Fermi-LAT recent results on Gamma-Ray Bursts

Frédéric Piron

LUPM (CNRS/IN2P3, Montpellier)

On behalf of the *Fermi* LAT and GBM collaborations

Content

- The individual and most interesting GRBs detected by the LAT in the past ~year will be presented in dedicated talks this week
- A review presentation on GRB theory later this morning

$$\Rightarrow$$

This review of LAT observational results is focused on recent population studies and GRB common properties:

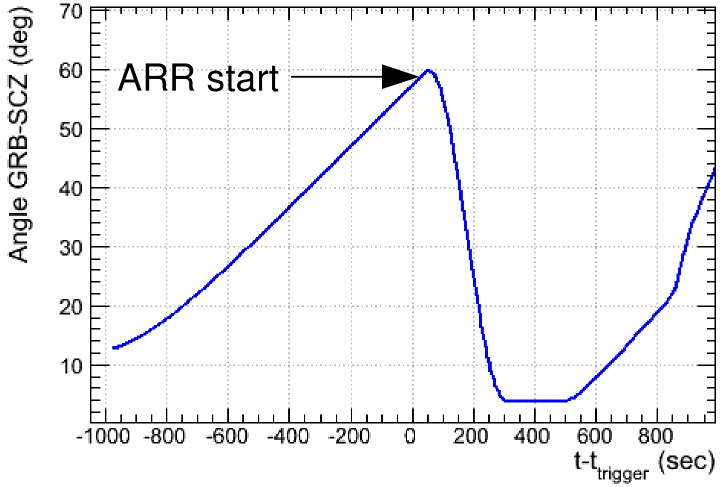
- What we have seen with the LAT: the first LAT GRB catalog
- What we missed with the LAT: non detections of bright GBM GRBs

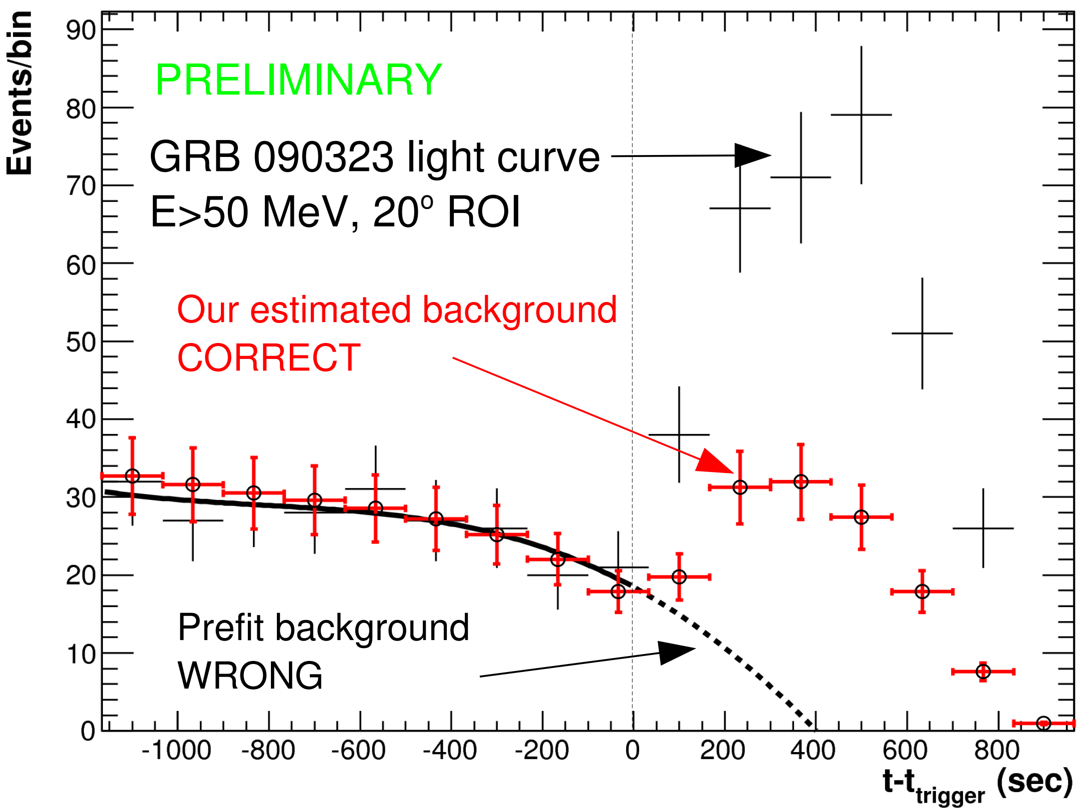
The first LAT GRB catalog

- First systematic study of GRB properties at high energies (above ~20 MeV)
- Covers a 3 year period starting from August 2008, including:
  - Tabulated GRB parameters
    - Start / end times, duration, average and peak fluxes, time of the peak flux, temporal decay slope, spectral evolution, fluence, energetics
    - Spectral components (from GBM+LAT joint spectral fits), evolution with time
  - Discussions on the unique properties of individual GRBs (presence of extra spectral components and of high-energy spectral cutoffs)
  - Details on the analysis: methodology, tools, methods and caveats
- Analysis now frozen, paper under internal review, to be submitted soon
- Selected results are highlighted in the following slides along with needed ingredients for this analysis work

Background estimation

Angle between GRB 090323 and the LAT's boresight





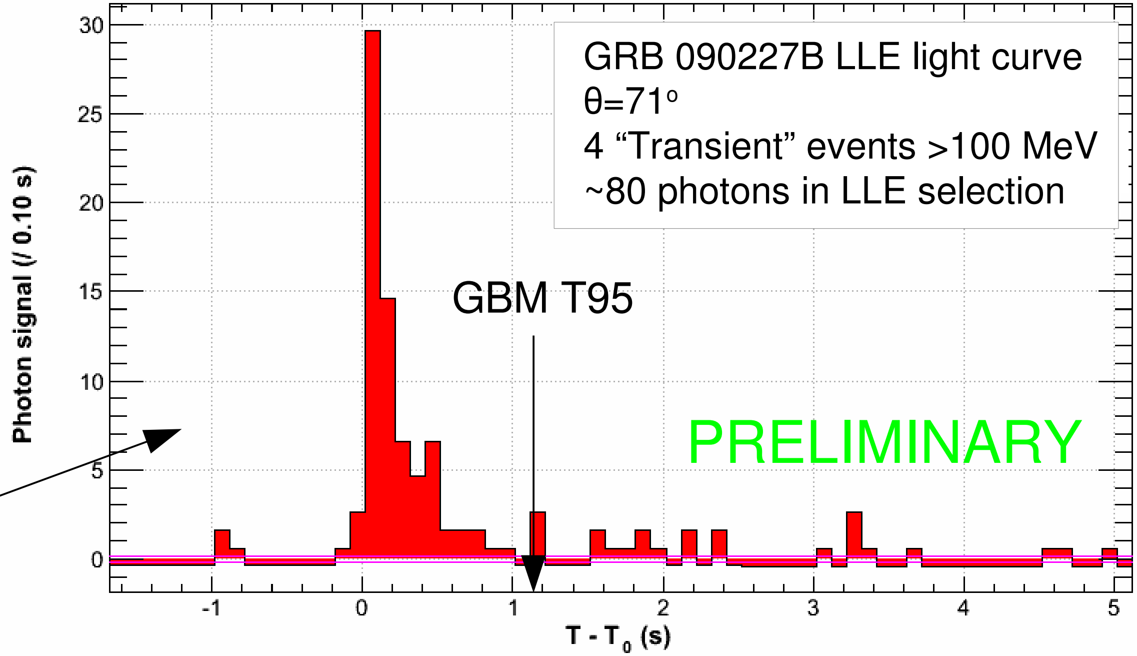
- A common method for estimating the background is:
  - by fitting the background before and after the GRB trigger time and interpolating
  - or by fitting the background before the GRB trigger time and extrapolating
- Wrong estimate if an autonomous repoint request (ARR) is initiated
  - An ARR causes rapid variations of source off-axis angle and exposure
  - Light curves thus can not be fitted in detected count space!
- A background-estimation tool that uses a model of the LAT backgrounds
  - described in our GRB 080825C paper
  - works for any observational conditions, ~10-15% accuracy
  - extensively used in the catalog's analyses: duration estimates, maximum likelihoods, event probabilities

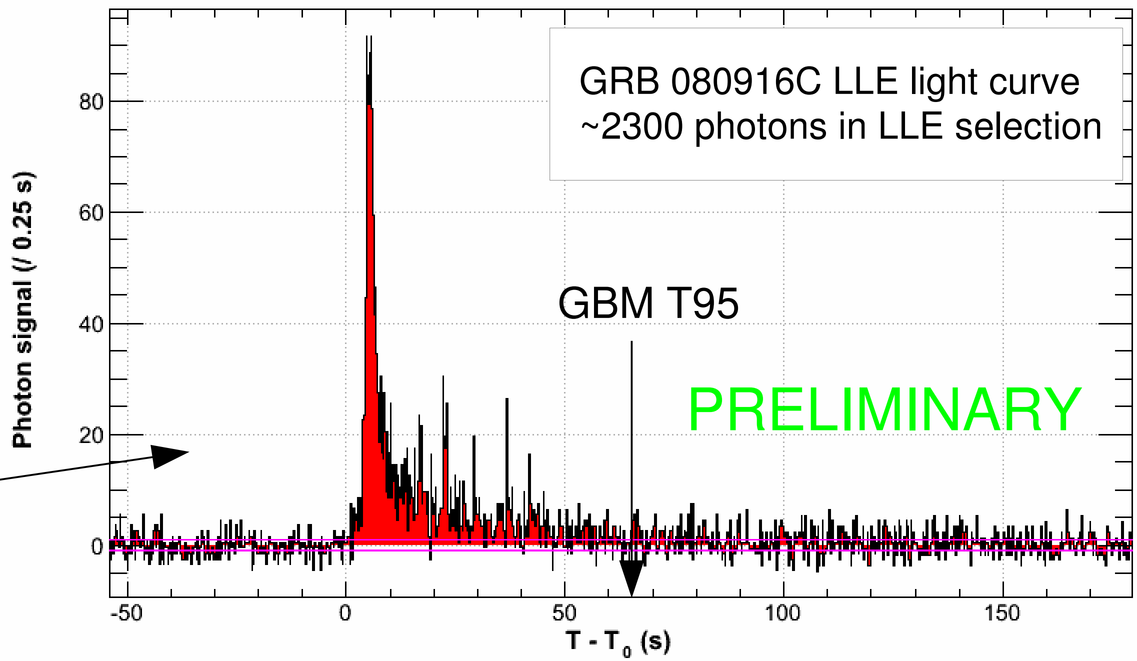
LAT Low-Energy (LLE) event class

- Most GRBs are detected by means of the standard event selection (P6_V3 "Transient") and analysis technique (unbinned maximum likelihood above 100 MeV)

- Some other GRBs are too weak, too soft, or at a too high off-axis angle (i.e. θ>70°) to be significantly detected

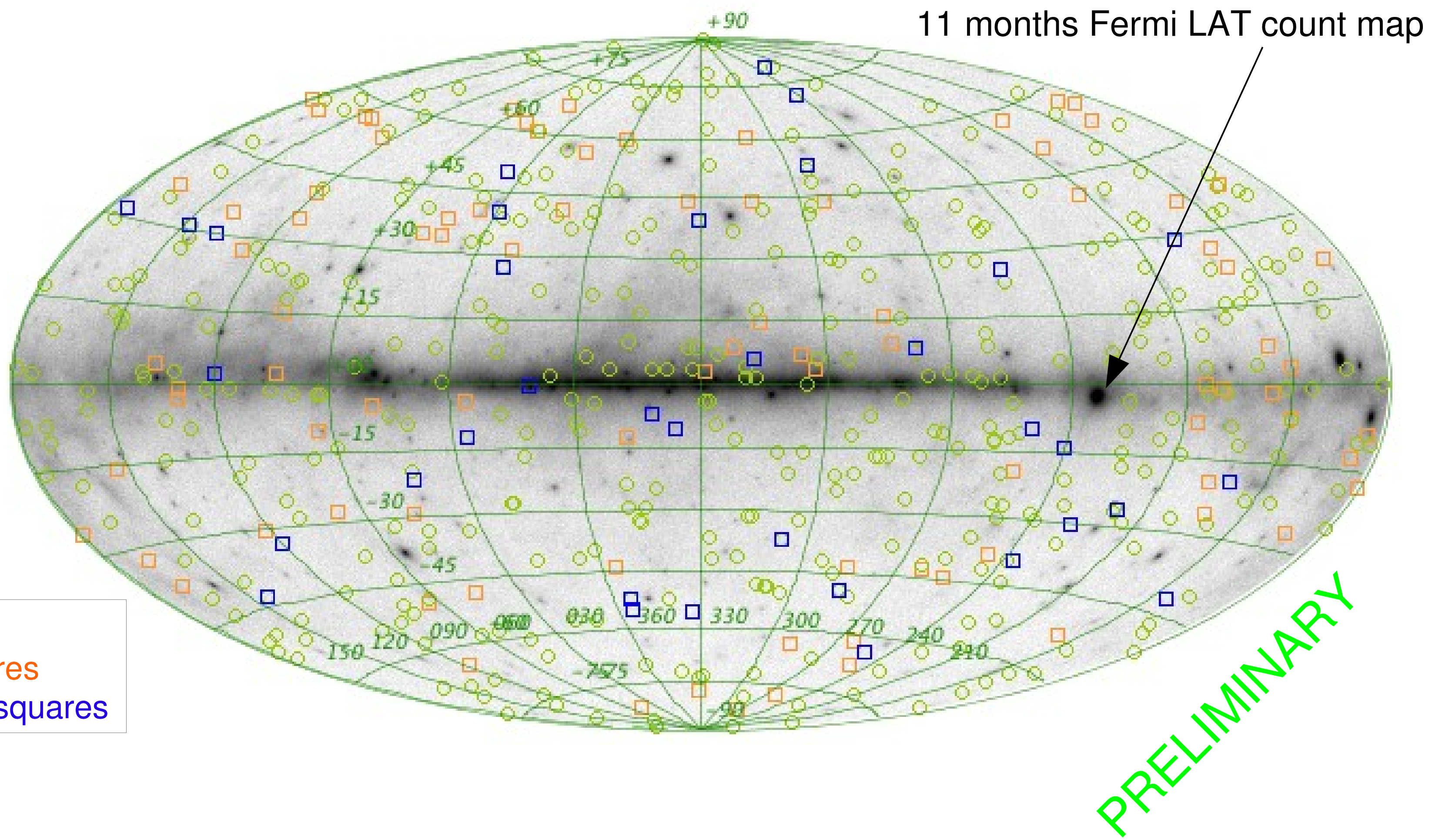
- We introduced the LLE event class (relaxed selection criteria)
  - Significantly higher effective area at tens-of-MeV energies and at larger off-axis angles
  - Despite a higher background, it provides the needed statistics to study GRB temporal properties at low energies in the LAT





Fermi GRB detection statistics

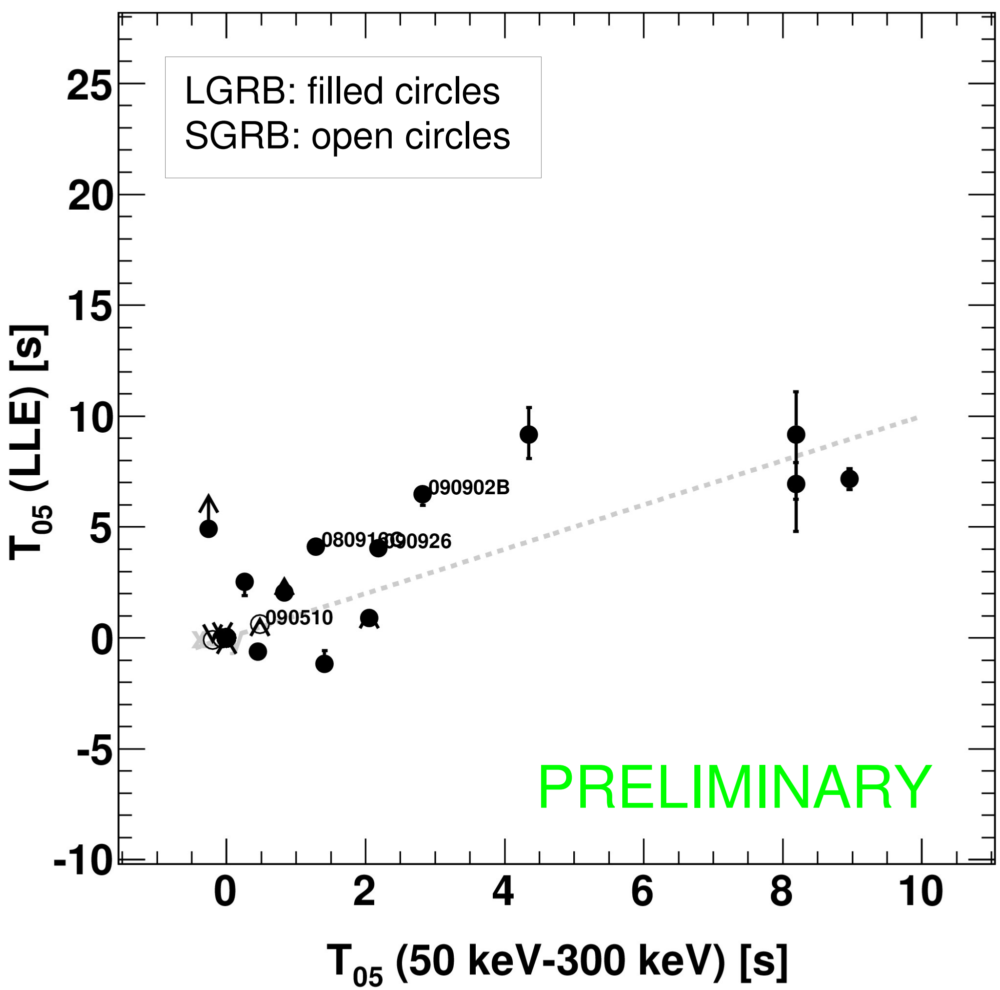
GBM 2-year catalog
LAT 3-year catalog

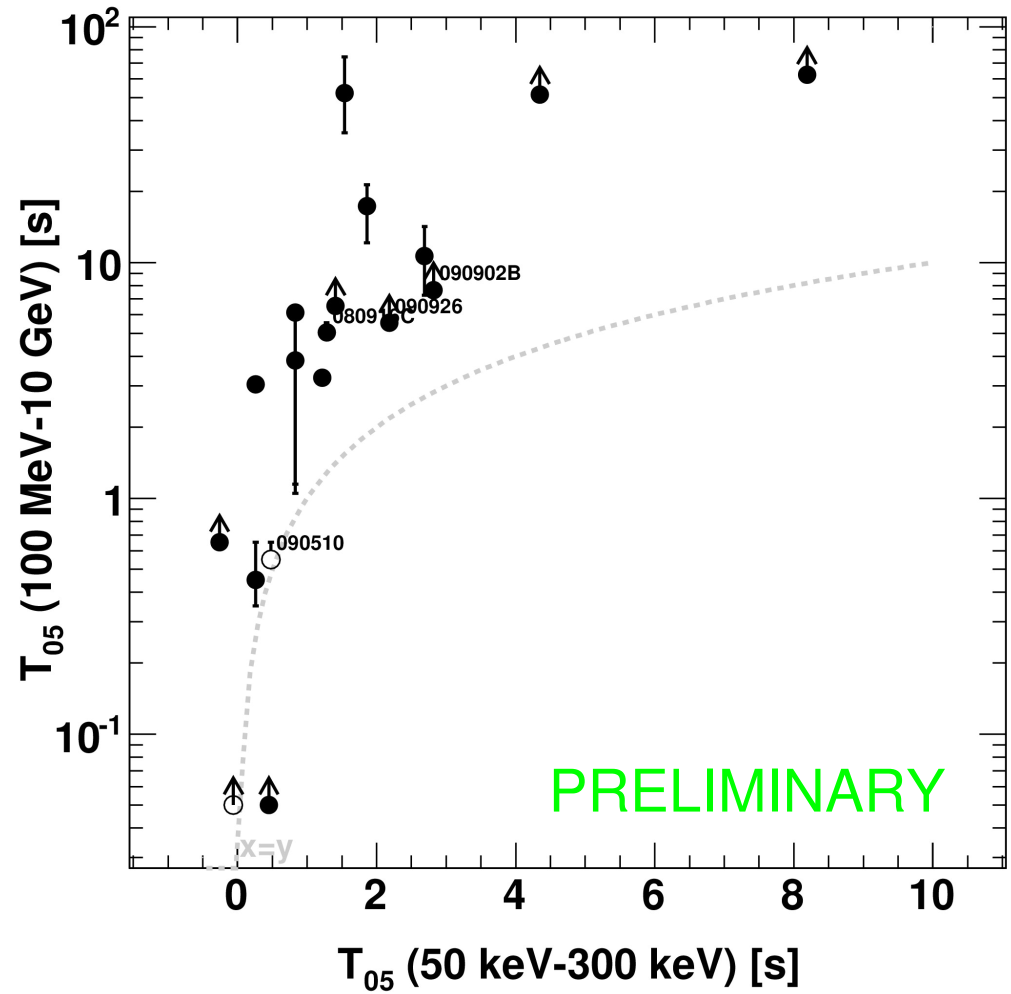


- The GBM detects ~250 GRBs / year, ~half in the LAT FoV
- The LAT detected 35 GRBs in 3 years (30 long, 5 short), including 7 “LLE-only” GRBs
  - ~Half with more accurate follow-up localisations by Swift and ground-based observatories (GROND, Gemini-S, Gemini-N, VLT)
  - 9 redshift measurements, from z=0.74 (GRB 090328) to z=4.35 (GRB 080916C)

Delayed onset of >100 MeV emission

- GBM T05 vs. LLE T05: onset of LLE emission is compatible with GBM
- GBM T05 vs. LAT T05: LAT >100 MeV emission is systematically delayed

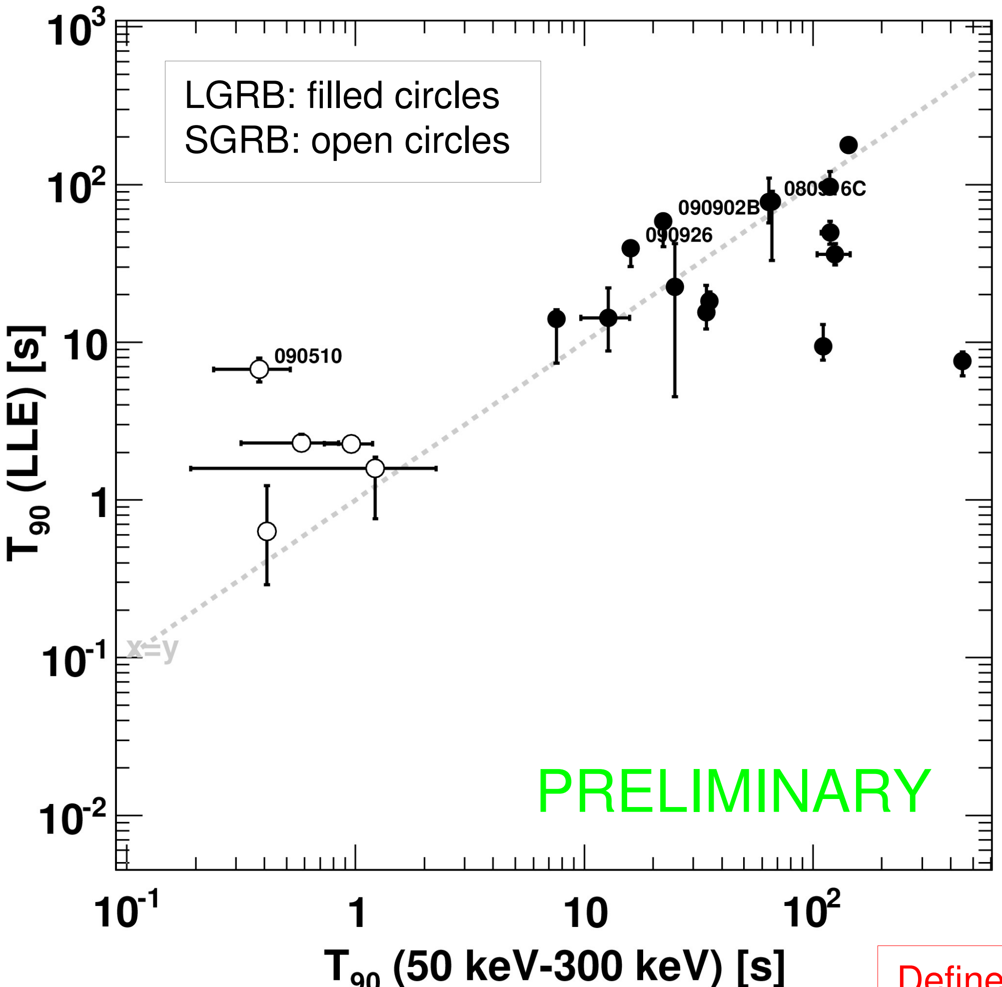


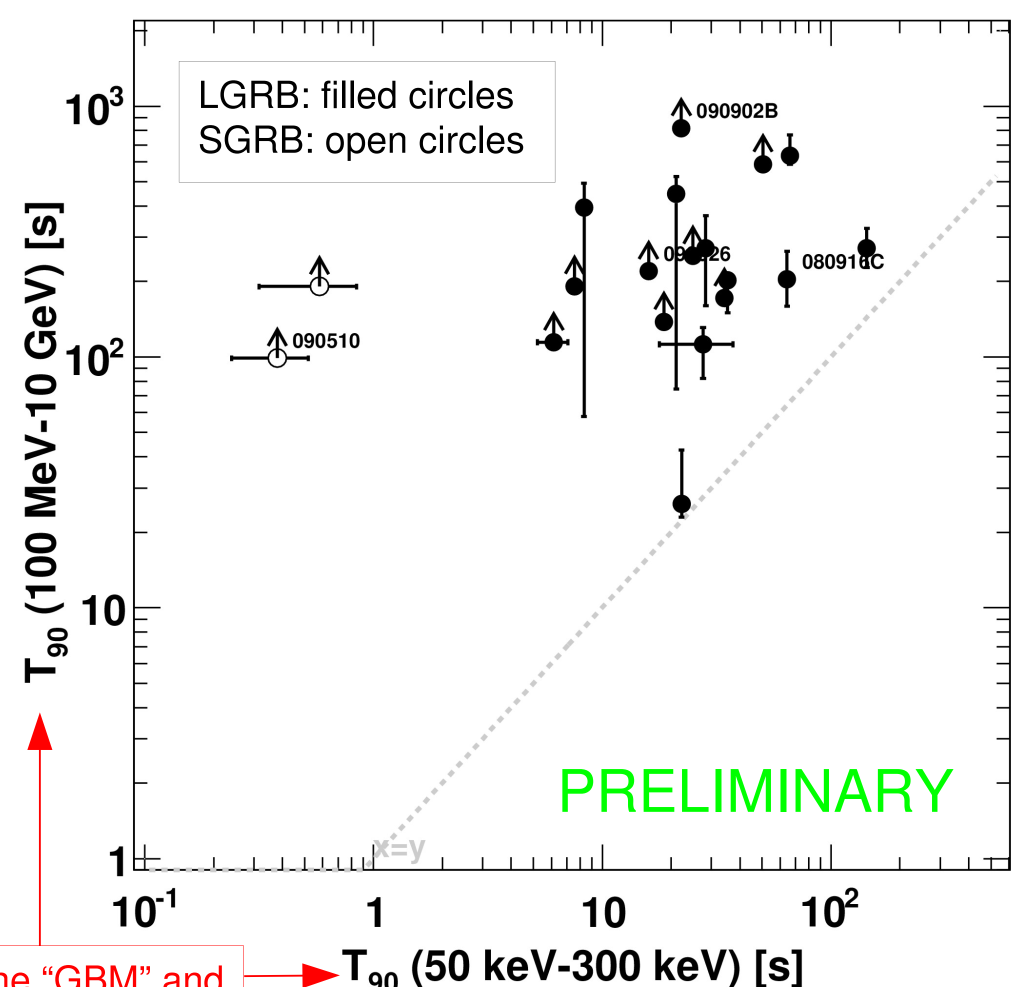


LAT >100 MeV emission is temporally extended

- GBM T90 vs. LLE T90: duration of LLE emission is compatible with GBM

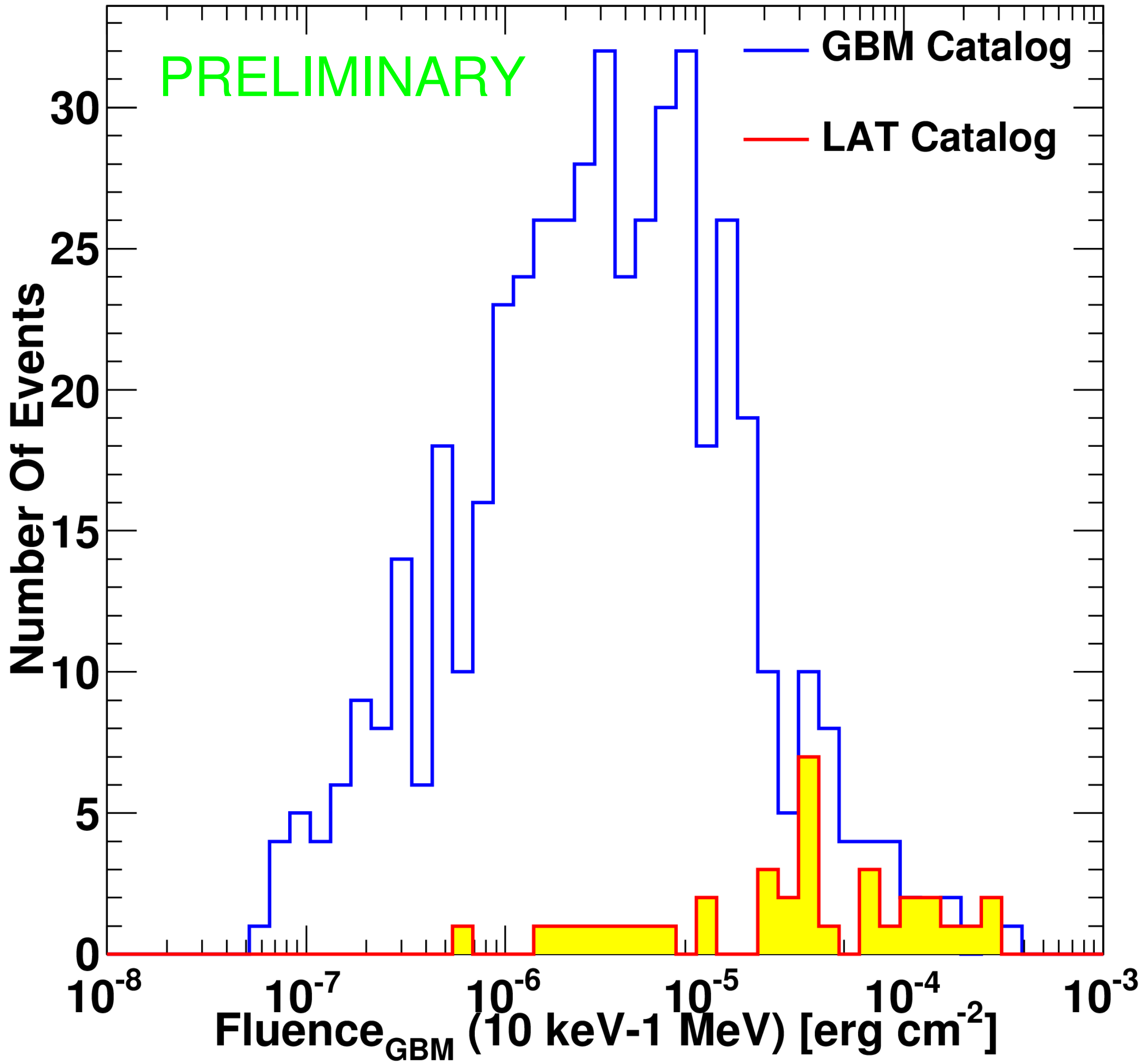
- GBM T90 vs. LAT T90: LAT >100 MeV emission lasts systematically longer
  - Different component or better sensitivity of the LAT detector than the GBM detector (background dominated)?





Define the “GBM” and “LAT” time windows

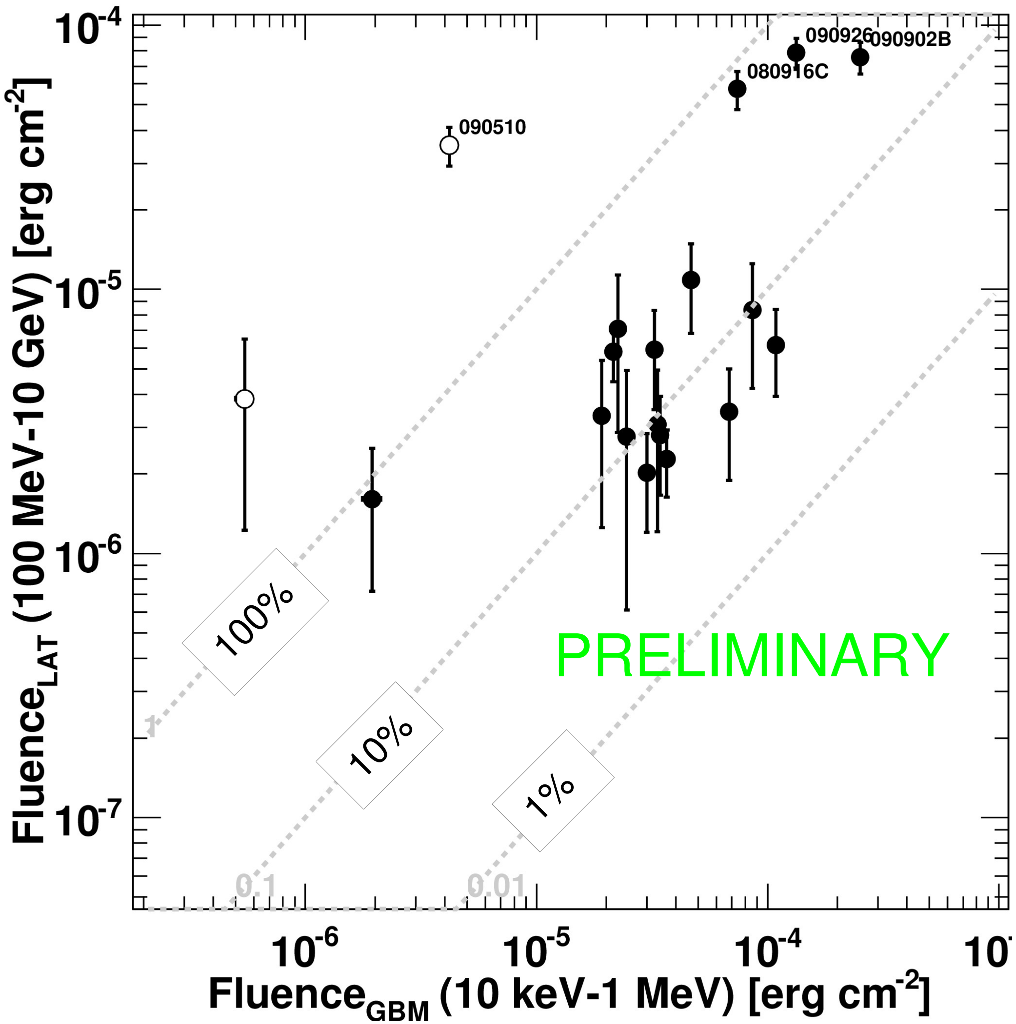
GBM fluence of LAT GRBs

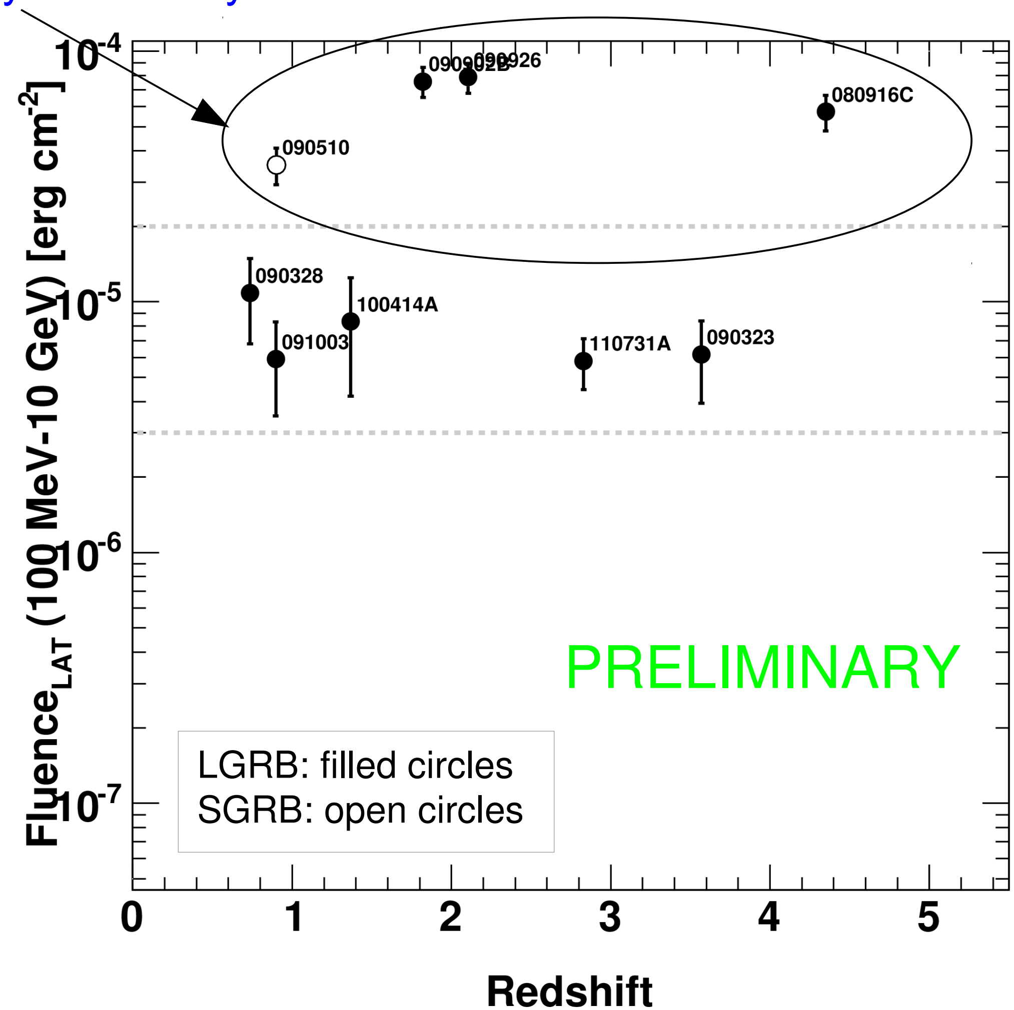


- Fluence in GBM energy range and "GBM" time window
  - LAT GRBs vs. entire sample in GBM spectral catalog (Goldstein et al. 2012)
- Not surprisingly, LAT GRBs are among the brightest GBM GRBs
  - Selection effects (ARRs) should be investigated though

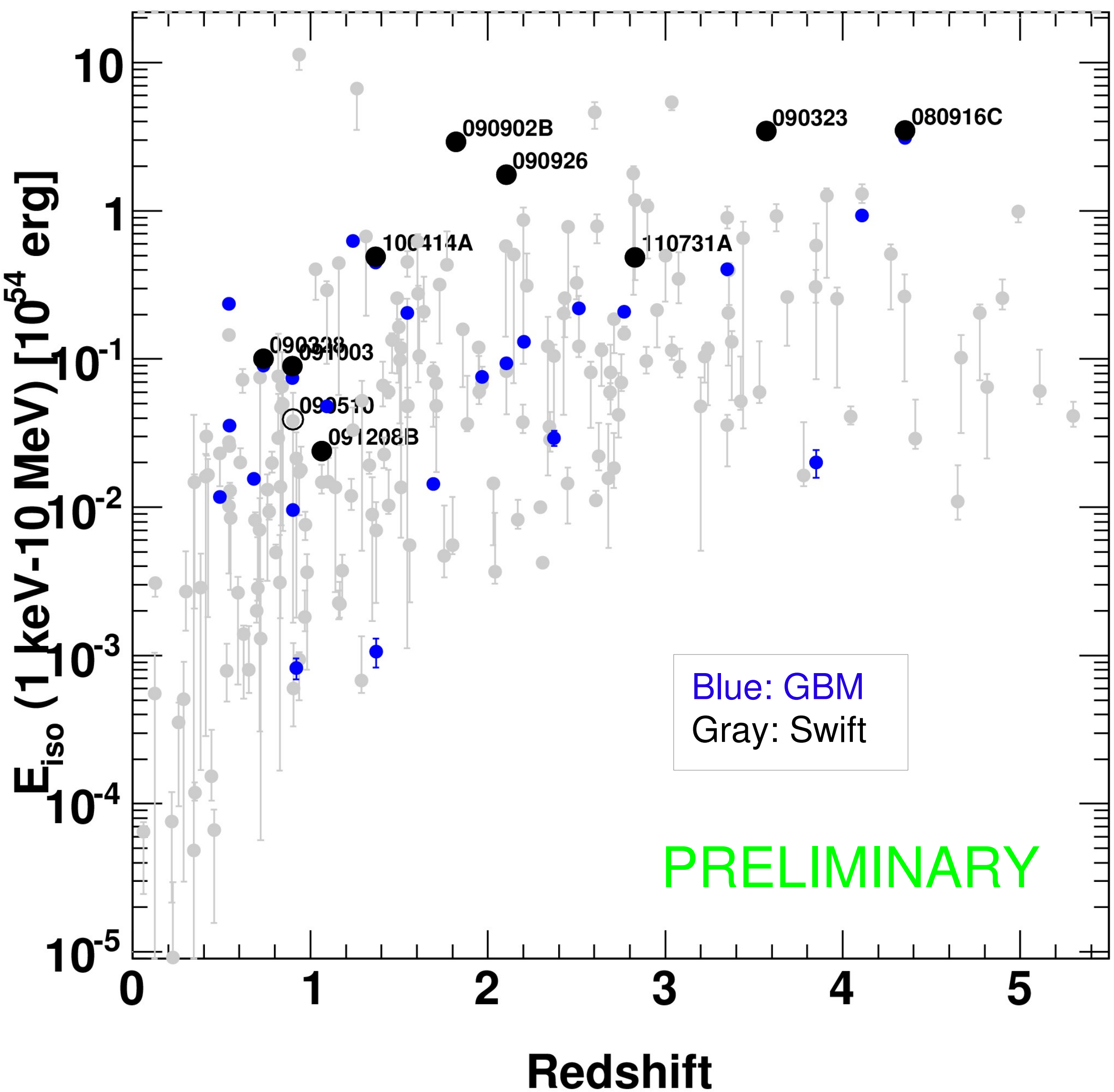
GBM vs. LAT fluences

- GBM and LAT fluences computed in "GBM" and "LAT" time windows, respectively
  - Long GRBs: LAT fluence ~10% of GBM fluence
  - Short GRBs: LAT fluence > GBM fluence
- Evidence of a hyper-energetic class: 080916C, 090510, 090902B, 090926A are exceptionally bright
  - They do not appear bright because they are systematically closer to us





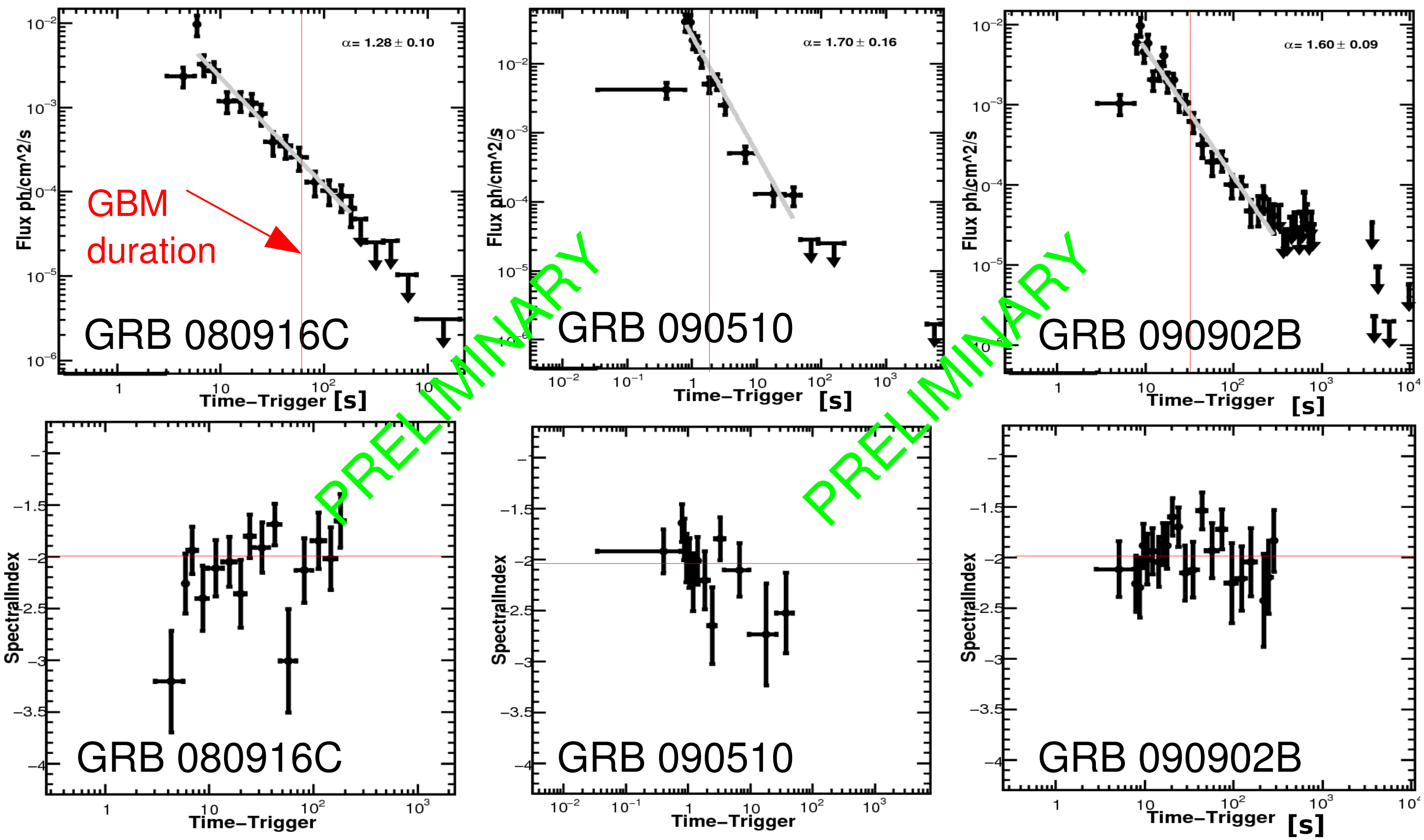
Energetics

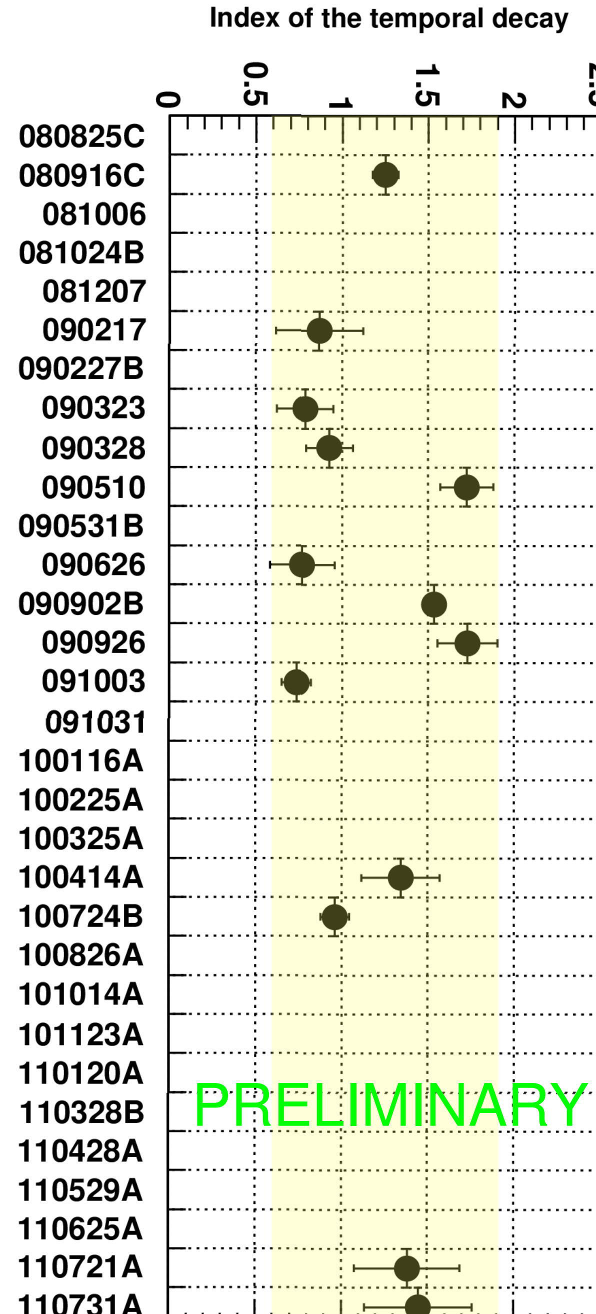


- 9 GRBs with redshift
- E_{iso} (1 keV-10 MeV) in "GBM" time window vs. redshift
  - LAT GRBs vs. GBM (Goldstein et al. 2012) and Swift (Butler et al. 2007) samples
- LAT GRBs are among the most energetic bursts
- GRB 090510 is also one of the most energetic short bursts
- No particular trend in redshift (small sample)

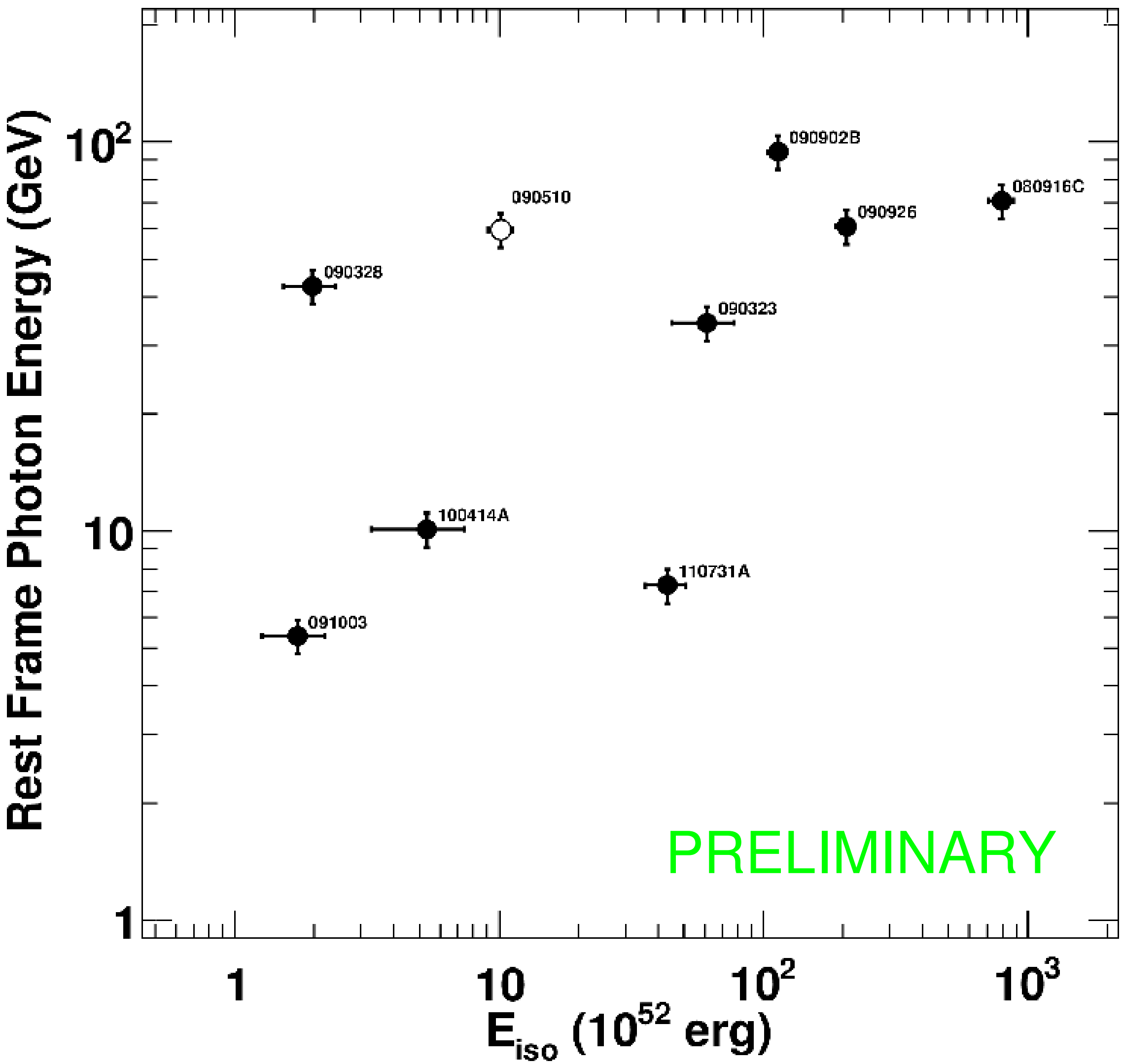
Time-resolved LAT extended emission

- >100 MeV flux in time bins of approx. constant significance
- Flux decays as a power law in time
  - Decay index between -0.8 and -1.8
  - Consistent with afterglow interpretations
- No obvious pattern in the spectral evolution
  - Photon spectral index typically averages around -2





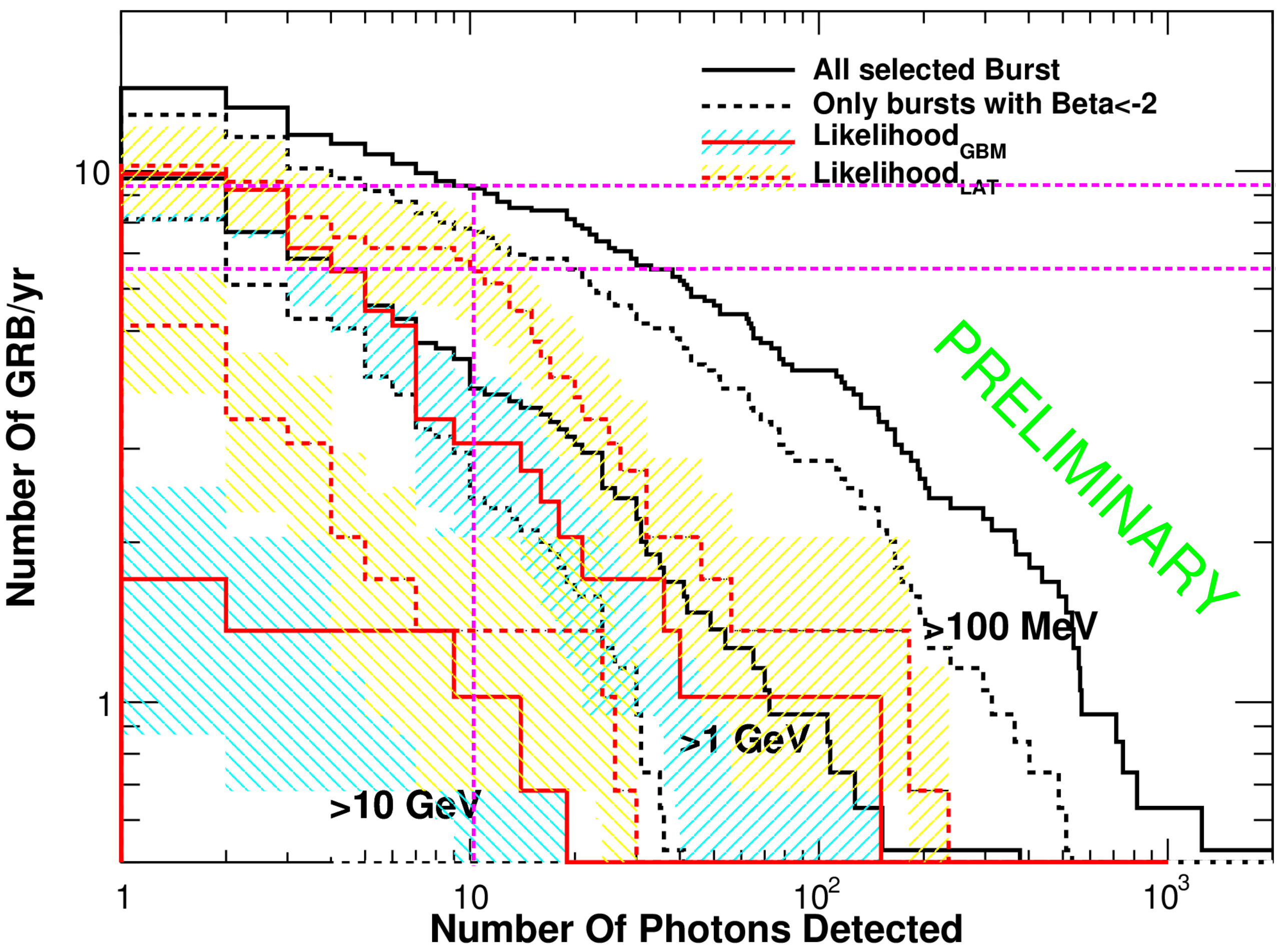
Highest-energy detected photons



- LAT-detected emission frequently reaches several-tens-of-GeV energies in the GRB frame
- Good signs for the detection prospects of VHE observatories

LAT GRB rate

- Pre-launch estimates (Band et al. 2009):
  - 9.3 GRBs expected / year with >10 photons above 100 MeV
- Compared with number of "predicted" photons from likelihood fit (in "GBM" and "LAT" time windows)
  - 6.3 GRBs observed / year with >10 photons above 100 MeV

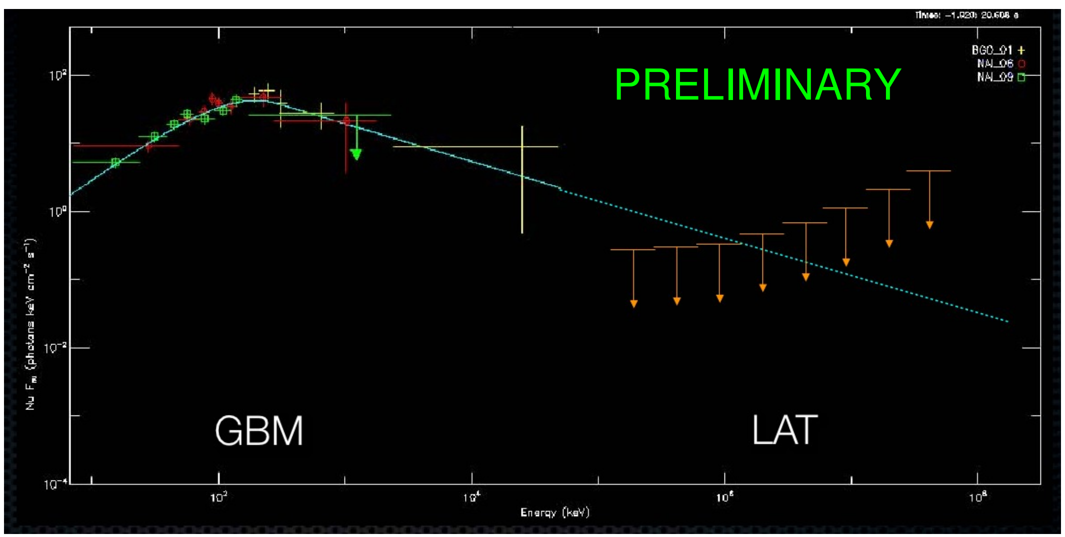


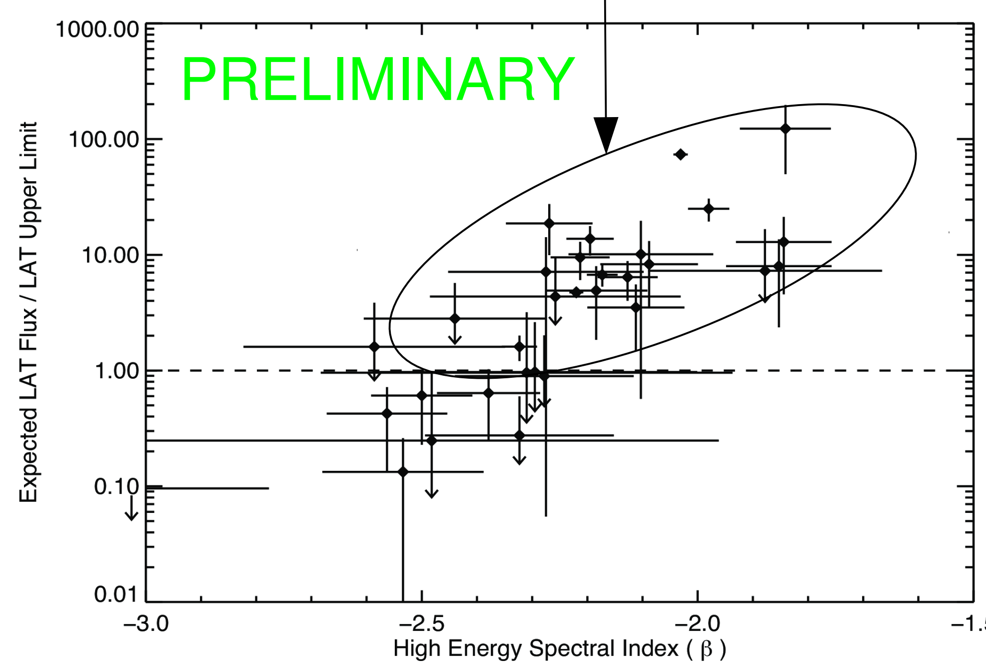
- Suggests that the LAT detects fewer GRBs than anticipated
  - Both analyses have their own systematic uncertainties
  - Extrapolating from BATSE energy range to the LAT energy range is uncertain (large lever arm, errors on beta)
  - Past estimates used simple detection threshold and negligible background
- Extra components must be rare
- Is the high-energy emission suppressed and do we see spectral cutoffs? (like for GRB 090926A)
- What about LAT non-detected GRBs in LAT field of view?

Explaining the absence of LAT detections (1/3)

- ~Half of GBM GRBs happen in the LAT FoV, however only ~10% are detected >100MeV
  - We investigated why we did not detect the rest 90%

- 1st step: estimated fraction of GRBs that should have been detected
  - Sample: 30 GBM GRBs with >70cts/s in the BGO and Δβ<0.5
  - Upper limits on LAT flux (0.1-10 GeV) over GBM duration were compared with predictions from extrapolation of the GBM spectral fit
  - 50% (15) have predicted flux>LAT UL (i.e. should have been detected by the LAT)

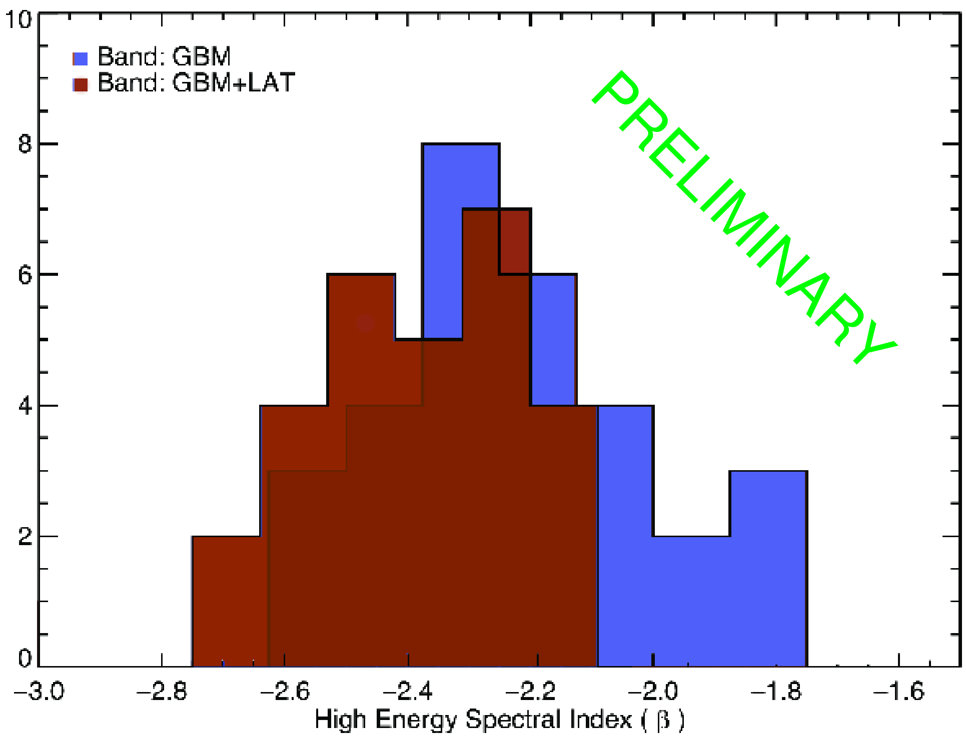


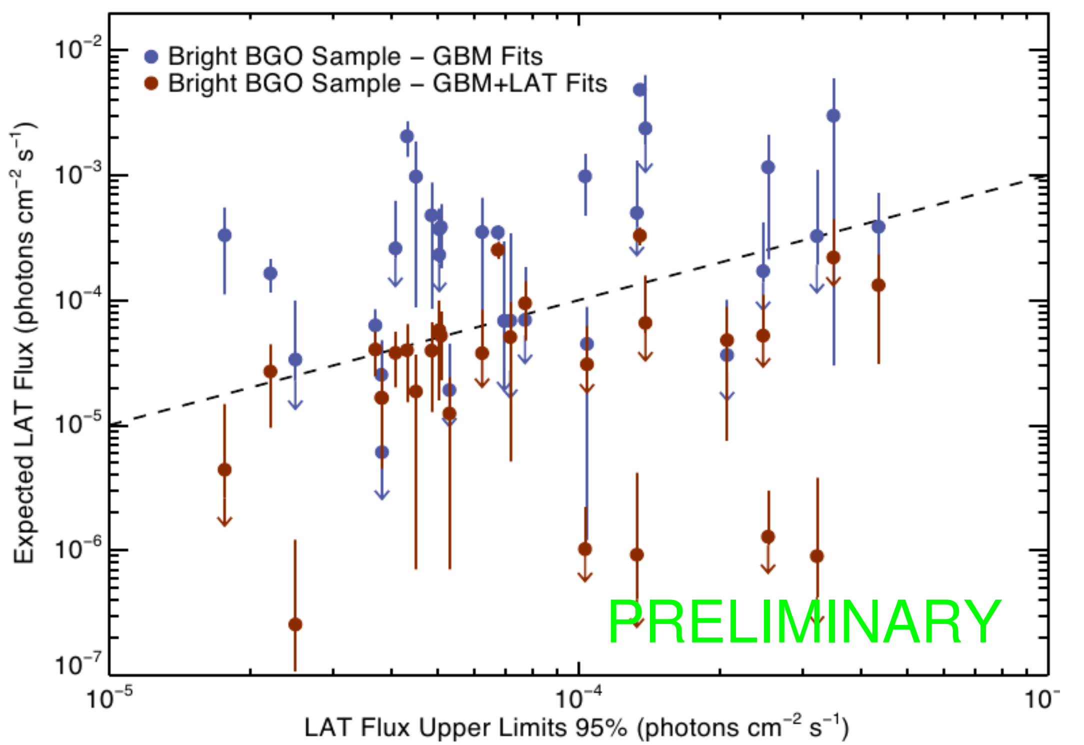


Explaining the absence of LAT detections (2/3)

- 2nd step: GBM+LAT joint spectral fits
  → β becomes considerably softer

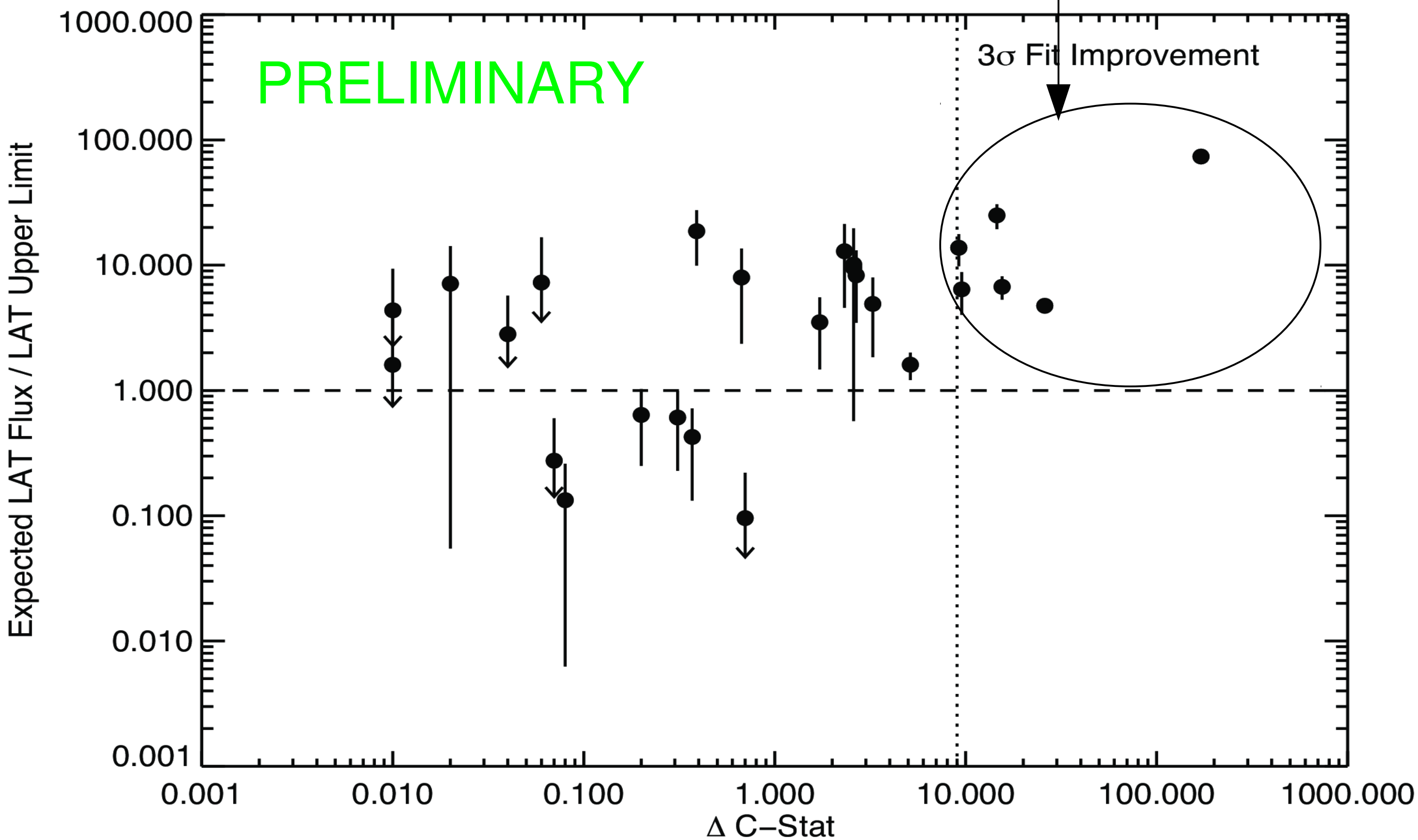
- Fraction of detectable but not detected GRBs down to ~23%





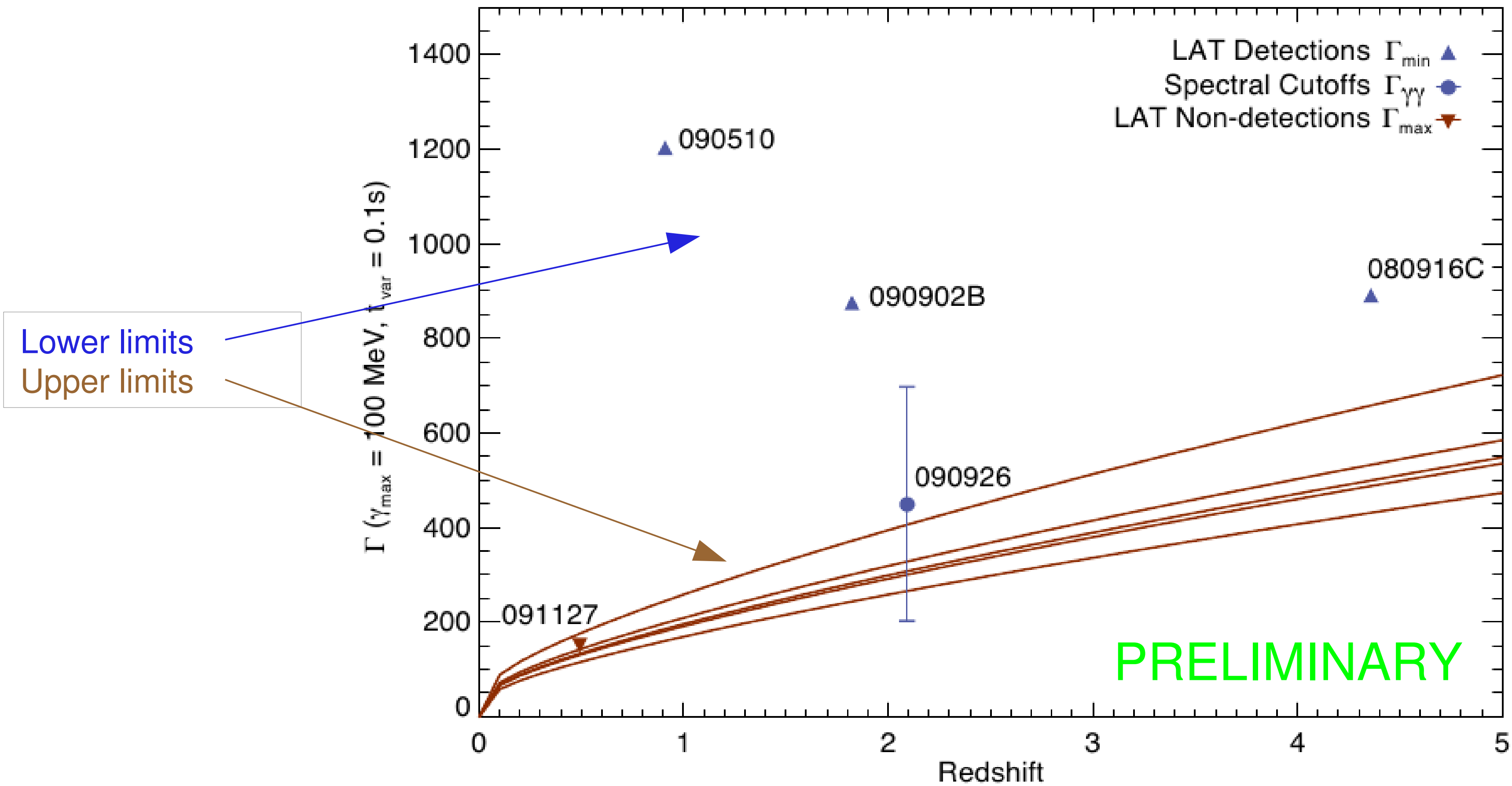
Explaining the absence of LAT detections (3/3)

- 3rd step: repeat joint fits with modified spectral model, adding a spectral softening in the model between BGO and LAT energy ranges
- Fit improved for 6 GRBs (20%) – some form of spectral softening at tens of MeV is required
  - The 6 GRBs have the smallest Δβ
  - Rest 80% of the GRBs consistent with a softer β



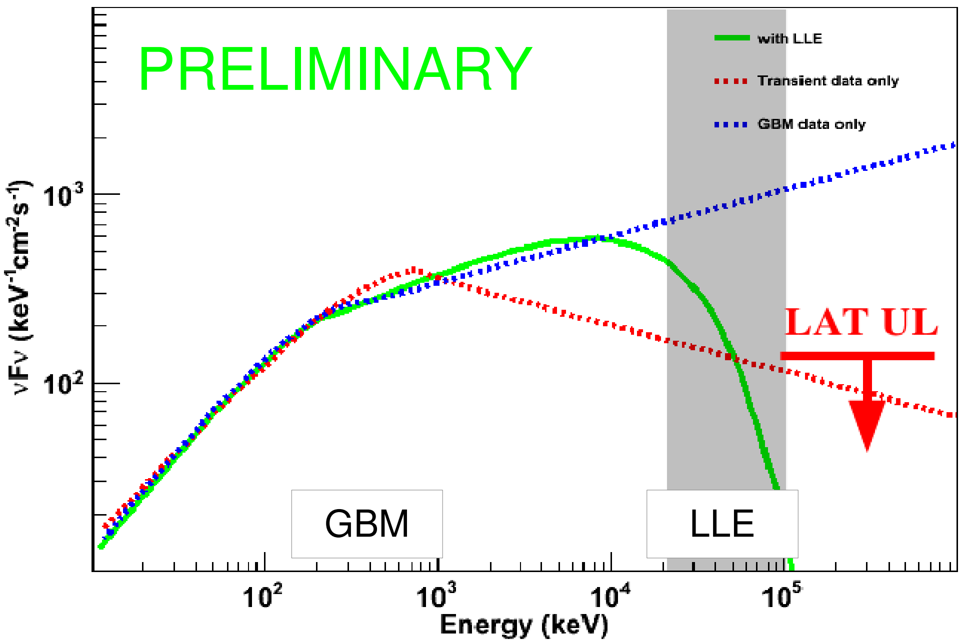
Limits on the bulk Lorentz factor

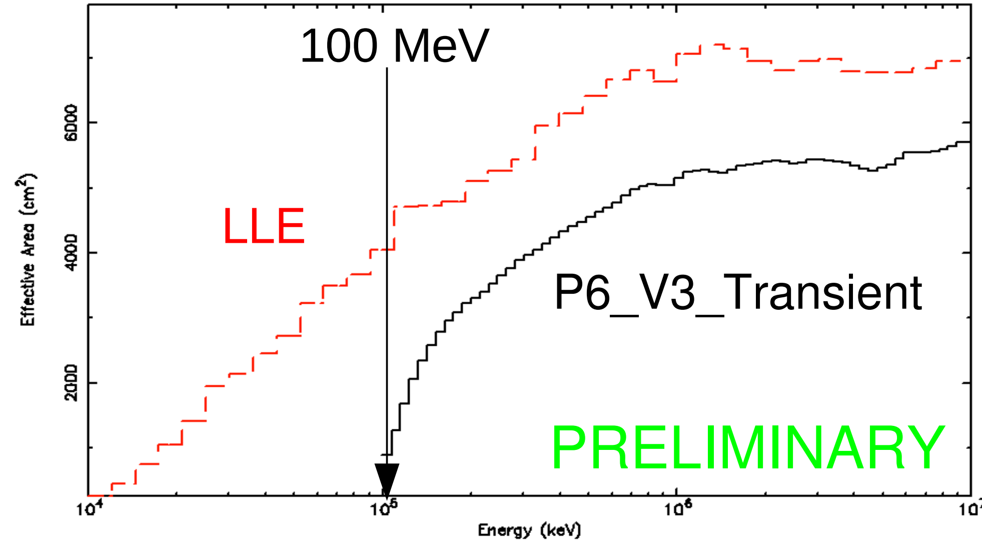
- Assuming that the spectral cutoffs in these 6 GRBs are due to internal opacity effects, we can set upper limits on the bulk Lorentz factors of their jets
  - We only know the redshift for 091127 so we set $\Gamma_{max}(z)$ for the rest
  - Γ_{max}~150-650 assuming 100 ms variability and 1<z<5

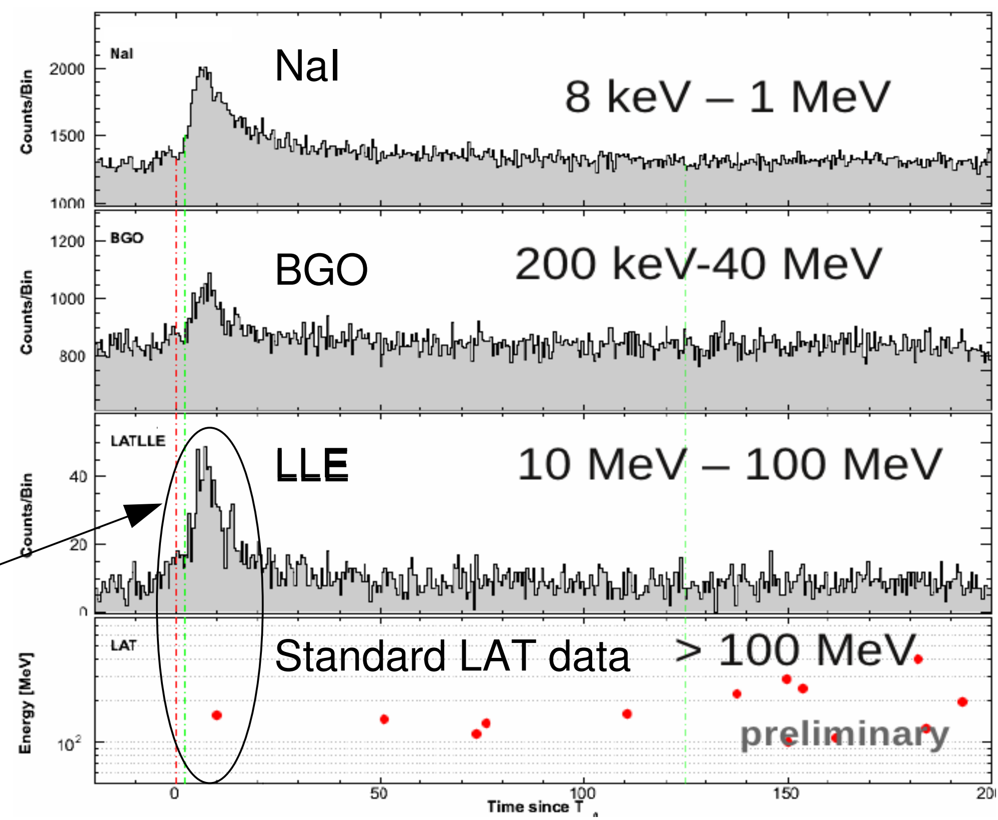


- Note: target photon field for $\gamma\gamma$ absorption assumed uniform, isotropic and time-independent (but error bar for GRB 090926A accounts for different models)

Spectral cutoffs and the LLE event class



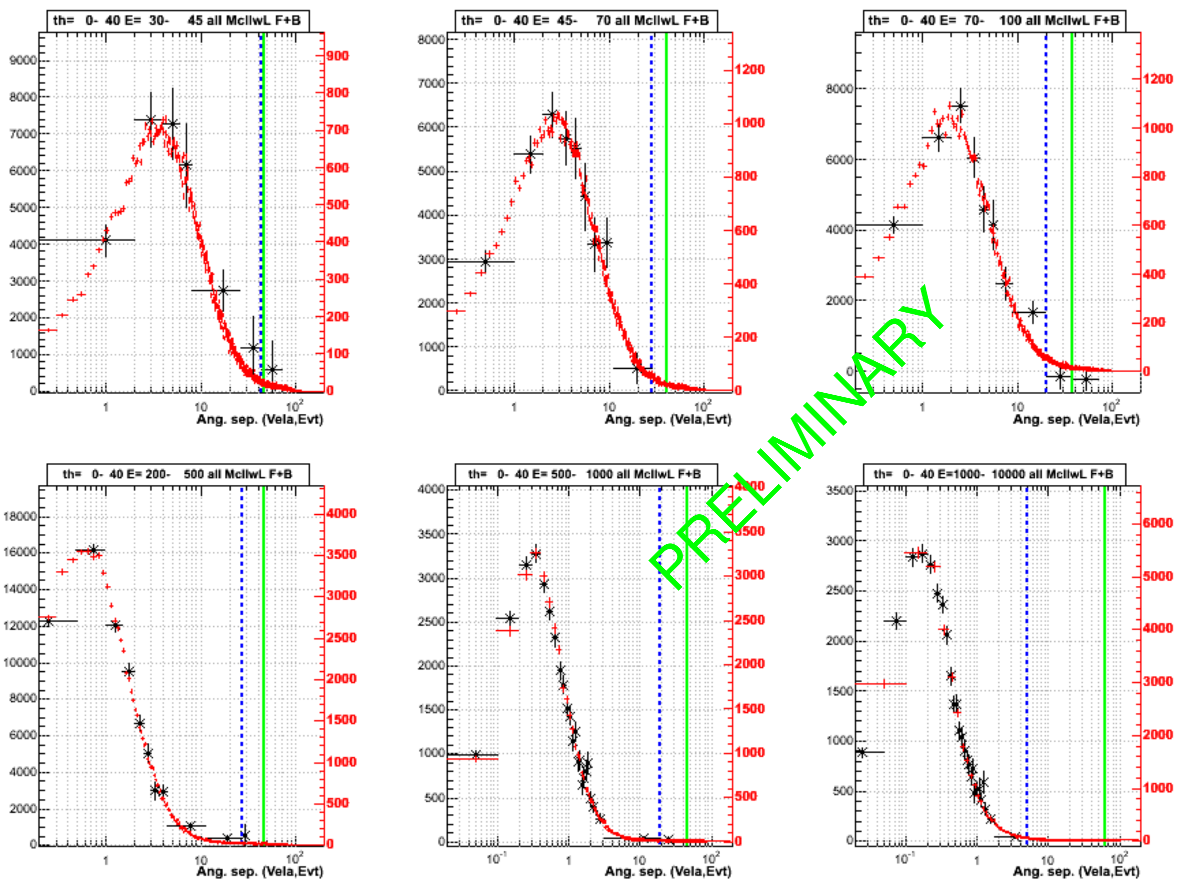




- Standard LAT "Transient" selection runs out of effective area below 100 MeV
- The LLE event selection provides plenty of statistics to probe GRB spectral cutoffs in the tens-of-MeV-energy gap

LLE data: validation and public release

- Validation of spectral reconstruction with LLE data is ongoing
  - Evaluation of systematic uncertainties in LLE effective area and PSF at various event energies, source off-axis angles and background levels



PSF from simulations
PSF from Vela data

MC / data (Vela 2 years) comparison of LLE PSF in different bins of energy (all events with $\theta<40^{\circ}$, from 30 MeV to 10 GeV)

Green lines: 95% cont. radius of MC PSF
Blue lines: explored radius

- Public release of LLE data in preparation at FSSC
  - All GRBs with $>4\sigma$ in LLE event selection, observed within 90° of LAT z-axis
  - Past GRBs with GCN notice + any new GRB (almost immediately) will be released
  - Data products: data (± 1000s around trigger time) and responses, quick look plots

Summary

- The *Fermi* GBM and LAT have jointly detected the keV-MeV-GeV emission from a large sample of GRBs

- A comprehensive analysis of the LAT-detected GRBs in the first 3 years of operations
  - 35 LAT GRBs detected by means of the standard likelihood technique (E>100 MeV) and/or using the new LAT Low-Energy (LLE) event class
  - Population studies indicate (or confirm) interesting patterns and emergent groups
    - Delayed onset of LAT >100 MeV emission with respect to GBM emission
    - Temporally extended LAT >100 MeV emission beyond the burst duration in GBM
    - LAT GRBs among the brightest sub-population of GBM GRBs, and the most energetic ones (if z available)
    - Evidence of a class of hyper-energetic GRBs (4 bursts)
  - A valuable tool for future theoretical research and a useful informational resource for scientists who wish to analyze LAT GRB data

- Fewer GRBs are detected by the LAT than would be expected by extrapolating BATSE/GBM spectra
  - Need for an overall softer spectrum or for high-energy cutoffs in GRB spectra (~20% in bright BGO sample examined) → upper limits on jet bulk Lorentz factors
  - More LAT GRBs will help to understand the cutoffs and to shed light on the LAT GRB rates
  - LLE data fill the gap between GBM and LAT and can also help to detect more cutoffs not detectable with the standard LAT analysis
    - Also helpful for variability studies at tens-of-MeV energies
    - Public release is imminent

More...

More *Fermi* presentations this week including LAT results:

- Sylvain Guiriec
  The *Fermi* Era: Towards a better understanding of the GRB prompt emission

- Elisabetta Bissaldi
  Bright High-Energy GRBs detected with *Fermi* GBM

- Felix Ryde
  The Photosphere in Gamma-Ray Bursts: Lessons Learned from *Fermi*

- Johan Bregeon
  Broadband observations of GRB 110731A with *Fermi*, Swift, GROND and MOA

- Daniel Kocevski
  Fermi-LAT Stacking Analysis of Swift-XRT Localized GRBs (P-II-29)

Backup

Backgrounds

- The backgrounds in the LAT for GRB studies
  - Charged cosmic rays (dominant in “Transient” event class and “LLE” data)
    - geomagnetic coordinates of the spacecraft
    - GRB position in instrument coordinates (since the effective area varies with the off-axis angle)
    - azimuthal angle of the GRB position in Earth coordinates (East-West effect)
  - Galactic, extra-galactic gamma rays, sources
    - GRB position in the celestial sphere
  - Earth’s albedo
    - GRB zenith angle (highest towards the Earth's limb)
- Backgrounds vary with time!
- “Transient” class events → background estimator
  - Use first 2+ years of data to build up the statistics needed to estimate the background in any position of the orbit, in any position in the sky, for any time interval
  - We remove the Earth's limb (cut on zenith angle)
- LLE data
  - Broad PSF: can not remove the contamination from Earth's limb
  - Background is modeled by a phenomenological function (poly in cos(theta(time)))
  - Fit the pre-burst and post burst intervals and interpolate

Duration estimation with the LAT

- GRB T90s (from LLE data or using “Transient” events above 100 MeV) are calculated from the time development of the cumulative background-subtracted light curve

- In low statistics light curves, individual fluctuations can introduce uncertainties in the choice of the plateau and can also “drive” the final T05 / T95

- To characterize these fluctuations we perform duration estimations on simulated light curves
  - Statistically compatible with the actual detected light curve
  - The final result comes from the median and $\pm 1\sigma$ quantiles of the simulated T05 / T95 / T90 distributions