Detecting Small Scale Component in Power Law Spectra
Executive Summary

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Although atmospheric lepton spectra are nowadays routinely reconstructed by large scale neutrino telescopes like IceCube and Antares, the obtained fluxes are subject to rather large uncertainties, especially at high energies. It is due to these large uncertainties that the specta do not allow to discriminate between different cosmic ray models. In addition, the extraction of physics parameters from the spectra is a challenging task, as fits to the extracted data points are not a suitable method. In this contribution we present a method to circumvent these challenges, via the application of functional data analysis and the utilisation of the minima in the energy weighted differential lepton fluxes.

Energy weighted lepton spectra $E^m \frac{d\Phi}{dE}$ are often utilised to display small scale structures in lepton fluxes. These structures are hardly visible, when considering the un-weighted fluxes $\frac{d\Phi}{dE}$, as the spectra can be approximated by steeply falling power laws. Weighted lepton spectra can, however, not only be utilised for visualisation purposes, as the position of the minima $E_{\mathtt{min}}$, depends on the magnitude m, as well as on the underlying cosmic ray model. In case $E_{\mathtt{min}}$ can be accessed with sufficient precision, this dependency can be utilised to discriminate between different cosmic ray models.

Lepton spectra measured by neutrino telescopes are expected to consist of a conventional and a so-called prompt component. For the case of neutrinos a diffuse flux of astrophysical neutrinos contributes to the spectrum as a third component. Utilising $E_{\mathtt{min}}$ and modelling all components as power-laws then allows for the extraction of physics parameters. The ratio of the normalisations of the conventional component and a component of interest $\Phi_{0,\mathtt{int.}}/\Phi_{0,\mathtt{conv.}}$ can, for example, be accessed via the following equation (we refer to the proceedings for a derivation):

$$\frac{\Phi_{0,\mathtt{int.}}}{\Phi_{0,\mathtt{conv.}}} = E_{\mathtt{min}}^{\gamma_{\mathtt{conv}}-\gamma_{\mathtt{int.}}} \frac{\gamma_{\mathtt{conv}} + m}{-\gamma_{\mathtt{int.}} + m}, \tag{1}$$

where $\gamma_{\mathtt{int.}}$ and $\gamma_{\mathtt{conv}}$ represent the spectral indices of the component of interest and the conventional component, respectively. For muons the component of interest corresponds to the prompt component of the atmospheric muon flux. For neutrinos, the component of interest corresponds to the diffuse astrophysical flux. In this case, however, the contribution of the prompt component is neglected. $\Phi_{0,\mathtt{conv.}}$ and $\gamma_{\mathtt{conv}}$ are obtained via a power law fit to simulated conventional fluxes, utilising assumptions on the cosmic ray flux and the hadronic interaction model.

Assuming a contribution of no more than two components to atmospheric lepton spectra, one can further derive a quantity $F(m)$, which depends on $E_{\mathtt{min}}$ and is equal to one, in case both components are modelled as power laws. Accordingly, $F(m)$ is distinctly altered by the presence of a third component and the size of the alteration depends on the normalisation of said additional component. Estimating $F(m)$ as a function of $E_{\mathtt{min}}$, especially investigations for a deviation from a horizontal line, can then be utilised for the detection of additional components, e.g. prompt atmospheric neutrinos, in lepton energy spectra.

In conclusion, investigating the positions of minima $E_{\mathtt{min}}$ in energy weighted differential spectra $E^m \frac{d\Phi}{dE}$, provides insight into the physics of atmospheric leptons for three reasons. First, studying $E_{\mathtt{min}}$ as a function of m allows to discriminate between cosmic ray models. Second, modelling all components as power laws, allows for the estimation of physics parameters. And third, the derived quantity $F(m)$ can be used for the detection of additional spectral components.