Ultra-High Energy neutrinos at the Pierre Auger Observatory

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Outline

• The Pierre Auger Observatory: a brief reminder
• Using the Surface Detector to search for neutrinos above 100 PeV
• Results of data unblinding 01/2004 – 08/2018
• Constraints to the flux of cosmogenic neutrinos

• Auger in the multi-messangers era:
  steady point sources
  transients: follow-up search of BNS merger GW170817
The Pierre Auger Observatory

35.5º S, 69.3º W
1400 m a.s.l.
(880 g cm⁻²)

Surface Detector: 1,660 Water Cherenkov Stations - 3,000 km²
The Pierre Auger Observatory

35.5º S, 69.3º W
1400 m a.s.l. (880 g cm\(^{-2}\))

Surface Detector: 1,660 Water Cherenkov Stations - 3,000 km\(^2\)
Primary goal: **study of UHECRs**

Detection of extensive air showers initiated by primaries in the atmosphere: sampling of shower particles at ground level (Cherenkov radiation in water)

~ 100% duty cycle

Typical energy: \( \text{EeV} = 10^6 \text{ TeV} \)
Searching for neutrinos with and air-shower detector

$\lambda_t \sim 50$ km @ 1 EeV

$\rightarrow$ Down-going (DG) showers: all flavours

$\rightarrow$ Earth-skimming (ES): $\nu_\tau$ only
Zenith $\theta > 60^\circ \rightarrow$ atmospheric depth $> 1700 \text{ g/cm}^2$  

- $p$, Fe: mostly muons $\rightarrow$ short signal  

- Deep $\nu$-induced shower $\rightarrow$ broader signal
Unblinding of data

Jan 2004
start of
data taking

2008
SD completed

Aug 2018

14.7 yr of operation
= 9.7 yr complete SD

Bkg expected: <1 event in 50 years

Data: 1 Jan 2004 - 31 Aug 2018. Mean=1.189, Sigma=0.074
Monte Carlo v: Mean=2.837, Sigma=0.723

(AoP) > 1.83

v-candidate region
~ 95% v-selection efficiency
Unblinding of data

Jan 2004
start of
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2008
SD completed

Aug 2018

14.7 yr of operation
= 9.7 yr complete SD

No neutrino candidate found

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M. Schimp

DGL 60°-75°
DGH 75°-90°
ES 90°-95°

DG split in two channels
to optimize the search
→ different combination of observables
→ same principle

Bkg expected: <1 event in 50 years

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C.Bleve - UHE neutrinos @ Pierre Auger Observatory | 30/06/2020
Energy range and exposure

Sensitivity to $\nu_{\tau}$ is dominant

- For a $E^{-2}$ spectrum (1:1:1)
  - channel relative contribution
    - ES: 21%
    - DG: 79%
  - flavour relative contribution $0.86 : 0.10 : 0.04$
  - 90% of the events in the range $0.1 - 25$ EeV
Where UHE neutrinos come from?

charged cosmic rays deflected by magnetic fields

accelerator
Where UHE neutrinos come from?

charged cosmic rays deflected by magnetic fields

COSMOGENIC FLUX

$E_{th} = 4 \times 10^{19} \text{ eV}$
(or $p \gamma \rightarrow p \pi^0$, no $\nu$)

GZK
Limits to the diffuse flux of UHE neutrinos

Best sensitivity $\sim 1$ EeV

Integral UL for a $k E^{-2}$ spectrum

$k \sim 4.4 \times 10^{-9} \text{ GeV cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$

Pierre Auger Coll., JCAP10 (2019) 022
Heavy constraints on scenarios assuming sources accelerating only $p$ and with strong evolution with $z$

Constraints on proton models → sources evolution $\sim (1+z)^m$ up to $z_{\text{max}}$
Where UHE neutrinos come from?

Photons and neutrinos are not deflected → they point back at the source → UHE photons: limited horizon (local universe) → UHE neutrinos: messengers from sources

Multi-messengers astronomy
Istantaneous effective area

Strong dependence on the zenith angle

For point sources (steady and transient) the capabilities of observation depend on where the source is in the FoV of the SD
Optimal observation position: source in the field of view of the Earth-skimming channel (right below the horizon)
Point-like steady sources (and long transients)

The total exposure depends on the source declination as it defines the fraction of sidereal day spent by the source in each search channel.
Limits to point-like steady sources

→ Good sensitivity in the EeV range in a broad range of declination

→ Maximum sensitivity at declinations $-53^\circ$ and $55^\circ$ (the source spends more time in the Earth-skimming channel)

Pierre Auger Coll., JCAP11 (2019) 004
Searching for UHE neutrinos in coincidence with a GW event: BNS merger GW170817 + short GRB


In the ES channel: sweet spot for Auger detection
Conclusions

- The Surface Detector of the Pierre Auger Observatory can be used as a large area detector for neutrinos at UHE energies (0.1 – 25 EeV)
- Mostly sensitive to tau neutrinos
- Strict limits to the flux of cosmogenic neutrinos

- Auger as key detector in multi-messenger astronomy at UHE energy:
  - Excellent sensitivity to neutrinos in the EeV range
  - Coverage of a large fraction of the sky

More results, including the follow-up search of Ligo/Virgo O1-O3 BBH mergers
THANK YOU

November 2019
Malargue Argentina

Celebration of the (first) 20 years of the Pierre Auger Observatory

THANK YOU