Gamma-Ray Burst observation with GLAST

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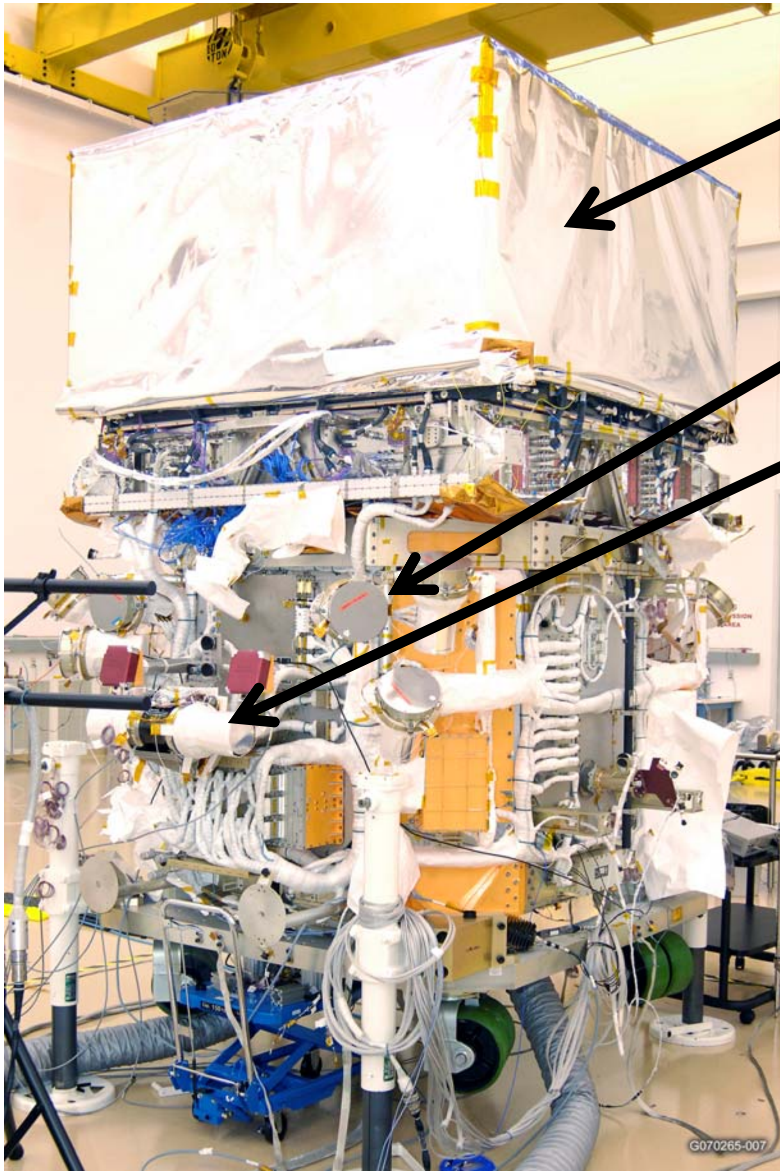
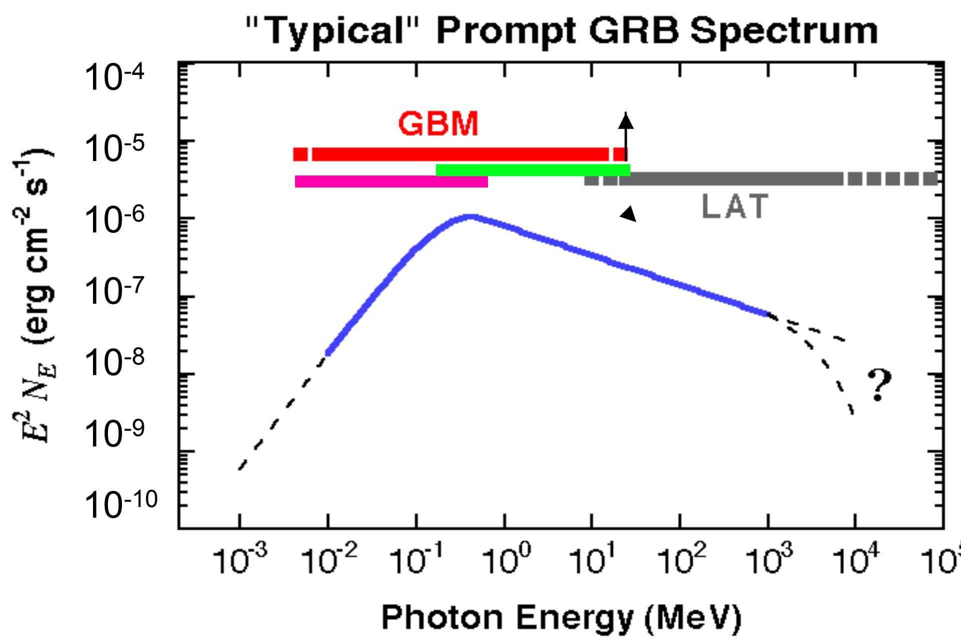
on behalf of
the GLAST/LAT collaboration

- Instruments performance
- Simulations and sensitivity studies
- Alerts and synergy with other observatories

The GLAST observatory

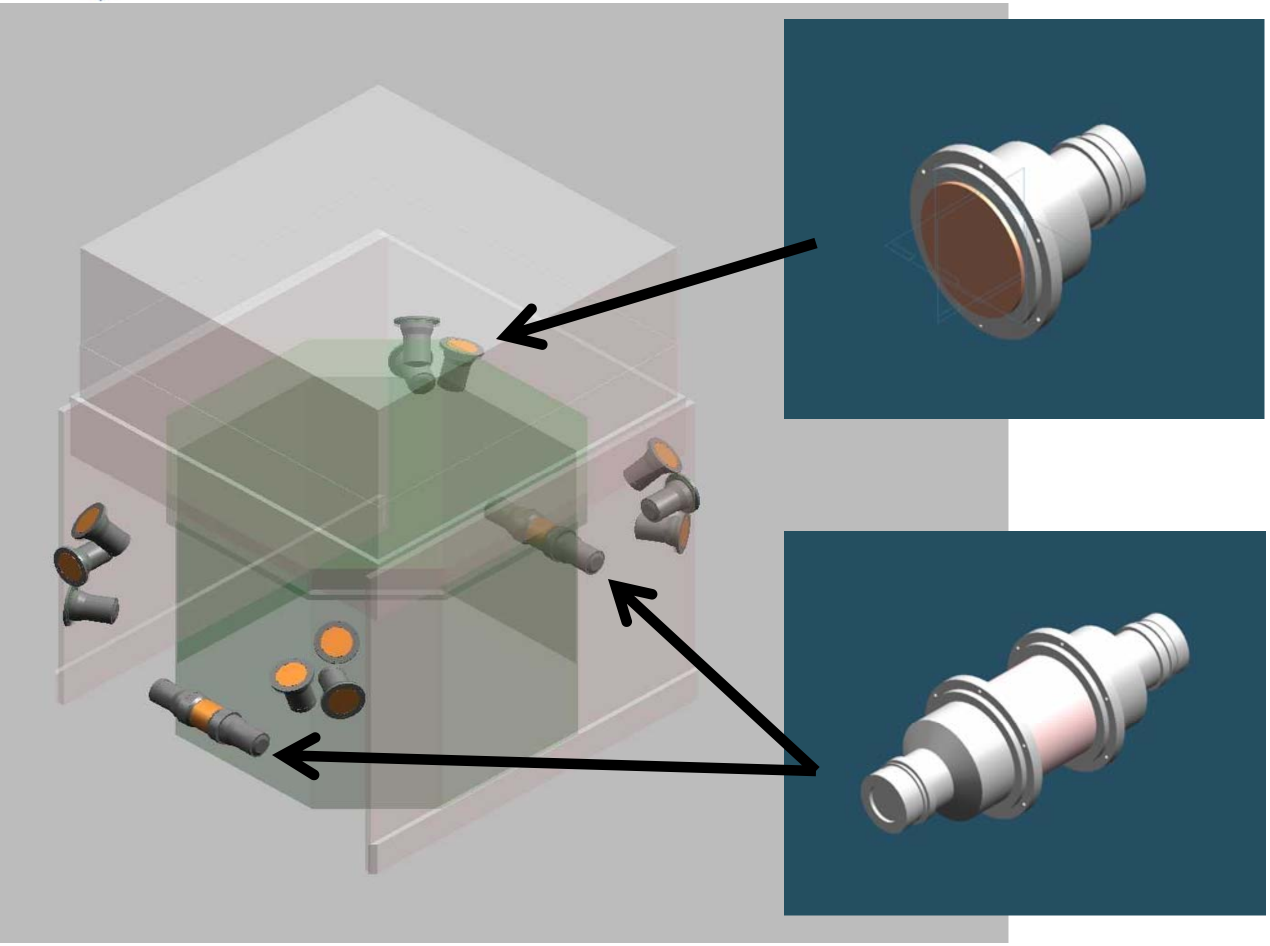


- **Large Area Telescope (LAT)**
  - **20 MeV to >300 GeV**
  - **onboard and ground burst triggers, localization, spectroscopy**
- **Glast Burst Monitor (GBM)**
  - **12 NaI detectors (8 keV to 1 MeV)**
    - **onboard trigger, onboard and ground localizations, spectroscopy**
  - **2 BGO detectors (150 keV to 30 MeV)**
    - **spectroscopy**

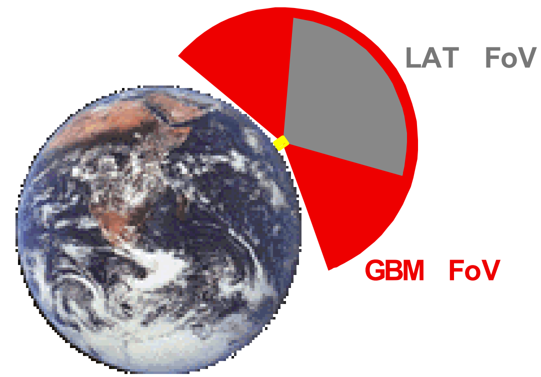


Exceptionally good spectral observations of the prompt phase of lots of GRBs

The Glast Burst Monitor



12 Sodium Iodide (NaI) scintillation detectors



2 Bismuth Germanate (BGO) scintillation detectors

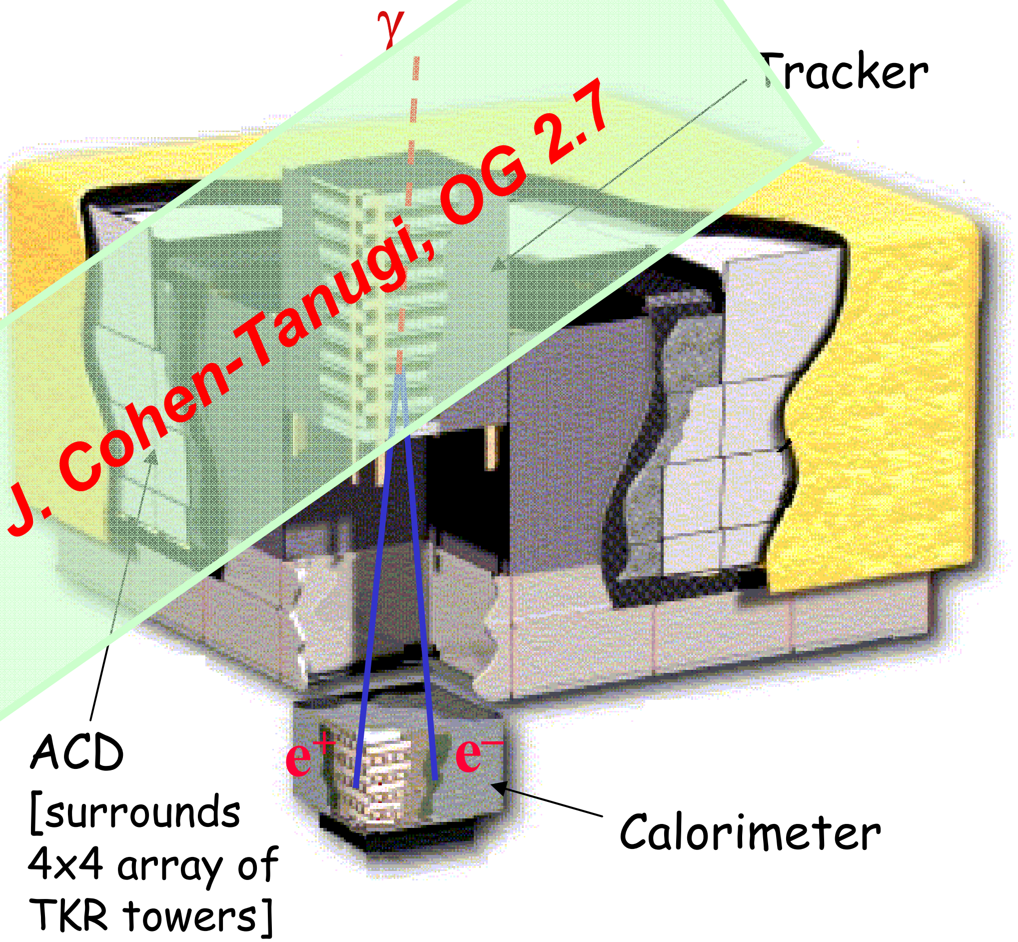
- **The LAT will provide new GRB observations, but they would be difficult to evaluate with respect to current knowledge without GBM context**
- **The GBM role is to provide:**
  - **spectra of GRBs from ~10 keV to 30 MeV**
  - **on-board GRB locations over the entire unocculted sky (FoV > 9.5 sr)**
    The observatory can be re-oriented to obtain LAT observations of afterglow from strong bursts

Performance of the GBM

- Expected burst-detection rate
  - Sensitivity of 0.8 $cm^{-2}s^{-1}$ (onboard, 50-300 keV, LAT axis)
  - Onboard triggers: ~200 GRBs / yr assuming a BATSE-like population of bursts
- Spectra from ~10 keV to 30 MeV (broader energy range than BATSE) with high time resolution
  - Measure E_{peak} for all GLAST detected GRBs (needed to calculate pseudo-redshifts)
  - Overlap with LAT energy range (connects ground-breaking LAT observations with "traditional" GRB range)
    - Compare low-energy vs. high-energy temporal variability (not possible with EGRET)
- Onboard trigger
  - Two or more detectors over threshold, with respect to the background rate
  - More flexible algorithm compared with BATSE: improved sensitivity to very short GRBs and to long soft GRBs
  - Onboard trigger classifications (solar flare, particle event, GRB, etc.)
  - Provides repoint recommendation to allow HE afterglow observations with the LAT
  - Provides rapid alert to GRB afterglow observers (via GCN)
- GRB localization
  - <15° initially (calculated onboard within 2 s)
  - Refinements to <5° (ground analysis within ~15-30 mins of GRB trigger)

The Large Area Telescope

- **Precision Si-strip Tracker (TKR)**
  - 18 XY tracking planes. Single-sided silicon strip detectors (228 μm pitch), 880,000 channels.
  - Tungsten foil converters
    - 1.5 radiation lengths
  - Measures the photon direction; gamma ID.
- **Hodoscopic CsI Calorimeter(CAL)**
  - Array of 1536 CsI(Tl) crystals in 8 layers. 3072 spectroscopy chans.
    - 8.5 radiation lengths
  - Hodoscopic array supports bkg rejection and shower leakage correction
  - Measures the photon energy; images the shower.
- **Segmented Anticoincidence Detector (ACD)**
  - 89 plastic scintillator tiles.
  - Rejects background of charged cosmic rays; segmentation minimizes self-veto effects at high energy.
- **Electronics System**
  - Includes flexible, robust hardware trigger and software filters.

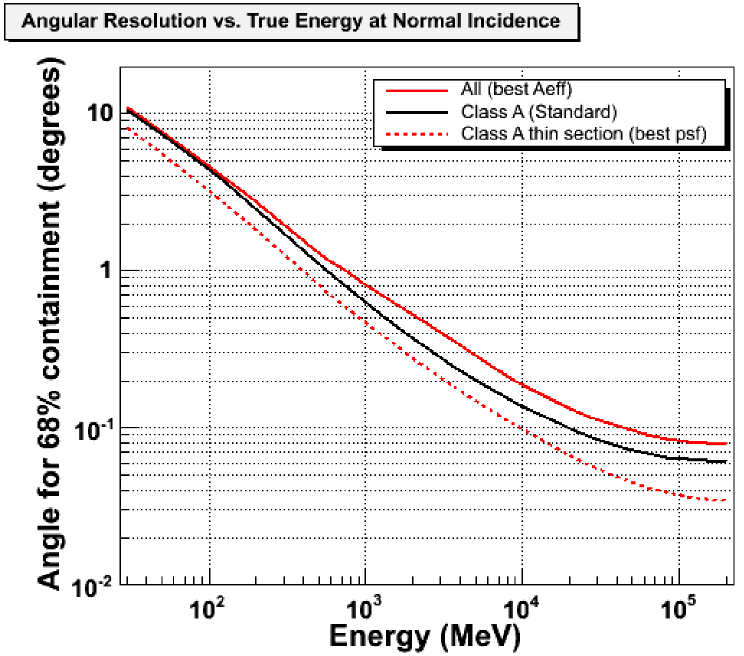


See poster 1295 by J. Cohen-Tanugi, OG 2.7

Systems work together to identify and measure the flux of cosmic gamma rays with energy between 20 MeV and 300 GeV.

Performance of the LAT

	LAT	EGRET
Energy range	20 MeV to >300 GeV	20 MeV – 30 GeV
Energy resolution (on axis, 100 MeV – 10 GeV)	<10%	10%
Peak effective area	9000 cm^2	1500 cm^2
Angular resolution (single photon, 10 GeV)	0.15°	0.54°
Field of view	>2.2 sr	0.4 sr
Deadtime per event	27 us	100 ms



- **Very major improvements in capabilities for GRB observations compared to previous missions**
  - **Efficient observing mode (don't look at Earth)**
  - **Wide FoV**
  - **Low deadtime**
    - **Studies of short bursts possible**
  - **Large effective area**
  - **Good angular resolution**
  - **Increased energy coverage (to hundreds of GeV)**

Many GRBs

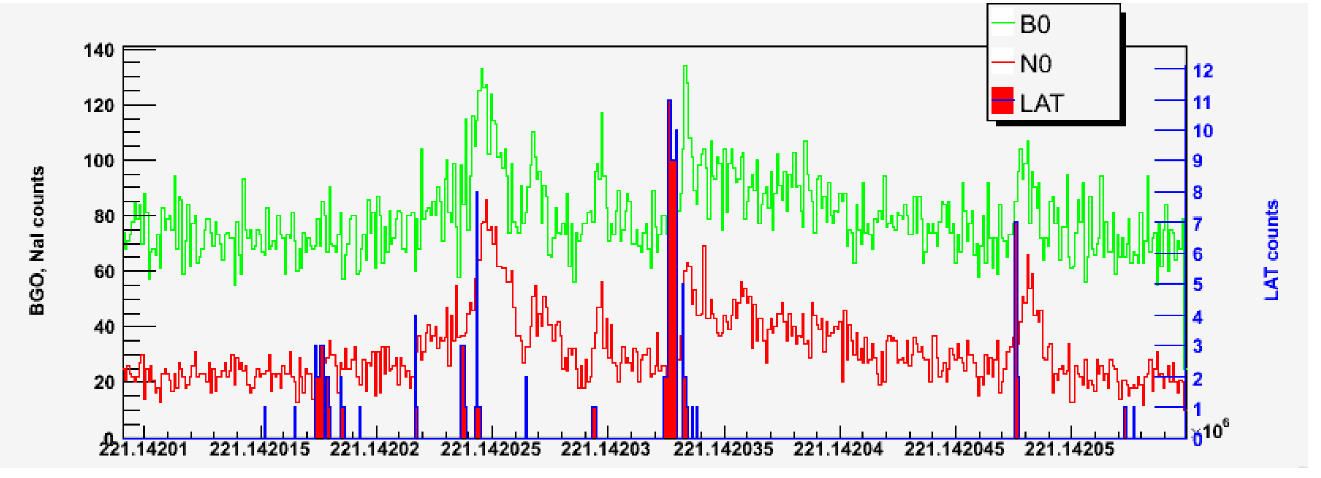
More photons detected from each GRB

Good GRB locations

GRB simulations for GLAST

- >60 GRBs / yr detected by the GBM will lie within the LAT FoV
- Fraction that will be detected by the LAT is unknown
- We can make an estimate by assuming that GRB properties measured at low energy (by BATSE) extrapolate to LAT energies
  - Ignores evidence from EGRET that there are additional HE components
  - Ignores the possibility of intrinsic cutoffs (from reaching the end of the particle energy distribution, or from internal opacity)
- Phenomenological approach
  - Assumes burst rate in the 4π sphere from BATSE statistics: 650 GRBs/yr
  - Pulse shape: double exponential shape and "pulse paradigm" from Fenimore '95, Norris '96
  - Spectral shape: Band model
  - Parameters (duration, peak flux, peak energy, spectral indexes) sampled from the BATSE distributions

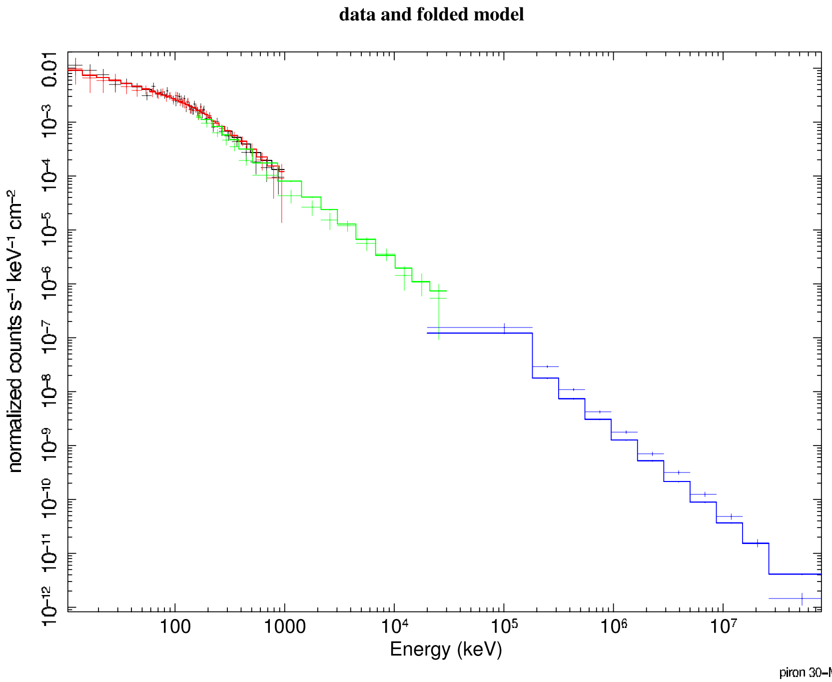
Combined signal from GBM (NaI/BGO) and LAT detectors

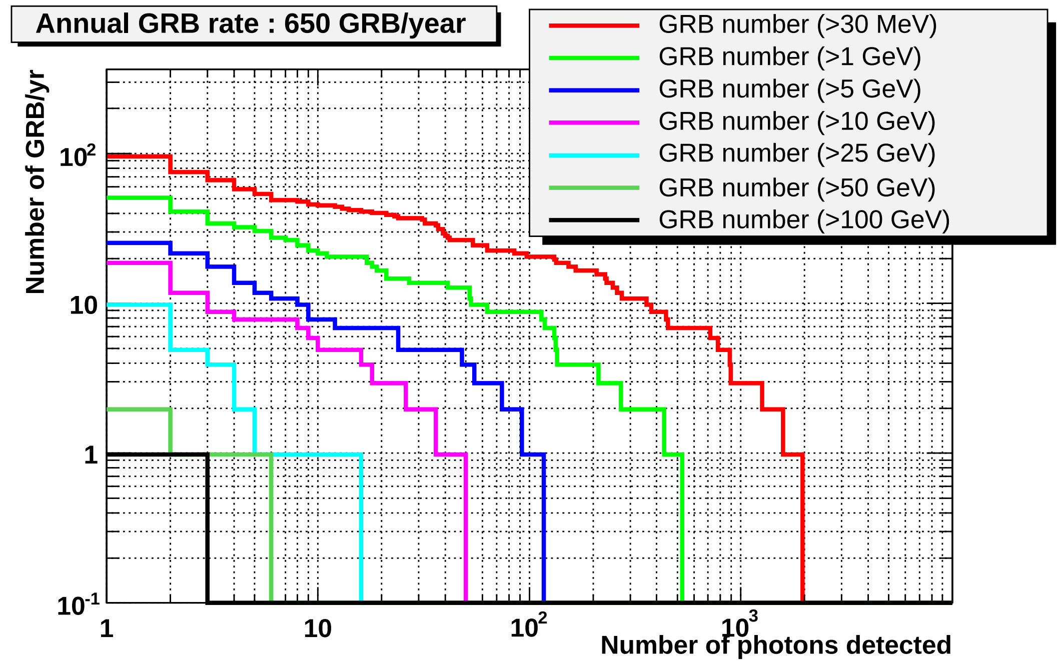


  - Redshift distributions for long (SFR, Porciani & Madau '01) and short (binary mergers, Guetta & Piran '05) GRBs
- EBL attenuation from Kneiske '04 (affects sensitivity above ~10 GeV)

How many LAT detected GRBs (1/2) ?

Joint GBM-LAT spectral fit to a Band function



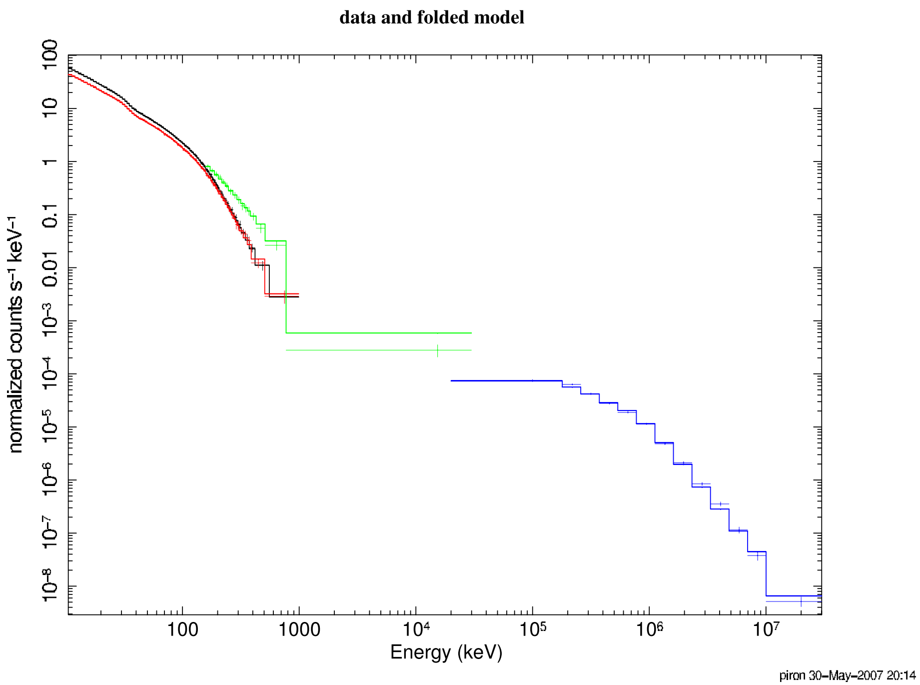


- For a trigger criterion of 10 photons above 30 MeV, **the LAT would detect ~50 GRBs / yr**
- 1 or 2 bursts per month with >100 photons
  - detailed (time resolved) spectral analysis possible
- A few GRBs / yr with HE prompt emission above 50 GeV

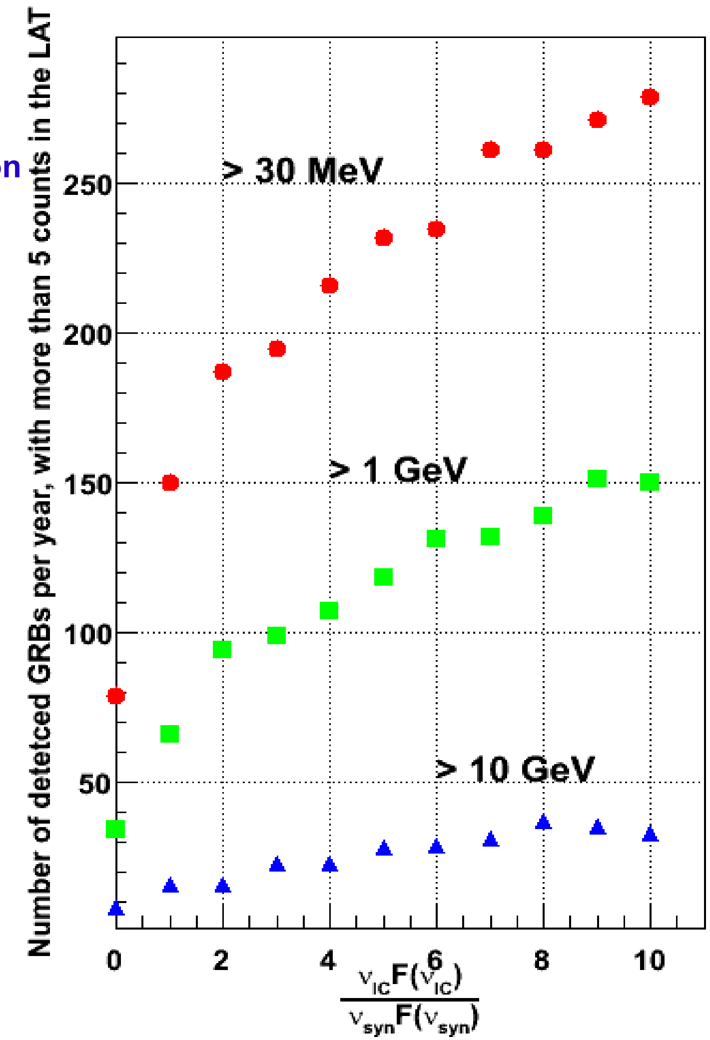
How many LAT detected GRBs (2/2) ?

- **Physical approach**
  - **Fireball model (Piran ‘99)**
  - **Shells emitted with relativistic Lorentz factors**
  - **Internal shocks (variability naturally explained)**
  - **Acceleration of electrons with a power law initial distribution**
  - **Non-thermal emission (Synchrotron and Inverse Compton) from relativistic electrons**

Joint GBM-LAT spectral fit (Synch + IC components)



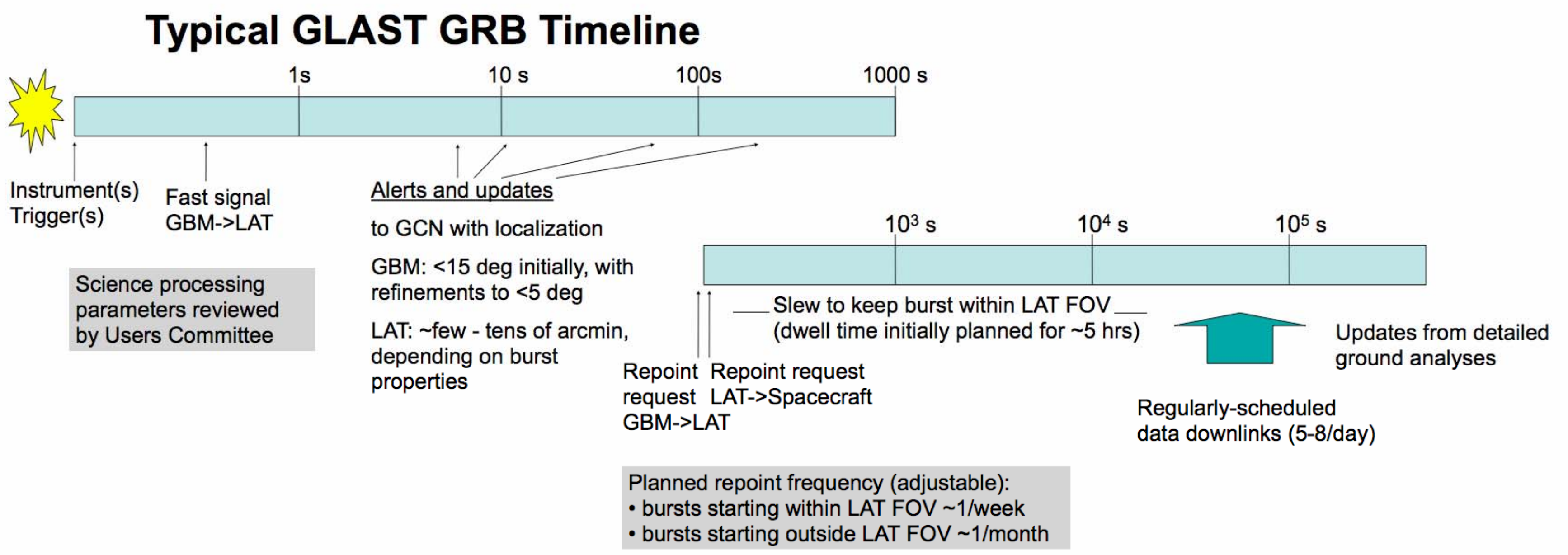
Simulated 650 Burst per year, full sky



- **Sensitivity evaluated as a function of the ratio of Inverse Compton to Synchrotron power outputs**
- **In this scenario, the LAT would be able to detect prompt emission from tens of GRBs / yr**

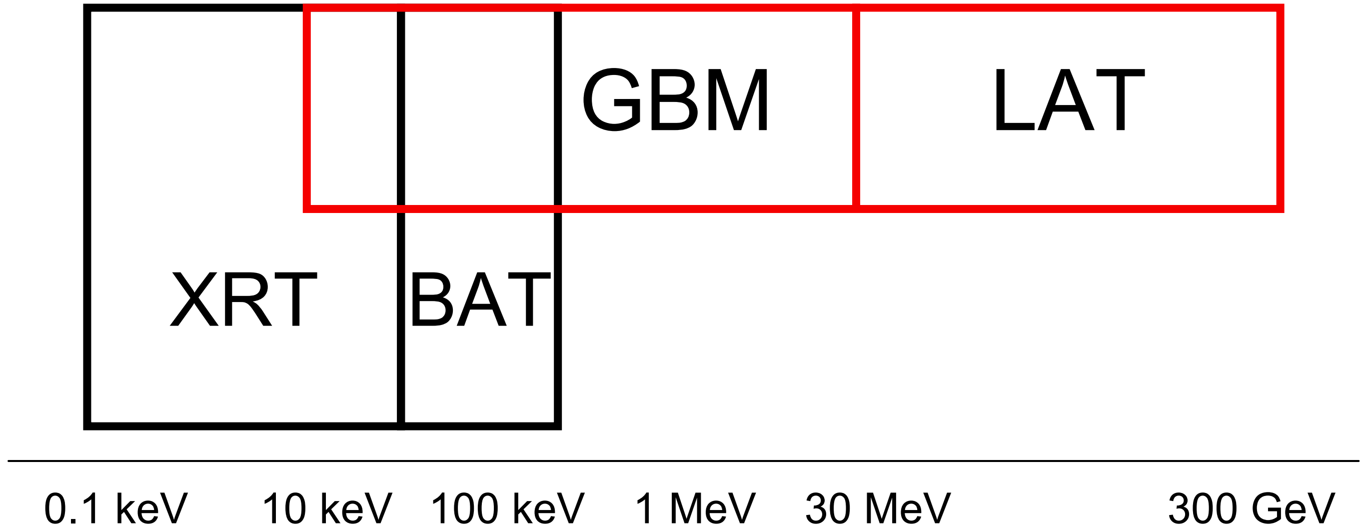
GLAST GRB response scenario: alerts and data flow

- Using TDRSS, **from burst trigger to GCN: ~10-15 s**



- **Onboard processing - GCN alerts:**
  - location, intensity (counts), hardness ratio, trigger classification, etc.
- **Ground processing of prompt data (~15 mins):**
  - updated GBM location, preliminary GBM lightcurve
- **LAT ground processing (5-12 hours):**
  - updated location, HE flux & spectrum (or UL), afterglow search results
- **Final ground processing (24-48 hours):**
  - GBM model fit (spectral parameters, flux, fluence), joint GBM-LAT model fit, raw GBM data available. Year 2 and beyond - LAT count data available

GLAST synergy with Swift



- **Swift and GLAST will measure GRB spectrum with a broad coverage, from 0.1 keV to hundreds of GeV (>9 decades!)**
  - **GLAST can provide alerts to GRBs that Swift can point for follow-up observations**
  - **GLAST will frequently scan GRB positions hours after the Swift alerts, monitoring HE emission**
  - **Swift UVOT and XRT and GLAST LAT will provide afterglow observations at optical, X-ray and HE gamma-ray wavebands**
- **Assuming a Swift GRB detection rate of 100 GRBs / yr, if the GLAST and Swift pointing directions are uncorrelated:**
  - **~20 Swift-detected GRBs / yr will occur within the LAT FoV**
  - **~25 GBM-detected GRBs / yr will be detected by Swift**
    - **⇒ GBM will dramatically improve the prompt energy spectral observations (up to 30 MeV) for 1/4 of Swift GRBs**

GLAST synergy with TeV observatories

- The ability of the LAT to determine the location of a GRB is strongly determined by the flux and spectrum of the GRB
  - Brighter, harder bursts are better localised
- Consider 2 cases:
  - 10 photons @ 100 MeV: 3.5/√10 ~ 1° localisation accuracy
  - 10 photons @ 10 GeV: 0.1/√10 ~ 1 arcmin localisation accuracy

- Sky coverage
  - Ground arrays (MILAGRO, etc.) have a high duty cycle (~100%) and large FoV (~20% of the sky)

    ⇒ no need for well localized positions (GBM + LAT burst alerts)
  - ACTs observe during clear and moonless nights: low duty cycles (~10%) and ~5° FoV (but can slew to any location within a few min and access ~20% of the sky)
    ⇒ need GRB position accuracy of ± 1° (LAT burst alerts only)

- GRB observation rates at TeV energies
  - Estimated as rate of useful alerts * duty cycle * fraction of sky covered
  - Prompt: ~40 alerts / yr for ground arrays (10 LAT only alerts)
    Only ~1 alert / yr for ACTs!
  - Afterglows: a few / yr can be followed up by ACTs, ground arrays less sensitive

Conclusions

- GLAST will open a new window on the gamma-ray sky, exploring uncovered region, with big impact on science!

See J. McEnery's talk on "The GLAST Mission: Capabilities and Opportunities"

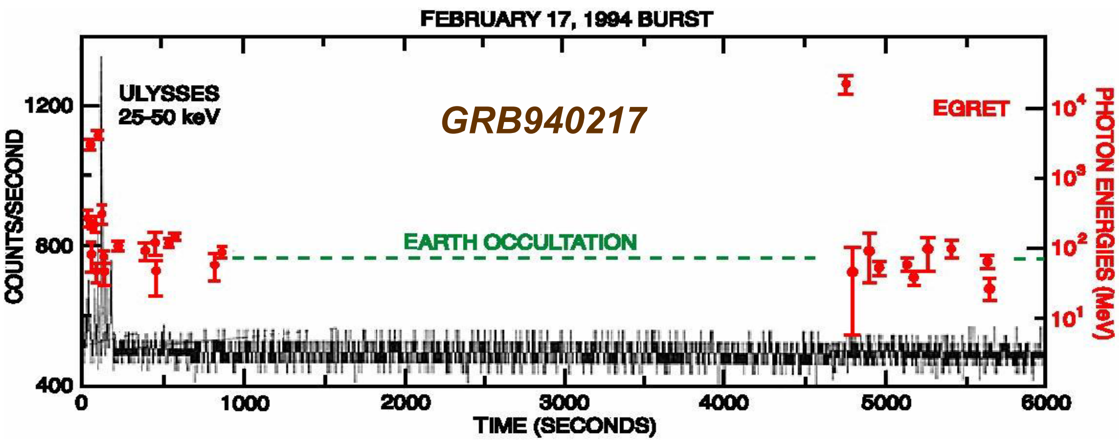
- GLAST has unique capabilities in observing GRBs from ~10 keV to >300 GeV
  - Connection of the known part of the GRB spectra to the unobserved HE region
  - Joint GBM and LAT observations will study the relationship between keV-MeV and GeV emission, probably solving many open problems in GRB physics
  - Detailed spectral studies (HE cut-offs or breaks, IC peaks)
  - Search for HE new components and delayed emissions

- Expected burst-detection rates, alerts
  - The GBM will detect ~200 bursts per year, >60 suitable for LAT observations
  - The LAT may detect ~50 bursts per year, depending on the HE properties of GRBs
  - Burst alerts will be sent to GCN (~10-15 s after trigger)
  - Burst position will be provided by both GBM ($<5^{o}$) and LAT (0.1^{o}-1^{o})
  - S/C can be repointed autonomously

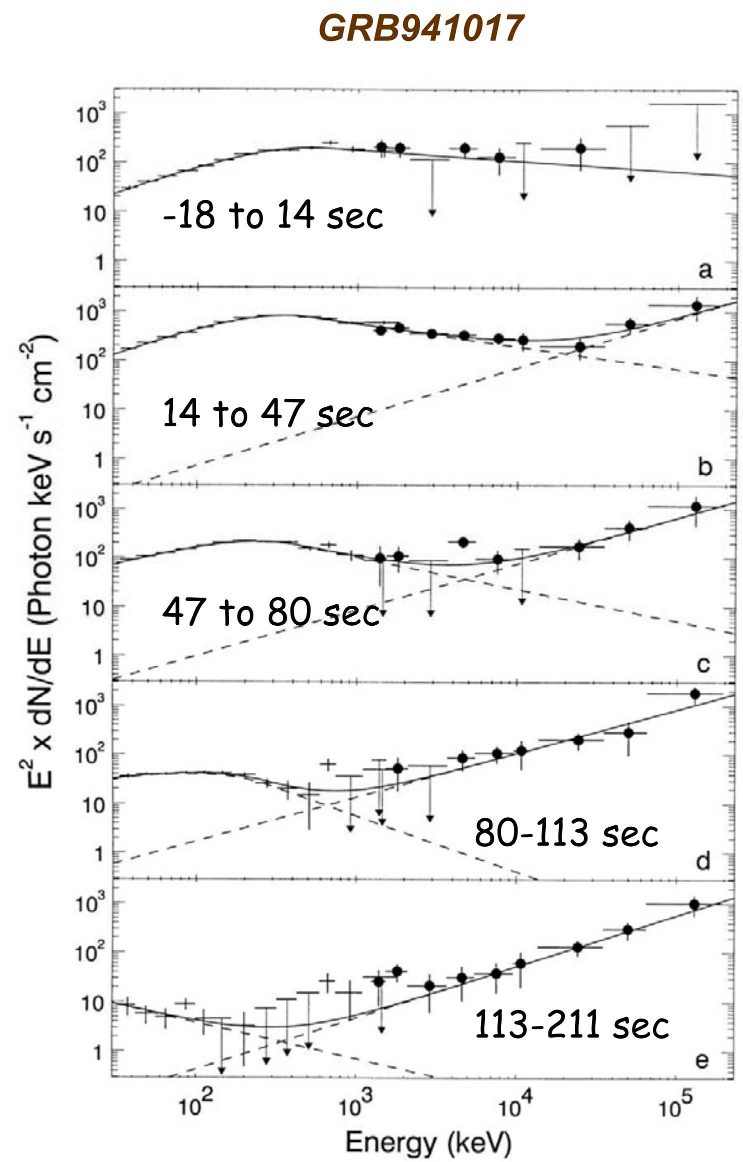
- Important synergy with Swift and TeV observatories

Backup slides

Gamma-Ray Bursts at high energy



- Little is known about GRB emission above ~100 MeV
- Prompt HE gamma emission
  - Prompt GeV emission with no HE cutoff (combined with rapid variability) implies highly relativistic bulk motion
  - EGRET detections from a few GRBs, e.g. GRB940217
  - New HE extra component, with "independent" temporal evolution
    Inconsistent with the synchrotron model! (Gonzalez '03)
- Extended or delayed HE emission
  - It may require more than one emission mechanism, and remains one of the unsolved problems
  - GRB940217
    - EGRET detected HE photons more than 1 hour after hard X-ray peak
    - One photon E > 10 GeV
- HE emission clearly has different time dependence
  - What is its spectral shape?
  - Need more sensitivity and larger FOV



Using GRBs as a probe for new physics

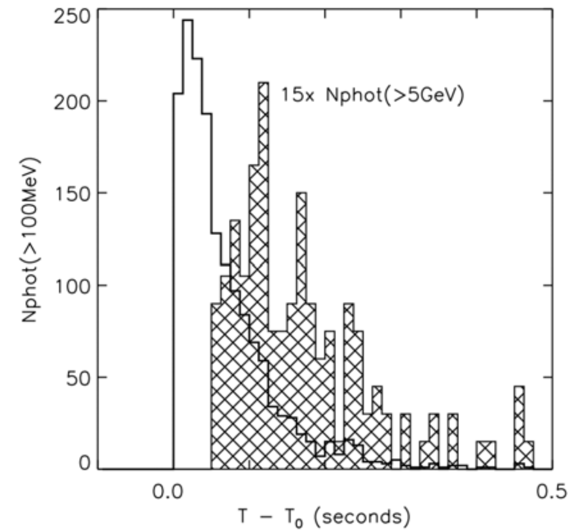
- **Measuring GRB at different redshift can be used as a probe for Lorentz invariance violation**
  - **Effects arise in some Quantum Gravity models**

$$v = \frac{dE}{dp} \approx c\left[1 - \xi \frac{E_\gamma}{E_{QG}}\right]$$

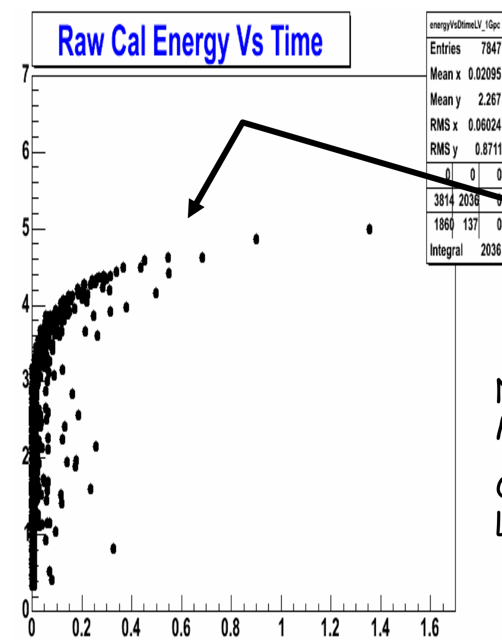
  - **Look for delayed arrival of photons as a function of energy**

$$\Delta t \approx 10\,\mathrm{ms} \times \left[\frac{E_\gamma}{1\,\mathrm{GeV}}\right] \times \left[\frac{d_{CM}}{1\,\mathrm{Gpc}}\right] \quad \text{using } E_{QG} = E_{Plank}$$

- **LAT provides a means to measure the HE photons and arrival**
  - **System clock: 50 ns**
- **Other observations required to localize and measure redshifts**



20 bright GRBs @ 1Gpc with QG



Dispersion due to QG

Norris, Bonnell, Marani, Scargle '99

Omodei, Cohen-Tanugi, Longo '04