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Ideas to measure the prompt component of the atmospheric muon flux

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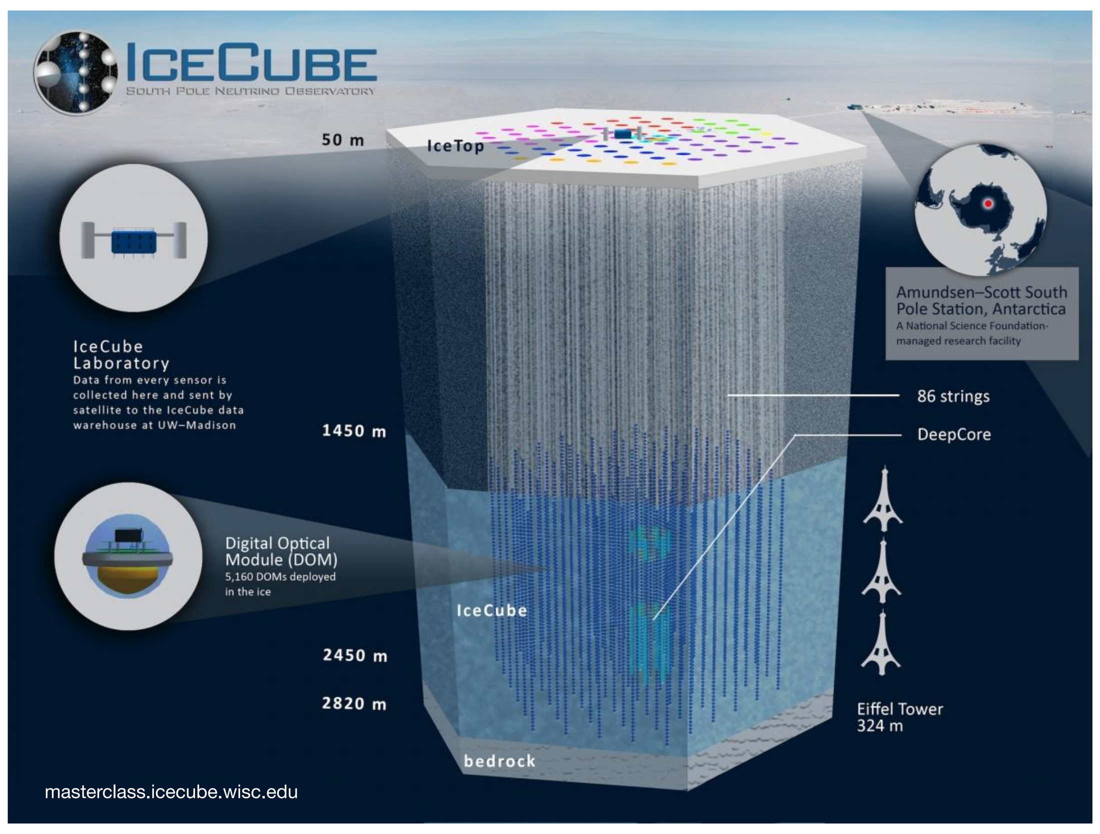
Introduction

Cosmic rays interact with our atmosphere and produce large air showers, generating several types of stable and unstable particles. The unstable daughter particles decay and muons can be produced, which are able to reach the earth's surface. This atmospheric muon flux is divided into a conventional and a prompt component. Conventional muons come from pions and kaons, which have a long lifetime compared to the other particles that are defined as prompt. Due to the short lifetime of the prompt particles, they decay nearly instantly and lose almost no energy. This means that the prompt muon flux follows the spectrum of the primary cosmic ray flux and starts to dominate at energies higher than TeV.

A significant discovery of the prompt muon flux has not yet been made. However, learning more about the prompt component can help us to better understand the physics of hadronic interactions.

In this analysis, new air shower simulations will be performed with the latest CORSIKA version, including hadronic interaction models describing the charm component as well as information about the particle history of muons. We intend to use these simulations to perform a measurement of the prompt muon flux using the IceCube Neutrino observatory.



Atmospheric Muon Flux

$$\Phi_{\mathrm{tot}} = \Phi_{\mathrm{conv}} + \Phi_{\mathrm{prompt}}$$

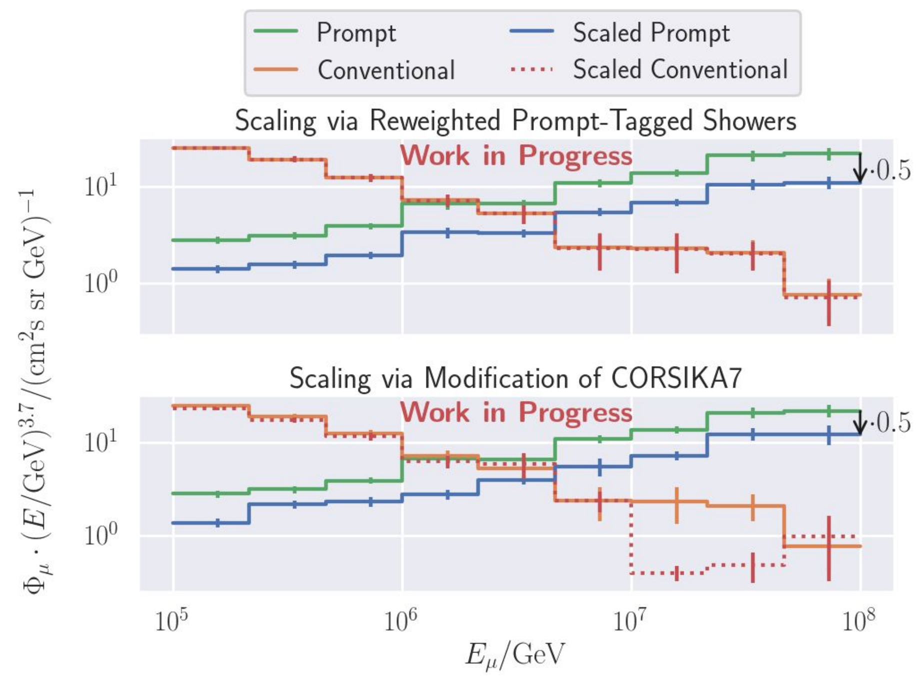
$\pi, K \propto E^{-3.7}$

prompt $\propto E^{-2.7}$ (Simple definition: all other particles)

Analysis idea

Our analysis idea is to compare IceCube data with Monte Carlo simulations, where the simulations can have a varied normalization of the prompt component. This is achieved by creating a single set of shower simulations, but applying a re-weighting to all shower events containting prompt muons, thus creating individual simulation sets with a different prompt normalization. This approach avoids the need to create new air shower simulations (which are computationally expensive to run) for each different prompt normalization

The plots above show the muon energies for simulations with different weights.

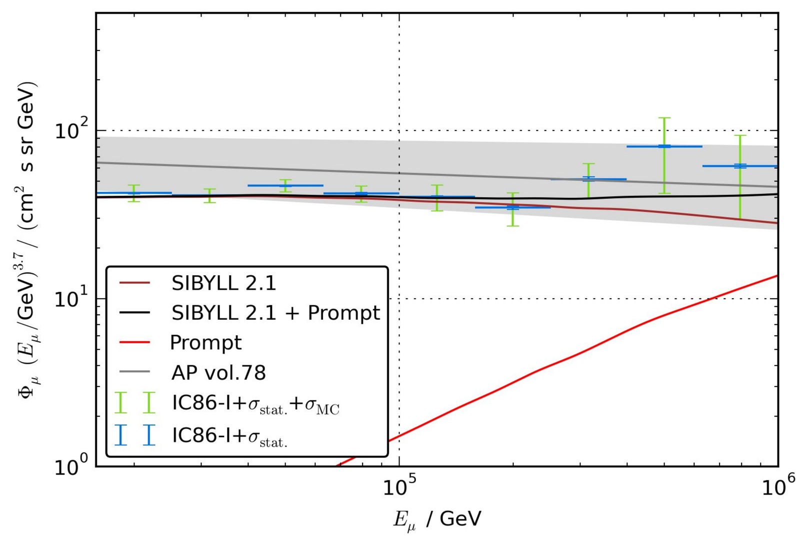


Sensitive to the normalization of the prompt component is the contribution of high-energy muons, but also zenith-dependent effects as well as seasonal variations.

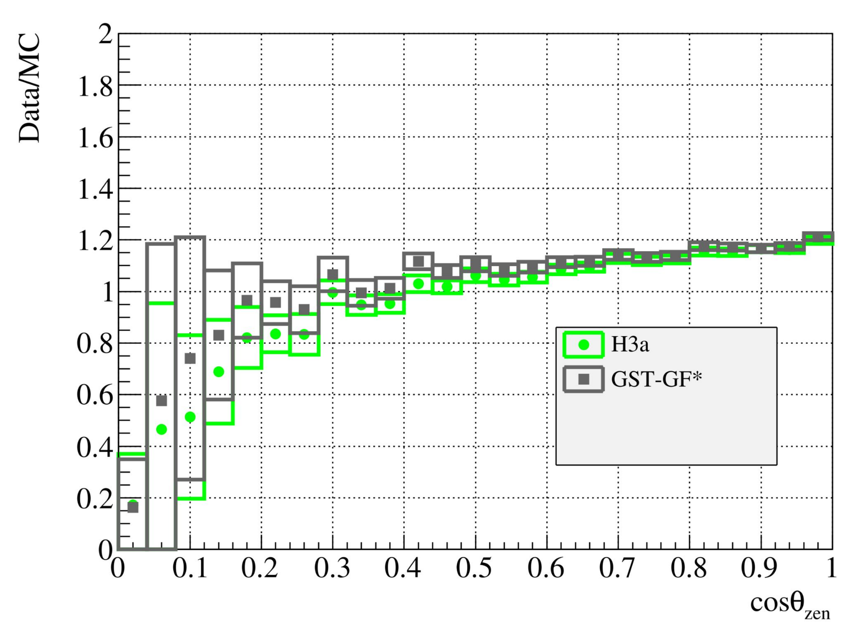
Former Analyses

An analysis to measure the prompt components was done by T. Fuchs in [1]. The energy spectrum of leading muons with $E_{\mathrm{max}} / E_{\mathrm{tot}} > 0.5$ was unfolded and a fit of the normalization was performed for several prompt models. Due to the lack of sufficient Monte Carlo simulations, the factor N_{prompt} describing the prompt component in this analysis has been determined to be compatible with zero.

$$\Phi(E) = N_{\mathrm{conv}} * \Phi_{\mathrm{conv}}(E) + N_{\mathrm{prompt}} * \Phi_{\mathrm{prompt}}(E)$$

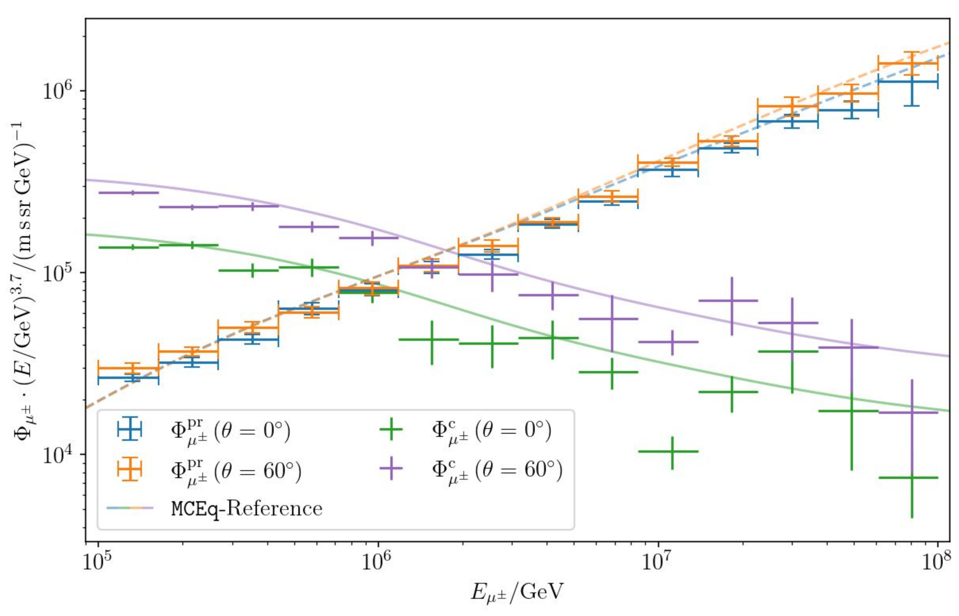


Another analysis was done in [2]. Hints of the prompt muon flux are already presented, but an unreasonable mismatch between data and MC occurs in the cosine zenith distribution. A constant offset of about 20 % more data is observed over the entire range on trigger level. After applying quality cuts, the ratio diverges. In both simulations, the hadronic interaction model SIBYLL 2.1 was used which does not consider charmed particles.

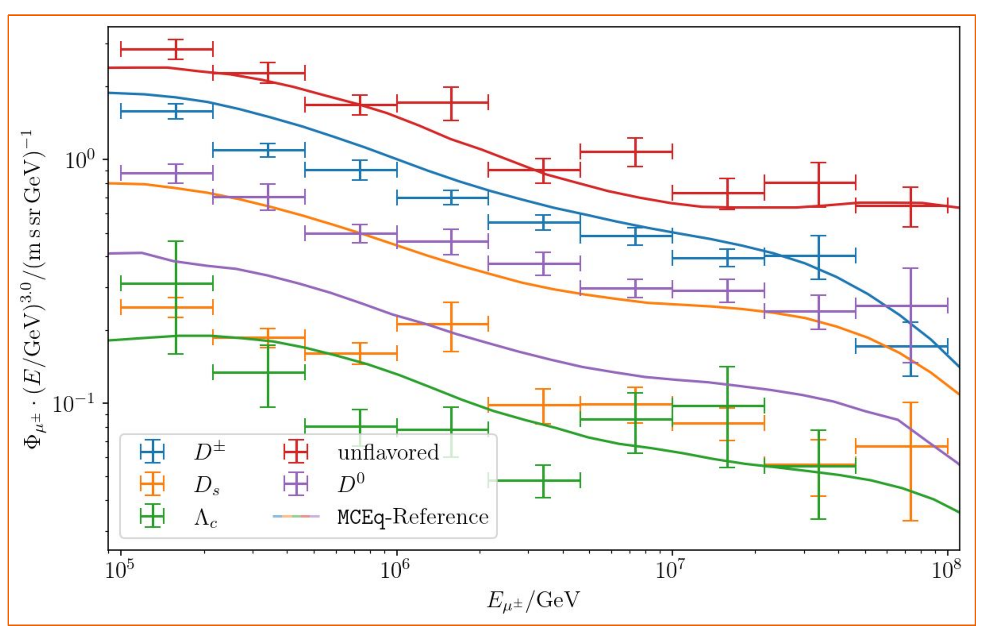


First feasibility studies

For a first test data set, we use the simulation framework CORSIKA to simulate ca. 40 Mio. air shower for two different injection angles θ and 5 Components. Hadronic interactions are modelled with SIBYLL 2.3d. Primaries are generated as with energies from 10^5 GeV to 5×10^{10} GeV using a powerlaw of E^{-1} reweighted to Gaisser H3a or GlobalSplineFit. To tag the parent particles of the muons, we use the extended history option (EHIST) of CORSIKA. The results are compared to curved produced with MCEq using SIBYLL 2.3c for the prompt and conventional component.



Furthermore, we compare the parent particle types of the prompt muons with the MCEq prediction from .



Current status and next Steps

- CORSIKA-EHIST succecfully implemented into the IceCube software
- Prompt Tagging now available in the IceCube software
- First look at a monte-carlo test-dataset
- Unfolding of the muon flux in energy/zenith bins and a fit of the normalization will be performed

References

[1] T. Fuchs, PhD Thesis, 10.17877/DE290R-17241
[2] Astropart. Phys. 78 (2016) 1-27
[3] Fedynitch et al., arXiv:1806.04140 [hep-ph]

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