PID in PFA-based detectors

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Outline

- Introduction
- PFA
- PID techniques in PFA-based detectors:
  - TPC
  - Calorimeters

- Conclusion

Introduction

Particles Identification is important for many studies. The most known are:

B-tag : Higgs, B oscillation..

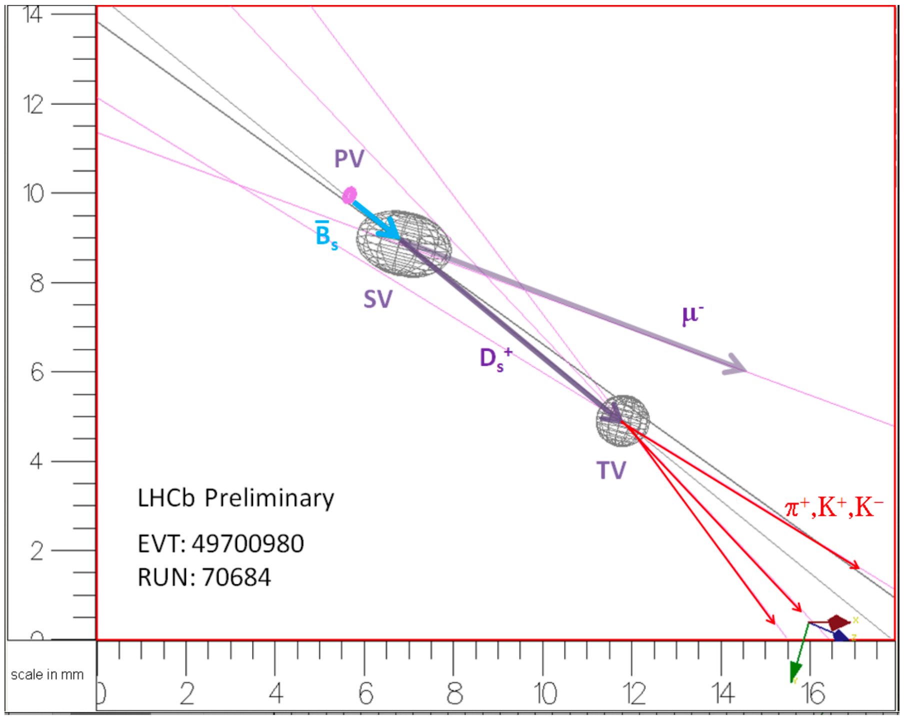
C-tag : Higgs, CP violation..

$\gamma - \pi^0$: τ polarization, jet construction

e-μ : Neutrino nature

$\mu -$ hadron : Energy reconstruction, NP

Identifiers :
Mass m , charge q, spin s…



Means:

- Standard: Time of Flight, dE/dX, Cerenkov light, Transition Radiation
- PFA-based: Shape, Time of Flight, dE/dX

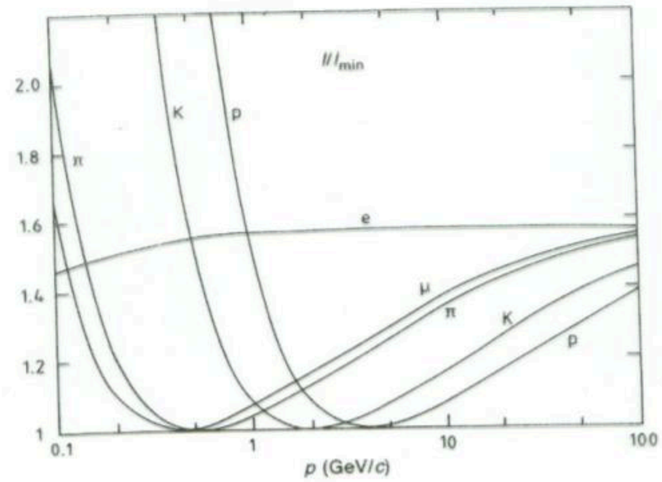
Standard PID techniques

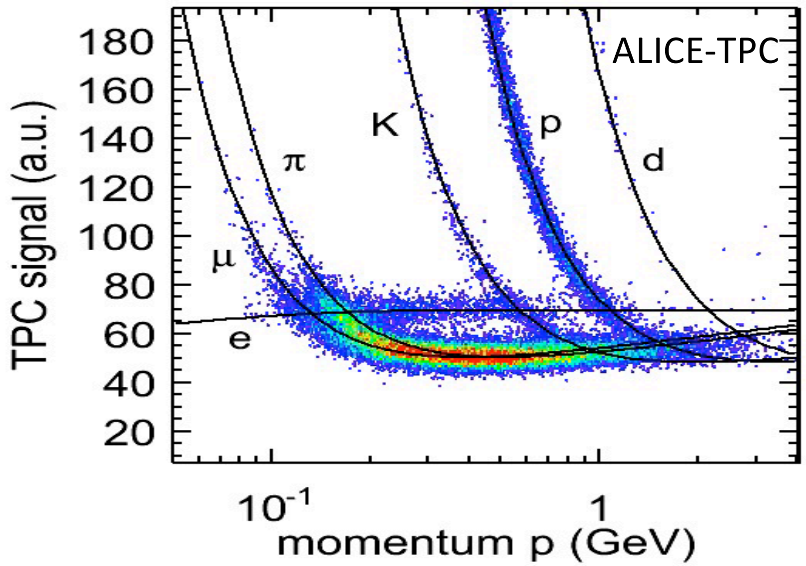
The deposit of energy by a particle crossing a part of the detector provides precious information on its nature thanks to Bethe-Block formula:

$$-\left\langle \frac{dE}{dx} \right\rangle = K z^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2 m_e c^2 \beta^2 \gamma^2 T_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

Z, T_{max} (M), β, γ depend on the incident particle

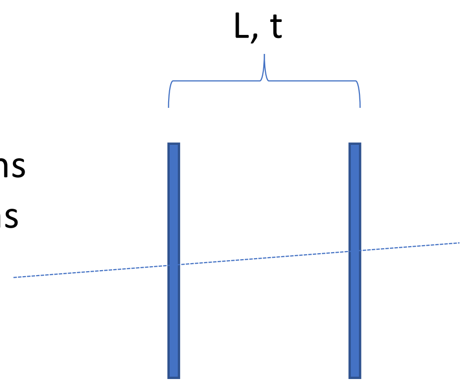
A resolution better than 5% on <dE/dx> measurement is needed to separate pions from kaons





Standard PID techniques

Time of Flight is an important technique to identify particles



$$m_0 = p\sqrt{\frac{c^2 t^2}{L^2} - 1}$$

t: time of flight between two positions
L: distance between the two positions

$$\frac{dm}{m} = \frac{dp}{p} + \gamma^2\left(\frac{dt}{t} + \frac{dL}{L}\right)$$

Excellent time resolution can discriminate particles:

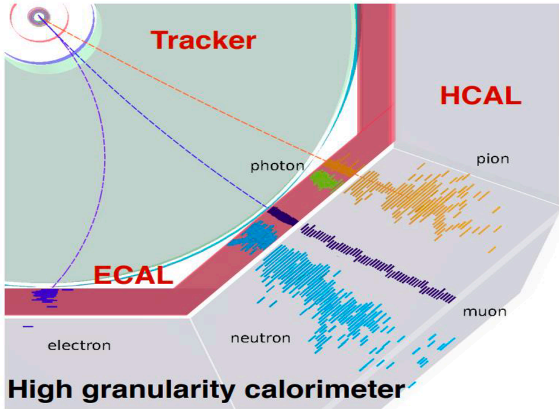
$$\sigma_t \approx \frac{Lc}{2p^2}\left(m_1^2 - m_2^2\right)$$

For a given time resolution, the discrimination power is more efficient for low P particles and for detectors far a part.

A resolution of a few hundreds ps can separate pions from kaons of a few GeV on a distance of 1 m

PFA

Particle Flow Algorithm is a way of reconstruction events produced in particles collisions to study them. It is based on separating the particles produced in each event and then measure their energy/momentum in the most adequate sub-detector.



In this way:
Charged particles are measured in the tracker
γ and electrons are measured in the ECAL
Neutral hadrons in the HCAL

The aim is to obtain the best Jet Energy Resolution (JET)
which is one of the the most relevant variable in the study of Higgs-Factories
and future High-Energy colliders where bosons such as H, Z and W are produced abundantly.

E_{jet} =	$E_{charged}$ +	E_{γ} +	E_{h0}
fraction	65%	26%	9%

Charged tracks resolution	$\Delta p/p \sim$ few10^{-5}
Photon(s) energy resolution	$\Delta E/E \sim 12\% / \sqrt{E}$
Neutral hadrons energy resolution	$\Delta E/E \sim 45\% / \sqrt{E}$

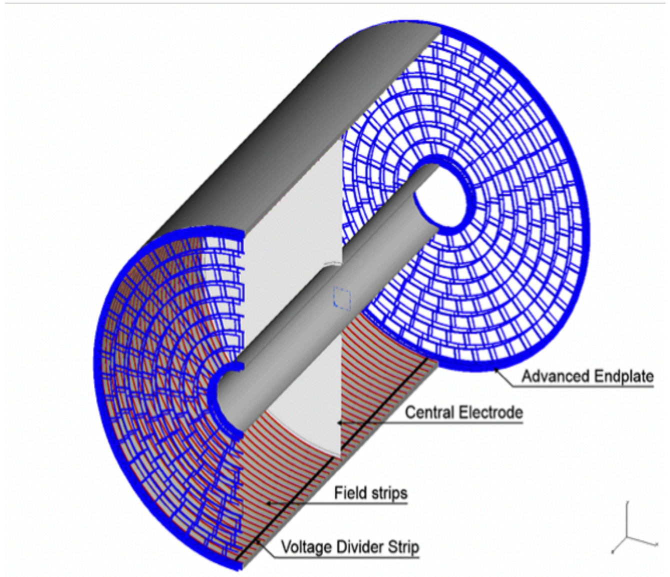
PFA detectors need to have excellent granularity in particular the calorimeters→
precision & shape → PID
PFA detectors equipped with timing provide excellent PID tools

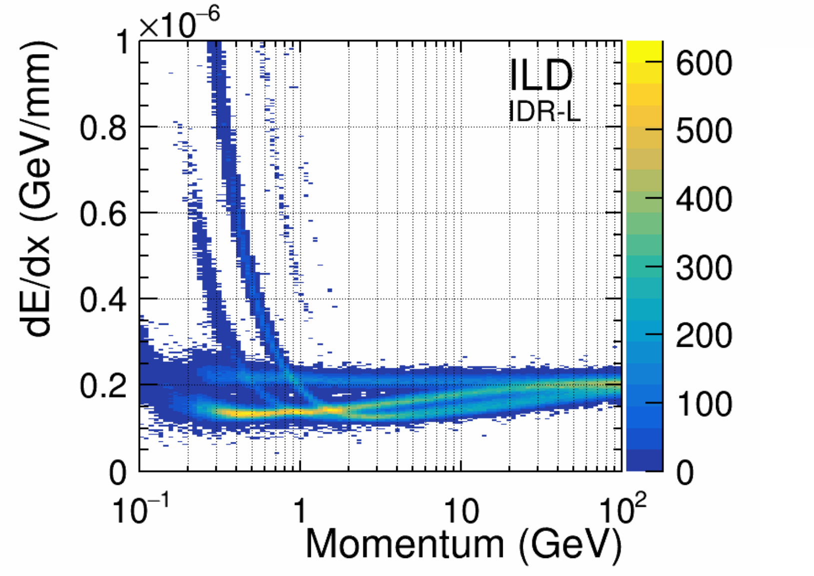
TPC

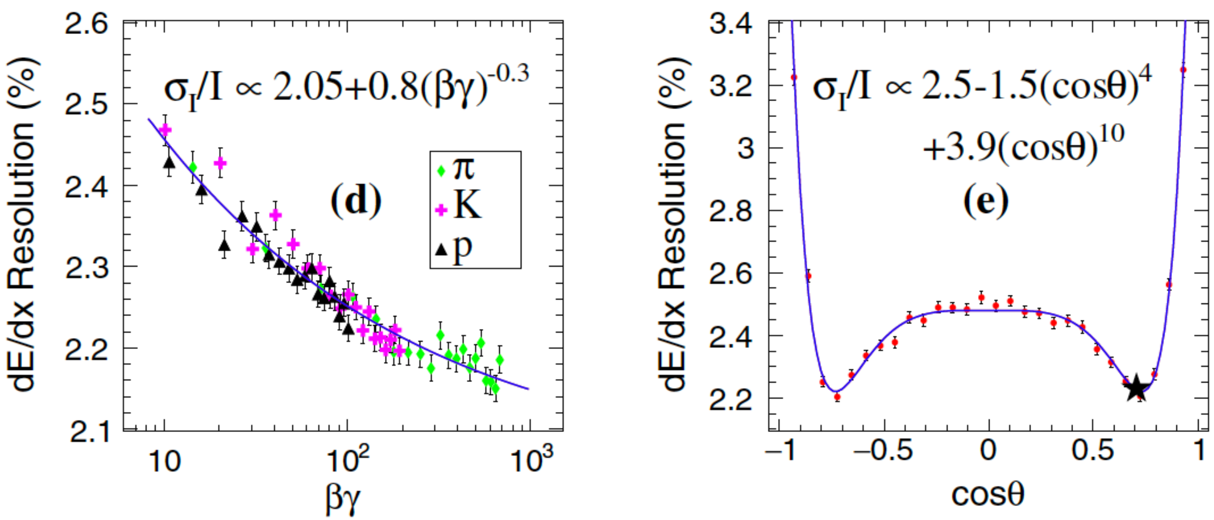
In PID-based detectors such as ILC and CEPC, the TPC will be equipped with MPGD (GEM or MicroMegas) with pickup pads of a few mm, providing an excellent spatial position and more than 200 measurement point/tra k

dE/dX resolution better than 5% is expected in the case of ILD.

For CEPC a resolution better than 2.5% for $\beta\gamma>10$ (up to 2-4 GeV)



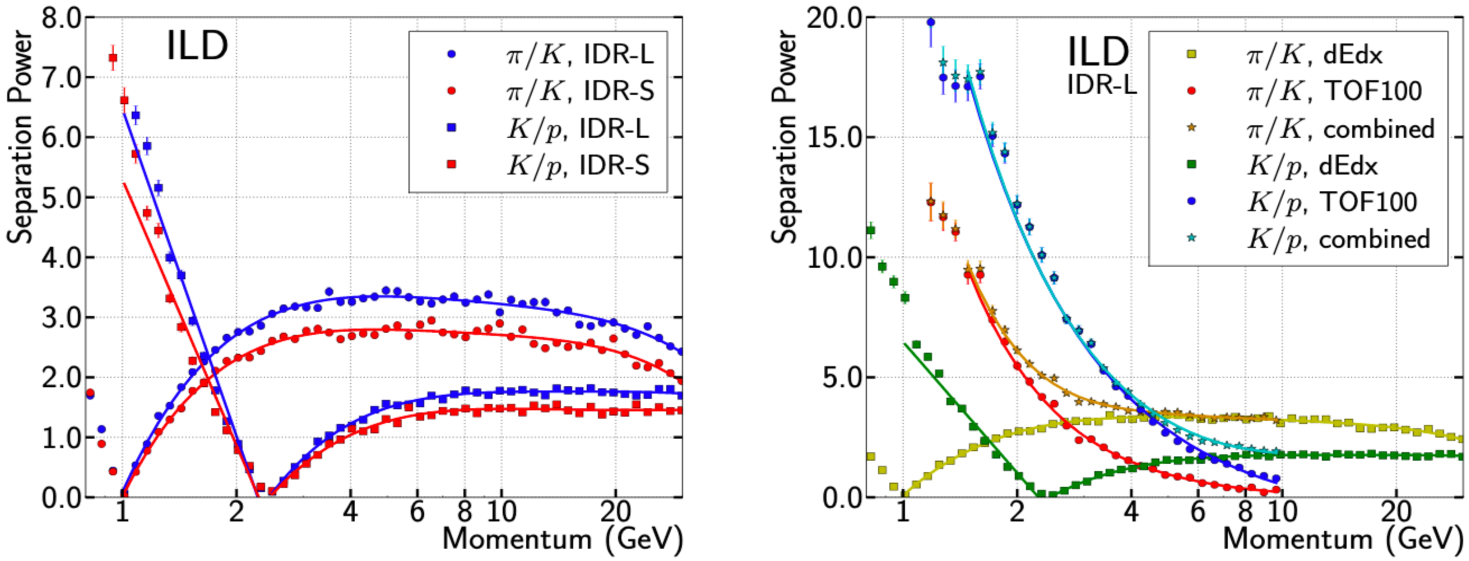




F. An et al., Eur. Phys. J. C (2018) 78:464

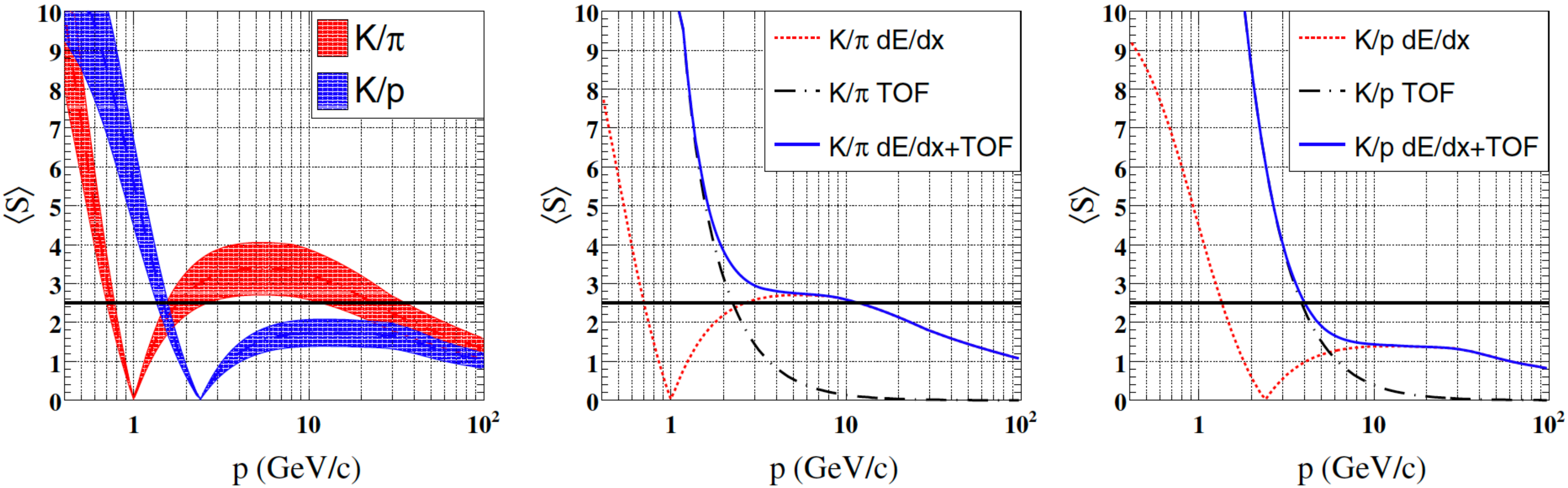
ILD-ILC:

Adding time information from first 10 ECAL hits that are the closest to th extrapolated track and assuming a time resolution of each hit of 100 ps, the separation power is greatly enhanced at low momentum.



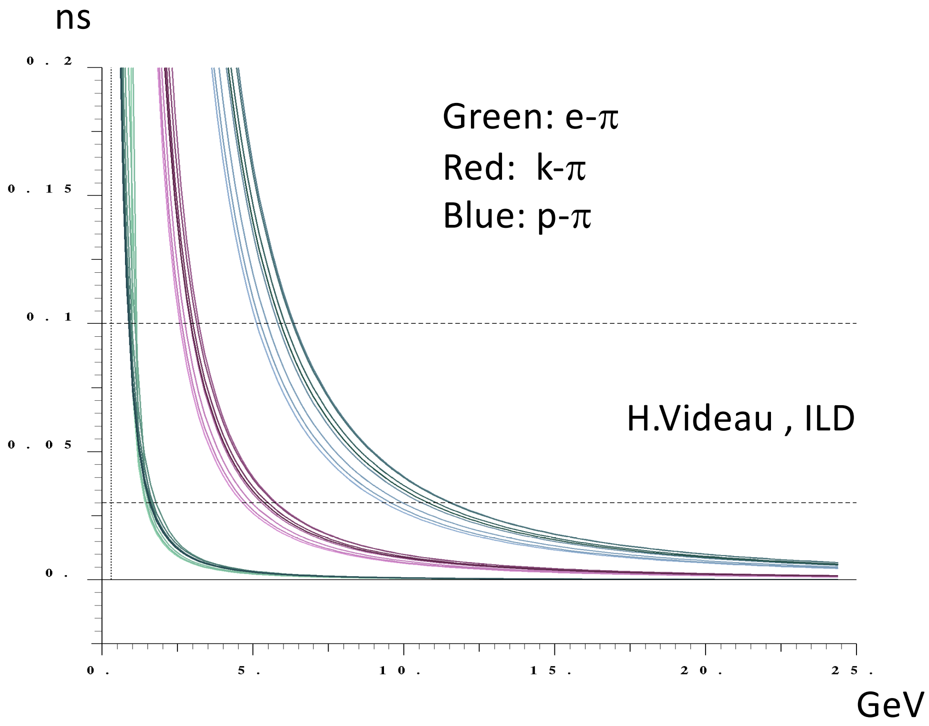
CEPC:

Adding time information from ECAL, assuming a time resolution of each hit of 50 ps, the separation power is largely improved at low momenta.
This improvement is from 1.5 σ to 3.2 σ for kaons/protons separation for those produced in
e e → Z –> qq in CEPC@Z pole. This leads to a kaon identification efficiency of 96.% with a purity of 97%



Impact of time resolution

$\delta p_T / p^2_T = 10^{-4}$ GeV^{-1} and $\delta\vartheta = 10^{-3}$ with $p = p_T / \sin\vartheta$:

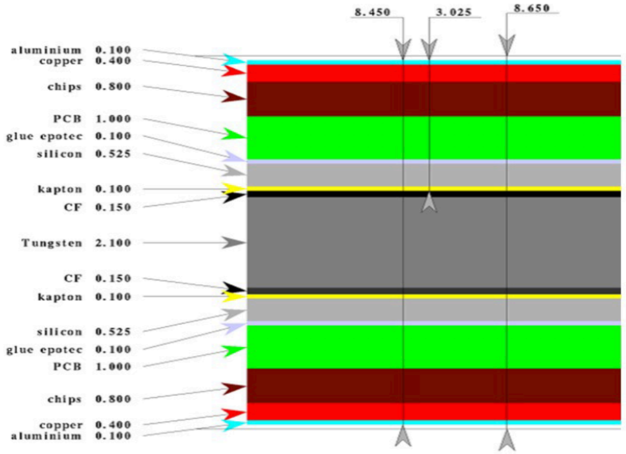


angle	10	20	30	40	50	60	70	80
proton	10.8	11.0	11.6	11.6	10.6	10.0	9.6	9.4
K	5.4	5.4	5.8	5.8	5.2	5.0	4.8	4.6
e	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.4

Difference in time of flight between electron, K or proton and pion for different polar angles versus the momentum (in ns). The horizontal lines correspond to 30 ps difference or 100 ps.

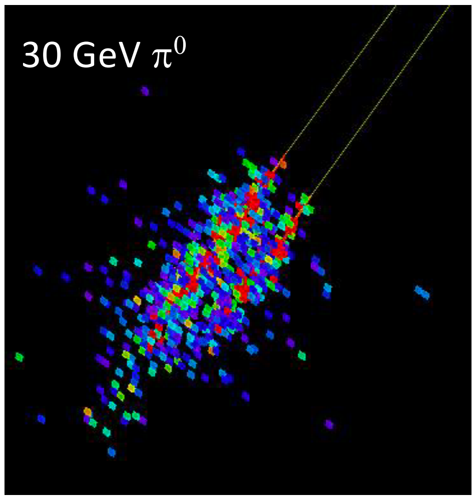
ECAL

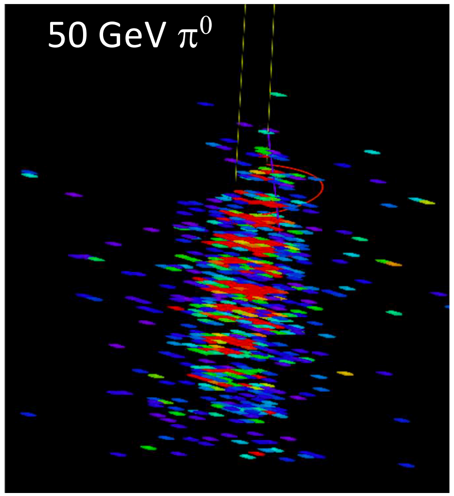
The lateral granularity (pads of 5 mm x 5 mm) but also the longitudinal granularity (< χ_0 /layer) of the PFA-based are big assets to separate EM particles such as electrons, photons and neutral pions from others.

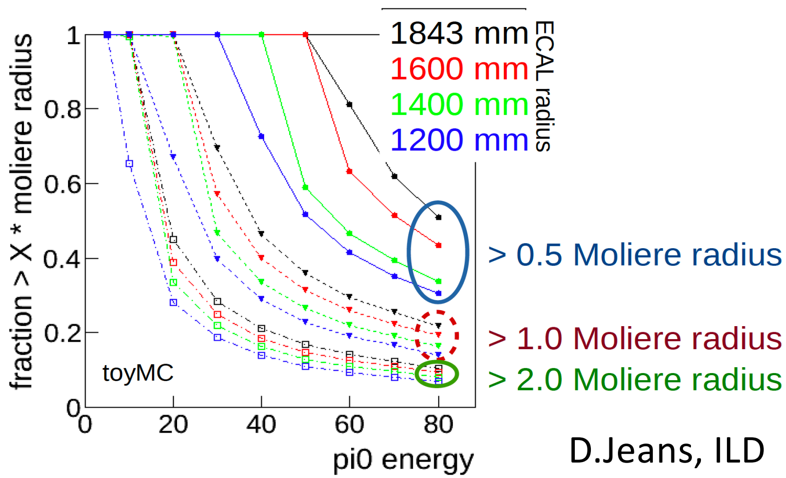


The excellent granularity allows also the separation between these EM particles as well. Separation between photons and neutral pions is possible for energies<30 GeV.

The granularity (in terms of Moliere radius) as well as the ECAL radius determines the capability to separate the two photons but an efficient reconstruction algorithm such **GARLIC** is needed





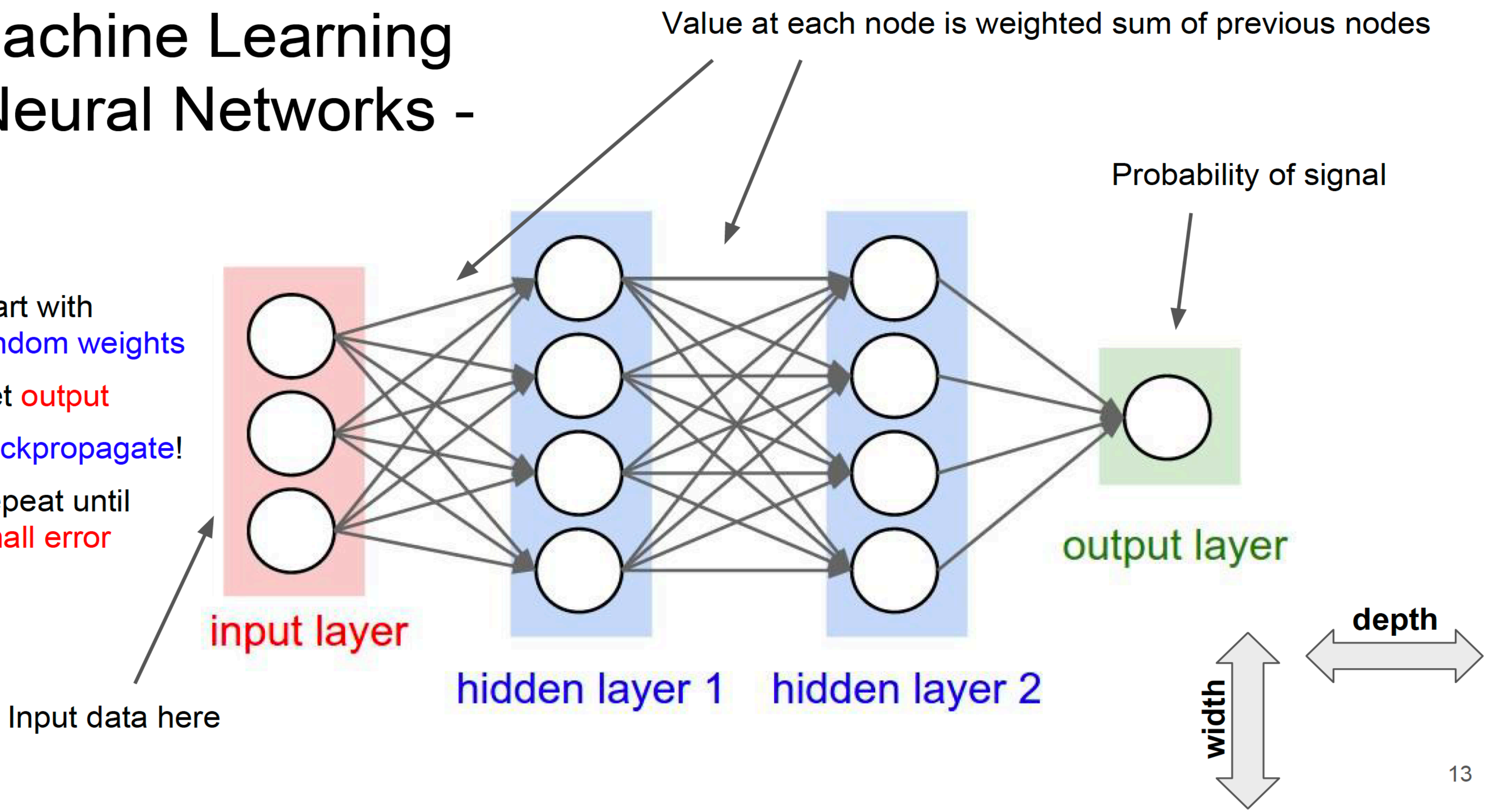


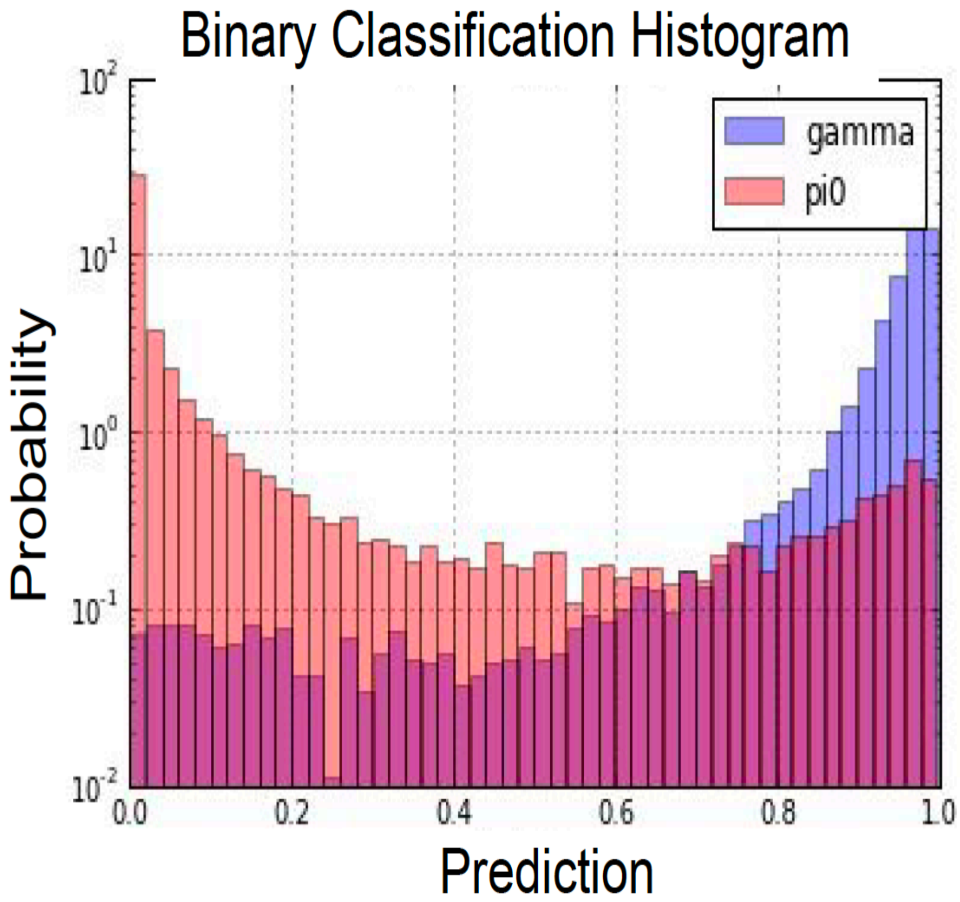
D.Jeans, ILD

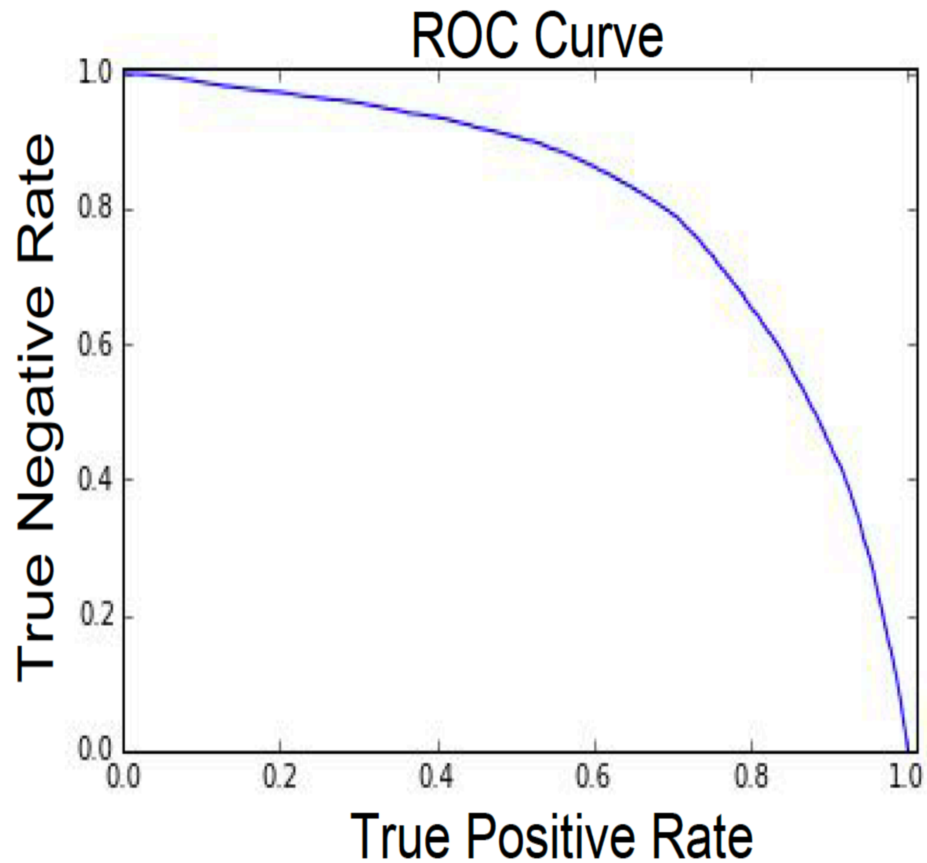
N. Howe, M. Pierini, J-R Vlimant

Machine Learning - Neural Networks -

- Start with random weights
- Get output
- Backpropagate!
- Repeat until small error



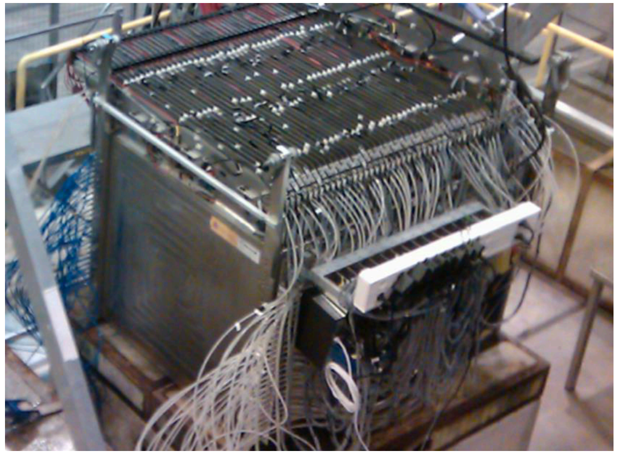


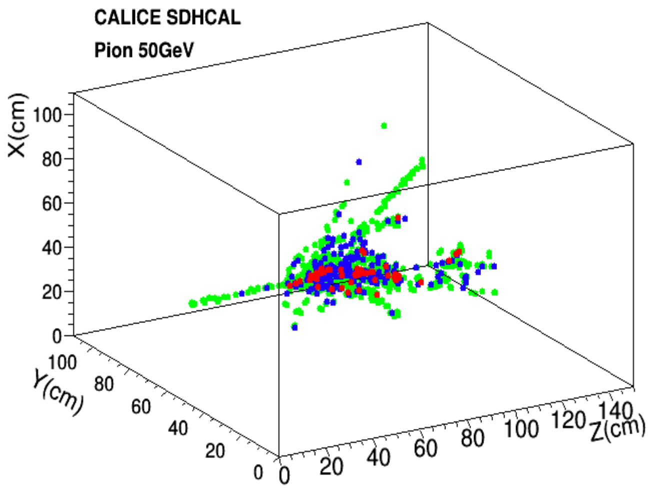


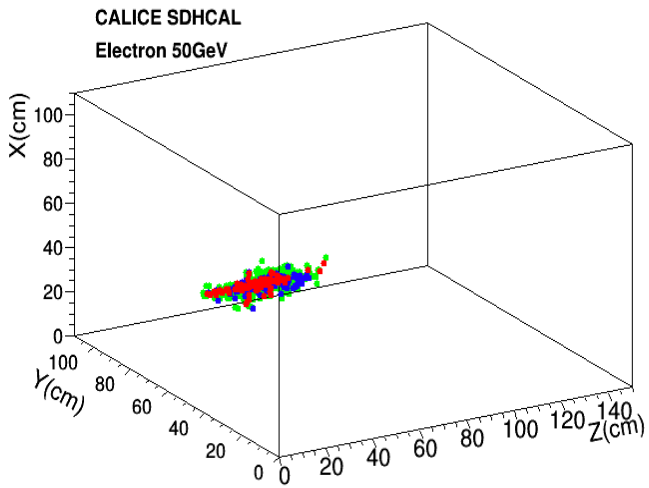
100 GeV particles simulated with LCD-CLIC calorimeter

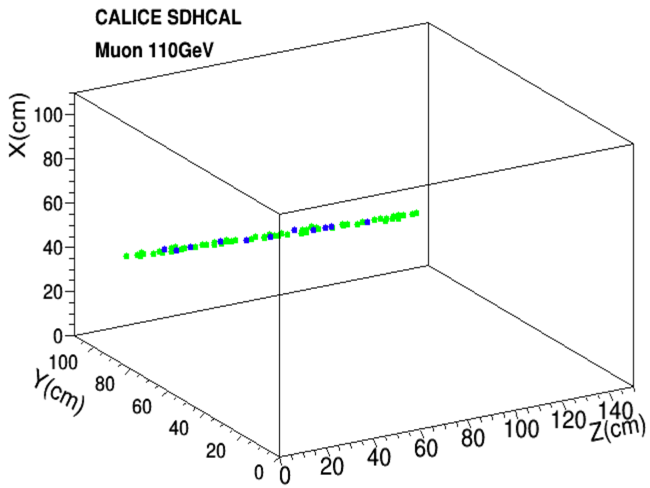
HCAL

SDHCAL, thanks tp its cells of 1 cm x 1cm and its 48 layers of 0.16 λ_I/layer, is a real imaging calorimeter. It provides a picture of the particle interaction and allows their discrimination.





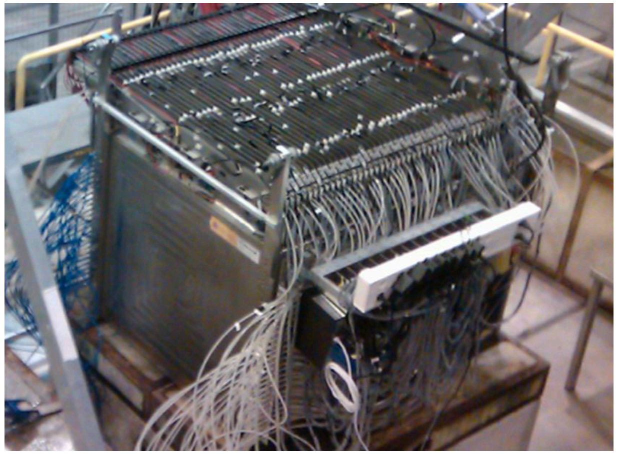


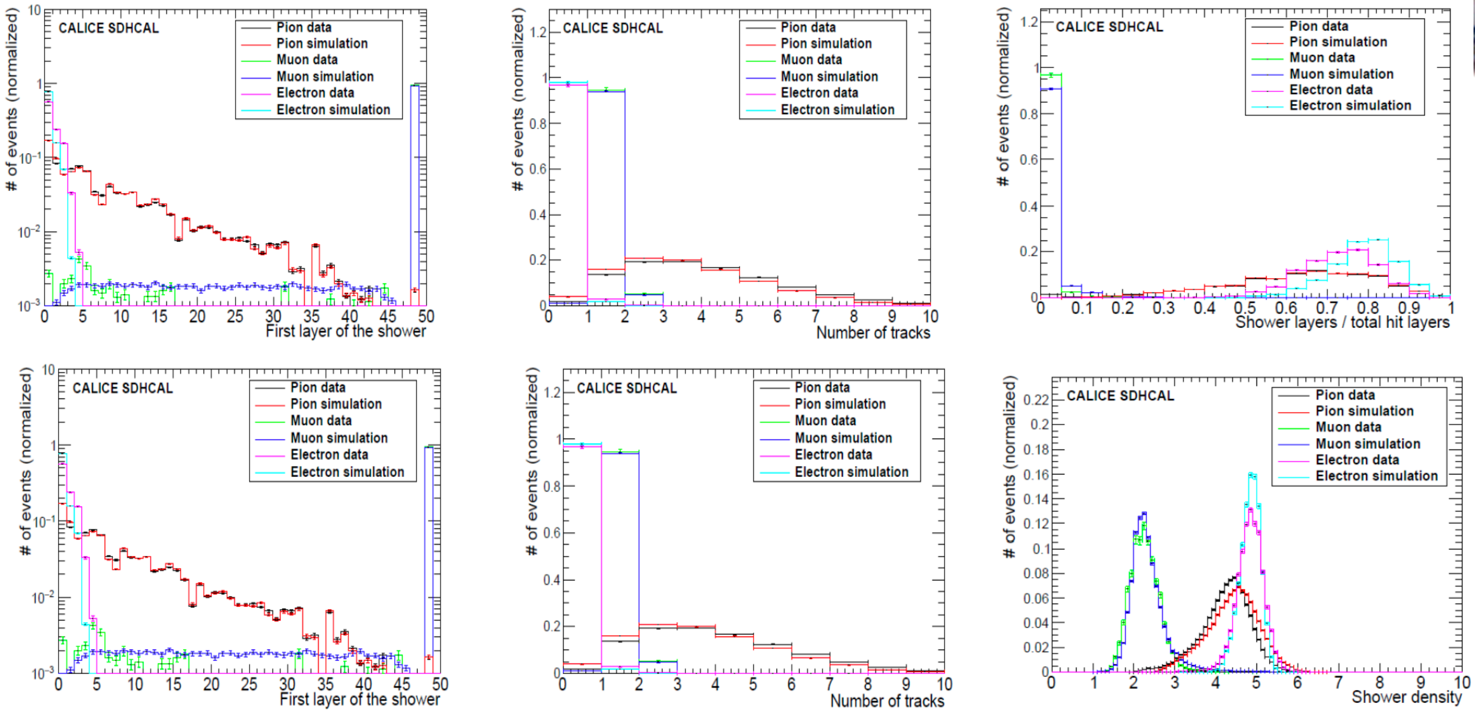


HCAL

SDHCAL, thanks tp its cells of 1 cm x 1cm and its 48 layers of 0.16 λ_I/layer, is a real imaging calorimeter. It provides a picture of the particle interaction and allows their discrimination.

For optimal exploitation of SDHCAL, MVT such as NN, BDT can be used.
MC and data samples were used for training and test sets.





1- First layer of the shower
2- Number of tracks in the shower
3- Ratio of shower layers over total fired layers
4- Shower density
5- Shower radius
6- Maximum shower position

Pion/electron, pion muon are efficiently separated
Using BDT technique.

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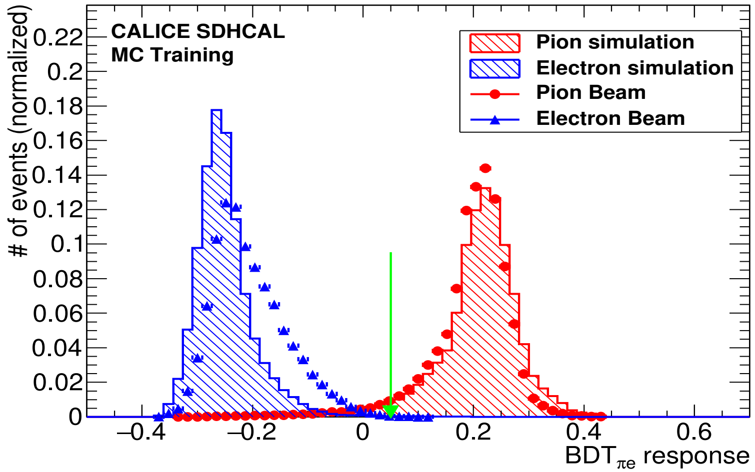
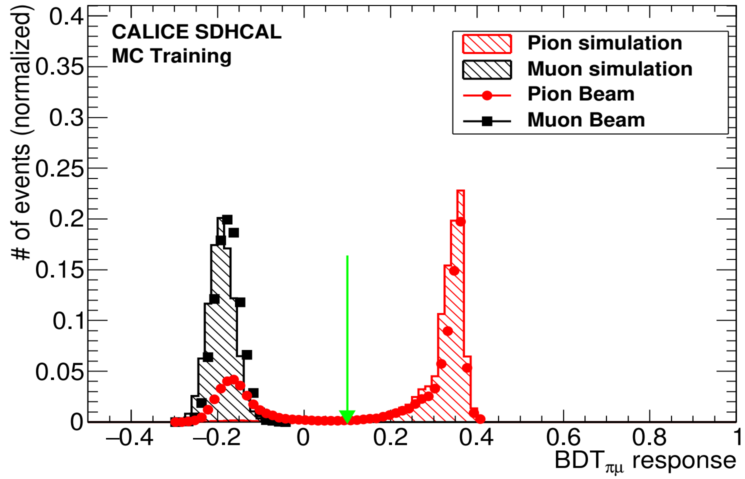
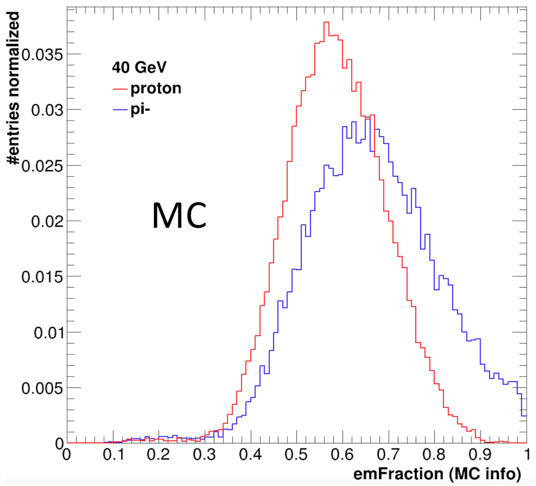
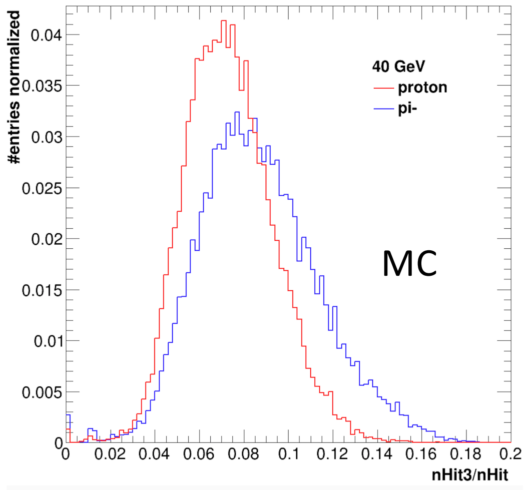
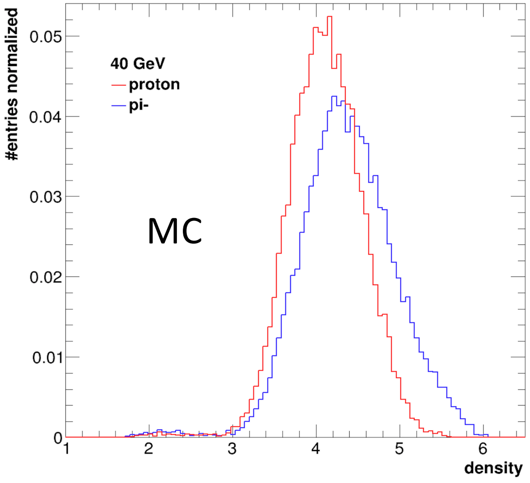


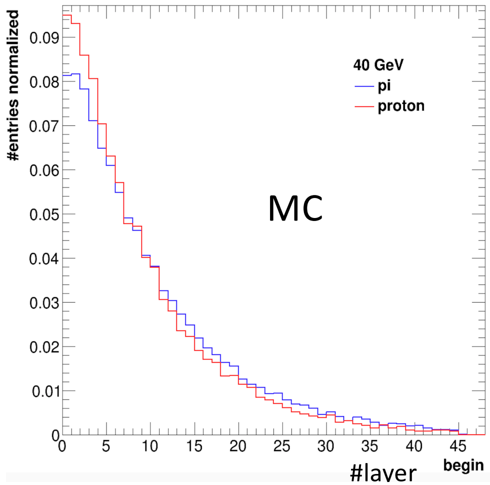


Pion/proton and pion/kaon could be also separated using the difference in nature (mainly the EM component and the interaction length and shape). This separation will be enhanced by using time information



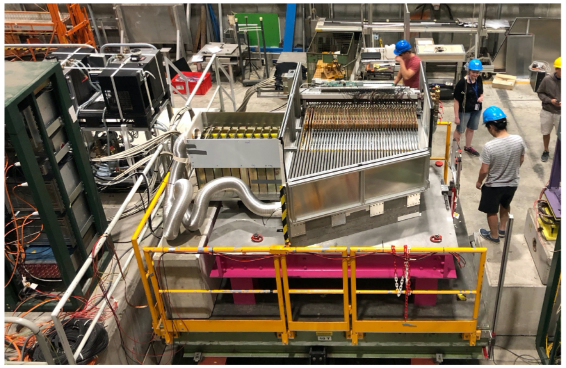






HCAL

Similar study is performed using the AHCAL with 3 cm x 3 cm tiles. The shape of the shower is exploited to separate pions from electrons and muons.



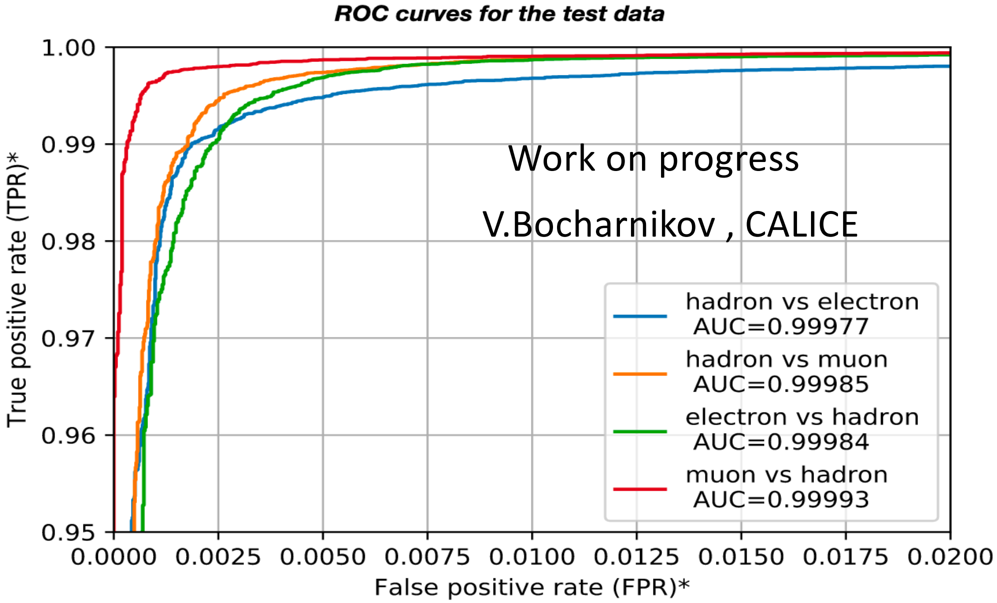
Multi log loss:

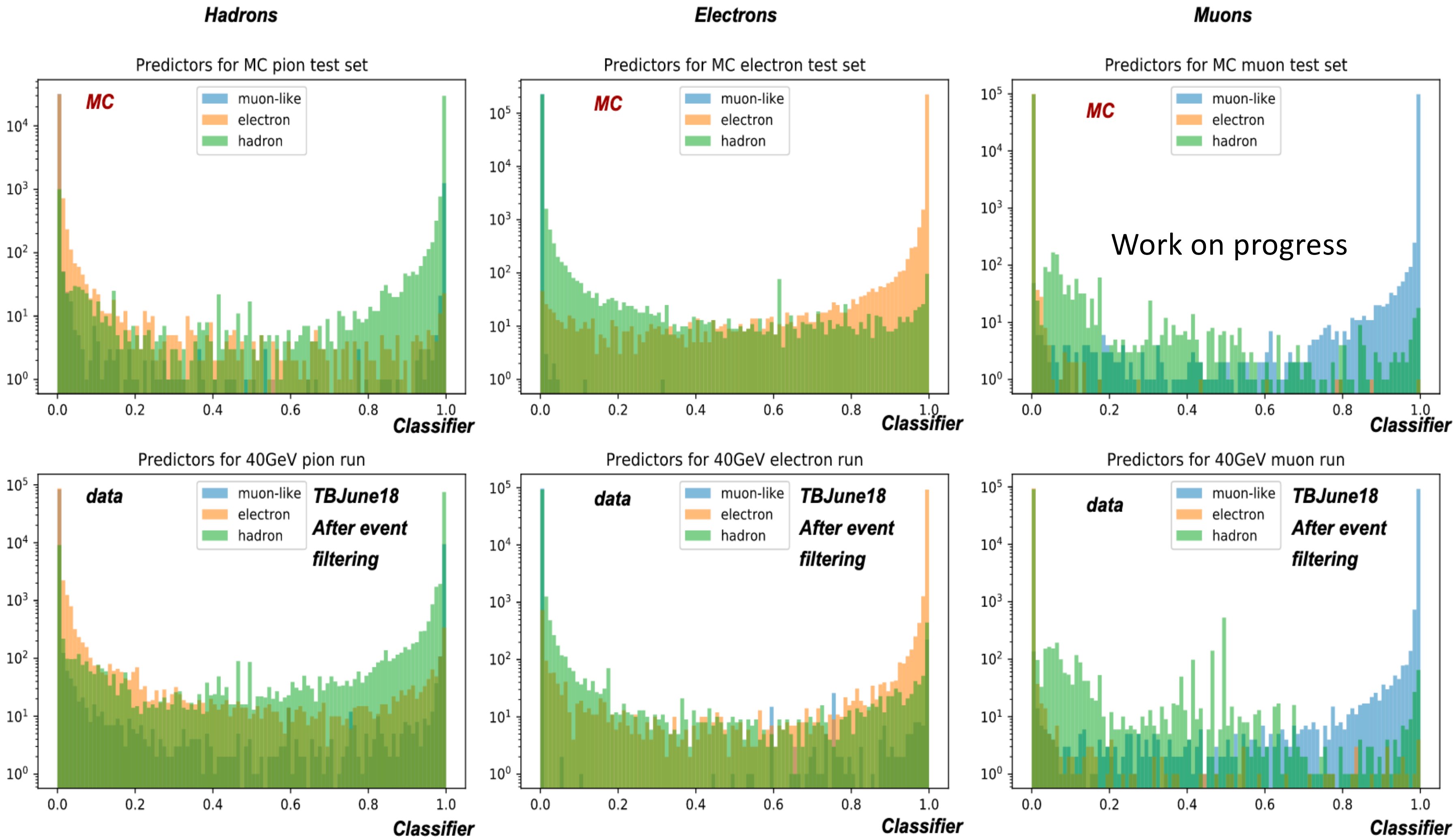
$$L = -\frac{1}{N}\sum_{i}^{N}\sum_{j}^{3} Y_{ij} ln(p_{ij})$$

Where *N* - number of events in the test sample, *3* - number of classes, Y_{ij} is binary variable with the expected labels and p_{ij} is he classification probability output by the classifier for the i-instance and the j-label.

Observables:

- Number of hits
- Shower start
- Event radius
- Center of gravity in z
- Energy fraction in first 22 layers
- Energy fraction in shower center
- Energy fraction in shower core
- Fraction of track hits
- Number of track hits
- Number of layers with hits from last 5
- Mean hit energy after shower start




Hadrons
Electrons
Muons
Predictors for MC pion test set
MC
muon-like
electron
hadron
Classifier
Predictors for MC electron test set
MC
muon-like
electron
hadron
Classifier
Predictors for MC muon test set
MC
muon-like
electron
hadron
Work on progress
Classifier
Predictors for 40GeV pion run
data
muon-like
electron
hadron
TBJune18
After event
filtering
Classifier
Predictors for 40GeV electron run
data
muon-like
electron
hadron
TBJune18
After event
filtering
Classifier
Predictors for 40GeV muon run
data
muon-like
electron
hadron
TBJune18
After event
filtering
Classifier

Conclusion

-PFA-based detectors with their high granularity provide a powerful tool to identify particles by providing a precise description of their interactions

-Use of MVT and ML techniques exploits the PFA-based detectors in optimal way. Increasing development In the near future.

-Adding ToF information to PFA-based detector improves greatly their PID power.