Event-counting methods for detection and study of the temporal profile of Fermi-LAT Gamma-Ray Bursts

Frédéric Piron (CNRS/IN2P3/LUPM), Vlasios Vasileiou (CNRS/IN2P3/LUPM), Giacomo Vianello (SLAC) and Nicola Omodei (Stanford University), on behalf of the Fermi Large Area Telescope Collaboration

Summary: *The standard technique for Gamma-Ray Burst (GRB) analysis with the LAT is based on the maximization of an unbinned likelihood function which makes use of the LAT instrument response functions (IRFs) on an event by event basis, in particular its point spread function (PSF). This standard analysis is restricted to events in the standard LAT data classes, which have good reconstruction quality, in order to minimize the systematic uncertainties due to the limited knowledge of the IRFs. Because the IRFs below 100 MeV are not well-characterized, standard LAT analyses are always performed using data with energies above this threshold. In the case of GRBs occurring at large inclinations with respect to the LAT boresight or having very soft spectra, the likelihood analysis can become difficult and/or signal limited. In this contribution, we present two alternate approaches for GRB detection and for the study of GRB temporal profiles, which require good photon statistics. Both methods consist of counting events in celestial regions of an energy-dependent radius that depends on the PSF. While the first approach considers data in the standard LAT data classes above a low-energy threshold of 50 MeV, the second one uses a more relaxed event selection, considering all LAT events that passed the onboard gamma filter with at least one well-reconstructed track in the LAT tracker and providing a rough direction measurement. We present the detailed implementation of these techniques, including the background estimation, the statistical methods for source detection and the calculation of signal significance, and the algorithms which are used to characterize the temporal profile of the LAT emission (onset, duration).*

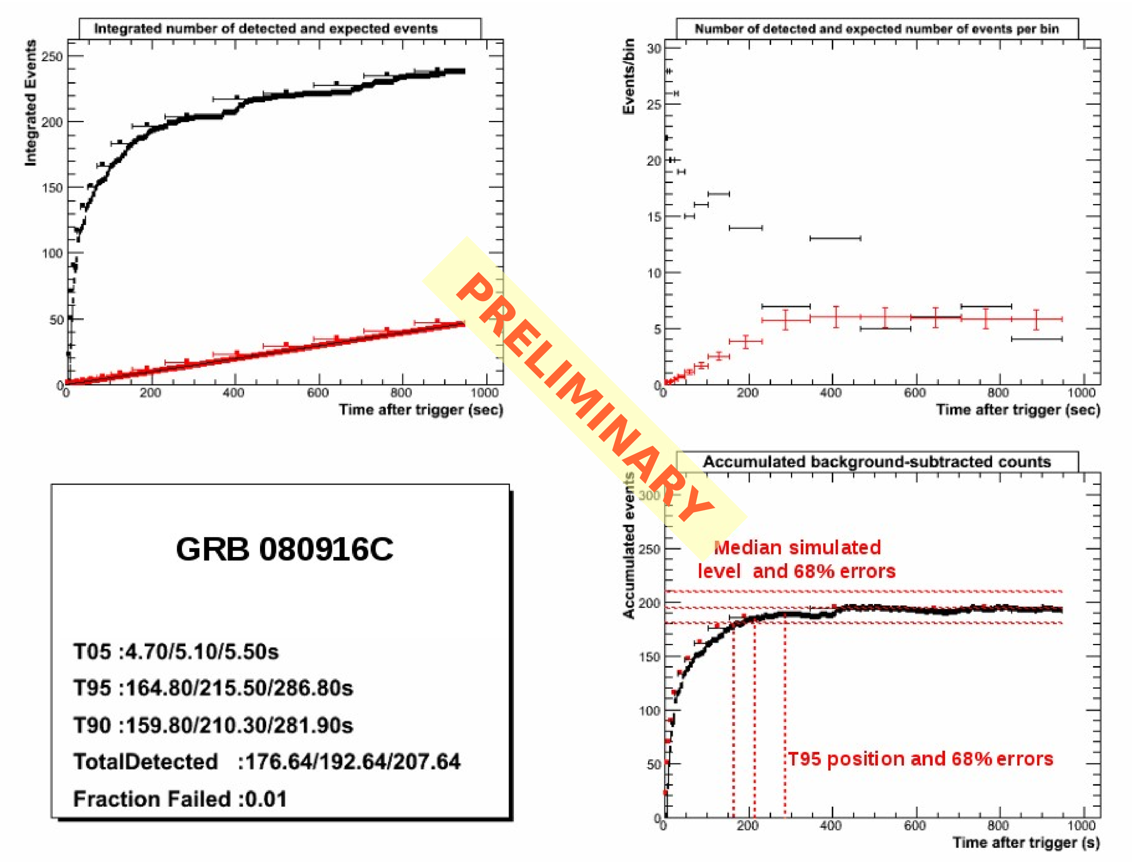
Method A: using LAT TRANSIENT-class events

Event-counting in an energy-dependent Region-Of-Interest (ROI) using TRANSIENT-class events.

1. Background estimation: the algorithm extensively employs a tool that was developed by the collaboration that estimates backgrounds at any time and for any orientation of the spacecraft. See [1] for more details.
2. Duration measurement: LAT T90 and its error are computed through simulations

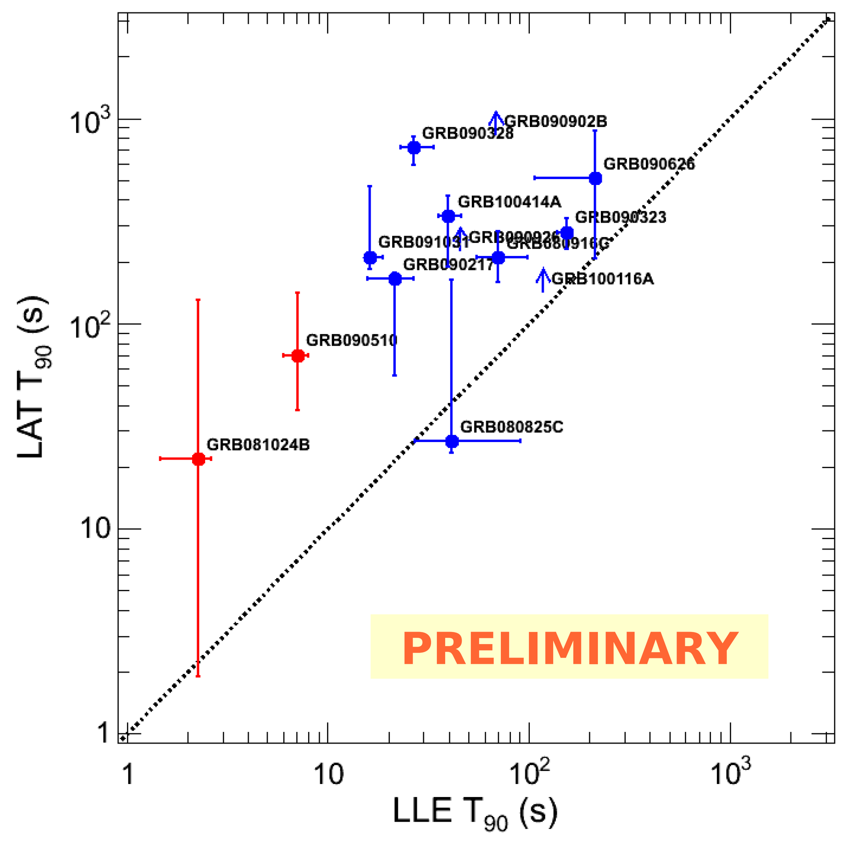
- The algorithm starts by estimating the background and counting the number of detected events in a variable ROI around the source in broad (up to 120s duration) consecutive steps in time.
- At each step, it progressively constructs a cumulative bkg-subtracted signal curve and searches for evidence of a plateau in its tail.
  - the plateau consists of an interval of duration >400 s (minimum duration increases as a fn of the time after trigger)
  - a plateau is found if the increase in the cumulative signal curve is negligible (<1.5σ pre-trials).
- After it finds a plateau, the algorithm starts again re-estimating the background and counting the number of detected events in fine steps (of a duration ranging from 0.2 to 2s) and up to the ending time of the detected plateau.
- The produced fine detected and estimated light curves are used as seed for a MC simulation, in which 50,000 simulated light curves are produced by applying Poissonian fluctuations on them. For each pair of simulated signal and background light curves, the algorithm produces a cumulative bkg-subtracted light curve and searches for a plateau in it.
  - the plateau in this case has a minimum duration of 120s and its possible ending time is throughout most of the light curve (instead of just at its end). A plateau is detected, similarly to the above, when the signal excess over the expected background is negligible throughout the duration of the potential plateau.
  - if a plateau is found, then, T05, T90, and T95 are computed and filled to corresponding distributions. If a plateau is not found, then the simulated light curves are regenerated.
- If a plateau is not found in >30% of the simulated light curves, the code exits and returns a lower limit on the duration.
- After the simulation finishes, the medians of the simulated T05, T90, and T95 distributions are returned as the duration measurements. The errors are given as the end points of the 68% intervals (shortest length) that contains the median.

GRB 080916C with method A



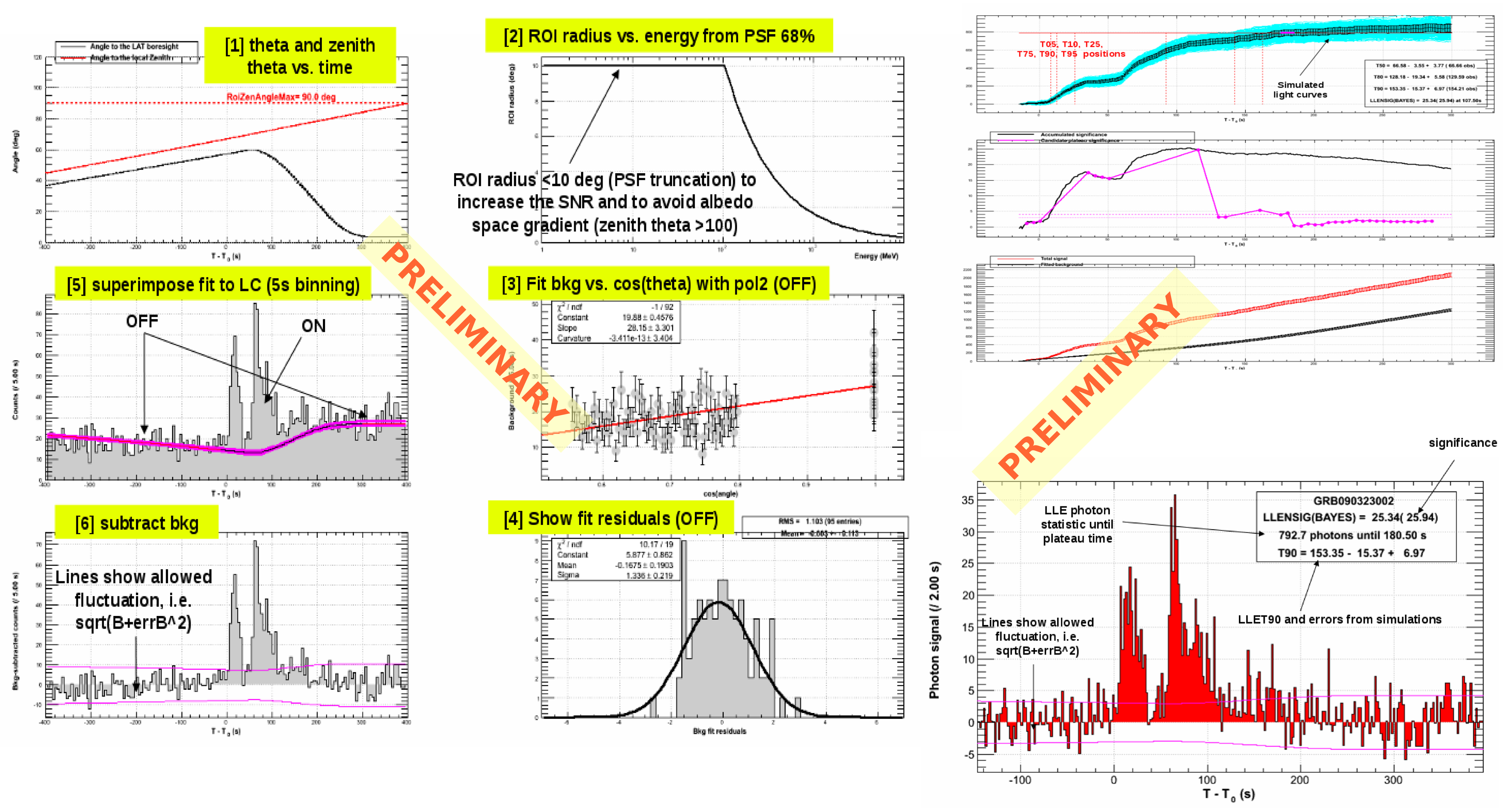
Comparing A & B

For 13 bursts in the Fermi-LAT GRB Catalog [3]



Whereas method B detects the bulk of the emission in the LAT (mostly <100 MeV), method A is sensitive to the temporally extended emission at higher energies

GRB 090323 with method B (first algorithm)



Method B: using LAT Low-Energy events

Event-counting in an energy-dependent ROI using LAT Low-Energy (LLE) events (i.e. passing the onboard GAMMA filter, one track required in the LAT tracker). See [2] for more details on this event selection.

FIRST ALGORITHM

1. Initializations: definition of ON (GRB) and OFF (BKG) time windows, choice of the maximum size of the energy-dependent ROI (to avoid any gradient of the Earth albedo contamination in the ROI which would complicate the bkg estimation).
2. Background estimation: fitted in the OFF window using a model B(t) = pol[C(t)], with C(t)=cos[θ(t)] (θ is the angle to the LAT boresight), and then subtracted. In practice, a pol2 (parabola) is good enough.

- θ is the main geometrical parameter that determines the background and its variations, yet other parameters (azimuth angle in the LAT, zenith angle, arclength of the Earth limb in the LAT field of view) might be added to the model in the future
- The extrapolation of the fit (and the propagation of the errors) allows to estimate the background B and its error errB for any value of θ, thus at any time in the ON region – B(t) and errB(t)

3. Signal significance: maximum value of the cumulative significance using a semi-Bayesian approach to account for errB – see [1] for details.
4. Duration measurement: LLE T90 and its error are computed through simulations

- The simulation is based on the actual observed light curve, and 1000 realizations are enough in practice for an accurate measurement.
- In each light curve (actual or simulated), a plateau candidate is found if the local slope, when extrapolated to the end of the GRB window, predicts an additional photon signal which is <3σ above the last point (flatness criterion)
- A plateau candidate becomes the current plateau if the additional photon signal which was accumulated since the last plateau is >4σ (>3σ since the start of the GRB window for the first plateau)
- Duration and error: median value and quantile of simulated distributions

SECOND ALGORITHM

1. Initializations: definition of ON & OFF time windows, along with a set of bin sizes and bin shifts. For every pair (bin size, bin shift):
2. Background estimation: using a model B(t) = pol(t)*C(t)

- For every bin in ON region, compute the Poisson probability of obtaining the observed counts given the background model (null-hypothesis probability)
- Take the bin with the minimum null-hypothesis probability, and correct the probability for the number of trials (i.e., the number of bins in the ON window)

3. Signal significance: choose the bin size & shift containing the bin with the minimum null-hypothesis probability (i.e., maximum significance)

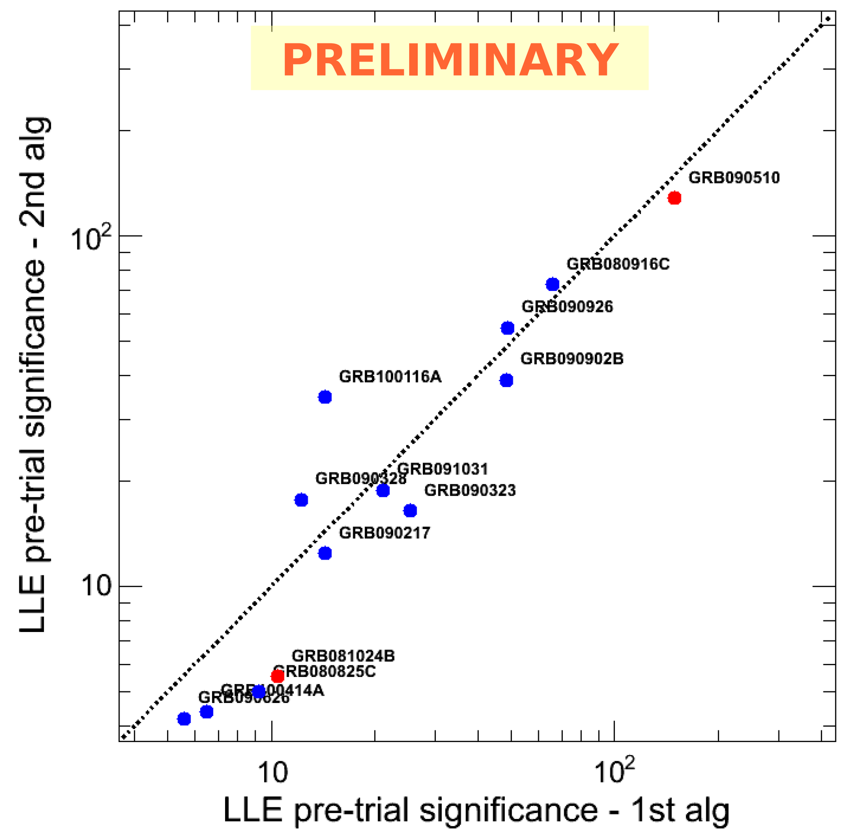
- Correct this probability for the effective number of trials (MC simulation)

4. Duration measurement: start from the most significant light curve found by the detection algorithm and do what a human eye would do:

- Find every high significance bin (>4σ)
- Follow the "mountain side" starting from every high significance bin, until reaching the background level and define a refined GRB window
- Measure the T90 and compute the total significance during this interval
- Define a set of bin sizes and shifts based on the T90, iterate previous two points for every pair (bin size, shift).
- Simulations showed that the best estimate for the duration is the T90 measured in the light curve with the maximum total significance.

COMPARISON

Excellent correlation between detection significances from both algorithms (any differences at low significances may be partially explained by the different number of effective trials)



References

[1] Abdo, A. A., et al. 2009, ApJ, 707, 580

[2] V. Pelassa, "Recovering LAT GRB prompt emission above 30 MeV with the LAT Low-Energy selection", this conference

[3] N. Omodei, "The Fermi-LAT GRB Catalog", this conference (paper in prep.)