

# Galactic Centre with H.E.S.S.: Search for Dark Matter and a PeVatron & Systematic Uncertainties

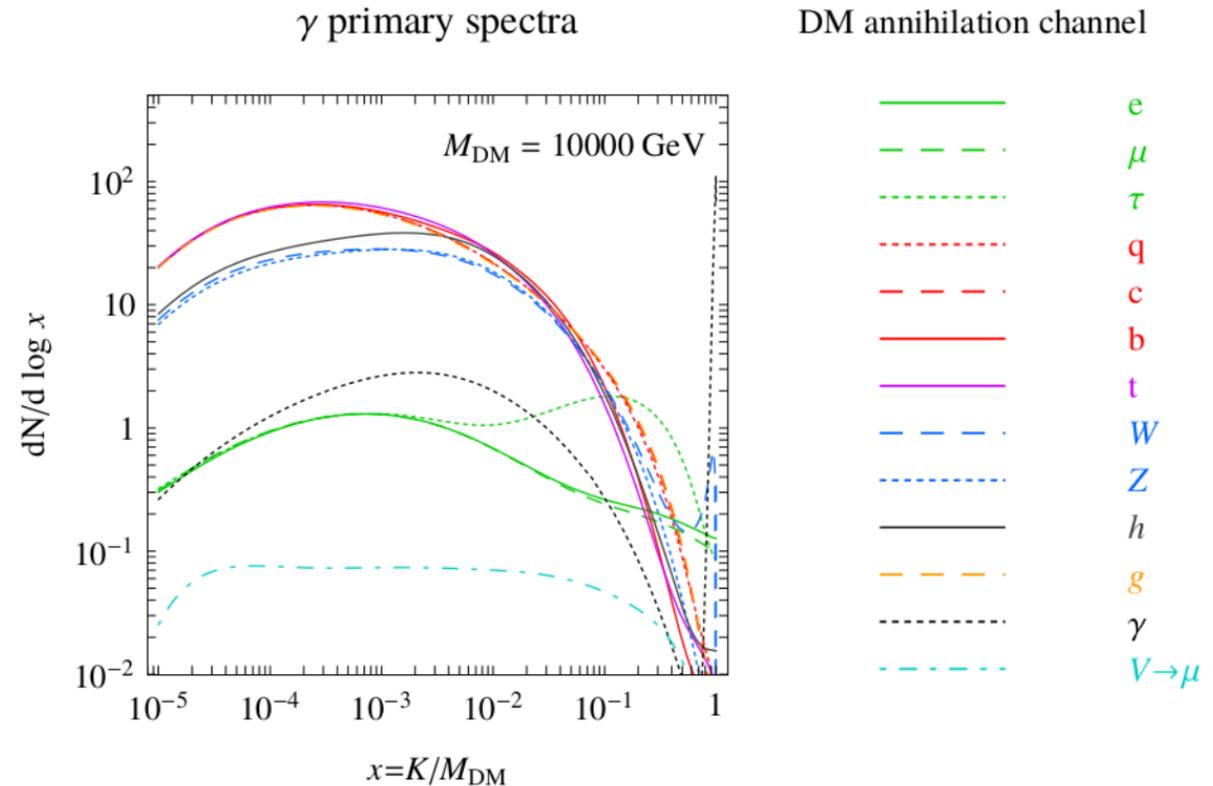
# Galactic Centre with H.E.S.S.:

## Search for Dark Matter and a PeVatron

### & Systematic Uncertainties

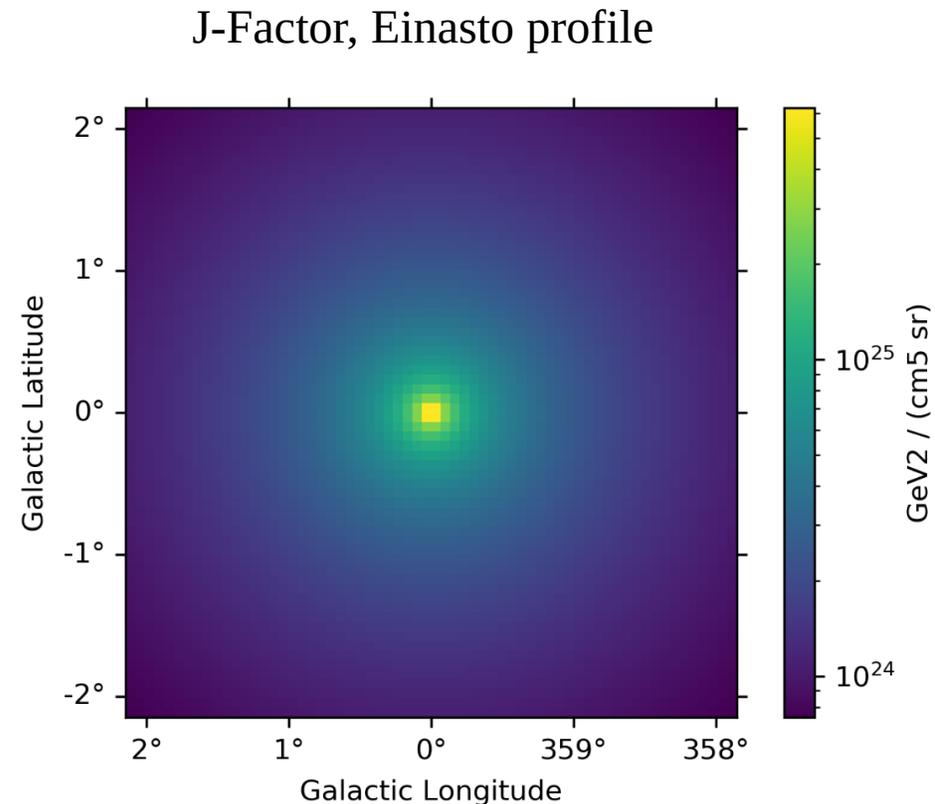
# Search for Dark Matter Annihilation

- WIMPs
- 3D Model:
  - Spectrum:
    - Assumed annihilation channel
    - Assumed DM mass
  - Spatial Morphology:
    - Assumed density profile
    - J-Factor
- Standard analysis: exclude excess along Galactic Plane
- Fitting and set limits on the annihilation cross-section



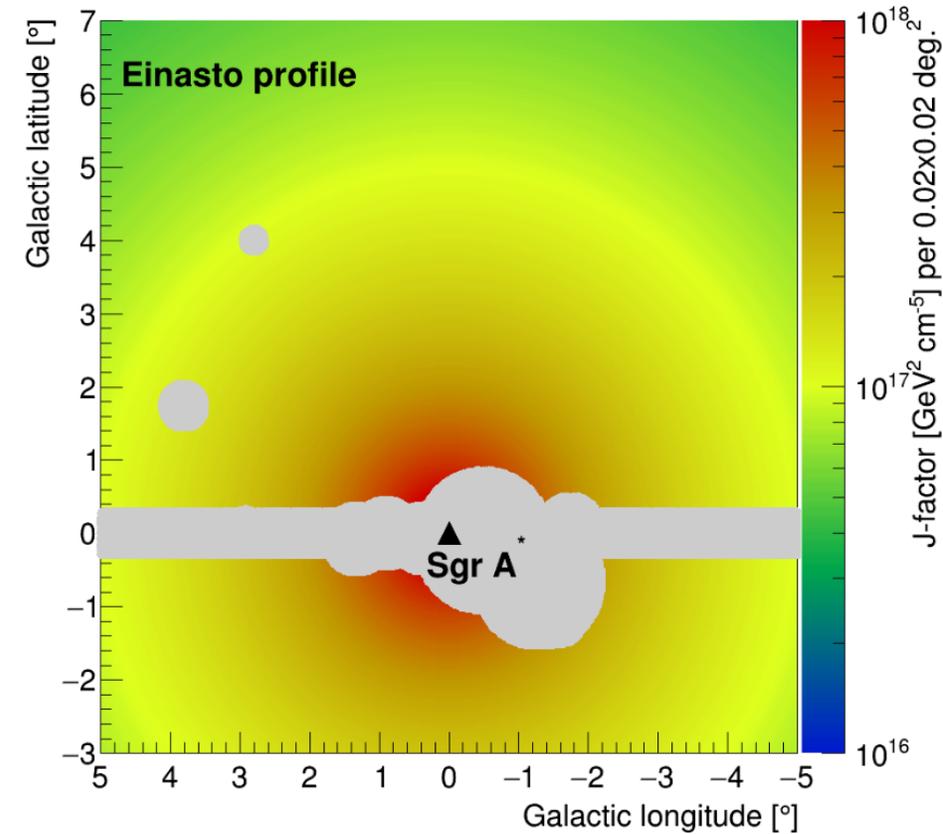
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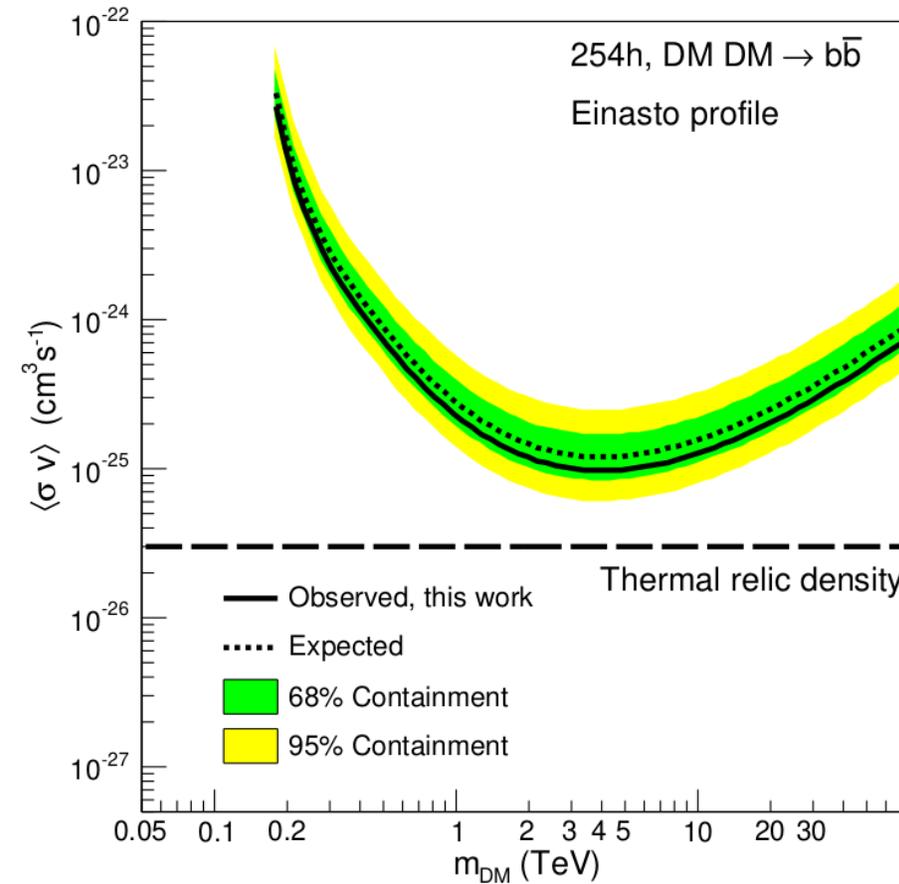
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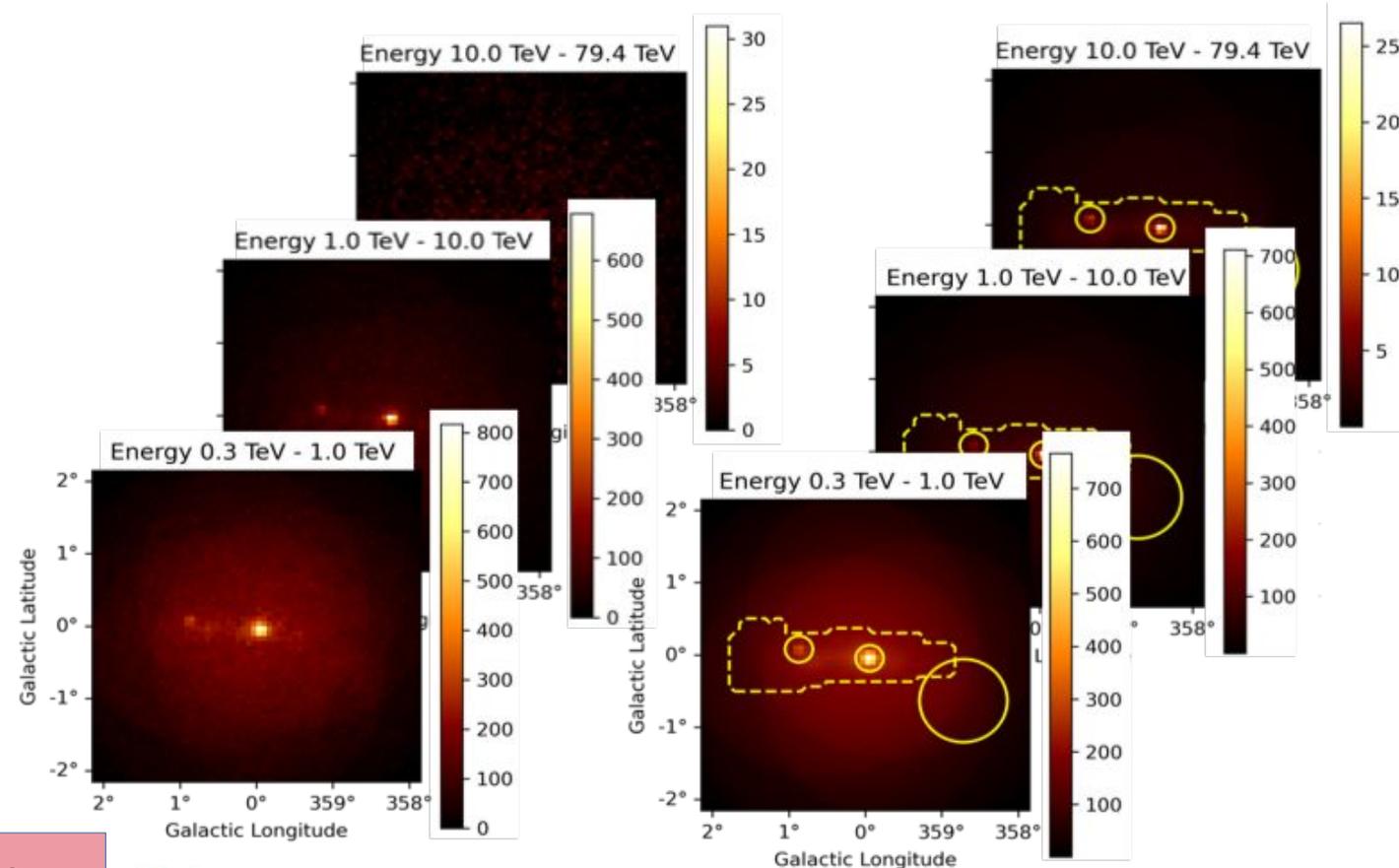
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3D + Source  
Modelling

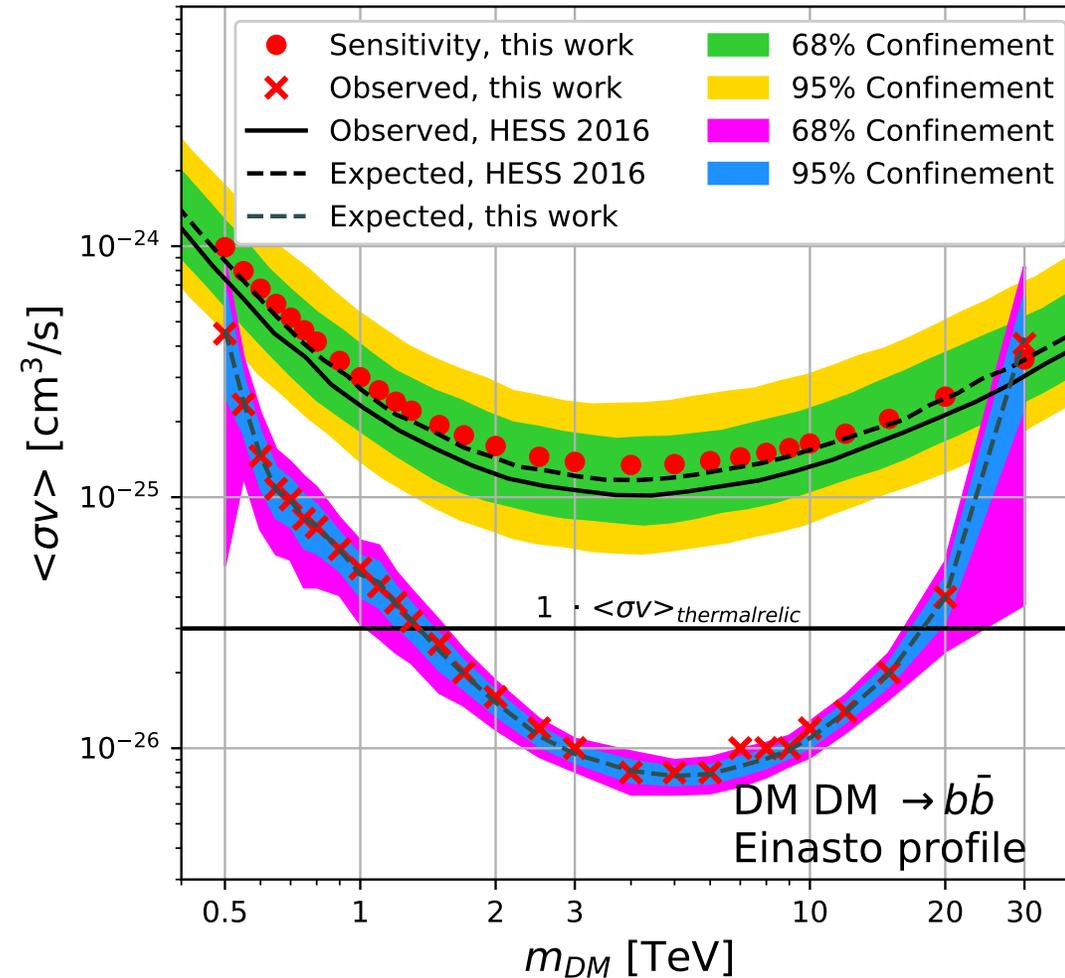
$\gamma\pi$

# Search for Dark Matter Annihilation

- Result:
  - Observed Limits order of magnitude “too good”
  - Limits based on simulations “correct”

• Conclusion:

Systematics!



# Galactic Centre with H.E.S.S.:

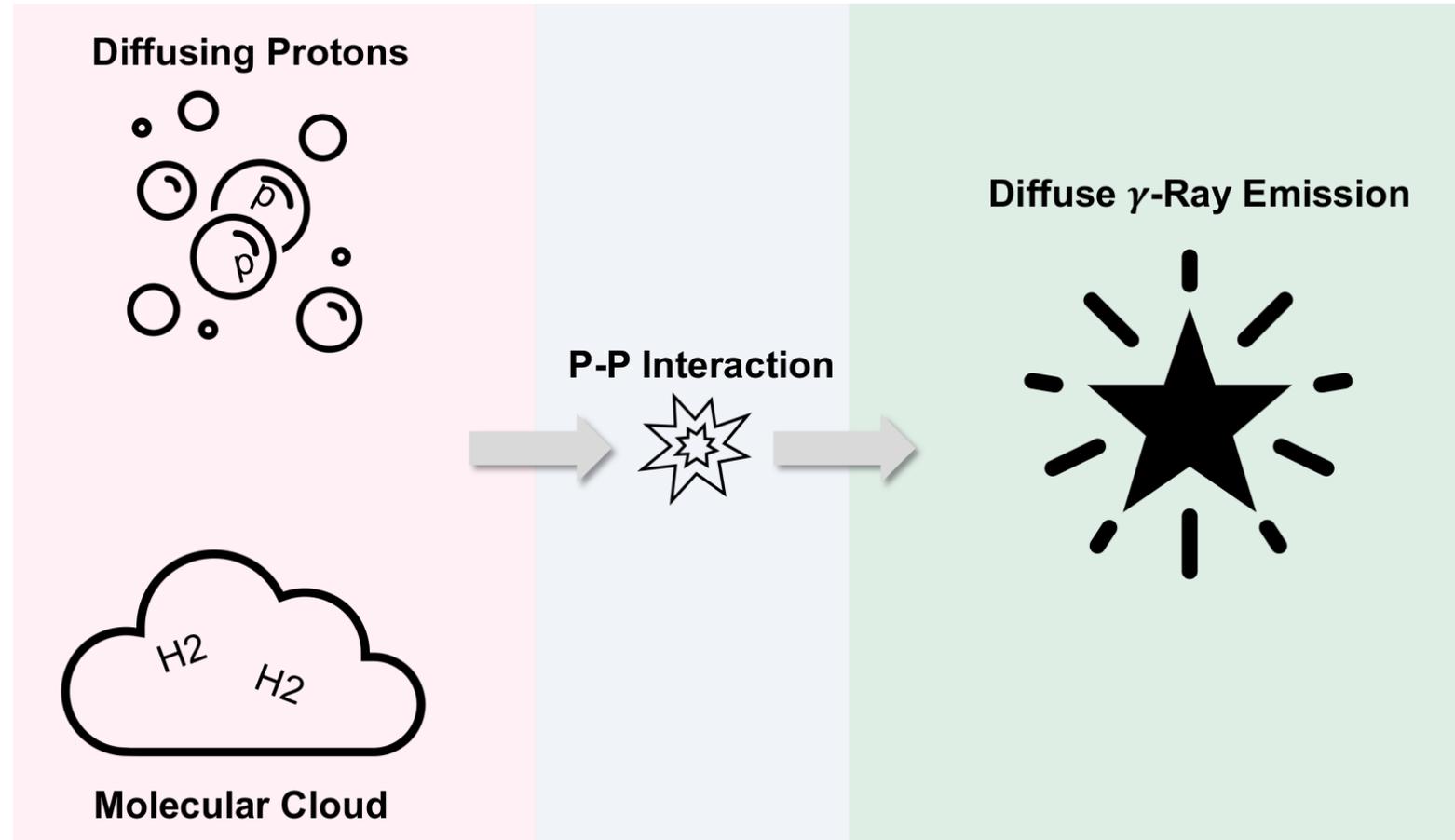
## Search for Dark Matter and a PeVatron & Systematic Uncertainties

Yu Wun Wong

# Diffuse $\gamma$ -Ray Emission

Motivation:

- Diffusion properties
- Proton energy cutoff



# Diffuse $\gamma$ -Ray Emission

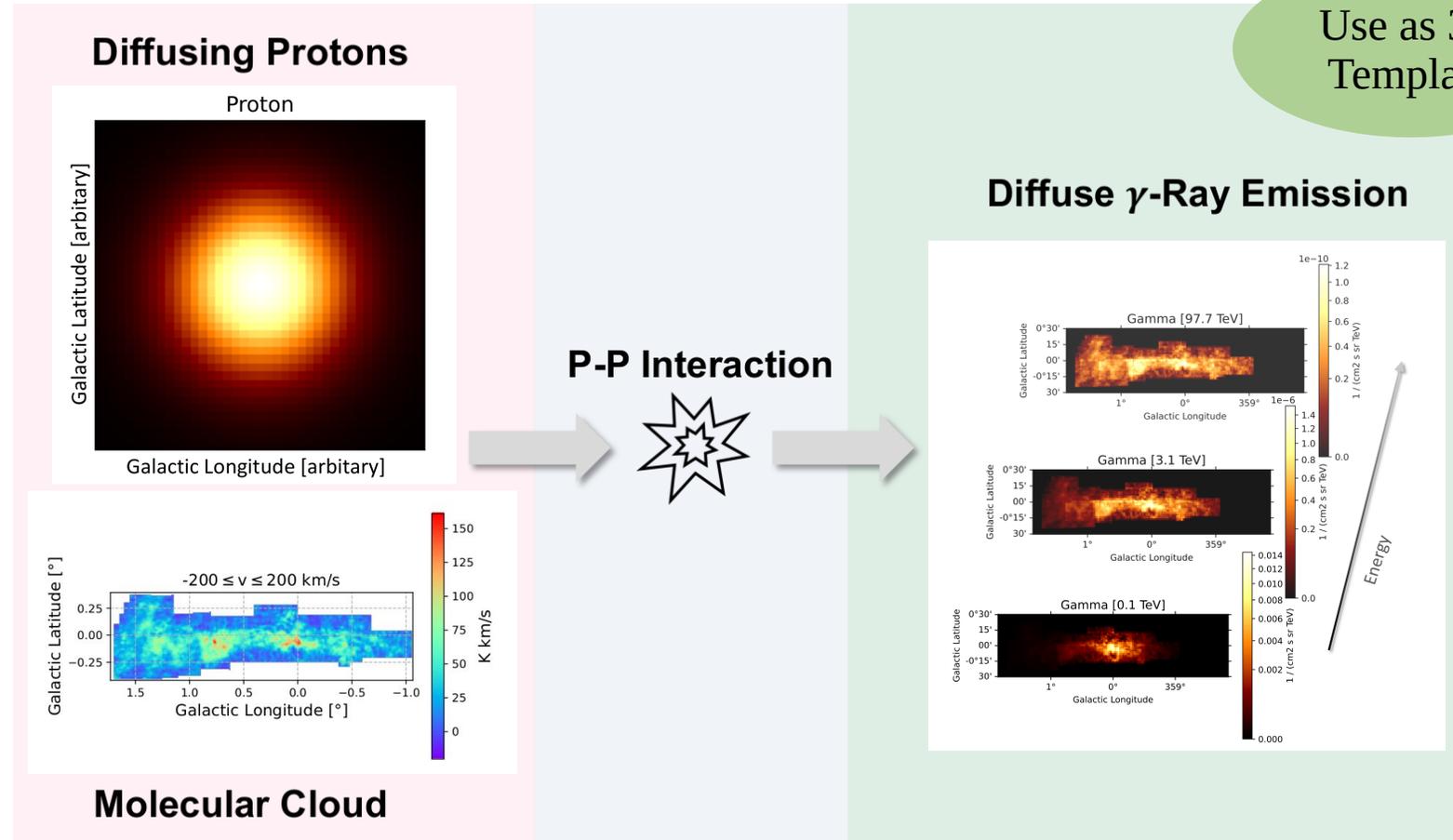
Solve diffusion equation:

$$\frac{\partial n(\vec{r}, E, t)}{\partial t} = D(E_p) \nabla^2 n(\vec{r}, E, t)$$

and proton spectrum:

$$\frac{dN_p}{dE_p} = N_0 E_p^{-\Gamma} e^{-E_p/E_c}$$

Use as 3D Template



Tsuboi et al (1999)  
Sawada et al (2004)

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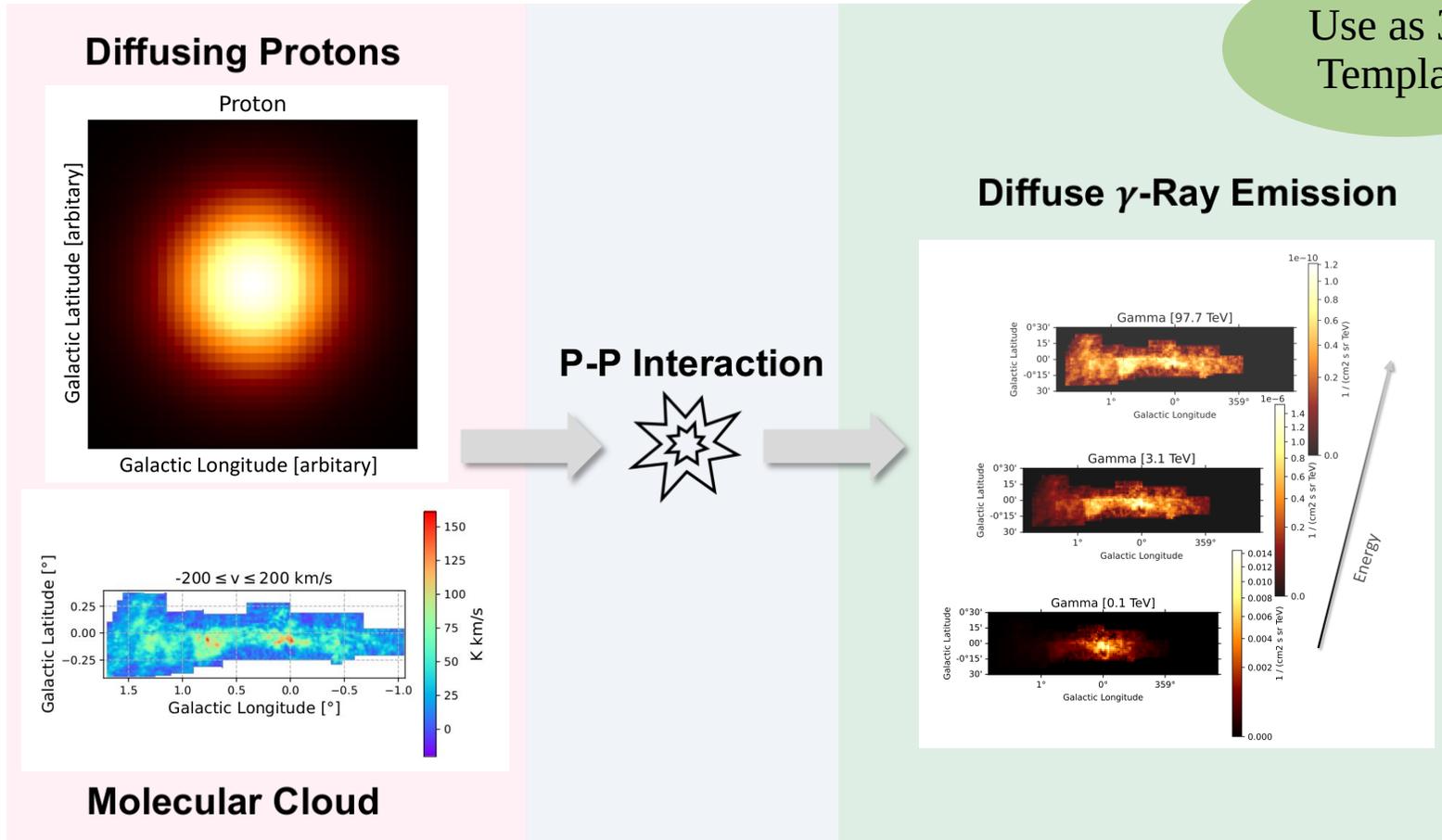
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$E_c$  [TeV]  
 $142 \pm 31$

Energy cutoff at  $> 1\text{PeV}$   
rejected by  $3.6\sigma$   
→ PeVatron in the GC  
unlikely to exist!

Systematics!



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# Galactic Centre with H.E.S.S.: Search for Dark Matter and a PeVatron & Systematic Uncertainties

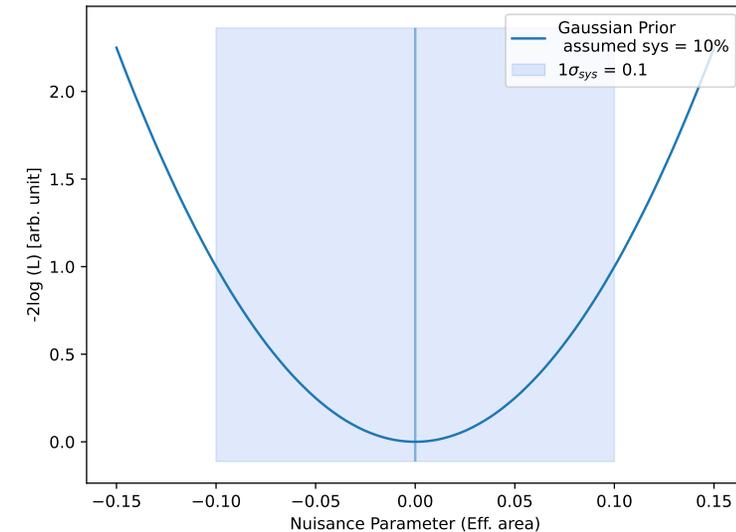
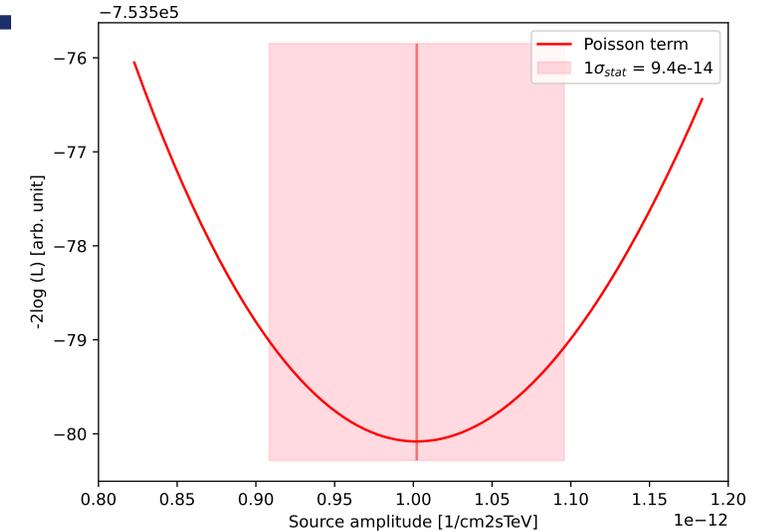
# Uncertainties – General Introduction

## Statistical Uncertainties $\sigma_{stat}$

- Due to intrinsic randomness of continuous variables
- Poisson term in Likelihood function
- Estimated via Likelihood-ratio test

## Systematic Uncertainties $\sigma_{sys}$

- Due to mismodelling of:
  - 3D BKG template
  - IRF (effective area, energy reconstruction, PSF)
- Described by “nuisance parameters”
- Gaussian prior term in Likelihood function  
= estimate of the magnitude of the systematic



# Uncertainties – General Introduction

## Statistical Uncertainties $\sigma_{stat}$

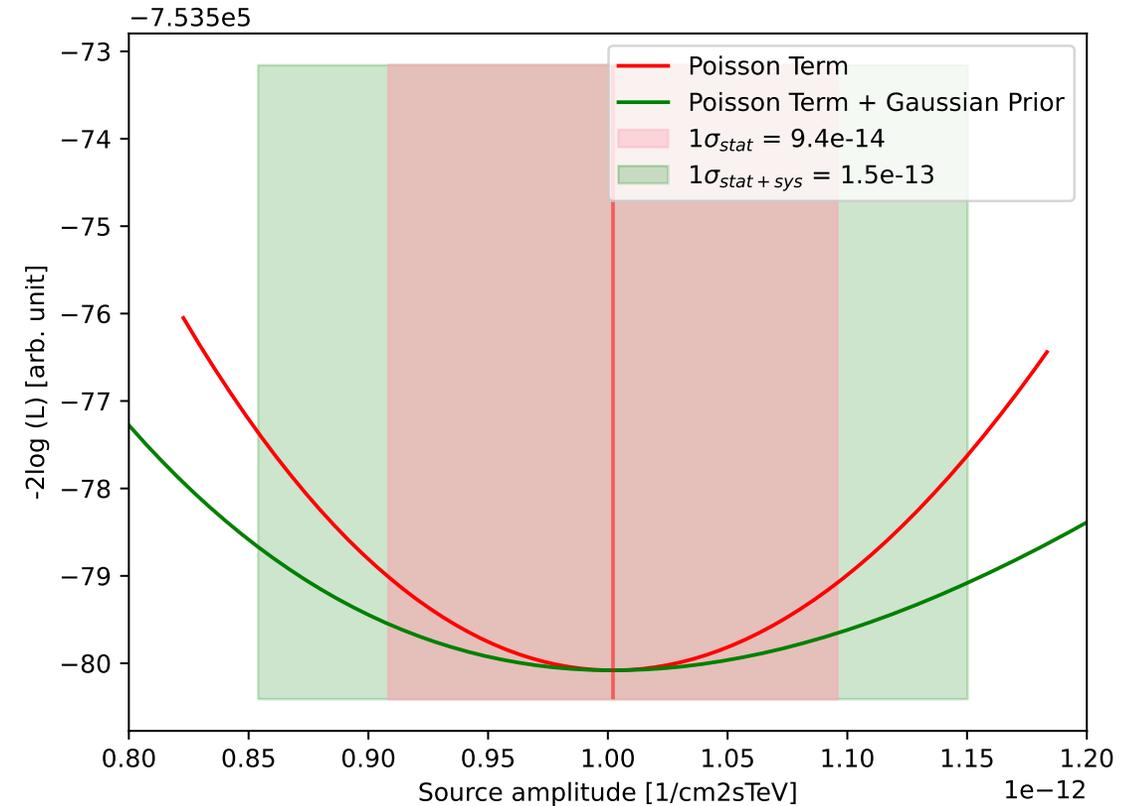
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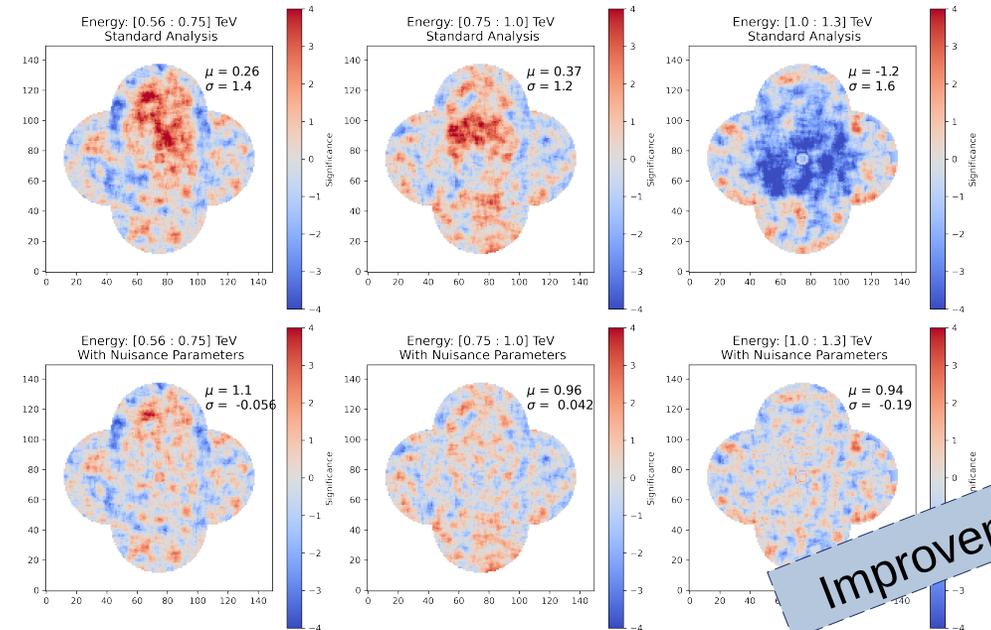
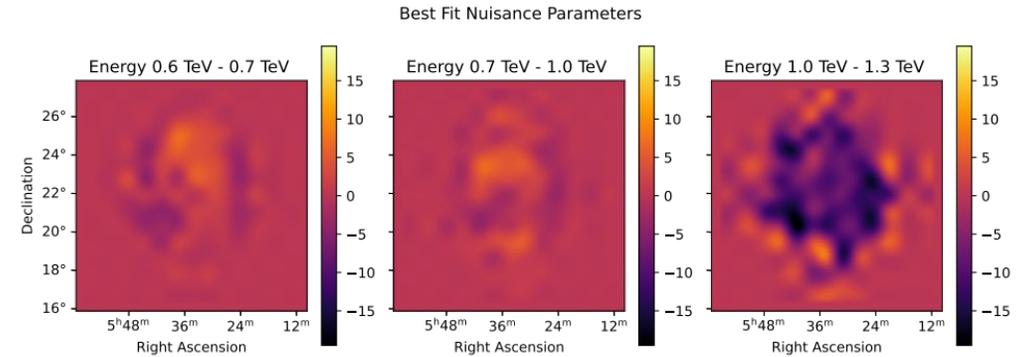
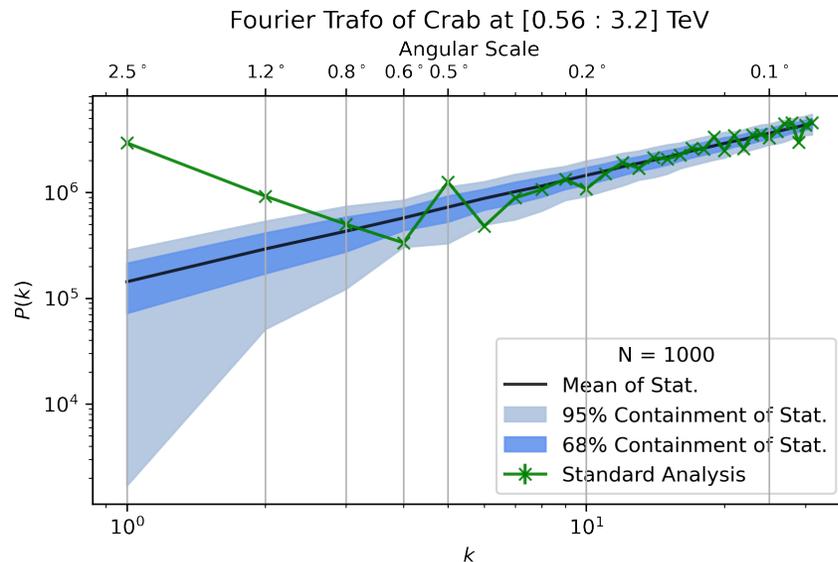


**Total uncertainty**  $\sigma^2 = \sigma_{stat}^2 + \sigma_{sys}^2$



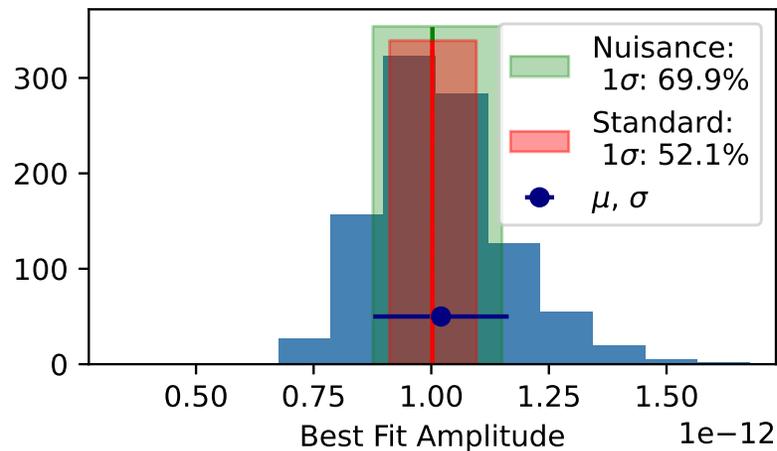
# Result (BKG Systematics)

- Setting up an energy dependent model with multiple nuisance parameters
- Estimate of the magnitude and correlation of the systematic as input to the Gaussian Prior  
→ Improved description of the FoV (bkg)



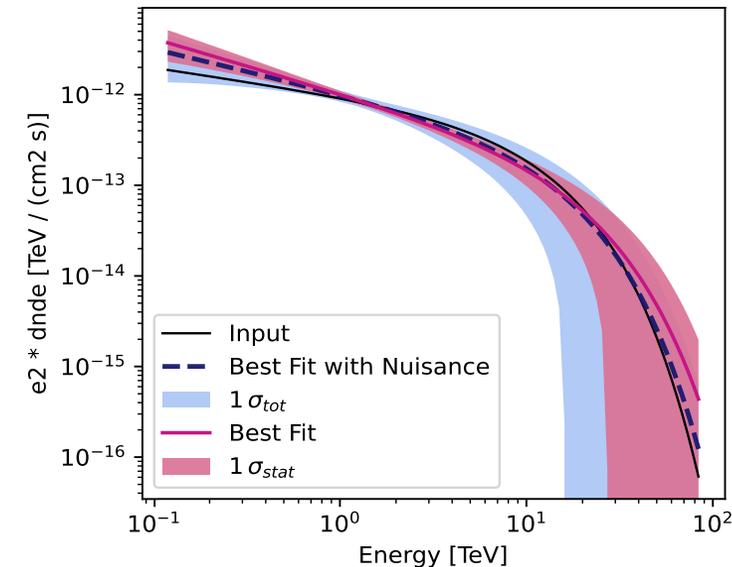
# Result (IRF Systematics)

- Setting up an energy dependent model with multiple nuisance parameters (energy bias, effective area, ... )
- Estimate of the magnitude and correlation of the systematic as input to the Gaussian Prior (tests on simulated datasets)
  - Systematic uncertainty of the model parameters



## Summary

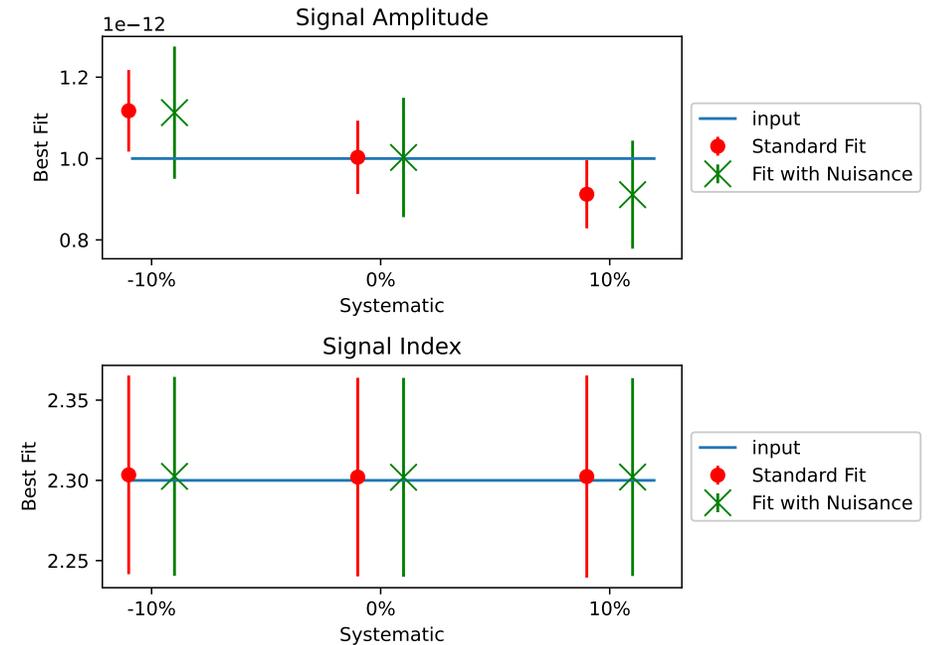
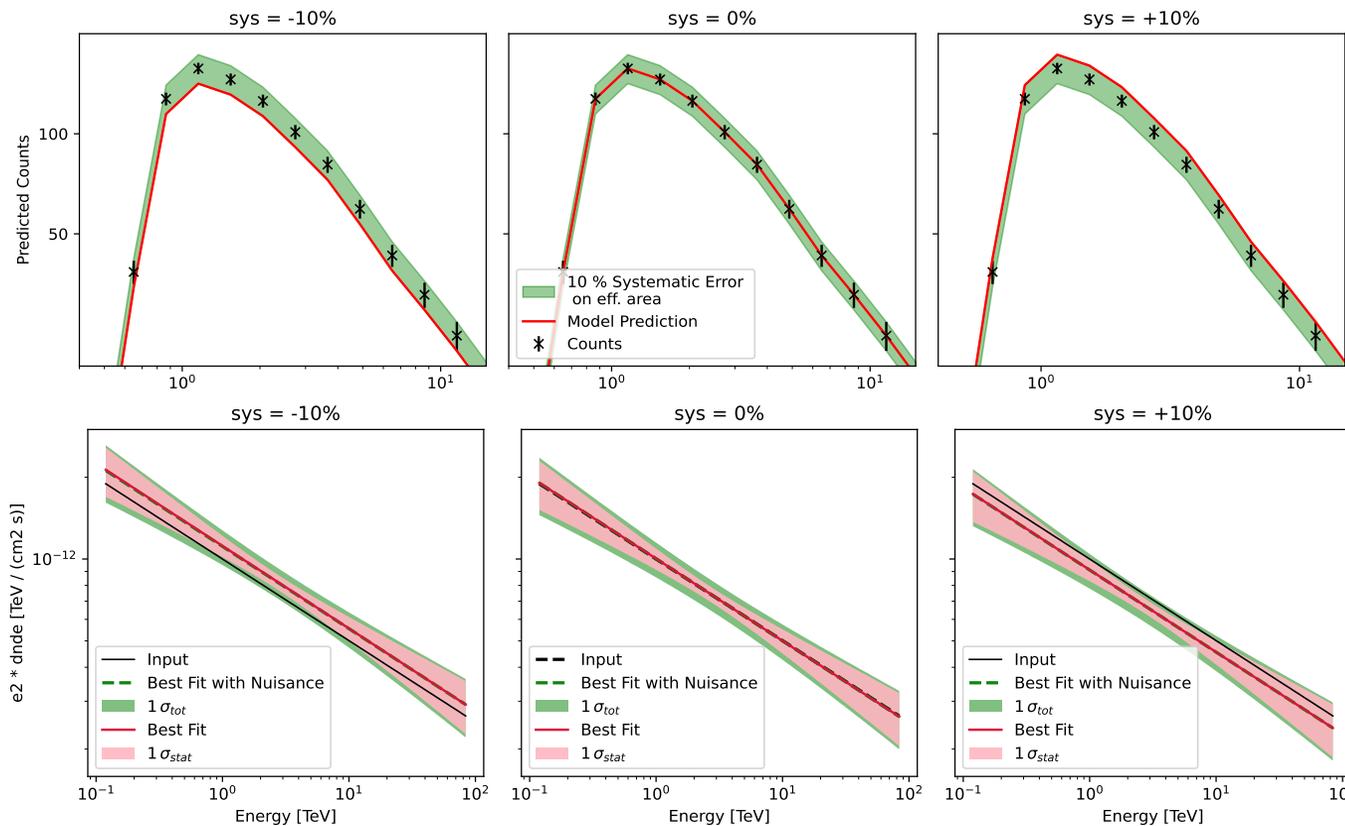
- Strong effect on energy dependent model parameters (DM cross-section, PeVatron Cutoff energy)
- Apply to H.E.S.S. data of the Galactic Centre



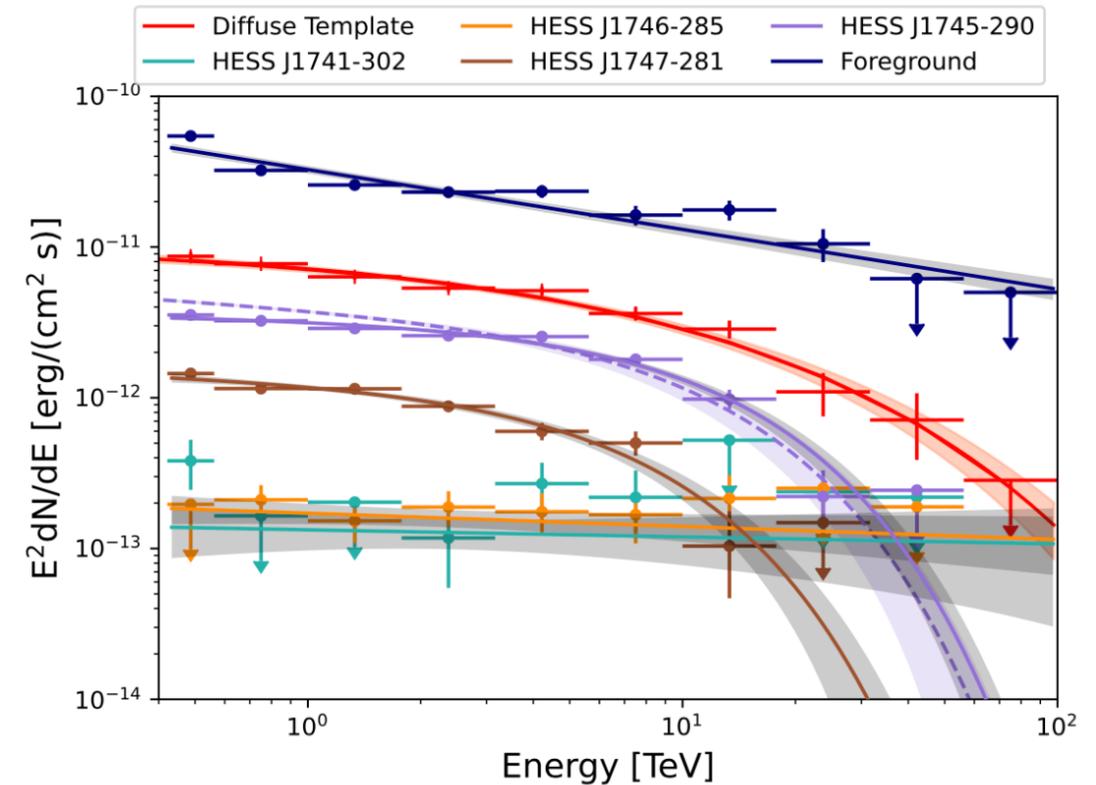
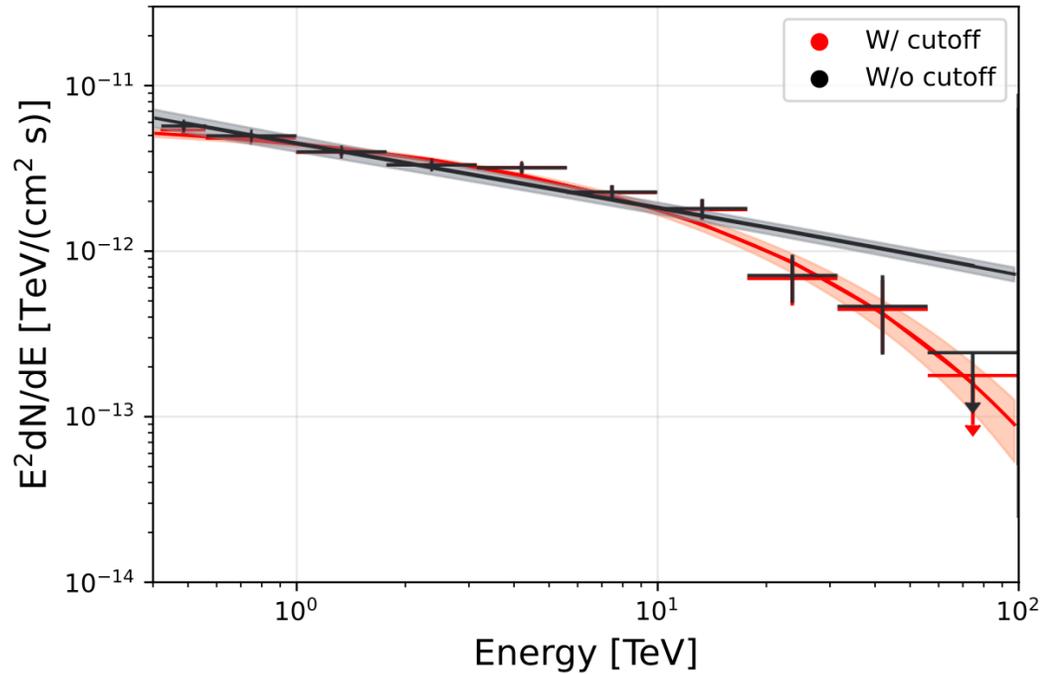
# Backup

# Uncertainties due to Effective Area

- Extreme cases:  $\pm 10\%$
- Best fit amplitude deviating from input
- With nuisance parameter: input value within the uncertainty!



# Diffuse $\gamma$ -Ray Emission – Fit Results

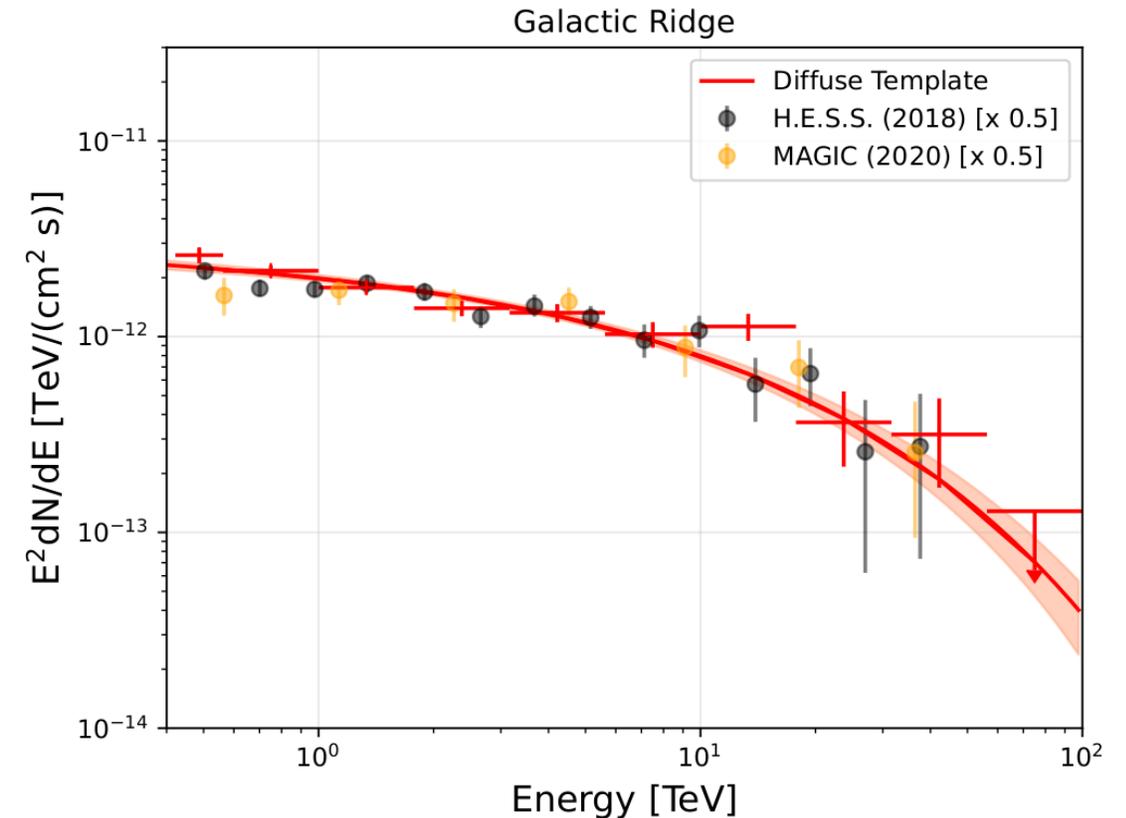
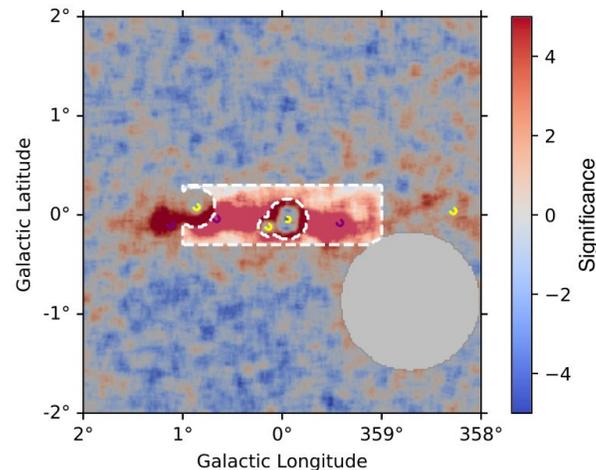


- $\gamma$ -ray spectrum with and without proton energy cutoff
- No cutoff worsens results by  $5.7\sigma$

- Best Fit spectra and fluxpoints of the sources  
Is the cutoff due to contamination from other sources?  $\rightarrow$  No, valid in masked region

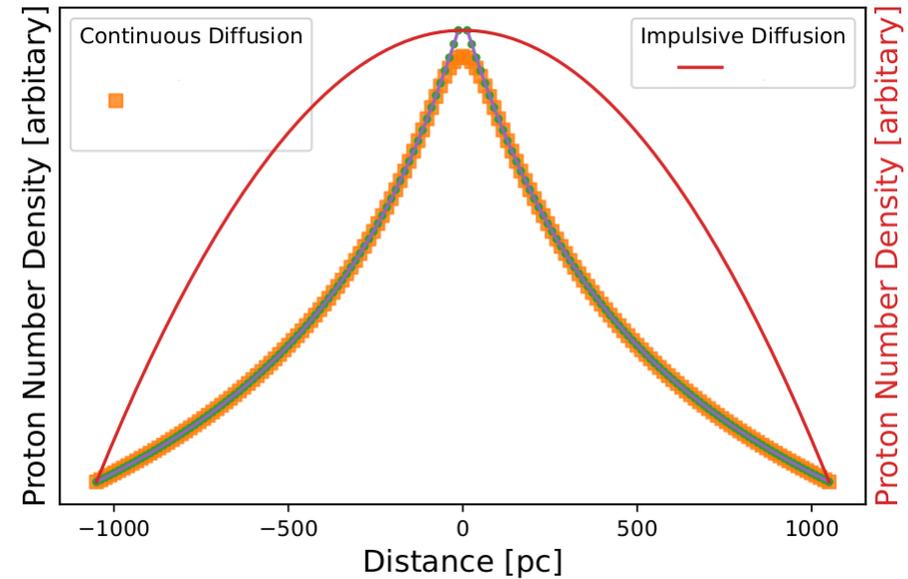
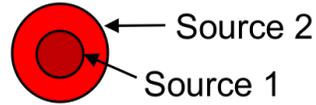
# Diffuse $\gamma$ -Ray Emission – Galactic Ridge

- Investigation of a smaller region:
  - $|l| < 1$  deg and  $|b| < 0.3$  deg
  - Circular mask around sources
- Comparison with H.E.S.S. (2018) and MAGIC (2020):  
Shift by a factor of 2
  - Contamination due to foreground and HESS J1745-290
  - Different methodology to obtain the spectrum
- Cut off still valid!



# Summary

- Hadronic scenario
- Two injection scenarios:
  - Continuous
  - Impulsive  
(additional Gaussian component)
- Diffusion properties  $E_c[\text{TeV}] = 142 \pm 31 (243 \pm 85)$
- Energy cutoff at  $> 1\text{PeV}$  rejected by  $3.6\sigma (2\sigma)$   
→ PeVatron in the GC unlikely to exist!



## Outlook

- Include energy loss
- Leptonic scenario
- Include systematics due to IRF