Detection of 0.1-50 MeV cosmic photons with the Zirè instrument onboard the NUSES space mission

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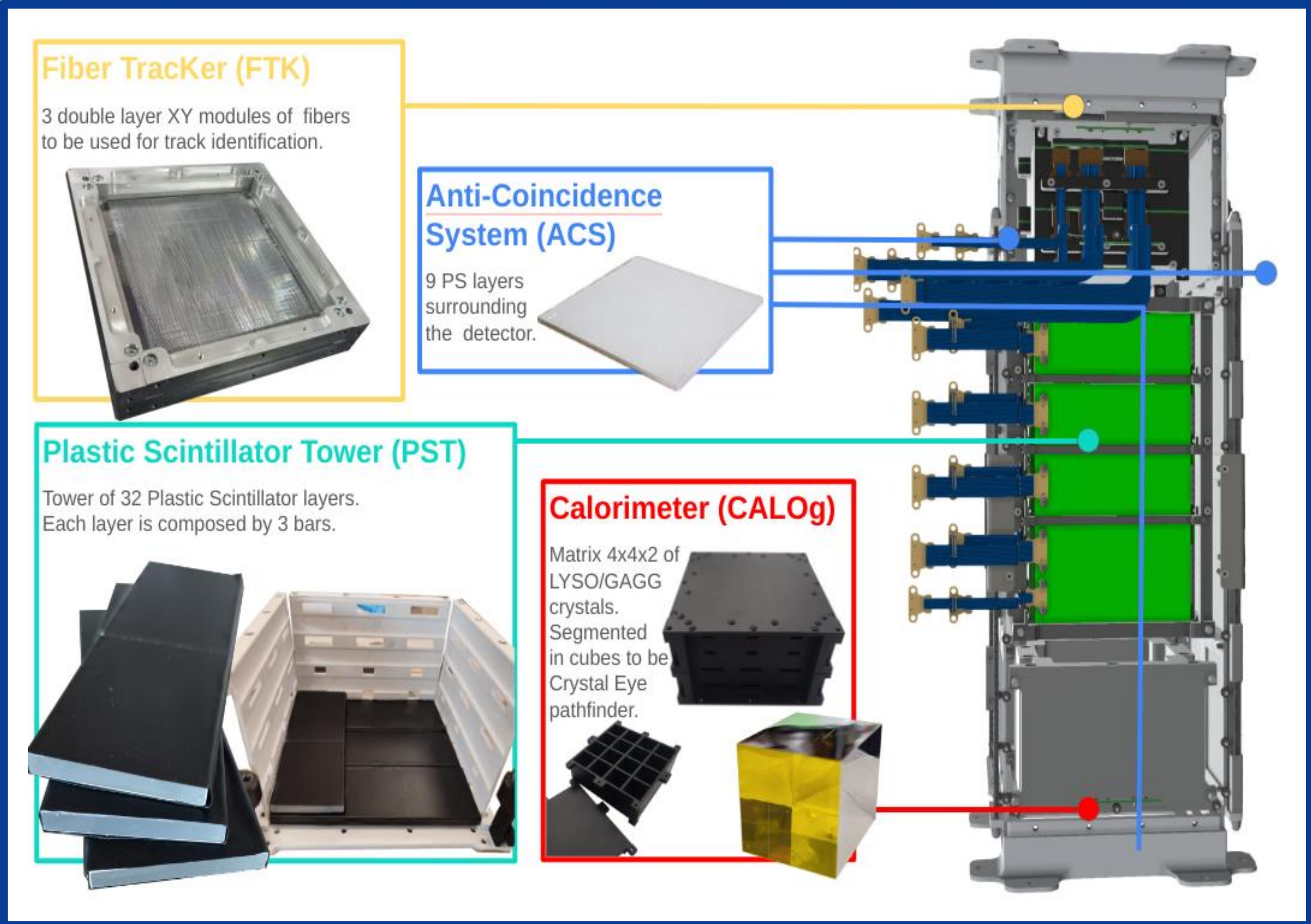
Abstract

Gamma Ray Bursts (GRBs) are mysterious yet powerful explosions in Universe. To understand them, numerous models and theories have been proposed. The Zirè instrument, on board the NUSES space mission, aims not only to measure cosmic electrons, protons, and nuclei (with energies below hundreds of MeV) but also to test new technologies for **the detection of gamma rays** in an energy range of **0.1 MeV to 50 MeV**, using Silicon Photomultipliers (SiPMs) as light readout tools.
The focus of this work is to simulate GRB induced signals, and the corresponding background, in order to determine Zirè's instrument response functions (effective area, sensitivity, etc).



Science Goal

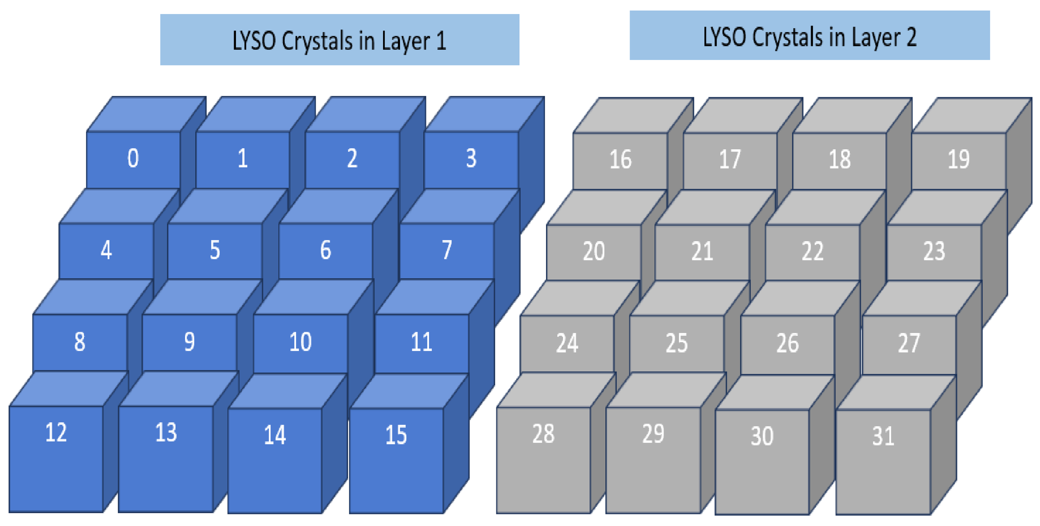
Gamma-ray bursts (GRBs) are short-lived bursts of the most energetic form of X- and gamma-rays, lasting from milliseconds to several minutes, emitted from sources, shining hundreds of times brighter than a typical supernova and about a million trillion times as bright as the Sun.

The scientific goal of Zirè includes:

- Studying photons within the energy range of 0.1 MeV to 50 MeV to gain insights into the emission processes during GRBs and other gamma sources like GW events and SN emission lines.
- Estimate the detection capabilities and potential observations of GRBs.
- Measure cosmic electrons, protons, and nuclei with energies below hundreds of MeV to advance understanding of cosmic ray phenomena and study space weathers.

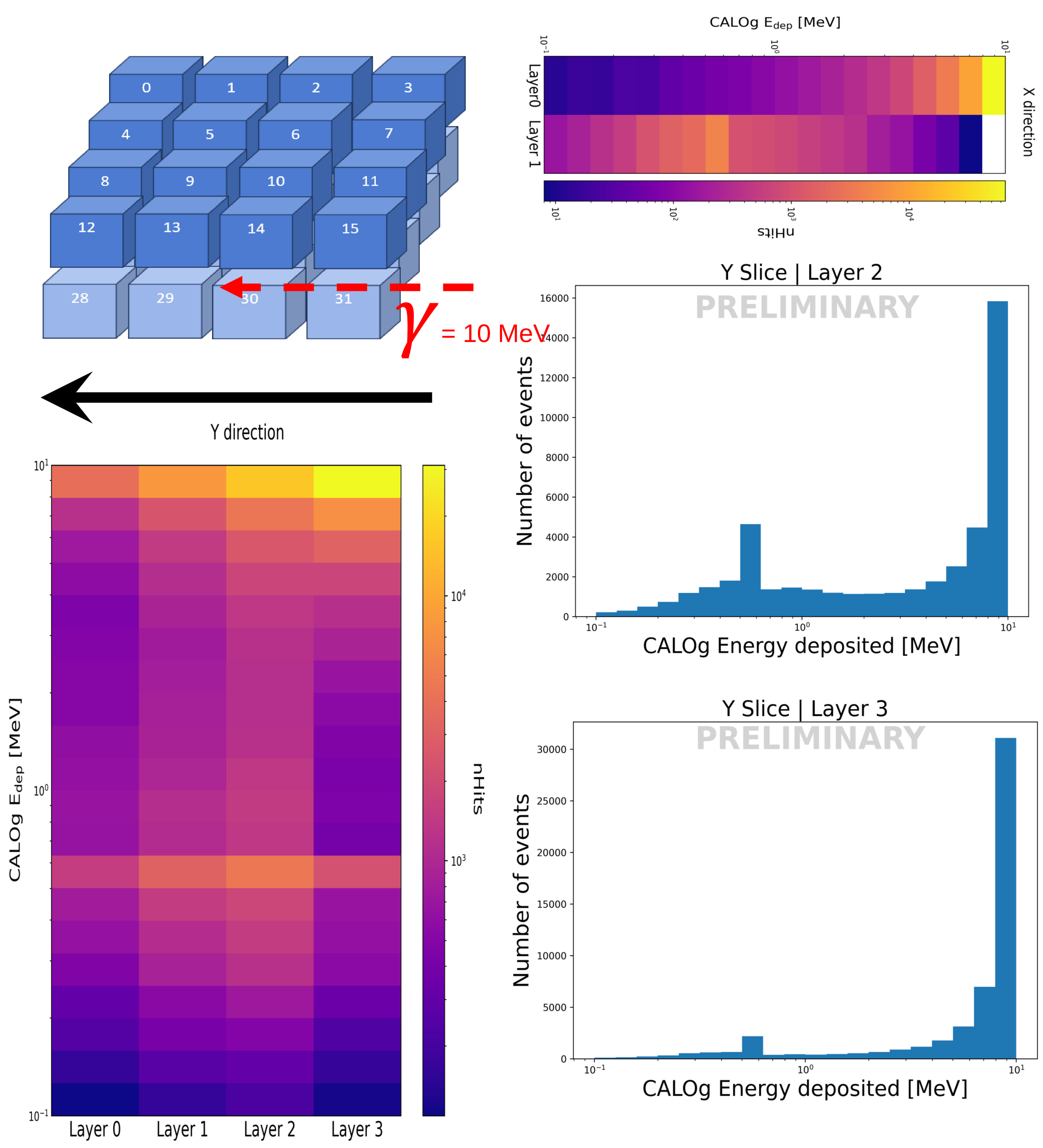
Calorimeter (CALOg)

- The CALOg is an sub-detector integrated within Zirè, designed specifically for studying low-energy gamma rays.
- Two windows in the structure surrounding the CALOg have been specifically included in the design for the purpose of gamma-ray detection.
- CALOg consists of 32 LYSO/GAGG crystals arranged in 2 layers, with each layer containing 8 crystals.
- Each LYSO/GAGG crystal, read by Hamamatsu MPPC arrays, exhibits high photon absorption probability, light yield, fast time response.
- In the case of LYSO, self-radiation calibration would also be possible.



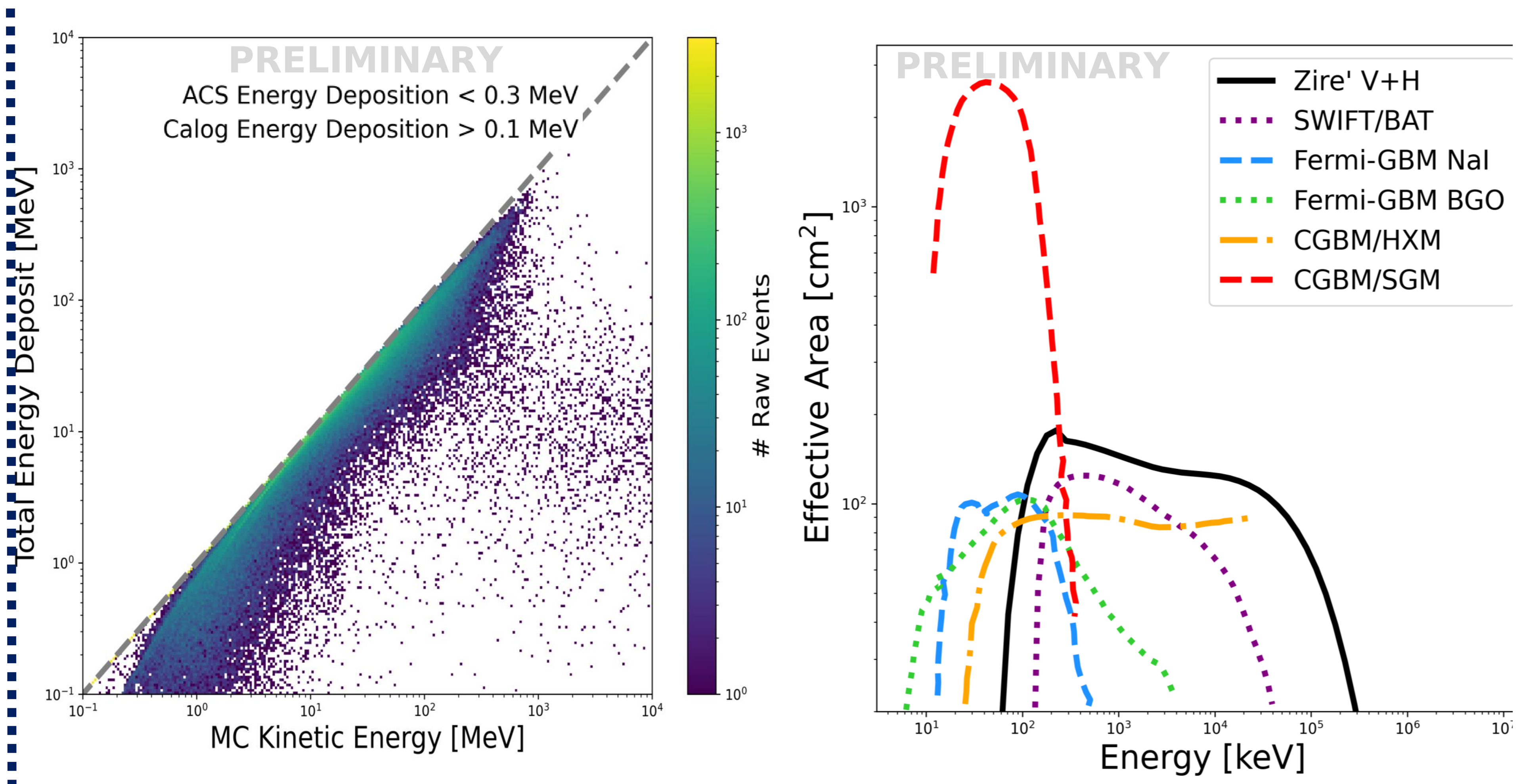
Simulations & Calorimeter Energy Deposition

- GEANT4 toolkit used to simulate several incident particles.
- The trigger condition considered is an energy deposit above 0.1 MeV in a single crystal.



- These plots indicate Zirè's particle detection and energy deposition in each calorimeter layer.
- The plots display detectable photons from x, y directions, with the source oriented vertically relative to the detector in our simulation.

Total Energy Deposition & Acceptance



- The left plot shows the relationship between the incoming photon and its total energy deposition at the CALOg.
- The grey line indicates the line of maximum energy deposition (i.e., the photon deposited its whole energy to the detector).
- The plot at right side shows the effective area of the detector as a function of the incident photon energy, for the two directions orthogonal to the observation windows (horizontal + vertical).

LYSO Background Simulation

- The plot shows simulated LYSO background containing 2.6% of Lu-176, which is self radioactive & self interactive, in the CALOg in the absence of incident photons.
- A BDT (Boosted Decision Tree) algorithm has been tested in order to distinguish between LYSO background and GRB signal (see the plot).
- Beta is the output of BDT which is correlated to the probability of the events to be background or signal.
- The BDT results are really promising. Preliminary studies show a background contamination of less than 1% for a signal efficiency of 60%. Further improvements are expected in the future.