Società Italiana di Fisica
106° CONGRESSO NAZIONALE
14 – 18 Settembre 2020

Multi-messenger Astrophysics with the Pierre Auger Observatory

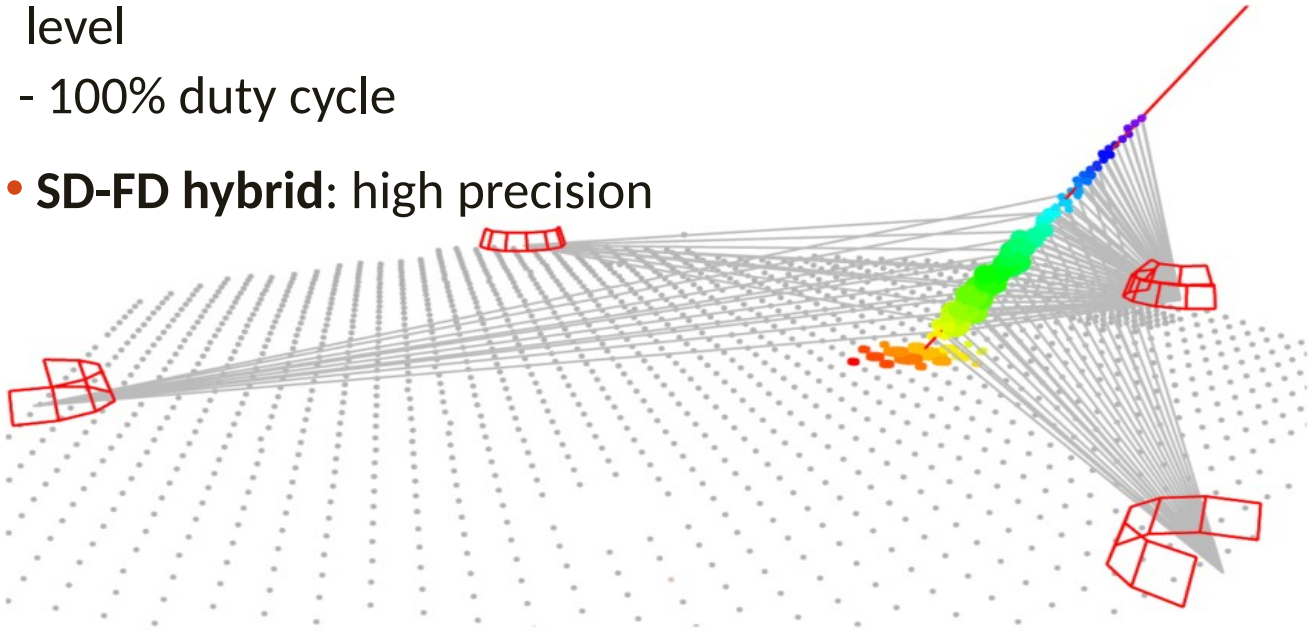
De Vito Emanuele[1] for the Pierre Auger Collaboration[2]

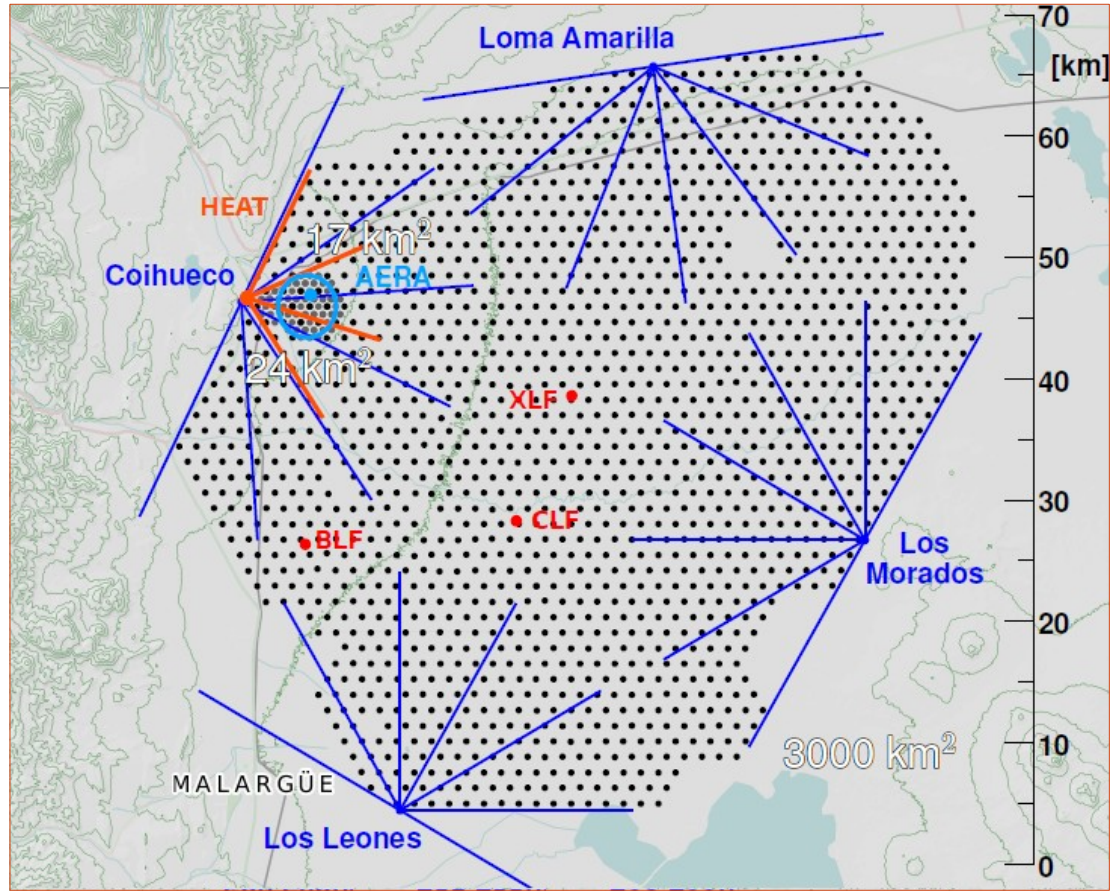
1 - Università del Salento, Lecce
2 - Full author list at www.auger.org/archive/authors_2020_06.html

The Pierre Auger Observatory

- **Surface Detector (SD)**: detection of extensive air showers (EAS) initiated by primaries in the atmosphere, sampling particles at ground level
  - 100% duty cycle
- **SD-FD hybrid**: high precision

- **Fluorescence Detector (FD)**: observation of the longitudinal profile
- - 15% duty cycle





Multi – Messenger approach

frontiers

Multi-Messenger Physics with the Pierre Auger Observatory

The Pierre Auger Collaboration [1]

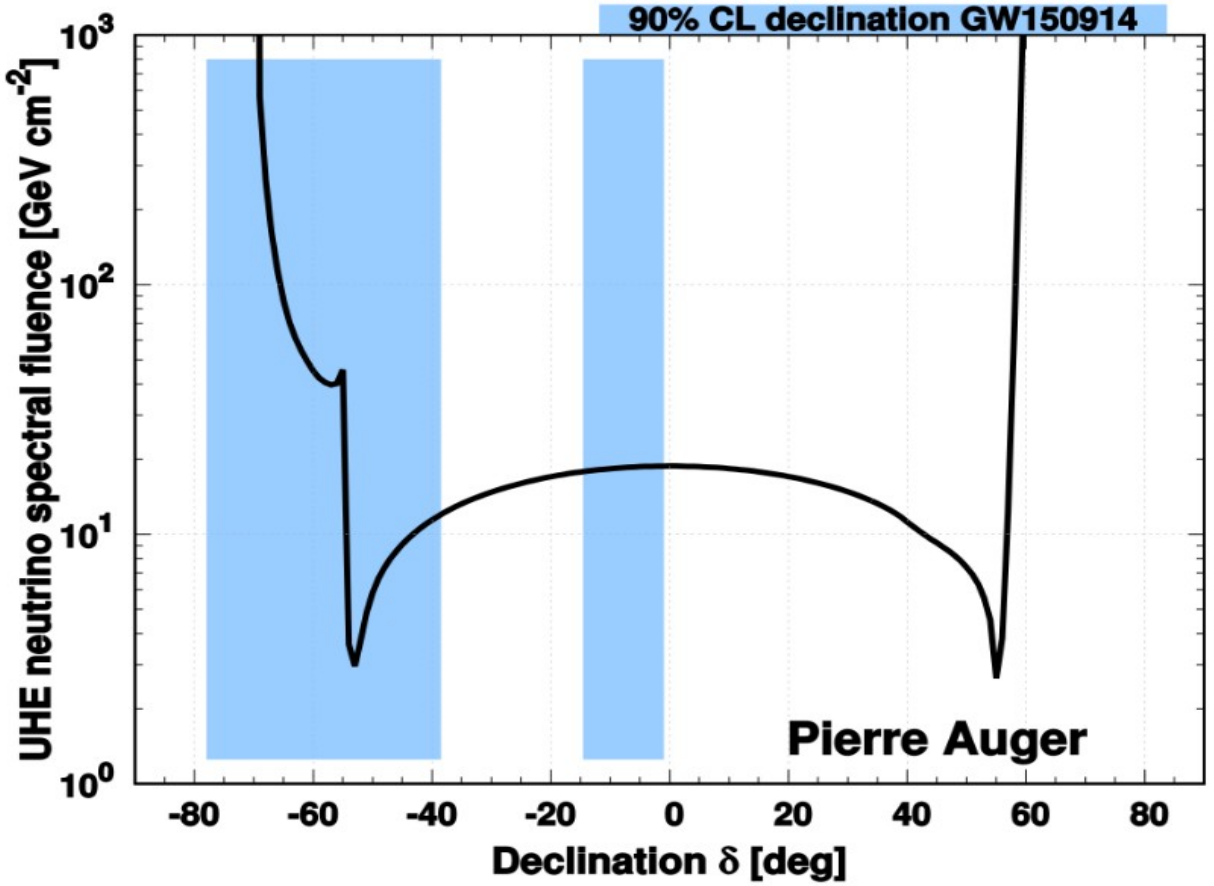
[1] Pierre Auger Observatory, Av. San Martín Norte 304, 5613 Malargüe, Argentina

The searches for Ultra High Energy neutrinos or photons rely on the discrimination of EASs induced by neutrinos or photons from those induced by Ultra High Energy Cosmic Rays (UHECRs):

- Neutrino induced EASs can be separated by hadronic showers in inclined events as they may induce a longer lasting signal, rich of electromagnetic paricle while hadron induced showers at large zenith angle exhibit short signals dominated by muons.
- Photons-induced EASs are distinguished from others based on several measurements such as steeper lateral distribution functions, deeper shower maxima, and smaller footprint at the ground.
- Neutrons-induced EASs are indistiguishable from those induced by protons, but neutrons travel in straight lines, so a flux of neutrons can be dected via an excess of the number of EASs from the direction of a specific source.

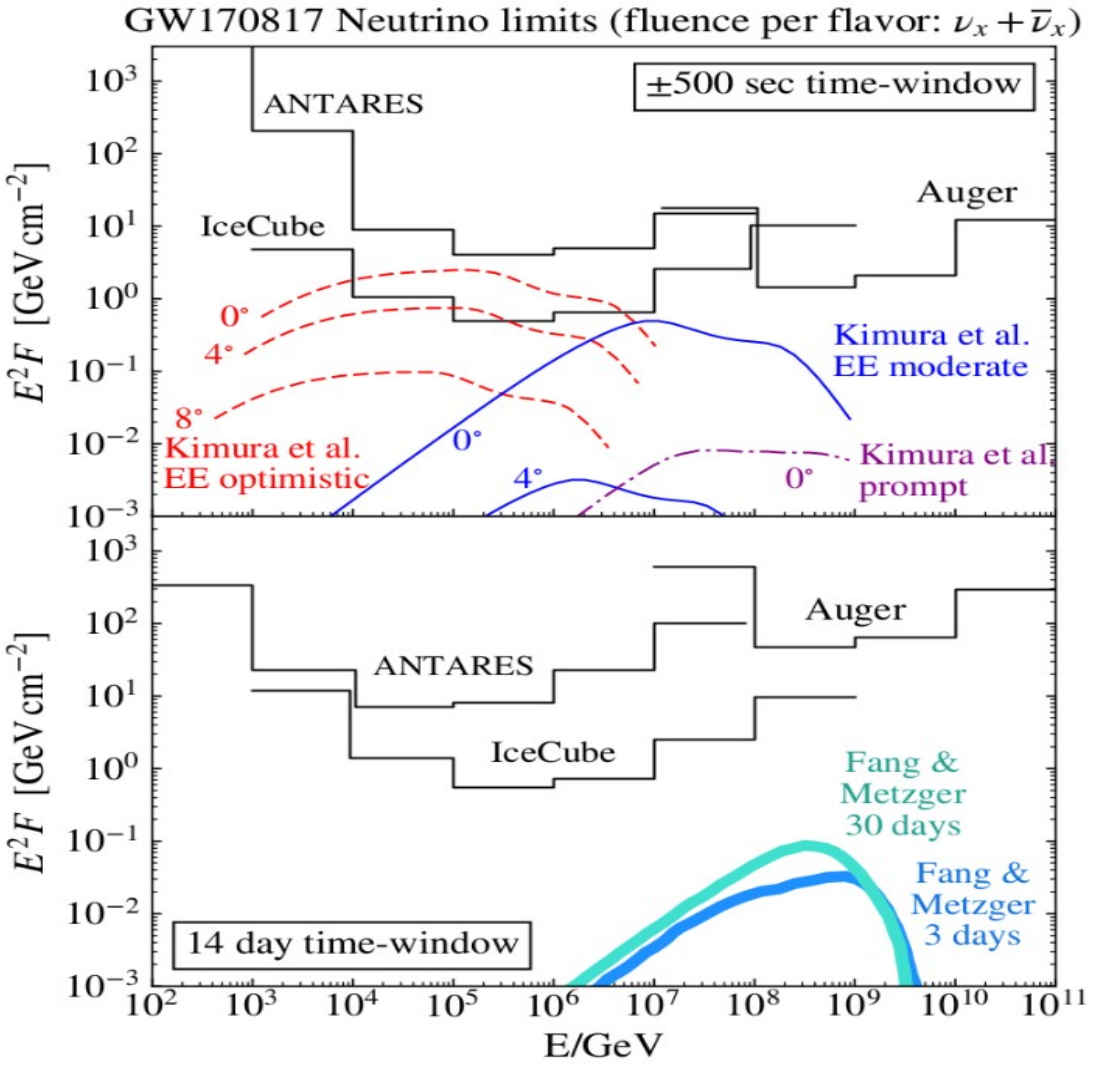
Search for UHE Neutrinos in coincidence with LIGO/Virgo Events

- Default neutrino search inside the 90% C.L. most probable localization region in the sky during a time range from 500 s before until 1 day after the merger
- No candidates have been found
- Figure shows the limits on UHE neutrino fluence as a function of the source declination for GW150914
- Declinations of the 90% C.L. sky localization of the source are highlighted in blue



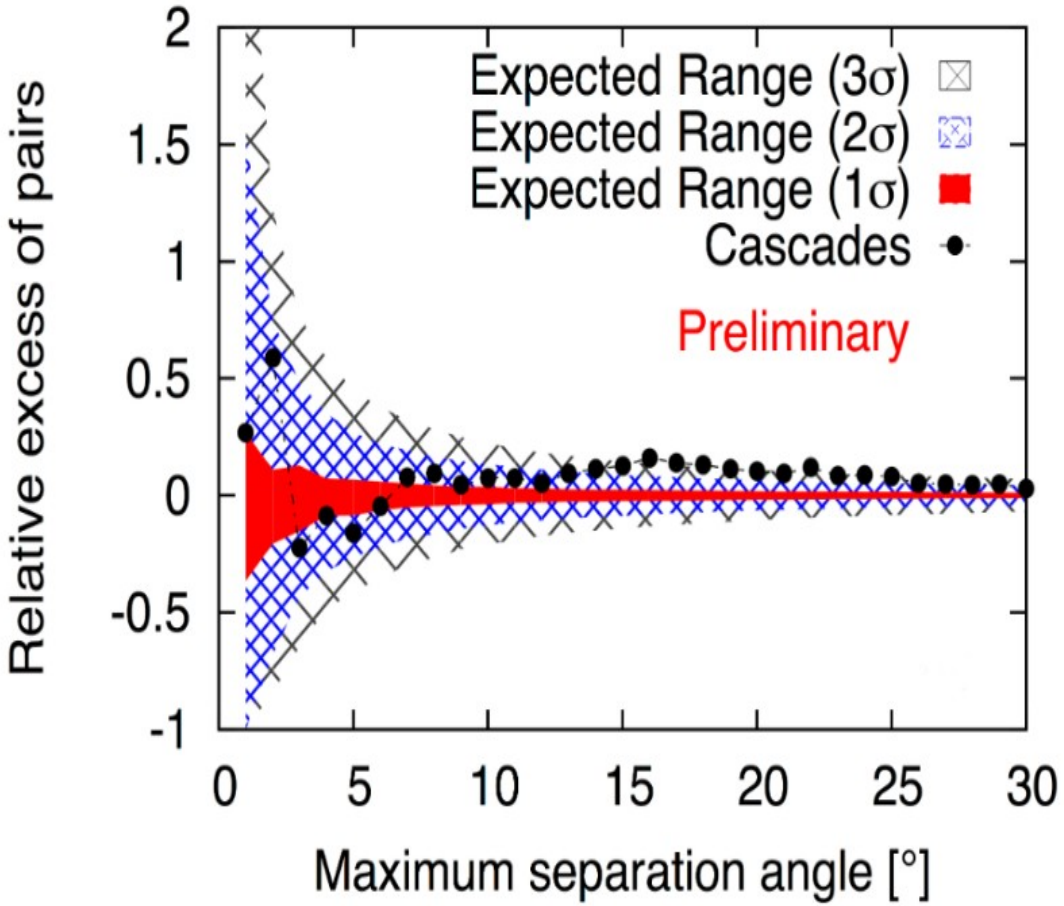
Search for UHE Neutrinos in coincidence with LIGO/Virgo Events

- Follow-up observations of GW170817 yielded signatures of a kilonova caused by a binary neutron star merger at the inferred location of the GW event
- Light curves of the source have been recorded for several weeks
- Therefore (in agreement wih IceCube) the time range for this specific event has been extended to 14 days
- Figure shows the limits on UHE neutrino fluence for ±500s around the merger (top) and 0-14 days time-window after the merger (bottom)



Correlations between UHECR and HE Neutrinos

- UHECRs with E > 50 Eev from both Pierre Auger and Telescope Array observatories and high-energy neutrinos (cascade and track-like events) from IceCube
- Studies with track-like neutrino events yielded no significant results
- A cross-correlation analysis with cascade-like events yielded significant excesses of correlation (the most significant one found for 22°)
- Figure shows the excess of pairs as a function of the maximum angular separation



Search for a flux of UHE Neutrons from the Galaxy

- Many source classes have been used as a combined target sets for neutron searches, such as the Galaxy center and plane as well as known photon source classes (like pulsars and X-ray binaries)
- The searches in the first 9,75 years of data taken by the observatory yielded no significant excess of EASs from the target sets
- 95% confidence level upper limits have been deduced for different target sets
- All these limits already exclude energy fluxes on the level of the measured TeV photon energy flux from the target sets
- This leds to an exclusion of an E^{-2} Fermi-acceleration of protons up to energies of several Eev.

Conclusions

- Even though the Pierre Auger Observatory is designed for the observation of UHECRs many Multi-Messenger studies can be performed
- Since no UHE neutrino events have been found in coincidence with a GW events detected by the LIGO/Virgo collaboration an upper limit on neutrino fluence has been deduced
- No excess in UHECR (from Auger and TA) has been found from a cross-correlation analysis with IceCube track-like UHE neutrino events
- The same analysis shows an excess with cascade-like events for a maximum angular separation of 22°
- Neutron studies show no significant excess for any class of sources

Conclusions

- More details on multi-messenger searches with the Pierre Auger Observatory can be found in
  - Kampert K.H., Mostafa M.A., Zas E. et al., **Multi-messenger Physics With the Pierre Auger Observatory**, Front. Astron. Space Sci. 6 (2019) DOI:10.3389/fspas.2019.00024
- For more details on the GW170817 follow-up
  - ANTARES Collaboration, IceCube Collaboration, The Pierre Auger Collaboration, and LIGO Scientific Collaboration and Virgo Collaboration, **Search for High-energy Neutrinos from Binary Neutron Star Merger GW170817 with ANTARES, IceCube, and the Pierre Auger Observatory**, Astrophys. J. Lett. 850 (2017) L35 DOI:10.3847/2041-8213/aa9aed

Thank you!