Cosmogenic photon and neutrino fluxes in Auger era

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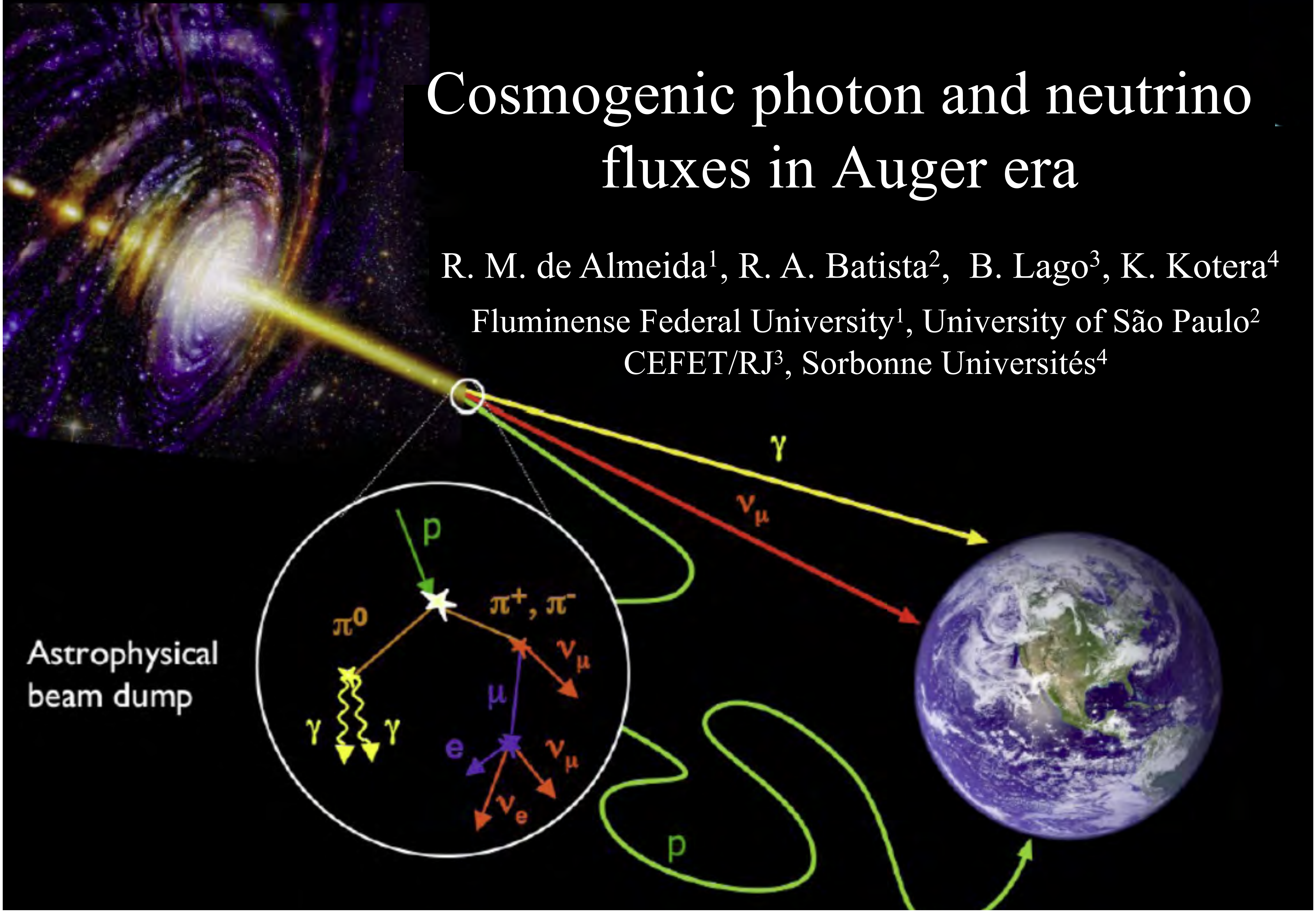
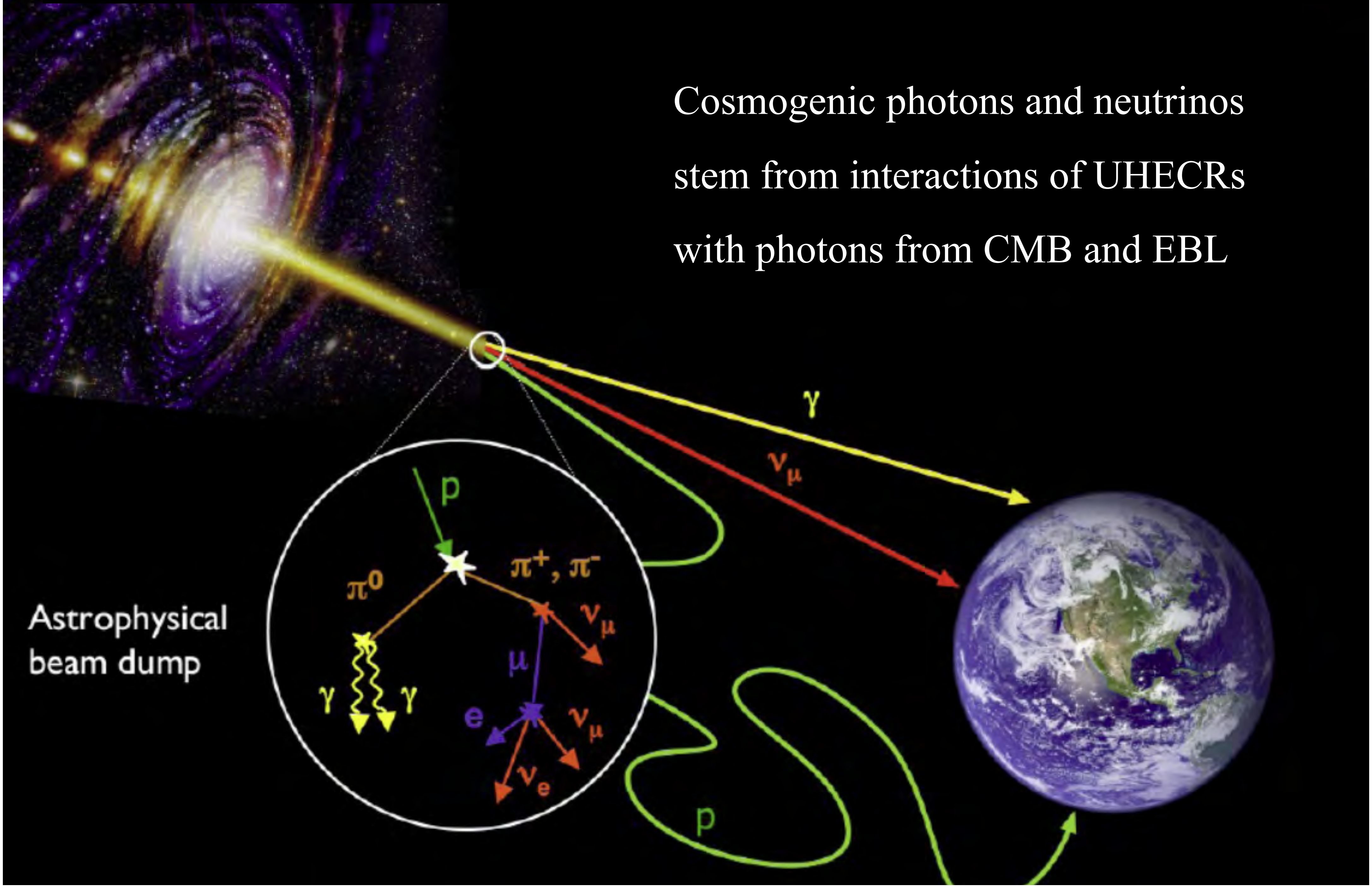


Outline

- Propagation of UHECRs, gamma rays and neutrinos
- Idea of this work
- Pierre Auger spectrum and composition measurements
- Propagation models and simulations
- Results of the fit
- Cosmogenic photons and neutrinos
- Conclusions

Propagation of UHECRs, gamma rays and neutrinos

Cosmogenic photons and neutrinos stem from interactions of UHECRs with photons from CMB and EBL



Propagation of UHECRs, gamma rays and neutrions and

Photopion production

$$P + \gamma_{bg} \rightarrow \Delta^+ \rightarrow \begin{cases} n + \pi^+ \\ p + \pi^0 \end{cases}$$

$$\pi^0 \rightarrow \gamma + \gamma$$

$$\pi^+ \rightarrow \mu^+ + \nu_\mu,$$
$$\mu^+ \rightarrow e^+ + \nu_e + \overline{\nu}_\mu$$

Z > 1:

- Photopion : superposition of the corresponding rates for nucleons

- Bethe-Heitler pair production

$${}^A_Z X + \gamma_{bg} \rightarrow {}^A_Z X + e^+ + e^-$$

cascades (photon flux)

- Photodisintegration: radiative decays of excited states produced in the photodisin. chain

$${}^A_Z X^* \rightarrow {}^A_Z X + q\gamma$$

copious amount of high energy photons

Idea of this work

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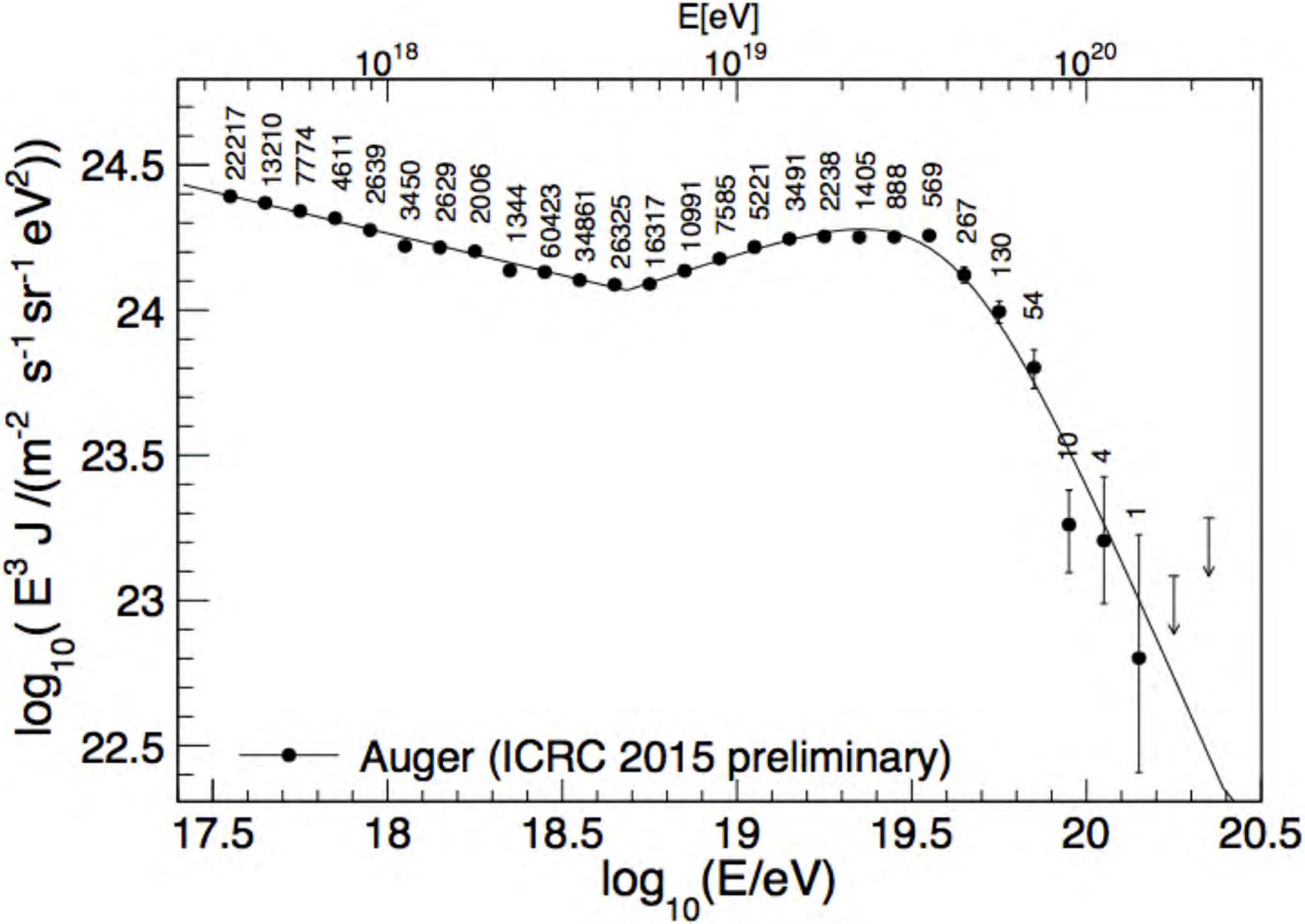
- Perform a fit of the spectrum and composition measured by the Pierre Auger Observatory for four source emissivity scenarios

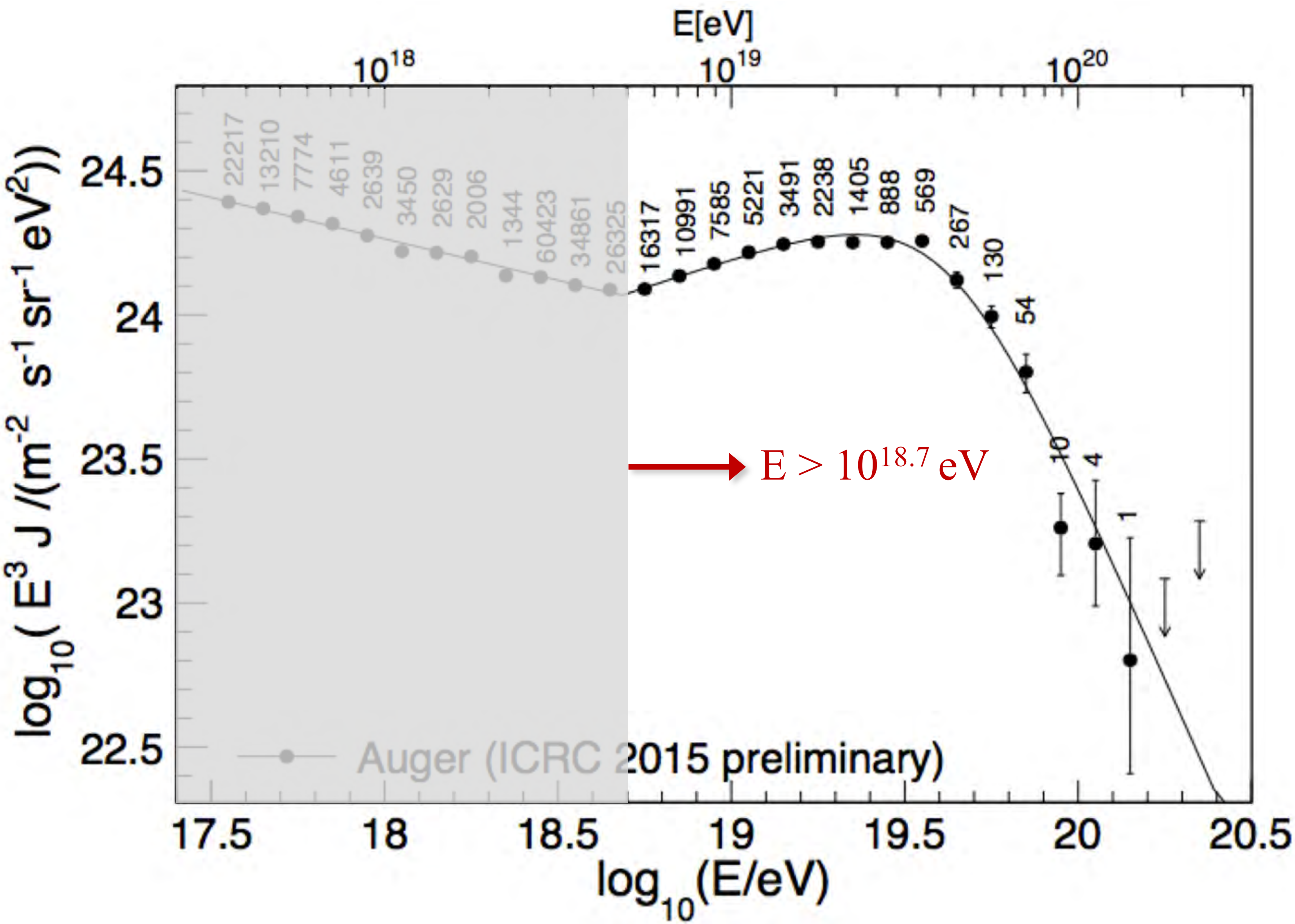
- Calculate the associated fluxes of neutrino and photons

- Prospects for the future generation of high-energy neutrino and gamma-ray observatories to constrain the sources of UHECRs

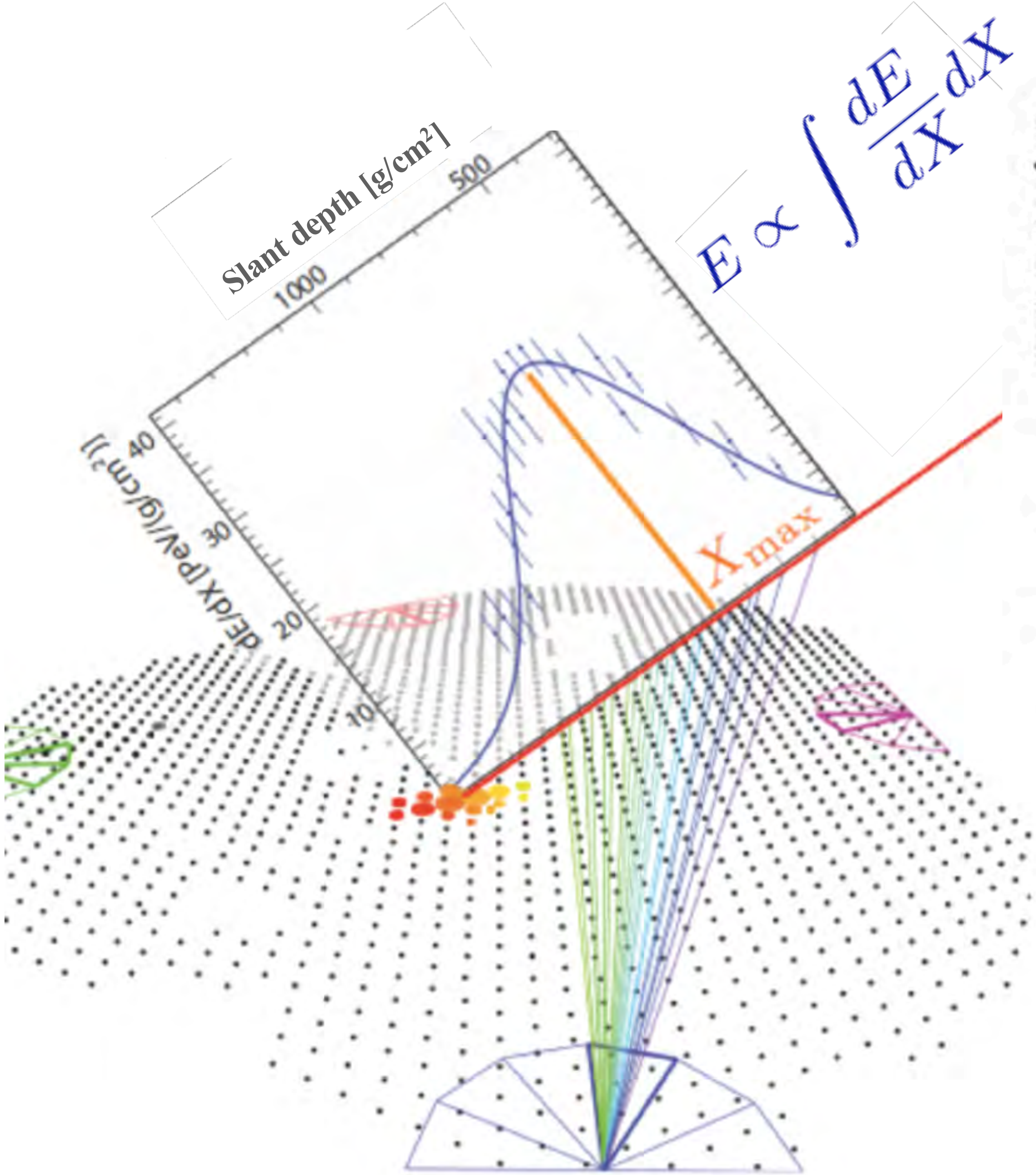
Auger Combined Energy Spectrum

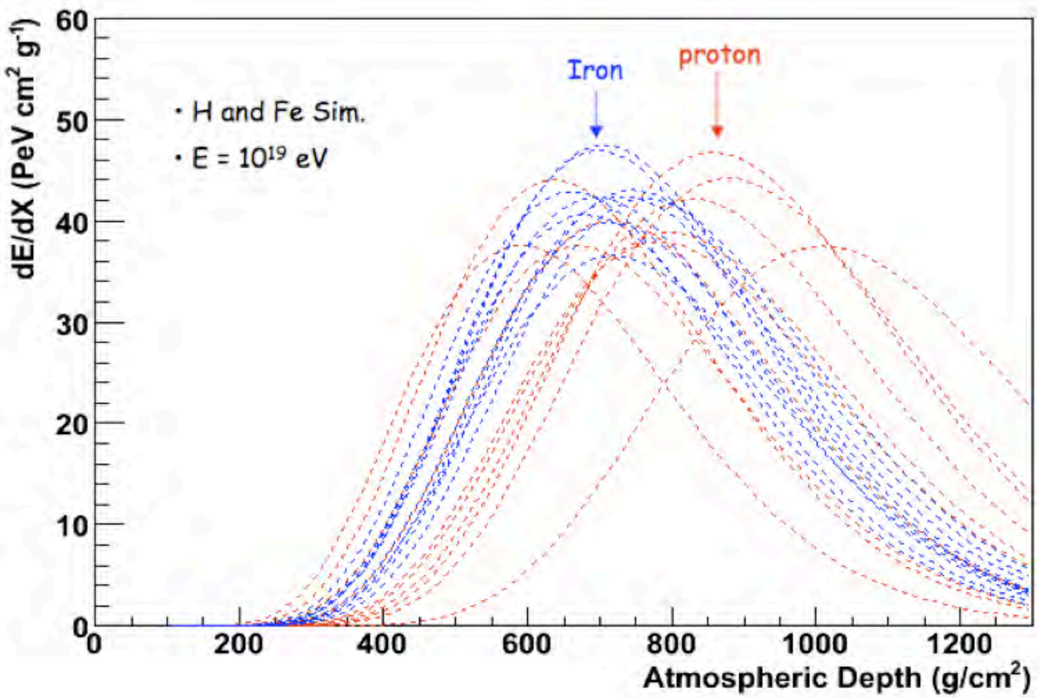


Auger Combined Energy Spectrum



Auger X_{max} distributions





For a given hadronic interaction model, Xmax is correlated with the mass of the incident cosmic ray particle

Auger X_{max} distributions

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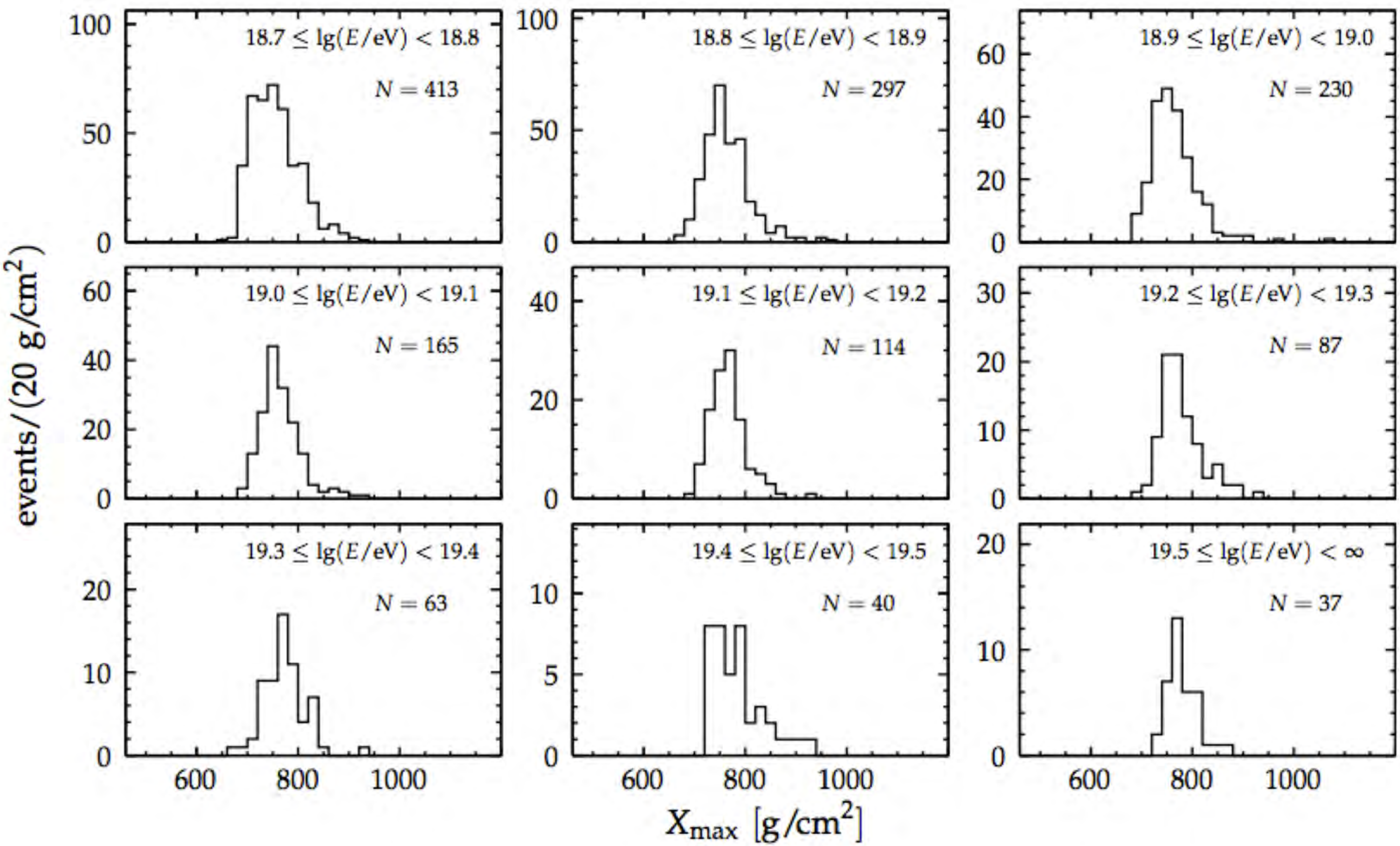


Propagation models and simulations

We fit the Pierre Auger data on UHECR spectrum and composition to simple astrophysical scenarios:

- Distribution of sources whose comoving emissivity evolves with redshift $$\dot{\varepsilon}(z) = \dot{\varepsilon}_0(1+z)^m$$
- Three other particular cases for source evolution: AGN, GRB and SFR
- Injection consisting only of H, He, N, Si, Fe nuclei
- Power-law spectrum with a rigidity-dependent broken exposnential cutoff

$$J(E) = J_0 \sum_j f_j E^{-\alpha} \begin{cases} 1 & \text{if } Z_j R_{\max} > E \\ \exp\left(1 - \frac{E}{Z R_{\max}}\right) & \text{if } Z_j R_{\max} \leq E \end{cases},$$

Free parameters (J_0, α , R_{max}, f_H, f_{He}, f_N, f_{Si}) besides m in the first scenario

Propagation models and simulations

R. A. Batista et al. JCAP 05 (2016) 038

Simulations were perfomed by using the CRPropa 3 code

- Propagation strongly sensitive to Photodisintegration cross-sections and Extragalactic background light spectrum
- We adopt EBL model by Gilmore et al. and TALYS 1.8 photonuclear cross section
- The mass composition of the simulated arriving particles are inferred using the Gumbel parametrization

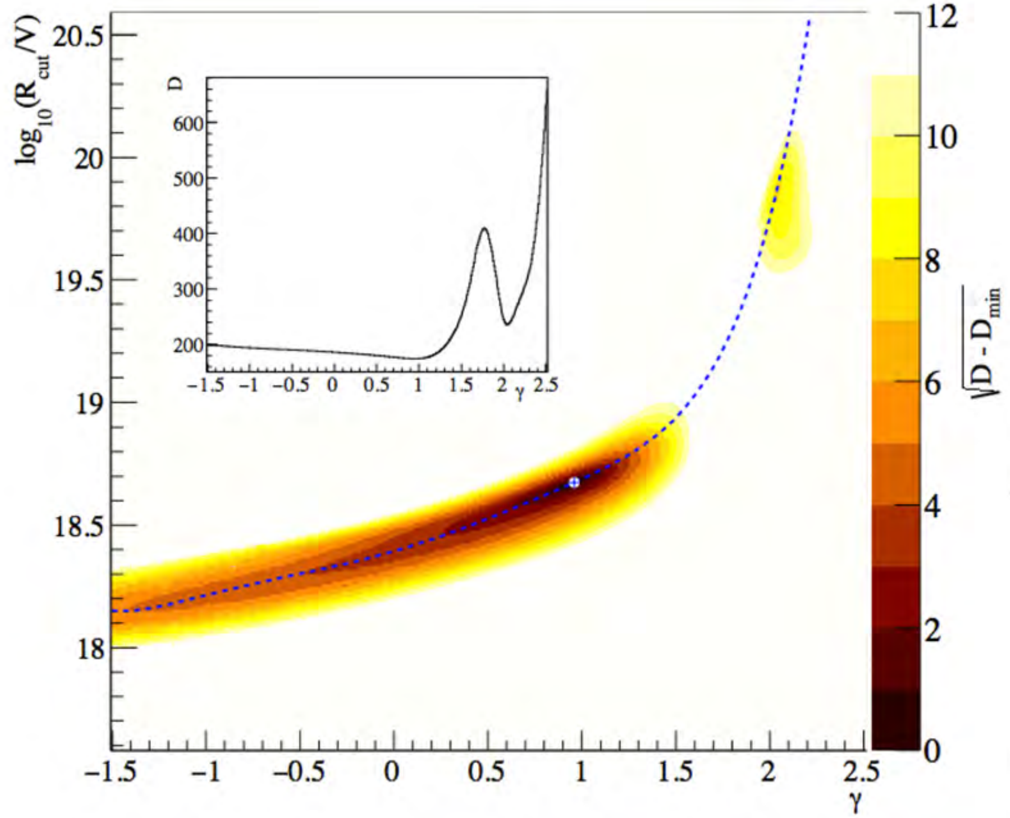
$$p(X_{\max}|\mu,\sigma,\lambda) = \frac{\lambda^{\lambda}\exp\left(-\lambda z - \lambda\exp(-z)\right)}{\sigma\Gamma(\lambda)}$$

$$z = \frac{X_{\max} - \mu}{\sigma}$$

Auger Combined fit (no source evolution m = 0)

Auger Collaboration, JCAP04(2017)038

SPG

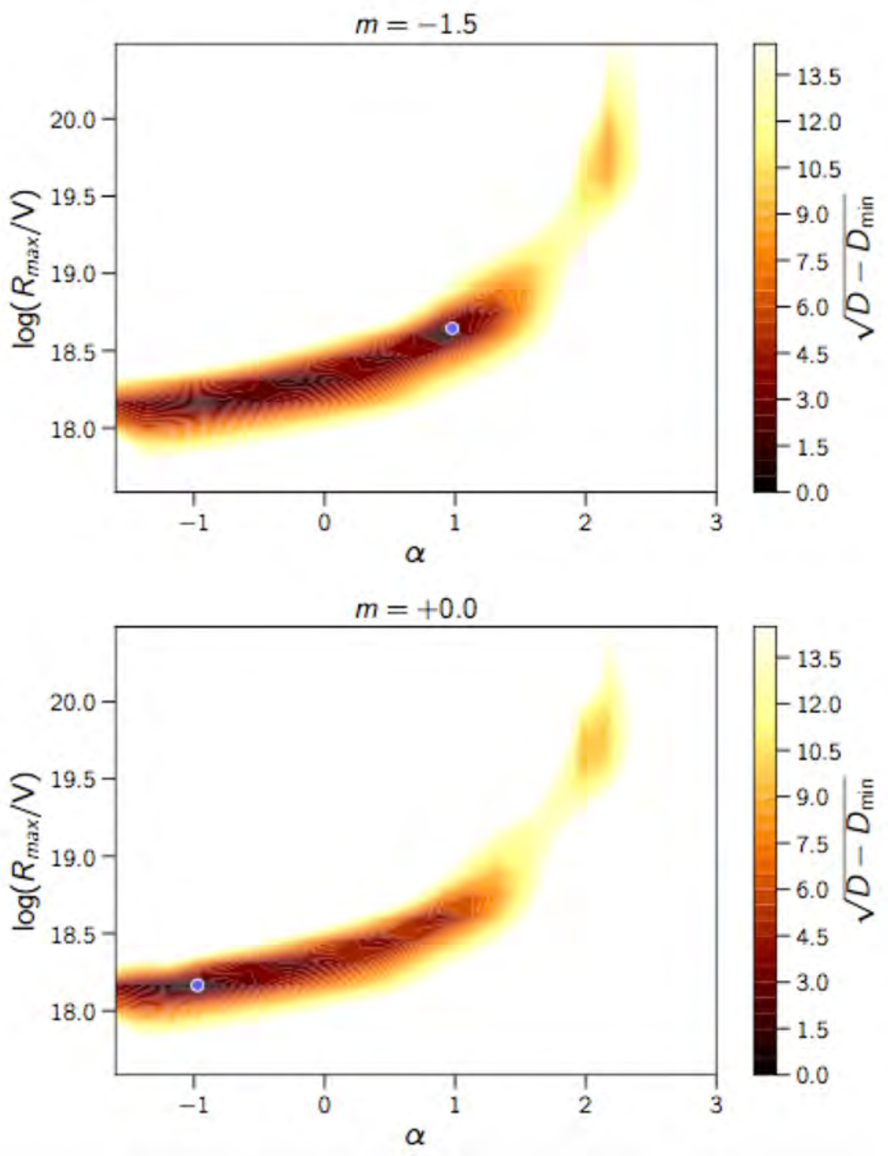


	MC code	σ_{photo}	
SPG	SimProp	PSB	[illegible]
STG	SimProp	TALYS	Gilmore 2012
SPD	SimProp	PSB	Domínguez 2011
CTG	CRPropa	TALYS	Gilmore 2012
CTD	CRPropa	TALYS	Domínguez 2011
CGD	CRPropa	Geant4	Domínguez 2011

model	γ	$\log_{10}(R_{cut}/V)$	D	$D(J)$	$D(X_{max})$
SPG	$+0.96^{+0.08}_{-0.13}$	$18.68^{+0.02}_{-0.04}$	174.3	13.2	161.1
STG	$+0.77^{+0.07}_{-0.13}$	$18.62^{+0.02}_{-0.04}$	175.9	18.8	157.1
SPD	$-1.02^{+0.31}_{-0.26}$	$18.19^{+0.04}_{-0.03}$	187.0	8.4	178.6
CTG	$-1.03^{+0.35}_{-0.30}$	$18.21^{+0.05}_{-0.04}$	189.7	8.3	181.4
	$+0.87^{+0.08}_{-0.06}$	18.62 ± 0.02	191.9	29.2	162.7
CTD	$-1.47^{+0.28}_{*}$	$18.15^{+0.03}_{-0.01}$	187.3	8.8	178.5
CGD	$-1.01^{+0.26}_{-0.28}$	18.21 ± 0.03	179.5	7.9	171.6

Results of the fit

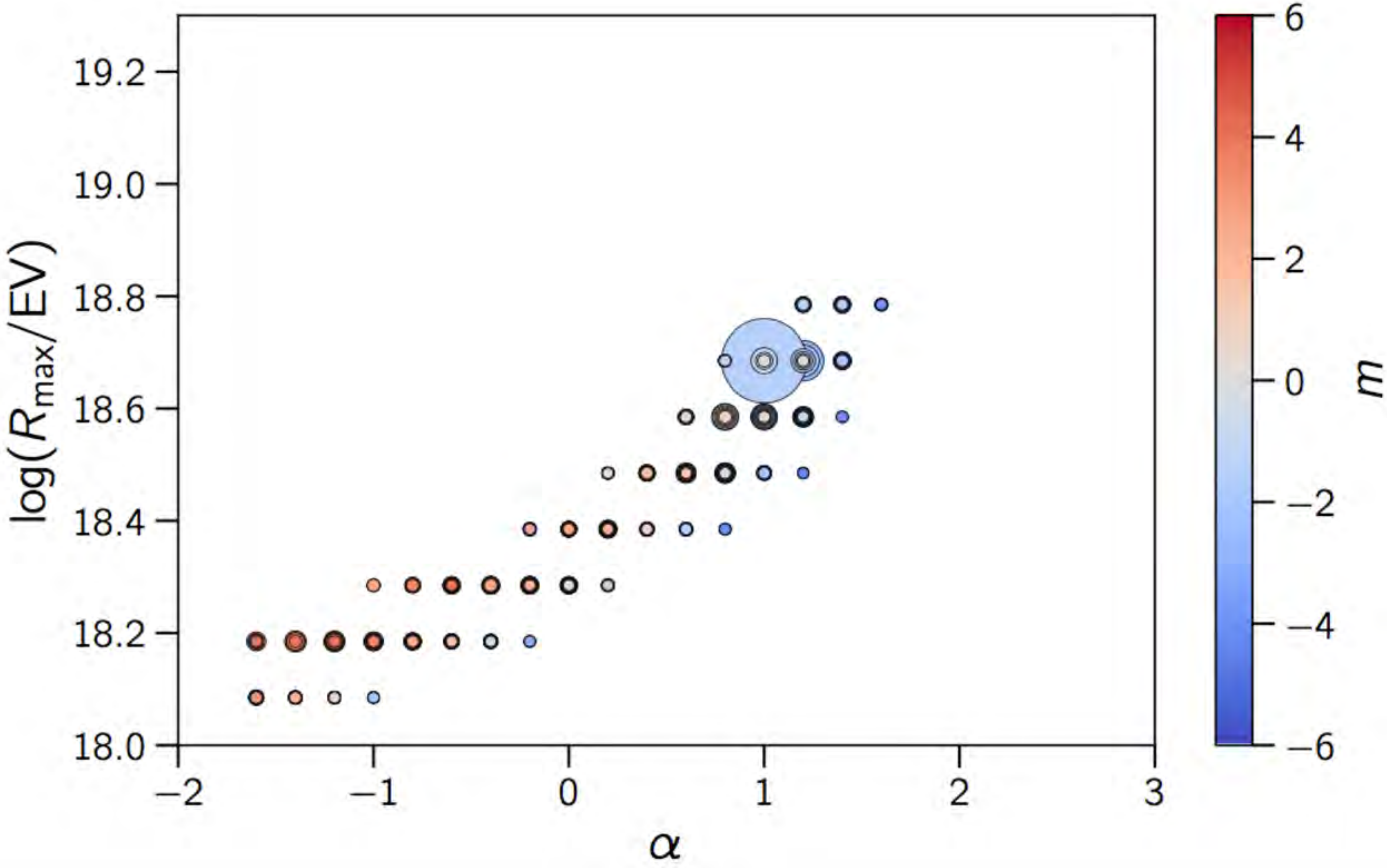
We fix the source evolution in order to obtain the best-fit spectral index (α) and maximal rigidity (R_{max})



➔ It suggests a trend that if source evolution is accounted in the fit, α becomes increasingly larger for negative values of m

Results of the fit

- Best-fit values at 99% confidence level
- Marker sizes with radii inversely proportional to the deviance



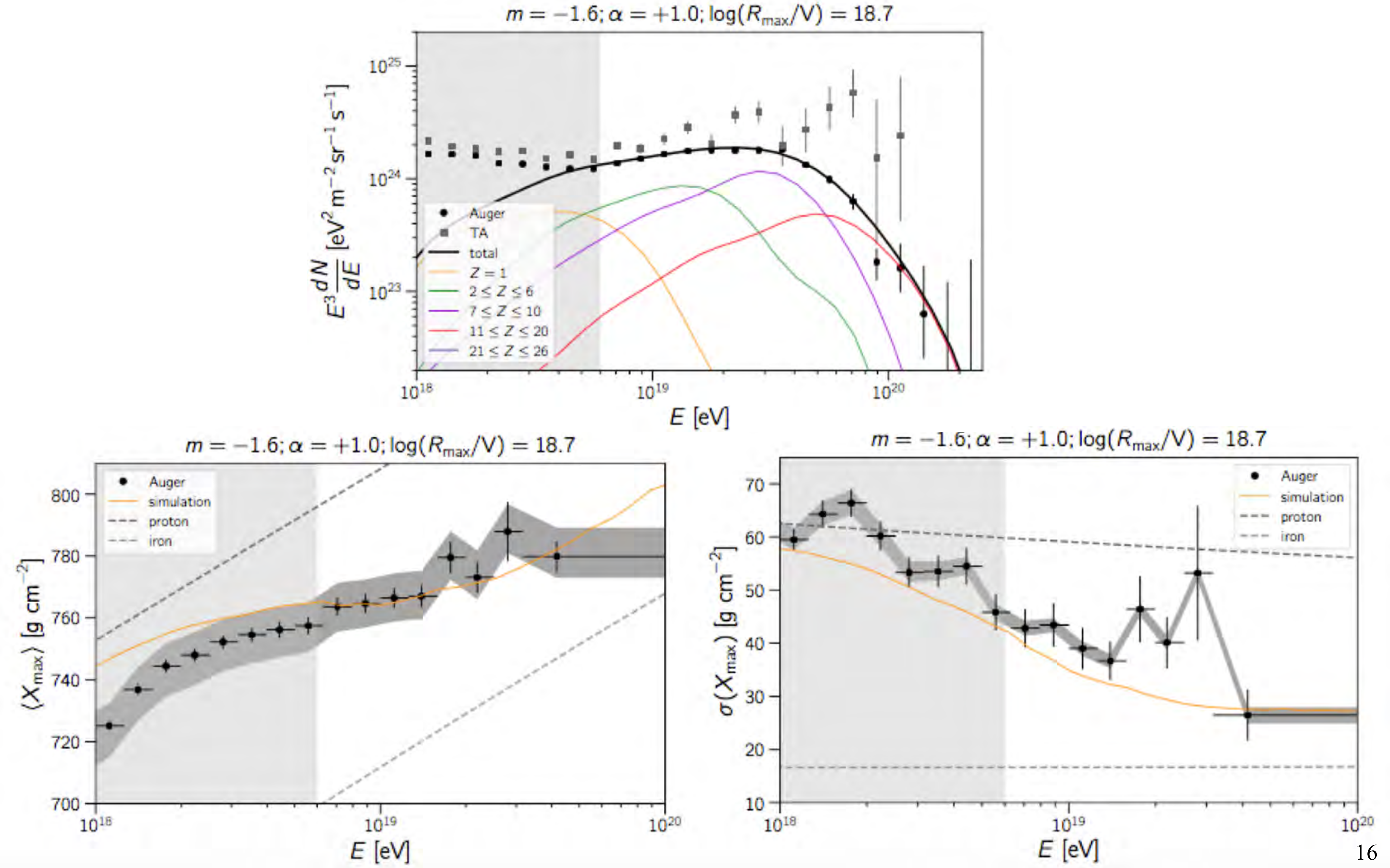
For the most common spectral indices found in the literature ($1 \lesssim \alpha \lesssim 2$) scenarios with positive source evolution ($m > 0$) are disfavoured

Best fit and Confidence Level bands

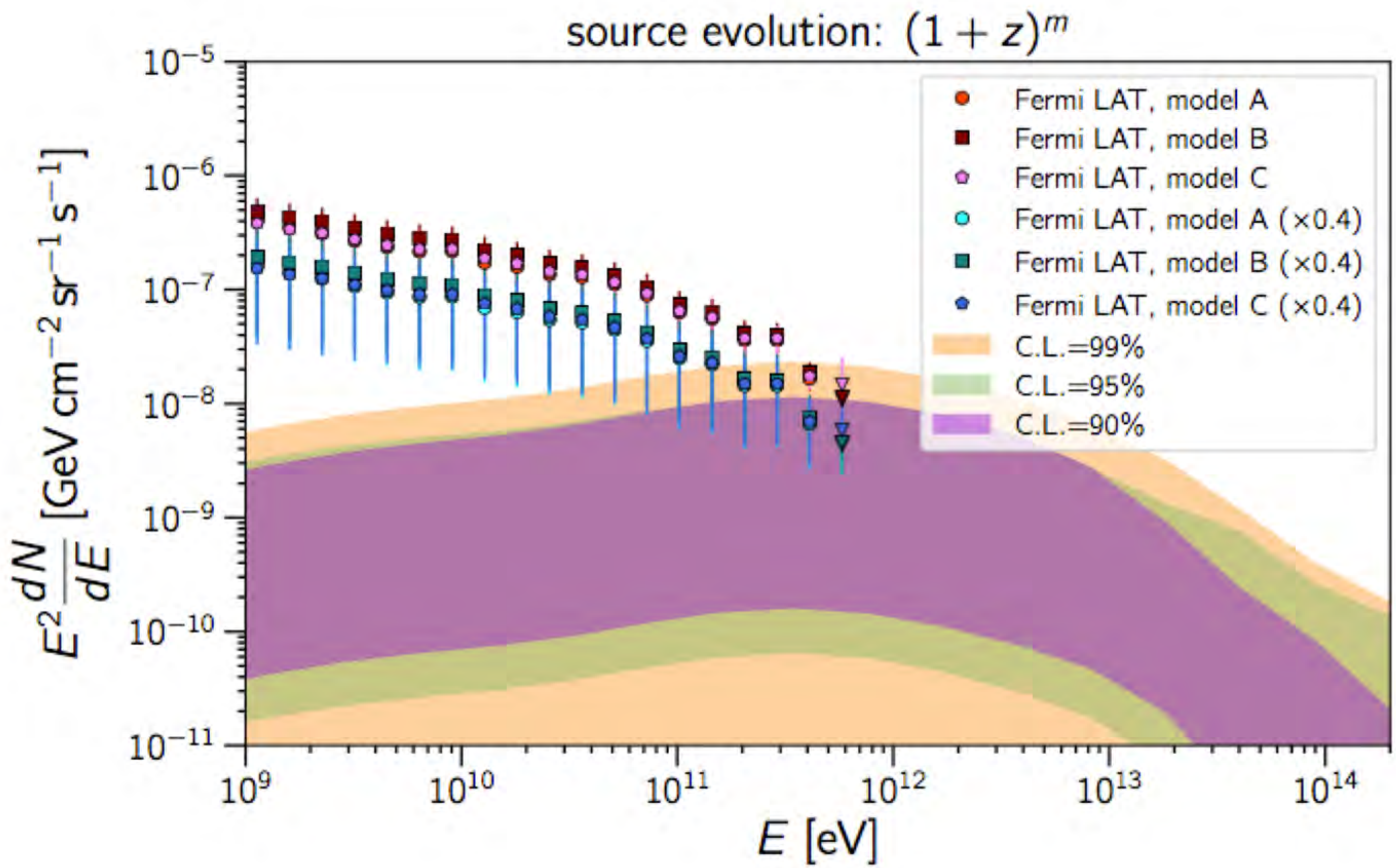
m	α	$\log(\frac{R_{\max}}{V})$	f_H	f_{He}	f_N	f_{Si}	f_{Fe}	χ^2_{comp}	χ^2_{spec}	χ^2
-1.6	+1.0	18.7	0.0003	0.0101	0.8906	0.0990	0.0	161.1	17.6	178.7
SFR	-1.3	18.2	0.1628	0.8046	0.0309	0.0018	0.0	184.4	19.9	204.3
AGN	-1.0	18.2	0.8716	0.0778	0.0469	0.0038	0.0	224.9	33.1	258.0
GRB	-1.5	18.2	0.5876	0.3973	0.0147	0.0004	0.0	170.8	20.1	190.9

C.L.	D	parameter range		
90%	< 2.71	$-4.3 \le m \le -0.7$	$+0.8 \le \alpha \le +1.2$	$18.6 \le \log(R_{\max}/V) \le 18.7$
95%	< 3.84	$-5.5 \le m \le +3.5$	$-1.6 \le \alpha \le +1.4$	$18.2 \le \log(R_{\max}/V) \le 18.7$
99%	< 6.63	$-6.0 \le m \le +4.2$	$-1.6 \le \alpha \le +1.6$	$18.1 \le \log(R_{\max}/V) \le 18.8$
90%	< 2.71	SFR	$-1.3 \le \alpha \le -1.2$	$18.2 \le \log(R_{\max}/V) \le 18.2$
95%	< 3.84	SFR	$-1.4 \le \alpha \le -0.6$	$18.2 \le \log(R_{\max}/V) \le 18.3$
99%	< 6.63	SFR	$-1.4 \le \alpha \le +0.1$	$18.2 \le \log(R_{\max}/V) \le 18.4$
90%	< 2.71	AGN	$-1.0 \le \alpha \le -0.9$	$18.2 \le \log(R_{\max}/V) \le 18.2$
95%	< 3.84	AGN	$-1.0 \le \alpha \le -0.9$	$18.2 \le \log(R_{\max}/V) \le 18.2$
99%	< 6.63	AGN	$-1.0 \le \alpha \le -0.4$	$18.2 \le \log(R_{\max}/V) \le 18.3$
90%	< 2.71	GRB	$-1.5 \le \alpha \le -1.4$	$18.2 \le \log(R_{\max}/V) \le 18.2$
95%	< 3.84	GRB	$-1.5 \le \alpha \le -0.7$	$18.2 \le \log(R_{\max}/V) \le 18.3$
99%	< 6.63	GRB	$-1.5 \le \alpha \le +0.4$	$18.1 \le \log(R_{\max}/V) \le 18.5$

Best fit for $(1+z)^m$ evolution scenario

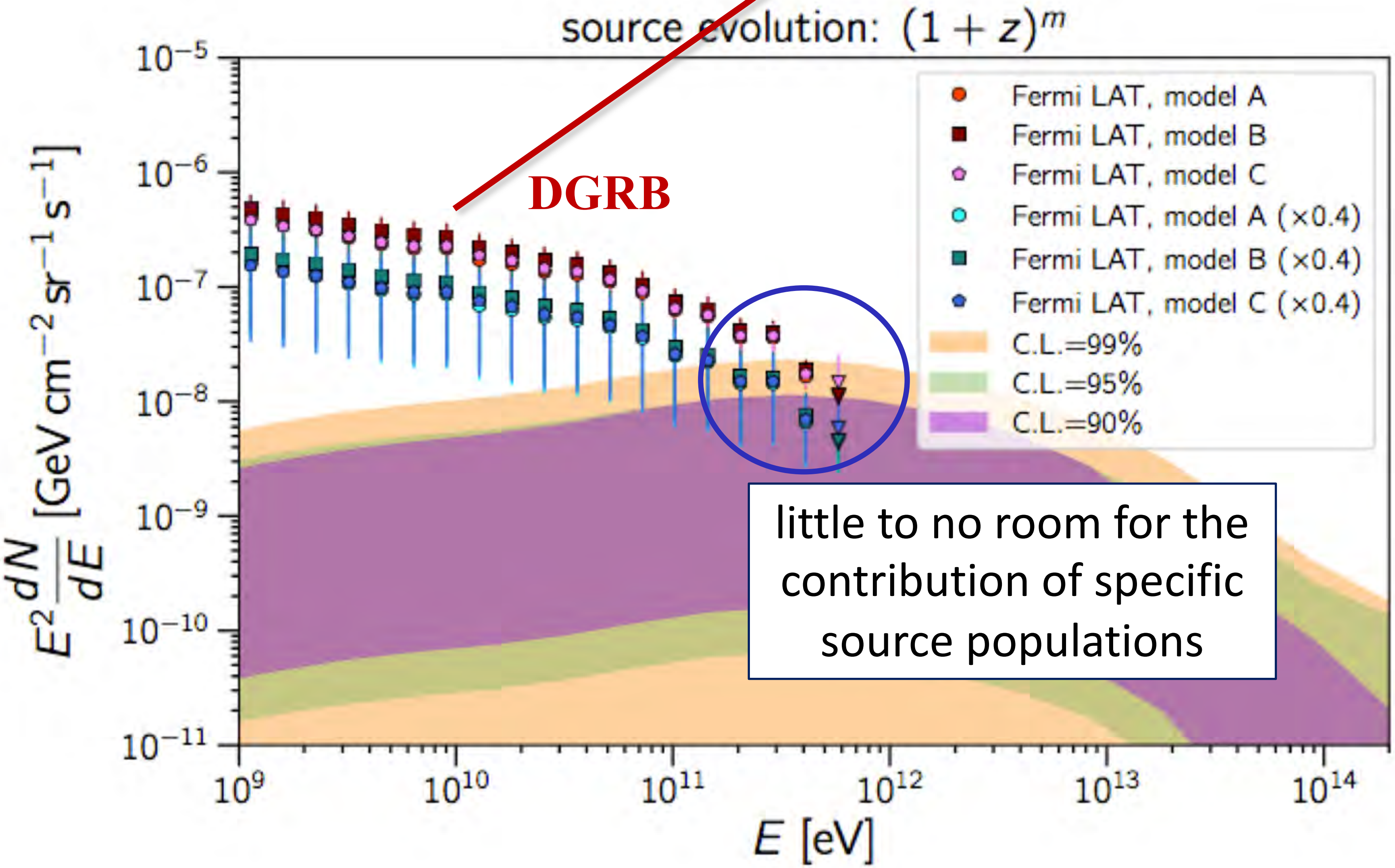


Cosmogenic photons (coming from z < 1)



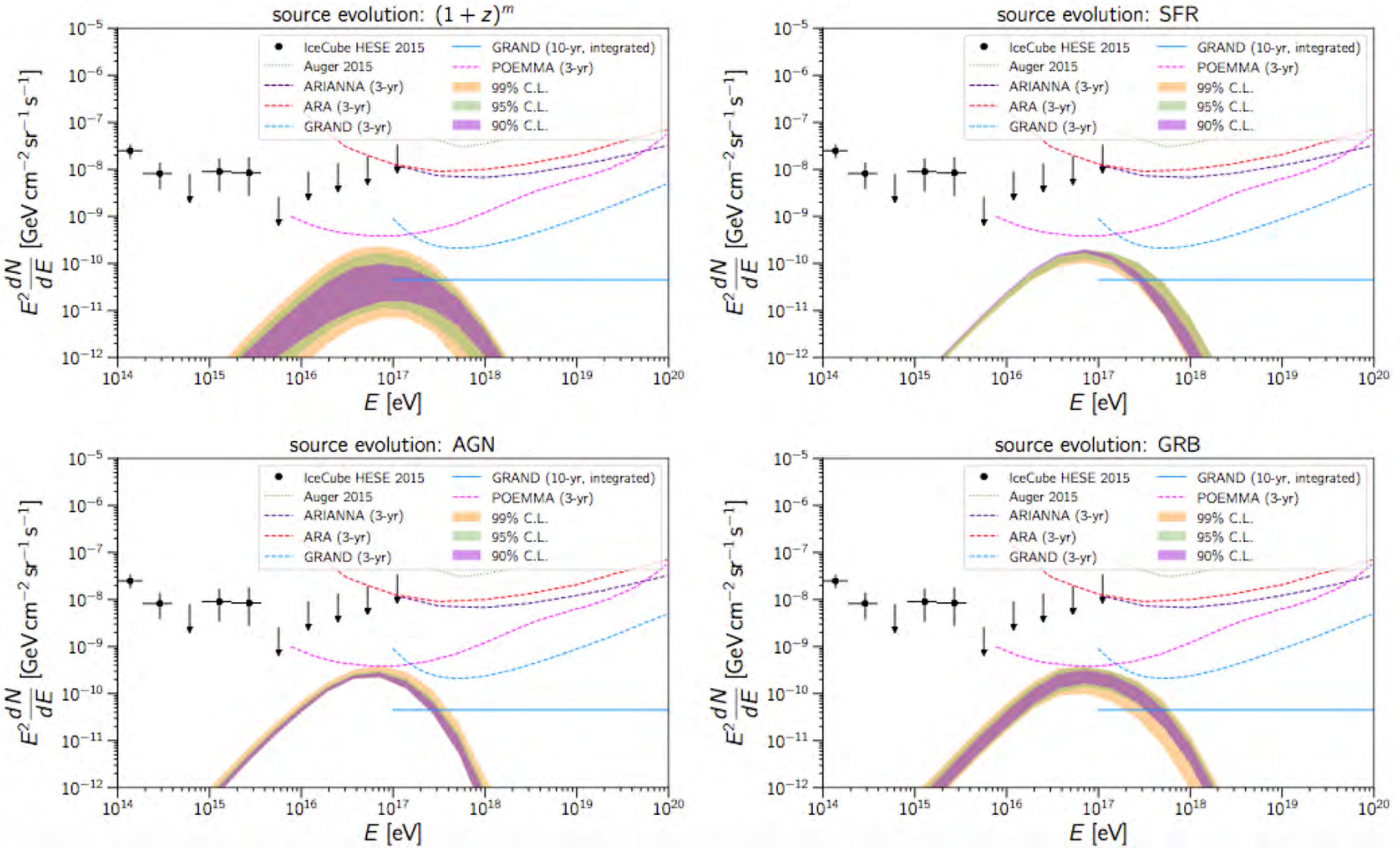
Cosmogenic photons

Contribution from cosmogenic neutrinos + blazars, misaligned AGNs, quasar outflows, star-forming regions, decay of very and super heaavy dark matter ...



little to no room for the contribution of specific source populations

Cosmogenic neutrinos (coming from z < 1)



Conclusions

- Best fit for $(1 + z)^m$ scenario is obtained for $\alpha \simeq 1$, for compositions at injection dominated by intermediate-mass nuclei (nitrogen and silicon groups). The value of m that minimises the deviance is m = -1.6
- Evolutions with m < 0.7 are favoured at a 90% C.L. (sources or local distribution?)
- Our best fits for $(1 + z)^m$ with the hardest spectral índices and z < 1 condition provide the lowest possible cosmogenic fluxes compatible with the observed data → pessimistic scenario
- Photon flux levels nearly exceed DGRB Fermi measurements → little room for contribution of specific source population; disfavour models that predict a significant contribution of dark matter decay and annihillation in this energy range.

Conclusions

- Our cosmogenic neutrino fluxes are rather low, due to the choice of $z < 1$. Nevertheless, even in this pessimistic case, GRAND would be able to detect cosmogenic neutrinos for sources evolving as SFR, GRB, and AGN, at a 99% C.L., within the first 5 years of operation

- If sources evolve as $(1 + z)^m$, the detection of cosmogenic neutrinos would be possible but not certain

- From a different perspective, low cosmogenic fluxes could be profitable for EeV neutrino astronomy. Such a scenario would imply that the neutrinos first detected by future experiments would likely be those produced directly at the sources, via interactions of UHECRs with photon and baryon fields in the source environment.