Search for very high energy γ-ray emission from GRB 190829A with LHAASO-WCDA triggerless data

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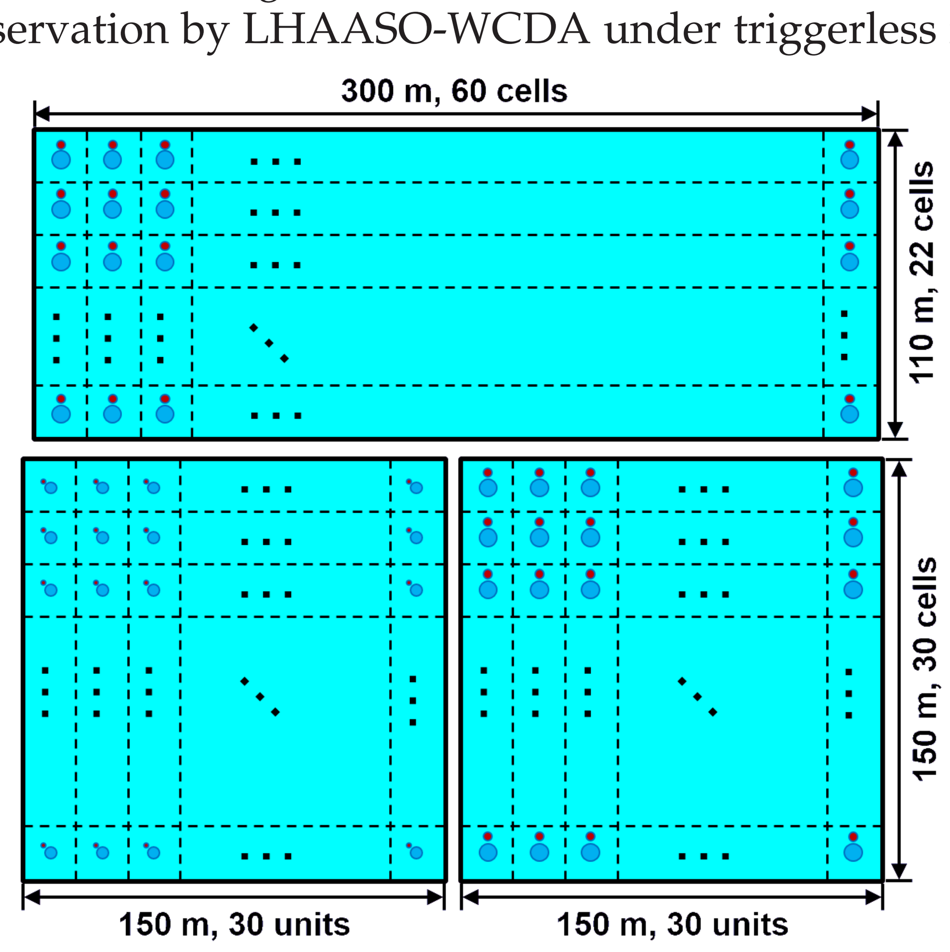
GRB 190829A

The observation of very high energy (VHE, >100GeV) photon from γ-ray bursts (GRBs) can advance our understanding of their radiation mechanism, the evolution of host-galaxies, violations of Lorentz invariance, extragalactic background light, and intergalactic magnetic field. Recently the measurements on VHE emission from afterglow phase have blossomed and borne fruit while detection of the prompt emission is rare.

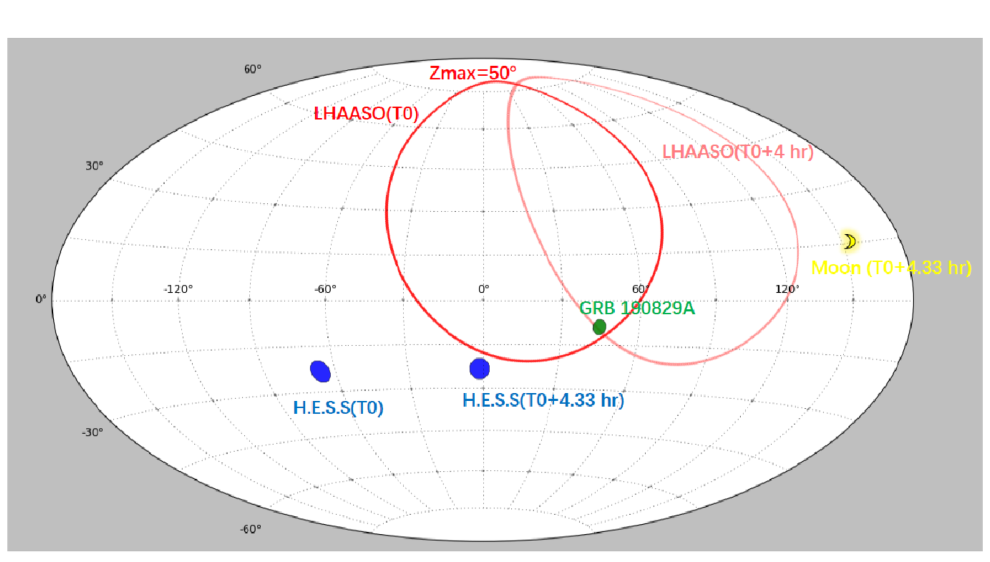
Among six GRBs reported with VHE emission observation by IACTs, GRB 190829A is the closest one, of which red-shift is ~ 0.0785. Occurring on 29 August 2019 at 19:55:53 (T_0), it was followed up by an enormous observational campaign covering a large fraction of the electromagnetic spectrum, including the VHE band afterglow emission measurements from T_0 + 4 hours to + 56 hours by H.E.S.S. [1]. GRB 190829A occurred on the edge of the FOV of LHAASO-WCDA when the first pond o LHAASO-WCDA was in the test running operation.

Follow-up with LHAASO

Large High Altitude Array Shower Observatory (LHAASO) is a newly-built γ-ray detector, which is located at about 4410 m above sea level. Water Cherenkov Detector Array (WCDA) is one of the major parts, consisting of 3120 water cells, totally covering an area of $78,000$ m^2. A quarter of LHAASO-WCDA, comprising 900 water cells, started its operation in April 2019. In March 2021, the full array is in operation. Up to June 2021, over 100 GRBs have been registered and allowed for follow-up observation by LHAASO-WCDA under triggerless mode.



In order to further reduce observational energy threshold, the data acquisition (DAQ) system of LHAASO-WCDA adopts a second triggerless mode as a complementary of the main pattern. With the help of external GRB alerts, in the triggerless mode, DAQ would keep all hit information (eg. charge and time) recorded on each fired detector from T_0 - 0.5 h to T_0 + 2 h, once the received GRB triggering at T_0 is in the FOV of LHAASO-WCDA.



GRB 190829A occurred at a zenith angle of $46°$ for LHAASO site. The $\sim$ 2.5 hours triggerless data collected with the first pond was used to search for high energy emission.

References

[1] H.E.S.S. Collaboration, H. Abdalla, F. Aharonian, et al. Revealing x-ray and gamma ray temporal and spectral similarities in the grb 190829a afterglow. Science, 372(6546):1081–1085, 2021.

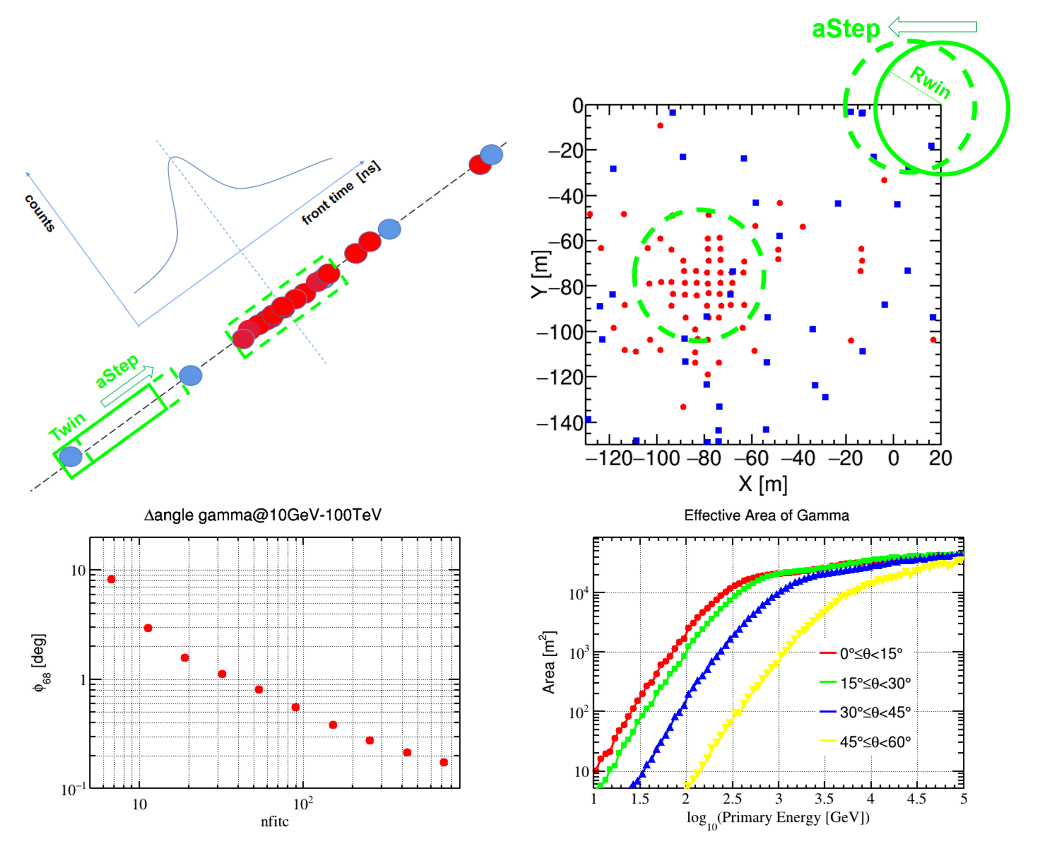
[2] O. Helene. Upper limit of peak area. Nuclear Instruments and Methods in Physics Research, 212(1-3):319–322, July 1983.

[3] Rudy C. Gilmore, Rachel S. Somerville, Joel R. Primack, and Alberto Domínguez. Semi-analytic modelling of the extragalactic background light and consequences for extragalactic gamma-ray spectra. MNRAS, 422(4):3189–3207, June 2012.

Methods and Performance

With the GRB location reported by satellites and concentrated space characteristics of air shower, a new self-triggered method is adopted to search for photons from GRBs, which can largely reduce random noises. Using a narrow temporal and spatial trigger window perpendicular to the source direction, hits of events from (or near to) the direction of the source are more likely to be preserved, a hit clustering is selected as seeds of a shower event. Afterward, more hits are identified by performing a flexible time search near the trigger time. At last this event is packed and used for reconstruction. All hits of a raw-data file are sorted with time, a sliding time window is used to loop over all hit clustering for candidate events.

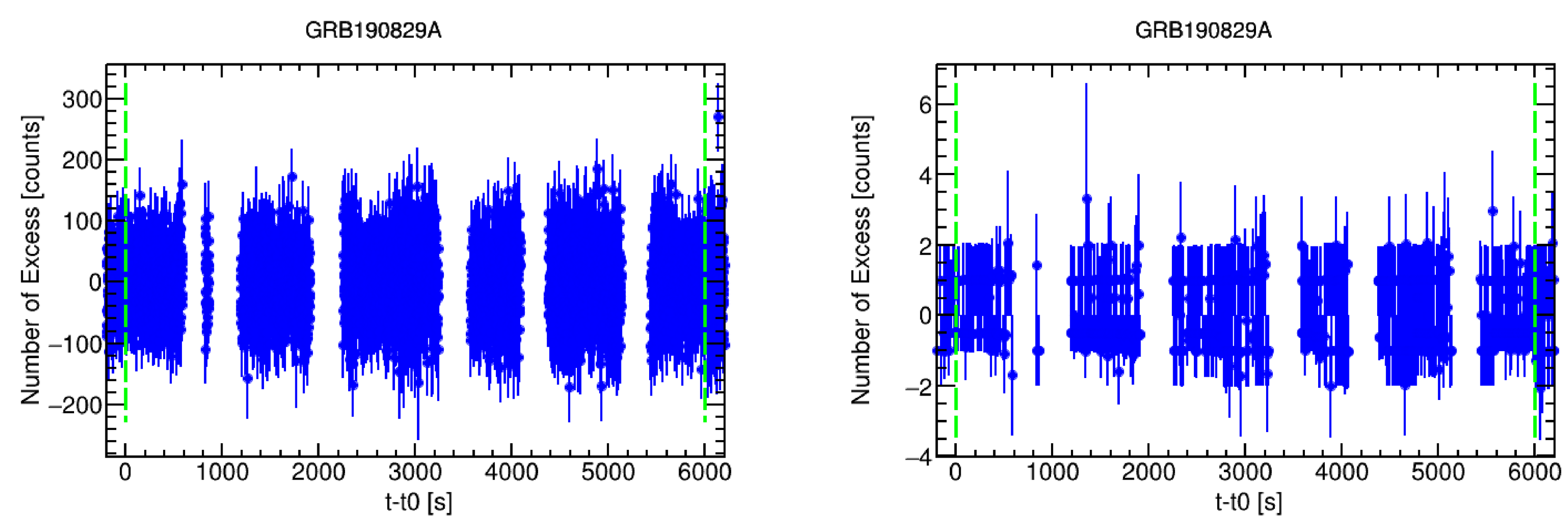
Using a Monte Carlo simulation of the detector response, the angular resolution and the effective area are demonstrated as follows. The angular resolution is used to determine the source-region to exclude events deviating from the source direction.



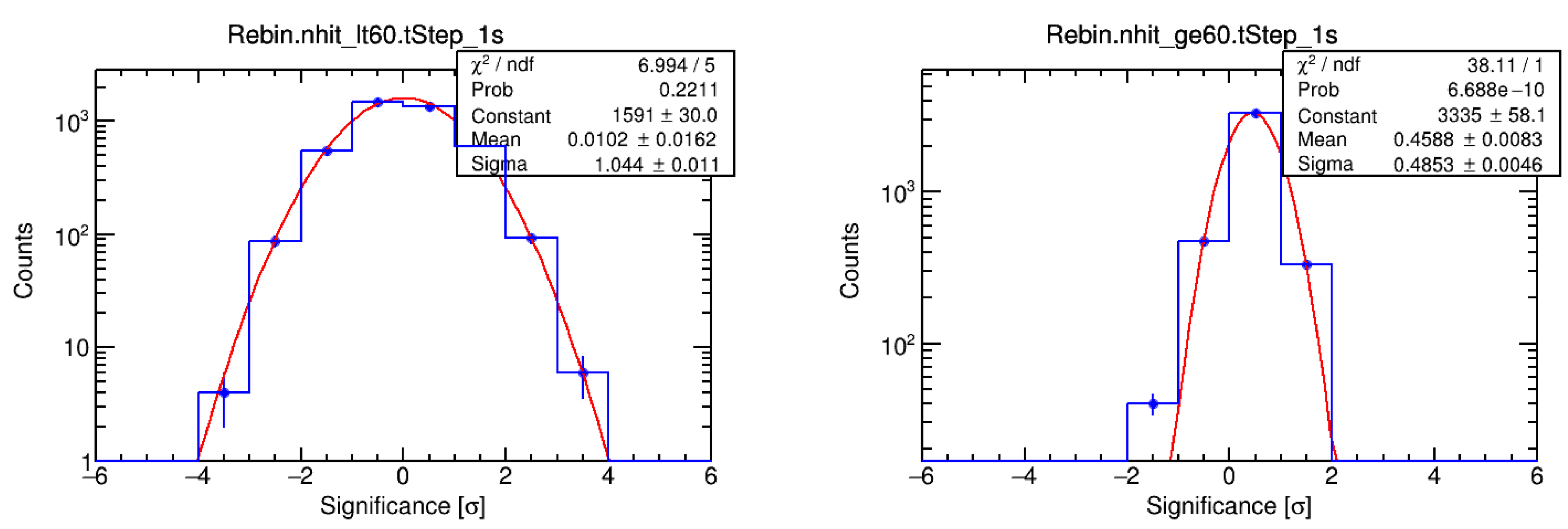
Two fake sources of equal-declination are adopted to estimate the number of background and signals.

Experimental Results

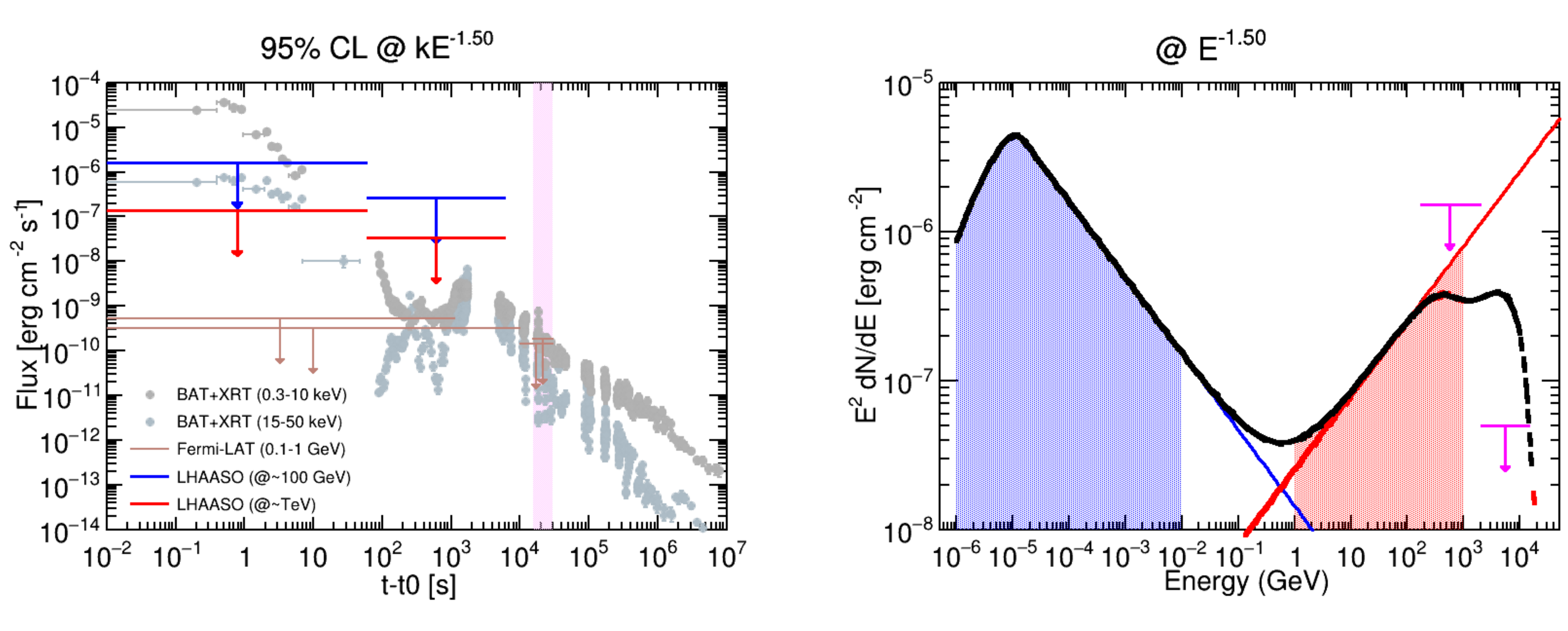
In this work, all reconstructed events are divided into hundred GeV and TeV energy categories according to the energy estimator nhit<60 and ≥ 60. The number of γ-ray events from source direction as a function of time around the T_0 is showed in below figures. No event excess was observed in both energies due to the large fluctuation.



The statistical distributions of significance-level are consistent with the Gaussian function.



No significant excess were detected by LHAASO-WCDA, thus 95% upper limits on the number of signal events are computed following the statistical method given by Helene [2]. By assuming an $E^{-1.5}$ power-law spectrum for GRB 190829A and considering the EBL absorption effect according to [3], with the detector response, the limit was then convert to flux units for two different energy bands.



Though no VHE signal was detected, the flux upper limits can provide important constraint information. During the prompt emission an extra power-law emission was phenomenologically modelled on the top of the Band spectra. Band function parameters are based on the Fermi-GBM, the extra component is described by a pow-law with a index β_{ext} and flux normalization R_{ext}. Right panel shows the spectra taking $R_{ext} = 0.1, \beta_{ext} = -1.5$. R_{ext} represents the ratio of fluences in the energy range 1 GeV $- 1$ TeV to that of 1 keV $- 10$ MeV, which are the red- and blue-shaded regions, respectively.

Conclusion

LHAASO-WCDA is a newly-built γ-ray array, its wide FOV, high duty cycle, low energy threshold make it suitable for the observation of GRBs. GRB 190829A is the closest GRB, the collected data by a quarter array array of LHAASO-WCDA were used to set an upper limit on high energy γ-ray flux for its prompt phase emission. Furthermore, we simply compared the upper limit with the flux of a phenomenological spectral model in the prompt phase. This results would be further used to constrain the magnetic field and other related parameters with detailed simulation works in future.