Search for ultra-high energy neutrinos with the Pierre Auger Observatory

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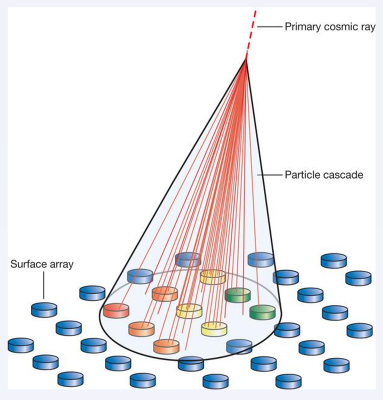
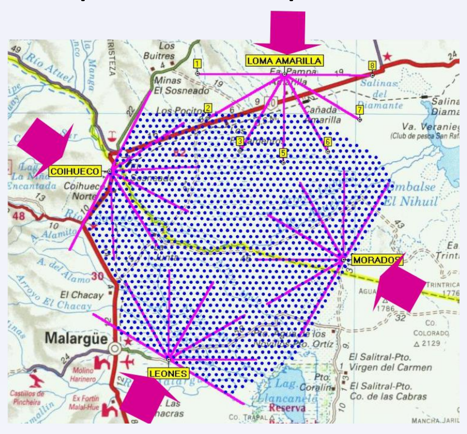
Ultra-high energy neutrinos at the Pierre Auger Observatory

- The Pierre Auger Observatory, near the town of Malargüe (Argentina), studies the ultra-high energy cosmic rays (above ~10^{18} eV) using a hybrid detector:

i. Fluorescence Detector (27 telescopes at 4 sites which collect ultraviolet light produced when the shower of particles, excite air nitrogen molecules)

ii. Surface Detector (1600 water Cherenkov stations on a 1.5 km triangular grid covering ~3000 km^2 containing three photo multiplies tubes, PMTs).


Layout of the SD array, the four fluorescence buildings at the edges of the observatory are also showed.
Left: One of the Cherenkov stations and one fluorescence building in the background.

- The existence of cosmic rays of energy above 10^{18} eV implies a flux of cosmic neutrinos at similar energies that can be produced by the interaction of accelerated protons or nuclei:

i. with matter or radiation fields at the astrophysical source

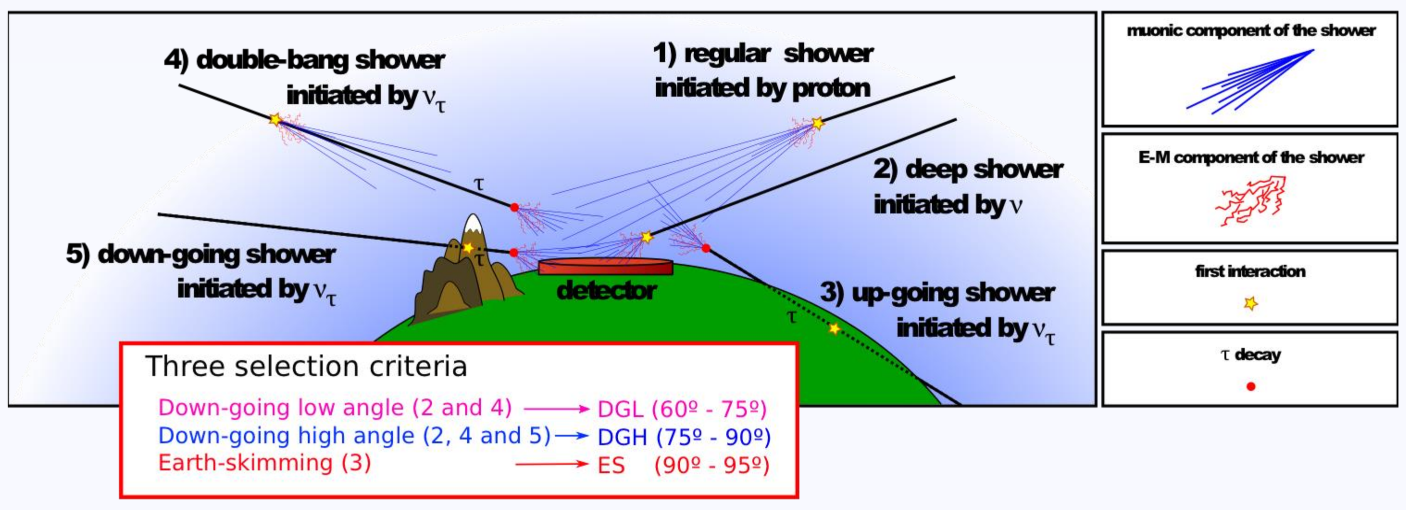
ii. with the cosmic microwave background photons when traveling intergalactic distances.

- Interactions of cosmic rays generate pions that produce an electron to muon neutrino flavor in the ratio 1:2. Due to neutrino flavor mixing, after travelling cosmological distances approximately equal fluxes of each flavor are expected.

- With Surface Detector of the Pierre Auger Observatory we are sensitive to neutrino-induced air showers above 10^{17} eV:

i. downward-going neutrinos of all flavors interacting in the atmosphere (DG, with arrival zenith angles 75°<ϑ<90°)

ii. decays of tau leptons from tau neutrino interactions in the Earth's crust (called "Earth-Skimming" ES, with arrival zenith angles 90°<ϑ<95°).



Different types of neutrino induced deep-inclined showers that can be detected with the Surface Detector array.

Neutrino-induced shower identification

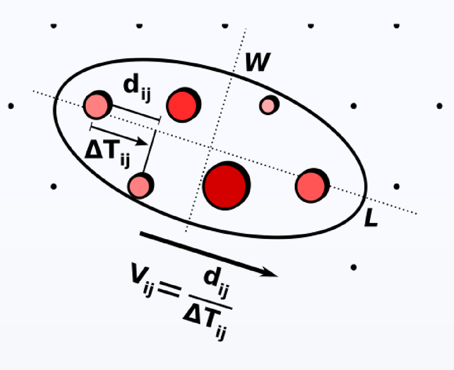
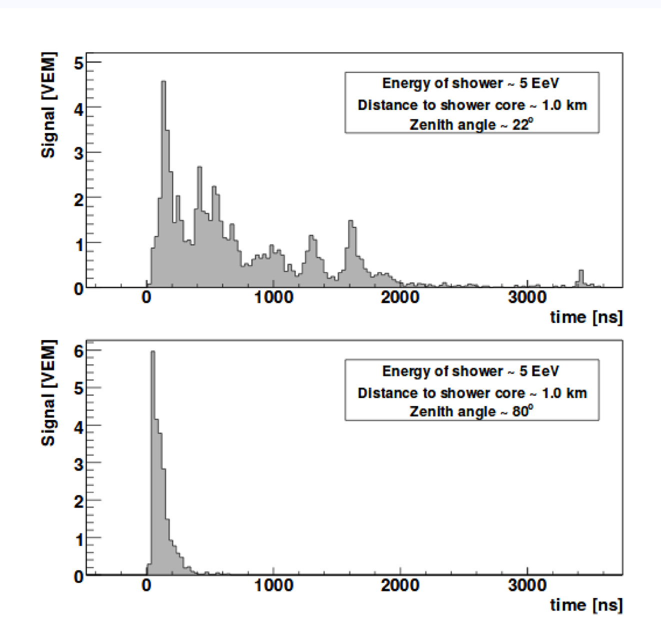
- The discrimination between cosmic ray (CR) and neutrino-induced showers is maximized for nearly horizontal events (DG and ES) at early stage of development.
- CR shower ⇒ electromagnetic component is absorbed in atmosphere and does not reach the ground
- Neutrino shower ⇒ can interact at any point in the atmosphere. If first interaction deep: electromagnetic component reaches the ground.

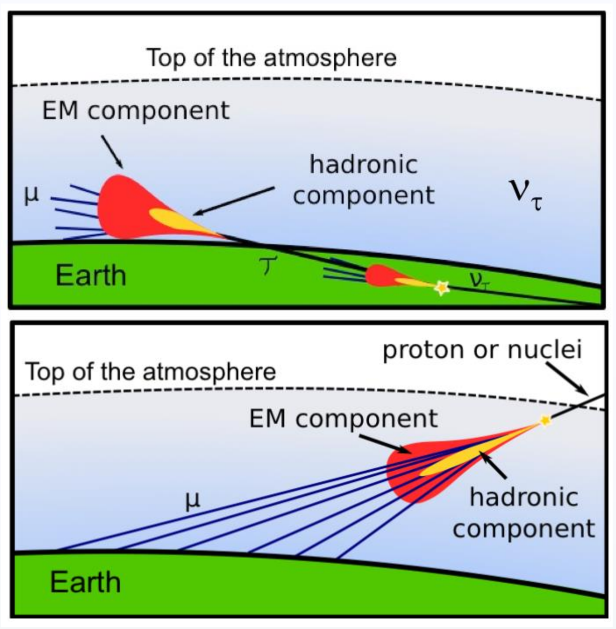
- Selection procedure of inclined & deep showers:

i. triggered stations exhibit an elongated pattern on the ground, assigning a length and a width and requiring its ratio to be large.

ii. Apparent speed of signal close to speed of light, compatible with an event traveling in the nearly horizontal direction.

iii. Signal in PMTs broad in time induced by electromagnetic instead of muonic component .

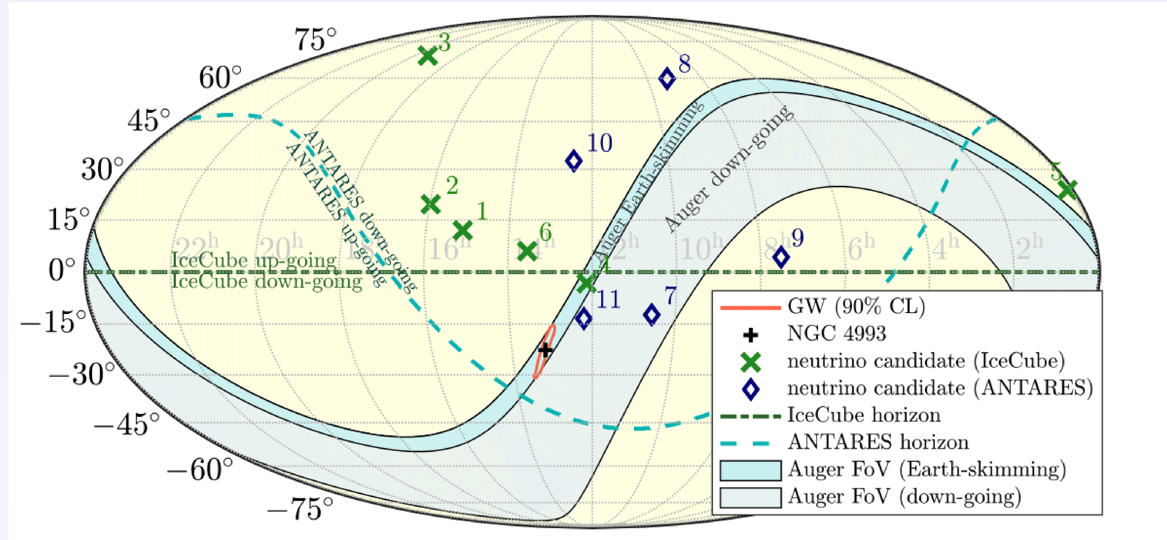





Variables sensitive to neutrino-induced shower selection. Left: definition of length, width and ground speed. Central: PMTs responses to a late and early developed air shower. Right: schematic representation of an Earth-Skimming event.

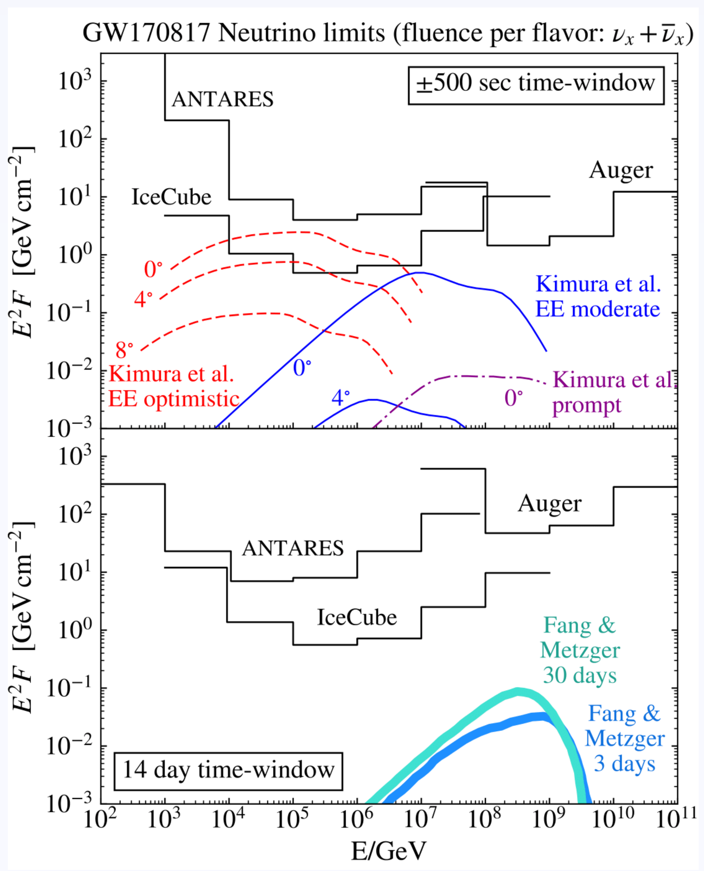
Ultra-high energy neutrinos follow-up of LIGO events

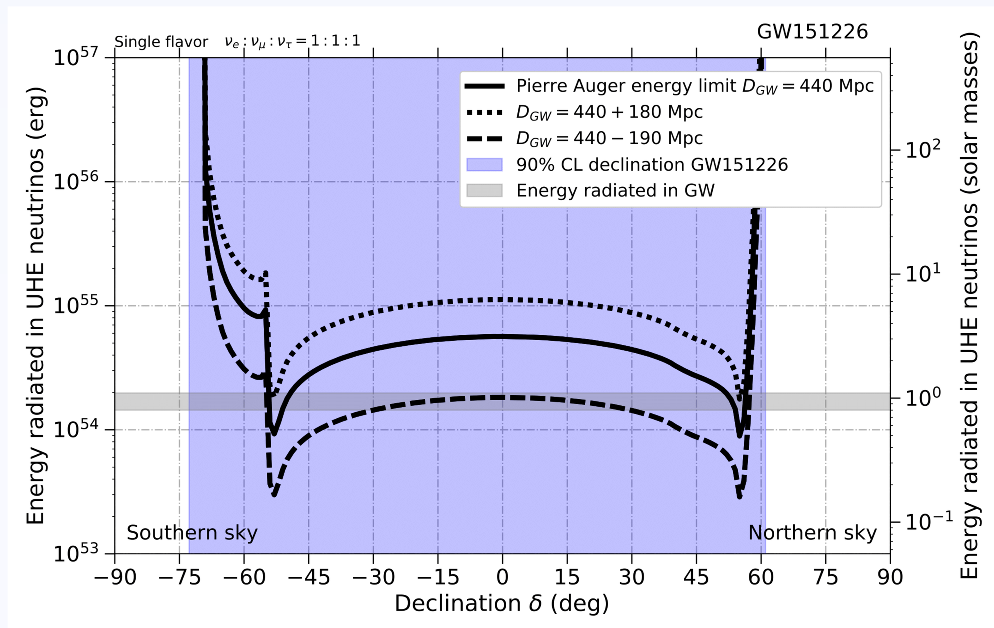
- Recently Advanced LIGO detectors observed gravitational waves transients: GW150914 and GW151226 arisen from the merger of black holes in binary systems (BBH) and GW170817 from a binary neutron star (BNS) infall, which has also an electromagnetic counterpart (a GRB)[1].



Localizations and sensitive sky areas at the time of the GW170817 (BNS) event in equatorial coordinates.

- In BBH, cosmic rays can be accelerated to ultra-high energies provided there are magnetic fields and disk debris remaining from collapse. For BNS the shock and mass ejecta provide the adequate site.
- The search for neutrinos in spatial coincidence with LIGO events was made in two periods: 500s around the UTC of the merger and 2 weeks (BNS) or one day (BBH) after, motivated by the duration of short GRBs afterglows.
- No neutrino candidate found in the time windows ⇒ assuming continuous neutrino emission during the search period ⇒ upper limit on the total energy radiated in neutrinos from BBH and BNS [2].
- BBH: Most restrictive for GW150914 ⇒ less than 7.7 x 10^{53}erg, which is 14% of the energy radiated in gravitational waves.
- BNS: Absence of neutrinos consistent with GRB observed at a large off-axis angle (≥ 20°)

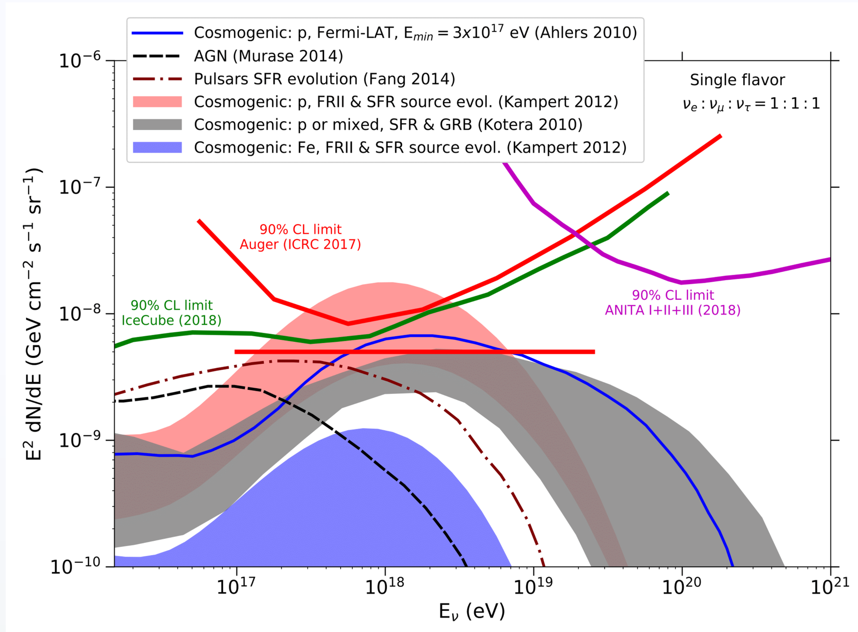
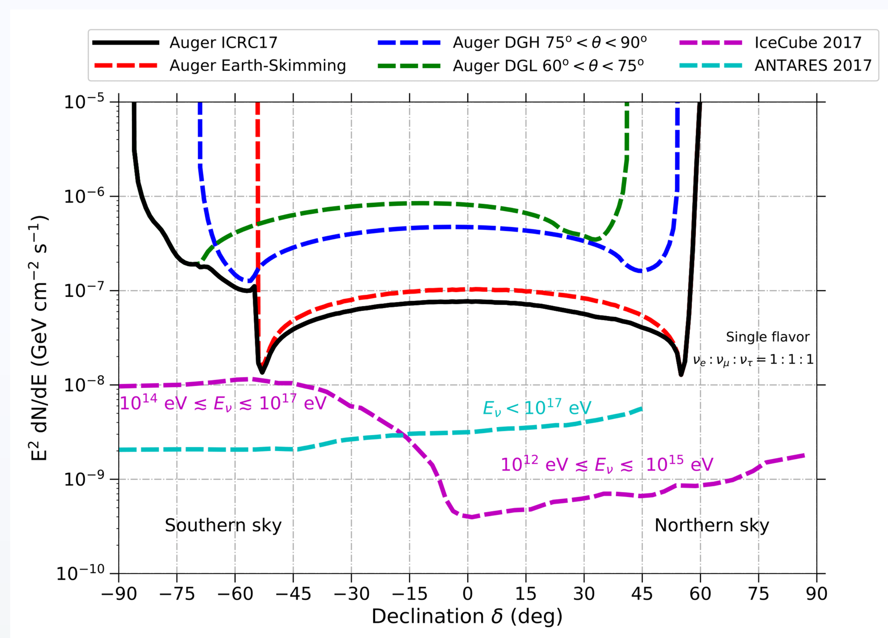




Left: Upper limit to the ultra-high energy neutrino fluence per flavor from GW170817 (Binary Neutron Star merger) . Right: Upper limit to the energy radiated in ultra-high energy neutrinos from GW151226 (Binary Black Hole merger) as a function of equatorial declination. The limits only apply in the blue band.

Limits to ν fluxes: diffuse and point-like

- Analysis of the data collected from 1 January 2004 to 31 March 2017 revealed no candidate events ⇒ most sensitive bounds on neutrino flux at 10^{18} eV [3].
- The Pierre Auger Observatory search for ultra-high energy [100PeV, 25EeV] neutrino emission is complementary to those of IceCube/ANTARES that apply in the energy range [100 GeV, 100 PeV]. Upper limits of the flux of ultra-high energy neutrinos can be placed for a diffuse flux (integral and differential) and as a function of declination [4].
- ES channel increases the possibility of detecting tau neutrinos, making the Pierre Auger Observatory the most sensitive detector in the EeV range .

Left: Integral upper limit (at 90% C.L.) for the normalization, k, of a diffuse flux dN/dEν = kE^{-2} of single flavor neutrinos and differential upper limit compared to other experiment and several model predictions. All flavors are assumed to have equal fluxes. Right: Upper limits at 90% C.L. for a single flavor neutrino flux as a function of declination, δ, for ES, DG channels, compared to other experiments.

References

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