photo: Coihueco © *Steven Saffi 2016*

Multimessenger studies with the Pierre Auger Observatory

Foteini Oikonomou

HAP Monitoring workshop-7/12/2016

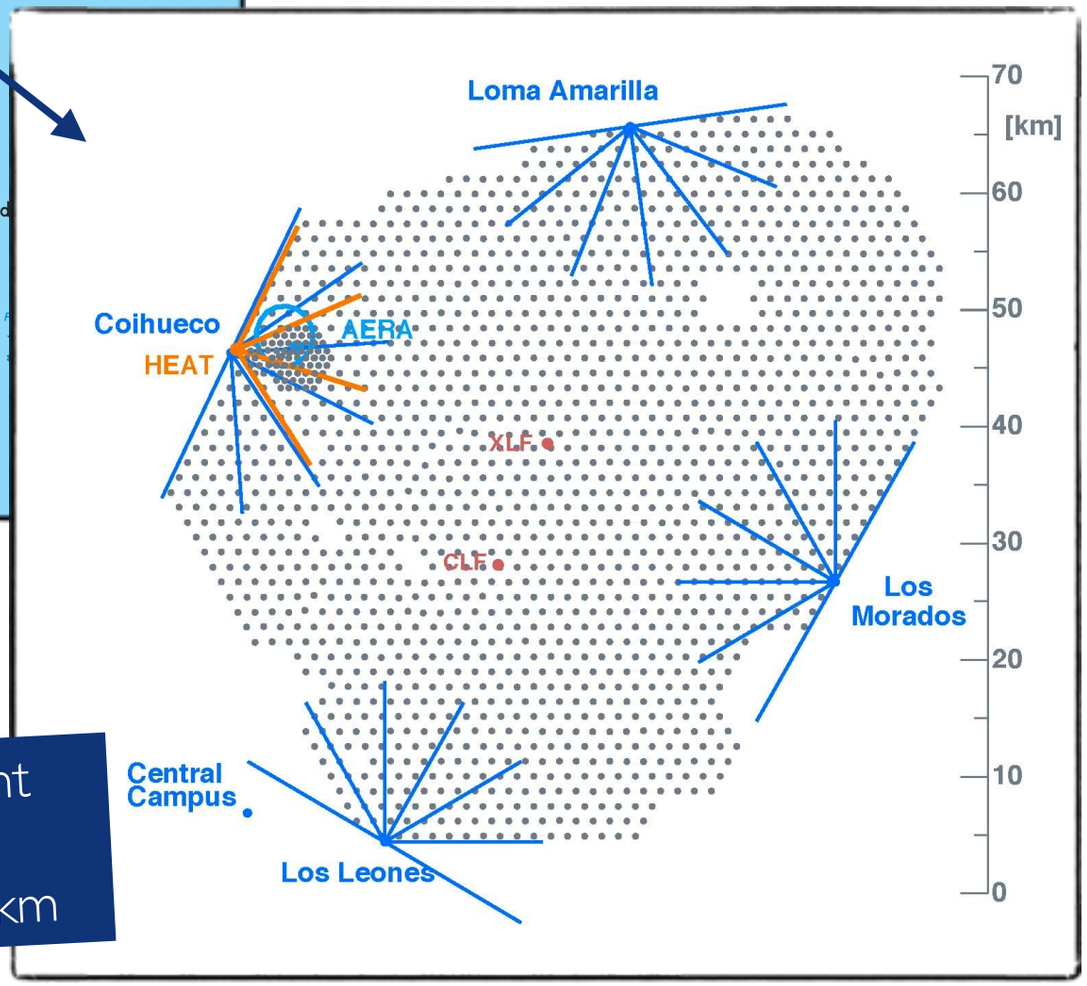
PIERRE AUGER OBSERVATORY

PennState Eberly College of Science

The Pierre Auger Observatory

The Pierre Auger Observatory

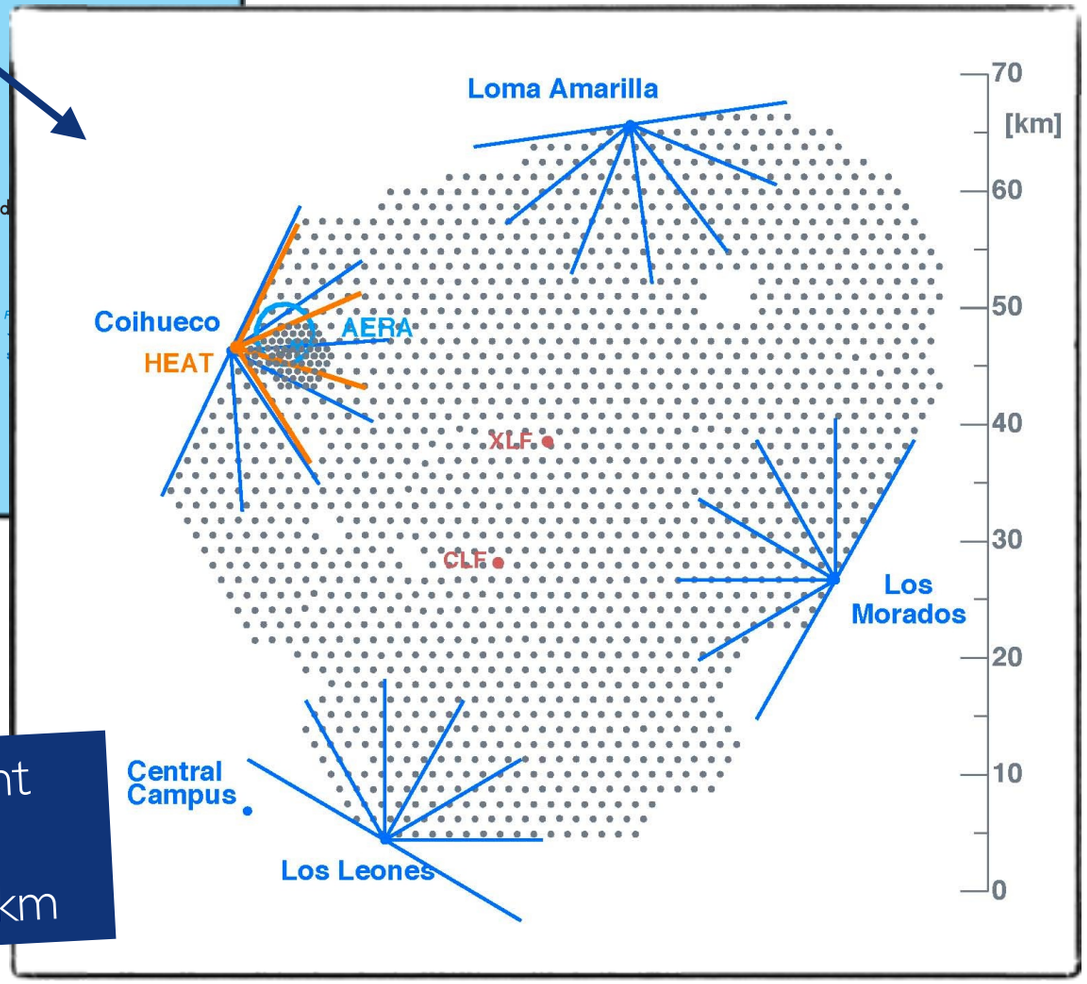
3000 km^2 in Mendoza



Array fully efficient
E > 3 EeV
SD spacing ~ 1.5 km

The Pierre Auger Observatory

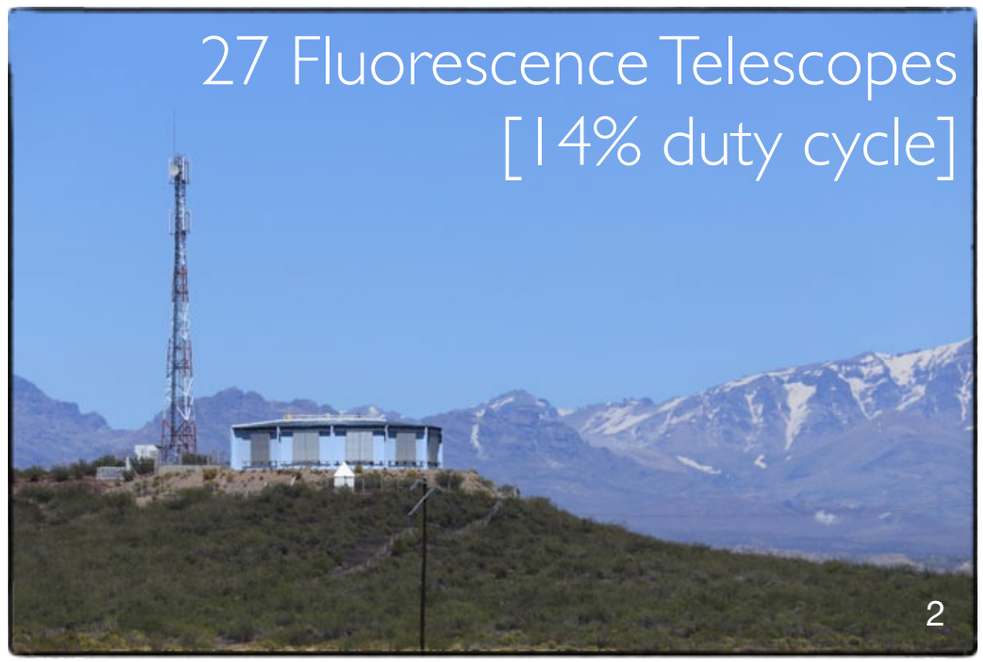
3000 km^2 in Mendoza



Array fully efficient
E > 3 EeV
SD spacing ~ 1.5 km

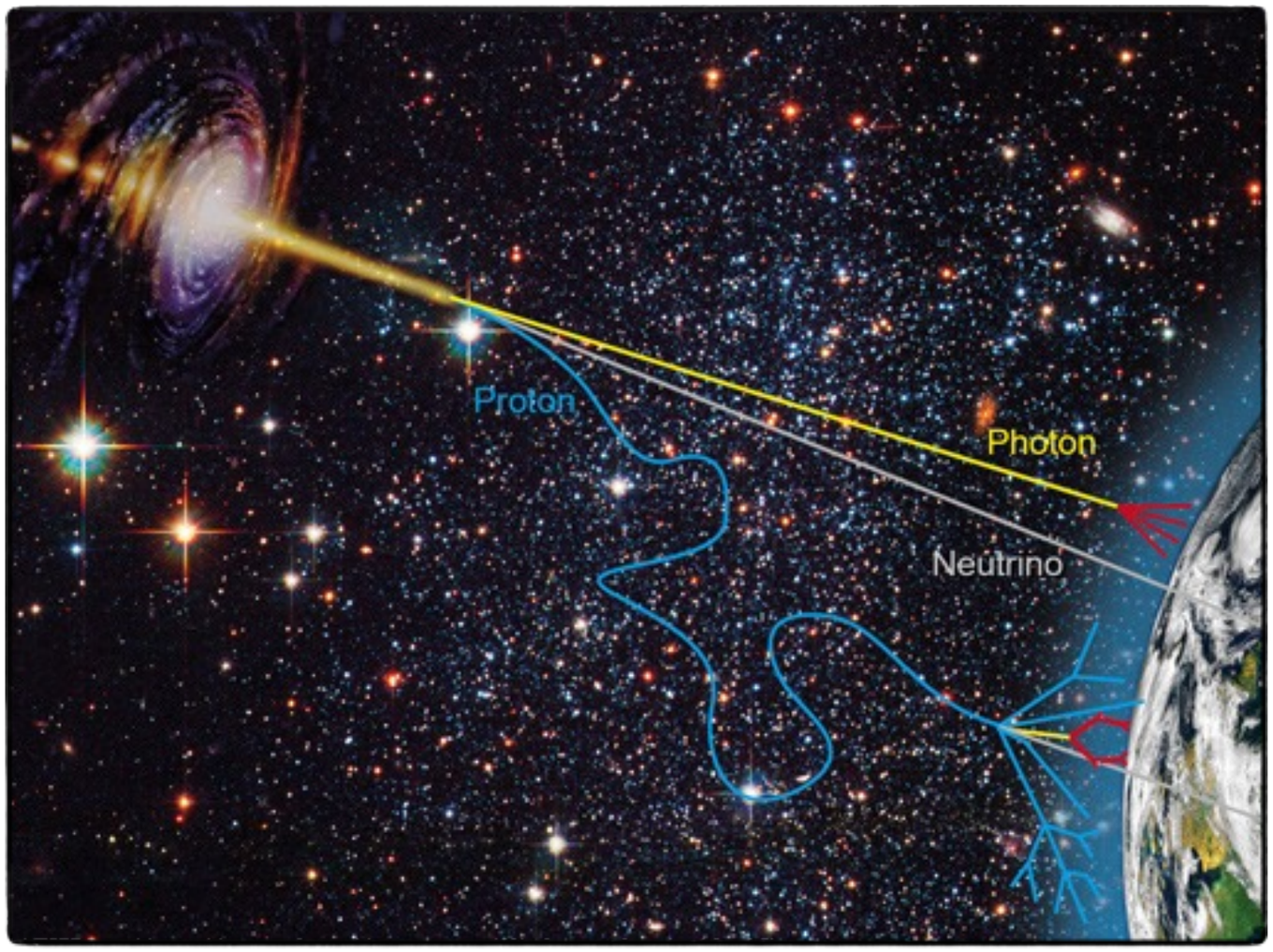
1660 Cherenkov tanks
[100% duty cycle]

27 Fluorescence Telescopes
[14% duty cycle]



Photographs ©Steven Saffi

Auger data of interest to multi-messenger monitoring



UHE neutrals guaranteed by UHECR observations:

$p + \gamma_{CMB/source} \longrightarrow n + \pi^{+}$

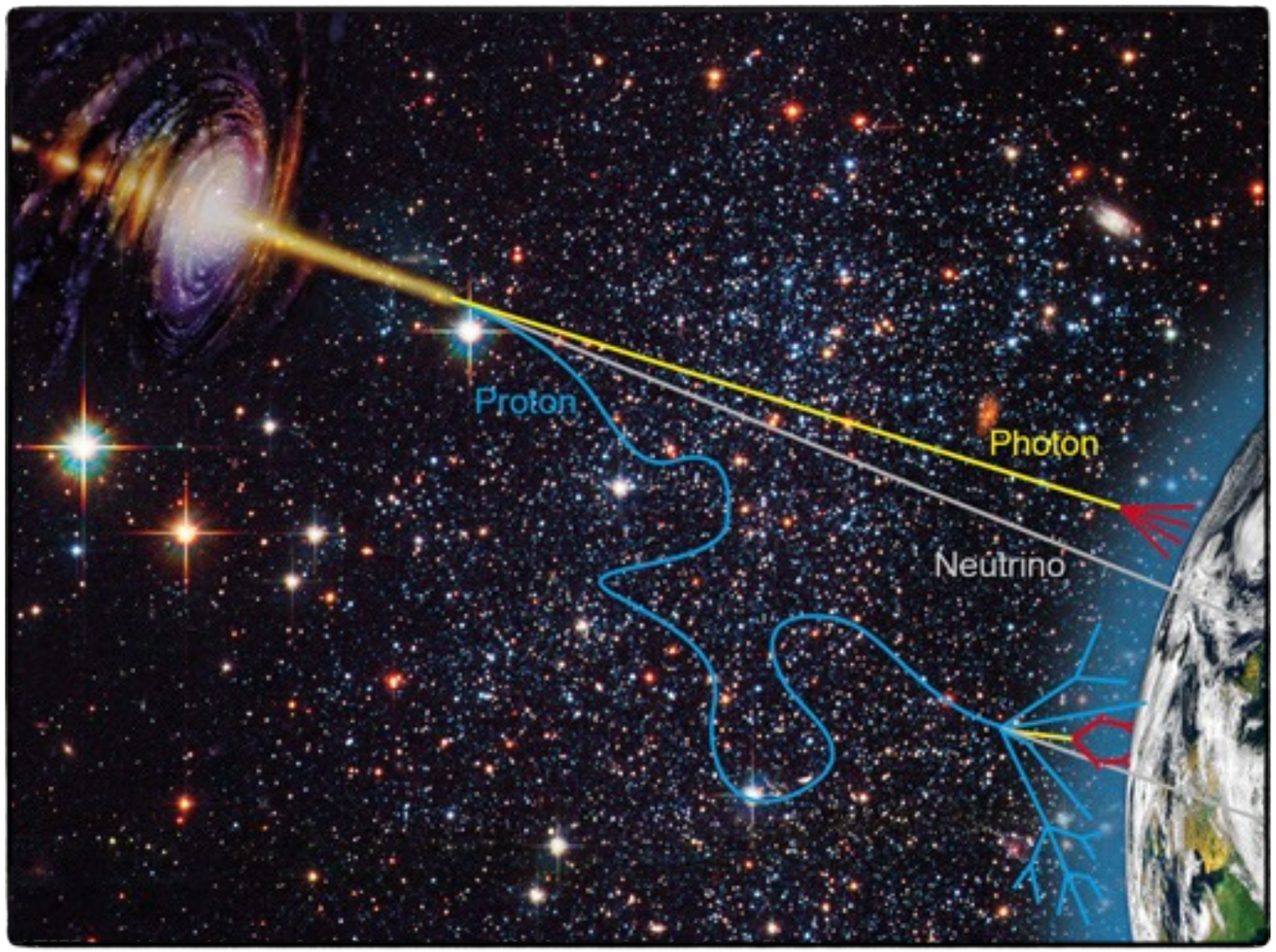
$n + \gamma_{CMB/source} \longrightarrow p + \pi^{0}$

$\hookrightarrow \gamma\gamma$

$n + \gamma_{CMB/source} \longrightarrow p + \pi^{+/-}$

$\hookrightarrow e^{+} + e^{-} + \nu\nu$

Auger data of interest to multi-messenger monitoring



- ☒ UHE charged hadrons
  (magnetic deflections/delays)
- ☑ UHE photons
- ☑ UHE neutrons
- ☑ UHE neutrinos

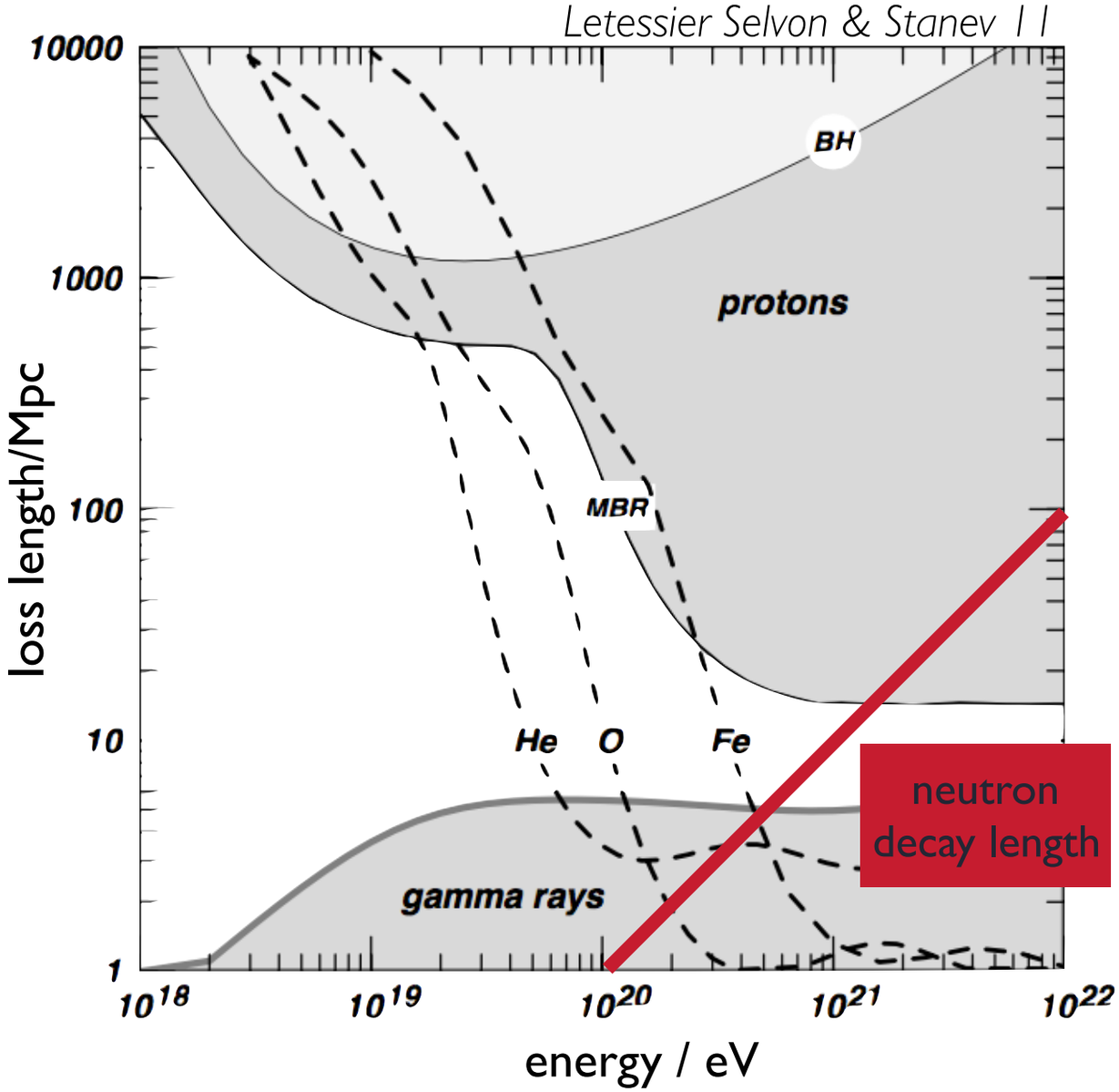
UHE neutrons

Can they reach us?

$L_n \sim c \cdot \tau_n \cdot \gamma_n \sim 9\ (E_n/1\ \mathrm{EeV})$ kpc

[c.f. Milky Way radius ~ 8 kpc]

Yes!!
Galactic
E > 1 EeV neutrons



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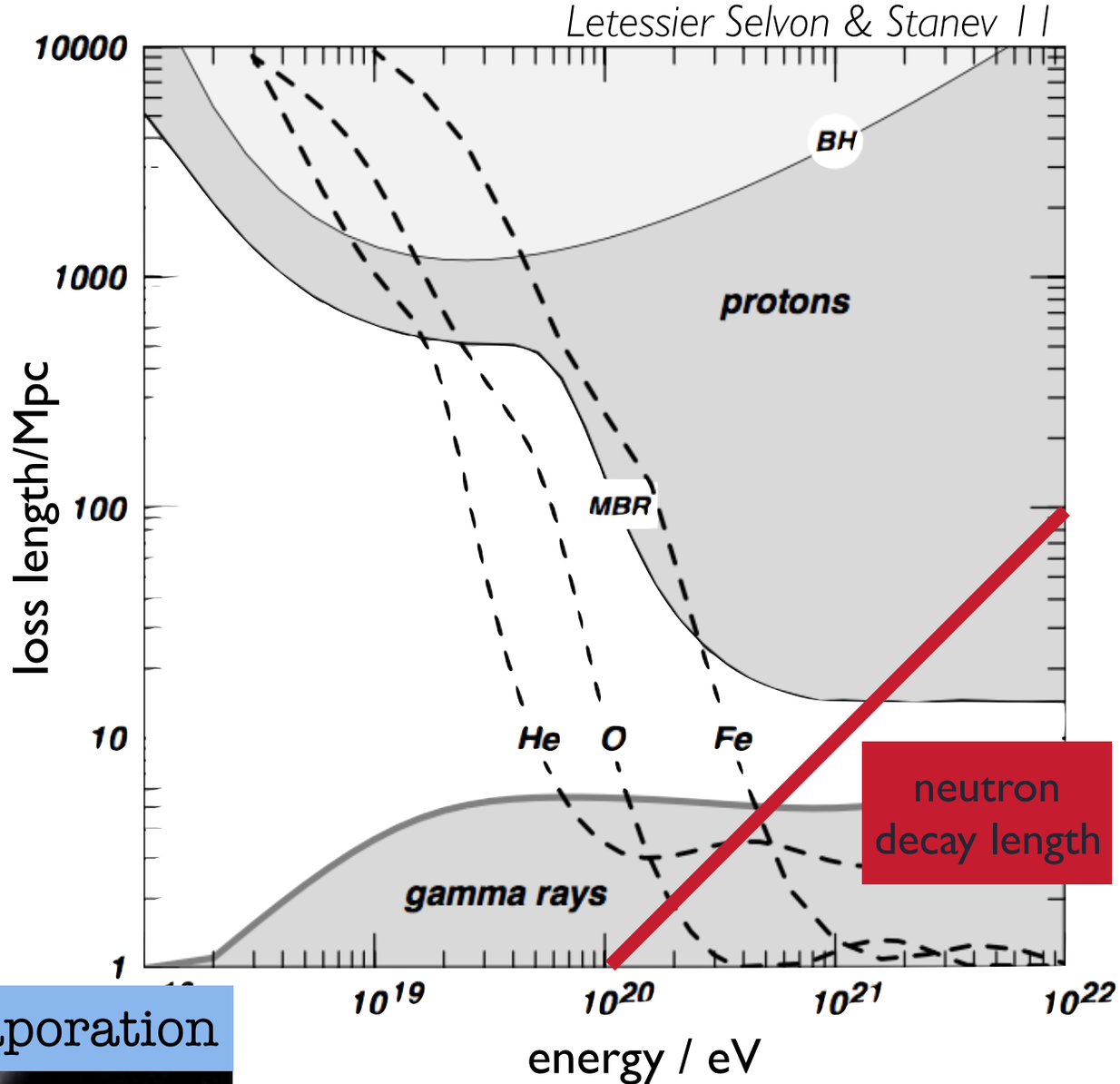
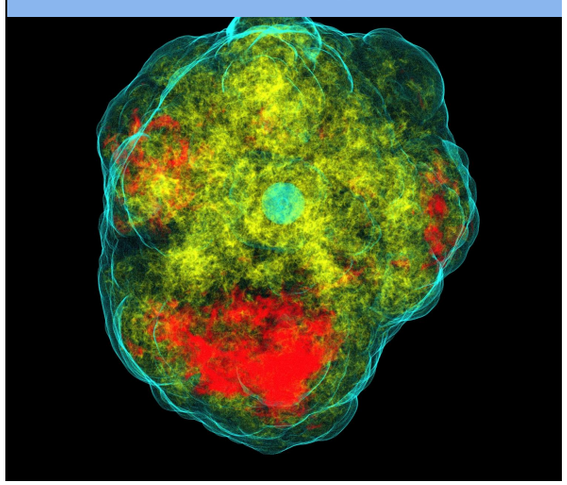


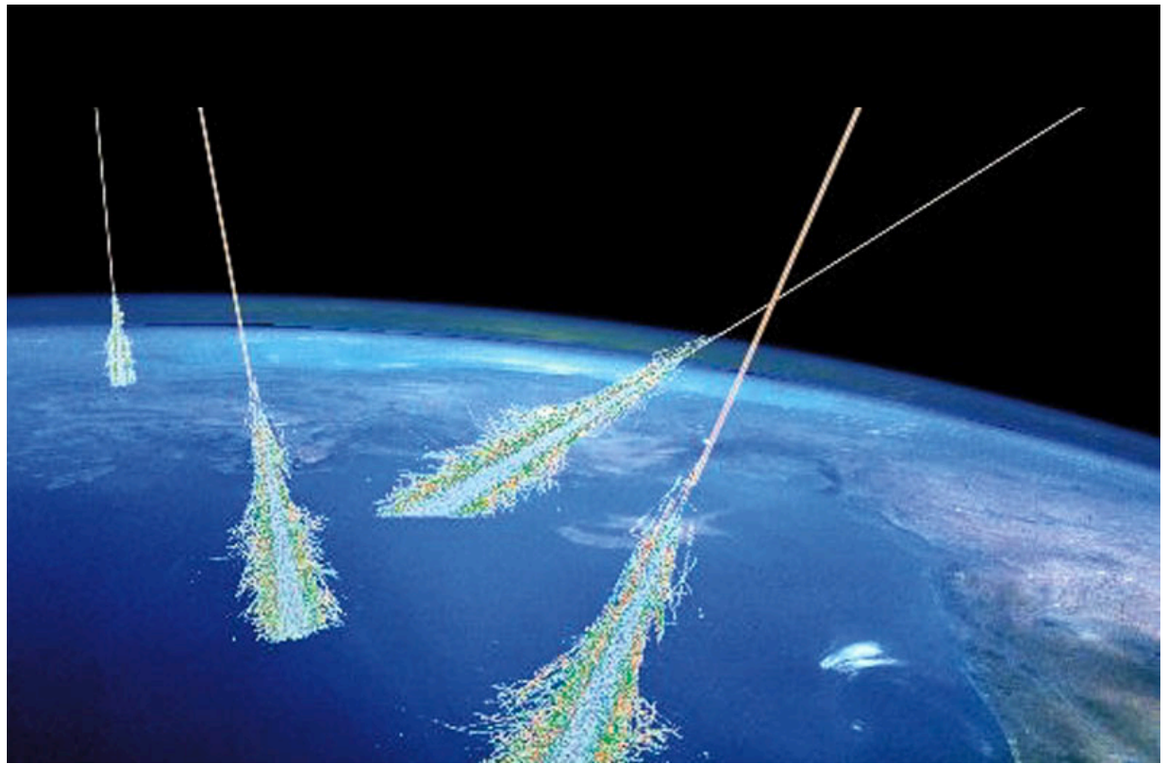
Core collapse SNe



Primordial BH evaporation

& other exotica..

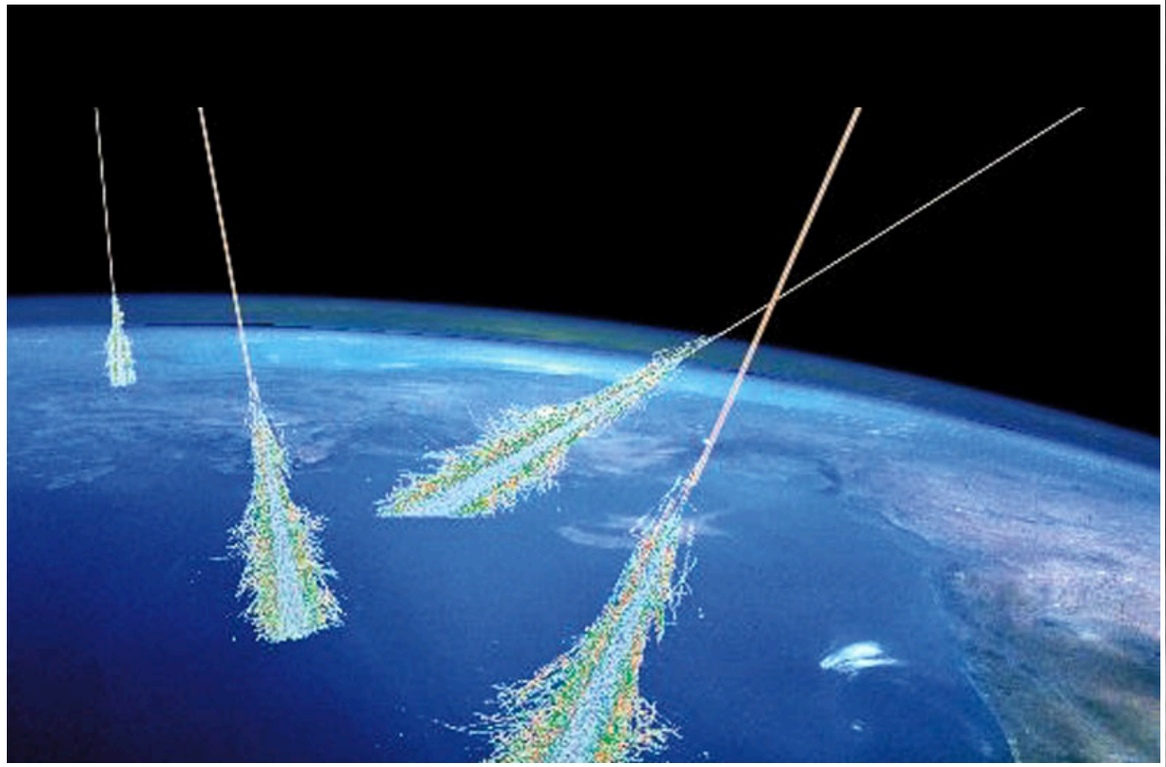
UHE neutrons in Auger



Neutron showers indistinguishable from proton showers

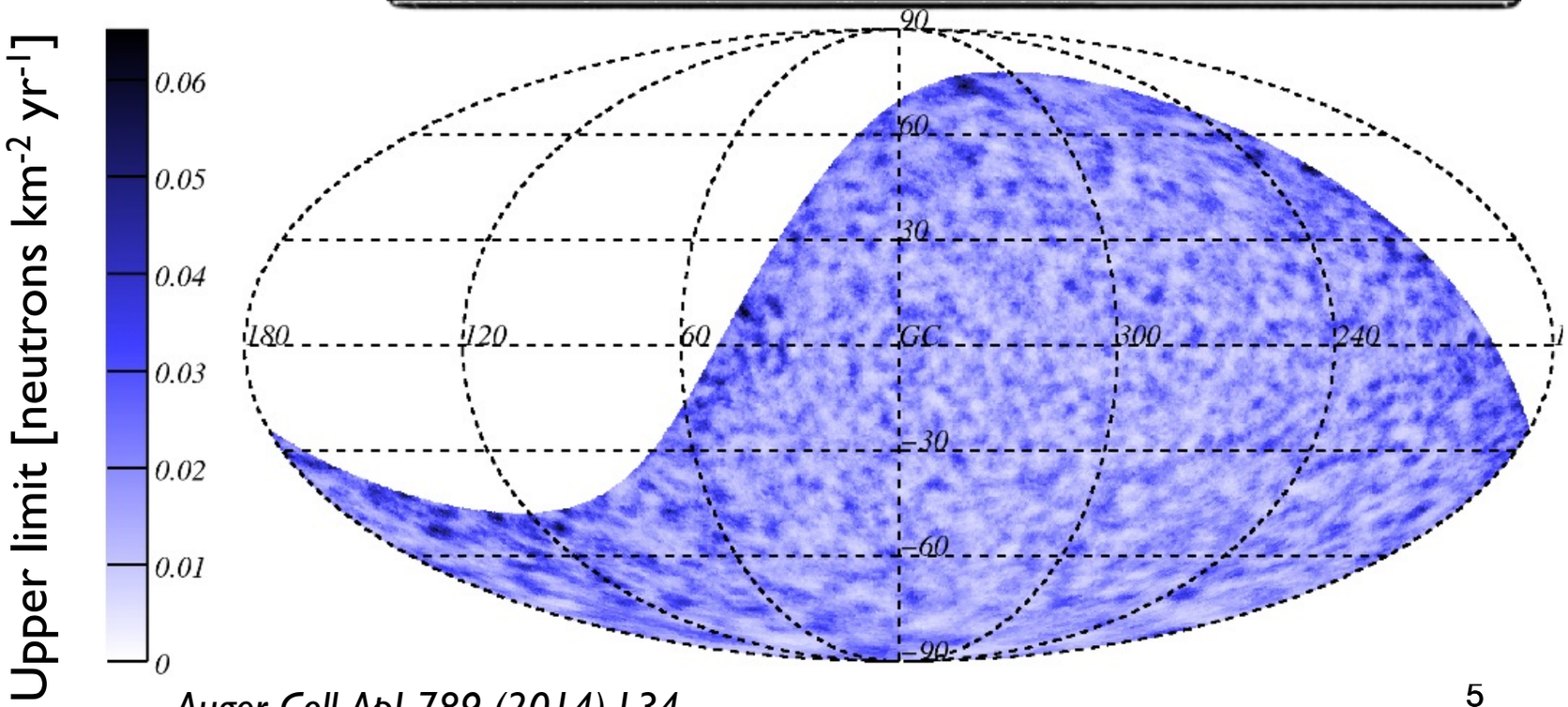
Identify from excess of CRs from source direction at E > 1EeV

UHE neutrons in Auger



Class	No.	Unweighted P-value P ≥1 EeV	1-2 EeV	2-3 EeV	≥3 EeV
msec PSRs	68	0.86	0.53	0.64	0.65
γ-ray PSRs	77	0.82	0.96	0.38	0.64
LMXB	87	0.041	0.12	0.13	0.54
HMXB	48	0.095	0.090	0.22	0.66
H.E.S.S. PWN	17	0.88	0.87	0.75	0.042
H.E.S.S. other	16	0.42	0.83	0.66	0.028
H.E.S.S. UNID	15	0.48	0.69	0.88	0.86
Microquasars	13	0.031	0.26	0.23	0.56
Magnetars	16	0.73	0.85	0.83	0.41
Gal. Center	1	0.24	0.48	0.22	0.17
Gal. Plane	1	0.96	0.91	0.70	0.25

Blind/targeted/ stacked searches have placed strong limits on neutron flux at E > 1 EeV from steady Galactic sources/ GC



Auger Coll. ApJ 789 (2014) L34

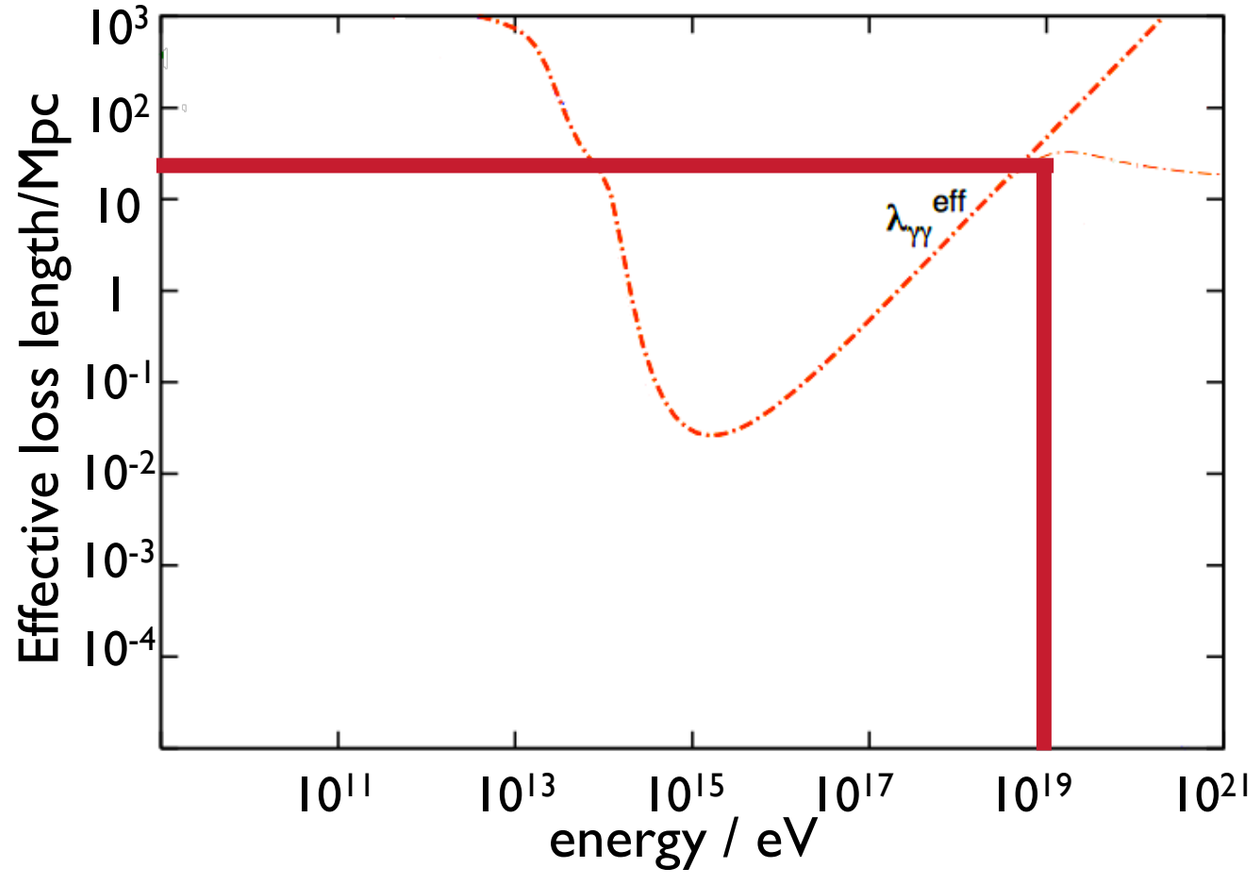
UHE Photons

see D. Kuempel's talk, Friday pm

$\gamma \longrightarrow e \longrightarrow \gamma$... (Stecker 73, Gould&Rephaeli 78)

Effective photon loss length @10^{20}eV~10-100 Mpc

Murase, ApJL 745:L16, 2012



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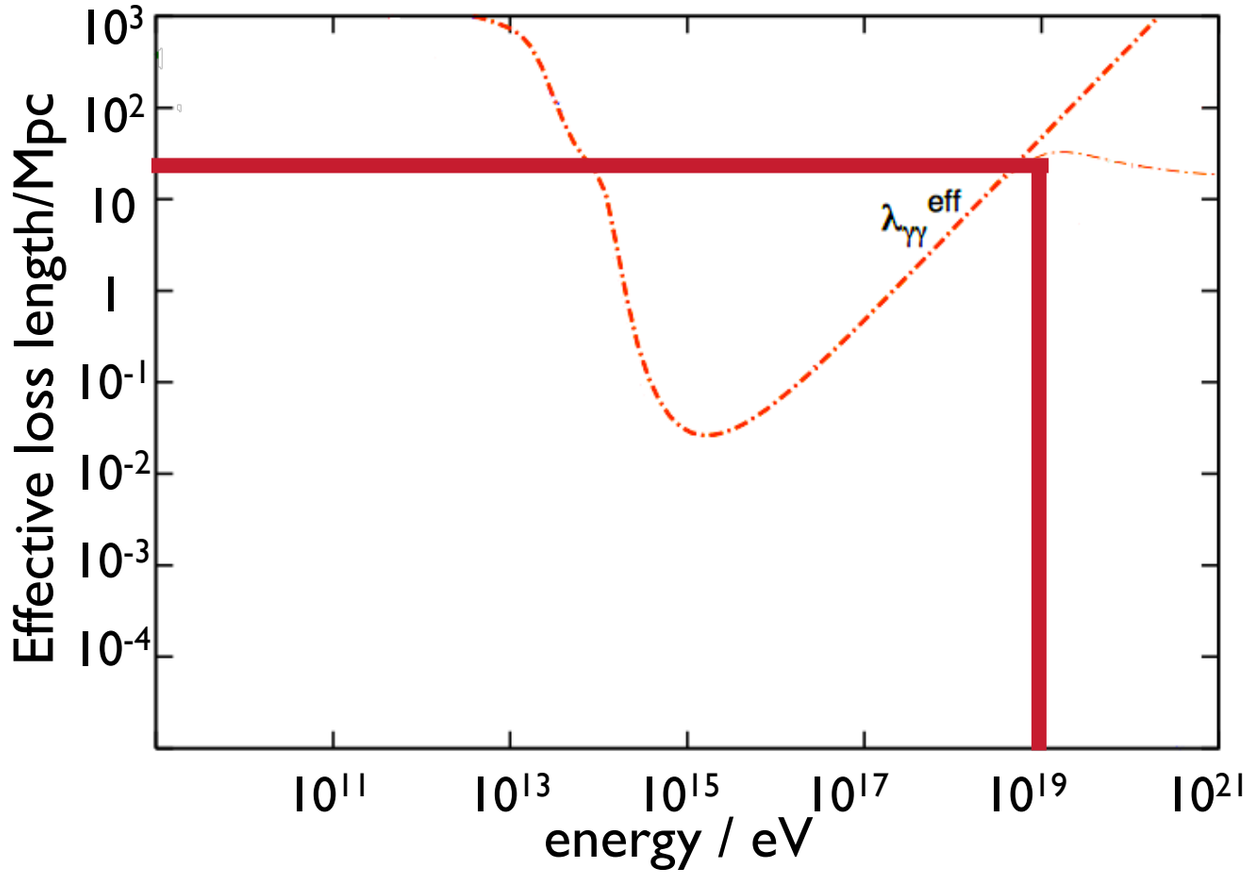
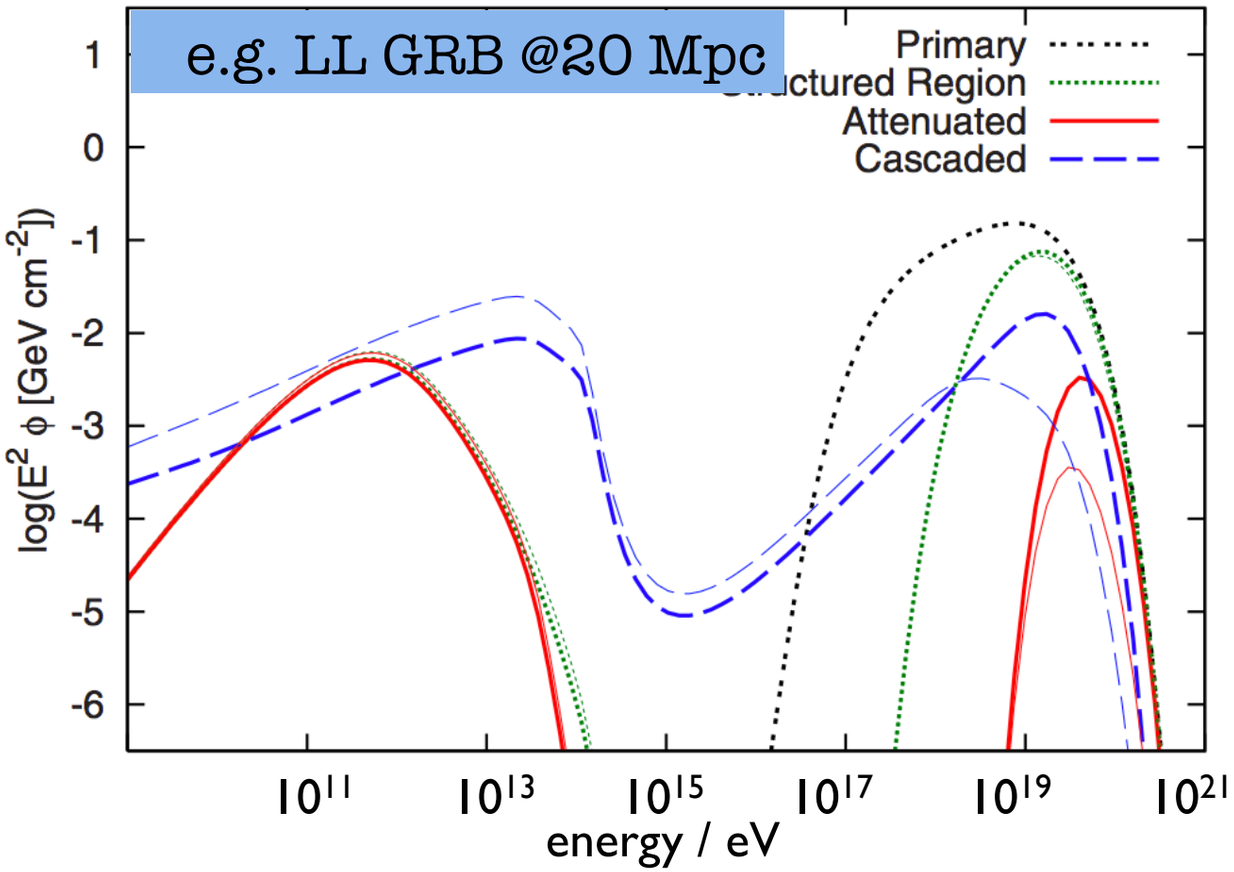


Murase, ApJL 745:L16, 2012



+AGN Flares

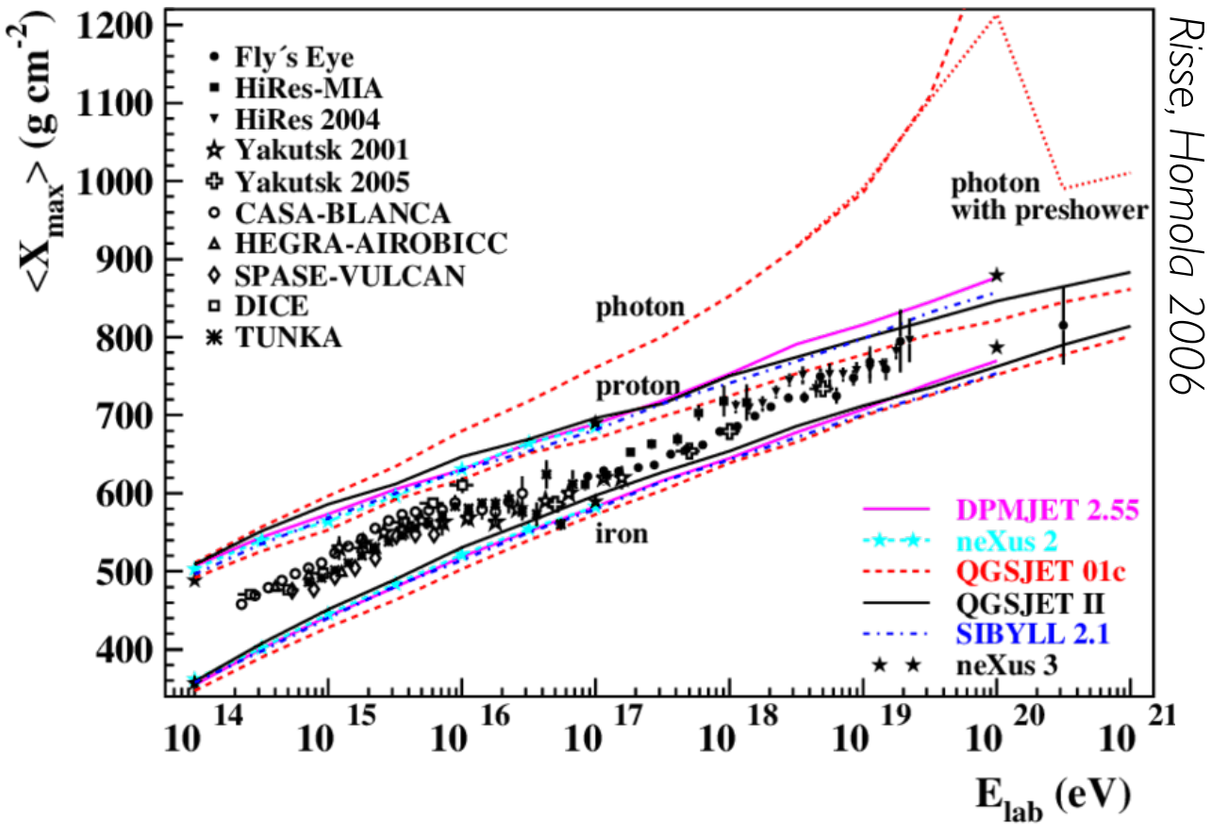
Magnetars/Pulsars

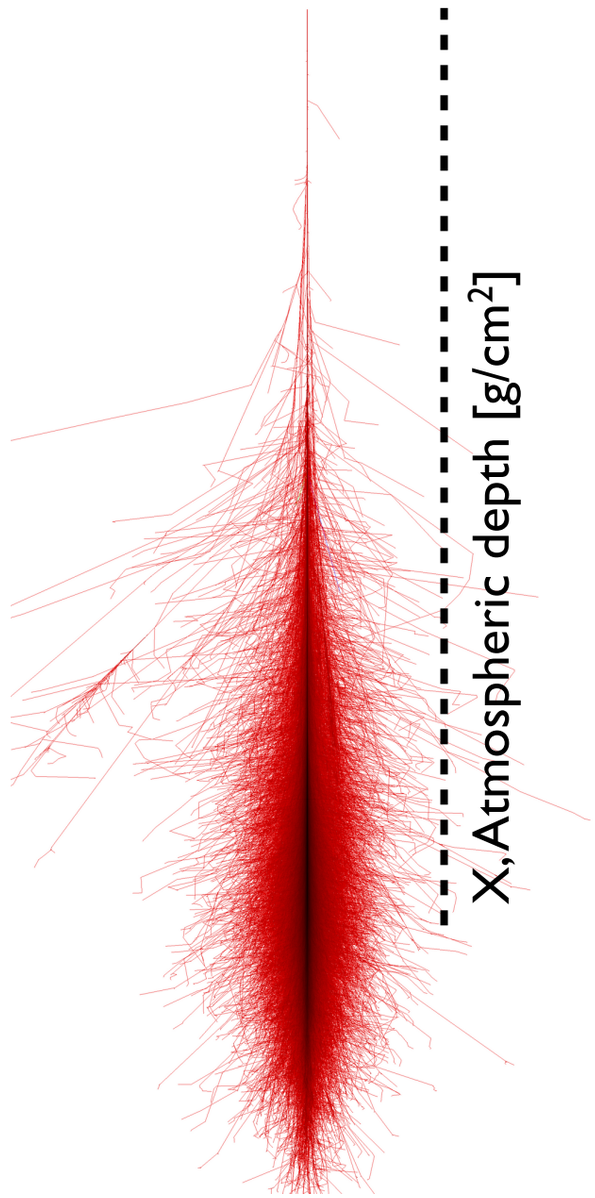
TDEs

Galactic γ-ray sources

see D. Kuempel's talk, Friday pm

X_{max} with Fluorescence Detector

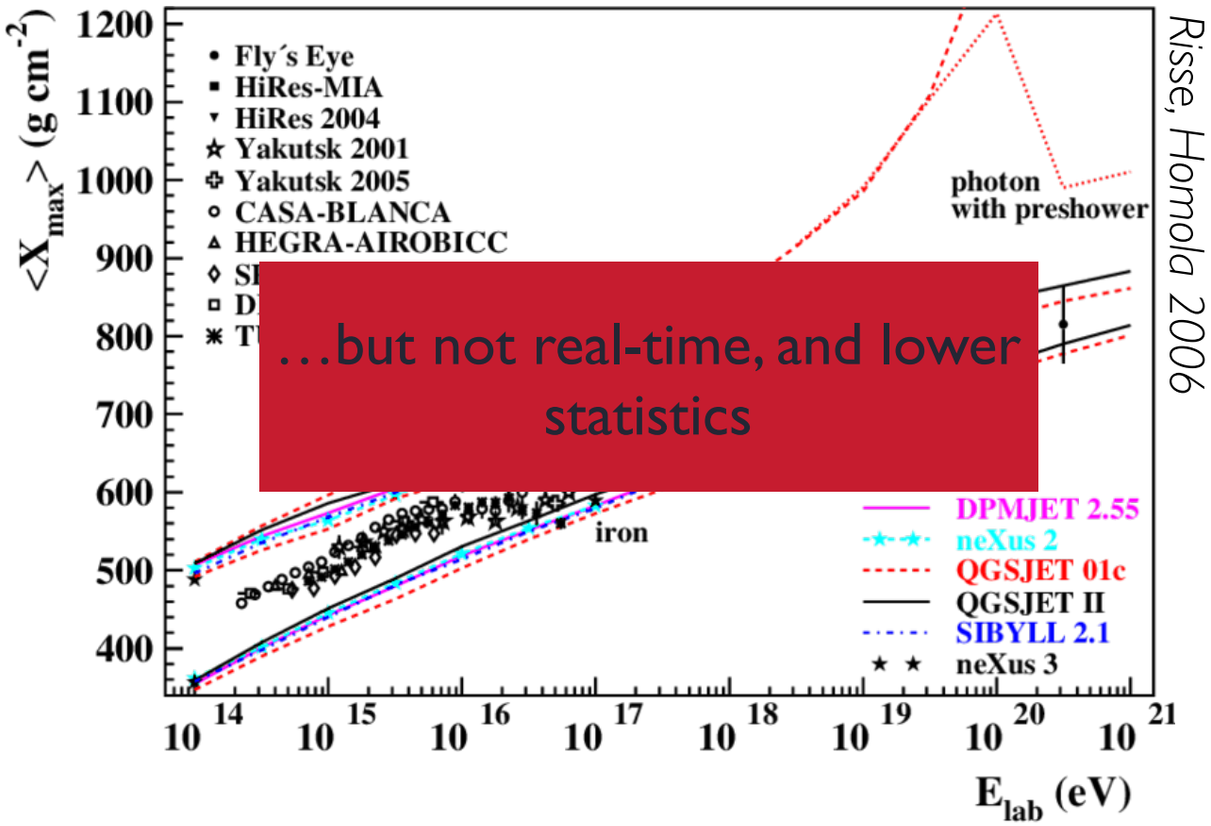




UHE Photons in Auger

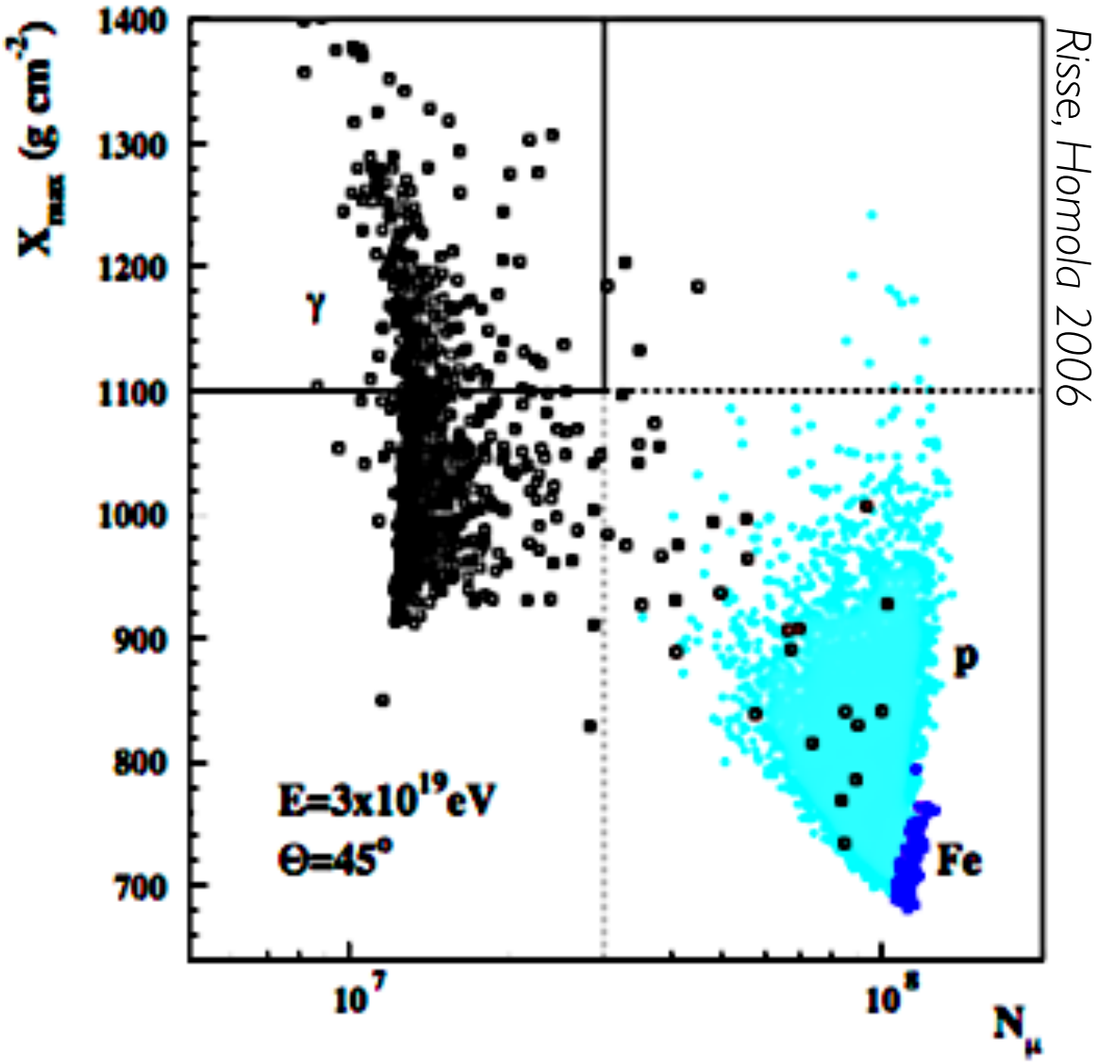
see D. Kuempel's talk, Friday pm

X_{max} with Fluorescence Detector



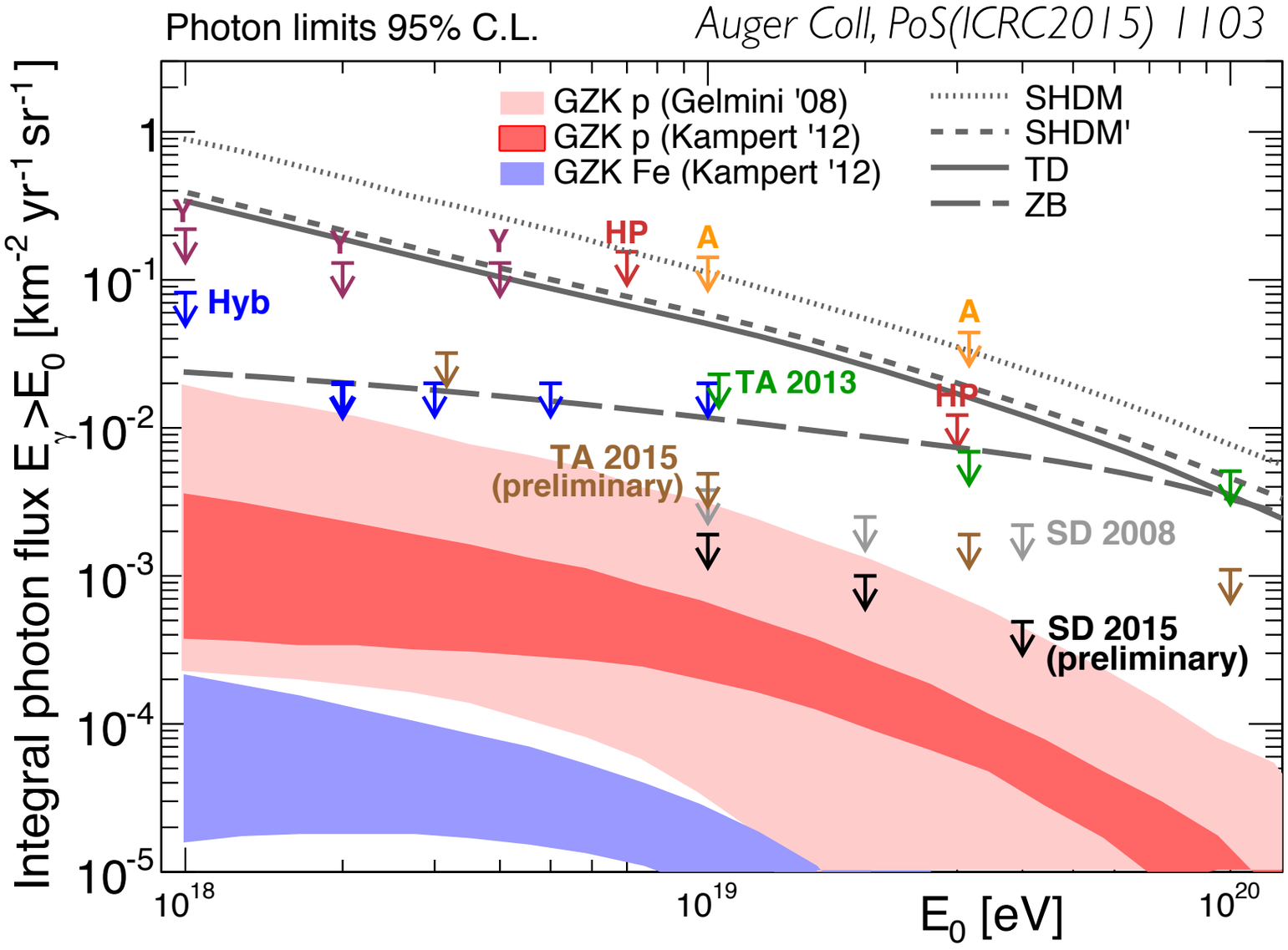
…but not real-time, and lower statistics

Shower muon content with surface detector



UHE Photons in Auger

see D. Kuempel's talk, Friday pm



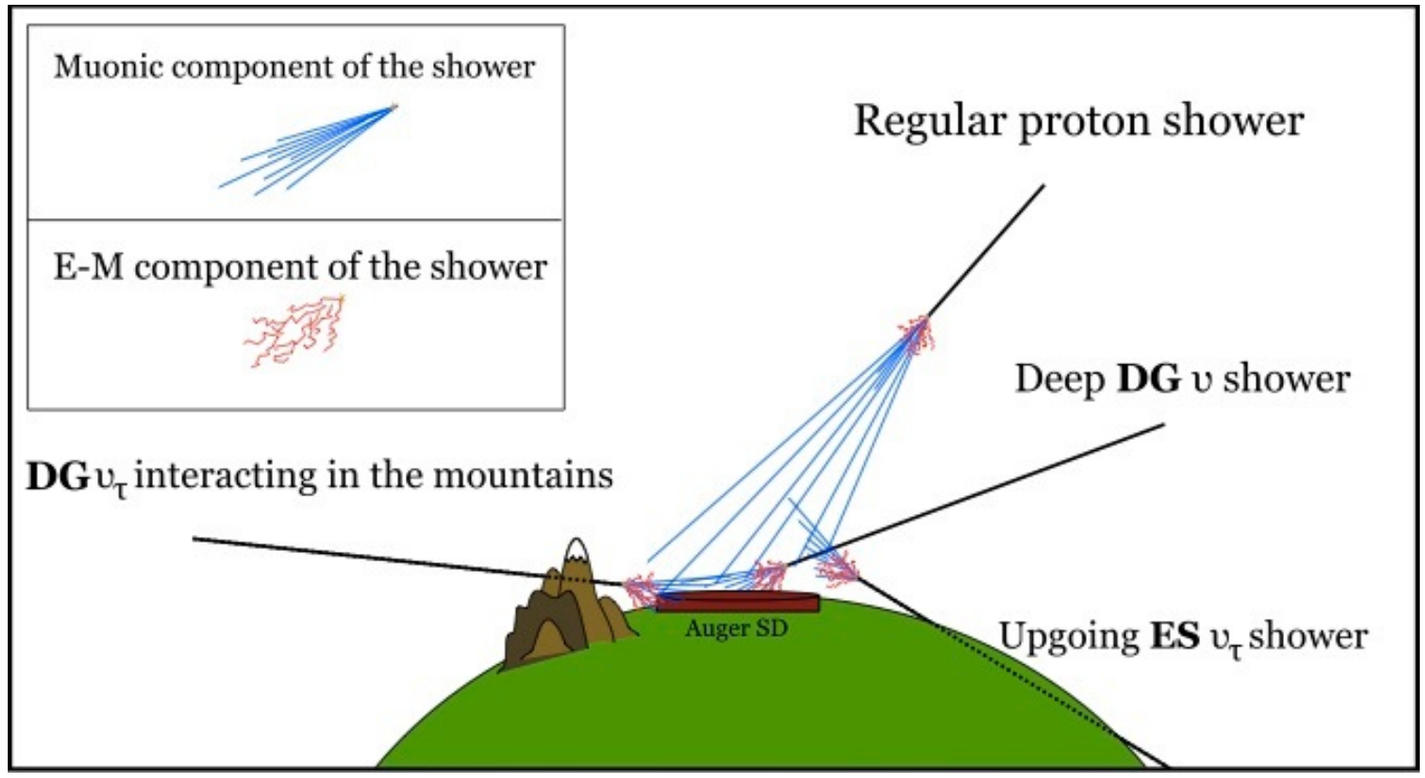
Strict limits at E > 1 EeV

No point-source detections

UHE neutrinos

L_ν (10^{20}eV) ~4 Gpc

Guaranteed GZK flux

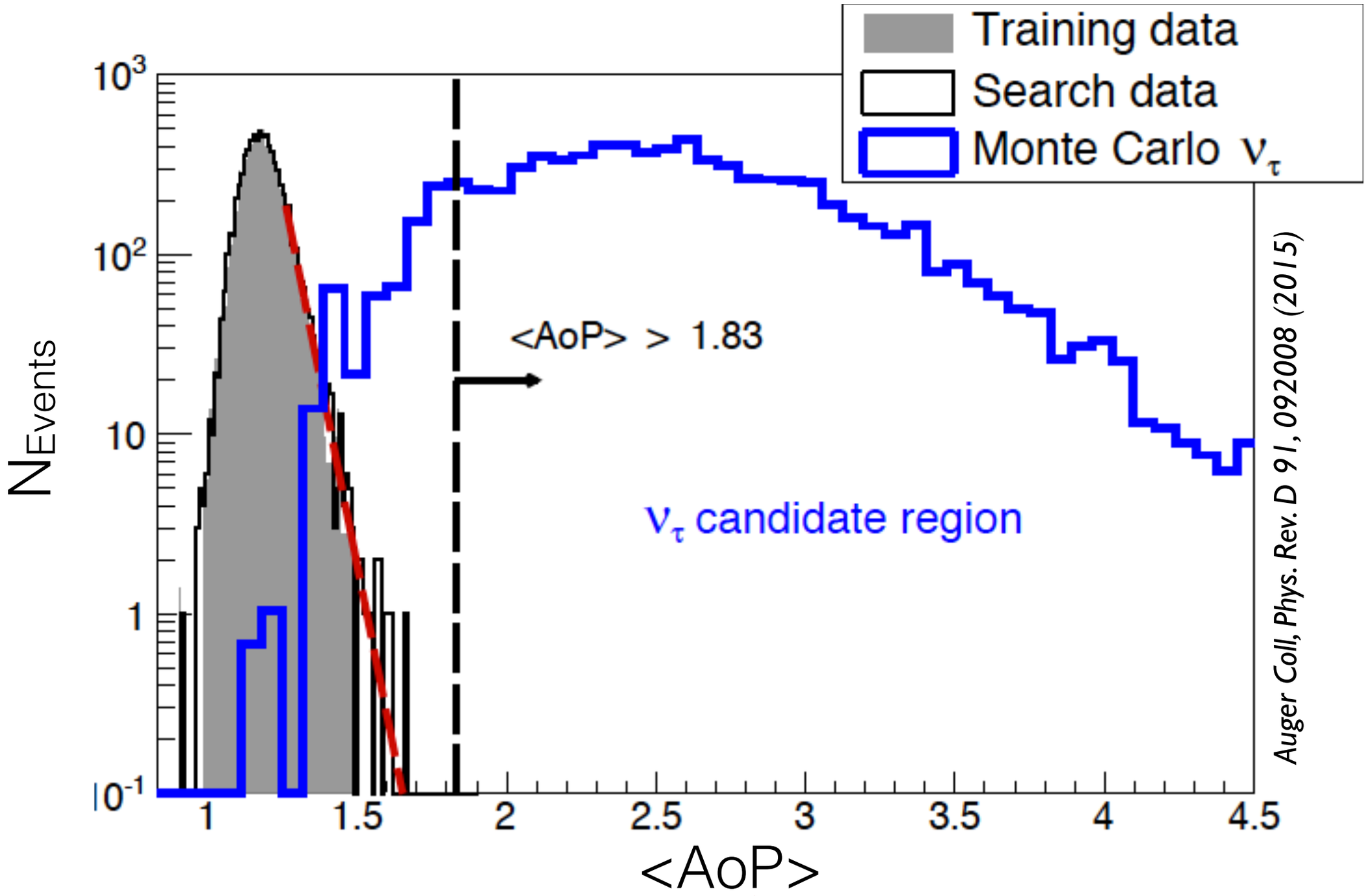


Auger SD sensitive to cosmogenic neutrino showers (peak sensitivity ~ 1EeV)

Neutrinos easy to identify (search exposure limited)

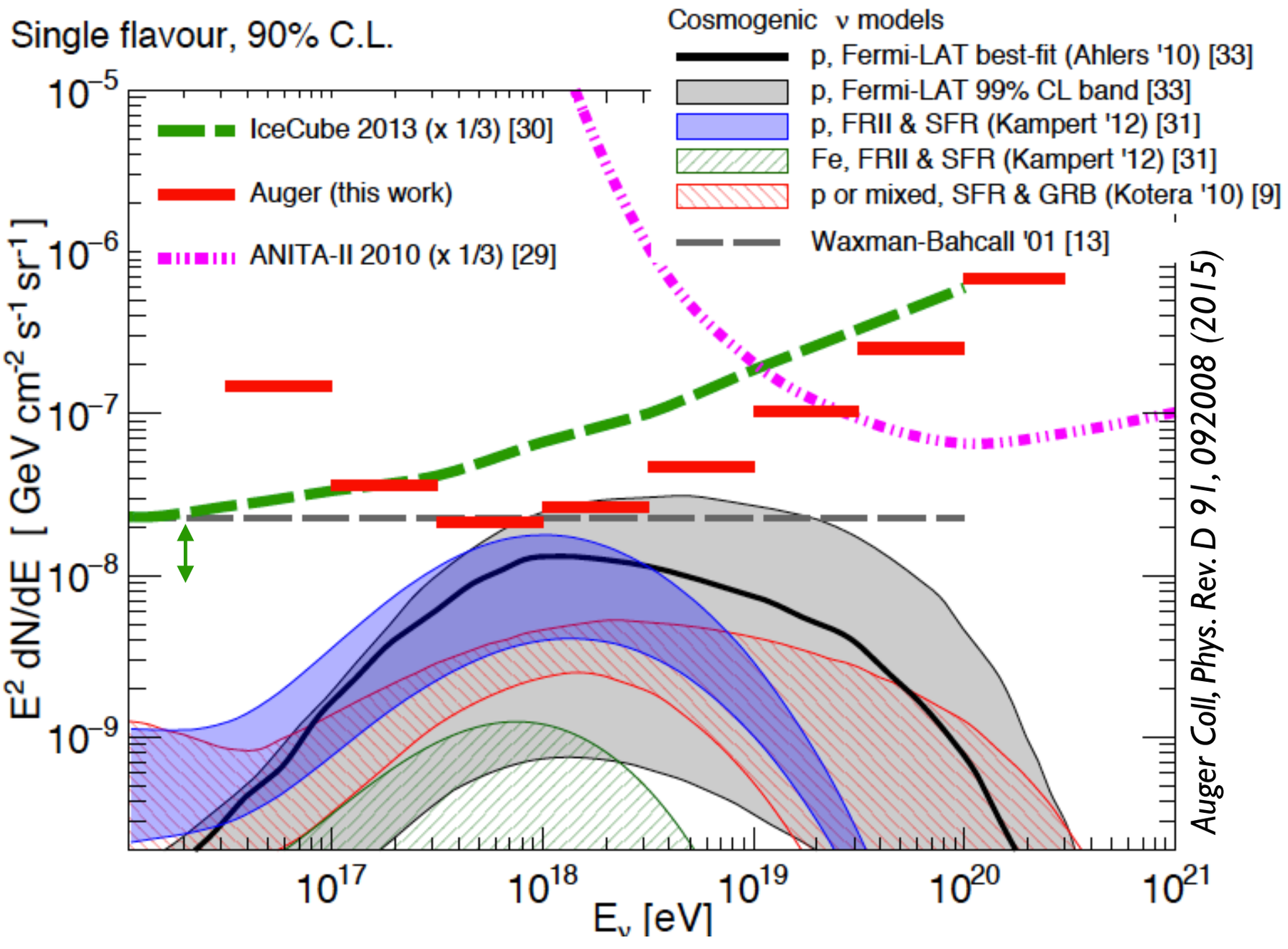
UHE neutrinos

Data 01/01/04 – 15/06/13



signal broadness in time

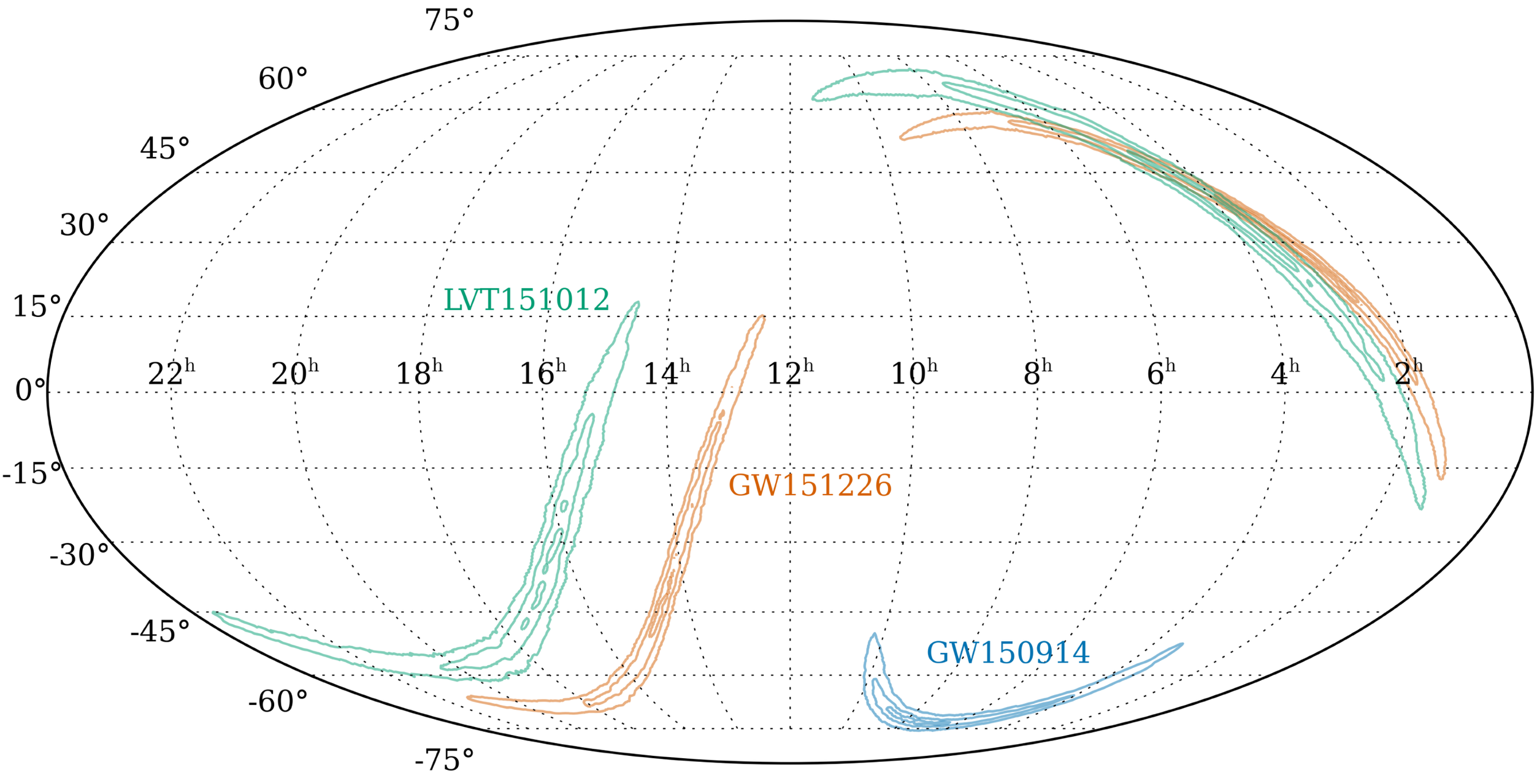
UHE neutrinos



Auger first observatory to place limit below Waxman-Bahcall bound

Towards transient UHE particle astronomy

UHE neutrino follow-up of LIGO GW detections

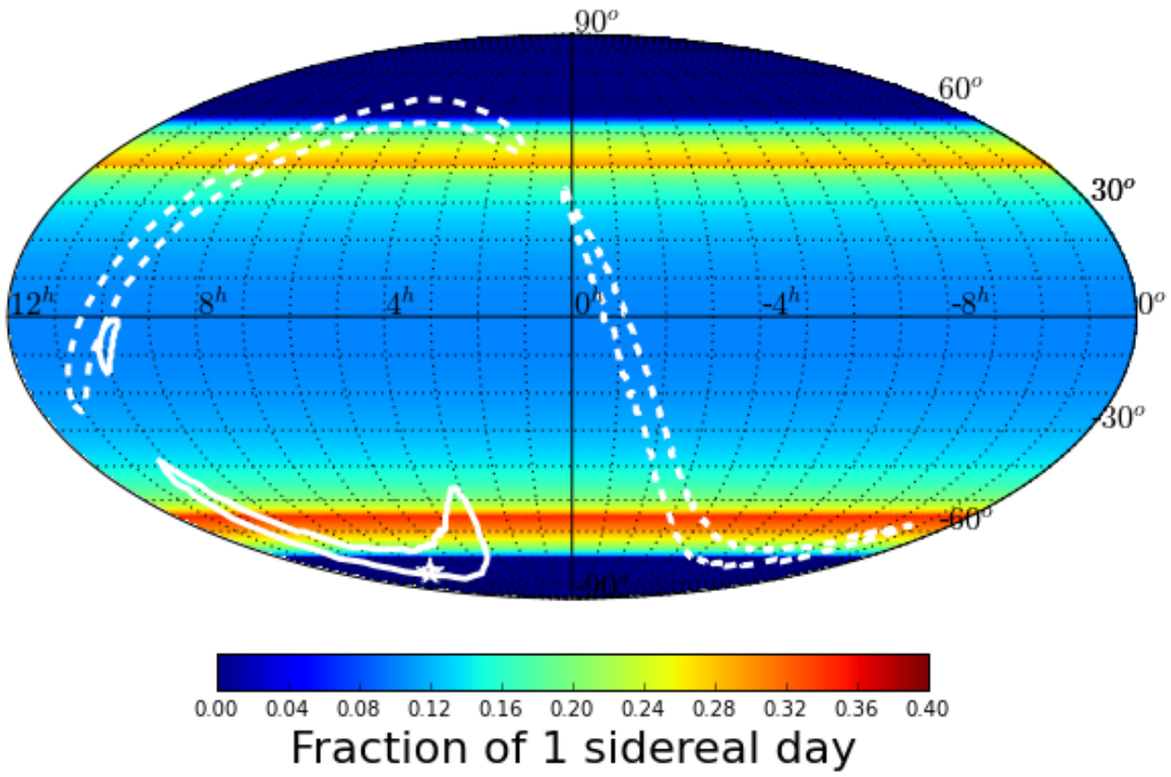


Auger followup of GW150914 and GW151226

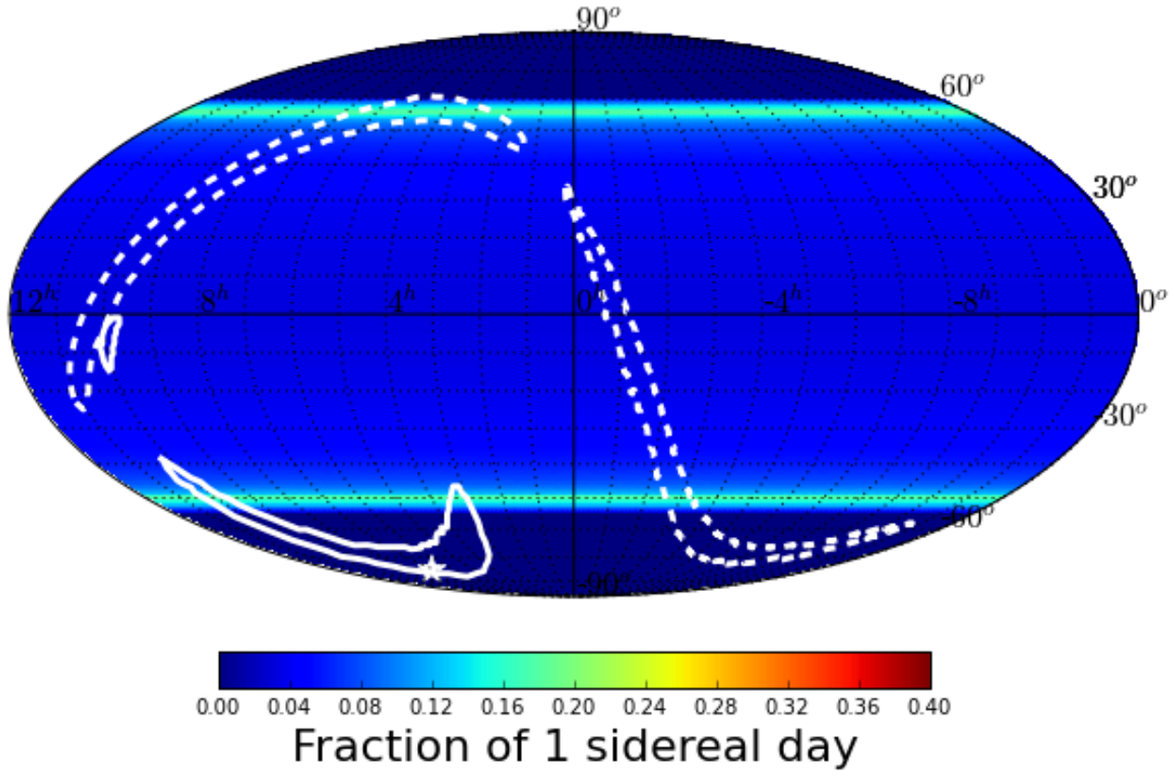
Auger Coll 2016, to appear in PRD

Binary BH mergers can produce UHE neutrinos, if there are magnetic fields and disk debris remaining from the formation of the two black holes (Kotera & Silk 2016, Anchordoqui 2016)

$75° \leq z \leq 90°$



$90° \leq z \leq 95°$

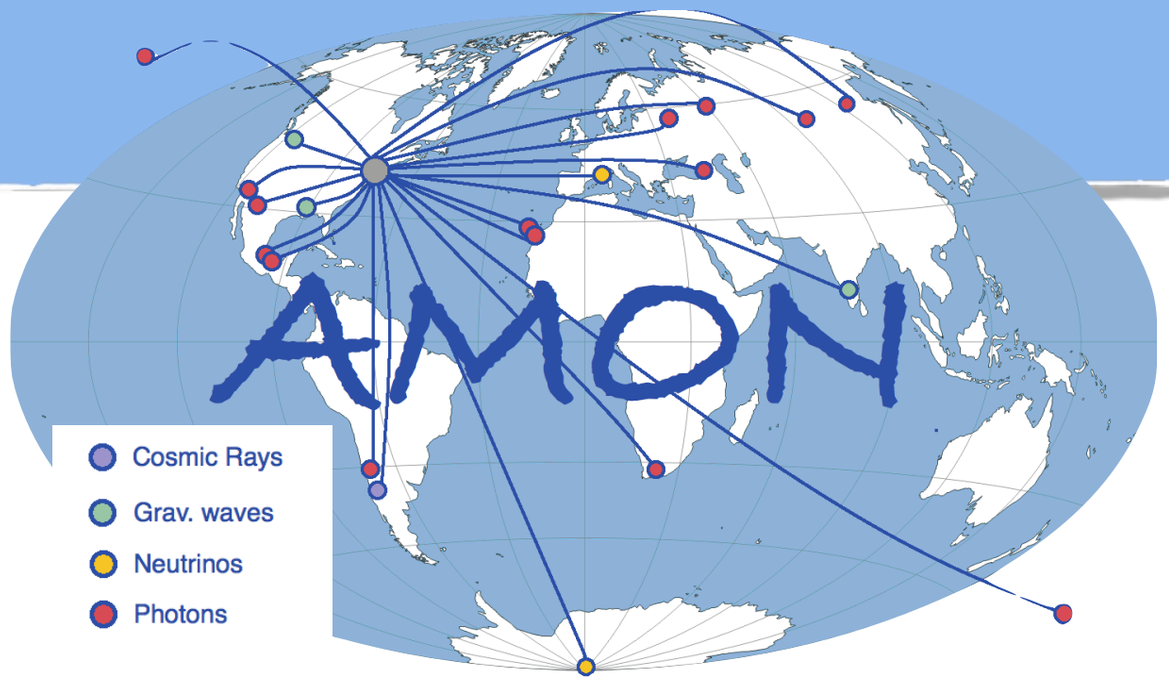


No candidates detected within 500s or 1 day after GW140914/GW15226/LVT15012

Limits in ~100 PeV-~25 EeV range:

$$E_{\nu,\mathrm{tot}}(\delta = -53°) < 7.7 \times 10^{53}\mathrm{erg}, \quad \text{for GW150914}$$
$$E_{\nu,\mathrm{tot}}(\delta = 55°) < 7.9 \times 10^{53}\mathrm{erg}, \quad \text{for GW151226}$$

Auger contribution to AMON



Auger trigger+follow-up partner

Link status:

☑ Auger data 2008-2014 in AMON database: 6T5 events, E > 3 EeV, Herald reconstruction, θ<60°, standard cuts [~10^5 events]

☑ Realtime stream from Malargüe to AMON established (latency ~2min)

☑ Realtime photon shower analysis under development

Each event is a neutron candidate for AMON

Background doublet rate~ 1/yr, threefold coincidences ~0.05/yr*

*sensitive to other experiments' data stream rate ***Smith et al. 2013, Astroparticle Physics, 45, 56-70***

Outlook

Auger triggering and follow-up partner for UHE neutrons/ neutrinos/photons in multi-messenger searches (active in AMON)

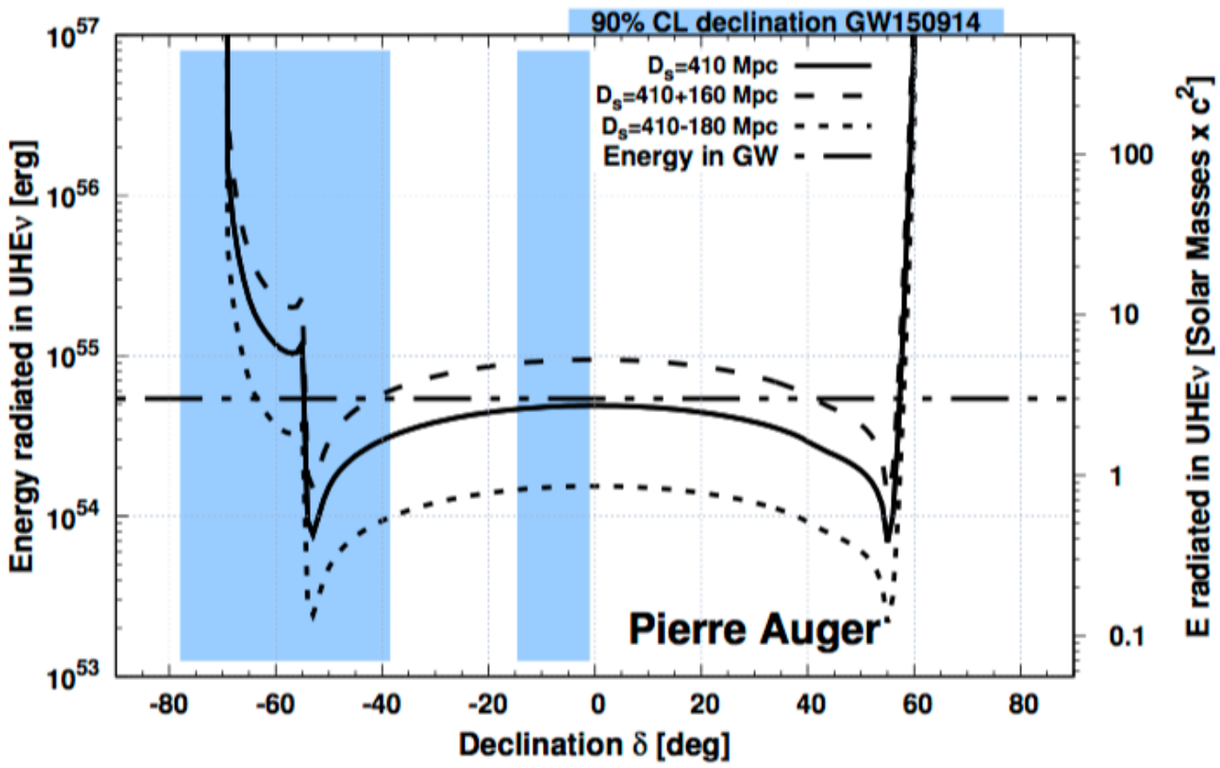
No neutral flux identified yet- strictest limits at UHE energies - close to benchmark cosmogenic predictions

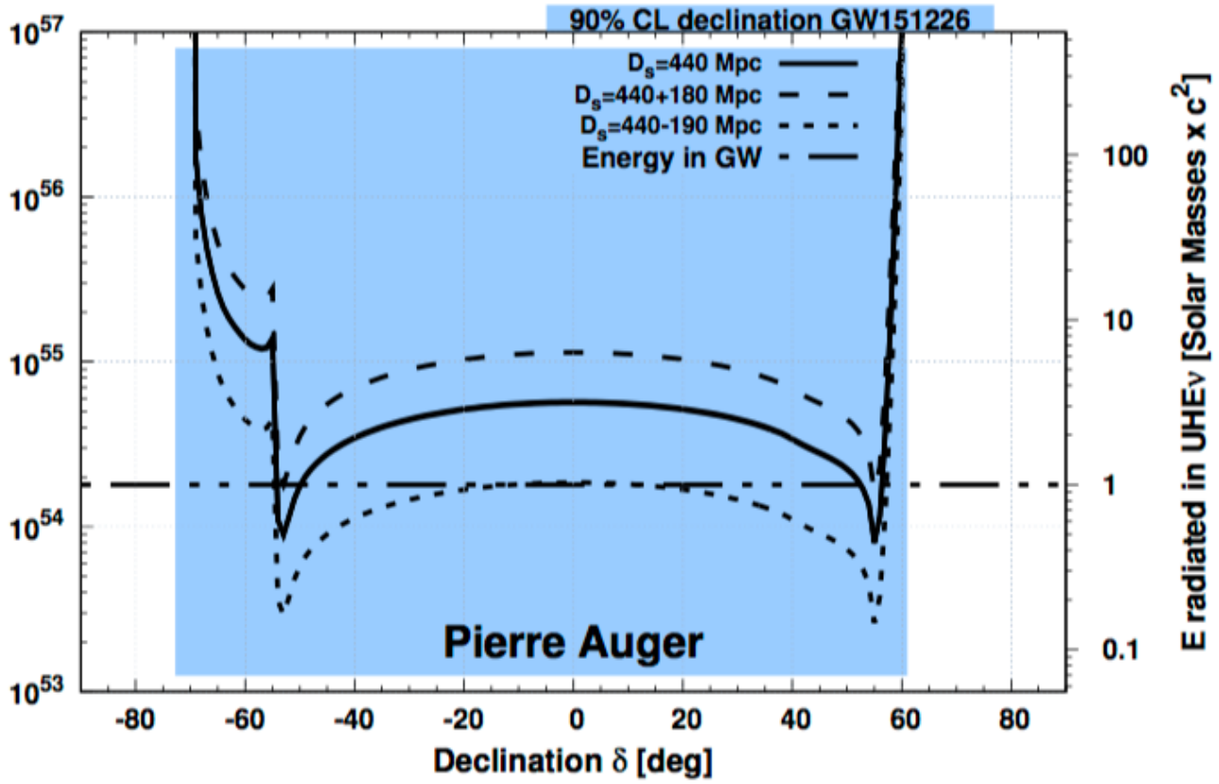
AugerPrime:
Surface detector upgrade
(run 2018-24)
Enhanced composition
discrimination

Back-up

Auger followup of GW150914 and GW151226

Auger Coll 2016, to appear in PRD





The future: AugerPrime

- Auger surface detector upgrade
- Run 2018-2024
- Composition information shower by shower

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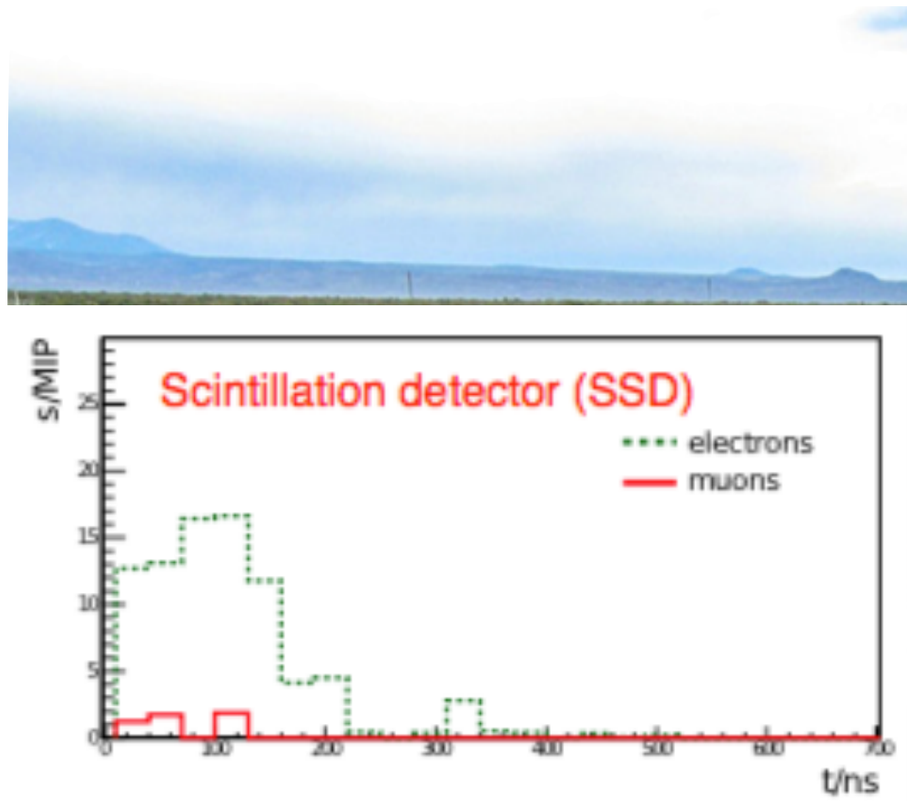
- Run 2018-2024
- Composition information shower by shower

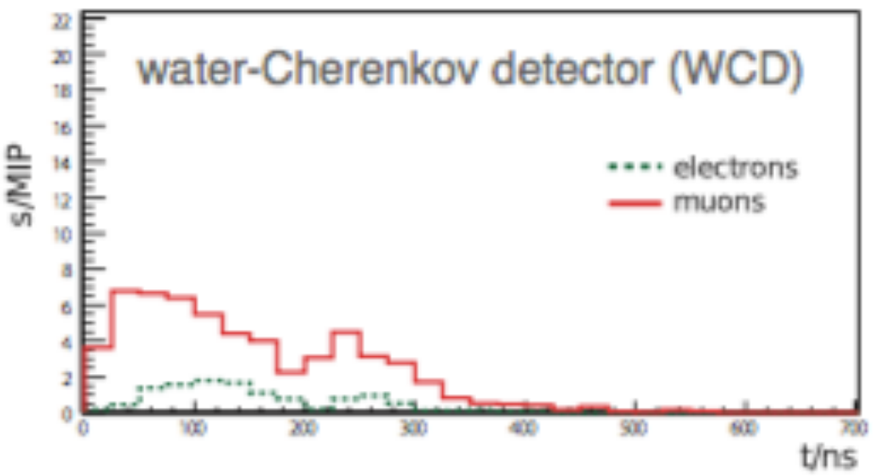
Main goals:

- Origin of the flux suppression
- Proton contribution in the flux suppression region
- Fundamental particle physics

The future: AugerPrime

The future: AugerPrime



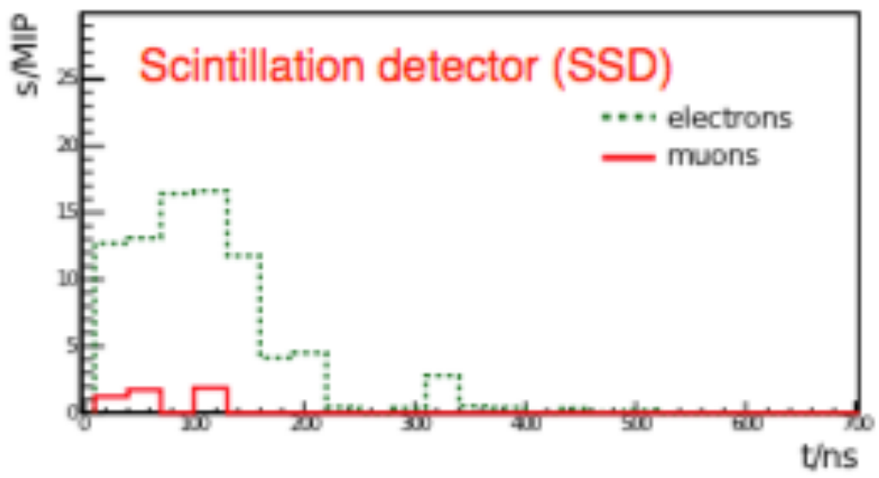


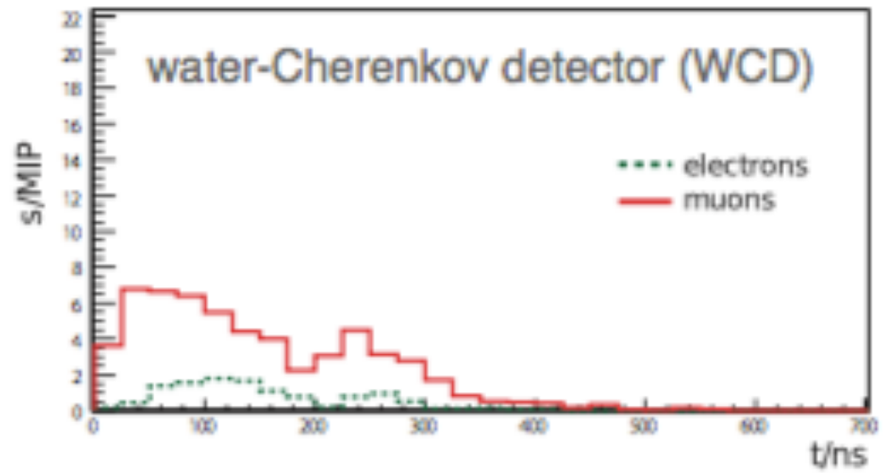
Enha

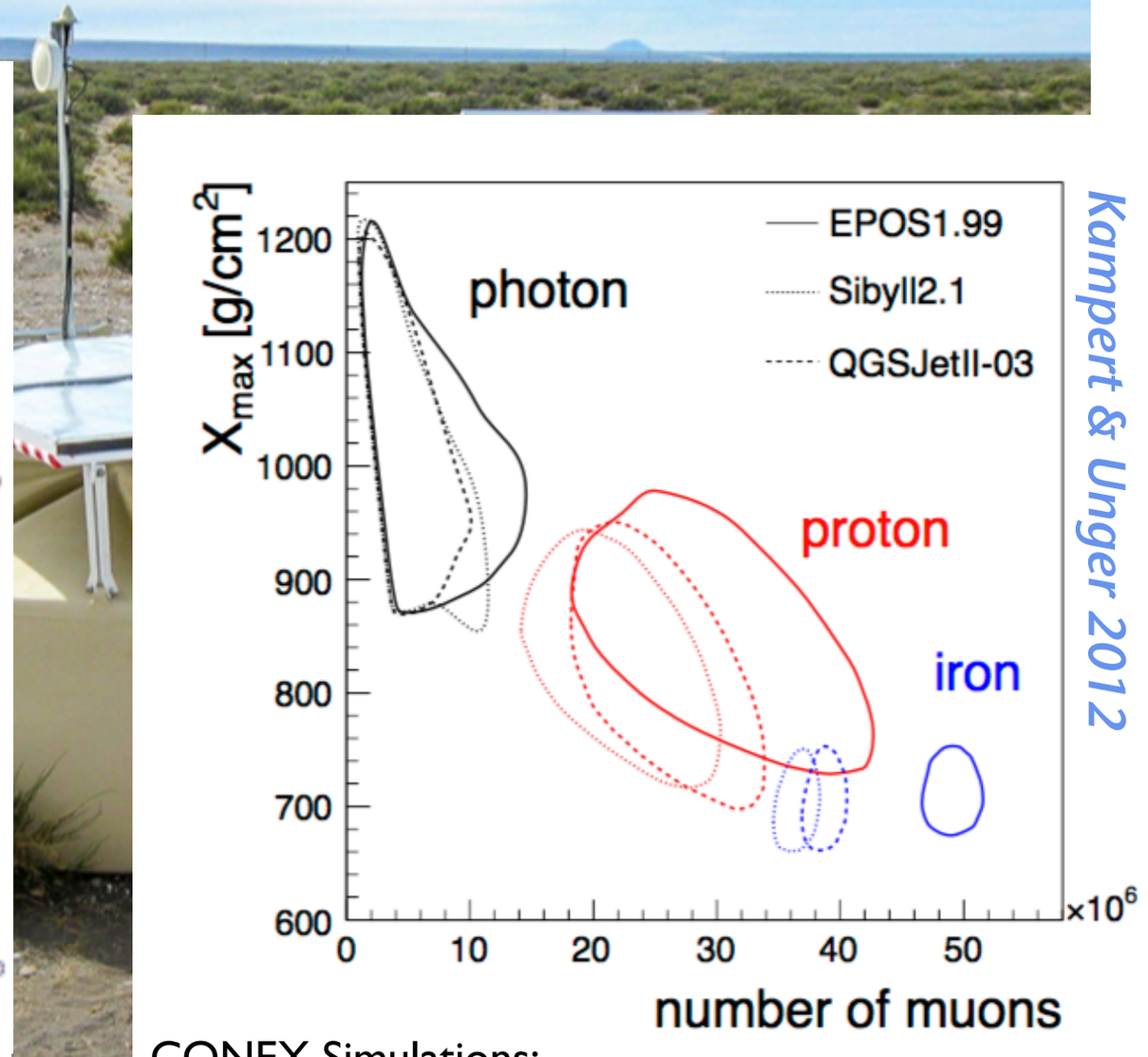
$$S_{\mu,\mathrm{WCD}} = aS_{\mathrm{WCD}} + bS_{\mathrm{SSD}}$$

+Improved new electronics upgrade to facilitate readout

The future: AugerPrime







Enha

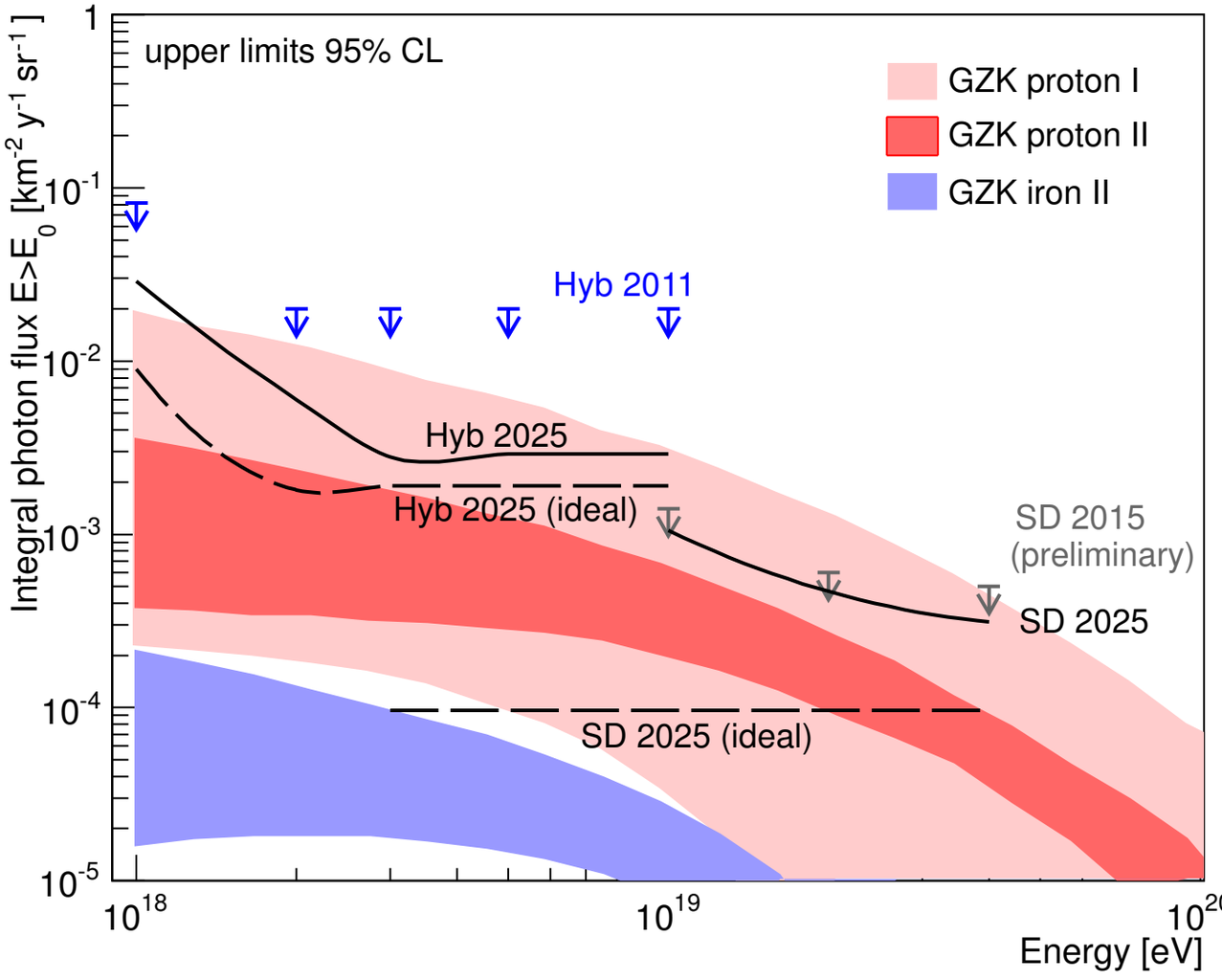
ics
out

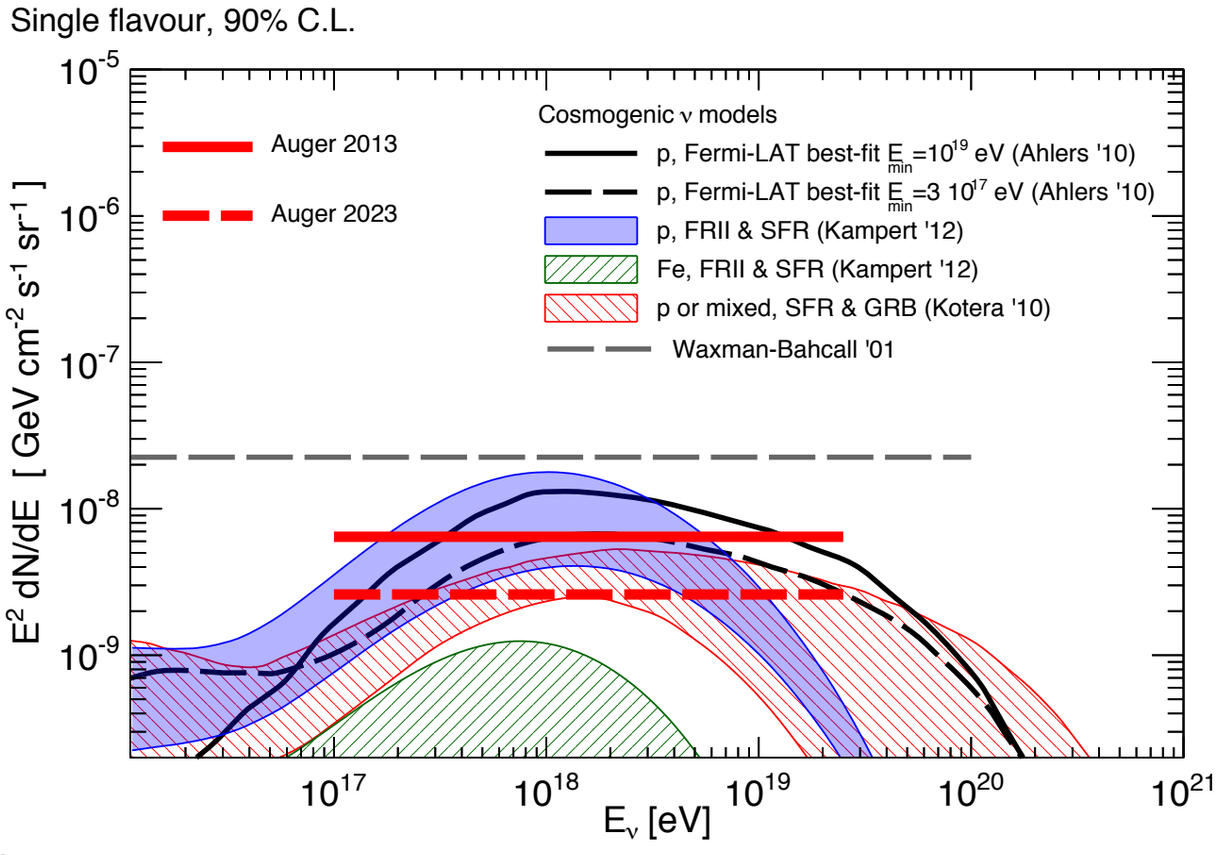
$$S_{\mu,\mathrm{WCD}} = a S_{\mathrm{WCD}} + b S_{\mathrm{SSD}}$$

CONEX Simulations:
E = 10^{19}eV
θ = 60°
90% CL
X_{ground} = 800g/cm^2

AugerPrime: Photon & Neutrino reach

Auger Coll, ICRC 2015





- increased exposure
- improved low-energy trigger (low-energy threshold)
- improved separation power (needs still to be evaluated)