

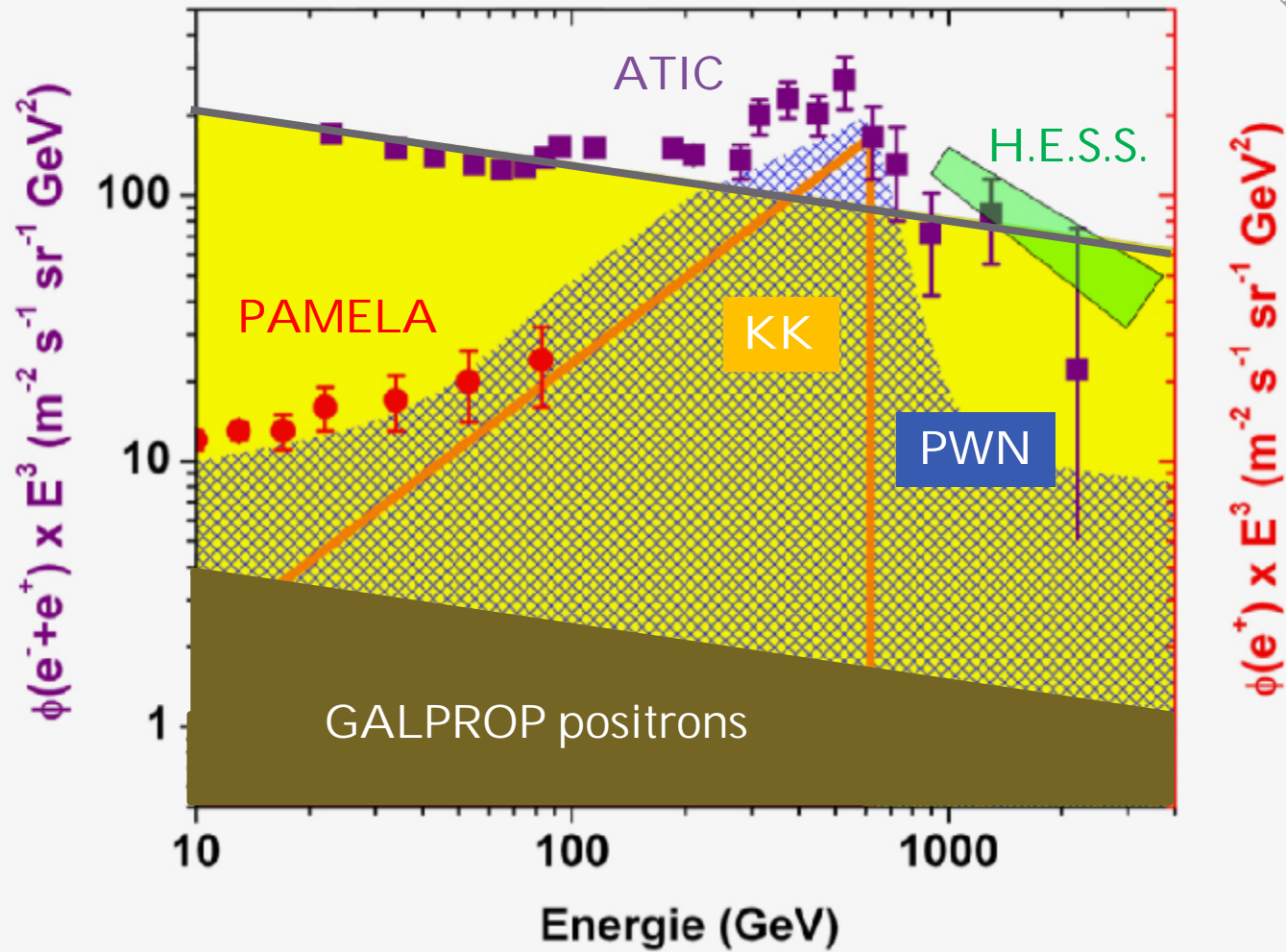
COSMIC RAY ELECTRON SPECTRUM: THE IACT CHALLENGE

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ITPA Würzburg

Tango@Paris, May 4th-6th, 2009

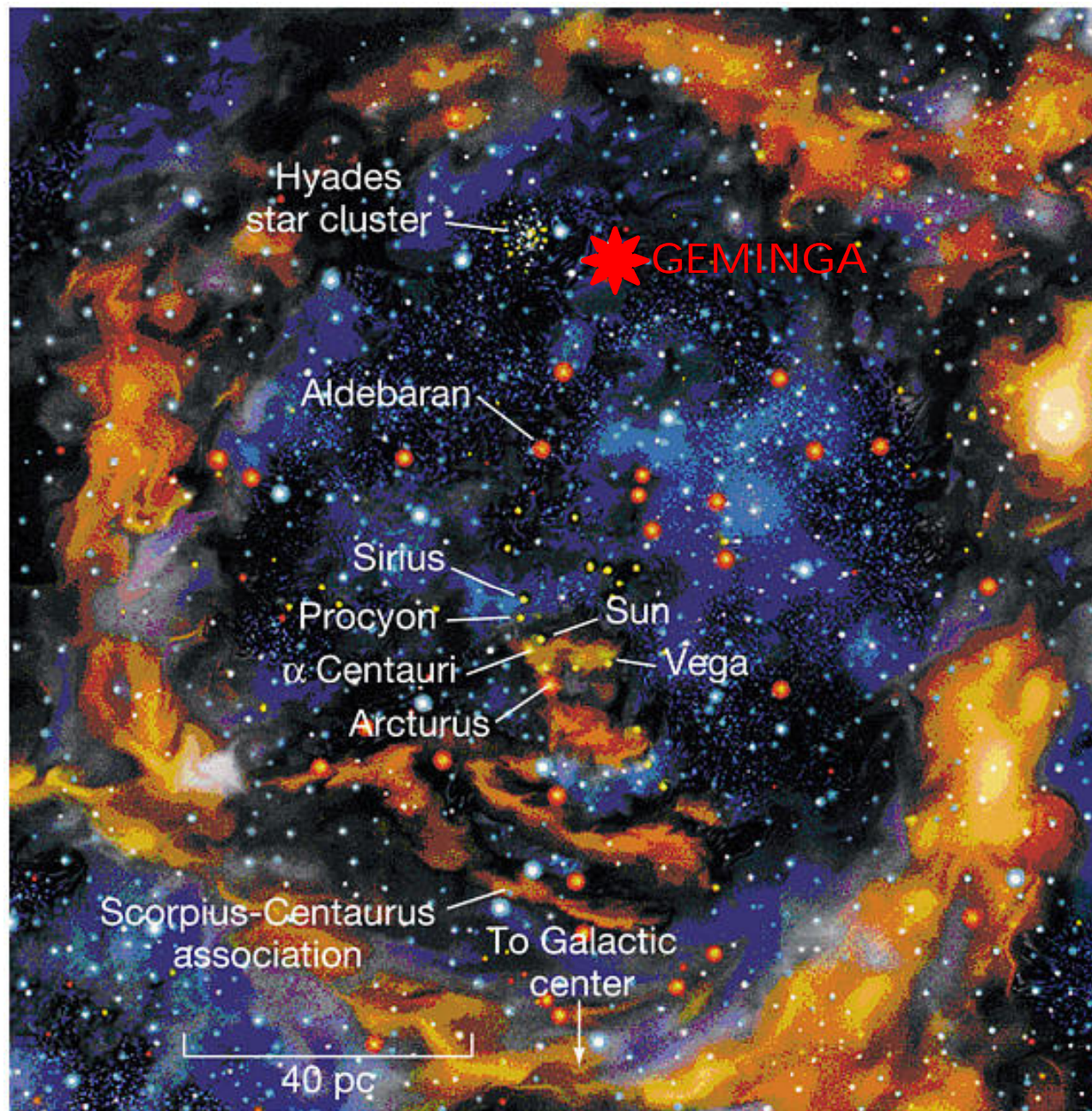
GALPROP electron spectrum $\sim E^{-3.25}$

Knee at
 ~ 50 TeV



The slope of the GALPROP spectrum

- .. Electron (primary, secondary) spectrum steepened due to diffusive transport with energy losses
- .. Diffusion coefficient $\kappa \sim E^{-\delta}$ ($\delta=0.5$ Kraichnan consistent with B/C)
- .. Anisotropy growing towards knee, may require Kolmogorov $\delta=0.3$
- .. **Caveat:** Leaky-box equations rely on separability of Boltzmann-equation (Wang&Schlickeiser) which fails for inhomogeneous media (**Local Bubble**)
- .. Energy loss time $t = 5 \times 10^5 (E/\text{TeV})^{-1} \text{ yrs}$
- .. Propagation distance $l = (D t)^{1/2} = 100\text{-}500 \text{ pc}$



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Effects not covered with GALPROP:

Low density of Local Bubble ISM reduces intensity of secondaries.

Next sources of primary electrons may be beyond the TeV horizon for electrons.

We are left with Local Bubble source(s) only

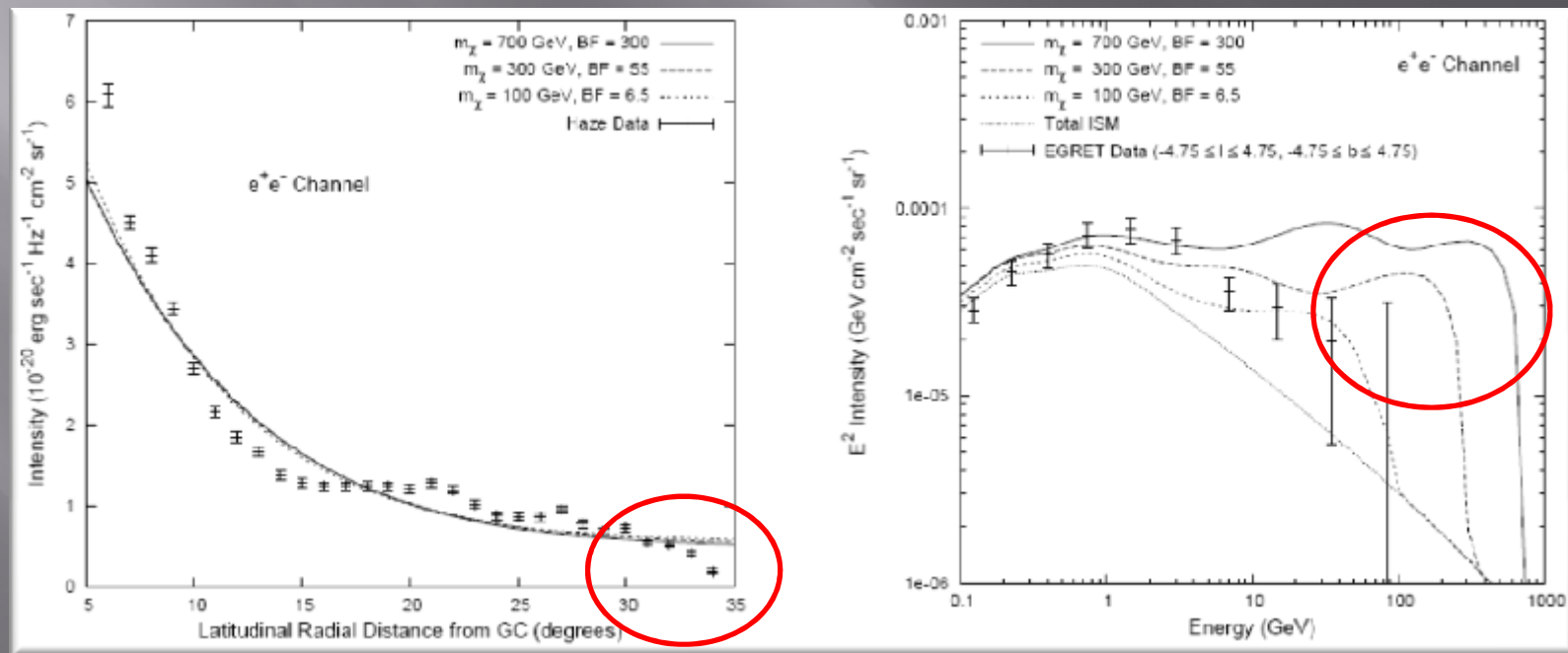
à Steepening at TeV theoretically possible.

Dark matter annihilation

Kaluza-Klein particles:

KK $\rightarrow e^+e^-$ (cf. Finkbeiner et al. 09) Problems already with this contrived model (less contrived KK models would have gamma rays at same level)

- Relic density?
- Sharp shoulder at 600 GeV (H.E.S.S. should not see excess)
- Galactic Center (IACT) overproduction
- WMAP haze at high galactic latitudes overproduction
- Diffuse gamma-ray emission (due to IC) overproduction



A visualization of a galactic dark matter halo simulation. The image shows a dense, spherical distribution of particles, primarily colored in shades of blue and purple, with a bright yellow-orange core. The particles are more concentrated towards the center, creating a radial gradient of brightness. The background is black, making the glowing particles stand out.

Many more clumps like the local clump...

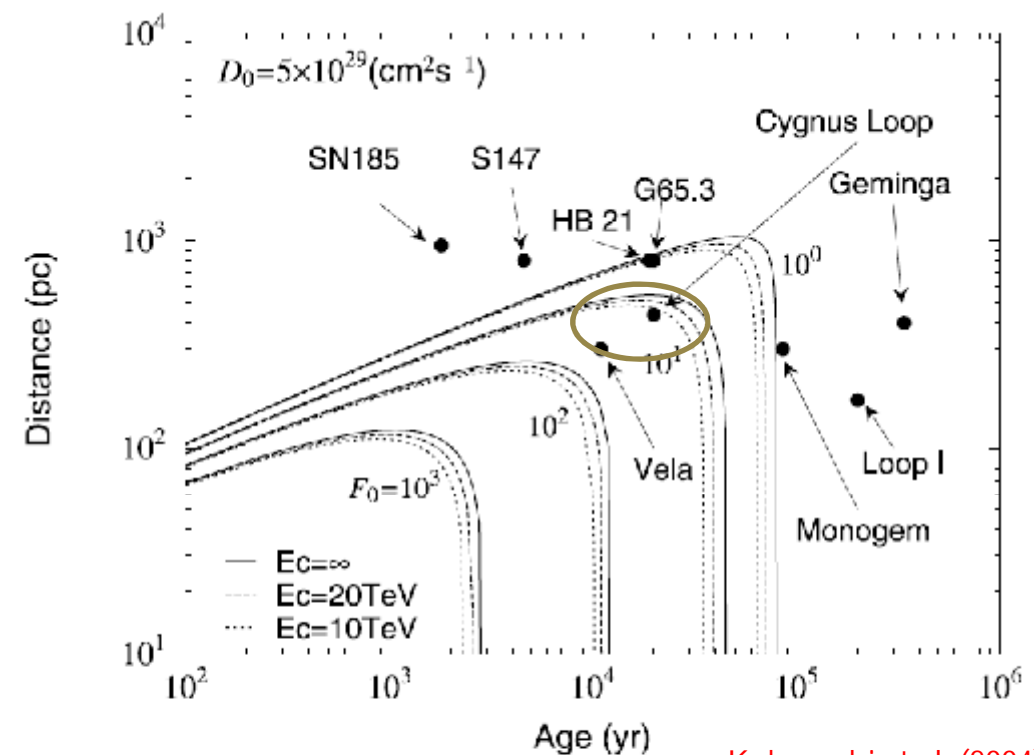
Galactic dark matter halo simulation (Springel et al. 2008)



"Say ... what's a mountain goat doing way up here in a cloud bank?"

Local Bubble Sources

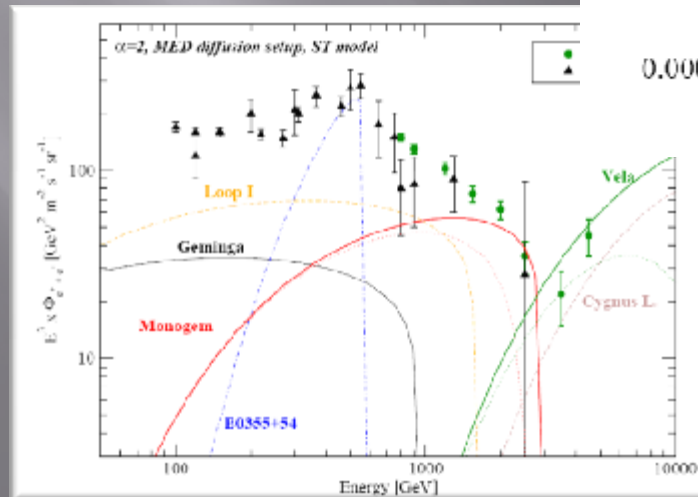
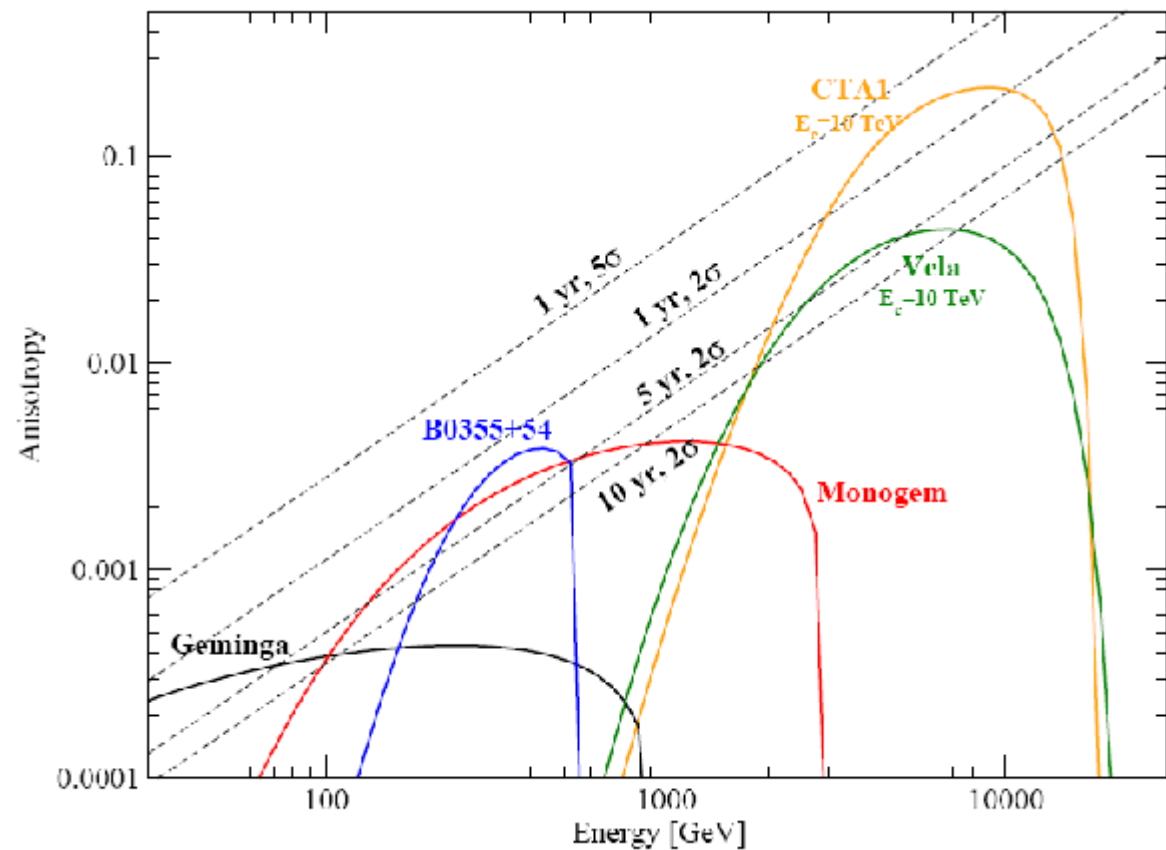
- Resolve enigma by assuming local component (Aharonian et al. 1995)
- Terminal Lorentz factor of pulsar winds with $\gamma \sim 10^6$ matches HESS-steepening
- Age and distance constraints render the overall energetics demanding
- Need time-dependent particle escape model for realistic assessment (Büsching et al. 2008)
- Use gamma-ray emission from pulsars as boundary condition for present-day activity



Kobayashi et al. (2004)

FIG. 2.—Contours of the electron flux at 3 TeV between distances and ages with the values of each SNR, in the case of the prompt release of electrons after the explosion. Lines show equal flux contour for $F_0 = (E/\text{GeV})^3 J \text{ GeV}^2 \text{ m}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$, where J is the flux of electrons at 3 TeV. Contour levels are 10^3 , 10^2 , 10^1 , and $10^0 \text{ GeV}^2 \text{ m}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$ with the output energy of electrons over 1 GeV of $W = 1 \times 10^{48}$ ergs per SN. Here the injection spectrum is a power law with an exponential cutoff of $E_c = 10 \text{ TeV}$ (dotted line), 20 TeV (dashed line), and ∞ (solid line). Upper and lower panels show the flux contours for $D = D_0 (E/\text{TeV})^{0.3}$ with $D_0 = 2 \times 10^{29}$ and $D_0 = 5 \times 10^{29} \text{ cm}^2 \text{ s}^{-1}$, respectively.

Anisotropy
challenge for **Fermi**
(Profumo 2009) due
to poor statistics at
highest energies



Opportunity for IACTs (large FOVs,
scanning surveys, low systematical errors)

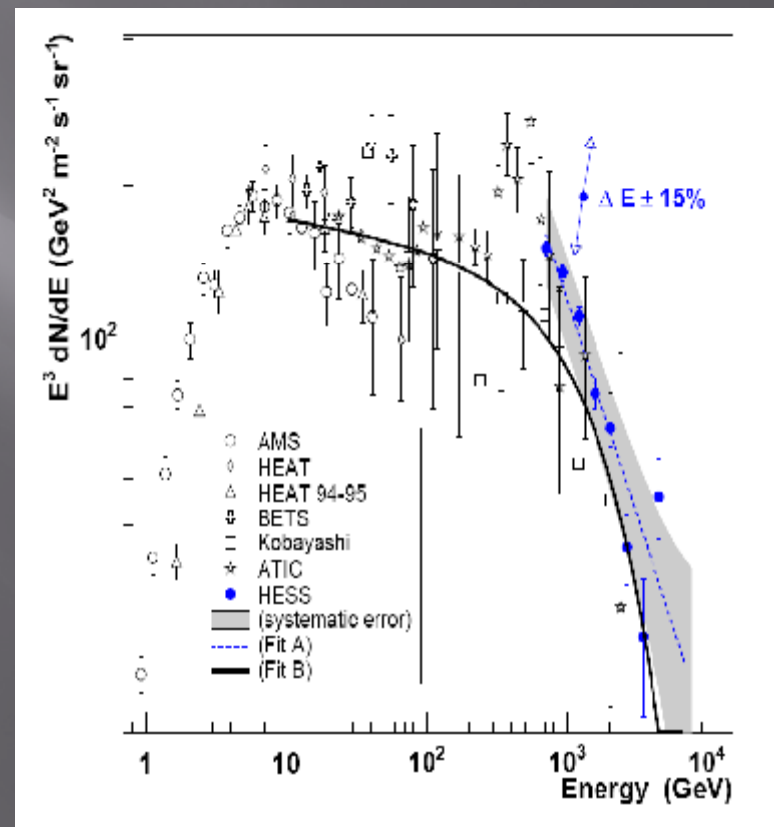
Trusting the data

Balloon (ATIC), near-Earth satellites (Pamela): Large background
IACT: H.E.S.S. 1st attempt with ground-based method

Can be cross-calibrated with Fermi

H.E.S.S.:

- Energy-dependent systematics?
[E.g., off-axis angle for accepted contained events]
- γ /hadron separation
[E.g., (multiple) π^0 carrying large momentum fraction]
- γ /e separation based on small (15%) difference in X_{\max}
 - Data far enough from disk?
 - Diffuse gamma rays from disk ($E^{-2.75}$) by same method?
 - Contamination with unknown, perhaps flaring, gamma ray sources?

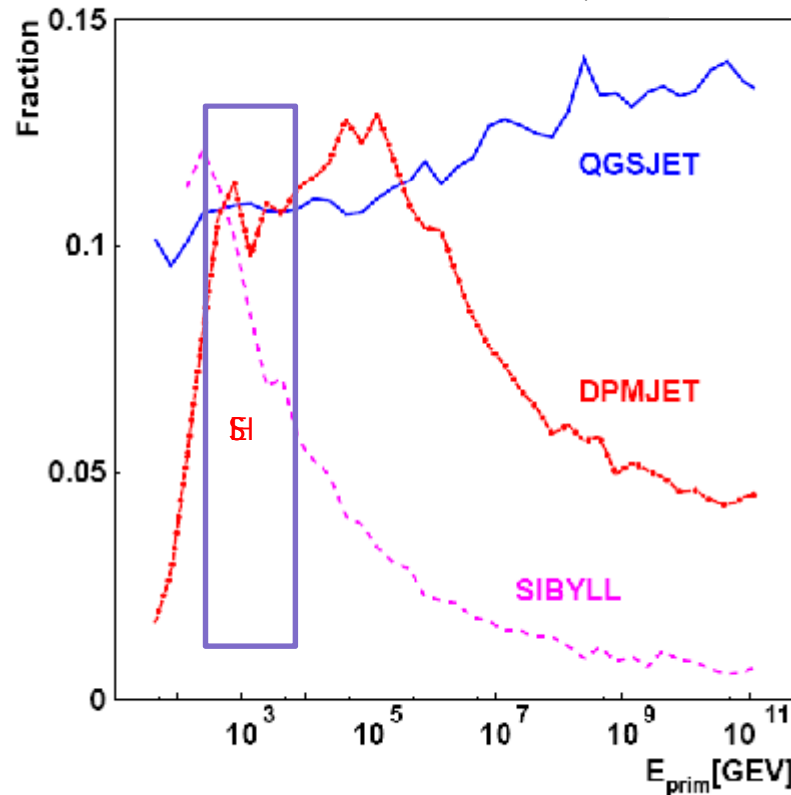


Diffractive events in proton-air interactions

TABLE III: Most energetic secondary particle probabilities.

	Pythia 6.2	Qgsjet 01	Qgsjet II	Sibyll 2.1
proton	55.29%	43.27%	62.08%	64.62%
neutron	27.34%	18.31%	19.68%	16.51%
Σ nucleons	82.63%	61.58%	78.76%	81.13%
π^\pm	10.28%	20.47%	6.77%	10.72%
π^0	4.89%	9.74%	3.02%	5.85%
K^\pm	1.57%	2.40%	0.73%	1.00%
K_L	0.63%	0.91%	0.44%	0.57%

Luna et al., 2004



Monte-Carlo Modeling of hadronic background for IACTs:

Uncertainties due to unknown
non-perturbative low-x physics
(reflected by very different
implementations of diffractive
events in SIBYLL and QGSJET)

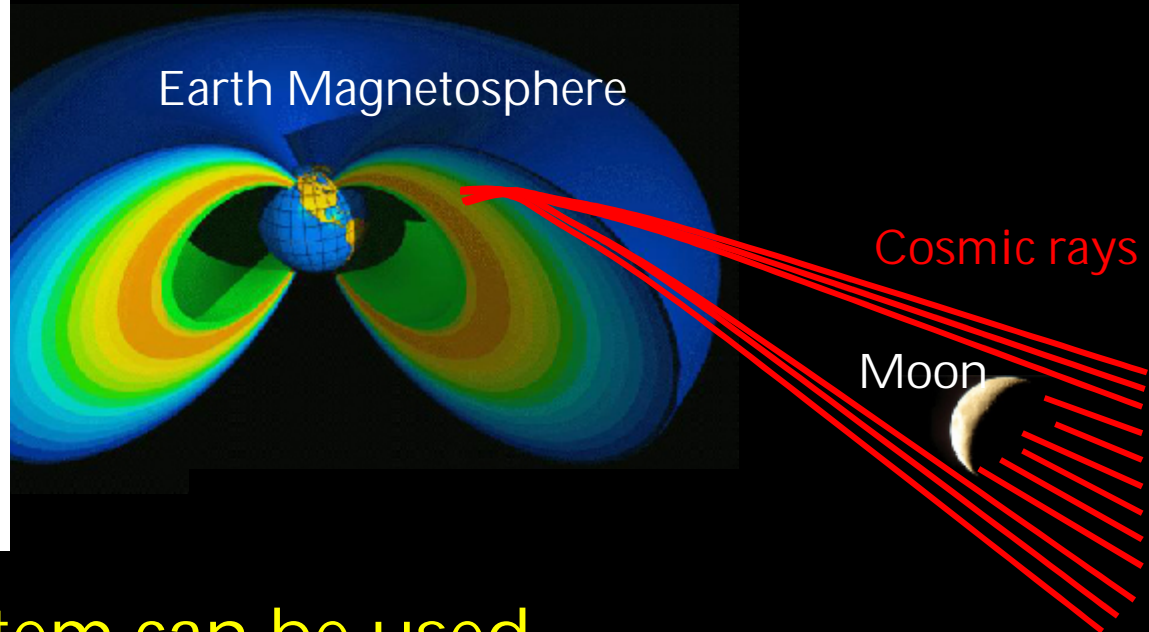
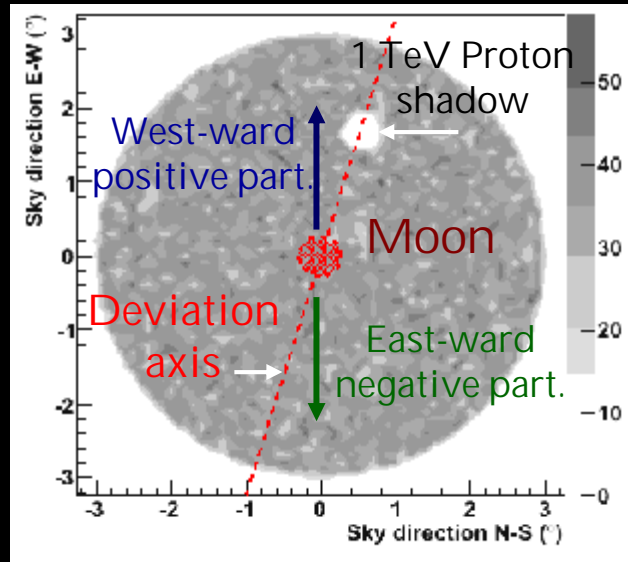
Suppression of diffractive
events reduces X_{\max}

The IACT Challenge

- .. Improve low-x physics in MC simulations
- .. Increase statistics
 - ı **MAGIC** has huge extragalactic exposure, **analysis ongoing...**
 - ú Lacking X_{max} from single dish, but with good control over NSB due to 2GHz sampling (timing analysis)
 - ı **CTA** with effective area of 10^6 m^2
- .. Search for electron anisotropy (should be highest at IACT energies)
- .. Observations of nearby pulsars to obtain boundary conditions for injection models (MILAGRO data from Geminga region!)
 - ı Pulsar observations with **MAGIC, H.E.S.S., VERITAS**
- .. Geomagnetic spectrometer: **Moon shadow** experiment (proposed by **MAGIC** cosmic ray working group)

MAGIC: Moon shadowing effect

(see poster by Pierre Colin)

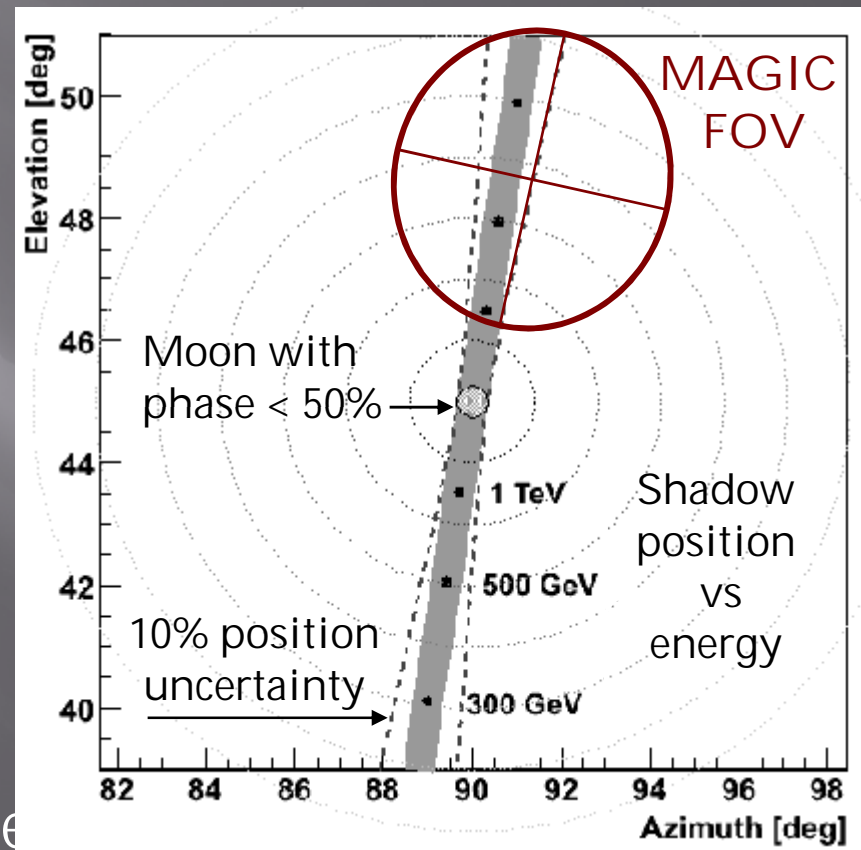


Earth-Moon system can be used
as a spectrometer .

- ∅ The Moon blocks CR and creates a deficit (shadow).
- ∅ The geomagnetic field deflects the Moon shadow position.
- ∅ IACT can reconstruct energy/direction of any particles and discriminate electromagnetic / hadronic showers.

Observation of Moon shadow with MAGIC-Stereo

- Position of the 300 GeV-1TeV shadows:
~ 3.5 deg from Moon
- Properties of the “anti-source”
 - 3/5% crab flux for electron
 - 0/2% crab flux for positron
 - Extension = ~2 x Moon area
- Difficulties:
 - Huge NSB (from moon light)
 - NSB gradient through field of view
 - Uncertainty on the shadow position (geomagnetic field effect)



Feasibility of this observation is under study: see Colin et al. ICRC 2009

Summary

- .. New era for particle transport theory:
Heliosphere à Local Bubble
- .. Improve understanding of time-dependent injection based on pulsar wind models
- .. Cross-calibration of IACT data with Fermi will improve MC background modeling and hadron/gamma/electron cuts.
- .. CTA will give boost to sensitivity for anisotropy studies and further extension of the spectrum