Pisa Meeting
on Advanced
Detector 2024

Particle identification in high-granularity 3D calorimeters for space-borne applications

C. Brugnoni[1,2], M.Duranti[2], V. Vagelli[3,2], L. Tabarroni[4,5], V. Formato[5]

[1]Università degli Studi di Perugia, [2]INFN Sezione di Perugia, [3]Agenzia Spaziale Italiana,
[4]Università degli Studi di Roma Tor Vergata,[5]INFN Sezione Roma Tor Vergata

Scientific motivation

A fine **3D segmentation** in homogeneous calorimeters can be used to reconstruct the **shape of electromagnetic and hadronic shower** cascades impinging **from any direction.**

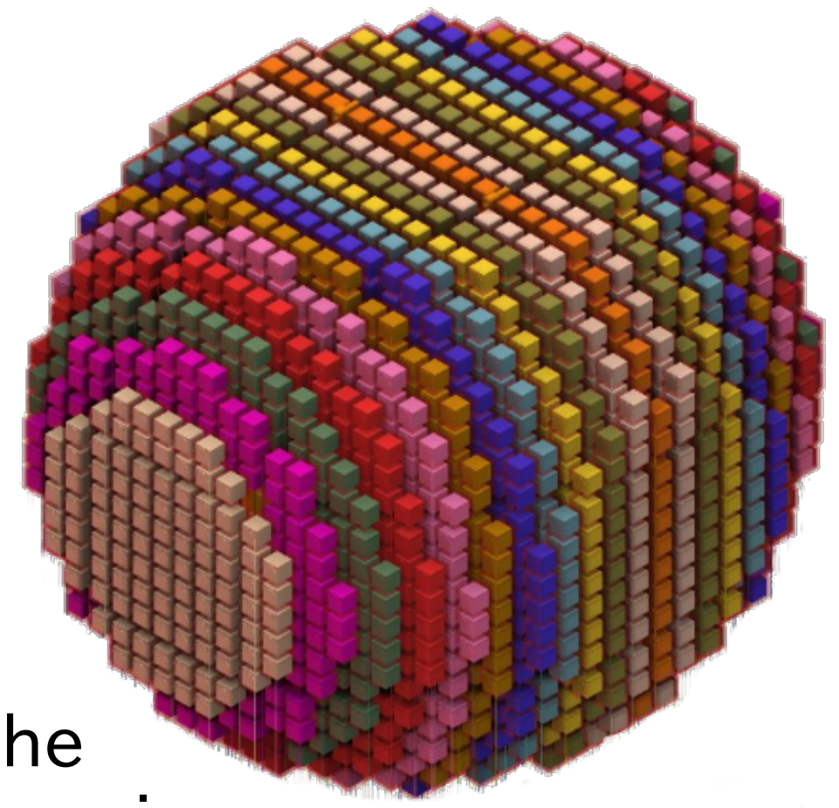
This capability can be exploited to study the shape of the showers generated from different particle species in order to build **powerful classificators.**

In this work we implemented a **likelihood test** based on the shower shapes for the discrimination of **electrons vs protons**.

This will be pivotal for the next generation of **space-borne cosmic rays detectors** (e.g. HERD[1], ALADInO[2], AMS-100[3]) that will measure the cosmic electron+positron flux at energies above 10 TeV with an **unprecedented interaction length** in the calorimeter >50 X_0 in an **extremely proton rich environment** ($p/e>10^3$).

Simulation

For the study we simulated – using GGS[4] – about **10^6 electrons and 10^6 protons**, with isotropic directions and an E^{-1} energy spectrum from **100 GeV to 10 TeV.**



The simulated detector is a sphere made out of **7500 LYSO cubes.**

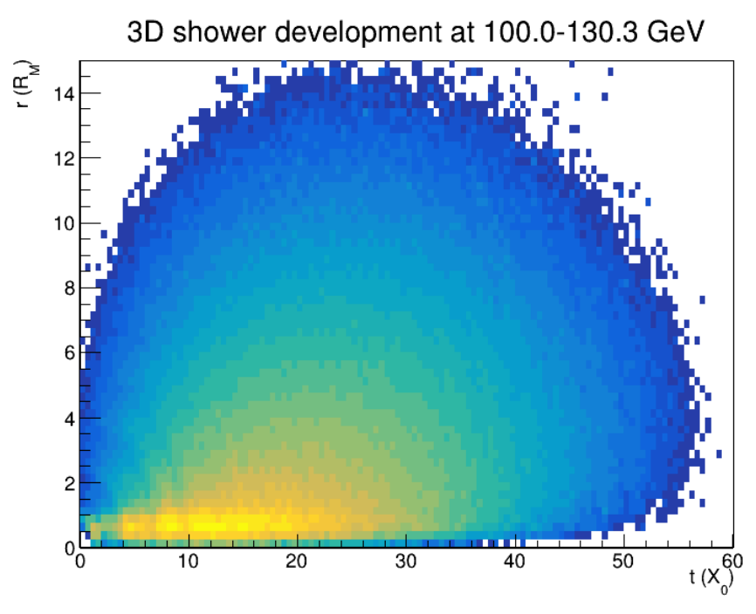
Each cube is 3x3x3 cm^3.

The cubes are placed at 0.4 cm distance one from the other and the intercube space is **filled with carbon** to take into account the effect of the **housing mechanics.**

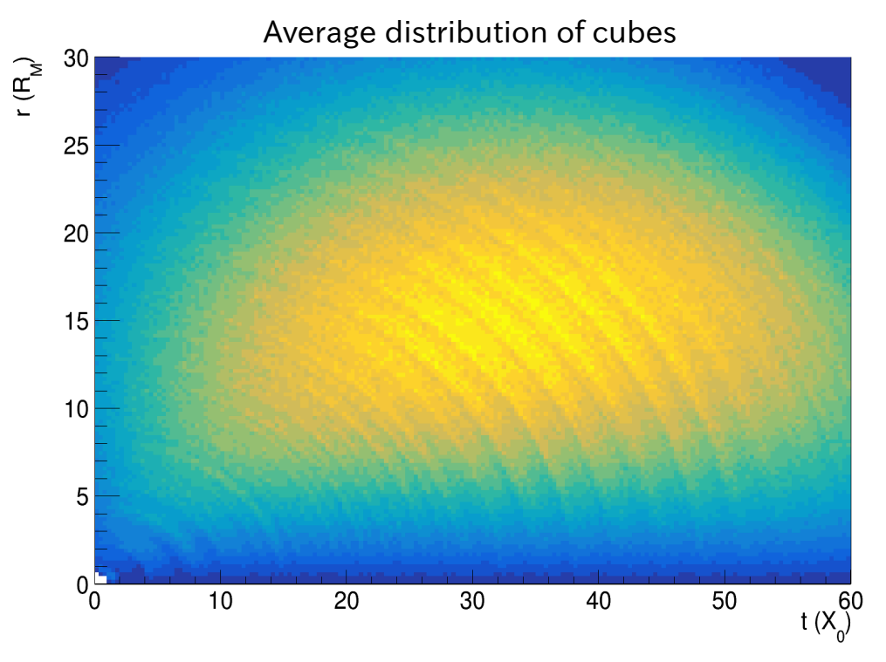
In order to have a good enough **reconstruction quality**, only the events that travel through LYSO for **at least 30 X_0** are selected for the analysis.

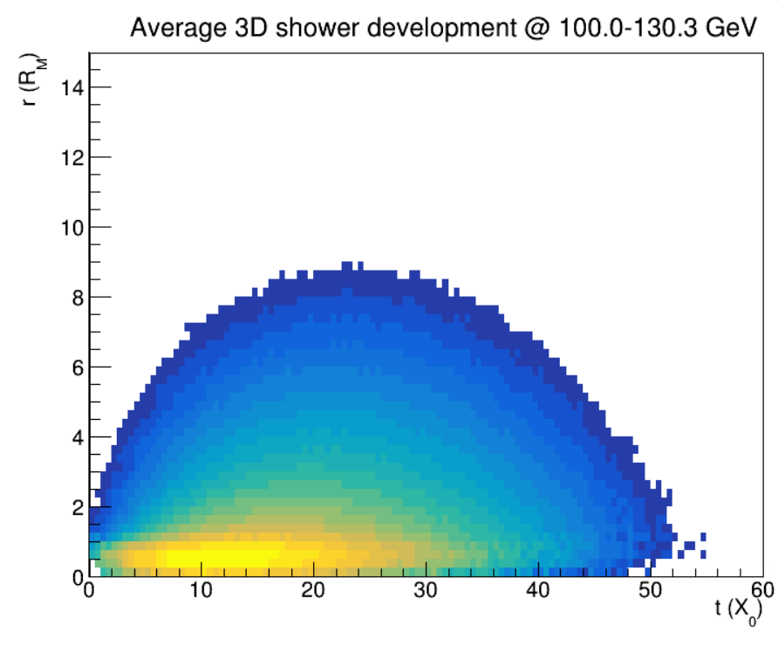
Data preparation

The **average spatial development** of the electron showers was described in **longitudinal** (*t*) vs **transversal** (*r*) reference frame.



Since the spatial distribution of the calorimeter cubes is not perfectly uniform in the (t,r) reference frame, the deposited energy was **reweighted according to the average number of cubes** in a (t,r) bin.



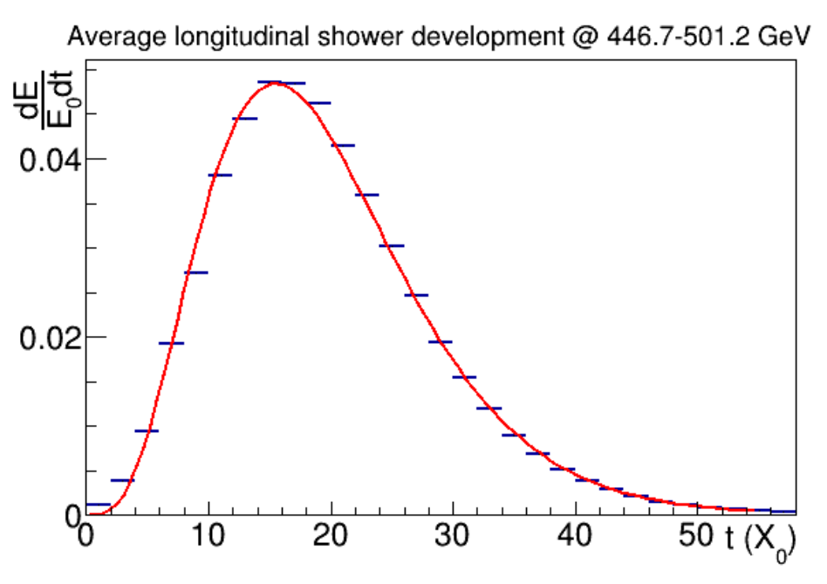


Parametrization

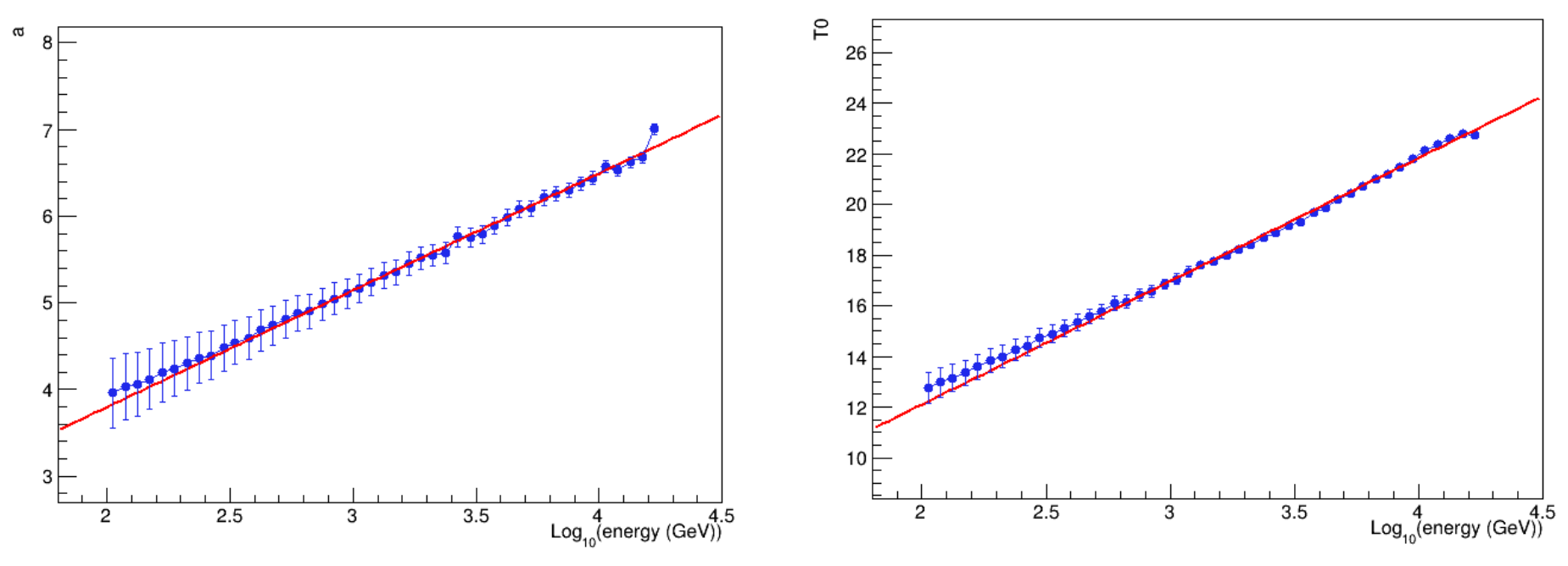
The **longitudinal development** of electron showers was parametrized using the expression

$$\frac{dE}{dt} = E_0 b \frac{(bt)^{a-1} e^{-bt}}{\Gamma(a)}$$

Only 2 free parameters that only depends on total energy



To describe the energy dependence of the parametrization, a and $T_0 = \frac{a-1}{b}$ have been fitted with a **linear model** wrt log(E).

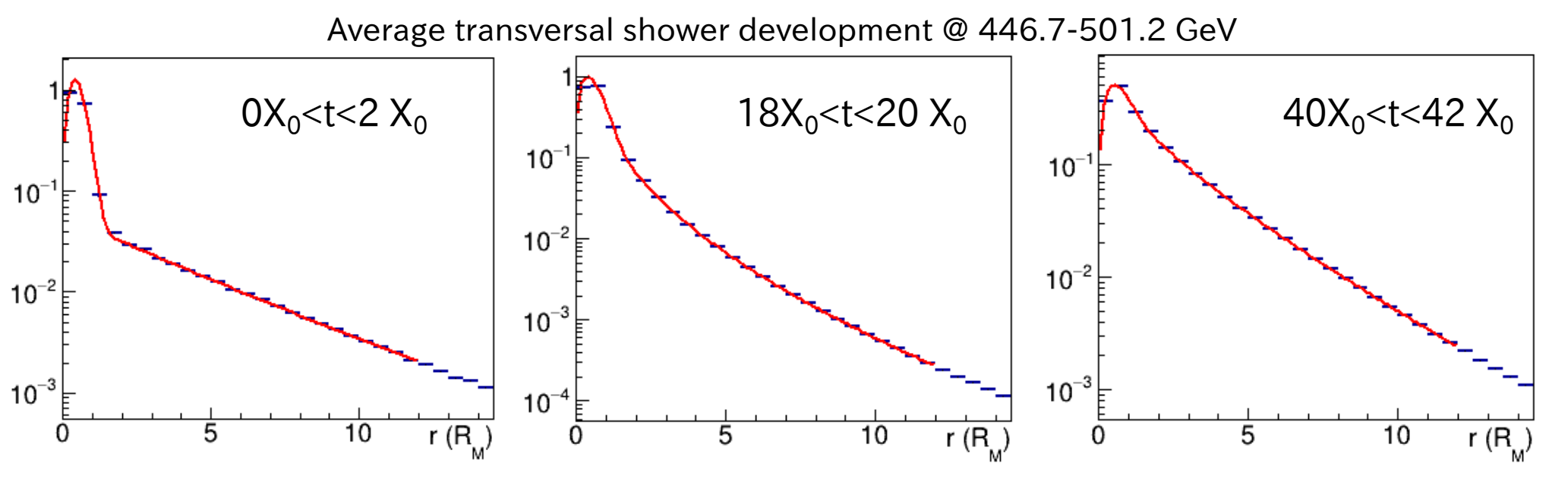


Parametrization

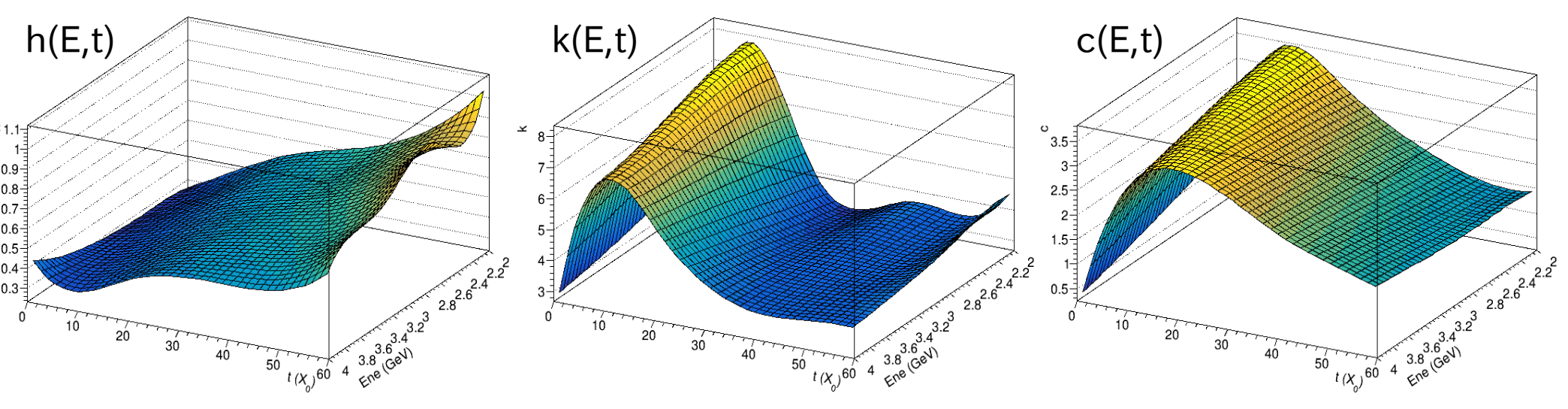
The minimal parametrization describing the **transversal energy deposit** has been found to be:

$$\frac{dE}{drdt} = Ae^{-r^2/h} + B\frac{e^{-r/k}}{(r+R)^c}$$

Parameters depend on both energy and t



The parameters have been interpolated by **2D spline.**



Parametrization

For every (t,r) bin the **distribution of the deposited energy** was characterized by means of an appropriately scaled **Poissonian** fit.

$$P(E^m|E_i^e,\eta_i) = e^{-E_i^e/\eta_i}\frac{(E_i^e/\eta_i)^{E^m/\eta_i}}{\Gamma(E^m/\eta_i+1)}$$

The parameter η_i is used for the conversion from **energy to number.**

As **average and variance** of deposited energy we expect the values

$$E[E^m] = E^e \qquad V[E^m] = E^e\eta$$

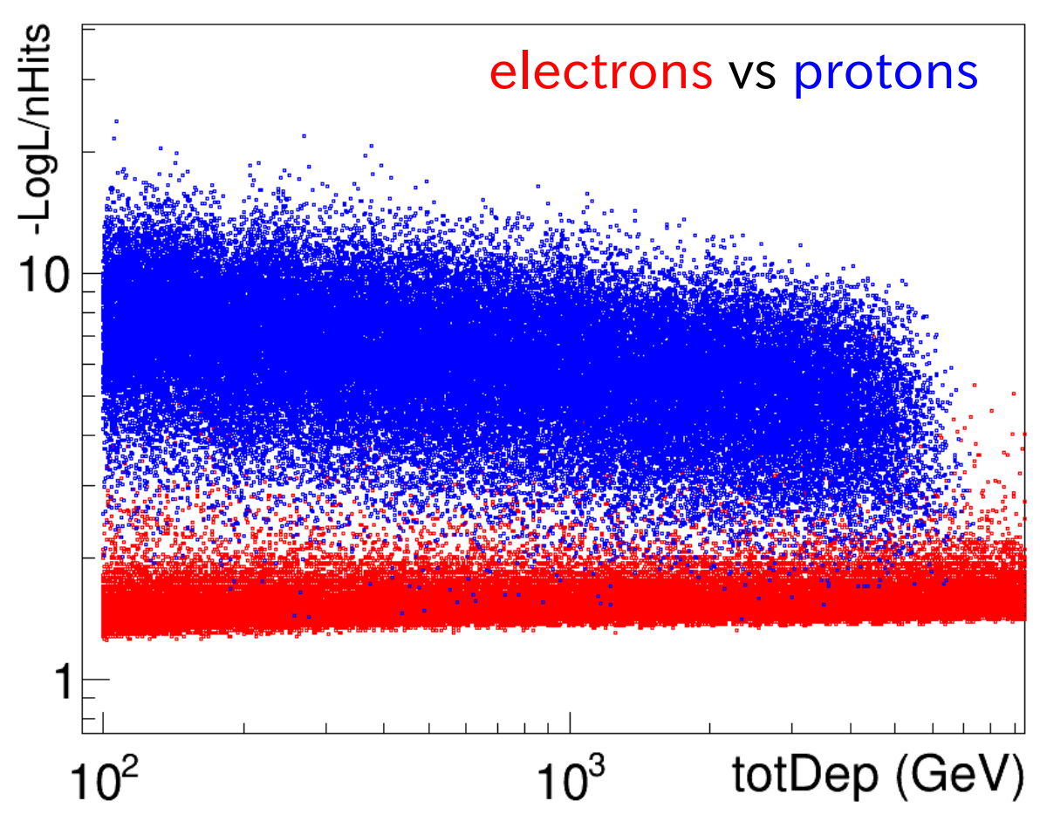
We mapped η_i computing the **ratio** between the **variance and the mean value** in bin i

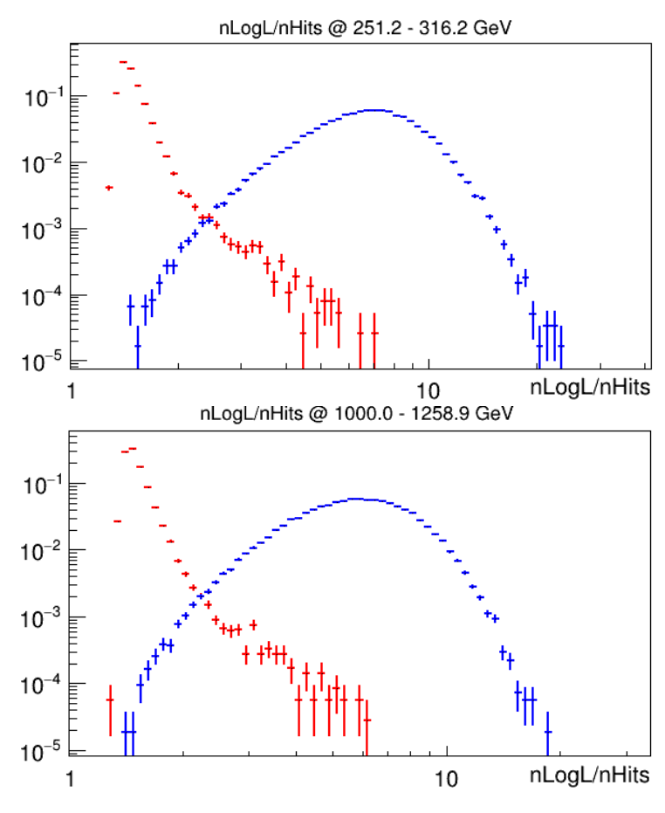
Likelihood test

The **negative log-likelihood** relative to **electroness hypothesis** was evaluated on every test event

$$nLogL = -Log\left(\prod_m P(E^m|E_i^e,\eta_i)\right)$$
$$= \sum_m E_i^e/\eta_i - E_i^m/\eta_i + Log(E_i^e/\eta_i) +$$
$$+ Log\Gamma(E_i^m/\eta_i+1)$$

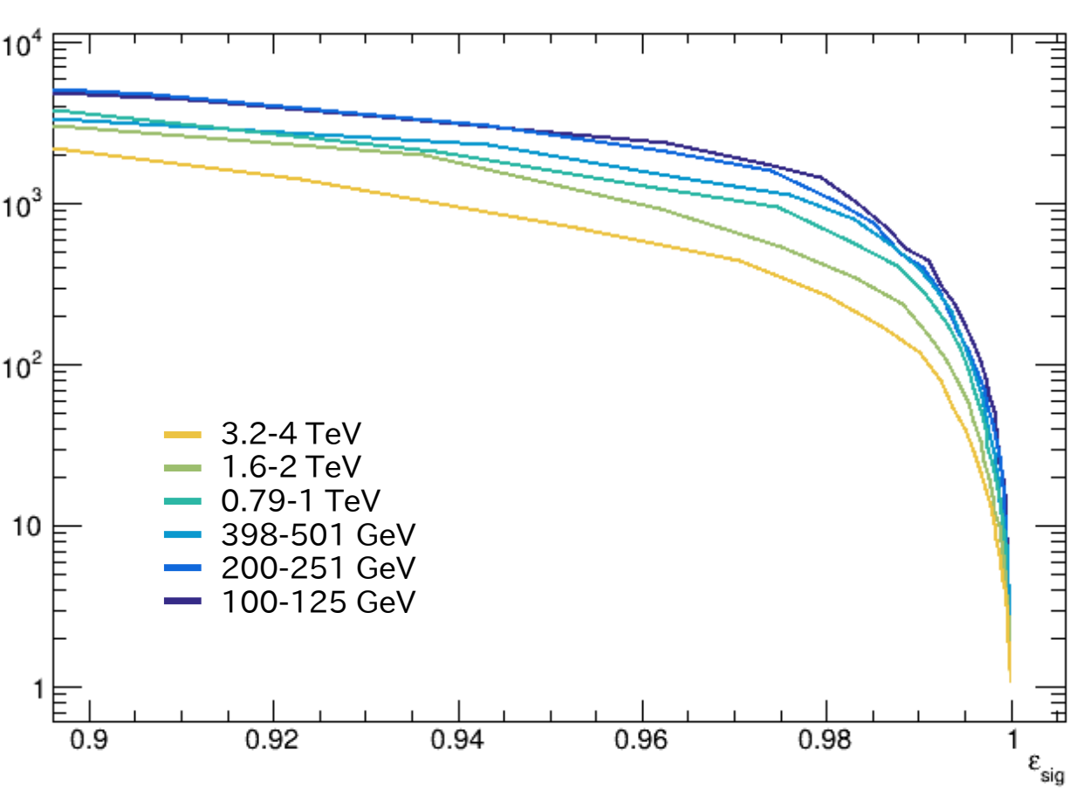
The value was **normalized wrt the number of hits** in a shower event

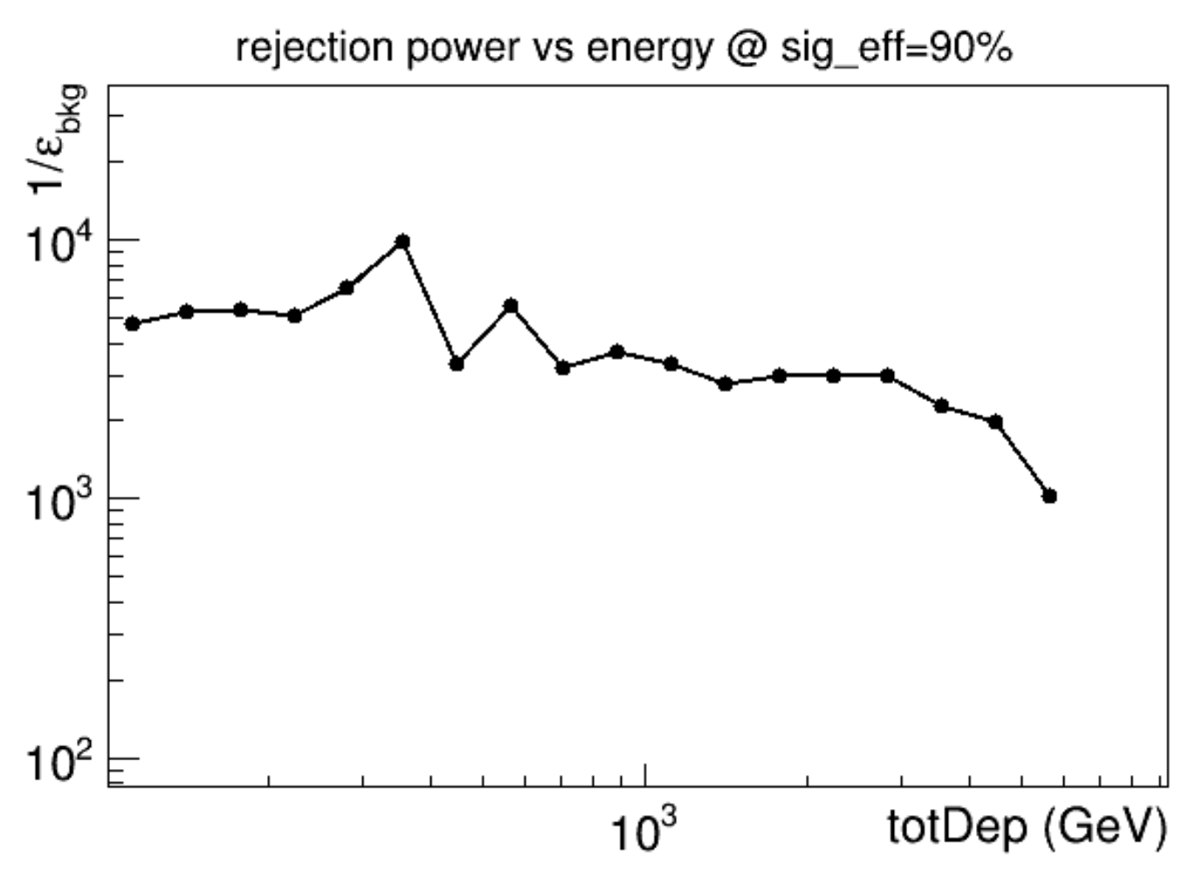




Rejection power

Cutting at different value of **nLogL/nHits** we obtain different level of **signal detection efficiency** (ε_{sig}) and **background suppression**($1/\varepsilon_{bkg}$).

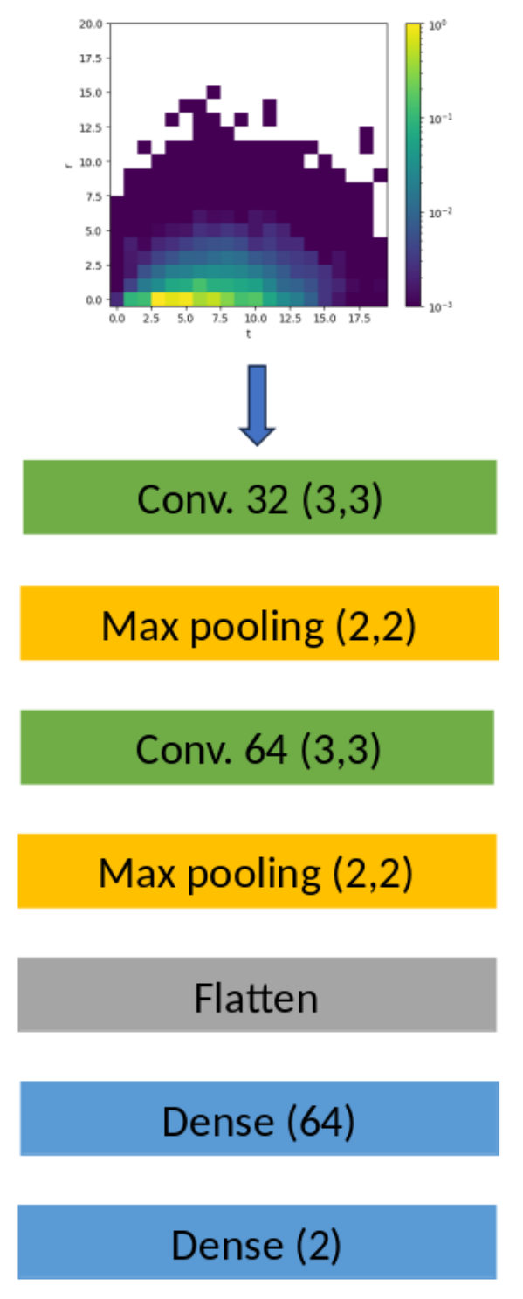


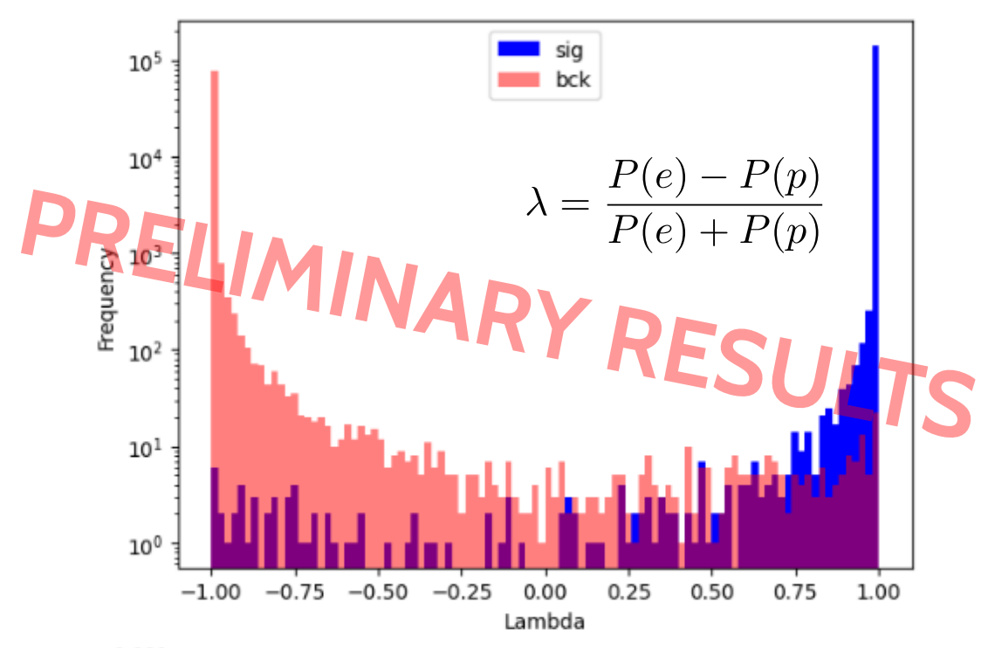


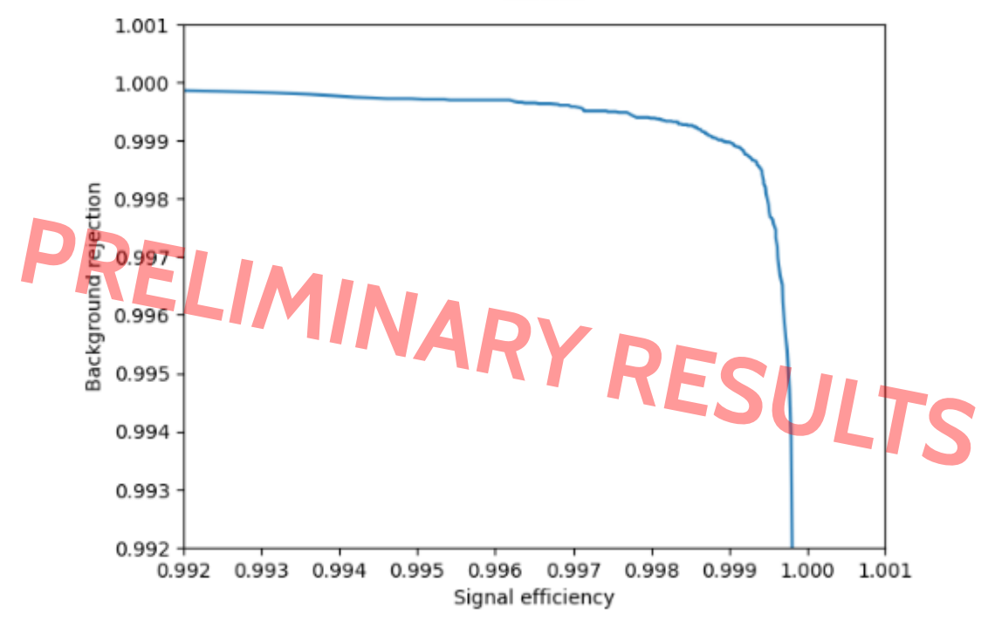
Fixing a **90% signal efficiency** we get a **rejection power >10^3** up to 5 TeV of deposited energy.

Alternative approach

The (t,r) map we get from a shower in the calorimeter is no different from a **simple picture.** Thus we can easily apply computer vision techniques such as **convolutional neural networks** to provide an independent tool for e/p discrimination based on the shape of the shower.







Future developments

The analysis technique is showing **promising results** but there are still many **steps forward** to take:

- **additional statistics** to be simulated to **improve the likelihood discrimination** at low energies
- **energy digitization** and **detector inefficiency** to be implemented in the simulation
- extension of results to **energies beyond 10 TeV** (requires **simulation of additional events**)

References

[1] Adriani O., et al. HERD proposal. https://indico.ihep.ac.cn/event/8164/material/1/0.pdf

[2] Adriani O., et al. Design of an Antimatter Large Acceptance Detector In Orbit (ALADInO). https://doi.org/10.3390/instruments6020019.

[3] Kirn, T., et al.The AMS-100 experiment: The next generation magnetic spectrometer in space. https://doi.org/10.1016/j.nima.2022.167215.

[4] Mori N., GGS: A Generic Geant4 Simulation package for small- and medium-sized particle detection experiments. https://doi.org/10.1016/j.nima.2021.165298.

We acknowledge the support of Agenzia Spaziale Italiana through ASI-INFN agreement No. 2021-43-HH.0