Finanziato dall'Unione europea NextGenerationEU | Ministero dell'Università e della Ricerca | Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA | ICSC Centro Nazionale di Ricerca in HPC, Big Data and Quantum Computing

GRAIS

Gamma Ray Artificial Intelligence System

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Outline

- Brief introduction about GRAIS astrophysical landscape
- Project overview
- What has been done so far
- Next steps
- Conclusions

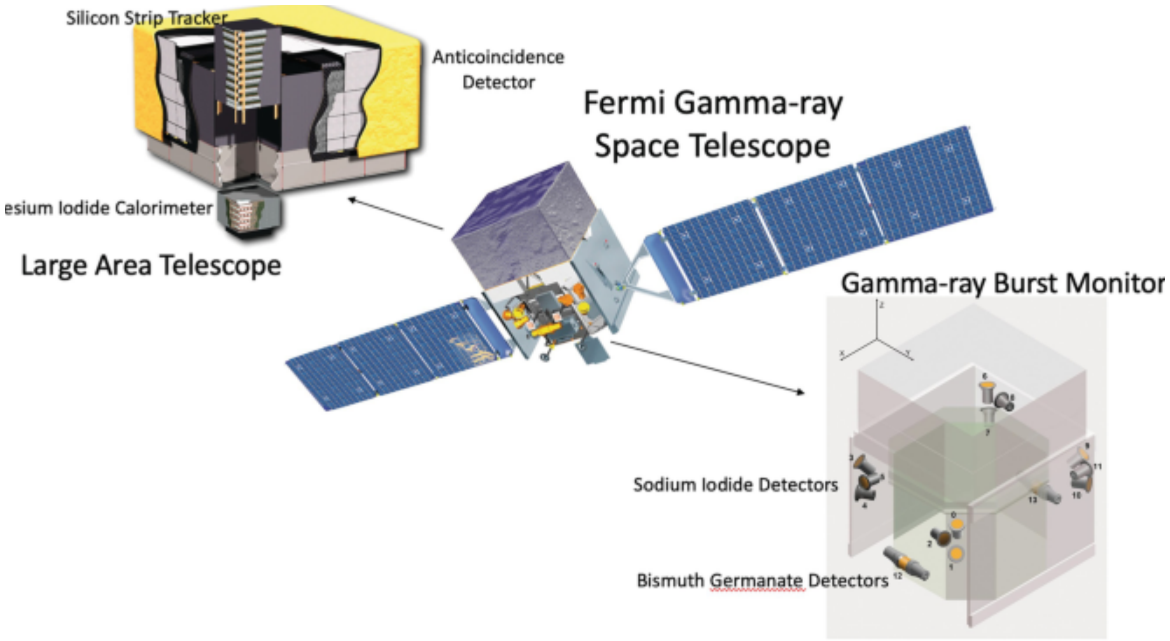
Astrophysical Framework

- Gamma-Ray Bursts (GRBs) are some of the most energetic events in the universe, characterised by short and intense flashes of gamma-ray radiation
- GRBs are characterised by a wide range of both emission time and total emitted energy (from a few seconds to ~10^3 seconds and from 10^{51} erg to 10^{54} erg)
- Space missions such as FERMI and AGILE have collected data and studied GRBs for over 15 years
- Recently, the scientific community has been focused on the detection of rapidly varying transient events, like the afterglows
- Orphan afterglows are transient events with an undetected prompt emission

Project Overview

The GRAIS project aims to develop Deep Learning and Generative AI solutions to identify high-energy transient events

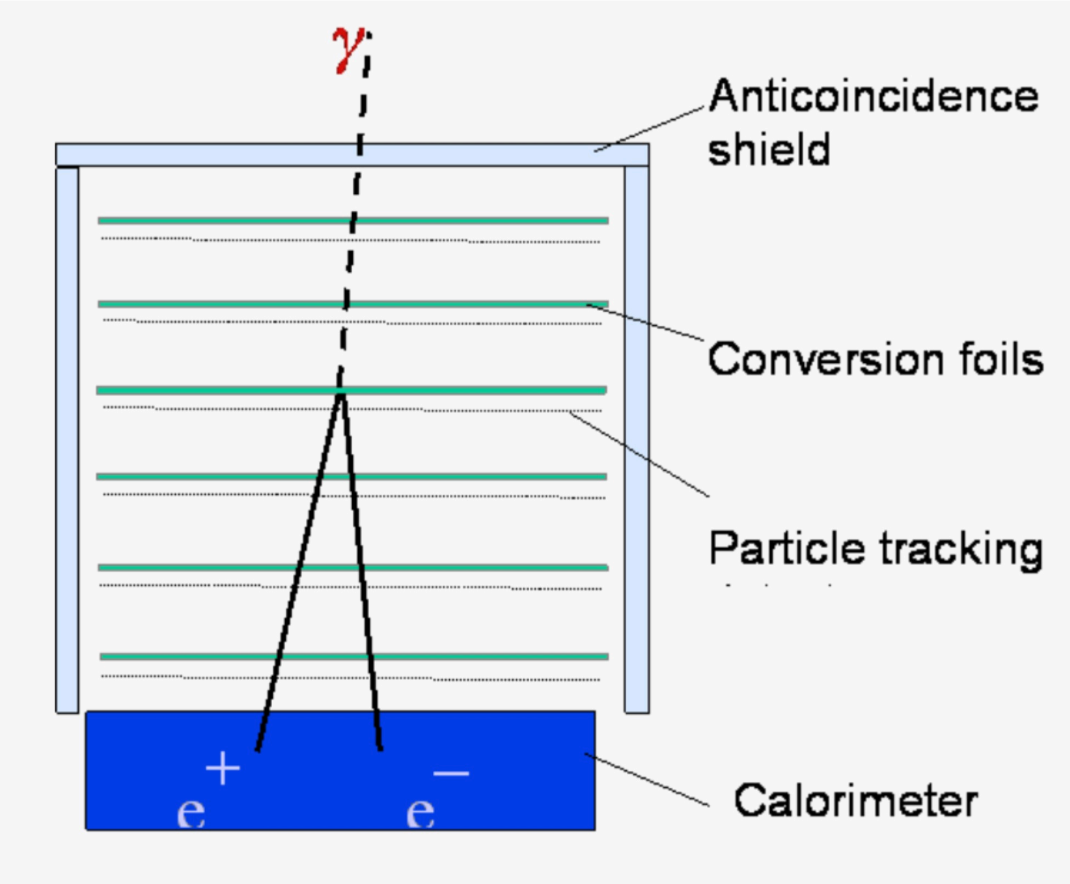
- Anomaly detection model to identify transient events
- Gen AI model to generate synthetic data of low-statistics observations
- Focus on the FERMI mission and the data collected by the Large Area Telescope (LAT) detector
- Project lifespan: from Dec 2024 to Nov 2025



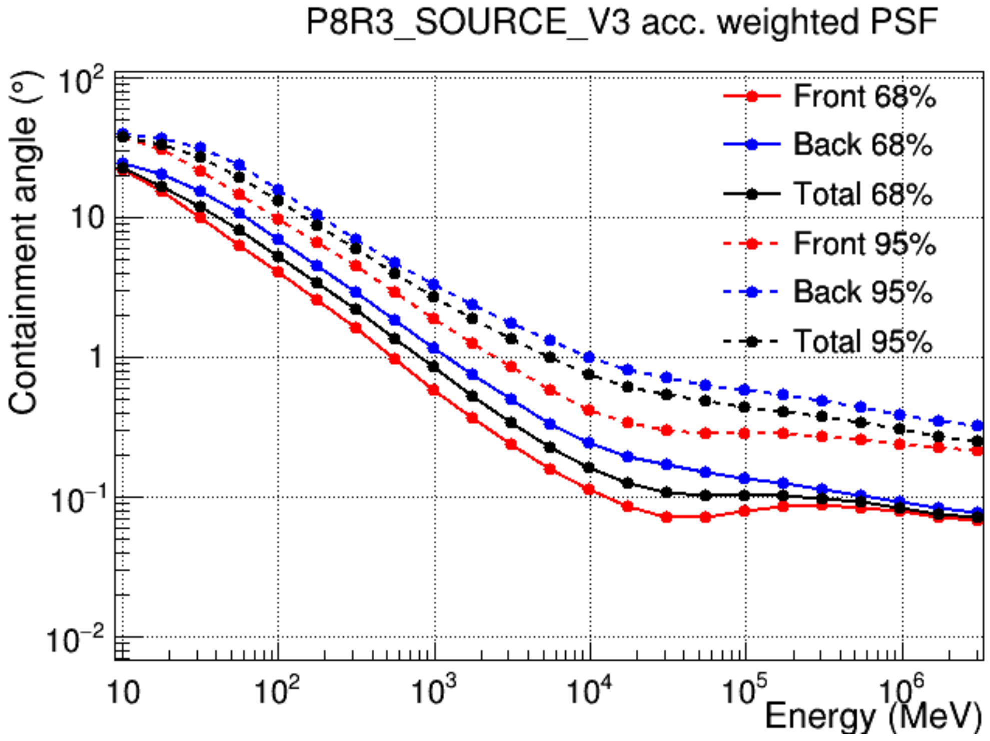
Fermi-LAT Dataset

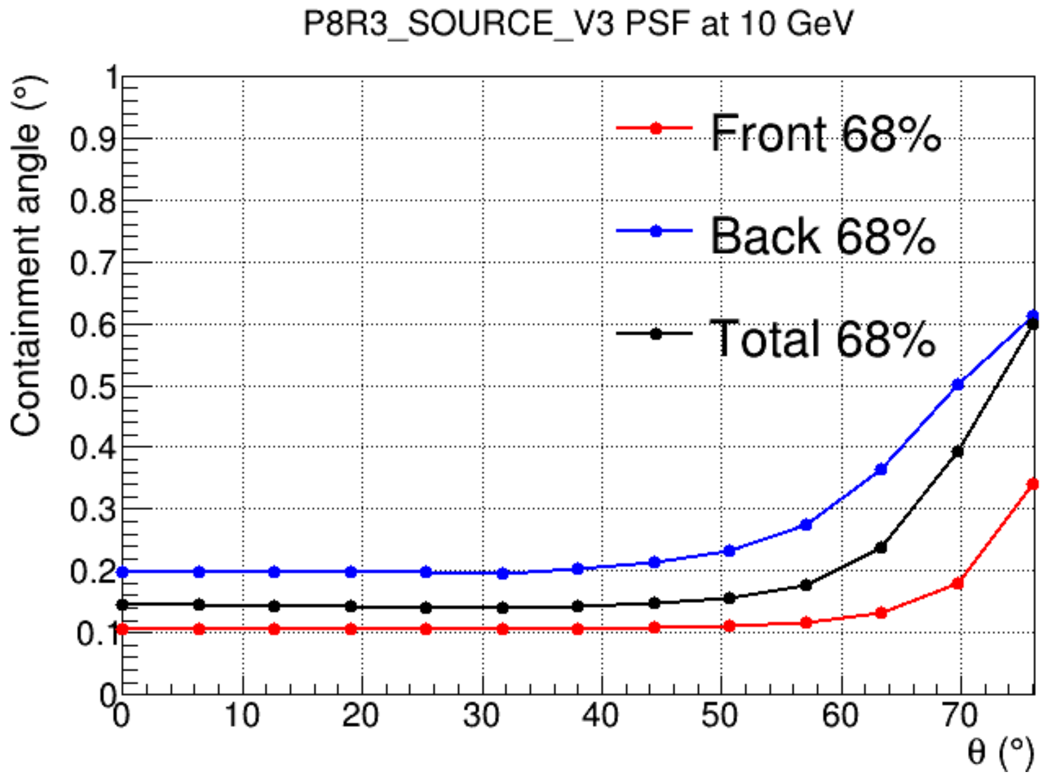
Two types of dataset:

- Data from the 2FLGC catalogue containing 228 GRBs detected from 2008 to 2022.
  - Validation of the anomaly detection model
  - Input date for the Gen AI model
- Single-photon dataset: photons detected by the LAT detector
  - **Key observation:** energy and angular resolution of each photon depends on energy, θ and conversion type (front or back)
- Performed extensive EDA on both datasets



Containment Angle vs Energy and θ





Anomaly Detection Model

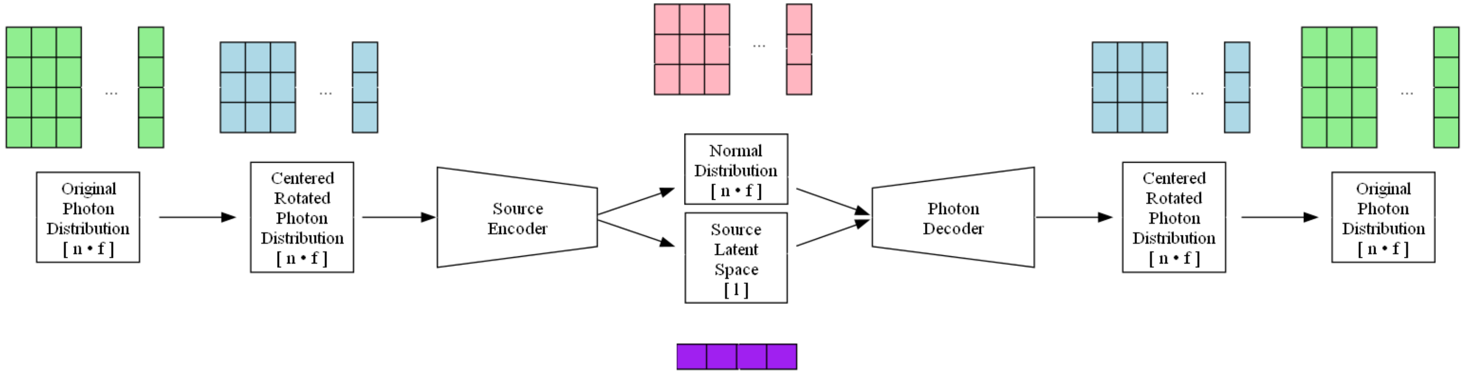
Implemented first benchmark anomaly detection model. **Key idea:** GRBs can be seen an increase of the flux of photons over the astrophysical background

- Approach based on Kerned Density Estimator (KDE) functions
- Ratio of spatio-temporal KDE over spatial KDE should highlight any photon clusters above the background
- KDEs built applying to each photon the weight $w_\gamma = 1/\theta^2_{ConAng}$
- Used preliminary weights due to the difficulty of computing the PSF for each photon due to the unknown true direction of the source
- Full pipeline implemented; preliminary results obtained
- More complex models will be tested (AutoEncoders, Variational AutoEncoders, …)
  - Need large dataset to train them

Gen AI Model

Generate vast synthetic GRBs dataset with Gen AI models

- Defined the architecture of the DeepLearning model
  - PointNet architecture ideal to deal with the generation of several features for each photon
- Several models have been considered; Variational AutoEncoders (VAE) are the first choice
  - Encode key dependencies of the input features into a lower dimensionality latent space
  - Probabilistic latent space where each input is mapped to gaussian with adjustable mean and sigma



Next Steps

- Obtain correct per-photon weight to apply throughout the entire project
- Improve current anomaly detection model and implement more sophisticated ones (possibly with KDEs as features of the models)
- Fully implement Gen AI model to produce synthetic GRBs data and train the anomaly detection model on it

Conclusions

- Studied catalogued and single-photon datasets to well understand the domain
  - Dedicated dashboards created to visualize most important features of the dataset
- Played around with FermiTools necessary for this project
- Requested and just obtained ISCRA-C computational resources to train our Deep Learning algorithms
- Implemented first benchmark model of anomaly detection to find transient events like orphan afterglow
- Fully designed architecture of Gen AI models to create synthetic GRBs datasets

Thanks

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Backup