# Mise à jour des prédictions pour les GRBs dans AMS suivant les résultats de Fermi

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**« La physique d' AMS : enjeux et perspectives scientifiques »**
**LAPP, 9-10 mars 2010**

# Outline

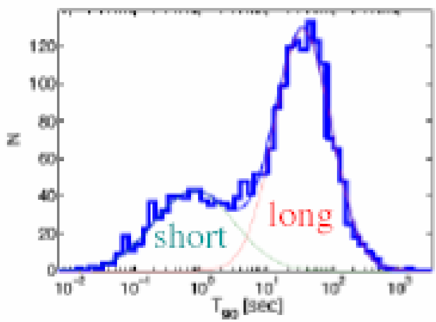
- GRB properties

- GRBs in Fermi
  - GBM and LAT GRBs
  - spectra and QG results

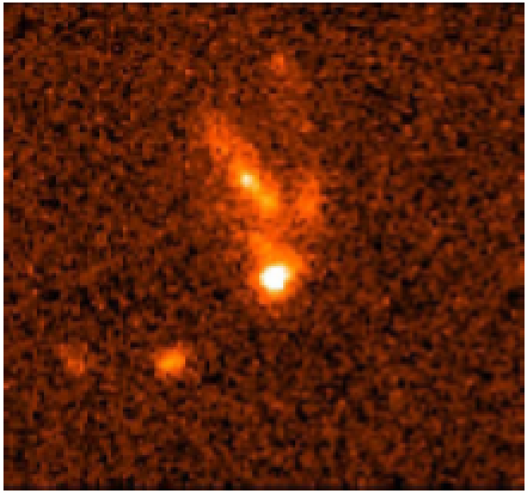
- Predictions for AMS with BATSE/EGRET data
  - frequencies
  - photon samples

- Predictions for AMS with Fermi data

# GRB properties




GRB 990123 - HST image



**Two types:**
Short GRBs (t < 2s)
Long GRBs (t > 2s)

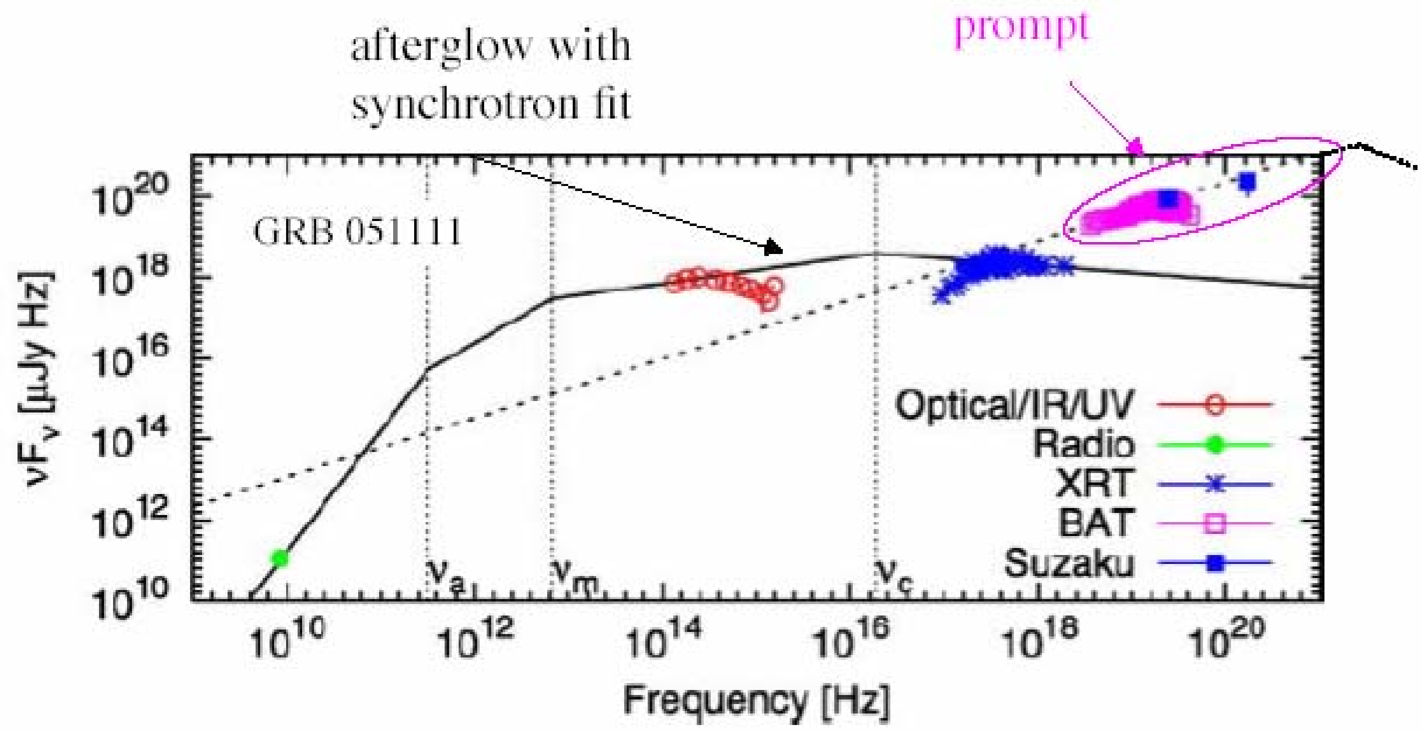
**Redshift range:**
0.2 - ~2 SGRBs
0.009 - 8.2 LGRBs

**Energy release in γ-rays:**
$10^{49}$-$10^{50}$ ergs SGRBs
$10^{50}$-$10^{51}$ ergs LGRBs

**Jet opening angle:**
~15 deg SGRBs
~5 deg LGRBs

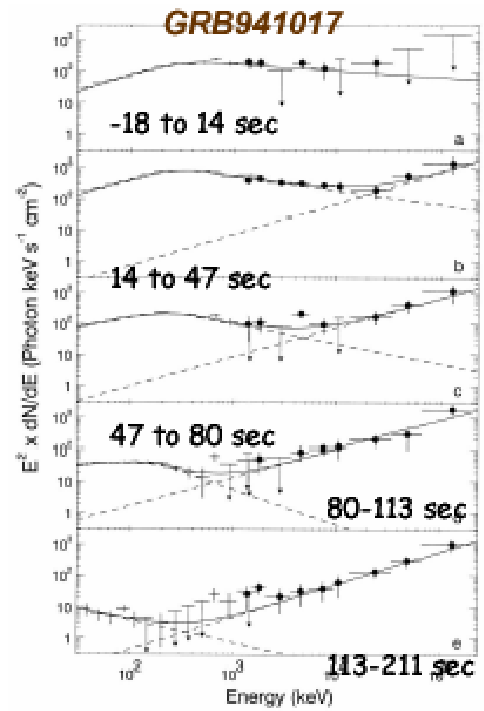
**Both types have delayed & extended high-E emission**

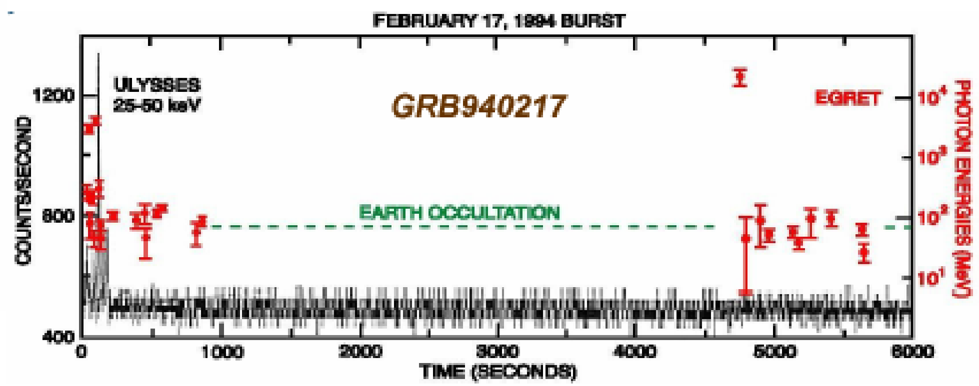
# GRB afterglow spectrum



# GRBs at high energies before Fermi

- 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 (GRB 941017)
    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
  - GRB 940217 (EGRET)
  - GRB 080514B (AGILE)
- HE emission clearly has different time dependence
  - What is its spectral shape?
  - Need more sensitivity and larger FOV

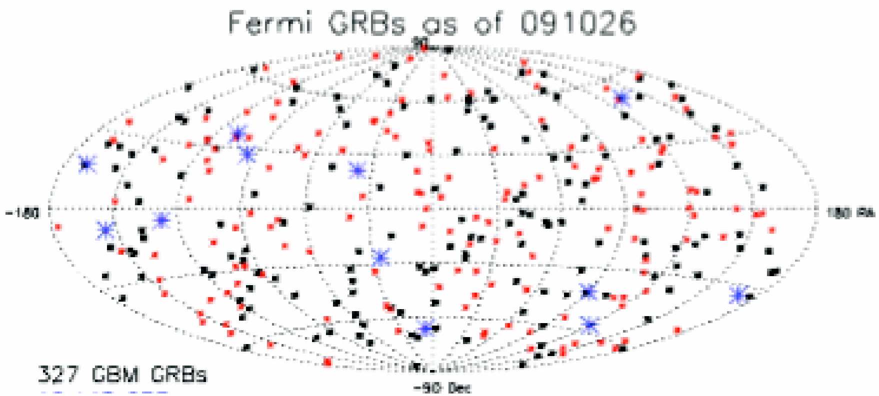


# Fermi LAT GRBs (01/2010)

| | | | |
|---|---|---|---|
| GRB 080825C | 22 s | | extended emission |
| GRB 080916C | 66 s | z = 4.35 | extended emission |
| GRB 081024B | 0.8 s | | extended emission |
| GRB 081215A | 7.7 s | | |
| GRB 090217 | 33 s | | |
| GRB 090323 | 150 s | z = 3.57 | extended emission |
| GRB 090328 | 100 s | z = 0.736 | extended emission |
| GRB 090510 | 2.1 s | z = 0.903 | extended emission |
| GRB 090626 | 70 s | | extended emission |
| GRB 090902B | 21 s | z=1.822 | 34 GeV photon |
| GRB 090926A | 20 s | z=2.1062 | extended emission |
| GRB 091003 | 21 s | | extended emission |
| GRB 091031 | | | |

short GRBs




| | |
|---|---|
| GBM out of LAT FoV | 186 |
| GBM in LAT FoV | 151 |
| LAT | 13 |

# Fermi LAT GRBs in 11 months

| GRB | redshift | duration | counts$\|_{LAT}$ | $E_{max}$ | $t_i^{LAT}$ | $t_f^{LAT}$ |
|---|---|---|---|---|---|---|
| 080916C | 4.35 | long | strong | 13 GeV | 4.5s | $> 10^3 s$ |
| 081024B | | short | | 3GeV | 0.2s | |
| 090510 | 0.9 | short | strong | $>$ 1GeV | $< 1s$ | $\gtrsim 60s$ |
| 090328 | 0.7 | long | | $> 1GeV$ | | $\approx 900s$ |
| 090323 | 4 | long | strong | $>$ 1GeV | | $> 10^3 s$ |
| 090217 | | long | | | $\sim 1s$ | $\approx 20s$ |
| 080825C | | long | weak | 0.6GeV | 3s | >40s |
| 081215A | | | weak | 0.2GeV | | |

31 GeV !

Open questions:

- Is the delayed GeV emission lingering prompt emission or afterglow?
- Are GeV bursts a separate class?
- What is the origin of GeV emission?
- What are the detailed properties of short GRBs?

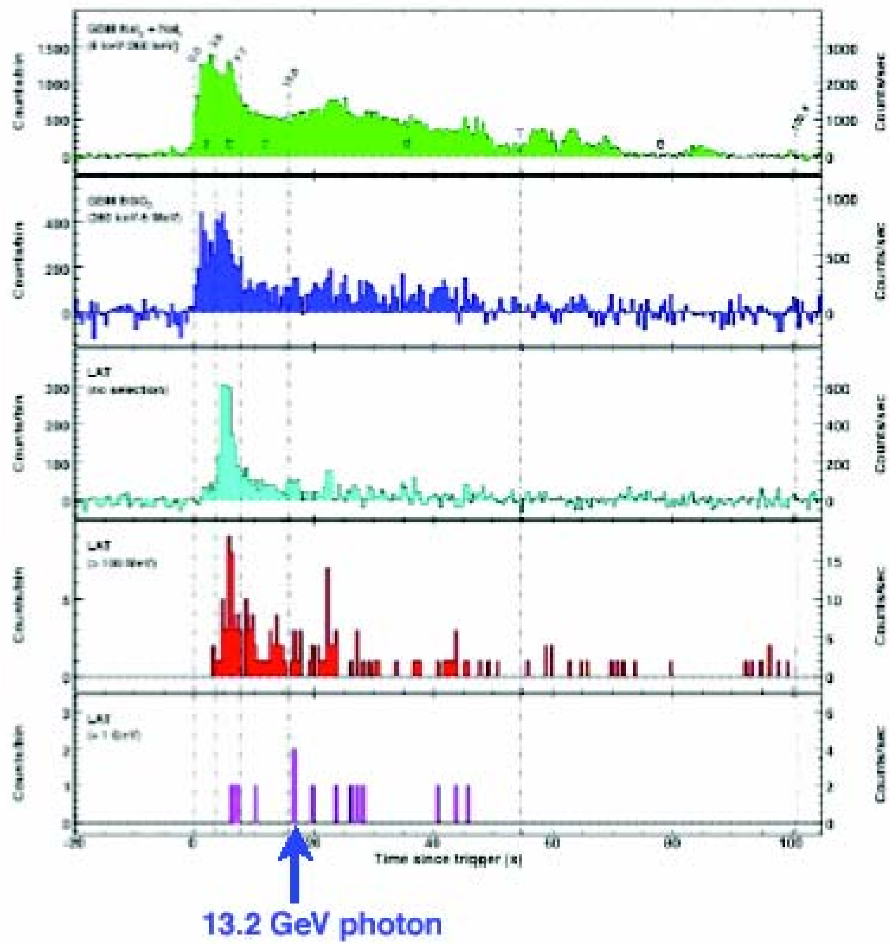
# Delayed HE emission: GRB 080916C

**Long GRB**

z = 4.35

Extended emission
Lag in MeV/GeV onset
Extended emission (18 min)
Lorentz factor (jet) > 860
(γγ absorption argument)

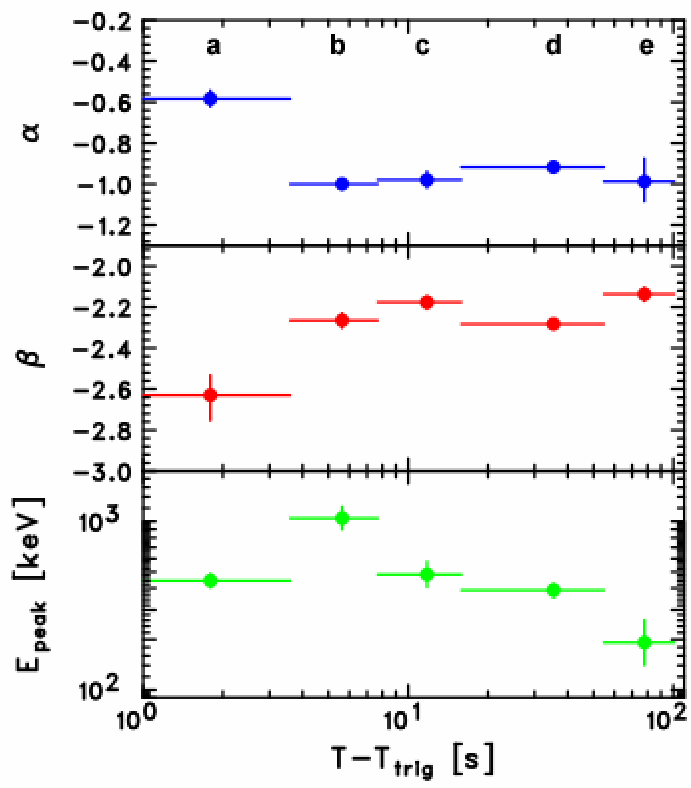
Highly luminous

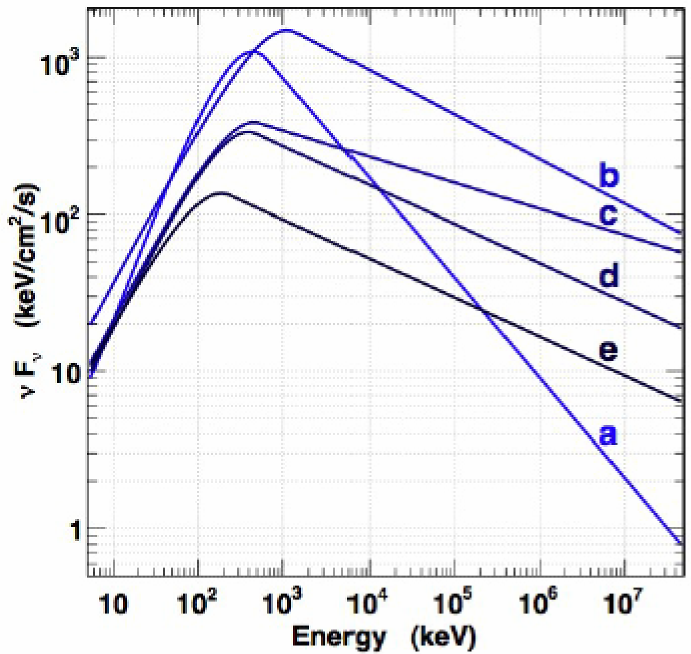



Abdo et al. Science 2009

# Fermi GBM/LAT: GRB 080916C

Spectral evolution:
soft-to-hard then hard-to-soft

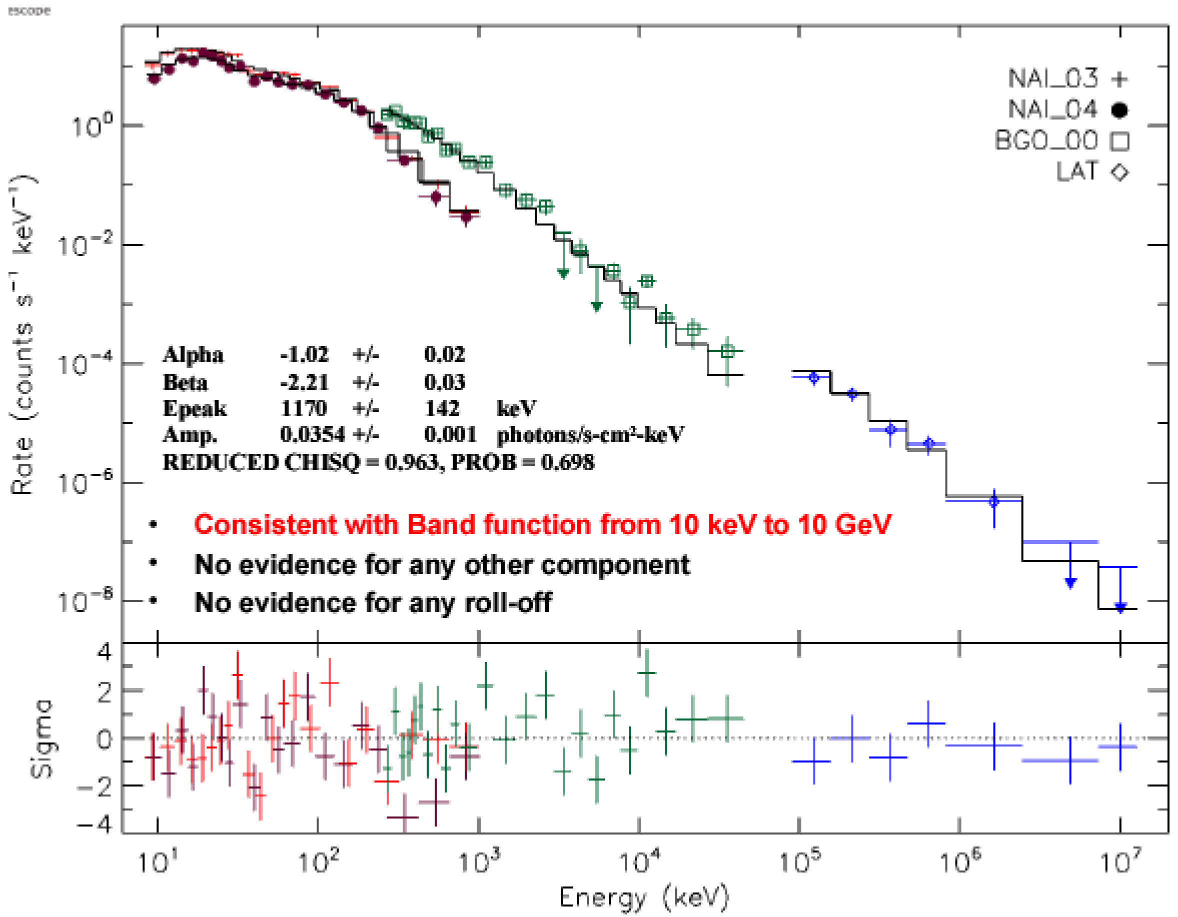



A. Jacholkowska, LAPP, 10/03/2010

# Fermi GBM/LAT: GRB 080916C

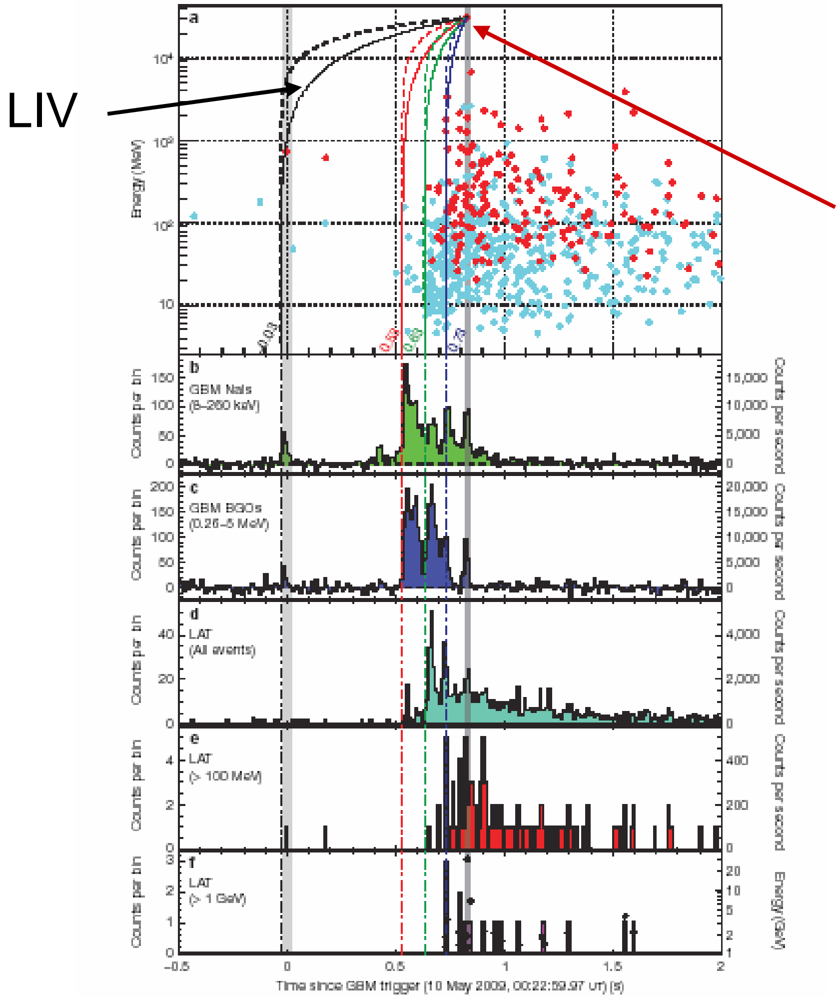
## Spectroscopy of main LAT peak (bin "b")



# Delayed HE emission: GRB 090510

→ $E_{QG} > 1.2\ E_P$ at 95% CL

*Fermi, Nature Letters, (2009)*




Short GRB, z = 0.903±0.003

- **single 31 GeV photon at 0.829s**
- **$10^{-7}$ probability to be background CR**
- **directional and temporary coincidence with GRB090510: > 5σ**
- **association of 31 GeV photon with different l.e. spikes leads to ξ > 100 !**

**this stringent photon dispersion limit disfavors linear variation of speed of light models predicting "foamy" structure of the space-time**

# Summary of LAT Bursts

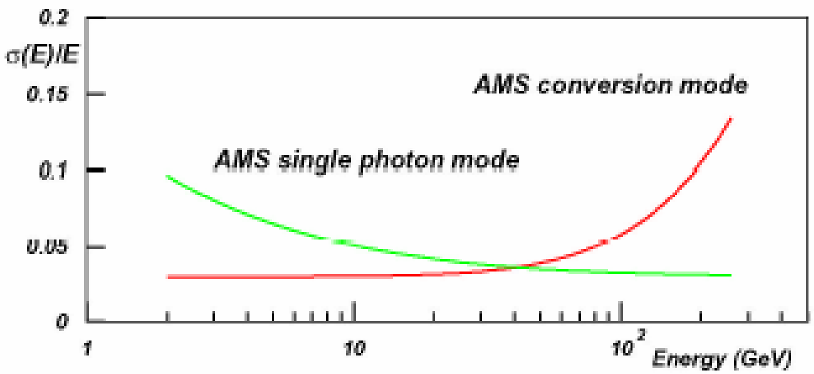
| GRB | duration | # of events > 100 MeV | # of events > 1 GeV | delayed HE onset | Long-lived HE emission | Extra Component | Highest Energy | Redshift |
|---|---|---|---|---|---|---|---|---|
| 080825C | long | ~10 | 0 | ? | ✔ | x | ~600 MeV | |
| 080916C | long | >100 | >10 | ✔ | ✔ | ? | ~ 13.2 GeV | 4.35 |
| 081024B | short | ~10 | 2 | ✔ | ✔ | ? | 3 GeV | |
| 081215A | long | — | — | — | — | -- | — | |
| 090217 | long | ~10 | 0 | x | x | x | ~1 GeV | |
| 090323 | long | ~20 | >0 | ? | ✔ | ? | ? | 3.57 |
| 090328 | long | ~20 | >0 | ? | ✔ | ? | ? | 0.736 |
| 090510 | short | >150 | >20 | ✔ | ✔ | ✔ | ~31 GeV | 0.903 |
| 090626 | long | ~20 | >0 | ? | ✔ | ? | ? | |
| 090902B | long | >200 | >30 | ✔ | ✔ | ✔ | ~ 33 GeV | 1.822 |
| 090926 | long | >150 | >50 | ✔ | ✔ | ✔ | ~20 GeV | 2.1062 |

# AMS resolutions

**Converted photon $\gamma \to e^- e^+$**

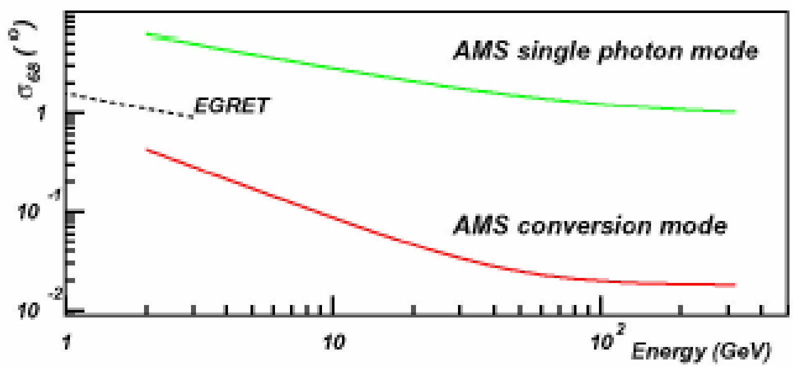
- some matter before the 1st TOF layer
  $\ell \sim 0.25\, X_0$
  conversion probability $\sim 20\ \%$
- $\gamma$ energy and direction reconstructed from charged pair
- energy range limited by double track reconstruction ($E \sim 200\, GeV$)
- large angular view ($\theta_{max} \sim 42°$)

mean acceptance $(10 - 250 GeV)$
$\sim 0.05\ m^2.sr$




**Non-converted photon**

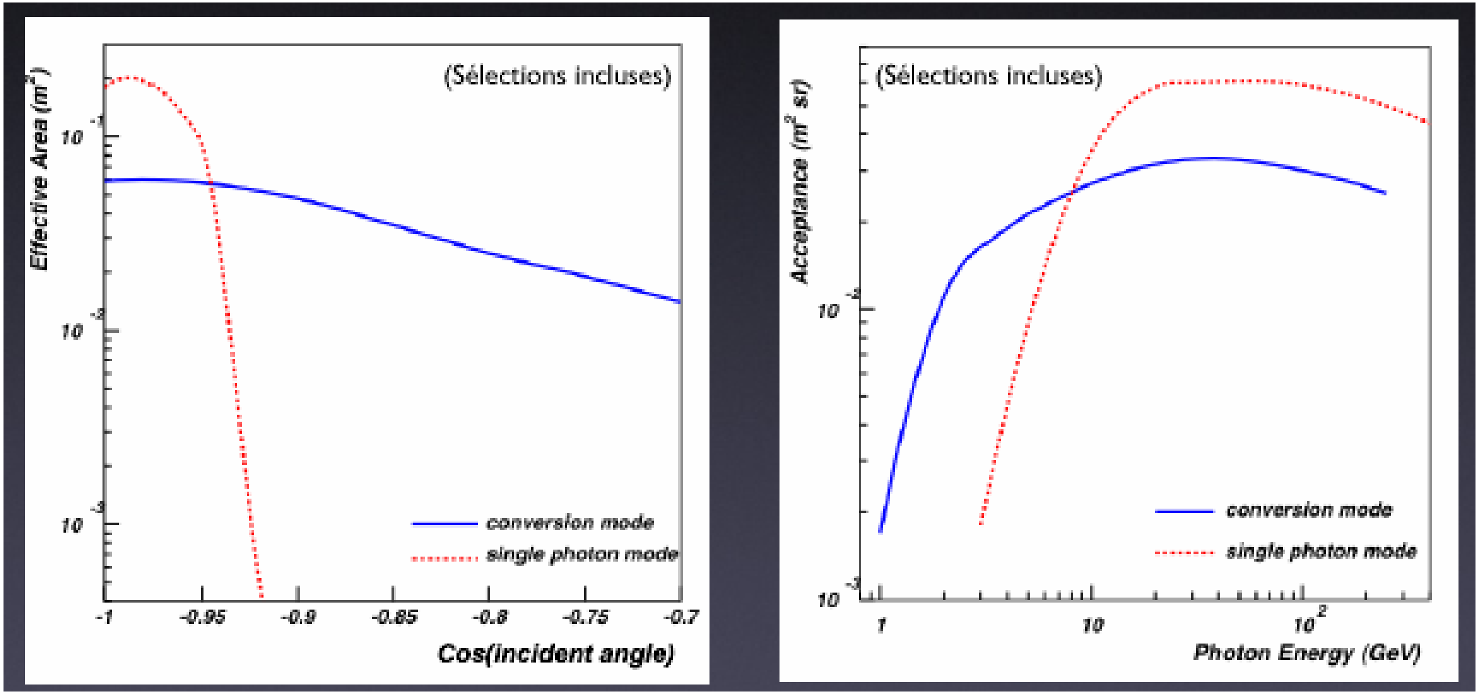
- direction of reconstructed photon inside fiducial region ($\theta_{max} \sim 22°$)
- large rejection power against protons and electrons ($\sim 10^6$)
- large energy range ($8\ GeV - 10^3\ GeV$)



# AMS acceptances for γ

The 2 modes are complementary or exclusive:

- SiTRK: better angular coverage
- ECAL:  better acceptance for E > 10 GeV



# AMS performance

| | LAT | EGRET | AMS |
|---|---|---|---|
| Energy range | 20 MeV to >300 GeV | 20 MeV – 30 GeV | 1 – 300 GeV |
| Energy resolution (on axis, 100 MeV – 10 GeV) | <10% | 10% | 3 – 5% |
| Peak effective area | 9000 $cm^2$ | 1500 $cm^2$ | 700 $cm^2$ |
| Angular resolution (single photon, 10 GeV) | 0.15° | 0.54° | 0.1° - 2.5° |
| Field of view | >2.2 sr | 0.4 sr | 0.75 sr |
| Deadtime per event | 27 us | 100 ms | 20 μs |

# Predictions for AMS before Fermi

Important for extrapolation:
- number of GRBs/year
- duration
- number of events with $E\gamma > 100$ MeV
  $E\gamma > 1$ GeV
- highest energy

Expected frequency of GRBs in AMS:
extrapolations from BATSE/EGRET data (2003)

AMS: $F_A = 1 - 3$/year
Fermi: $F_F = 30 - 100$/year

scales as
$F_F/F_A = (\text{Eff area*FoV})_F/(\text{Eff area/FoV})_A \sim 30$

# Predictions for AMS before Fermi

Detailed study of expected γ yield from GRBs in AMS:
(S. Sajjad M2 internship, GAM 2002)

Study case: GRB 941017 detected by EGRET ($t_{GRB}$ = 80s)

| Zenith angle | Energy range | Nγ conversion | Nγ single | Nγ total |
|---|---|---|---|---|
| 0° | > 1 GeV | 13 | 16 | **29** |
| | > 5 GeV | 3 | 10 | **13** |
| 20° | > 1 GeV | 13 | 4 | **17** |
| | > 5 GeV | 3 | 3 | **6** |
| 30° | > 1 GeV | 11 | 0 | **11** |
| | > 5 GeV | 3 | 0 | **3** |

Conclusions: spectral study difficult with expected no of γ
hadron bckg ~ $10^{-2}$ h
But: hadron rejection optimized for diffuse γ emission !

# Predictions for AMS with Fermi

- Fermi observes at least 5 times less GRBs in LAT than expected from BATSE/EGRET extrapolations
  *little evidency for a second – high energy component*

  → AMS < 1 GRB/year
  < 1 GRB/2years with redshift

- GRB 090510 – lasted 2 sec
  No of γ with E > 0.1 GeV > 150
  E > 1 GeV 20
  Limiting factors for AMS:
  effective area, strong dependence on zenith angle
  → need of simulations !

# Conclusions

• AMS has a potential to detect at most 1 GRB/year
once detected (mostly by SiTRK)
few dozens of γ avalable for source studies
standard studies of morphology and energy spectra

• Possible improvements:
Low trigger threshold
Optimize low energy reconstruction in ECAL (< 1 GeV)
Analysis: relaxe of Hadron suppression !

• Small but long-term contribution to the overall GRB studies

# Results on Quantum Gravity scale

| Source | Experiment | Method | Results linear, quadratic (GeV) |
|---|---|---|---|
| GRB 021206 | RHESSI | Fit + Mean arrival time in a spike | $M_{QG} > 1.5x10^{17}$ |
| **GRB 080916C** | **Fermi GBM + LAT** | **$\Delta t$ = t(Photon with highest E) – $t_0$** | **$M_{QG} > 1.5x10^{18}$** |
| **GRB 090510** | **Fermi GBM + LAT** | **CCF, cost function/Shannon** | **$M_{QG} > 1.2x10^{19}$, $> 0.5\ 10^{11}$** |
| 9 GRBs | BATSE + OSSE | Wavelets | $M_{QG} > 0.6x10^{16}$ |
| 15 GRBs | HETE-2 | Wavelets | $M_{QG} > 0.4x10^{16}$ |
| 17 GRBs | INTEGRAL | Likelihood | $M_{QG} > 0.4x10^{11}$ |
| 35 GRBs | BATSE + HETE-2 + SWIFT | Wavelets | $M_{QG} > 1.4x10^{16}$ |
| Mrk 421 | Whipple | Likelihood | $M_{QG} > 0.6x10^{17}$ |
| Mrk 501 | MAGIC | ECF + Likelihood | $M_{QG} > 0.3x10^{18}$ , $> 0.3\ 10^{11}$ |
| PKS 2155-304 | H.E.S.S. | MCCF + Wavelets + Likelihood | **$M_{QG} > 2.0x10^{18}$, $> 0.6\ 10^{11}$** |
| CRAB pulsar | EGRET | $\Delta t$ of photons > 2 GeV | $M_{QG} > 0.2x10^{16}$ |

# Fundamental Astrophysics workshop 2-3 June 2010

*http://indico.in2p3.fr/conferenceDisplay.py?confId=2779*

Lorentz Invariance Violation (LIV) is a good observational window on Quantum Gravity models. Within last few years, all major Gamma-ray experiments have published results from the search for LIV with variable astrophysical sources: Gamma-ray Bursts with detectors on-board satellites and Active Galactic Nuclei with ground-based experiments. In addition, most of future experiments (SVOM, CTA and others) put the search for LIV in their main physics goals. As the latest results tend to disfavor first order effects with energy, excluding a whole set of models based on space-time "foam", it is possible that the whole theoretical landscape will change in the next years. In light of these exciting new results, a status report about both the theoretical and observational aspects would be of great interest.

The meeting will be dedicated to the following aspects of the Fundamental Physics:

– Searches for Lorentz Invariance violation effects and signatures of Quantum Gravity
– studies of the quantum structure of the vacuum, in particular those of the Quantum Vacuum Friction (QVF) effects with Magnetars as predicted by of Quantum Electro-Dynamics
– tests of the Gravity law at large scales and of the General Relativity.

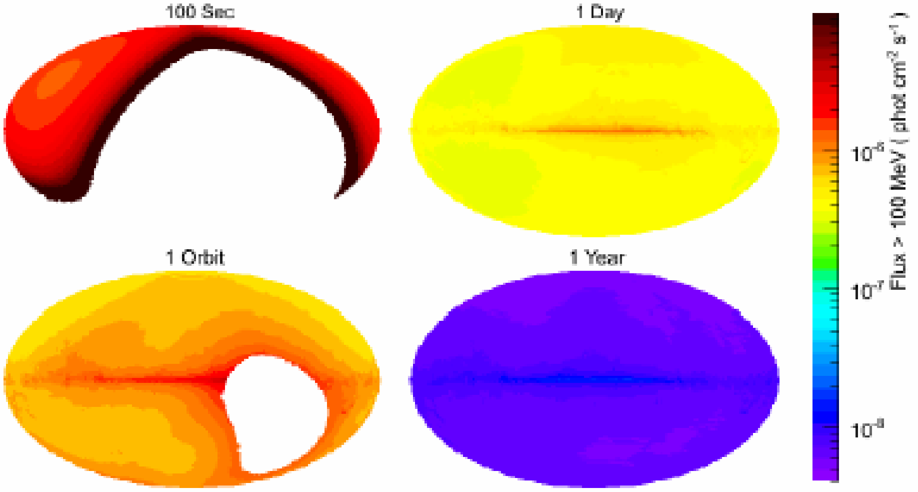
The workshop will deal with recent developments in these rapidly progressing areas. It will favour contacts between physicists working in various experiments, as between the theoreticians and the experimentalists. Discussions will take place on different methods used for the analyses of data and interpretation of the results.

**Place: Room "Joncquille" LPNHE - Universités Paris 6 et 7, IN2P3/CNRS**
**4, place Jussieu, Tour 43 – RdC, 75252 PARIS cedex 05**

**Organizing Committee:**
**J. Bolmont (LPNHE/UPMC, bolmont@in2p3.fr)**
**A. Blanchard (LATT/UPS)**
**A. Jacholkowska (LPNHE/UPMC)**
**S. Reynaud (LKB/UPMC)**
**C. Rizzo (UPS-IRSAMC/LCA)**

# Back-up slides

# Operating modes

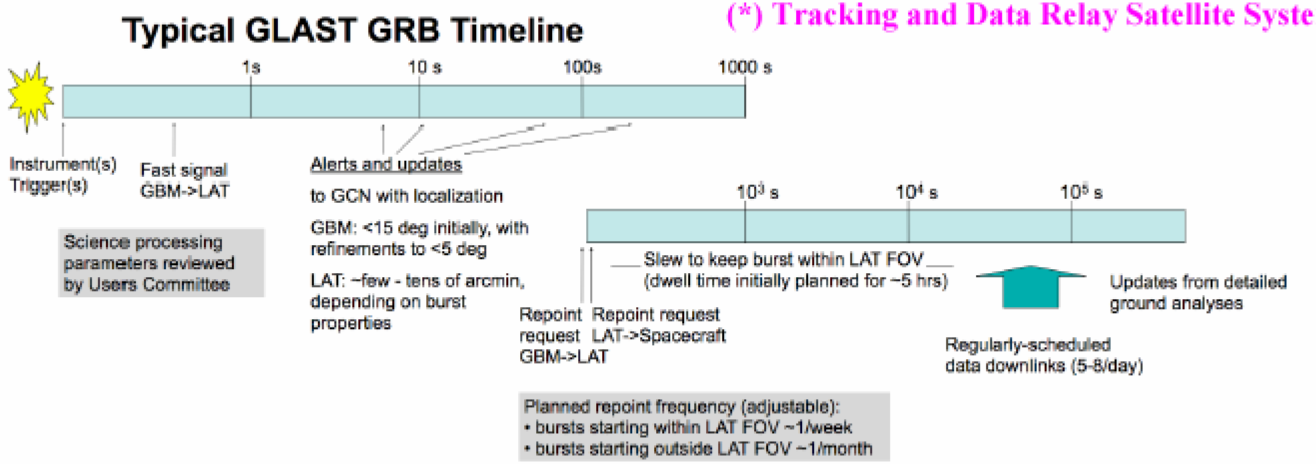



- Primary observing mode is Sky Survey
  - Full sky every 2 orbits (3 hours)
  - Uniform exposure: each region viewed for ~30 minutes every 2 orbits
  - Best serves majority of science, facilitates multiwavelength observation planning
  - EGRET sensitivity reached in days
- Pointed observations when appropriate (selected by peer review in later years) with automatic earth avoidance selectable
- Target of Opportunity pointing
- The observatory can be repointed (ARR) to obtain LAT observations of afterglow from strong bursts

# *Fermi* GRB response scenario: alerts and data flow

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

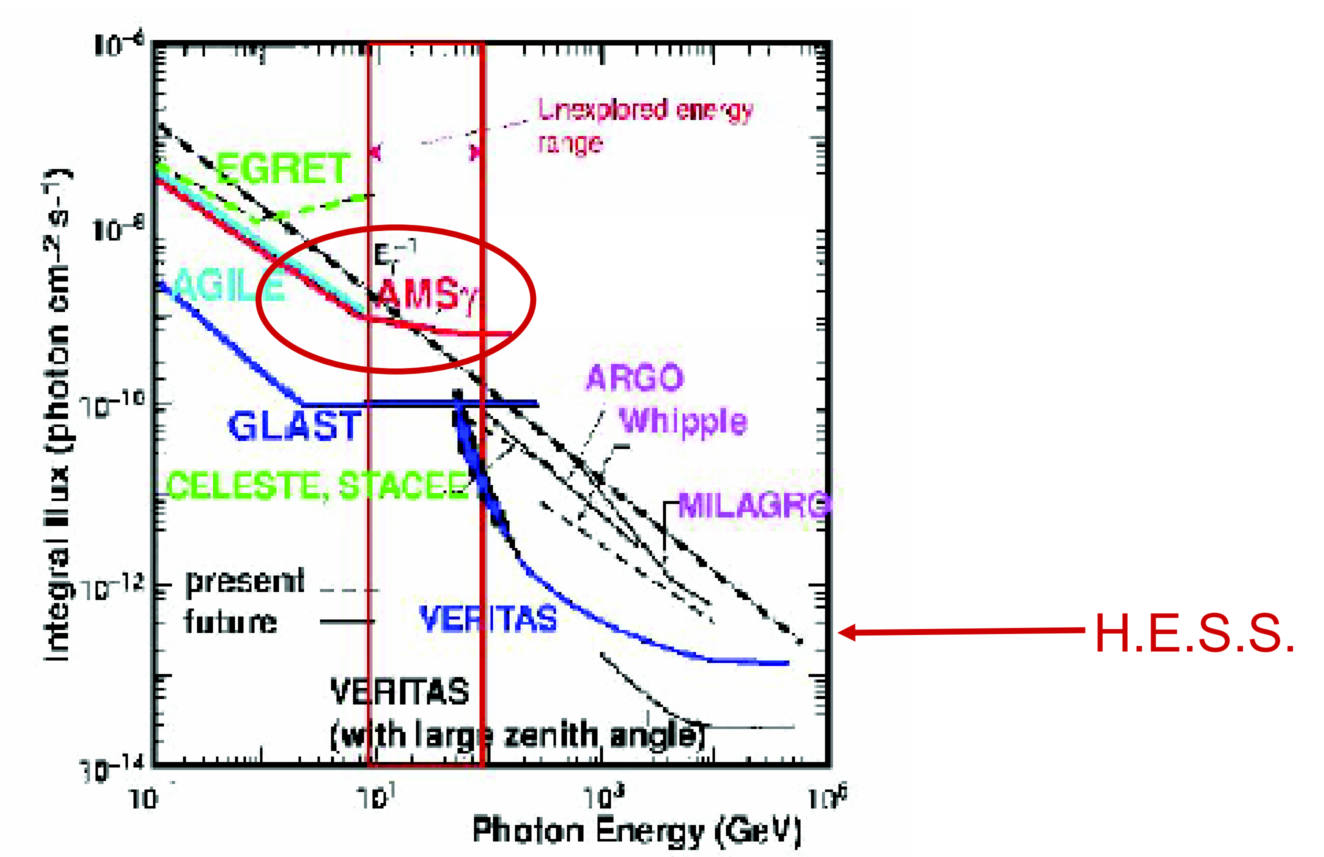
(*) Tracking and Data Relay Satellite System




- **Onboard processing - GCN alerts:**
  - **GBM location (<15° initially, within 2 s), intensity (counts), hardness ratio, trigger classification, LAT location**
- **Ground processing of prompt data (~15 mins):**
  - **Updated GBM location (<5°), preliminary GBM light-curve**
- **LAT ground processing (5-12 hours):**
  - **Updated location, HE flux & spectrum (or UL), afterglow search results**
- **Final ground processing (24-72 hours):**
  - **GBM model fit (spectral parameters, flux, fluence), joint GBM-LAT model fit, raw GBM data available**

# AMS sensitivity

Satellites: 1 year
Ground-based telescopes: 50 hrs of CRAB




A. Jacholkowska, LAPP, 10/03/2010

# LAT performance

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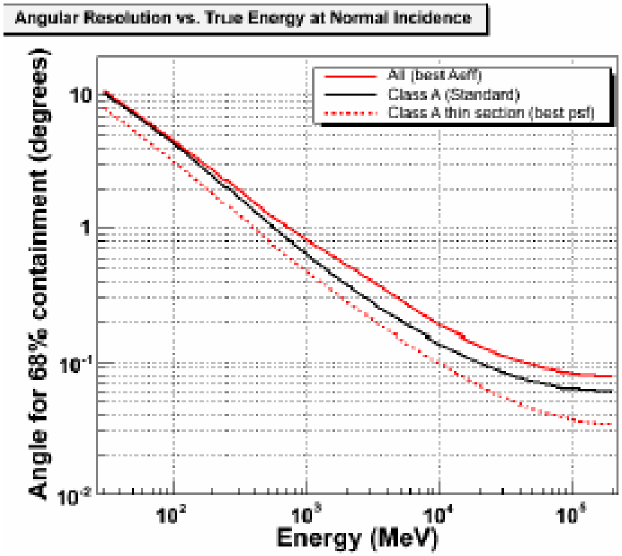


**Major improvements in capabilities for GRB observation**

- **Efficient observing mode (don't look at Earth)**
- **Wide FoV**
- **Low deadtime (exploring dt's down to μsec)**
  - **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