SNOWMASS 2021 Topical Group
CF1 - Particle Dark Matter -
CF1 Meeting: Indirect Detection for Heavy Dark Matter (GeV+ energies)

— Indirect Searches with Neutrinos —

Carsten Rott

Sungkyunkwan University, Korea

rott@skku.edu

CF1 Meeting: Indirect Detection for Heavy Dark Matter (GeV+ energies)

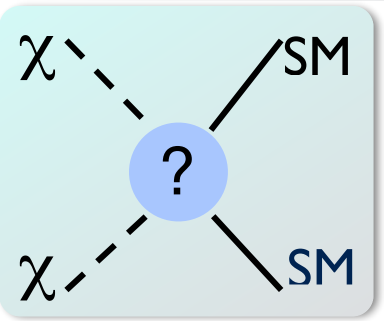
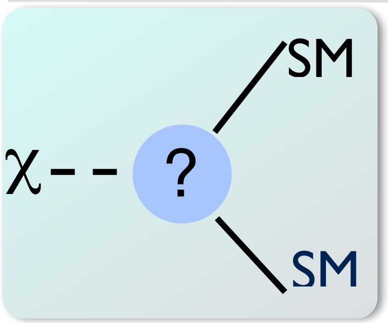
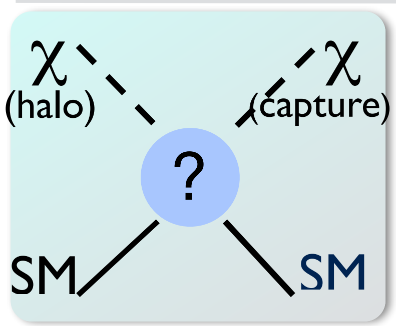
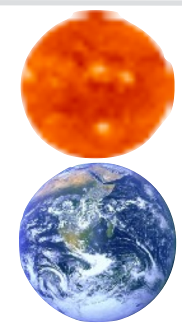
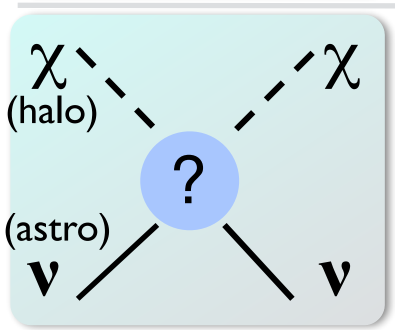
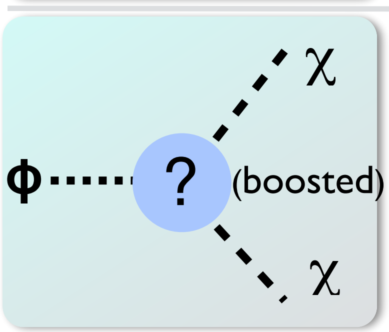
Aug 14, 2020

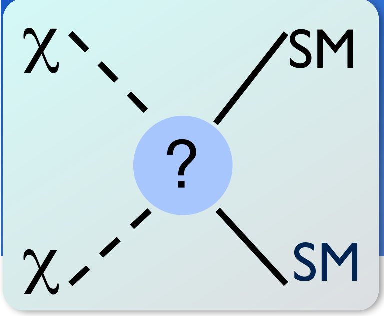
CF1 - Indirect Searches with Neutrinos

- Why neutrinos:
  - Explore energy scales beyond the reach of colliders and those accessible by other indirect search channels
  - Large variety of dark matter model hypotheses can be probed
  - Searches are largely model independent

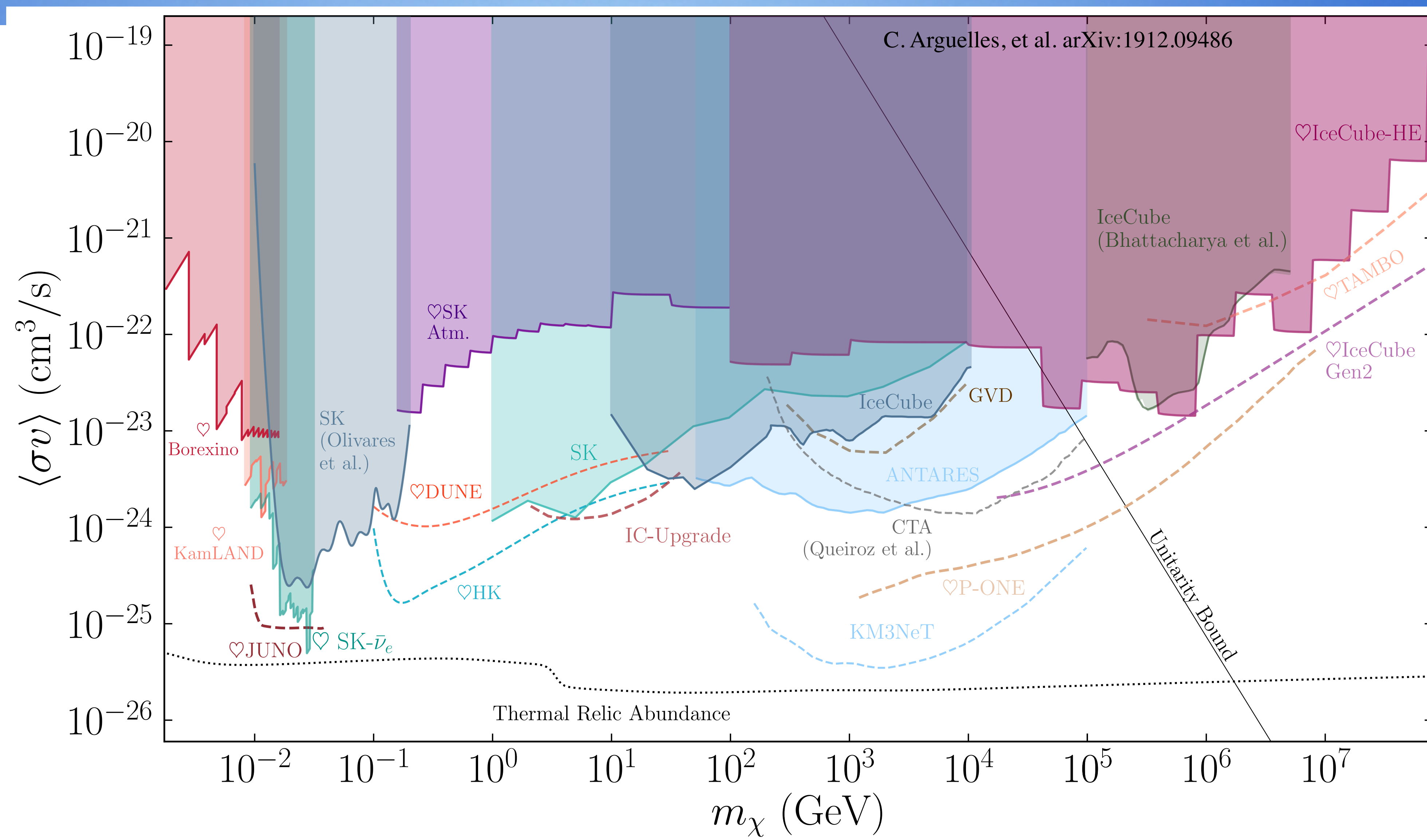
CF1 Meeting: Indirect Detection for Heavy Dark Matter (GeV+ energies)
Disclaimer: Focus on dark matter above GeV - realm of the optical neutrino telescopes

Signatures of Dark Matter (χ) in Neutrino Detectors

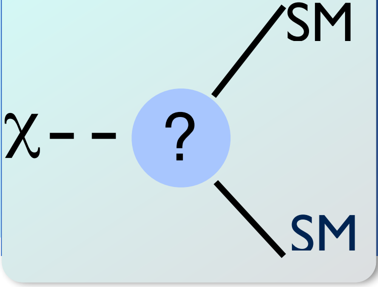
Channel	Type of Search	Typical Sources		Measures
	**DM Annihilation searches** ν from SM particle decay, direct neutrinos helicity suppressed for Majorana DM	• Galactic Center • Galactic Halo • Dwarf Spheroidals • Galaxy clusters • …		Self-annihilation cross section $\boldsymbol{<\sigma v>}$ DM Mass $\mathbf{m}_\chi$ (Branching fractions)
	**DM Decay searches** ν from SM particle decay or directly produced	• Extragalactic • Galactic Halo • Galaxy clusters • …		DM Lifetime τ_χ DM Mass $\mathbf{m}_\chi$ (Branching fractions)
	**DM Nucleon scattering** Following χ capture, annihilation. Once annihilation and capture in balance (equilibrium) - no dependence on $\boldsymbol{<\sigma v>}$ Test SD/SI scattering	• Sun • Earth		DM-Nucleon scattering cross section $\boldsymbol{\sigma^{SD}}$ / $\boldsymbol{\sigma^{SI}}$ DM Mass $\mathbf{m}_\chi$ (Branching fractions)
	**Neutrino DM scattering** Astrophysical ν from distant sources probe rare interactions / Astrophysical ν interact with χ from Galactic halo → Anisotropy, spectral distortions, and time delays	• Galactic Halo • Distant point sources		Combination of coupling strength **g** and masses $\mathbf{m}_\phi$ $\mathbf{m}_\chi$
	**Boosted DM** Highly boosted χ from the decay or annihilation of a heavy DM particle $\mathbf{m}_\phi$ interacts directly in the detector	• Galactic Center • Galactic Halo • Sun • …		DM Lifetime τ_χ … or self-annihilation cross section $\boldsymbol{<\sigma v>}$ DM mass $\mathbf{m}_\phi$



Search Dark Matter Annihilation

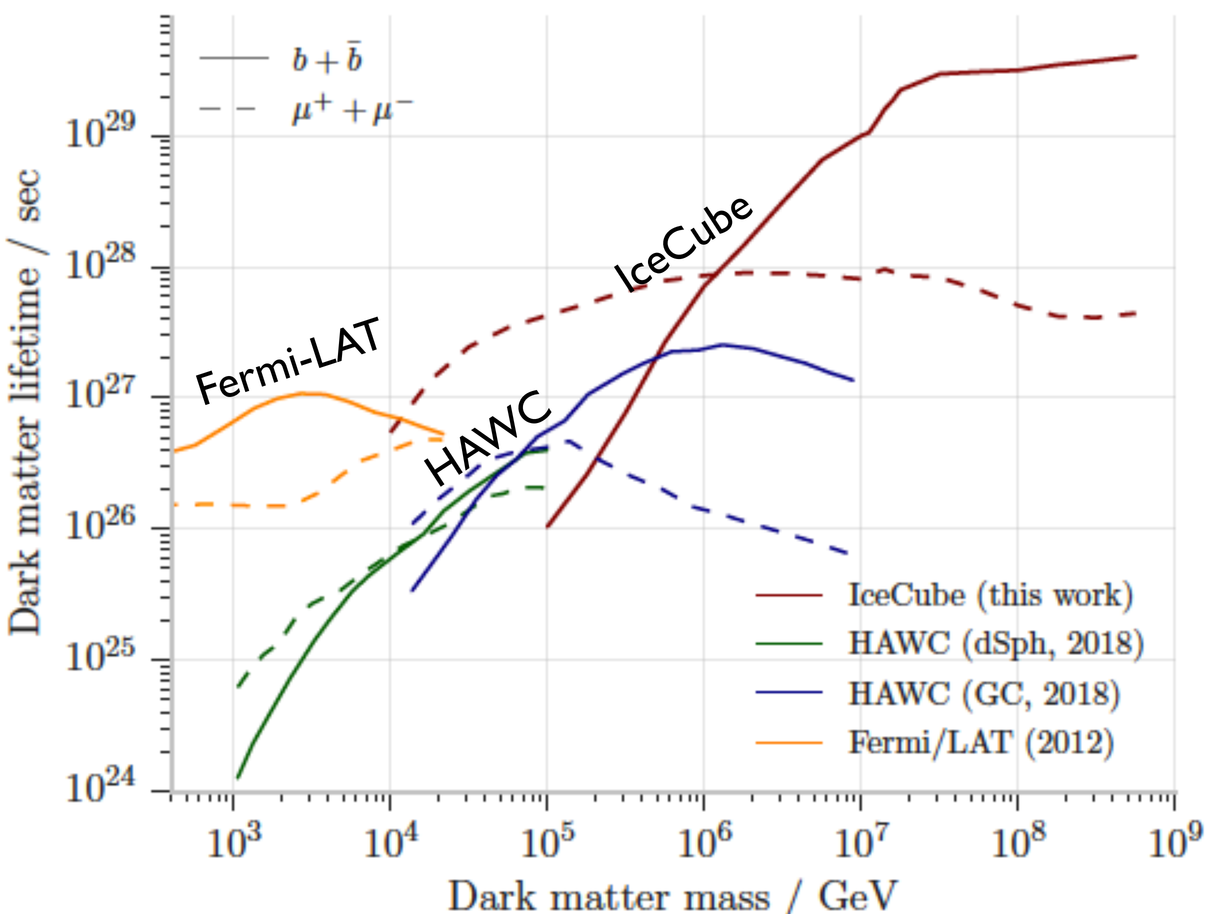


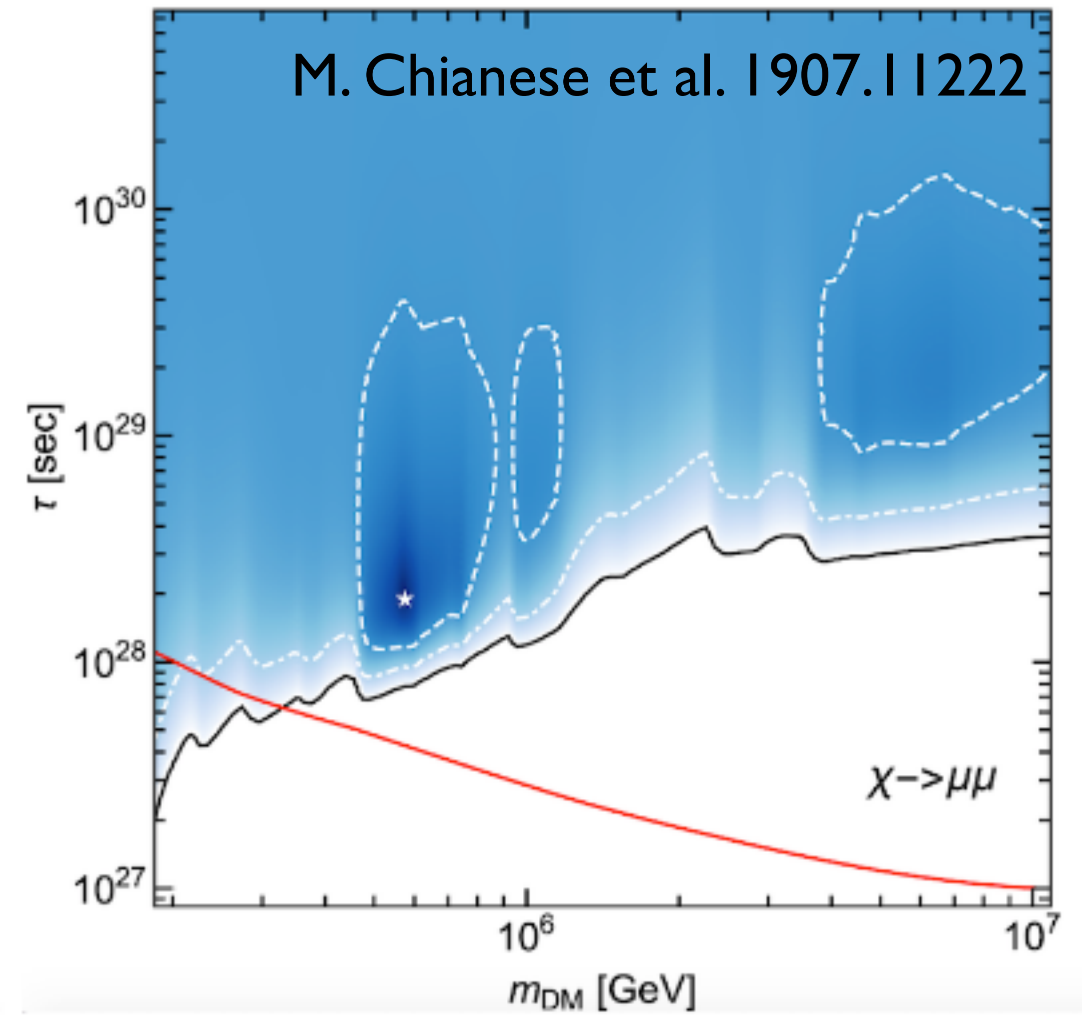
- **Current status**
  - Most competitive with other messengers for heavy dark matter and channels with high neutrino yields
  - Neutrino searches have been important test to probe models motivated by observations with other messengers (example the cosmic-ray positron excess (PAMELA, AMS-02, …))
- **Future prospects**
  - Reaching the thermal relic cross section remains challenging even with next generation detectors
  - Searches are very generic, do not rely on WIMP hypothesis.
    - Go beyond WIMP scenarios (high-mass, enhanced annihilation cross section, evade unitarity bound)



Heavy Dark Matter Decay

IceCube Collaboration arXiv:1804.03848v1 (published EPJC)

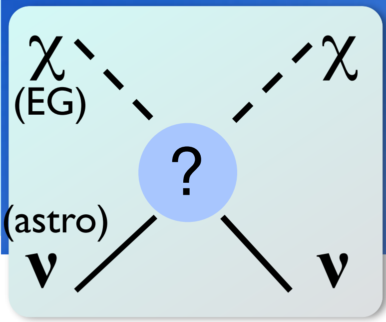




- **Current status:**
  - IceCube provides leading bounds (~10^{28}s) on heavy decaying dark matter / Neutrinos extremely competitive above ~10TeV
  - Dark matter alone cannot explain the observed astrophysical neutrino flux
- **Future prospects and priorities**
  - Opportunities for combined searches in TeV range (broader coverage of models), extremely competitive at high energies
  - Highest priority - understand astrophysical neutrino spectrum
    - Is IceCube's data already showing any hints of dark matter (TeV excess ?)

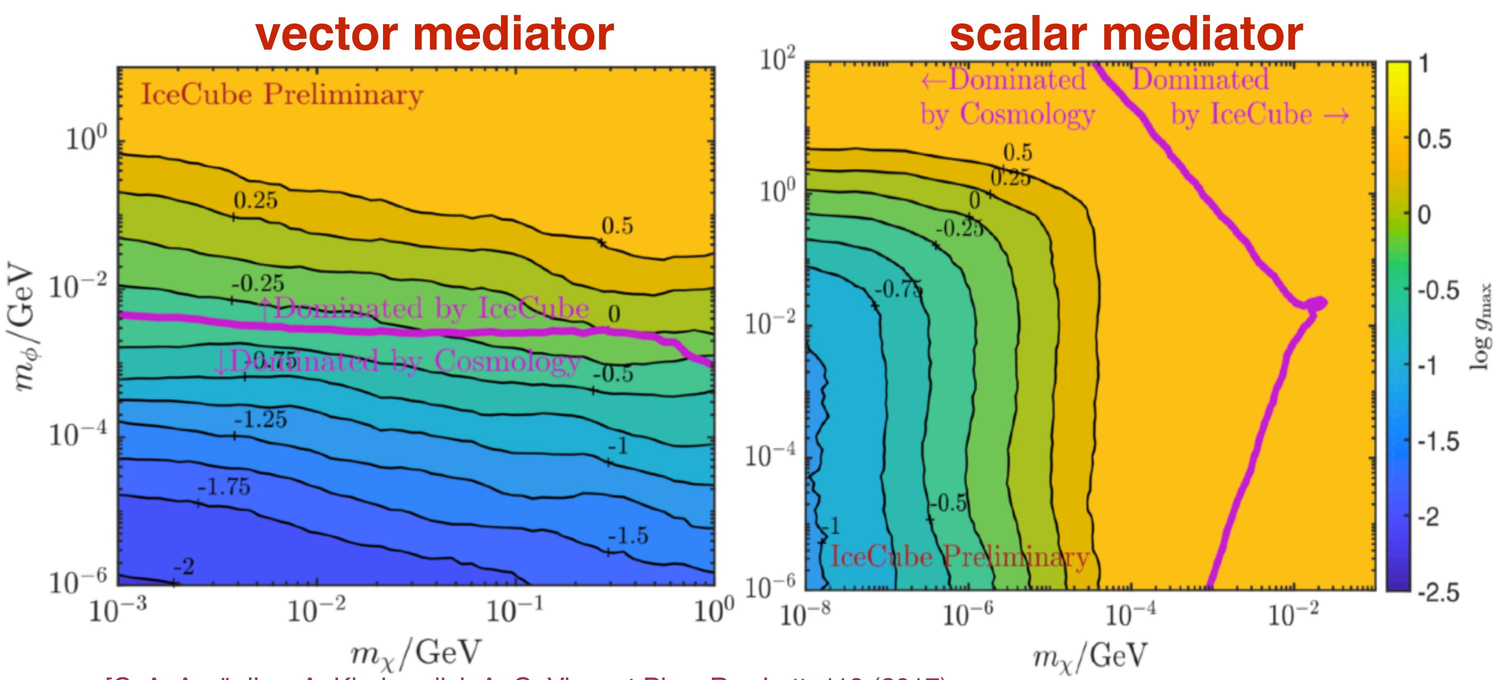
Evidence for dark matter in in the diffuse high-energy astrophysical neutrino flux ?

- B. Feldstein, A. Kusenko, S. Matsumoto, and T. T. Yanagida, PRD 88 no. 1, (2013) 015004, arXiv:1303.7320
- A. Esmaili and P. D. Serpico, JCAP11(2013) 054, arXiv:1308.1105
- Y. Ema, R. Jinno, and T. Moroi, PLB 733 (2014) 120–125, arXiv:1312.3501
- A. Bhattacharya, M. H. Reno, and I. Sarcevic, JHEP06 (2014) 110, arXiv:1403.1862
- C. Rott, K. Kohri, and S. C. Park, PRD 92 no. 2, (2015) 023529, arXiv:1408.4575
- K. Murase, R. Laha, S. Ando, and M. Ahlers, PRL 115 no. 7, (2015) 071301, arXiv:1503.04663
- L. A. Anchordoqui, V. Barger, H. Goldberg, X. Huang, D. Marfatia, L. H. M. da Silva, and T. J. Weiler, PRD 92 no. 6, (2015) 061301, arXiv:1506.08788. [Erratum: PRD 94, 069901 (2016)].
- M. Chianese, G. Miele, and S. Morisi, PLB 773 (2017) 591-595, arXiv:1707.05241
- M. Ahlers, Y. Bai, V. Barger, and R. Lu, PRD 93no. 1, (2016) 013009, arXiv:1505.03156
- ….

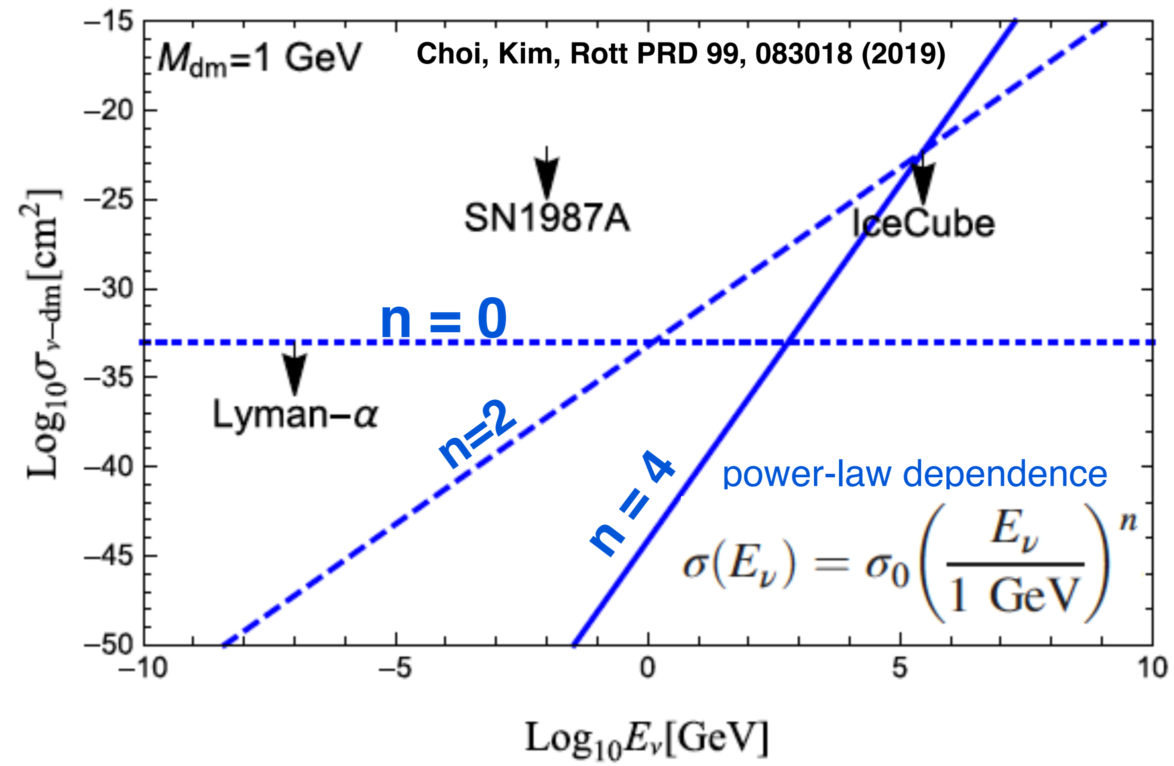


Neutrino Dark Matter Interactions

- Scattering of high energy astrophysical neutrinos on DM
  - "Isotropic" astrophysical neutrino flux on Galactic dark matter halo
  - Opportunities to probe very rare processes by observing neutrinos from distant sources
    - Example IceCube-170922A : Scattering of high energy astrophysical neutrinos from Blazar TXS0506+056 (z=0.33 / 5.7 billion light-years)

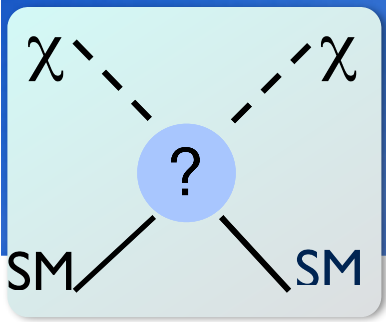


[C. A. Argüelles, A. Kheirandish A. C. Vincent Phys.Rev.Lett. 119 (2017) no.20, 201801 (arXiv:1703.00451)]

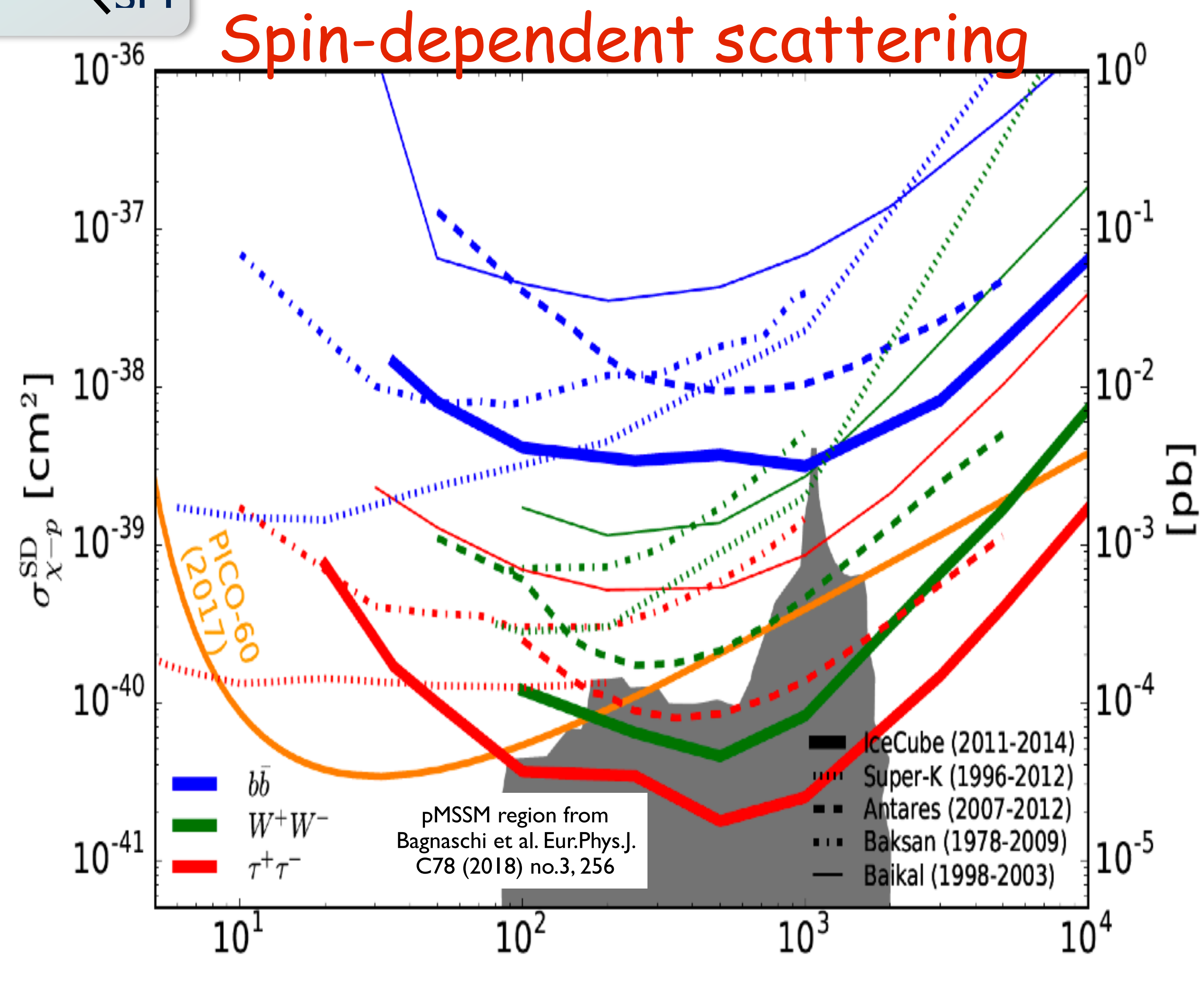


- **Current status**
  - First experimental searches have started - competitive with cosmological bounds
- **Future prospects and priorities**
  - Identification of new astrophysical neutrino sources in the future could increase sensitivities
  - High statistics sample of astrophysical neutrinos essential

see also DM-neutrino coupling by looking for neutrino survival from a point source (https://arxiv.org/abs/1808.02889), deviations on the shape of the spectrum (https://arxiv.org/abs/1401.7019, but at higher energies, like https://arxiv.org/abs/2001.04994), or delays in arrival times (https://arxiv.org/abs/1903.08607).

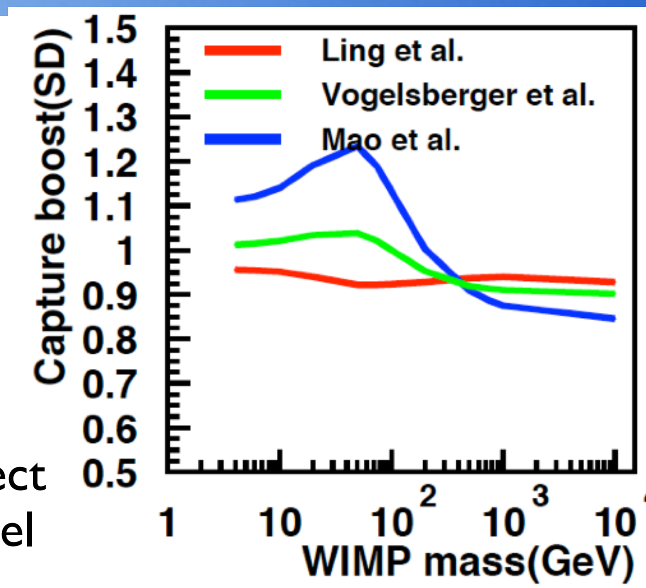


Solar Dark Matter



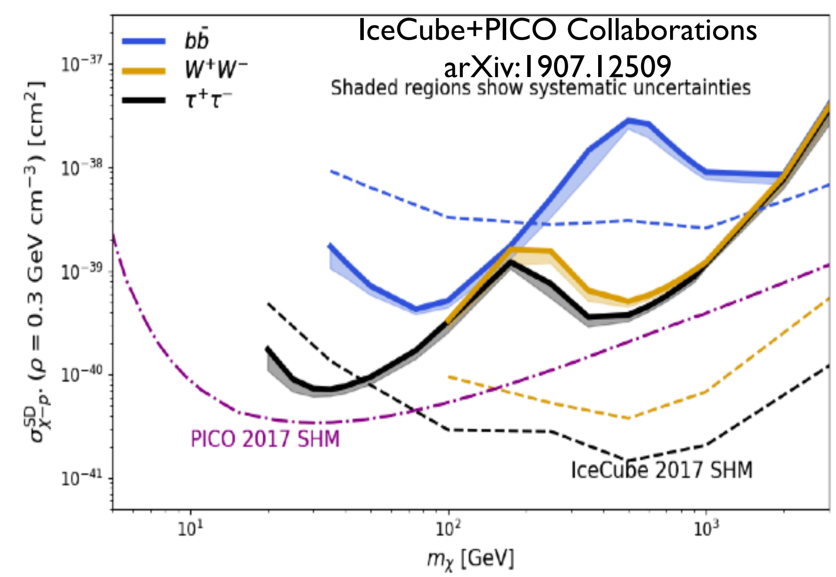
Largely halo model independent

see for example: Choi, Rott, Itow (2014), Danninger & Rott (2014), Nuñez-Castiñeyra, Nezri, Bertin (2019)



Combination with direct detection formal model independent results

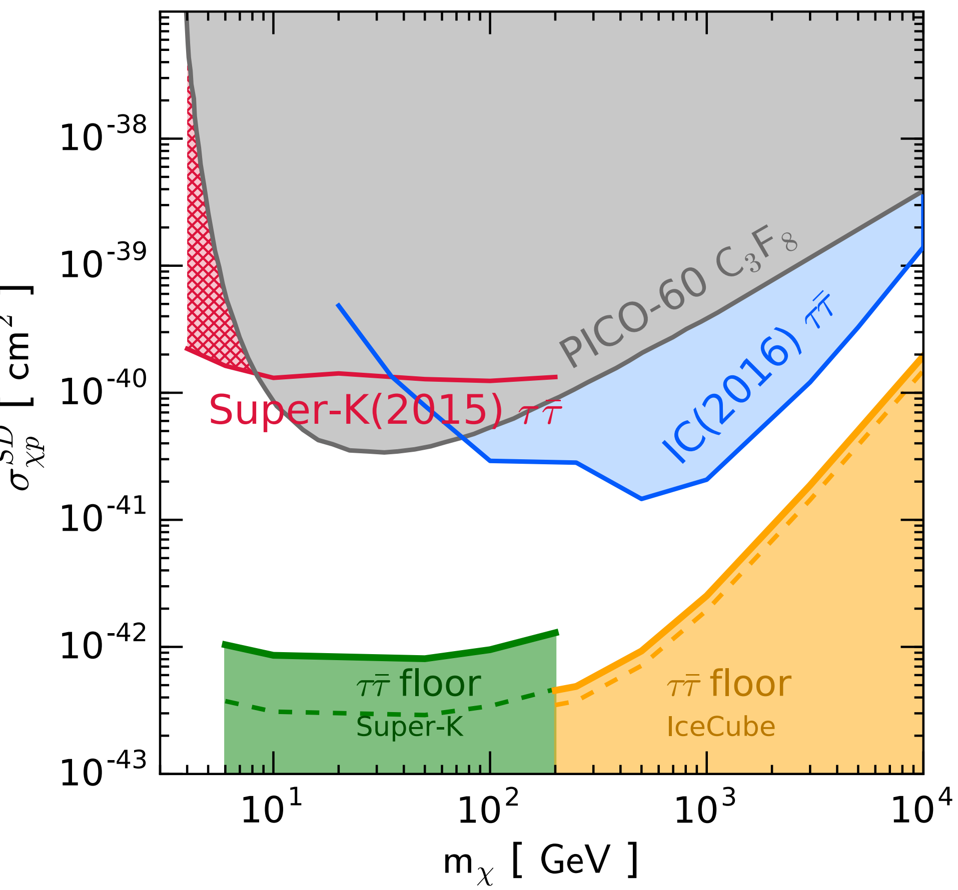
following: Ferrer Ibarra & Wild (2015)

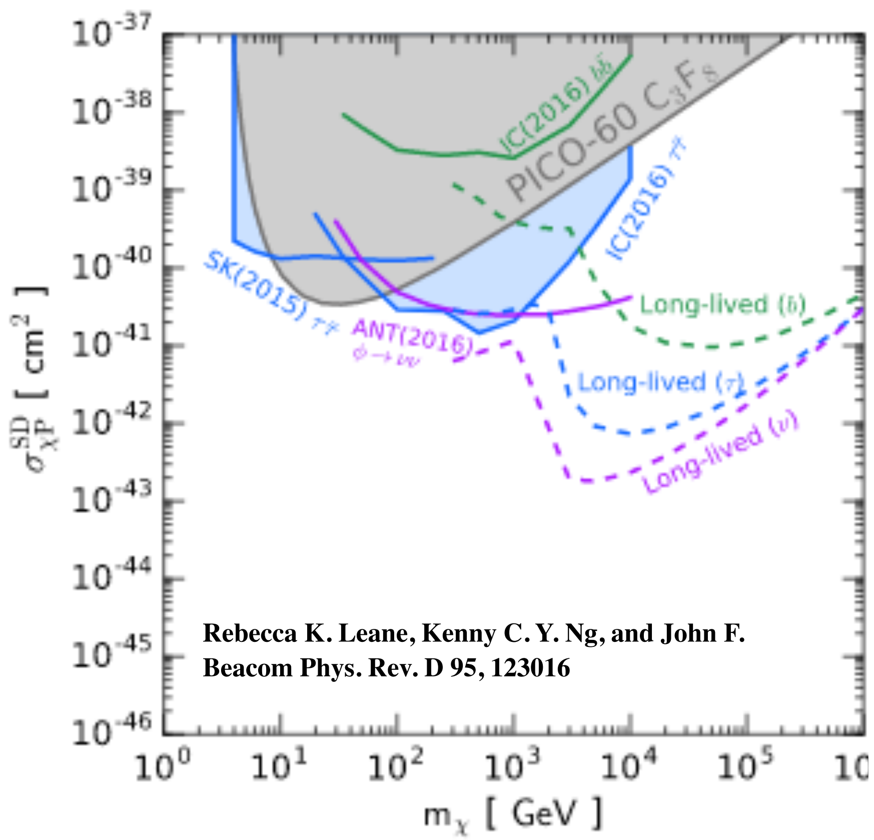


- **Current status**
  - Very strong bounds on spin-dependent DM nucleon scattering. Leading bounds from IceCube and Super-K
  - Velocity independent framework in combination with direct detection
- **Future prospects**
  - Extremely competitive to explore DM model space from GeV - TeV range
  - Complementarity to direct detection & minimal halo model dependence
  - Marching towards the solar atmospheric neutrino floor (~x10 below current bounds) … new physics !

Neutrino Floor / Boosted / Secluded Dark Matter

Ng, Beacom, Peter, Rott Phys.Rev. D96 (2017) no.10, 103006



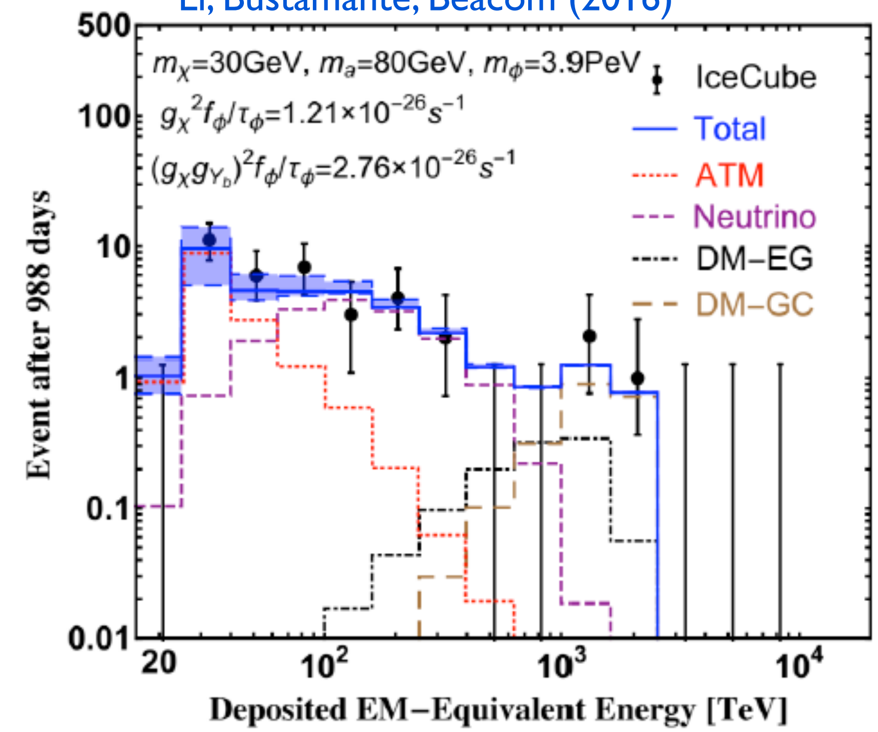


Rebecca K. Leane, Kenny C. Y. Ng, and John F. Beacom Phys. Rev. D 95, 123016

First proposed
Atri Bhattacharya, Raj Gandhi, Aritra Gupta
JCAP03(2015)027 / arXiv:1407.3280
see also
Atri Bhattacharya, Raj Gandhi, Aritra Gupta, Satyanarayan Mukhopadhyay JCAP05(2017)002 / arXiv:1612.02834

Kopp, Liu, Wan (2015)

Li, Bustamante, Beacom (2016)



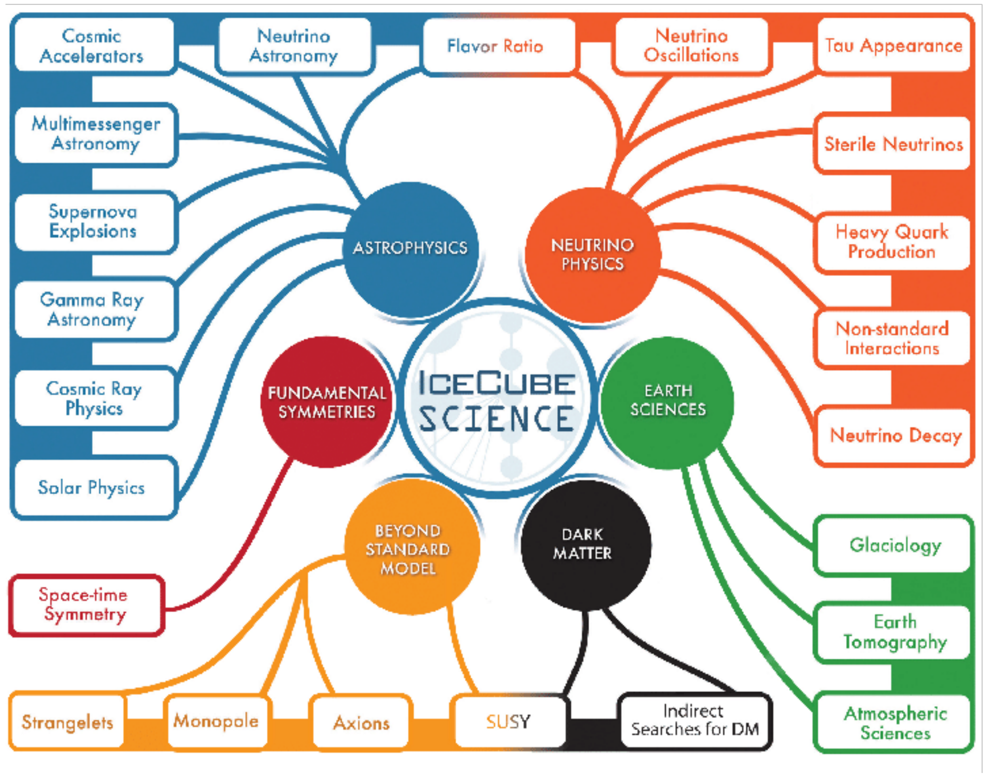
Solar Atmospheric Neutrinos / Atmospheric Neutrino Floor:

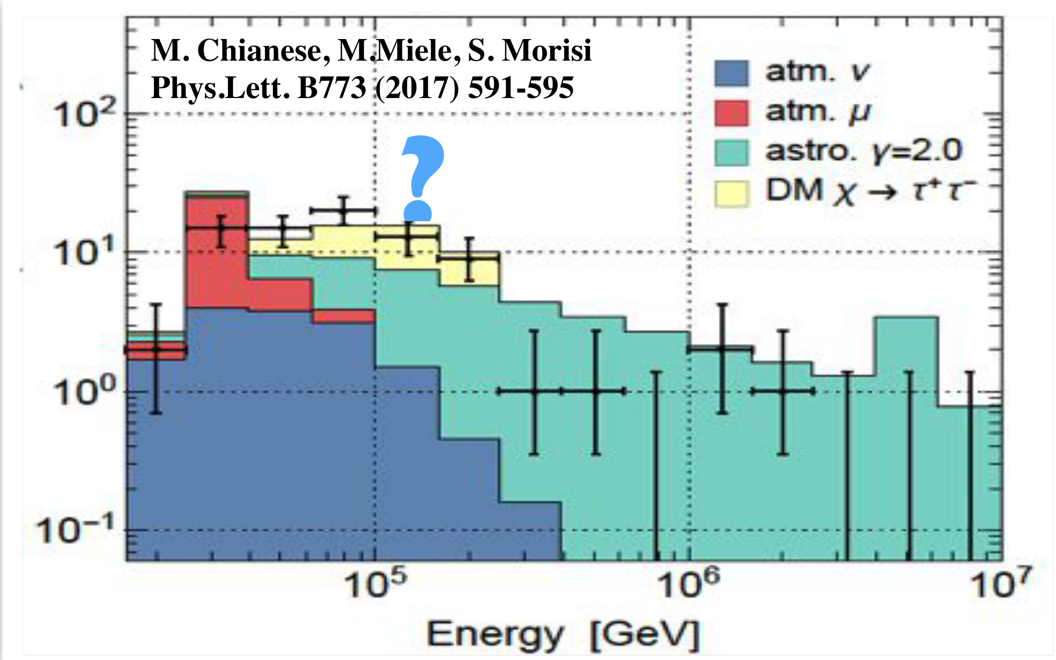
- C. Argüelles, G. de Wasseige, A. Fedynitch, B. Jones **JCAP 1707 (2017) no.07, 024** [arXiv:1703.07798]
- K. Ng, J. Beacom, A. Peter, C. Rott **Phys.Rev. D96 (2017) no.10, 103006** [arXiv:1703.10280]
- J. Edsjö, J. Elevant, R. Enberg, and C. Niblaeus, **JCAP 2017 .06 (2017), p. 033**, arXiv: 1704.02892 [astro-ph.HE]
- M. Masip **Astropart.Phys. 97 (2018) 63-68** [arXiv: 1706.01290]

- Current status:
  - Growing interest in scenarios that go beyond the WIMP hypothesis
- Future Prospects:
  - Excellent prospects to explore scenarios with energetic neutrinos from the Sun
  - As a side product of solar dark matter neutrino search can lead to a guaranteed signal of solar atmospheric neutrinos

Complementarity & Outlook

- Neutrino Telescopes are discovery experiments, exploring the unknown, with a tremendous potential for BSM physics searches
  - Guaranteed science for dark matter searches & discovery potential
  - Observed astrophysical neutrino spectrum remains to be understood
    - Guaranteed discoveries, including potential to observe dark matter
  - BSM physics searches at neutrino telescopes come at essentially no additional costs (highly leveraged)
  - Independent from direct detection or other indirect searches
  - Rapidly evolving field that can provides unexpected new opportunities (example observation of new astrophysical sources or transient events)

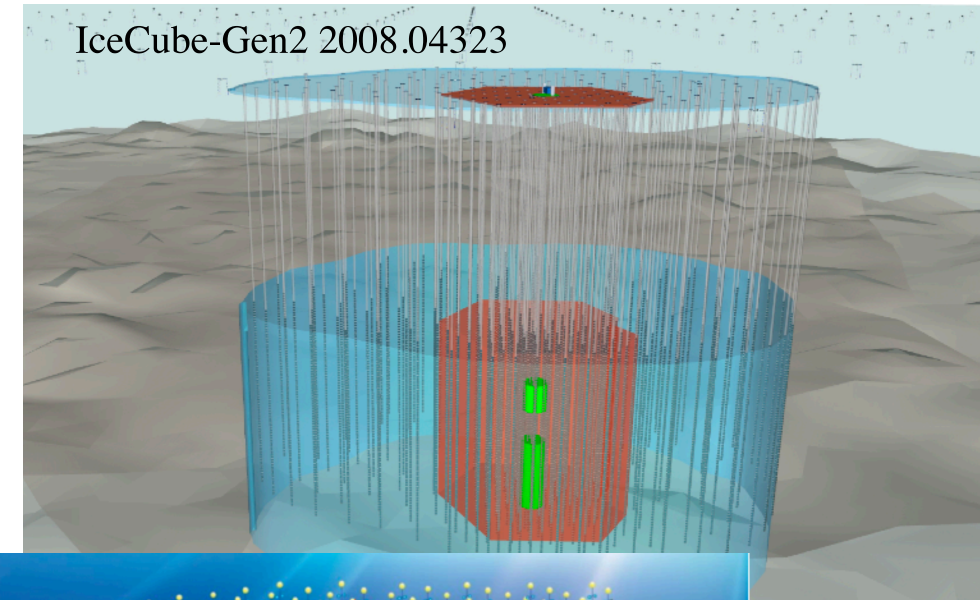


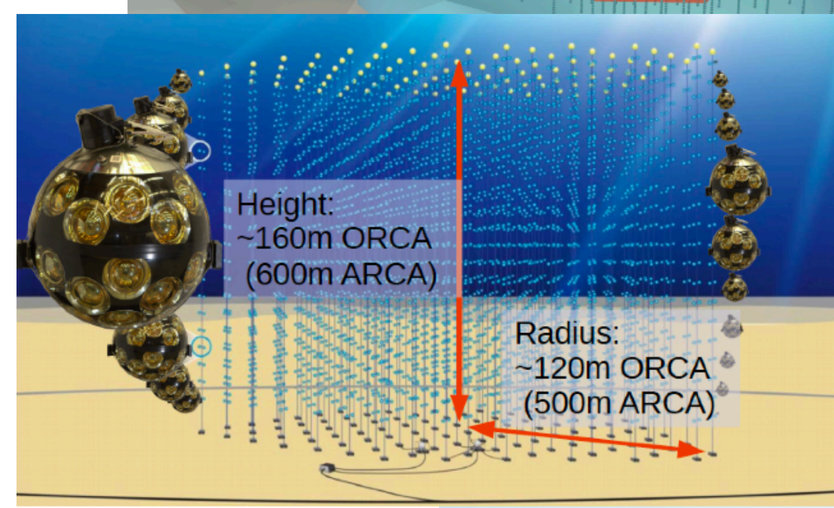


High-energy astrophysical neutrino flux can only be understood with significantly higher event statistics (x10)

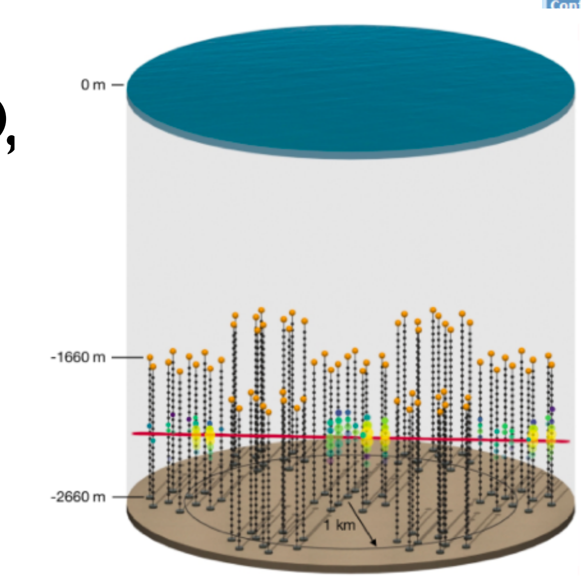
CF1 - Neutrinos - Global Picture

- US based experiments (IceCube) has an excellent track record in delivering very high impact science. IceCube experimental data was undoubtedly the most critical of the indirect search landscape over the last decade
  - US is well positioned to continue experimental leadership with IceCube-Gen2
  - Desirable to maximize scientific returns with US based analyses
- Strong international interest in next generation neutrino telescopes (Baikal-GVD, KM3NeT, P-ONE)
  - Complementarity of the instrumentation can increase the reach further (strong international collaboration desired)

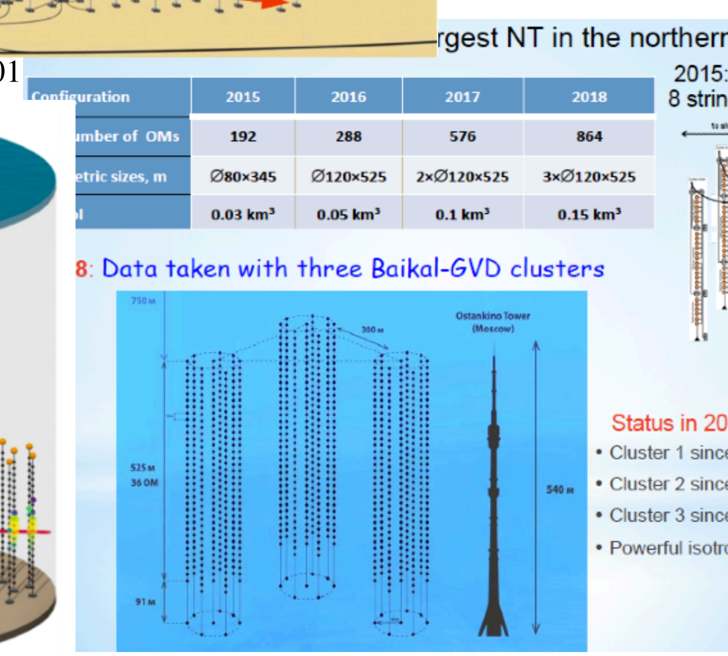

IceCube-Gen2 2008.04323



KM3NeT *J.Phys.G* 43 (2016) 8, 084001



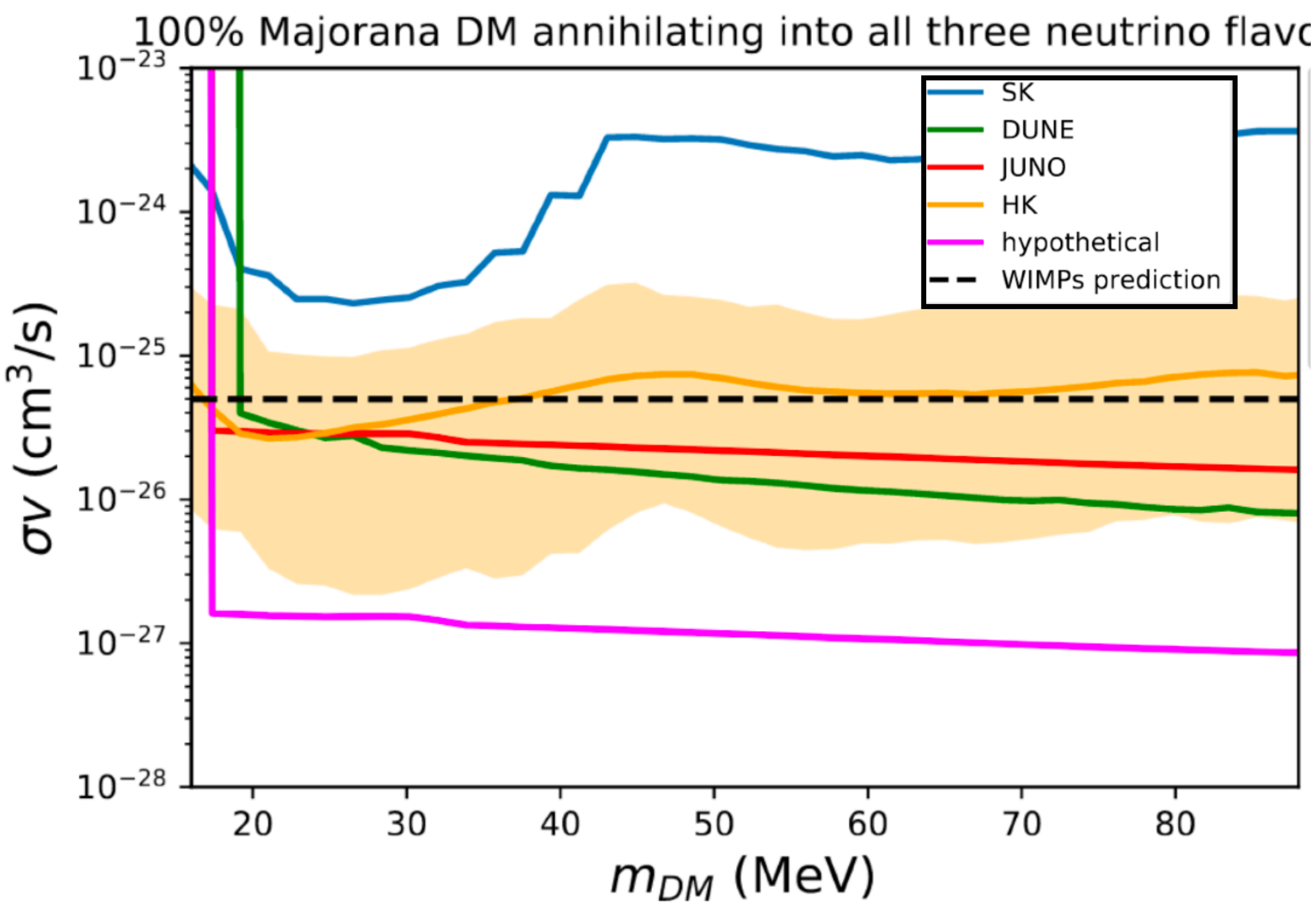
P-ONE 2005.09493



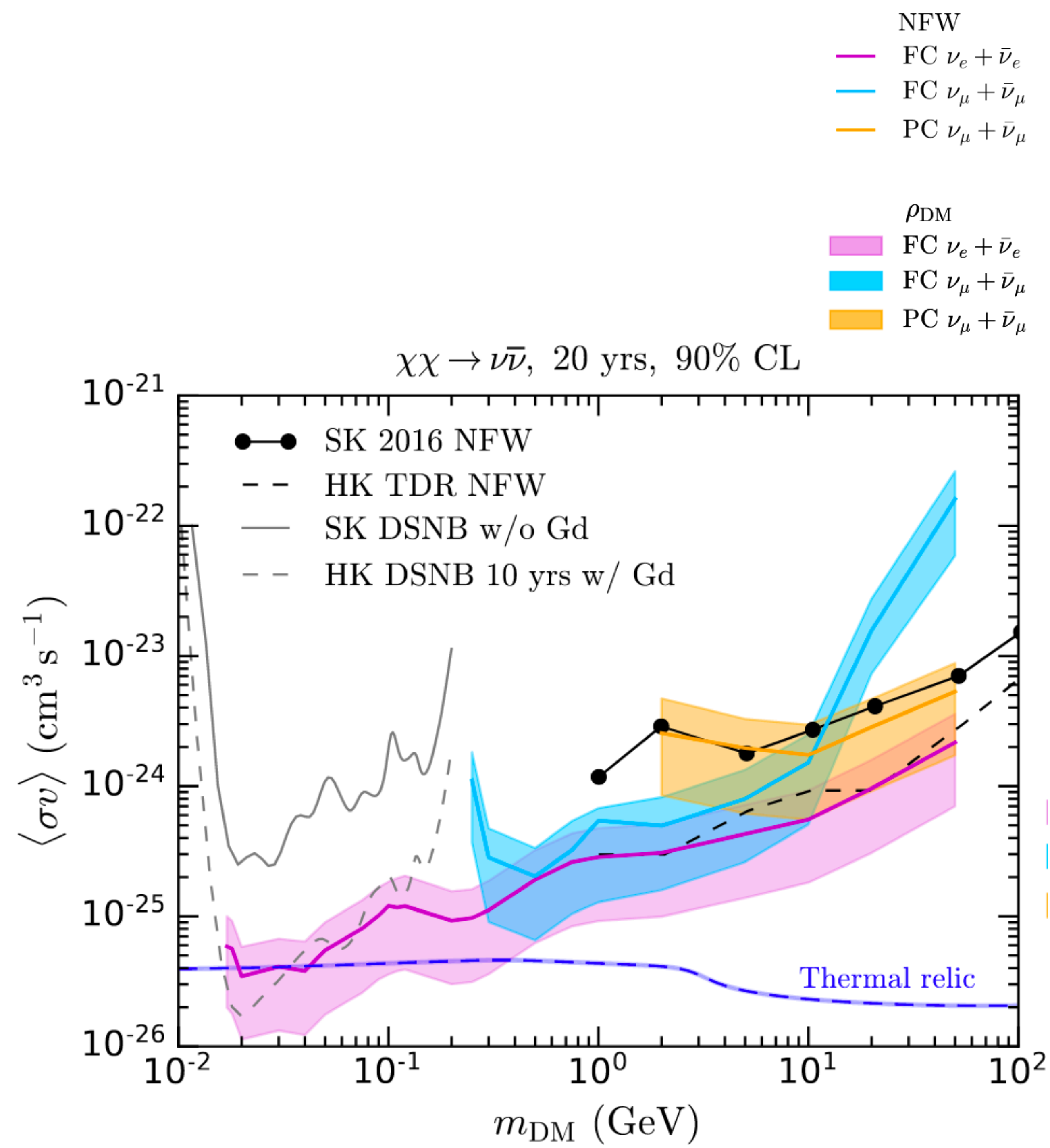
Baikal GVD *EPJ Web Conf.* 209 (2019) 01015

Back up

Next generation large volume neutrino detectors can reach the thermal relic cross section for sub-GeV DM



N. Klop and S. Ando, Constraints on MeV dark matter using neutrino detectors and their implication for the 21-cm results ,Phys. Rev.D98(2018) 103004, [1809.00671]

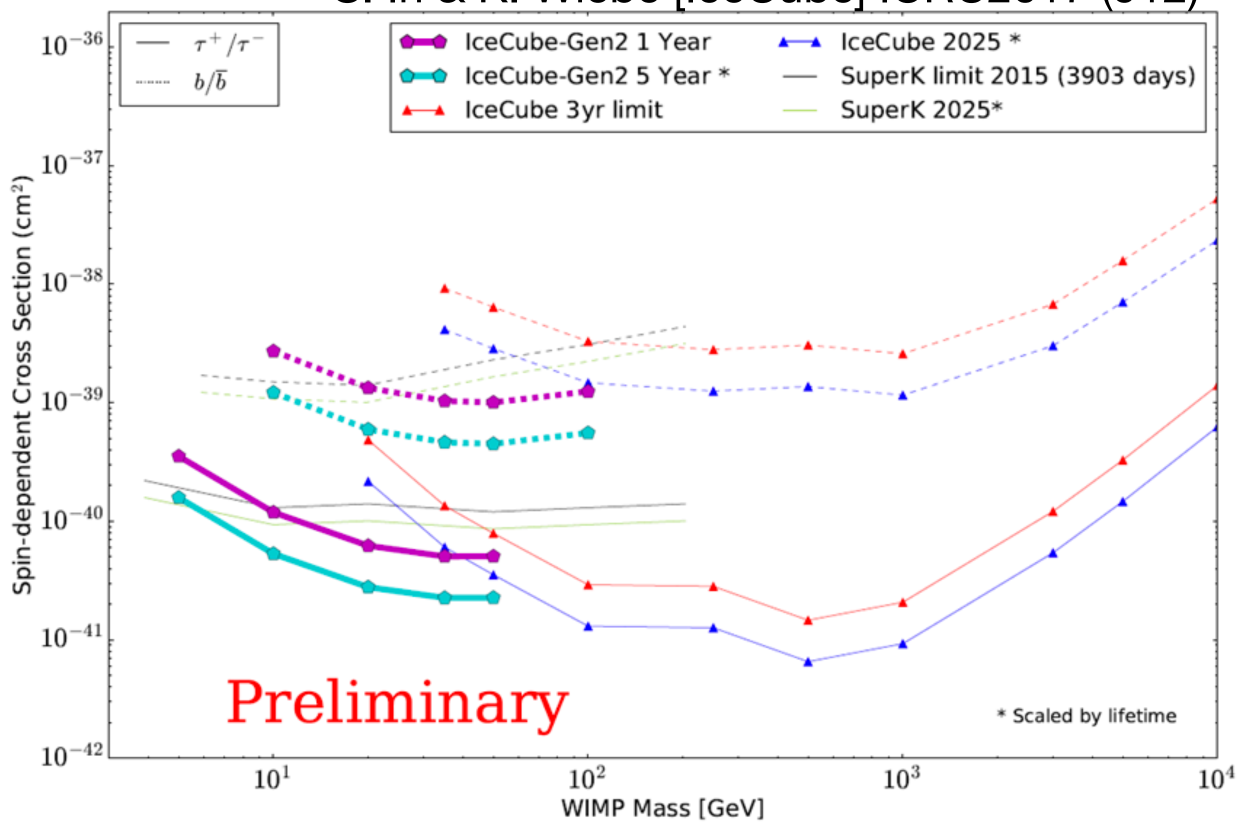


Nicole F. Bell, Matthew J. Dolan, and Sandra Robles arXiv:2005.01950

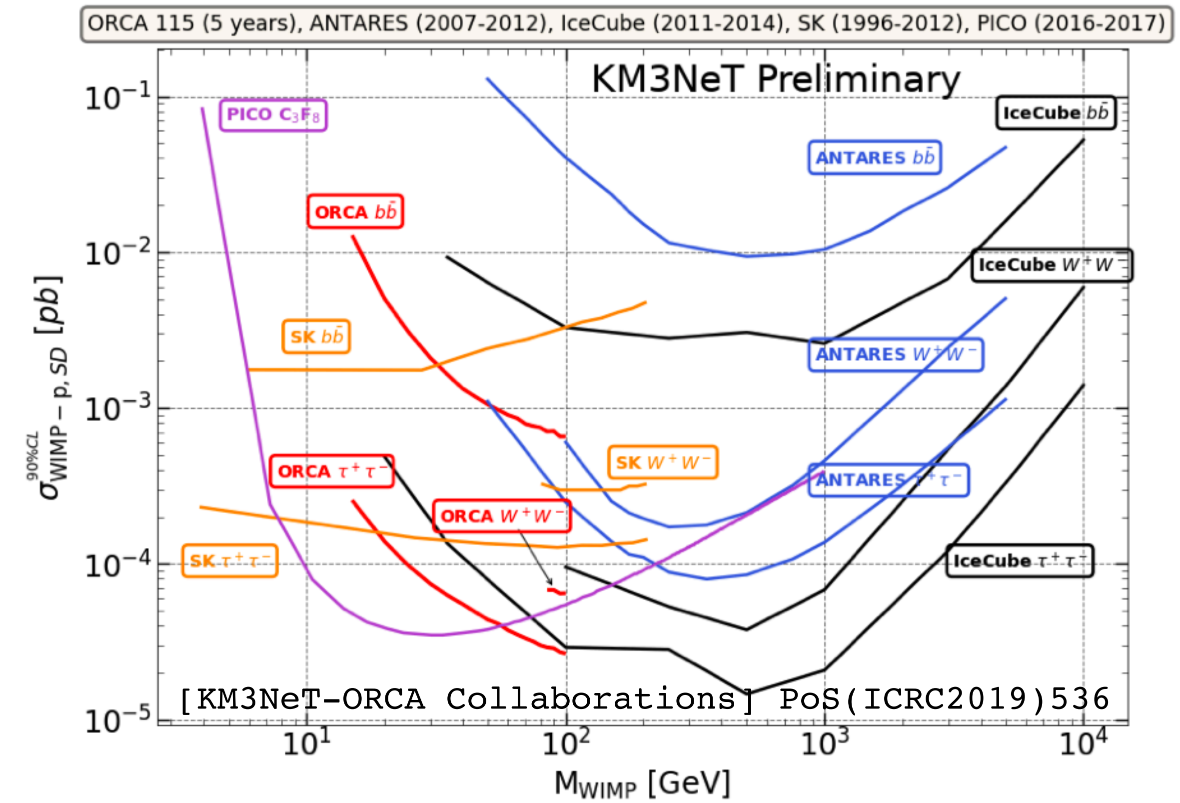
Next generation neutrino detectors

IceCube Upgrade Sensitivity

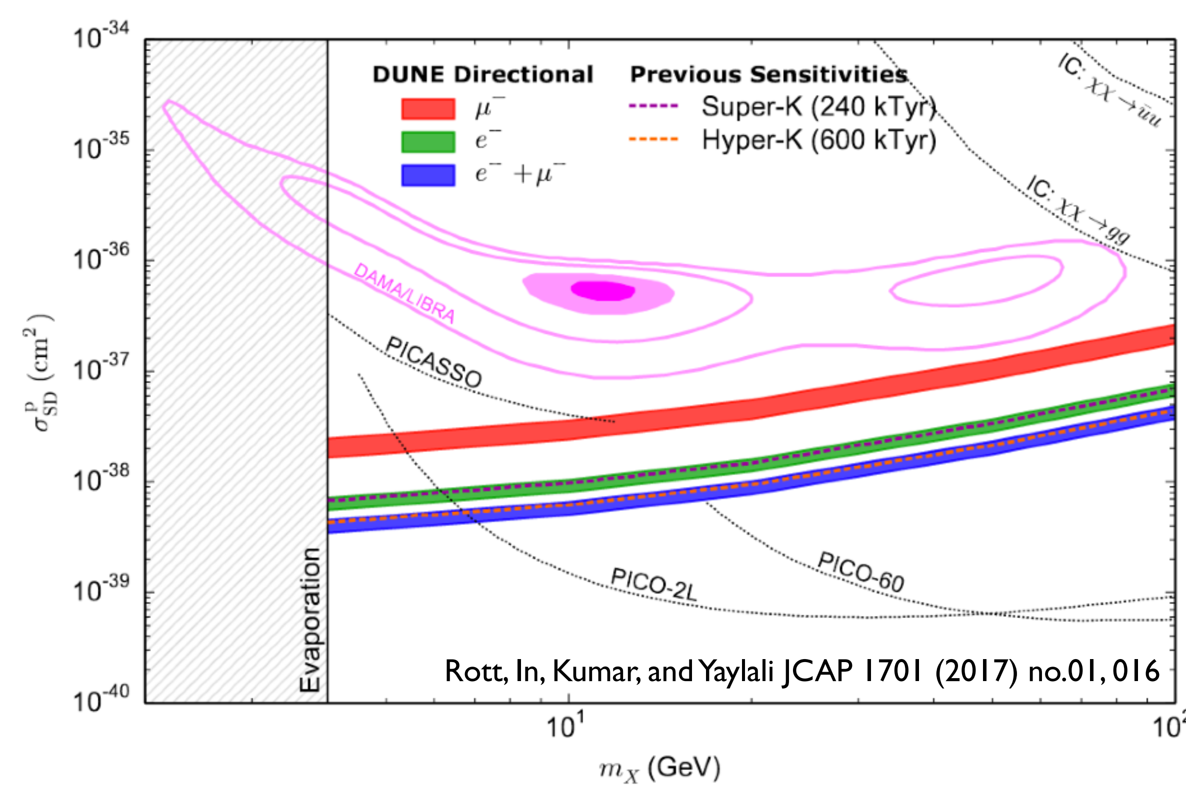
S. In & K. Wiebe [IceCube] ICRC2017 (912)

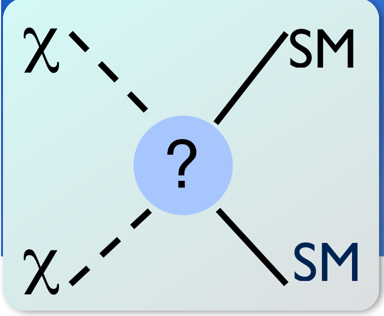


5 years of ORCA (115 lines)

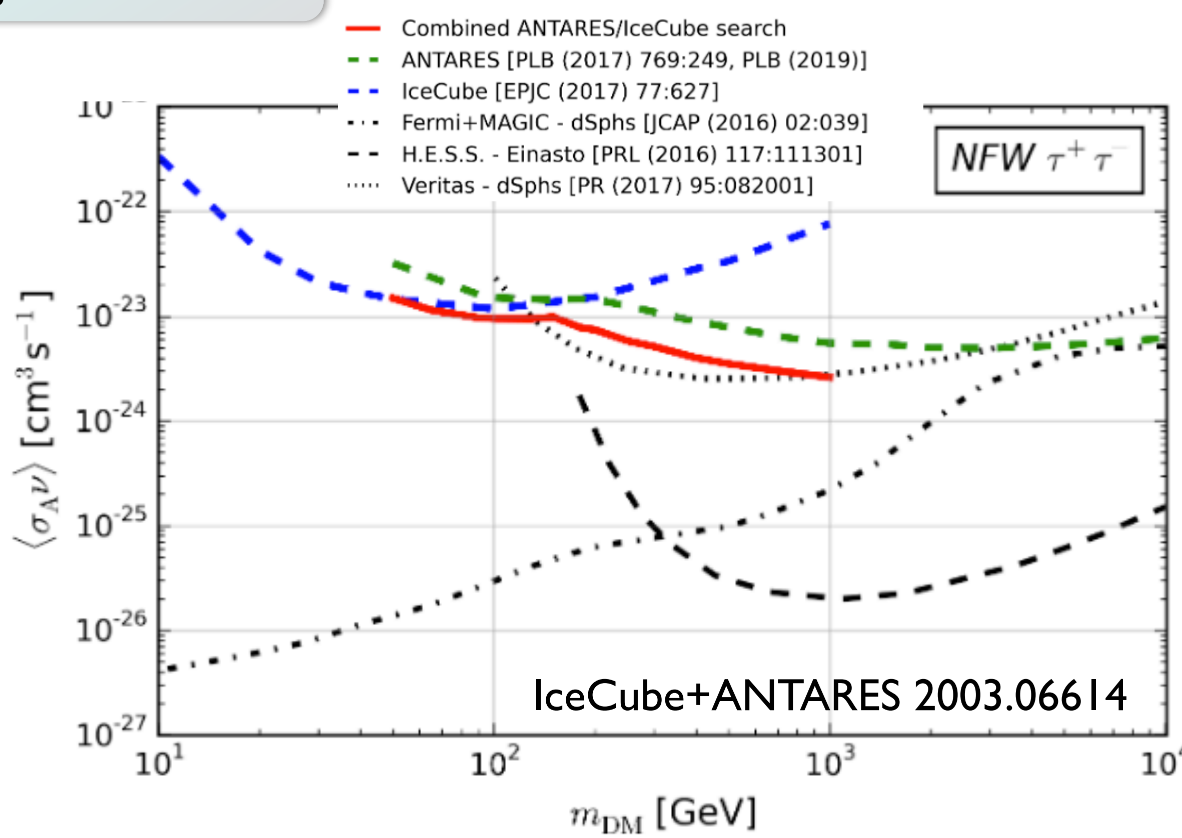


- ORCA and IceCube Upgrade have unique capability to explore DM between 4-50GeV in indirect solar DM searches
- Hyper-K / DUNE can further extend searches with new detection channels

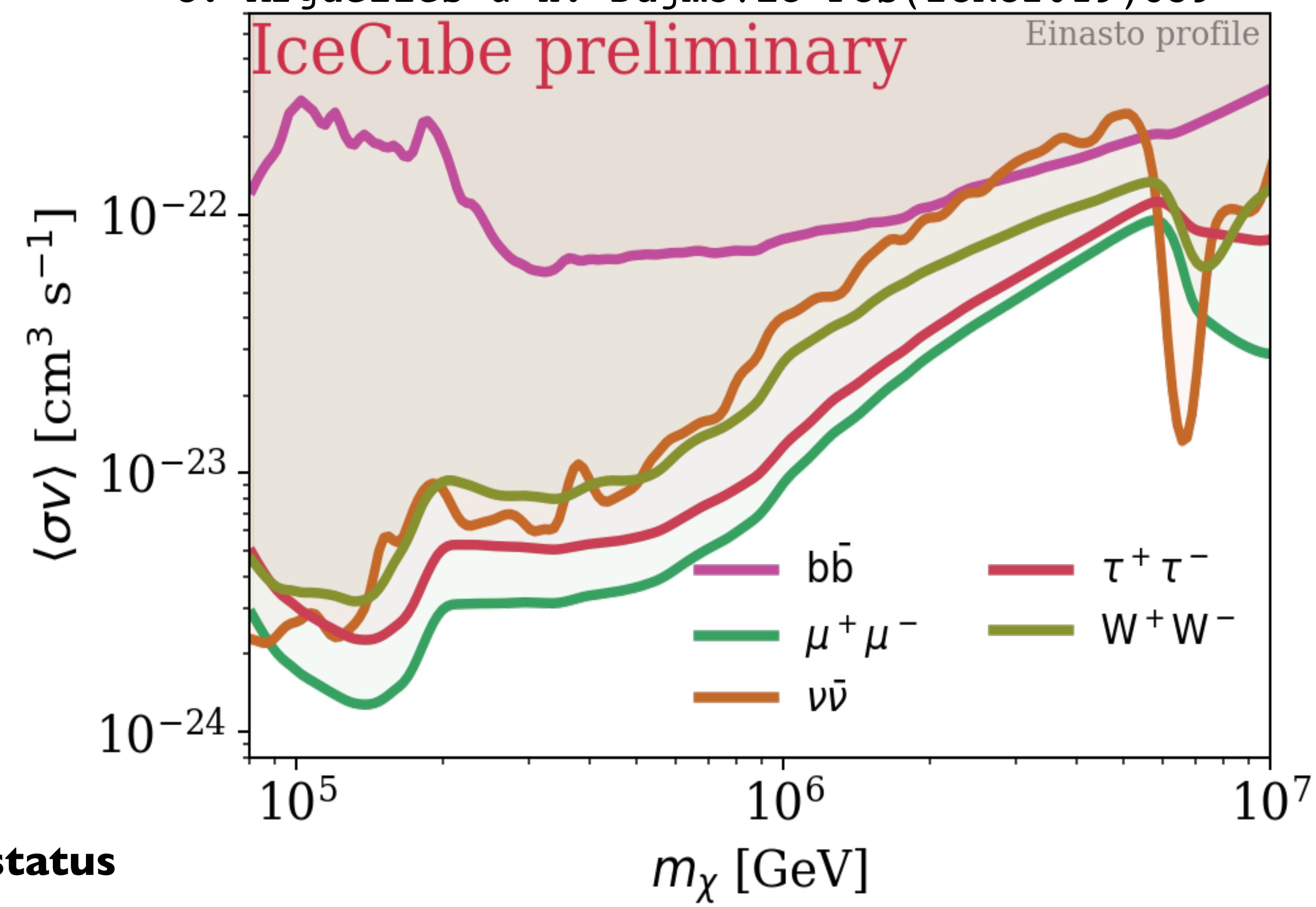




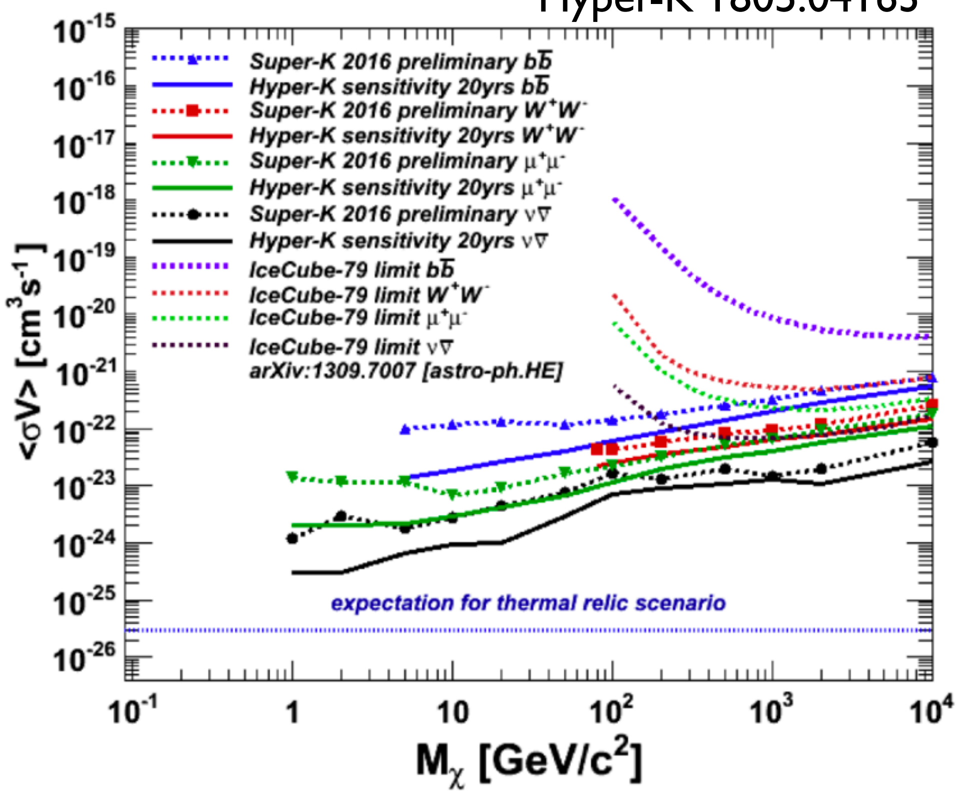
Search Dark Matter Annihilation



C. Arguelles & H. Dujmovic PoS(ICRC2019)839



Hyper-K 1805.04163



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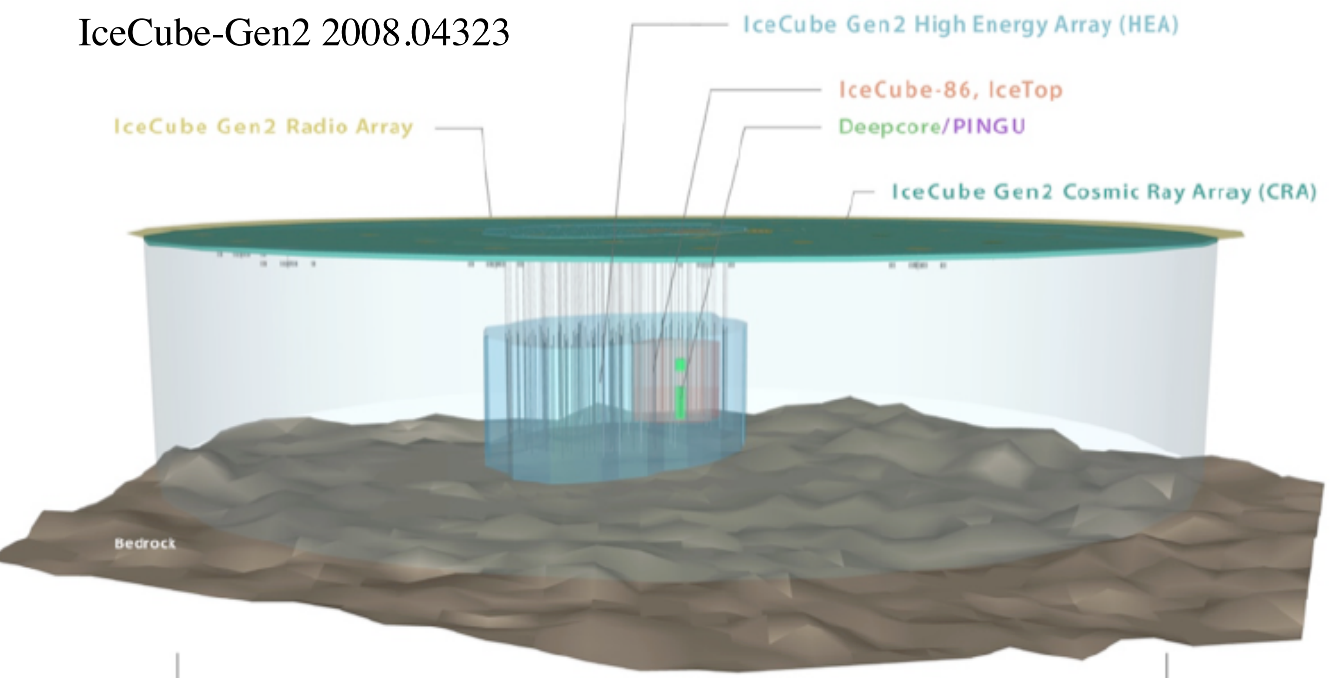
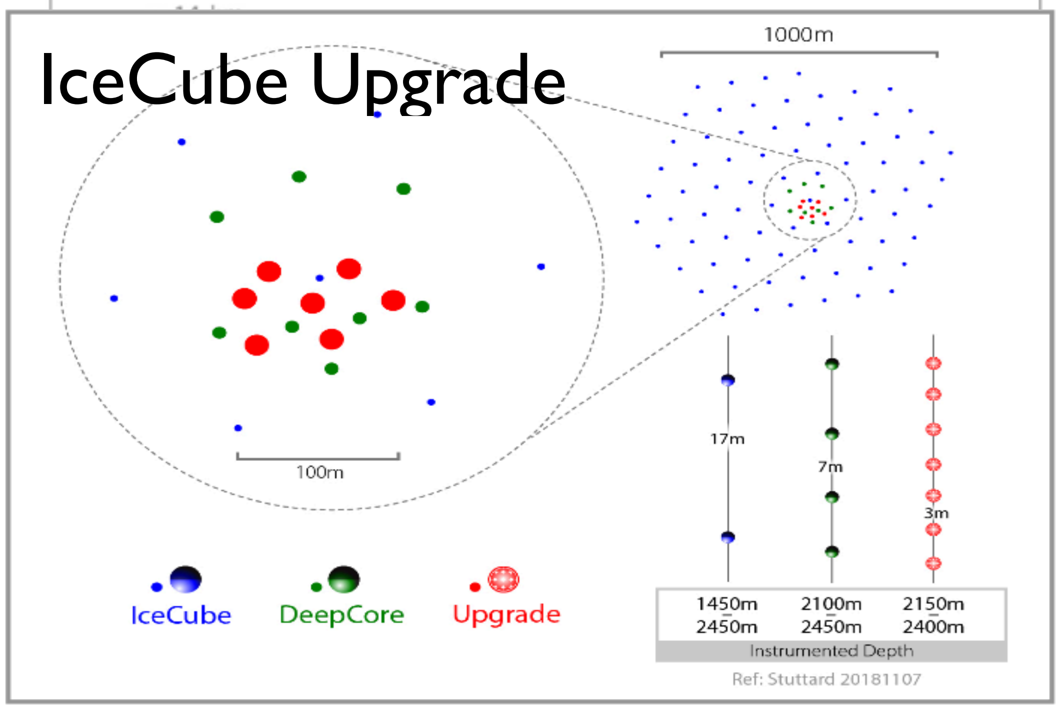
Neutrino telescope landscape expanding quickly

IceCube-Gen2 2008.04323





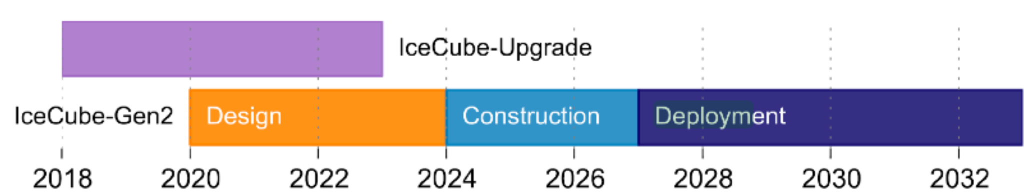
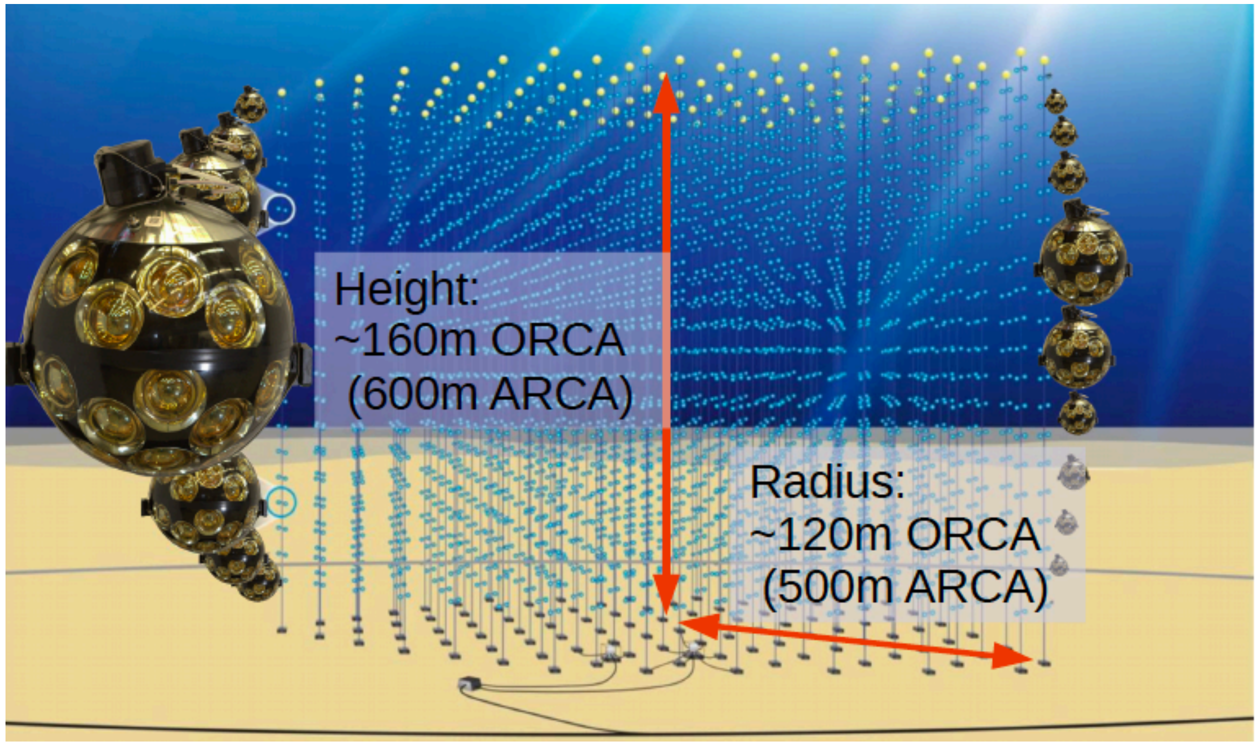
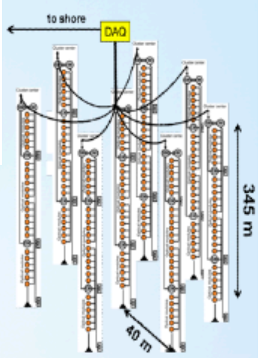


Figure 29: Time line for the IceCube Upgrade and projected time line for IceCube-Gen2.

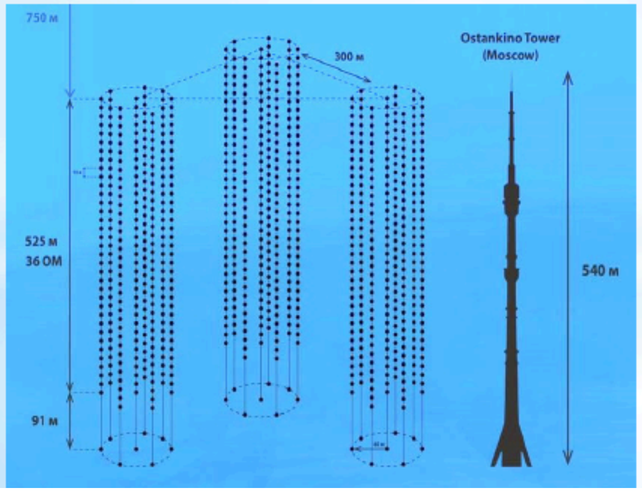


BAIKAL-GVD

hern latitudes
2015: «Dubna»
strings (192 OMs)



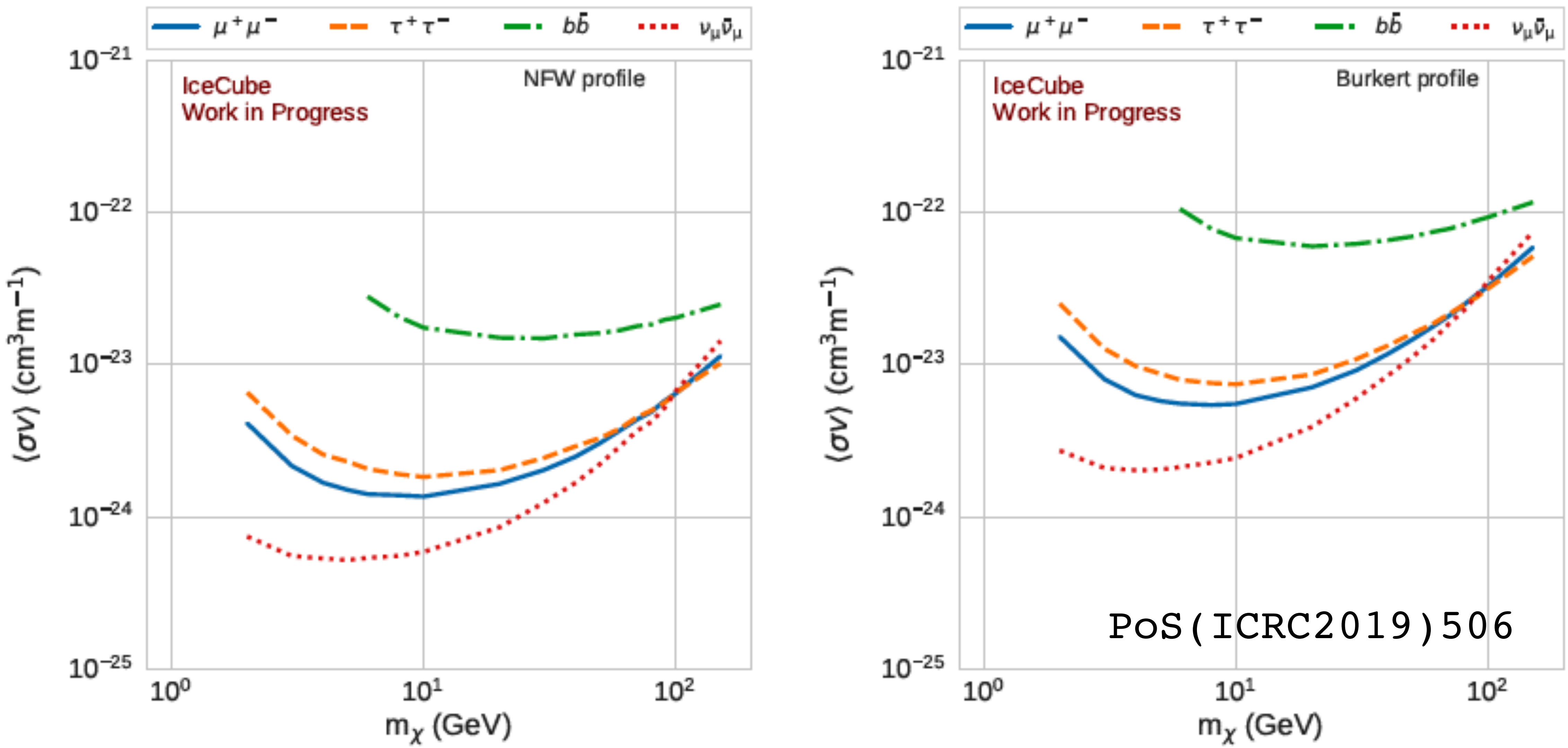
2018: Data taken with three Baikal-GVD clusters



Status in 2018

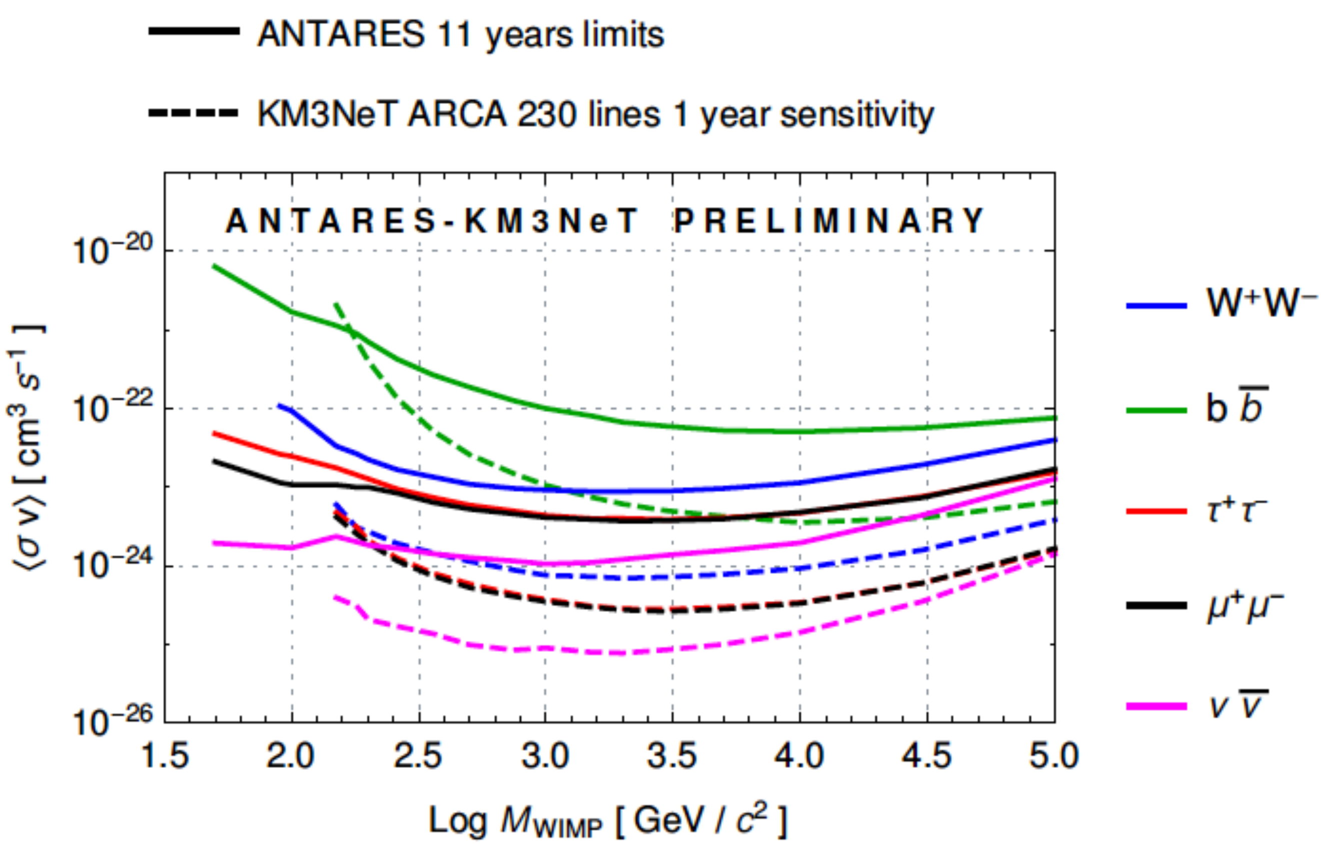
- Cluster 1 since 2016
- Cluster 2 since 2017
- Cluster 3 since 2018
- Powerful isotropic laser source

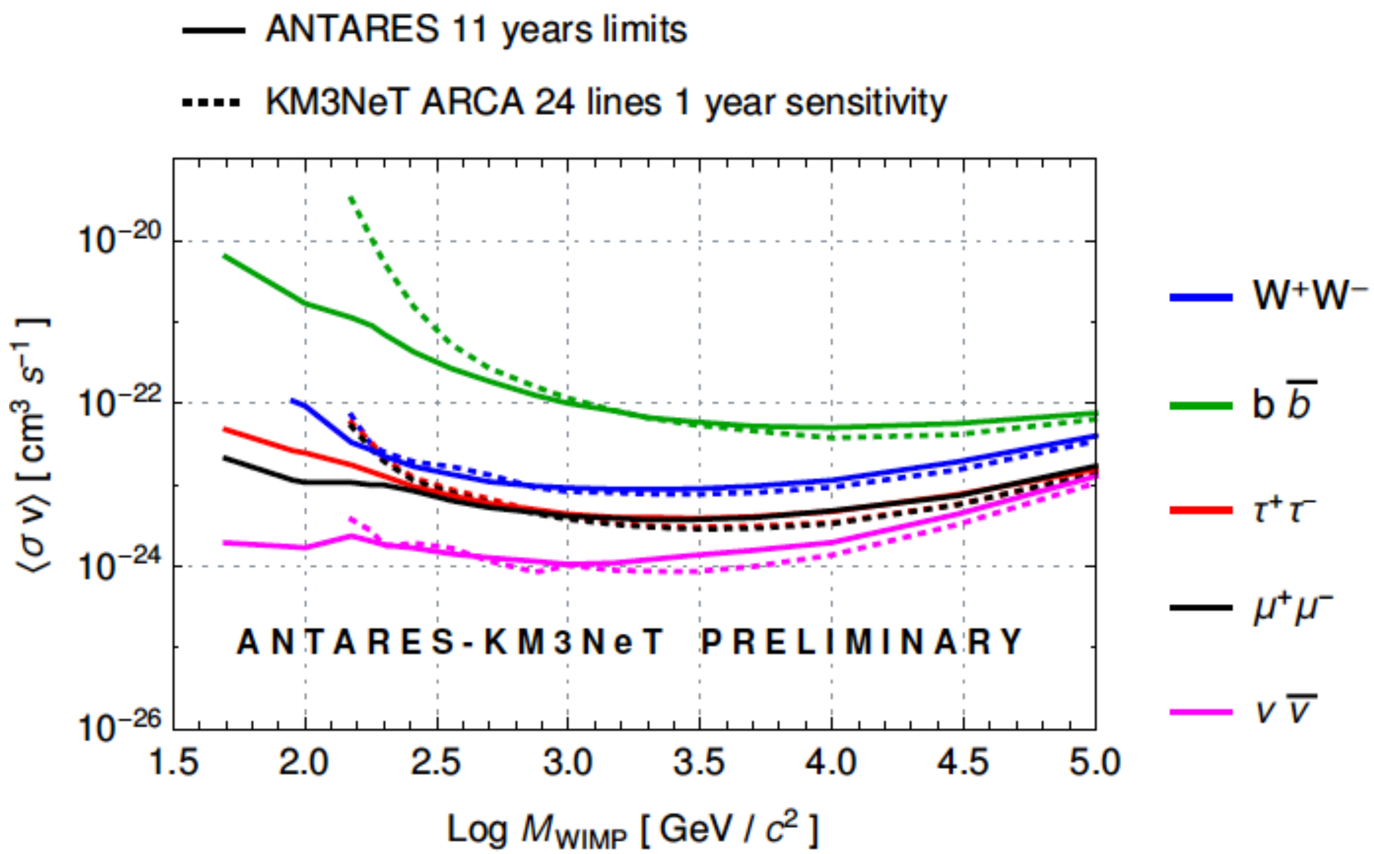
IceCube Upgrade

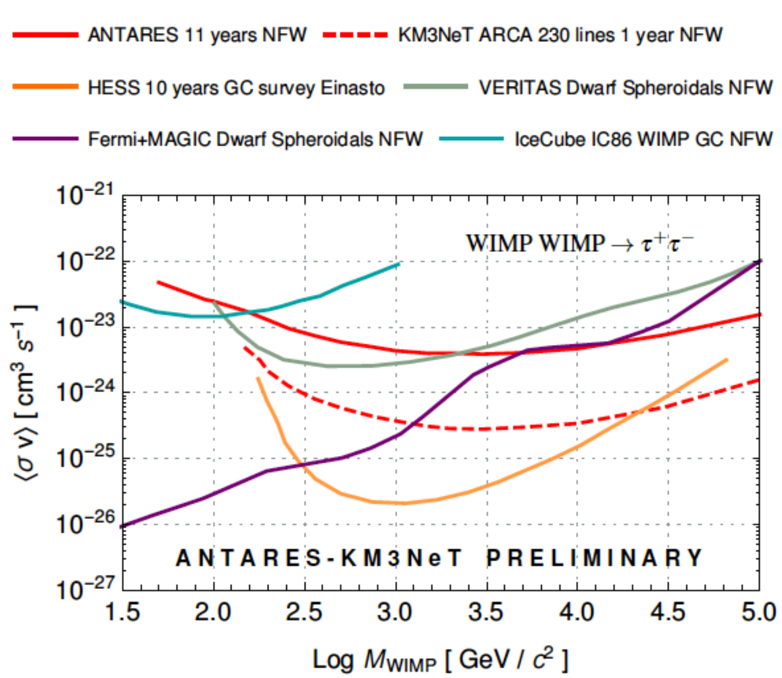


KM3NeT Sensitivity

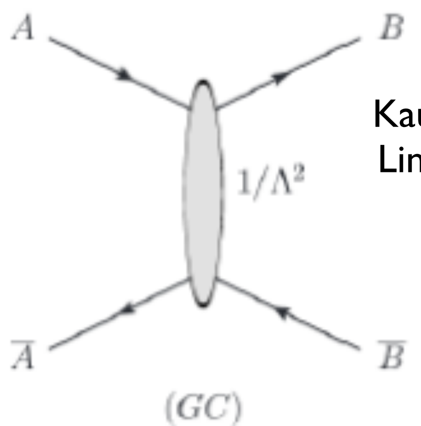
[ANTARES/KM3NeT Collaborations] PoS(ICRC2019)552



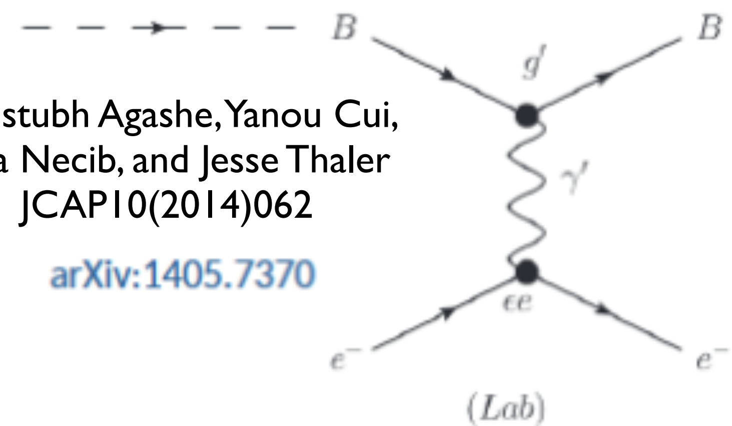




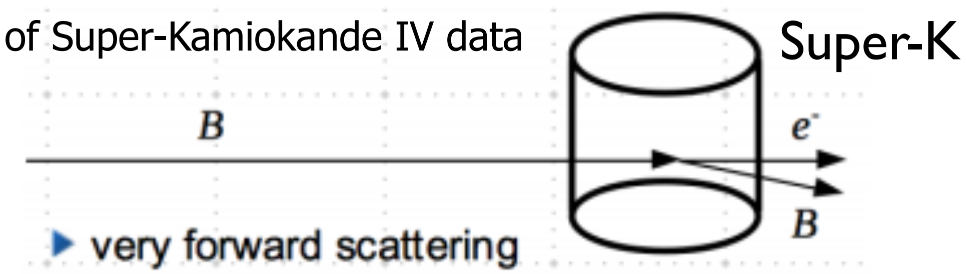
Super-K Boosted Dark Matter



Kaustubh Agashe, Yanou Cui, Lina Necib, and Jesse Thaler
JCAP10(2014)062
arXiv:1405.7370

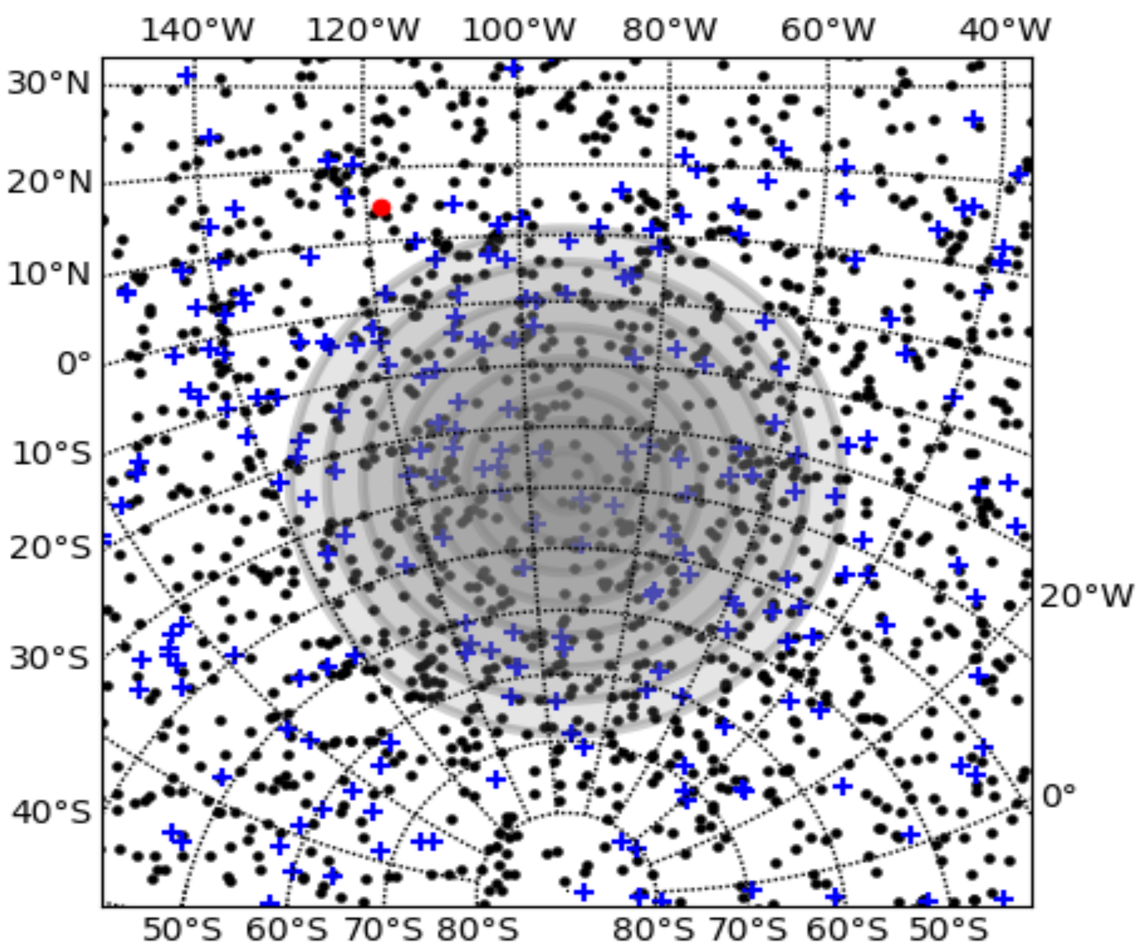


161.9 kiloton-years of Super-Kamiokande IV data



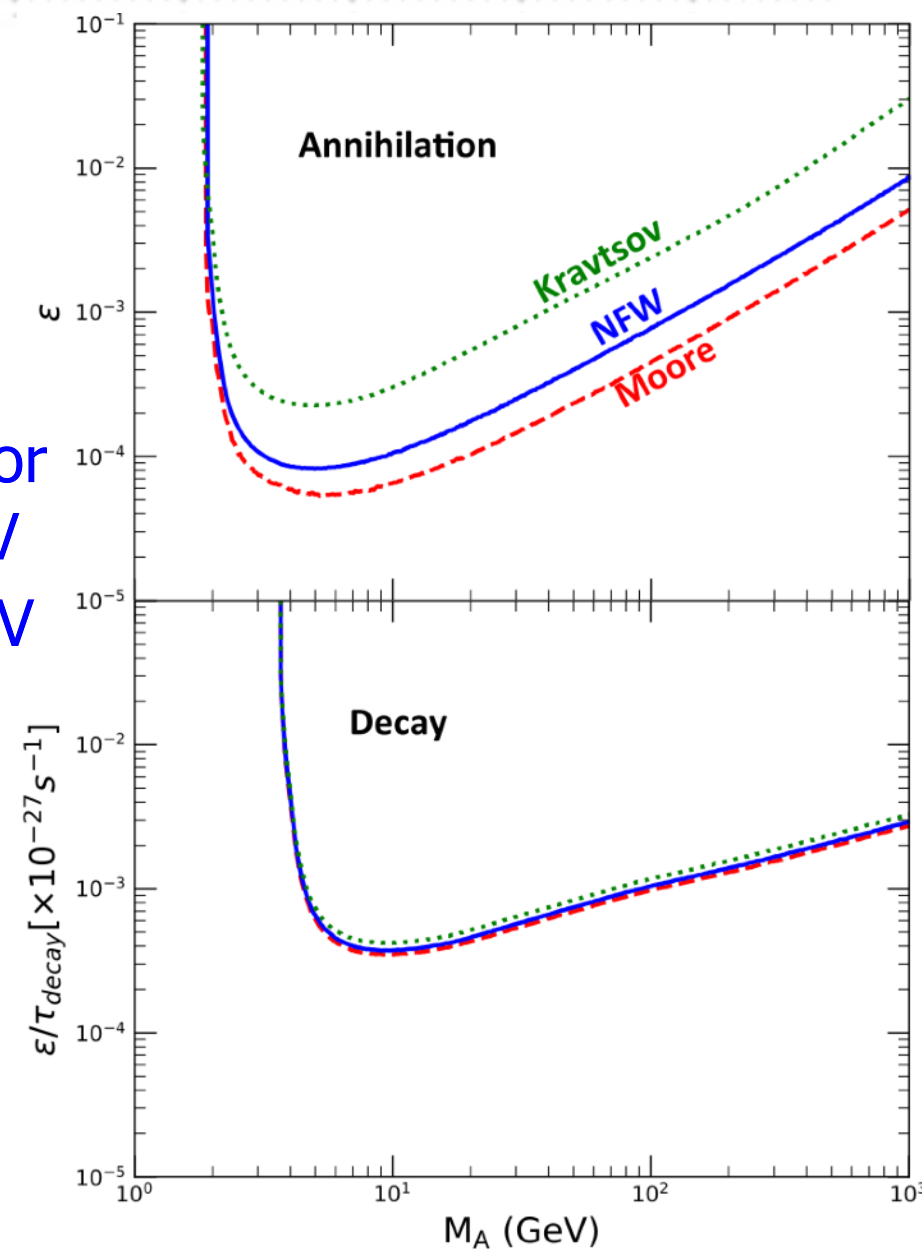
- very forward scattering
- electromagnetic shower
- no hadrons → no decay e, no neutrons

Cone search: 8 cones from 5° to 40° around GC
➔ no cluster found around Galactic Center



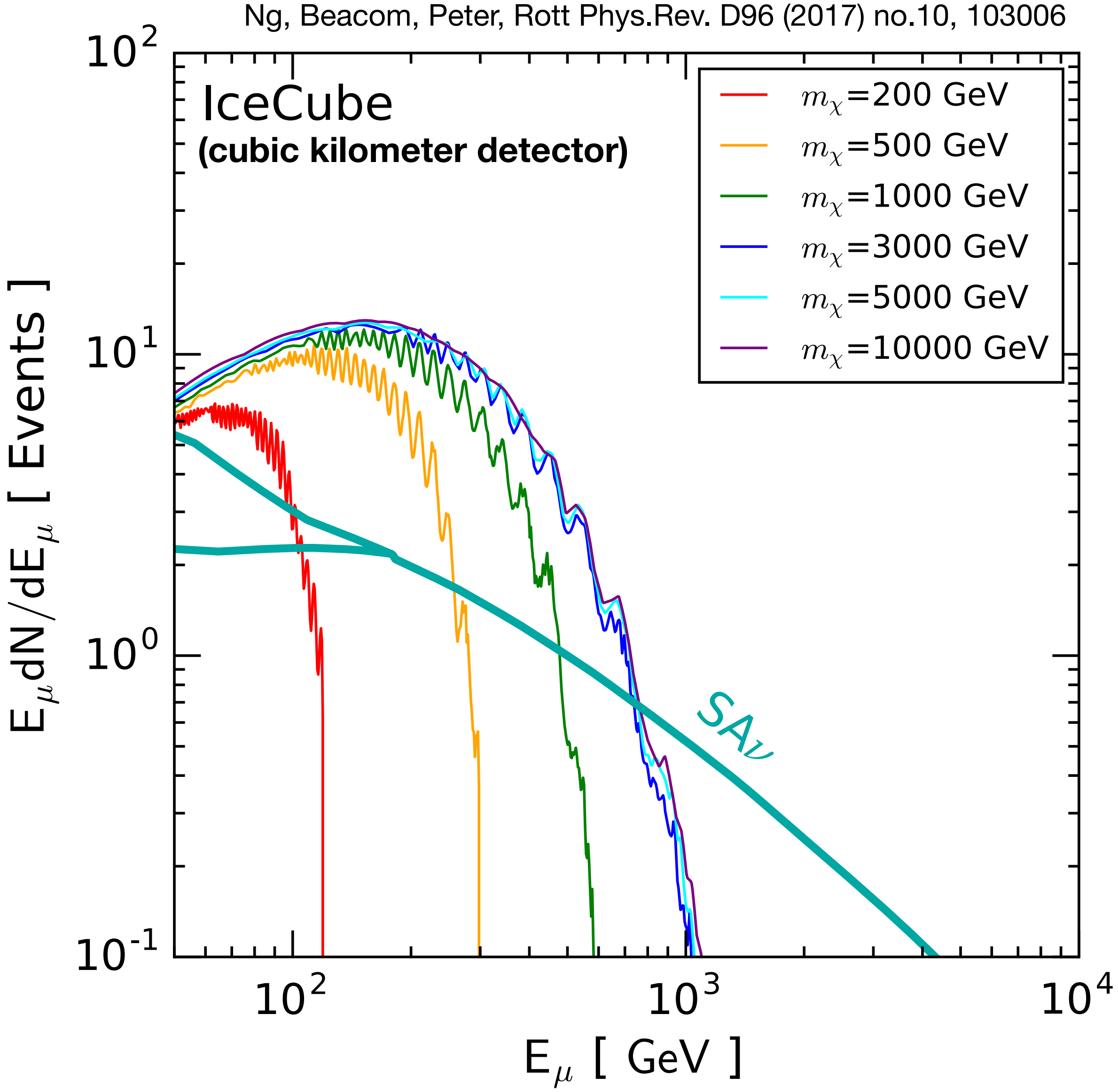
• < 1.33 GeV + 1.33 GeV-20 GeV • >20 GeV

90% limits for
$m_{\gamma'}$=20 MeV
m_B=200 MeV
g'=0.5

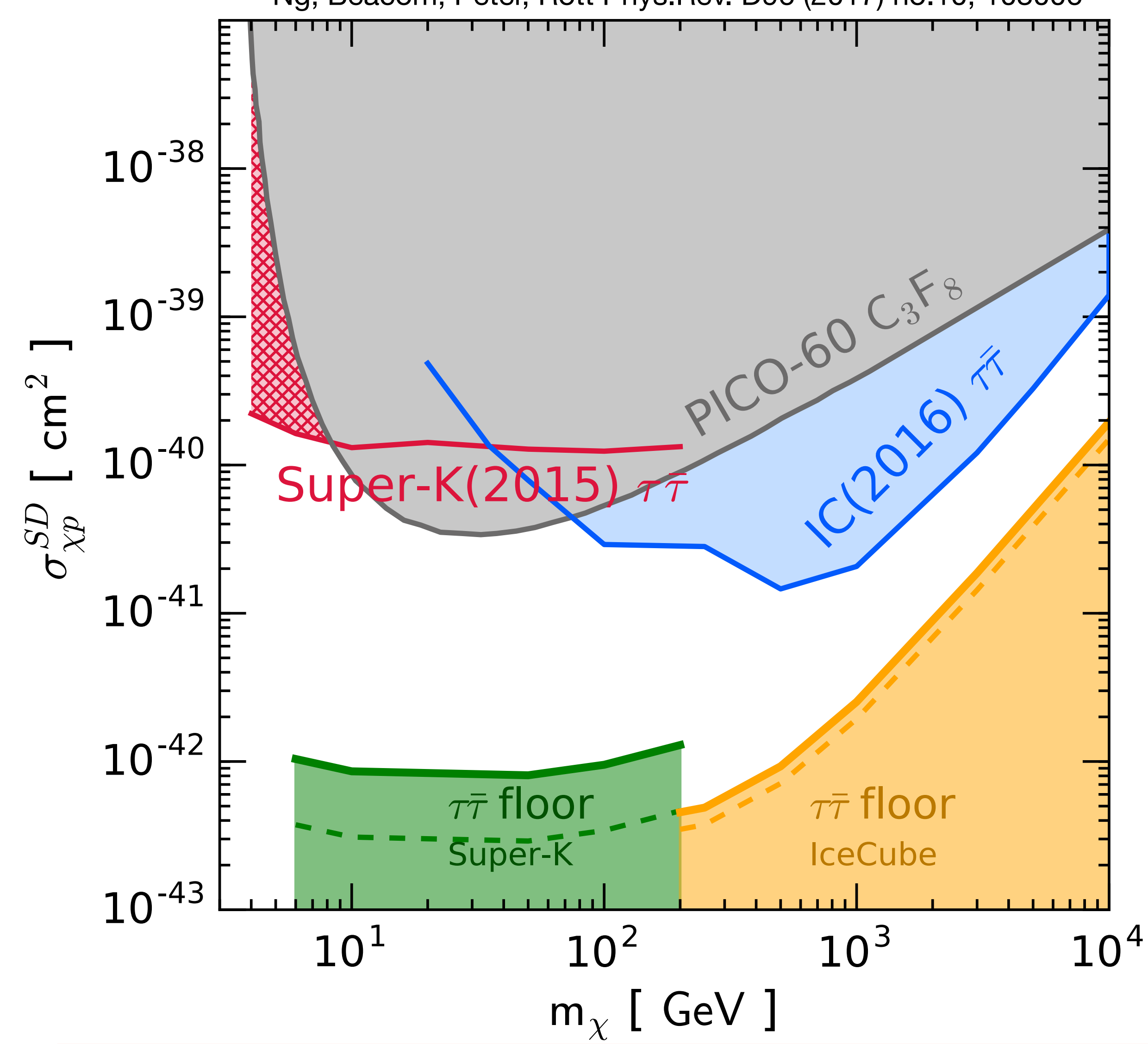


Cosmic background from the Sun

Ng, Beacom, Peter, Rott Phys.Rev. D96 (2017) no.10, 103006



Ng, Beacom, Peter, Rott Phys.Rev. D96 (2017) no.10, 103006



- Solar Atmospheric neutrinos give a new background to solar dark matter searches
  - However, energy spectrum expected to be different
  - In DM annihilation neutrinos significantly attenuated above a few 100GeV

Expect ~2events per year at cubic kilometer detector

Solar Atmospheric Neutrinos / Atmospheric Neutrino Floor:

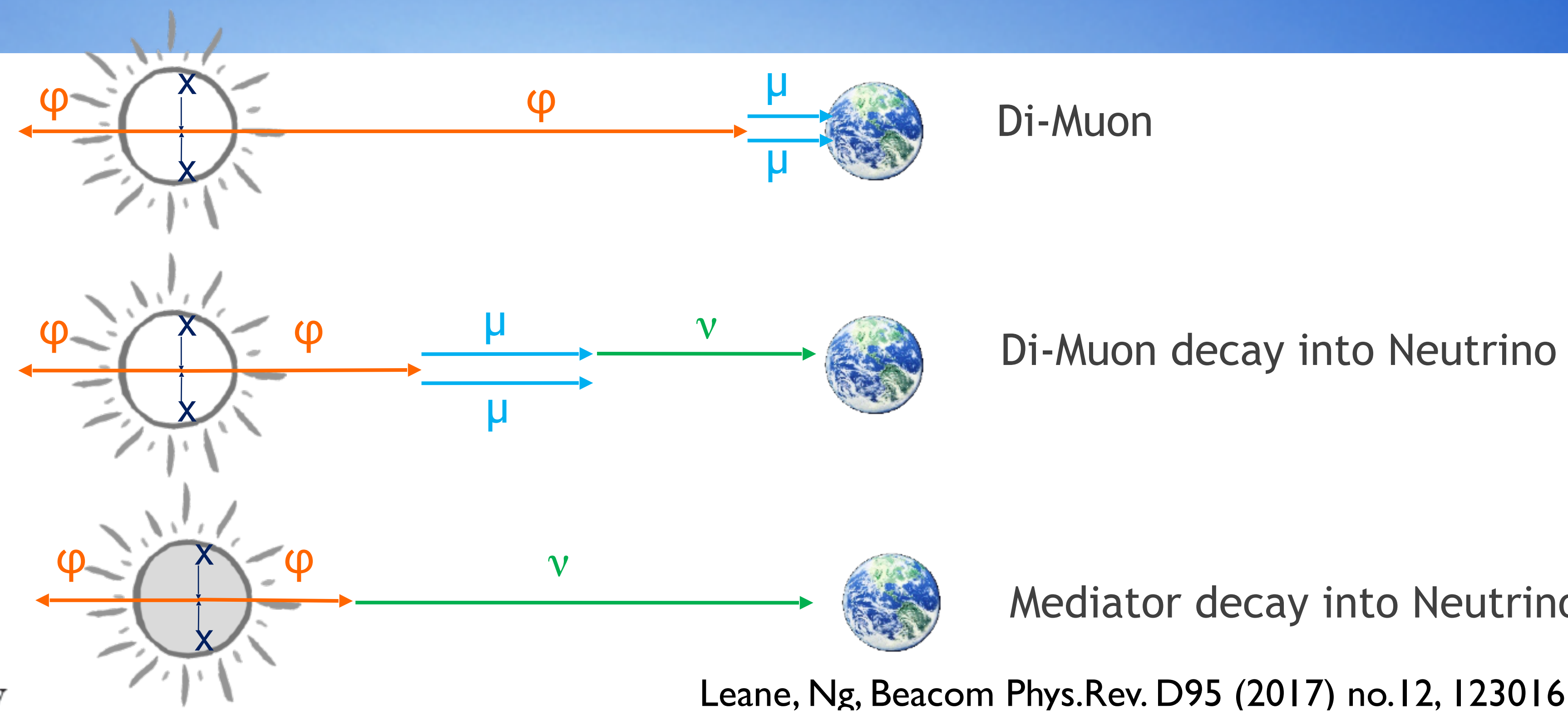
- C. Argüelles, G. de Wasseige, A. Fedynitch, B. Jones **JCAP 1707 (2017) no.07, 024** [arXiv:1703.07798]
- K. Ng, J. Beacom, A. Peter, C. Rott **Phys.Rev. D96 (2017) no.10, 103006** [arXiv:1703.10280]
- J. Edsjö, J. Elevant, R. Enberg, and C. Niblaeus, **JCAP 2017 .06 (2017), p. 033**, arXiv: 1704.02892 [astro-ph.HE]
- M. Masip **Astropart.Phys. 97 (2018) 63-68** [arXiv: 1706.01290]

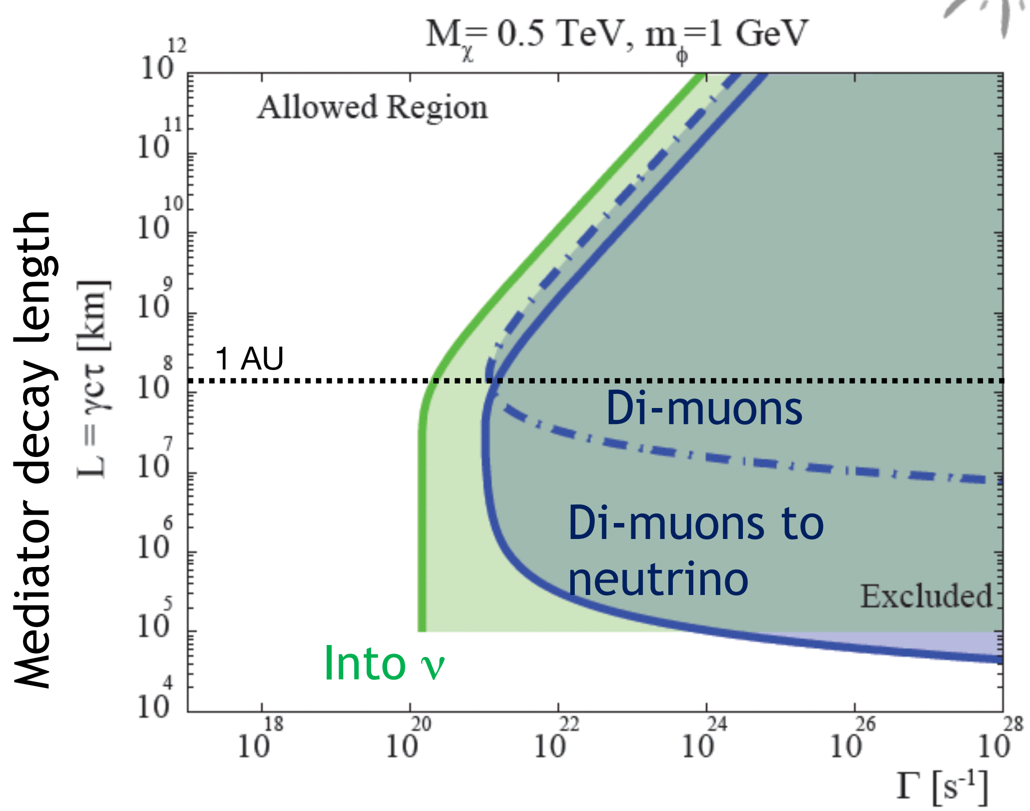
Experimental Search:
S. In & C. Rott ICRC2017 (965) / IceCube Coll. 1912.13135

ANTARES Coll. JCAP 1605 (2016) no.05, 016

ANTARES Secluded Dark Matter

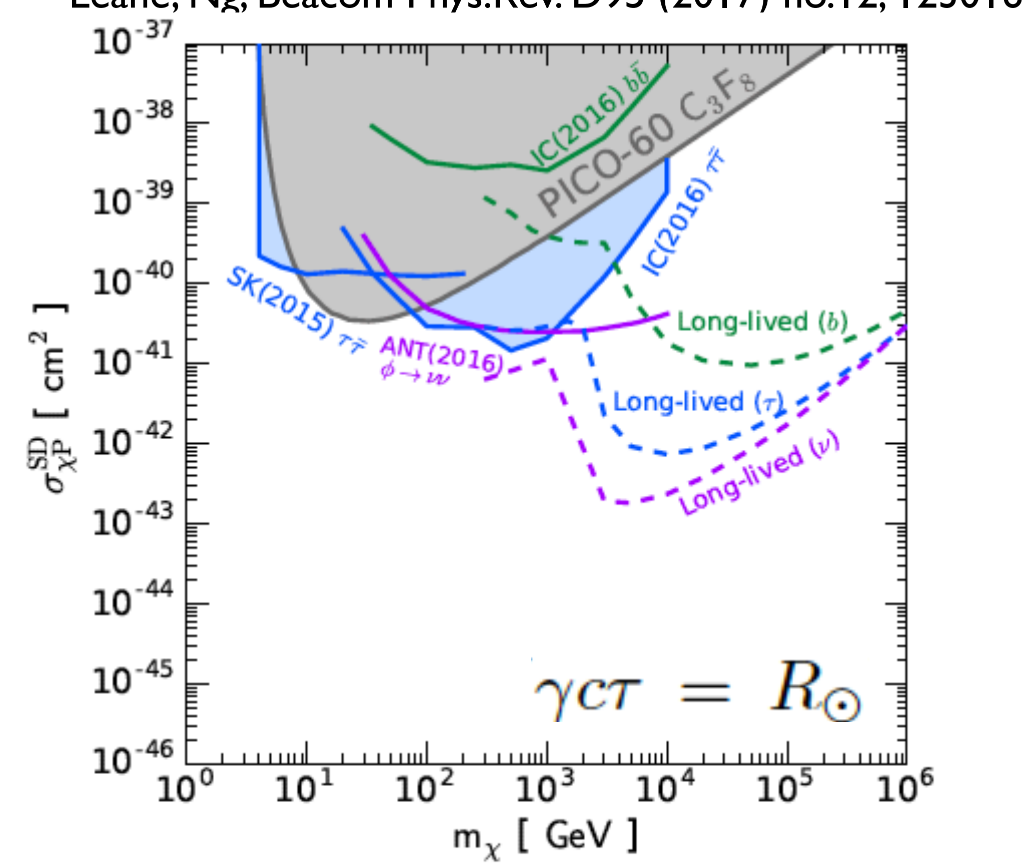
- Dark matter annihilates into meta-stable particle
    - χχ annihilates into mediator φ
        - φ → νν or μμ
- Livetime of 1321 days (Jan 2007 to Oct 2012)





Annihilation of DM in the Sun x Branching ratio

Leane, Ng, Beacom Phys.Rev. D95 (2017) no.12, 123016

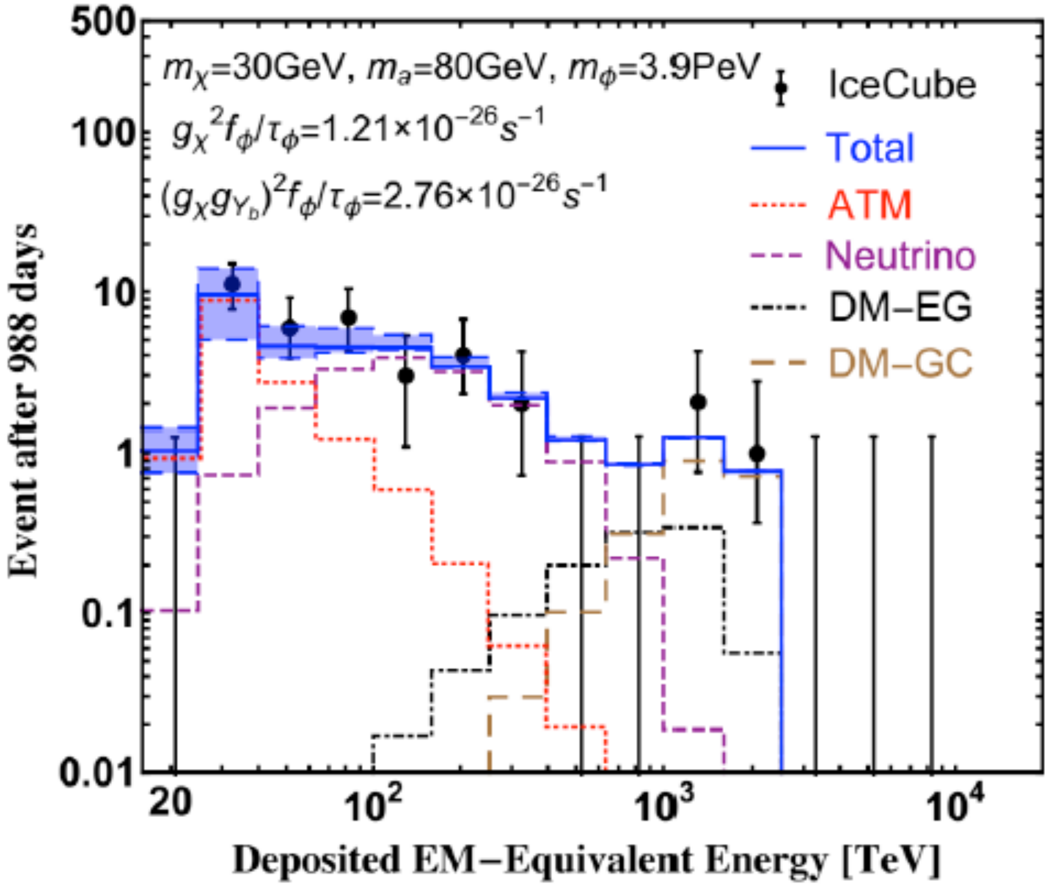


- Contrarily to standard solar WIMP scenarios, secluded dark matter can produce neutrinos > 1TeV
- For most channels, EM signals are expected, cross checks with HAWC, etc. possible

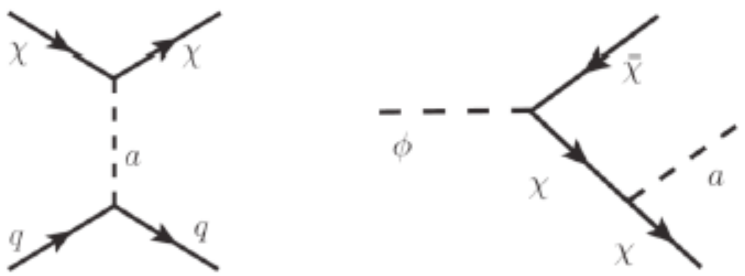
IceCube Boosted Dark Matter

First proposed
Atri Bhattacharya, Raj Gandhi, Aritra Gupta JCAP03(2015)027 / arXiv:1407.3280
see also
Atri Bhattacharya, Raj Gandhi, Aritra Gupta, Satyanarayan Mukhopadhyay JCAP05(2017)002 / arXiv:1612.02834

- Following search proposed by Kopp, Liu, Wan (2015)
- using "Echo Technique" Li, Bustamante, Beacom (2016)

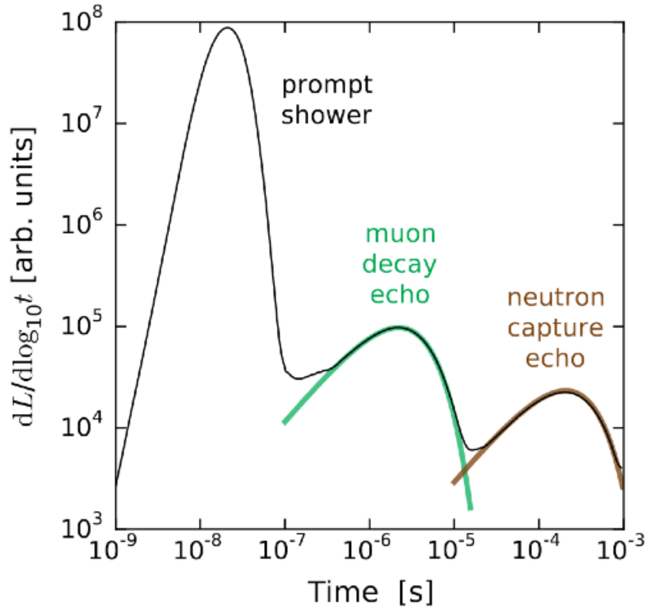


Very heavy dark matter particle ϕ decays to lighter stable dark matter χ →boost!



Recoil (only hadronic cascades)

$\phi \to \chi \bar{\chi}$ a, a → b $\bar{b}$ →ν's

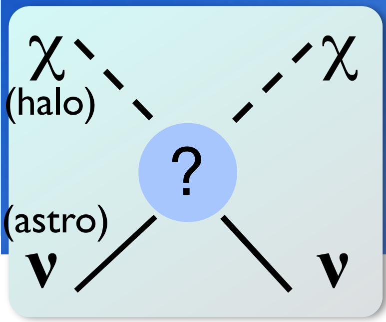


Neutrons capture on hydrogen and product 2.2MeV gamma. In seawater, 33% of neutrons capture on Cl; the emitted gamma rays have 8.6 MeV, making the neutron echoes more visible

"Echo Technique" holds prospects to individually tag high-energy NC and CC interactions !

May sound crazy, but is just an example for exotic interactions in IceCube detectable via recoil

see also A. Steuer, L. Koepke [IceCube] PoS(ICRC2017)1008

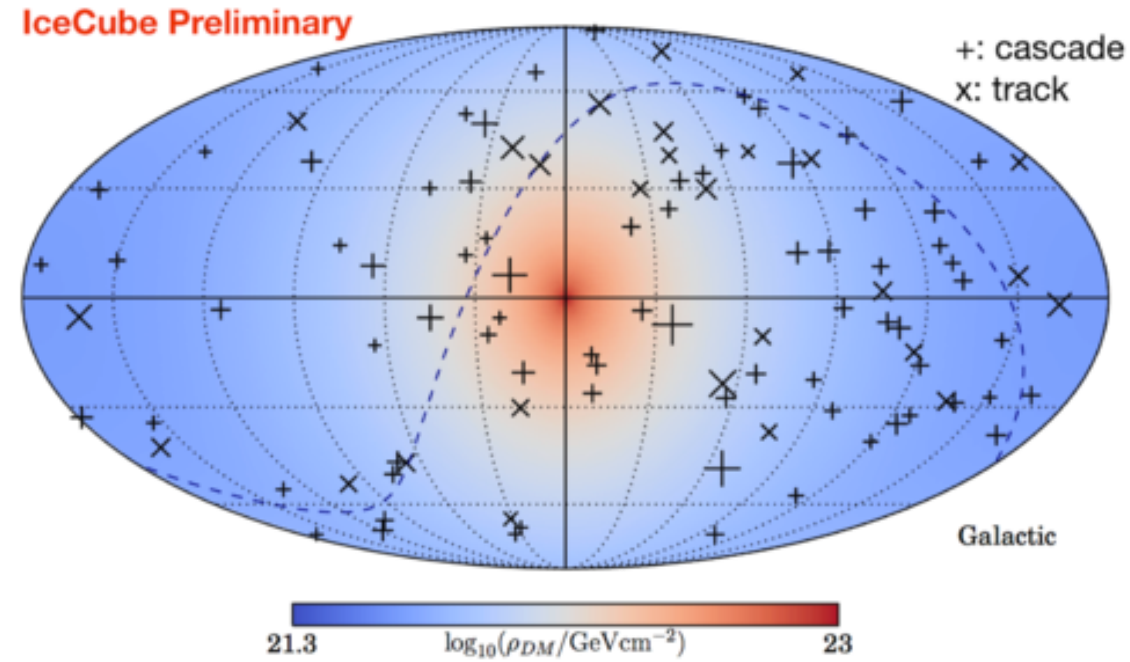


Probing dark matter neutrino interactions with HESE 7.5yrs and Galactic Halo

[C. A. Argüelles, A. Kheirandish A. C. Vincent Phys.Rev.Lett. 119 (2017) no.20, 201801 (arXiv:1703.00451)]

Dark Matter - Neutrino Interaction

- Scattering of high energy astrophysical neutrinos on DM in the Galactic halo can lead to a deficit of high energy neutrinos
  - Neutrino-DM interactions mediated by a scalar or vector mediator f.
  - Limits on coupling constant, g, possible by measuring the isotropy of the HE neutrino flux

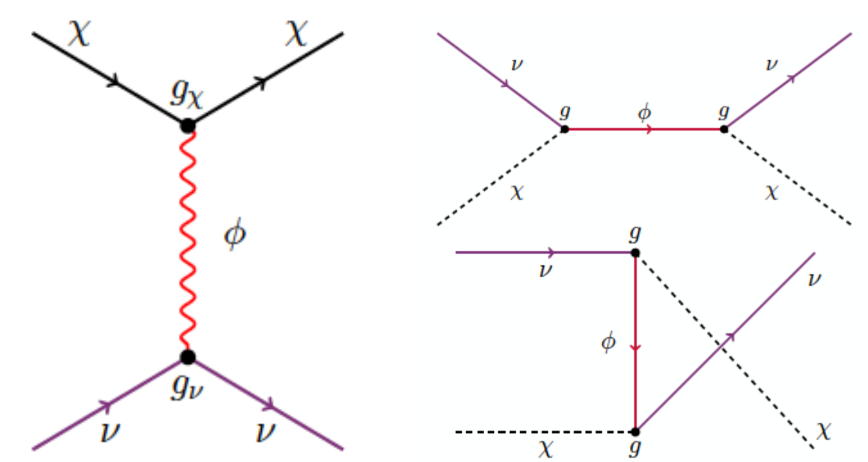


Assume:

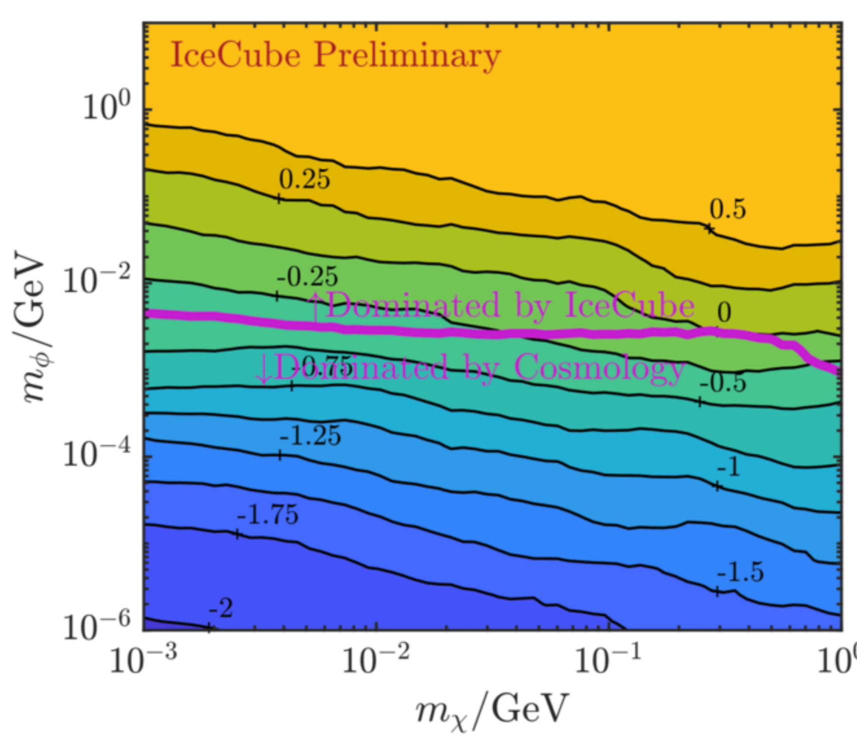
$$\sigma_{DM-\nu} \propto E_\nu^2$$

(1) Fermionic DM, vector mediator

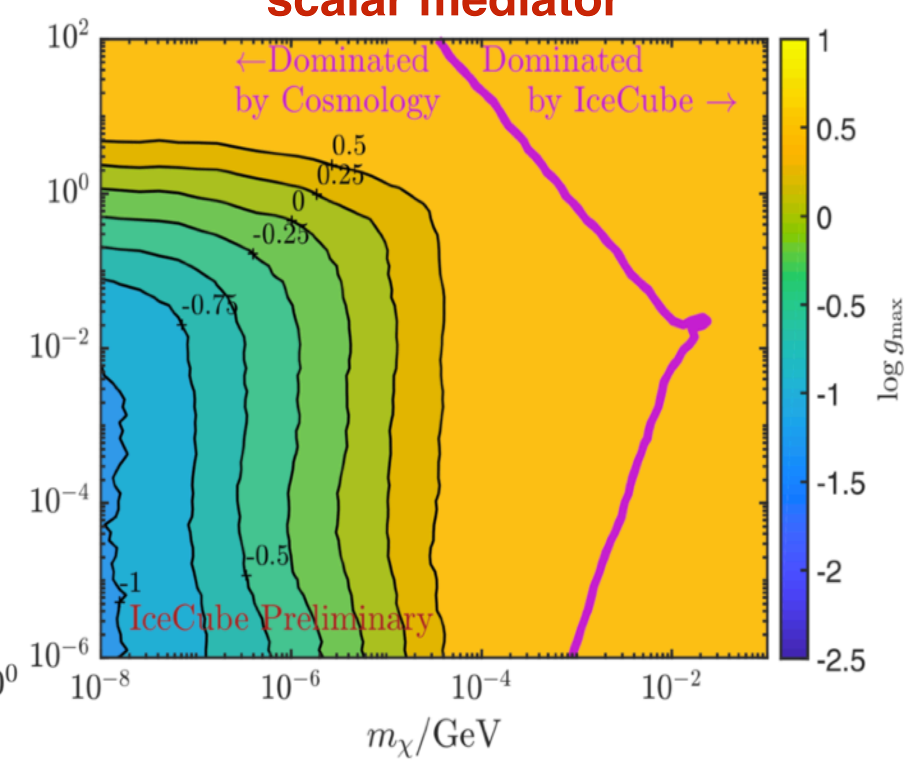
(2) Scalar DM, ferminonic mediator



vector mediator



scalar mediator



KM3NeT/ORCA Sensitivity

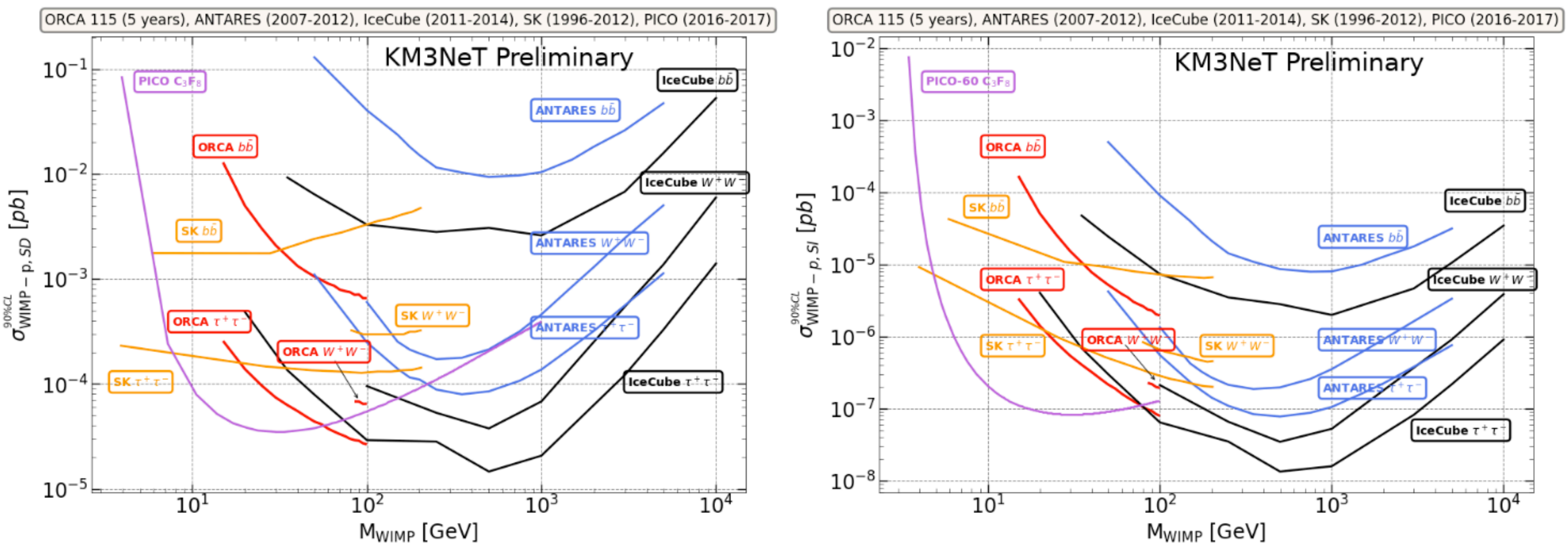
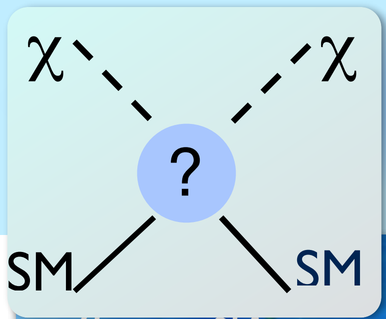
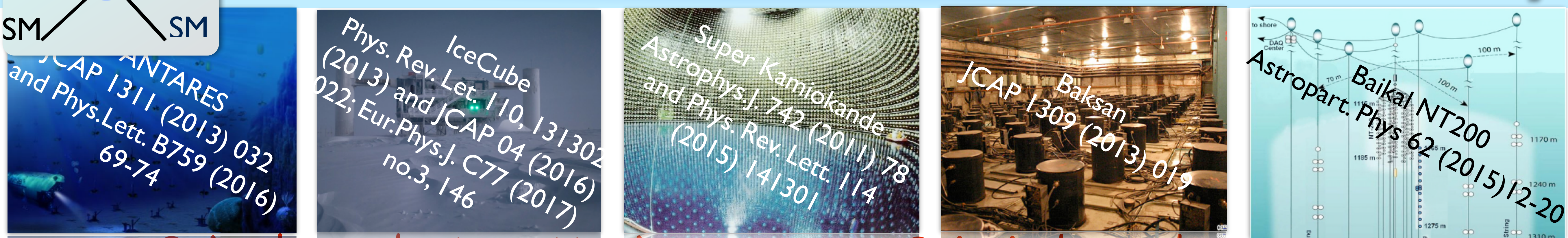


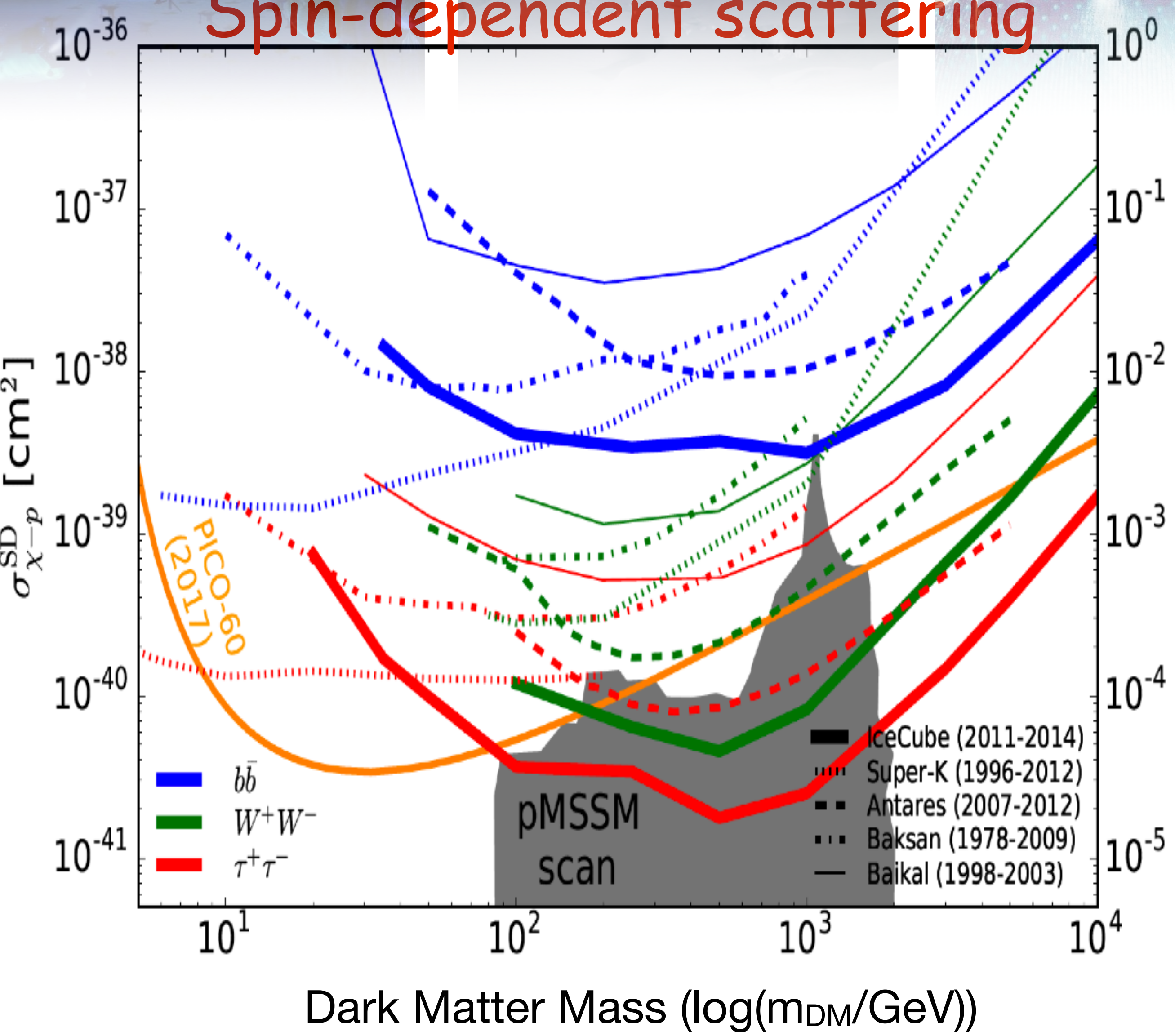
Figure 4: WIMP-proton SD (left) and SI (right) scattering cross-sections limits as a function of WIMP mass for the three annihilation channels considered. Comparative between 5 years of ORCA simulated data, 5 years of ANTARES data [16], Ice Cube 3 years of data [22], Super Kamiokande 16 years [23] and PICO-60 C_3F_8 [24] 1 year.



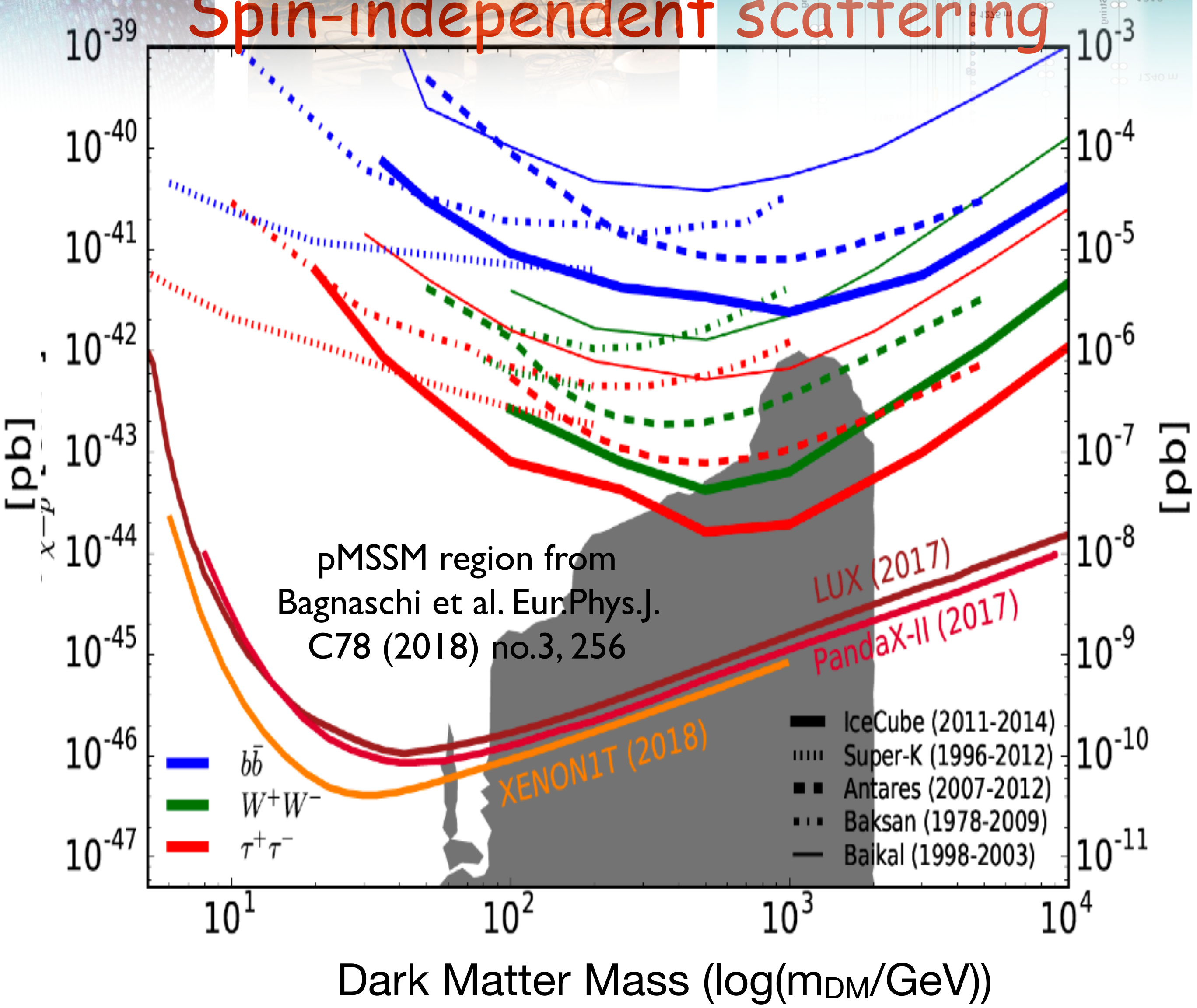
Solar Dark Matter Summary



Spin-dependent scattering



Spin-independent scattering



Delivered worlds strongest bounds on dark matter scattering also in velocity independent framework in combination with PICO-60 (see IceCube+PICO Collaborations arXiv:1907.12509)

Romero-Wolf et al Phys.Rev. D99 (2019) no.6, 063011 (arXiv:1811.07261)

ANITA Anomalous Events

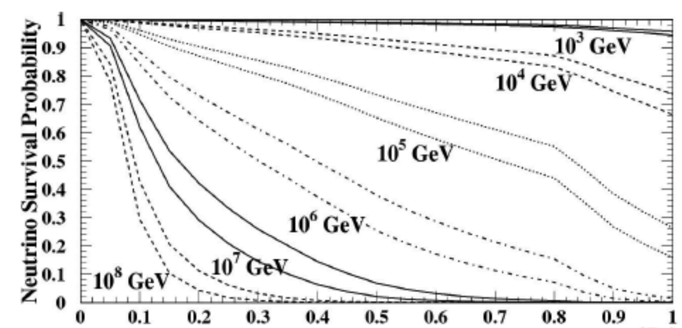
Fox et al (2019)

TABLE I. Properties of the ANITA Anomalous Events

Property	AAE 061228	AAE 141220
Flight & Event	ANITA-I #3985267	ANITA-III #15717147
Date & Time (UTC)	2006-12-28 00:33:20	2014-12-20 08:33:22.5
Equatorial coordinates (J2000)	R.A. 282°.14064, Dec. +20°.33043	R.A. 50°.78203, Dec. +38°.65498
Energy ε_{cr}	$0.6 \pm 0.4\,\mathrm{EeV}$	$0.56^{+0.30}_{-0.20}\,\mathrm{EeV}$
Zenith angle z'/z	$117°.4$ / $116°.8 \pm 0°.3$	$125°.0$ / $124°.5 \pm 0°.3$
Earth chord length ℓ	$5740 \pm 60\,\mathrm{km}$	$7210 \pm 55\,\mathrm{km}$
Mean interaction length for $\varepsilon_\nu = 1\,\mathrm{EeV}$	290 km	265 km
$p_{\mathrm{SM}}(\varepsilon_\tau > 0.1\,\mathrm{EeV})$ for $\varepsilon_\nu = 1\,\mathrm{EeV}$	4.4×10^{-7}	3.2×10^{-8}
$p_{\mathrm{SM}}(z > z_{\mathrm{obs}})$ for $\varepsilon_\nu = 1\,\mathrm{EeV}$, $\varepsilon_\tau > 0.1\,\mathrm{EeV}$	6.7×10^{-5}	3.8×10^{-6}
$n_\tau(1\text{–}10\,\mathrm{PeV}) : n_\tau(10\text{–}100\,\mathrm{PeV}) : n_\tau(> 0.1\,\mathrm{EeV})$	34 : 35 : 1	270 : 120 : 1

- Emerged from the Earth at ~27 degrees below the horizon
- Earth chord length 5740 km (~15 interaction lengths for incoming EeV neutrino)

- Emerged from the Earth at ~35 degrees below the horizon
- Earth chord length 7210 km (~27 interaction lengths for incoming EeV neutrino)



Albuquerque+ 02

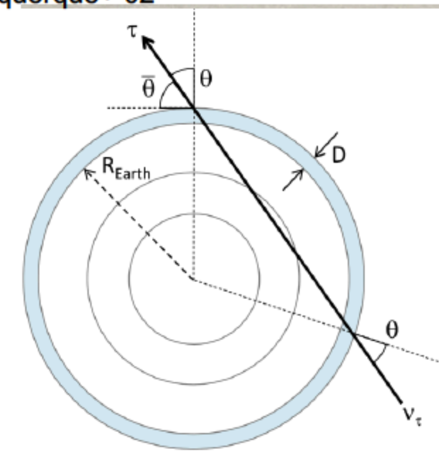
K. Murase LHC-Results Forum 2019

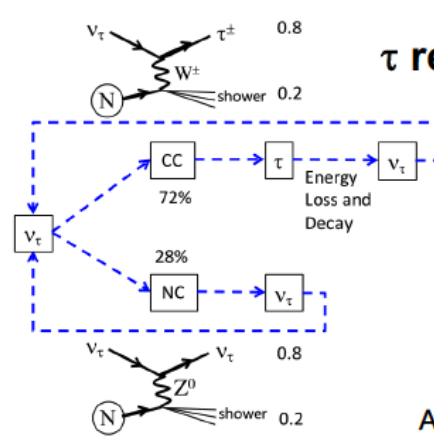
$\sigma_{\nu N}$~10^{-32} cm2 @ EeV

ρ_{Earth}~5.5 g cm-3

chord length~7300km

-> $\tau_{\nu N}$~60 >> 1





τ regeneration

NuTauSim

Alvarez-Muniz+ 08

New Physics Implications

Standard model explanation can be excluded (if we consider the ANITA signals as real)

- Inconsistency with energy and zenith angle of events
- Inconsistency with observed astrophysical neutrino flux by IceCube

- SUSY (Long-lived particles) - NLSP stau / NLSP bino / CHAMPS / sphaleron configurations
  - Long-lived stau (Fox et al 2018, Collins et al 2018, Anchordoqui & Antoniadis 2018, … Albuquerque 2004/2007)
- Leptoquarks
  - Chauhan & Mohanty 2018
- Dark matter related models
  - Heurtier et al 2019, Anchordoqui et al. 2018
- Sterile neutrinos
  - Cherry & Shoemaker 2018, Huang 2018

Connolly et al arXiv:1807.08892

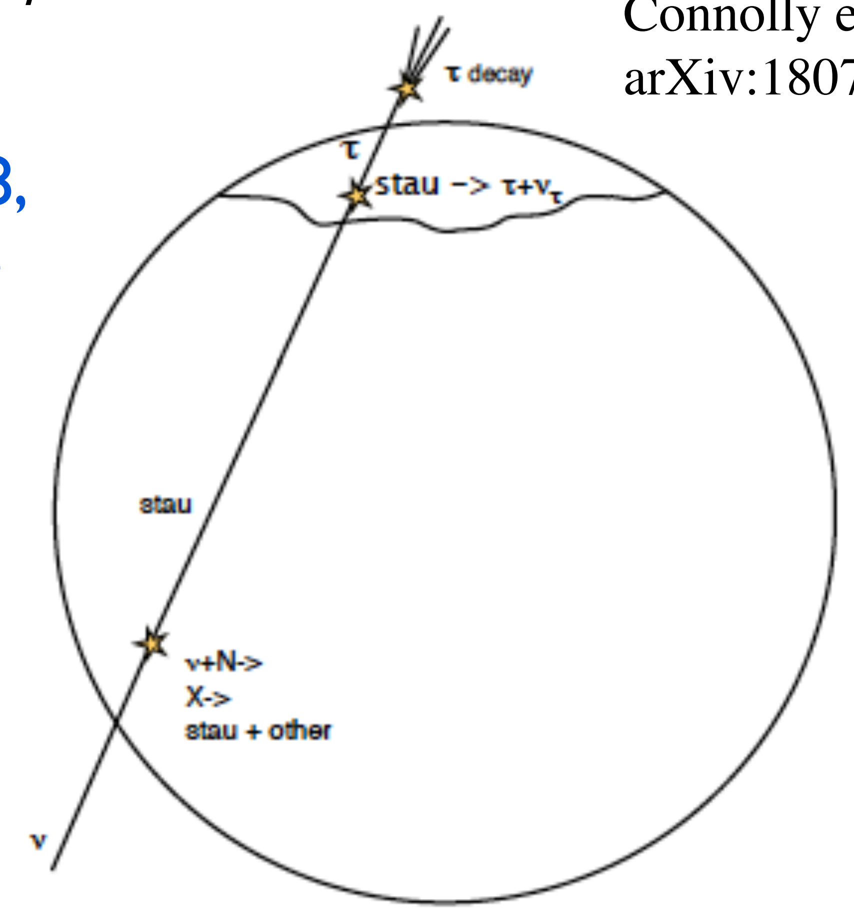
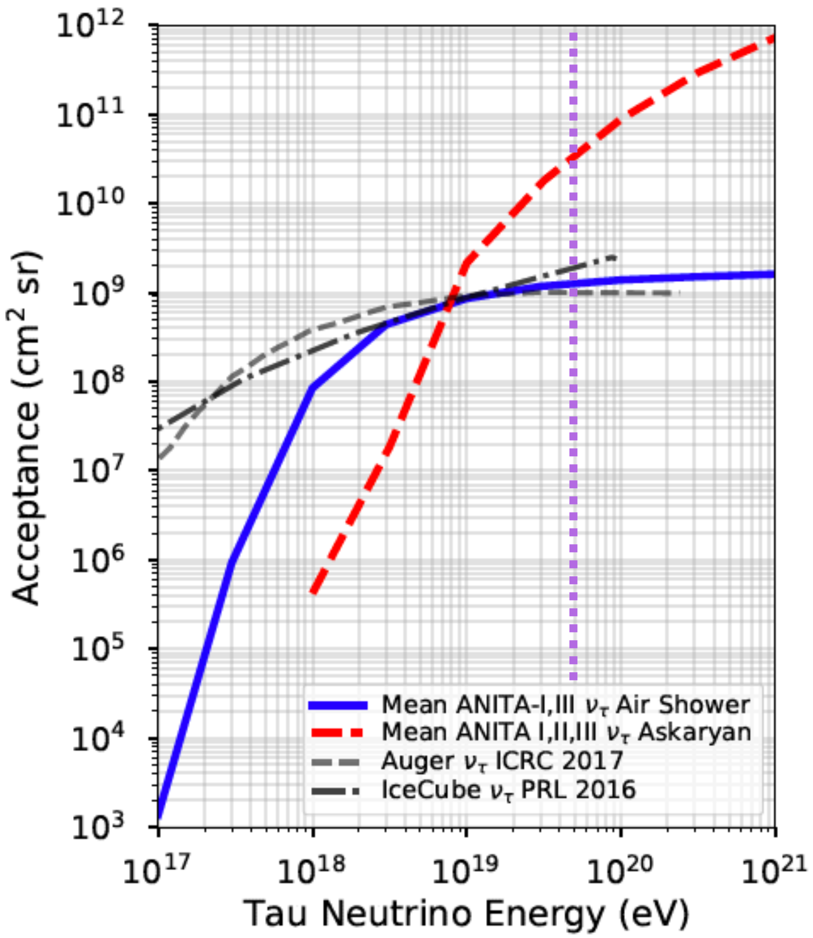


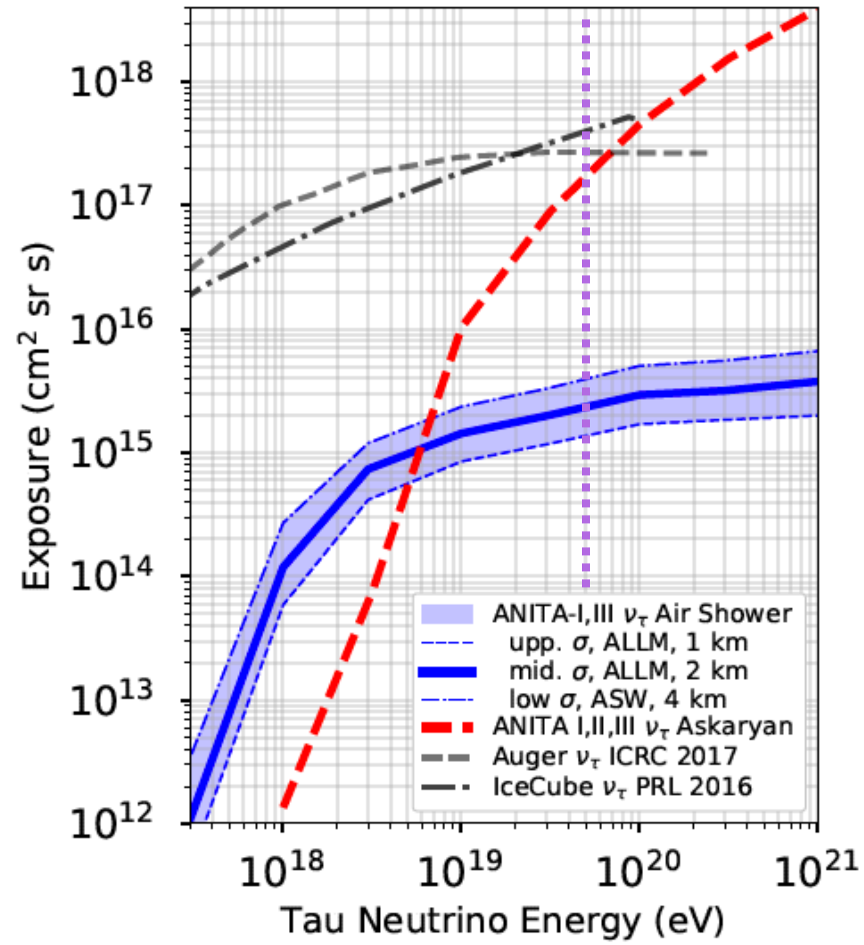
Figure 2: Sketch of the signature being considered here. Although the figure shows one stau being produced in the νN interaction, a stau pair could be produced instead, doubling the probability of detection.

Romero-Wolf et al Phys.Rev. D99 (2019) no.6, 063011 (arXiv:1811.07261)

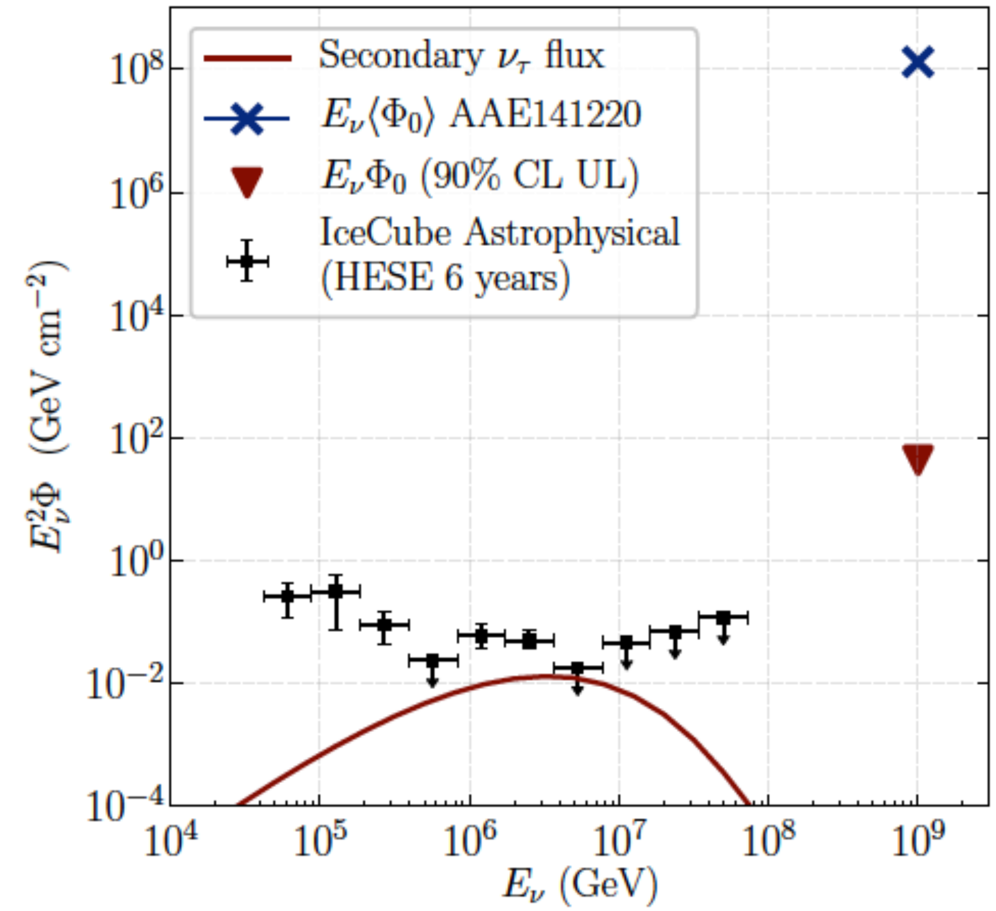
Consistency among experiments



Romero-Wolf et al. (2018)

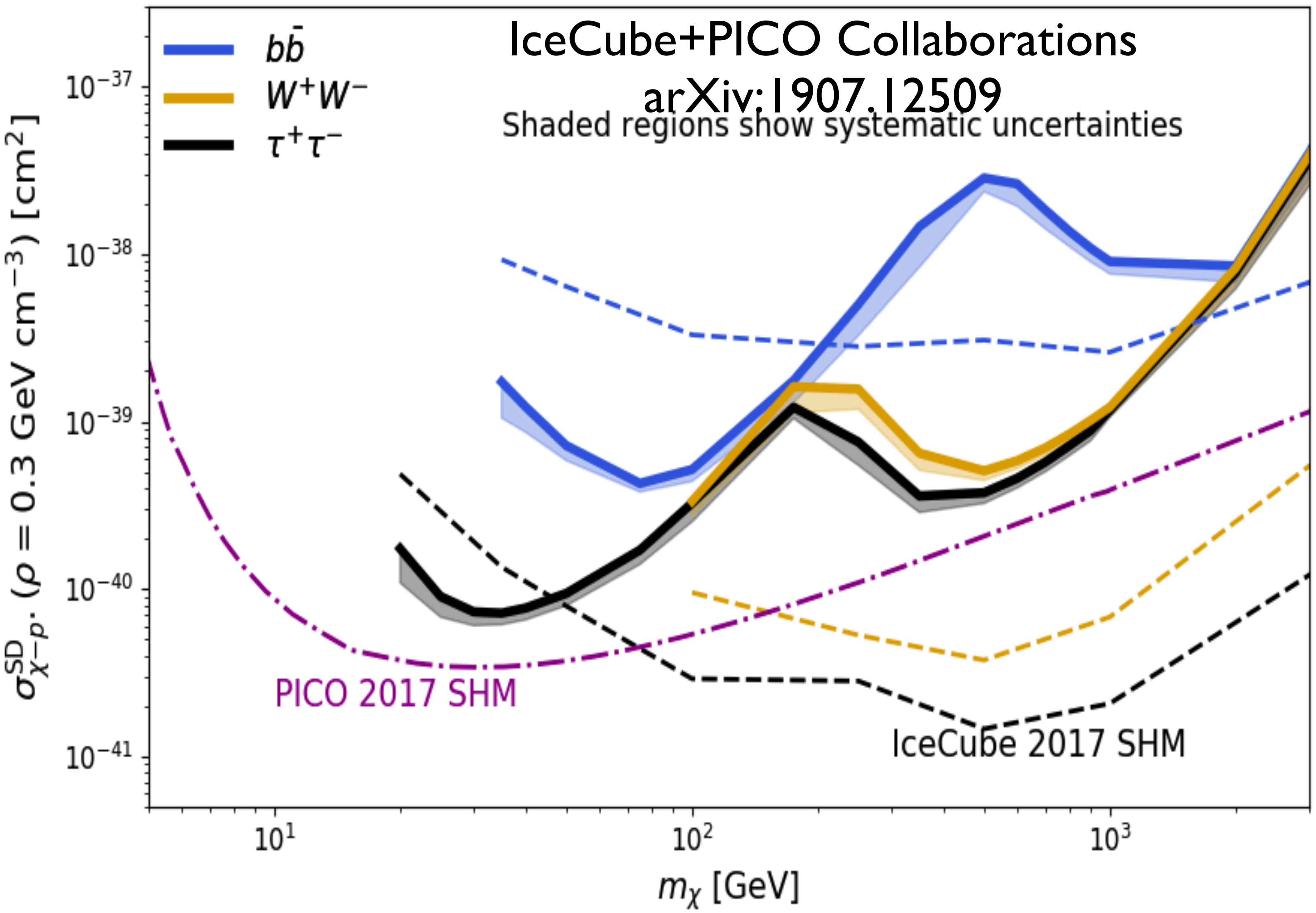


Safa et al. PoS(ICRC2019)995



- Many more events in IceCube & Auger data expected for $E<10^{19.5}$ eV … but not reported
- Any flux from the direction of the ANITA events should be accompanied by secondary tau-neutrinos detectable at IceCube
- Maximum allowed secondary flux at IceCube at 10^6 inconsistent with ANITA event
- (Kistler & Laha PRL 120 (2018) no.24, 241105 - very high-energy tau tracks)

PICO-IceCube Combined Limit



Halo Model independent bound (Extremely conservative, decomposing the velocity distribution in dark matter streams with fixed velocity)

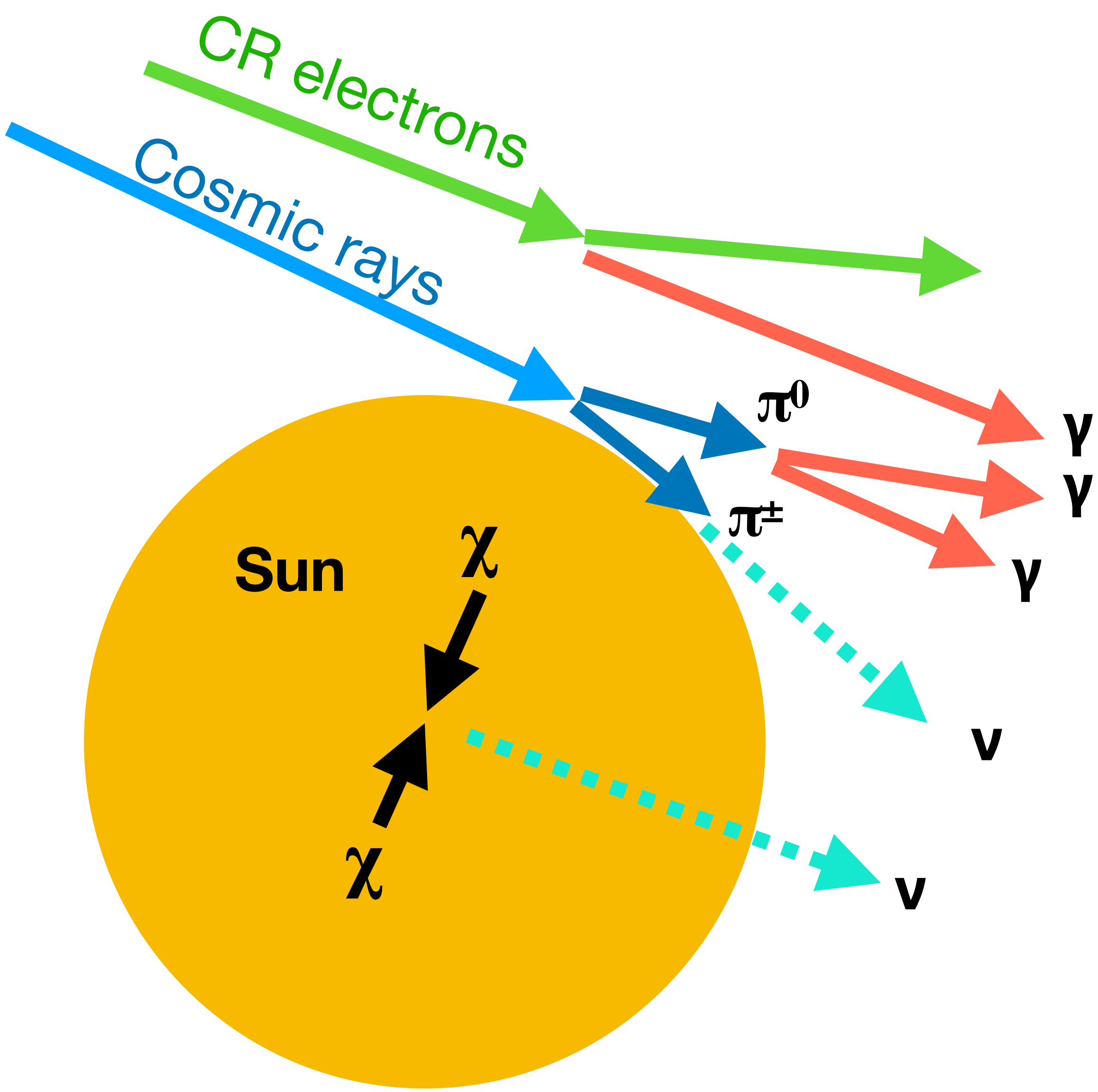
Combines data from

- PICO-60 C_3F_8 superheated bubble chamber experiments - 1167 kg-days
- IceCube 3years data

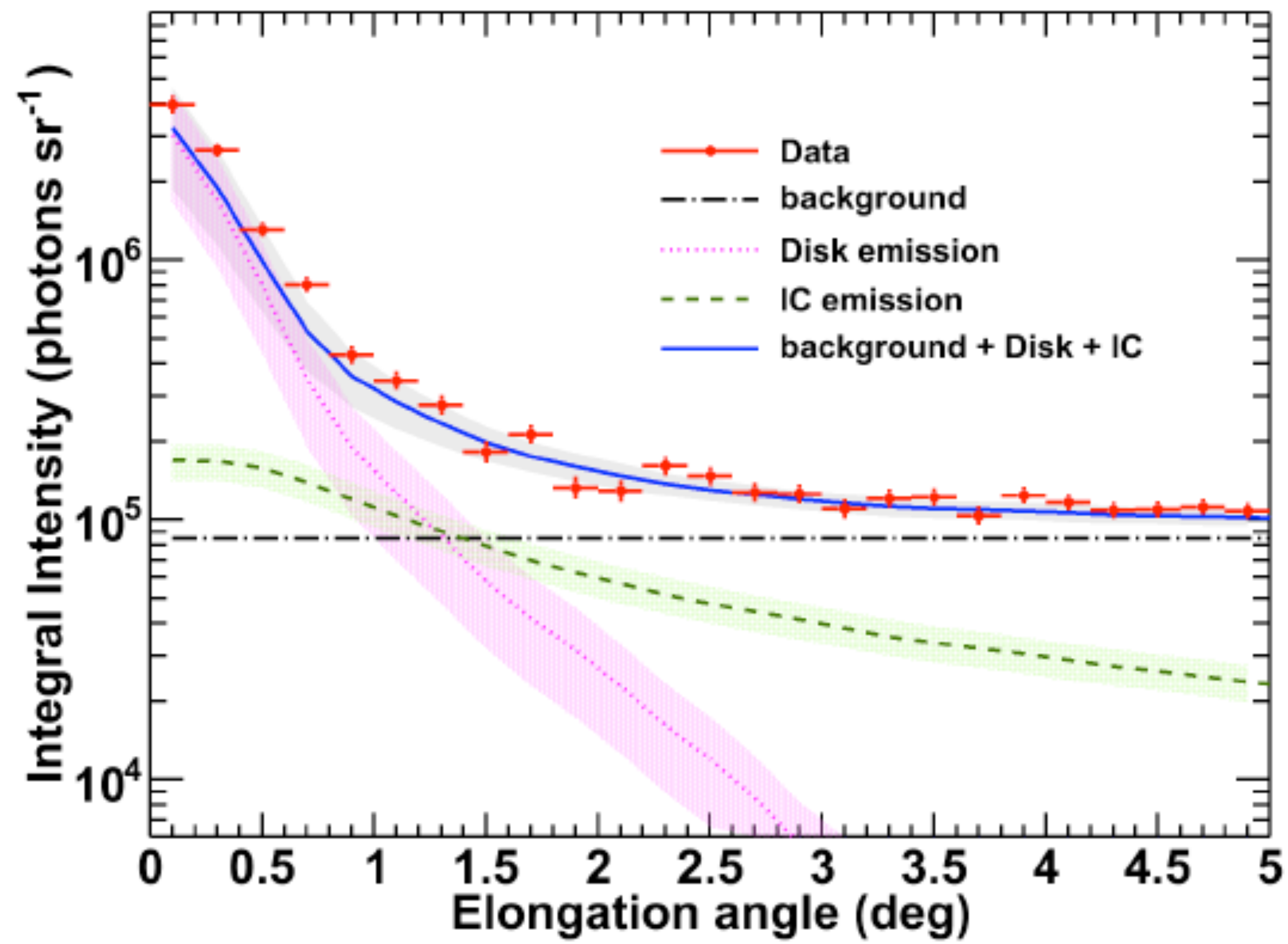
Exploit the complementarity of direct and indirect searches (see F. Ferrer, A. Ibarra and S. Wild, JCAP1509, no. 09, 052(2015))

Standard method to compute bounds assuming Standard Halo Model (SHM) of an isotropic Maxwellian velocity distribution

Cosmic ray interactions with the Sun



see Fermi-LAT Collaboration: The Astrophysical Journal 734 (2011) 116 (arxiv:1104.2093)



- Cosmic ray interactions in the solar atmosphere produce gamma-rays and neutrinos
- Background to dark matter searches from the Sun that are becoming very relevant and also harbor the opportunity to detect a high-energy neutrino point source

Leptonic

- Moskalenko, Porter, Digel (2006)
- Orlando, Strong (2007)

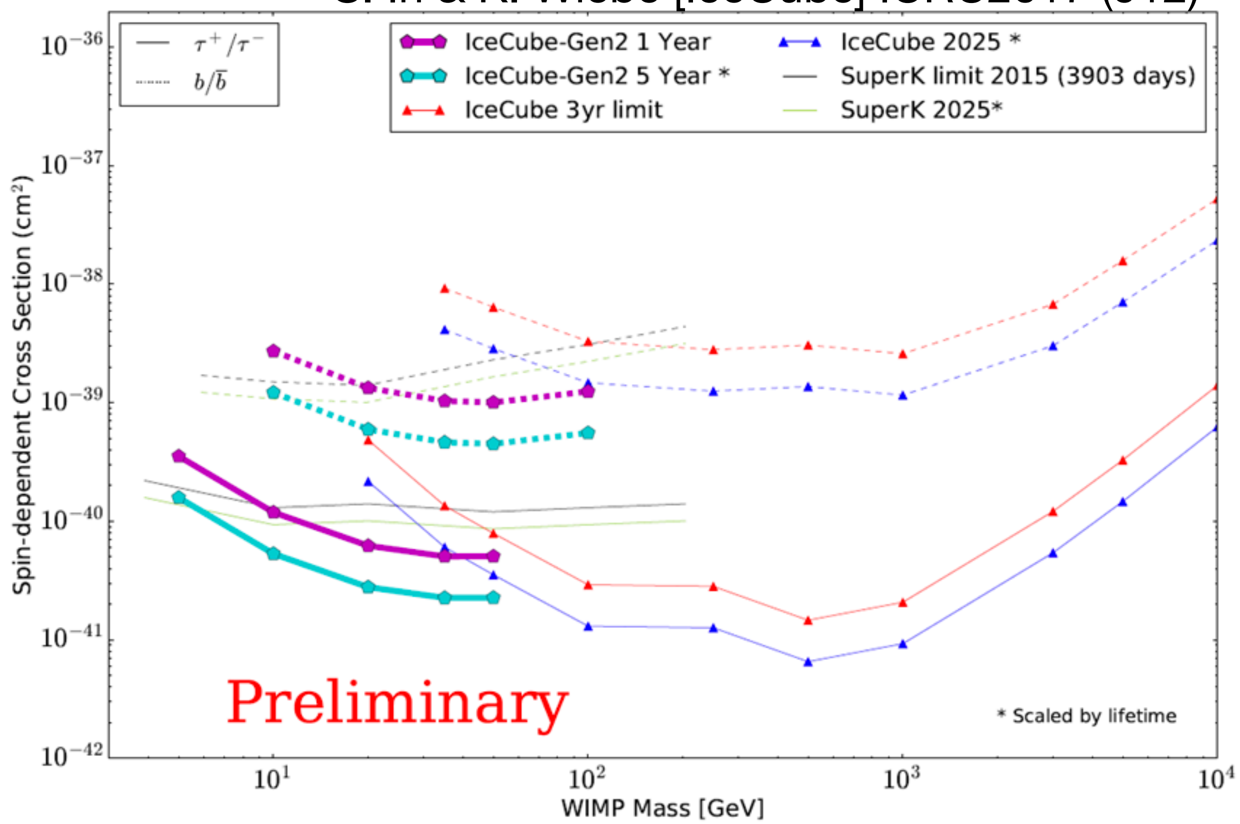
Hadronic

- Seckel, Stanev, Gaisser (1991)
- Moskalenko, Karakula (1993)
- Ingelman & Thunman (1996)

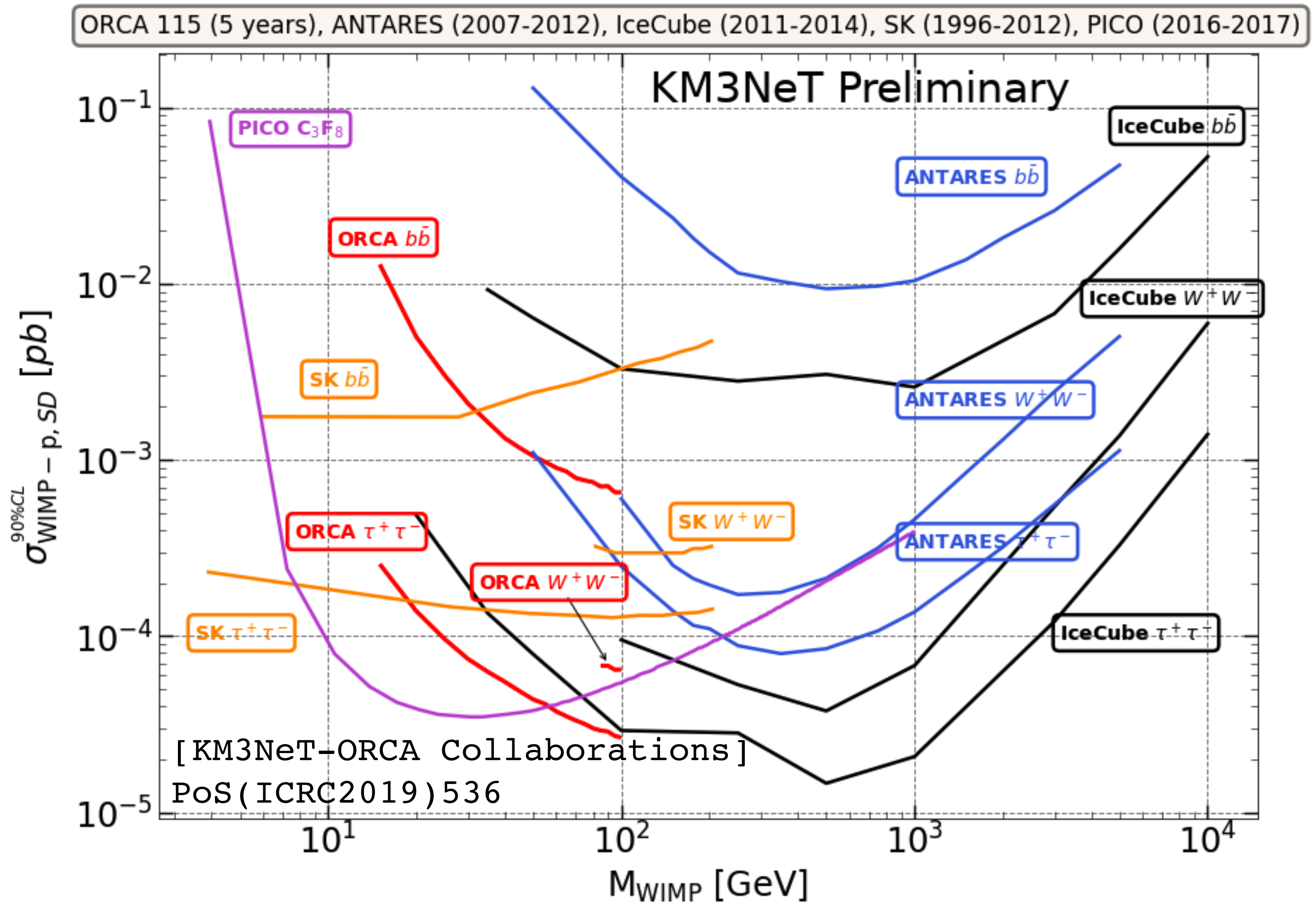
Next generation neutrino detectors

IceCube-Gen2 (IceCube-Upgrade)

S. In & K. Wiebe [IceCube] ICRC2017 (912)



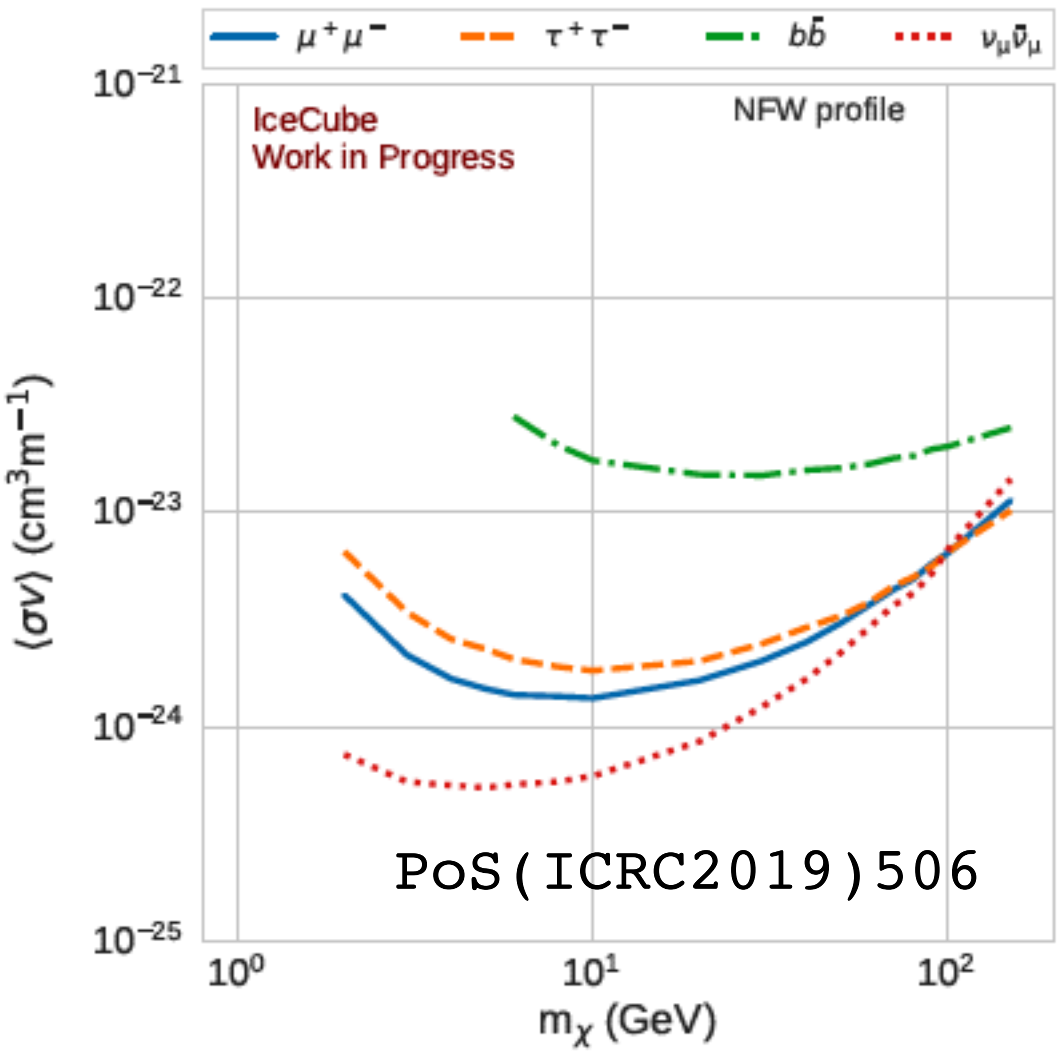
5 years of ORCA (115 lines)



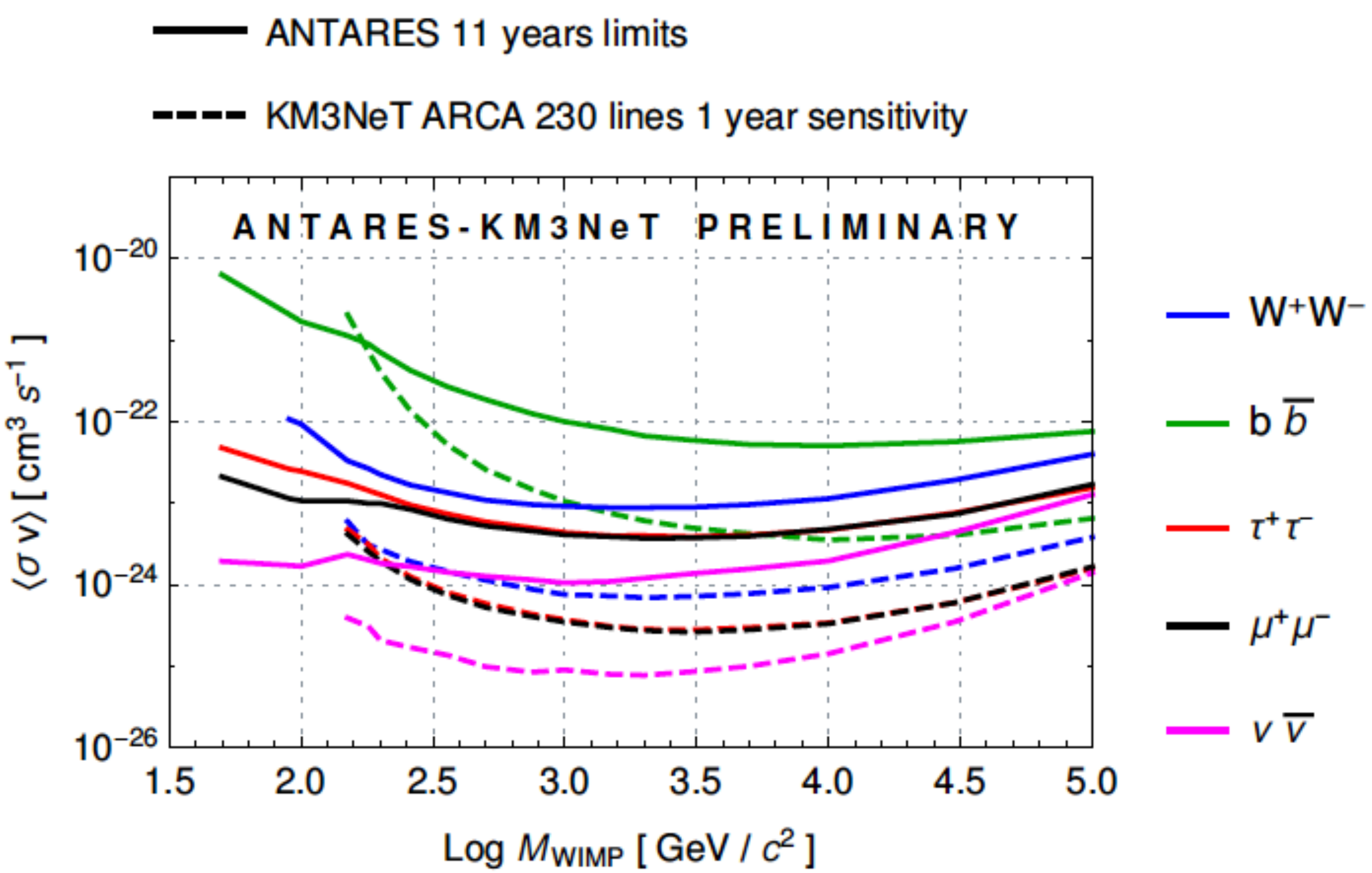
- IceCube Upgrade (to be deployed 2022/2023) and ORCA (under construction) will be able to improve Solar Dark Matter sensitivity for masses below 100GeV
- IceCube recalibration campaign will result in improved limits for higher dark matter masses

Galactic Halo - Dark Matter Self-annihilation cross section

IceCube Upgrade Sensitivity
3yrs of data



[ANTARES/KM3NeT Collaborations]
PoS(ICRC2019)552



- Sensitivity approaching thermal relic cross section
- IceCube Upgrade sensitivity reaches down to 5GeV dark matter masses

Secluded Dark Matter

Gozzini et al. [ANTARES Collaboration] PoS(ICRC2019)519

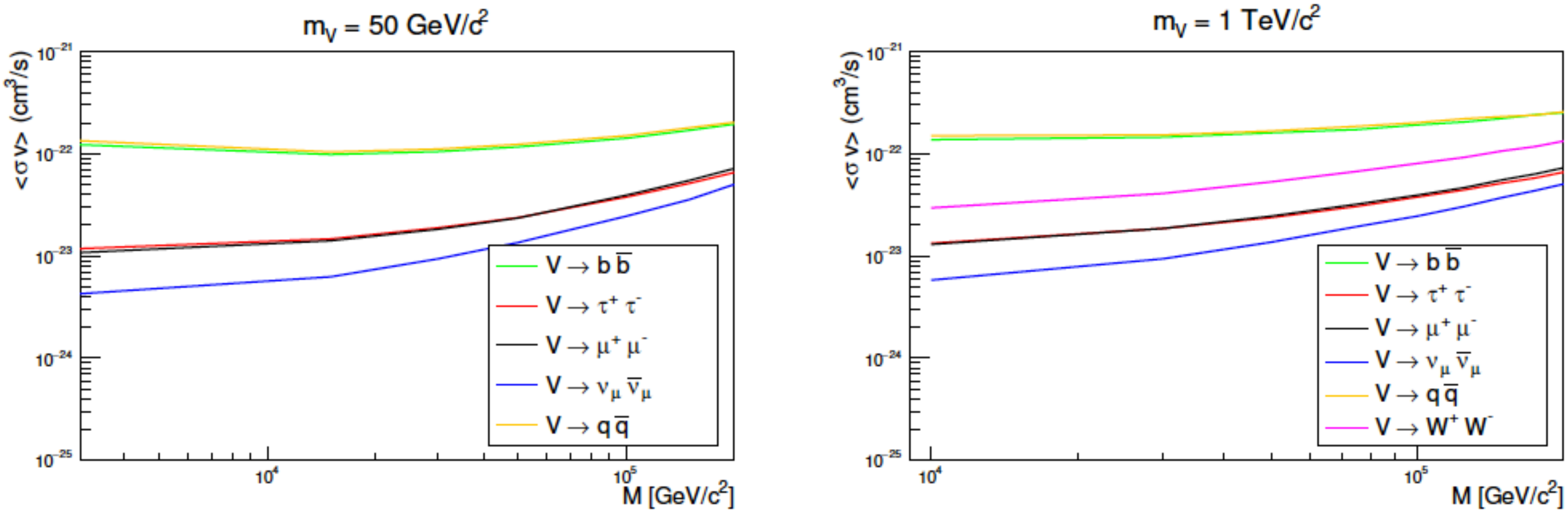
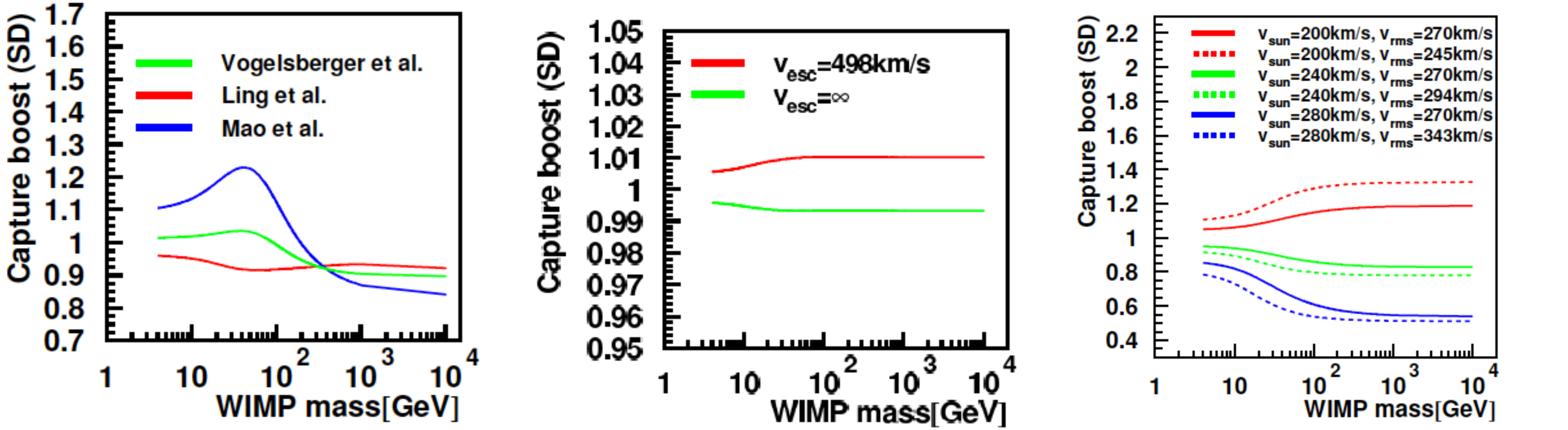


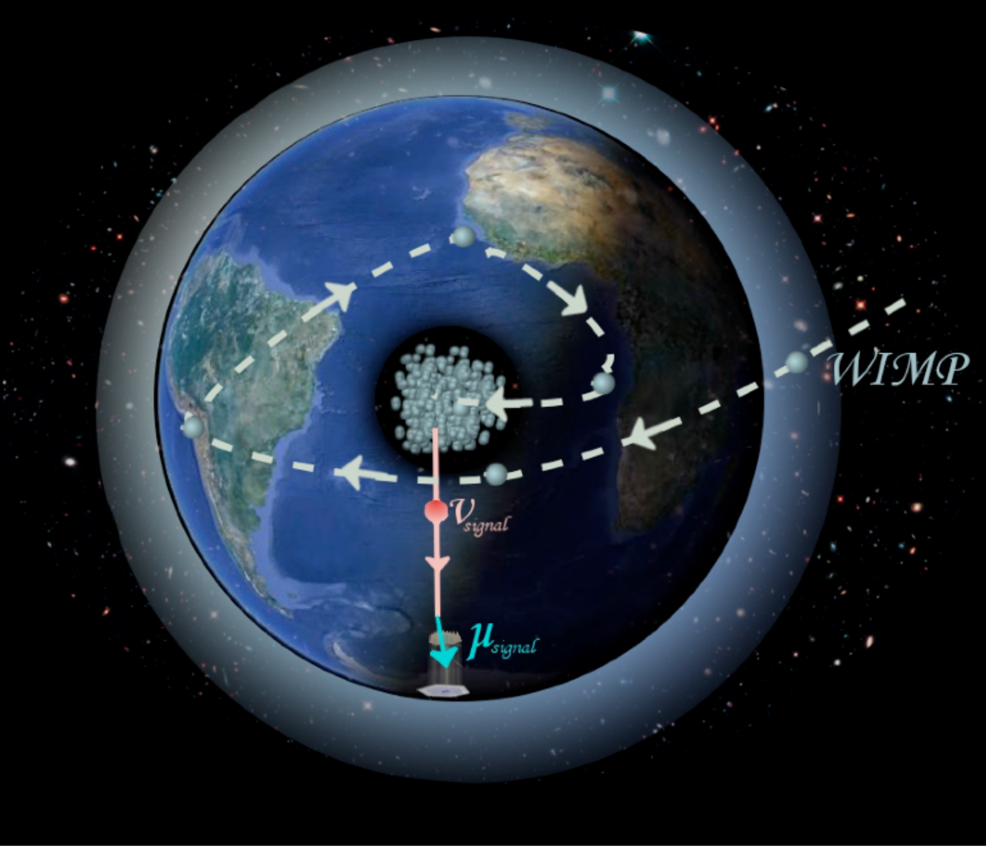
Figure 3: Sensitivities reached with 9 years of ANTARES data on the effective cross-section for DM pair-annihilation into a mediator pair, where the label in the figure indicates the decay channel of a single mediator. The mediator mass is $m_V = 50$ GeV/c^2 (left) and $m_V = 1$ TeV/c^2 (right)

Uncertainty on Dark Matter Capture in the Sun

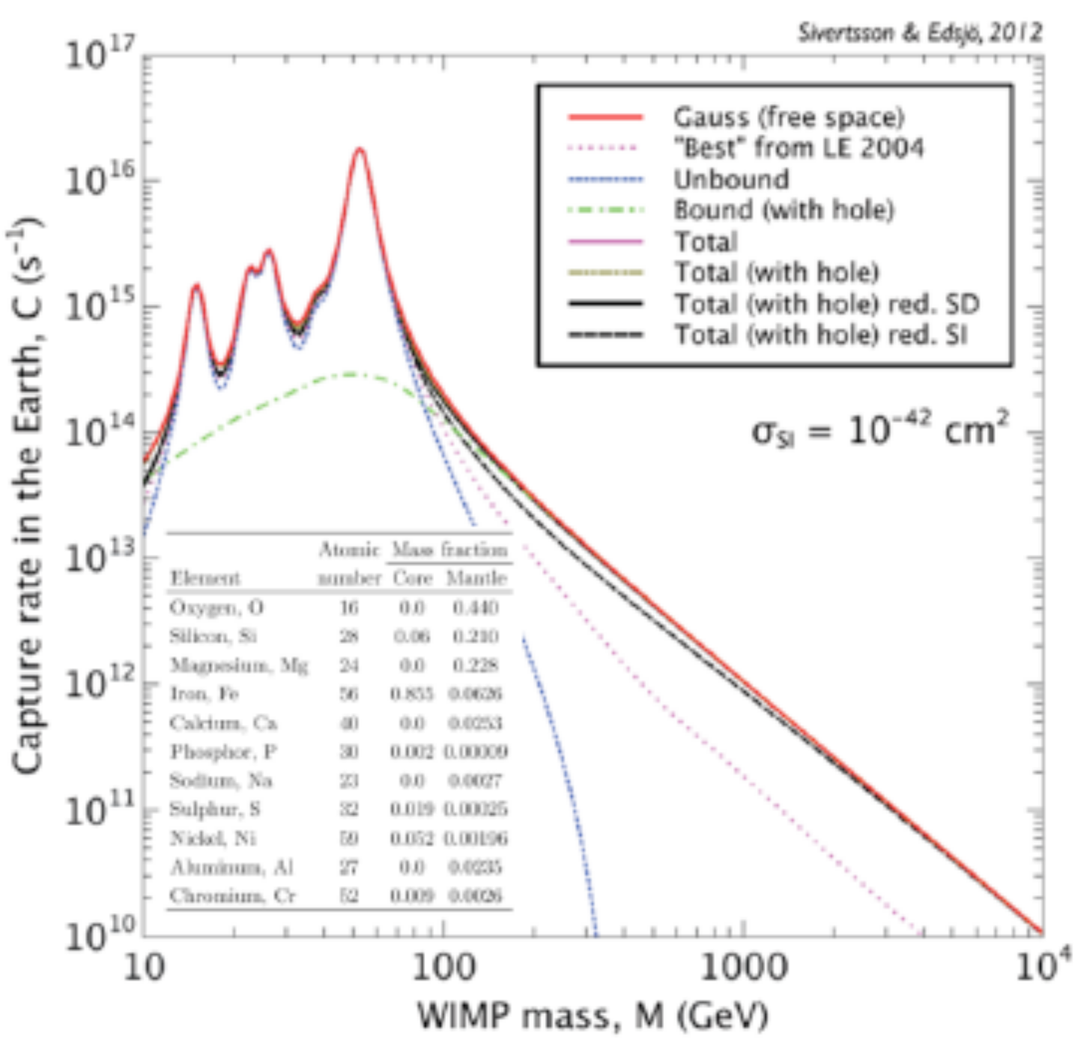
- Dark Matter capture in the Sun is rather insensitive to the underlying dark matter velocity distribution



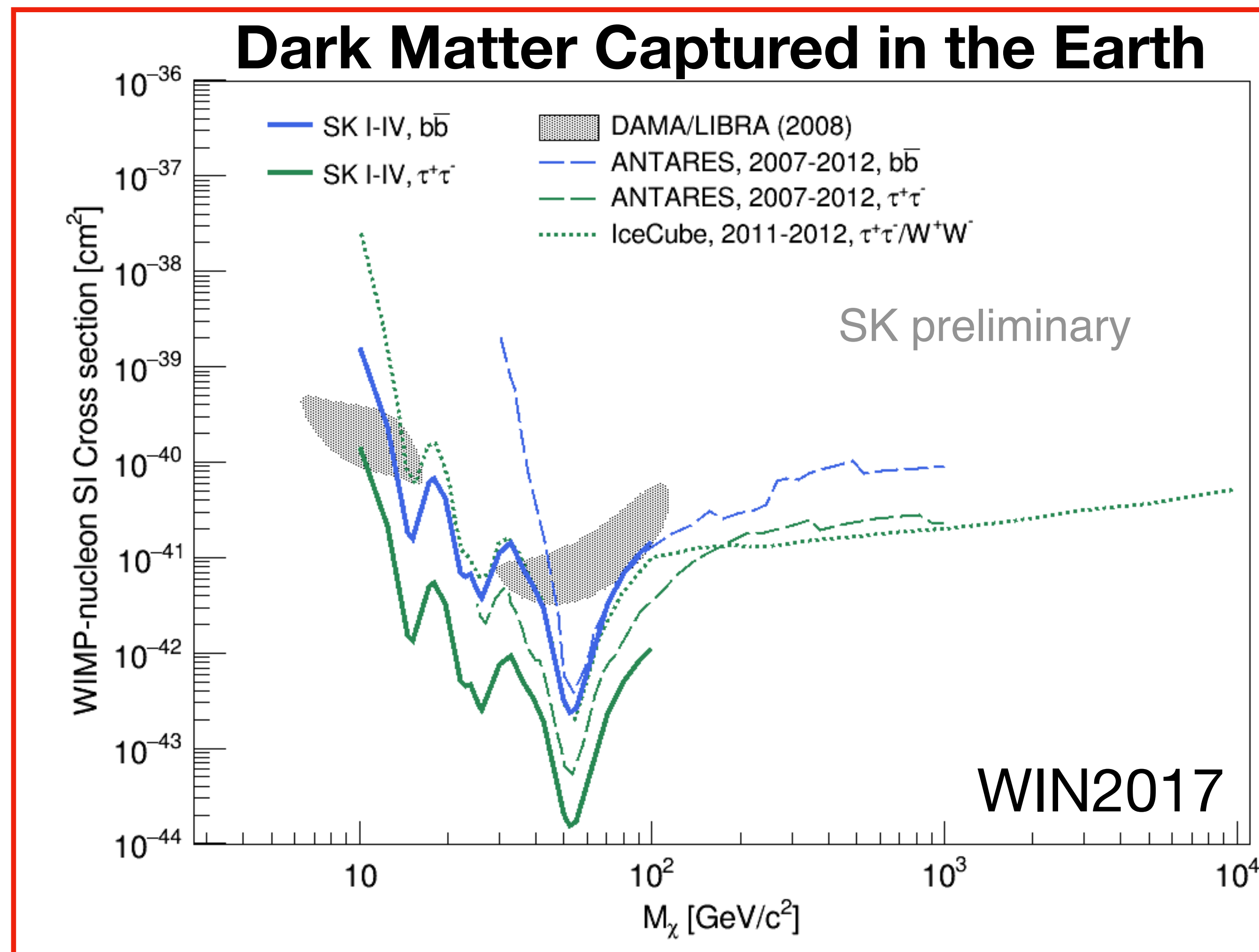
Earth WIMPs



- Dark Matter could be captured in the Earth and produce a vertically up-going excess neutrino flux
- No off-source region



Element	Atomic number	Mass fraction Core	Mantle
Oxygen, O	16	0.0	0.440
Silicon, Si	28	0.06	0.210
Magnesium, Mg	24	0.0	0.228
Iron, Fe	56	0.855	0.0626
Calcium, Ca	40	0.0	0.0253
Phosphor, P	30	0.002	0.00009
Sodium, Na	23	0.0	0.0027
Sulphur, S	32	0.019	0.00025
Nickel, Ni	59	0.052	0.00196
Aluminum, Al	27	0.0	0.0235
Chromium, Cr	52	0.009	0.0026



ANTARES Galactic Center

[ANTARES/KM3NeT Collaborations] PoS(ICRC2019)552

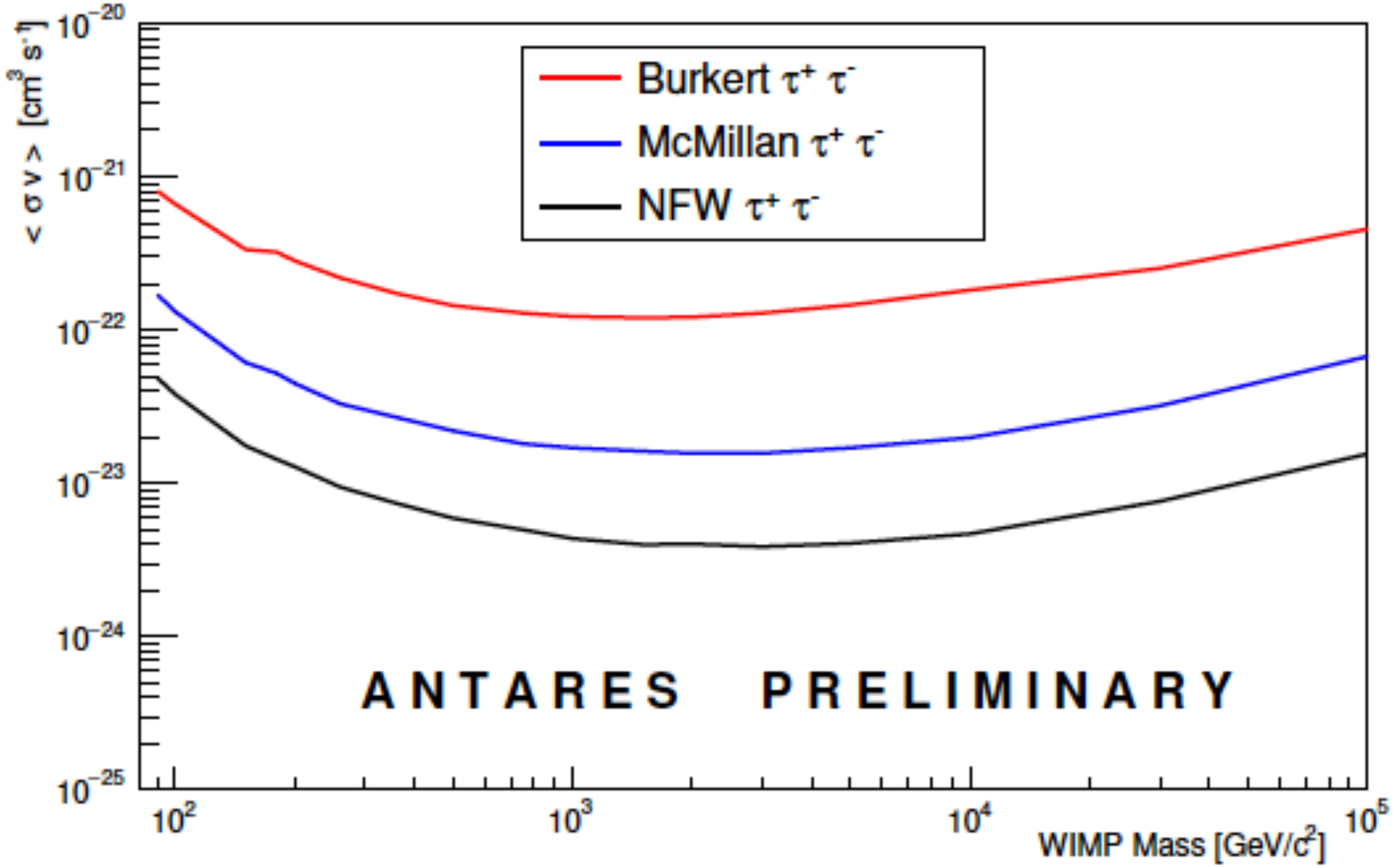


Figure 2: Upper limits at 90% C.L. on the thermally averaged cross-section for WIMP pair annihilation as a function of the WIMP candidate mass set with 11 years of ANTARES data for three different halo models. Here the $\tau^+\tau^-$ channel is shown.