



A novel approach for \overline{He} research in cosmic rays with Neural Networks

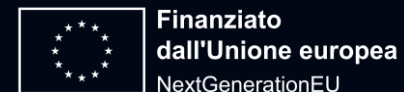
Francesco Rossi^{1,2}, Paolo Zuccon^{1,2}

¹ University of Trento, Trento, Italy

² TIFPA-INFN, Trento, Italy

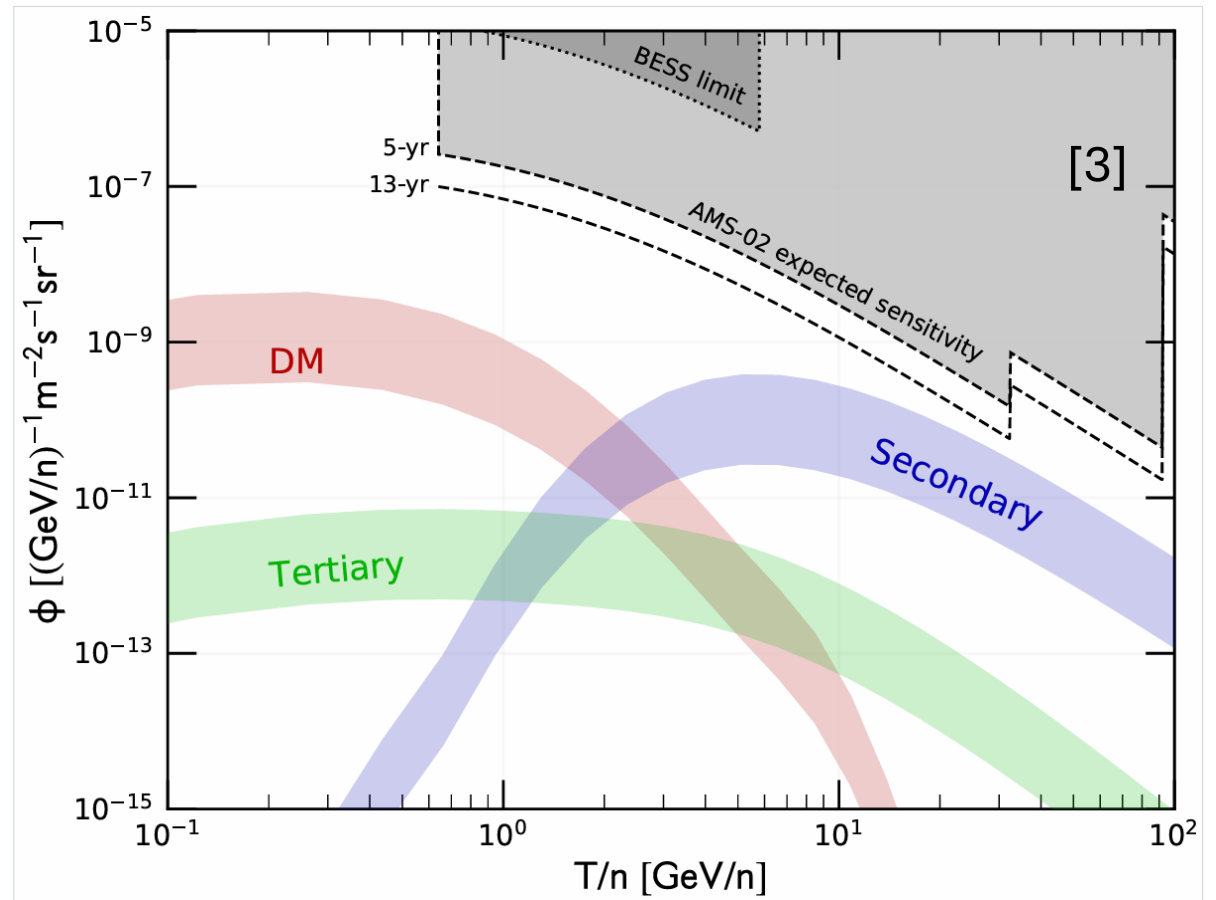


ICHEP 2024



The rationale

- Anti-nuclei heavier than \bar{d} are unlikely to be formed during cosmic rays (CRs) propagation, as confirmed by the **PHENIX** [1] and **ALICE** [2] collaborations.
- \overline{He} observations could be related to **Dark Matter** interactions or **primordial origin**.
- **The main background is He nuclei misidentified as \overline{He} .**
- **The Alpha Magnetic Spectrometer claims few \overline{He} candidates. Our work focuses on developing a classifier to study each possible \overline{He} event.**



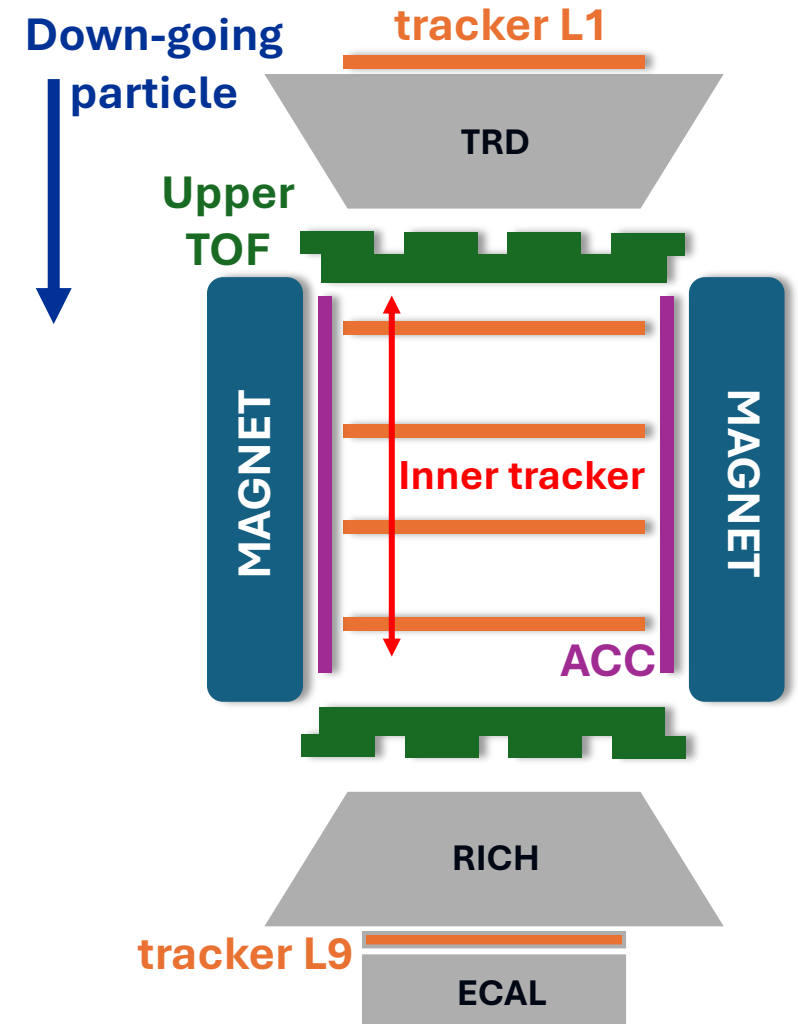
[1] Phys. Rev. Lett. 94, 122302 (2005)

[2] Measurement of anti- 3He nuclei absorption in matter and impact on their propagation in the Galaxy

[3] Prospects to verify a possible dark matter hint in cosmic antiprotons with antideuterons and antihelium

Monte Carlo simulation of He events

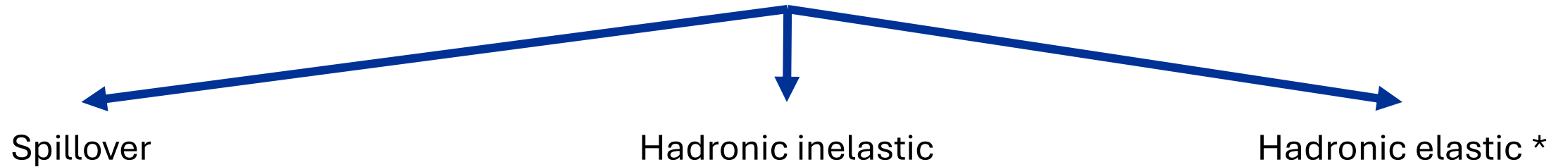
- Only events of 4He nuclei are simulated.
- The Monte Carlo simulation mimics the response of an **AMS-02-like detector**
- The Alpha Magnetic Spectrometer (AMS-02 [4]) is a particle physics detector operating on the International Space Station (ISS).
- Only the responses of the **Silicon Tracker (TRK)**, the **Time of Flight (TOF)** and the **Anti-Coincidence system (ACC)** are simulated.



[4] The Alpha Magnetic Spectrometer on the International Space Station

Sources of charged confused events

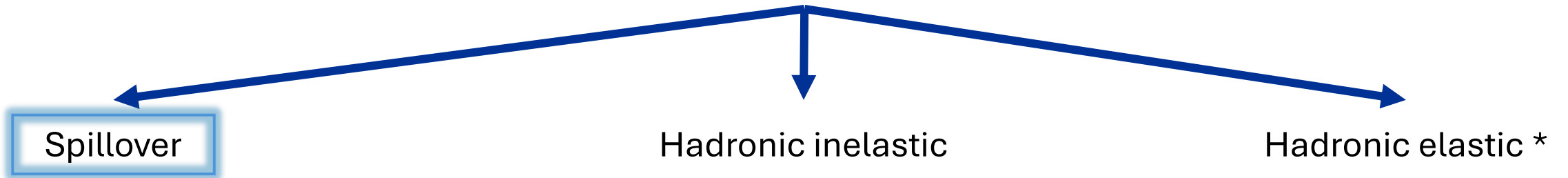
Selecting the **reconstructed events with the wrong rigidity sign** ($R = \frac{p}{Z}$), we identified **three sources of charge confusion**



* Large angle scattering

Sources of charged confused events

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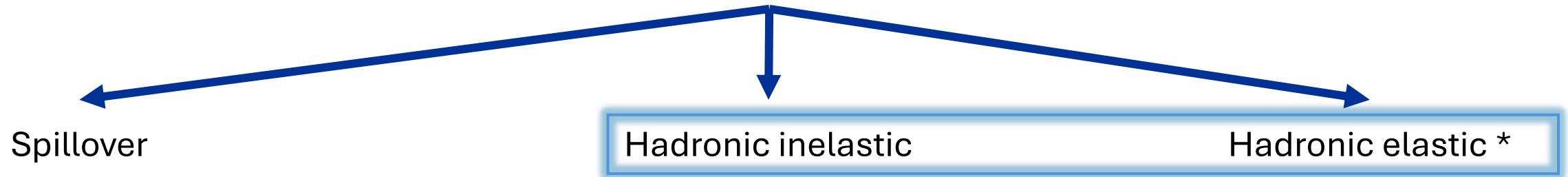


Silicon tracker finite resolution

* Large angle scattering

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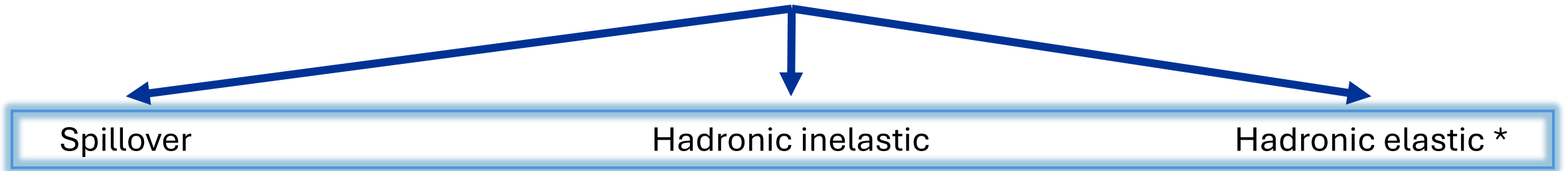


Interactions within the detector

* Large angle scattering

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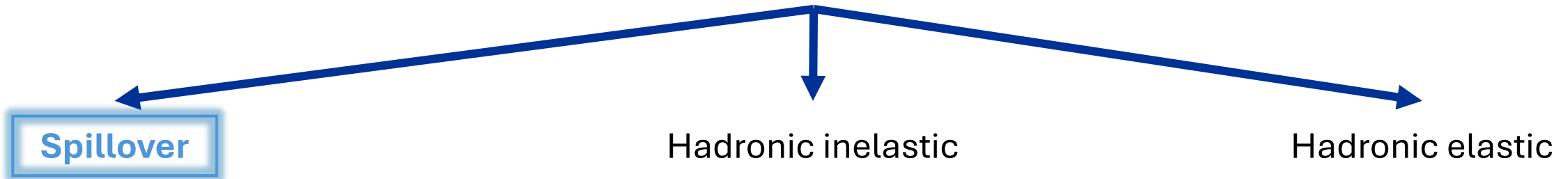


For each source, we select a sample to be used in the training of a Fully Connected Neural Network

* Large angle scattering

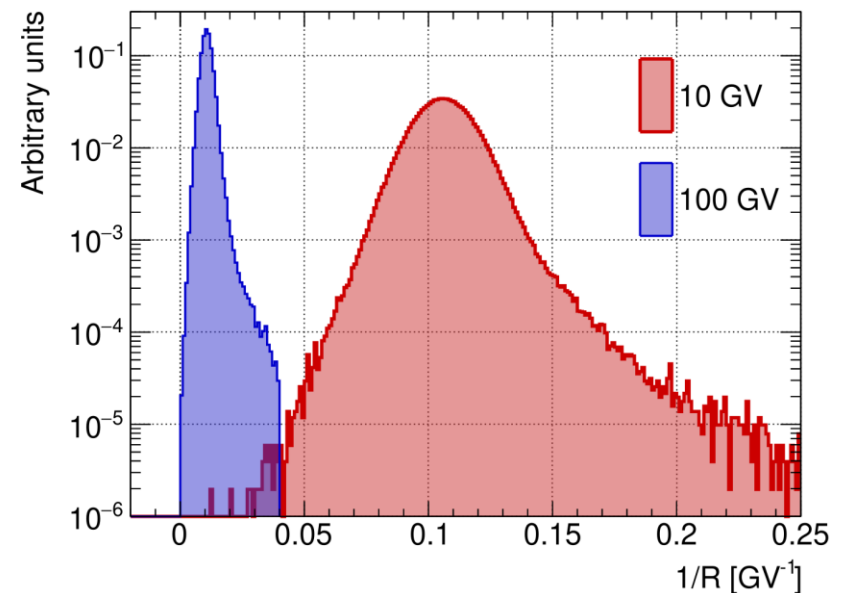
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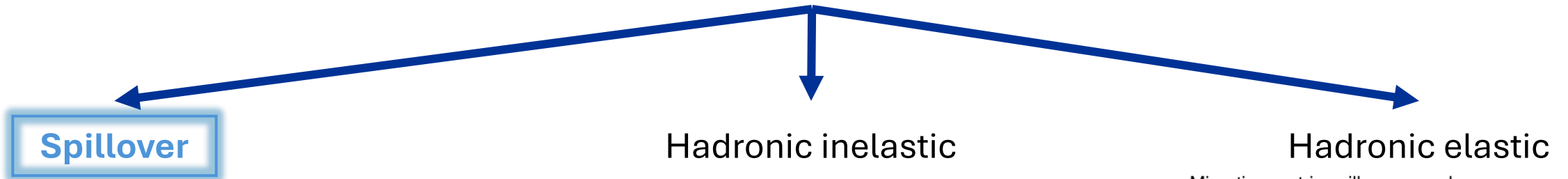
The tracker measures $\frac{1}{R}$, thus higher R have the expected distribution's mean closer to 0.

The probability of measuring $\frac{1}{R} < 0$ increases with R leading to an enhancement of charged confused events.



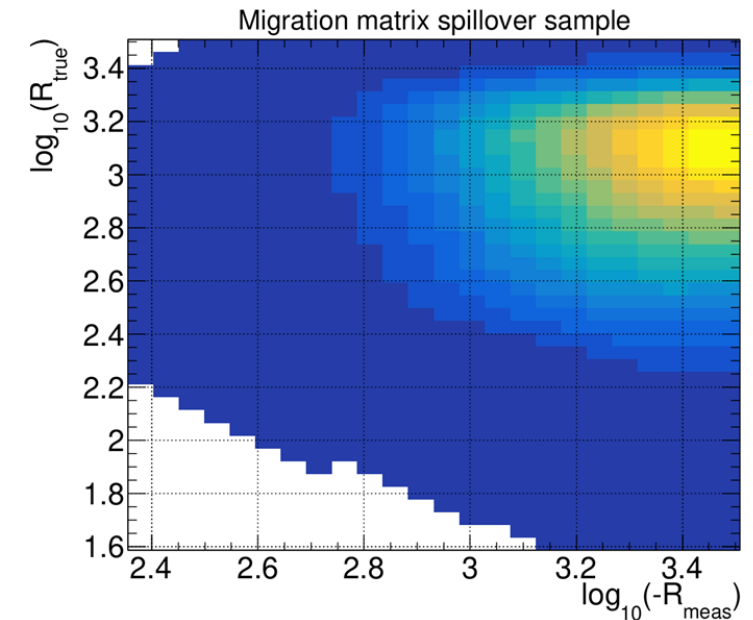
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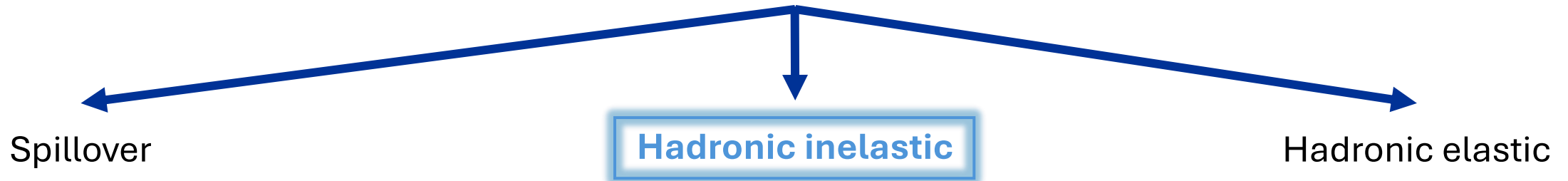
Sample selection:

- no interactions within the inner tracker
- high energy events



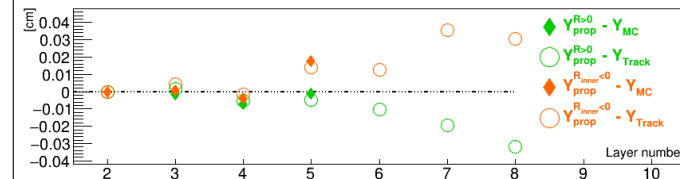
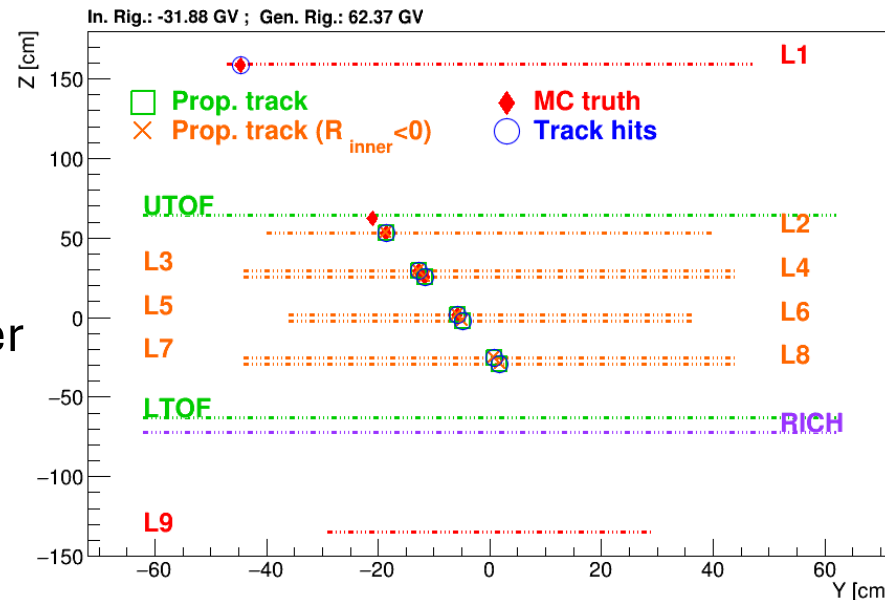
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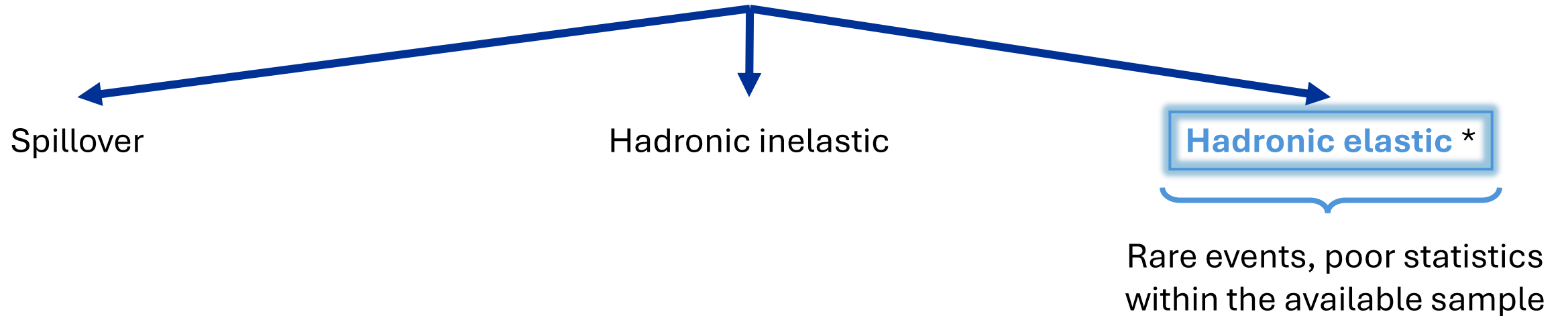
Sample selection:

- MC interaction flag
- interaction within the inner tracker



Sources of charged confused events

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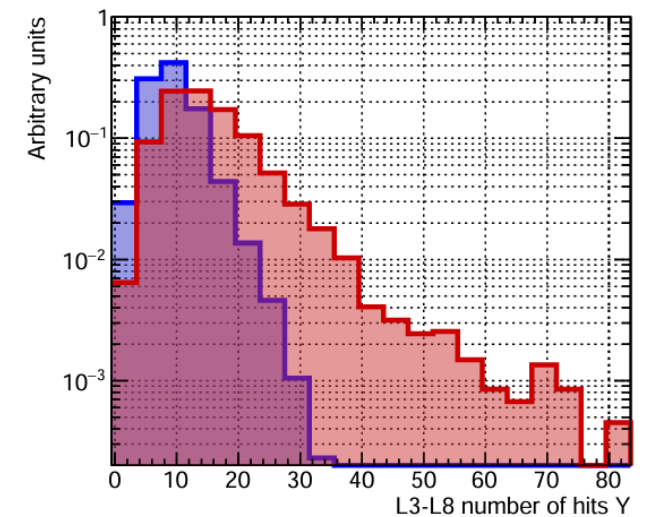
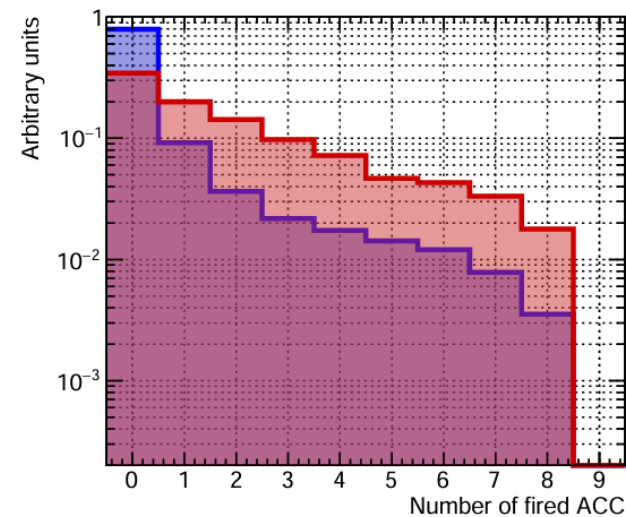
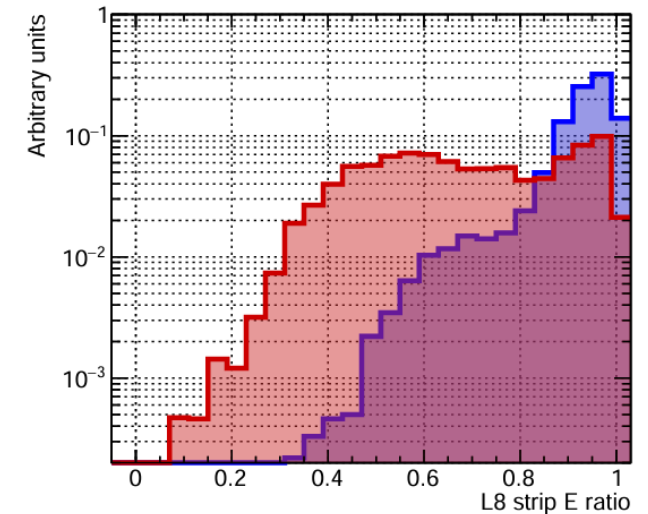
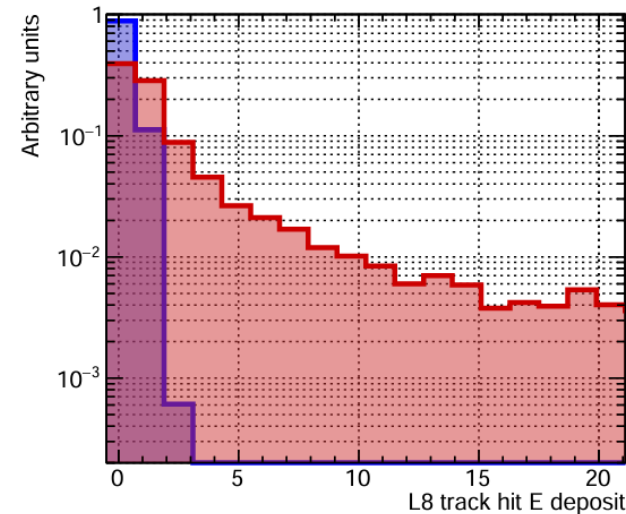
* Large angle scattering

Input features for Fully Connected Neural Network (FCNN)

12 optimized input features feed the FCNN

- Track hit energy deposition on L8.
- Ratio between strip energy deposition and its neighbouring 10 strips, on L8.
- Number of fired ACC.
- Number of hits in inner tracker (L3-L8).

Spillover ■
Had. Inel ■

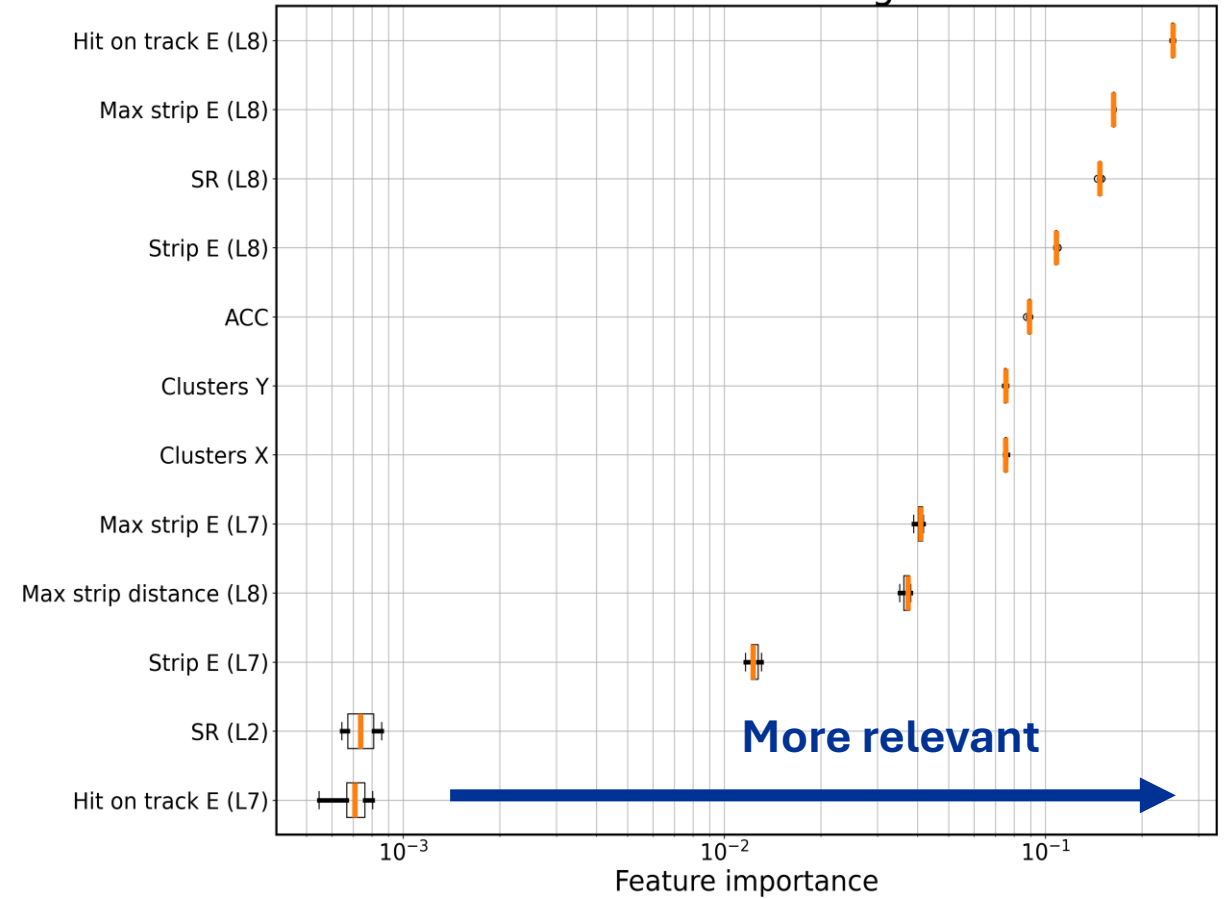


Correlation matrix and features ranking

Correlation matrix

Hit on track E (L8)	1.00	-0.04	0.17	-0.10	-0.11	-0.04	-0.08	-0.08	-0.15	-0.11	-0.08	-0.14
Max strip E (L8)	-0.04	1.00	-0.08	0.05	0.05	0.02	0.04	0.04	0.07	0.05	0.04	0.07
SR (L8)	0.17	-0.08	1.00	-0.21	-0.21	-0.08	-0.17	-0.17	-0.30	-0.22	-0.17	-0.28
Strip E (L8)	-0.10	0.05	-0.21	1.00	0.13	0.05	0.10	0.10	0.18	0.13	0.10	0.17
ACC	-0.11	0.05	-0.21	0.13	1.00	0.05	0.10	0.10	0.19	0.13	0.11	0.17
Clusters Y	-0.04	0.02	-0.08	0.05	0.05	1.00	0.04	0.04	0.07	0.05	0.03	0.06
Clusters X	-0.08	0.04	-0.17	0.10	0.10	0.04	1.00	0.08	0.14	0.11	0.08	0.13
Max strip E (L7)	-0.08	0.04	-0.17	0.10	0.10	0.04	0.08	1.00	0.15	0.10	0.08	0.13
Max strip distance (L8)	-0.15	0.07	-0.30	0.18	0.19	0.07	0.14	0.15	1.00	0.18	0.14	0.24
Strip E (L7)	-0.11	0.05	-0.22	0.13	0.13	0.05	0.11	0.10	0.18	1.00	0.10	0.17
SR (L2)	-0.08	0.04	-0.17	0.10	0.11	0.03	0.08	0.08	0.14	0.10	1.00	0.13
Hit on track E (L7)	-0.14	0.07	-0.28	0.17	0.17	0.06	0.13	0.13	0.24	0.17	0.13	1.00
	Hit on track E (L8)	Max strip E (L8)	SR (L8)	Strip E (L8)	ACC	Clusters Y	Clusters X	Max strip E (L7)	Max strip distance (L8)	Strip E (L7)	SR (L2)	Hit on track E (L7)

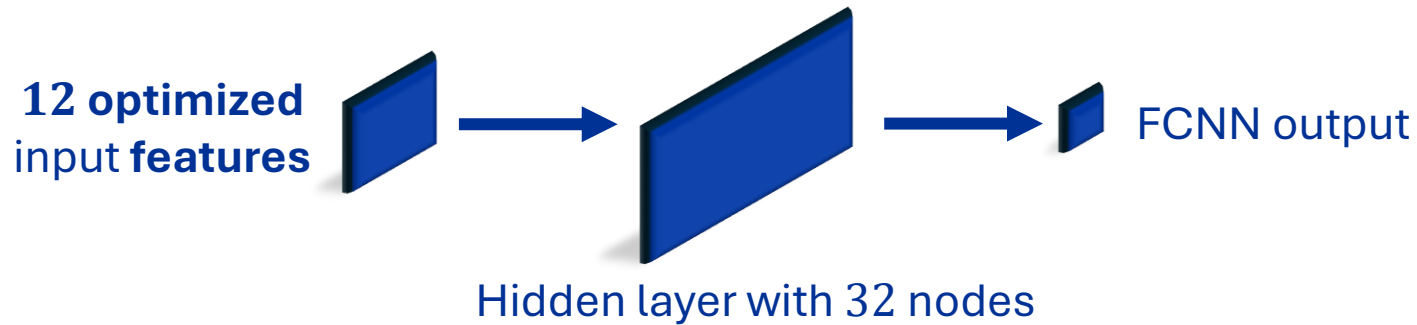
Feature ranking



Fully Connected Neural Network (FCNN) for classification

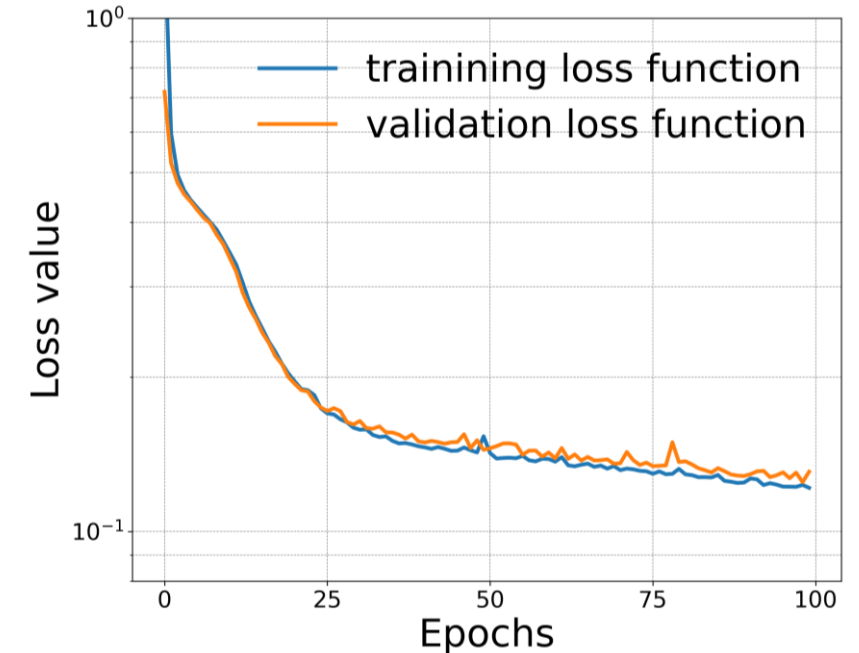
- **FCNN structure:**

- PyTorch
- Three linear layers: 12 nodes, 32 nodes, 1 node.



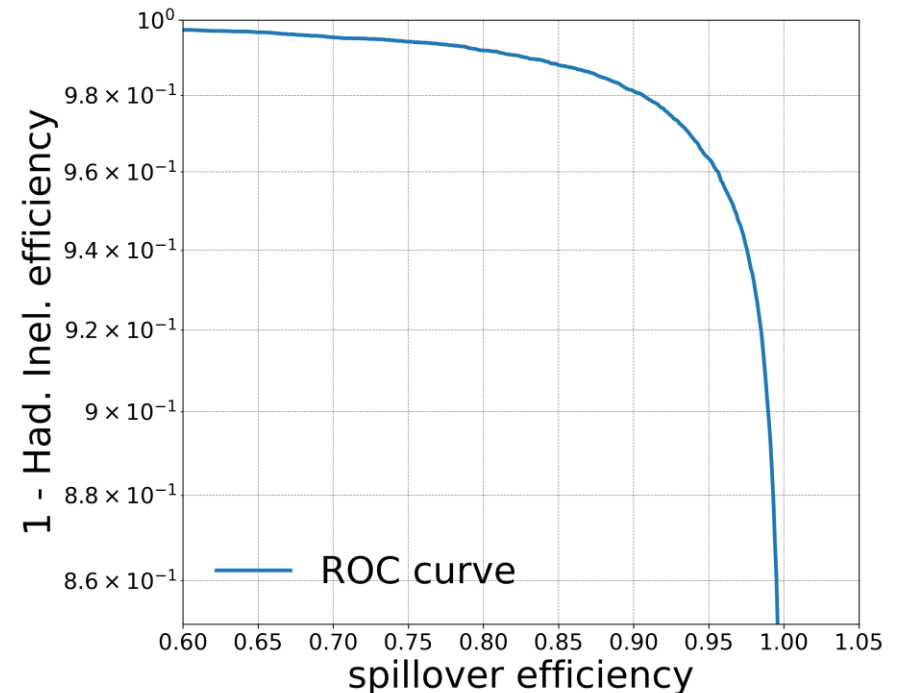
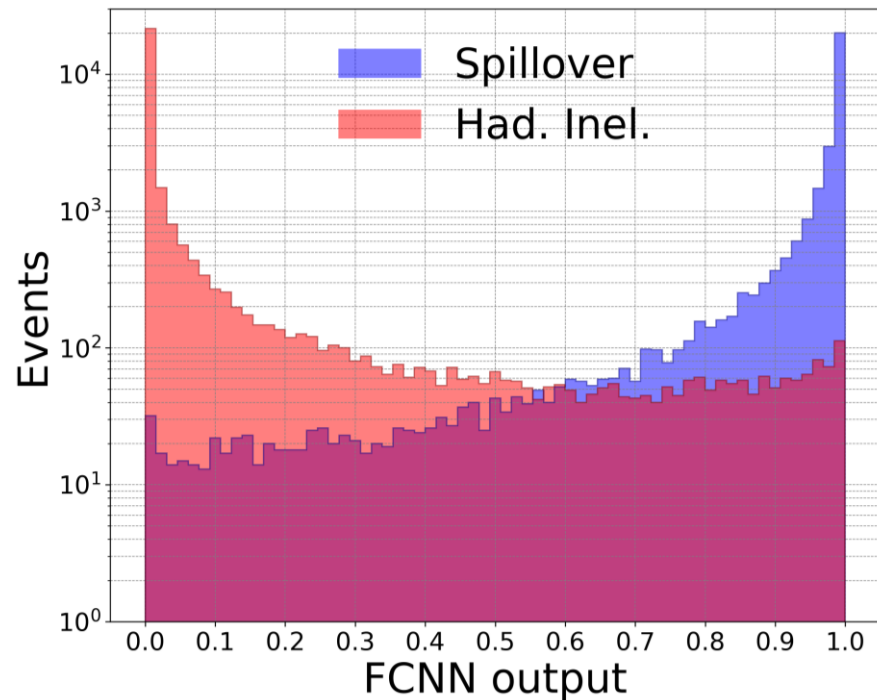
- **FCNN hyperparameters:**

- Optimizer: Adam
- Learning rate: $1.0 \cdot 10^{-3}$
- Batch size: $2.5 \cdot 10^3$
- Loss function: Binary Cross Entropy



FCNN classifier performance

- **Training sample: $1.4 \cdot 10^5$ events**
- **Validation sample: $0.6 \cdot 10^5$ events.**
- 50% spillover and 50% inelastic interaction events.
- The **output of the FCNN** is a number $\in [0,1]$, corresponding to the **probability that an event is spillover**.



Conclusions

- We developed a Monte Carlo toy of **pure He events**.
- We found **three different sources of charge confusion**.
- With the available statistics, a **FCNN classifier** was trained showing good performances in **distinguishing between spillover and inelastic interaction events**.

Prospects

- Train the classifier on hadronic inelastic interactions.
- **More statistic is required** to add one more class to the FCNN classifier.
- Detailed study of the classifier behaviour.
- Applying the same selection and classifier to the real data it will be possible to **reduce the He background for the research for \overline{He} in cosmic rays**.

Supernova explosion



He
nuclei

Interstellar
medium

International
Space Station



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Thank you for your attention!

Supernova explosion



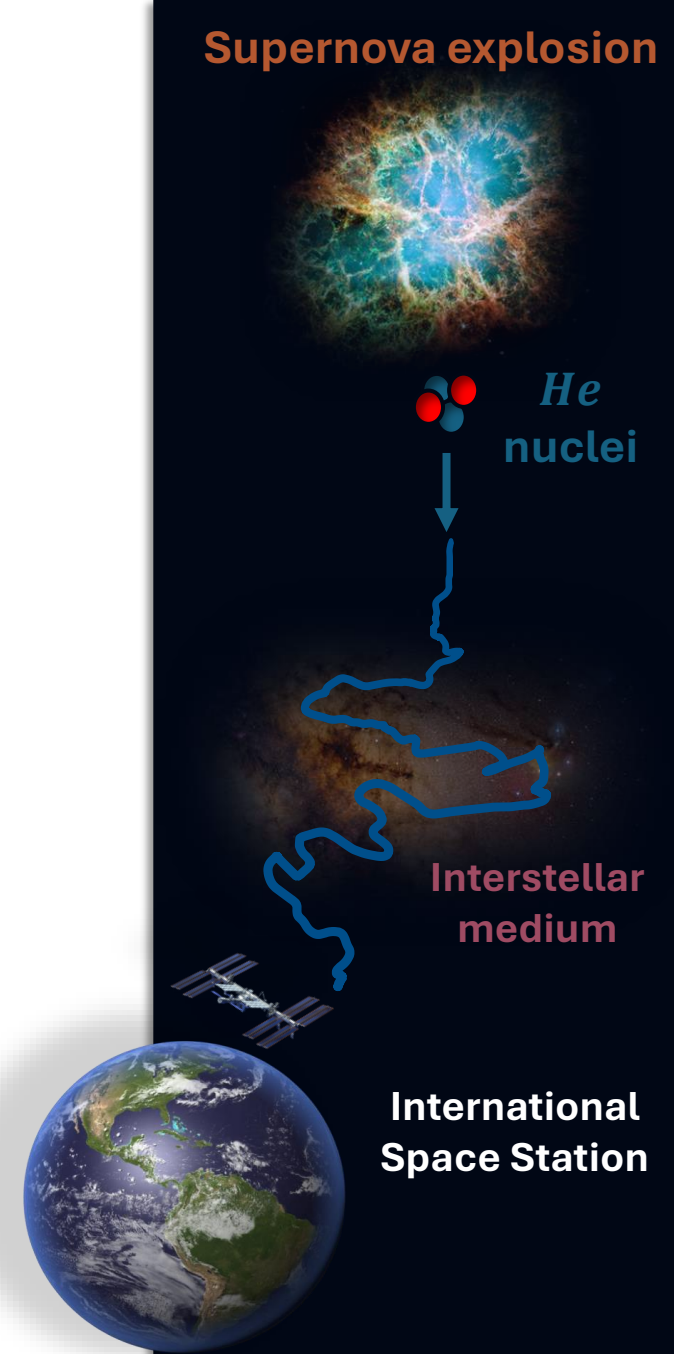
He
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Backup



Events selection

- Inner TRK charge $\in [1.7, 2.4]$
- L1 TRK charge $\in [1.6, 3.0]$
- Upper TOF charge $\in [1.5, 3.0]$
- Lower TOF charge > 1.5



Reconstructed charge

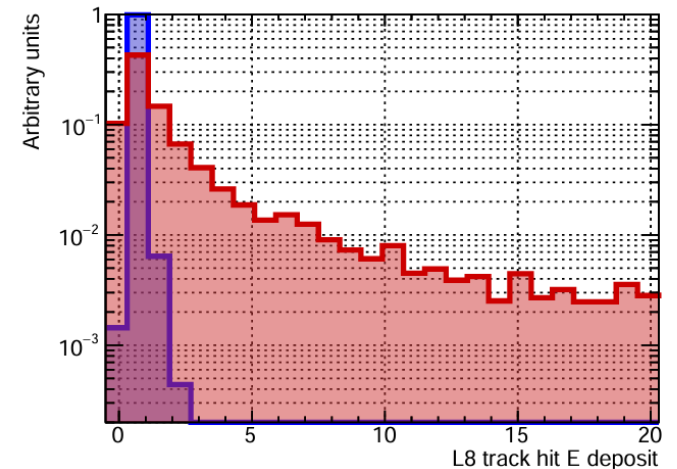
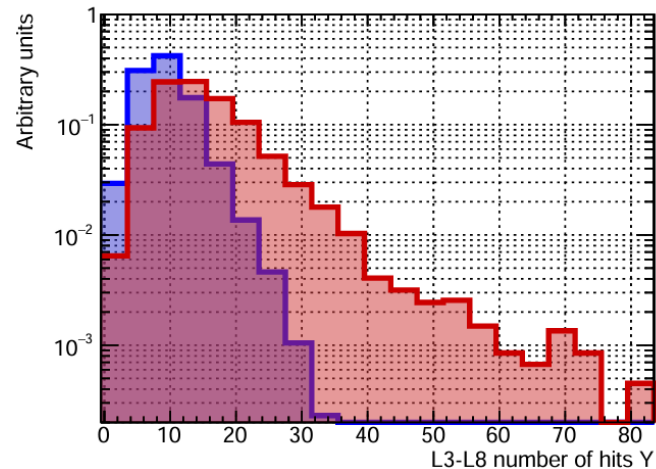
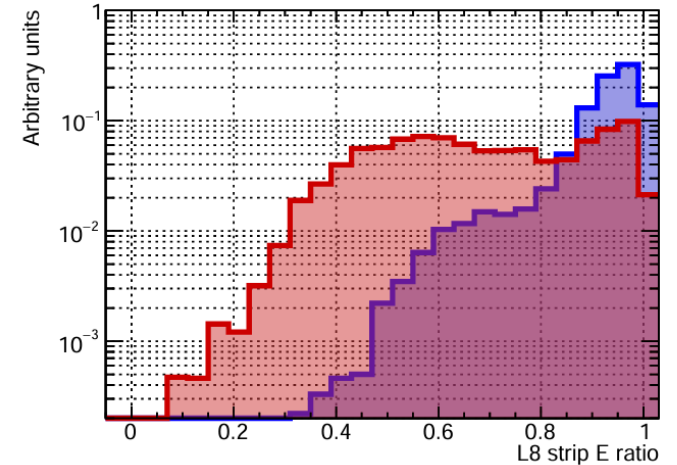
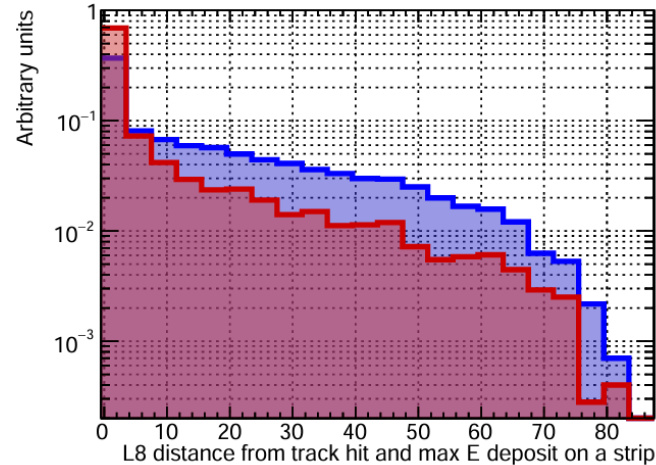
- Down-going particle
- 4/4 TOF hits
- Track hits 8/8
- Track $\chi^2_{bending} < 10$



Event's quality

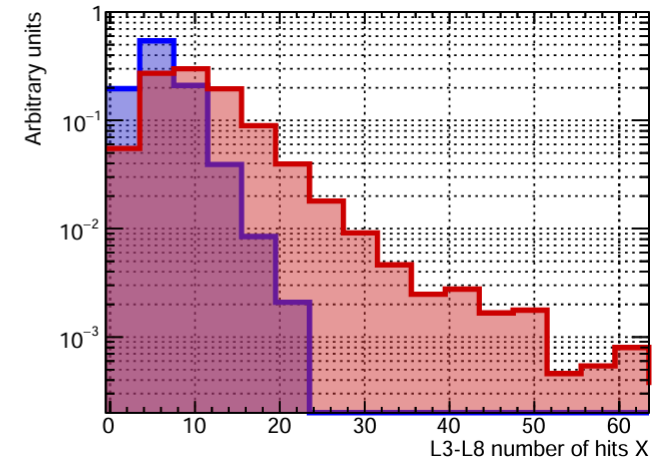
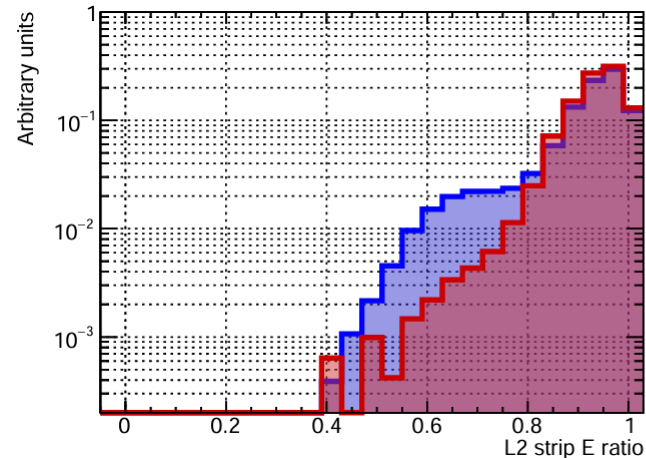
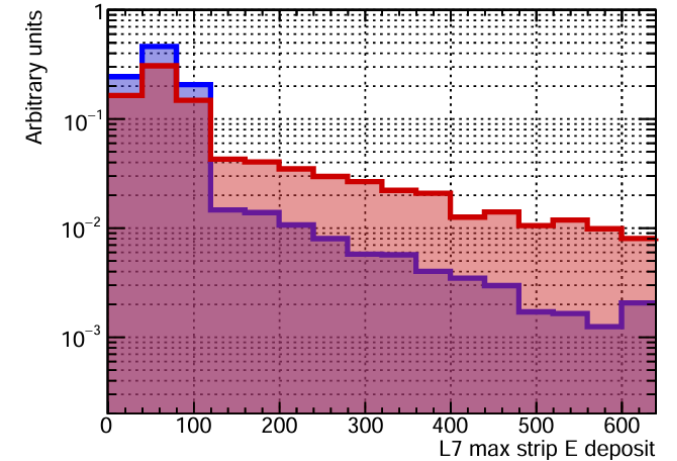
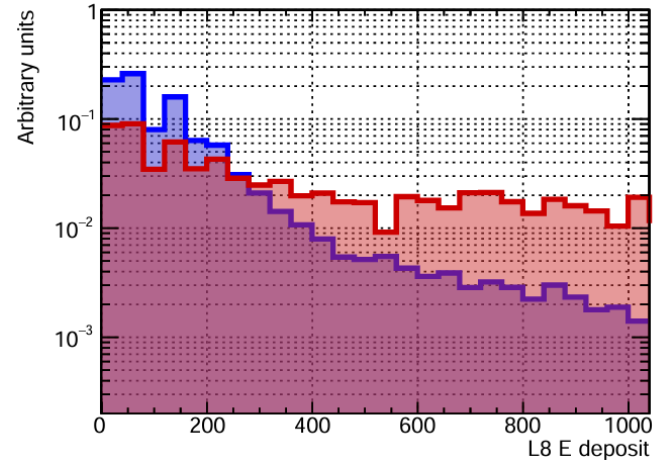
Input features 1

- Distance between track hit and strip with max energy deposit on L8.
- Ratio between strip energy deposition and its neighbouring 10 strips, on L8.
- Number of hits in L3-L8 inner tracker Y side.
- Track hit energy deposition on L8.



Input features 2

- Total energy deposition on L8.
- Max energy deposit on a single strip on L7.
- Ratio between strip energy deposition and its neighbouring 10 strips, on L2.
- Number of hits in L3-L8 inner tracker X side.



Input features 3

- Track hit energy deposition on L7.
- Total energy deposition on L7.
- Number of fired ACC.
- Max energy deposit on a single strip on L8.

