

# Complex spectro-temporal behaviour of Mrk 501 from unbiased monitoring

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for the FACT and the HESS Collaborations



Monitoring the Non-thermal Universe 2018  
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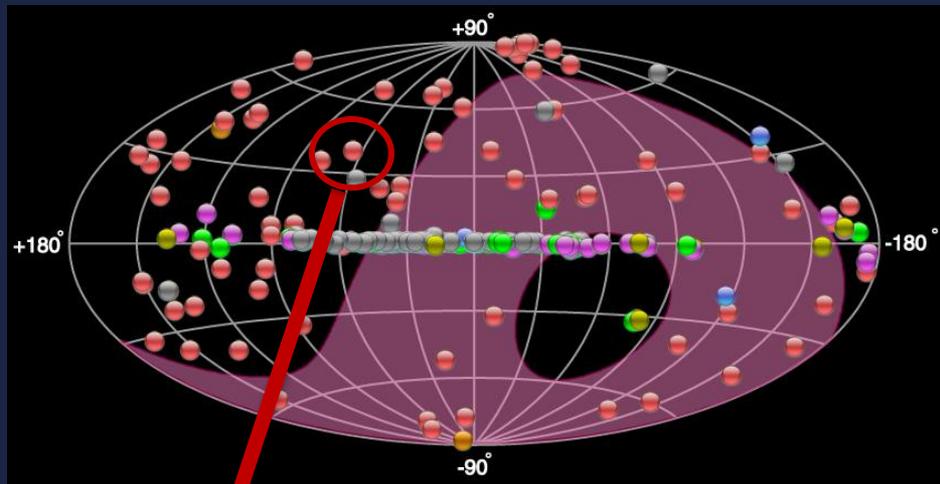
## Markarian 501

- Second extragalactic source discovered at TeV energies (Quinn et al. 1996)
- Nearby ( $z = 0.034$ )

Several observation campaigns on it  
(Albert et al., 2007, Anderhub et al., 2009, Fermi-LAT, MAGIC, VERITAS, 2011)

We should have a good knowledge of it, but it still surprises us!

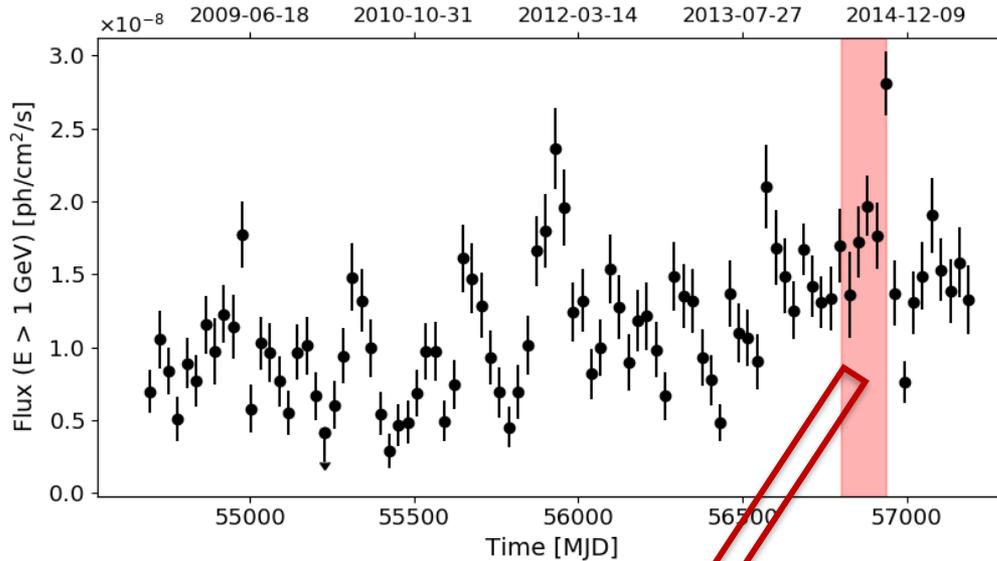
HE behaviour very complex:  
hints of multiple components  
(e.g. Shukla et al. 2015)  
very hard photon index during flares  
(e.g. Neronov et al. 2011)  
**The more we look, the more interesting it gets!**



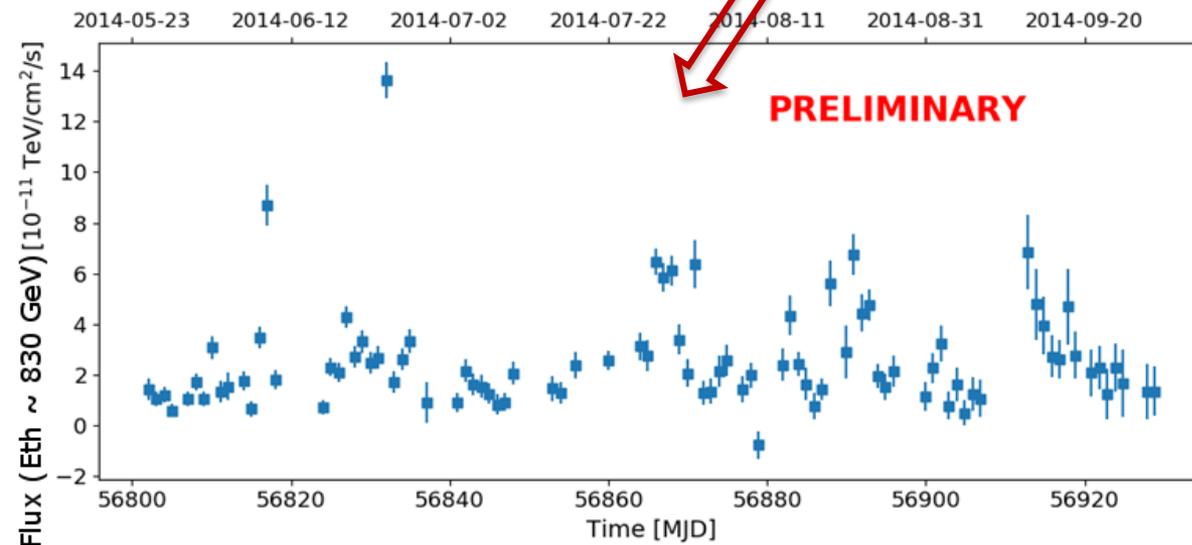
Mrk 501

At the visibility edge for HESS:  
Visible only in high state and with large  
energy threshold

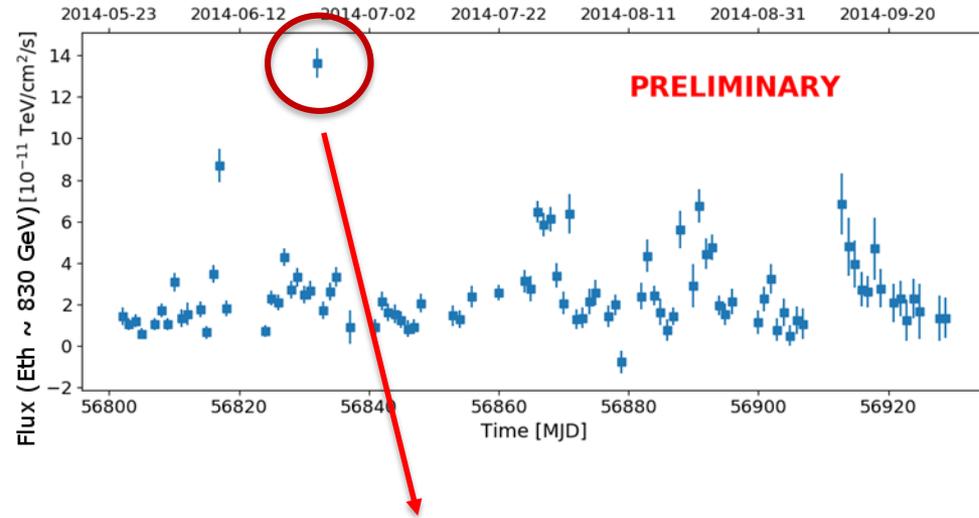
# Flaring activity in June 2014



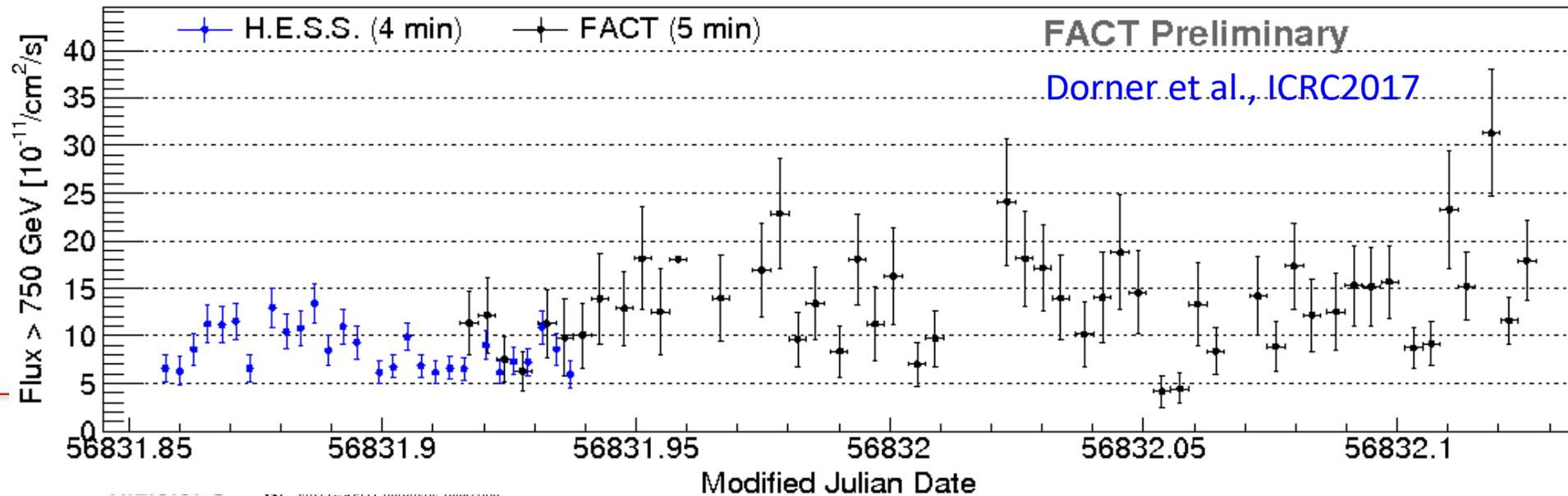
- HESS observations triggered by a FACT alert (Cologna et al., Chakraborty et al., ICRC 2015, GAMMA 2016)
- Detection of flare close to historical maximum
- Fermi-LAT data over multi-year interval



## Flaring activity in June 2014

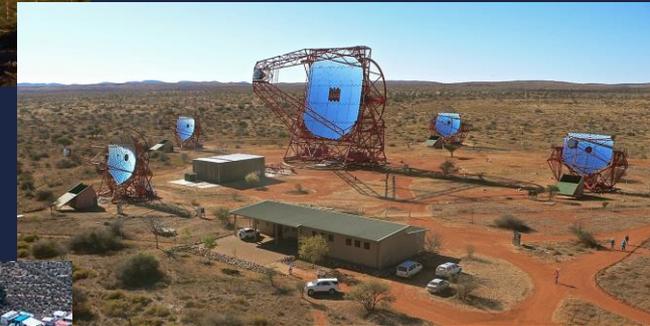
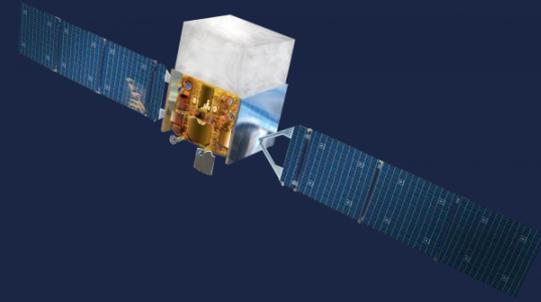


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# Monitoring at HE and VHE

- Various instruments to explore the behaviour at the highest energies
  - Fermi-LAT
  - FACT
  - Classic (IACT)
  - (HAWC)



See HAWC talk on Friday  
by M.M. Gonzalez

No HAWC data for this dataset  
HAWC monitoring potential  
(Dorner et al. 2016;  
HAWC Coll., 2017)



# LAT – FACT – HESS



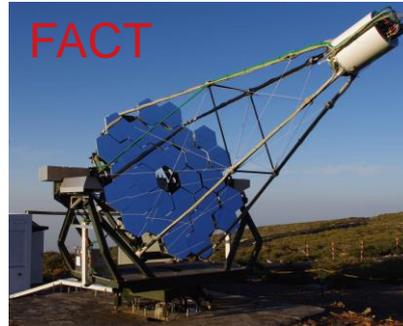
*Fermi-LAT*

## GOOD

Energy range:  
 $100 \text{ MeV} < E < \sim O(100 \text{ GeV})$   
 Large field of view: 2.4 sr  
 Synoptic – unbiased  
 monitoring

## NOT SO GOOD

Small effective area:  $\sim 1 \text{ m}^2$



FACT

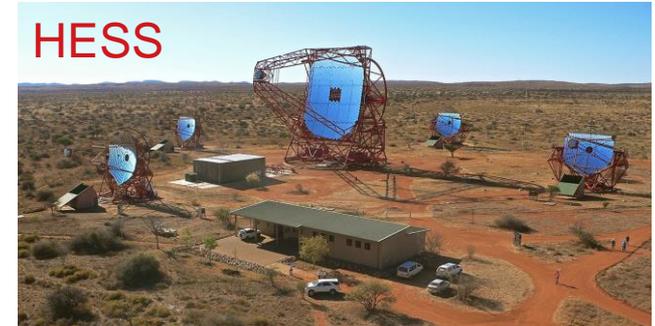
## GOOD

Energy range:  
 $E > \sim O(1 \text{ TeV})$

Monitoring strategy

## NOT SO GOOD

Low sensitivity



HESS

## GOOD

Energy range:  
 $E > \sim O(1 \text{ TeV})$  for Mrk501

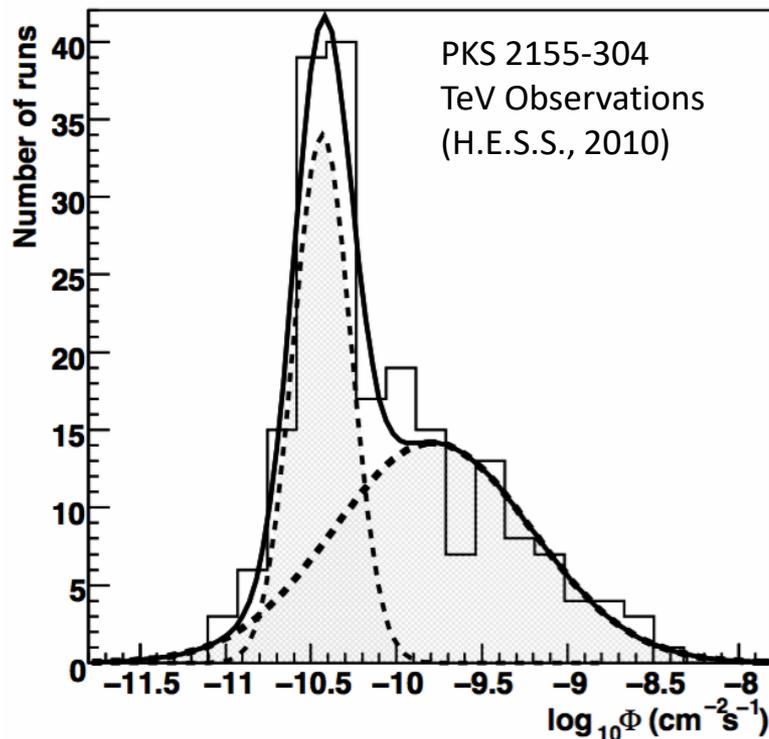
High sensitivity

## NOT SO GOOD

Biased observations

# Flux distributions: normality vs log-normality

- The flux distribution gives insight on the processes responsible for the source variability
- Normal (Gaussian) flux Probability Density Function implies additive processes in the emission
- Log-normal PDF would naturally arise from multiplicative processes

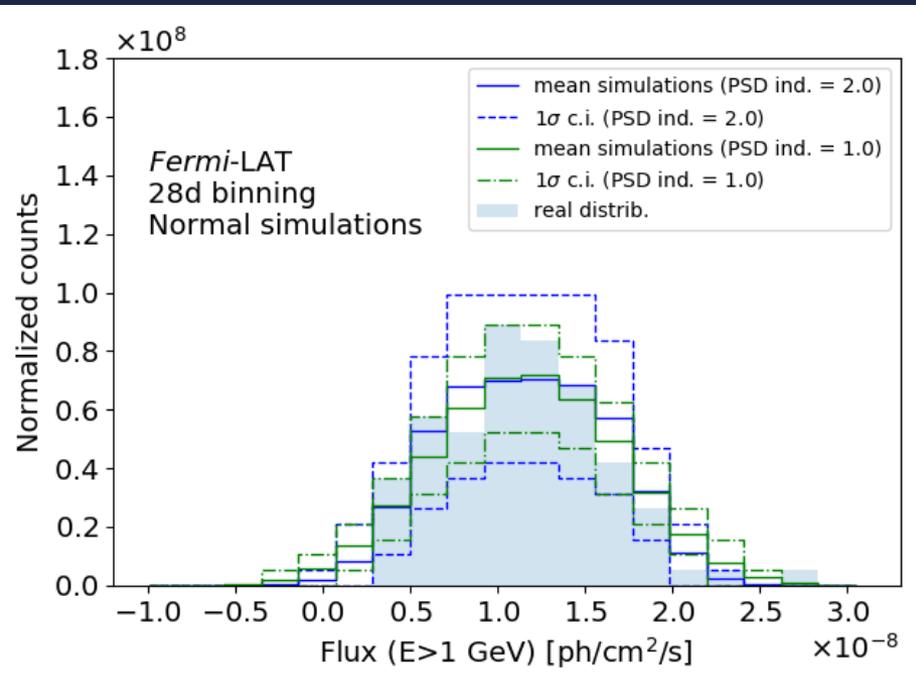


Many examples of Log-normal behaviour in AGNs

Favour multiplicative processes => constrain standard additive multi-zone framework (e.g. Uttley et al. 2005)

Mathematical caveat : large number ( $O(10^3)$ ) of additive components (Biteau Thesis)

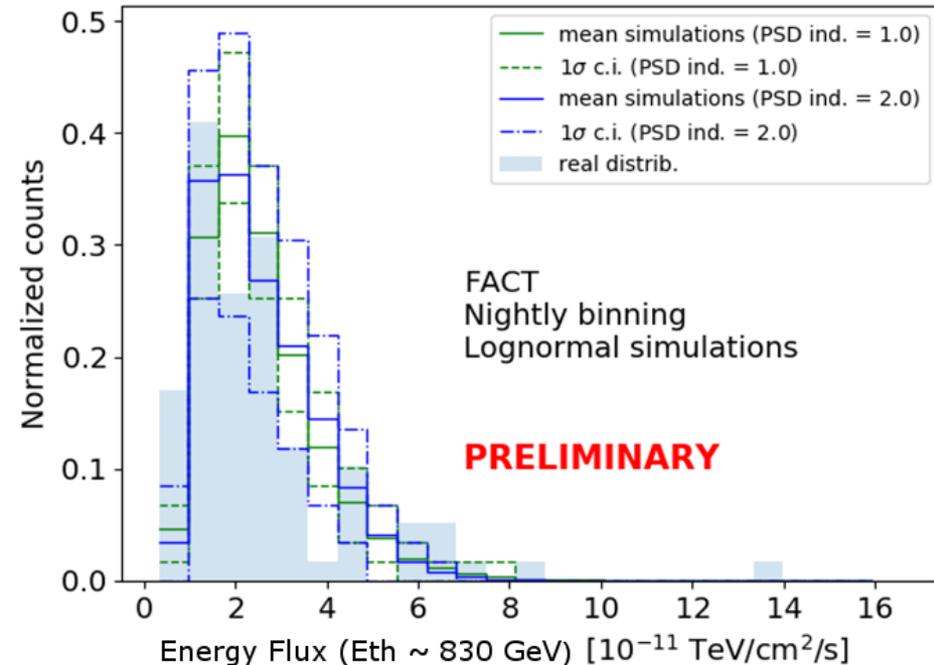
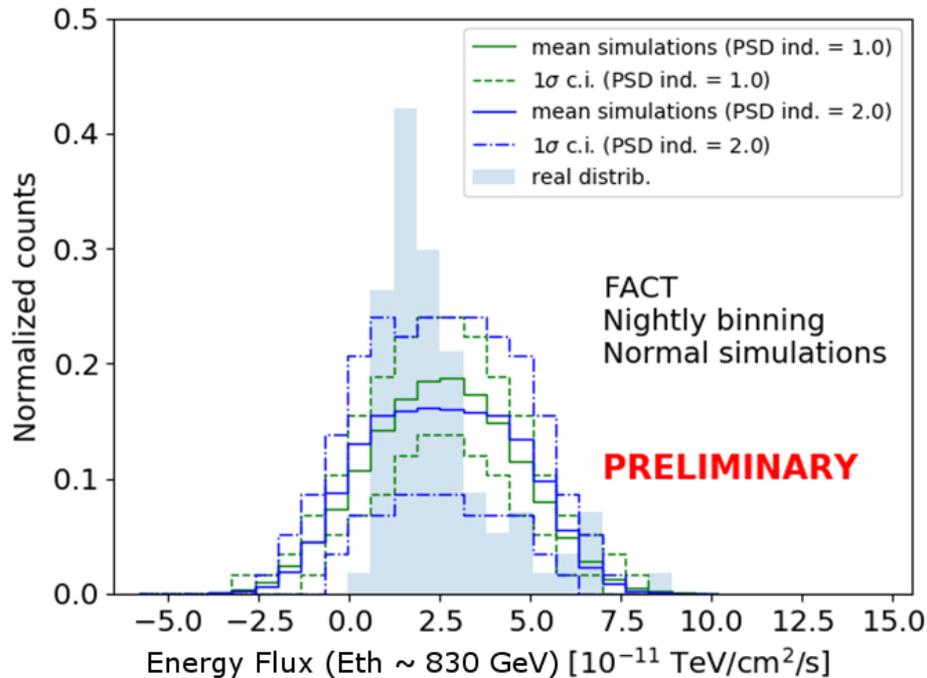
## Flux distributions: Fermi - LAT



- Normal distribution consistent with the data (log-normal not)
- Shorter time-scales not enough precision to have a meaningful histogram
- Remaining questions:
  - Normality at low energies?
  - Normality at monthly timescales?

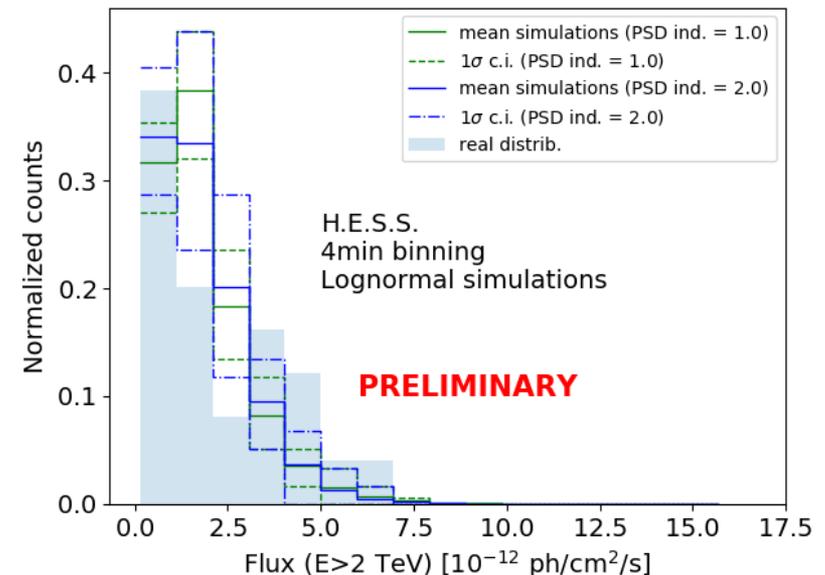
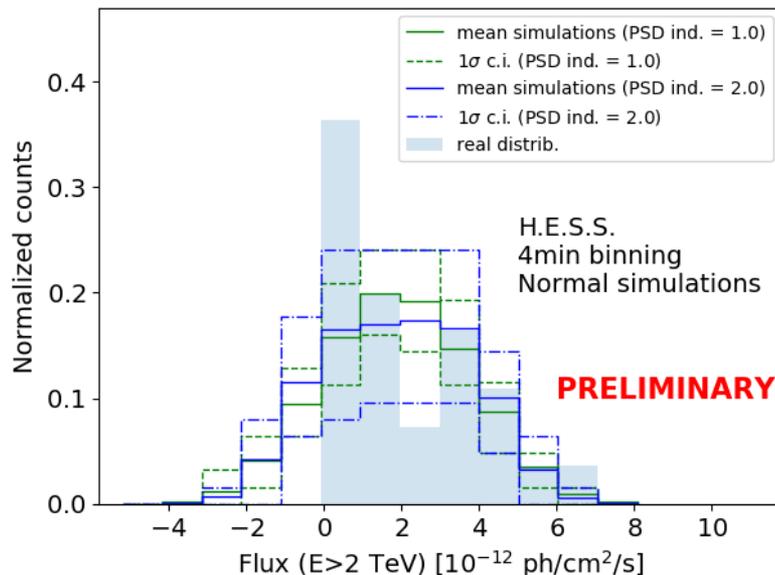
# Flux distributions: FACT

- In the **nightly light-curve** for an energy threshold of 830 GeV there is a clear preference for log-normal flux distribution



# Flux distributions: HESS

- Above 2 TeV, on 4-min light-curve: still preference for log-normal flux distribution



Current observations show a stronger preference for lognormal distribution for nightwise LCs at TeV energies than monthly LCs at GeV energies – tricky to separate the temporal and spectral effects

*Improved solution => unbiased monitoring*

# Flux – Index relations

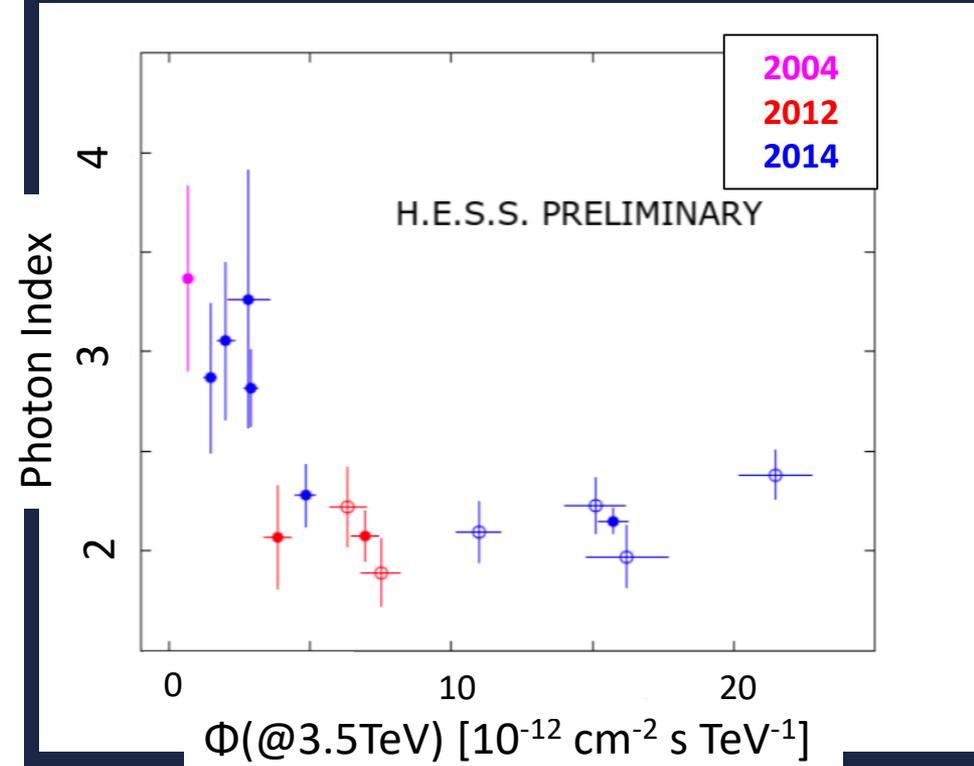
- Beside the flux variations, we can look also at spectral ones.
- Reconstruct the relations between flux level and photon index of the source
  - At TeV energies often observed a "harder-when-brighter" behaviour (Mrk 501 - [Cologna et al., ICRC2015](#); IC 310 - [MAGIC Coll., 2017](#), ...) even though the relation can be more complex (e.g. PKS 2155-304 flare, [HESS Coll., 2010](#))
- Exploration of the existing relations for Mrk 501 in the different energy bands and different timescales sampled by LAT, FACT and HESS

# Flux – Index relations TeV energies (HESS)

- Historical HESS observations on Mrk 501
- The HESS results with the “harder-when-brighter” behaviour

MAGIC also reports similar behaviours (Anderhub et al., 2009)

See also talk by D. Paneque on Thursday on Mrk 501 and Mrk 421

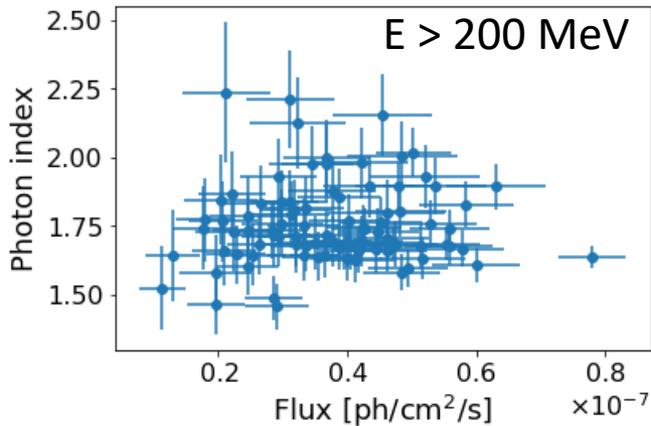


Cologna et al., ICRC2015

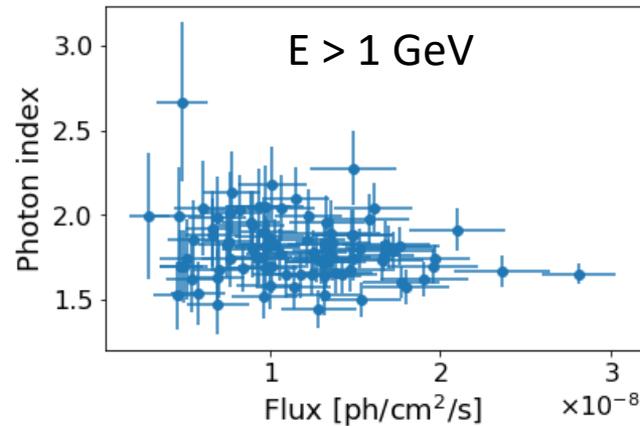


# Flux – Index relations GeV energies

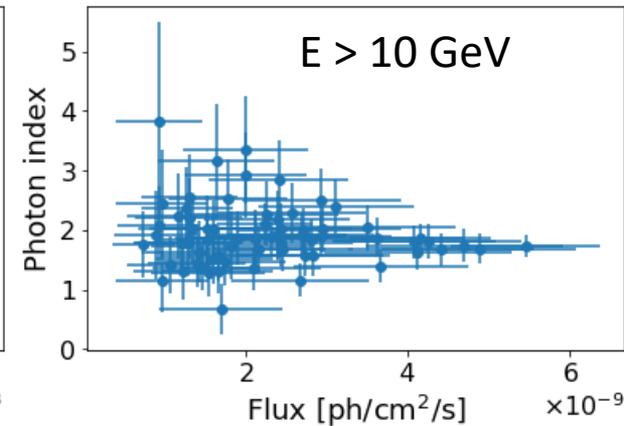
- Fermi-LAT allows exploration in different energy bands
- Pearson's coefficient to check correlation between Flux and Index



Monthly LC  
Pearson-r = 0.04



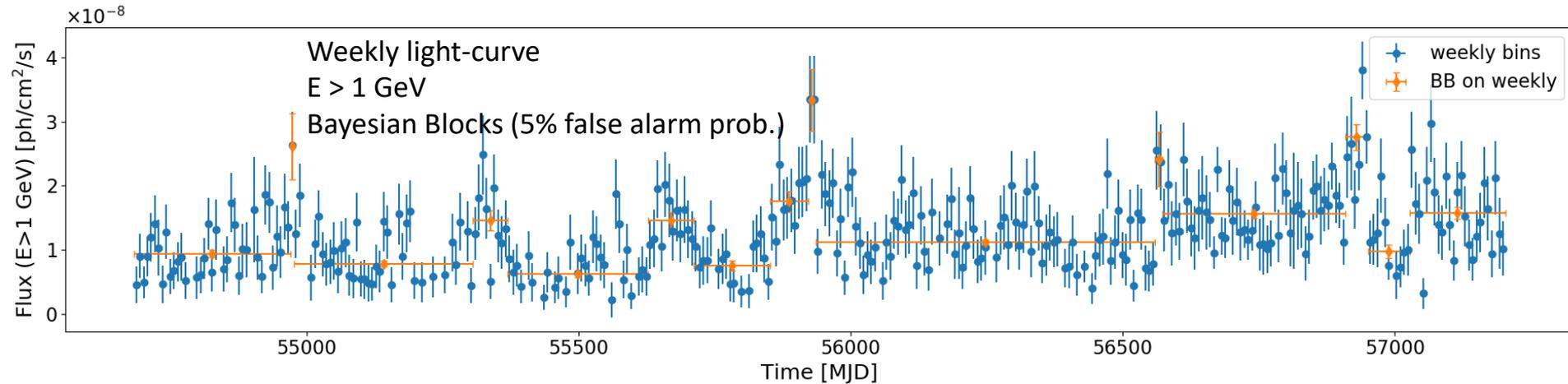
Monthly LC  
Pearson-r = -0.19



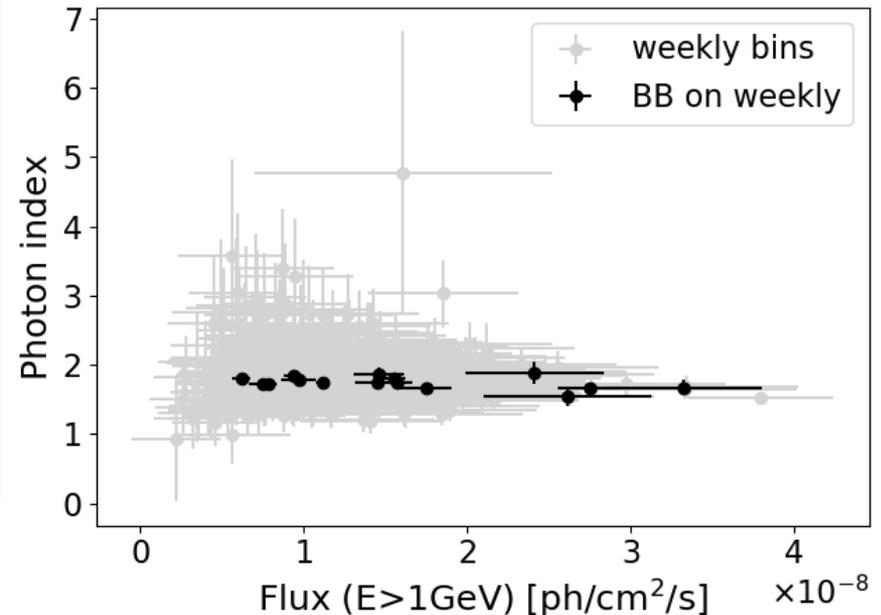
Monthly LC  
Pearson-r = -0.11

(Similar distributions already in Shukla et al. 2015 and hint towards multiple spectral components)

# Flux – Index relations Fermi-LAT above 1 GeV

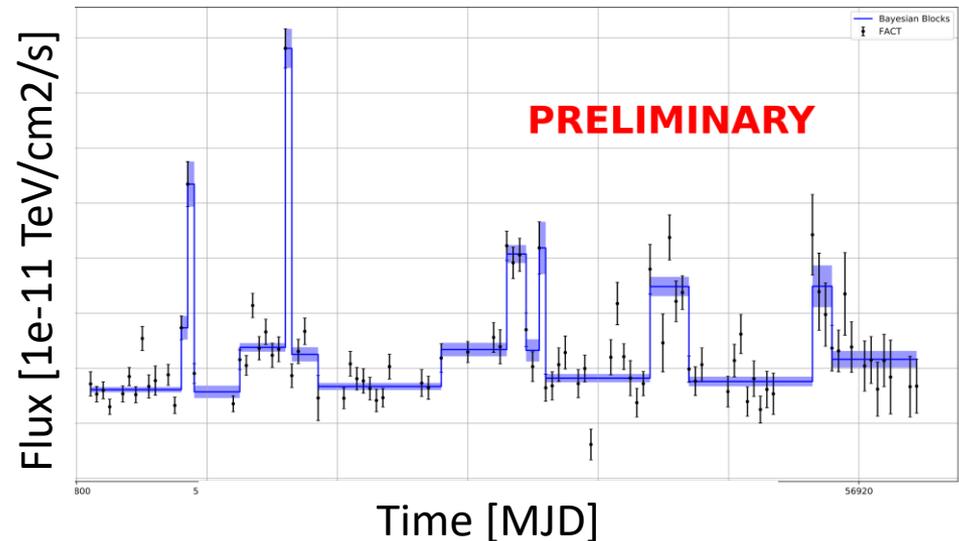
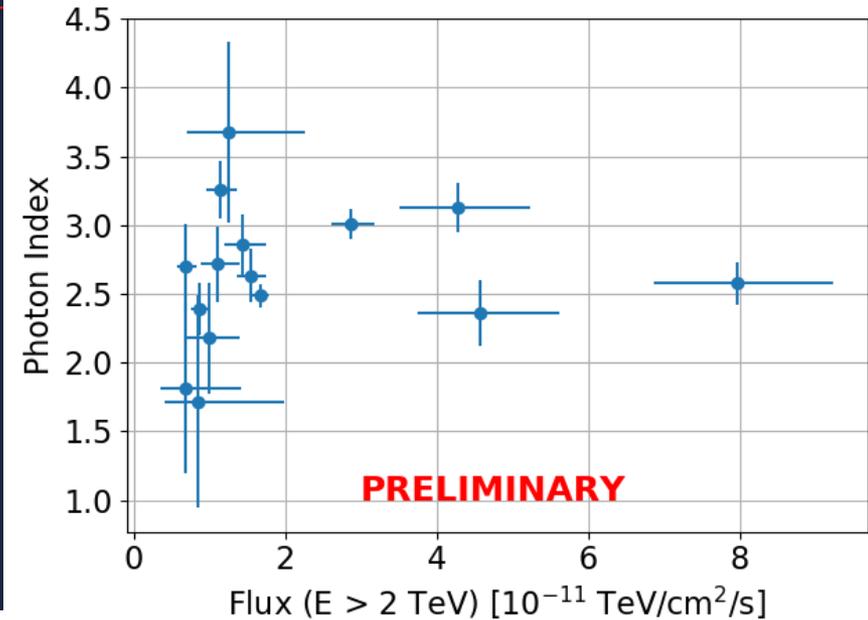


- Computation of Bayesian Blocks on weekly light-curve for  $E > 1$  GeV
- Photon index becomes completely independent from the flux level



# Flux – Index relations TeV energies (FACT)

- FACT using Bayesian Blocks on nightly LC
- Larger spread of indices at low fluxes
- More similar to what seen in the Fermi-LAT data
- The relation for this source at TeV and GeV energies is more complex than previously thought.



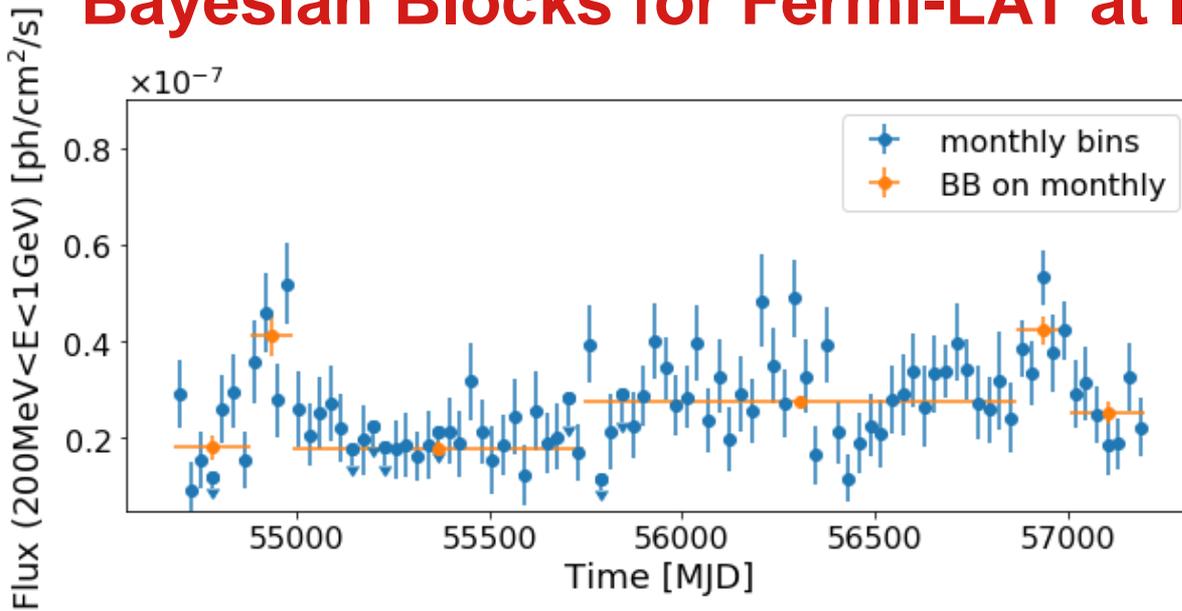
# Conclusions

- Evident log-normality in the flux distributions in the VHE regime at different timescales
- Different case for Fermi-LAT where flux distribution on monthly timescales is perfectly compatible with a Gaussian
- *"Harder-when-brighter"* behaviour at TeV energies could be an effect of observational bias.
- Need to disentangle between time-scale effects and overlay of different processes
- **Unbiased monitoring fundamental to investigate properly the spectral and temporal properties**



# Back-up slides

# Bayesian Blocks for Fermi-LAT at lower energies



Fermi-LAT analysis between  
200 MeV and 1 GeV  
Monthly lightcurve

