Joint-instrument analyses with Gammapy

Tim Unbehaun – MMS annual meeting 2023
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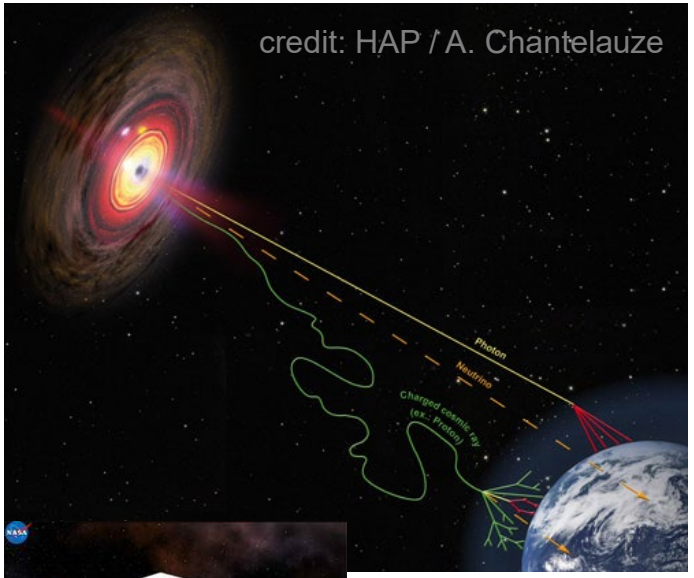
H.E.S.S.

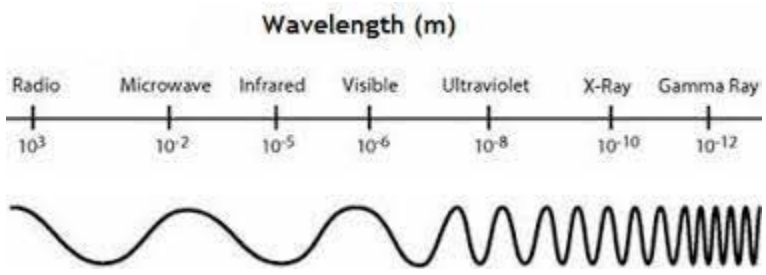
ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

Motivation

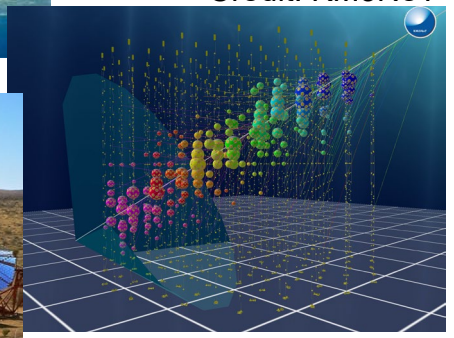
- Use as much data as possible to answer physics questions
- Use large energy range
- Use different messenger particles
- Consistent analysis of the different data





credit: labman.phys.utk.edu

Credit: KM3NeT



3D analyses with Gammapy

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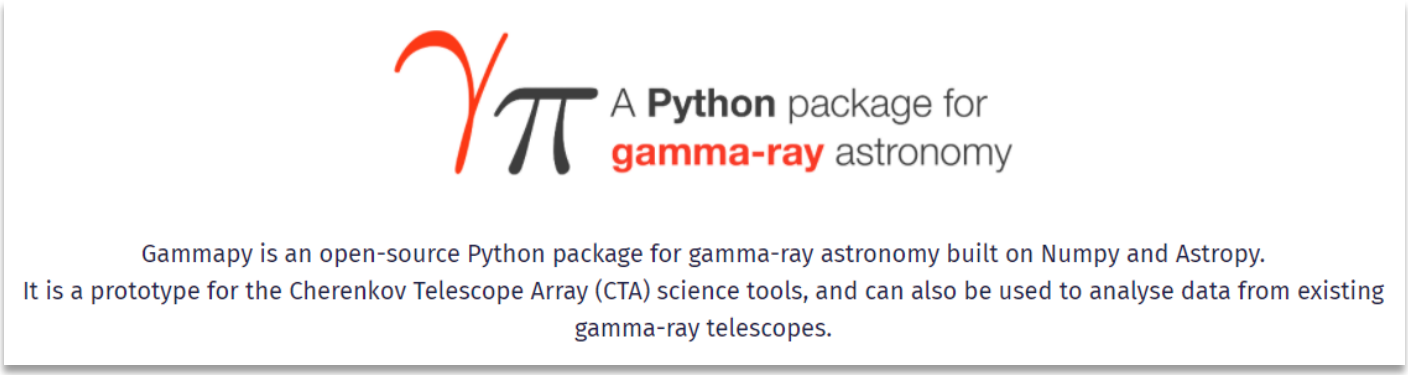

- Likelihood analysis in 3D (2 spatial, 1 energy)
- Combination of different data sets at likelihood level
  → can fit same physical model to data from different instruments
- Requirement: instrument data (DL3) in common format
  → can also include i.e neutrino data,
  although package is designed for γ-ray data analysis

3D analyses with Gammapy

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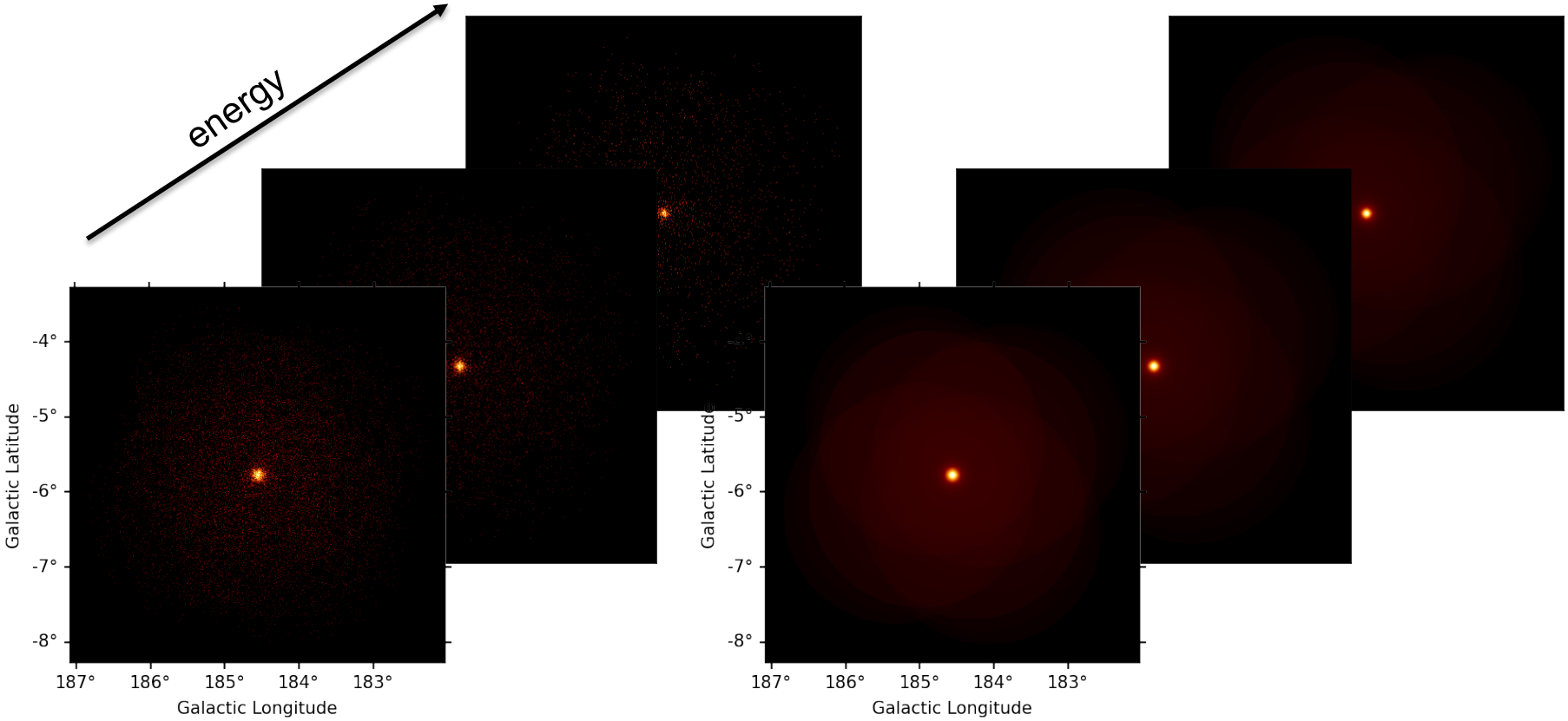
Counts map:
each event is filled into a 3D Map

Predicted counts map:
from models and Instrument Response Functions



3D analyses with Gammapy

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- Binned Likelihood fitting:
  - Poisson probability in pixel i to measure n counts given the model prediction $\nu(\xi)$ for parameters ξ

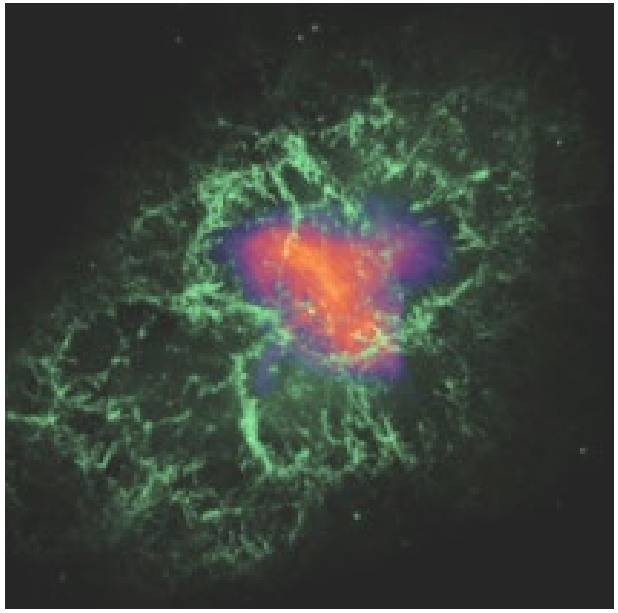
$$P\left(n_i \,\middle|\, \nu_i(\xi)\right) = \frac{\nu_i(\xi)^{n_i}}{n_i!} \times \exp(-\nu_i(\xi))$$

  - LogLikelihood:

$$-\ln \mathcal{L}(\xi) = -\sum_{i=1}^{N} \ln\left[\frac{\nu_i(\xi)^{n_i}}{n_i!} \times \exp(-\nu_i(\xi))\right]$$

  - Minimizing $\mathrm{TS} \equiv -2 \ln \mathcal{L}$ maximizes the Likelihood

Combined Fermi + HESS analysis on the Crab nebula



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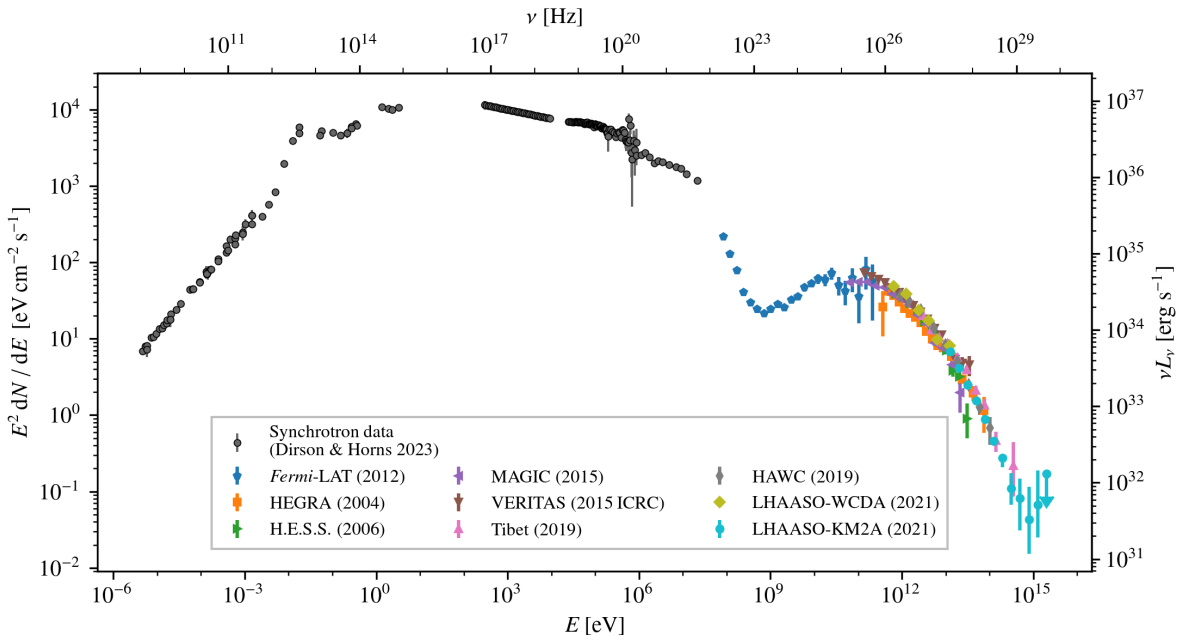
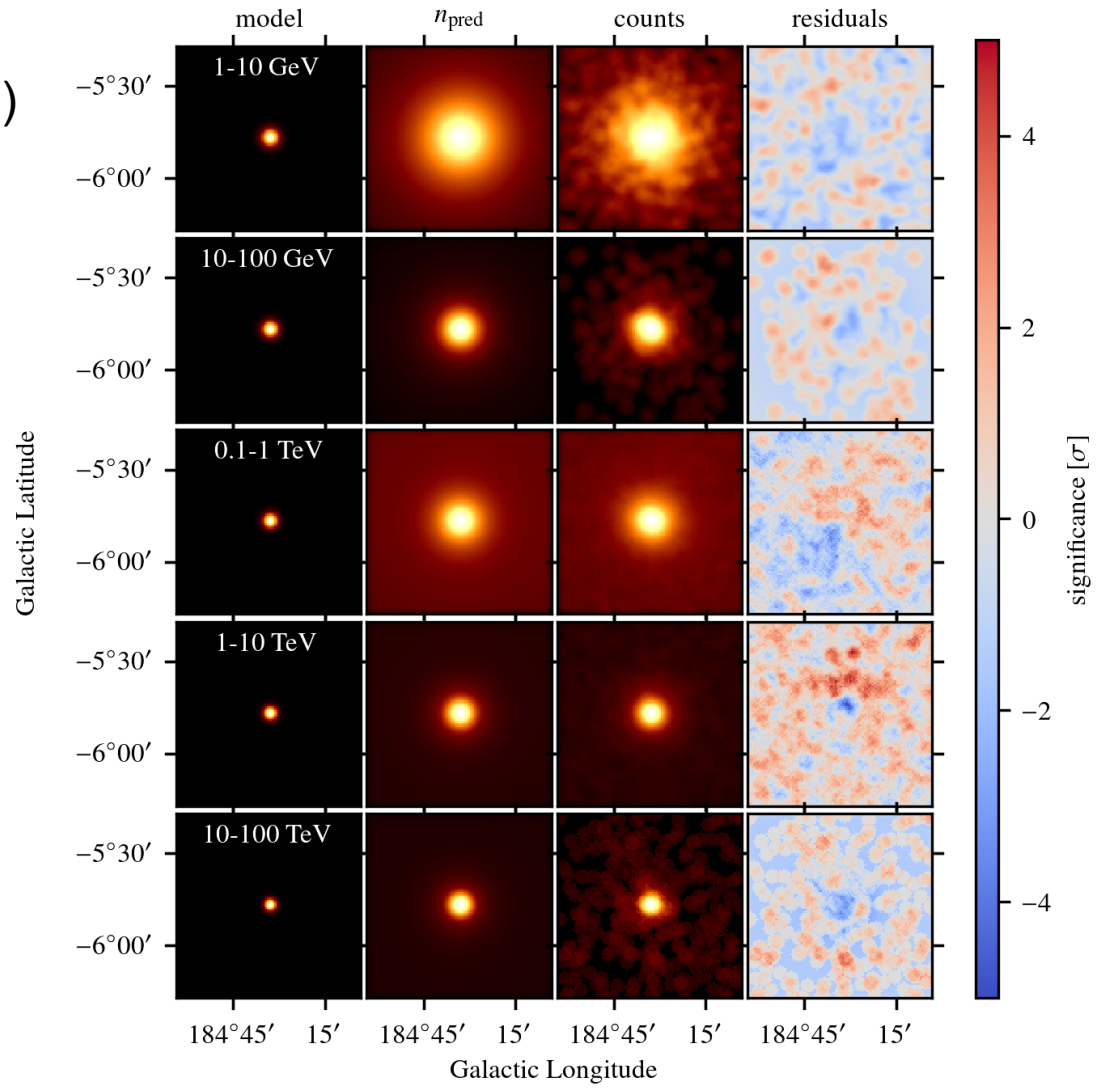
Fermi Gamma-ray Space Telescope



Fermi + HESS on the Crab

- One 3D analysis over the whole Inverse Compton (IC) energy range (1 GeV – 100 TeV)
- Consistent analysis between Fermi and HESS (proof of concept)
- Modelling of the SED
- Measuring the extension and its energy dependency

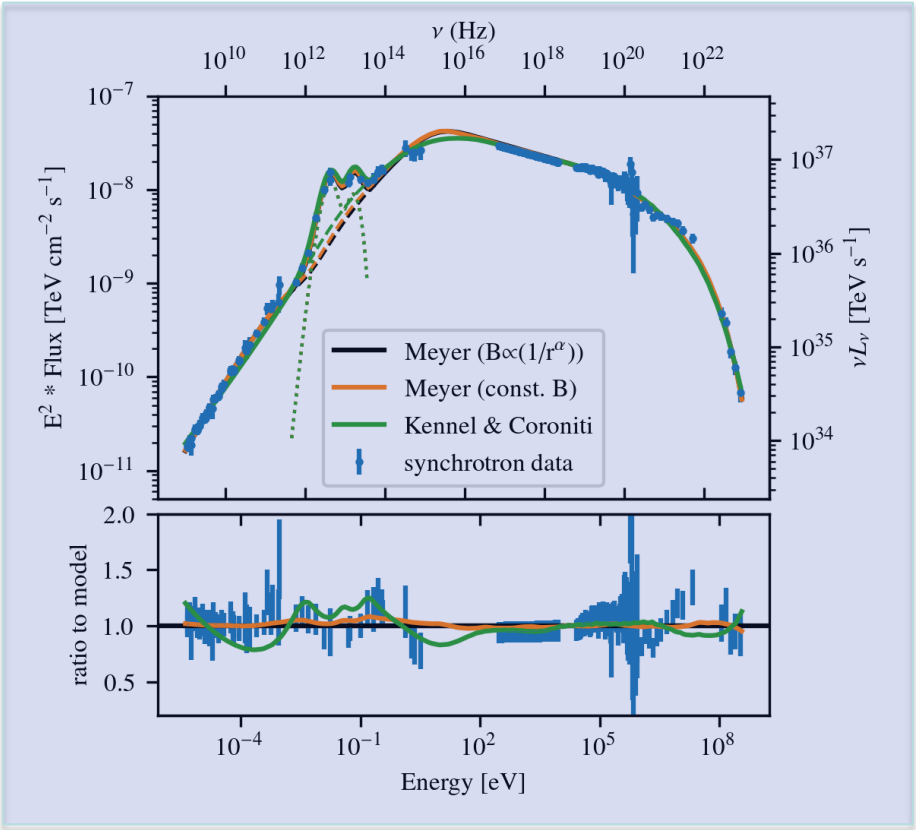


Fermi + HESS on the Crab

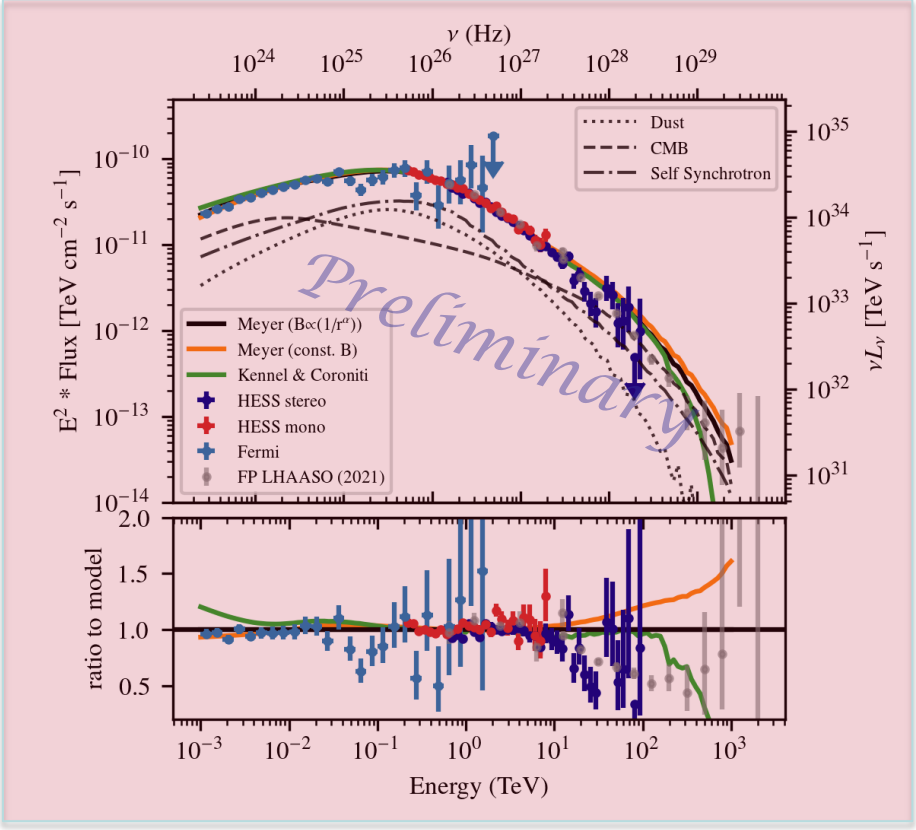
- Fitting 3 Self-Synchrotron Compton models to the data
- Adding the χ^2-value of the synchrotron component to the TS-value of the IC Fit

$$\mathrm{TS_{tot}} = -2\ln \mathcal{L}_{tot} = -2\ln \mathcal{L}_{IC} + \chi^2_{SYN}$$

1D flux points -- Synchrotron

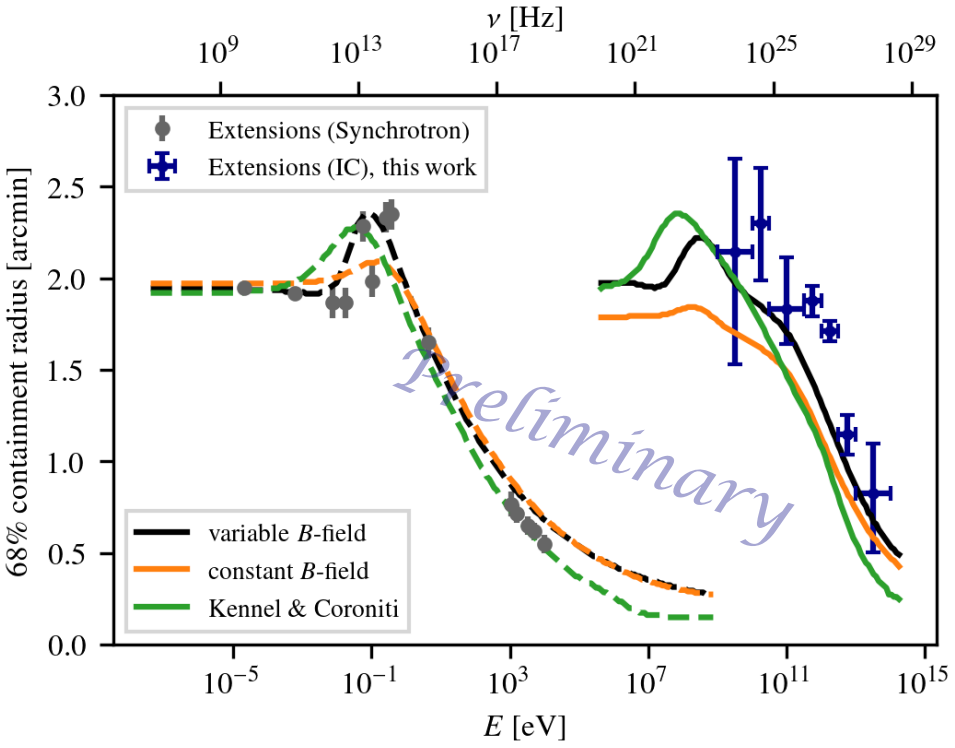


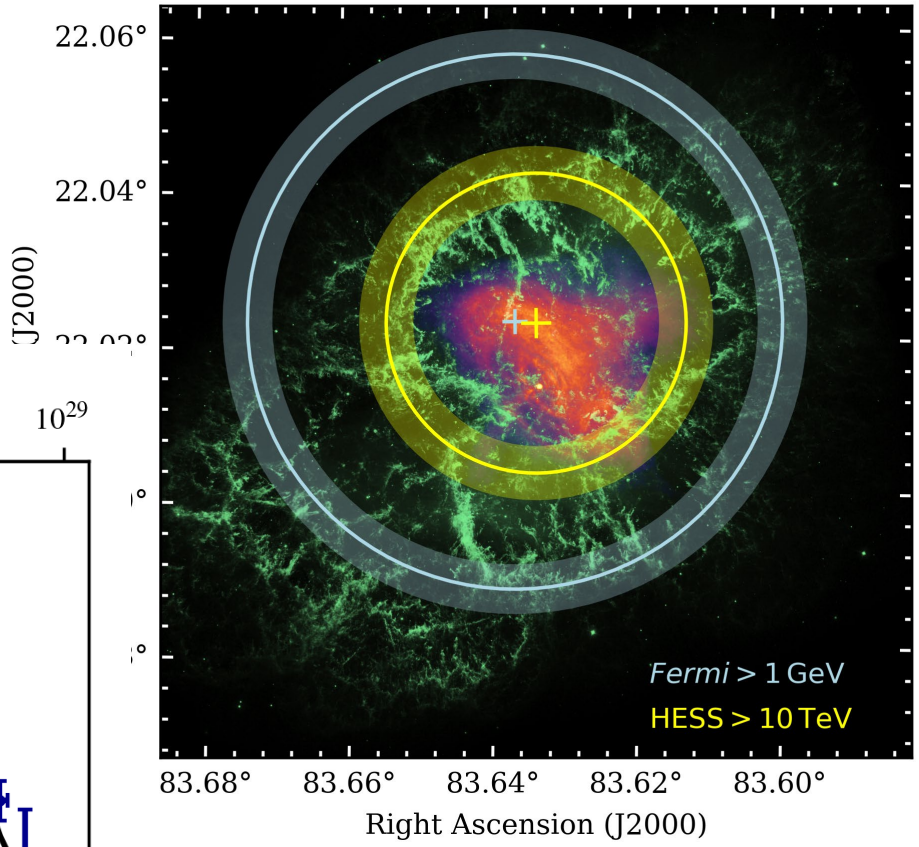
Inverse Comptron -- 3D data sets



Fermi + HESS on the Crab

- Measuring the extension in energy intervals
- Compare the IC extensions to the synchrotron extensions



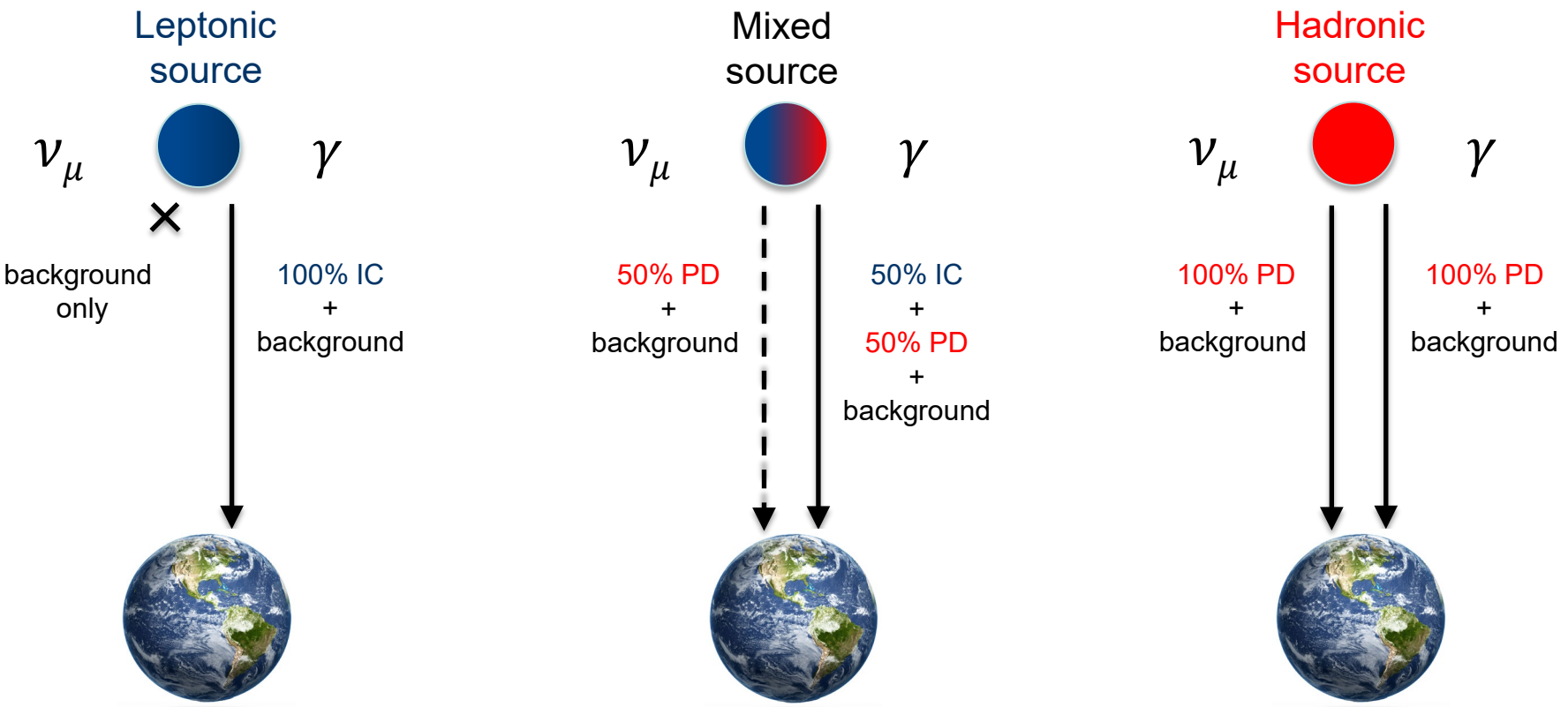


Combined CTA + KM3NeT analysis

“Are there Galactic gamma-ray sources for which the combined analysis of data from KM3NeT and CTA would help us to discriminate between hadronic and leptonic emission scenarios?“

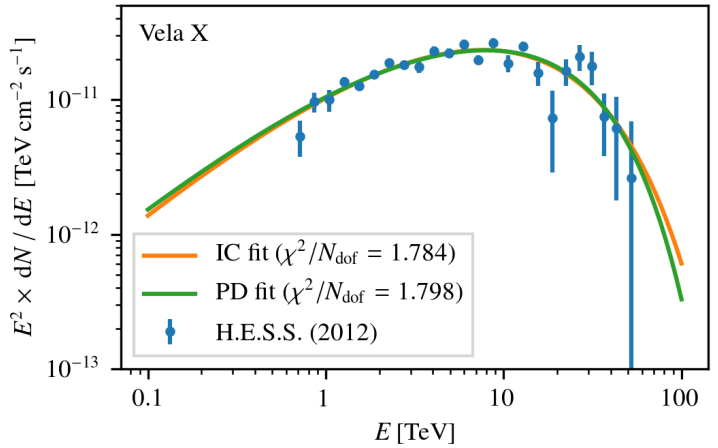
Motivation

- Differentiating between leptonic and hadronic emission scenarios

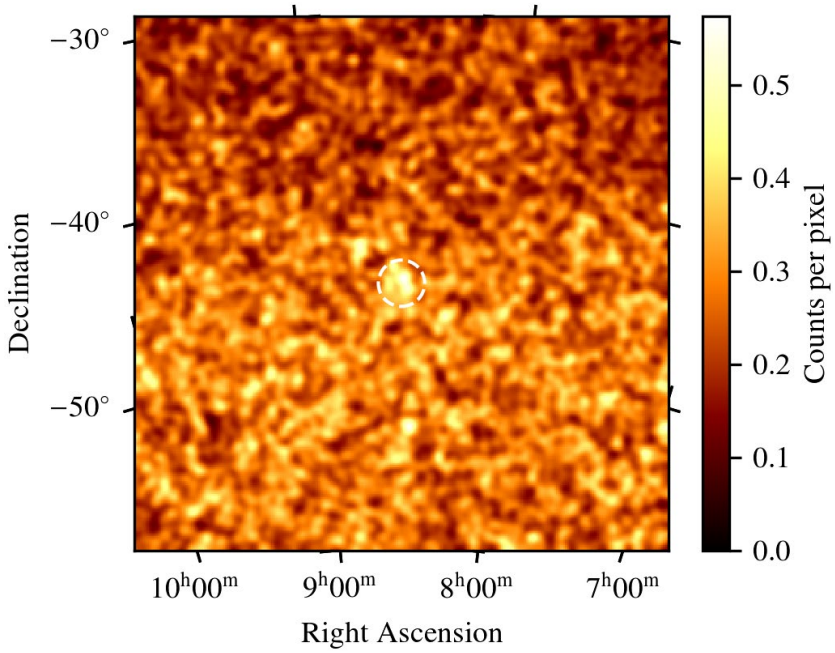


Generation of KM3NeT data sets

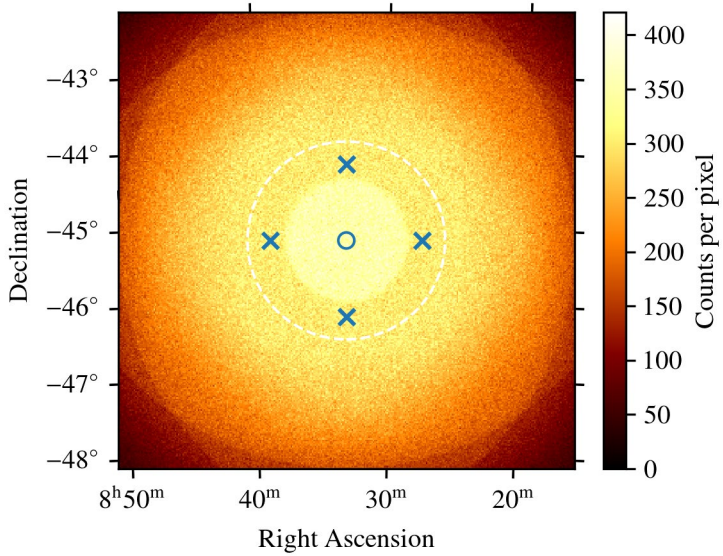
- gamma-ray spectra are very similar
- Need to include neutrino information



Simulated data set for KM3NeT with 10 yr observation time

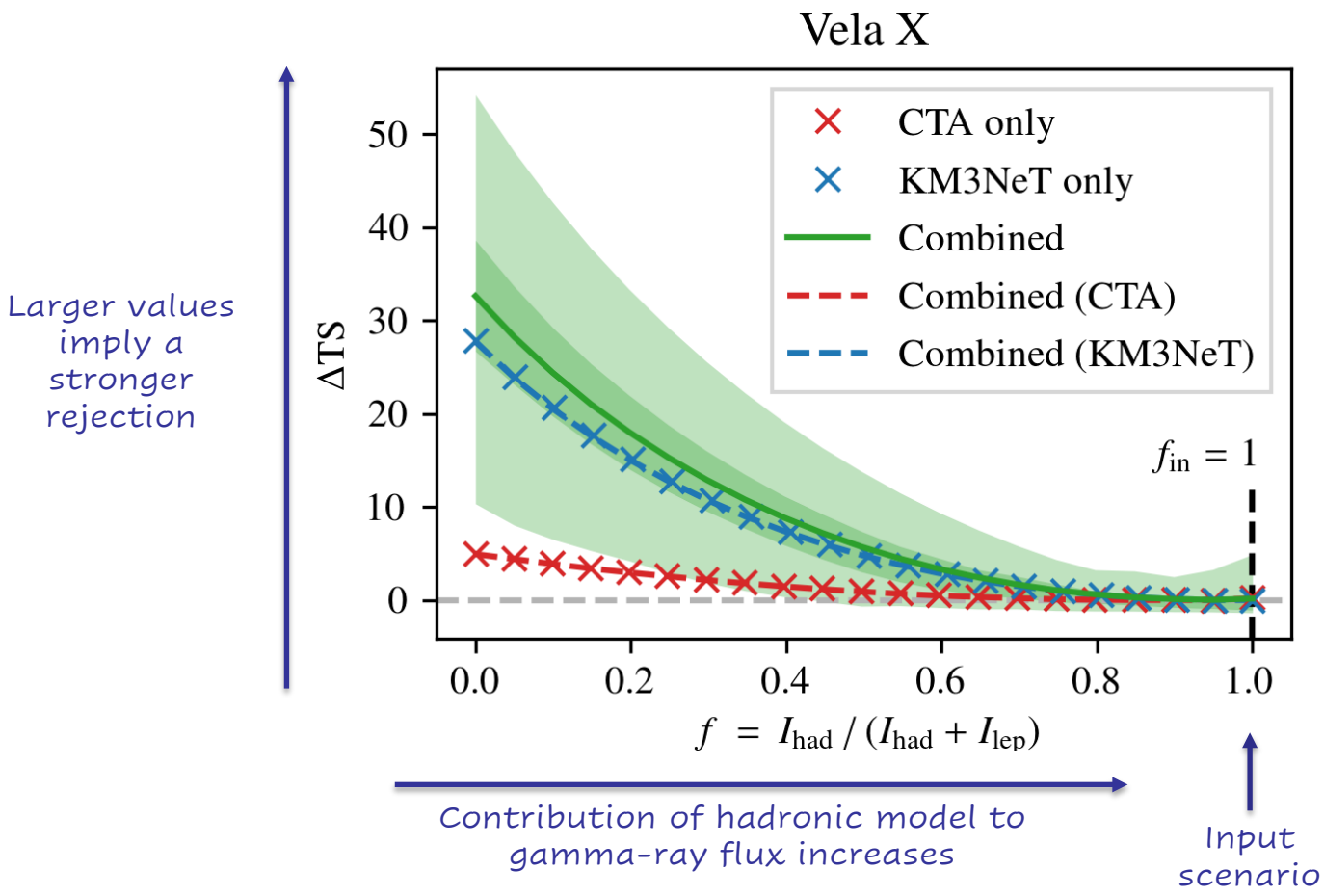


Simulated data set for CTA with 200 h observation time



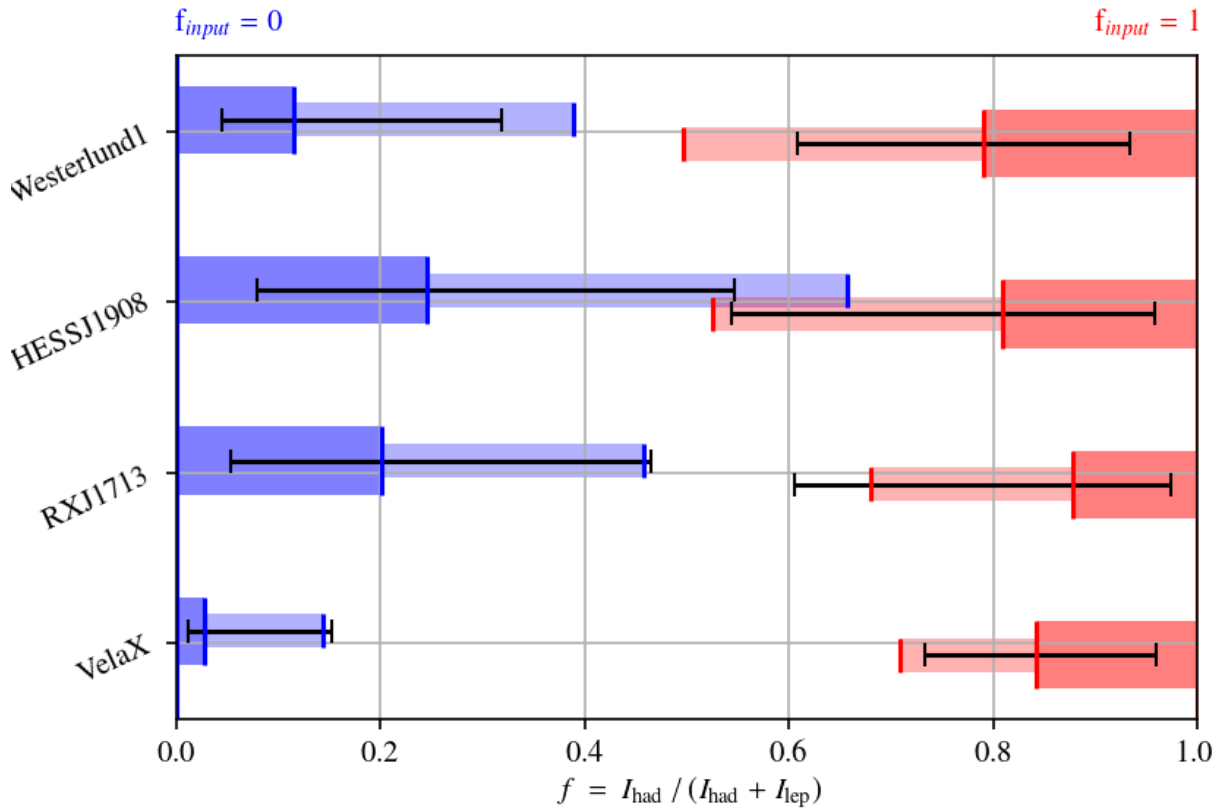
Limits on the hadronic contribution

- Perform *likelihood-profile* scans of the hadronic contribution *f*



Limits on the hadronic contribution

- Distribution of the best-fit values together with the average uncertainty



Summary

- Combined likelihood fit of Fermi + HESS data / CTA + KM3NeT data
  - Extended gamma-ray energy range
  - Combination of gamma-ray and neutrino data
- Flexible analysis framework of GAMMAPY
  - Fit customized physical models to the data
  - Include prior terms on parameters

Thanks for your attention!

Bundesministerium
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