Photon Reconstruction for H.E.S.S. Using a Semi-Analytical Shower Model

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The Model Analysis

Advanced analysis method that has become standard in the H.E.S.S. collaboration (reference publication: [1]).

Event Reconstruction

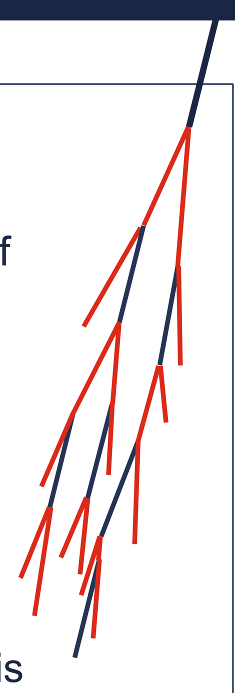
- A likelihood value is calculated for each pixel (see below)
- Pixel-wise values are combined to an overall log-likelihood value (ln L)
- Optimisation of ln L to obtain direction Dir, E, T, and R using a Levenberg-Marquardt algorithm ([2], [3])
- Using second derivatives of ln L to estimate parameter uncertainties (e.g. ΔDir)

Further variables:

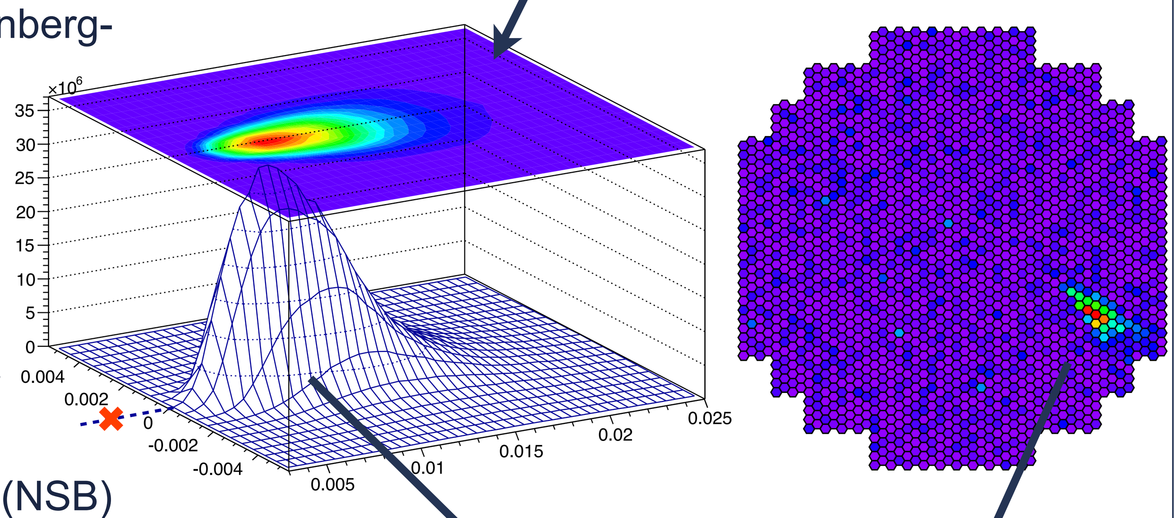
- G_{SG}: shower goodness, quantifies the "γ-likeliness" of a shower
- G_{NSB}: night-sky background (NSB) goodness; rejects events that are compatible with NSB

Based on a semi-analytical model of electromagnetic showers.
Parameters:

- First interaction depth T
- Impact distance R
- γ-ray energy E
- Zenith angle ϑ



The expected Cherenkov emission is stored in templates.



$$P(s|\mu,\sigma_p,\sigma_\gamma,\sigma_c) = \sum_n \frac{\mu^n e^{-\mu}}{n!\sqrt{2\pi(\sigma_p^2+n\sigma_\gamma^2+n^2\sigma_c^2)}} \exp\left(-\frac{(s-n)^2}{2(\sigma_p^2+n\sigma_\gamma^2+n^2\sigma_c^2)}\right)$$

Analysis Modes

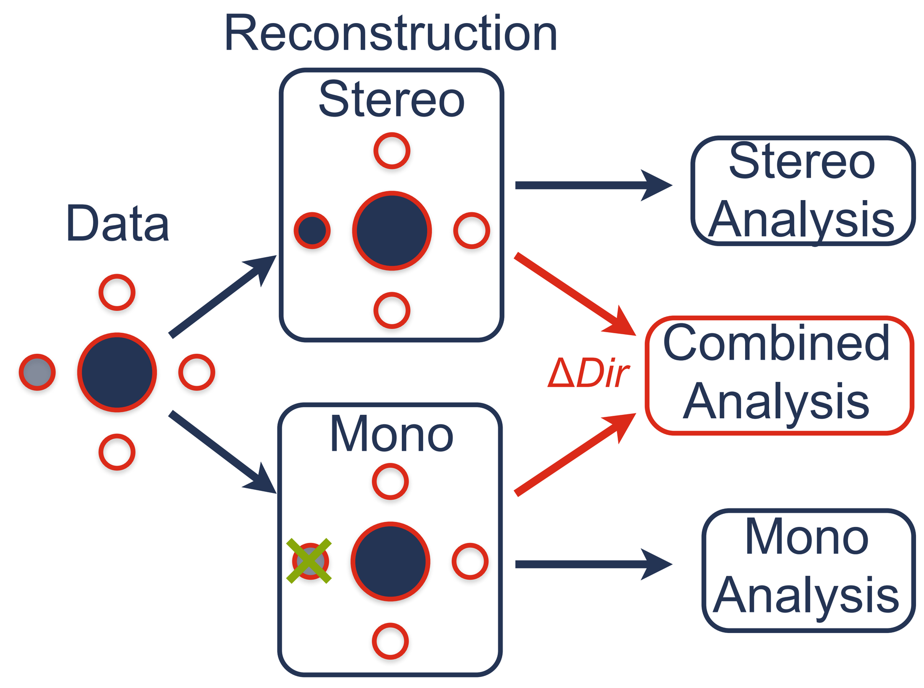
The H.E.S.S. array triggers on

- Monoscopic events from CT5
- Stereoscopic events from CT1-5

Cut Configurations

Acceptance ranges of respective standard configurations (Combined ones are preliminary):

	Mono	Stereo	Combined
G_{SG}	[-4,0.6]	[-4,0.9]	[-4,0.9]
G_{NSB}	> 32	> 28	> 32
T	[-1.1,1.3]	[-1.1,3.4]	[-1.1,3.4]
ΔDir	< 0.3°	< 0.2°	< 0.3°
ϑ^2 cut (deg^2)	< 0.015	< 0.006	< 0.015



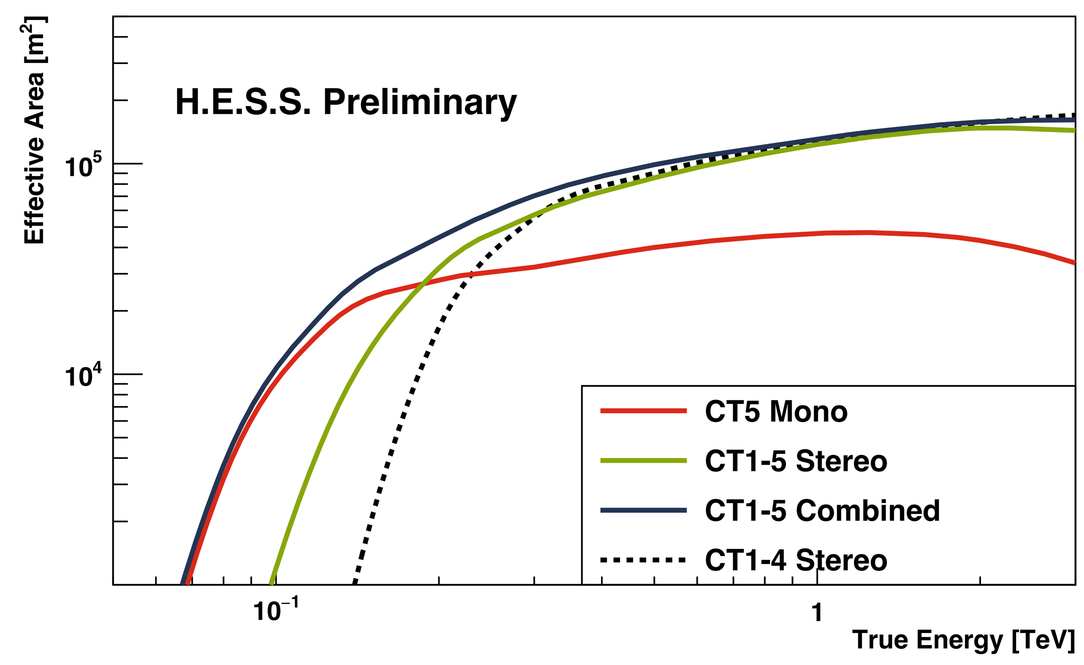
Sketch of the analysis modes. Stereoscopic events are also reconstructed monoscopically. The decision for the Combined analysis is based on ΔDir.

Performance

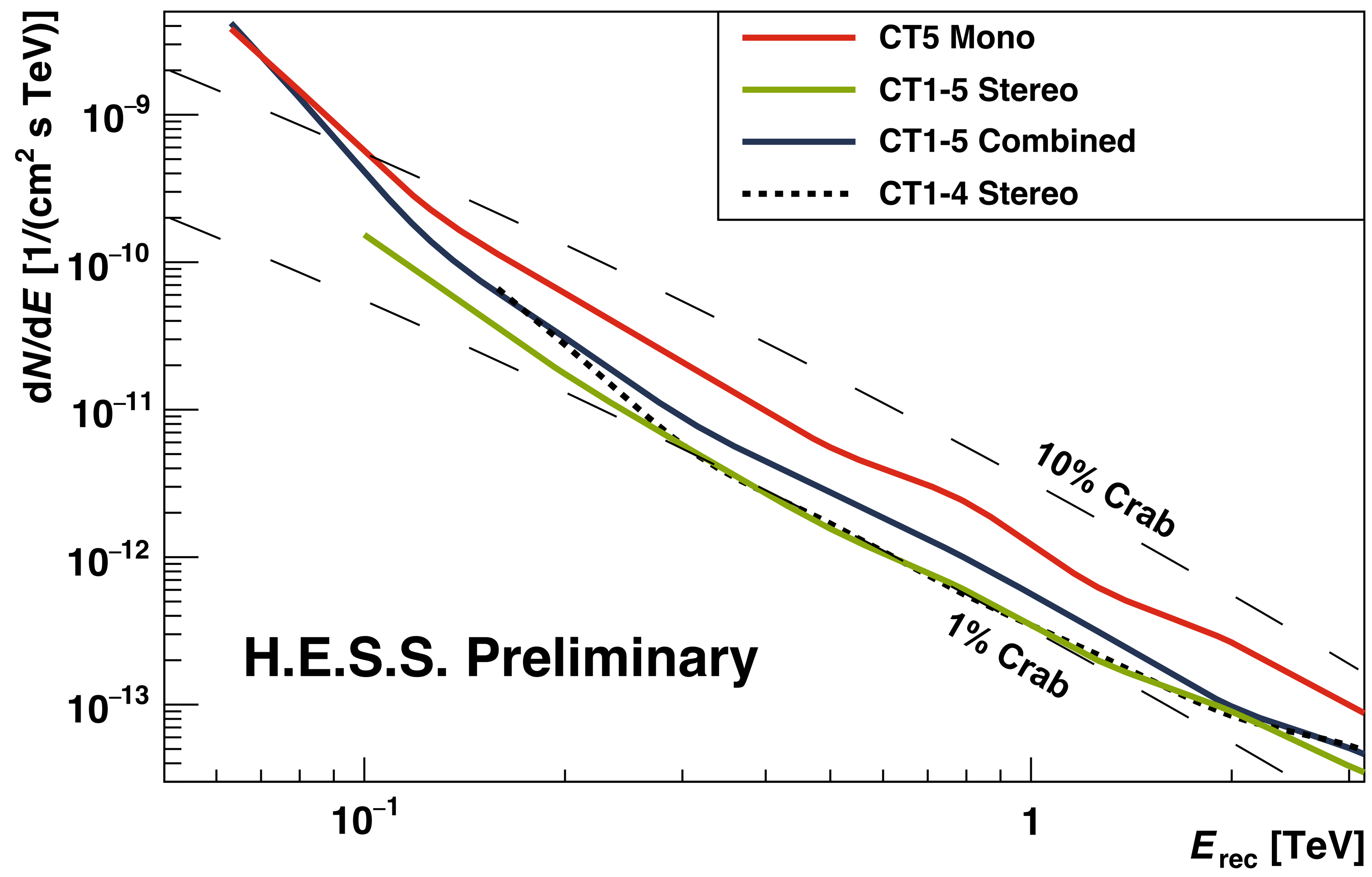
Performance evaluation for low zenith angles. Using

- simulated γ-rays with 18° zenith and 180° azimuth angle
- background events from data (for the sensitivity)

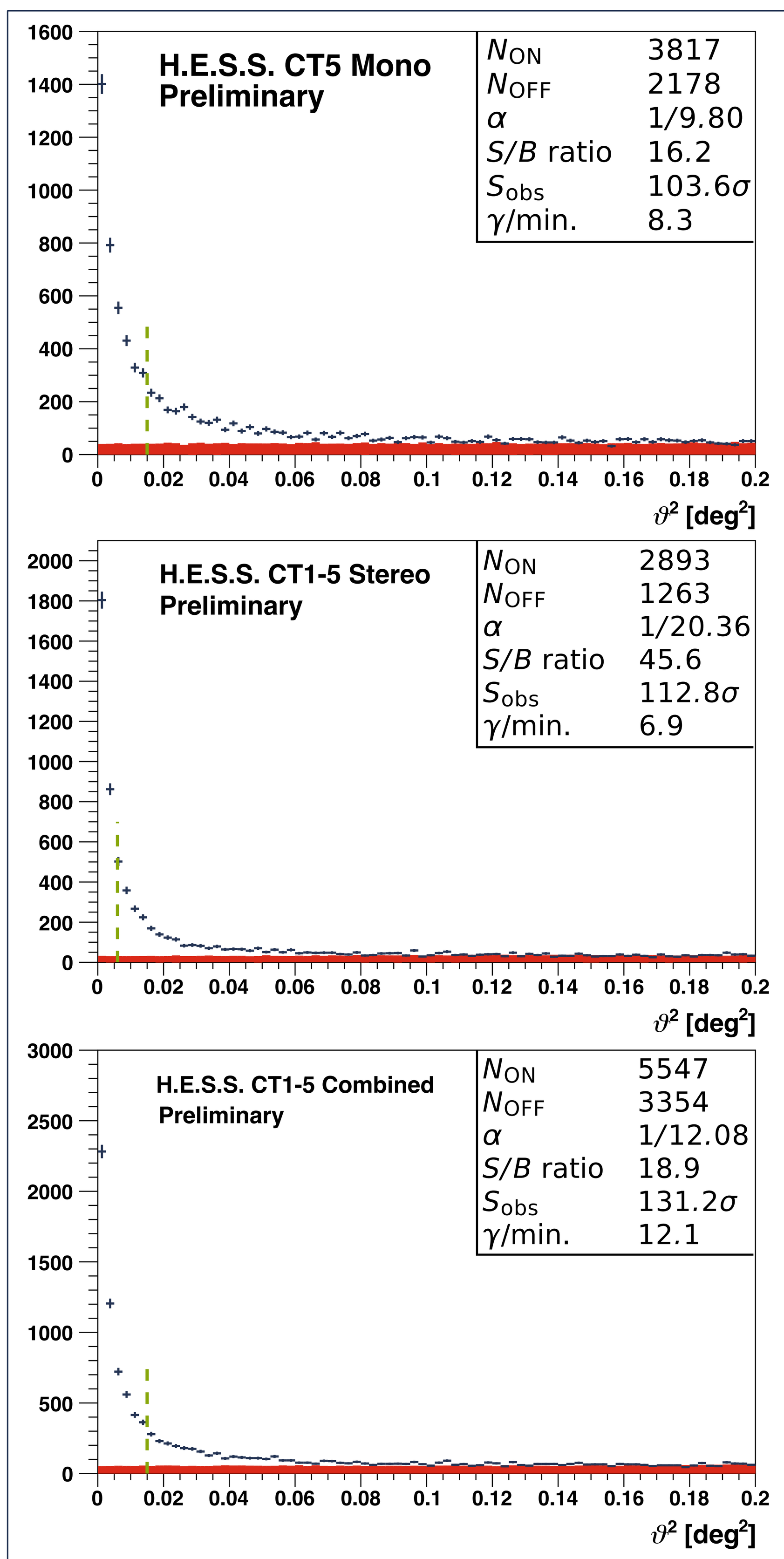
The Combined mode best covers the whole energy range (see effective area on the right). It is however less sensitive than the Stereo mode at medium and high energies (see below), mostly due to more background which is a consequence of the larger ϑ^2 cut.



Analysis effective area of the model analysis for different analysis/reconstruction modes.



Differential sensitivity of the model analysis for the different analysis modes of H.E.S.S. data, calculated using the simplified significance calculation. All curves correspond to observations at low zenith angles, an observation time of 50 h, and 5 bins per decade. A minimum of 10 excess counts and a S/B ratio of 0.05 was required for each bin. The reference spectrum of the Crab Nebula was taken from [4].



Angular distribution of γ-like events from the Crab Nebula.

The Crab Nebula

All three analysis modes were applied to data of the Crab Nebula.

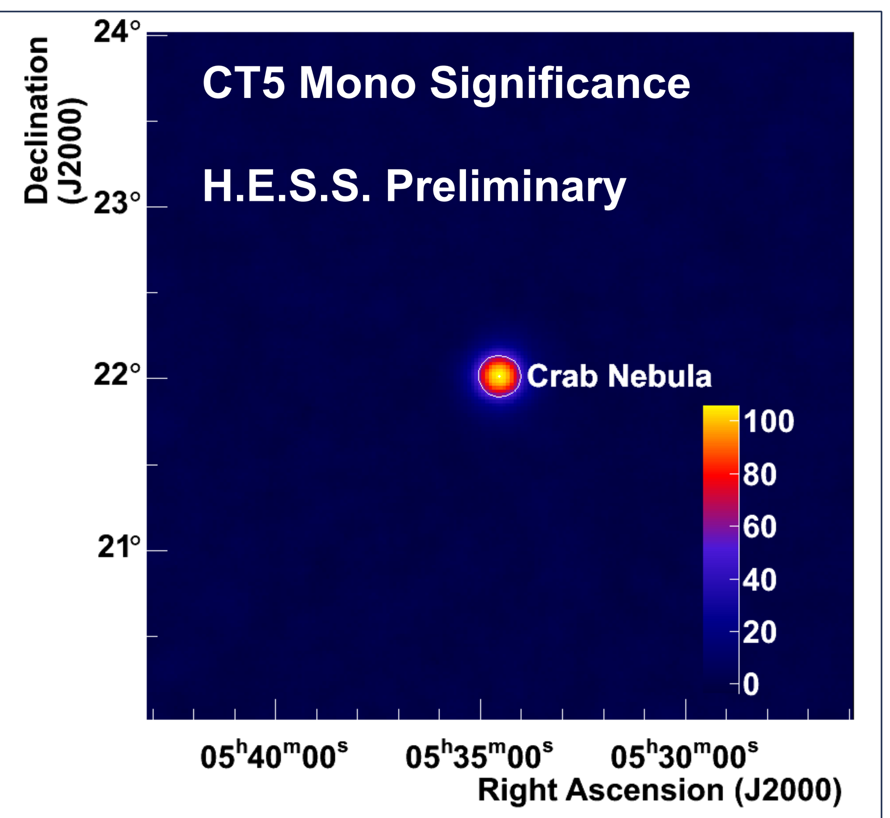
- Good-quality data, taken October and November 2014
- Raw live time 7.47 h
- Dead time-corrected live time:
  - 7.2 h (Mono and Combined)
  - 6.8 h (Stereo)
- Zenith angle range 45-55°

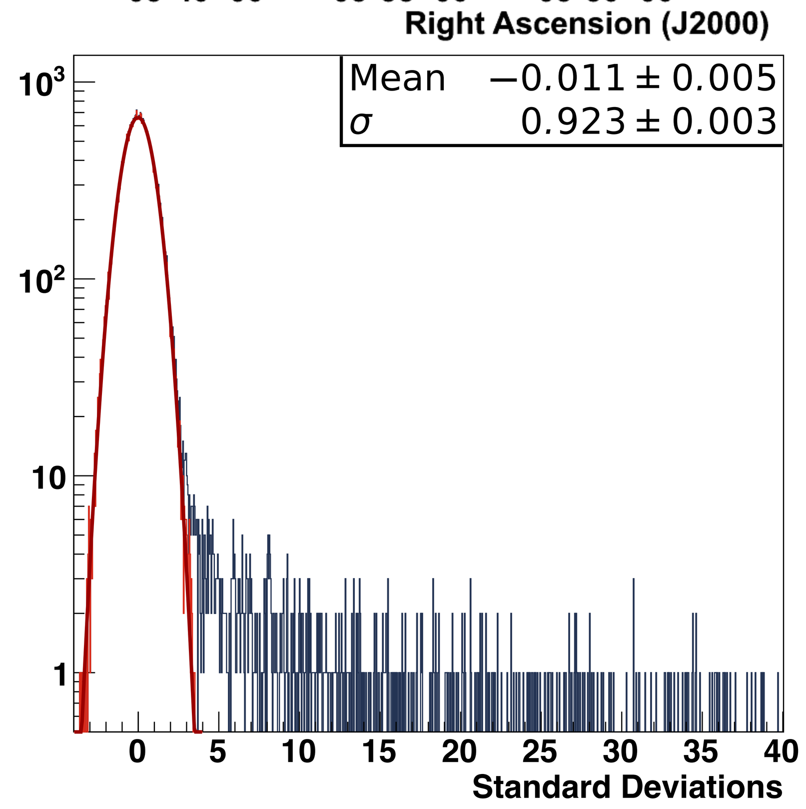
Analysis Results

Angular distributions and event statistics are given on the left (dashed green line corresponds to respective ϑ^2 cut).

- Corresponding energy thresholds: ≈ 250 GeV for Mono and Combined, ≈ 350 GeV for Stereo (possible to go lower, systematics to be understood)
- All histograms well normalised
- Combined mode provides highest excess rate and significance
- Stereo mode performs best in terms of S/B ratio

The significance map (Mono) and its distribution of values are shown on the right. The map is well normalised.





Mono Significance map of the region around the Crab Nebula (*top*). *Bottom:* distribution of significances (zoomed) for the whole map (dark blue) and the background regions (red).

Conclusions

- Advanced reconstruction method adapted to H.E.S.S. II
- Combined analysis of monoscopic and stereoscopic events allows the best energy coverage
- Model analysis for H.E.S.S. II a very sensitive method
- All three analysis modes successfully applied to the Crab Nebula

References

- [1] M. de Naurois and L. Rolland, *Astroparticle Physics* 32 (2009), 231-252.
- [2] K. Levenberg, *The Quarterly of Applied Mathematics* 2 (1944), 164-168
- [3] D. Marquardt, *SIAM Journal on Applied Mathematics* 11 (1963), 431-441
- [4] J. Aleksić et al., *Journal of High Energy Astrophysics* 5-6 (2015), 30-38

Acknowledgments

Please see standard acknowledgments in H.E.S.S. papers, not reproduced here due to lack of space.

H.E.S.S.