A Combined Fit of the Diffuse Neutrino Spectrum using IceCube Muon Tracks and Cascades

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Introduction

The IceCube Neutrino Observatory has confirmed the measurement of a diffuse extra-galactic neutrino flux in several detection channels such as: high energy starting events [1], through-going muon tracks [2] and cascades [3]. In 2015, the first combined analysis of IceCube's high energy neutrino data was performed [4]. A new combined analysis targeting the energy spectrum of the diffuse astrophysical neutrino flux is currently being prepared. It relies on a consistent modeling of the neutrino flux components and corresponding uncertainties as well as a consistent treatment of detector systematic uncertainties across all measurement channels for which a novel Monte Carlo (MC) simulation technique is used.

Objectives

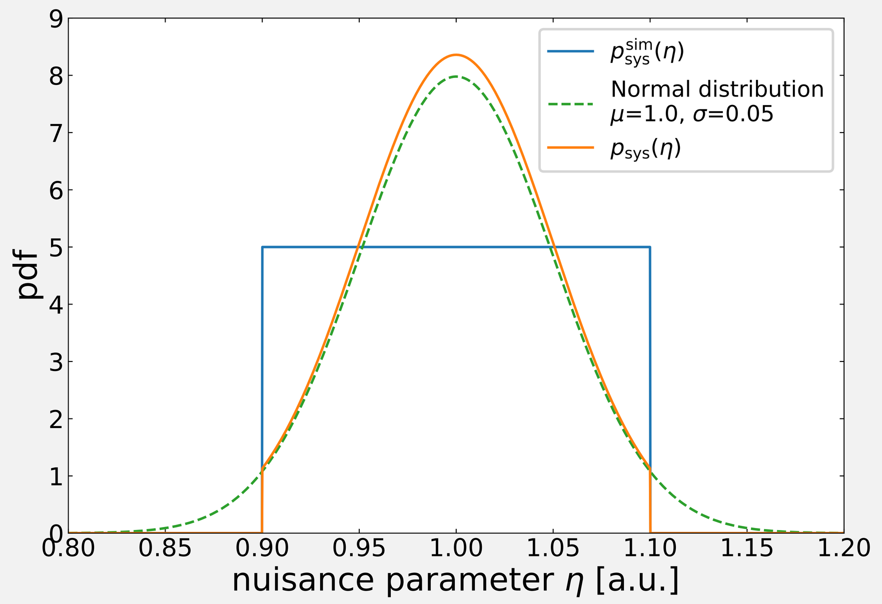
- Combination of two of IceCube's high energy neutrino detection channels into a combined fit of the diffuse energy spectrum: through-going muon tracks and cascades
- Application of a new method for using a SnowStorm event ensemble [5] for treating detector systematic uncertainties
- Sensitivity study of a of combined fit of both event samples

Event Samples

- Through-going muon track sample
  - Focus on up-going track-like events: reduced atmospheric muon background by using the Earth as a shield
  - Additional BDT separating atmospheric muons from CC muon neutrino interactions: high purity of about 99.7%
- Cascade data sample
  - Full-sky sample of cascade like events
  - About 8% atmospheric muon background contamination
- Events that are present in both samples contribute less than 0.1 %, most of these being starting track events. For combined analysis, obtain disjunct samples by considering these events only once.

Modeling detector systematic uncertainties

- SnowStorm event ensemble [5]: Each event of a MC set is simulated with a certain set of (detector) nuisance parameters $\vec{\eta}$ sampled from a continuous (here: uniform) distribution
- Predictions of analysis variable distributions for a specific choice of η: Re-weight the simulated distribution of events $p^{\mathrm{sim}}_{\mathrm{sys}}(\eta)$ to a Gaussian distribution $\mathscr{G}(\eta, \mu, \sigma)$
  - μ is set to the value of η one wants to obtain the prediction for
  - σ can be used to limit the range of events used for the re-weigthing



Analysis method

- Two dimensional Likelihoof fit of reconstructed energy and zenith using the binning of the individual analyses [2, 3]
- In the case of fully disjunct samples, a combined Likelihood can be obtained by the product of the per-bin (for each event selection) Poisson Likelihoods $\mathscr{L}_i$:

$$\mathscr{L}_{\mathrm{combined}} = \prod_{\mathrm{bin}\, i}^{N_{\mathrm{bins}}} \mathscr{L}_i(n_i, \mu_i(\vec{p}, \vec{\eta})) \times \prod_j \pi(\eta_j)$$

  - The per-bin expectation μ_i is a function of the signal $\vec{p}$ and nuisance parameters $\vec{\eta}$
- Single power-law (SPL) model of the astrophysical neutrino flux:

$$\Phi^{\mathrm{astro}}_{\nu+\bar{\nu}} = c_{\mathrm{units}} \times \Phi^{\mathrm{astro}}_0 \times \left(\frac{E_\nu}{100\,\mathrm{TeV}}\right)^{-\gamma_{\mathrm{astro}}},$$

with $c_{\mathrm{units}} = 10^{-18}\,\mathrm{GeV}^{-1}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{sr}^{-1}$.

Results/Sensitivities

- Estimated sensitivity of a combined for a single power-law diffuse astrophysical neutrino flux, assuming an Asimov signal of $\Phi^{\mathrm{astro}}_0 = 1.36$ and $\gamma_{\mathrm{astro}} = 2.37$ and a lifetime of 10 years:

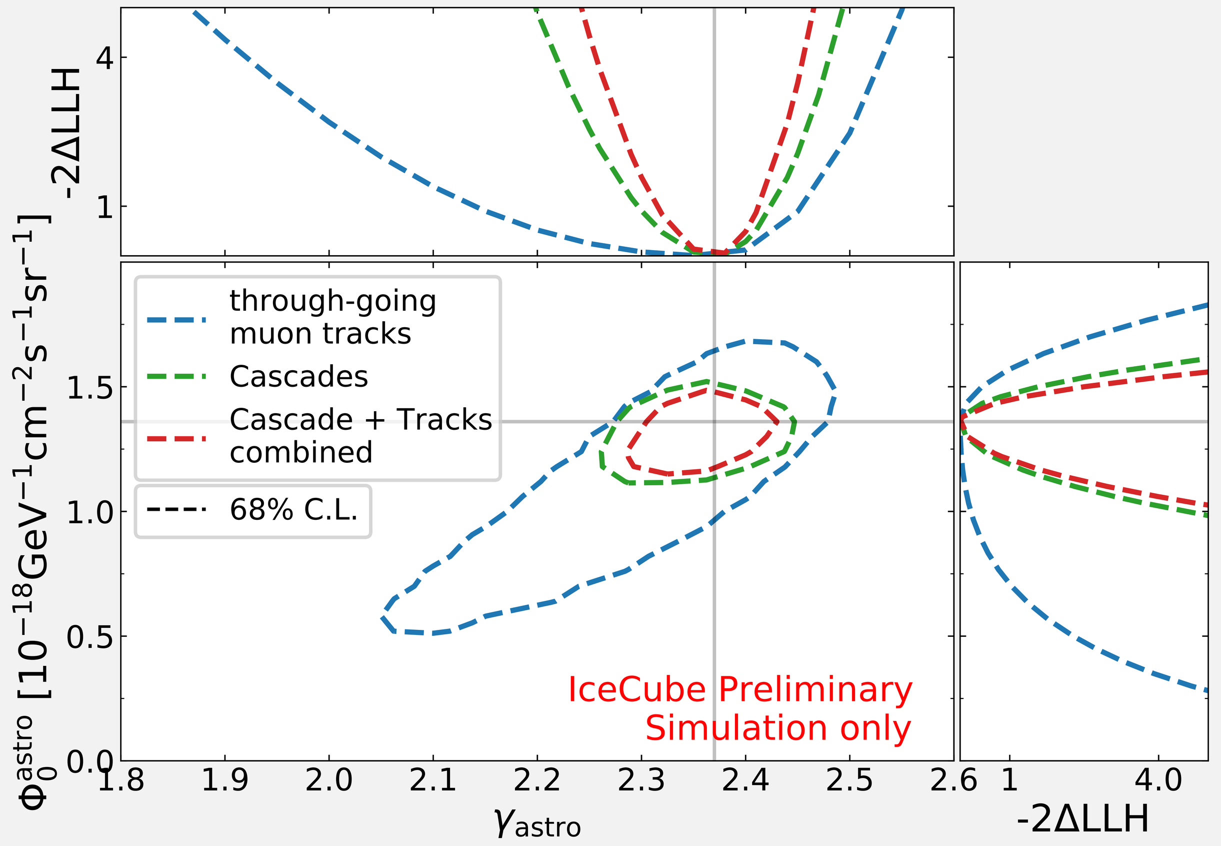


Figure: 68% CL contours of the signal parameters Φ^{astro}_0 and γ_{astro}. The combined fit is shown in red, individual results in blue (tracks) and green (cascades).Top and right plots show 1D profile Likelihood scans of the signal parameters.

- Sensitivity of the combined analysis of both event selections is increased compared to both individual analyses
- Measurement of both signal parameters is independent on the decision from which sample to remove the events being present in the individual samples

- Piecewise model fitting an independent normalization for each neutrino energy bin using a fixed spectral index of $\gamma_{\mathrm{astro}} = 2$ in each bin:

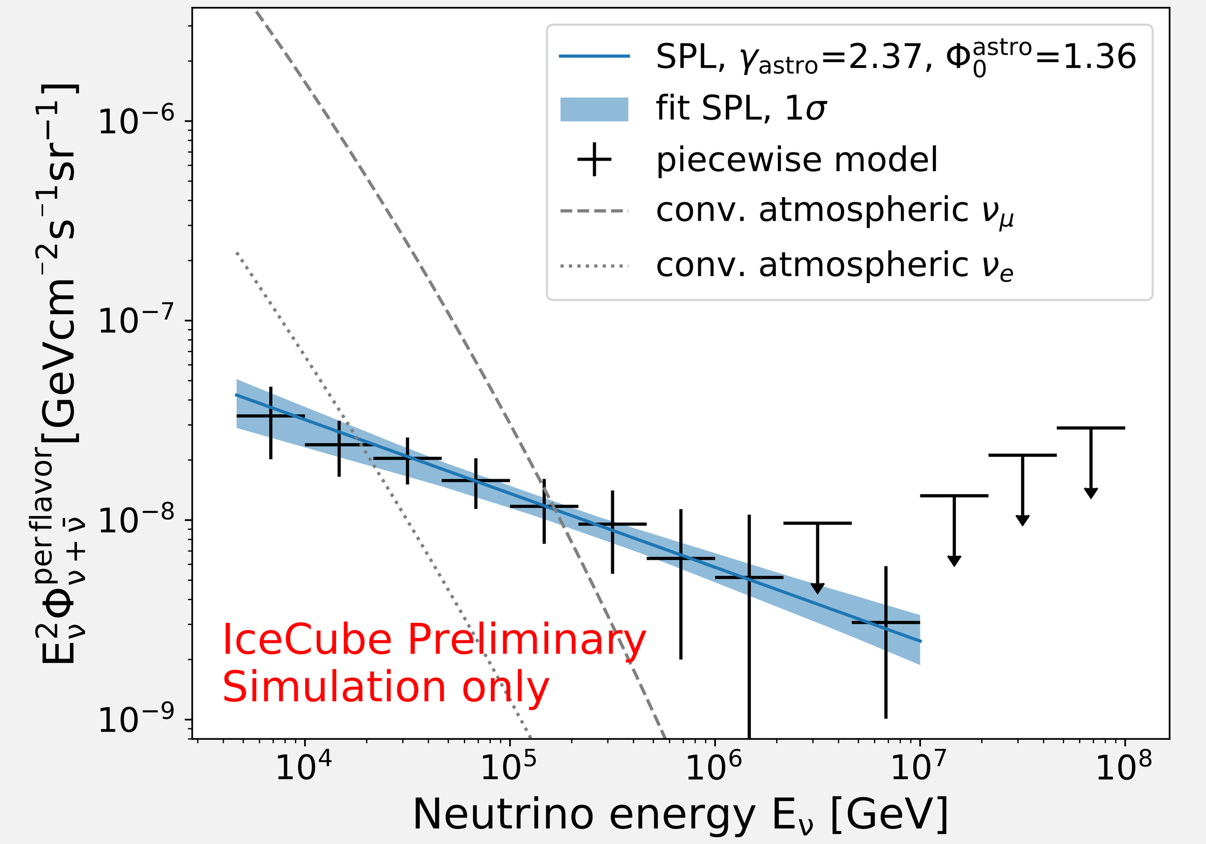


Figure: Inferred neutrino spectrum from the combined analysis. Asimov signal and the 68% best-fit SPL contour in blue, piecewise model with independent contributions from different energy bins with a fixed spectral index of $\gamma_{\mathrm{astro}} = 2$ in black.

- Comparison of the sensitivities obtained with the individual and the combined event selection

	through-going tracks	cascades	combined fit
Φ^{astro}_0	$1.36^{+0.21}_{-0.65}$	$1.36^{+0.11}_{-0.17}$	$1.36^{+0.09}_{-0.15}$
γ_{astro}	$2.37^{+0.08}_{-0.23}$	$2.37^{+0.05}_{-0.07}$	$2.37^{+0.04}_{-0.05}$

Table: Estimated 68% sensitivities for an Asimov signal fit of an injected single power-law astrophysical neutrino flux.

References

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