Studying the galactic center at very high energies with H.E.S.S. and gammapy

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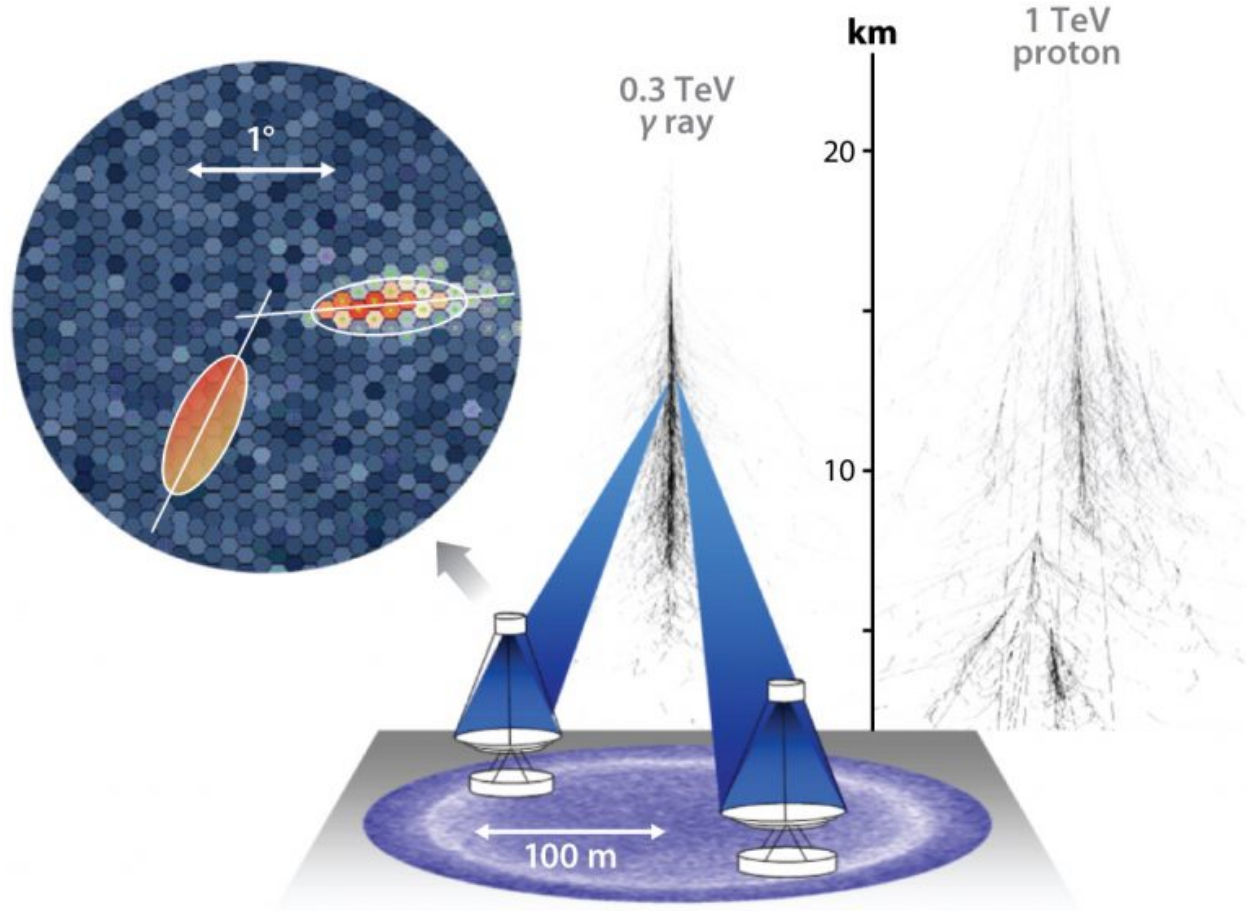
Surveying the sky at very high energies

Since 2004, H.E.S.S. (High Energy Stereoscopic System) is observing gamma rays at energies ranging from 300 GeV to 100 TeV, using the Vavilov-Cherenkov effect in the atmosphere

Figure 1 – H.E.S.S. on site in Namibia

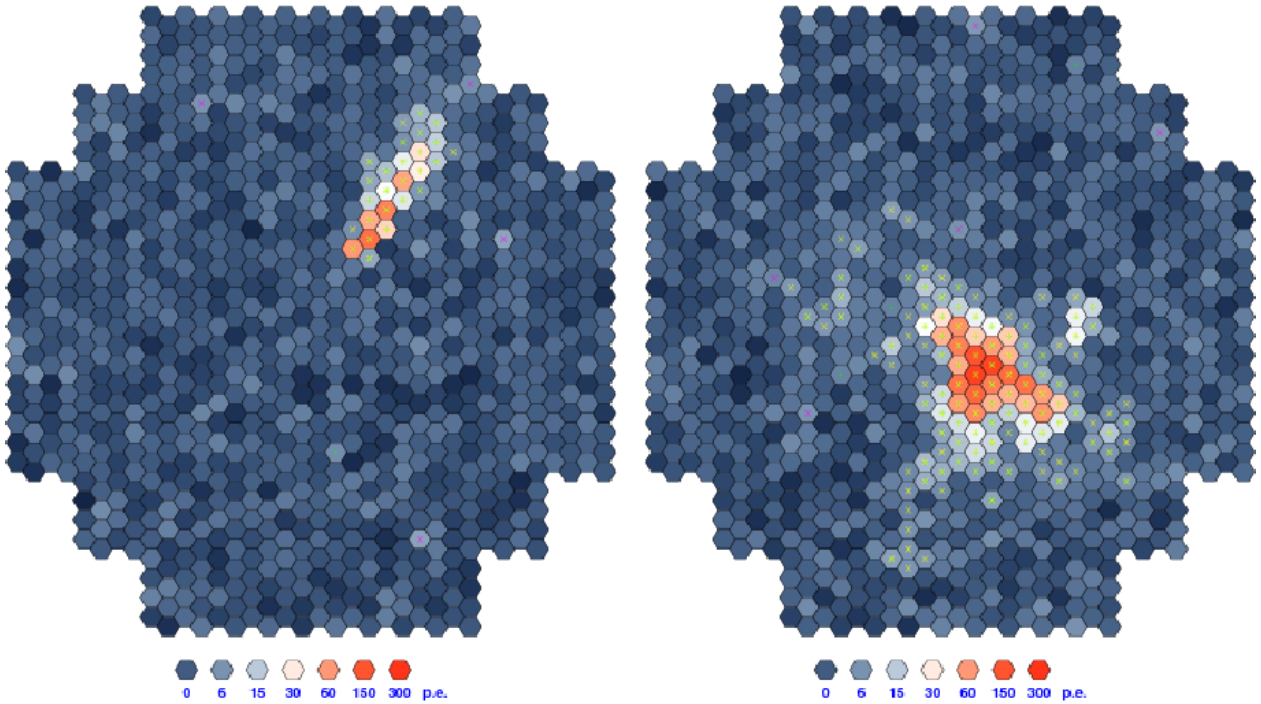
Detecting and reconstructing events



Hinton JA, Hofmann W. 2009.
Annu. Rev. Astron. Astrophys. 47:523–65

γ rays or cosmic rays ?

10^5 cosmic rays for each γ ray $\longrightarrow$ need to discriminate γ rays from the CR background



1.0 TeV gamma shower

2.6 TeV proton shower

Figure 2 – Images of EM shower (left) and hadron shower (right) on a single telescope

Identifying gamma photons

Both the reconstruction of events and γ/CR discrimination can be done in various ways.

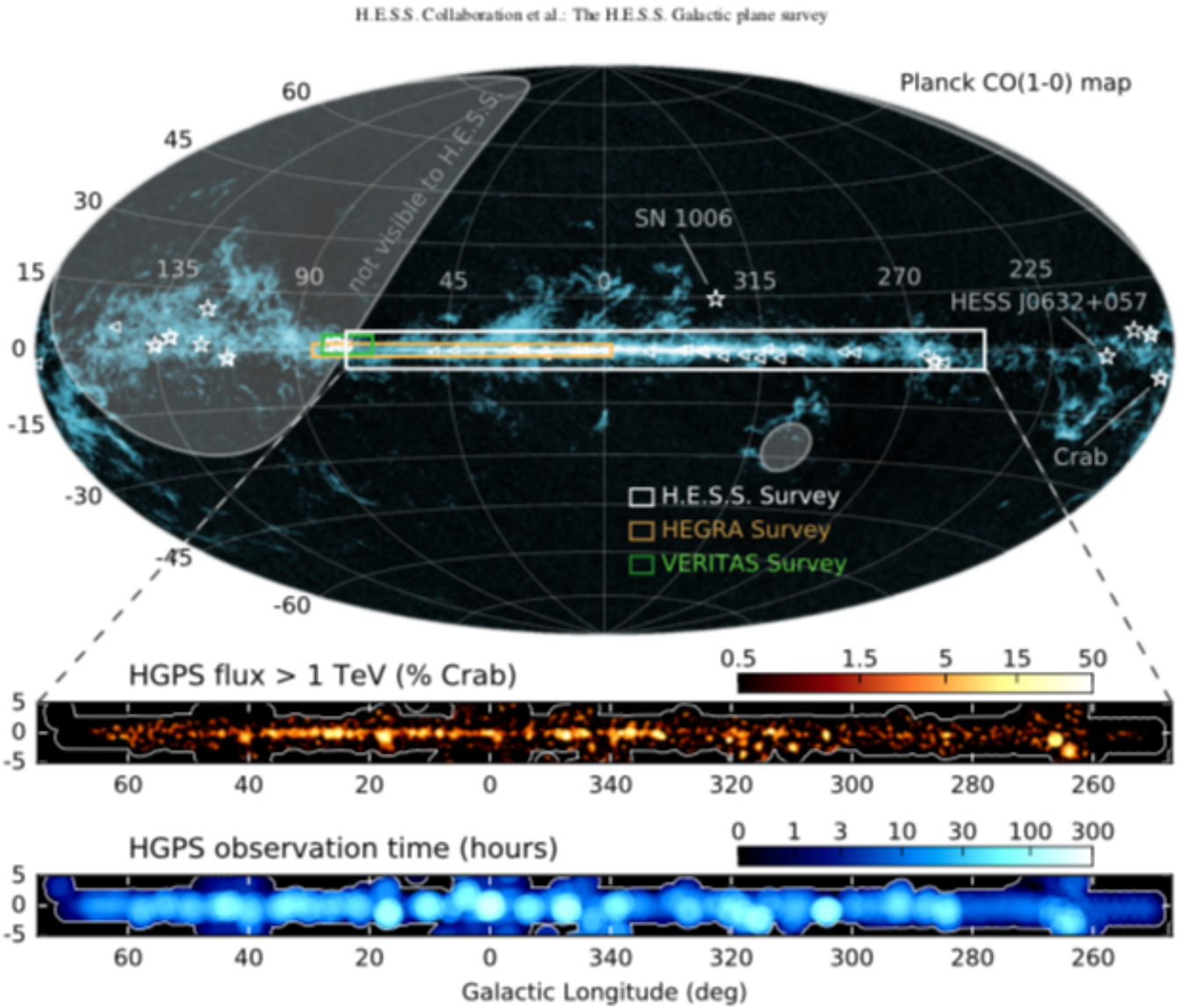
Reconstruction : either using a 2D models (to fit the image on the camera) or a 3D model of the shower in the sky.

γ/CR discrimination : a multivariate analysis using Boosted Decision Trees over different parameters and criteria (geometrical, convergence of reconstruction methods, etc.)

A cut can be applied to remove events whose "charge" (meaning photo-electrons) is too low.

Different choices of methods lead to different analysis channels and configurations (one channel has different configuration depending on what is needed)

H.E.S.S. galactic plane survey



A few facts

The inner 200 pc :

- high quantity of molecular gas
- high star formation rate
- high supernovae rate (1 every few milennia) $\longrightarrow$ makes it a good location for cosmic ray (CR) injection and acceleration

The supermassive black hole SgrA* :

- very likely there
- a good candidate for CR acceleration...
- ... but it's currently relatively "inactive"

The galactic centre with H.E.S.S

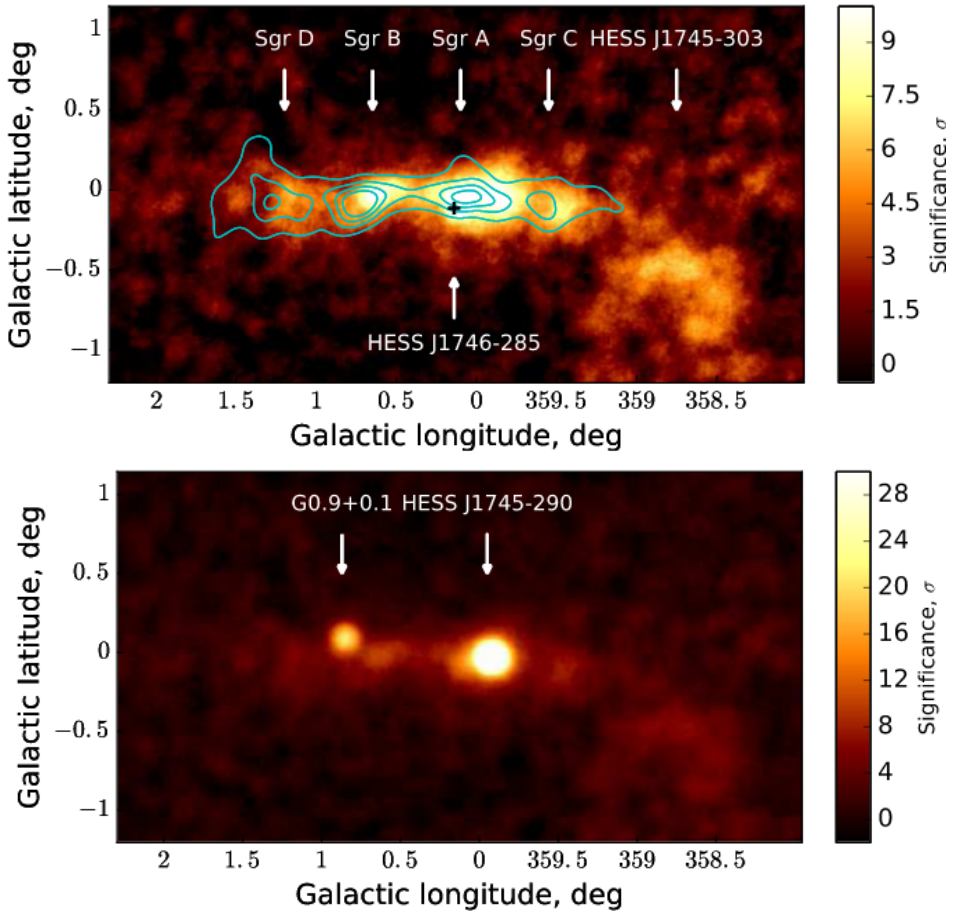


Figure 3 – Top : Residual emission with CS gas outline. Bottom : significance map. Source : H.E.S.S Collaboration 2018

HESS J1745-290 = SgrA* ?

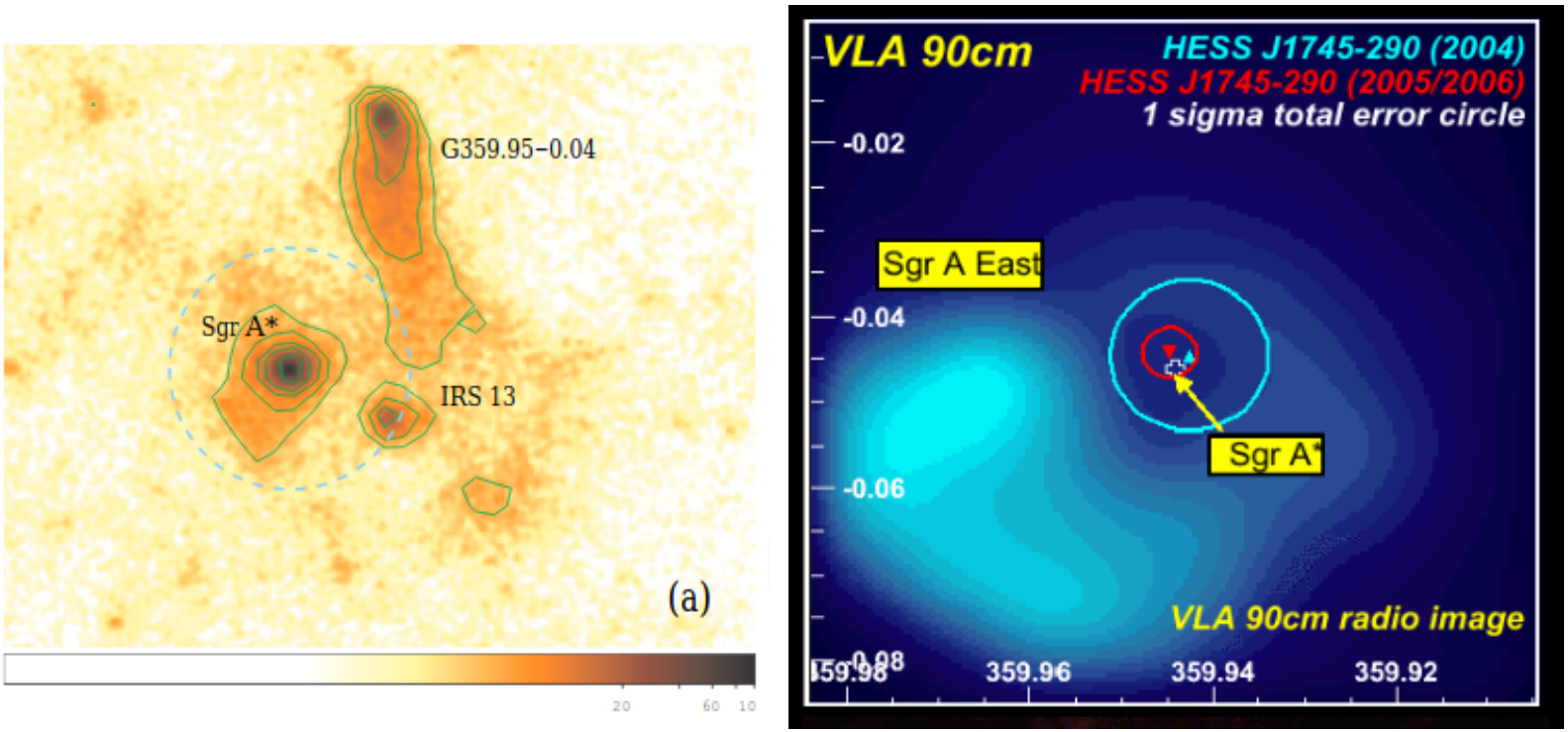


Figure 4 – Left : from Wang et al. (2013) X-ray map of the GC (1-9 keV, with Chandra), dashed circle radius is 4″.
Right : VLA observation with HESS J1745-290 position

Studying HESS J1745-290

Objective : Look for long term variability of HESS J1745-290 source. This could help identify the source as the TeV counterpart of Sgr A* if a variability was found.

Approach : Time resolved 3D analysis of HESS J1745-290 taking into account diffuse emission with gammapy (modelled as in the 2018 H.E.S.S paper)

Goals :

- Determine HESS J1745-290 intrinsic spectrum
- Establish its light curve over the last 15 years
- Study systematic effects comparing with diffuse emission

What observation runs should we choose ?

To alleviate systematics :

- limit zenith angle of observations to 50°
- limit selected area to 1.8° around the pointing direction

Instrument Response Functions (IRF) are less trustworthy outside these conditions.

HAP-fr ash and HAP-hd std ImPACT configuration do not give the exact same set of runs to work with, e.g : there are no valid runs for 2017 with HAP-fr

Fitting a source model to observational data

We limit the "box" where we fit our models

- in space : only the central (4°,3°) in galactic coordinates, around (l=0°,b=0°), and excluding the vicinity of HESS J1745-303
- and in energy : from 500 GeV to 100 TeV

Fitting a point-like source relies a lot on a proper estimate of the background.
Problem : in the central 200 pc, a diffuse emission of gamma rays hinders this estimation.

1. The H.E.S.S experiment
2. The galactic central region
3. Studying HESS J1745-290
   - Spectrum
   - Variability

Spectral models

The event density depends on the energy as an [Exponentially cutoff] power law (ECPL) :

$$\frac{dn}{dE} = \phi(E) = \phi_0 \left(\frac{E}{E_{ref}} \right)^{-\Gamma} \exp(-(\lambda E)^{\alpha})$$

with :

- $\alpha = 1$
- $E_{ref} = 1.0$ TeV
- $\Gamma = 1.5 - 2.3$ (from hardest to softest)
- $\lambda = 1/E_{cutoff}$, with a cutoff energy around 10 TeV fot HESS J1745-290

λ and Γ are *heavily* correlated, $\lambda = 0$ TeV^{-1} for an assumed infinite cutoff energy (or no cutoff).

Spatial models

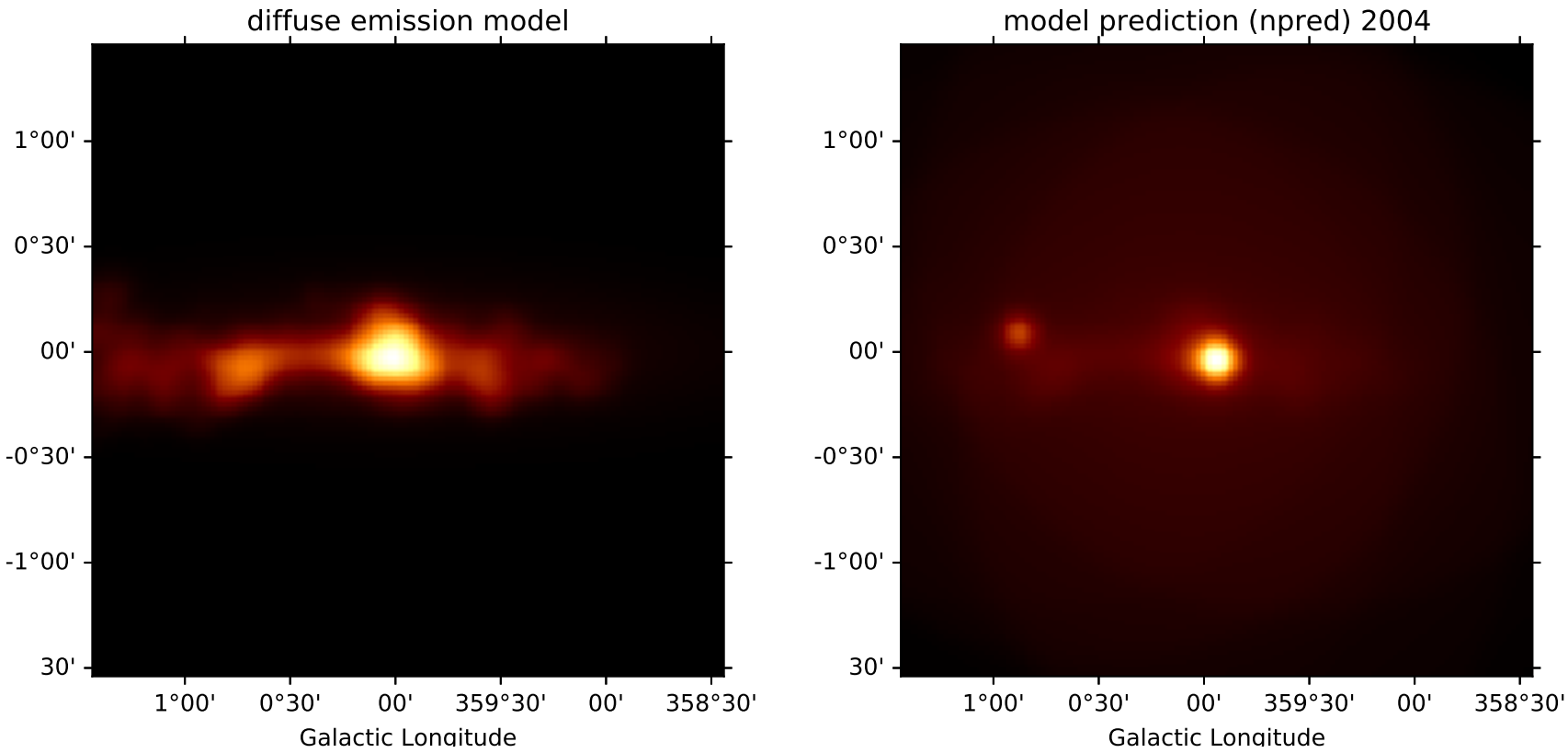


Figure 5 – left : DE model only, right : DE + G09+01 + HESS J1745-290 (from HAP-hd analysis) both smoothed with 0.05 deg kernel

3D Fitting of the spectra

Doing a 3D (spatial + spectral) fit allows to seperate the central source from the diffuse emission (impossible with 1D spectrum analysis)

3D analysis done with a "joint fit" of the data from the 3 periods of the HESS intsrument (HESS1, HESS2 and HESS1u)

- HESS J1745-290 (referred as "GC") : point-like with ECPL spectra
- Diffuse emission (DE) : template model with PL (or ECPL) spectra
- G09+01 : point-like with PL spectra

Morphological modelling of the DE

For the diffuse emission, from H.E.S.S Collaboration 2018, using three components :

- Dense gas component (taken from a CS gas map, with a $\sigma = 1.11$ deg on top)
- Small scale component (centered on SgrA*, $\sigma = 0.11$ deg)
- Large scale component ($\sigma_x = 0.97$ deg and $\sigma_y = 0.22$ deg)

Following the final model of the article, the relative intensities of the component are fixed at 4.3/1.03/2.68

Fitted spectra and "flux points" (left : HAP-fr, right : HAP-hd)

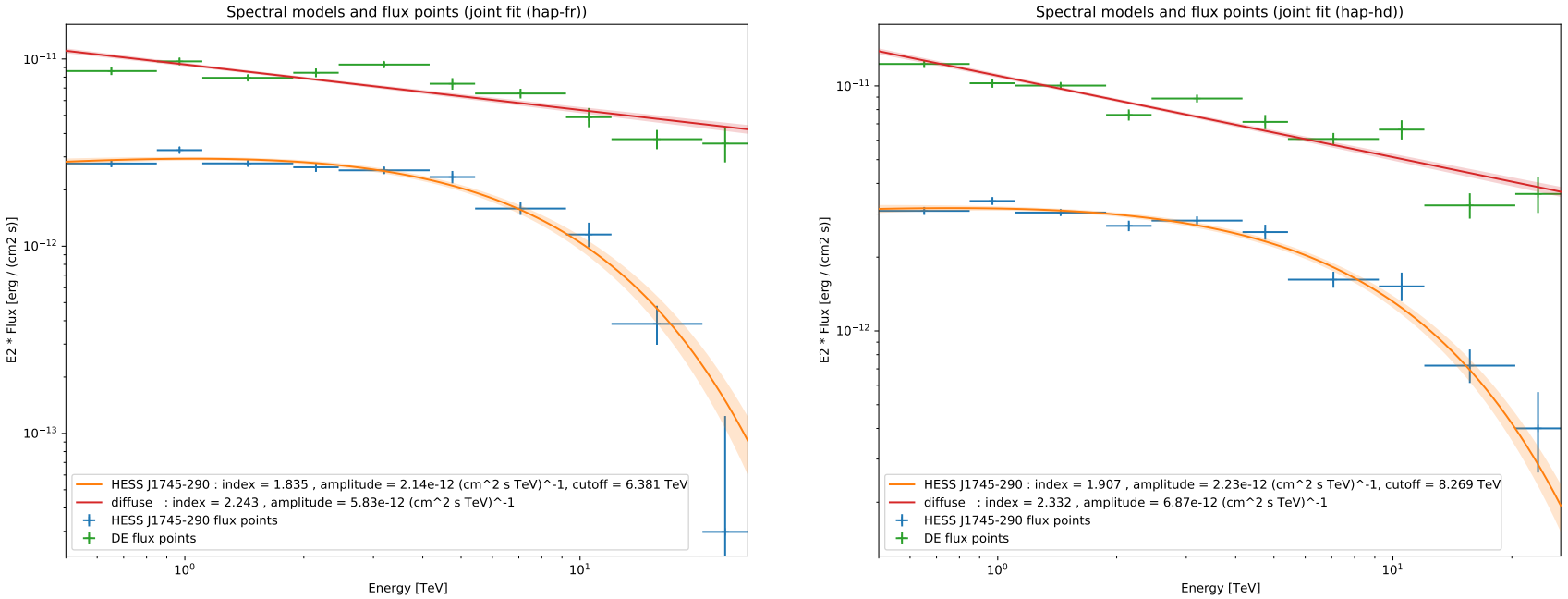


Figure 6 – orange : $E^2 \times$Flux (TeV.cm^{-2}.s^{-1}) for HESS J1745-290, red : diffuse emission, points are relevant flux points : using a given spectral model, the normalisation is re-evaluated on each energy bin.

Spectral parameters

parameter	HAP-fr	HAP-hd
index GC	1.83 ± 0.06	1.90 ± 0.05
index DE	2.24 ± 0.02	2.33 ± 0.02
E_{cutoff} GC	6.38 ± 0.7 TeV	8.26 ± 0.6 TeV

Table 1 – Without an energy cutoff for the diffuse emission

Fit quality

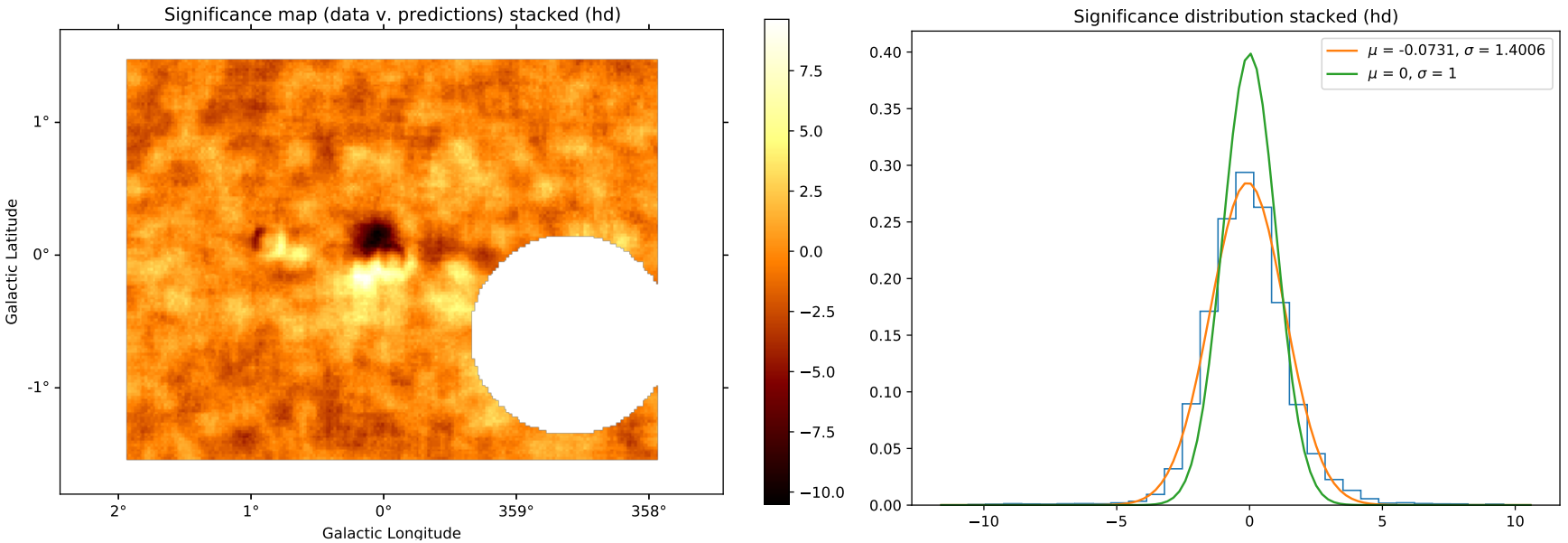


Figure 7 – For HAP-hd channel, with all the data available. Left : Li-Ma significance (applied on data - predictions). Right : distribution of significances compared to a normal gaussian

A cutoff energy for the diffuse emission ?

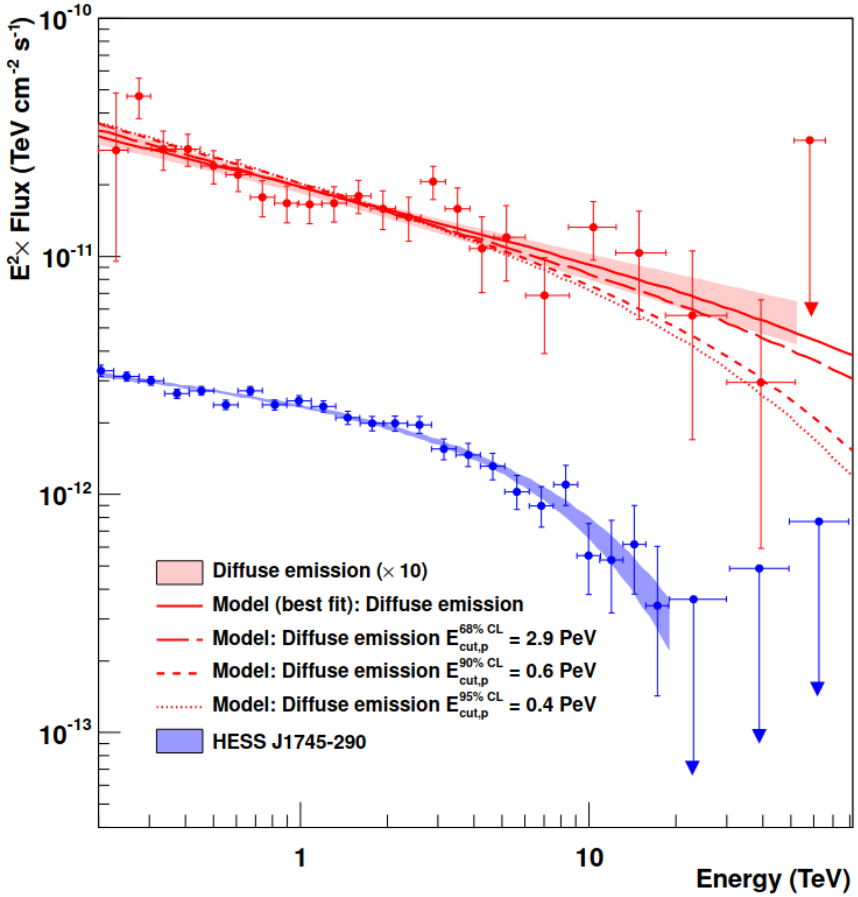


Figure 8 – Taken from H.E.S.S. Collaboration 2016, later data seem to indicate that the diffuse spectrum shows a cut-off above 20 TeV

1. The H.E.S.S experiment
2. The galactic central region
3. Studying HESS J1745-290
   - Spectrum
   - Variability

HESS J1745-290 variability, back in 2009

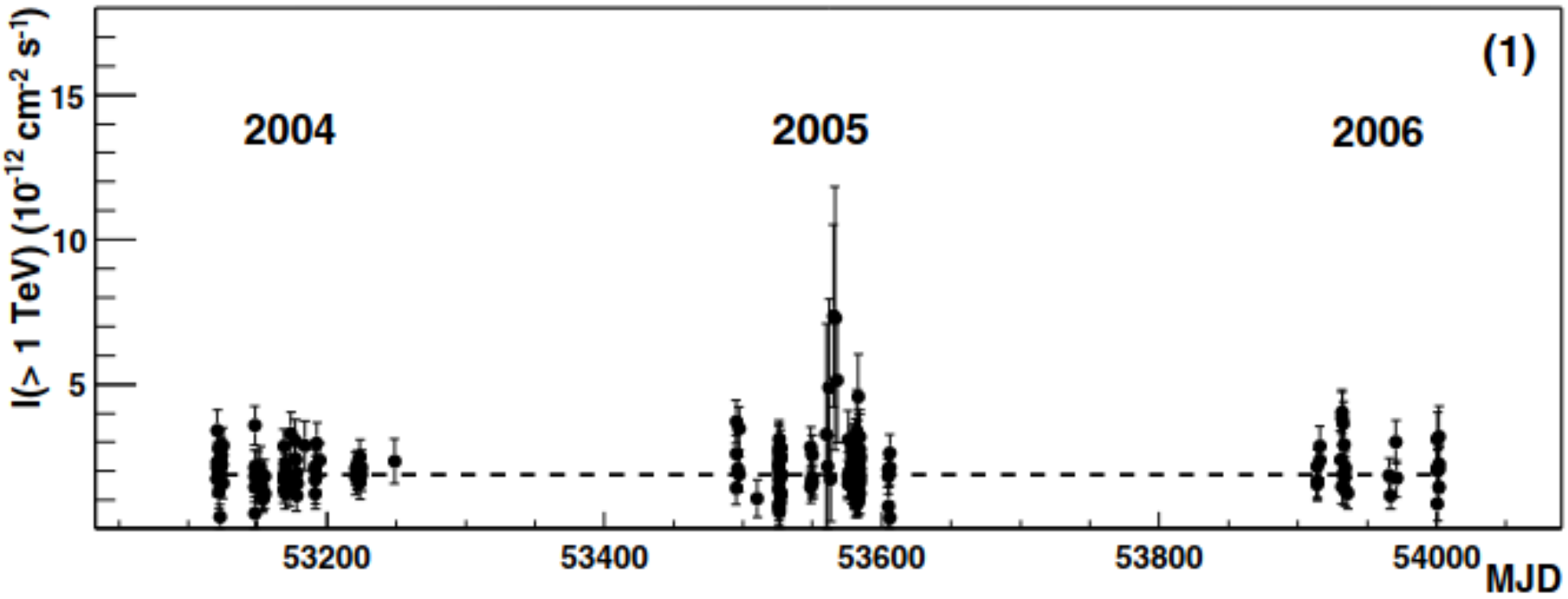


Figure 9 – Source : Aharonian et al. 2009

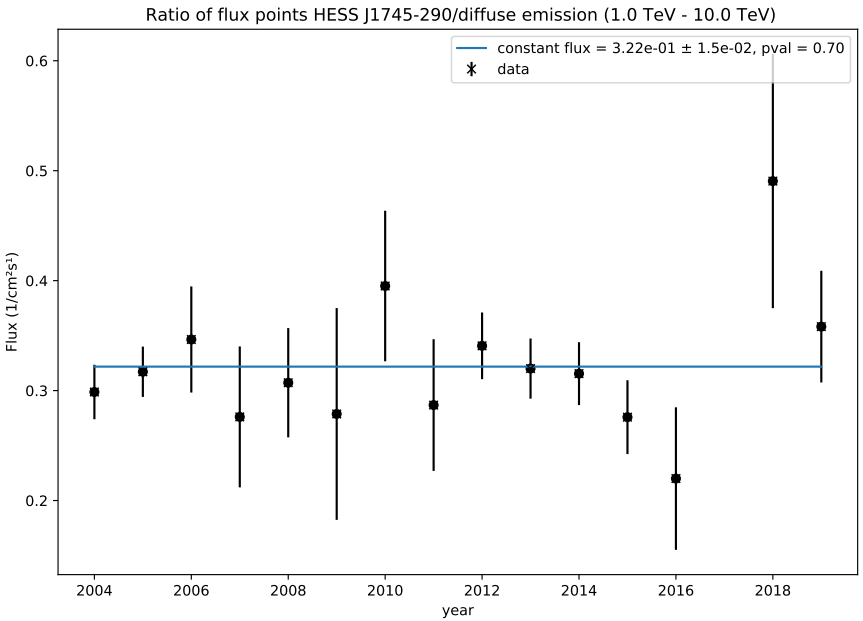
How we look for variability

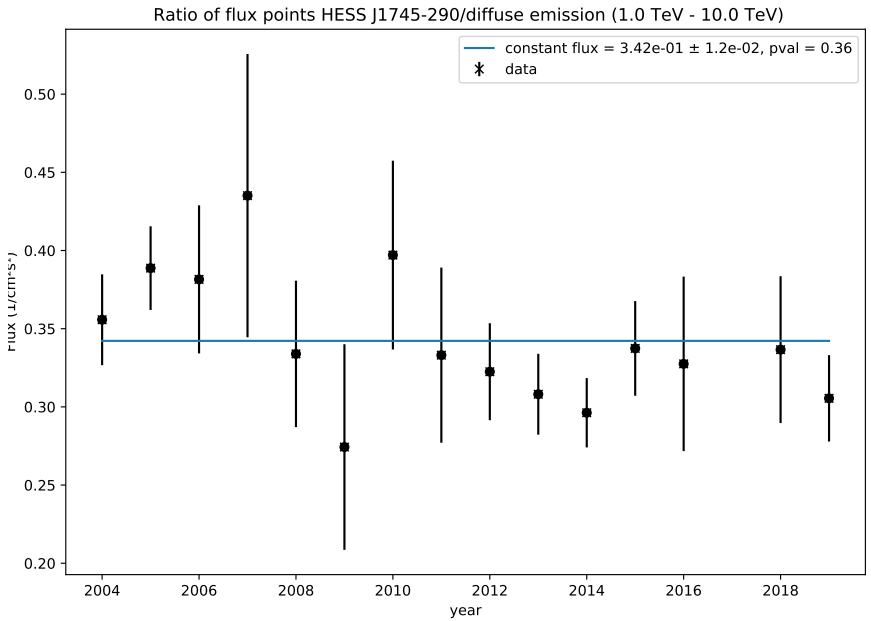
We prefer to look at fluxes averaged over a year :

- Observations are taken in a few months period every year
- run to run variation (28 minutes time scale) is relevant when looking for X-ray flare counterparts, which is so far inconclusive

We use the diffuse emission as our "constant" reference point to evaluate relative variations of HESS J1745-290 : the diffuse emission isn't suppose to vary on the year timescale.

Flux ratio GC source/DE (1 to 10 TeV)





	HAP-fr	HAP-hd
constant	0.322 ± 0.01	0.342 ± 0.01
p-value	0.70	0.36

Fit quality

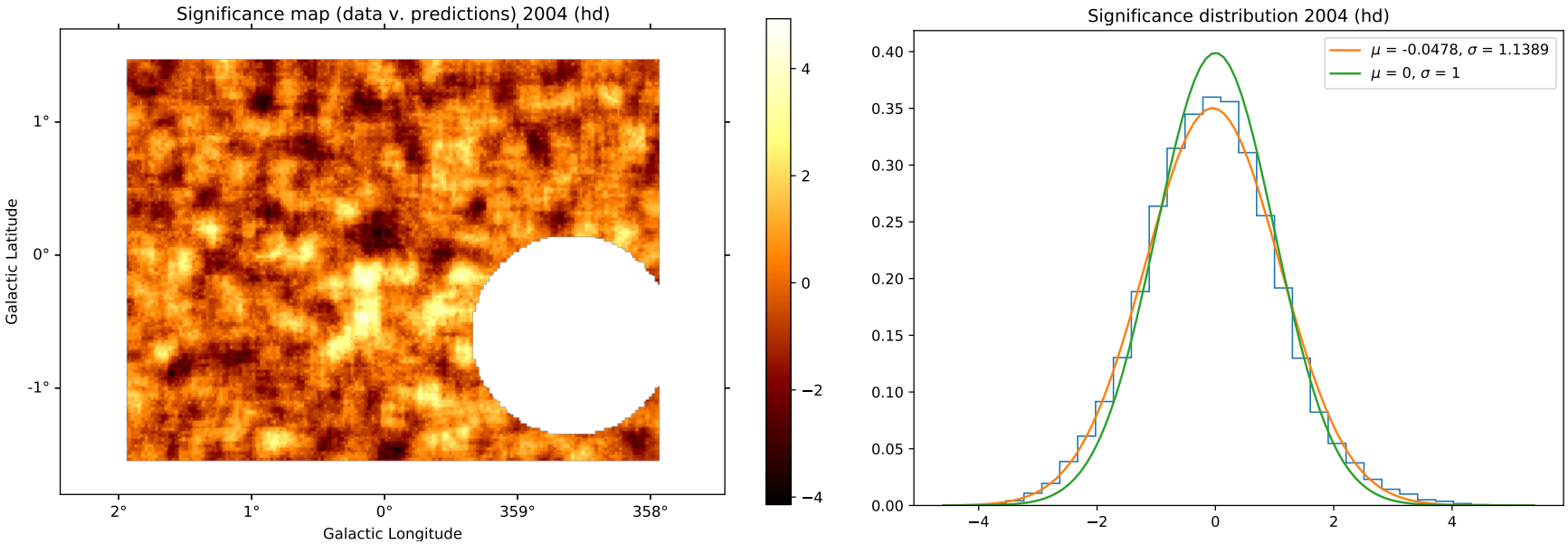


Figure 10 – For HAP-hd channel, 2004 only. Left : Li-Ma significance map. Right : distribution of significances compared to a normal gaussian

Conclusion

- No evidence for yearly variability, independently of model hypothesis
- Disagreement on spectral parameters between the two data configurations
- Overall ower cutoff energies for HESS J1745-290 than previously measured (possibly because diffuse emission contribution was removed)
- spectral shapes found are highly period dependent
- improvements to be made on later datasets (post-2013)

Thank you for your attention