Results from a search for secluded dark matter in the Sun using 6 Years of IceCube data

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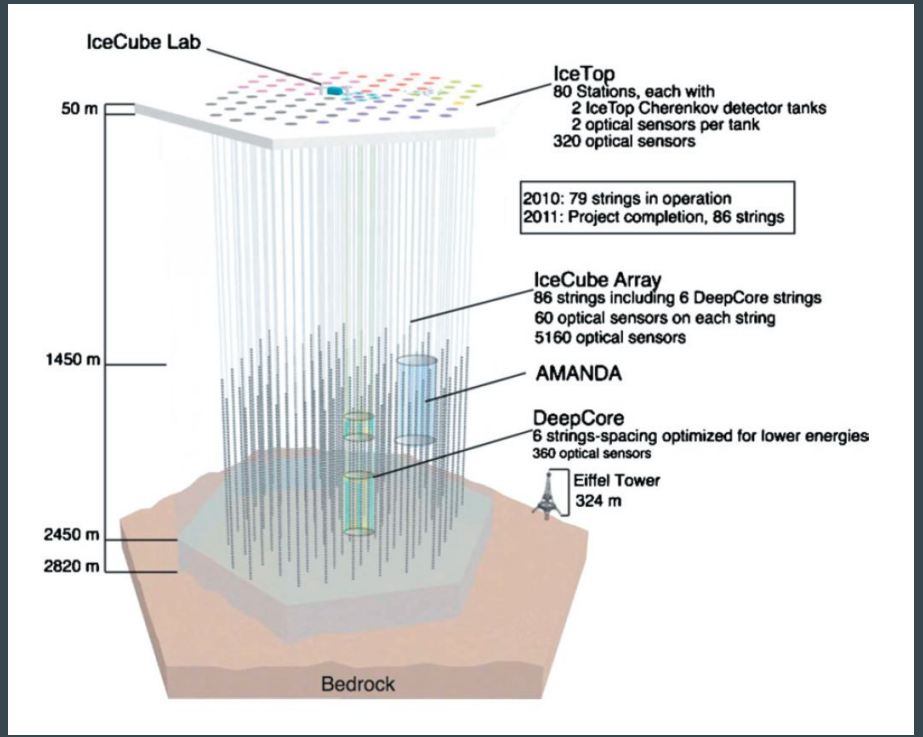
IceCube
South Pole Neutrino Observatory

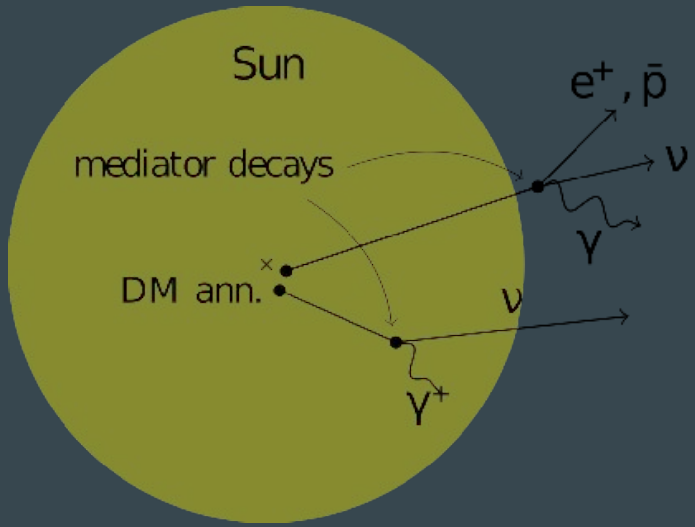
The IceCube detector

- The to date largest neutrino detector with one km^3 instrumented volume
- Located at the geographic south pole
- Detects neutrinos via cherenkov radiation induced by muons from neutrino interactions and electromagnetic cascades from electrons and tauons produced by neutrinos in the detector volume



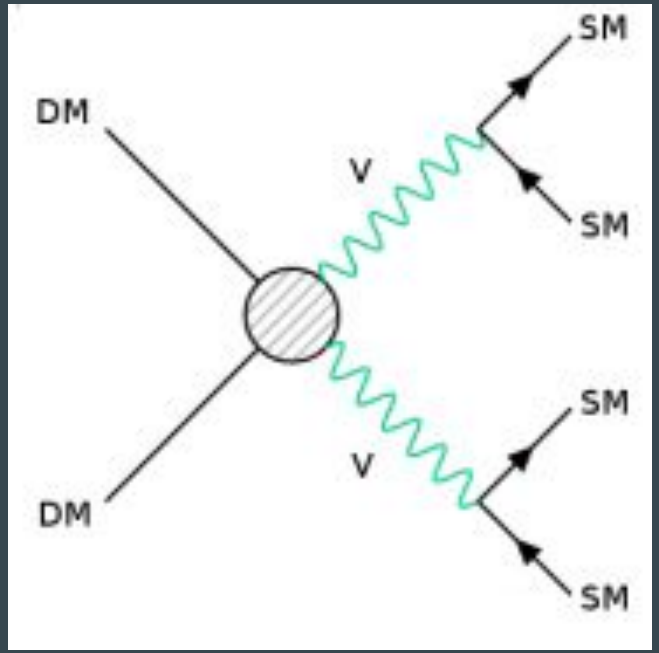
Secluded dark matter

- Secluded dark matter is a unique type of model for dark matter
- In this model Dark matter particles do not directly decay or annihilate into standard model particles
- Instead in dark matter annihilations metastable mediators are produced
- After a lifetime that can range from microseconds to 10 seconds the mediator decays into some standard model particle
- This mediator is itself not a standard model particle and can avoid interactions with baryonic matter, yielding significantly enhanced neutrino fluxes at high neutrino energies.



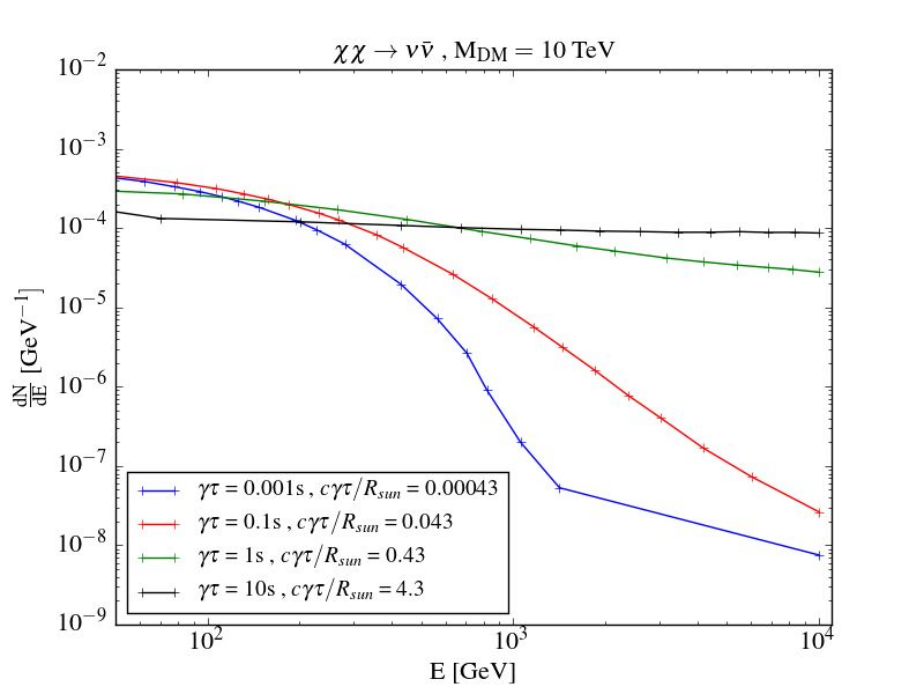
Theoretical motivation

- Secluded dark matter is theoretically well motivated
  - Can explain the positron excess detected in PAMELA, AMS-II and FERMI (F. Chen, J. M. Cline, A. R. Frey, Phys. Rev. D 80 (2009) 083516.)
  - Many dark matter models naturally include a mediator like dark photons or Z' models (M. Pospelov, A. Ritz and M. B. Voloshin, Phys. Lett. B 662 (2008) 53. ; I. Z. Rothstein, T. Schwetz and J. Zupan, JCAP 07 (2009) 18.)



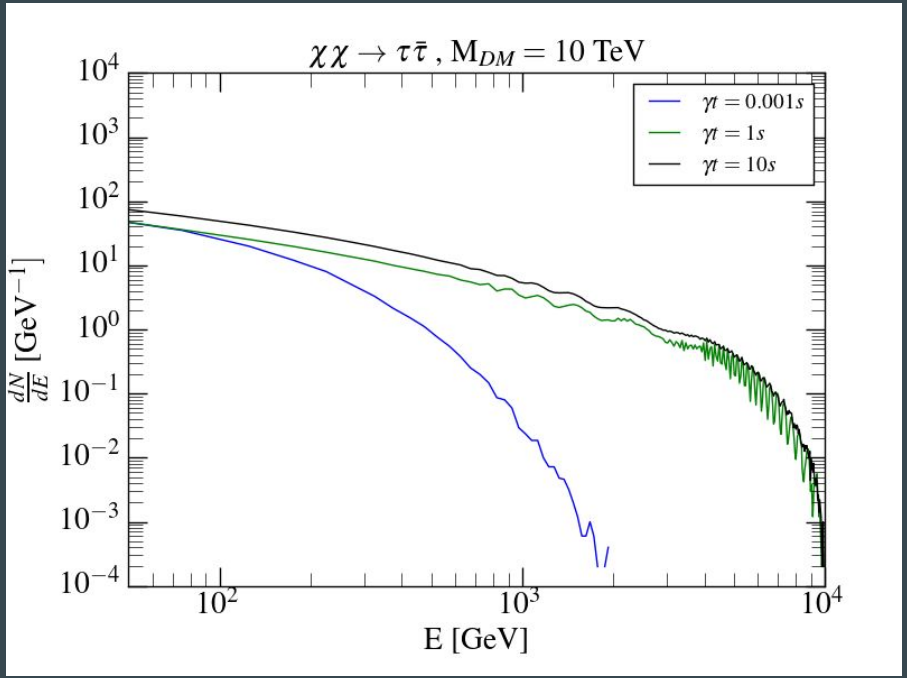
This analysis

- This analysis looks for secluded dark matter in the Sun
- Due to absorption in the Sun neutrino signals are strongly reduced at all energies
- Beyond 1 TeV of energy almost all neutrinos are being absorbed
- For lifetimes above 2.3 s mediators generated by dark matter in the Sun will escape the Solar plasma before decay
- In such a case the neutrino signal would be significantly enhanced



WIMPSIM spectra

- Spectra have been generated for dark matter masses of up to 75 TeV and cover dark matter decays into W-bosons and tau leptons
- Other channels were not used a s in WIMPSIM there is no implementation for the BRW electroweak correction
- Different masses of the mediator ranging from 1 GeV to 1 TeV were simulated
- Mediator decay lengths from 0.001 solar radii to 10 solar radii were used
- The spectra include effects from neutrino oscillations



Method

- An unbinned likelihood method is used with the following likelihood function:

$$\mathcal{L}(n) = \prod_{i=0}^{N} \left(\frac{n}{N} S(\psi_i, E_i) + \frac{N-n}{N} B(\psi_i, E_i) \right)$$

- N is the sample size, S describes the signal behaviour as a function of the angular separation of an event to the Sun ψ_i and its energy E_i for event number i. B is the corresponding function describing the background.
- The background part of the likelihood is generated from time scrambled data
- Using this likelihood the IceCube northern tracks sample from 2011 to 2016 with 1057.8 days of livetime is being analysed
- This sample consists only of muon neutrinos that come from the northern hemisphere
- Signal and background are differentiated based on the neutrino energy and arrival direction

Sensitivity and limit conversion

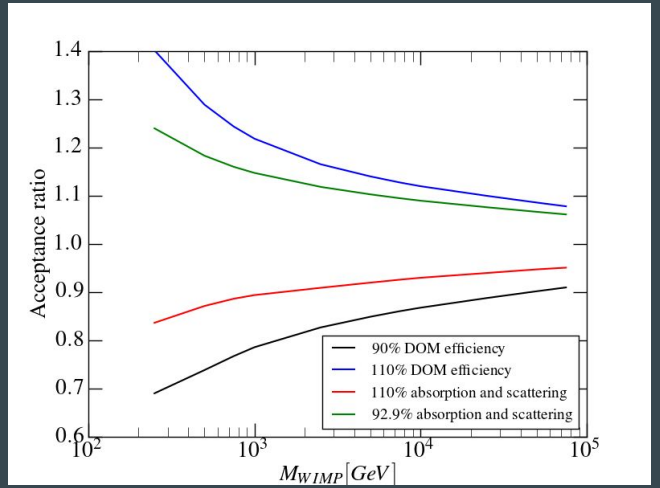
- This analysis seeks out to detect dark matter or, in the case of a null result, to restrict dark matter model parameters
- In the case of the latter and to compute sensitivities a conversion from neutrino fluxes to dark matter-nucleon scattering
- First neutrino fluxes Φ_ν are converted to annihilation rates with the equation

$$\Gamma_{ANN} = \Phi_\nu \frac{4\pi r_{Sun}^2}{\int \frac{dN}{dE} dE}$$

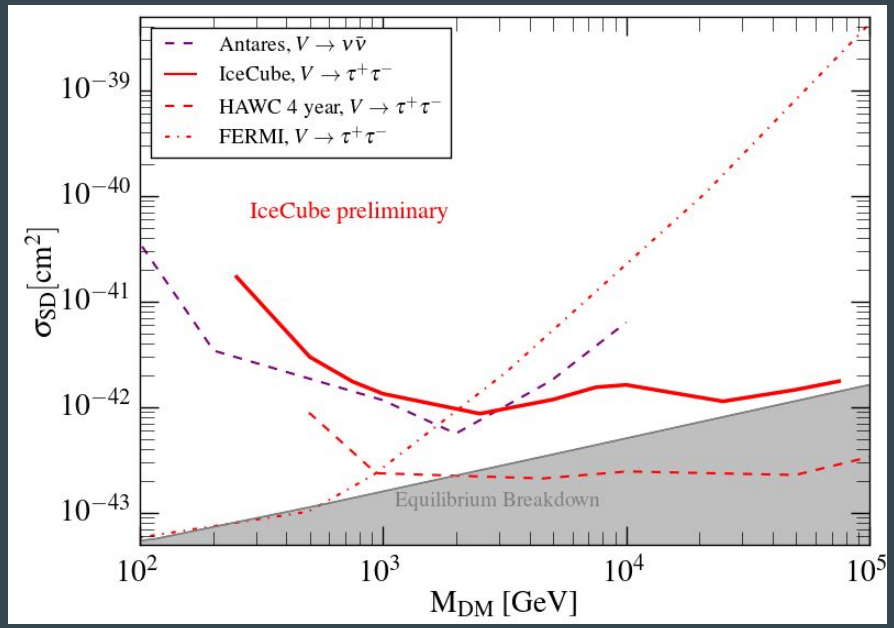
- r^2_{Sun} is the radius of the earth's orbit and the integral over the neutrino spectrum dN/dE is the number of neutrinos generated per annihilation
- The annihilation rate can be related to dark matter nucleon scattering assuming an equilibrium between dark matter capture in the Sun and using conversion factors calculated with the DarkSUSY simulation package

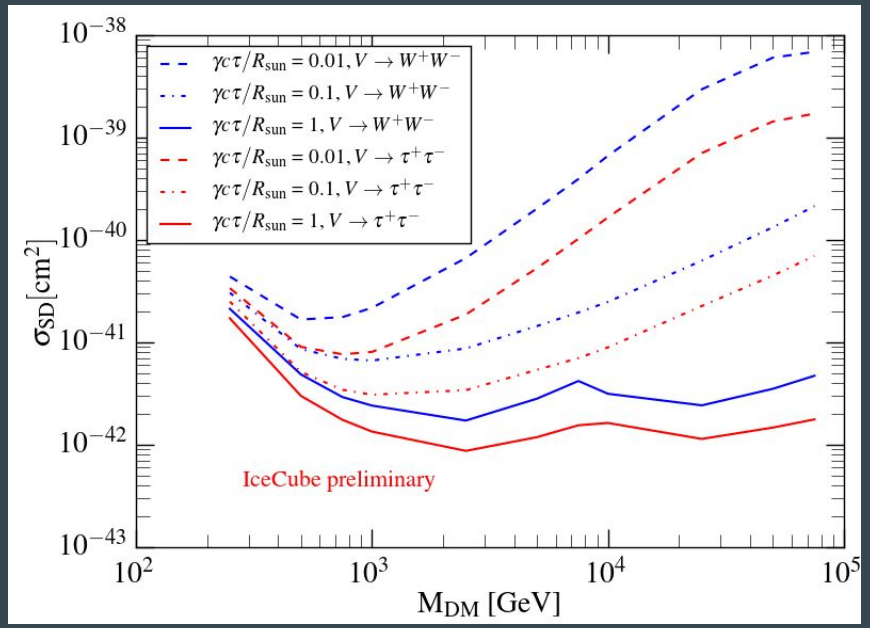
Systematics

- On the right the effect of the systematics is shown for mediators decaying into neutrinos (top) and tauons (bottom)
- The systematic effects are in the expected range and are evaluated as the ratio of signal acceptance for the systematics to the reference assumption of 100% DOM efficiency, scattering and absorption
- Systematic effect due to Sun shadow is supposed to be implemented after unblinding as this systematic is expected to improve limits
- The plot on the left shows an example for a 100 GeV mediator decaying into tauons. The systematic effect can be as large as 40% depending on the dark matter mass



Limits





No significant excess above the expected background was found in the examined dataset. The set limits are the best of any current neutrino experiment above 3 TeV accounting for differences in mediator decay channel.

Summary

- A first analysis of a 6-year set of IceCube data searching for secluded dark matter has been completed
- No significant excess above the background has been observed
- The best limits for secluded dark matter from neutrino experiments above 3 TeV DM mass were set for mediator decays into tauons and W bosons
- An update to the analysis using 9 years of data is underway