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ON THE RELEVANCE OF THE PROTON TO ELECTRON LUMINOSITY RATIO FOR HIGH ENERGY NEUTRINOS

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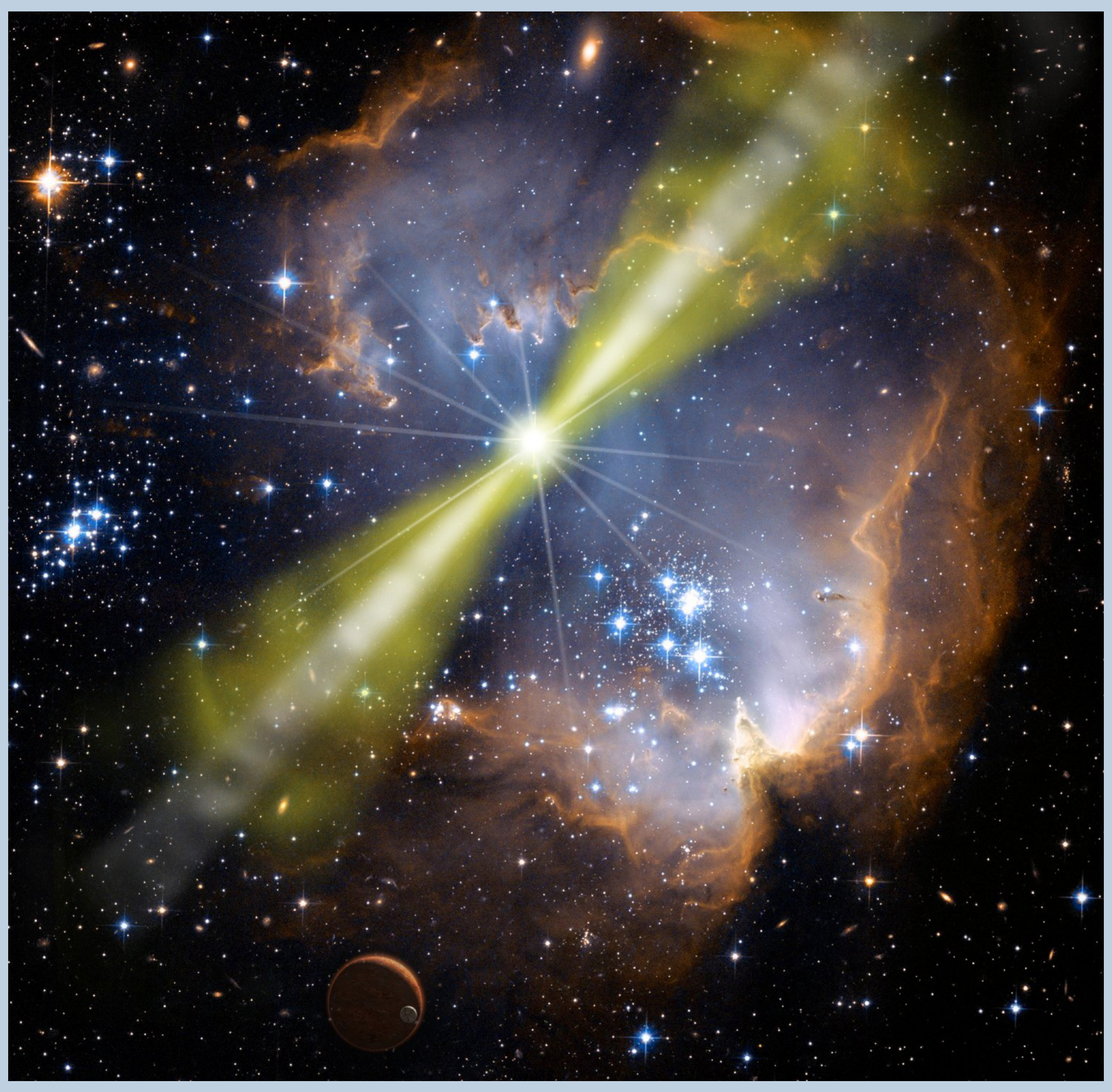

Figure 1: GRB produce cosmic rays, neutrinos and photons. To predict the neutrino flux the proton to electron luminosity ratio is essential [1].

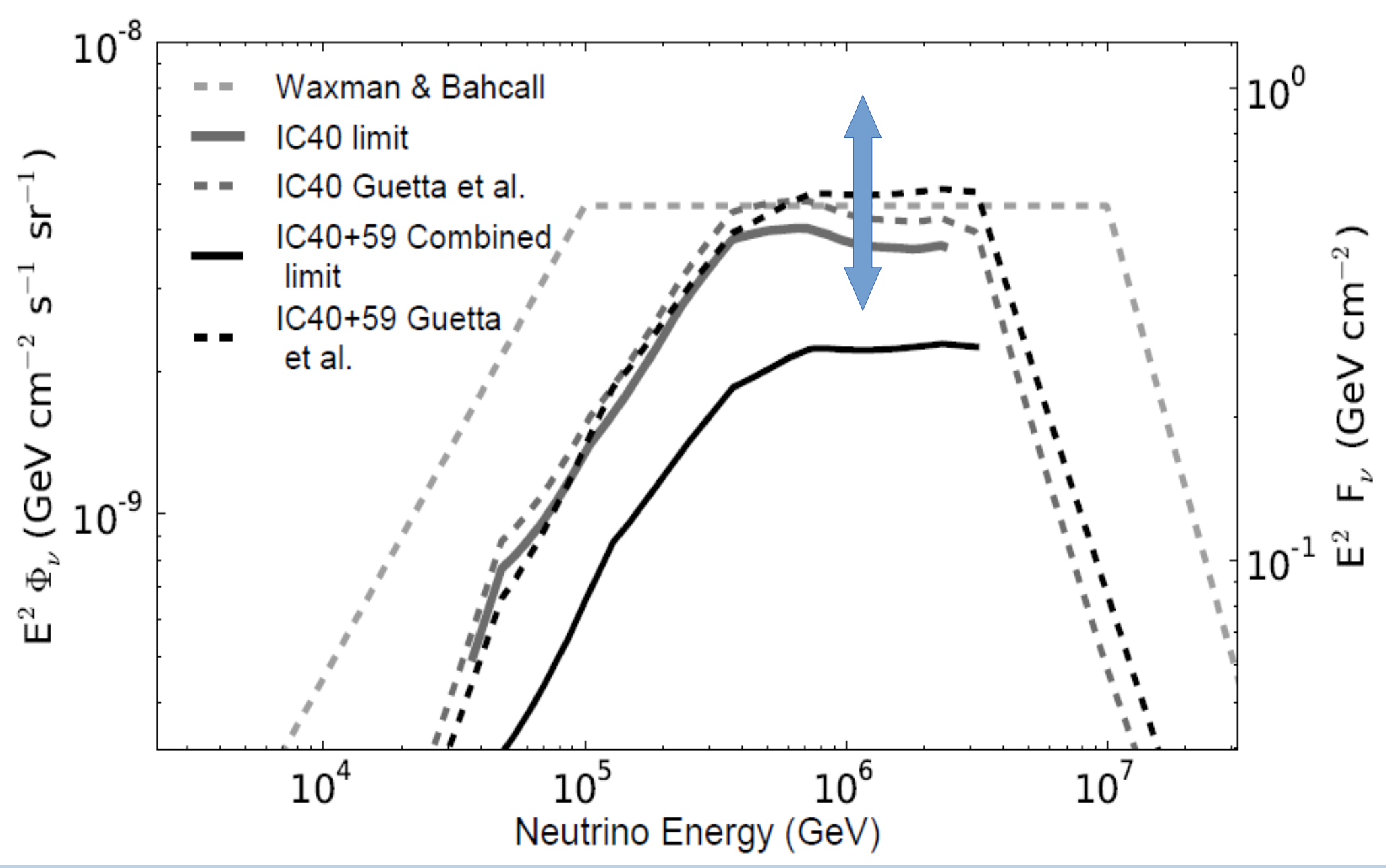

Figure 2: The predicted neutrino flux is proportional to the proton flux. Since the proton spectrum is calculated from leptonic synchrotron radiation L_v scales with f_e [6].

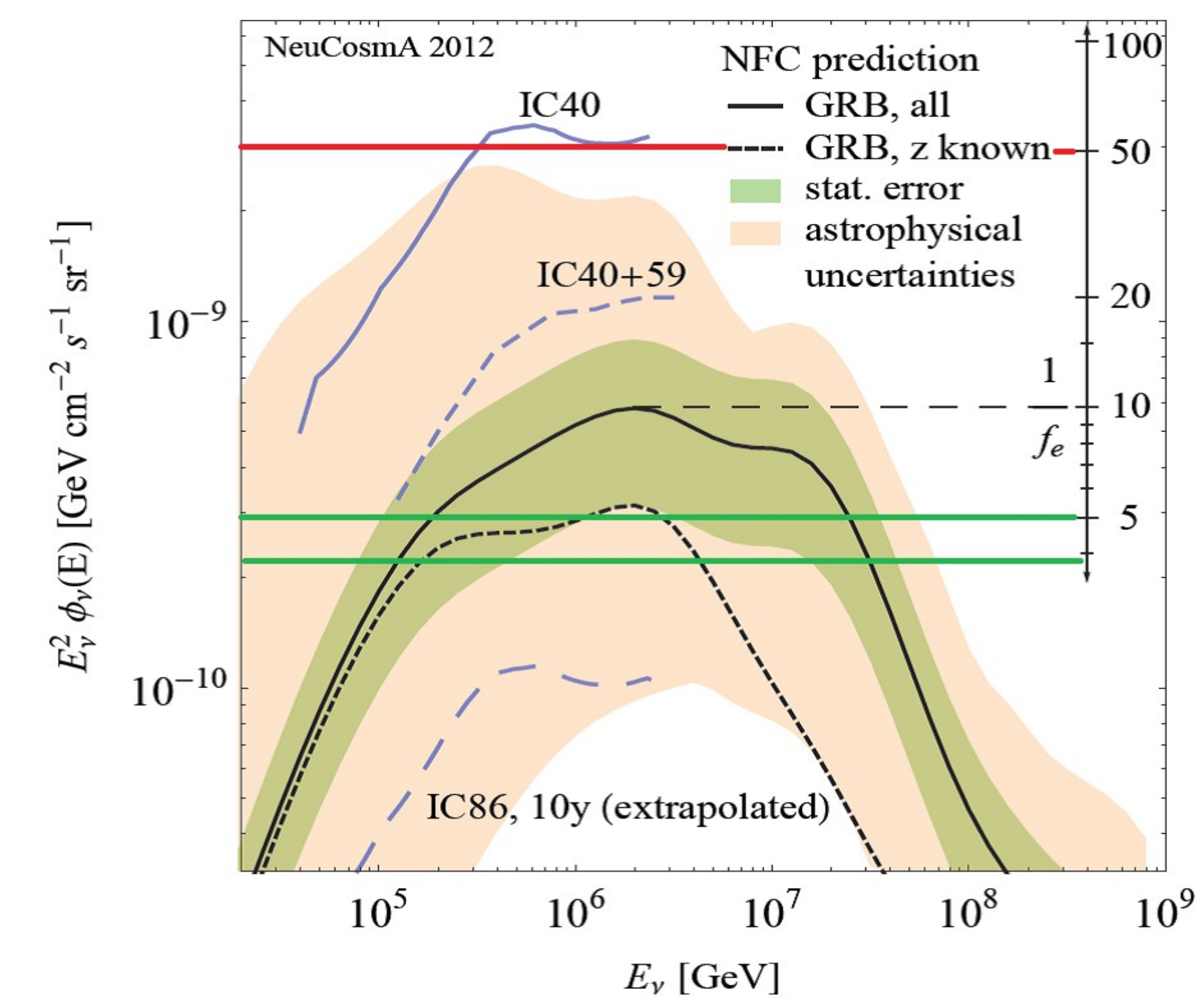

Figure 3: The neutrino normalization scales with $1/f_e$. The red line indicates the lower limit for equal indices. A spectrum for different spectral indices has to be fixed between the green lines [7].

How is f_e related to neutrino fluxes?

A direct and unique allocation of a cosmic ray spectrum with a specific GRB is impossible due to deflection in magnetic fields. The observation of the neutrino flux L_v, which is proportional to the proton flux, is interesting because it clearly pinpoints to the source. A common technique to predict L_v uses the chargeless synchrotron radiation produced in leptonic processes:
The electron spectrum can be derived from the synchrotron measurement. Thus, if the electron-proton luminosity ratio f_e is known, it is possible to estimate the neutrino spectrum from leptonic data. This assumption leads to the fact that L_v is proportional to f_e (Fig 2, 3).

$$\frac{\mathrm{d}N_\mathrm{p}}{\mathrm{d}p} = a_\mathrm{p} \cdot p^{-\alpha_\mathrm{p}}\;;\; \frac{\mathrm{d}N_\mathrm{e}}{\mathrm{d}p} = a_\mathrm{e} \cdot p^{-\alpha_\mathrm{e}}$$
$$T_{0,\mathrm{p}} = T_{0,\mathrm{e}} := T_0$$
$$N_\mathrm{p,tot} = \int_{T_0}^{\infty} \frac{\mathrm{d}N_\mathrm{p}}{\mathrm{d}T}\,\mathrm{d}T = \int_{T_0}^{\infty} \frac{\mathrm{d}N_\mathrm{e}}{\mathrm{d}T}\,\mathrm{d}T = N_\mathrm{e,tot}$$

Equation 1: The assumptions we used for our calculation

What is the conventional ratio?

The conventional luminosity ratio $f_{e,\ conv.}$ (e.g. [2]) is derived for equal spectral indices a_i above a minimal kinetic energy T_0. This leads - for the common assumption a_i=2.2 - to $f_{e,\ conv}$ =1/100. But from GRB observations it is known that it should be around $f_{e,\ GRB}$ = 1/10 [3]. Furthermore, $f_{e,\ conv.}$ is not energy dependent and therefore giving rise to problems.

$$N(T) := \frac{\mathrm{d}N_\mathrm{e}/\mathrm{d}T}{\mathrm{d}N_\mathrm{p}/\mathrm{d}T} = \frac{a_\mathrm{e}}{a_\mathrm{p}} \cdot T^{\alpha_\mathrm{p}-\alpha_\mathrm{e}} \cdot \frac{1+\frac{m_\mathrm{e}}{T}}{1+\frac{m_\mathrm{p}}{T}} \cdot \frac{\left(1+2\frac{m_\mathrm{e}}{T}\right)^{-(\alpha_\mathrm{e}+1)/2}}{\left(1+2\frac{m_\mathrm{p}}{T}\right)^{-(\alpha_\mathrm{p}+1)/2}}$$
$$f_\mathrm{e}(T_\mathrm{max}) := \left(\int_{T_0}^{T_\mathrm{max}} \frac{\mathrm{d}N_p}{\mathrm{d}T'} \cdot T'\mathrm{d}T'\right)^{-1} \cdot \left(\int_{T_0}^{T_\mathrm{max}} \frac{\mathrm{d}N_e}{\mathrm{d}T'} \cdot T'\mathrm{d}T'\right)$$

Equation 2: Definition for the differential particle number ratio and the luminosity ratio f_e.

The new calculation

In our more detailed study the assumption of equal spectral indices was dropped (Equation 1). Different loss processes could affect the indices in such a way that the proton distribution is slightly steeper than the electron one [4,5]. This leads to an energy dependent luminosity ratio. All results were solved analytically and no approximations or numerical methods were needed. The definition of f_e is shown in Equation 2.

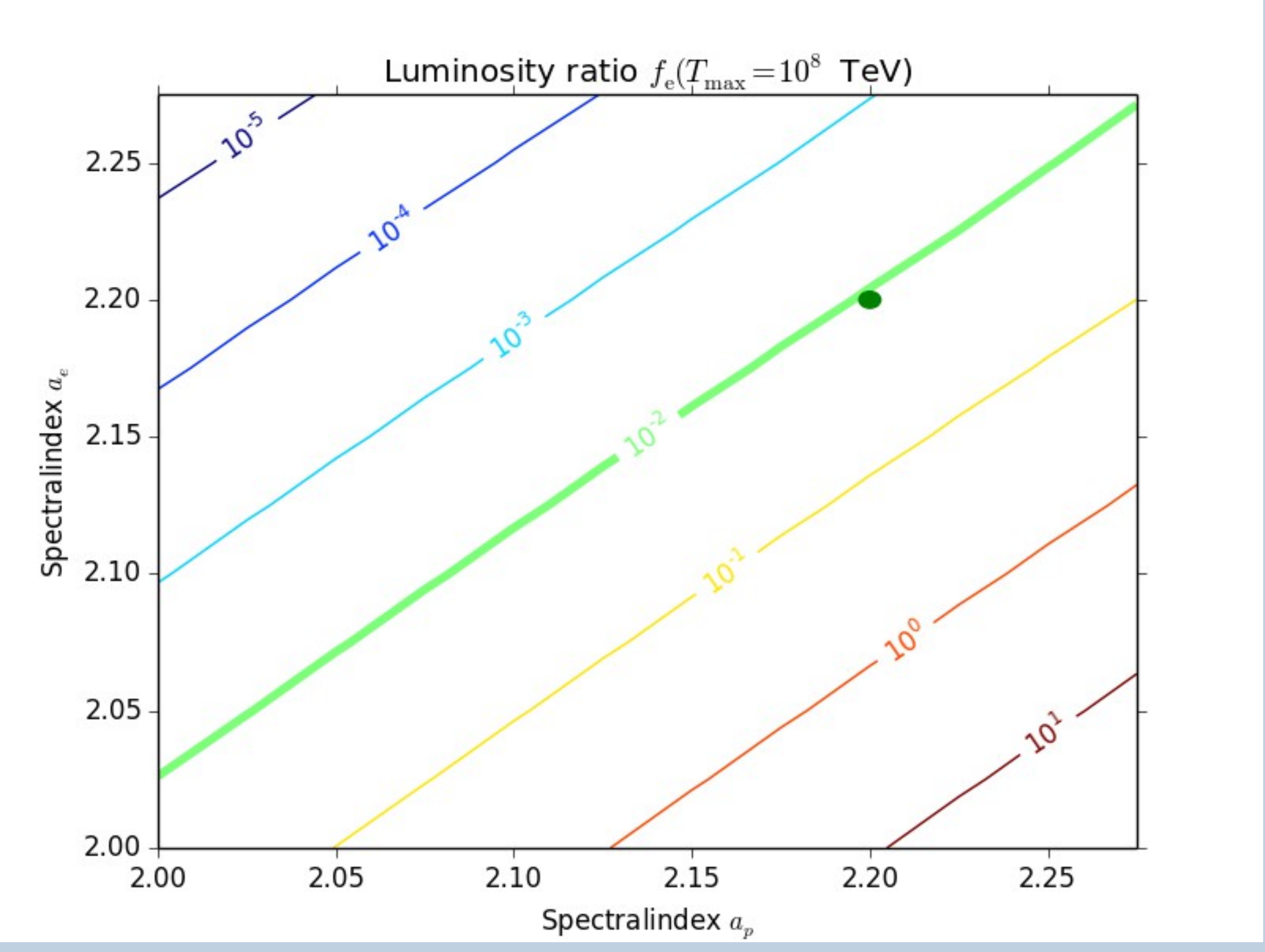

Figure 4: Luminosity ratio for fixed kinetic energy and varying spectral indices. Deviations from conventional ratio grow exponentially with increasing index difference [4].

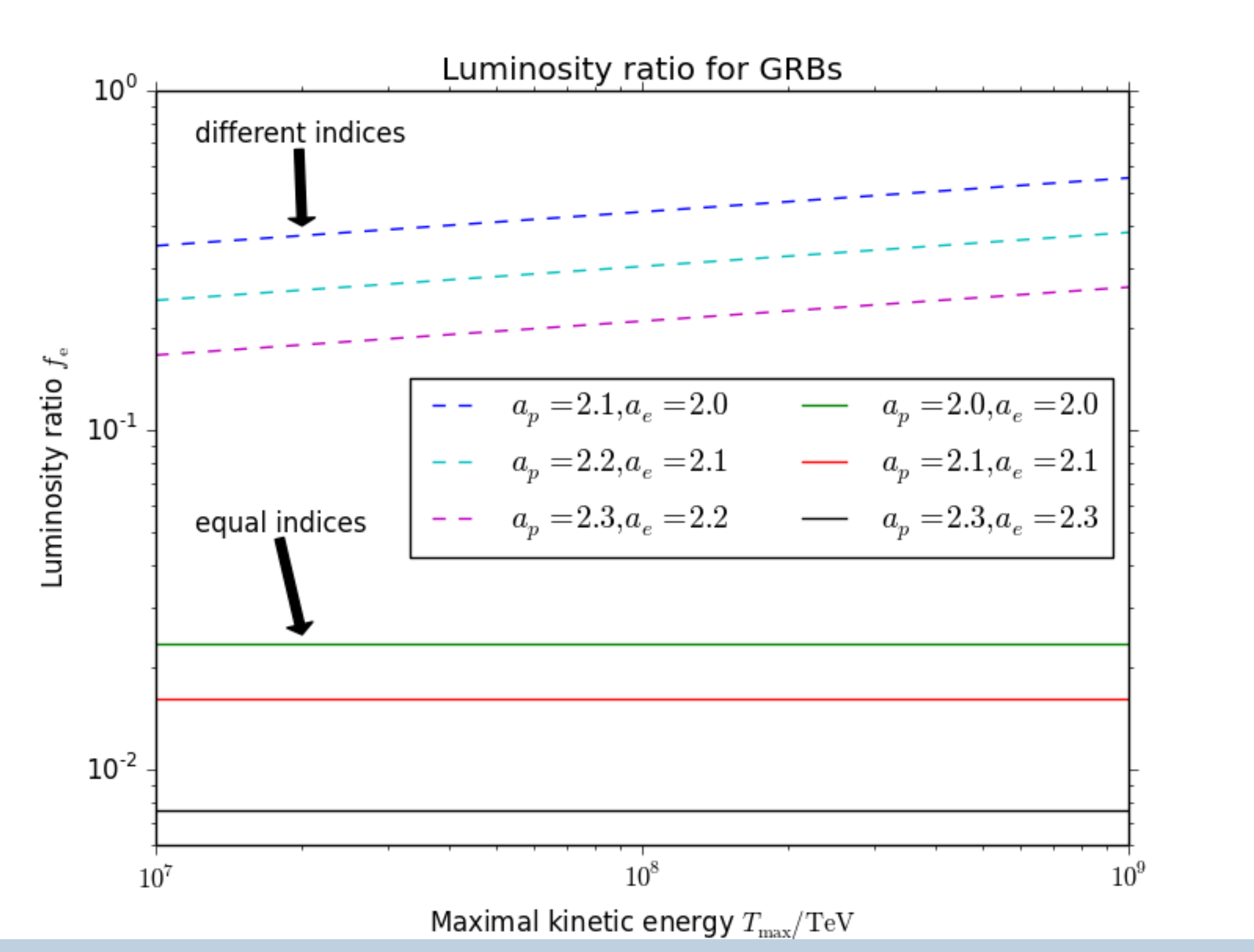

Figure 5: Luminosity ratio for different spectral index combinations. Deviations from the conventional ratio are visible. For different indices the energy dependency is noticeable [4].

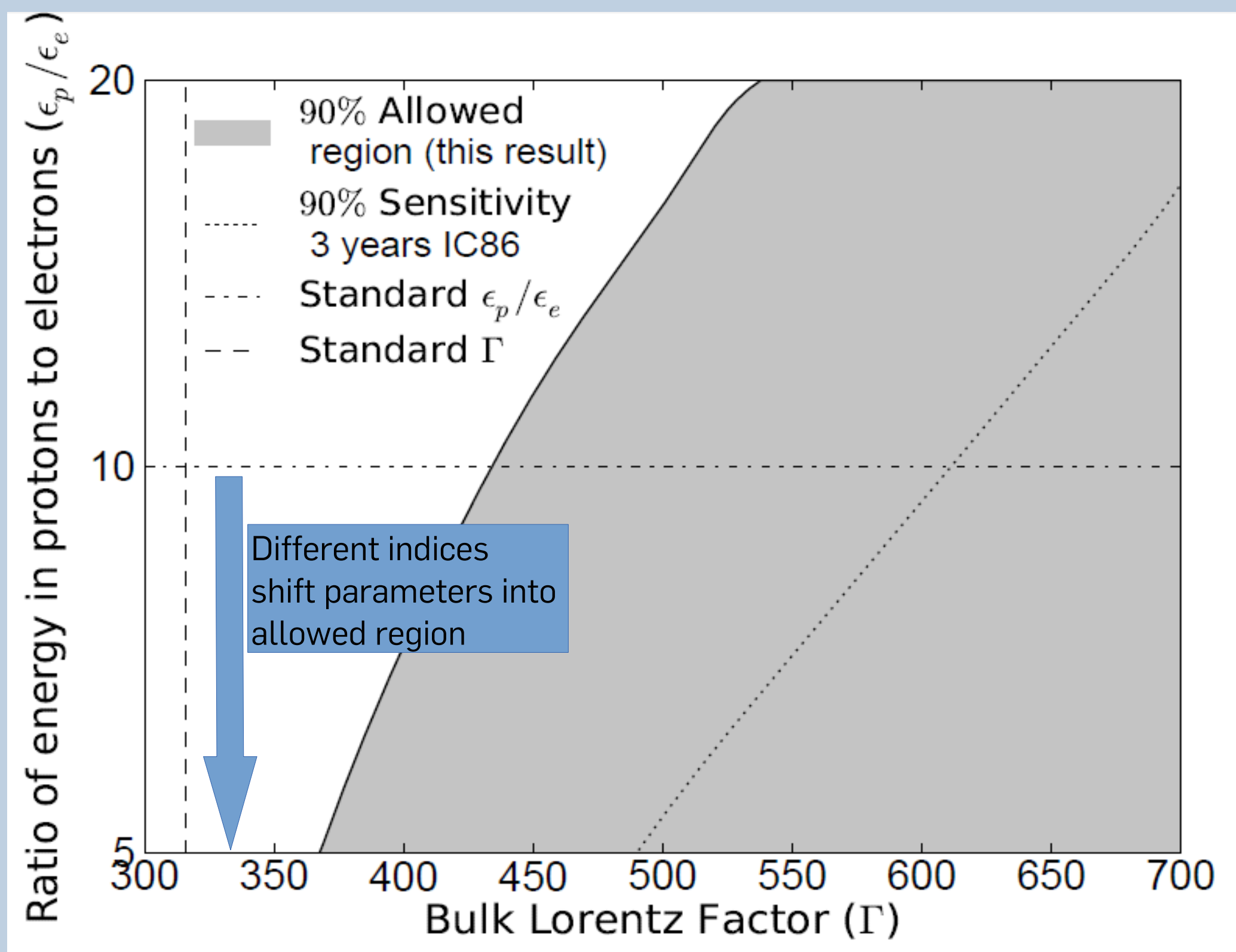

Figure 6: GRBs are excluded with 90 % possibility for conventional f_e and an average Lorentz factor of 300. For different spectral indices the parameters could be shifted into the allowed region [6].

Conclusion

What are the consequences of f_e for neutrino fluxes?

Our results are presented in Figures 4 and 5. The energy dependency of f_e is clearly visible in Figure 5. Figure 4 shows that for fixed T_{max} the dominant effect is given by the index difference.

- For equal spectral indices ($2.0<a_e=a_p<2.3$) we derived: $0.008<f_e<0.02$
- For different spectral indices with $a_p-a_e=0.1$: $0.2<f_e<0.3$

➡ Standard prediction overestimates the neutrino flux ➡ larger allowed region (Figure 6)

Take-home message

- The conventional ratio is insufficient for flux prediction of sources with different spectral indices.
- Our new results provide the opportunity to handle these sources correctly and will soon be available [4].

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