Search for heavy dark matter with IceCube

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for the IceCube collaboration

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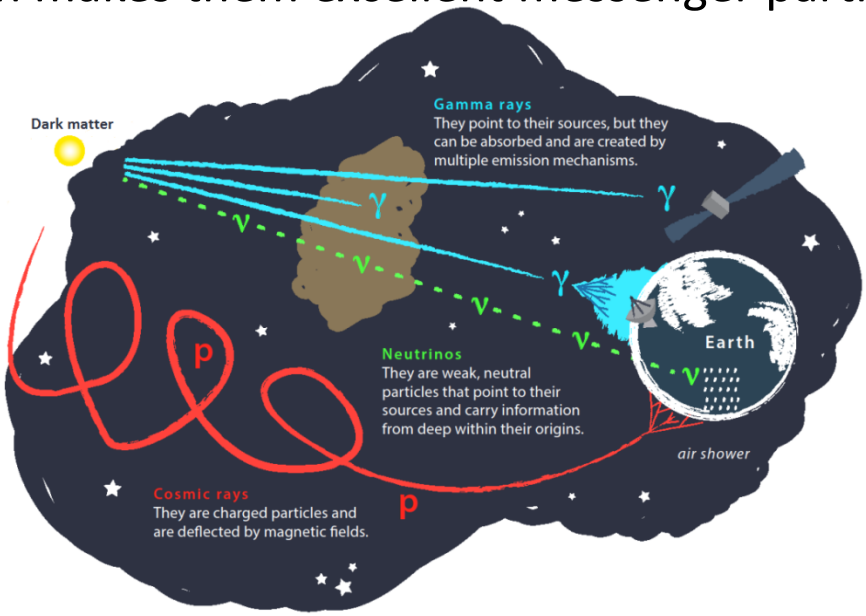
Neutrinos as dark matter messengers

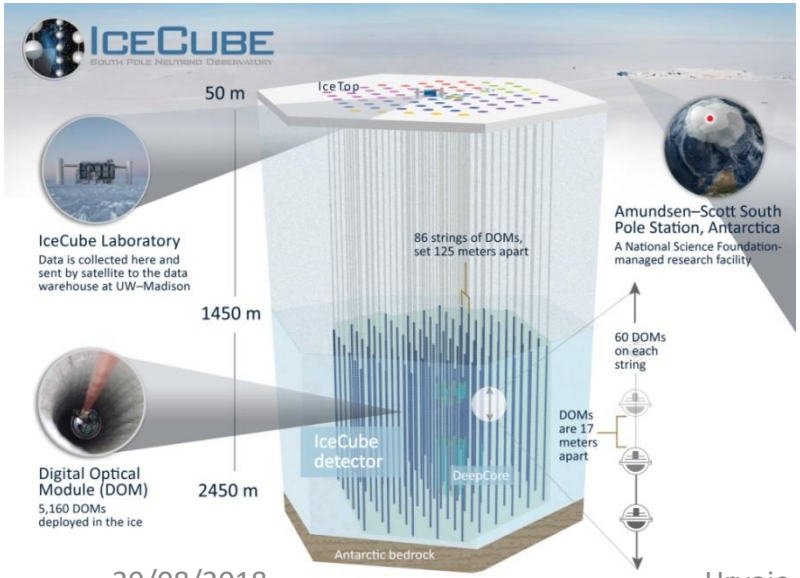
- Despite many strong pieces of evidence for its existence, the nature of dark matter remains one of the main open questions in particle and astrophysics
- Annihilation or decay of the dark matter particles are expected to produce neutrinos
- Their low cross sections means neutrinos do not get attenuated on their way to Earth, which makes them excellent messenger particles



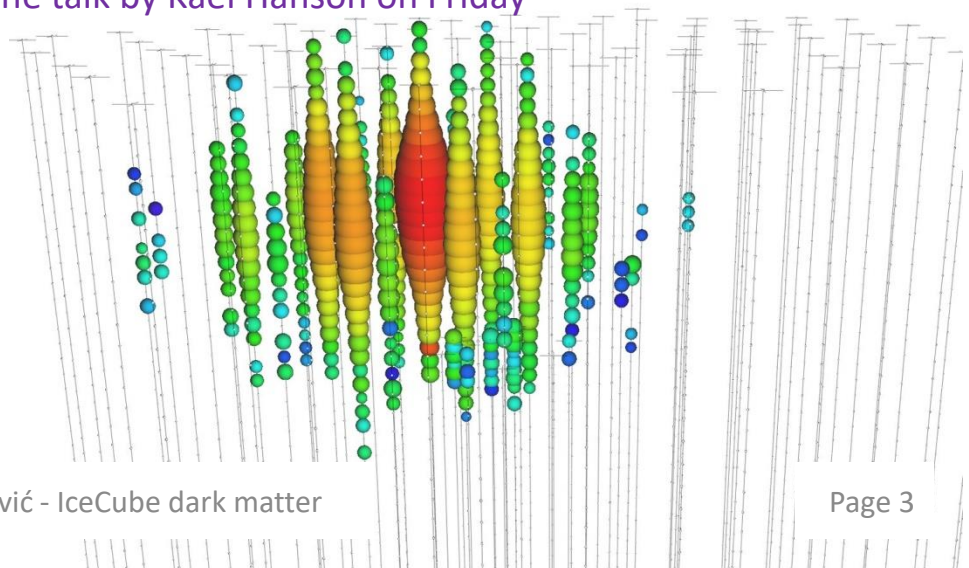
The IceCube Neutrino Observatory

Located at the South Pole, IceCube is a gigaton-scale neutrino telescope

- Neutrinos interacting with atomic nuclei in the ice produce secondary charged particles
- 5160 digital optical modules detect secondary particles via their Cherenkov radiation
- From the gathered data, the energy and the direction of the primary neutrino can be reconstructed



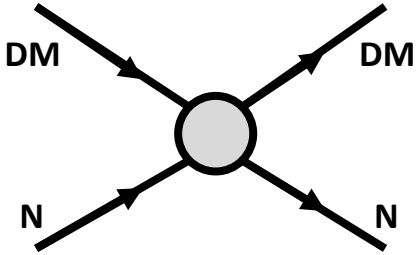
For IceCube astrophysics results,
see the talk by Kael Hanson on Friday

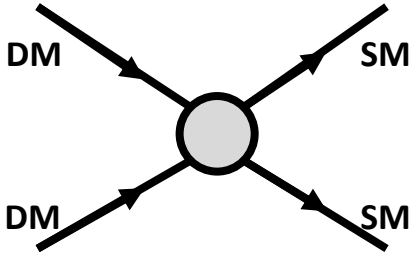


Dark matter searches in IceCube

DM annihilation in the Sun/Earth

Probing of DM-nucleon scattering: $\sigma_{DM\text{-}N}$



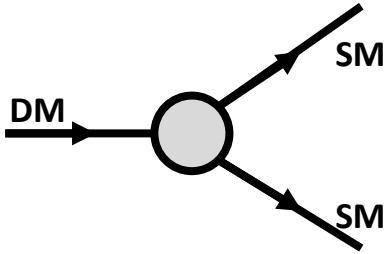


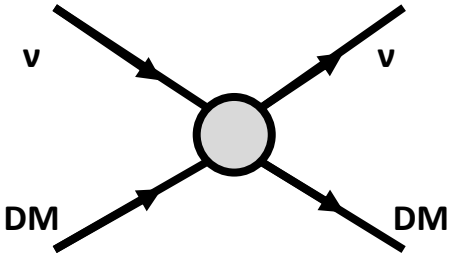
DM annihilation in the Galactic centre/halo

Probing of the velocity averaged self-annihilation cross-section: $\langle \sigma_{DM\text{-}DM}\, v \rangle$

Galactic and extragalactic DM decay

Probing of the dark matter lifetime: τ_{DM}





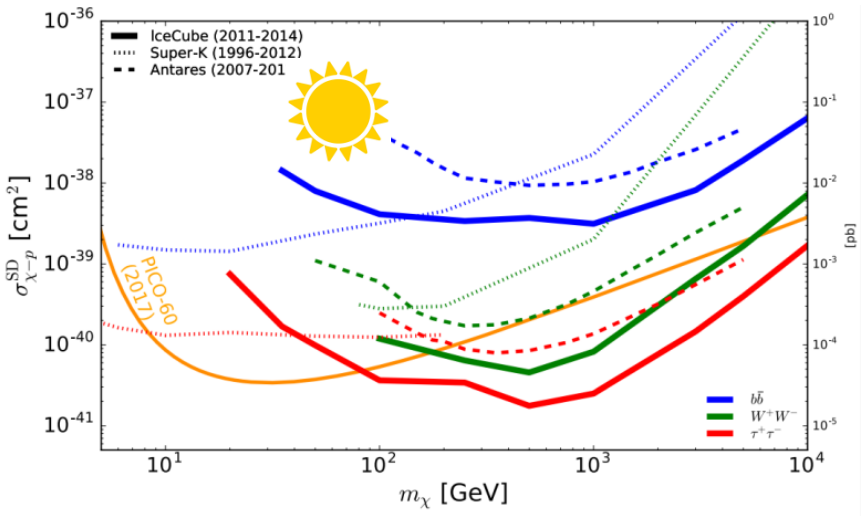
ν-DM scattering in the Galactic halo

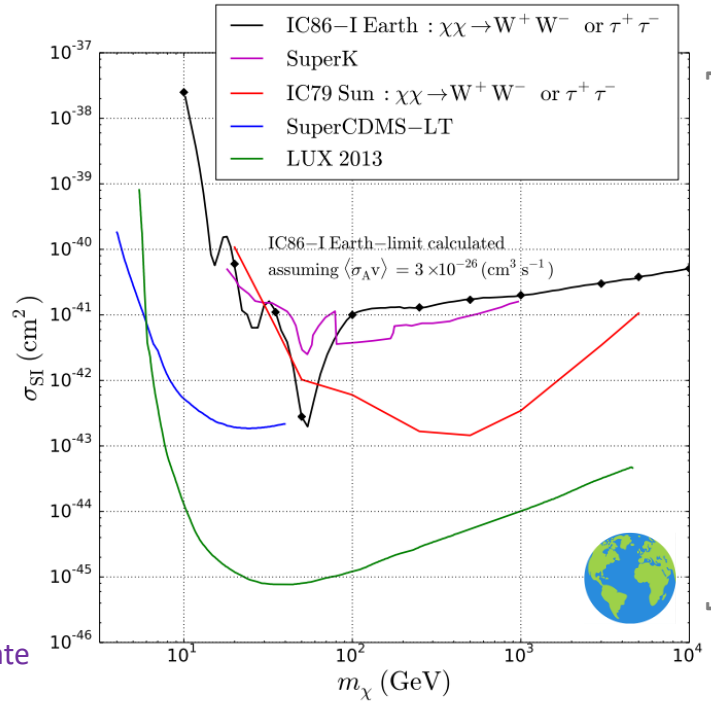
Probing of the dark matter-neutrino scattering cross-section: $\sigma_{DM\text{-}\nu}$

Dark matter in the Sun/Earth results

- Dark matter capture rate in the Sun(Earth) dominated by σ_{SD} (σ_{SI})
- In equilibrium annihilation rate = capture rate/2
- Sensitive to DM masses ~10 GeV – 10 TeV
- Limits complementary to direct detection experiments (different systematics)

[IceCube EPJC 2017 77: 146]



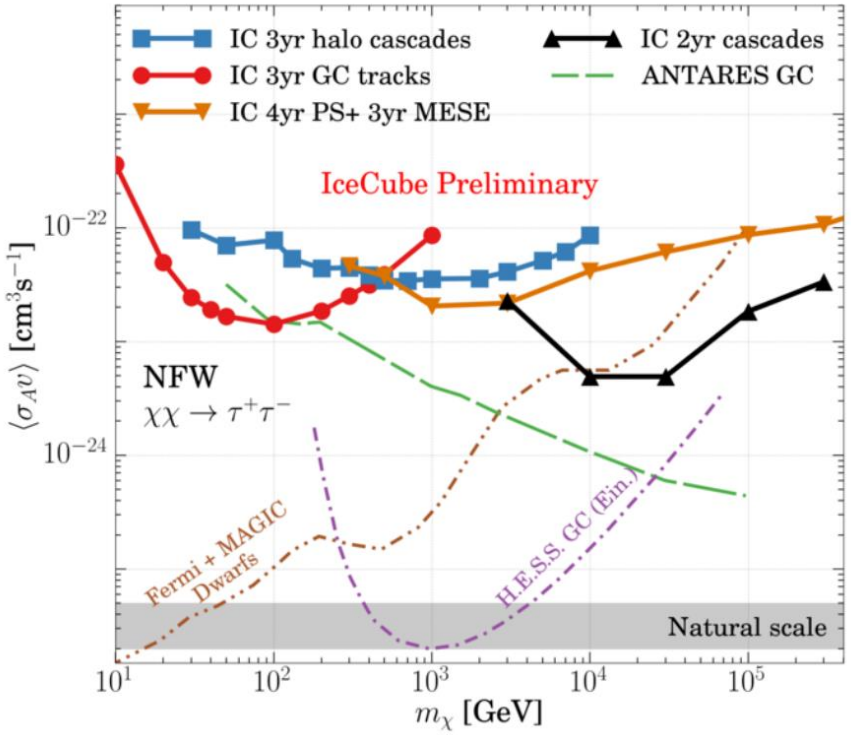


[IceCube EPJC 2017 2 77:82]

Plots from the papers, direct detection limits not fully up-to-date

Galactic dark matter annihilation results

- Multiple analyses have been performed looking for DM self-annihilation in the Galactic Centre/Halo
- Mostly focused on the masses ~ 10 GeV-300 TeV



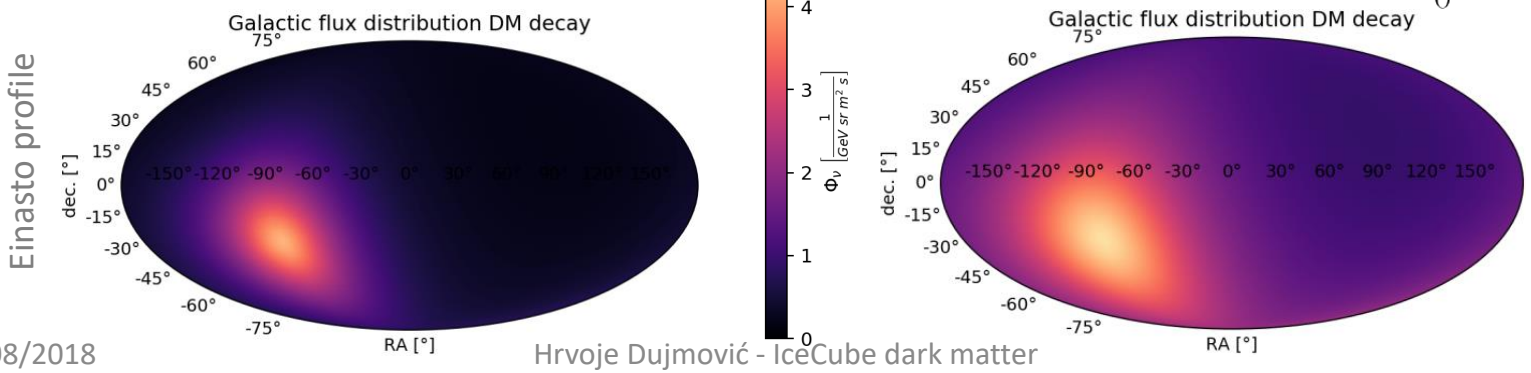
[IceCube, PoS(ICRC2017)906]

Heavy dark matter annihilation/decay

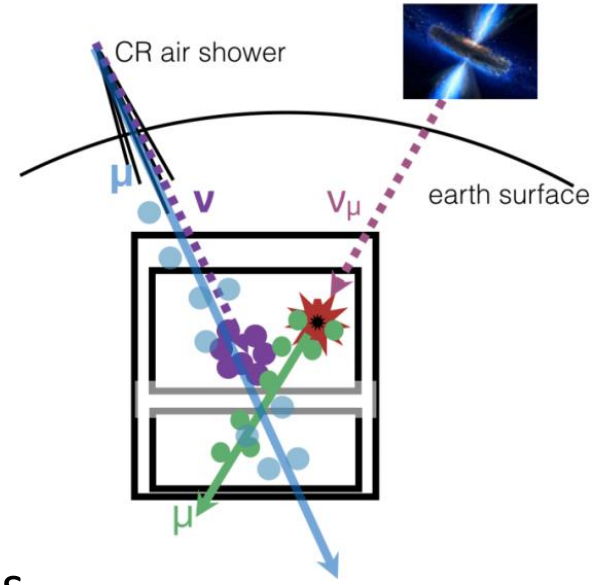
- Recently, the masses range of the dark matter searches has been extended to PeV masses
- In most models heavy dark matter tends to be less stable
- Due to different scaling, the dark matter decay searches become more relevant at high masses
- Analysis methods very similar, extragalactic dark matter has to be taken into account for decay
- Different halo profiles are investigated, decay analysis not effected as much as annihilation

$$\frac{d\Phi_{Ann}}{dE_\nu} = \frac{\langle\sigma v\rangle}{4\pi m_{\mathrm{DM}}^2}\frac{dN_\nu}{dE_\nu}\int_0^\infty \rho_{\mathrm{DM}}^2(s)\,ds$$

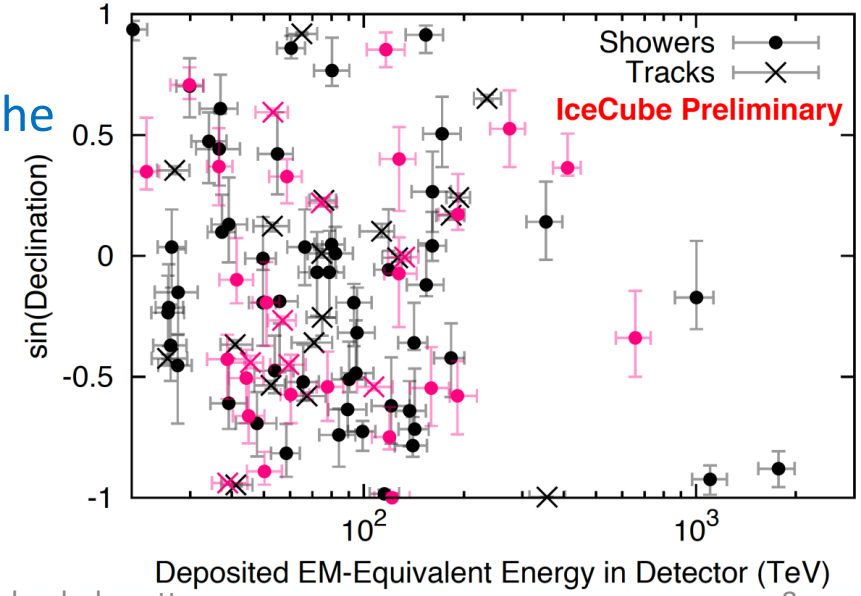
$$\frac{d\Phi_{Decay}}{dE_\nu} = \frac{1}{4\pi m_{\mathrm{DM}}\tau_{\mathrm{DM}}}\frac{dN_\nu}{dE_\nu}\int_0^\infty \rho_{\mathrm{DM}}(s)\,ds$$



7.5 years High Energy Starting Events (HESE) data



- In IceCube down-going events are dominated by atmospheric μ
- To reduce the background, the cuts are used:
  - Outer layer of the detector acts as a veto
  - Require a total of >6000 pe deposited
- The sample gives us a high purity of astrophysical νs (~75% above 60 TeV)
  - Previous HESE analyses have lead to the discovery of the astrophysical ν flux
- 6 previously analyzed years are reanalyzed using better detector-and ice-modeling
- 1.5 years of new data are added

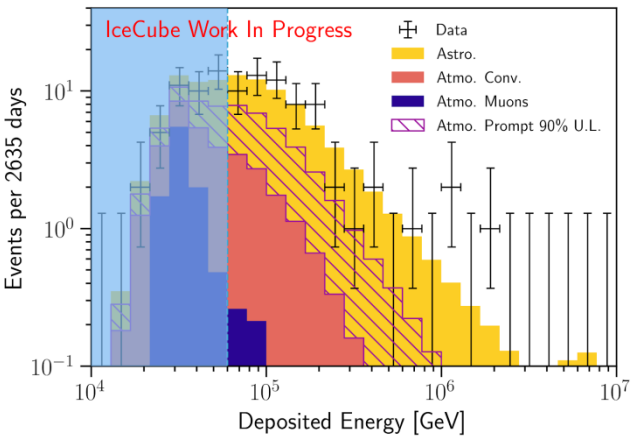


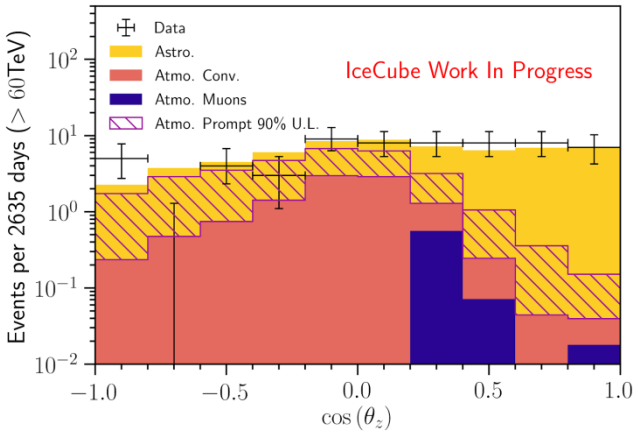
Analysis method

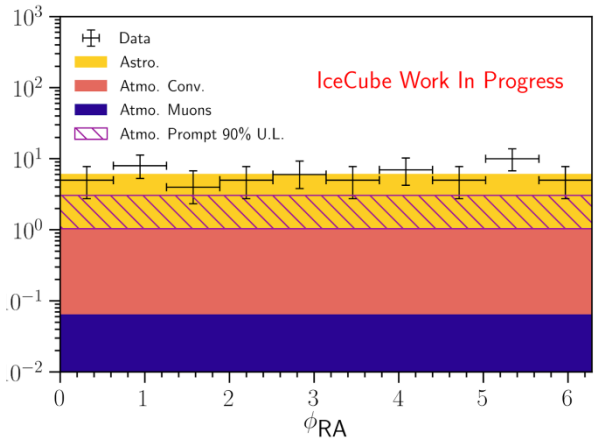
- All events with E>60 TeV are binned in logE, sinδ, (RA)
- A likelihood fit is performed using different flux components:
  - ν from π/K decay in cosmic ray air showers (Conventional. Atm.)
  - ν from D decay in cosmic ray air showers (Prompt Atm.)
  - μ from cosmic ray air showers
  - An isotropic single power-law astrophysical ν flux
  - Dark matter signal

Backgrounds

Signal

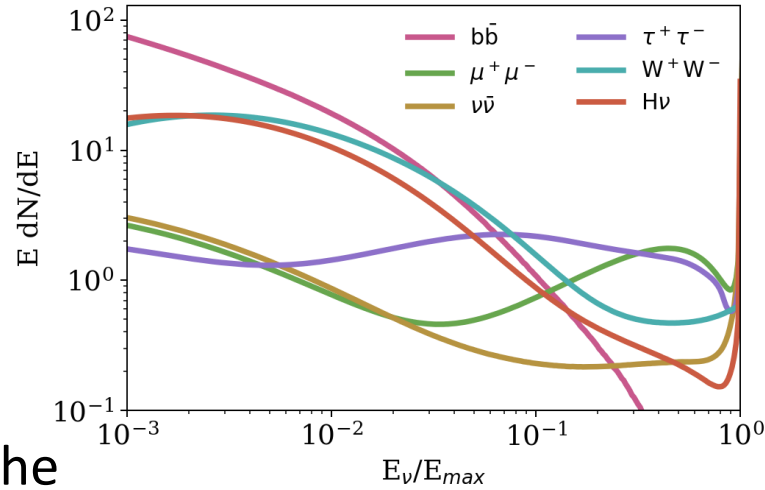


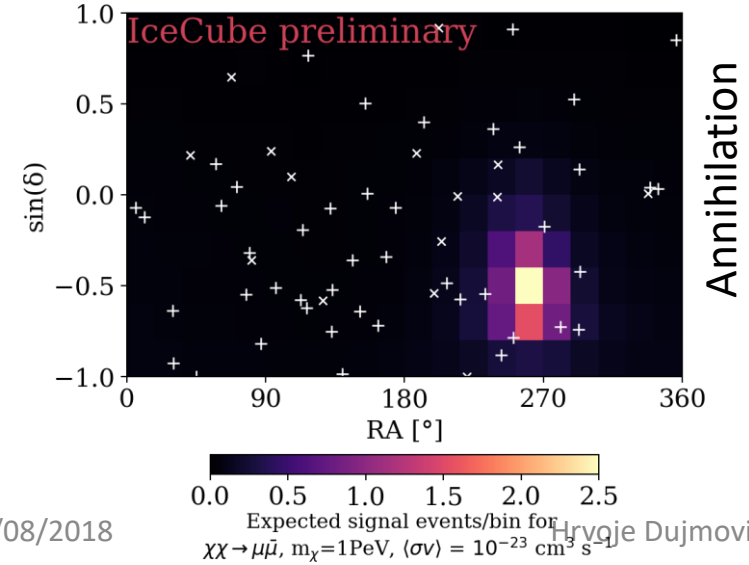


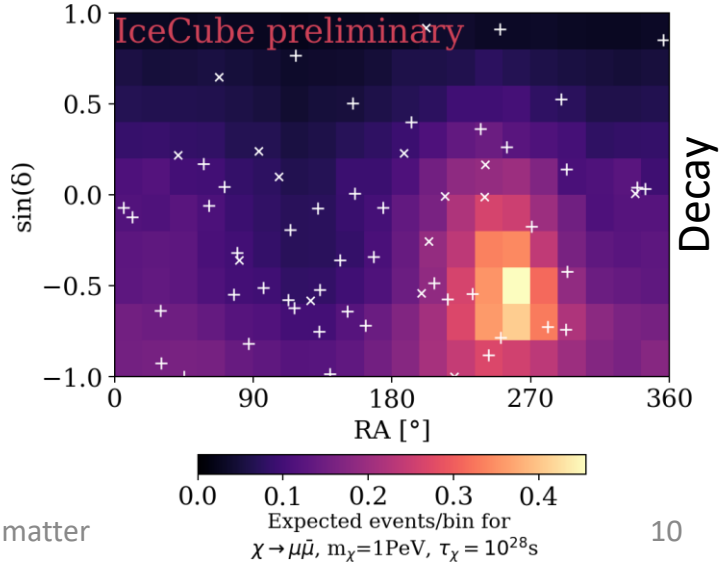


Dark matter signal expectation

- ν spectra at origin for various channels are obtained from a PYTHIA simulation
  - Decay/annihilation spectra are identical up to a scaling factor
- ν are propagated to the Earth
- Detector simulation is used to calculate the expected signal for a given dark matter model



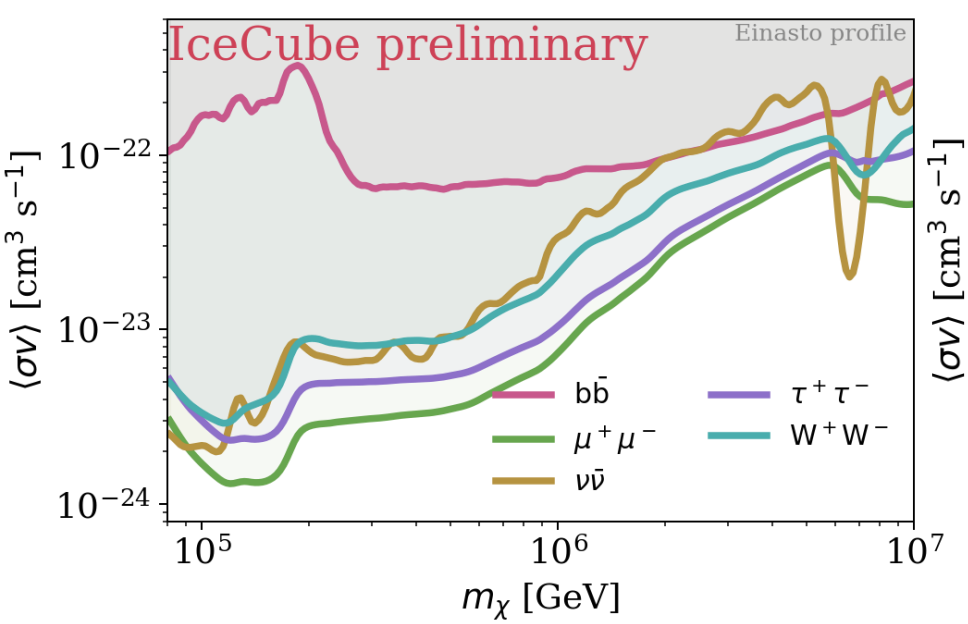


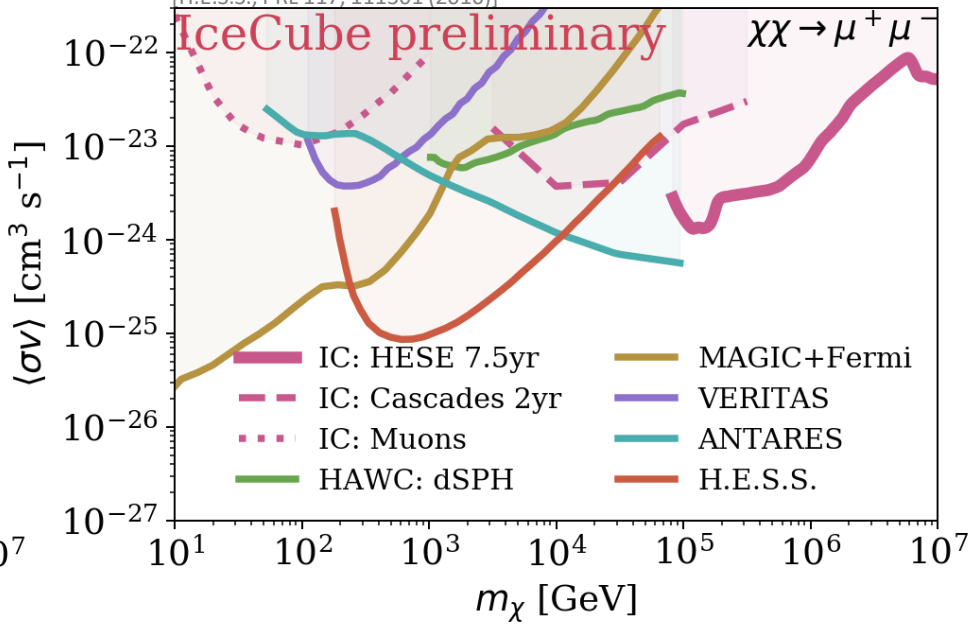


HESE 7.5 dark matter annihilation limits

- The lack of a significant dark matter signal is used to derive upper limits on the dark matter self-annihilation cross-section
- The existing limits have been extended to an experimentally unexplored part of the parameter space up to m_{DM}=10 PeV

[VERITAS, PRD 85, 062001 (2012)], [S.Flies, PhD thesis (2017)], [IceCube, EPJC 77, 627 (2017)], [HAWC, APJ 853 2, 154 (2018)], [Fermi & MAGIC, JCAP 1602 2 (2016)], [ANTARES, Phys.Lett. B769 (2017)], [H.E.S.S., PRL 117, 111301 (2016)]

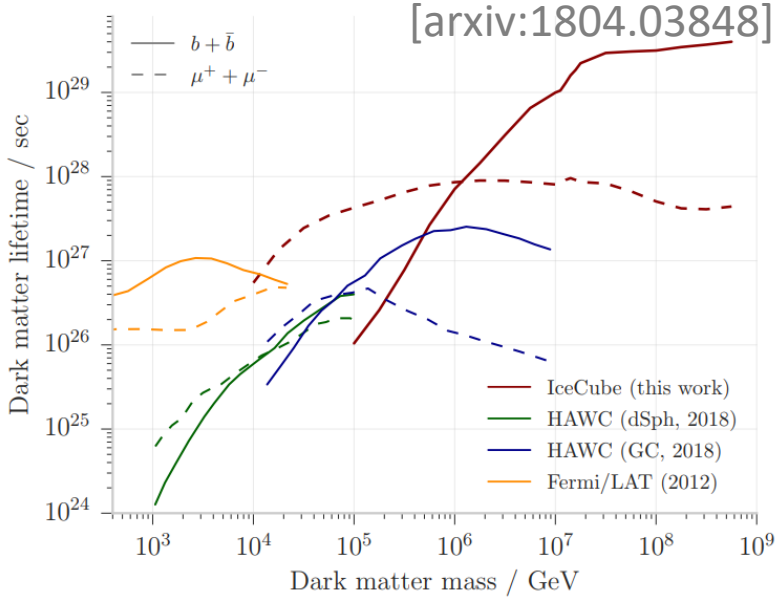




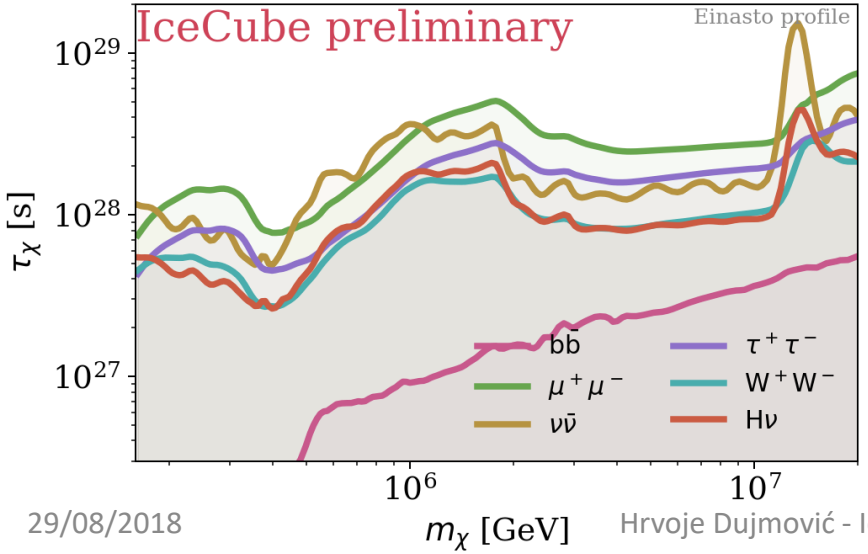
Dark matter decay limits

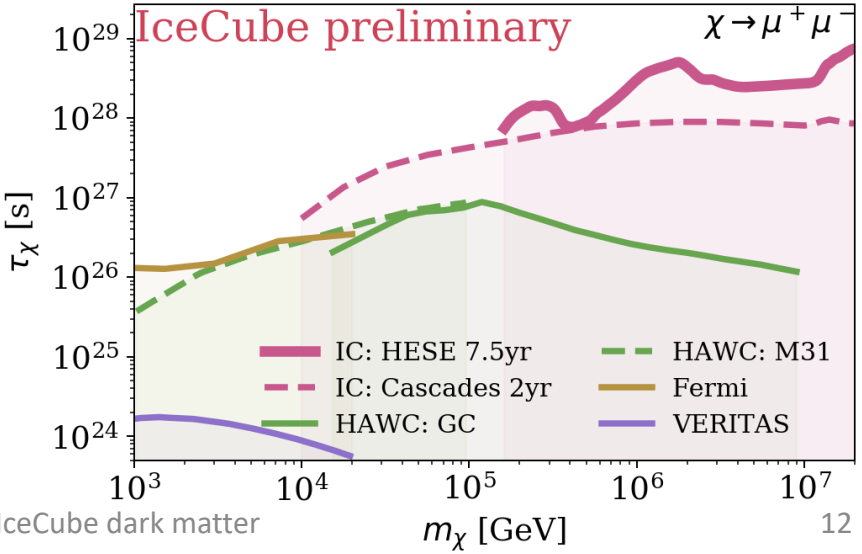
- Recent IceCube result has placed strong lower limits on dark matter lifetimes for: 10 TeV < m_{DM} < 500 PeV
- The HESE 7.5 analysis improves these limits at high masses

[arxiv:1804.03848]



[HAWC, APJ 2018 2, 049 (2018)], [HAWC, arXiv:1804.00628 (2018)], [FERMI, APJ 761 2, 91 (2012)], [VERITAS, PRD 85, 062001 (2012)]

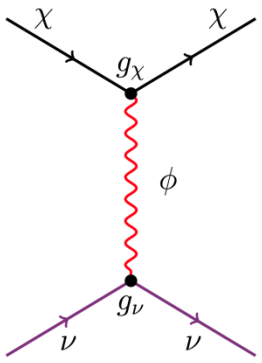


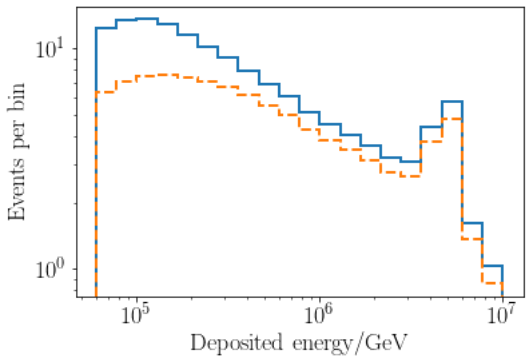


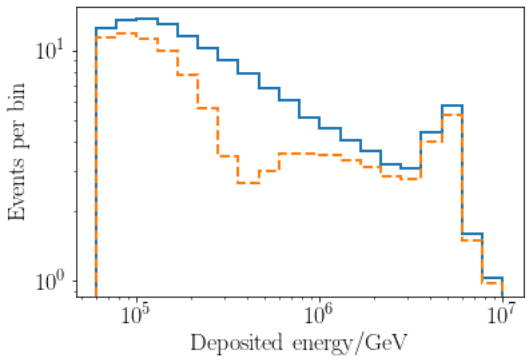
HESE 7.5 dark matter scattering

- High energy astrophysical ν interacting with dark matter would lead to a reduced ν flux and a modified spectrum
- Sensitive to very light dark matter m<GeV
- The effect depends on the DM column density
  - Strongest when looking at the Galactic Centre
- Two models with different types of interactions are invetigated

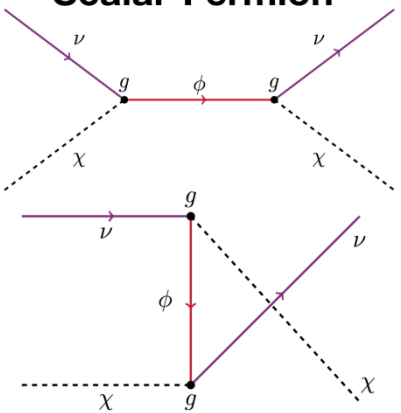
Fermion-Vector





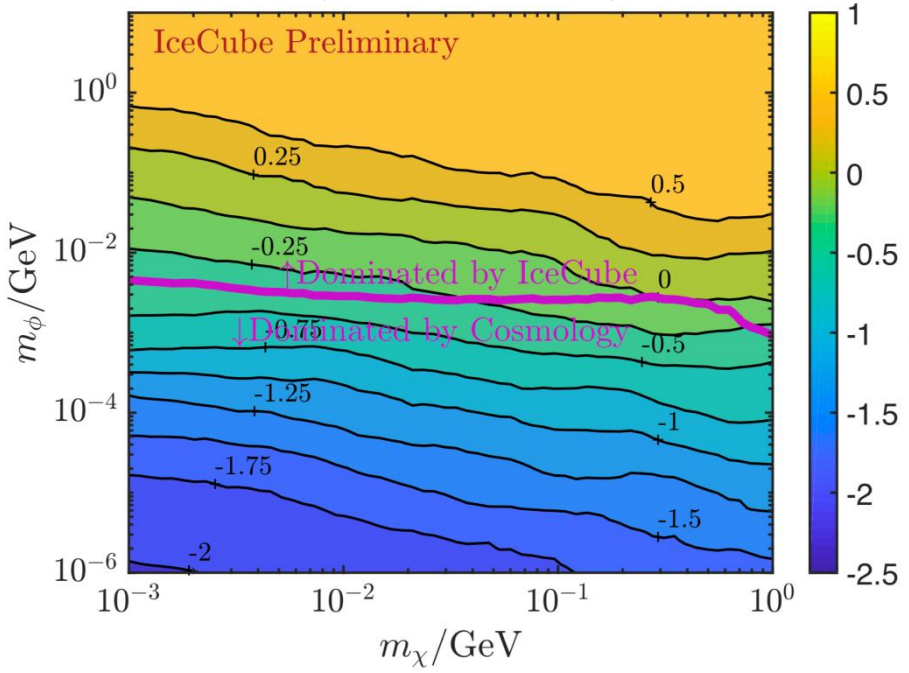


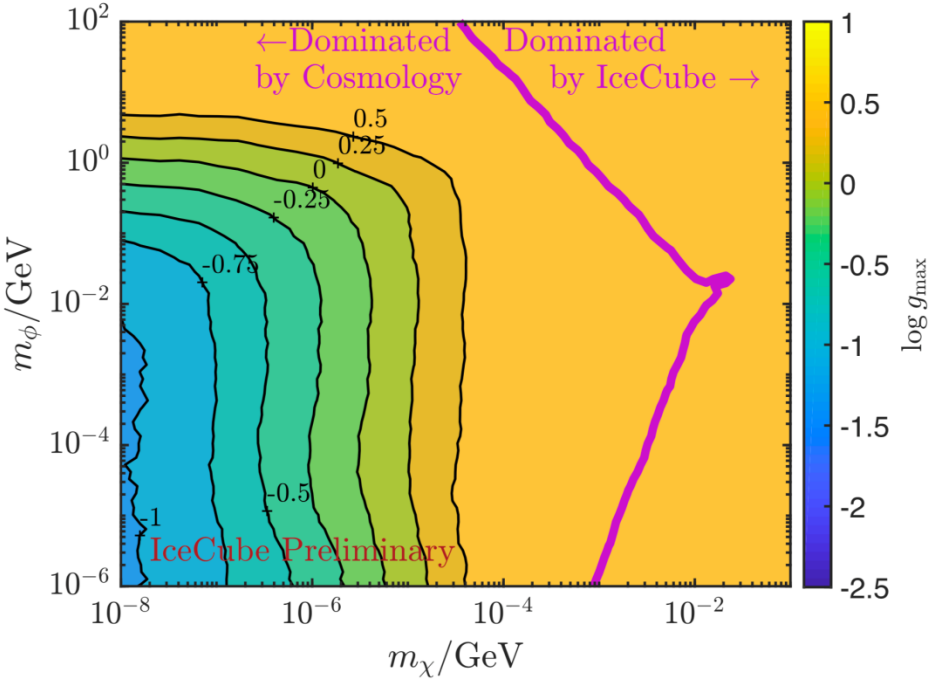
Scalar-Fermion



HESE 7.5 dark matter scattering limits

- The isotropy of the astrophysical ν flux is used to derive limits on the DM-ν coupling strength for different dark matter and mediator masses
- The limits improve on the existing cosmological limits for large parts of the parameter space





Conclusions

- The nature of dark matter remains one of the most important questions in modern physics
- IceCube is uniquely suitable to test various dark matter models:
  - Dark matter searches in the Sun/Earth are complementary to direct detection experiments
  - Galactic halo analyses offer strong limits on dark matter self-annihilation rates
  - Recent analyses have focused on the mostly unexplored parameter space of heavy PeV dark matter
    - Strong bounds on both dark matter self-annihilation and decay rates have been obtained
  - Dark matter-neutrino scattering allows testing of very light dark matter models
- Stay tuned for publications outlining the new results in the near future