

Time-dependent modeling of PKS 1510-089 July 2019 flare

**Pierre Pichard on behalf of the
H.E.S.S. collaboration**

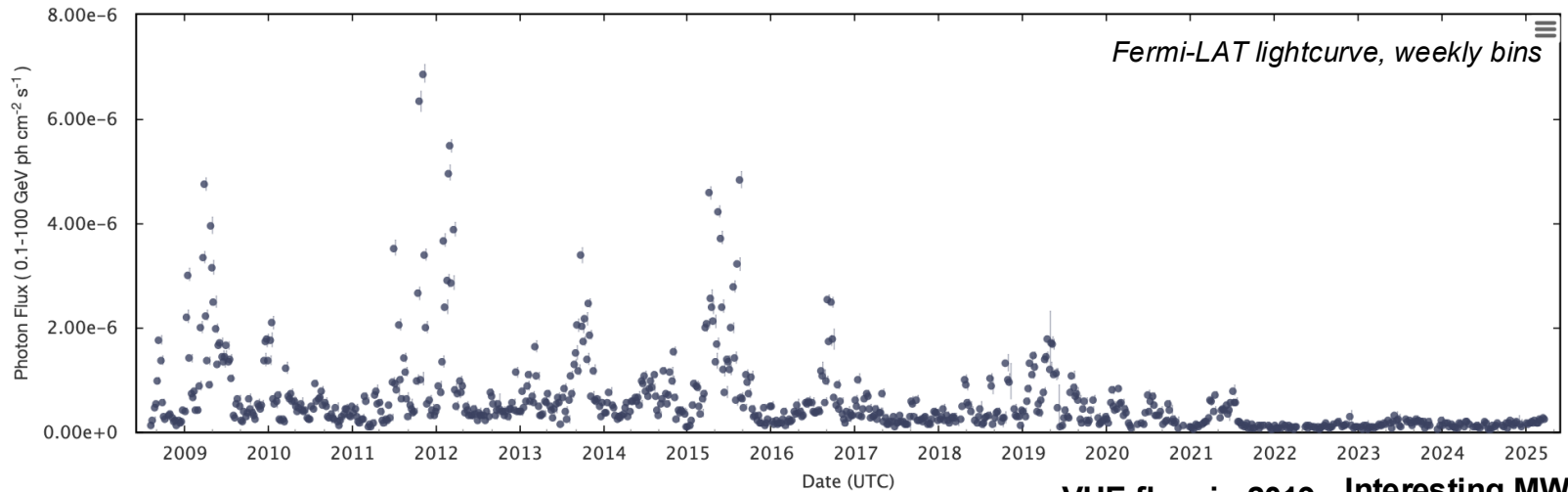
MuMeNTA Athens

March 2nd 2026



Université
Paris Cité

Context on the source



**Detection in 2009
(H.E.S.S.)**

**VHE flare in 2015
(MAGIC)**

**VHE flare in 2016
(MAGIC + H.E.S.S.)**

**VHE flare in 2019
(this work, in
preparation)**

**Interesting MWL
behaviour in 2021
2022 (H.E.S.S.)**

**2nd FSRQ at
the time
($z=0.36$)**

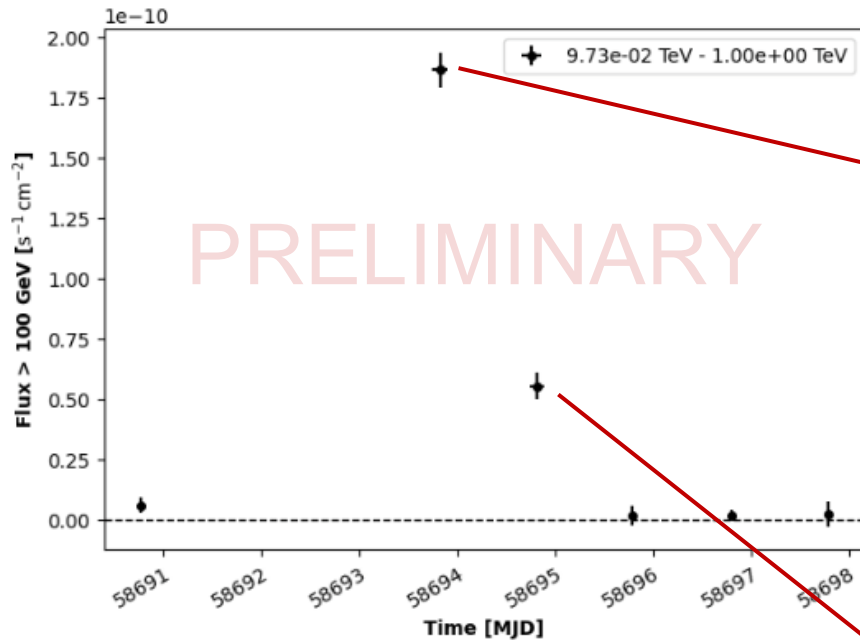
**Night-to-night
variability**

**Intra-night
variability
(1.5h
timescale +
drop with
20min
timescale)**

???

**HE emission
dropped, VHE
and X
remained
→ 2 different
zones**

July 2019 flare: detection

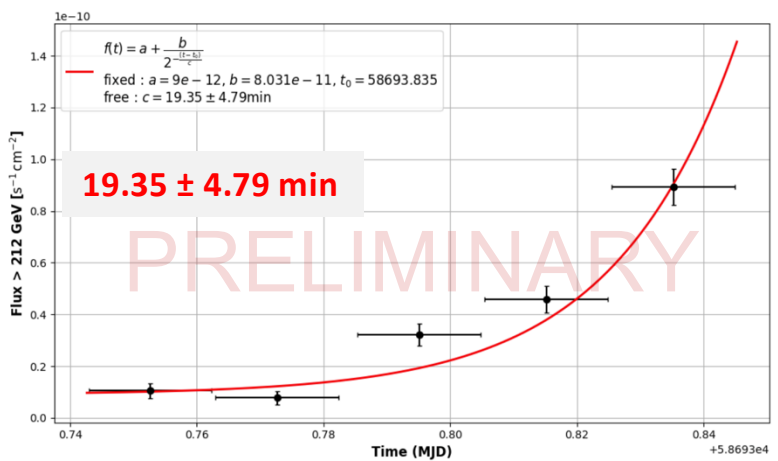
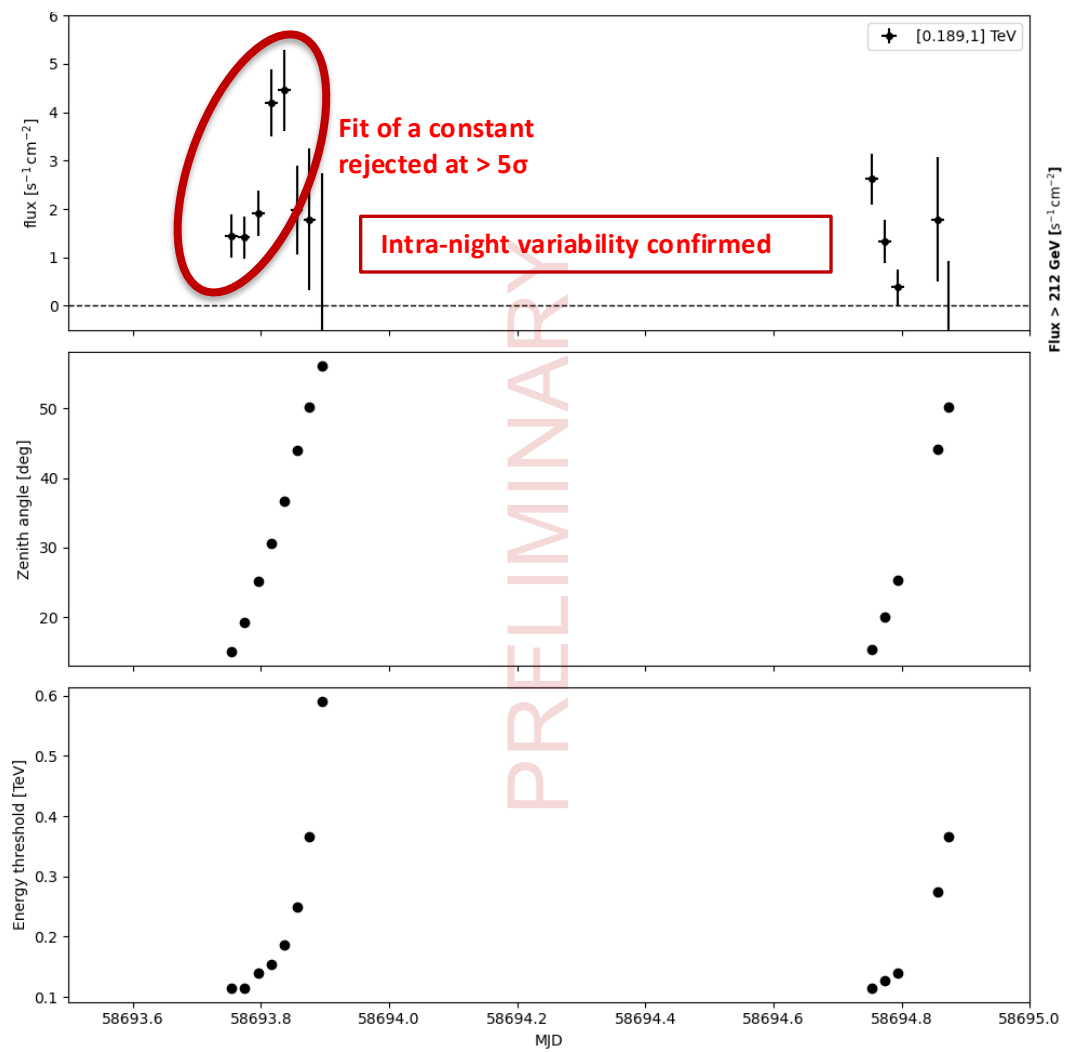


MJD 58693 (29/07/2019)
45 σ significance

Detection on 2 consecutive nights

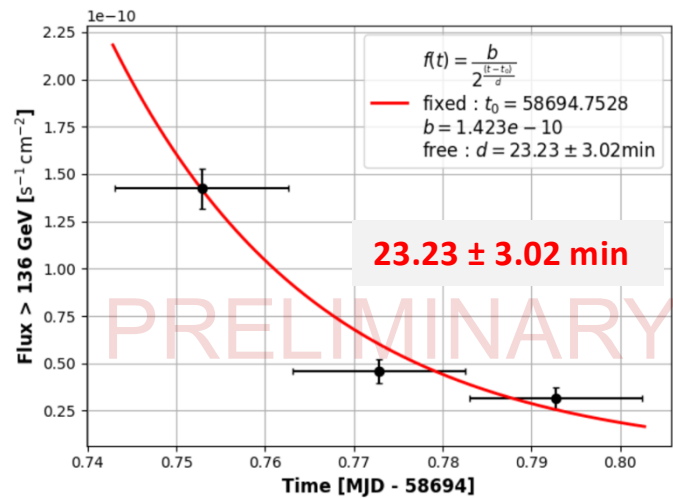
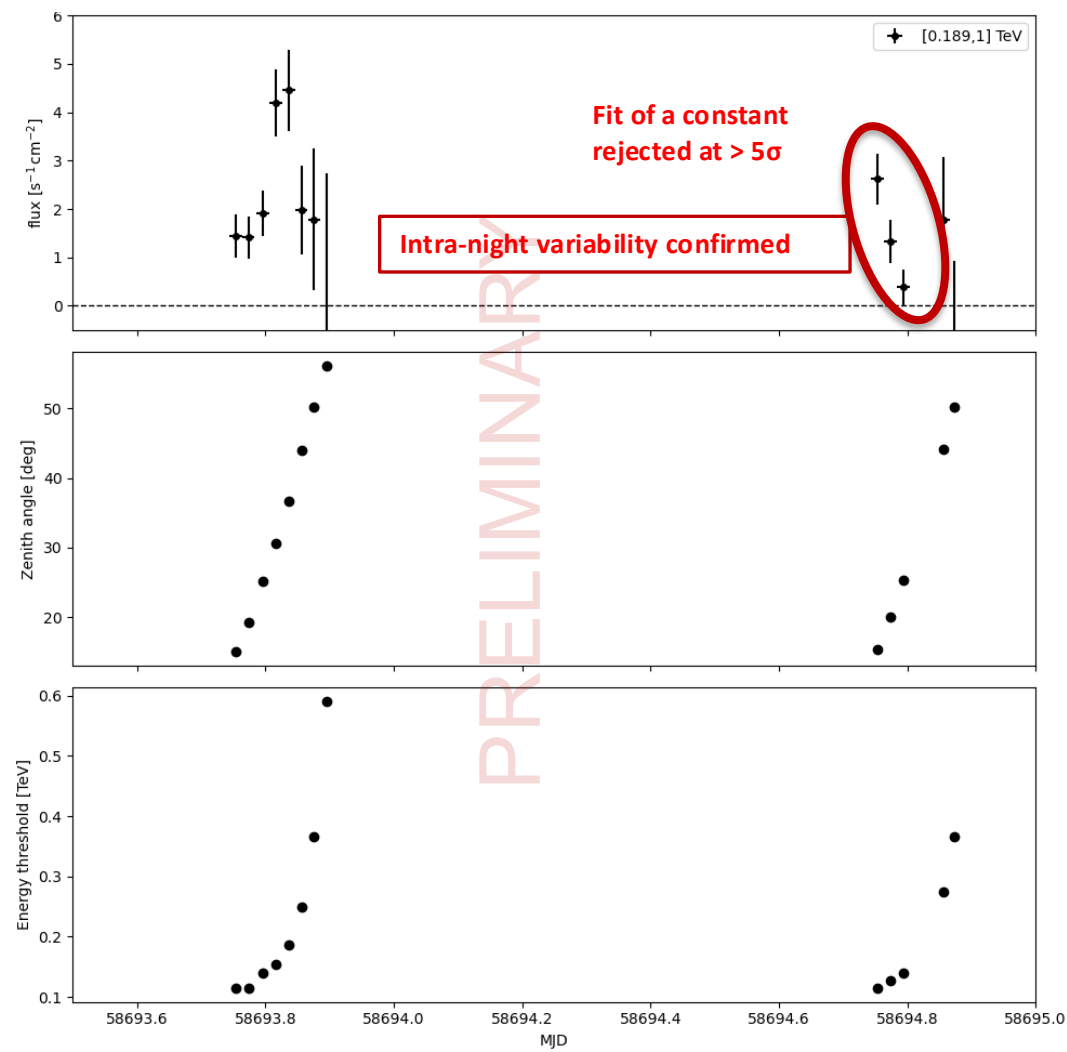
MJD 58694 (30/07/2019)
28 σ significance

Estimation of intranight variability



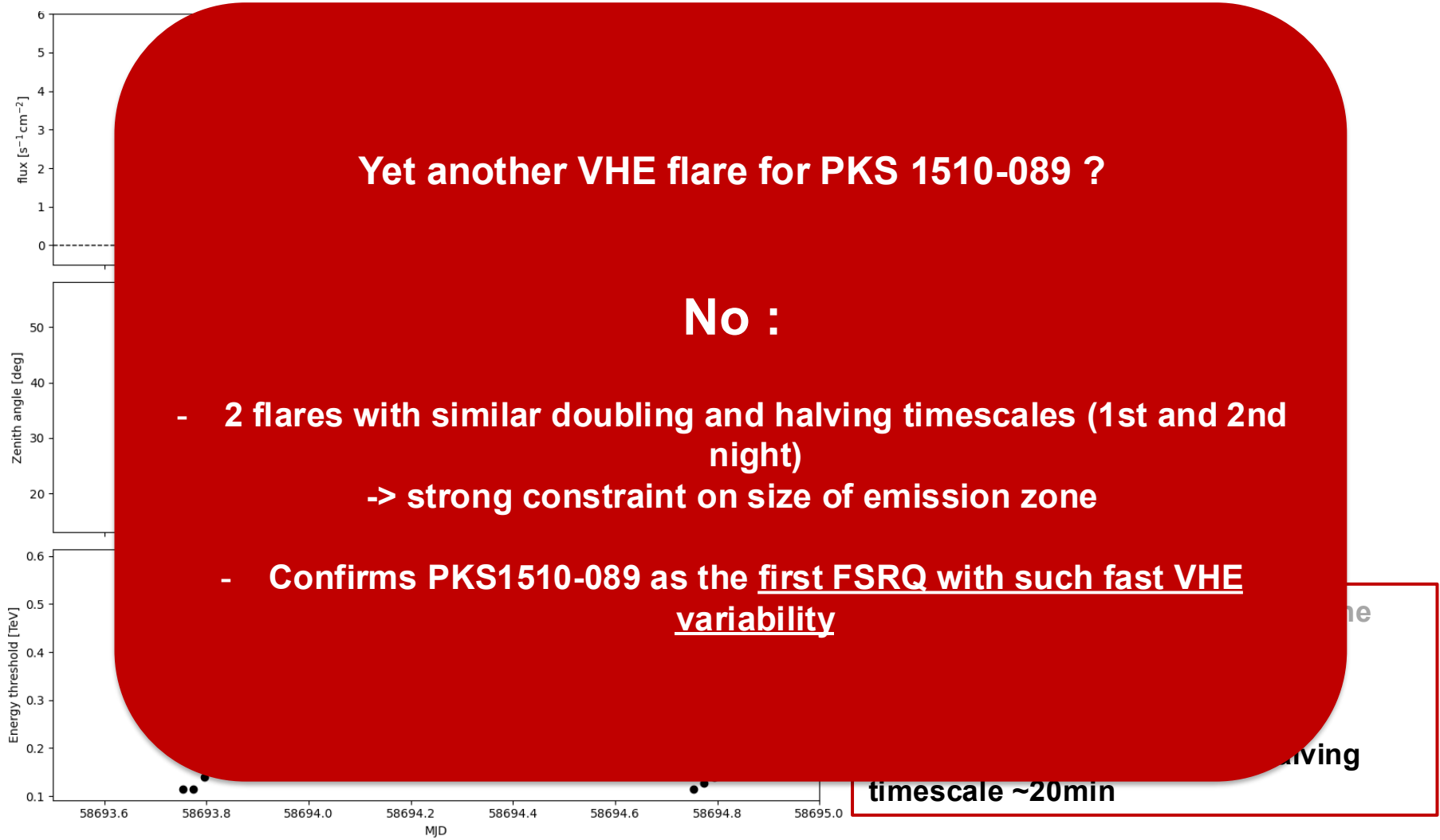
**Very fast intranight variability
in the first night : doubling
timescale ~20min ...**

Estimation of intranight variability



Very fast intranight variability in the second night : halving timescale $\sim 20 \text{ min}$...

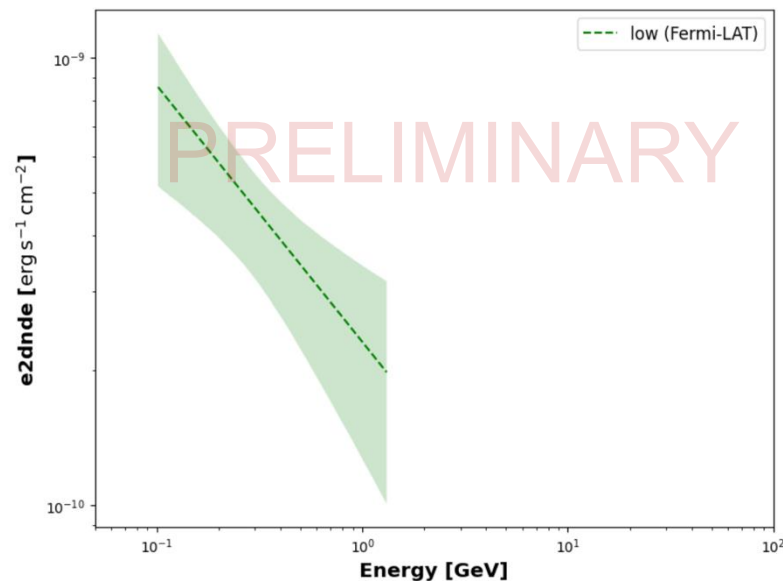
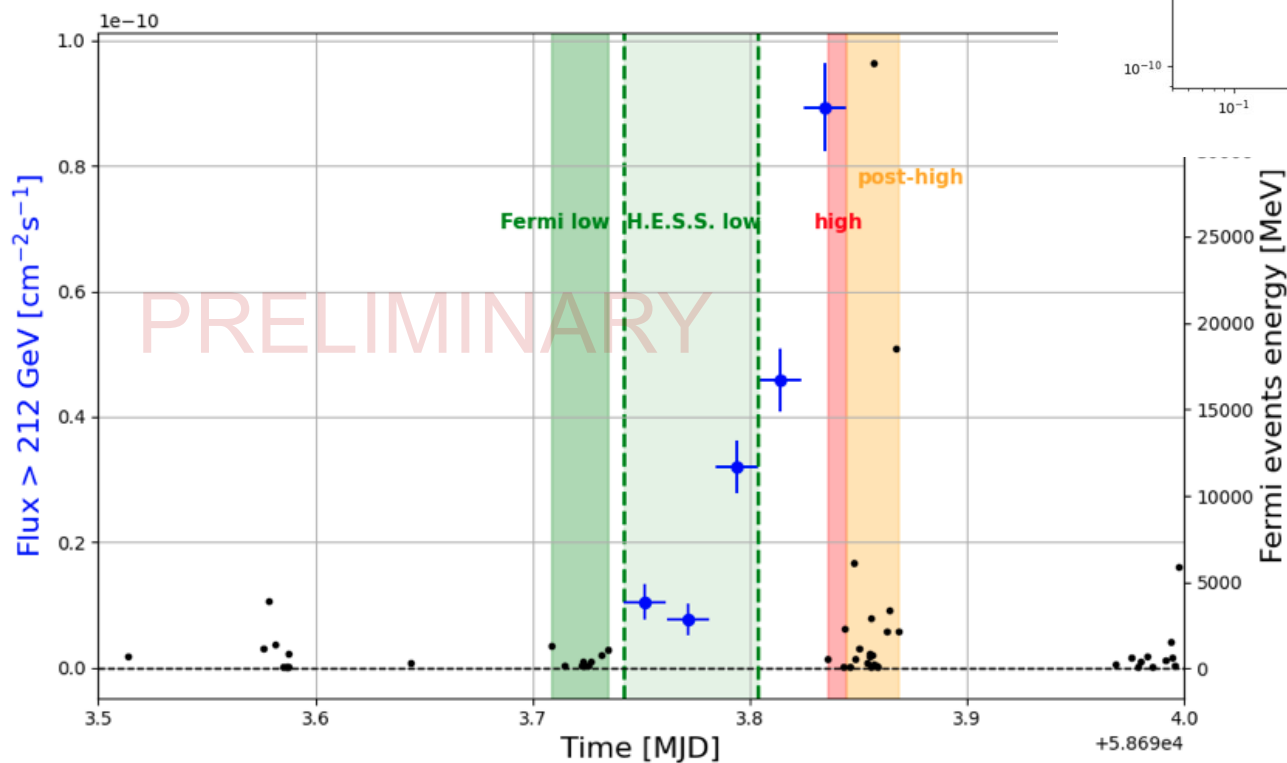
July 2019 : yet another flare ?



MWL picture :

When digging into **very fast variability**

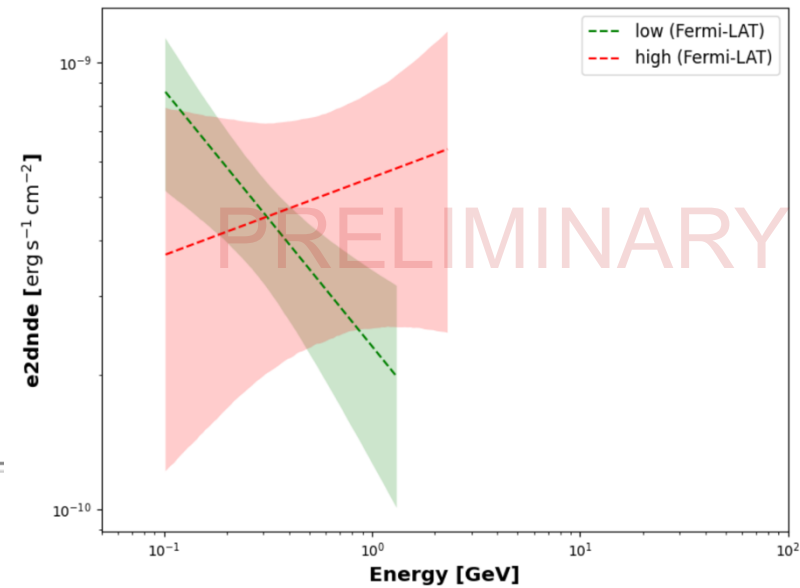
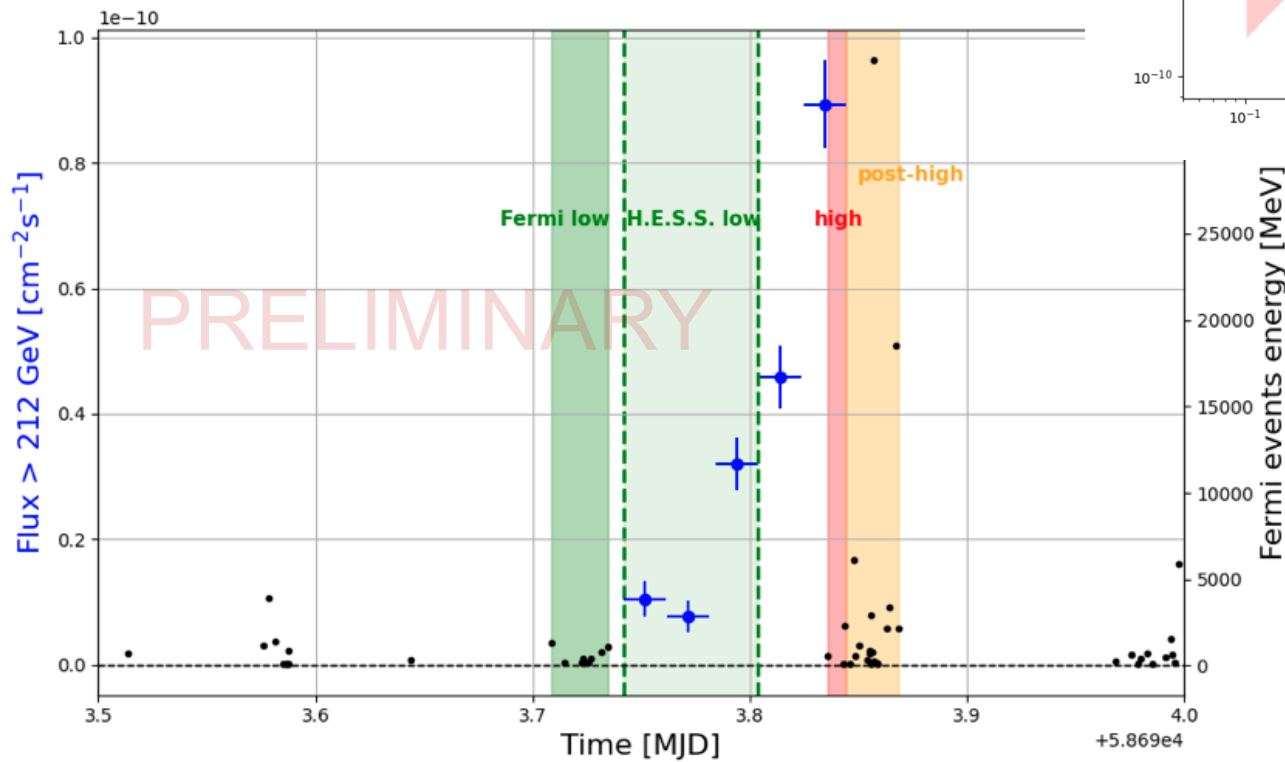
→ need to be careful about Fermi orbits : exposure has holes in it



MWL picture :

When digging into **very fast variability**

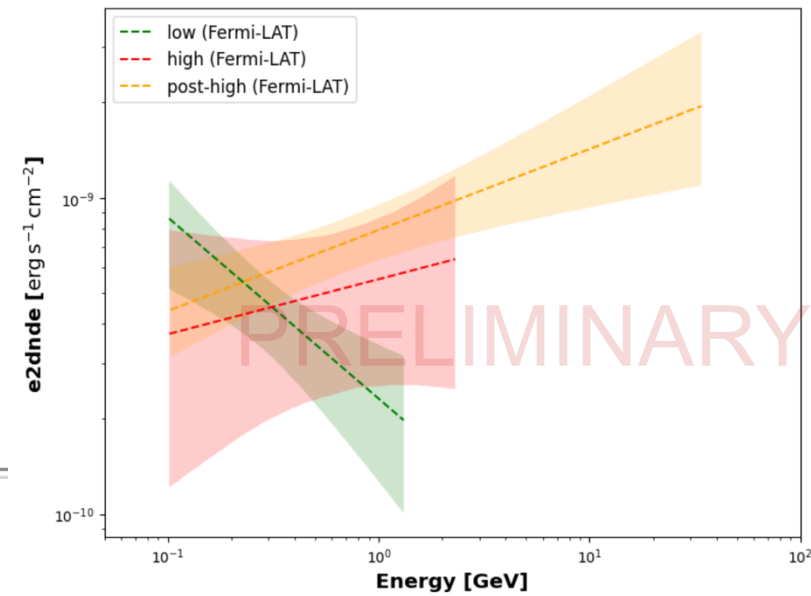
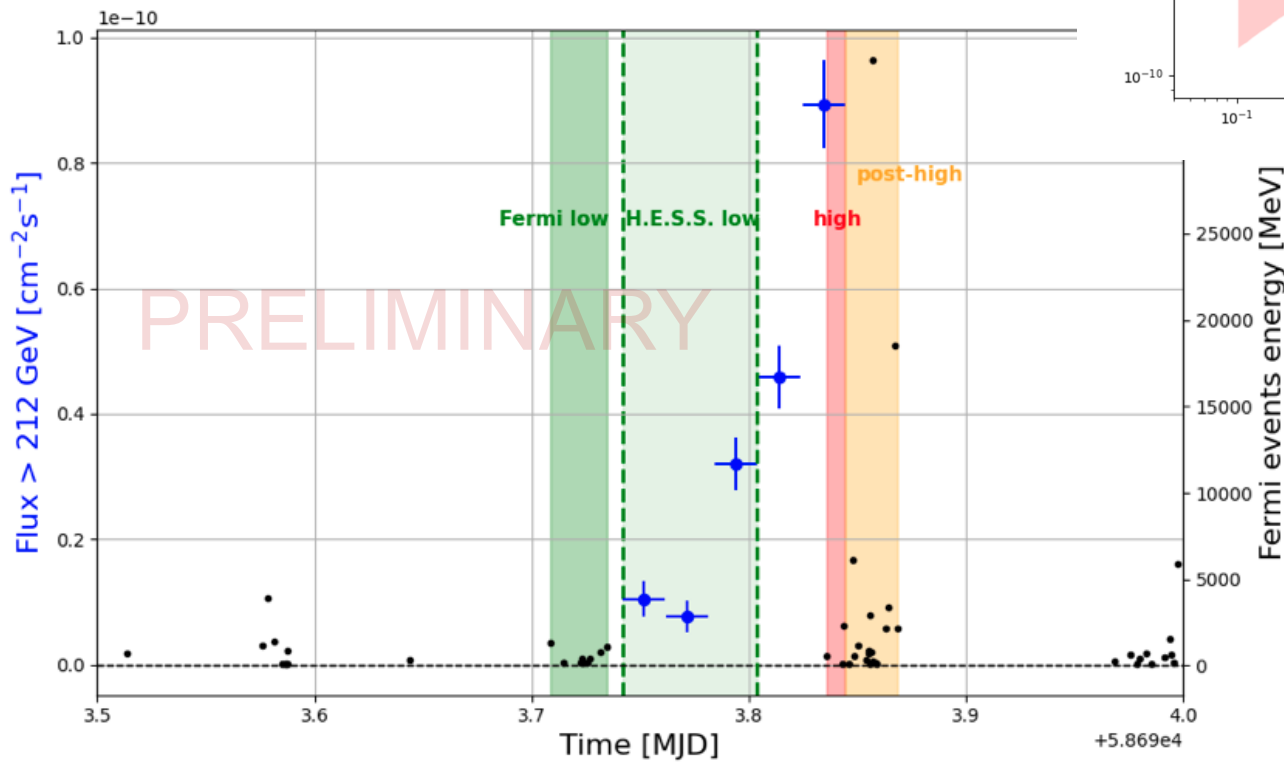
→ need to be carefull about Fermi orbits : exposure has holes in it



MWL picture :

When digging into **very fast variability**

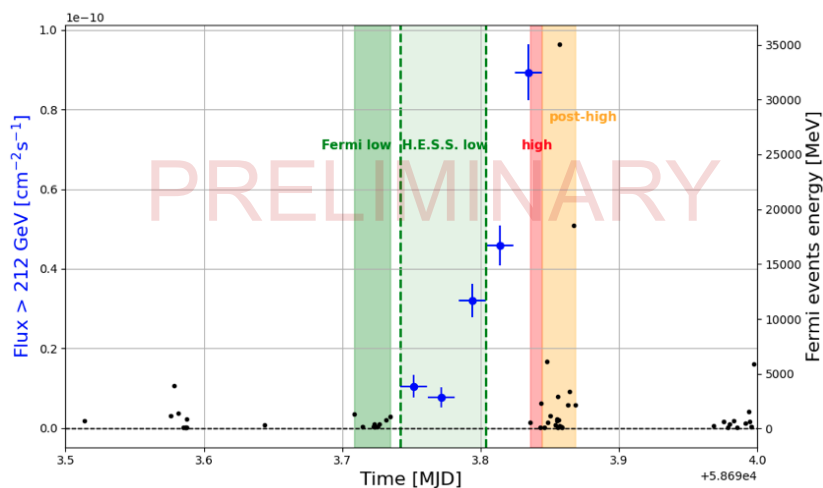
→ need to be carefull about Fermi orbits : exposure has holes in it



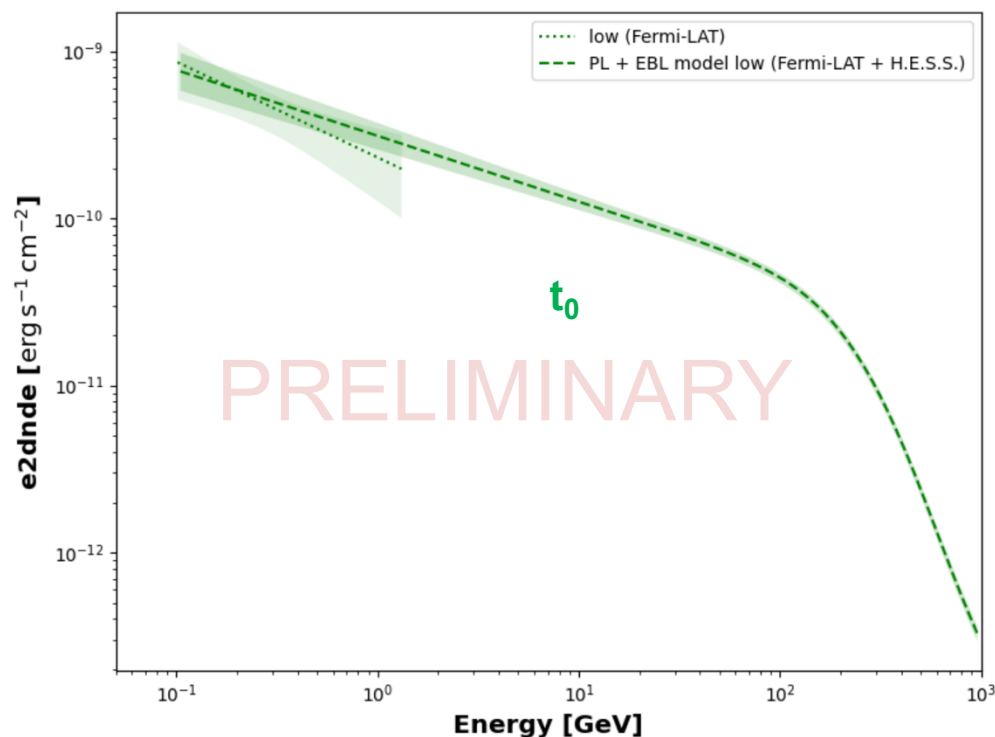
MWL picture :

When digging into **very fast variability**

→ need to be carefull about Fermi orbits : exposure has holes in it



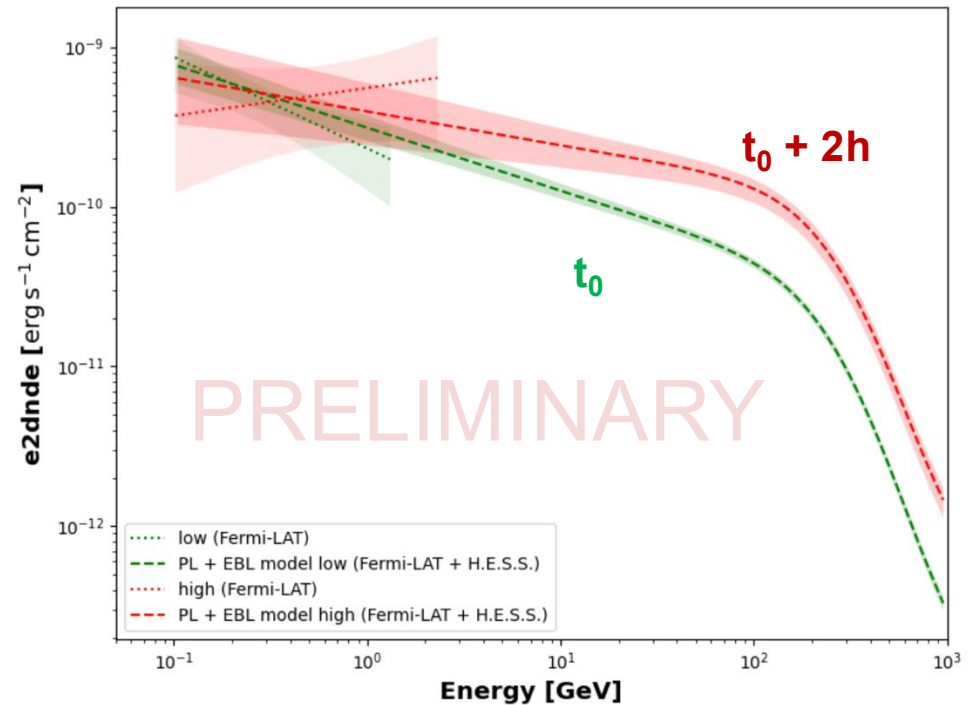
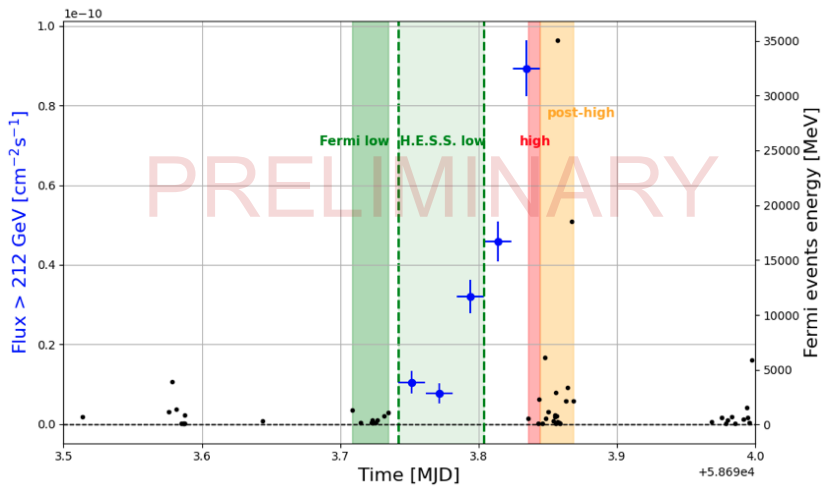
$\gamma\pi$



MWL picture :

When digging into **very fast variability**

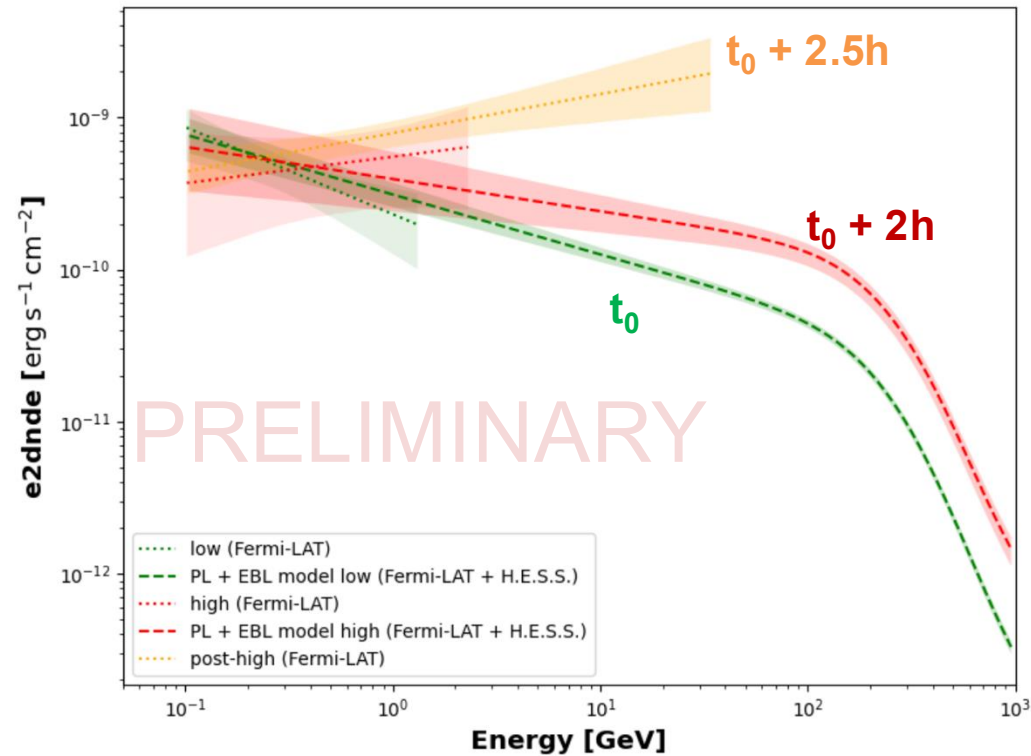
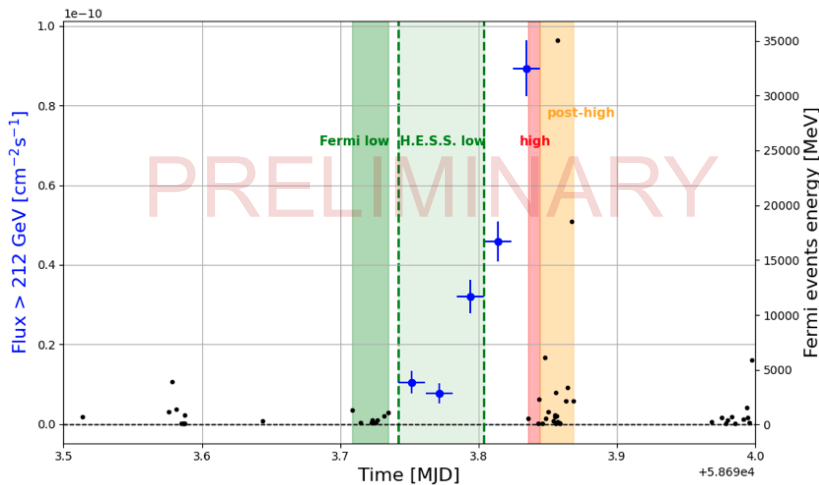
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MWL picture :

When digging into **very fast variability**

→ need to be carefull about Fermi orbits : exposure has holes in it



July 2019 : yet another flare ?

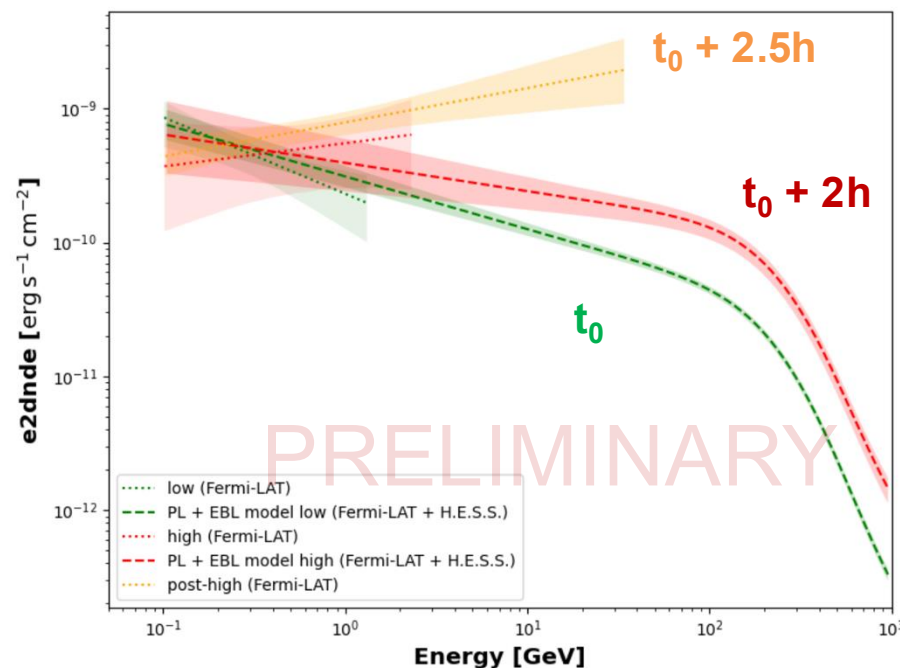
Yet another flare in terms of MWL behaviour?

No :

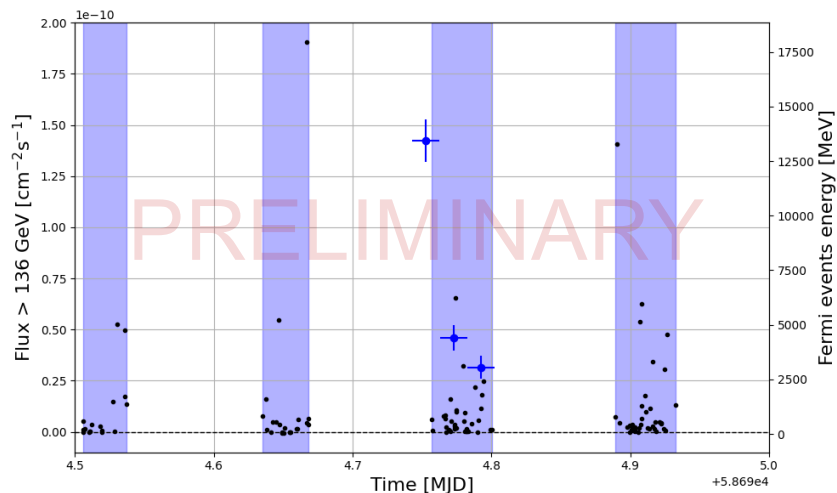
- 1 snapshot with quasi-simultaneous Fermi-LAT + H.E.S.S. data (in a ~low state where it shouldn't evolve much)
- 1 snapshot exactly simultaneous (in a high state)

Very rich dataset for modeling

- Clear spectral variability between two HE + VHE SEDs ~2h apart (very uncommon)



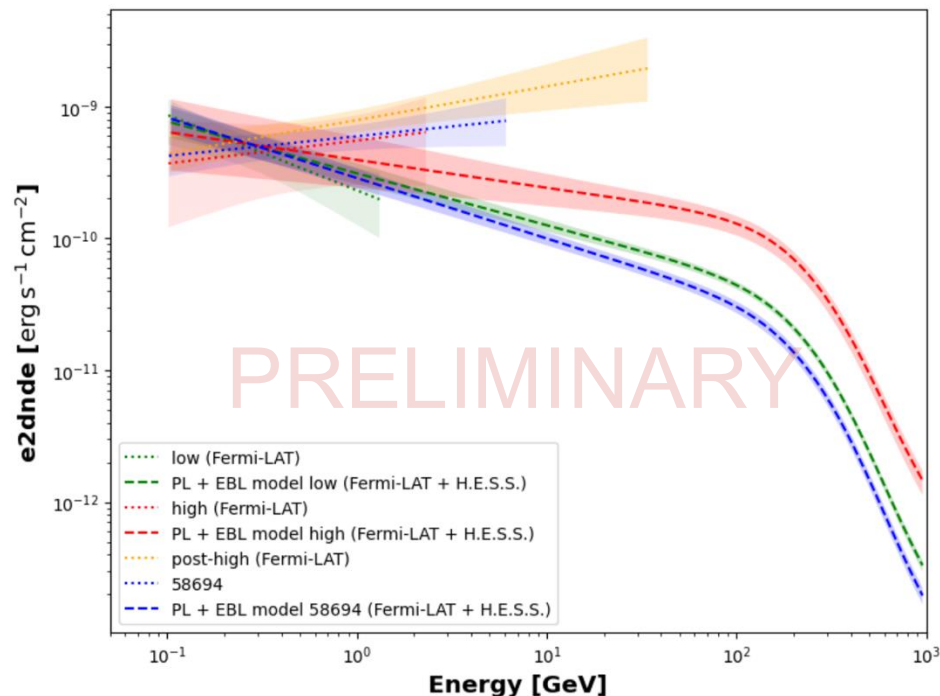
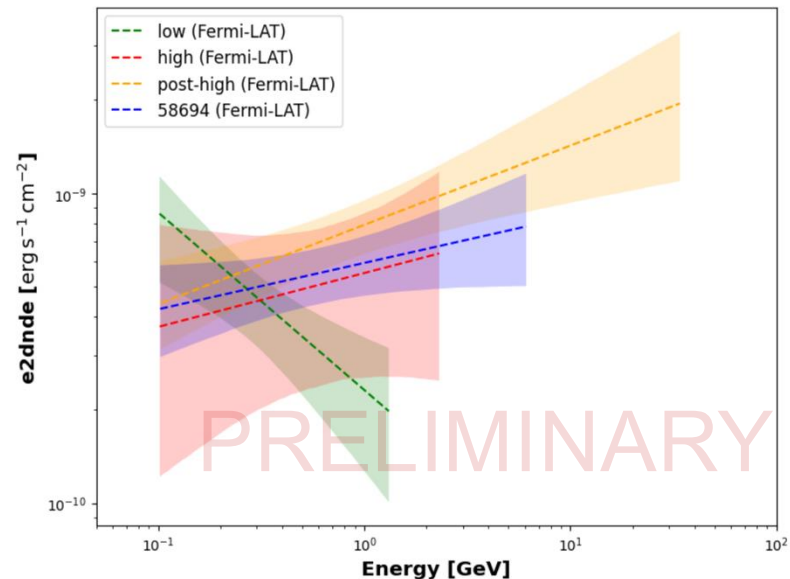
MWL picture (second night) :



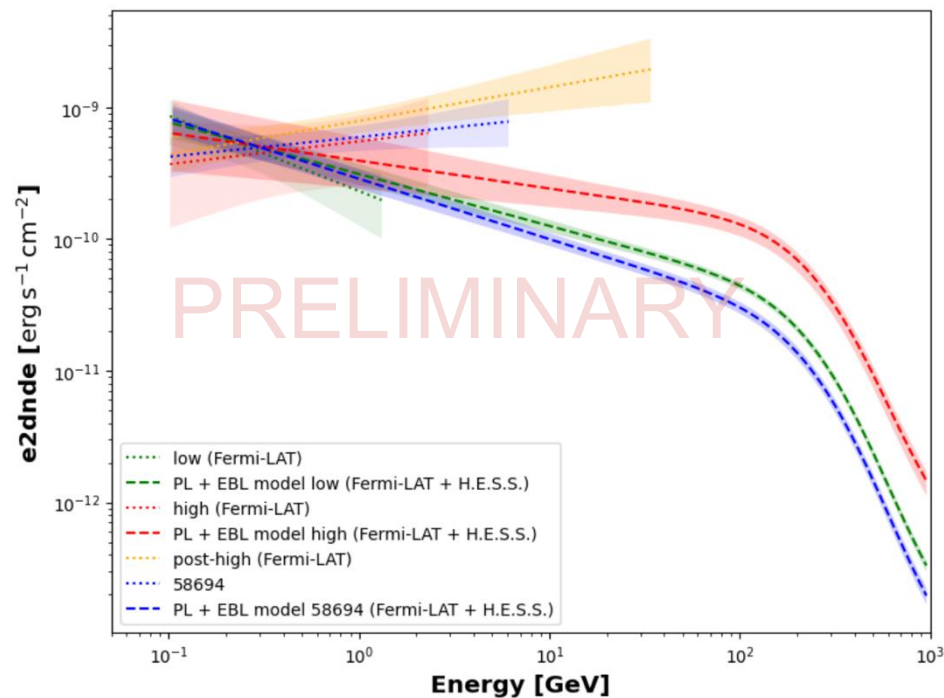
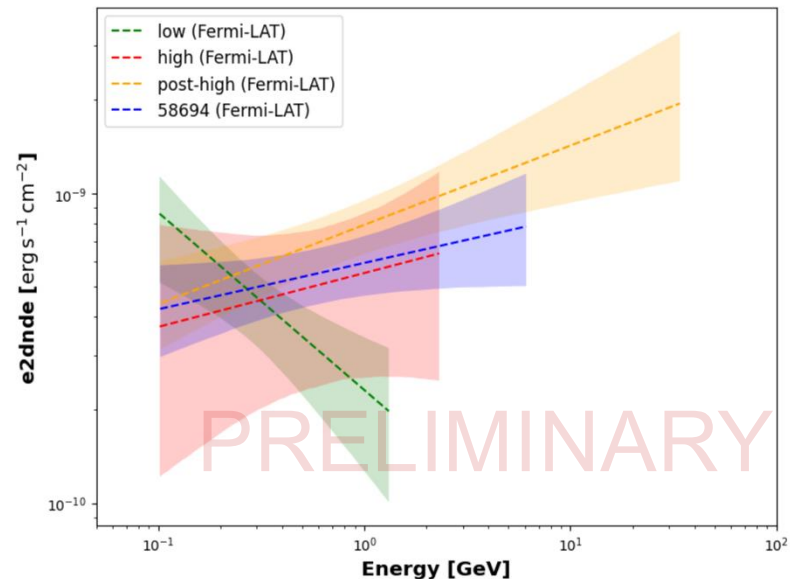
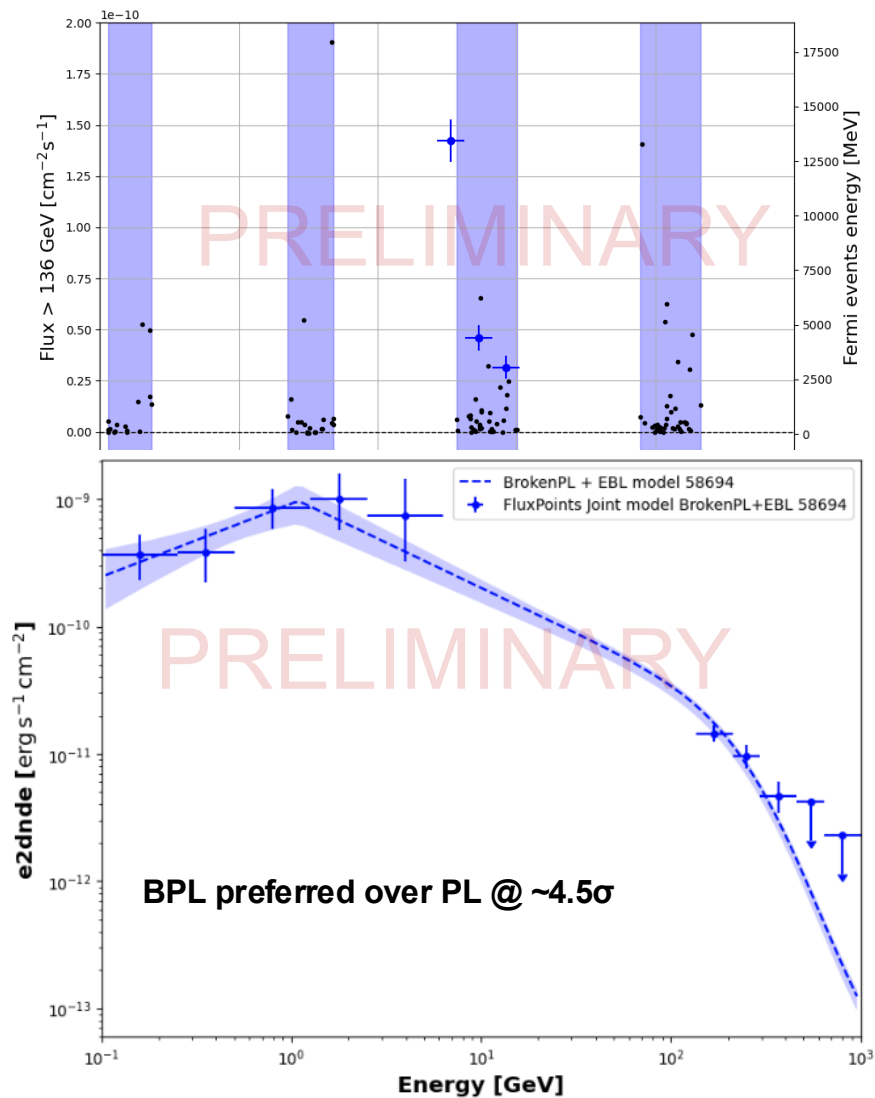
For the second night (MJD58694) :
1 strictly simultaneous snapshot between
H.E.S.S. and Fermi-LAT

What we see :
H.E.S.S. is in a lower state, Fermi spectrum
is still very hard

PL+EBL joint fit doesn't agree with Fermi-
only: need to introduce a break?



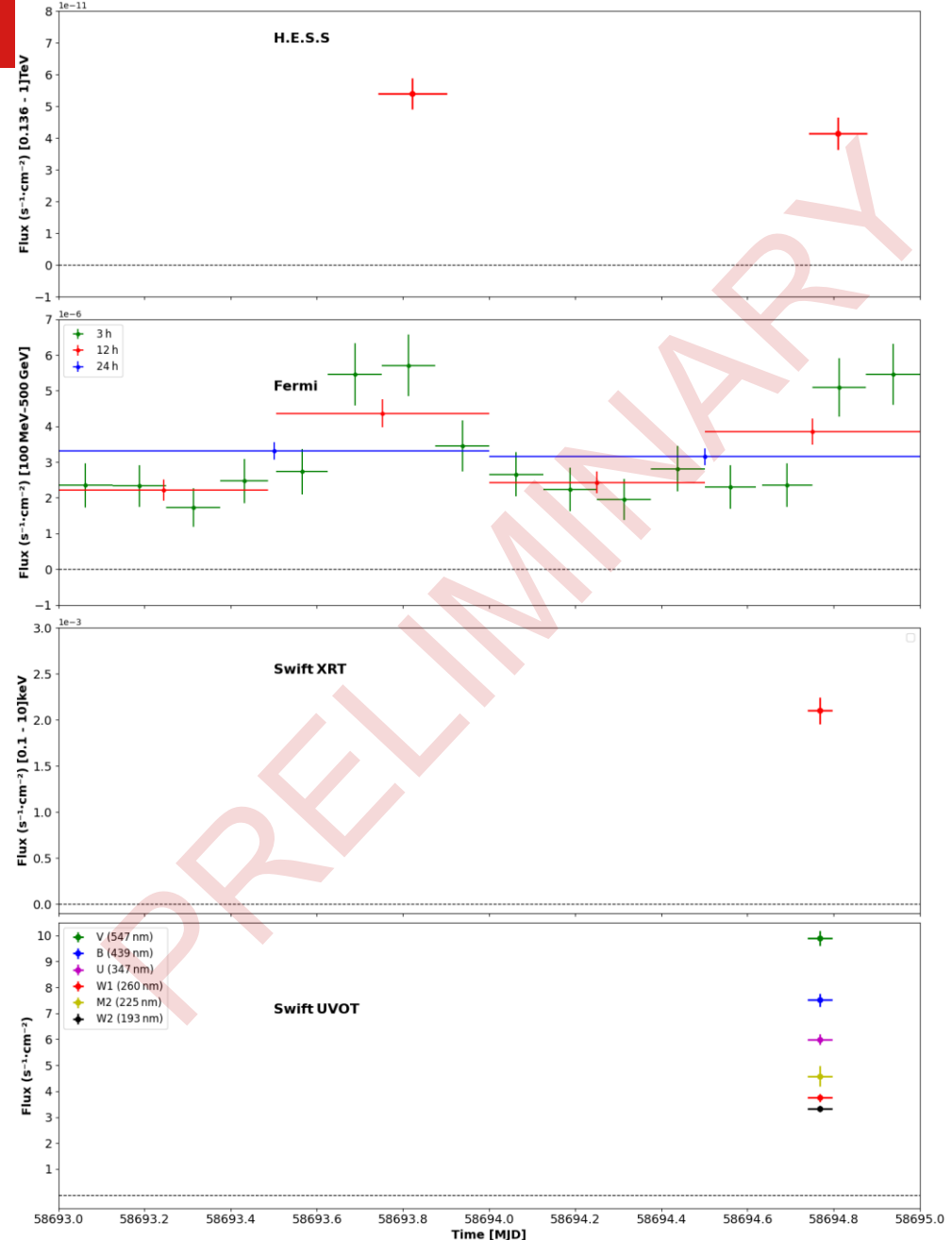
MWL picture (second night) :



MWL picture:

First night : No instruments other than Fermi-LAT and H.E.S.S. for now
(optical ATOM data being analysed)

Second night : Strictly simultaneous X-Rays and optical data from Swift (XRT + UVOT)
(also LCO + ATOM data being analysed)



MWL picture:

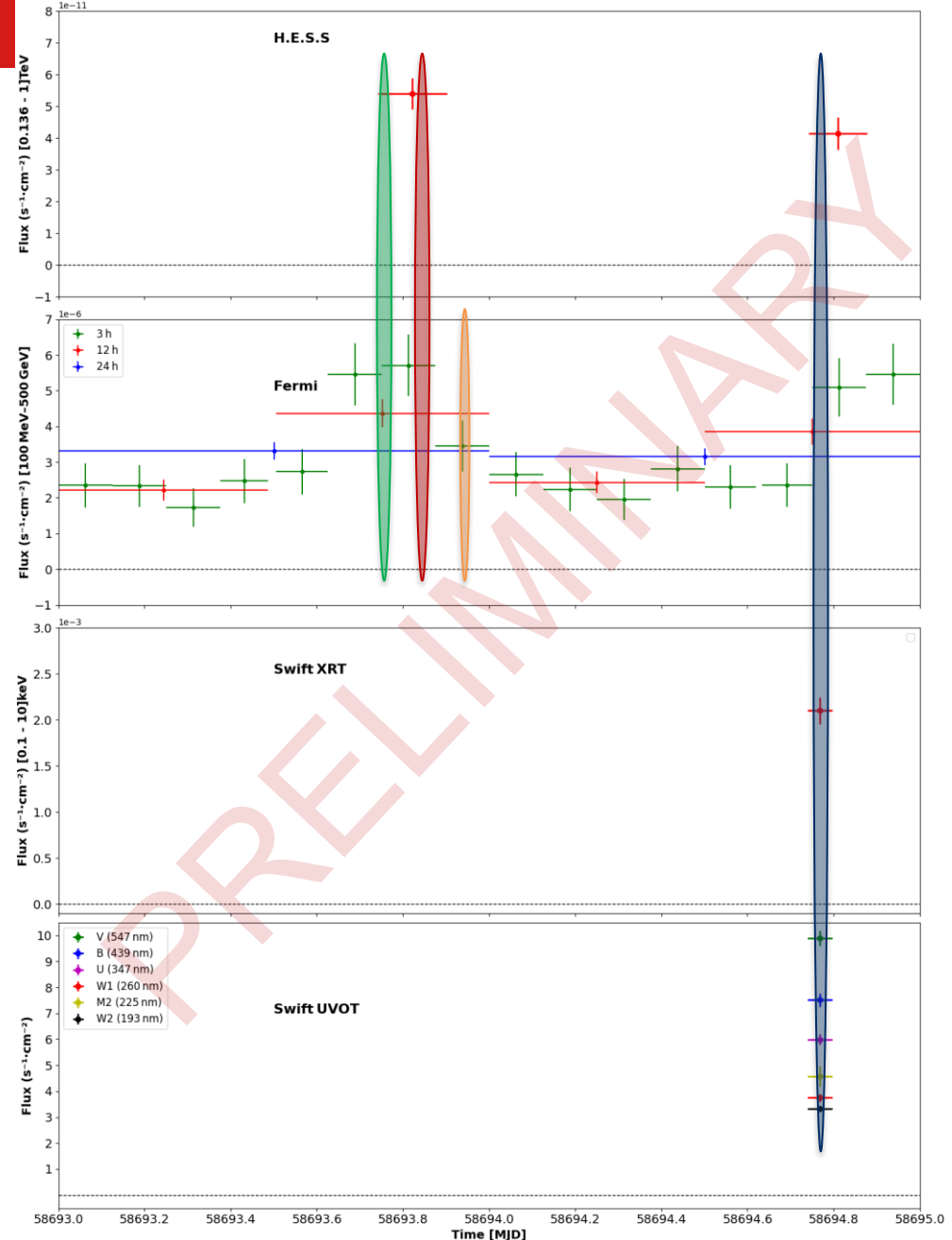
Modeling plan :
3 models for 3 snapshots

MJD58694 with strictly simultaneous H.E.S.S.
+ Fermi-LAT + Swift-XRT + Swift-UVOT

MJD58693 during H.E.S.S. low(er) state :
~1h apart H.E.S.S. + Fermi-LAT

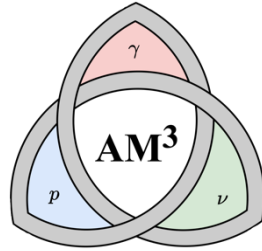
MJD58693 during H.E.S.S. high state : strictly
simultaneous H.E.S.S. + Fermi-LAT

(MJD58693 post H.E.S.S. high state : only
Fermi-LAT, but can be used to confirm trend
of evolution)



Modeling

Method:



- fast and complex MWL spectral variability: AM^3 for time-dependent modeling
- For us : one-zone leptonic model, with external photon fields (added multi-line BLR spectrum following Telfer 2002)

Gameplan:

- Constraining physical parameters of the source with 2nd night SED
 - environment geometry (temperature, opacity)
 - Emitting zone parameters (size, distance from black-hole, magnetic field)
- evolution inter-night and intra-night : modification of the e- population (minimal and maximal energies, index of spectrum, ...)
- Link them in a credible scenario

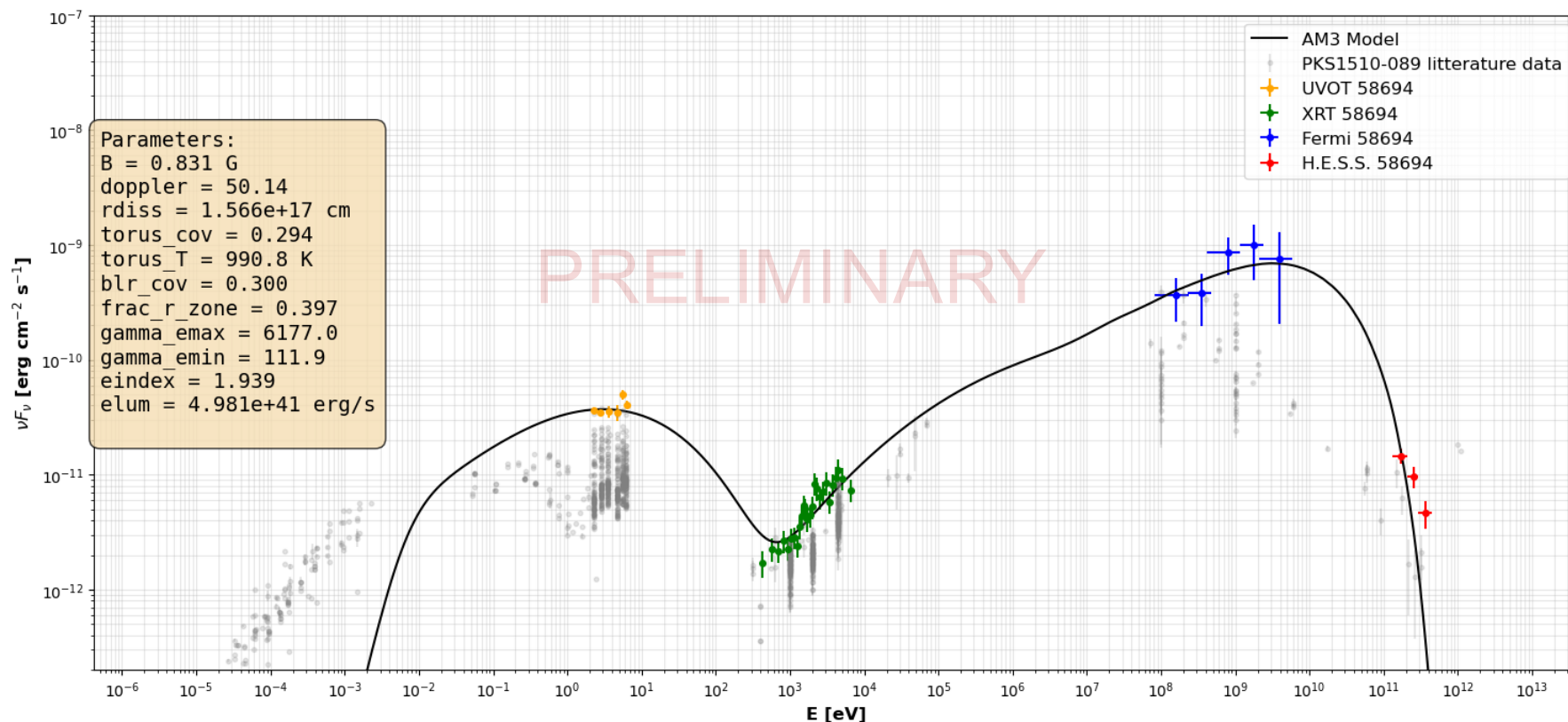
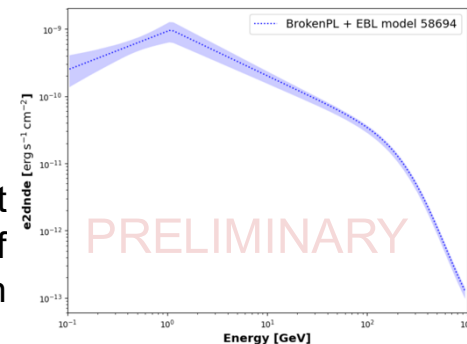
Modeling

Gameplan:

- Constraining the physical parameters of the source with the simultaneous 2nd night SED
 - environment geometry (temperature, opacity)
 - Emitting zone parameters (size, distance from black-hole, magnetic field)

Strategy:

- Joint analysis FluxPoints
- Minuit fit within AM3
- weighted chi2 (to account for difference in number of points between instruments)



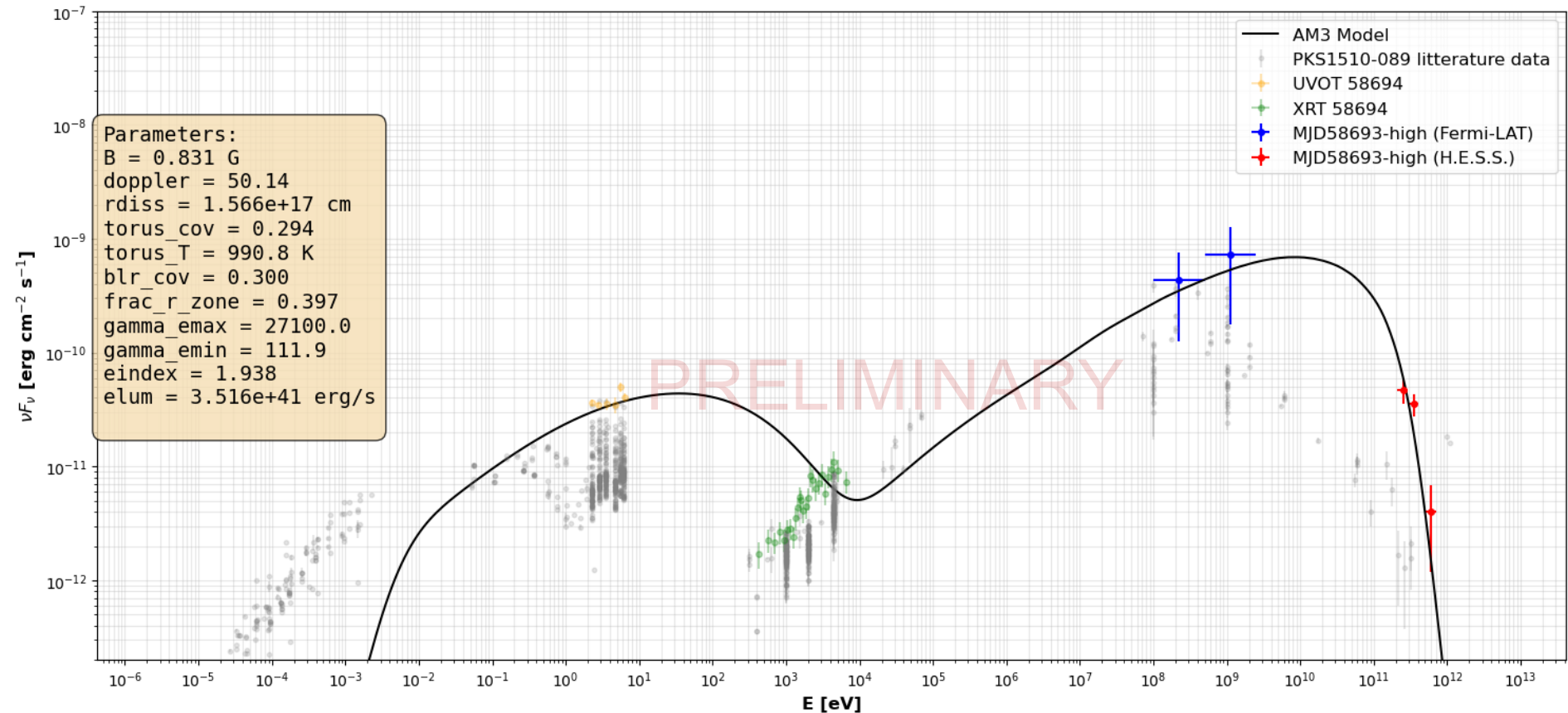
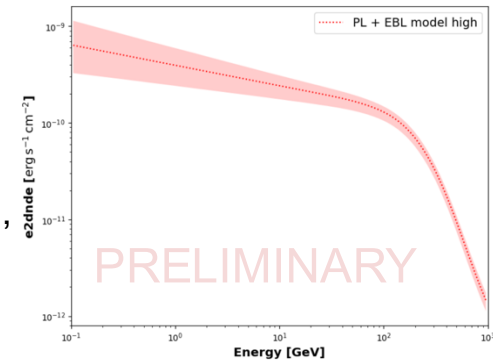
Modeling

Gameplan:

- To account for evolution inter-night and intra-night : modification of the e- population (number, minimal and maximal energies, index of spectrum)

Strategy:

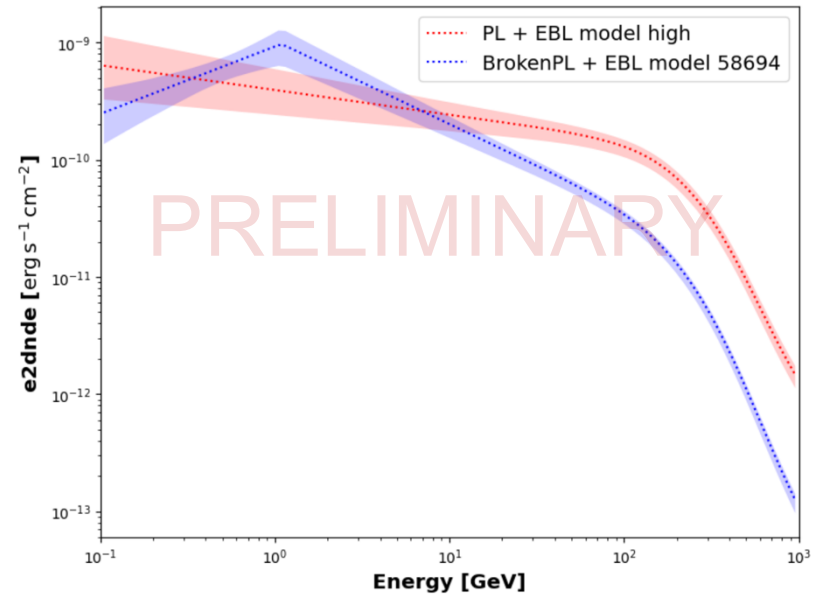
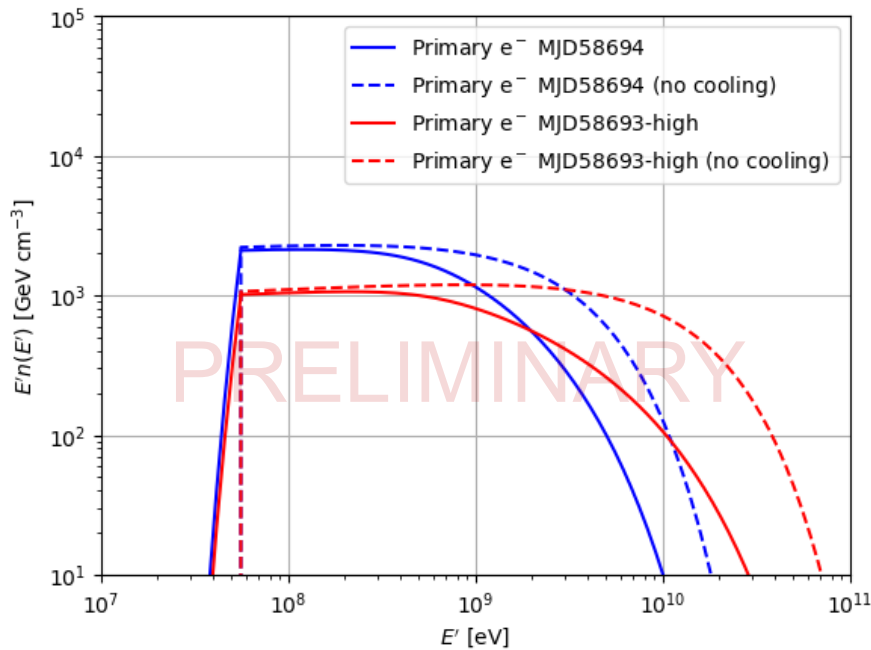
Most parameters are frozen to 2nd night results, e- population is free to vary (gamma_max + elum)



Modeling

Gameplan:

- To account for evolution inter-night and intra-night : modification of the e- population (number, minimal and maximal energies, index of spectrum)



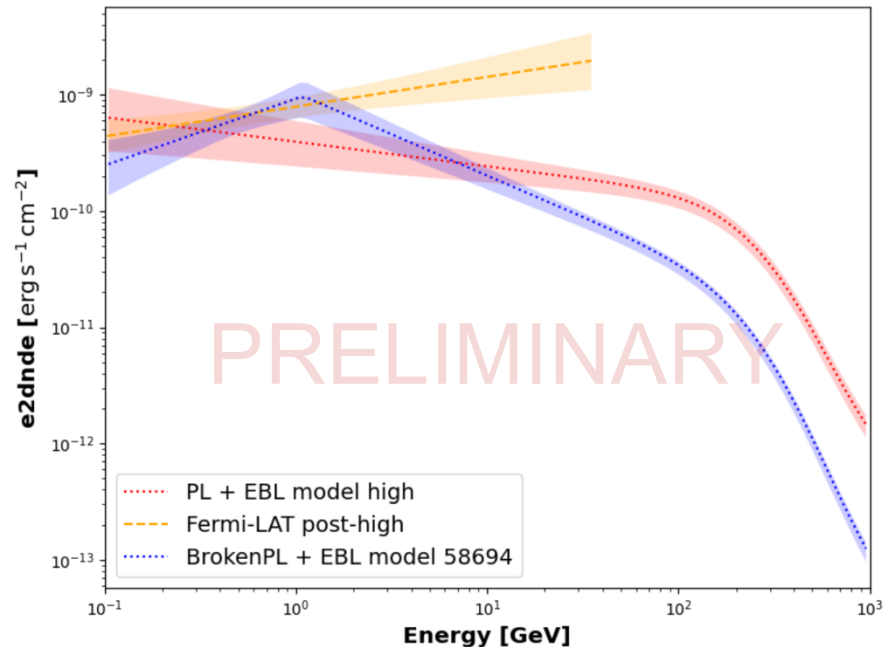
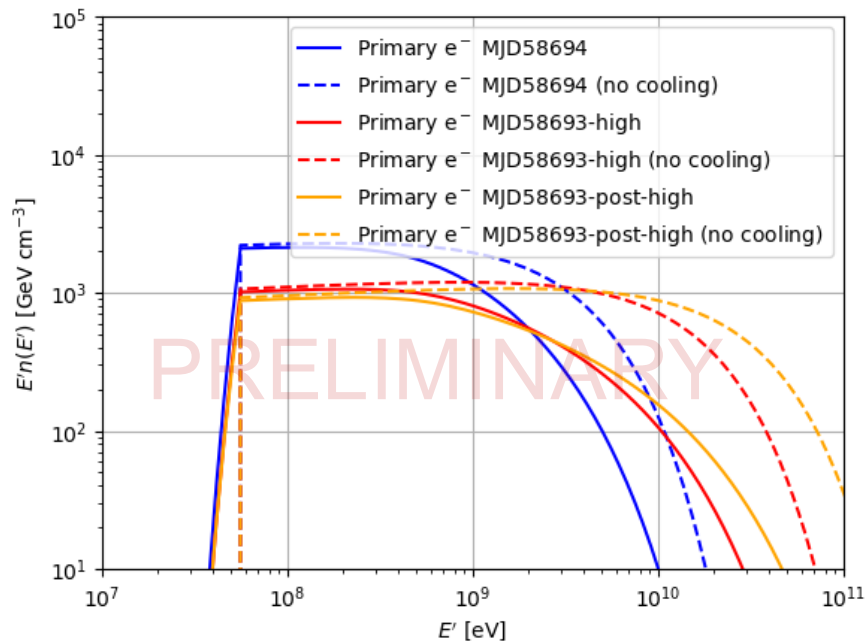
Current result:

- From **high** to the **second night**: change of gamma_{emax} (and e- luminosity accordingly) is sufficient

Modeling

Gameplan:

- To account for evolution inter-night and intra-night : modification of the e^- population (number, minimal and maximal energies, index of spectrum)



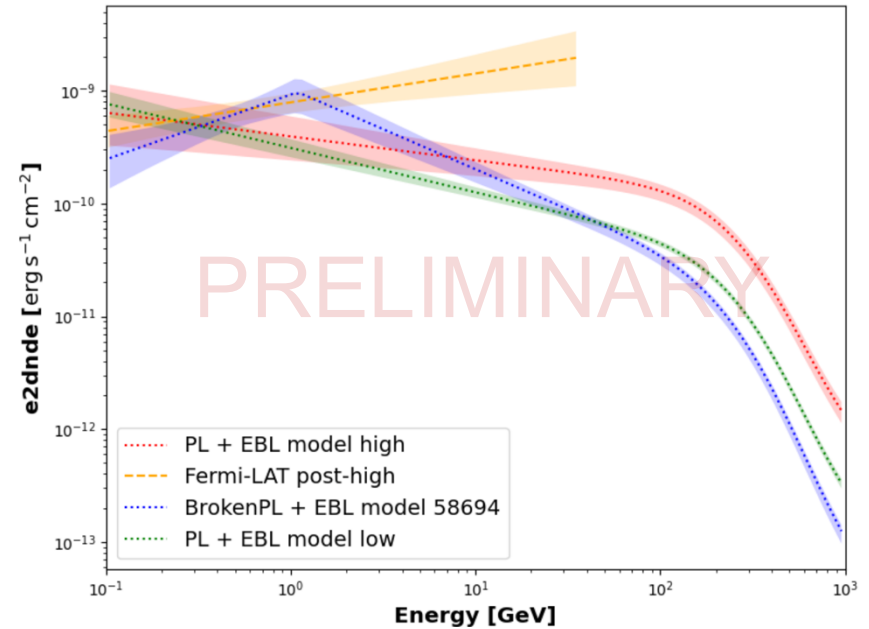
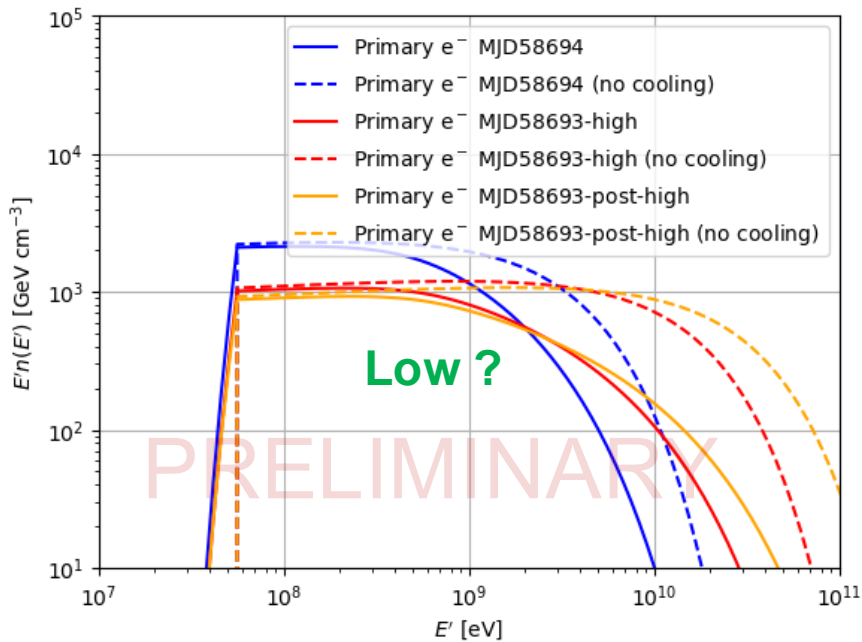
Current result:

- From **high** to **post-high** to the **second night**: a change of γ_{max} (and e^- luminosity accordingly) is a sufficient explanation

Modeling

Last challenge:

- **MJD58693-low**, very different Fermi spectrum -> Fermi is softer, H.E.S.S. is higher
gamma_emax not sufficient to explain it



Next step: Add another zone as in H.E.S.S. 2023

Summary

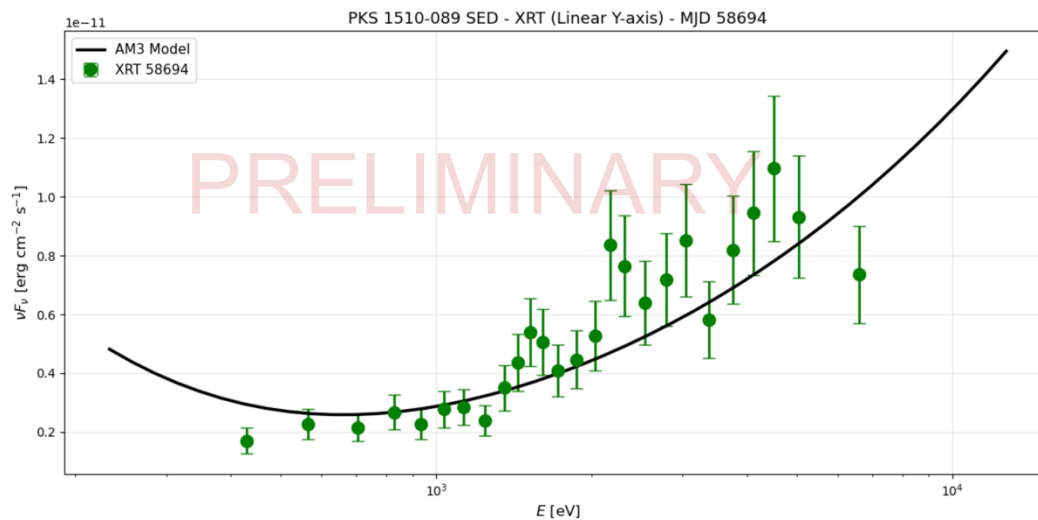
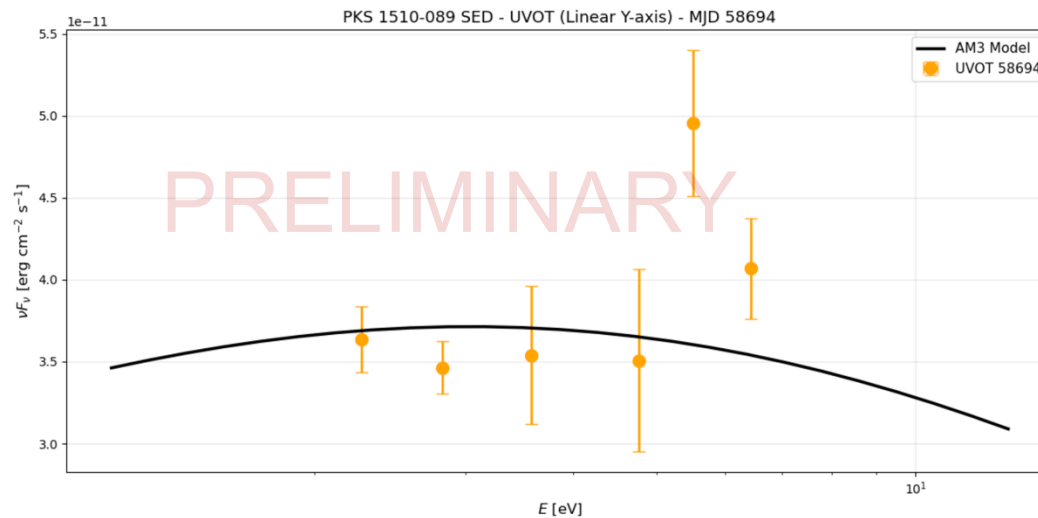
- PKS 1510-089 July 2019 flare is a **very** exciting dataset :
 - Unheard of VHE variability behaviour for a FSRQ: 20min smooth doubling and halving timescale
 - it shows intra-night MWL spectral variability between very close snapshots (~2h)
- fast variability => time-dependent modeling code => AM³ is a good candidate
- We constrain the source parameters using strictly simultaneous data from the flare's second night
- Evolution of the electron population during the first night (preliminary, only gamma_max and normalisation change for now)
- Low state seems more challenging => need to introduce 2 zones as in *H.E.S.S.23* paper ?

Summary

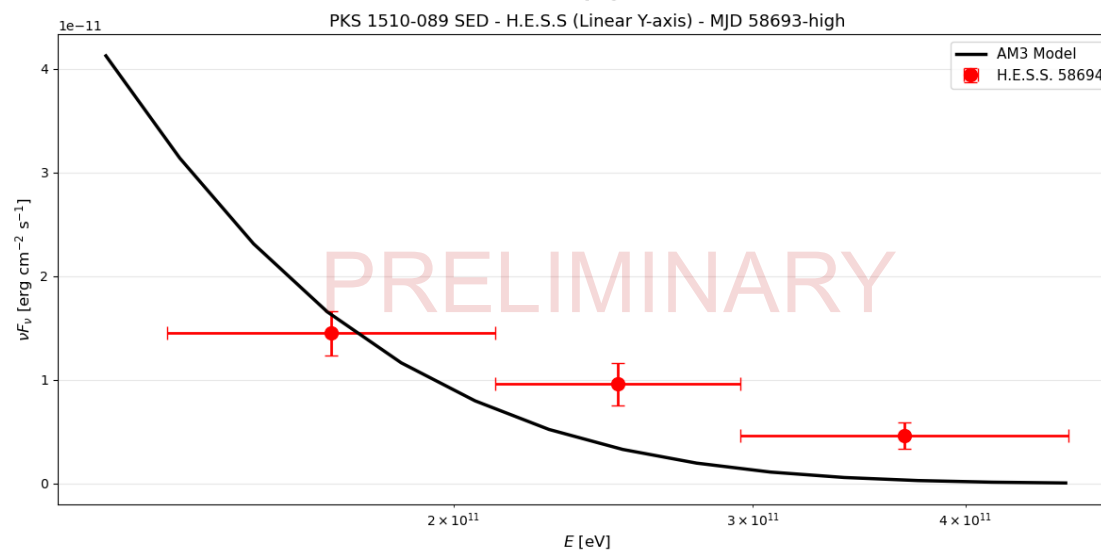
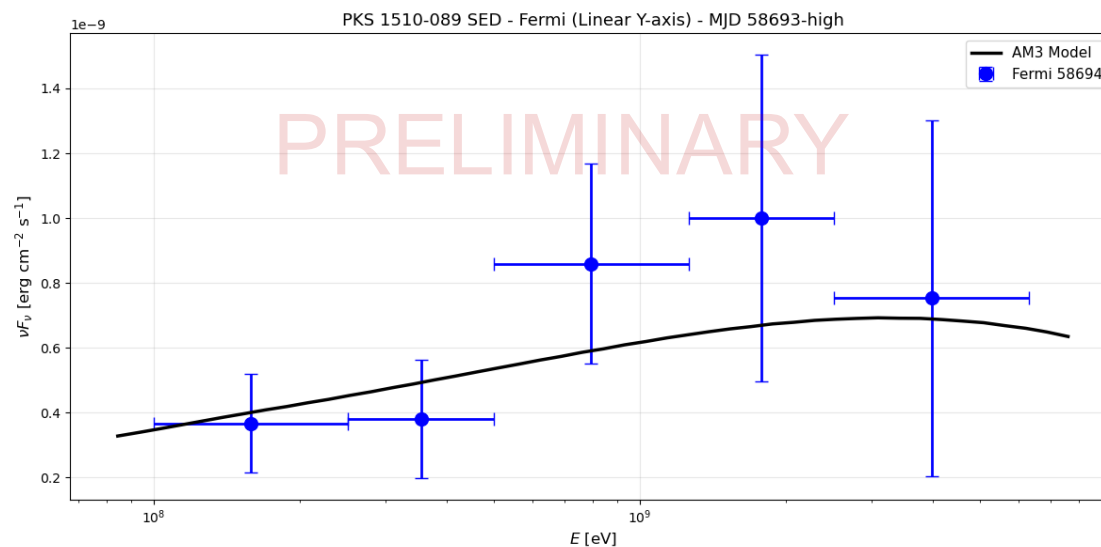
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Thank you

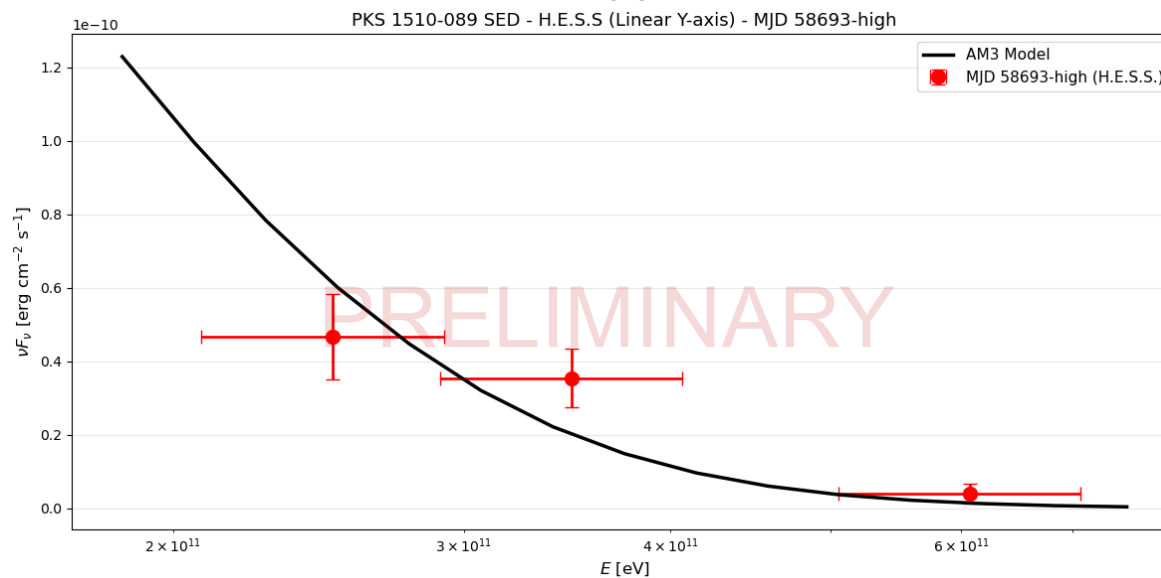
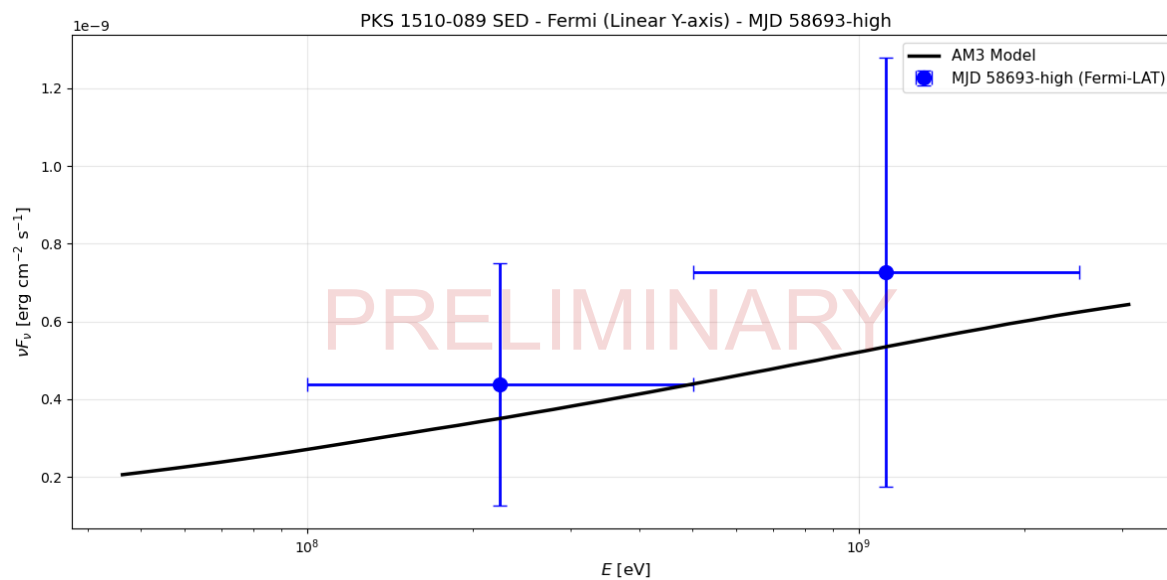
Linear zoom-ins



Linear zoom-ins



Linear zoom-ins



Backup

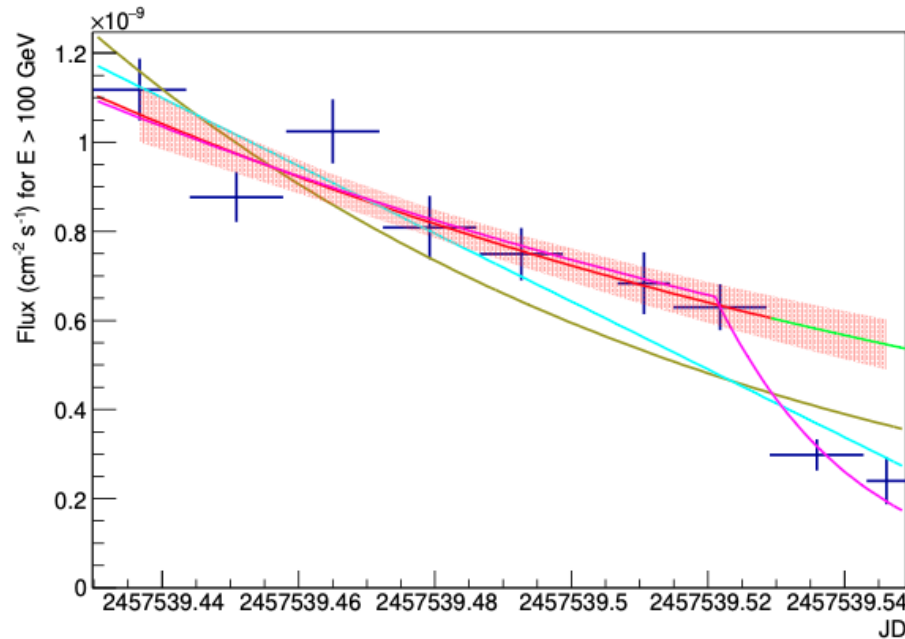


Fig. 11. Various fits to the MAGIC light curve above 100 GeV on JD 2457539. Olive green line shows the exponential fit, magenta the broken exponential and cyan the linear fit. The exponential fit to the first seven points of the light curve is shown with red line, with the red shaded region showing the 68% C.L. uncertainty band and the green line shows its extrapolation to the end of the light curve.

Significant deviation from the 1.5h timescale at the end of the MAGIC lightcurve, proof of a cessation in flux (of order 20min)

From
« *H.E.S.S. and MAGIC observations of a sudden cessation of a very-high-energy γ -ray flare in PKS 1510-089 in May 2016* »
H.E.S.S. + MAGIC Collaborations 2021, A&A

<https://doi.org/10.1051/0004-6361/202038949>