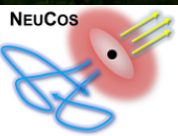


Using cosmogenic neutrinos to determine the fraction of protons in ultra-high-energy cosmic rays

Arjen van Vliet

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Jörg Hörandel



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TeVPA

Berlin - 31/08/2018

CR/Propa

Radboud University

Image: Pierre Auger Observatory



A diagram illustrating the propagation of Ultra-High-Energy Cosmic Rays (UHECR). A yellow line labeled 'CR' starts from a galaxy on the left and curves towards a central cluster of blue and red spheres representing a nucleus. From this nucleus, a yellow line curves towards the Earth on the right. A red horseshoe magnet labeled 'EGMF' is positioned above the nucleus, and another labeled 'GMF' is below it. A blue line labeled with the Greek letter ν (neutrino) and an orange line labeled with the Greek letter γ (gamma ray) also originate from the nucleus. A large blue and orange oval labeled 'CMB EBL' is positioned above the nucleus, with a cone-shaped beam pointing towards it. The Earth is shown at the bottom right, with a purple and white spiral galaxy in the background.

CR

UHECR propagation:

- Creation at sources
- Deflections by magnetic fields
- Interactions with CMB and EBL
- Nuclear decay
- Creation of secondary particles
- Detection at Earth

Presentation: Rafael Alves Batista

CRPropa 3

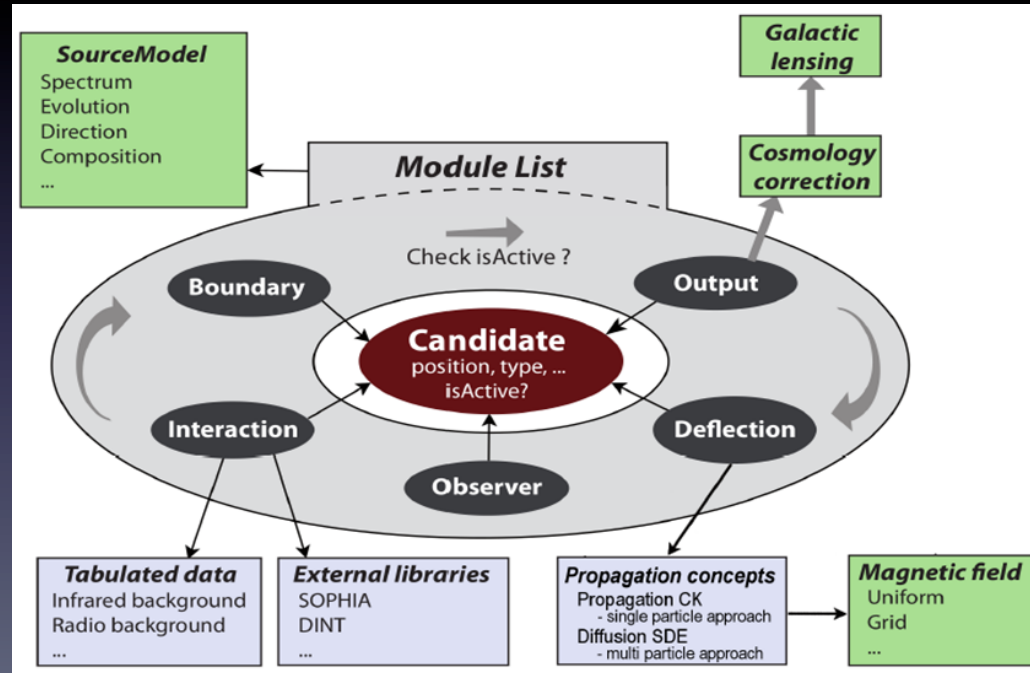
R. Alves Batista, A. Dundovic, M. Erdmann, K.-H. Kampert, D. Kümpel, G. Müller, G. Sigl, A. van Vliet, D. Walz and T. Winchen, JCAP 1605 (2016) 038

- A public astrophysical simulation framework for propagating extraterrestrial high-energy particles

- Available from

crpropa.desy.de

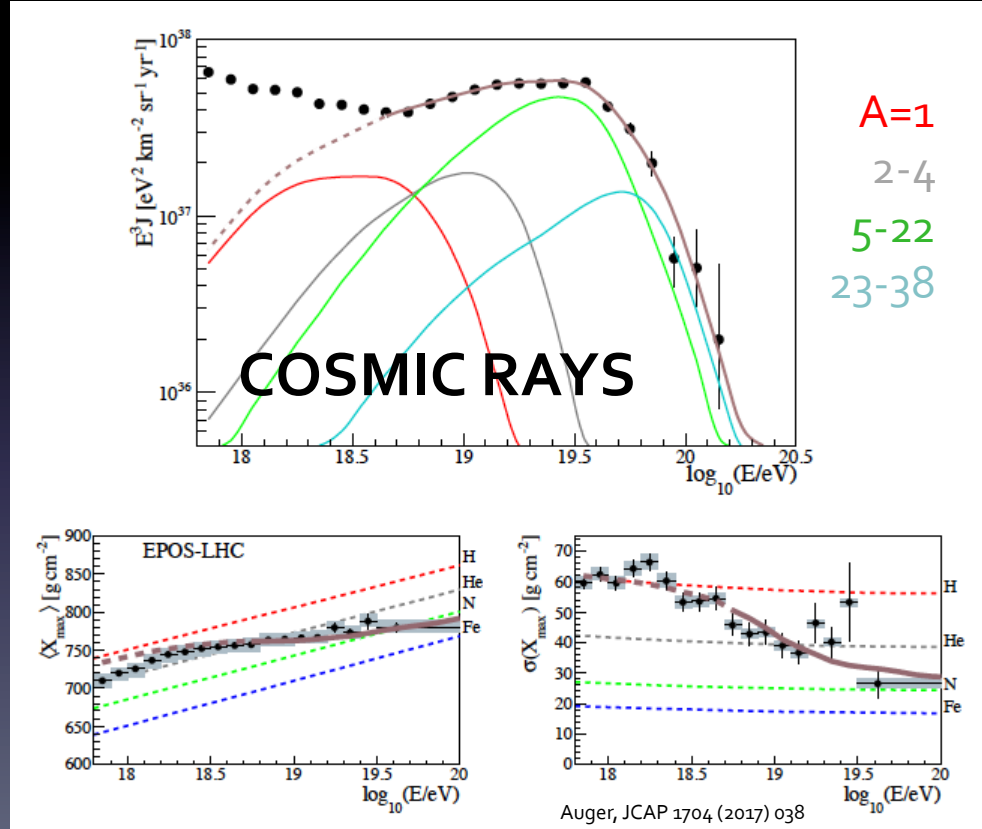
Presentation: Lukas Merten



Combined Fit

Auger, JCAP 1704 (2017) 038

- Continuous source distribution of identical sources
- Comoving source evolution
- Composition at the sources:
88% Nitrogen, 12% Silicon
- Spectrum at the sources:
 $\frac{dN}{dE} \propto E^{-\alpha} \exp(-E/ZR_{\text{cut}})$
- $\alpha = 0.87$
- $R_{\text{cut}} = 4.2 \text{ EV}$



Combined Fit

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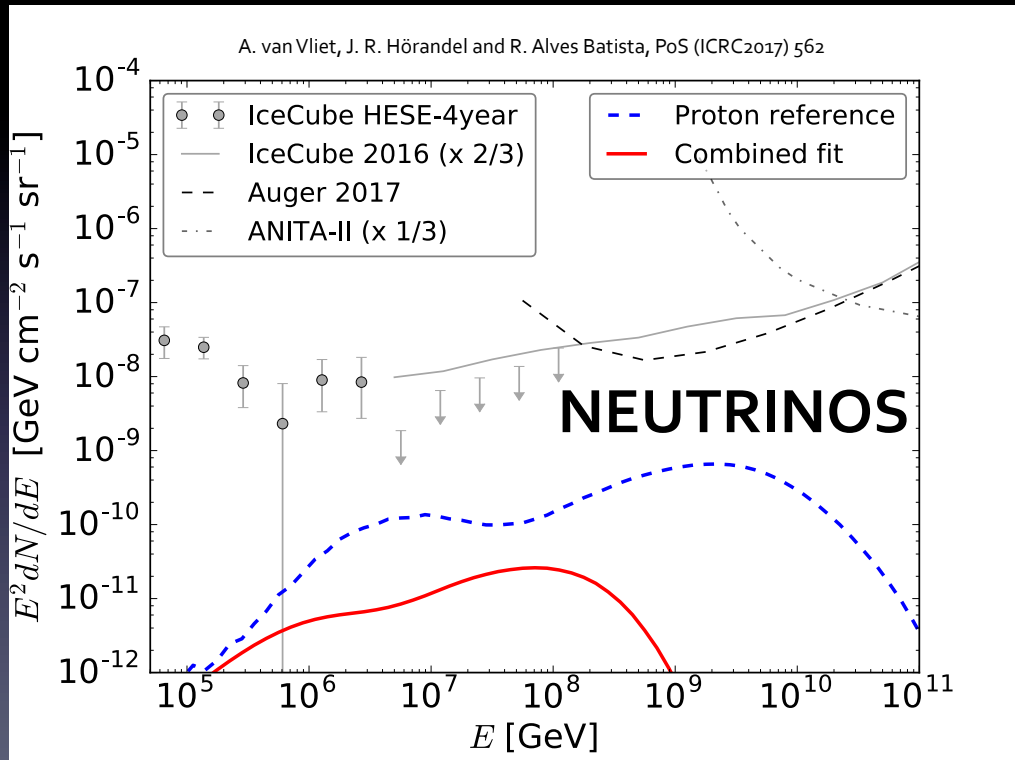
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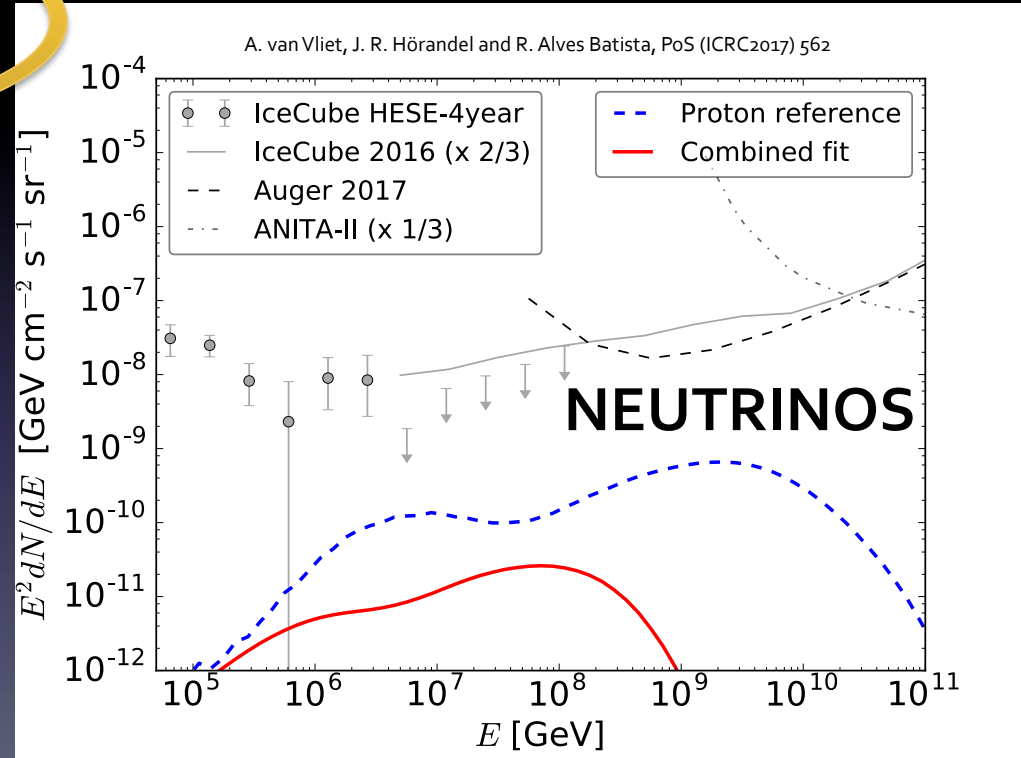
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Neutrinos at 1 EeV

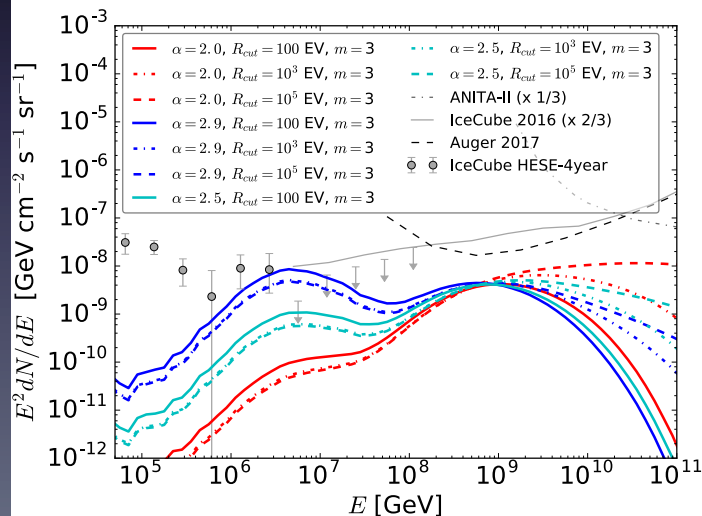
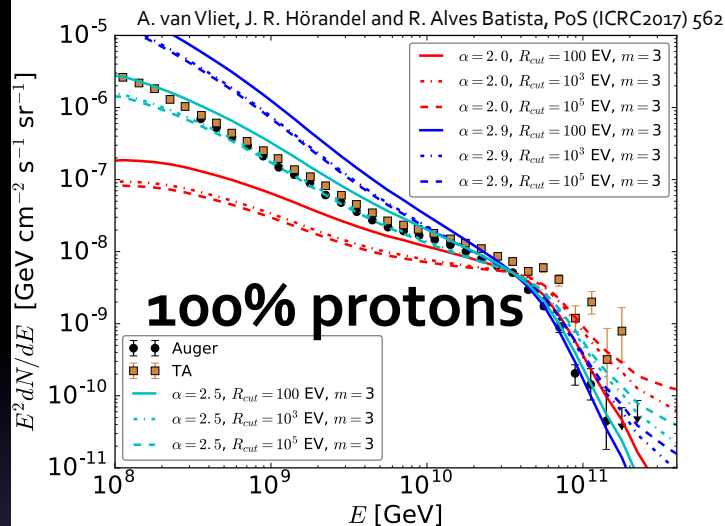
- Cosmogenic neutrino flux depends on:

- Spectral index α
- Max. rigidity R_{cut}
- EBL model
- Composition (proton fraction)
- Source evolution

- Sweet spot at ~ 1 EeV, only depends on:

- Composition (proton fraction)
- Source evolution ($z_{\text{max}} = 4$)

$$\begin{cases} (1+z)^m \\ 1 \end{cases} \quad \text{if } z > 1.5 \text{ and } m > 0$$



Neutrinos at 1 EeV

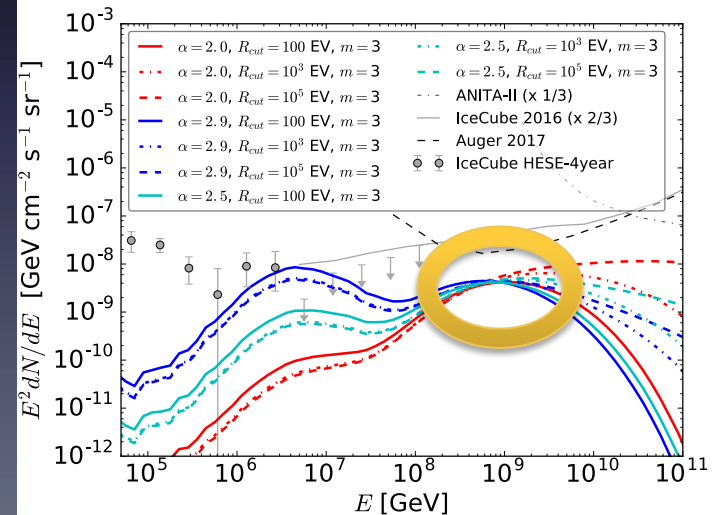
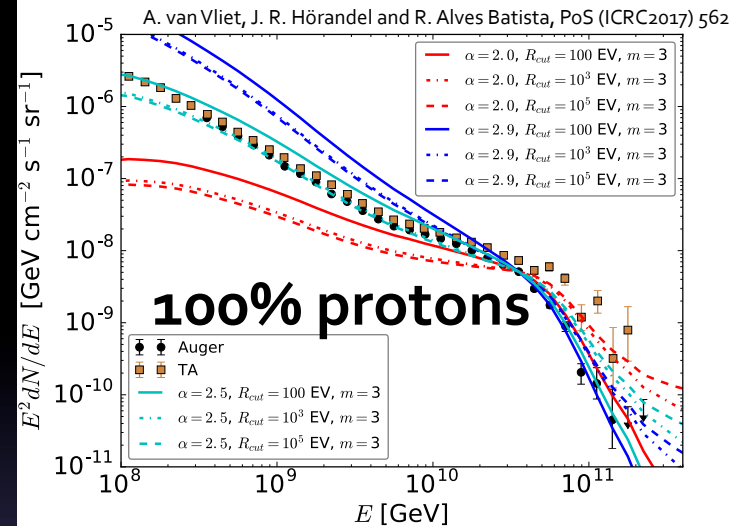
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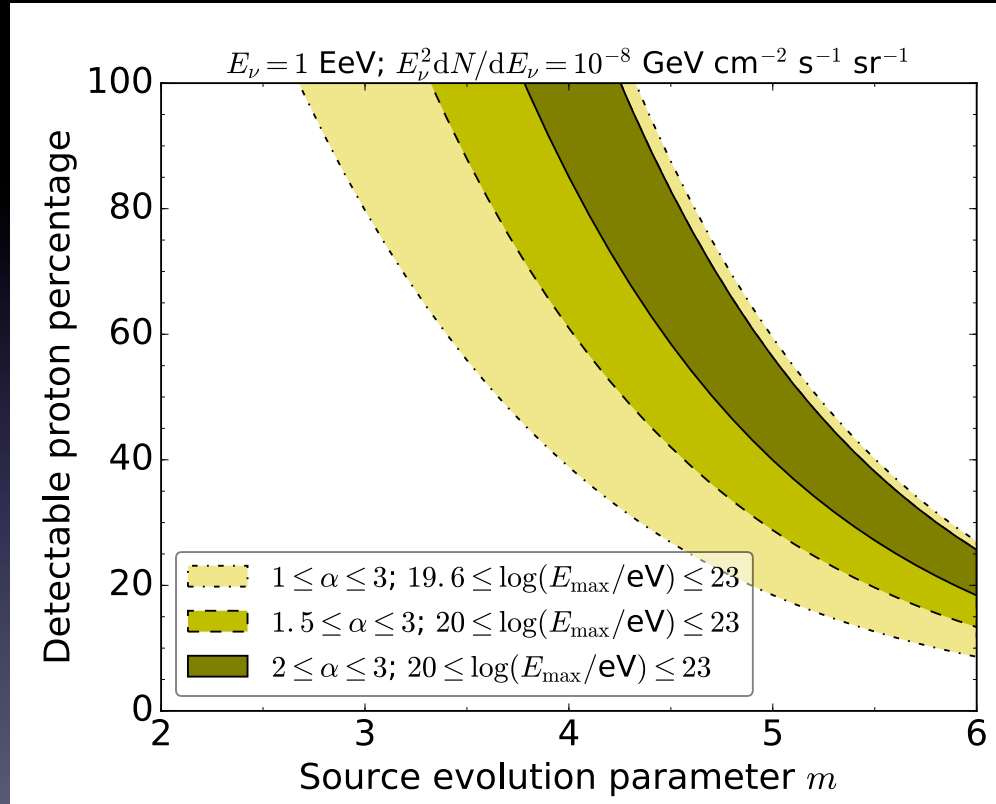
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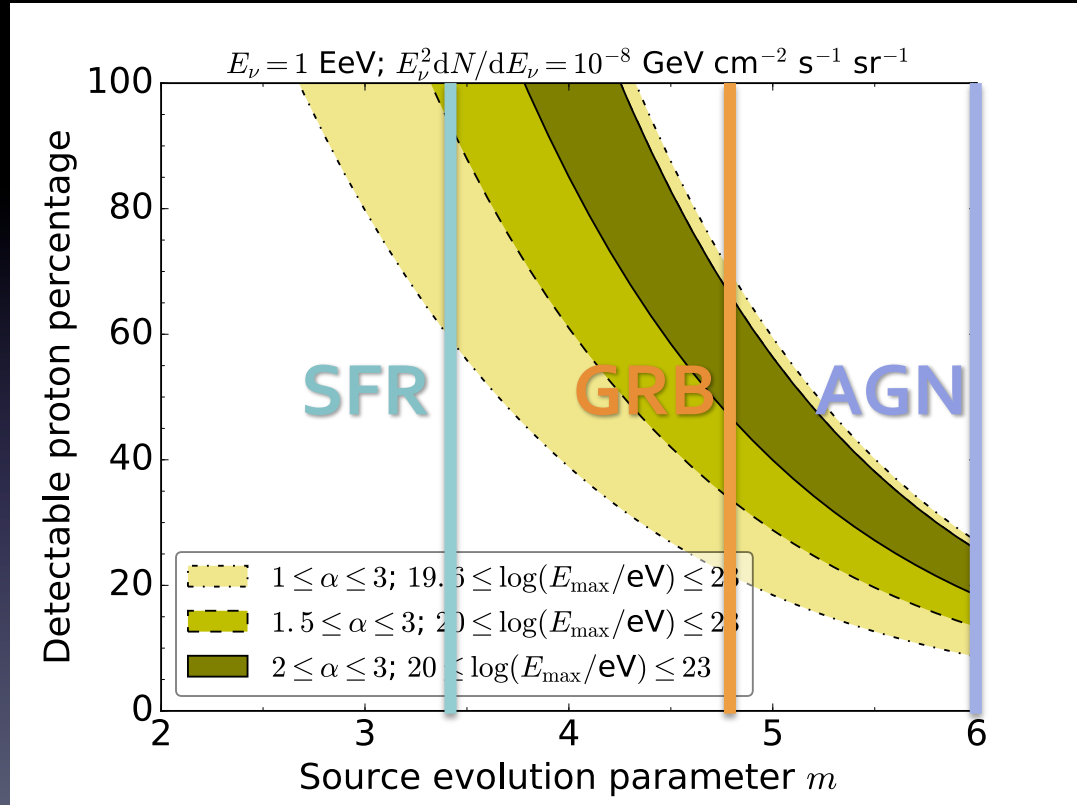
Current Sensitivity

- Single-flavour neutrino flux at ~ 1 EeV
- Auger and IceCube are both close to $\sim 10^{-8} \text{ GeV cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$
- Large proton fraction and strong source evolution ruled out

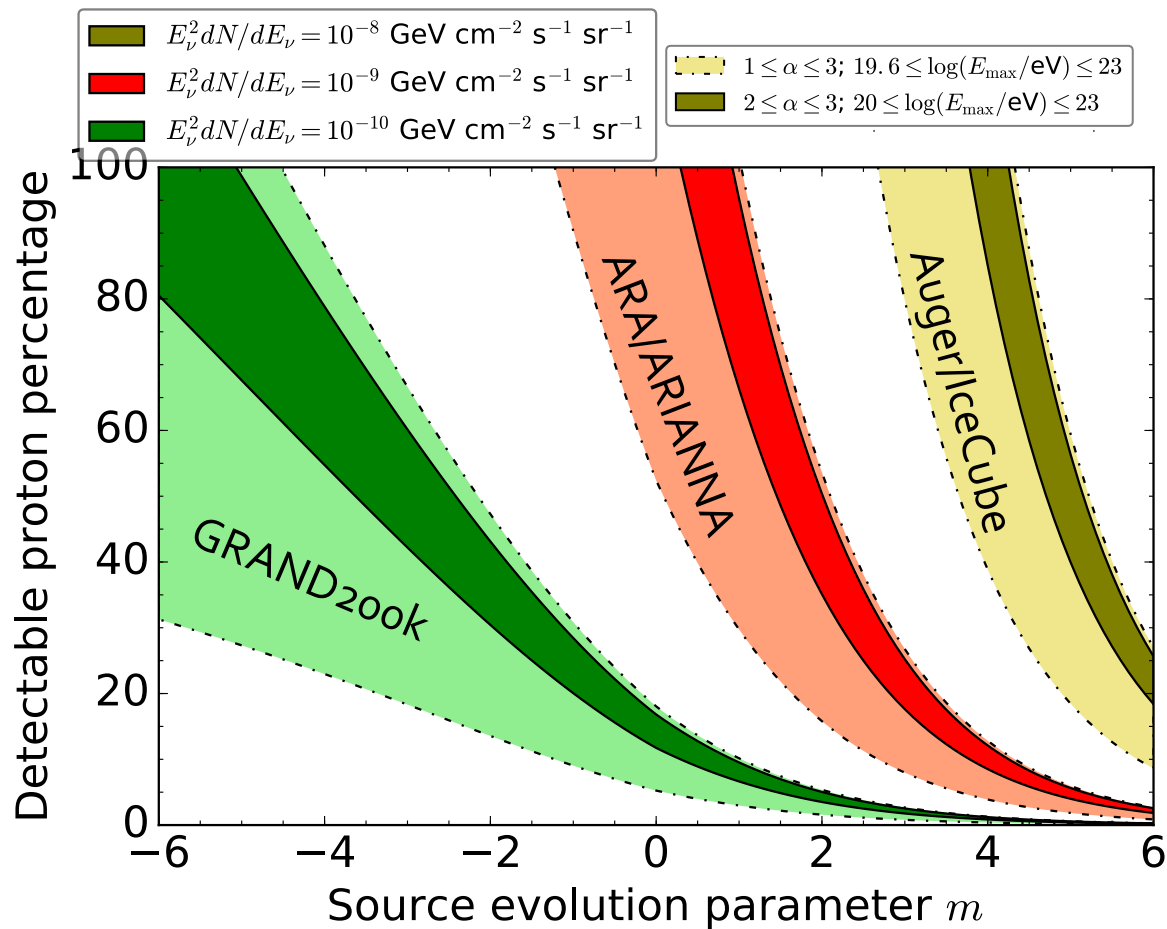


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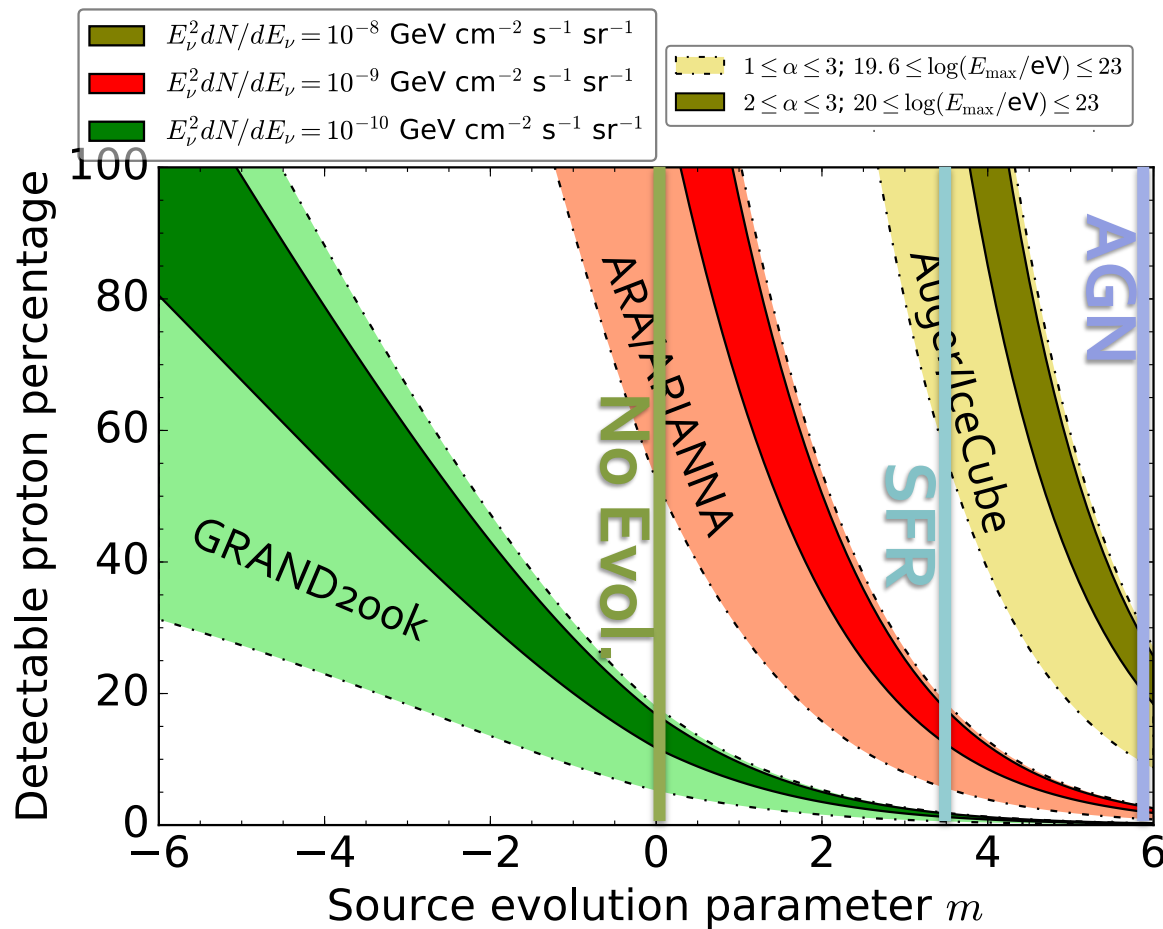
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Upcoming Experiments



Upcoming Experiments



Conclusions

- Neutrino limits at ~ 1 EeV are able to constrain the proton fraction and source evolution of UHECR sources
- The combination of a large proton fraction and a strong source evolution is already ruled out
- Strong potential for upcoming experiments
- Determine proton fraction in UHECRs independent of hadronic interaction models

BACKUP SLIDES

Proton vs. Iron

- Protons vs. Iron
- $R_{\text{cut}} = 200 \text{ EV}$
- $\alpha = 2.5$
- Comoving source evolution
- Neutrino flux strongly reduced in the case of iron primaries

