Multi-Messenger Astonomy with Cen A?

Michael Kachelrieß

NTNU, Trondheim

Outline of the talk

1. Introduction
2. Dawn of charged particle astronomy?
   - Expectations vs. Auger data
   - Effects of cluster fields
3. Multi-messenger astronomy with Cen A?
4. Conclusions

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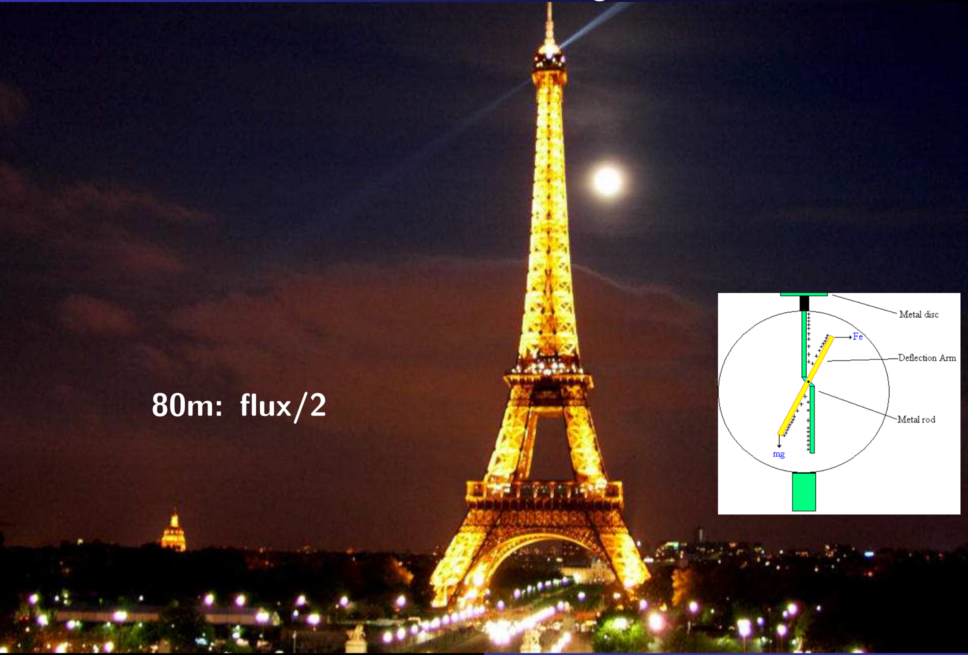

80m: flux/2

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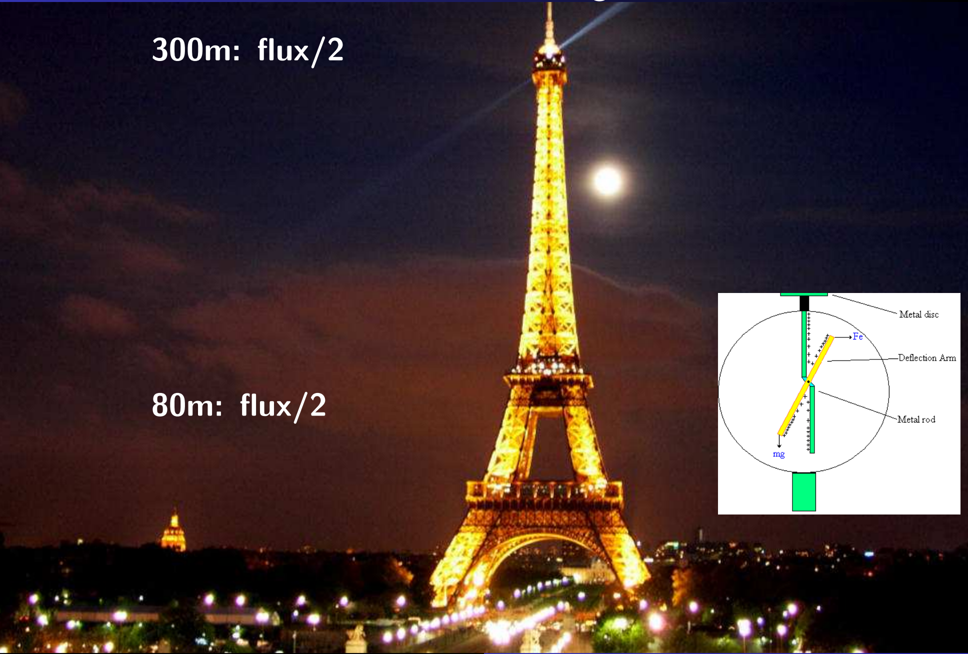
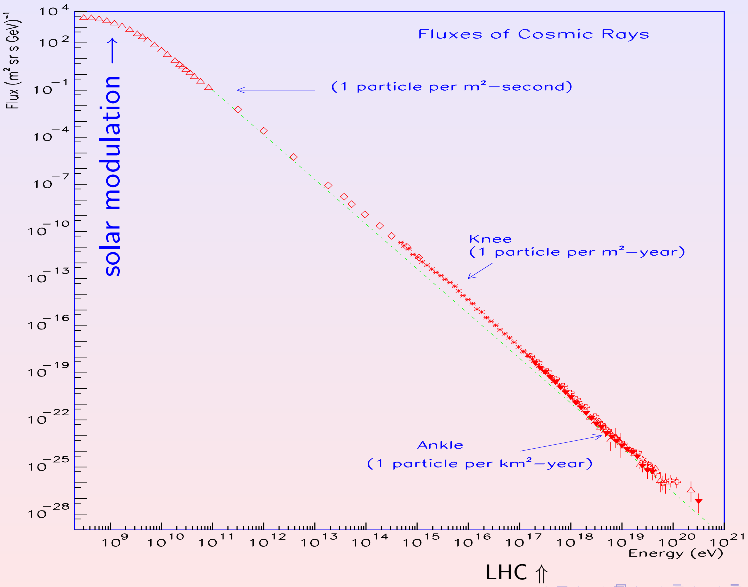


What do we know 98 years later?



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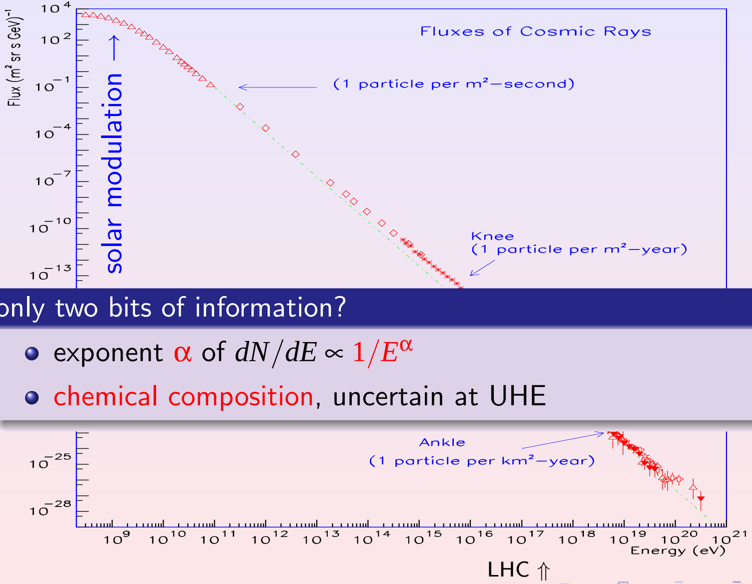
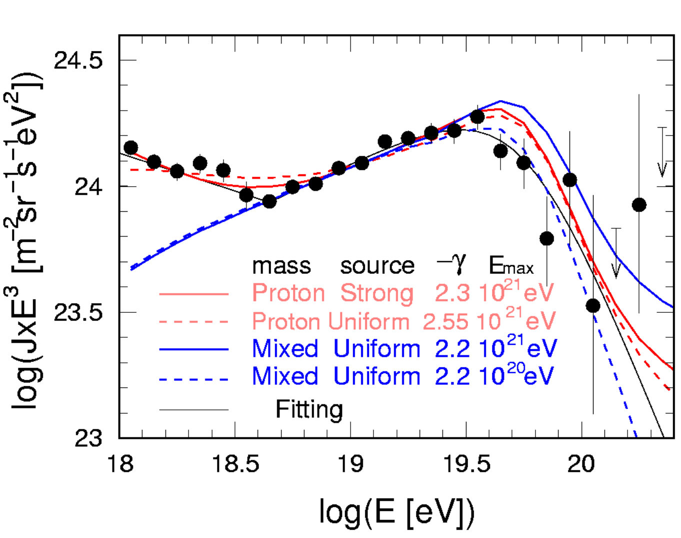


only two bits of information?

- exponent α of $dN/dE \propto 1/E^{\alpha}$
- chemical composition, uncertain at UHE

PAO data: energy spectrum



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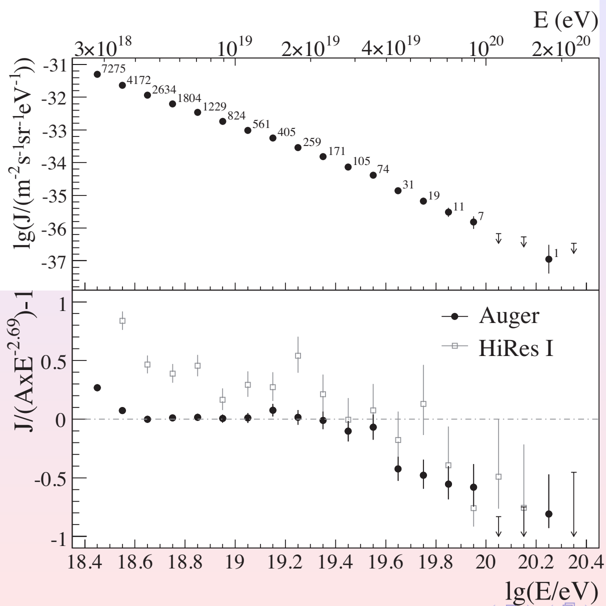

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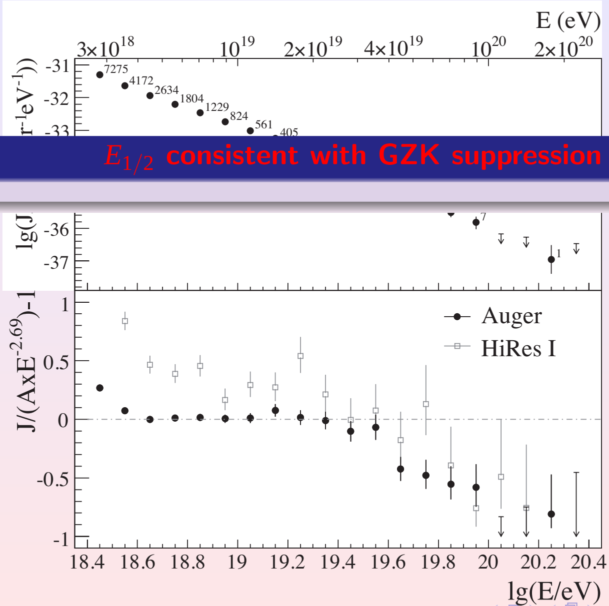
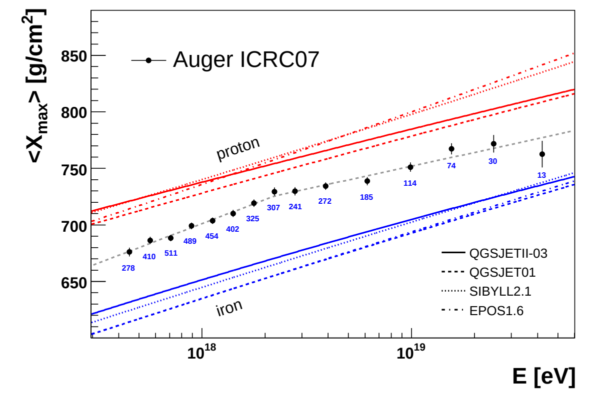


$E_{1/2}$ **consistent with GZK suppression**

PAO data: chemical composition



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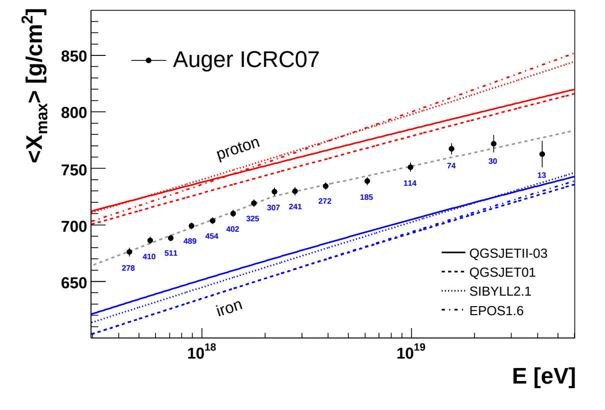

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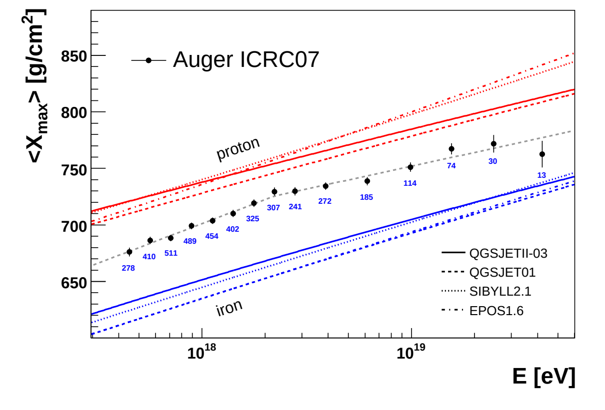

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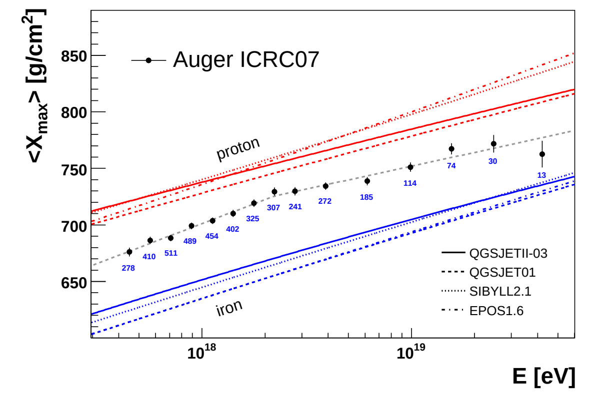

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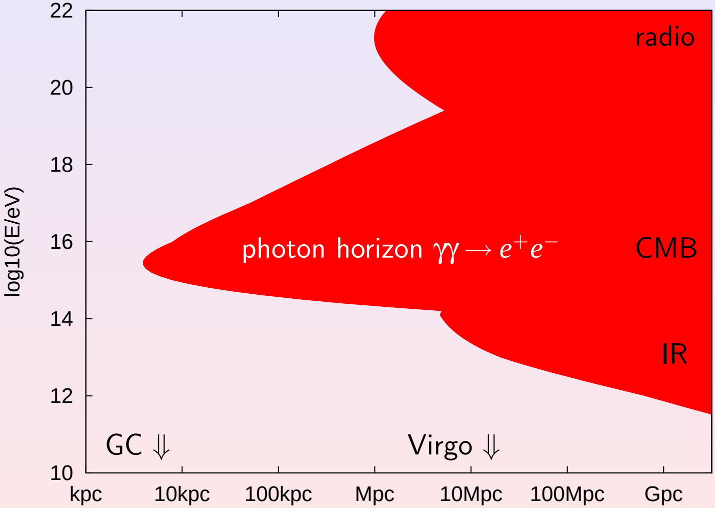
- points to heavier composition at UHE
- supported by fluctuations of $X_{\rm max}$

What is the bonus of UHECR astronomy?

- astronomy with VHE photons restricted to few Mpc:



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  - small event numbers: $\lesssim$ few/yr for PAO or ICECUBE
  - identification of steady sources challenging

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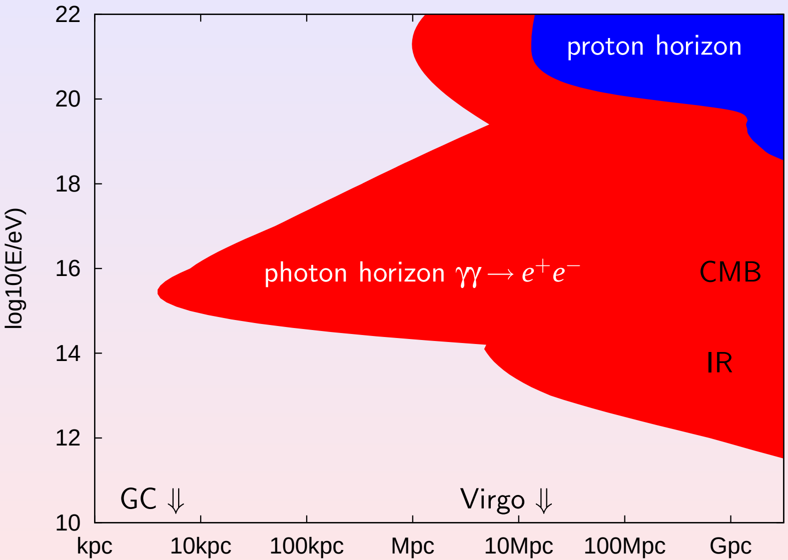

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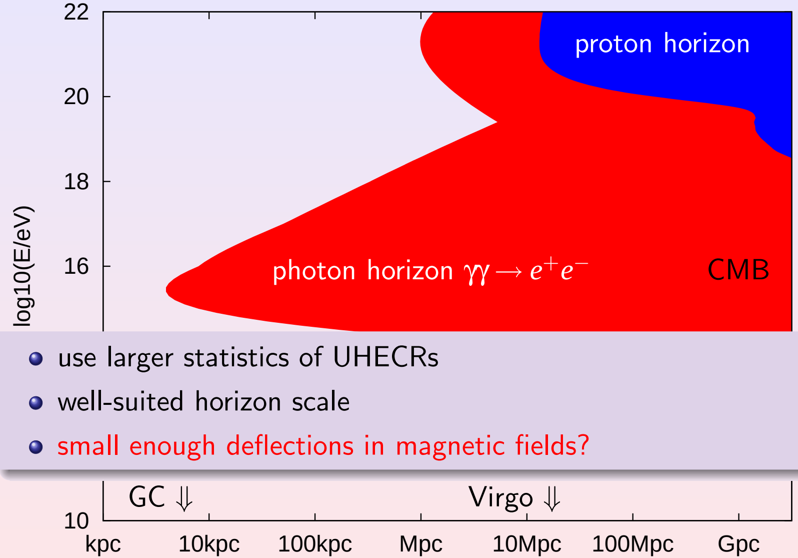
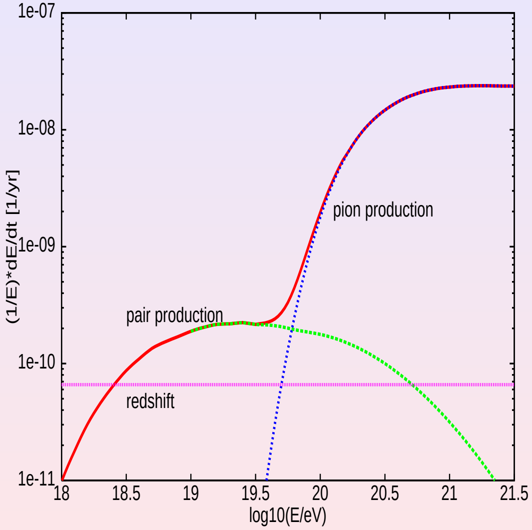


- use larger statistics of UHECRs
- well-suited horizon scale
- small enough deflections in magnetic fields?

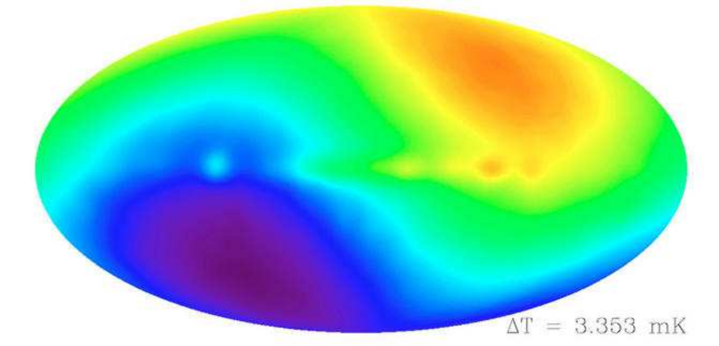
Energy losses, the dip and the GZK cutoff



- at $E \sim 4 \times 10^{19}$ eV: $N + \gamma_{3K} \to \Delta \to N + \pi$ starts and reduces free mean path to ~ 20 Mpc
- pair production leads to a dip at $\sim 10^{19}$ eV

Possible anisotropies of extragalactic CRs:

1. Dipole anisotropy – cosmolog. Compton-Getting effect
   - induced by motion of Sun relative to cosmological rest frame
   - requires $\lambda_{\mathrm{CR}}(E) \gtrsim \lambda_{\mathrm{LSS}}$



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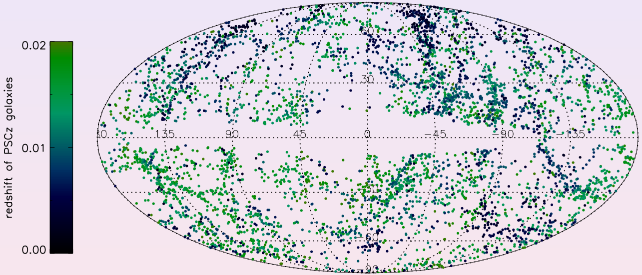

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4. Correlations with specific sources
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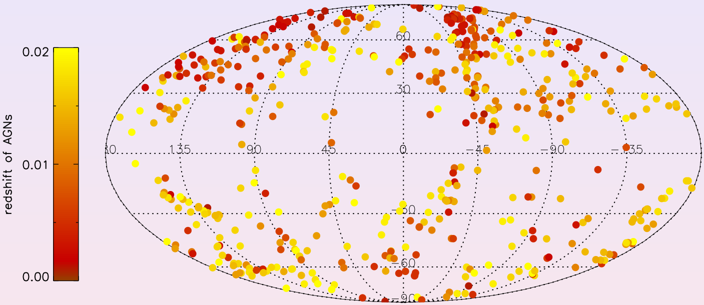
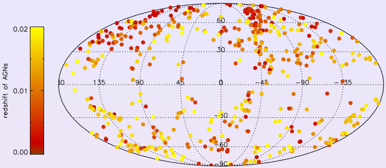
AGN from VCC catalogue:



Correlations with AGNs: Auger analysis



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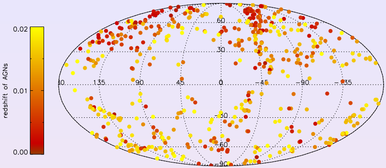

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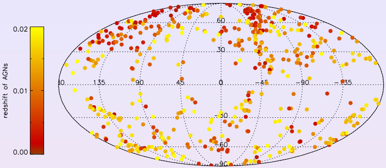

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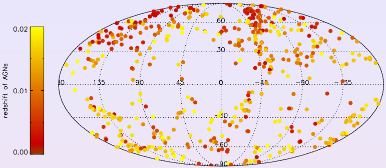

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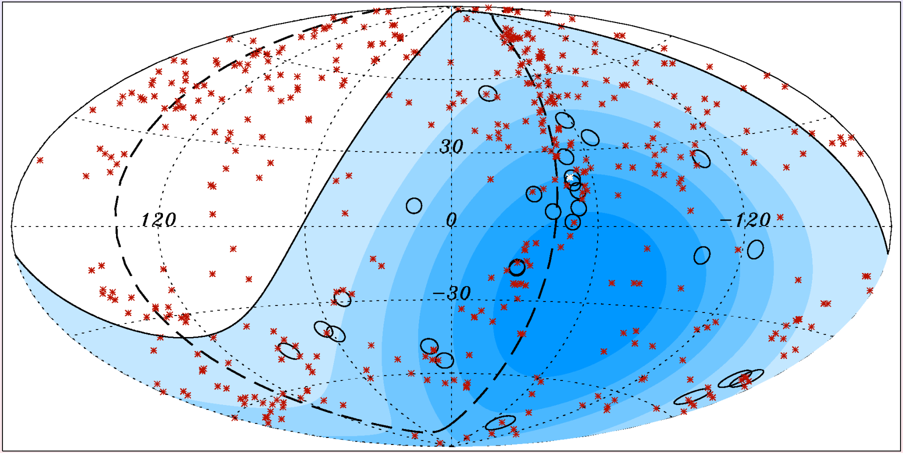
- AGN or something with similar distribution?

Correlations with AGNs: PAO analysis

- 27 CRs ($\odot$) and 472 AGN ($*$):



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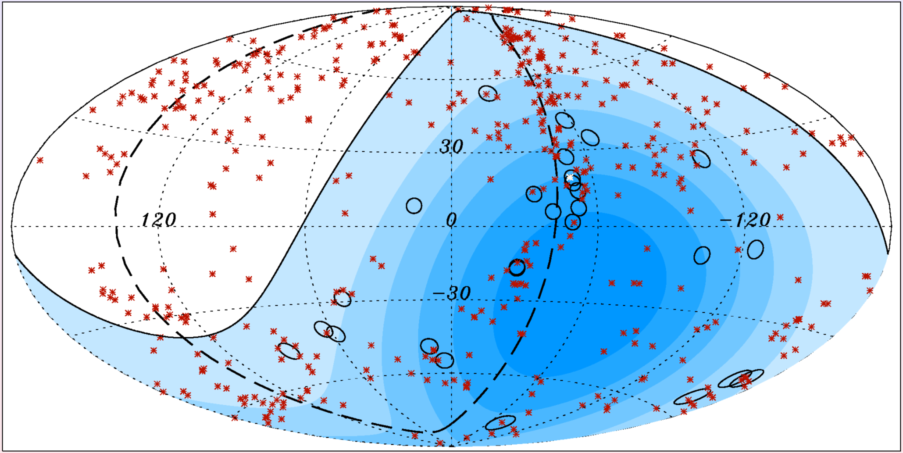
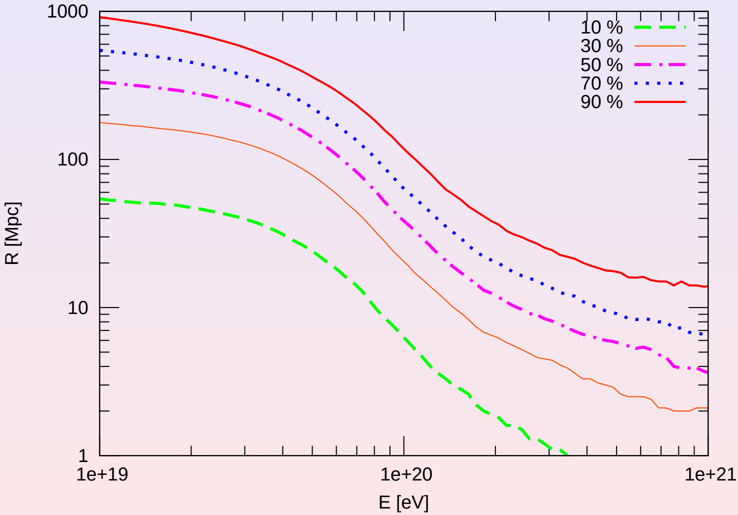


Virgo does not contribute [Gorbunov et al. '08]

Energy threshold consistent with GZK horizon?

- 8 out of 13 CRs ($E \geq 57\,\text{EeV}$) correlated within 75 Mpc:



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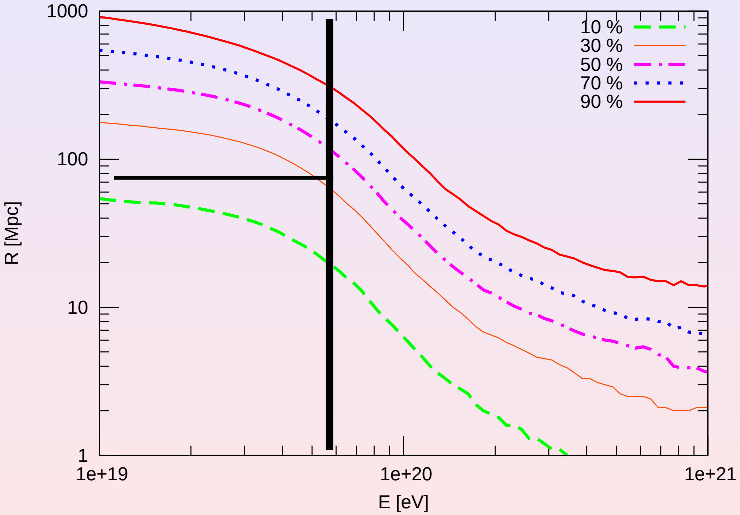

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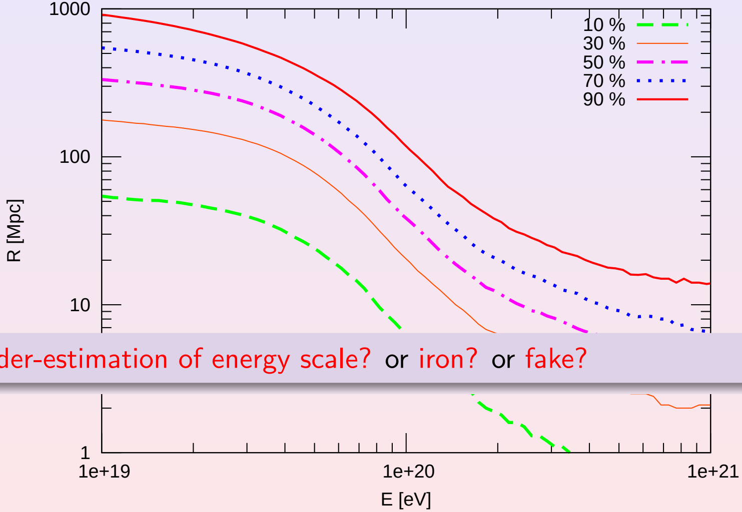

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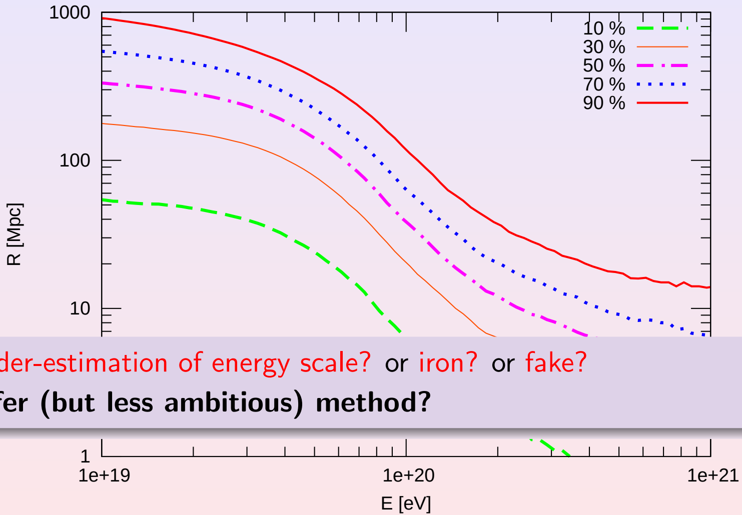

under-estimation of energy scale? or iron? or fake?

safer (but less ambitious) method?

Comparing with sources:

- Use the auto-correlation function,

$$w(\vartheta) = \frac{DD(\vartheta)}{RR(\vartheta)} - 1\,,$$

where

- DD: number of pairs in catalogue
- RR: number of pairs in random sets

for most popular sources of UHECRs:

Comparing with sources:

[A. Cuoco et al. '07, '08]

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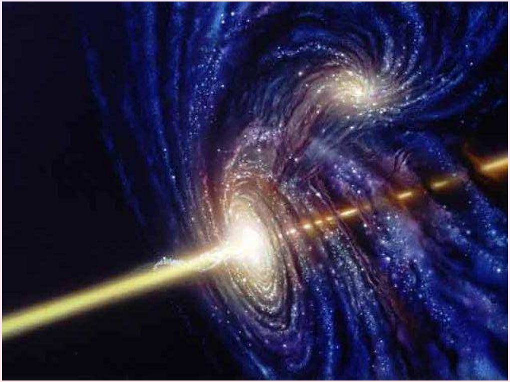

Comparing with sources:

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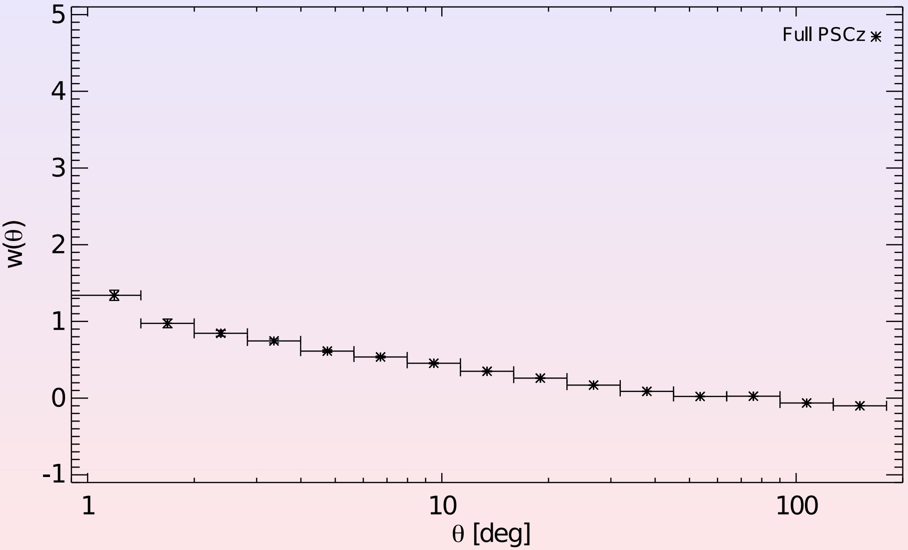
Auto-correlation function of different sources: [A. Cuoco et al. '07]



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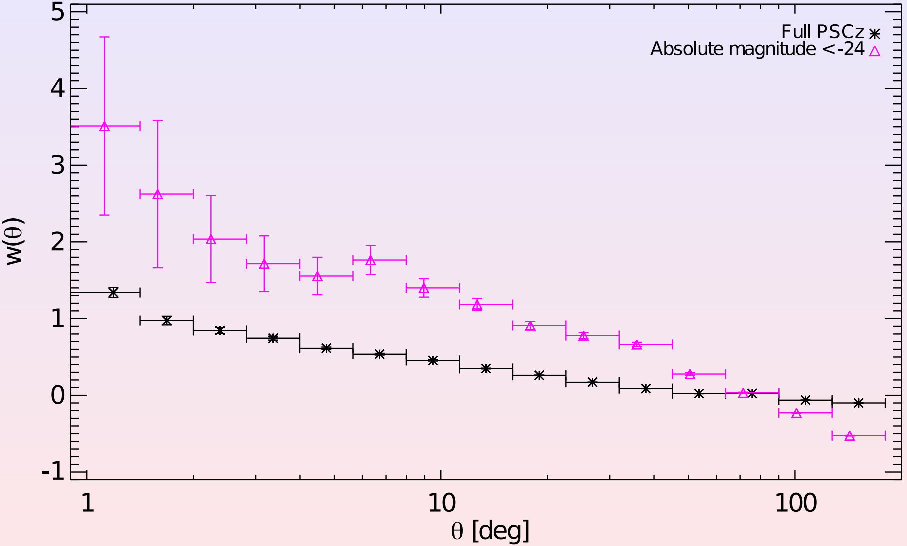

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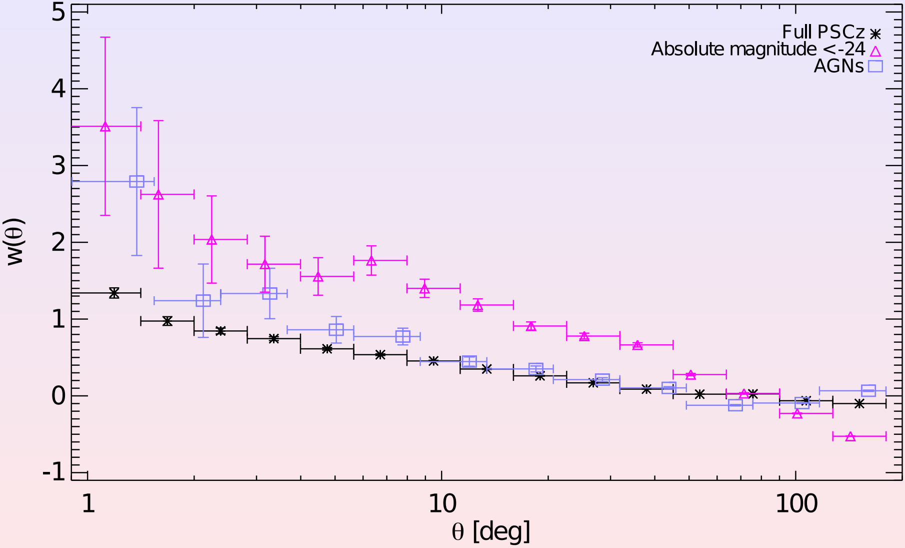

Auto-correlation function of different sources: [A. Cuoco et al. '07]

- differences on all angular scales
- reduced statistical error
- reduced dependence on B:
  - global comparison on all scales
  - only relative deflections enter
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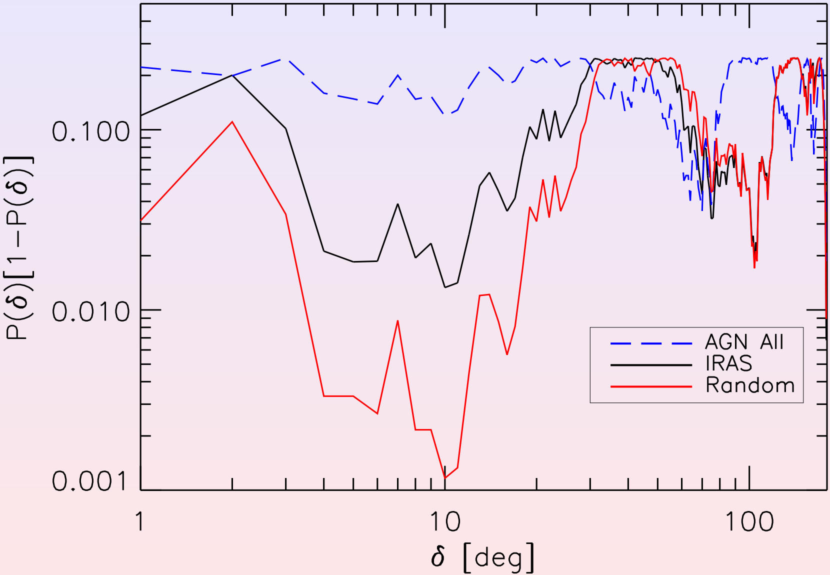
Clustering signal for the PAO–Science data

[A. Cuoco et al. '08]



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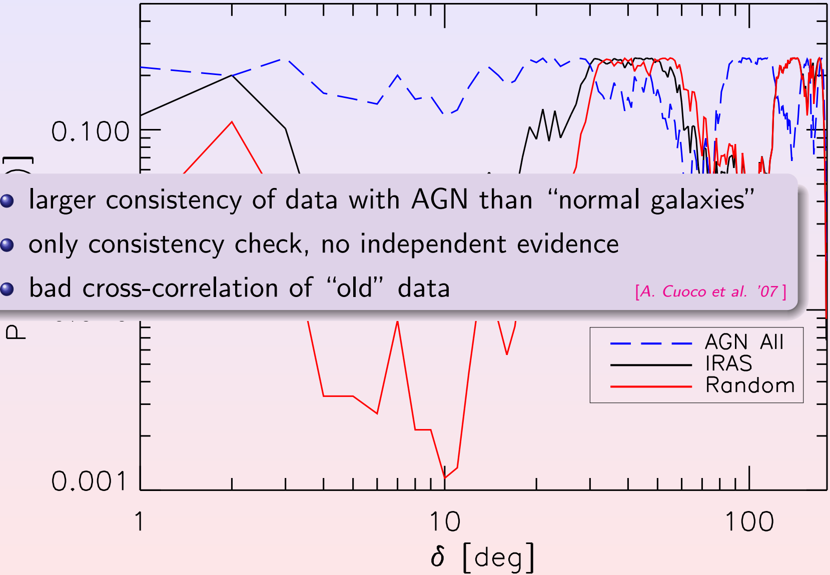
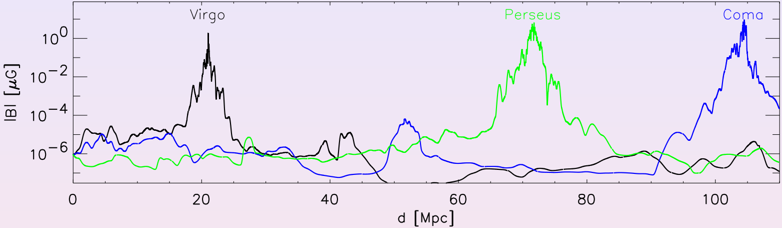


- larger consistency of data with AGN than "normal galaxies"
- only consistency check, no independent evidence
- bad cross-correlation of "old" data [A. Cuoco et al. '07]

Effects of cluster fields

- Sources sit in regions with $\rho \gg \langle\rho\rangle$ and $B \gg \langle B\rangle$



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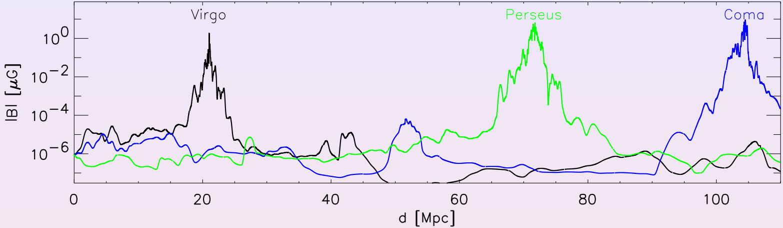
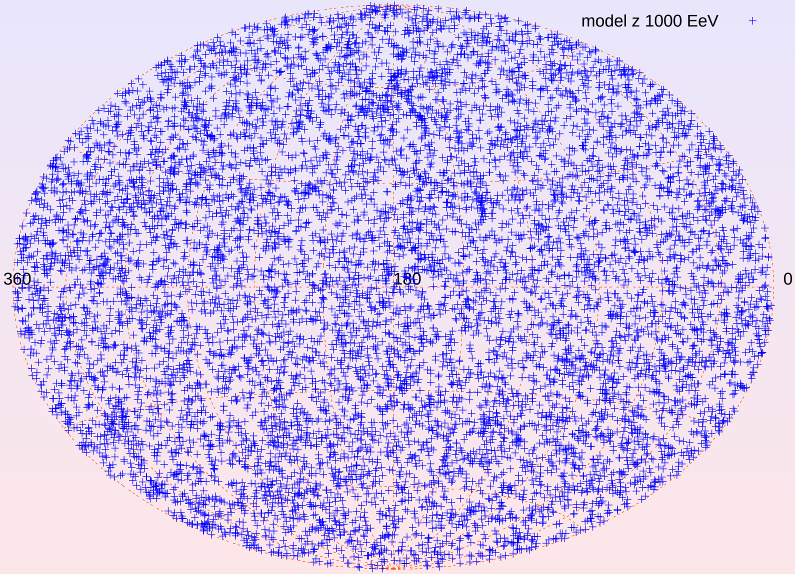


- what are effects of cluster fields?

Anisotropies of a single source at 1000 EeV/Z



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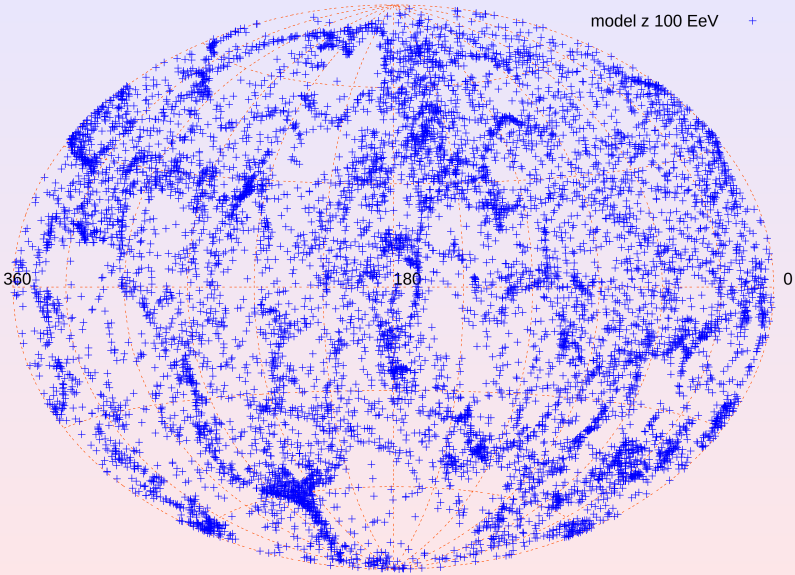
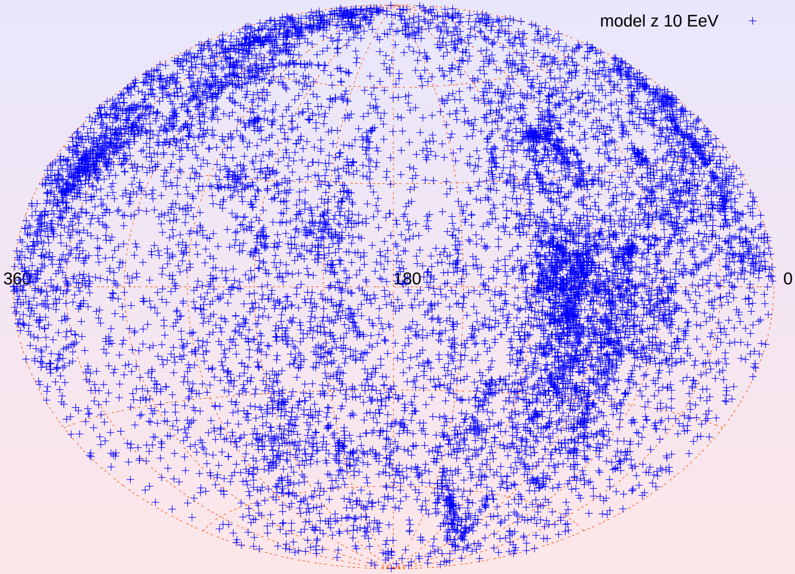


Anisotropies of a single source at 10 EeV/Z



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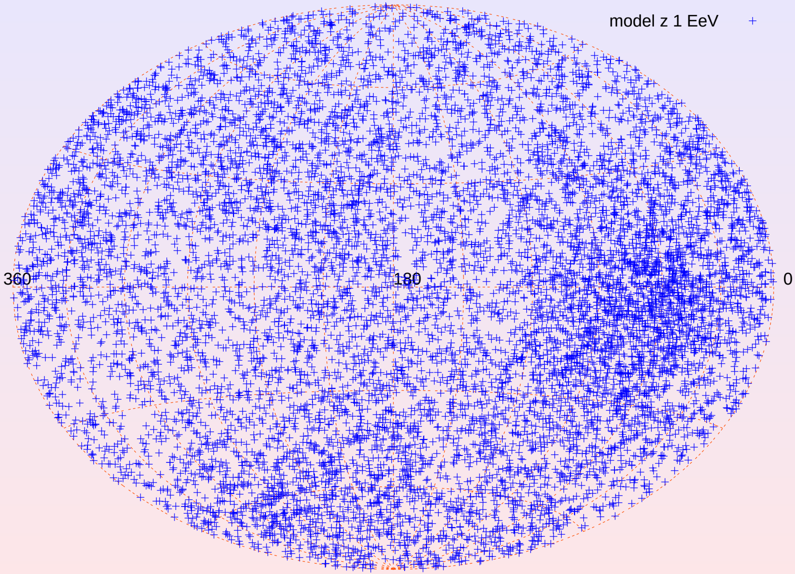
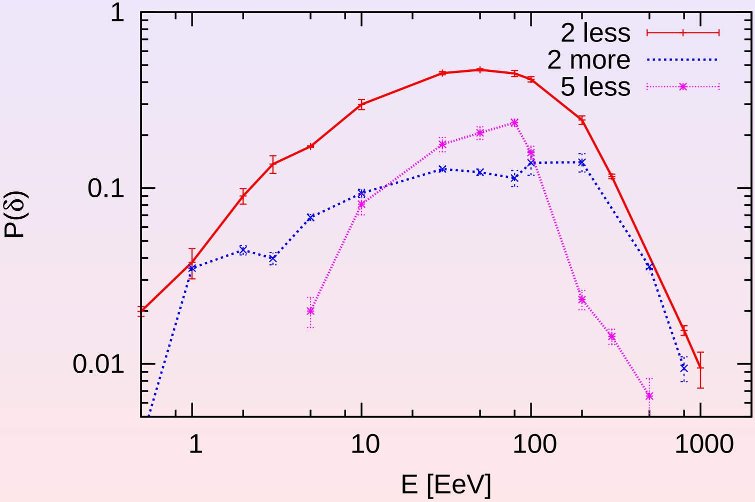


[K. Dolag, MK, D. Semikoz '08]

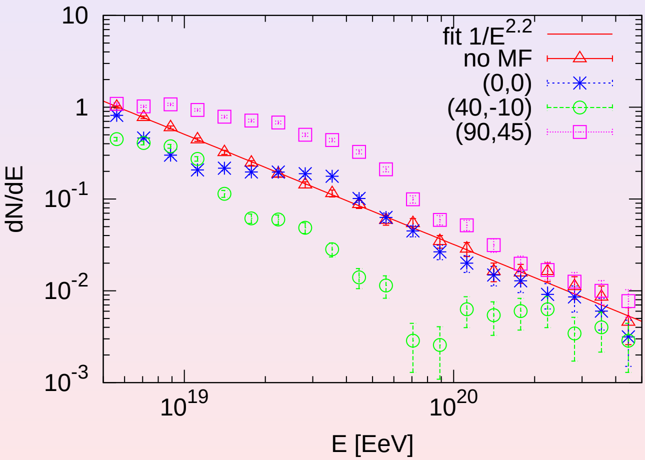
- anisotropies hide cluster for part of observer



Effects of cluster fields:

[K. Dolag, MK, D. Semikoz '08]

- anisotropies hide cluster for part of observer
- modulate the energy spectrum



Multi-Messenger Astronomy with Cen A?

MK, S. Ostapchenko, R. Tomàs '08

Possible source/acceleration scenarios for Cen A:

- mechanism: shock acceleration vs. acceleration in regular fields
- location: core, hot spots, along the jet
- target: gas vs. photons

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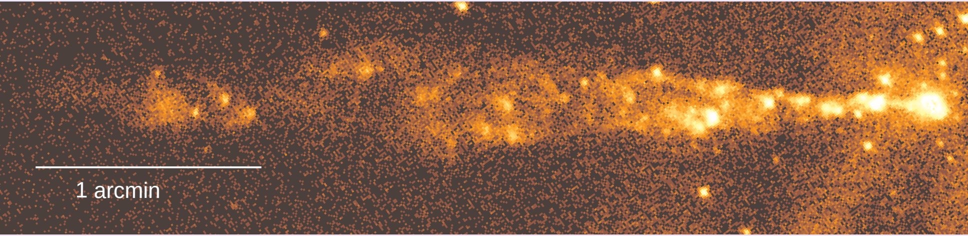
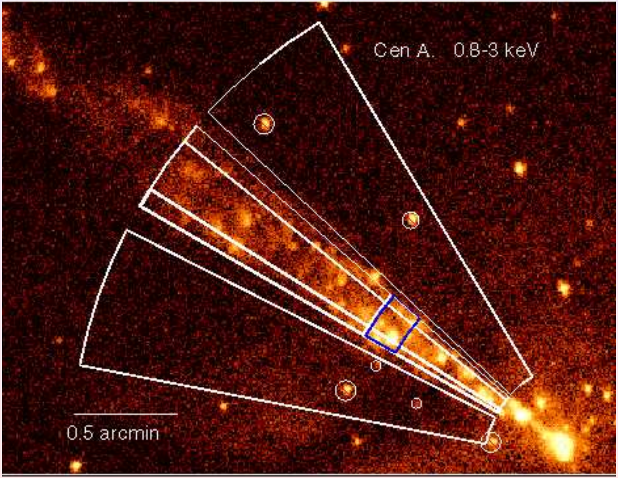
- neglect acceleration
- fix 2 basic scenarios: "core" and "jet"
- fix n_γ and n_H by observations
- normalization of UHECRs by PAO AGN hypothesis

Chandra observation of X-ray emission in the jet

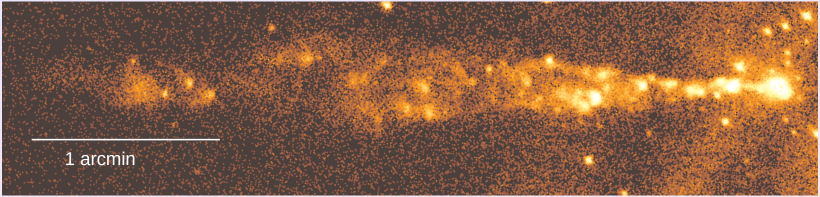


Chandra observation of X-ray emission in the jet

- divide in subareas
- separate fit to gas column density X and spectral index α



Chandra observation of X-ray emission in the jet: Results



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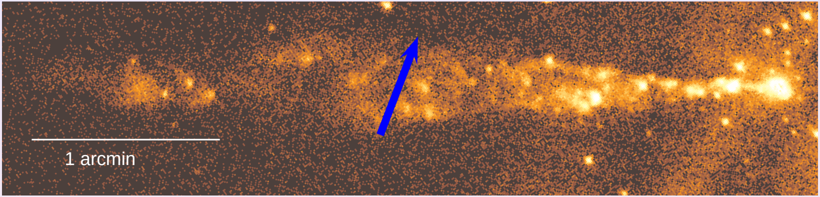
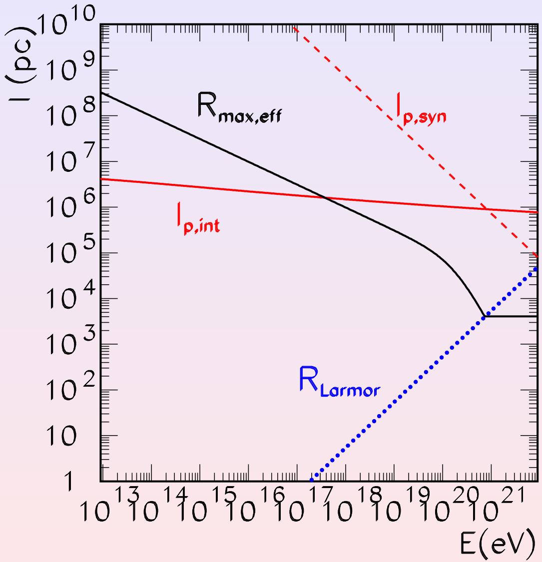


- $X = 1.5 \times 10^{21}/\text{cm}^2$ in the jet
- with $d = 0.4\,\text{kpc}$ and $\sigma_{pp} = 150\text{mbarn}$:

$\Rightarrow$ interaction depth $\tau_{pp} \sim 0.01$

Length scales for acceleration in the jet



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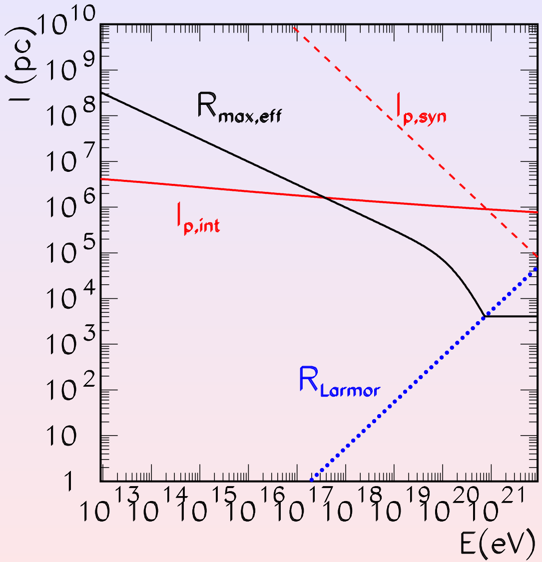

- diffusion increases effective size

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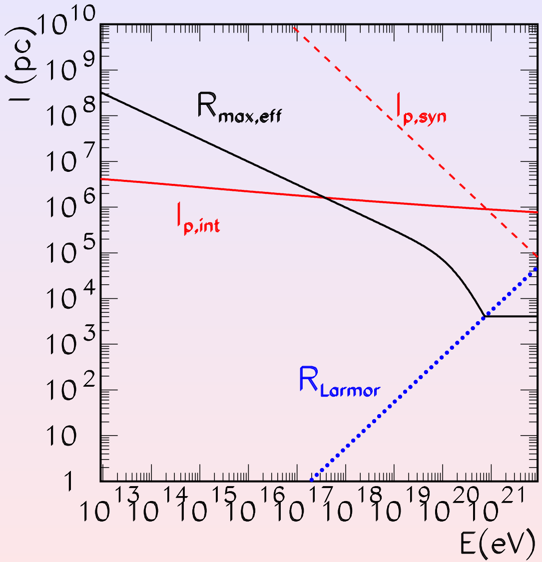


- diffusion increases effective size
- for pp no threshold
- $\tau = 1$ for $E = 10^{17}$eV, optimal for neutrino telescope

Our two base models

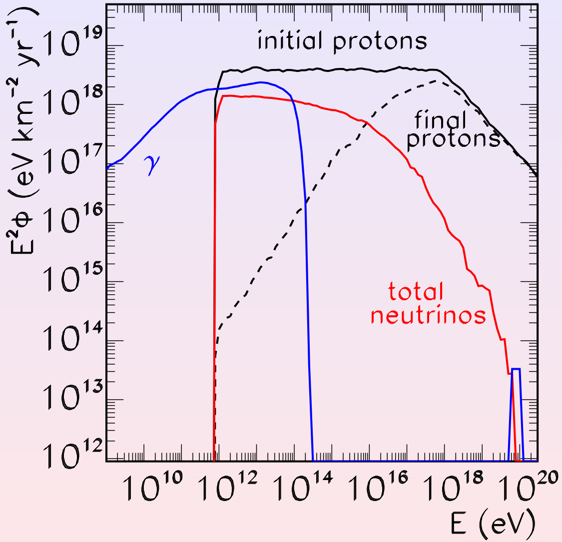
acceleration close to the core

- acceleration in accretion shock/regular fields
- pγ interactions
- $\tau_{\gamma\gamma} \gg 1$, synchrotron losses for $e^{\pm}$

acceleration in jet

- shock acceleration
- pp interactions
- $\tau_{\gamma\gamma} \ll 1$, synchrotron losses for $e^{\pm}$

Results for acceleration in jet: broken power-law



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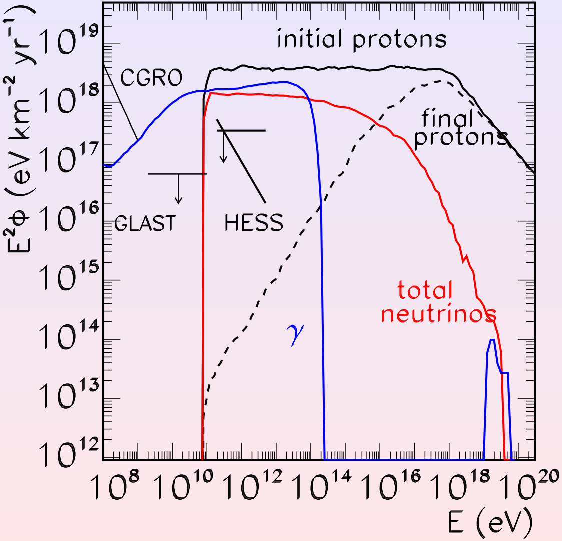
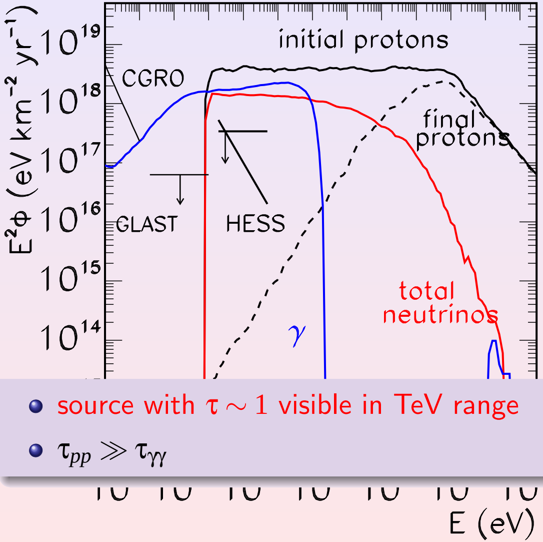
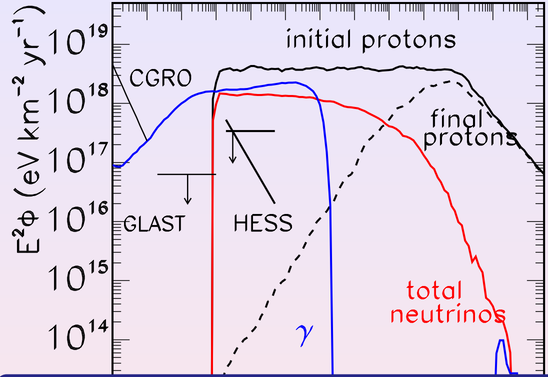




- source with $\tau \sim 1$ visible in TeV range
- $\tau_{pp} \gg \tau_{\gamma\gamma}$

Results for acceleration in jet: broken power-law



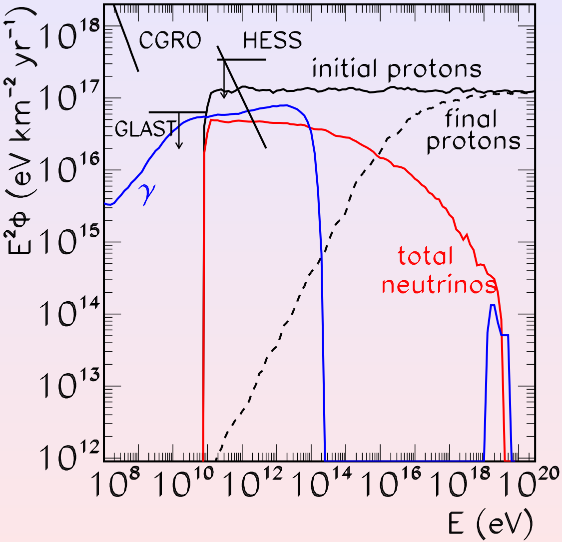
$\alpha = 2.7$ required for diffuse CR flux in "dip model"

- disfavoured as spectrum of single source Cen A

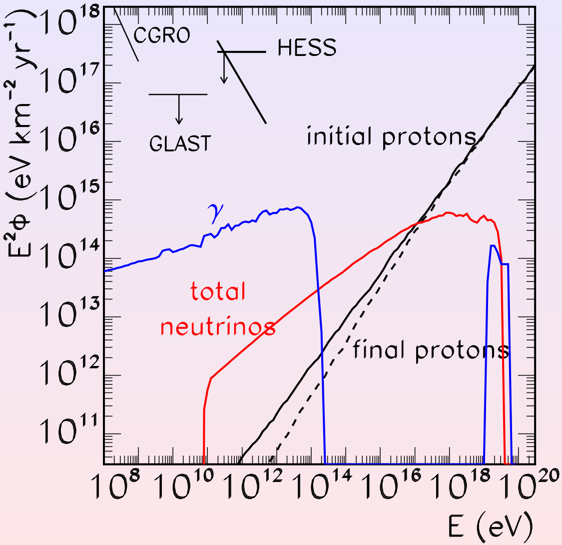
⇒ diffuse spectrum = superposition of single sources with $dn/dE_{\max}$ distribution

- HE γ observations constrain UHECR models

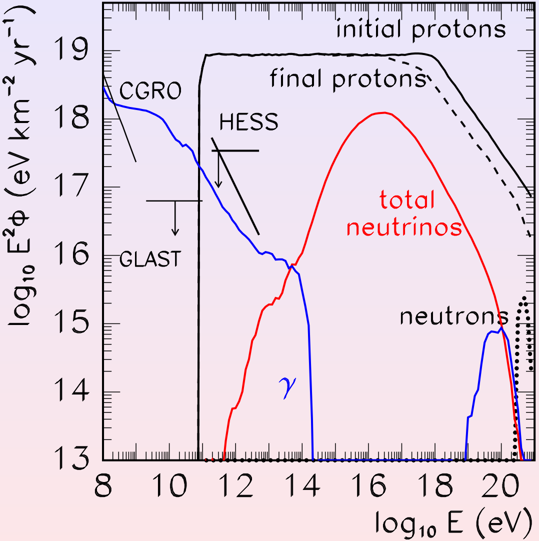
Results for acceleration in jet: $\alpha = 2$



Results for acceleration in jet: $\alpha = 1.2$



Results for acceleration close to the core: broken power-law



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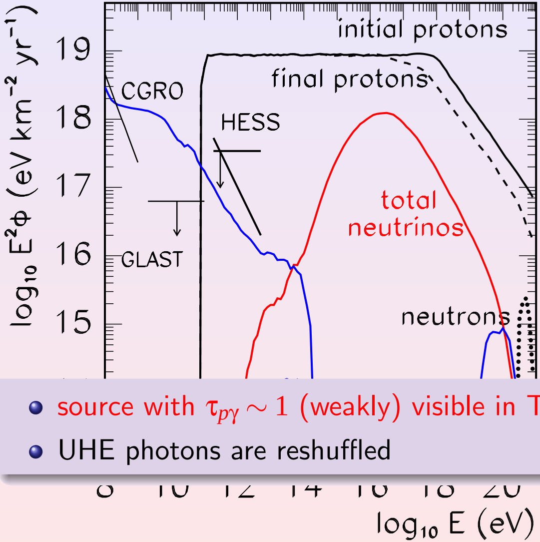
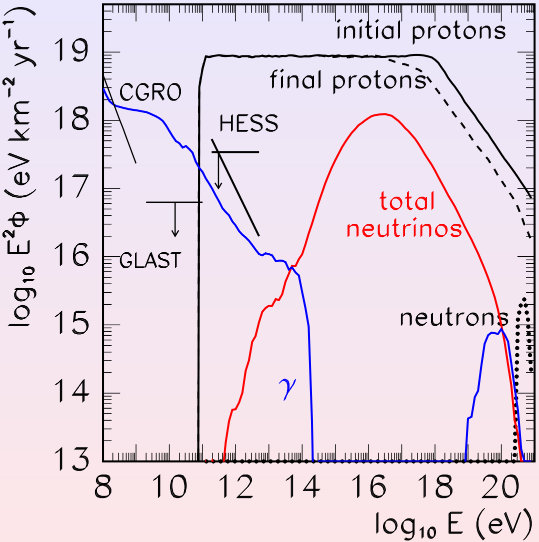


- source with $\tau_{p\gamma} \sim 1$ (weakly) visible in TeV range
- UHE photons are reshuffled

Results for acceleration close to the core: broken power-law



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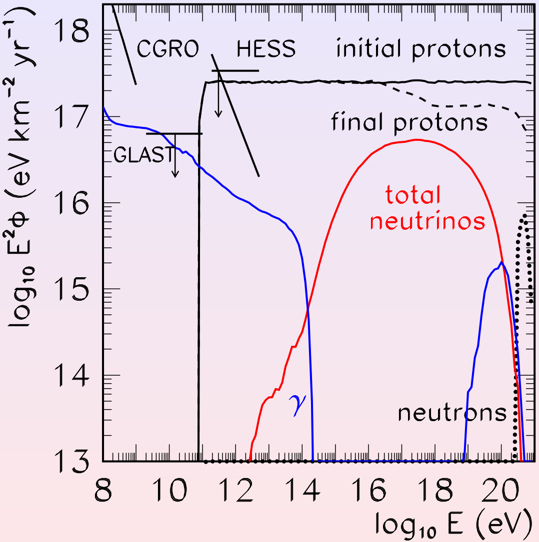

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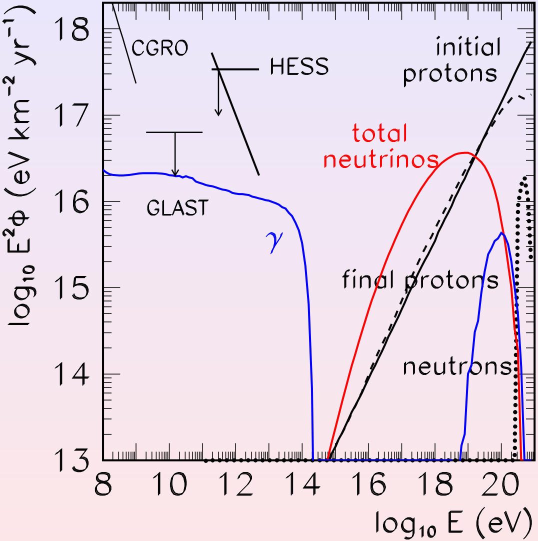

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[*Koers, Tinyakov '08*]

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