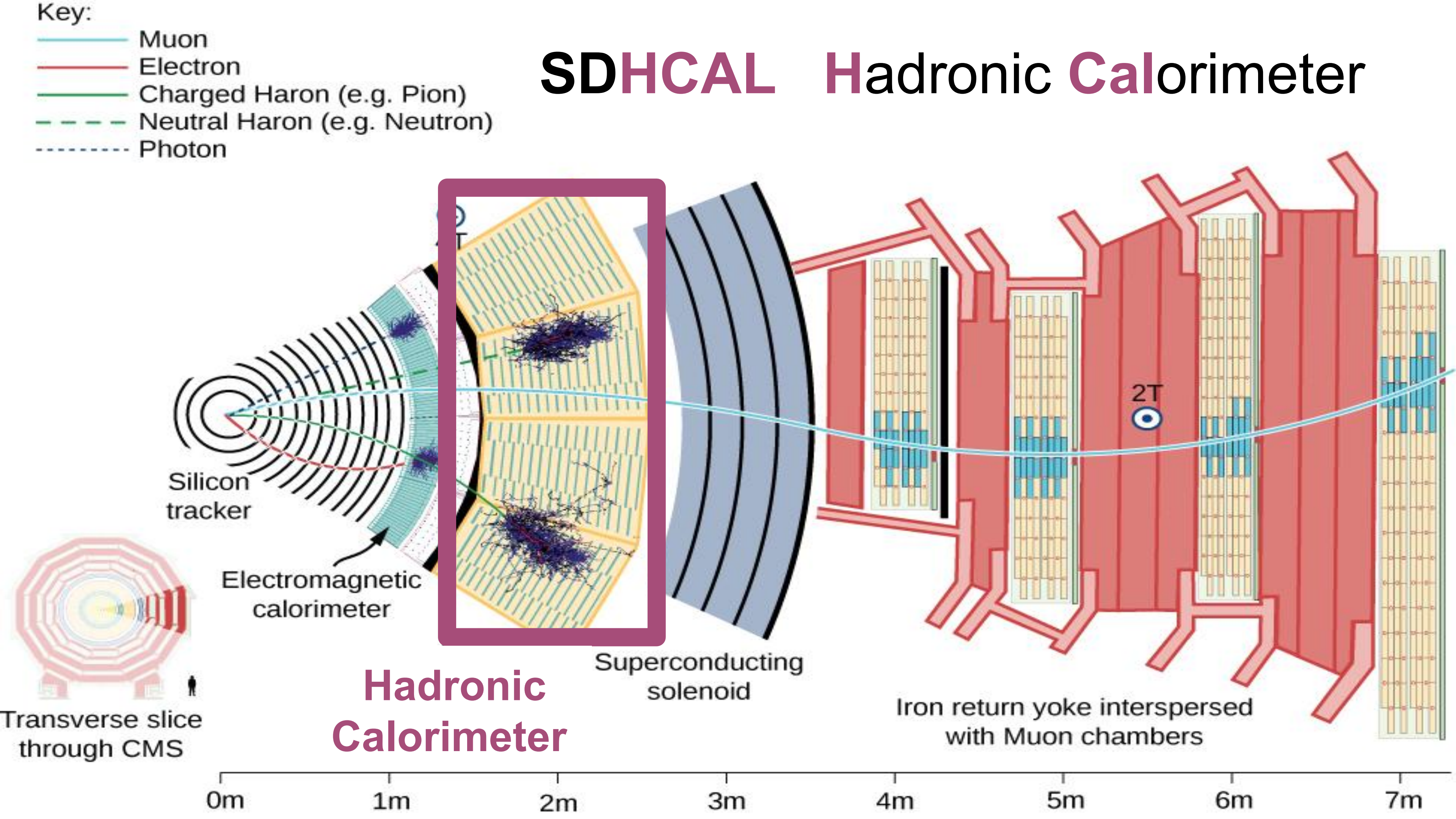
Particle Meeting

Timing - **S**emi **D**igital **H**adronic **Cal**orimeter

T-SDHCAL

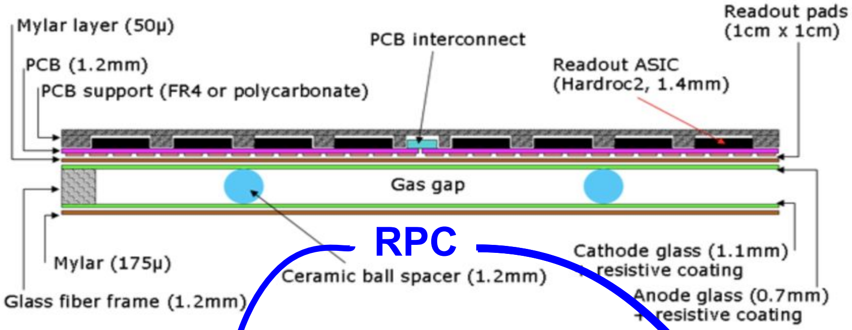
SDHCAL Hadronic Calorimeter



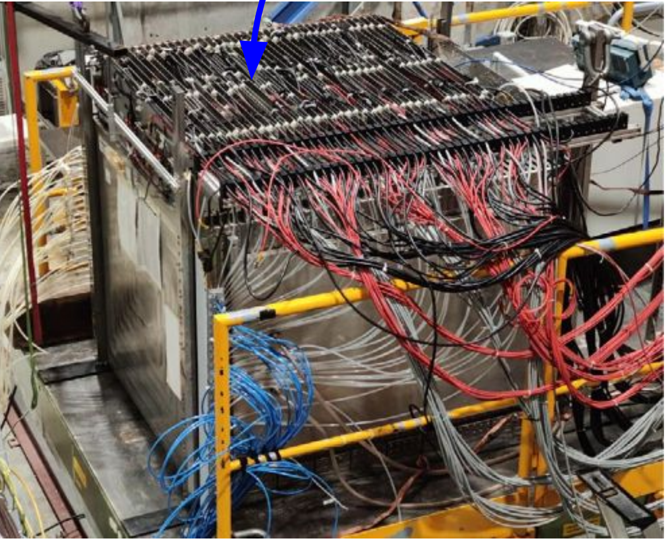
Hadronic Calorimeter

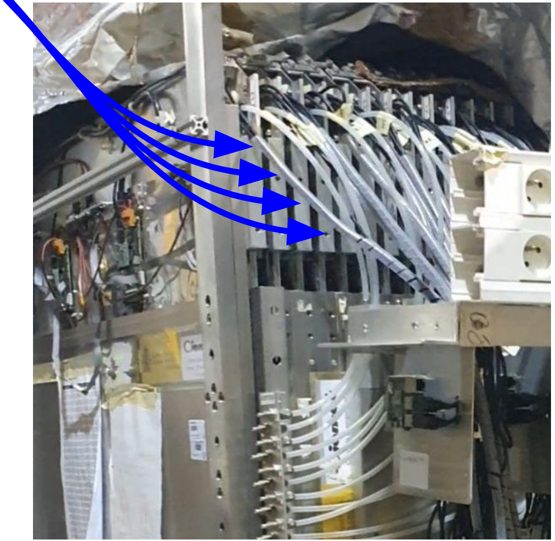
(Timing) - Semi Digital Hadron Calorimeter T-SDHCAL

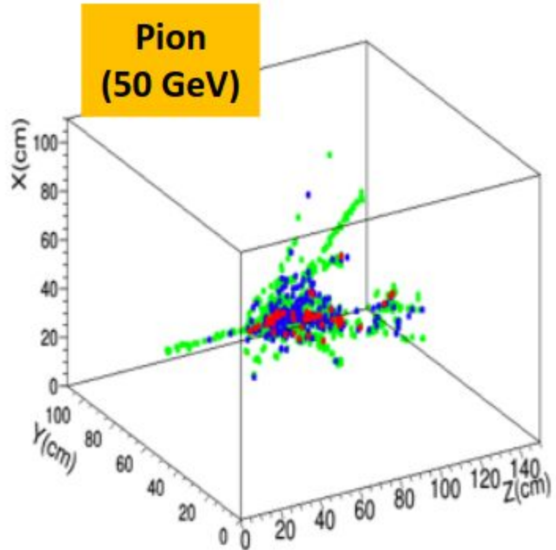
- **Gaseous detector** using **RPC** technology



- 48-50 of layers (~6λ_I); **~1.3m³ prototype**
- **Gas mixture** : TFE (93%), CO2 (5%) and SF6 (2%)
- **1cm x 1cm granularity**; ~450k channels
- **3-threshold readout** with 64-ch HARDROC ASICs
- Designed originally for **ILC** (**I**nternational **L**inear **C**ollider)
- In adaptation for future circular colliders (**FCC**, CPEC)
  - ↳ **Includes time information** thanks to **RPC** -> **MRPC**



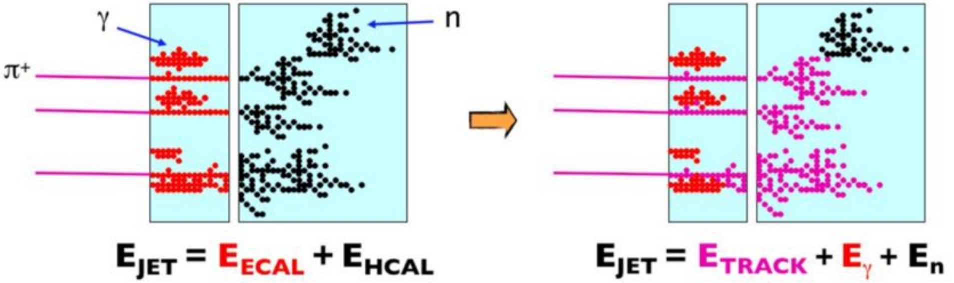




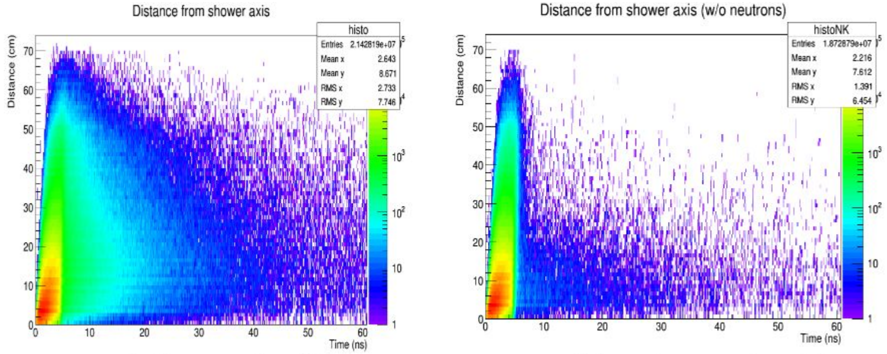
Time information benefits for Particle Flow Algorithms PFA

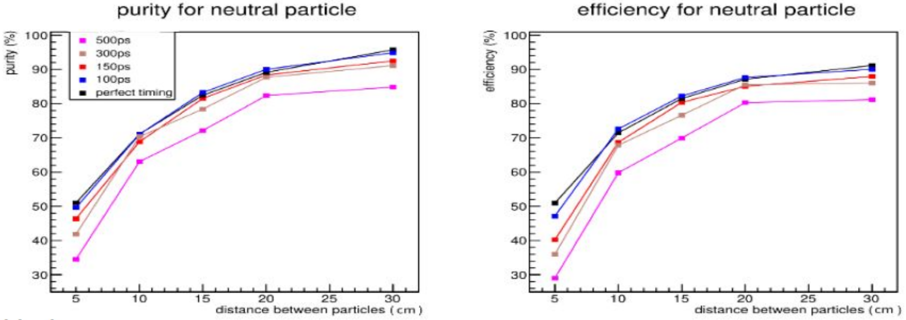
- **PFA** is one of the approaches chosen for future Higgs factories using optimal sub-detector for jet energy estimation
- Timing **at object level** could allow event pile-up mitigation and characterization
- Timing **at shower level** could improve particle identification and object reconstruction
- Timing **at cell level** could facilitate shower reconstruction and energy corrections. leading to better energy reconstruction

➡ Our goal is to achieve **100ps timing resolution**

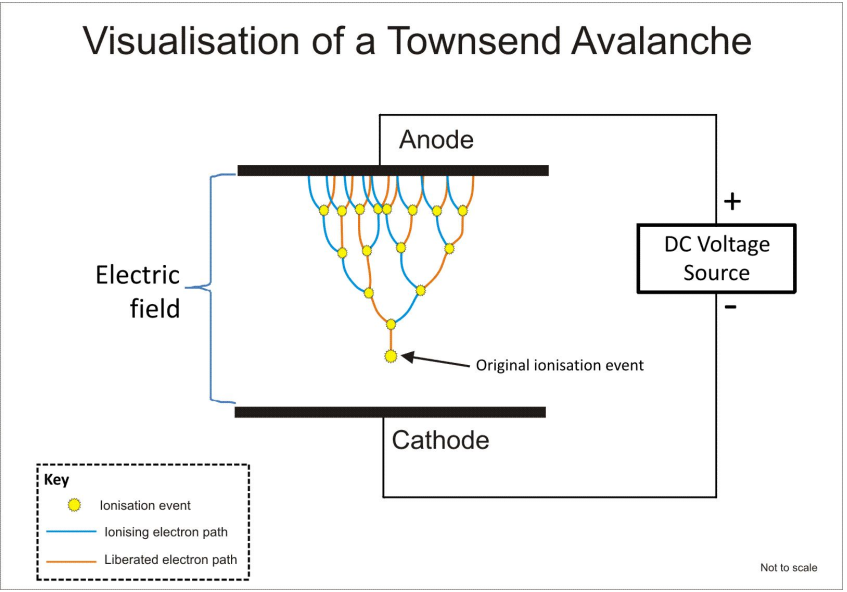


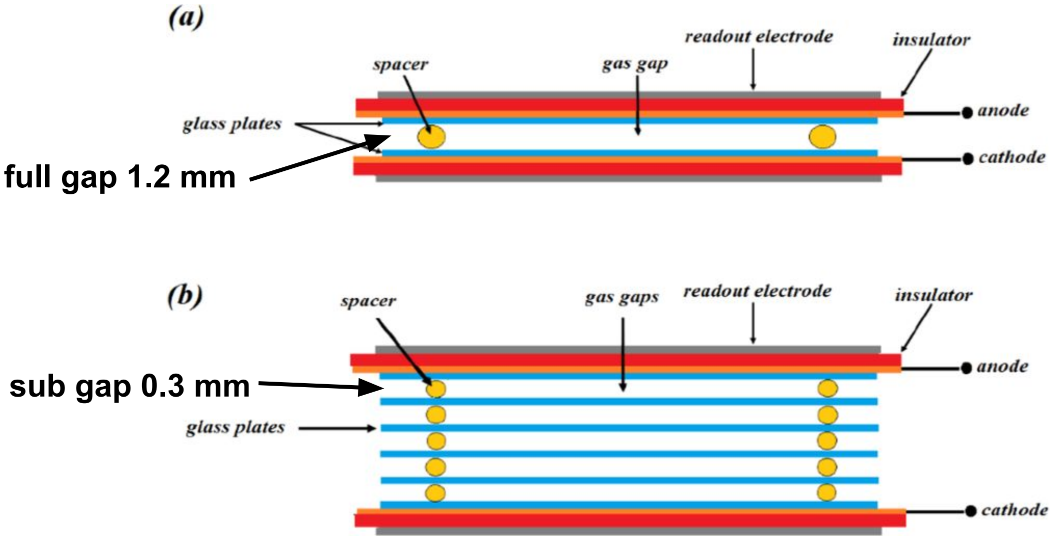
$E_{JET} = E_{ECAL} + E_{HCAL}$ 	$E_{JET} = E_{TRACK} + E_{\gamma} + E_{n}$





RPC and MRPC : Multigap Resistive Plate Chamber
From Physics Principles to Signal Production



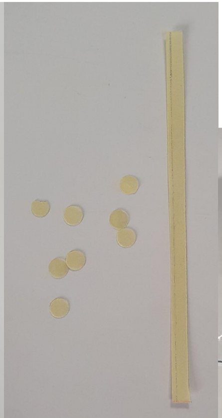


1. Primary **ionisation** -> Creation of e- A+ pairs
2. Electric field -> Avalanche (**Amplification**)
3. Charge displacement -> Current -> **Electric signal**

- Approximately same total gas thickness (NOT SCALED)
- Signal : sum of sub-gaps contributions
- Less dispersion thanks to thinner sub-gaps
  - **Better timing resolution (~100ps)**

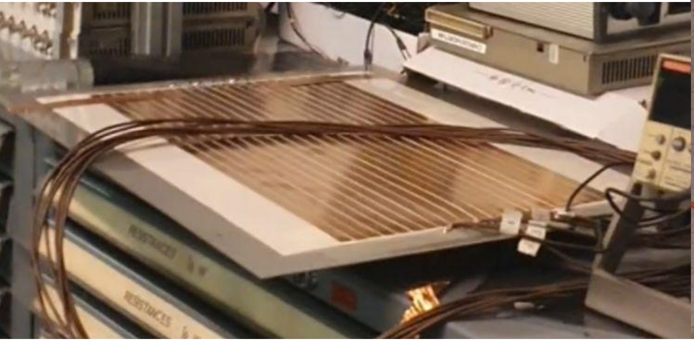
MRPCs prototypes construction at IP2I

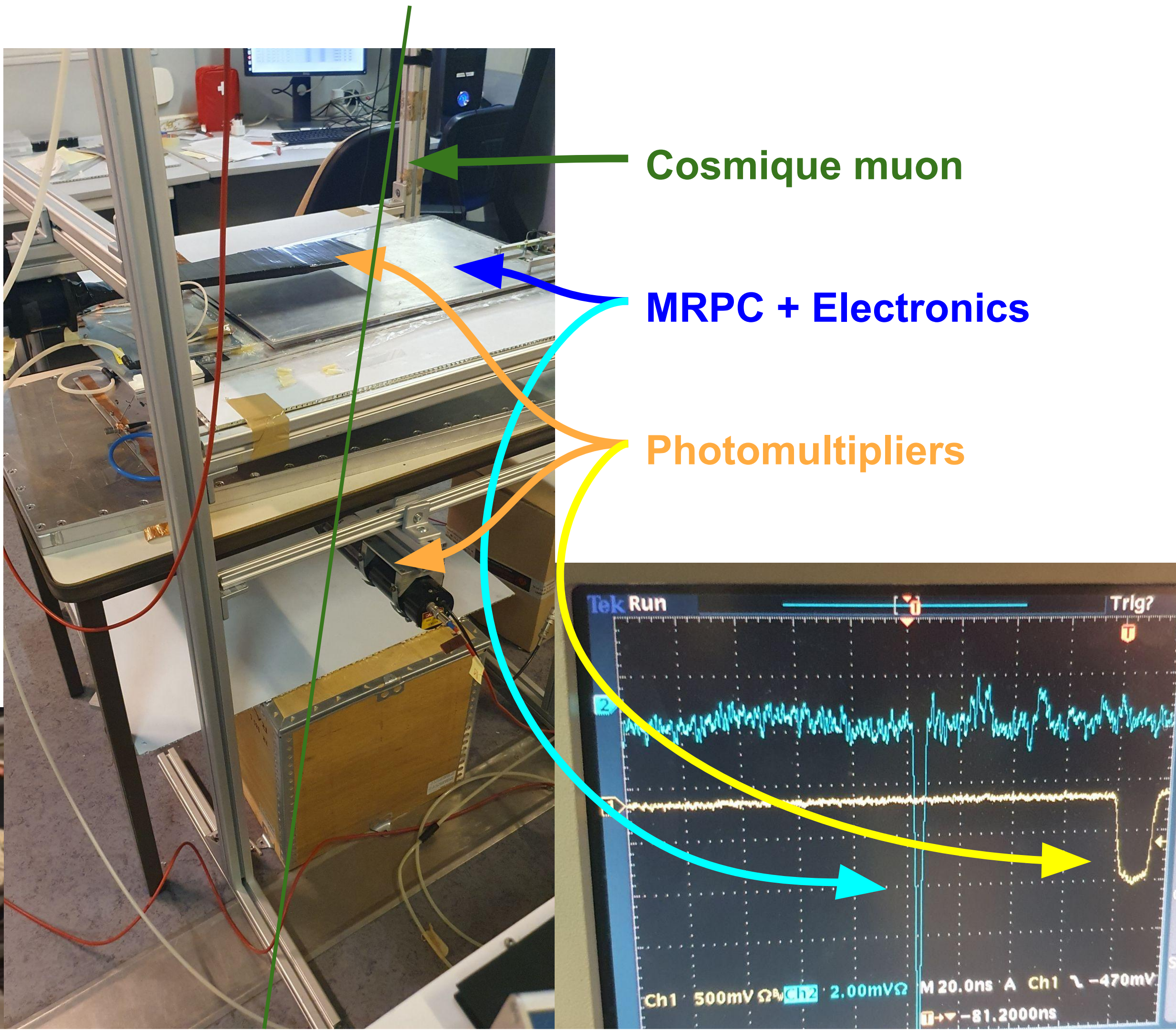
1. Cut of **330µm thick glass plates** (from 1mx1m to 50cmx33cm)
2. Application of **conductive paint** on the external glass plates
3. Production of circular and rectangular **mylar spacers**
4. Placement of spacers in a **tiled pitch pattern** on glass plates
5. Realization of **gas inlets** and **outlets**
6. Cut and placement of **epoxy sticks to support the structure**
7. **Sealing** of the detector using **silicone**
8. Connection to **high voltage** by copper strip



Tests of the **MRPCs**

- **Source**
  - Cosmic muons
    - ► Cheap but slow
    - ► Not controlled
- **Triggers**
  - PM in coïncidence
    - ► Slow signal
- Electronic used :
  - PCB with copper strips
  - Oscilloscope





Cosmique muon

MRPC + Electronics

Photomultipliers

Characterization of the **MRPCs** - Efficacy and Noise plots

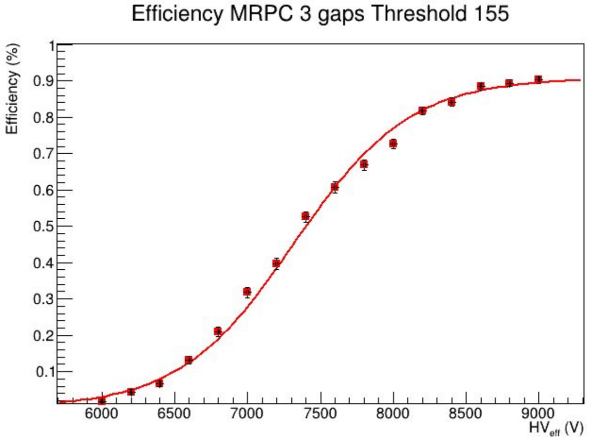
Tension Scan :

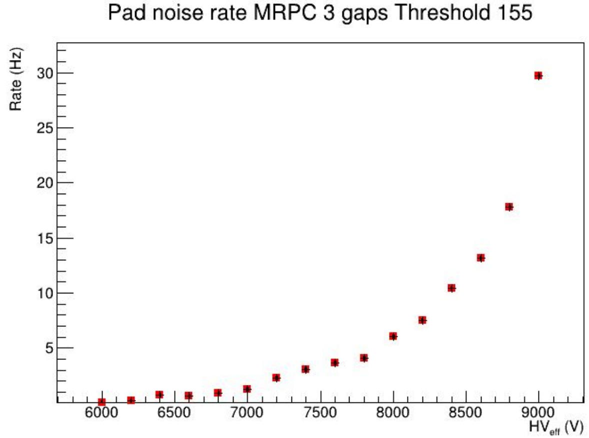
- At **low tension**, the electric field is too low for the primary ionizations to start avalanches, **no signal detected**
- At **medium tension**, the probability of primary ionizations starting avalanches is increasing rapidly with the tension, **transition regime**
- At **high tension**, all of primary ionizations start avalanches, **efficiency plateau**

100% efficiency is never achieved because the probability of no primary ionizations is non zero.

Allows us to find the **Working Point** of the **MRPCs**:
$HV_{WP} = HV_{95\%} + 120V$, where $HV_{95\%}$ corresponds to the HV at which the efficiency reaches 95% of its maximum

Working Point at **lower tension** means **less noise**


Efficiency MRPC 3 gaps Threshold 155

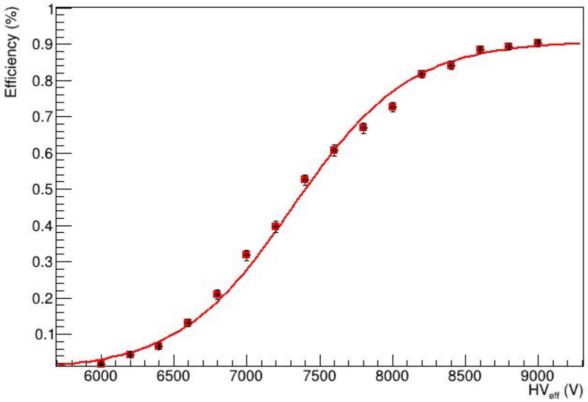

Pad noise rate MRPC 3 gaps Threshold 155

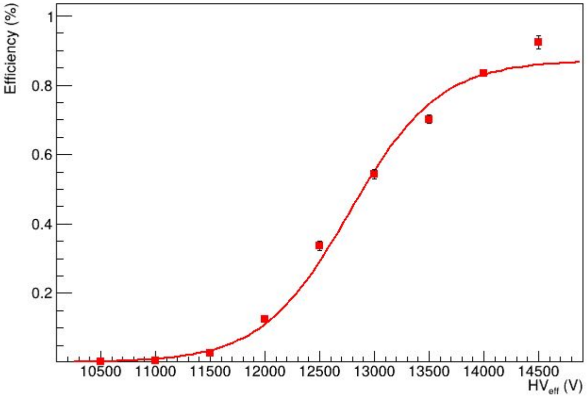
Characterization of the **MRPCs** - Number of gaps study

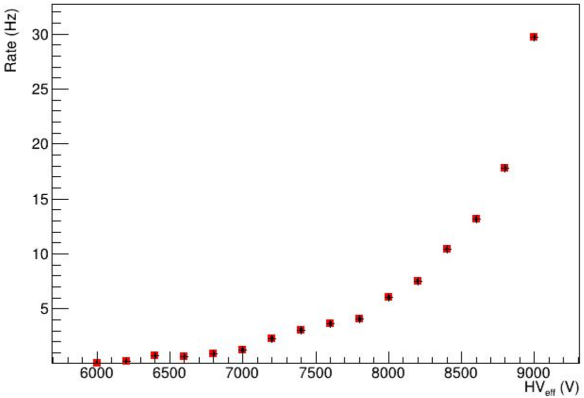
More gaps :

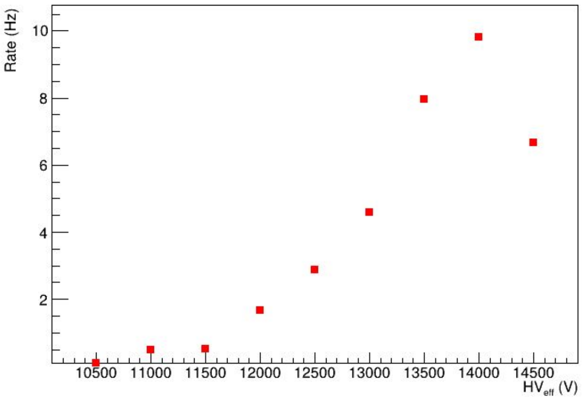
- ❖ **Pros**
  - ➢ Better efficiency for ~similar noise
  - ➢ Better timing resolution
- ❖ **Cons**
  - ➢ Harder to build
  - ➢ More expensive
  - ➢ Thicker cassette

The goal of the study is to determine **how many gaps** are needed **to achieve** the time resolution we aim at : **100ps**

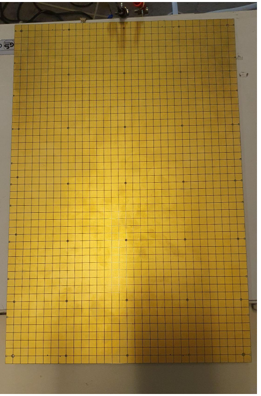

Efficiency MRPC 3 gaps Threshold 155


Efficiency 5 gaps Avril 2025

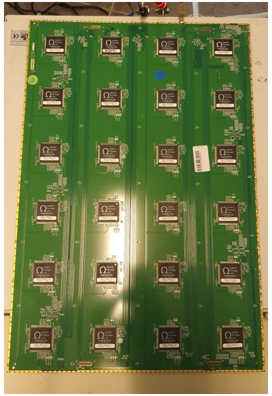

Pad noise rate MRPC 3 gaps Threshold 155


Pad noise rate 5 gaps Avril 2025

Characterization of the **MRPCs** - Noise study

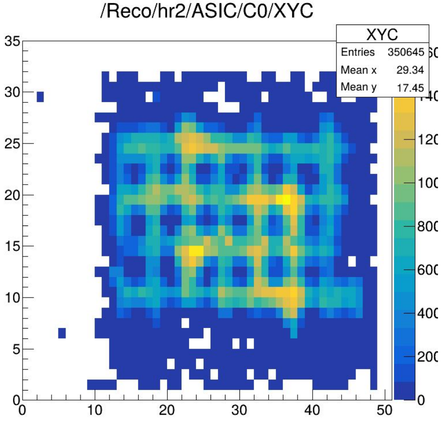


1cm² pads

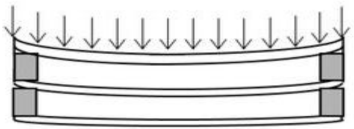


ASICS

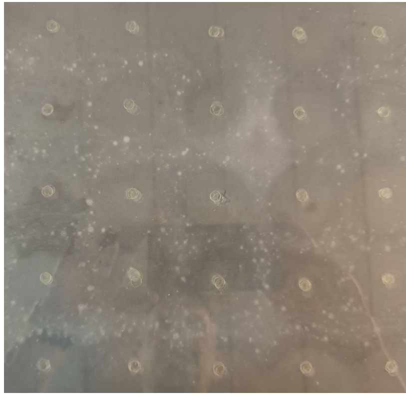
Signal recorded by 24 HARDROC ASICs 64 channels
(1 channel = 1 pad 1cm²)



5cm pitch : **Noise structure**



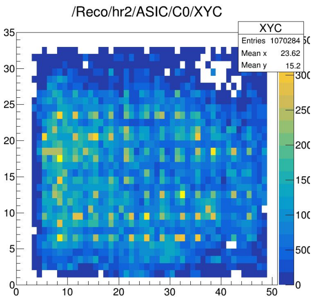
Glass deflection



5cm pitch
Visible HF deposits

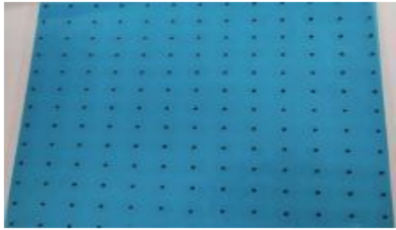
Spacers too far apart ► Glass deflection ► Higher EM field ► Discharges ► Creation of **hydrofluoric** acid (HF) ► **OUCH**

Quick solution :
Reduce 5cm pitch to 3cm pitch
-> **Noise factor reduction of 10**
BUT
-> Time consuming
-> More deadzone



3cm pitch : **No noise structure**

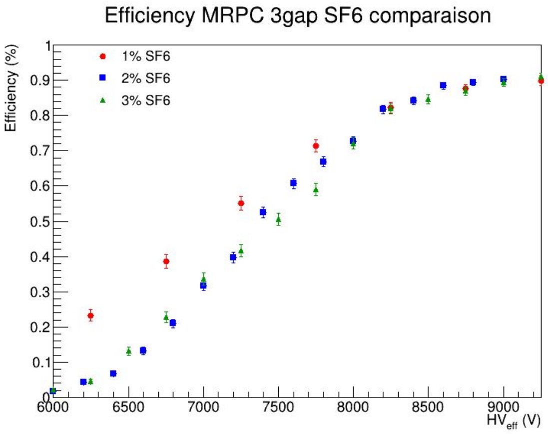
Long term solution :
Prepared sheet of finer spacers pitch
-> Time efficient
-> Less deadzone

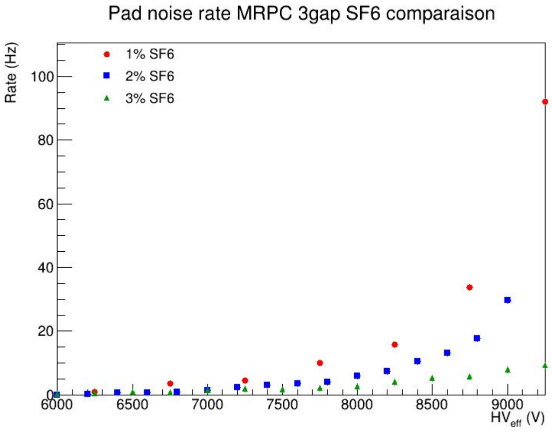


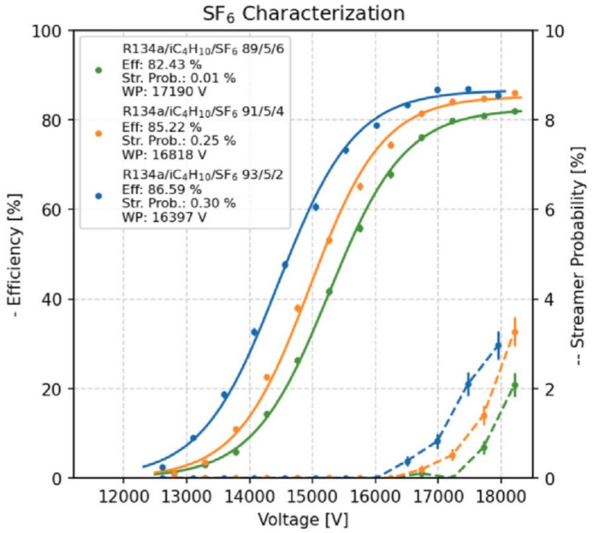
1.6cm pitch, 1.23% dead zone

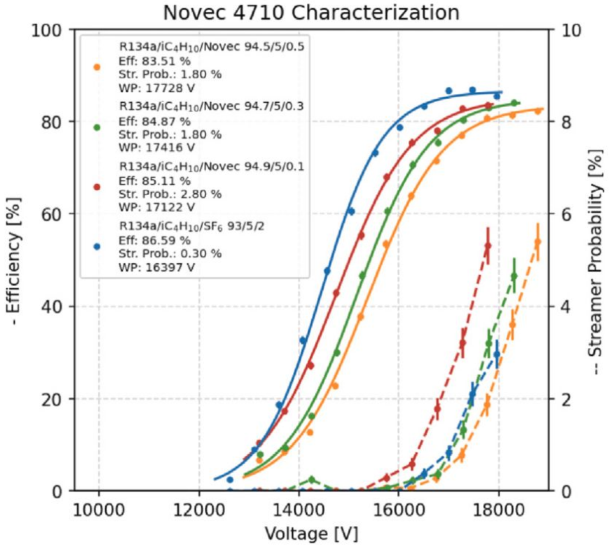
Characterization of the **MRPCs** - Gas mixture study

TFE (Fluor gas)	GWP = ~1400	Low Ionization Potential (**93%**)
↳ HFO-1234z	GWP = 7	Low Ionization Potential
Isobutane	GWP = 3	Photon Quencher (**5%**)
SF6 (Fluor gas)	GWP = 22800	Electron Quencher (**2%**)
↳ NOVEC 4710	GWP = ~ 2000	Electron Quencher


Efficiency MRPC 3gap SF6 comparaison


Pad noise rate MRPC 3gap SF6 comparaison


SF_6 Characterization


Novec 4710 Characterization

M. Verzeroli et al, NIMA 1078 (2025) 170591

Software - Energy Reconstruction

Linear dependence between **energy** and **number of hits** at low energies, then **saturation**

3 Thresholds = 2 bit (Semi-Digital)
Used to **correct saturation**

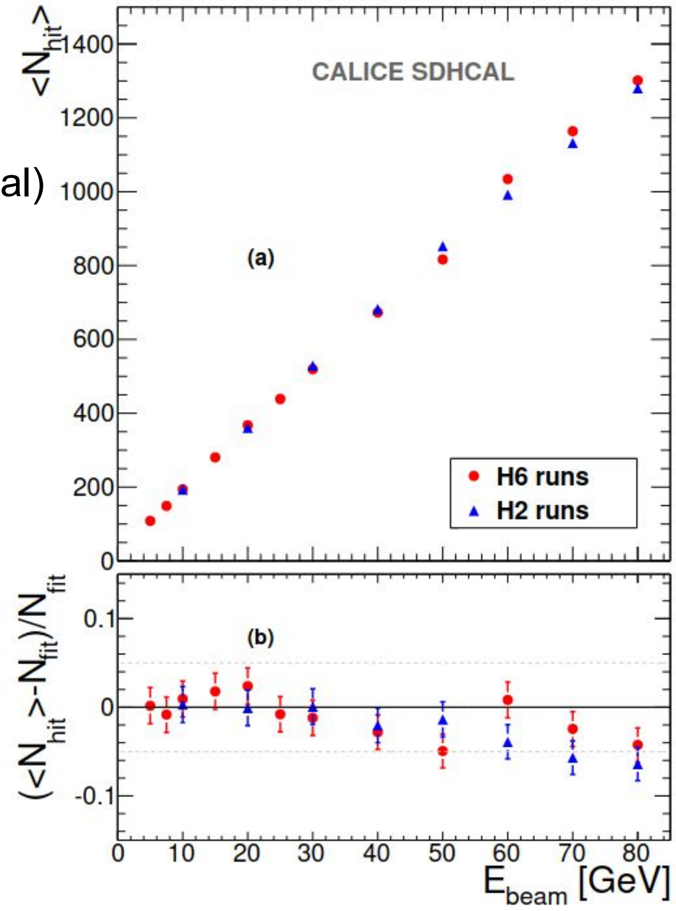
Classical formula

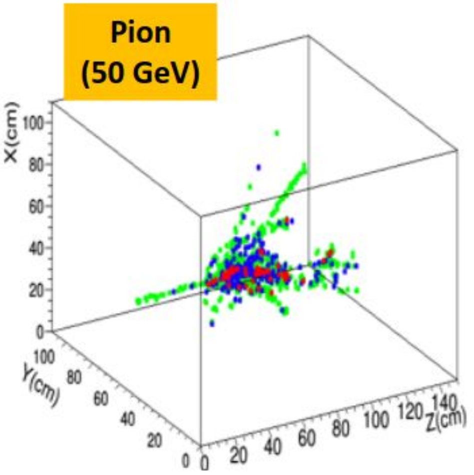
$$E_{reco} = \alpha_1 N_1 + \alpha_2 N_2 + \alpha_3 N_3$$

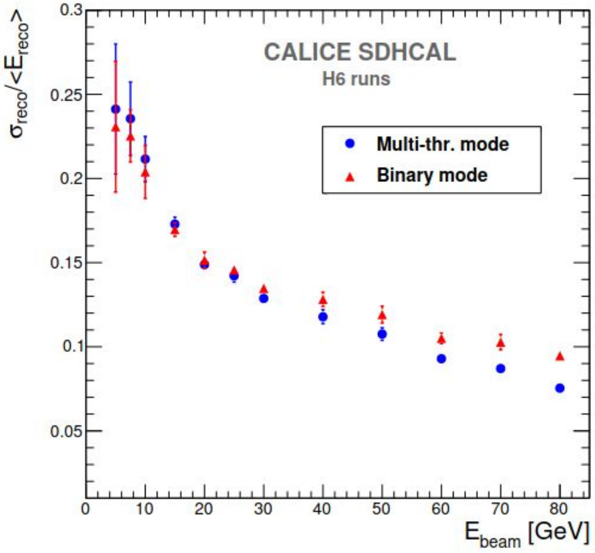
$$\alpha_i = a_i N_{hit}^2 + b_i N_{hit} + c_i$$

Boosted Decision Tree BDT
Event level features
coming from Physics Variables

Deep Learning models
Hit level features
Position, Threshold, Timing







Software - Energy Reconstruction - Datasets

- **Single particles** : 100k pi- or 100k proton
- **Initial position and launch angle** : particle simulated to traverse the center of the proto (T-)SDHCAL with a little gaussian in launch angle
- **Applied cuts** : remove hits with time > 10ns, remove events that did not start showering within the (T)-SDHCAL
- **Smearing of 100ps** for time information

Continuous Datasets for training :

- **Uniform energy from 1MeV to 100GeV**

Discrete Dataset for testing :

- **Discrete energy from 5GeV to 80GeV, each 5GeV**

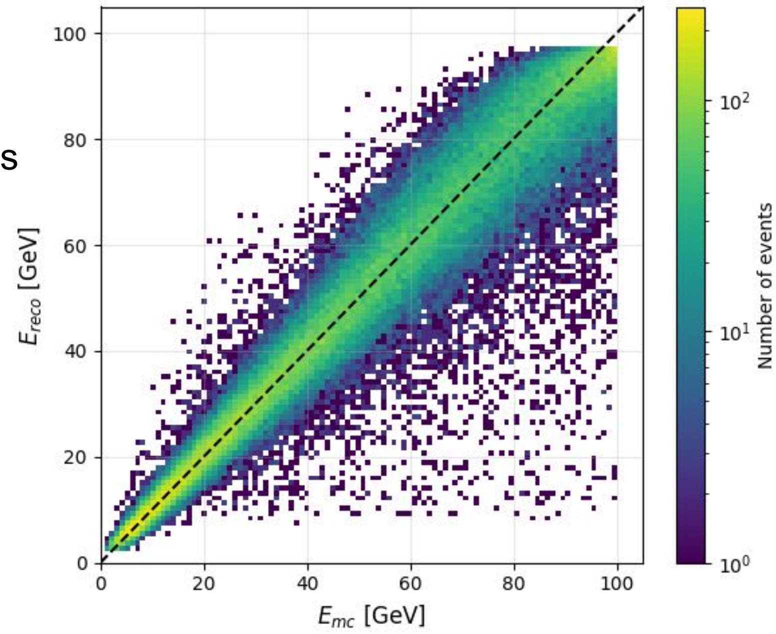
Machine Learning model used :

- **Point cloud based model**

Inputs : Hits as nodes

- Hit level features : **Position, Threshold, Timing**
- Event level features : **Number of hits, ratio of threshold 3, number of hits in last layer, first interaction layer**

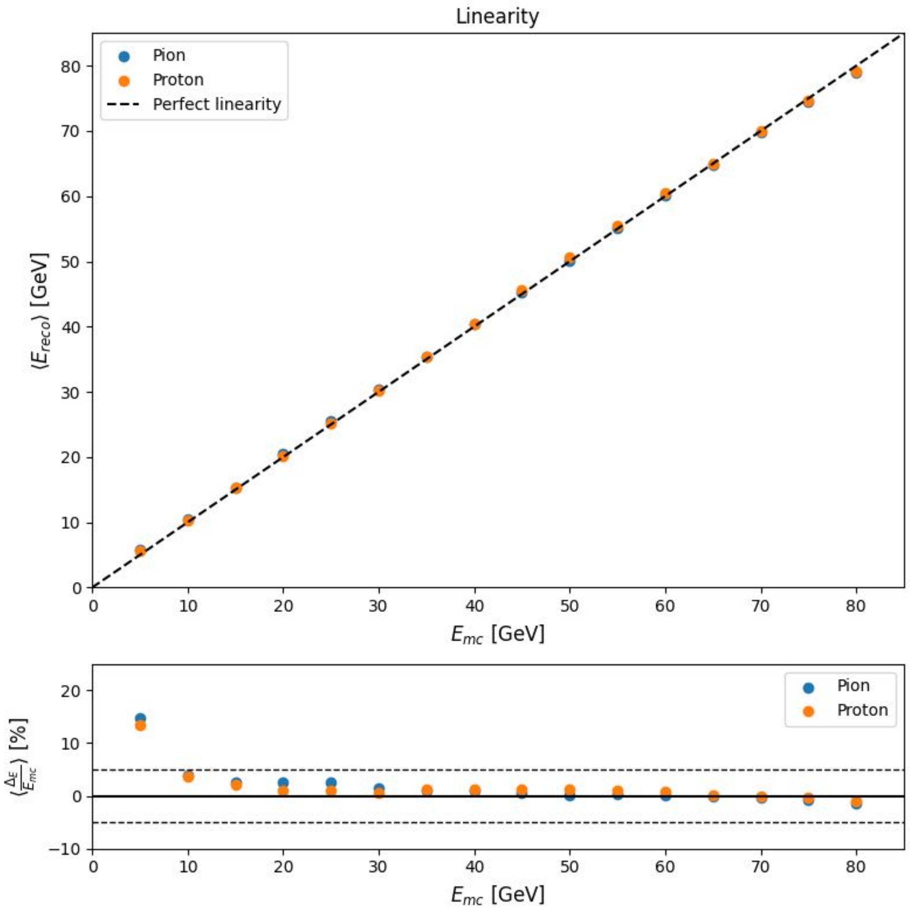
Single pi-



Datasets :

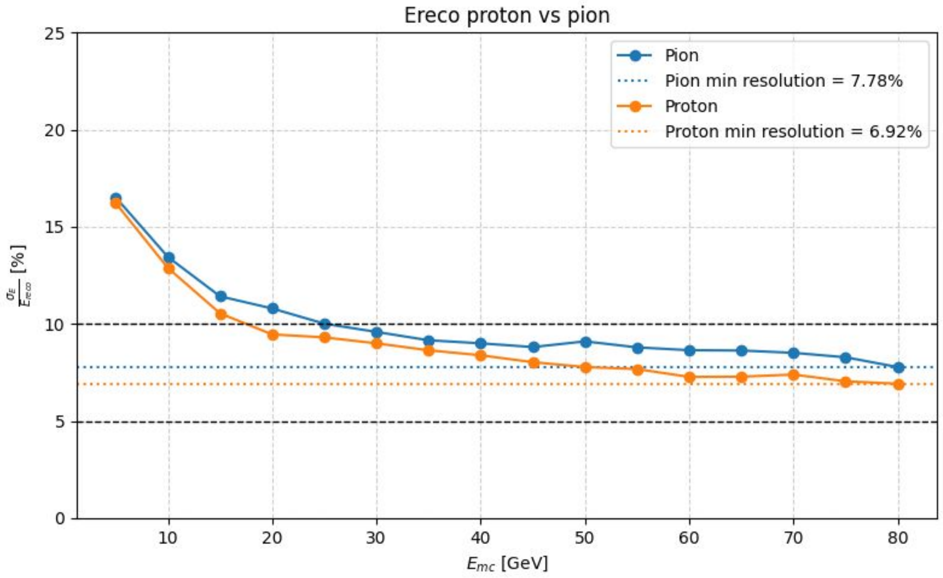
- Train on **Continuous**
- Test on **Continuous**

Software - Energy Reconstruction - Linearity and Resolution



Datasets :

- Train on **Continuous**
- Test on **Discrete**

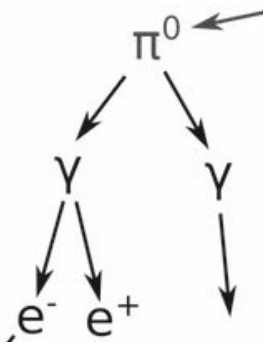


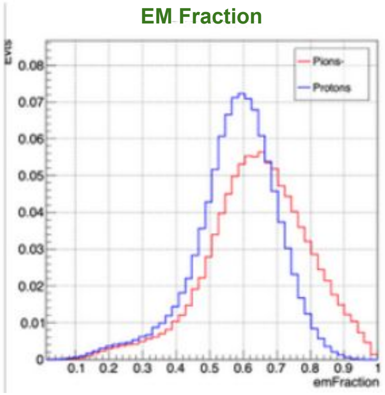
Resolution defined as :

- First gaussian fit giving μ_1 and σ_1
- Second gaussian fit in the $\pm 1.5\sigma_1$ range giving σ_2 as $\boldsymbol{\sigma_E}$ and μ_2 as $\mathbf{E_{reco}}$

Software - Particle Identification PID - protons/pi-

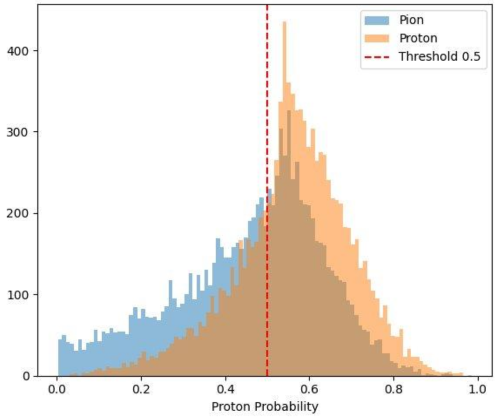
- **Charged pions** produce a lot of neutral pions, which decay only through photons
- The **electromagnetic fraction** is higher for **charged pions** than for **protons**
- **Protons** produce less saturation, leading to better energy reconstruction
- The next step consists in **using the hadron PID prediction to reconstruct the energy** with species-specific models.

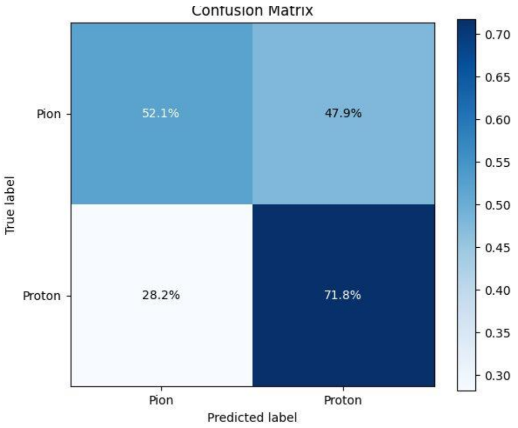




<u>Datasets :</u>

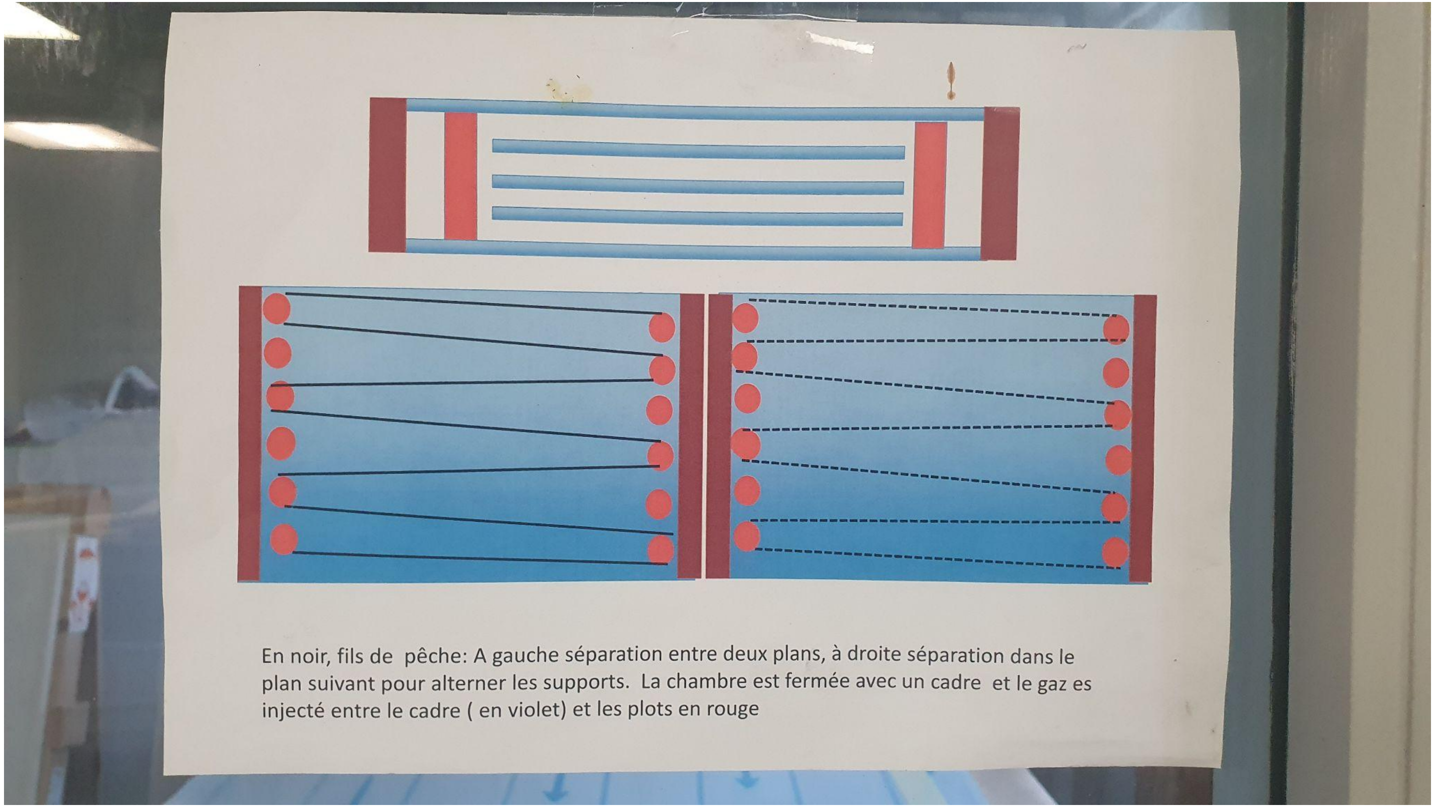
- Train on **Continuous**
- Test on **Continuous**



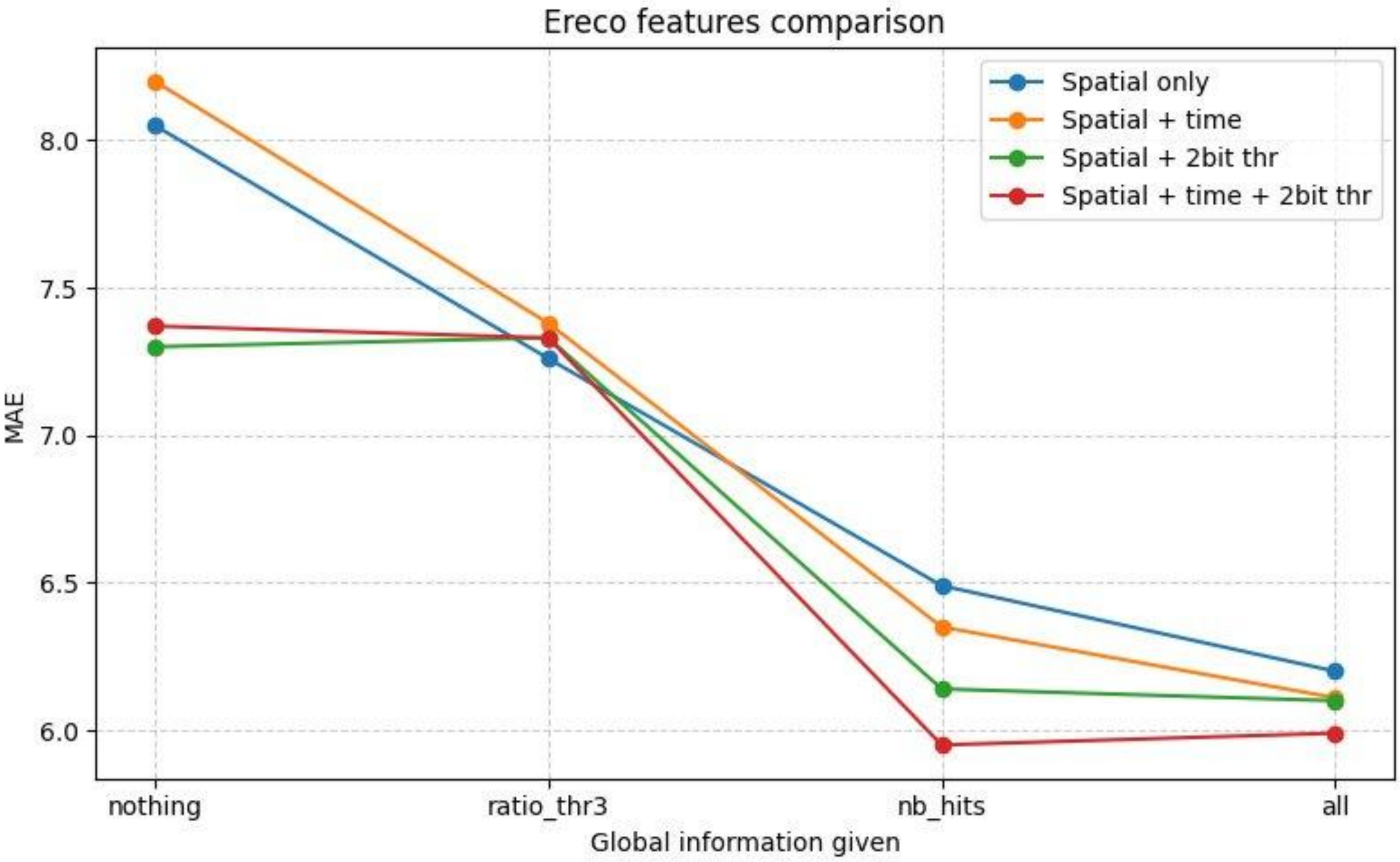


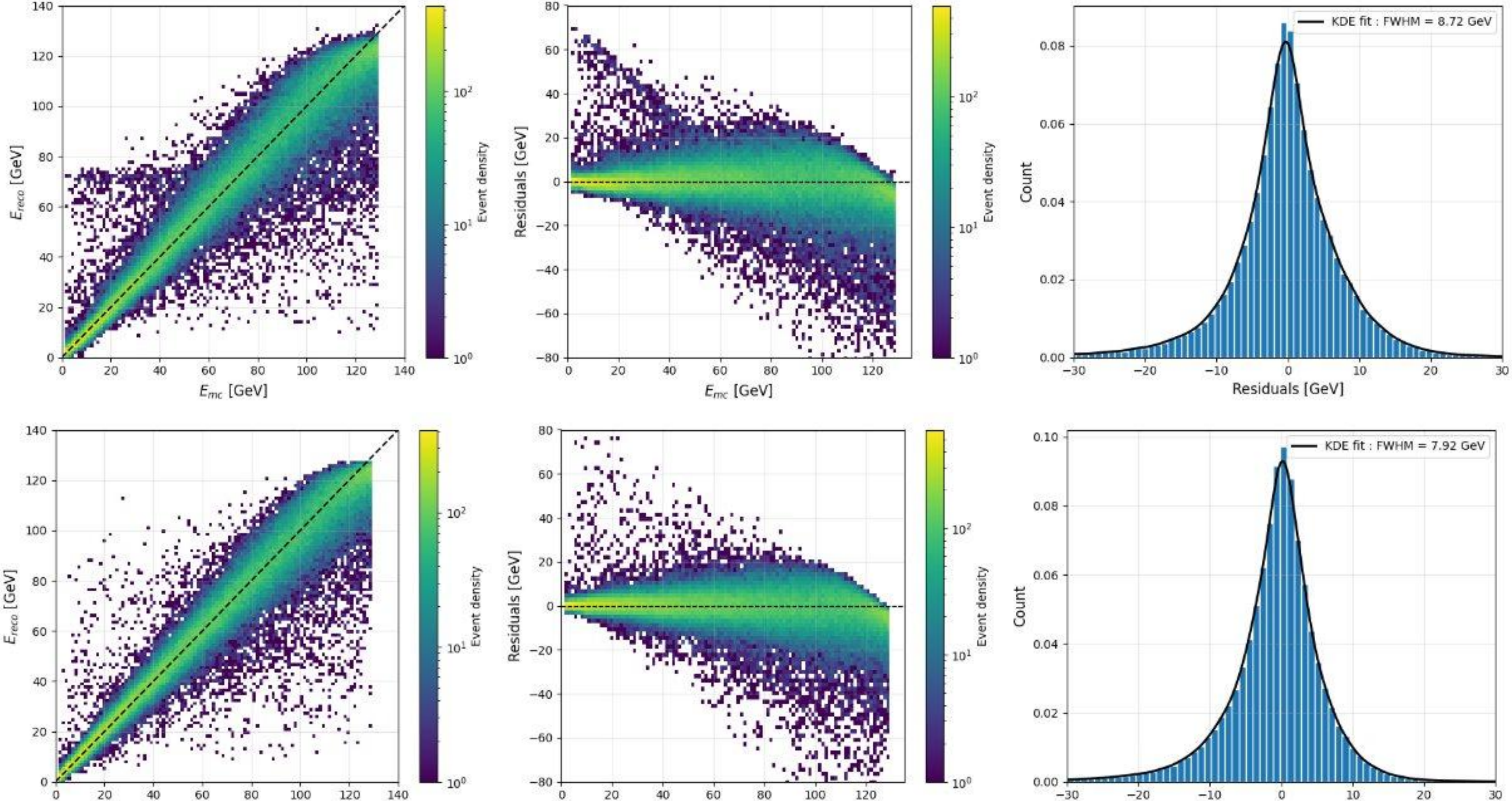
	Pion	Proton
Pion	52.1%	47.9%
Proton	28.2%	71.8%

Backups

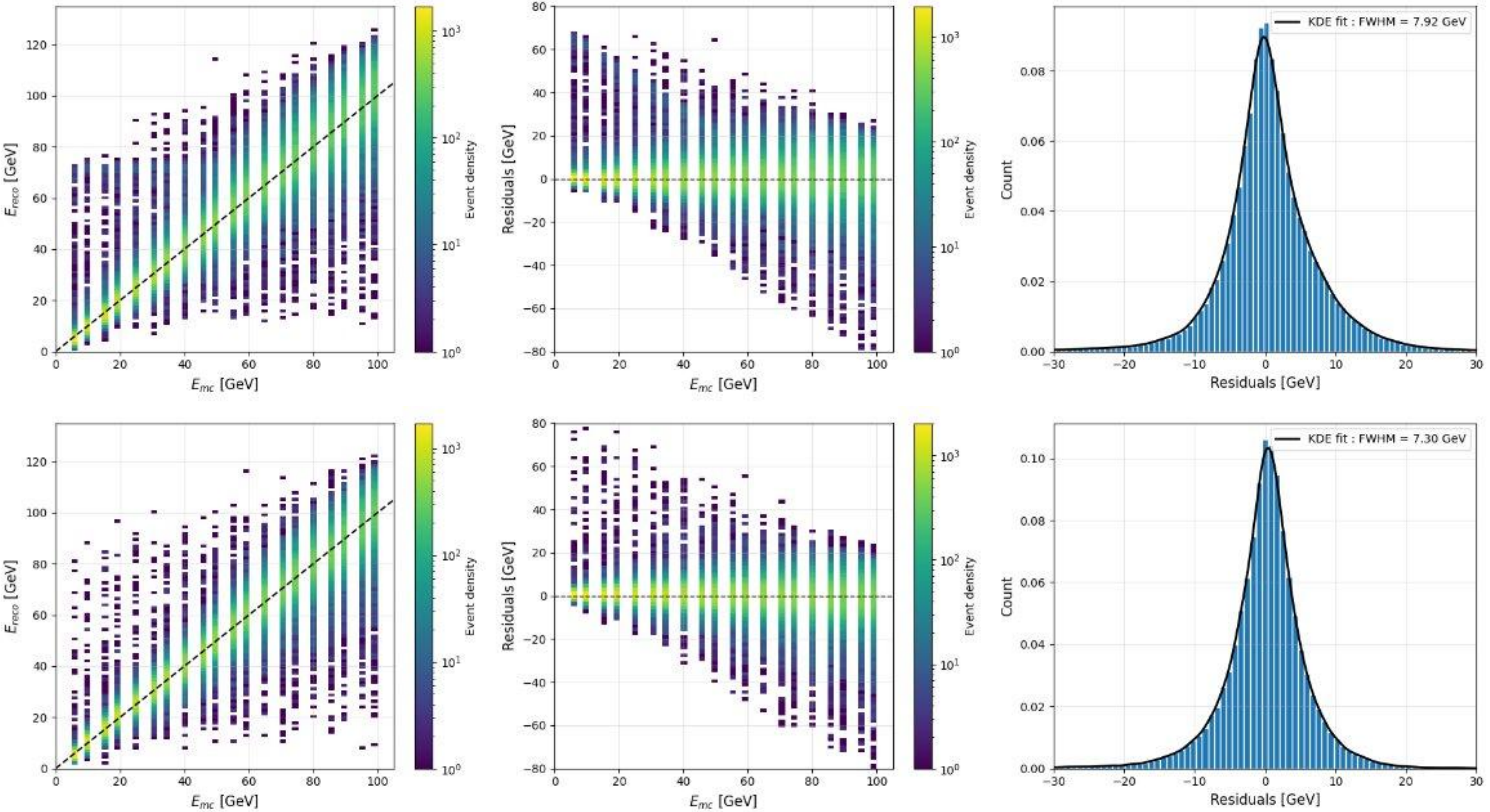


En noir, fils de pêche: A gauche séparation entre deux plans, à droite séparation dans le plan suivant pour alterner les supports. La chambre est fermée avec un cadre et le gaz es injecté entre le cadre (en violet) et les plots en rouge


Ereco features comparison
MAE
8.0
7.5
7.0
6.5
6.0
nothing
ratio_thr3
nb_hits
all
Global information given
Spatial only
Spatial + time
Spatial + 2bit thr
Spatial + time + 2bit thr

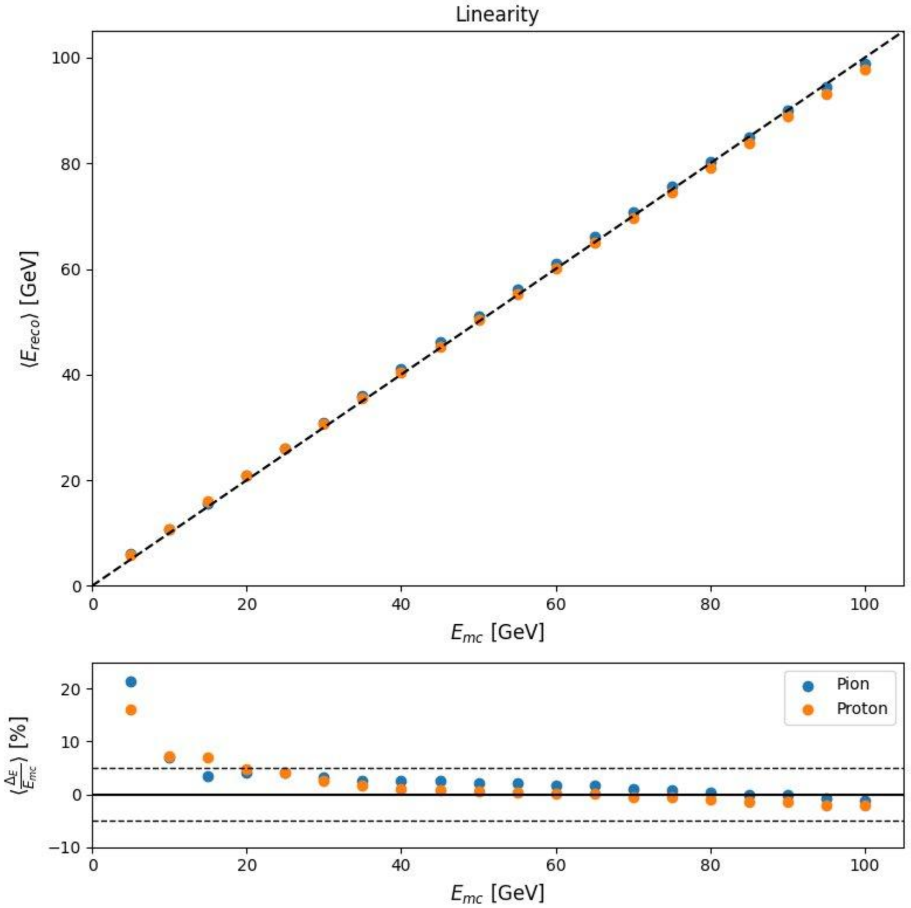


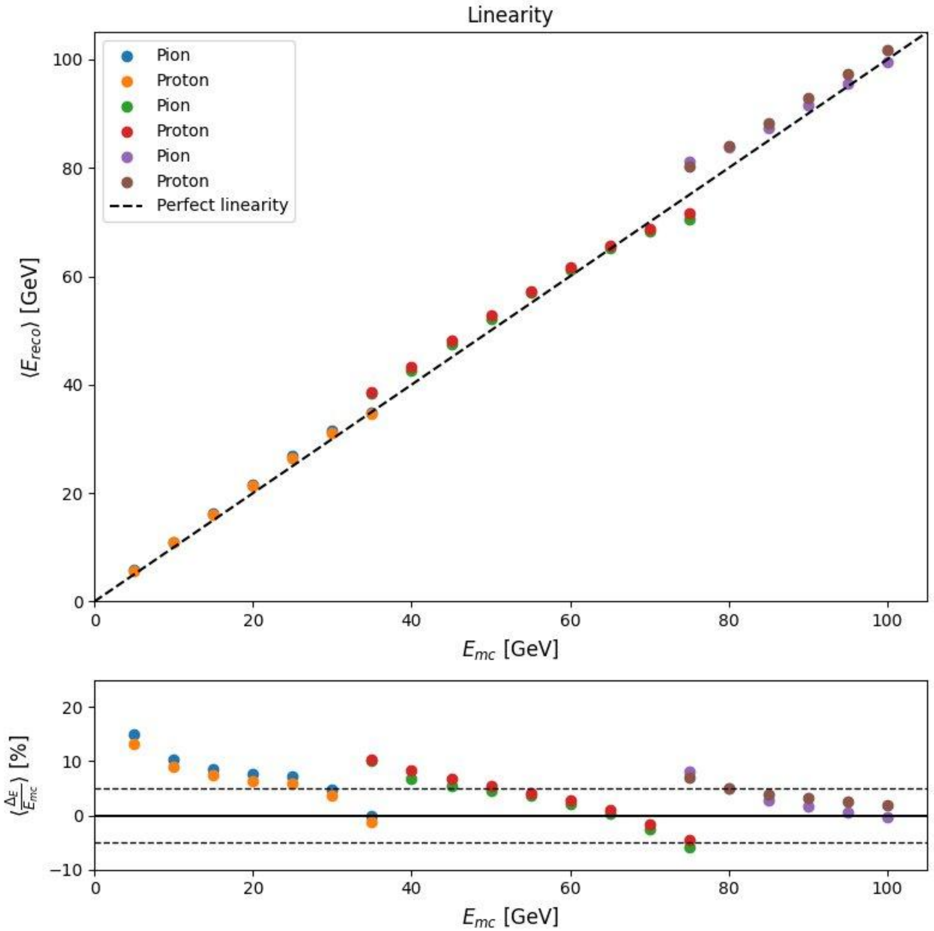
E_{reco} [GeV]
E_{mc} [GeV]
Event density
Residuals [GeV]
E_{mc} [GeV]
Event density
Count
Residuals [GeV]
KDE fit : FWHM = 8.72 GeV
E_{reco} [GeV]
Event density
Residuals [GeV]
Event density
Count
KDE fit : FWHM = 7.92 GeV
10^0
10^1
10^2



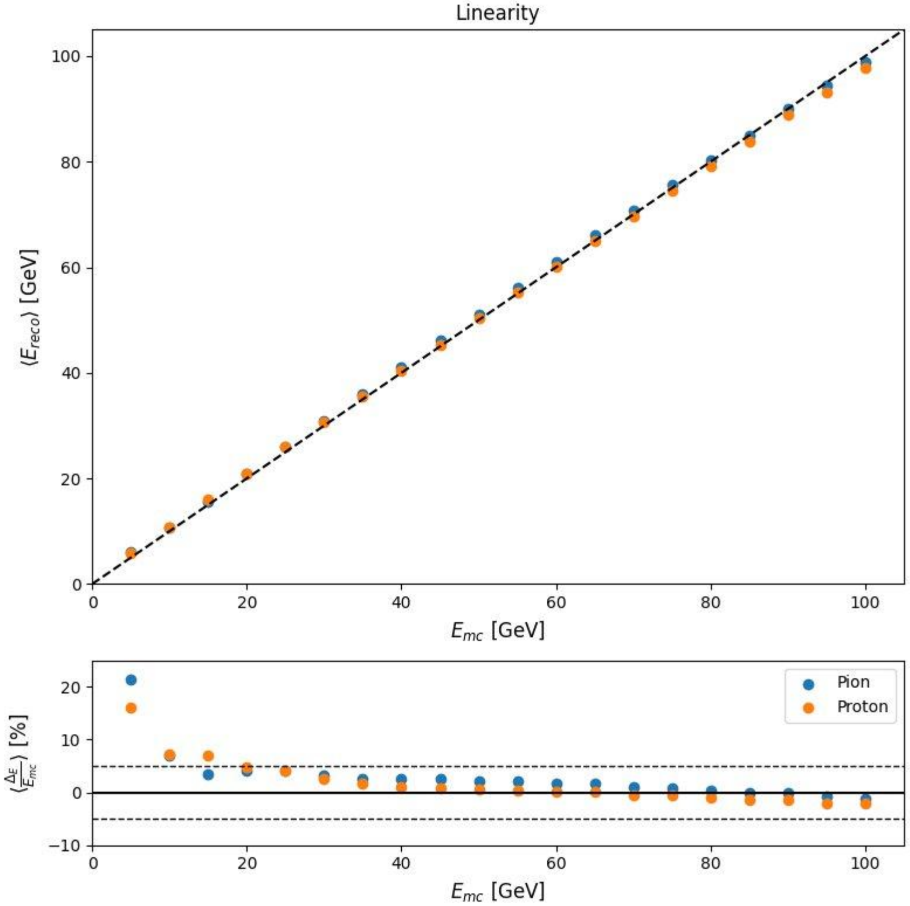
E_{reco} [GeV]
E_{mc} [GeV]
Event density
Residuals [GeV]
E_{mc} [GeV]
Event density
KDE fit : FWHM = 7.92 GeV
Count
Residuals [GeV]
E_{reco} [GeV]
E_{mc} [GeV]
Event density
Residuals [GeV]
E_{mc} [GeV]
Event density
KDE fit : FWHM = 7.30 GeV
Count
Residuals [GeV]

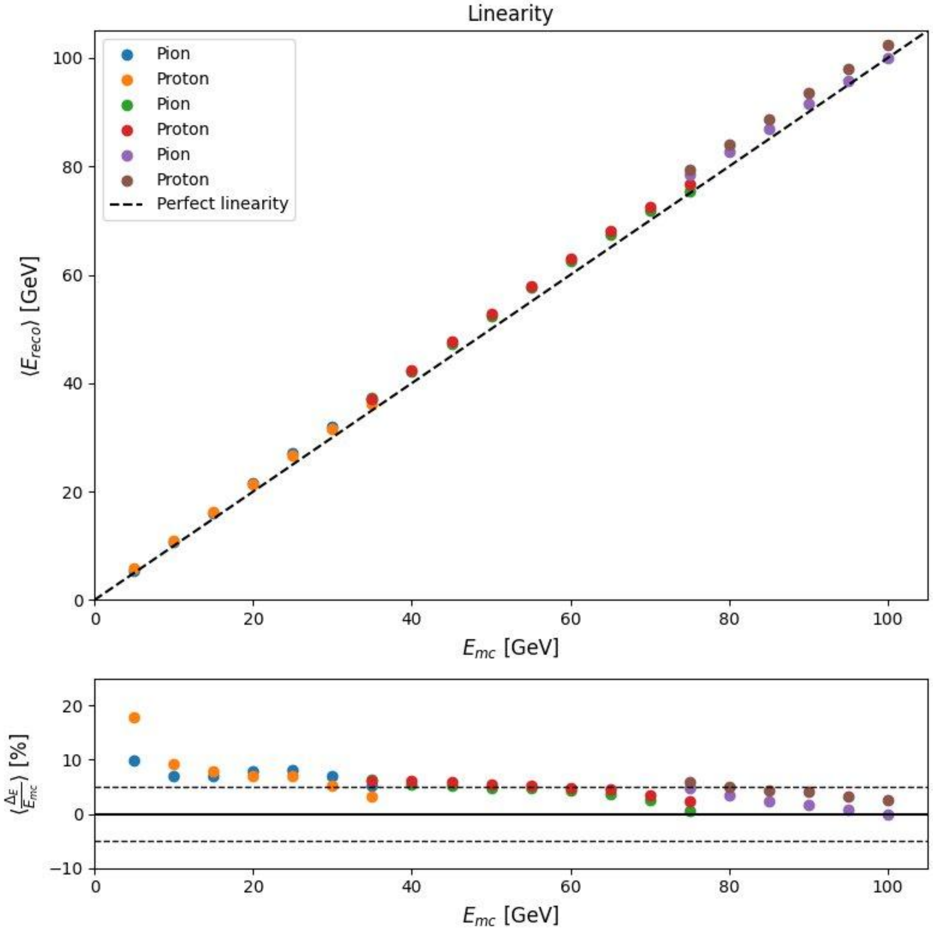
Software - Energy Reconstruction - Linearity multi models



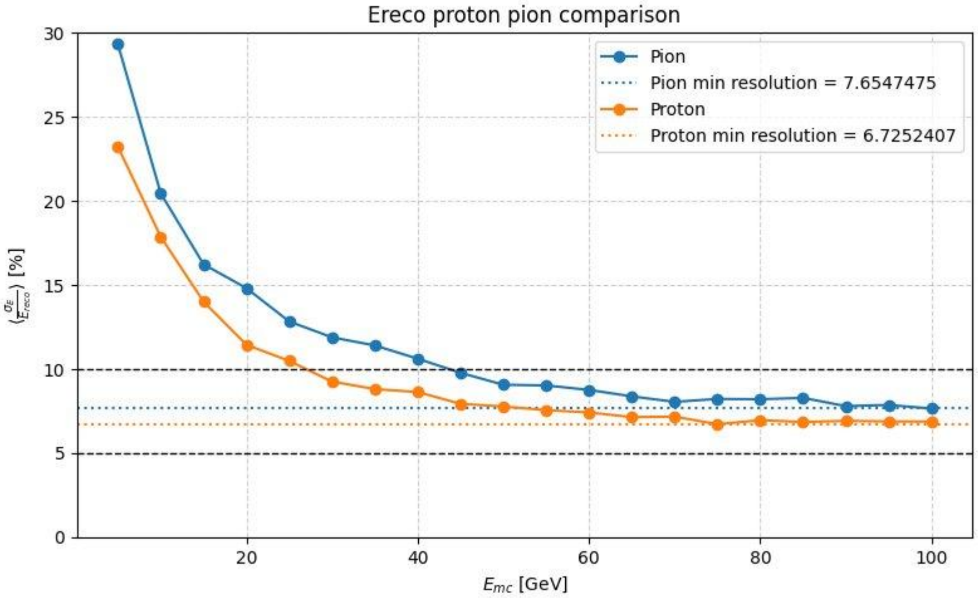


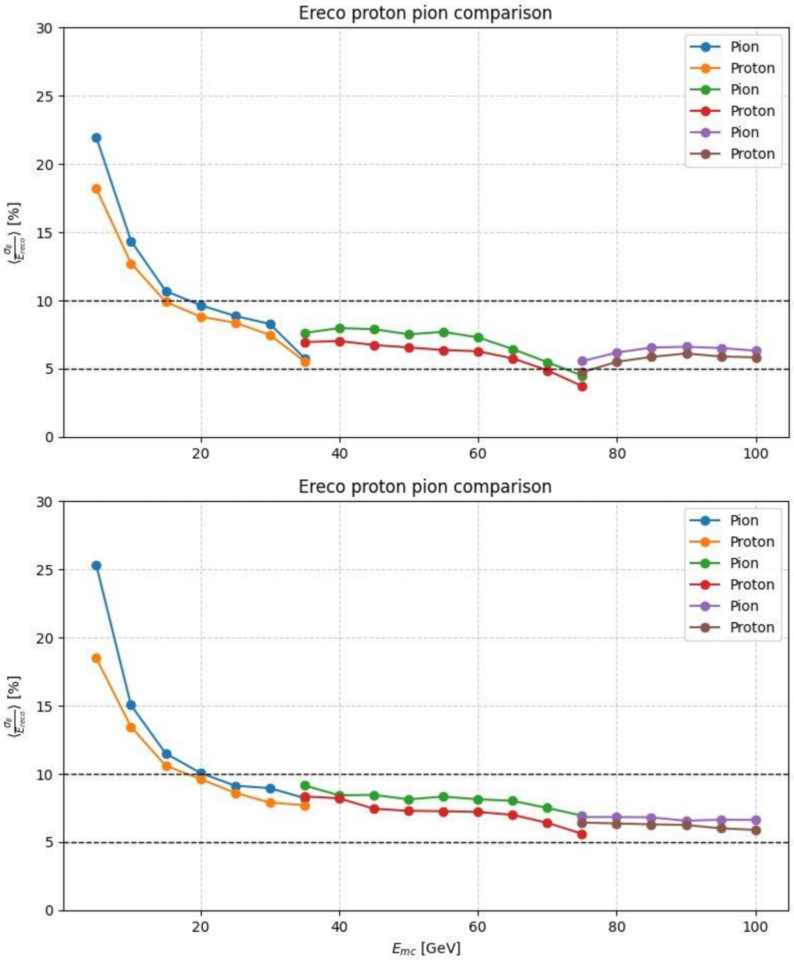
Software - Energy Reconstruction - Linearity multi models



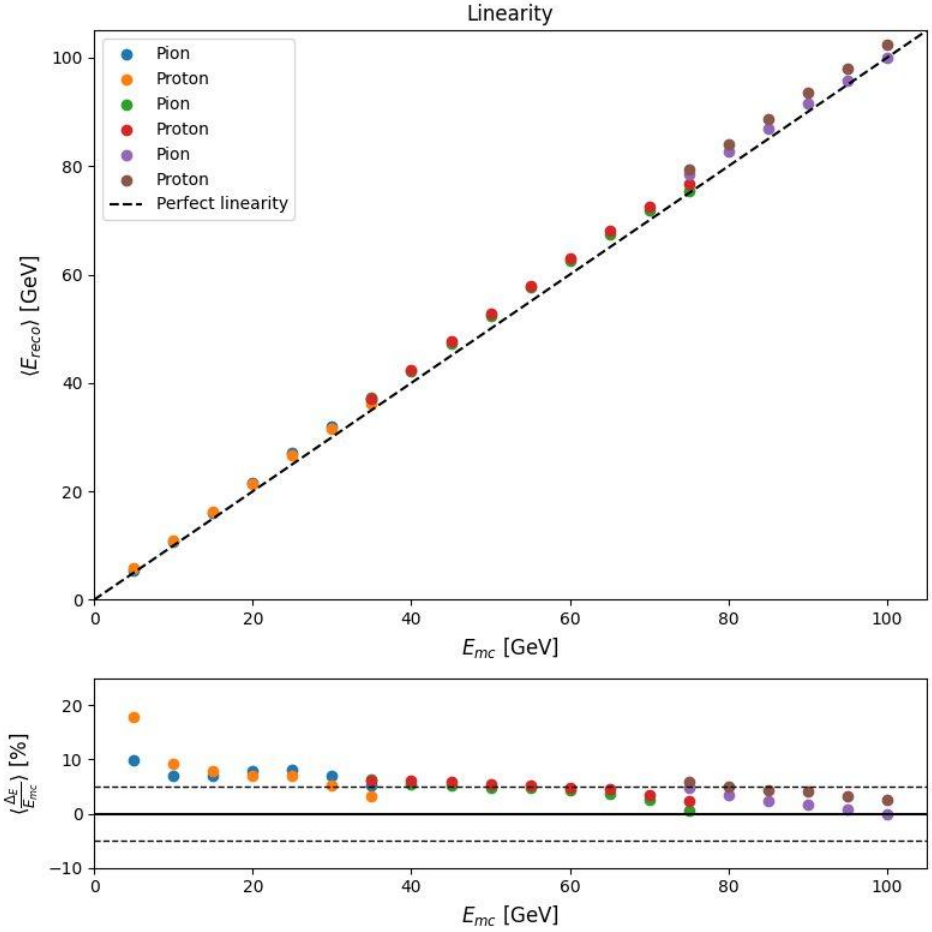


Software - Energy Reconstruction - Resolution multi models

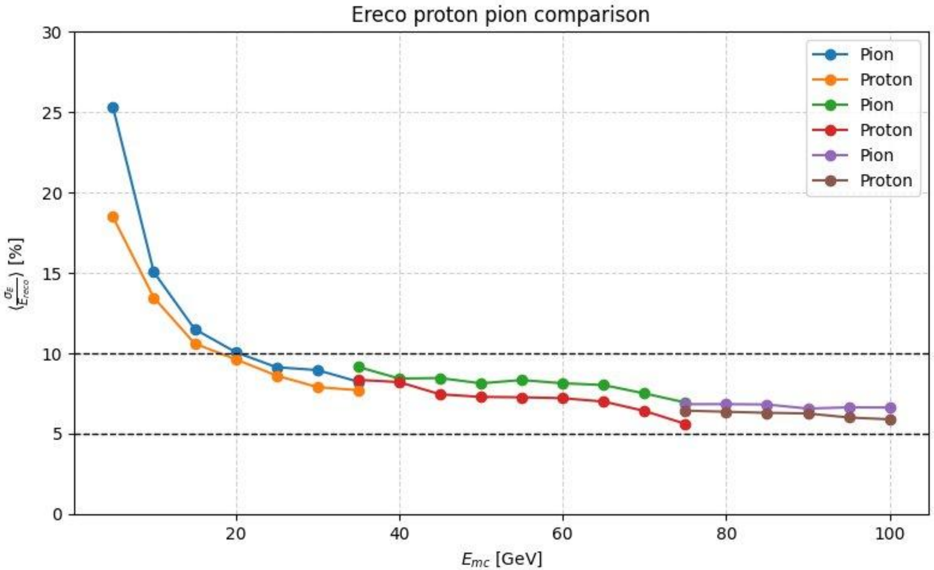




Software - Energy Reconstruction - Linearity and Resolution

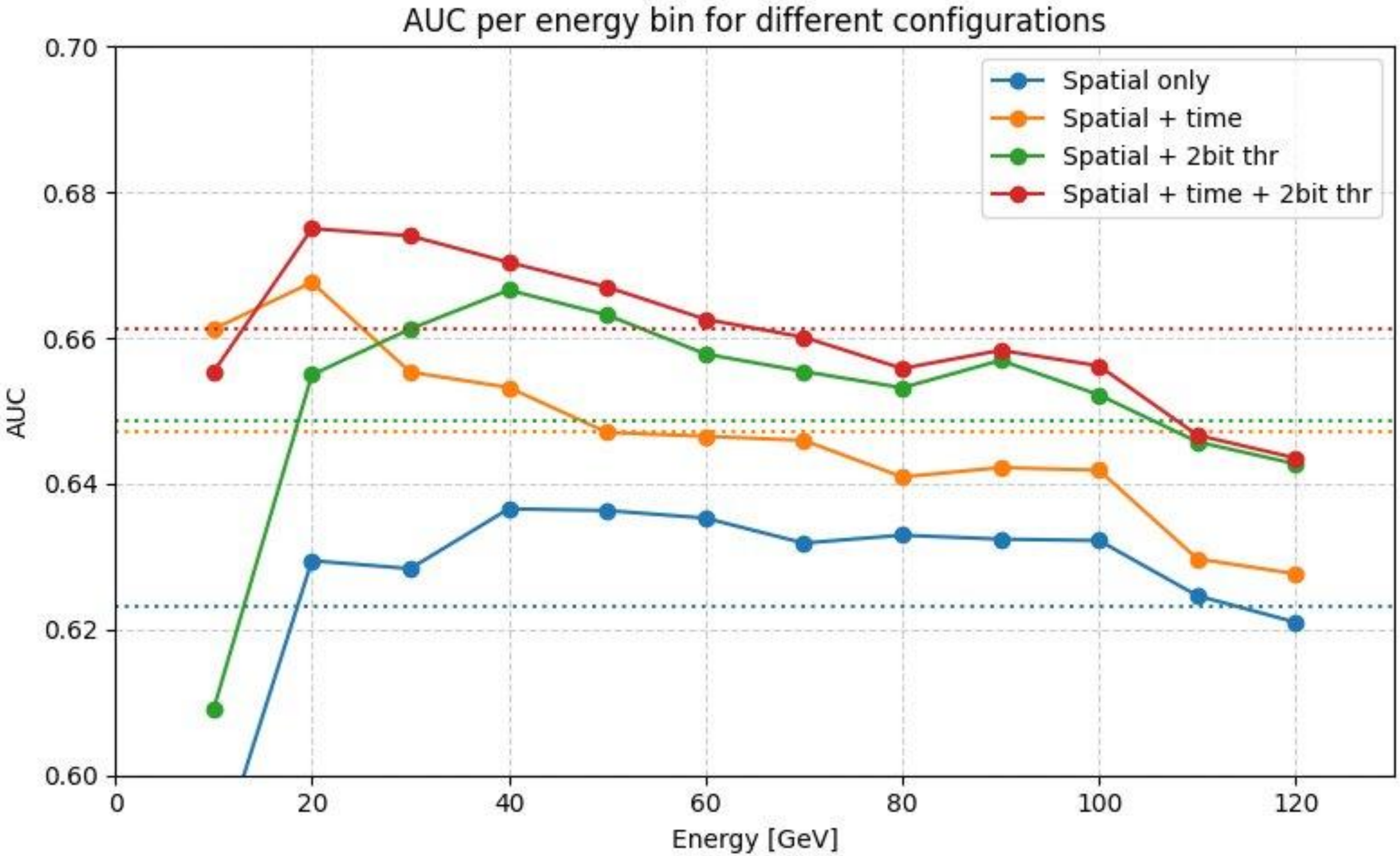


3 models are trained on different energy ranges
[1;50] GeV, [30;90] GeV, [70;130] GeV
So far we ‘cheat’ by using the mc Energy to associate events to models with the right energy range

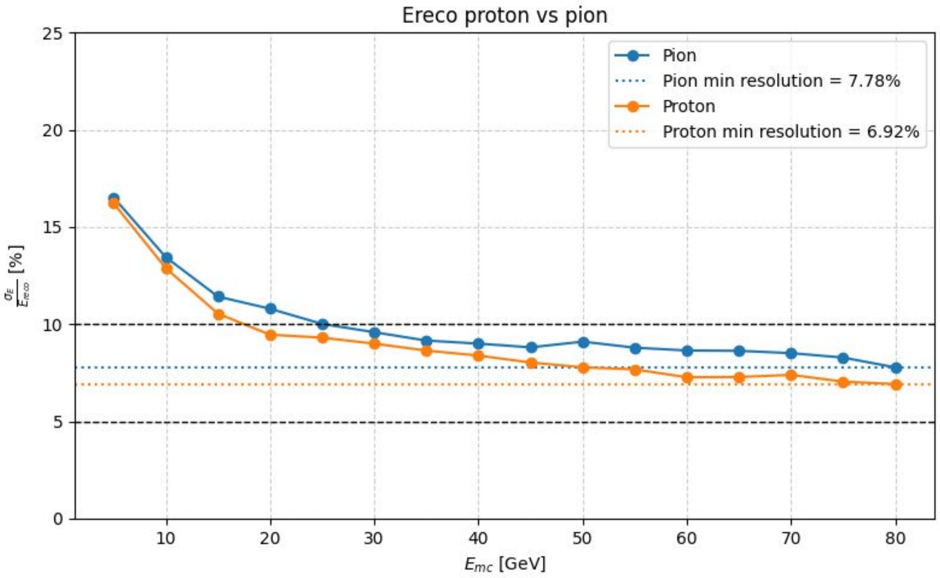


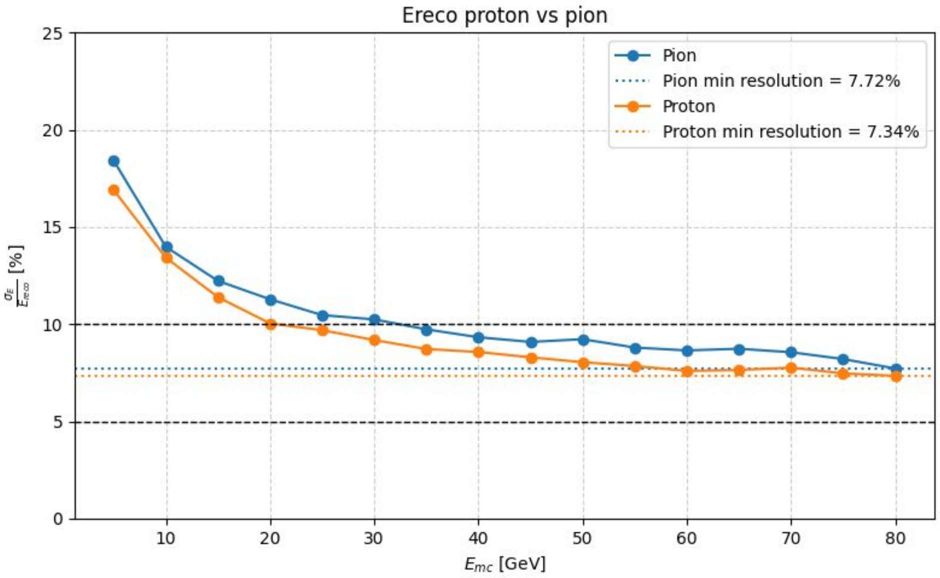
Datasets :

- Train on **continuous**
- Test on **discrete**


AUC per energy bin for different configurations
AUC
Energy [GeV]
0.70
0.68
0.66
0.64
0.62
0.60
0
20
40
60
80
100
120
Spatial only
Spatial + time
Spatial + 2bit thr
Spatial + time + 2bit thr

Software - Energy Reconstruction - with vs without Timing





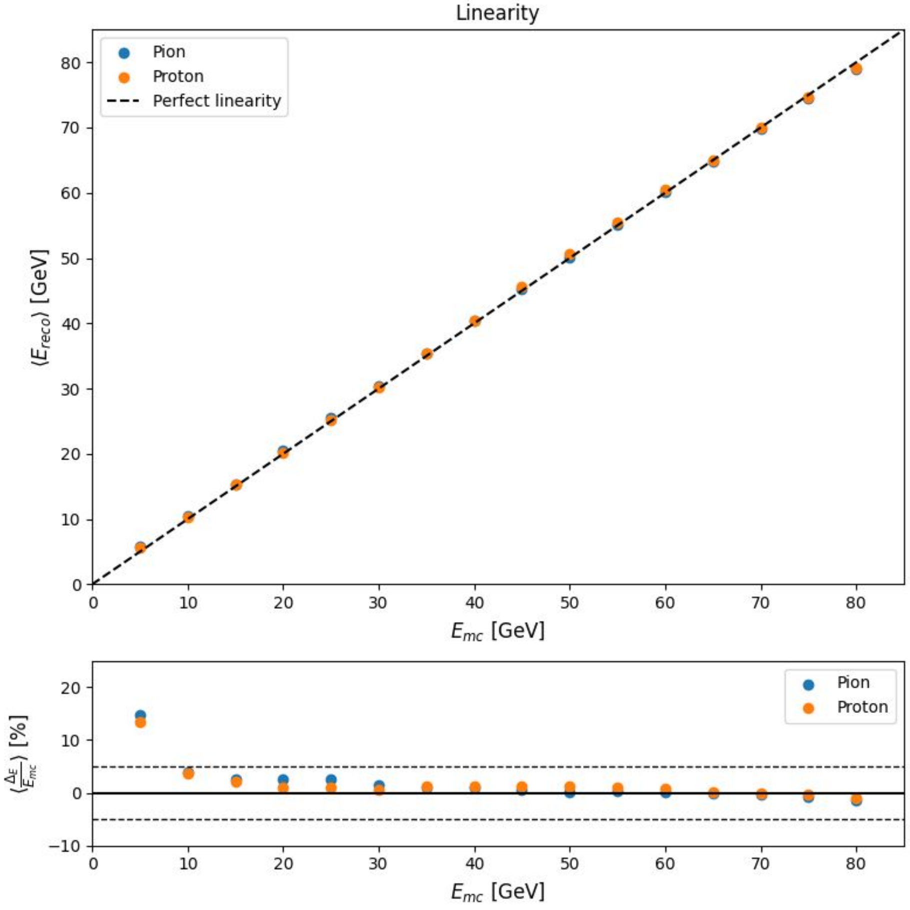
With Timing

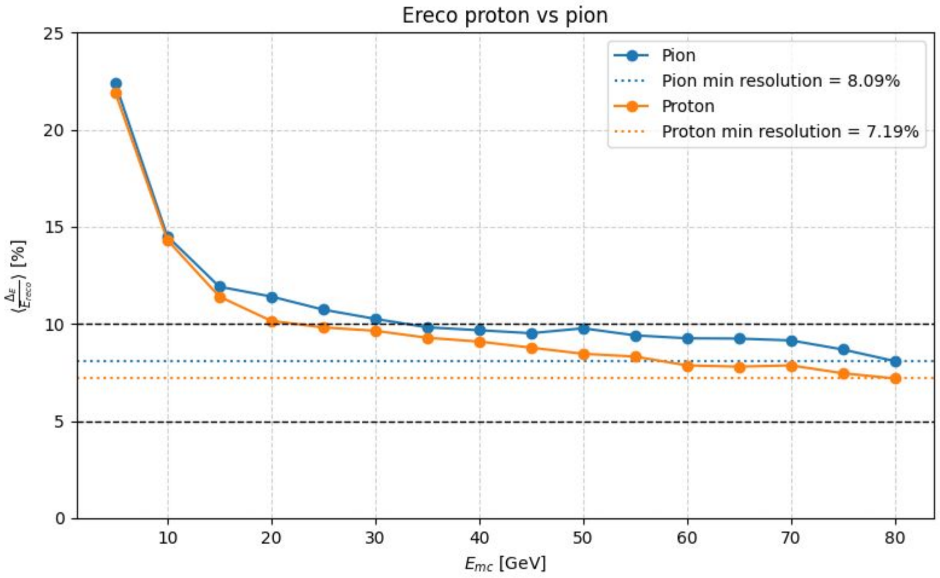
Without Timing

Datasets :

- Train on **continuous**
- Test on **discrete**

Software - Energy Reconstruction - Residuals

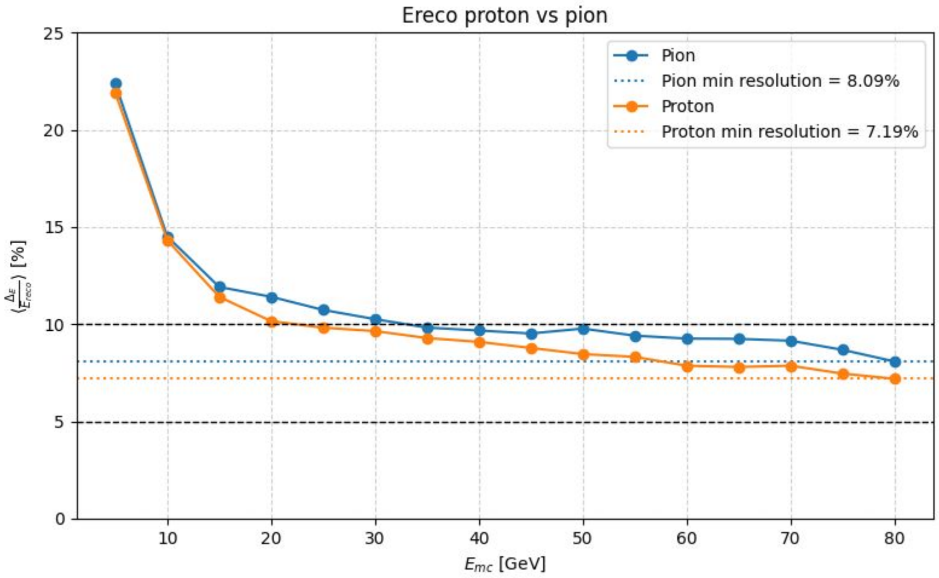


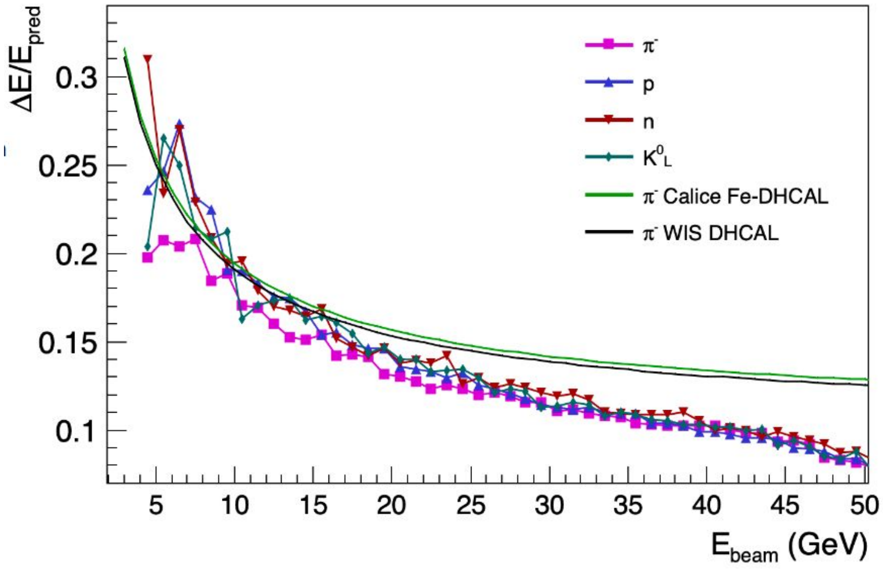


Datasets :

- Train on **continuous**
- Test on **discrete**

Software - Energy Reconstruction - Residuals vs DHCAL





Datasets :

- Train on **continuous**
- Test on **discrete**