Search for Dark Matter Captured in the Sun with the IceCube Neutrino Observatory

The IceCube Collaboration

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Detector Overview: IceCube and DeepCore

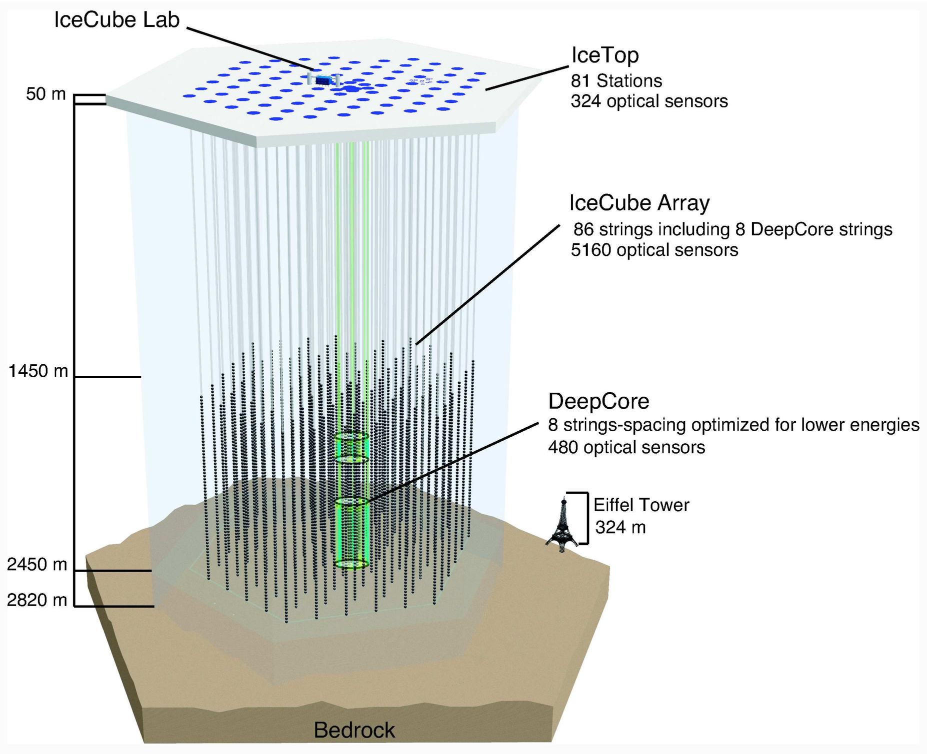


Figure: IceCube and DeepCore Detector

- Cherenkov light from relativistic charged particles recorded by PMTs
- Instruments 1 km^3 of Antarctic glacial ice
- 5160 Digital Optical Modules (DOMs) on 86 strings
- 1450m-2450m below the surface
- DeepCore: More densely instrumented subarray in the center of the detector [1]
  - Extends sensitivity to lower energy neutrinos
  - Allows southern sky searches through use of the surrounding detector volume as an active veto

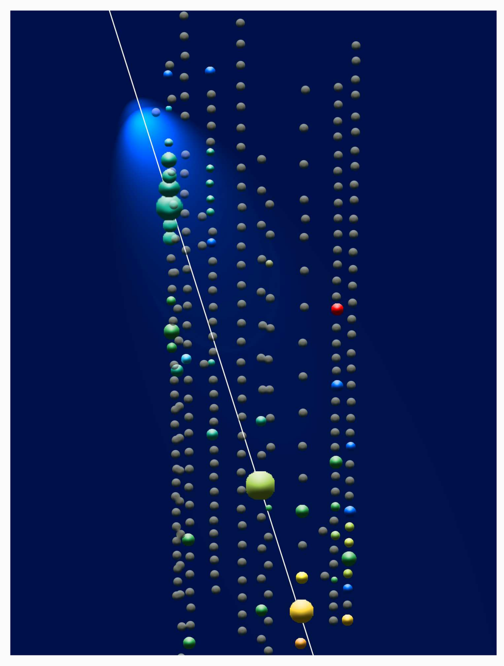


Figure: Cherenkov Light Emission

Indirect Detection of Dark Matter

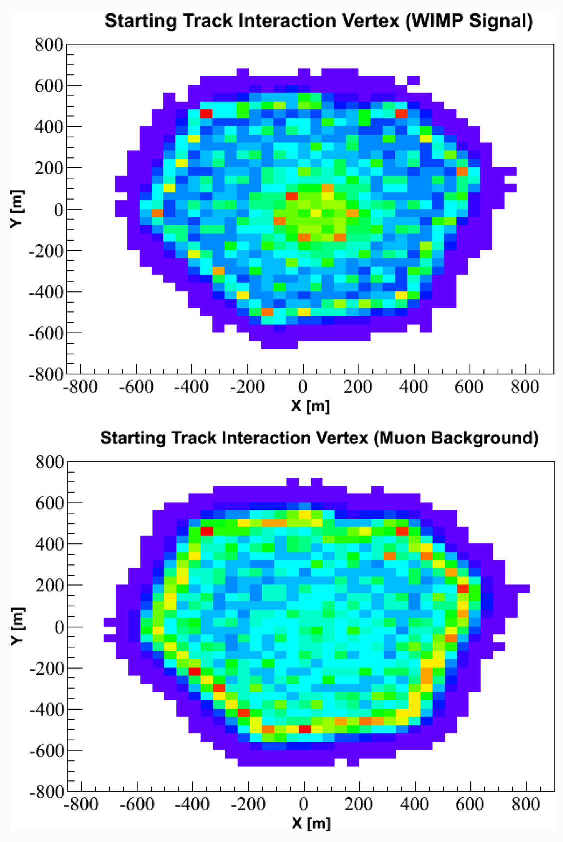
- Dark Matter distributed in the Galactic Halo
- Swept up and gravitationally captured in the center of massive objects (Sun)
- Self-annihilation to standard model particles results in flux of neutrinos

$$\chi\chi \rightarrow W^+W^-, b\bar{b}, \ldots \rightarrow \nu's$$

- Neutrinos propagate to detector, convert to muons in the ice

IceCube 79-String Dataset

- Dataset: May 2010 to May 2011, 318 days livetime
- Extended triggers and improved DAQ capture more low energy physics events (10-200 GeV)
- Low level online filters developed to reduce muon backgrounds by several orders of magnitude
- Dataset split into austral summer (above horizon) and austral winter (below horizon) samples
- In the southern sky (summer sample), veto based on events with an interaction vertex within the detector. Reduces the through going muon background by a factor ~ 100. See figure to right
- Extension to southern sky has the potential to gain up to factor 2 in effective Volume, depending on neutrino energy



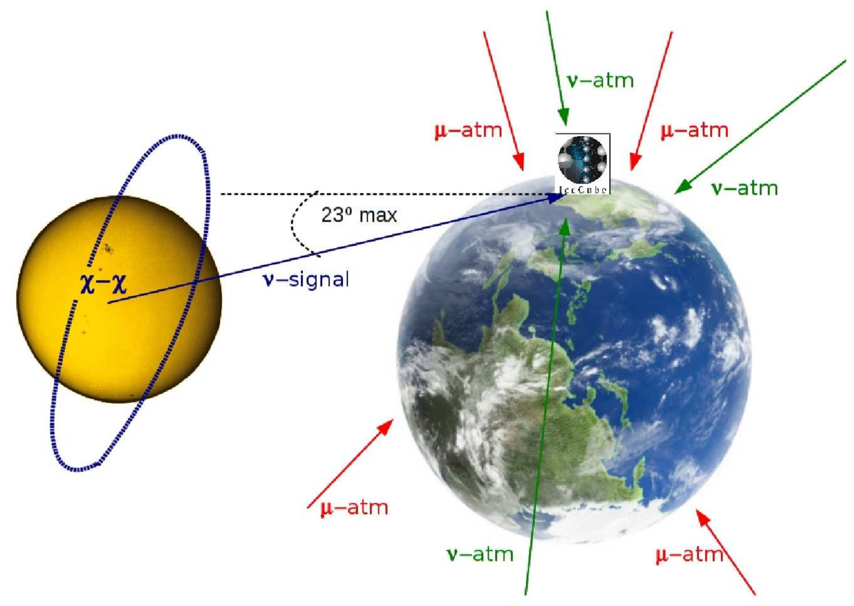


Figure: WIMP Capture & Annihilation in the Sun

References

[1] R. Abbasi et al.,Astropart. Phys. **32**, 749(2012)
[2] P. Gondolo et al.,JCAP **0407**, 008(2004).
[3] G.J.Feldmann et al.,Phys.Rev.D **57** 7(1998).

IceCube 79-string Analysis Strategy

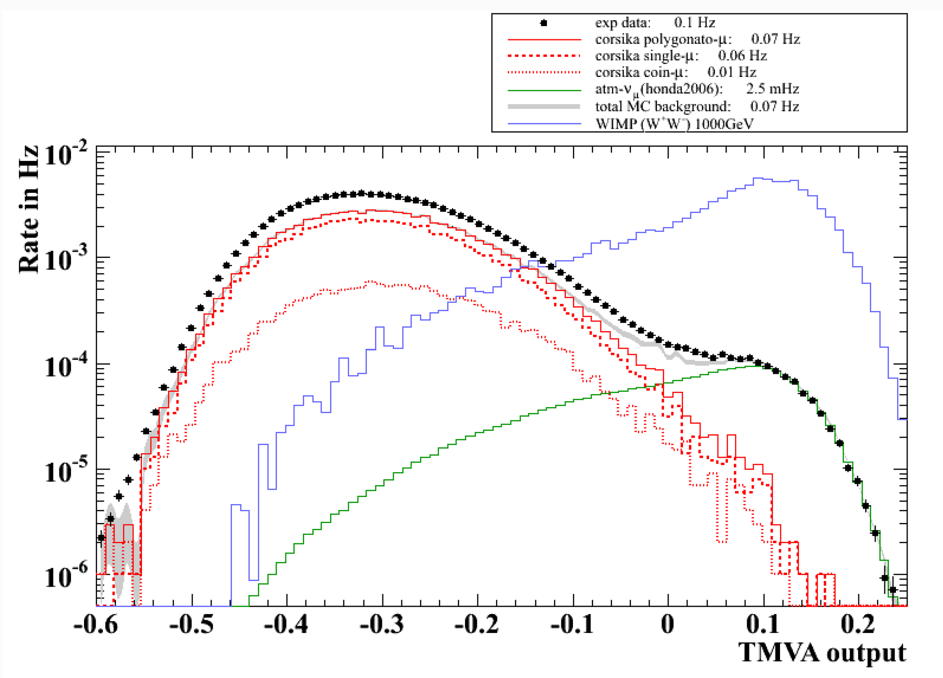


Figure: Output of the 14 parameter Boosted Decision Tree to achieve the final IceCube dominated high energy data sample. 1000 GeV W^+W^- WIMP signal shown for comparison

- Neutrino fluxes from WIMP annihilation in the Sun computed with DarkSUSY [2]
- High statistics simulation of atmospheric muon and neutrino backgrounds
- Winter sample split into IceCube and DeepCore dominated subsets (2 set of cuts $\rightarrow$ **IChigh** and **DClow** energy event signatures)
- Summer sample focuses on strong vetoes against downgoing muons (1 set of cuts focusing on low energy, contained event signatures)
- Remove atmospheric muon events until data sample is dominated by atmospheric neutrino events
- Signal events within IceCube may have low mean muon energy in detector $\rightarrow$ short tracks with few hits
- Cut on reconstruction parameters, maximizing horizontal low energy muon track selection
- Final data selection $\rightarrow$ determine effective Volume, V_{eff}, and effective Area, A_{eff}
- Assuming no detected signal, we can derive average Feldman-Cousins upper limit of signal induced events, N_{90}, at the 90% confidence level [3]
- Calculate limits on annihilation rate, Γ_A, muon flux, Φ_μ, capture rate, C_c, and cross sections, e.g., σ_{SD}

$$\text{using Ref.[2],} \quad \Gamma_{\nu\mu} = \frac{N_{90}}{V_{\mathrm{eff}} \cdot t_{\mathrm{live}}} \Rightarrow \Gamma_A \Rightarrow \Phi_\mu \Rightarrow C_c \propto \sigma_{SD}$$

Likelihood Based Shape Analysis

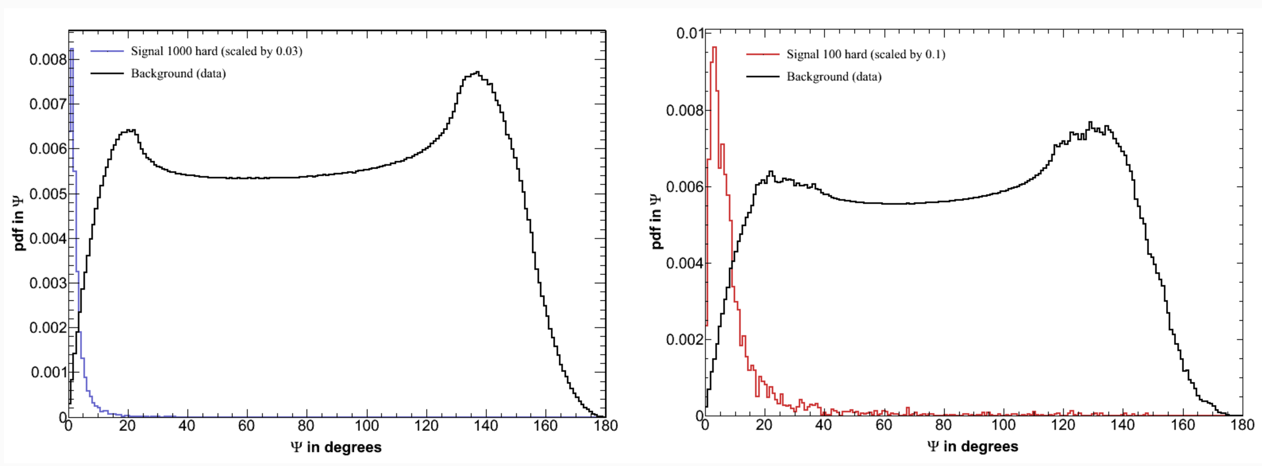


Figure: Space angle between reconstructed muon track and Sun for signal and background in the winter analysis. High energy sample on left, low energy sample on right.

- Construct signal and background PDFs for each of 3 samples
- Compare distribution of the final sample to these PDFs to determine most likely signal content
- Combine likelihoods, weighted by relative livetime

$$\mathcal{L}(\mu) = \prod_i^{n_{obs}} f(\Psi_i|\mu), \quad \text{where} \quad f(\Psi|\mu) = \frac{\mu}{n_{obs}} f_s(\Psi) + (1 - \frac{\mu}{n_{obs}}) f_{bg}(\Psi)$$

Sensitivity to Dark Matter Annihilation in the Sun

Preliminary Sensitivities based on likelihood method shape analysis:

- Shown for each of 3 independent data samples, as well as combined
- Assume equilibrium between capture and annihilation in the Sun
- Inclusion of DeepCore improves sensitivities at low masses (low energy neutrinos)

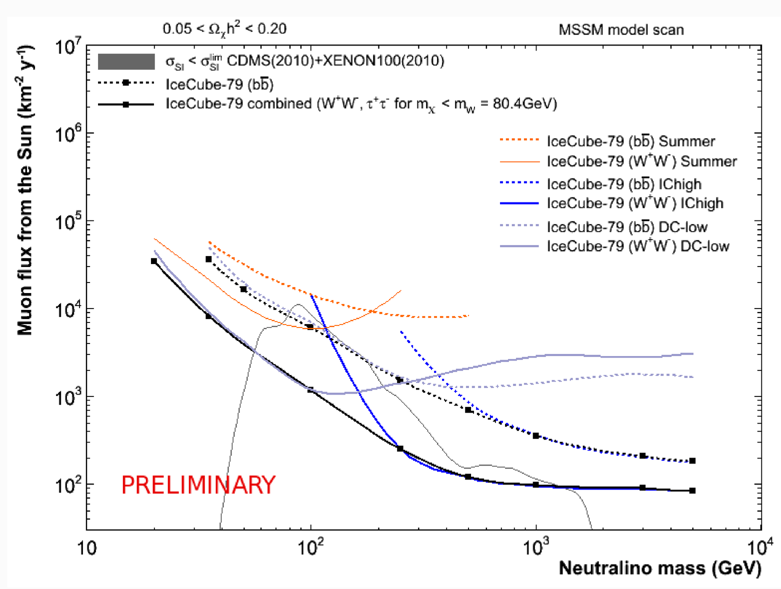


Figure: muon flux

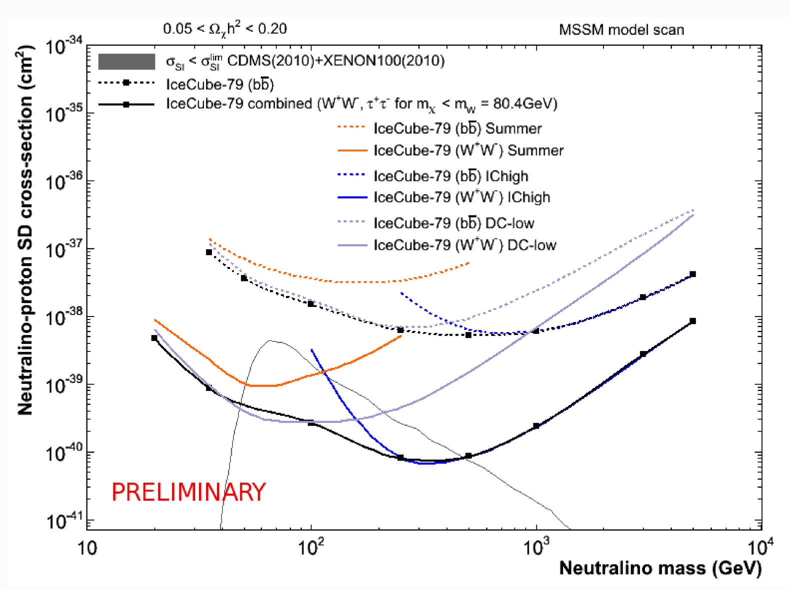


Figure: SD scattering cross section