

# **cosmogenic neutrinos with GRAND: Auger-compatible fluxes**

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GRAND White Paper Workshop  
Nijmegen, The Netherlands  
February/2018

# fitting the UHECR spectrum and composition

Pierre Auger Collaboration. JCAP 04 (2017) 038.

| model | $\gamma$                | $\log_{10}(R_{\text{cut}}/V)$ | $D$   | $D(J)$ | $D(X_{\text{max}})$ |
|-------|-------------------------|-------------------------------|-------|--------|---------------------|
| 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               |
|       | $+0.87^{+0.08}_{-0.06}$ | $18.62 \pm 0.02$              | 191.9 | 29.2   | 162.7               |
| CTD   | $-1.47^{+0.28}_{*}$     | $18.15^{+0.03}_{-0.01}$       | 187.3 | 8.8    | 178.5               |
| CGD   | $-1.01^{+0.26}_{-0.28}$ | $18.21 \pm 0.03$              | 179.5 | 7.9    | 171.6               |

\*This interval extends all the way down to  $-1.5$ , the lowest value of  $\gamma$  we considered.

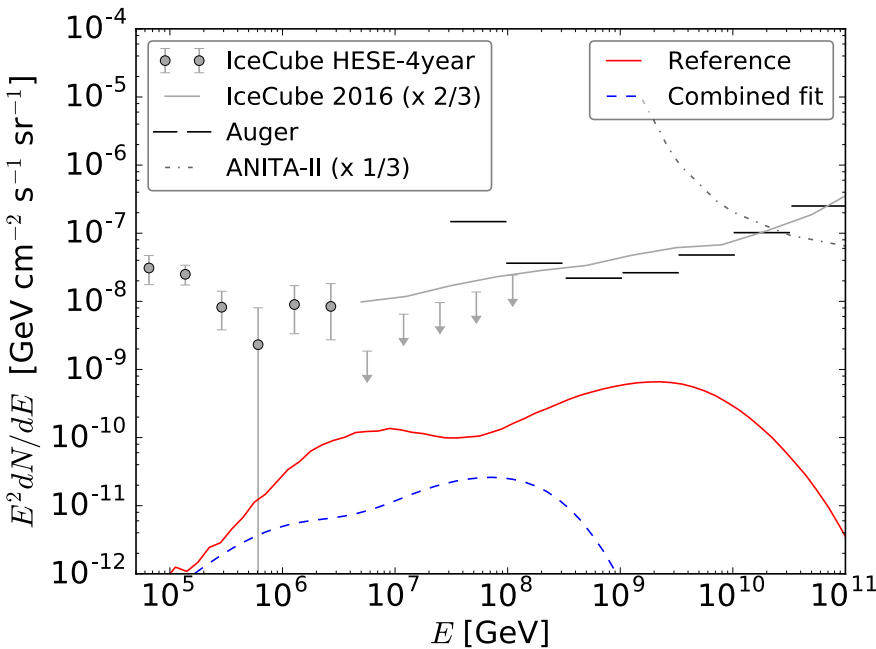
**Table 8.** Best-fit parameters and 68% uncertainties for the various propagation models we used (see table 7). For the CTG model we report the two main local minima, whose total deviances differ by 2.2.

- ▶ spectral indices are very hard, incompatible with most acceleration models
- ▶ low spectral indices decrease the flux of neutrinos
- ▶ source evolution was not accounted for in the fit (how important is it?)

# interlude: what does the neutrino spectrum depend on?

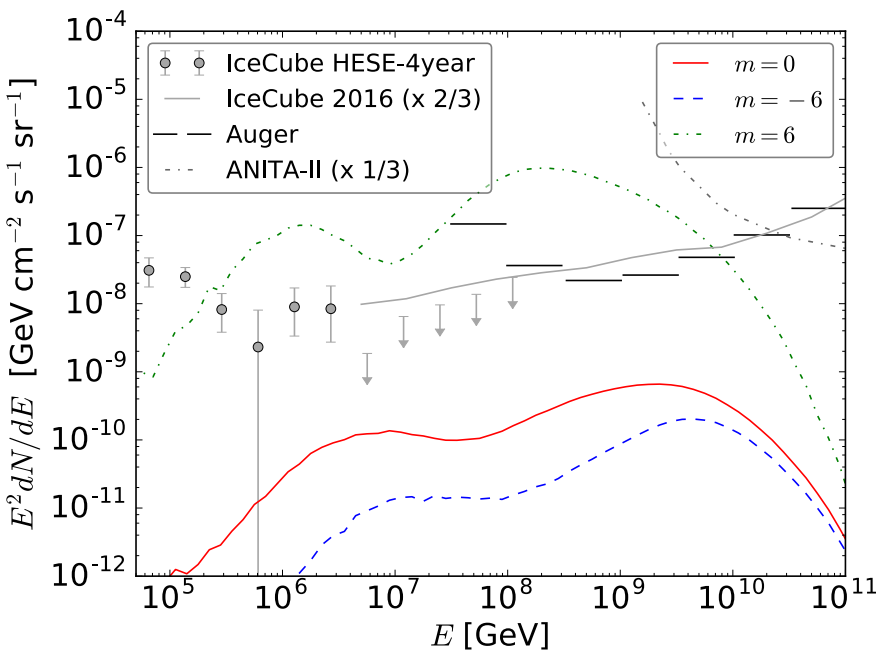
A. van Vliet, J. Hörandel, R. Alves Batista. PoS (ICRC2017) 562. arXiv:1707.04511

## Auger best fit

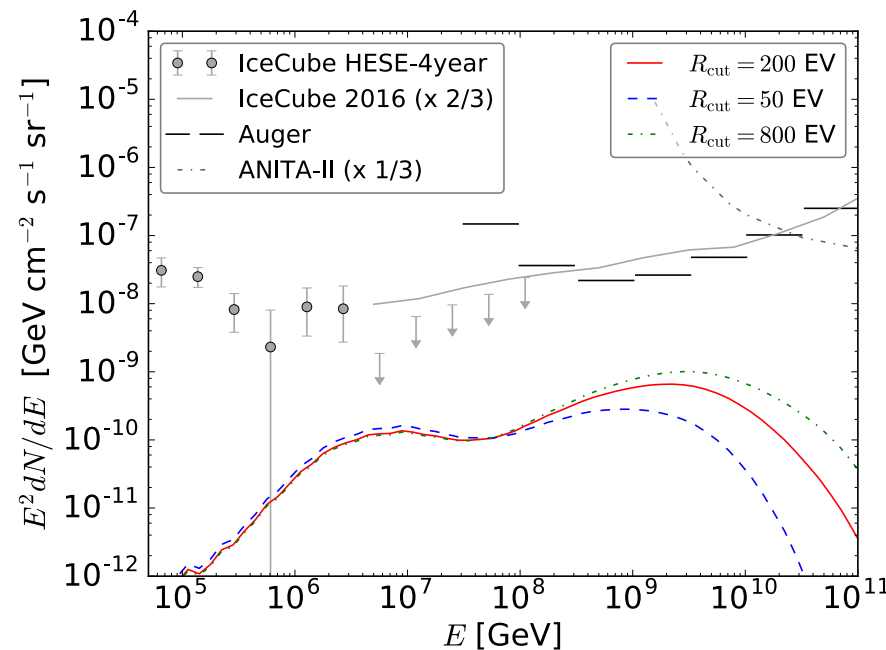


- ▶ what parameters are more relevant to compute the cosmogenic neutrino spectrum?
- ▶ let's adopt a reference scenario to get an idea:  $R_{\text{cut}}=200$  EV,  $m=0$ ,  $\alpha=2.5$
- ▶ we vary one parameter at a time

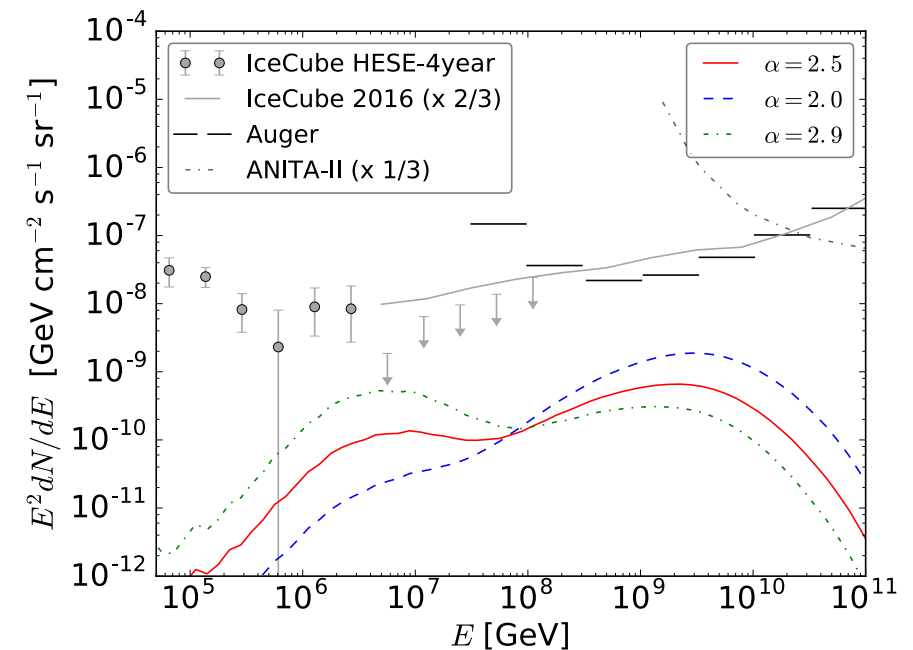
## source evolution



## maximum rigidity



## spectral index



# fitting the Auger data (+ source evolution)

*R. Alves Batista, R. M. de Almeida, B. Lago, K. Kotera. In preparation*

**Table 1.** Best-fit parameters for specific spectral indices.

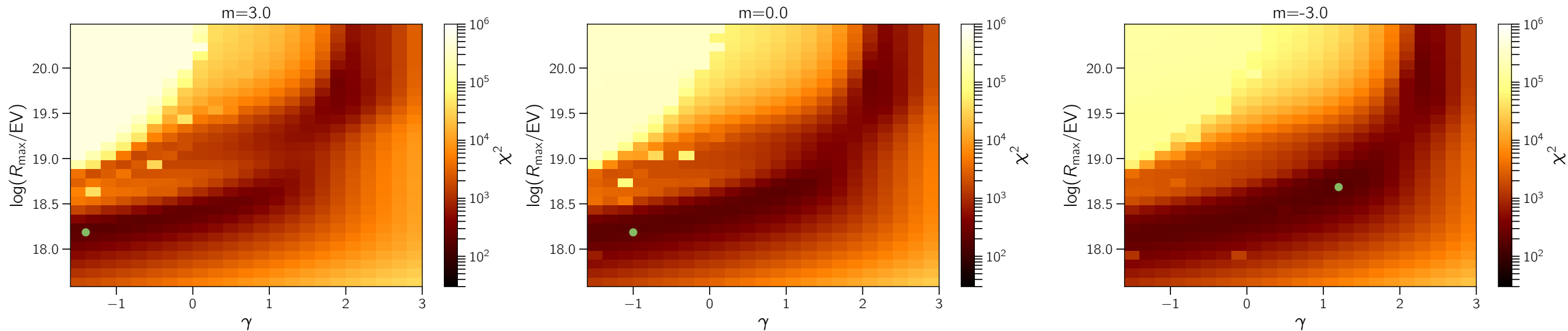
| $\alpha$ | $m$   | $\log(R_{\max}/\text{EV})$ | $f_p$  | $f_{\text{He}}$ | $f_{\text{N}}$ | $f_{\text{Si}}$ | $f_{\text{Fe}}$ | $\chi^2$ |
|----------|-------|----------------------------|--------|-----------------|----------------|-----------------|-----------------|----------|
| -1.60    | +2.50 | 18.19                      | 0.4516 | 0.5274          | 0.0205         | 0.0005          | 0.0000          | 190.8    |
| -1.40    | +2.00 | 18.19                      | 0.6869 | 0.2993          | 0.0135         | 0.0004          | 0.0000          | 187.7    |
| -1.20    | +1.50 | 18.19                      | 0.6752 | 0.3104          | 0.0138         | 0.0006          | 0.0000          | 188.0    |
| -1.00    | +0.00 | 18.19                      | 0.6927 | 0.2950          | 0.0117         | 0.0006          | 0.0000          | 190.9    |
| -0.80    | -1.50 | 18.19                      | 0.7174 | 0.2704          | 0.0115         | 0.0007          | 0.0000          | 194.4    |
| -0.60    | +0.50 | 18.29                      | 0.2307 | 0.7193          | 0.0467         | 0.0032          | 0.0000          | 194.7    |
| -0.40    | -0.50 | 18.29                      | 0.4167 | 0.5429          | 0.0371         | 0.0033          | 0.0000          | 192.6    |
| -0.20    | -2.50 | 18.29                      | 0.5063 | 0.4585          | 0.0317         | 0.0034          | 0.0000          | 193.2    |
| +0.00    | -5.00 | 18.29                      | 0.4960 | 0.4671          | 0.0326         | 0.0043          | 0.0000          | 194.5    |
| +0.20    | -2.50 | 18.39                      | 0.2168 | 0.6902          | 0.0817         | 0.0113          | 0.0000          | 192.8    |
| +0.40    | -1.50 | 18.49                      | 0.0001 | 0.7586          | 0.2183         | 0.0229          | 0.0000          | 195.6    |
| +0.60    | -3.00 | 18.49                      | 0.0000 | 0.7950          | 0.1756         | 0.0294          | 0.0000          | 189.3    |
| +0.80    | -1.50 | 18.59                      | 0.0000 | 0.4917          | 0.4506         | 0.0577          | 0.0000          | 183.3    |
| +1.00    | -1.50 | 18.69                      | 0.0004 | 0.0002          | 0.8970         | 0.1024          | 0.0000          | 178.7    |
| +1.20    | -2.50 | 18.69                      | 0.3088 | 0.0005          | 0.5983         | 0.0924          | 0.0000          | 179.9    |
| +1.40    | -4.50 | 18.69                      | 0.3201 | 0.1544          | 0.4221         | 0.1031          | 0.0000          | 192.9    |
| +1.60    | -5.50 | 18.79                      | 0.3192 | 0.0006          | 0.5374         | 0.1426          | 0.0000          | 209.0    |
| +1.80    | -6.00 | 18.79                      | 0.3519 | 0.0510          | 0.3691         | 0.2276          | 0.0000          | 257.0    |
| +2.00    | +0.50 | 19.89                      | 0.0000 | 0.0000          | 0.6515         | 0.3485          | 0.0000          | 275.9    |
| +2.20    | -5.00 | 19.89                      | 0.0000 | 0.0001          | 0.8791         | 0.0772          | 0.0000          | 248.9    |
| +2.40    | -6.00 | 19.79                      | 0.3237 | 0.1312          | 0.1454         | 0.3997          | 0.0000          | 292.8    |
| +2.60    | -6.00 | 19.99                      | 0.5813 | 0.0013          | 0.0002         | 0.4153          | 0.0000          | 501.5    |
| +2.80    | -6.00 | 20.09                      | 0.6774 | 0.0000          | 0.0000         | 0.1105          | 0.0000          | 1167.5   |
| +3.00    | -6.00 | 20.49                      | 0.6808 | 0.0000          | 0.0000         | 0.0001          | 0.0000          | 2422.3   |

$\chi^2 < 200$

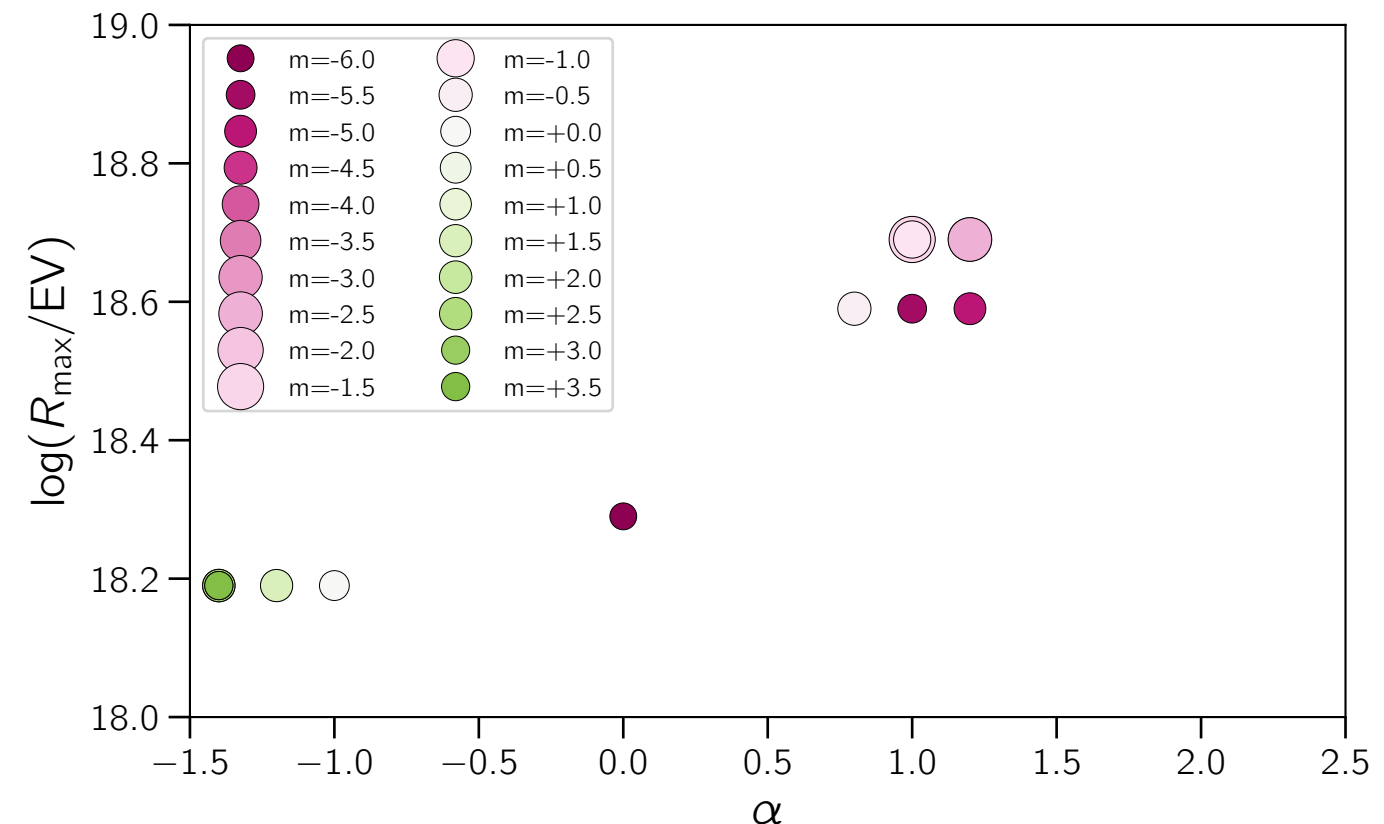
theoretically-  
motivated range

# fitting the Auger data (+ source evolution)

*R. Alves Batista, R. M. de Almeida, B. Lago, K. Kotera. In preparation*

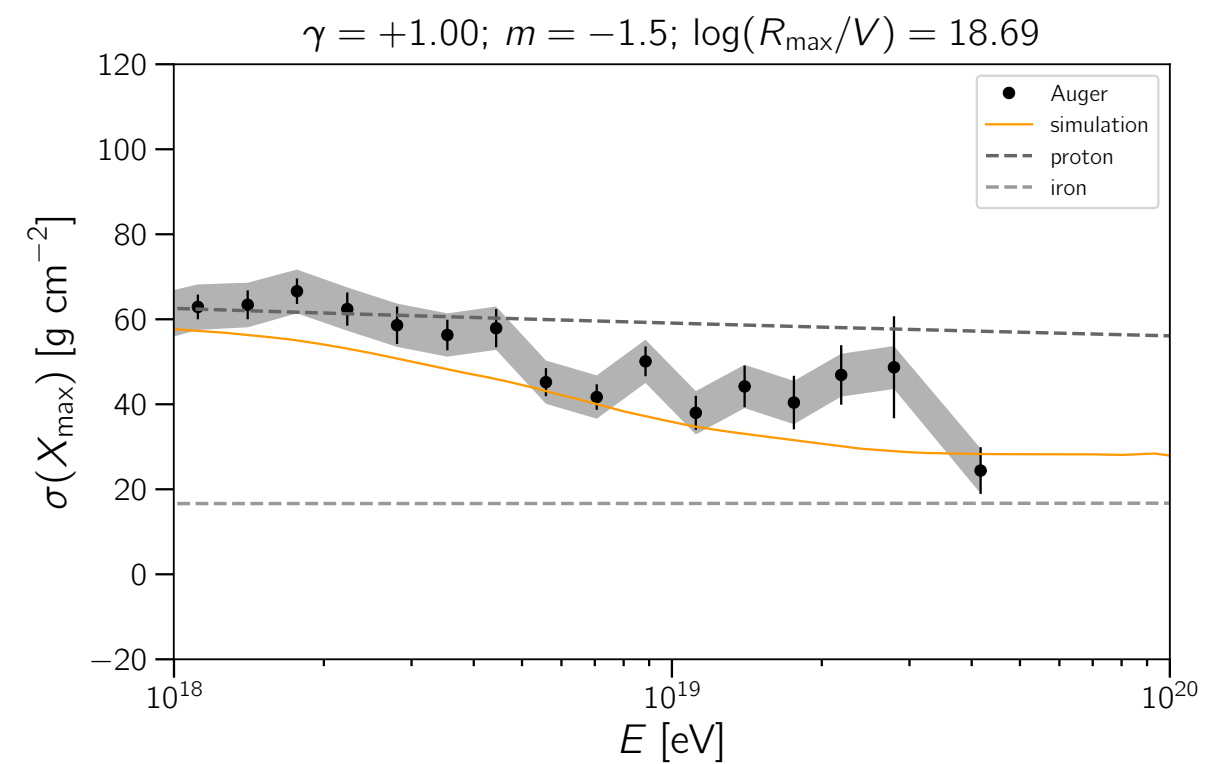
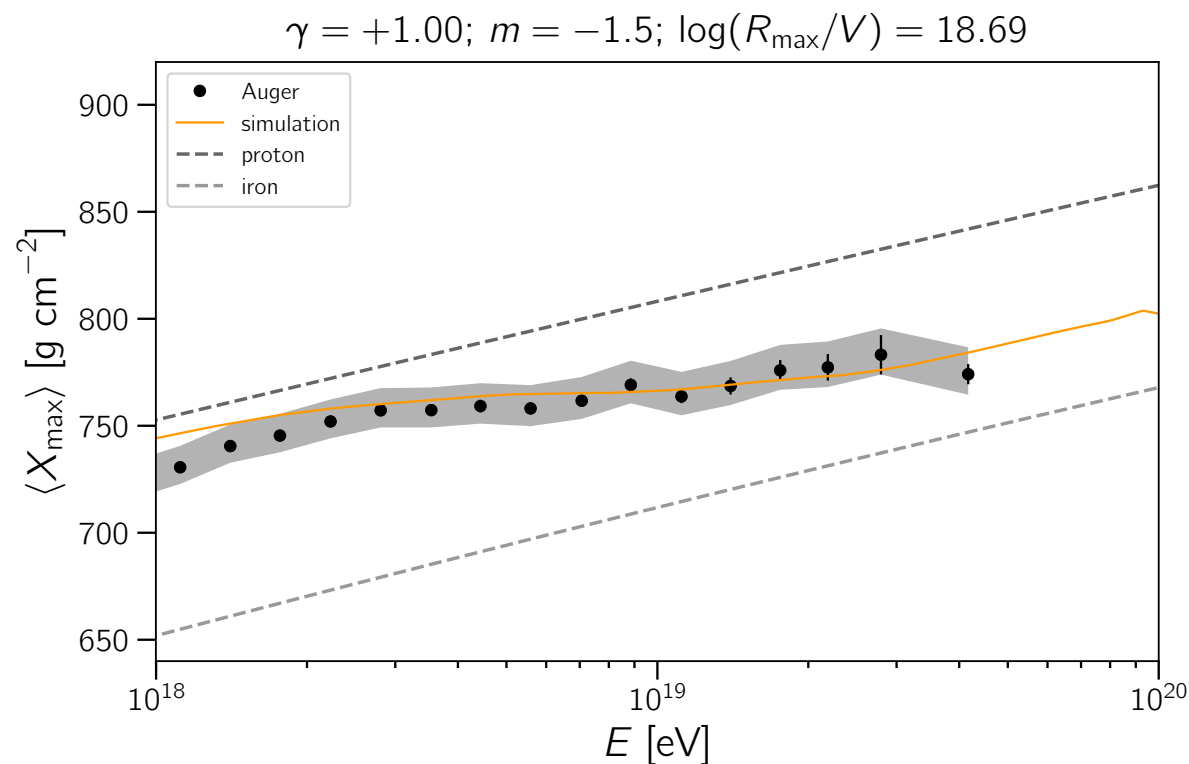
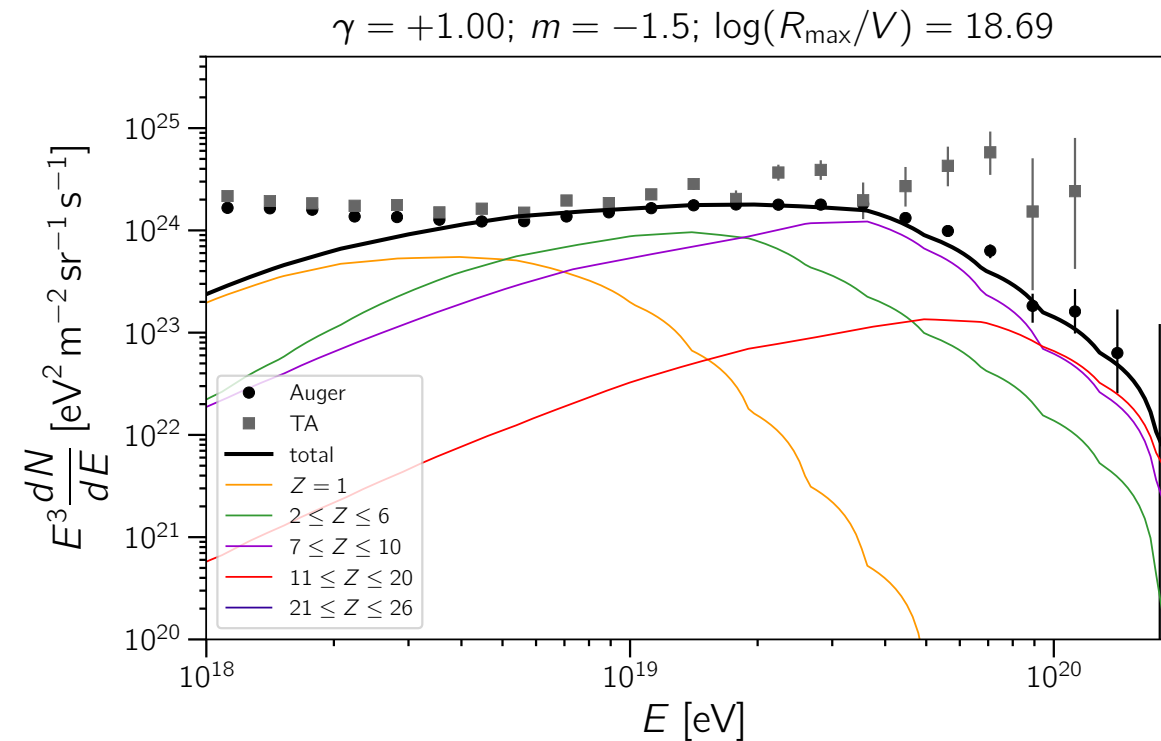


- ▶ negative source evolutions favoured in the fits
- ▶ more reasonable source models allowed, with spectral indices larger than 1.



# fitting the Auger data (+ source evolution)

R. Alves Batista, R. M. de Almeida, B. Lago, K. Kotera. In preparation

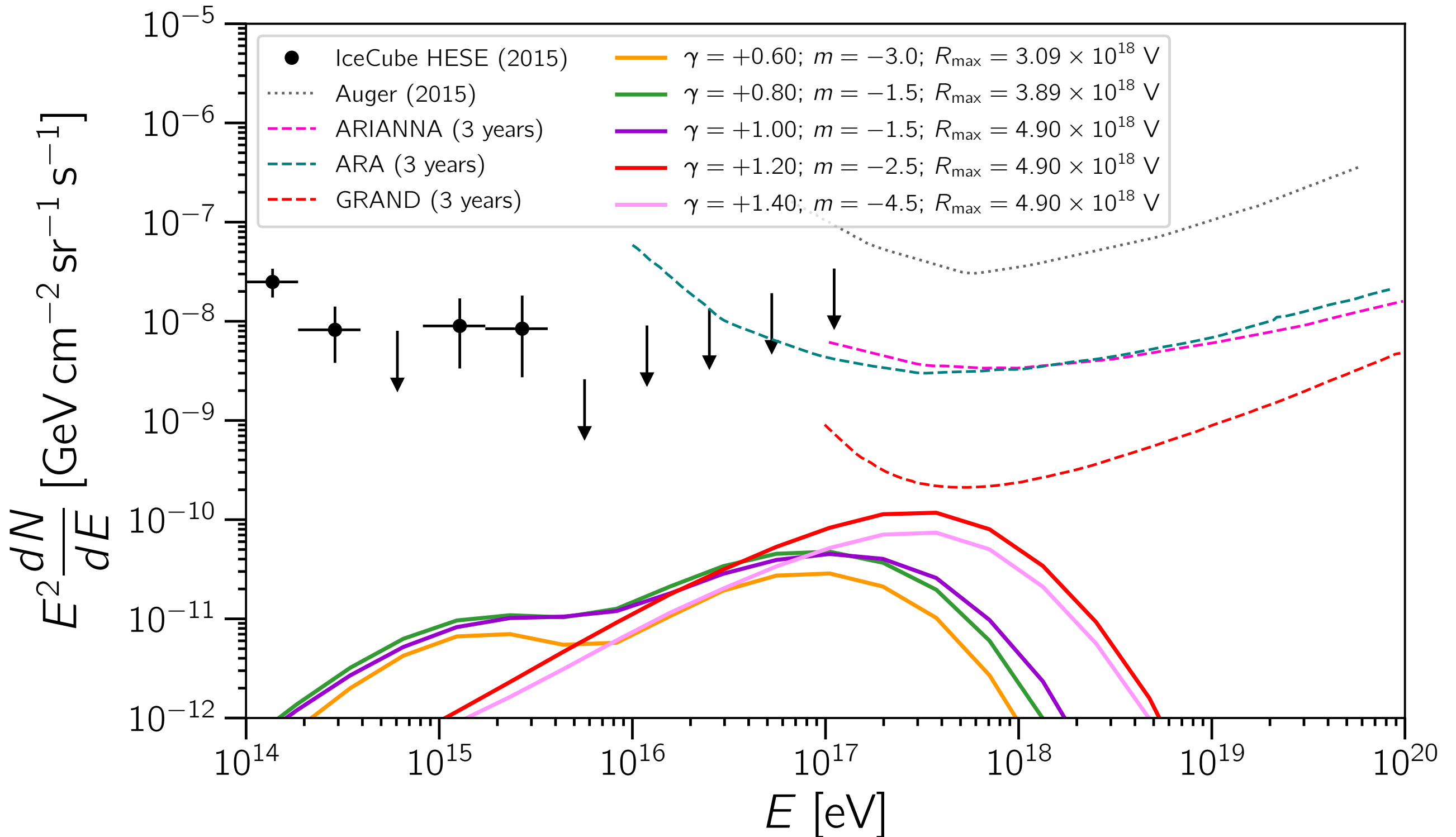




# cosmogenic neutrinos

preliminary

R. Alves Batista, R. M. de Almeida, B. Lago, K. Kotera. In preparation

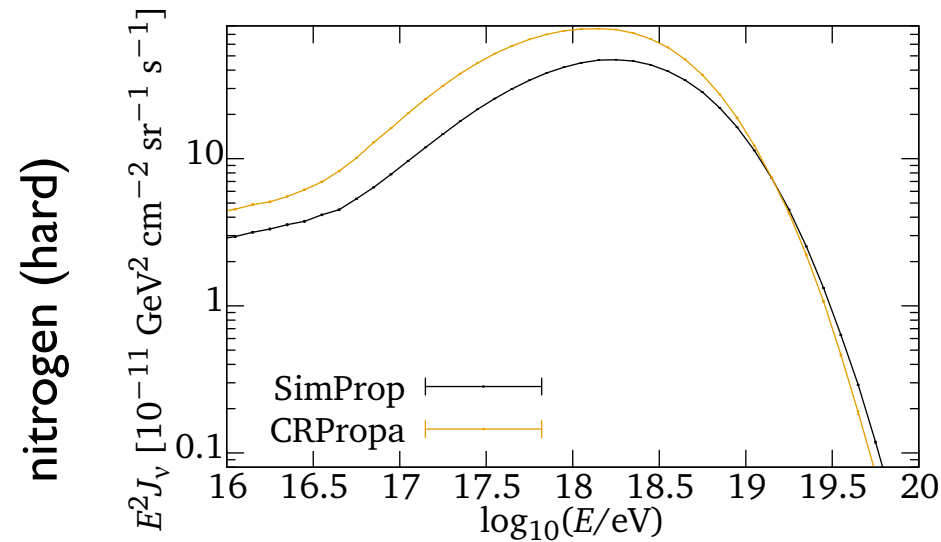


# sources of uncertainties on neutrino fluxes

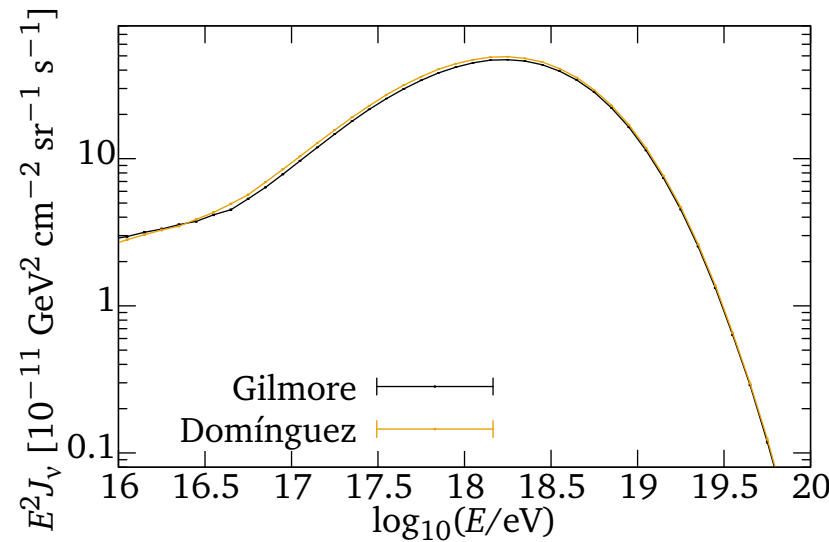
preliminary

R.Alves Batista, D. Boncioli, A. di Matteo, A. van Vliet. In preparation

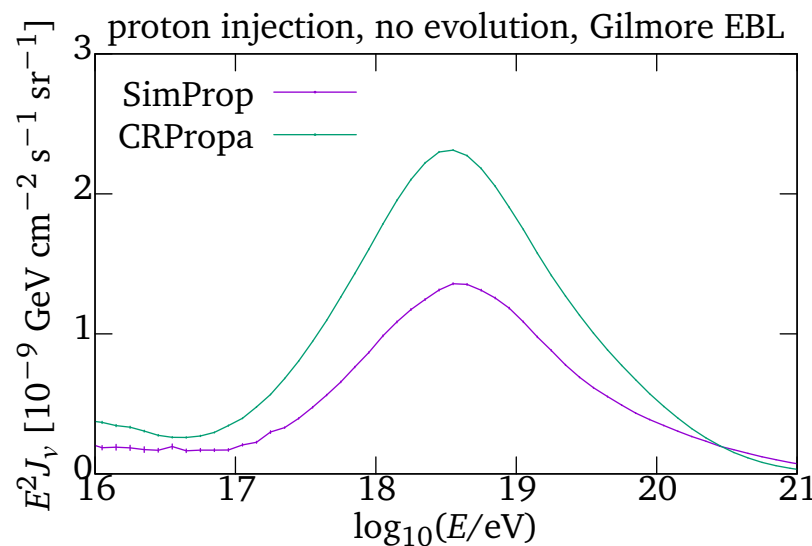
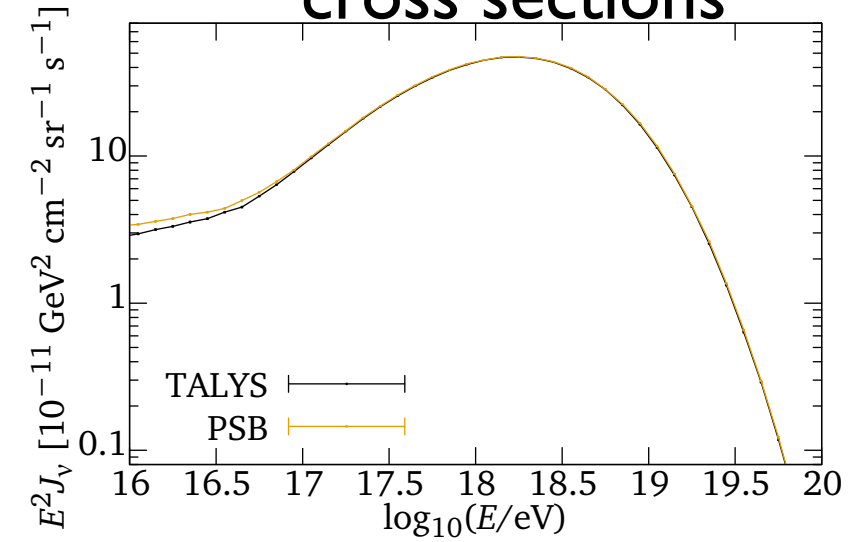
simulation codes



EBL models



photodisintegration cross sections



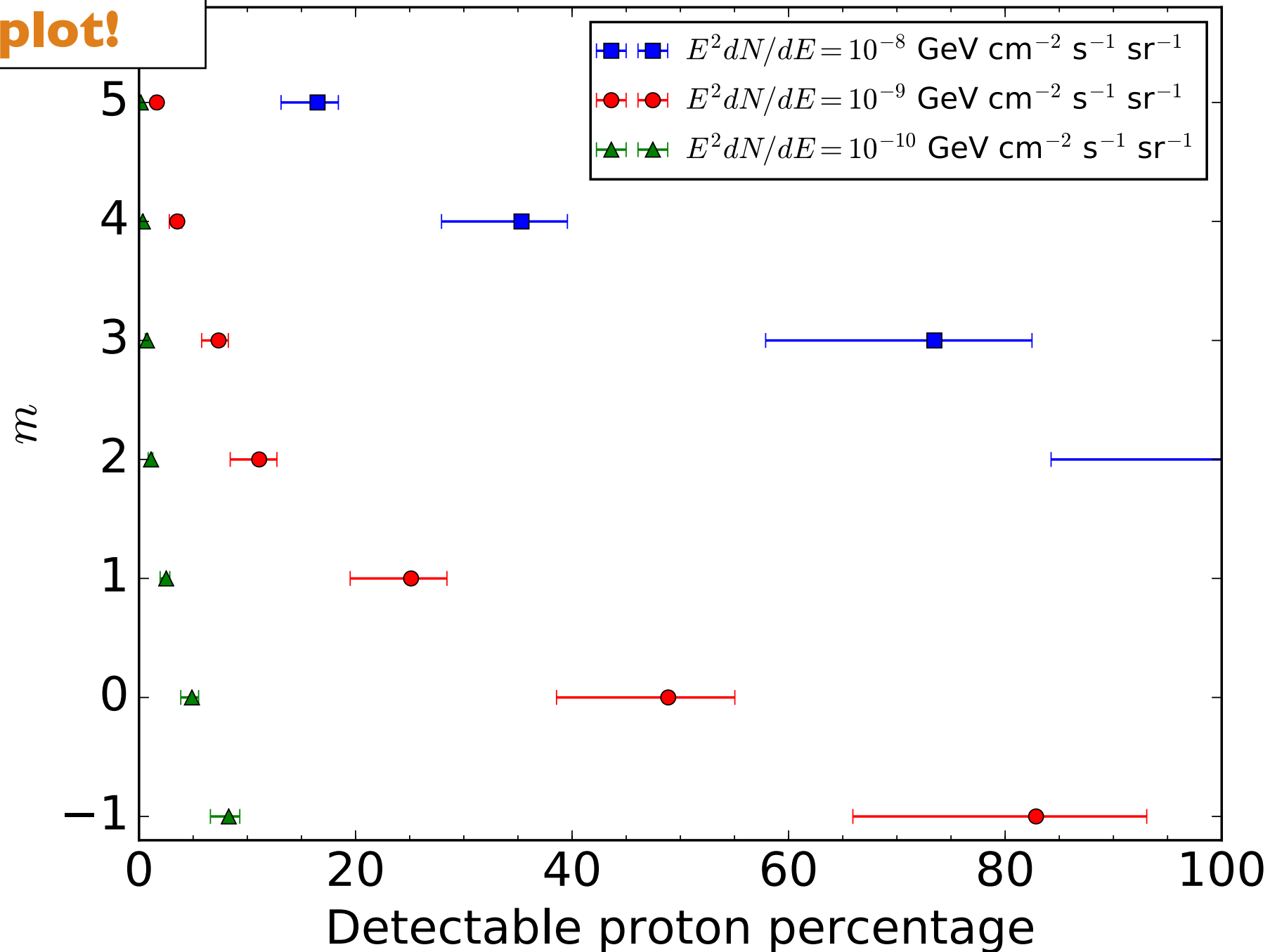
- ▶ EBL models don't affect the neutrino spectrum significantly
- ▶ photodisintegration cross sections have a small impact on the neutrino spectrum at  $E \sim 10 \text{ PeV}$
- ▶ different simulation codes give different results for the neutrino fluxes.
- ▶ CRPropa's treatment is more complete and uses fewer simplifications in the treatment of interactions



# detectable proton fraction

*A. van Vliet, R. Alves Batista, J. Hörandel. In preparation*

include these  
numbers in WVP?  
**money plot!**



- ▶ Auger fit redone including source evolution
- ▶ in the limit of no evolution, we retrieve Auger's best-fit (agreement better than 1%)
- ▶ the fits suggest a negative source evolution for UHECR sources
- ▶ low spectral index vs. low source evolution parameter, which one dominates?
- ▶ the most pessimistic Auger-compatible cases are a factor 3 below GRAND 200k projected sensitivity for 3 years
- ▶ GRAND may be able to reach the required level of sensitivity with ~10 years of data
- ▶ GRAND will have enough sensitivity to set limits on the fraction of UHE protons even in pessimistic scenarios with negative source evolution.