photo: Coihueco © *Steven Saffi 2016*

The Auger Contribution to AMON

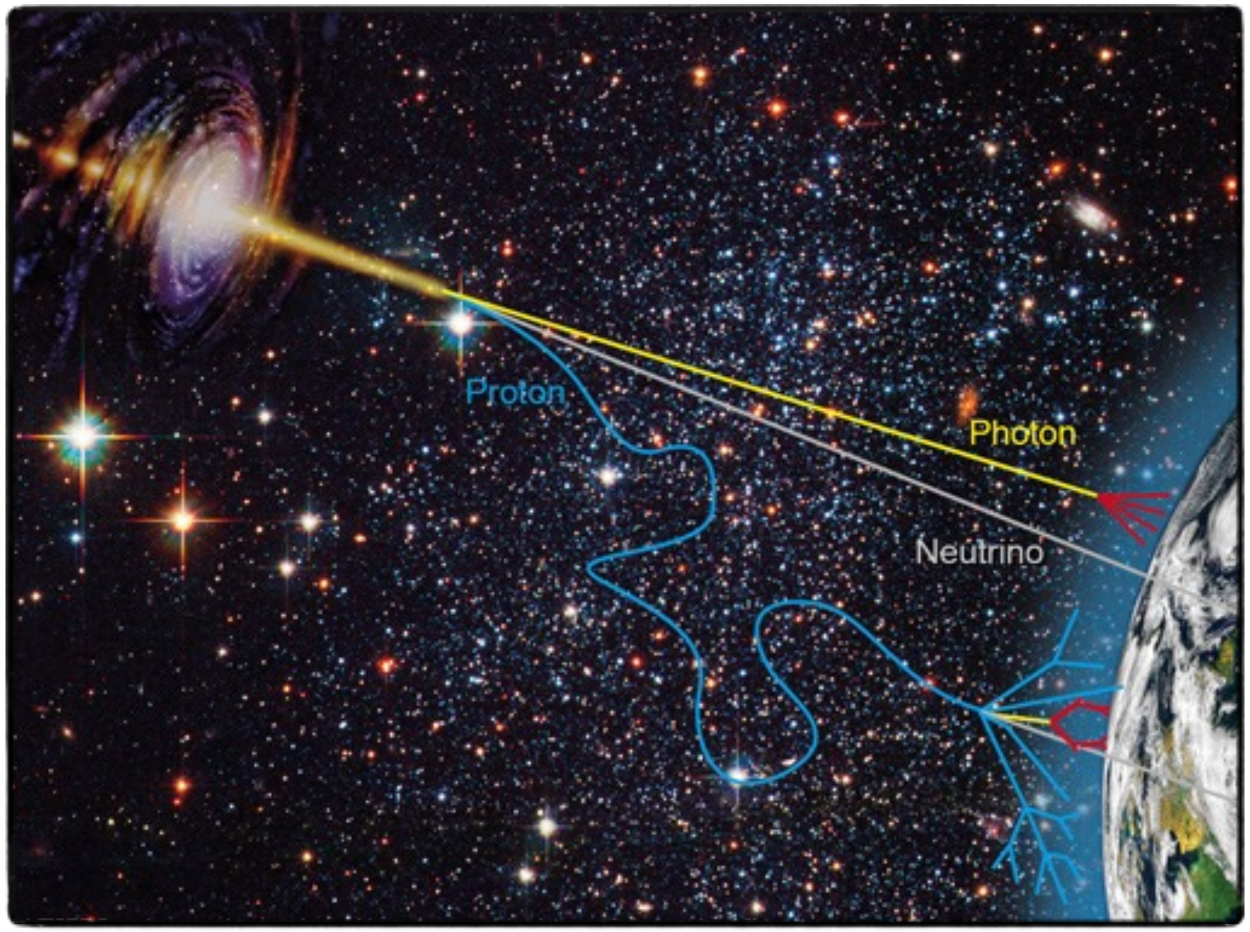
PIERRE AUGER OBSERVATORY

PennState Eberly College of Science

Foteini Oikonomou

AMON workshop-10/12/2016

Auger data of interest to multi-messenger monitoring



UHE neutrals guaranteed by UHECR observations:

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

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

$$n+\gamma_{\mathrm{CMB/source}} \longrightarrow p+\pi^{+/-}$$
$$\hookrightarrow e^+ + e^- + \nu\nu$$

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

Auger contribution to AMON

- ☑ Triggering + follow-up AMON partner

- ☑ 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 (latency ~2min)

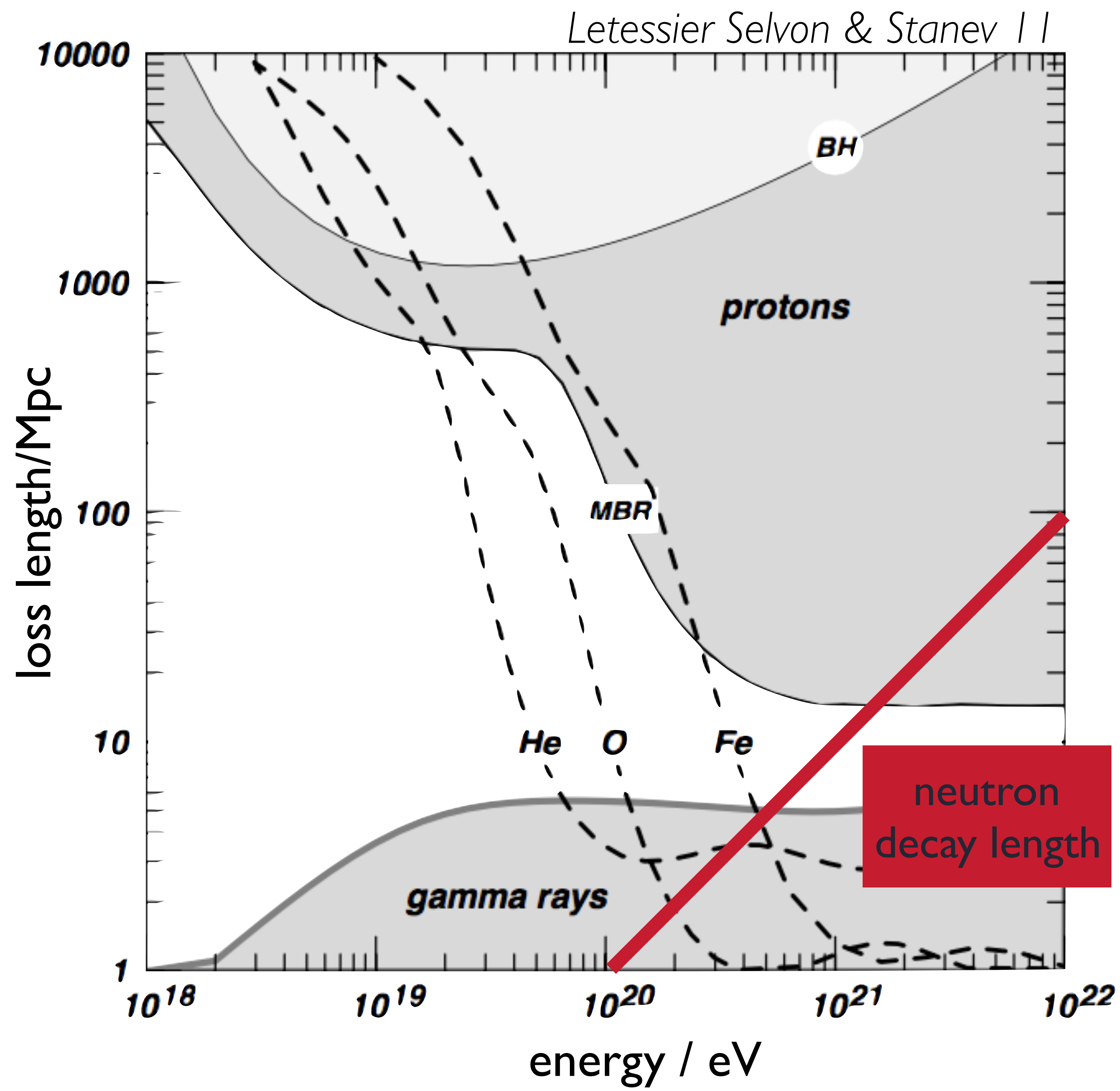
- ☑ Realtime photon analysis under development

UHE neutrons

Can they reach us?

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

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



UHE neutrons

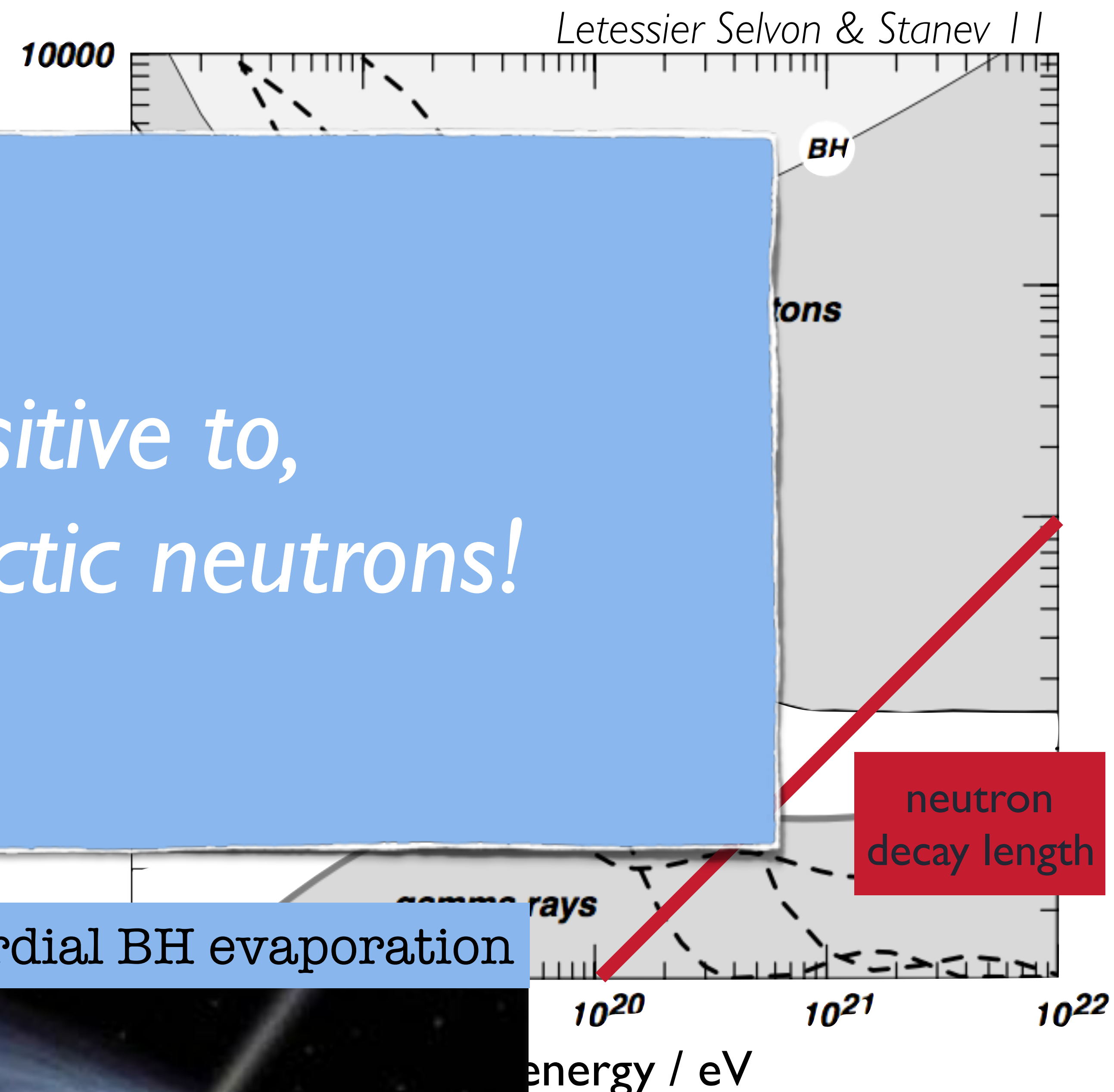
Can t

$L_n \sim$ c

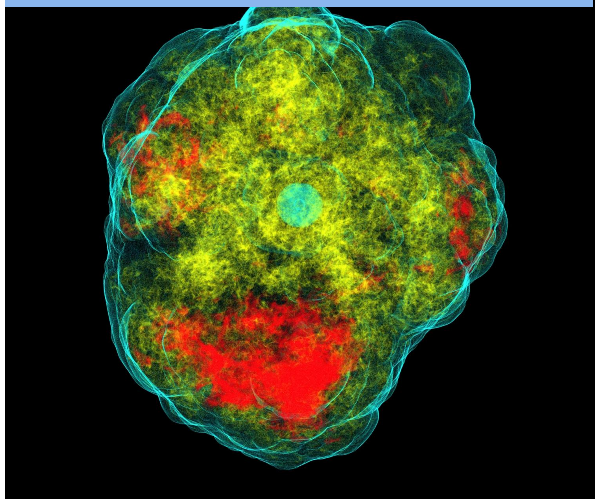
[c.f. M

Auger sensitive to,

E > 1 EeV, Galactic neutrons!



Core collapse SNe

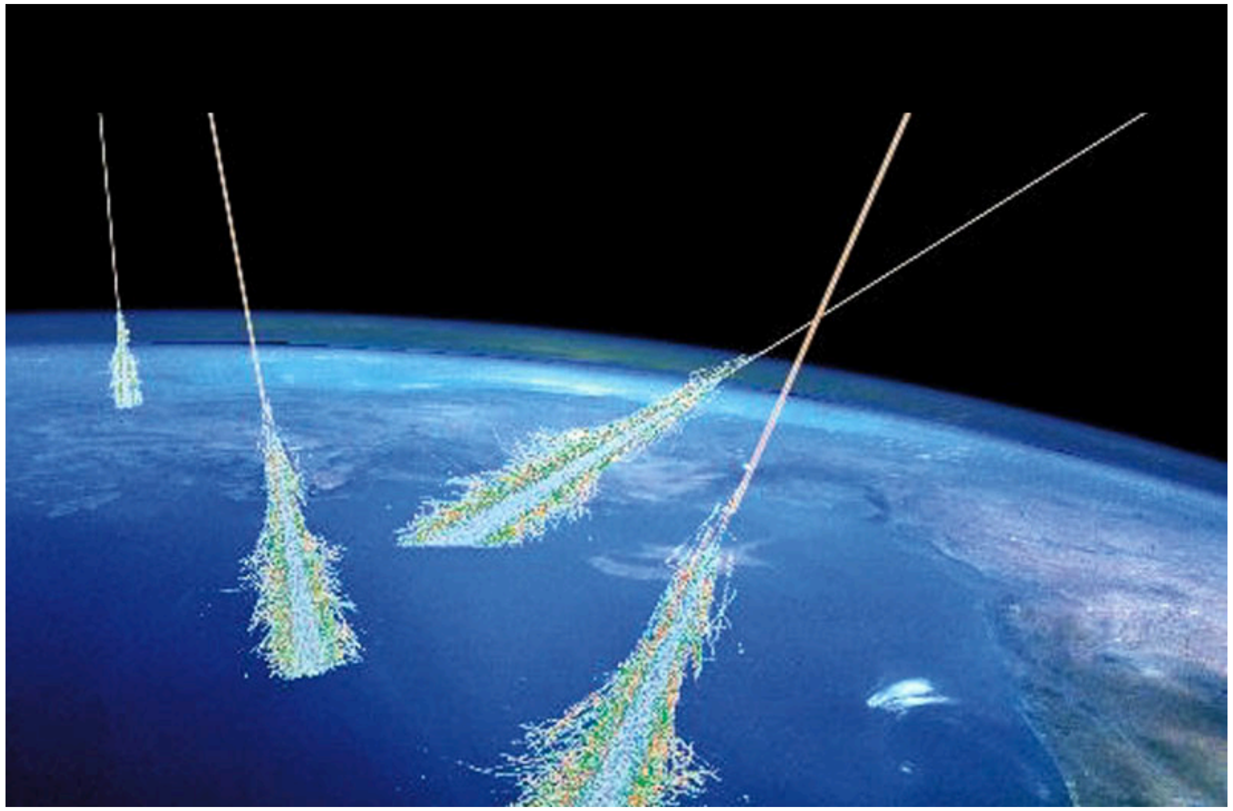


Primordial BH evaporation

e.g. Tešic PoS(ICRC2015)328

& other exotica..

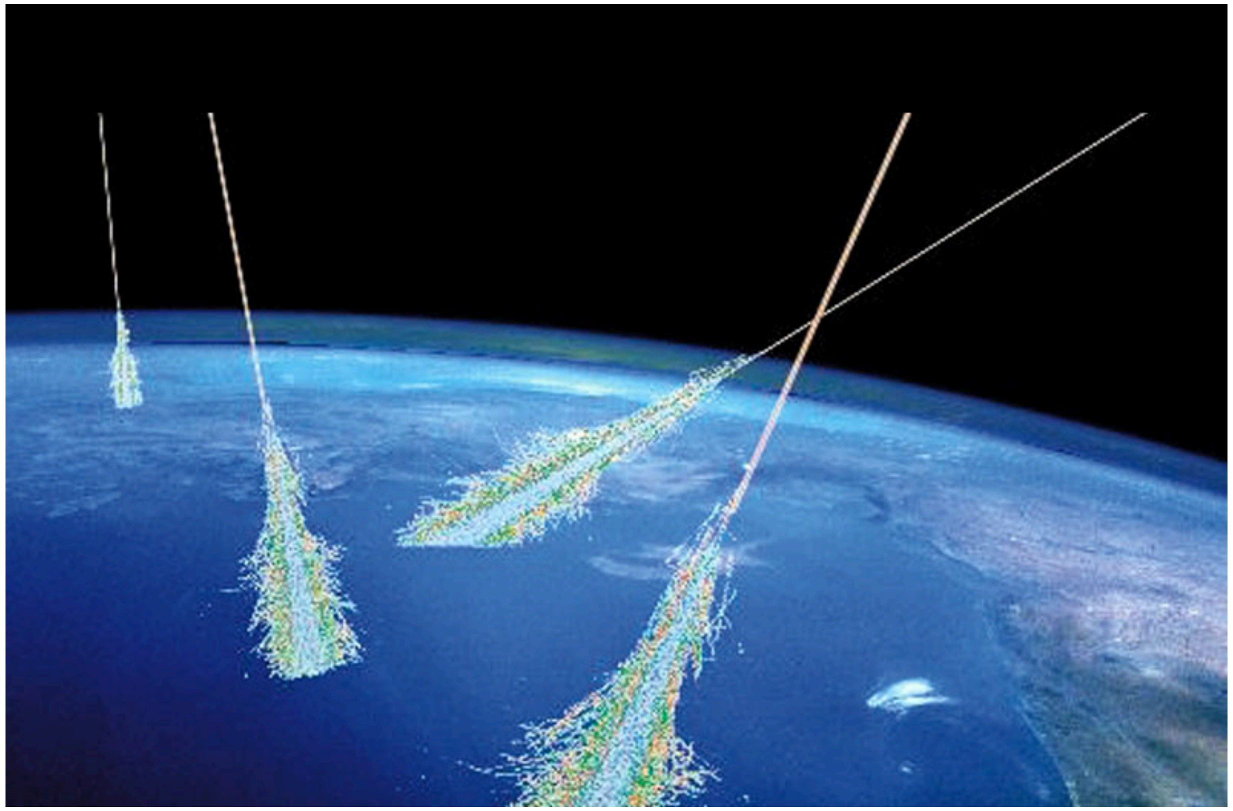
UHE neutrons in Auger



Neutron showers indistinguishable from proton showers

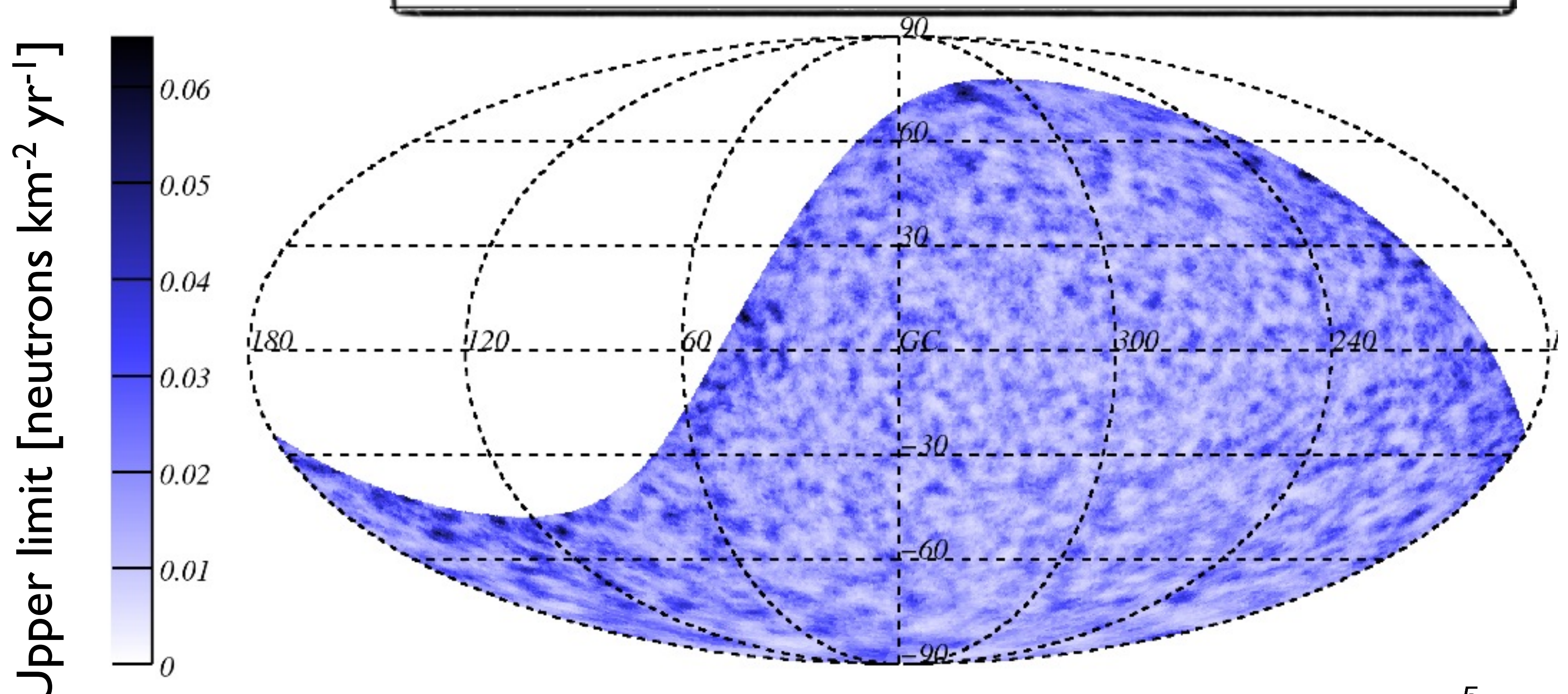
Identify from excess of CRs from source direction at E > 1EeV

UHE neutrons in Auger



Class	No.	≥1 EeV	1-2 EeV	2-3 EeV	≥3 EeV
		Unweighted P-value P			
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

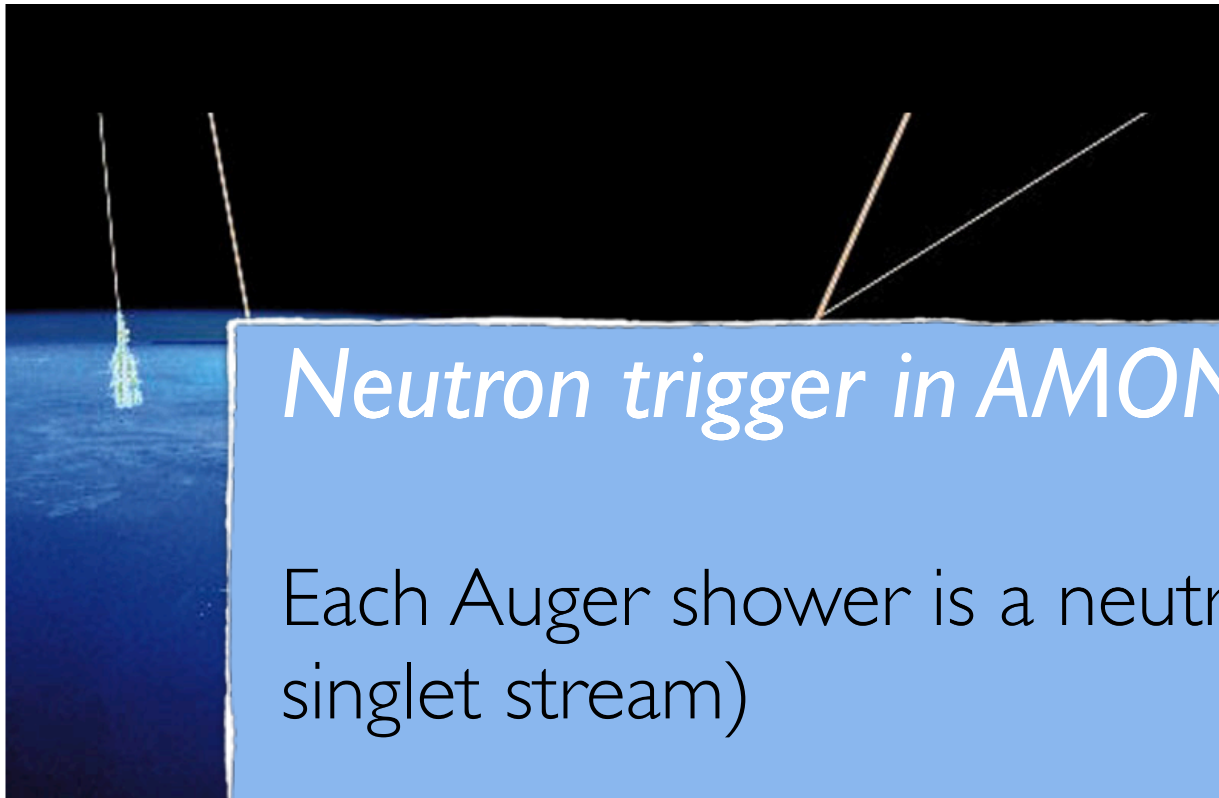
Blind/targeted/ stacked searches have placed strong limits on neutron flux at E > 1 EeV from steady Galactic sources/ GC



Auger Coll. ApJ 789 (2014) L34

UHE neutrons in Auger

		Unweighted P-value P			
Class	No.	≥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
				75	0.042
				66	0.028
				88	0.86
				23	0.56
				33	0.41
				22	0.17
				70	0.25



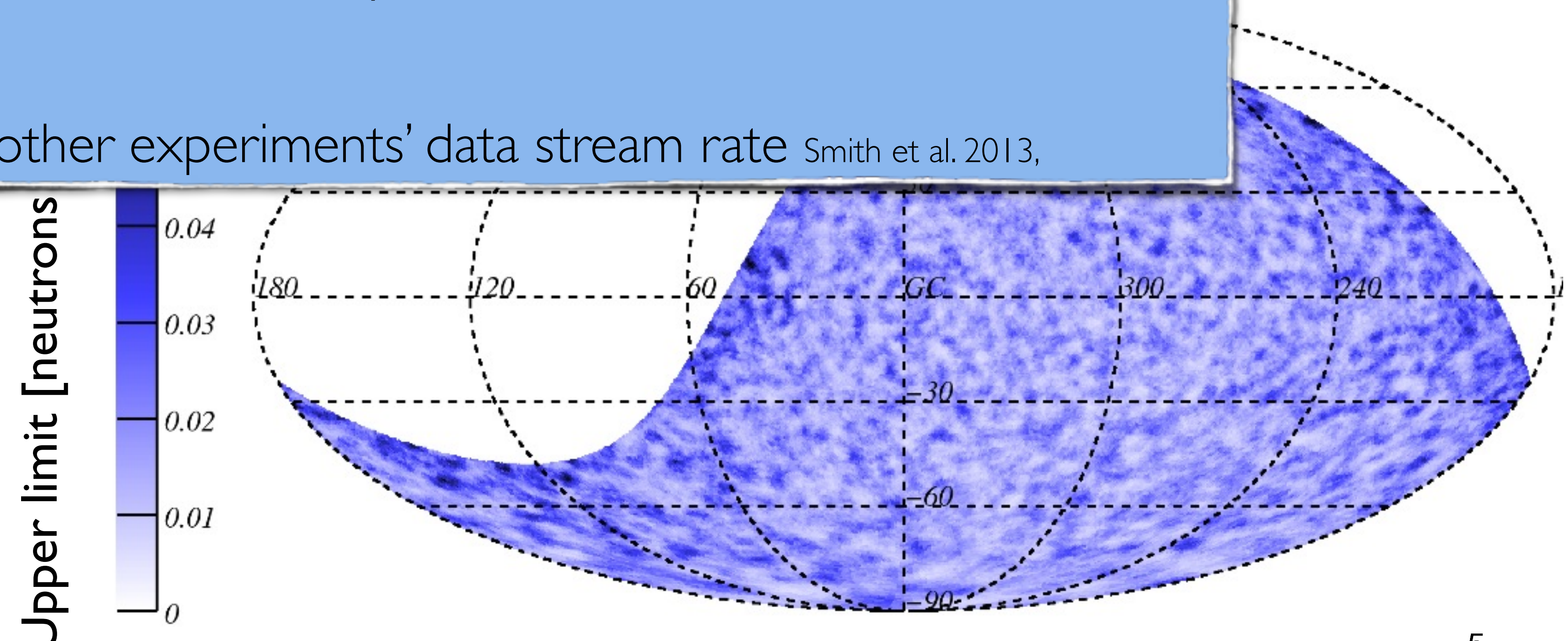
Neutron trigger in AMON:

Each Auger shower is a neutron candidate (cf. IceCube singlet stream)

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

*sensitive to other experiments' data stream rate Smith et al. 2013,

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



Auger Coll. ApJ 789 (2014) L34

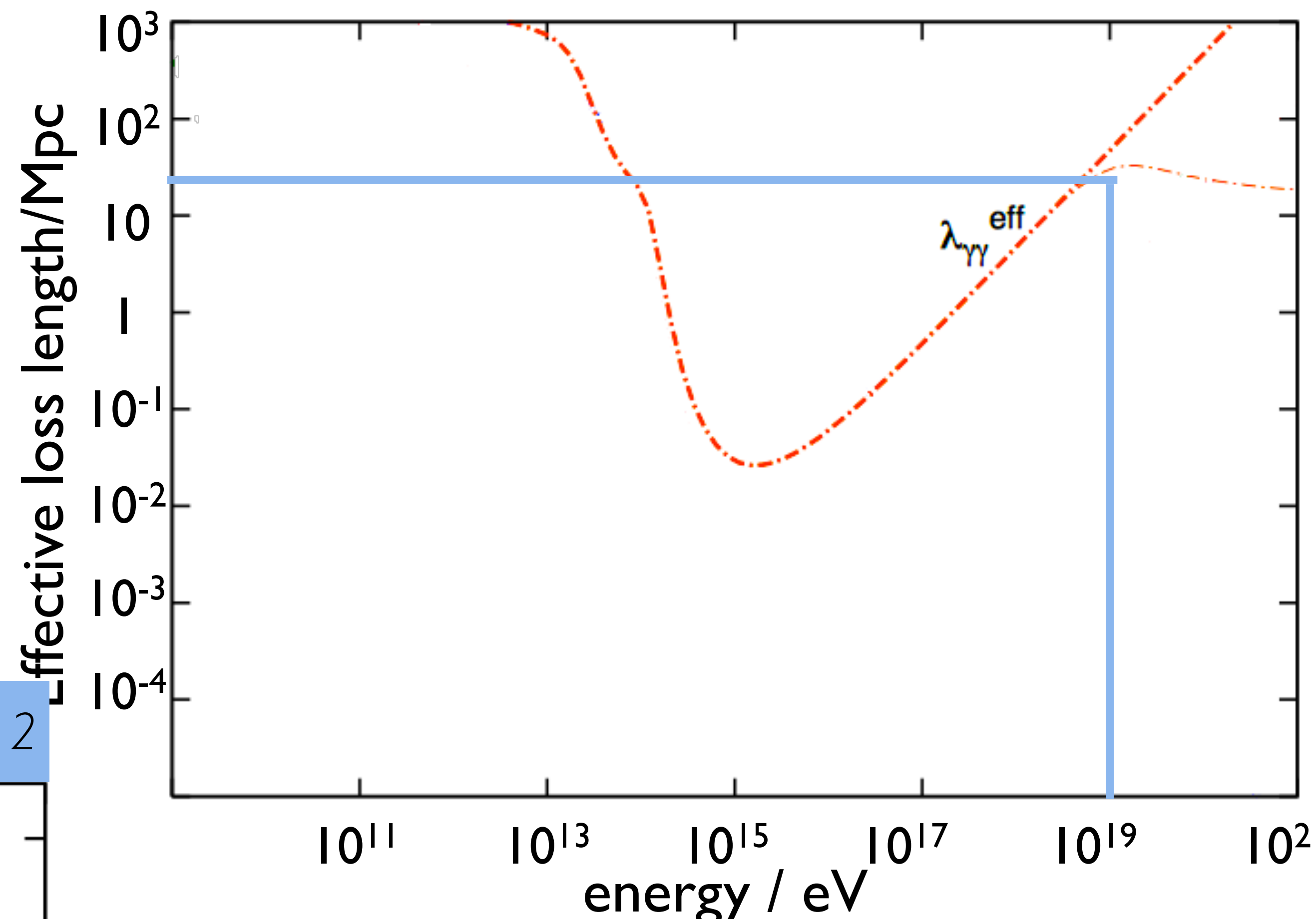
UHE Photons

talk by **D. Kuempel**
yesterday

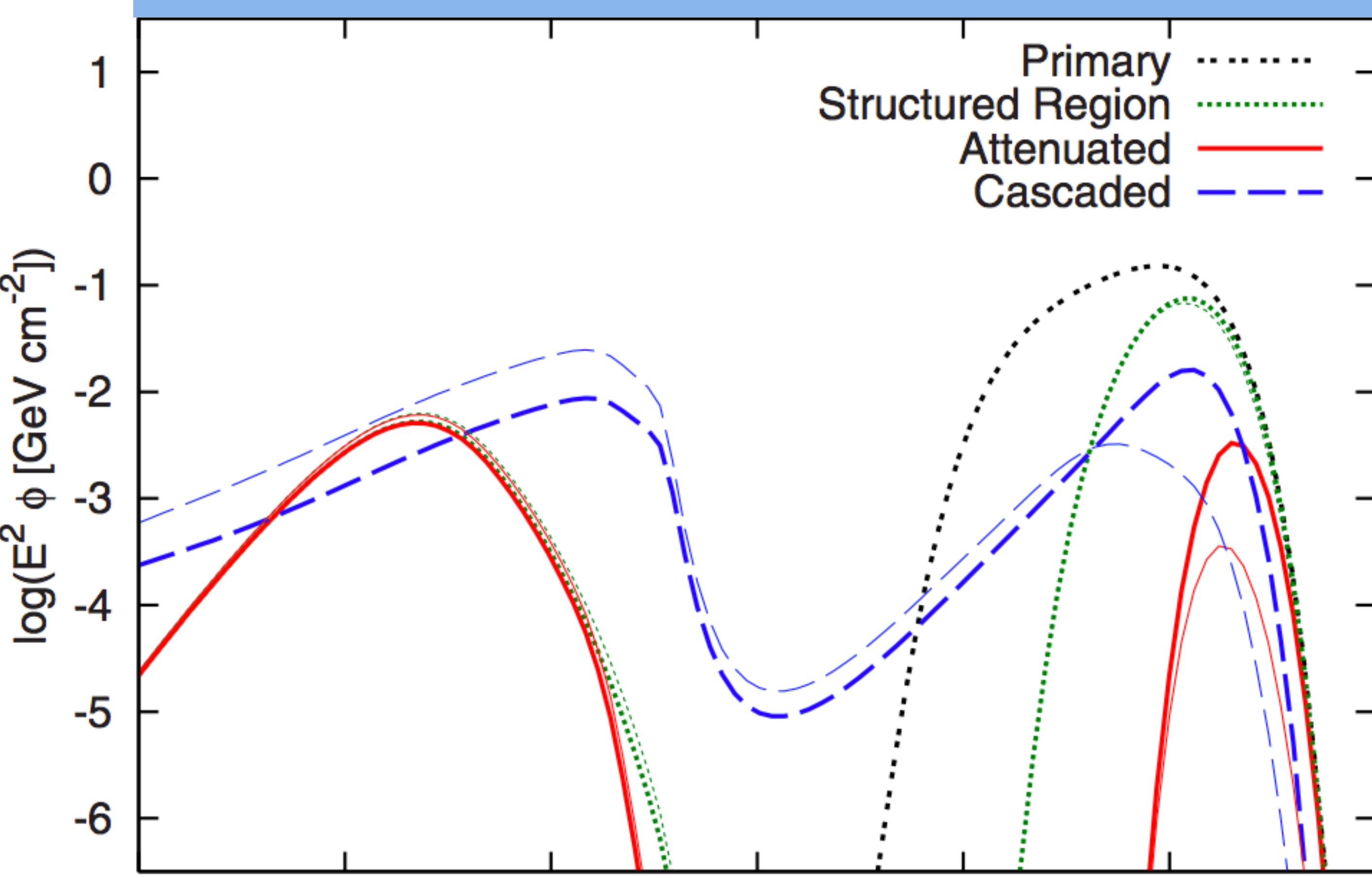
$\gamma \longrightarrow e \longrightarrow \gamma$… (Stecker 73, Gould&Rephaeli 78)

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

Murase, ApJL 745:L16, 2012



e.g. LL GRB @20 Mpc *Murase, ApJL 745:L16, 2012*



+AGN Flares

Magnetars/Pulsars

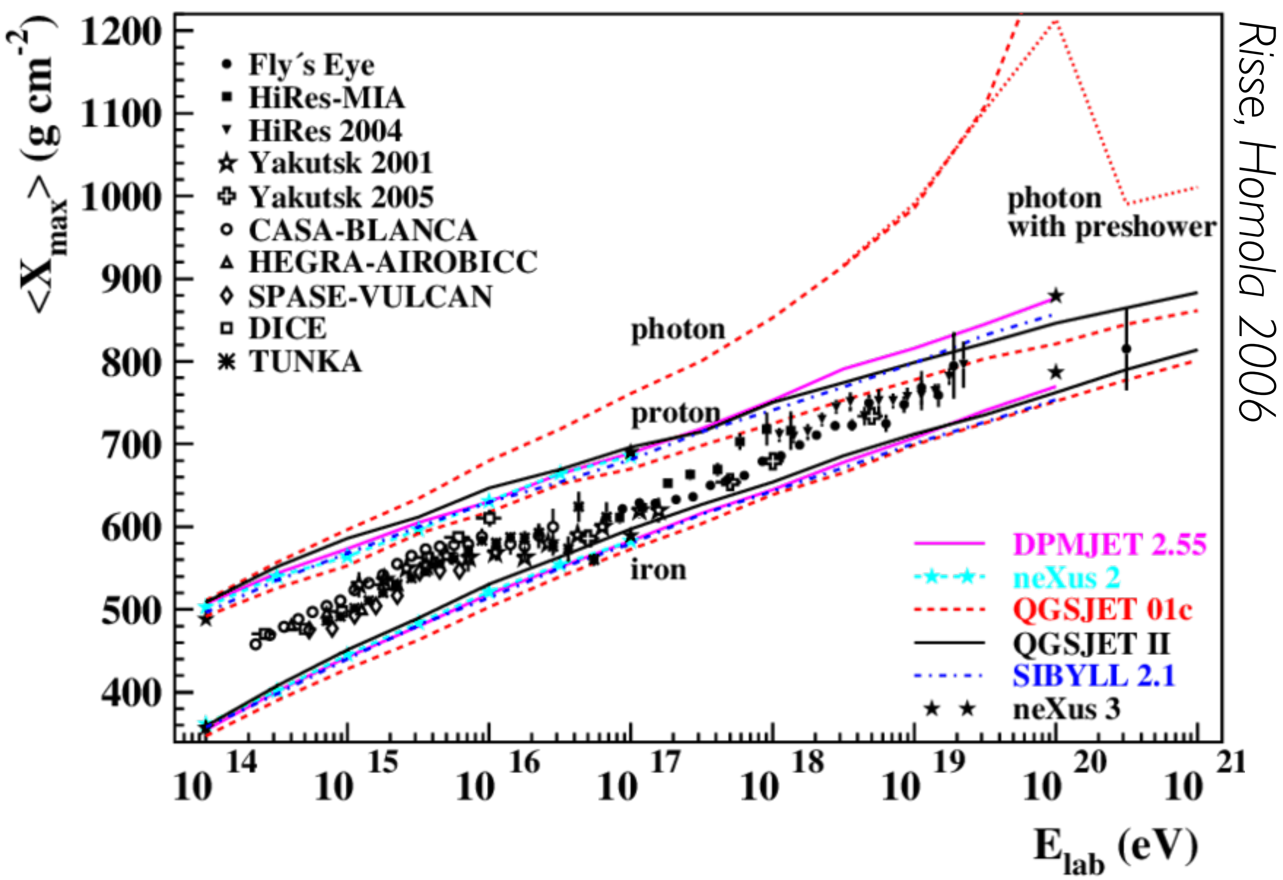
TDEs

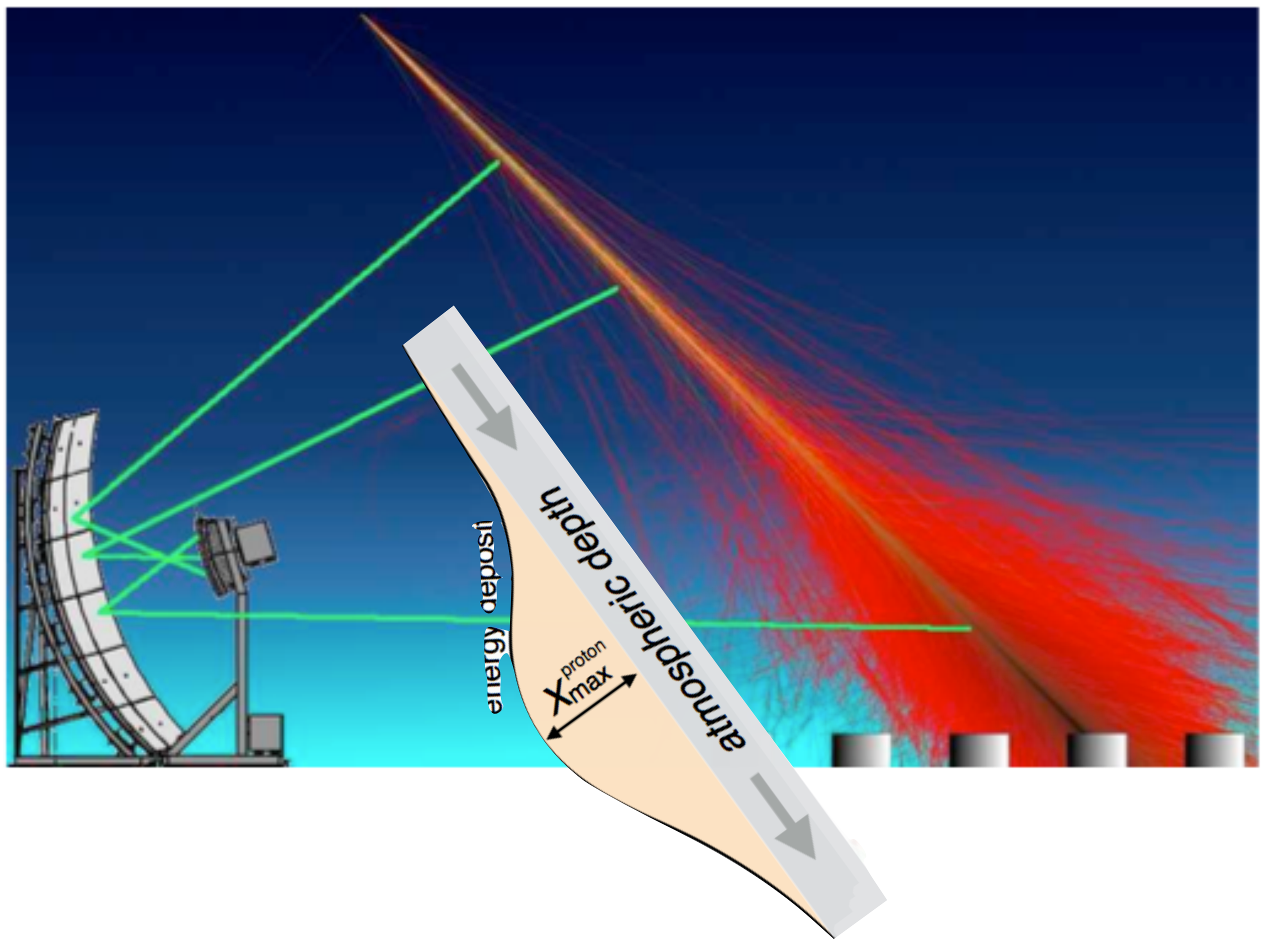
Galactic γ-ray sources

UHE photon searches: Experimental Observables

UHE photons distinguishable from hadronic showers

FD: state of the art (X_{max})





UHE photon searches: Experimental Observables

UHE photons distinguishable from hadronic showers

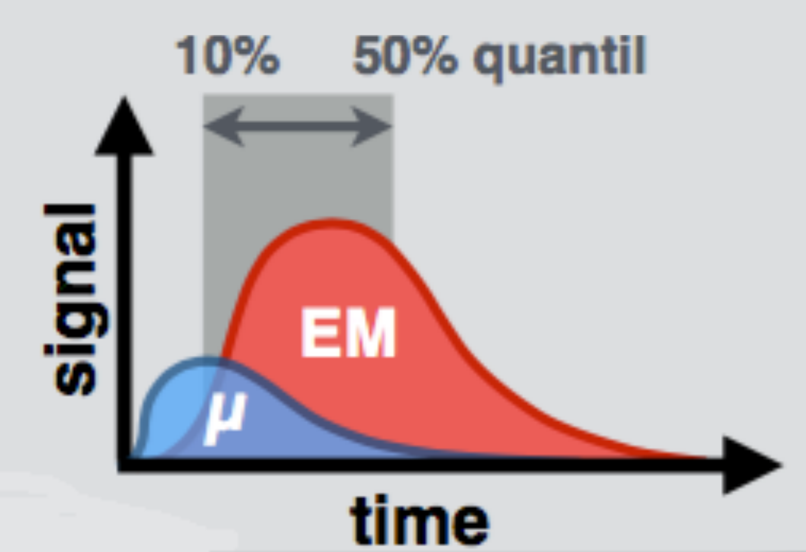
SD: Universality/shower radius of curvature/risetime/ muon content) ⟶Much higher statistics, real-time reconstruction

Risetime:

Time difference between 10% and 50% quantile of signal in surface detector

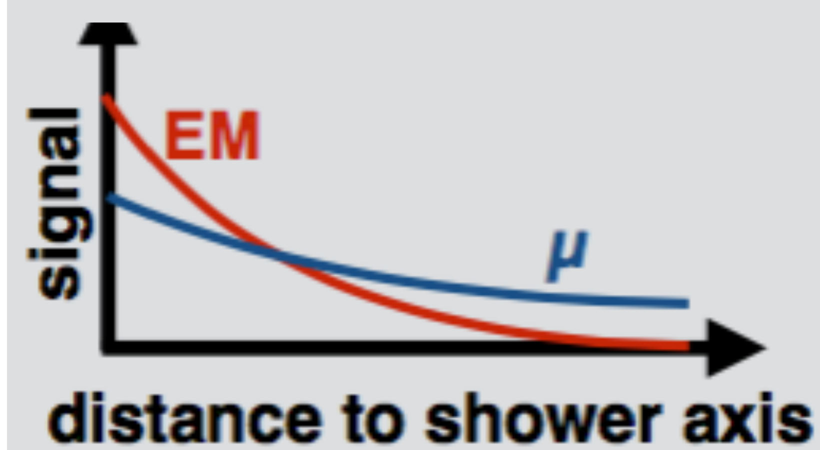
Larger for:

- Signals dominated by EM component
- Deep developing showers



Lateral distribution:

Lateral distribution function (LDF) of EM rich events is steeper compared to average.



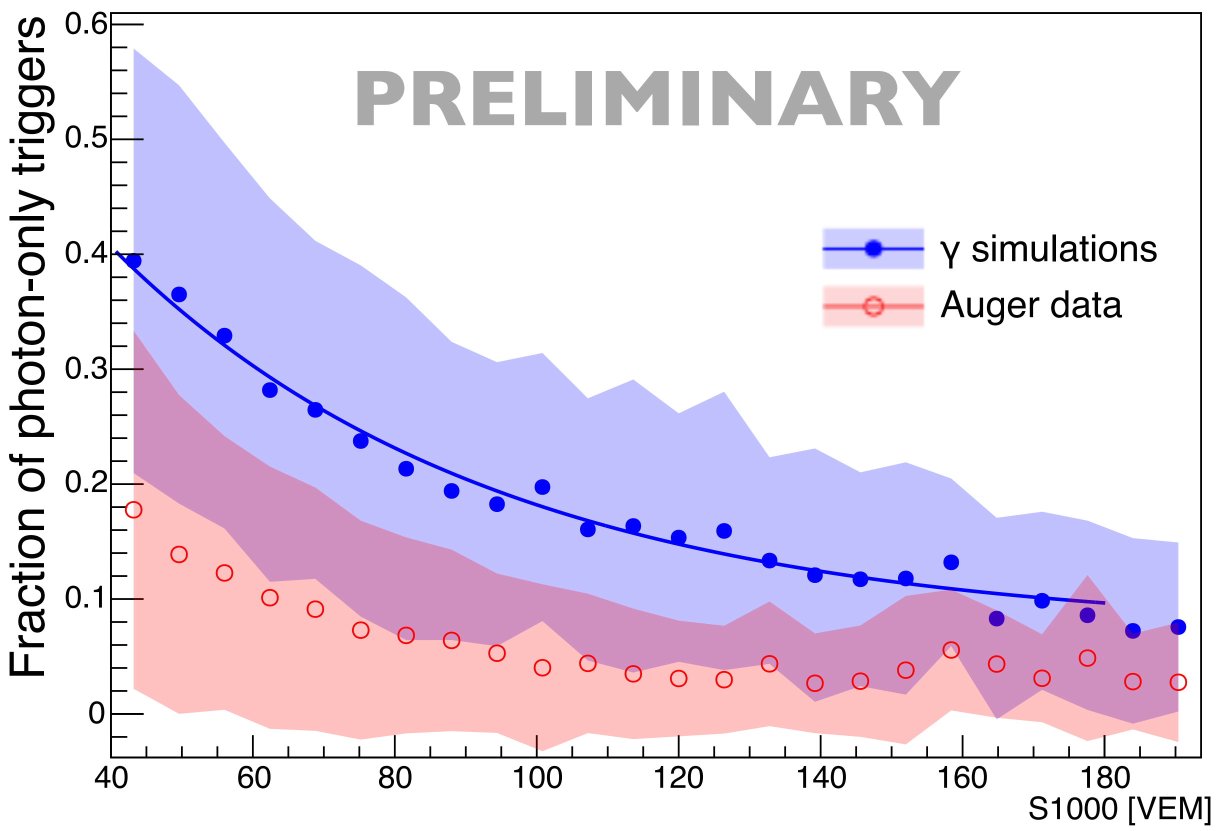
Realtime photon tagging for AMON

-New triggers installed in 2013 in SD array

-Trigger probability, at large distance from shower axis significantly enhanced for photons

-100 x previous search statistics (lower E threshold)/new triggers used

-γ-like showers trigger AMON



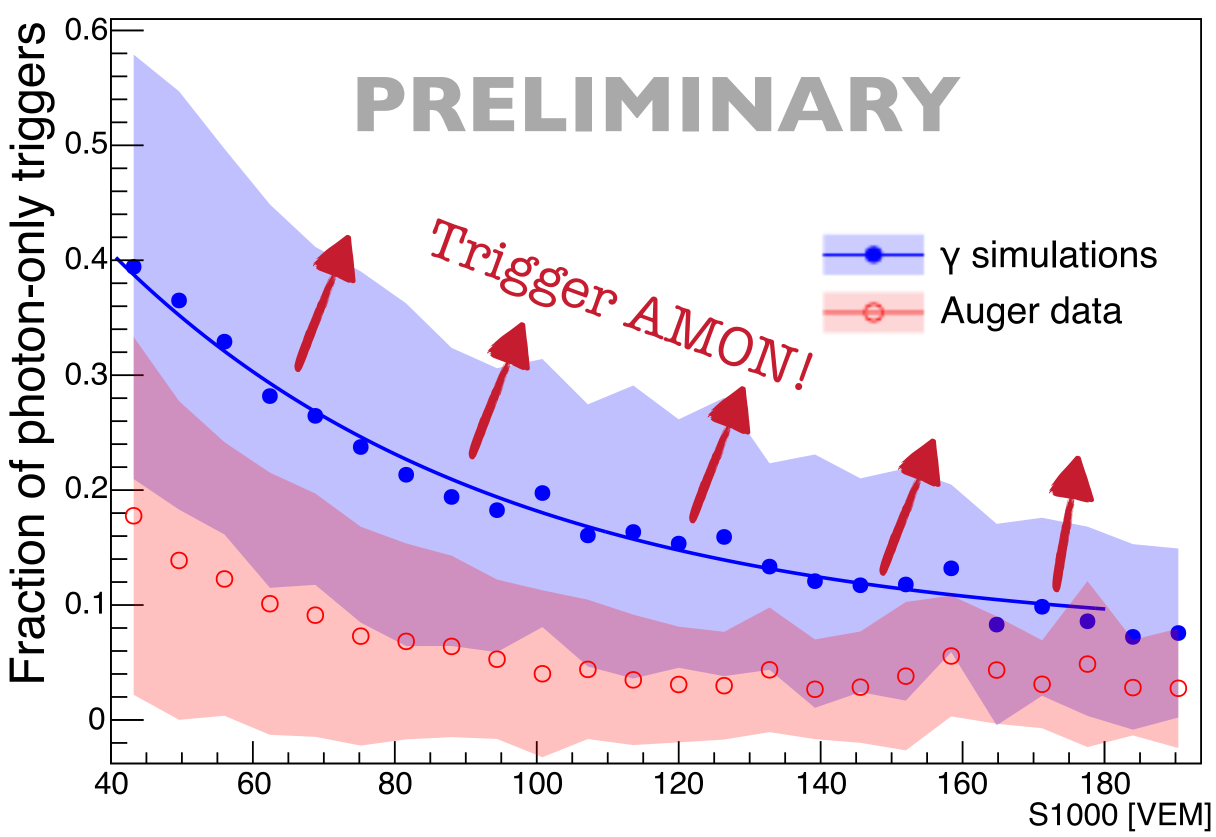
Realtime photon tagging for AMON

-New triggers installed in 2013 in SD array

-Trigger probability, at large distance from shower axis significantly enhanced for photons

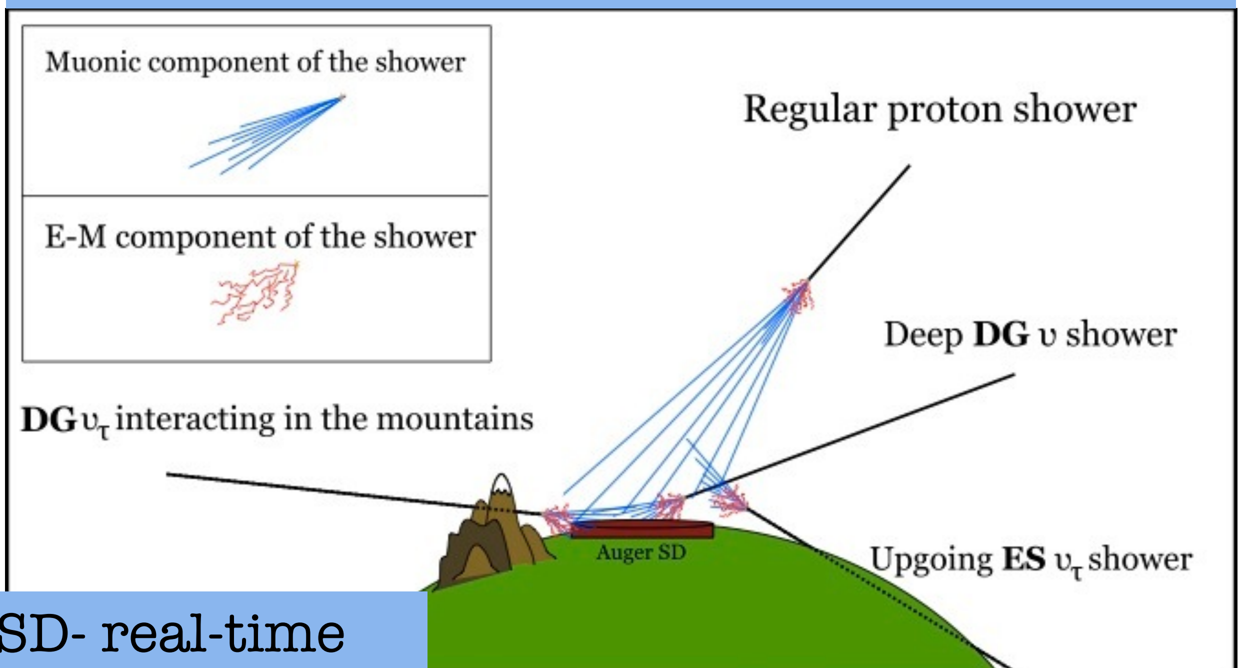
-100 x previous search statistics (lower E threshold)/new triggers used

-γ-like showers trigger AMON

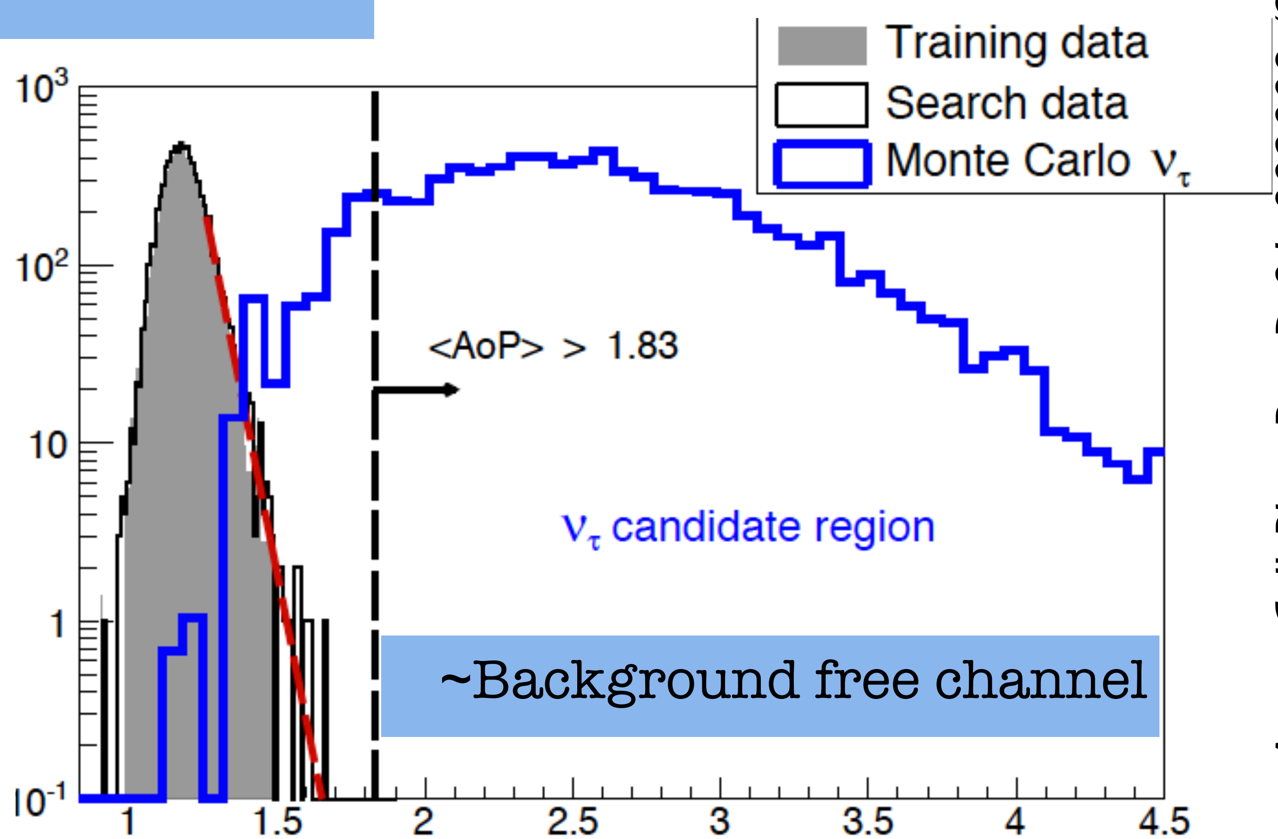


UHE neutrinos

Highly inclined or Earthskimming showers

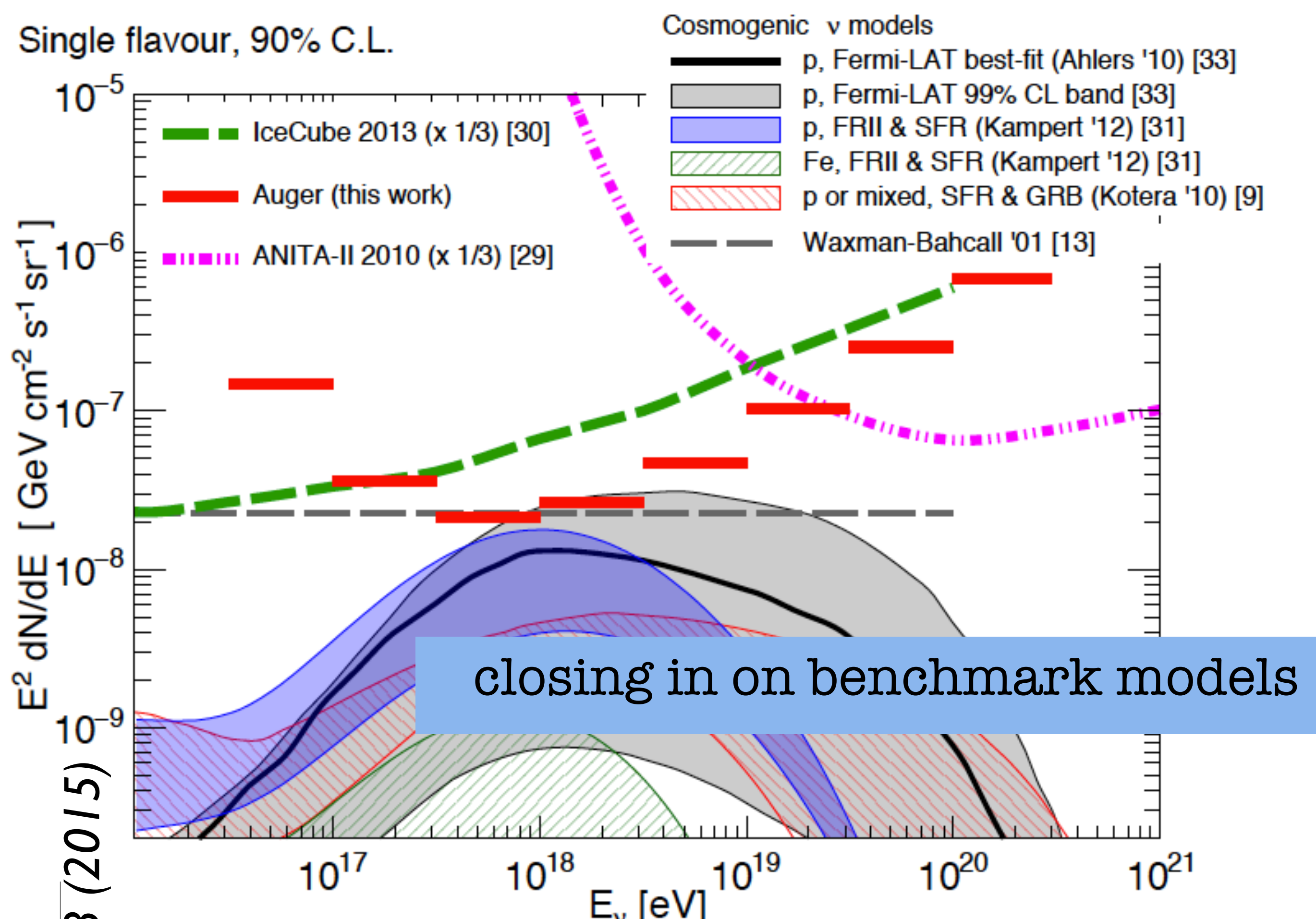


SD- real-time reconstruction



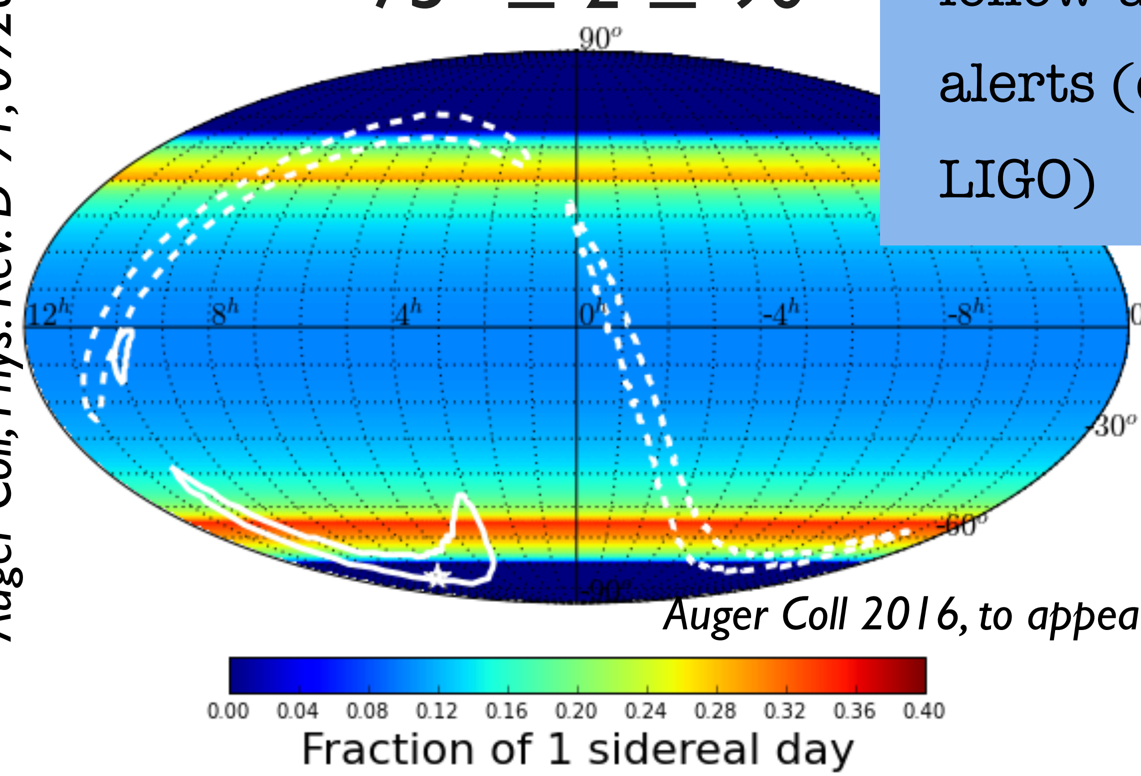
~Background free channel

Auger Coll, Phys. Rev. D 91, 092008 (2015)



closing in on benchmark models

$75° \leq z \leq 90°$



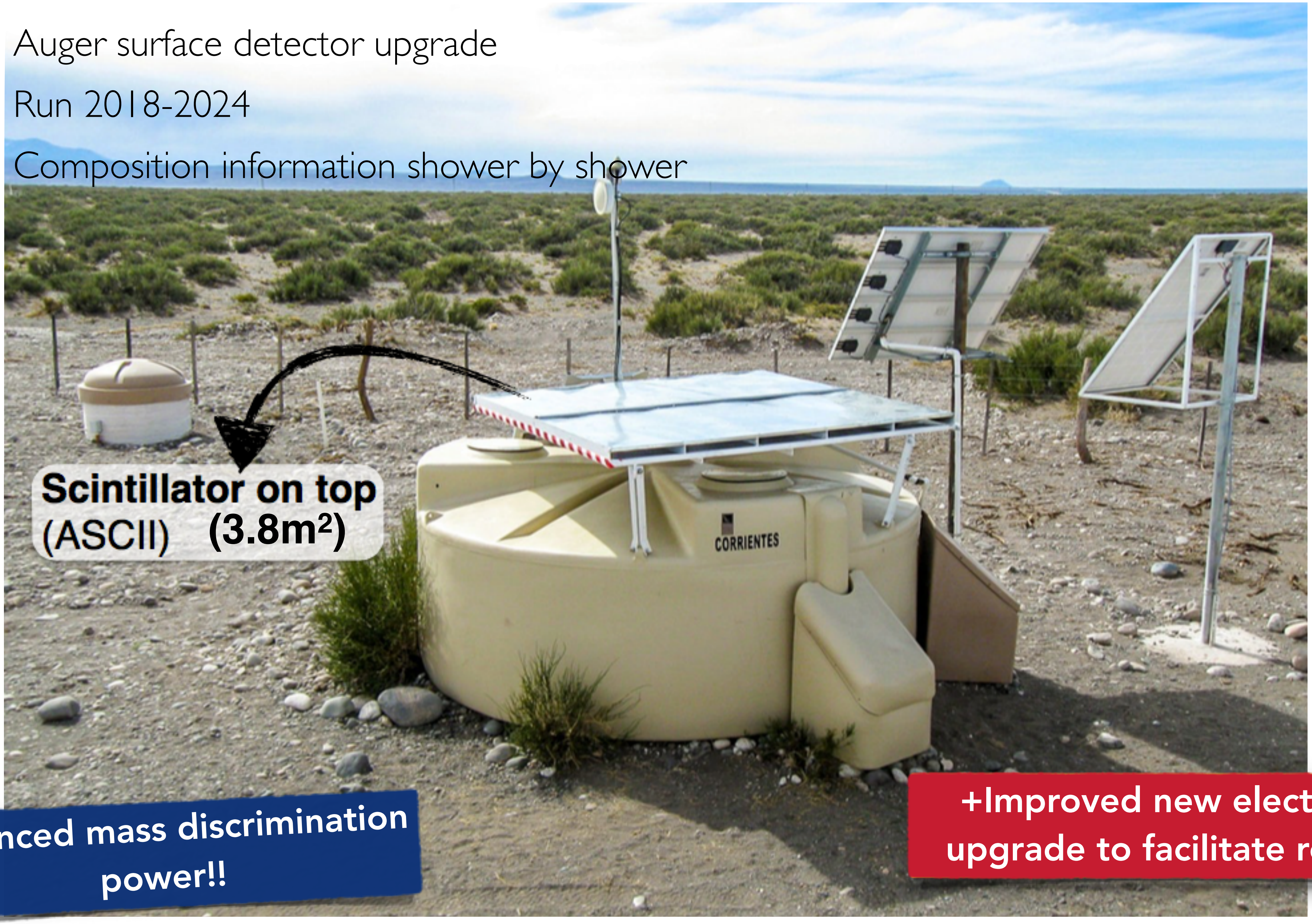
follow-up alerts (e.g. LIGO)

Auger Coll 2016, to appear in PRD

0

The future: AugerPrime

see Julian Kemp's poster!

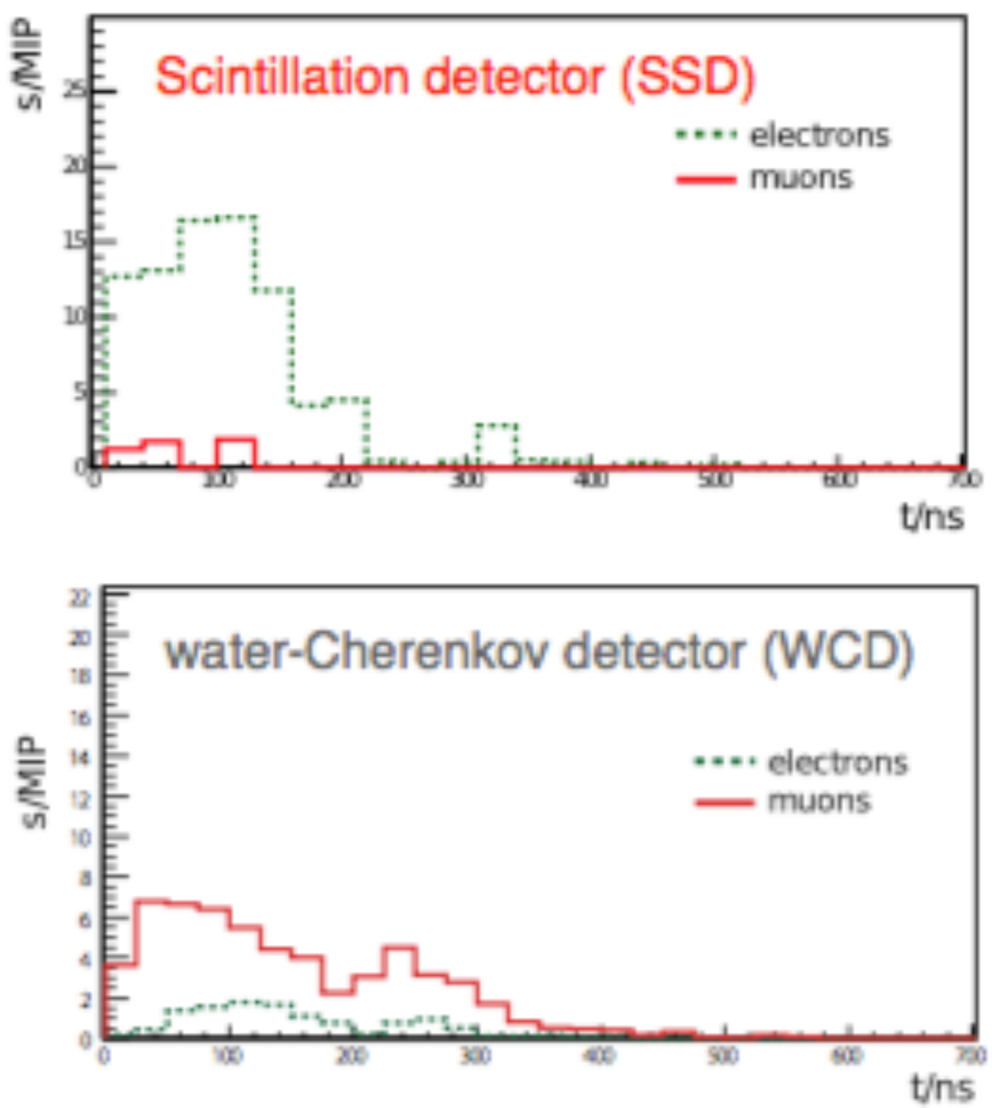


Enhanced mass discrimination power!!

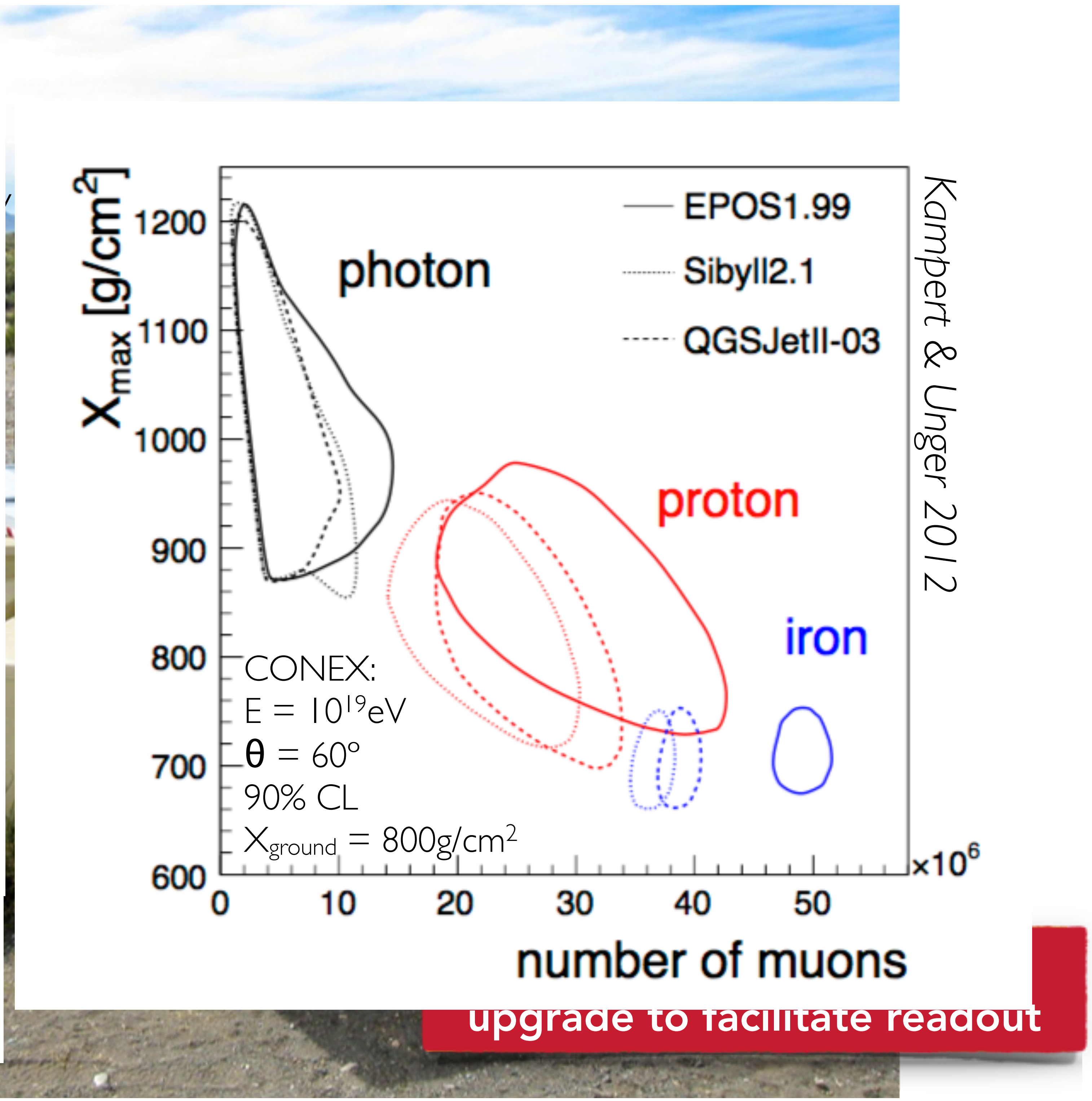
+Improved new electronics upgrade to facilitate readout

The future: AugerPrime

see **Julian Kemp's** poster!



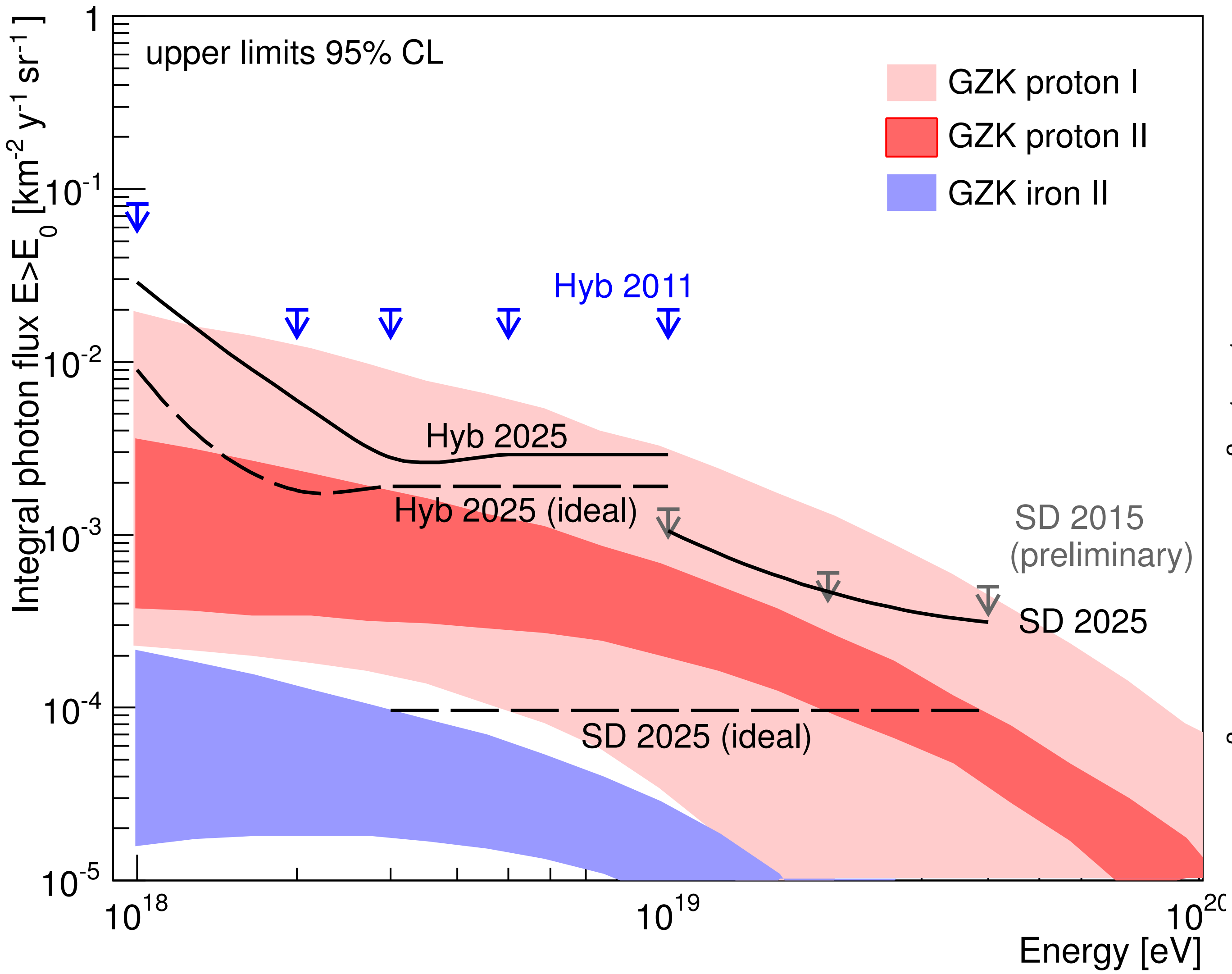
$$S_{\mu,\mathrm{WCD}} = a S_{\mathrm{WCD}} + b S_{\mathrm{SSD}}$$

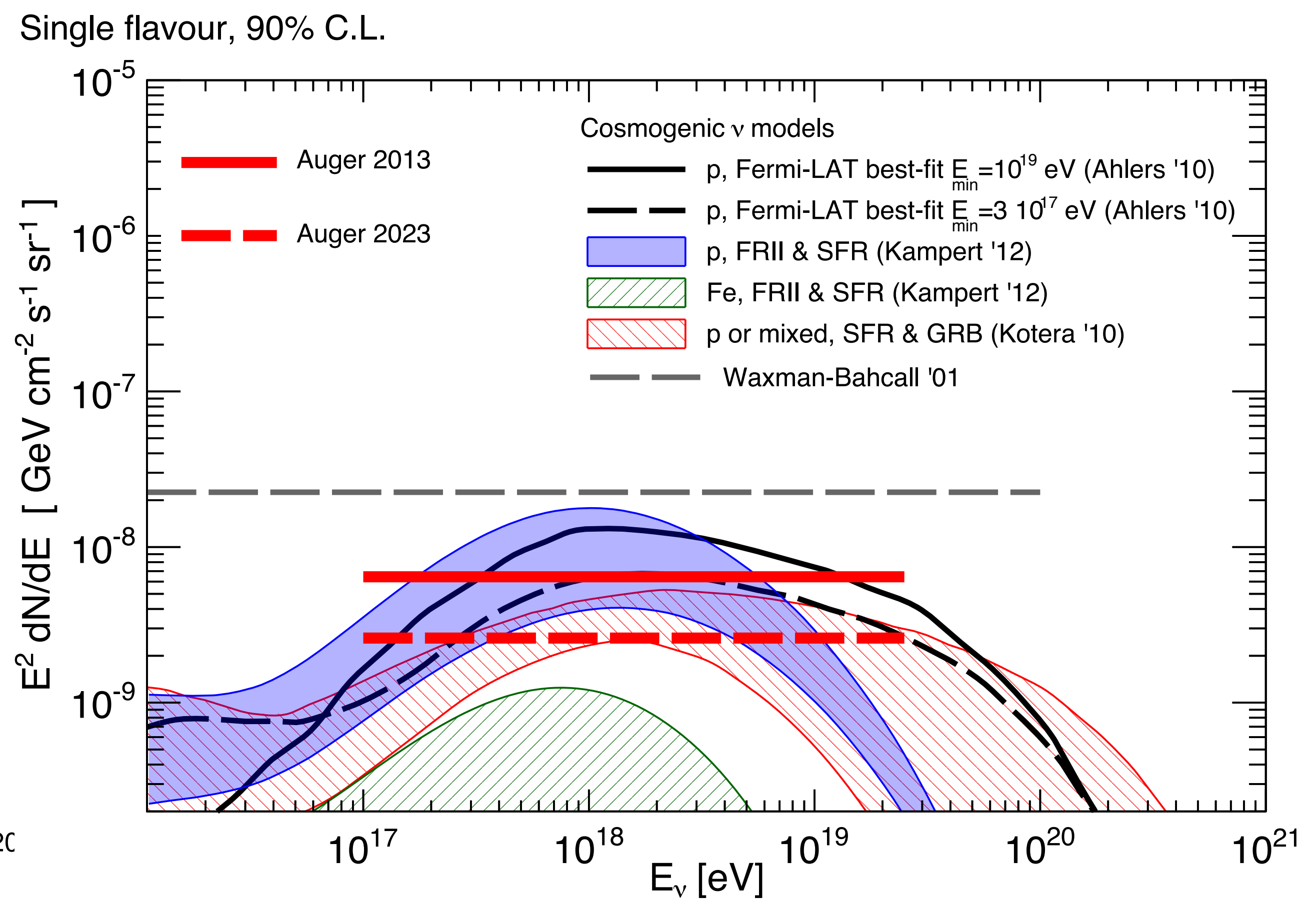


AugerPrime: Photon & Neutrino reach

Auger Coll, ICRC 2015

Increased exposure
Improved low-energy trigger (low-energy threshold)
Improved mass discrimination power





Outlook

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

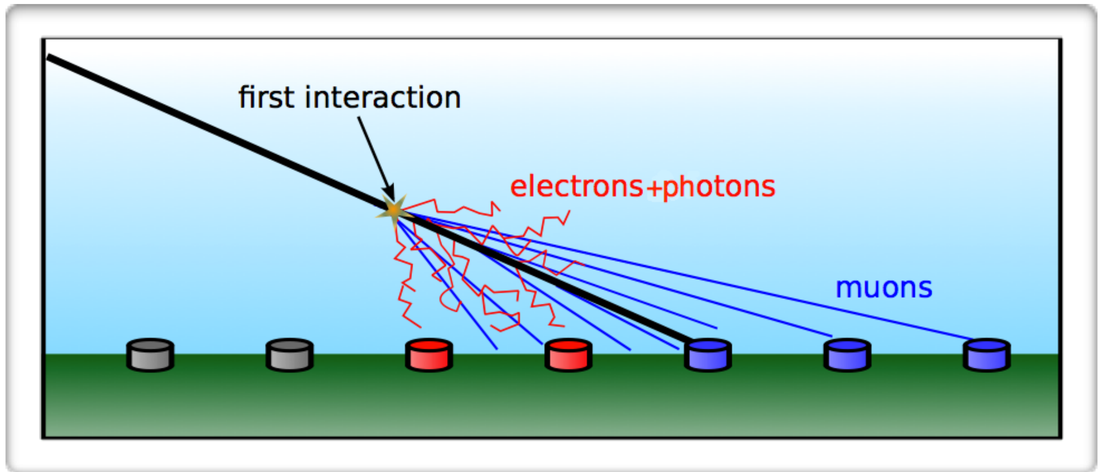
No neutral flux identified yet- but close to benchmark cosmogenic predictions

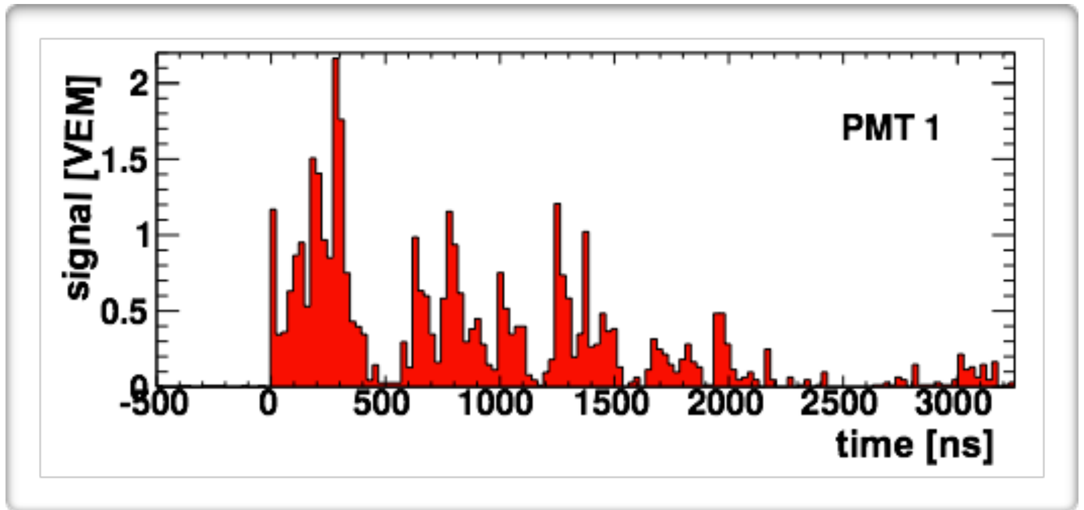
Surface detector upgrade will facilitate detection of UHE neutrals + follow-up alerts!

Back-up

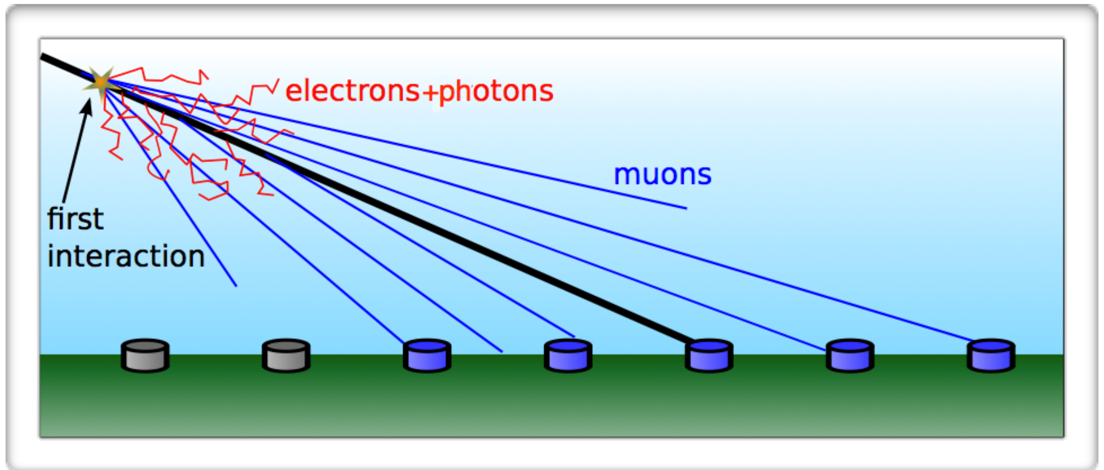
UHE neutrinos

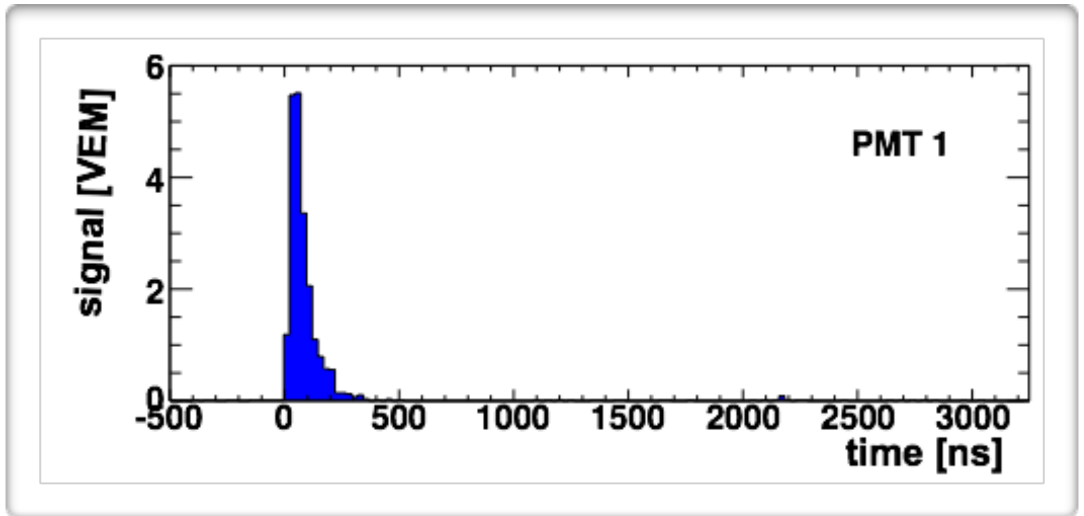
``Young” EM shower front





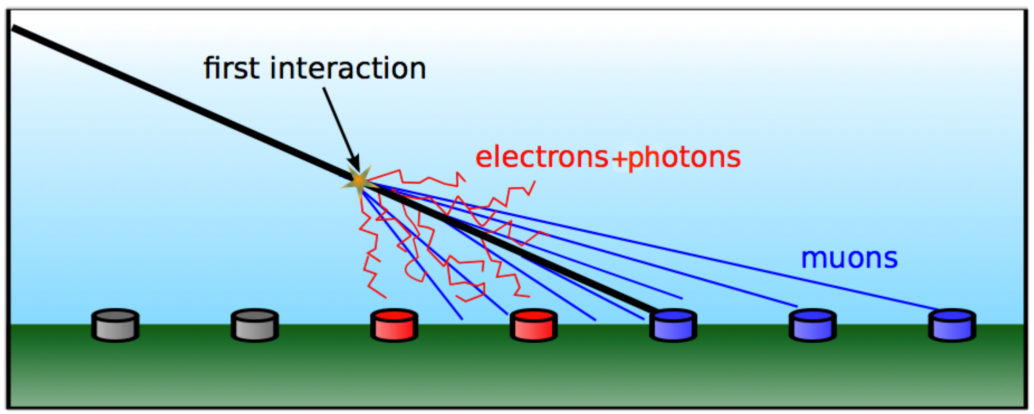
``Old” muonic shower front



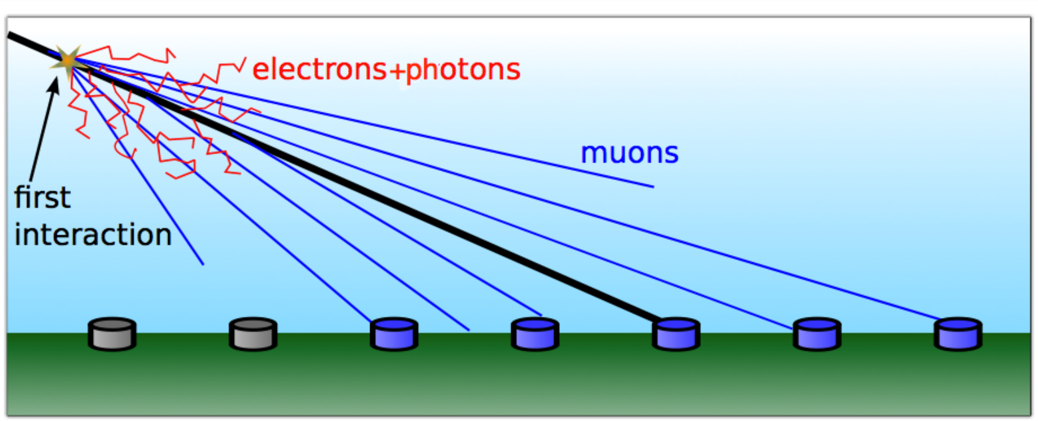


UHE neutrinos

``Young" EM shower front

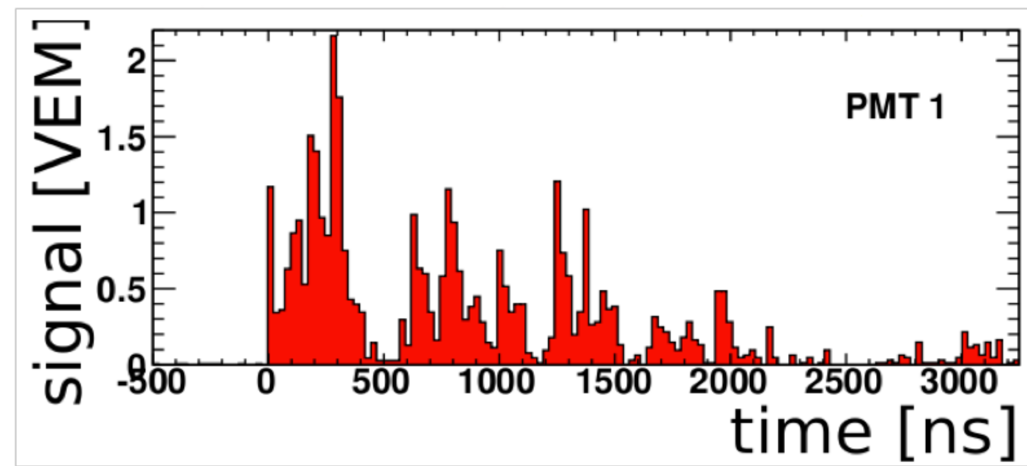


``Old" muonic shower front

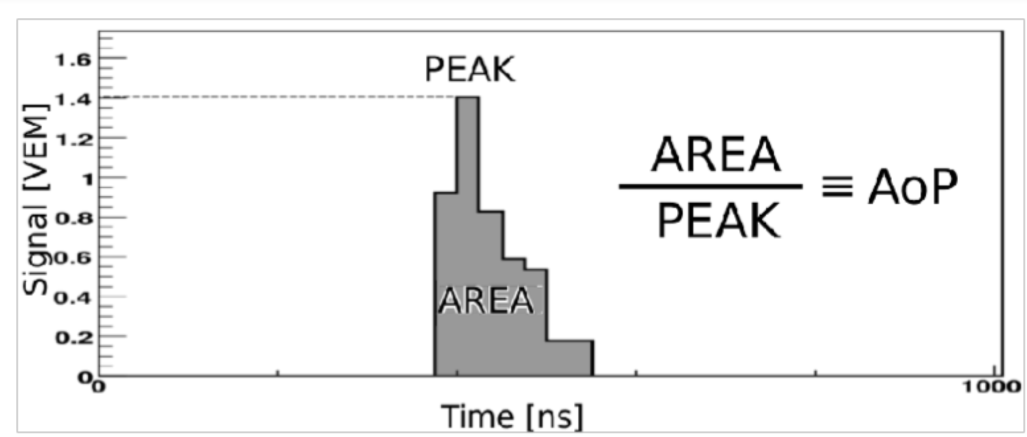


Signatures of young/inclined showers:

Time-over-threshold (ToT) trigger:



and/or large Area-over-Peak:



UHE photon search results

Auger Coll, PoS(ICRC2015) 1103

Data 01/01/04 – 15/06/13, zenith 30°-60°

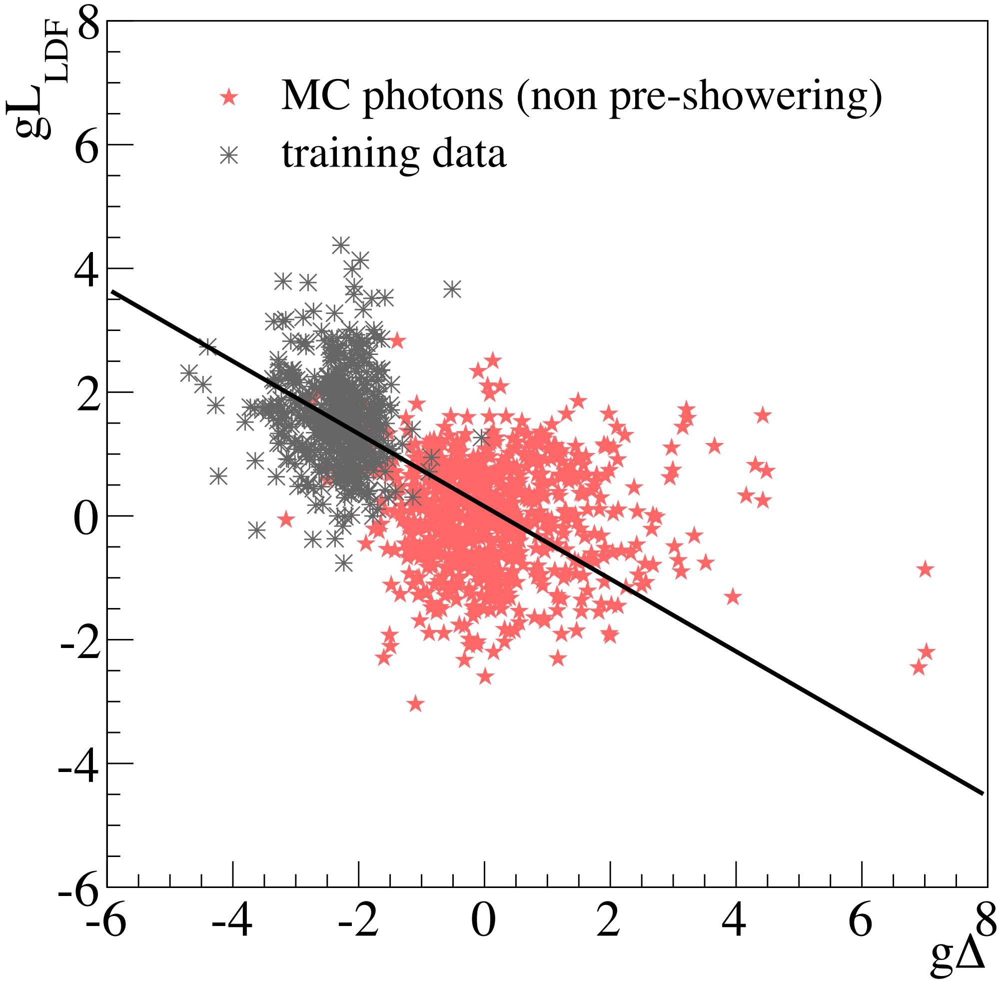
E > 10 EeV

Search data sample (98% of the total): 22853 events

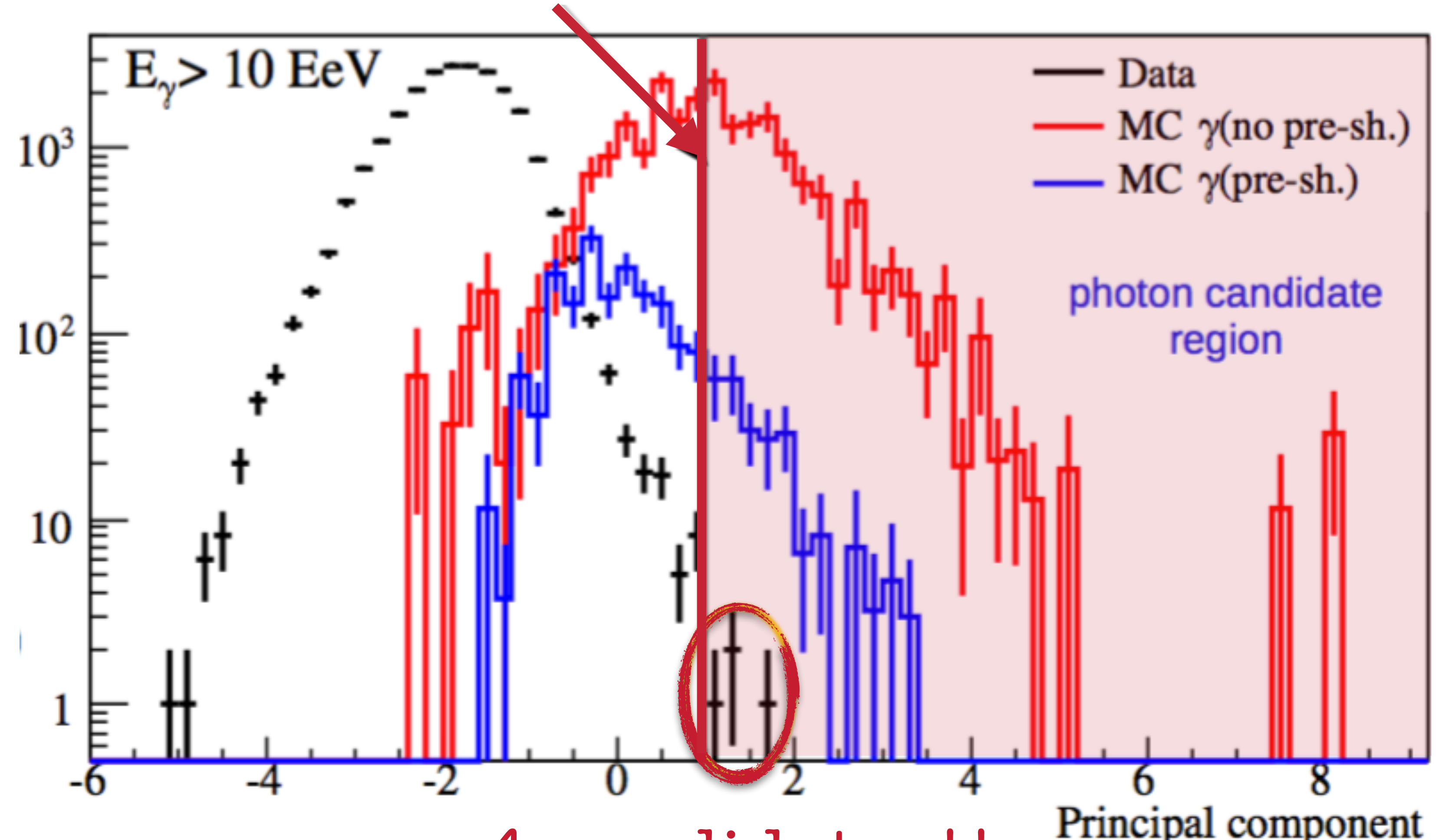
Observables:

L_{Ldf} - deviation from average data LDF

Δ - rise time deviation from the data benchmark

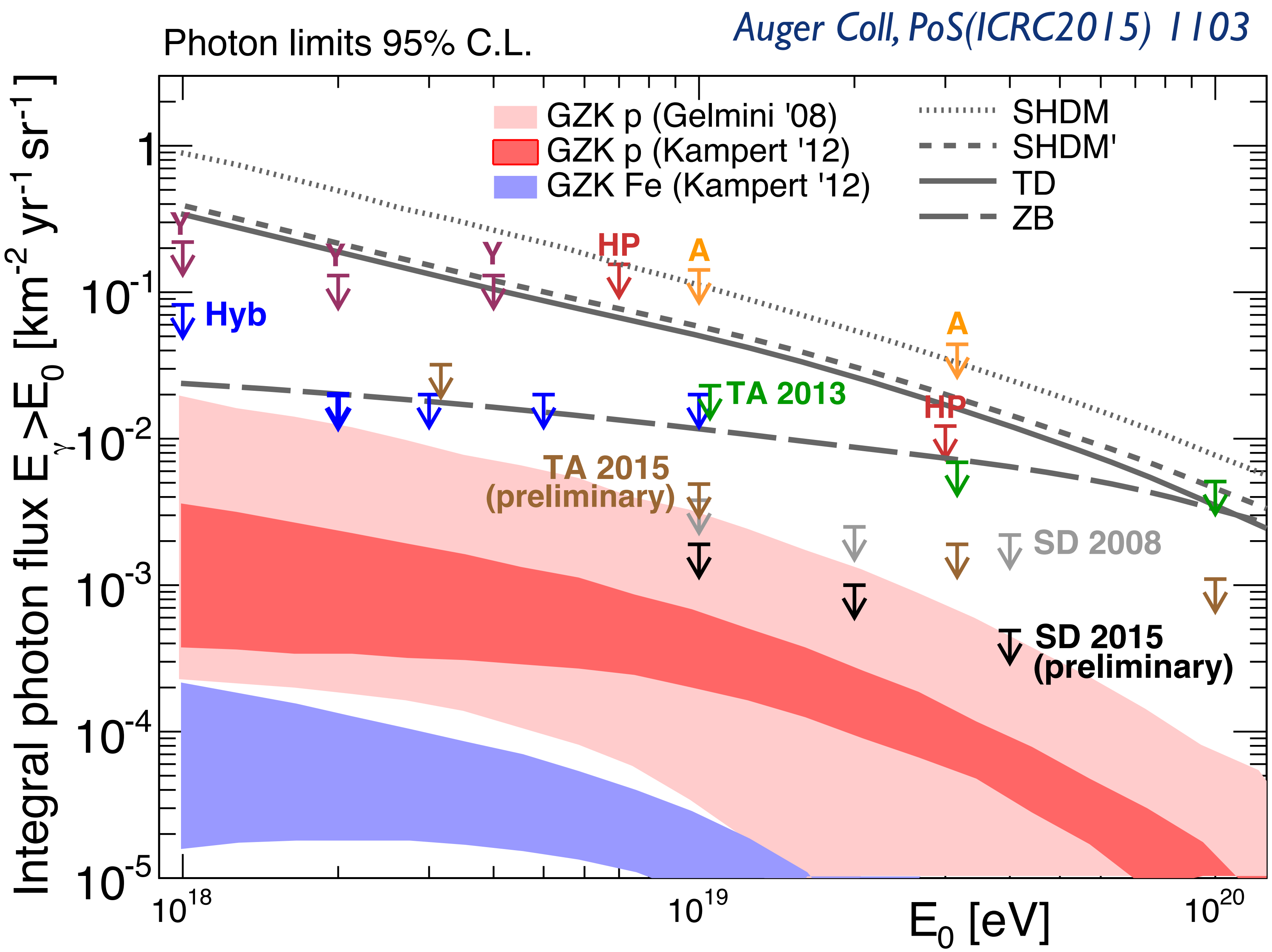


cut in median photon distribution (spectrum ~E^{-2})



4 candidates!!

UHE photon search results



Feldman-Cousins upper limit number of photons

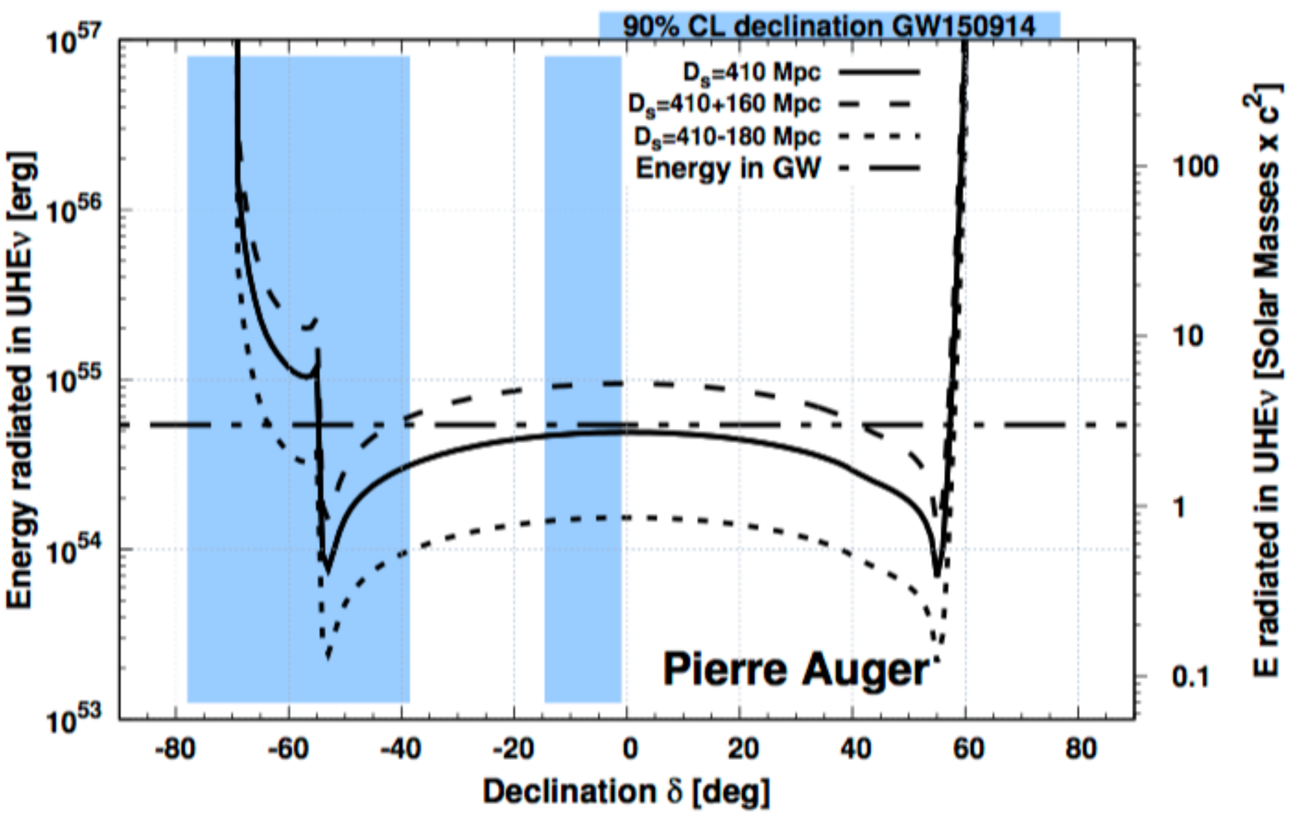
$$F_\gamma(E_\gamma > E_0) = \frac{N_\gamma}{<\mathcal{E}>}$$

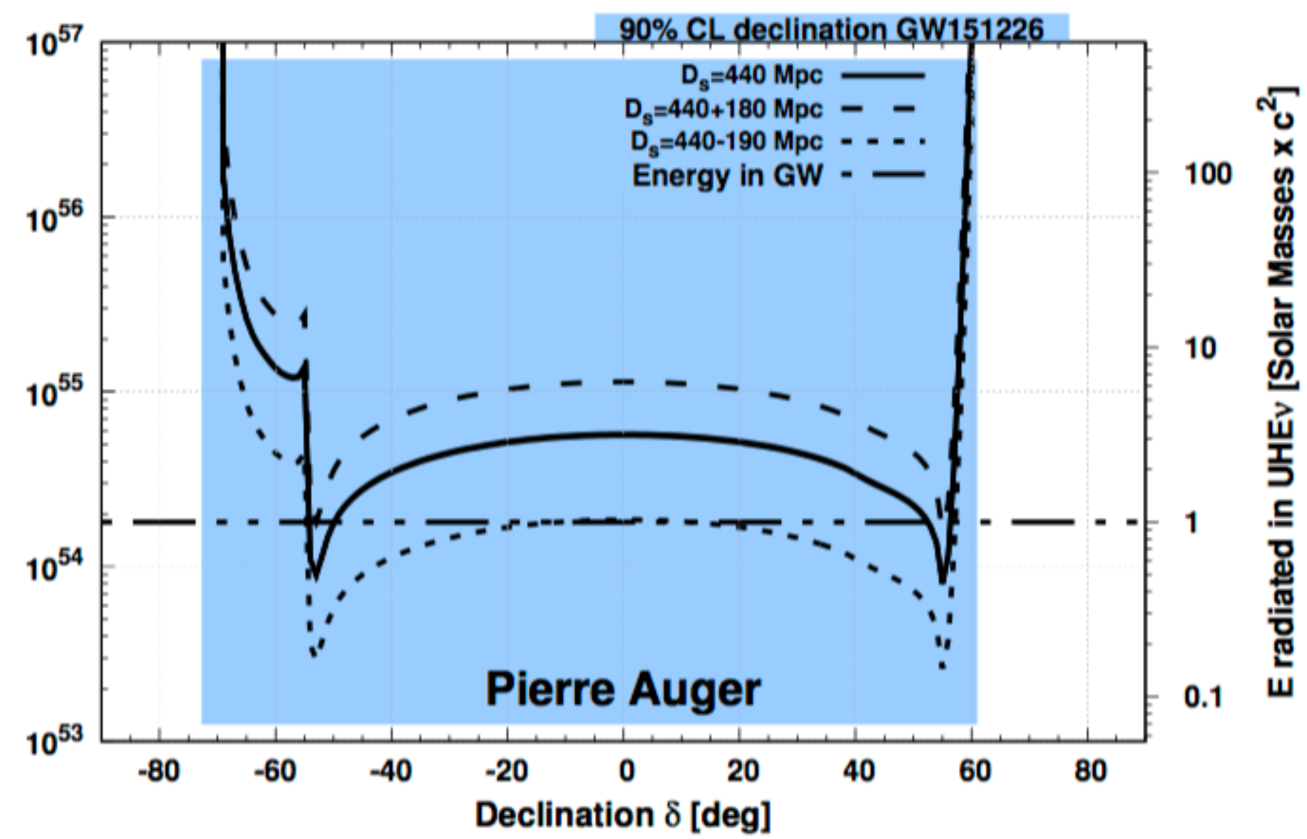
E^{-2} spectrum weighted average exposure

- Strictest limits in range E > 1 EeV
- Top-down models severely constrained by current limits
- Pure p composition of UHECRs+strong source evolution disfavoured
- No point-sources detected

Auger followup of GW150914 and GW151226

Auger Coll 2016, to appear in PRD

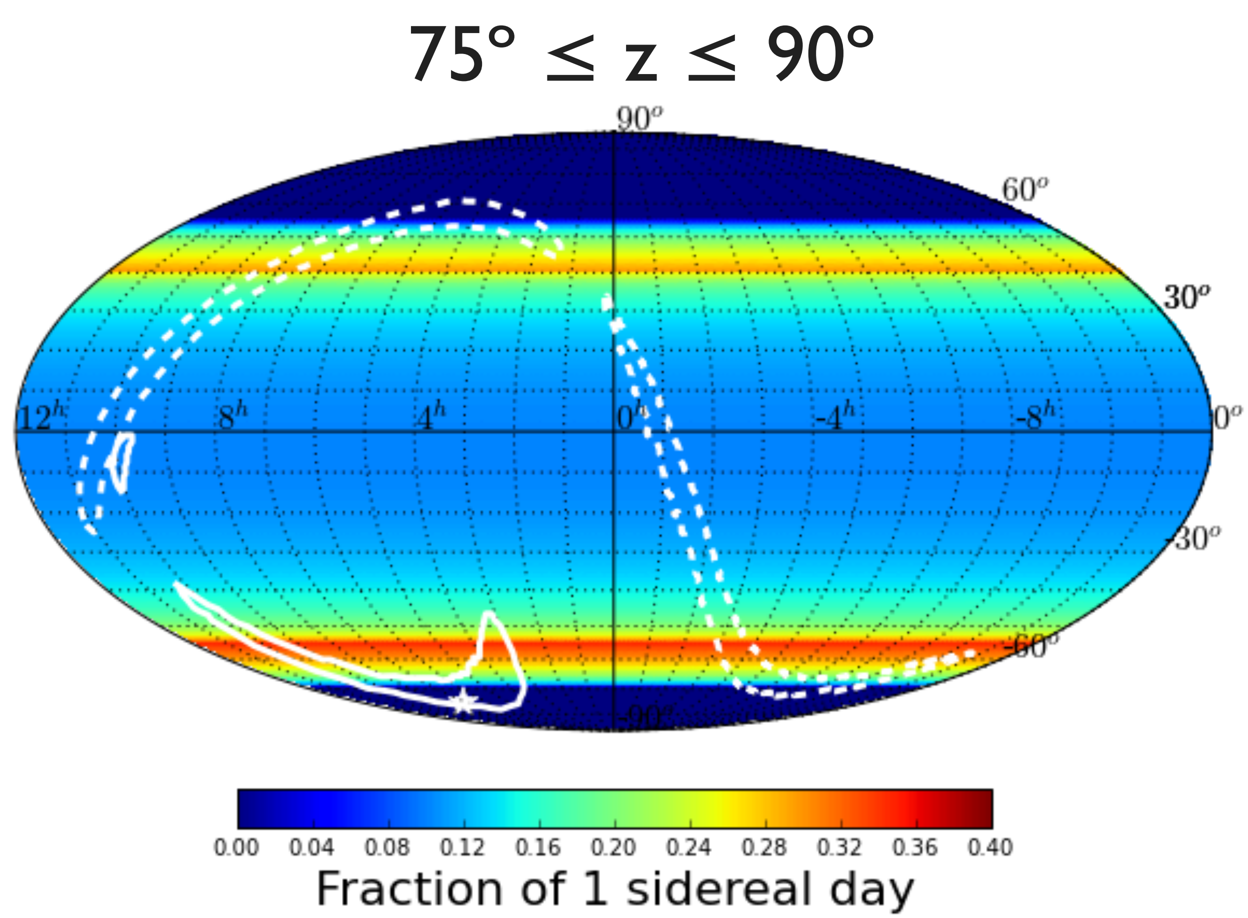


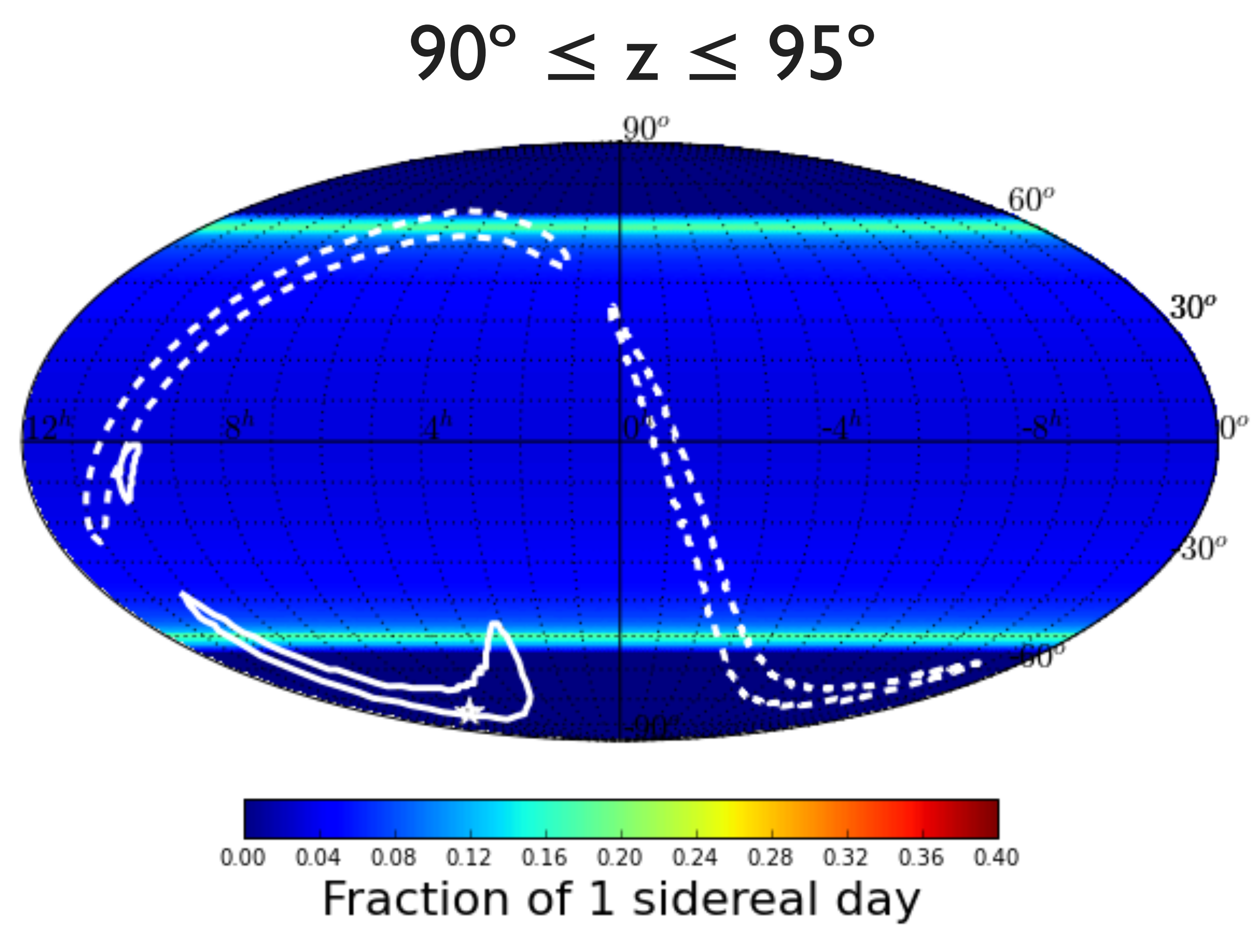


Auger followup of GW150914 and GW151226

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)

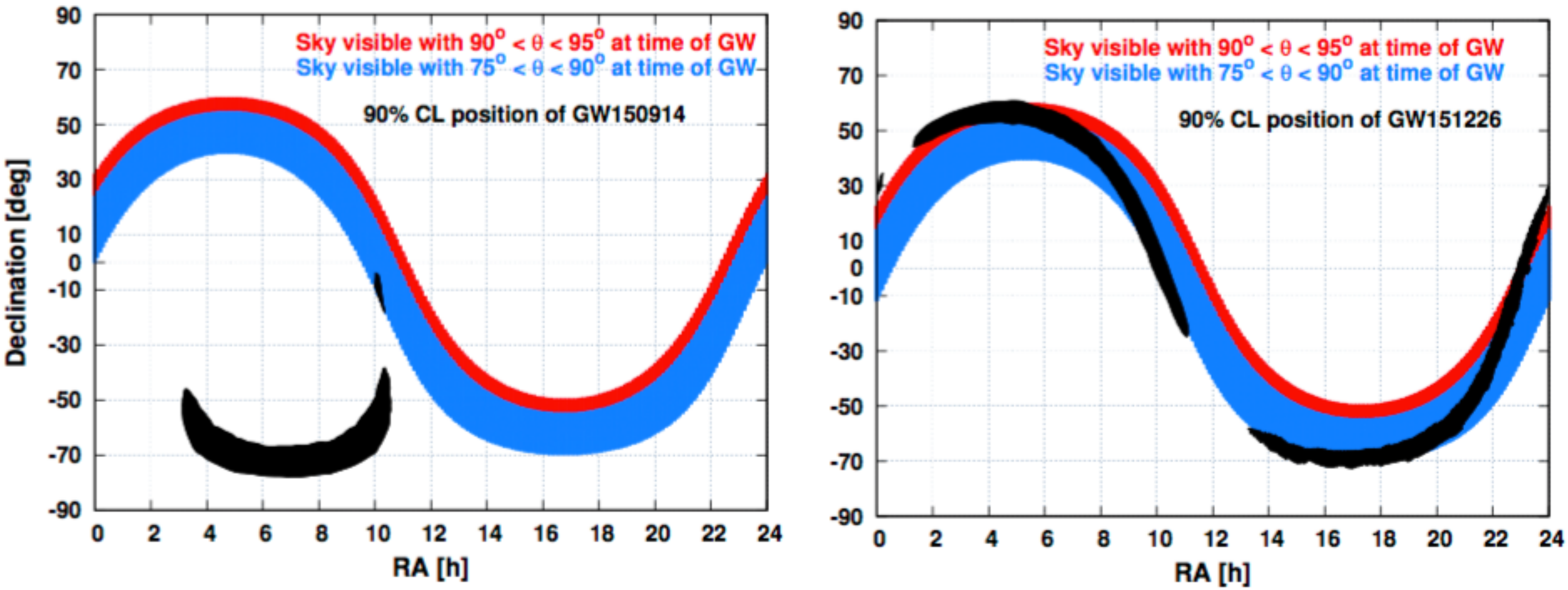




Auger followup of GW150914 and GW151226

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)



- No candidates detected within 500s or 1 day after GW140914/GW15226/LVT15012
- Limits in ~100 PeV-~25 EeV range:

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