Pierre Auger Observatory
studying the universe's highest energy particles

Ultra-High Energy Neutrinos at the Pierre Auger Observatory

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For the Pierre Auger Collaboration

See: Pierre Auger Collaboration, ApJ Letters, In press
arXiv:1107.4809
ArXiv:1107.4804
Science, 318, 938 (2007)

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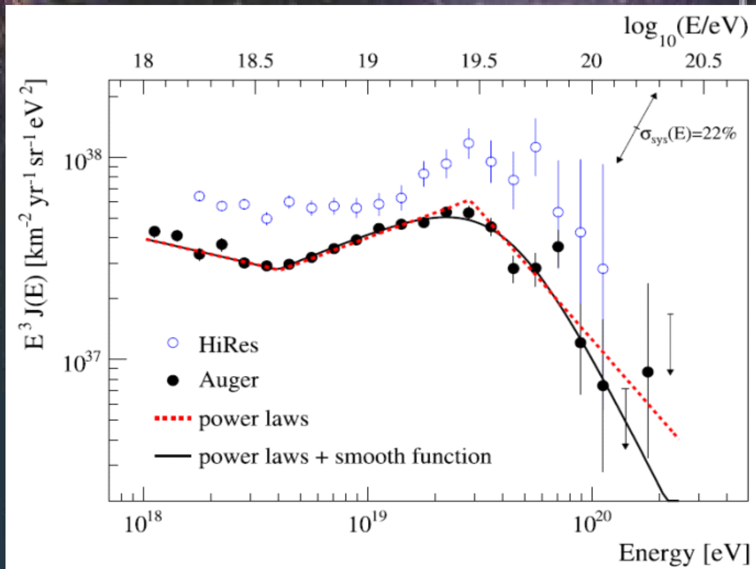
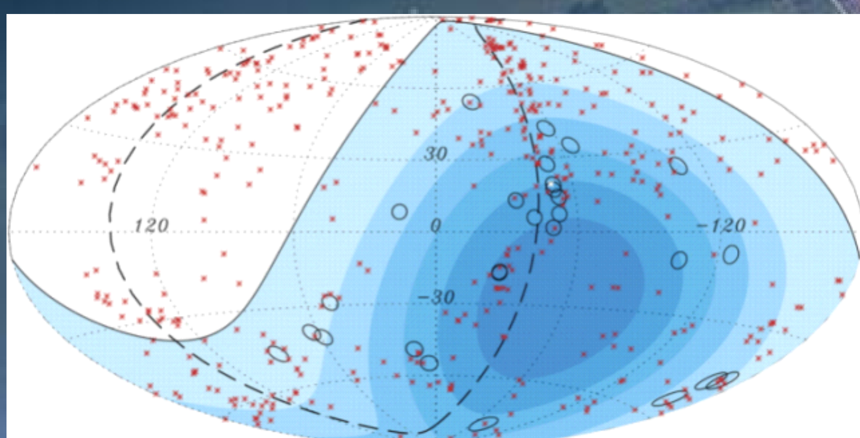


Energy Spectrum

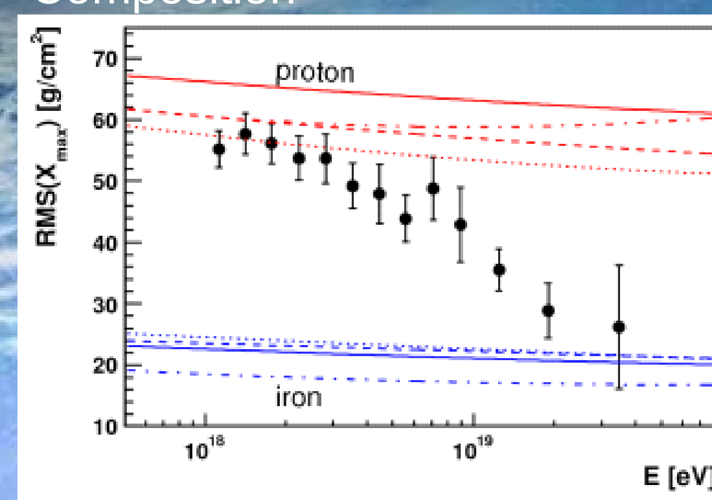
We now know in great detail about cosmic rays above ~1 EeV (10^{18} eV).

BUT we don't know exactly where they come from – they are charged and so get deflected in intergalactic magnetic fields.

Arrival Directions



Composition



The cosmic ray energy spectrum shows a cut-off as predicted: GZK cut-off. We assume that this is correct.

The GZK cut-off specifically refers to photo-pion production from cosmic ray protons and astrophysical (blue shifted to gammas) background photons.

Π^+ decays to 3 neutrinos plus a positron.

The resulting neutrinos are NEITHER absorbed nor deflected. They may point to the cosmic ray source.

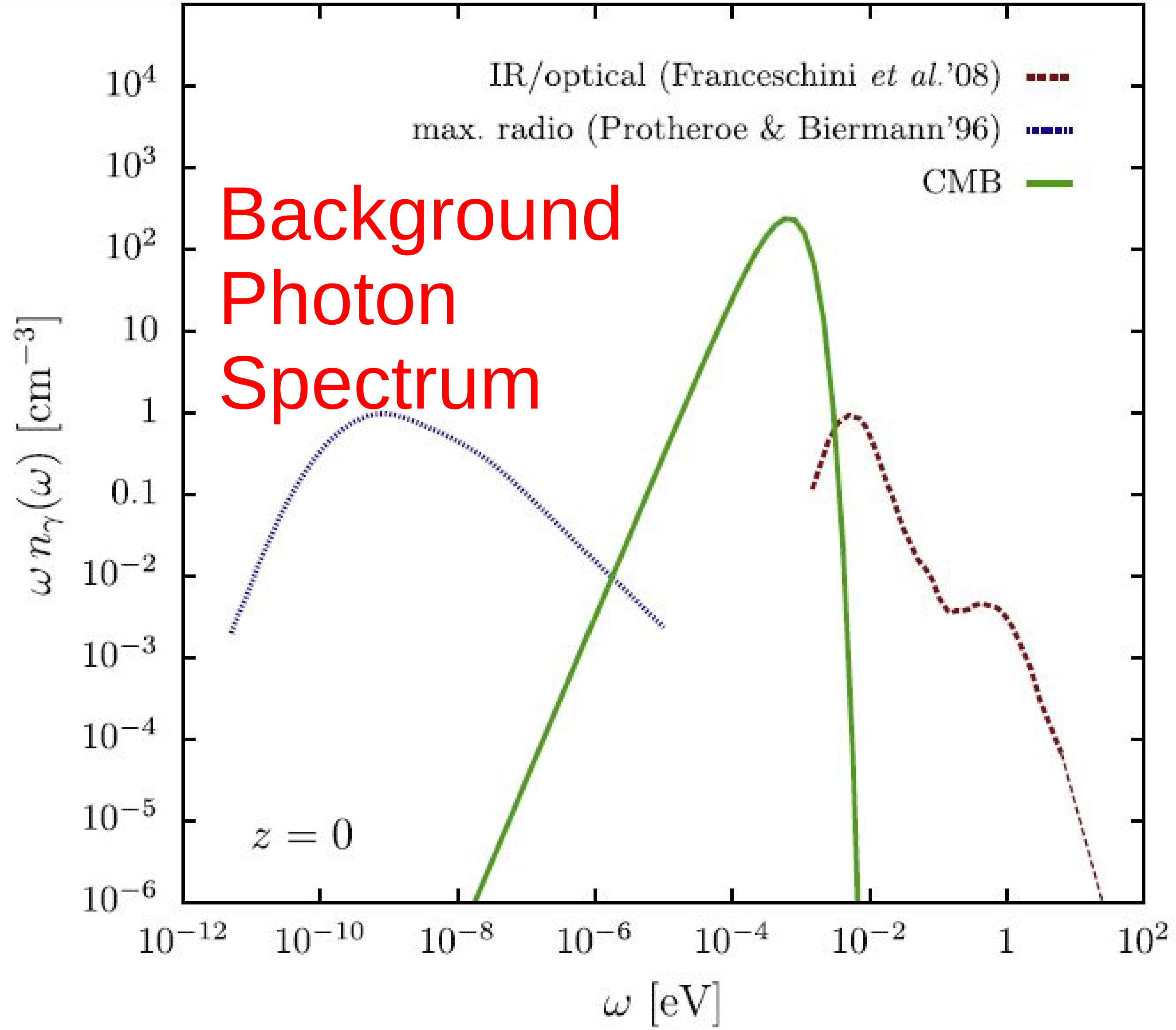


Fig. 6. The energy spectrum of the CMB [23] and the CIB in the IR/optial [48] and radio [54] range at $z = 0$. The thin dashed line shows our extrapolation to UV energies.

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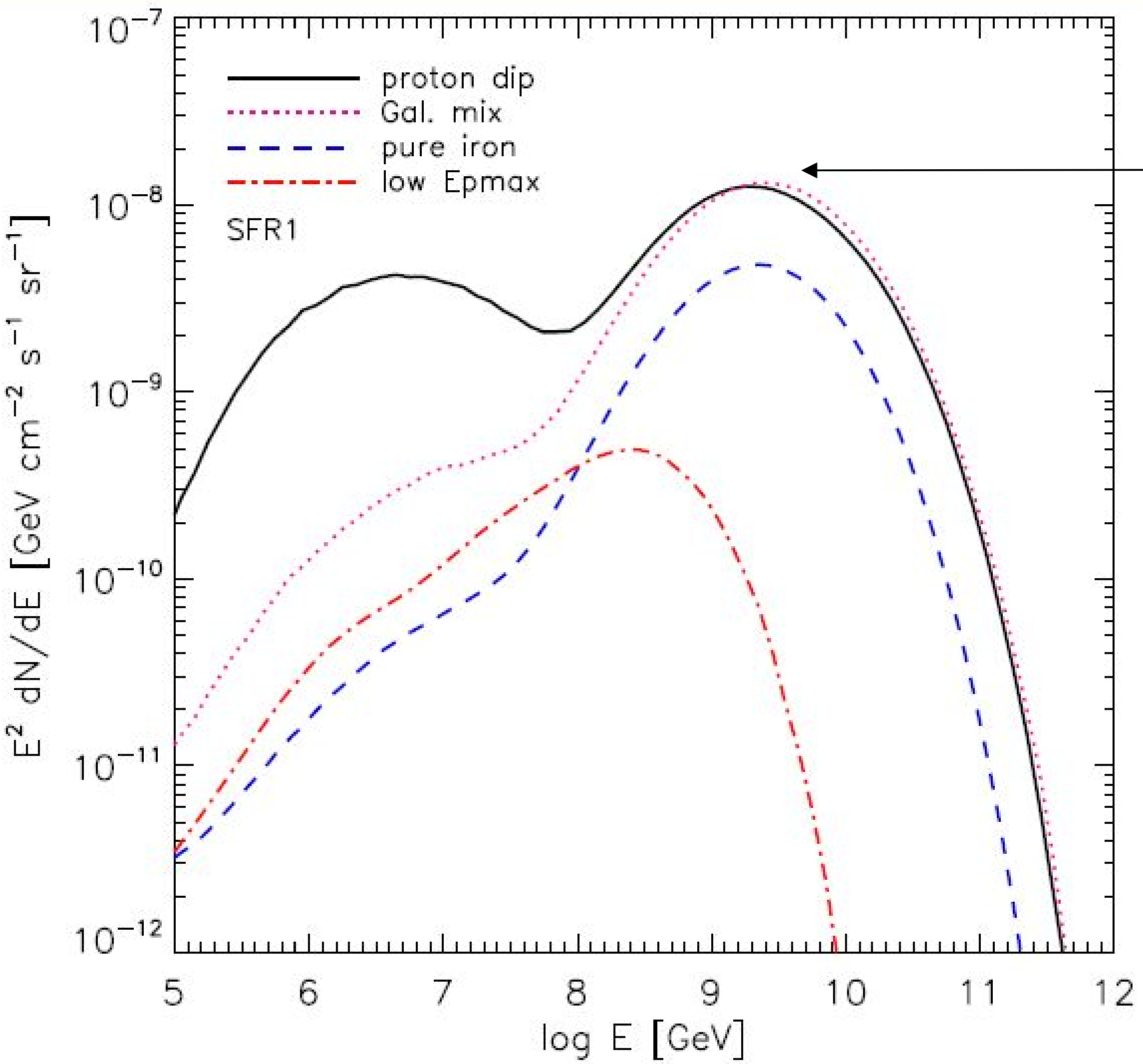
Ahlers et al.
Astroparticle Phys.
34, 106-115, 2010



Auger is sensitive here.

Predicted Neutrino Spectrum

Figure 7. Effects of various compositions on neutrino fluxes for all flavors. We present the cases of (i) a pure proton injection assuming a dip transition model (black solid), (ii) a proton dominated Galactic type mixed composition (pink dotted), (iii) pure iron composition (blue dashed) and (iv) the iron rich low $E_{\rm p,max}$ model (red dash-dotted).

Kotera, Allard and Olinta arXiv:1009.1382

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Interactions to search for:

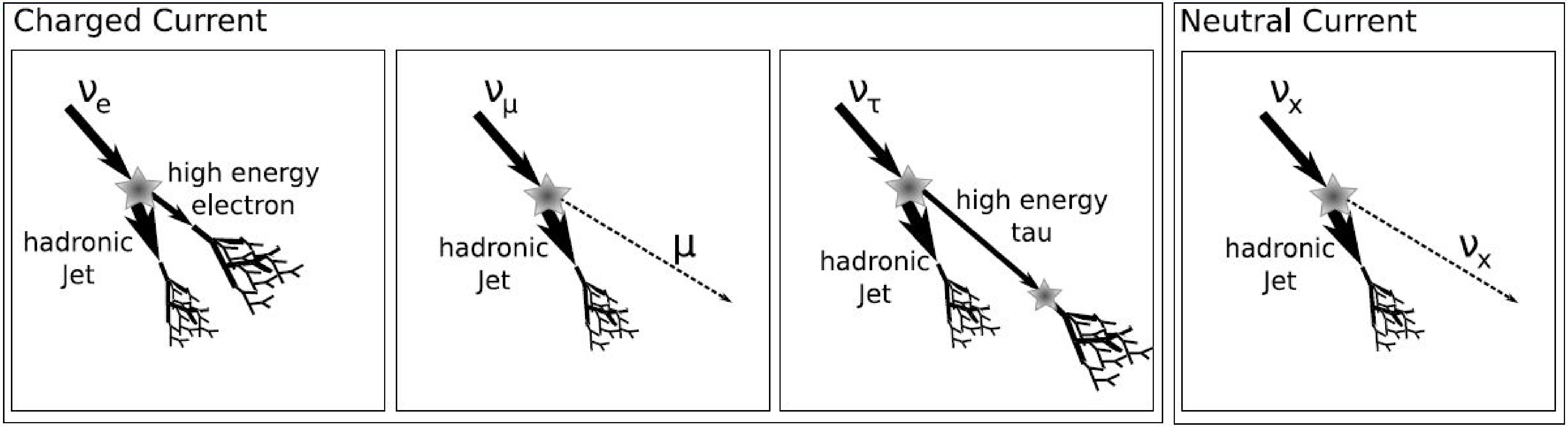

FIG. 2. Different types of atmospheric showers induced by neutrinos.

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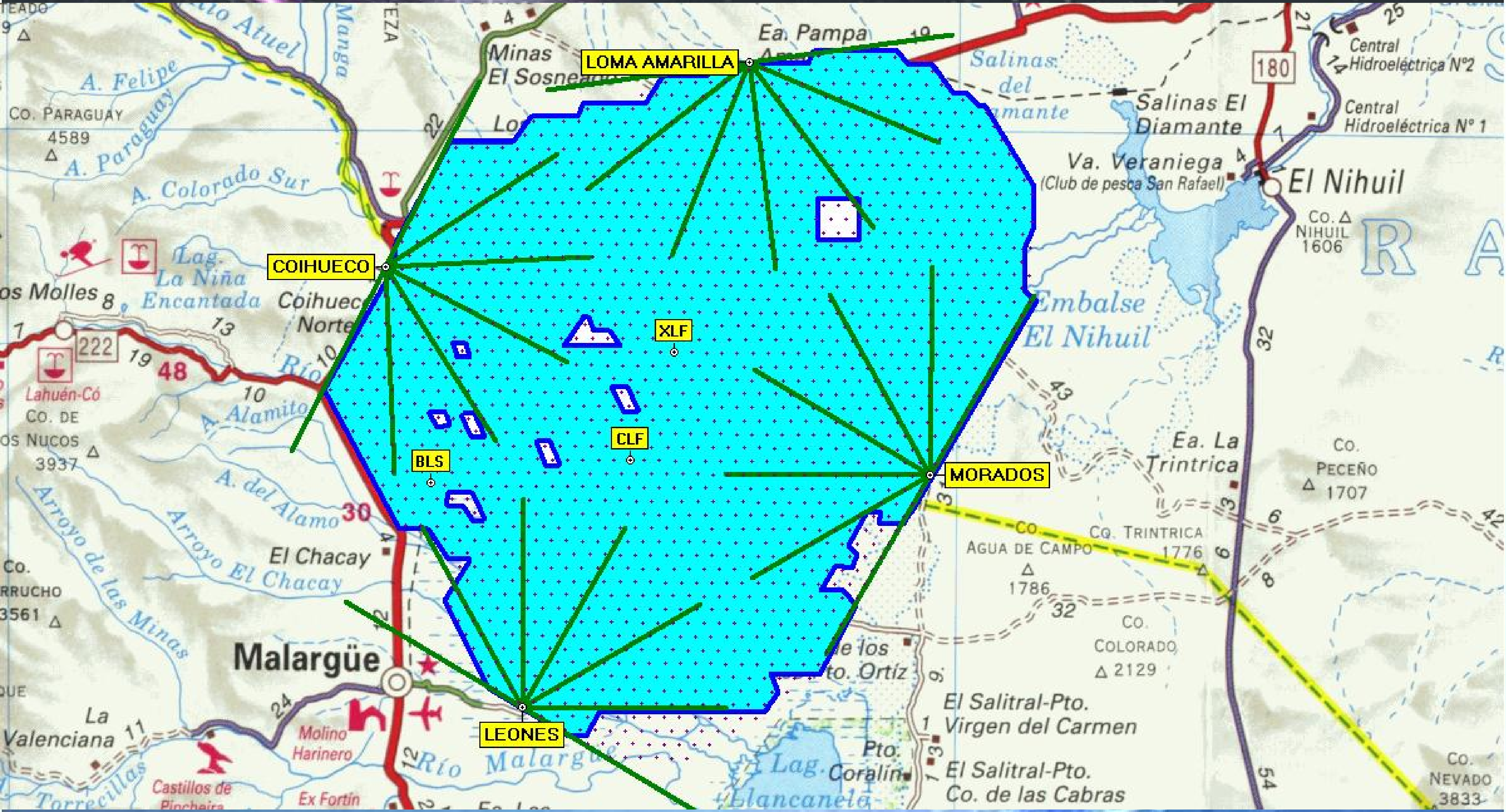
LOMA AMARILLA
COIHUECO
XLF
CLF
BLS
MORADOS
LEONES
Malargüe
El Nihuil
Embalse El Nihuil
Salinas El Diamante
Va. Veraniega
(Club de pesca San Rafael)
Central Hidroeléctrica Nº2
Central Hidroeléctrica Nº 1
Ea. Pampa
Minas El Sosneado
Coihueco Norte
El Chacay
Ea. La Trintrica
Lahuén-Có
Molino Harinero
Castillos de Pincheira
Ex Fortín
Lag. Llancanelo
El Salitral-Pto. Virgen del Carmen
El Salitral-Pto. Co. de las Cabras
Pto. Coralino
La Valenciana

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Possible event types: 'down going' and 'Earth-skimming'.

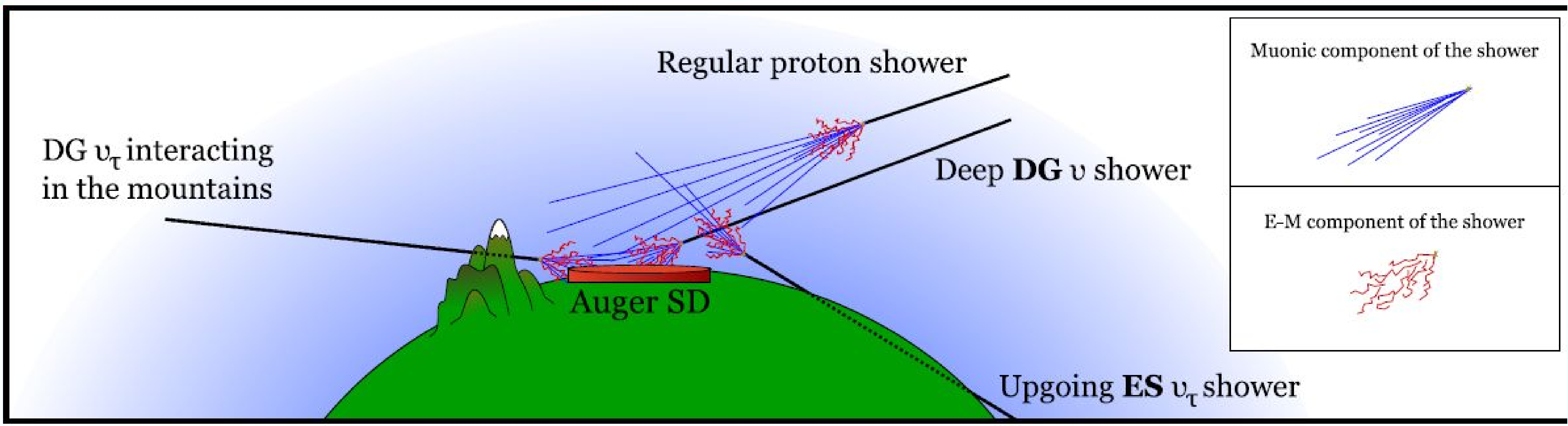

FIG. 1. Pictorial representation of the different types of showers induced by protons, heavy nuclei and "down-going" (DG) a well as "Earth-skimming" (ES) neutrinos. The search for down-going showers initiated deep in the atmosphere is the subjec of this work.

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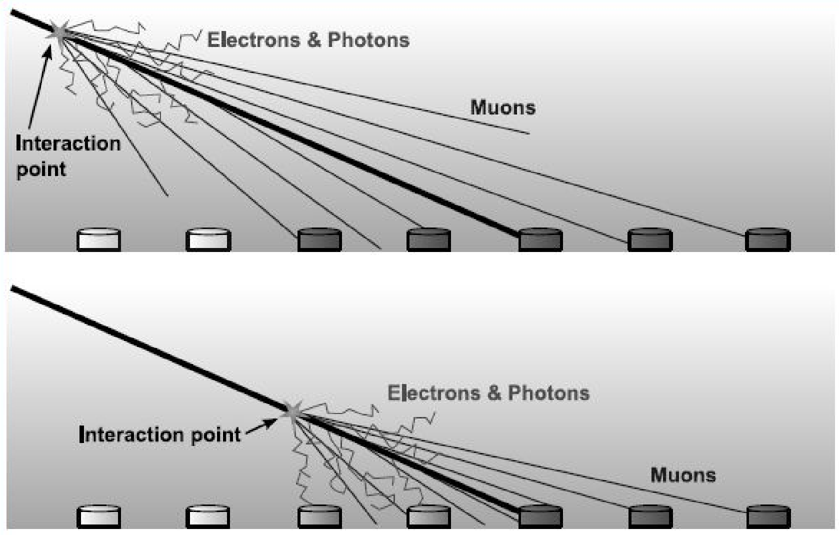
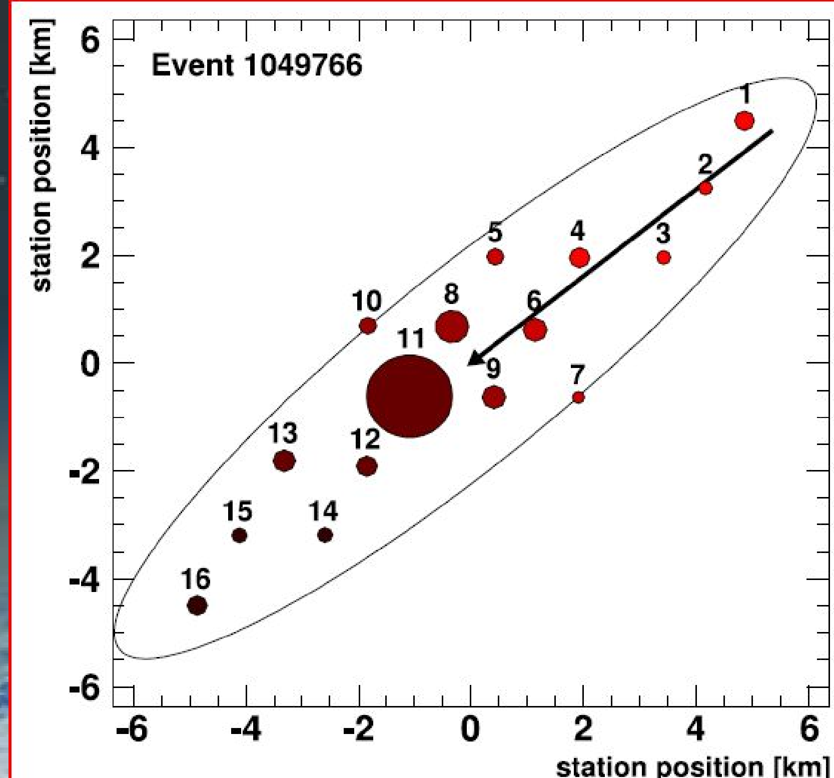


FIG. 5. *Upper panel*: sketch of an inclined shower induced by a hadron interacting high in the atmosphere. The EM component is absorbed and only the muons reach the detector. *Lower panel*: deep inclined shower. Its early region has a significant EM component at the detector level.



We can use expected physical properties of the showers – content, timing, footprint shape etc. To build up a set of criteria to be satisfied by neutrino showers.

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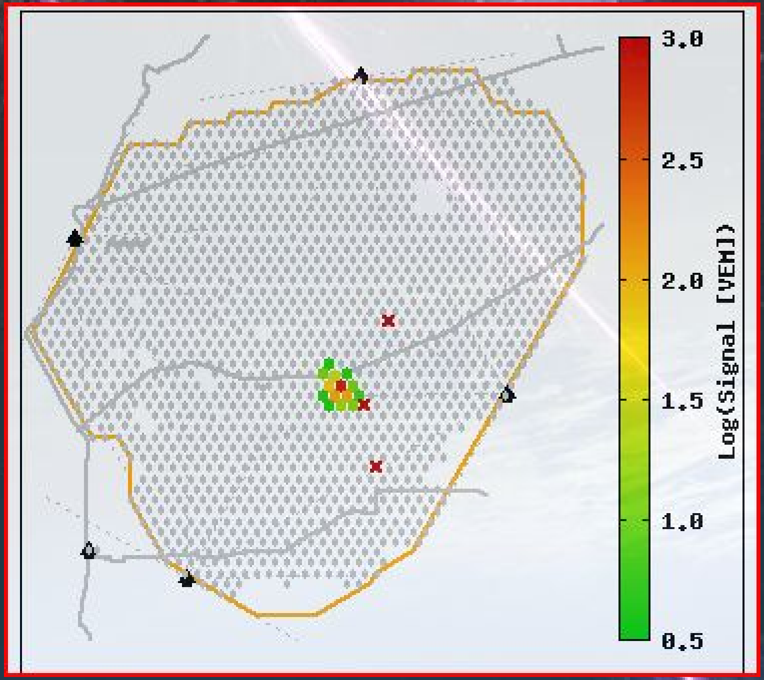
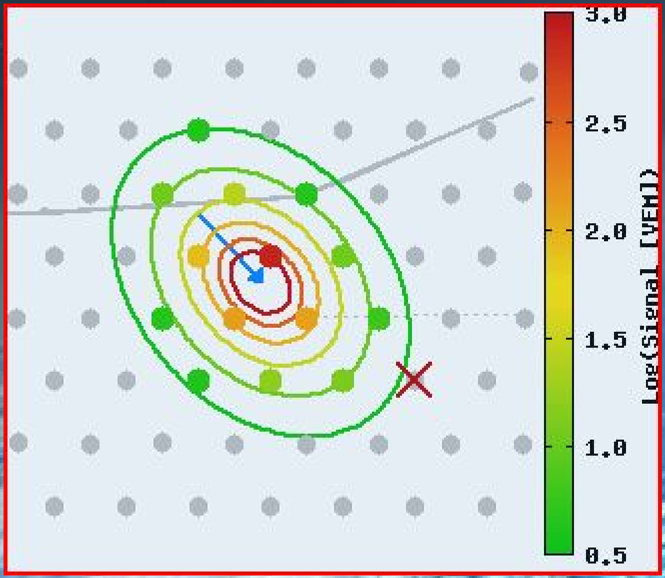
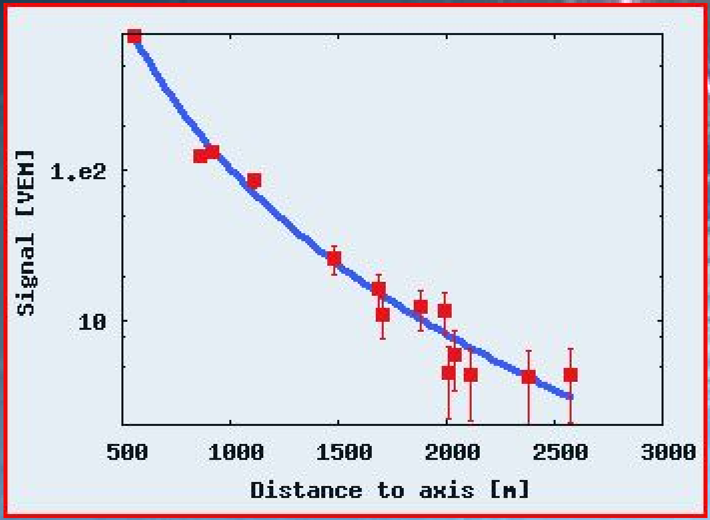
A 'normal' event.







See http://auger.colostate/edu/ED/

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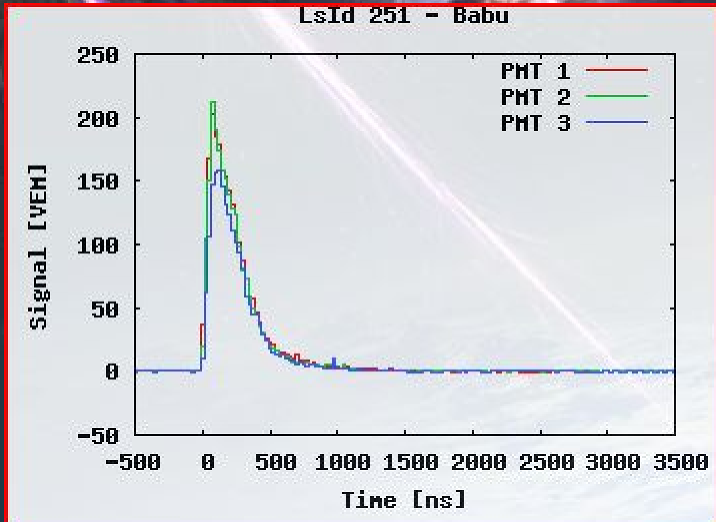
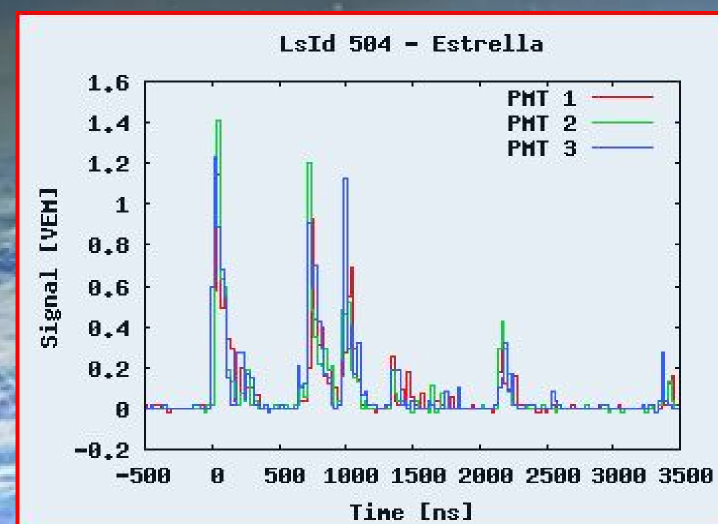
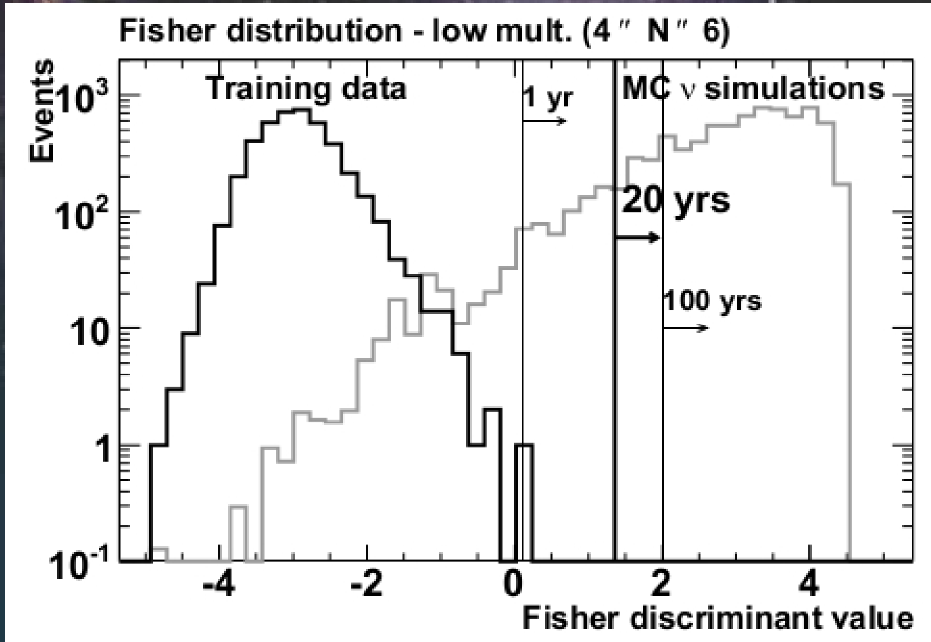


Close to the shower core

At a large core distance.



Detector station (10 m^2 water Cherenkov tank) signals

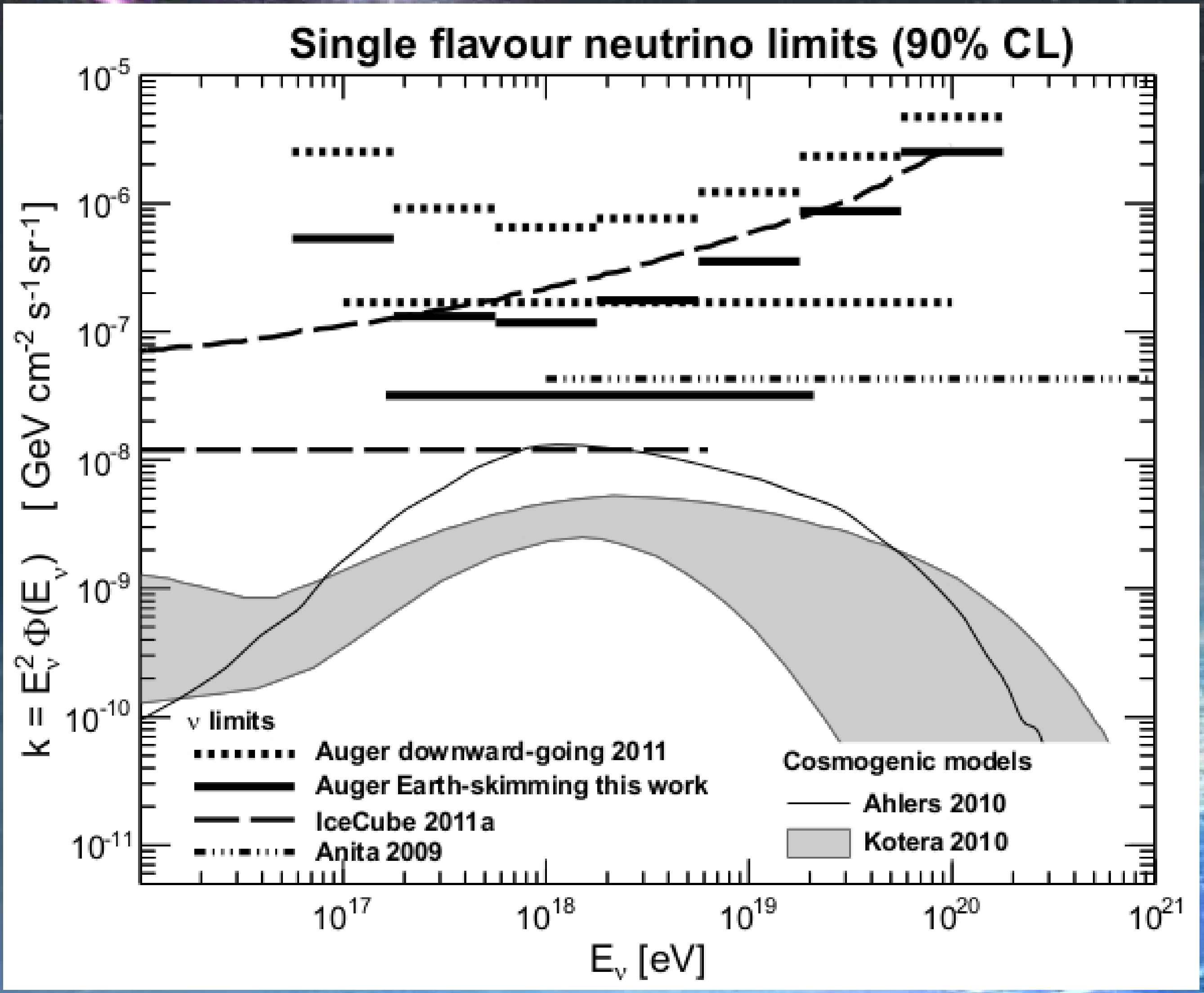


Developing Neutrino Search Criteria

Table 1: Criteria to select Earth-skimming ν_τ and down-going ν. See text for details.

	Earth-skimming	Down-going
Inclined Showers	N° of Stations ≥ 3 $L/W > 5$ $0.29\,\frac{\text{m}}{\text{ns}} < V < 0.31\,\frac{\text{m}}{\text{ns}}$ RMS(V)$< 0.08\,\frac{\text{m}}{\text{ns}}$ -	N° of Stations ≥ 4 $L/W > 3$ $V < 0.313\,\frac{\text{m}}{\text{ns}}$ $\frac{\text{RMS}(V)}{V} < 0.08$ $\theta_{rec} > 75°$
Young Showers	ToT fraction>0.6	Fisher discriminator based on AoP

Search Criteria:


Single flavour neutrino limits (90% CL)
k = E$_\nu^2$ Φ(E$_\nu$) [GeV cm^{-2} s^{-1}sr^{-1}]
E$_\nu$ [eV]
ν limits
Auger downward-going 2011
Auger Earth-skimming this work
IceCube 2011a
Anita 2009
Cosmogenic models
Ahlers 2010
Kotera 2010

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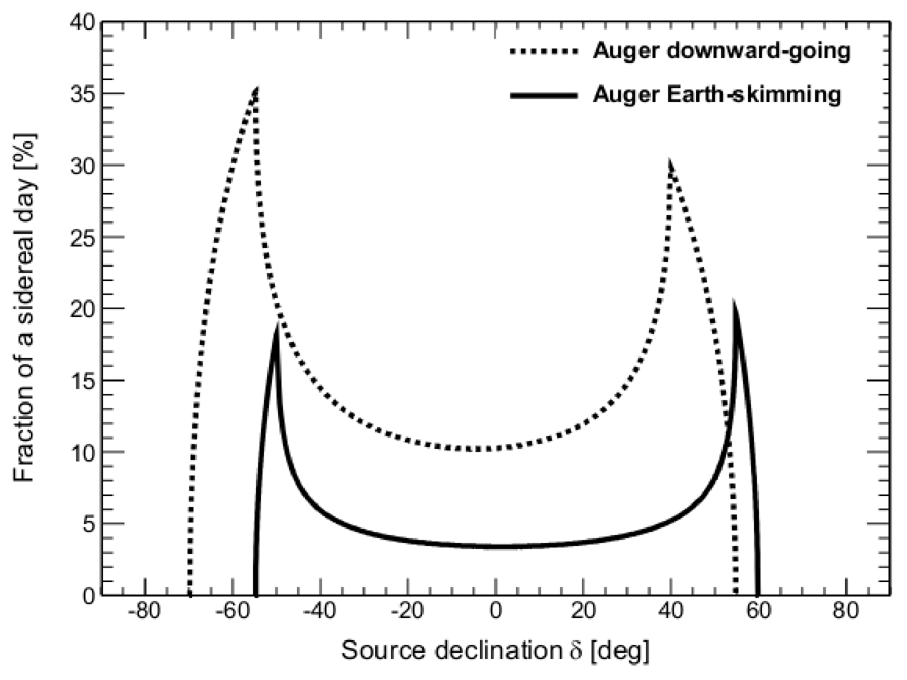
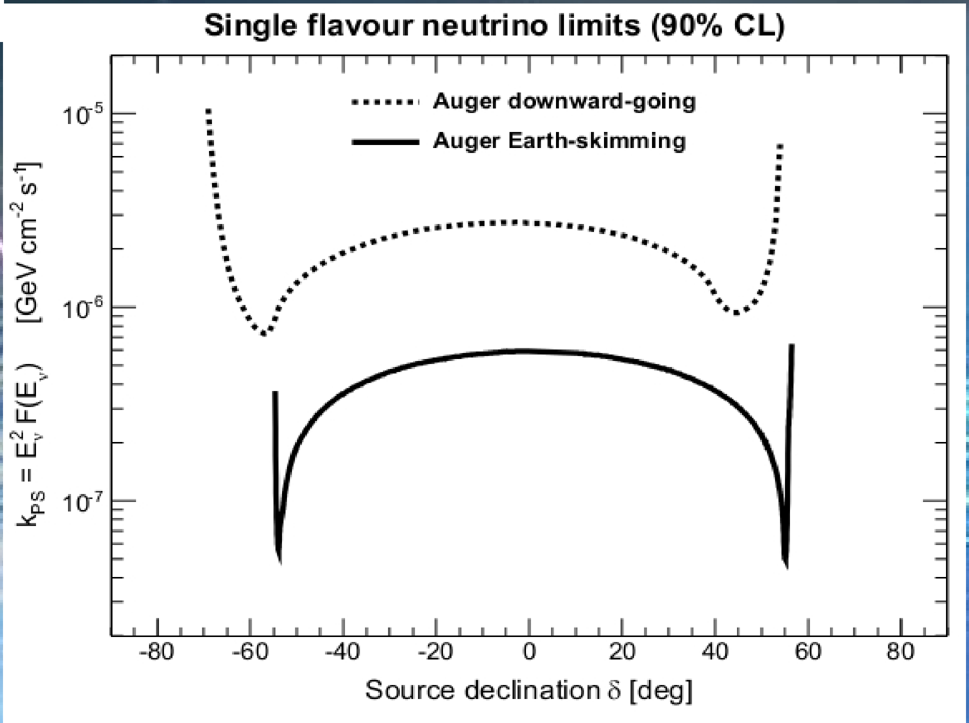


Rather strange directional exposure

The resulting upper limits



To Look for Specific Point Sources

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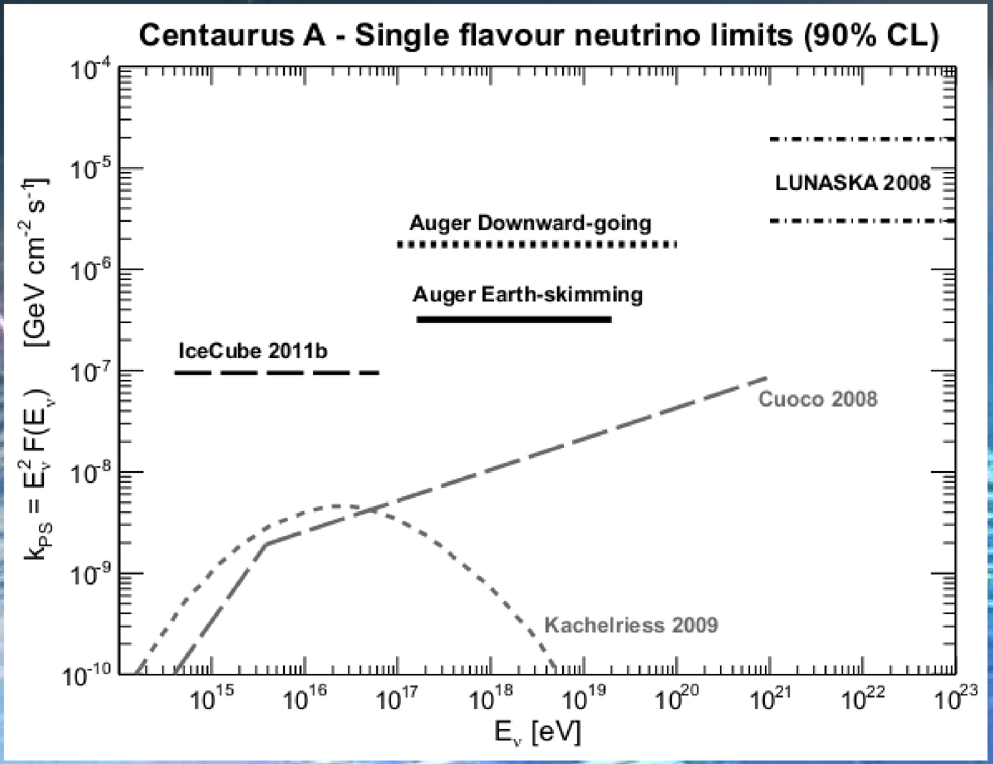
Centaurus A (NGC 5128) is a 'nearby' likely source. The limits are tightening for its models also.

Table 2: Expected number of events for two diffuse neutrino flux models and two CenA neutrino flux models.

Diffuse flux model	Earth-skimming	Down-going
Cosmogenic	0.71	0.14
Exotic	3.5	0.97
CenA flux model	**Earth-skimming**	**Down-going**
Cuoco *et al.*	0.10	0.02
Kachelriess *et al.*	0.006	0.001



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Summary

The Pierre Auger Observatory:

Has measured fundamental astrophysical quantities (directions, composition, spectrum) at energies above ~10^{18} eV (to > 10^{20} eV).

We still have not identified specific sources and neutrino studies seem to offer a way of doing directional astrophysics for that.

The energy spectrum seems to show a GZK cut-off – neutrino studies should confirm or deny this.

Auger is competitive in UHE neutrino studies of the Southern skies.


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Thanks