THE COSMIC-RAY ELECTRON SPECTRUM MEASURED WITH H.E.S.S.

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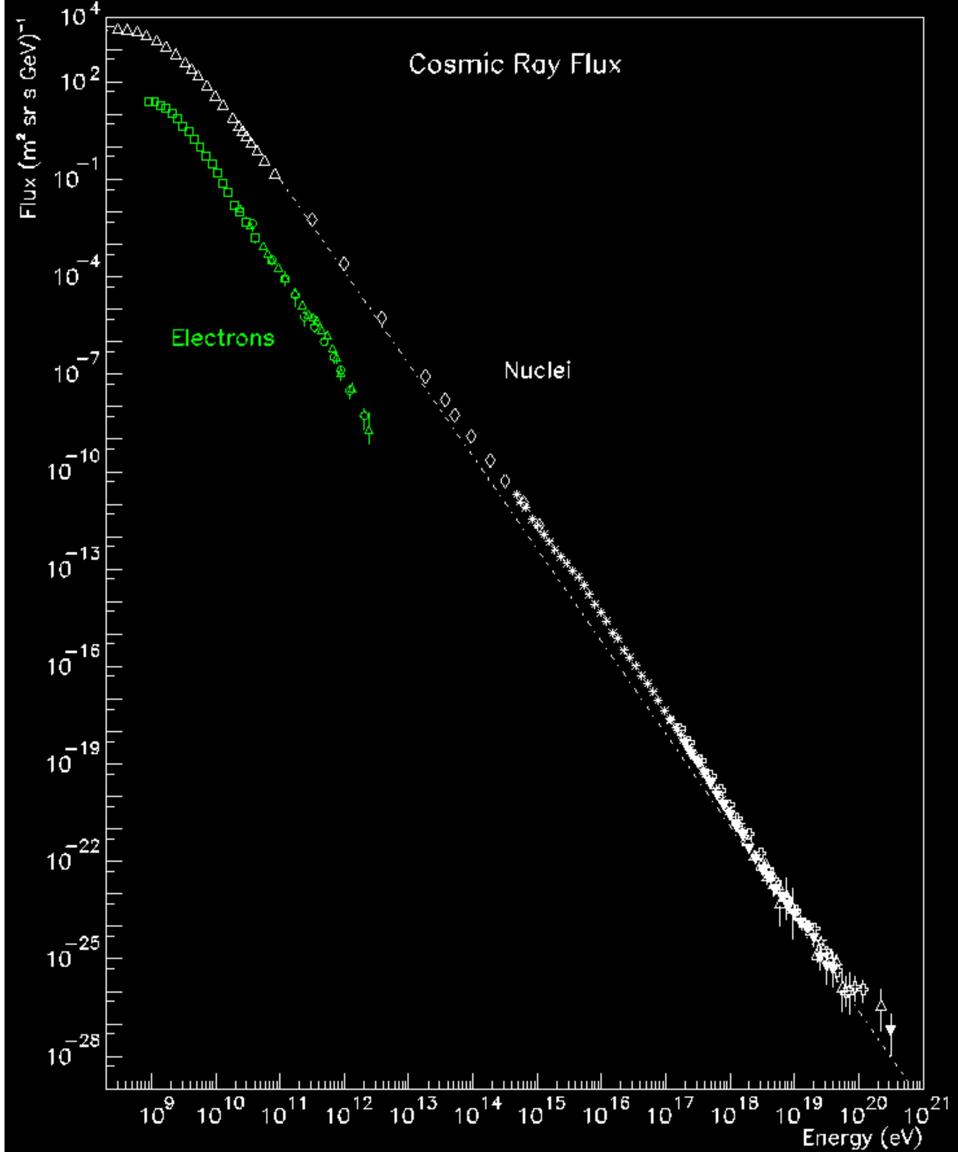
Outline

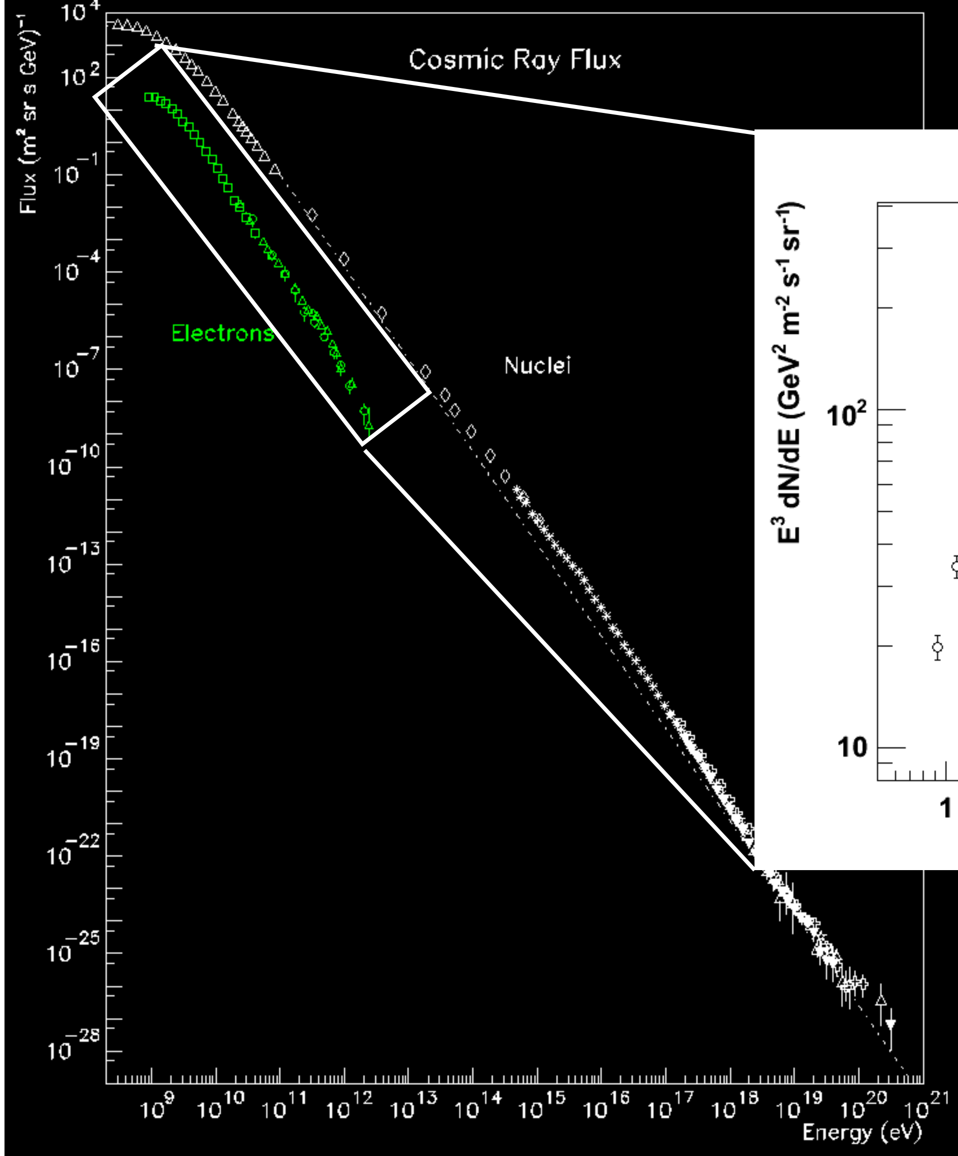
- Introduction
- The H.E.S.S. Experiment
- The H.E.S.S. Electron Measurement
  - Gamma-Ray Background
  - Hadronic Background
  - Spectrum Determination
  - CR Electron Spectrum
- Systematics + Interpretation
- Conclusion + Outlook

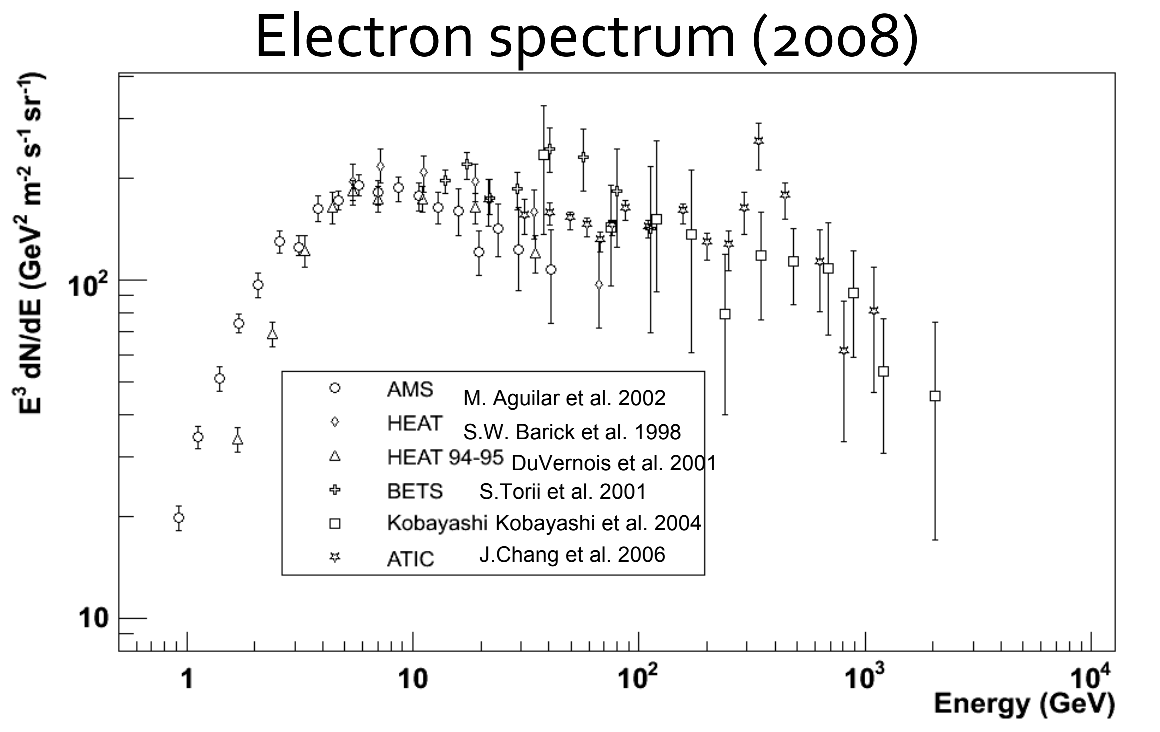
Cosmic-Ray Electrons



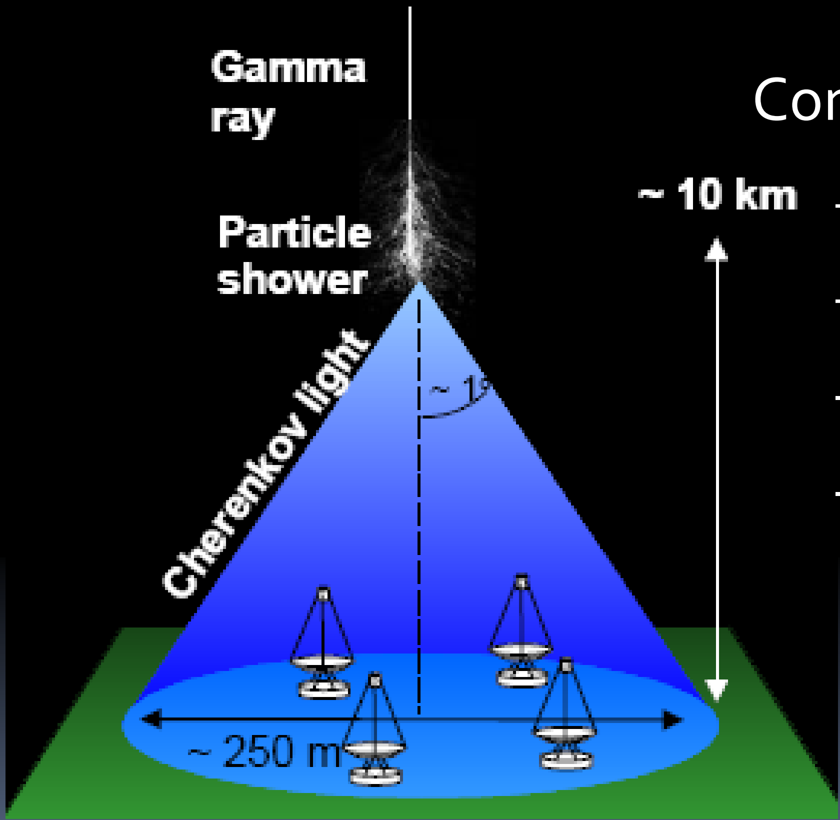
- „Electrons" = $e^+ + e^-$
- Cosmic-ray nuclei spectrum covers range of >11 decades in energy
- TeV electron flux ≈0.1% of hadron flux
- Electrons have a steeper spectrum (Γ=3.3 vs. 2.7)
- Up to 2008: No electron measurement beyond 2 TeV

Cosmic-Ray Electrons





Why measure CR electrons ground based?



Compared to direct measurements:

+ High statistics (collection areas ≈10^5 m^2)

+ Energy resolution improving with energy

- High background level

- Large systematics

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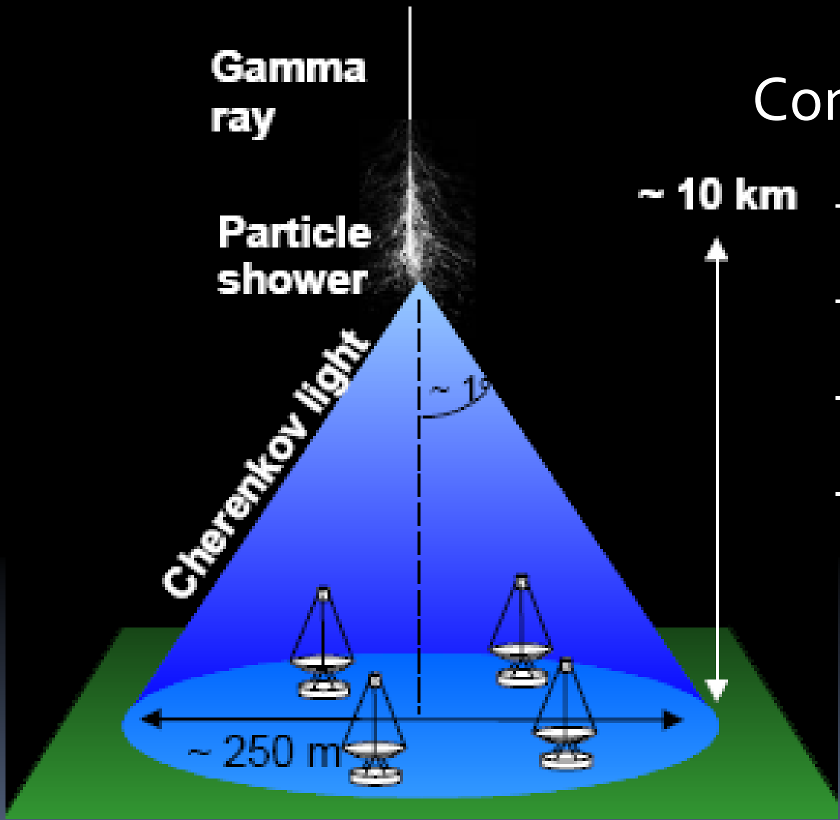

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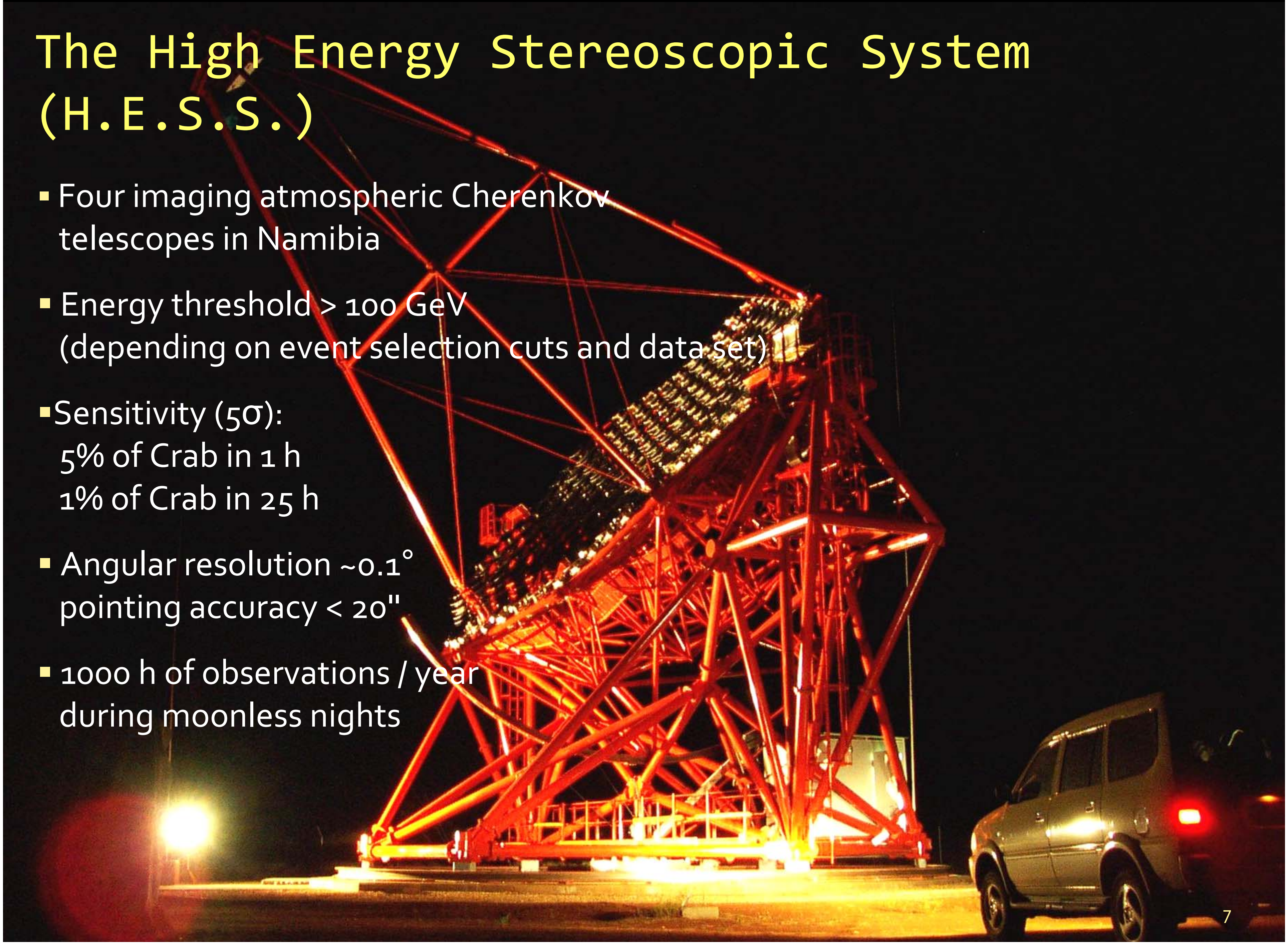
Dependence on atmospheric conditions!

The High Energy Stereoscopic System (H.E.S.S.)

- Four imaging atmospheric Cherenkov telescopes in Namibia
- Energy threshold > 100 GeV (depending on event selection cuts and data set)
- Sensitivity (5σ):
  5% of Crab in 1 h
  1% of Crab in 25 h
- Angular resolution ~0.1°
  pointing accuracy < 20''
- 1000 h of observations / year during moonless nights

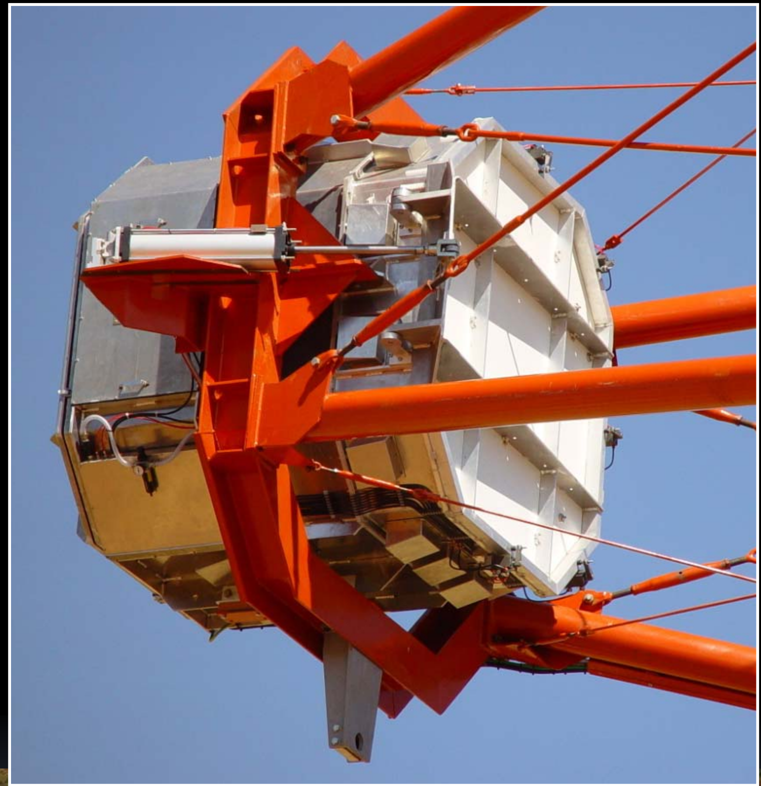


The Mirrors

- 13 m diameter
- 382 mirror facets with 60 cm diameter
- Total mirror area of 107 m^2

The H.E.S.S. Cameras

- 960 PMTs with 0.16° aperture each
- 5° diameter field of view
- total weight of ~800 kg

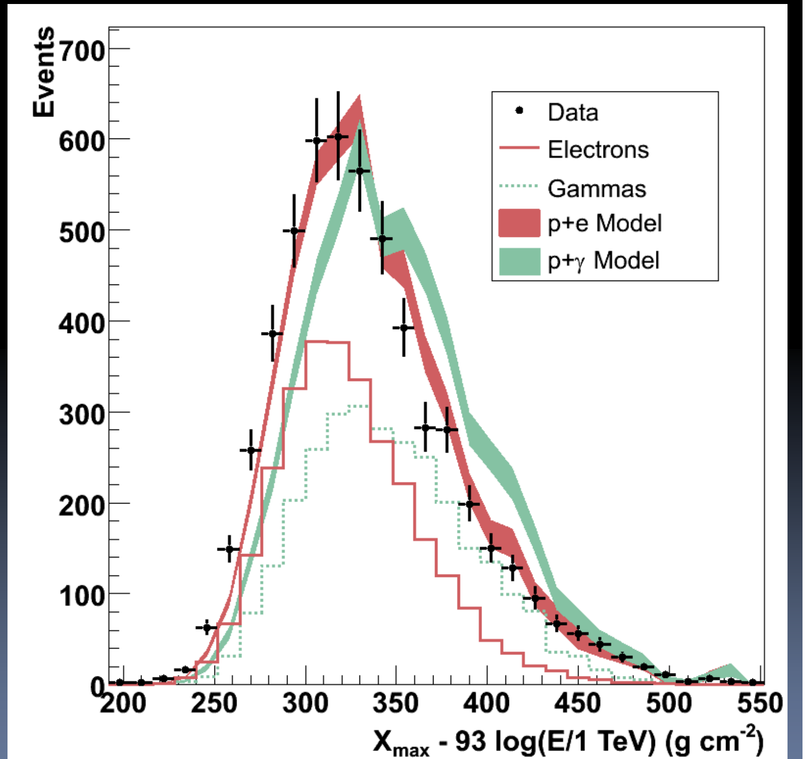


The H.E.S.S. Electron Measurement

- Electron and gamma-ray air showers are very similar
- Electrons isotropic:
  any (gamma-ray free) data can be used for the analysis
- 2 analyses optimized for high energies and low energies
- Data sets:
  - Central 3° of field of view, gamma-ray sources within 0.4° excluded
  - Livetime: 239 h (high-energy analysis) / 77 h (low-energy analysis)
  - Effective area: 5×10^4 m^2 at 1 TeV / 4×10^4 m^2 at 340 GeV
  - Effective exposure: 8.5×10^7 m^2 sr s at 1 TeV / 2.2×10^7 m^2 sr s at 340 GeV
  - Different directions are covered
- Background contributions:
  - Gamma rays
  - Hadrons

Gamma-Ray Background

- Hard to distinguish from electrons
- Avoided by choice of data set:
  Galactic plane and potential gamma-ray sources are excluded
- Remaining background:
  diffuse extragalactic gammas
  - Very low fluxes are expected due to pair creation on radiation fields
  - Experimental discrimination: X_{max}
    - Occurs ½ radiation length higher for electrons
    - Cannot exclude maximum of 50% gamma contamination



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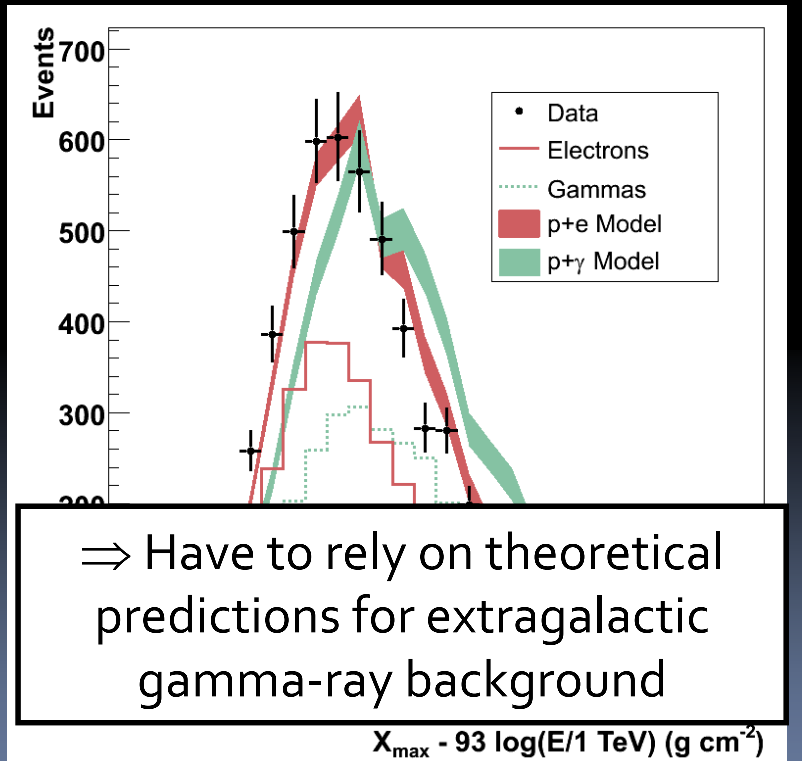
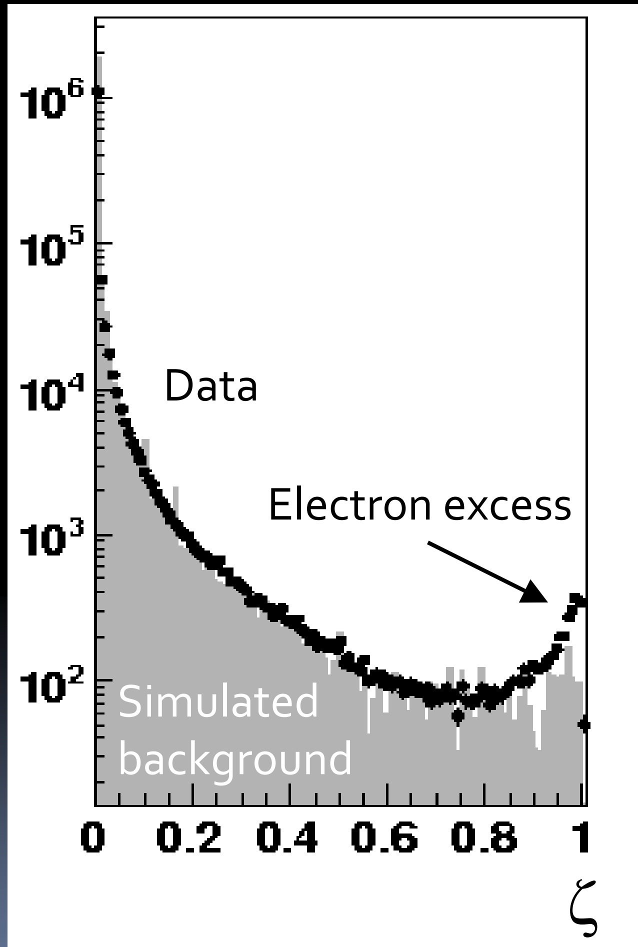


⇒ Have to rely on theoretical predictions for extragalactic gamma-ray background

Hadronic Background

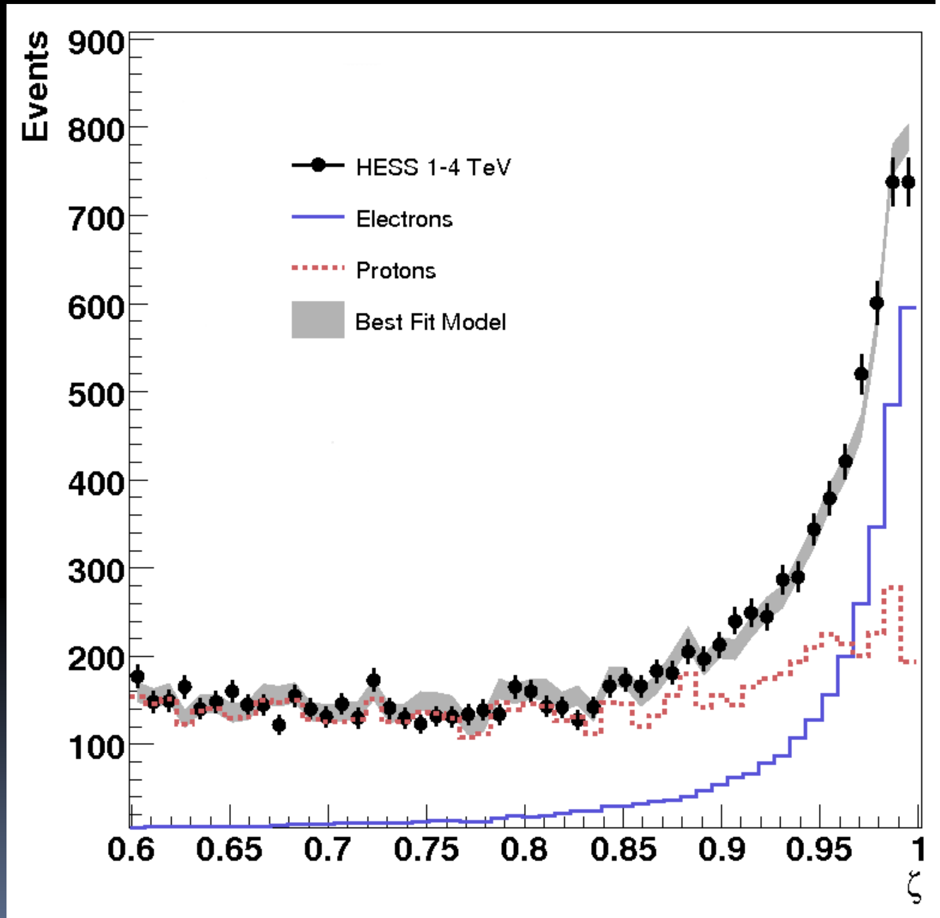
- Broader and less regular than electromagnetic showers
- Electron-hadron separation with the machine-learning algorithm **Random Forest** (RF)
- RF converts image parameters into output parameter $\zeta \in [0,1]$:
  - ζ=1: electron-like
  - ζ=0: background
- ζ describes *electron-likeness* of an event
- Cut ζ>0.6 is applied for a 98-99.5% background suppression



Hadronic Background

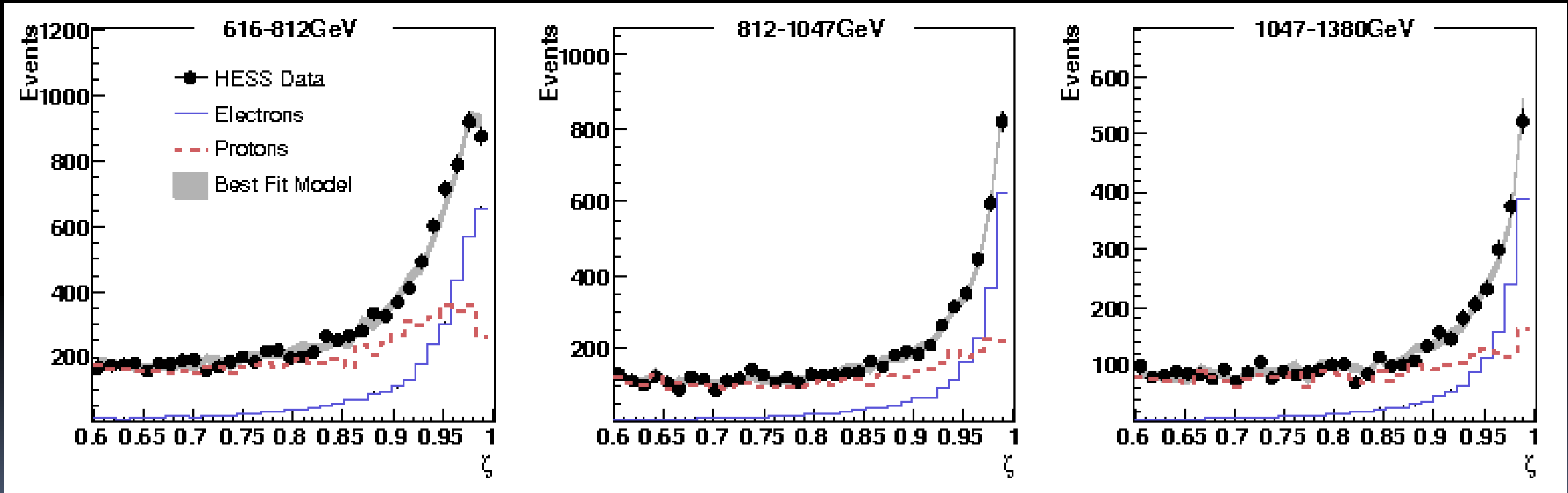
- Remaining background level determined by a fit in ζ with electron and proton simulations
- The hadronic background can be modelled with protons only because heavier nuclei are sufficiently suppressed by ζ cut

Dependence on hadronic model!



Spectrum Determination

- Fit in ζ in independent energy bands
  $\Rightarrow$ determine number of electrons N_e in each band



$\Rightarrow dN/dE = N_e / (A_{eff} \times T_{live} \times \Omega \times \Delta E)$

The H.E.S.S. Electron Spectrum

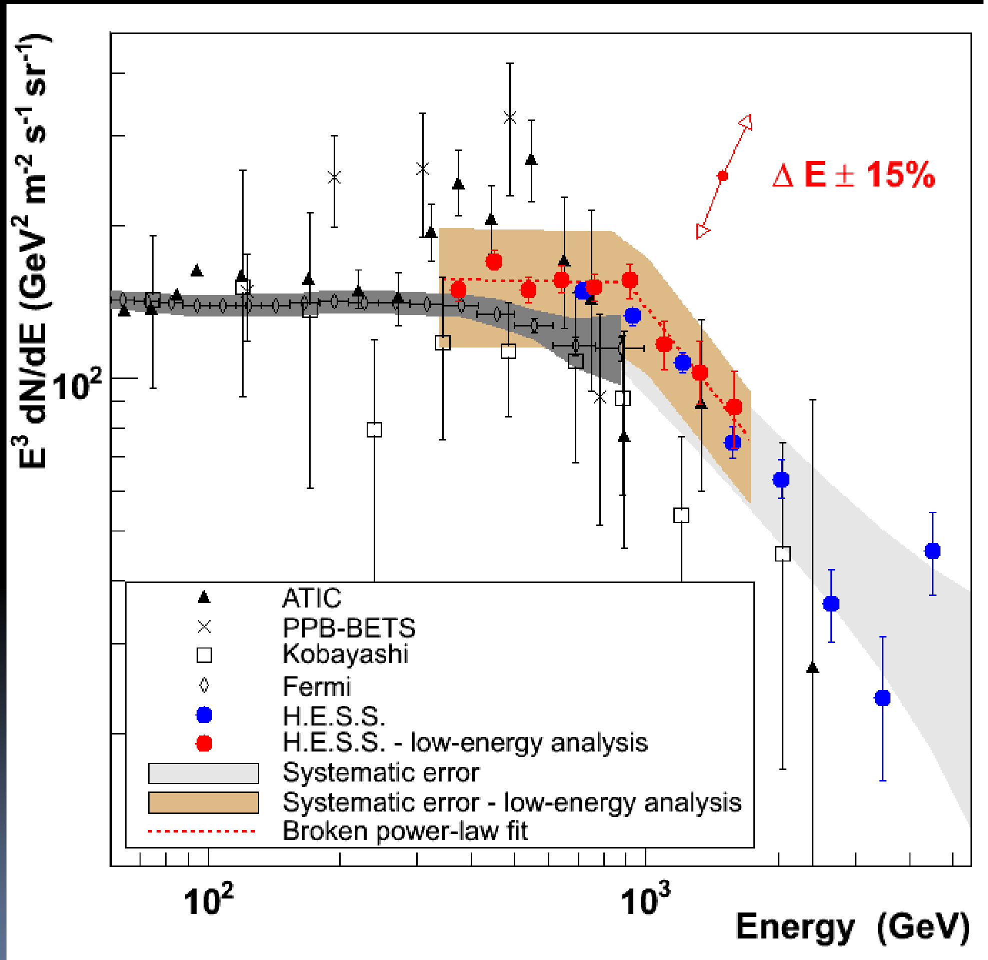
High energies (blue)

- Cuts:
  - impact distance < 200 m
  - image size in each camera > 200 photo electrons

- Spectral index:
  $3.9 \pm 0.1_{stat.} \pm 0.3_{syst}$

- Syst. uncertainty: atmospheric variations + model dependence of proton simulations (SIBYLL vs. QGSJET-II)

- H.E.S.S. energy scale uncertainty of 15%



F. A. Aharonian et al., A&A, 508 (2) 561 (2009)

The H.E.S.S. Electron Spectrum

Low energies (red)

- Cuts:
  - impact distance < 100 m
  - image size in each camera > 80 photo electrons
  - Data set of 2004/2005
- Spectral index:
  $\Gamma_1 = 3.0 \pm 0.1_{stat.} \pm 0.3_{syst.}$
  $\Gamma_2 = 4.1 \pm 0.3_{stat.} \pm 0.3_{syst.}$
- Syst. uncertainty: atmospheric variations + model dependence of proton simulations (SIBYLL vs. QGSJET-II)
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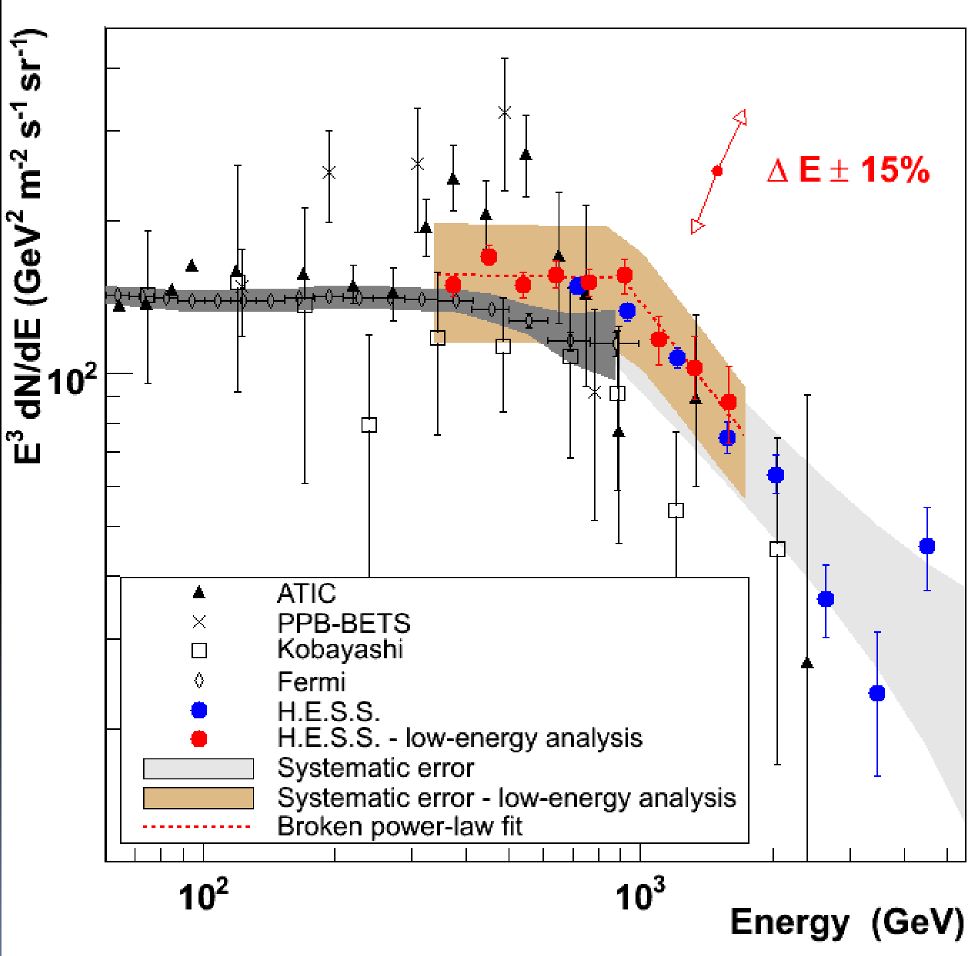

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Systematics

- Systematic studies:
  - Data - investigation of dependence on: sky field, zenith angle, event selection cuts, distance from Galactic plane…
  - Analysis – comparison of different fitting parameters (instead of ζ), different fitting algorithms, different hadronic models
- Normalisation varies $\rightarrow$ band of systematic uncertainty
- Spectral shape is very stable ($\Delta\Gamma \leq 0.3$)

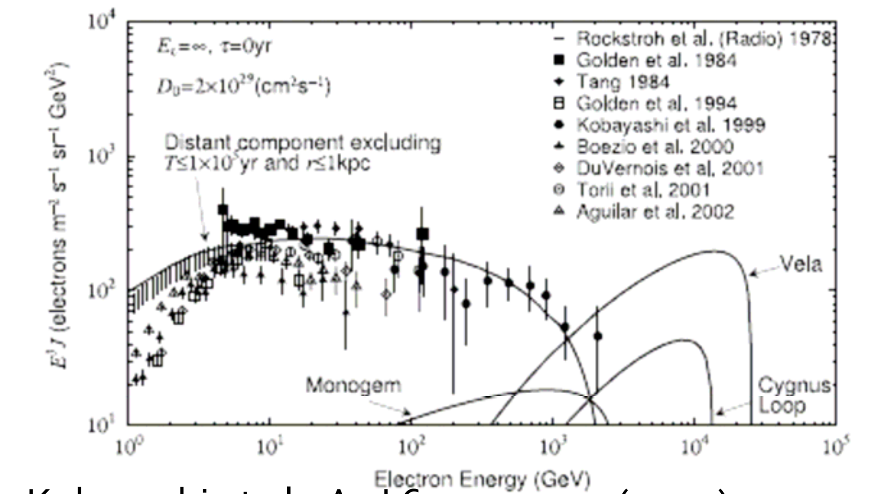
Interpretation

Low-energy spectrum:

- No contradiction to ATIC data due to H.E.S.S. energy scale uncertainty
- No indication of a bump in the spectrum, KK scenario excluded at 99% C.L.
- Compatible with less pronounced DM scenarios/electron acceleration in astrophysical objects

High-energy spectrum:

- Existence of a local accelerator within ≈1 kpc
- Some scenarios of very close sources can be excluded



Kobayashi et al., ApJ 601 340-351 (2004)

Conclusion

- Ground-based measurements are an attractive alternative to direct measurements especially at high energies
- H.E.S.S. measured cosmic-ray electrons between 340 GeV and 5 TeV
- Systematic uncertainties include atmospheric variations, uncertainties in hadronic interaction models and H.E.S.S. energy scale uncertainty
- The H.E.S.S. electron spectrum is a smooth spectrum that steepens at about 1 TeV

Outlook: Future ground-based measurements?

- H.E.S.S. Phase II
  - 600 m^2 mirror area
  - 20 GeV energy threshold

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Future ground-based measurements?

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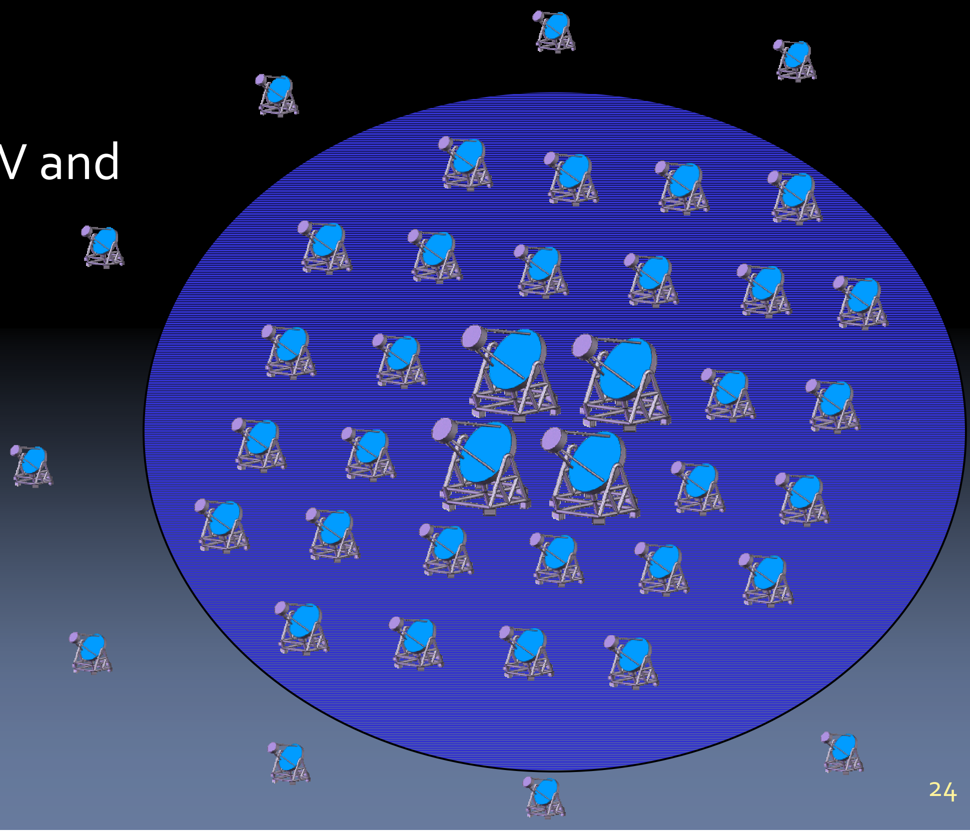
Low energies: difficult
+ already covered by Fermi

High energies: maybe…

Outlook:
Future ground-based measurements?

- H.E.S.S. Phase II
- Cherenkov Telescope Array (CTA)
  - Telescope array observatory
  - 5-10 x sensitivity of H.E.S.S.
  - Energy range:
    a few tens of GeV up to 100 TeV and higher
  - In the phase of design study



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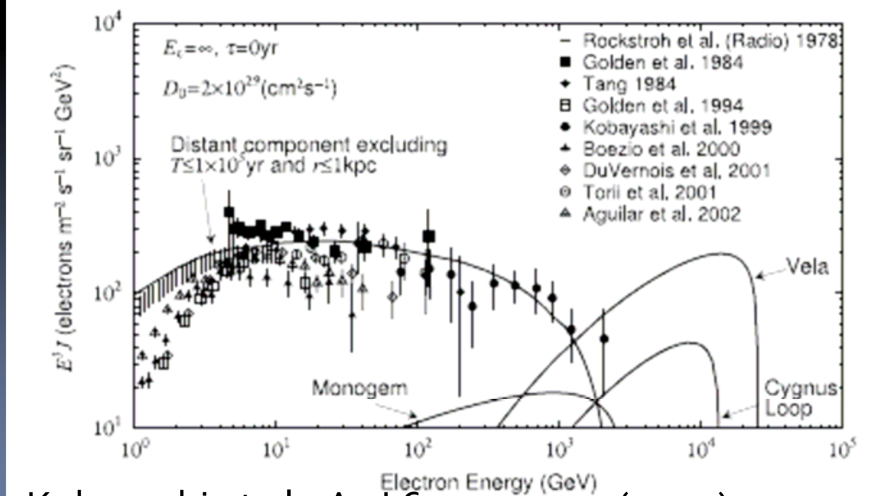
Low energies: difficult
+ already covered by Fermi

High energies: potential to see signatures of local sources in the electron spectrum



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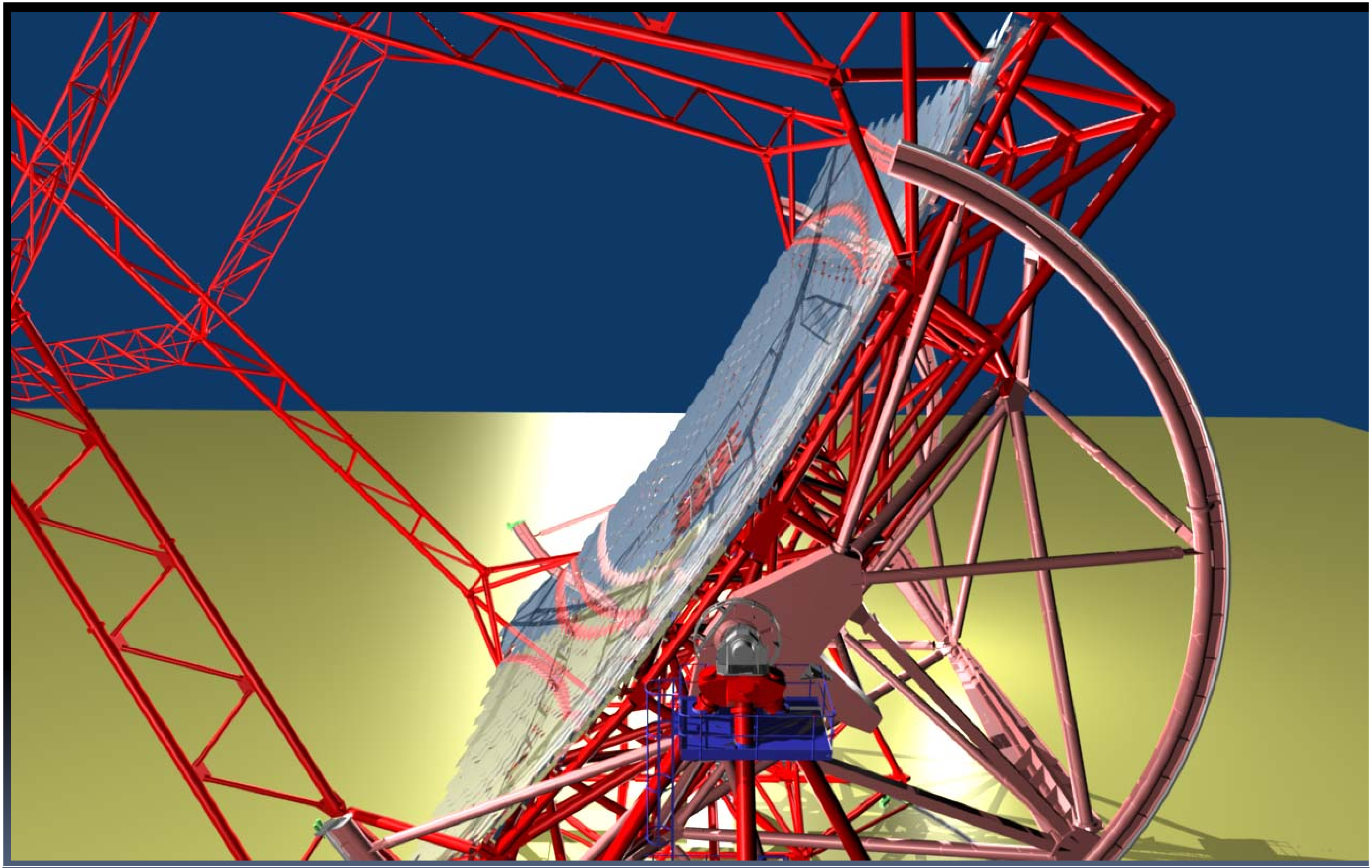

Thank you!

Backup Slides

Interpretation + Systematics

- No contradiction to ATIC data due to H.E.S.S. energy scale uncertainty
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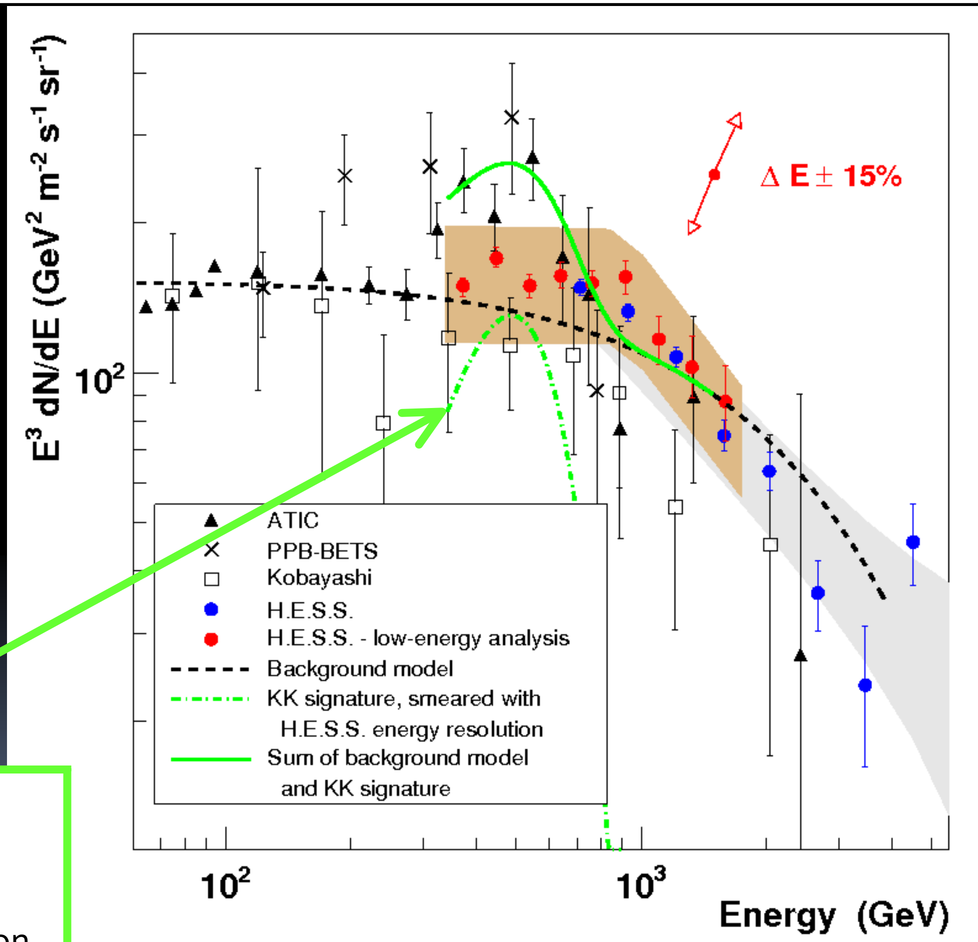
How would a KK signature look like in the H.E.S.S. data?



620 GeV KK with flux matching the ATIC data
(J. Chang et al., Nature, 456, 362, 2008),
smeared out with H.E.S.S. energy resolution

…A. Aharonian et al., A&A, 508 (2) 561 (2009)

CTA

- Implementation of first prototype telescope(s) of the system could start in 2010 after a period of a detailed design study and optimization, site evaluation and production of industrial prototypes of components

- CTA is included in the 2008 roadmap of the European Strategy Forum on Research Infrastructures (ESFRI), it is one of the "Magnificent Seven" of the European strategy for astroparticle physics published by ASPERA, and highly ranked in the "strategic plan for European astronomy" (leaflet) of ASTRONET

The High Energy Stereoscopic System (H.E.S.S.)

- 13 m diameter mirrors (107 m^2)
- Cameras: 960 pixels, 5° field of view (moon 0.5°)
- Energy threshold > 100 GeV
  (depending on event selection cuts and data set)