Is Hcal useful for PID?

Some feedback based on Run-3 studies

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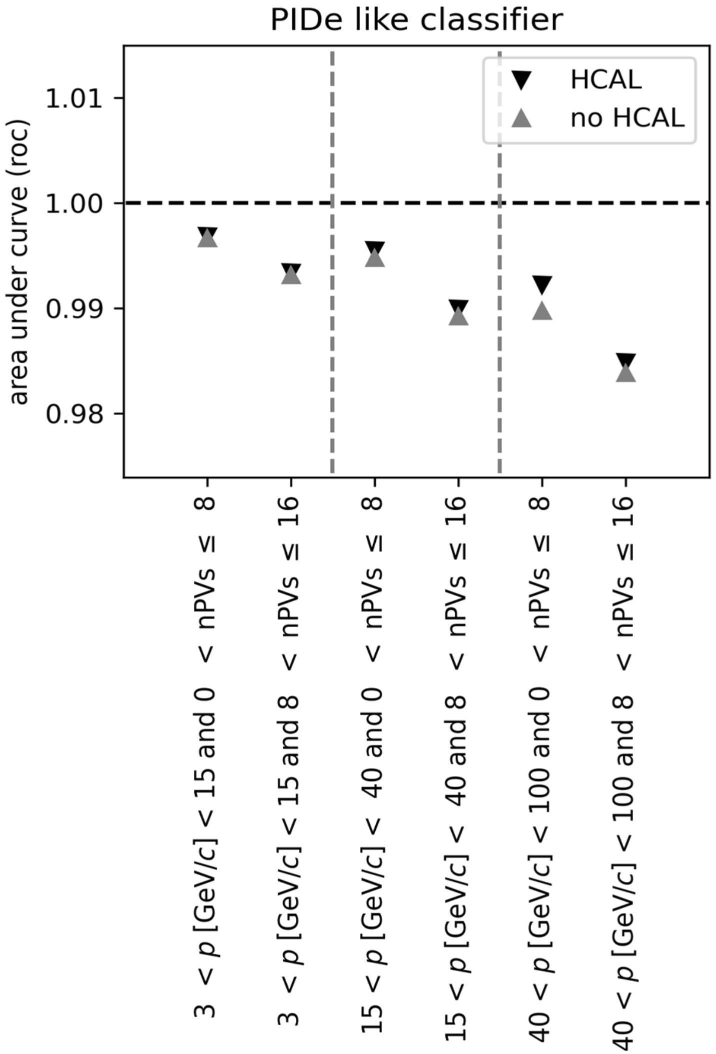
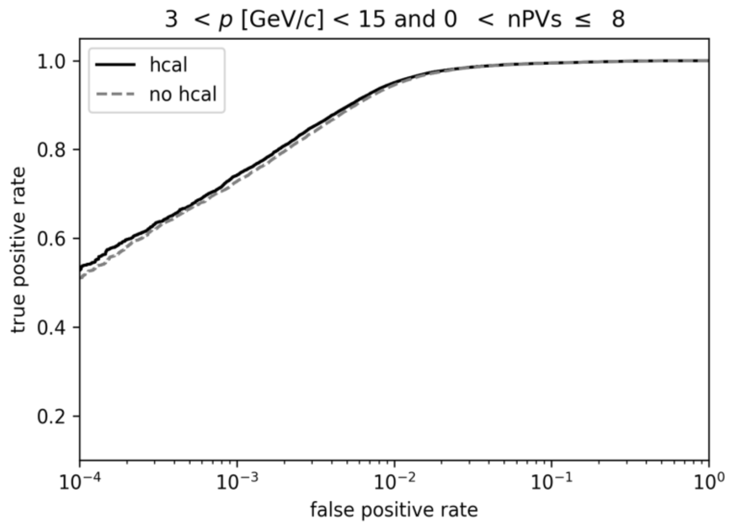
Introduction

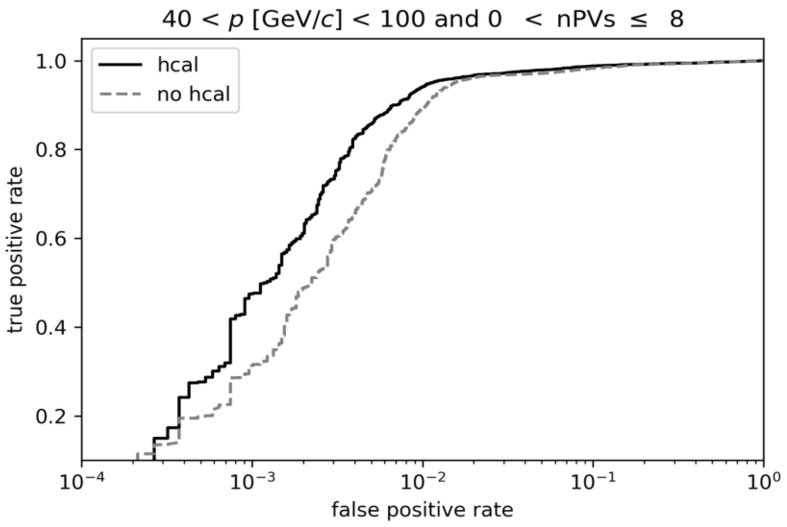
- Agenda of previous discussion session about Hcal at Run 4/5 here.
- In this talk, show the impact of Hcal on PID classifiers of :
  - Electrons and muons (versus pions) done by Maarten.
  - Photons (versus hadrons and pile-up clusters) done by Míriam.
- Summary: the removal of Hcal for electrons, muons and photons seems not to be critical.
  - Ecal information already provides enough discrimination power between electromagnetic particles and hadrons.
  - Mainly Ecal energy/p ratio for electron/hadron separation (see previous report by Maarten).
  - Shape of the shower in Ecal for photon/hadron separation.
    - Hadronic showers are wider and start later than electromagnetic ones.
  - PicoCal larger granularity and longitudinal segmentation will be very helpful for the discrimination.

Electron PID

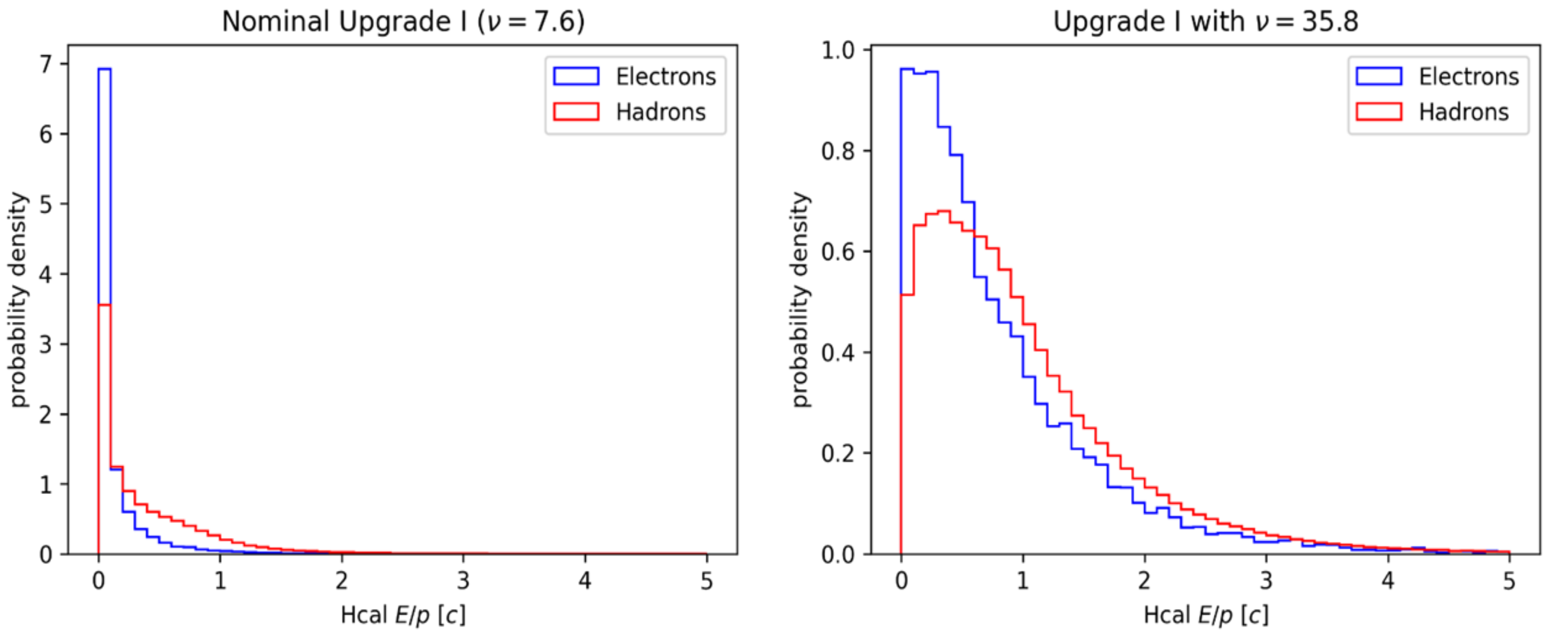
- Built a classifier electron *vs* pion.
  - *GradientBoostingClassifier* from *Sklearn* with Ecal PIDe inputs (except brem related), RICH and muon DLL (with optional Hcal E/p input).
  - Run-3 MC samples of $B \rightarrow J/\Psi(\rightarrow ee)X$ decays.
- Performance/training in bins of true momentum of particle/track and number of PVs.
  - Better performance for lower occupancy and lower momentum (thanks to the RICH).







How **Hcal energy/p ratio** looks like for two different luminosity Run-3 MinBias MC samples:

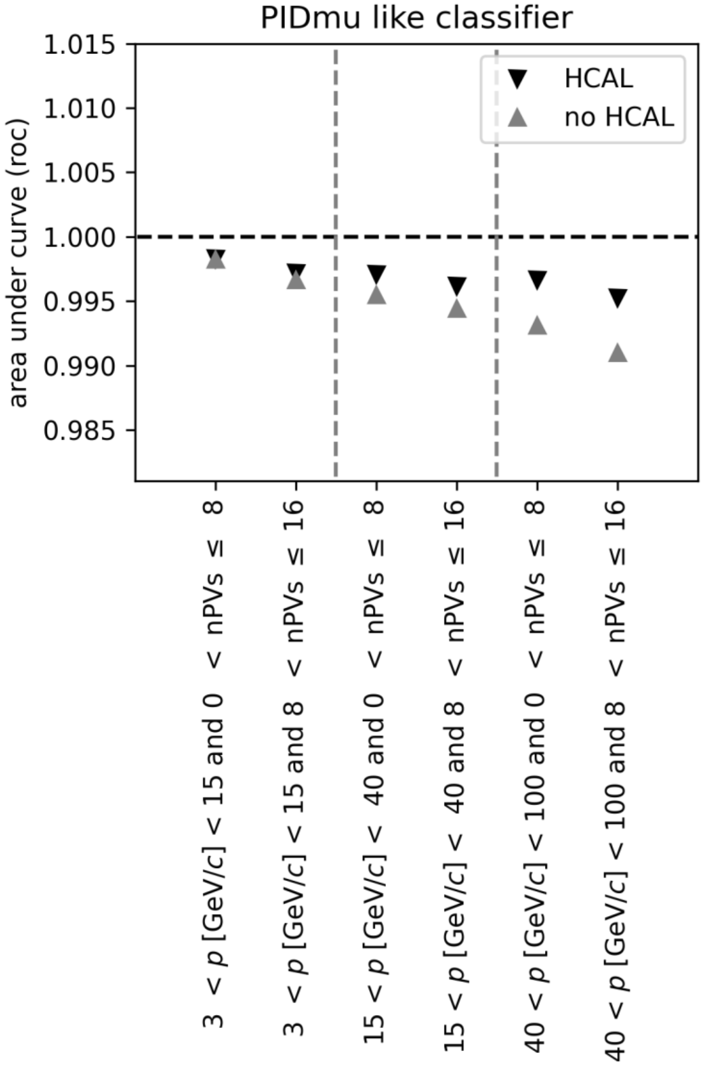


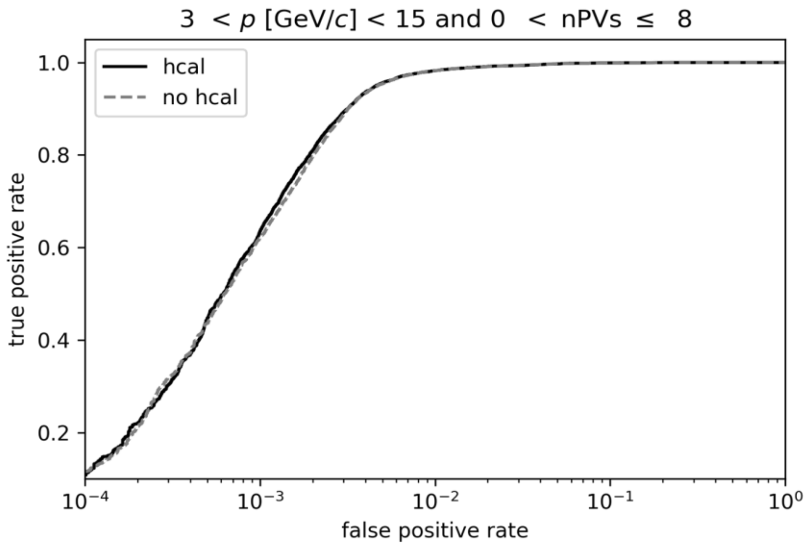
Here electrons are mostly of low energy (from converted photons at high pseudorapidity).

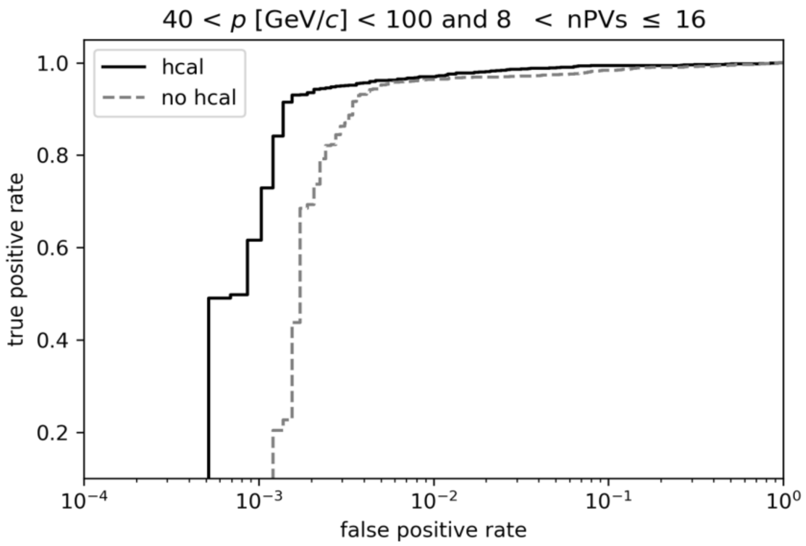
For large luminosities Hcal might be less useful (due to its large cell sizes, energy deposits from other particles unavoidable).

Muon PID

- Built a classifier muon *vs* pion.
  - *GradientBoostingClassifier* from *Sklearn* with Ecal PIDmu inputs, RICH and muon DLL (with optional Hcal E/p input).
  - Run-3 MC samples of $B \to J/\Psi(\to \mu\mu)X$ decays.
- Performance/training in bins of true momentum of particle/track and number of PVs.
  - Better performance for lower occupancy and lower momentum.

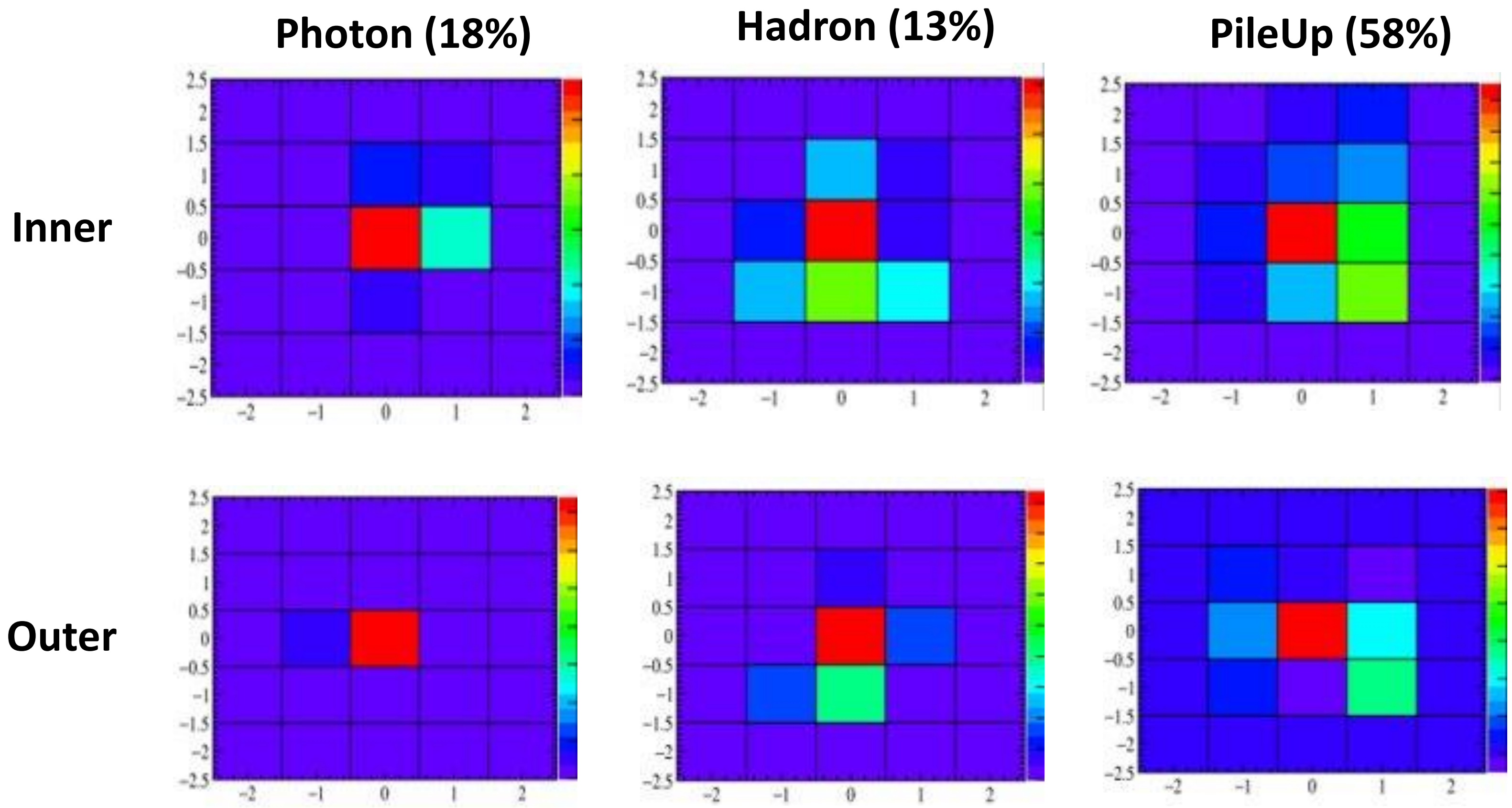






Photon PID

Currently, IsNotH is a MLP with 3x3 cluster digits (normalized to the total energy) as input, trained on photons as signal and both hadrons and pile-up clusters as background. One classifier per Calo region.

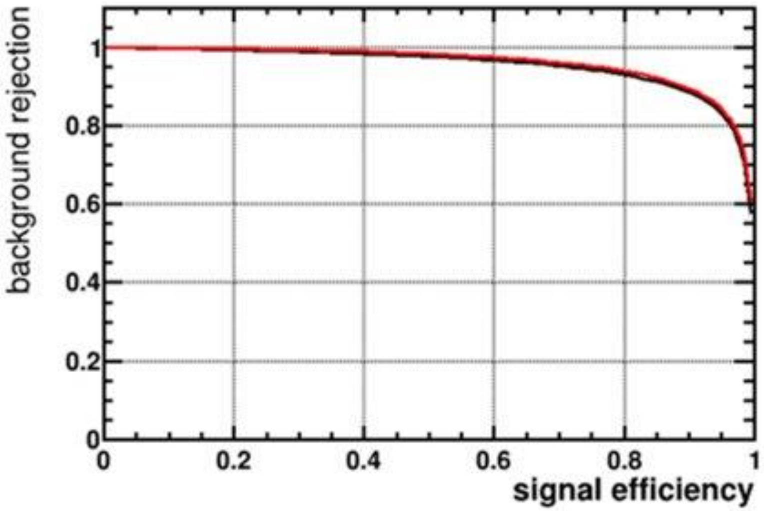


Details on this link

- The smaller is the cell size, the better is the discrimination (as expected).
- Adding **Hcal2Ecal ratio** as input variable does not improve significantly the performance in the inner and middle regions, but helps a bit in the outer region.

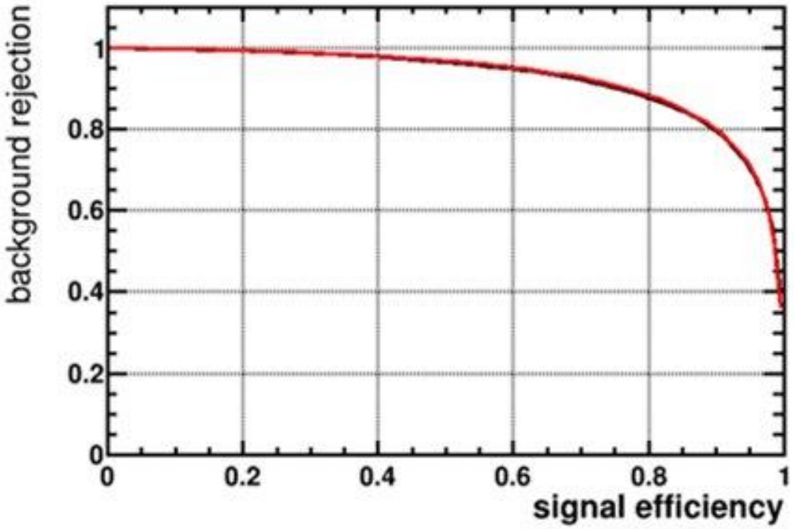
ROC curves, colour code:
- **Default IsNotH**
- **IsNotH including Hcal2Ecal as input**

Inner



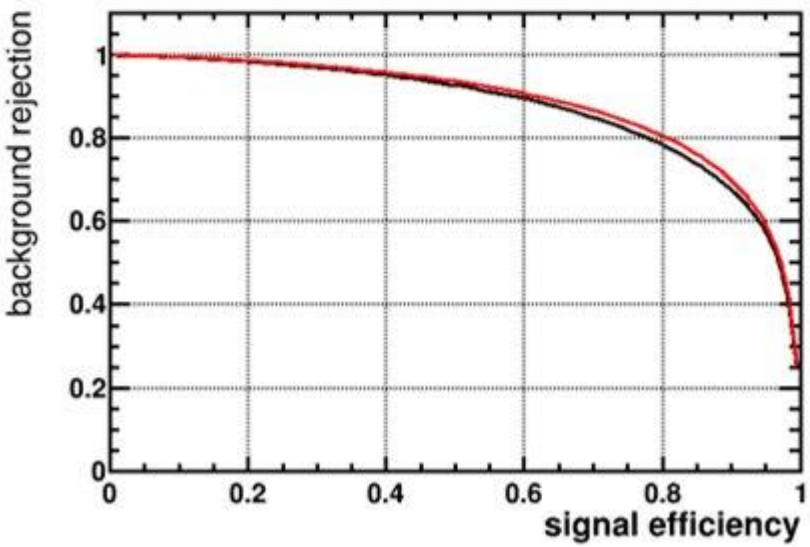
AUC: 0.96

Middle



AUC: 0.92

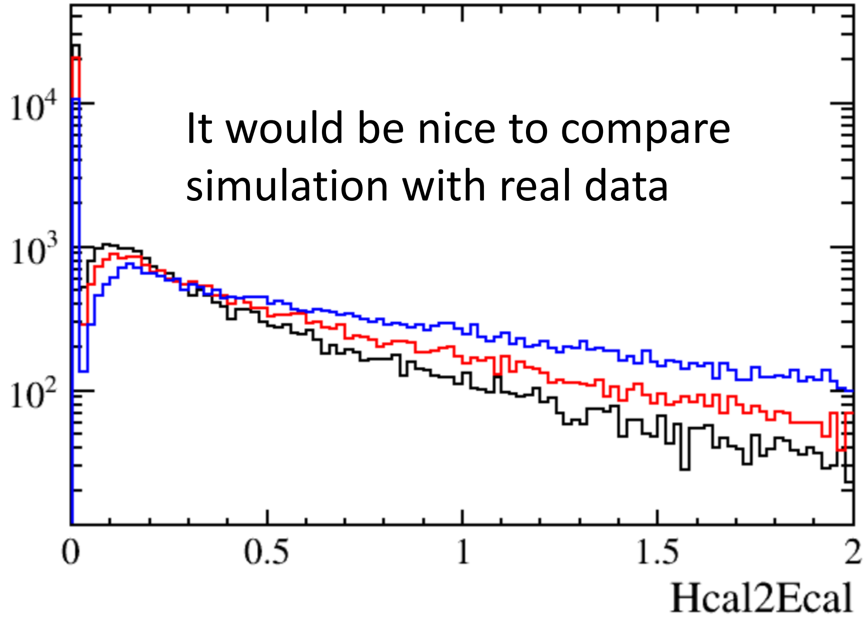
Outer

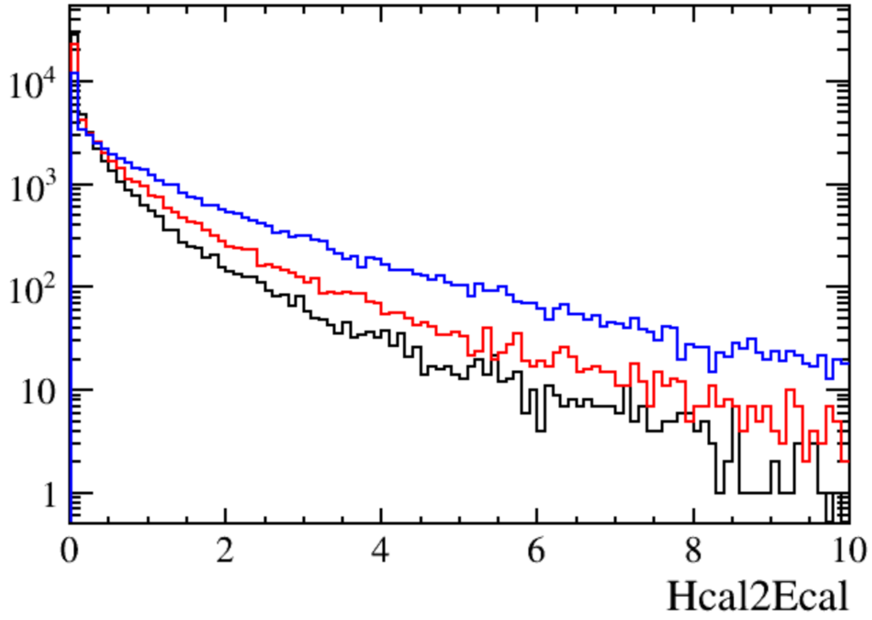


AUC: 0.87/0.88

How **Hcal/Ecal energy ratio** looks like for neutral clusters with $E_T > 150\ MeV$:

Photons
Hadrons
PileUp





Mean values:

	Photon	Hadron	PileUp
Inner	0.77	1.27	2.46
Middle	0.38	0.62	1.06
Outer	0.24	0.51	0.84
ALL	**0.37**	**0.61**	**1.33**

1 Hcal inner cell ~ 3x3 Ecal inner cells
2x2 Ecal middle cells

1 Hcal outer cell ~ 2x2 Ecal outer cells
4x4 Ecal middle cells

PID with an SpaCal-type module

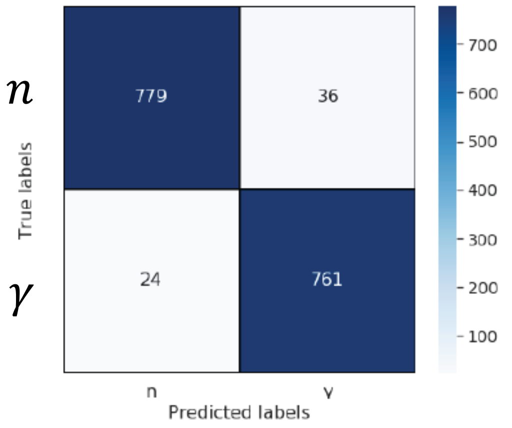
- Study done by Alex Rua (master’s thesis at La Salle), presented at CHEP 2021 (Slides and Proceedings).
- CNN for particle classification with only Ecal information. A PGun and a standalone simulation of a Spacal module (7x7 cells of 1.5 cm size) was used.
- Photons and electrons found to be clearly distinguishable from hadrons and muons.

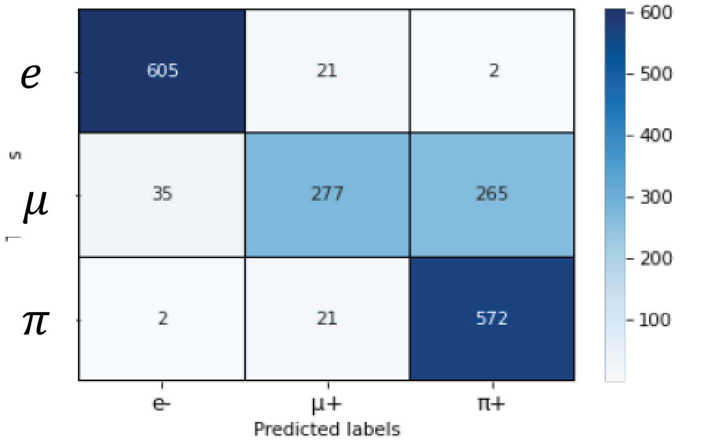
Table 2. Performance on neutral particles classification.

Particle	Precision	Recall	False Positive Rate	F1
n	0.97	0.956	0.03	0.963
γ	0.955	0.969	0.044	0.962

Table 3. Performance on three particles classification.

Particle	Precision	Recall	False Positive Rate	F1
$e-$	0.942	0.963	0.031	0.953
$\mu+$	0.868	0.480	0.034	0.618
$\pi+$	0.682	0.961	0.222	0.798





Summary

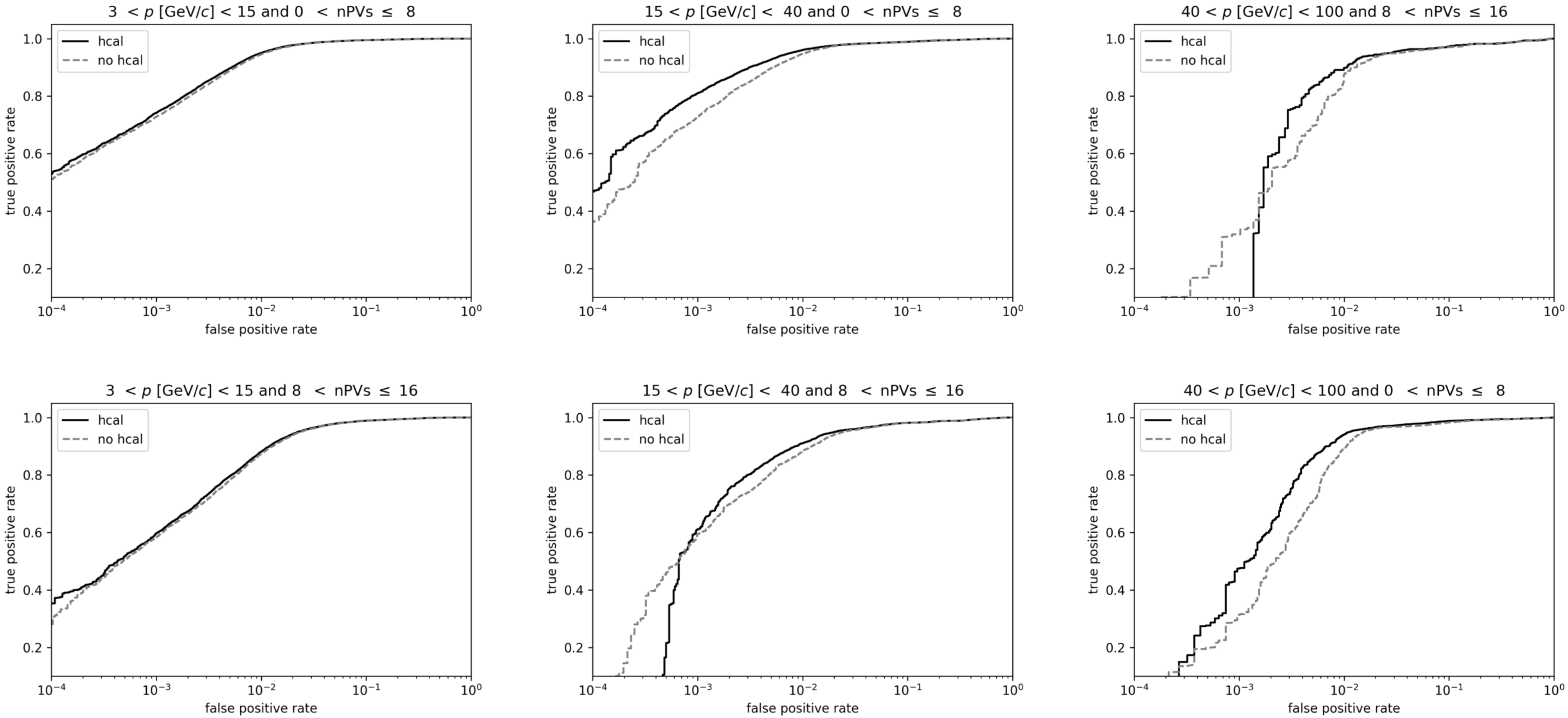
- It seems that we could survive without Hcal for PID of electrons, muons and photons, in particular with larger granuality and longitudinal segmentation in Upgrade II.
- However Hcal seems still useful for jet reconstruction and EW energy ranges (see details here).

Backup slides

PIDe like classifier

Has Ecal PIDe inputs (except brem related), RICH and muon DLL (with optional Hcal E/p input)

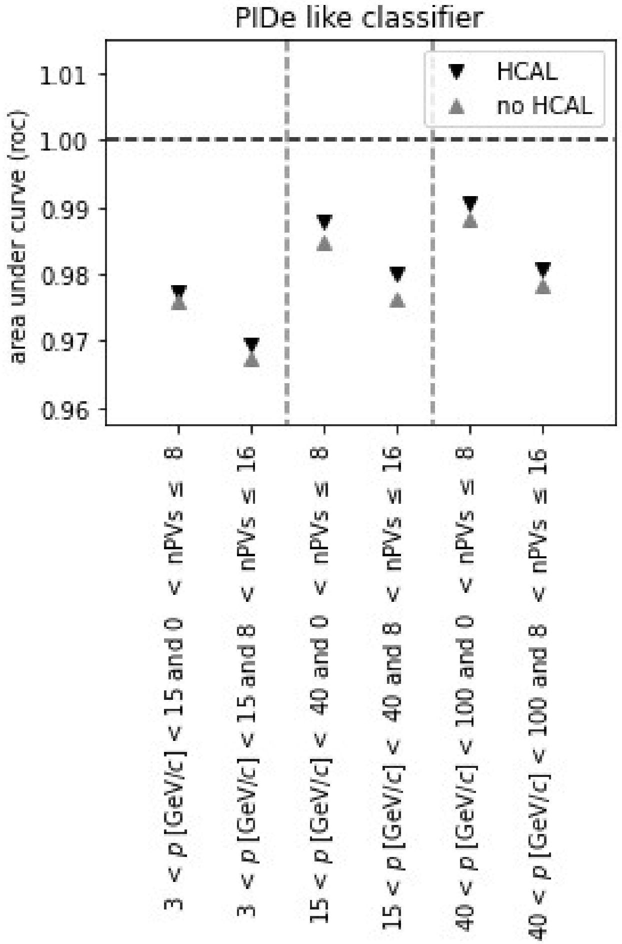
GradientBoostingClassifier from *Sklearn*



AUCs without RICH input

Inputs used:

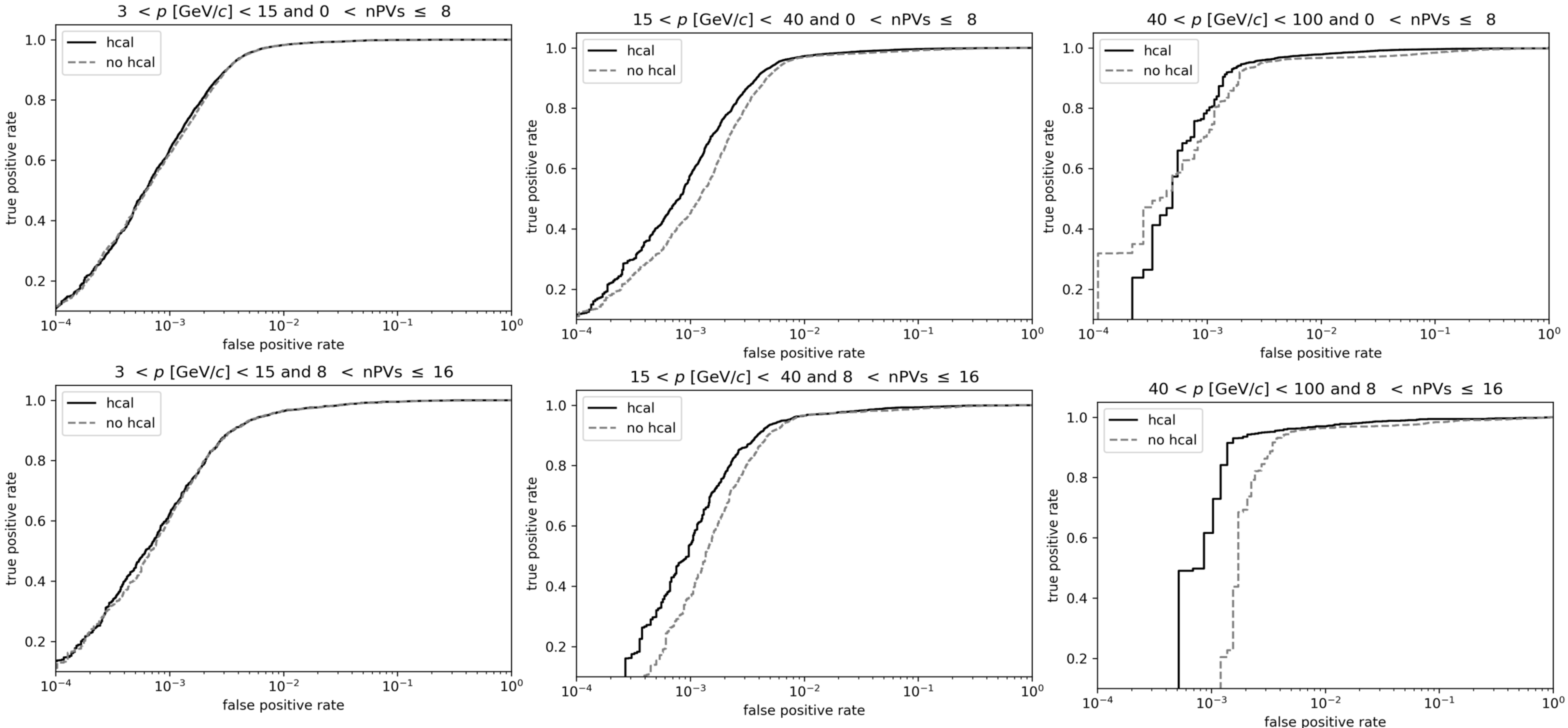
- From RICH: RICHDLLe
- From Ecal: ElectronShowerDLL, ElectronShowerEoP
- From Hcal: HcalEoP
- From Muons: MuonLLMu-MuonLLBg



PIDmu like classifier

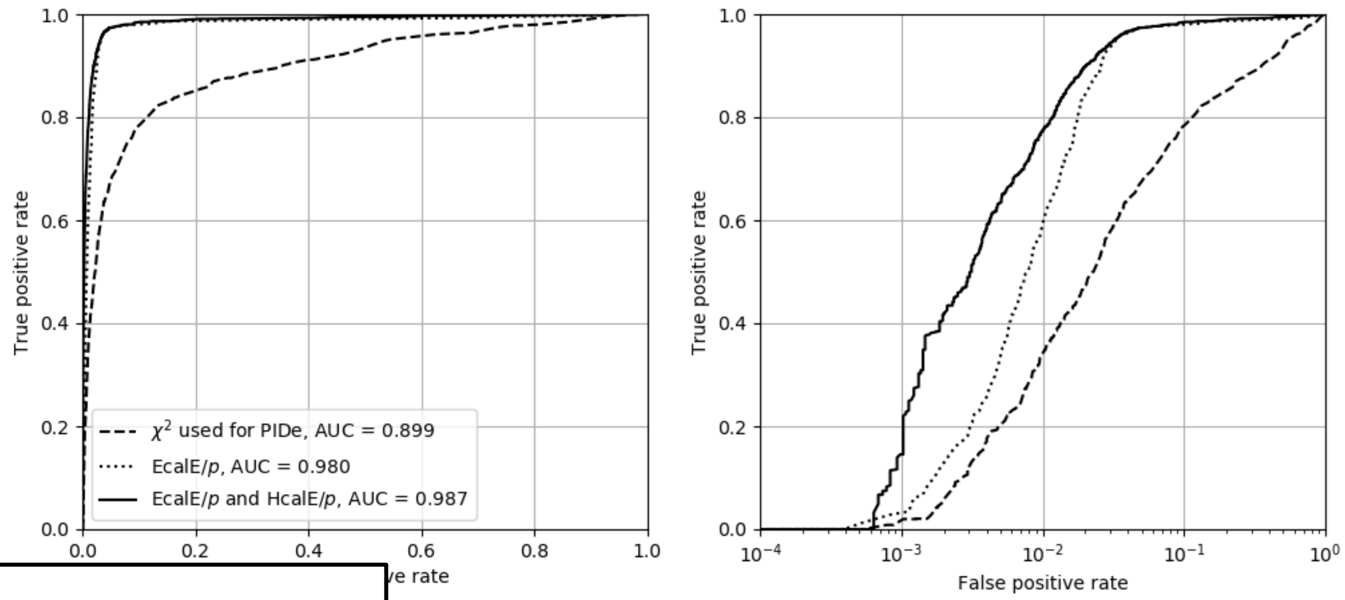
Has Ecal PIDmu inputs, RICH and muon DLL (with optional Hcal E/p input)

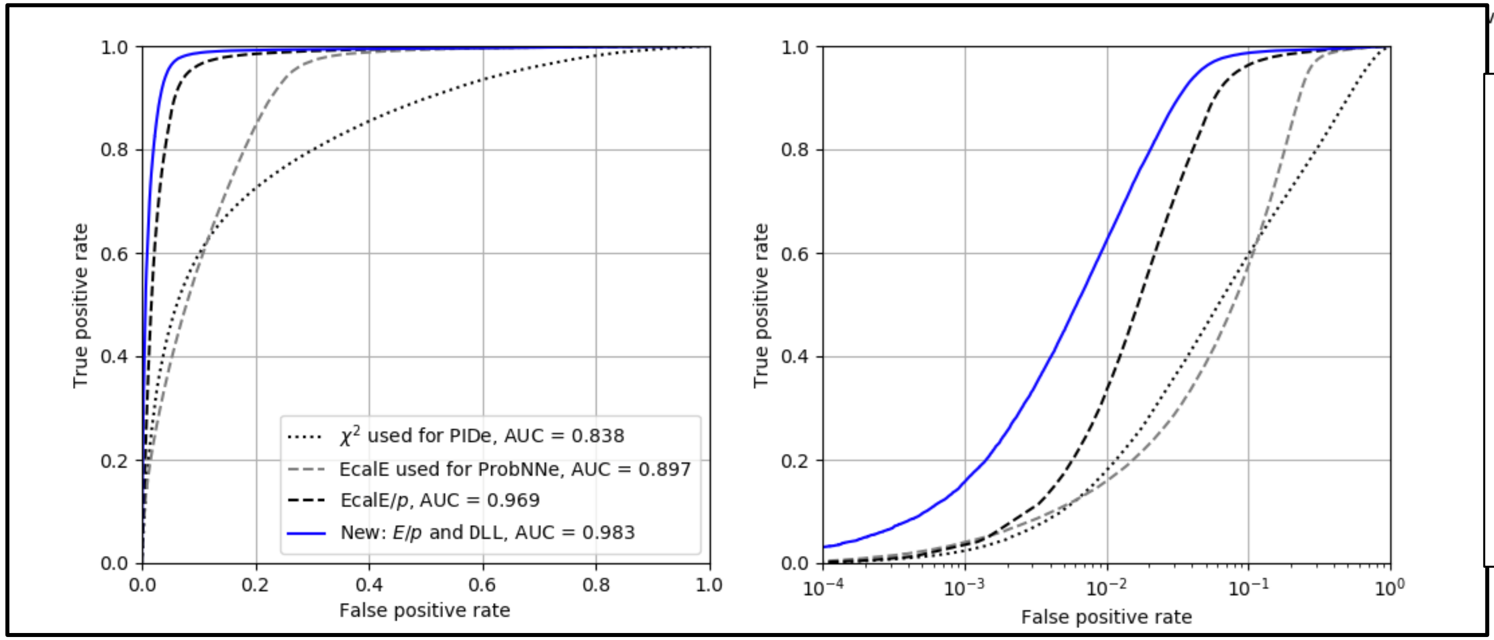
GradientBoostingClassifier from *Sklearn*

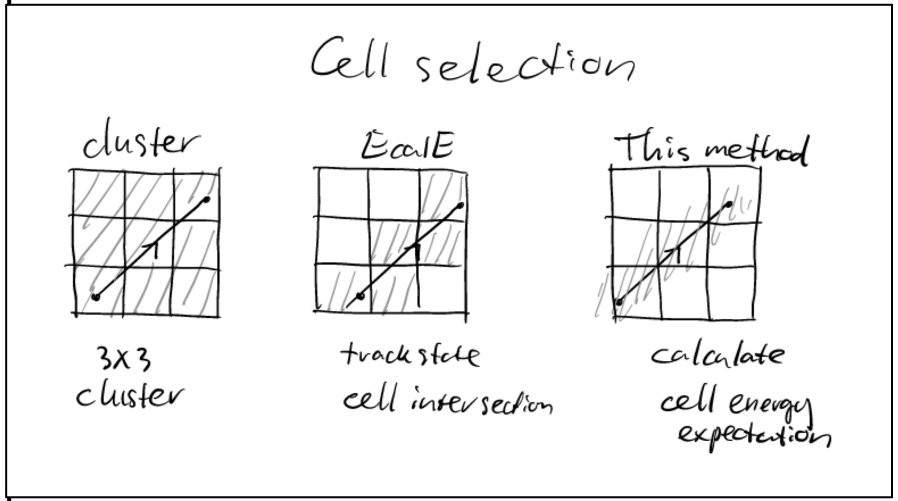


Hcal PID w.r.t better Ecal occupancy handling

- Ecal PIDe is using new cell selection method.
- More is gained by improving occupancy handling in Ecal than adding Hcal info! But Hcal does give independent information.



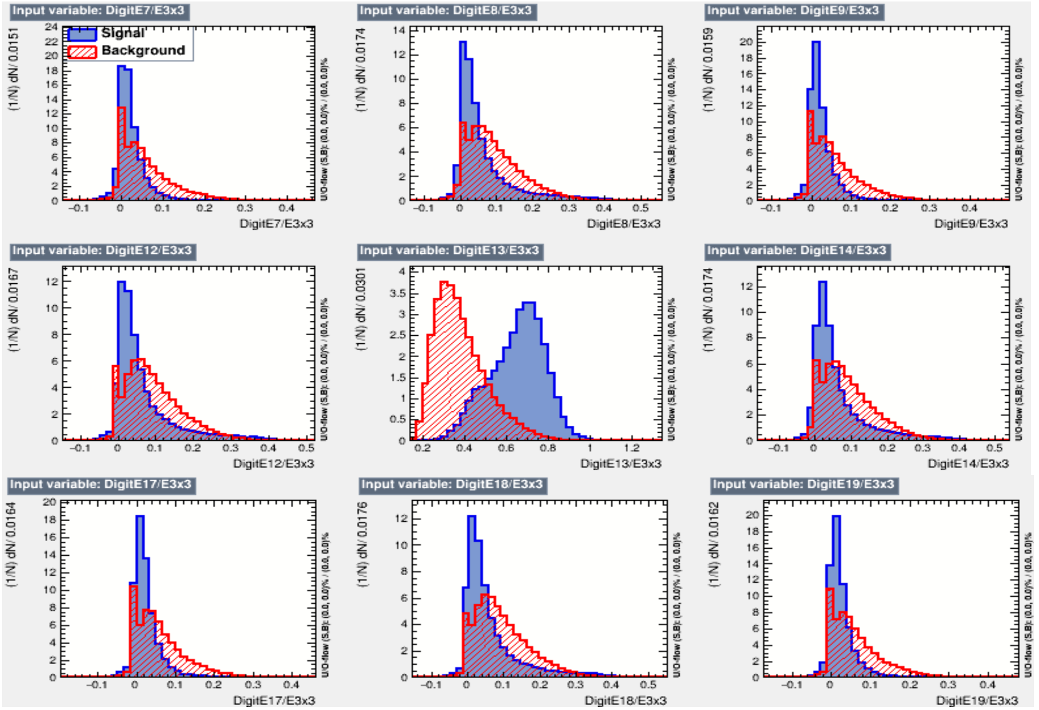




IsNotH

- TMVA MLP trained with MCUpgrade samples (StdLoosePhotons).
  - One NN per Calo region (different cell sizes).
  - Considered both **hadrons and pile-up** clusters as background sample. More than half reconstructed photons correspond to pile-up clusters.

Input variables (INNER): E_i/E_{3x3}



NN output (INNER):