Time evolution of the spectral break in the high-energy extra component of GRB 090926A

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On behalf of the Fermi GBM and LAT collaborations

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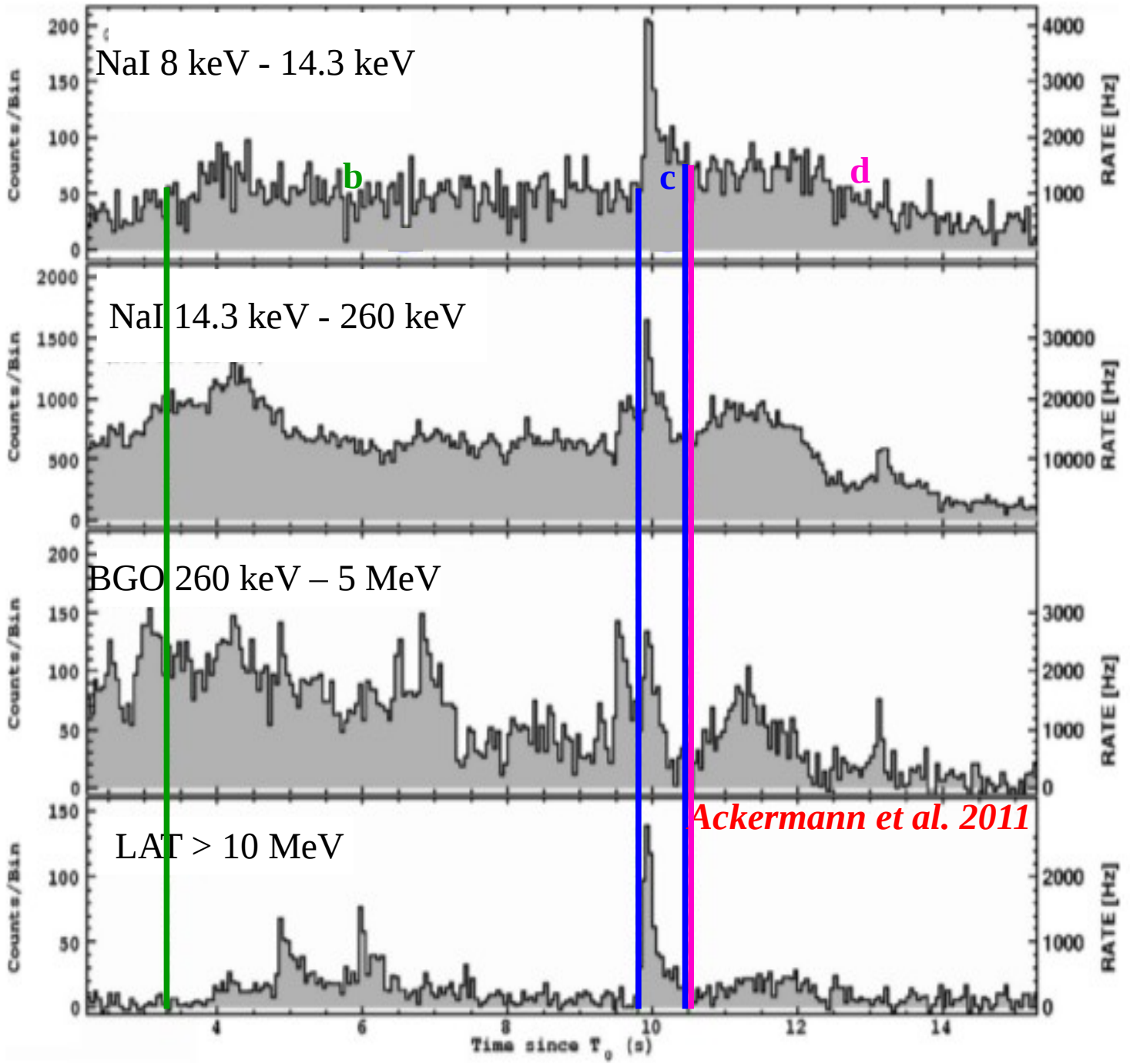
Outline

- **Physical motivations**
- **New time resolved spectral analysis**
  - Best fit model
  - High energy cutoff : significance and temporal evolution
- **Interpretation and new constraints on the jet Lorentz factor**
- **Summary**

GRB 090926A prompt emission (1/2)



Correlated variability in various bands with a sharp spike at T_0 +10 s

All energy ranges synchronized (<50 ms)

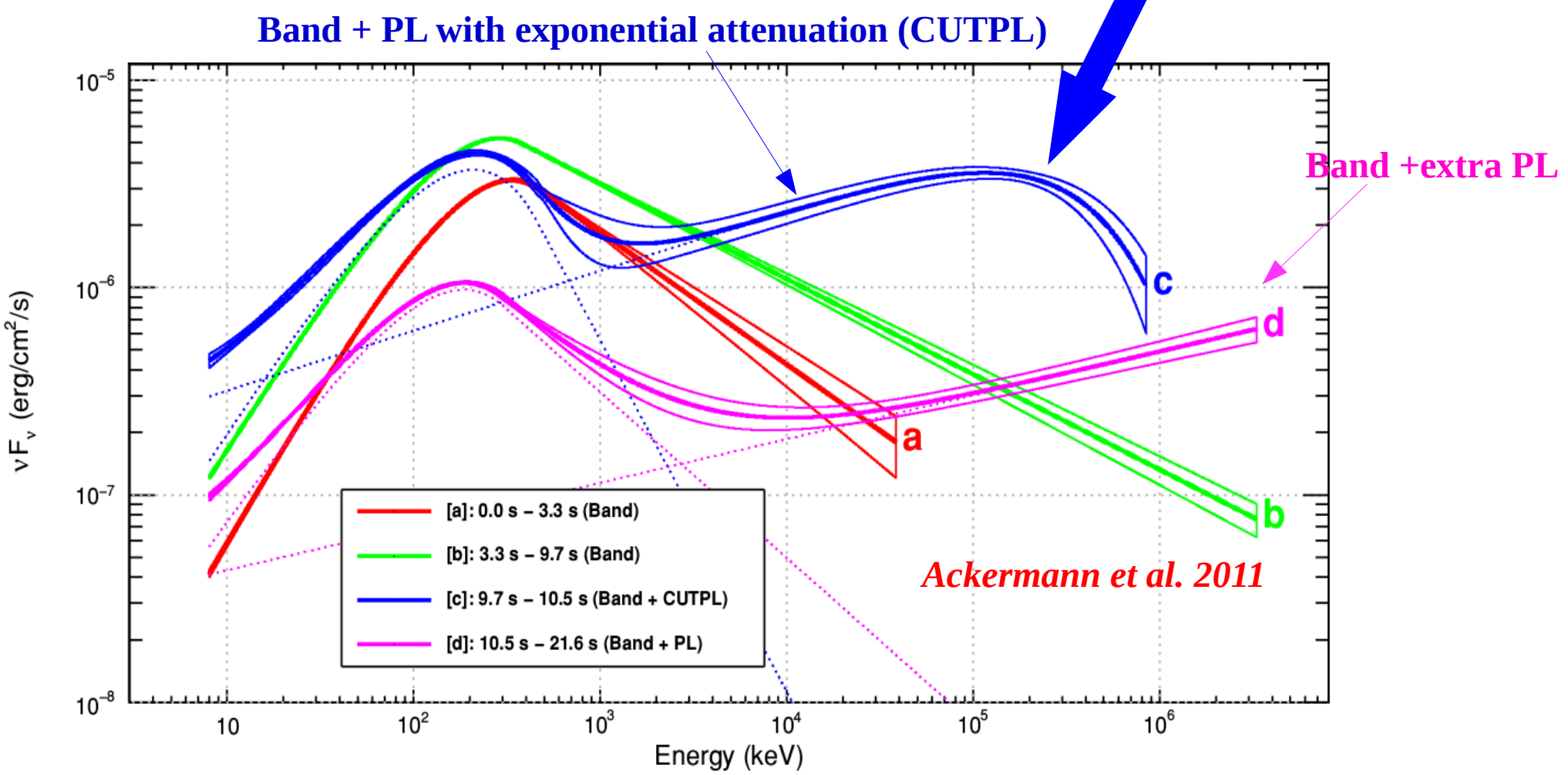
Favors internal origin for prompt emission from 10 keV up to GeV energies

Ackermann et al. 2011

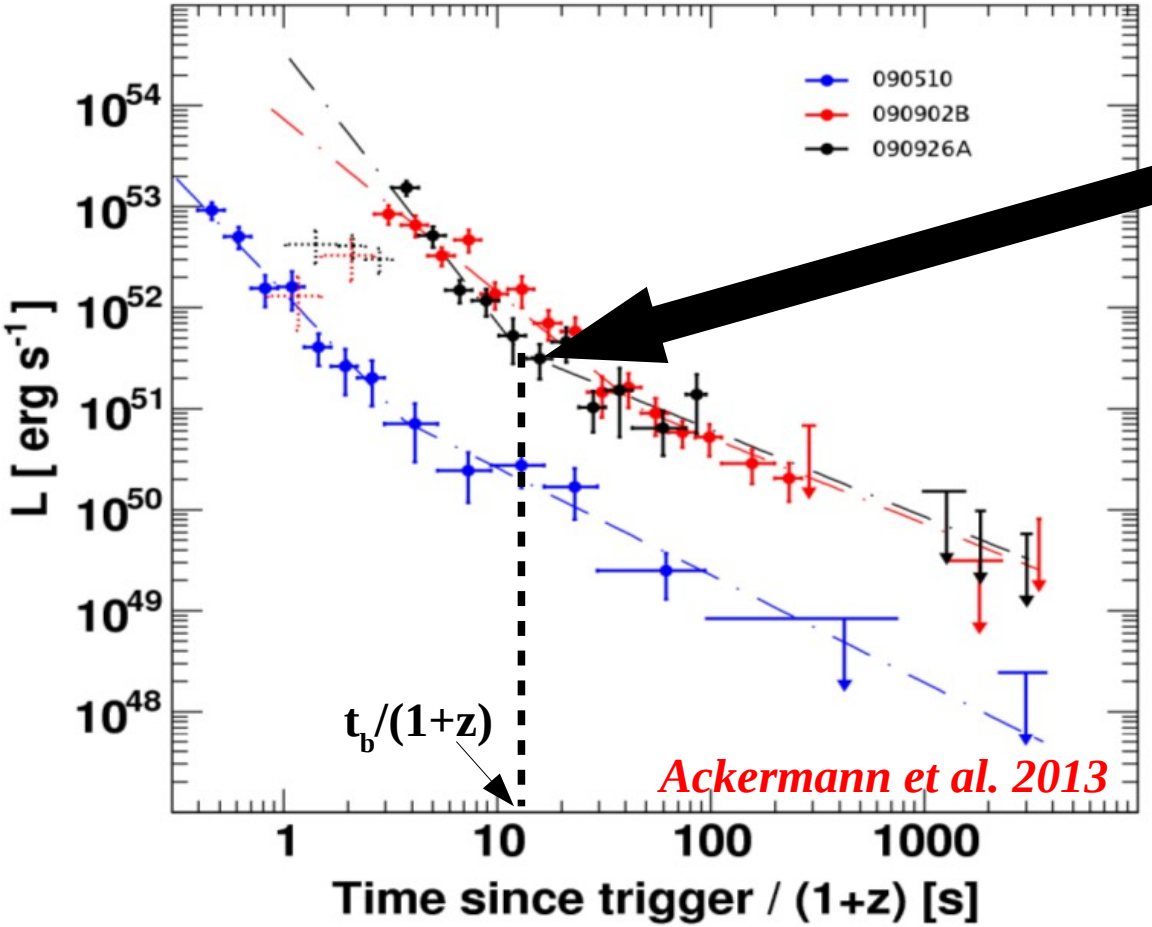
GRB 090926A prompt emission (2/2)

The emergence of the high-energy power law component coincides with the sharp spike (time bin c)

Cutoff at ~ 400 MeV in time bin c
If attributed to γγ absorption and used to constrain the jet Lorentz factor : Γ ~ 200 – 700



Luminosity temporal decay



Ackermann 2013 (LAT catalog)

- A break in the temporal decay of the gamma ray luminosity is observed at $t_b \sim T_0 + 40$ s (observer frame)
- Break time t_b well after the end of the prompt MeV emission ($T_0 + 22$ s)
- Afterglow emission after t_b vs. prompt emission dominated phase before t_b

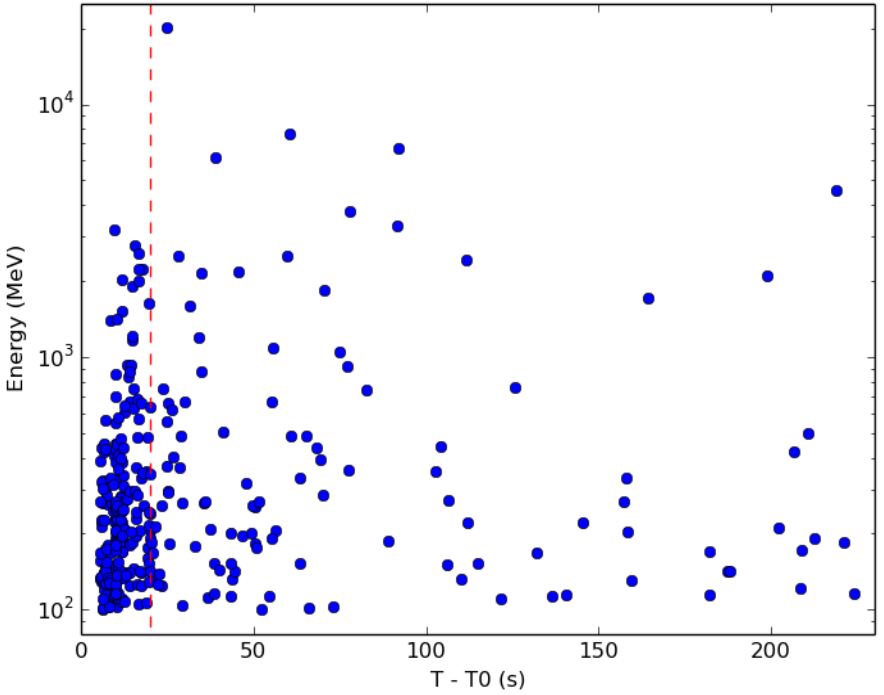
This work :

- Reanalyse the first 22 s of GRB 090926A with the best data set (Pass 8)
- **Interpretation : Inverse Compton emission / γγ absorption**

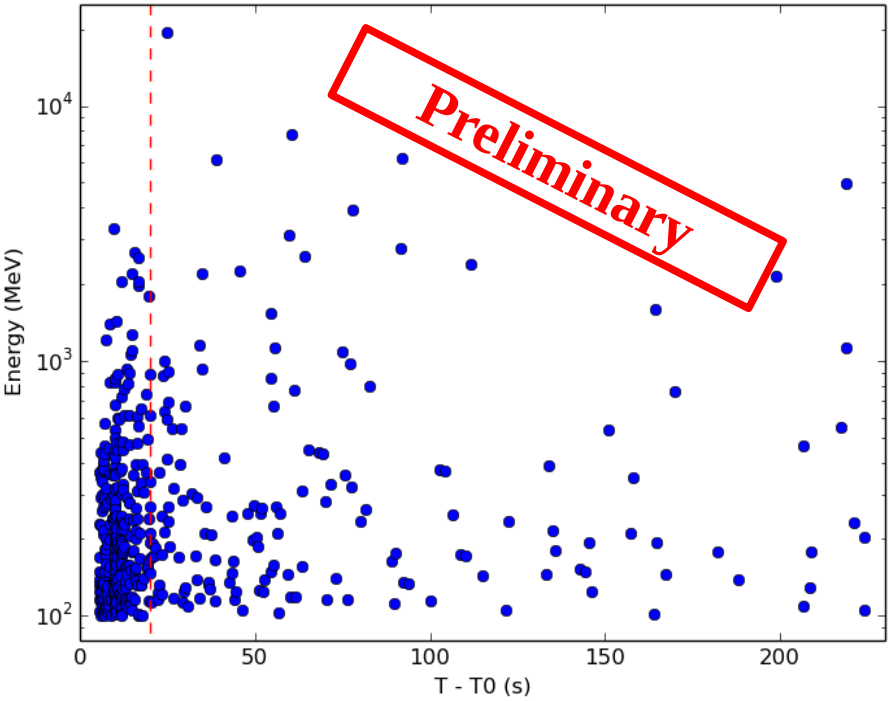
GRB 090926A event statistics at high energies

LAT T90 [5 s-209.8 s]	Pass 7	Pass 8	Pass 8/Pass 7
Number of events	447	1088	2.4
[30 MeV-50 MeV]	33	243	7.4
[50 MeV-100 MeV]	95	381	4.0
[100 MeV-0.5 GeV]	257	391	1.5
[0.5 GeV-1 GeV]	29	40	1.4
[1 GeV-10 GeV]	32	32	1
> 10 GeV	1	1	1

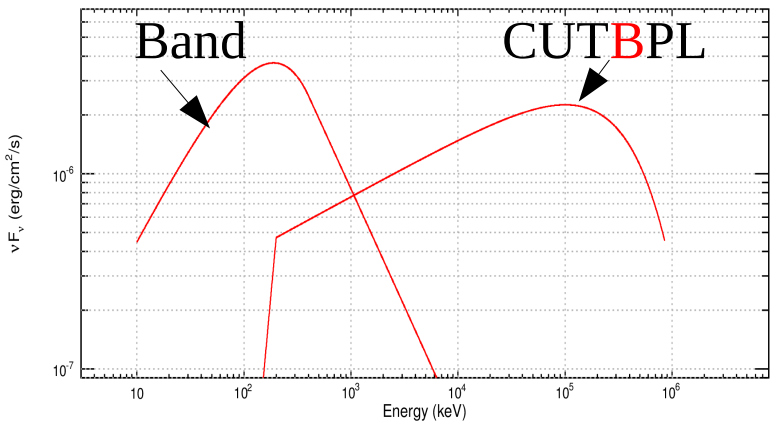
Pass 7



Pass 8



Best fit model (1/2)

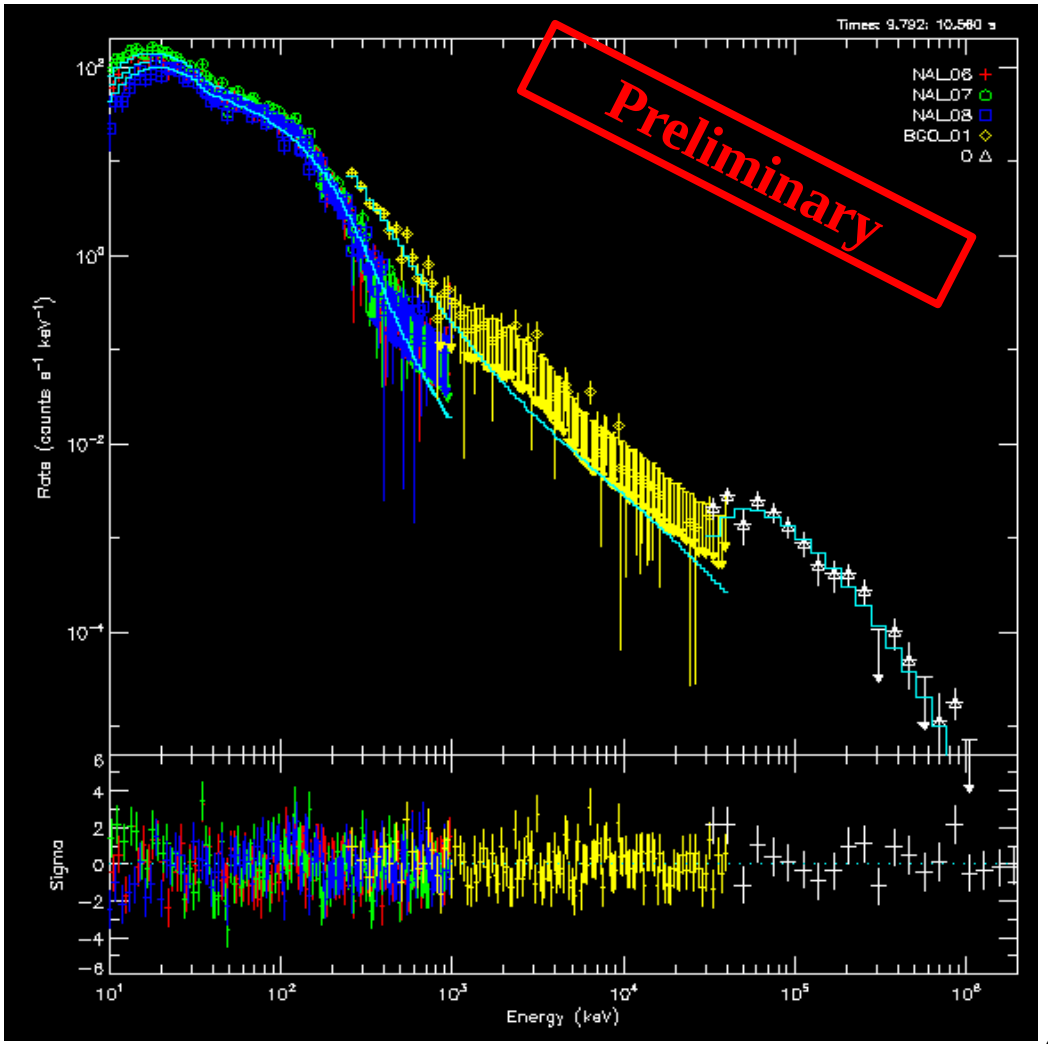


An extra high-energy power law (CUTPL) extending down to ~10 keV is not physically motivated (not expected from an IC component)

→ Use a power law with a break at low energy (Band + CUTBPL)

Time bin c

Parameters	Band+CUTBPL
Band	
α	-0.94 – 0.02 + 0.03
β	-3.20 – 0.89 + 0.24
Epeak (keV)	190 - 9 + 9
CUTBPL	
Photon index	-1.48 - 0.08 + 0.09
E folding (MeV)	335 - 45 + 65
C-stat / DOF	604.7 / 518
ΔC-stat w.r.t Band+CUTPL	15



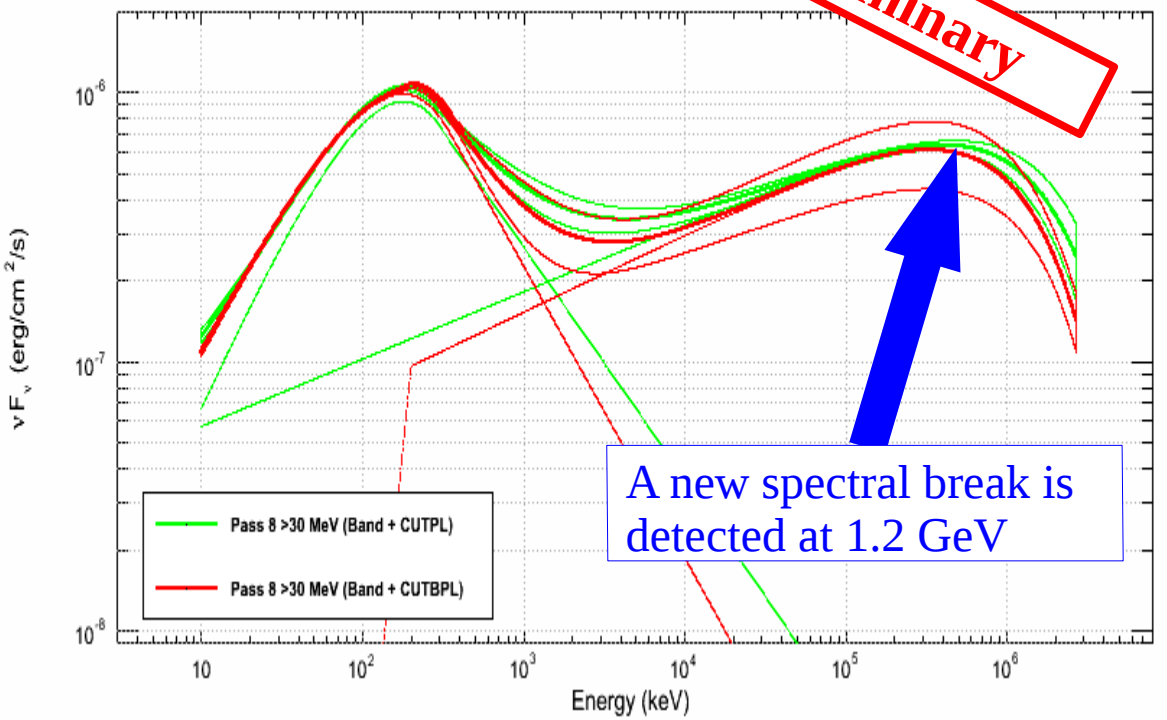
Best fit model (2/2)

Use a power law with a break at low energy (Band + CUTBPL)

Time bin d

Parameters	Band+CUTBPL
Band	
α	-0.86 - 0.03 + 0.01
β	-3.1 - 0.5 + 0.2
Epeak (keV)	177 - 3 + 7
CUTBPL	
Photon index	-1.71 - 0.05 + 0.05
E folding (GeV)	1.20 - 0.18 + 0.22
C-stat / DOF	652.7 / 518
ΔC-stat w.r.t Band+CUTPL	12

Preliminary



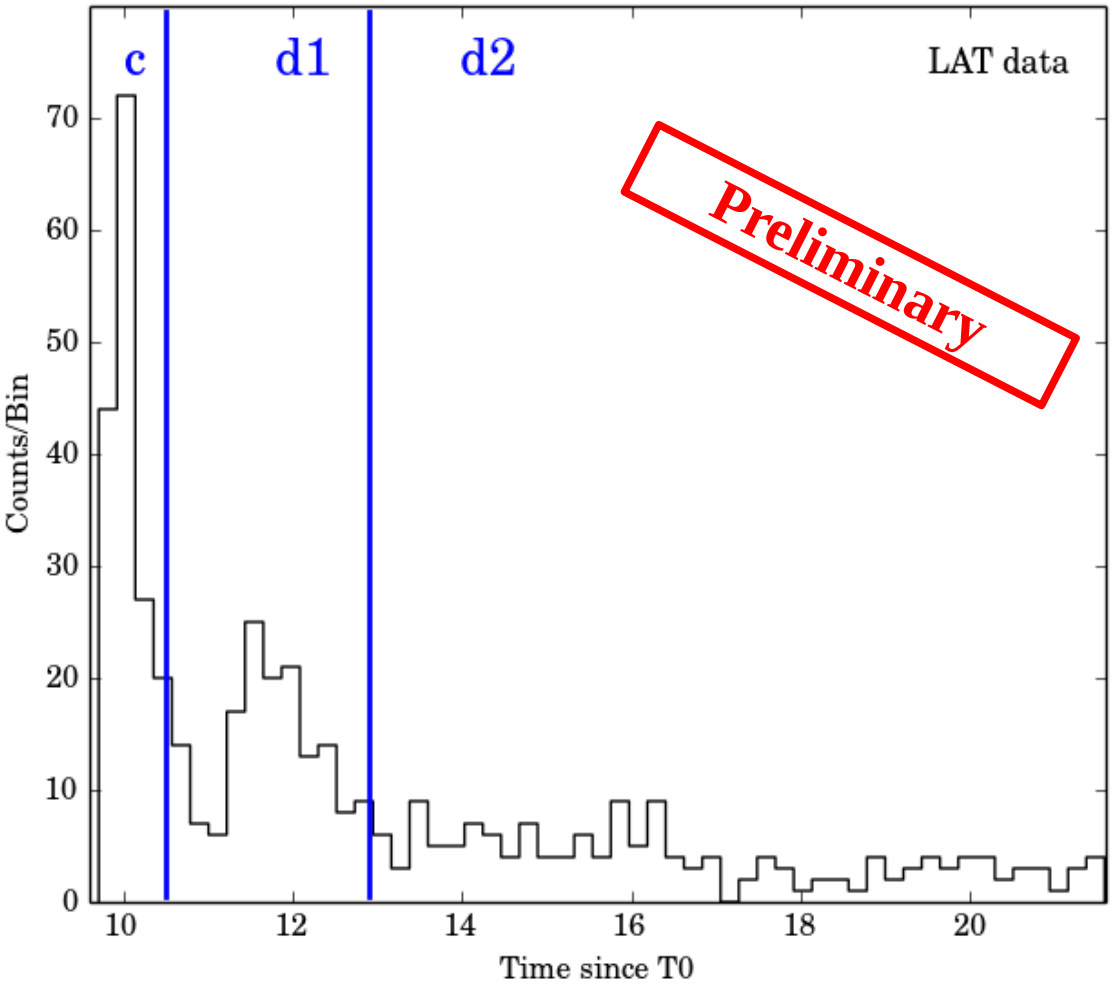
The Band + CUTBPL model fits well the data in the time bins c and d

Cutoff significance and temporal evolution

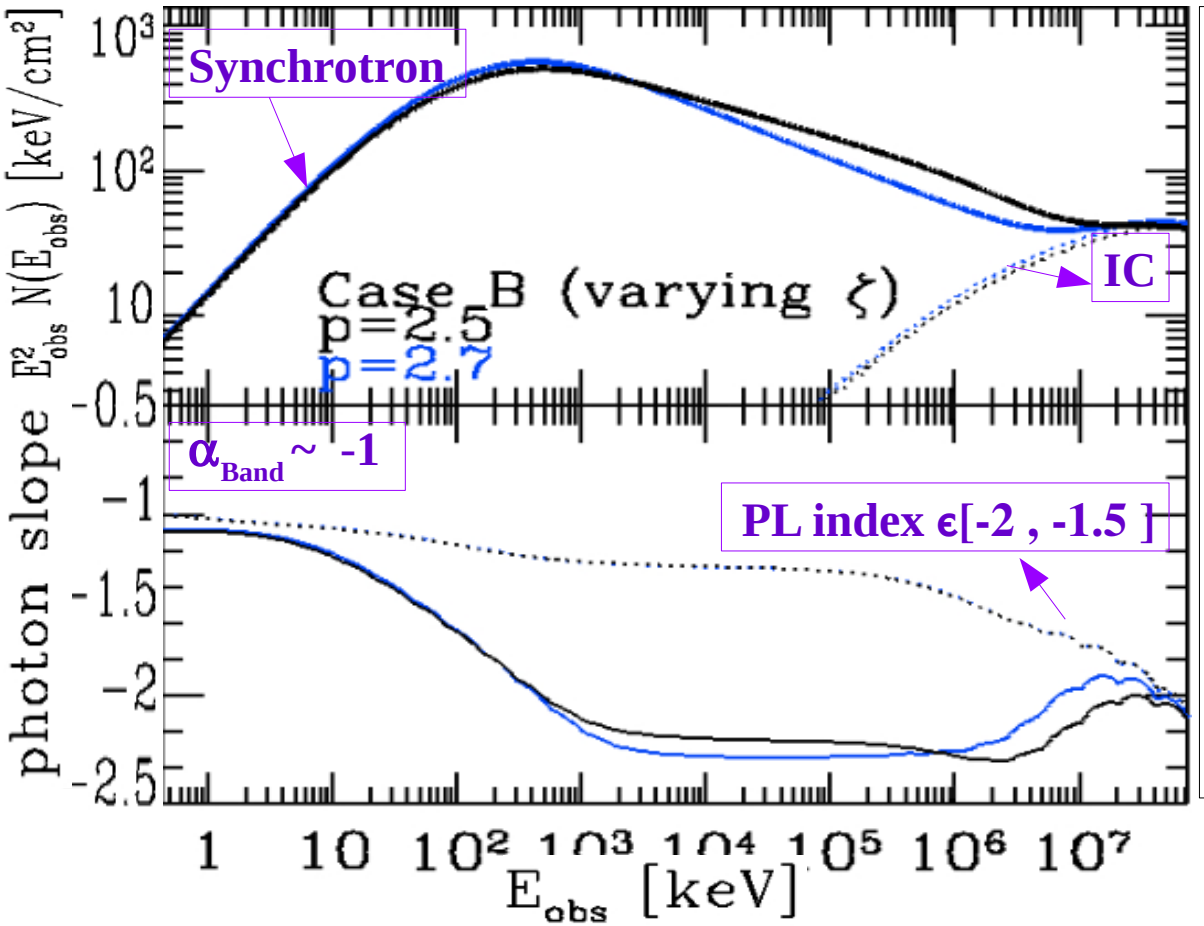
Time bins	c [9.8 s, 10.5 s]	d [10.5 s, 21.6 s]	d1 [10.5 s, 12.9 s]	d2 [12.9 s, 21.6 s]
Efolding (MeV)	335 -45 +65	(1.20 -0.18 +0.22) x10^3	550 -100 +130	(1.44 -0.25 +0.49) x10^3
Significance (nb. sigma)	7.6	6.1	4.3	5.1

Significance of the cutoff
Time bin c :
better constrained
Time bin d :
new spectral break is detected at 1.2 GeV

Temporal evolution
Time bin c :
no evolution was found
Time bin d :
Increase from 550 MeV (d1) to 1.4 GeV (d2)



Interpretation 1 : HE break = IC curvature



Comparison to the predictions obtained in the framework of the internal shock model ***Bošnjak & Daigne 2014***

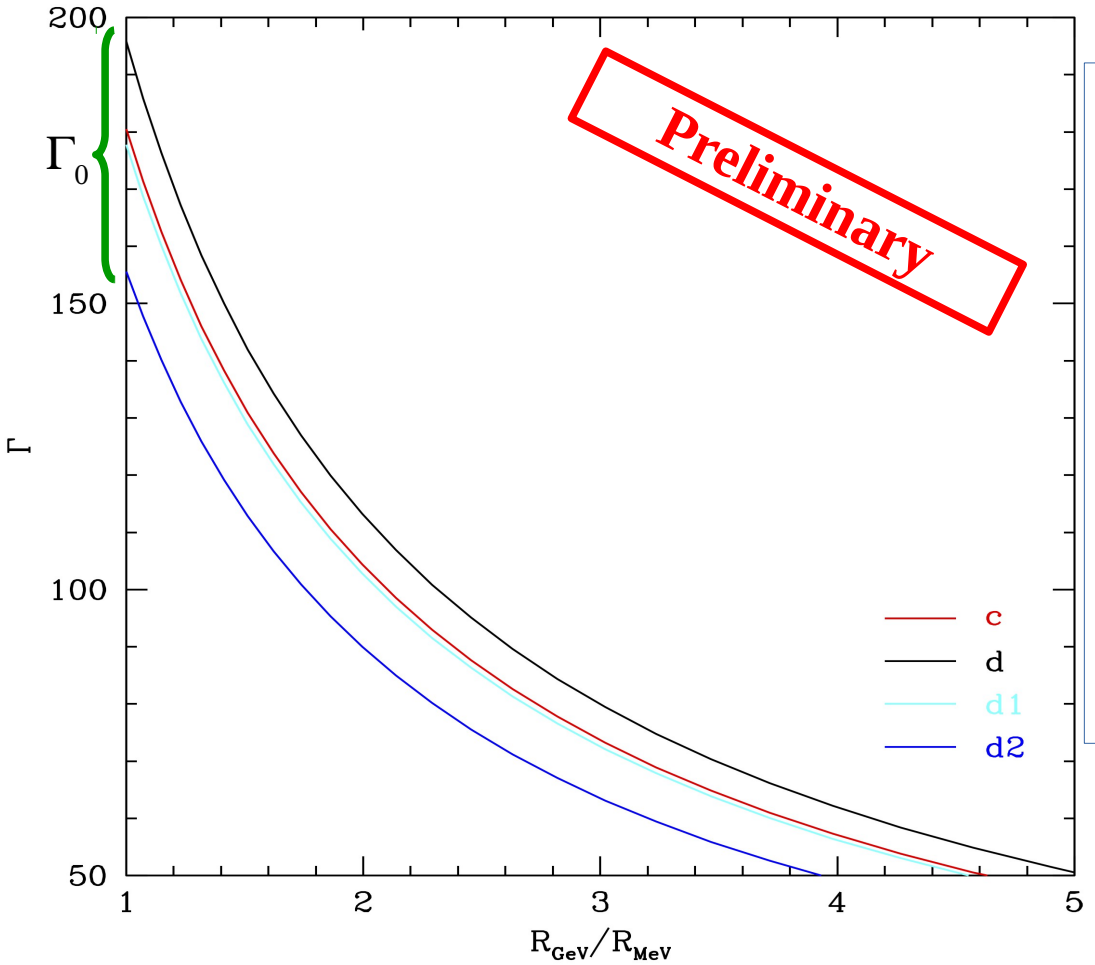
- MeV component (Band): fast cooling synchrotron radiation, modified by IC in KN regime : $\alpha_{Band} \rightarrow -1$
- High-energy component (CUTBPL) :

  - IC with a high-energy shape affected by KN + γγ attenuation

  - Low-energy slope : -2 → -1.5

- Example of a single pulse synthetic burst (not adjusted to reproduce GRB 090926A)
- Observed spectral evolution, Ebreak(CUTBPL) ↗ : KN → Thomson when Epeak(Band) ↘ ?
- The comparison with the observed slopes is promising
- The detailed shape (peaks, fluence ratio) is not reproduced yet : a better comparison needs a dedicated simulation of GRB 090926A (ongoing work)

Interpretation 2 : HE break = γγ attenuation



- Following ***Hascoët et al. 2012***

$$\Gamma = \Gamma_0(E_{cutoff}, \Delta t_{var}) \left[\frac{1}{2}\left(1+\frac{R_{GeV}}{R_{MeV}}\right)\left(\frac{R_{GeV}}{R_{MeV}}\right)\right]^{-1/2}$$

- $150 < \Gamma_0 < 200$ (similar to Ackermann 2011)
- Γ decreases with increasing ratio between the GeV and MeV emission radii
- Similar Γ values in the 4 time bins

Time bins (duration)	c (0.7s)	d (11.1s)	d1 (2.4s)	d2 (8.7s)
Ecutoff (MeV)	335	1.2×10^3	550	1.4×10^3
Δt_{var} (s)	0.15	1	0.5	1

Summary

- GRB 090926A prompt emission has been reanalysed using LAT Pass 8 data
- The attenuation of the high-energy extra PL is detected from T_0 + 10 s to T_0 + 22 s
- With a significant temporal evolution of the break energy from ~330 MeV to ~1.4 GeV
- Interpretation in terms of SSC internal shock emission is ongoing
- If Ebreak attributed to $\gamma\gamma$ attenuation → new constraints on the jet velocity : $\Gamma \sim 200$ (for $R_{GeV}/R_{MeV}=1$) from T_0 + 10 s to the end of the MeV prompt emission

Backup slides

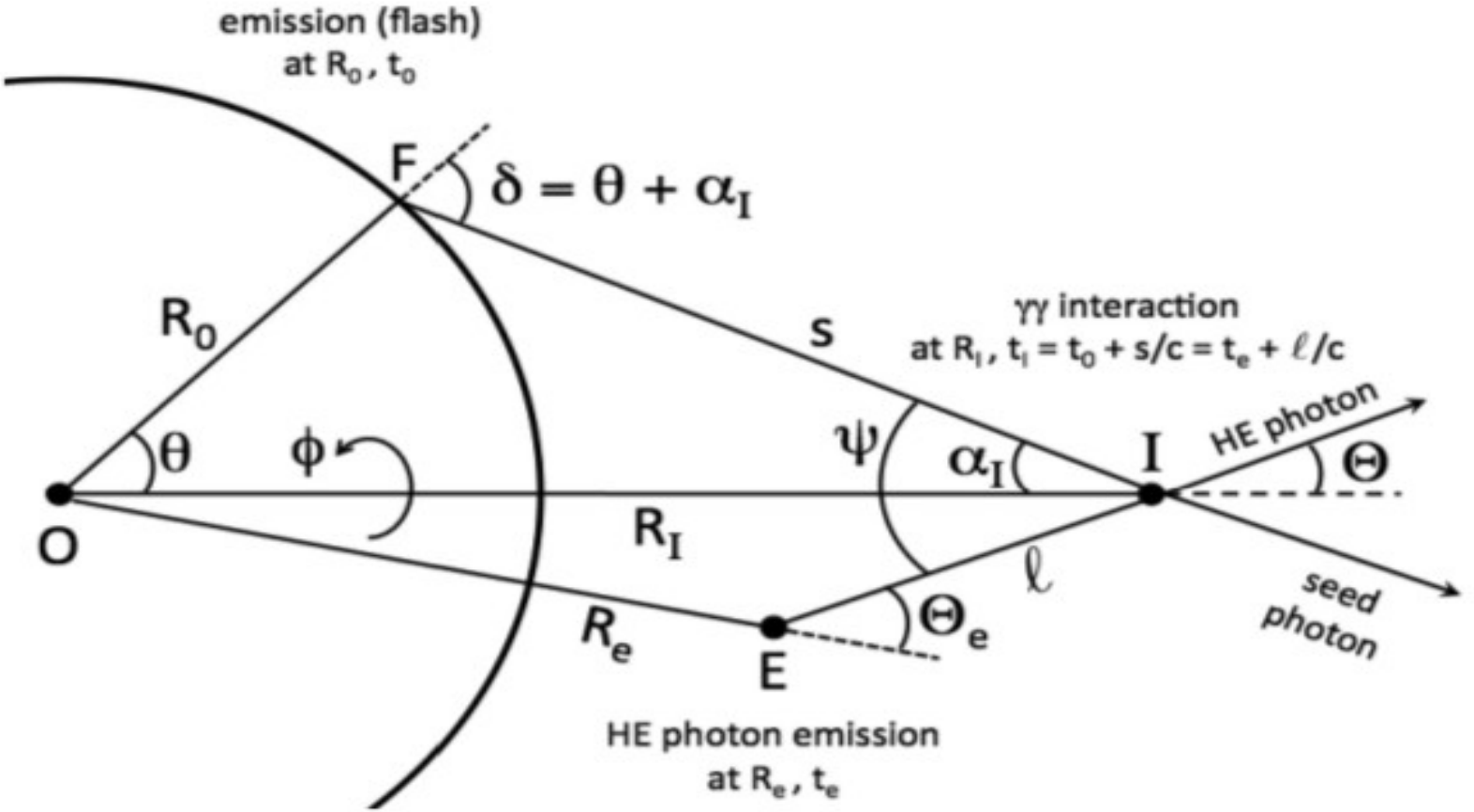
Black-body component ?

- Adding a BB component for bins c and d does not improve the fit significantly

Preferred model	Parameters	Castor C-stat
Band function		**Band**
A (ph. cm-2. s-1. keV-1)	0.31 +/- 0.0044	892.07/521
Epeak	278.7 +/- 3.50	
alpha	-0.55+/- 0.011	
beta	-2.33 +/- 0.0098	
Power law		**Band + PL**
B (1e-4 cm-2 s-1 keV-1)	0.38 +/- 0.167	884.61/519
Index	-1.89 +/- 0.088	
Epiv (MeV)	1	
Black-body		**Band + BB**
Amplitude (1e-6 ph.s-1 cm2 keV)	2.92 +/- 0.563	851.06/519
kt (keV)	92.48 +/- 3.02	

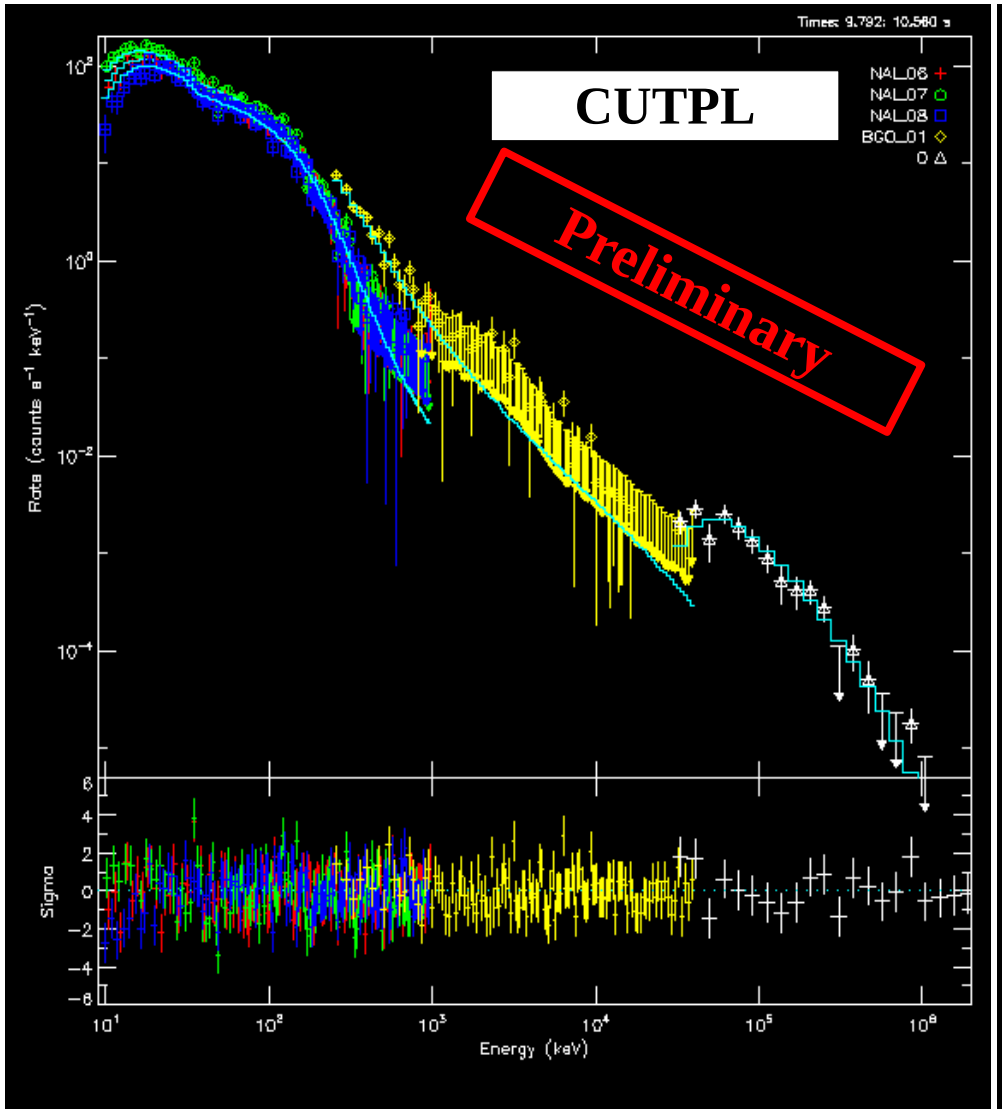
- In time bins c and d the best model remains Band + PL*HighCutoff
- Fitting time bin b with Band + BB model improves the C-stat value by 40 with rmfit (~ 20 with Autofit) w.r.t a Band model.
- In agreement with Guiriec+15 (BB significant at early times)

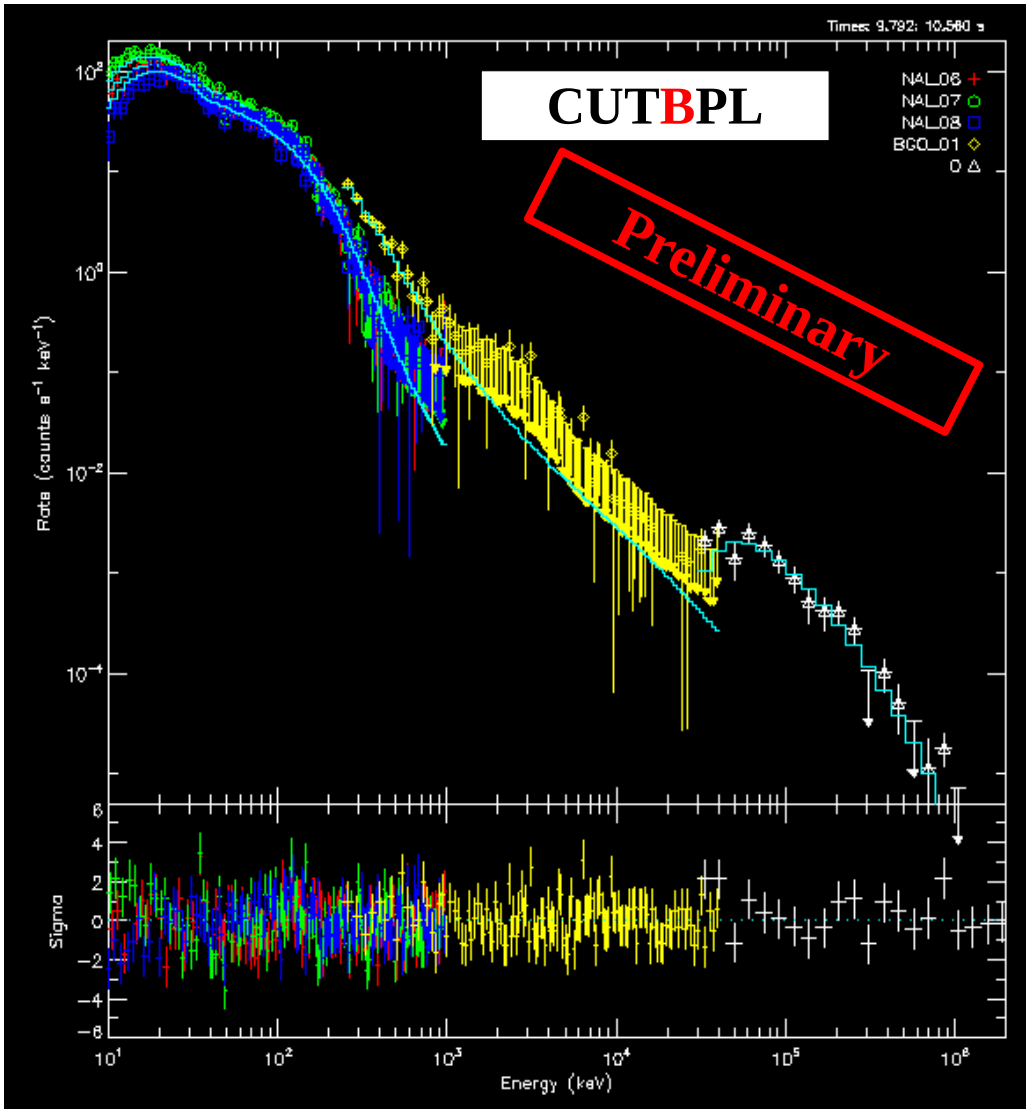
R_{GeV}/R_{MeV}



$$\Gamma_{\rm min} \simeq \frac{\left[C_1 2^{1+2\beta}\mathcal{I}(\beta)\right]^{1/2(1-\beta)}}{\left[\frac{1}{2}\left(1+\frac{R_{\rm GeV}}{R_{\rm MeV}}\right)\left(\frac{R_{\rm GeV}}{R_{\rm MeV}}\right)\right]^{1/2}}\,(1+z)^{-(1+\beta)/(1-\beta)}$$
$$\times\left\{\sigma_{\rm T}\left[\frac{D_{\rm L}(z)}{c\Delta t_{\rm var}}\right]^2 E_{\rm c}F(E_{\rm c})\right\}^{1/2(1-\beta)}\left[\frac{E_{\rm max}E_{\rm c}}{(m_{\rm e}c^2)^2}\right]^{(\beta+1)/2(\beta-1)} \quad (59)$$

Time bin c


Times: 9.792: 10.560 s
CUTPL
Preliminary
N4L_06
N4L_07
N4L_08
BGO_01
0
Rate (counts s^{-1} keV^{-1})
Sigma
Energy (keV)


Times: 9.792: 10.560 s
CUTBPL
Preliminary
N4L_06
N4L_07
N4L_08
BGO_01
0
Rate (counts s^{-1} keV^{-1})
Sigma
Energy (keV)