# Ultra-high energy neutrinos at the Pierre Auger Observatory

PIERRE AUGER OBSERVATORY

Jan Ebr for the Pierre Auger Collaboration

- Ultra-high energy neutrinos hold the key to many exciting puzzles in contemporary cosmic-ray physics
- The Pierre Auger Observatory is the largest cosmic ray detector ever built and it happens to also be sensitive to neutrinos
- Neutrinos are detected as extensive air showers that originate very deep in the atmosphere or even in the ground
- Spoiler alert! Neutrinos observed so far:

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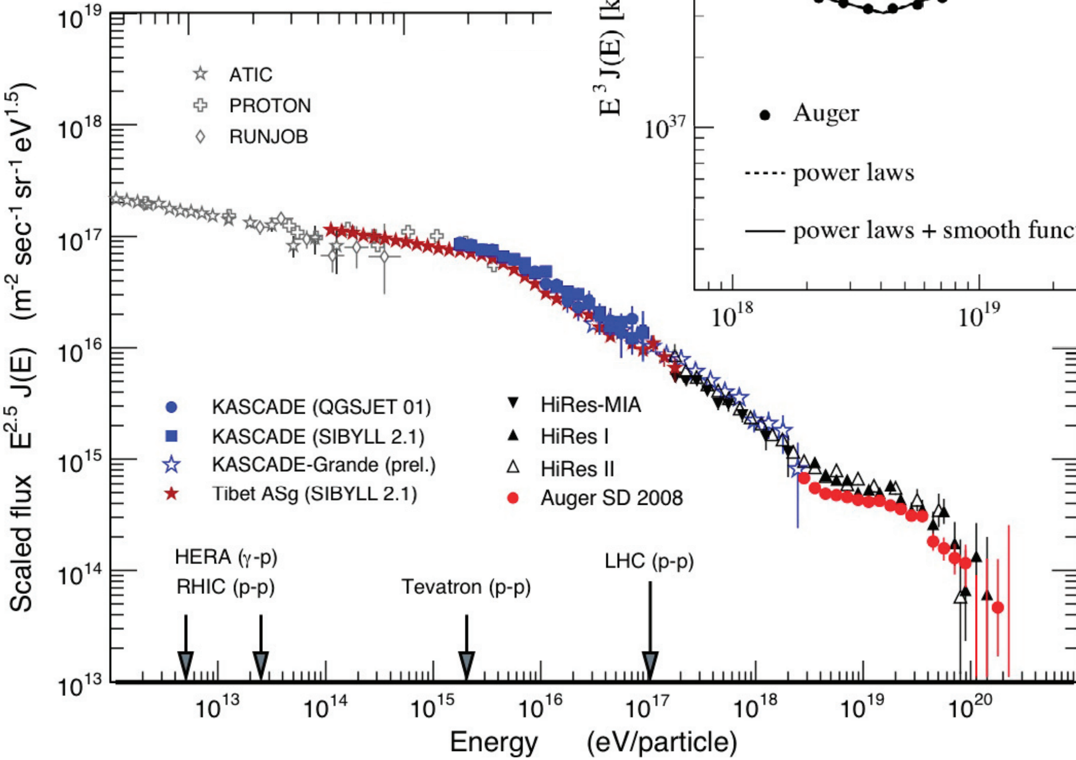
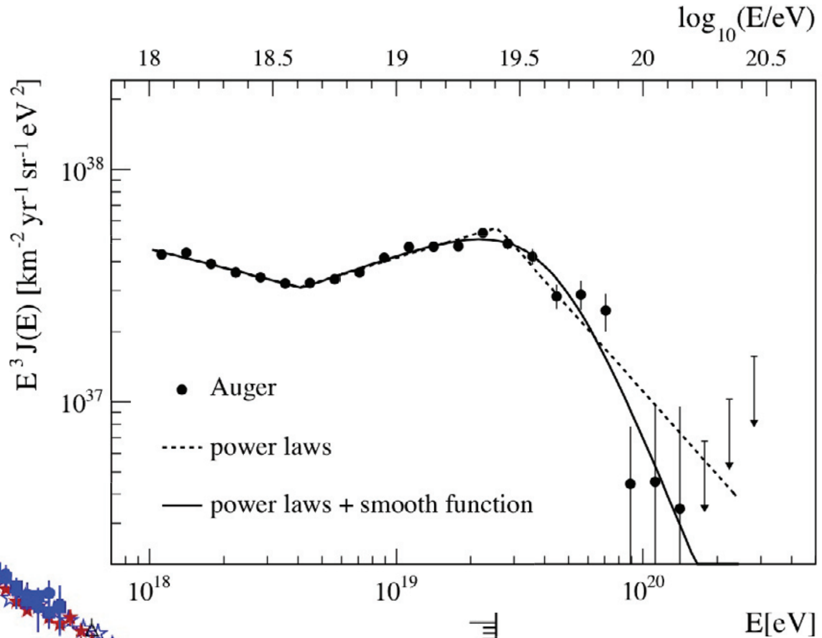
- Spoiler alert! Neutrinos observed so far: ***none***

**Cosmic rays:** 10 orders of magnitude, 30 orders of flux

- from direct detection on a balloon to the 3000 km² array



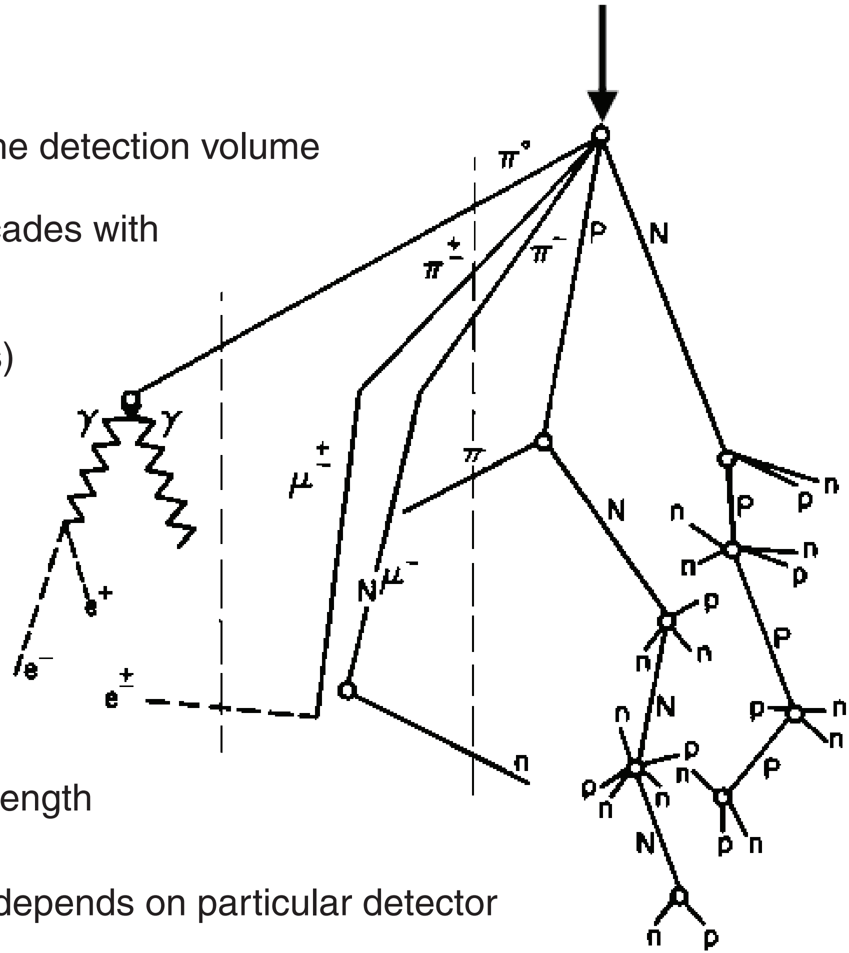



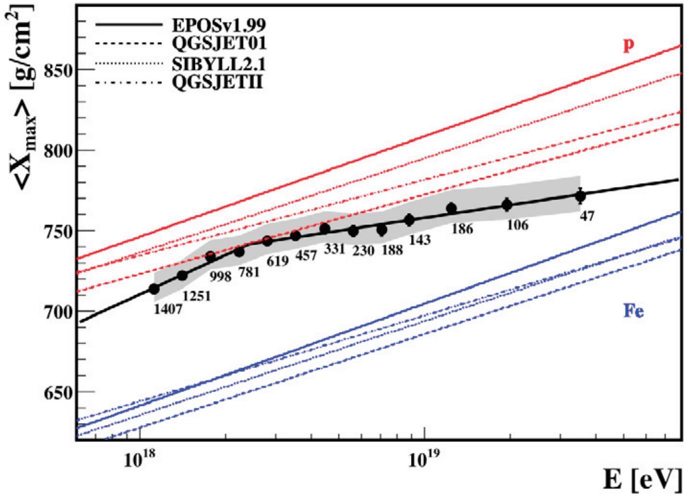

**What is the suppression?**

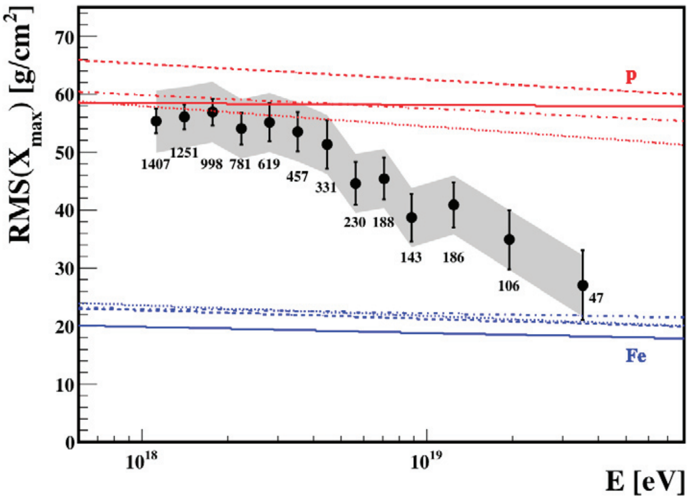
GZK (protons) or photo-disintegration (iron) or an intrinsic feature of sources?

# Extensive air showers

- low flux: using atmosphere as the detection volume
- interactions with air initiate cascades with billions of particles
- **fluorescence light** (dark nights)
  - calorimetric information on primary energy
  - longitudinal shower development (nature of primary particle)
- **ground particle detection** (100 % uptime)
  - primary energy from signal strength (calibrated by fluorescence)
  - shower age, muon content ... depends on particular detector
- n. b.: angular resolution good with both methods (geometry, timing)





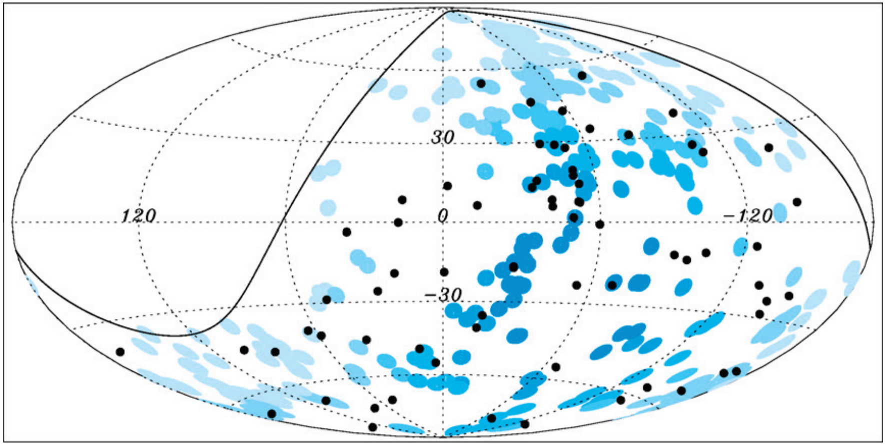




**What are they actually?**

Longitudinal shower development suggests transition to higher masses, but dependent on models

**Where do they come from?**

Particles deflected by magnetic fields. Correlation with AGNs, matter distribution, ... but weak.



# How can ultra-high energy neutrinos help answer these questions?

- **cosmogenic (diffuse) neutrinos**
  - GZK effect: pions vs. photo-disintegration: free neutrons
  - both sources of neutrinos, but GZK much stronger for ultra-high energy

- **neutrino point sources**
  - unaffected by magnetic fields
  - essentially any acceleration mechanisms produces high-energy pions → pro neutrinos from cosmic-ray sources

- Even if none is observed, putting limits can strongly constrain many models.

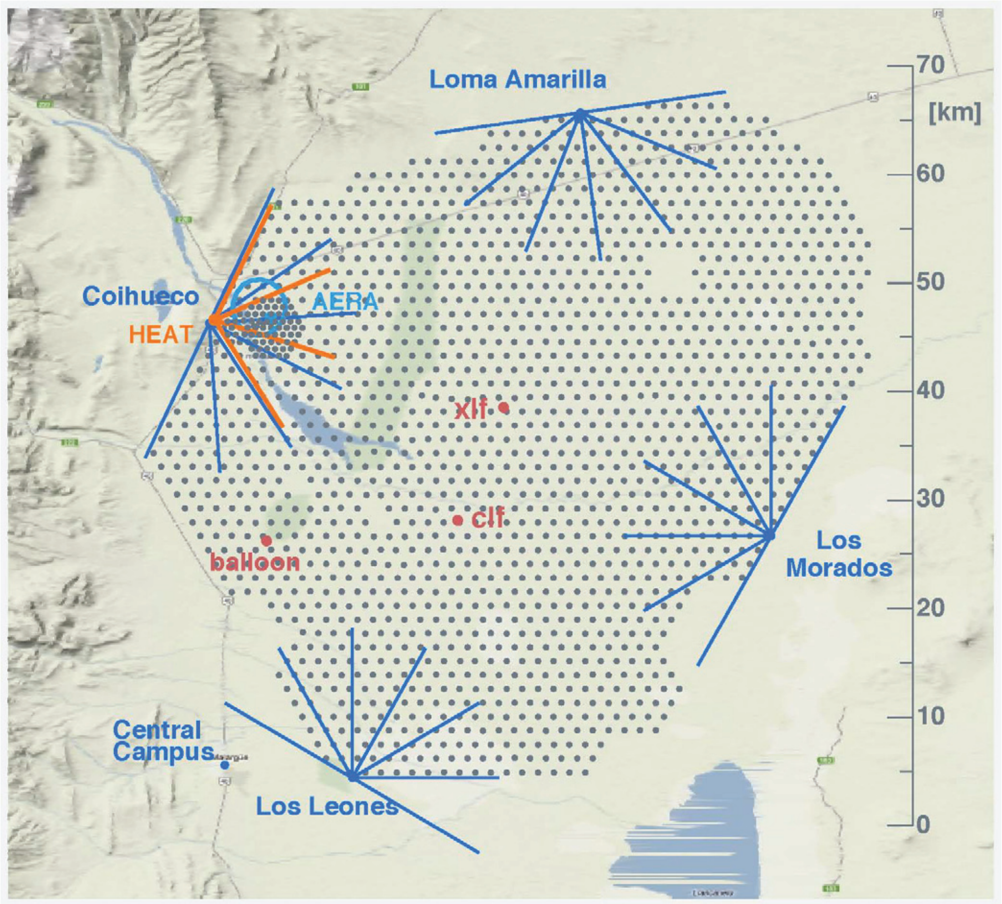
- **IceCube:** two PeV neutrinos + recently 26 more at ~100 TeV
  - seemingly incompatible with atmospheric background – but any interpretation is solely up to the IceCube collaboration!
  - nevertheless encouraging: there is something out there ...

# The Pierre Auger Observatory

- **surface detector**
  - 1600 water Cherenkov detectors (3.6 m diameter) in a triangular grid with 1500 meter spacing, covering 3000 km$^2$
  - sensitive to both electromagnetic and muonic component, some identification power using time structure of signals

- **fluorescence detector**
  - 24+3 telescopes with photomultiplier cameras
  - so far not used for neutrino search (low statistics); Czech group involved

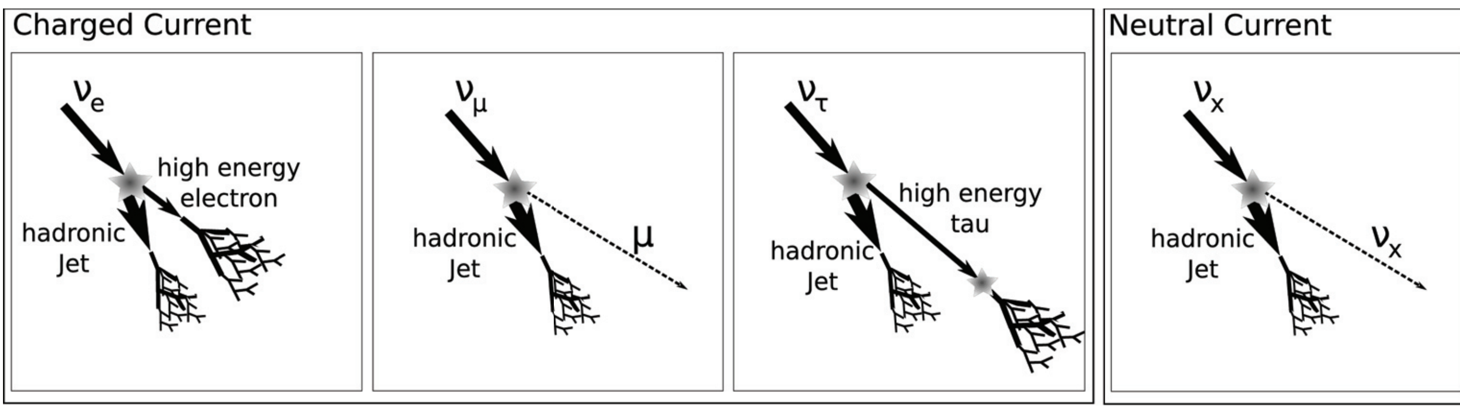
# The Pierre Auger Observatory



# Neutrino channels at the Pierre Auger Observatory

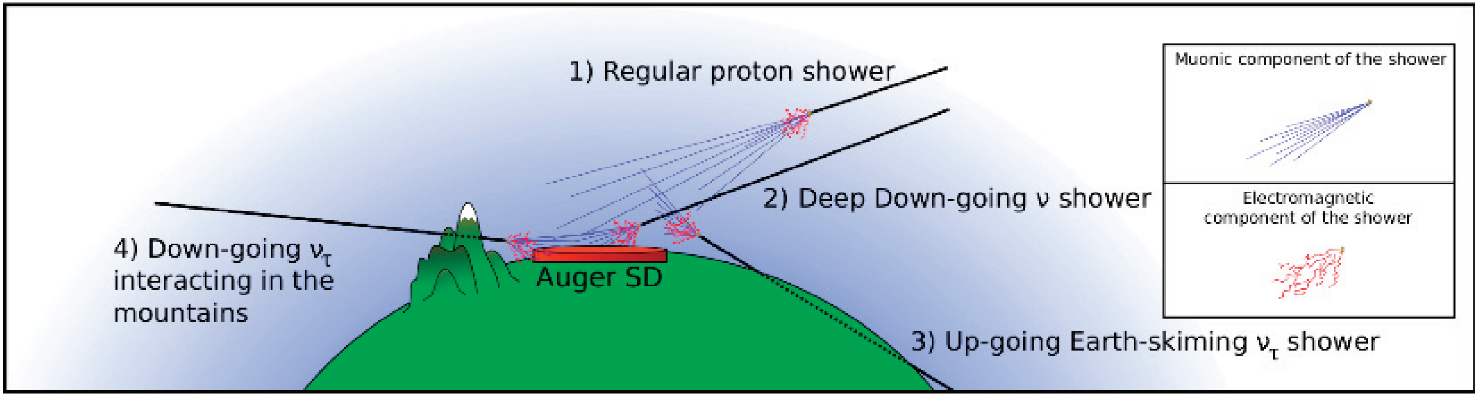
- central idea: separate neutrinos from the overwhelming cosmic-ray background using their ability to pass through a lot of matter

- **down-going neutrinos**
  - cosmic rays (protons, nuclei, possibly a small amount of photons) usually interact high in the atmosphere, whereas neutrinos interact anywhere
  - at zenith angles > 75° the amount of atmosphere is sufficient for discrimination based on “shower age” (still trade-offs to be made)
  - all flavours, both CC and NC contributions, incl. $\nu_\tau$ interactions in the Andes



# Neutrino channels at the Pierre Auger Observatory

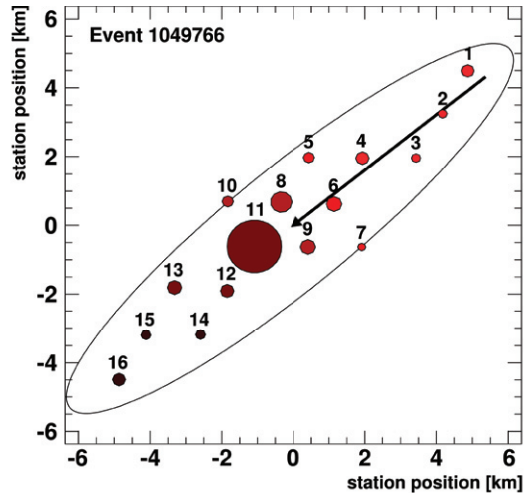
- **Earth-skimming neutrinos**
  - up-going $\nu_\tau$ interacts in the crust via CC → produces $\tau$ → decays after ~10 km above the array into an electron or a number of pions (~17 % muon channel unobservable)
  - not relevant for $\nu_e$ (electron does not escape the ground) nor $\nu_\mu$ (no shower)
  - must be very nearly horizontal (within 5°) for the shower particles to reach the detector via lateral spread
  - virtually zero background when such showers are properly identified



# How to identify neutrino showers?

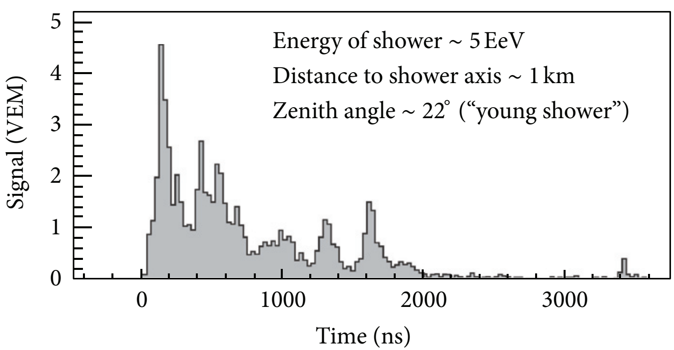
**1. Select inclined and Earth-skimming events**

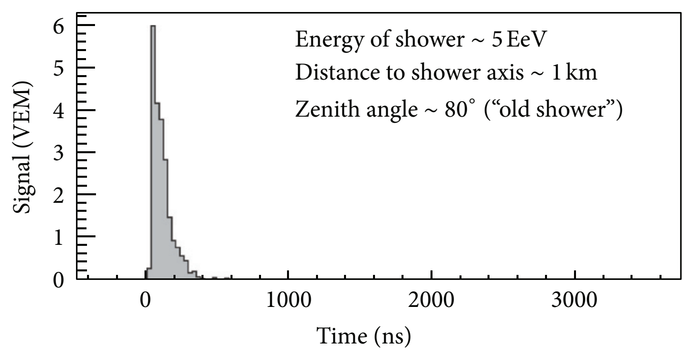
- geometry: highly eccentric elliptic footprint
- relative timing: ground velocity *v~c* (vertical showers *v>>c)*




**2. Select "young showers" close to the ground**

- "old showers": dominated by muonic component, very short pulses
- "young showers": electromagnetic component, broad signals



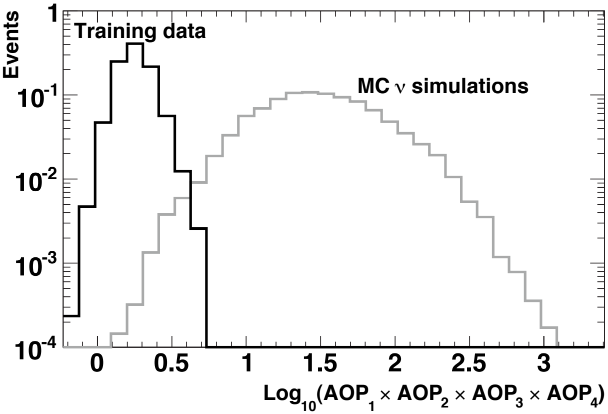



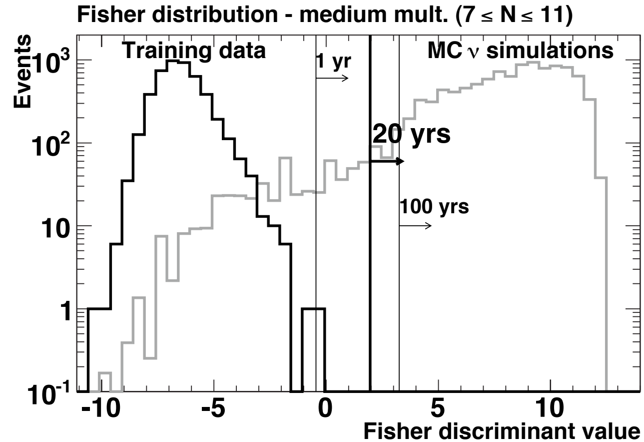
# How to identify neutrino showers?

**3. Fix specific values for the cuts using neutrino and background showers**

- neutrino showers simulated in broad parameter space to avoid boundary effects
- simulations of cosmic-ray showers uncertain (i.e. primary composition still unknown) → use a chosen “training” period of data as background
- background more important for down-going → longer training period (less data)
- for Earth-skimming neutrinos: require 0 background events during training period

# How to identify neutrino showers?



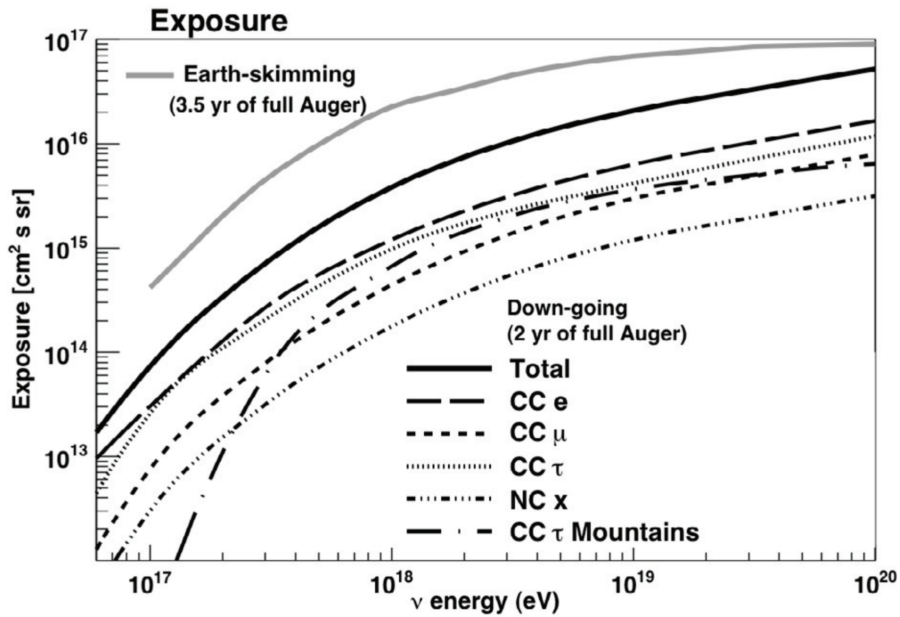

- for down-going: “Fischer discriminant” - allows to select background rejection vs. efficiency: require 1 background event in 20 years → 90 % neutrinos accepted (10 % falsely rejected)

**4. After fixing the method, “unblind” rest of the data and look for neutrinos**

- Published data up to May 31, 2010. Data up to end of 2012 to be unveiled at ICRC 2013.

# Converting observed rates to flux

- **Calculate exposure using simulations of neutrino showers**
  - find for which geometries, energies and array positions of the neutrino interaction is the shower observed




- **Identify systematic uncertainties of exposure**
  - shower simulation, neutrino-nucleus cross-section at ultra-high energy, τ energy losses, topography (not accounted for in Earth-skimming analysis)
  - approximately +35 %, –15 % for Earth-skimming, +13 %, – 34 % for down-going

# Results

- No neutrino candidates observed → upper limit of 2.44 events at 90 % CL
- Assuming flux $dN/dE = k \cdot E^{-2}$ we obtain both differential and integral limits