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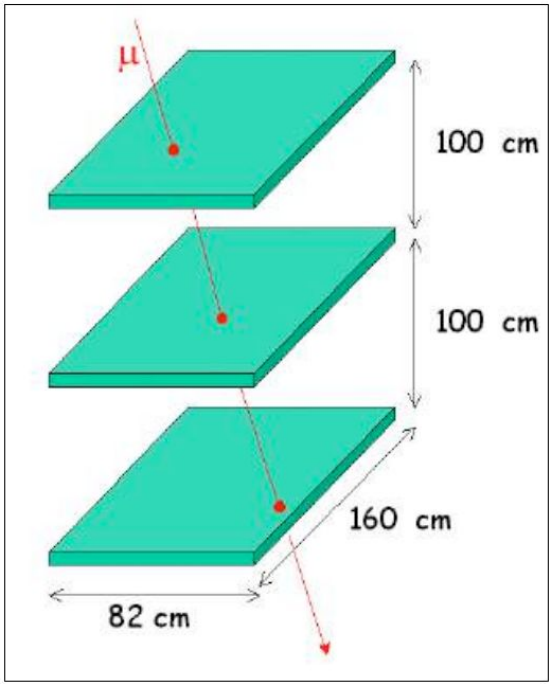
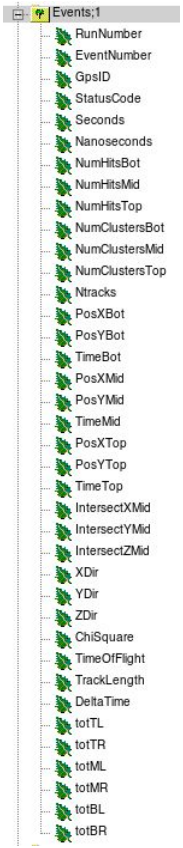
Unsupervised ML for χ^2

- Single Telescope (~Good Rate>15 Hz)
- `BOLO-01-2025-12-24-00001_dst.root`
- Single Telescope Analysis
- Learn χ^2 from Events Features

- Design Matrix X = Events Features
- Target Vector y = χ^2



Unsupervised ML for χ^2: Basic Features

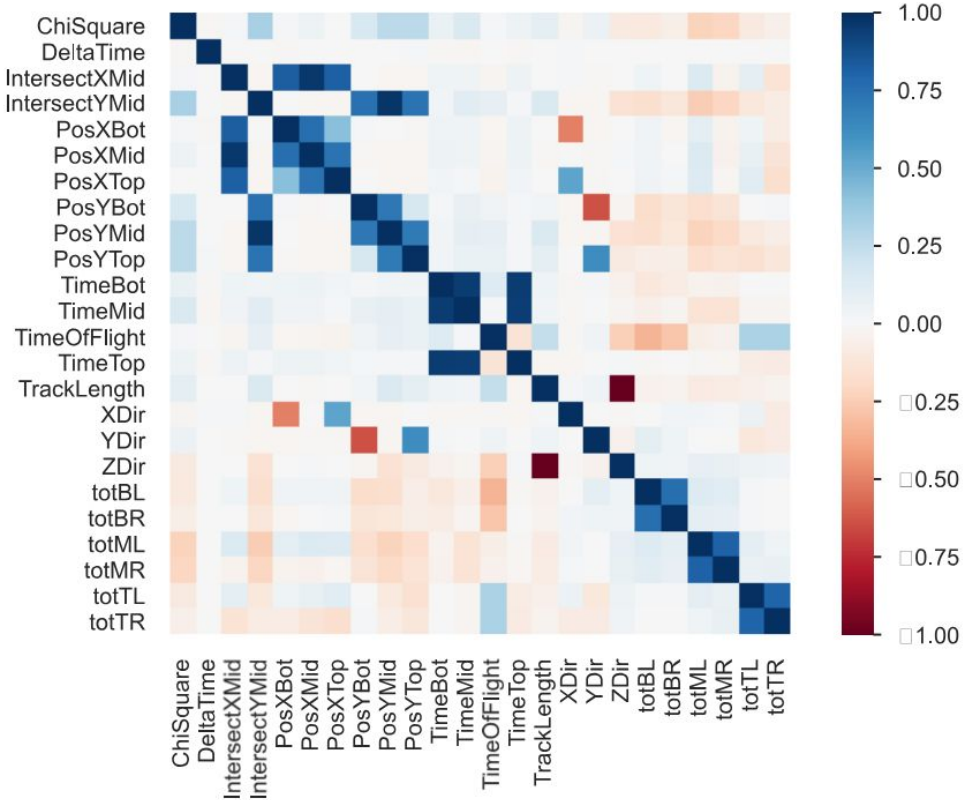


- Which Features in the Design Matrix X?
- Design Matrix over Events:
  - Ntracks = 1 Single Event
  - Ntracks >= 1 Showers
- Design Matrix over Tracks?
- Target y = χ^2 or y = log(χ^2)

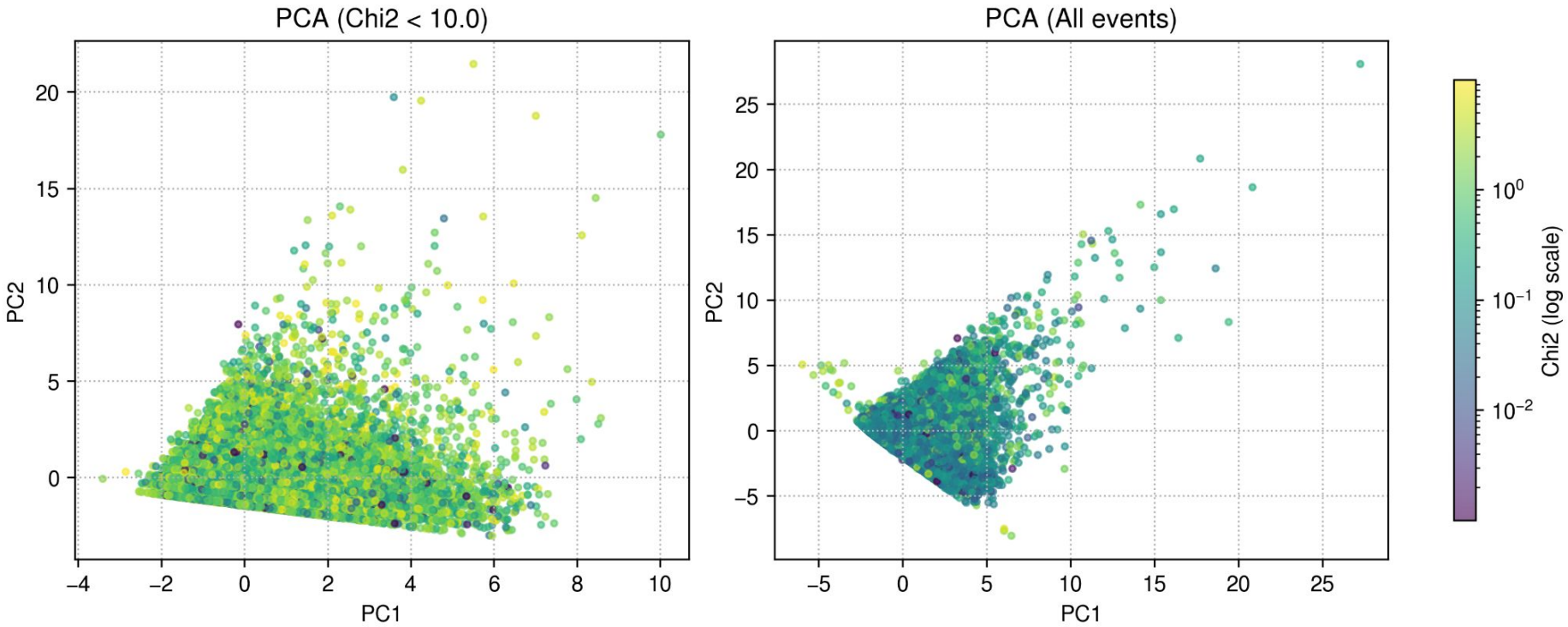
$$\begin{bmatrix} x_1^{(1)} & x_2^{(1)} & x_3^{(1)} & x_4^{(1)} \\ x_1^{(2)} & x_2^{(2)} & x_3^{(2)} & x_4^{(2)} \\ \vdots & \vdots & \vdots & \vdots \\ x_1^{(150)} & x_2^{(150)} & x_3^{(150)} & x_4^{(150)} \end{bmatrix}$$

Unsupervised ML for χ^2: Correlation Features

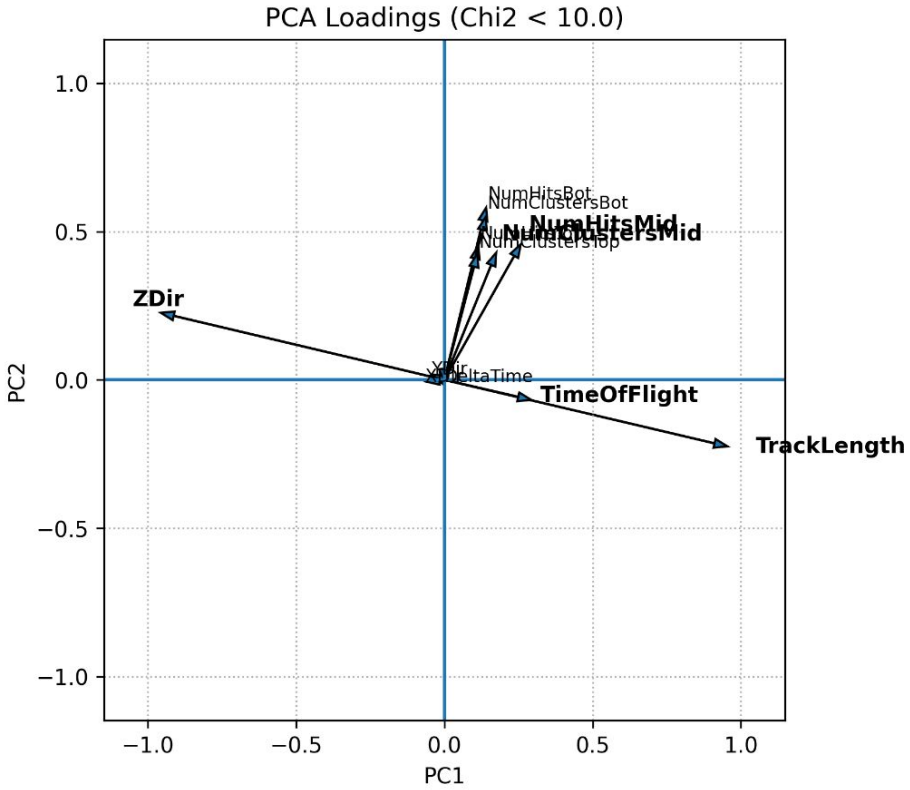
- Ntracks == 1 Single Event
- Target y = χ^2
- Features from Events tree
- Add T and P?

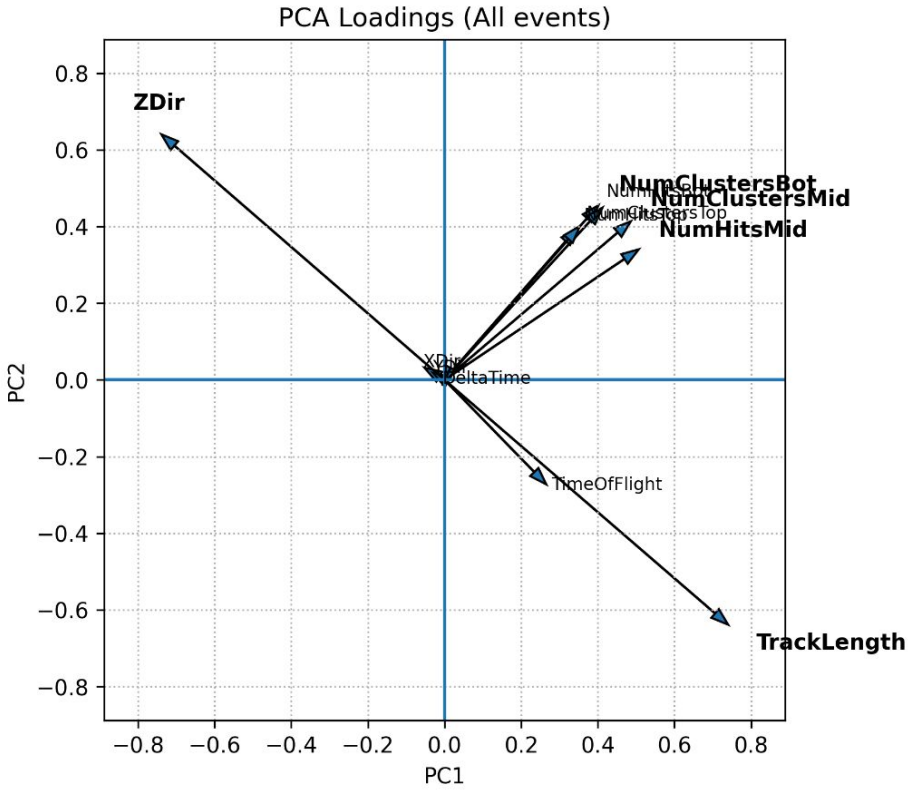


Unsupervised ML for χ^2: PCA Components



Unsupervised ML for χ^2: PCA Loadings





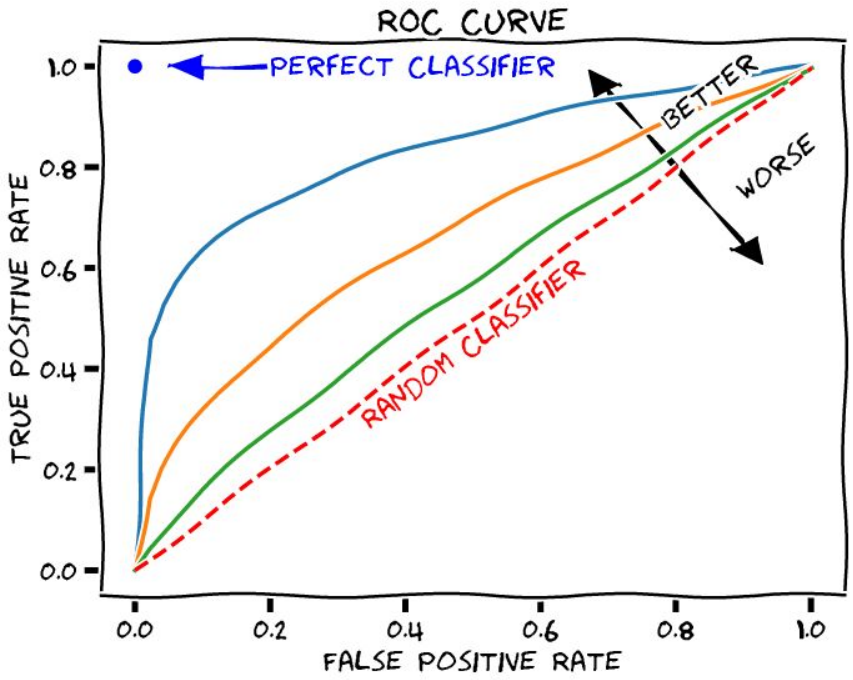
Unsupervised ML for χ^2: Features Classification

Features Classification:

- Linear
- Random Forest
- XGBoost

- TPR = TP / (TP + FN)
- FPR = FP / (FP + TN)
- AUC: area sotto la curva

Outcome Type	Prediction	Reality
True Positive (TP)	Anomaly	Anomaly
True Negative (TN)	Normal	Normal
False Positive (FP)	Anomaly	Normal
False Negative (FN)	Normal	Anomaly



Unsupervised ML for χ^2: Features Classification

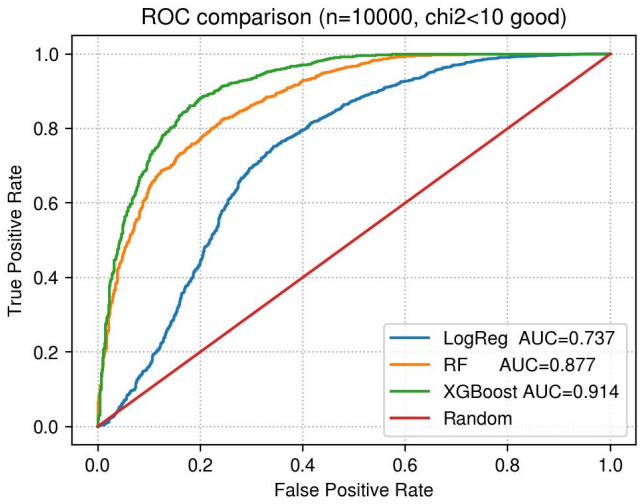
Features Classification:

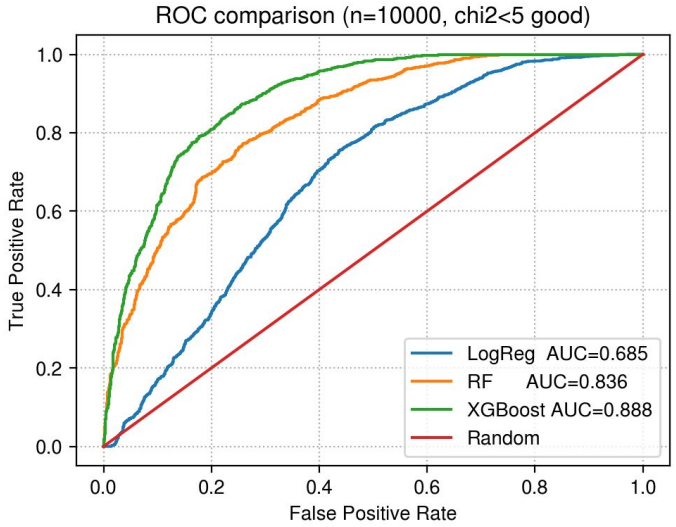
- Linear
- Random Forest
- XGBoost

```
=== Importances ===

[LogReg] Top coefficients (abs)
TimeMid                -2.046508
TrackLength            -1.295242
PosXMid                -1.014878
TimeBot                +0.967232
ZDir                   -0.936164
```

```
=== Importances ===

[RF] Top feature_importances_
IntersectYMid          0.179528
PosYMid                0.111862
PosYTop                0.062334
YDir                   0.059582
PosYBot                0.052446
```

```
=== Importances ===

[XGBoost] Top gain
IntersectYMid          2.696106e+01
PosYMid                1.753588e+01
IntersectXMid          9.044178e+00
PosYBot                7.199484e+00
PosXMid                6.082290e+00
```





Unsupervised ML for χ^2: Features Engineering

Combing features to improve classification:

- **Velocity**

$$\beta = \frac{\text{TrackLength}}{\text{TimeOfFlight} \times c}$$

- **Time Consistency**

$$\Delta T_{\text{check}} = \text{TimeMid} - \frac{\text{TimeTop} + \text{TimeBot}}{2}$$

- **Residuals Calculated**

$$X_{\text{exp}} = X_{\text{Bot}} + (X_{\text{Top}} - X_{\text{Bot}})$$
$$\text{Residual}_X = |X_{\text{Mid}} - X_{\text{exp}}|$$

- **Theta Zenith**

$$\theta = \arccos(|Z_{\text{Dir}}|)$$

- **TOT Asymmetry**

$$\text{Asym}_{\text{Top}} = |\text{totTL} - \text{totTR}|$$

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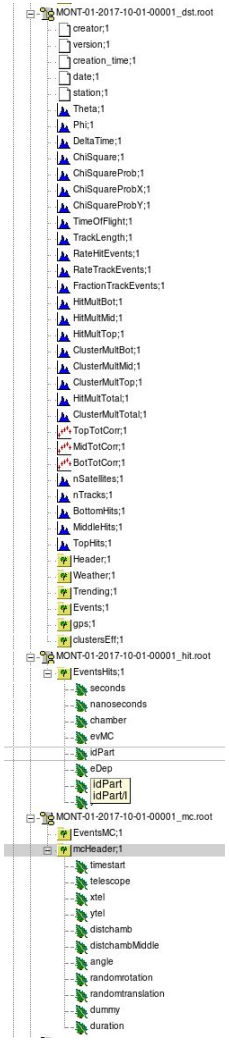
Supervised ML con Monte Carlo

MC Truth → Hit → Digit → DST

- **MC Truth:** informazioni ideali
- **Hit:** interazioni nei piani MRPC
- **Digit:** Digitalizzazione elettronica
- **DST:** Data Summary Tree



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