Measuring the Neutrino Cross Section Using 8 years of Upgoing Muon Neutrinos Observed with IceCube

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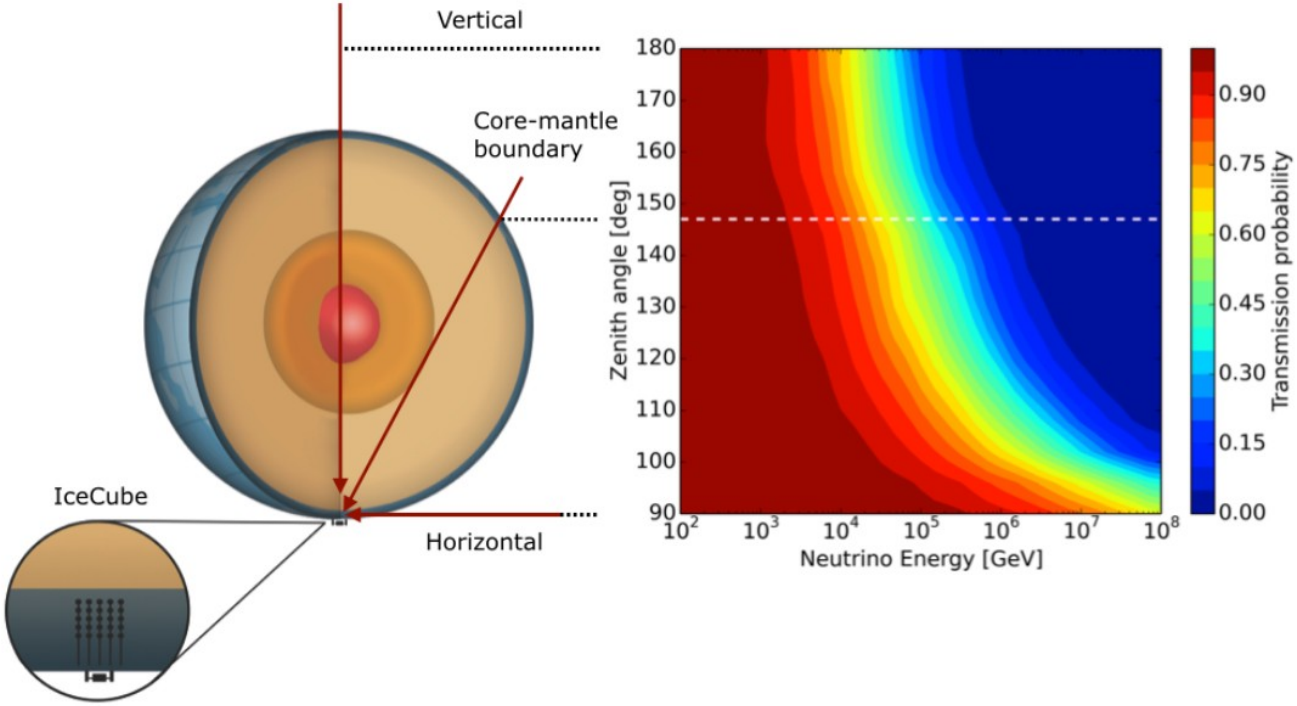
ICRC 2021

Neutrino Cross Section Measurements

At energies above 40 TeV, the Earth absorbs neutrinos. The Earth can then be used as the medium by which to measure cross section.

The neutrino flux is fitted using poisson likelihood with standard atmospheric and astrophysical parameters, with neutrino absorption allowed to vary.



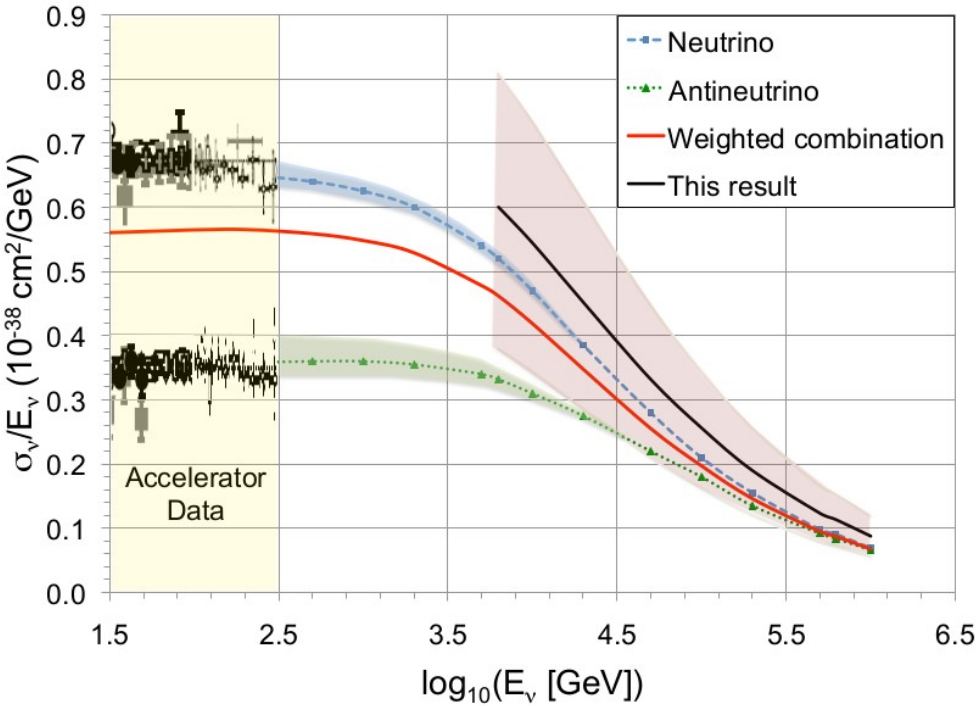
Previous Measurements

1 year Diffuse Upgoing Neutrino

1 year of up-going IC79 ν_μ data was binned in (E_μ, $\cos(\theta_z)$) with no binning in neutrino energy, result was within standard model

$R=1.30\ ^{+0.21}_{-0.19}\ (\text{stat})\ ^{+0.39}_{-0.43}\ (\text{syst.})$

$6.3\ \text{TeV} < E_\mu < 980\ \text{TeV}$

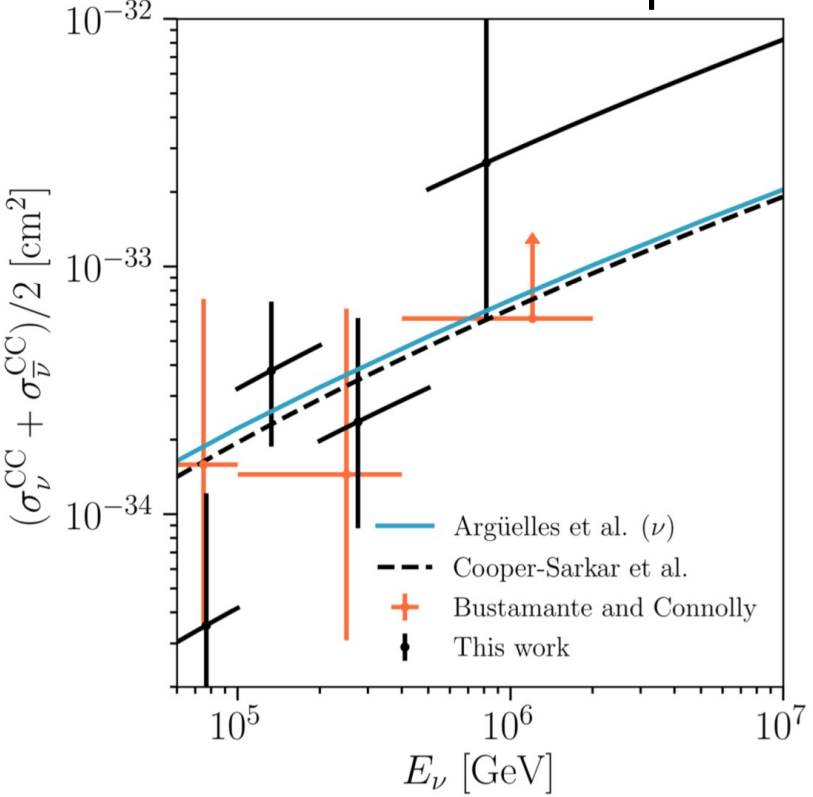


IceCube Collaboration, M. G. Aartsen et al. Nature 551 no. 7682, (2017) 596–600.

HESE All Flavor

7.5 years of High Energy Starting Events (ν_μ, ν_τ, ν_e) binned between 60 TeV<E_ν<10 PeV

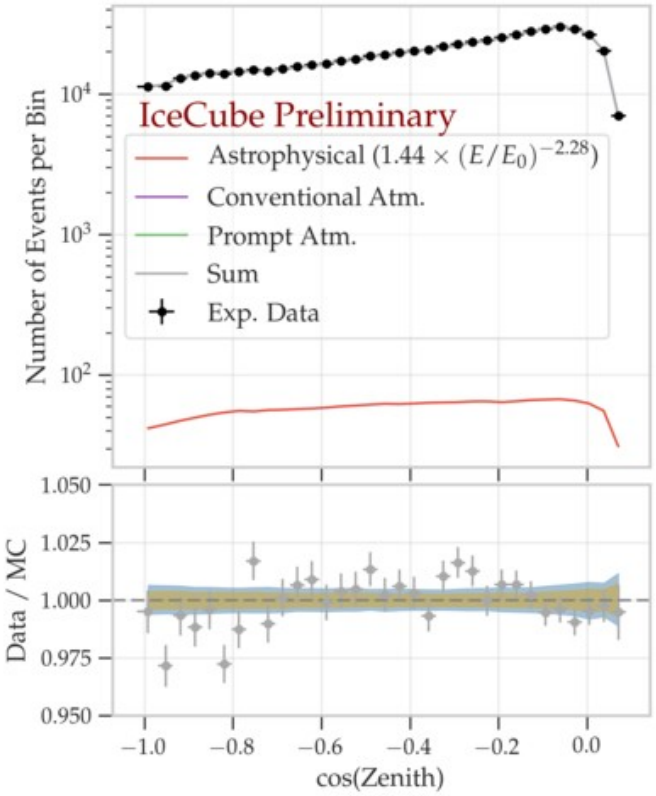
All four energy bins found to be within standard model prediction.

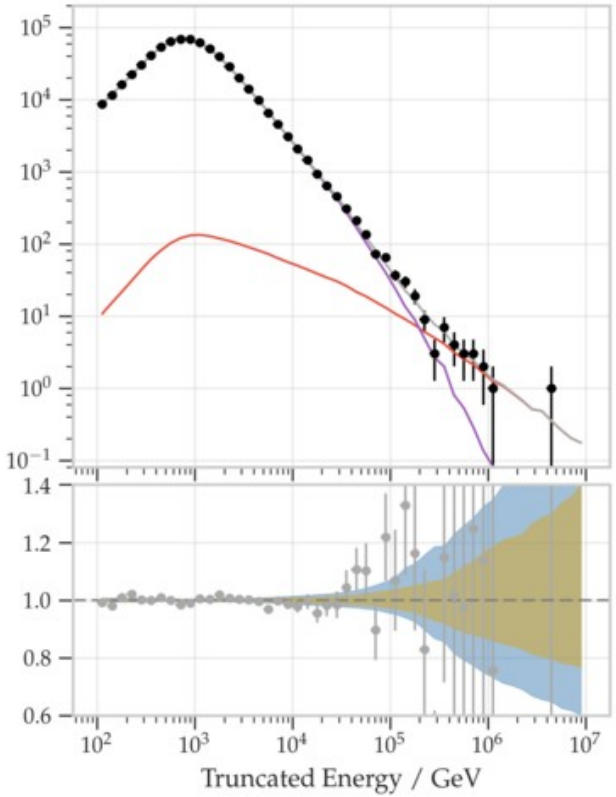


IceCube Collaboration, R. Abbasi et al. arXiv e-prints (2020) arXiv:2011.03560.

Current Cross Section Analysis

The method is the same as for previous analyses; using the absorption of the Earth to fit a possible multiple "R" of the Standard Model cross section using a likelihood fit.



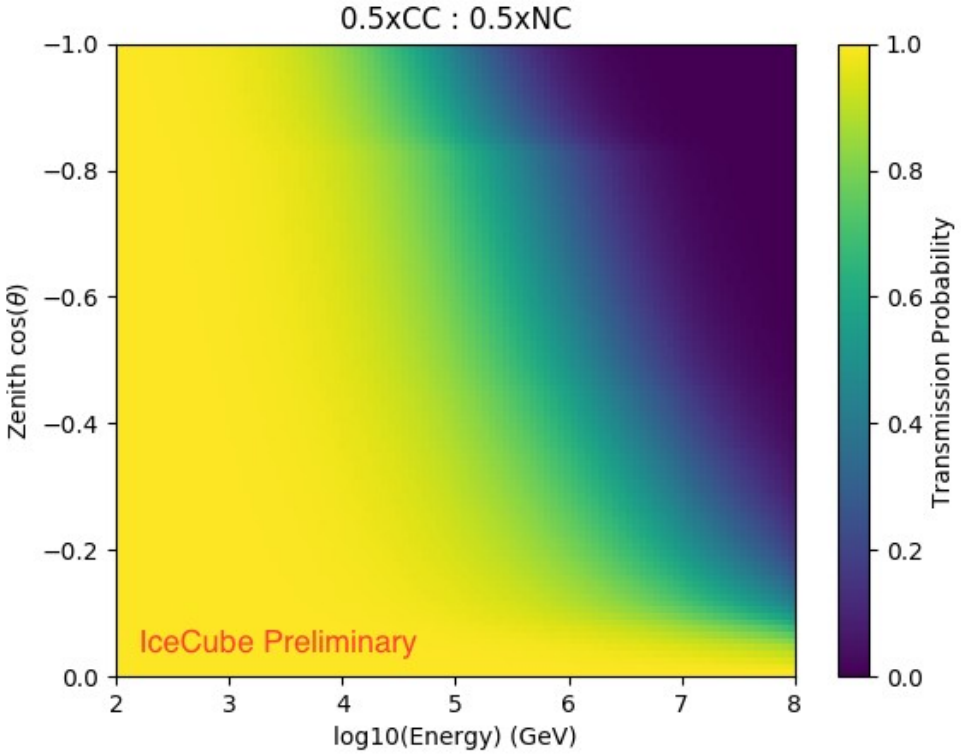


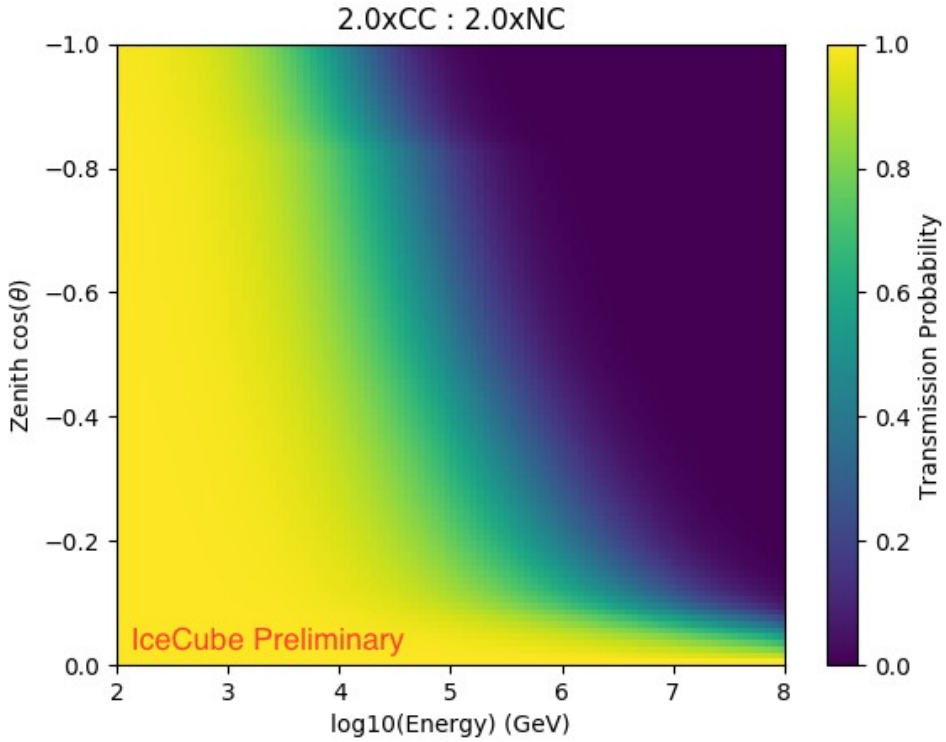
- Currently analyzing 8 years 2011-2018
- This analysis is built from the current IceCube Diffuse muon neutrino analysis with current Monte Carlo and systematic uncertainty treatment

IceCube Collaboration, PoS(ICRC2019)1040.

Transmission Probability

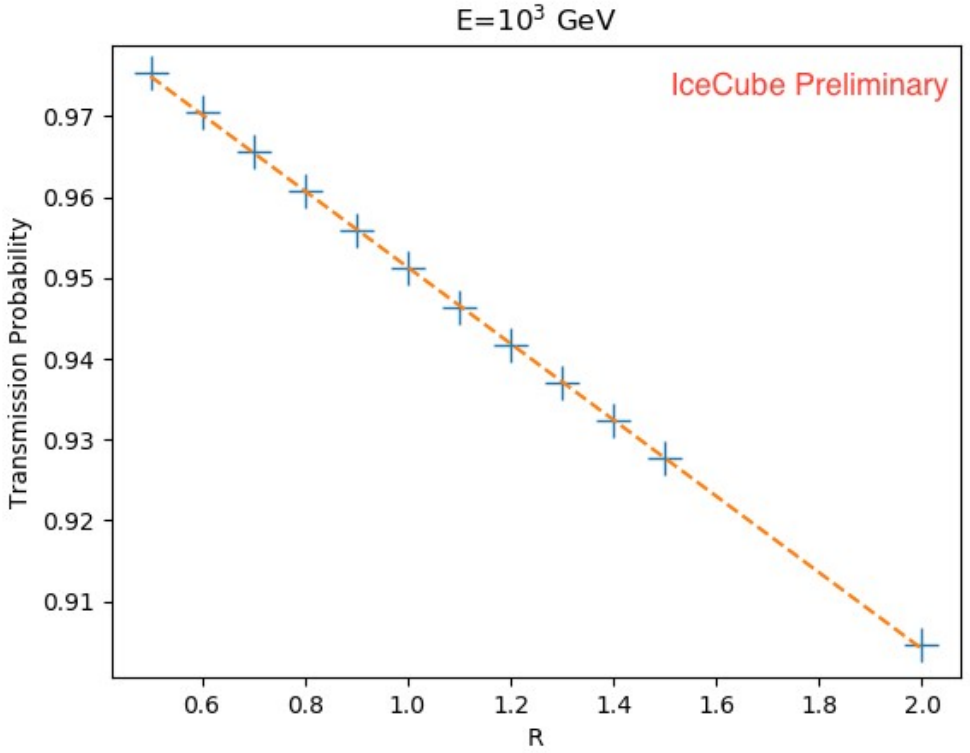
Probability of a neutrino surviving traveling through the Earth without absorption. NuSQuIDs is a neutrino propagation library, which accounts for interactions and oscillations through a medium, here Earth.
The cross section was adjusted by a multiple of the standard model, R. Done for both Neutral current (NC) and charge current (CC) interaction. CC will affect the absorption, NC will affect the energy distribution of the surviving neutrinos.

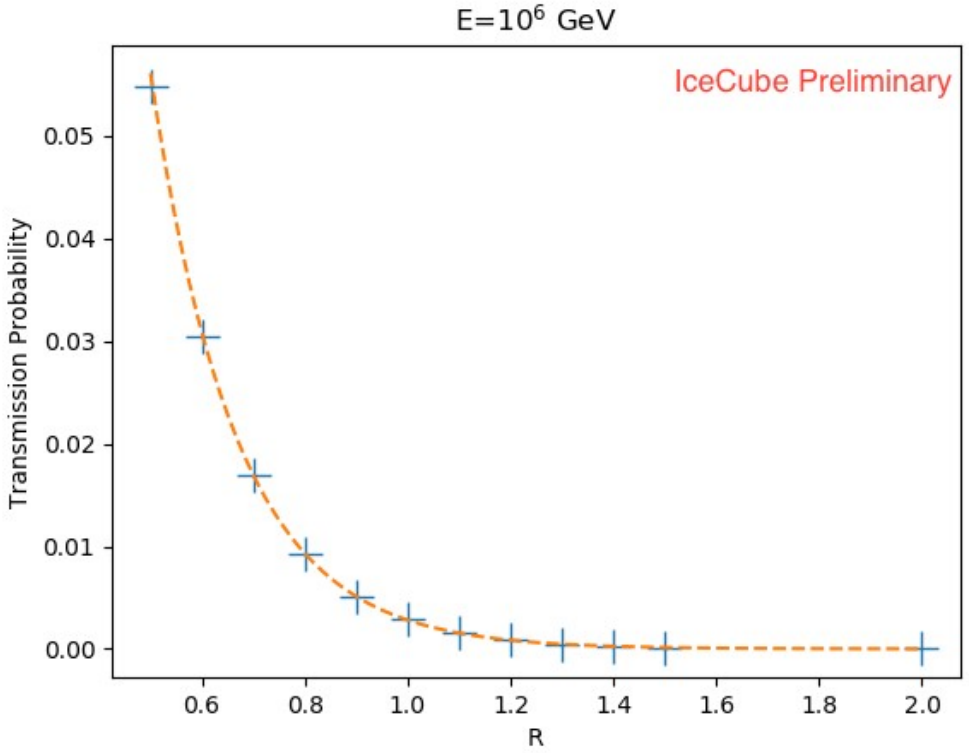




Transmission Probability Interpolation

In the likelihood fit the cross section parameter applies a re-weighting of the flux based on the transmission probability.
The cross section parameter comes from an interpolation of the transmission probability, which is linear for low energy ($E<10^5$ GeV) and exponential for high energy ($E>10^5$ GeV)





Monte Carlo Likelihood Fits

Three cross section parameters with their preliminary energy ranges:

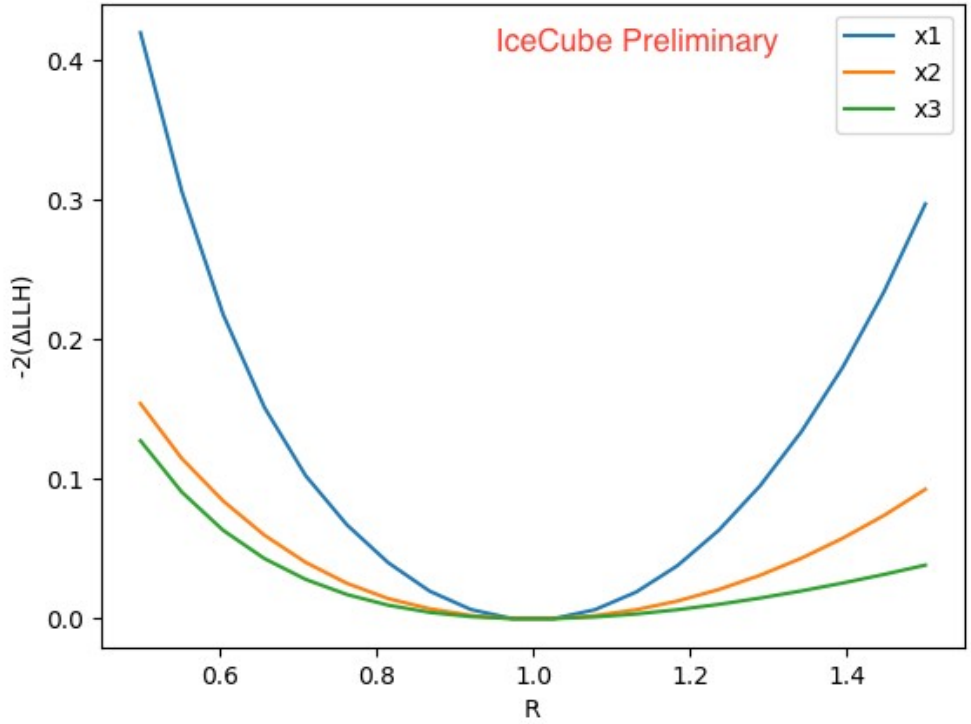
x1: 10^3 GeV<E_ν<10^4 GeV

x2: 10^4 GeV<E_ν<10^6 GeV

x3: 10^6 GeV<E_ν<10^8 GeV

The pseudo data Asimov scans are likelihood fits for each cross section energy bin.

The high energy bin x3 is where beyond standard model physics would appear, by a change in R. The energy ranges for each bin have been chosen to have similar likelihood widths.



IceCube Diffuse Likelihood Fit

Nuisance Parameter	Priors	Range
Astrophysical Spectral Index		
Astrophysical Flux Normalization		
Conventional Flux Normalization		
Prompt Flux Normalization		
Cosmic-Ray model interp.	0 ± 1.0	(-1, 2)
Muon Template Normalization	1.0 ± 0.5	(0,inf)
Cosmic-Ray spectral index		
Barr H±	0 ± 0.15	(-0.8, 0.8)
Barr W±	0 ± 0.40	(-0.6, 0.6)
Barr Y±	0 ± 0.30	(-0.6, 0.6)
Barr Z±	0 ± 0.12	(-0.6, 0.6)
Hole-Ice p0		
Bulk Ice Scattering		
Bulk Ice Absorption		
Optical Efficiency		

Parameters and priors used in the upgoing muon neutrino diffuse likelihood fit. [IceCube Collaboration PoS ICRC2019 (2019) 1017]

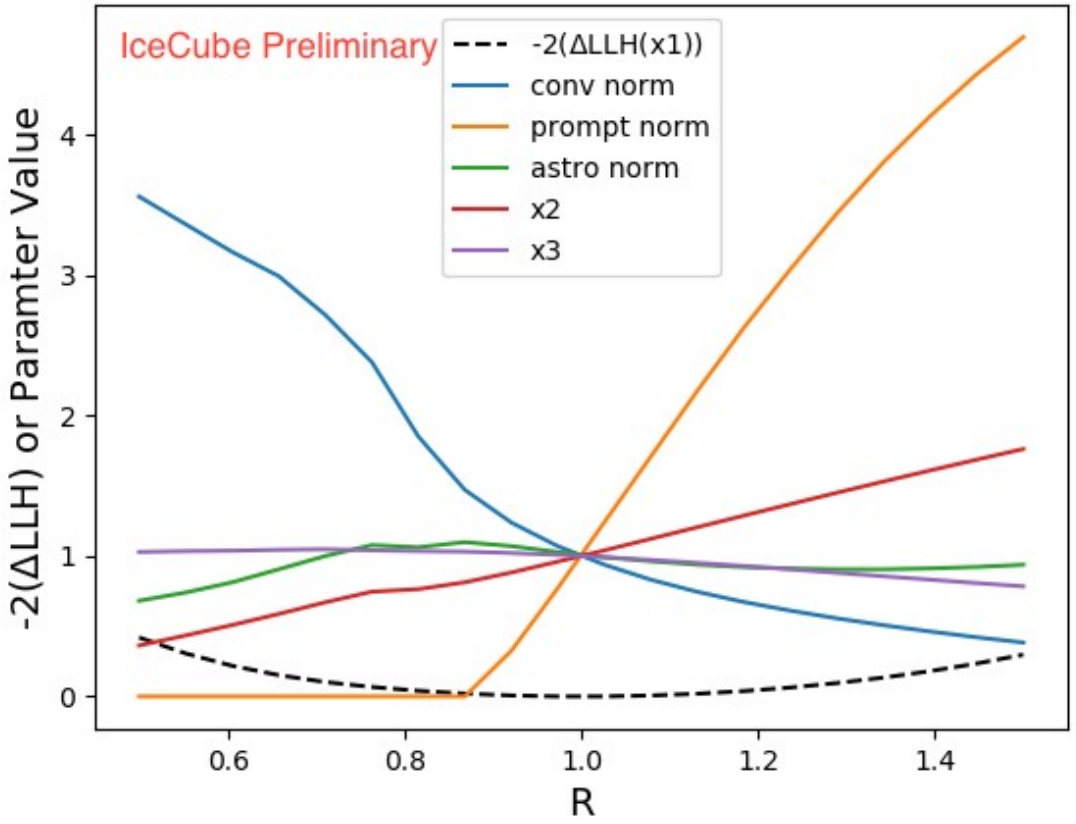
New parameters

- **Hole Ice**: larger scattering in the refrozen ice around each DOM
- **Barr parameters:** hadronic production in cosmic ray air showers as calculated in [G. D. Barr, S. Robbins, T. K. Gaisser, and T. Stanev Phys. Rev. D 74 no. 9, (2006) 094009.]

Monte Carlo Likelihood Fits

The pseudo data Asimov scan likelihood fit for one energy bin x1, with nuisance parameters shows that the parameters with the most effect are the conventional, prompt and astrophysical normalizations.

An increase in cross section will result in a decrease in conventional normalization as fewer neutrinos are expected to traverse the Earth.



Likelihood Priors

To keep the fit within known physical regions, gaussian priors are placed on the normalization parameters.
The conventional and prompt normalization are based on MCEq using SIBYLL23c.

- This should have a negligible difference to BERSS

The astrophysical normalization prior is based on HESE. The widths of the prior are kept large so as to cover the range of all current results.

Parameter	Prior/width	Range
Astro norm	2.1 ± 0.6	(0,inf)
Conv norm	1 ± 0.25	(0,inf)
Prompt norm	1 ± 2	(0,inf)

Summary

We present the extended cross section analysis using 8 years of upgoing muon neutrinos. The analysis uses updated; transmission propagation, systematic parameters and likelihood fit method.

- Monte Carlo studies have been done for the three cross section energy bins
- Currently finalizing the analysis and moving towards unblinding of the 8 year data set.
- Potential to detect Beyond Standard Model physics at the highest energies.
- Further studies can be done on neutrino interactions including nuclear effects.