# Confronting observations of VHE gamma-ray blazar flares with reconnection models

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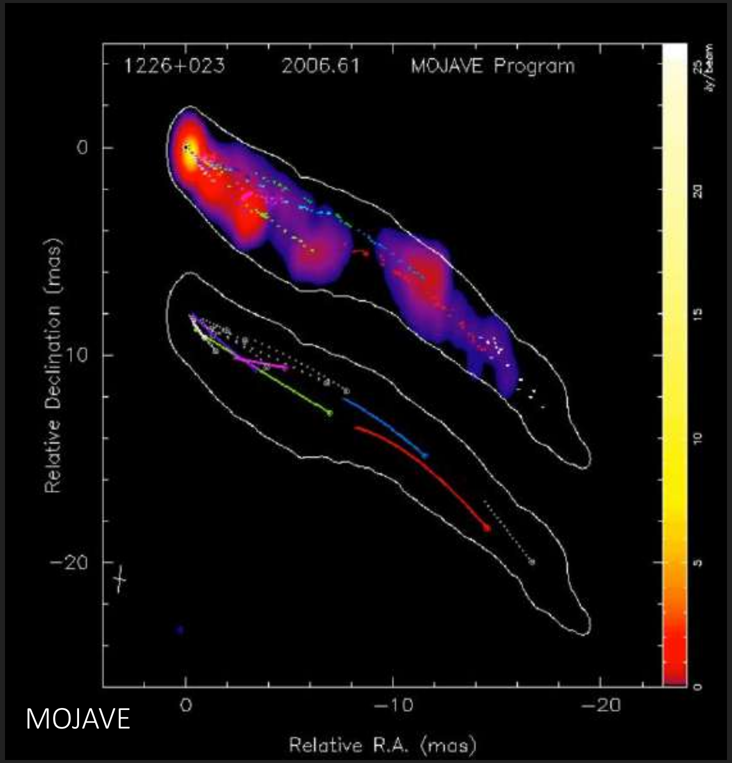
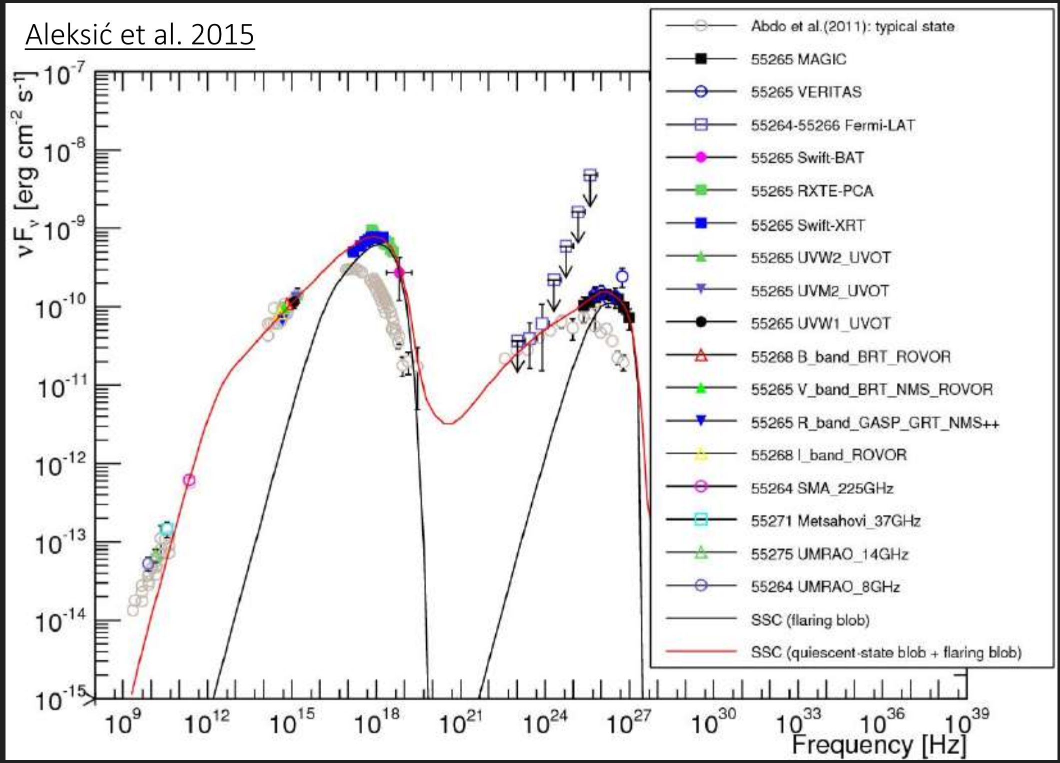
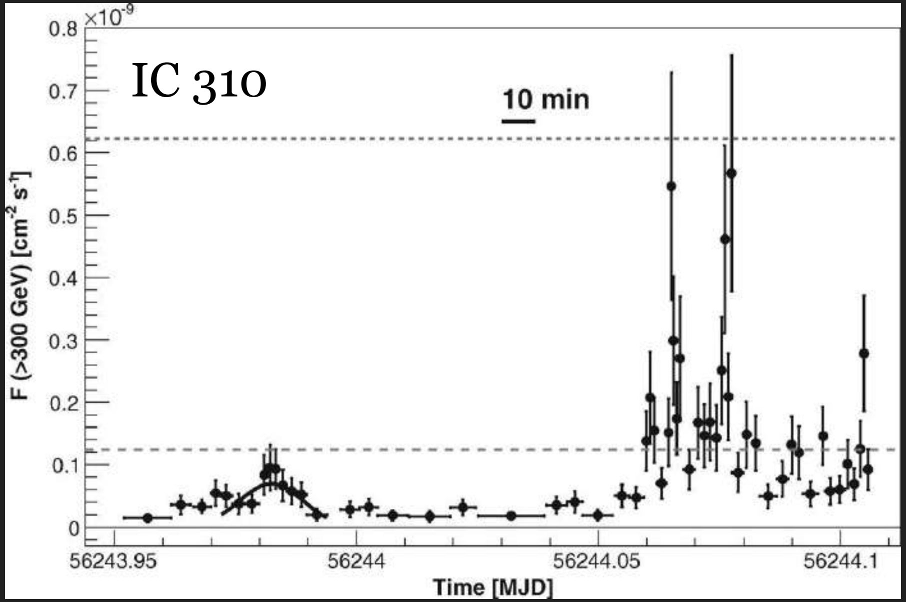
# Introduction

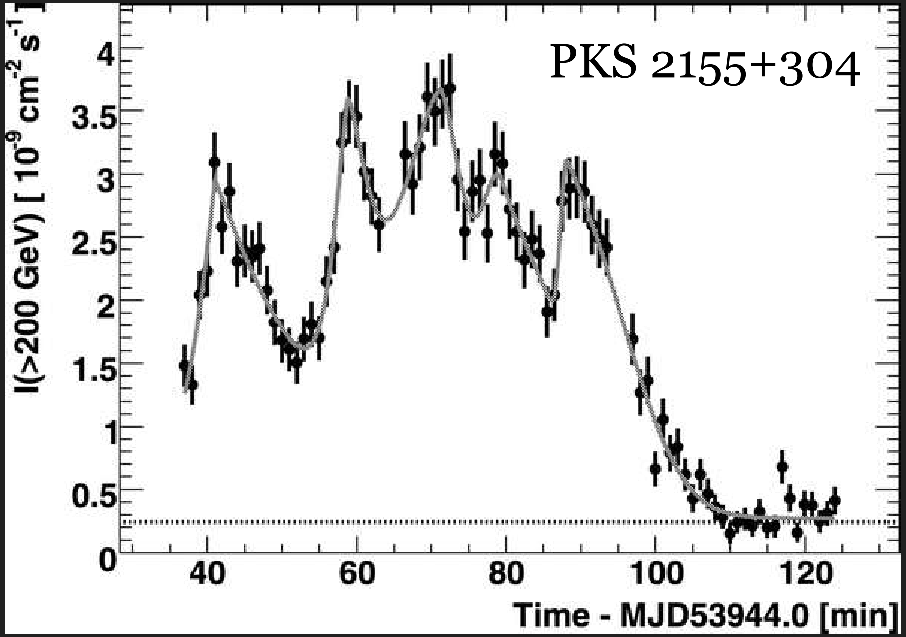
- Relativistic jets launched by supermassive black holes are among most extreme particle accelerators in the universe
- Multiwavelength observations can be used to estimate some characteristics of the jet
    - **Fitting the spectral energy distribution (SED)** with assumed emission components
- **Very Long Baseline Interferometry (VLBI)** can be used to map the inner jet structure in detail
- Results from the SED modelling and VLBI don't always agree and there are also parameters we cannot constrain with these methods, thus additional constraints are needed






Aleksić et al. 2014



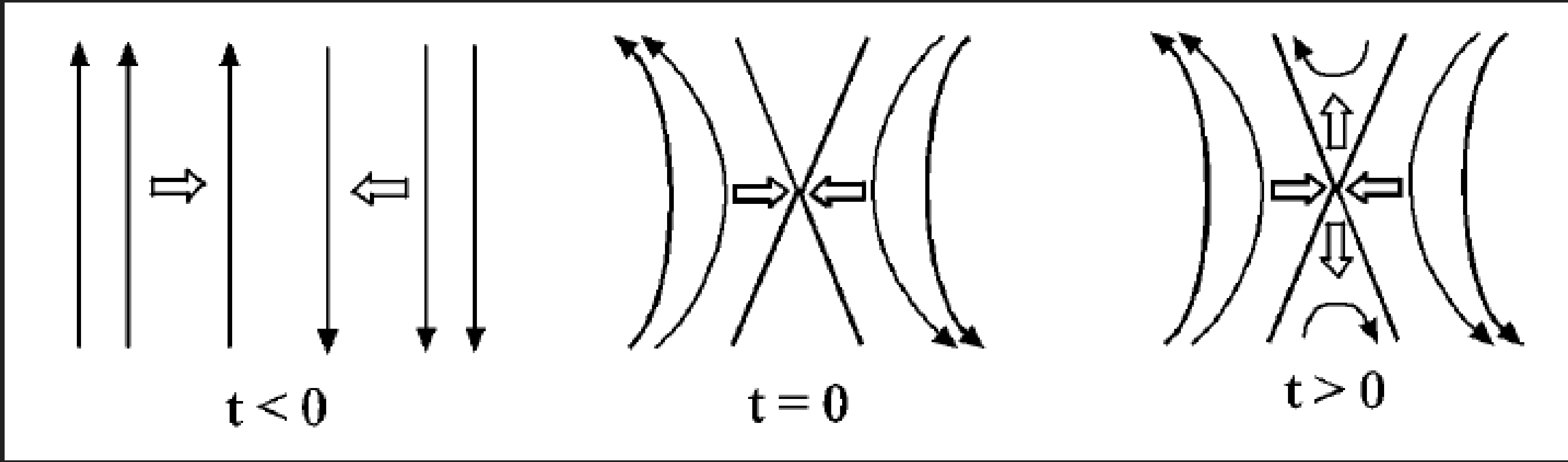

Aharonian et al. 2007

# Introduction

- Extremely **fast flares** have been observed from a handful of blazars in the **very high energy (VHE) gamma-rays** (100 GeV – 100 TeV)
  - Time scales of these flares are ranging from hours to minutes
- Several models have been invoked to explain blazar variability, typically shocks
  - Shocks manage to explain the slower variability in the lower energies well
  - Need a mechanism that can produce fast flares → **Magnetic reconnection** is one possibility

# Motivation

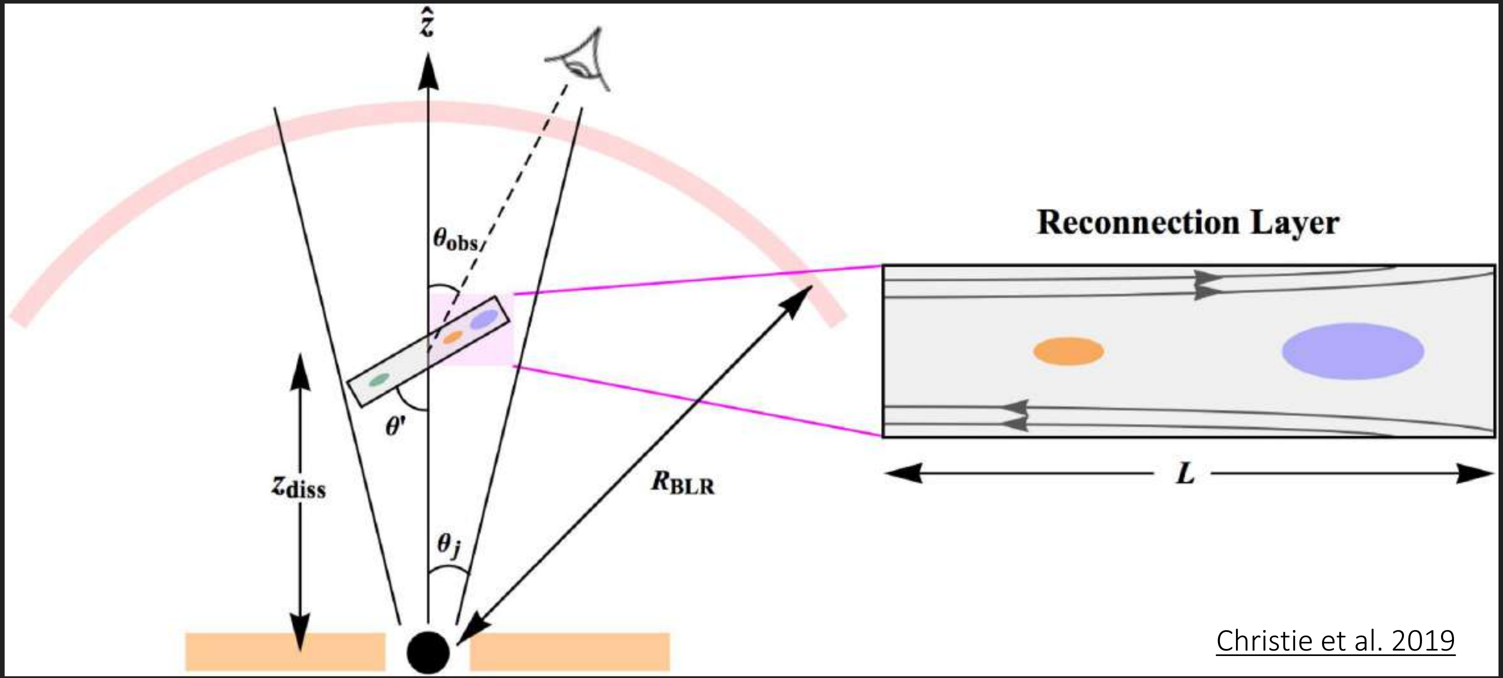
- Magnetic reconnection can occur in magnetically dominated plasmas
- In magnetic reconnection, two field lines of opposite polarity **break and reconnect** due to the instabilities of their environment
  - Magnetic energy is converted into heat, **bulk kinetic energy of the plasma, and non-thermal particle energy**




Kilpua & Koskinen 2016

# Motivation

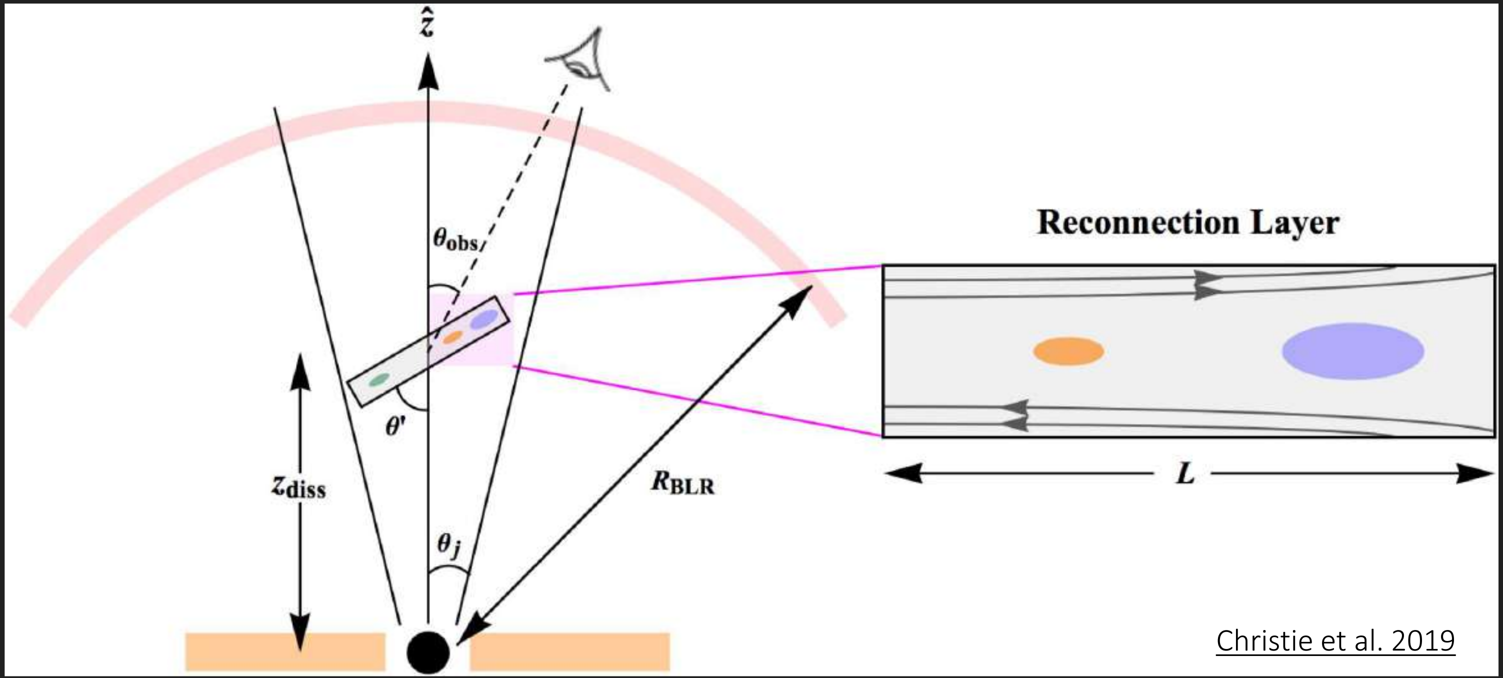
- One possible model of magnetic reconnection in blazar jets presented in Christie et al. 2019:
  - Instabilities of the jet create current sheets where reconnection takes place
  - Current sheets are disrupted into **a chain of plasmoids**: “blobs”
- Use **particle-in-cell (PIC) simulations** to produce simulated light curves
  - Obtain different jet scenarios by varying the viewing angle $\vartheta_{obs}$, the reconnection layer angle $\vartheta'$, magnetic field $B$, and magnetization $\sigma$: 285 simulations in total with three different values of B, five different observation angles, and 19 layer angles




Christie et al. 2019

# Motivation

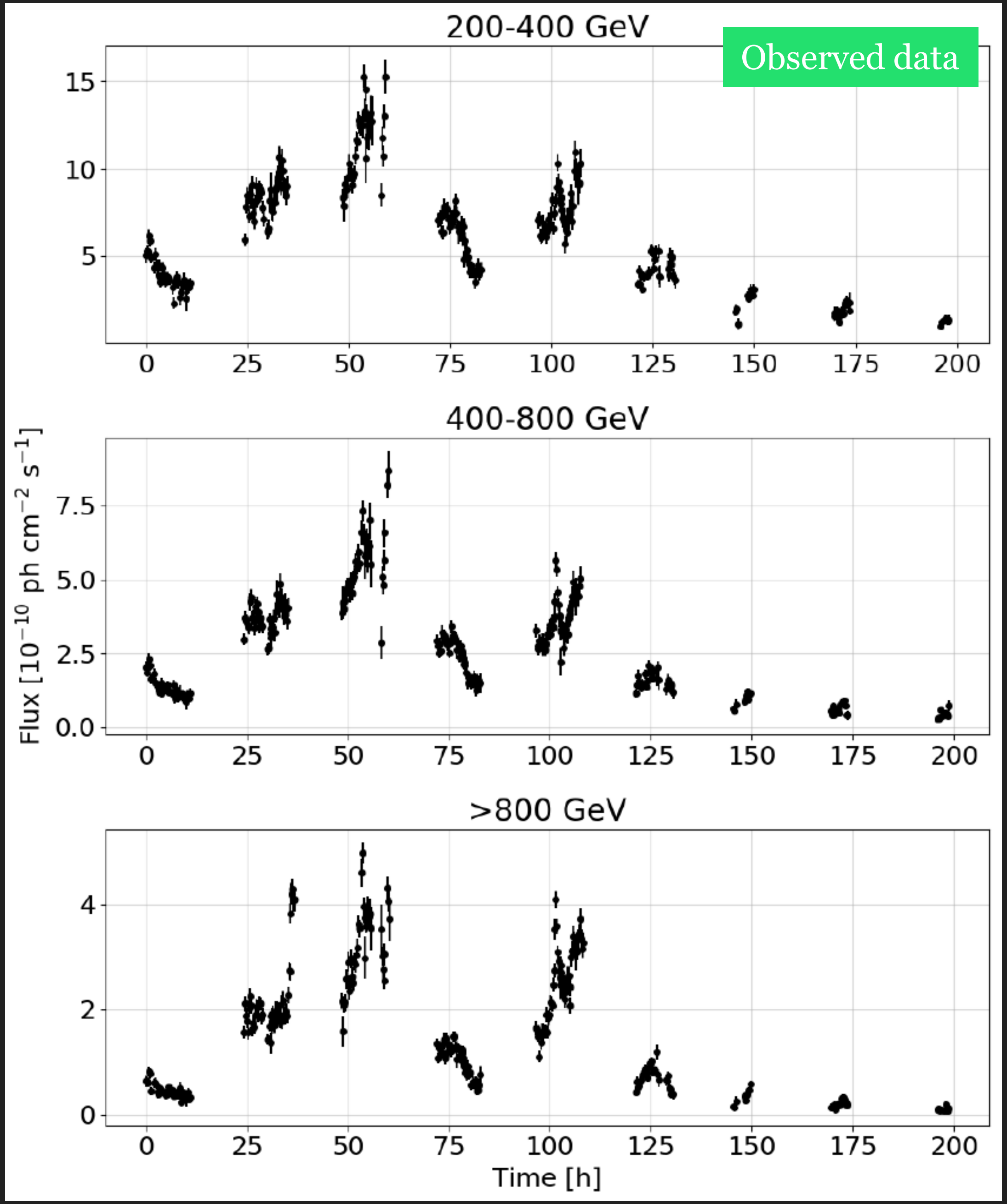
- **Can we constrain the unknown simulation parameters using observations?**
  - Several free simulation parameters that we set on a more realistic range by using observed values (VLBI observations, SED modelling)
    - Jet power, bulk Lorentz factor, viewing angle, SED peak, and $\gamma_{max}$
  - Compare the simulated light curves with the observed ones to try to find estimates for those parameters unobtainable from observations




Christie et al. 2019

# Observed data

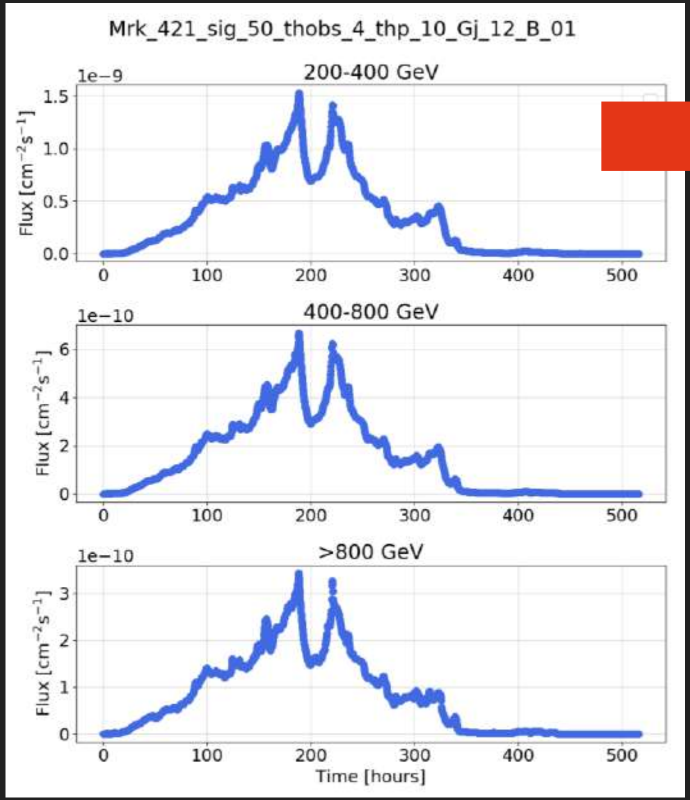
- For the introduction of the method only one source, **Mrk 421**, was used in this analysis
  - Observing campaign with MAGIC and VERITAS in 2013 when the source was flaring
  - Particularly well-sampled light curves in three energy bands
  - Magnetic reconnection was already suggested to explain the variability of Mrk 421 for this data set in Acciari et al. 2020
    - Only for a limited range of parameters

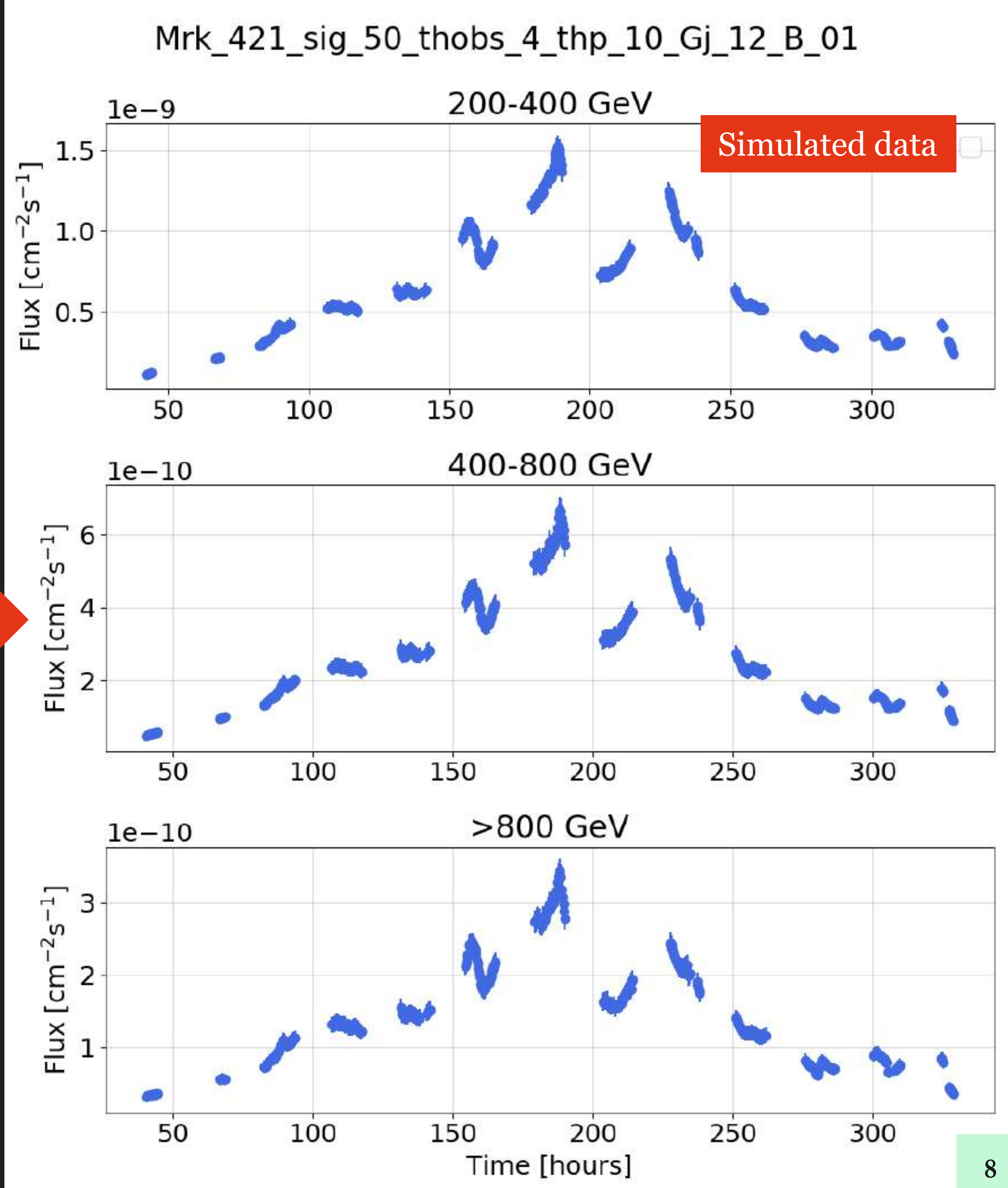



Acciari et al. 2020

# Simulated data

- Several things had to be taken into account in the **treatment of the raw simulated light curves** before comparison → sample simulated LCs
  - Energy range of the observations, observed flux units, binning and **observed cadence**, error assignment, etc.



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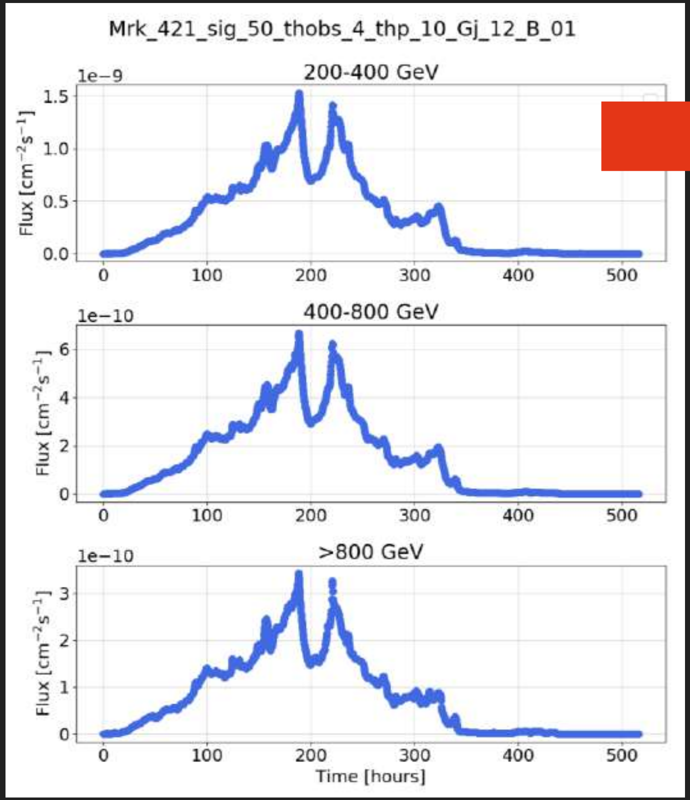
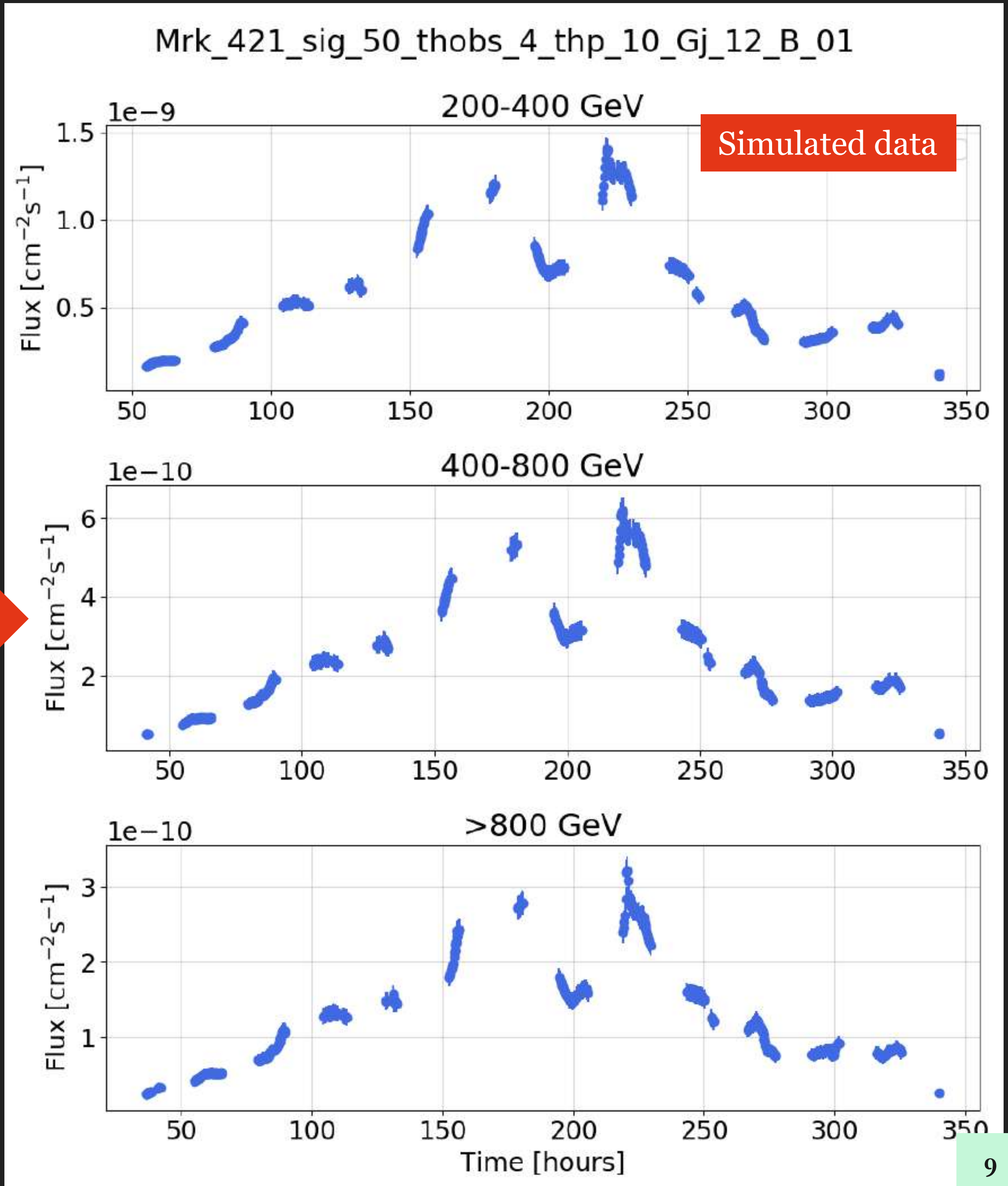
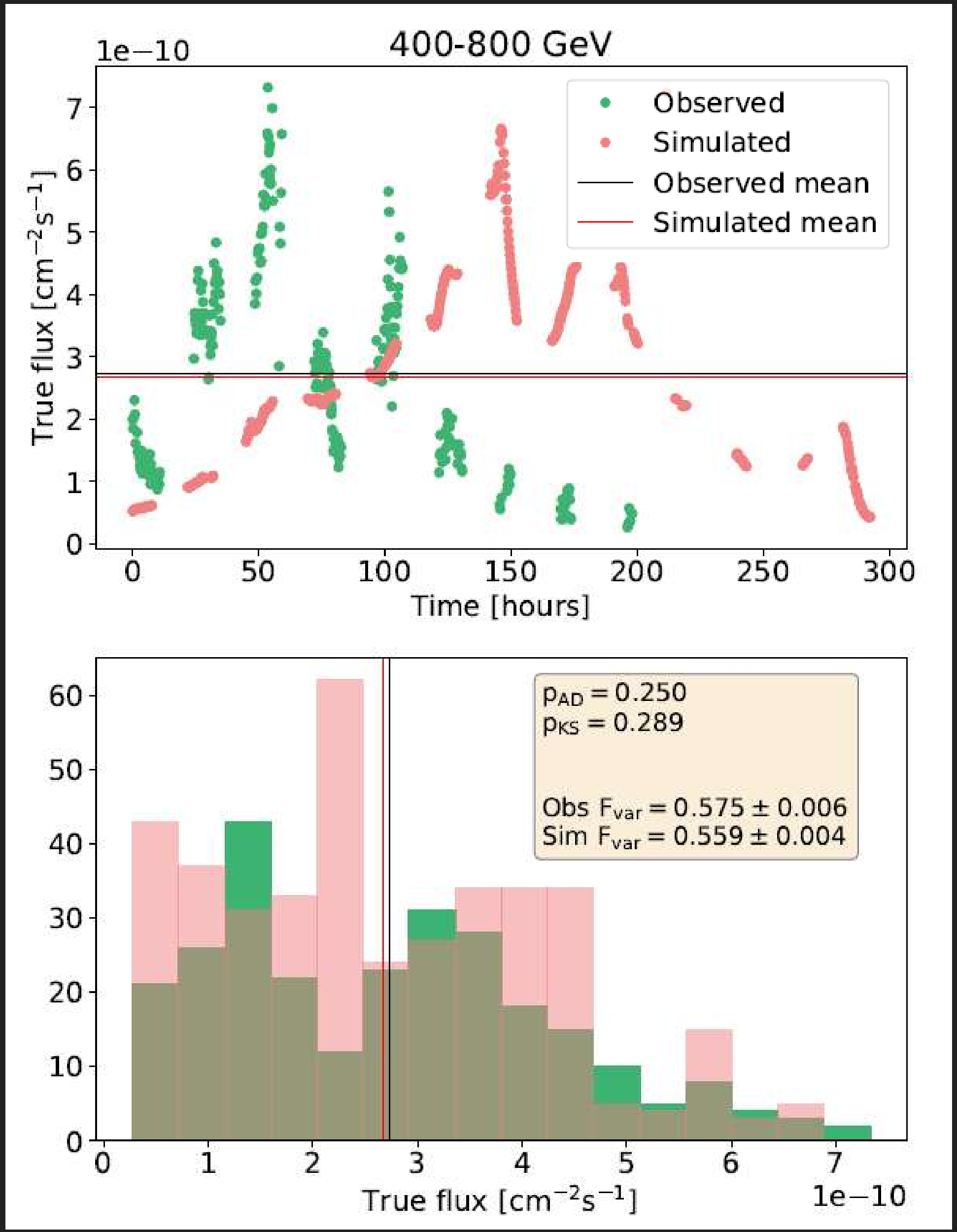


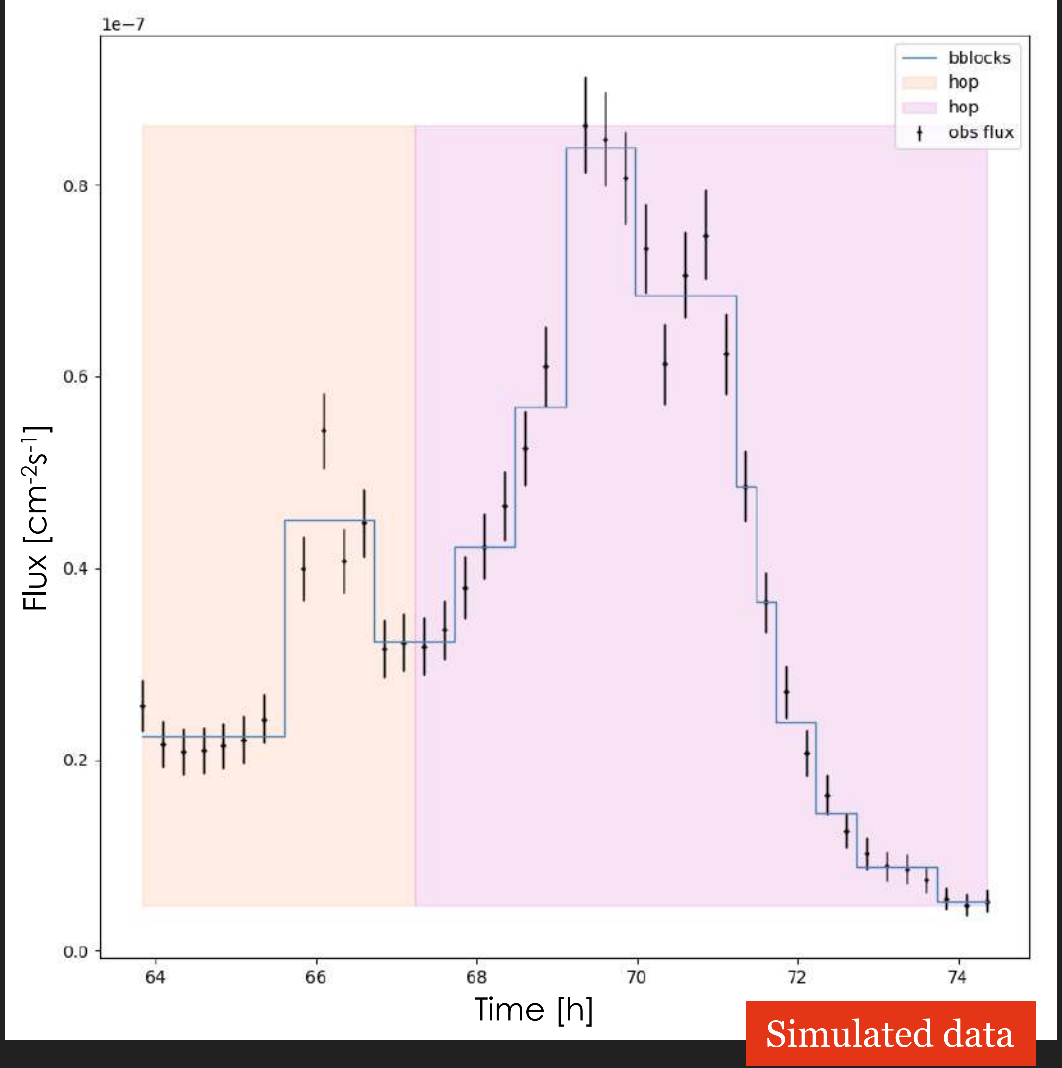






# Analysis methods

- **Combine several methods** in the analysis process to get a versatile view of the simulated data
  - **Flux amplitudes**
    - Flux distributions: can we find matching distributions of flux?
    - Fractional variability: how do the fractional variability factors of sampled light curves compare to the observed value?

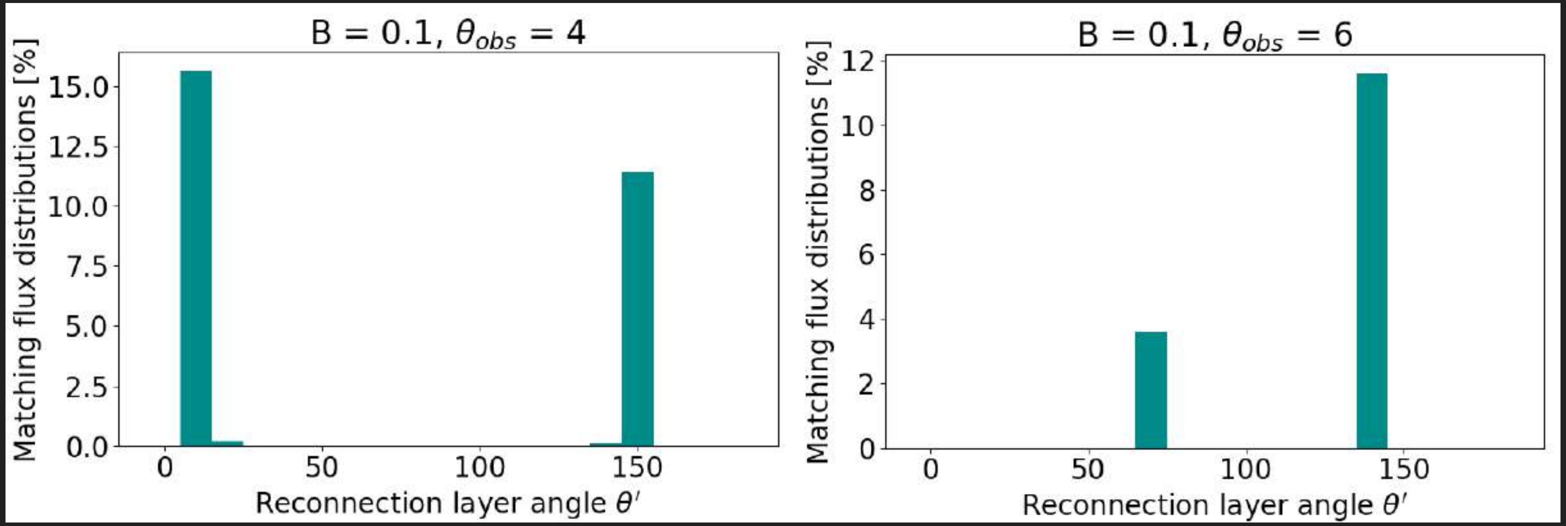
# Analysis methods



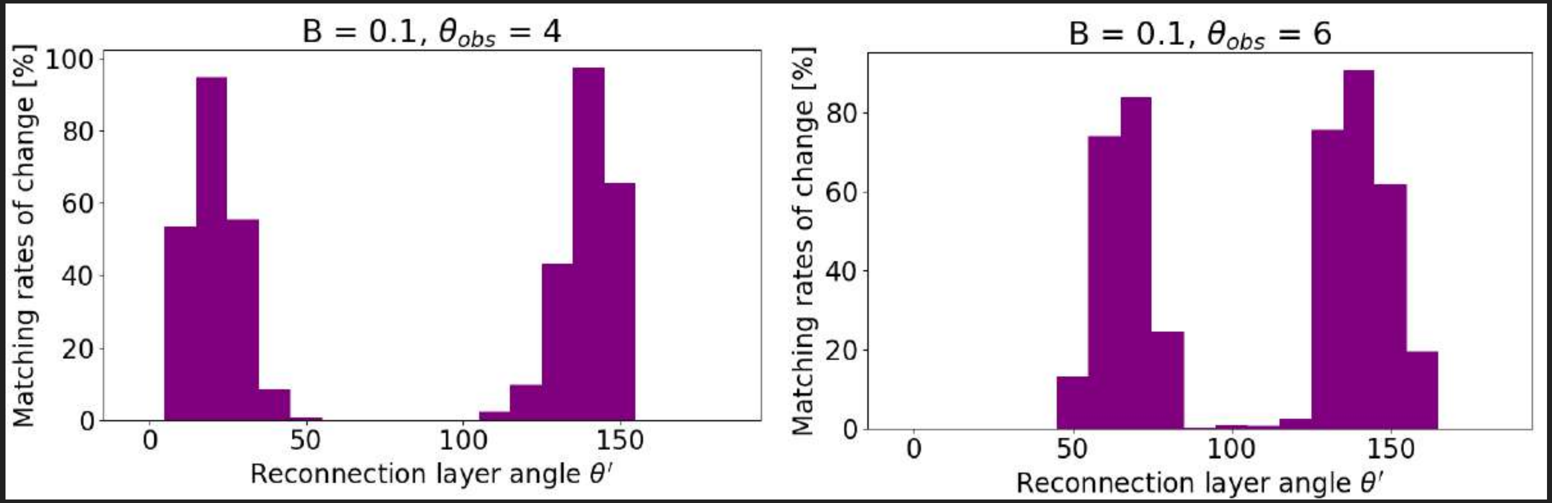

- **Combine several methods** in the analysis process to get a versatile view of the simulated data
  - **Time scales**
    - Risetimes: what kind of ”flares” do we see in the simulated data compared to the observed?
    - Use Bayesian blocks to determine ”rate of change”

# Results

- Simulations with B = 0.1 G:
  - We are able to find simulations that match the criteria set by these tests for the most part
    - We find matches in the two lower energy bands
    - High energy spectrum not reproduced with this model, but could be modified e.g. by changing the electron injection rate
  - The matches that we find for these simulations are in observation angles 4° and 6° instead of the typical 0°



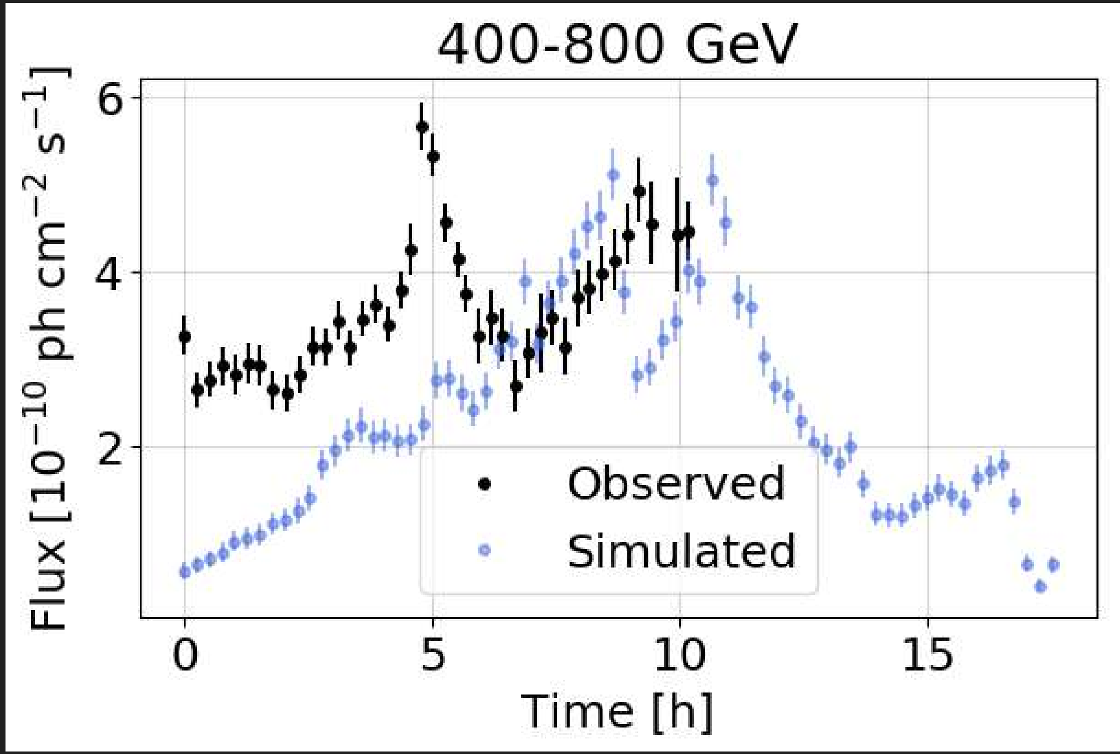

200-400 GeV




200-400 GeV

# Results

- Simulations with B = 1 G:
  - In order to keep the jet power constant we decrease the layer length when increasing the magnetic field strength respectively
    - Shorter simulation durations, lower fluxes, softer spectra
  - At , $\theta_{obs}$ = 0° the fluxes are at a similar level than the observed data and the some of the time scales match that of the flares seen for Mrk 421
    - However, because at this angle the simulations are also very short (10-20h) we cannot make a strong statistical claim on this result
  - It is still possible that the variability that we see in Mrk 421 2013 light curve could result from several reconnection layers with B = 1 G with different orientations θ'




Mrk 421 night 5 overplotted with simulation with B = 1 G, $\theta_{obs}$ = 0°, θ' = 70°

# Summary and future steps

- These methods help us narrow down the already limited ranges of parameters to an even more specific range or a set of parameters
  - Strong constraints can be put in place to still find matching simulations!
- Combining several analysis methods to statistically compare observations and simulations is the key to constraining the parameter space of the simulations
- Importance of creating methods that will be applicable to different models and sources!
  - We plan to make a similar comparison with other sources where intranight VHE variability has been observed
  - Possibility of using these methods in different time scales and energies, useful for example for CTA