Multimessenger particles: Ultra High Energy Cosmic Rays and Neutrinos

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thanks to Pierre Auger, Telescope Array and IceCube collaborations

IAP

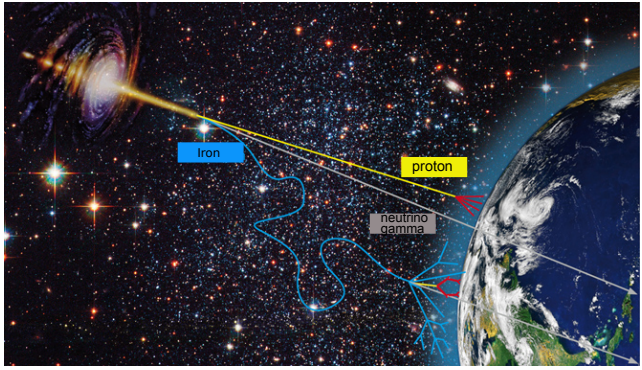
21 December 2017, Brussels

Ultra High Energy Cosmic Rays and Neutrinos

Which are the sources?

How are accelerated?

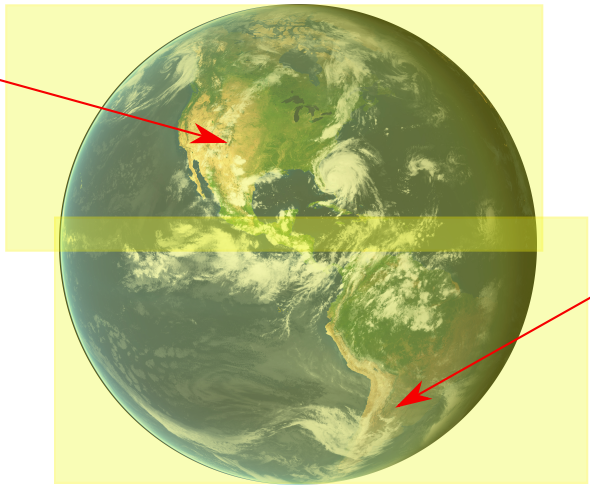
New fundamental physics?



- UHECRs: Charged and deflected in magnetic fields, probe the nearby Universe at 10^{20} eV
- Neutrinos: Straight path and no energy losses, probe the entire Universe

UHECRs with full sky coverage and complementary techniques

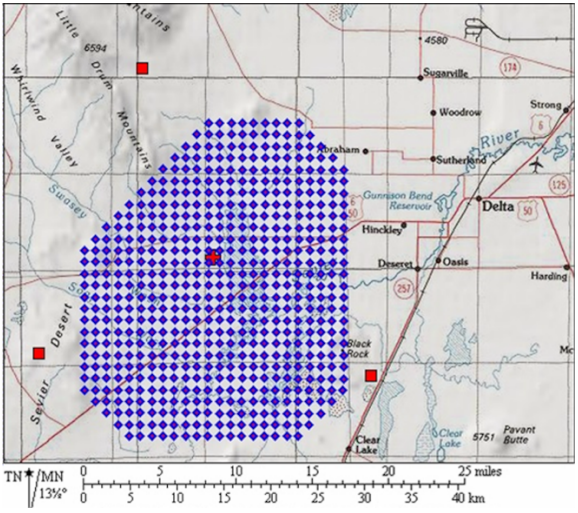
Telescope Array
Delta, Utah, USA



Pierre Auger Observatory
Province of Mendoza,
Argentina

Combining the data from the two largest observatories.

Telescope Array

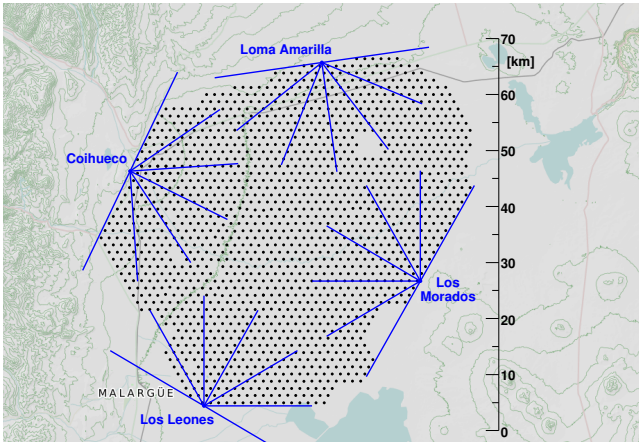


680 km^2(507 scintillators), 36 telescopes

Fluorescence telescopes

Surface detectors

Pierre Auger Observatory

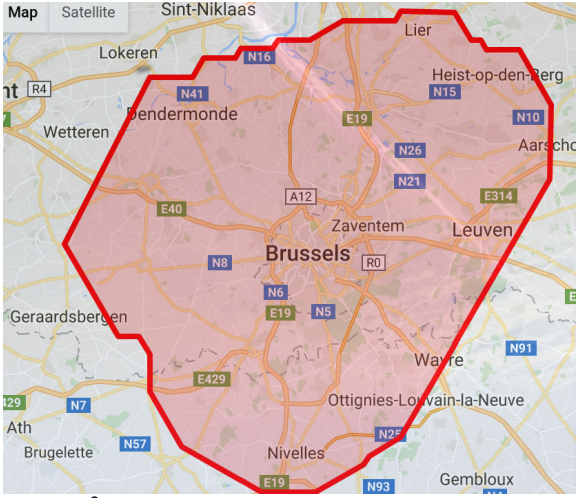


Fluorescence Telescopes

Surface detectors

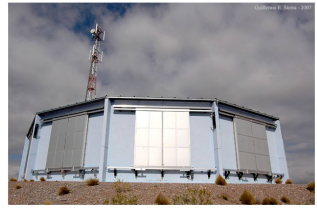
3000 km^2 (1660 water Cherenkov detectors), 27 telescopes

Pierre Auger Observatory



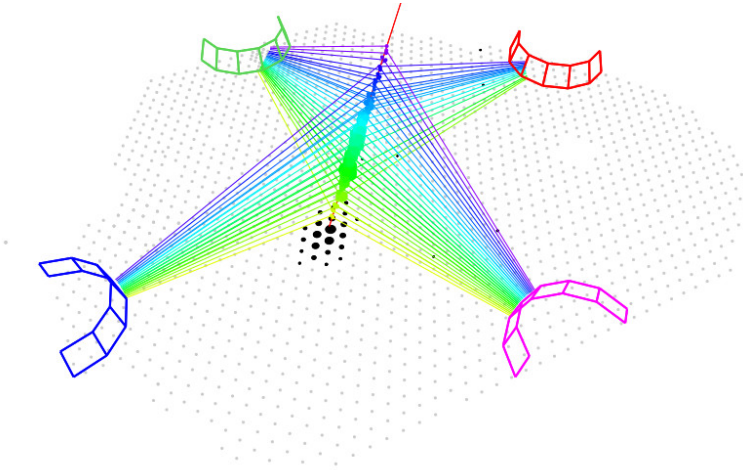
3000 km^2 (1660 water Cherenkov detectors), 27 telescopes

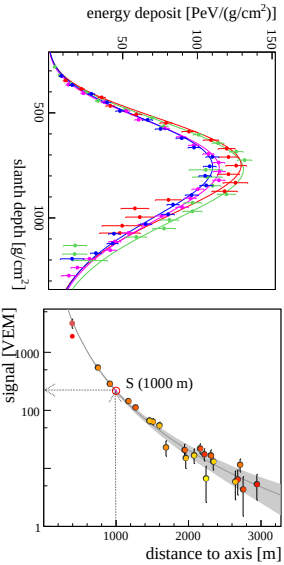
Fluorescence Telescopes



Surface detectors

Indirect measurements of UHECRs via the air-showers

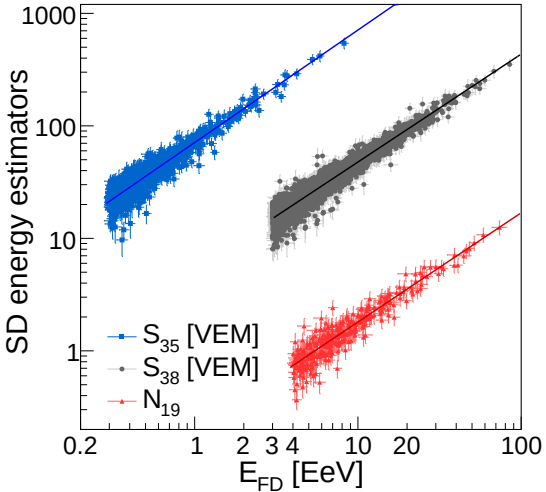


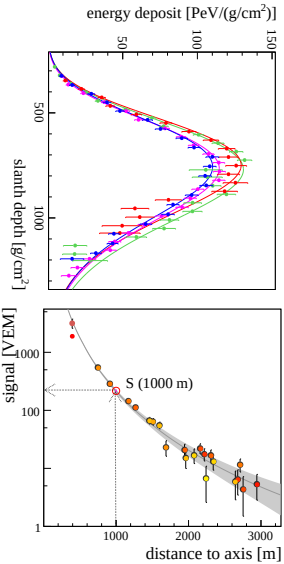


$E_{FD} = \int dE/dX +$ invisible energy correction, $\sigma_E \approx 8\%$, $\sigma_{sys} \approx 15\%$

$E_{SD} = f(\theta, S1000)$, $\sigma_E \approx 10\%@10EeV$

Indirect measurements of UHECRs via the air-showers





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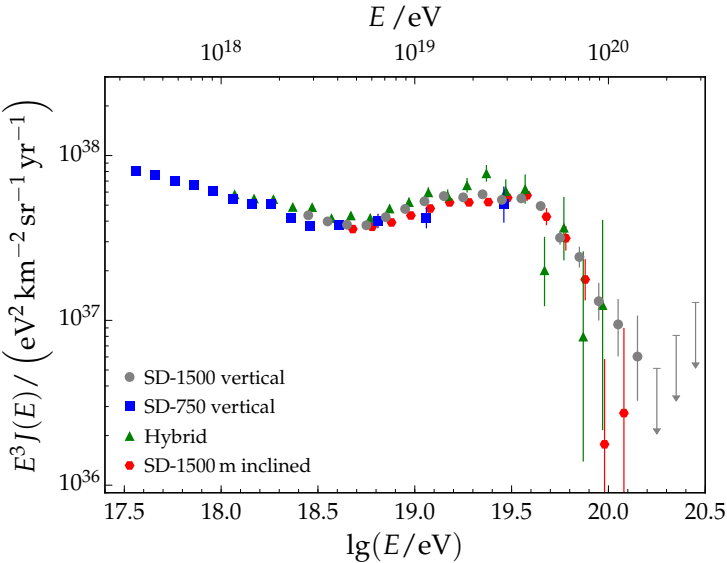
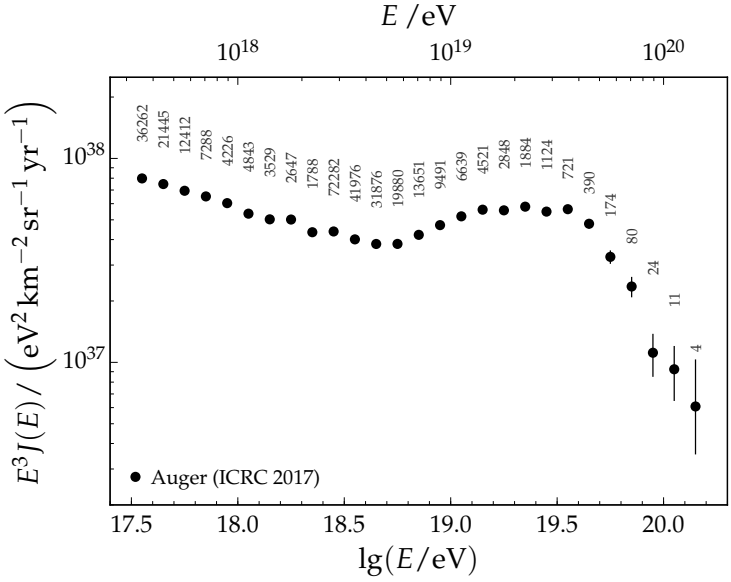
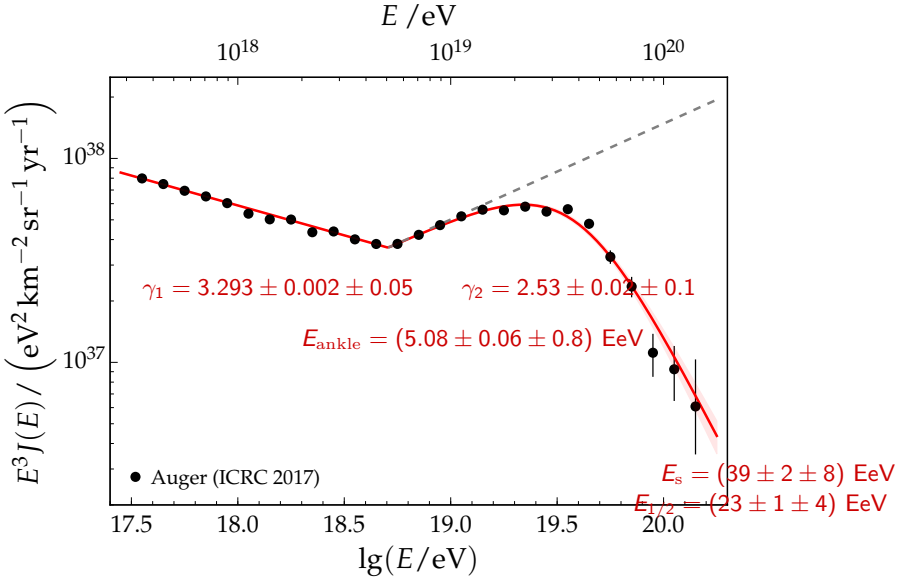
Energy spectrum



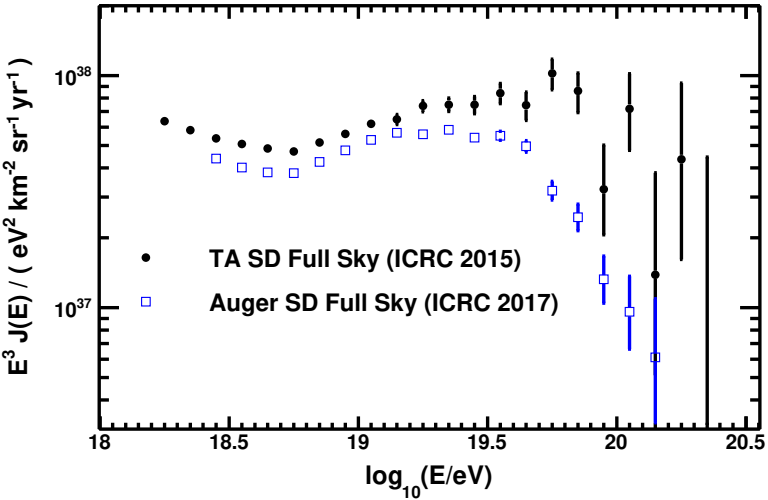
Combined energy spectrum



Combined energy spectrum

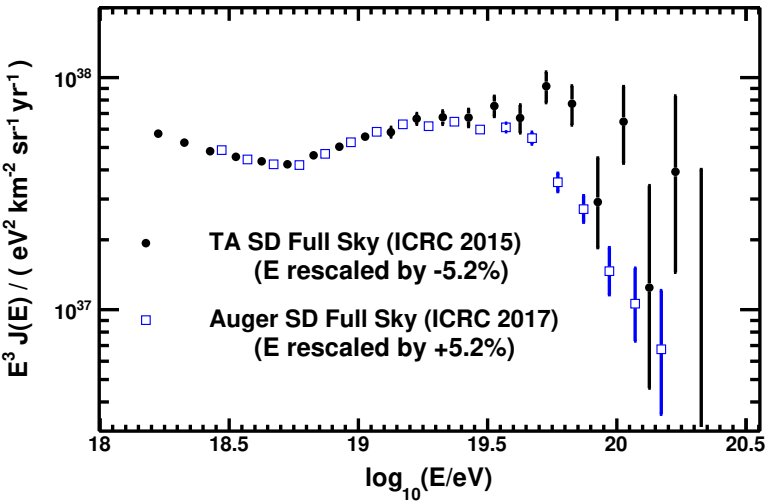


Comparison with Telescope Array



TA-Auger energy spectrum working group

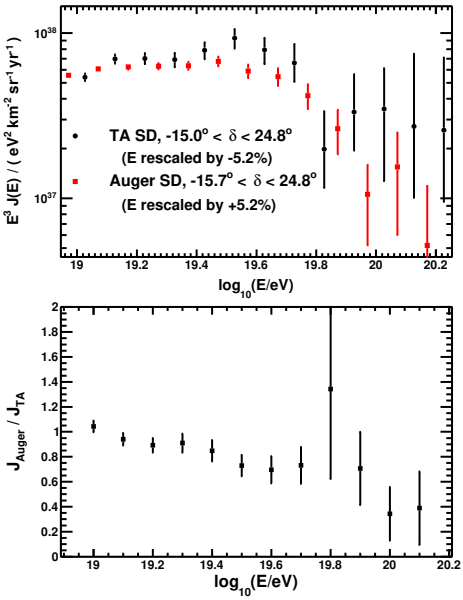
Comparison with Telescope Array

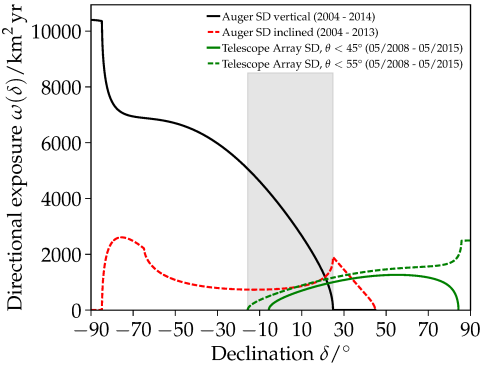


TA-Auger energy spectrum working group

$\Rightarrow$ difference above 40 EeV (caused by different sky coverages?)

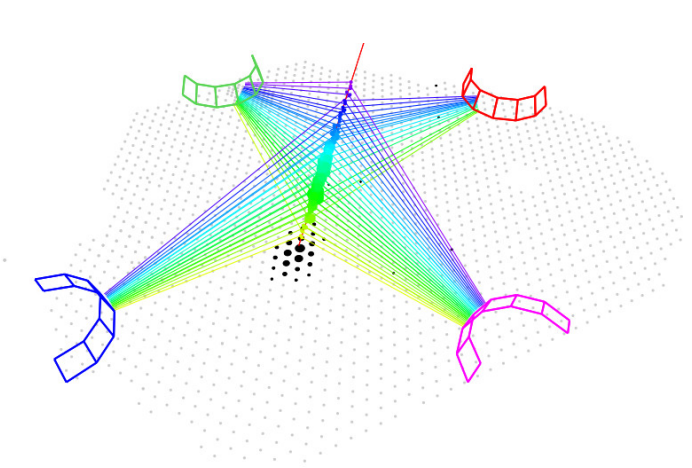
Looking at the same part of the sky

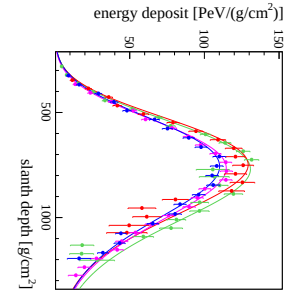


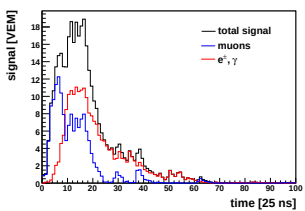


→ slightly better agreement, but an energy dependent difference still present

Sensitivity to mass composition with FD and SD



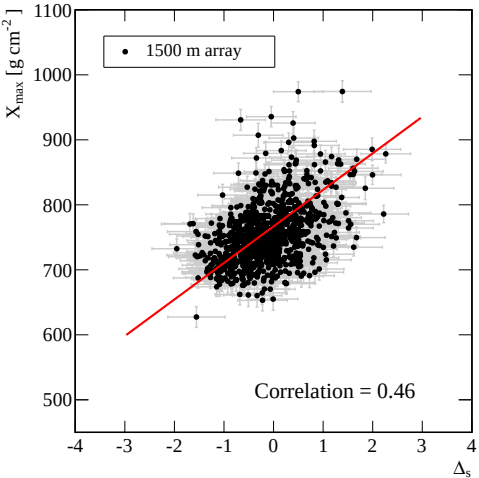


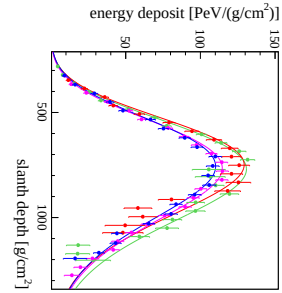


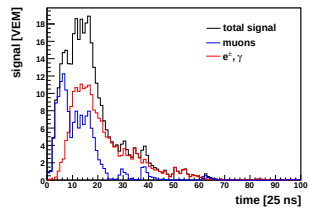
X_{max}: depth of the maximum of the air-shower development

Δ_S: evolution of the signal with time, related to the risetime

Sensitivity to mass composition with FD and SD







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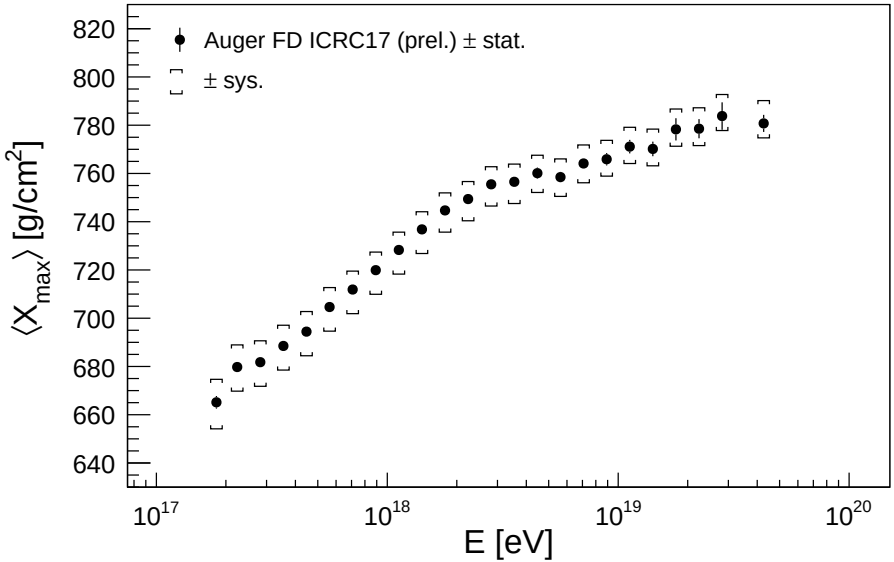
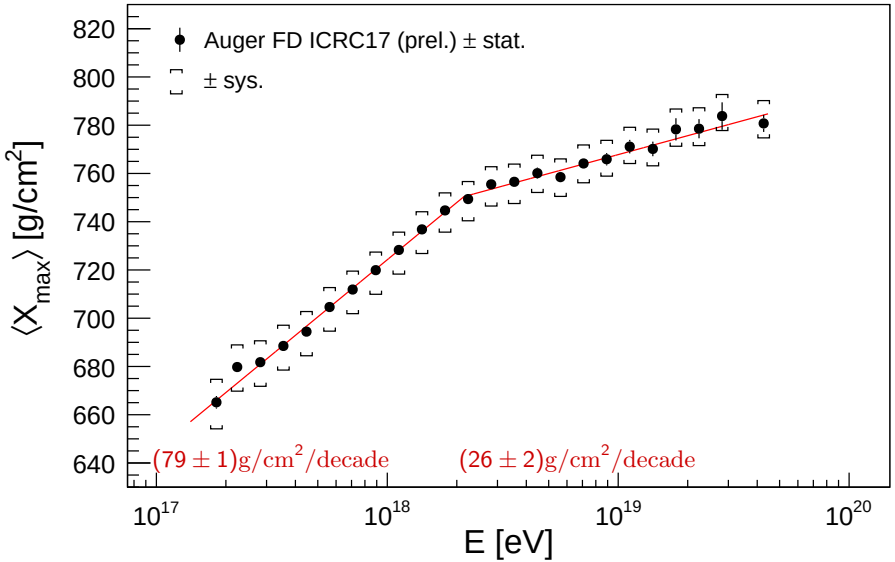
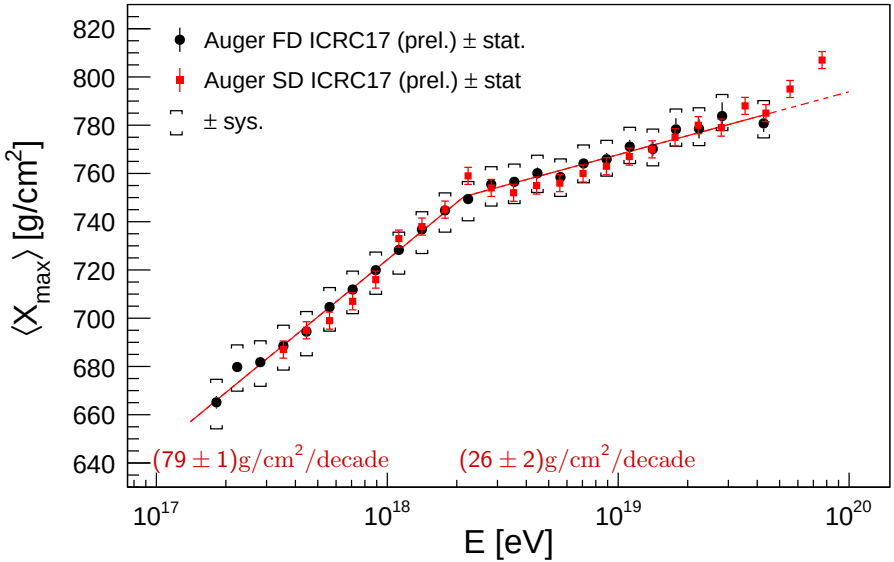
Average X_{max} with Fluorescence Detector



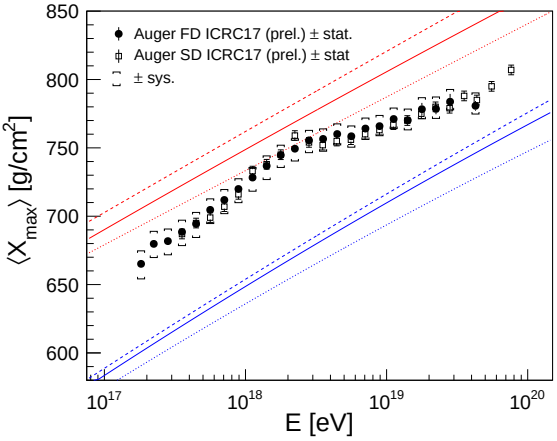
Average X_{max} with Fluorescence Detector

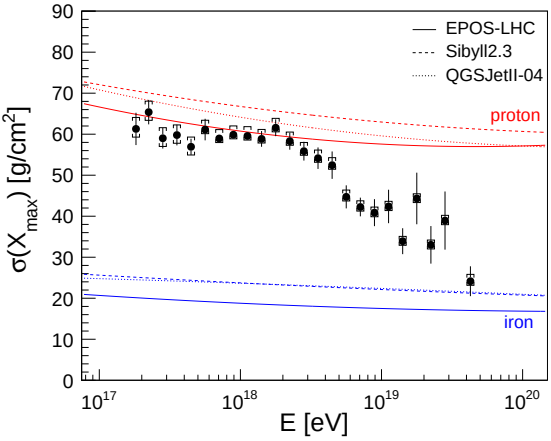


Average X_{max} with Fluorescence and Surface Detector



Average $X_{\max}$ and $X_{\max}$-fluctuations



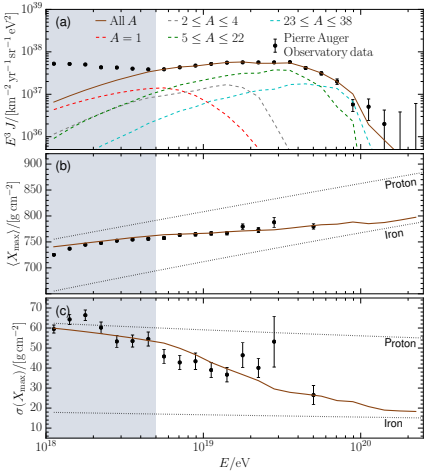


lines: simulations using post-LHC hadronic interaction models

Mass composition at sources

rigidity-dependent cutoff at source: $E_{\rm max} = R_{\rm cut}\, Z$, power law injection $E^{-\gamma}$

no EGMF



Source properties	4D with EGMF	4D no EGMF	1D no EGMF
γ	1.61	0.61	0.87
$\log_{10}(R_{\rm cut}/\mathrm{eV})$	18.88	18.48	18.62
$f_{\rm H}$	3 %	11 %	0 %
$f_{\rm He}$	2 %	14 %	0 %
$f_{\rm N}$	74 %	68 %	88 %
$f_{\rm Si}$	21 %	7 %	12 %
$f_{\rm Fe}$	0 %	0 %	0 %

Suppression of the flux dominated by max. injection energy

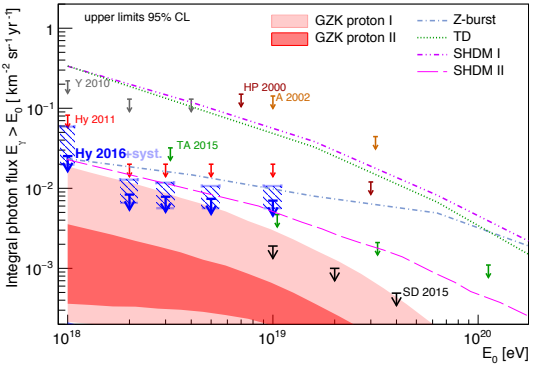
Very hard index of power law at injection

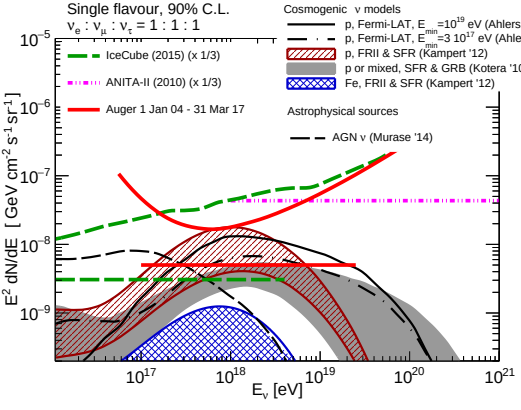
Mainly primaries of the CNO and Si group injected, no Fe, very little p (spallation)

Searches for cosmogenic photons and neutrinos

$$p + \gamma_{CMB} \rightarrow p + \pi^0 \searrow \gamma\gamma$$

$$p + \gamma_{CMB} \rightarrow n + \pi^+ \searrow e^+ + 3\nu$$



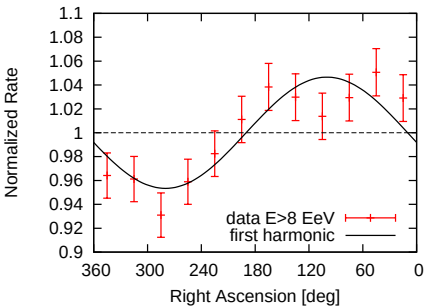


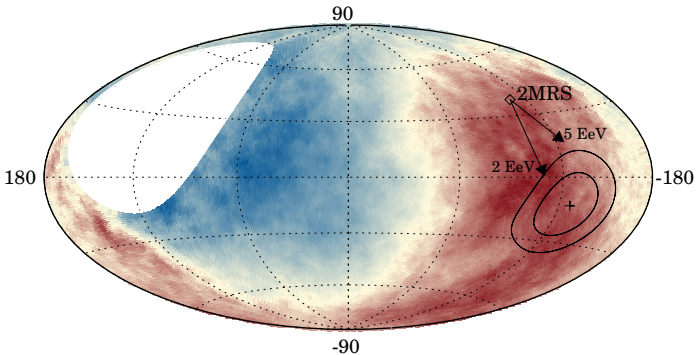
Current limits start reaching the GZK expectations

Large-scale anisotropy

Harmonic analysis in right ascension α

Significant dipolar modulation (5.2σ) above 8 EeV: $(6.5^{+1.3}_{-0.9})\%$ at $(\alpha, \delta) = (100^\circ, -24^\circ)$



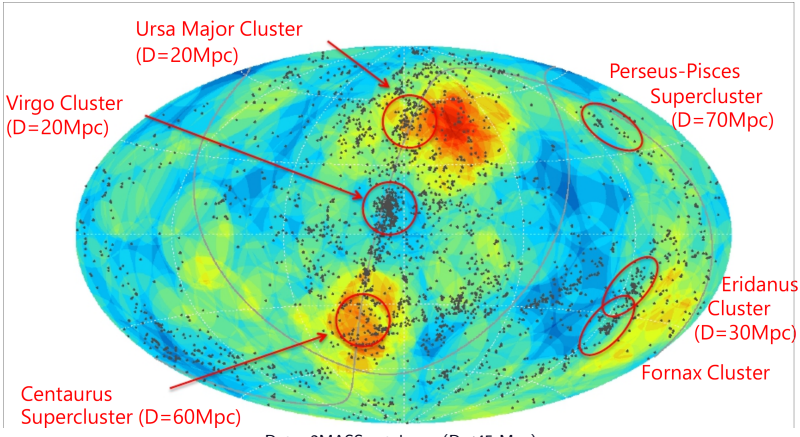


→ Expected if cosmic rays diffuse in Galaxy from sources distributed similar to near-by galaxies

→ Strong indication for extragalactic origin

physics world TOP 10 BREAKTHROUGH 2017

Hot/warm spots with combined data (about 3σ)



Dots: 2MASS catalogue (D<45 Mpc)

Naive superposition of the highest energy data!

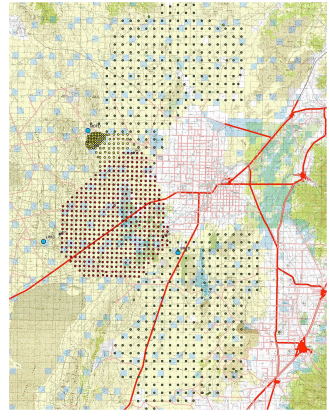
AugerPrime

Water Cherenkov detectors with $4m^2$ scintillators

Enhance the sensitivity of the surface detectors

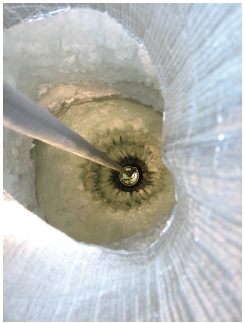
Telescope Array x 4

Increase the surface detector by a factor 4!

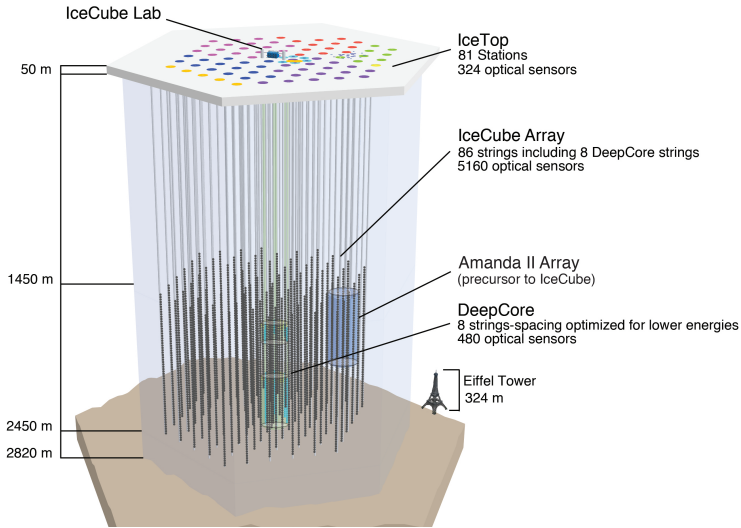


Mass composition with surface detectors (AugerPrime) and increased statistics

IceCube neutrino observatory

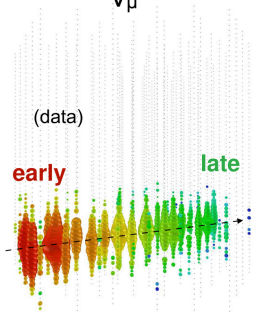


Full operation since 2011



Types of neutrino events

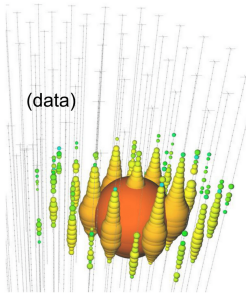
Charged-current ν_μ



Up-going track

Factor of ~2 energy resolution
< 1 degree angular resolution

Neutral-current / ν_e

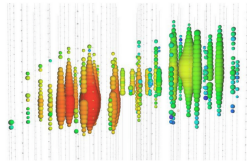


Isolated energy deposition (cascade) with no track

15% deposited energy resolution
10 degree angular resolution
(above 100 TeV)

Charged-current ν_τ

(simulation)



Double cascade

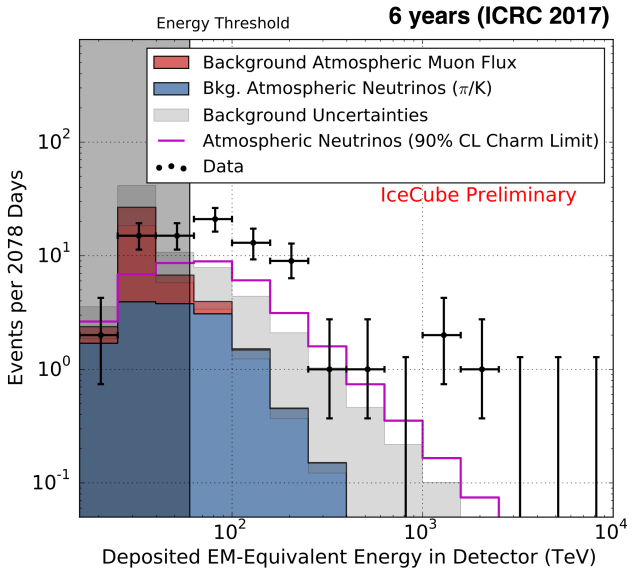
(resolvable above ~100 TeV deposited energy)

Astrophysical neutrinos

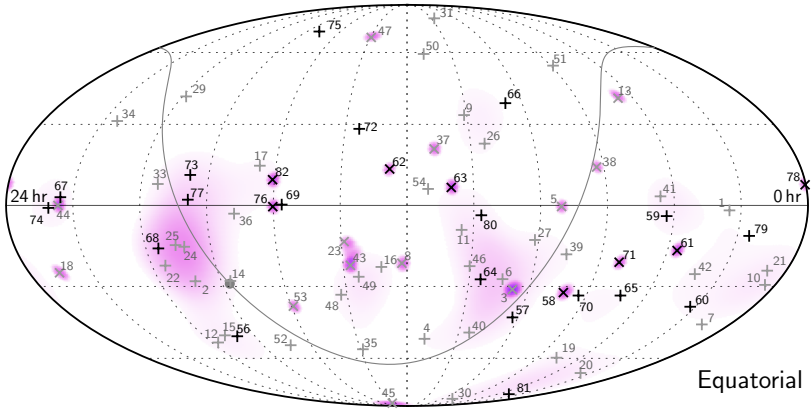
82 events
(expected background $15.6^{+11.4}_{-3.9}$)

energy $> 30\,\mathrm{TeV}$

spectral index: $2.92^{+0.33}_{-0.29}$

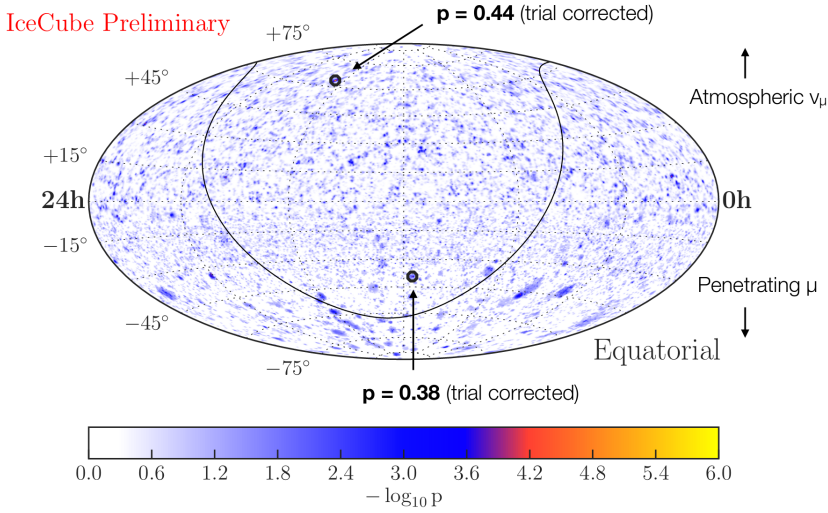


Point sources: clustering of astrophysical neutrinos?



No evidence of clustering in the directions of high-energy neutrinos

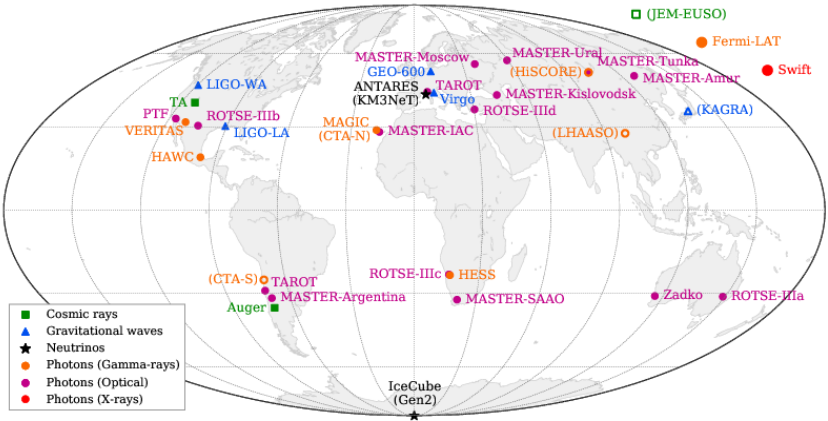
Point sources: clustering of astrophysical neutrinos?



Lowering the required energy still no significant clustering

Realtime alerts and transient sources

- Astrophysical Multimessenger Observatory Network (AMON) and Gamma-ray Coordination Network (GCN)
- Understand the Universe with photons, neutrinos, UHECRs and gravitational waves
- Principle: seen something interesting $\rightarrow$ alert fast the community



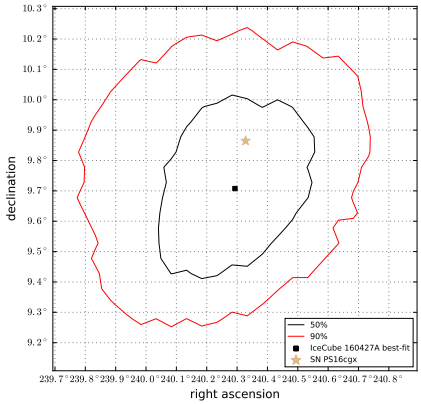
Neutrinos and gamma rays

Supernova PS16cgx descovery triggered by a high energy neutrino

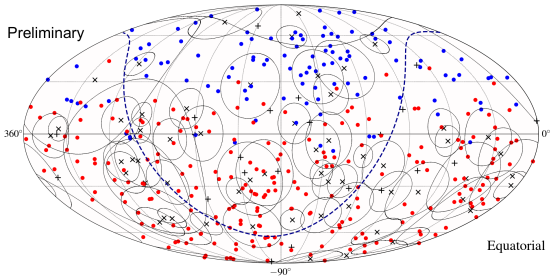
PAN-Starrs followed up IceCube HESE alert on 2016-04-27 and found a recent supernova at z=0.3

GEMINI: Optical spectroscopy

Chance probability: $< 1\%$ if Ic
$< 10\%$ if Ia

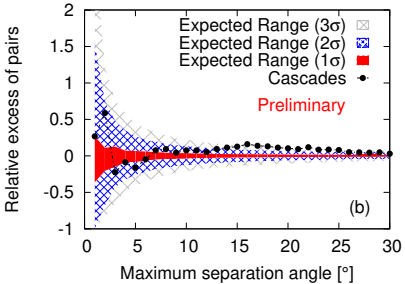


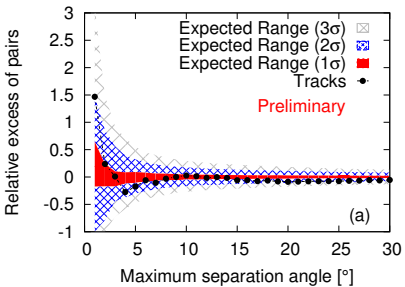
Neutrinos and UHECRs



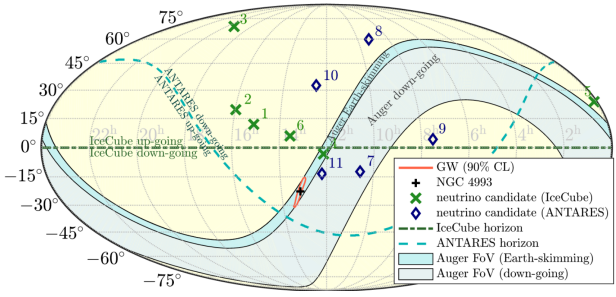
Auger (231 events) TA (109 events) IceCube(58+ 49 events)

No significant correlation ($< 3\sigma$)

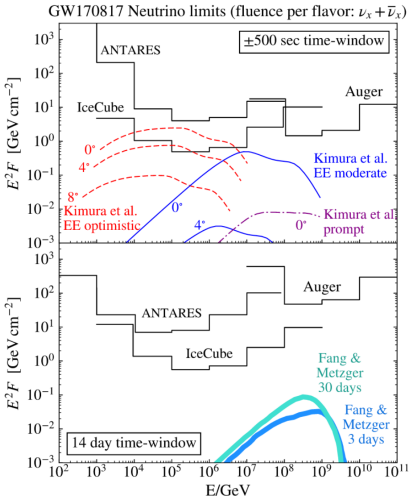




Multimessenger astronomy: GW, gamma rays and neutrinos



GW170817 about 40 Mpc away (NCG4993)



UHECRs and neutrinos: plans and future

Heading towards particle astronomy

- Important Belgian contribution in the multimessenger astrophysics (phenomenology and experimental)
- Ultra High Energy Cosmic Rays: towards mass composition and high statistics (AugerPrime, TA upgrade)
- Neutrinos: increase the statistics of high energy neutrinos (IceCube-Gen2)

APPEC:" To improve understanding of our Universe, APPEC identified as a very high priority those research infrastructures that exploit all confirmed high-energy messengers (cosmic particles that can provide vital insights into the Universe and how it functions). These messengers include gamma rays, neutrinos, cosmic rays and gravitational waves. "