High Energy Neutrino Parameter Estimation

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Overview/Motivation

1. GRAND will measure the cosmogenic flux (in most cases).
2. What next? What can we learn once it is measured?
   - Minimal input from other experiments
3. Expect a degeneracy between redshift evolution and composition
   - Can this be broken?
4. What experimental parameters will help?

Means of determining UHECR parameters

Composition:

1. $X_{\rm max}$ ($X^{\mu}_{\rm max}$)
2. Anisotropy (known sources/B fields)
3. Cosmogenic neutrino flux

Redshift evolution:

1. Provides an indication of the sources
2. UHECR measurements constrain local normalization
3. Cosmogenic neutrinos are a function of the total flux to high redshift

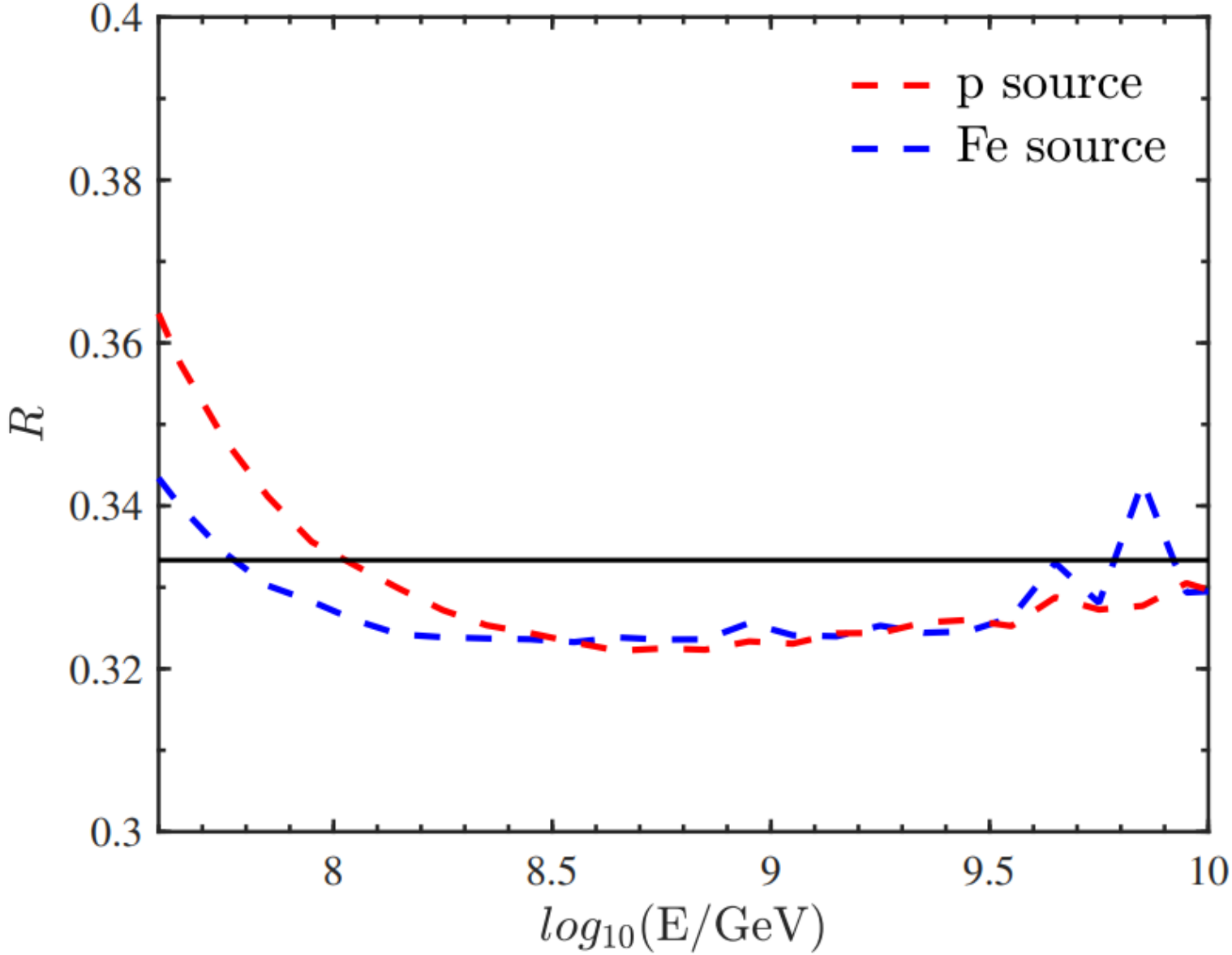
Method

1. CRPropa3
2. Fit normalization and γ to Auger's high energy spectrum

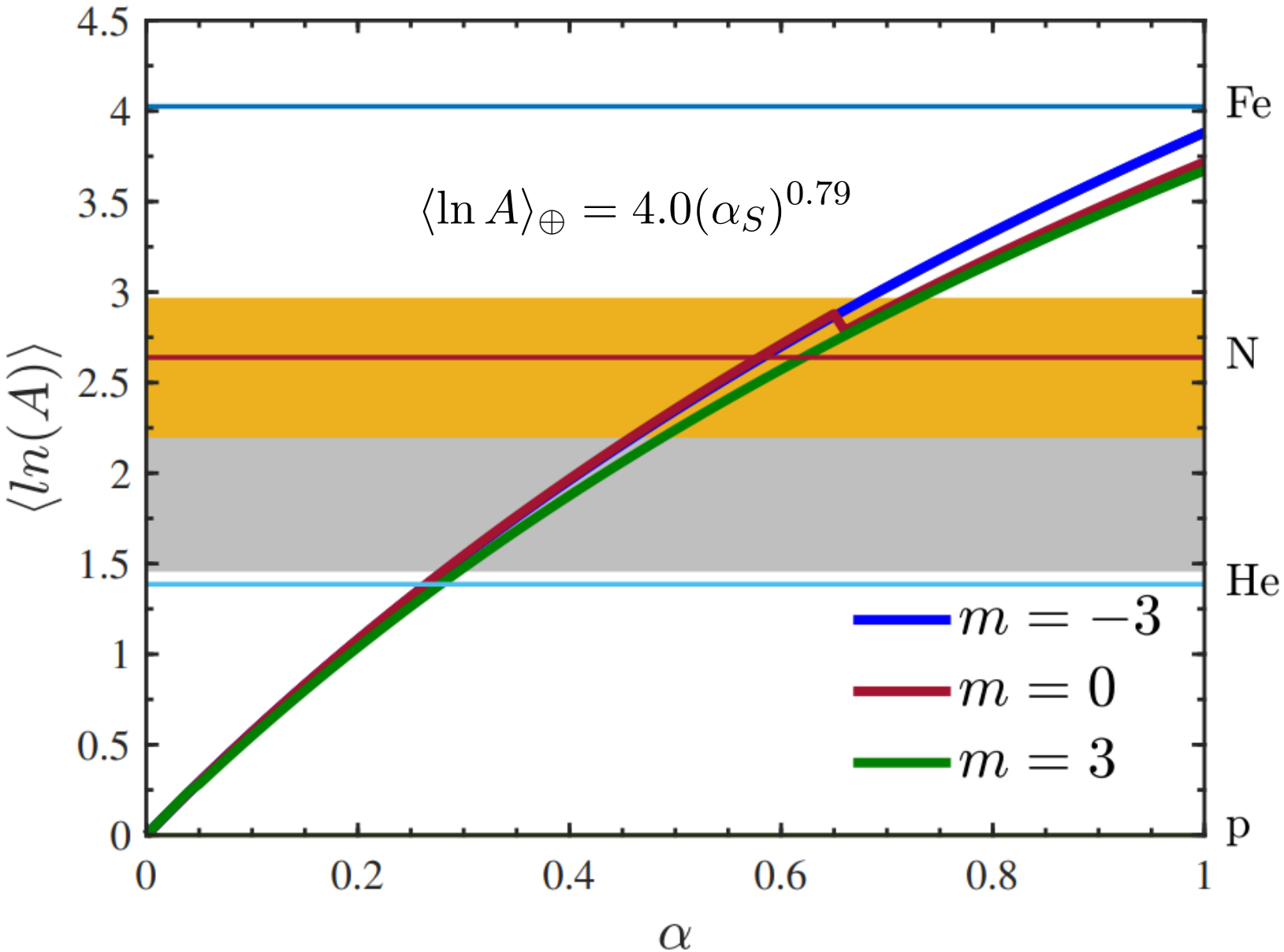
   consistent at $< 2\sigma$ (stat)
3. Two parameters:
   - Redshift evolution slope: $\rho(z) = (1+z)^{\boldsymbol{m}}$ up to $z = 1$
   - Composition proxy: $(1 - \boldsymbol{\alpha_S}) I_p + \boldsymbol{\alpha_S} I_{Fe}$
4. Take $\Delta \log_{10} E_\nu = 0.25$ $(^{+78\%}_{-44\%})$

Flavor Ratio

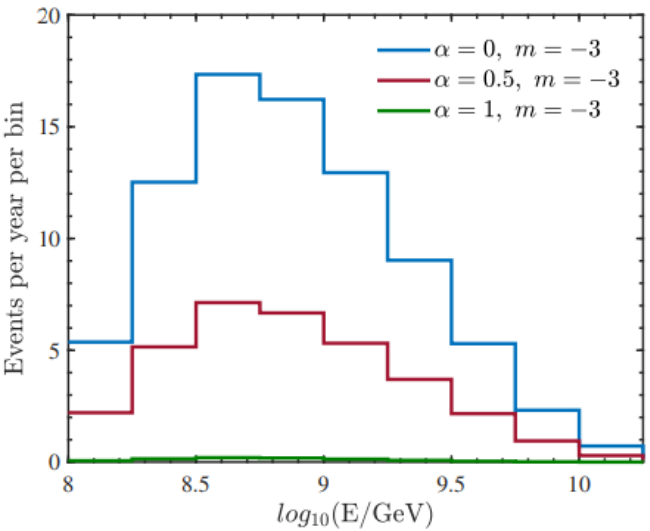
$\frac{I_{\nu_e}}{\sum_\alpha I_{\nu_\alpha}}$ at production

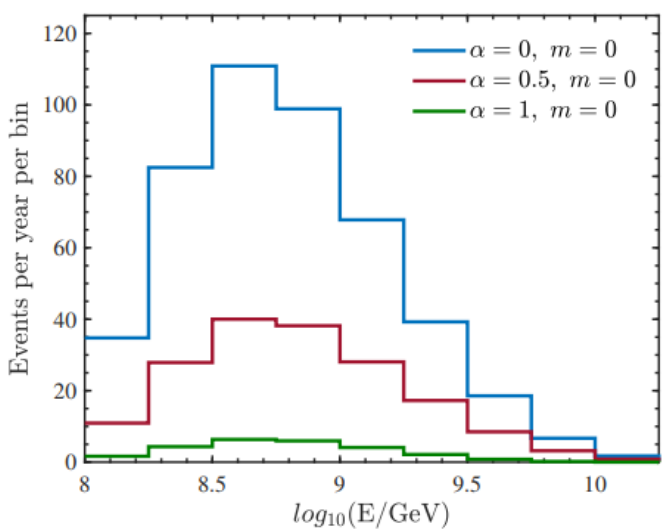


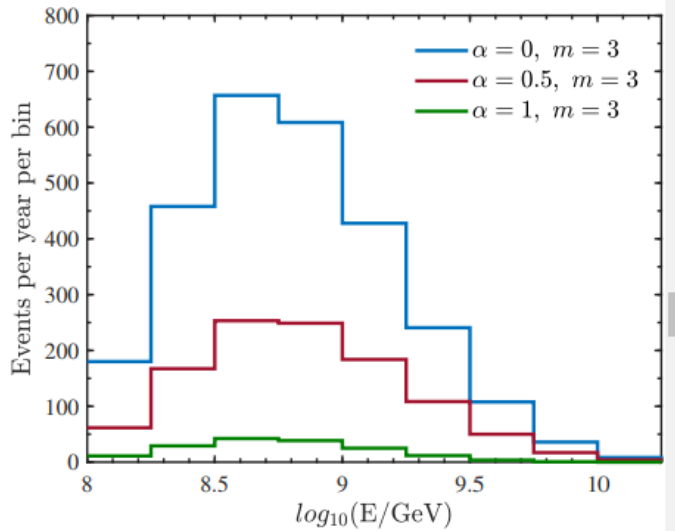
Converting EECR Composition from Source to Earth



Event Rate

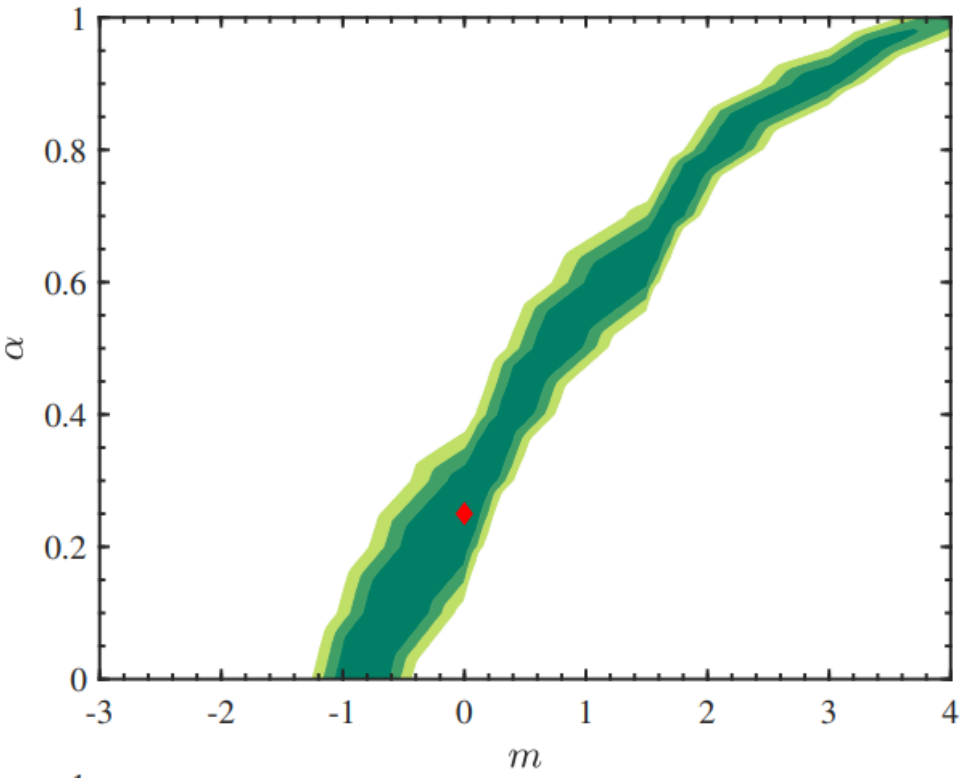


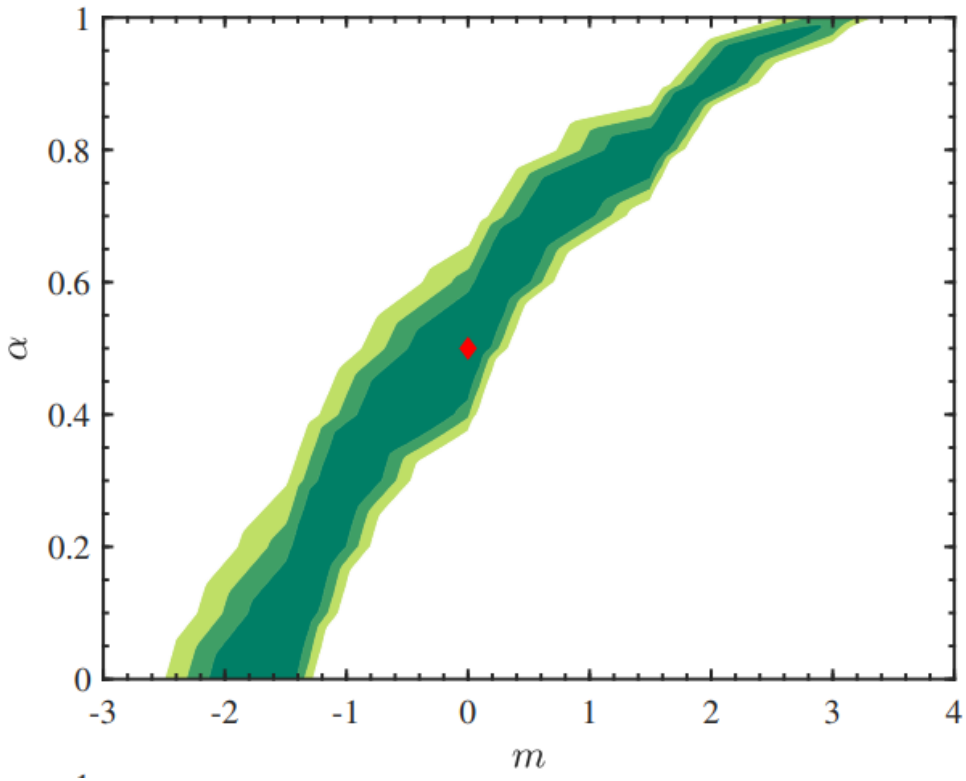




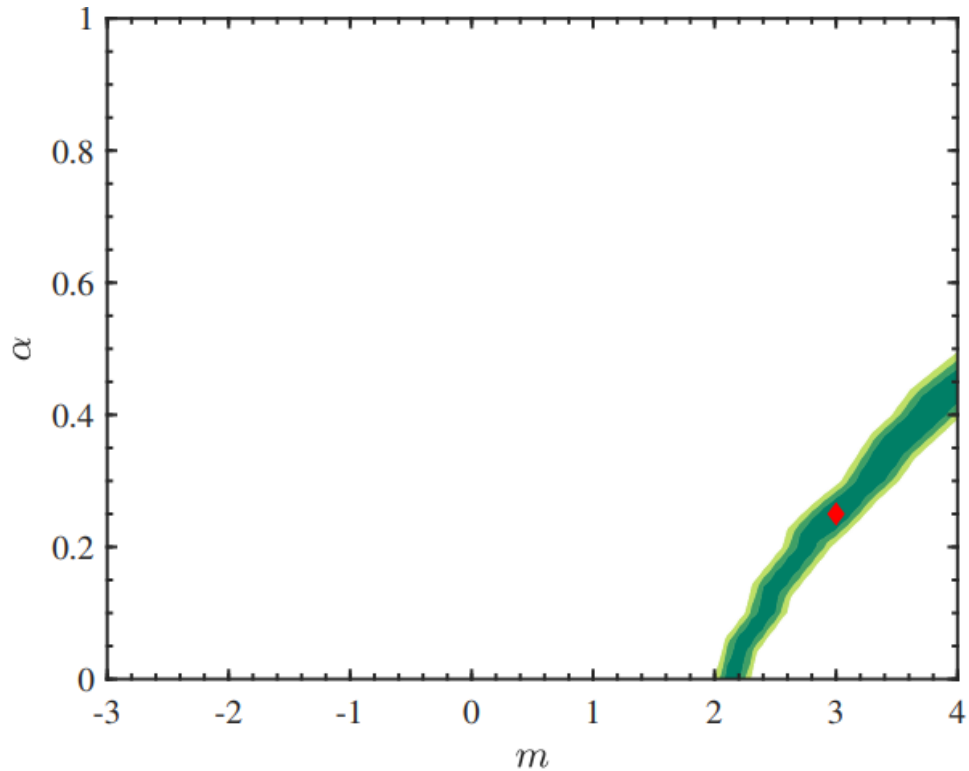
N increases with m and decreases with α_S.

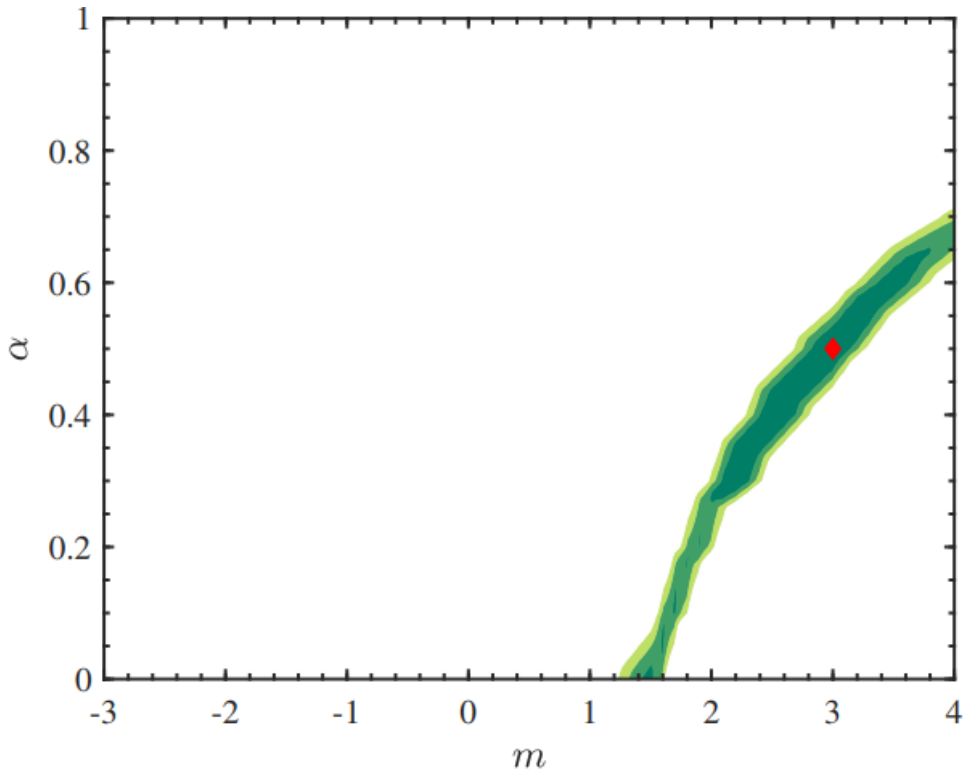
2D Projections: Degeneracy





2D Projections: Degeneracy





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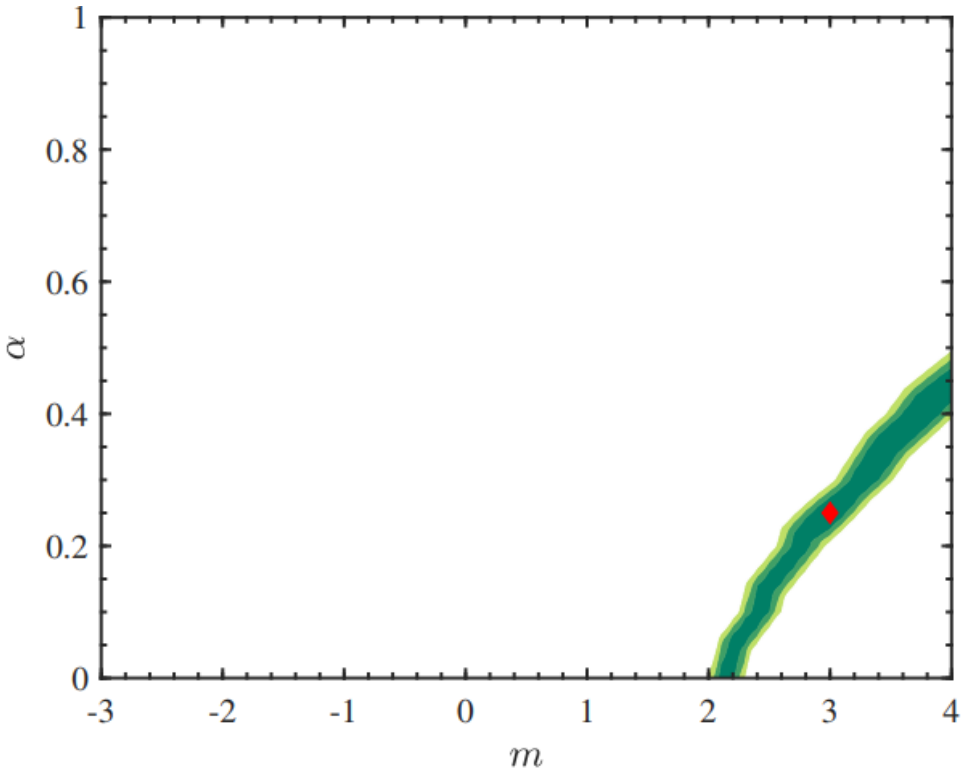
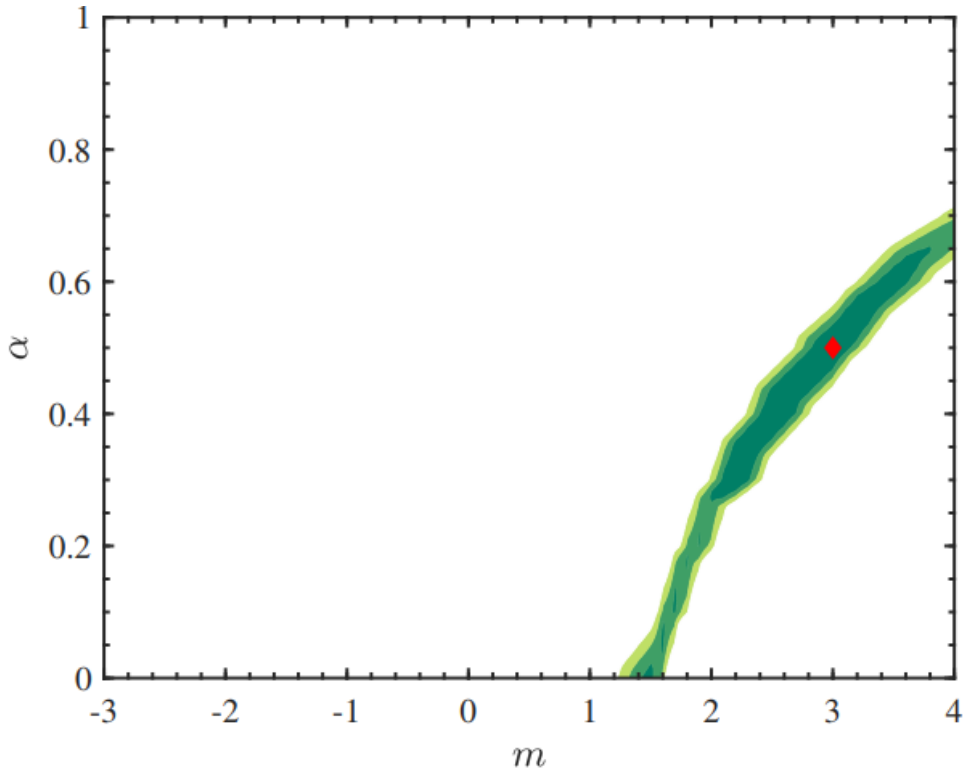
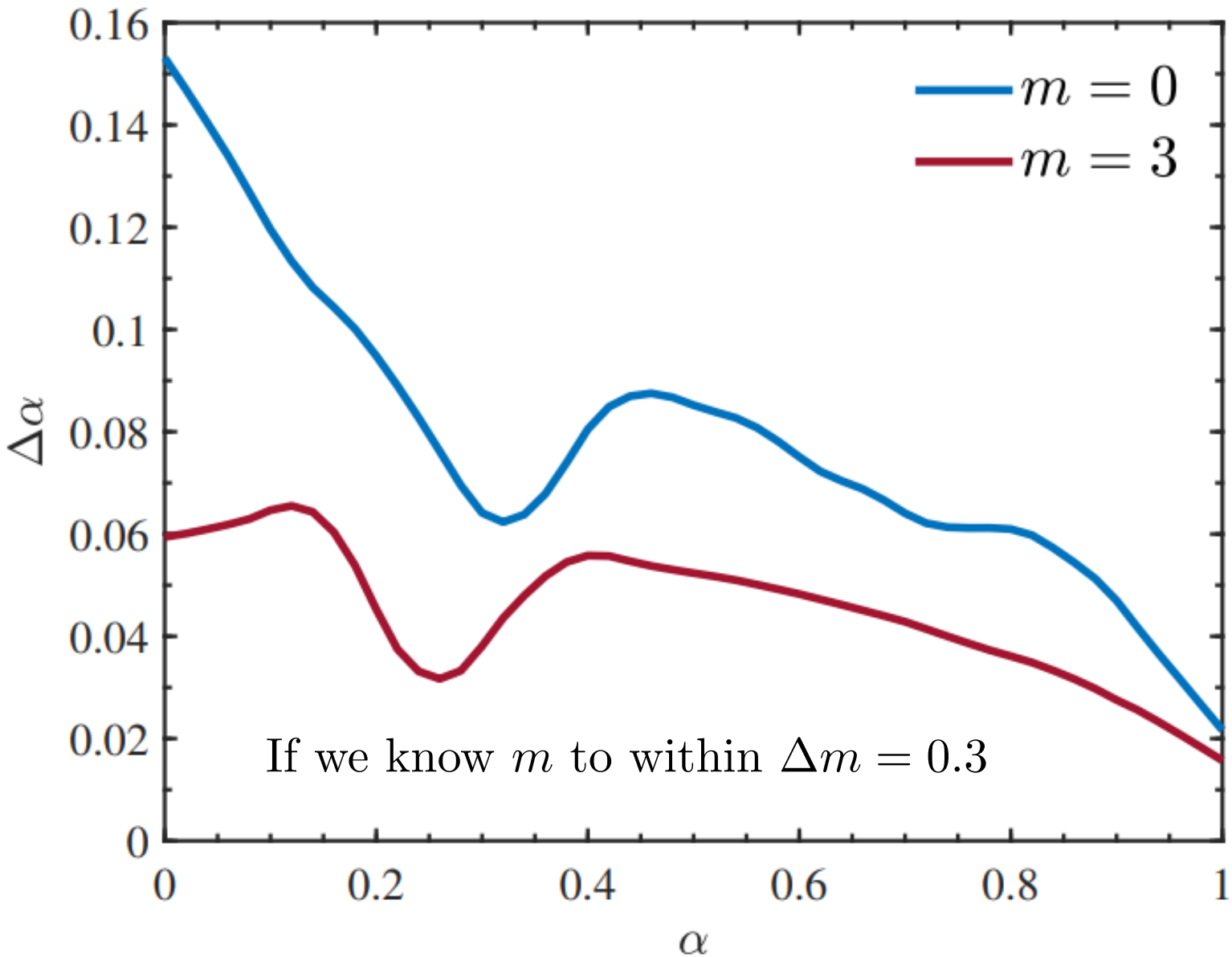




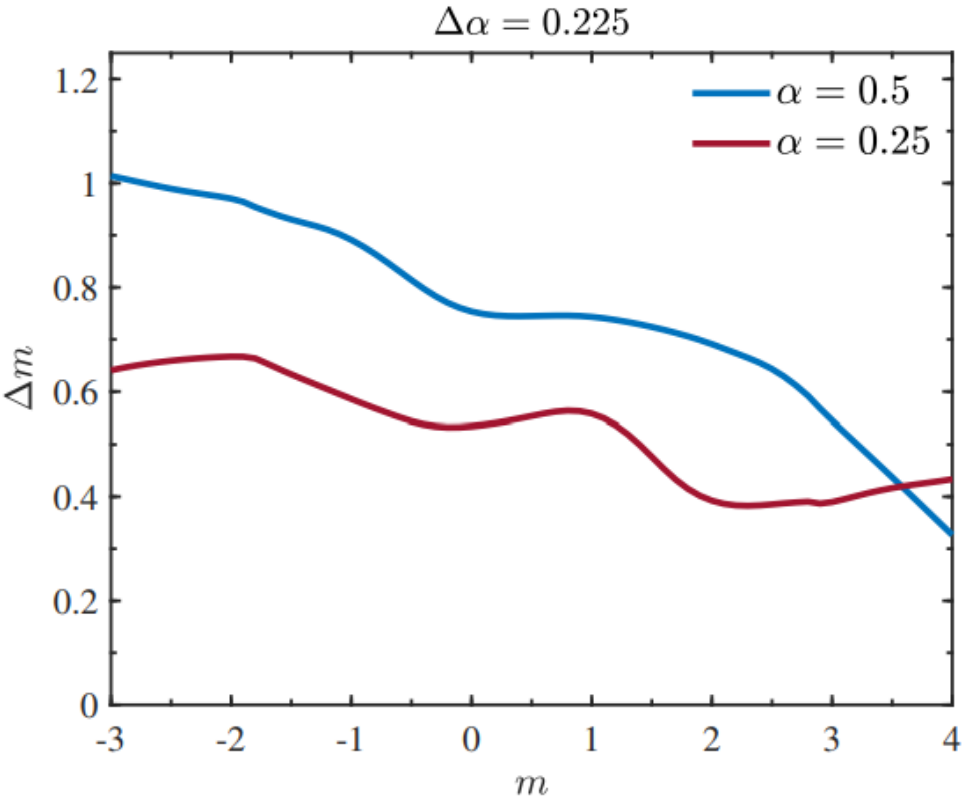
$\Delta \log_{10} E_\nu = 0.25 \to 0.1$ $\left(^{+26\%}_{-21\%}\right)$ changes nothing!

1D Projection with Input

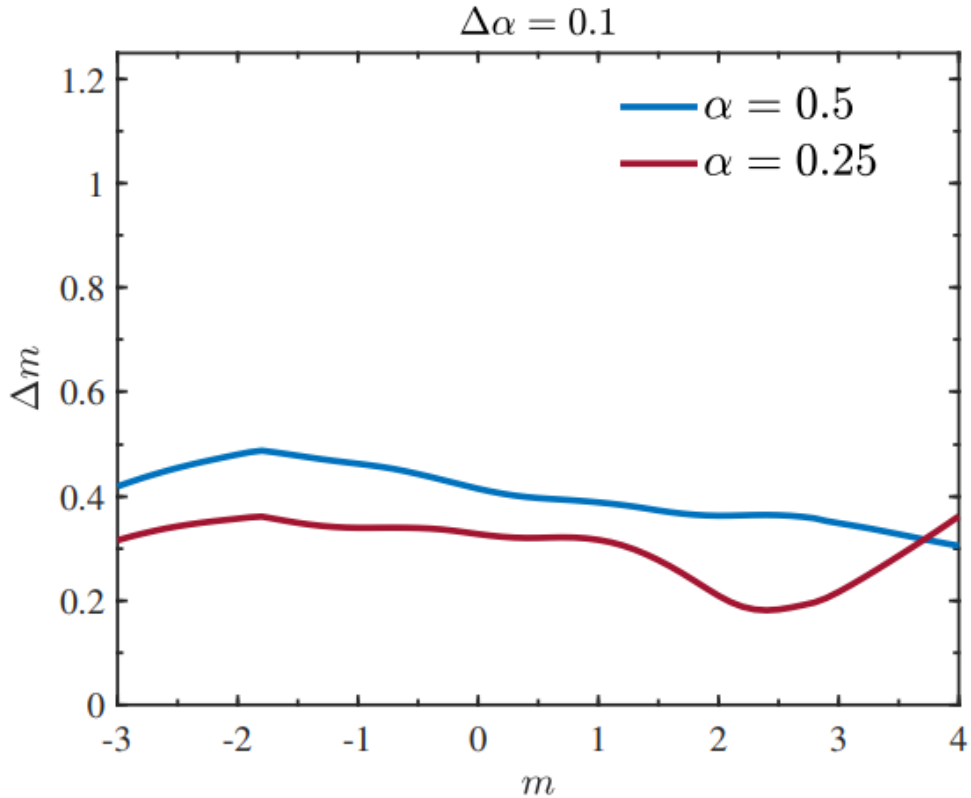


1D Projection with Input

Input $X_{\max}$ from Auger



With hadronic modeling uncertainties



Without hadronic modeling uncertainties

Other issues

1. Other high energy astrophysical sources
   - Connecting with IceCube and KM3NeT is important
2. BSM:
   - Oscillation: Decay, NSI, unitarity, ...
   - Particle: DM decay/annihilation, ...
   - Fundamental: LIV, ...

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Theory effort:

1. Absorption $\rightarrow$ cross sections
2. Air shower spectrum to neutrino spectrum: unfolding
3. Anisotropy exposure with multiple sites
4. ...

Wrap-up

1. Degeneracy between composition and redshift evolution slope
   - with EECR spectrum input.
2. With additional information we could reach:
   - $\Delta\alpha_S = 0.05 \rightarrow \Delta\langle \ln A \rangle_\oplus \sim 0.2$

     Compare with $\Delta\langle \ln A \rangle_\oplus \simeq 0.4$ excluding hadronic
     - with redshift evolution information
   - $\Delta m = 0.4$
     - with $X_{\rm max}$ information
3. Good neutrino energy resolution not too important, **but!**
4. Connection with IceCube flux is very important

Backups

Intermediate elements