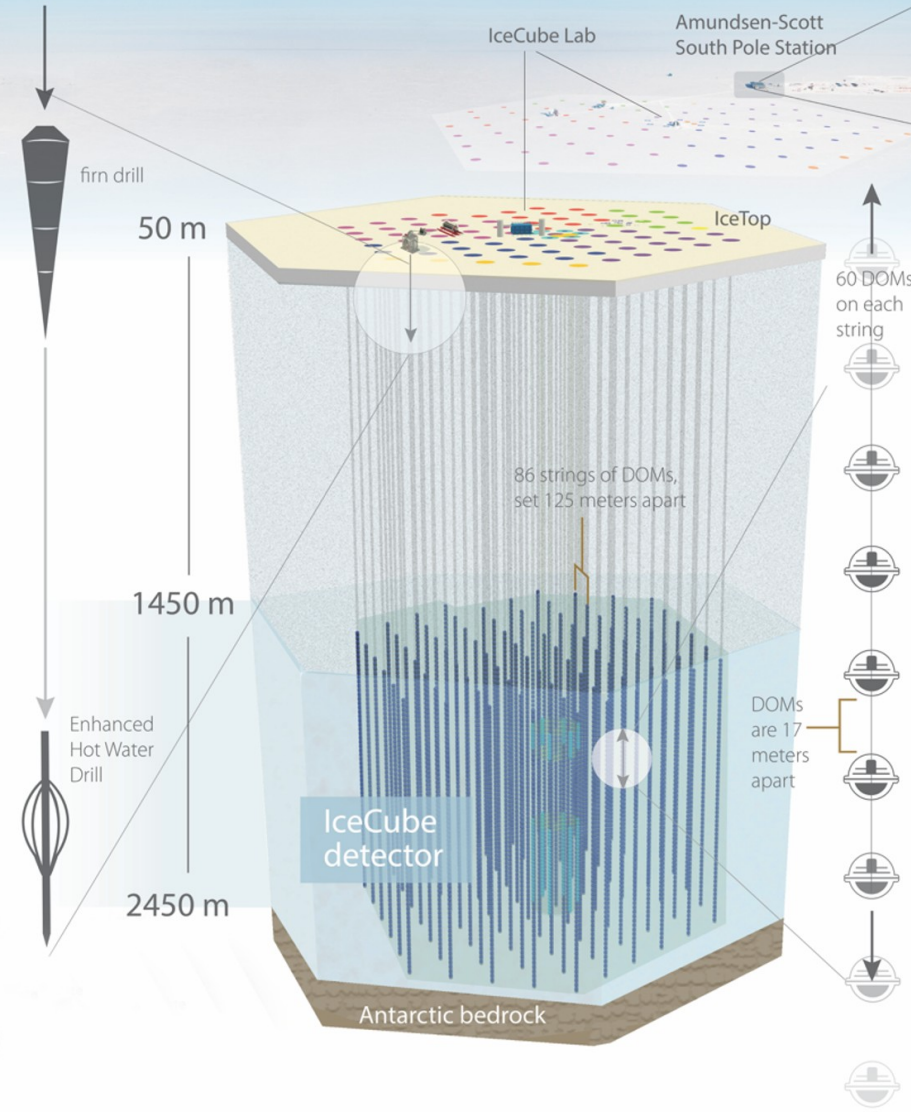
IceCube
South Pole Neutrino Observatory

Indirect searches for dark matter with IceCube

Sebastian Baur
for the IceCube collaboration

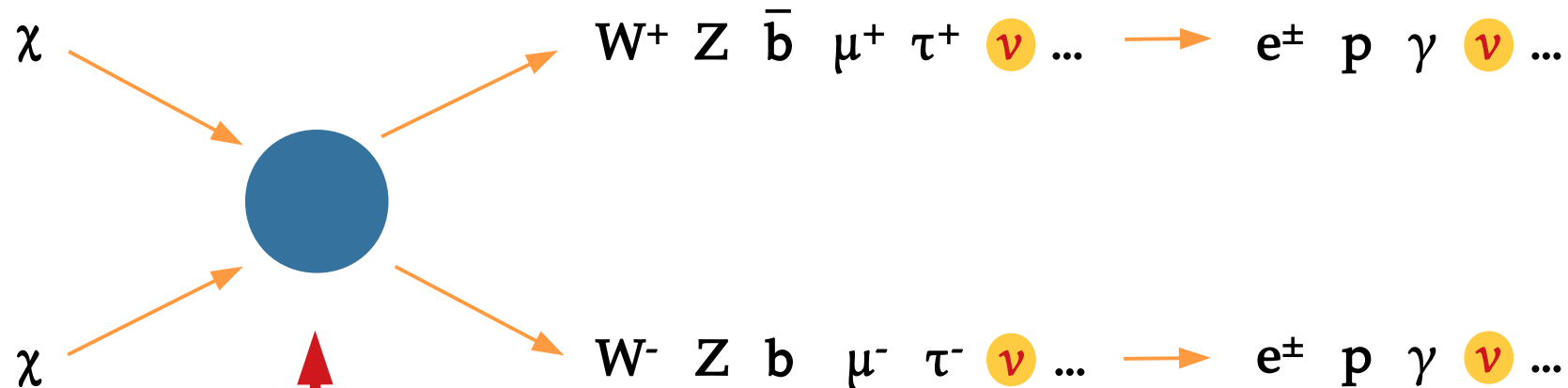
iihe ULB



IceCube
South Pole Neutrino Observatory

- Geographic South Pole
- 5,160 Digital Optical Modules (DOMs)
- 86 string with 60 DOMs each
- 6 denser strings called DeepCore

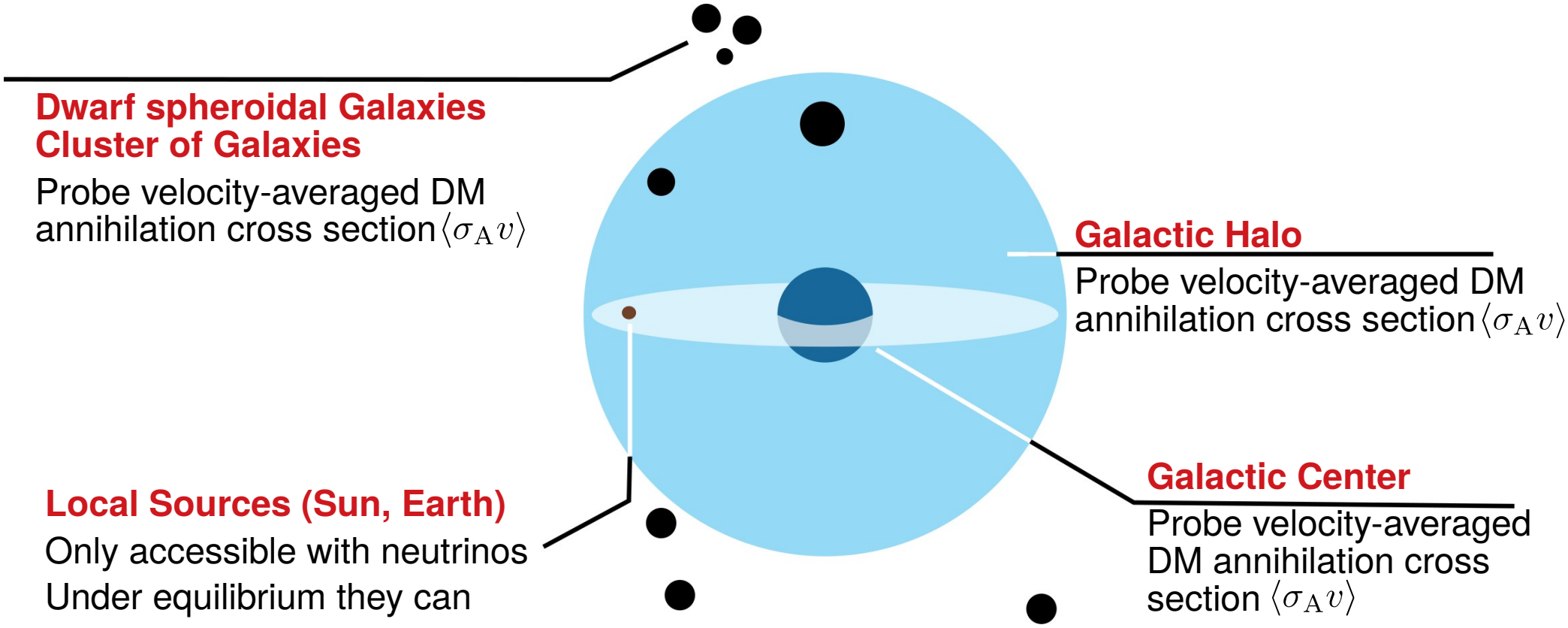
From dark matter to neutrinos



Secondary production: annihilation, decay (with or without mediators)

Where to look for: Focus on large reservoirs of dark matter

Source regions



Dwarf spheroidal Galaxies
Cluster of Galaxies

Probe velocity-averaged DM annihilation cross section $\langle \sigma_{\mathrm{A}} v \rangle$

Galactic Halo

Probe velocity-averaged DM annihilation cross section $\langle \sigma_{\mathrm{A}} v \rangle$

Local Sources (Sun, Earth)

Only accessible with neutrinos
Under equilibrium they can probe σ_{SI} and σ_{SD}

Galactic Center

Probe velocity-averaged DM annihilation cross section $\langle \sigma_{\mathrm{A}} v \rangle$

[from J.A. Aguilar]

The basic method (annihilation case)

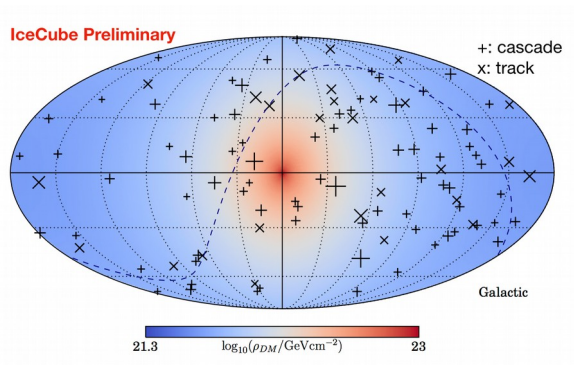
$$\frac{\mathrm{d}\Phi_\nu}{\mathrm{d}E_\nu} = \frac{1}{4\pi} \frac{\langle \sigma_A v \rangle}{2m_\chi^2} \frac{\mathrm{d}N_\nu}{\mathrm{d}E_\nu} \int_0^{\Delta\Omega} \mathrm{d}\Omega \int_{\mathrm{l.o.s.}} \rho_\chi^2 (s, \phi, \theta)\, \mathrm{d}s$$

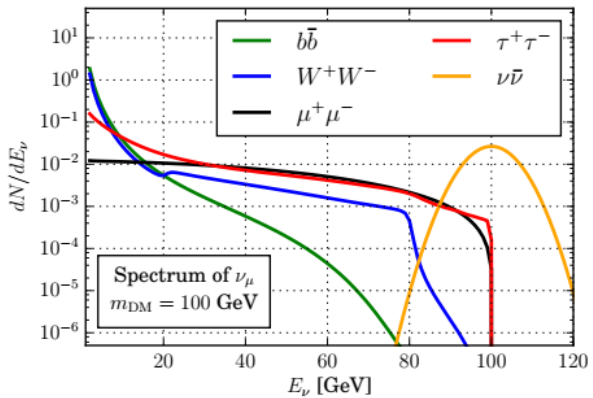
Measurement:
Neutrino flux

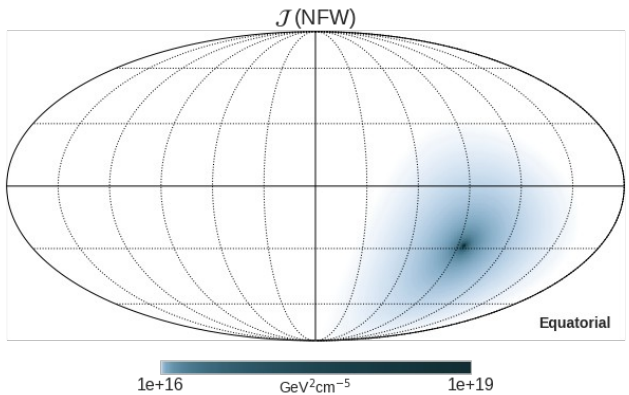
Constrain:
annihilation cross section

Theory input:
Dark matter mass and final state energy spectra

Astrophysical input:
Dark matter density distribution along the line of sight



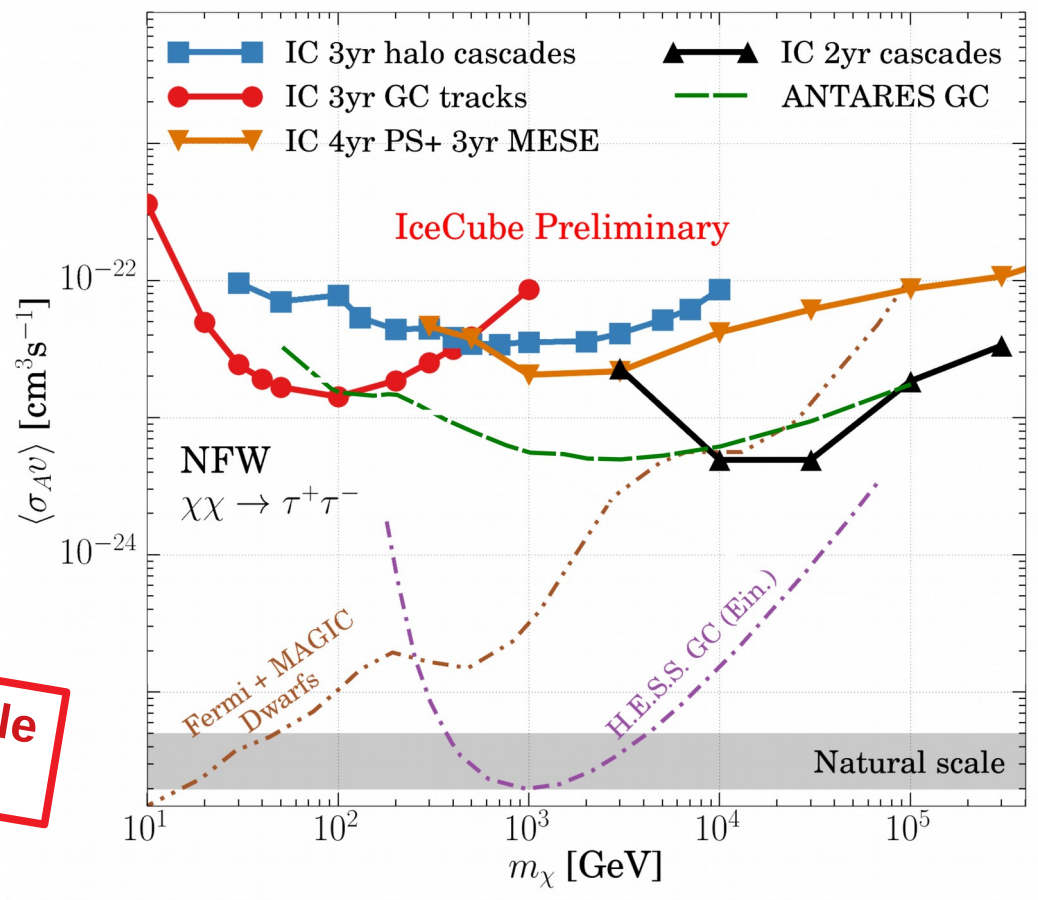




Galactic center

To date 4 different IceCube analyses with different event samples covering masses 10 GeV – 300 TeV

[EPJC 77 (2017) 627]

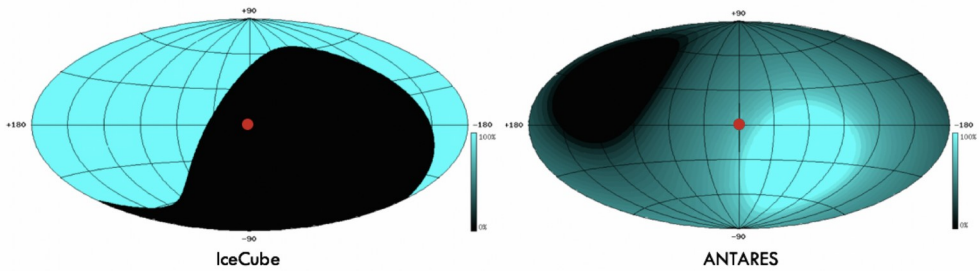


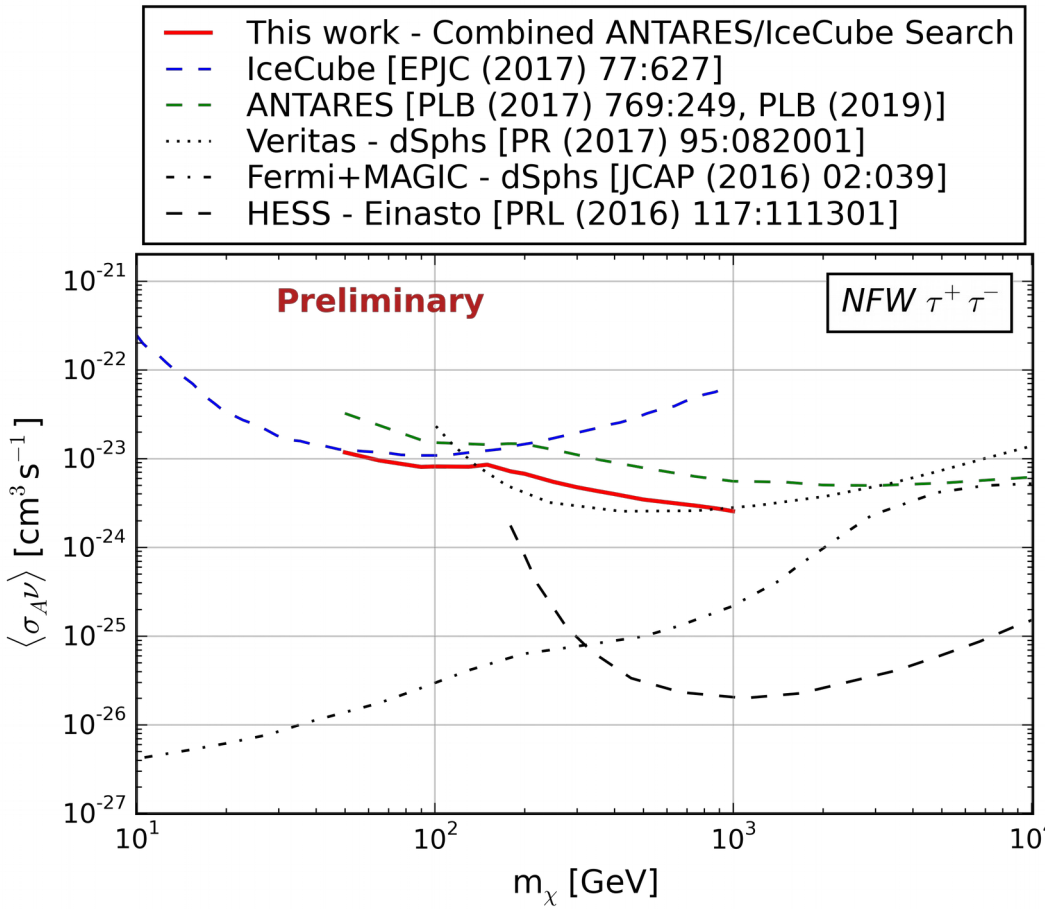
New analysis with improved event sample and more data in preparation!

Galactic center

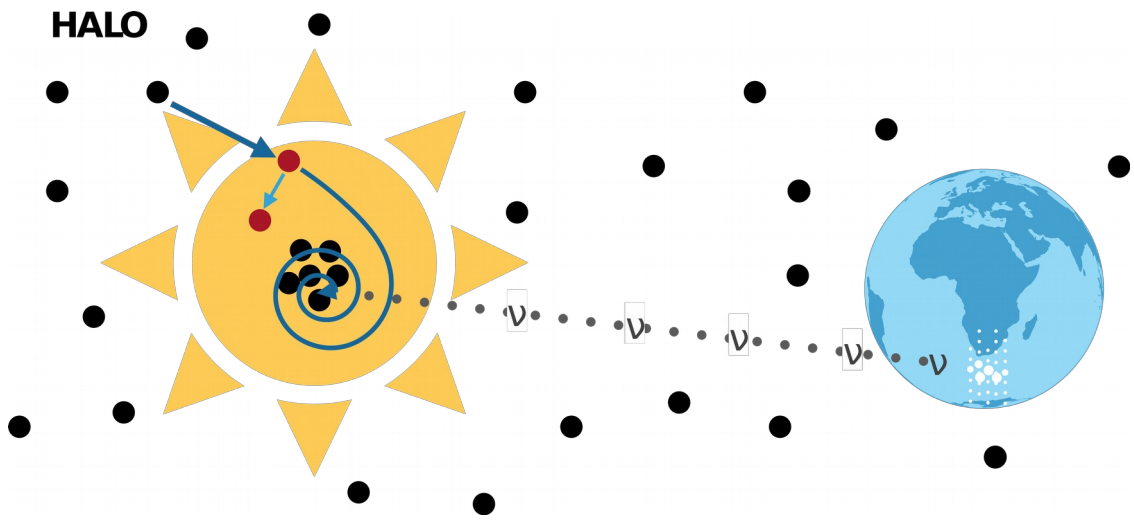
[PoS (ICRC2019) 522]

- First combination with ANTARES in common mass-range
- Combine different field-of-views
- Unify theoretical input and likelihood minimization





Capture and self-annihilation in the Sun



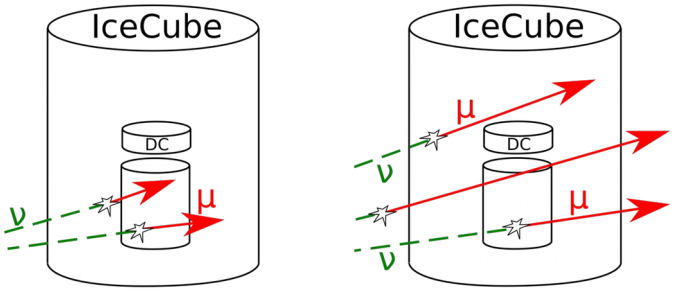
$$\frac{\mathrm{d}N}{\mathrm{d}t} = C_{\mathrm{C}} - C_{\mathrm{A}} N^2$$

Capture $\sigma_{\chi-p}$

Annihilation σ_{A}

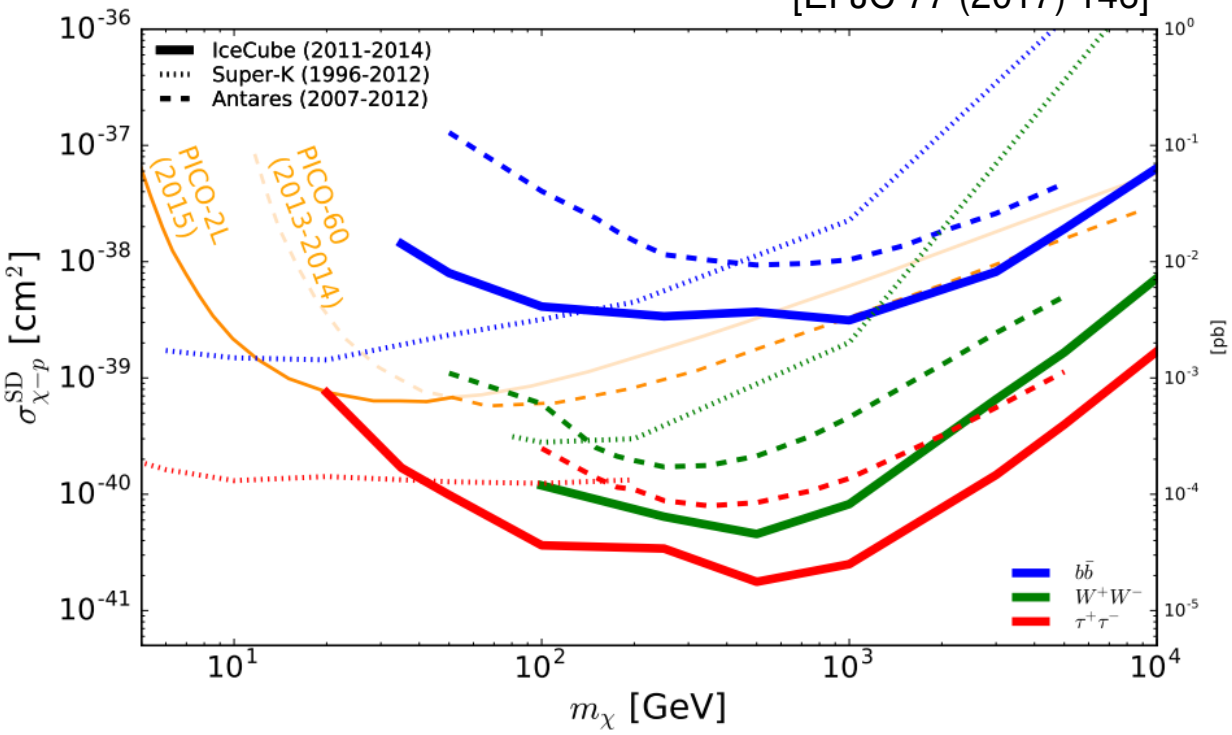
- Local density model independent $\sim 0.3\ \mathrm{GeV/cm^3}$
- In equilibrium $\mathrm{dN/dt} = 0$: probe SD cross section on H

Capture and self-annihilation in the Sun



- Two event samples for low and high energies
- Most sensitive for low masses due to neutrino escape from the sun

[EPJC 77 (2017) 146]



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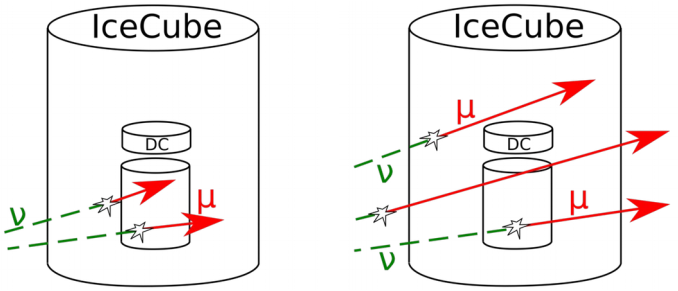

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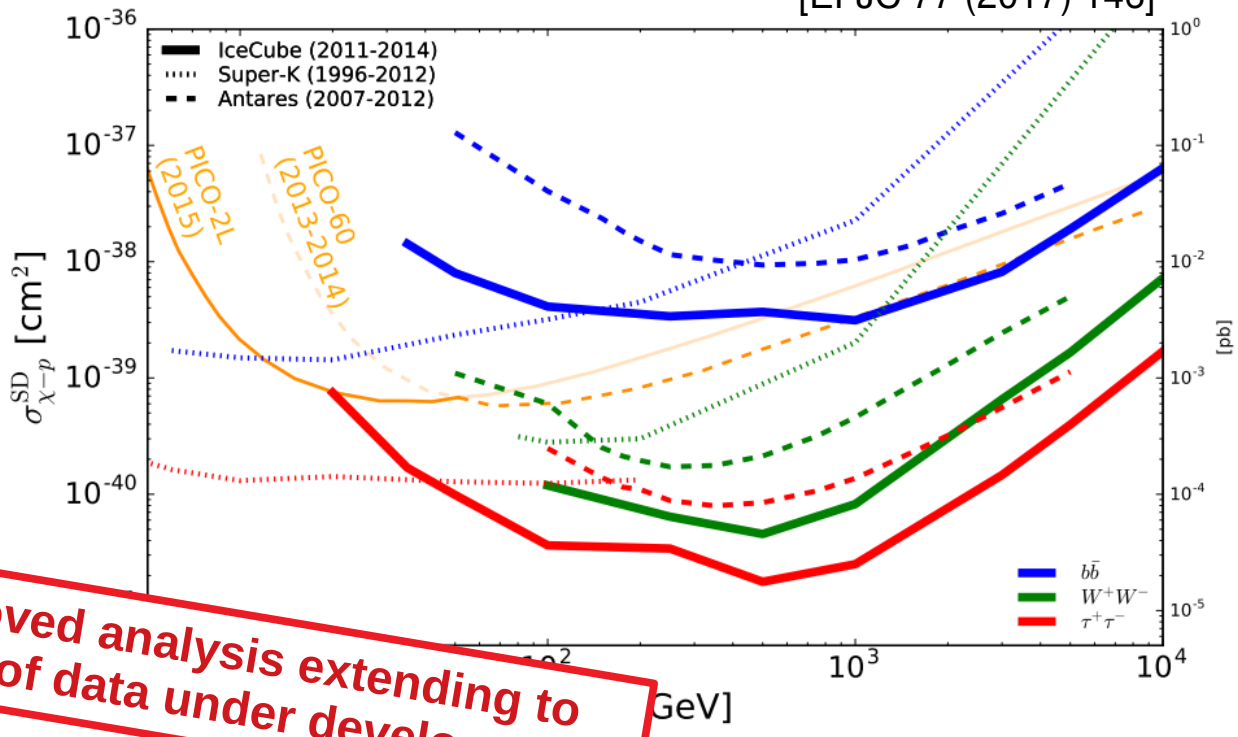
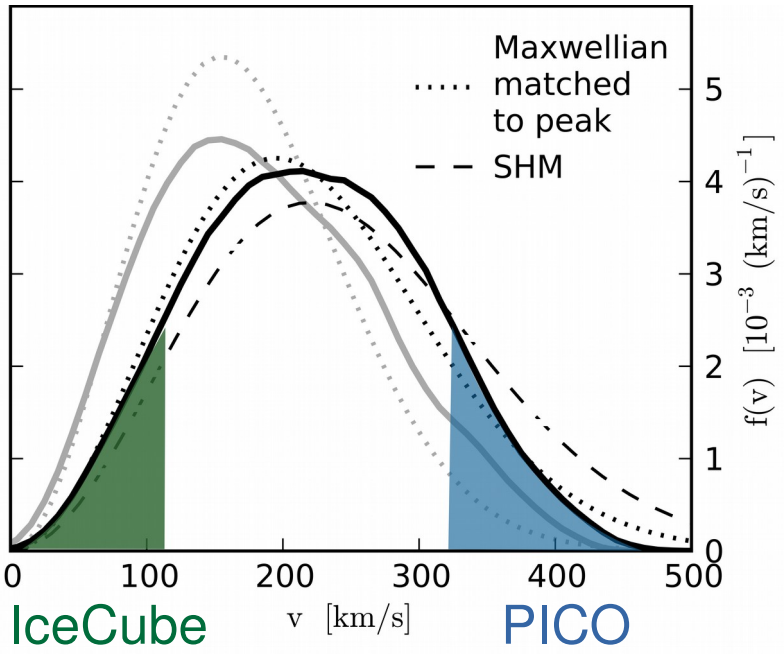
[EPJC 77 (2017) 146]



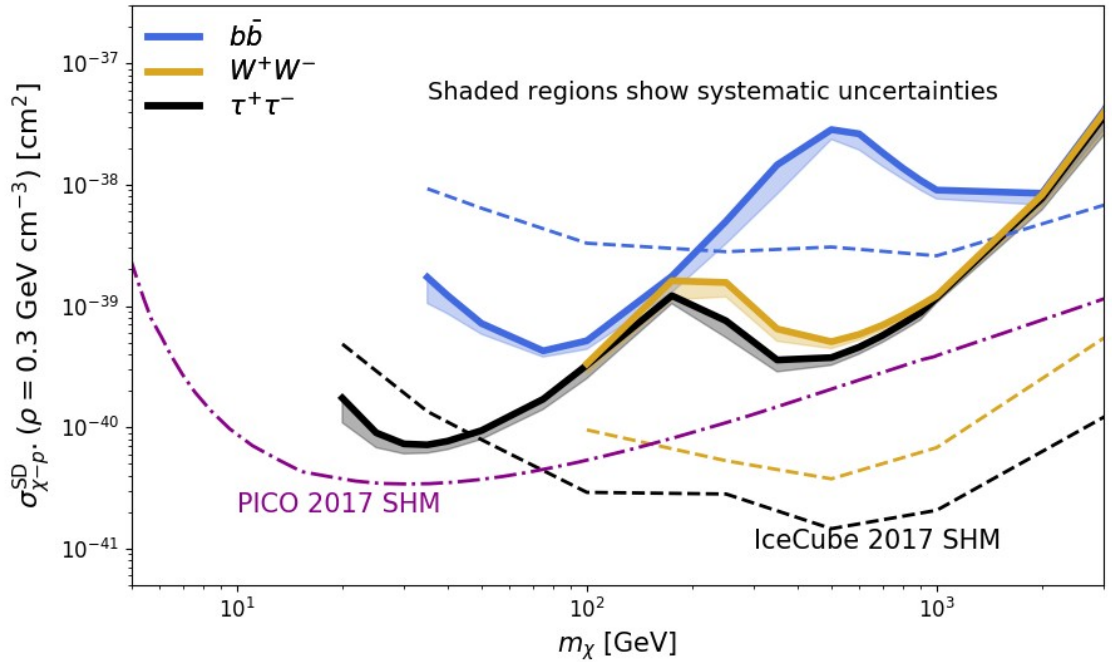
Improved analysis extending to 7 years of data under development!

IceCube+Pico: velocity independent limits

[Figure from arXiv:1308.1703]



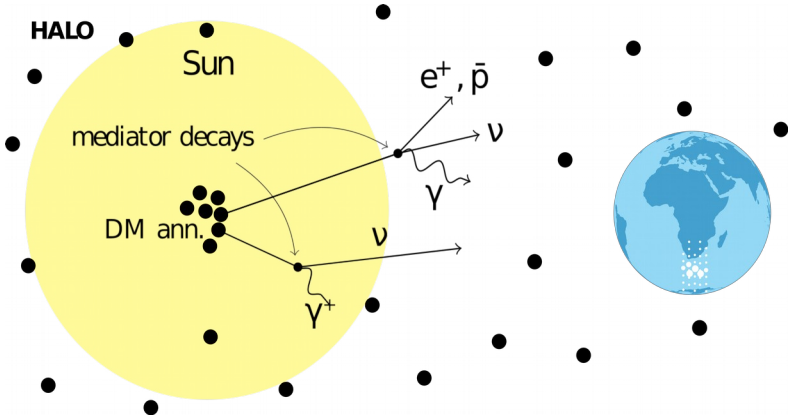
[arXiv:1907.12509]



Assume superposition of streams with fixed velocity

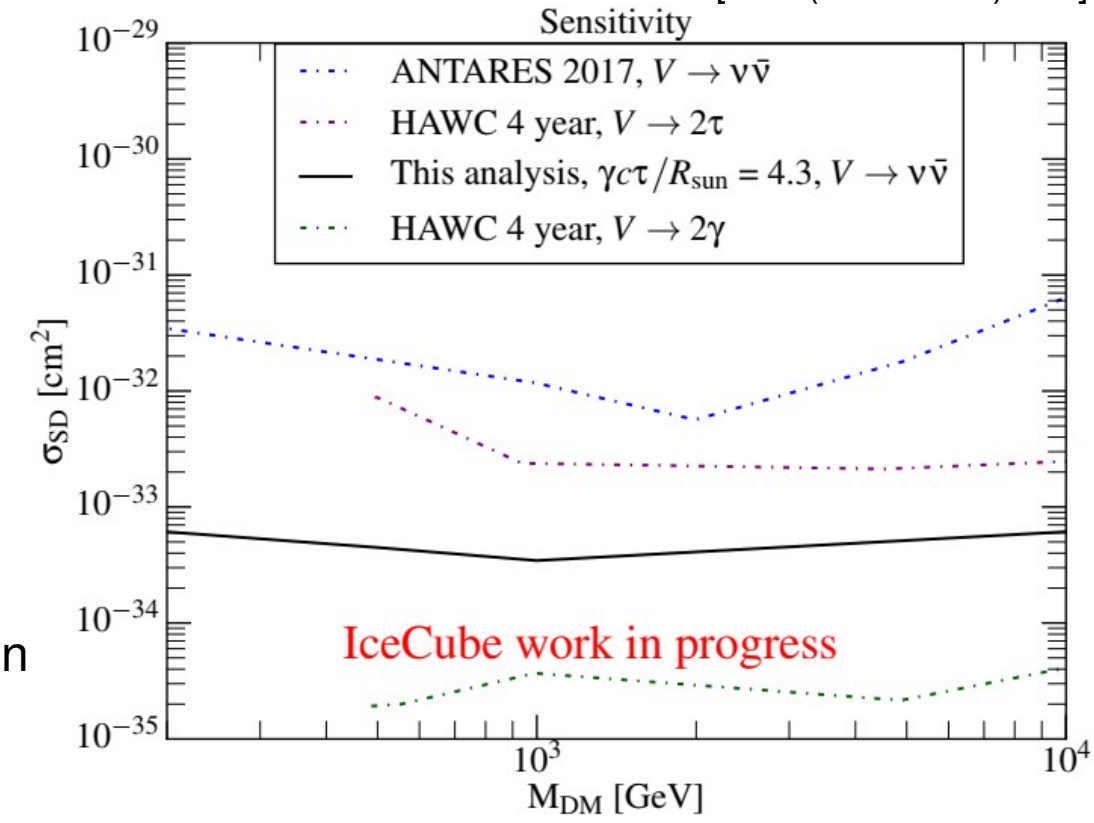
→ conservative limits by choosing the stream with highest allowed cross section

Secluded dark matter from the Sun

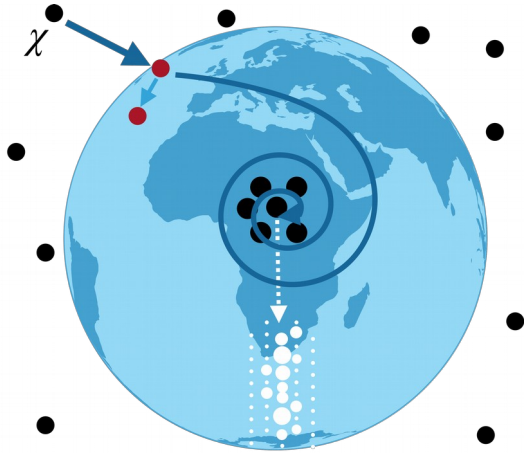


- DM annihilates into mediator *V* which decays close to the sun surface
- No limitations due to neutrino attenuation in the sun
- Mediator mass and lifetime are free parameters

[PoS (ICRC2019) 548]

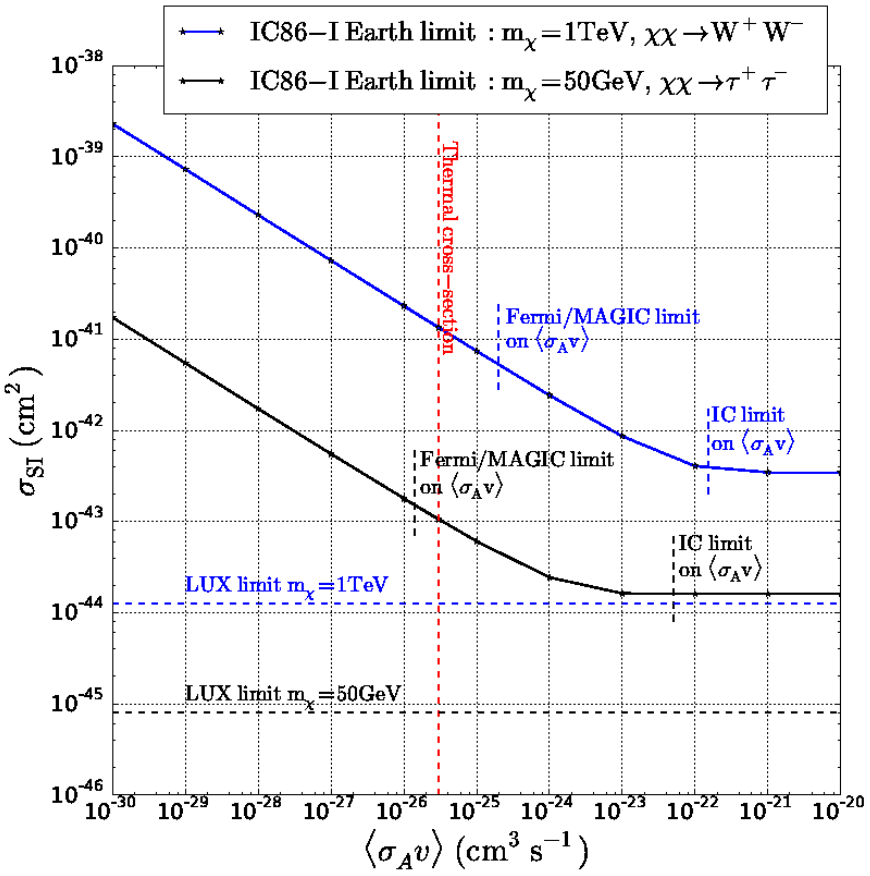


Capture and self-annihilation in the Earth

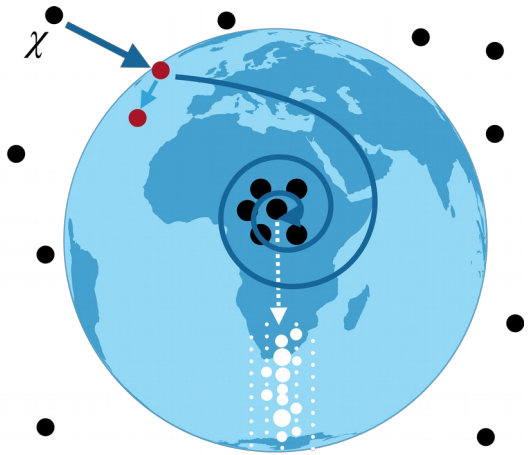


- Challenging analysis due to unique position of Earth
- No equilibrium assumed
  → limits on $\langle \sigma_A v \rangle / \sigma_{SI}$

[EPJC 77 (2017) 82]



Capture and self-annihilation in the Earth



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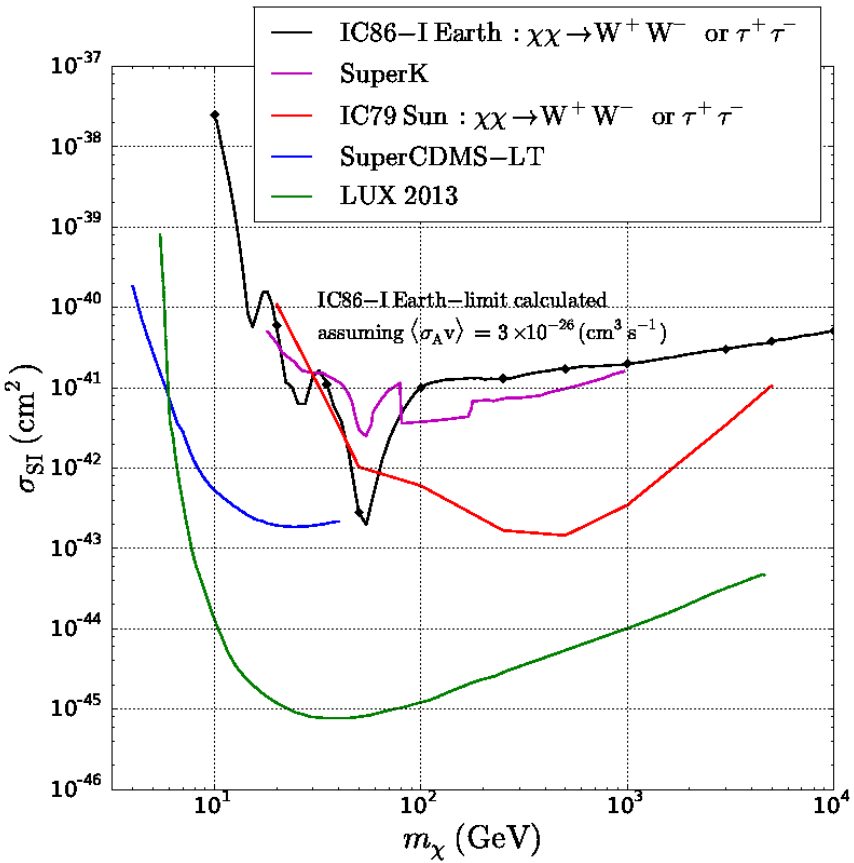
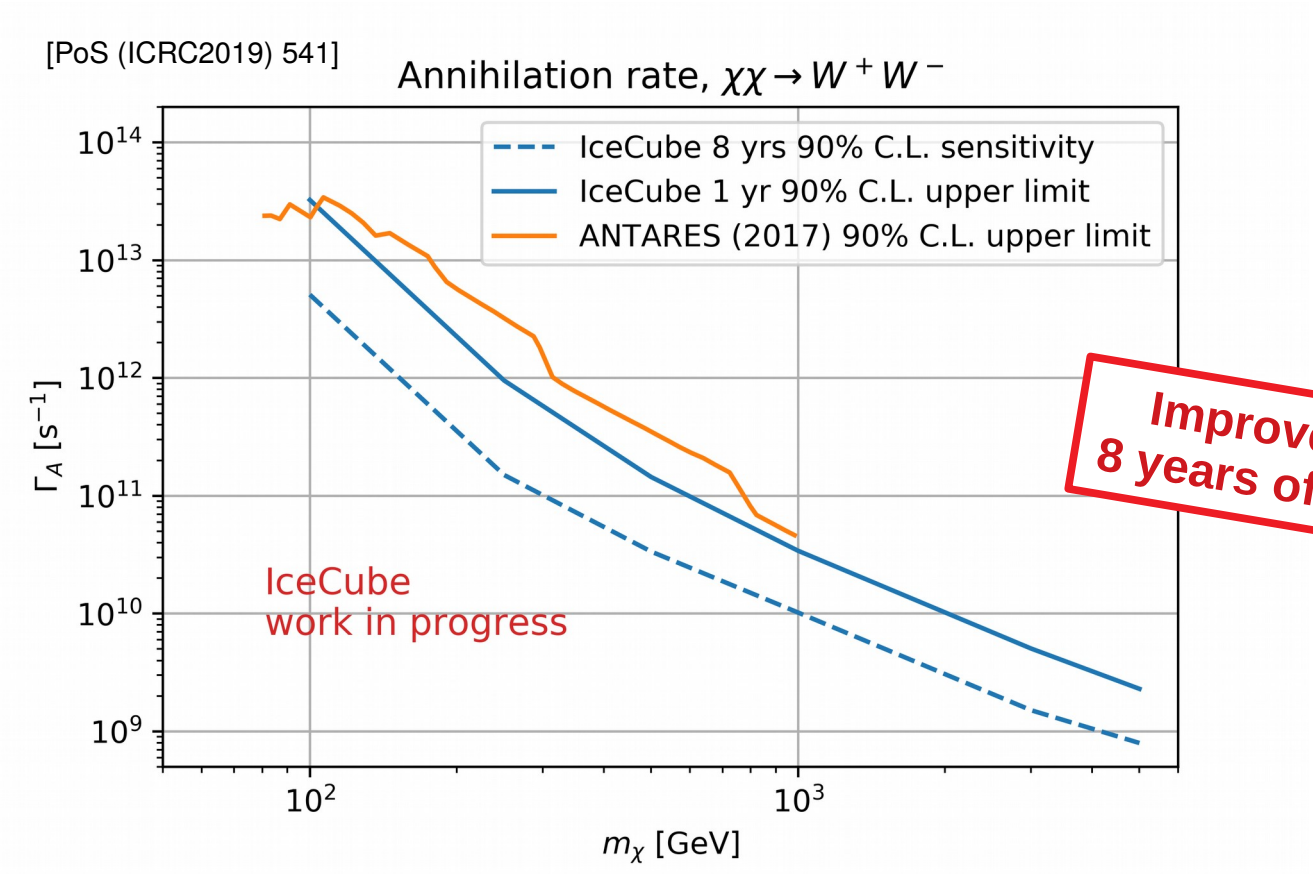
[EPJC 77 (2017) 82]



Capture and self-annihilation in the Earth



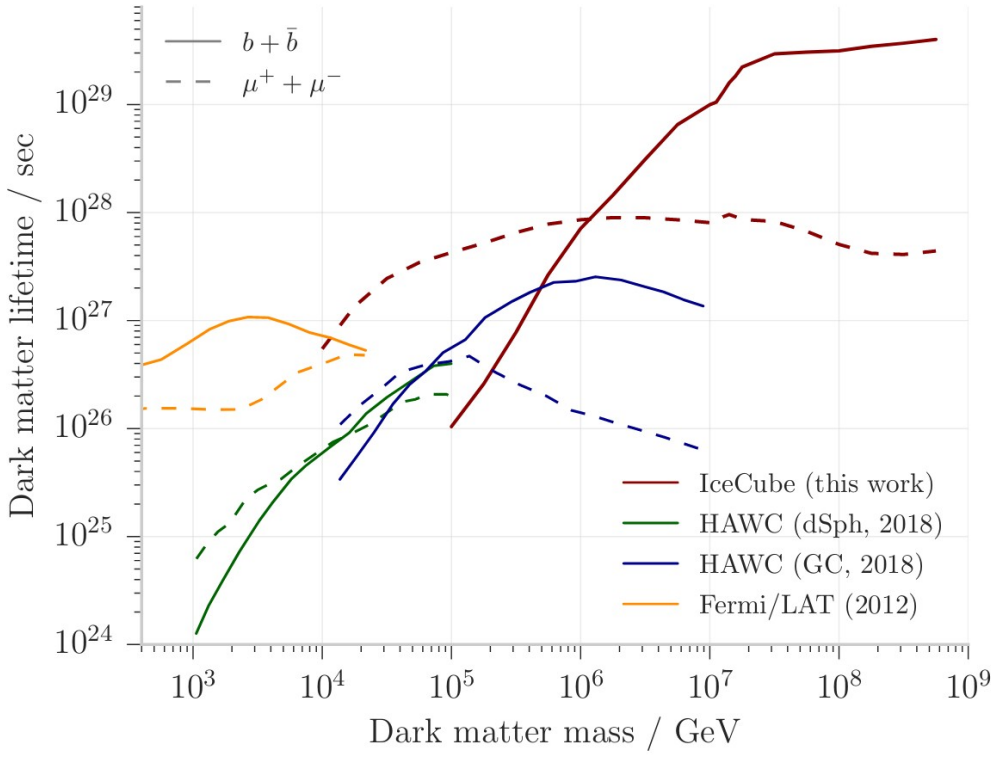
Improved analysis extending to 8 years of data under development!

Decaying dark matter in the galactic halo

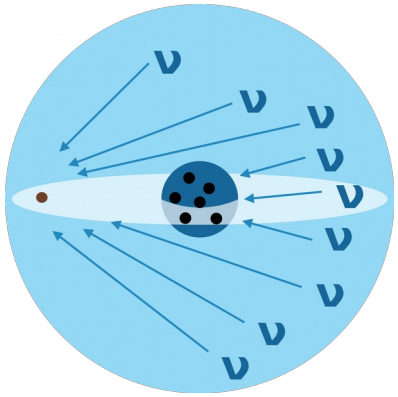
$$\frac{\mathrm{d}\Phi_\nu}{\mathrm{d}E_\nu} = \frac{1}{4\pi}\frac{1}{m_\chi \tau_\chi}\frac{\mathrm{d}N_\nu}{\mathrm{d}E_\nu}\int_0^{\Delta\Omega}\mathrm{d}\Omega\int_{\mathrm{l.o.s.}}\rho_\chi\left(s,\phi,\theta\right)\mathrm{d}s$$

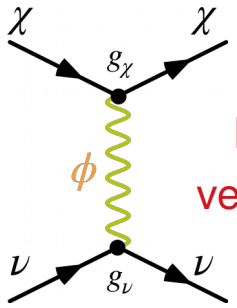
- Signal less concentrated on the Galactic Center
- Two independent data samples:
  - Track-like with 6 years of data
  - Cascade-like with 2 years of data
- Include also contributions from extra-galactic DM

[EPJC 78 (2018) 831]



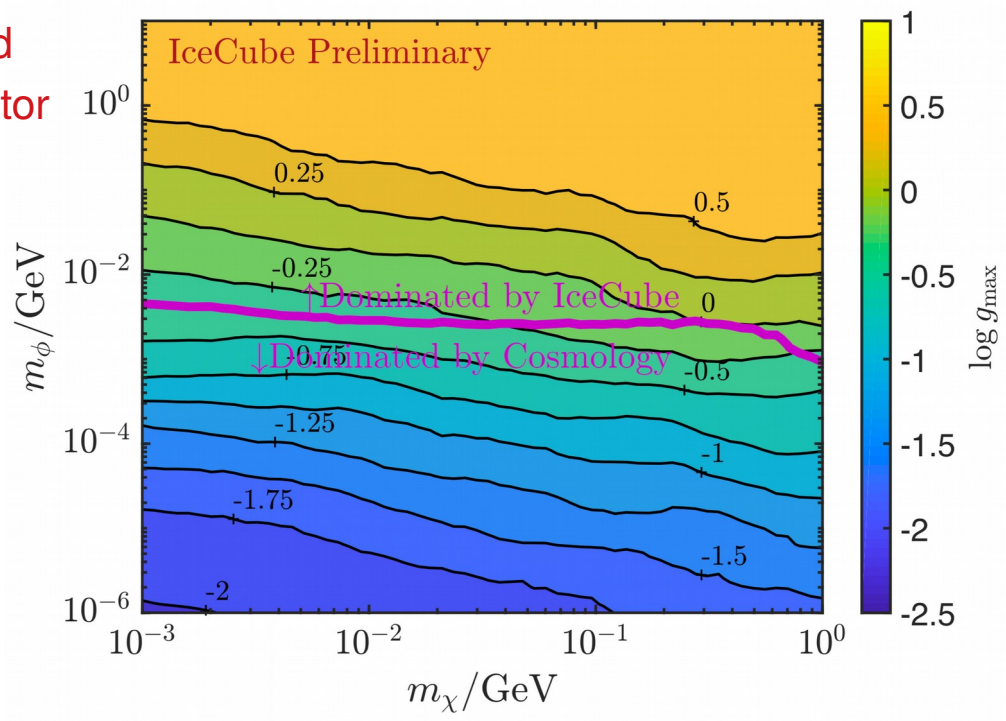
Dark matter – neutrino scattering





Fermionic DM and
vector boson mediator

[PoS (ICRC2019) 839]



DM – ν scattering leads to deviations in the isotropic cosmic neutrino flux

→ focus on high energies

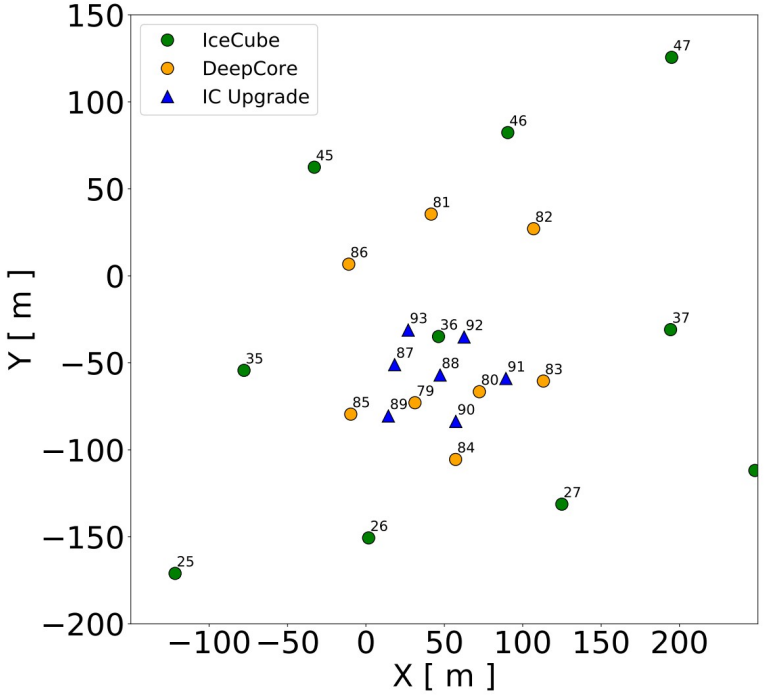
→ 7.5 years of high energy starting events support isotropic flux

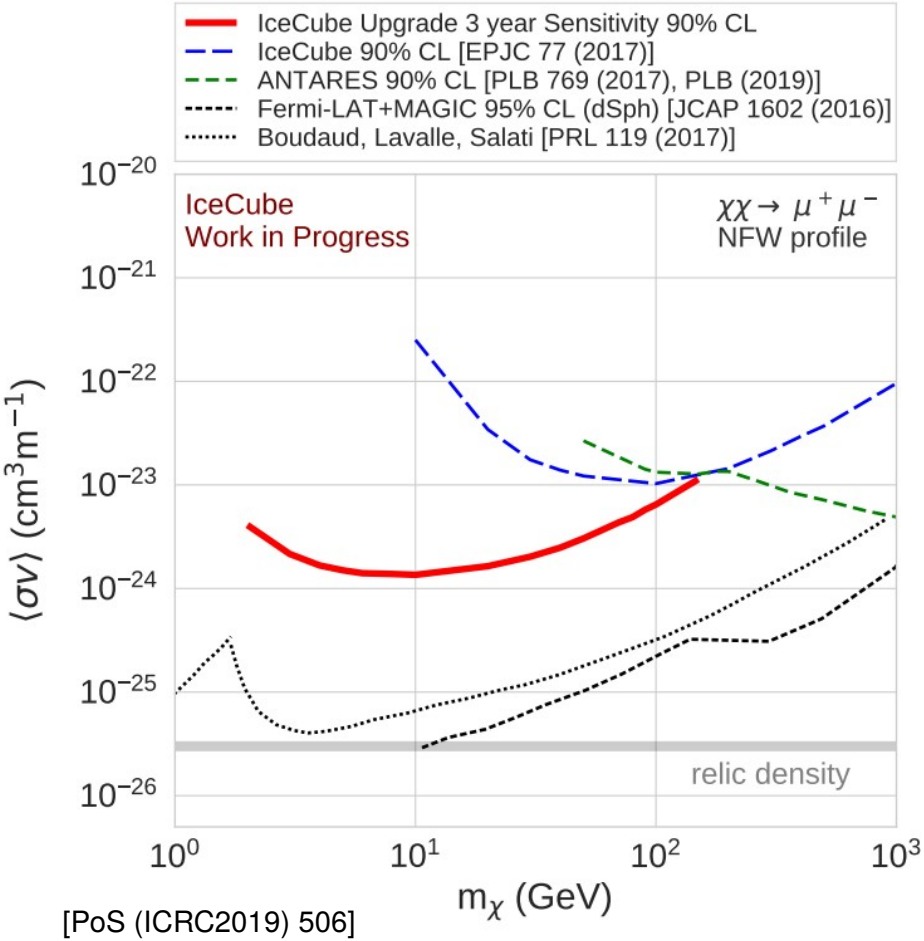
→ upper limit on allowed couplings

A glimpse to the future

Seven new strings in 2022/2023:

Better efficiency and reconstruction at low energies





[PoS (ICRC2019) 506]

Summary

IceCube has a lively and expanding program of indirect searches for Dark Matter:

- No observation of a neutrino excess in IceCube compatible with dark matter expectations
- Results are competitive and complementary to other messengers
- More scenarios are being probed and constrained
- Many ongoing analyses with more data, improved event selection and reconstruction