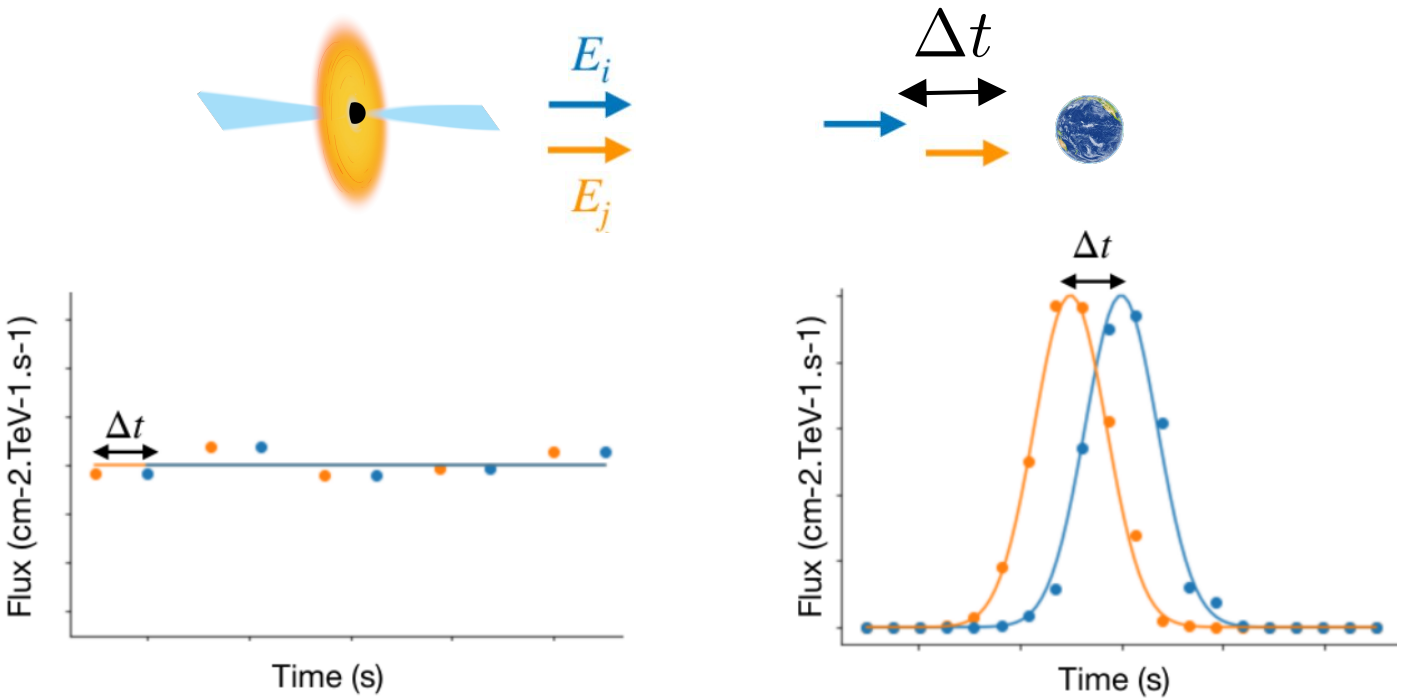
Lorentz invariance violation (LIV)

$$E^2 = p^2c^2 \rightarrow E^2 = p^2c^2 \times \left[1 \pm \sum_{n=1}^{\infty} \alpha_n \left(\frac{E}{E_{QG}}\right)^n\right] \rightarrow v_\gamma(E_\gamma) \neq c$$



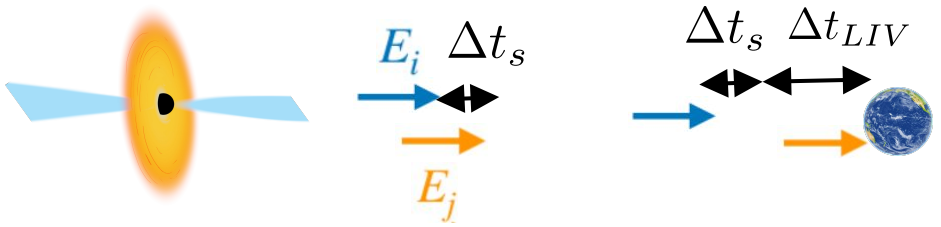
$$\lambda_n = \frac{\Delta t_n}{\Delta E_n \kappa_n(z)} = \pm \frac{n+1}{2H_0 E_{QG}^n}$$

Limit at n=1

→ Blazars, GRBs, pulsars

→ Intrinsic lag

$$\Delta t = \Delta t_{LIV} + \Delta t_{source}$$



Δt_{source}	Δt_{LIV}
Redshift-independent	Redshift-dependent
Sources and flares -dependent	Sources and flares -independent

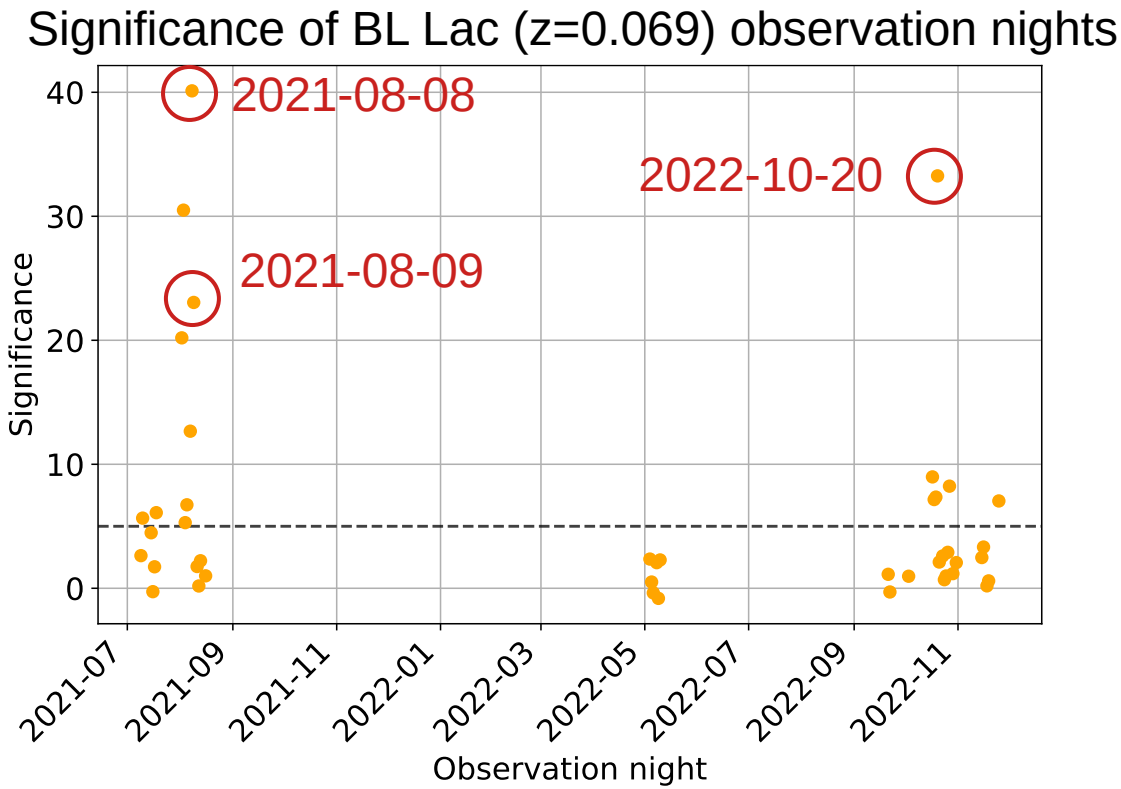
→ Combine different flares and sources

→ Consortium H.E.S.S. , MAGIC, VERITAS, LST-1

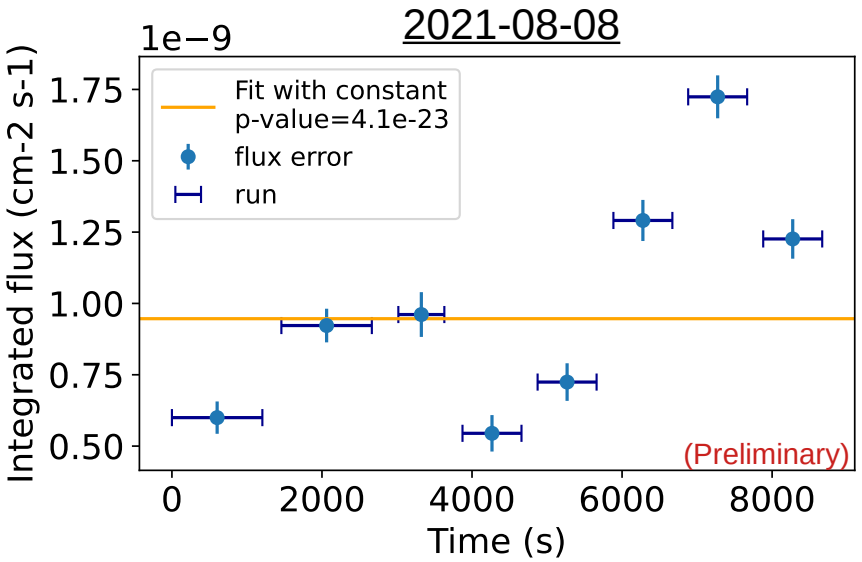
All blazar data of LST-1 from January 2021 to June 2023

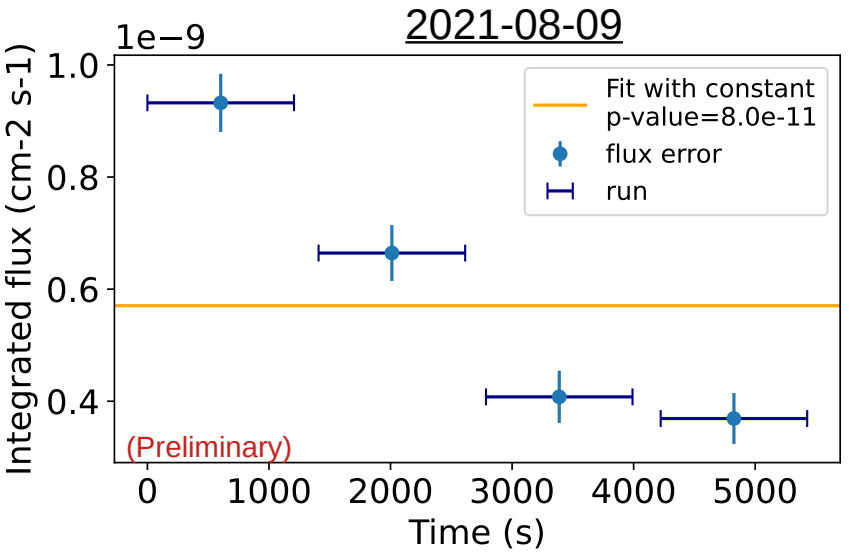
- Standard run quality selection
- Standard gammaness cut at 0.6
- All sky MC IRFs and RFs
- Energy range = [150GeV ; 10TeV]

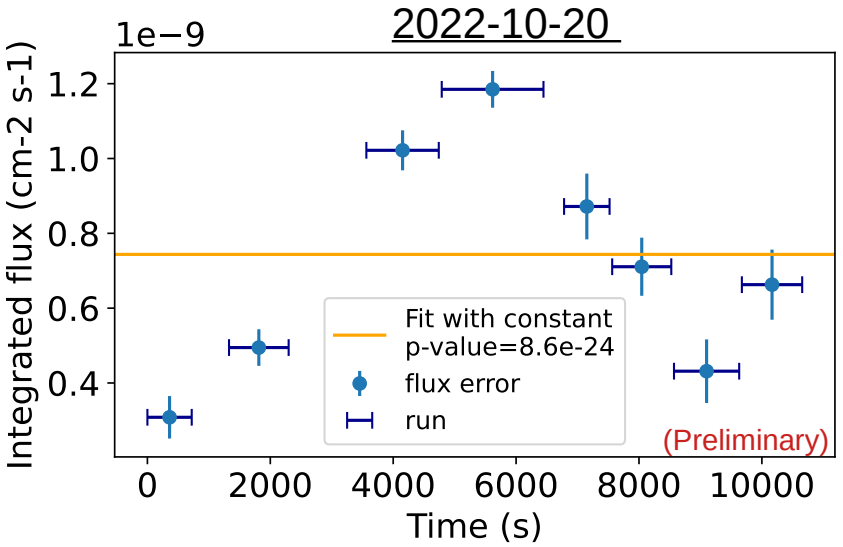
- Search for significant nights (Li&Ma) , S > 5σ
- Variability : fit lightcurve with constant function, variable if pvalue < 5σ



BL Lac variable nights



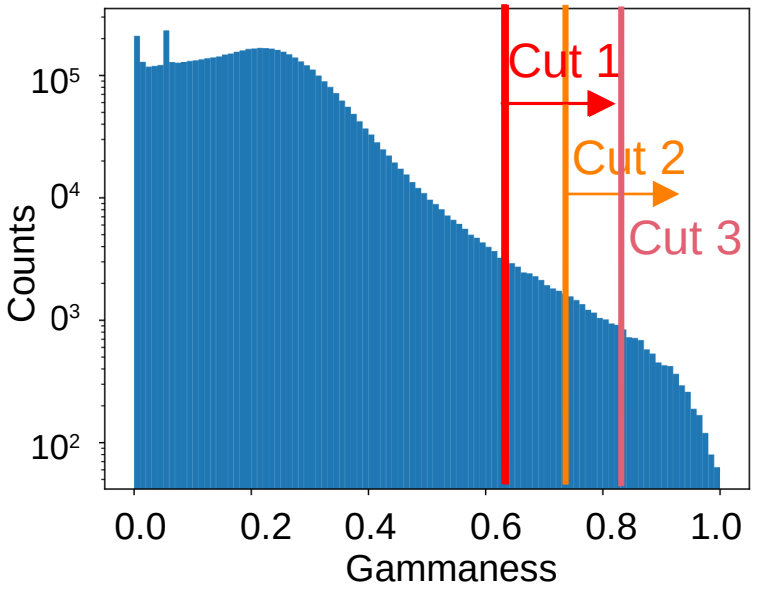


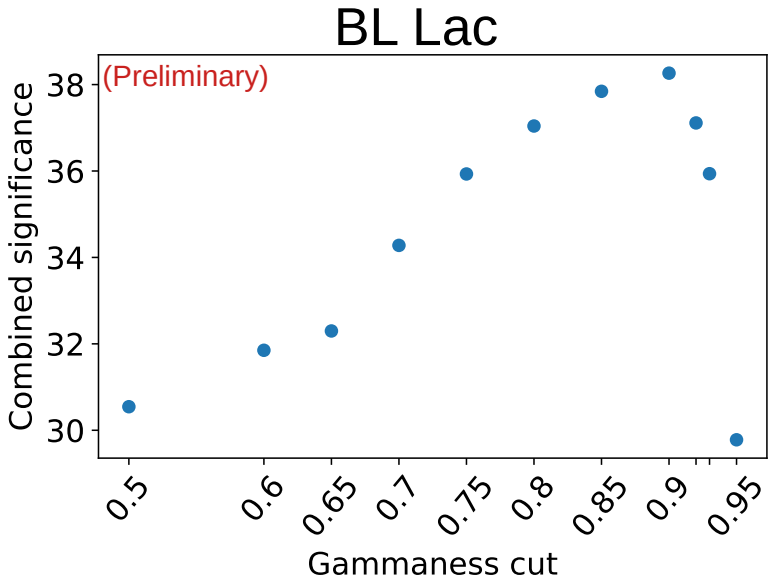


Non-variable sample

↓

Select different gammaness cuts and search for the significance





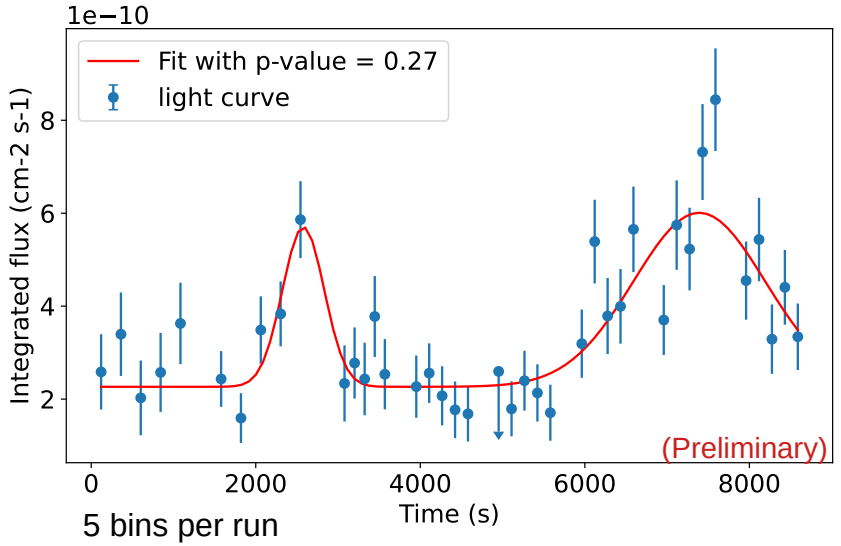
$$S_{cut} = \sqrt{\sum_{non-var\ night} S_n^2}$$

→ For BL Lac : 0.9

Search for a variability template and extract sample properties (energetic and temporal distributions)

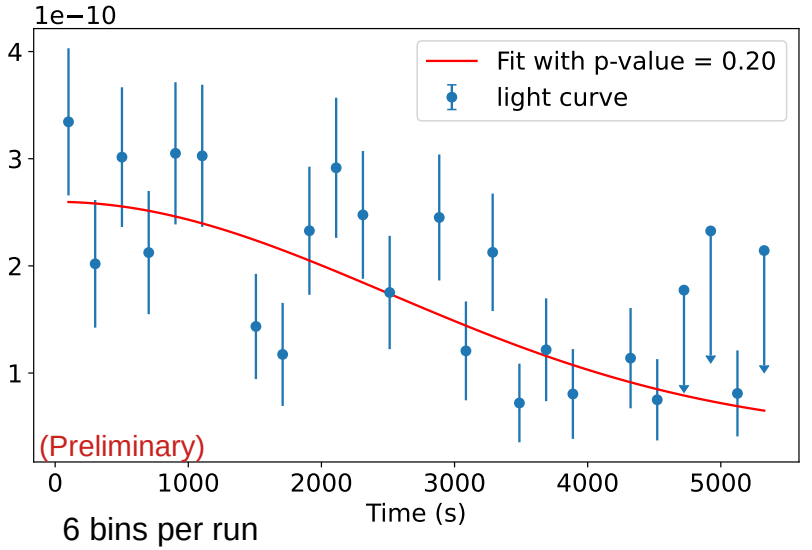
- Define two energy bins : **lower** and **higher** than median of counts
- Find a parametric model for the lightcurve of the low energies sample : selected if p-value > 0.05 (2σ)
- No significant disagreement between low and high energies

BL Lac 2021-08-08



5 bins per run

BL Lac 2021-08-09

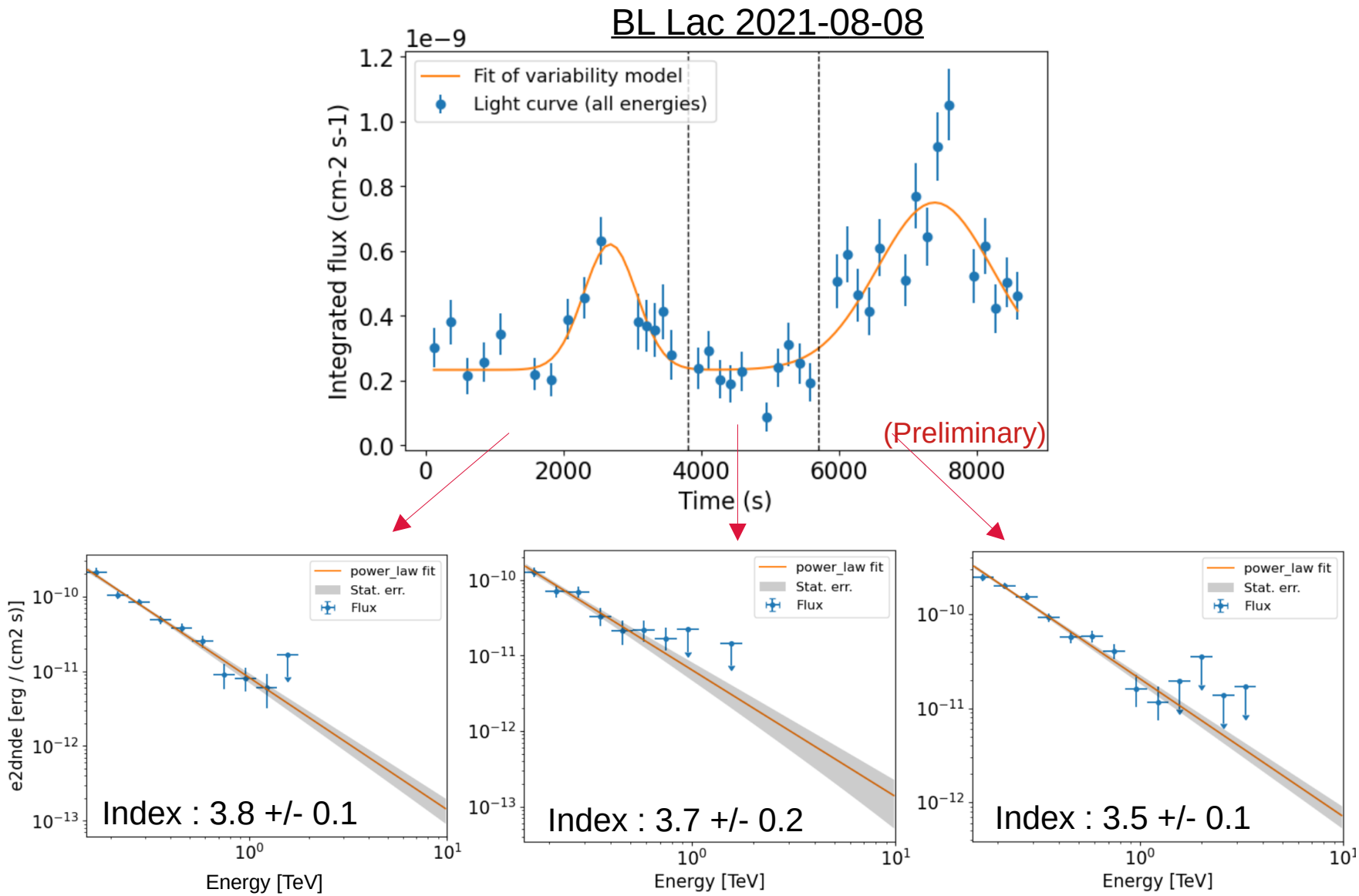


6 bins per run

$$f(t) = A_1 e^{-\frac{(t-\mu_1)^2}{2\sigma_1^2}} + A_2 e^{-\frac{(t-\mu_2)^2}{2\sigma_1^2}} + C_0$$

$$g(t) = A e^{-\frac{(t-\mu)^2}{2\sigma^2}} + C$$

- No significant time-variation of spectra parameters

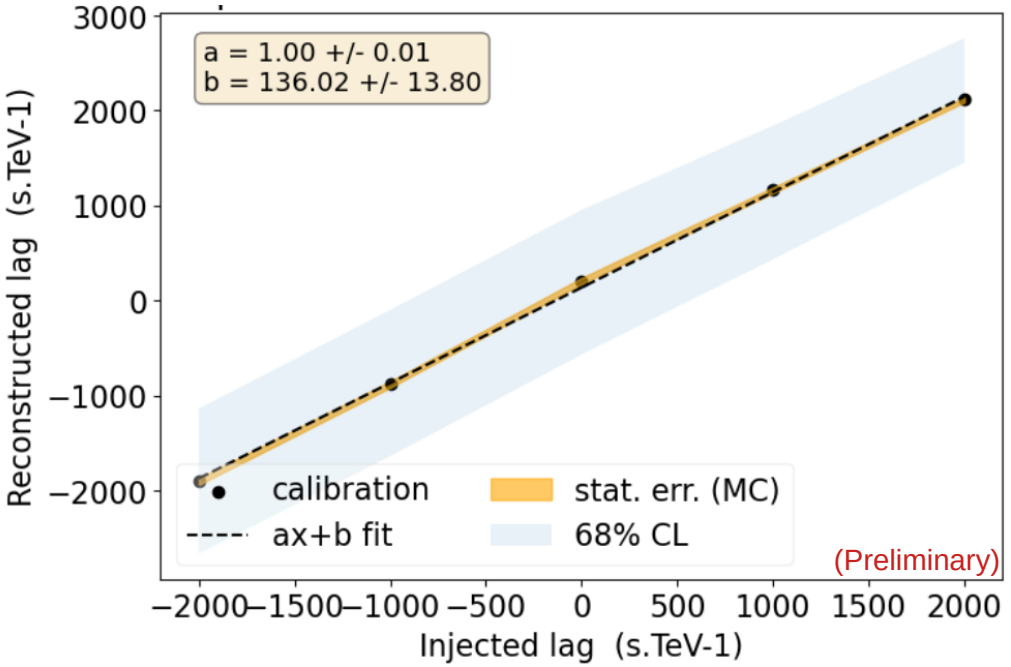


- LIVelihood software : likelihood method
- Lag λ = free parameter that minimizes the likelihood

Sample simulations to validate LIV analysis

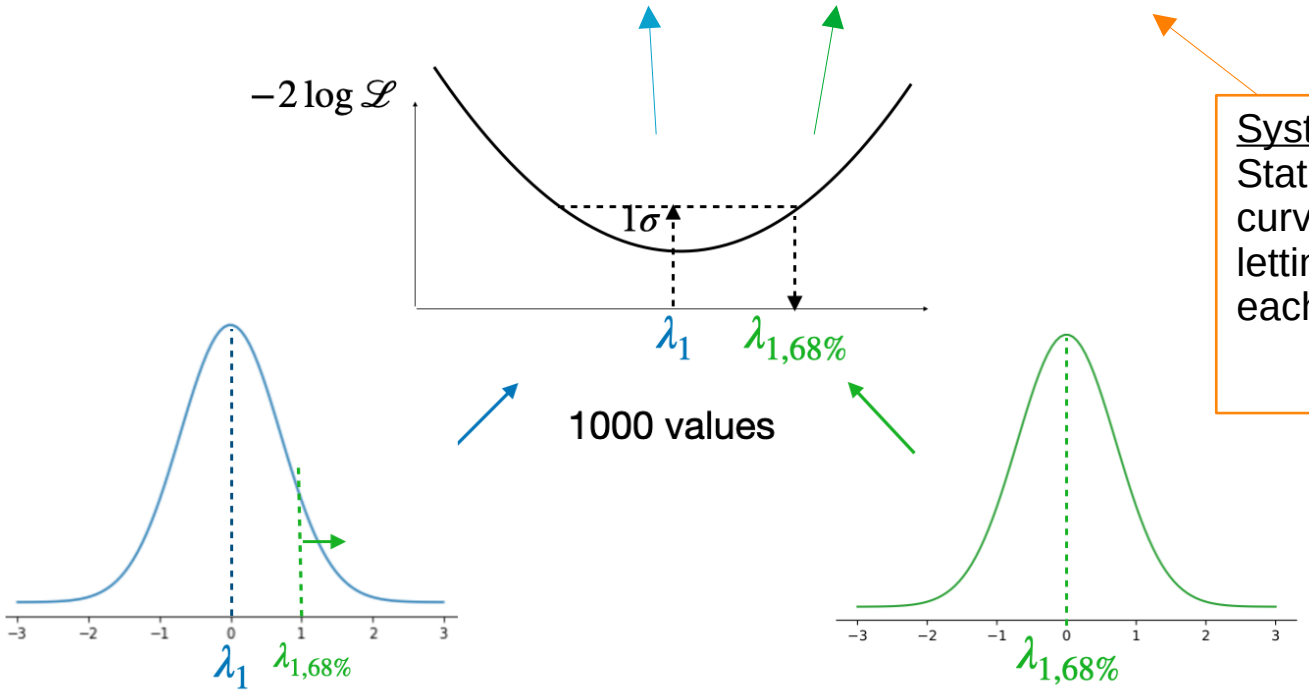
- Perform 1000 dataset simulations
- Calibration : inject lag to verify that LIVelihood reconstructs it well

BL Lac 2021-08-08 and 08-09 combined



LIV analysis on real data

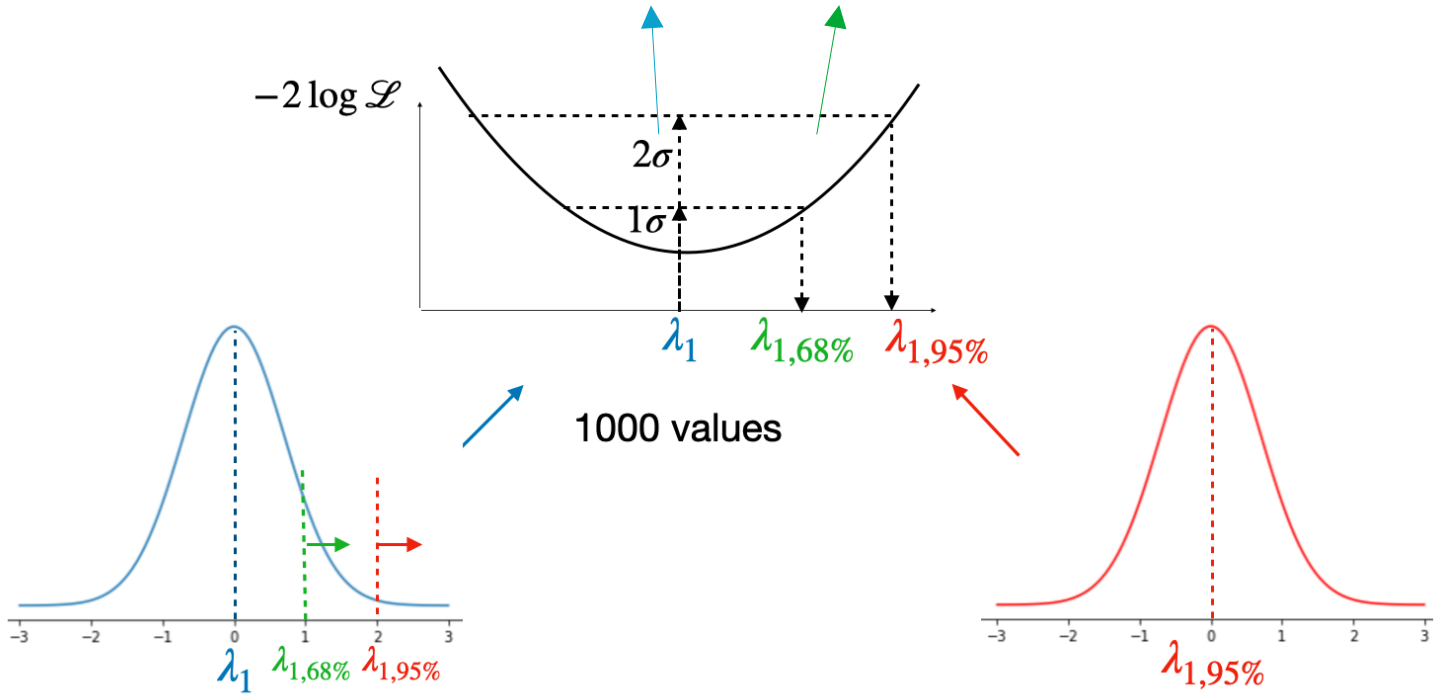
Time delay : $\lambda_1 = (2060\ ^{+2811}_{-2899}\ ^{+2479}_{-2143})$ s.TeV^{-1}



Systematics :
Statistical uncertainty of the light curve template : obtained by letting all parameters free in each of the 1000 simulations

LIV analysis on real data

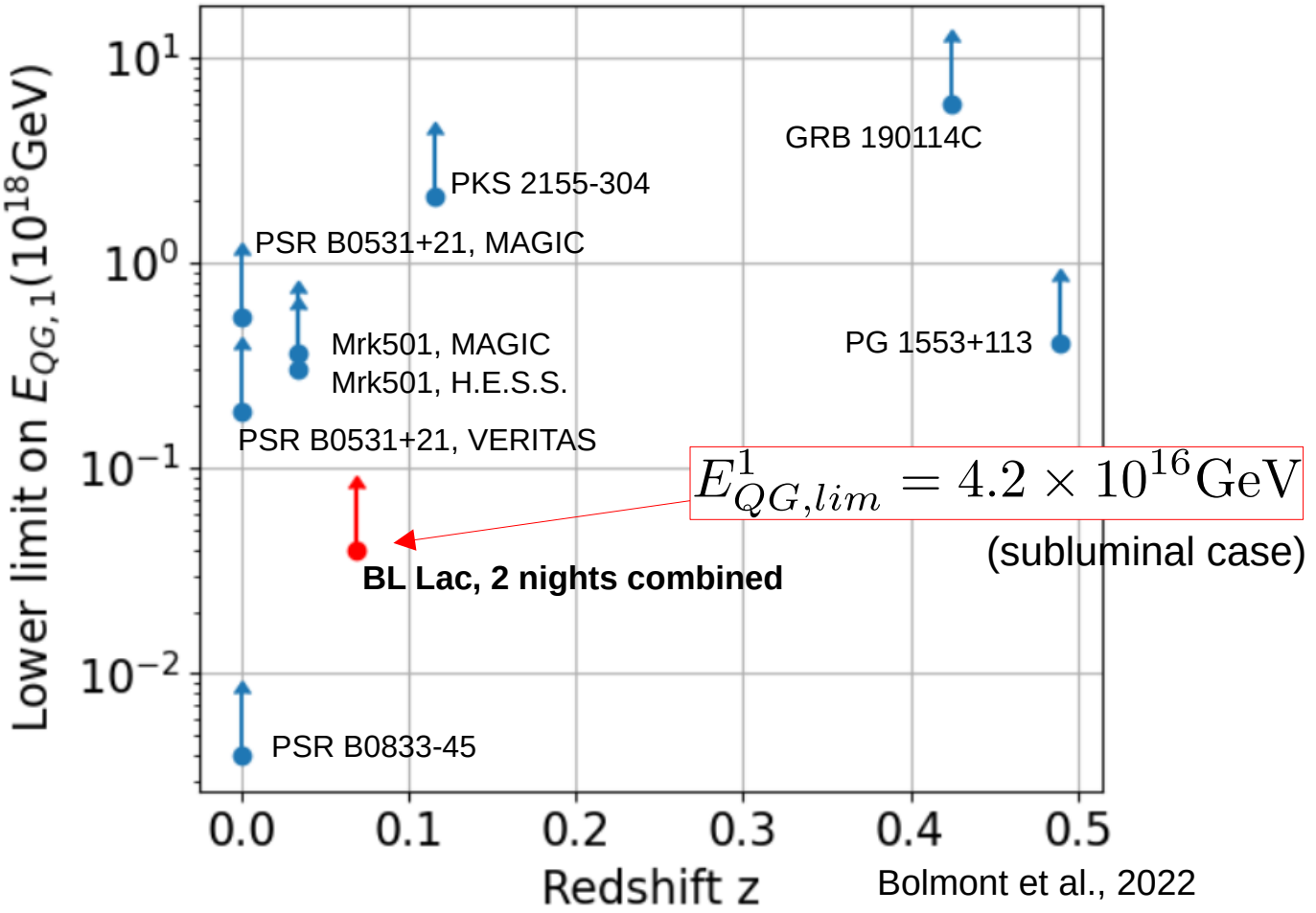
Time delay : λ_1 = (2060 $^{+2811}_{-2899}$ $^{+2479}_{-2143}$)s.TeV^{-1}



Use $\lambda_{1,95\%} = \pm\dfrac{n+1}{2H_0 E^1_{QG,lim}}$ to extract : $E^1_{QG,lim} = 4.2 \times 10^{16}\mathrm{GeV}$

(subluminal case)

Comparison with other limits



$$E^{1}_{QG,lim} = 4.2 \times 10^{16}\mathrm{GeV}$$

(subluminal case)

Bolmont et al., 2022

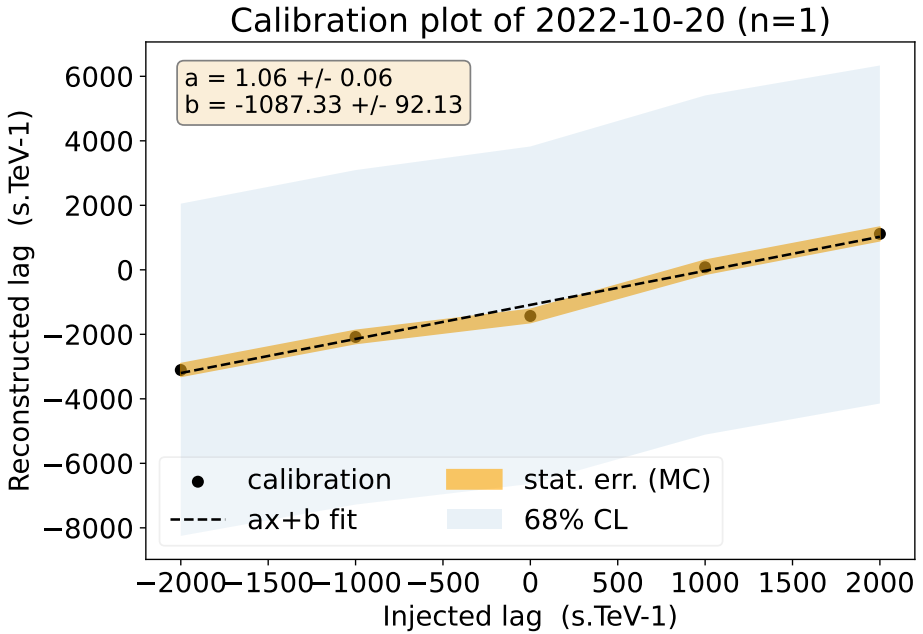
Ongoing work :

- Until now, used arbitrarily Emin = 0.15TeV ;

  Updated the analysis with a safe mask threshold on the energy range : percentage of the effective area (10%) ;

  21-08-08 : Emin = 0.25TeV
  21-08-09 : Emin = 0.19TeV
  22-10-20 : Emin = 0.40TeV

→ Combining 3 nights : offset in 2022-10-20 calibration plot → investigating



- Producing data for gammaness E-dependent (θ² E-dependent in the future)