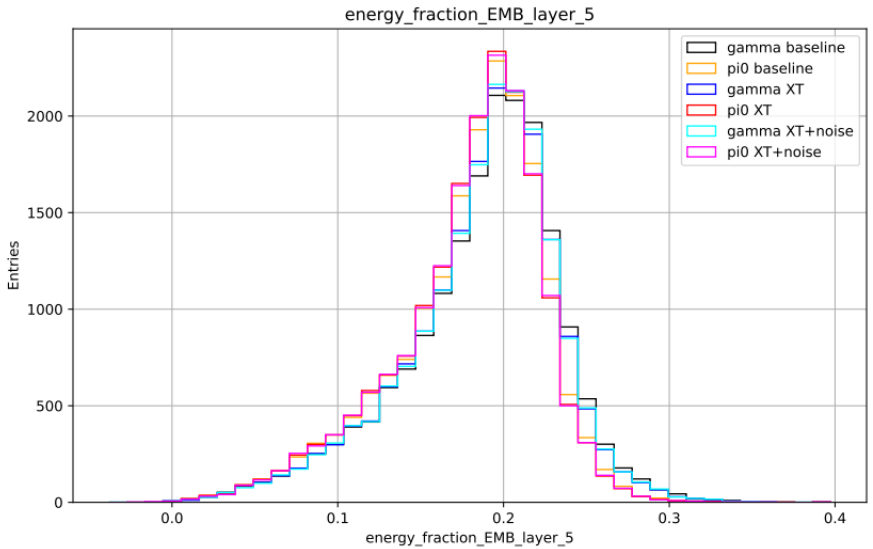
List of cross-talk coefficients.

Type	1: Radial	2: Theta	3: Diagonal	4: Tower
Coefficient	0.7%	0.2%	0.04%	0.1%

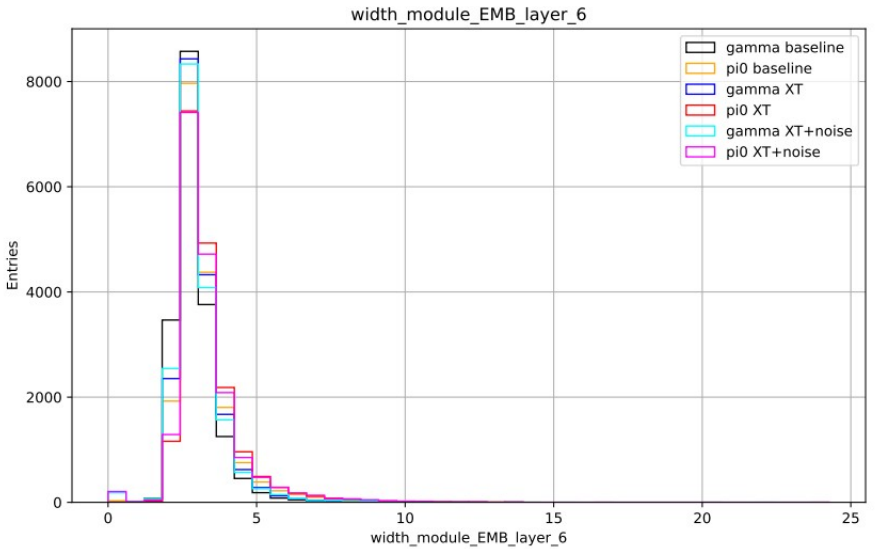
- No outer/inner asymmetry is assumed for cross-talk coefficients between radial neighbours.
- Values are taken from Juska's measurement on CERN PCBv1.

BDT training with SW clusters

- Shower shape variables with some highest feature importance.



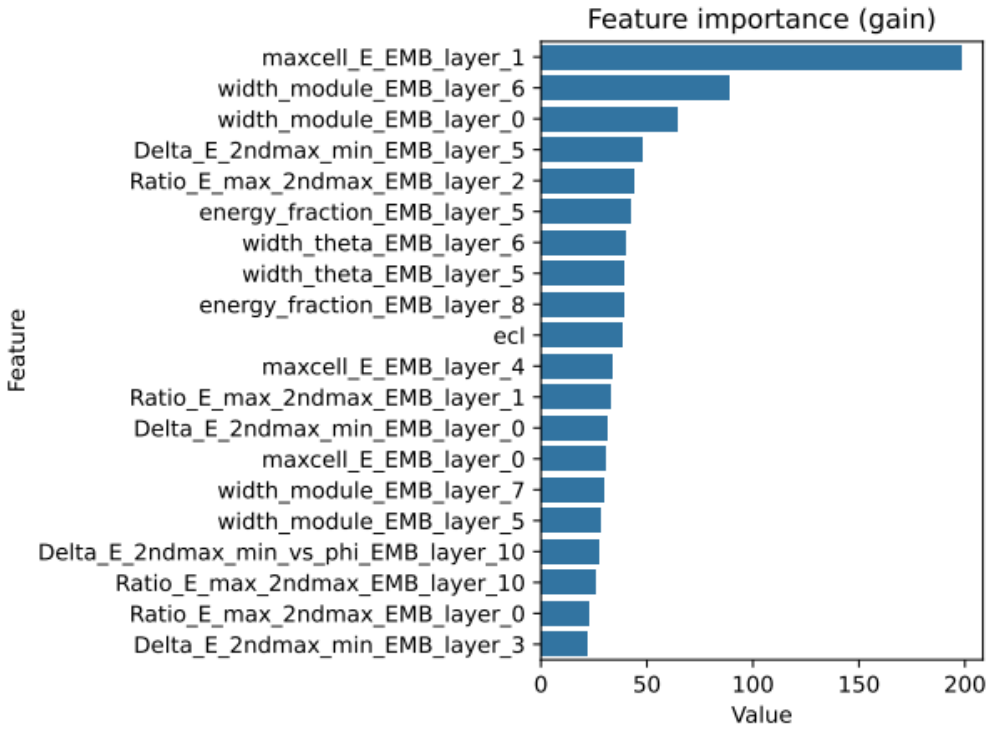
The energy fraction of layer 5



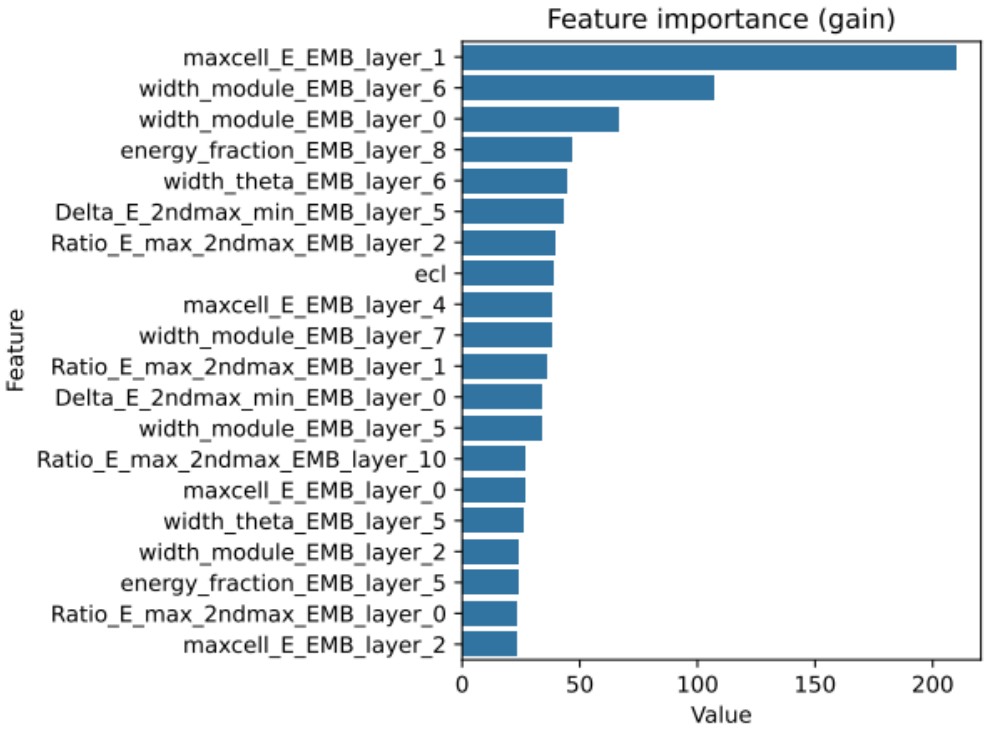
Width in module direction on layer 6

BDT training with SW clusters

- Ranking of feature importance for cross-talk and cross-talk & noise.



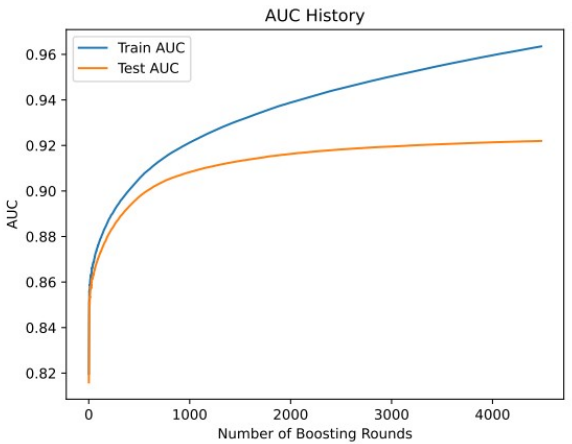
Cross-talk



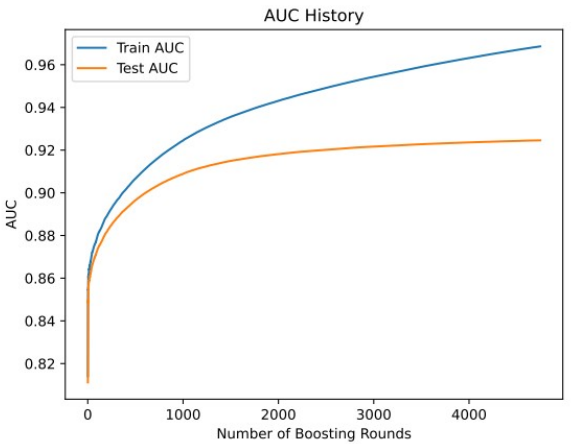
Cross-talk & noise

Training objective

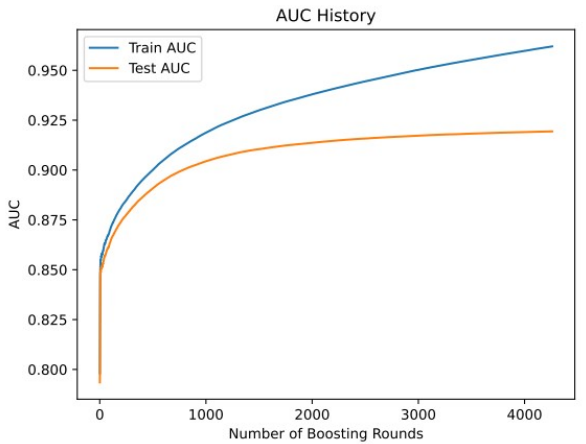
- SW clusters



Baseline



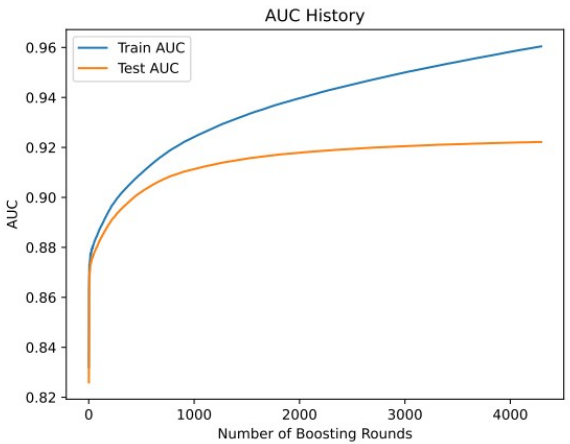
Cross-talk



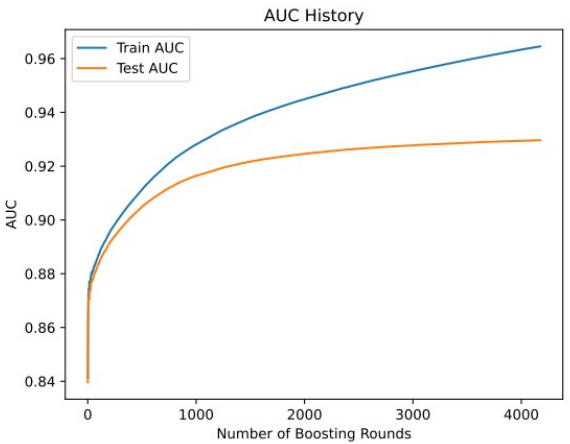
Cross-talk & Noise

Training objective

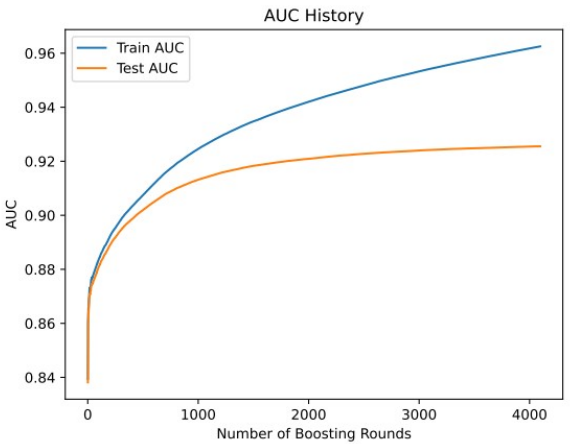
- Topo clusters



Baseline



Cross-talk



Cross-talk & Noise

Pi0 reconstructed as two photon clusters

- 2D cluster energy distribution after the red dashed line cut and the mass window cut of 135 +/- 60 MeV.