A deep learning method for the γ-ray identification with the DAMPE space mission

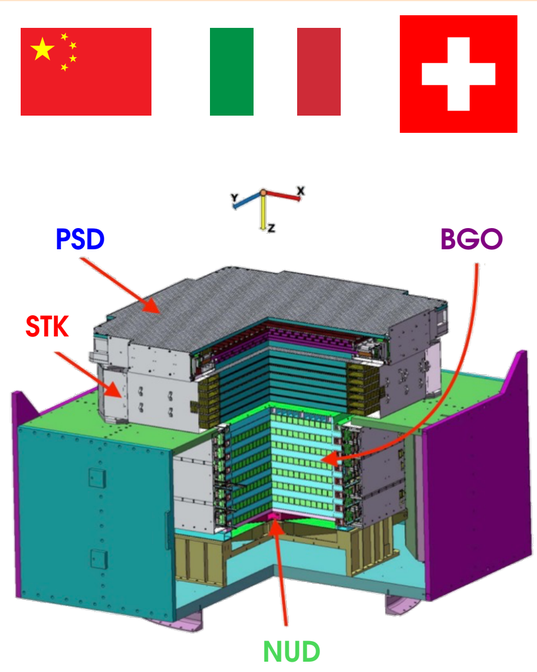
Jennifer Maria Frieden*[1], Loïs Niggli[1], Chiara Perrina[1]

[1] Institute of Physics, Ecole Polytechnique Fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland

EuCAIFCon 2024, Amsterdam, the Netherlands *jennifer.frieden@epfl.ch

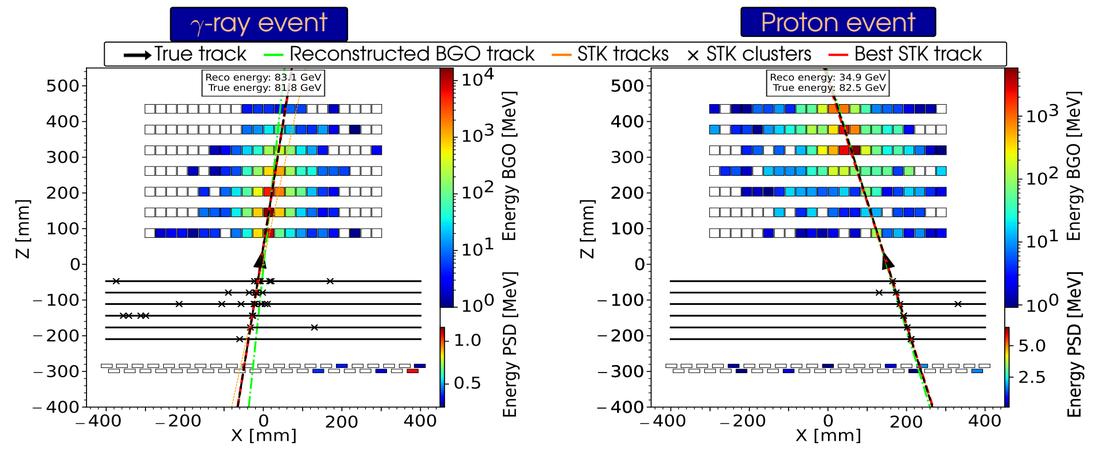
The DArk Matter Particle Explorer (DAMPE)

- Satellite on a sun-synchronous low Earth orbit ($\sim$ 500 km altitude) since December 2015[1]
- **Main goals:** Cosmic-ray spectrum and composition measurement, indirect search for DM signatures in e^++e^- and γ spectra, high-energy γ-ray astronomy
- Consists of 4 subdetectors:
  - **P**lastic **S**cintillator **D**etector
  - **S**ilicon-**T**ungsten trac**K**er-converter
  - **B**ismuth **G**ermanium **O**xide calorimeter
  - **NeUtron Detector**



Motivations

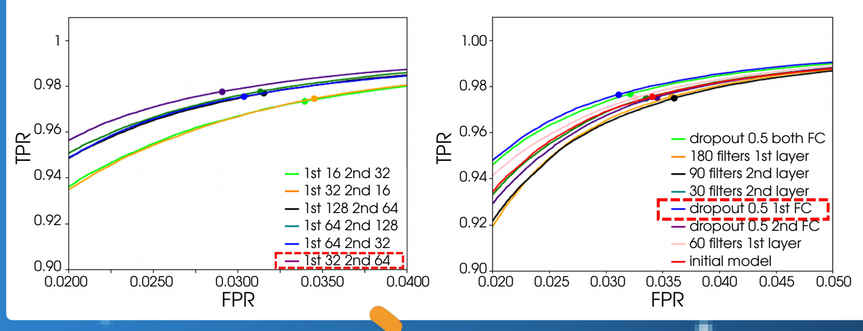
- 1st step of every γ-ray analysis: selection of γ-ray events
- Most abundant cosmic-ray component: **protons**
- Main difference between γ-rays and protons: **shower topology** in the BGO



⟹ **Convolutional Neural Network (CNN):** Class of neural networks, very efficient for image processing, object classification and pattern recognition[2]

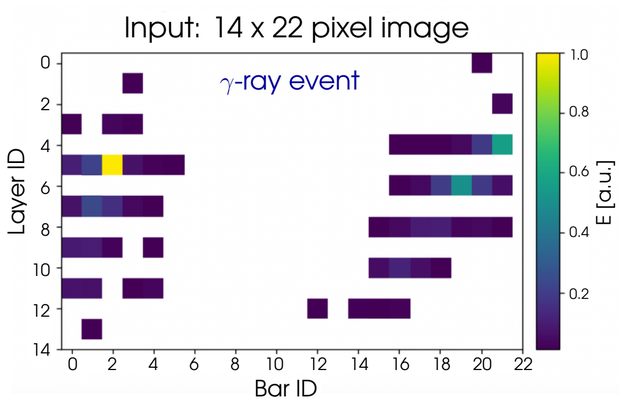
CNN parameter optimisation

- The best architecture is selected based on the ROC curves: (TPR, FPR) —> (1, 0) (**T**rue **P**ositive **R**ate and **F**alse **P**ositive **R**ate)



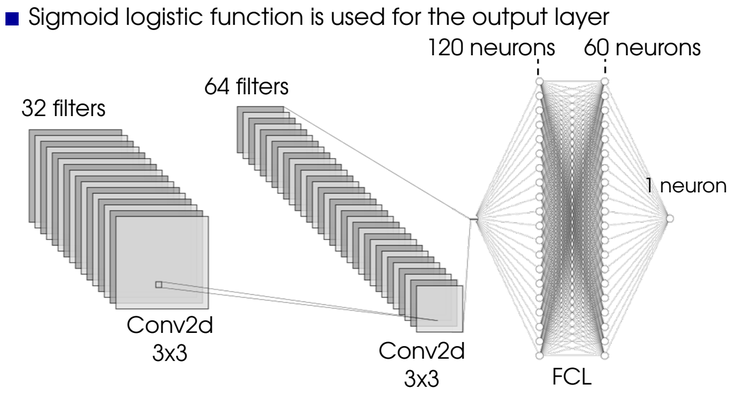
CNN Input: BGO images

- Images of Monte-Carlo (MC) protons and MC γ-rays crossing the BGO: BGO consists of 14 layers (7 in XY plane and 7 in YZ plane), each containing 22 bars
- Preliminary cut-based selection:
  1. Reconstructed energy in the BGO 1 GeV $\leq E_{reco} \leq$ 300 GeV
  2. Shower core contains at least 90% of E_{reco}
  3. Shower axis reconstructed with BGO passes through PSD



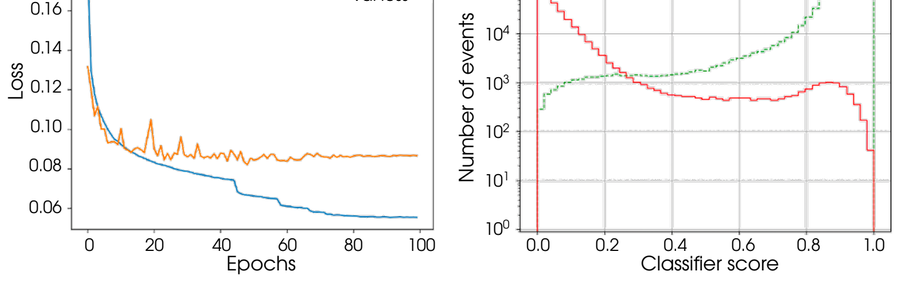
Final CNN architecture

- Leaky Rectifying Linear Unit (ReLU) is used as activation function for the hidden layers: $f(x) = \max(\alpha x, x)$
- Dropout rates added after FCL 1 and 2
- Sigmoid logistic function is used for the output layer



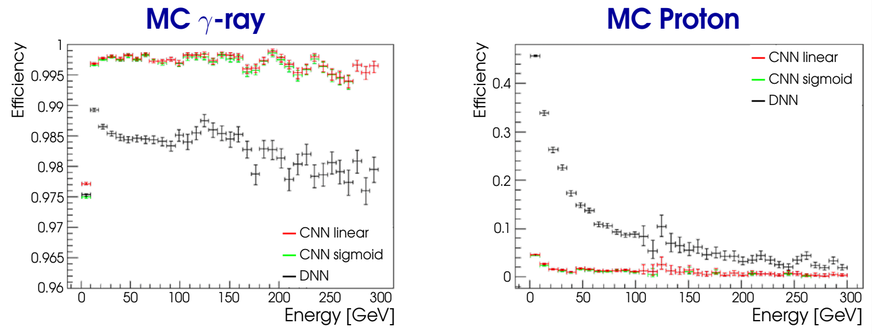
Final CNN model performance

- The steps in the training are due to the adaptive learning rate
- The classifier score of type sigmoid attributes scores from 0 to 1: the closer to 1 (0), the higher the probability it is a γ-ray (proton)



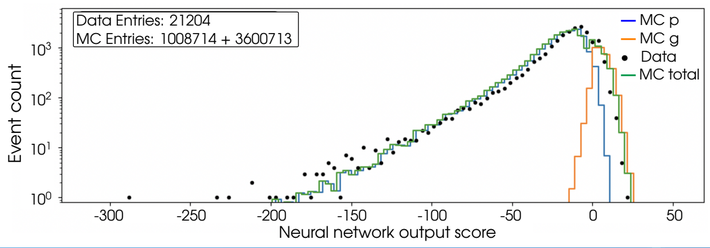
CNN classification efficiency

- This method significantly outperforms all the existing algorithms, both in γ-ray efficiency and proton rejection
- This method is slated to be employed in the upcoming DAMPE γ-ray analysis



CNN model validation

- Weight the MC distributions accordingly to their expected flux
- Scale flight data to the regions where MC γ (p) are dominant
- Use output without logistic sigmoid function at the end (unbounded output score)
- A selection is applied to the flight data to reject electrons (dedicated boosted-decision-tree model) and particles with charge $|Z| \geq 2$ (PSD charge) and to reject all the events collected when the satellite is in the South Atlantic Anomaly



References

1. C. Perrina et al., *Performance of the DAMPE silicon-tungsten tracker-converter during the first 5 years of in-orbit operations*, 15-22th.07.2021
2. Keiron O'Shea and Ryan Nash, *An Introduction to Convolutional Neural Networks* , 02.12.2015

Acknowledgments

The authors gratefully acknowledge the financial support from the Swiss National Science Foundation (SNSF-PZ00P2_193523).