# SAND ECAL clustering and PID

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# ECAL overview

SAND employs an existing superconducting magnet successfully operated at INFN-LNF for the KLOE experiment.

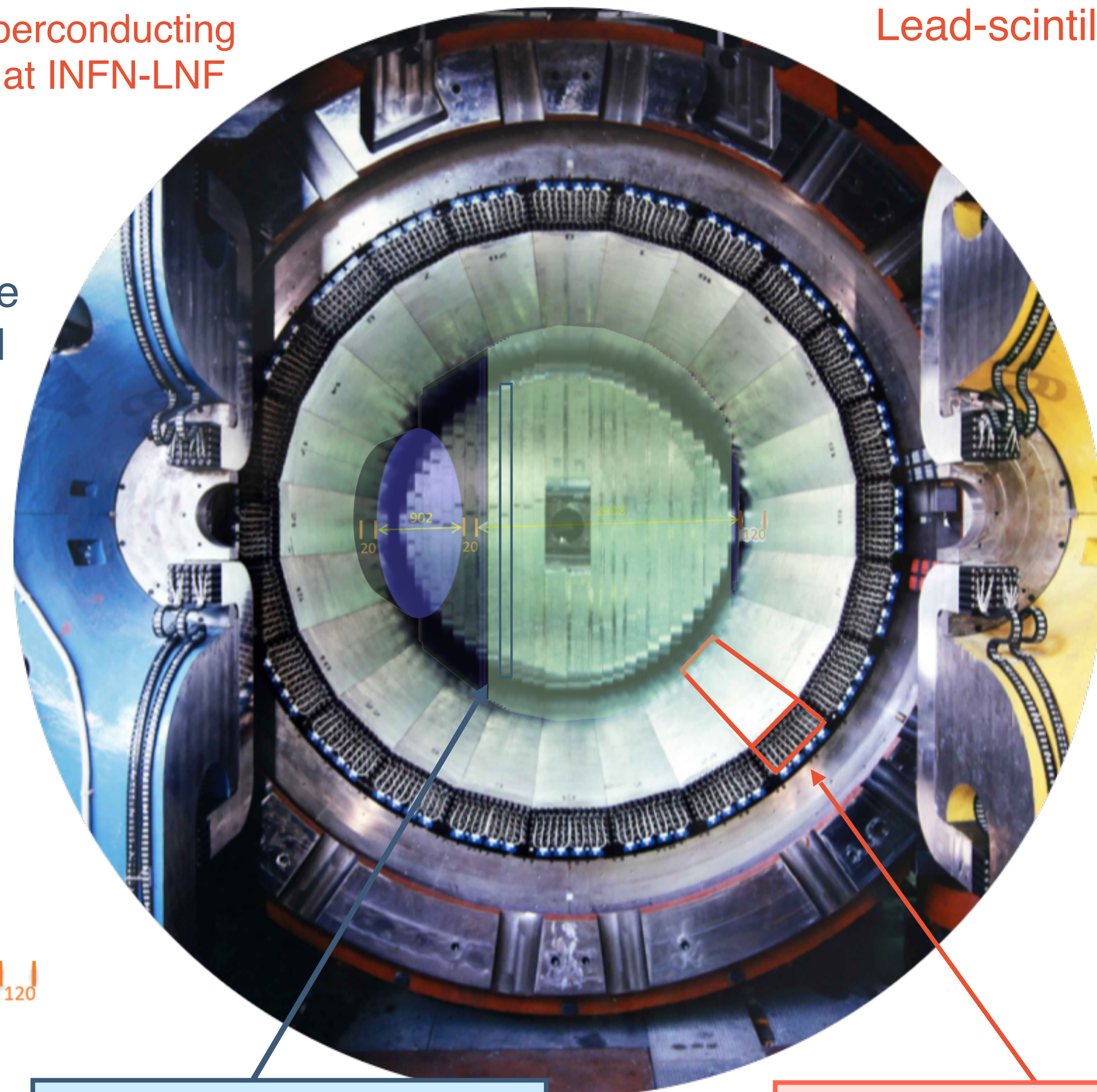
- Coil

Superconducting to produce 0.6 T over a 4.3 m long and 4.8 m diameter volume. located inside a cryostat.

- Iron yoke

~ 470 t

Lead-scintillating fiber sampling calorimeter.

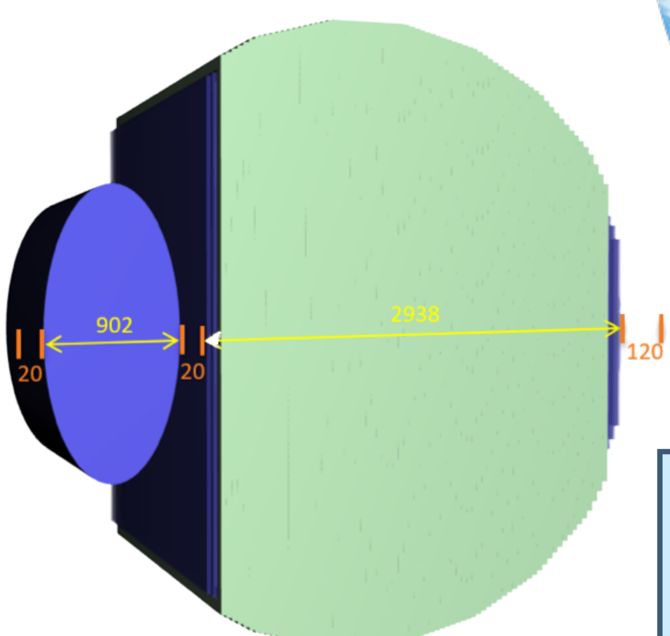


All modules are composed of alternated foils

- 200 lead foils, 0.5 mm thick, grooved to host fibers.
- 200 layers of cladded fibers glued together with special epoxy, 1mm diameter.

Average density $\sim 5 g/cm^3$, for an overall thickness of ~15 radiation lengths.

Readout at both ends of each module via PMTs




Endcap

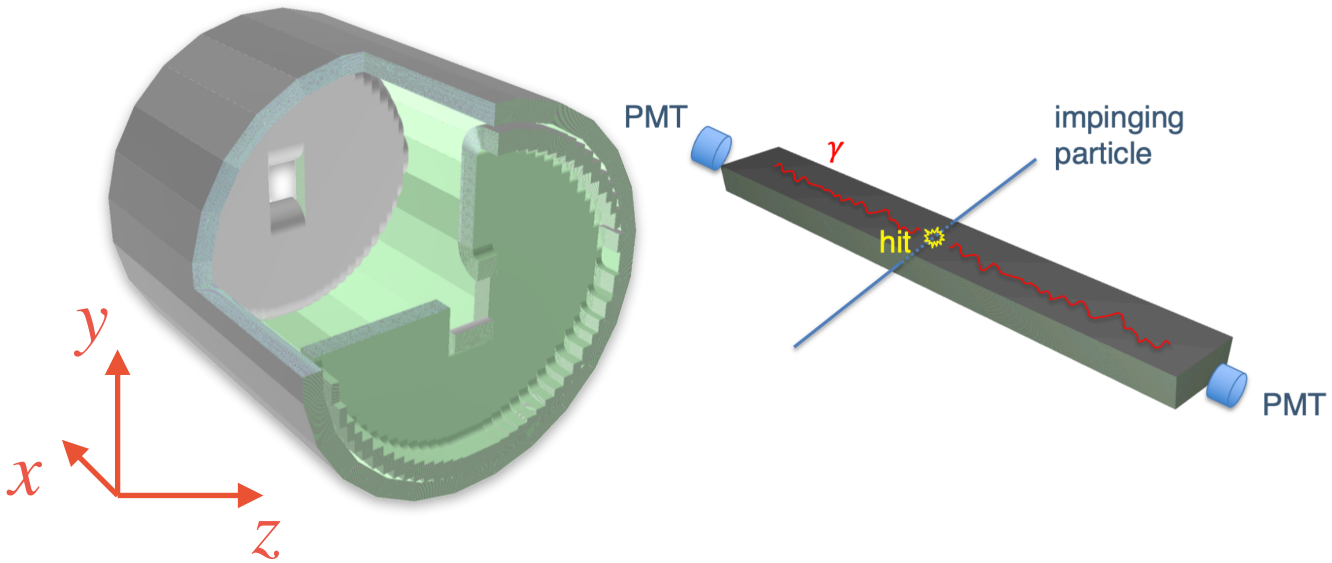
32 C-shaped, different dimensions.

Barrel

24 modules, same dimensions.

# ECAL reconstruction workflow

Reconstruction of the signal position and time




The coordinate along the barrel (endcap) module length x(y) is derived by time difference between two ends while z(x) and y(z) are given by the geometrical center of the fired cell.

$$t^e = \frac{t^A + t^B}{2} - \frac{L}{2v} \qquad x^e = \frac{v}{2}\left(t^A - t^B\right)$$

*edep-sim* simulation of energy deposited hits.

ECAL digitization

Conversion into **DAQ detector digits** stored in a ROOT TTree.

- Photoelectrons generating the photo signals (hits time and index).
- Photo signals (side A,B) with ADC, TDC.
- Cells with photo signals.

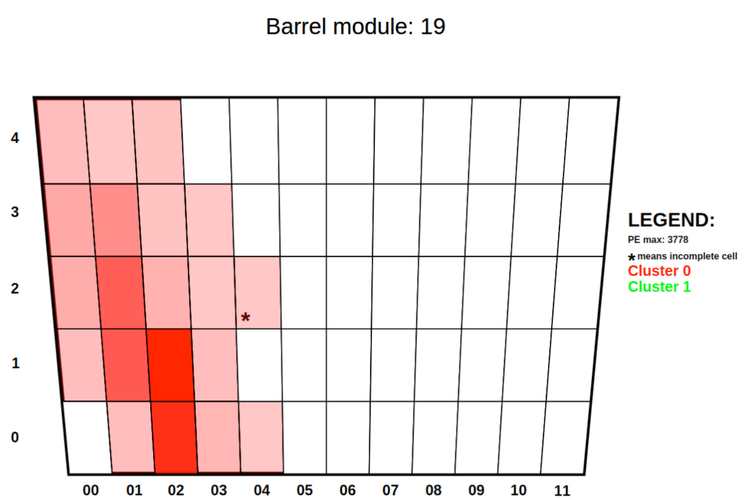
Clustering

ROOT TTree with **cluster** of cells with photo signals.

- Cluster information.
- Cells composing the cluster.

# ECAL reconstruction: clustering

## Pre-clustering




**Spatially** neighbour cells are added together

Pre-cluster variables: energy, position, time (as the energy weighted mean of the reconstructed time of the cluster cells), collection of reco cells.

## Splitting

Cluster overlapping are checked evaluating the pre-cluster spread in **time**.

If criteria are satisfied pre-clusters are divided into time quadrants

## Merging

Check for pre-clusters that have been split incorrectly.

**Position** and **time** are evaluated.

### Cluster output structure

- Energy.
- Position.
- Time.
- Collection of reco cells:
  - Cell geo info.
  - Reco energy.
  - Reco time.
  - Photo-signal$_{A,B}$.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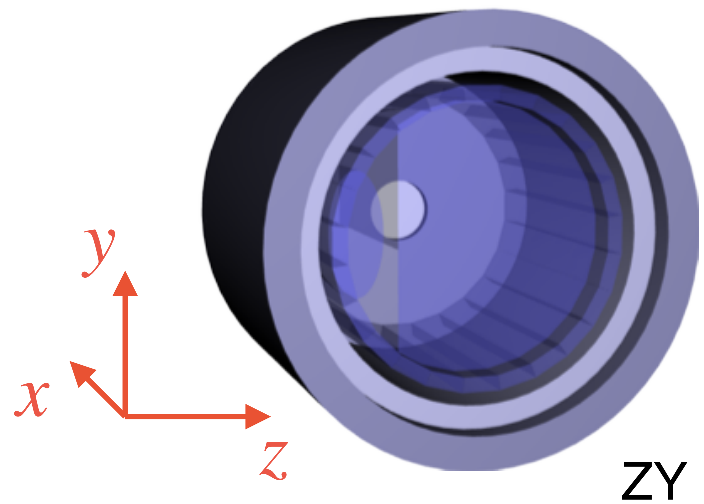
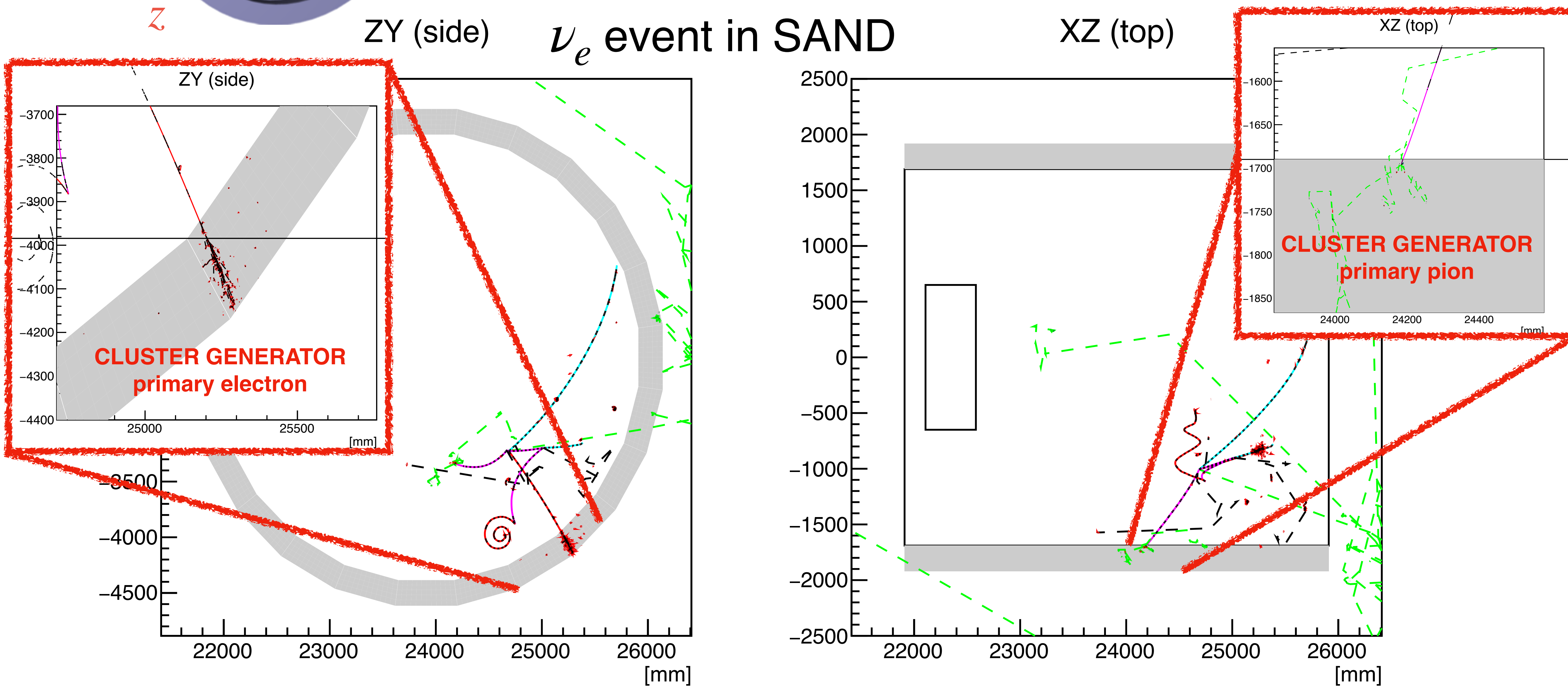
# Association MC - cluster generator




- **Validate** clustering algorithm.
- **Analysis** for ECAL particle reconstruction performances.

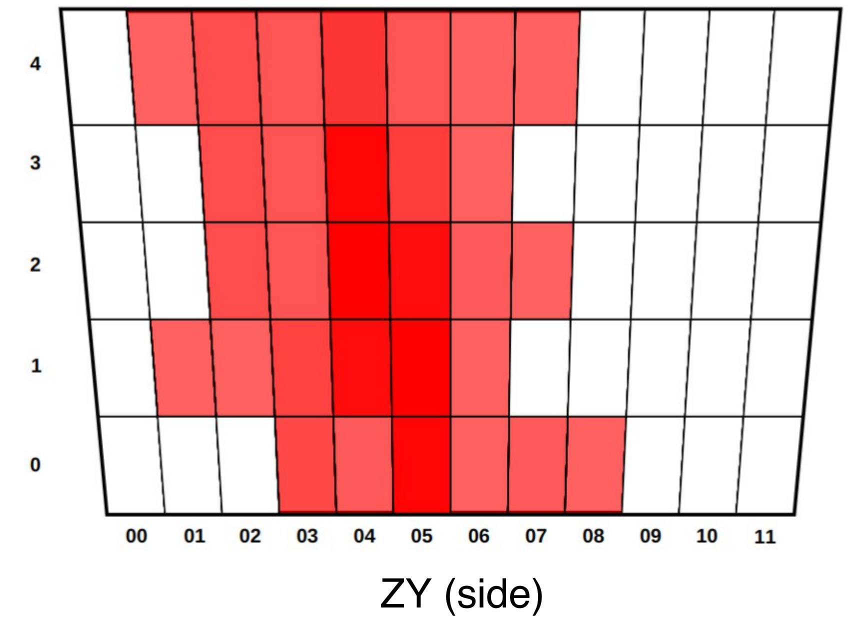
**First step: MC - cluster association**



# Association MC - cluster generator

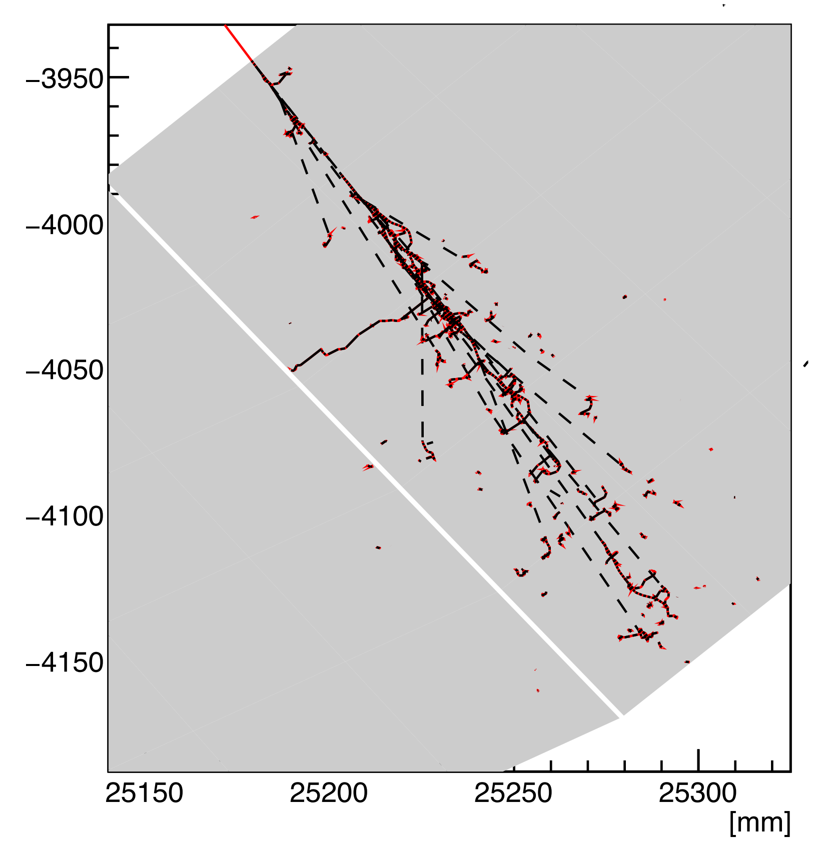
Cluster object contains:

- Reconstructed energy, position, time.
- Reconstructed cells.




Using the information from the MC objects:

- Hits.
- Trajectories.



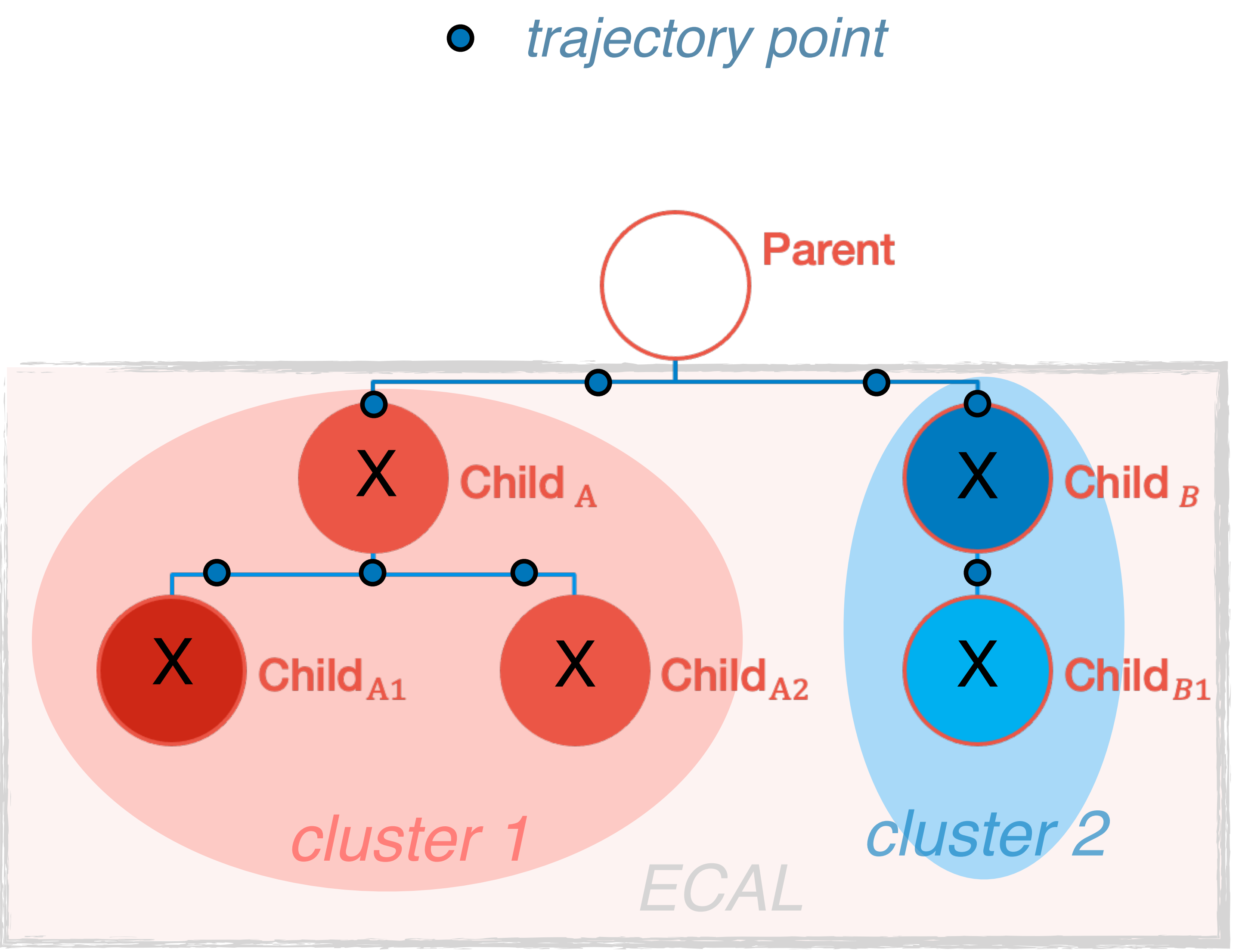

We want, for each reco cluster, a **truth cluster**:

- True deposited energy, position, time.
- Vector generators:
  - track Id/PDG code
  - initial momentum
  - deposited energy

# Association MC - cluster generator

Collect all the MC trajectories that have **hits** generating signal in the cluster

**OLD:** Starting from each trajectory with **hits** navigate the tree backwards checking if there are trajectories *entering in the ECAL* **with hits** in the cluster.

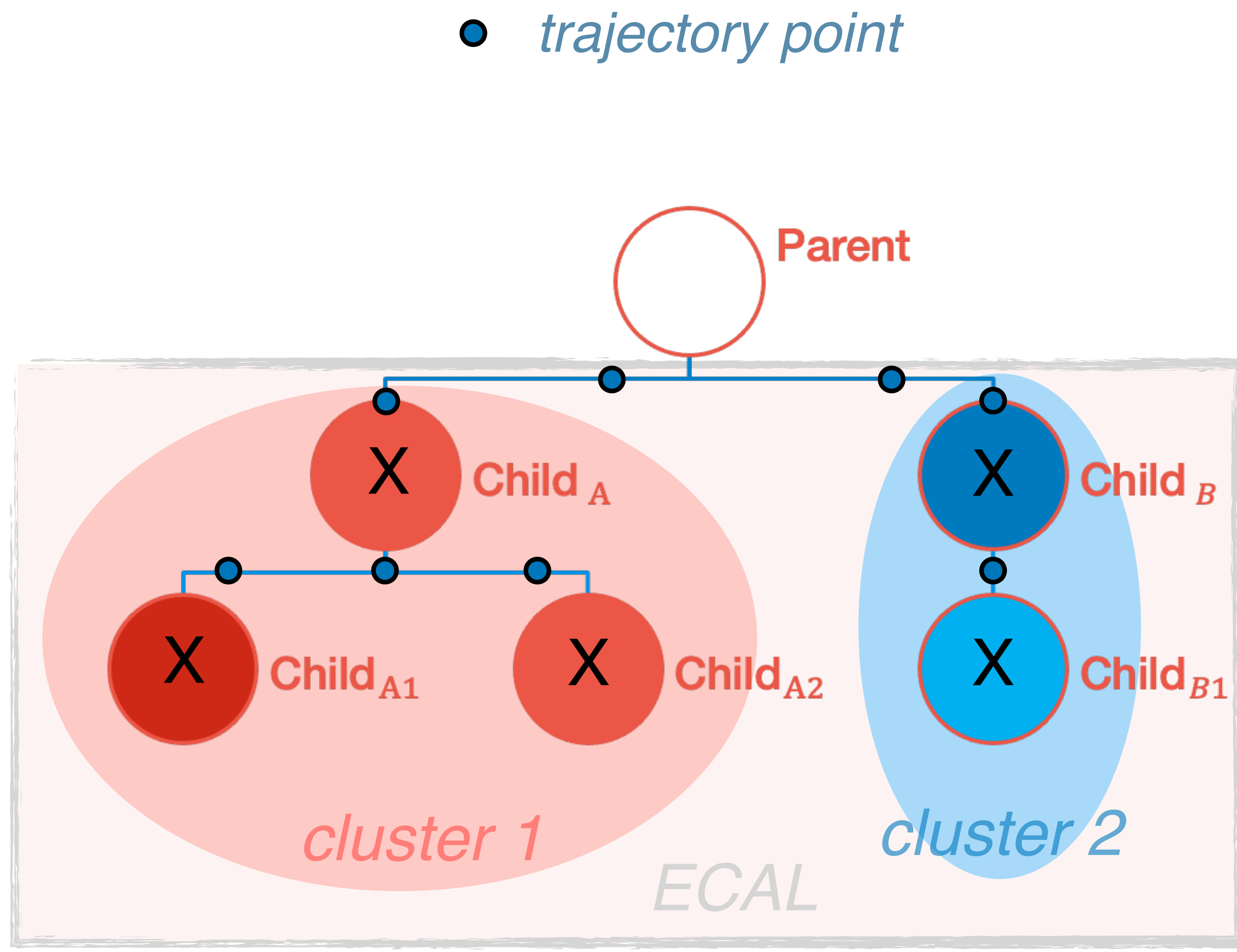


# Association MC - cluster generator

Collect all the MC trajectories that have **hits** generating signal in the cluster

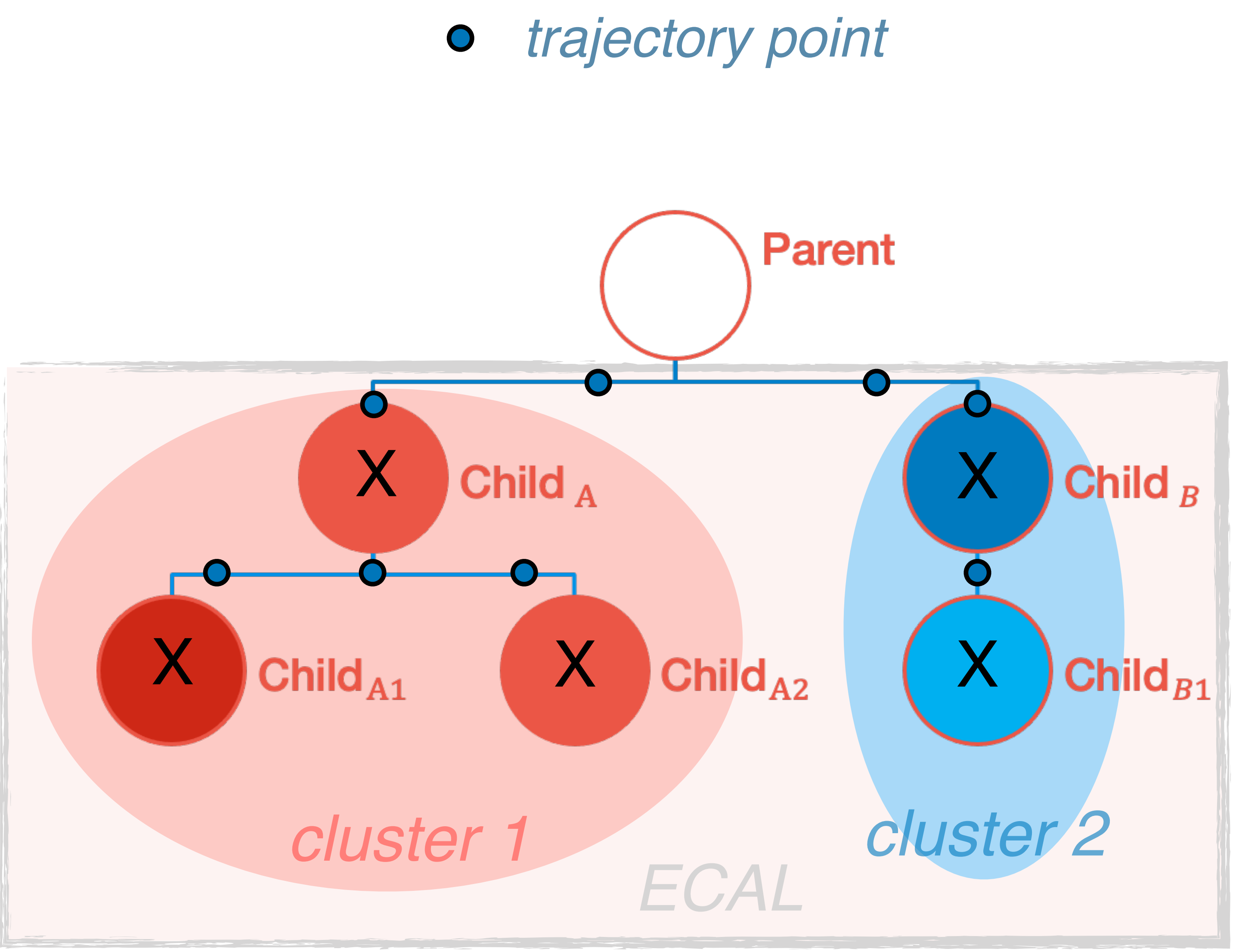
**OLD:** Starting from each trajectory with **hits** navigate the tree backwards checking if there are trajectories *entering in the ECAL* **with hits** in the cluster.

**NEW:** Starting from each trajectory with **hits** navigate the tree backwards checking if there are trajectories *entering in the CLUSTER* **with trajectory points** in the cluster.



# Association MC - cluster generator

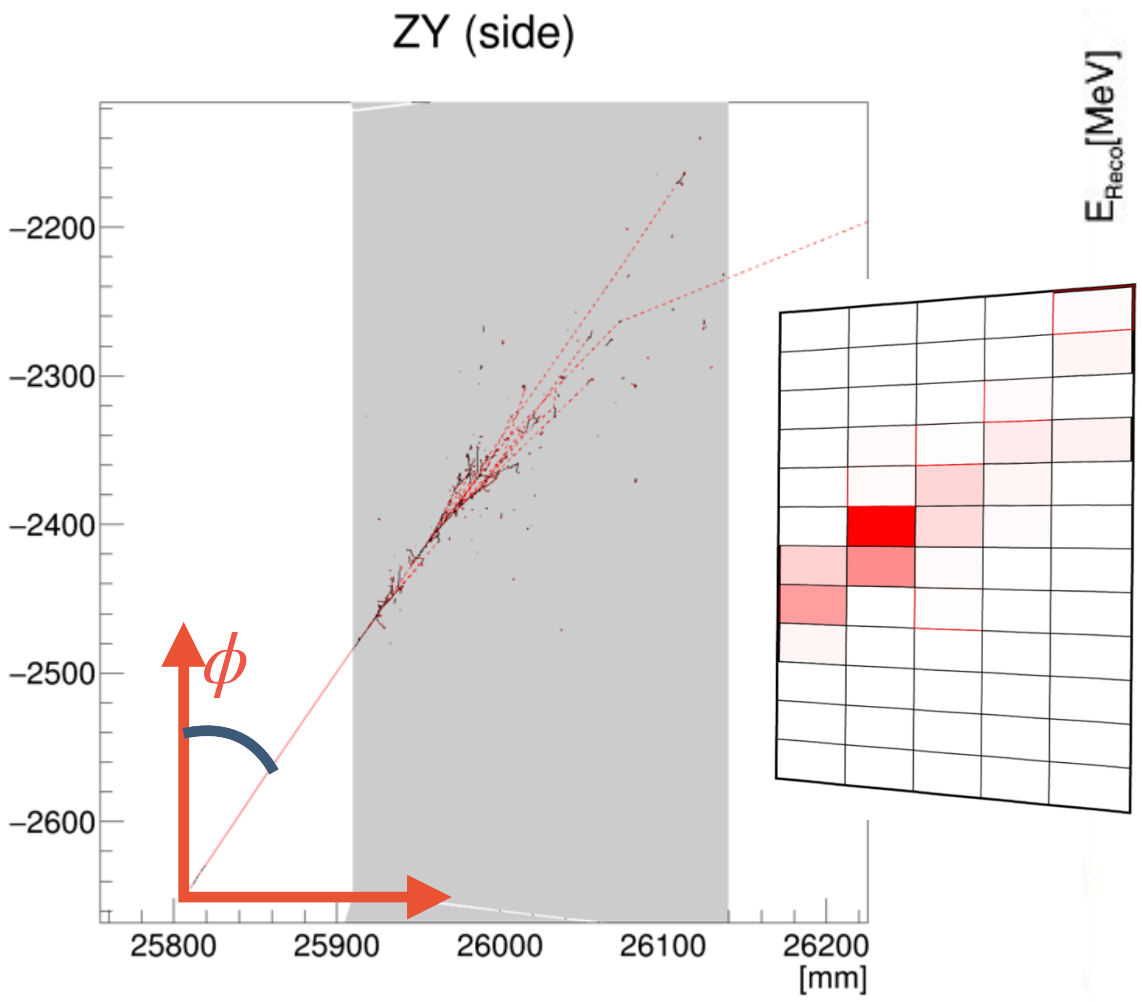
Collect all the MC trajectories that have hits generating signal in the cluster

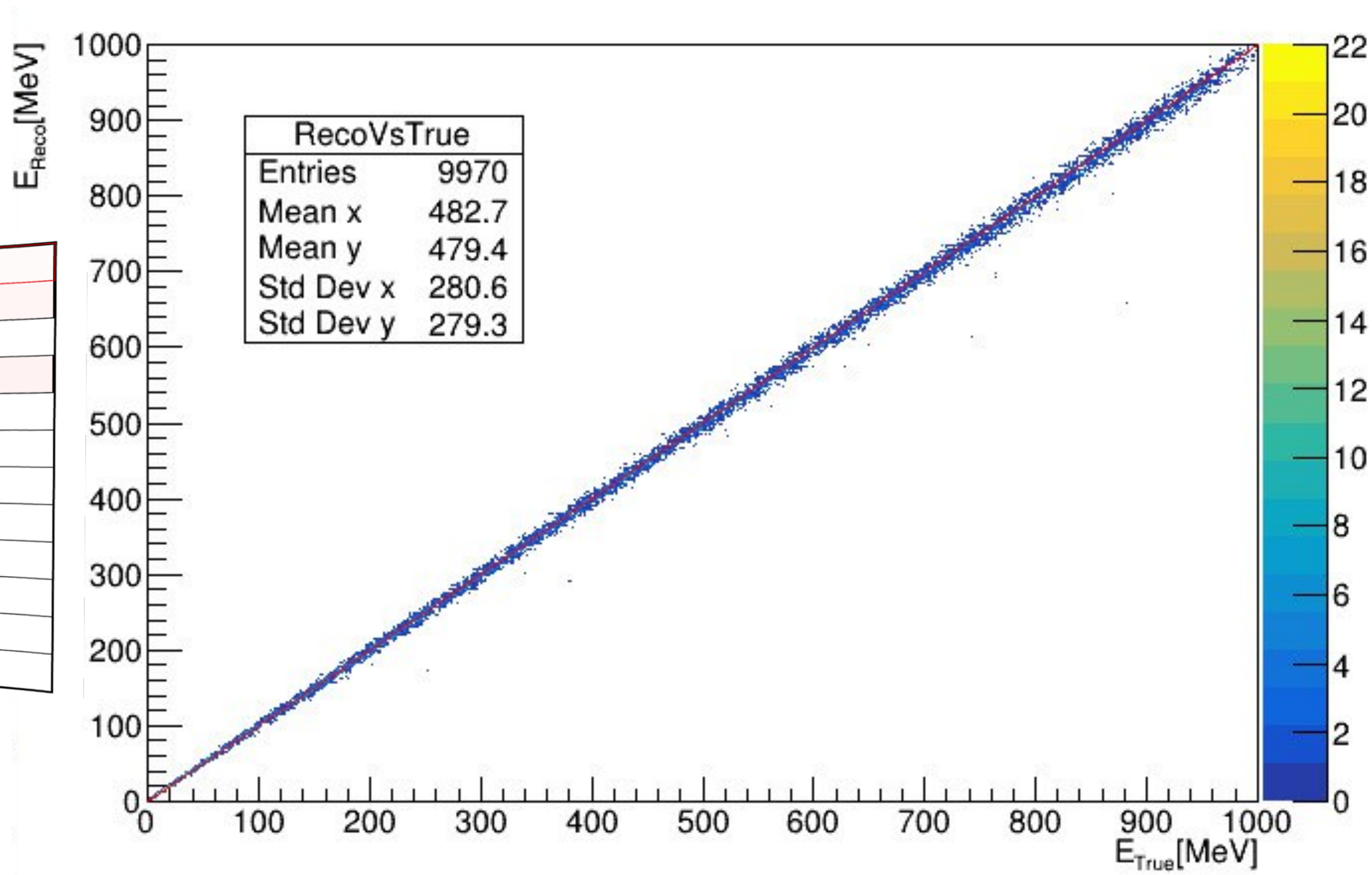



Child A is the generator of cluster 1
Child B is the generator of cluster 2

# Clustering validation: energy

**Sample**: 10 k electrons 0-1 GeV fixed angle. Old generator association algorithm.





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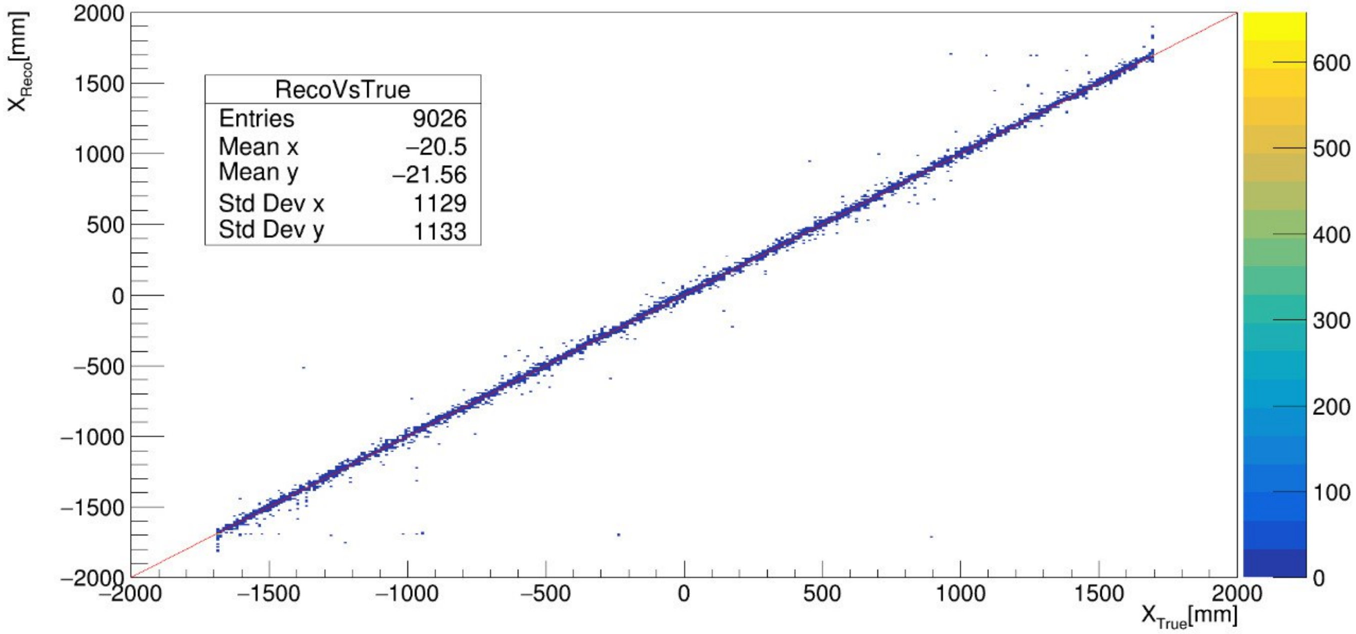
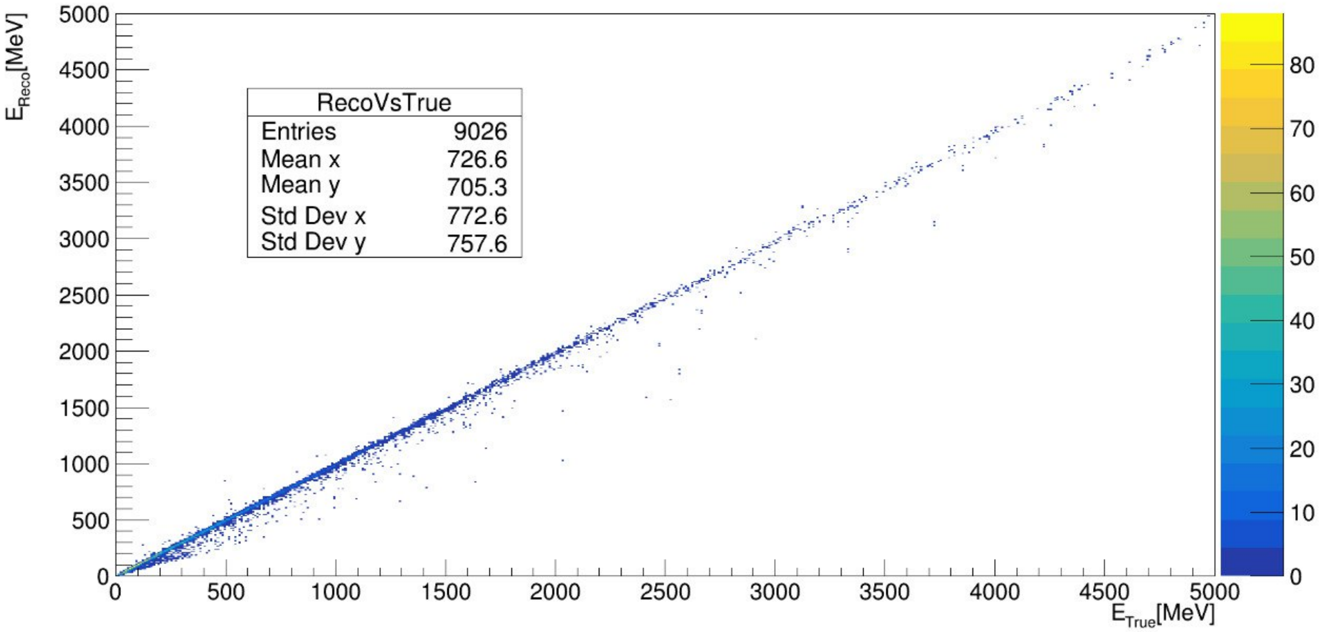
# Clustering validation: position

**Sample:** 30k $\nu_e$ with beam energy spectrum, interacting in STT volume, all the interactions are selected, no overlays.

*SAND center: (0.0, -2384.73, 23910.0)mm*




**Selection**: Primary electrons with only one generator/cluster, $E_{True}$ deposited in the ECAL active volume by the generator. Old generator association algorithm.

# Single particle discrimination: $e/\pi$

**Sample:** 30k $\nu_e$ with beam energy spectrum, interacting in STT volume, all the interactions are selected, no overlays.

## Selection applied

- Only one generator/cluster. Old generator association algorithm.
- Generator particles $e^{\pm}, \pi^{\pm}$ + condition on Track ID of the ($\nu_e$) *parent* = -1.
- *ECAL* variables (**reconstructed**) from clustering algorithm.
  - Cluster energy, Ncells, layer energy, …
- *Tracker* variable (**MC+smearing**) of the generator + smearing.
  - Generator initial momentum with 4% smearing.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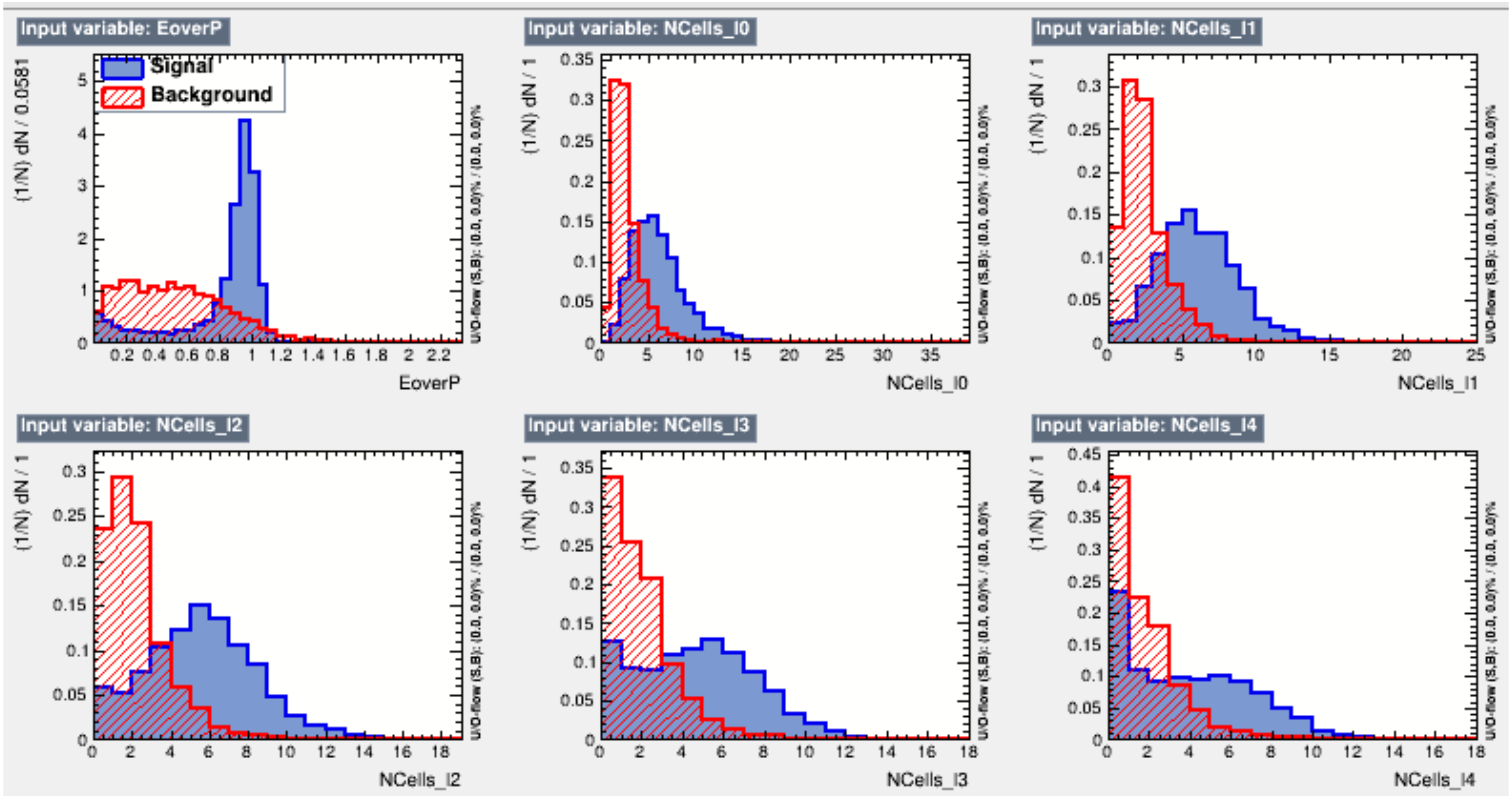
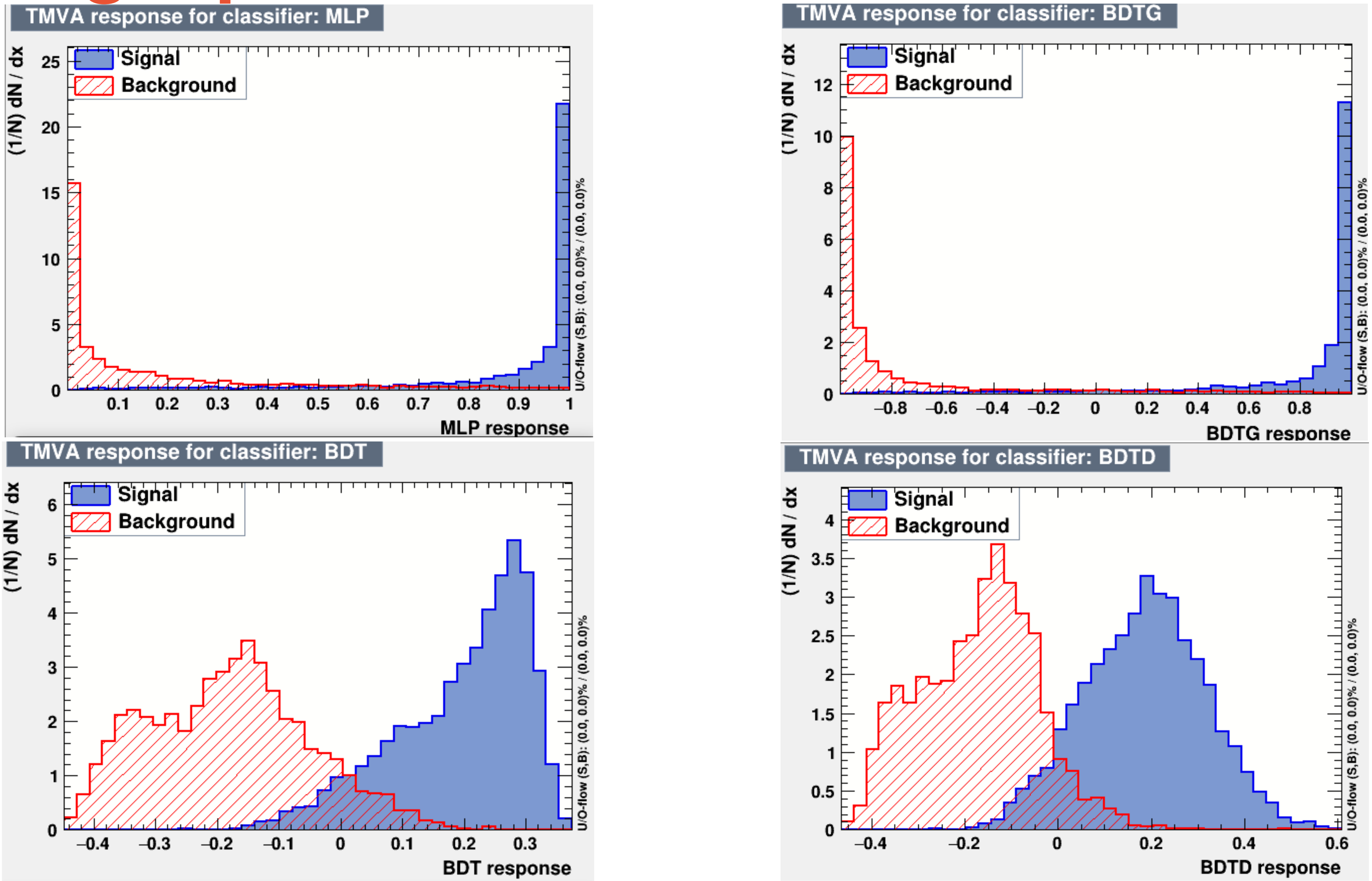
# Single particle discrimination: $e/\pi$

## Input variables (& more)



# Single particle discrimination: $e/\pi$



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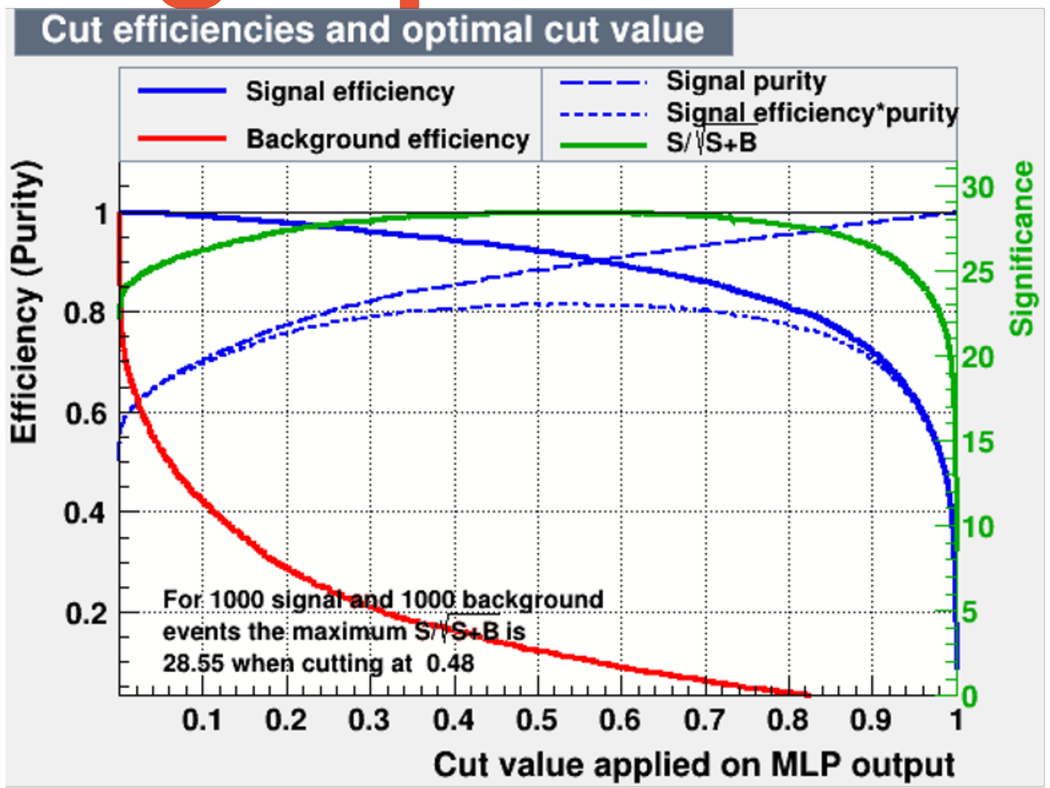
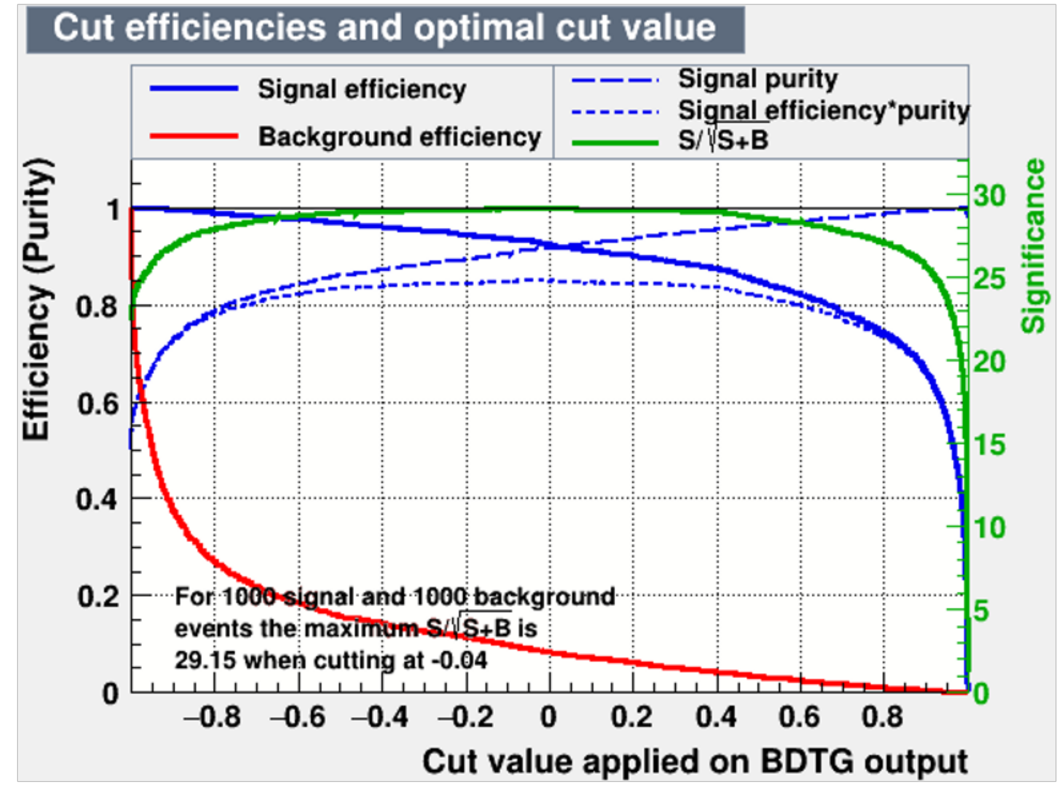
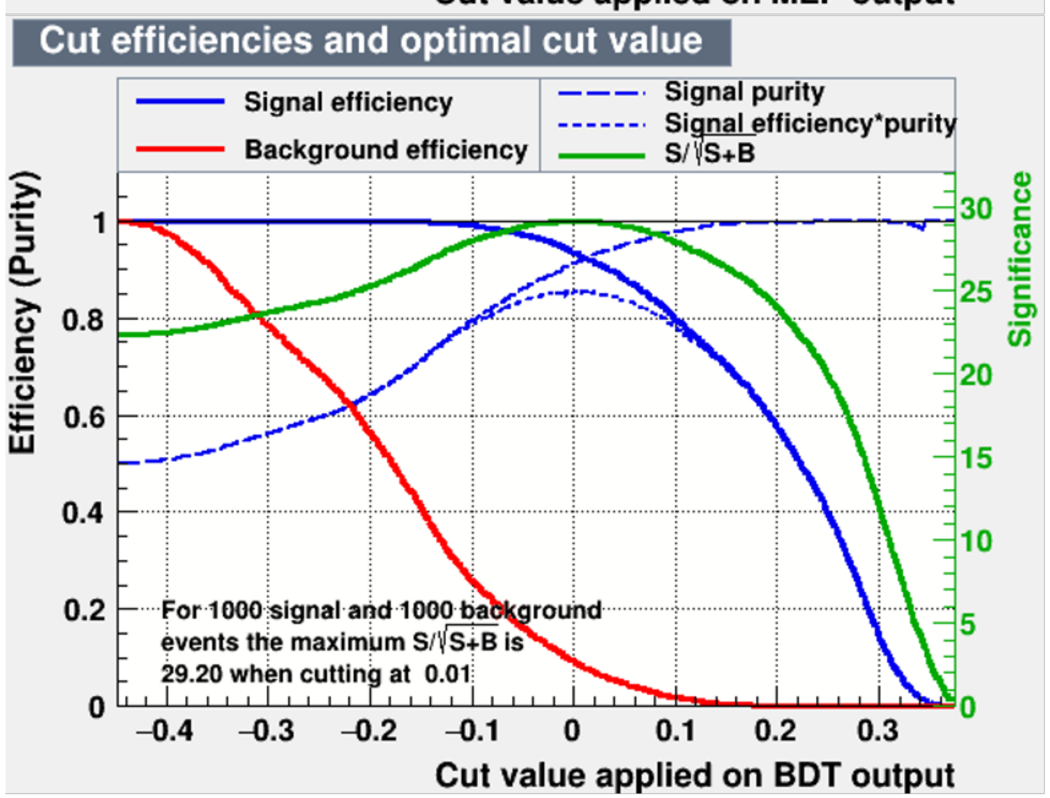
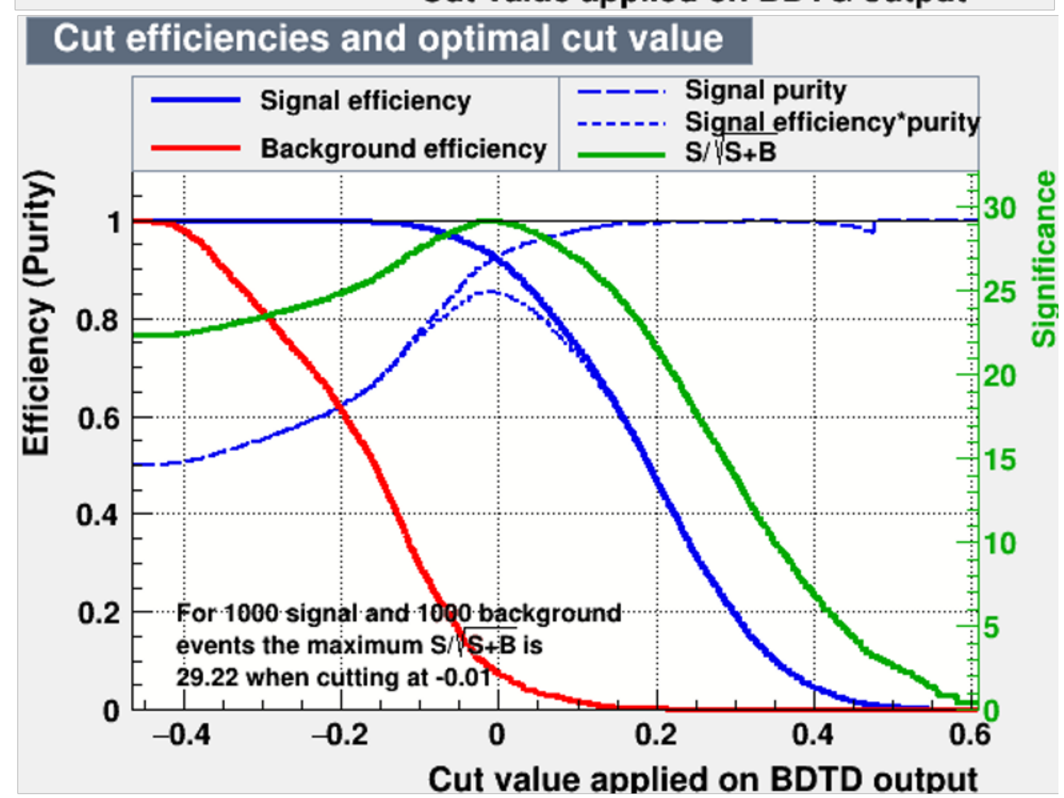
# Single particle discrimination: $e/\pi$





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# Single particle discrimination: $e/\pi$

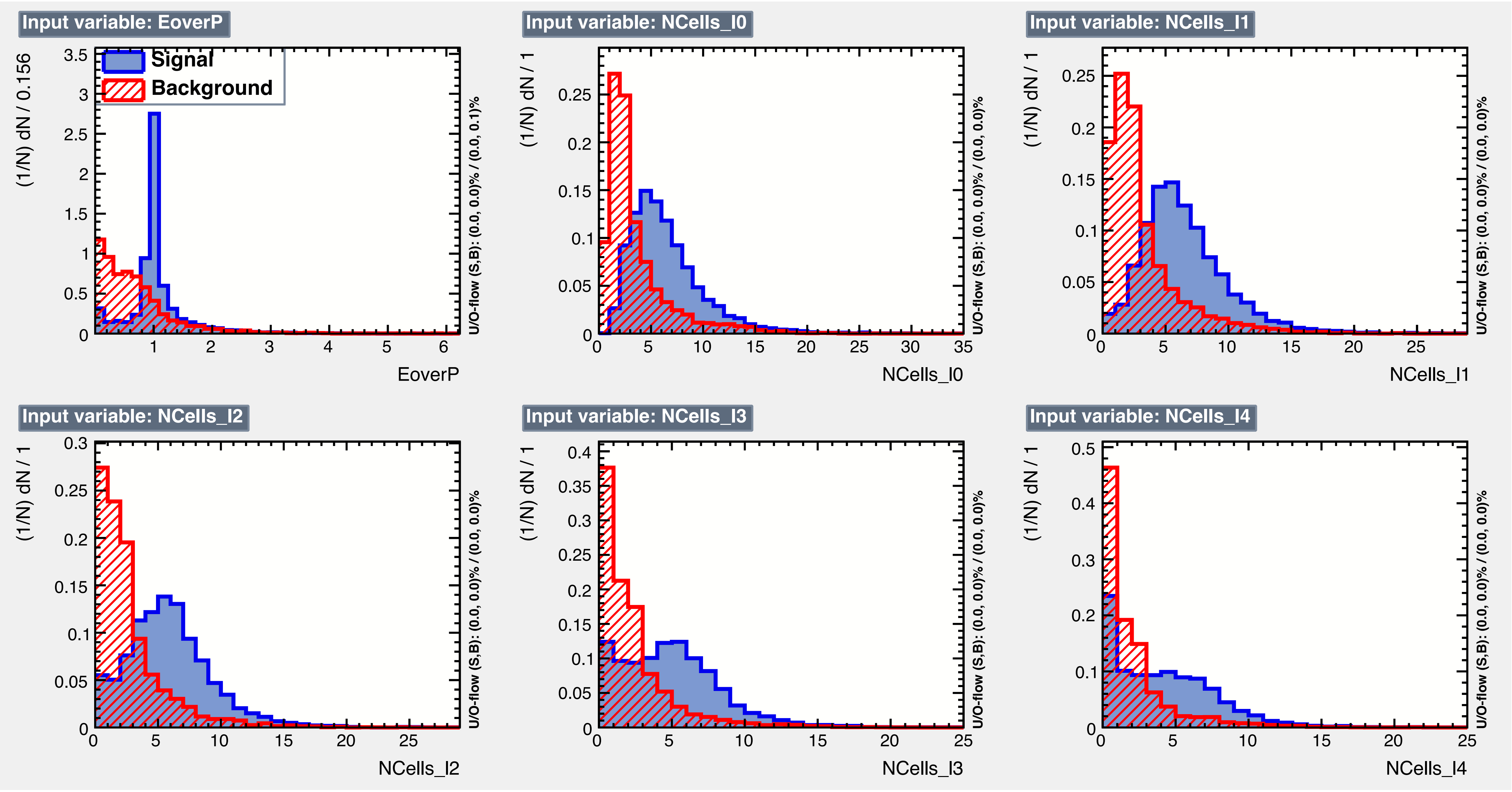
- **Sample:** 30k $\nu_e$ with beam energy spectrum, interacting in STT volume, all the interactions are selected, no overlays.

Selection applied

- At least one $e/\pi$ primary as the generator with more energy deposited in the cluster. NEW generator association algorithm.
- Generator particles $e^{\pm}, \pi^{\pm}$ + condition on Track ID of the ($\nu_e$) *parent* = -1.
- *ECAL* variables (**reconstructed**) from clustering algorithm.
  - Cluster energy, Ncells, layer energy, …
- *Tracker* variable (**MC+smearing**) of the generator + smearing.
  - Generator initial momentum with 4% smearing.

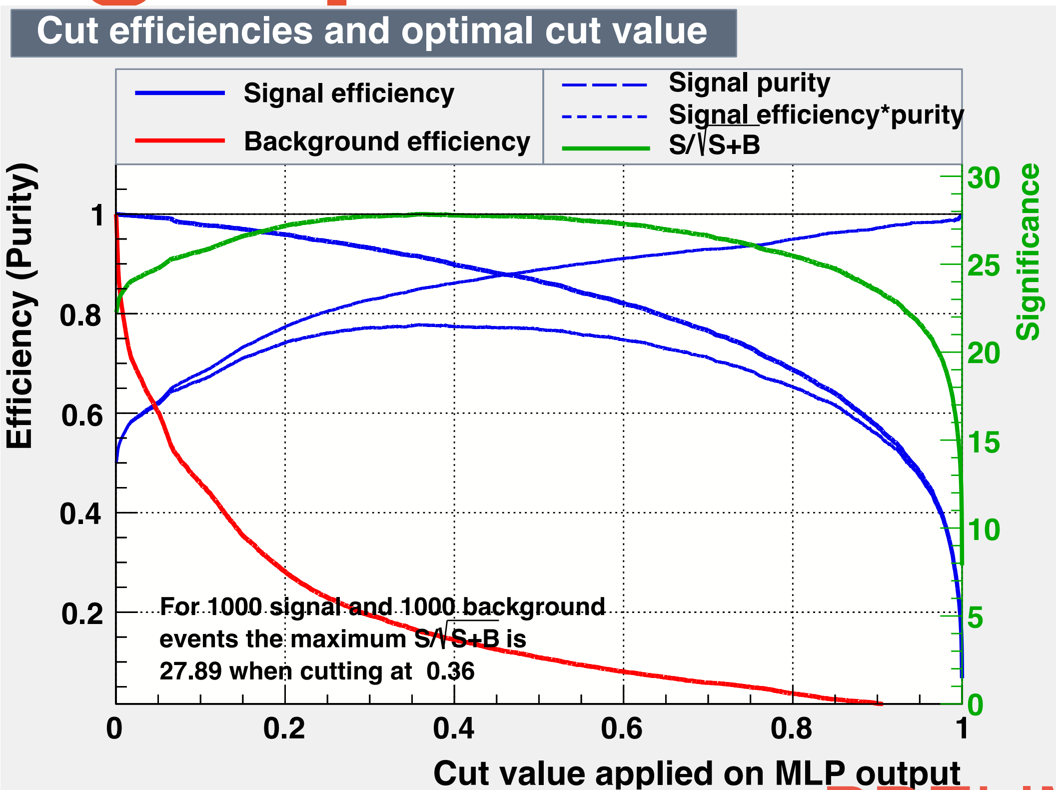
# Single particle discrimination: $e/\pi$

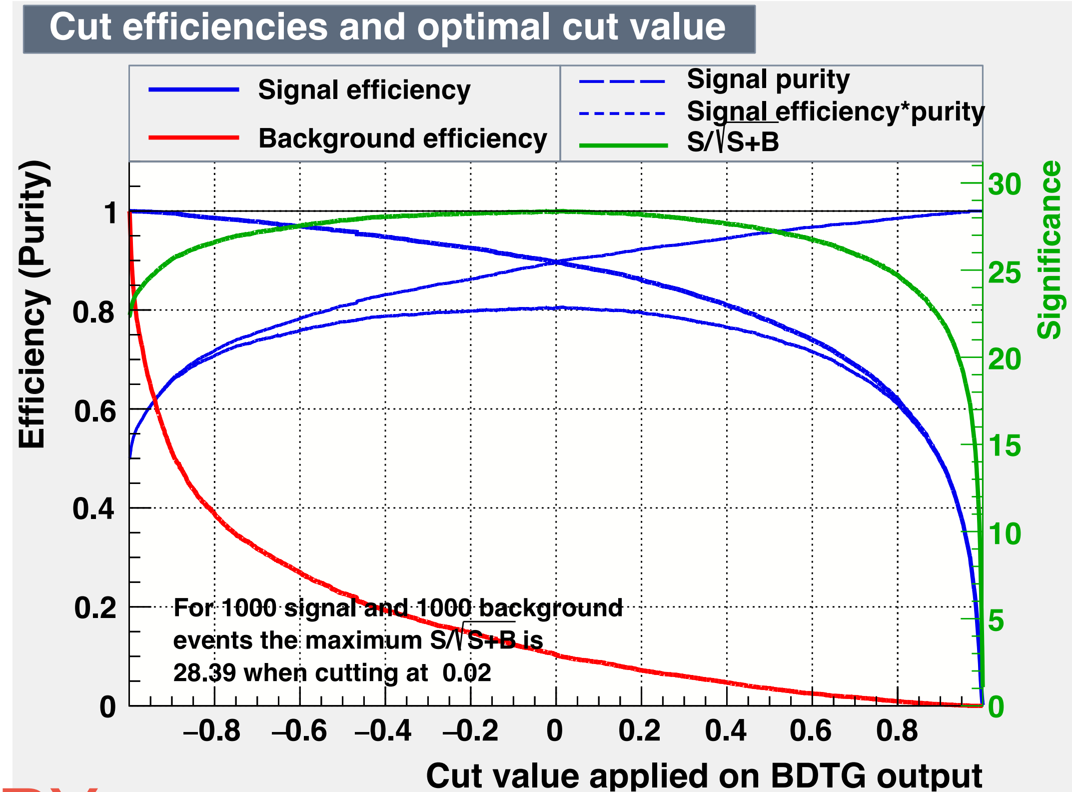
## Input variables (& more)



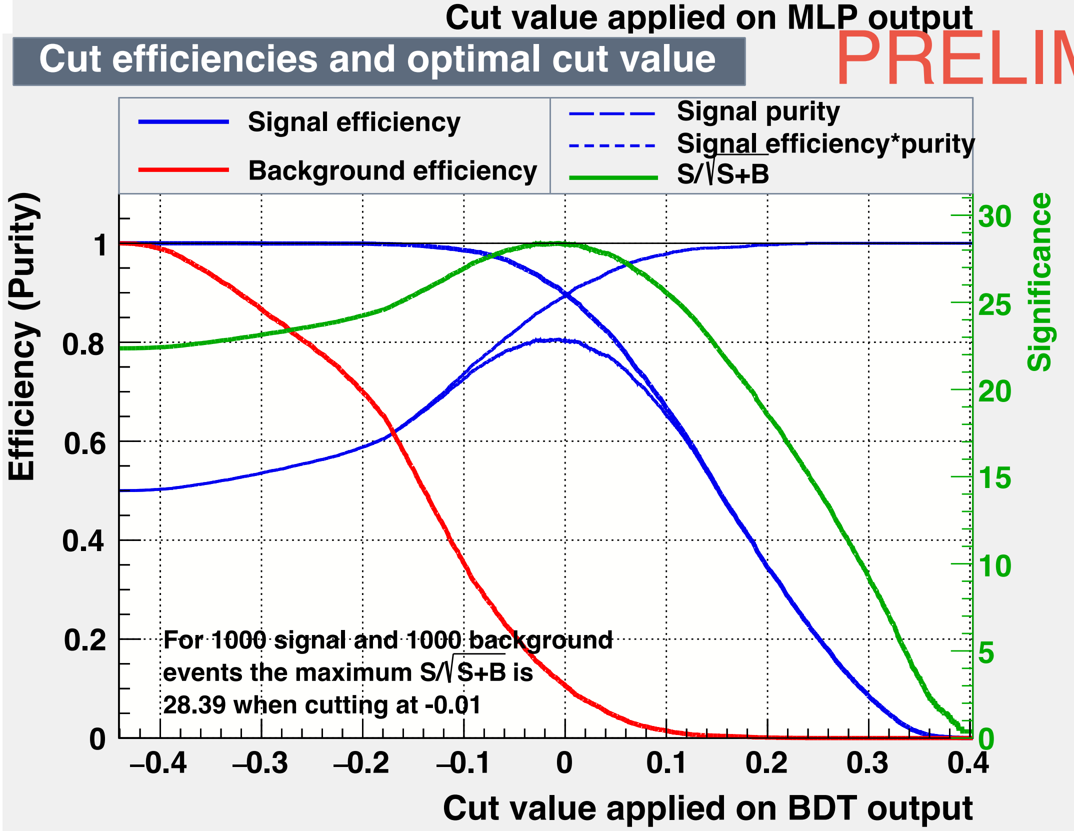

PRELIMINARY

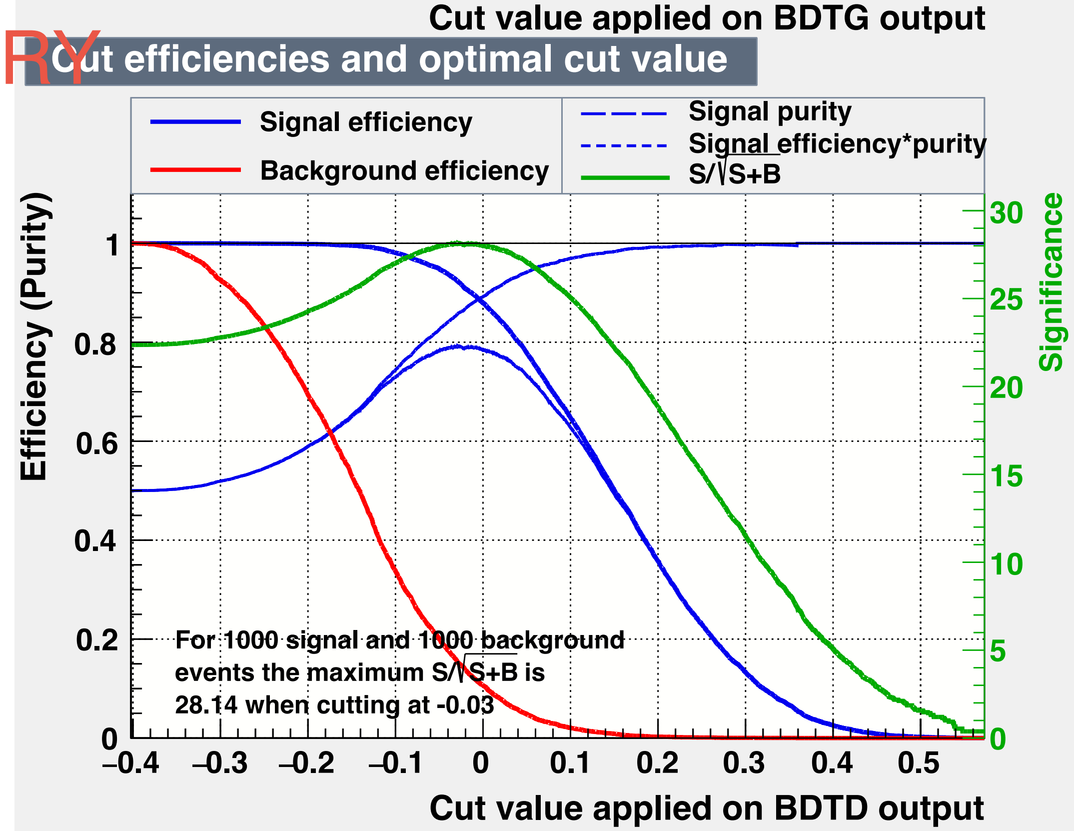
# Single particle discrimination: $e/\pi$



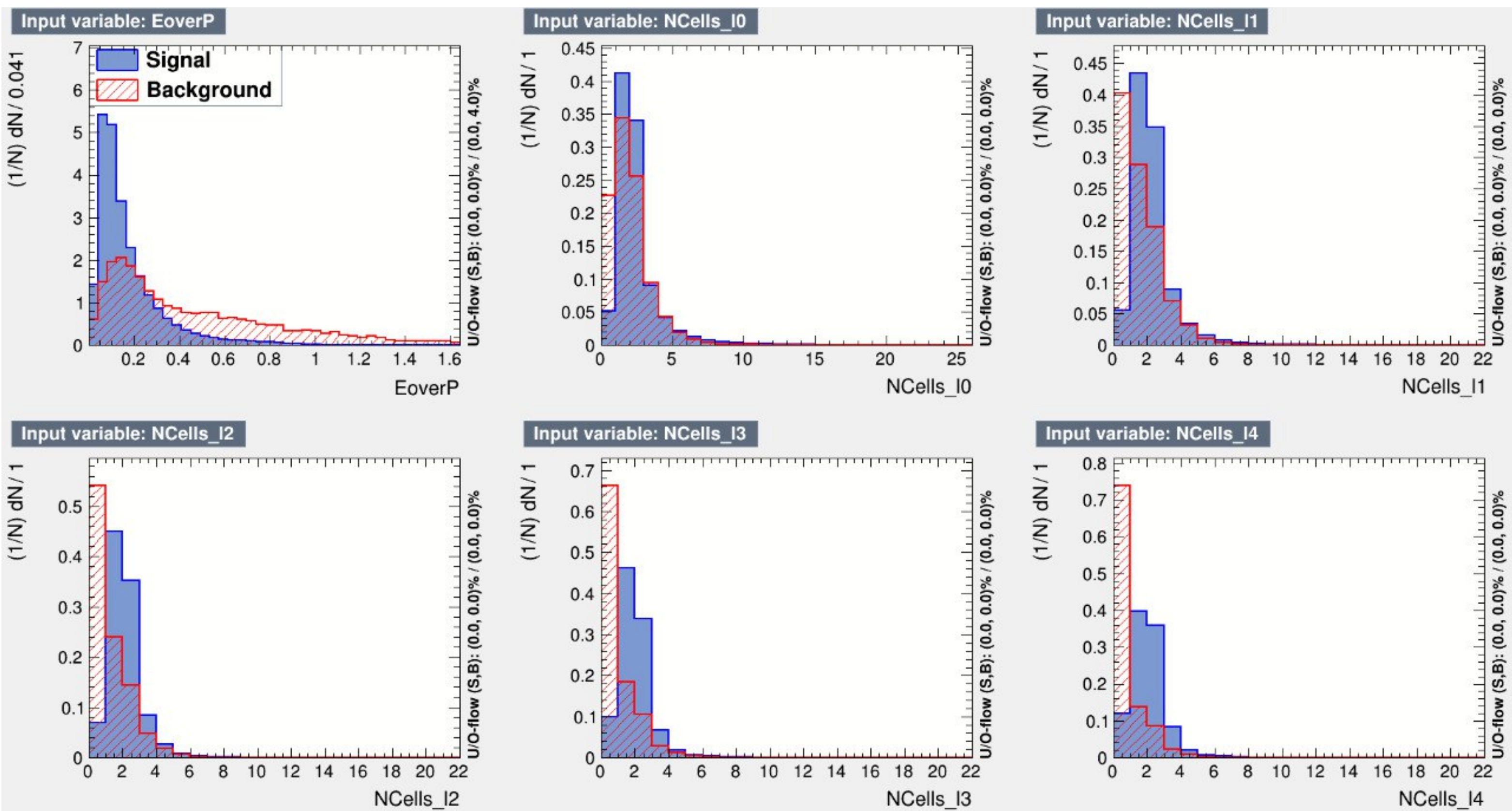

PRELIMINARY



# Single particle discrimination: $\mu/\pi$

- **Sample:** 1000k $\nu_\mu$ with beam energy spectrum, interacting in STT volume, all the interactions are selected, no overlays. NEW generator association algorithm.



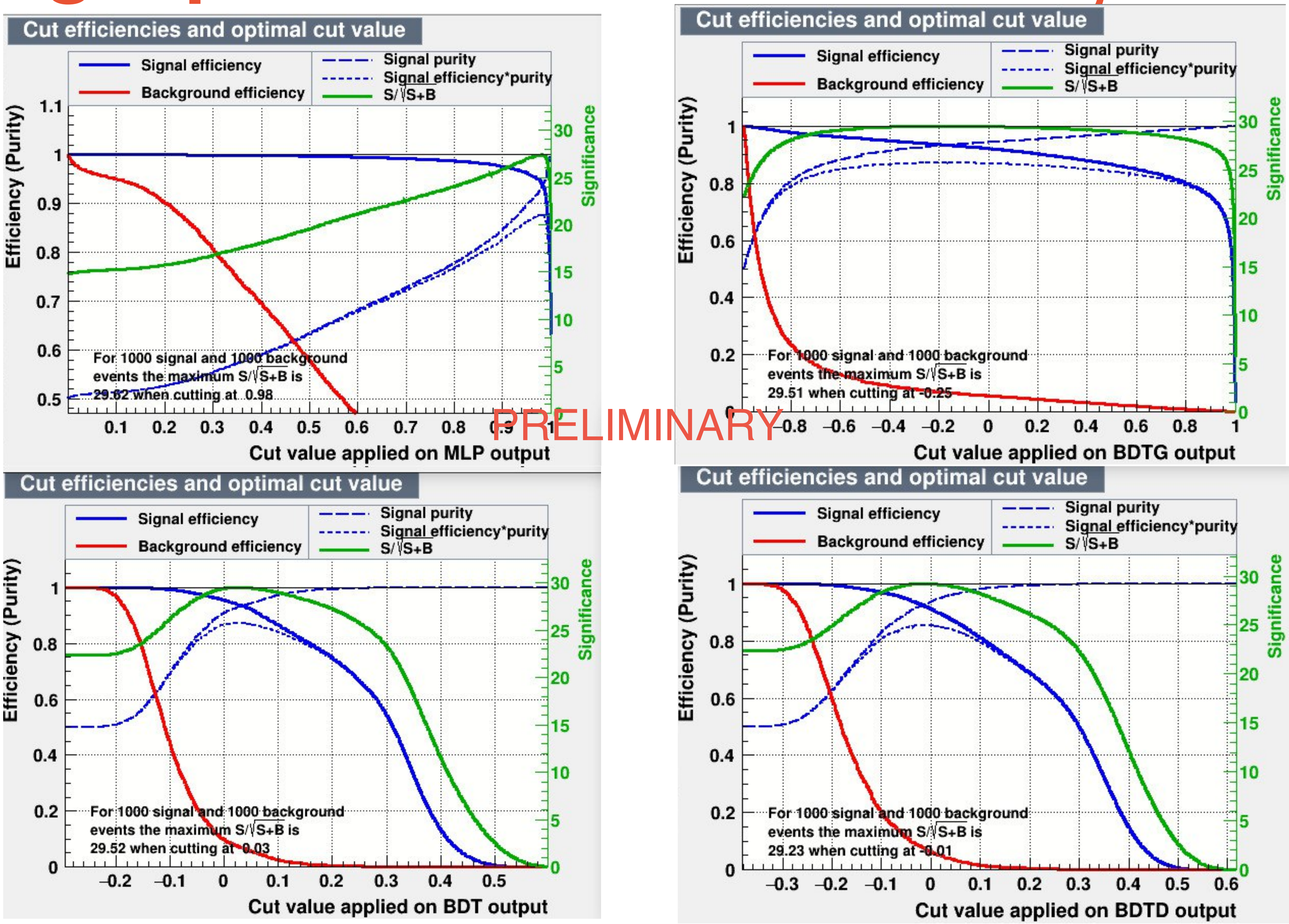

Signal: $\mu$
Bkg: $\pi$

PRELIMINARY

Selection applied

- At least one $\mu/\pi$ as the generator with more energy deposited in the cluster. NEW generator association algorithm.
- Generator particles $\mu^{\pm}, \pi^{\pm}$ + condition on Track ID of the ($\nu_\mu$) *parent* = -1.
- *ECAL* variables (**reconstructed**) from clustering algorithm.
  - Cluster energy, Ncells, layer energy, …
- *Tracker* variable (**MC+smearing**) of the generator + smearing.
  - Generator initial momentum with 4% smearing.

# Single particle discrimination: $\mu/\pi$



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# Next steps: reconstruction

- Using output from ML in the reco to have a guess for particle assignment to each cluster in the event.

Reconstruction flow:
Digitization -> clustering -> reconstruction.

- **Clusterize** creates cluster objects with the variables that can be given to ML *(already in sandreco Reconstruct)*.
- ML with ECAL + **p** from tracker variables as input to have a guess on the cluster-particle association. *(not in sandreco Reconstruct yet)*

**ECAL + tracker p only**

To be eventually integrated with tracker output info (track presence (neutral/charged), primary particle or not, ...)

# Next steps: reconstruction

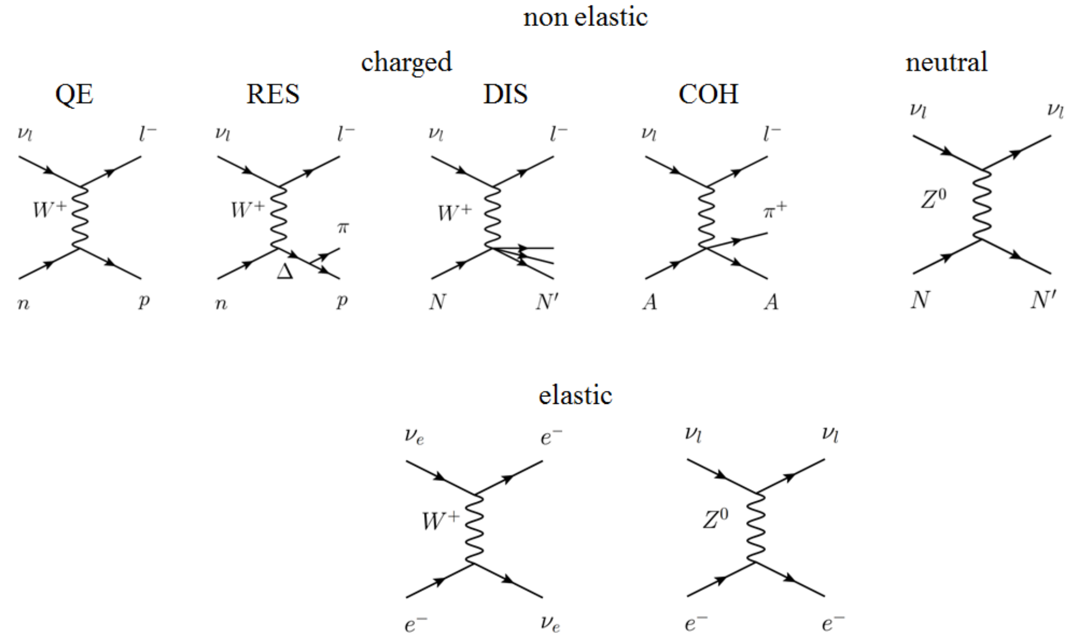
How to say we are satisfied in particle discrimination/identification?

1. If particles that reach the ECAL producing clusters are identified correctly using ML output.

2. Just a start of event reco with ECAL only, if $\nu_l$ is identify correctly. (If it is not can be due to the tracker info lack or ECAL-only reco algorithm failing)

- Simulating $\nu_l$ with no overlay, with no info about the vertex from the tracker, we can say:

If there are in the ECAL $l + X$ clusters → we guess a $\nu_l$ X non elastic CC.





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# Conclusions & next steps

- ECAL **simulation** chain (edep-sim + digitization + clustering) almost ready, first version available on GitHub sandreco.

- MC - cluster association tool new version under testing, the old one has been used (with a gold sample selection) to:

    1. Reconstruction **algorithm** evaluation.

        - ECAL **clustering** validated with energy and position variables.

    2. **Analyses**.

        - Single particle discrimination ongoing for $e/\pi$ ECAL separation power with ML.

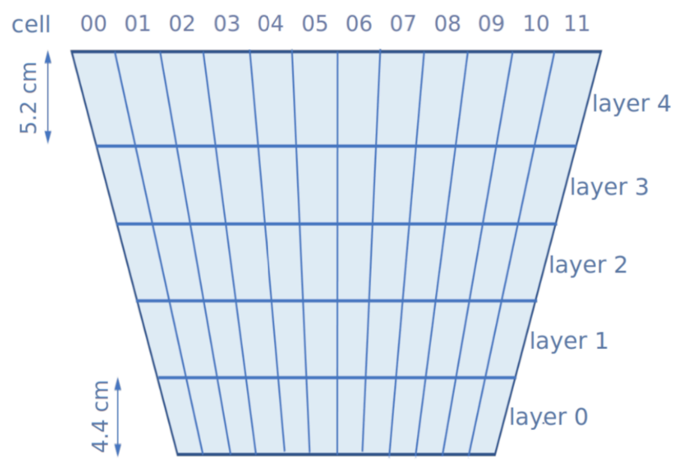
        - Future particle identification evaluation from reco.

# Thank you for the attention!

# BACKUP

# ECAL reconstruction: digitization

## Module segmentation




Segmentation of the modules in 5 layers and cells of $4.4 \cdot 4.4(5.2) cm^2$ granularity.

Cell id: 20 1 11

Layer 0-4

Module barrel/endcap
00-23/30&40

Cell barrel/endcap
0-11/0-89

## Digit formation in cells

- $N_{pe}$ number of photoelectron produced by an hit is extracted by Poisson distribution with
$$\mu_{pe} = dE \cdot E_{pe} \cdot A_l$$
- Arrival time [ns].
$t_{pe} = t_{cross} + t_{decay} + t_{prop} + Gauss(1ns)$
- ADC counts $S_i^{B,A} = N_{pe} \cdot peADC$ .
- TDC: 2 options constant fraction or fixed threshold.

**Digit structure:**
- Cell information.
- Photo-signals$_{A,B}$:
  - ADC, TDC.
  - Collection of pe:
    - Hit index.
    - Time.