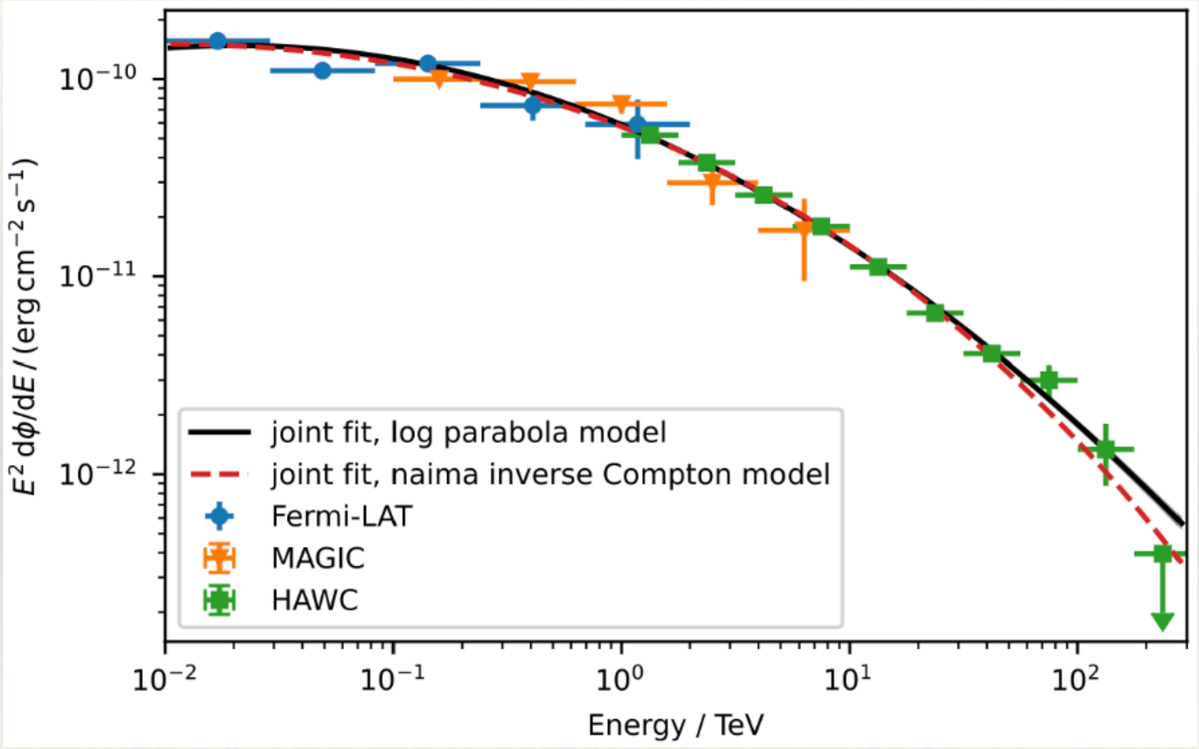
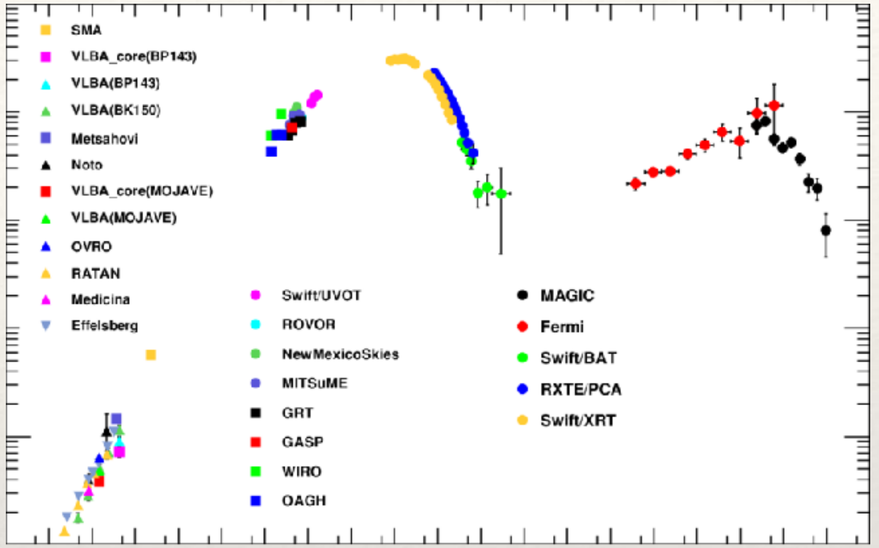
Multi-instrument fitting with Gammapy

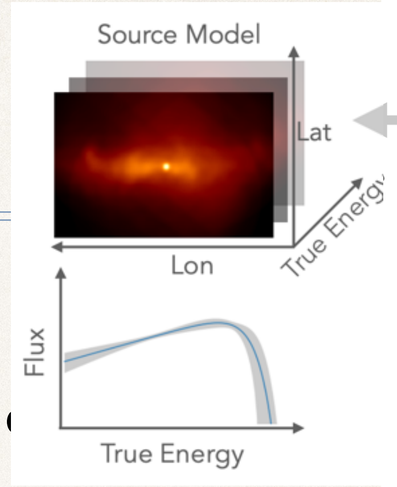


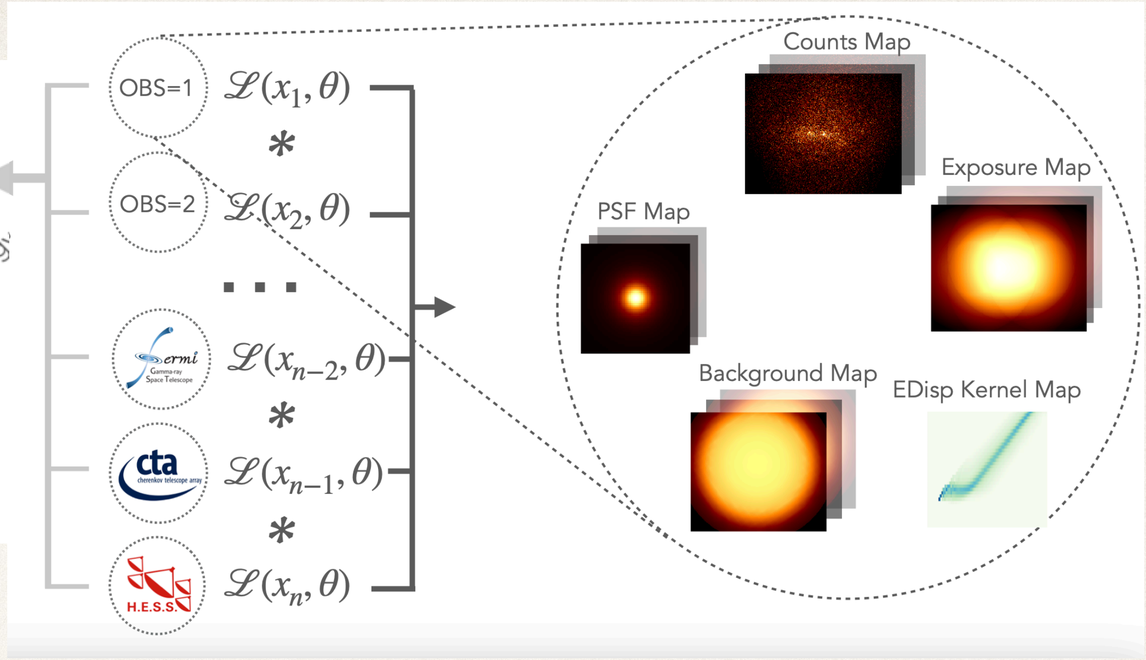
- Frequently, one needs to fit data from multiple instruments together
  - Broadband SED modelling
  - Fermi-LAT + IACT modelling
  - Multiple IACTs
- Traditionally:
  - Extract flux points (“DL5”), fit fluxes from different instruments
  - Cons:
    - Cannot take instrumental systematics into account
    - Dependence on how fluxes were extracted
    - Difficult to take upper limits into account



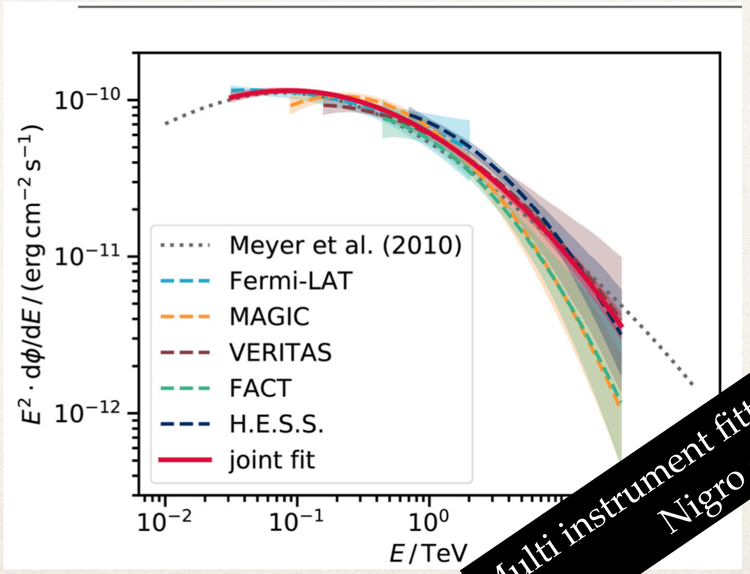
Abdo et al, 2011

Joint likelihood





- Simultaneous fitting of various
- Likelihood evaluated per dataset, individual likelihoods combined to get global likelihood
- May come from the same or different instruments
- Possible to combine DL4 and DL5 data

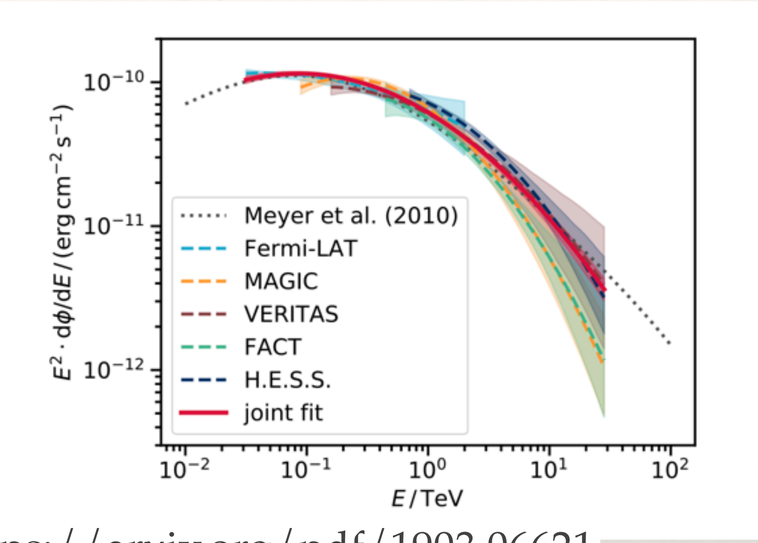


Multi instrument fitting of Crab Nebula
Nigro et al, 2019

uly, 2

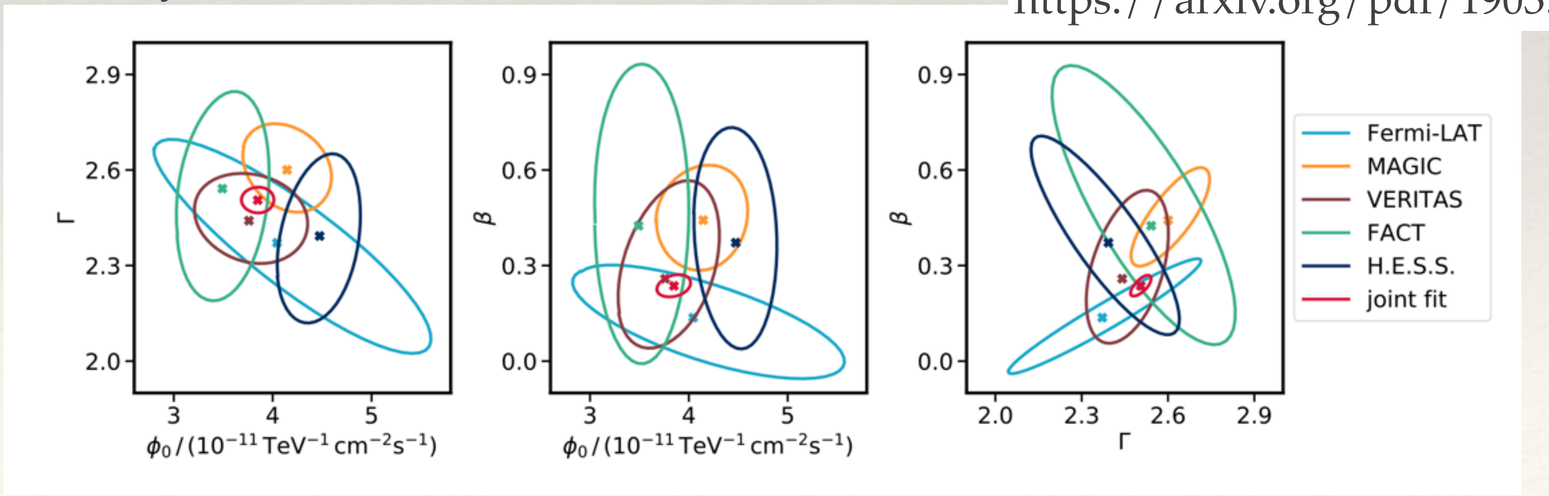
Multi instrument analysis

- A Spectral Fit combining different types of data
  - Fermi-LAT DL4 data - full 3D analysis, 7yrs of data
  - MAGIC DL3 data - point like 1D spectral analysis 40 mins of data
  - VERITAS DL3 data - point like 1D spectral analysis 40 mins of data
  - FACT - point like 1D spectral analysis, 10.3 hrs of data
  - H.E.S.S. - full containment 3D analysis, 2 hrs of data



https://arxiv.org/pdf/1903.06621

Better constrain on parameters

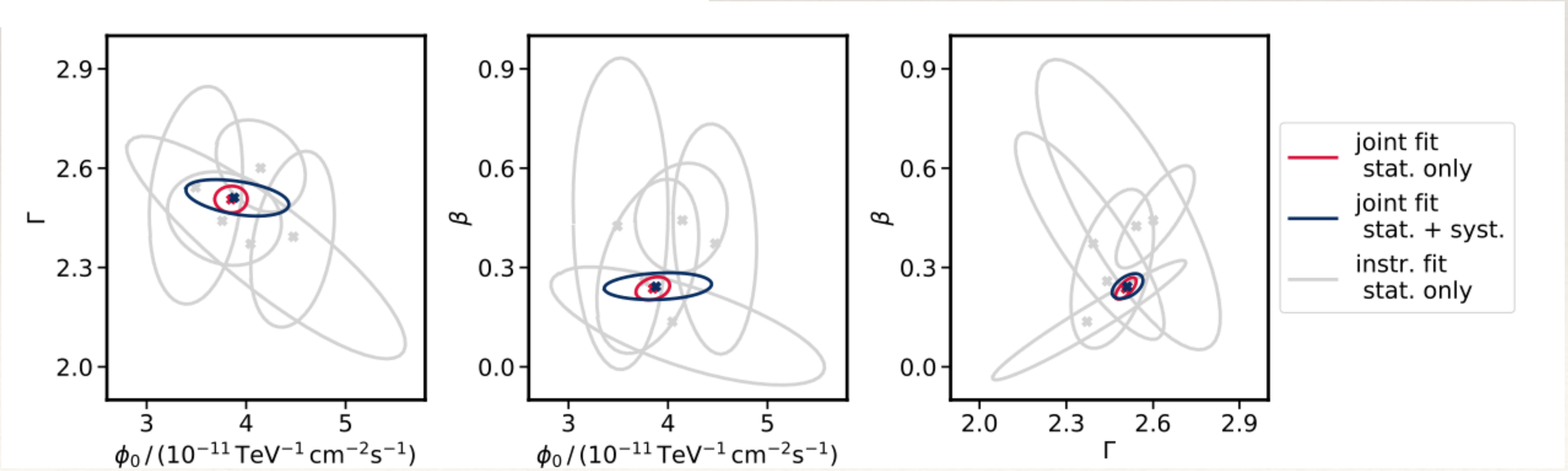


Instrumental systematics

- A modified likelihood with systematics on the energy scale
  - Directly obtain statistical error on the parameters

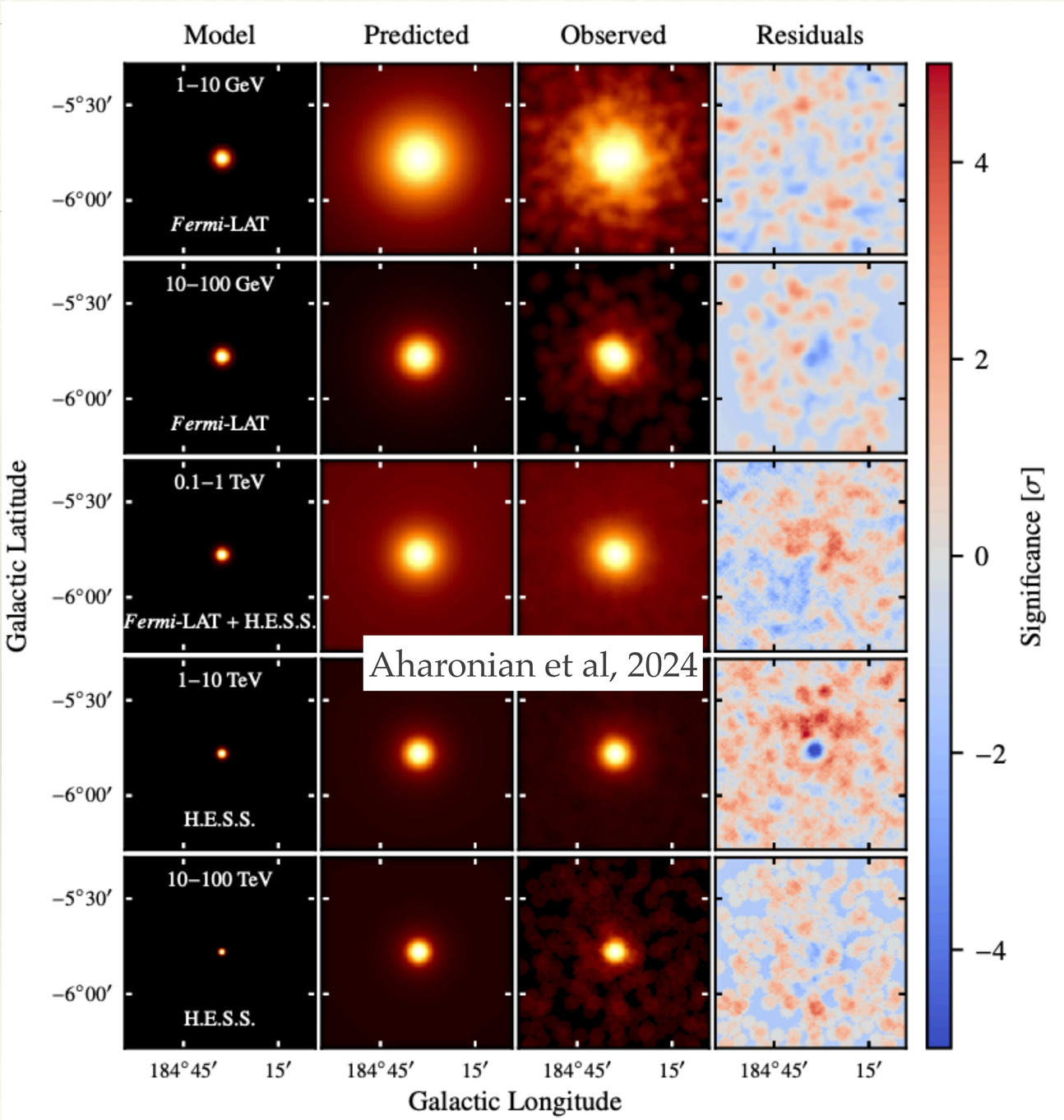
$$\frac{\mathrm{d}\tilde{\phi}}{\mathrm{d}\tilde{E}} = \frac{\mathrm{d}\phi}{\mathrm{d}E}\frac{\mathrm{d}E}{\mathrm{d}\tilde{E}} = \phi_0 \left(\frac{E/(1+z)}{E_0}\right)^{-\Gamma+\beta\log_{10}\left(\frac{E/(1+z)}{E_0}\right)} \left(\frac{1}{1+z}\right)$$

$$z_i = \frac{\tilde{E}-E}{E} = \frac{\tilde{E}}{E} - 1$$



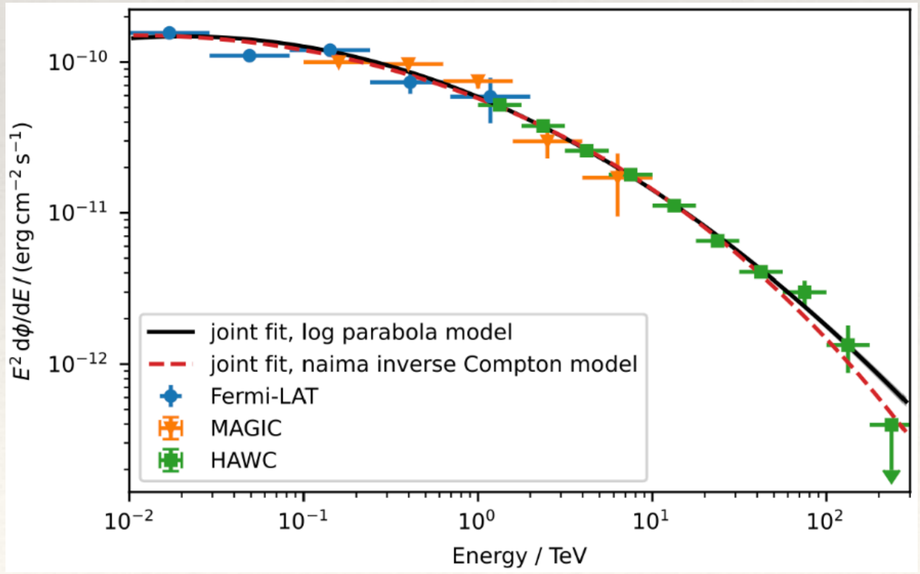
Constrain extensions

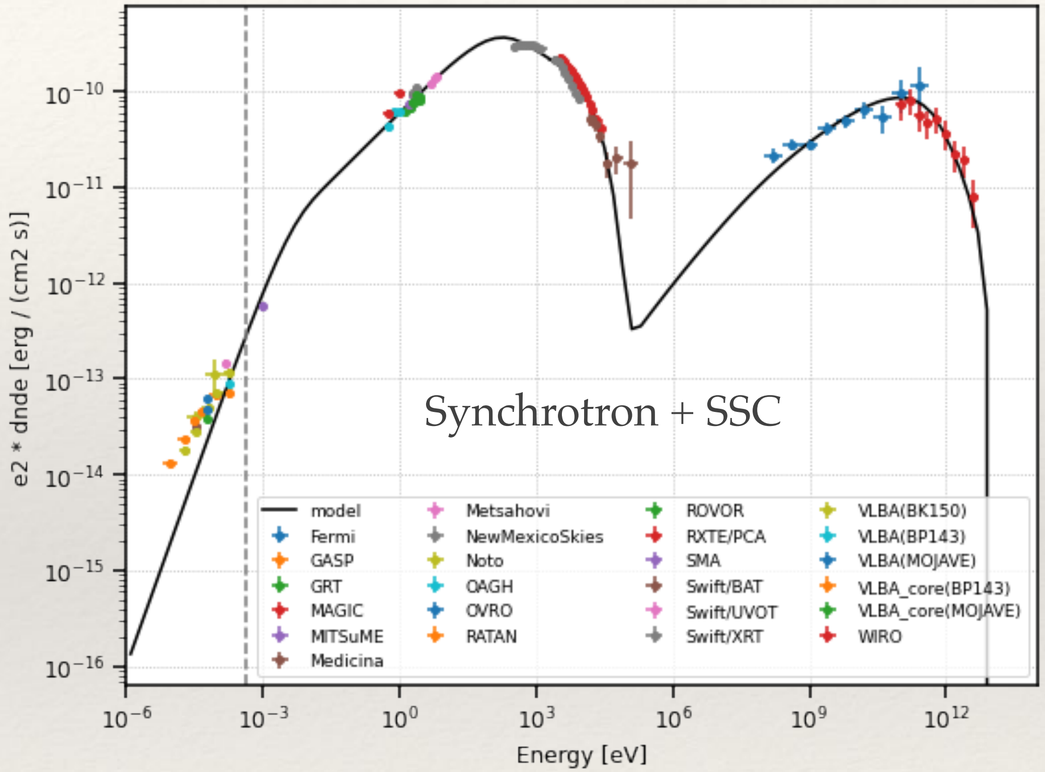
- Joint Fermi-LAT H.E.S.S. analysis used to constrain the extension of the Crab Nebula
  - Probe structures to understand the underlying mechanisms



Directly fit physical models

- Directly fit physical models to the data
  - In-built gammapy wrapper around naima routines
  - Underlying fitting API for agnpy and JetSet





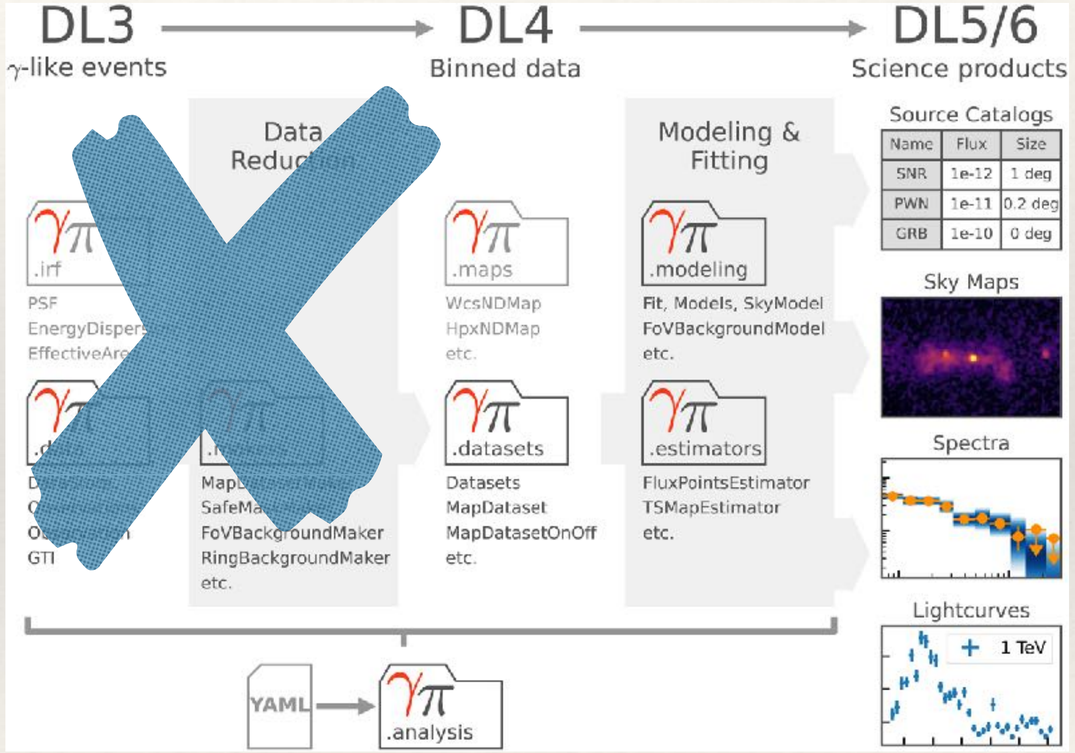
Analysis of non-pointing instruments
Fermi-LAT, HAWC, etc

https://docs.gammapy.org/1.2/tutorials/data/fermi_lat.html#sphx-glr-tutorials-data-fermi-lat-py

https://docs.gammapy.org/1.2/tutorials/data/hawc.html#sphx-glr-tutorials-data-hawc-py

Fermi-LAT with Gammapy

- Analysis starts from DL4 data levels:
  - After binning and reproduction
- Once you have a DL4 product “Dataset”, modelling and and fitting proceeds as before
- Bonus: Simulating datasets
- Note: Fermi-LAT analysis is always 3D



HAWC with Gammapy

- TLDR: You CAN, but its not straight forward
- Events: DL3 level
- IRFs: DL4 level
- Joint analysis for different fHit bins
- Background and exposure calculated per transit for a source
  - Correct by the number of transits per source computed from the GTIs

X-ray with Gammapy

- X ray data are similar to gamma rays : list of photons + responses
- **1D analysis (spectral only) is almost straightforward**
- Prototype analysis for **X-ray data from XMM Newton on HESS J1702-420 (**https://zenodo.org/records/7092736**)**
- Ongoing tests for 3D analysis
- Can be extended down to Swift UVOT

Beyond photons… GADF to VODF

ASTRI - Astronomia a Specchi a Technologica Replicante Italiana, (IACT telescope)

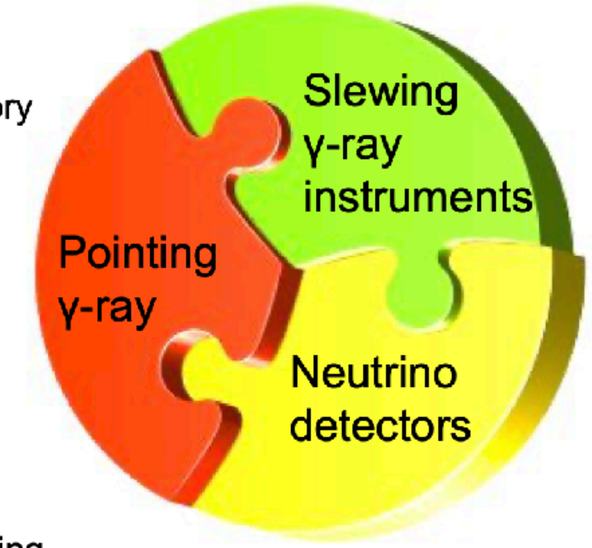
CTAO - Cherenkov Telescope Array Observatory (IACT observatory)

FACT - First APD Cherenkov Telescope (IACT telescope)

H.E.S.S. - High Energy Stereoscopic System (IACT Array)

MAGIC - Major Atmospheric Gamma-ray Imaging Cherenkov telescope (IACT array)

VERITAS - Very High Energy Radiation Telescope Array System (IACT array)



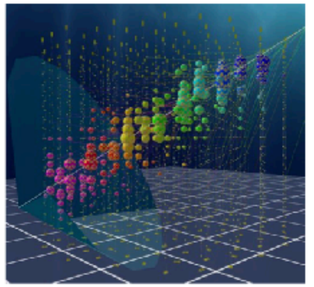
Fermi-LAT - Large Area Telescope on the Fermi Space Telescope (High-energy Space Observatory)

HAWC - High-Energy Water Cherenkov telescope (WCT)

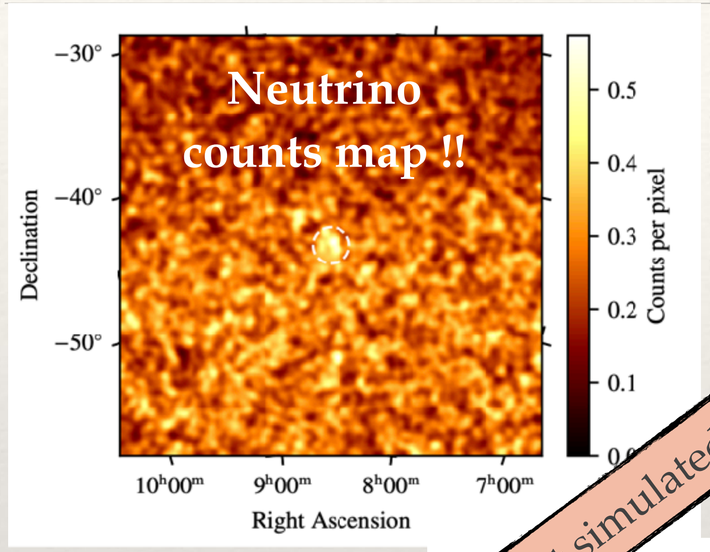
SWGO - Southern Wide-Field Gamma-Ray Observatory (WCT)

IceCube - Neutrino Observatory

KM3NeT - The Cubic Kilometre Neutrino Telescope (neutrino telescope)

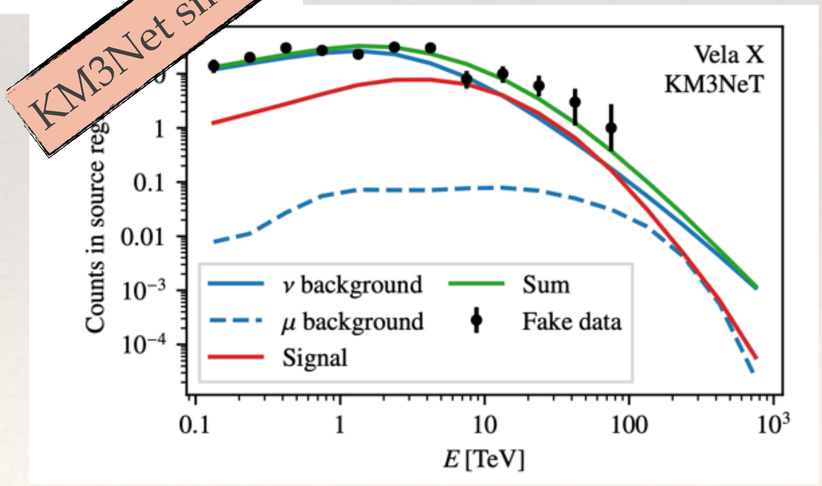


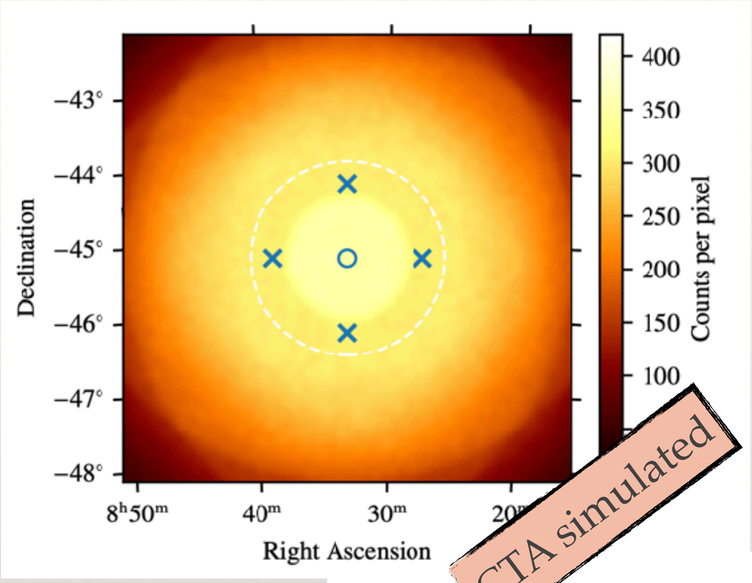
Prototype KM3NeT analysis with Gammapy



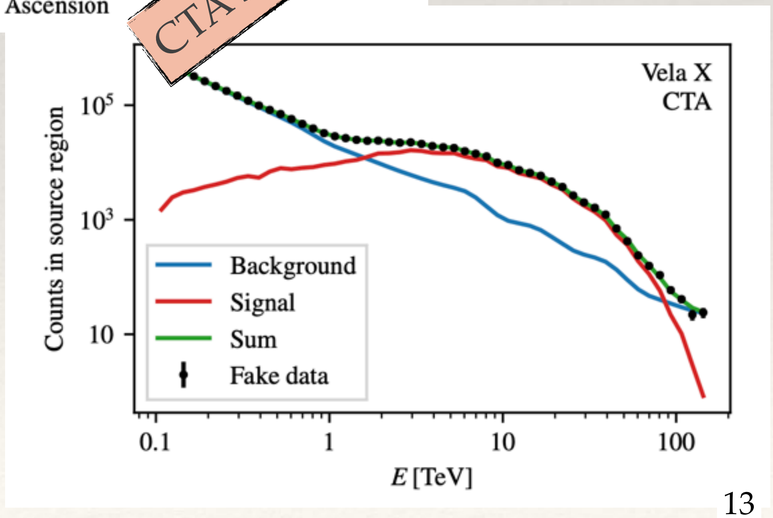
Demonstration
@doctoral thesis
Tim Unbehaun

KM3Net simulated

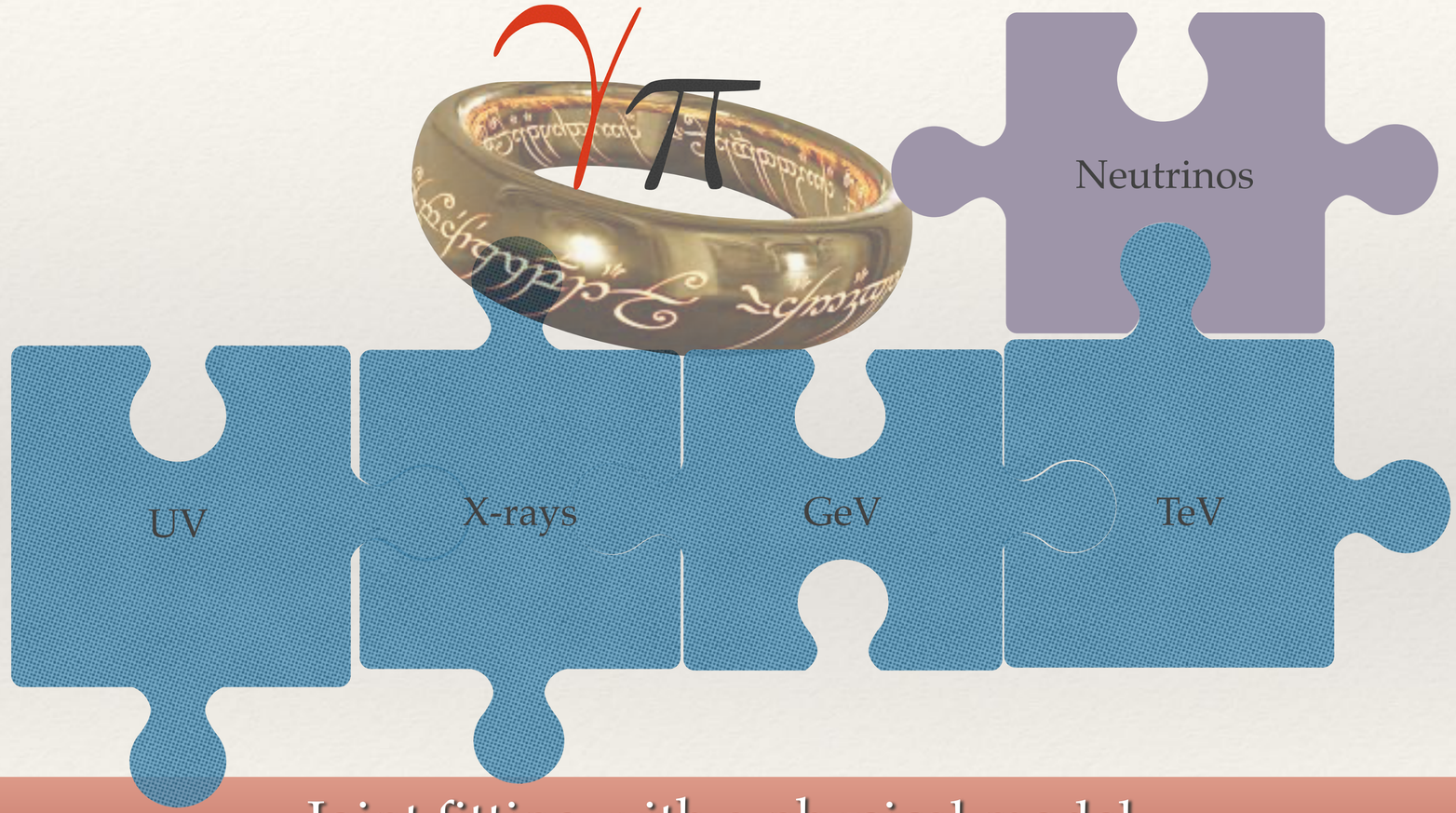




CTA simulated



One tool to fit them all
(And in the gamma-ray darkness bind them)



Joint fitting with a physical model