Lorentz invariance violation search with the CTAO Large-Sized Telescope

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for the CTAO-LST project

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Supported by:

I- LIV search with time delays Δt of photons

- Looking for a **lateshift** in arrival time of photons from sources:

$$\lambda = \frac{\Delta t}{\kappa(z)\Delta E} = \pm \frac{1}{H_0 E_{LIV}}$$

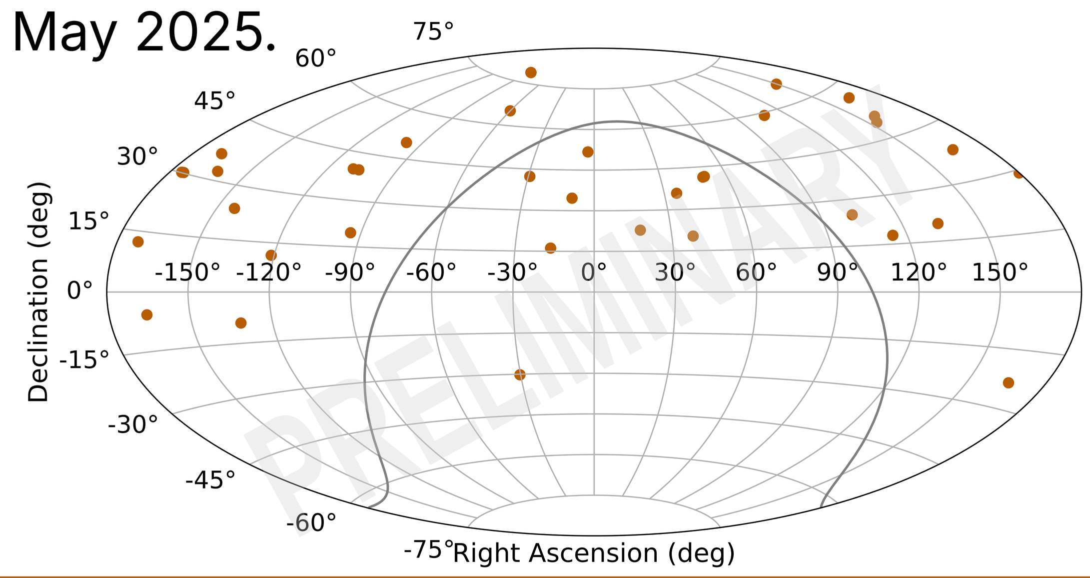
$\kappa(z)$ propagation factor (Jacob & Piran, 2008)

ΔE photons differential energy

- If no detection, set a **lower limit** on the **characteristic energy** E_{LIV}
- Need sources with **fast temporal variability** of their light curves (flux as a function of time), a wide energy range, and distributed over a large range of redshifts (z), like active galactic nuclei (**AGN**).

II- Dataset: all AGN observed by LST-1

- All data of LST-1 on AGN with known redshift: 37 sources.
- Dark conditions & standard quality selection.
- From Jan. 2021 to May 2025.
- Final dataset:
  - **33 sources**
  - 510 hours
  - 505 nights.



III- Optimizing cuts with Crab Nebula observations

- Need to **tune the gammaness cut** (Abe et al., 2022) **for each source** to maximize its detection.
- **Correcting the Crab Nebula excess** to mimic a given source by providing values of its redshift, spectral index and integrated intrinsic spectrum for bins of zenith angle.
- Deriving the corresponding significance (Li & Ma, 1983) from Crab Nebula datasets reconstructed with different values of gammaness cut. Selecting the cut yielding the **highest significance**.
- Produced a **catalog of cuts** from 155 hours of Crab Nebula observations (same selection as of AGN dataset).

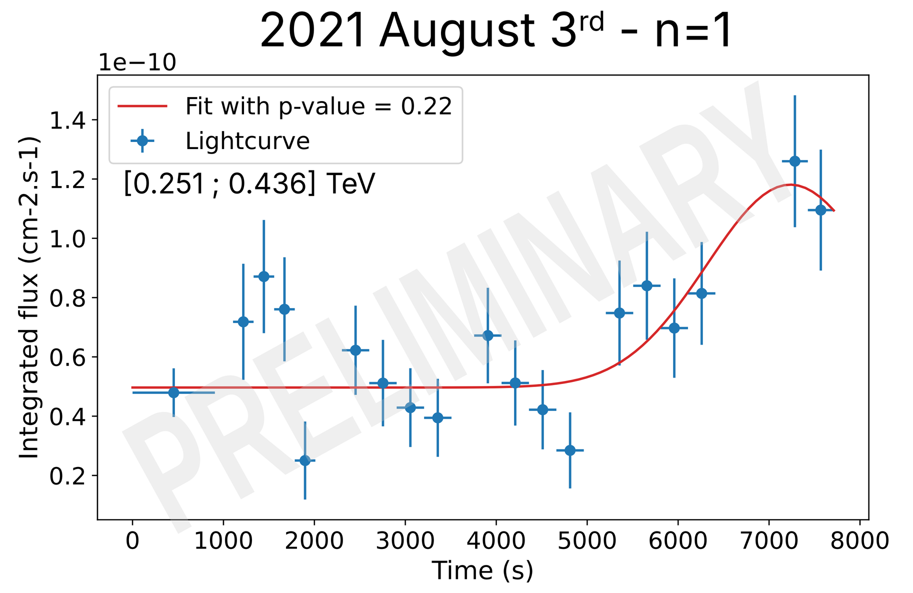
IV- Time-variability search in LST-1 AGN

- Searching for observing nights with significance > 5σ: **163 nights for 9 detected sources**.
- Light curves fitted with a constant function.
- Intra-night variability threshold: p-value < 5×10^{-7} (5σ level).
- Sanity-check on Crab Nebula data: no variability detection.
- Result: time variability in **4 nights of BL Lacertae** (z=0.069).

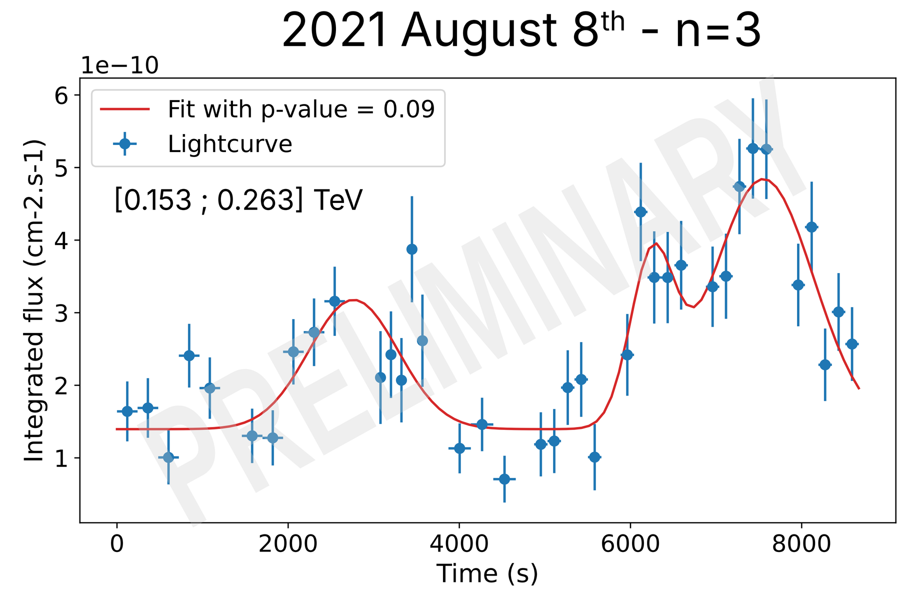
V- Characterization of time distribution

- Light curves **fitted** by $f(t) = C + \sum_n \mathrm{Gauss}_n(t, A_n, \mu_n, \sigma_n)$ with n = lowest value yielding a fit with p-value > 0.05 (2σ level).
- Need of a LIV-free sample: using energies < median energy of events distribution (hypothesis that LIV effects are negligible at low energies)

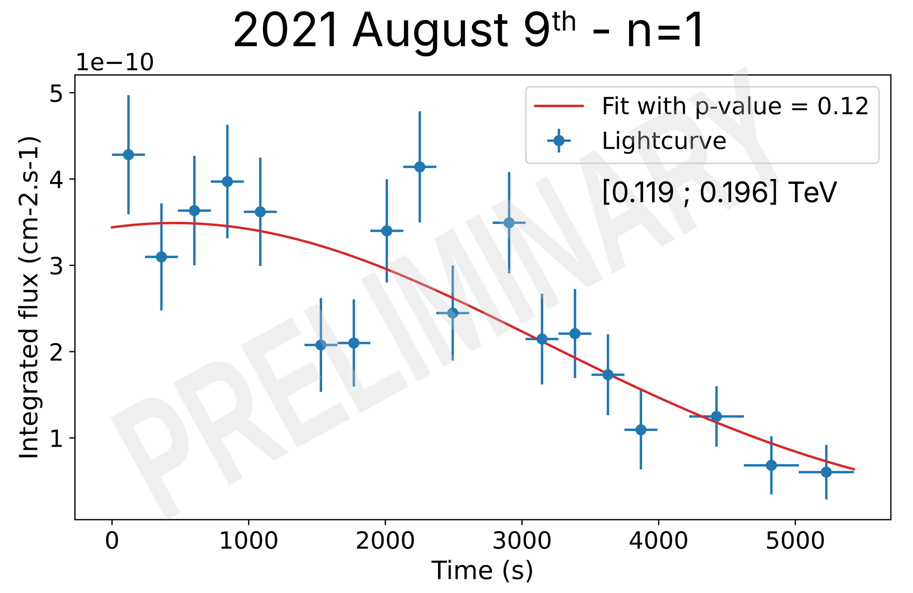
2021 August 3rd - n=1



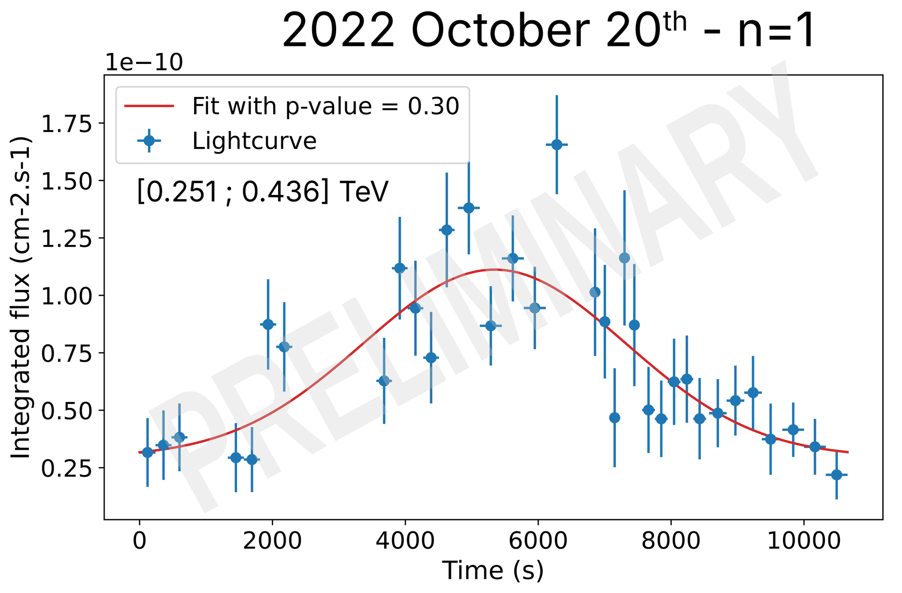
2021 August 8th - n=3



2021 August 9th - n=1



2022 October 20th - n=1

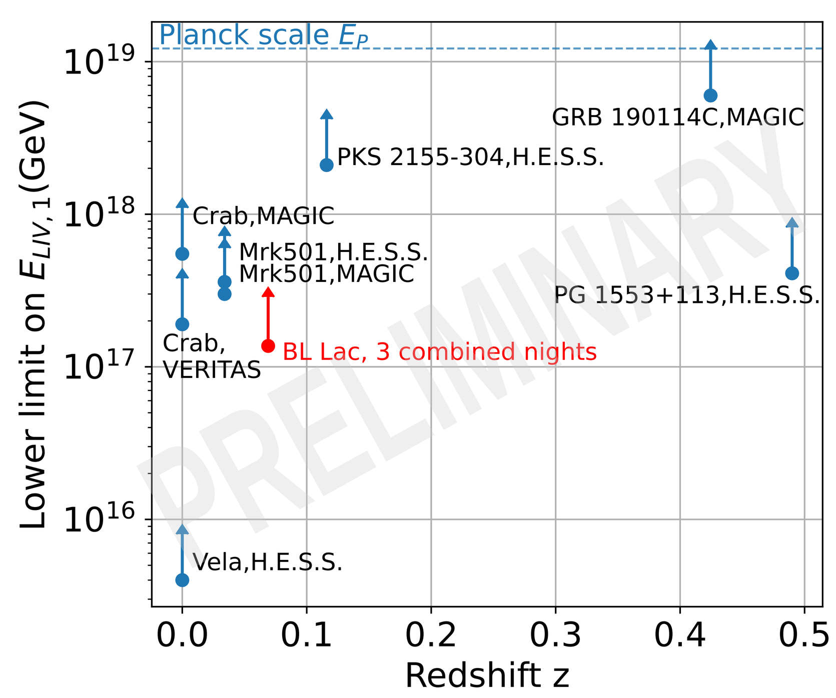


VI- Extraction of a constraint on LIV

- Using the maximum likelihood method (Bolmont et al., 2022).
- 2021 August 9th night is excluded from the analysis (further investigation needed).
- Using bootstrap simulations (interchanging time of events in dataset) to correct the lateshift by $2792\ \mathrm{s\ TeV^{-1}}$.
- **No detection** of a LIV-induced lateshift (1σ): $\lambda = (-839 \pm 1783 \pm 461)\ \mathrm{s\ TeV^{-1}}$
- Setting a **2σ lower limit** on the characteristic energy:

Subluminal case: $E_{LIV} > 1.37 \times 10^{17}\ \mathrm{GeV}$

Superluminal case: $E_{LIV} > 0.9 \times 10^{17}\ \mathrm{GeV}$



Comparison of limits (subluminal case) from other experiments (Bolmont et al. 2022)

- A constraint on LIV effects from a **combination** of this dataset with data from H.E.S.S., MAGIC and VERITAS is presented in contribution P02-925.

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