Astrofisica Nucleare e Subnucleare

GALI a Gamma-ray Burst Localizing Instrument

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GALI a Gamma-ray Burst Localizing Instrument

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ABSTRACT

The detection of astrophysical Gamma-Ray Bursts (GRBs) has always been intertwined with the challenge of identifying the direction of the source. Accurate angular localization of better than a degree has been achieved to date only with heavy instruments on large satellites, and a limited field of view. The recent discovery of the association of GRBs with neutron star mergers gives new motivation for observing the entire γ-ray sky at once with high sensitivity and accurate directional capability. We present a novel γ-ray detector concept, which utilizes the mutual occultation between many small scintillators to reconstruct the GRB direction. We built an instrument with 90 $(9\,\mathrm{mm})^3$ CsI(Tl) scintillator cubes attached to silicon photomultipliers. Our laboratory prototype tested with a 60 keV source demonstrates an angular accuracy of a few degrees for $\sim$25 $\mathrm{ph\,cm^{-2}}$ bursts. Simulations of realistic GRBs and background show that the achievable angular localization accuracy with a similar instrument occupying 1l volume is $< 2°$. The proposed concept can be easily scaled to fit into small satellites, as well as large missions.

Keywords: Gamma-ray bursts, scintillators, silicon photomultipliers, directional gamma-ray detector, small satellites, detector simulations

Scope of the paper

- In traditional astrophysical γ-ray detectors, scintillators are built with different cross-sections towards different directions to produce a gradually varying response with angle. These systems rely on the scintillators facing various orientations to reconstruct the direction of the source.
- In contrast, the γ-ray-burst Localizing Instrument (GALI) concept presented here exploits mutual occultation of numerous small scintillators, distributed within a small volume, to provide directional information.
- The method relies on the entire array looking significantly different from different directions. Due to the occultation, the count rates from each scintillator will vary dramatically as a function of the source direction, even for small angle differences. In a sense, this is similar to the coded mask aperture method, but the mask itself is composed of detecting scintillators, so that no precious photons are lost. The low count rates in each individual small scintillator are compensated by the large number of scintillators. As in traditional approaches, the sensitivity to weak sources depends on the total size of the detecting volume.

Detector concept

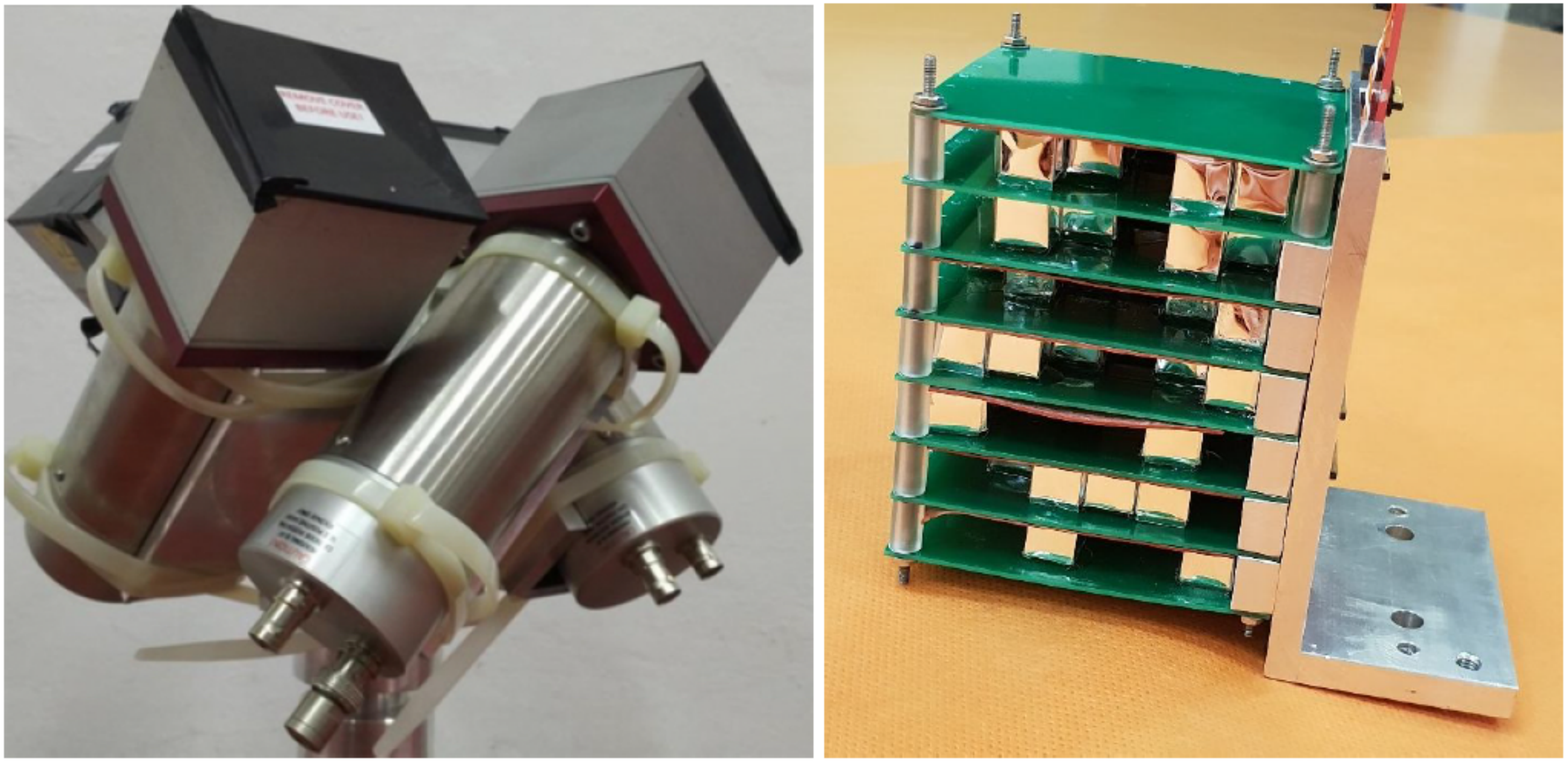

Fig. 1

Detector Concepts simulated

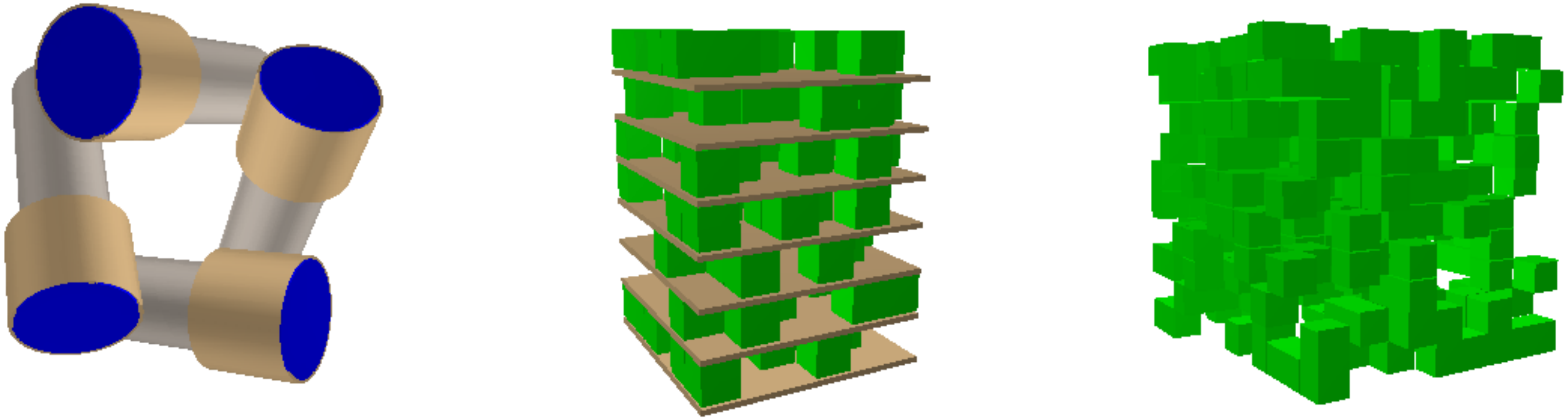

Fig. 2

Results

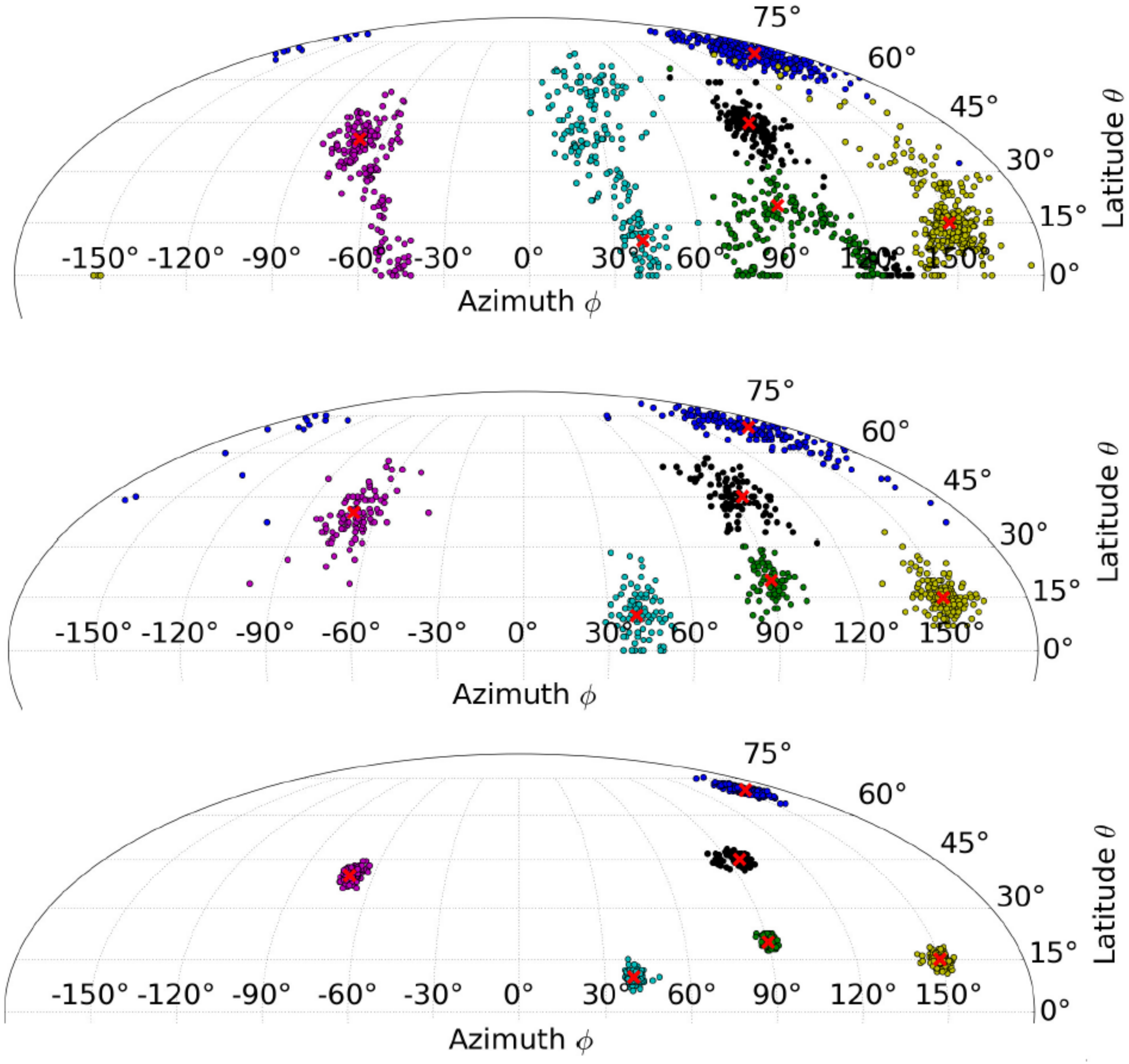

Fig. 3

Experimental Setup

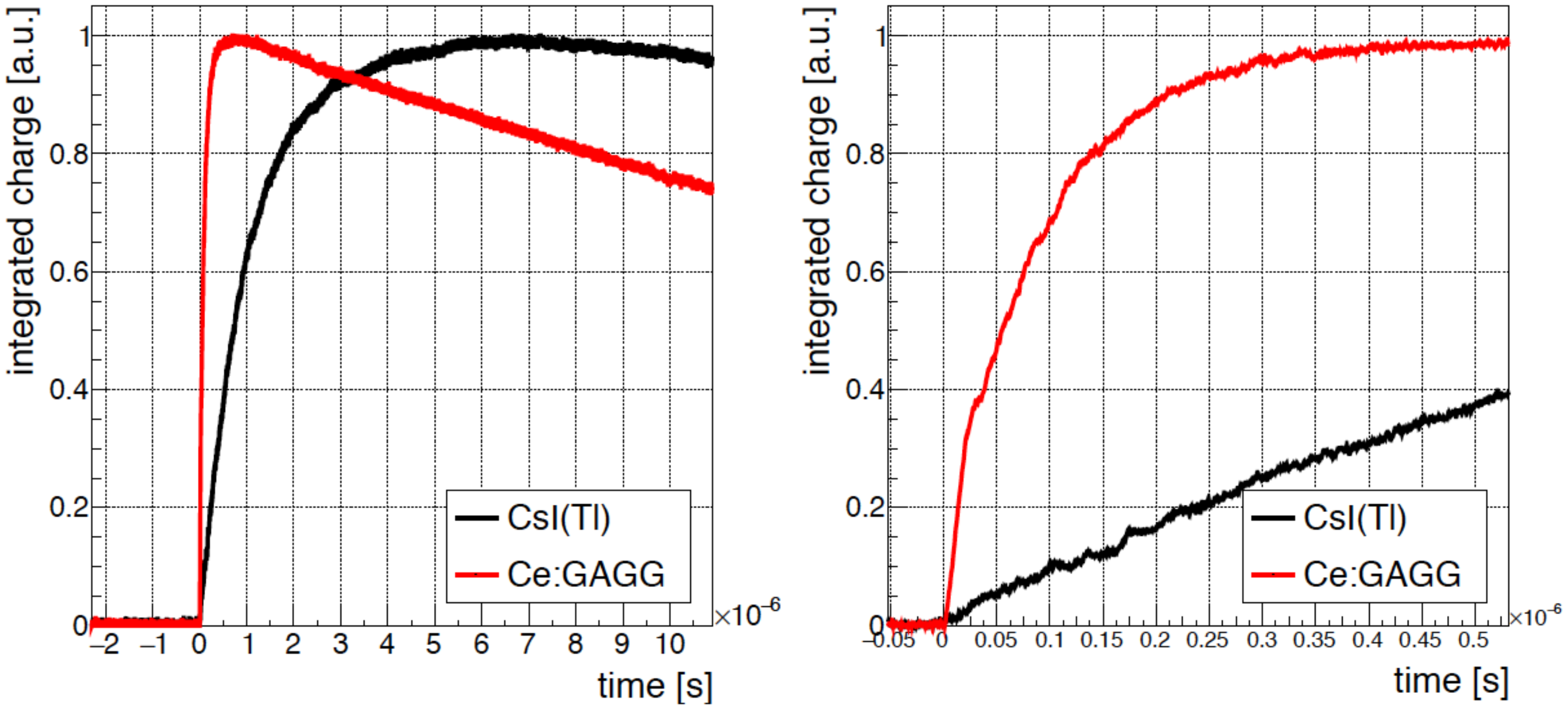

Fig. 4

Experimental Setup

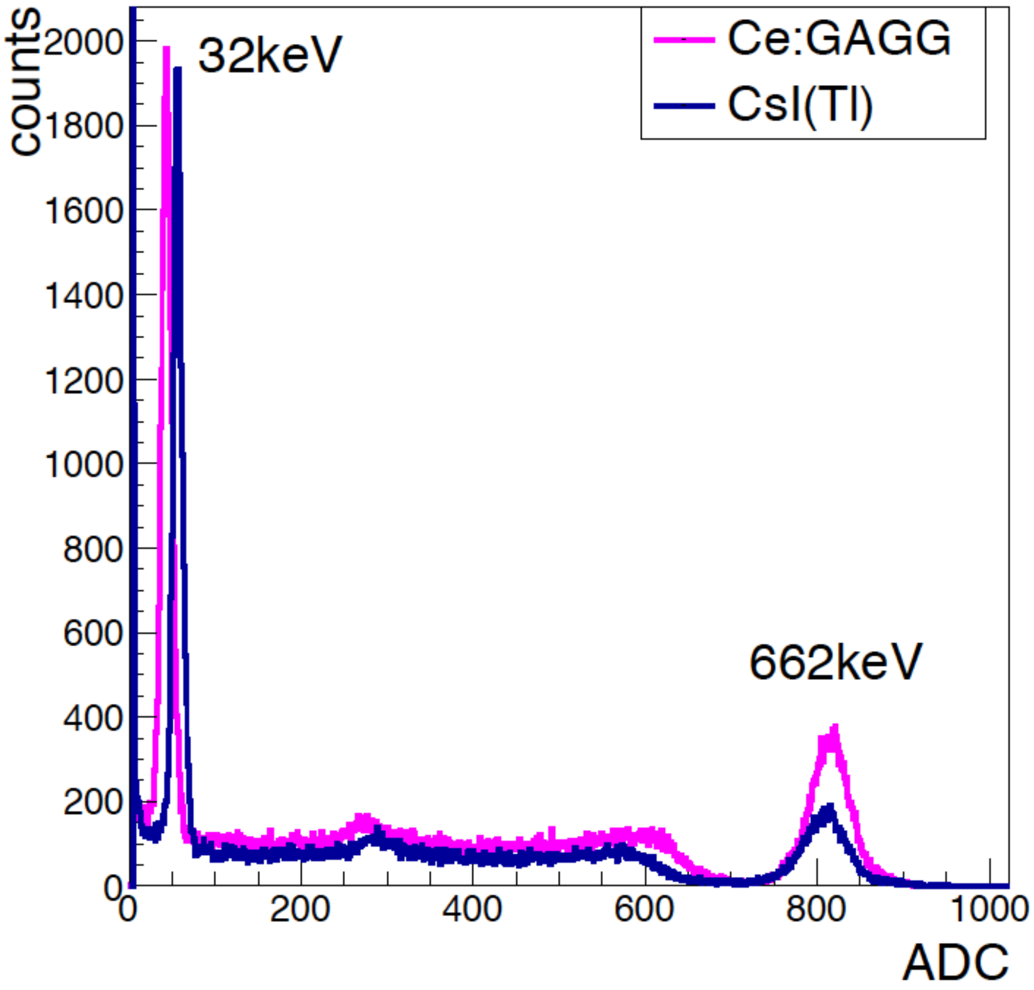

Fig. 5

Experimental Setup

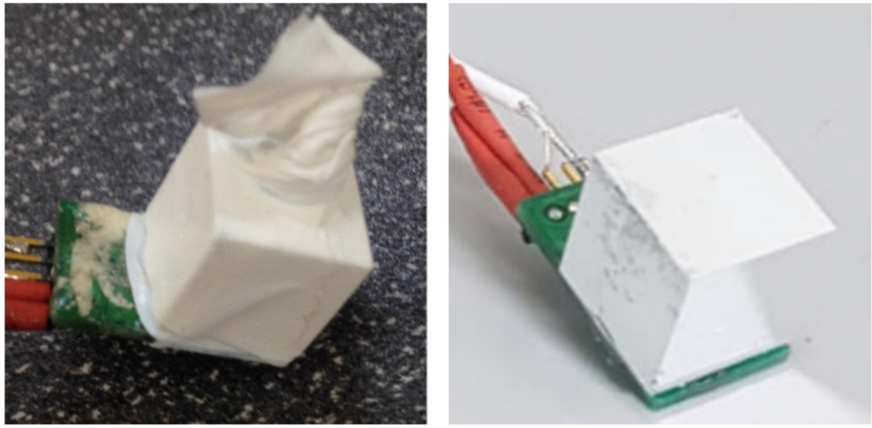

Figure 6: **Left:** A CsI(Tl) crystal coupled to a SiPM and then wrapped in Teflon tape. **Right:** A CsI(Tl) crystal coated with Al and Ag and coupled to a SiPM.

Figs. 6 - 7

Figure 7: From left to right, the CsI(Tl) crystal wrapping process with Vikuiti ESR.

Experimental Setup

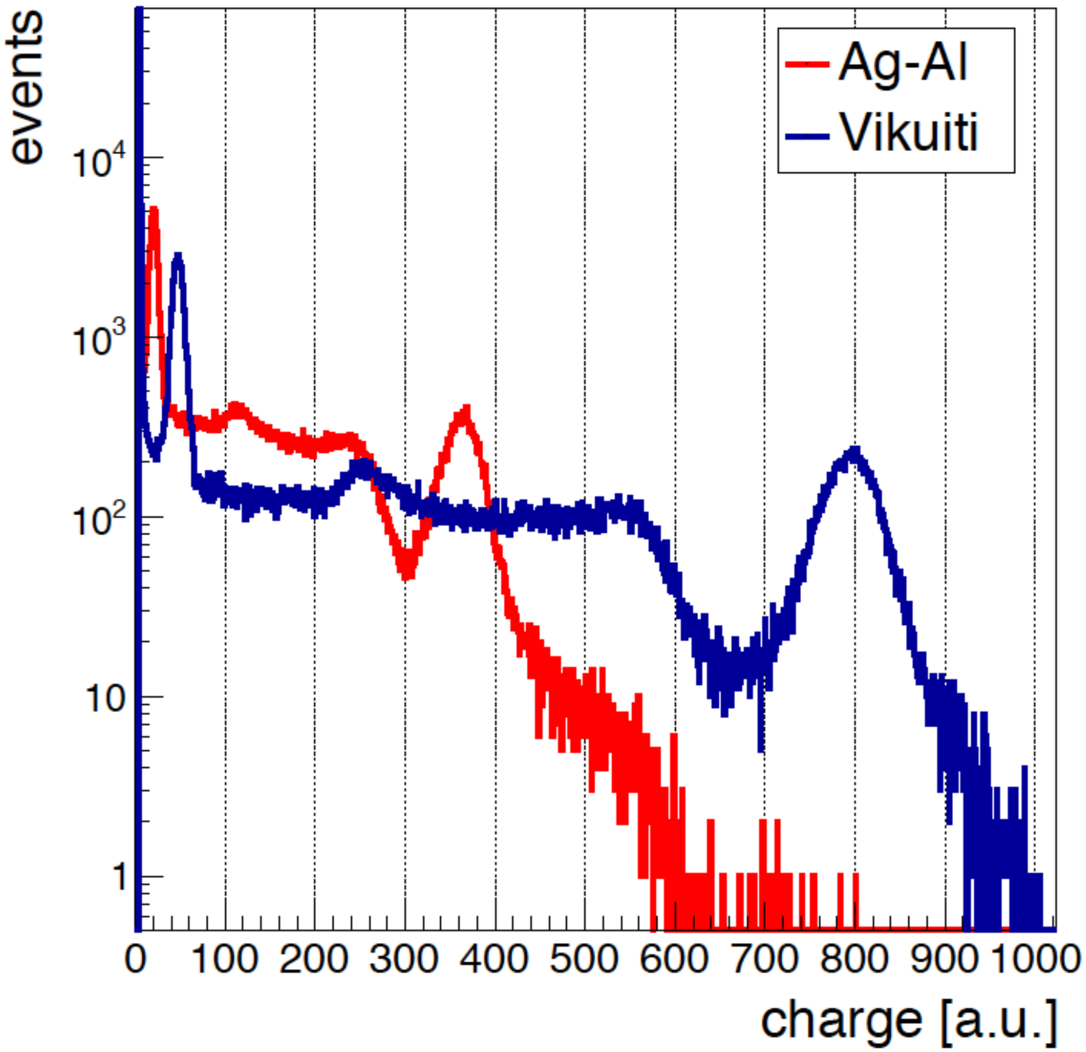

Fig. 8

Experimental Setup

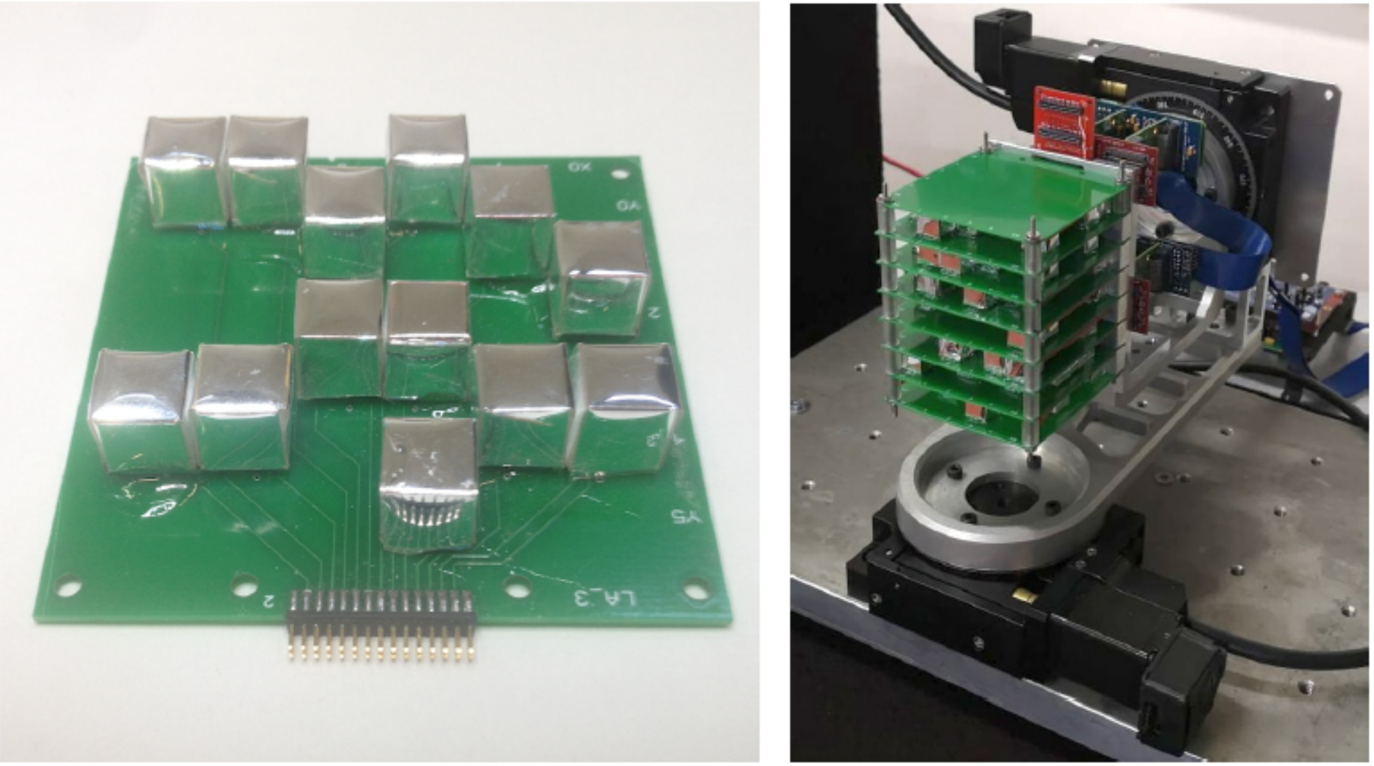

Fig. 9

Conclusions

- We present a novel directional GRB detector concept based on mutual occultation of numerous, small scintillator elements.
- For this purpose, we explored both CsI(Tl) and Ce:GAGG scintillators, as well as their coating and wrapping procedures. Two SiPM readout elements were also compared. We chose for the current experiment to use CsI(Tl) coated with SiO2 and wrapped by a Vikuiti ESR reflector.
- We built a laboratory prototype consisting of 90 CsI(Tl) (9mm)3 cubes stacked in 7 layers. Relative count rates were measured at angles over the entire hemisphere with long (60 s) exposures, and used as reference. Subsequently, the direction reconstruction capability was tested on short bursts (0.5 s).
- Experimental results with the 59.6 keV peak of 241Am show that short bursts (~25 ph cm^-2) can be localized to within 1-3 deg
- Simulations of a 350-scintillator instrument, including true LEO background and GRB spectra, show an accuracy of ~1.7deg which outperforms any existing scintillator-based GRB instrument that we are aware of, including much bigger ones.

Conclusions

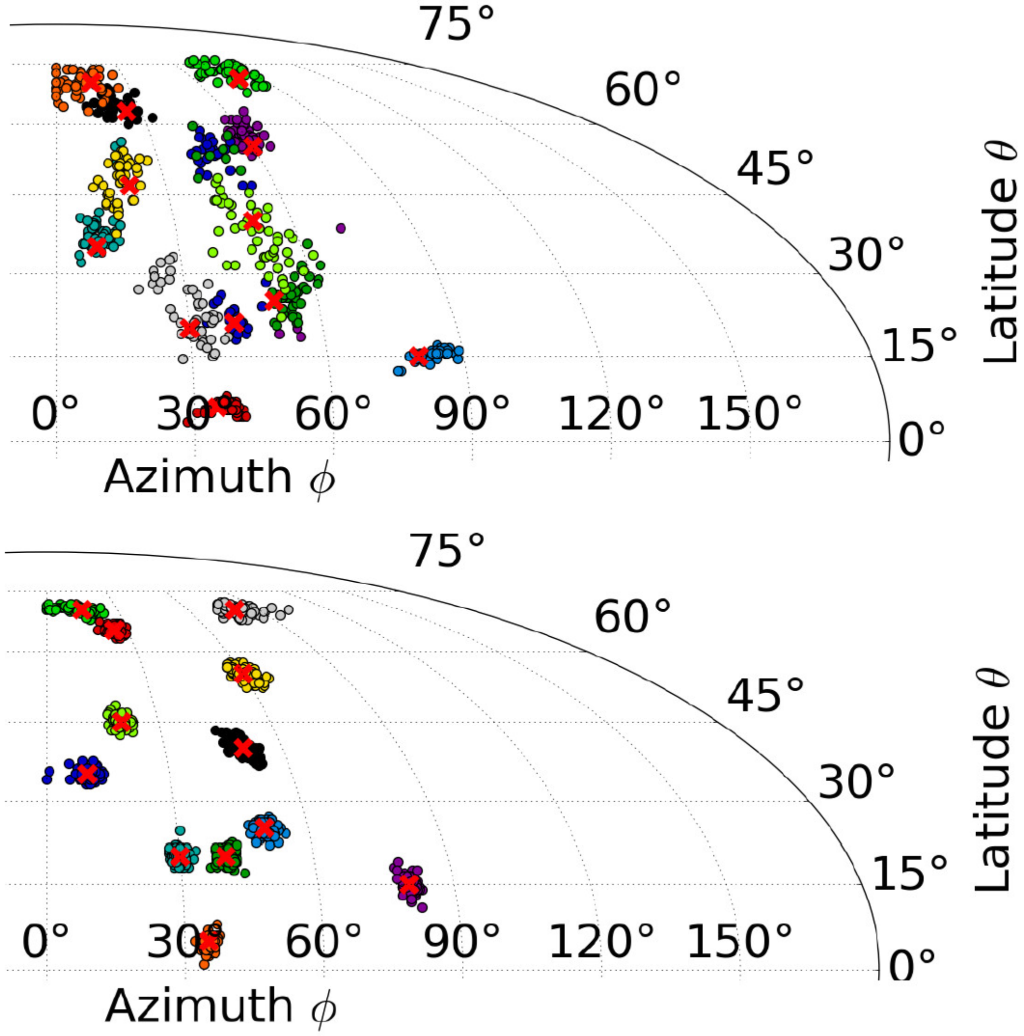

Fig. 10