Strongly Interacting Neutrinos at Ultra High Energies

(astro-ph/0506698 with A. Ringwald and H. Tu)

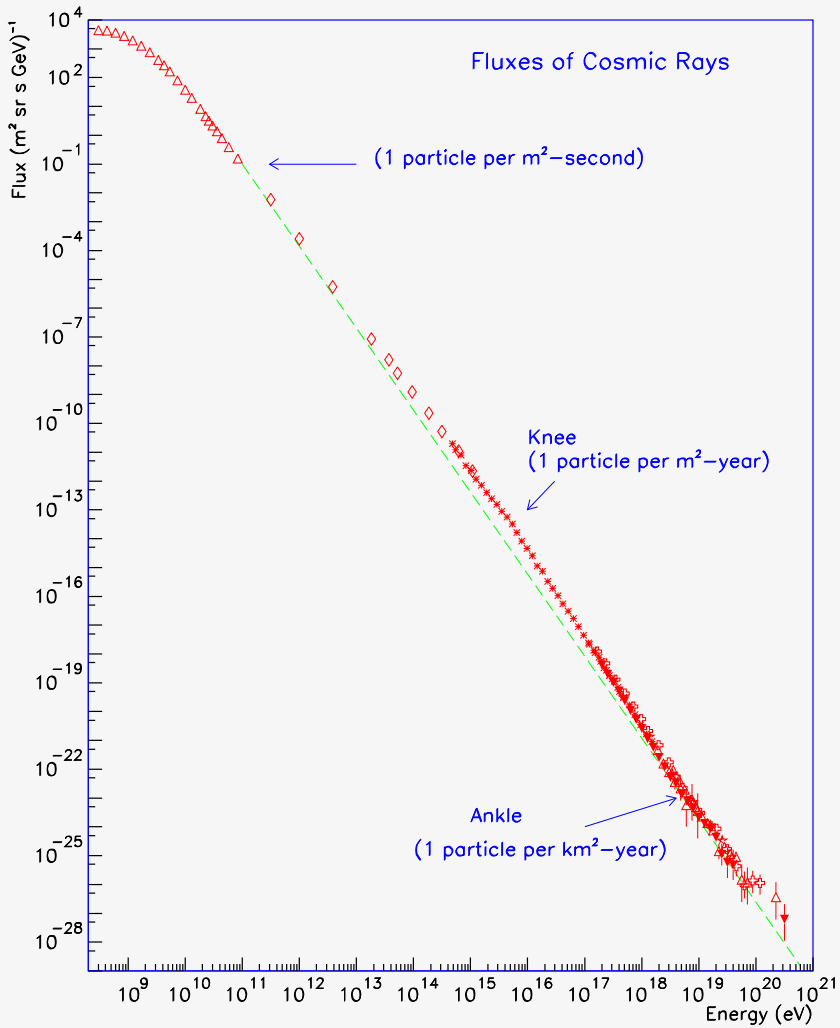
Markus Ahlers

DESY Hamburg

2nd Vienna Central European Seminar on Particle Physics and Quantum Field Theory

Outline

Cosmic Ray Spectrum



[plot from Bhatacharjee/Sigl '98]

The origin and chemical composition of ultra high energy (UHE) comic rays (CRs) is still an open question in astrophysics.

(cp. talk of A. Ringwald)

CRs around the "ankle" seem to be dominated by extragalactic protons.

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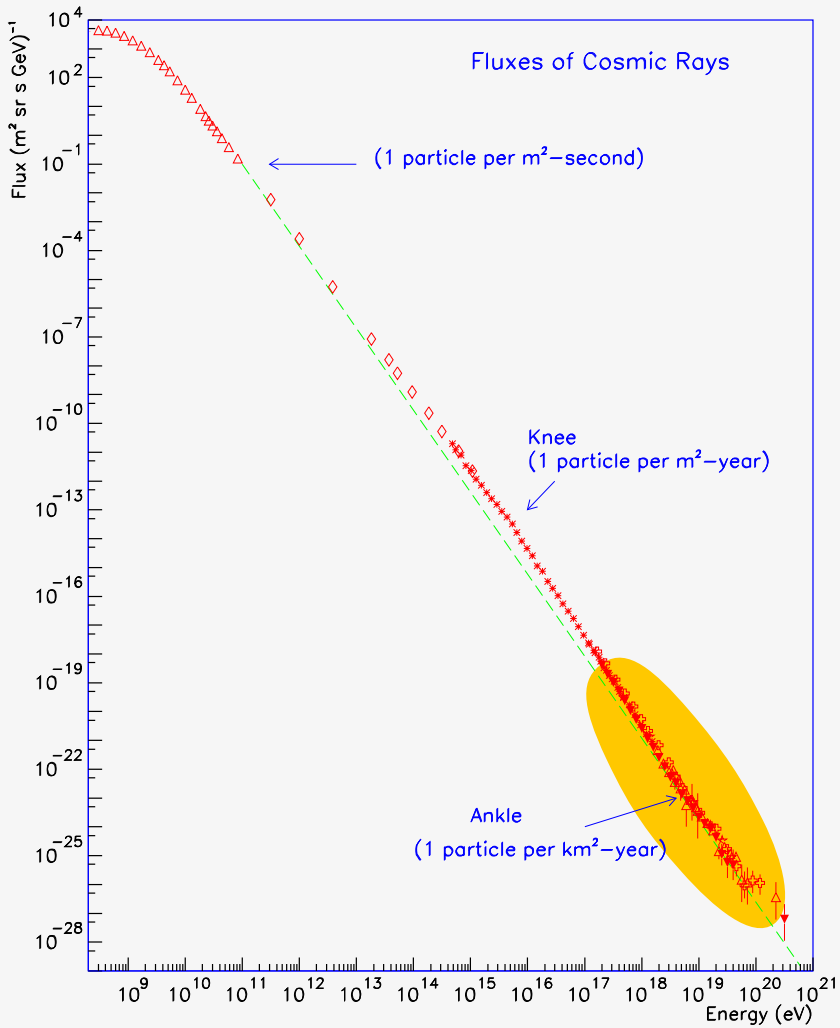

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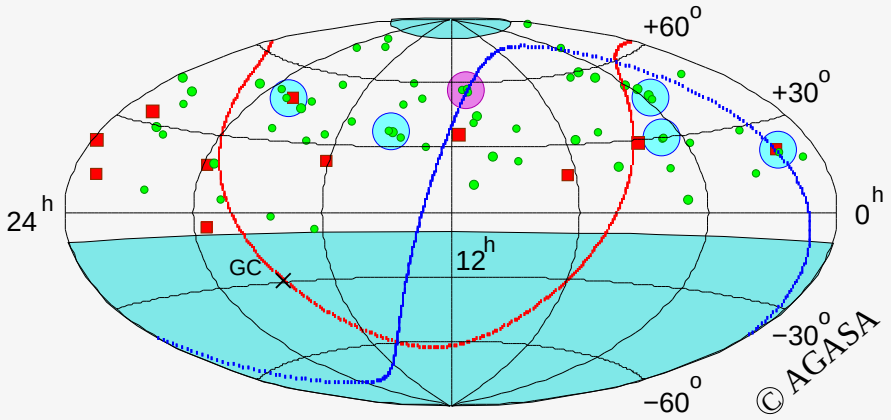
Cosmic Ray Spectrum

Signs for extragalactic protons:

- √ large–scale isotropy
- √ composition measurements
- √ ”dip” and ”bump”
- ? Greisen–Zatsepin–Kuzmin (GZK) cutoff (large systematic errors and low statistics!)



[AGASA - Feb. 17, 1990 – Jul. 31, 2002]

- $4 \times 10^{10}\mathrm{GeV} < E < 10^{11}\mathrm{GeV}$
- $E > 10^{11}\mathrm{GeV}$
- small–scale anisotropy (?)

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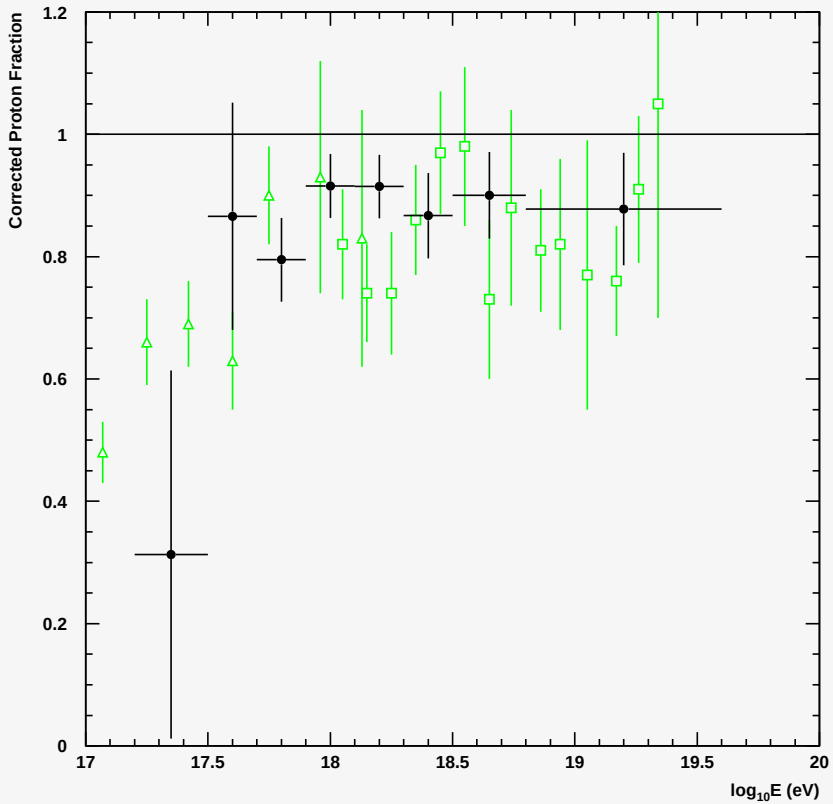

HiRes-MIA/Stereo and HiRes-II:
$\sim$ 80% protons above $10^{8.6}$GeV

[Bergman ’04]

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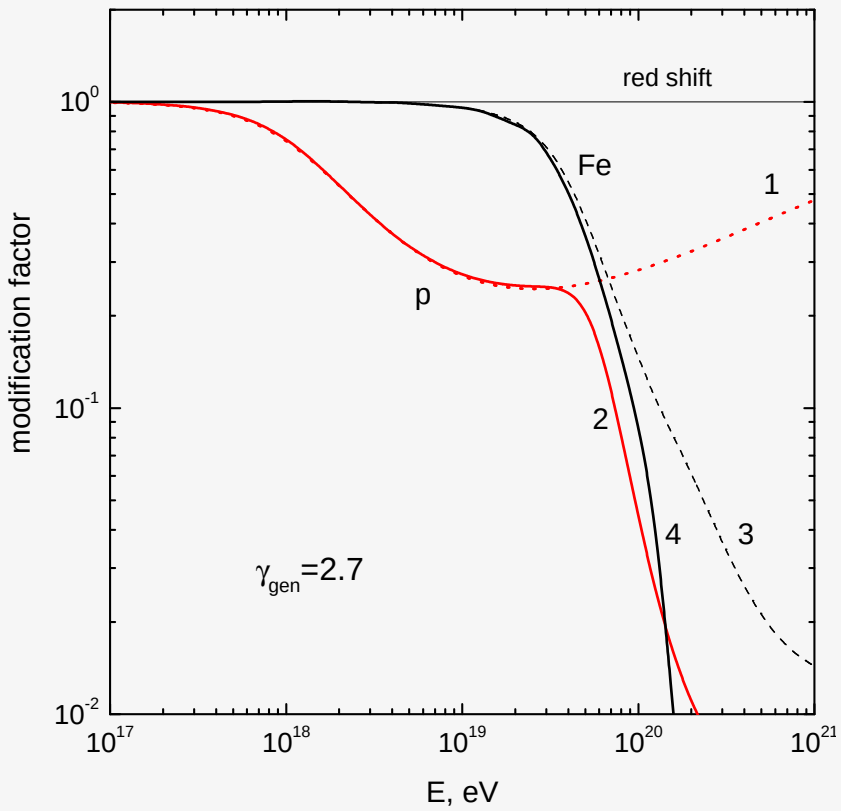

characteristic modifications from e^+e^- and photopion production in CMB

[Berezinsky/Gazizov/Grigorieva ’02/’04]

Cosmic Ray Spectrum

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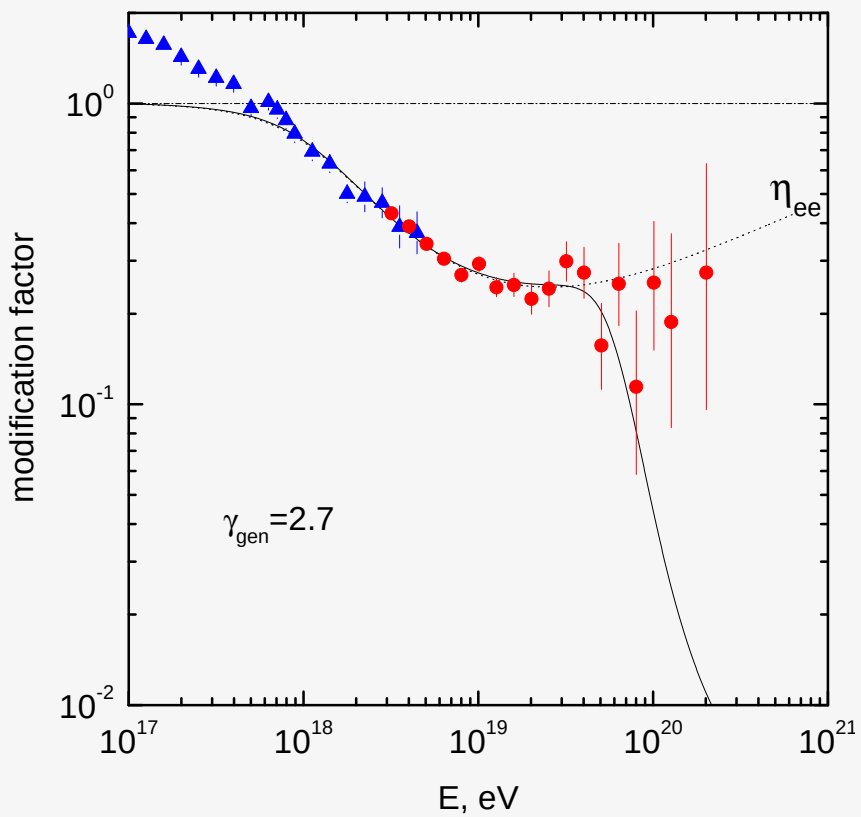

confirmed at Akeno+AGASA
(also Fly’s Eye, HiRes, Yakutsk)

[Berezinsky/Gazizov/Grigorieva ’02/’04]

Cosmic Ray Spectrum

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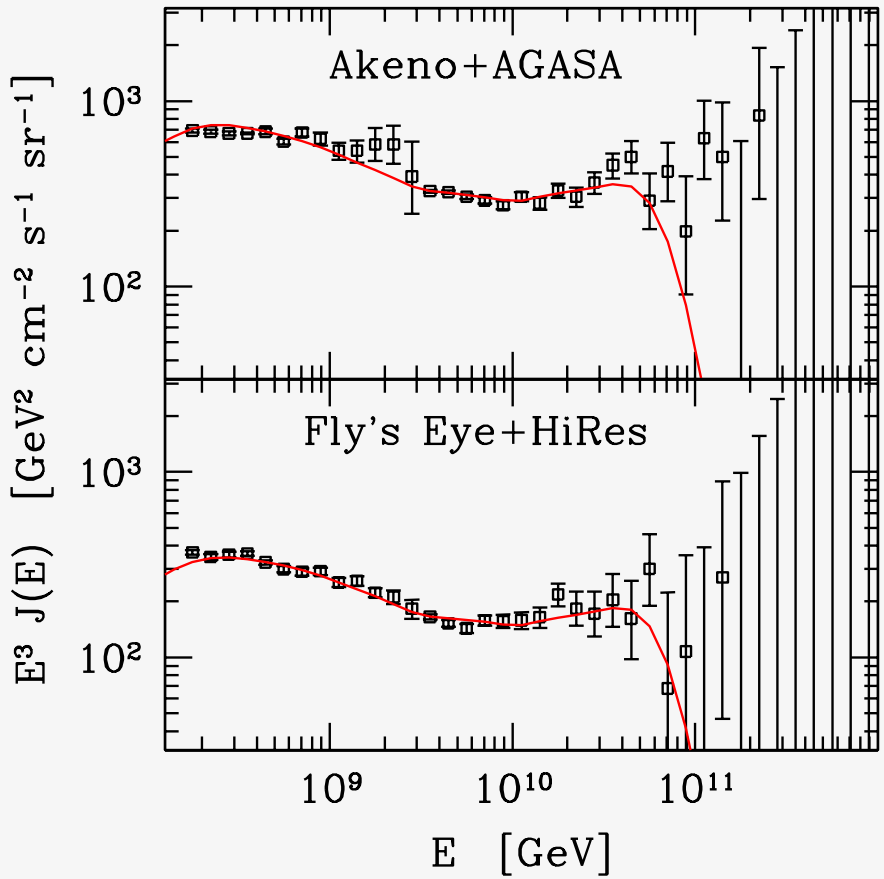


[plot from MA et al. ’05]

Super-GZK protons?

Sources of extragalactic protons:

”Bottom–Up”

Astrophysical accelerators

- active galactic nuclei?
- gamma ray bursts?
- . . .

”Top–Down”

Decay of superheavy X particles

- from topological defects?
- superheavy dark matter?
- . . .

Super-GZK protons?

Sources of extragalactic protons:

”Bottom–Up”

Astrophysical accelerators

- active galactic nuclei?
- gamma ray bursts?
- . . . In general, too distant!

”Top–Down”

Decay of superheavy X particles

- from topological defects?
  Overproduction of GeV-photons?
- superheavy dark matter?
  Anisotropy from Galactic halo?
- . . .

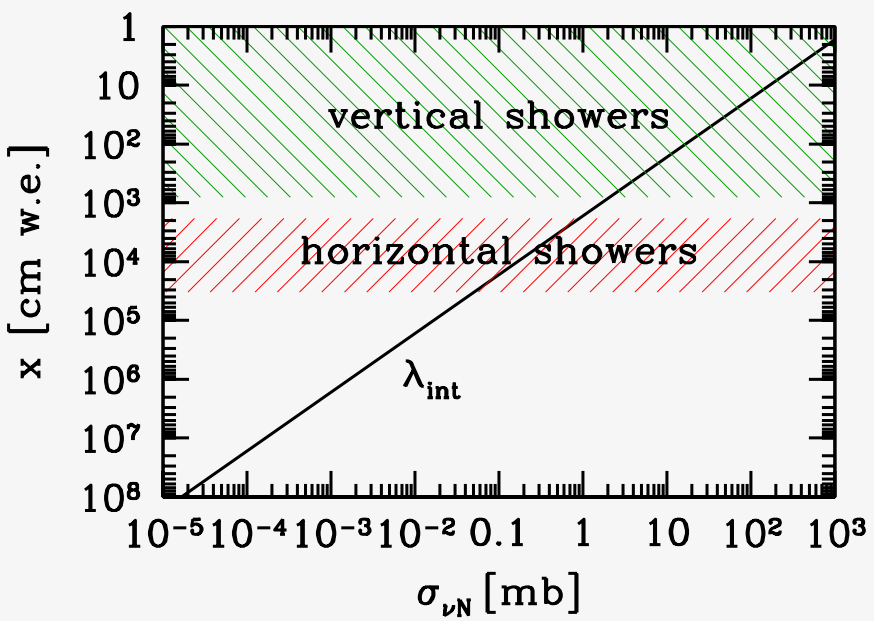
A new component might be responsible for super-GZK events.

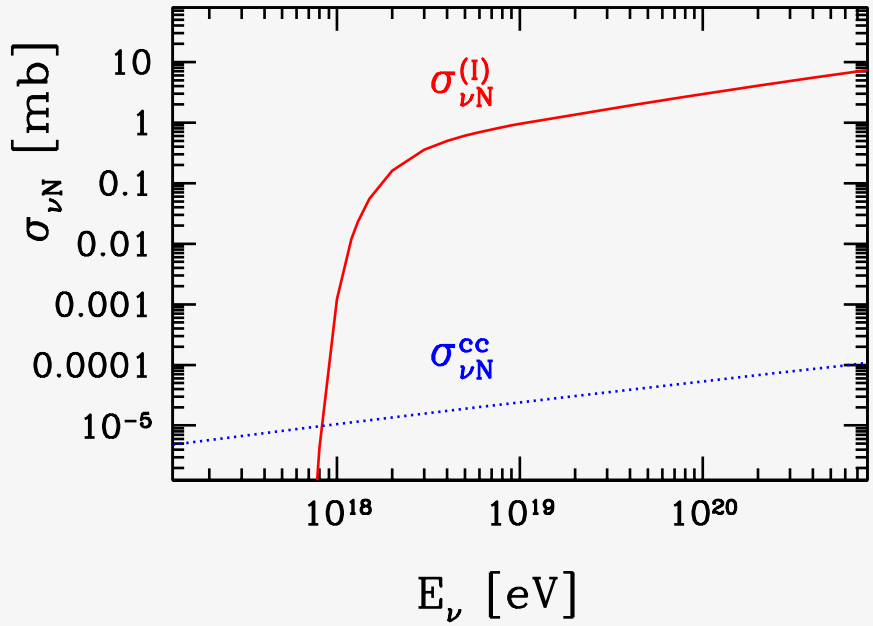
Strongly Interacting Neutrinos

Still an attractive possibility:

”Cosmic Rays at Ultra High Energies (Neutrino ?)”

[Berezinsky/Zatsepin ’69]





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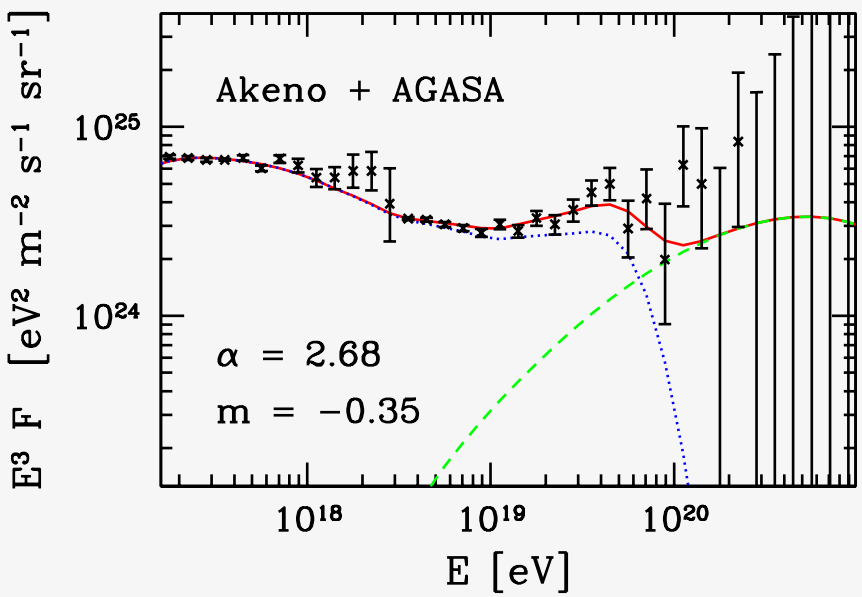

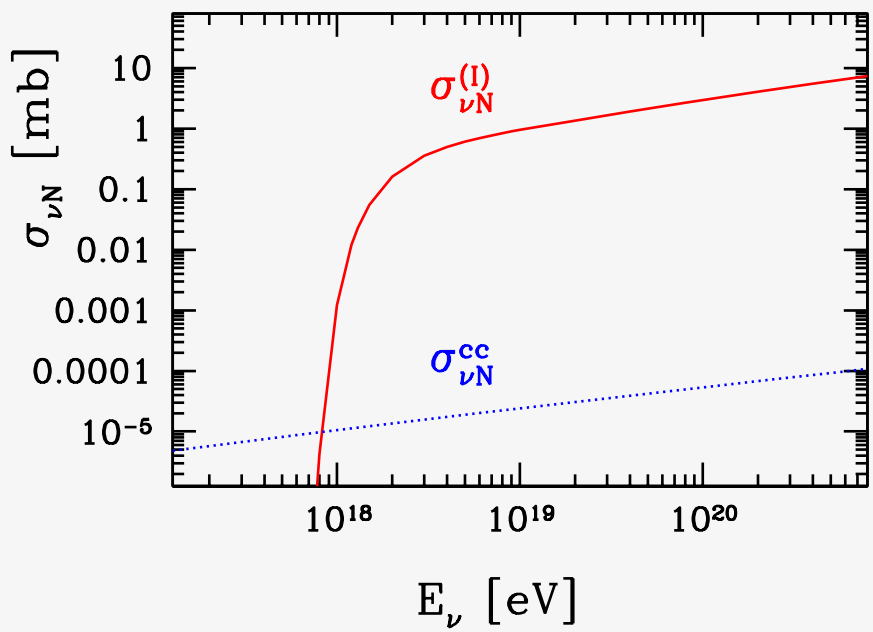

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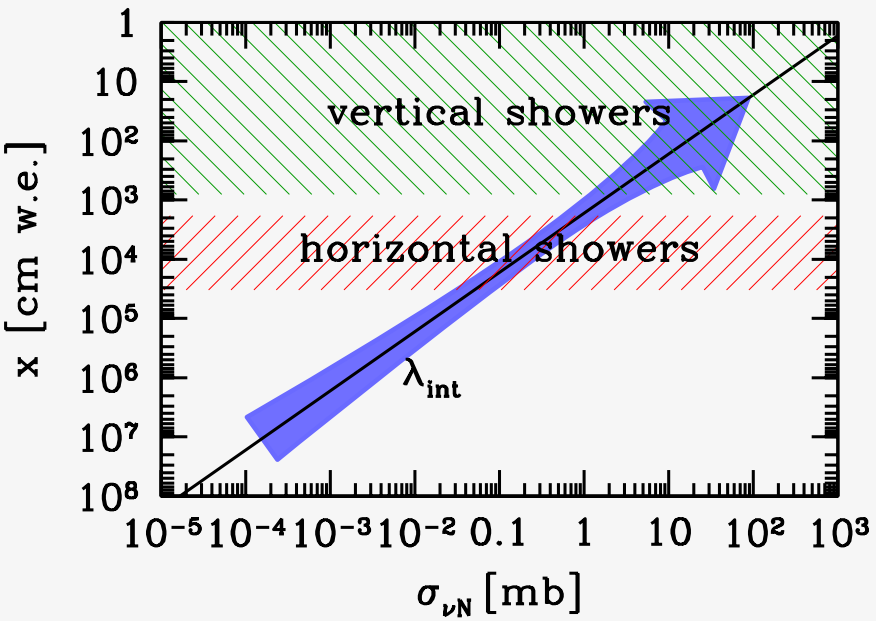
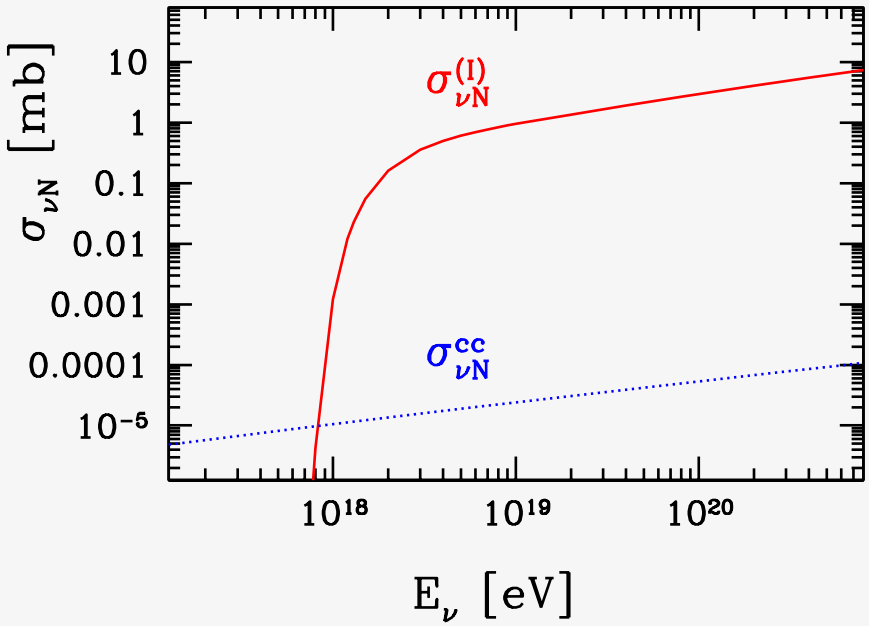




Strongly Interacting Neutrinos

Physics beyond the (perturbative) Standard Model (SM) predicts strongly interacting neutrinos, e.g. ...

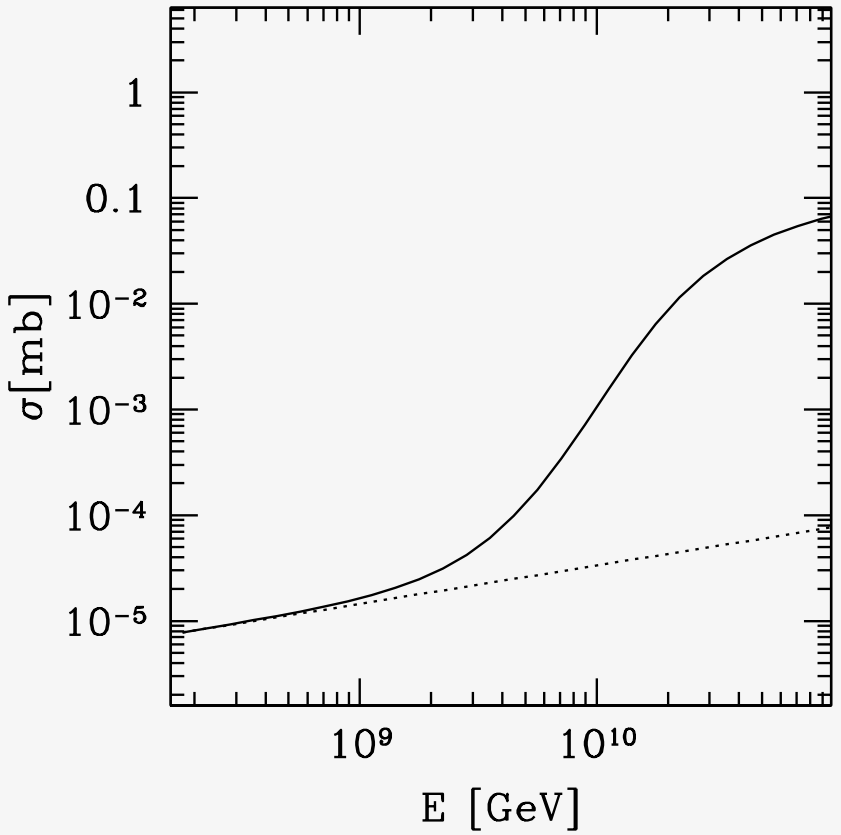
- electroweak sphalerons [Aoyama/Goldberg '87,Ringwald '90,Han/Hooper '03]
- compositeness [Domokos/Nussinov '87,Bordes et al. '97/'98]
- Kaluza-Klein modes [Domokos/Kovesi-Domokos '98,Nussinov/Shrock '98]
- string excitations [Domokos et al. '00]
- p-brane production [Ahn et al. '02,Anchordoqui '02]
- ...

Strongly Interacting Neutrinos

Parameterizing strong νN interactions according to:

- the characteristic scale E_{th},
- the amplification $\mathcal{A}$,
- the width of the transition $\mathcal{B}$.

$$\log_{10}\left(\frac{\sigma^{\mathrm{new}}}{\mathcal{A}\,\sigma^{\mathrm{SM}}}\right) = \frac{1}{2}\left[1+\tanh\left(\log_{\mathcal{B}}\frac{E_\nu}{E_{\mathrm{th}}}\right)\right]$$



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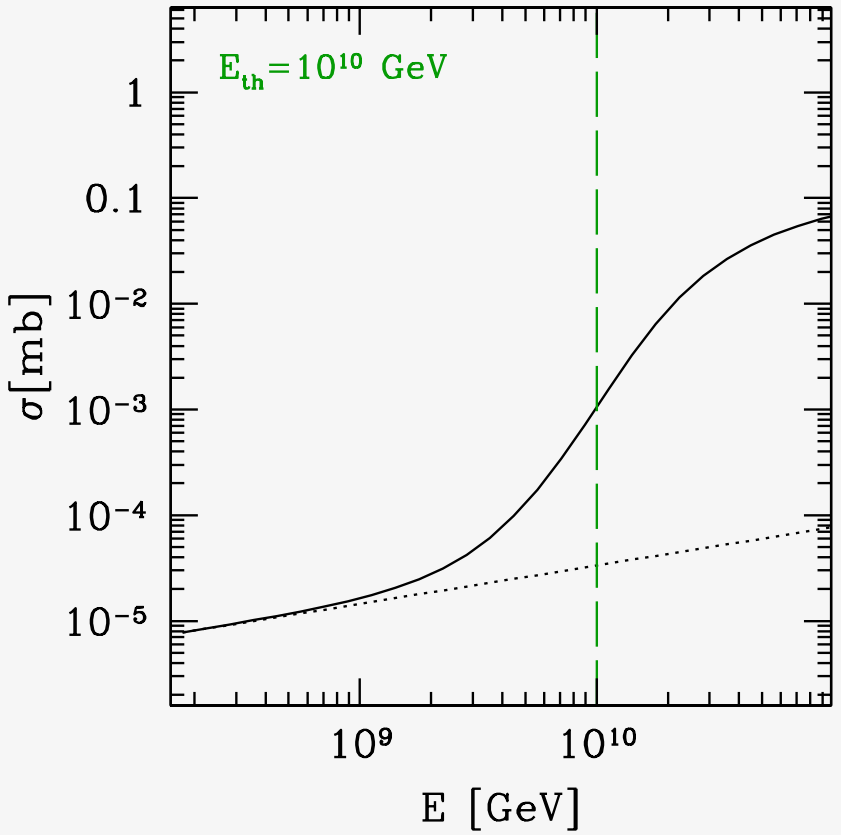

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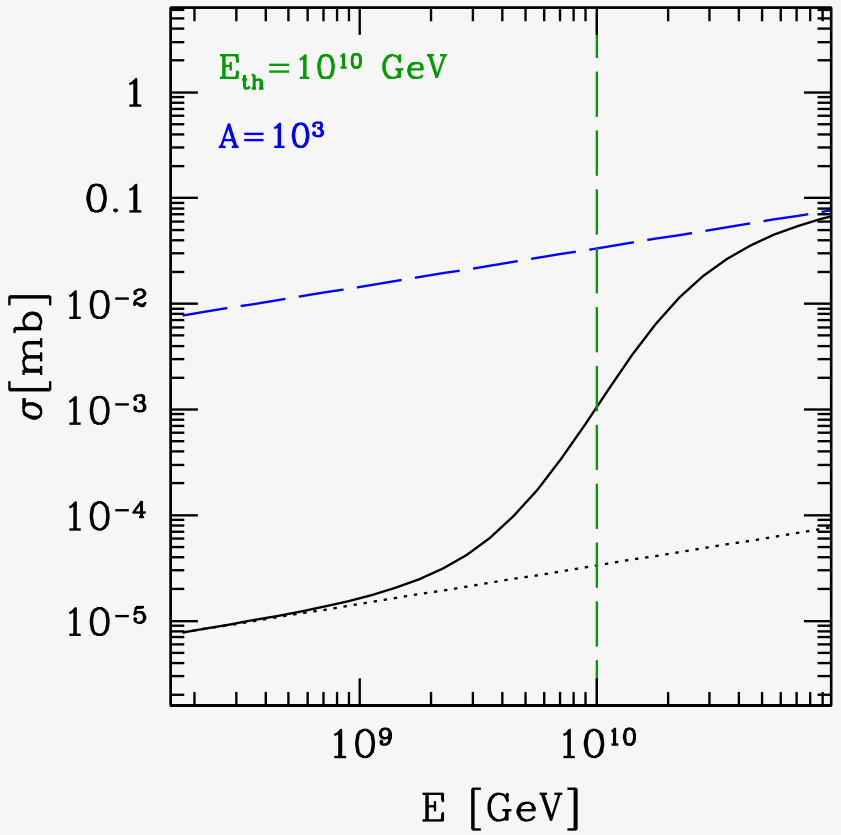

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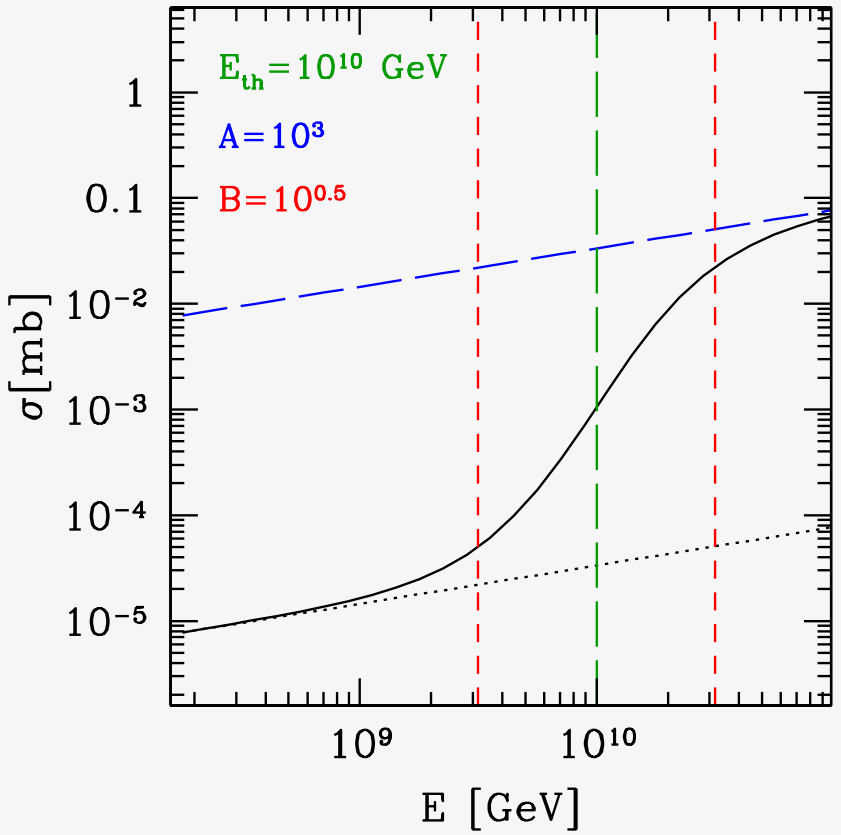

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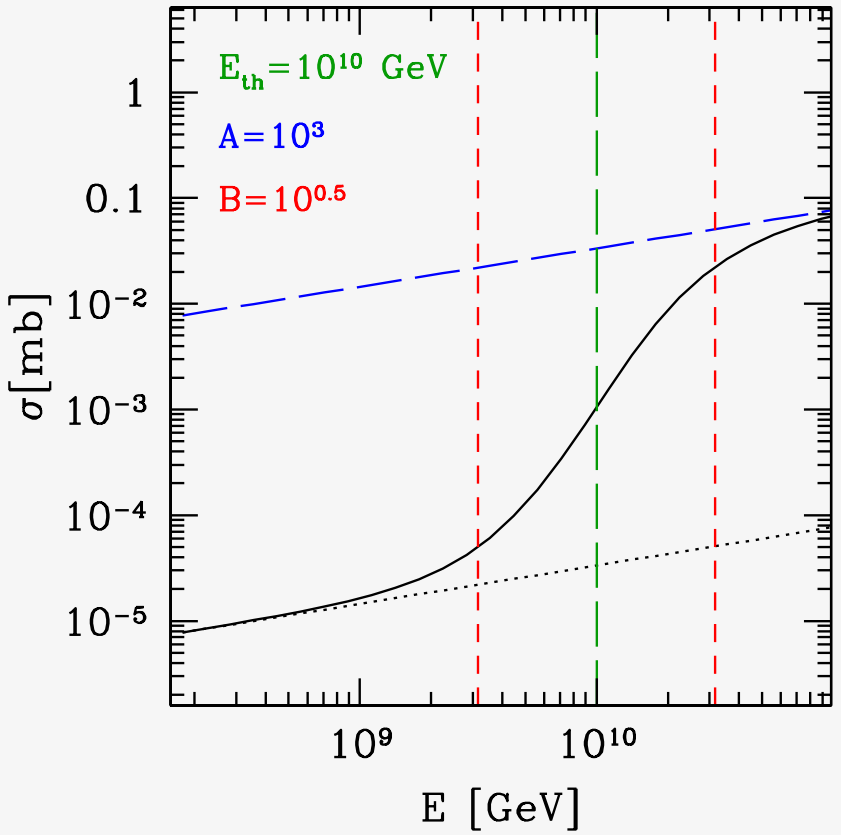


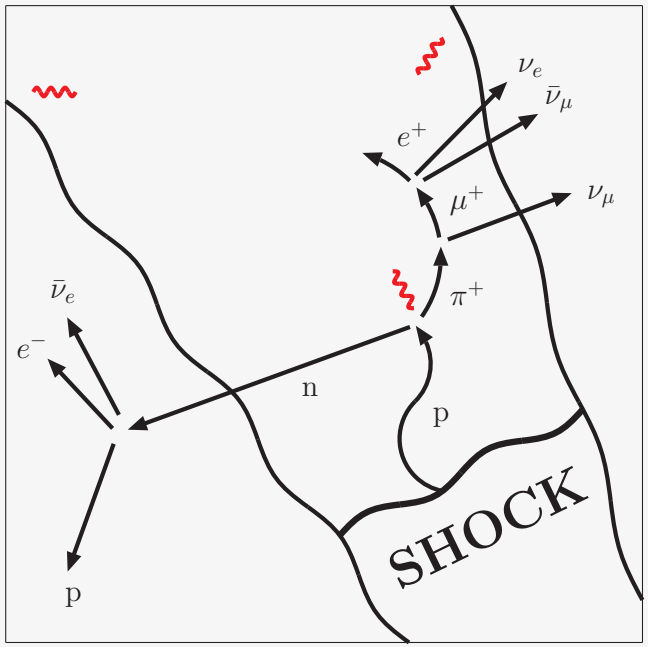
Extragalactic Particle Production

"Guaranteed" UHEνs from CR protons due to photopion production in ...

- ...cosmic microwave background: *cosmogenic neutrinos*.
- ...cosmic ray accelerators.

CR vs. neutrino

$$\underbrace{\mathcal{L}_\nu(E_\nu) \approx 3 \left\langle \frac{E_{\rm CR}}{E_\nu} \right\rangle \mathcal{L}_{\rm CR} \left(\left\langle \frac{E_{\rm CR}}{E_\nu} \right\rangle E_\nu \right)}_{\text{optically thin}}$$



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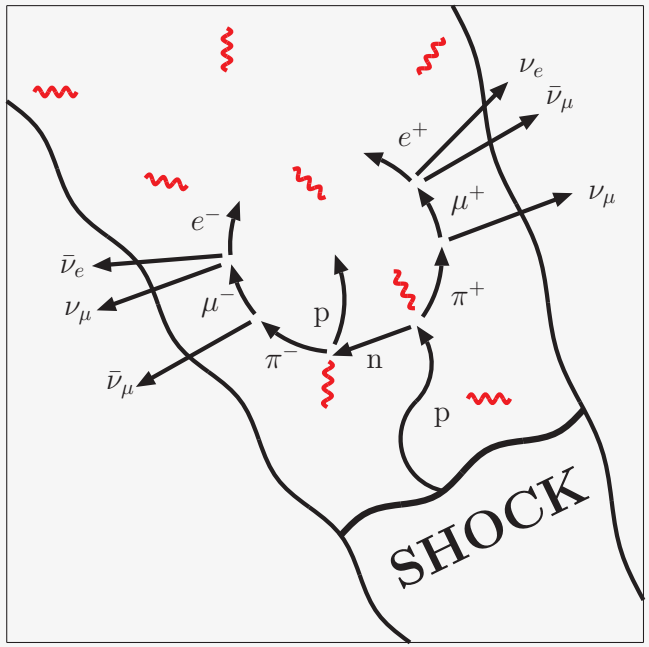

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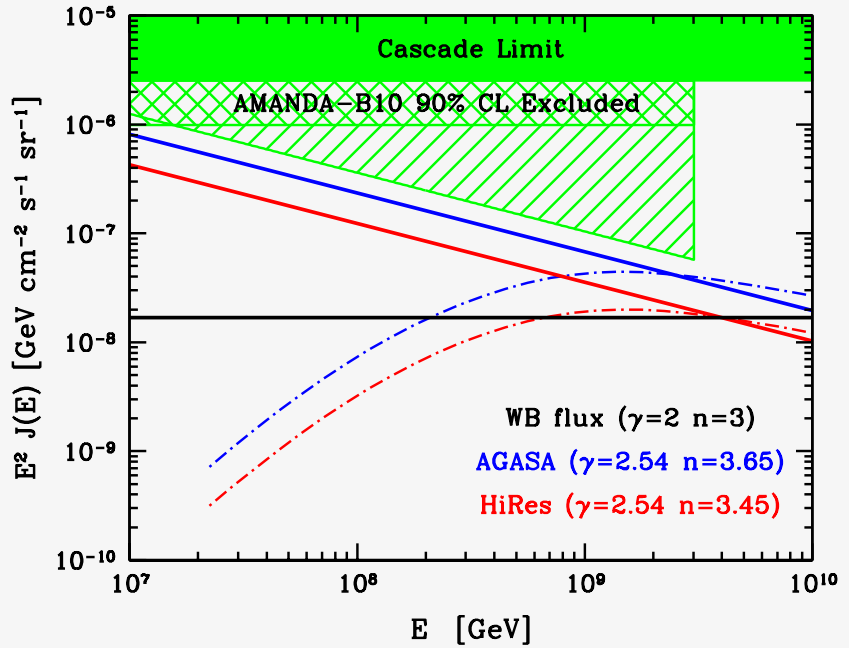
Neutrinos from photopion production close to be measured!

[MA/Anchordoqui/Goldberg/Halzen/Ringwald/Weiler ’05]



Extragalactic Particle Production

Ansatz:

- spatially homogeneous and isotropic source distribution
- factorization of red-shift evolution
  with $z_{\mathbf{min}} = 0.012$ and $z_{\mathbf{max}} = 2.0$
- single power–law with exponential cutoff $E_{\max} = 10^{12}\mathrm{GeV}$
- optically thin sources
- low cross-over (galactic→extragalactic) at $10^{8.6}$ GeV

$$\mathcal{L}_{\mathrm{CR}}(z, E_{\mathrm{CR}}) \propto (1+z)^n \, E_{\mathrm{CR}}^{-\gamma} \, e^{-\frac{E_{\mathrm{CR}}}{E_{\max}}}$$

$$z_{\min} < z < z_{\max}$$

$$\mathcal{L}_{\nu}(z, E_{\nu}) = 3 \left\langle \frac{E_{\mathrm{CR}}}{E_{\nu}} \right\rangle \mathcal{L}_{\mathrm{CR}} \left(z, \left\langle \frac{E_{\mathrm{CR}}}{E_{\nu}} \right\rangle E_{\nu} \right)$$

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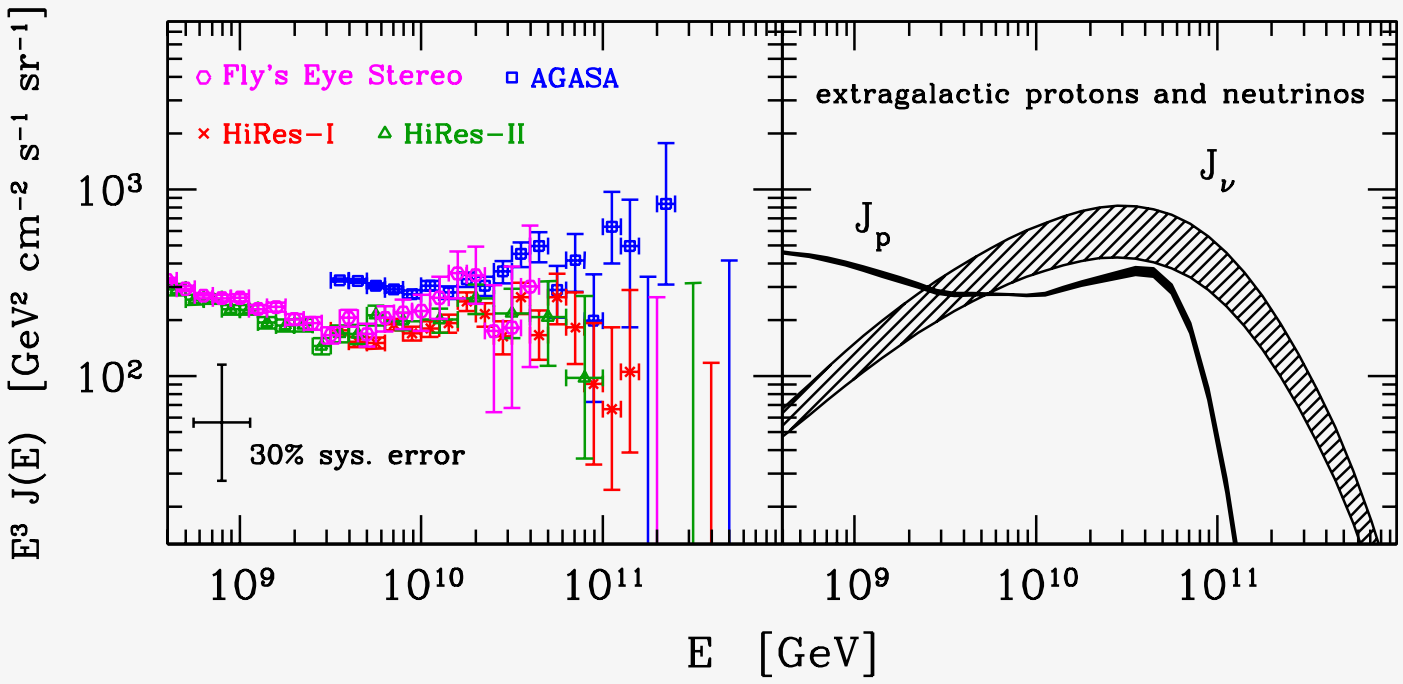
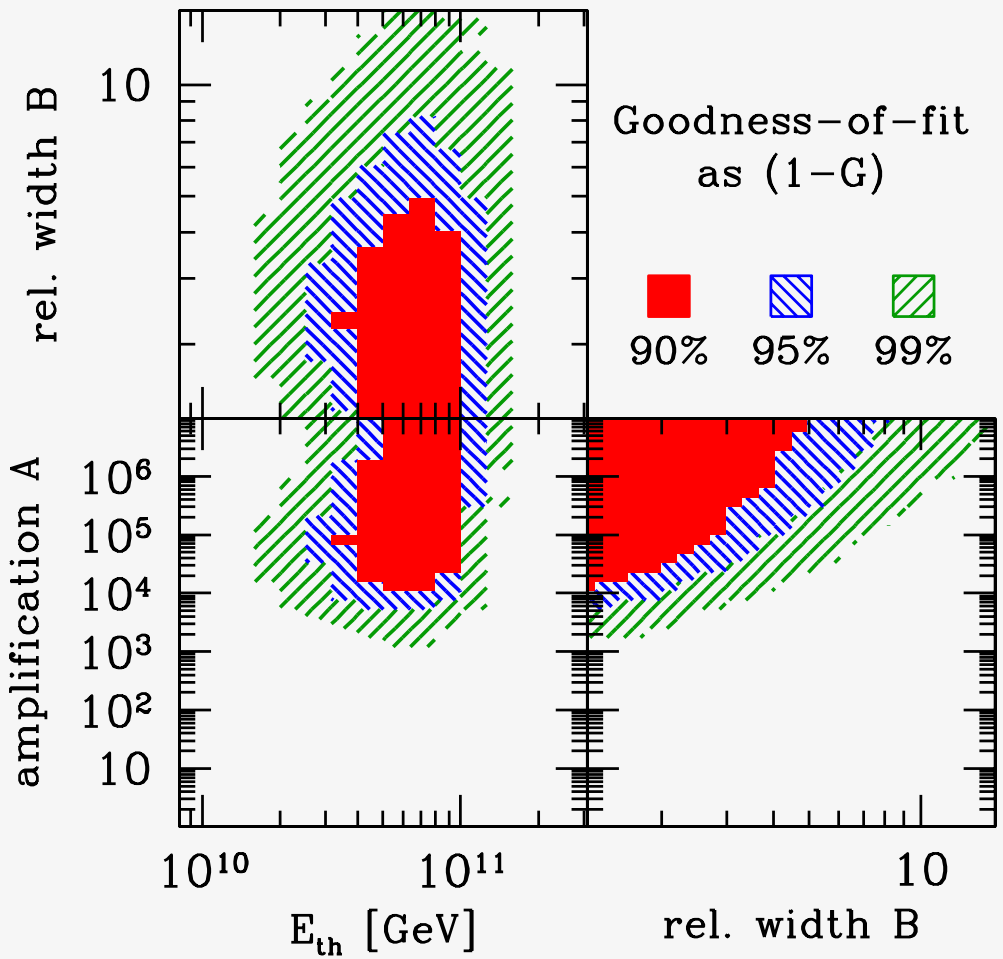
Incident flux of protons and neutrinos

propagation effects:

- e^+e^- pairproduction in CMB
- photopion production in CMB ($\rightarrow$*cosmogenic neutrinos*)
- red–shifting



Results



[MA/Ringwald/Tu '05]

Goodness-of-fit test for:

- AGASA, HiRes-I/II and Fly's Eye Stereo
- horizontal events at AGASA
- contained events at RICE

- $\mathcal{A} > 10^4$ at 90% CL
- $\mathcal{B} < 10^{0.5}$ at 90% CL

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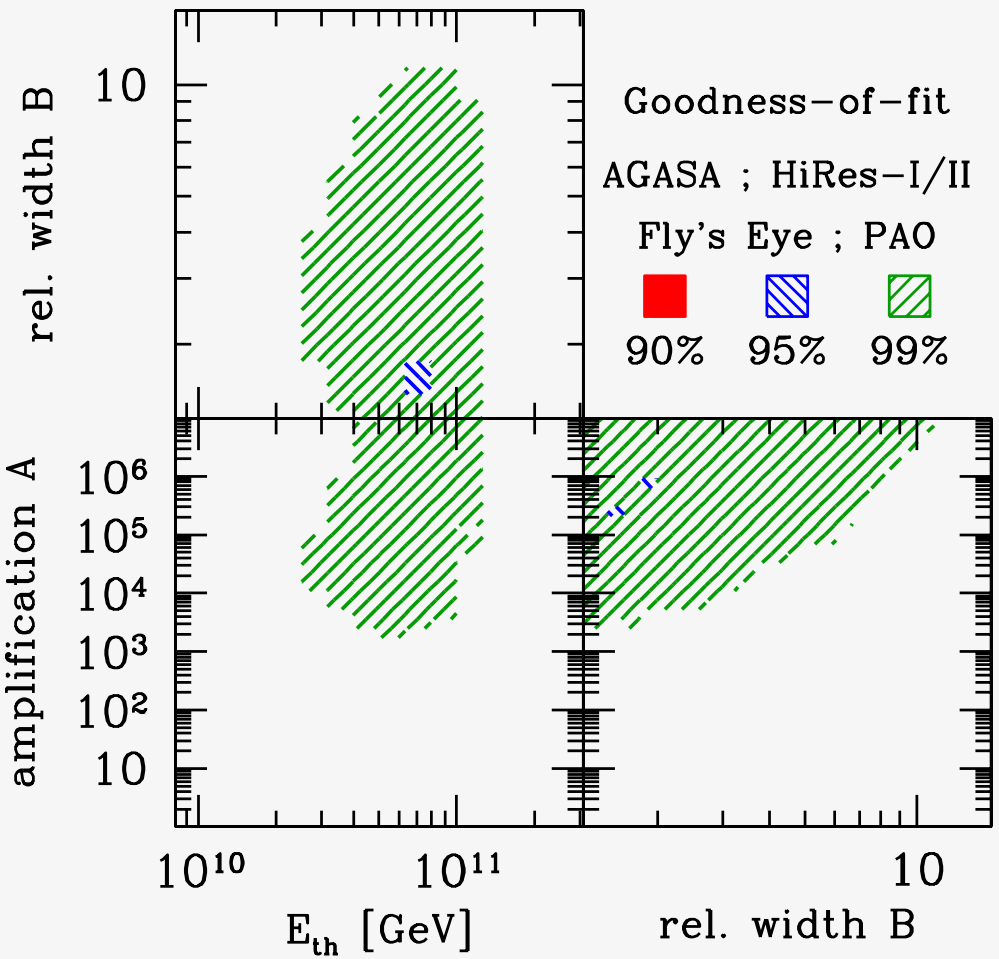

[MA/Ringwald/Tu '05]

Goodness-of-fit test for:

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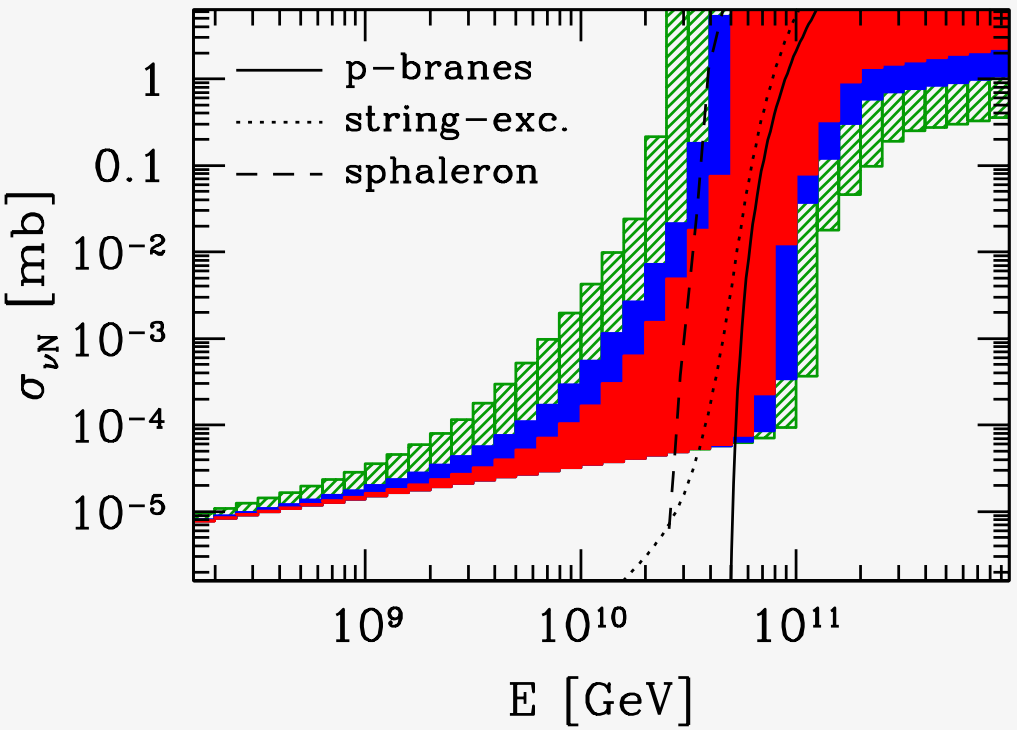
- $\mathcal{B} < 10$ at 99% CL

Results

"Quick test" for σ^{new}



goodness-of-fit < 99%/95%/90% CL

[MA/Ringwald/Tu '05]

Strong neutrino nucleon interaction induced by:

- electroweak sphalerons
  g. o. f. $\sim$ 98% CL
  [Ringwald '03,Han/Hooper '03]
- p-branes
  g. o. f. $\sim$ 83% CL
  [Anchordoqui/Feng/Goldberg '02]
- string excitations
  g. o. f. $\sim$ 84% CL
  [Burgett/Domokos/Kovesi–Domokos '04]

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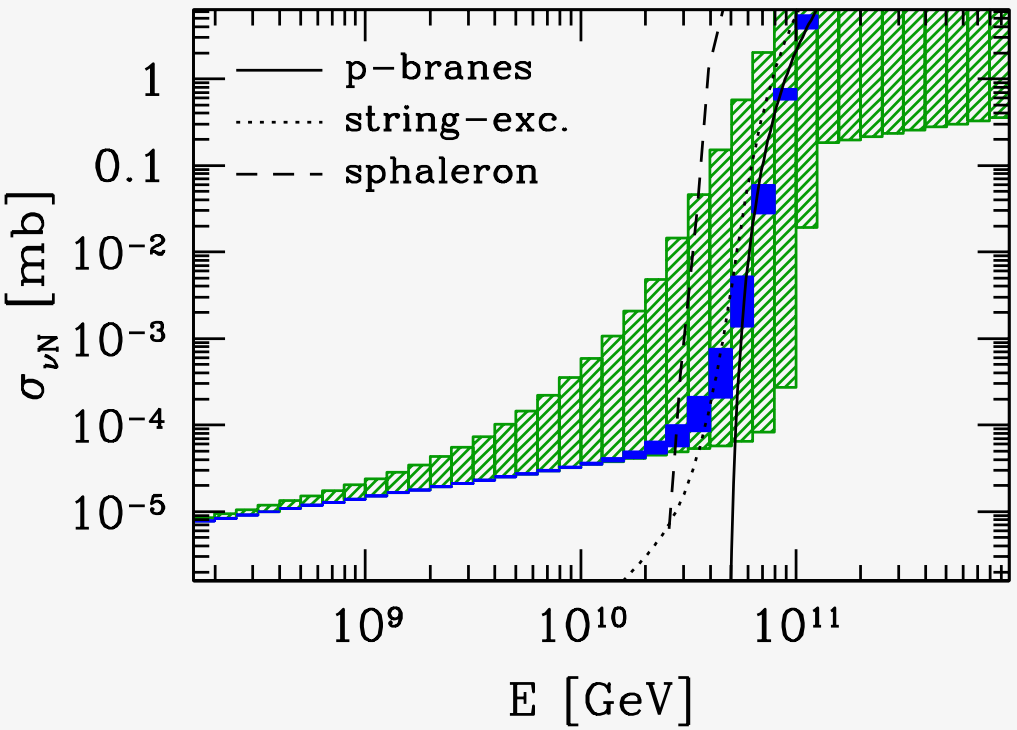

goodness-of-fit < 99%/95%/90% CL

[MA/Ringwald/Tu '05]

Survives inclusion of Pierre Auger data at the 95% CL.

Conclusion and Outlook

- Strongly interacting neutrinos might contribute to cosmic rays around and above the GZK–cutoff.
- Our statistical method provides a quick check for strongly interacting neutrino scenarios, taking into account various cosmic ray data sets and cosmic neutrino flux limits.
- Flux of UHEνs is model dependent!
  More information on the origin of cosmic rays soon available:
  $\rightarrow$ IceCube, PAO, ...
- Inclusion of additional data on UHE neutrino rates:
  $\rightarrow$ horizontal events from PAO, ...

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Statistical analysis

Goodness-of-fit test

In frequentists statistic the level of agreement of a particular hypothesis $\mathcal{H}$ with the experimental data can be represented by

$$\mathcal{G}(\mathcal{H}) = \sum_{N' | P(N') < P(N_{\mathrm{exp}})} P(N'|\mathcal{H}),$$

the integrated probability of those samples N' which have a smaller probability P than the actual experimental result N_{exp}. In general, $\mathcal{H}$ is then accepted (or rejected) at a chosen significance level $\mathcal{G}$ corresponding to a confidence level $1 - \mathcal{G}$.

Dispersion relations

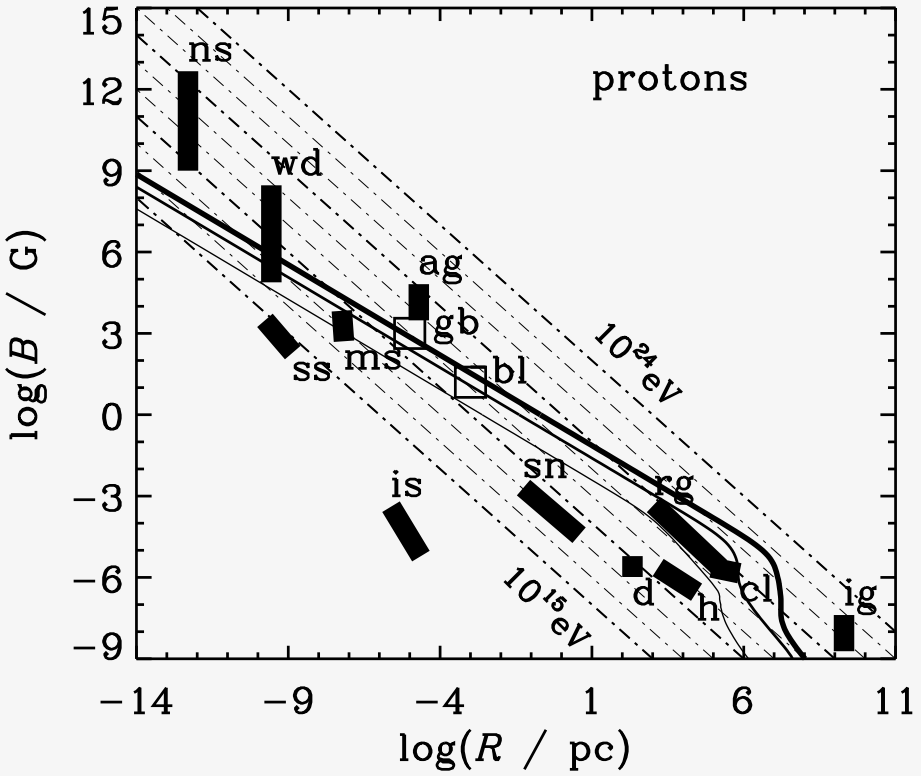
The relative contribution of new physics to the real scattering amplitude $\Re A_{\text{new}}/\Re A_{\text{SM}}$ at low energies is determined by dispersion relations:

$$\frac{\Re A_{\text{new}}(E_\nu)}{\Re A_{\text{SM}}(E_\nu)} \approx \frac{\sqrt{2}E_\nu}{0.637\pi G_{\text{F}}} \int_{E_-}^{\infty} \mathrm{d}E' \frac{\sigma^{\text{SM}}}{E'} \frac{\mathrm{d}}{\mathrm{d}E'} \left(\frac{\sigma^{\text{tot}}}{\sigma^{\text{SM}}} \right)$$

For the confidence levels of strongly interacting neutrinos this gives:

best fit	90% CL	95% CL	99% CL
0.091	≤ 0.13	≤ 0.15	≤ 0.21

Hillas Diagram



The dashed-dotted lines refer to different maximal energies of the proton assuming repeated scattering off plasma shock fronts in a source with caracteristic size R and magnetic field B:

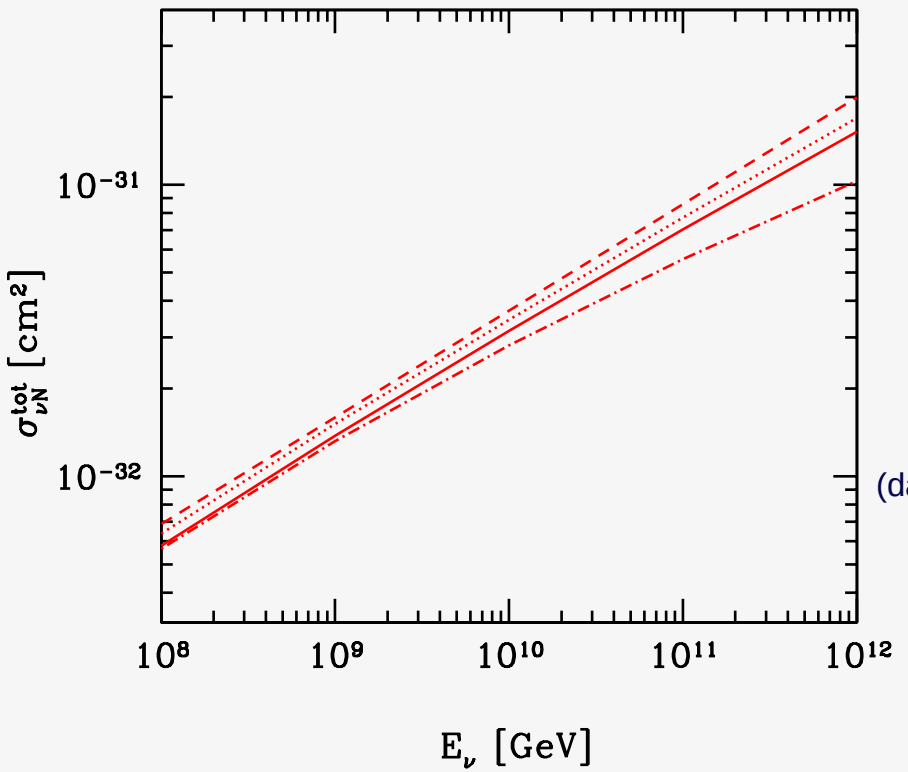
$$E_{\max} \sim 2\beta ceBR.$$

[from Protheroe '04]

The sources are: neutron stars (ns), white dwarfs (wd), sunspots (ss), magnetic stars (ms), active galactic nuclei (ag), interstellar space (is), supernova remnants (sn), galactic disk (d), halo (h), radio galaxy lobes (rg), clusters of galaxies (cl) and intergalactic medium (ig). Also shown are jet-frame parameters for blazers (bl) and gamma ray bursts (gb).

Charged and neutral current interactions

Various approximations for $\sigma^{\rm tot}_{\rm SM}$:



$$\sigma^{\rm SM}_{\rm tot} \approx 7.8 \times 10^{-36}{\rm cm}^2 \left(\frac{E_\nu}{1{\rm GeV}}\right)^{0.363}$$

[Gandhi/Quigg/Reno/Sarcevic '98]

(solid) unified BFKL-DGLAP

(dotted) CTEQ PDF

(dash-dotted) unified BFKL-DGLAP supplemented with saturation effects

(dashed) GRV dynamical partons