The LAT Low-Energy technique for Fermi Gamma-Ray Bursts spectral analysis.

V. Pelassa, F. Piron
LPTA, CNRS/IN2P3 - Université Montpellier 2

R. Preece, S. Guiriec
NSSTC, MSFC - UAH

N. Omodei
INFN, Pisa University

on behalf of the Fermi LAT and GBM collaborations

Fermi Large Area Telescope (LAT) data analyses based on event reconstruction and classification are so far restricted to events of measured energy larger than 100 MeV. We present a new technique to recover the signal from Gamma-Ray Bursts’ (GRB) prompt emission between $\sim$30 MeV and 100 MeV, which differs from the standard LAT analysis. Filling the gap between the energy ranges where the Gamma-ray Burst Monitor (GBM) and LAT operate is important to better constrain the high-energy spectra of GRBs. The LAT Low-Energy (LLE) technique is described, first performance studies are presented, as well as preliminary spectral re-analyses of two Fermi GRBs.

I. INTRODUCTION

Since the launch in June 2008, the Gamma-ray Burst Monitor (GBM) onboard Fermi detected over 300 Gamma-Ray Bursts (GRB), 12 of which were detected and studied above 100 MeV with the Fermi Large Area Telescope (LAT). The GBM enables GRB spectroscopy from 8 keV to 40 MeV, and the standard LAT analysis is performed using events of energies above 100 MeV only.

Here we propose a non-standard LAT analysis which allows to recover the prompt emission from GRB between $\sim$30 MeV and 100 MeV, joining the two instruments’ energy ranges. This so-called LAT Low-Energy (LLE) technique also improves the photon statistics above 100 MeV, and will allow us to better define the GRB prompt emission spectral characteristics. It is important to note that this analysis is based on non-public data and software, and is still under improvement and calibration at the time of this proceeding.

Section II describes the LLE technique objectives and principles. Performance studies are presented in section III. Preliminary re-analyses of the bright GRB 080916C and GRB 090510 are presented in section IV.

II. THE “LAT LOW-ENERGY” TECHNIQUE

A. Motivation

The LAT standard analysis is based on a sophisticated reconstruction and classification procedure [1]. The probability for each event to be a photon is estimated using the event topology and the reliability of its reconstruction.

![FIG. 1: GRB 090510 spectral energy distribution [2].](image)

Top: the time-integrated spectrum clearly shows an additional power-law component. Bottom: time-resolved spectroscopy. In bin ‘a’ no signal was detected in the LAT. Bins ‘b’ and ‘c’ show an additional power-law component. No signal is detected in the GBM after 0.9 s (bin ‘d’). The 40 – 100 MeV gap is highlighted.

The characteristics of the particle backgrounds below 100 MeV is still under study and makes this classification more complicated. Moreover, the LAT effective area suffers from systematic effects which are not well determined yet in this energy range. Although the standard LAT analysis currently starts at 100 MeV, public datasets and responses should allow for analyses starting at energies lower than 100 MeV for any kind of source in the future.

On the one hand, faint or soft GRB emissions (e.g. bin ‘a’ of GRB 090510, see fig. I) are not detected so far above 100 MeV, while they can exhibit additional components which become dominant above few tens
FIG. 2: GRB 080916C prompt emission between 30 MeV and 100 MeV. Top: the lightcurve is used to define “ON” and “OFF” emissions. The “OFF” rate is extrapolated to estimate the background level in the “ON” interval. Bottom: signal and extrapolated background spectra in the “ON” interval.

of MeV. Their signal above this energy can be rejected by the usual quality selections or be intrinsically too faint. An improved spectral analysis above 40 MeV would reveal any kind of feature, e.g. a faint additional component, a cutoff, or a simple power-law behaviour. The use of the present technique should improve the statistics above 100 MeV as well, although it is not yet clear whether it will substantially improve the sensitivity of the spectral analysis.

On the other hand, bright spectra (e.g. bin 'b' to 'd' of GRB 090510, see fig. or GRB 080916C ) are currently reconstructed above 100 MeV. Adding a LAT low-energy signal to the available standard dataset would help to better constrain the spectral parameters of such features (see section IV).

B. Principle

The LLE technique makes use of the analysis software RMfit, which is commonly used for all GBM spectral and temporal analyses. It consists of the forward-folding analysis of a background-subtracted binned event rate, using a Detector Response Matrix (DRM) for model-folding (fig. 3). A temporal selection defines the “ON” interval containing the emission and the “OFF” interval(s) used to extrapolate the background rate in the “ON” interval, in each energy bin (fig. 2).

In contrast with the standard analysis, the LLE event selection does not include strict quality criteria. We consider every event passing the onboard GAMMA filter and for which at least one track could be found in the tracker. Many of these events do not have a reliable direction, therefore no “region of interest” can be defined around the source position in the sky. A binning is applied on the measured energy (see section IV).

Once the “ON” and “OFF” intervals have been selected, the background rate time profile is fitted with a polynomial function in each energy bin, which yields an estimate of the background spectrum in the “ON” interval. The background spectrum can vary with time so the “OFF” intervals cannot be chosen too far from the “ON” interval, nor too close nor short to allow for a good fit precision. The same precautions are usually taken for spectral analyses of GBM data.

The DRM is built from a dedicated extensive simulation of a bright point source using the GLEAM soft-
FIG. 4: Fraction of events from a large set of simulated photons passing the standard Pass6 “transient class” quality selections (squares) and LLE relaxed selections (circles), both normalized to the onboard GAMMA filter.

TABLE I: LLE energy measurement resolution for simulated photons of inclination angle $\theta < 40^\circ$ (top) or $40^\circ < \theta < 70^\circ$ (bottom). Energies are in MeV. True energy $E_{MC}$ lines of width 4 MeV were selected. The resolution is here defined as $\text{RMS}/<E_{mes}>$ and the error as $(<E_{mes}> - E_{MC})/E_{MC}$.

| $E_{MC}$ (MeV) | $<E_{mes}>$ (MeV) | RMS | Resolution (%) | Error (%) |
|---------------|------------------|-----|----------------|----------|
| 30            | 27               | 10  | 37%            | -10%     |
| 50            | 45               | 16  | 36%            | -10%     |
| 100           | 90               | 27  | 30%            | -10%     |
| 500           | 490              | 70  | 14%            | -2%      |
| 30            | 30               | 14  | 47%            | 0%       |
| 50            | 44               | 18  | 41%            | -12%     |
| 100           | 85               | 34  | 40%            | -15%     |
| 500           | 470              | 80  | 17%            | -6%      |

TABLE II: Spectral parameters of the simulated GRB spectrum, and reconstructed spectra using standard Pass6 transient events only, or LLE events as well. Only statistical errors are shown. Though the use of LLE data reduces the uncertainties, a systematic error appears.

| Spectrum     | $N_0$ \left(10^{-9} \text{ ph.cm}^{-2}\text{s}^{-1}\right)$ | $\beta$   |
|--------------|------------------------------------------------|-----------|
| input        | 1.19                                            | 2.1       |
| fit without LLE | $1.36 \pm 0.13$                            | $2.21 \pm 0.06$ |
| fit with LLE | $1.60 \pm 0.12$                             | $2.02 \pm 0.02$ |

C. Reconstruction capabilities

To study the reconstruction capabilities of the LLE technique, a bright GRB was simulated as a point source with a simple power-law spectrum: $N(E) = N_0(E/E_0)^{-\beta}$. No background was added to the data and this spectrum was analyzed using the standard tool XSPEC (HEASARC). The reconstruction was performed using only the standard Pass6 transient data (above 100 MeV), or using both the LLE (30 MeV to 100 MeV) and Pass6 transient data. Both reconstructions yield similar results (table II), with a smaller uncertainty on the index $\beta$ when using LLE data. A systematic error yet appears, which will be investigated after the technique has been fully calibrated.
IV. PRELIMINARY RE-ANALYSES

New analyses of two bright bursts were performed and yield encouraging results.

GRB 080916C time-integrated spectrum was fitted using only GBM and standard transient events (above 100 MeV) (fig. 5). The LLE dataset was added but not used for the fit. The good residuals in the LLE energy range (30 MeV – 100 MeV) show the good agreement between this technique and the standard procedure.

GRB 090510 time-integrated spectrum was fitted using all datasets: GBM, LAT Pass6 transient, LLE. A Band function with an additional power-law component yields the best fit, like in the standard analysis. The high-energy component is more significant when using LLE data ($N_\sigma = 8.9$ instead of 5.6 without LLE). The spectral evolution observed in this bright burst’s prompt emission will certainly better show up if the LLE data are used in the time-resolved spectroscopy.

V. CONCLUSION

The LLE technique presented here can be used in principle for any kind of flaring source: GRB prompt emission, AXP, pulsars (see [6] for details), etc.

In particular it appears to be very promising for GRB prompt emission spectral analyses, revealing or better defining GRB spectral features above 30 MeV.

The validation study of these analyses is yet still ongoing (acceptance and energy calibration, systematics effects). The reconstruction of a simulated spectrum has shown a bias, such effects have to be characterized and understood. The performances that are yet measured from sets of simulated photons have to be confronted to data, e.g. using Vela on-pulse emission as a pure sample of real photons.
[1] W.B. Atwood et al., “The Large Area Telescope on the Fermi Gamma-ray Space Telescope”, ApJ, 697, 1071 (2009)

[2] A.A. Abdo et al., “Fermi Observations of GRB 090510: a short hard Gamma-Ray Burst with power-law emission from 10 keV to GeV energies”, ApJL, submitted (2010)

[3] A.A. Abdo et al., “Fermi observations of high-energy gamma-ray emission from GRB 080916C”, Science, 323, 1688 (2009)

[4] L. Baldini et al., “GLAST LAT full simulation”, Nuc. Phys. B, 39, 62 (2006)

[5] A.A. Abdo et al., “Fermi observations of high-energy gamma-ray emission from GRB 080825C”, ApJ, 707, 580 (2009)

[6] M. Burgess, “Pulsar studies using the LLE technique”, these proceedings