Disentangling intrinsic effects from LIV: AGN modelling and CTAO simulations

AGN GRB ASTROVIBE QUANTUM GRAVITY

CTAO

cnrs

SORBONNE UNIVERSITÉ

LPNHE PARIS

l'Observatoire de Paris

Disentangling intrinsic effects from LIV: AGN modelling and CTAO simulations

Would CTA be able to detect intrinsic time delays from flaring blazars?

Would CTA be able to detect global time delays (intrinsic + LIV) from flaring blazars?

How can we discriminate LIV from intrinsic time delays?

AGN Modeling: AGNES

Hypothetical Flare:
One-zone SSC model parameterization
~5.5hrs evolution of the flare

Injected LIV: +/- 400 s/TeV (linear effect)
+/- 200 s/TeV (linear effect)

Input: AGN time-dependent spectral model

CTA-AGN-VAR Pipeline

A python package based on Gammapy.

- ❑ Simulate gamma-like events from AGN observations with CTA in a realistic manner.
- ❑ Dynamical selection of CTA Instrument Response Functions (IRFs - Pord5 v0.1).
- ❑ Takes into account observational constraints.
- ❑ Light curve reconstruction from input model.

- ❑ Light curve comparison with and without LIV induced time delay in different energy bands.
- ❑ Would CTA detect intrinsic time delays?
- ❑ Is there an observable LIV signature?
- ❑ How can we discriminate LIV from intrinsic time delays?

TIME-DEPENDENT AGN MODELING: AGNES

- Based on Mrk 421 bright TeV flare of Feb, 2010.
- One-zone SSC model parameterization.
- ~5.5 h evolution of the flare.
- Output: SED snapshots with different values of injected LIV delays.

LIV injection:

- 1st order correction to the dispersion relation:

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

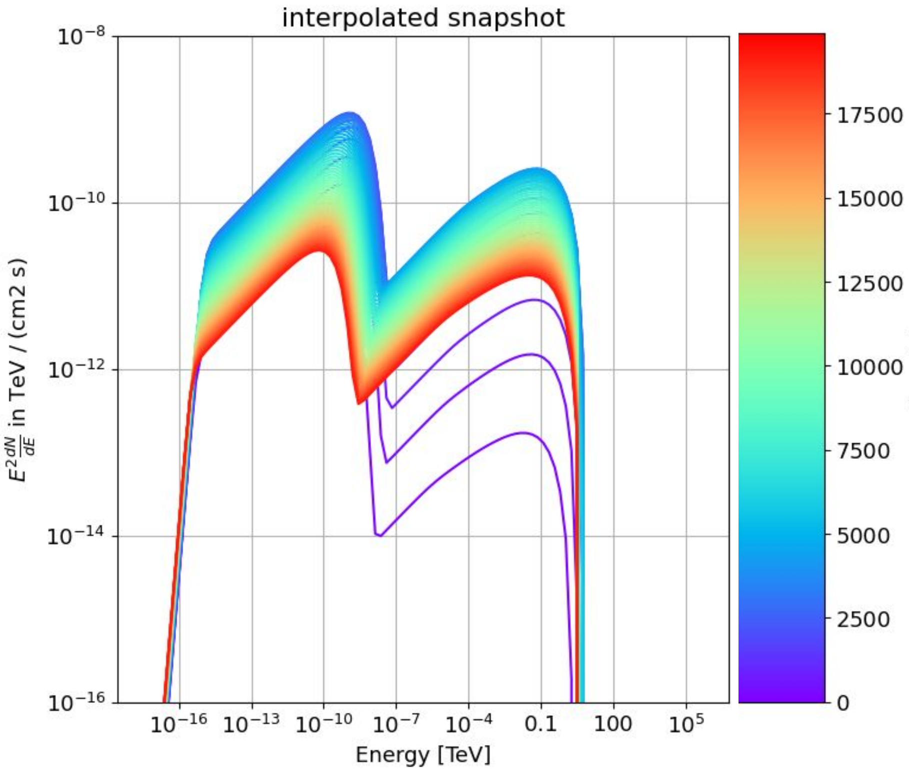
- Test subluminal and superluminal LIV effects:
  Injected LIV time delays: ±400, ±200 s/TeV.

Physical Model Parameters	
δ	60
B_0	300 mG
R_0	6×10^{15} cm
N_0	600 cm^{-3}
γ_{cut}	4×10^4
α	2.4
z	0.031
Evolution Parameters	
A_0	5.5×10^{-5} s^{-1}
m_a	6.0
m_b	2.0

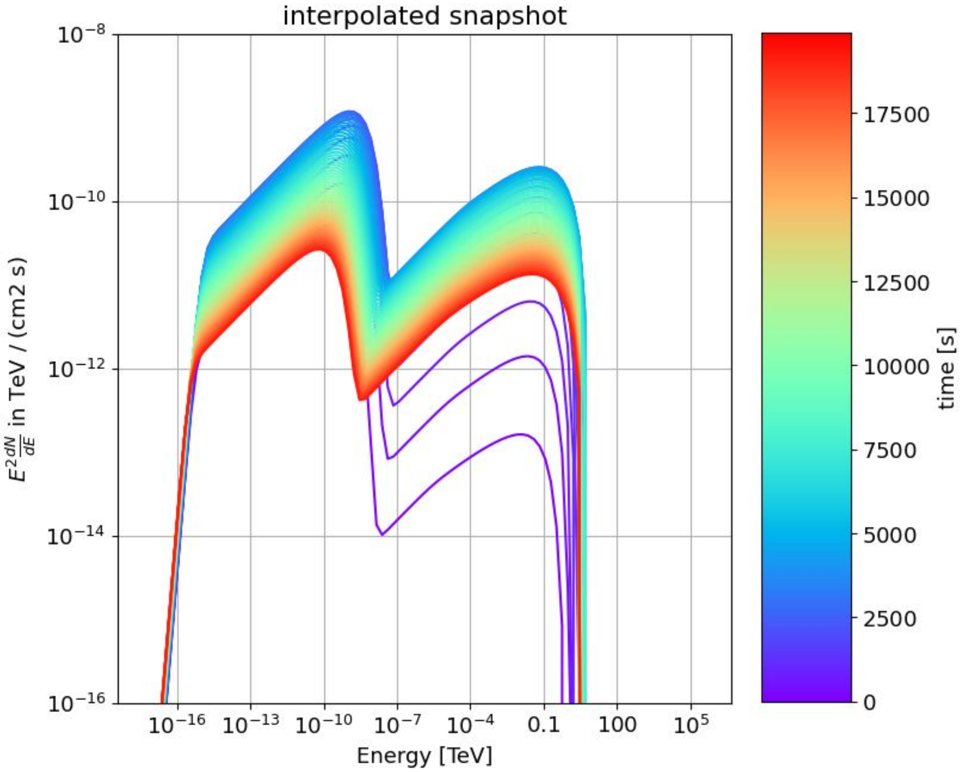
Model parameters used in AGNES to compute the time evolution of a TeV blazar flare.

AGNES Models

Input Model: Intrinsic

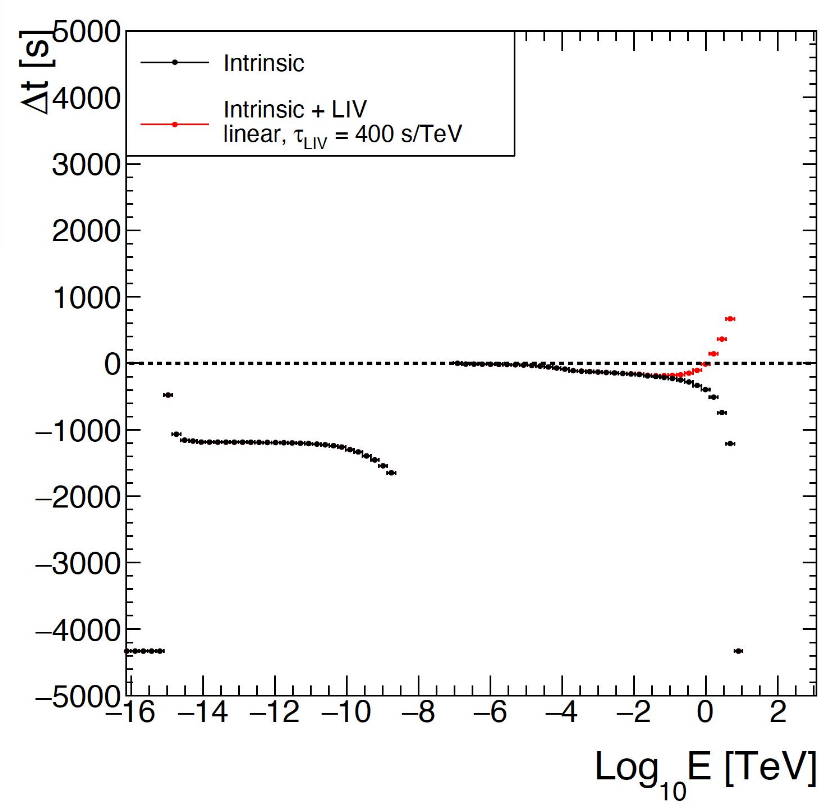


Input Model: Intrinsic + LIV

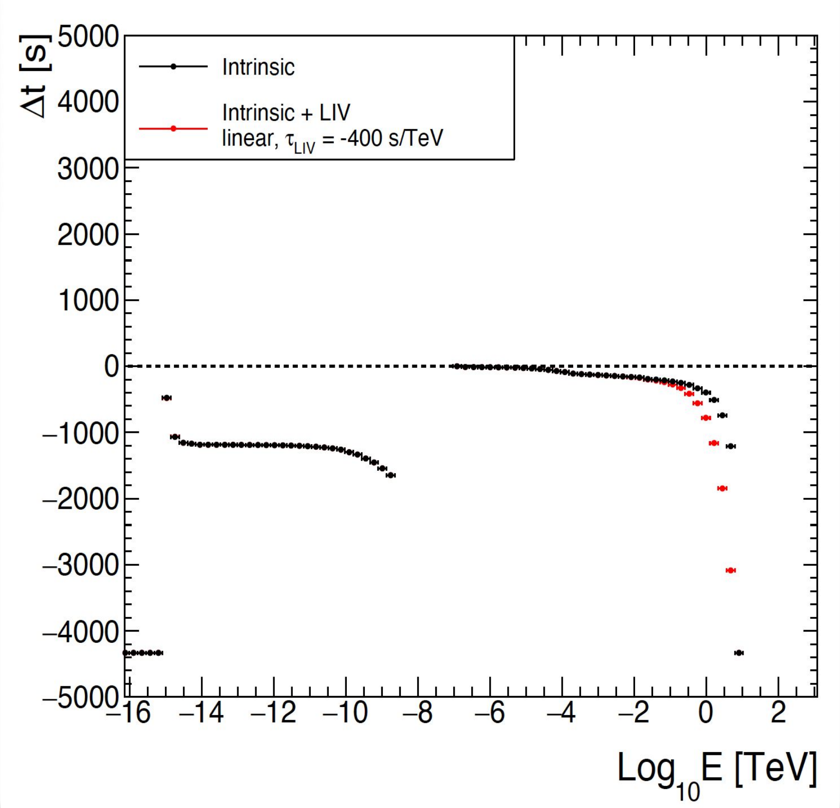


DIFFERENT VALUES OF INJECTED LIV:

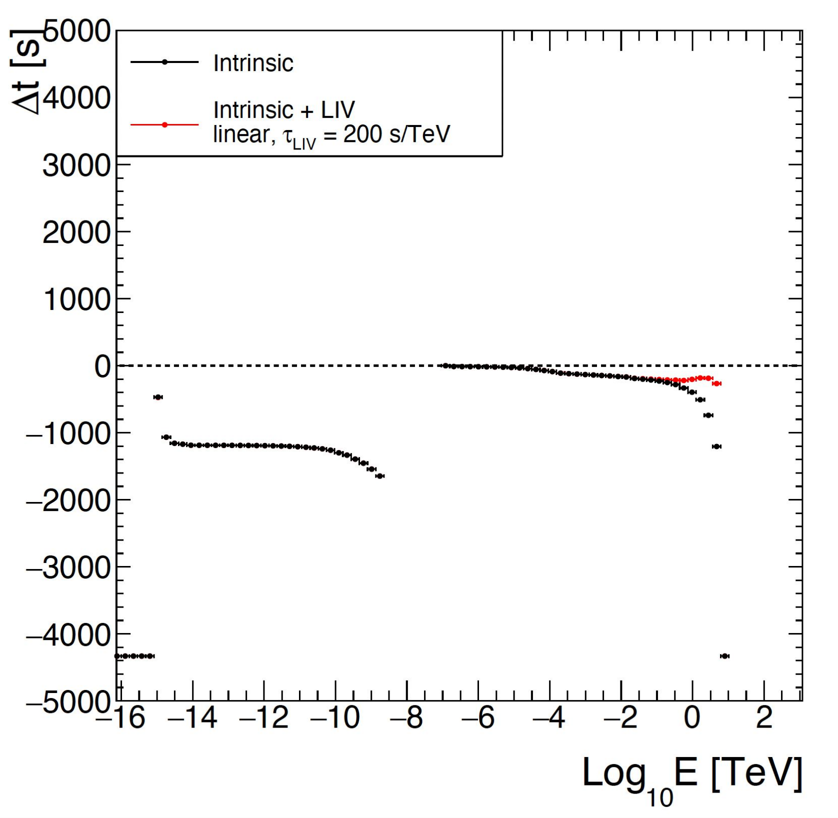
+400 s/TeV



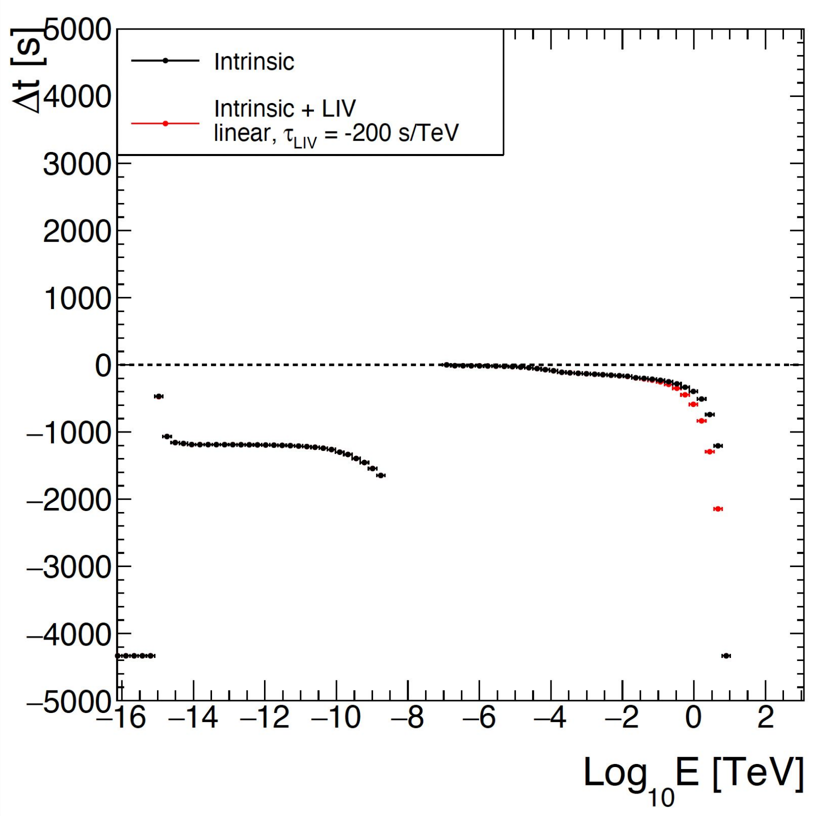
-400 s/TeV



+200 s/TeV



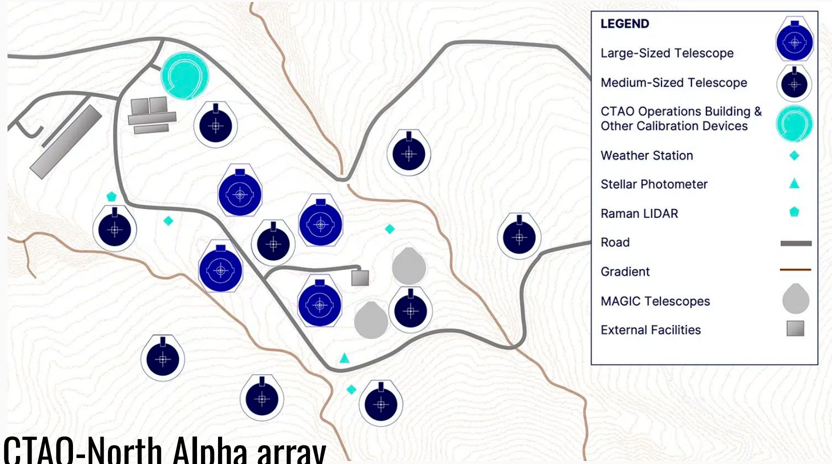
-200 s/TeV



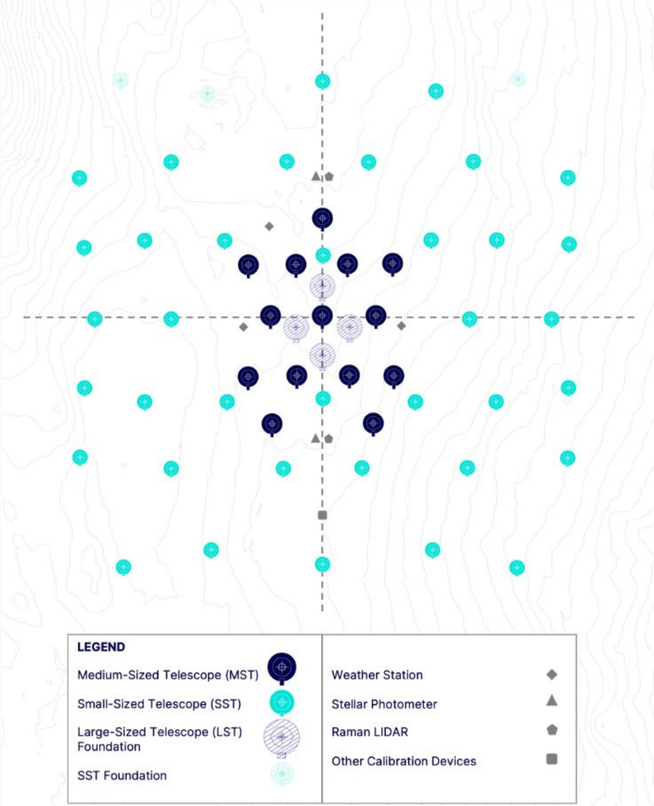
SIMULATIONS: THE CTA-AGN-VAR PIPELINE

- Alpha array configuration:
  CTAO-North: 4 LSTs and 9 MSTs
  CTA-South: 14 MSTs and 37 SSTs

- Omega array configuration:
  CTAO-North: 4 LSTs and 15 MSTs
  CTAO-South: 4 LSTs, 25 MSTs, 70 SSTs



CTAO-North Alpha array



CTAO-South Alpha array

SIMULATIONS: THE CTA-AGN-VAR PIPELINE

- Prod5 v0.1 IRFs

- Follow-up of Mrk421 by CTA-N
  and of a virtual twin flare by CTA-S.

- Fit an analytical spectral model:
  Power Law + Exp Cut-Off

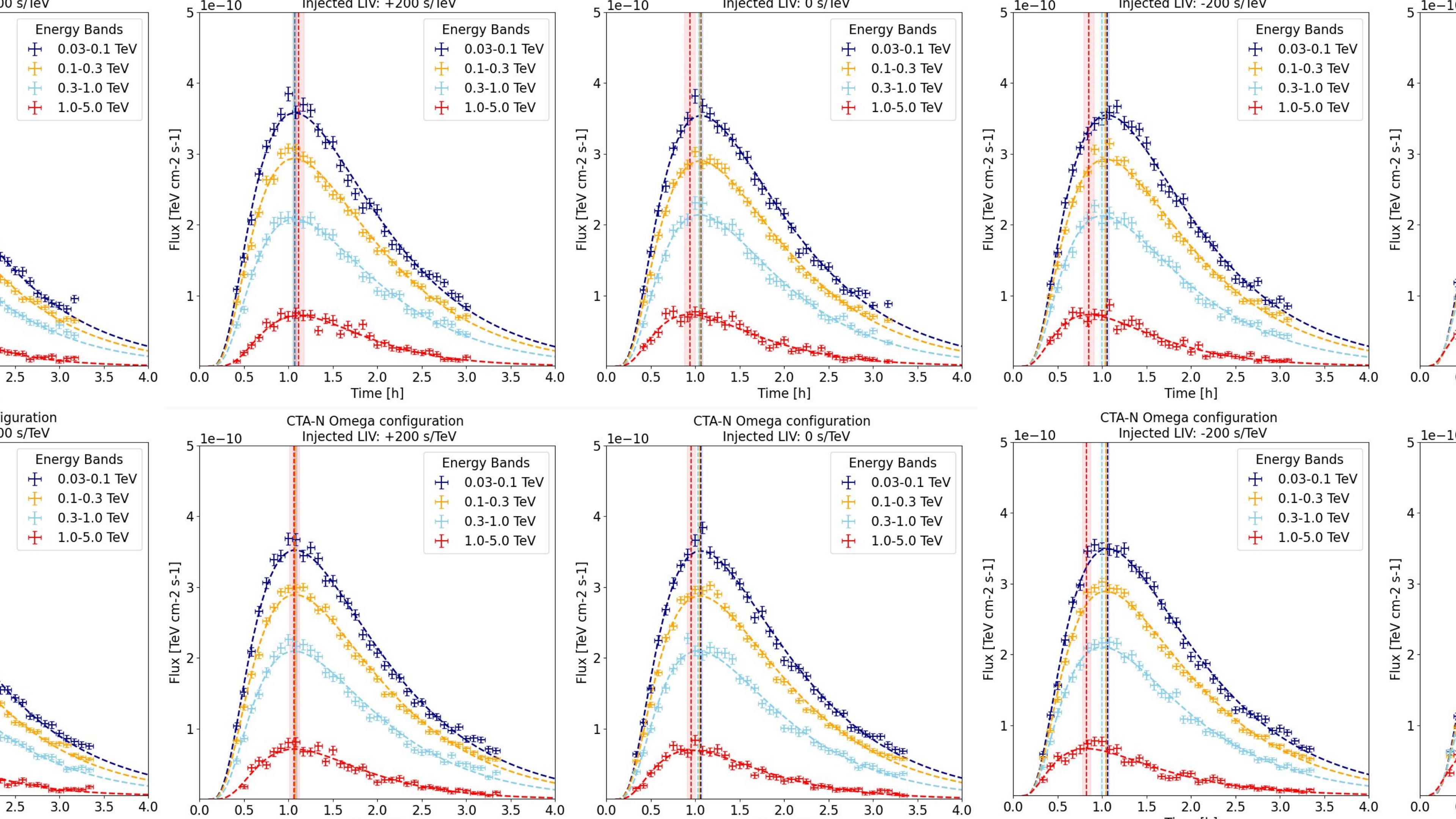
- Extragalactic Background Light (EBL) attenuation effect.

- Input: Temporal evolution of the SED during flare with and without an injected LIV delay.

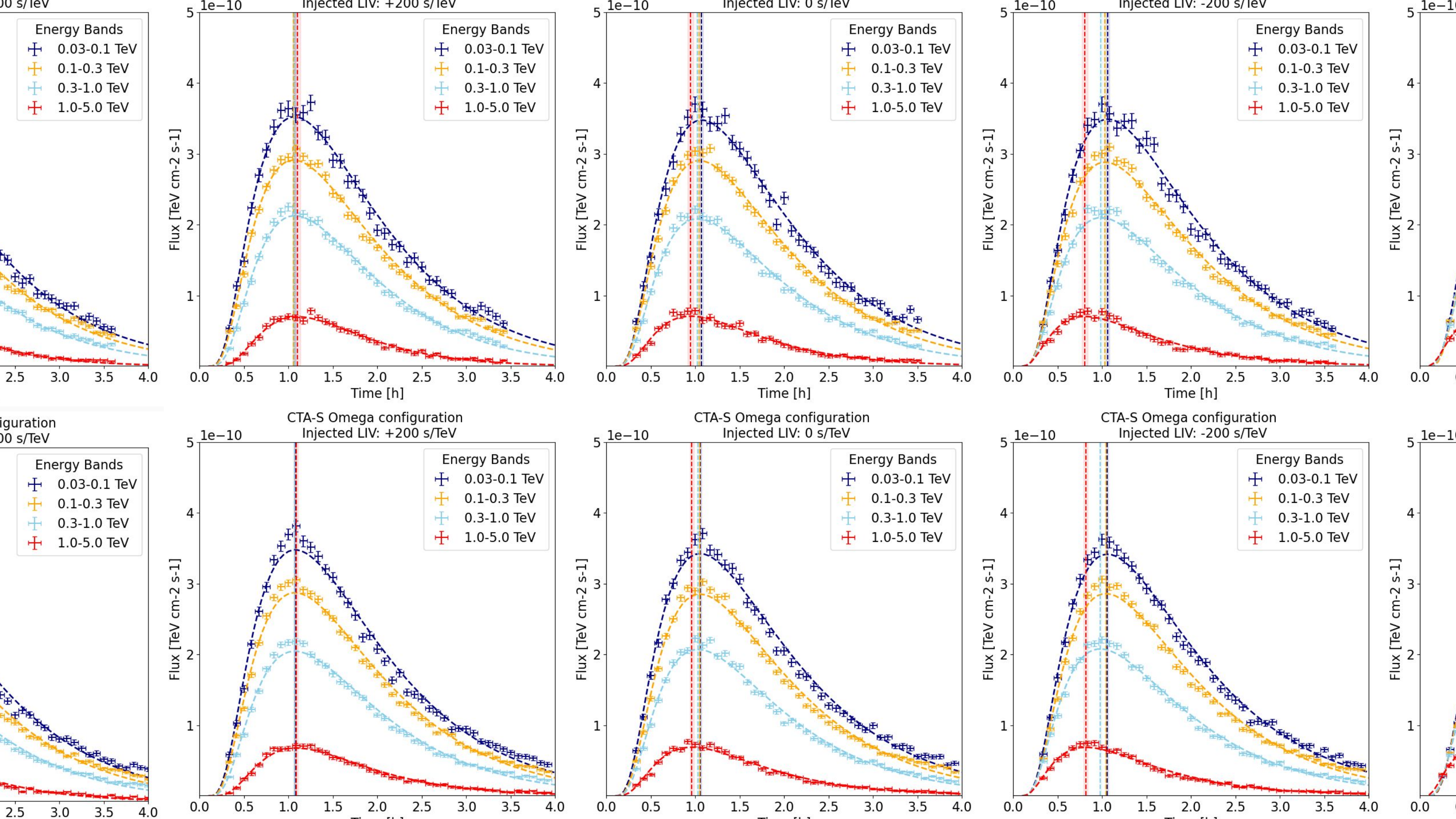
- Output: Reconstructed light curves from simulations on different energy bands.

- Light curves are fitted using a Fast Rise Exponential Decay (FRED) function.

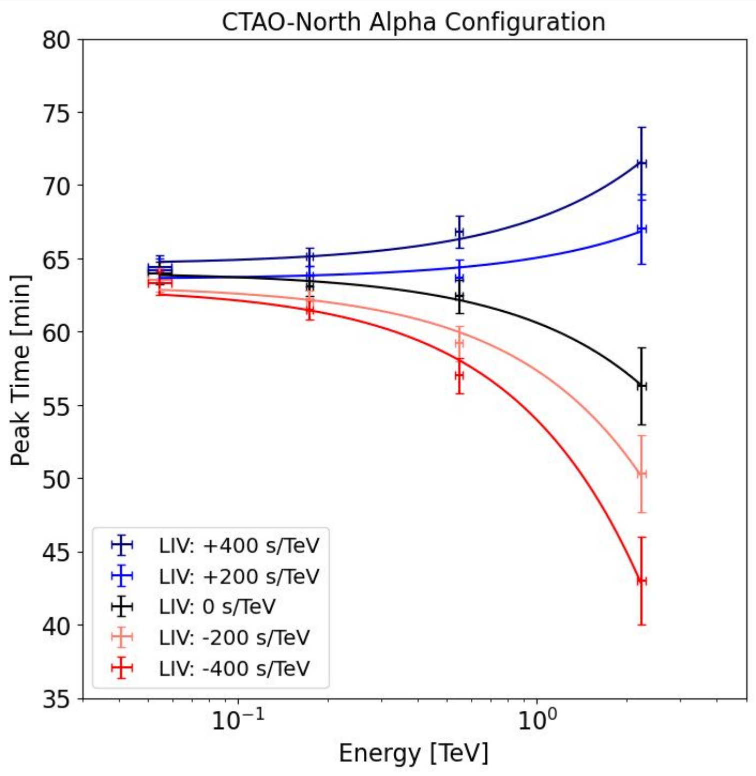
$$F(t) = A\lambda e^{\left(-\frac{\tau_1}{t-t_s} - \frac{t-t_s}{\tau_2}\right)} \qquad \lambda = e^{(2\tau_1/\tau_2)^{1/2}}$$

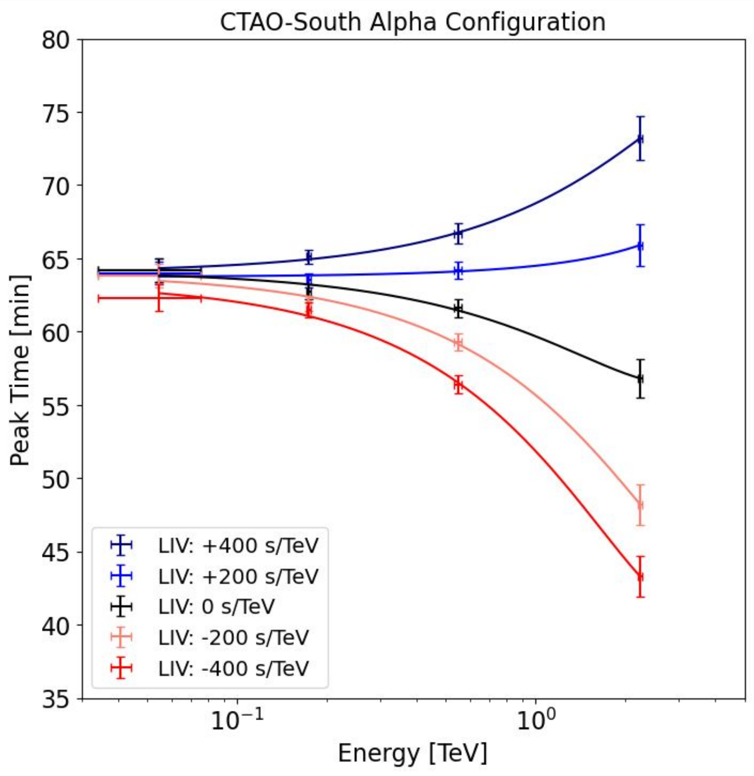


Injected LIV: +200 s/TeV
Injected LIV: 0 s/TeV
Injected LIV: -200 s/TeV
CTA-N Omega configuration
Injected LIV: +200 s/TeV
CTA-N Omega configuration
Injected LIV: 0 s/TeV
CTA-N Omega configuration
Injected LIV: -200 s/TeV
Energy Bands
0.03-0.1 TeV
0.1-0.3 TeV
0.3-1.0 TeV
1.0-5.0 TeV
1e−10
Flux [TeV cm-2 s-1]
Time [h]

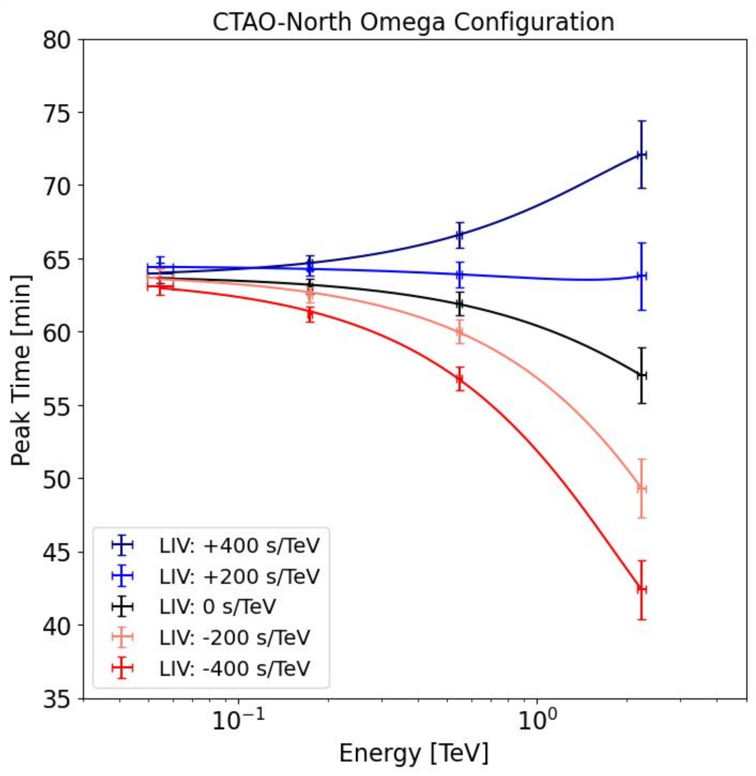

Injected LIV: +200 s/TeV
Injected LIV: 0 s/TeV
Injected LIV: -200 s/TeV
CTA-S Omega configuration
Injected LIV: +200 s/TeV
CTA-S Omega configuration
Injected LIV: 0 s/TeV
CTA-S Omega configuration
Injected LIV: -200 s/TeV
Energy Bands
0.03-0.1 TeV
0.1-0.3 TeV
0.3-1.0 TeV
1.0-5.0 TeV
Flux [TeV cm-2 s-1]
Time [h]
1e−10

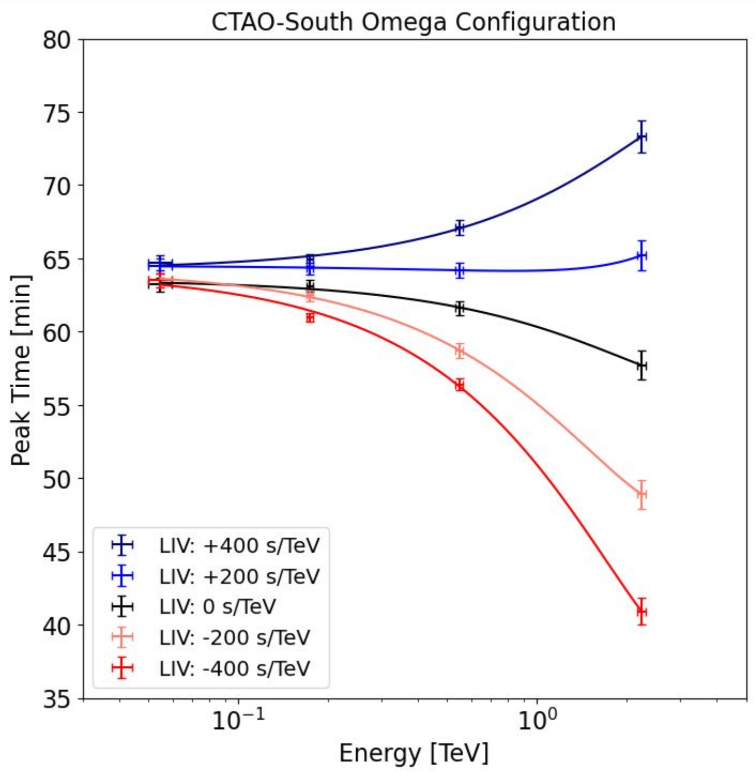
CTA-N Alpha configuration array seems to be sensitive at TeV energies to the effect of the injected LIV time delays.





CTA-S Omega array has the best performance overall. The uncertainty on the measured time delay can be reduced ~30% in comparison to the Alpha array.



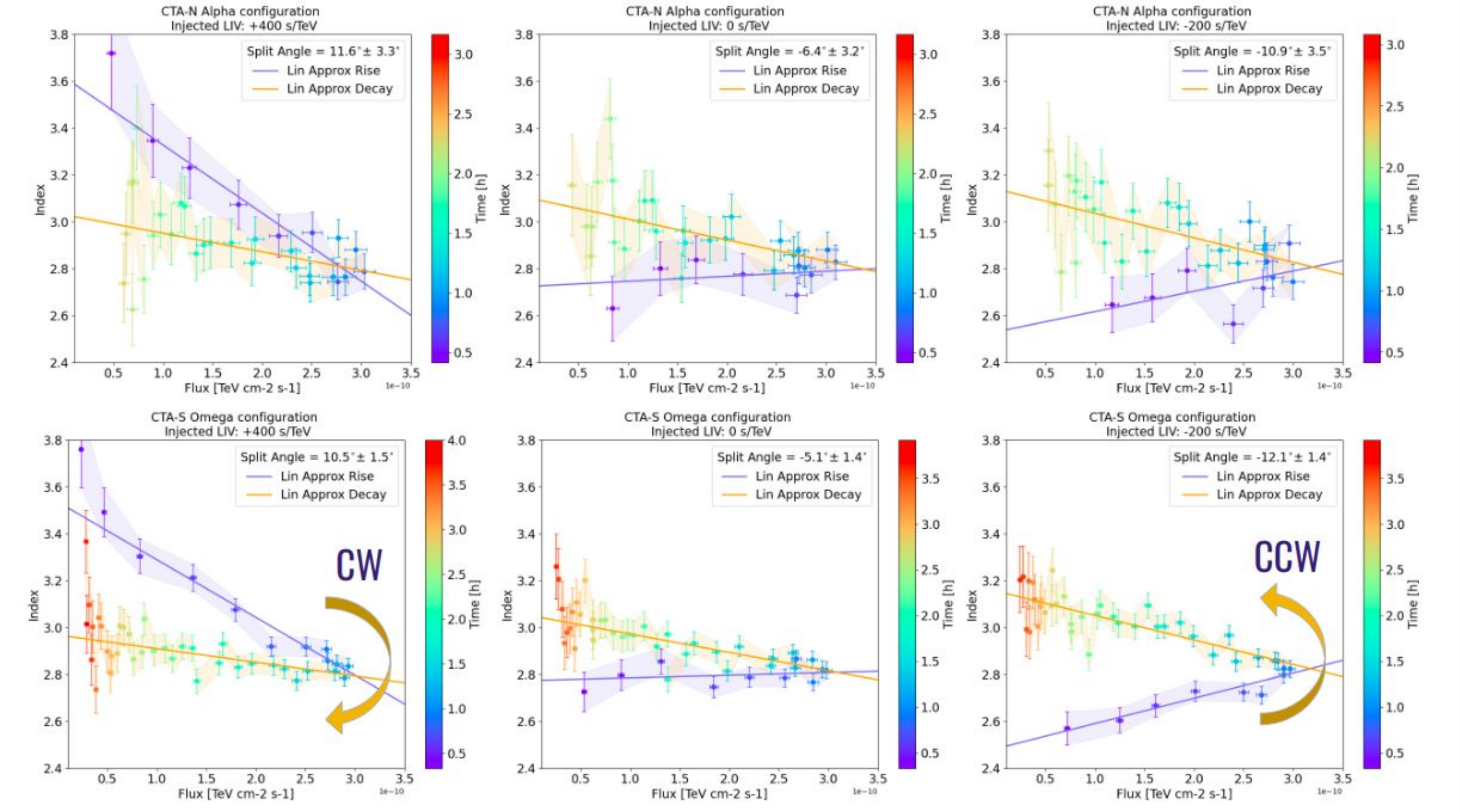


$\Delta t_{LIV} = t_{HE} - t_{LE}$	$\Delta t \pm \sigma t$ [min] LIV= 400 s/TeV	$\Delta t \pm \sigma t$ [min] LIV= 200 s/TeV	$\Delta t \pm \sigma t$ [min] LIV= 0 s/TeV	$\Delta t \pm \sigma t$ [min] LIV= -200 s/TeV	$\Delta t \pm \sigma t$ [min] LIV= -400 s/TeV
CTA-N Alpha	6.6 ± 2.6	2.7 ± 2.6	-7.7 ± 2.7	-12.4 ± 2.7	-18.1 ± 3.1
CTA-N Omega	8.0 ± 2.4	-0.6 ± 2.4	-6.6 ± 2.0	-14.3 ± 2.1	-19.7 ± 2.1
CTA-S Alpha	9.0 ± 1.8	2.0 ± 1.6	-7.4 ± 1.5	-15.6 ± 1.6	-19.1 ± 1.7
CTA-S Omega	8.6 ± 1.2	0.7 ± 1.1	-5.6 ± 1.1	-14.6 ± 1.1	-22.6 ± 1.0

Table 1. Predicted peak time difference for the CTA configuration arrays between HE (1-5 TeV) and LE (0.03-0.1 TeV) band light curves. The color scale indicates the significance of the delay: $<2\sigma t$, $\geq 2\sigma t$, $\geq 3\sigma t$, $\geq 5\sigma t$; where σt considers only statistical errors.

- An injected LIV of 200 s/TeV compensates the effect of the intrinsic time delay.
- For the intrinsic case (LIV=0 s/TeV), the significance of the time delay is ~2.9σ level for the CTA-N Alpha array and ~5.1σ level for CTA-S Omega array.
- CTA-S array (Alpha and Omega) with an injected LIV of ±400 s/TeV would perceive a significant time delay.

HYSTERESIS:


CTA-N Alpha configuration
Injected LIV: +400 s/TeV
Split Angle = 11.6°± 3.3°
Lin Approx Rise
Lin Approx Decay
CTA-N Alpha configuration
Injected LIV: 0 s/TeV
Split Angle = -6.4°± 3.2°
Lin Approx Rise
Lin Approx Decay
CTA-N Alpha configuration
Injected LIV: -200 s/TeV
Split Angle = -10.9°± 3.5°
Lin Approx Rise
Lin Approx Decay
CTA-S Omega configuration
Injected LIV: +400 s/TeV
Split Angle = 10.5°± 1.5°
Lin Approx Rise
Lin Approx Decay
CW
CTA-S Omega configuration
Injected LIV: 0 s/TeV
Split Angle = -5.1°± 1.4°
Lin Approx Rise
Lin Approx Decay
CTA-S Omega configuration
Injected LIV: -200 s/TeV
Split Angle = -12.1°± 1.4°
Lin Approx Rise
Lin Approx Decay
CCW
Index
Flux [TeV cm-2 s-1]
1e-10
Time [h]

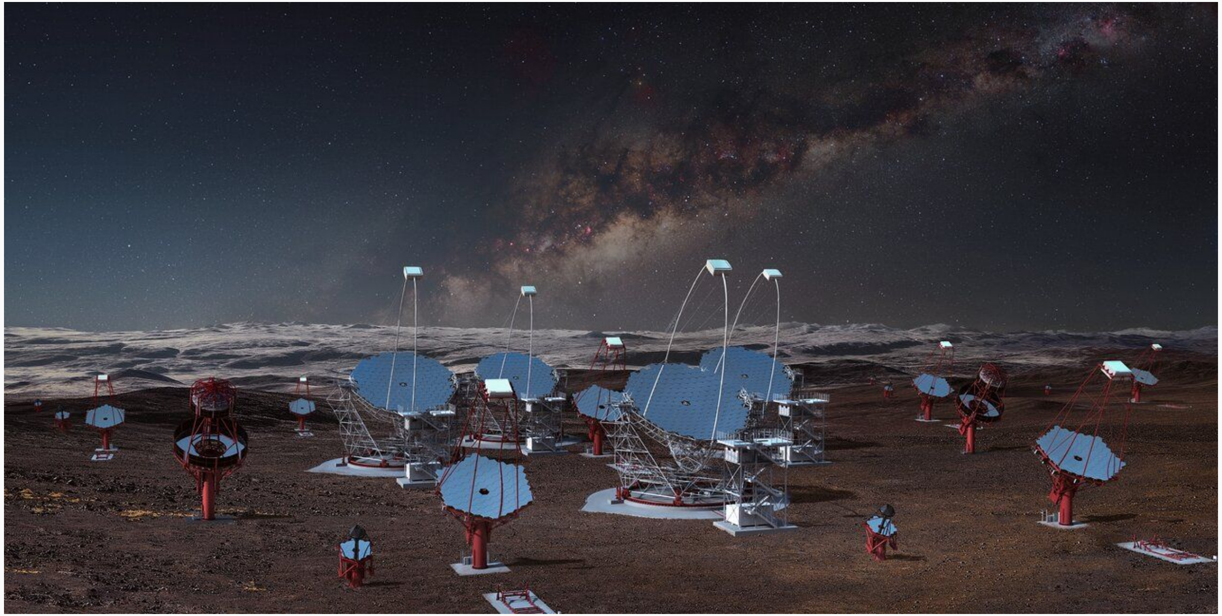
- ❖ The orientation (CW/CCW) of the hysteresis patterns (and split angle between the linear approximations) characterize the regime of the delays (increasing or decreasing trend with energy at VHE).
- ❖ Comparing hysteresis between X-rays and γ-rays could allow discriminating LIV from intrinsic delays: opposite orientation in VHE would indicate the presence of non-intrinsic effects, possibly due to LIV.

CONCLUSION

From this analysis of a bright SSC flare, the CTA-N (CTA-S) Alpha configuration array seems sensitive to intrinsic time delays at ~2σ (>3σ) significance level. The Omega configuration will improve the significance of the measurements and seems to be required to open the possibility to search for LIV time delays. Furthermore, simultaneous X-ray data would be needed to discriminate LIV from intrinsic time delays.

What is left to do in the project?

- X-ray simulations to compare with the current results.
- Perform a full analysis to assess the systematic errors.
- For the next stage of the project: Apply the corresponding LIV delay to a simulated photon list and use LIVelihood to obtain the limits of the possibly observed LIV delay.



...and wait for the telescopes to be finished, to contrast the experimental results with the predictions.

Thanks for your attention

"SCIENCE IS NOT A COLLECTION OF FACTS; IT IS A PROCESS OF DISCOVERY."
ROBERT ZUBRIN