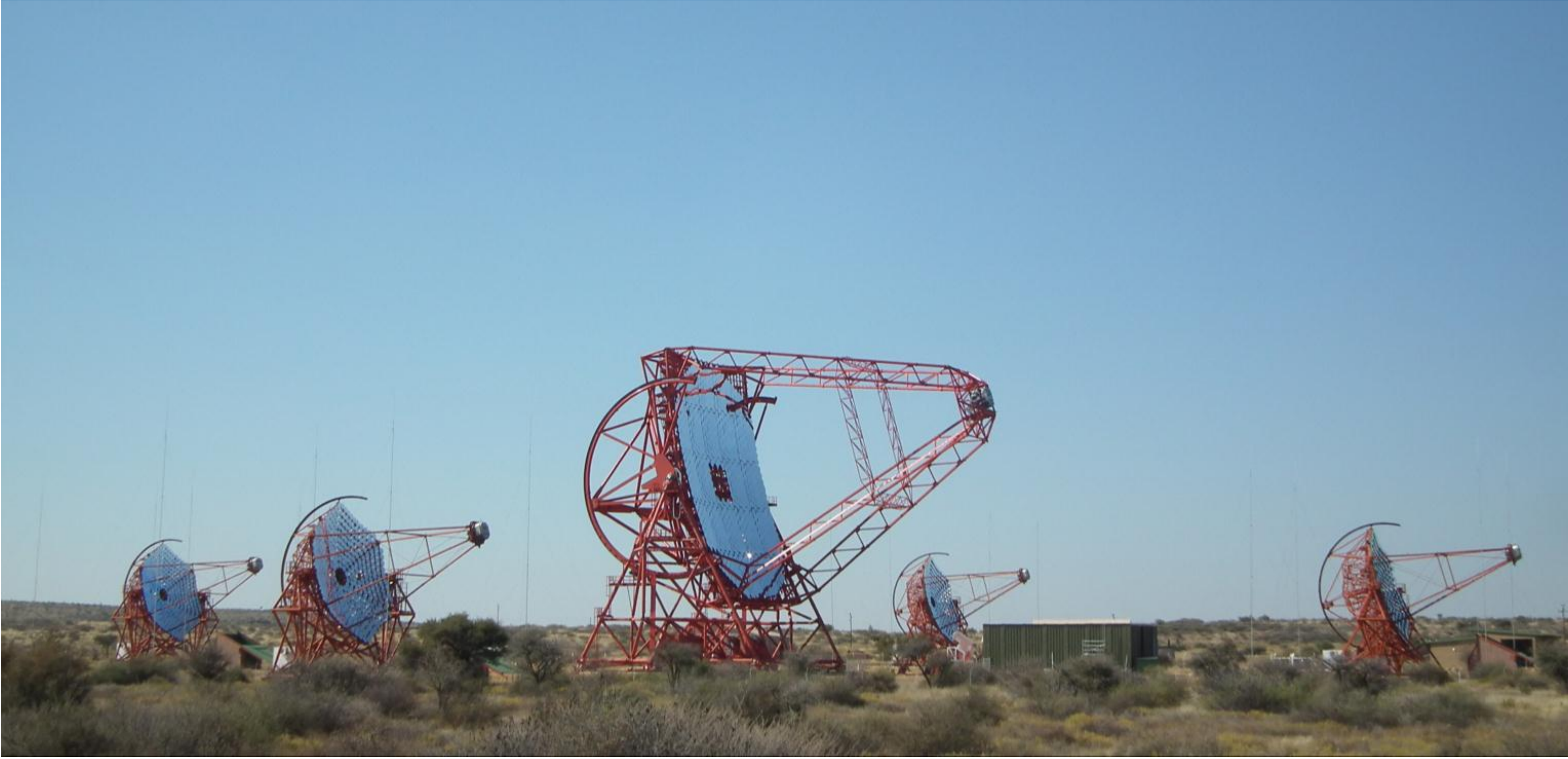


Searching for dark matter annihilation lines with HESS II

Knut Dundas Morå for the HESS collaboration

H.E.S.S.

Oskar Klein centre

Stockholm University

Outline

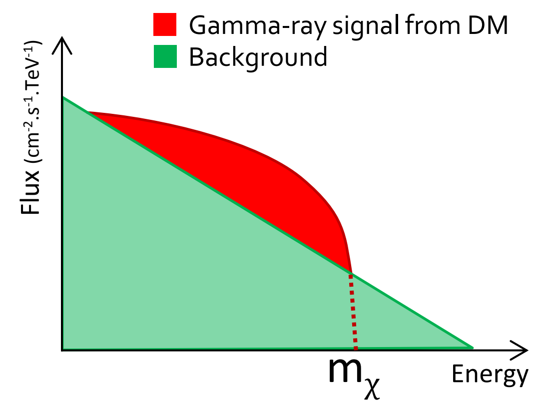
- Indirect Dark Matter detection
  - Dark Matter signatures
  - Dark Matter distributions
- Fermi Line Search
- The HESS Experiment
- HESS 1 Line Search
- HESS 2 Line
  - Telescope
  - Background techniques
  - Instrument Response
  - Line search
- Conclusions

Indirect Dark Matter Signatures

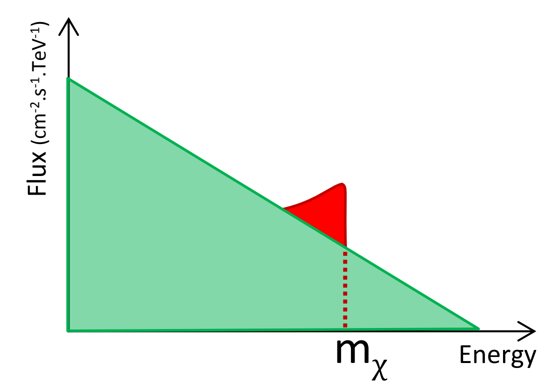
- The expected flux of gamma rays from dark matter annihilation may be factorized into an astrophysical and particle physics factor.
- The particle physics factor contains the thermally averaged cross-section, as well as the energy spectrum of dark matter to gamma rays
- In the case of a direct two-body annihilation to one or two photons, a distinctive spectral peak would appear

$$\frac{\mathrm{d}\Phi}{\mathrm{d}E}(E,\Delta\Omega) = \Phi_{\mathrm{astro}}(\Delta\Omega)\cdot\frac{\mathrm{d}\Phi^{\mathrm{particle}}}{\mathrm{d}E}(E)$$

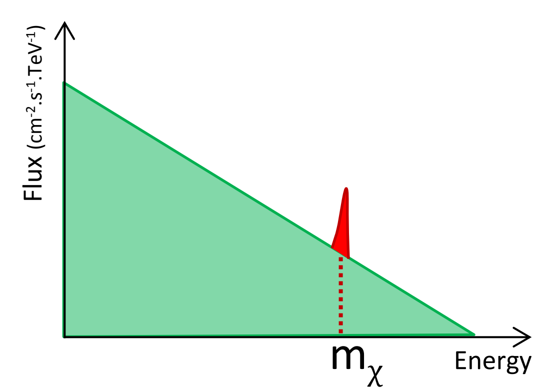
$$\frac{\mathrm{d}\Phi^{\mathrm{particle}}}{\mathrm{d}E}(E) = \frac{<\sigma v>}{8\pi m^2}\cdot\frac{\mathrm{d}N}{\mathrm{d}E}(E)$$



Continuous spectrum



Extended spectral features

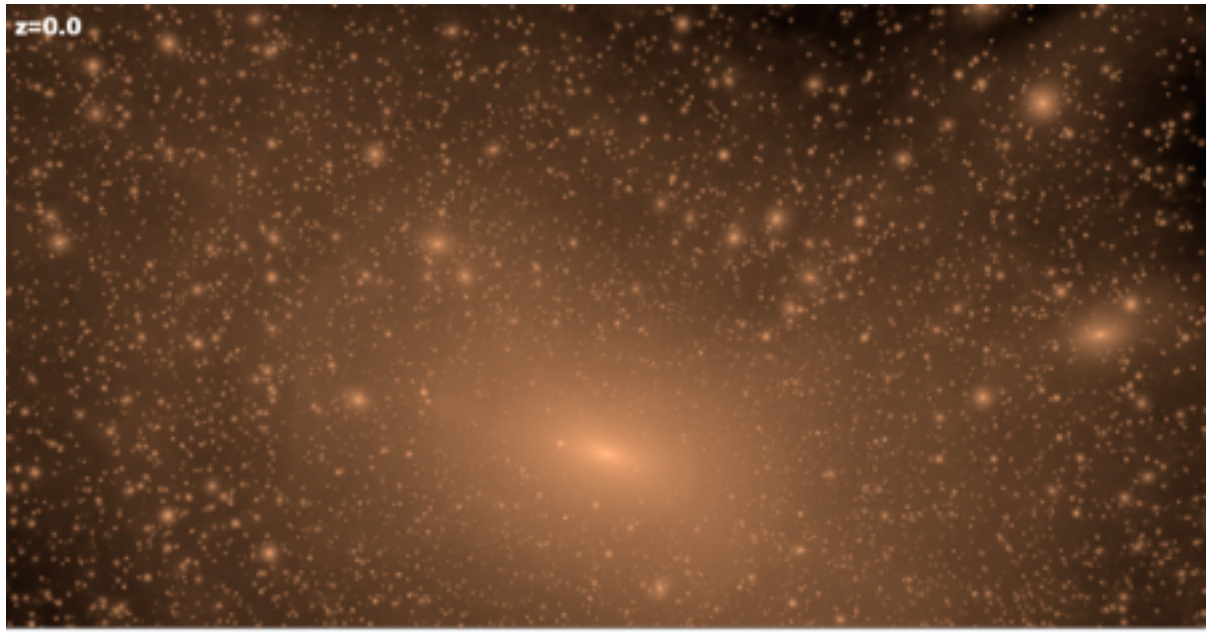


Monochromatic line

Dark matter distribution

- The astrophysical factor contains the line-of-sight integral of the squared dark matter density.
- Many models of dark matter densities are peaked towards the center- leading to a large signal from the center of a dark matter halo.
- Typical targets are either high signal sources, such as the galactic center, or have a large fraction of inferred dark matter versus ordinary matter- such as dwarf galaxies.

$$\Phi_{\rm astro}(\Delta\Omega) = \int_{\Delta\Omega} \mathrm{d}\Omega \int_{\rm Line-of-sight} \rho^2(r)\mathrm{d}l$$



Via Lactea n-body simulation of a galaxy

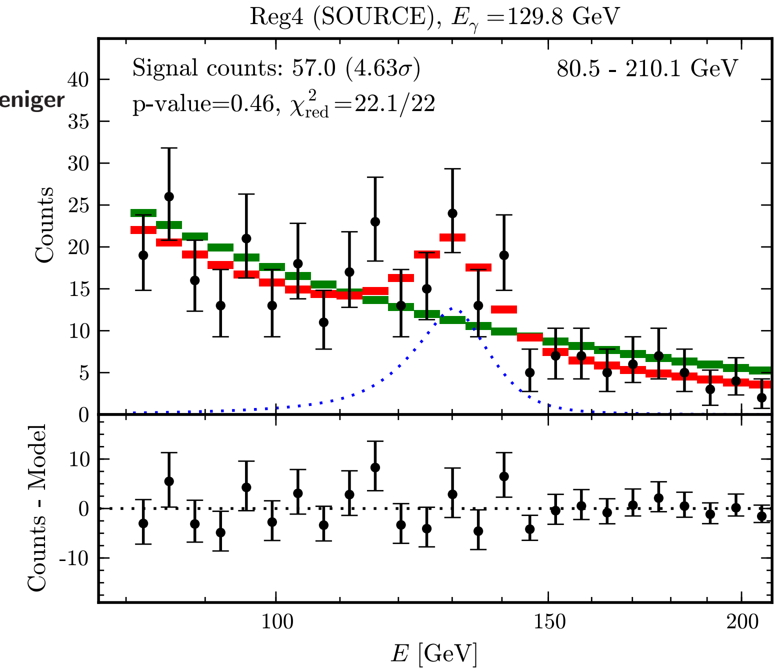
$$\rho_{\rm NFW} = \frac{\rho_0}{\frac{r}{R_s}(1+\frac{r}{R_s})^2}$$

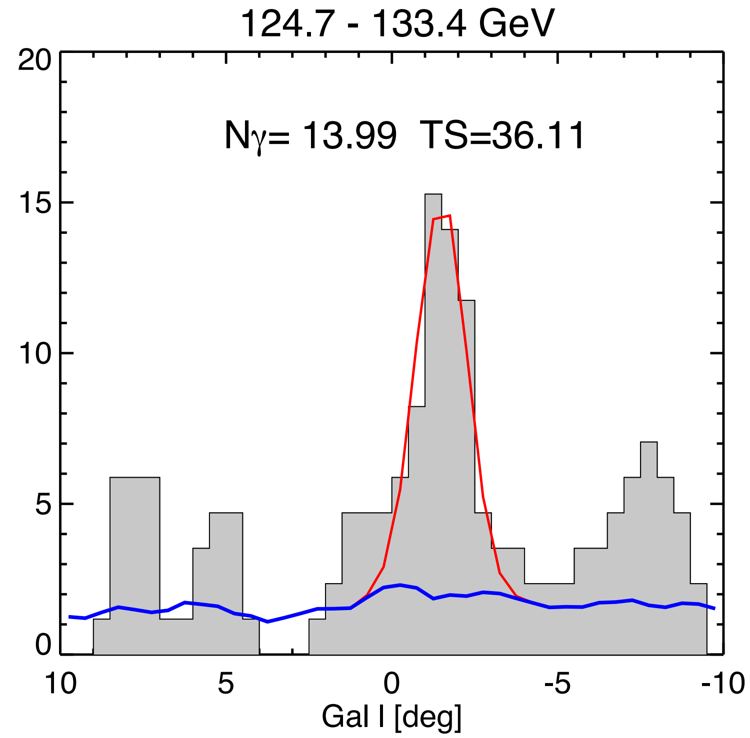
The Fermi Line

- An analysis by Weniger of Fermi-LAT data(arxiv:1204.2797v2) showed a line feature in the spectrum at 130 GeV from the galactic center, with a 3.2σ significance.
- The feature corresponded to a cross section of <σv>=1.27e-27 cm^3/s (NFW)
- Su and Finkbeiner (arxiv: 1206.1616) located the signal at 1.5° west of the galactic center, and found a 5σ detection.
- The significance has been seen to be decreasing with more data.

A Tentative Gamma-Ray Line from Dark Matter Annihilation at the Fermi Large Area Telescope

Christoph Weniger

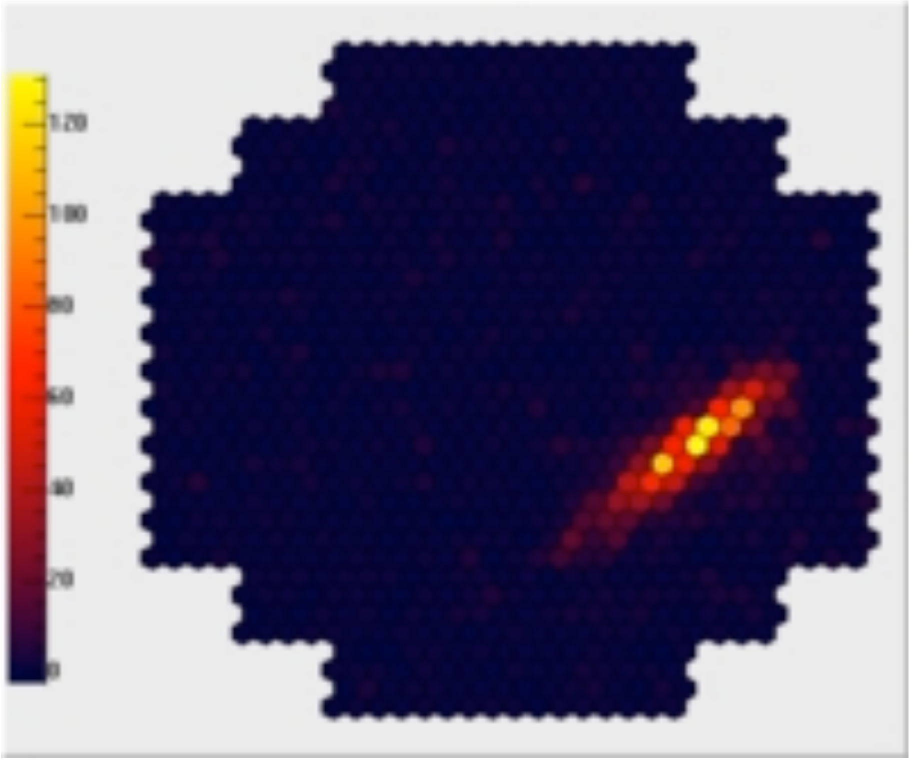




H.E.S.S.

The HESS telescope

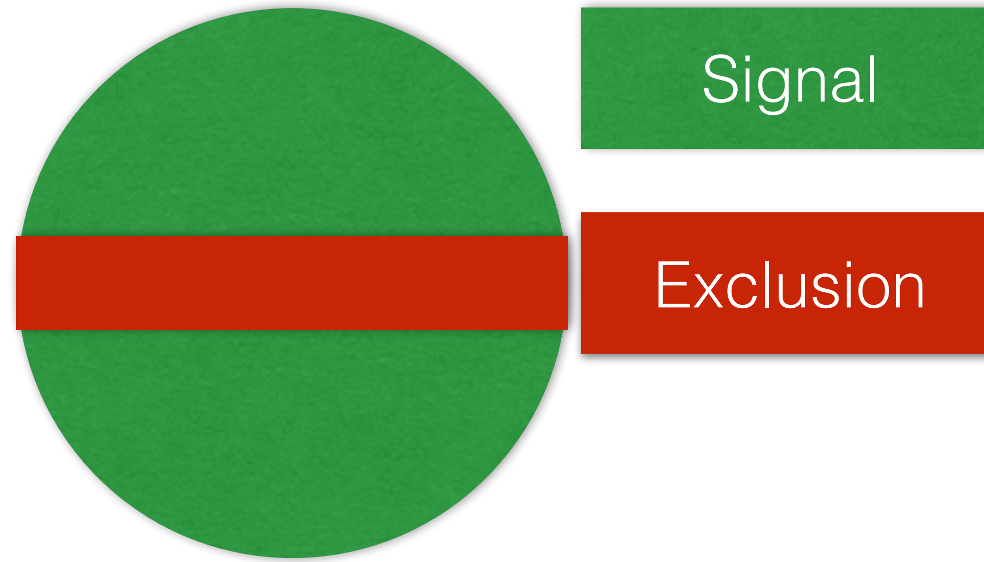
- The High Energy Stereoscopic System is an Air Cherenkov Telescope located in the Namibian Khomas Highlands.
- Four 10-meter telescopes collect Cherenkov light of showers from high energy particles impacting the atmosphere
- The HESS array detect gamma rays from 200GeV to >30TeV for energy spectrum analysis.



The HESS 1 Line search

1301.1173v1

- A HESS search for a spectral line was published in 2012
- For a fixed line mass, a gaussian with the width of the energy dispersion was fit to the data together with a modified power law using a binned likelihood:



$$\frac{dN}{dE_\gamma} = a_0 \left(\frac{E_\gamma}{1\,\text{TeV}}\right)^{-2.7} [P(x) + \beta G(x)]$$

$P(x)$: $\exp\left(a_1 x + a_2 x^2 + a_3 x^3\right)$

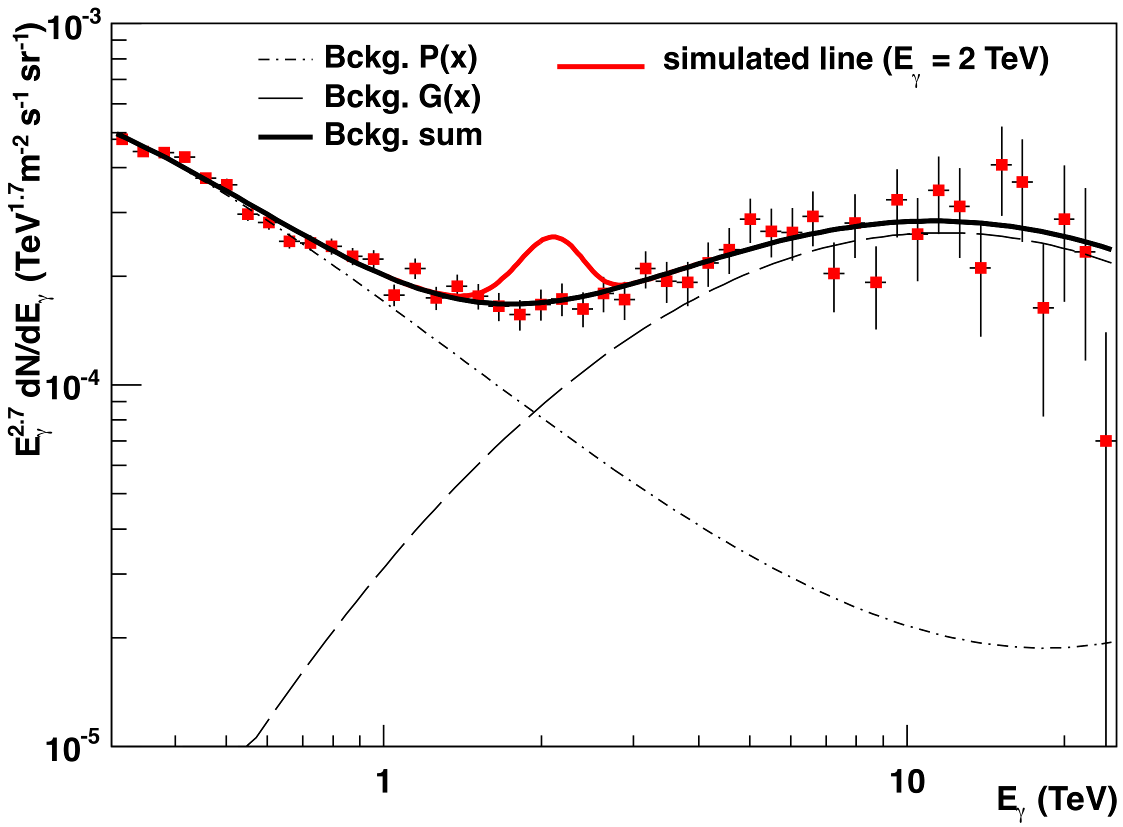
$G(x)$: Gaussian(μ_x,σ_x)

$x = \log_{10}(E_\gamma / 1\,\text{TeV})$

$$\ln \mathcal{L} = \sum_{i=1}^{N_{bins}} n_i \ln \lambda_i - \lambda_i$$

λ_i: Expected number of counts in bin i

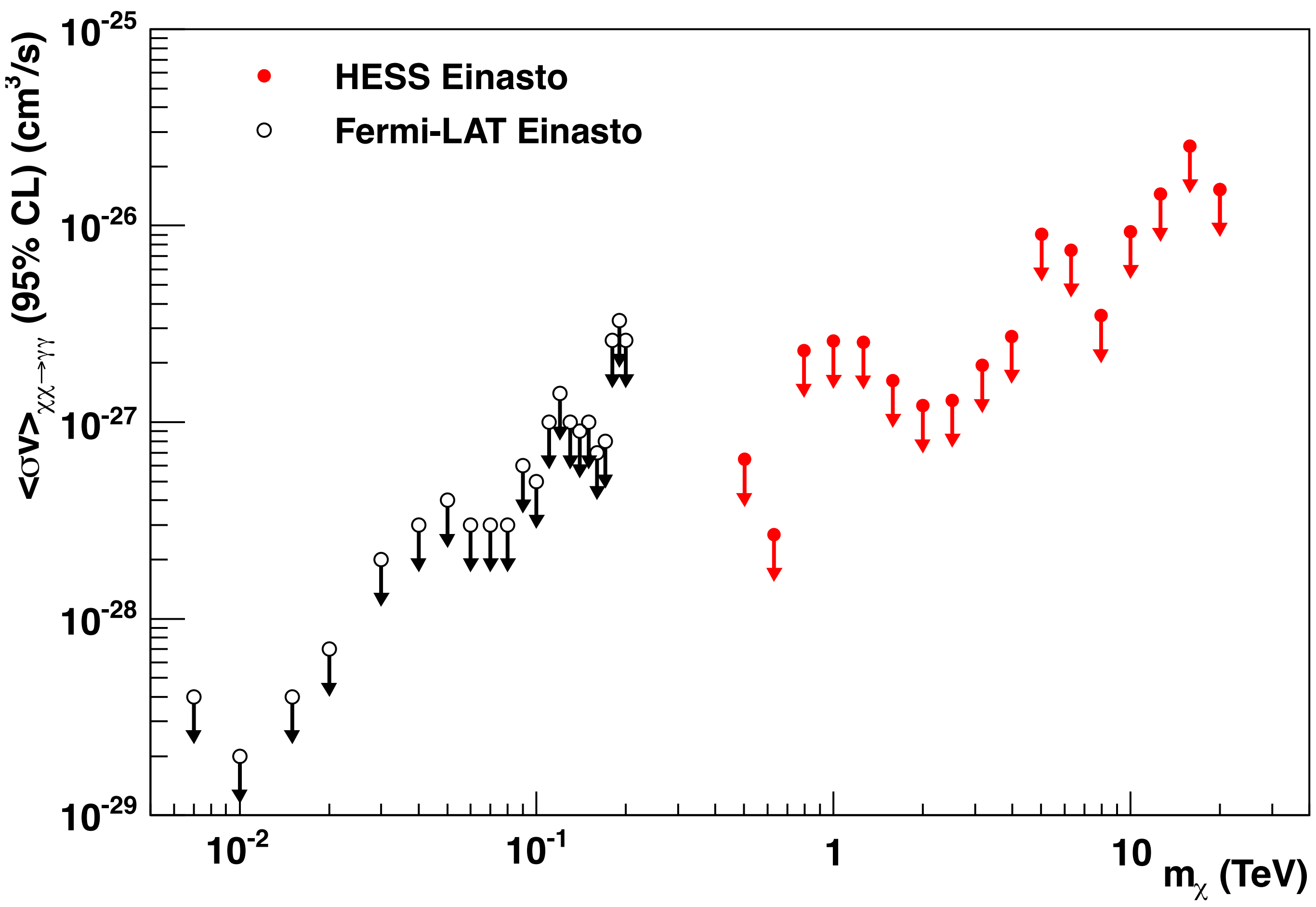
n_i: Number of reconstructed counts in bin i



HESS 1 results

1301.1173v1

- The HESS collaboration published a limit based on 112 hours of data.
- Below, the computed limit from HESS (red points) and Fermi-LAT are shown.



The HESS 2 telescope

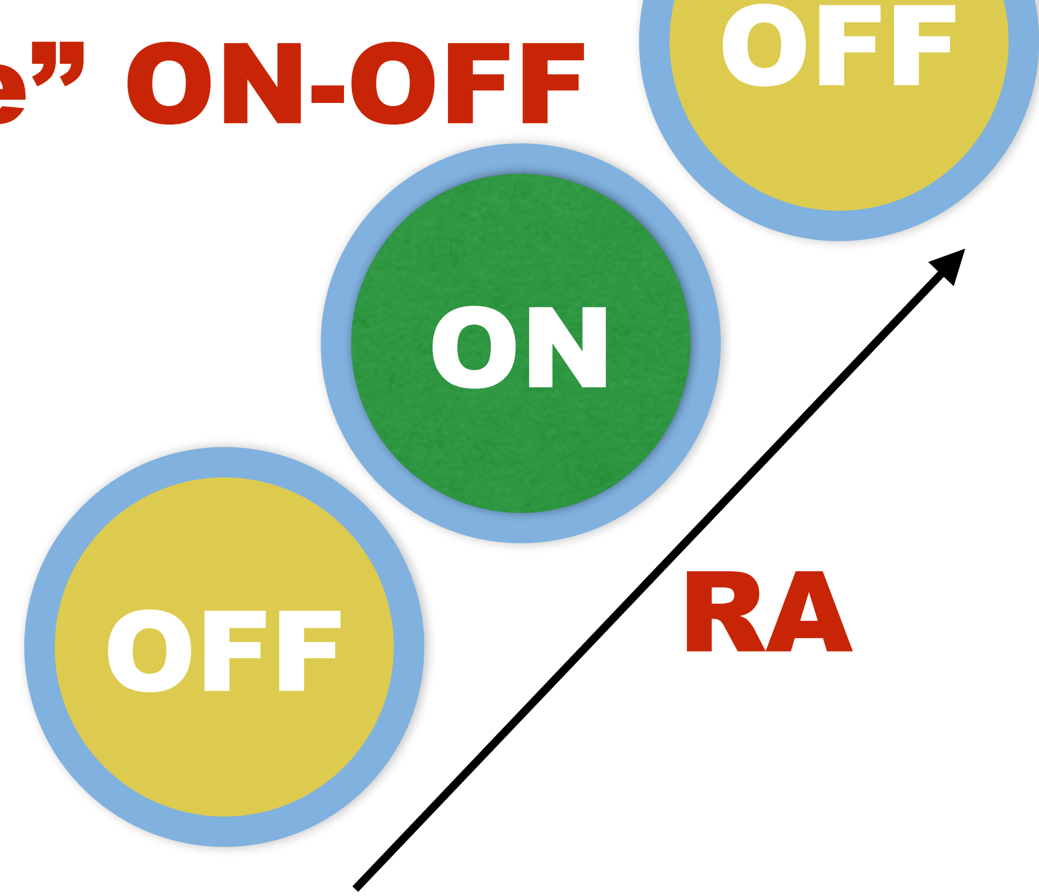
- The HESS 2 telescope is an additional, larger (28m) telescope located in the center of the HESS array
- The larger telescope (6X the area) collects more light from fainter air showers, allowing HESS 2 to reach lower energies- below 100 GeV for a spectrum analysis.
- The camera features 2000 photomultipliers, which may be read out at 3600 images/second- ten times the speed of HESS1
- This allows HESS 2 to complement the Fermi line search.

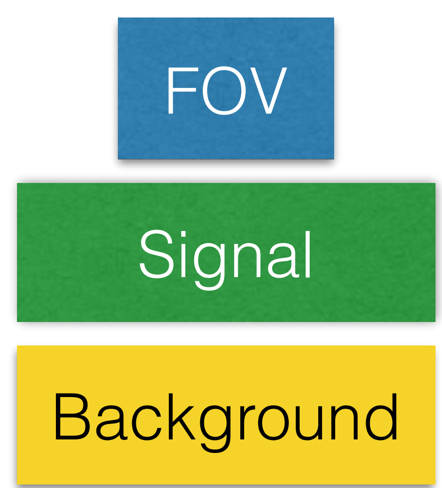
H.E.S.S.

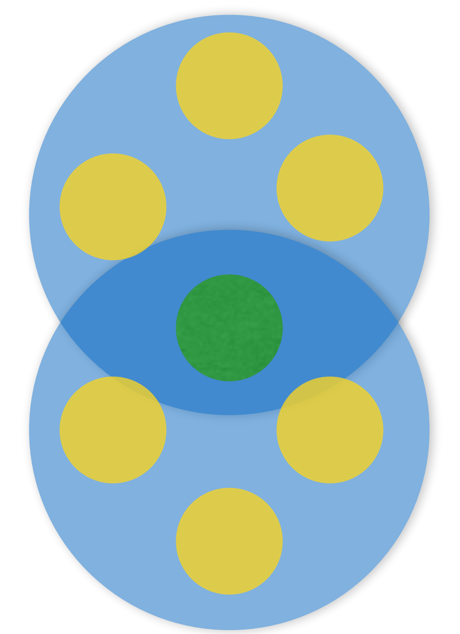
Cherenkov telescope background estimation

- The largest background in Cherenkov telescopes is cosmic rays that are misidentified as gamma rays
- As the atmosphere, as well as the background from e.g. star and moonlight changes, it is necessary to have background (OFF) regions.
- One may either define separate OFF pointings, or point the telescope at an offset, and define on and off regions in the camera field of view
- The first method allows for larger signal regions, up to the size of the FOV, at the expense of using 2/3 of the time off the signal region

“True” ON-OFF



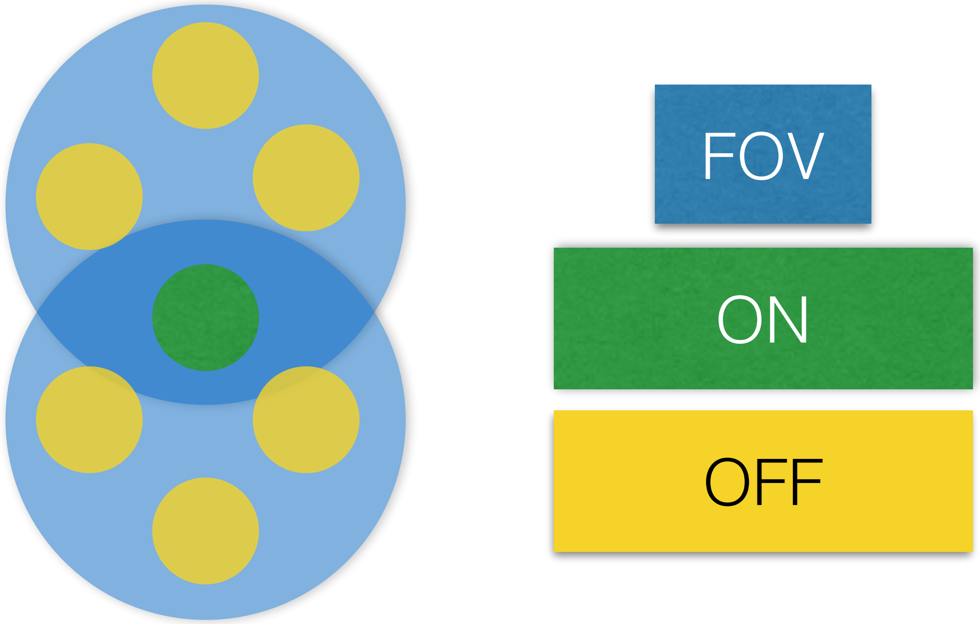




Wobble

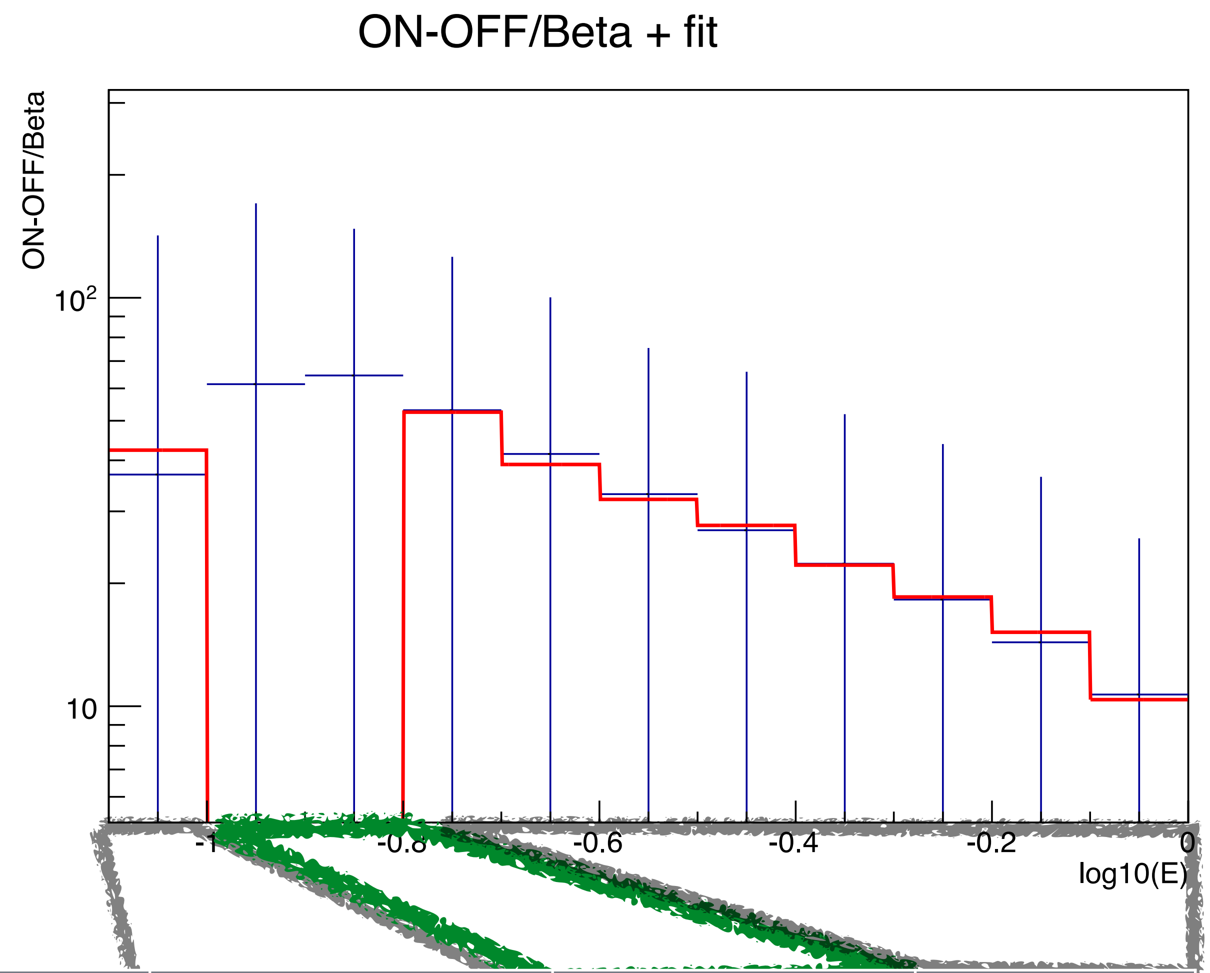
Computing Sensitivities

- A simplified sensitivity procedure has been made to a full likelihood method.
- The method uses sidebands both spatially, as well as in energy to compute an estimate of the background.



log_10(E)	-1.1 to -1	-1 to -0.8	-0.8 to 0
ON	Lower Energy Sideband	Signal Region	Upper Energy Sideband
OFF		Background Region	

Computing Sensitivities



- In the energy sidebands, the program fits a power-law (convolved with the instrument response) to any broad-spectrum excess.

- Together with the OFF-counts in the energy search region, an estimate of the expected number of events in the signal region is computed:

log_10(E)	-1.1 to -1	-1 to -0.8	-0.8 to 0
ON	Lower Energy Sideband	Signal Region	Upper Energy Sideband
OFF	Lower Energy Sideband	Background Region	Upper Energy Sideband

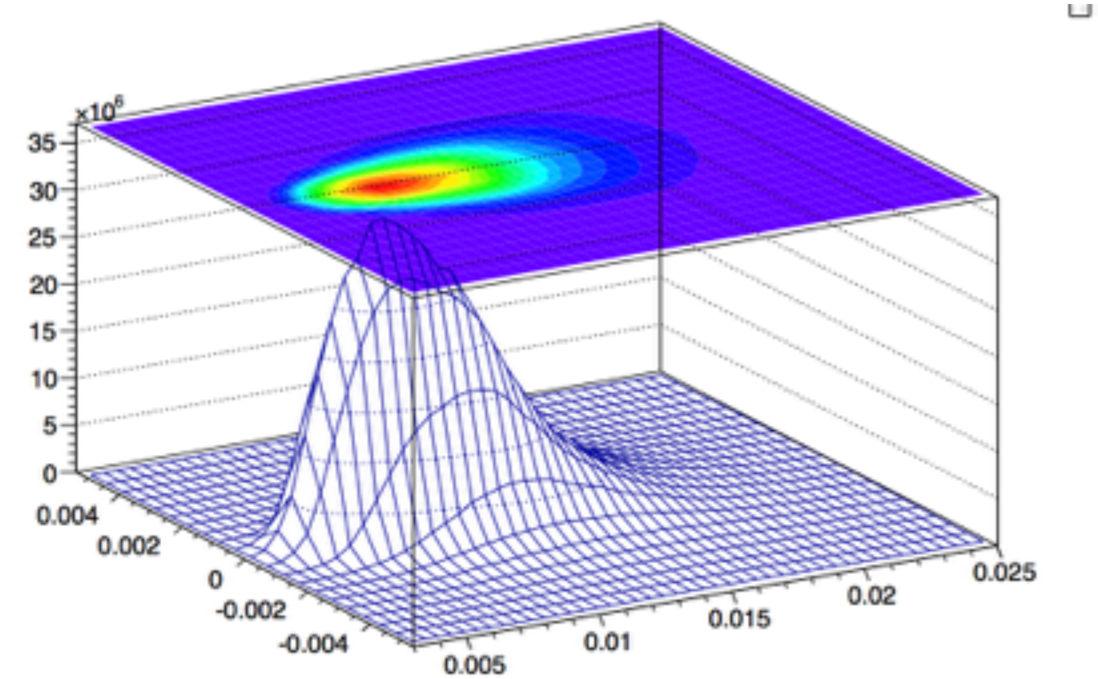
$$n_{ON\ bkg\ estimate} = n_{ON-OFF\ fit}(E_{search}) + n_{OFF\ bkg}(E_{search})/\beta$$

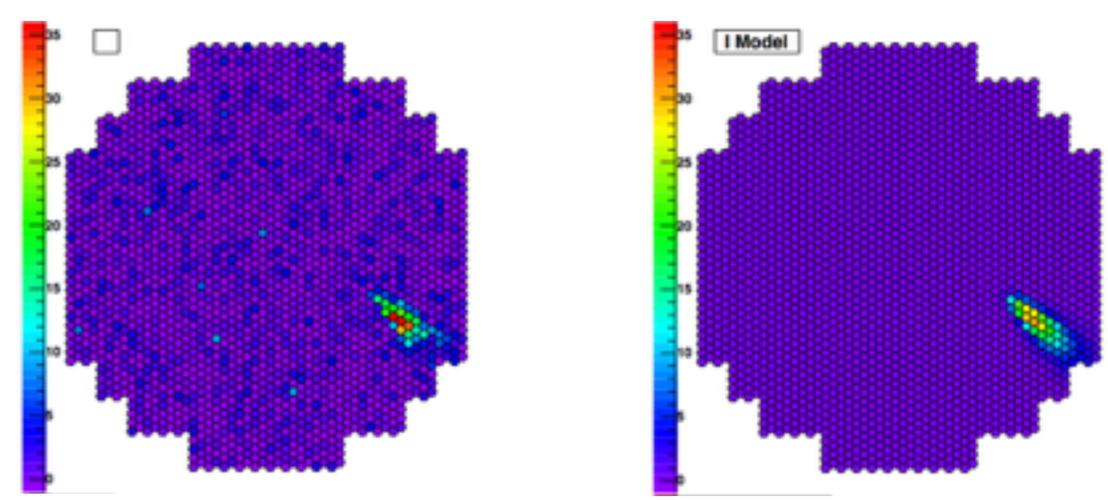
$$\sigma_{estimate} = \sqrt{\sigma^2_{ON-OFF\ fit} + n_{OFF}(E_{search}/\beta^2}$$

The Model (Mono) Reconstruction

Plots from H.E.S.S. Highlights TevPa talk by Christian Stegeman

- Reconstructing shower events from a single telescope image is a challenge
- HESS-2 results have so far been produced with Model Mono
- The Model reconstruction uses a semi-analytical shower model, that is then fitted to the image

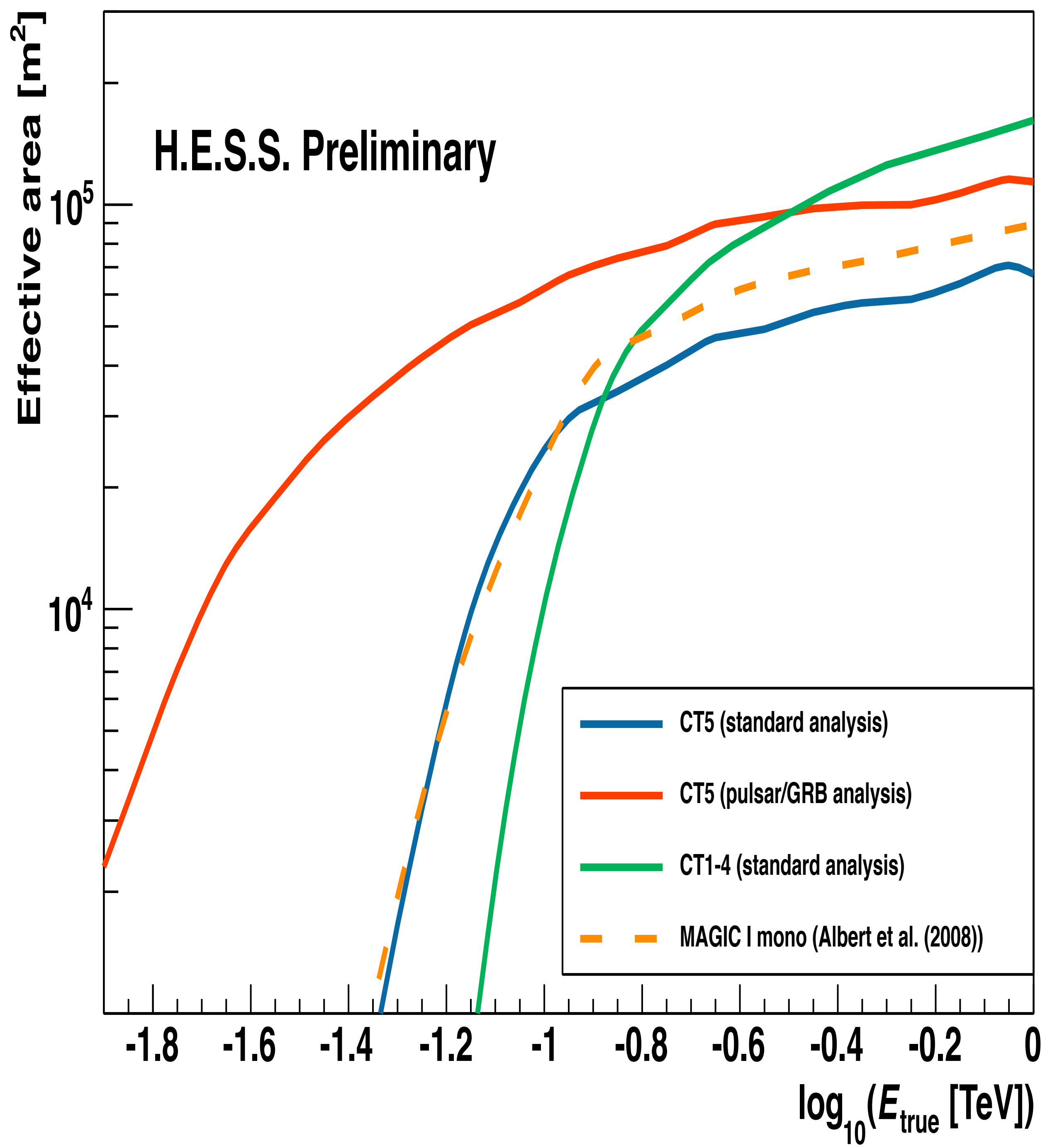




IRF

Plots from H.E.S.S. Highlights TevPa talk by Christian Stegeman

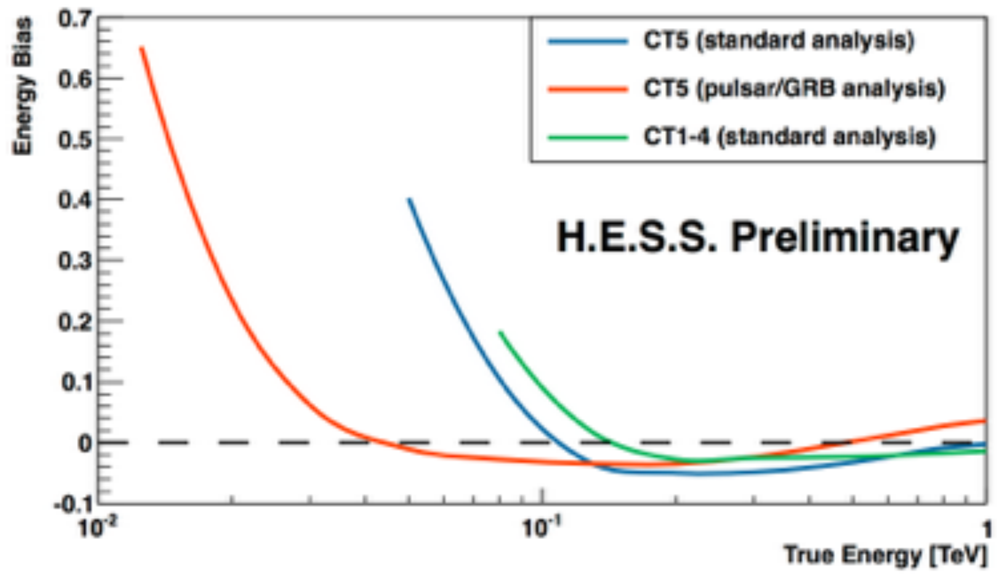
- The efficiency of HESS is expressed as the effective area it presents to gamma-rays
- HESS-2 is expected to give a marked improvement in the energy threshold from ~300GeV, down to ~80 GeV.
- In addition to Mono and HESS-1 effective area curves, a hybrid reconstruction, with CT5 plus one or more of the smaller telescopes for a stereoscopic reconstruction.

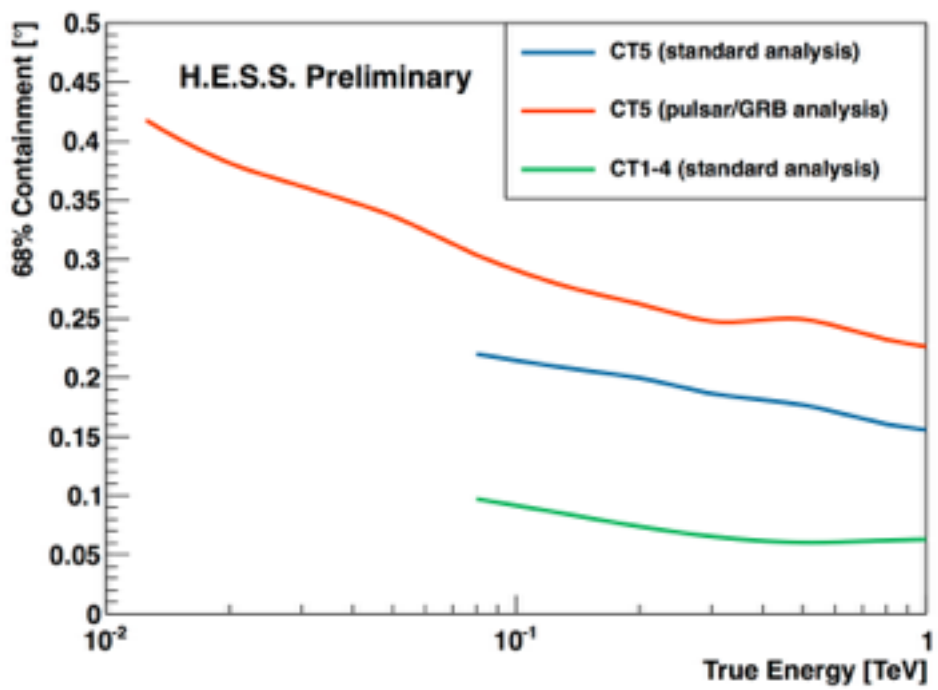


IRF

Plots from H.E.S.S. Highlights TevPa talk by Christian Stegeman

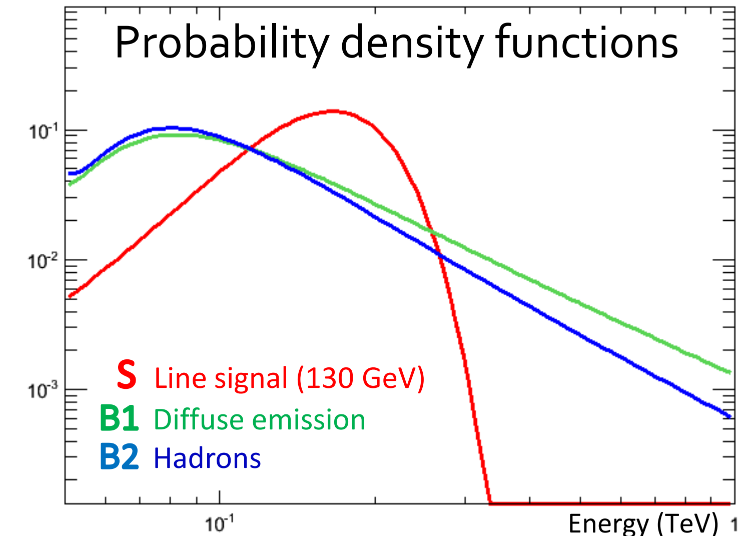
- In addition to the acceptance, the bias (right) and dispersion in energy need to be taken into account.
- Spatial resolution (lower right).
- Radial acceptance- the reduction in effective area with increasing distance to the center of the telescope
- Lastly, all instrument response functions are a function of pointing, zenith angle and night-sky background

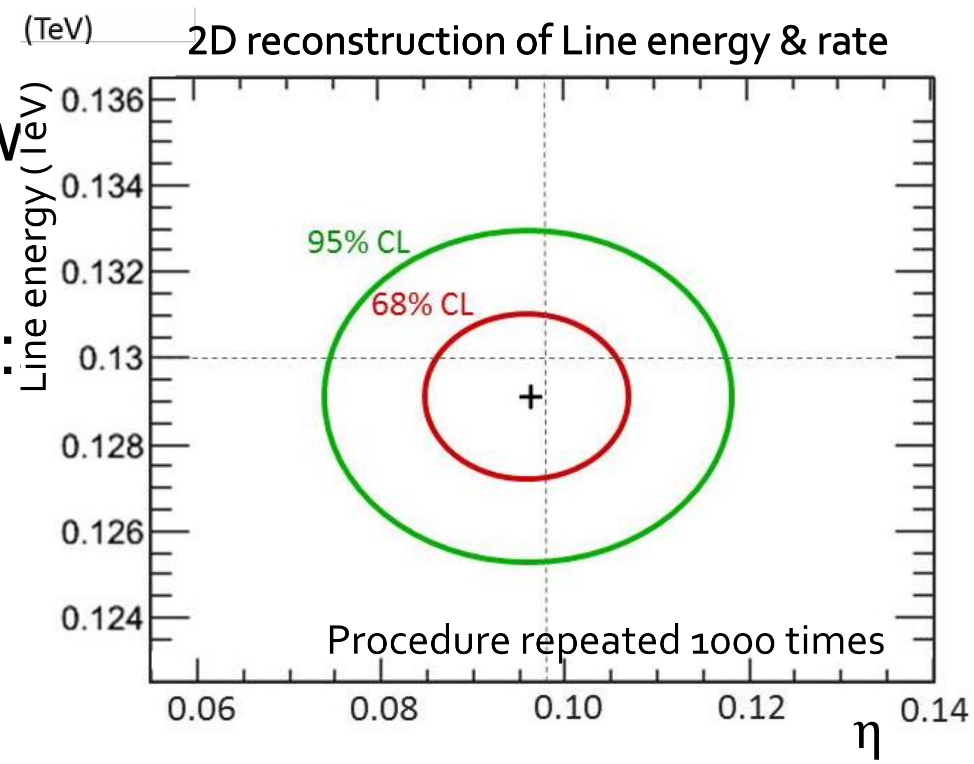


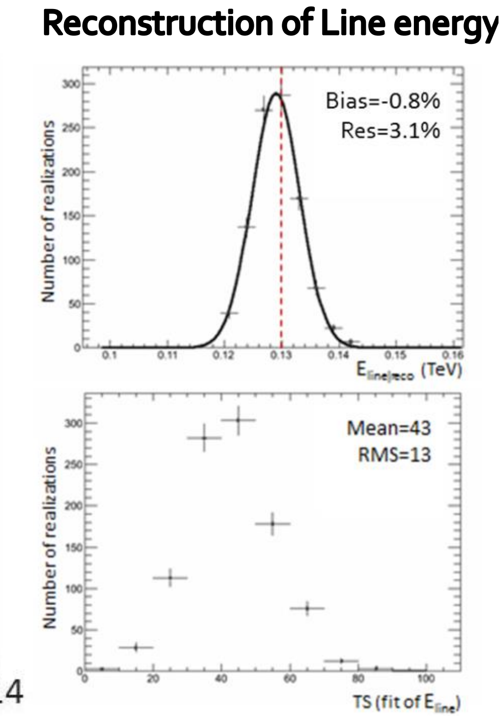


The HESS 2 Line search

- A new line search using the HESS 2 telescope is underway
- Since 2013, data from the galactic center has been collected. A total of ~670 hours are available for observation at zenith angles below 35°
- Two main sources of background:
  - hadrons that may be estimated from off-regions
  - Diffuse sources of gamma-rays, as well as contamination from known sources







$$\mathcal{L}(N_{EST}, M(\theta)|N_{OBS}, E_1, ..., E_{N_{OBS}}) = \frac{N_{EST}^{N_{OBS}}}{N_{OBS}!} e^{-N_{EST}} \times \prod_{i-1}^{N_{OBS}} \mathcal{P}(E_i; M(\theta))$$

Conclusions

- The HESS 2 line paper will extend the HESS limits to lower energies.
- Based on Monte Carlo and OFF data, the choices of ROI are made to minimize the expected upper limit.
- The HESS data comprises galactic center data, as well as data on the Fermi Hotspot. There are around 600 hours of possible dark-time for the Galactic Center every summer, which is attenuated by both the instrument uptime and weather. In addition, this is the most requested observation period
- The analysis has an expected significance of over 5 sigma for a benchmark signal with the mass and flux as reported by Weniger.