Search for Solar Atmospheric Neutrinos with the IceCube Neutrino Observatory

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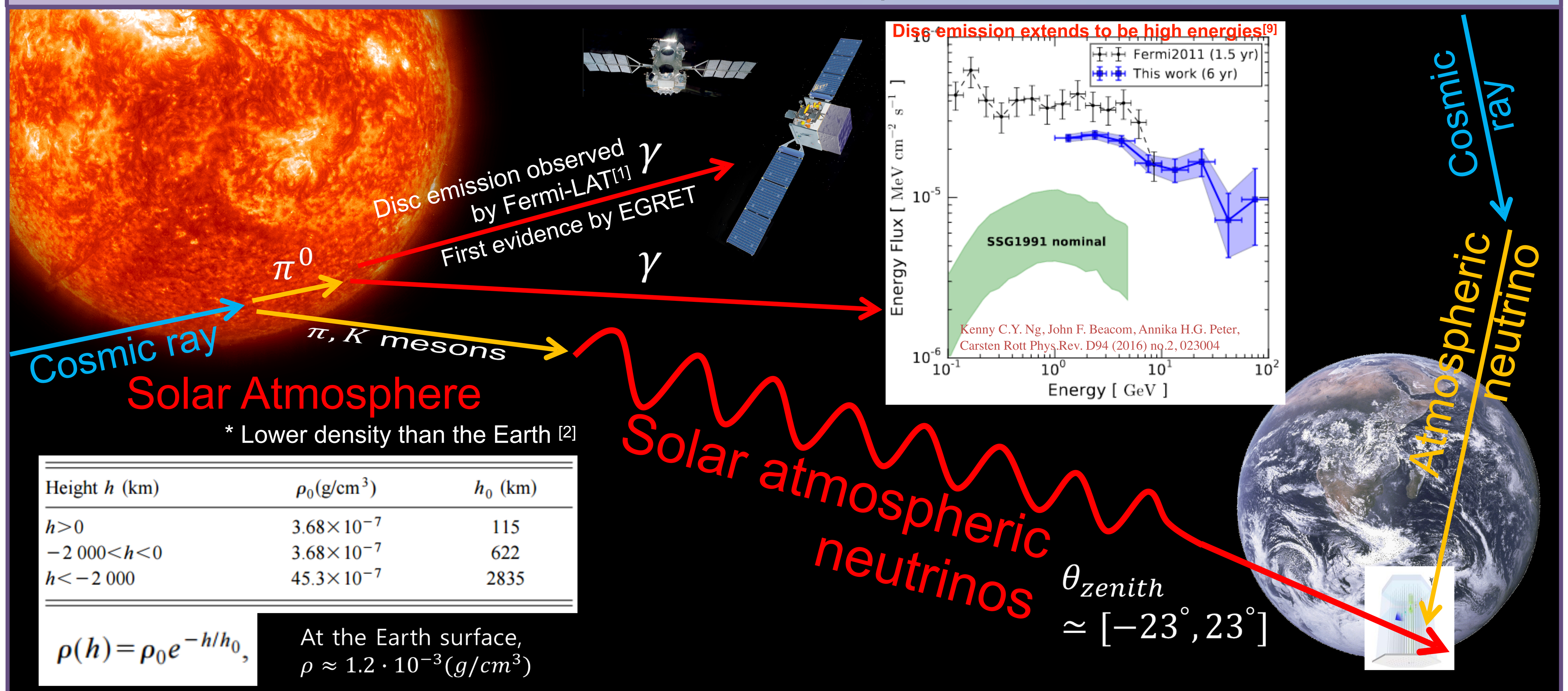
Abstract

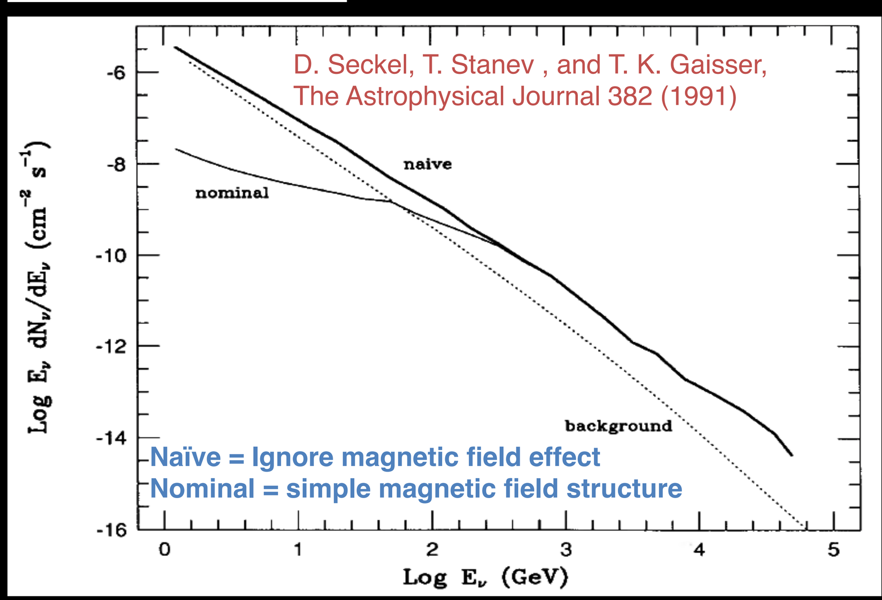
Cosmic ray interactions with the solar atmosphere are expected to generate energetic neutrinos that might be observable with neutrino telescopes, such as IceCube. These so called solar atmospheric neutrinos are expected to have a harder energy spectrum compared to those generated in the Earth atmosphere. The difference originates from the lower atmospheric density of the Sun, which allows secondary particles to decay rather than to reinteract. We present the sensitivity of the first search for solar atmospheric neutrinos, using seven years of data collected with IceCube. To distinguish signal from backgrounds we perform a likelihood analysis using directional and energy spectral information. The analysis method and optimization will be introduced and sensitivities presented.

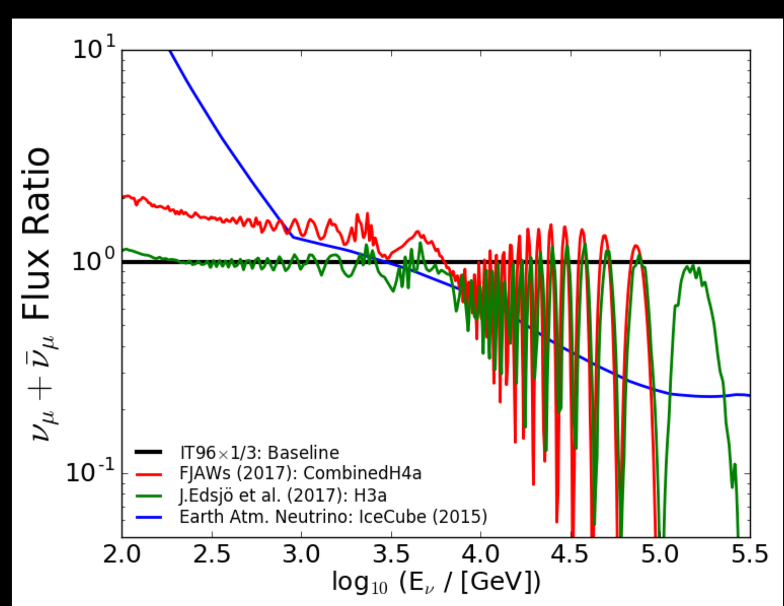
Solar Atmospheric Neutrinos



Height h (km)	ρ_0(g/cm^3)	h_0 (km)
$h>0$	3.68×10^{-7}	115
$-2\,000<h<0$	3.68×10^{-7}	622
$h<-2\,000$	45.3×10^{-7}	2835

$\rho(h)=\rho_0 e^{-h/h_0}$, At the Earth surface, $\rho \approx 1.2\cdot10^{-3}(g/cm^3)$

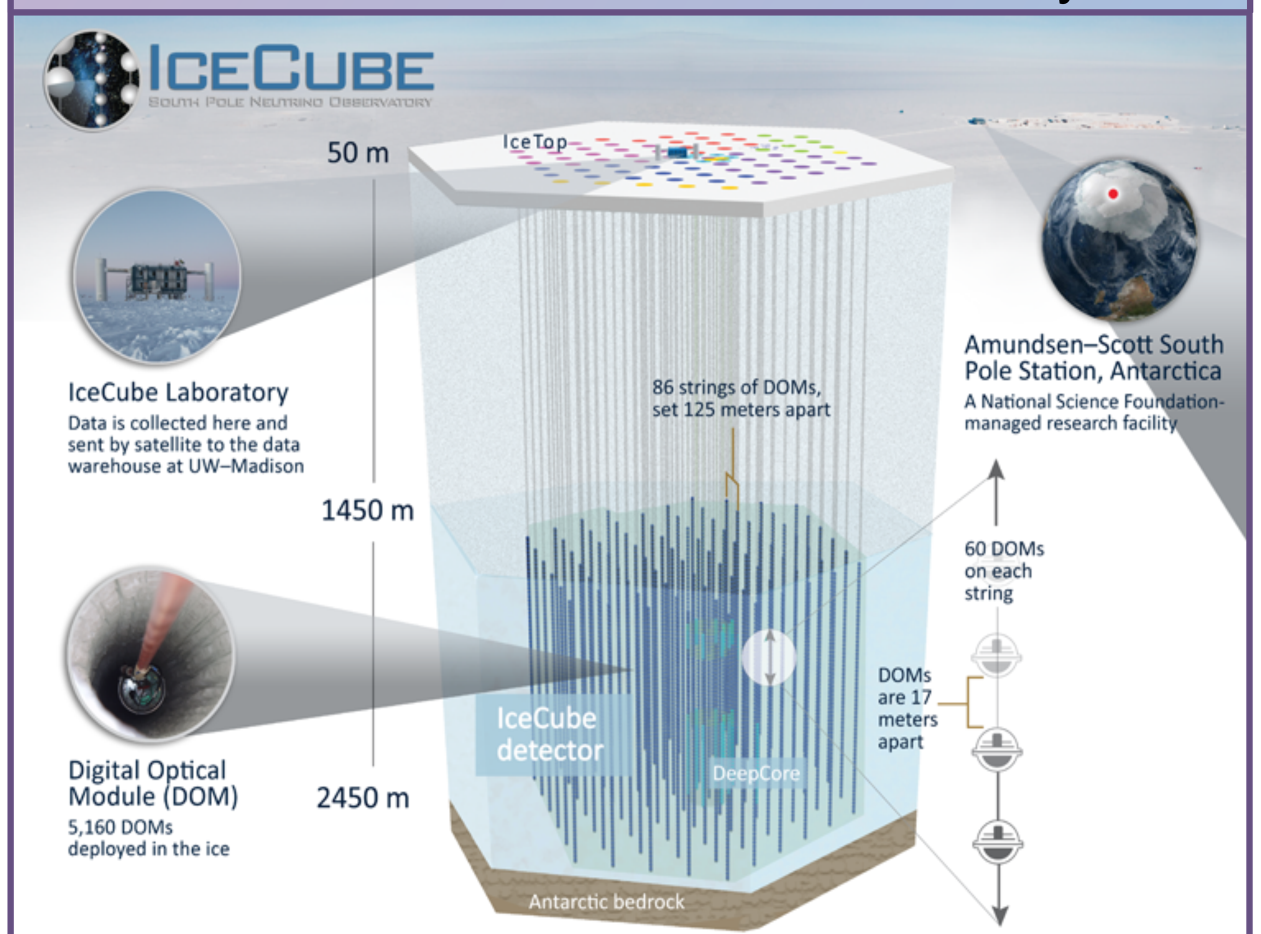




- Solar atm. neutrinos are generated when cosmic rays produce particle showers in the Solar atmosphere
  - The first flux estimation dates back to Seckel Stanev Gaisser (1991)[3]
- Below O(100GeV) significant dependence on solar magnetic fields

The solar atmospheric neutrino flux has been predicted in several independent works [2,3,4,5]
Models are in good agreement and we choose two benchmark models for this analysis

The IceCube Neutrino Observatory

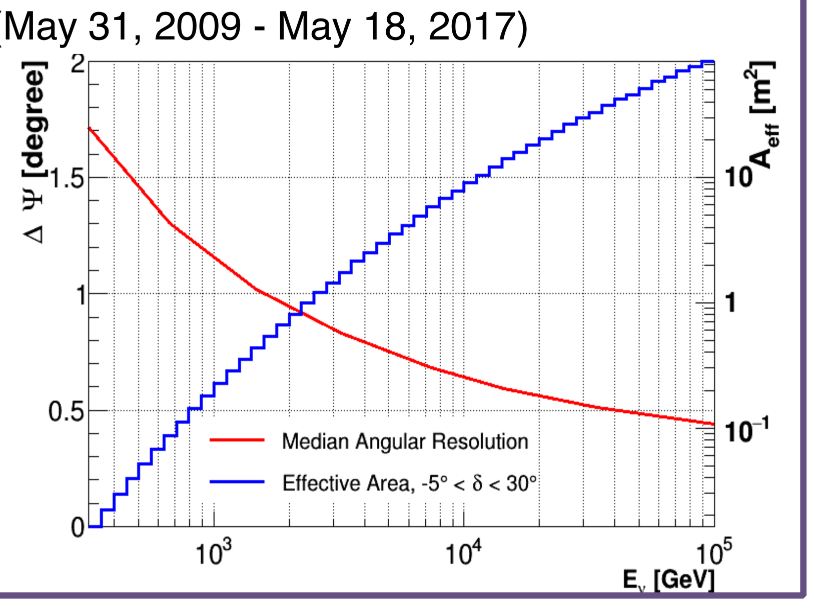


- The largest neutrino telescope in the world [2]
- Located at geographical South Pole
- 86 strings with 60 DOMs each
- Volume ~ 1km^3, $E_{Threshold}$ ~ 5 GeV (DeepCore)
- ~ 10^2 neutrinos / day at filter level

Data Sample

- Rely on well established IceCube event reconstruction [7]
- Upgoing[a] ν_μ[b] samples are optimized at this analysis
- Livetime = 7 years (May 31, 2009 - May 18, 2017)

a. The Earth can be used as a atmospheric μ veto and the events are chosen within [85°,180°]
b. Sub-degree precision for angular resolution



Likelihood Analysis & Sensitivities in IceCube as a signal

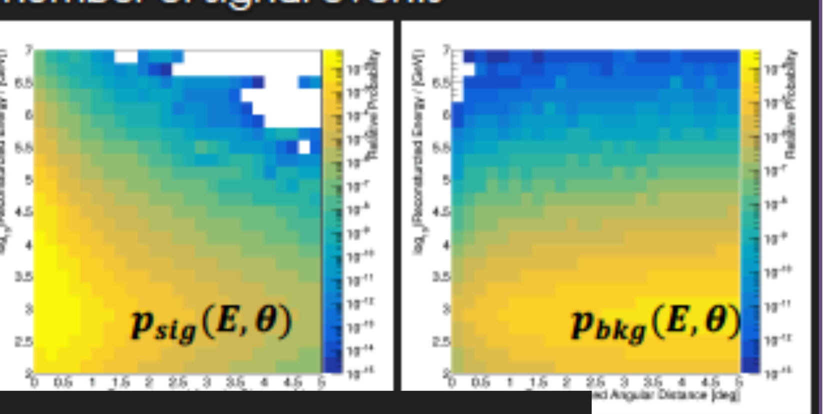
- Region of interest = $\theta < 5°$ from the Sun, E = $[10^{2.2}, 10^{7.2}]$ GeV (IC79-2010/2011)
  = $[10^2, 10^7]$ GeV (IC86-2011/2016)
- We estimated the sensitivity as using maximum LLH method

  Likelihood function ($L(E,\theta|\mu)$) is defined as a function of energy(E) and angular distance(θ) from the Sun

$$L(E,\theta|\mu) = (\mu/N) * p_{sig}(E,\theta) + (1-\mu/N) * p_{bkg}(E,\theta))$$

where N = total number of events in pseudo experiment, μ = number of signal events

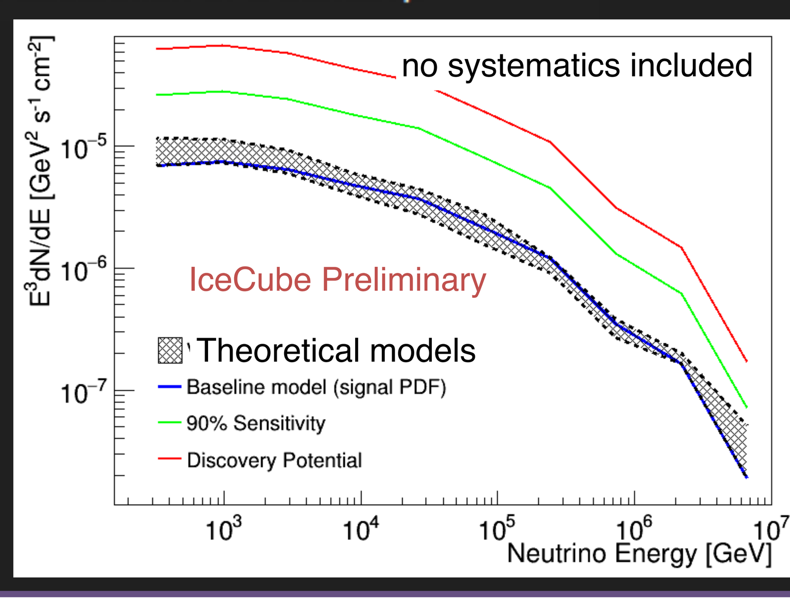
$$p_{sig}(E,\theta) = \frac{1}{2\pi\sigma^2}\exp\left(-\frac{\theta^2}{2\sigma^2}\right)\cdot p^E_{sig}(E,\theta)$$
$$p_{bkg}(E,\theta) = \frac{n_a}{N}\cdot p_{astro}(E,\theta) + \left(1-\frac{n_a}{N}\right)\cdot p_{atmo}(E,\theta)$$



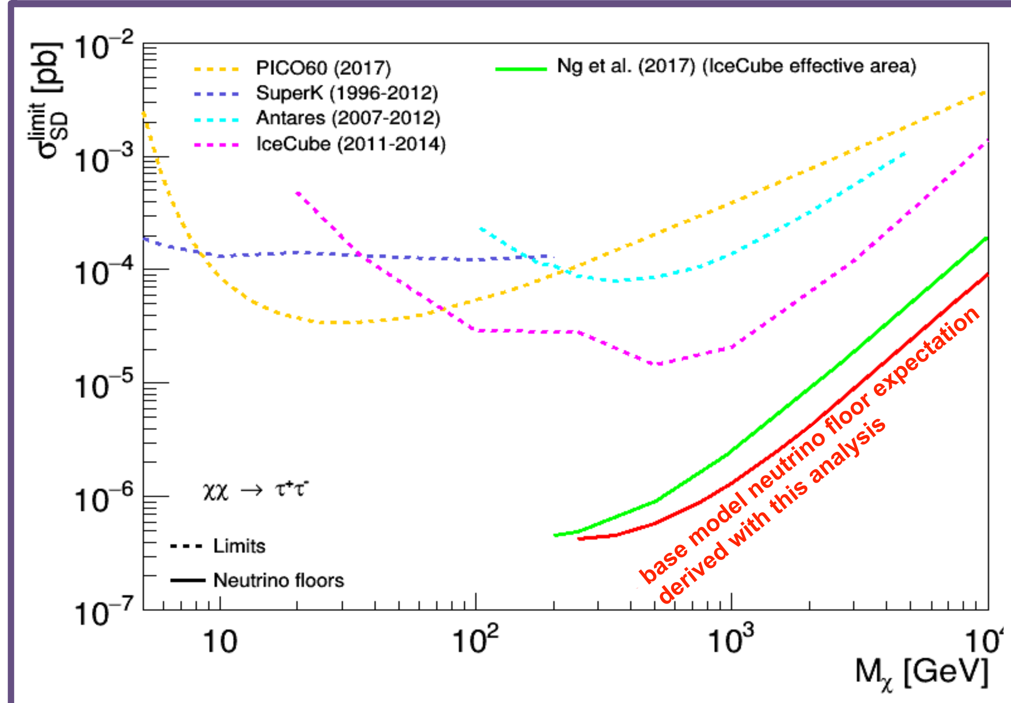
- Position of the Sun is homogeneously randomized within solar radius from the events → called circle distribution
- $p^E_{sig}(E,\theta)$ is obtained by re-weighting the Sample to the baseline model
- Null hypothesis = background only, TS = -2ln($L(0)/L(\hat{\mu})$)
- Sensitivities are defined by test statistic distributions obtained by pseudo experiments
- 90% confidence level and discovery potential are estimated by TS distribution of a certain μ

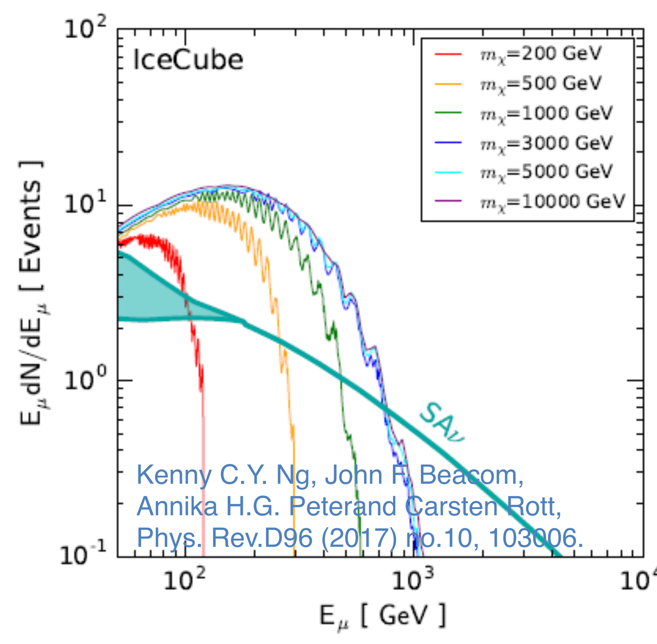
Preliminary systematic uncertainty study

- Signal prediction:
  - ~28% Energy spectrum and angular distribution
- Detector uncertainties:
  - ~<20% DOM efficiency
  - ~<13% Ice properties
- Background prediction:
  - ~6% Cosmic ray shadow

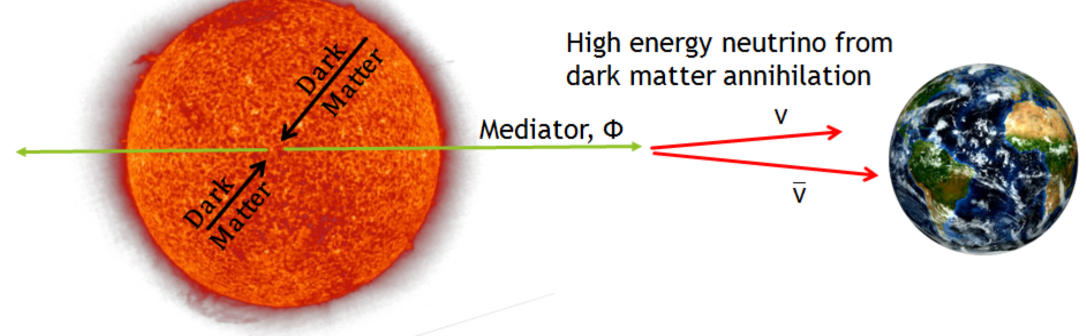


Solar Dark Matter and the Neutrino Floor [4,5,8]





- Solar atmospheric neutrinos form a natural background to dark matter searches, that can be visualized in form of a neutrino floor.
  - A series of recent works quantified this floor [4,5,8].
  - We computed the solar atm. neutrino floor by requiring equal number of events from dark matter annihilation and solar atmospheric neutrinos.
- In standard solar dark matter scenarios, annihilations occurs in the center of the Sun. Due to neutrino absorption above 100GeV the neutrino spectrum from dark matter annihilation can be expected to be significantly different compared to that from of solar atmospheric neutrinos.
- Scenarios with "secluded dark matter", could yield a high energy neutrino flux from the Sun. A separate IceCube search is on-going.



Conclusions

- Solar Atmospheric neutrinos might be observable with IceCube
- We have determined IceCube's sensitivity for this signal using a log likelihood analysis
- Systematic studies are on-going and unblinding is expected in the near future
- Observing solar atmospheric neutrinos is important for:
  - Understanding solar magnetic fields;
  - Cosmic ray propagation in the inner solar system;
  - Improving models of cosmic ray interactions in the solar atmosphere;
  - Finding a high-energy neutrino point source

References

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