gLike for Lorentz invariance violation time-of-flight searches: A joint-likelihood framework and a case study on BL Lacertae

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Annecy, 4 February 2026

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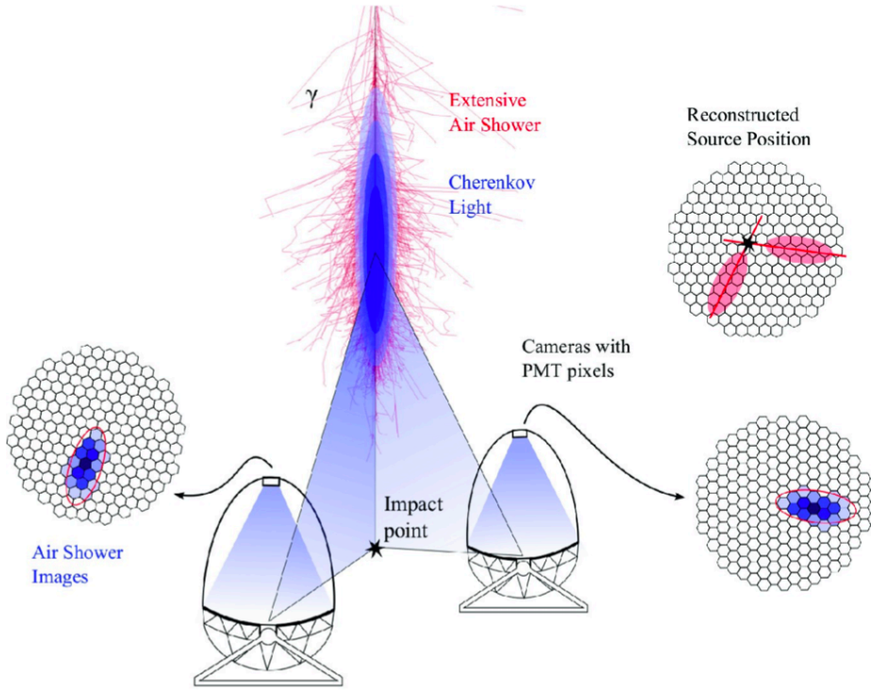
Overview

- Instruments
- Source
- Data
- Astrophysical modeling
- gLike LIV results
- Outlook

Instruments

- Imaging atmospheric Cherenkov telescopes: MAGIC and LST-1.



- Optimised for gamma-ray observations between ~10 GeV and ~100 TeV

BL Lacertae flaring activities – about the source

- RA: $22^h\,02^m\,43.3^s$, dec: +42° 16′ 40″ in constellation Lacerta (lizard).
- Discovered by C. Hoffmeister (1929) and **misinterpreted as a variable star.**
- $z = 0.069$.
- Prototype for BL Lacertae objects:
  - Rapid and large-amplitude flux variability.
  - Significant optical polarization.

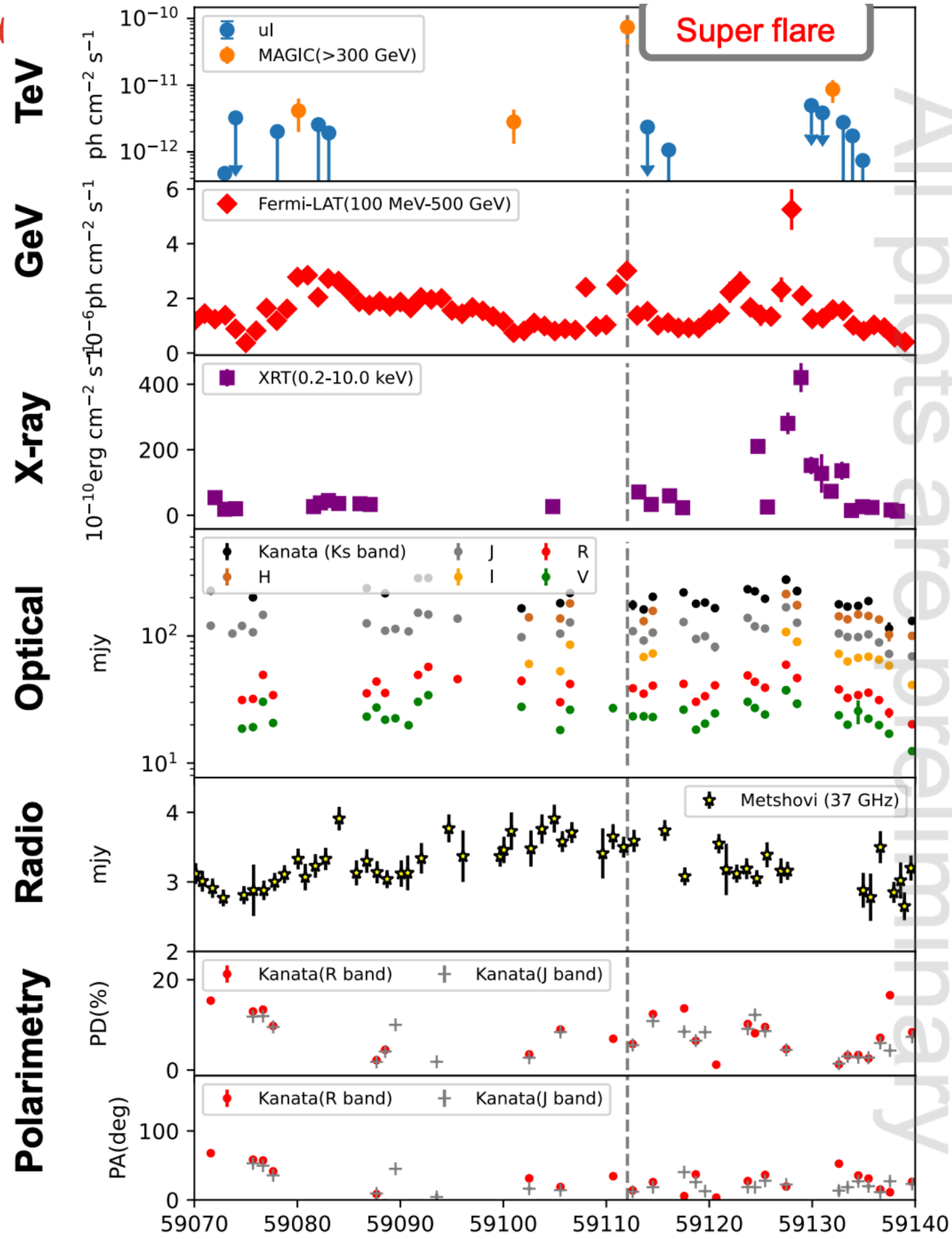
BL Lacertae observations by MAGIC from August to October 2020

- The Astronomer's Telegram:
  - 13963
  - 14032

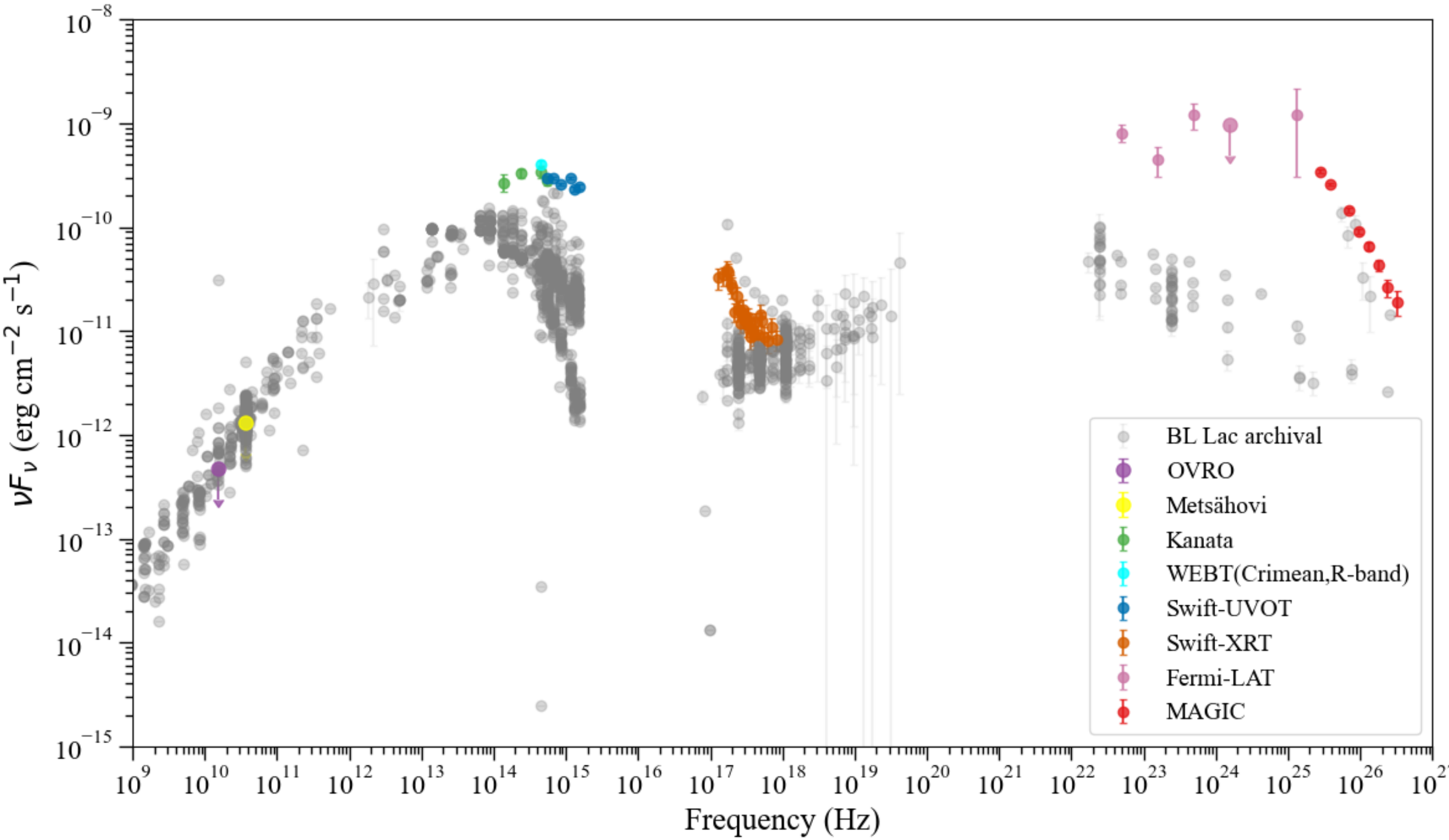
ST.03.14			ST.03.15		
Date	**T_{obs} [h]**	**$\sigma_{Li\&Ma}$**	**Date**	**T_{obs} [h]**	**$\sigma_{Li\&Ma}$**
2020-08-11	0.9	3.0	2020-09-20	5.2	110
2020-08-12	0.8	1.1	2020-09-21	0.7	0.2
2020-08-13	0.7	0.2	2020-09-22	1.9	2.3
2020-08-15	0.5	1.3	2020-09-24	0.4	0.4
2020-08-17	0.5	2.5	2020-09-25	0.5	0.5
2020-08-19	1.3	8.3	2020-09-26	Bad weather	
2020-08-21	0.5	4.3	2020-09-27	Bad weather	
2020-08-22	1.5	7.4	2020-10-08	0.7	4.8
2020-08-26	Bad weather		2020-10-09	1.3	3.9
2020-08-27	Bad weather		2020-10-10	0.7	6.6
2020-08-28	Bad weather		2020-10-11	0.6	3.4
2020-09-07	1.0	2.2	2020-10-12	0.7	0.8
2020-09-08	Bad weather		2020-10-13	0.7	0.5
2020-09-09	Bad weather		2020-10-14	Bad weather	
2020-09-10	1.0	2.3	2020-10-17	Bad weather	
2020-09-11	0.5	1.8			
2020-09-12	Bad weather				
2020-09-13	0.4	1.5			

Multiwavelength LC

- Simultaneous observations with several instruments.

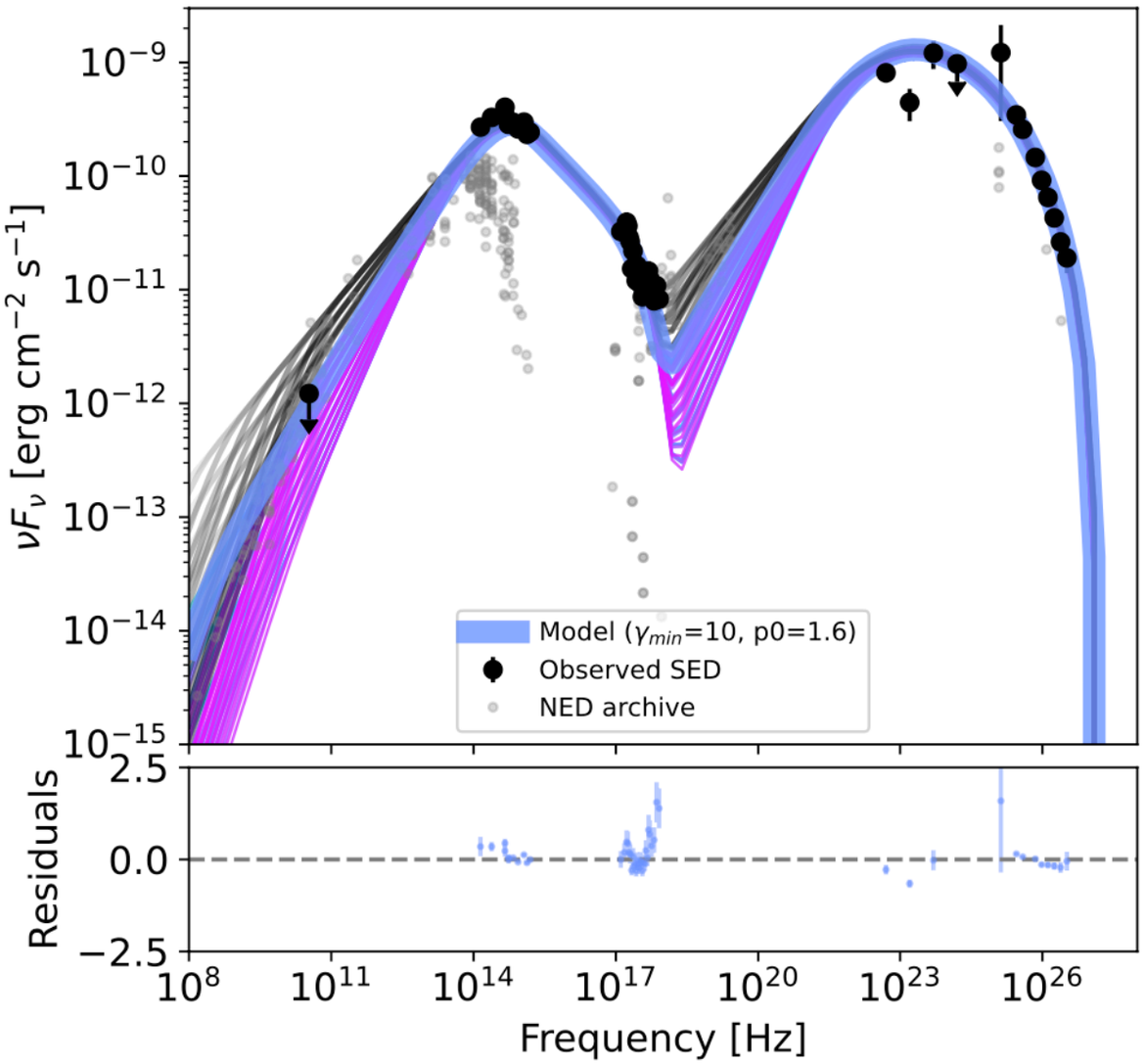


BL Lacertae 19-20 September 2020



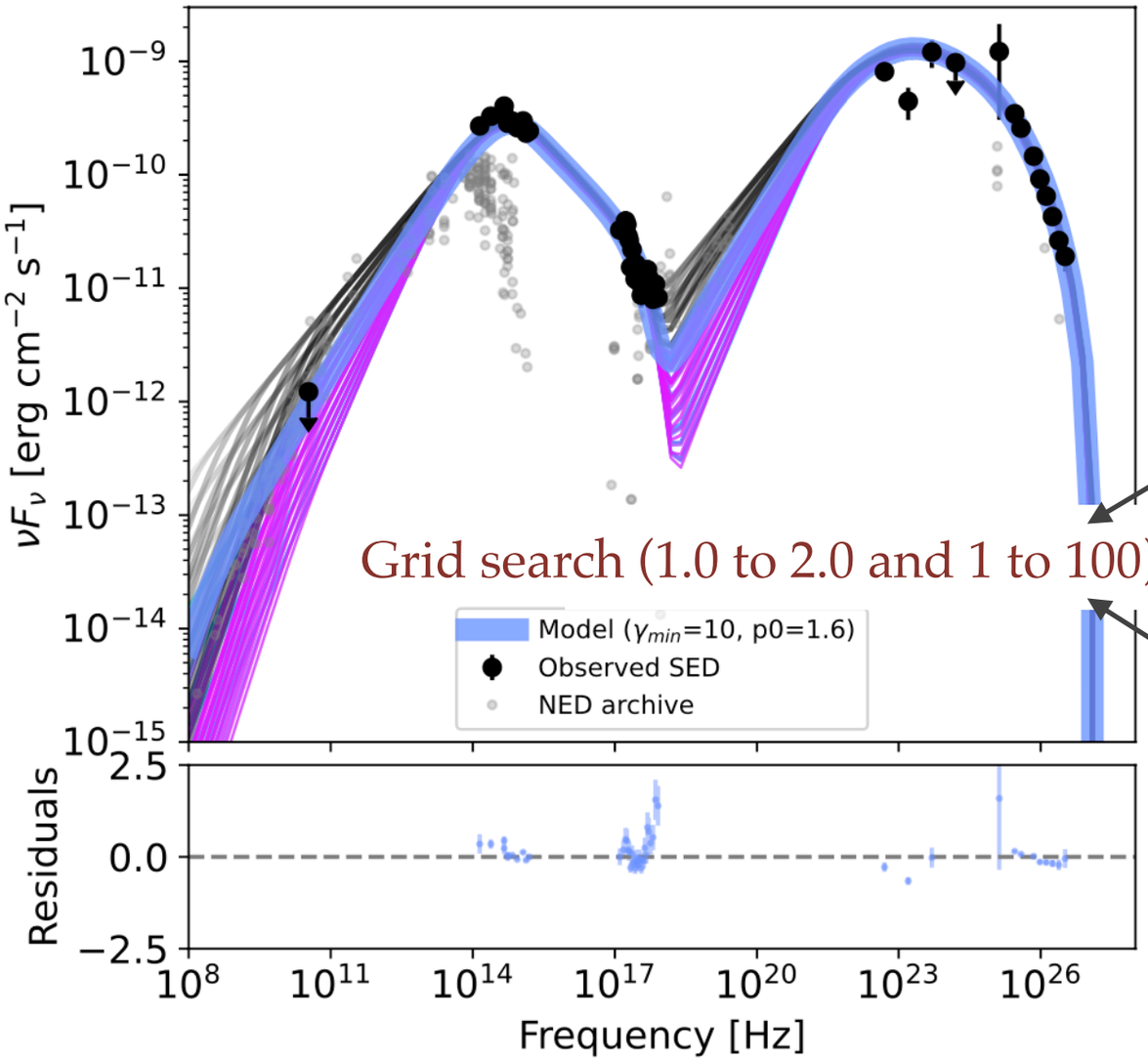
Multiwavelenght SED

BL Lacertae SED modelling - 1 zone SSC



SED modelling results for BL Lacertae on 19-20 September 2020.

BL Lacertae SED modelling - 1 zone SSC



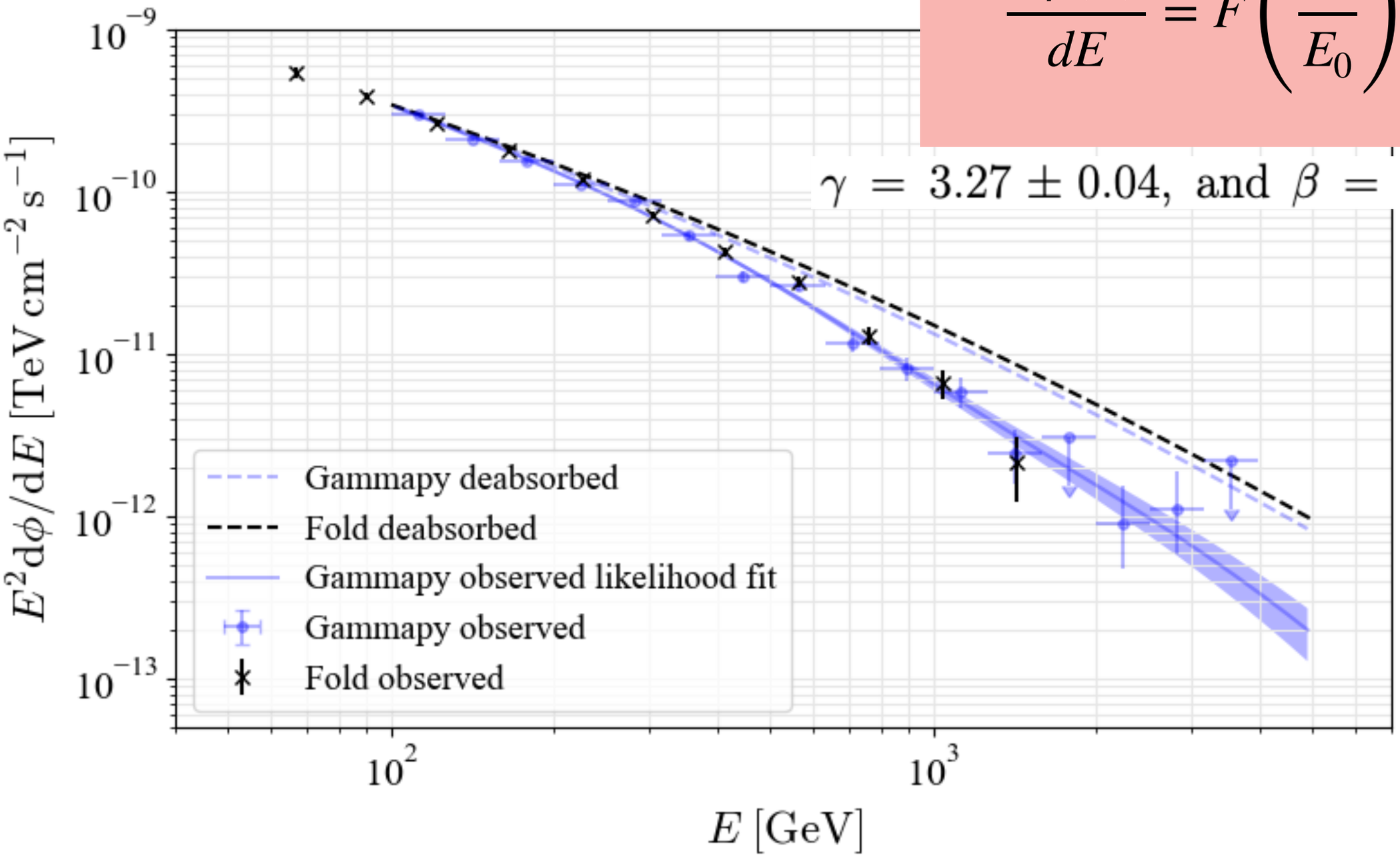
Parameter	Symbol	Best fit value
Electron normalization [$\times 10^{45}$]	K_e	$2.0^{+1.6}_{-0.9}$
Magnetic field [$\times 10^{-2}$ G]	B	$2.2^{+0.5}_{-0.4}$
Doppler factor [$\times 10$]	δ_D	$4.9^{+1.1}_{-0.9}$
Low-energy spectral index	p_0	1.6
High-energy spectral index	p_1	3.9 ± 0.1
Break Lorentz factor [$\times 10^3$]	γ_b	11.0 ± 0.2
Minimum Lorentz factor	$\gamma_{\rm min}$	10
Maximum Lorentz Ffctor [$\times 10^5$]	$\gamma_{\rm max}$	$2.5^{+0.6}_{-0.5}$

SED modelling results for BL Lacertae on 19-20 September 2020.

BL Lacertae SED MAGIC

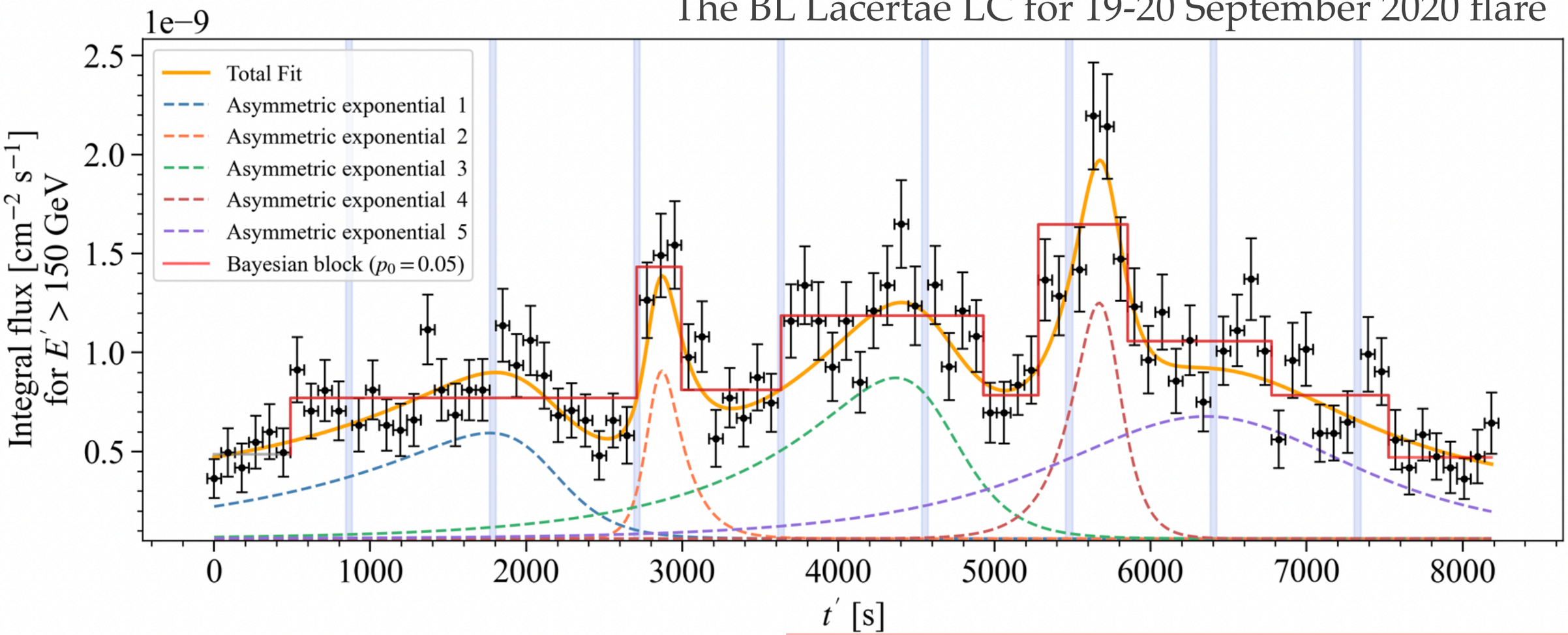
$$\frac{d\phi(E)}{dE} = F\left(\frac{E}{E_0}\right)^{-\gamma-\beta\ln\left(\frac{E}{E_0}\right)}$$

$\gamma = 3.27 \pm 0.04$, and $\beta = 0.09 \pm 0.04$



BL Lacertae - Light curve

The BL Lacertae LC for 19-20 September 2020 flare

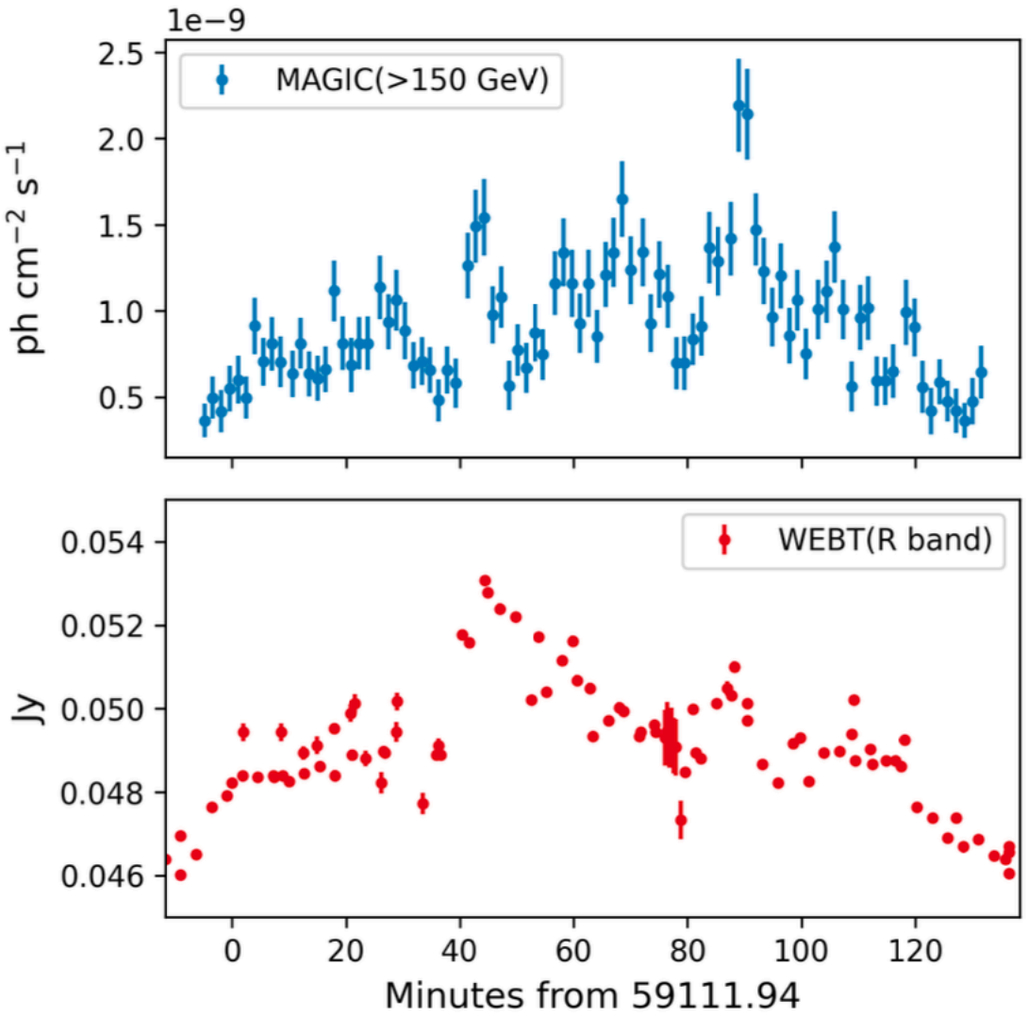


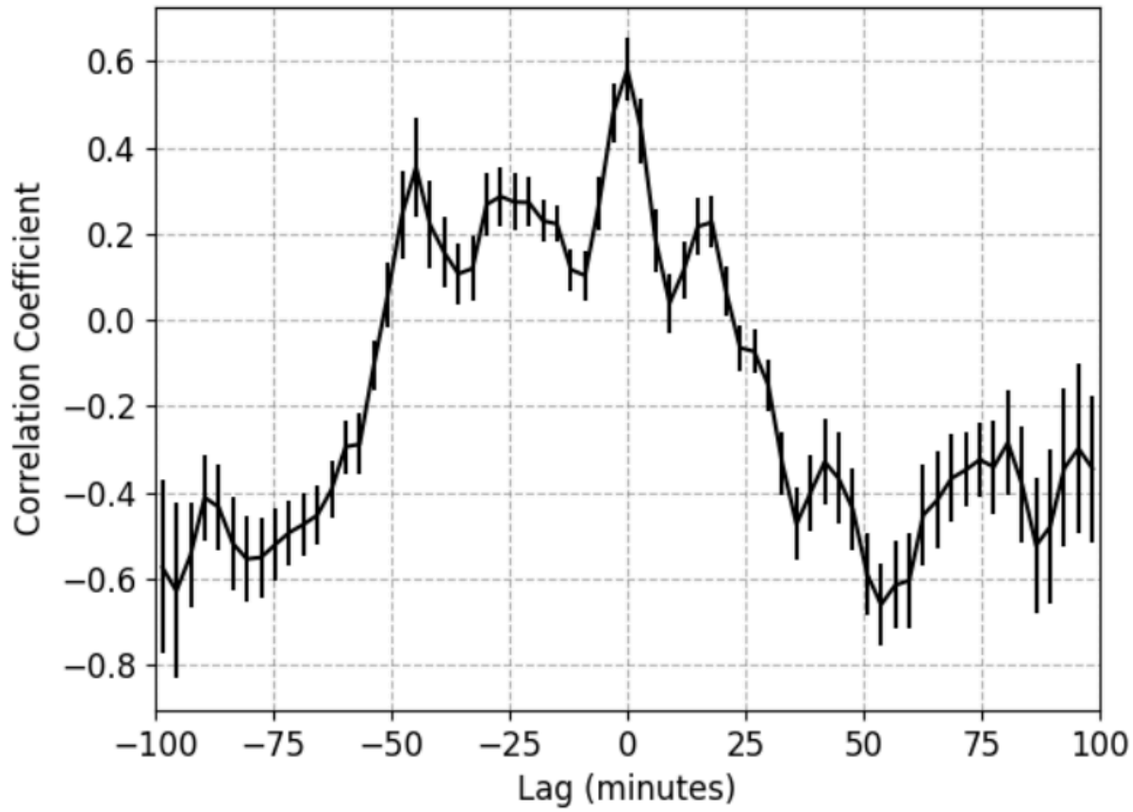
$$F(t) = \sum_{i=1}^{N} \left[\frac{f_{0,i}}{\exp\left(\frac{t_{0,i} - t}{t_{r,i}}\right) + \exp\left(\frac{t - t_{0,i}}{t_{d,i}}\right)} \right] + f_c$$

p-values =4.3%

BL Lacertae - Optical vs VHE

- The DCF indicates no time lag and a correlation coefficient of ~0.6 with a width ±5 minutes between the two light curves.

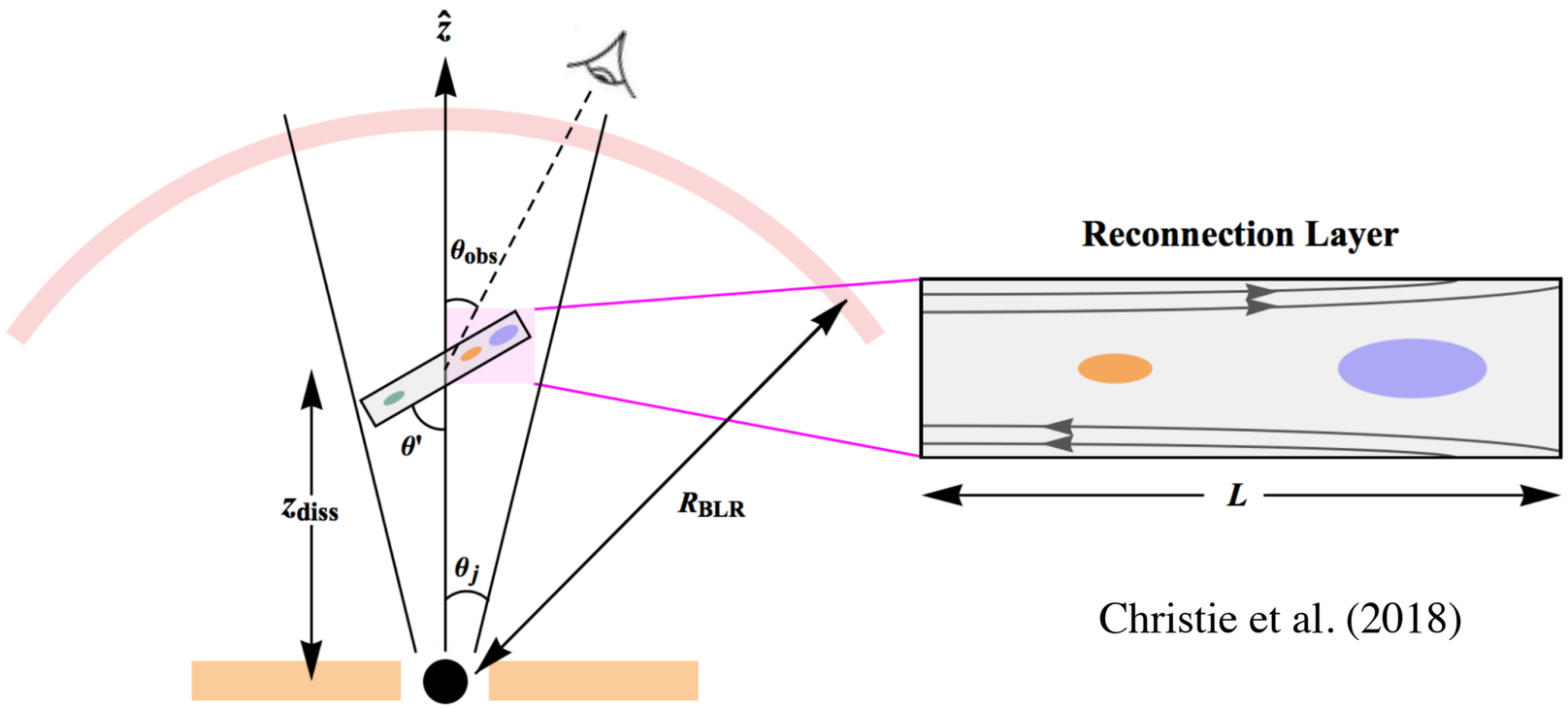




By Ryo Imazawa

Modelling

- Relativistic magnetic reconnection process as a source of blazar emission
- Quasi-spherical plasmoids, containing relativistic particles and magnetic fields, associated with the emission sites in blazar jets.
- Magnetic reconnection enables localized particle acceleration within the jet, it is capable to explain the extremely fast variability observed on timescales of just a fewmminutes.



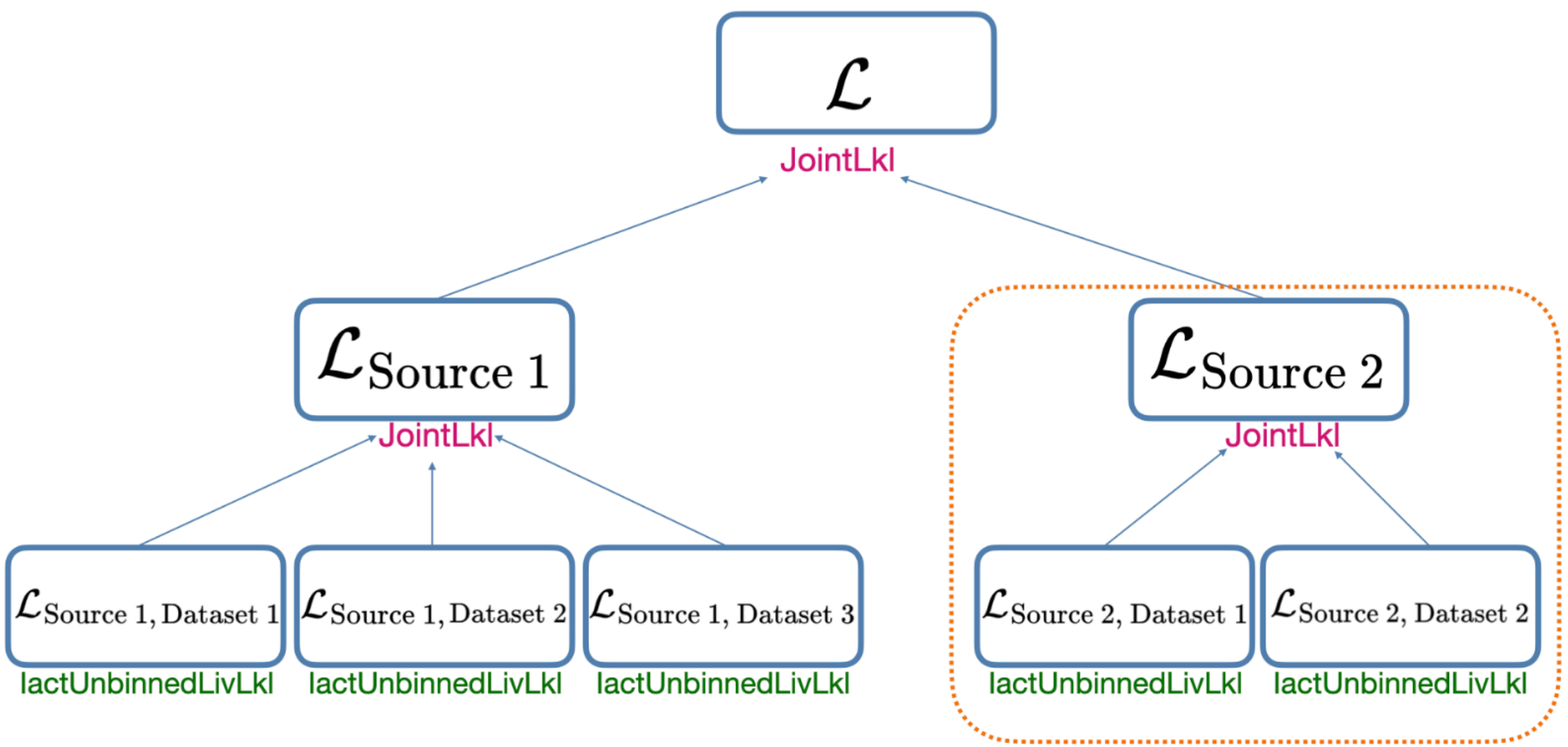
Christie et al. (2018)

BL Lacertae future work

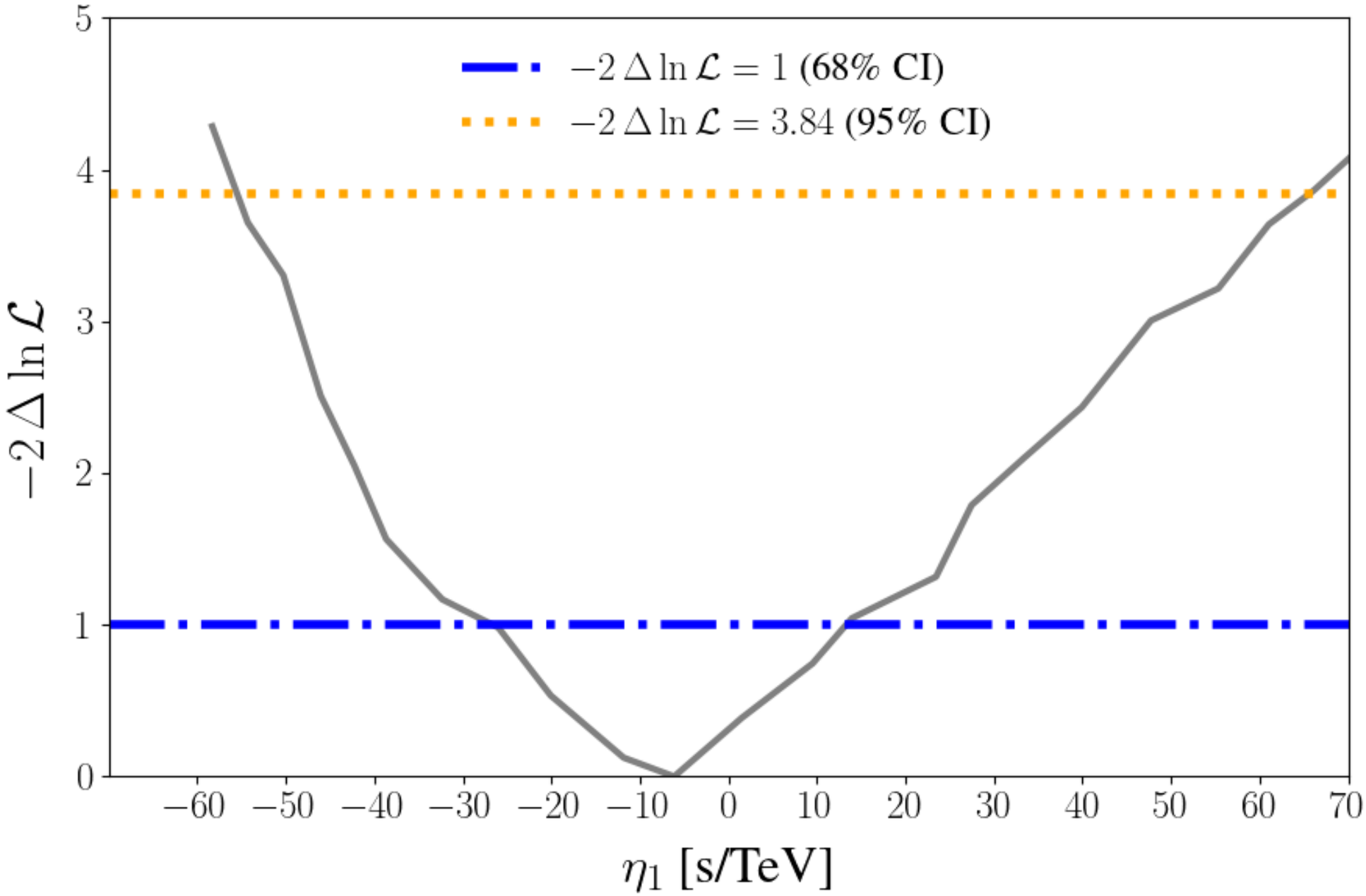
- Low data coverage in radio and MeV range → out of our control.
- One zone SSC shows come caveats → under our control.
- Complex light curve structure requires improved modelling → an ongoing effort.
- Fast variability description → ongoing effort.

gLike

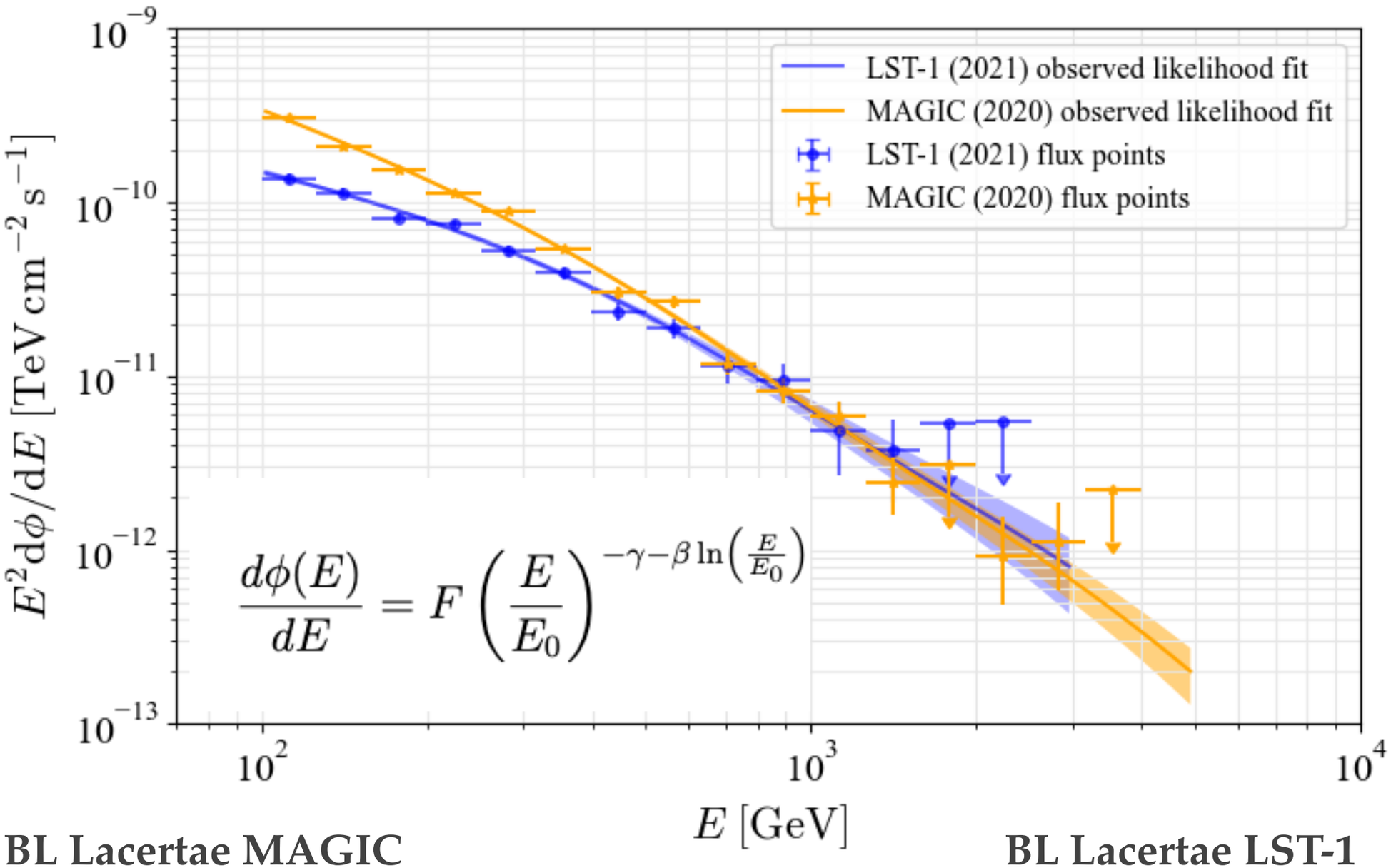
- ROOT-based code framework for the numerical maximisation of joint likelihood functions.
- The joint likelihood function has one free parameter and as many nuisance parameters as wanted.



MAGIC:


$-2\,\Delta \ln \mathcal{L} = 1$ (68% CI)
$-2\,\Delta \ln \mathcal{L} = 3.84$ (95% CI)
$-2\,\Delta \ln \mathcal{L}$
η_1 [s/TeV]
5
4
3
2
1
0
−60
−50
−40
−30
−20
−10
0
10
20
30
40
50
60
70

BL Lacertae falare observed by LST-1 on 8–9 August 2021



BL Lacertae MAGIC

$\gamma = 3.27 \pm 0.04$

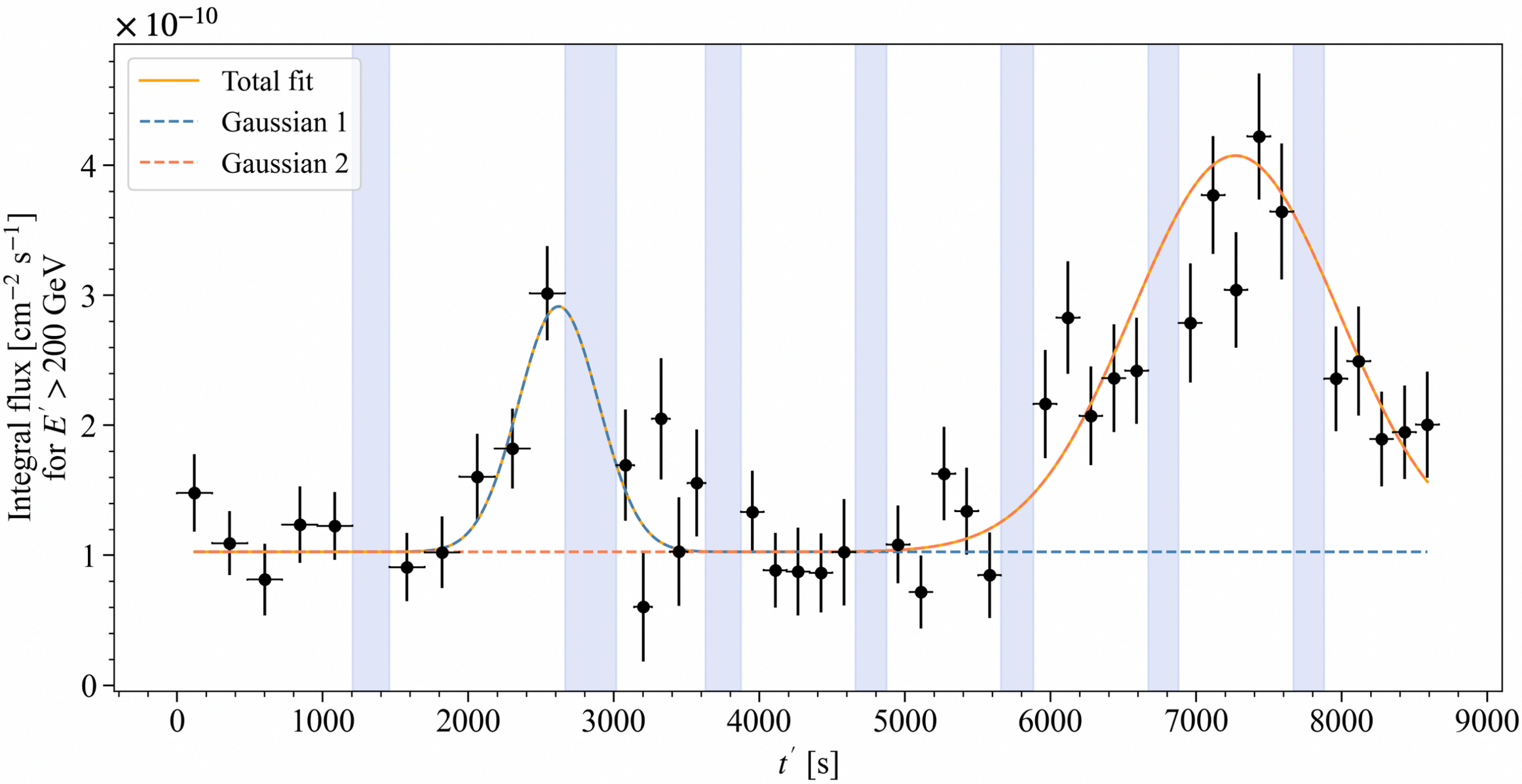
$\beta = 0.09 \pm 0.04.$

BL Lacertae LST-1

$\gamma = 3.01 \pm 0.05,$

$\beta = 0.13 \pm 0.07.$

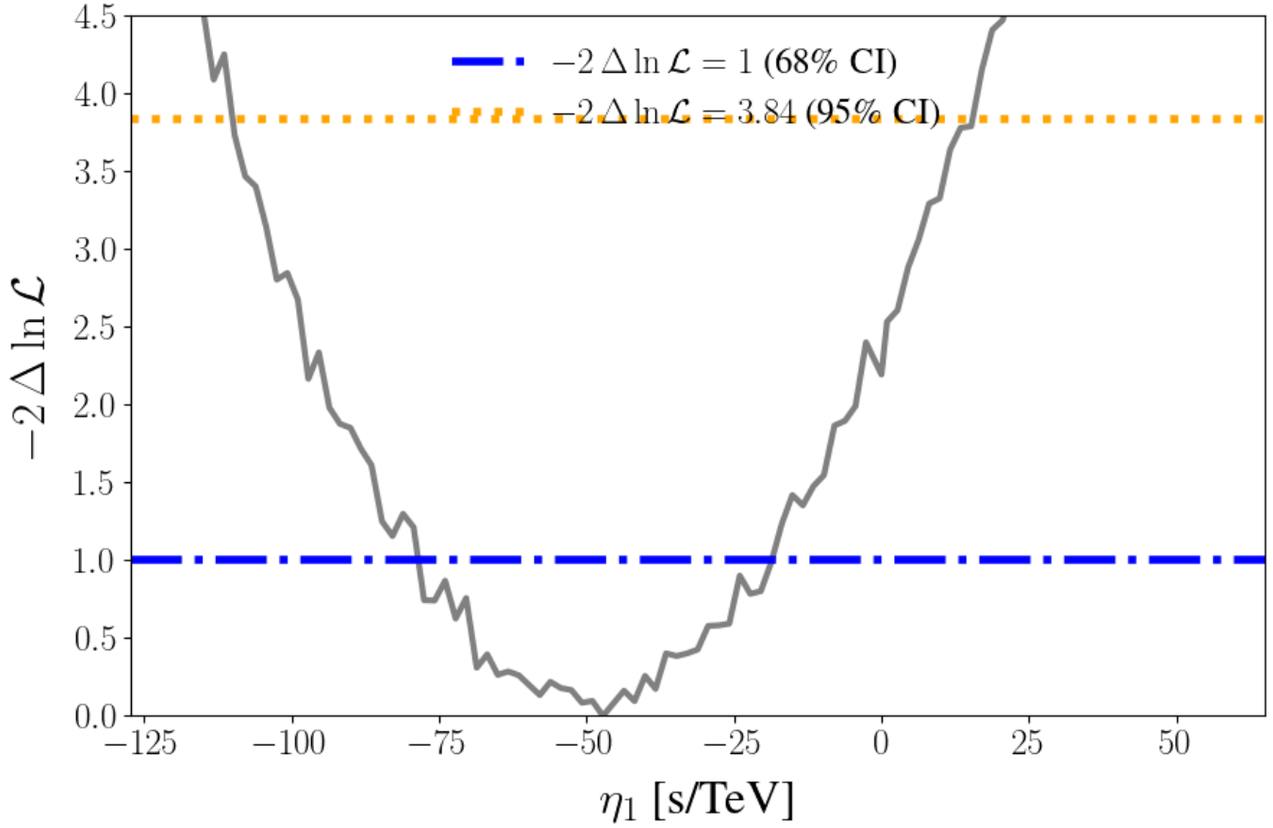
BL Lacertae falare observed by LST-1 on 8–9 August 2021



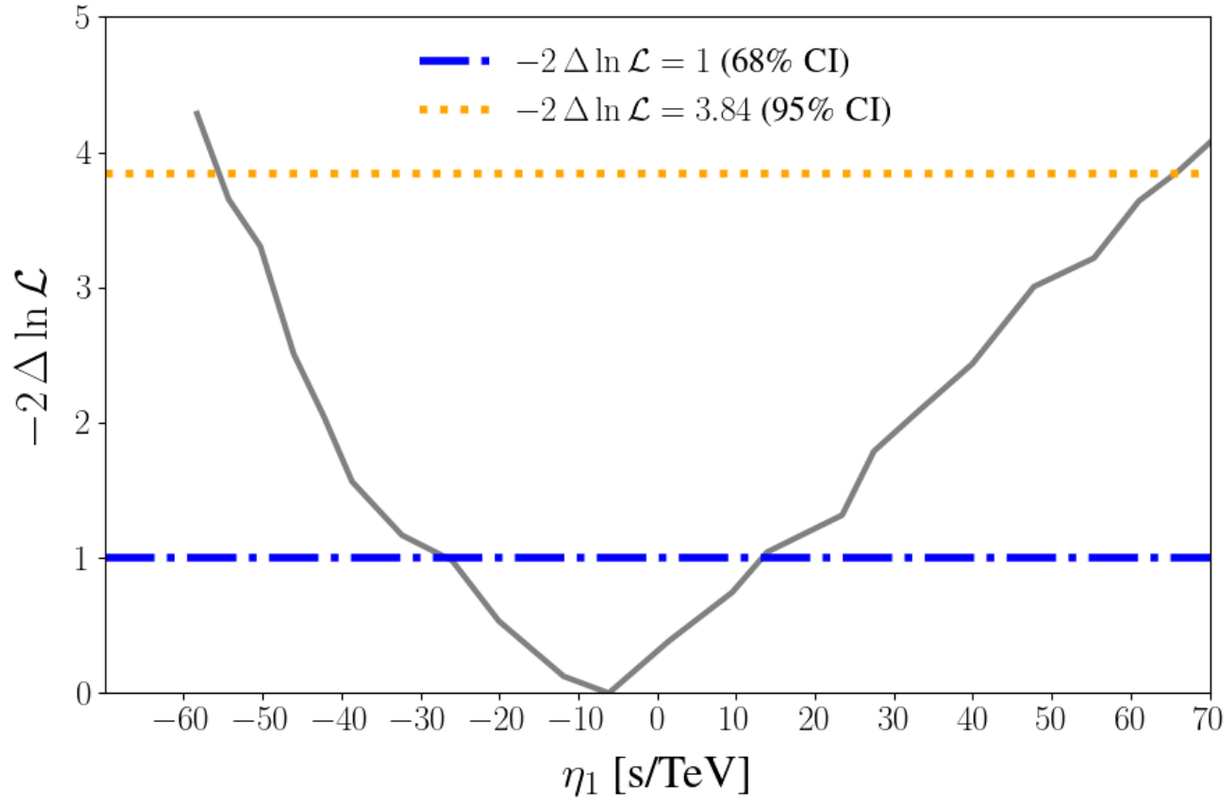
$$F(t) = A_1 \exp\left(-\frac{(t-\mu_1)^2}{2\sigma_1^2}\right) + A_2 \exp\left(-\frac{(t-\mu_2)^2}{2\sigma_2^2}\right) + C_0,$$

Results

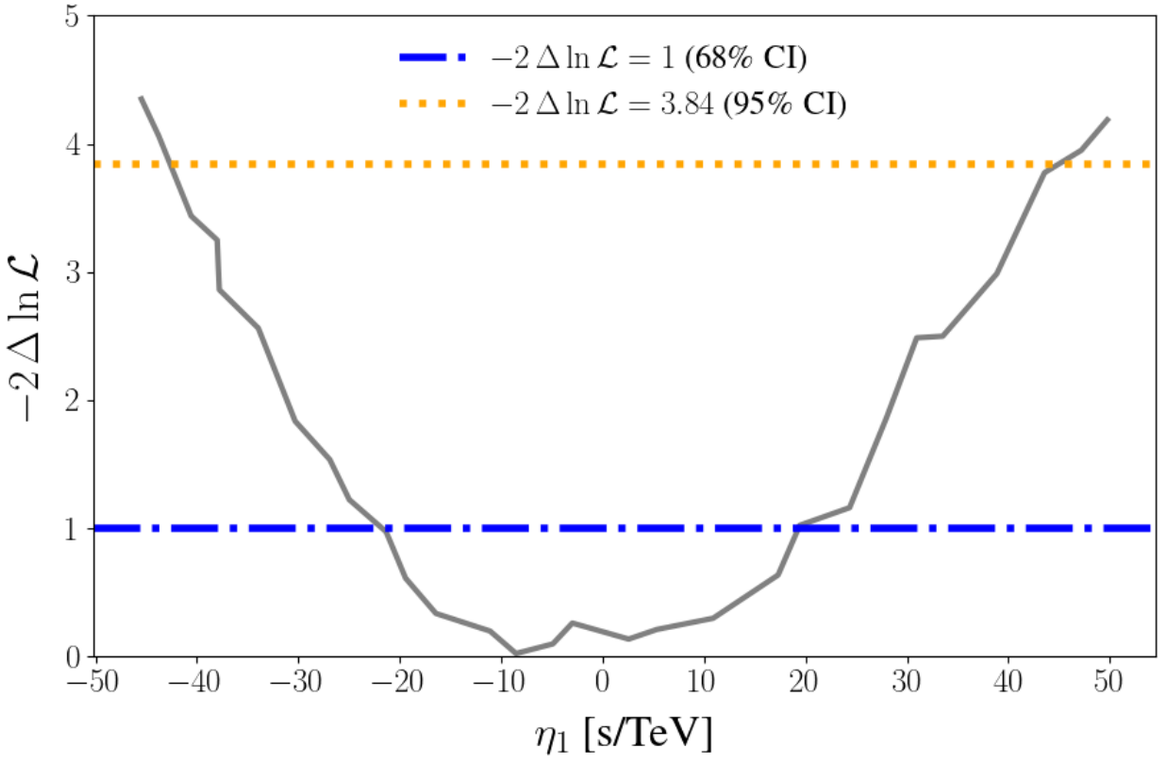
MAGIC



LST-1



MAGIC + LST-1



Combined LIV searches using BL Lacertae flares observed with MAGIC and LST-1

	MAGIC	LST-1	Combined
Superluminal	5.5×10^{17}	2.8×10^{17}	7.2×10^{17}
Subluminal	4.8×10^{17}	1.9×10^{18}	7.0×10^{17}

Obtained limits on the QG energy scale for the linear scenario in [GeV].

Outlook

- BL Lacertae:
  - Better modelling of the LC for the MAGIC 2020 flare.
  - More complex SED modelling.
  - LC modelling.

- LIV:
  - We need to combine even more sources: γLIV WG
  - Combine multiple effects, not just *time delay*.

Acknowledgements

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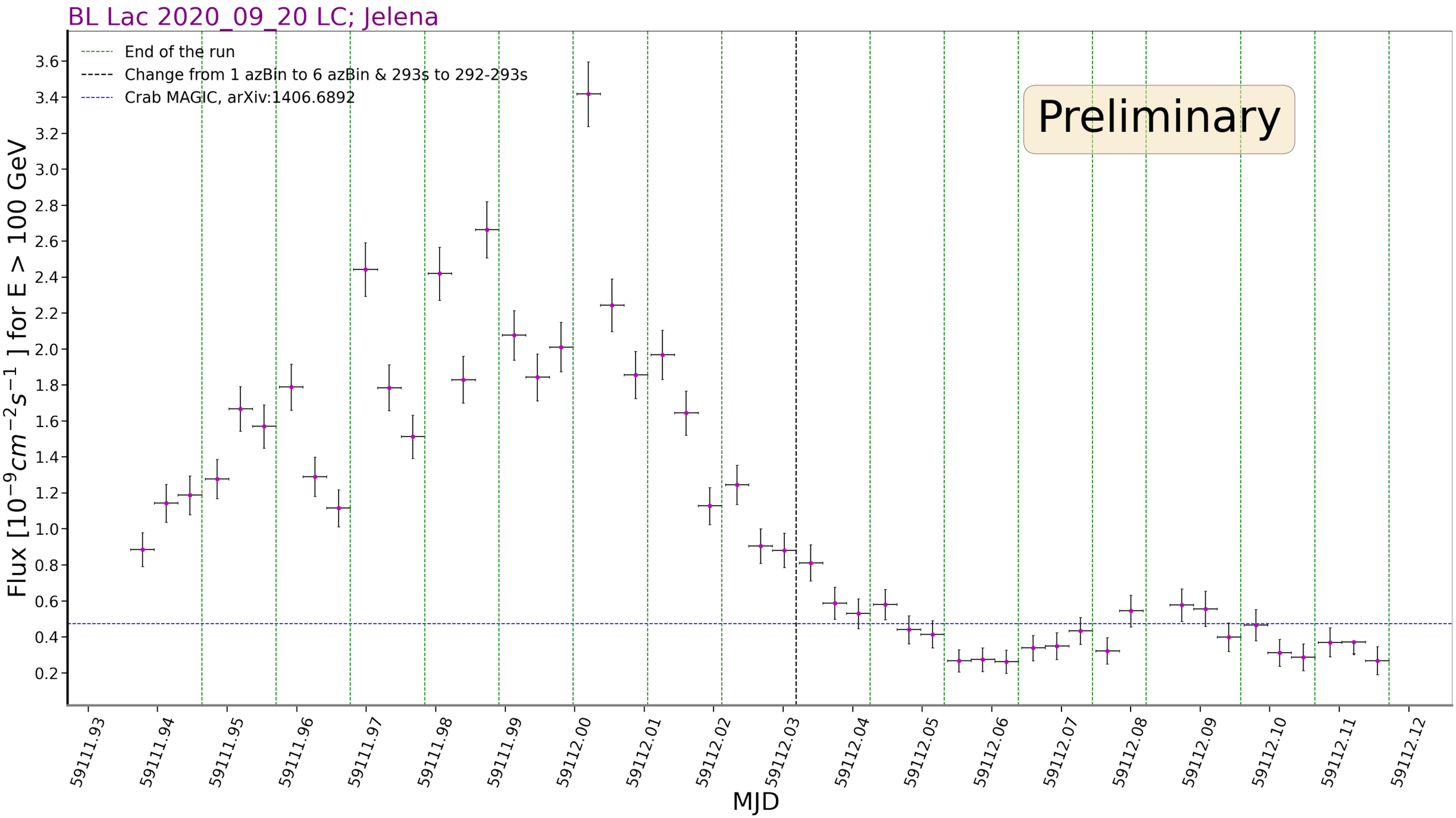
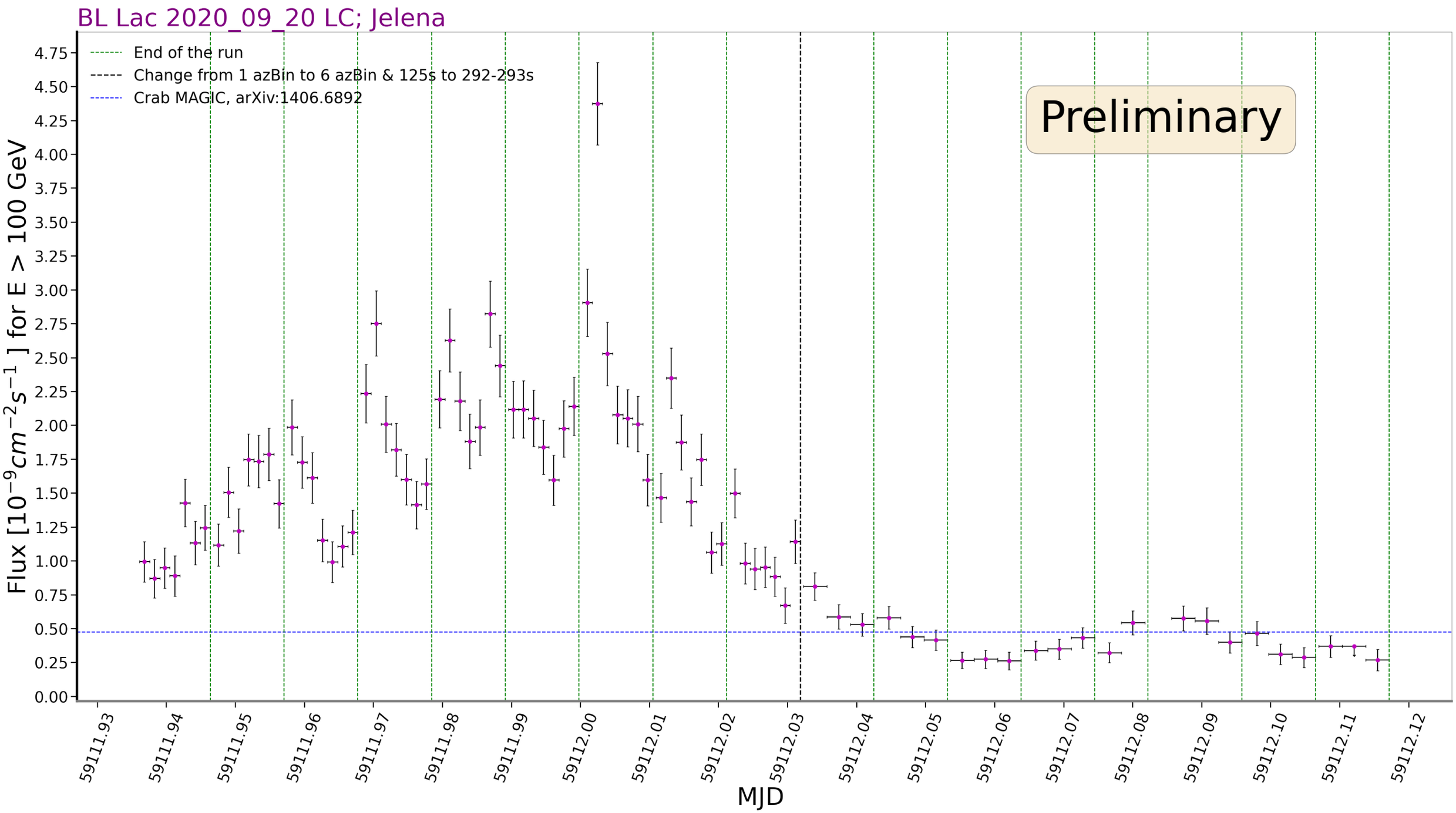
NextGenerationEU

581-UNIOS-102

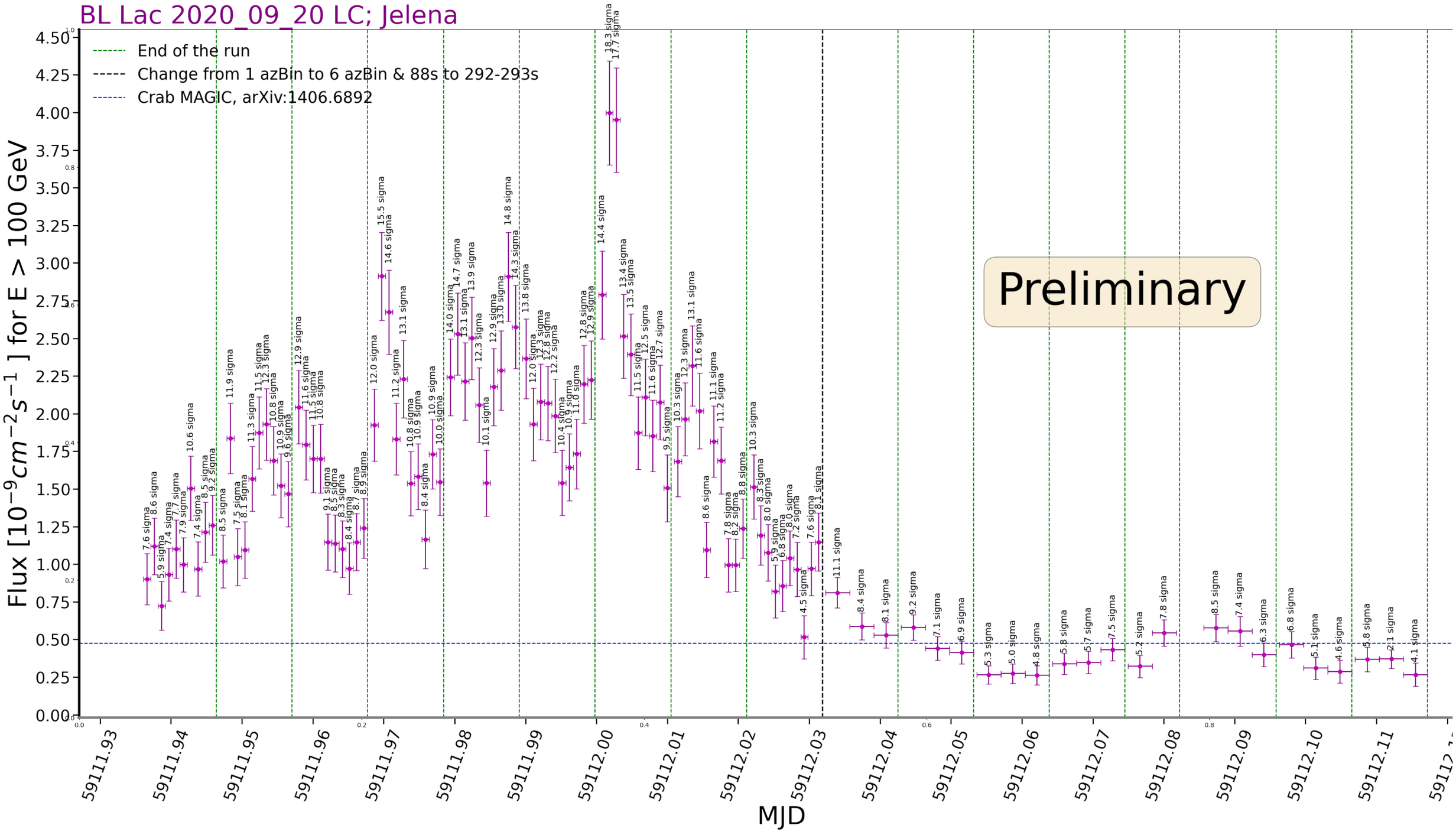
BL Lacertae 20/09/2020 LC - 5 min



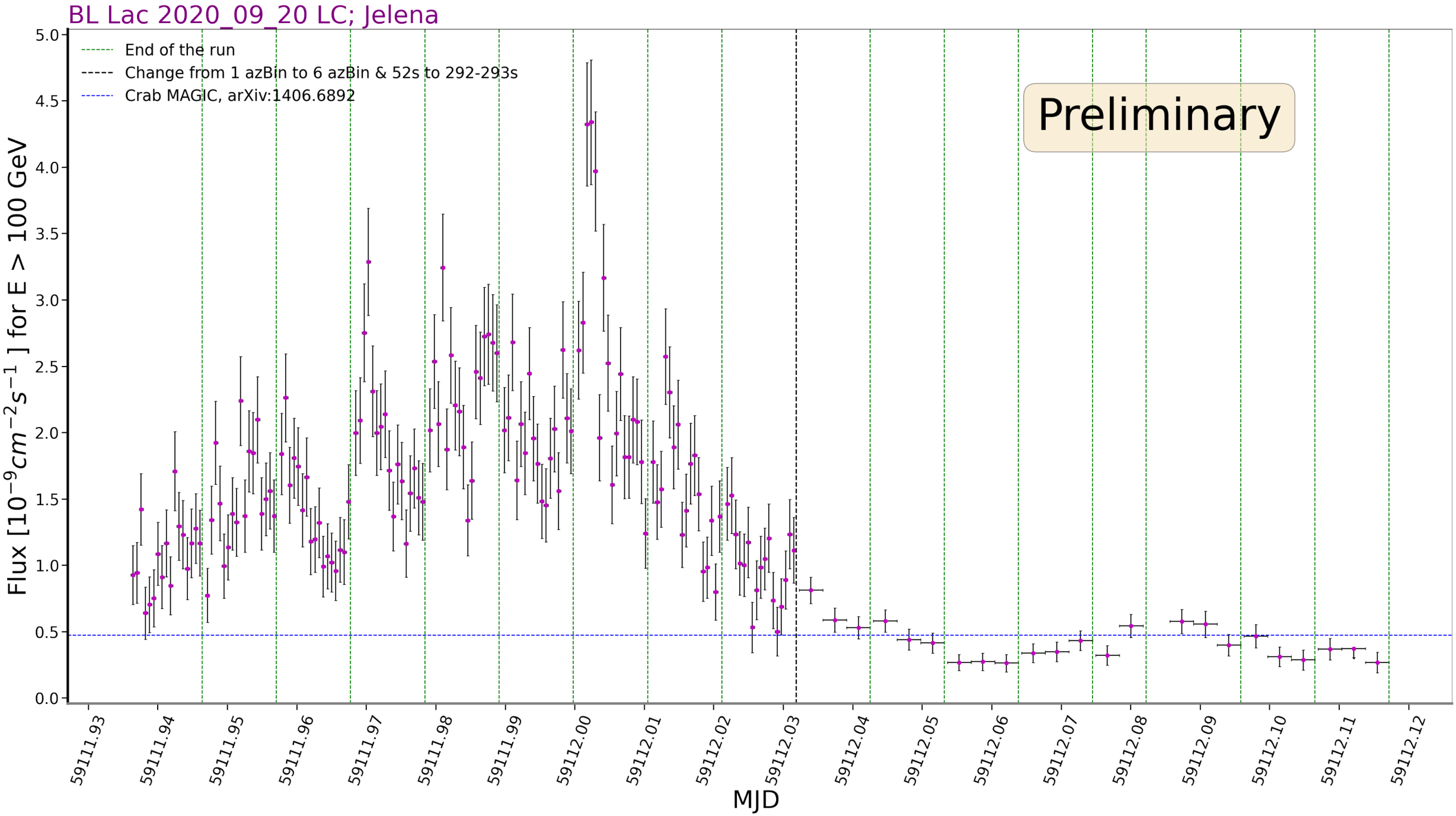
BL Lacertae 20/09/2020 LC - 2 min



BL Lacertae 20/09/2020 LC - 1.5 min



BL Lacertae 20/09/2020 LC -1 min



LC 22s (first part)

BL Lac 2020_09_20 LC; Jelena