Pierre Auger Observatory

studying the universe's highest energy particles

PIERRE AUGER OBSERVATORY

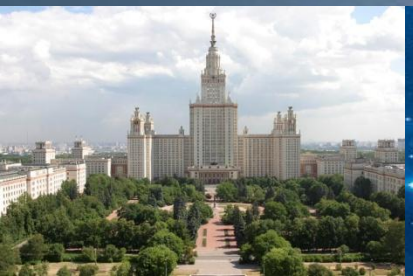
Astronomy of ultra-high energy neutral particles with the Pierre Auger Observatory

J.L. Navarro[1] for the Pierre Auger Collaboration[2]

[1] *Dpto. Física Teórica y del Cosmos & CAFPE, University of Granada, Spain*

[2] *Avd. San Martin Norte S/N, Malargüe, Argentina*

Universidad de Granada

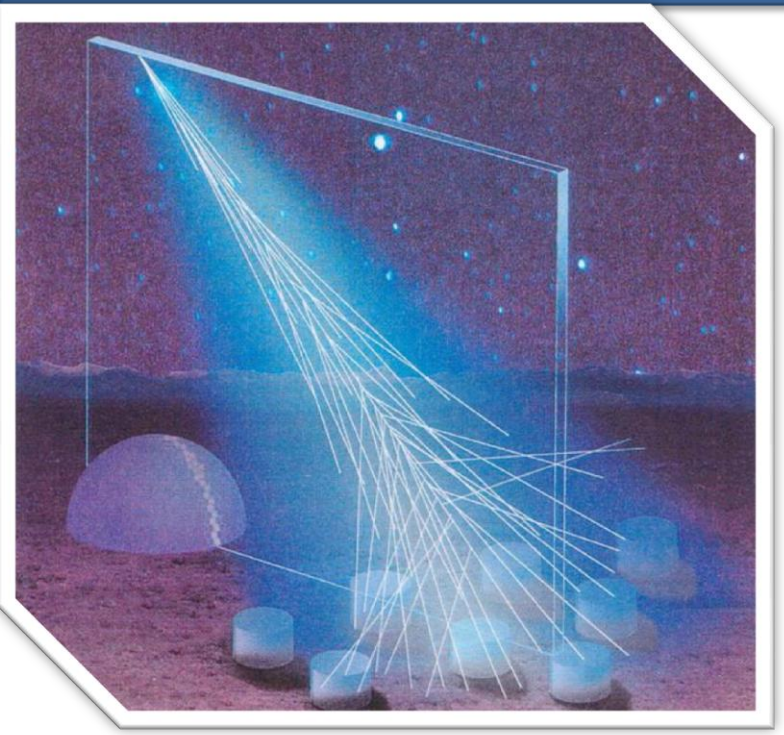


23rd European Cosmic Ray Symposium

"Lomonosov University", Moscow.

July 3-7 2012

Short review of the Pierre Auger Observatory



Hybrid detector of Cosmic Rays. Objectives:

Energy

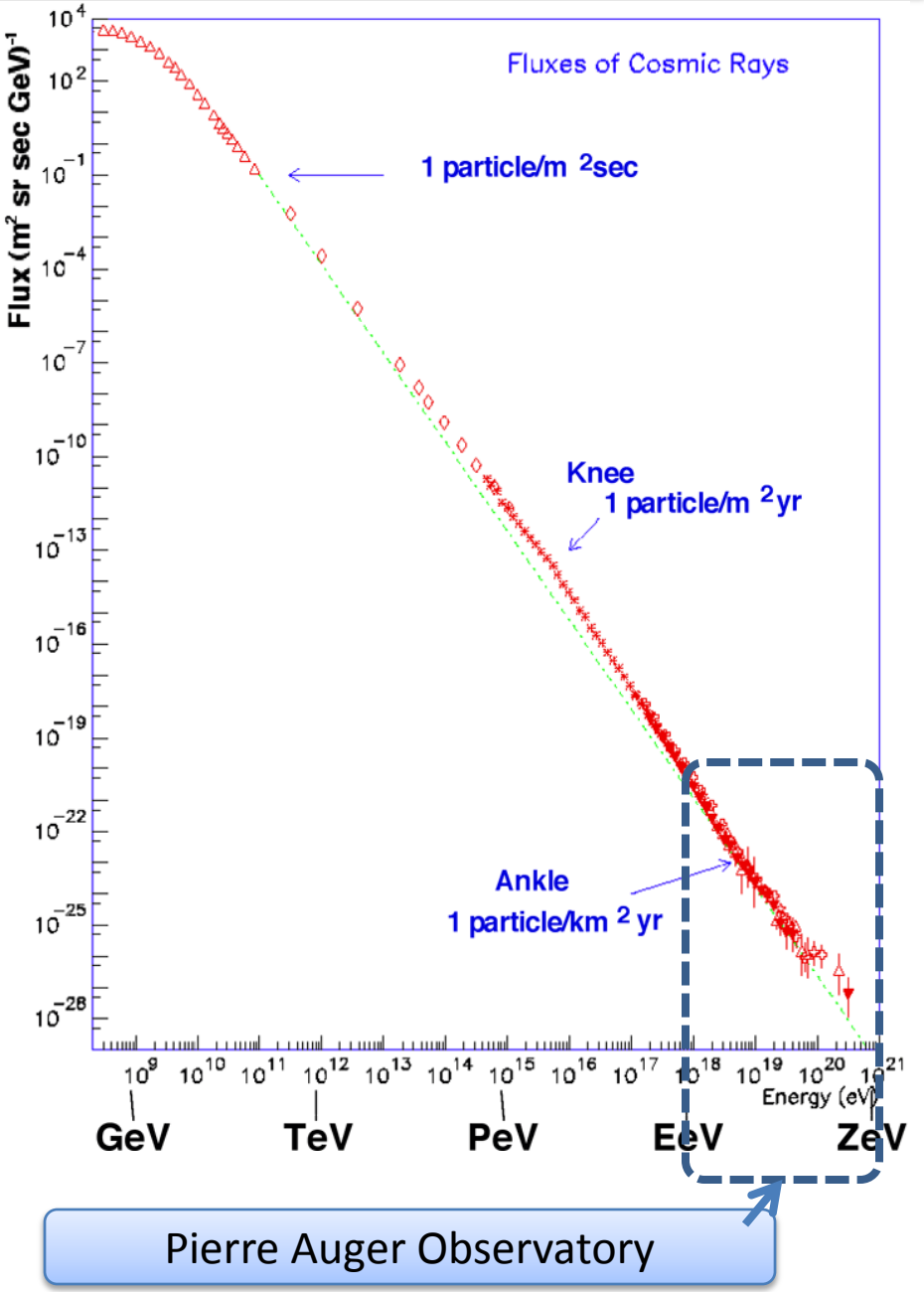
- Cutoff at the highest energies? Ankle?

Direction

- Is the UHECR flux isotropic ?
- Which are the UHECRs sources?

Mass composition

- Is the UHECR flux dominated by light/heavy ions?



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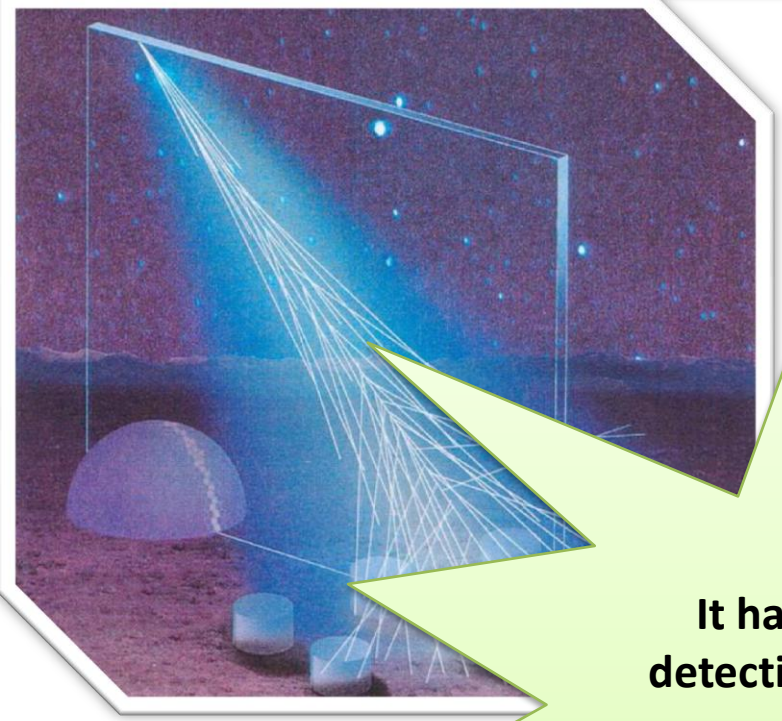
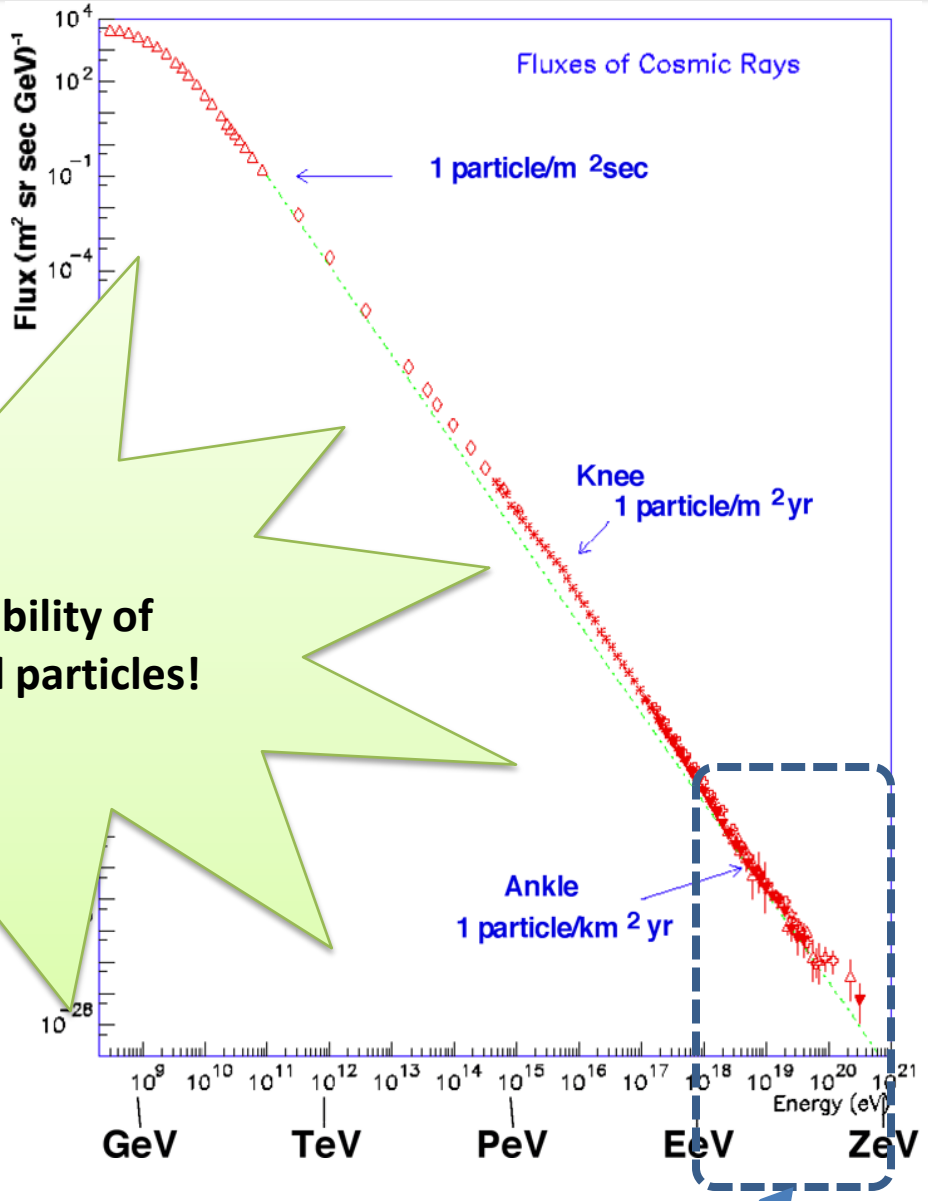


It has the capability of detecting neutral particles!



Hybrid detector of Cosm

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Pierre Auger Observatory

Three neutral particles:

Photons:
Electromagnetic interaction

-Deep interaction in the atmosphere
- Electromagnetic shower (high e-m content, absence of muons)

Neutrinos:
Weak interaction

- Interact at any point of atmosphere
- Hadronic + electromagnetic extensive air shower

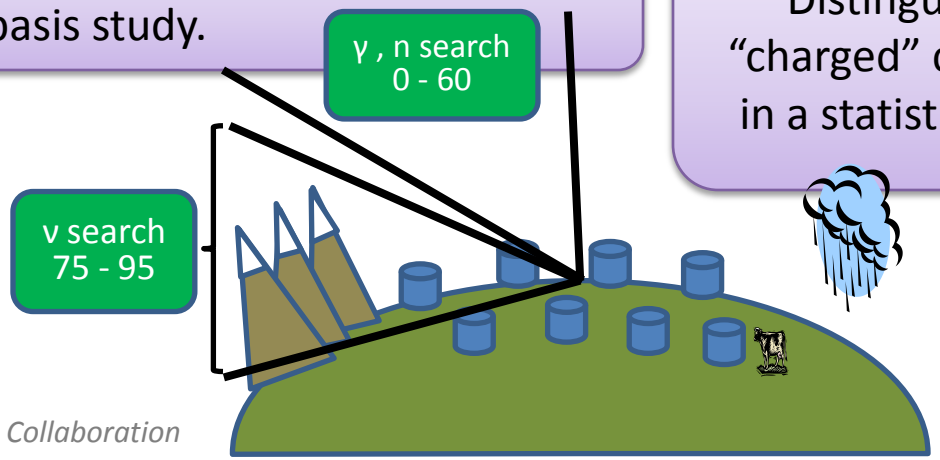
Neutrons:
Strong interaction

- Interaction at top of atmosphere
- Hadronic extensive air shower

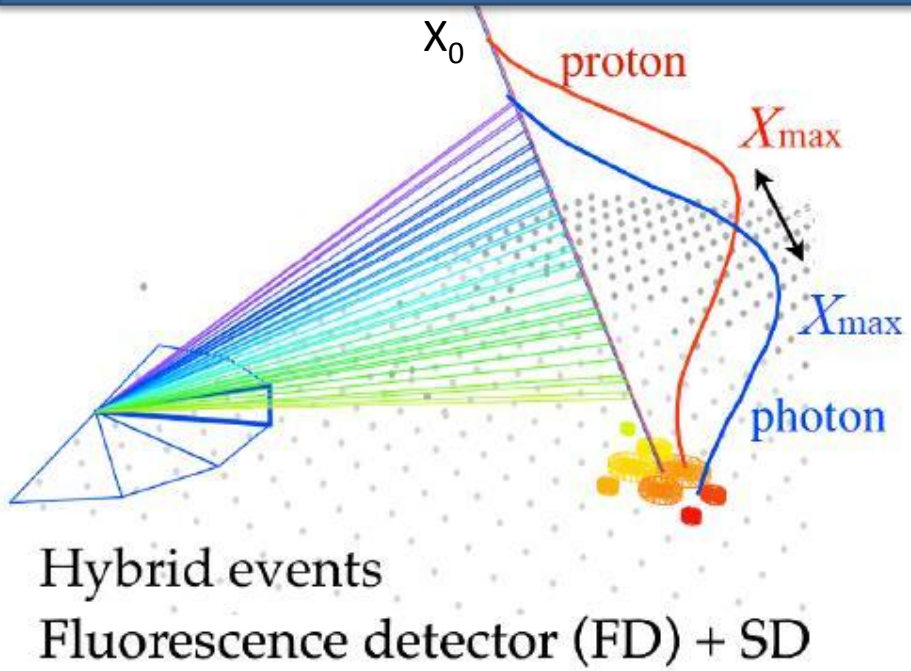
Distinguishable from "charged" cosmic rays in an event by event basis study.

Distinguishable from "charged" cosmic rays only in a statistical basis study.

Neutrino detection requires large amount of atmosphere



Photon analysis at the Pierre Auger Observatory



Hybrid events

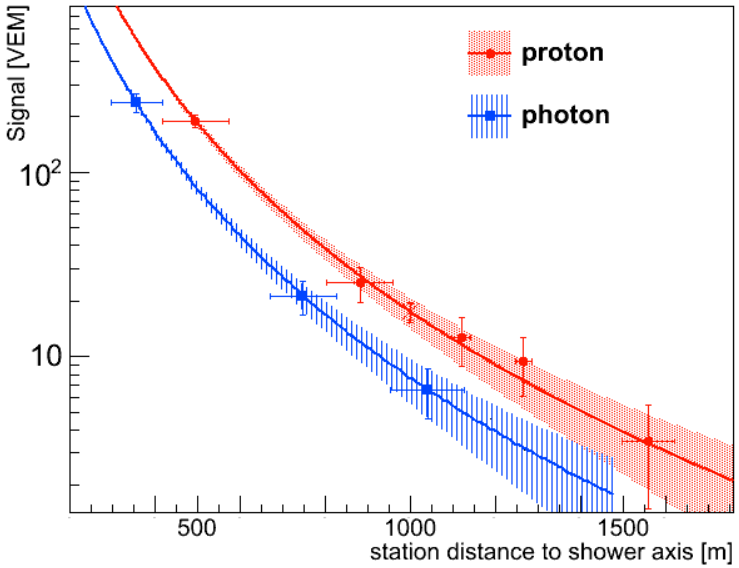
Fluorescence detector (FD) + SD

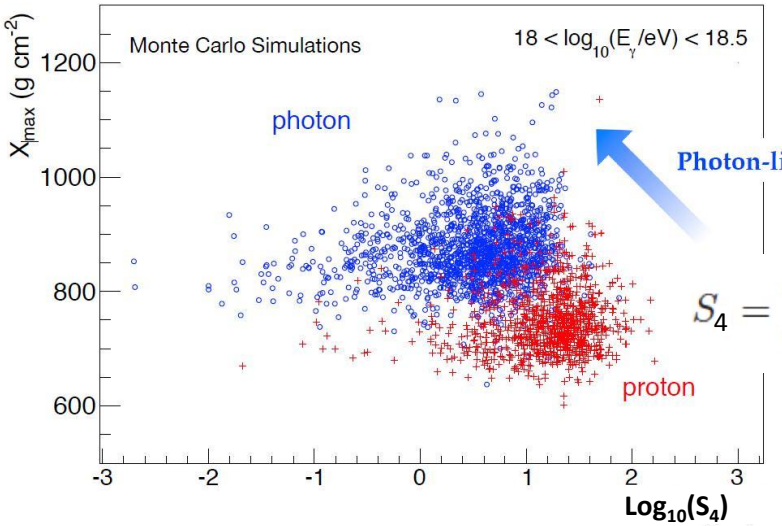
Photon signature:

- Big value of X_{Max} from fluorescence detector
- Smaller signal in surface detectors (S_b) and less stations triggered.

Event Selection:

- X_{Max} fully contained in field of view
- Zenith angle < 60º
- At least 4 active stations within 2 km of axis





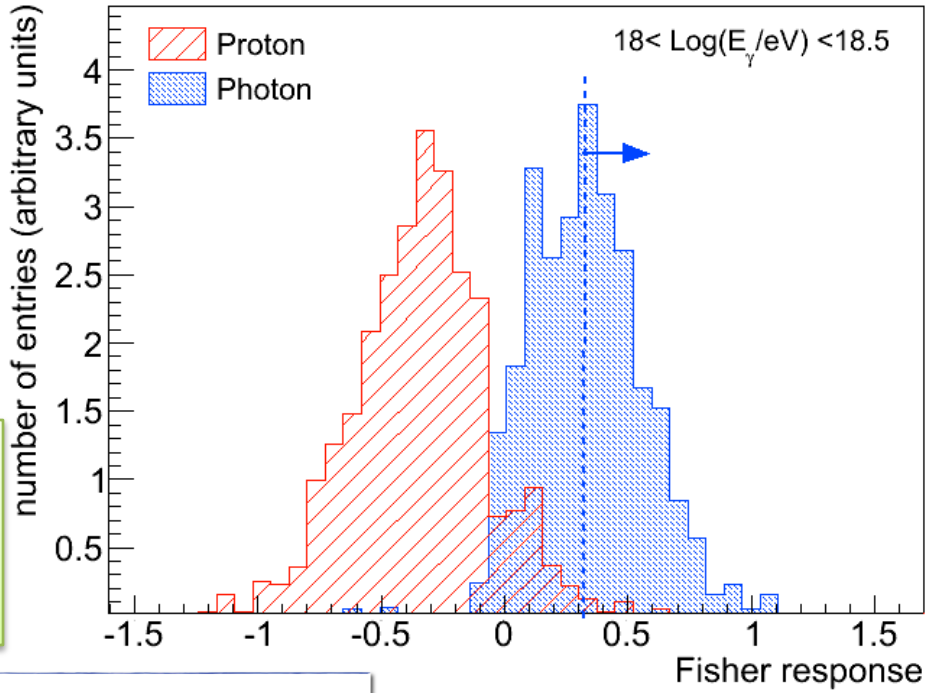
$$S_4 = \sum_i S_i \left(\frac{R_i}{1000}\right)^4$$

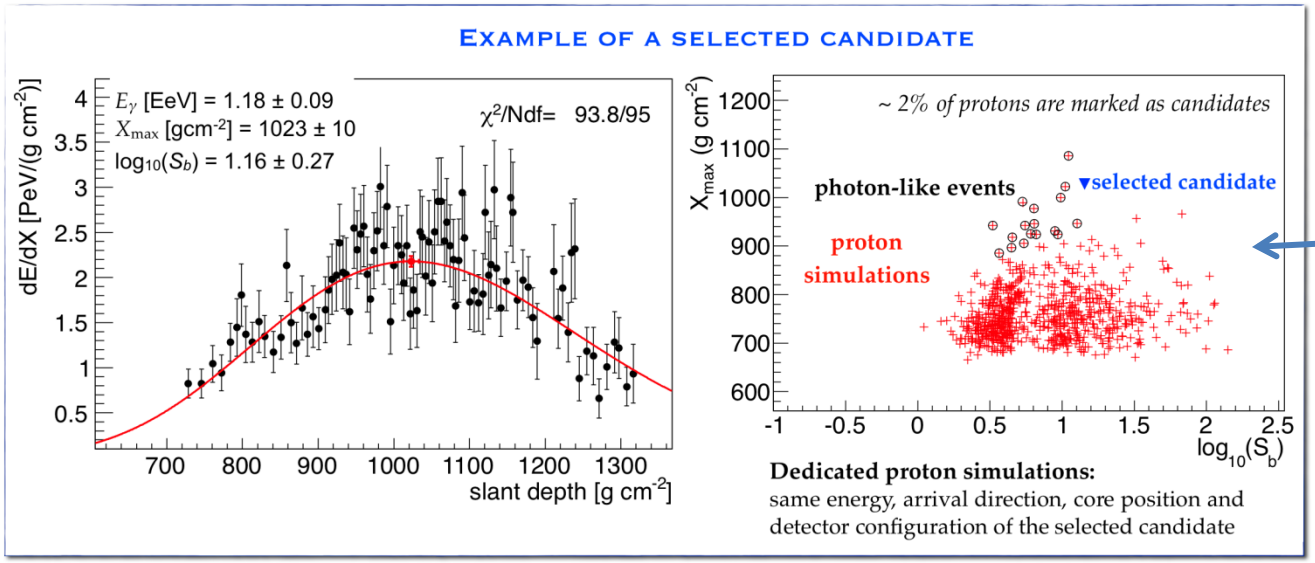
Photon analysis at the Pierre Auger Observatory

Photon Selection:

- Fisher Discriminant in 3 energy bins
  1 – 3 EeV, 3 – 10 EeV and E>10 EeV
- Energy resolution
- Photon selection efficiency 50 %
- Proton Background < 1 %

Search Period: Jan 2005 to Sep 2010
6, 0, 0, 0, 0 candidates above 1, 2, 3, 5, 10 EeV
Compatible with expected **background**





Dedicated simulation for candidates study. ~2% selected

Photon analysis at the Pierre Auger Observatory

$$\Phi_\gamma^{95CL} = \frac{N_\gamma^{95CL}(E_\gamma > E_0)}{\mathcal{E}_{\gamma,\mathrm{min}}}$$

$\mathcal{E}_{\gamma,\mathrm{min}}$ is the exposure for the search period

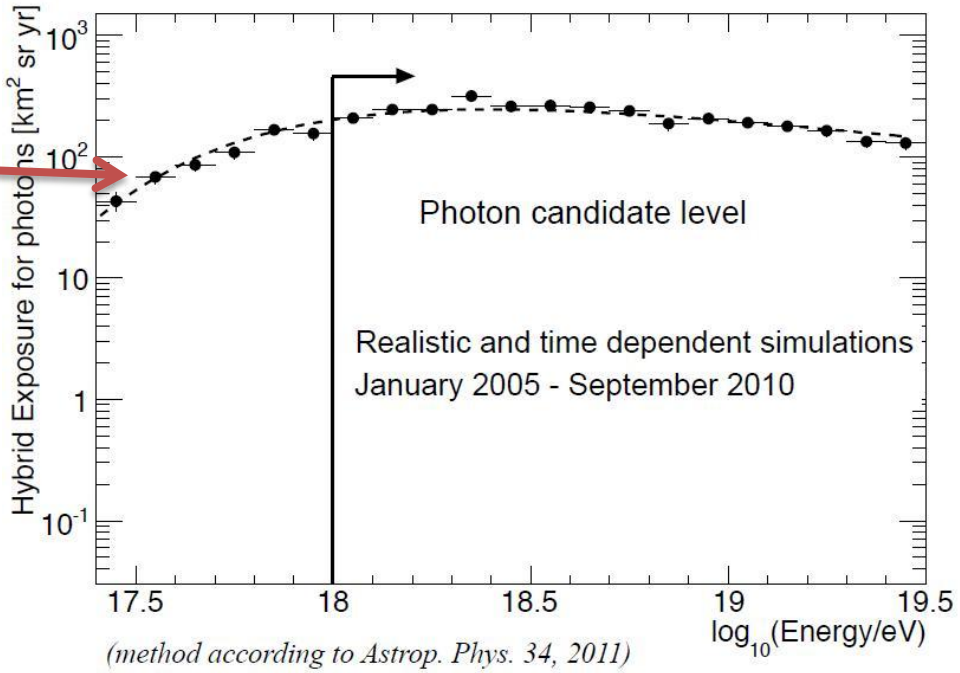
N_γ^{95CL} is the number of observed candidates with energy E_γ above E_0 (Poisson 95%)

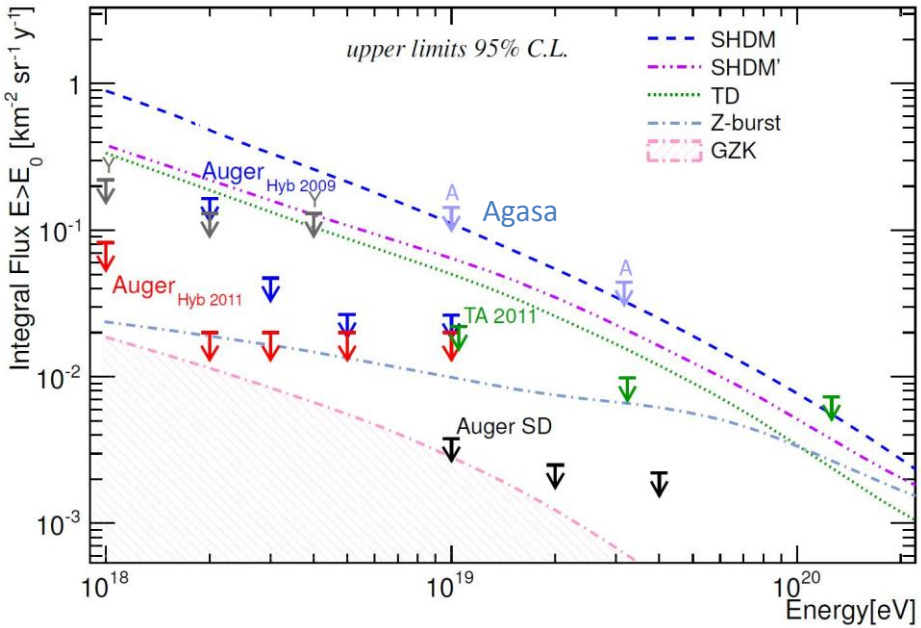
E [EeV]	N_γ	Φ_γ^{95CL} $E_\gamma>E_0$ [km^{-2} sr^{-1} yr^{-1}]
1	6	8.2 x 10^{-2}
2	0	2.0 x 10^{-2}
3	0	2.0 x 10^{-2}
5	0	2.0 x 10^{-2}
10	0	2.0 x 10^{-2}

Systematic uncertainties:

$^{+20\%}_{-64\%}$ $(E_0 = 1$ EeV)

$^{+15\%}_{-36\%}$ $(E_0 > 1$ EeV)

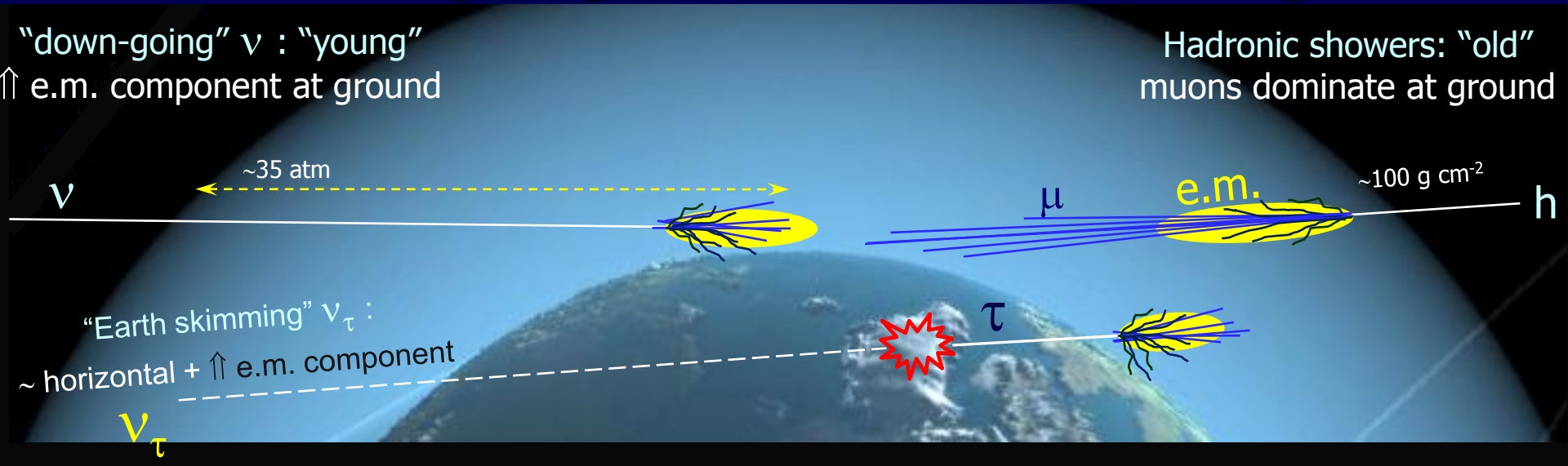




Upper limits to the integral photon fraction assuming the **Auger Spectrum**
(F. Salamida for the Pierre Auger Collaboration, ICRC 2011*)*

0.4%, 0.5%, 1.0%, 2.6% and 8.9% @ E>1, 2, 3, 5 and 10 EeV

Neutrinos at the Pierre Auger: Two analyses, "down going" and "Earth-skimming"



"down going" neutrinos

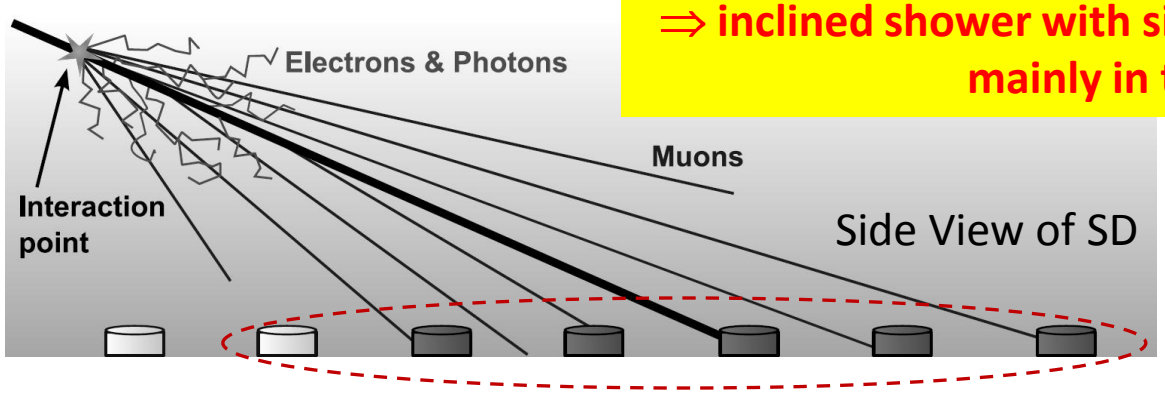
- ↑ Sensitivity to ALL ν flavours
- ↑ Sensitive to ALL interaction channels (CC & NC)
- ↑ Large solid angle (75º → 90º)
- ↓ Dilute mass target (air)

"Earth skimming" tau neutrinos

- ↑ τ travels long distances in the Earth without losing too much E before decaying
- ↓ Sensitivity to ν_τ CC channel
- ↓ Small solid angle (90º – 95º)
- ↑ Dense mass target (Earth crust)

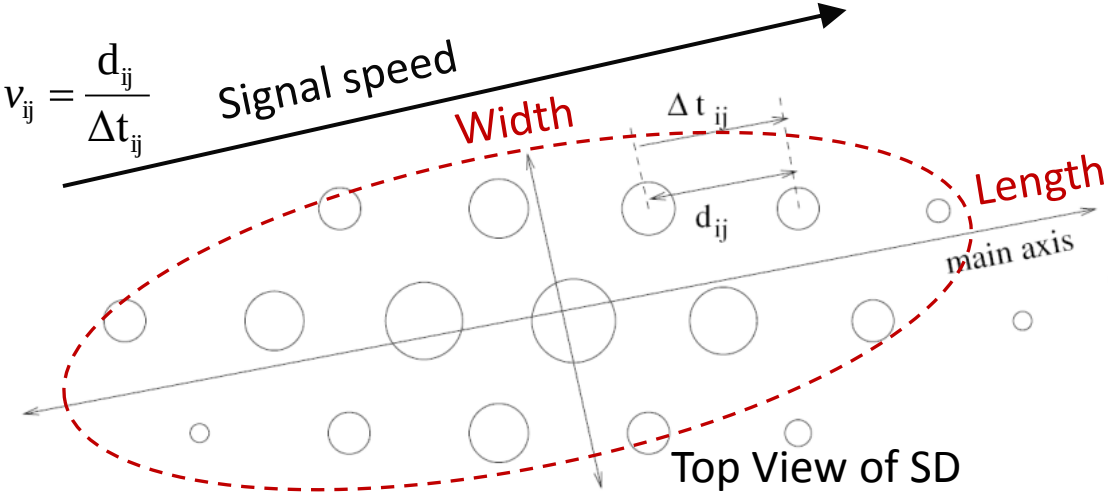
SIGNATURE

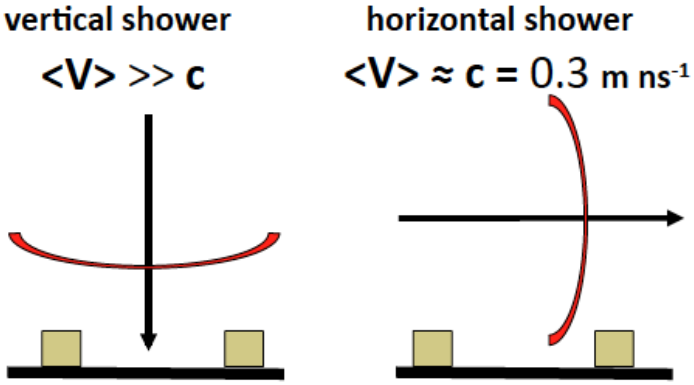
⇒ inclined shower with significant electromagnetic content, mainly in the "early" stations



Only observables of the **surface detector** are **used**

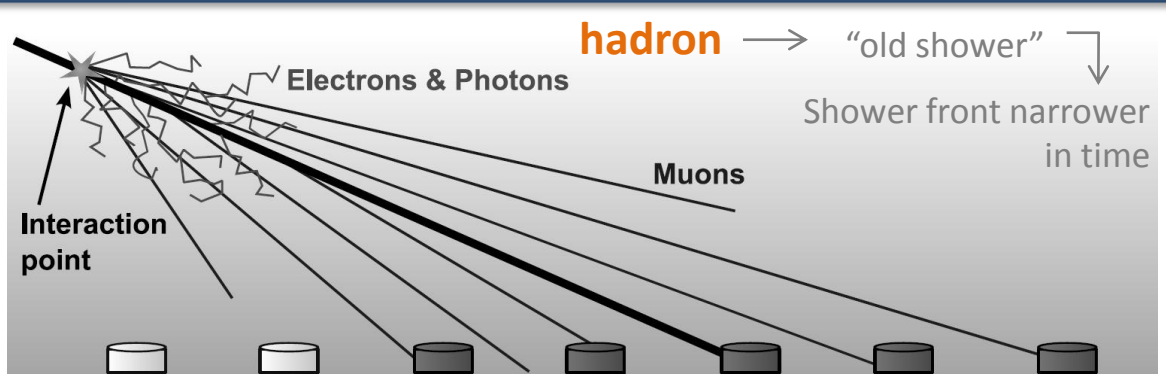
$$v_{ij} = \frac{d_{ij}}{\Delta t_{ij}}$$

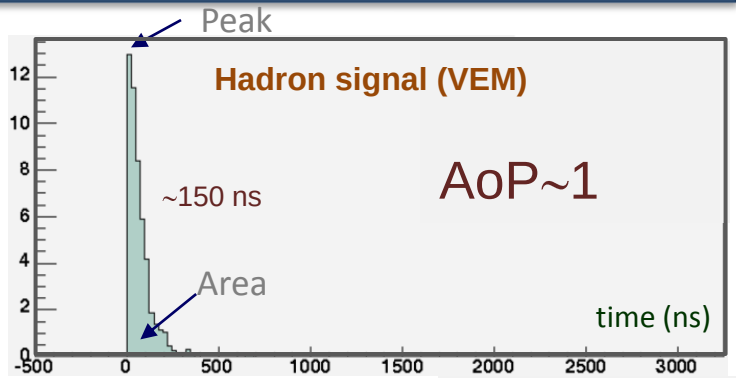


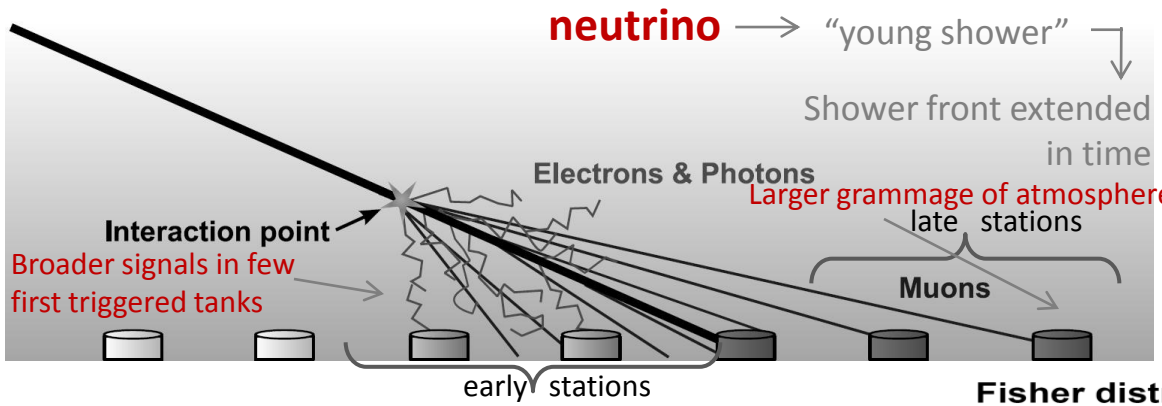


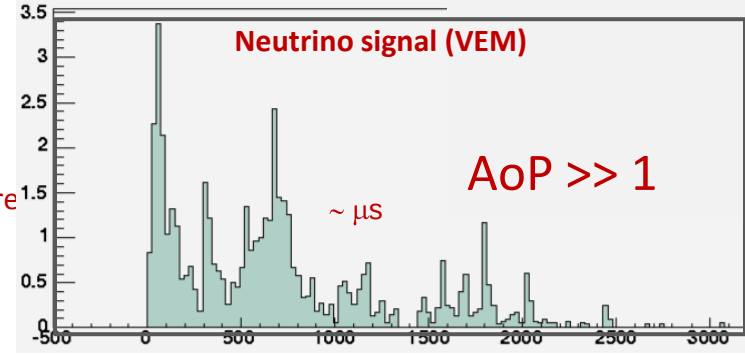
- **Down-going** ($\theta > 75^o$)
  - At least 4 triggered stations
  - $\langle signal\ speed \rangle < 0.31$ m ns^{-1}
  - L/W > 3
- **Earth-skimming** ($90 < \theta < 95^o$)
  - At least 3 triggered stations
  - 0.29 m ns^{-1} < $\langle signal\ speed \rangle$ < 0.31 m ns^{-1}
  - L/W > 5

Neutrino analysis at the Pierre Auger Observatory









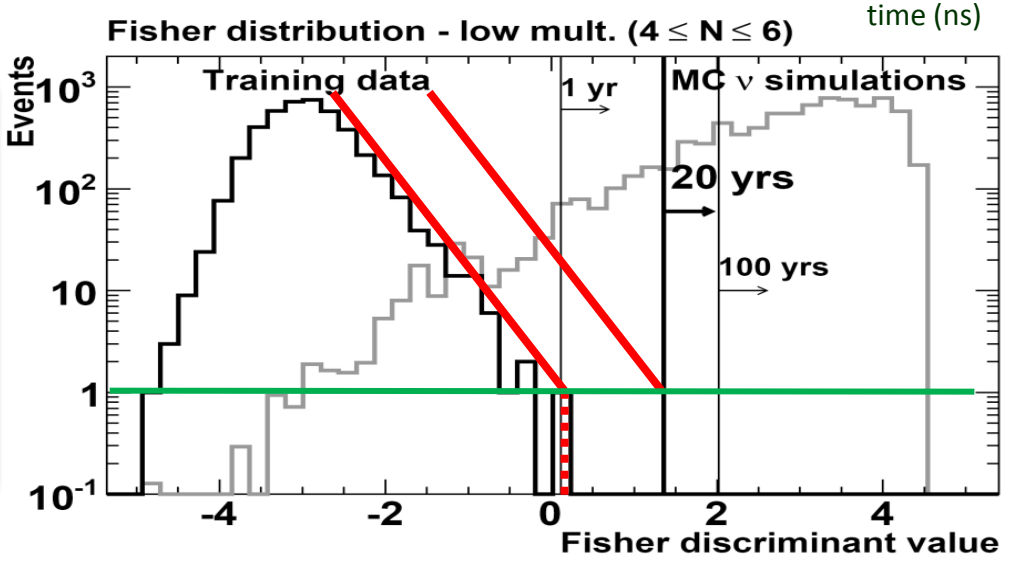
Neutrino Selection based on a Fisher discriminant.

Search Period:

Down-going: Nov 2007 – May 2010

Earth-Skimming: Jan 2004 – May 2010

0 CANDIDATES FOUND



Neutrino analysis at the Pierre Auger Observatory

Integrated Neutrino Limits:

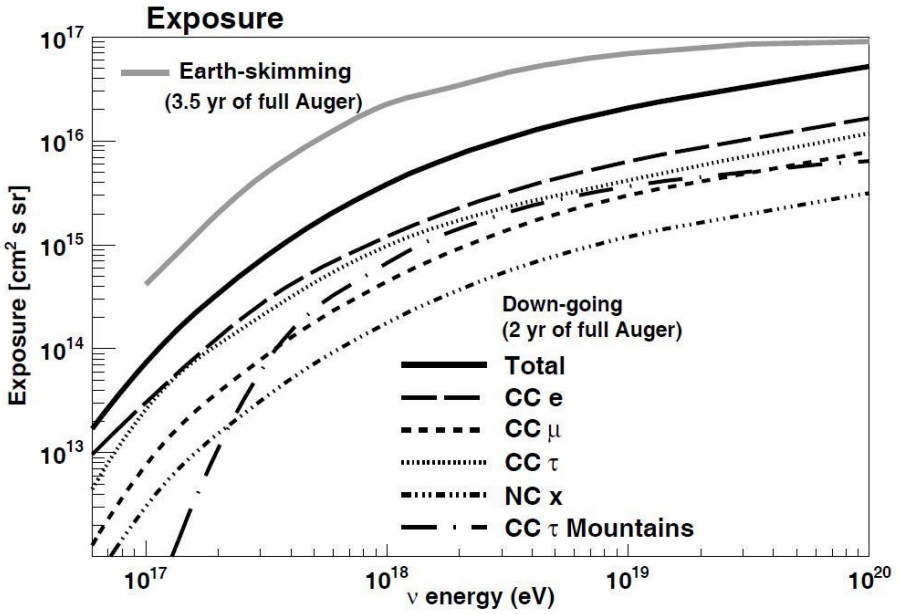
Down-going: 1.7 x 10^{-7} GeV cm^{-2} s^{-1} sr^{-1}

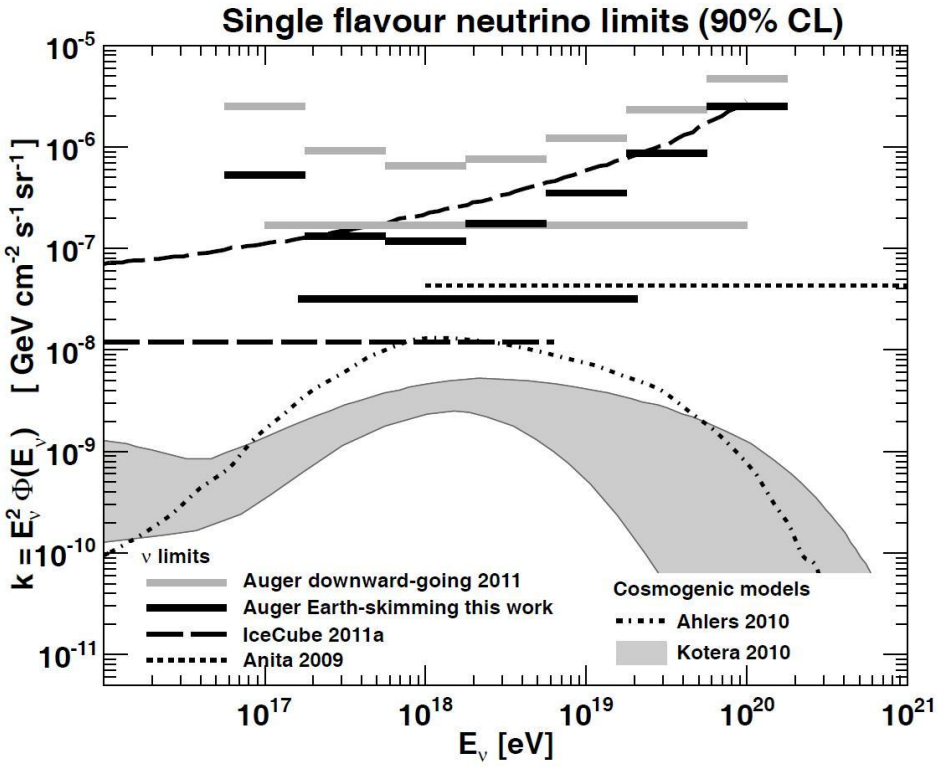
Earth-skim.: 2.8 x 10^{-8} GeV cm^{-2} s^{-1} sr^{-1}

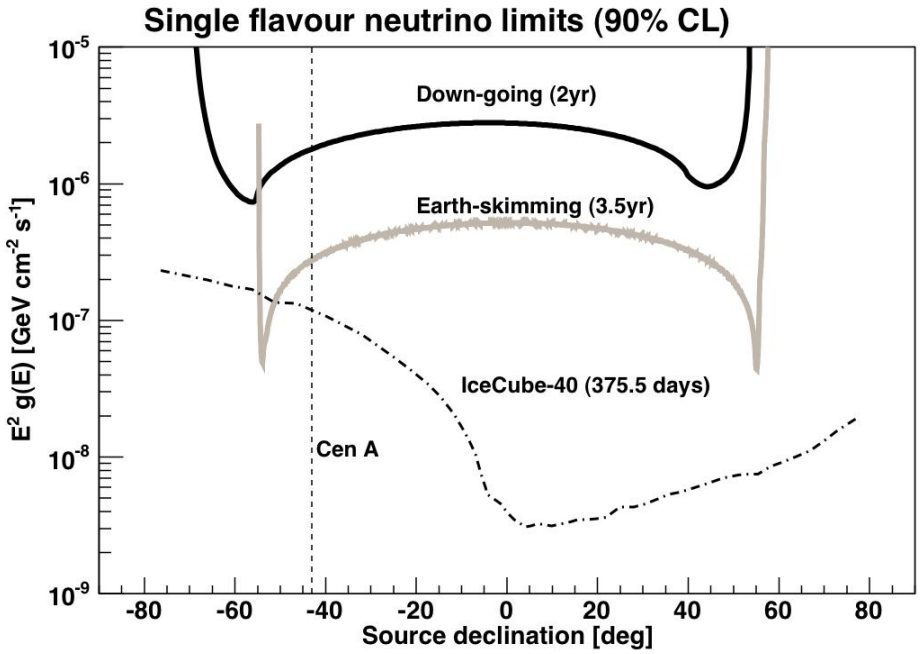
Limit to Cen A flux:

Down-going: 1.75 x 10^{-6} GeV cm^{-2} s^{-1}

Earth-skim.: 3.17 x 10^{-7} GeV cm^{-2} s^{-1}



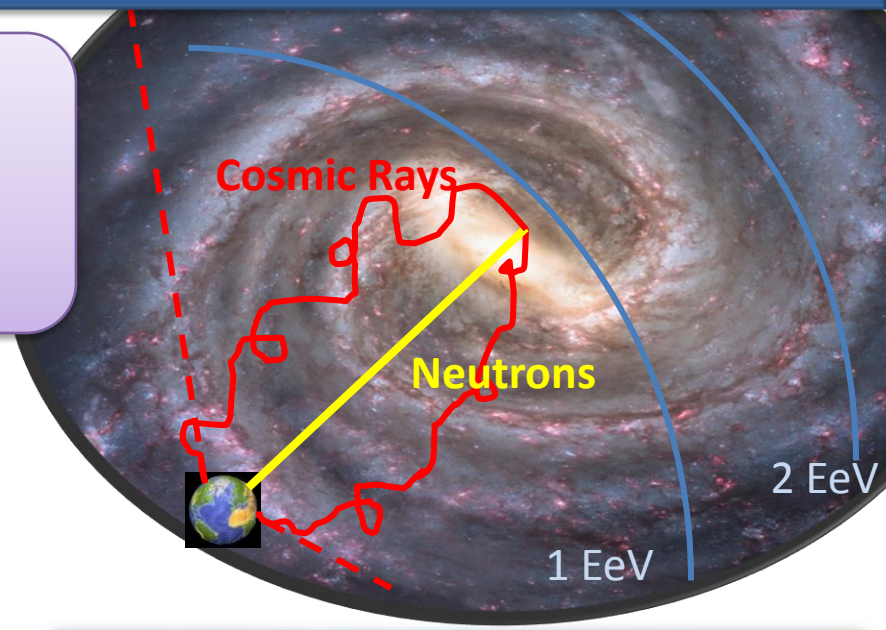




Neutron analysis at the Pierre Auger Observatory

Neutrons

- Unstable: Only galactic neutrons detectable
- Neutral: Travel in straight lines



Two approaches:

Blind **Search of over-densities**

Angular resolution :

- 1.8º if E>1EeV
- 1.5º if E>2EeV

Li-Ma significance study

Targeted Search

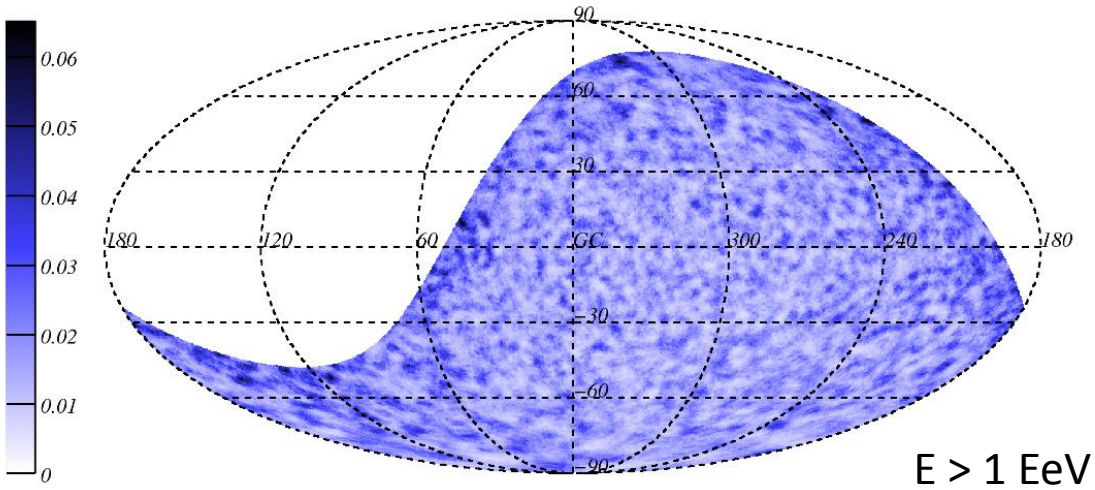
Search excess in gamma-ray sources

Two set of sources from:

- Fermi Lat point source catalog
- H.E.S.S. source catalog

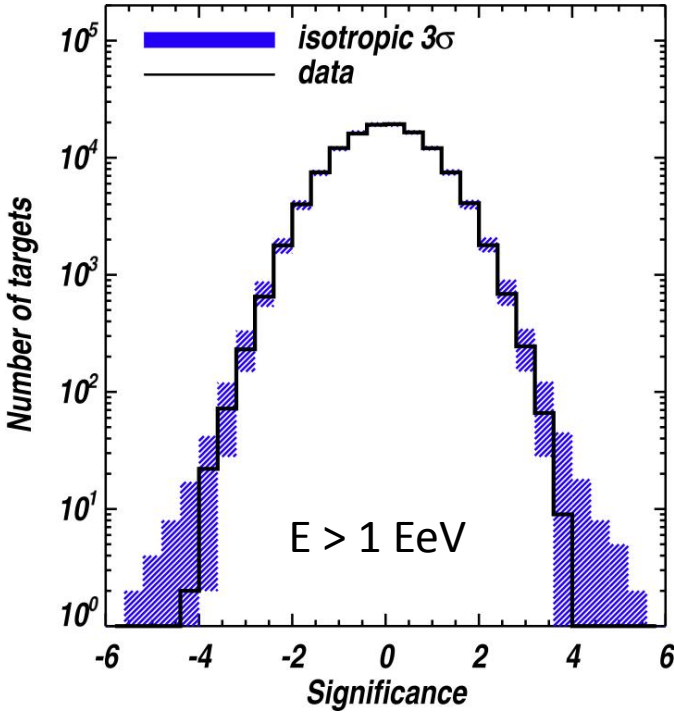
Neutron analysis at the Pierre Auger Observatory

No significant excess found.
Upper Limits: [km^{-2} yr^{-1}]
- 0.024 for E ∈ [1,2] EeV
- 0.014 for E ∈ [2,3] EeV
- 0.026 for E ≥ 1 EeV



No significant excess found in any analysis.
Data scanned from
Jan 2004 to Oct 2010

Set of Sources	Energy Bin [EeV]	S_{staked}
Fermi LAT Point Source Catalog	1 – 2	2.07
	2 – 3	0.51
	≥ 1	2.35
H.E.S.S. Source Catalog	1 – 2	-0.75
	2 – 3	-0.40
	≥ 1	-0.89



Summary

- The Pierre Auger Observatory is a hybrid detector of Cosmic Rays that has the capability of detecting neutral primaries.

- We have placed stringent limits to the flux of incoming photons, neutrinos and neutrons.

For **detailed** information on **photon and neutron analysis** refer to:

The Pierre Auger Collaboration, **"The Pierre Auger Observatory III: Other Astrophysical Observations",** Contributions to the 32nd International Cosmic Ray Conference, 2011

arXiv:1107.4805v1

For **detailed** information on **neutrino analysis** refer to:

The Pierre Auger Collaboration, "**Search for ultrahigh energy neutrinos in highly inclined events at the Pierre Auger Observatory",** Physical Review D 84, 122005 (2011)

arXiv:1202.1493

More results in:

www.auger.org

Backup

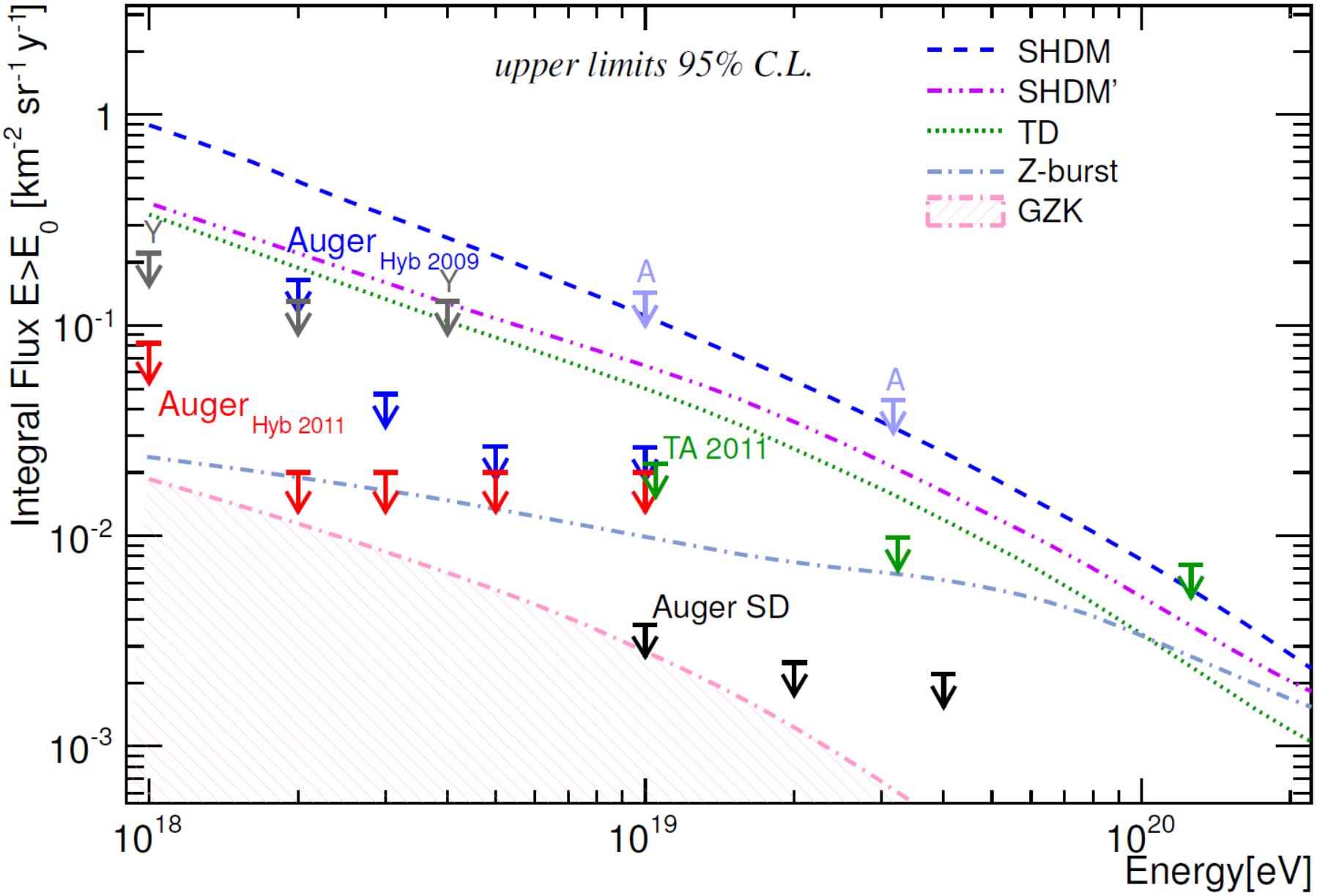
Backup – Photons - Summary

- Fit Gaisser Hillas $\chi^2 < 2.5$
- X_{max} in the field of view
- Energy uncertainty < 20%
- Cherenkov light contamination < 50%
- Only periods with good measurement of aerosols and no clouds.
- At least 4 SD active within 2 km from the axis.
- QGSJETII and FLUKA hadronic models used.
- Fisher Trained with 30000 proton and photon CORSIKA showers.
- Hadronic background checked with 1000 simulations

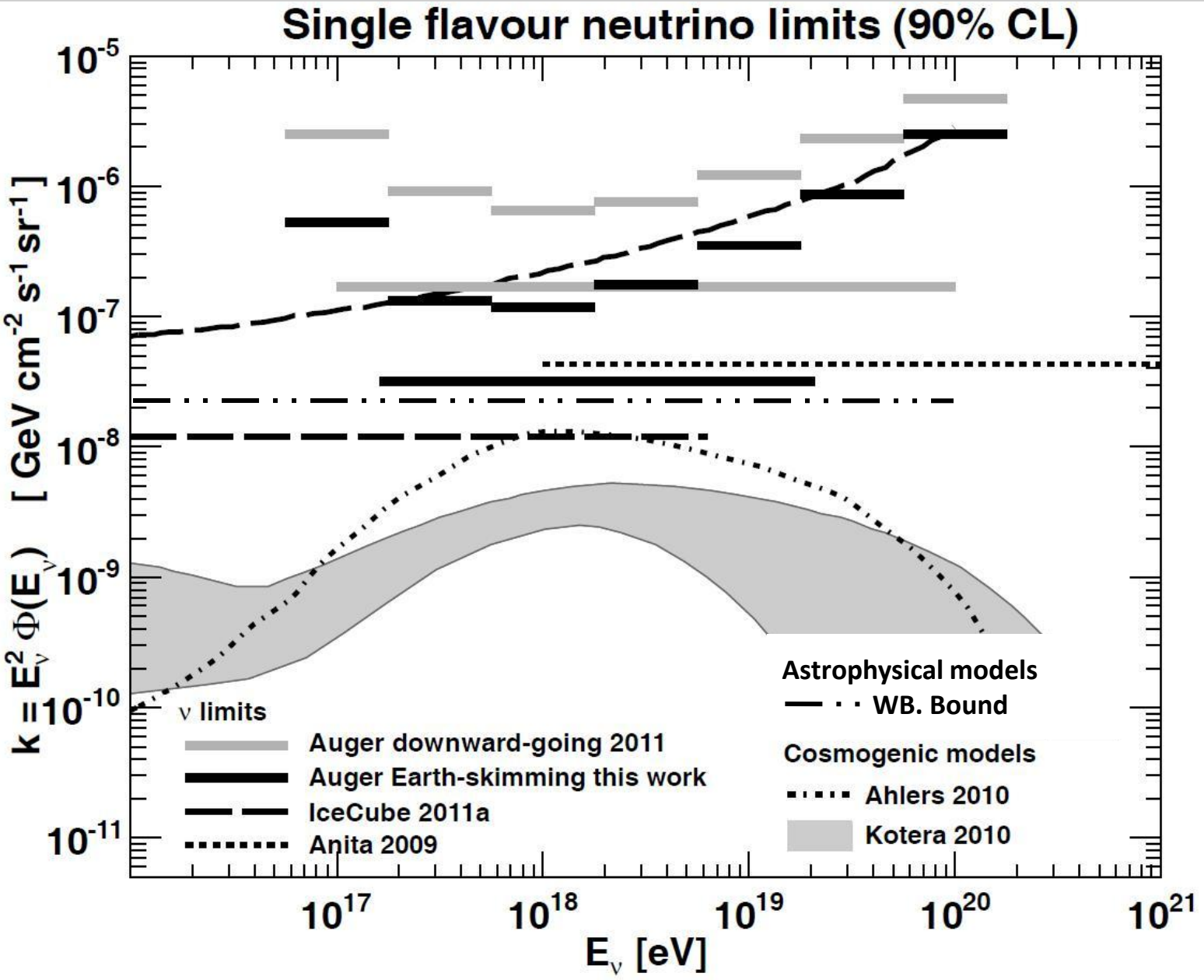
Uncertainties:

- ΔX_{max} = 13 g cm^{-2} , +1 (-2) candidates above 1 EeV, 0 in other energies. +10%, -25% lim.
- ΔSb = 5%
- Exposure 5%
- Energy scale 22%, +1 (-4) cand. above 1 EeV, 0 in other en.
  --> +14%, -54% above 1EeV, +6%,-7% other en.

Backup - Photons



Backup – Neutrino Result



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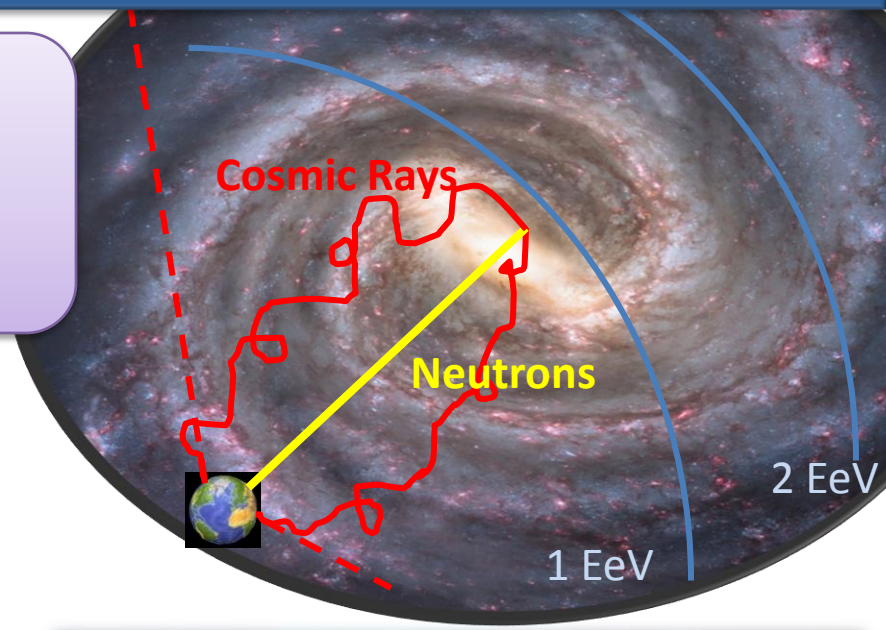

Two approaches:

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Li-Ma significance study

Targeted Search

Search excess in gamma-ray sources

Two set of sources from:

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- H.E.S.S. source catalog

Backup – Neutron summary

- Mean free path before decay: 9.2 E /EeV kpc
- Distance to galactic center: 8.3 kpc
- Galactic radius: 15 kpc
- Only SD events with $\theta < 60^{o}$
- Systematic uncertainty in energy determination: 22 %
- Angular resolution (68% containment radius)
    - 1.8 above 1 EeV
    - 1.5 above 2 EeV
    - ~10% influence in total systematic
- HEALPIX with resolution $N_{side} = 128$
- Limit computed at 95% cl with Zech (1989) approach.

Backup – Neutron Targeted Search

Fermi LAT Point Source Catalog				H.E.S.S. Source Catalog			
Name 1FGL	**L [deg]**	**B [deg]**	**Distance [kpc]**	**Name HESS**	**L [deg]**	**B [deg]**	**Distance [kpc]**
J0835.3-4510	263.55	-2.79	0.29 ± 0.02	J0852-463	266.28	-1.24	0.2
J1709.7-4429	343.10	-2.69	1.4 – 3.6	J0835-455	263.85	-3.09	0.29
J1856.1+0122	34.70	-0.42	2.8	J1713-397	347.28	-0.38	1
J1809.8-2332	7.39	-1.99	1.7 ± 1.0	J1616-508	332.39	-0.14	6.5
J1801.3-2322c	6.57	-0.21	1.9	J1825-137	17.82	-0.74	3.9
J1420.1-6048	313.54	0.23	5.6 ± 1.7	J1708-443	343.04	-2.38	2.3
J1018.6-5856	248.32	-1.70	2.2	J1514-591	320.33	-1.19	5.2
J1028.4-5819	285.06	-0.49	2.3 ± 0.7	J1809-193	10.92	0.08	3.7
J1057.9-5226	285.98	6.65	0.7 ± 0.2	J1442-624	315.41	-2.30	2.5
J1418.7-6057	313.33	0.14	2 - 5	J1640-465	338.32	-0.02	8.6

Backup