



# Photon- $\pi^0$ discrimination using ALLEGRO ECAL shower shape variables

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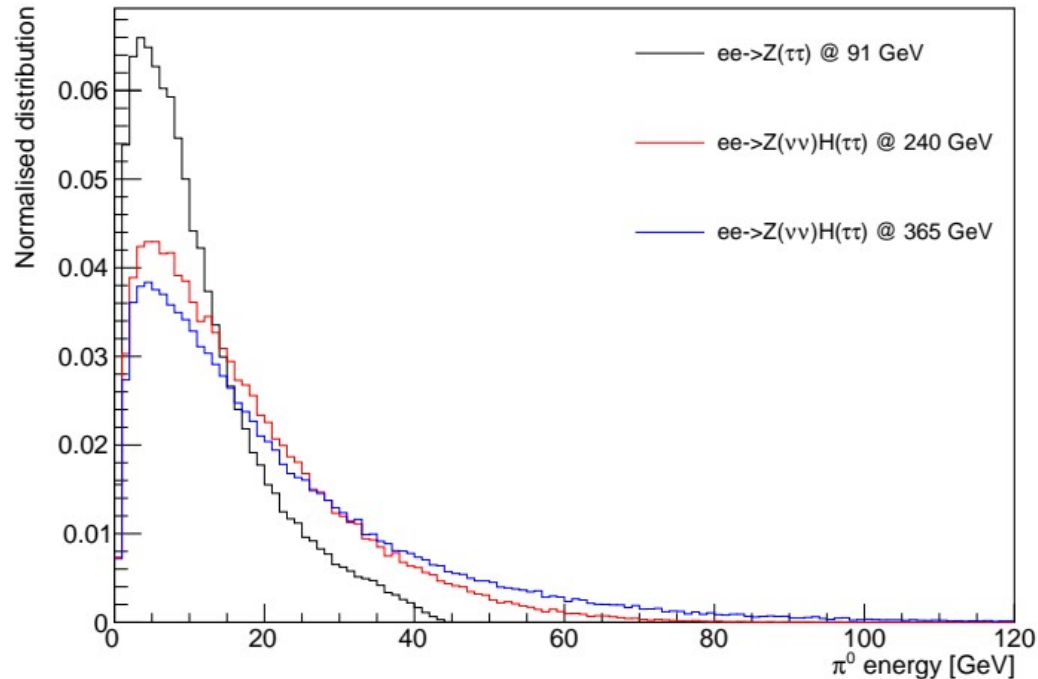
# Motivations

- At FCC-ee, taus will be crucial to both EW precision measurement (tau polarisation with  $Z \rightarrow \text{tautau}$ ) and Higgs & BSM physics programs ( $ee \rightarrow ZH$ ,  $H \rightarrow \text{tautau}$ ). See [Maria's talk](#) for more details.
- High performance photon- $\pi^0$  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- $\pi^0$  separation using shower shape variables.

Preliminary results comparing different cross-talk and noise settings based on SW cluster will be reported (topo cluster results in the backup).

# 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.

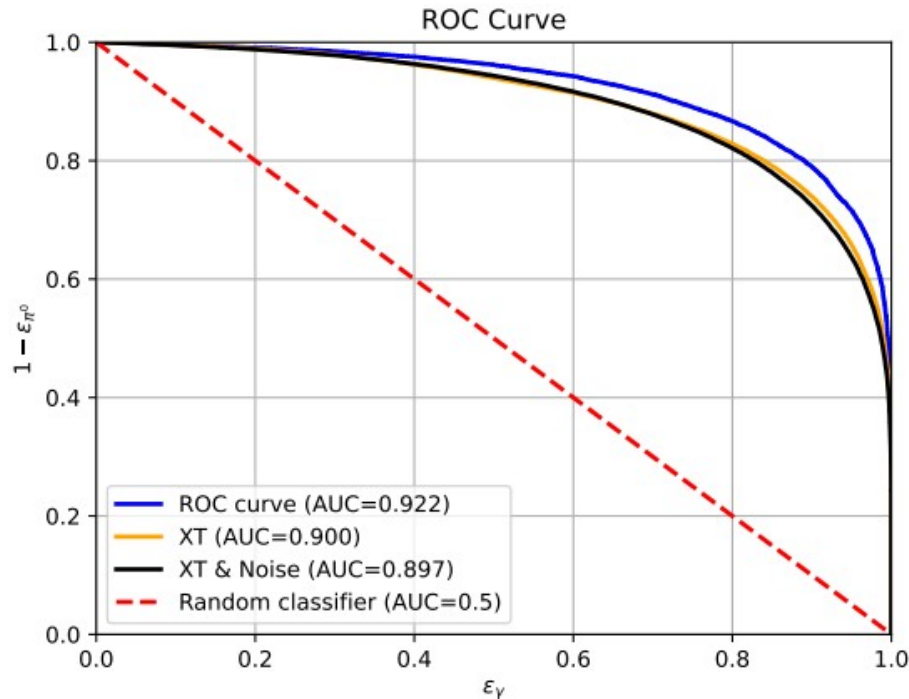
It might be worth having a look at the photon energy distribution from the di-photon background.

# Photon-pi0 separation in ALLEGRO ECAL

- 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: (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

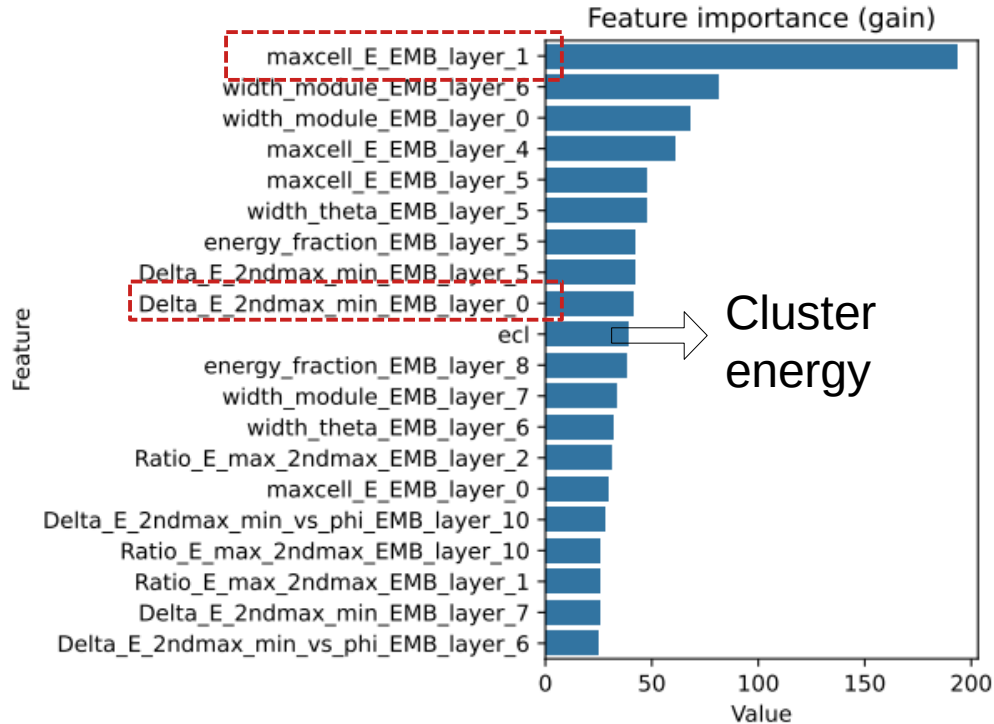
- Applying the baseline training model to a simulation with cross-talk and noise leads to a degradation in photon- $\pi^0$  separation performance.



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

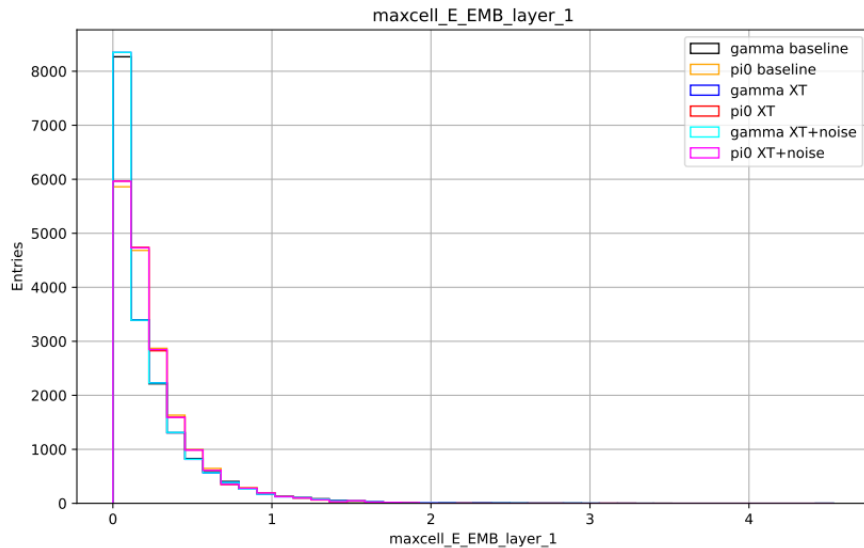
- Ranking of feature importance in the baseline training.



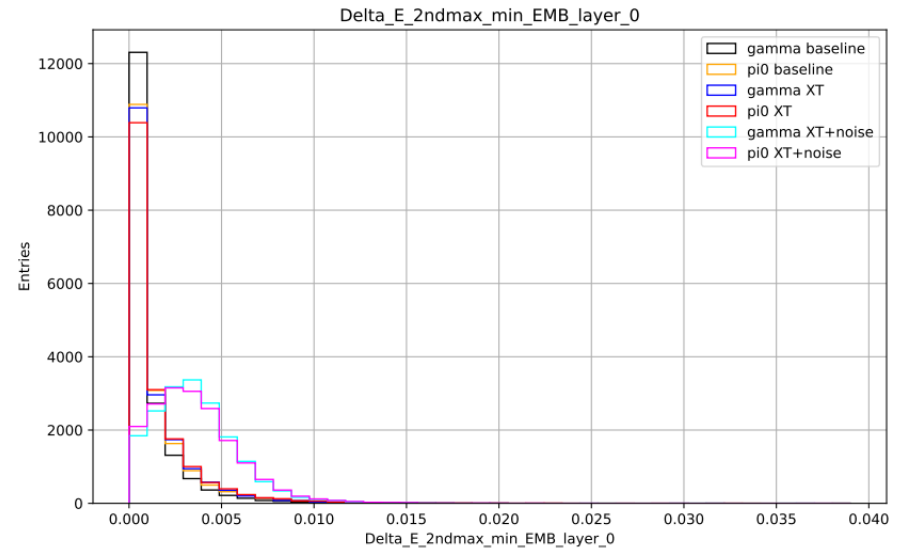
With the large energy range of [1, 100] GeV, the cluster mass doesn't seem to be one of the most important features.

# BDT training with SW clusters

- Shower shape variables with some highest feature importance.



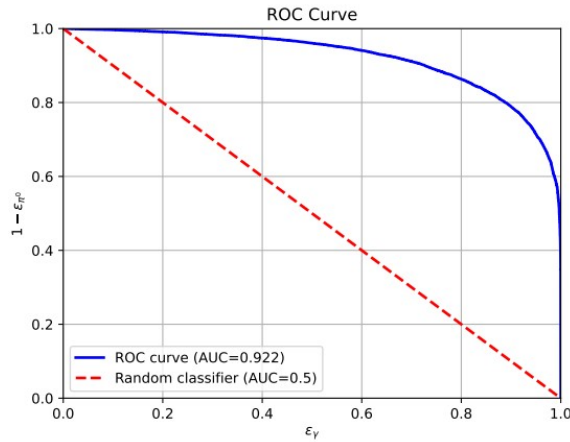
Maximum cell energy on layer 1



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

# BDT training with SW clusters

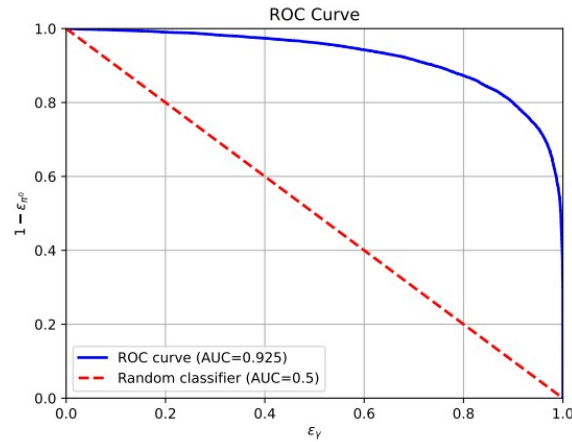
- The inclusion of cross-talk and noise in the input recovers the ROC-AUC.



Train & test with:

Baseline

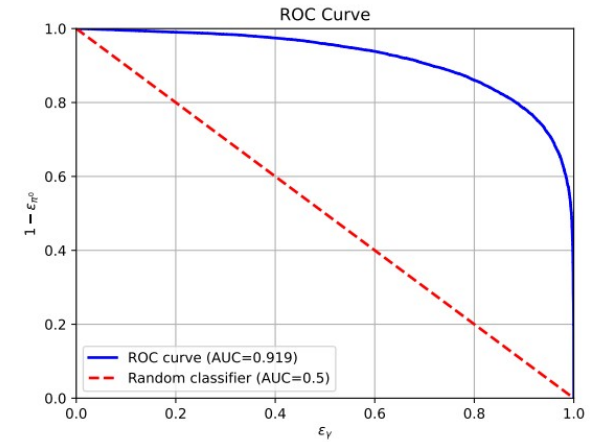
AUC=0.922



Train & test with:

Cross-talk

AUC=0.925



Train & test with:

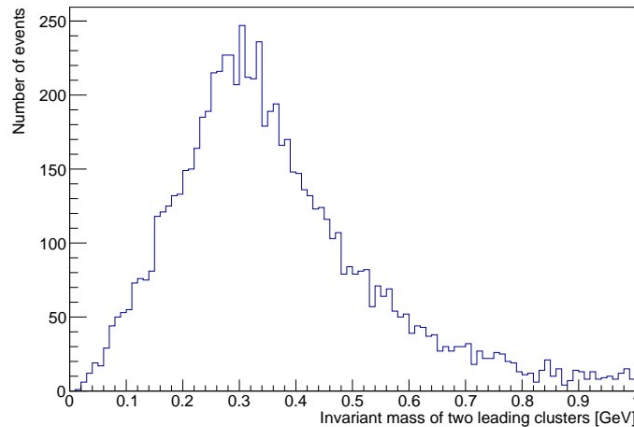
Cross-talk & Noise

AUC=0.919

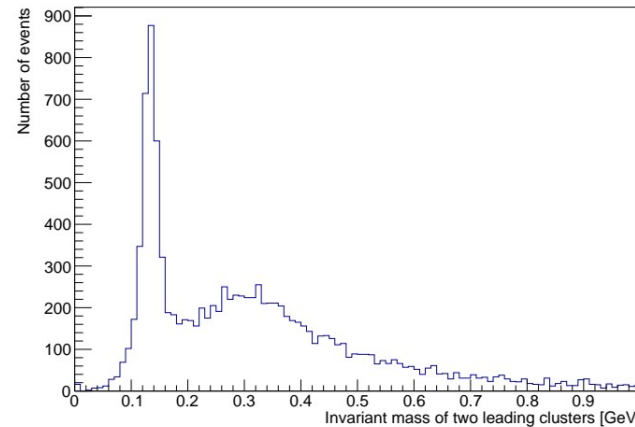


# Pi0 reconstructed as two photon clusters

- 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).

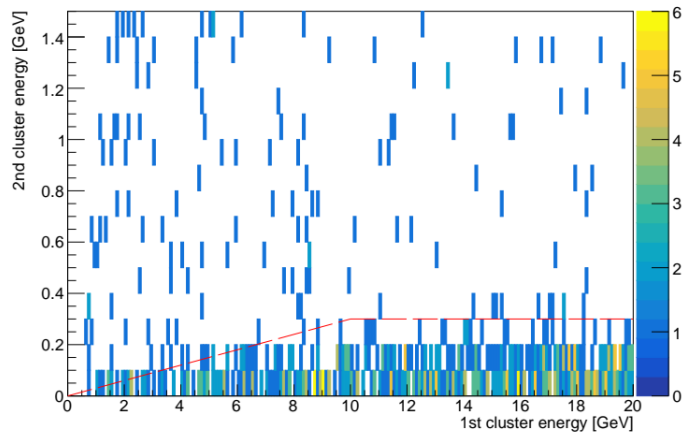


Particle gun pi0 with energy in [1, 100] GeV (SW clusters).

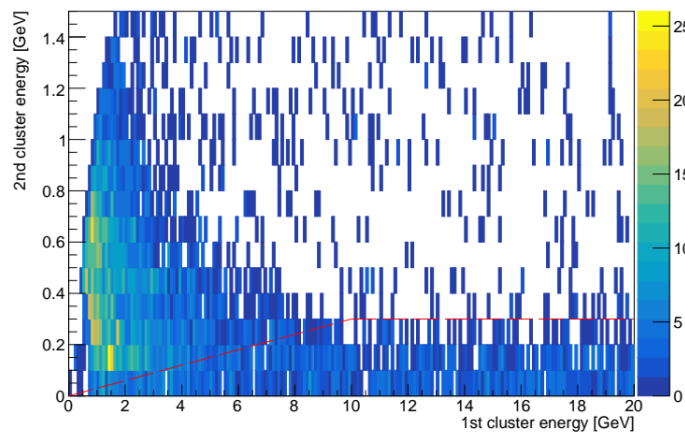
Some event selection is needed before the calculation of invariant mass.

# 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).



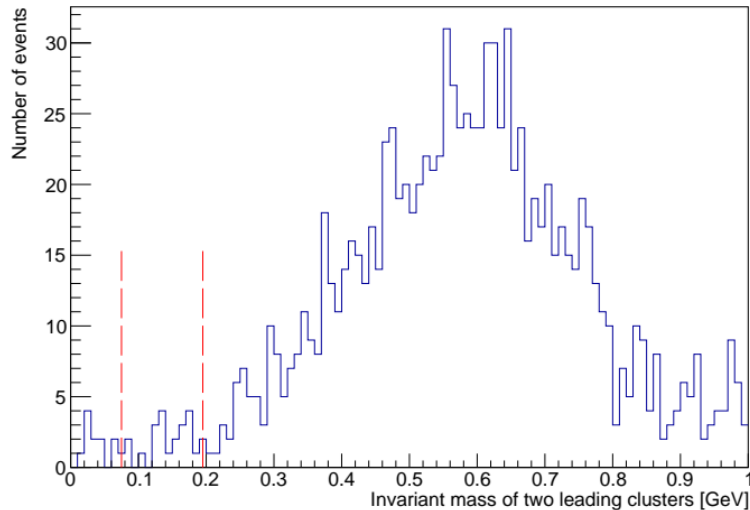
Particle gun pi0 with energy in [1, 100] GeV (SW clusters).

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

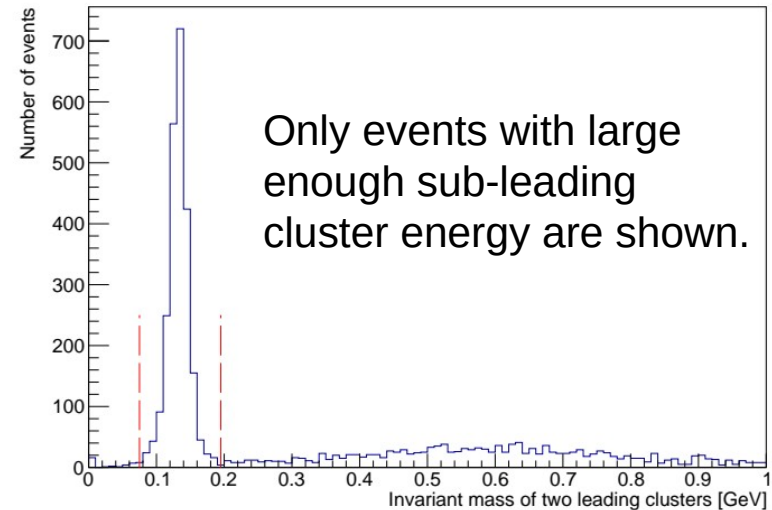
→ This might have a significant effect at the Z-pole.

# Invariant mass distribution

- Reject events with small sub-leading cluster energy.
- Count number of events in the interval of  $135 \pm 60$  MeV.



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



Particle gun  $\pi^0$  with energy in  $[1, 100]$  GeV (SW clusters).  
Fraction =  $2359/99999 = 2.4\%$

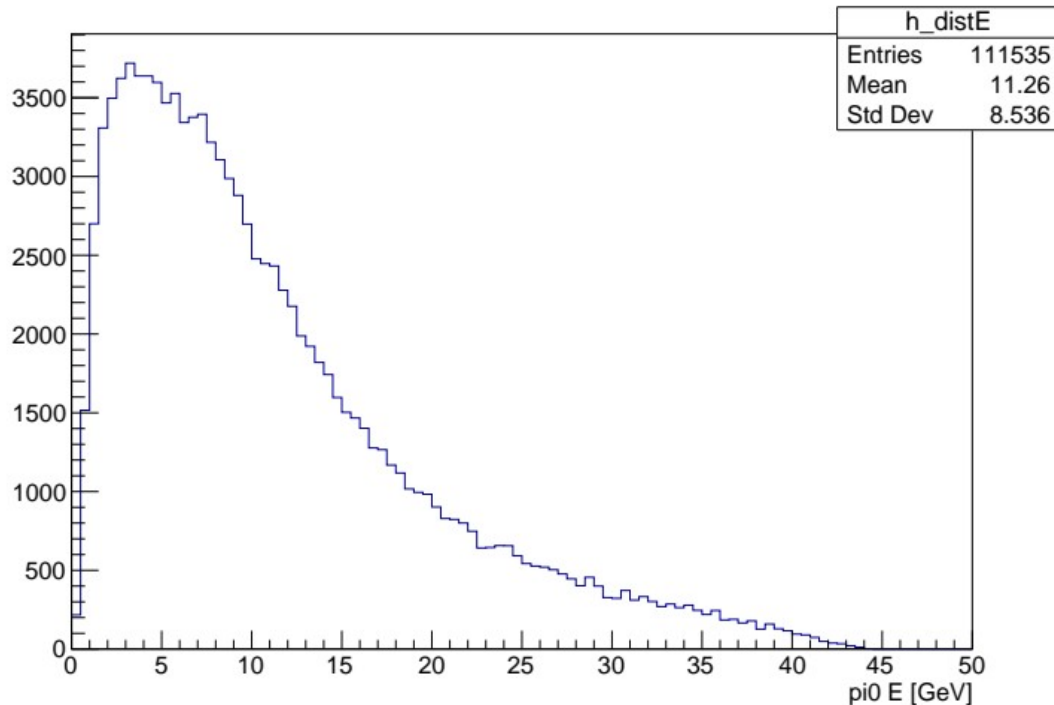
# Summary

- Energy distributions of  $\pi^0$  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- $\pi^0$  separation in ALLEGRO ECAL is studied with the addition of cross-talk and noise, using photons and  $\pi^0$  in a wide energy range. A 2% impact of cross-talk and noise on the BDT performance can be restored by including the relevant effects in the input to the training.
- There is a possibility to improve the photon- $\pi^0$  separation by selecting events where the  $\pi^0$  is reconstructed as two photon clusters, prior to the BDT training. The improvement might reach percent level, depending on how the  $\pi^0$  reconstruction is defined.

# Backup

# Pi0 energy distribution

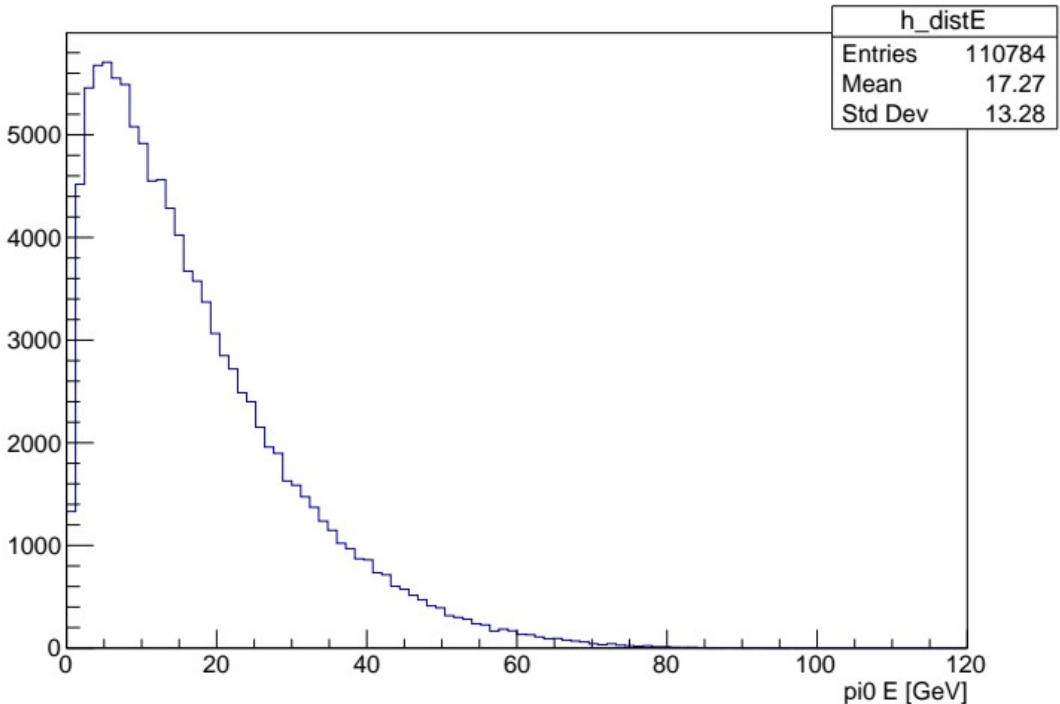
- $ee \rightarrow Z(\text{tautau}) @ 91 \text{ GeV}$



100k events were generated.  
/eos/experiment/fcc/ee/  
generation/DelphesEvents/  
winter2023/IDEA/  
p8\_ee\_Ztautau\_ecm91/  
events\_111404736.root

# Pi0 energy distribution

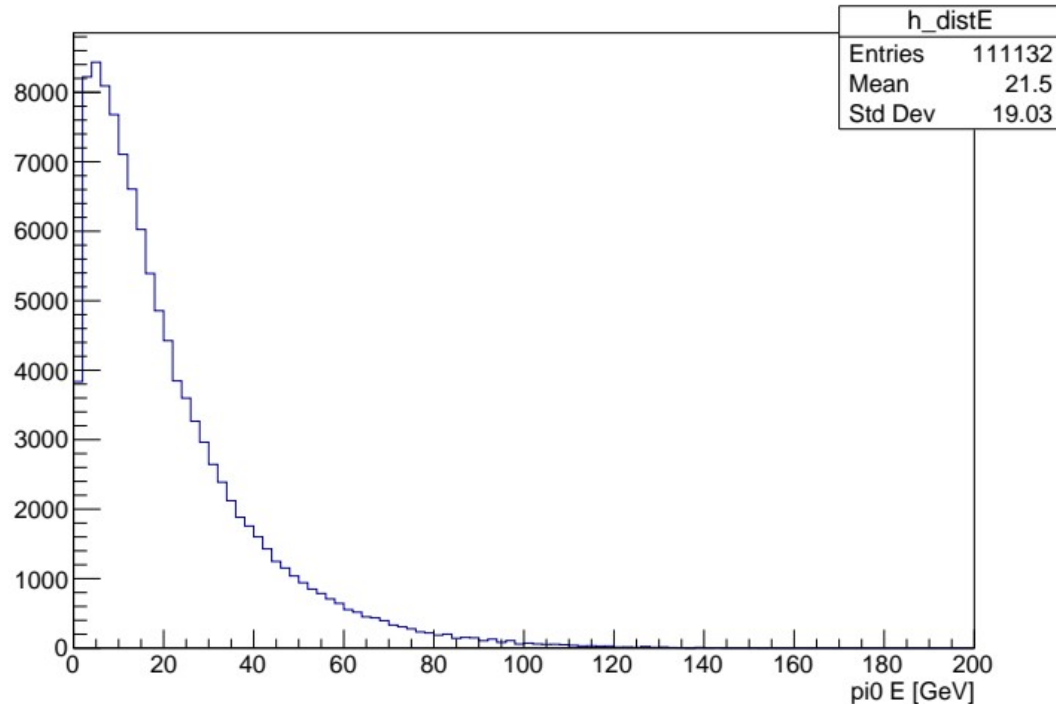
- $ee \rightarrow Z(\nu\nu)H(\text{tautau}) @ 240 \text{ GeV}$



100k events were generated.  
/eos/experiment/fcc/ee/  
generation/DelphesEvents/  
winter2023/IDEA/  
wzp6\_ee\_nunuH\_Htautau\_ecm  
240/events\_078984367.root

# Pi0 energy distribution

- $ee \rightarrow Z(\nu\nu)H(\text{tautau})$  @ 365 GeV



100k events were generated.  
/eos/experiment/fcc/ee/  
generation/DelphesEvents/  
winter2023/IDEA/  
wzp6\_ee\_nunuH\_Htautau\_ecm  
365/events\_112729784.root



# Types of cross-talk neighbours

- 4 types of neighbours are considered\*.

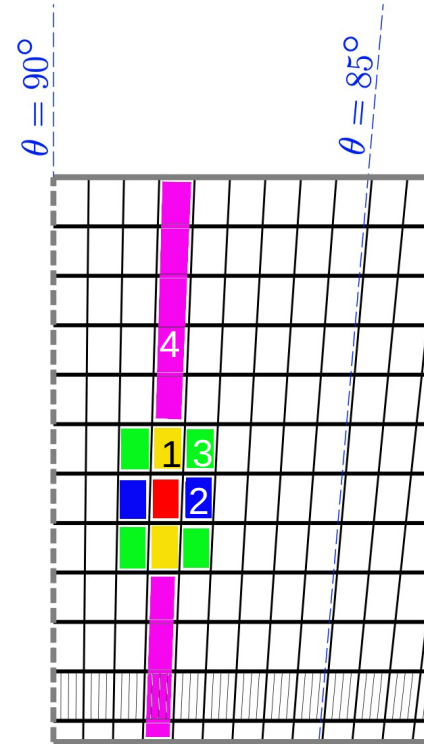
Type 1: Direct radial neighbours.

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

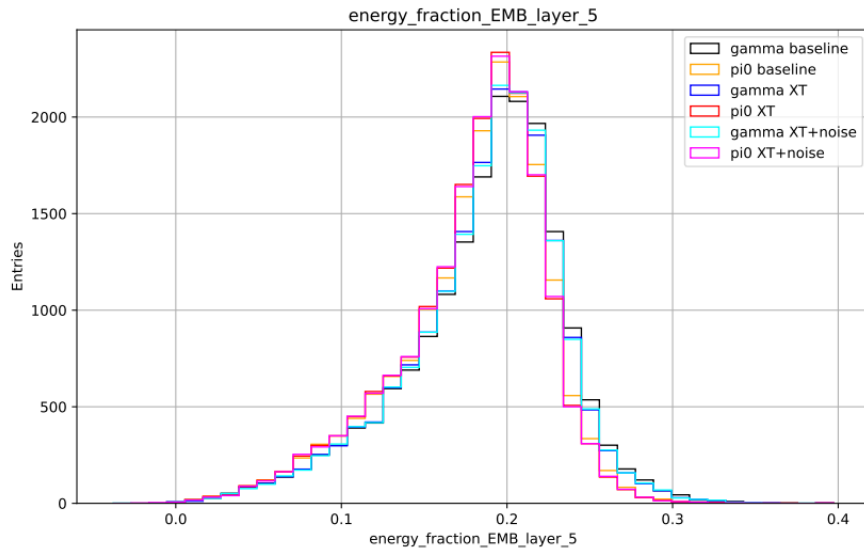
List of cross-talk coefficients.

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

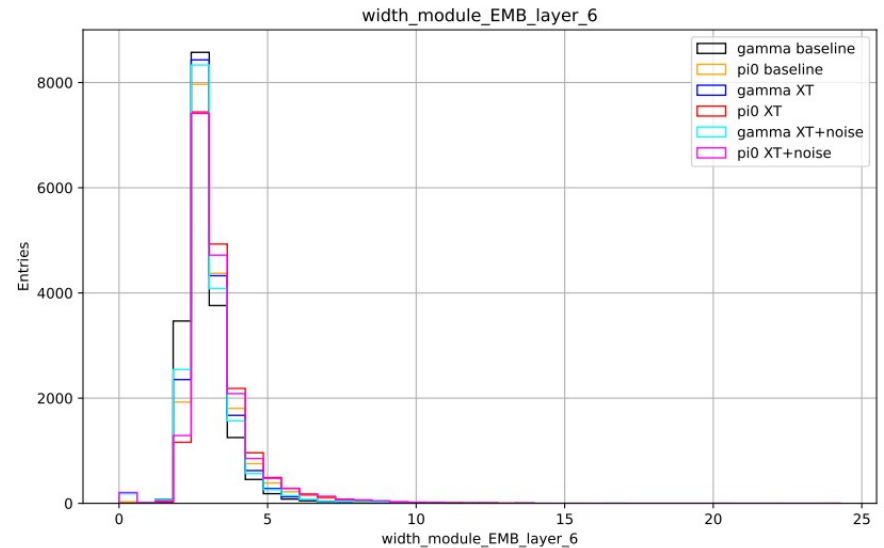
- No outer/inner asymmetry is assumed for cross-talk coefficients between radial neighbours.
- Values are taken from [Juska's measurement](#) on CERN PCBv1.

# BDT training with SW clusters

- Shower shape variables with some highest feature importance.



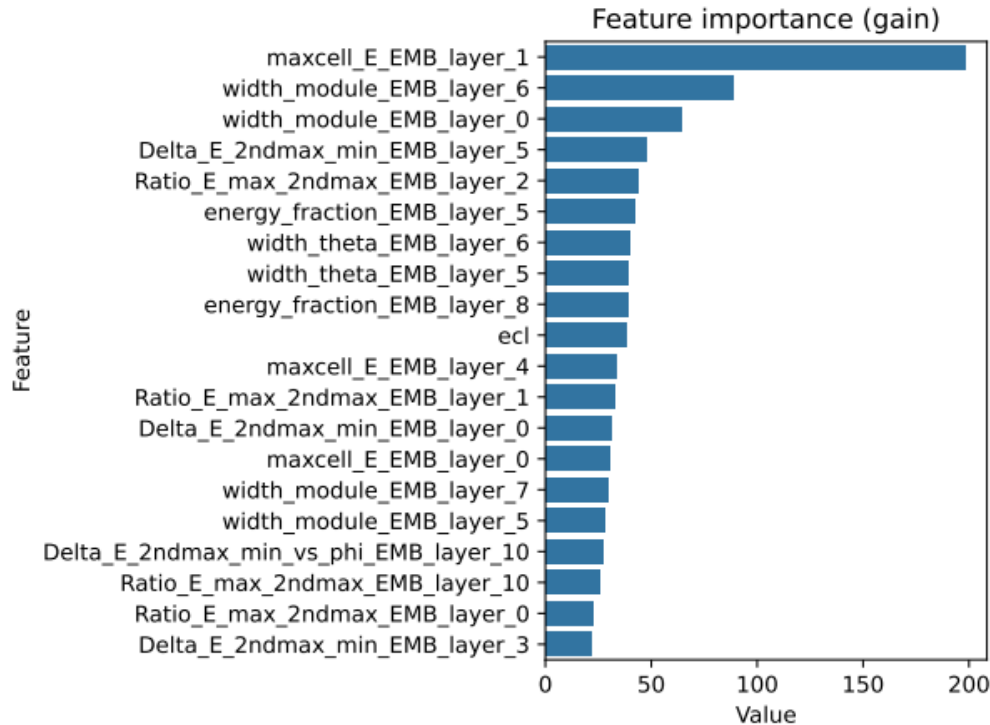
The energy fraction of layer 5



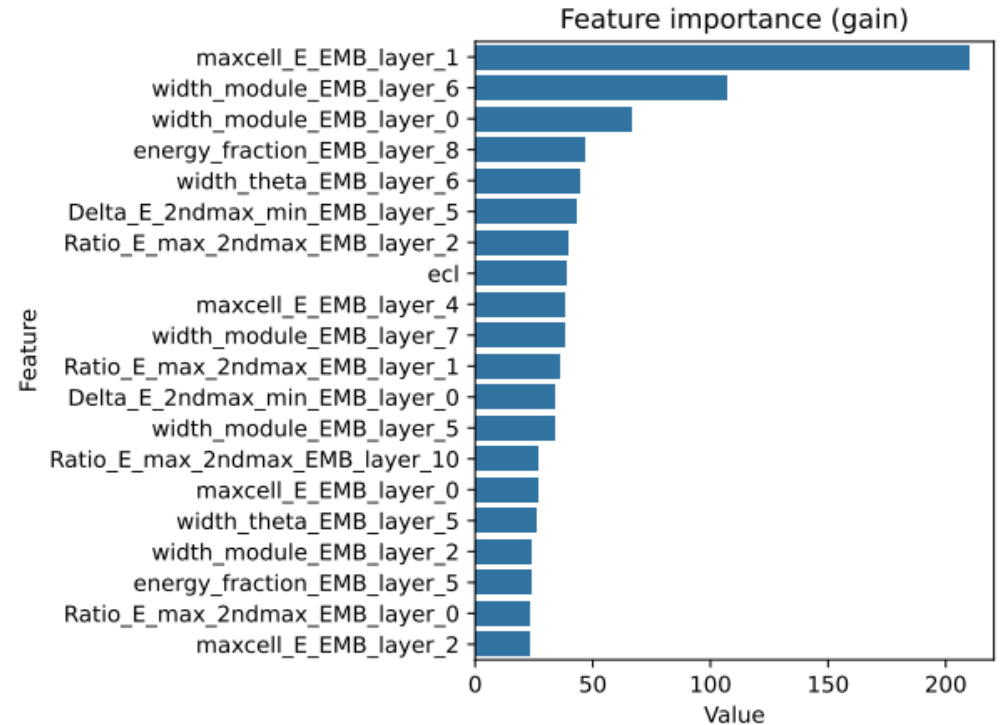
Width in module direction on layer 6

# BDT training with SW clusters

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



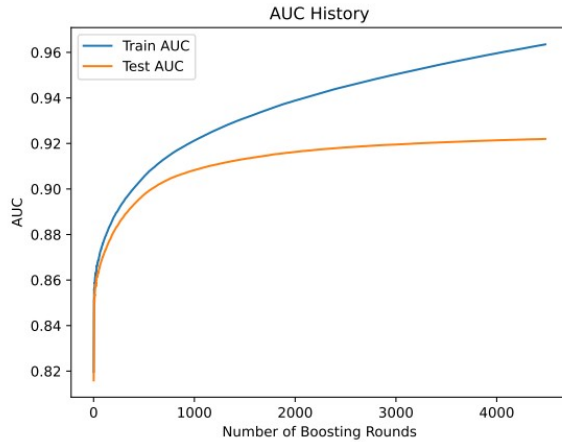
Cross-talk



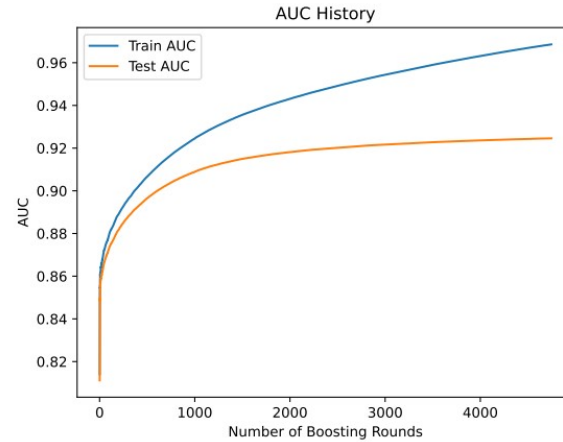
Cross-talk & noise

# Training objective

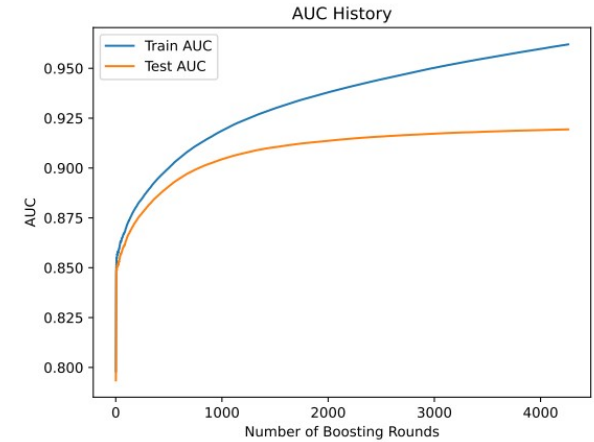
- SW clusters



Baseline



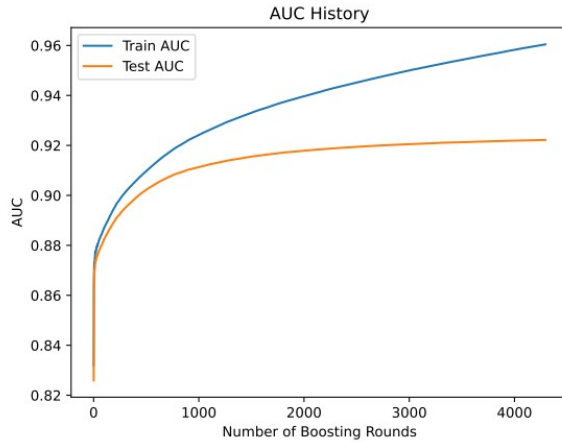
Cross-talk



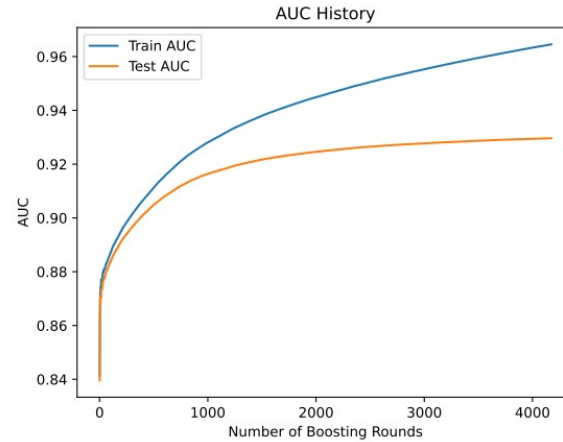
Cross-talk &  
Noise

# Training objective

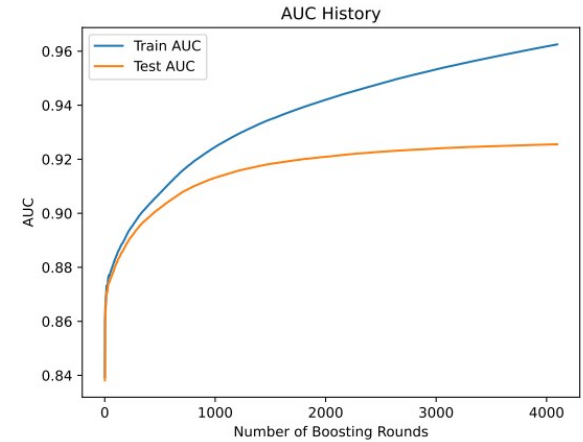
- Topo clusters



Baseline



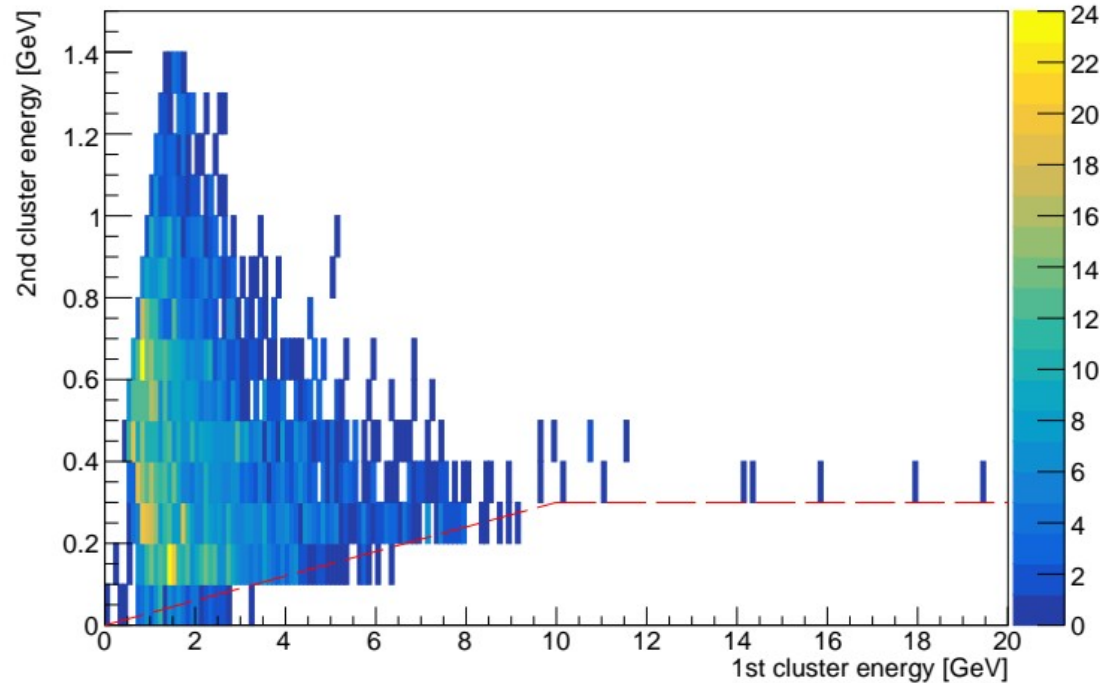
Cross-talk



Cross-talk &  
Noise

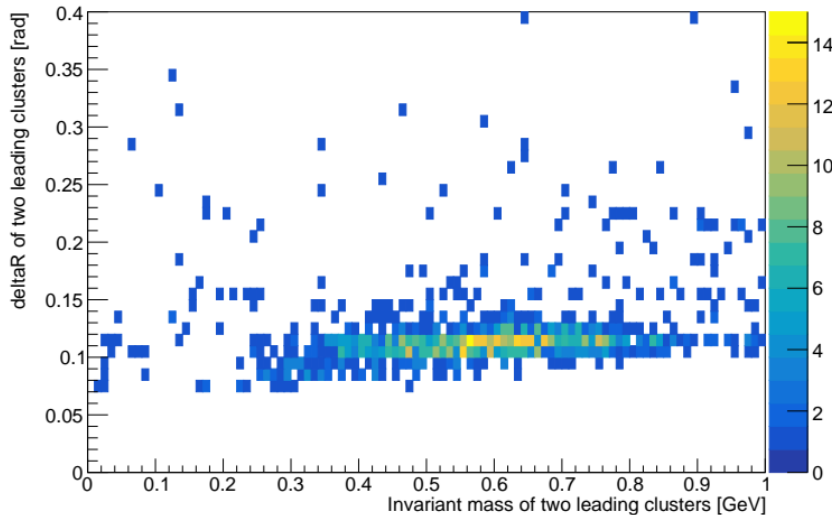
# Pi0 reconstructed as two photon clusters

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

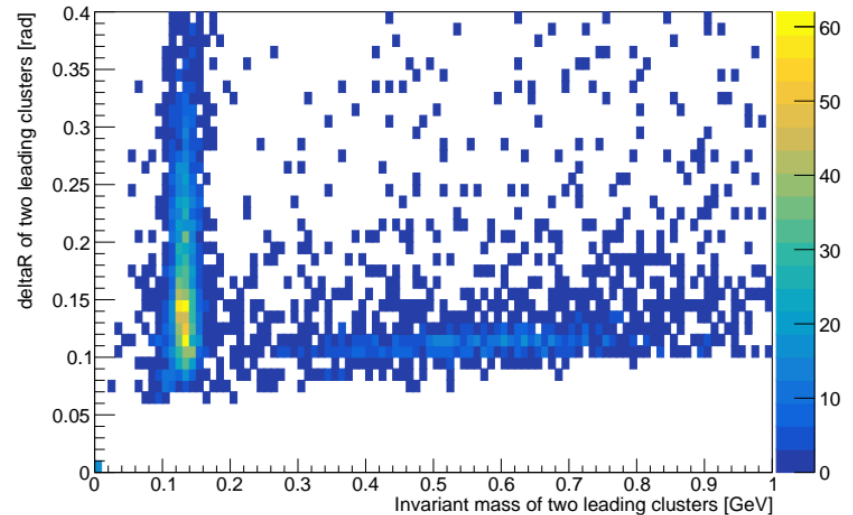


# DeltaR vs invariant mass

- Reject events with small sub-leading cluster energy.
- $\Delta R = \sqrt{\Delta\phi^2 + \Delta\theta^2}$



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

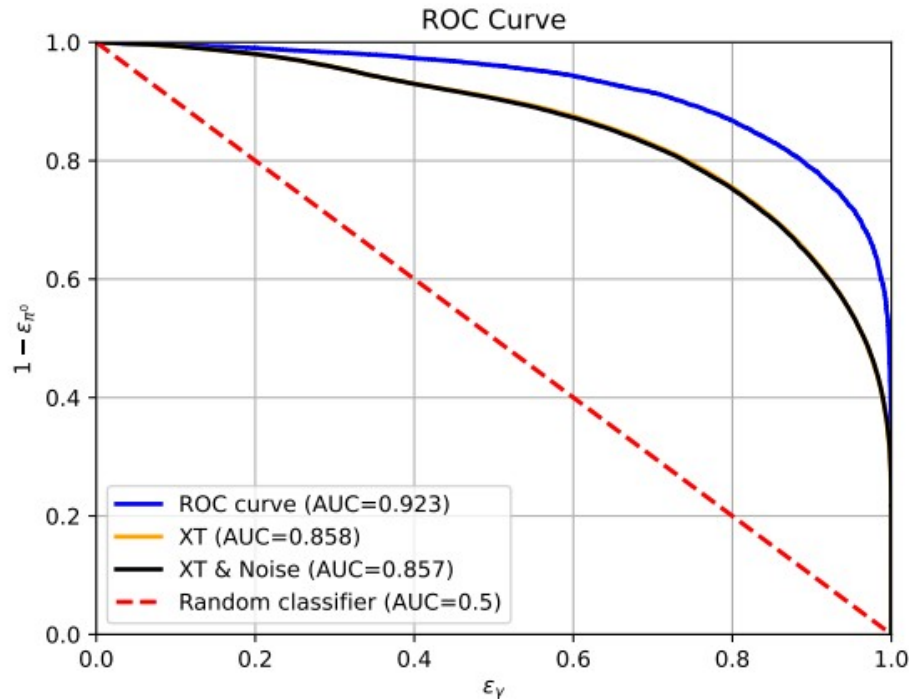


Particle gun pi0 with energy in [1, 100] GeV (SW clusters).



# BDT training with **topo clusters**

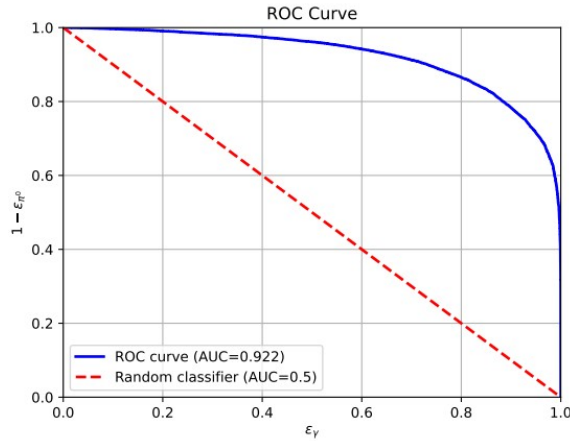
- Applying the baseline model to datasets with cross talk and noise leads to an even larger degradation in photon- $\pi^0$  separation with topo clusters.



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

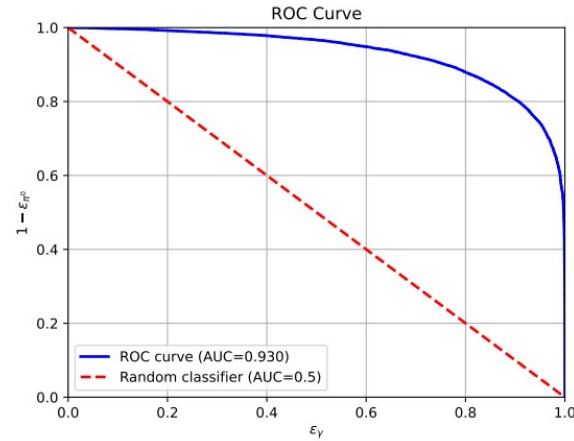
- The inclusion of cross-talk and noise in the input recovers the ROC-AUC.



Train & test with:

Baseline

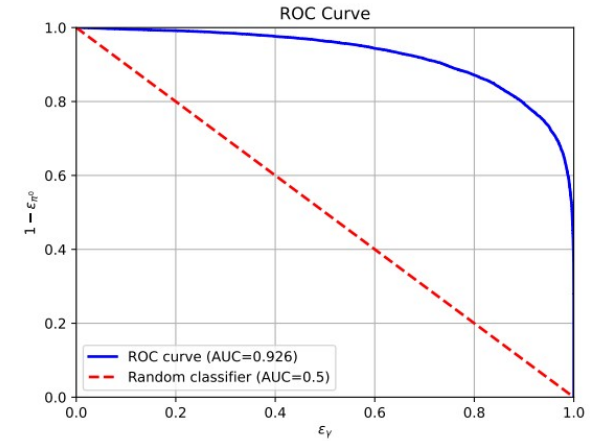
AUC=0.922



Train & test with:

Cross-talk

AUC=0.930



Train & test with:

Cross-talk & Noise

AUC=0.926