GRB emission models and multiwavelength properties

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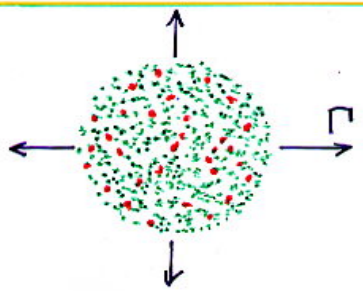
The "standard" model

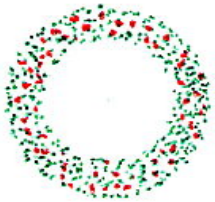
Explosion $E_i = \frac{10^{52}\ \text{erg}}{N_i}$

$R_0 \simeq R_s$?



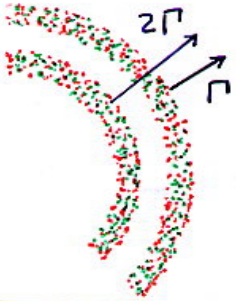
Fireball

Acceleration $\Gamma \sim \frac{R}{R_0}$



Coasting

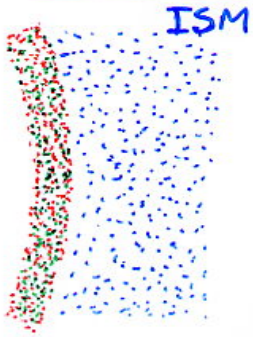
$\Gamma \sim$ const



Internal shocks ⇒ burst

shell-shell-interactions

$R_i \simeq R_0 \Gamma^2$



External shocks

⇒ Afterglow

$R_D = 5.5 \times 10^{16} \left(\frac{E_{52}}{\Gamma_2^2 n N} \right)^{1/3}$ cm

"The" model: Internal/External Shocks

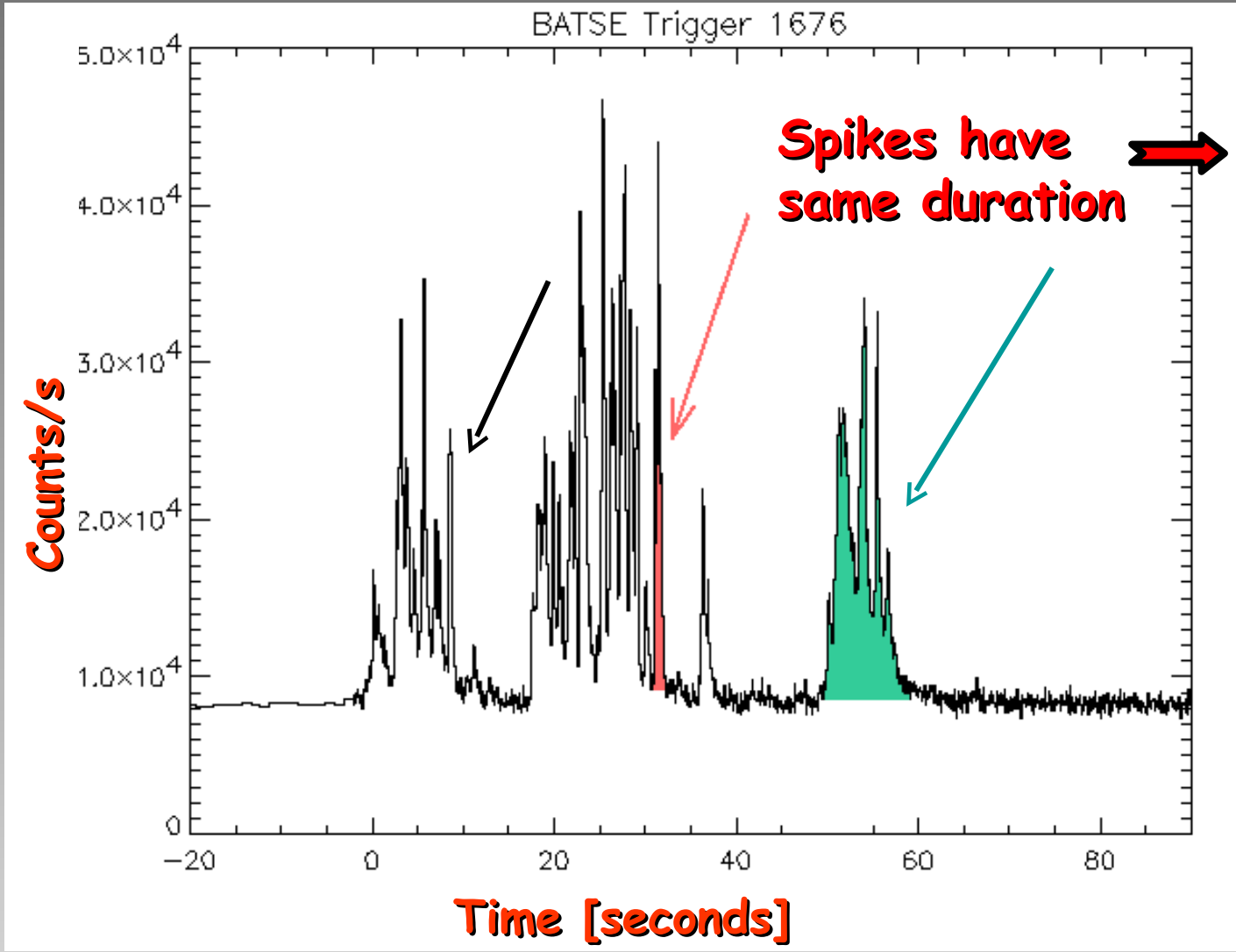
Rees-Meszaros-Piran

Shell still opaque

Relativ. e^- + B: synchrotron??

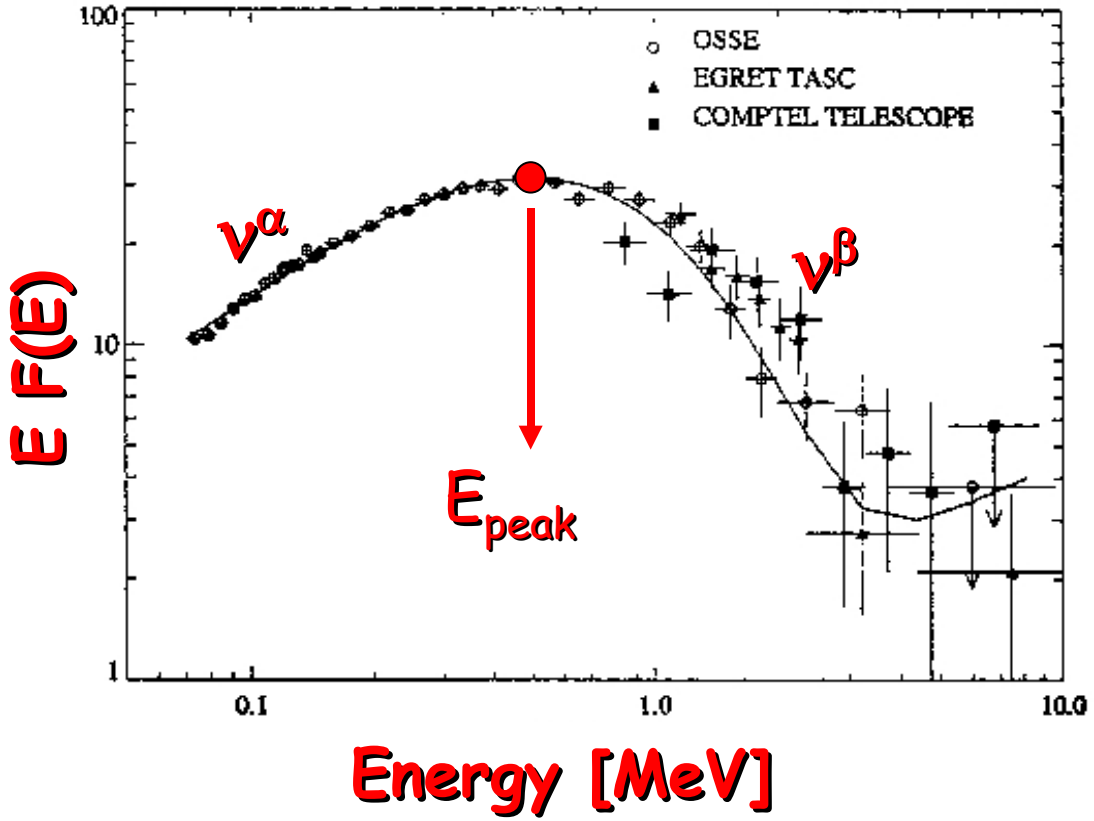
Relativ. e^- + B: synchrotron

Why internal shocks?



A process that repeats itself

Spectra



Fishman & Meegan 1995

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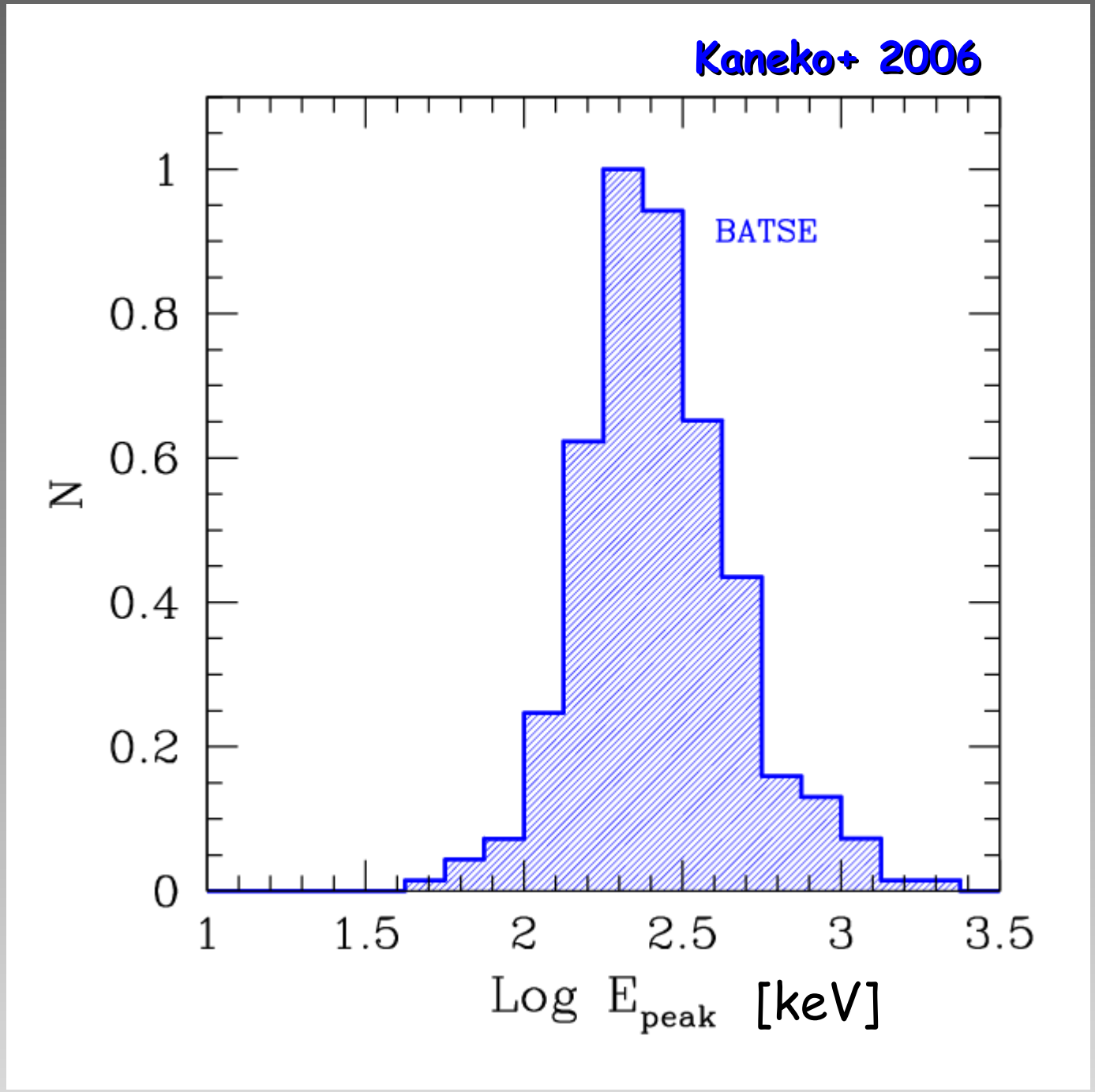
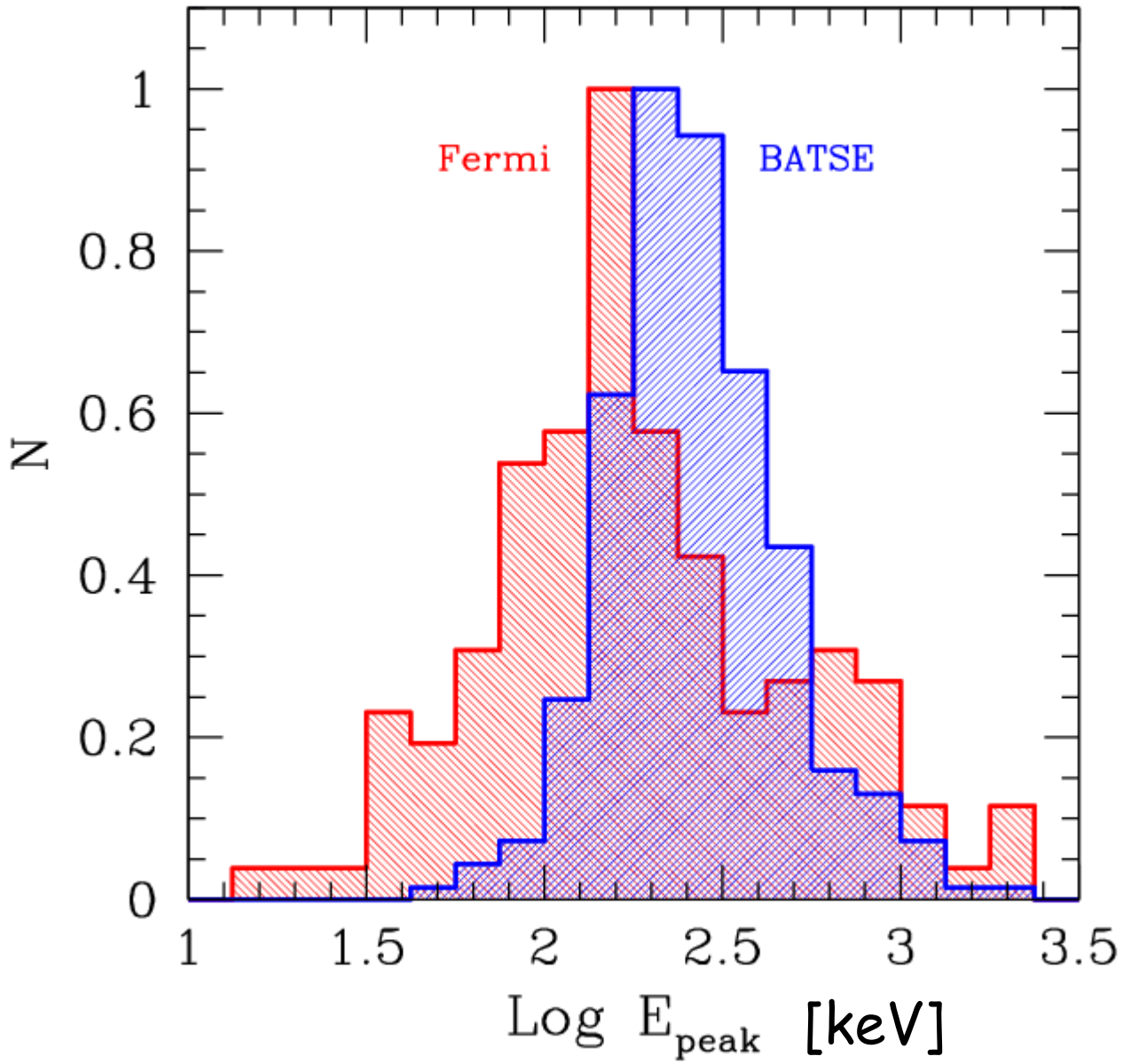

Kaneko+ 2006
BATSE
N
0
0.2
0.4
0.6
0.8
1
1
1.5
2
2.5
3
3.5
Log E_{peak} [keV]

Nava PhD thesis 2009

Kaneko+ 2006



Prompt radiation: Synchrotron?

Synchrotron γ-ray emission?

The shell itself carries B-field

B can also be produced and amplified by the internal shock

The shock can accelerate e- to relativistic energies

⟹ Synchrotron seems a good choice

⟹ $h\nu_{syn}$ ~ a few hundreds keV seems reasonable

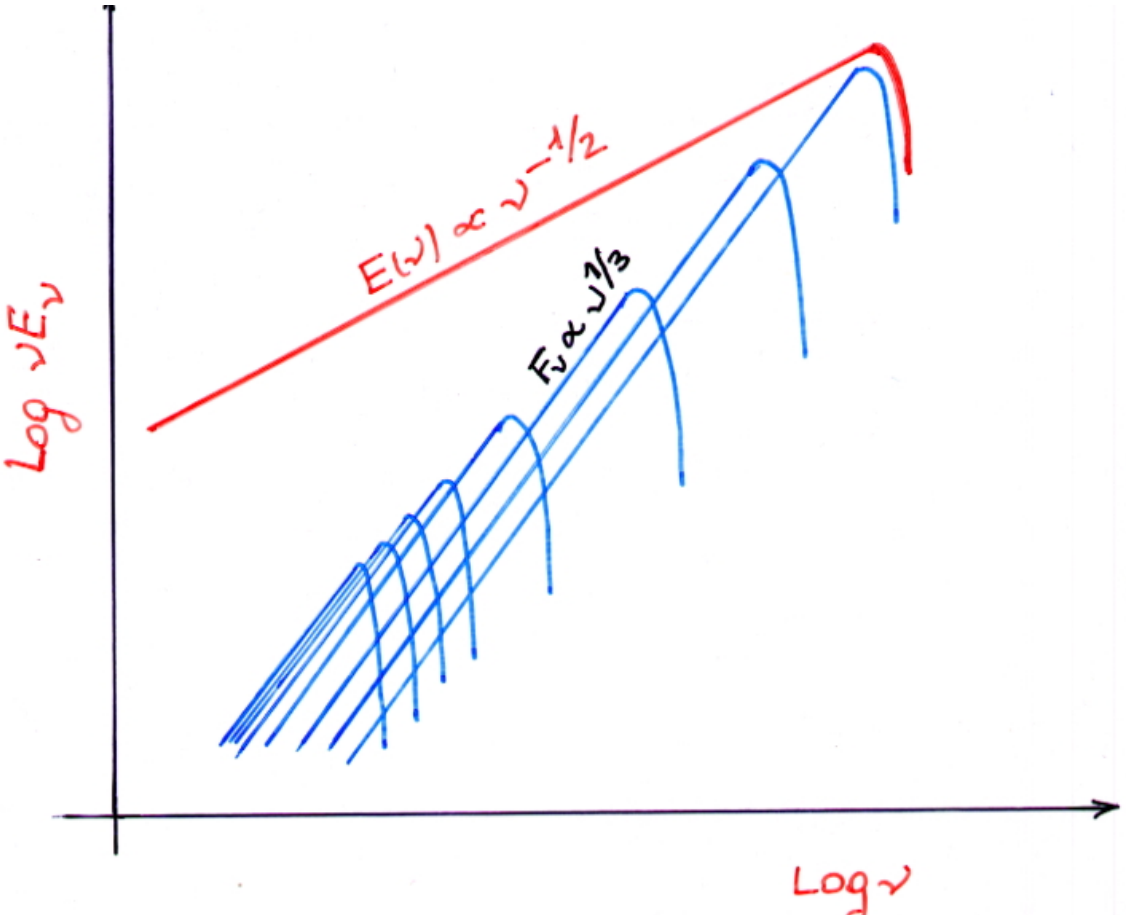
Synchrotron γ-ray emission?

Radiative cooling is (and must be) very rapid

$$t_{cool} \sim 10^{-7} \frac{\varepsilon_e^3 (\Gamma/100)}{\nu_{MeV}^2} \text{ sec}$$

- Extremely short - No way to make it longer
- $t_{cool} << t_{dynamical} \sim 10^{-2}$ sec
- It **must** be short: if not, how can the flux vary?

Energy spectrum of a cooling electron



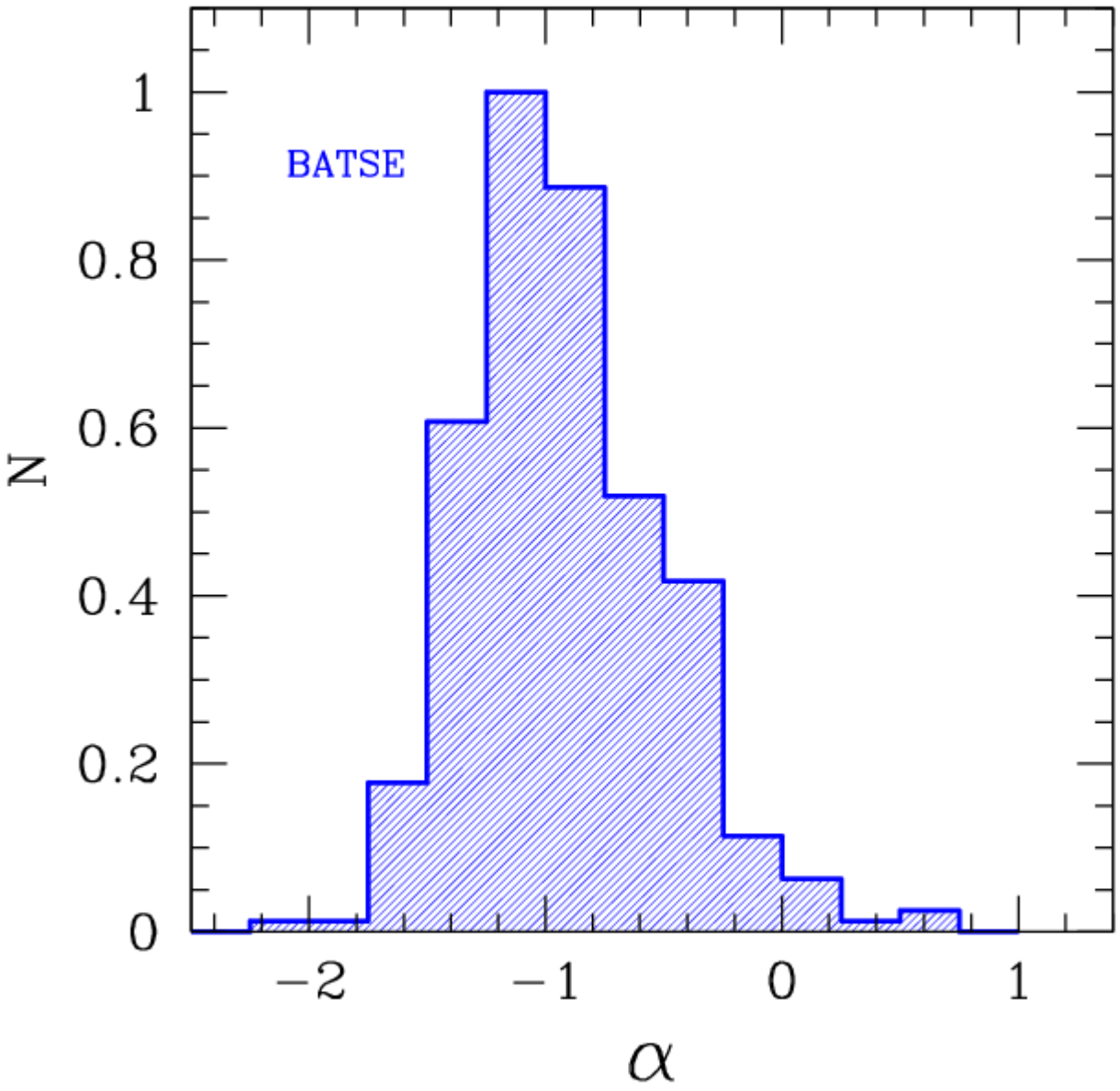
Fast cooling + synchro:

$E(\nu) \propto \nu^{-1/2}$

$N(\nu) \propto \nu^{-3/2}$

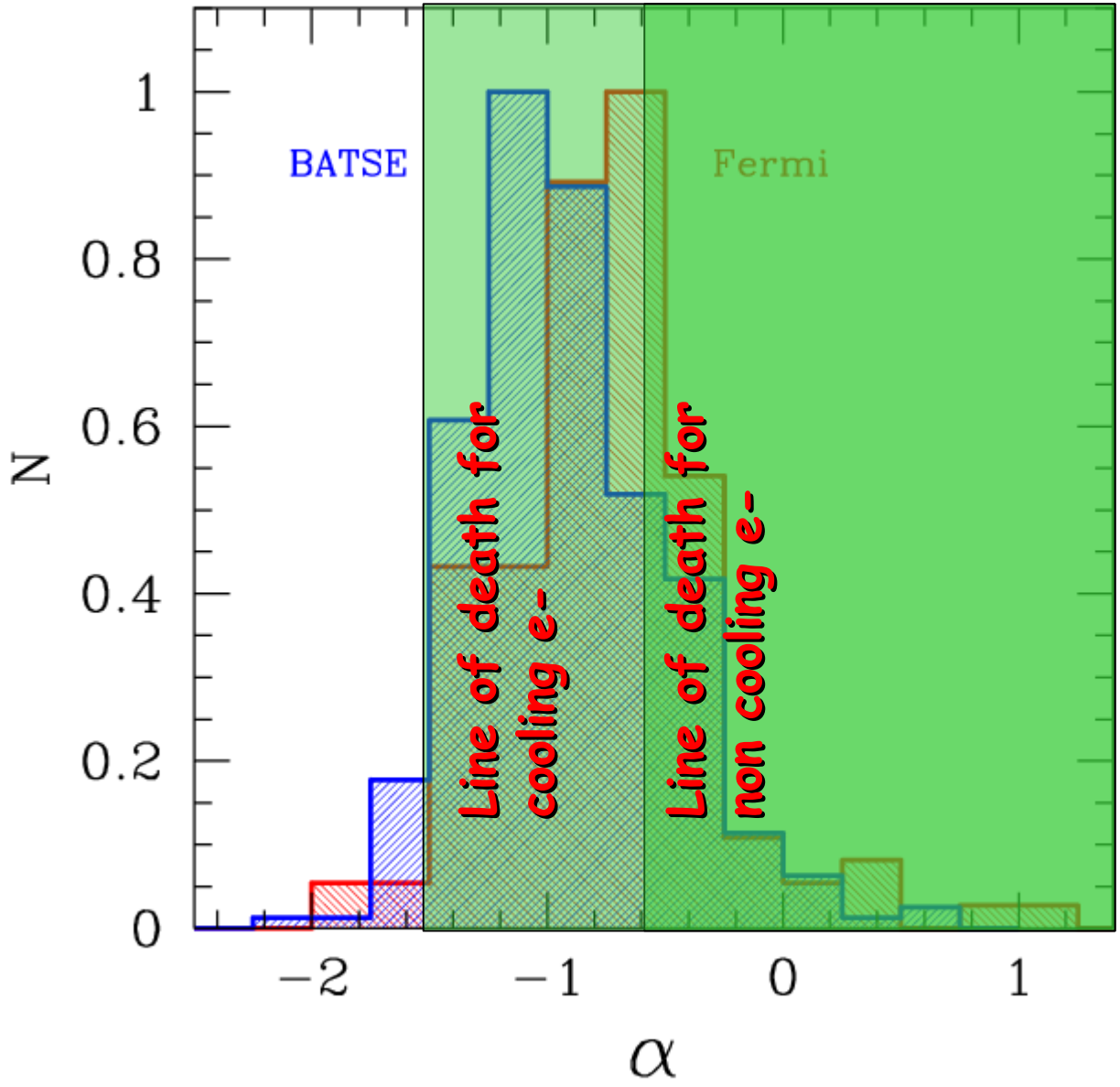
Photon index α

Kaneko+ 2006



Kaneko+ 2006

Nava PhD thesis 2009

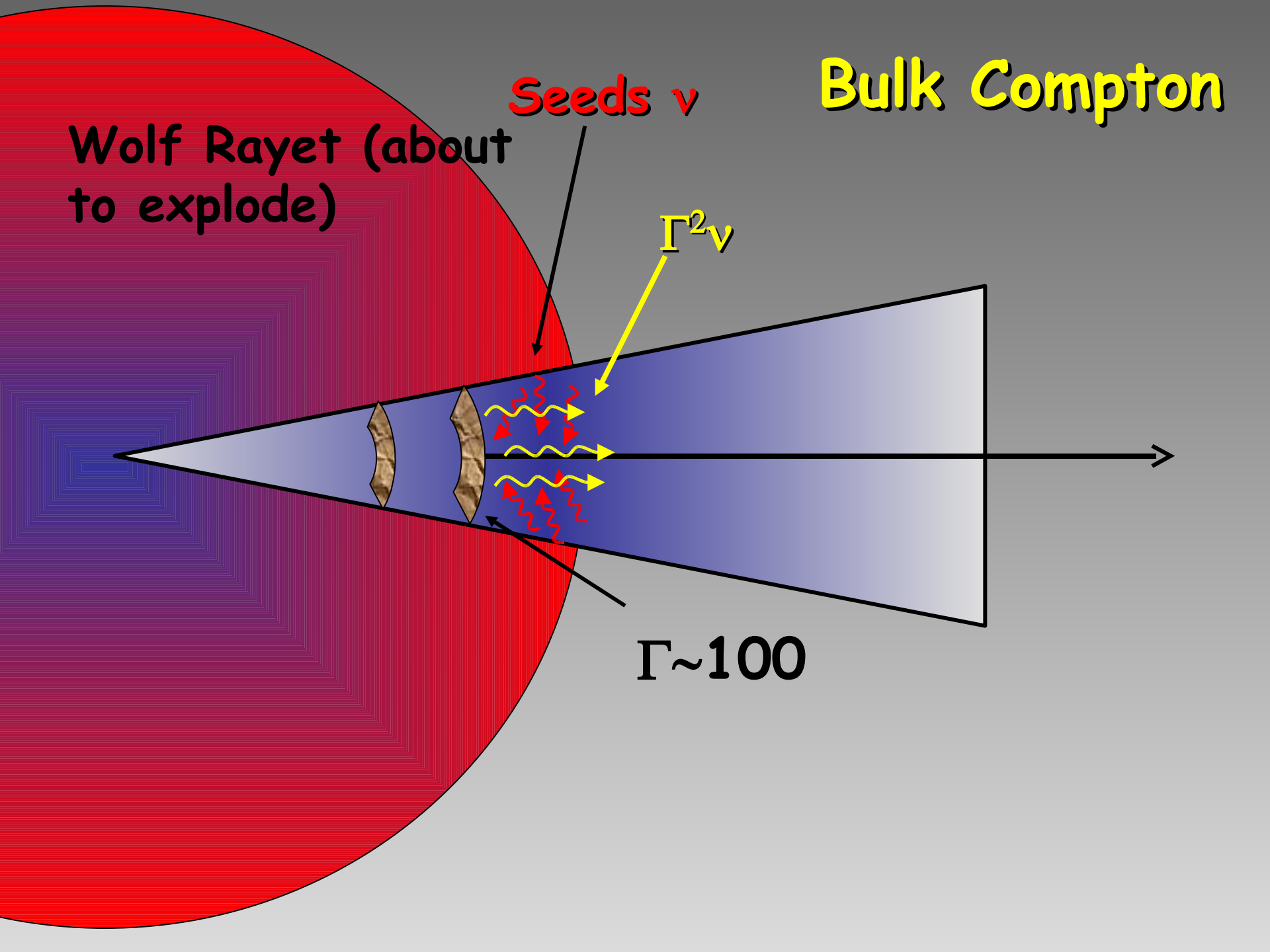


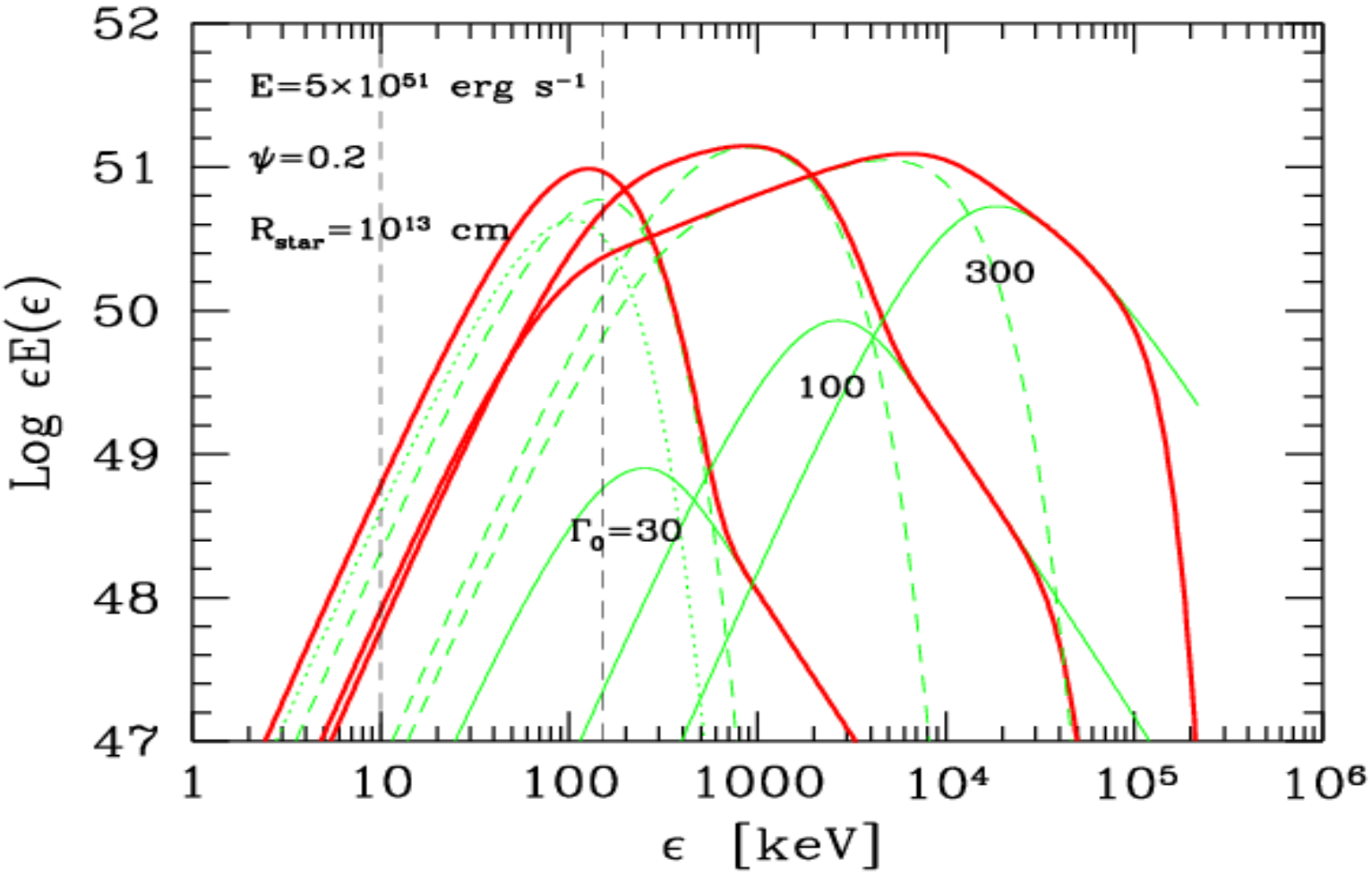
Can it be rescued by:

- Reacceleration? No, in IS e- are accelerated only once. More generally, only few selected e- (and always the same) must be (re)accelerated
- Adiabatic losses? No, too small regions would be involved, large e- densities, too much IC
- Fast decaying B-field? No, synchro not efficient and too much IC
- Self absorption? No, lots of e- needed, too much IC
- Self Compton? No, t_{cool} too small even in this case
- Small pitch angles? No, Very very small to avoid cooling, becomes inefficient
- External shocks to avoid cooling? No, same reason

Seeking alternatives…

- **Bulk Compton** (Lazzati+ 2000; GG+ 2000)
- **Quasi-thermal Comptonization** (GG & Celotti 1999)
- **Black-body from "deep impacts"** (Thompson+2007; GG+ 2007; Lazzati+ 2009)
- **Reconnection and continuous heating** (Giannios 2008)


Bulk Compton
Seeds ν
Wolf Rayet (about to explode)
Γ²ν
Γ~100


E=5×10^51 erg s^-1
ψ=0.2
R_star=10^13 cm
300
100
Γ_0=30
Log εE(ε)
ε [keV]
52
51
50
49
48
47
1
10
100
1000
10^4
10^5
10^6

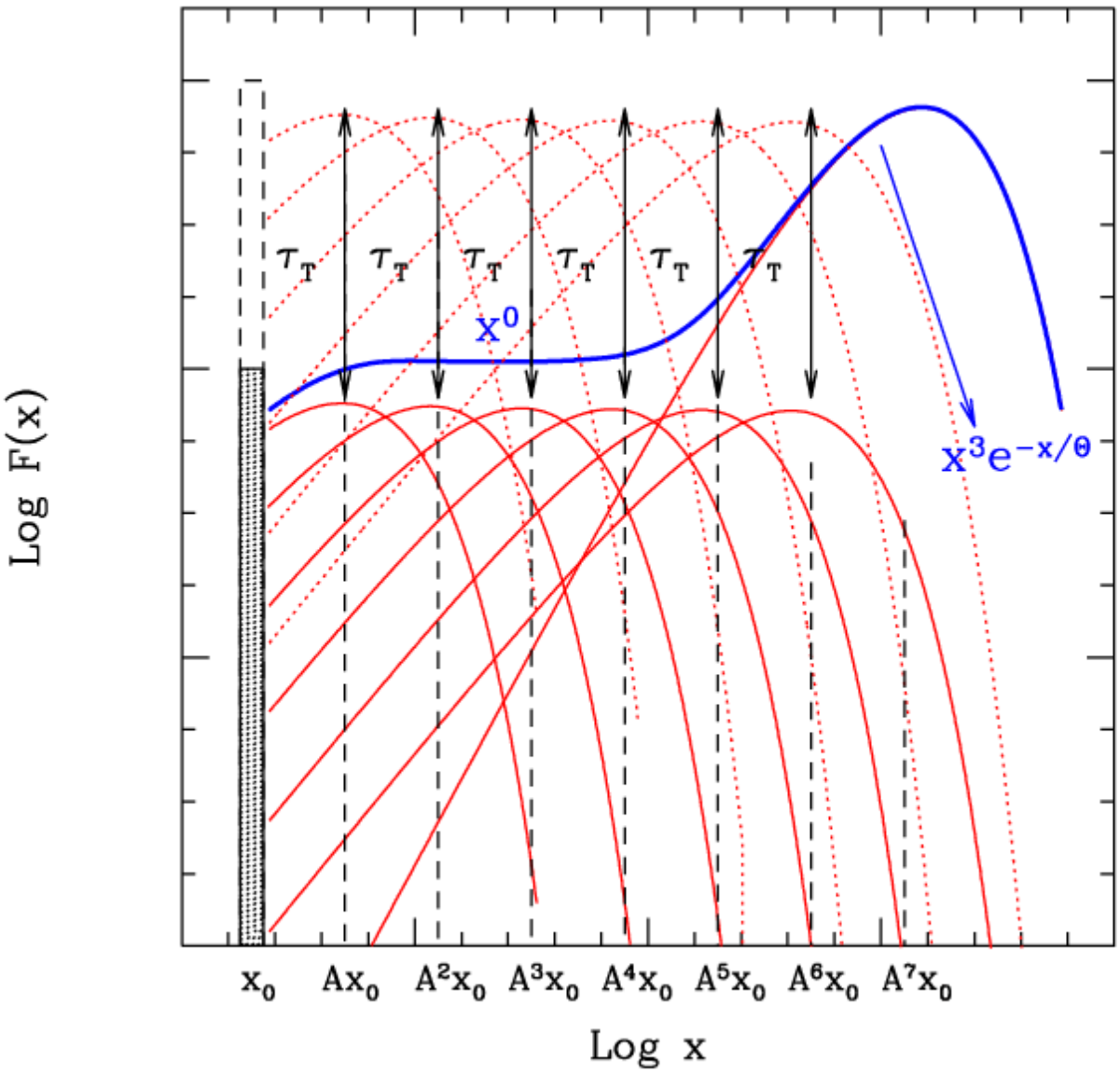
Problems

- Time to refill the funnel of seeds
- Needs a lot of seeds, not clear if the funnel is sufficient
- Does not work for short (they do not have a SN)

Quasi thermal Componization

- Heating for r/c, not instantaneous acceleration
- Cooling=Heating ⟹ sub-relat. "T"
- Synchro is self absorbed and produces seeds for quasi saturated Comptonization
- y needs to be >10

Quasi-saturated spectrum: ν^0+Wien



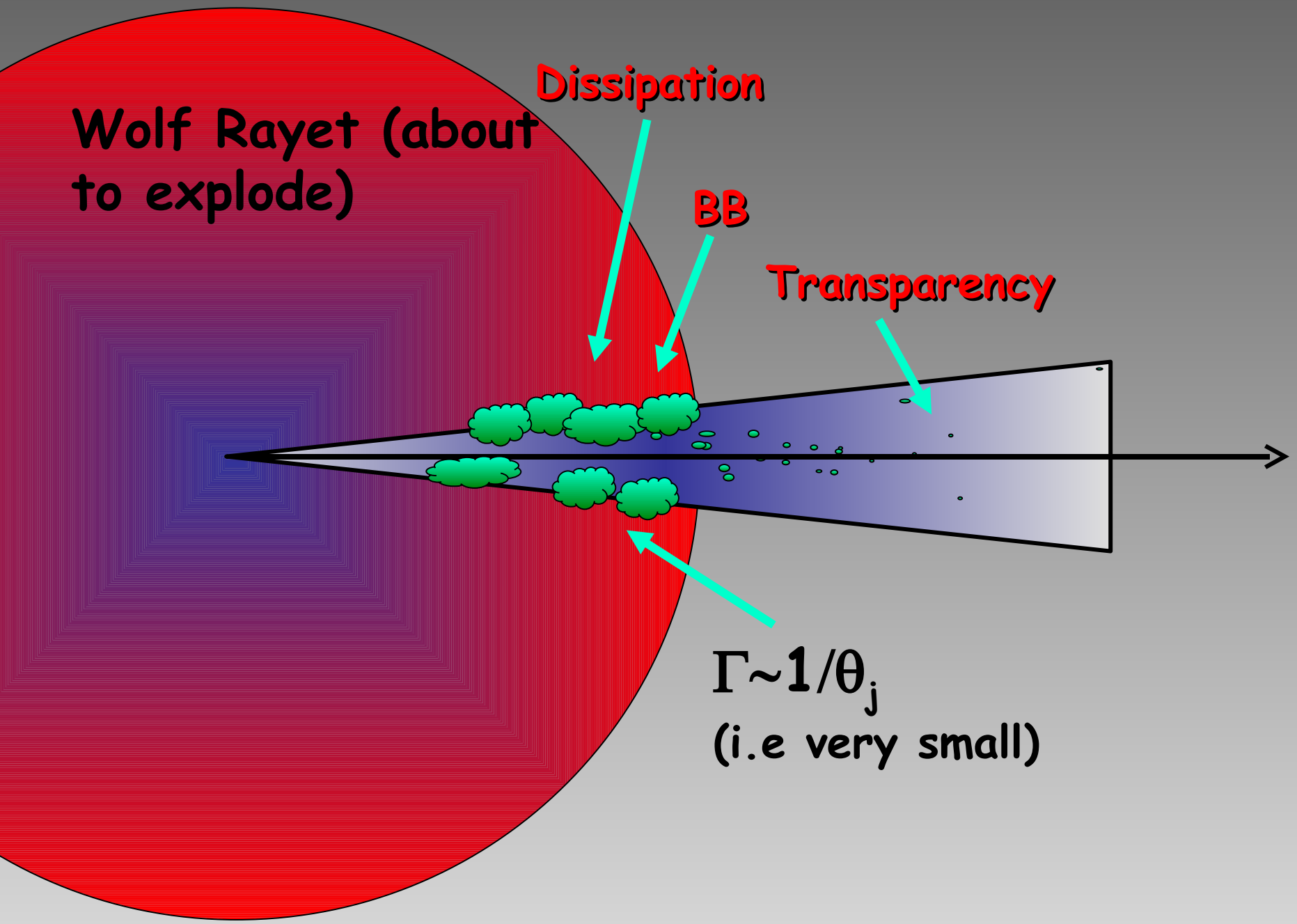
Problems

- $E_{peak} \sim \Gamma\, kT$ too high
- Needs time (τ must be large)
- Wien peak not observed
- Seeds should be distributed in the center, e- more externally, to explain $\alpha > -1$

"Deep impacts"

Thompson, Meszaros & Rees 2007
Lazzati, Morsony Begelman 2008
GG+ 2007

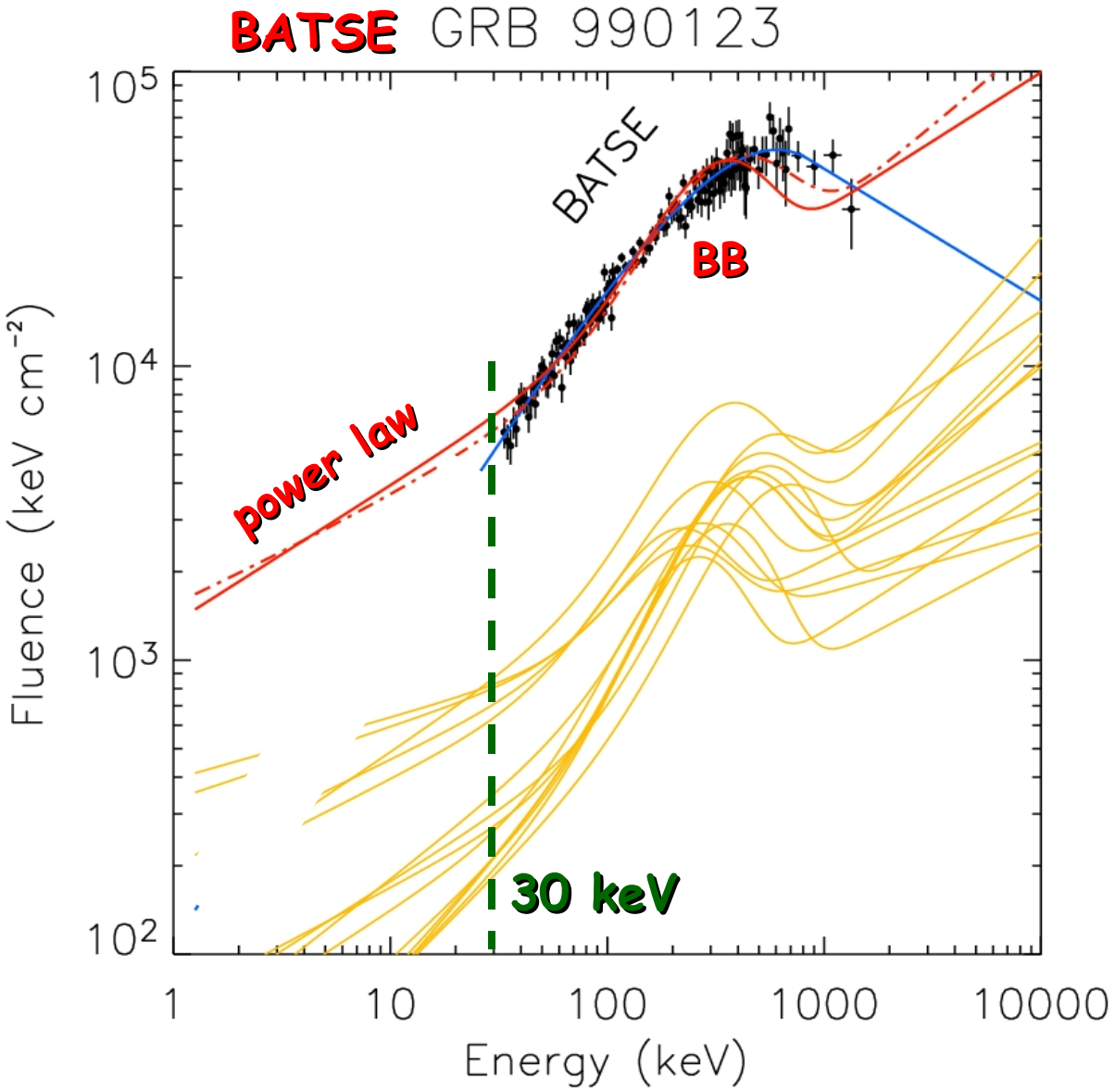
At R ~ R_{star} the fireball dissipates part of its energy → BB


Wolf Rayet (about to explode)
Dissipation
BB
Transparency
$\Gamma \sim 1/\theta_j$
(i.e very small)

Problems

- Γ fine tuned (and small) in Thompson+ 2008
- BB??

There can be a Black Body … but

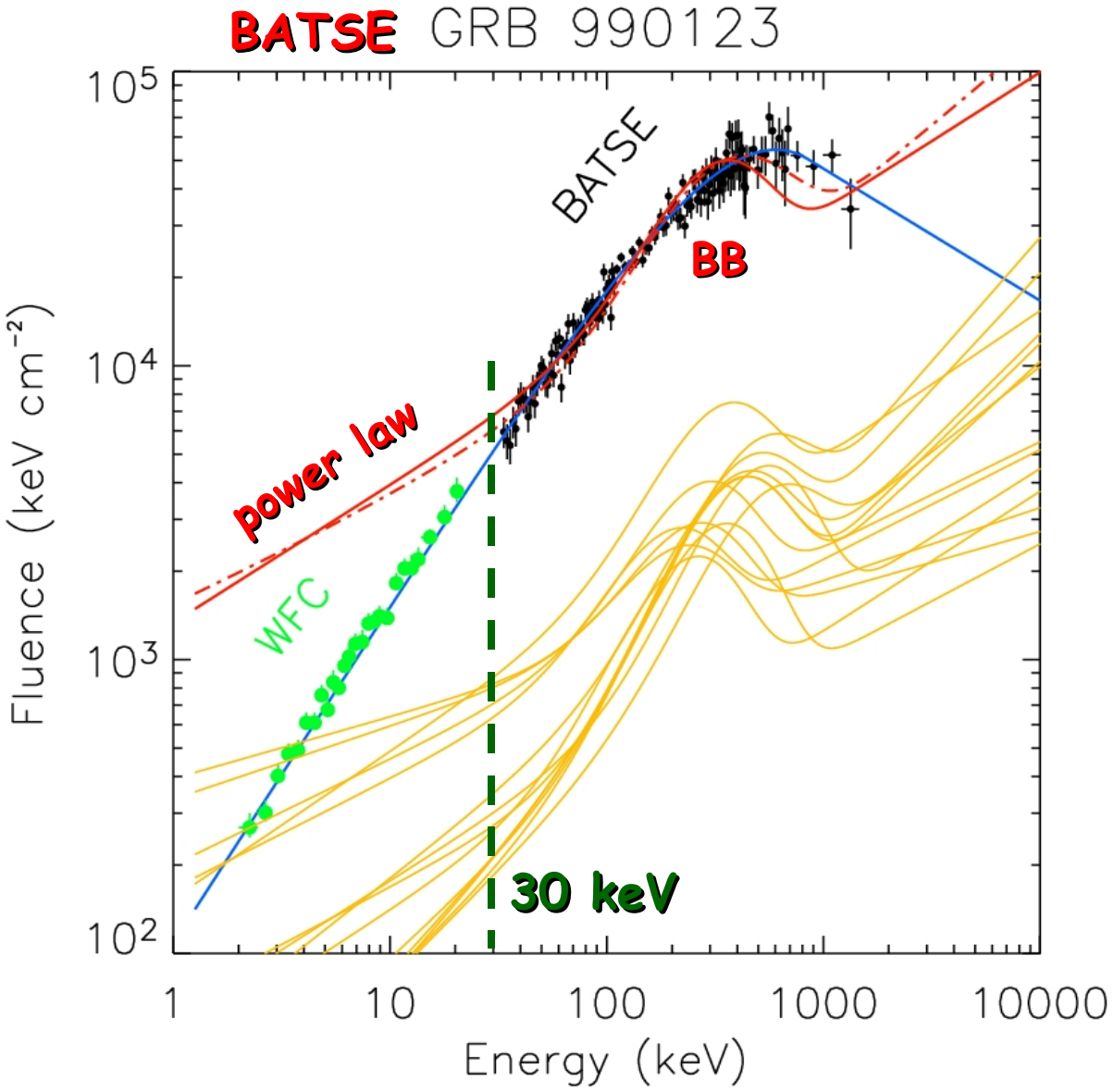


Time integrated spectrum

Time resolved spectra

Ghirlanda+ 2007

There can be a Black Body … but

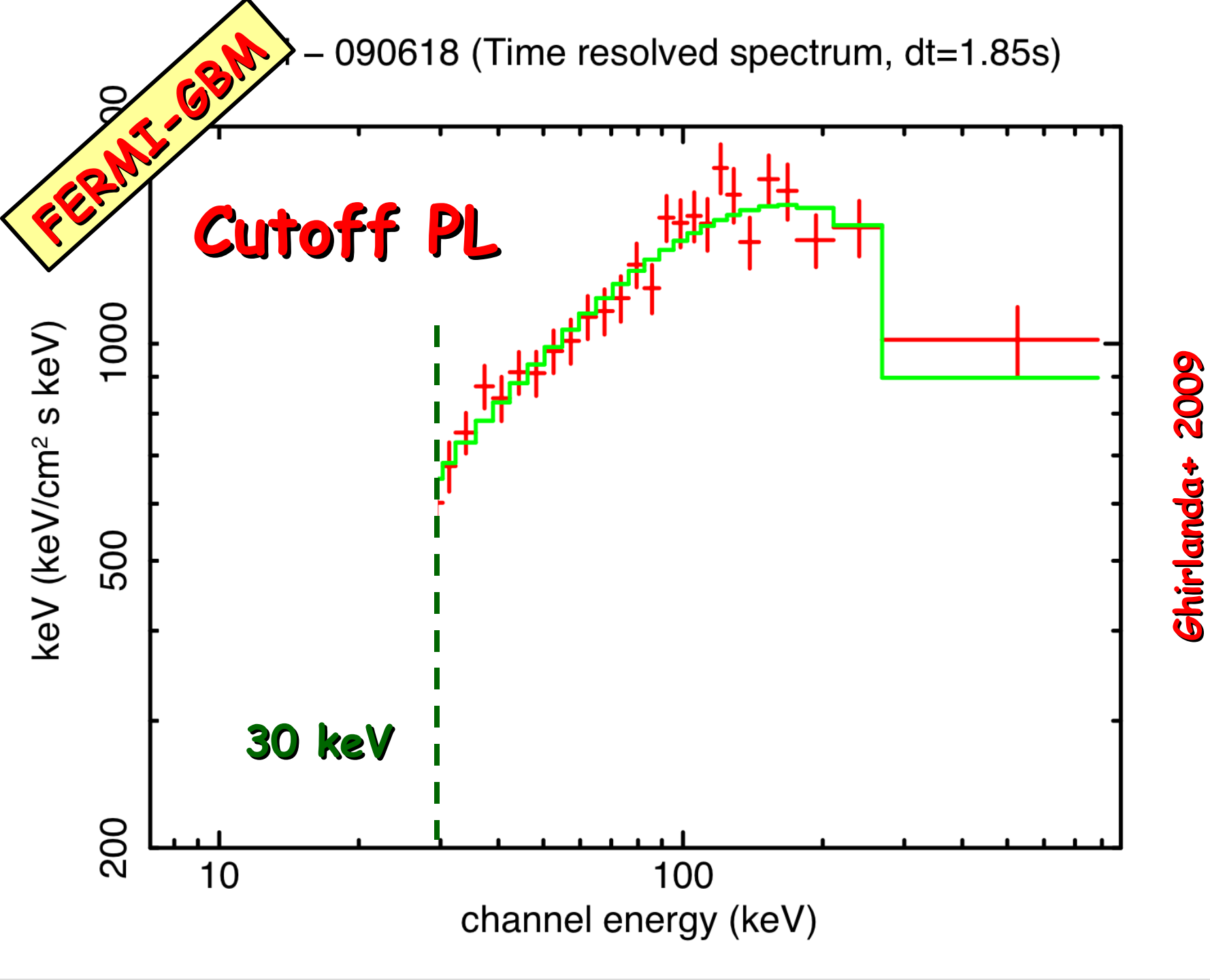


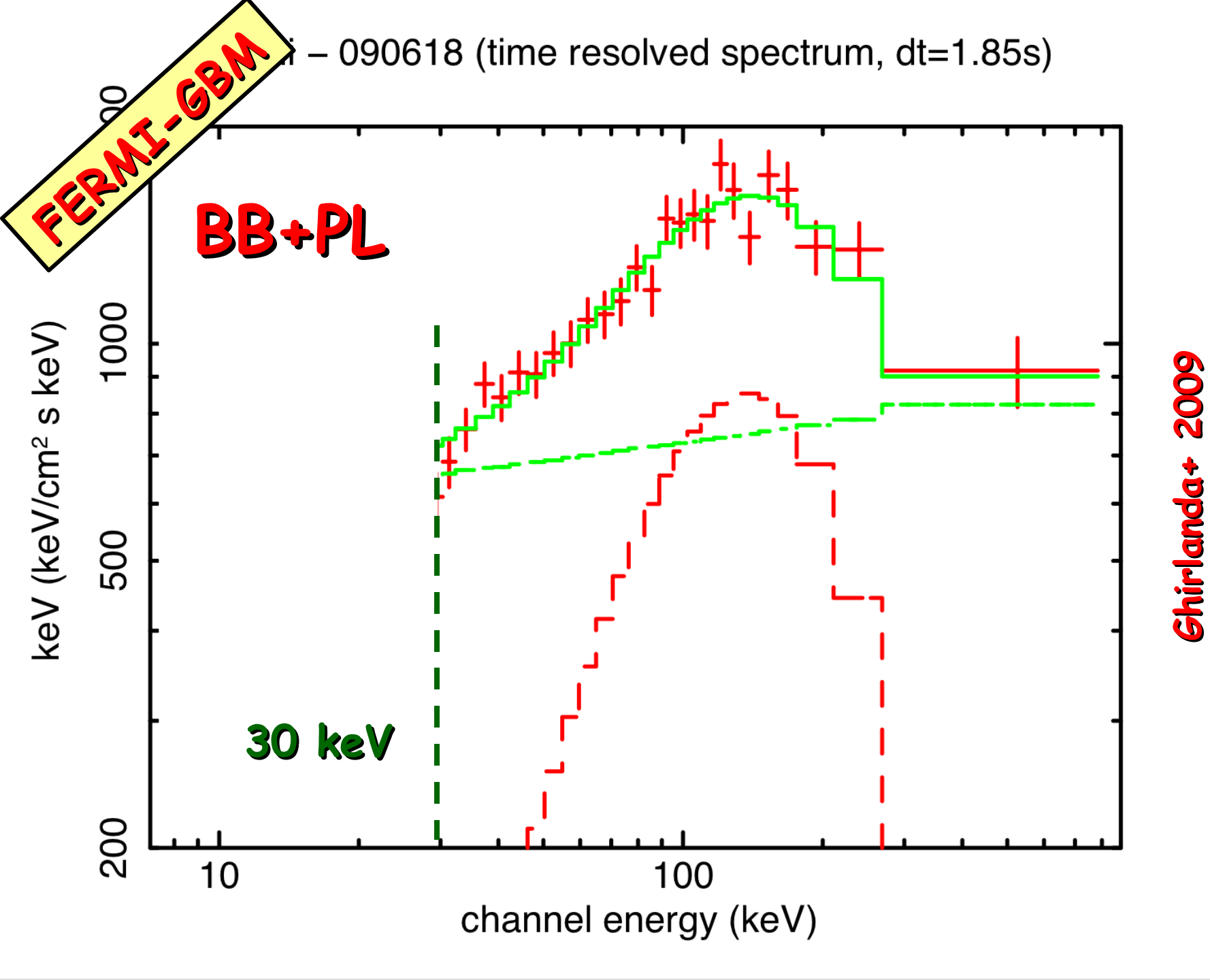
Time integrated spectrum

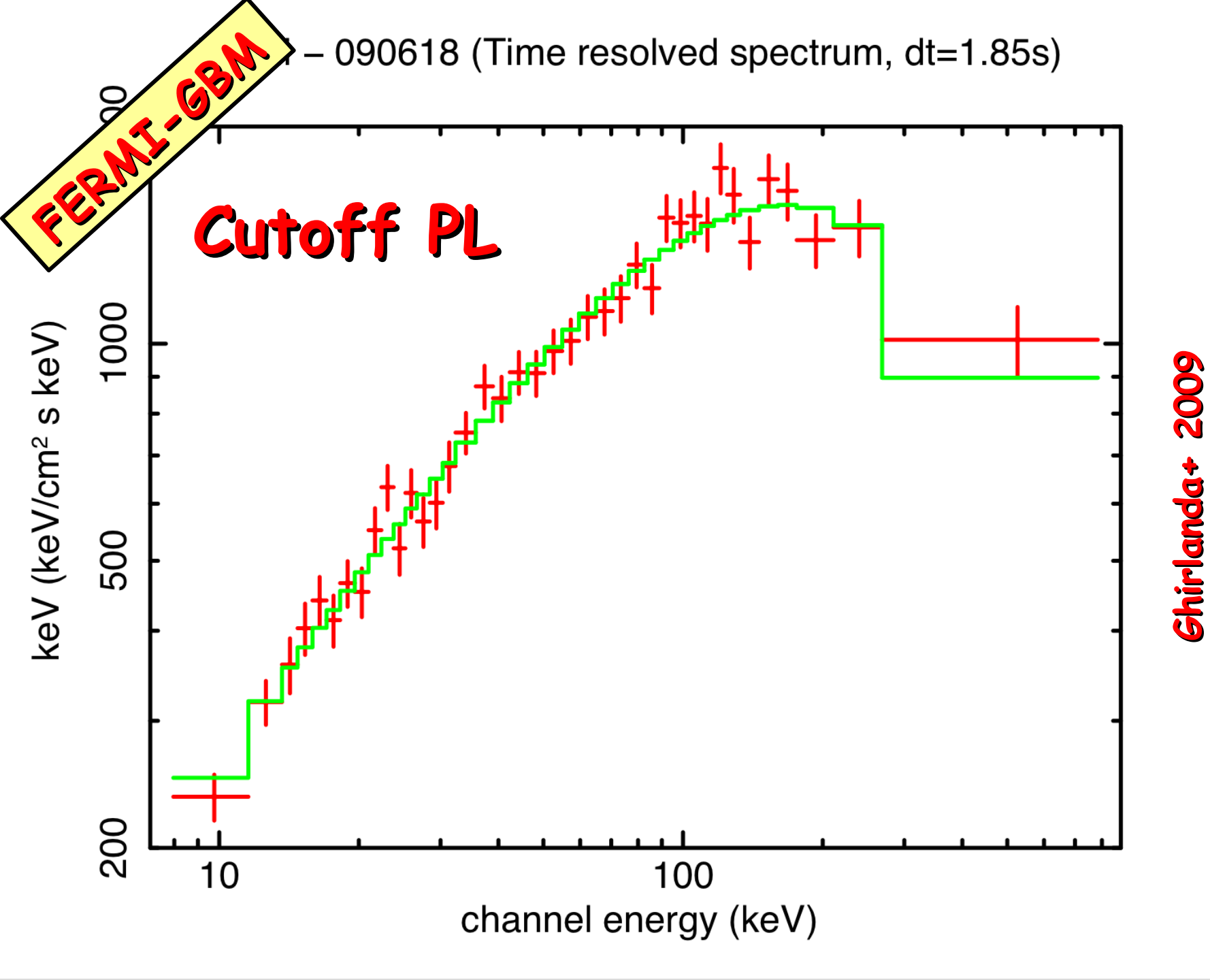
Time resolved spectra

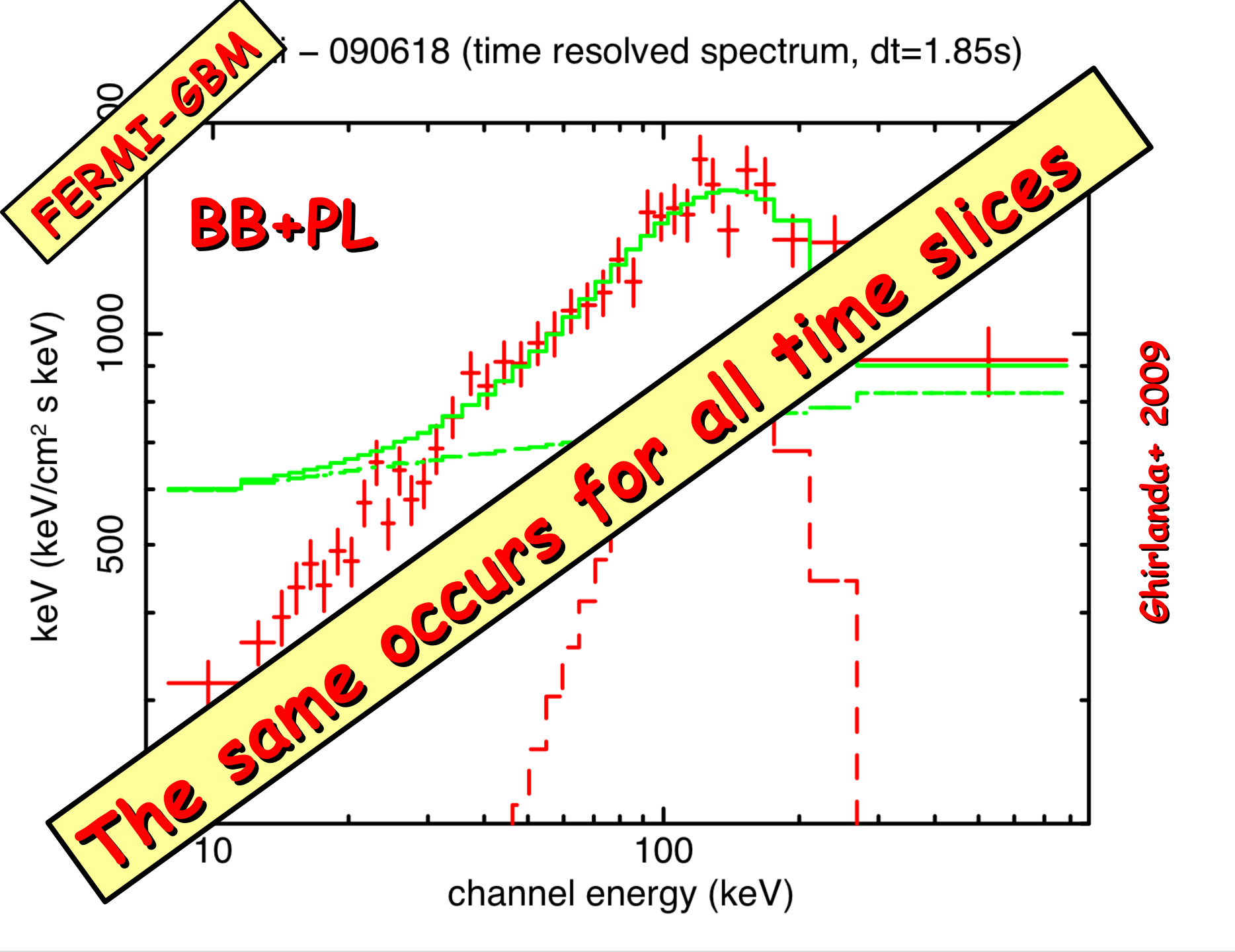
The same occurs for ALL GRBs detected by BATSE and with WFC

Ghirlanda+ 2007

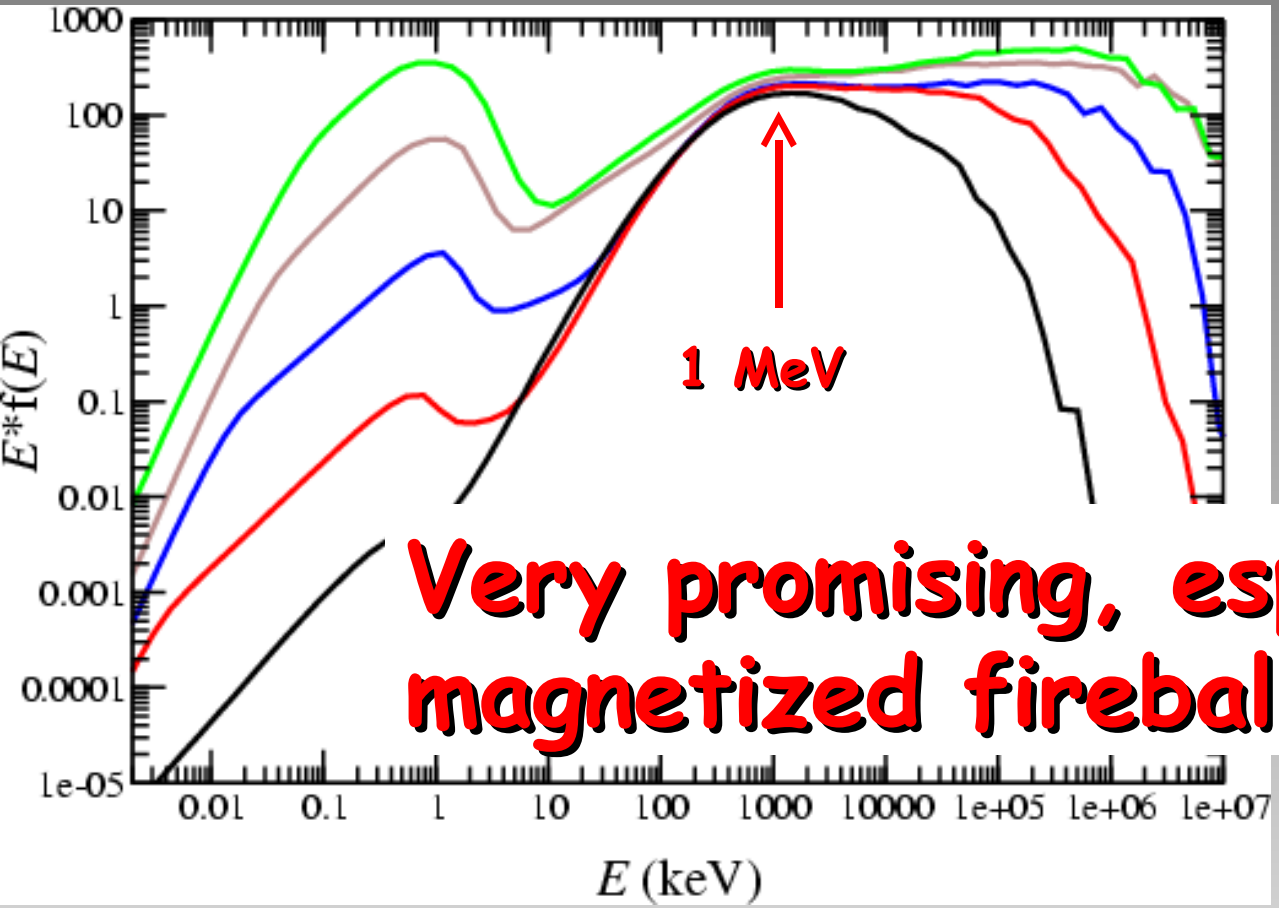

FERMI-GBM
– 090618 (Time resolved spectrum, dt=1.85s)
Cutoff PL
30 keV
keV (keV/cm² s keV)
channel energy (keV)
200
500
1000
10
100
Ghirlanda+ 2009


FERMI-GBM
– 090618 (time resolved spectrum, dt=1.85s)
BB+PL
30 keV
keV (keV/cm² s keV)
1000
500
200
10
100
channel energy (keV)
Ghirlanda+ 2009


FERMI-GBM
– 090618 (Time resolved spectrum, dt=1.85s)
Cutoff PL
keV (keV/cm² s keV)
1000
500
200
10
100
channel energy (keV)
Ghirlanda+ 2009

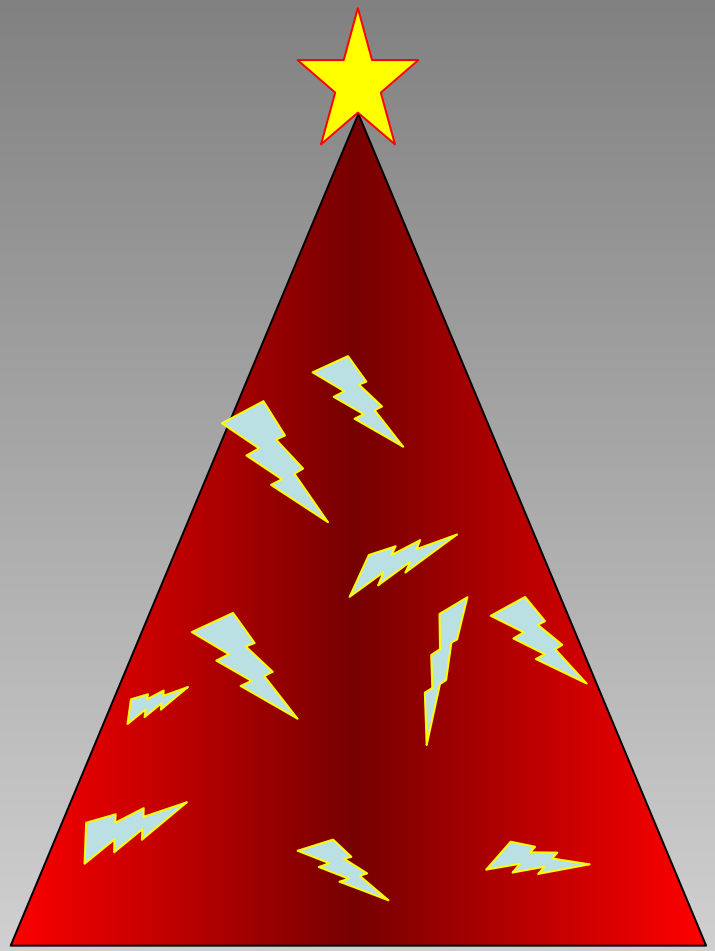

FERMI-GBM
– 090618 (time resolved spectrum, dt=1.85s)
BB+PL
The same occurs for all time slices
keV (keV/cm² s keV)
1000
500
10
100
channel energy (keV)
Ghirlanda+ 2009

Reconnection and continuous heating (Giannios 2008)



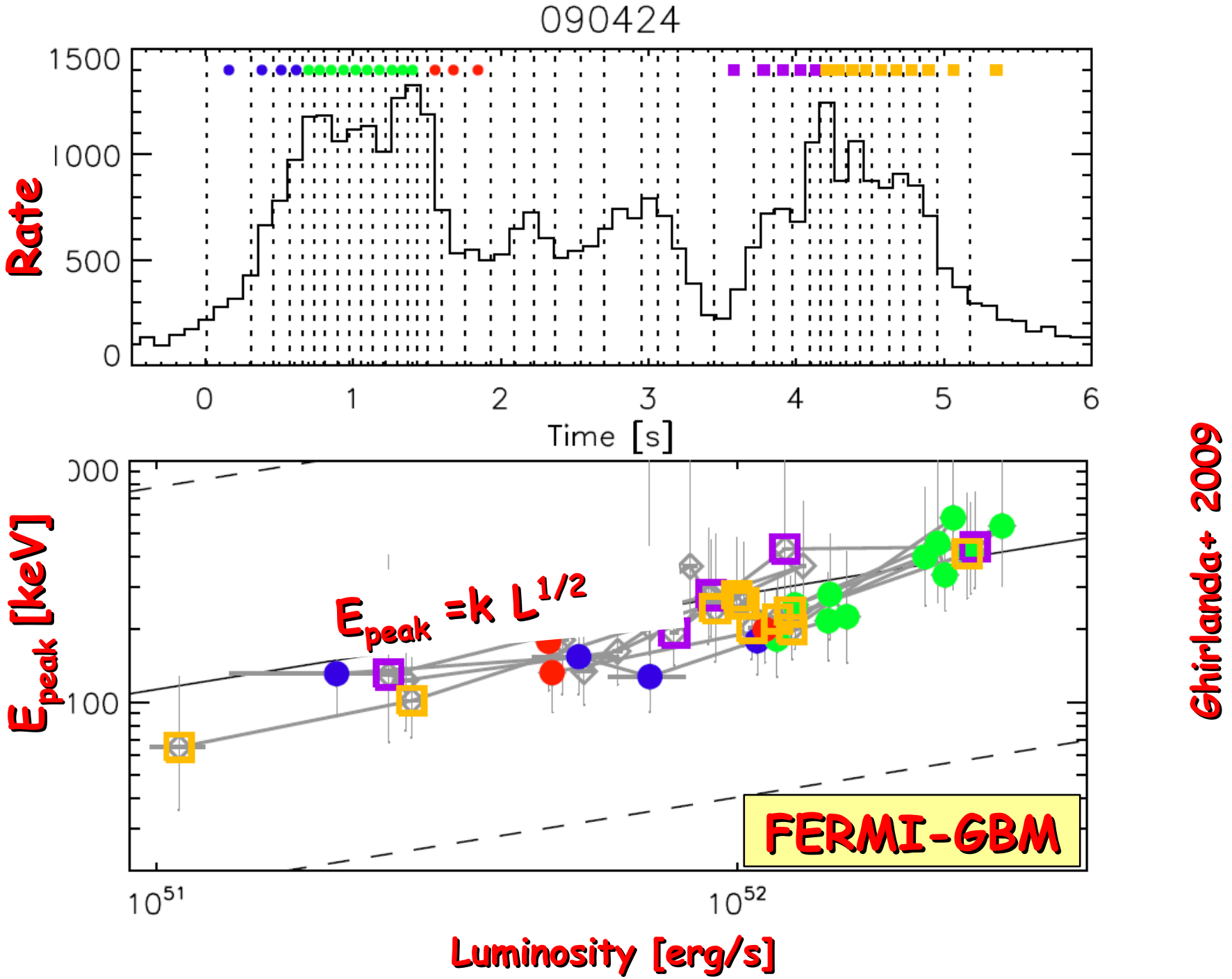
Very promising, especially for magnetized fireballs, but….

Reconnecting regions should behave randomly



Reconnecting regions should behave randomly

Instead there are trends


090424
Rate
1500
1000
500
0
0
1
2
3
4
5
6
Time [s]
E_{peak} [keV]
$E_{peak} = k\ L^{1/2}$
100
10^{51}
10^{52}
Luminosity [erg/s]
FERMI-GBM
Ghirlanda+ 2009

How to explain it?

It is NOT DUE to selection effects!!!!!!

It indicates something fundamental and very robust… that we do not understand yet.

Geometrical? Difficult

Sequence of Γ? Difficult

Radiation process? Likely, but which one?

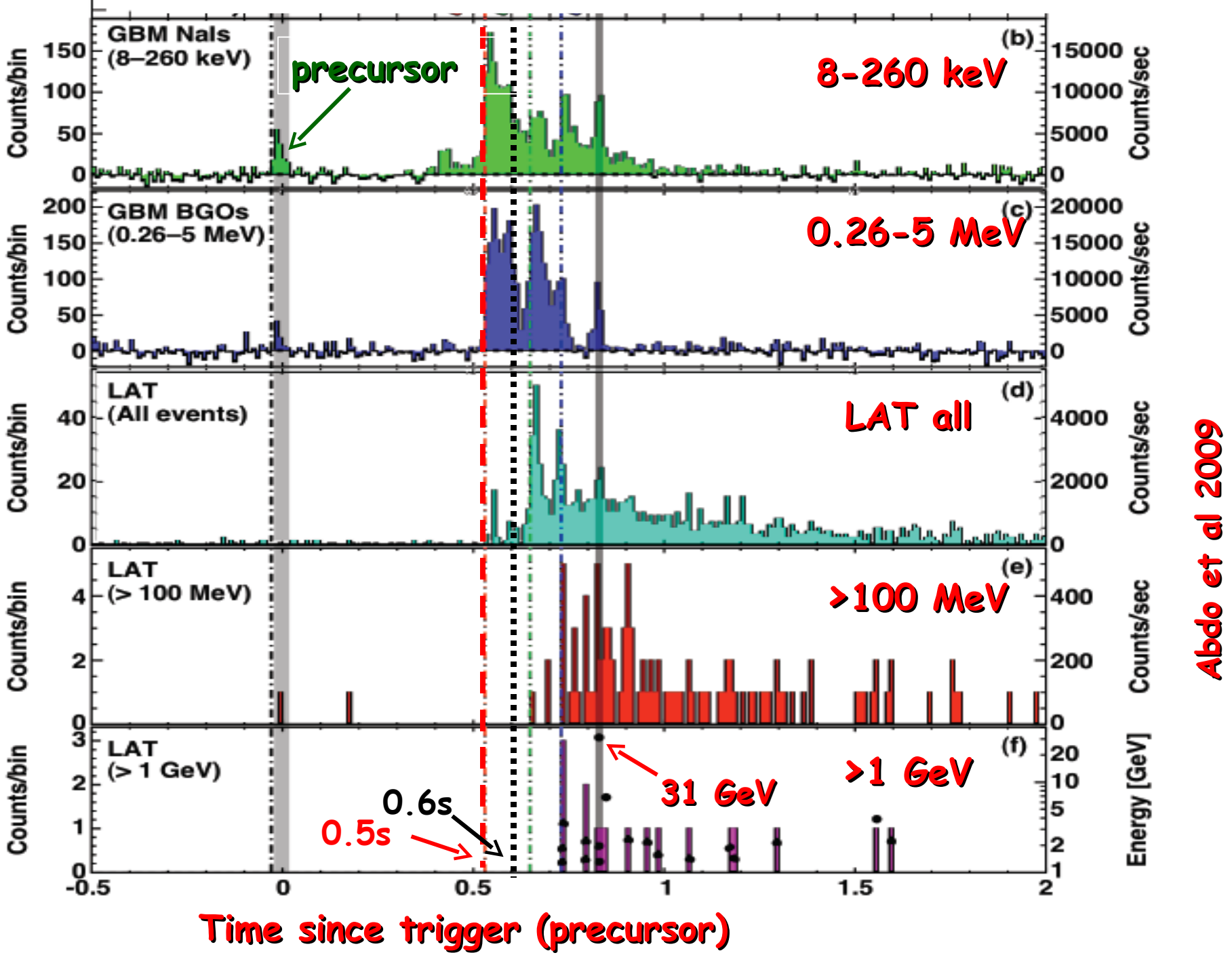
First conclusion

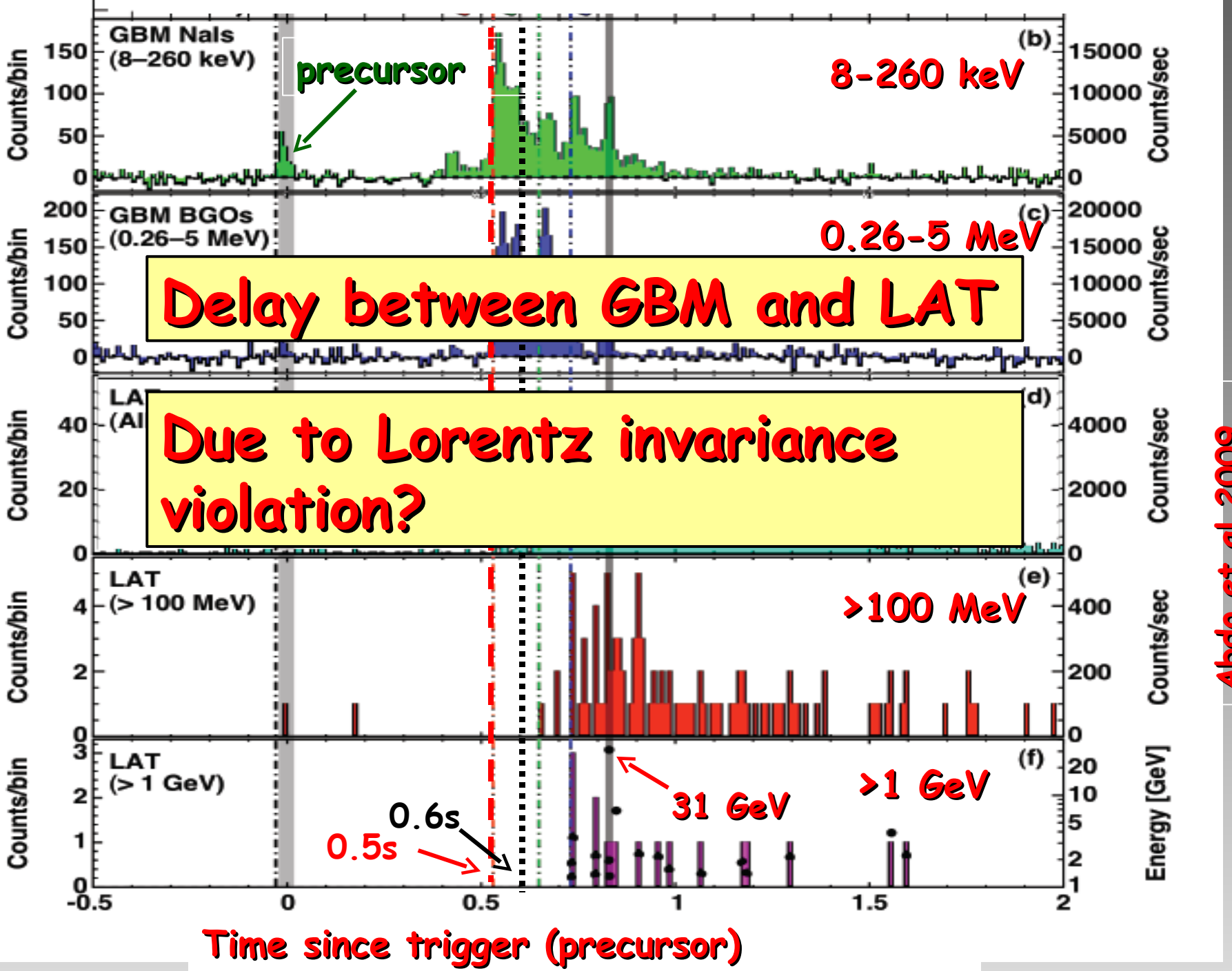
- We do not know yet what is the emission mechanism of the prompt

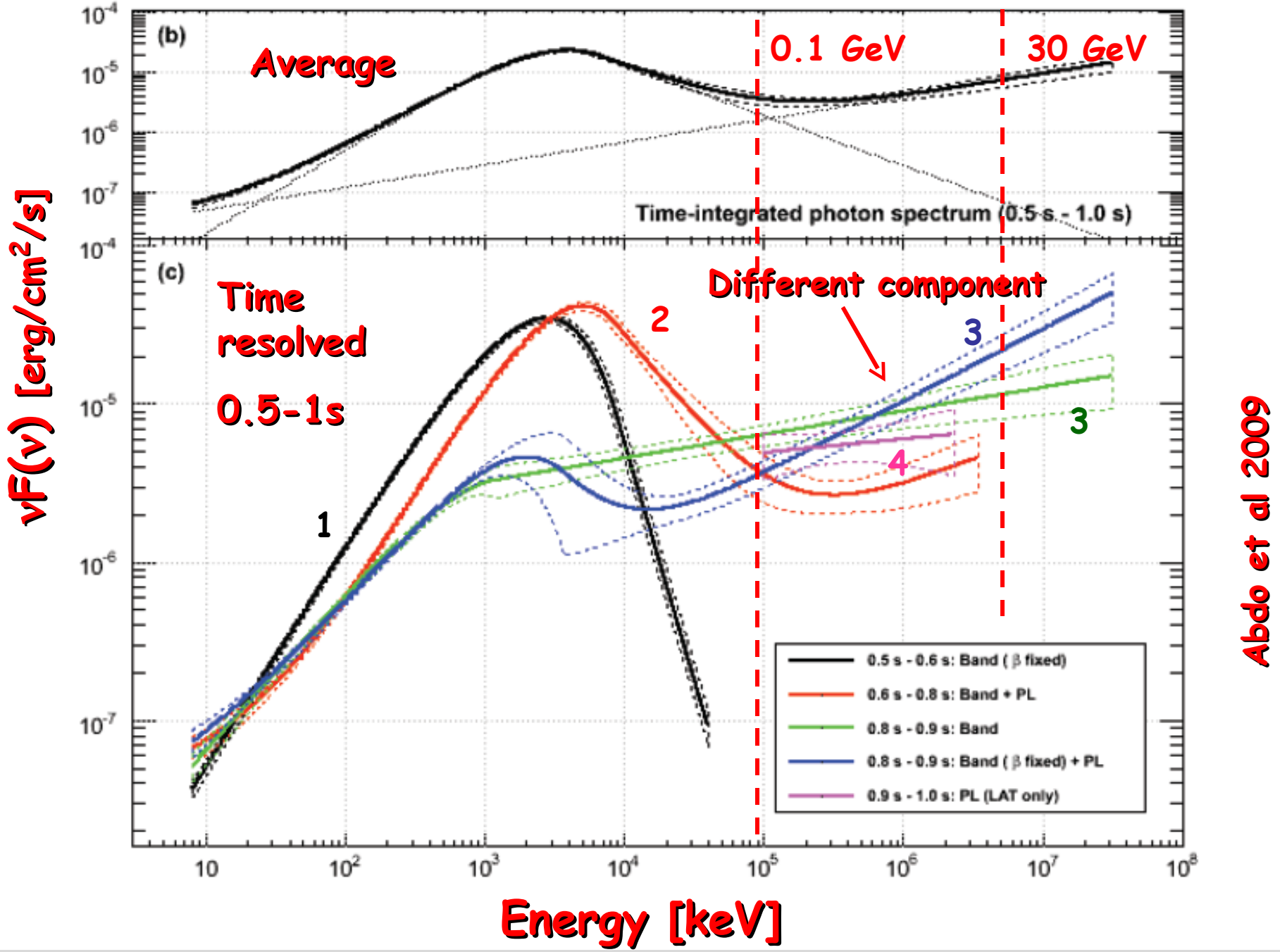
Fermi-LAT

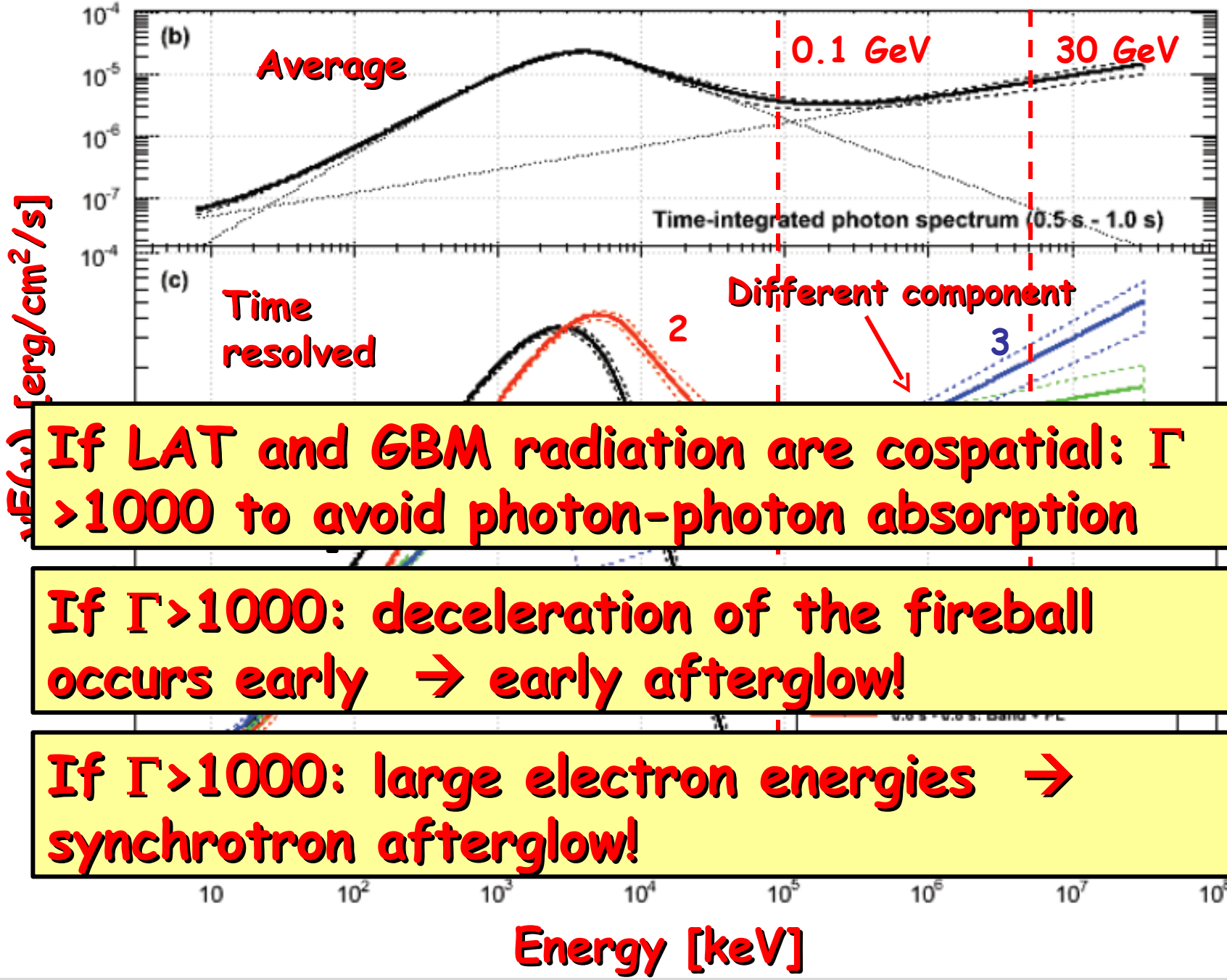
GRB 090510

- Short
- Very hard
- z=0.903
- Detected by the LAT up to 31 GeV!!
- Well defined timing
- Delay: ~GeV arrive after ~MeV (fraction of seconds)
- Quantum Gravity? Violation of Lorentz invariance?


GBM NaIs
(8–260 keV)
precursor
(b)
8-260 keV
GBM BGOs
(0.26–5 MeV)
(c)
0.26-5 MeV
LAT
(All events)
(d)
LAT all
LAT
(> 100 MeV)
(e)
>100 MeV
LAT
(> 1 GeV)
(f)
>1 GeV
31 GeV
0.6s
0.5s
Counts/bin
Counts/sec
Energy [GeV]
Time since trigger (precursor)
Abdo et al 2009


GBM NaIs
(8–260 keV)
precursor
8-260 keV
GBM BGOs
(0.26–5 MeV)
0.26-5 MeV
Delay between GBM and LAT
Due to Lorentz invariance violation?
LAT
(> 100 MeV)
>100 MeV
LAT
(> 1 GeV)
>1 GeV
31 GeV
0.6s
0.5s
Counts/bin
Counts/sec
Energy [GeV]
Time since trigger (precursor)
Abdo et al 2009


(b)
Average
0.1 GeV
30 GeV
Time-integrated photon spectrum (0.5 s - 1.0 s)
(c)
Time resolved
0.5-1s
Different component
1
2
3
3
4
0.5 s - 0.6 s: Band (β fixed)
0.6 s - 0.8 s: Band + PL
0.8 s - 0.9 s: Band
0.8 s - 0.9 s: Band (β fixed) + PL
0.9 s - 1.0 s: PL (LAT only)
νF(ν) [erg/cm²/s]
Energy [keV]
Abdo et al 2009

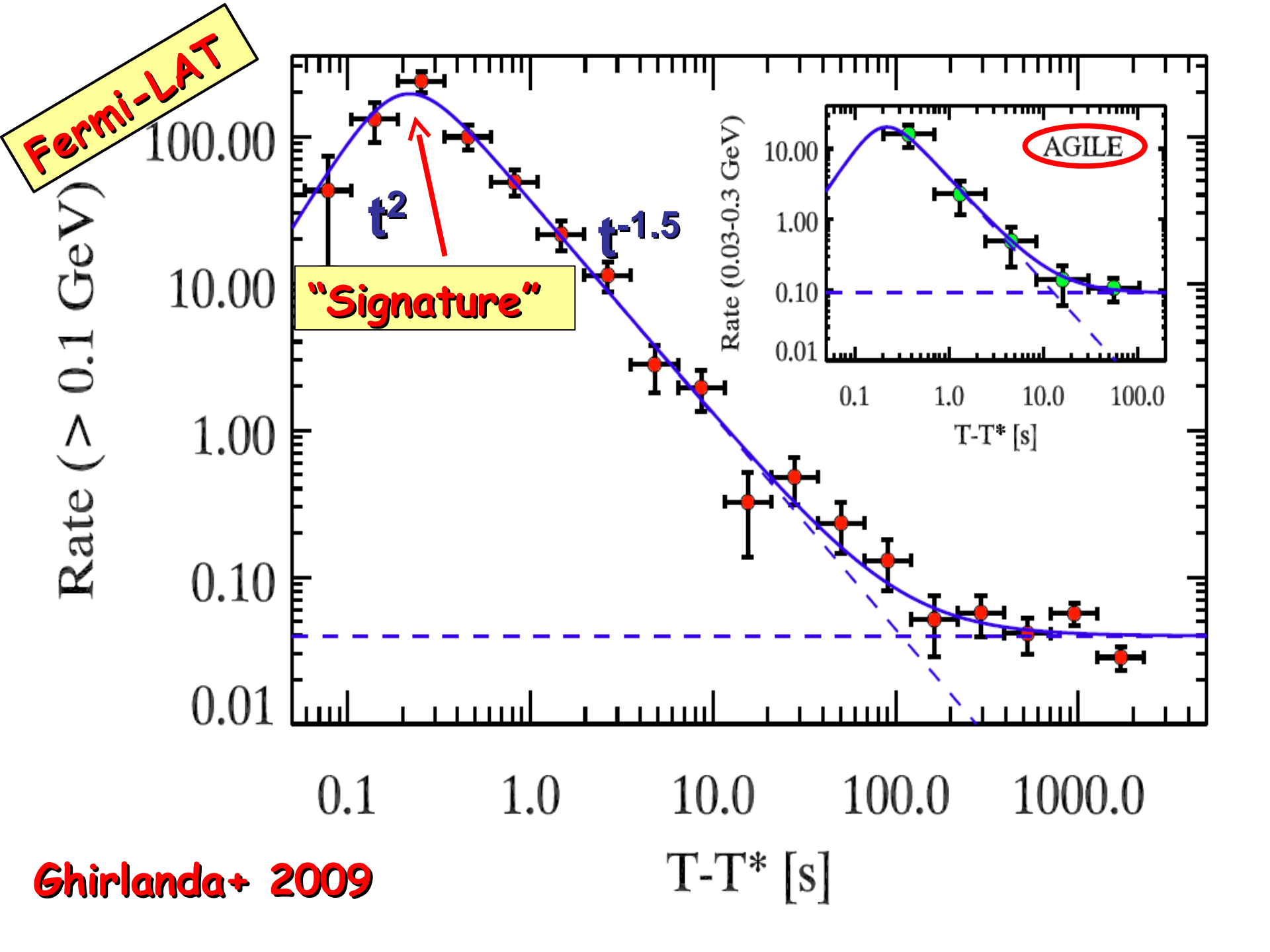


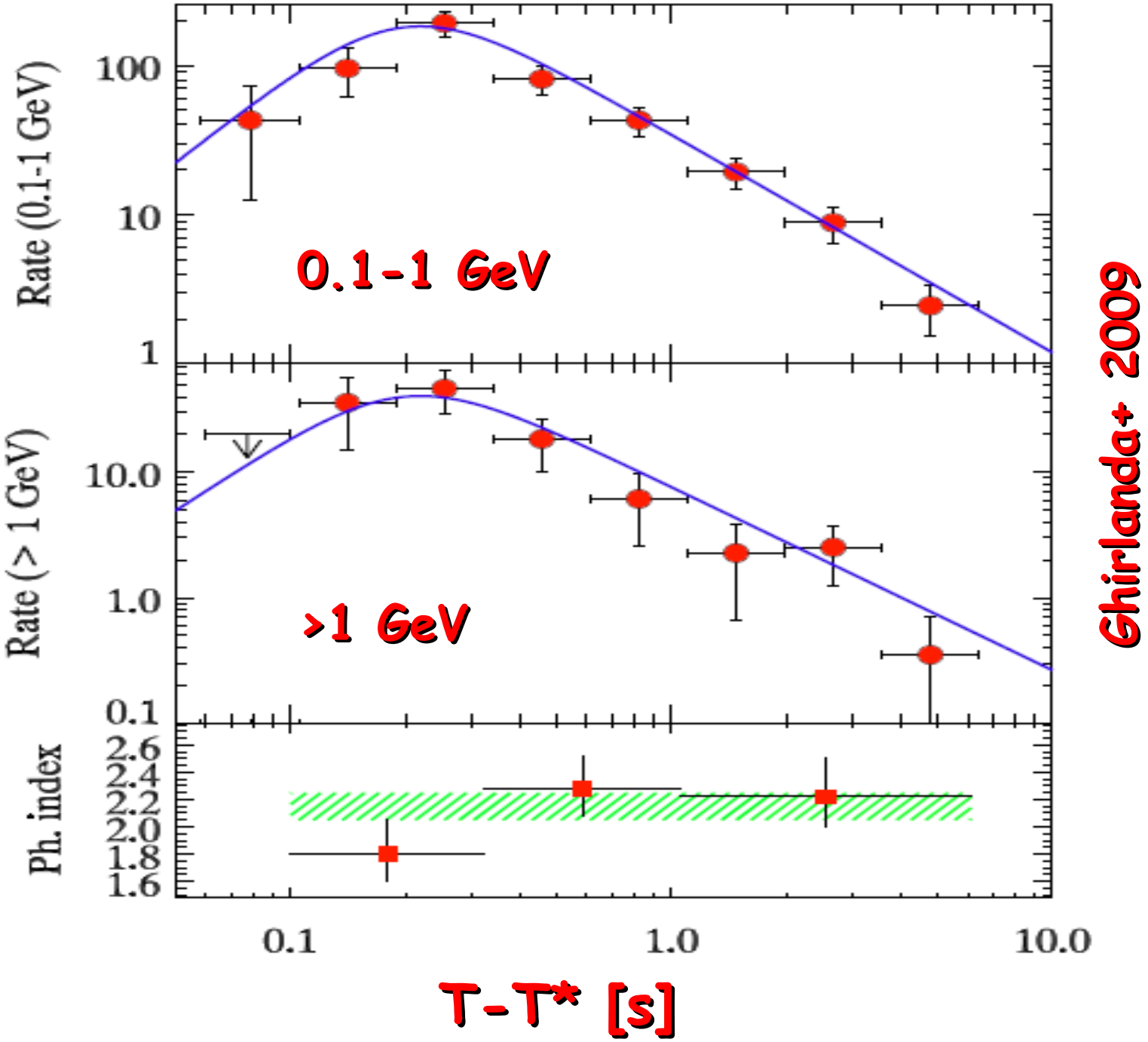
If LAT and GBM radiation are cospatial: Γ >1000 to avoid photon-photon absorption

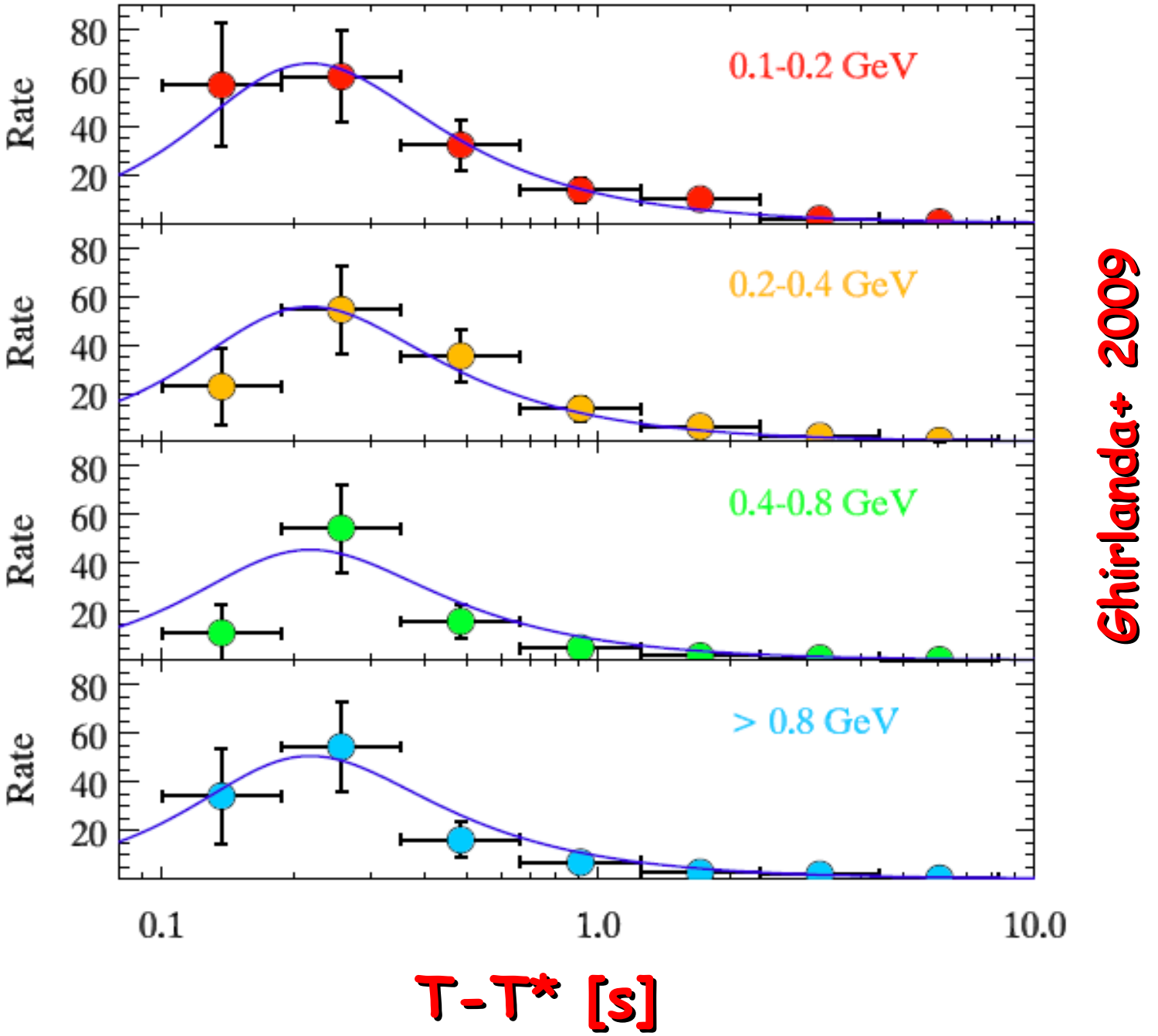
If Γ>1000: deceleration of the fireball occurs early → early afterglow!

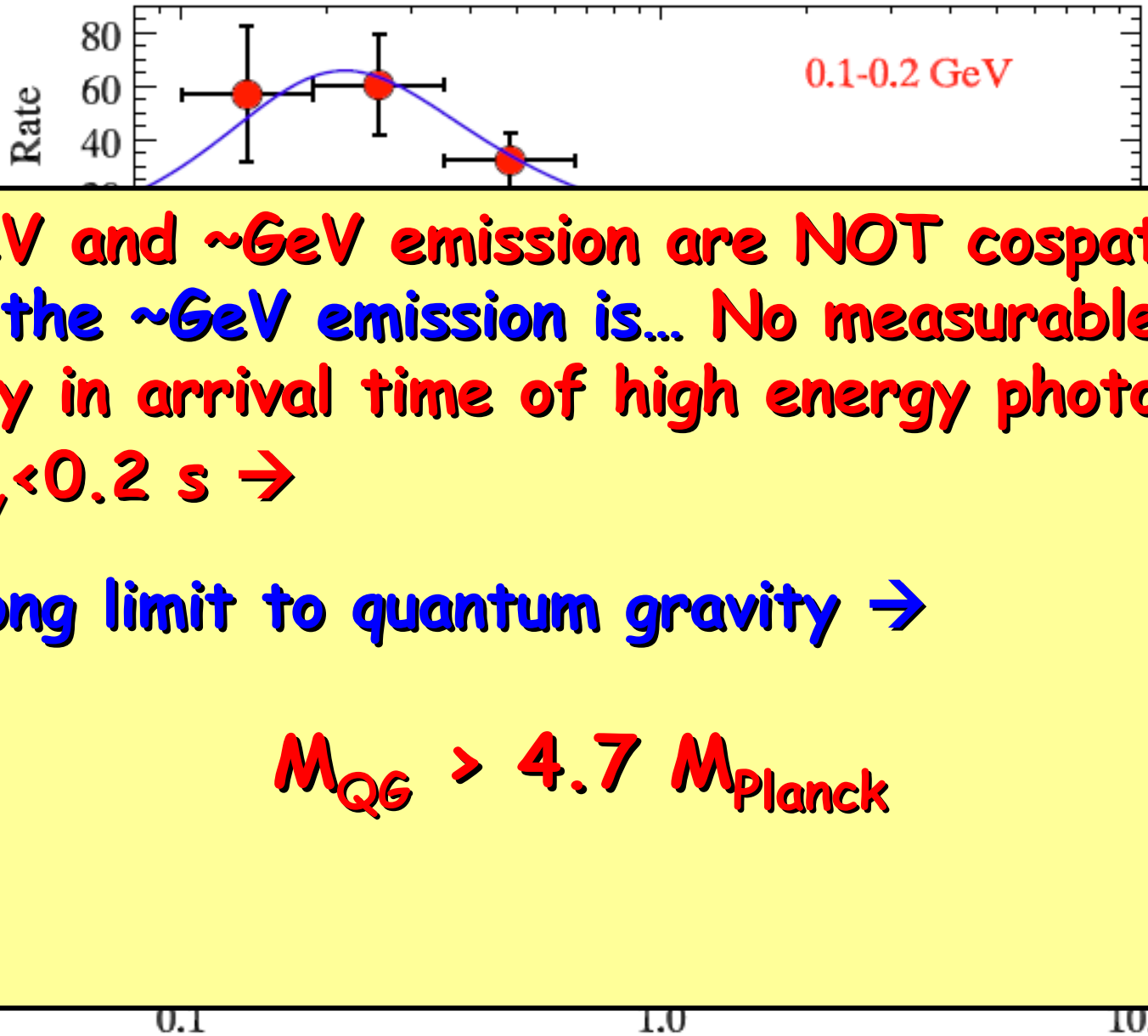
If Γ>1000: large electron energies → synchrotron afterglow!

Abdo et al 2009


Fermi-LAT
100.00
10.00
1.00
0.10
0.01
Rate (> 0.1 GeV)
t2
t-1.5
"Signature"
AGILE
Rate (0.03-0.3 GeV)
10.00
1.00
0.10
0.01
0.1
1.0
10.0
100.0
T-T* [s]
0.1
1.0
10.0
100.0
1000.0
T-T* [s]
Ghirlanda+ 2009


Rate (0.1-1 GeV)
100
10
1
0.1-1 GeV
Rate (> 1 GeV)
10.0
1.0
0.1
>1 GeV
Ph. index
2.6
2.4
2.2
2.0
1.8
1.6
0.1
1.0
10.0
T-T* [s]
Ghirlanda+ 2009


Rate
80
60
40
20
0.1-0.2 GeV
0.2-0.4 GeV
0.4-0.8 GeV
> 0.8 GeV
0.1
1.0
10.0
T-T* [s]
Ghirlanda+ 2009



~MeV and ~GeV emission are NOT cospatial. But the ~GeV emission is… No measurable delay in arrival time of high energy photons: $t_{delay} < 0.2$ s →

Strong limit to quantum gravity →

$$M_{QG} > 4.7\ M_{Planck}$$

Conclusions

- "Paradigm": internal+external shocks, synchrotron for both: it does not work
- Problems: efficiency, spectrum, trends
- Fermi/LAT detection → large Γ → Early high energy afterglow
- Violation of the Lorentz invariance? No (not yet)