Indirect Dark Matter Searches with the IceCube Neutrino Observatory

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WIN 2015
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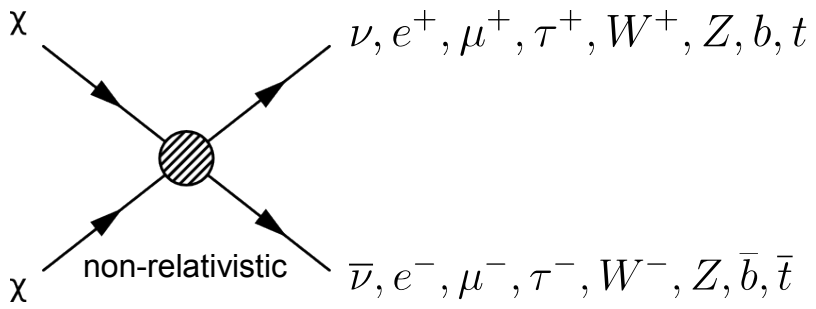
IceCube

Universitet Stockholms

Oskar Klein centre

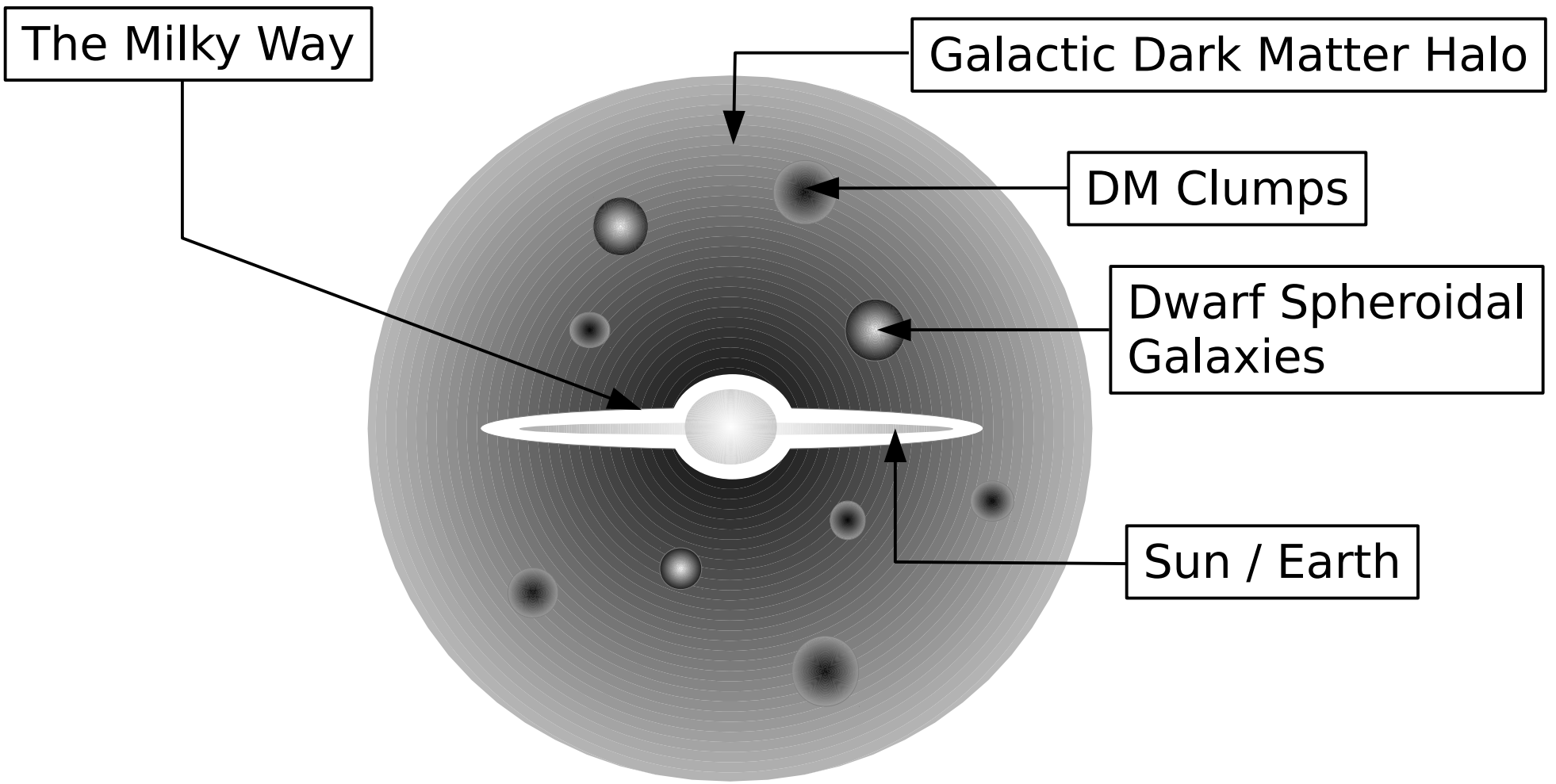
Indirect DM Search Principle

Target over-dense regions of DM where self-annihilation may occur at significant rate



- Annihilation products may decay, producing neutrinos
- Sensitive DM mass range for IceCube: ~10 GeV - ~100 TeV
- Consider 100% branching ratio for each channel
- Consider “extrema” soft & hard ann. channels to bracket possible real neutrino spectrum
- Setting upper limits on:
  - DM velocity-averaged self-ann. cross-section $\langle \sigma_A v \rangle$ ((extra-)gal. analyses)
  - DM-nucleon scattering cross-sections (Sun, Earth analyses)

Indirect DM Searches with IceCube

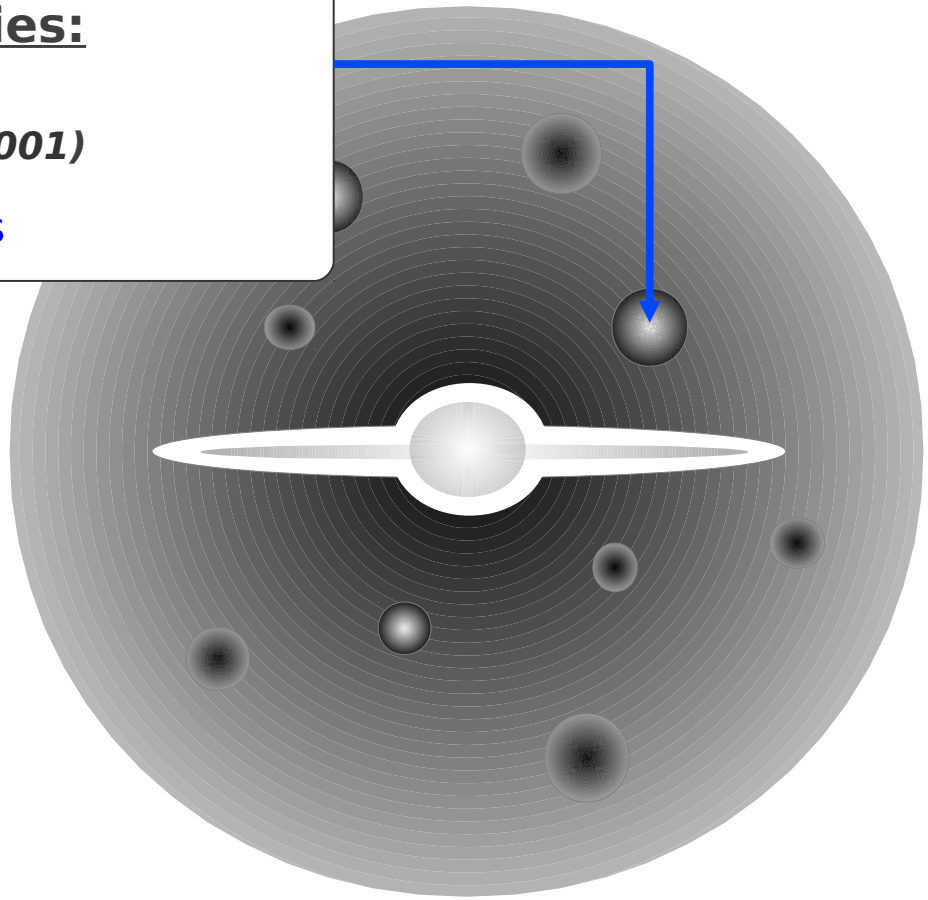


Indirect DM Searches with IceCube

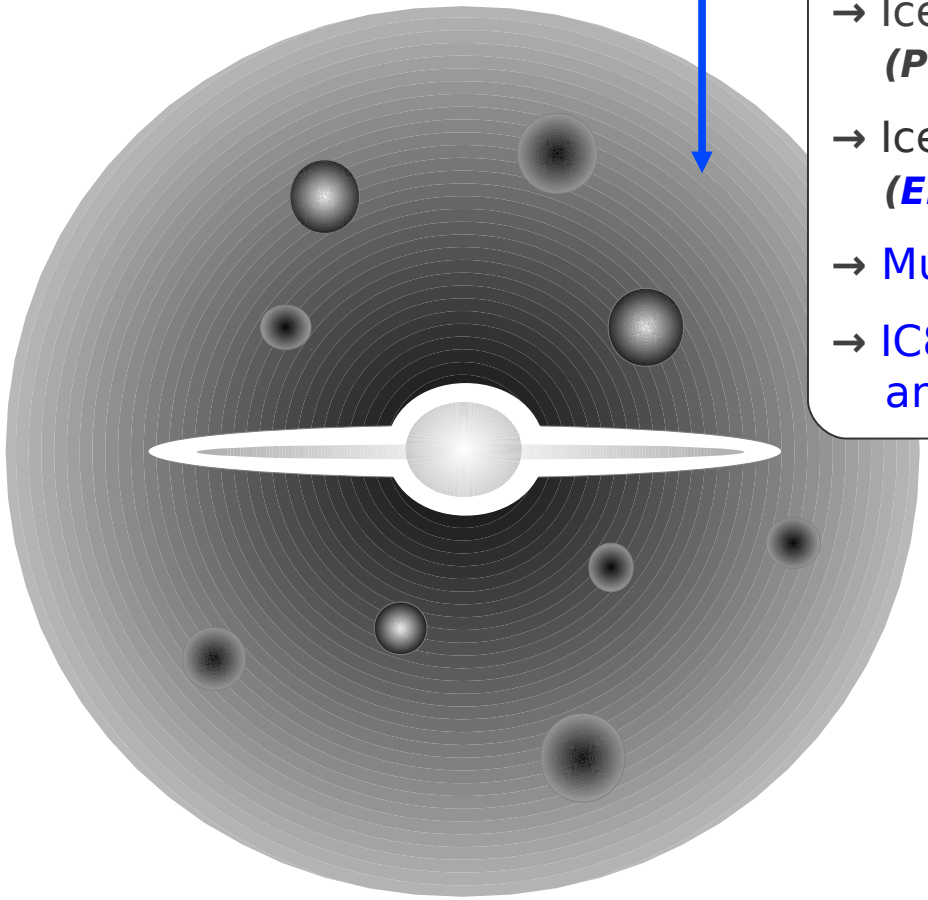
Dwarf spheroidal Galaxies & Clusters of Galaxies:

→ IceCube-59 limits
(PRD 88 (2013) 122001)

→ IceCube-86 analysis



Indirect DM Searches with IceCube



Galactic Halo:

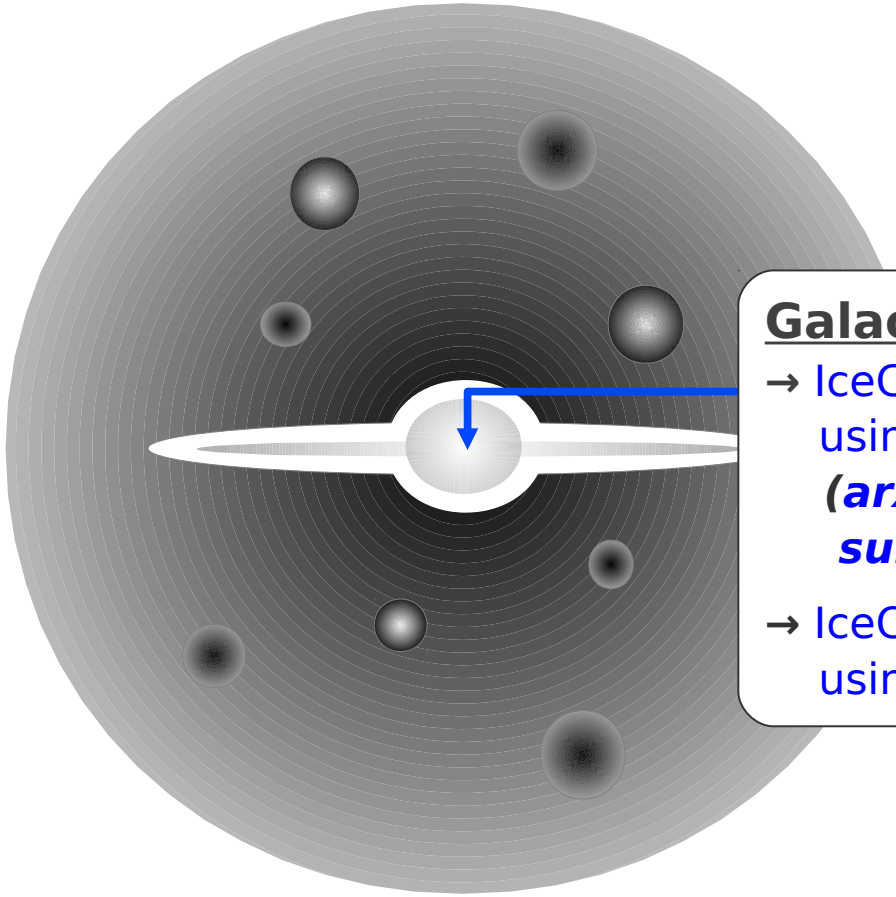
→ IceCube-22 limits
(PRD 84 (2011) 022004)

→ IceCube-79 multipole limits
(EPJ-C 01/2015 75(20))

→ Multi-year track LH analysis

→ IC86 PeV Gravitino decay analysis

Indirect DM Searches with IceCube

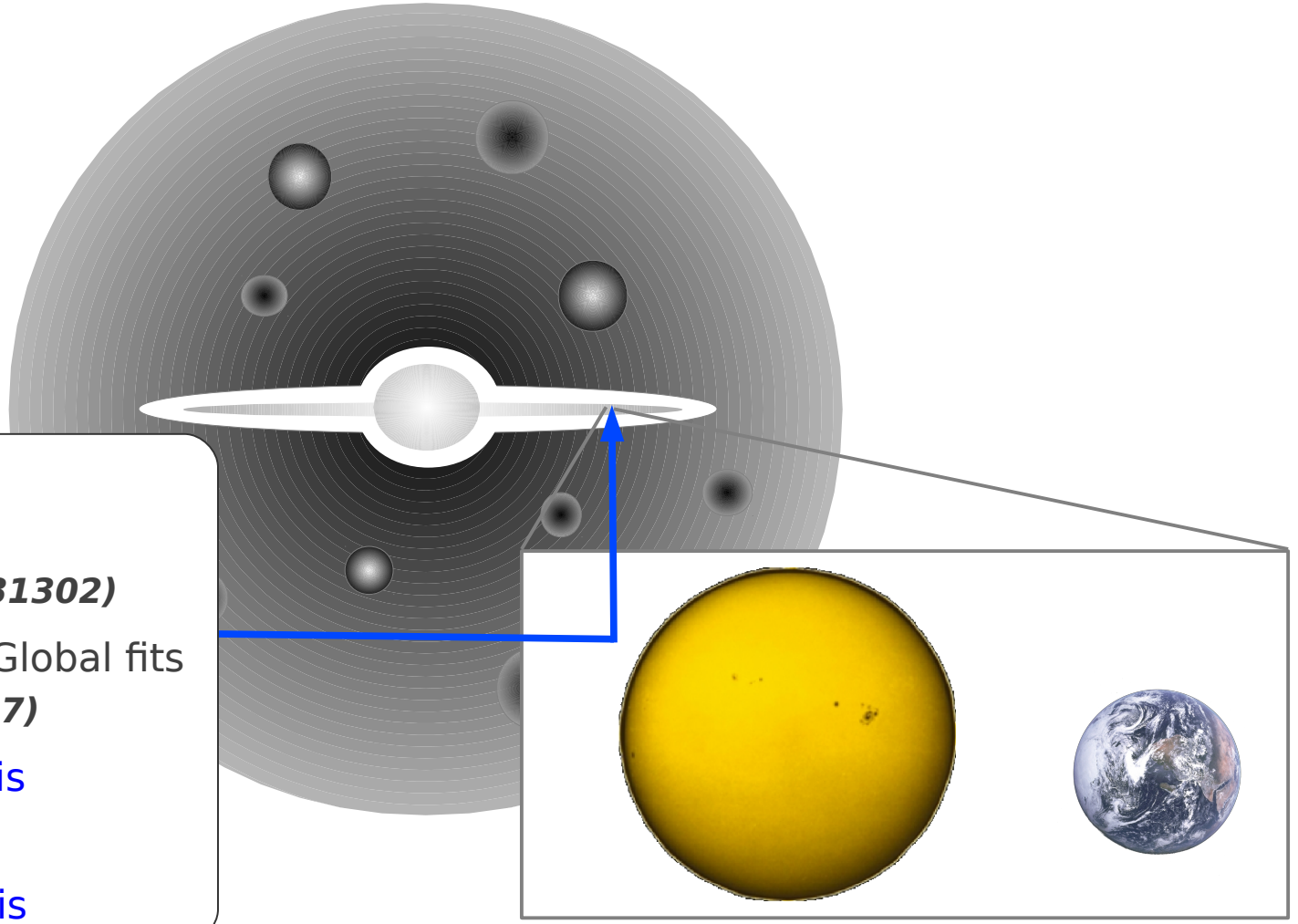


Galactic Center:

→ IceCube-79 limits using tracks ***(arXiv:1505.07259 submitted to EPJ-C)***

→ IceCube-86 analysis using cascades

Indirect DM Searches with IceCube



Sun:

→ IceCube-79 limits
(PRL 110 (2013) 131302)

→ Specific models & Global fits
(JCAP 11 (2012) 057)

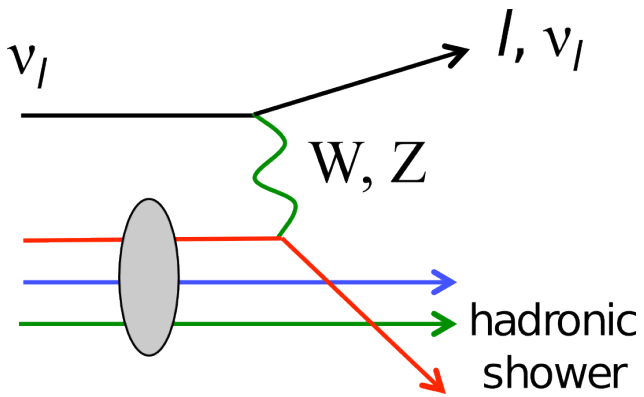
→ IceCube-86 analysis

Earth:

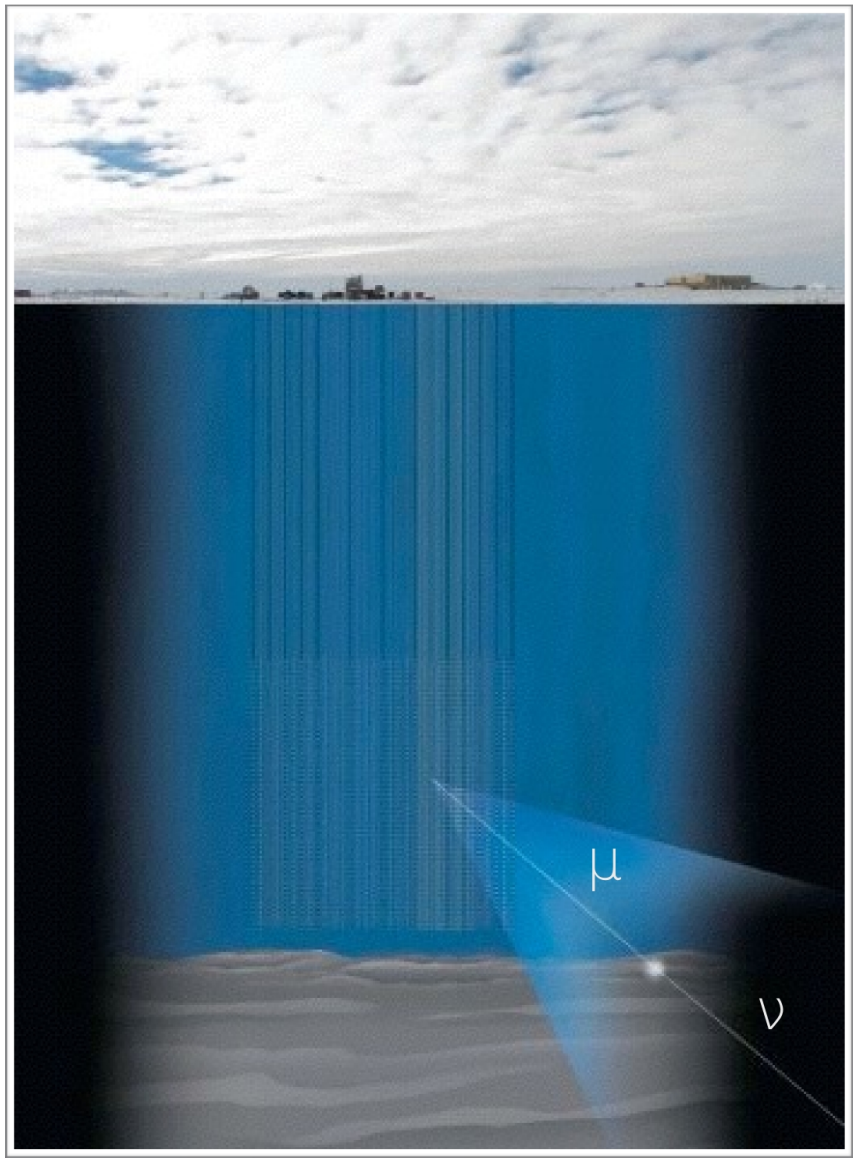
→ IceCube-86 analysis

Neutrino telescopes – detection principles

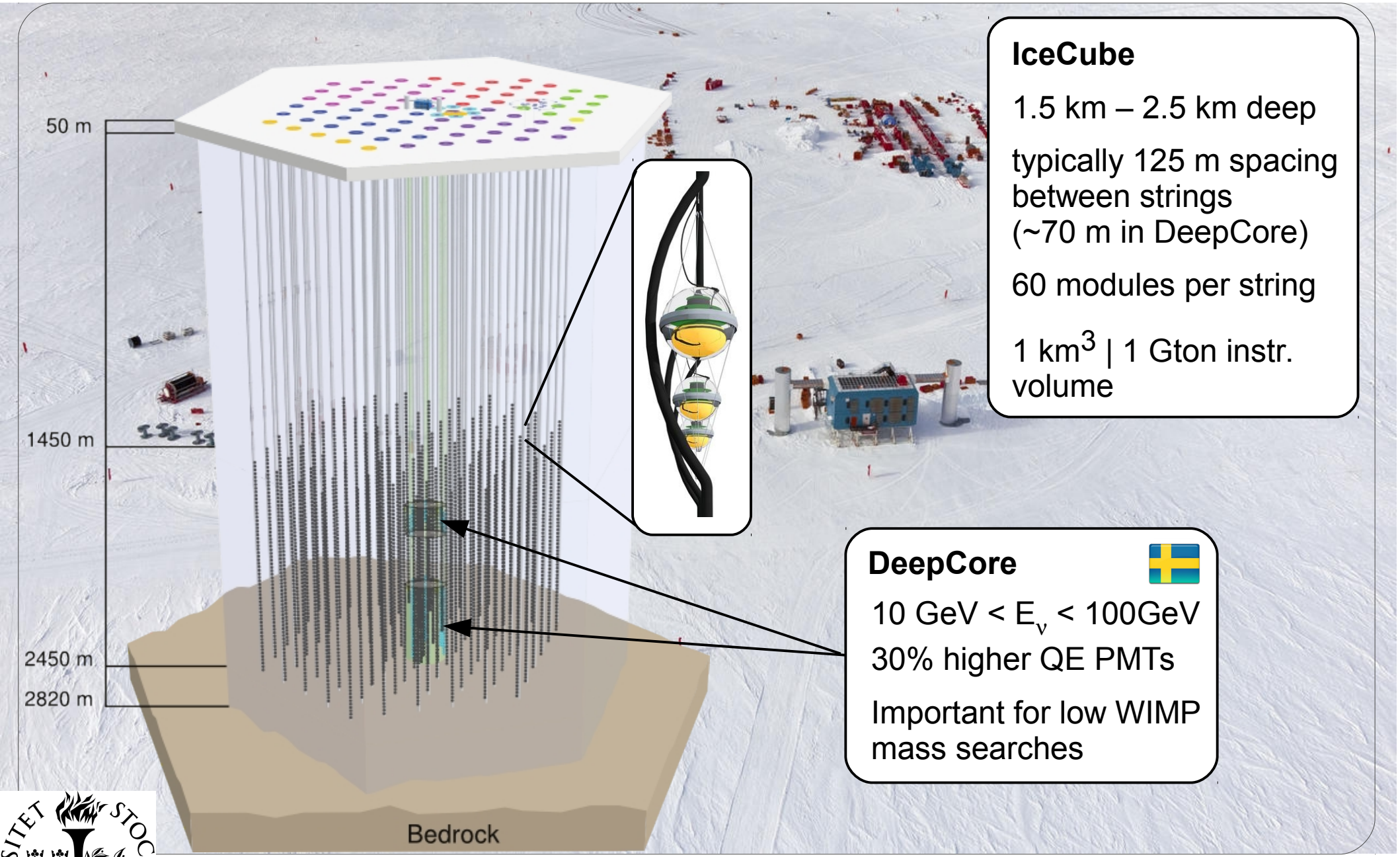
Neutrinos interact in or near the detector



- O(km) muon tracks from ν_μ $W^{\pm}$-int. (CC)
- O(10m) cascades from ν_e CC, low energy ν_τ CC, and ν_l Z^0-int. (NC)
- Cherenkov radiation detected by 3D array of optical sensors



The IceCube Neutrino Observatory



IceCube

1.5 km – 2.5 km deep

typically 125 m spacing between strings (~70 m in DeepCore)

60 modules per string

1 km^3 | 1 Gton instr. volume

DeepCore

10 GeV < E_ν < 100GeV

30% higher QE PMTs

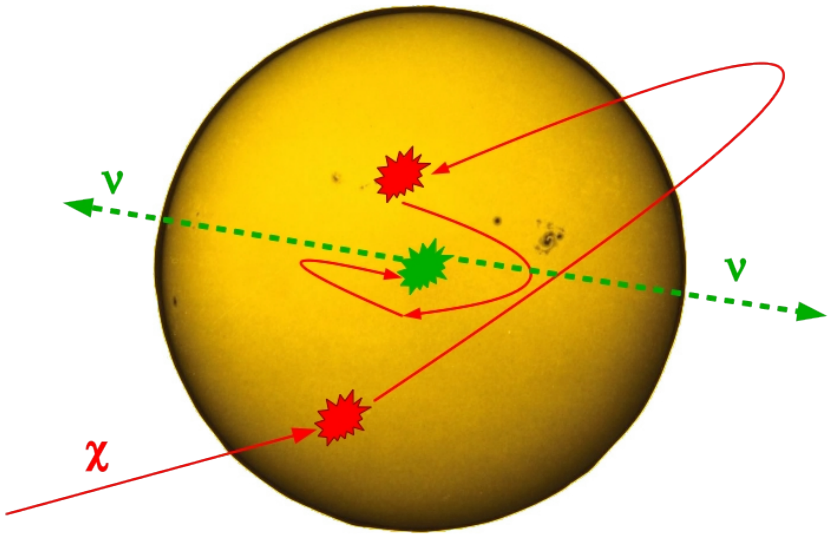
Important for low WIMP mass searches

IceCube Solar WIMP searches

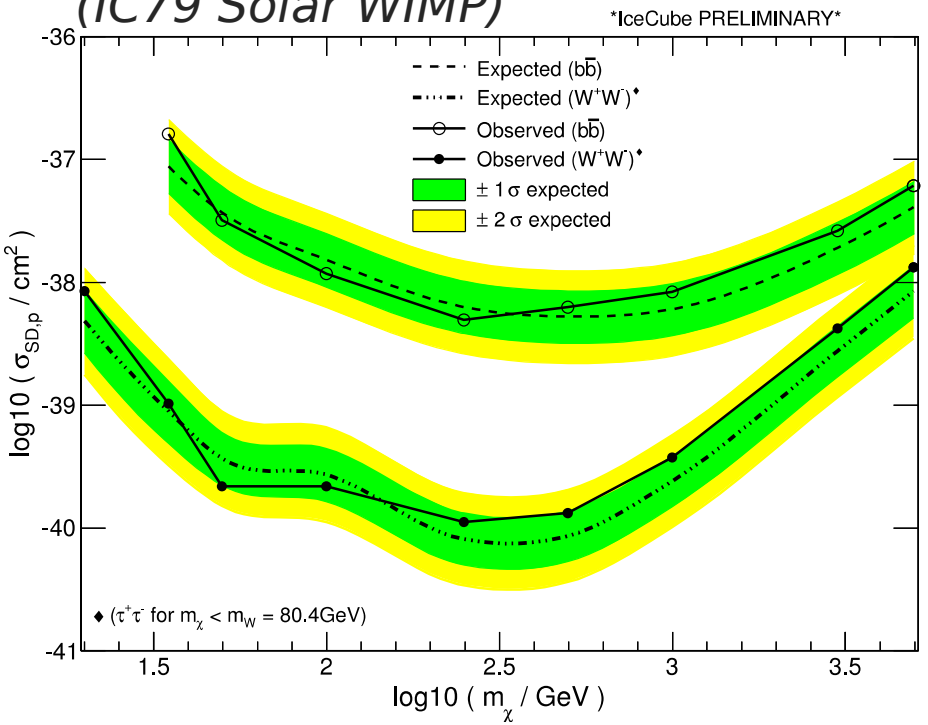
- WIMPs could be captured by the Sun through WIMP-nucleon scattering
  - WIMP annihilation
- Capture & Annihilation rate in equilibrium
  - Analysis sensitive to WIMp scattering cross-sections (SI & SD)
- Dependent on WIMP mass & ann. channel

$$\frac{dN}{dt} = C_{capt.} - C_{ann.}$$

$$C_{ann.} = C_{capt.} \rightarrow \sigma_{total}$$



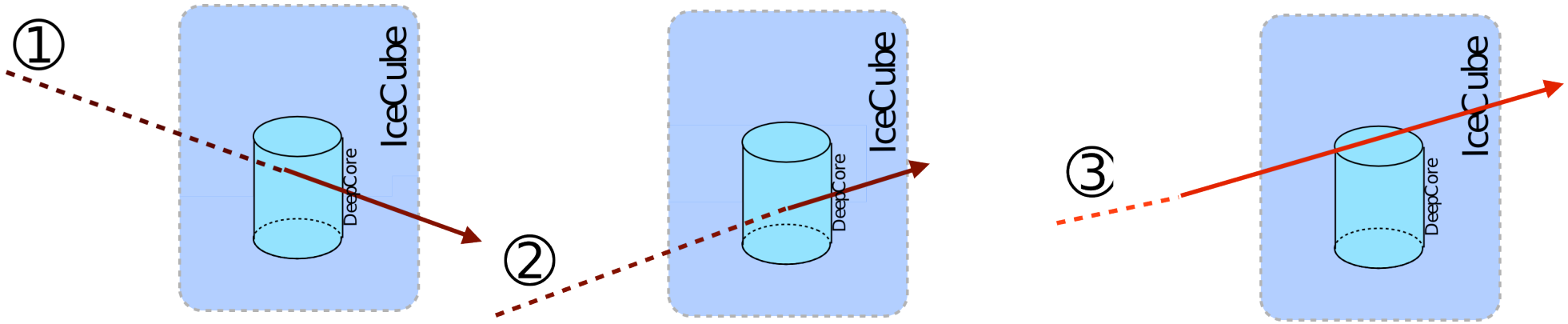
Expected sens. vs. observed result (IC79 Solar WIMP)



IceCube Solar WIMP searches

Split 1 year data into 3 samples

(1) Summer (Sun above horizon → atm. muon background)
(2) Winter Low-Energy (Sun below horizon → atm. neutrino background)
(3) Winter High-Energy

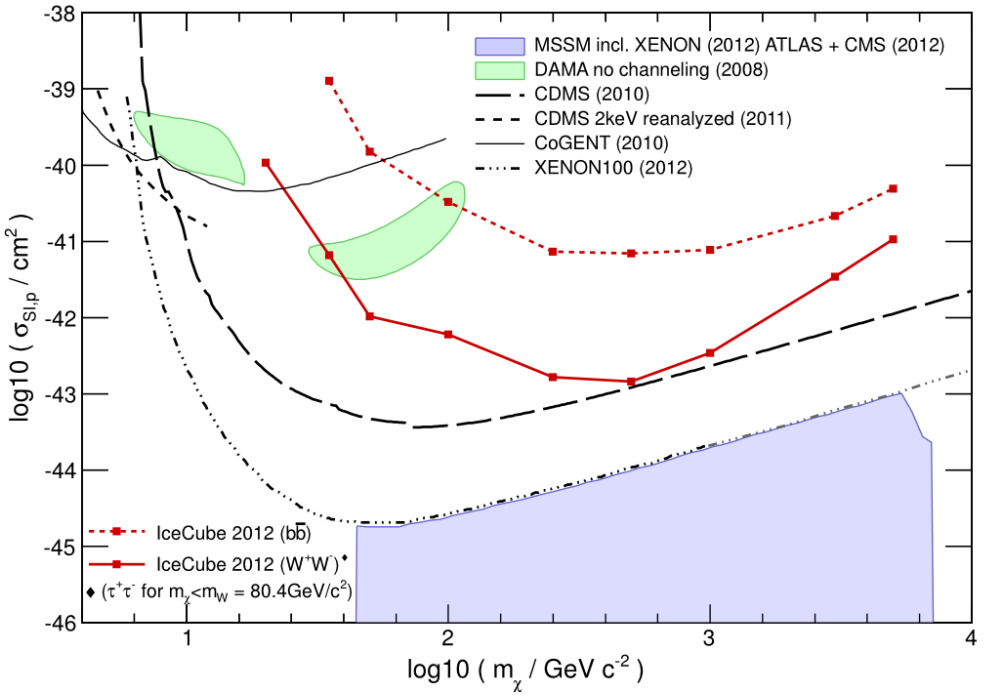


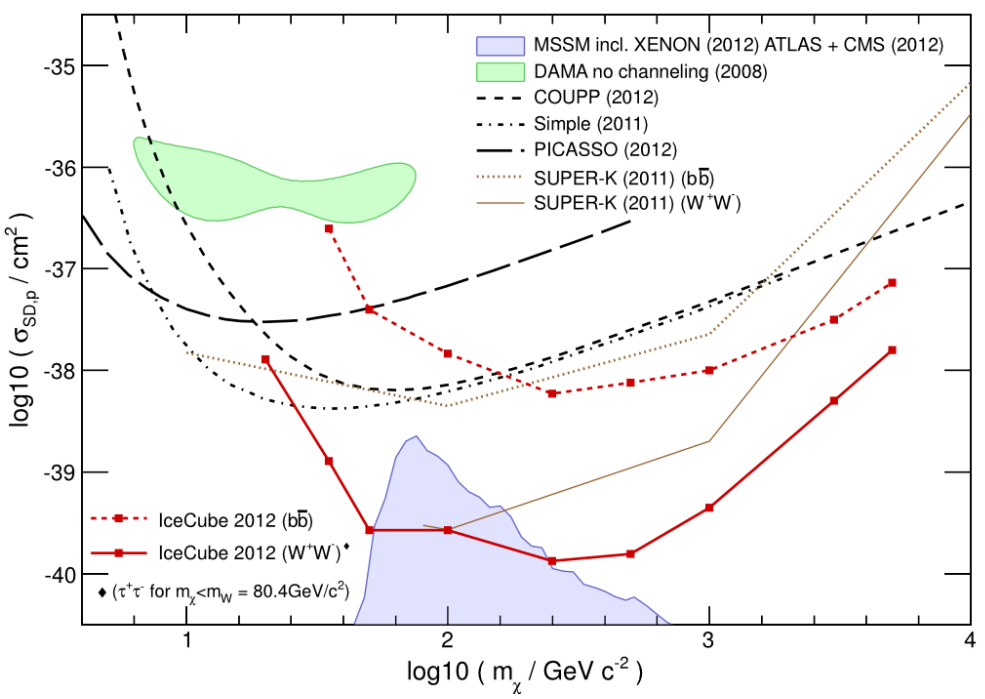
- Select starting events in DeepCore
- Use surrounding IceCube as veto
- DeepCore most sensitive to E < 120 GeV as low as 10 - 20 GeV

- Select upwards-going events
- Use Earth as atm. muon absorber
- Maximum ν effective area for HE

→ Use **combined Maximum LH analysis** with signal & background PDFs
→ weight samples by livetime & effective volume

IceCube-79 Solar WIMP search results



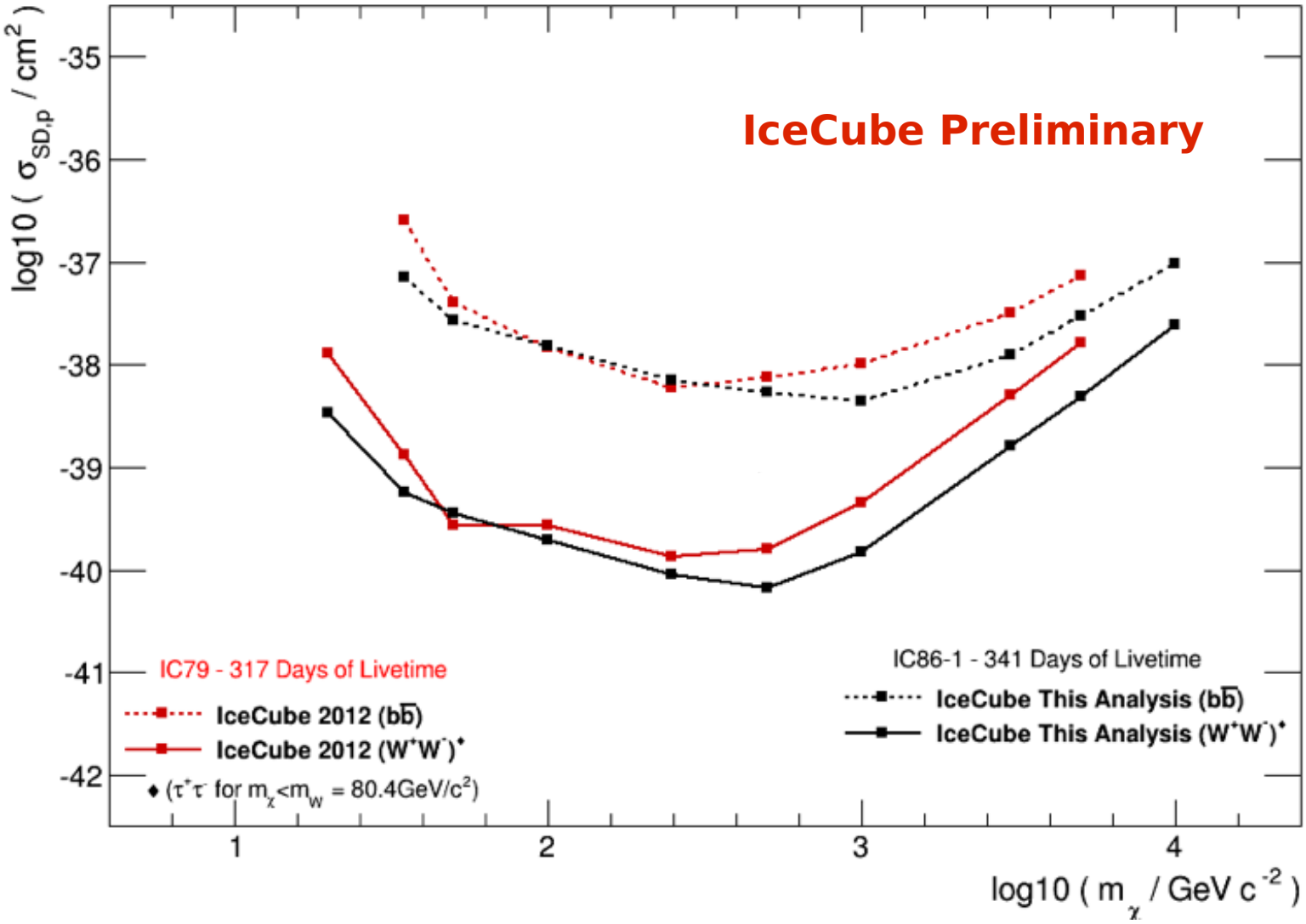


Phys. Rev. Lett., 110(13) (2013) 131302.

- Most stringent SD cross-section limit for most models m_χ >200 GeV
- Complementary to direct detection search efforts
- Different astrophysical & nuclear form-factor uncertainties

IceCube-86 Solar WIMP search

- Improved event selection & LH analysis (utilizing event energy information)
- One-year analysis shown below → soon to be extended to 3 years



Galactic Indirect DM searches

Neutrino flux from DM annihilation:

Measured ν-flux

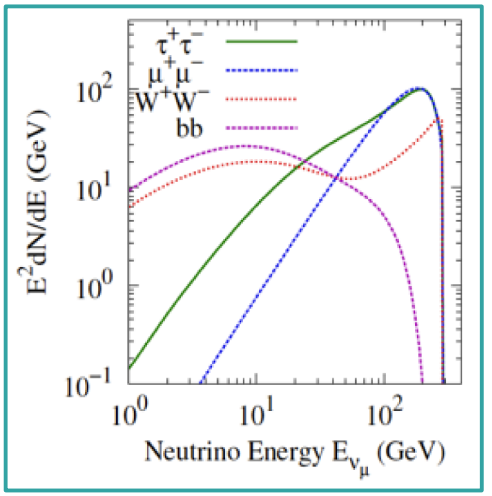
$$\frac{\mathrm{d}\Phi_\nu}{\mathrm{d}E}(E,\theta,\phi)$$

=

Particle Physics

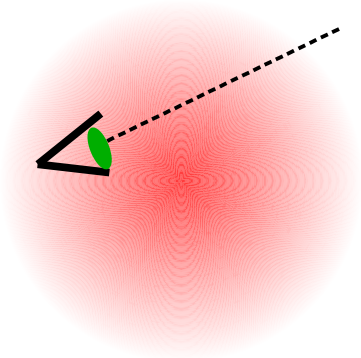
$$\frac{1}{4\pi}\frac{\langle\sigma_A v\rangle}{2m_\chi^2}\sum_f \frac{\mathrm{d}N_\nu}{\mathrm{d}E}B_f$$

x



Dark Matter Distribution

$$\int_{\Delta\Omega(\theta,\phi)} \mathrm{d}\Omega' \int_{\mathrm{l.o.s.}} \mathrm{d}l(r,\phi')\rho^2(r(l,\phi'))$$

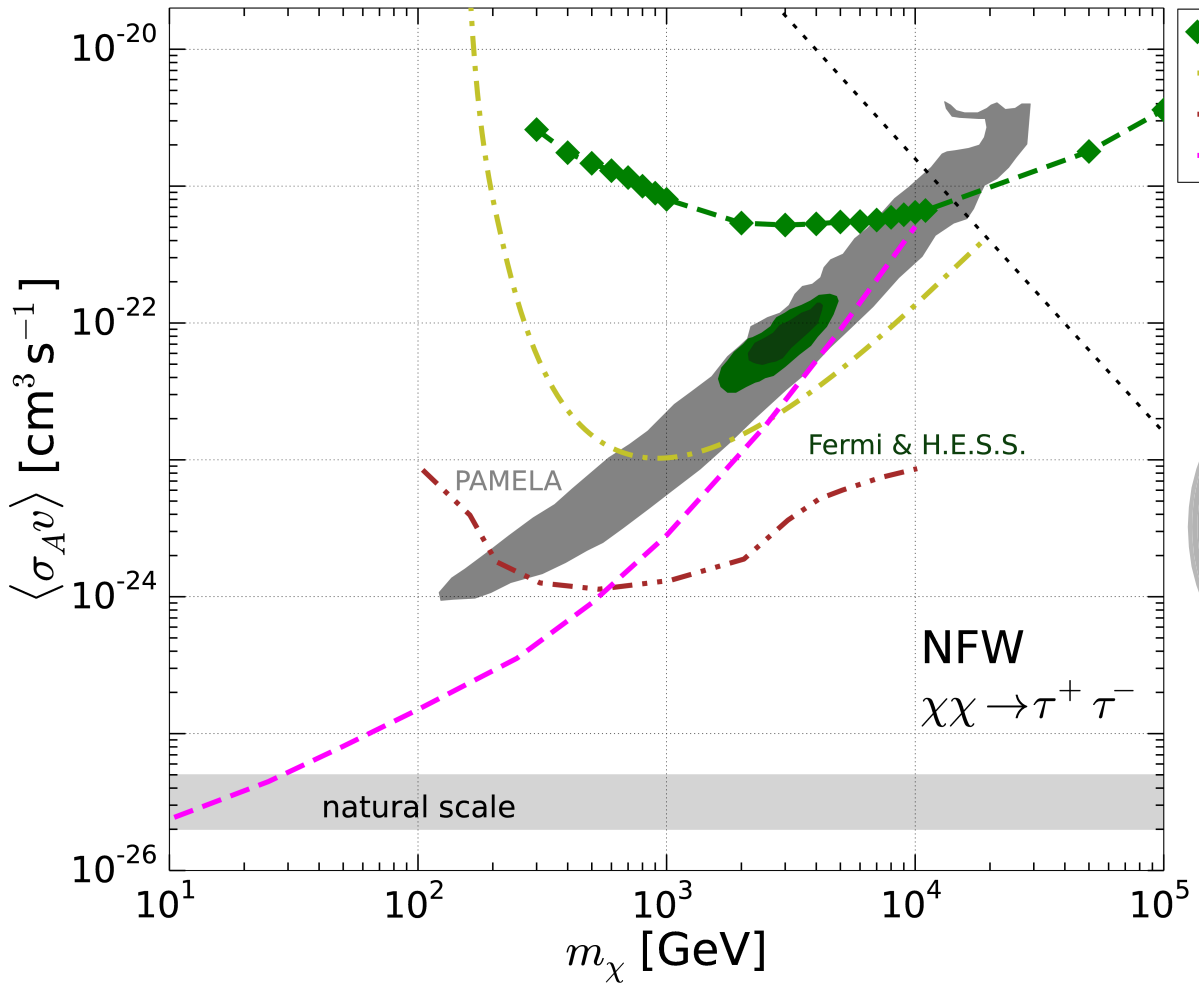


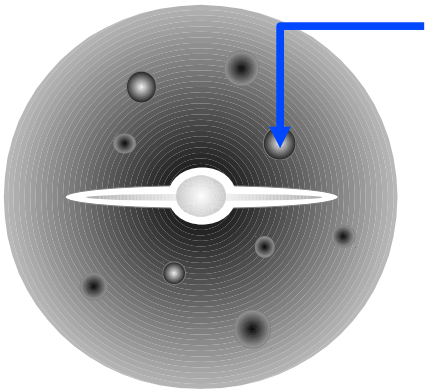
line of sight (l.o.s)

ρ is defined by the DM density model,
e.g. NFW [APJ 462, 563 (1996)] or
Burkert [APJ 447, L25 (1995)]

and their parameter values, e.g. the local DM density

Galactic Indirect DM searches



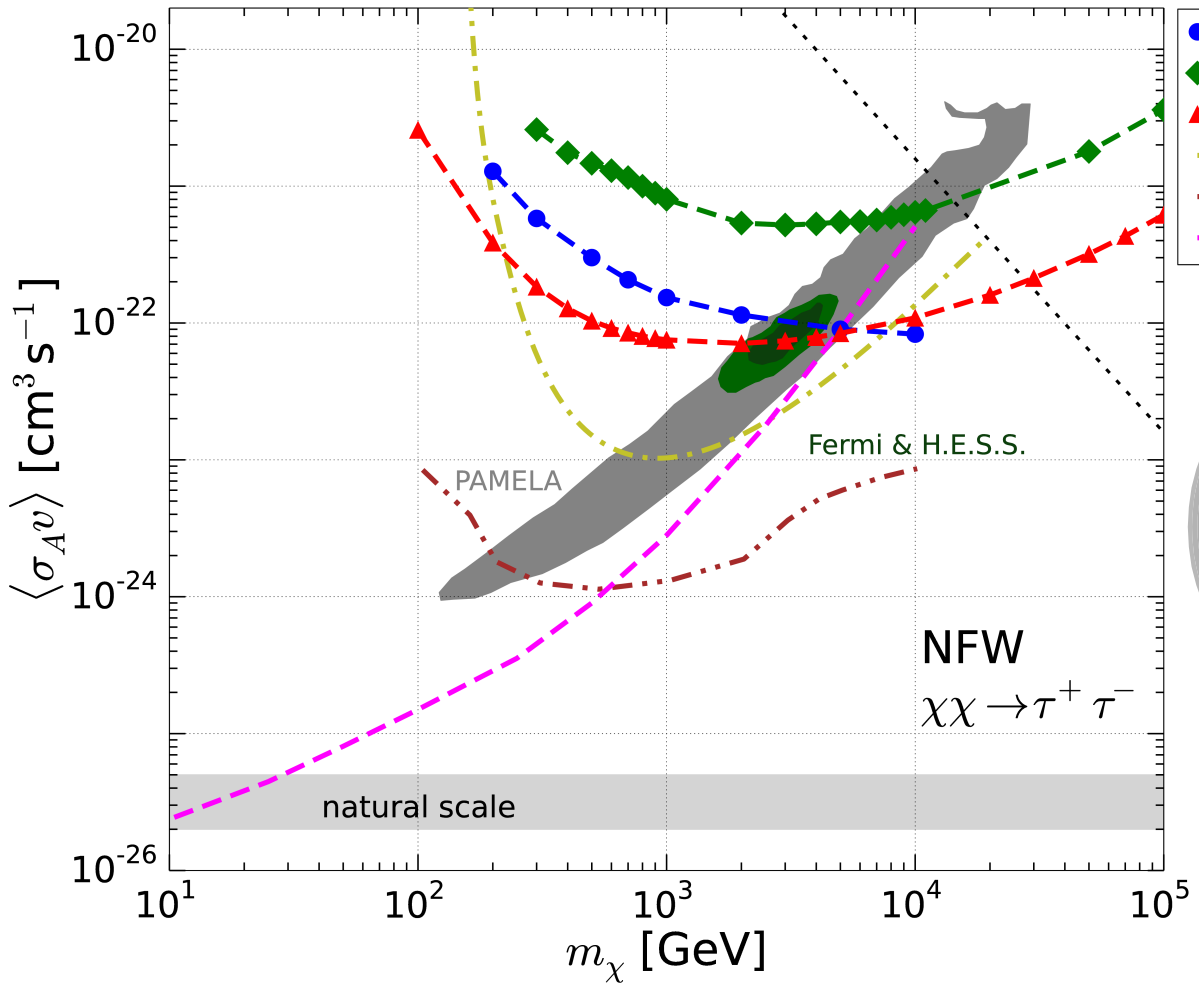


(all IceCube limits at 90% C.L.)

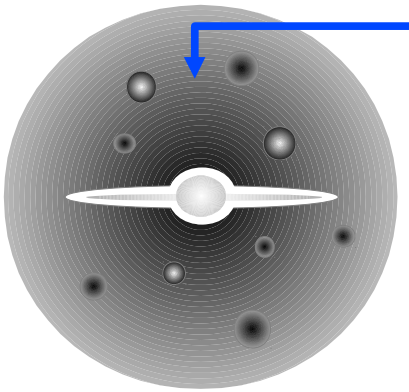
IC59 Dwarf Galaxy & Clusters of Galaxies analysis

- Source stacking analysis (340 days)
- Optimized cuts & size of search window for 5 TeV WIMPs

Galactic Indirect DM searches



IC22 Halo, PRD 84 (2011) 022004
IC59 Dwarfs, PRD 88 (2013) 122001
IC79 Halo, EPJ-C 75, 20 (2015)
VERITAS Seg1 95%C.L., PRD 85 (2012) 062001
MAGIC Seg1 95%C.L., JCAP 02 (2014) 008
Fermi Dwarfs 95%C.L., PRD 89 (2014) 042001

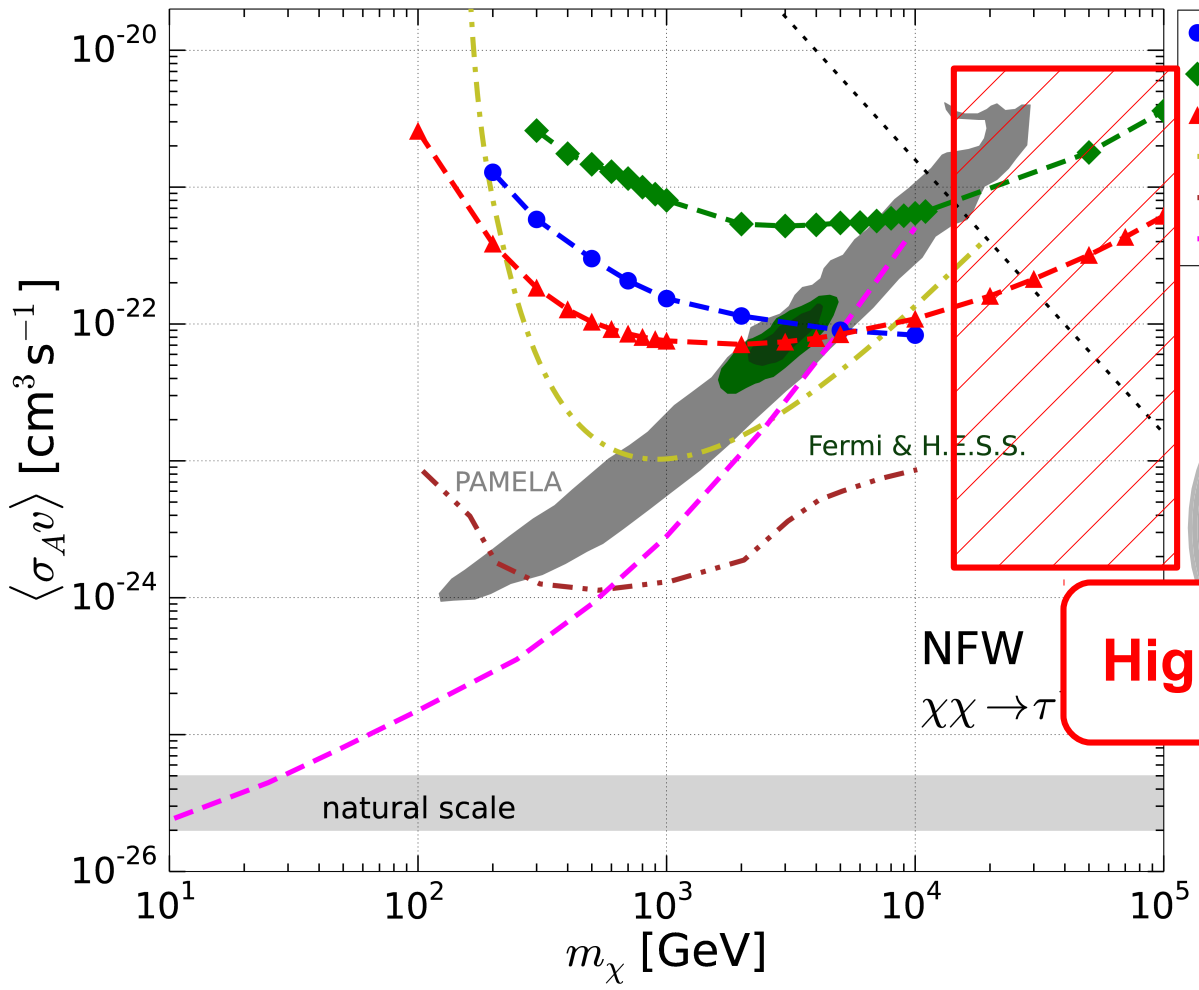


$\rho_{\mathrm{local}} = 0.471\ \mathrm{GeV\ cm^{-3}}$
[JCAP 1307, 016 (2013)]

IC22 Cut&Count (275d) & IC79 Multipole (316d) analysis

- Small halo-model dependency
- Multipole Analysis: focus on large scale anisotropies (l<100)

Galactic Indirect DM searches



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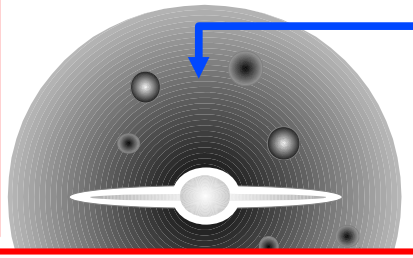

High WIMP mass limits

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[JCAP 1307, 016 (2013)]

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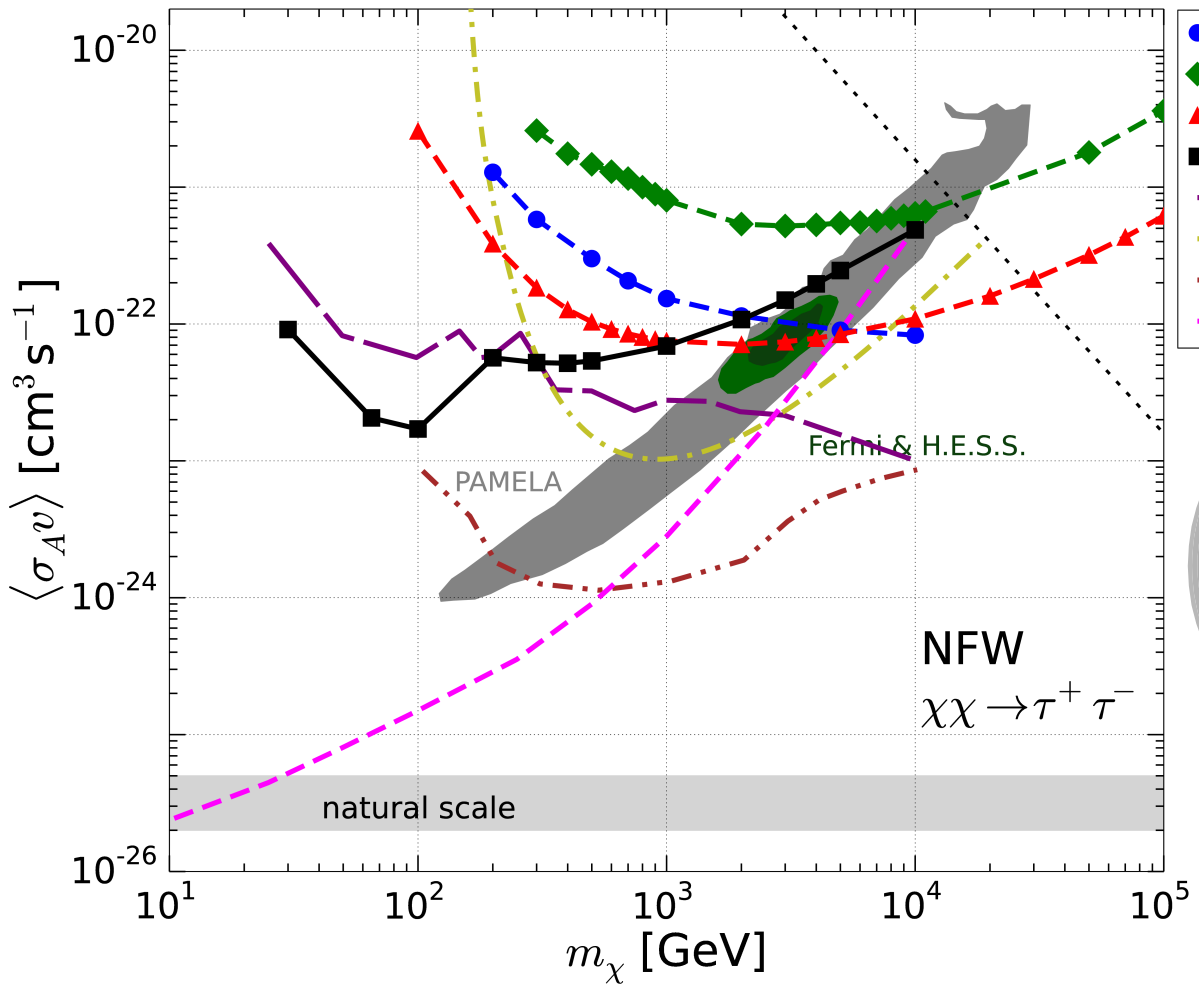
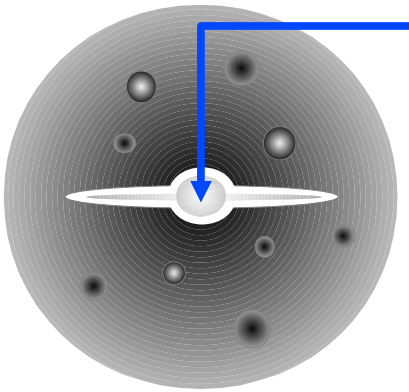




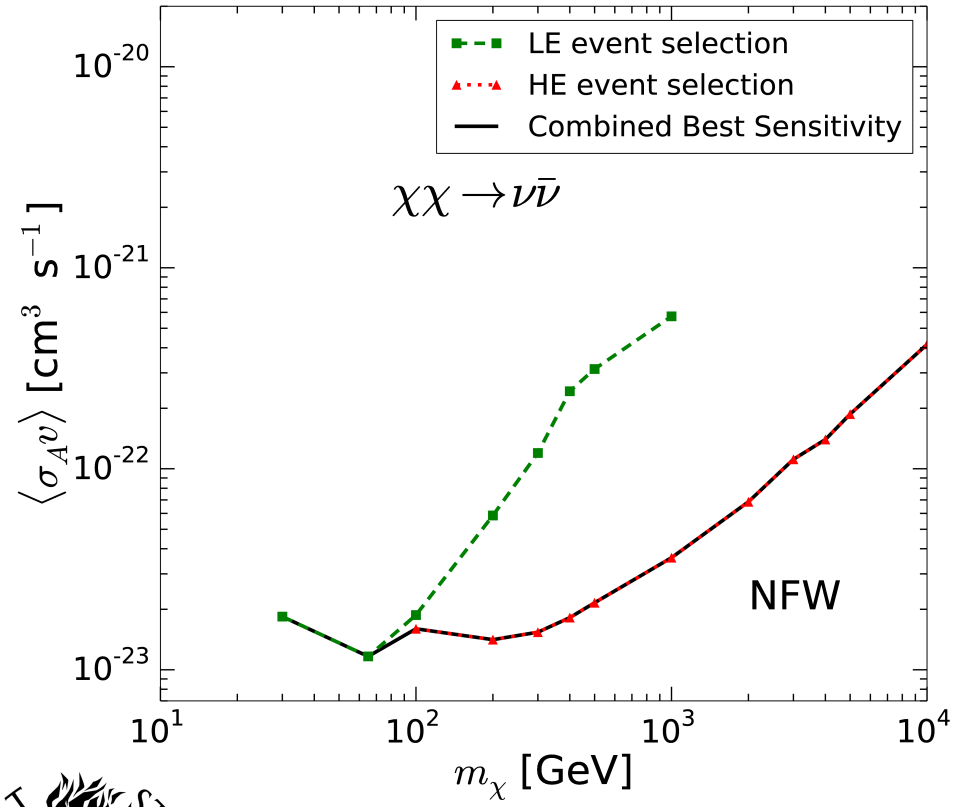
$\rho_{\rm local} = 0.471$ GeV cm^{-3}
[JCAP 1307, 016 (2013)]

IC79 GC Maximum LH analysis (320d)

- 2 event selections (LE & HE)
- Explicit use of DeepCore & new veto techniques

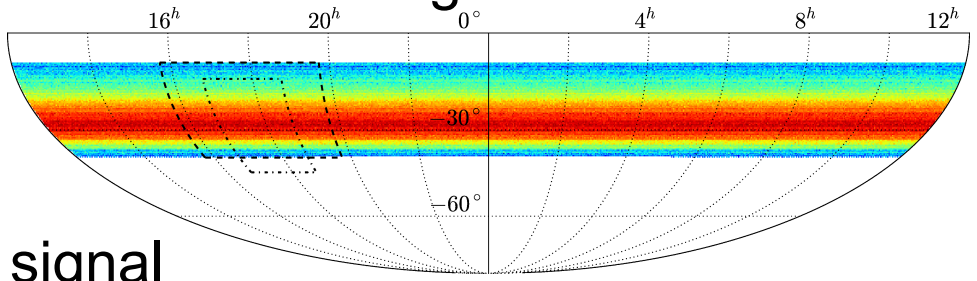
IceCube-79 Galactic Center Analysis

- Galactic Center above horizon
  - veto down-going CR muon bg
- 2 event selections (LE & HE)
- Choice based on best sensitivity for particular mass & ann. channel

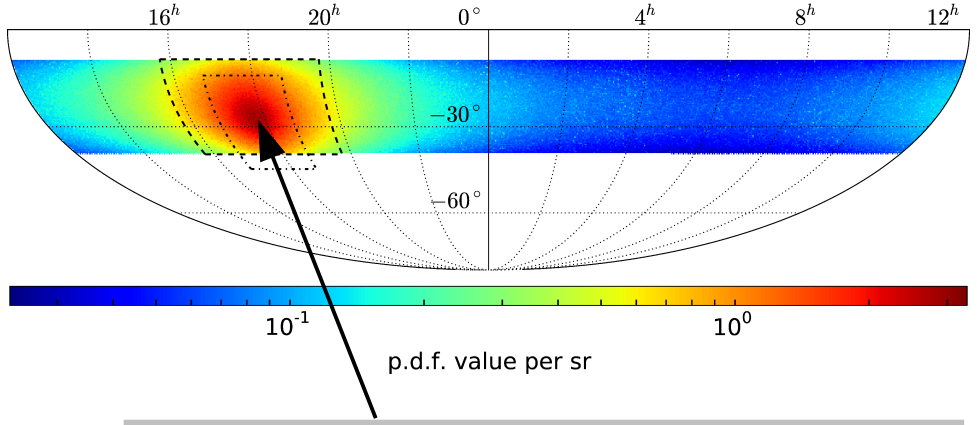


- Shape max. likelihood analysis
- 2D skymap PDFs generated with healpix

scrambled background

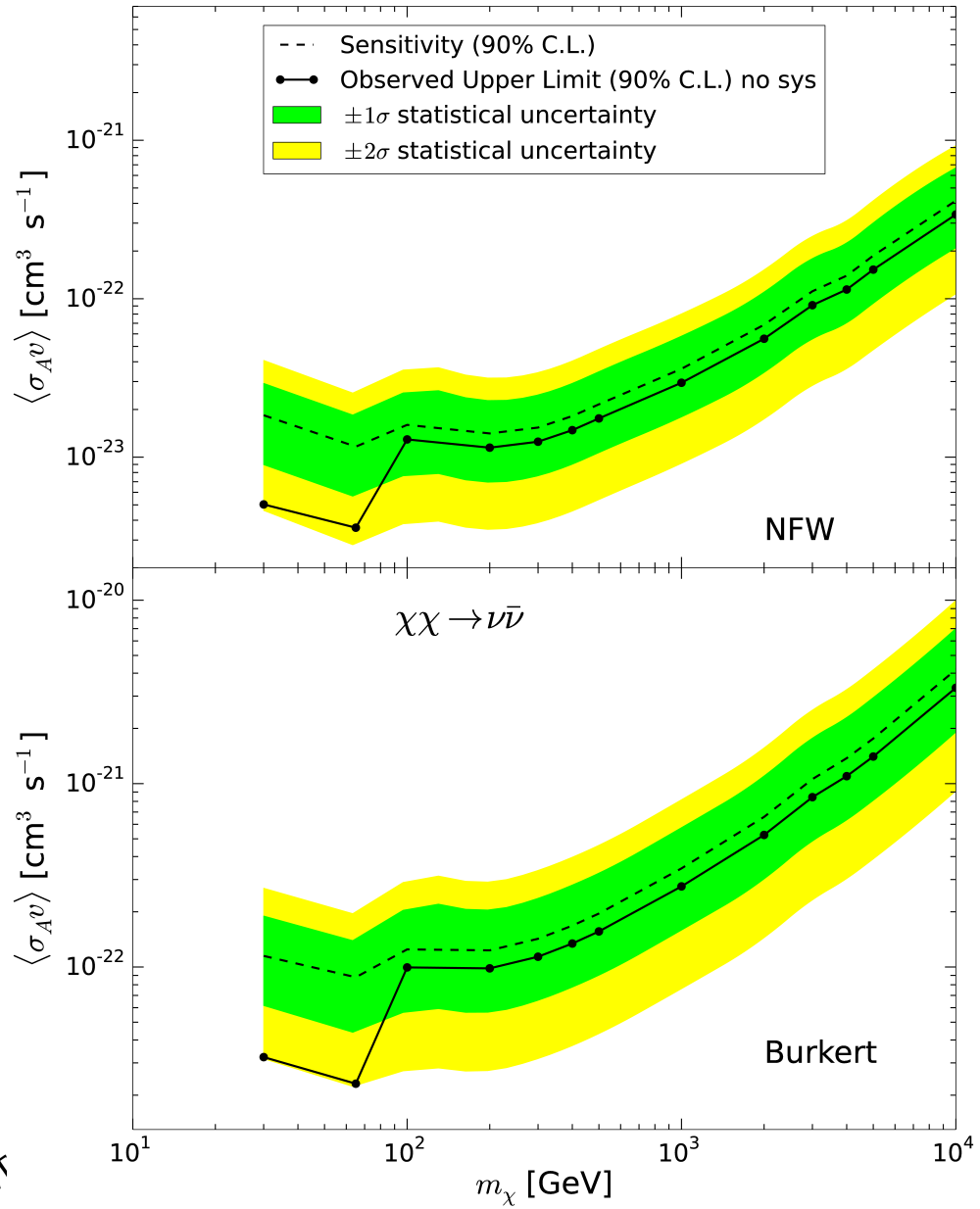


signal



Galactic Center @ 266° RA; -29° Dec

IceCube-79 Galactic Center Analysis



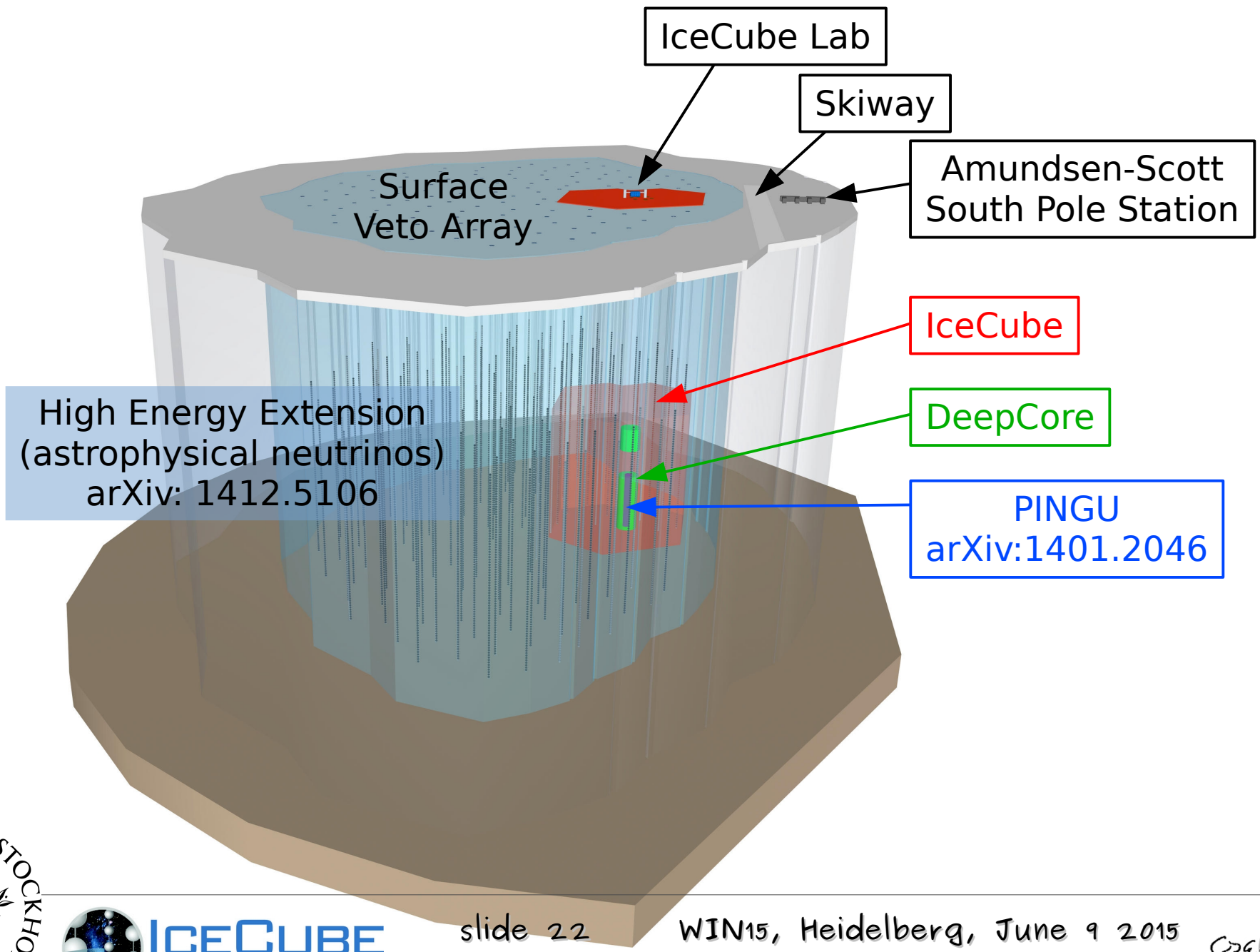
- Results compatable with background-only hypothesis (2σ under-fluctuation)

Stringent limits on direct neutrino annihilation channel

→ complementary to searches by gamma-ray telescopes

- Consider flat-cored DM density profile "Burkert" [APJ 447, L25 (1995)]

Future IceCube Detector Extensions



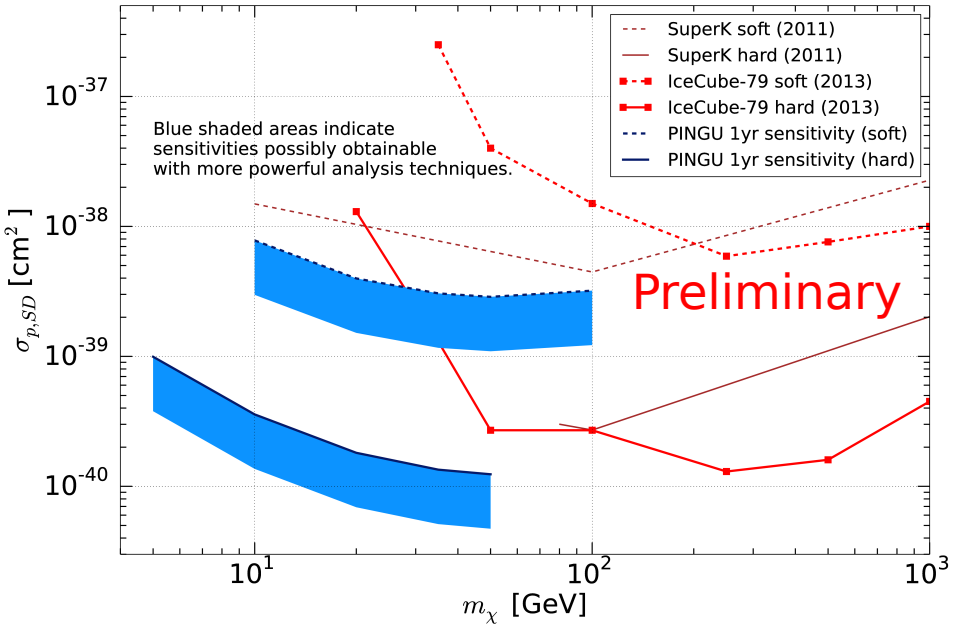
Indirect DM Searches with Generation 2

PINGU

Improved sensitivity for Solar WIMP Searches to masses near 5 GeV

Estimates indicate the ability to reach world-competitive spin-dependent limits with approximately 1 year of data

PINGU Collaboration arXiv:1401.2046

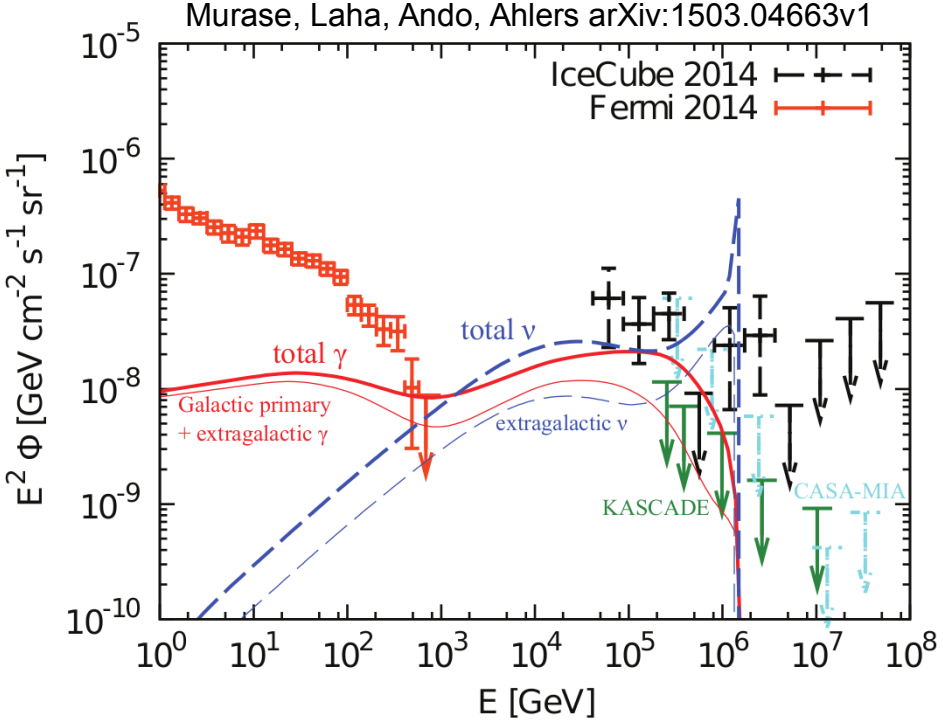


High Energy Extension

Improved sensitivity high mass DM

Potential to rule out the Very Heavy DM scenario (astrophysical neutrinos) in 3-5 years

Murase, Laha, Ando, Ahlers arXiv:1503.04663v1



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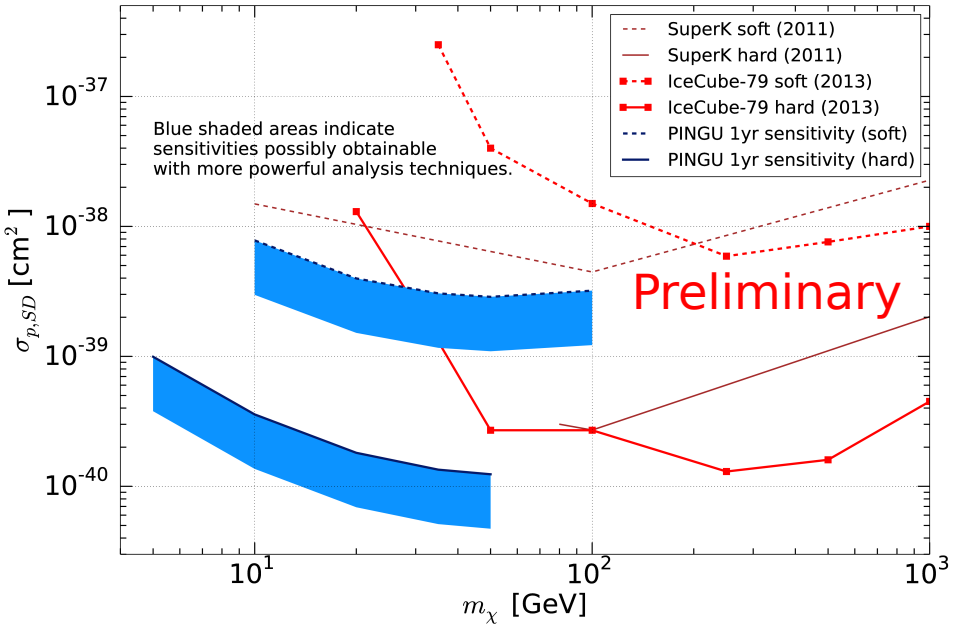

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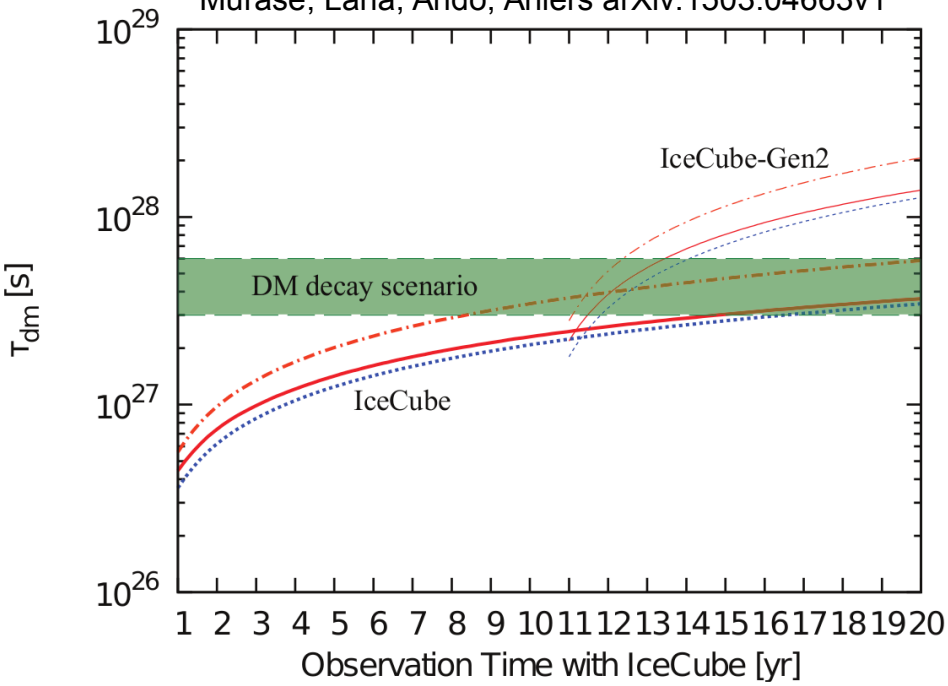

Summary

- Neutrinos provide high discovery potential for indirect Dark Matter searches
  - complementary to searches using other astrophysical messengers & direct detection searches
- DeepCore accesses Southern Hemisphere for low WIMP masses
- First neutrino analysis looking at GC for low WIMP masses (30 GeV - 10TeV)
- More signal detection channels via cascade event detection
- IceCube provides most stringent limits on the SD-WIMP-proton scattering cross section for WIMP masses above 200 GeV
  - Improved Solar WIMP search under way
- Future LE & HE detector extensions could improve WIMP searches and could rule out VHDM scenarios within 3-5 years

Additional Material

PINGU Solar WIMP sensitivity

- PINGU LoI: [arXiv 1401.2046]
- 40 add. strings within DeepCore
- 1 year live-time
- $\nu_e + \nu_\mu$ signal channel
- Cut-&-Count analysis approach
- 10º search cone around the Sun
- WIMP masses as low as 5 GeV