Joint-instrument analyses with Gammapy

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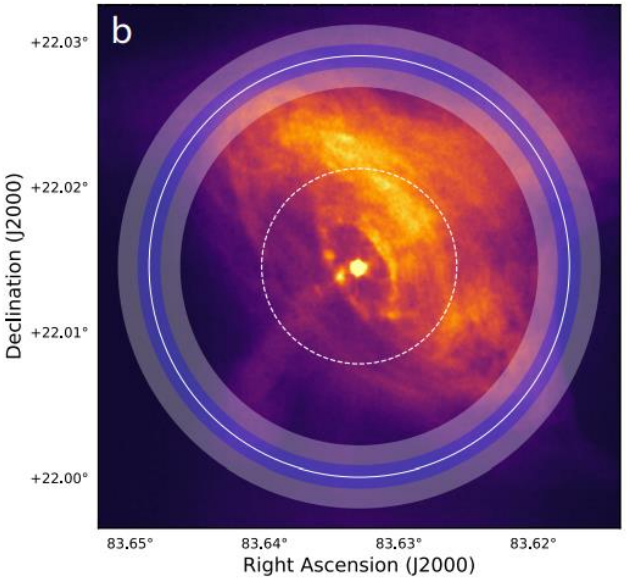
ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

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



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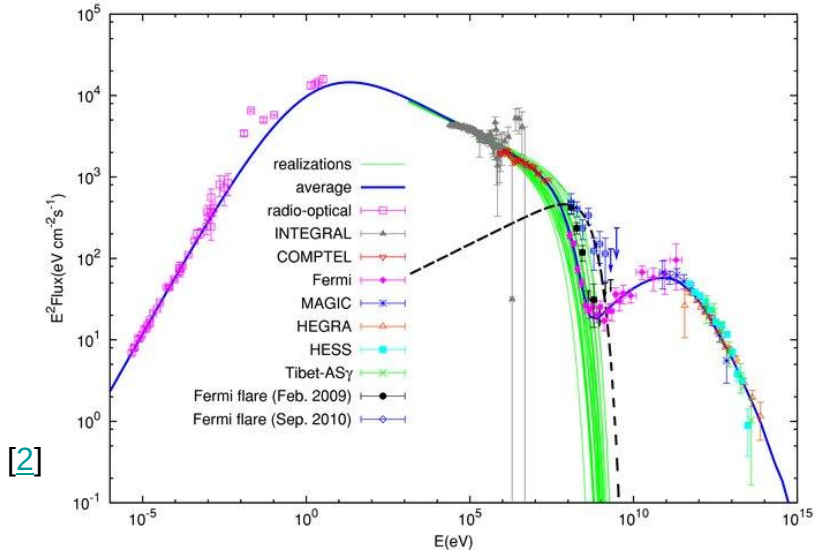

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3D analyses with Gammapy

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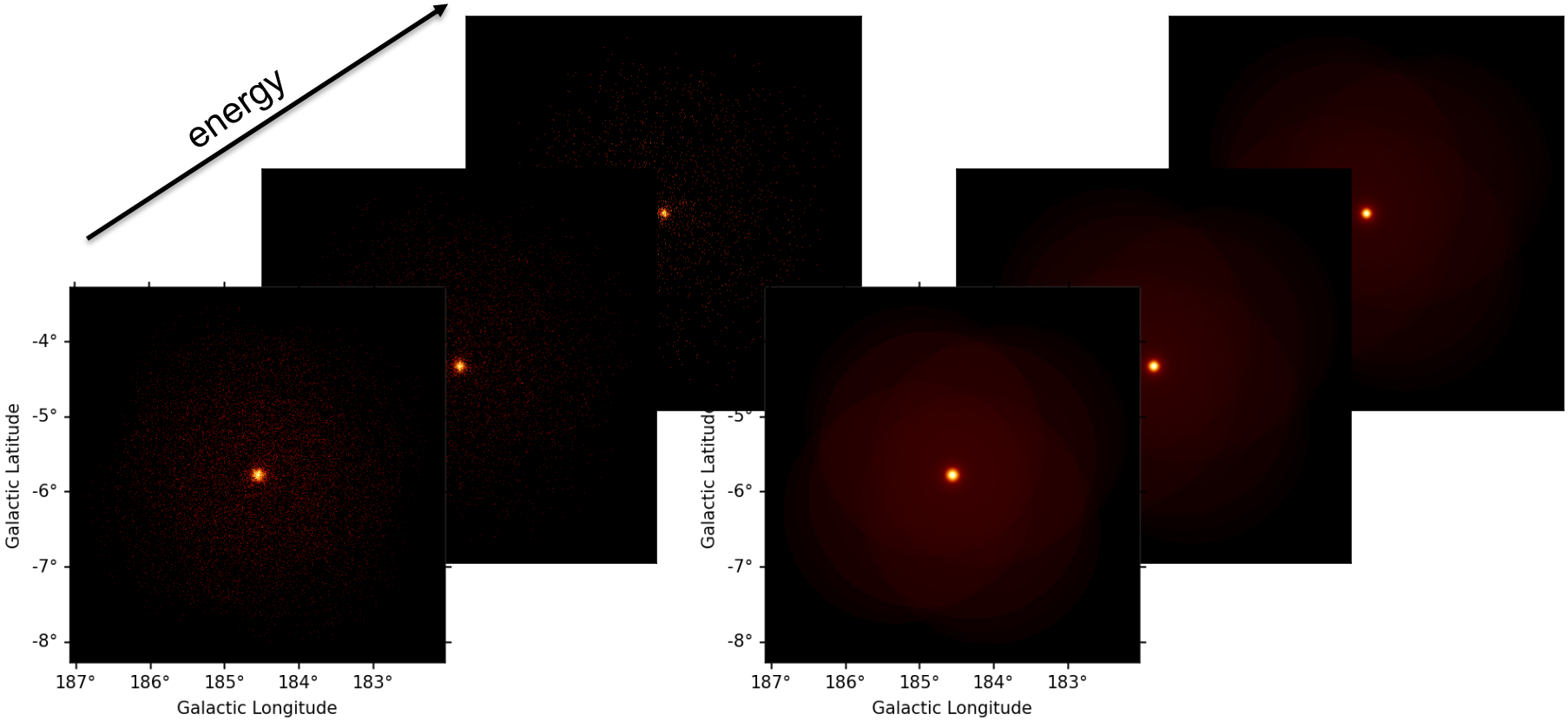
- Likelihood analysis in 3D (2 spatial, 1 energy)
- Combination of different data sets at likelihood level
  → can fit same physical model to data from different instruments
- Requirement: instrument data (DL3) in common format
  → can also include e.g. neutrino data,
  although package is designed for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

3D analyses with Gammapy

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

Predicted counts map:
from models and IRFs



3D analyses with Gammapy

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- 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:

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

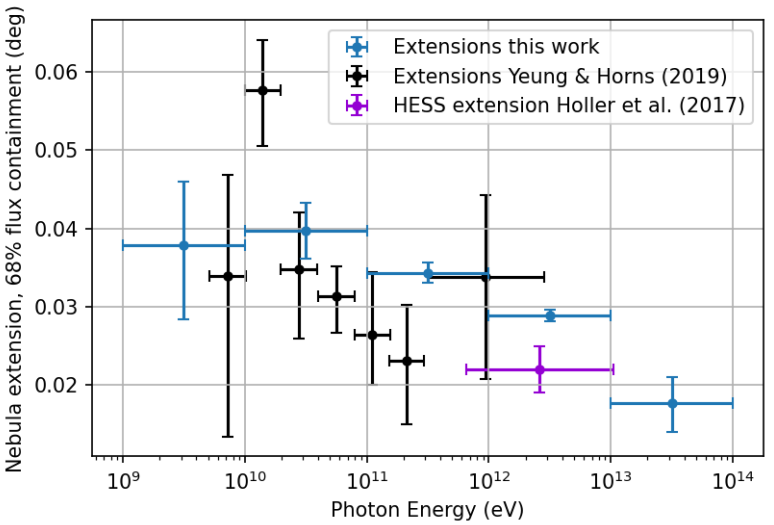
  - Minimizing $\mathrm{TS} \equiv -2 \ln \mathcal{L}$ maximizes the Likelihood

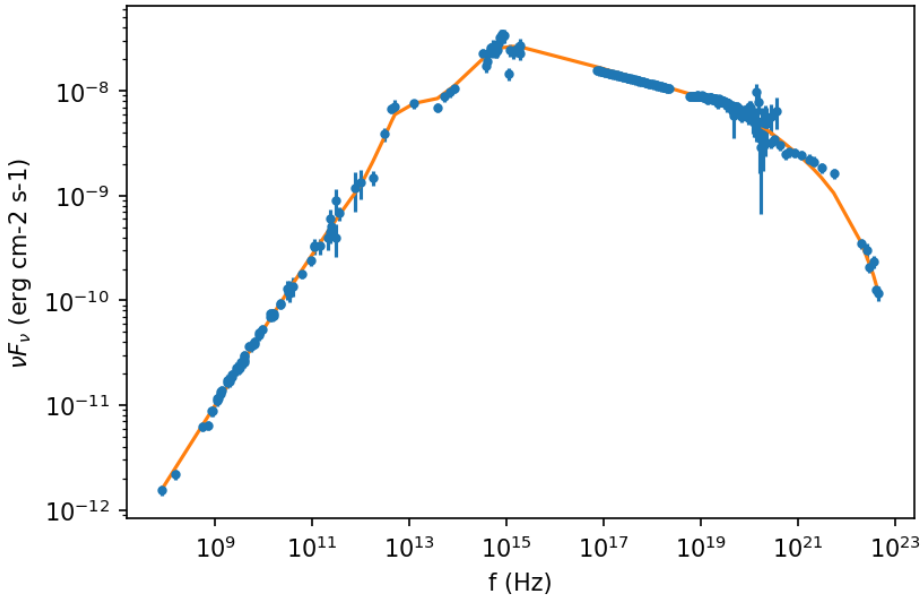
Combined Fermi + HESS analysis on the Crab nebula

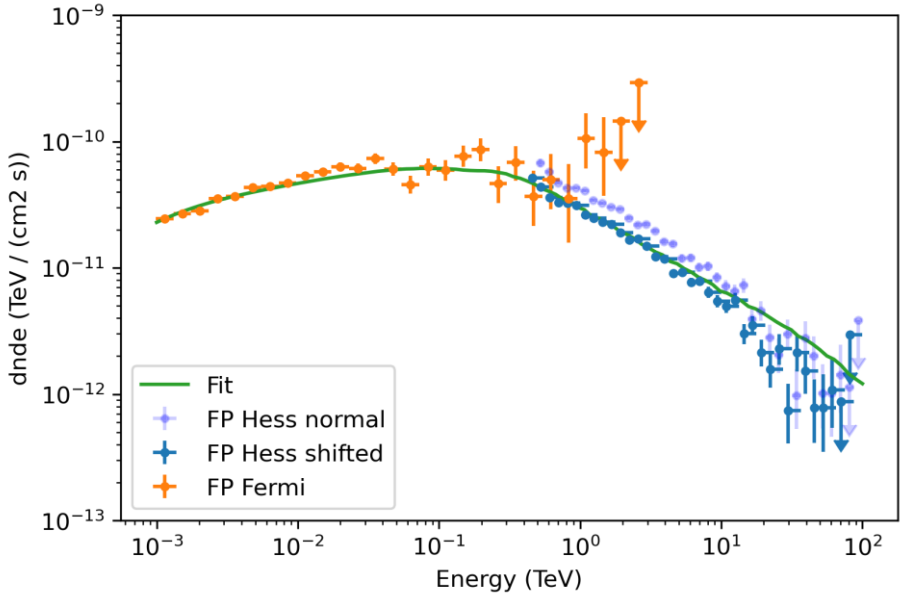
Fermi + HESS on the Crab

- Fitting a SSC-model to the data
- Adding the χ^2-value of the synchrotron component to the TS-value of the IC Fit

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







Fermi + HESS on the Crab

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- Flexible analysis tool, many options to customize analyses
- Rather easy to implement and use custom models
- Combine different data sets if event data and IRFs are available
- Use prior functions to constrain the fit

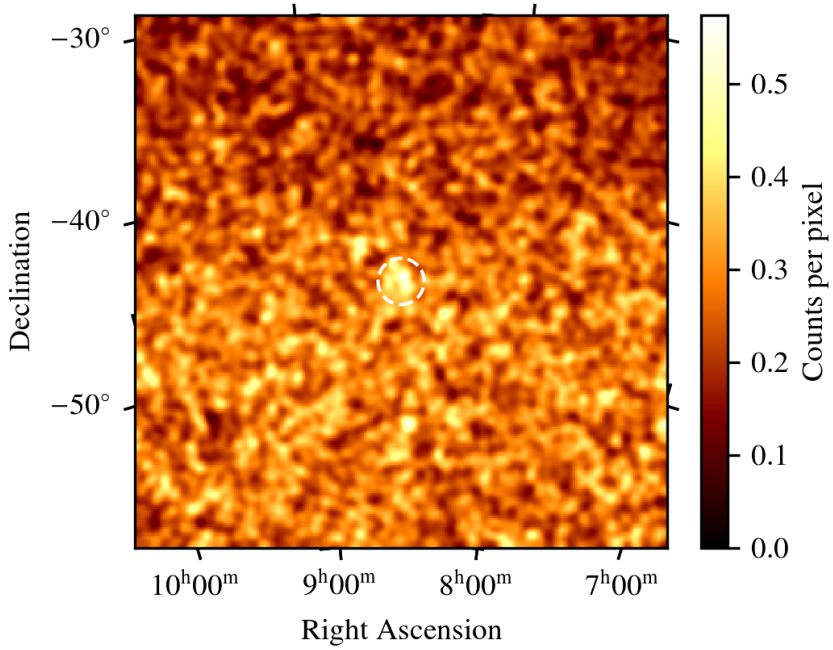
Combined CTA + KM3NeT analysis

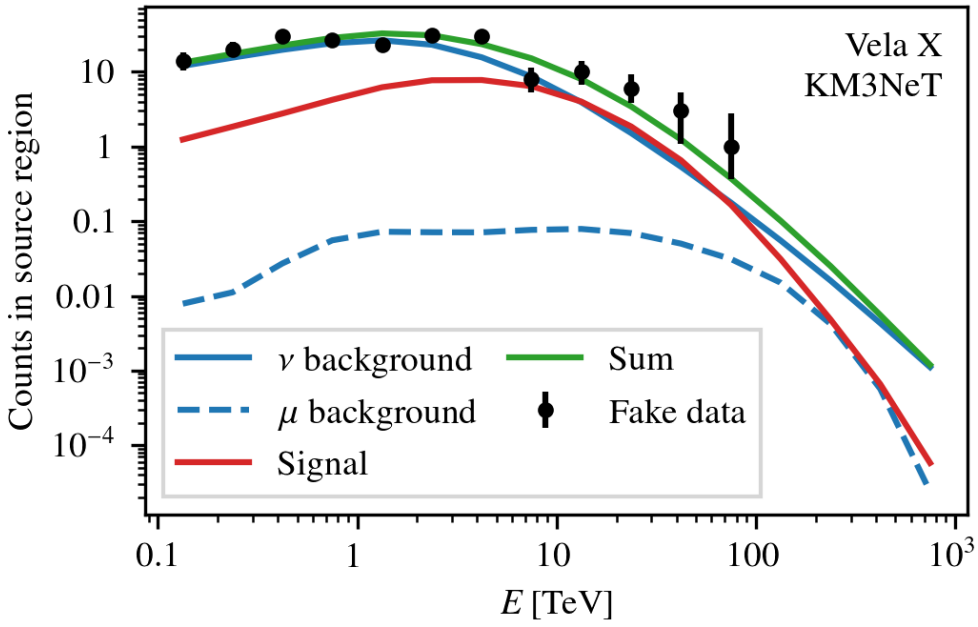
“Are there Galactic gamma-ray sources for which the combined analysis of data from KM3NeT and CTA would help us to discriminate between hadronic and leptonic emission scenarios?“

Generation of KM3NeT data sets

- IRF production based on simulations
- Source model based on gamma-ray observations
- Set Poisson randomized counts based on model prediction

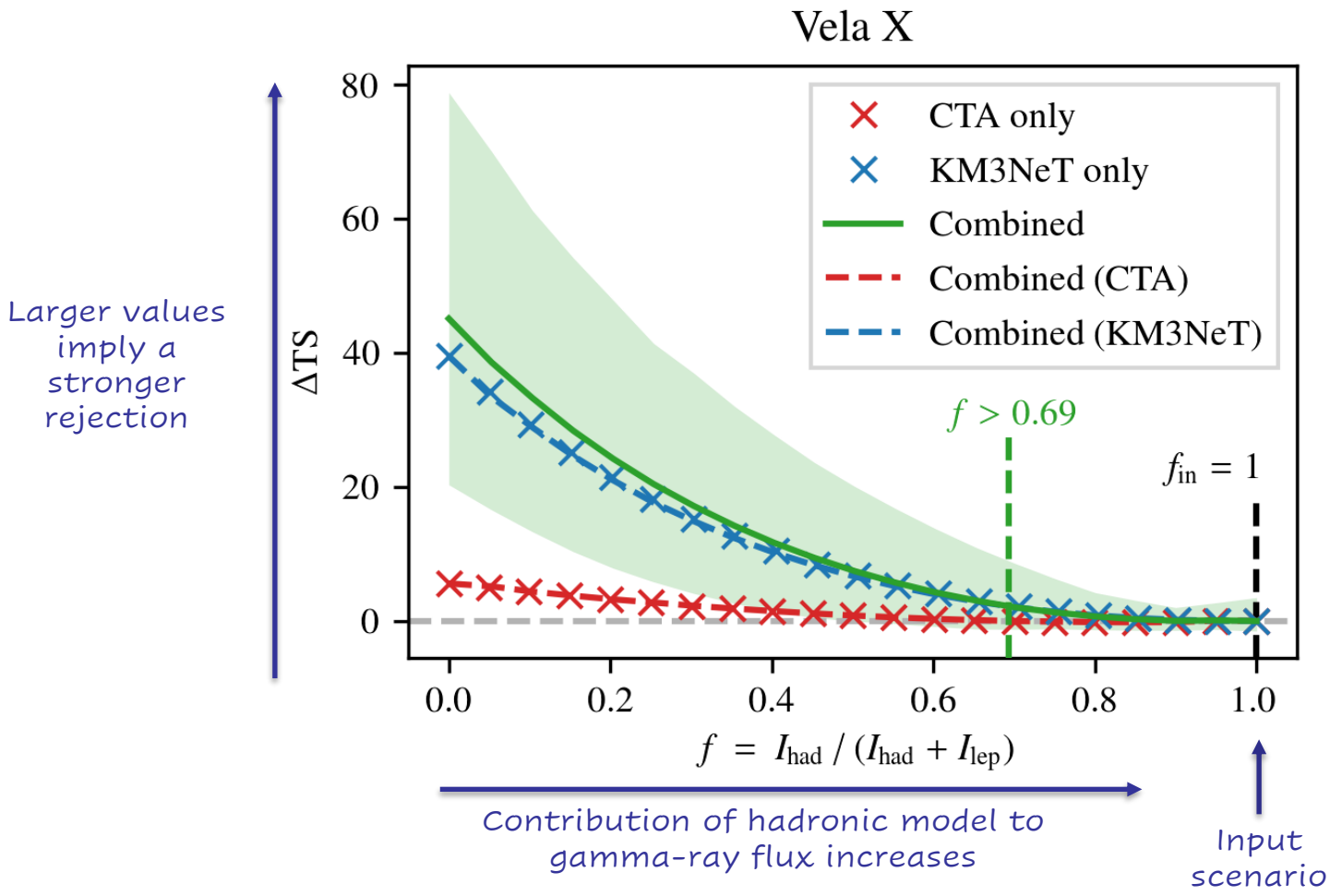
Example data set for Vela X with 10 yr observation time





Limits on the hadronic contribution

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



Thanks for your attention!

Bundesministerium
für Bildung
und Forschung

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References

- [1] Hess Collaboration, "*Resolving the Crab pulsar wind nebula at teraelectronvolt energies*", Sep 2019, https://arxiv.org/abs/1909.09494
- [2] Yuan, Qiang, "*A Statistical Model for the γ-ray Variability of the Crab Nebula*", 2011, https://arxiv.org/abs/1012.1395