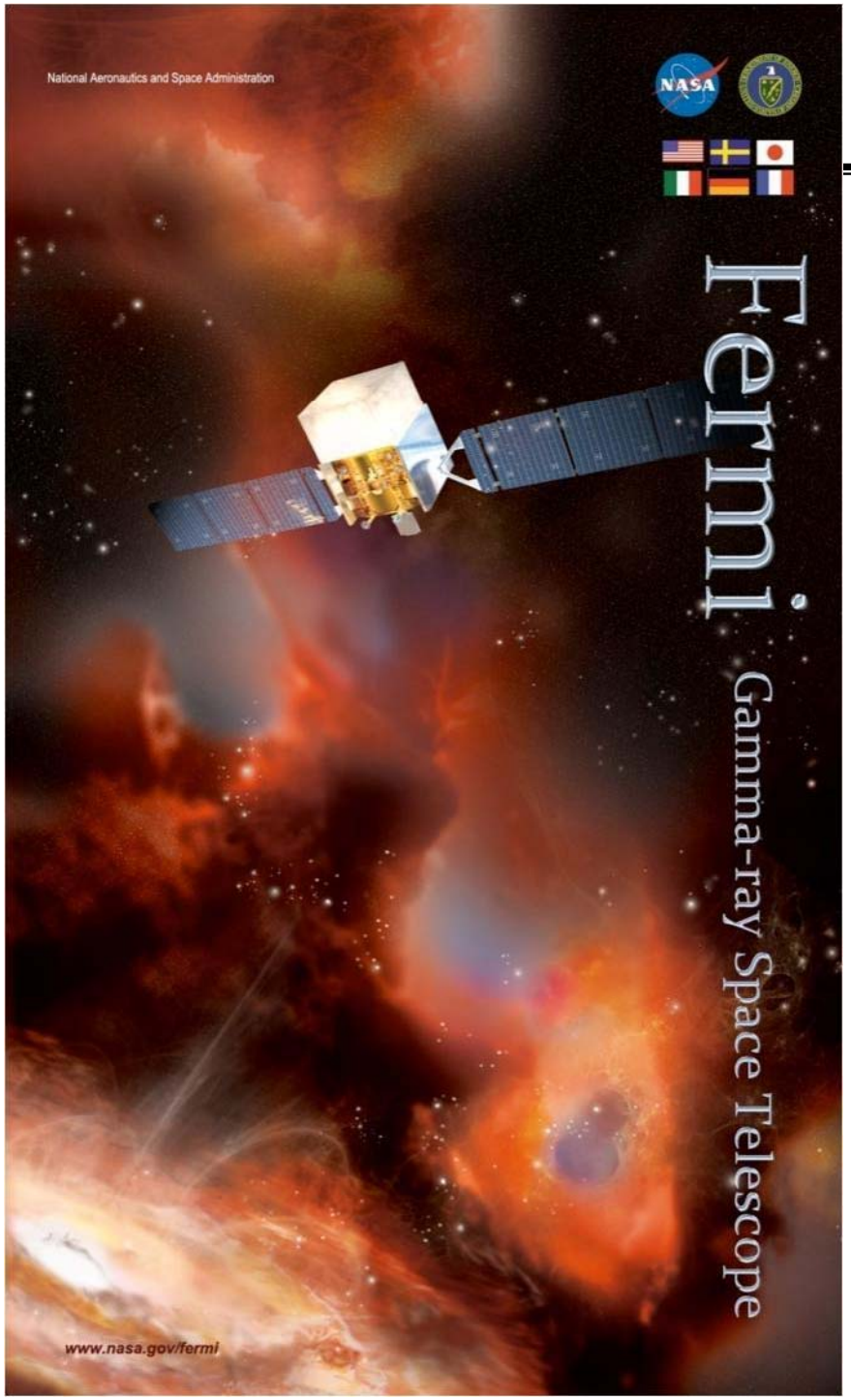

Study of the quasar 3C 454.3 with Fermi during two exceptional events

(December 09 – April 10)

arXiv 1007.0483 (accepted by ApJ)

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On behalf of the Fermi-LAT collaboration

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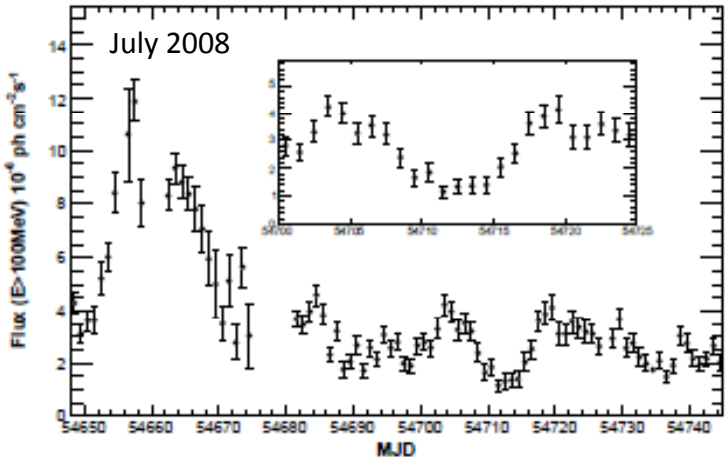
The *Fermi*-LAT telescope

The LAT is particularly suited to blazars observation :

- scans the sky constantly
  - → 20% of the sky is covered at any time
  - → all-sky coverage in 3hr
- is very sensitive (25x EGRET)
- covers the energy range 100 MeV-300 GeV

3C 454.3 : context

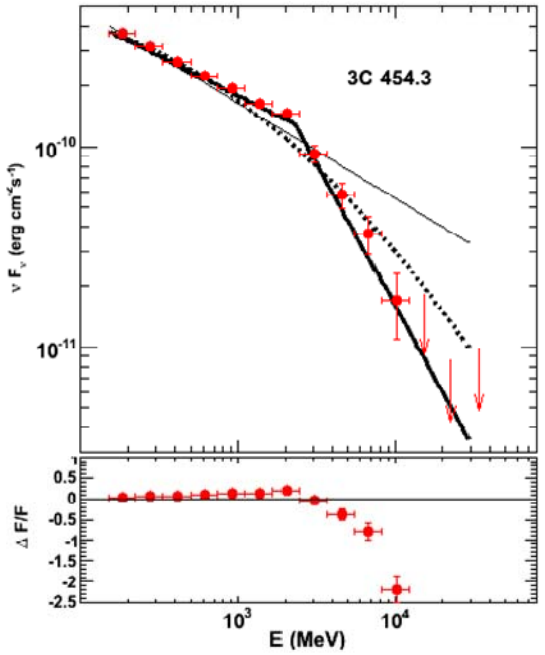
✓FSRQ
✓z=0.859
✓ Very bright source since 2000
✓ Intensively studied at all wavelengths



Previous Fermi results :

→ **shortest variability time scales of 2 days**
(Abdo et al., 2009 *ApJ* **699** 817)

→ **Break energy ~ 2GeV** (Abdo et al., 2009 *ApJ* **699** 817)
- Observed on almost all bright FSRQs and low-peaked BL Lacs (Abdo et al., 2010 *ApJ* **710** 1271)
- Possible origins : KN effect, break in the electron energy distribution…

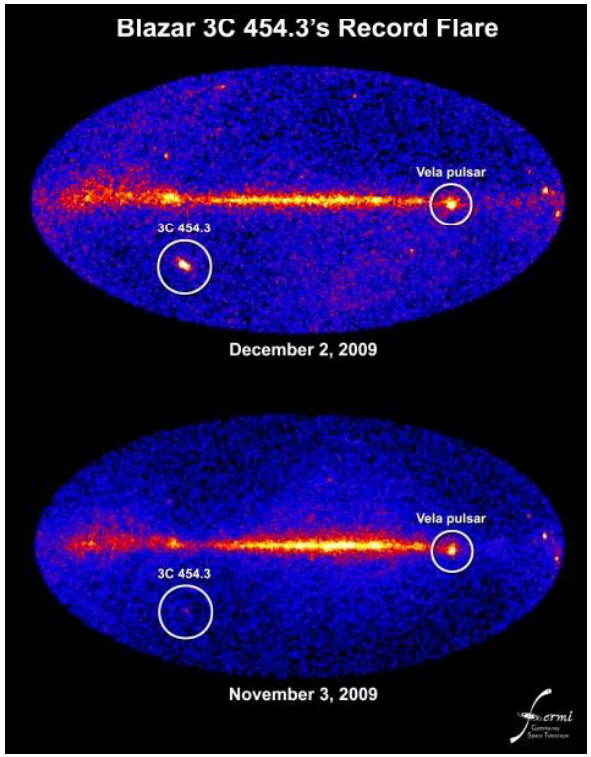


→ **Weak spectral variation** (2010 *ApJ* **710** 1271)
Γ=2.4, ΔΓ<0.3 for flux variations > 7

Context (cont.)

Dec. 2nd, 2009 → **F[>100 MeV]=22x10^{-6} ph cm^{-2} s^{-1}**
→**The brightest gamma-ray source in the sky for over one week (>2F$_{Vela}$)**

April 2010 : another flare
→ Pointed mode observation triggered.



Previous results on these flares :

❖ Tavecchio et al. (2010) → (Fermi results) variability on timescales of a few hours, implications on the size and distance to the BH of the emitting region
❖ Bonnoli et al. (2010) → (MW results + Fermi) single-day broadband SEDs → single-zone EC+synchrotron self-Compton
❖ Pacciani et al. (2010) → (MW results) additional component required to fit the data
❖ Foschini et al. (2010) → (Fermi ToO) shortest variability time scales of a few hours
❖ Striani et al. (2010) → (Agile) shortest variability time scales of a few hours + strong spectral variability

Aim of this analysis

Make the most of an exceptional situation to study temporal and spectral properties of 3C 454.3 and address a few open questions :

- ✓ Variability time scales ? → size of the system (causality)
- ✓Spectral variations ? → acceleration/cooling process for e^- populations ?
- ✓ Origin of the spectral break ?

In this analysis : gamma-ray properties only.

Analysis parameters

❖Data collection : between Aug. 27, 2009 and April 21, 2010.

❖ Source model :
- Point source : various models (PL, BPL)
- Extragalactic : isotropic_iem_v02.txt
- Galactic : gll_iem_v02.fit
- All point sources in the ROI + surrounding 5°-wide annulus with a flux greater than ~1% of the quiescent level of 3C 454.3 modeled with PL distributions

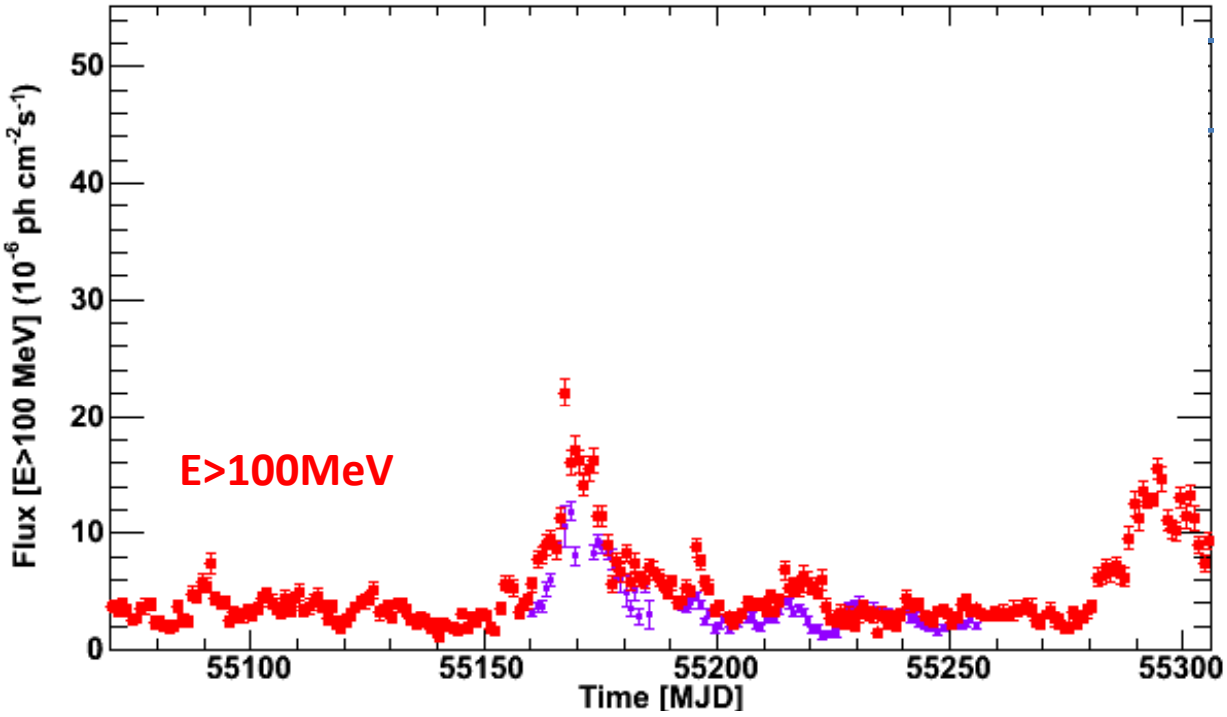
❖ IRF : P6_V3_DIFFUSE

❖Cuts : Zmax=105° (zenith angle), |rocking angle|<52 deg

❖ ROI=10°

❖ E>100MeV

❖Science Tools v9r15p5



- July 2008 flare shifted by 511 days
- **ΔT=1d**
  MJD=55070-55307
  (Aug.27, 09 – Apr.21, 10)
  E>100MeV

Implications on the source : γ- ray apparent isotropic luminosity

z=0.859

F [E>100MeV]

Γ

L_γ [E>100MeV] = 3.8x10^{49} erg s^{-1}

~3 L_γ(PKS1502+106, z=1.839), Aug.08
(Abdo et al., 2010, ApJ, 710, 810)

<L_γ(PKS 1622-297)=5.1x1049 erg s^{-1}, 1995
(Mattox et al. 1997)

Implications on the source : Doppler factor

$\tau_{\gamma\gamma}(\varepsilon_1)<1$

$$\delta_{min} \cong \left[\frac{\sigma_T d_L^2 (1+z)^2 f_{\hat{\epsilon}} \epsilon_1}{4 t_{var} m_e c^4}\right]^{1/6} \qquad \hat{\epsilon} = 2\delta^2/(1+z)^2\epsilon_1$$

$\delta_{D,min} \approx 15$

$f_{\hat{\epsilon}}$: υF_υ of the target photons ($\hat{\epsilon}$) with which the γ preferentially interacts in the pair creation process.

→ Swift/XRT $\upsilon F_\upsilon(4keV) \approx 6.10^{-11}$ erg.cm^{-2}.s^{-1} (Bonnoli et al. 2010)

ϵ_1 : energy of the most energetic γ photon

→ $E_{max}(\theta_{95\%})$ = 20.7 GeV (IC model)

d_L: luminosity distance

$\hat{\epsilon}$: energy of the target photons

ε_1 : energy of the most energetic photon

$f_{\hat{\epsilon}}$: υF_υ target photons

t_{var} : shorter variability time scales observed in the gamma-ray range

Implications on the source : Location of the emission region with respect to the BH

$\Gamma \approx 20$ (Jorstad et al. 2005)

$t_v \approx 6h$

The emission region is located at a distance :

$$r \lesssim 2c\Gamma_b^2 t_{\rm var}/(1+z) \approx 0.2\Gamma_{15}^2 t_{\rm var,d} \ \ {\rm pc}$$

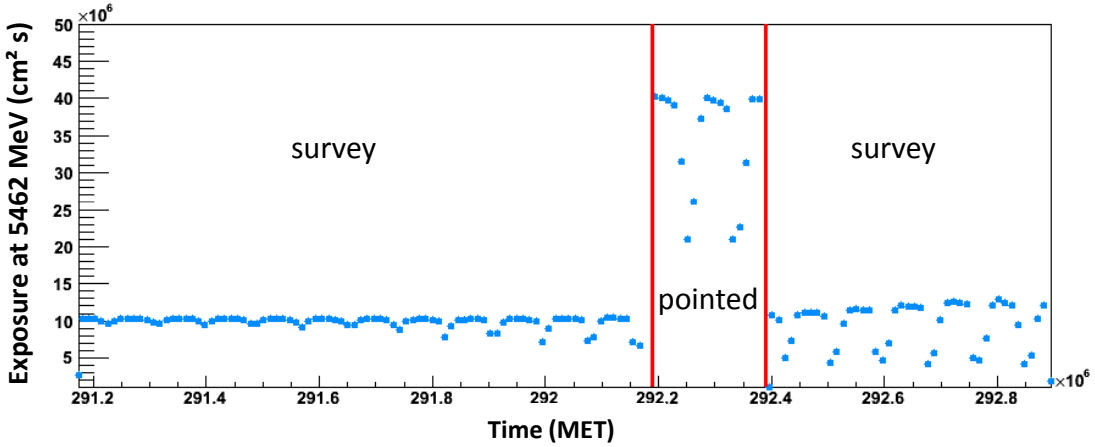
(towards the outer parts of the Broad Line Region)

→ Seems to disfavour the models in which IC is made on photons from the torus or further in the jet.

- Pointed mode (April 5-8, 2010, 200ks)-

Gain of exposure by a factor of 3.5
→improvement of the statistic accuracy in both flux and index measurement.

Do we observe shorter variability time scales thanks to this gain of exposure ?

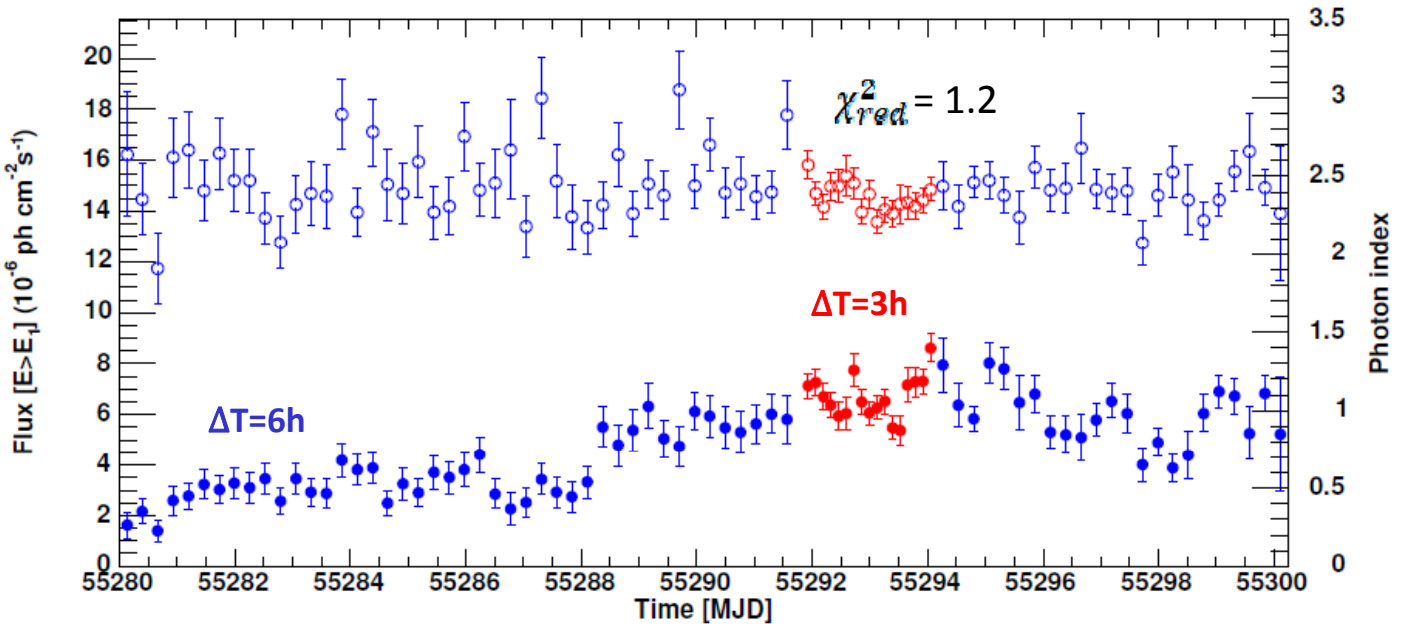


Variation of exposure with time

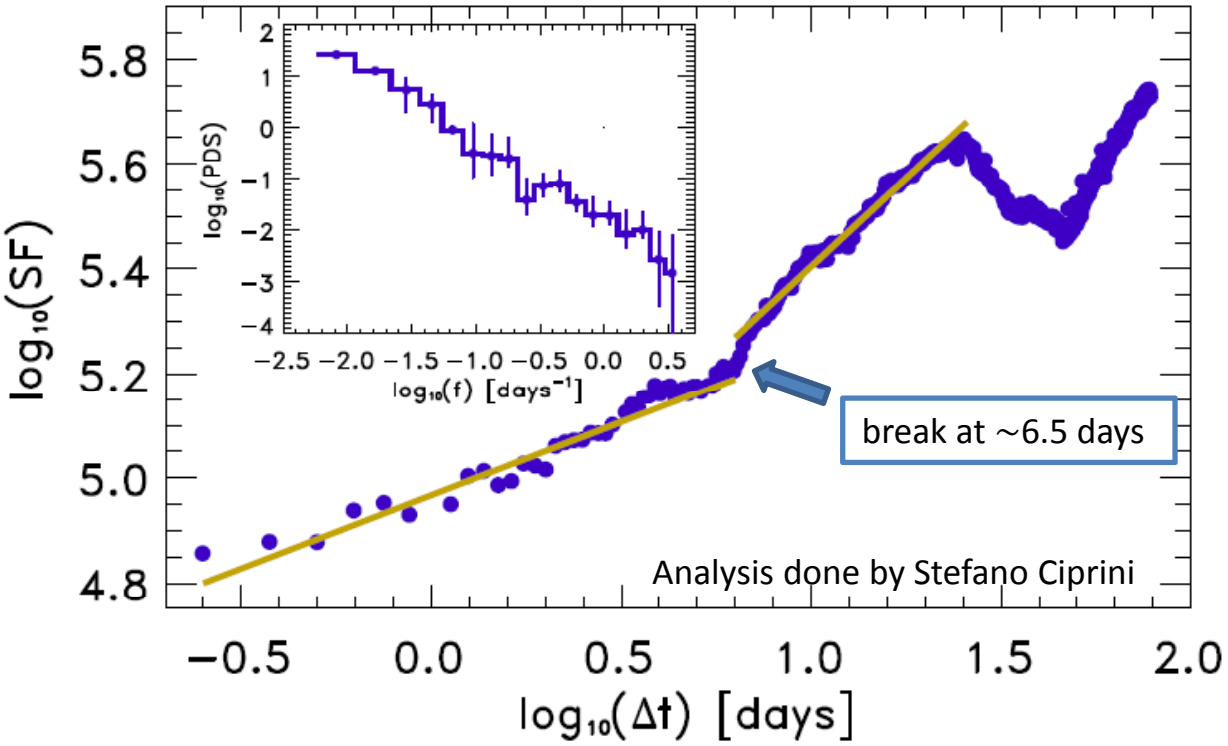
NO !

→ These very short variability time scales remain exceptional.

- pointed (ToO)
  ΔT=3h
- survey
  ΔT=6h



- Structure function -



Structure function of the 3h-bin flux light curve for the period 2009 Nov. 5 – 2010 Mar. 4 and corresponding power density spectrum (inset).

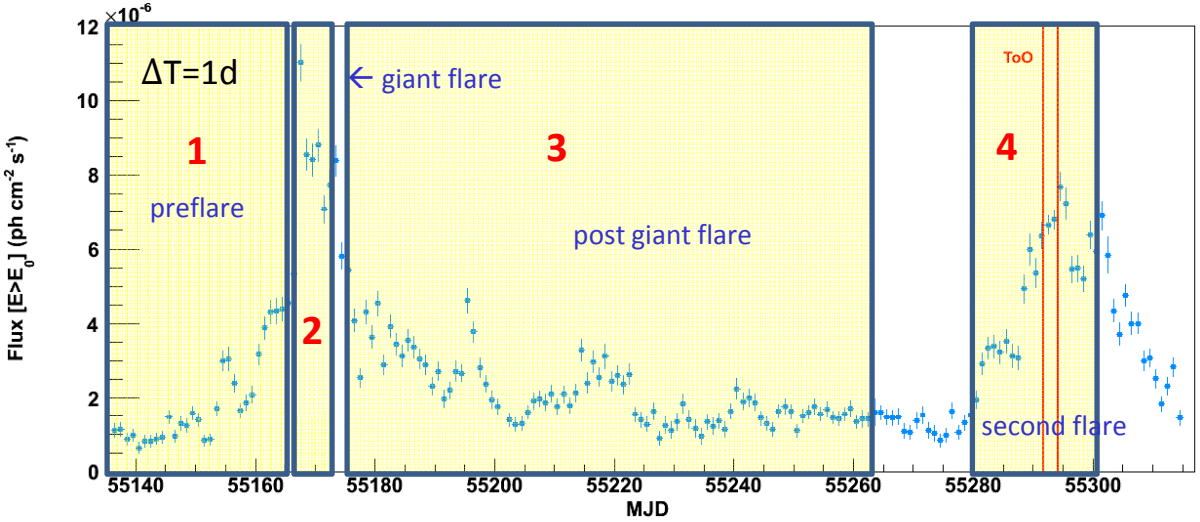
→For the first time, this exceptional flux allows us to study the temporal properties of the source over time scales from a few hours to several weeks.

→Break around **6.5 days** (log(ΔT)~0.8).

→ does it represent a characteristic time ?

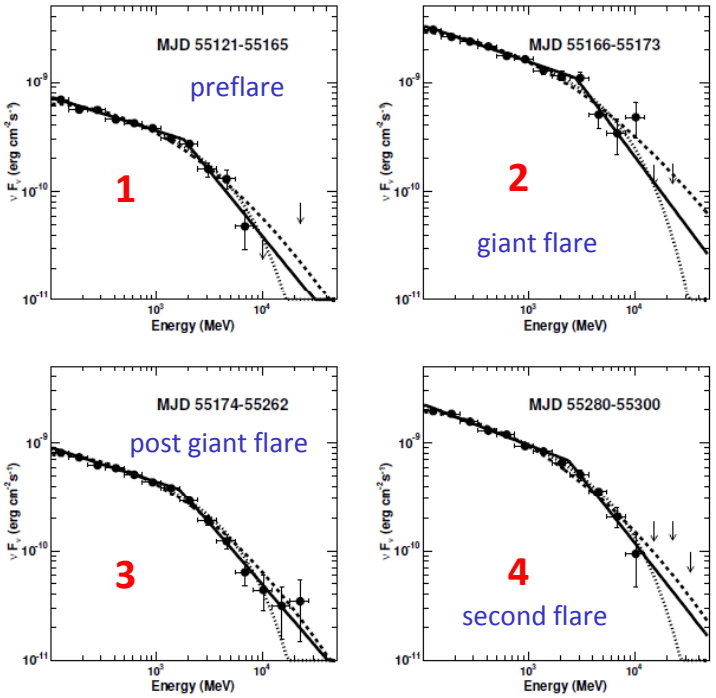
→ alternative explanation : 2 power-laws with different indices that join at about 6.5 days.

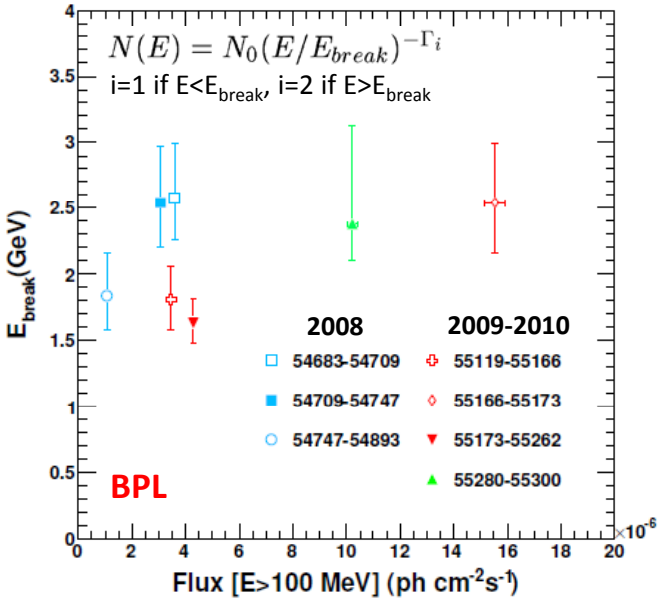
Break evolution

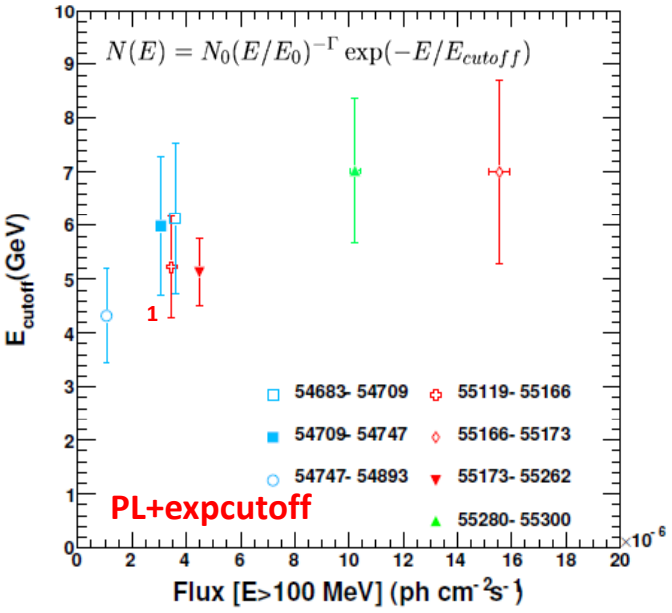


The first time the position of the break can be evaluated with only **one week** of time integration !

The position of the break seems roughly constant (<x2) despite large flux variations (x4).

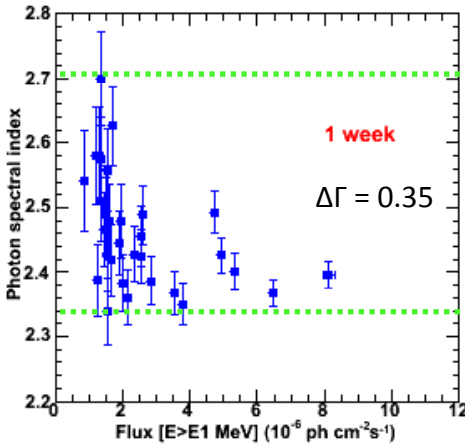


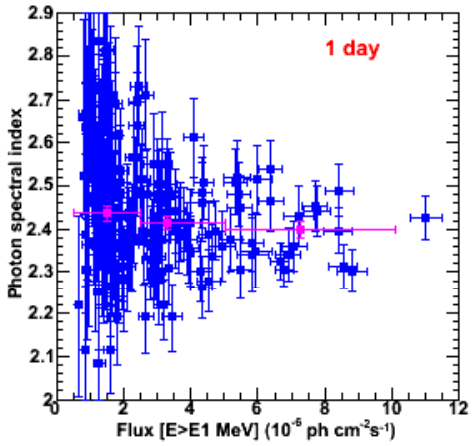


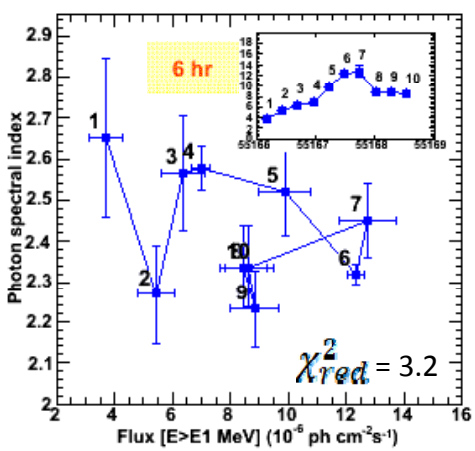


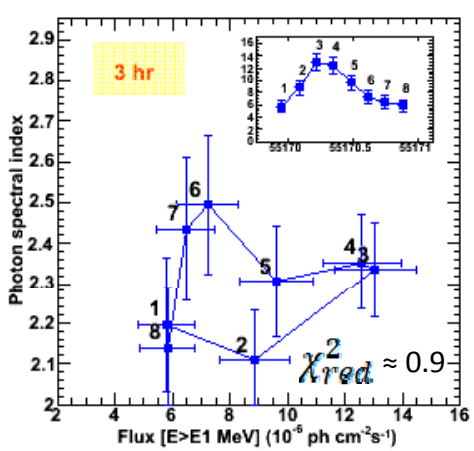
- Index/flux correlation-

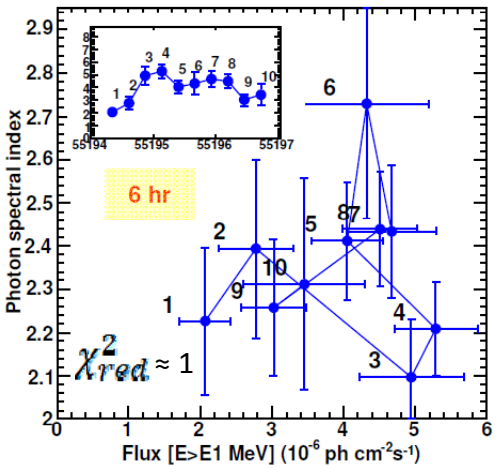
The correlation between index and flux provides insight into acceleration/cooling processes.











A weak harder when brighter effect is observed.

We are looking for loop patterns in the most rapid flares.

What is expected in a cooling scenario : after a flare→ softer spectrum (cooling effect)

What is observed :

No universal behavior.

Hardly a weak hardening during the flux decrease.

→ Weak indication of a « hard-lag » (linked to acceleration)

Can a KN effect explain a quasi-constant break energy ?

Transition fr

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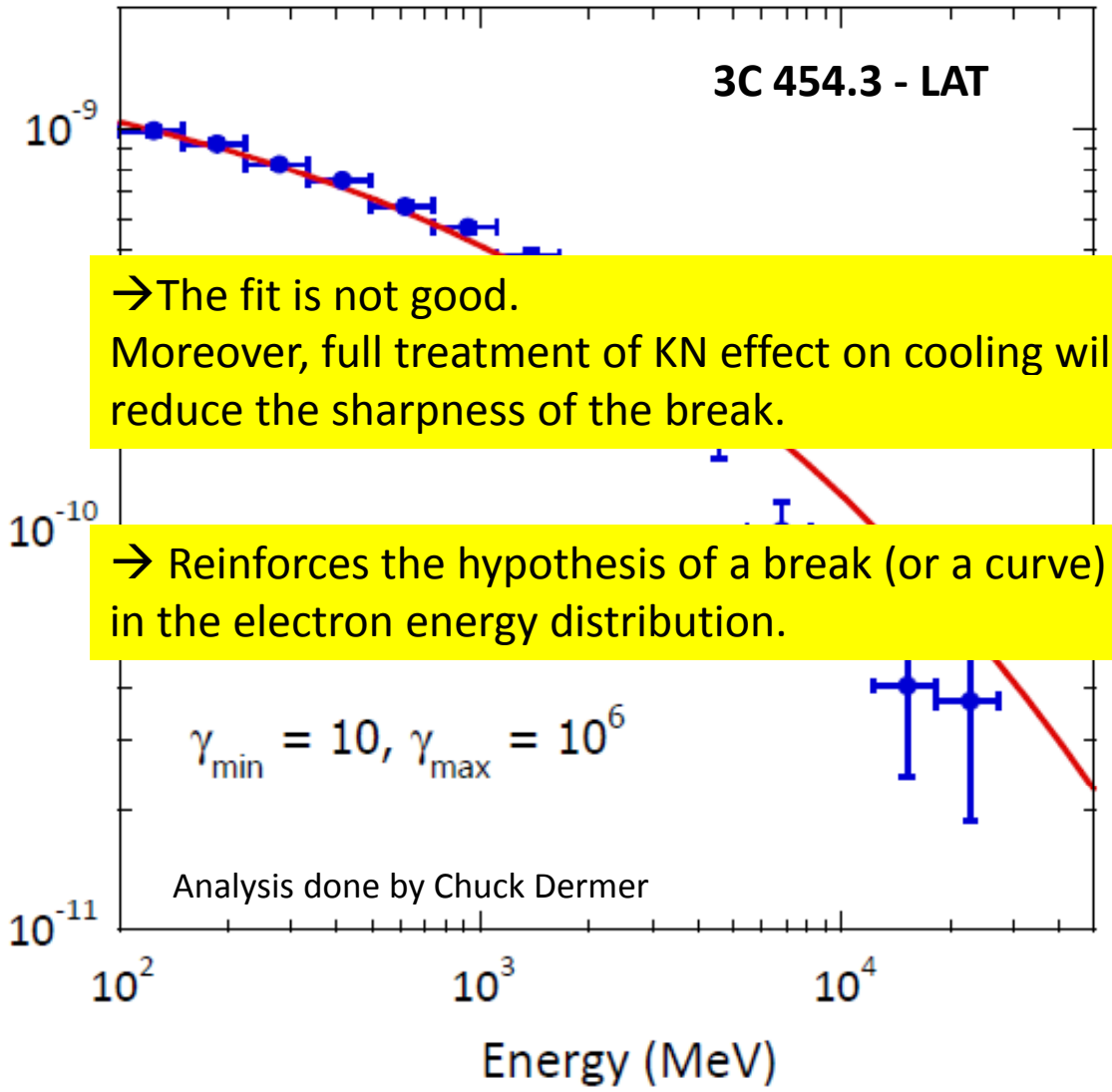

→The fit is not good.
Moreover, full treatment of KN effect on cooling will reduce the sharpness of the break.

→ Reinforces the hypothesis of a break (or a curve) in the electron energy distribution.

Conclusions

✓ The highest flux ever observed for a blazar in the GeV range

✓ Very short variability time scales (the shortest ones ever observed in this energy range), in the order of 3 hours
→ $\delta_{min} \approx 15$

✓ Weak spectral index variation despite large flux variations
→ no strong apparent cooling/acceleration effect on the electron population

✓ Quasi-constant break energy in the spectrum.
→ KN effect explored and seemed to be ruled out
→ Reinforces the hypothesis of a break in the energy spectrum of the electrons

Thanks for your attention !