Combined Search for UHE Neutrinos from Binary Black Hole Mergers with the Pierre Auger Observatory

Michael Schimp[1] for the Pierre Auger Collaboration[#]

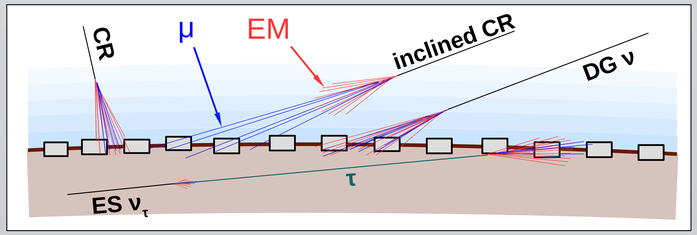
[1]Bergische Universität Wuppertal [#]Full author list at http://www.auger.org/archive/authors_icrc_2021.html or

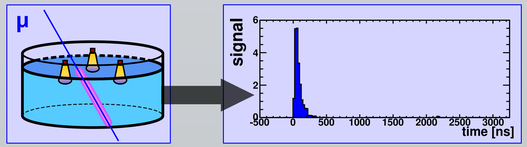
Discussion Zoom Link (Jul 20, 18:00 UTC+2)

Neutrino air showers at Auger [1]

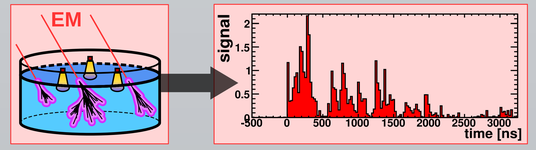
- Classes of ultra-high energy (UHE; > 0.1 EeV) **neutrino** events:
  - **Down-going (DG) all-flavor**
    - Interact **deep in the atmosphere**
      - ➔ Induced air showers (all-flavor NC or $\nu_{e/\tau}$ CC interaction) reach surface with **large electromagnetic (EM) particle fraction**
  - **Earth-skimming (ES) ν_τ**
    - **Interact most likely inside the Earth**, producing τ leptons (CC interaction), inducing air showers when decaying close to the surface
      - ➔ Also **large fractions of EM particles**
- **Highly inclined cosmic-ray (CR)** induced showers have **very small fractions of electromagnetic particles** at the surface

⇒ We search for **inclined showers** (zenith angle > 60°) with **significant electromagnetic components**.



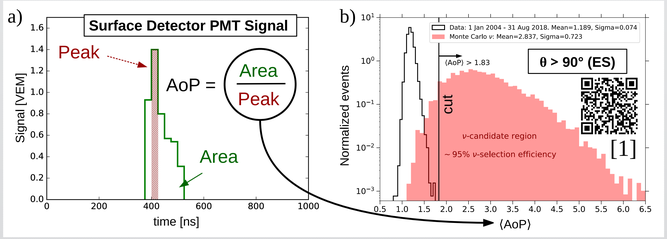


Single particles → short signal

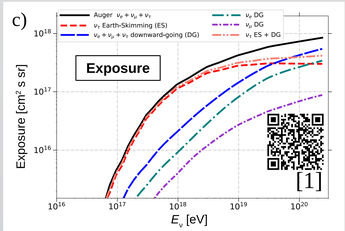


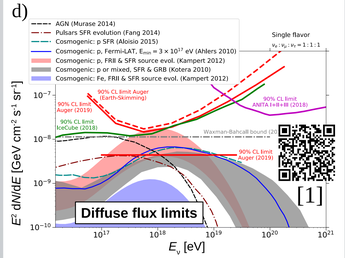
Many cascades → long signal

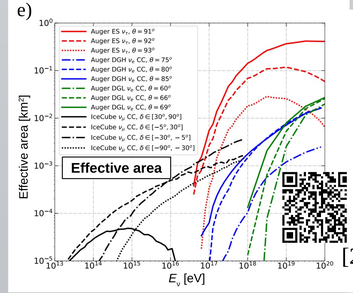
Ultra-high energy neutrino searches [1, 2]

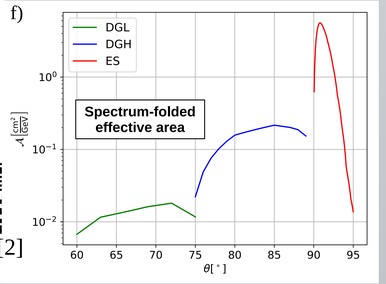


No neutrino candidates in DG and ES searches









a) Area over Peak (AoP) illustration

b) ⟨AoP⟩ distributions of ES neutrinos (MC) and measured data

c) UHE neutrino exposure for different directions and flavors

d) Upper limits on the diffuse flux of UHE neutrinos + model fluxes

e) Effective area for different zenith angles for Auger (colored) and different declinations for IceCube (black)

f) E^{-2}-spectrum-folded effective area:

$$\mathcal{A}(\theta) = \int_0^\infty E_\nu^{-2}\, A_{\mathrm{eff}}(E_\nu, \theta)\, \mathrm{d}E_\nu$$

Combining binary black hole (BBH) mergers and follow-up search for neutrinos

Search properties

- Automatic follow-up search routine
  - 2 search periods: starting at t_0 (time of merger), lasting 1 and 60 days
  - Direction: 90% C.L. most probable localization region (Ω_{90})
- All BBH merger events published by LIGO/Virgo
  - Transient catalogues GWTC-1 (O1+O2) [3], GWTC-2 (O3a) [4]
  - O3b open public alerts [5]
- **No** neutrino candidates found

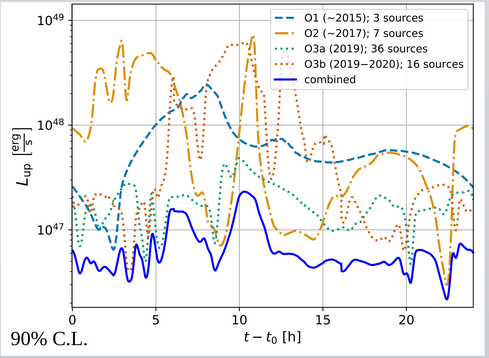
Part of the pixelized directional localization probability $P_{p,s}$ for GW150914

Combined limit on universal source luminosity

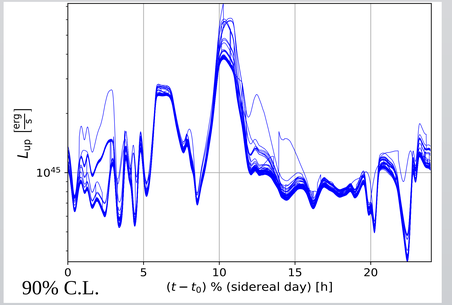
- Assuming E^{-2} spectrum
- Parameters considered **for each source *s***:
  - **Directional** localization probability $P_{p,s}$ in equatorial healpix pixels p
  - Luminosity **distance PDF** for each healpix pixel p: $\Pi_{p,s}$
  - Time-dependent effective area (local zenith angle + time → healpix pixel p)
- Limit formula:

$$L_{\mathrm{up}}(t-t_0) = \frac{N_{\mathrm{up},\nu}}{T}\left(\sum_s \sum_{p\in\Omega_{90}(s)} P_{p,s}\mathcal{A}_{p,s}(t-t_0)\int_0^\infty \frac{\Pi_{p,s}(r)}{r^2}\,\mathrm{d}r\right)^{-1}$$

Animated skymap of this product for an exemplary source in the flash talk



Alternating domination by different sources due to time-dependent visibility

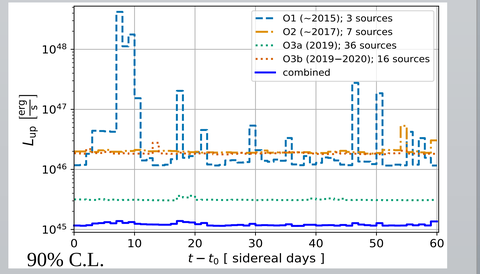


T = 60 d upper limit wrapped around; deviations due to minor changes in SD status

Integral over search period (~duration independent)

→ Upper limit on **total emitted energy** in UHE neutrinos: $\boldsymbol{E_{\mathrm{up}} \sim 6 \cdot 10^{51}\ \mathrm{erg} \sim M_\odot c^2 / 300}$

Typically, BBH mergers emit $> M_\odot c^2$ in gravitational waves [3, 4]



Daily mean luminosity limit

References: [1] JCAP **10**, 022 (2019) [2] JCAP **11**, 004 (2019) [3] Phys. Rev. X **9**, 031040 (2019) [4] arXiv:2010.14527 [5] GCNs 26245, 26202, 26383, 26334, 26518, 26570, 26572, 26715, 26906, 26926, 27036, 27214, 27262, 27229, 27292, 27382