Leptonic and hadronic models for the extra components in Fermi-LAT GRBs

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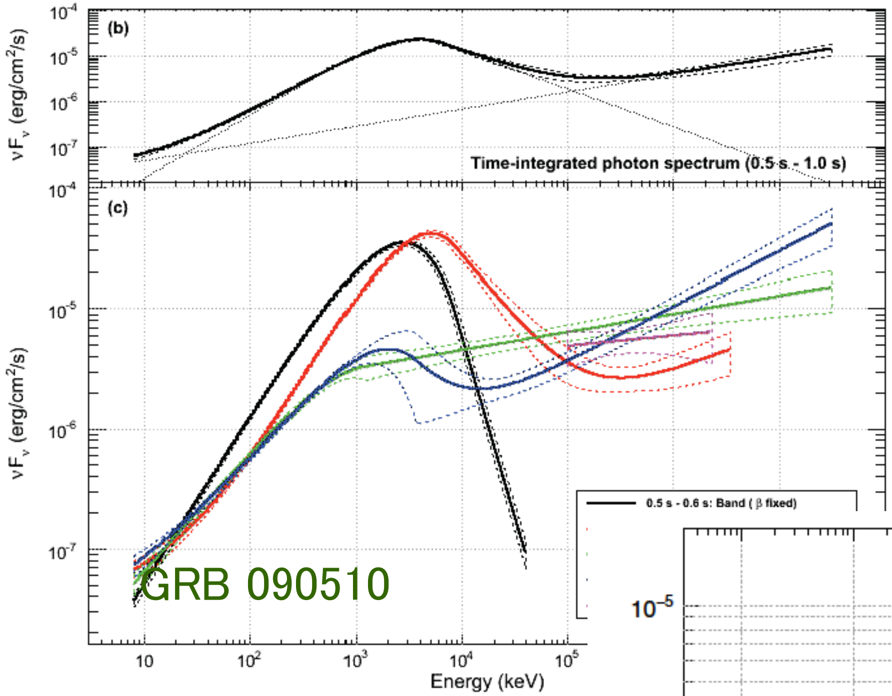
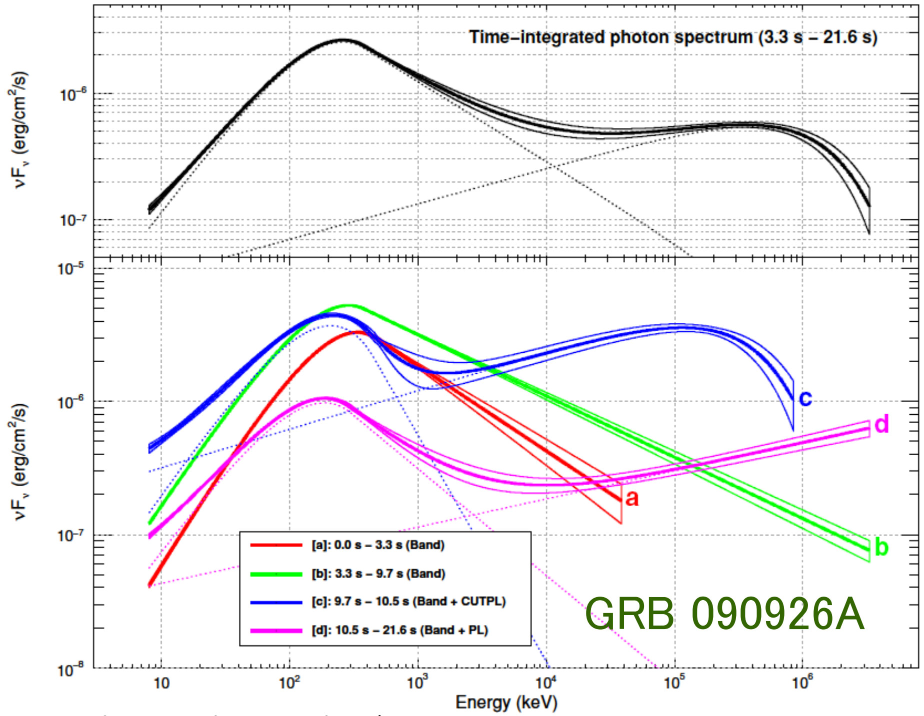
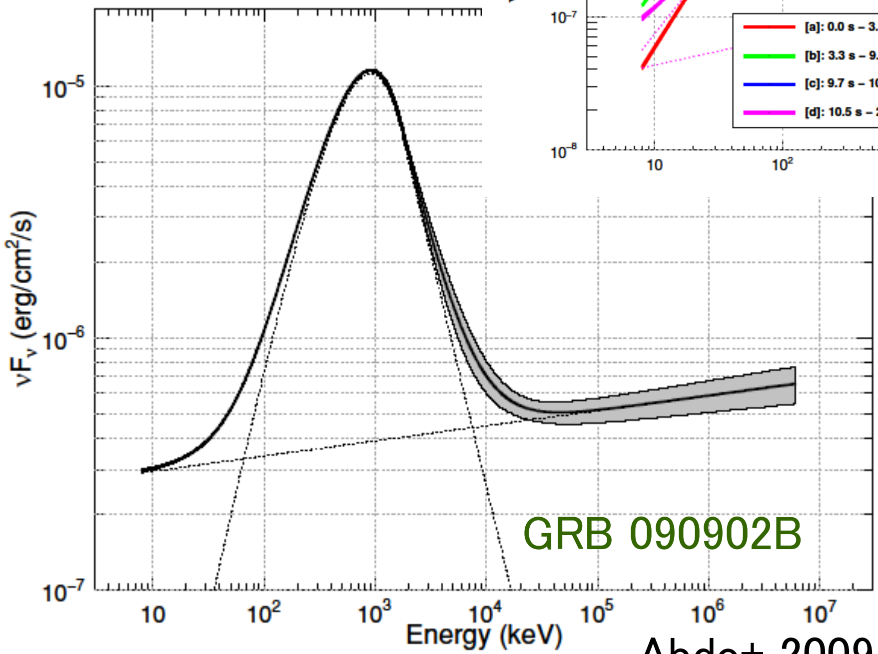
Extra Spectral Components detected with Fermi



Ackermann+ 2010



Ackermann+ 2011

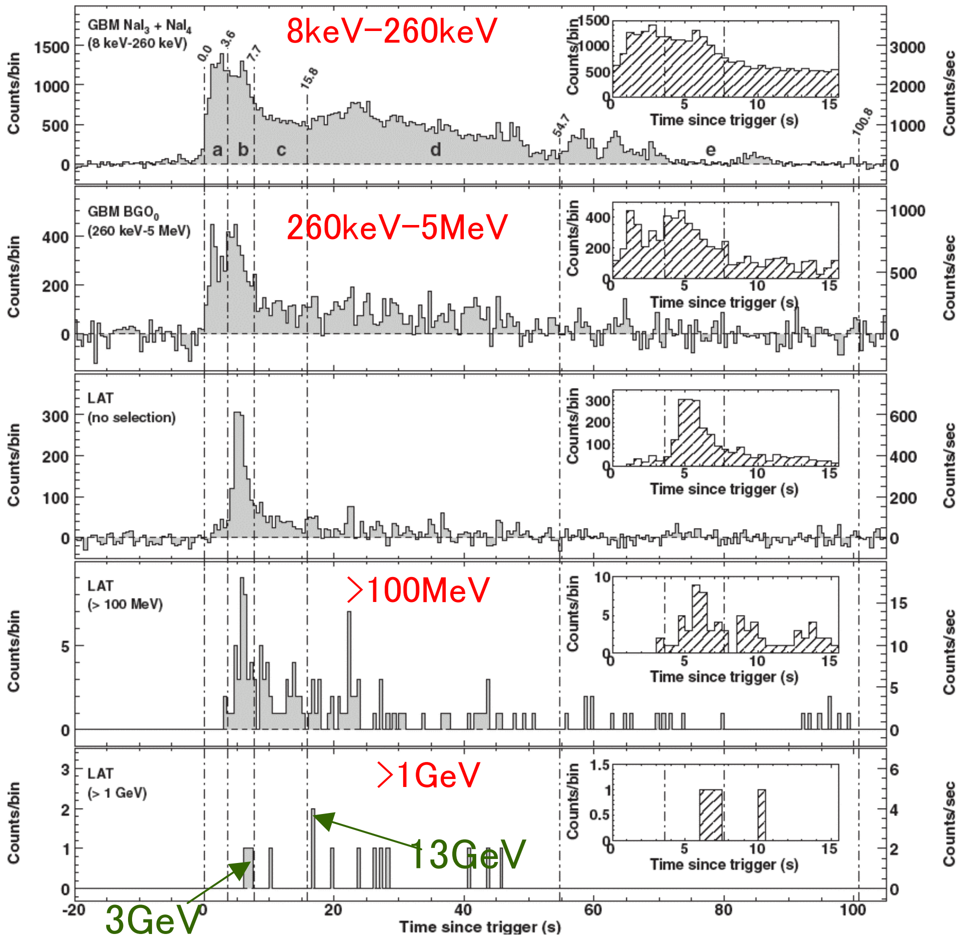


Abdo+ 2009

Fermi detected extra spectral components, which dominates GeV, in the prompt phase for several GRBs. Some of them dominates keV band as well.

Delayed GeV emission

GRB 080916C

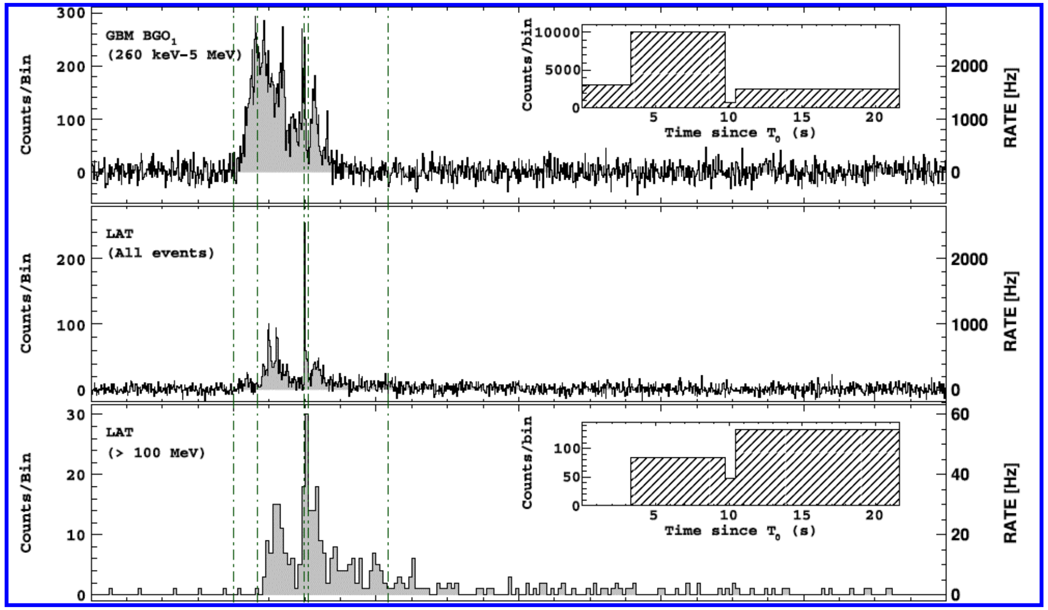


Abdo+ 2009

z=4.35

$E_{iso}=8.8\times10^{54}$erg

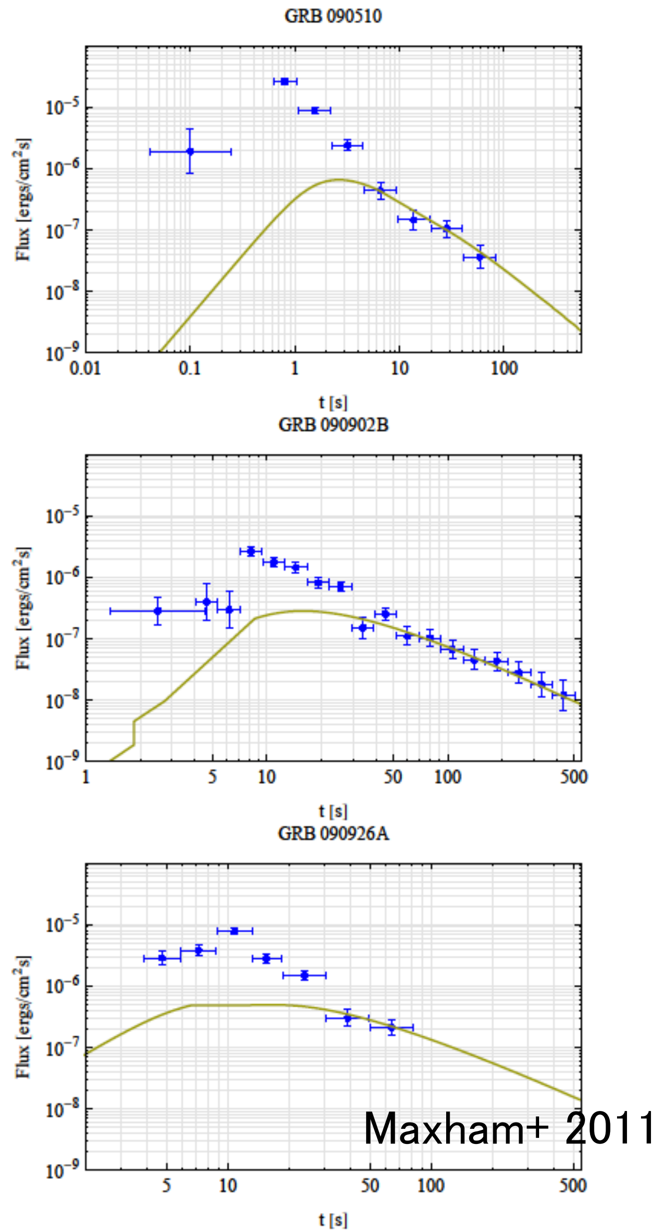
GRB 090926A



The onset of GeV emissions tends to be delayed relative to MeV emissions.
The extra components are due to early onset of afterglow? (Ghisselini+ 09, Kumar & B.Duran 09)

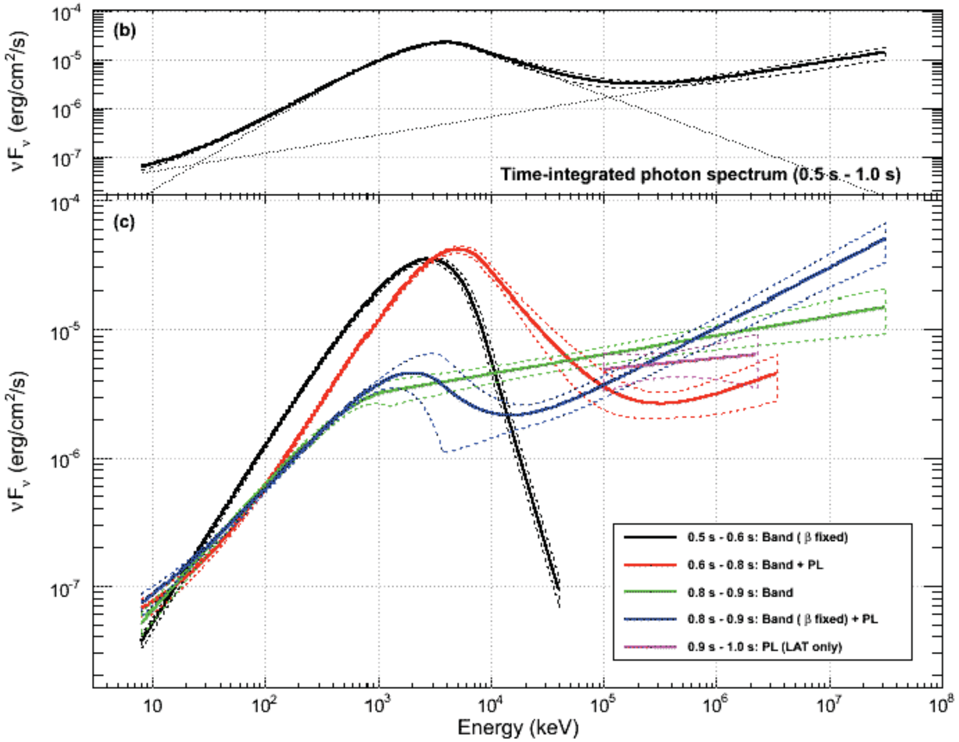
Internal origin?

- The origin of the GeV-extra components is internal shock region?
- Maxham+ (2011): GBM data suggest that the outflow energies are not sufficient to reproduce the early GeV emissions.
- As seen in GRB 090926A, spiky structures are seen in lightcurves.
- Here, we focus on theoretical models that can reproduce the extra components and delayed onset as well.



Hadronic model

GRB 090510



Abdo+ 2009, Ackermann+ 2010

- 1.5 s Short GRB.
- An extra component dominates both the GeV and keV regions.
- Simple IC emission cannot make soft excess(?).

Let us consider…

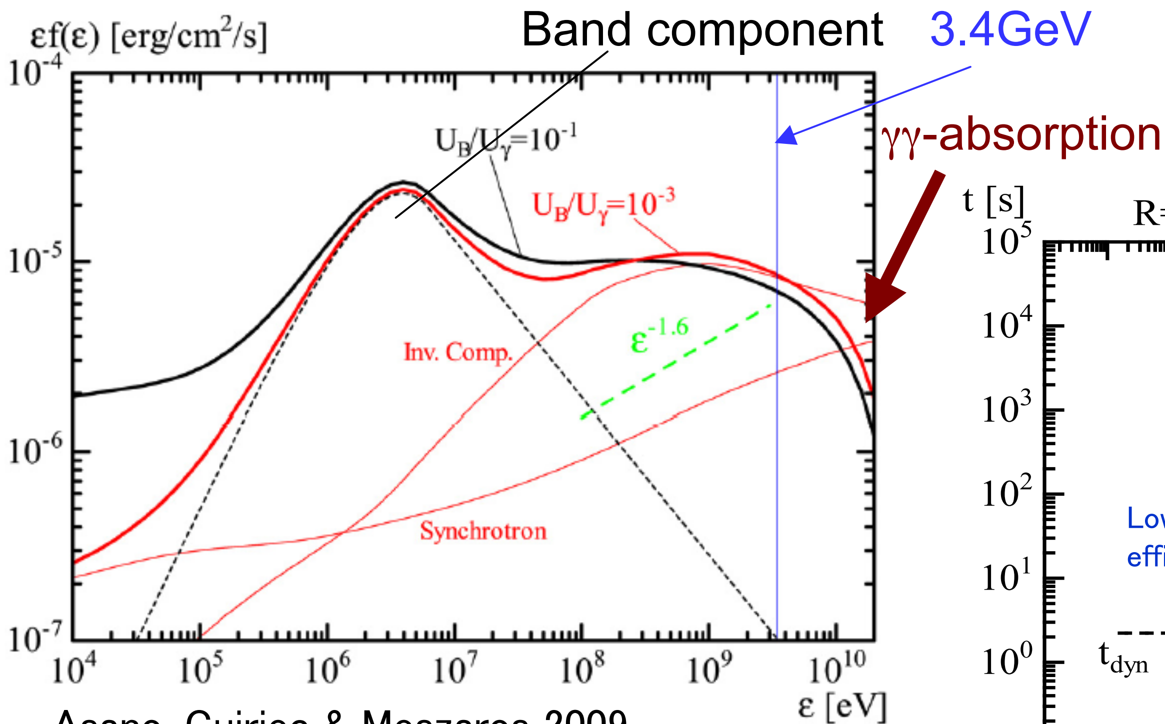
Hadronic Cascade

- $p+\gamma \rightarrow p(n)+\pi^0(\pi^+)$
- $p+\gamma \rightarrow p+e^+ + e^-$
- $\pi^0 \rightarrow \gamma+\gamma$, $\pi^+ \rightarrow \mu^+ + \nu_\mu$
- $\mu^+ \rightarrow e^+ + \nu_\mu + \nu_e$
- Synchrotron from $\pi^+, \mu^+, e^\pm$
- Inverse Compton from $\pi^+, \mu^+, e^\pm$
- $\gamma+\gamma \rightarrow e^+ + e^-$
- Synchrotron Self Absorption

Asano, Guiriec & Meszaros 2009
Asano, Inoue and Meszaros 2009
Asano & Inoue 2007
Asano & Takahara 2003

See also,
B¨ottcher & Dermer 1998
Gupta & Zhang 2007

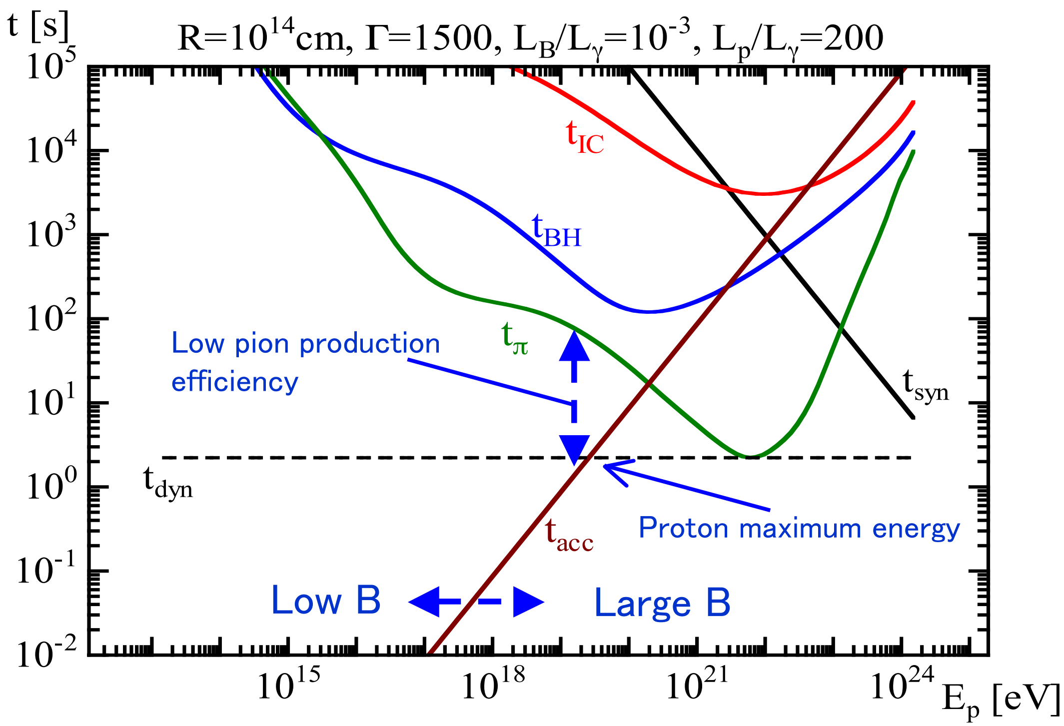
Electromagnetic cascade



Asano, Guiriec & Meszaros 2009

$$t_{dyn} / t_\pi \propto R^{-1}\Gamma^{-2}$$

Cooling Timescales



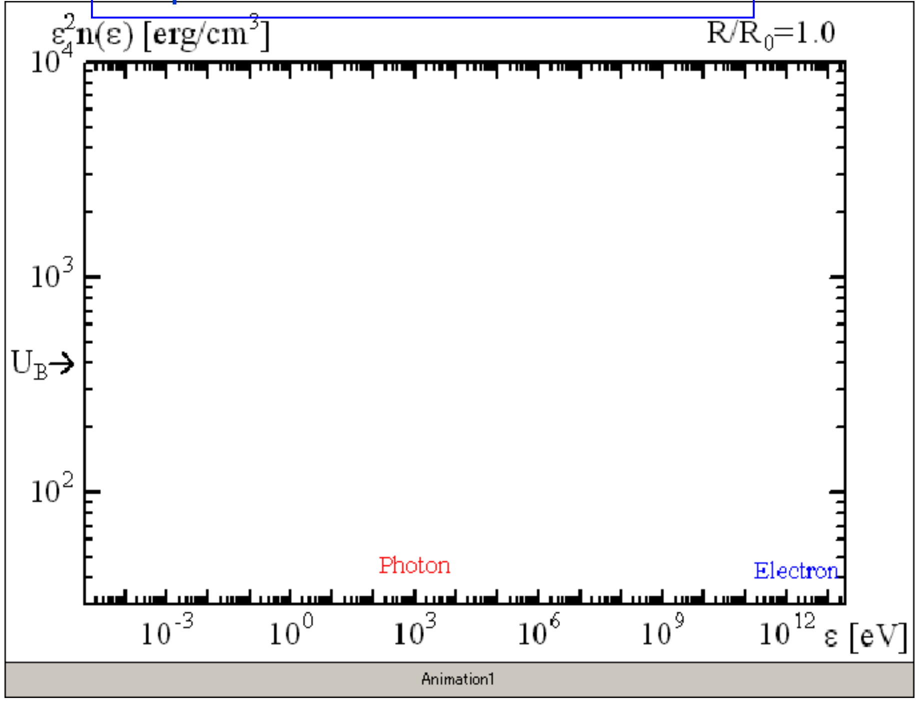
R=10^{14} cm $U_B / U_\gamma = 10^{-3}$

Γ=1500 $L_p / L_\gamma = 200$

- ･High-energy gamma-rays from pions induce electromagnetic cascade.
- ･To produce a hard spectrum, IC component is required. This implies low magnetic field.
- ･The low magnetic field lowers the proton maximum energy. This implies low efficiency of pion production.
- ･As a result, the required amount of protons is >100x γ-rays
- ･The high Γ required to emit GeV photons also lowers the efficiency.

Leptonic model

Time-dependent simulation
Spectra in the shell frame



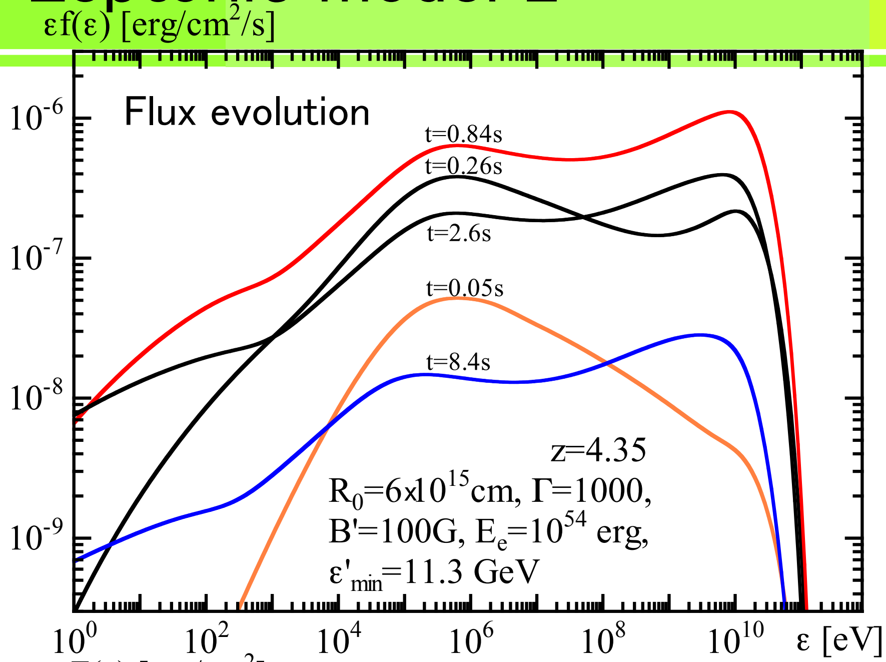
Asano & Meszaros in prep.

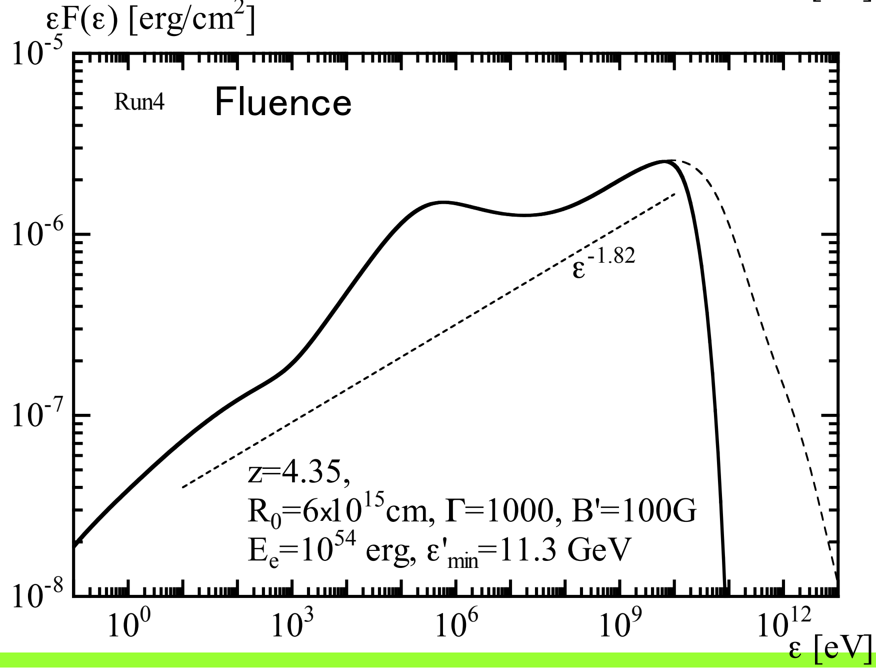
R_0=6x10^{15} cm, Γ=1000,
B'=100G, Ee=10^{54} erg,
γ'_{min}=11.3 GeV

See also,
Pe'er & Waxman 2005
Vurm & Poutanen 2009
Bosnjak, Daigne, & Dubus 2009
Daigne, Bosnjak, & Dubus 2011

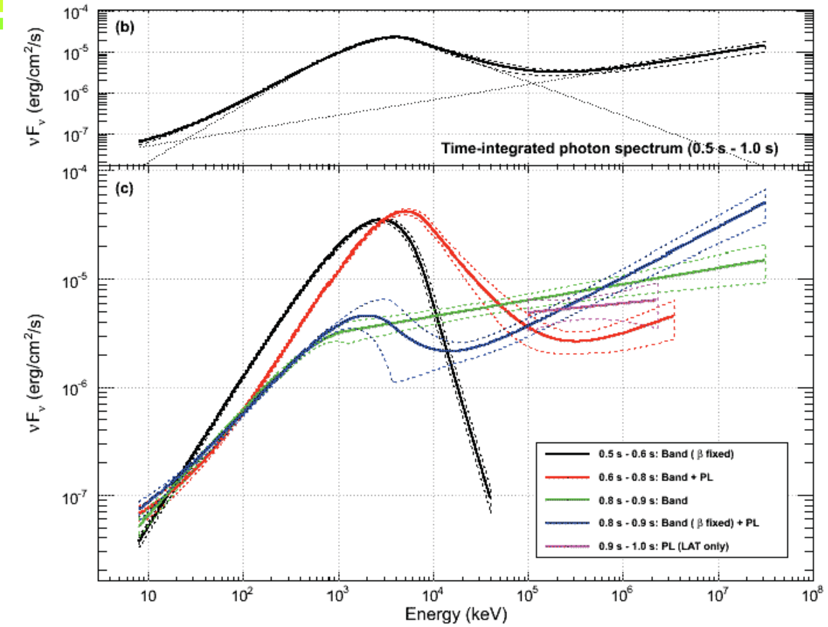
- Power-law electrons are injected during a finite time.
- Initially synchrotron component grows, and IC component grows later.
- In the later stage the injected electrons cool mainly via IC rather than synchrotron, so the synchrotron component starts to decay earlier than the IC component.
- After the end of the electron injection, the photon density decreases owing to the shell expansion and photon escape.
- At the end of the electron injection, cooled electrons are still relativistic so that "late synchrotron emission" continues and it produces a spectral bump at ～0.1 eV.

Leptonic model 2

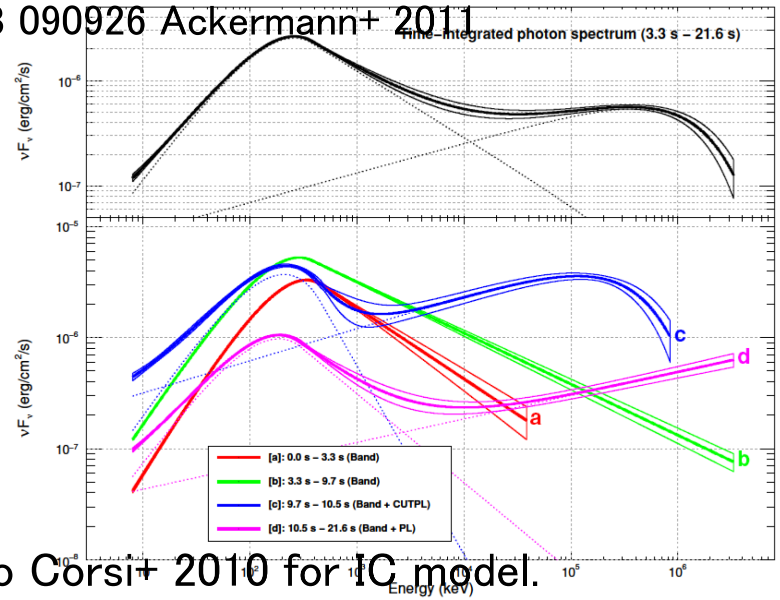




GRB 090510



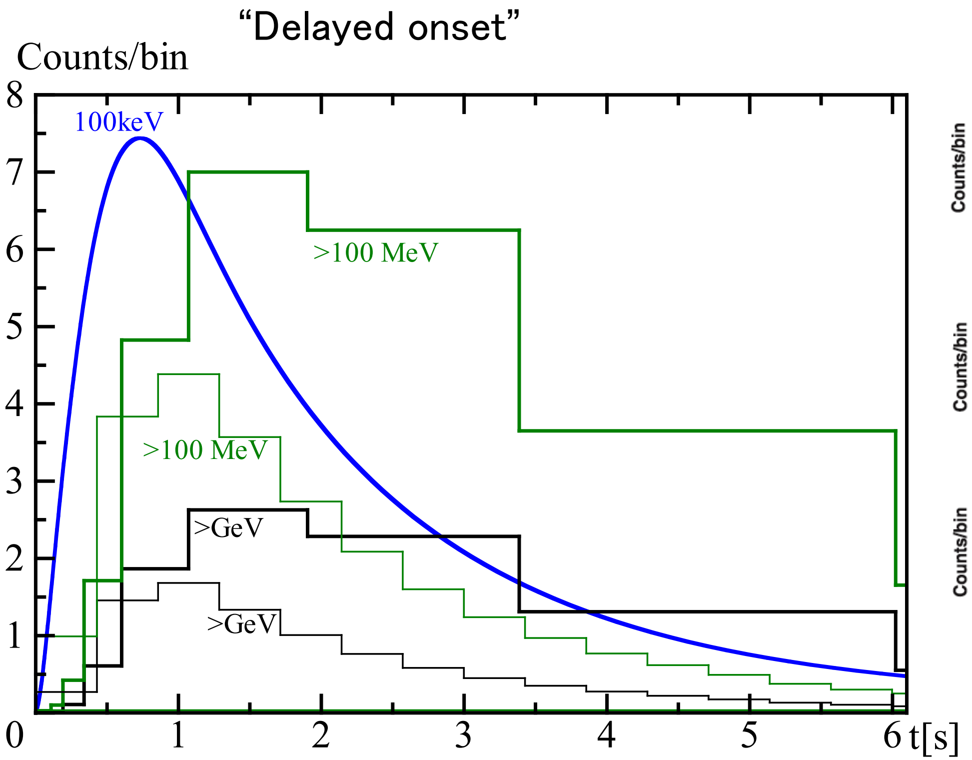
GRB 090926 Ackermann+ 2011



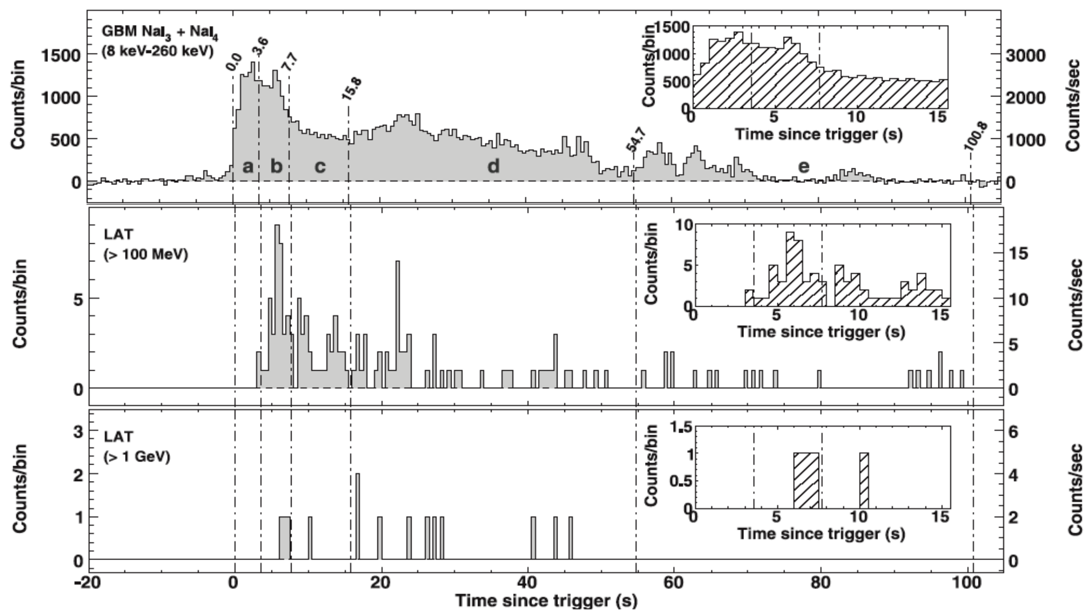
See also Corsi+ 2010 for IC model.

Leptonic model 3

Lightcurve



GRB 080916C Abdo+ 2009



Mimic the Fermi effective area with z=4.35

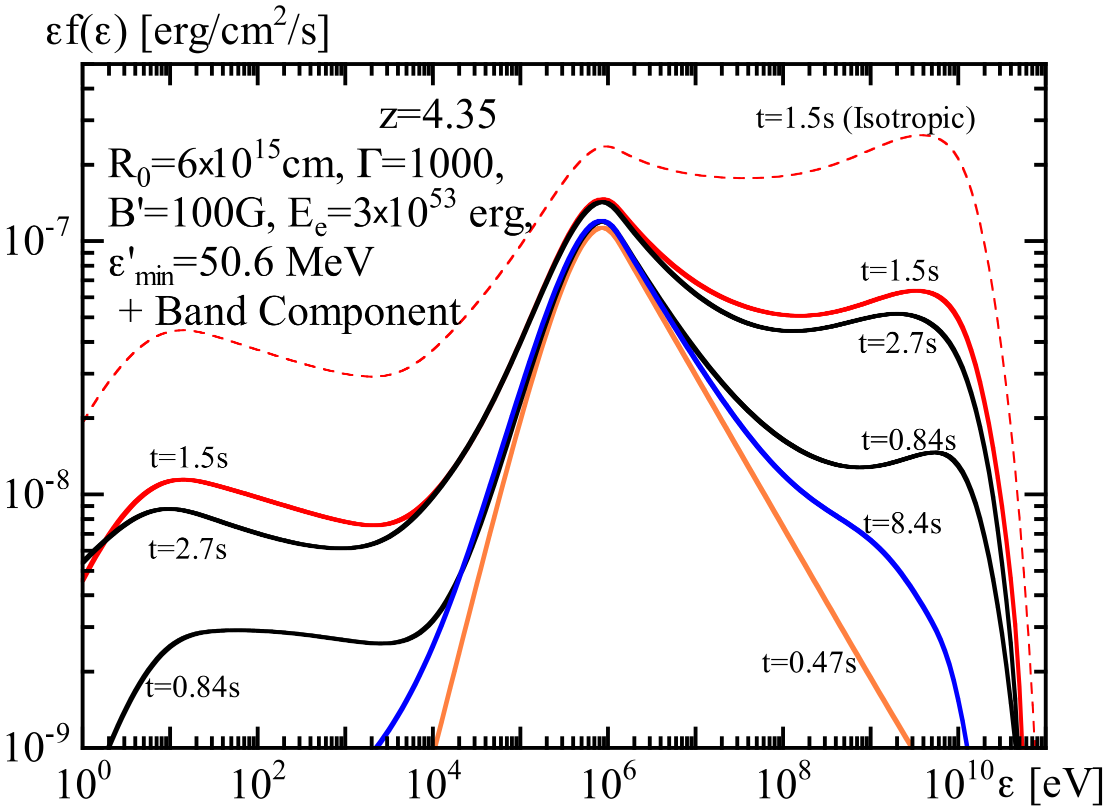
The first photon above GeV would be detected after one second.

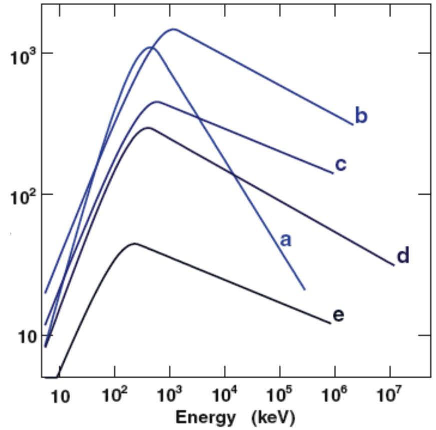
The delayed growth of the IC component causes the delayed GeV onset.

The extra component and the delayed onset of GeV emission would be explained.

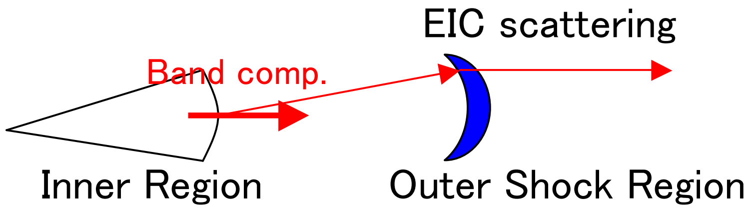
But the delay is within the pulse timescale, while it's 4 s in GRB 080916C.

External photons + Internal shock





GRB 080916C
Abdo+ 2009

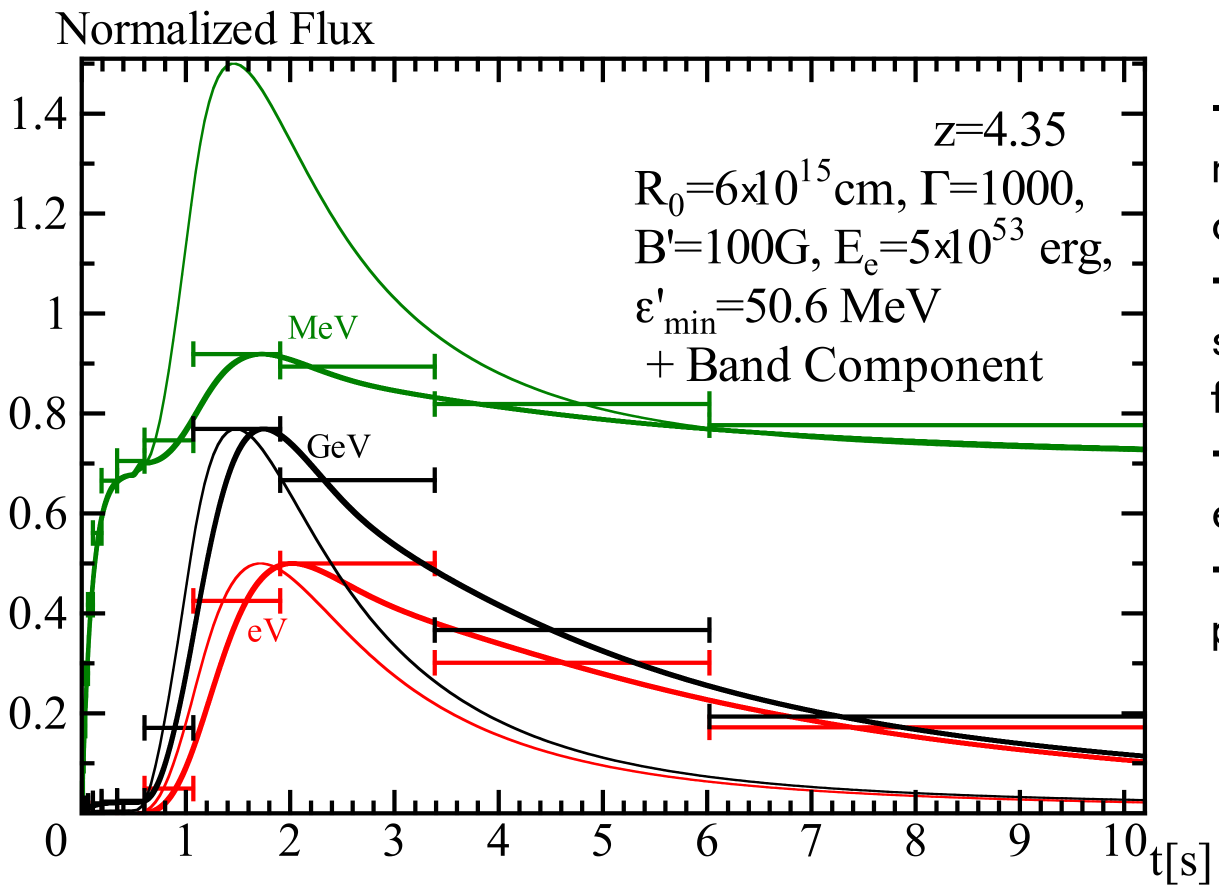


Thick: Fully-beamed approximation
Thin dashed: Isotropic approximation

The seed photons coming from a inner region are anisotropic in the outer shell frame.
The anisotropy affects the flux evolution.

- Toma+ 2009, 2010
- External MeV component.
- GeV emission is due to up-scattering of MeV component.
- The spectral evolution is similar to the observation.

Lightcurves in EIC model

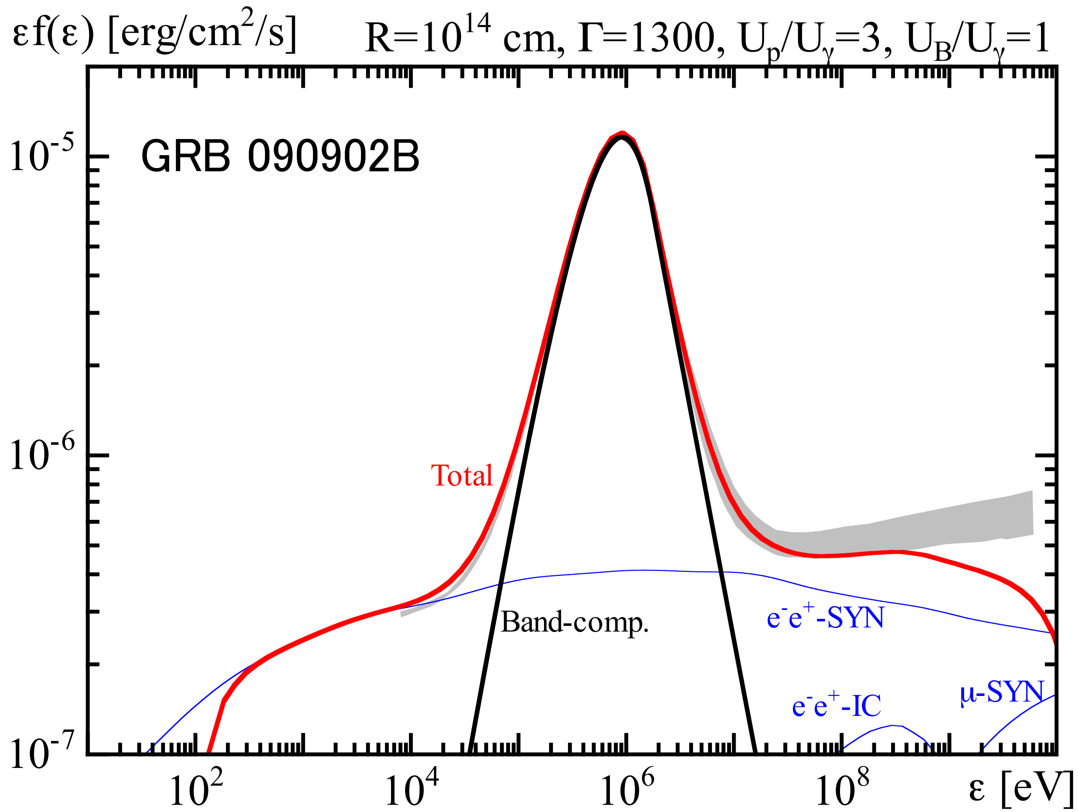


Thick: Fully-beamed approximation
Thin dashed: Isotropic approximation

- The geometrical configuration in EIC model naturally yields the delayed onset of GeV emission.
- The anisotropy of seed photons in the shell frame leads to enhance emissions from higher latitude.
- The higher-latitude emissions lead to an extra factor for the delay timescale.
- The EIC model with anisotropic effect produces long tails of lightcurves.

Leptonic models can reproduce the extra components and delayed onset.
The leptonic models seem to be reasonable…

Hadronic Case?



Asano, Inoue and Meszaros 2010

·The MeV component is very narrow (photospheric?).

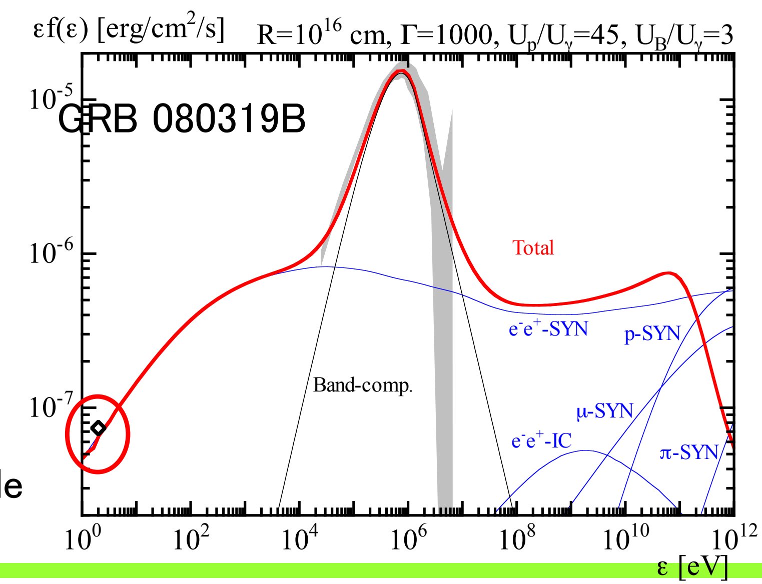
·The flat extra component would be due to synchrotron emission from pair cascade.

·We do not need IC, so the strong magnetic field is OK. As a result, the required amount of protons seems reasonable.

·The low-energy excess is also naturally explained.

Also applicable for the naked eye GRB.

Optical Excess due to hadronic cascade



Summary

- We consider internal shocks outside the photosphere.
- Both the hadronic and leptonic models can explain the spectral shape of the extra components.
- However, the hadronic model for the hard spectrum requires huge energy of protons.
  - Note; GRB-UHECR scenario requires a larger energy of protons than gamma-rays.
- The leptonic models can explain both low- and high-energy excesses in the spectrum by IC and late synchrotron emissions.
- Retarded growth of IC components may partially explain the delayed onset of GeV emissions.
- The EIC model has advantage to explain the timescale of delayed onset and spectral evolution.
- For GRB 090902B, the hadronic model can explain the spectrum with a fiducial parameter set.