

The High Energy Universe: Observations and Implications

Andreas Ringwald

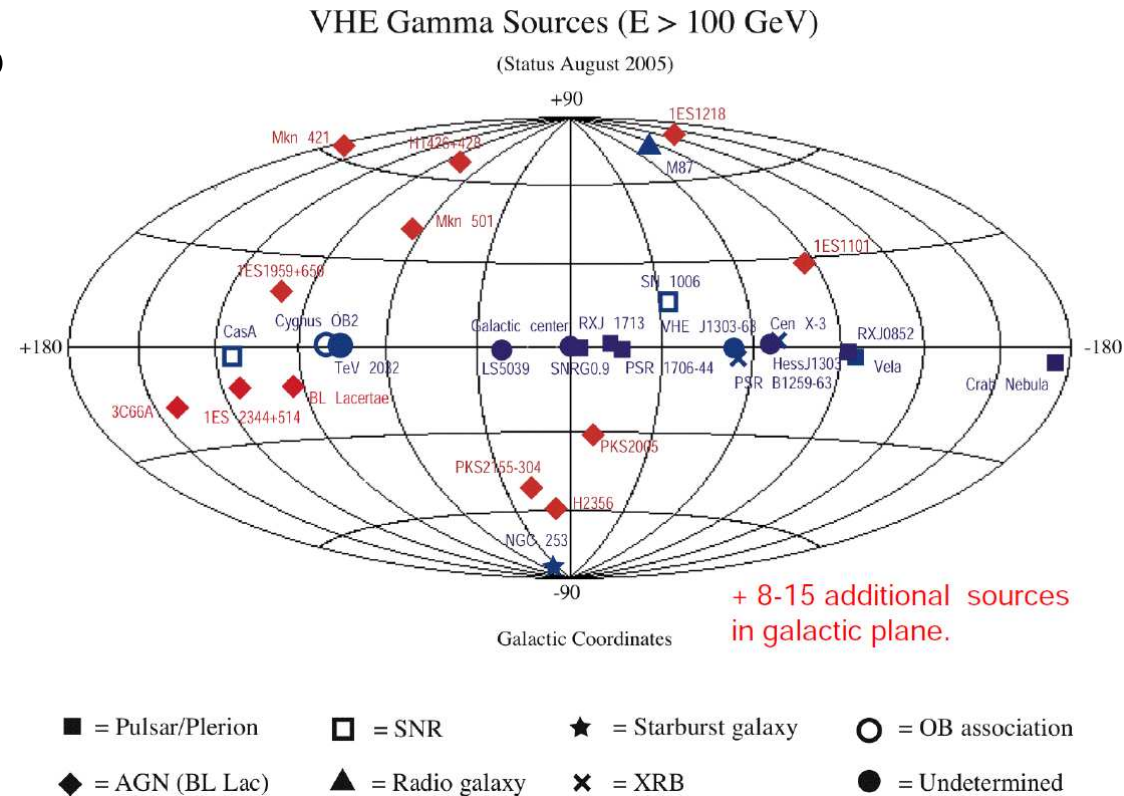
<http://www.desy.de/~ringwald>



**2nd Vienna Central European Seminar on Particle Physics and
Quantum Field Theory, "Frontiers in Astroparticle Physics",
November 25 - 27, 2005, Vienna, Austria**

1. Introduction

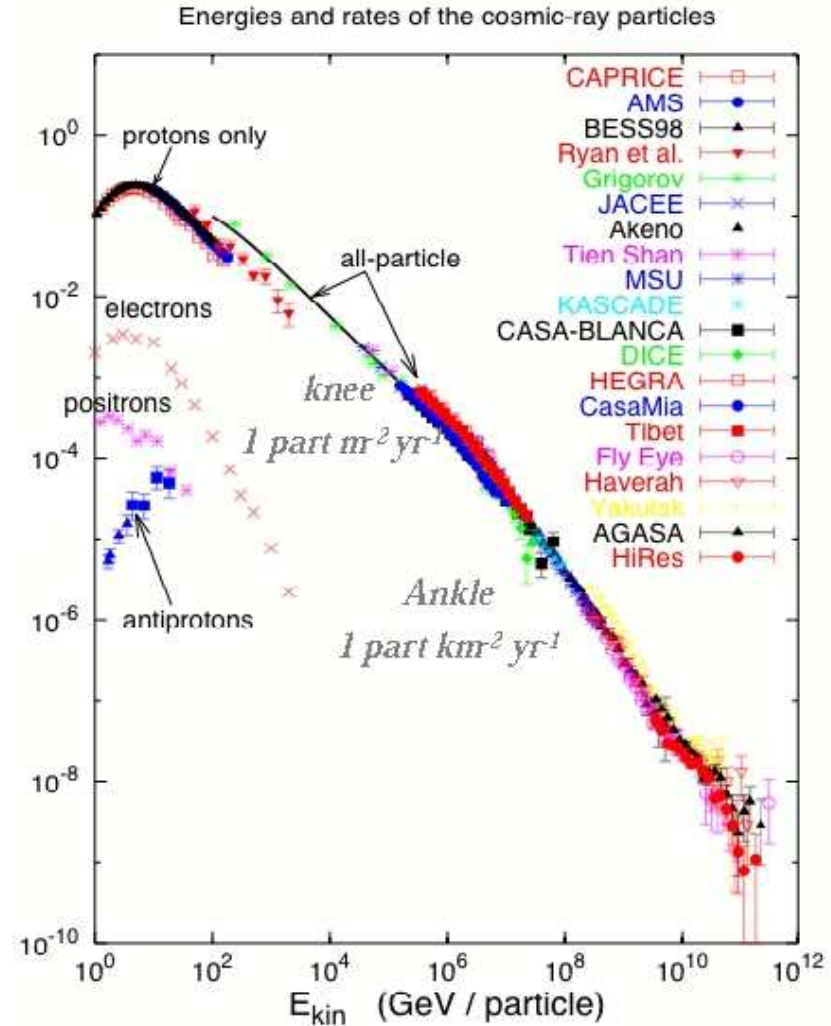
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Gamma rays have been identified up to energies $E \lesssim \text{few} \times 10^3 \text{ GeV}$



[M. Martinez '05]

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[T. K. Gaisser '05]

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- **It is under active observation:**
Gamma ray observatories: e.g. **H.E.S.S., MAGIC**
Air shower detectors: e.g. **Pierre Auger Observatory**

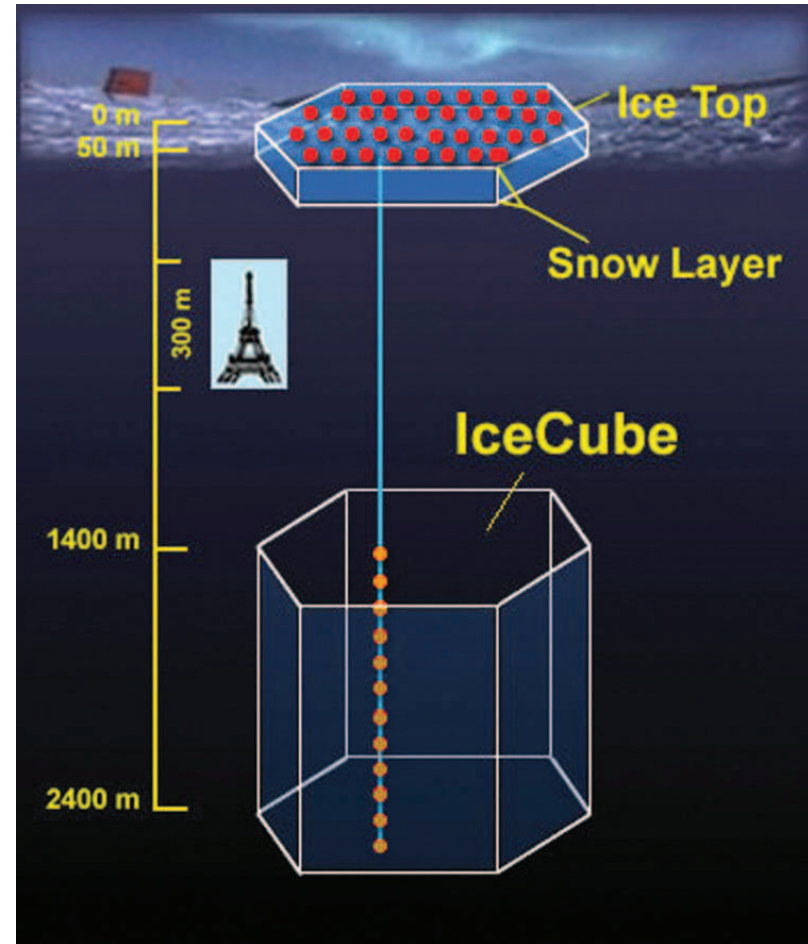


[www.auger.org]

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- **It is under active observation:**
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Air shower detectors: e.g. **Pierre Auger Observatory**
Neutrino telescopes: e.g. **IceCube**
- **Attack fundamental questions:**
What is it made of? What are the cosmic accelerators? Can we exploit them also for particle physics?



[icecube.wisc.edu]

Outline:

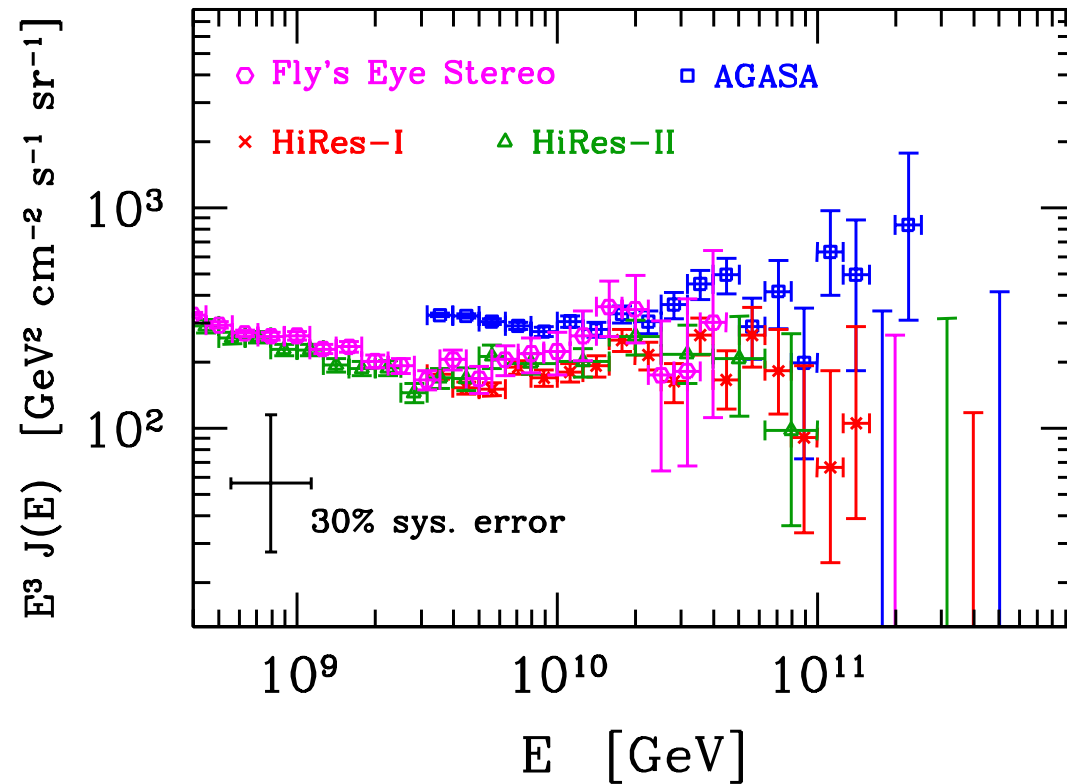
- 2. Observations at ultrahigh energies**
- 3. Non-observations at ultrahigh energies**
- 4. Future observations at ultrahigh energies**
- 5. Conclusions**

2. Observations at ultrahigh energies

- **Spectrum:** Large statistical and systematic uncertainties

⇐ low flux

⇐ energy from shower simulations



[Ahlers *et al.* '05]

2. Observations at ultrahigh energies

- **Spectrum:** Large statistical and systematic uncertainties
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 - ⇐ energy from shower simulations
- Crucial improvement by **PAO**:
 - ⇐ huge size ⇒ better statistics
 - ⇐ hybrid observations ⇒ better energy calibration through Fly's Eye technique, direction from ground array



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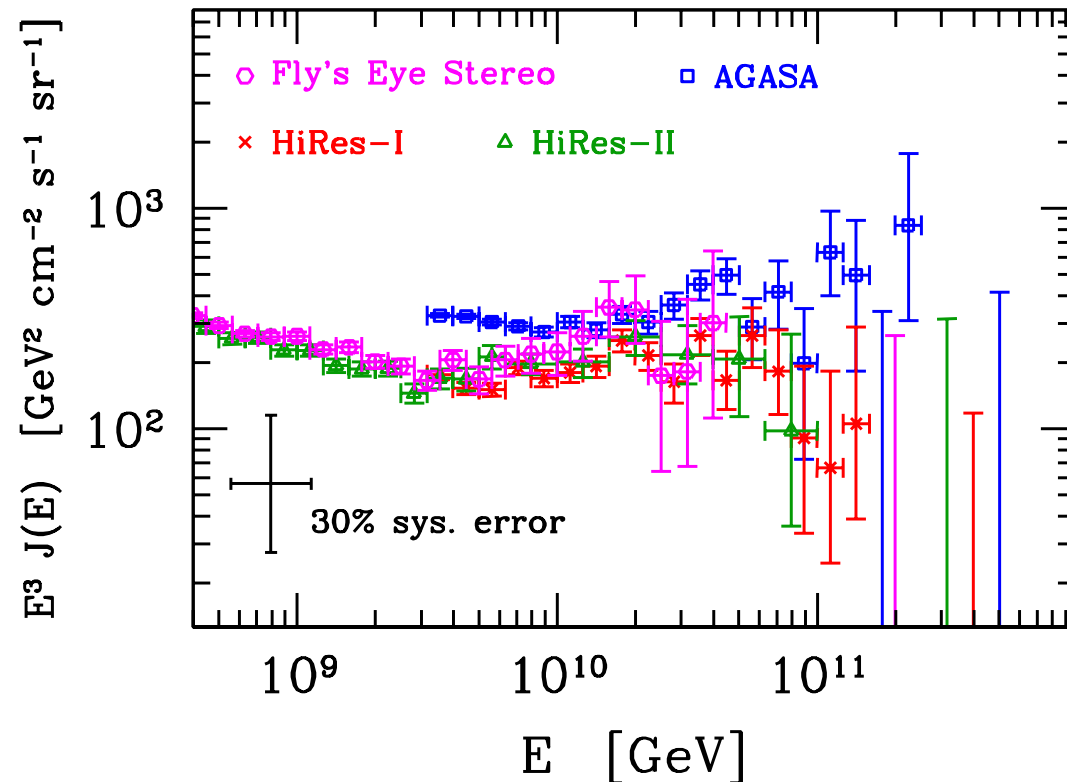
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- It works

A. Ringwald (DESY)



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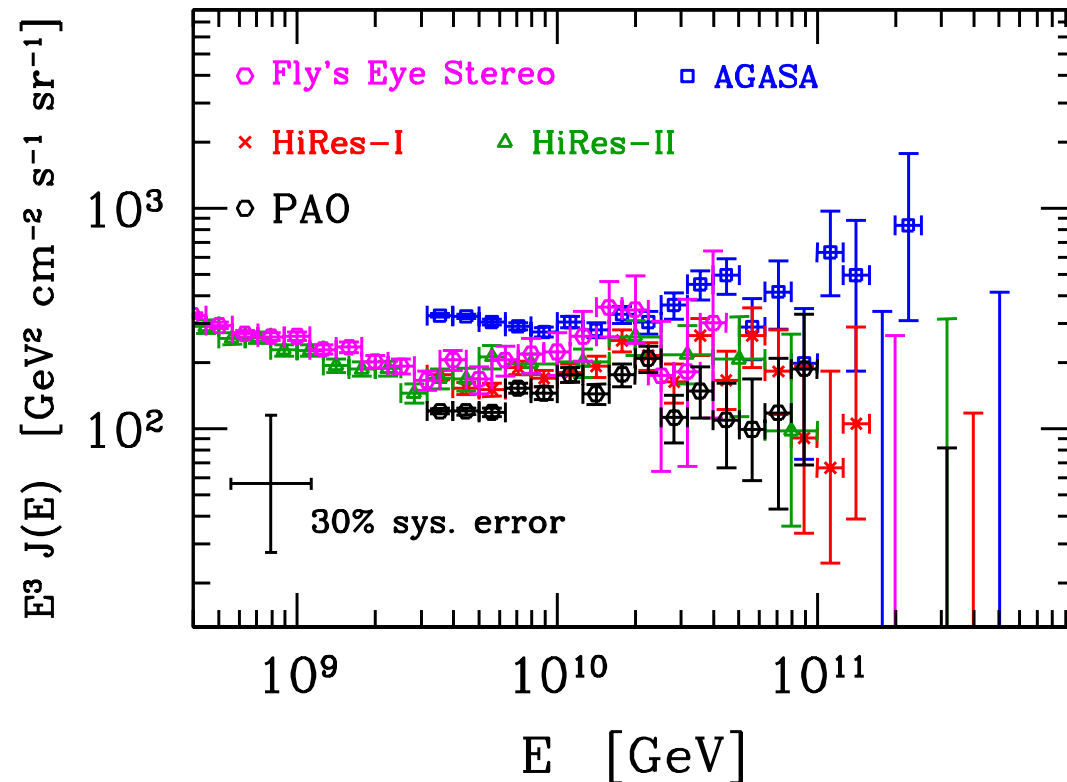
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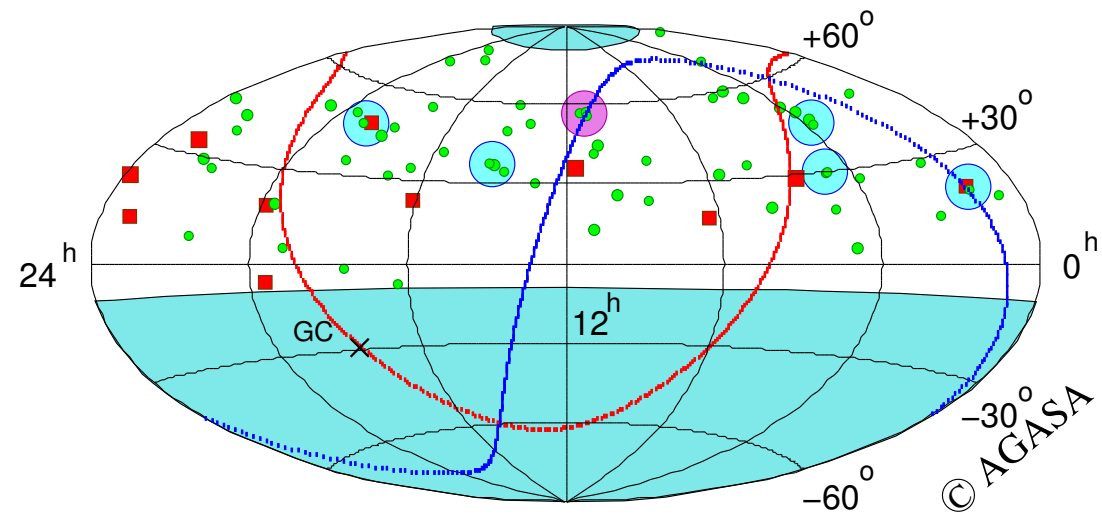


[Ahlers *et al.* '05]

2. Observations at ultrahigh energies

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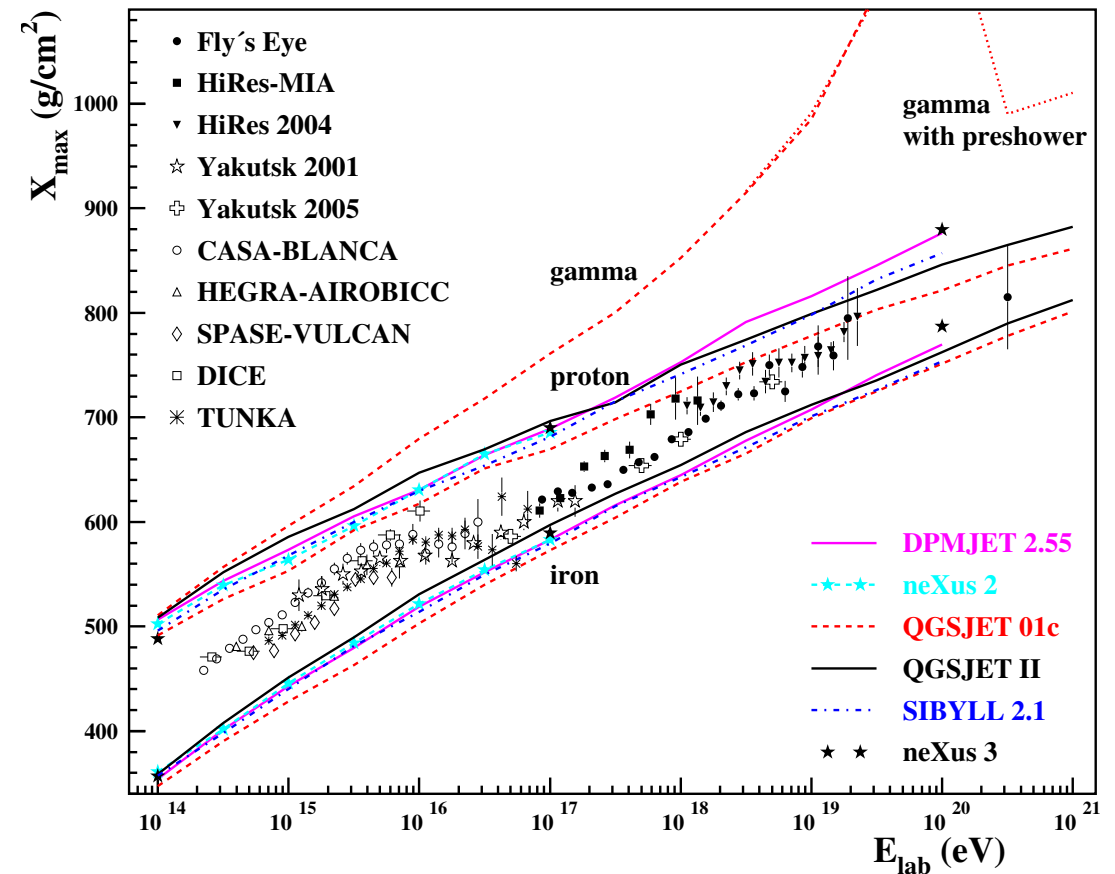
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- **Angular distribution:** \approx isotrop
- **Composition:** Large uncertainty
⇐ studies rely on simulations
- Cosmic rays above $\gtrsim 10^{17.6}$ eV
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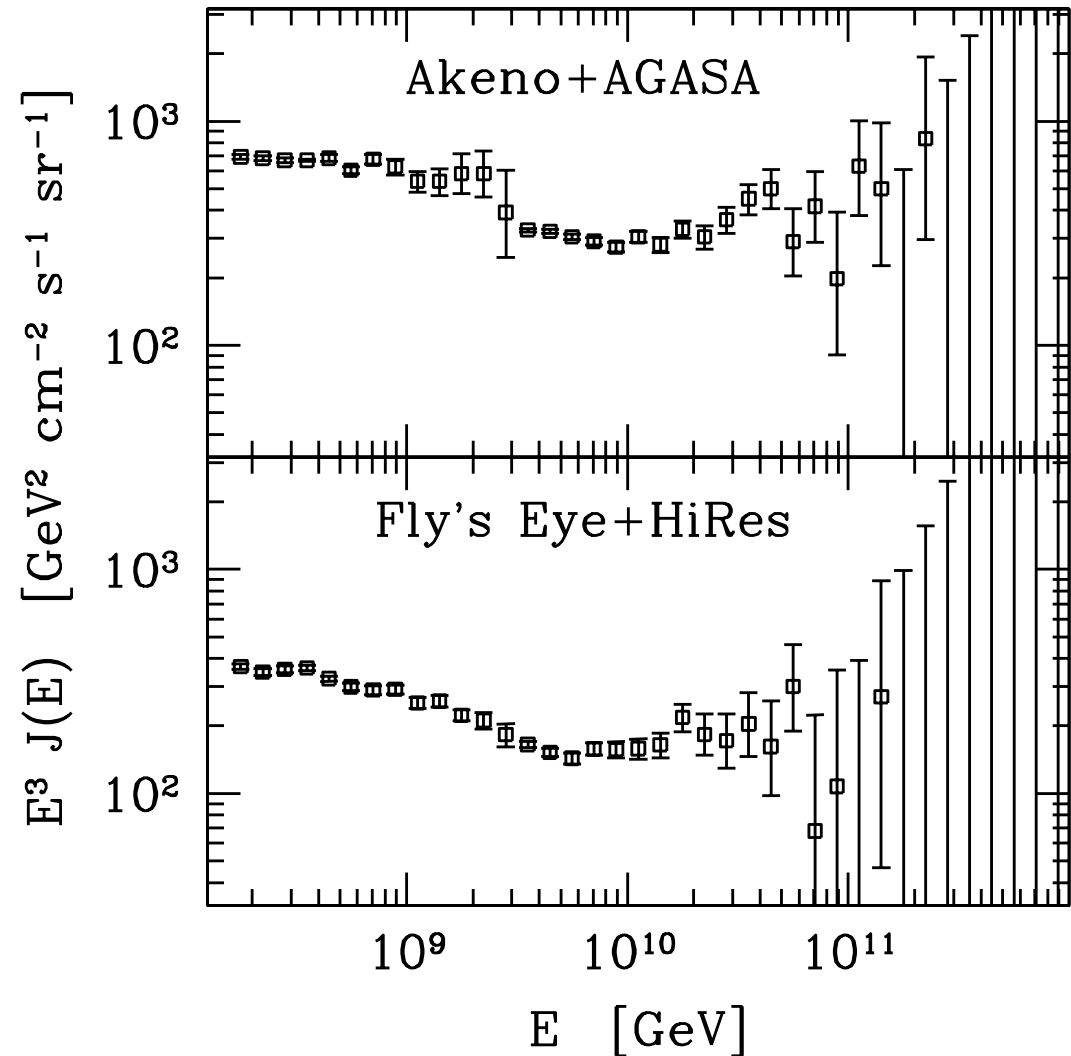
[Heck '05]

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- **Angular distribution:** \approx isotrop
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- Cosmic rays above $\gtrsim 10^{17.6}$ eV, the “second knee”, dominantly protons
- Assume that CR's in $10^{[8.6,11]}$ GeV range originate from isotropically distributed extragalactic proton sources, with simple power-law injection spectra $\propto E_i^{-\gamma}(1+z)^n$

[Berezinsky,..'02-'05;...;Ahlers *et al.* '05]



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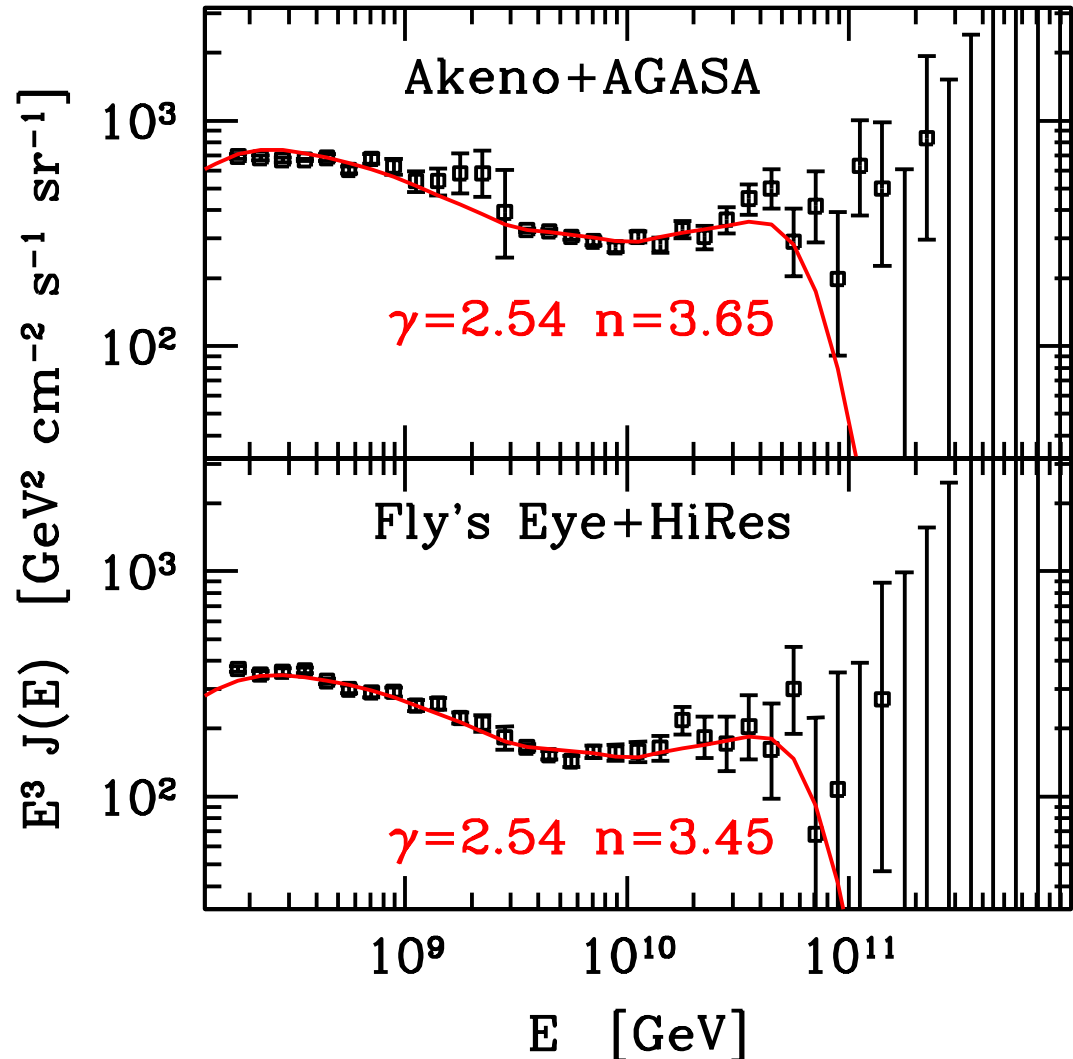
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[Berezinsky,..'02-'05;...;Ahlers *et al.* '05]

\Rightarrow Good fit; inelastic interactions with **CMB** (e^+e^- “dip”; π “bump”) visible; some **post-GZK events**?

A. Ringwald (DESY)

[Greisen;Zatsepin,Kuzmin '67]



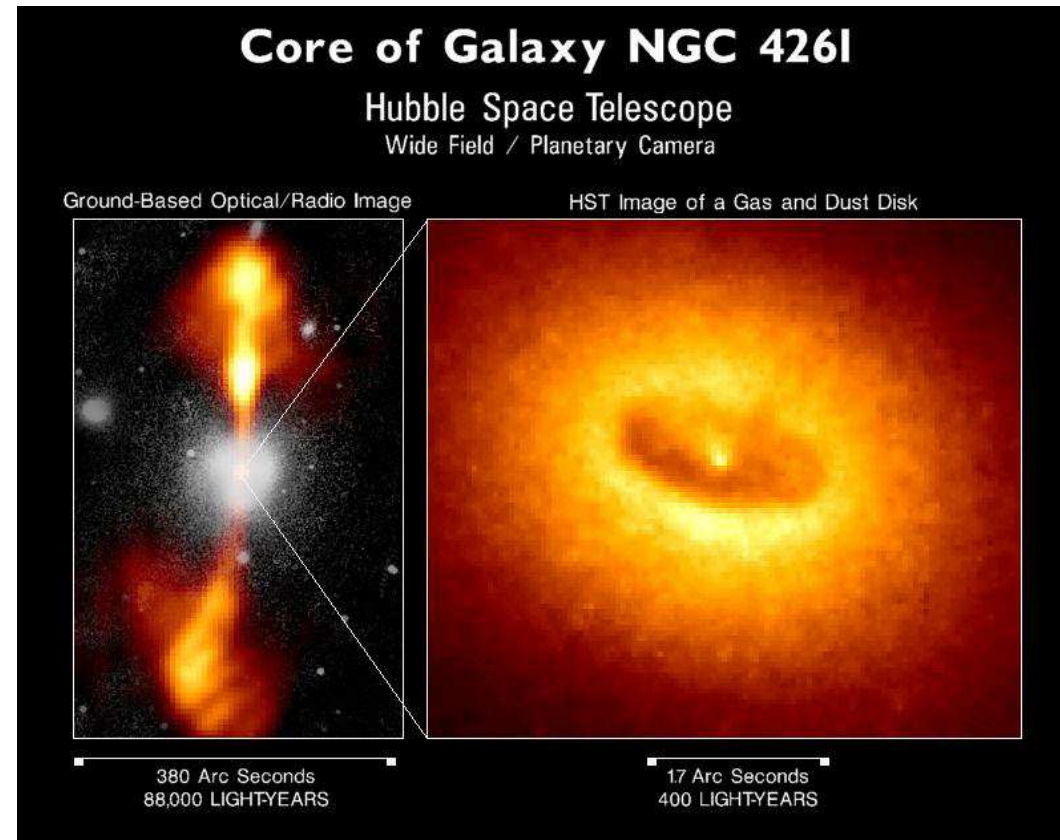
[Ahlers *et al.* '05]

Frontiers in Astroparticle Physics, Vienna, Nov 2005

– The High Energy Universe –

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- Possible sources of these protons:
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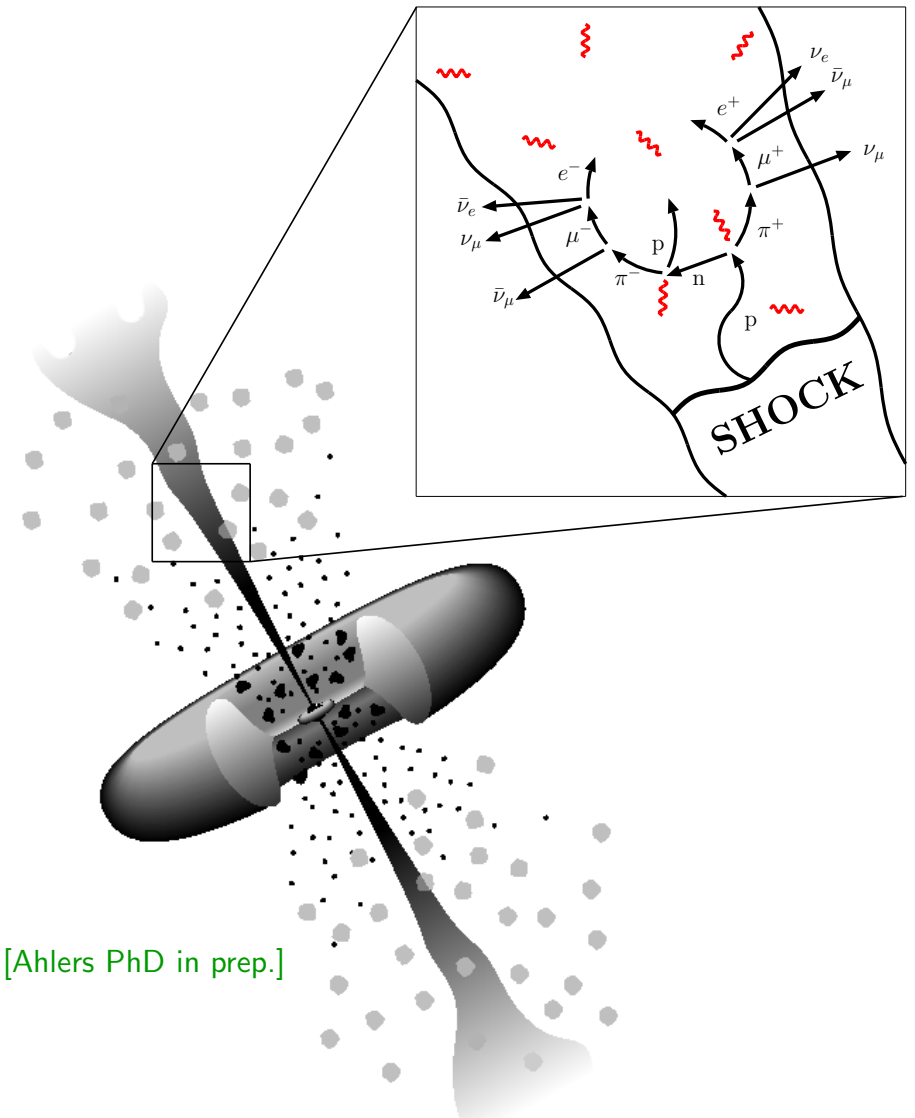


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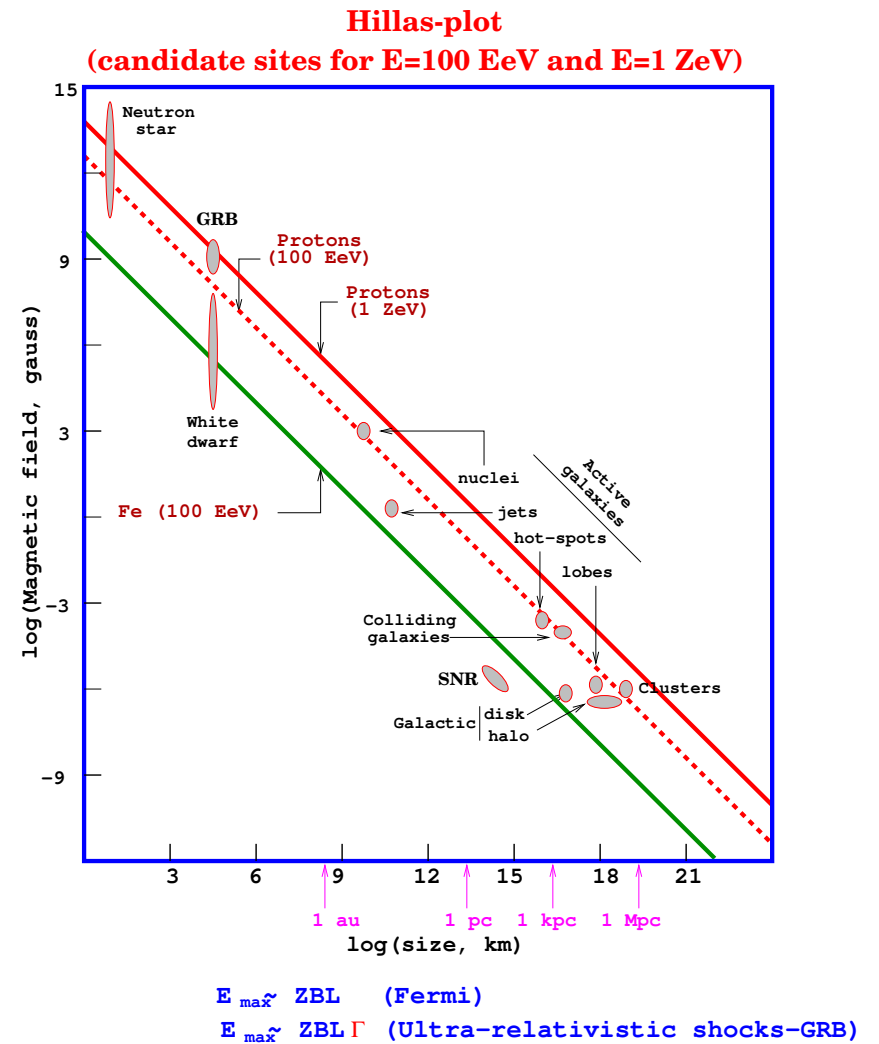
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 - p 's, confined by magnetic fields, accelerate through repeated scattering by plasma shock fronts



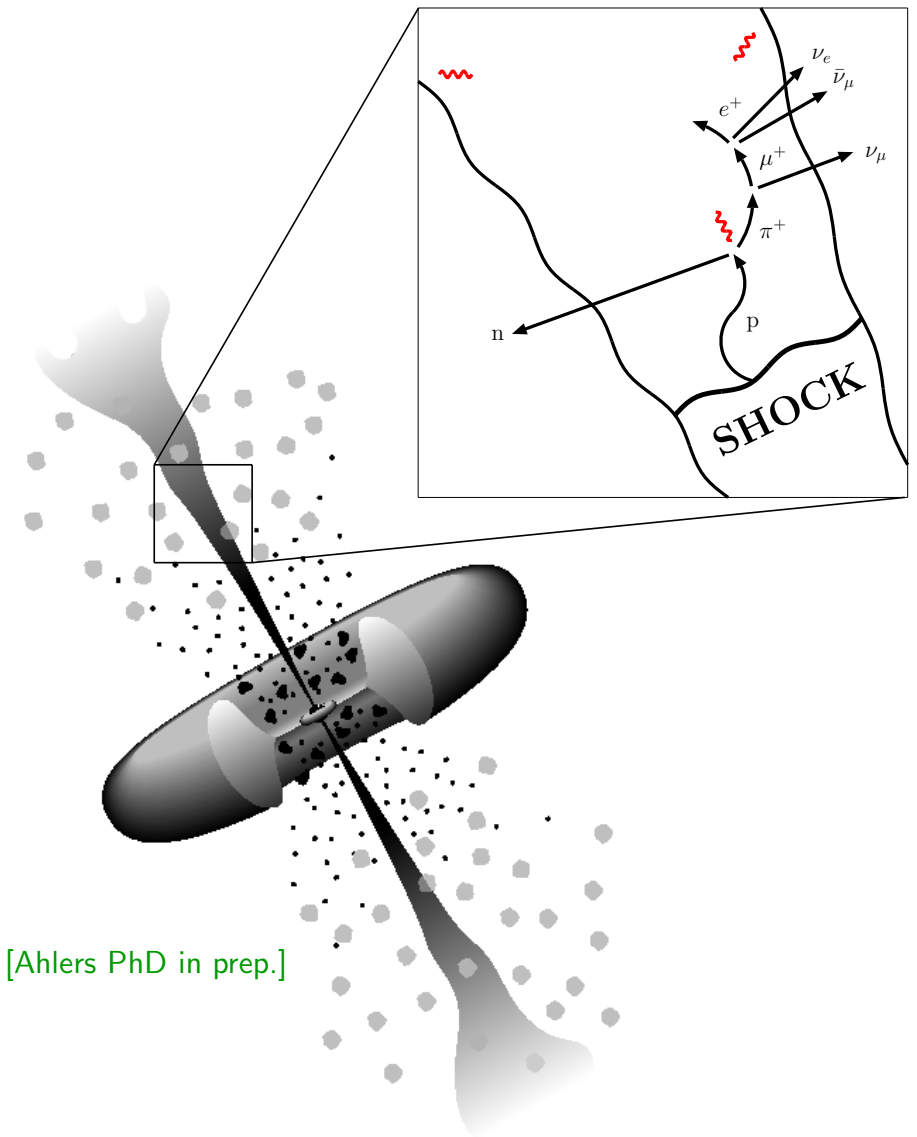
[Ahlers PhD in prep.]

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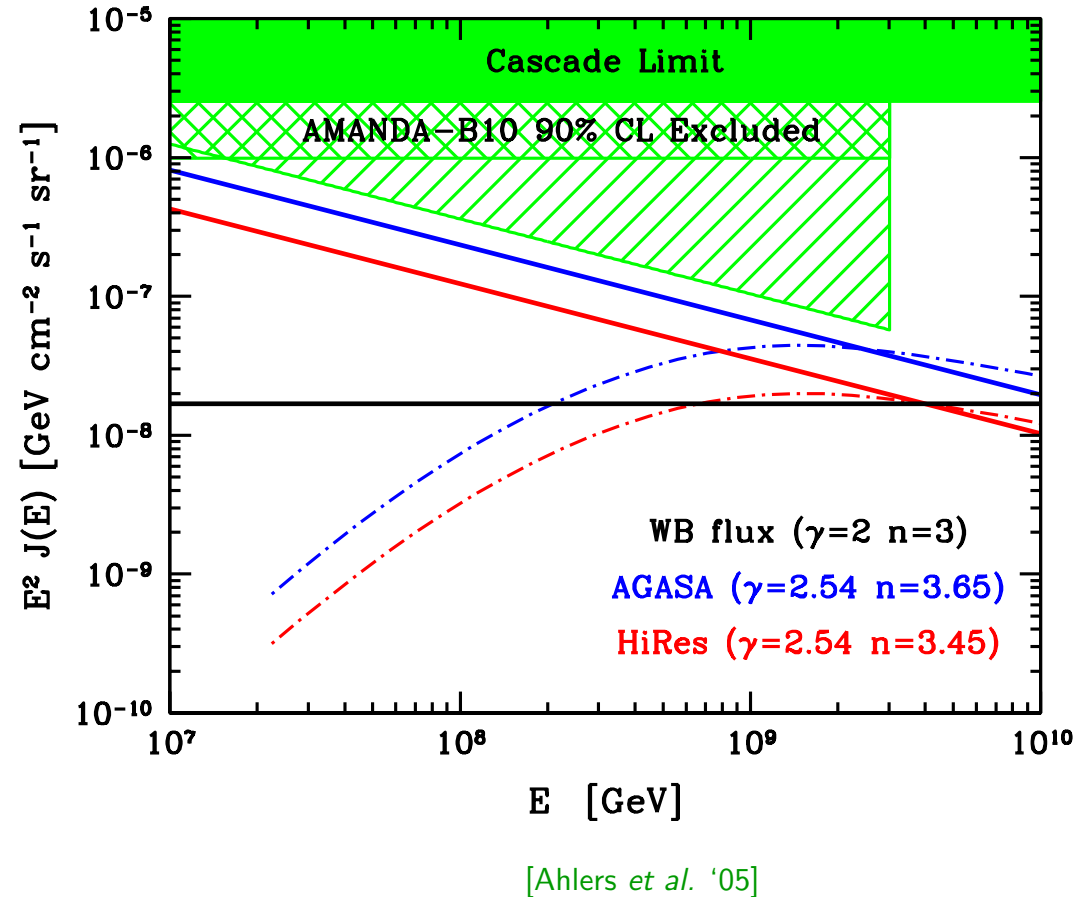
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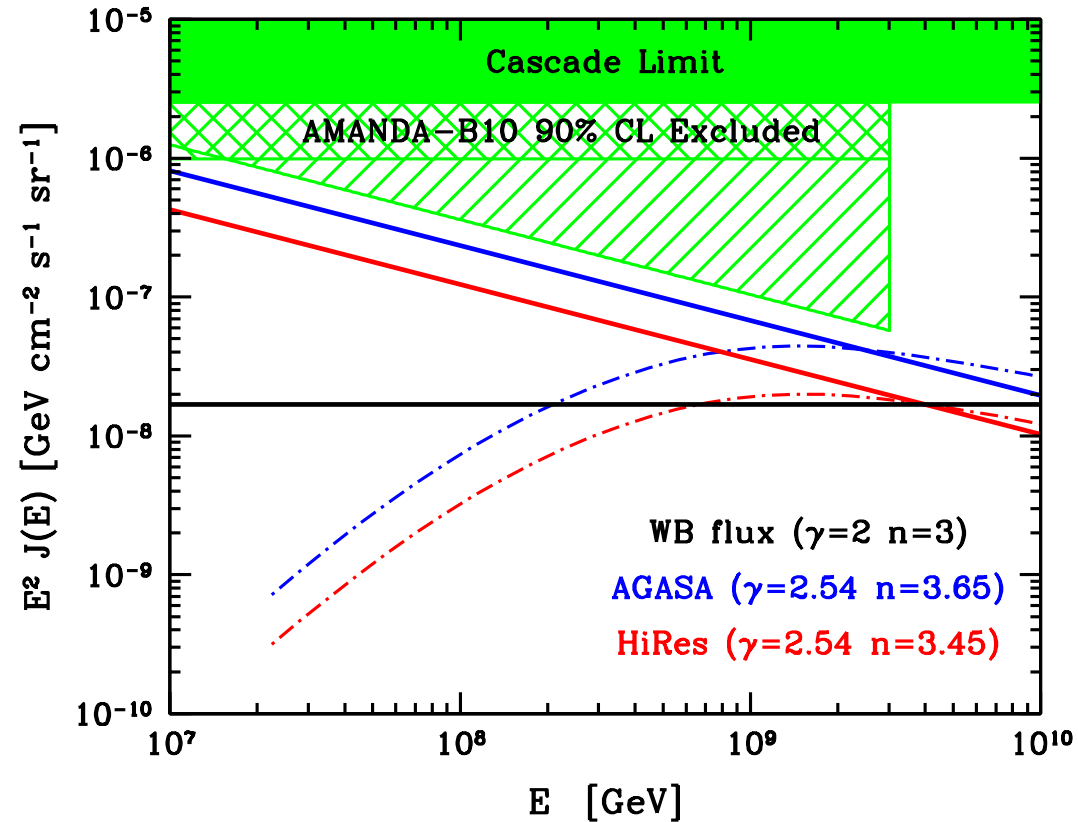
- **Neutrinos as diagnostic tool:**

- ν 's from sources ($p\gamma \rightarrow n + \pi$'s) close to be measured
- Cosmogenic neutrino flux (from $p\gamma_{\text{CMB}} \rightarrow N\pi$'s) dominates above 10^9 GeV



3. Non-observations at ultrahigh energies

- $C\nu$'s with $E_\nu \gtrsim 10^8$ GeV probe νN scattering at $\sqrt{s_{\nu N}} \gtrsim 14$ TeV (**LHC**)

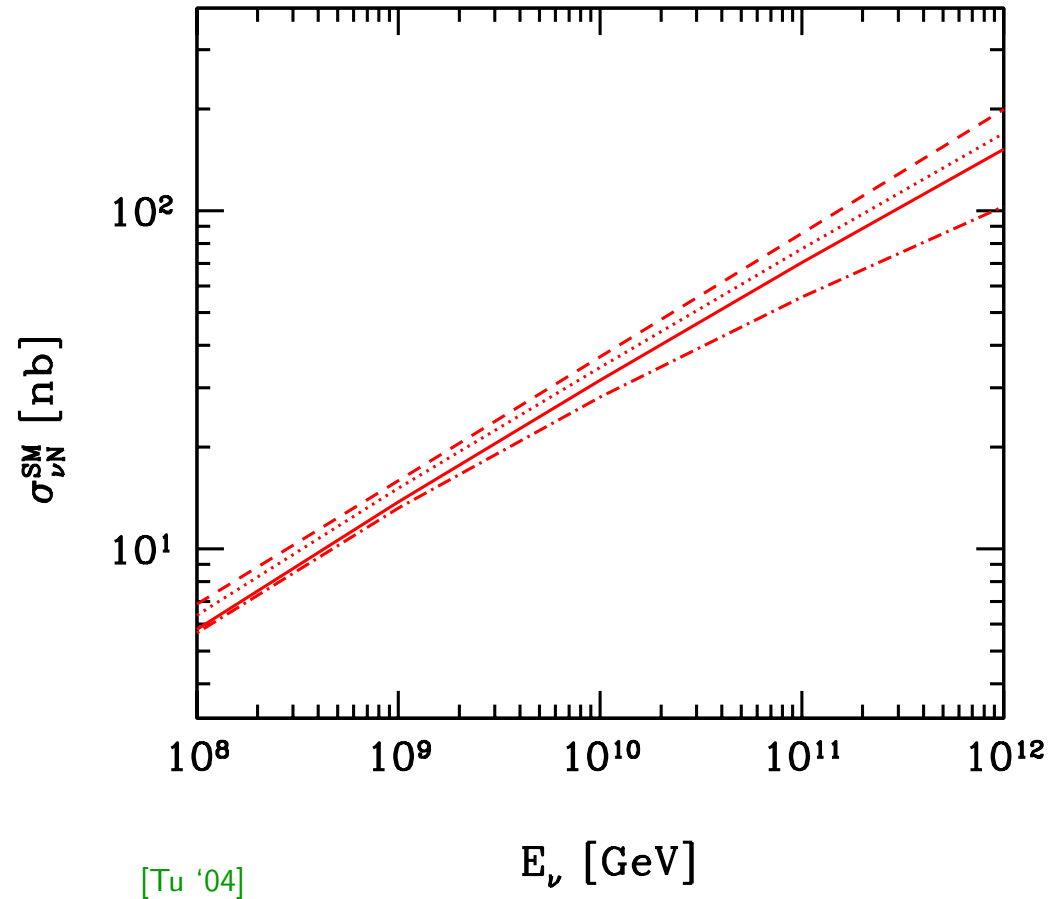


[Ahlers et al. '05]

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[Gandhi *et al.* '98; Kwiecinski *et al.* '98; ...]



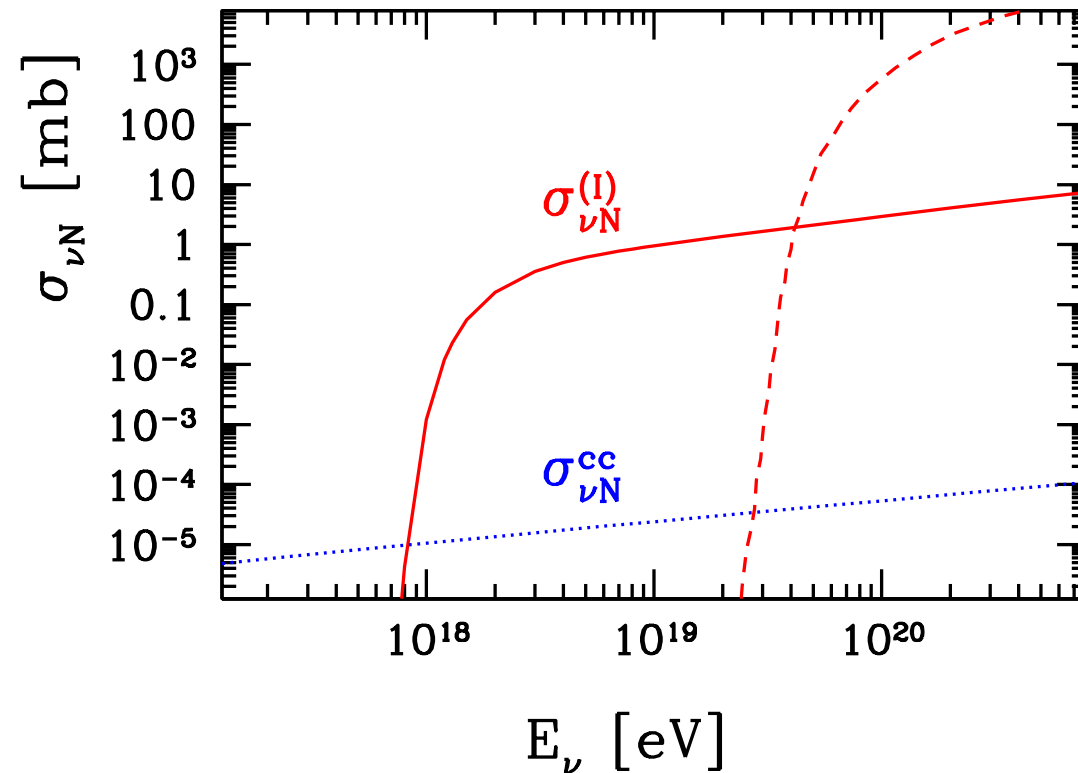
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\Rightarrow Search for enhancements in $\sigma_{\nu N}$ beyond (perturbative) SM:

◇ **Electroweak sphaleron production** ($B + L$ violating processes in SM)



[Fodor, Katz, AR, Tu '03; Han, Hooper '03]

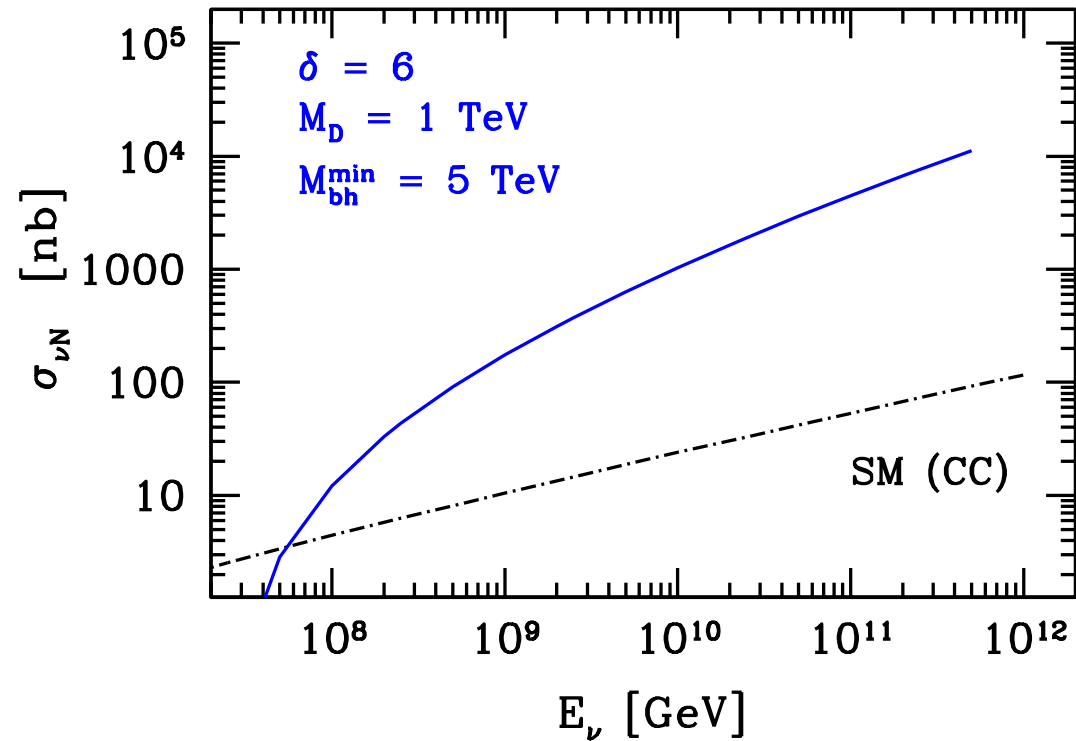
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\Rightarrow Search for enhancements in $\sigma_{\nu N}$ beyond (perturbative) SM:

- ◇ Electroweak sphaleron production ($B + L$ violating processes in SM)
- ◇ Kaluza-Klein, **black hole**, p -brane or string ball production in TeV scale gravity models
- ◇



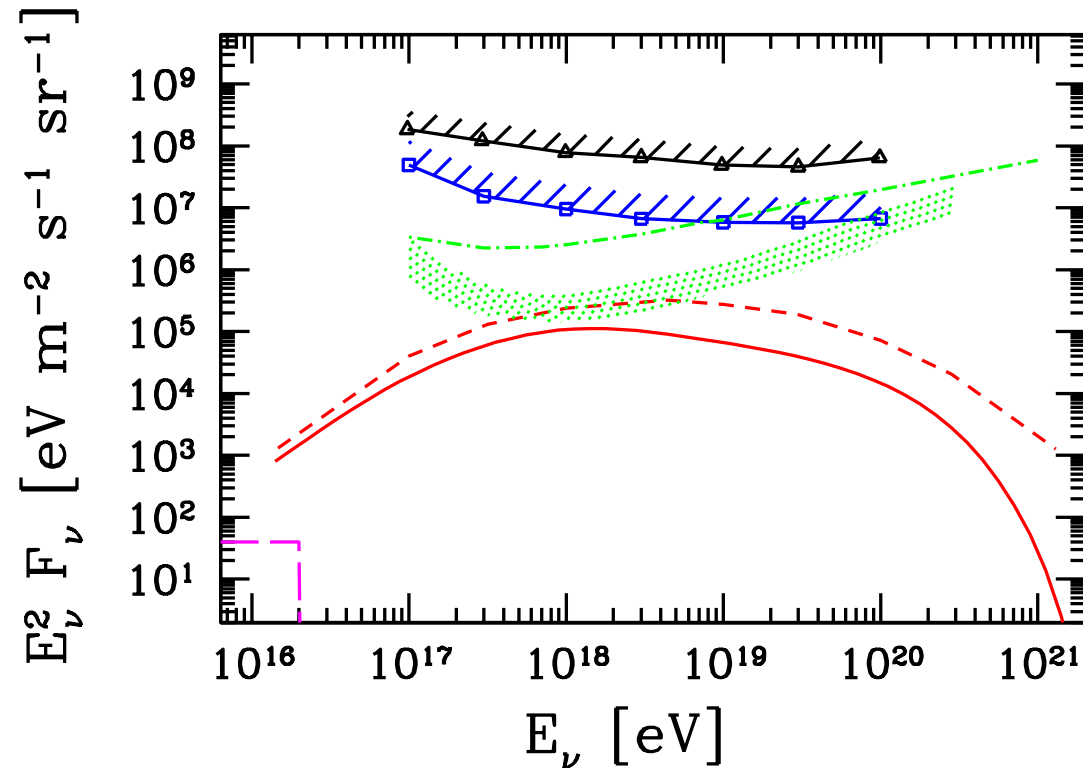
[AR, Tu '01; Tu '04]

“Model-independent” upper bounds on $\sigma_{\nu N}$

$$\frac{dN}{dt} \propto \int dE_{\nu} F_{\nu}(E_{\nu}) \sigma_{\nu N}(E_{\nu})$$

⇒ Non-observation of deeply-penetrating particles, together with lower bound on F_{ν} (e.g. cosmogenic ν 's) ⇒ upper bound on $\sigma_{\nu N}$

[Berezinsky,Smirnov '74; Morris,AR '94; Tyler,Olinto,Sigl '01;...]



[Anchordoqui,Fodor,Katz,AR,Tu '04]

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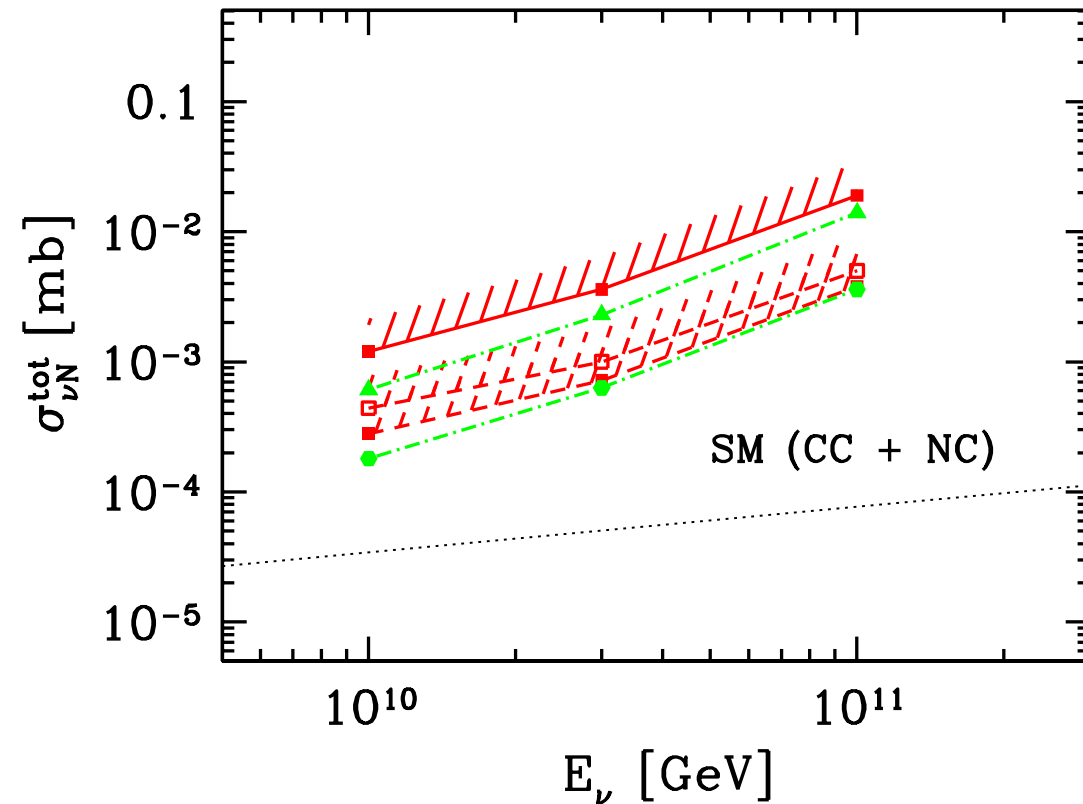
• Recent quantitative analysis:

[Anchordoqui,Fodor,Katz,AR,Tu '04]

◇ Best current limits from exploitation of **RICE** search results

[Kravchenko *et al.* [RICE] '02,03]

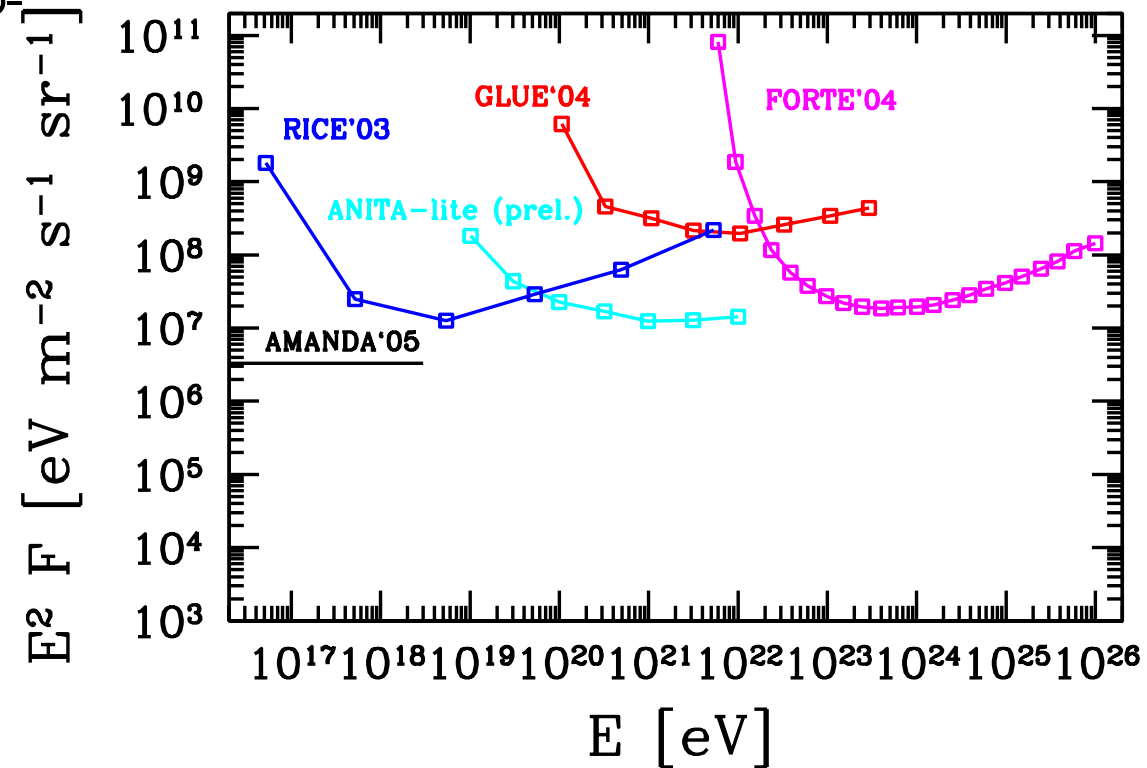
◇ **Auger** will improve these limits by one order of magnitude



[Anchordoqui,Fodor,Katz,AR,Tu '04]

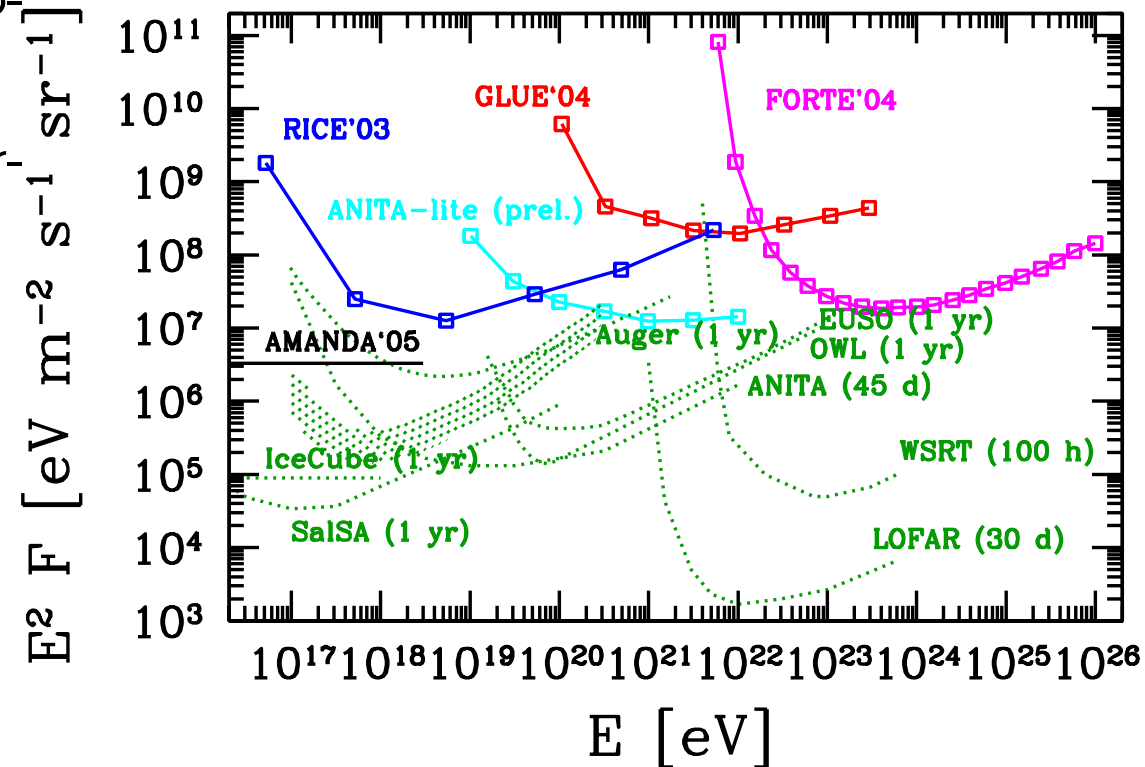
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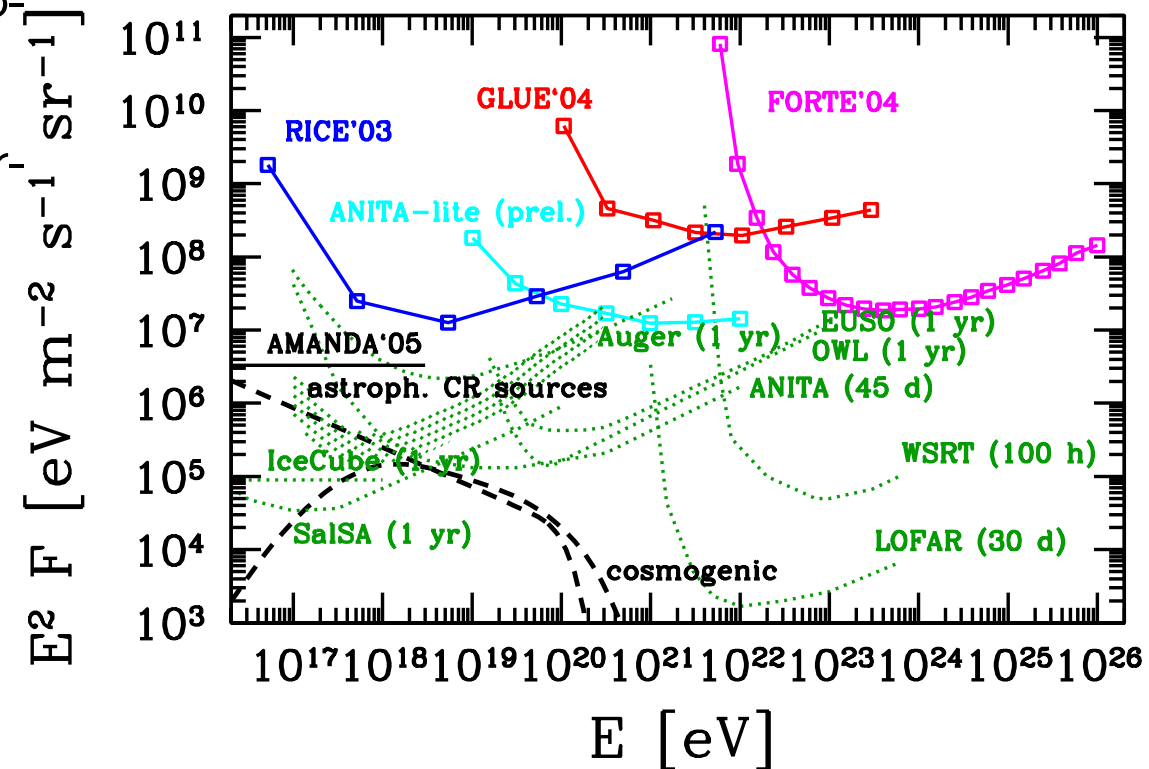
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\rightarrow **Astrophysics** of cosmic rays

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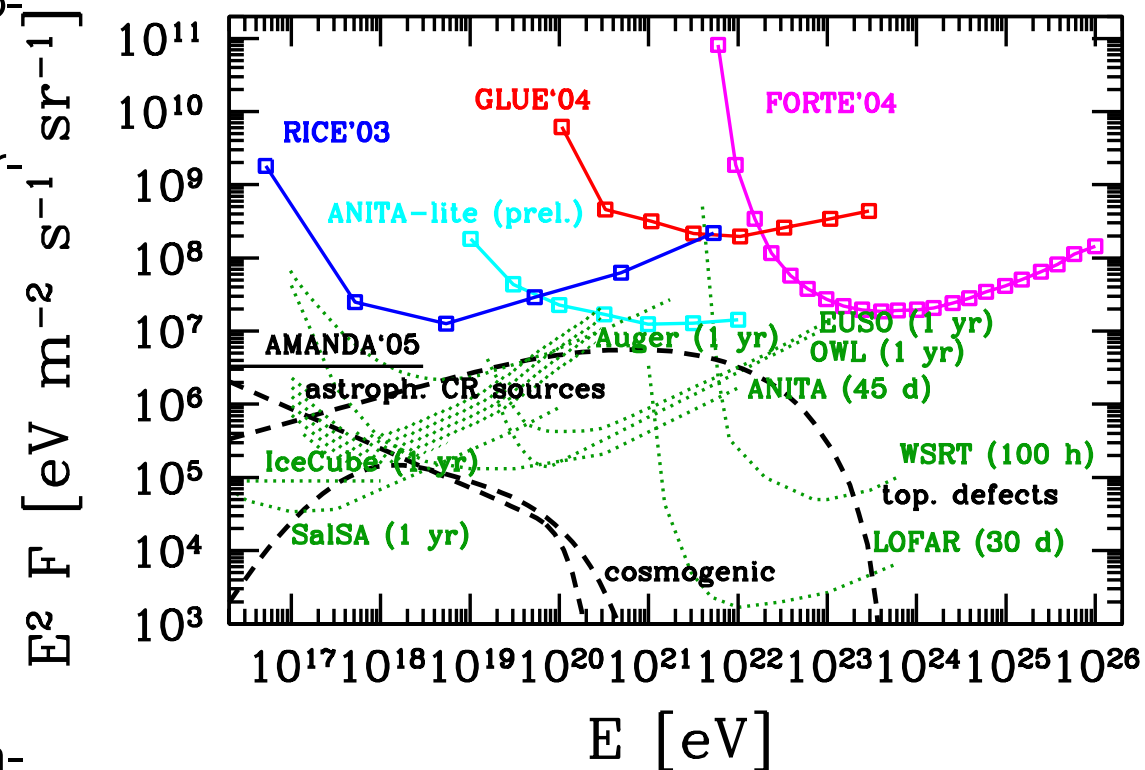
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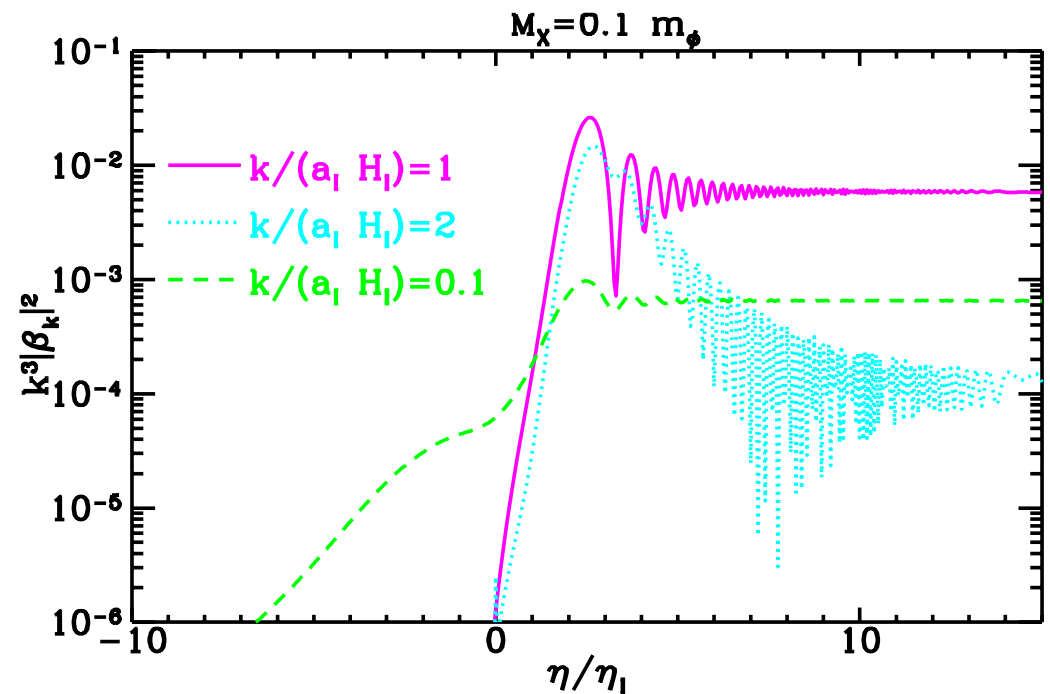
$\Rightarrow E \geq 10^{21}$ eV:

\rightarrow **Cosmology**: relics of phase transitions; absorption on big bang relic neutrinos



Top-down scenarios for super-GZK neutrinos

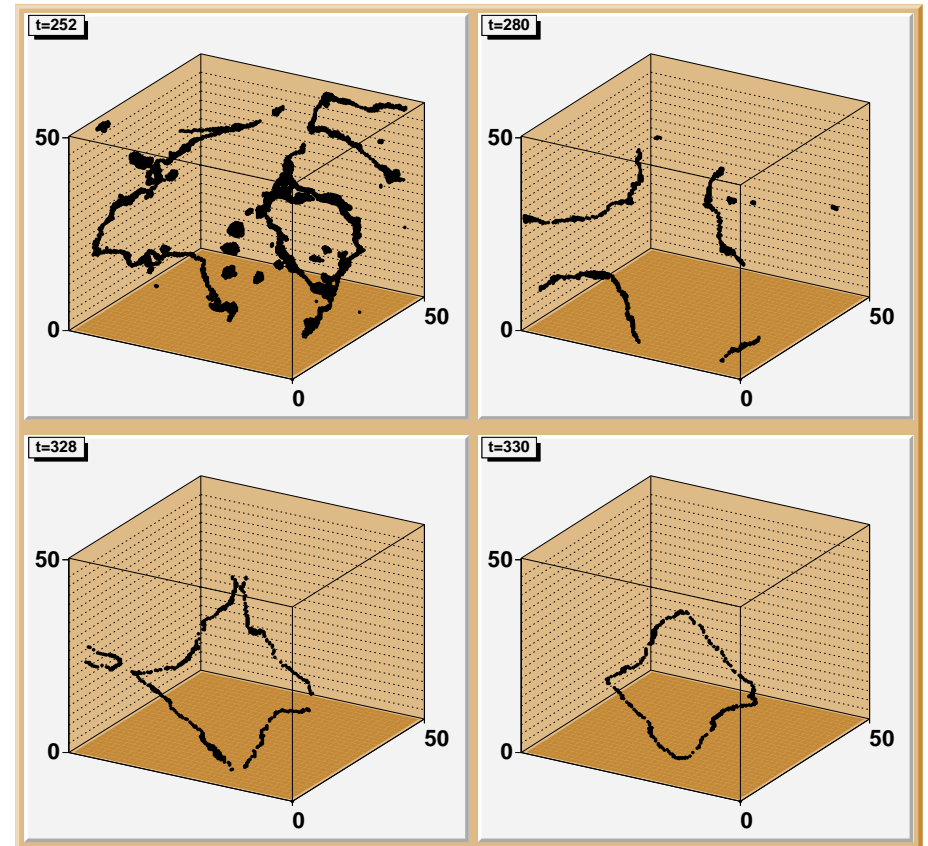
- Existence of superheavy particles with $10^{12} \text{ GeV} \lesssim m_X \lesssim 10^{16} \text{ GeV}$, produced during and after inflation through e.g.
 - particle creation in time-varying gravitational field



[Kolb, Chung, Riotto '98]

Top-down scenarios for super-GZK neutrinos

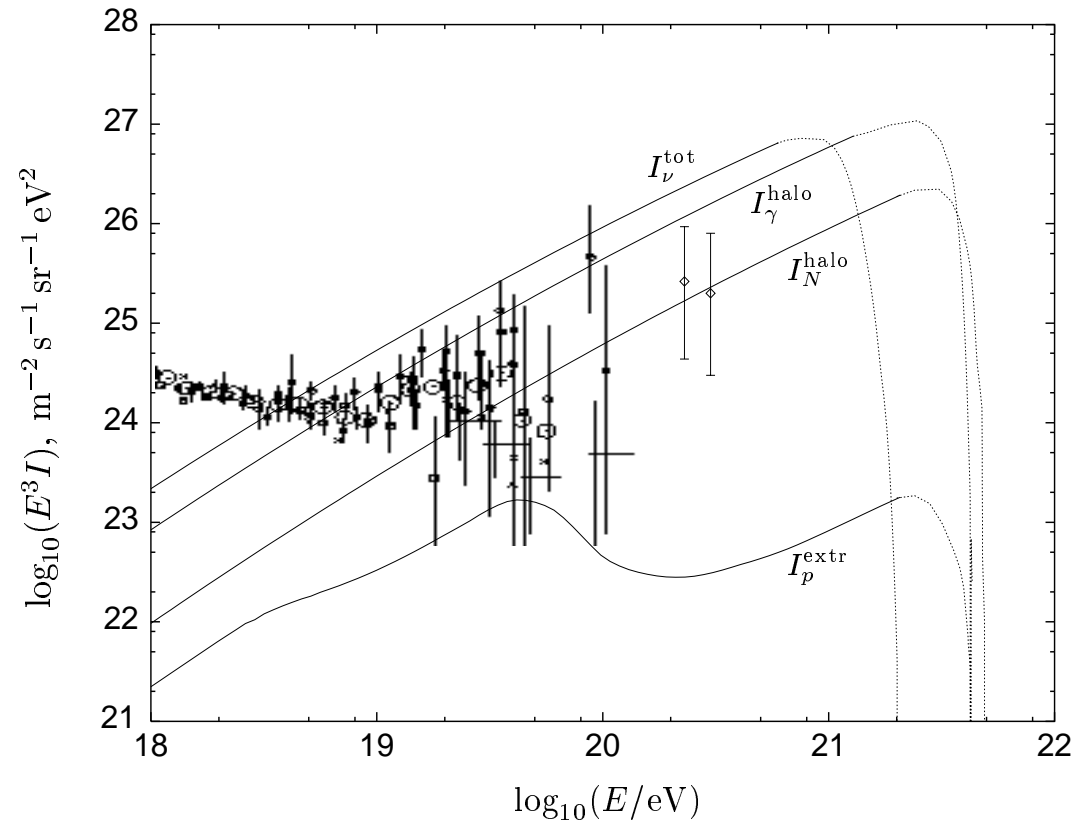
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 - particle creation in time-varying gravitational field
 - decomposition of topological defects, formed during preheating, into their constituents



[Tkachev, Khlebnikov, Kofman, Linde '98]

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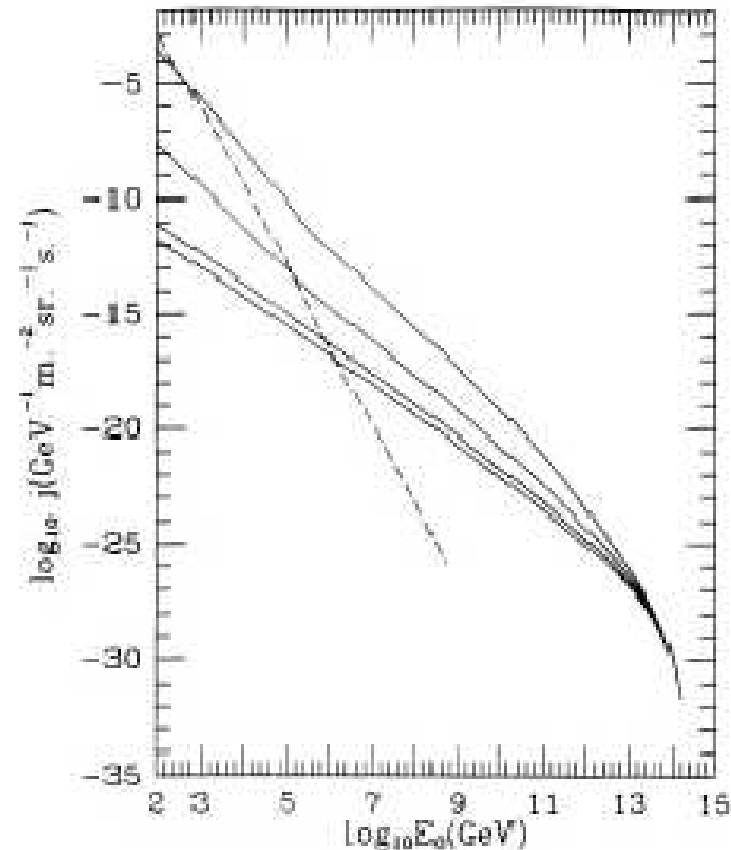
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 - ⇒ super-GZK ν 's from decay or annihilation of superheavy dark matter (for $\tau_X \gtrsim \tau_U$)
 - decomposition of topological defects, formed during preheating, into their constituents



[Berezinsky, Kachelriess, Vilenkin '97]

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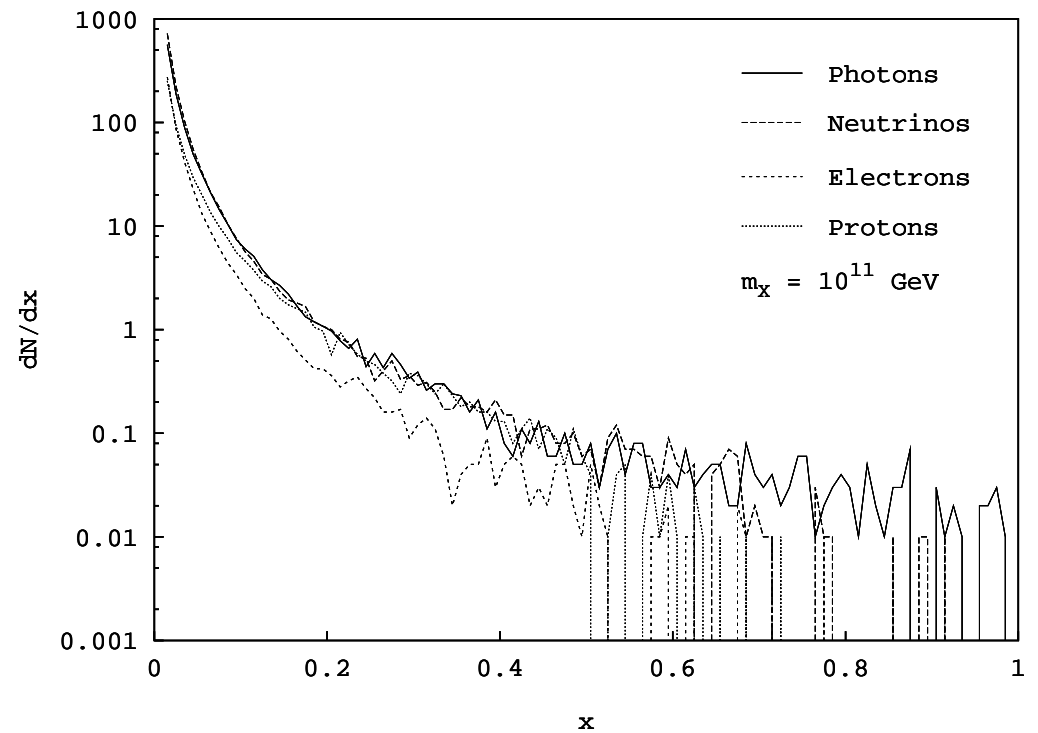
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 - ⇒ super-GZK ν 's from topological defects



[Bhattacharjee, Hill, Schramm '92]

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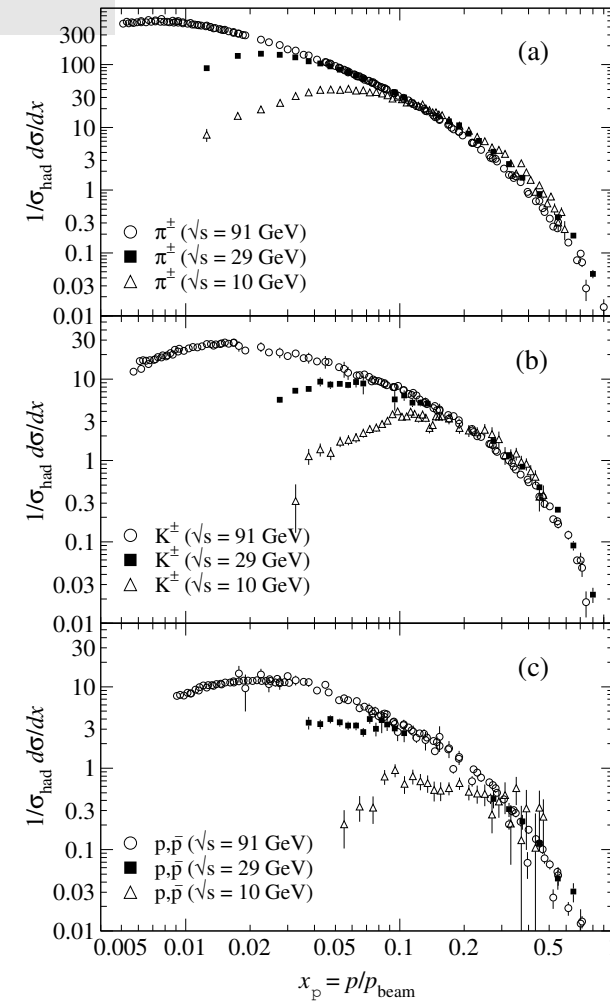
- **Injection spectra:** fragmentation functions $D_i(x, \mu)$, $i = p, e, \gamma, \nu$, determined via
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[Birkel, Sarkar '98]

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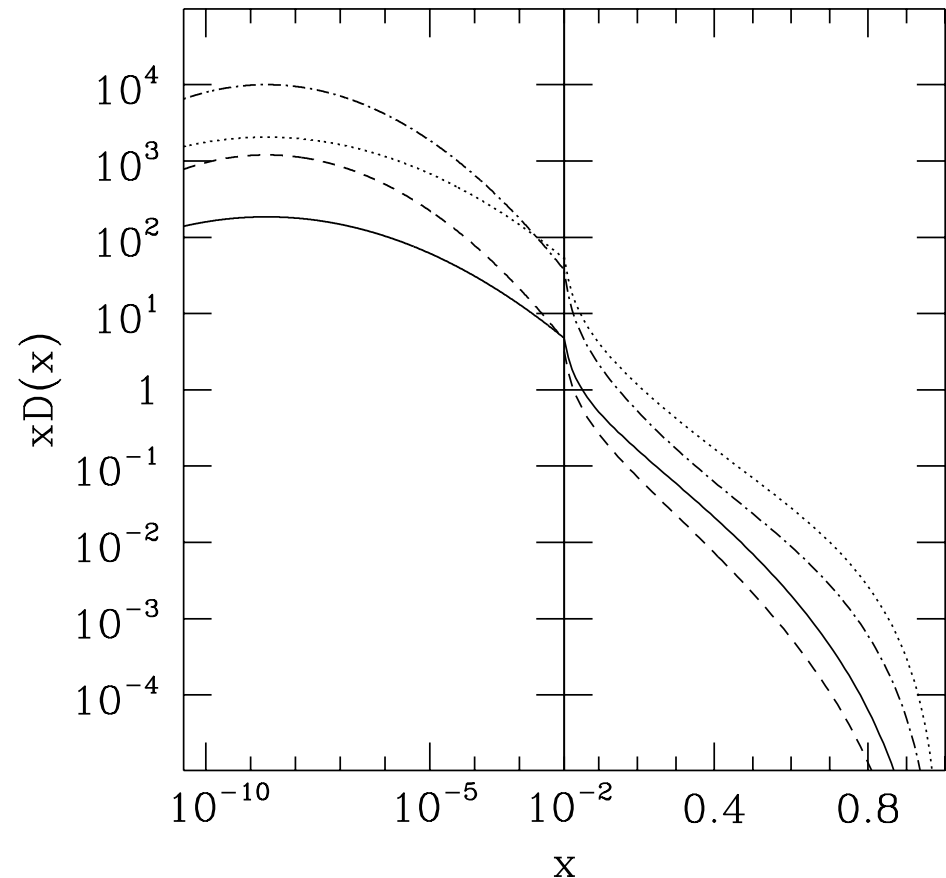
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[Particle Data Group '04]

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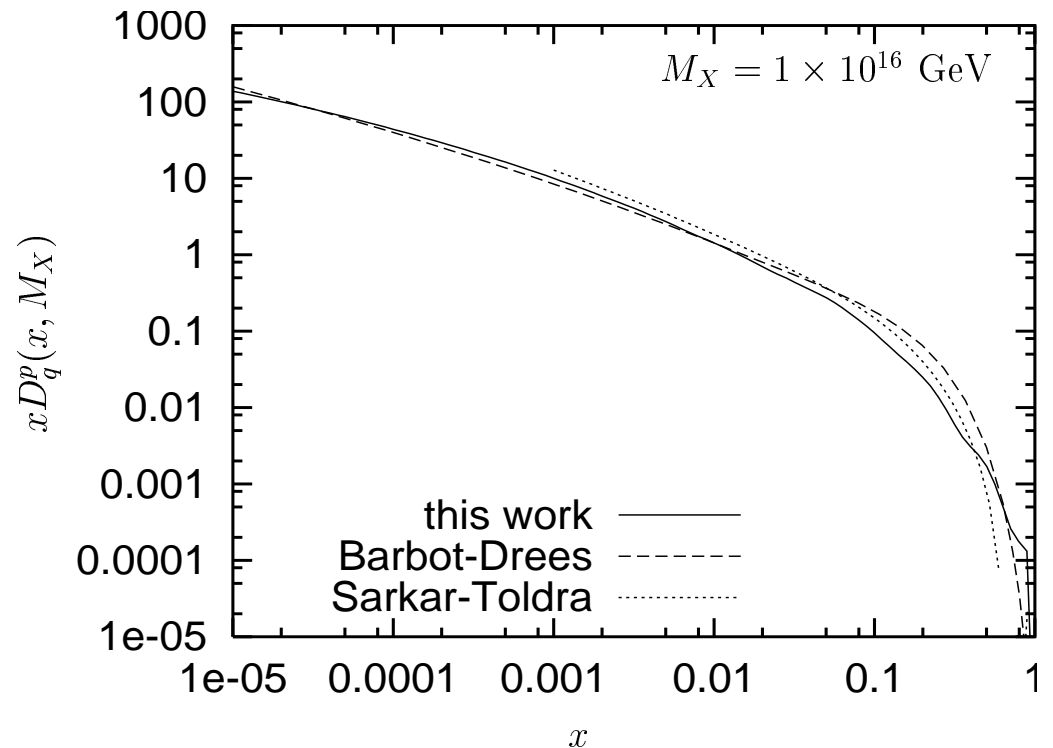


[Fodor, Katz '01]

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⇒ Reliably predicted!



[Aloisio, Berezhinsky, Kachelriess '04]

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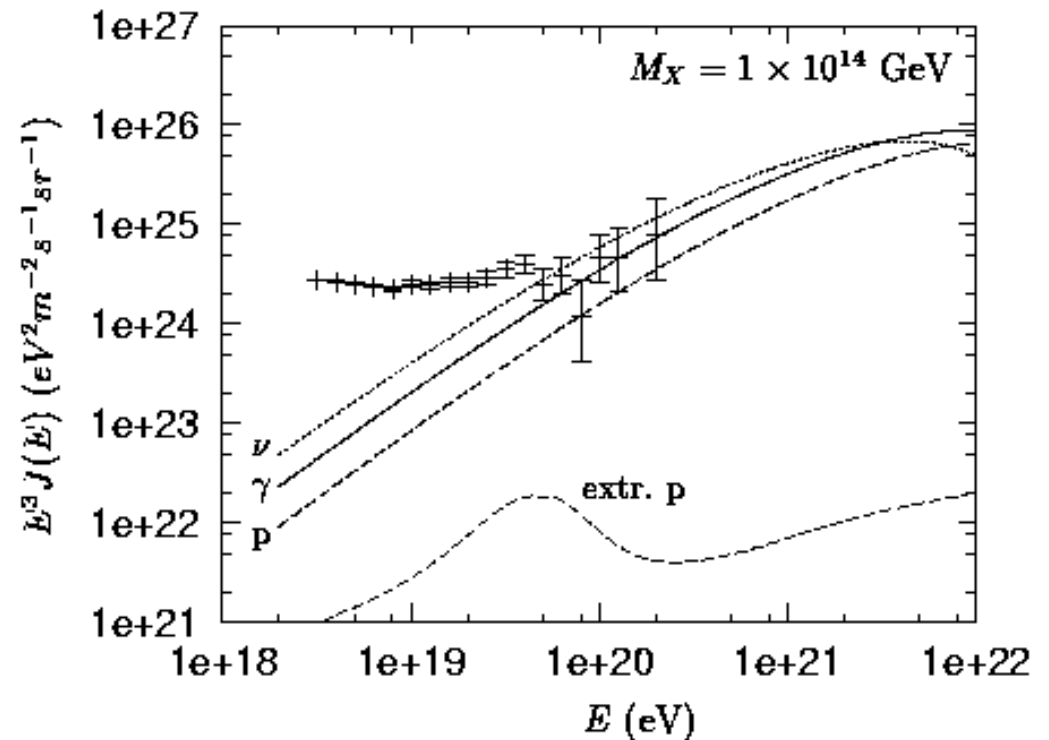
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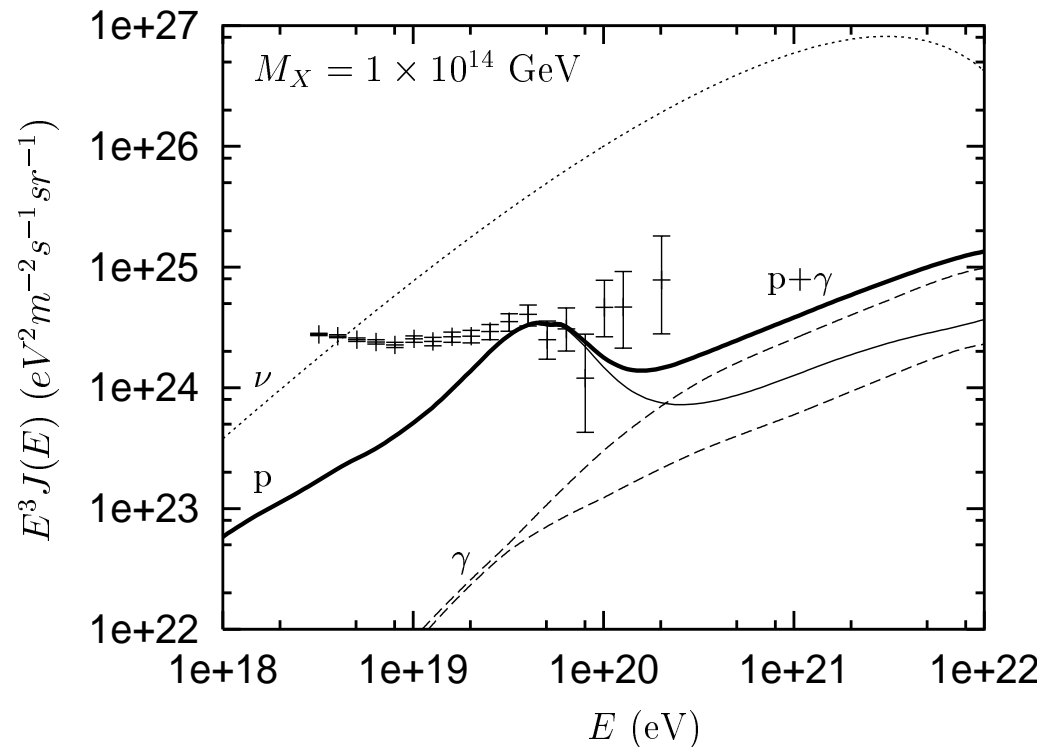
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- **Spectra at Earth:**

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- for topological defects, injection far away: $j_\nu \gg j_\gamma \sim j_p$

A. Ringwald (DESY)



[Aloisio, Berezhinsky, Kachelriess '04]

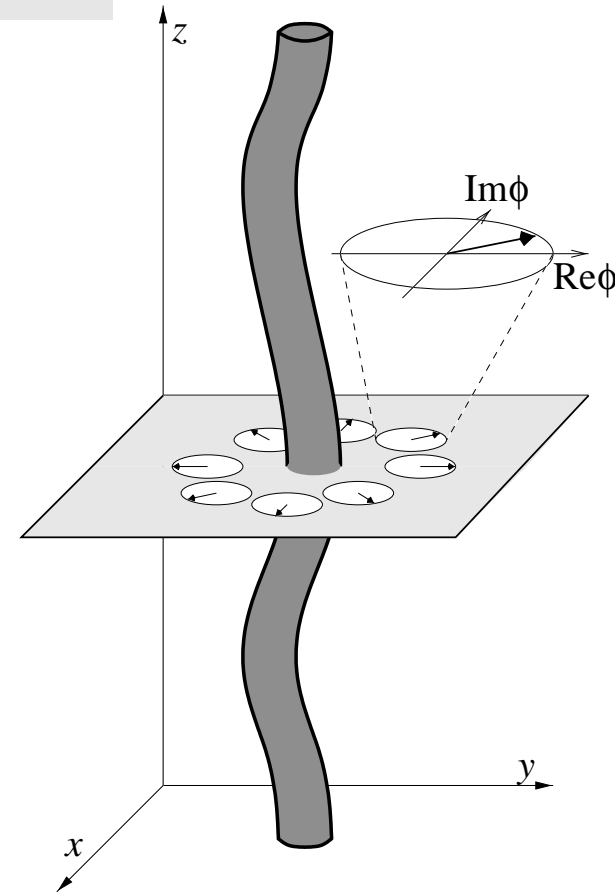
Frontiers in Astroparticle Physics, Vienna, Nov 2005

Top-down scenarios for super-GZK neutrinos

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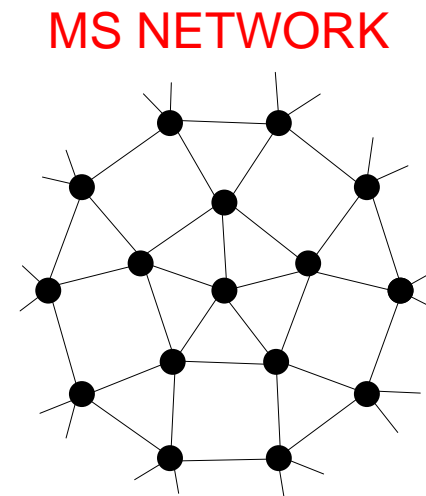
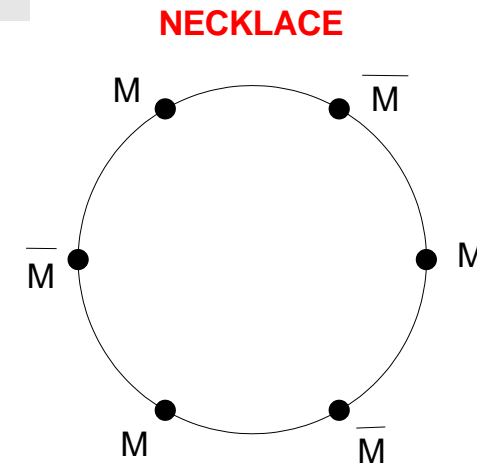
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 - * $U(1)$ SB: ordinary or superconducting strings



[Rajantie '03]

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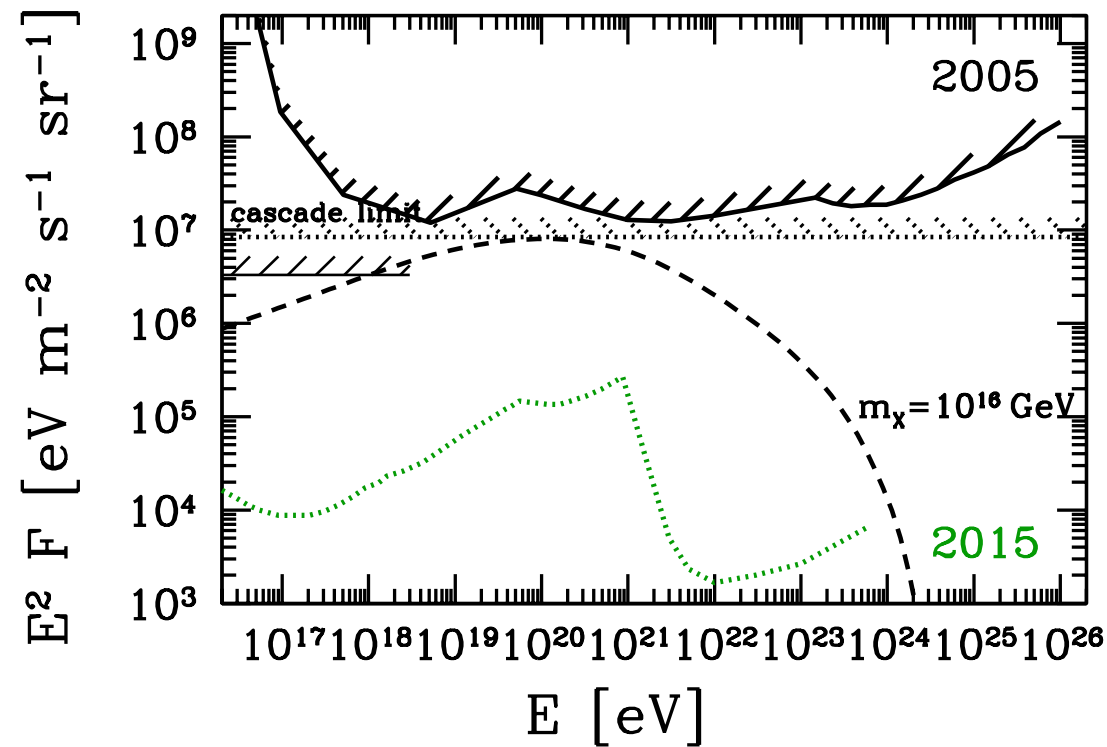
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 - * $U(1)$ SB: ordinary or superconducting strings
 - * $G \rightarrow H \times U(1) \rightarrow H \times Z_N$ SB: monopoles connected by strings



[Berezinsky '05]

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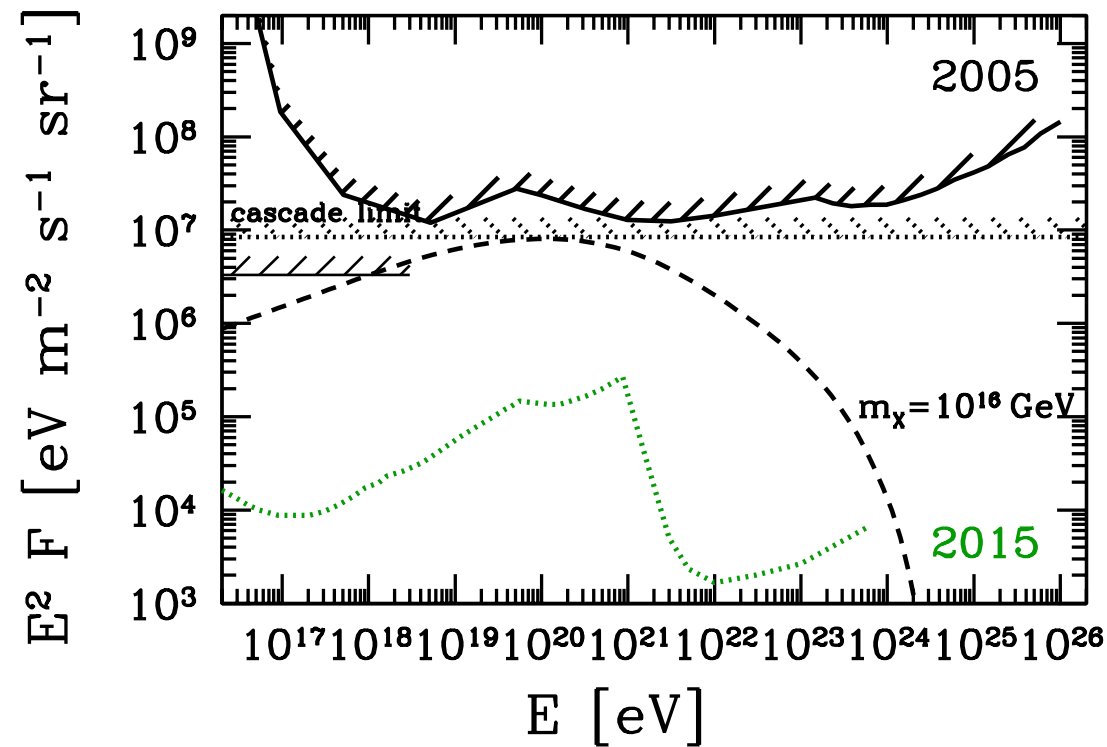
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[Fodor, Katz, AR, Weiler, Wong, in prep.]

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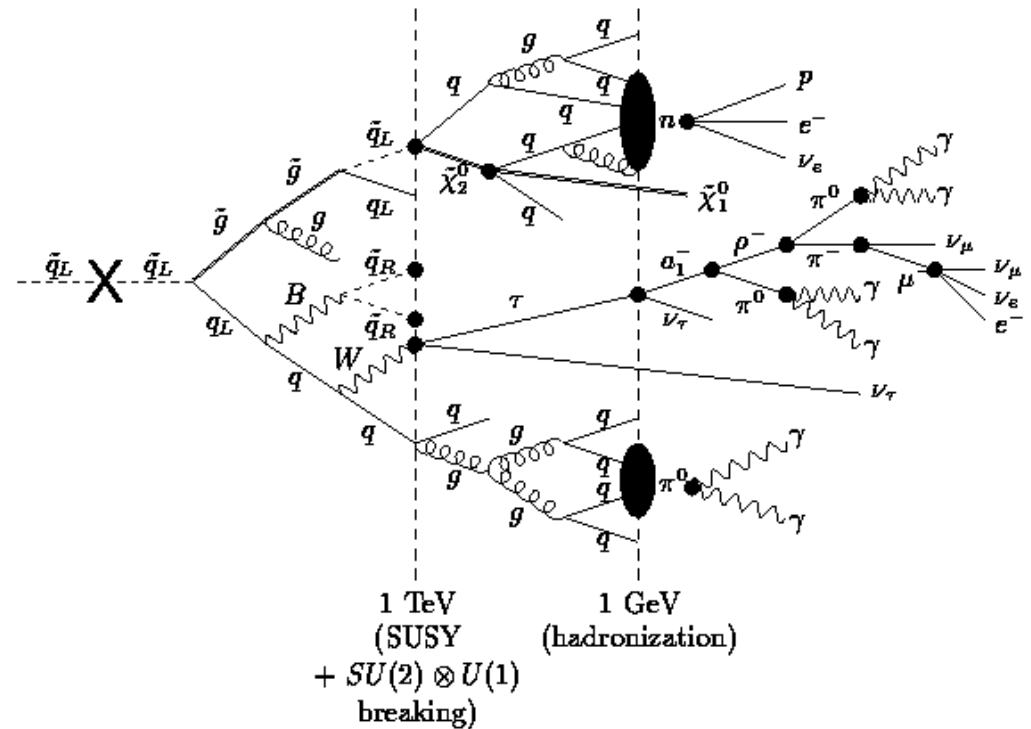
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 - * GUT parameters, e.g. m_X
 - **cosmology**



[Fodor, Katz, AR, Weiler, Wong, in prep.]

Top-down scenarios for super-GZK neutrinos

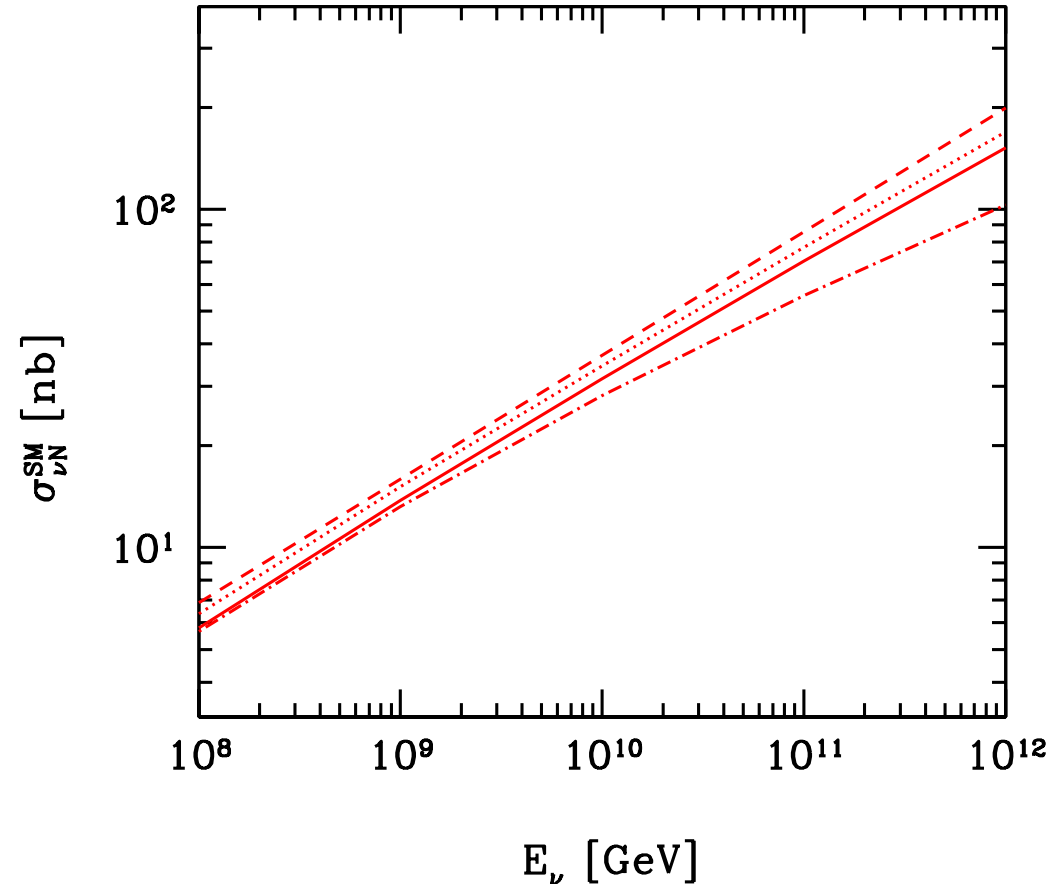
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[Barbot,Drees '02]

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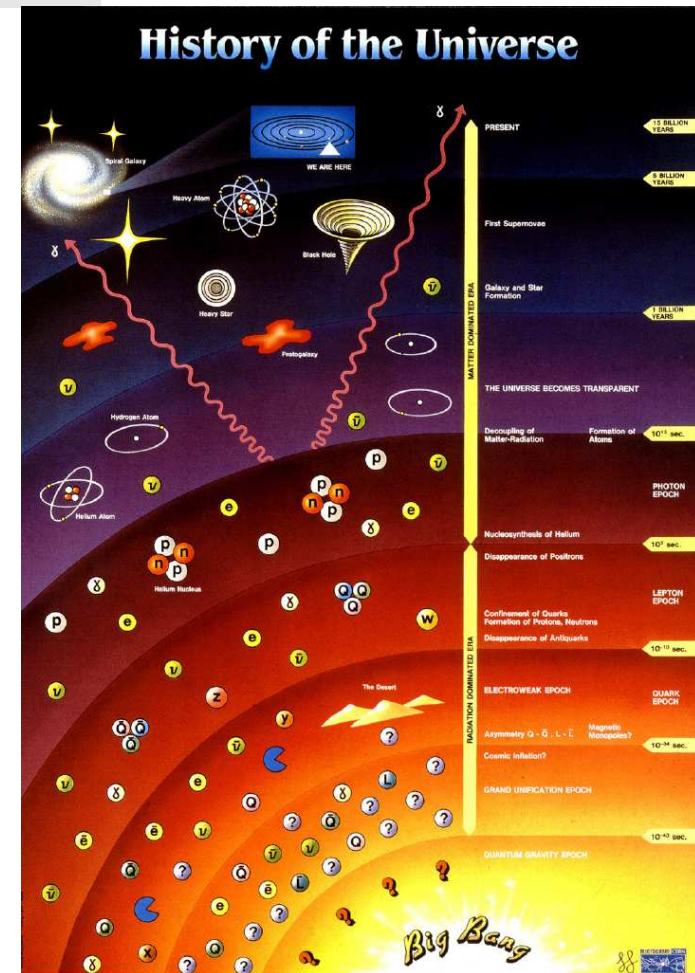
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[Tu '04]

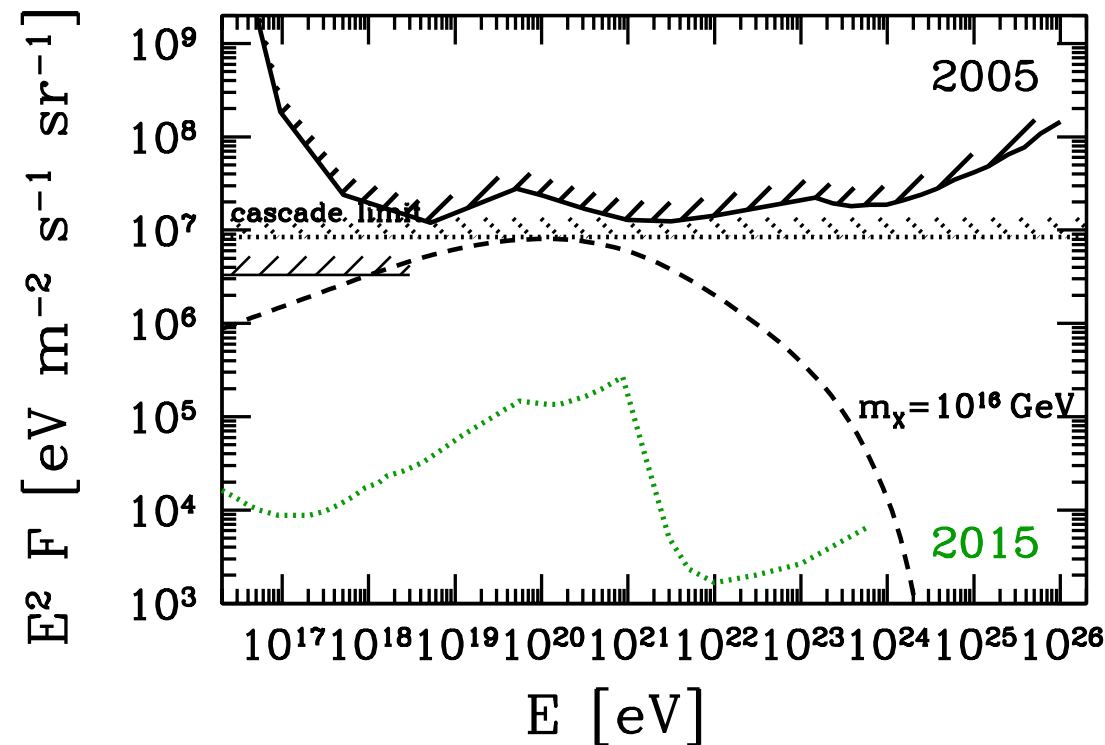
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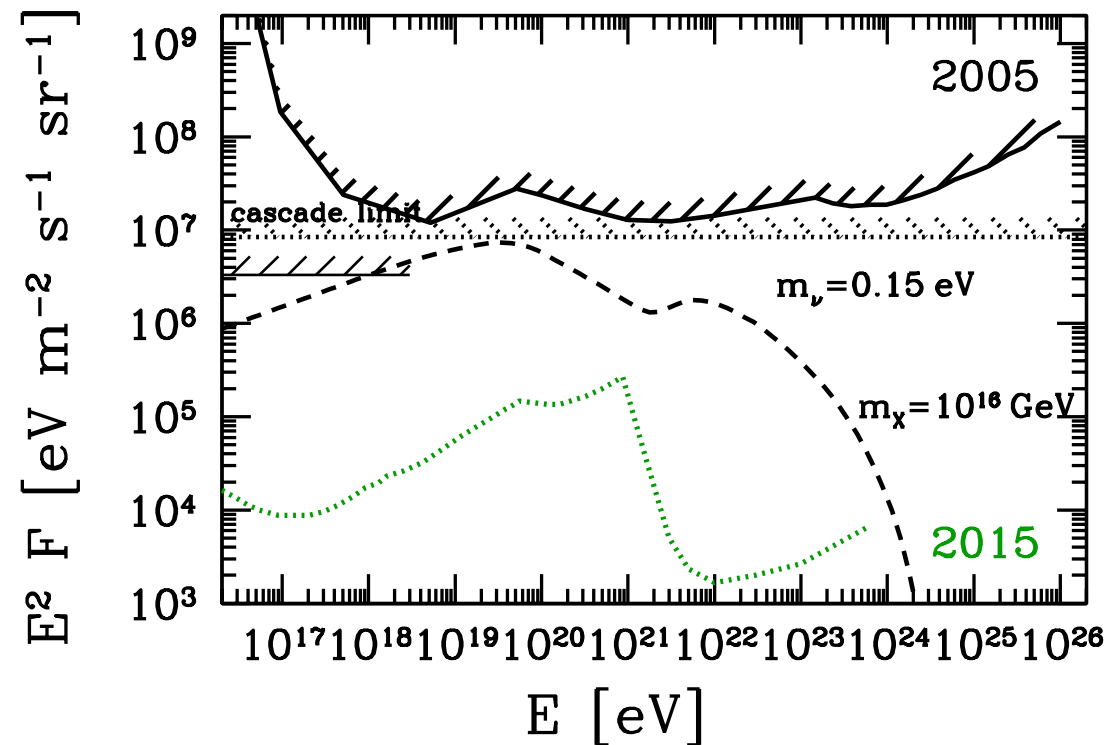
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5. Conclusions

- Exciting times for ultrahigh energy cosmic rays and neutrinos:
 - many observatories under construction
 - ⇒ appreciable event samples
- Expect strong impact on
 - astrophysics
 - particle physics
 - cosmology

