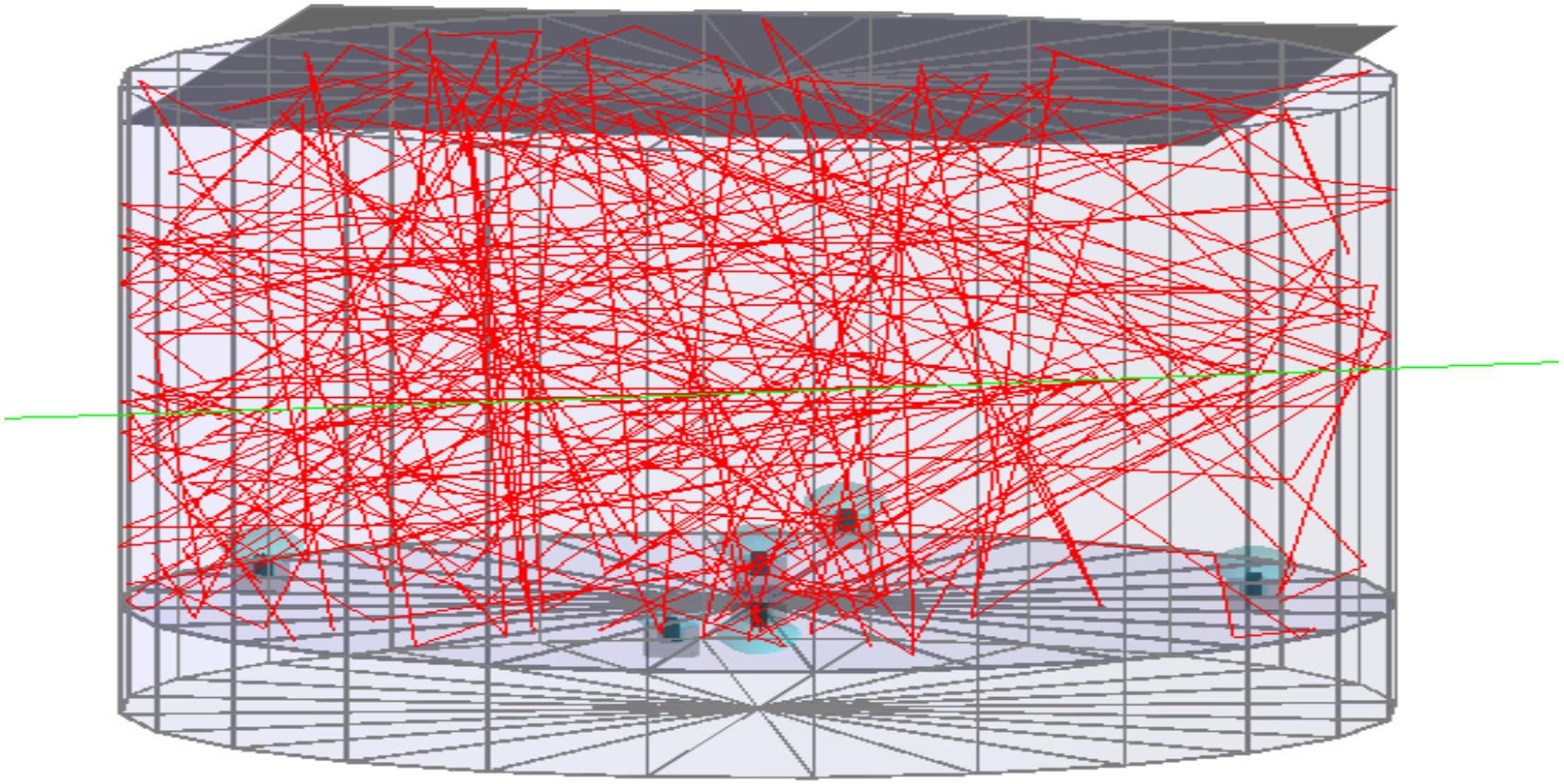
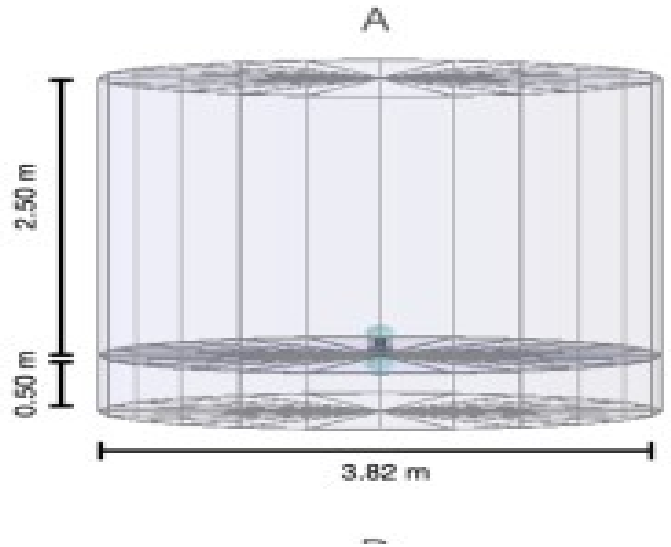
SWGO Framework with RPC

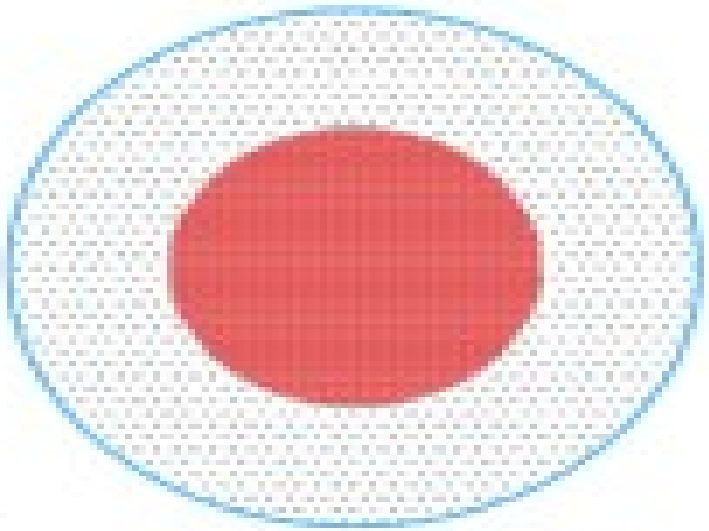
Fernanda Heredia, Claudio Casentini, Gonzalo Rodriguez



26/03/2025

SWGO Framework with RPC





- Double layer cilindrical tank with RPC

- A1 array layout as reference.

- We will focus on the inner array R=160m

SWGO Framework with RPC

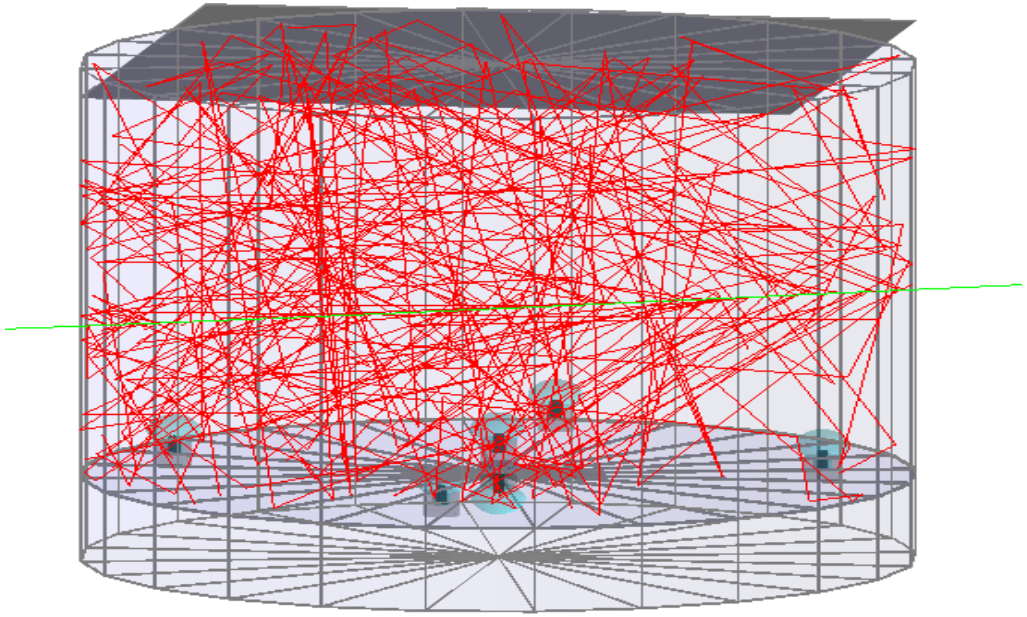
CORSIKA SIMULATIONS:

(http://swgo.umd.edu/)

Gamma → powerlaw with 5e7 events
Proton → powerlaw with 5e7 events

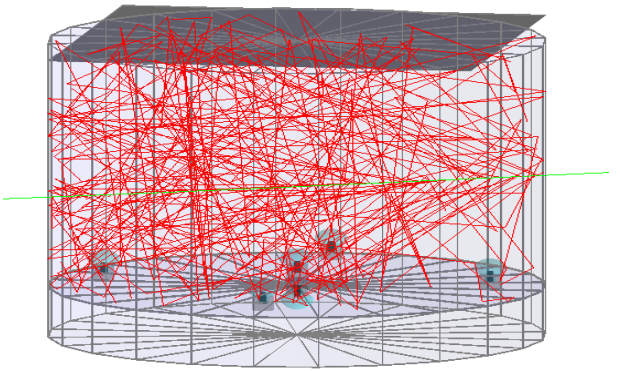
Gamma & Protons at fixed energy and zenith 20 deg.

100 GeV → 500K
200 GeV → 500K
500 GeV → 50K
1 TeV → 50K
2 TeV → 50K
5 TeV → 50K
10 TeV → 50K
100 TeV → 50K



SWGO Framework with RPC

PIPELINE



CORSIKA Simulation

SWGO Geant4 Simulation

Output SWGO format-sim

Python RPC Angular+LDF+had

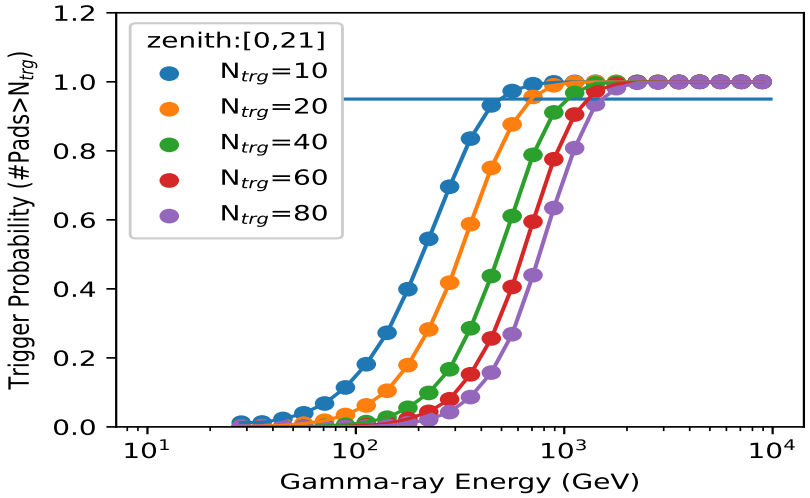
Output ASCII file – csv format

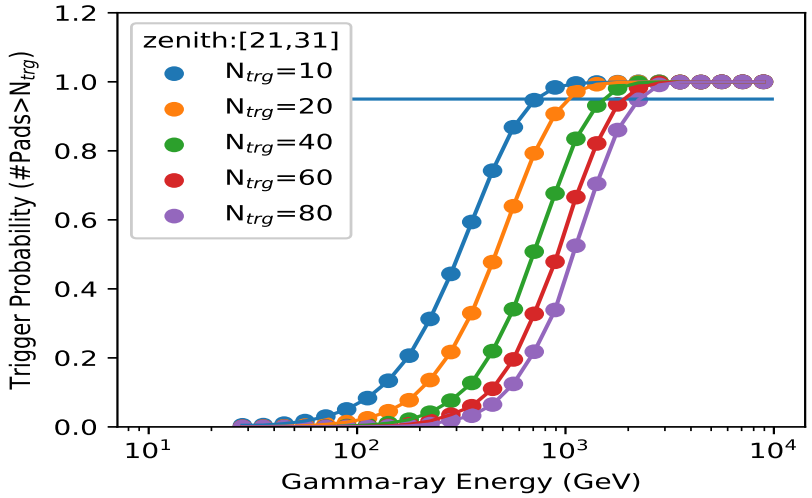
SWGO Tank Calibration & Rec

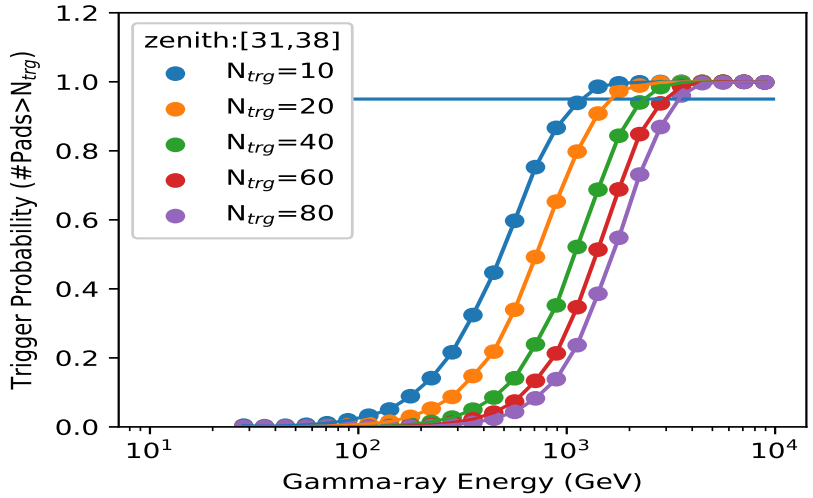
Output SWGO format-rec

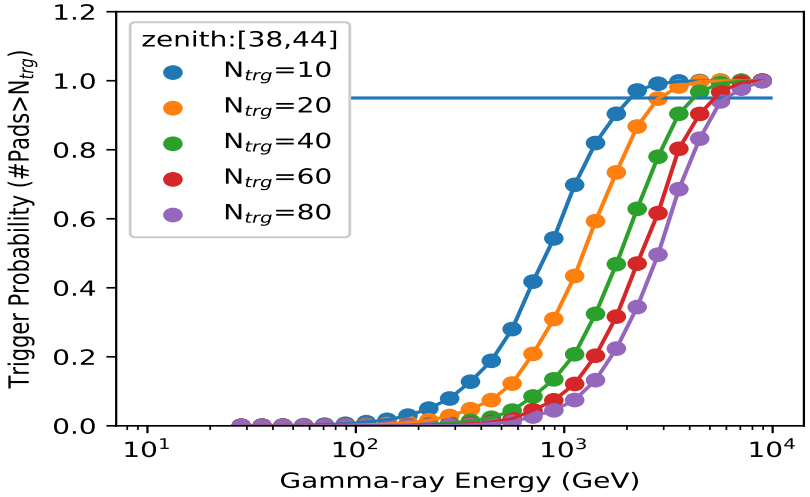
Merger RPC+SWGO – csv format

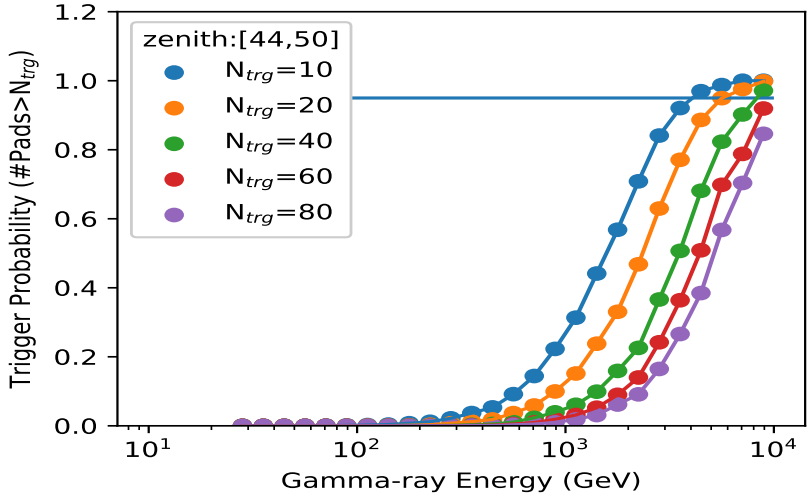
Trigger probabilty
Spectrum events



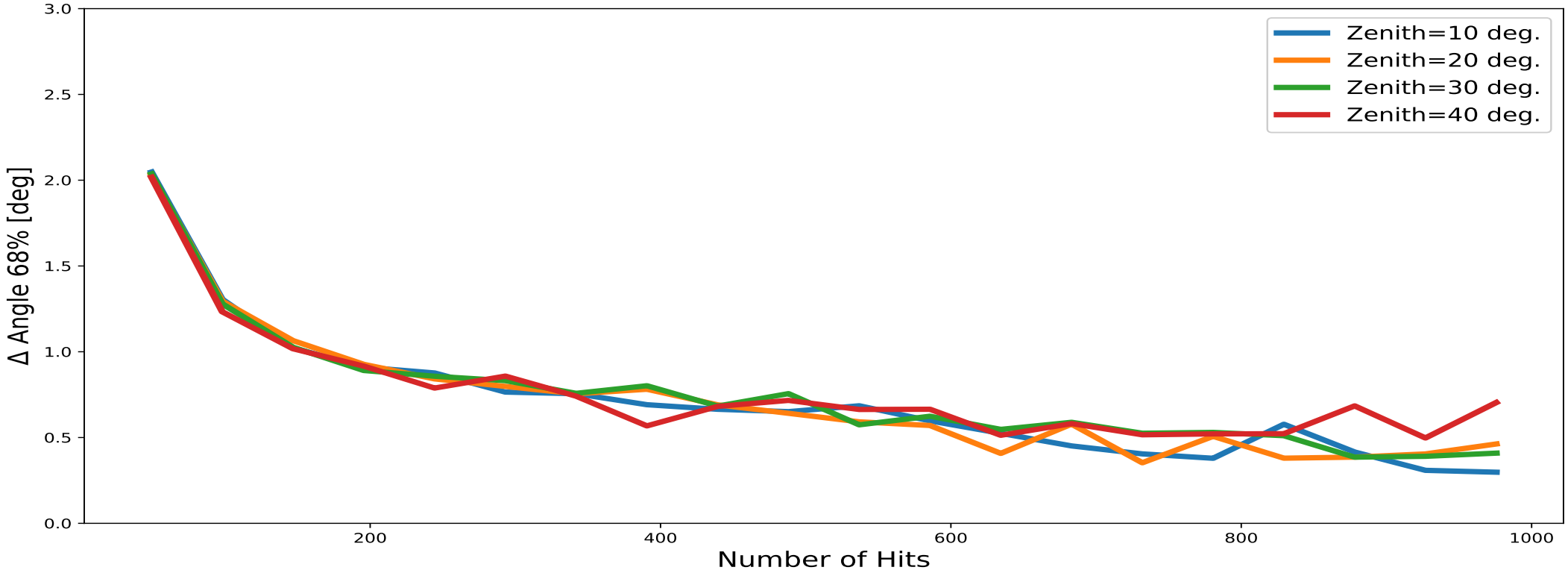








RPC Angular Reconstruction:
Plane fit + curve Fit



RPC Angular Reconstruction:
Curvature parameter

Gamma

Proton

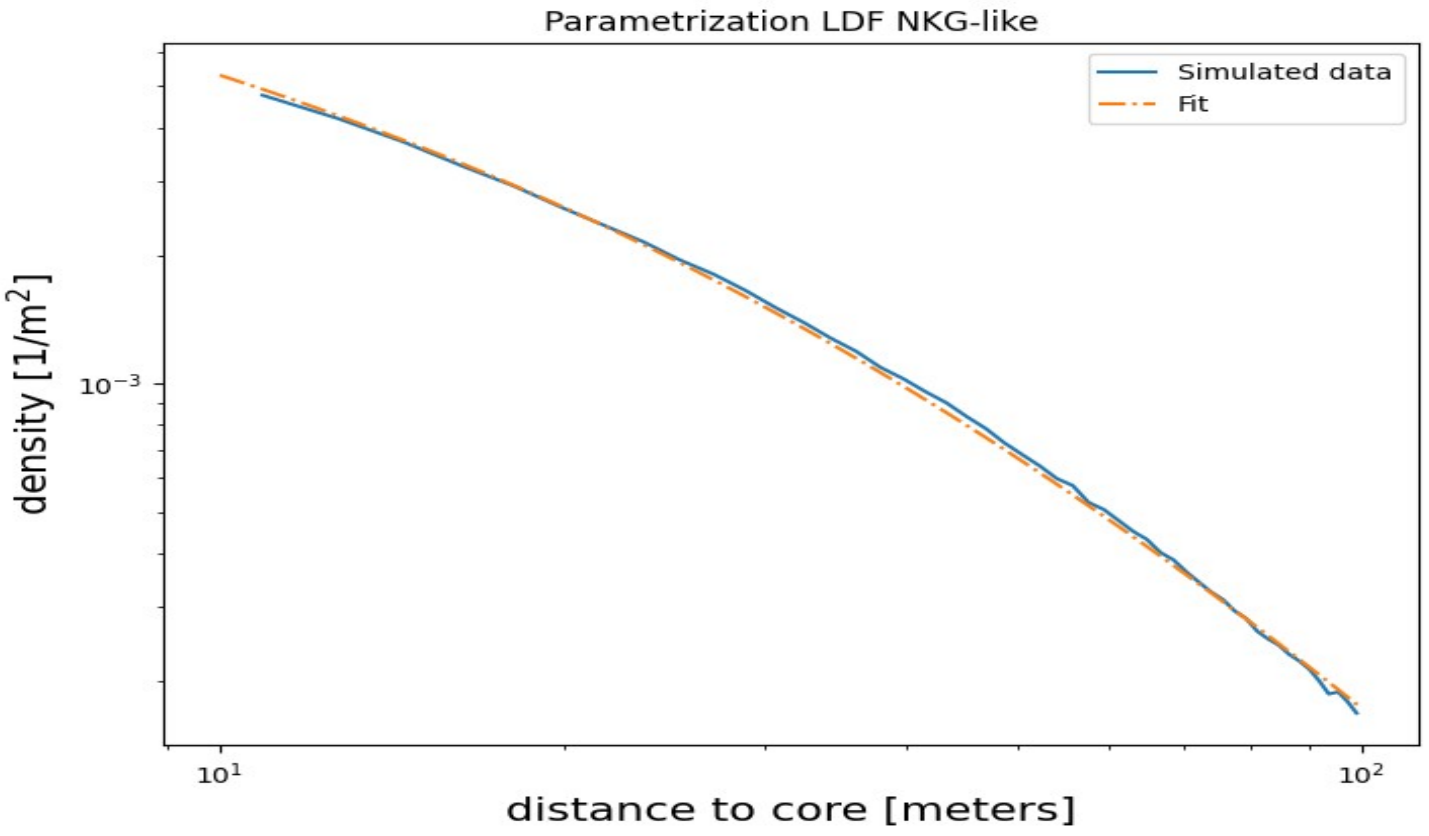
LDF reconstrution

$$\rho_2(r) = N_e C(s) \left(\frac{r}{r_0}\right)^{s-\alpha} \left(1 + \frac{r}{r_0}\right)^{s-\beta}$$

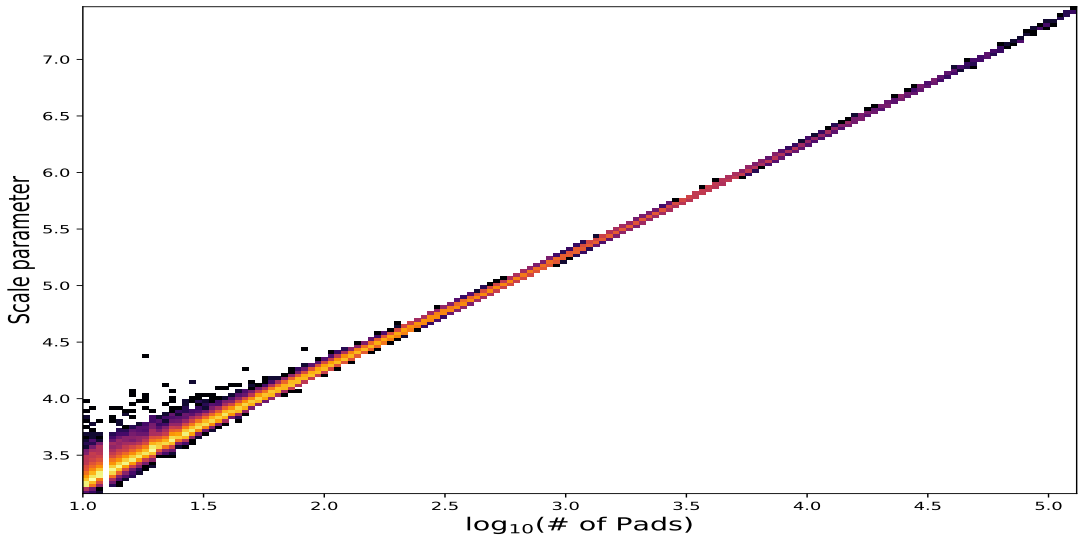
where

$$C(s) = \frac{1}{2\pi r_0^2} \times \frac{\Gamma(\beta - s)}{\Gamma(s - \alpha + 2)\Gamma(\alpha + \beta - 2s - 2)}$$

alpha= 1.5
beta=3.6
r0=35m



LDF reconstrution



zenith= 45^0

zenith= 0^0

Proton

Gamma

Gamma-Hadron separation Machine learning

- **Handling Complex Data**
  Experimental data exhibits non-linear relationships that traditional methods struggle to capture;

- **Learning Complex Patterns**
  Models like Random Forest and/or XGBoost are powerful to uncover intricate relationships between different features in order to effectively distinguish between Proton and Gamma events;

- **Automation & Adaptability**
  ML-based approaches automate the classification process, reduce human error, and adapt as new data becomes available.

- **Continuous Evaluation & Optimization**
  Performance metrics (accuracy, AUC, precision, recall) provide immediate feedback, enabling ongoing model improvements and informed decision-making.

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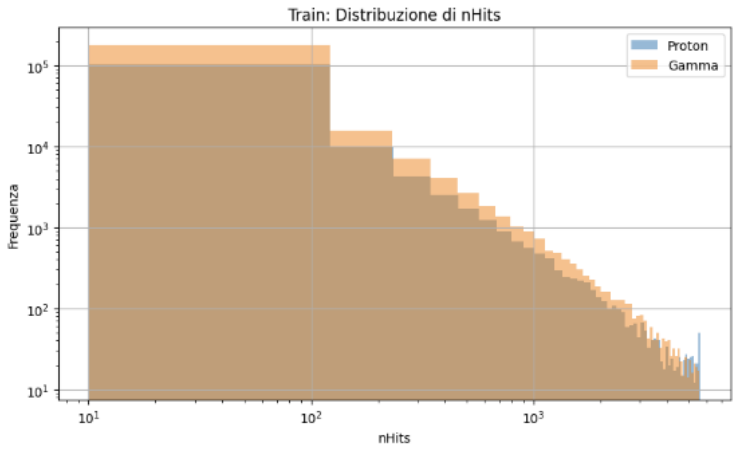
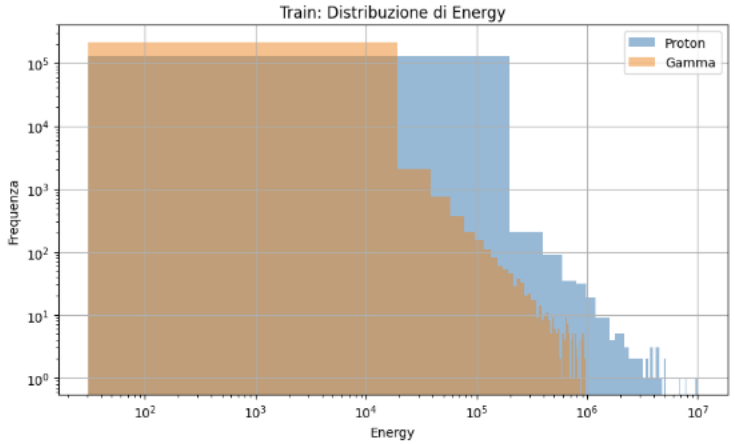
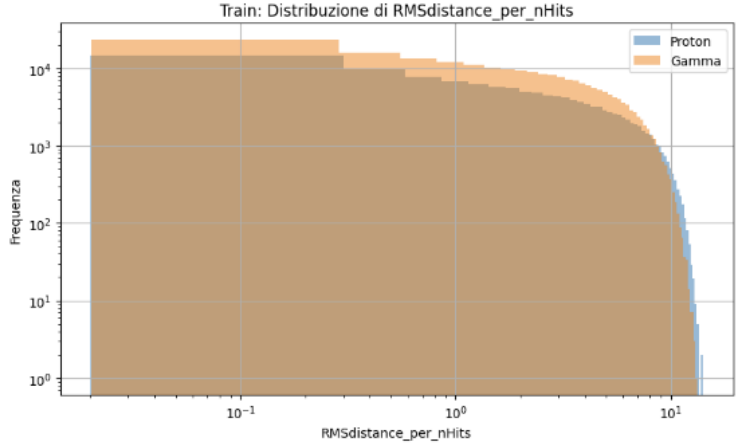
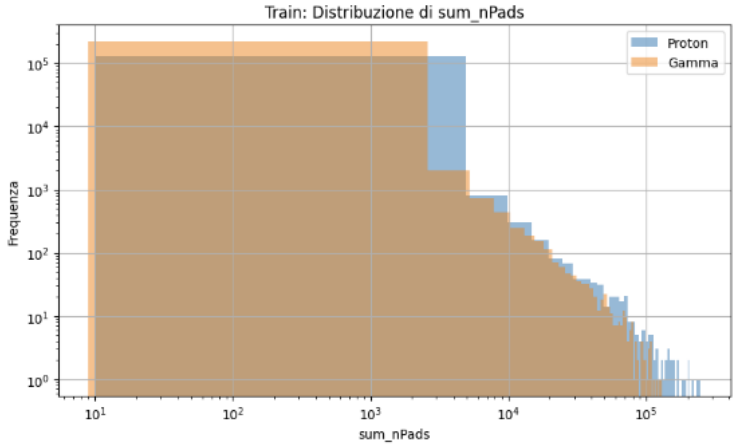
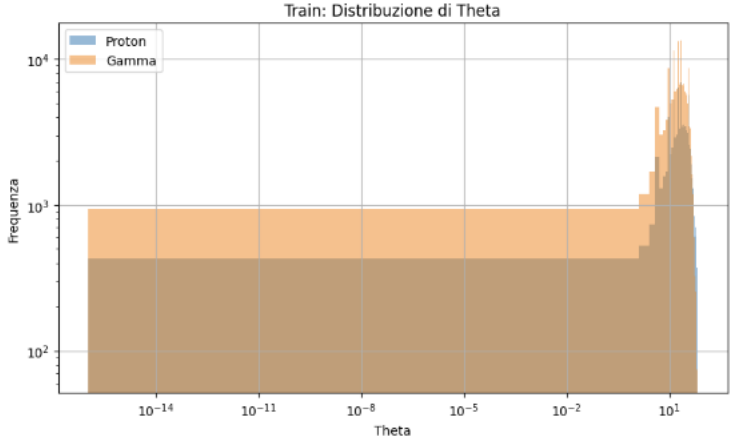
Gamma-Hadron separation

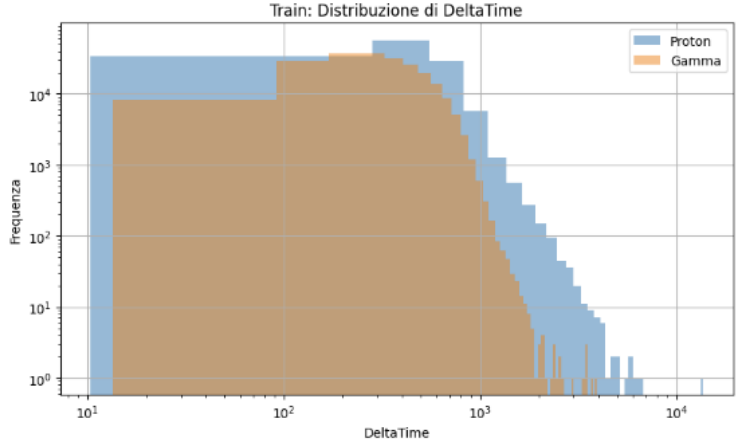












No clear separation using distributions of single variables

Gamma-Hadron separation Multivariate analysis

Multivariate Analysis: Variables & Their Combination

- **Event Intensity & Physical Parameters:**
  nHits: Total number of RPC hits in the event.
  sum_nPads & mean_nPads: Overall intensity measures, capturing the total and average number of activated pads.
  Energy, Theta, XMax: Event's energy, incident angle, and shower maximum depth.
- **Spatial Distribution Metrics:**
  RMSdistance: Root mean square distance of all hits from the event's centroid (computed from xRPC and yRPC).
  RMSdistance_per_nHits: Normalized RMS distance, dividing by the number of hits to adjust for event multiplicity.
- **Hit Concentration & Distribution Shape:**
  fractionHits20 & fractionHits40: Fractions of hits within 20 and 40 units from the centroid, indicating how concentrated the event is.
  skewDist & kurtDist: Statistical measures (skewness and kurtosis) of the hit distance distribution, reflecting asymmetry and tail behavior.
- **Temporal Spread:**
  DeltaTime: Time difference between the first and last hit, quantifying the event duration.
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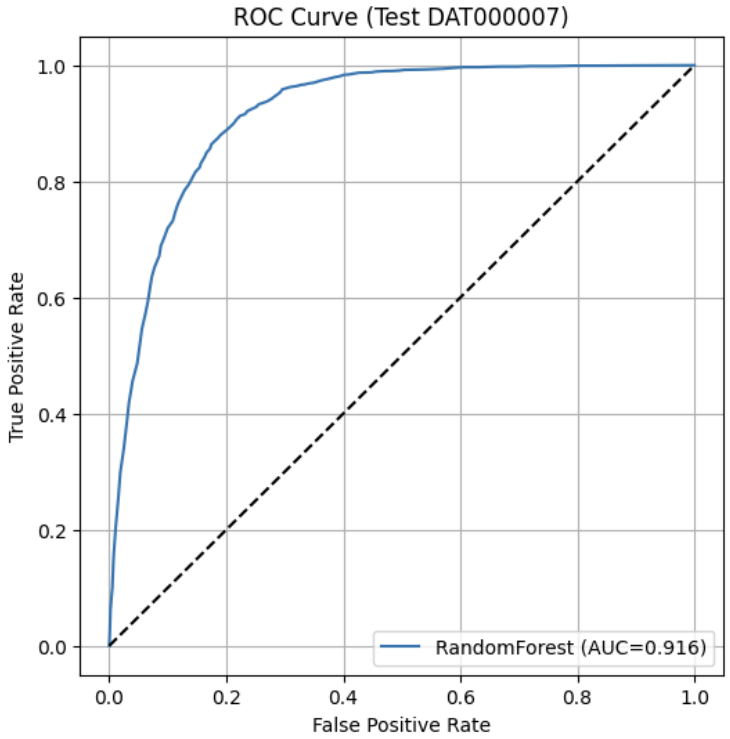
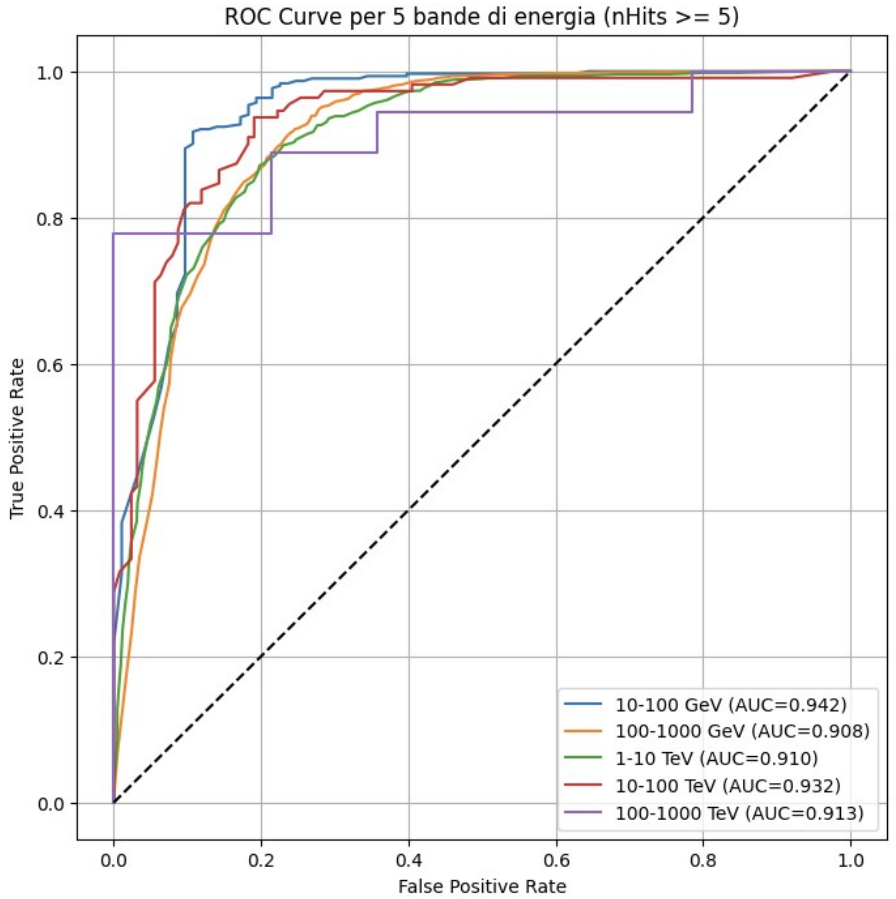
-
- **Combination Strategy:**
  By integrating geometric, intensity, and temporal features, the classifier can capture complex, non-linear correlations that a single parameter alone would miss—resulting in a more robust and discriminative model.

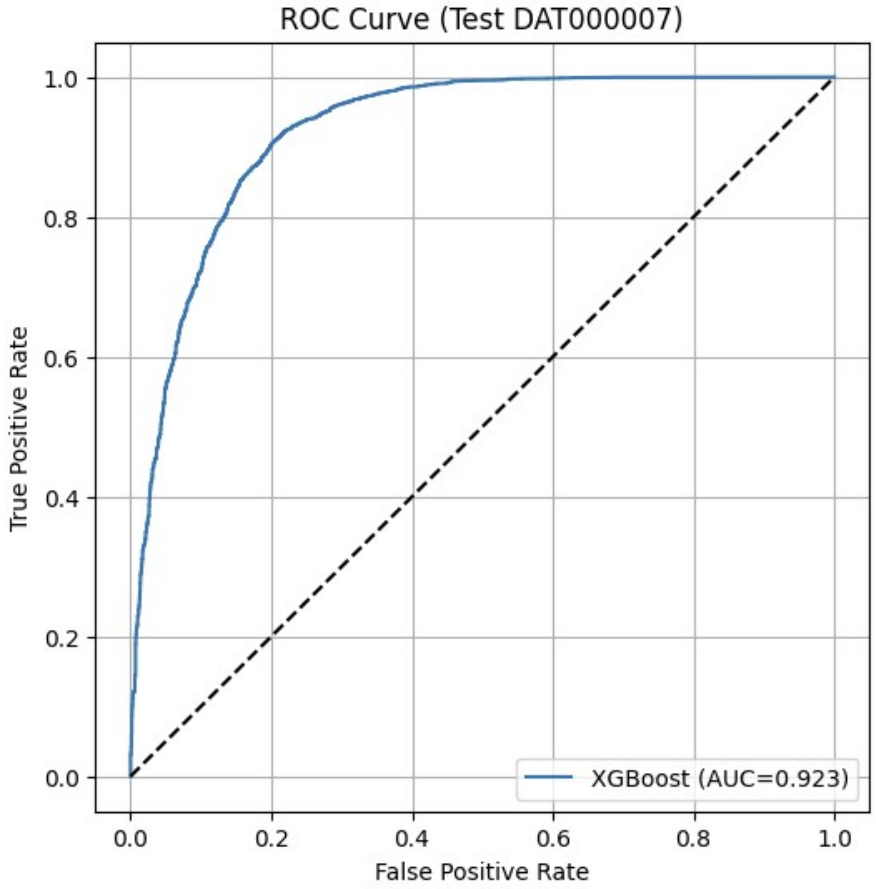
Gamma-Hadron separation
Random forest

```
Confusion Matrix (Test DAT000005):
[[1709  572]
 [ 282 3630]]

Classification Report (Test DAT000005):
              precision    recall  f1-score   support

      Proton       0.86      0.75      0.80      2281
       Gamma       0.86      0.93      0.89      3912

    accuracy                           0.86      6193
   macro avg       0.86      0.84      0.85      6193
weighted avg       0.86      0.86      0.86      6193
```





Gamma-Hadron separation XGBoost




```
Confusion Matrix (Test DAT000005):
[[1717  564]
 [ 245 3667]]

Classification Report (Test DAT000005):
              precision    recall  f1-score   support

      Proton       0.88      0.75      0.81      2281
       Gamma       0.87      0.94      0.90      3912

    accuracy                           0.87      6193
   macro avg       0.87      0.85      0.85      6193
weighted avg       0.87      0.87      0.87      6193
```

Gamma-Hadron separation
Future steps

- Include more dataset to the training -> from 100 datasets to 1000;
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- Include more parameter to the multivariate analysis, like the LDF;
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- Compare our results with the Gamma-Hadron separation of SWGO;

Gamma-Hadron separation
IACT method