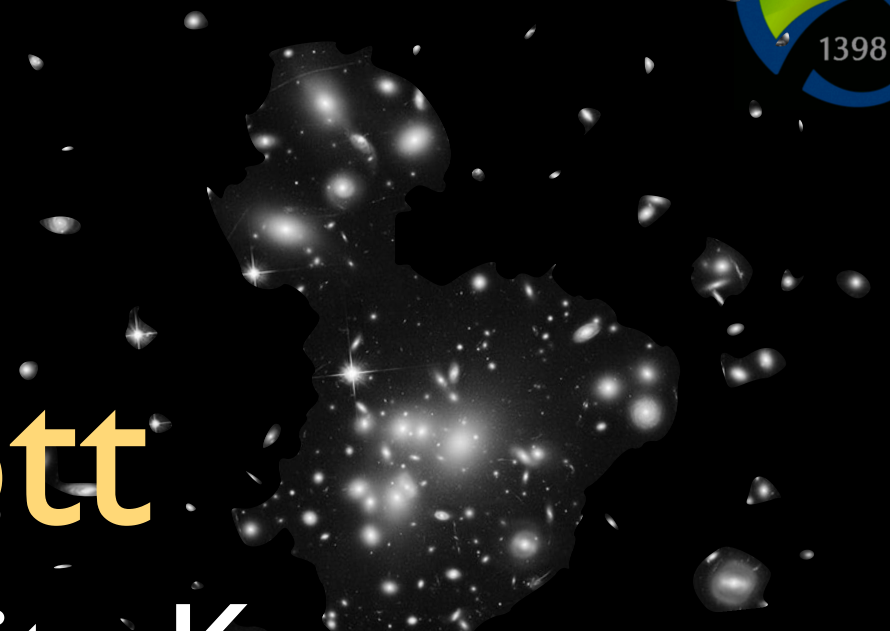

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Feb 21, 2018

Indirect Searches for Dark Matter with Neutrinos

UCLA Dark Matter - February 21-23, 2018

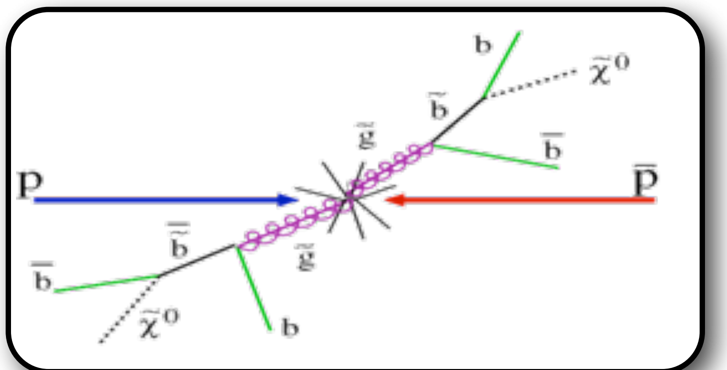
Image Credits:
ESA/Hubble Galaxy Cluster Abell 1689
ESO/Digitized Sky Survey 2 - Fornax dSph
M31 Andromeda

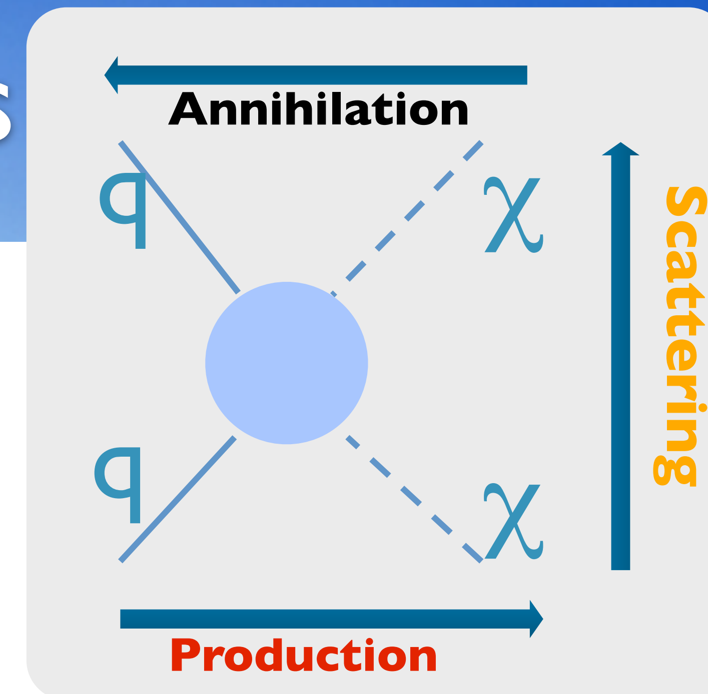
Outline

- Motivation
- The case for neutrinos
- Search for self-annihilating dark matter
- Astrophysical neutrinos and decaying dark matter
- Dark Matter capture in the Earth and the Sun
- Solar Atmospheric Neutrino Floor
- Outlook & Conclusions

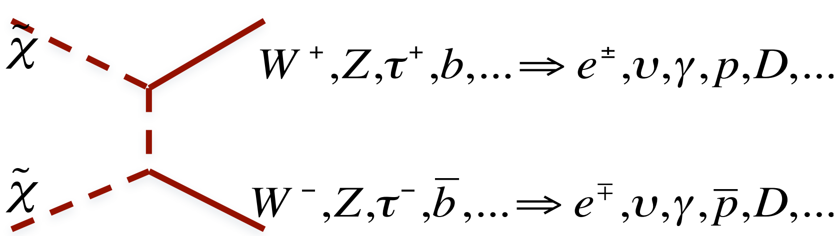
Role of Neutrinos

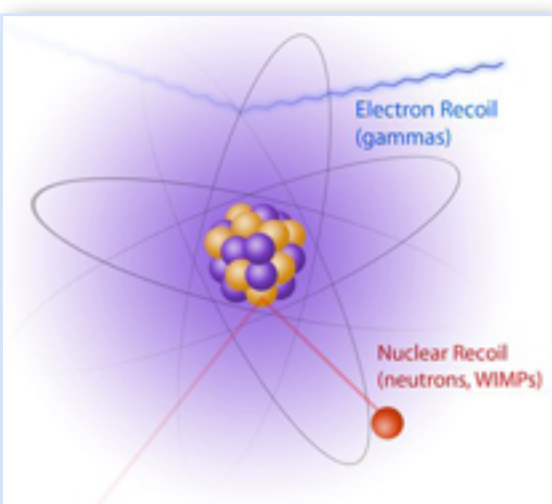
WIMP - Weakly Interacting Massive Particle





- **Production**
  - Colliders
- **Indirect Searches**
  - Dark Matter Decay
  - Annihilation of Dark Matter in Galactic Halo, ...
    - Gamma-rays, electrons, neutrinos, anti-matter, ...
  - Annihilation signals from WIMPs captured in the Sun (or Earth)
    - Neutrinos
- **Direct Searches**
  - WIMP scattering of nucleons → Nuclear recoils





Dark Matter Lifetime

Dark Matter Self-annihilation cross section

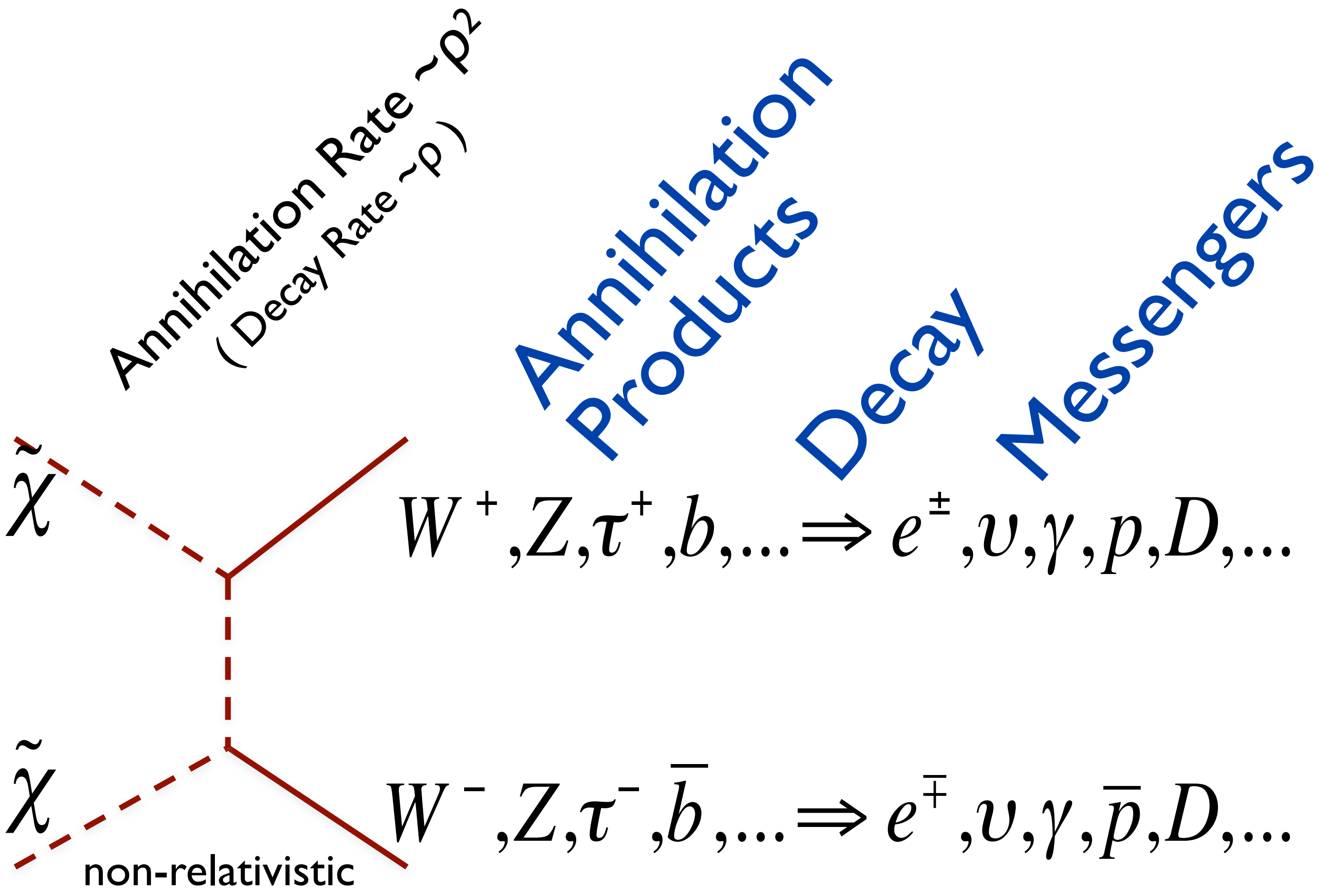
DM -Nucleon Scattering cross section

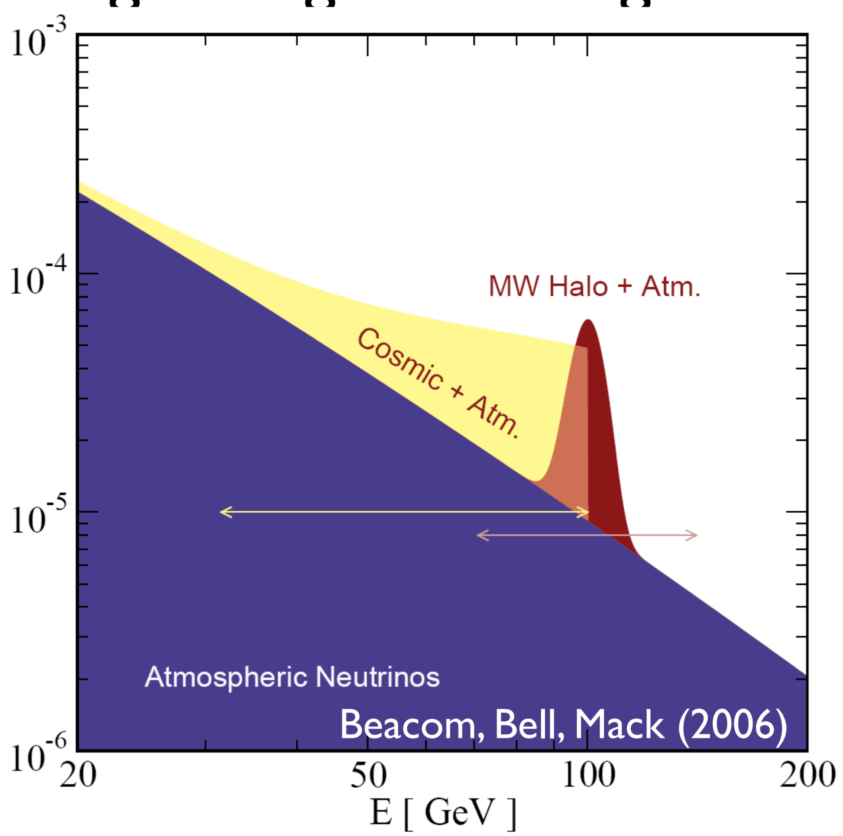
Dark Matter Signals

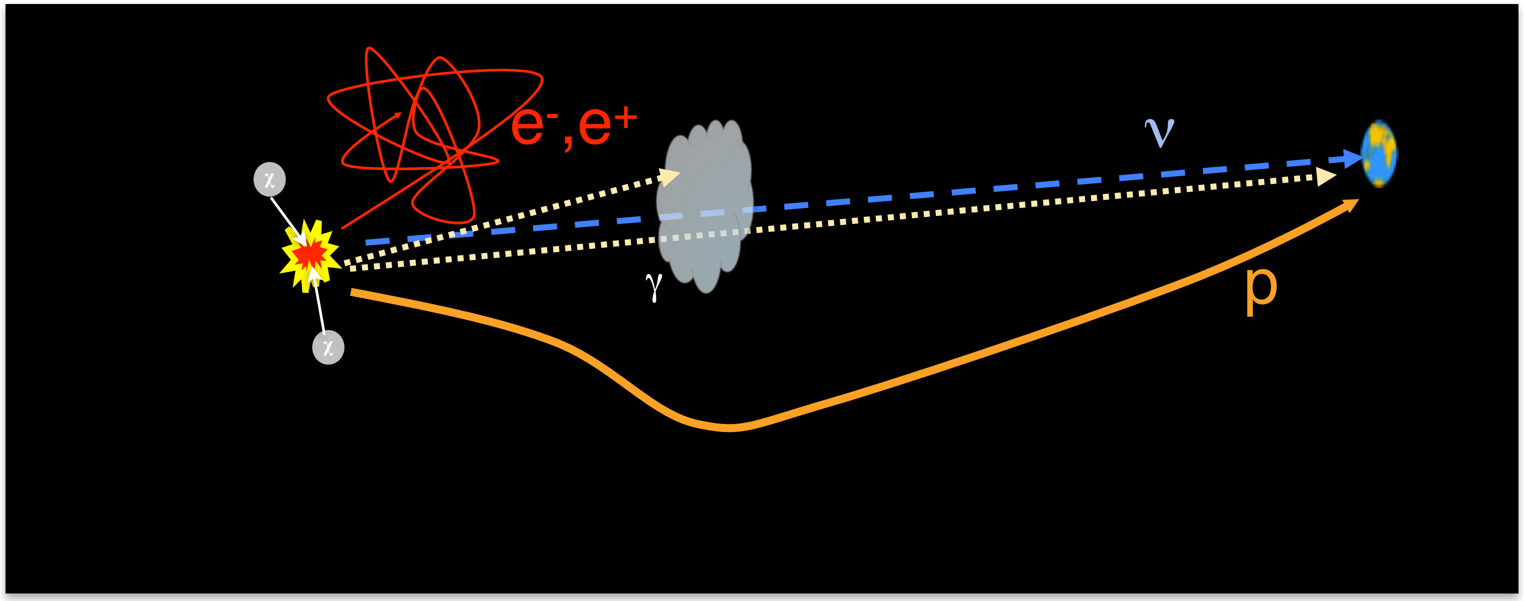
- Identify overdense regions of dark matter

  ⇒self-annihilation can occur at significant rates

- Pick prominent Dark Matter target
- Understand / predict backgrounds
- Exploit features in the signal to better distinguish against backgrounds



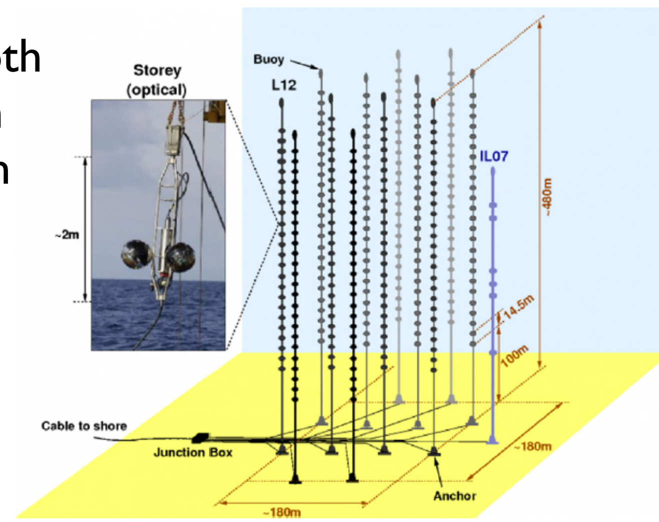


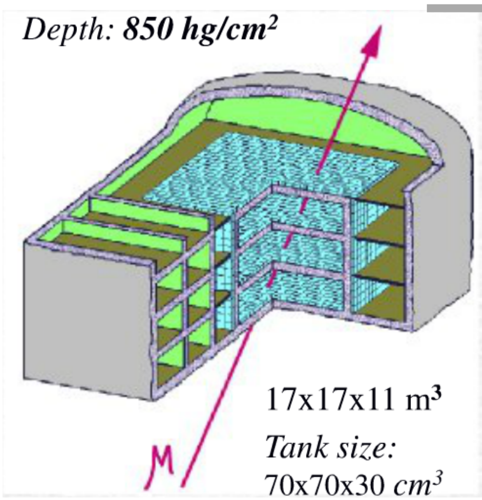


Neutrino Telescopes & Detectors

Neutrino Telescopes / Detectors

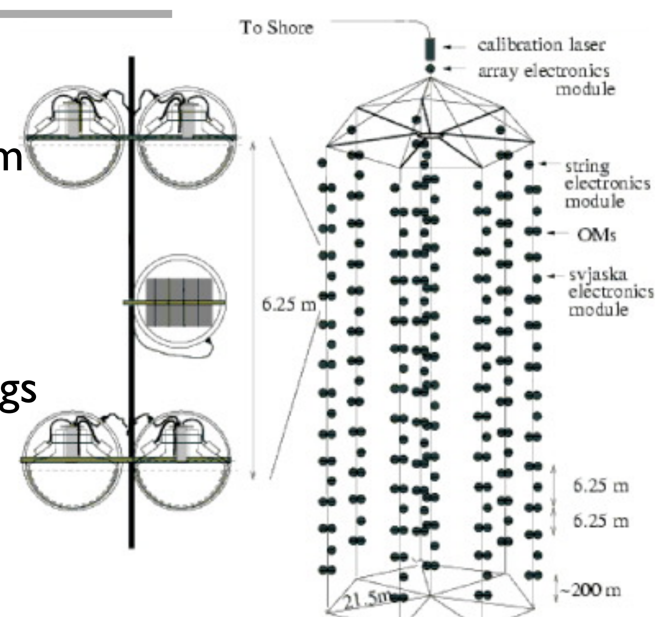
- **ANTARES** is located at a depth of 2475 m in the Mediterranean Sea, 40 km offshore from Toulon
- Consists 885 10"PMTs on 12 lines with 25 storeys each.
- Detector was competed in May 2008



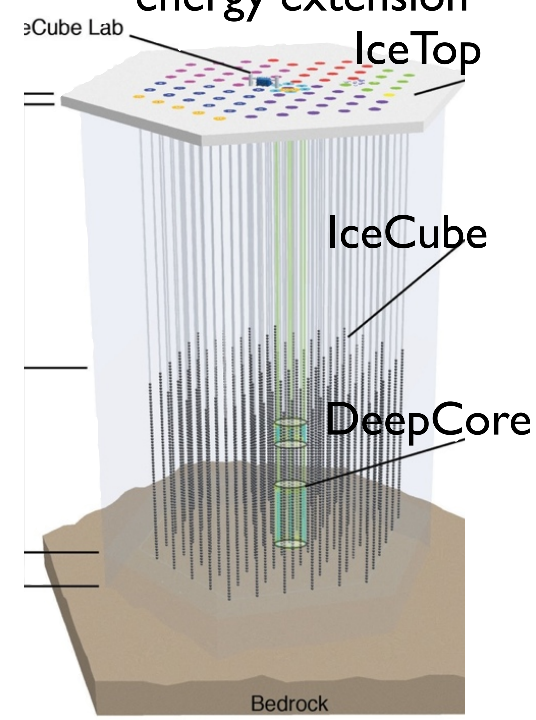


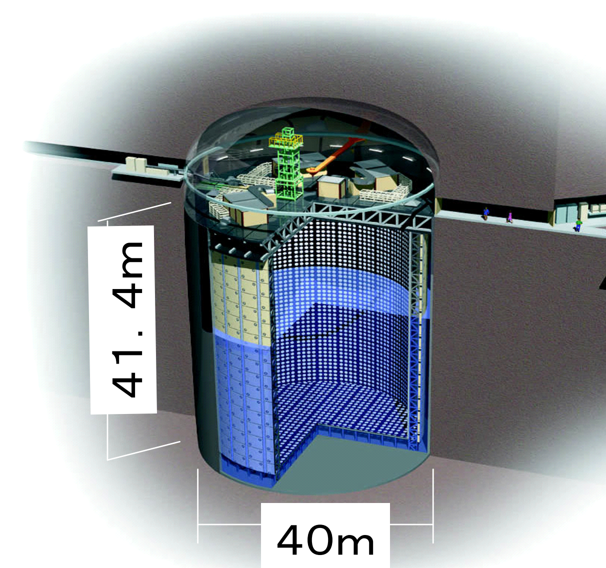
- **Baksan** Underground Scintillator Telescope with muon energy threshold about 1 GeV using 3,150 liquid scintillation counters
- Operating since Dec 1978 ; More than 34 years of continuous operation

- Lake **Baikal**, Siberia, at a depth 1.1 km NT36 in 1993
- NT200 (since Apr 1998) consists of one central and seven peripheral strings of 70m length



- **IceCube** at the Geographic South Pole
- 5160 10"PMTs in Digital optical modules distributed over 86 strings instrumenting ~1km³
- Physics data taking since 2007 ; Completed in December 2010, including **DeepCore** low-energy extension





- **Super-Kamiokande** at Kamioka uses 11K 20" PMTs
- 50kt pure water (22.5kt fiducial) water-cherenkov detector
- Operating since 1996

Dark Matter Self-annihilations

$<\sigma_A v>$

Dark Matter Annihilation

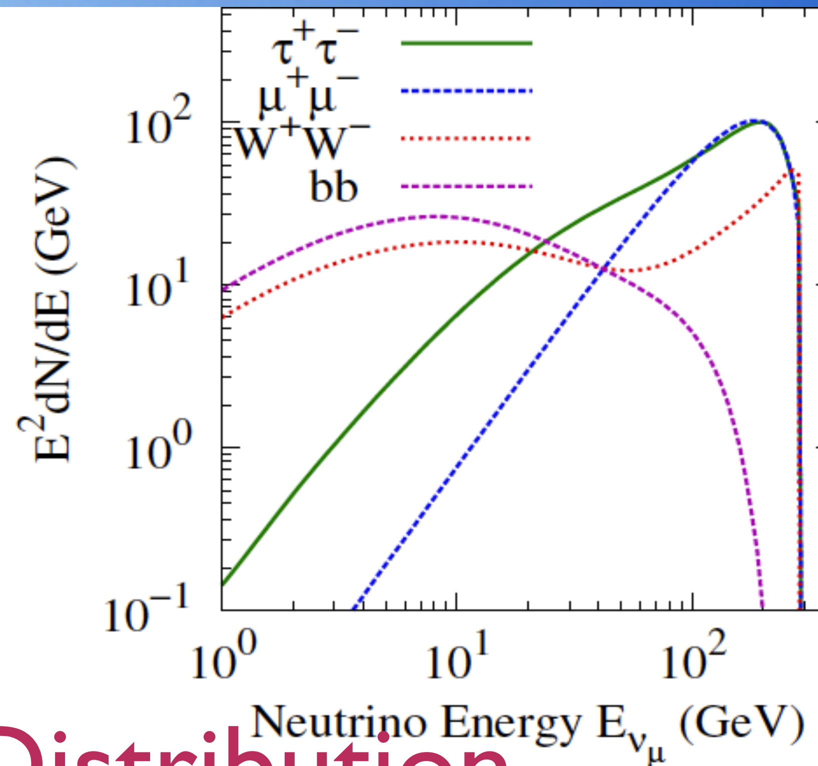
Measure Flux

$$\frac{d\Phi}{dE}(E,\phi,\theta)$$

=

Particle Physics

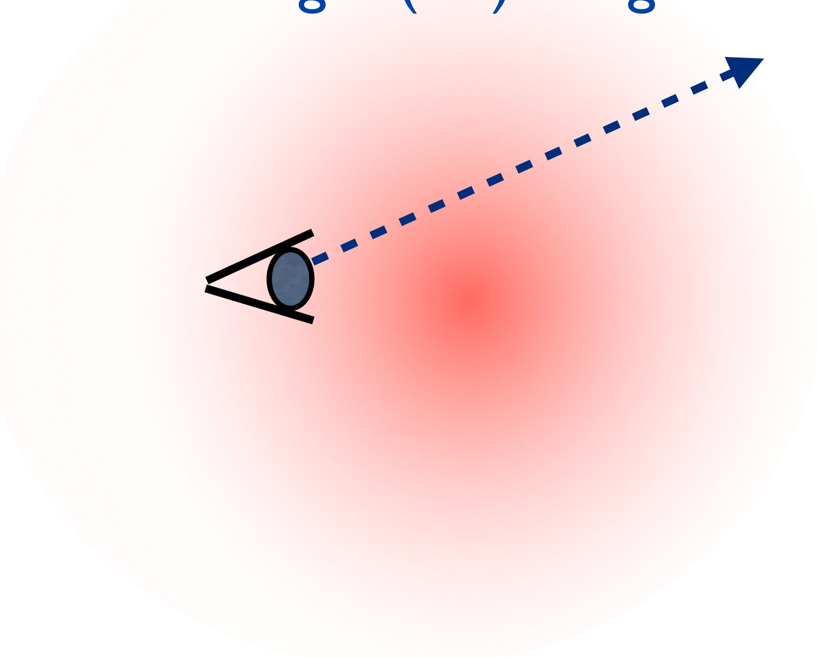
$$\frac{1}{4\pi}\frac{\langle\sigma_A v\rangle}{2m_\chi^2}\Sigma_f\frac{dN}{dE}B_f$$



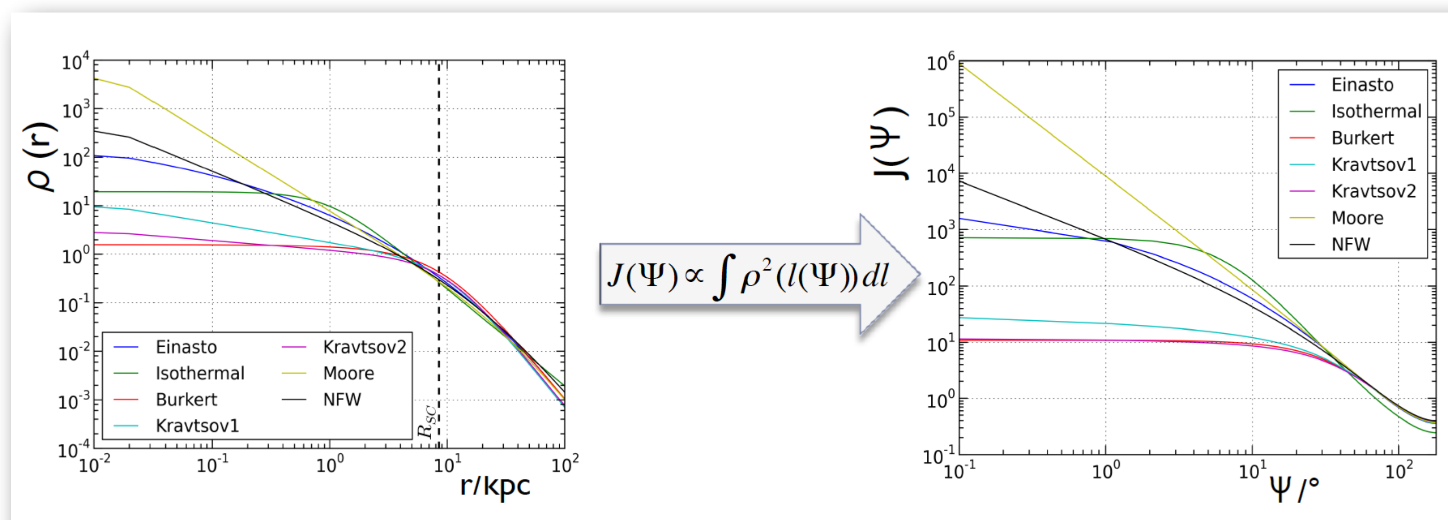
x

Dark Matter Distribution

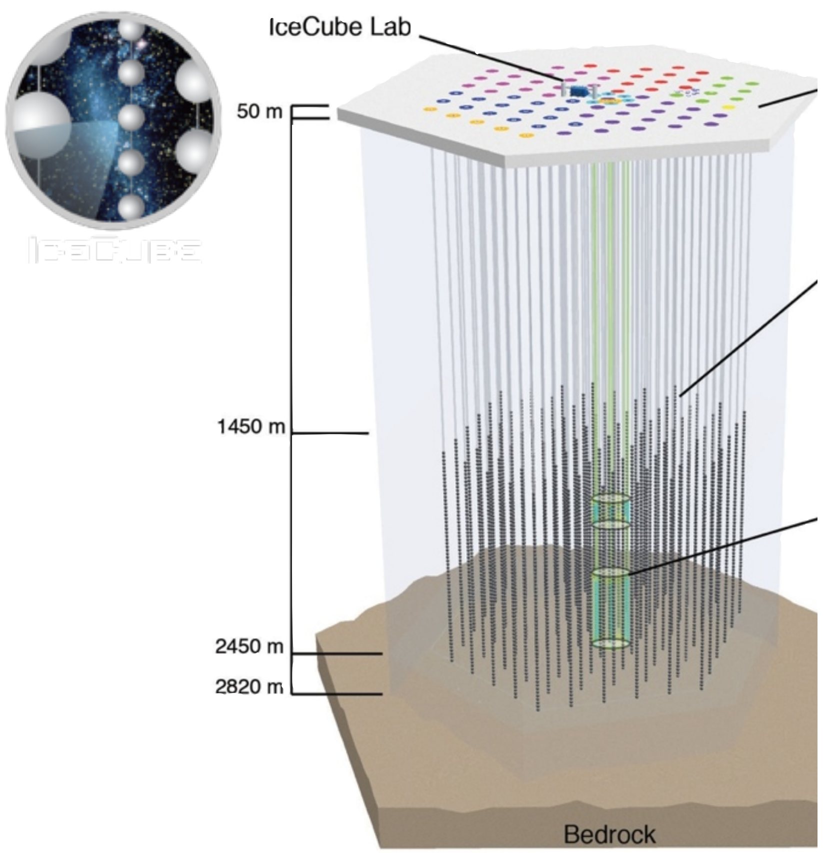
line of sight (los) integral

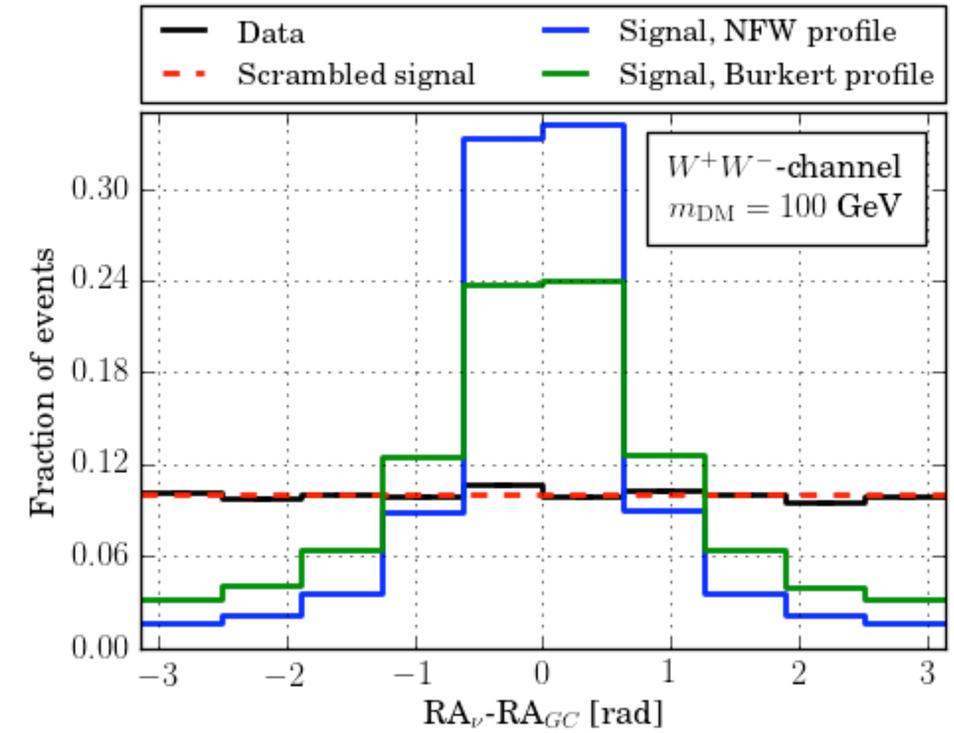


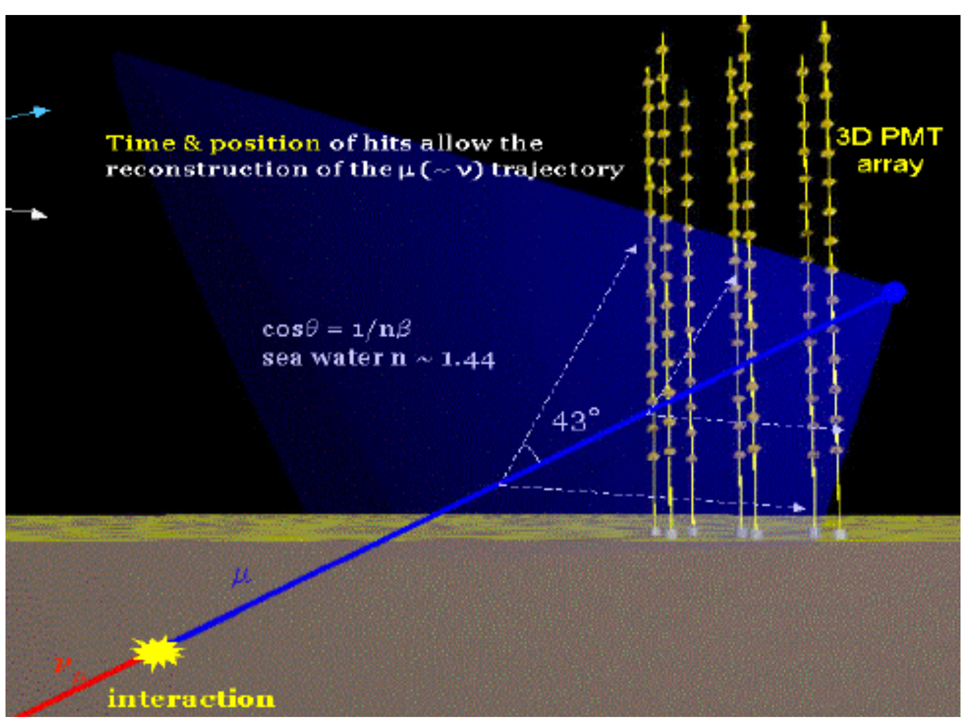
$$\int_{\Delta\Omega(\phi,\theta)} d\Omega' \int_{\mathrm{los}} \rho^2(r(l,\phi'))dl(r,\phi')$$

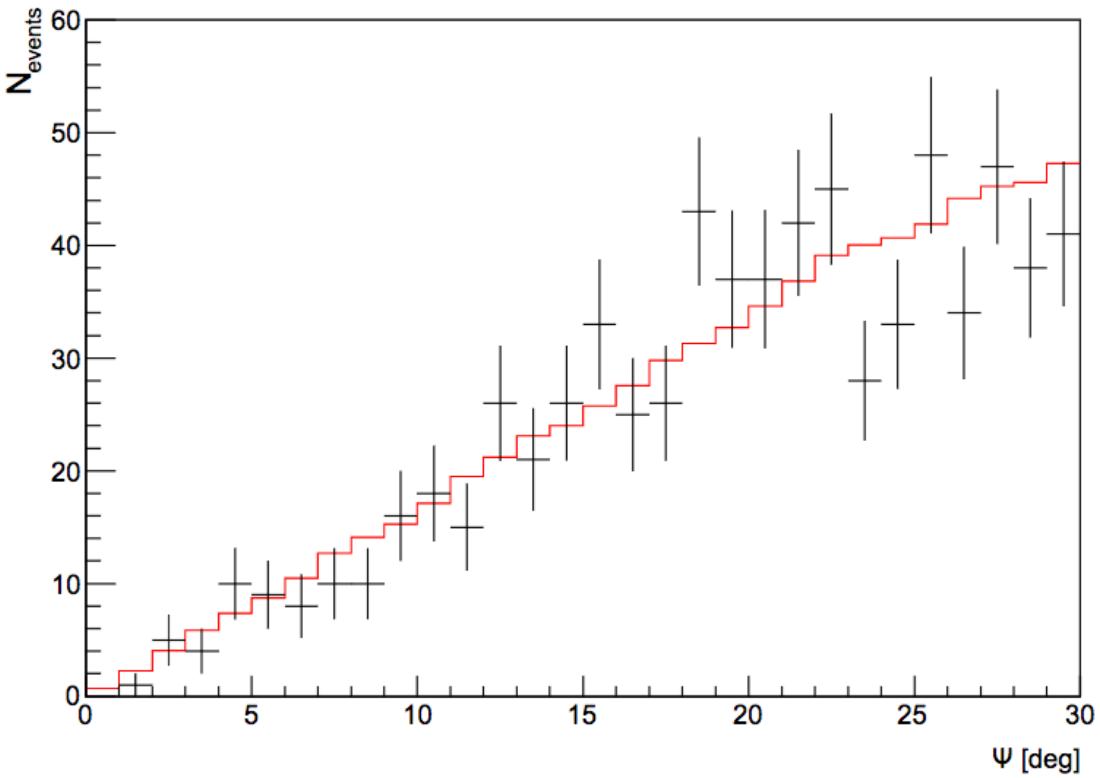


INDIRECT DARK MATTER SEARCHES IN ICECUBE / ANTARES









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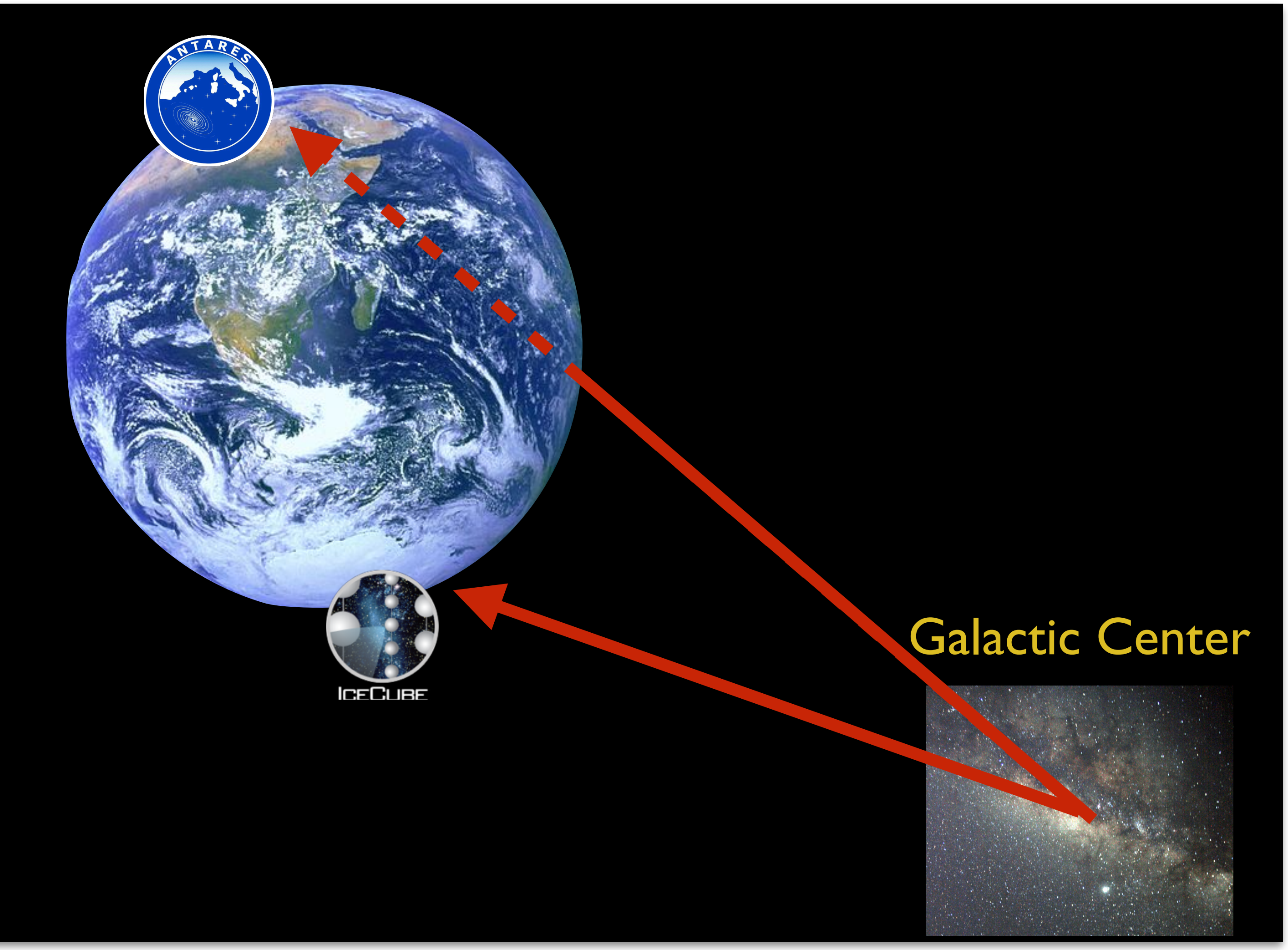
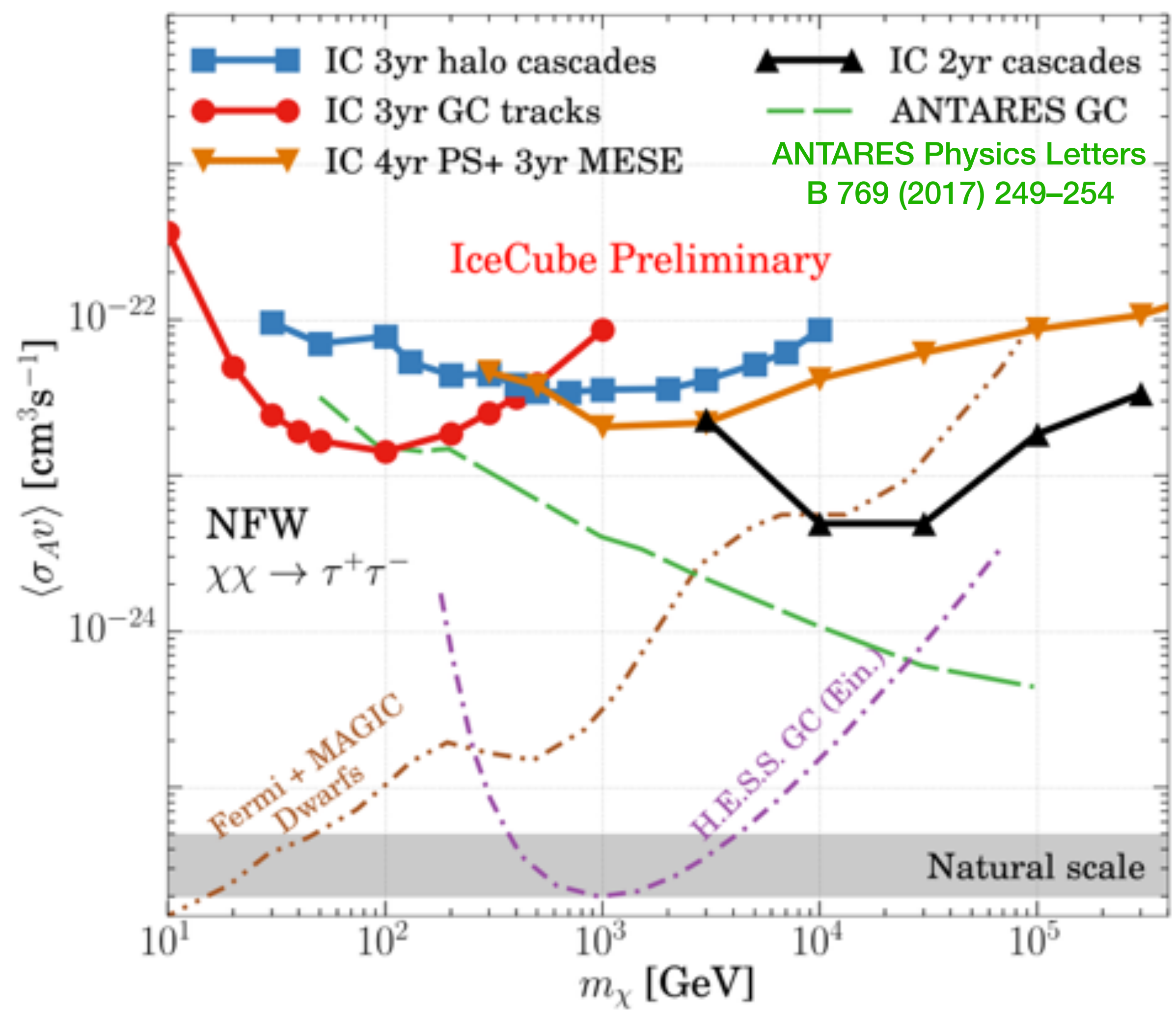


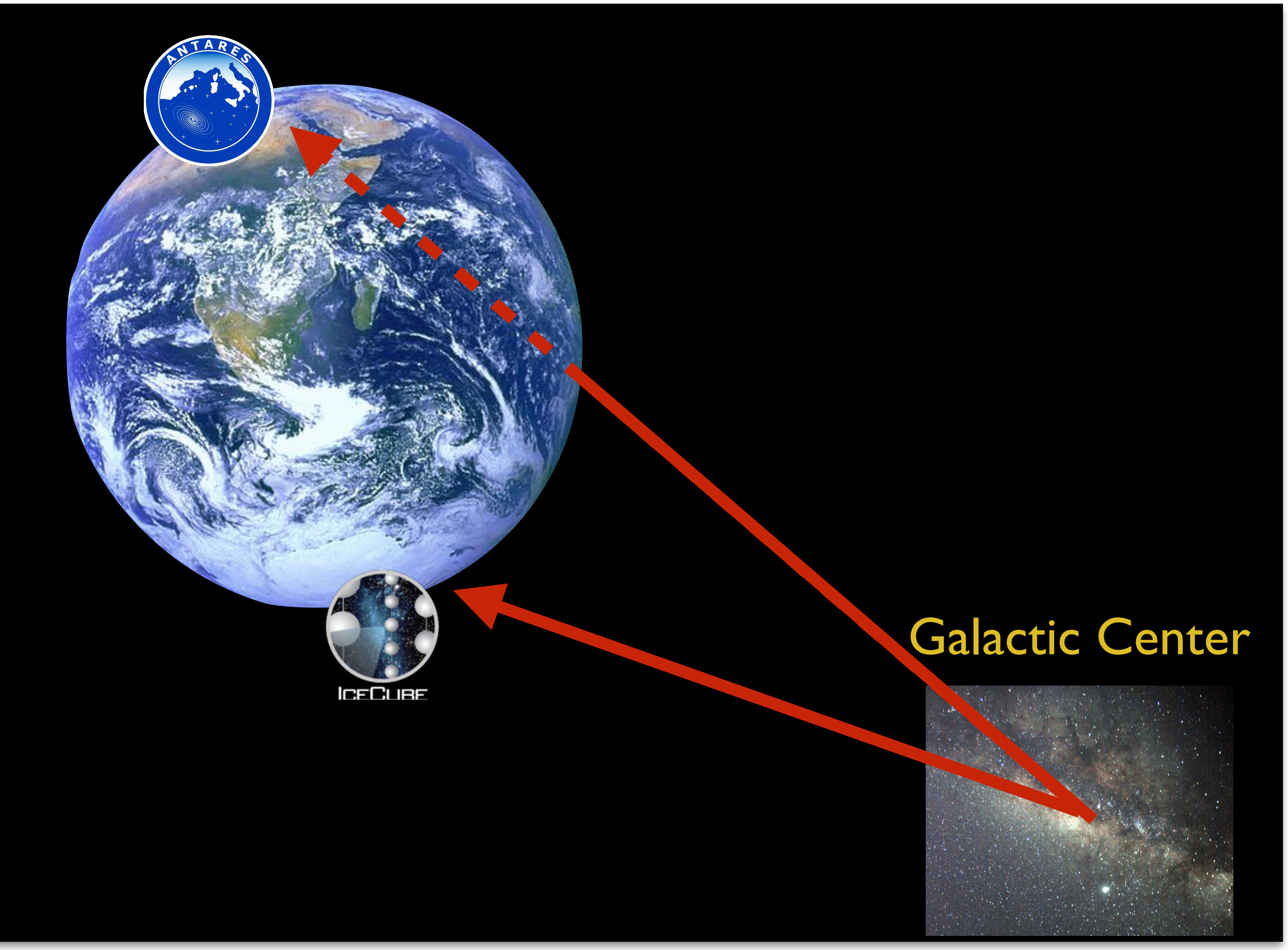
- ANTARES and IceCube complementary positioned on Northern and Southern Hemisphere
- Galactic Center only accessible in down-going events for IceCube
- Weak halo model dependence for observation of extended DM halo

Galactic Halo DM annihilation searches cover 10 GeV - 300 TeV Dark Matter masses with 4 analyses:

- ANTARES GC 2007 to 2015
- IceCube Galactic Halo Cascades 2yrs
- IceCube Galactic Center Tracks 4yrs (incl. 3yr MESE)
- IceCube Galactic Center Track 3yrs (low-energy)
  - IceCube [arXiv:1705.08103] Eur. Phys. J. C (2017) 77: 627



INDIRECT DARK MATTER SEARCHES IN ICECUBE / ANTARES



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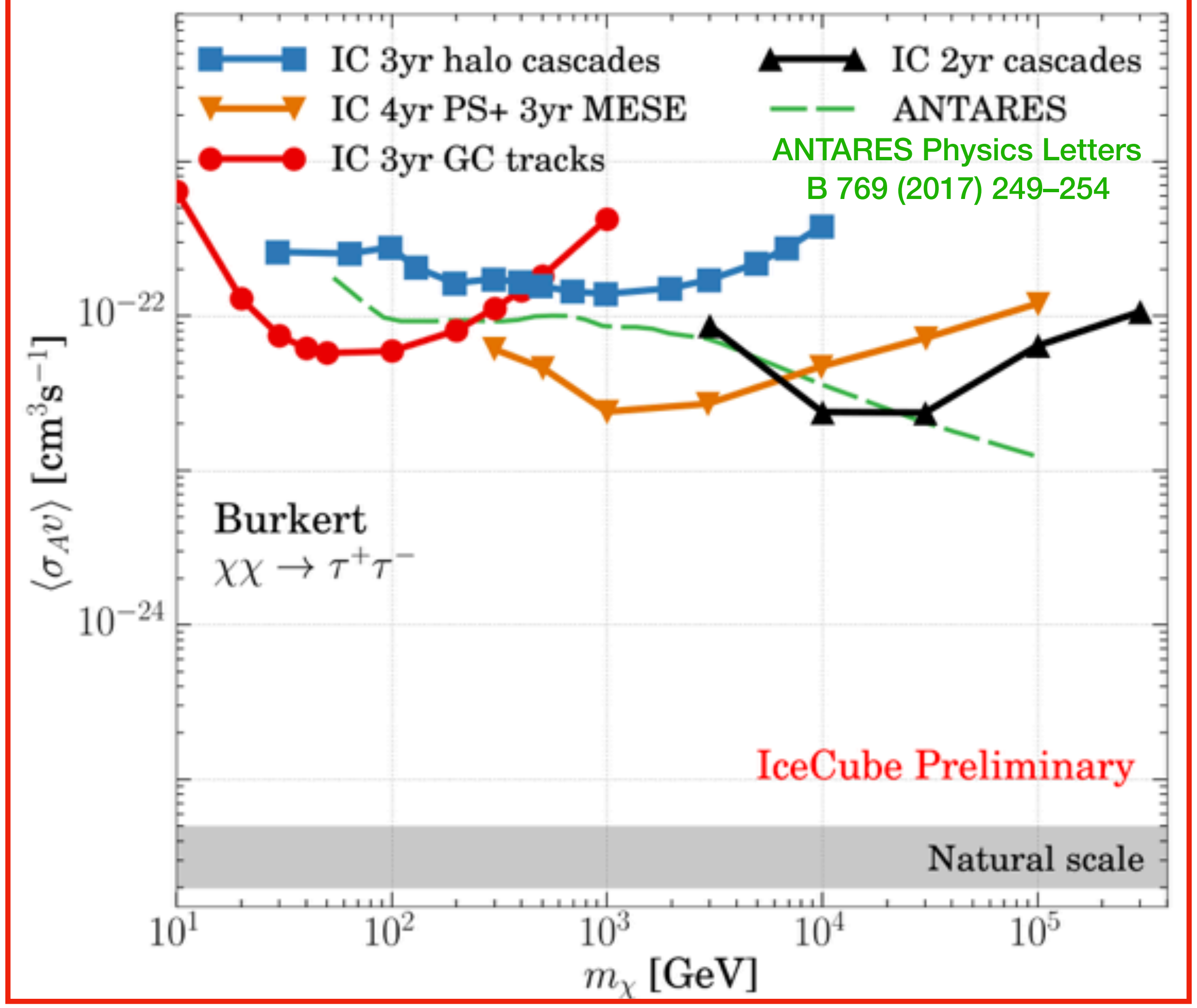
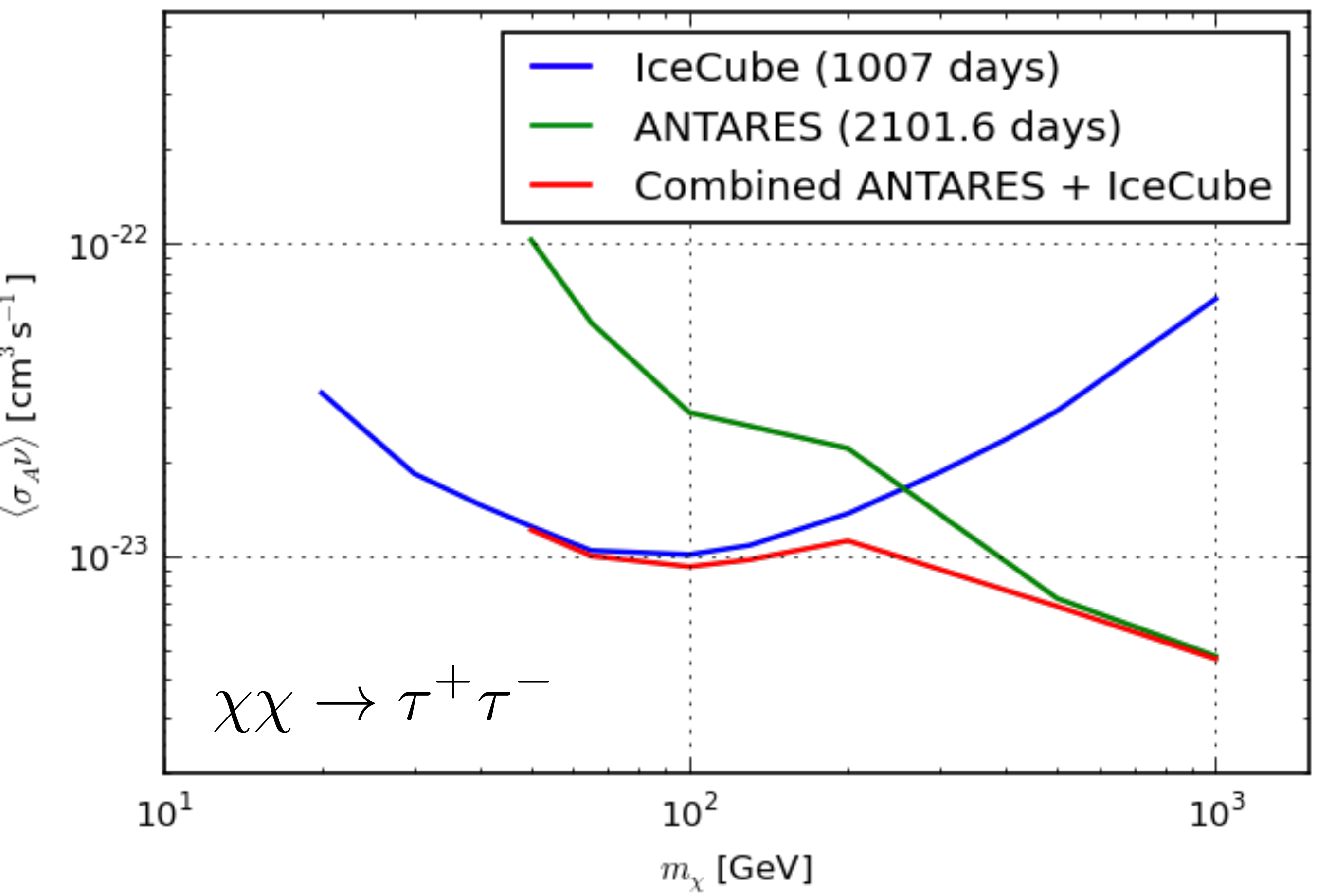
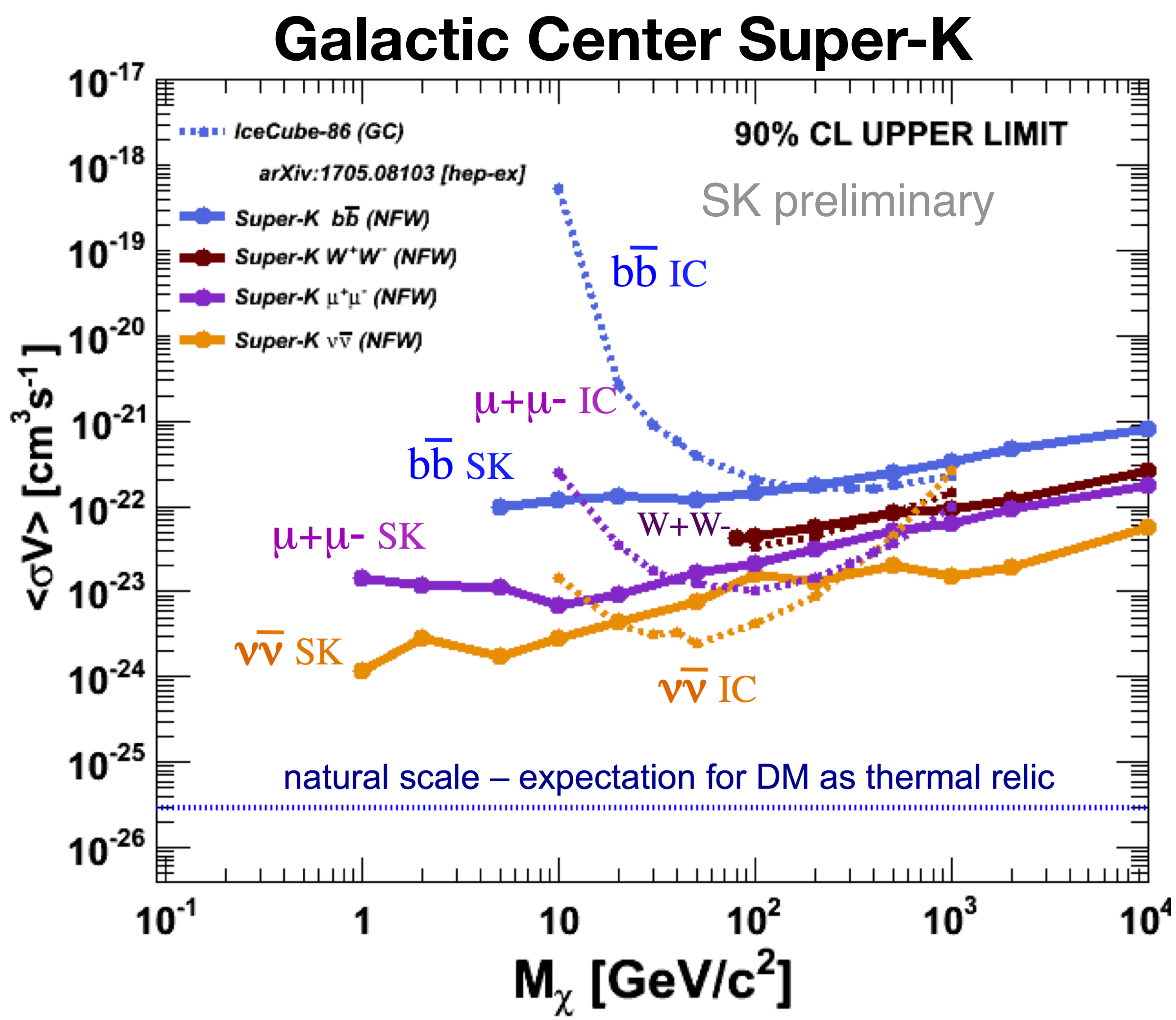


Galactic Center / Galactic Halo - IceCube/ ANTARES/Super-K

J.A. Aguilar Sánchez [ANTARES & IceCube] ICRC2017 (911)

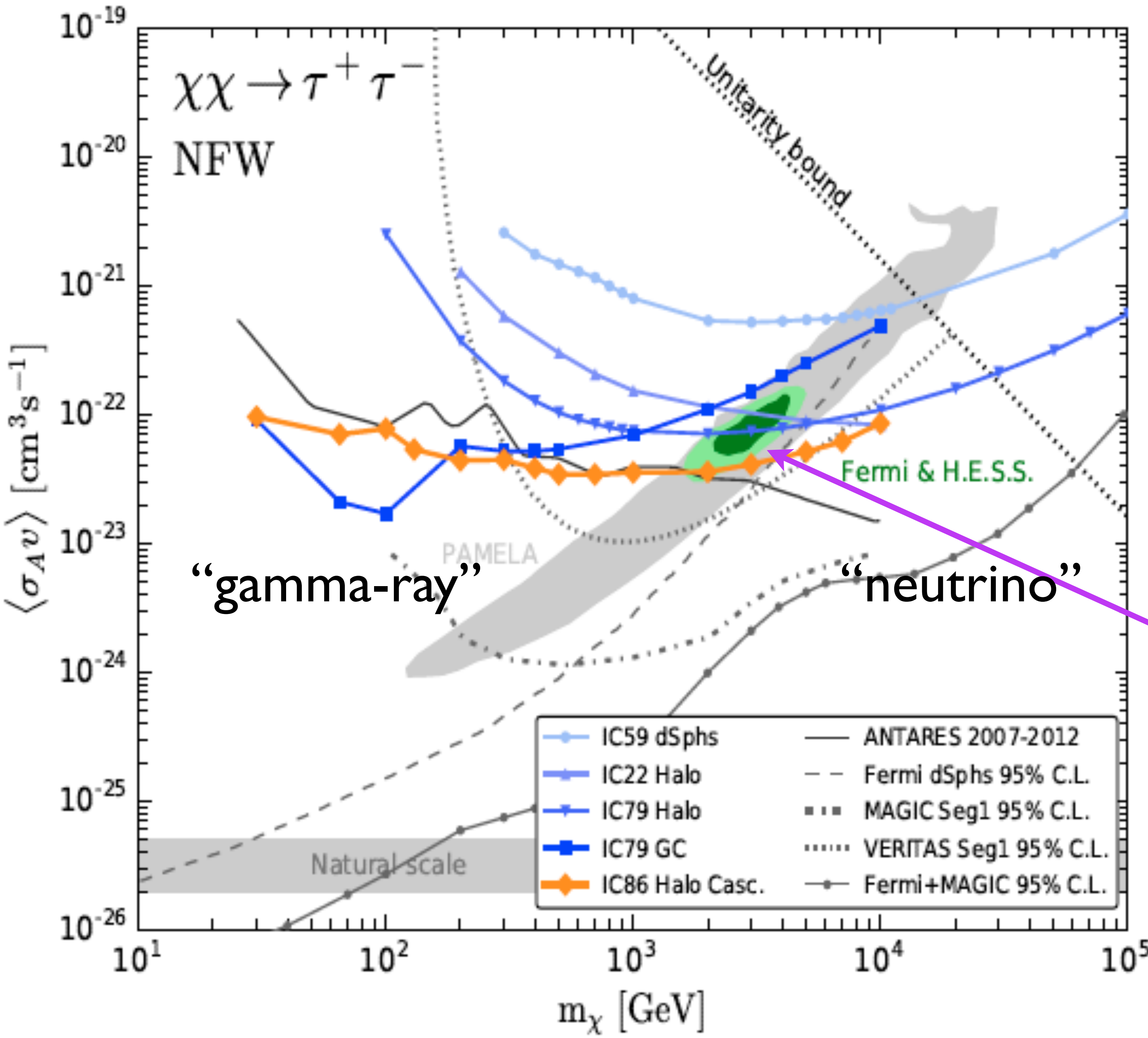


Combined Search for Neutrinos from Dark Matter Annihilation in the Galactic Center using IceCube and ANTARES



- Combined analysis enhances sensitivity in overlap region and helps to make analyses more comparable
- Very competitive result from Super-K for dark matter masses below a 100GeV

Neutrinos test lepton anomalies



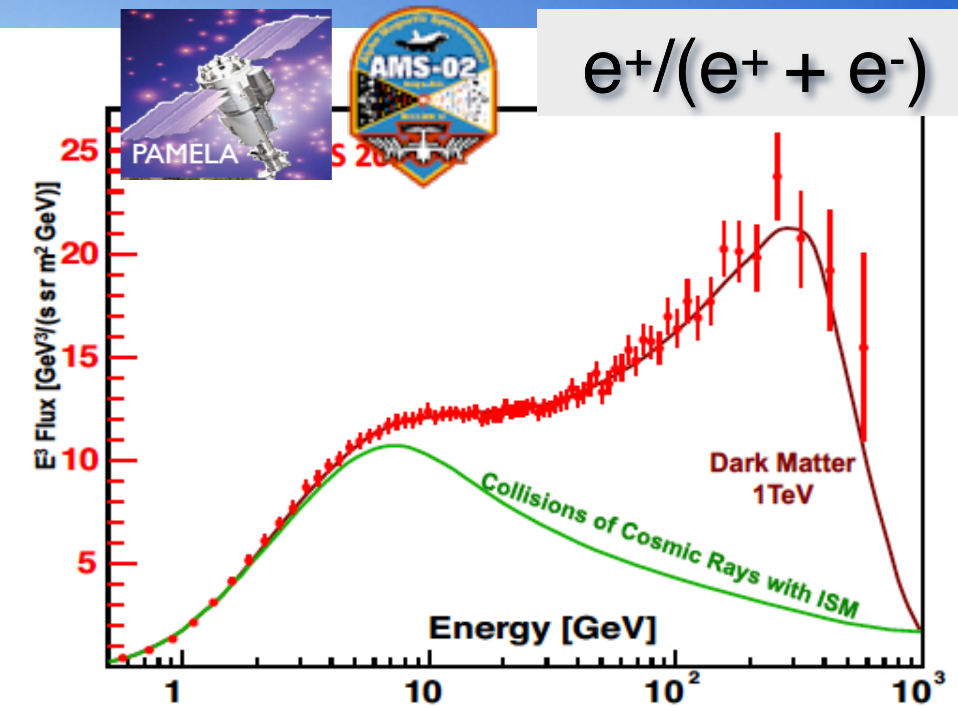
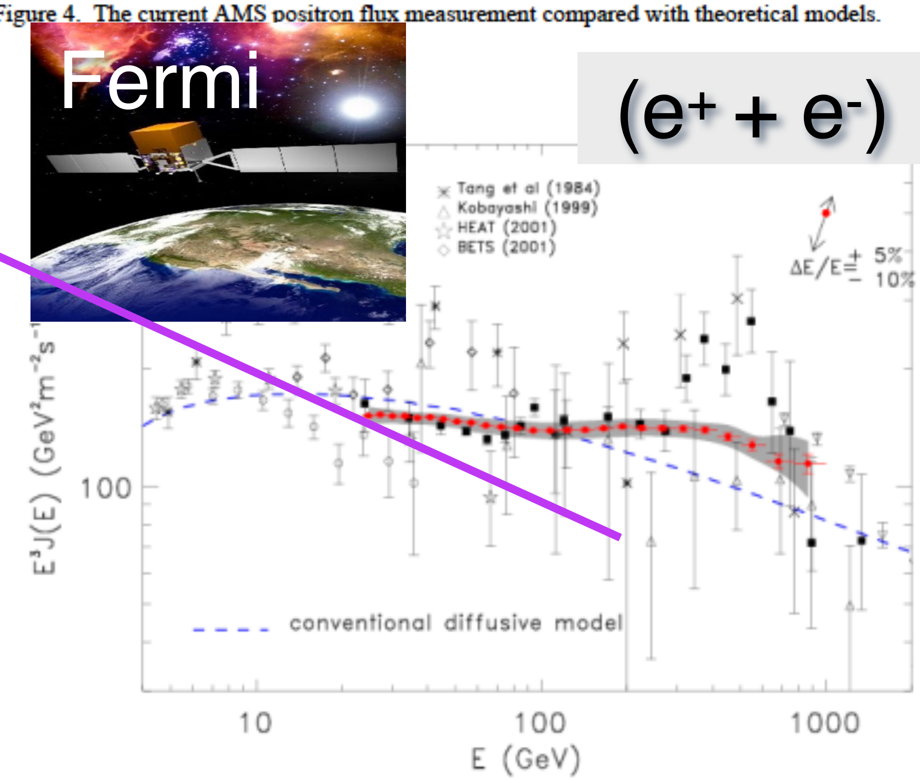
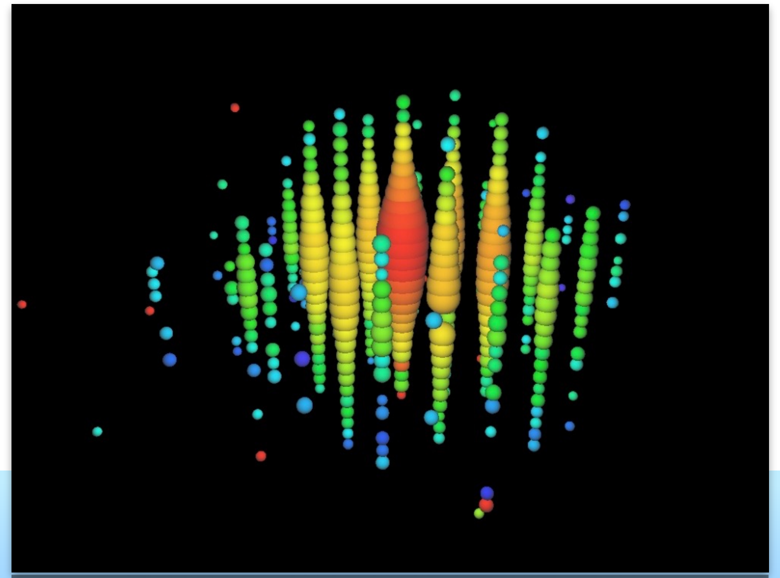


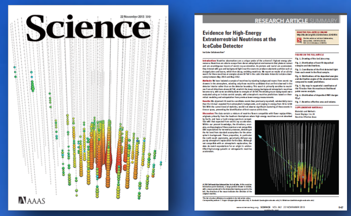
Figure 4. The current AMS positron flux measurement compared with theoretical models.



Neutrino Telescopes can probe models motivated by the observed lepton anomalies



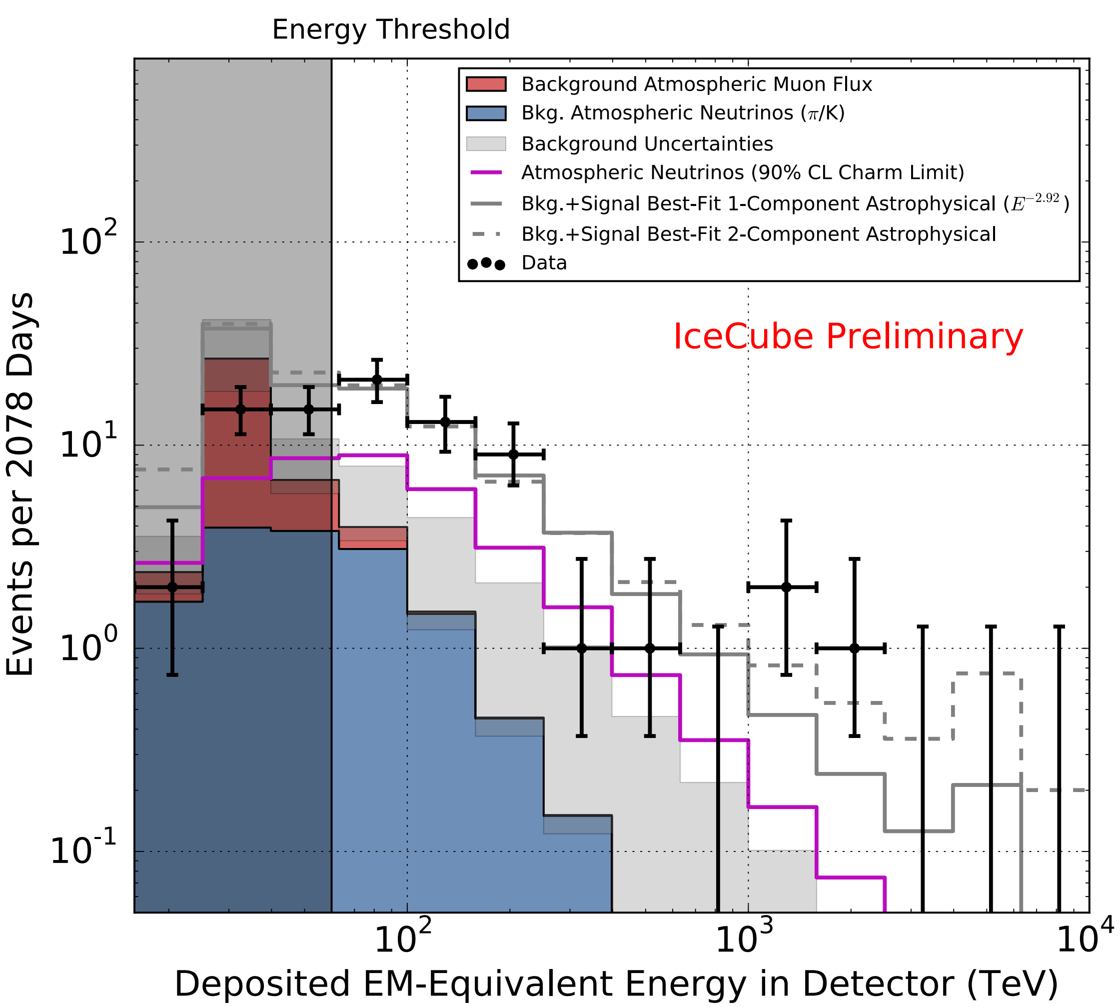
Dark Matter Decay / Astro-physical Neutrinos

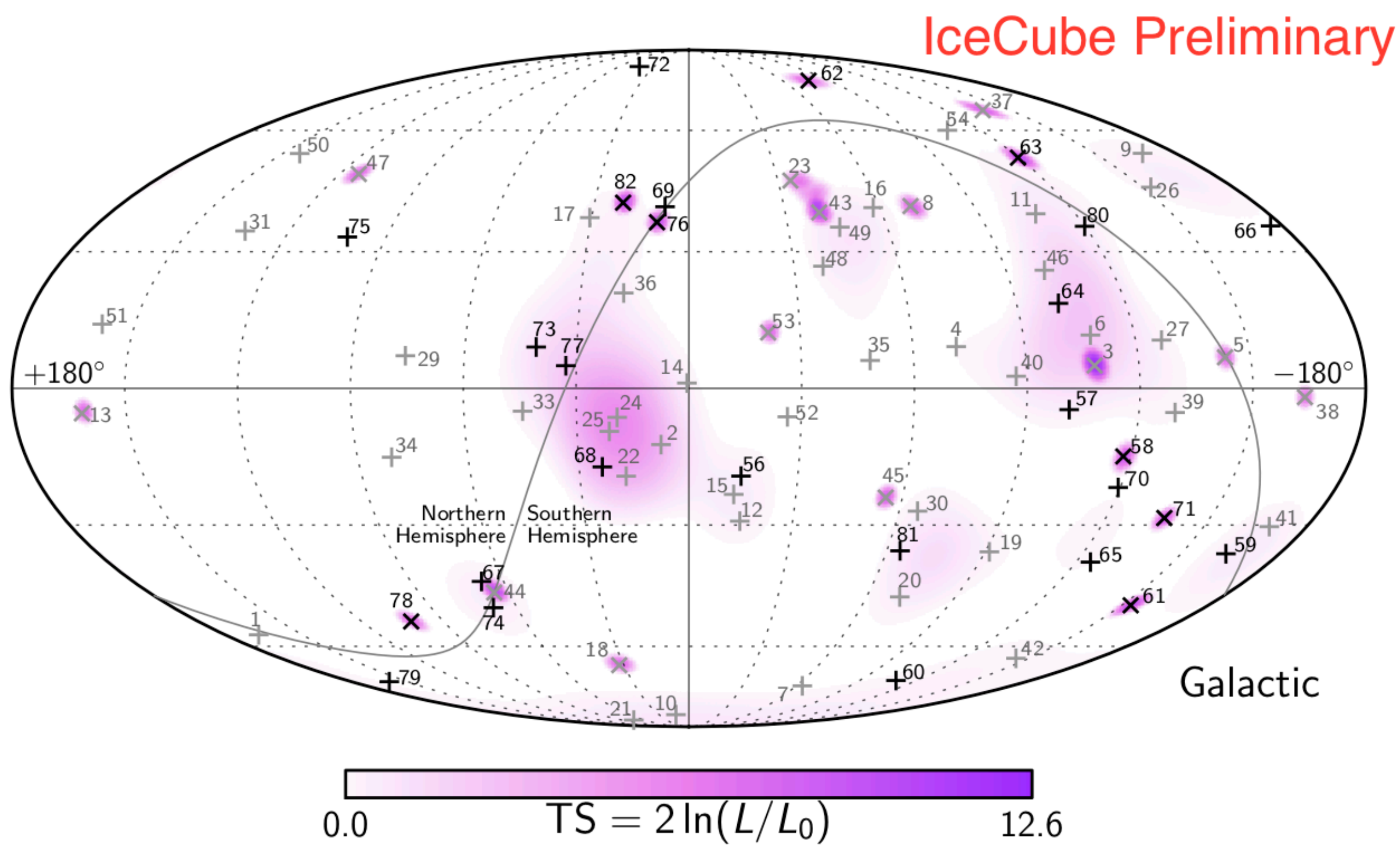


IceCube - High-energy neutrino search 6years

IceCube Collaboration, *Science 342, 1242856 (2013),*
IceCube Collaboration, *Phys. Rev. Lett 113, 101101 (2014)*

80 events (track-like & showers) observed
Expected from the Earth atmosphere ~41events



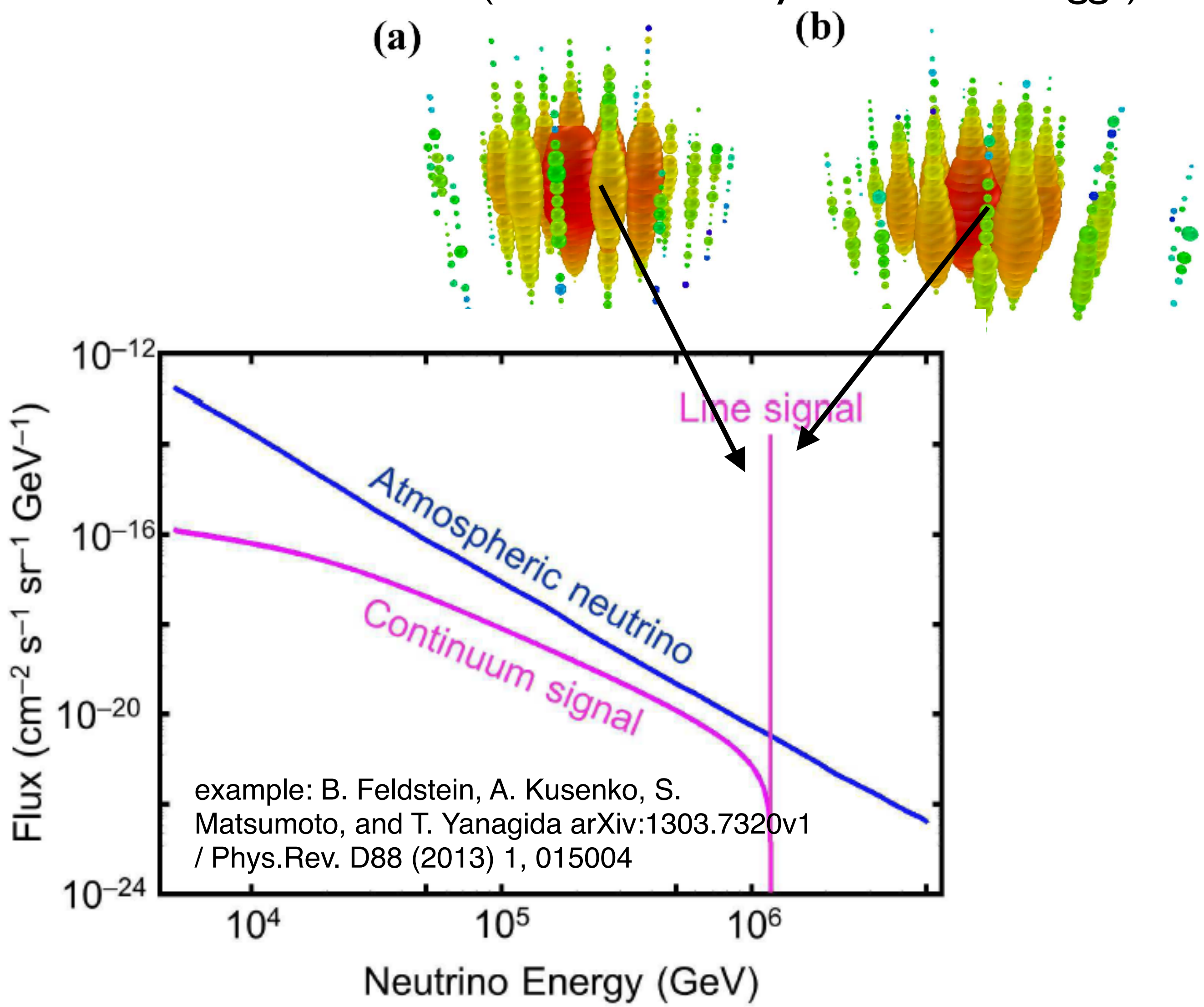


Best fit spectral index ($E^{-\gamma}$):
$\gamma=-2.92^{+0.33}_{-0.29}$

no significant clustering observed

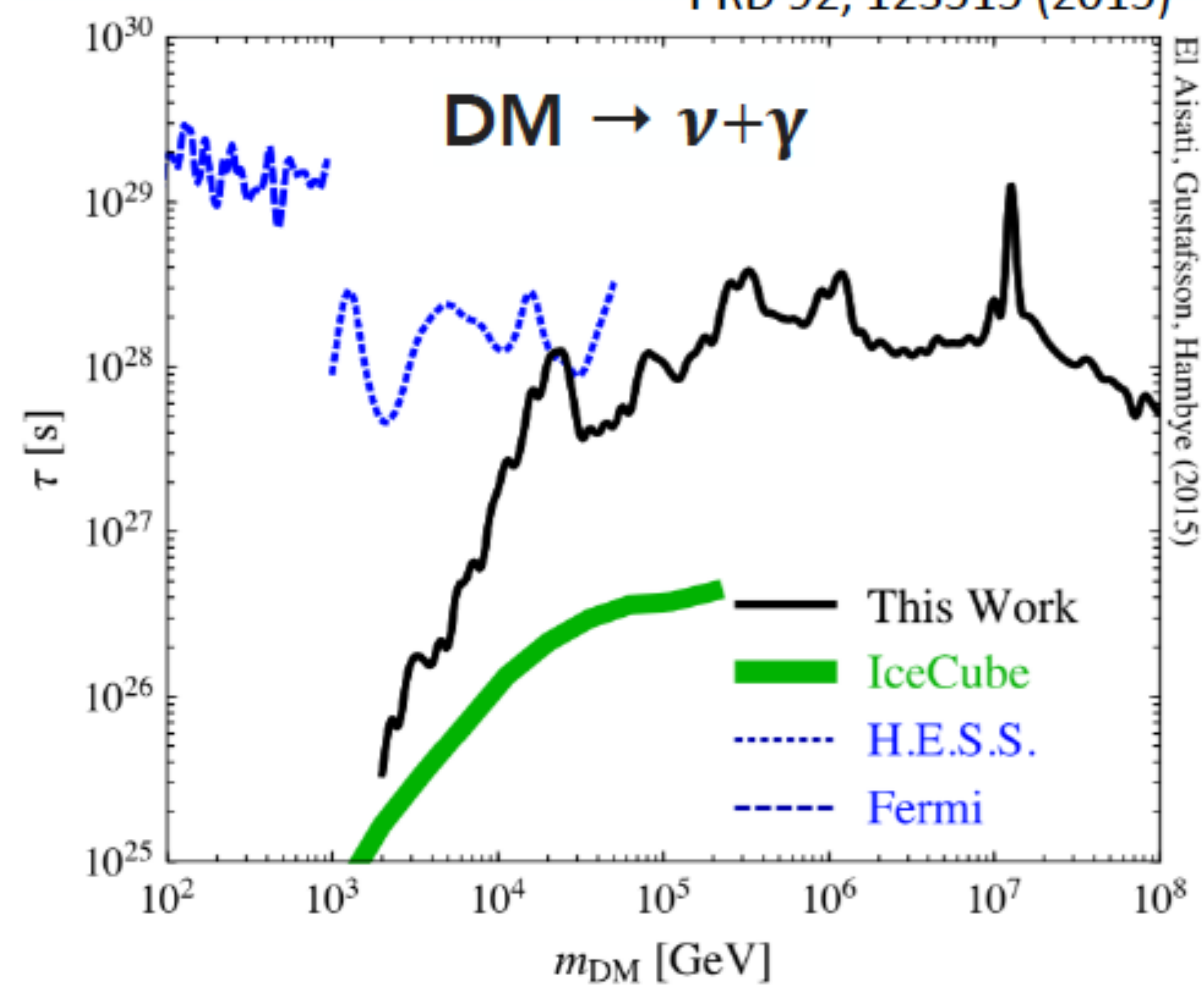
Heavy Dark Matter Decay

- Heavy Decaying Dark Matter (example $\chi \rightarrow \nu h$)
- Focus on most detectable feature (neutrino line)
- Backgrounds steeply falling with energy, highest energy events provide best sensitivity
- Continuum and spacial distribution could help identify a signal
- Bounds from Fermi-LAT and PAMELA derived from search for bb annihilation channel (dominant decay channel of Higgs).



Bound on lifetime ~10^{28}s derived with IceCube data

PRD 92, 123515 (2015)



Heavy DM bounds with neutrinos, see also
Murase and Beacom JCAP 1210 (2012) 043
Esmaili, Ibarra, and Perez JCAP 1211 (2012) 034
El Aisati, Gustafsson, Hambye 1506.02657

Dedicated IceCube analysis can improve on these bounds …

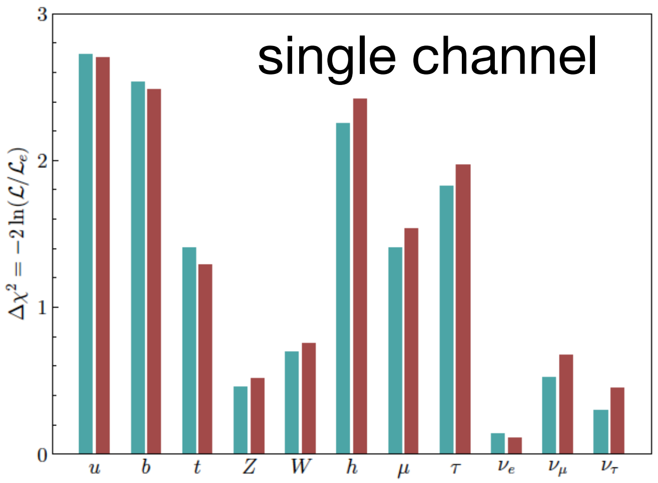
Heavy Decaying Dark Matter

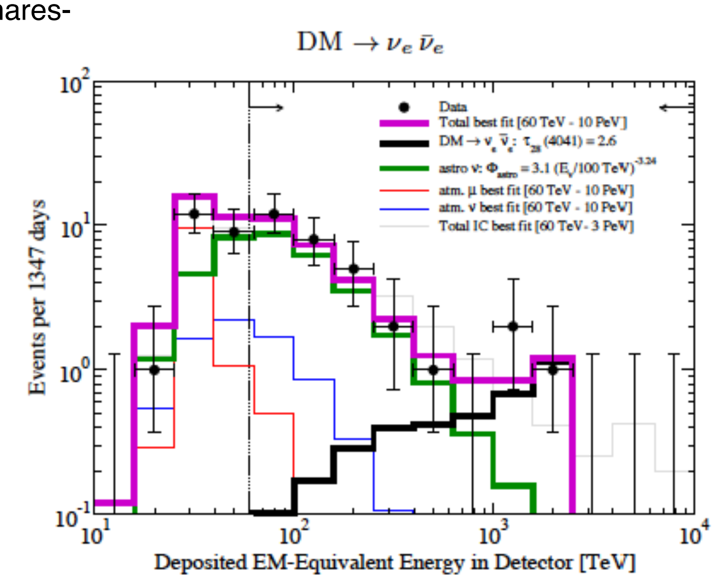
Could the observed neutrino flux be due to only dark matter decaying into multiple channels?

$$\frac{d\Phi_{\mathrm{DM},\nu_\alpha}}{dE_\nu} = \frac{d\Phi_{\mathrm{G},\nu_\alpha}}{dE_\nu} + \frac{d\Phi_{\mathrm{EG},\nu_\alpha}}{dE_\nu}$$

Take Galactic and Extra galactic contributions into account

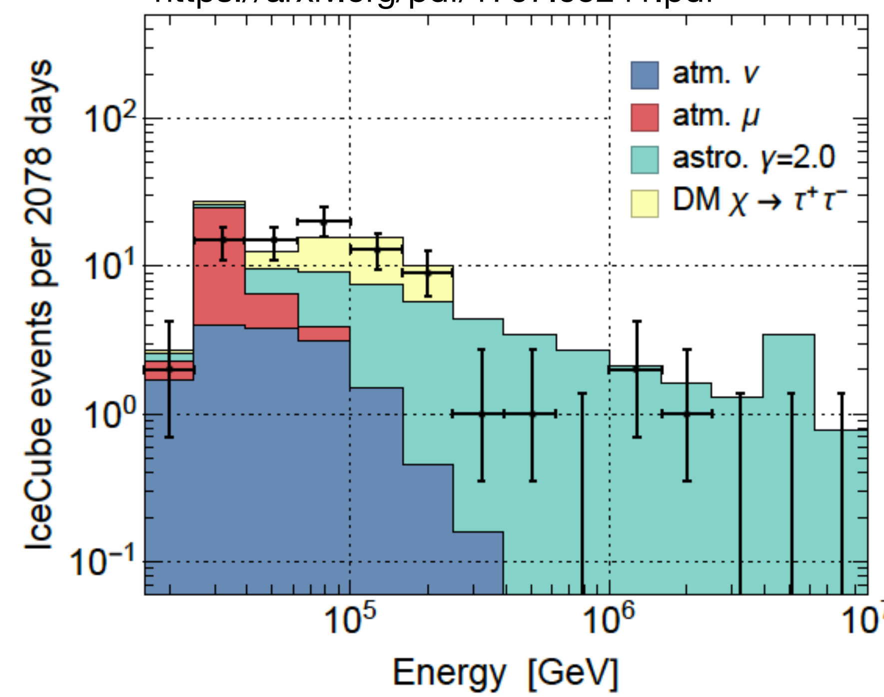
Atri Bhattacharya, Arman Esmaili, Sergio Palomares-Ruiz and Ina Sarcevic, arXiv:1706.05746

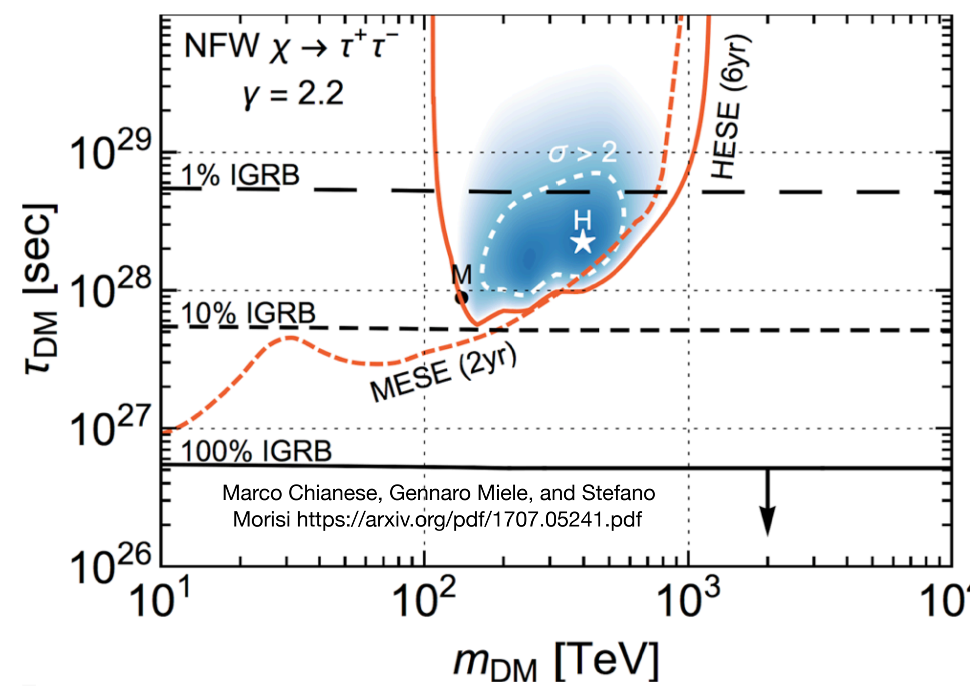




Find that HESE data can be best described with the combination of the astrophysical neutrino flux and the dark matter decay

Marco Chianese, Gennaro Miele, and Stefano Morisi
https://arxiv.org/pdf/1707.05241.pdf





Caution when interpreting HESE events:
- Earth absorption needs to be considered
- Outcome strongly depends on background assumption

Heavy DM bounds with neutrinos, see also
Murase and Beacom JCAP 1210 (2012) 043
Esmaili, Ibarra, and Perez JCAP 1211 (2012) 034
Rott, Kohri, Park PRD92, 023529 (2015)
El Aisati, Gustafsson, Hambye 1506.02657

Dark Matter Decay with IceCube

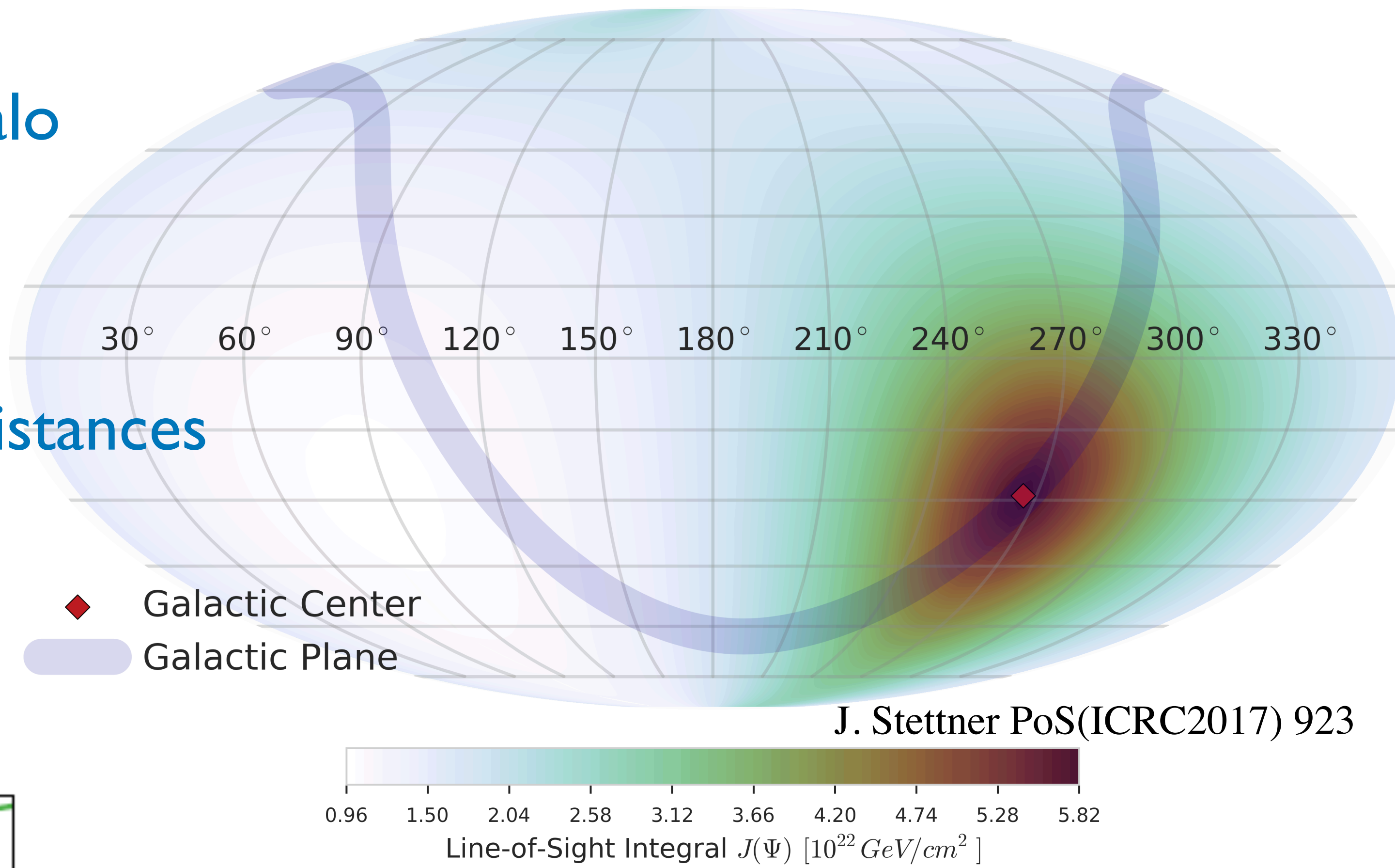
Two expected flux contributions:

- Dark Matter decaying in the Galactic Halo (Anisotropic flux + decay spectrum)

$$\frac{\mathrm{d}\Phi^{\mathrm{G}}}{\mathrm{d}E_\nu} = \frac{1}{4\pi\, m_{\mathrm{DM}}\, \tau_{\mathrm{DM}}} \frac{\mathrm{d}N_\nu}{\mathrm{d}E_\nu} \int_0^\infty \rho(r(s,l,b))\, \mathrm{d}s$$

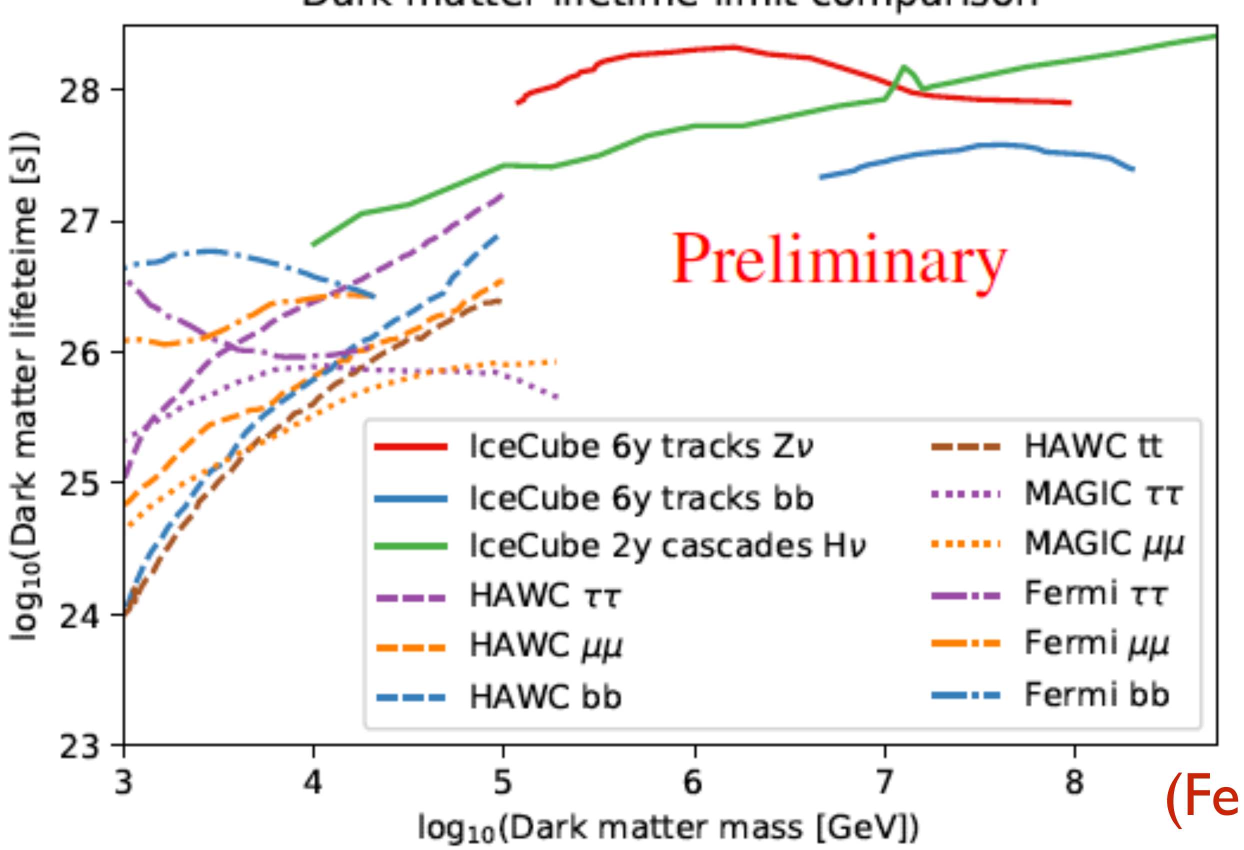
- Dark Matter decaying at cosmological distances (Isotropic flux + red-shifted spectrum)

$$\frac{\mathrm{d}\Phi^{\mathrm{EG}}}{\mathrm{d}E} = \frac{\Omega_{\mathrm{DM}}\, \rho_{\mathrm{c}}}{4\pi\, m_{\mathrm{DM}}\, \tau_{\mathrm{DM}}} \int_0^\infty \frac{1}{H(z)} \frac{\mathrm{d}N_\nu}{\mathrm{d}E_\nu} [(1+z)E_\nu]\, \mathrm{d}z$$



J. Stettner PoS(ICRC2017) 923

Dark matter lifetime limit comparison



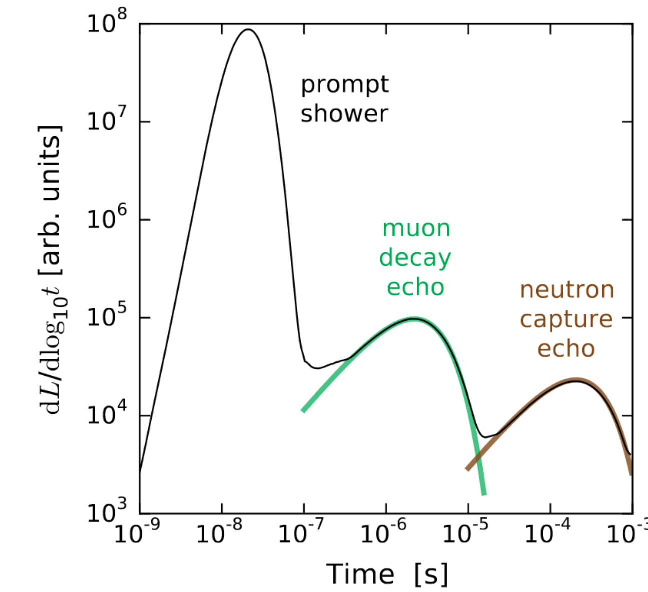
Test-Statistic: $TS = 2 \times \log \frac{\mathcal{L}(X|\tau^{DM}, M^{DM}, \Phi^{Astro}, \gamma^{astro})}{\mathcal{L}(X|\tau^{DM} = \infty, \hat{\Phi}^{Astro}, \hat{\gamma}^{astro})}$

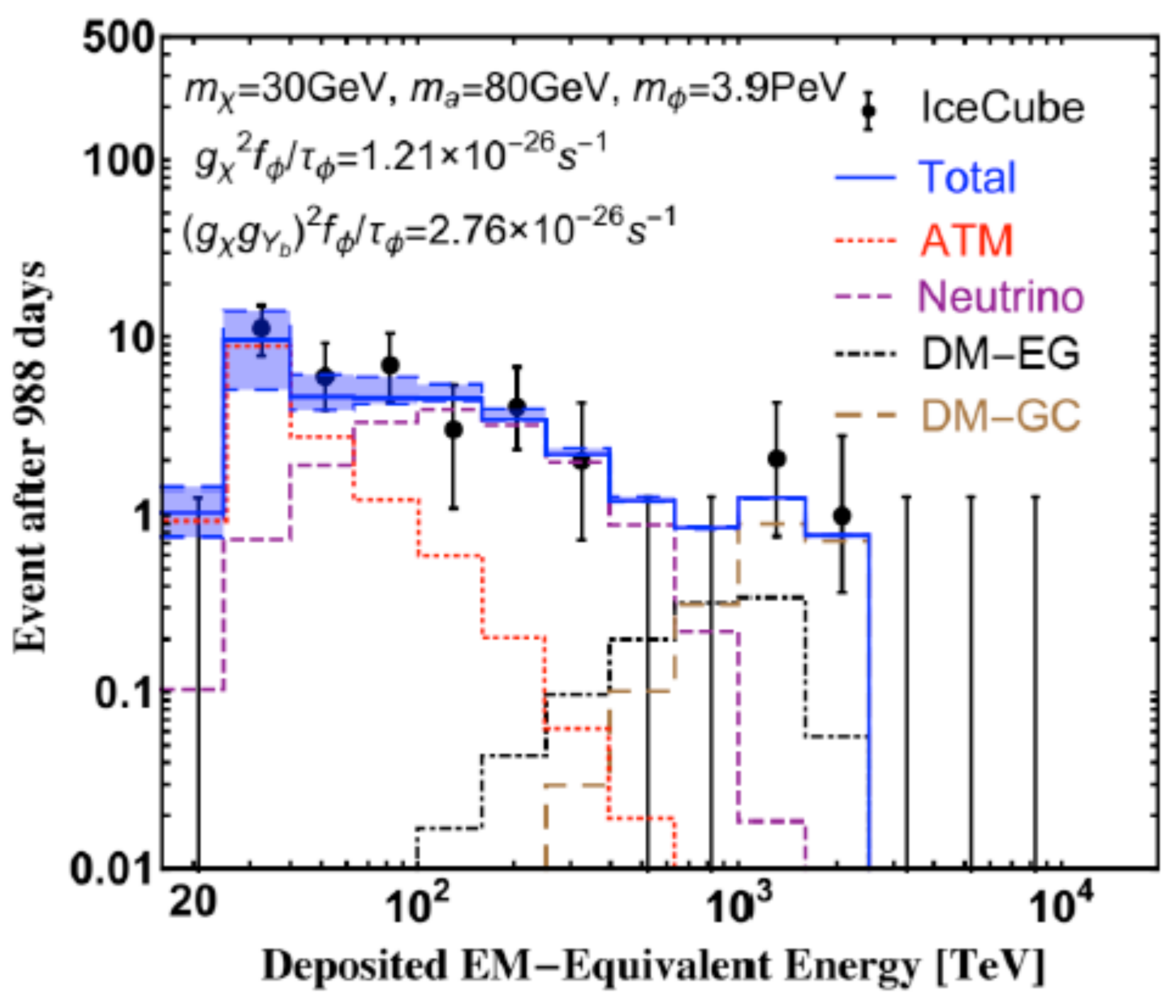
Bound on DM lifetime at ~10^{27}s obtained with IceCube data for m_{DM}>10TeV

(Fermi-LAT and HAWC results see talk by Simona Murgia)

IceCube Boosted Dark Matter

- "Boosted Dark Matter Search"
  - 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!

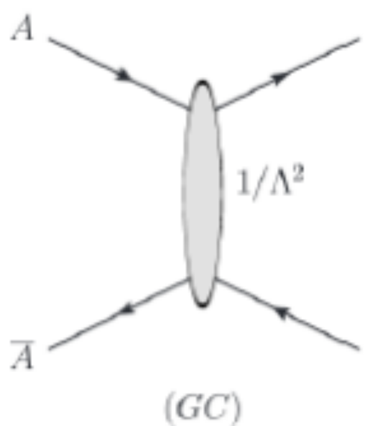
Recoil (only hadronic cascades)

$\phi \rightarrow \chi\,\bar{\chi}\,a,\ a \rightarrow b\,\bar{b} \rightarrow \nu$'s

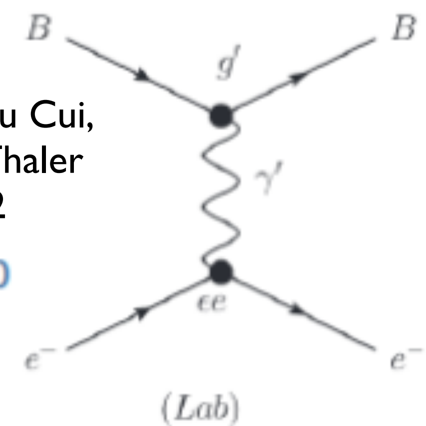
see also A. Steuer, L. Koepke [IceCube] PoS(ICRC2017)1008

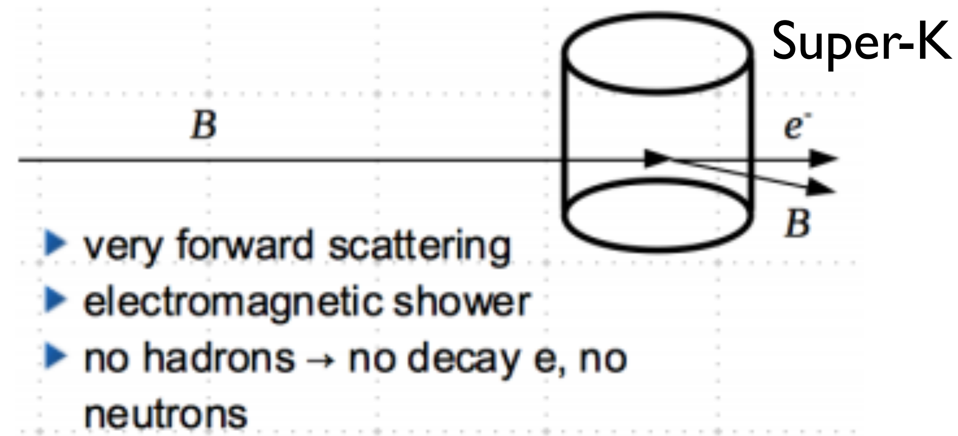
May sound crazy, but is just an example for exotic interactions in IceCube detectable via recoil

Boosted Dark Matter

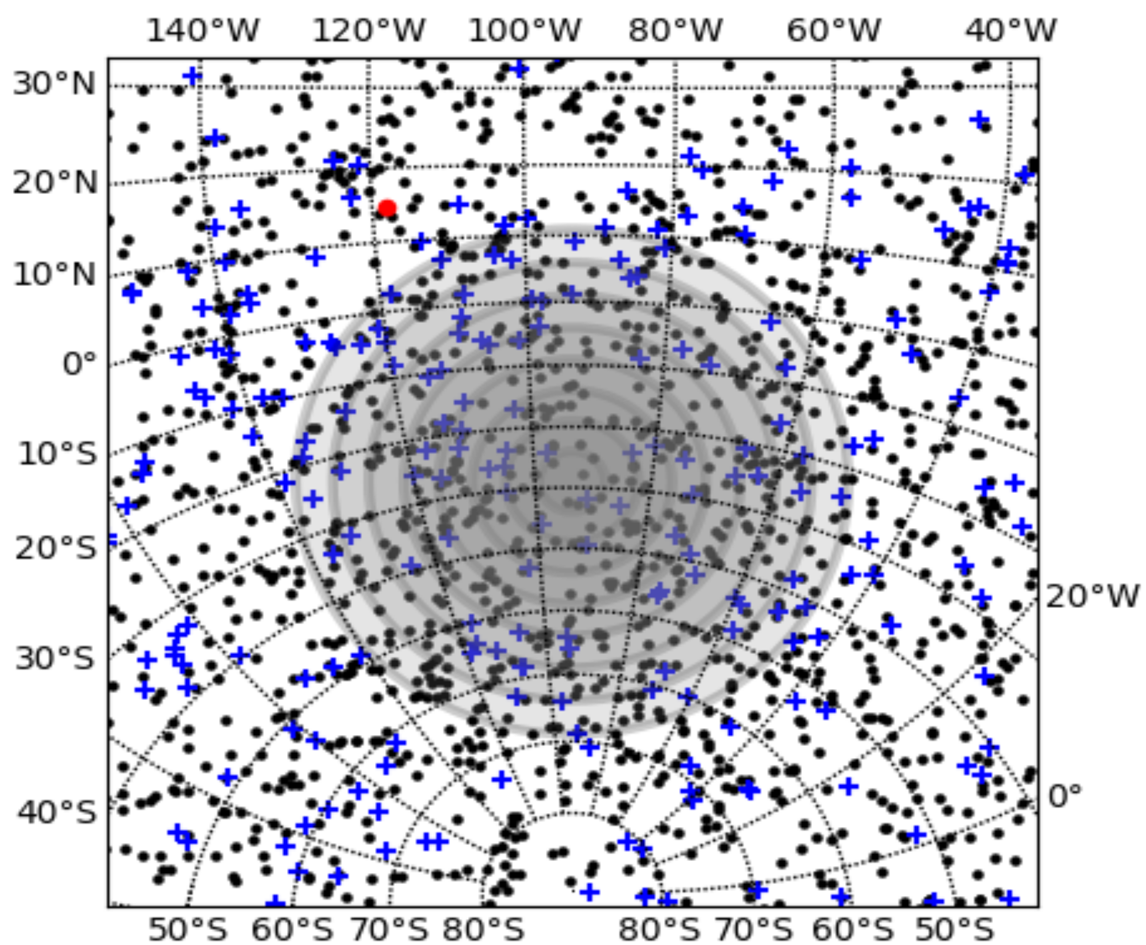


Kaustubh Agashe, Yanou Cui, Lina Necib, and Jesse Thaler
JCAP10(2014)062
arXiv:1405.7370



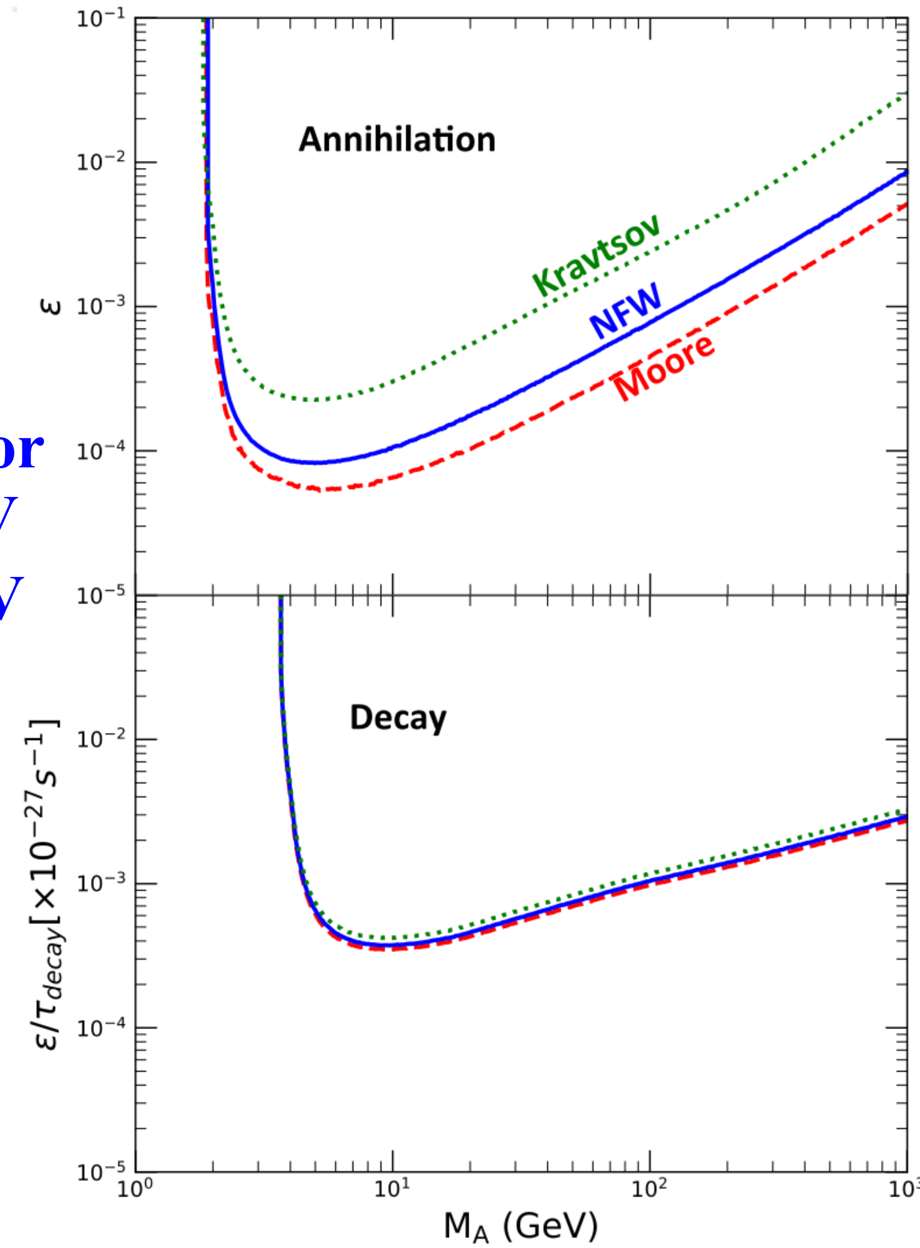


Cone search: 8 cones from 5° to 40° around GC
→ no cluster found around Galactic Center



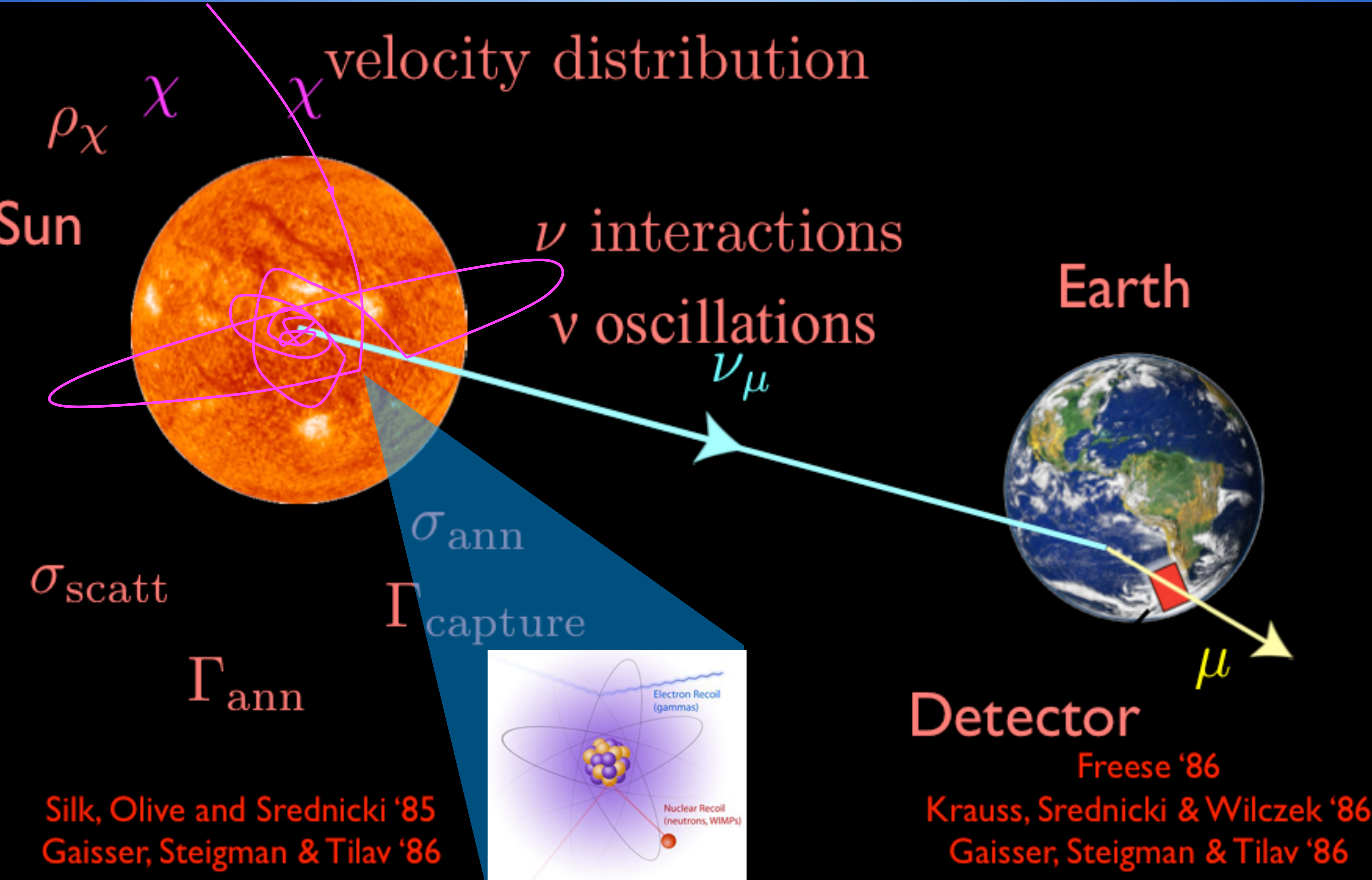
• < 1.33 GeV + 1.33 GeV-20 GeV • >20 GeV

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



Dark Matter Capture in the Sun

Solar Dark Matter

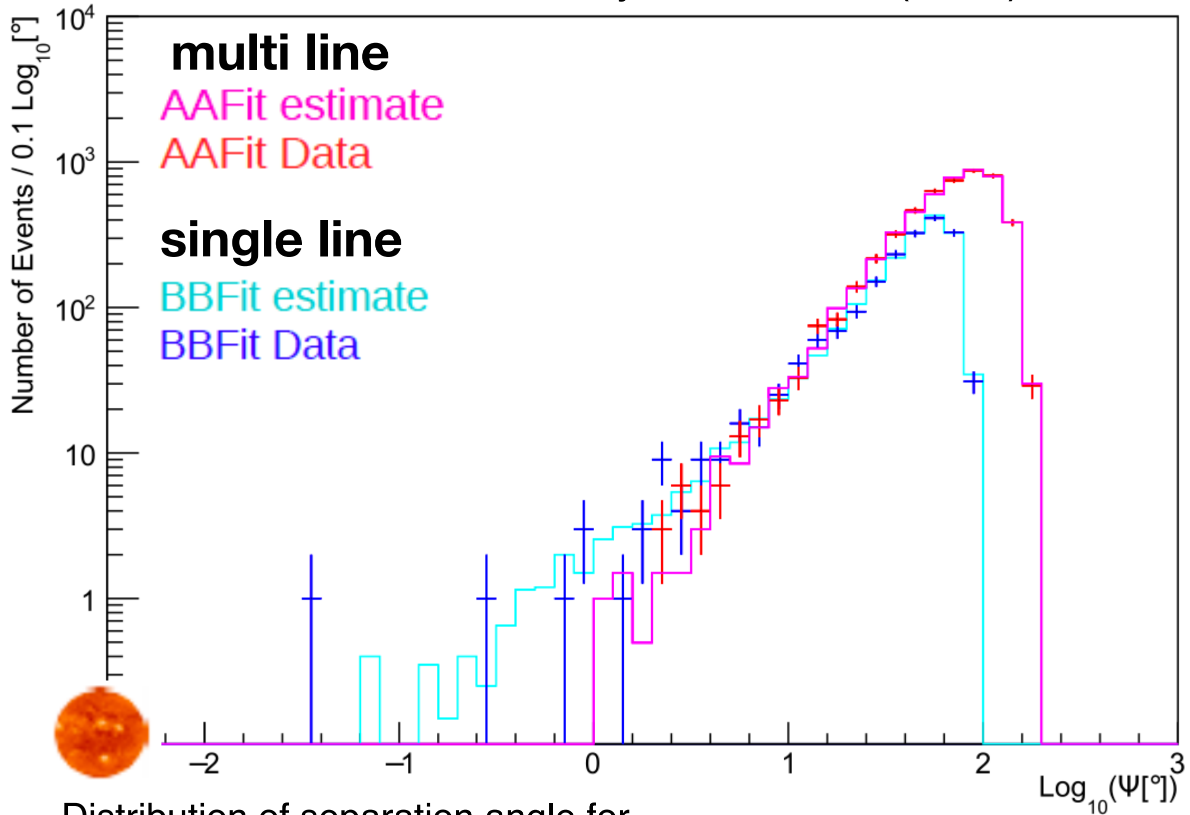


Silk, Olive and Srednicki '85
Gaisser, Steigman & Tilav '86

Freese '86
Krauss, Srednicki & Wilczek '86
Gaisser, Steigman & Tilav '86

ANTARES

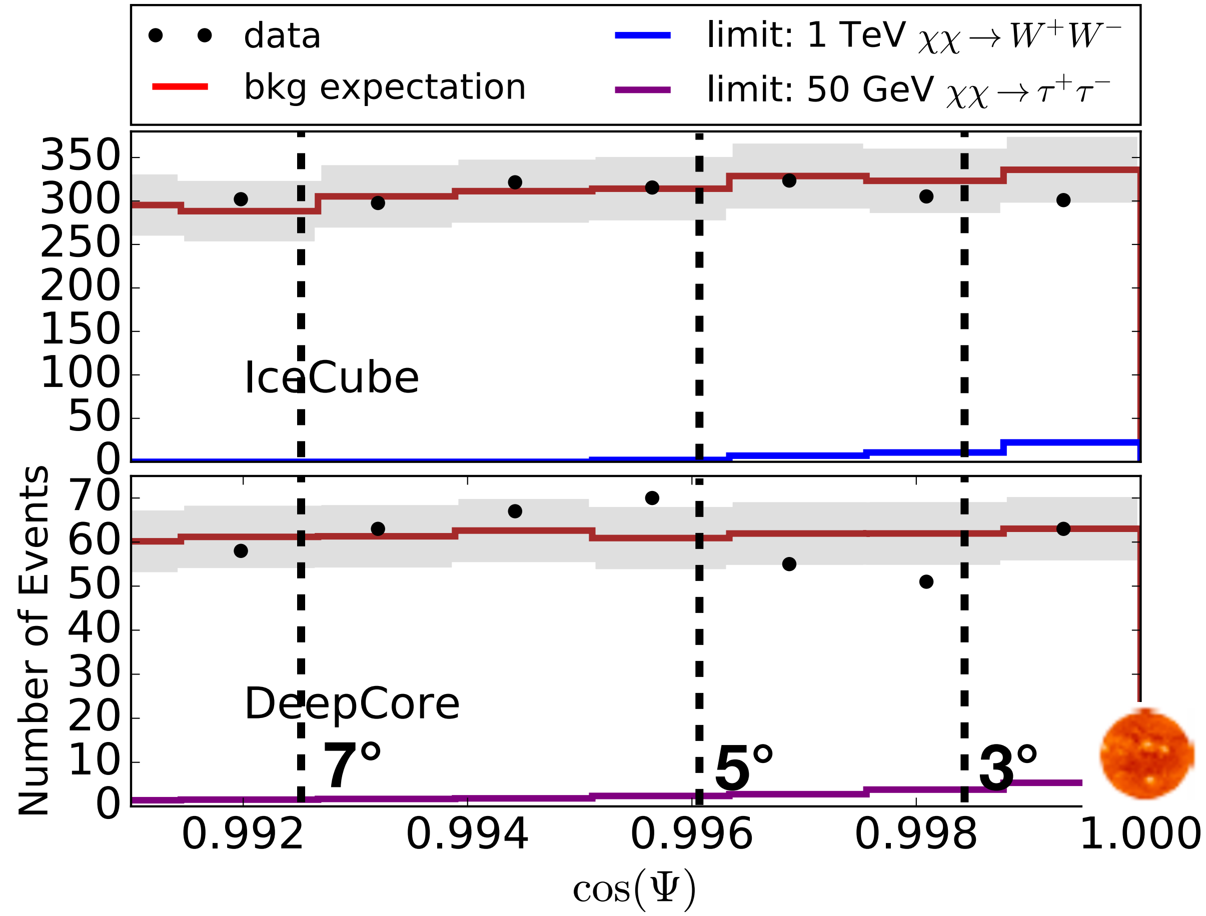
ANTARES - Phys.Lett. B759 (2016) 69-74



Distribution of separation angle for 2007-2012 ANTARES data

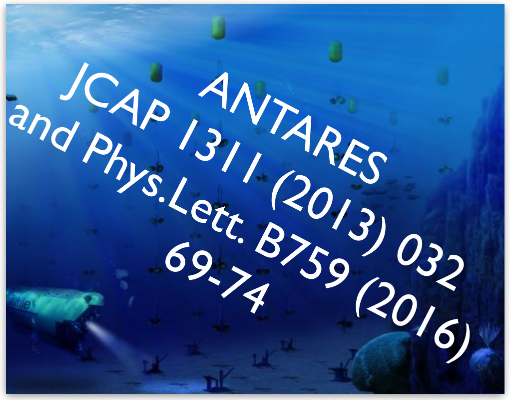
IceCube

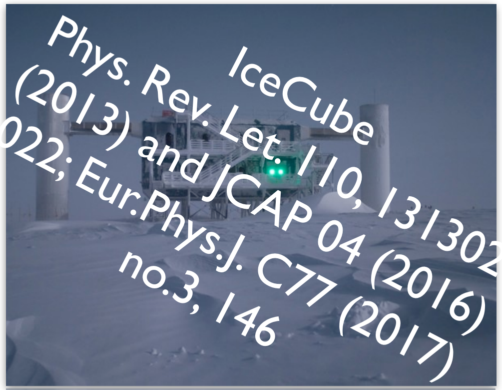
IceCube Eur.Phys.J. C77 (2017) no.3, 146

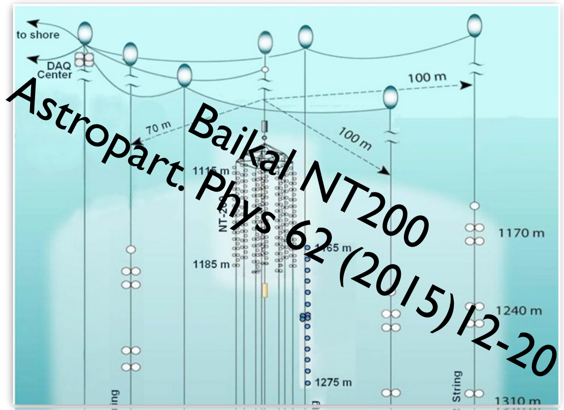


- Search for an excess in direction of the Sun
- Off source region used to reliable predict backgrounds from data

Solar Dark Matter Summary

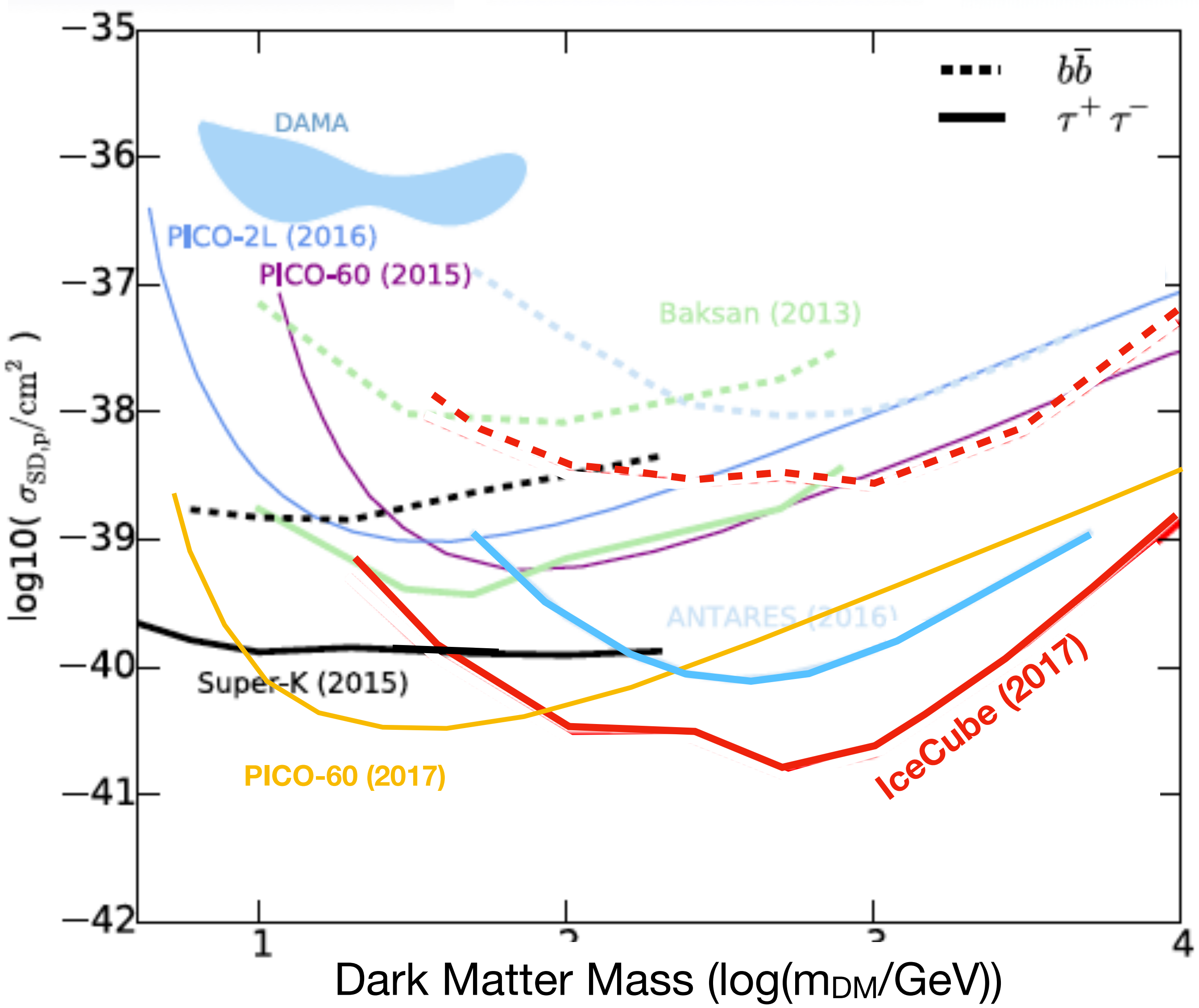


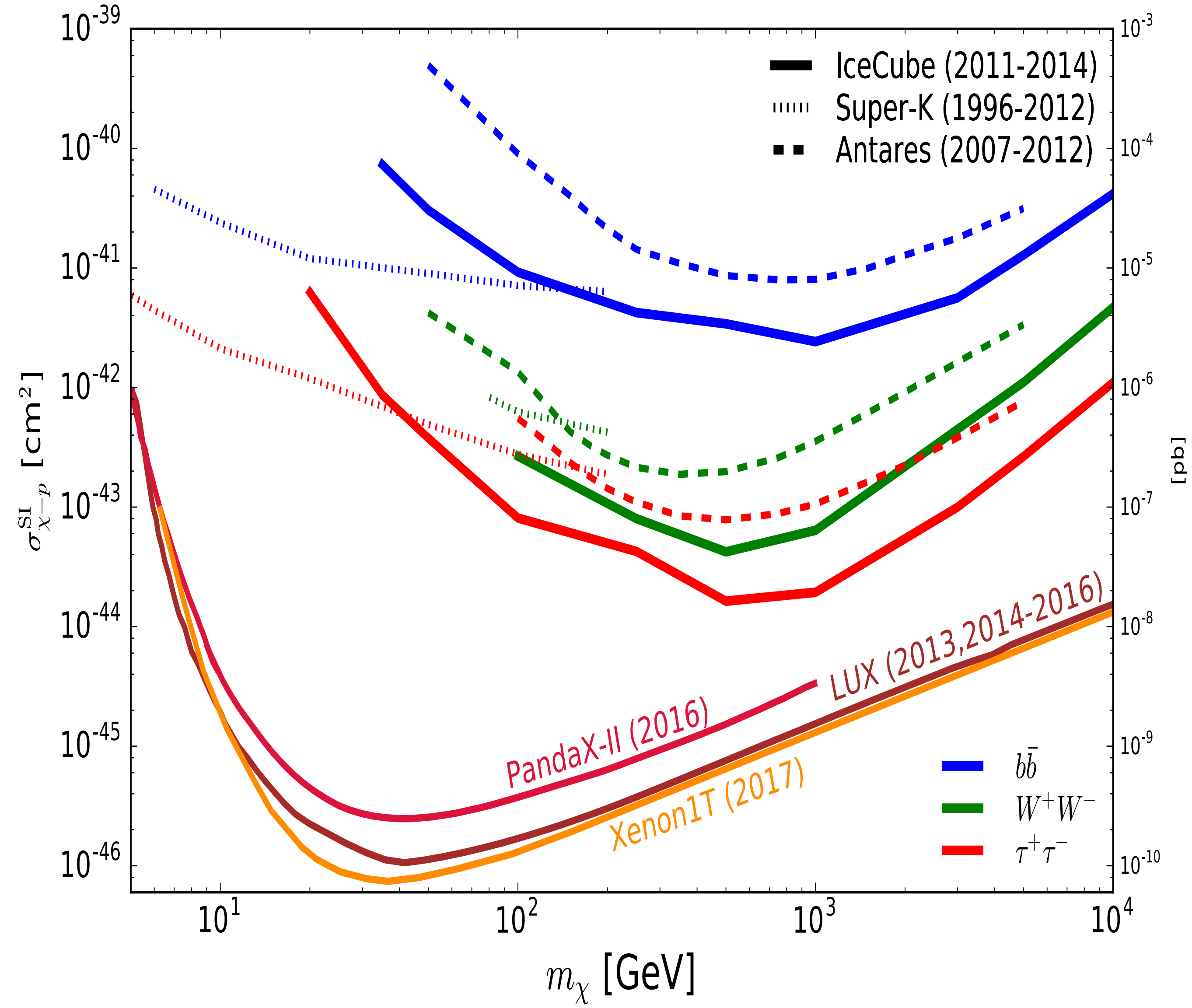




Spin-dependent scattering

Spin-independent scattering



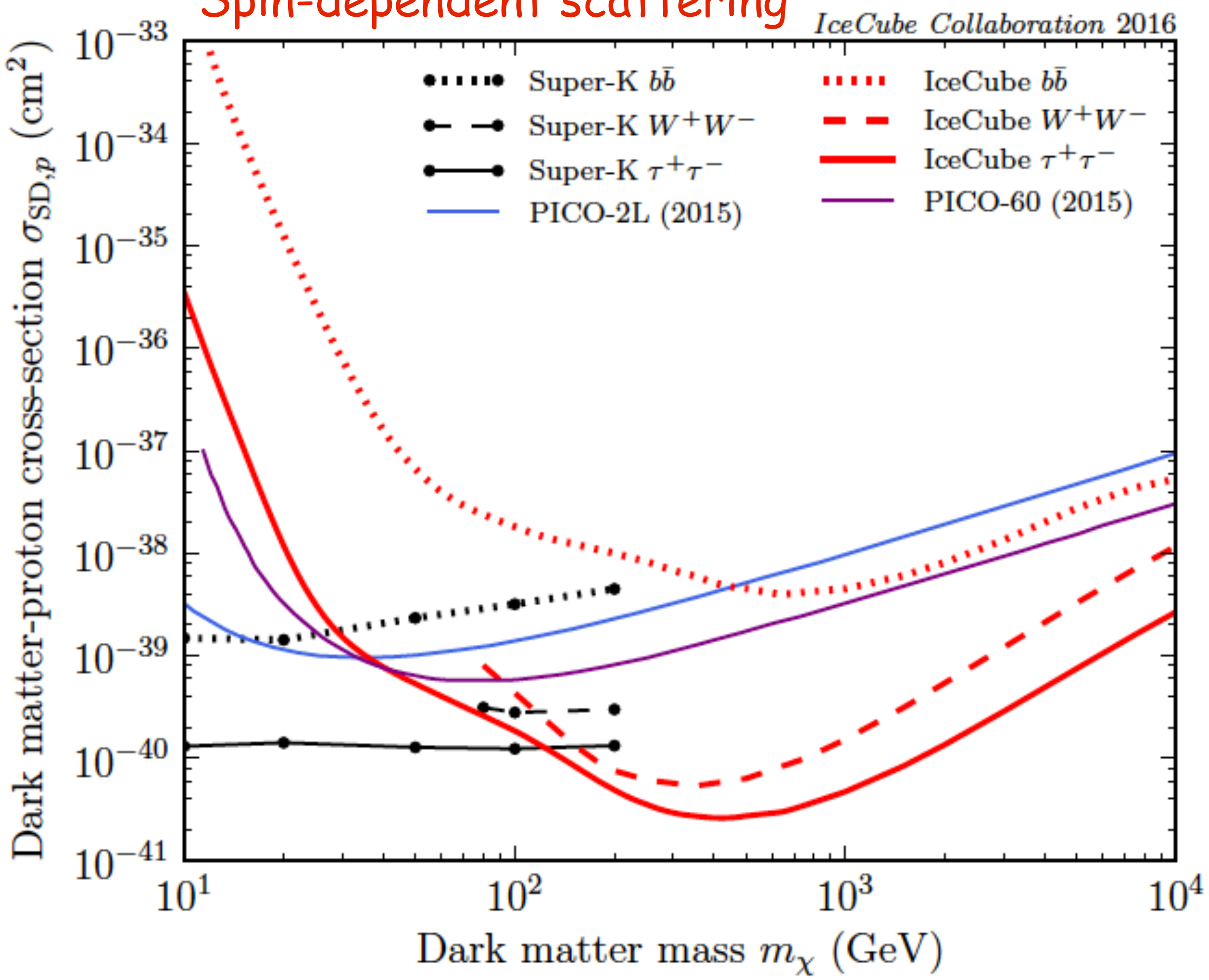


http://nulike.hepforge.org./

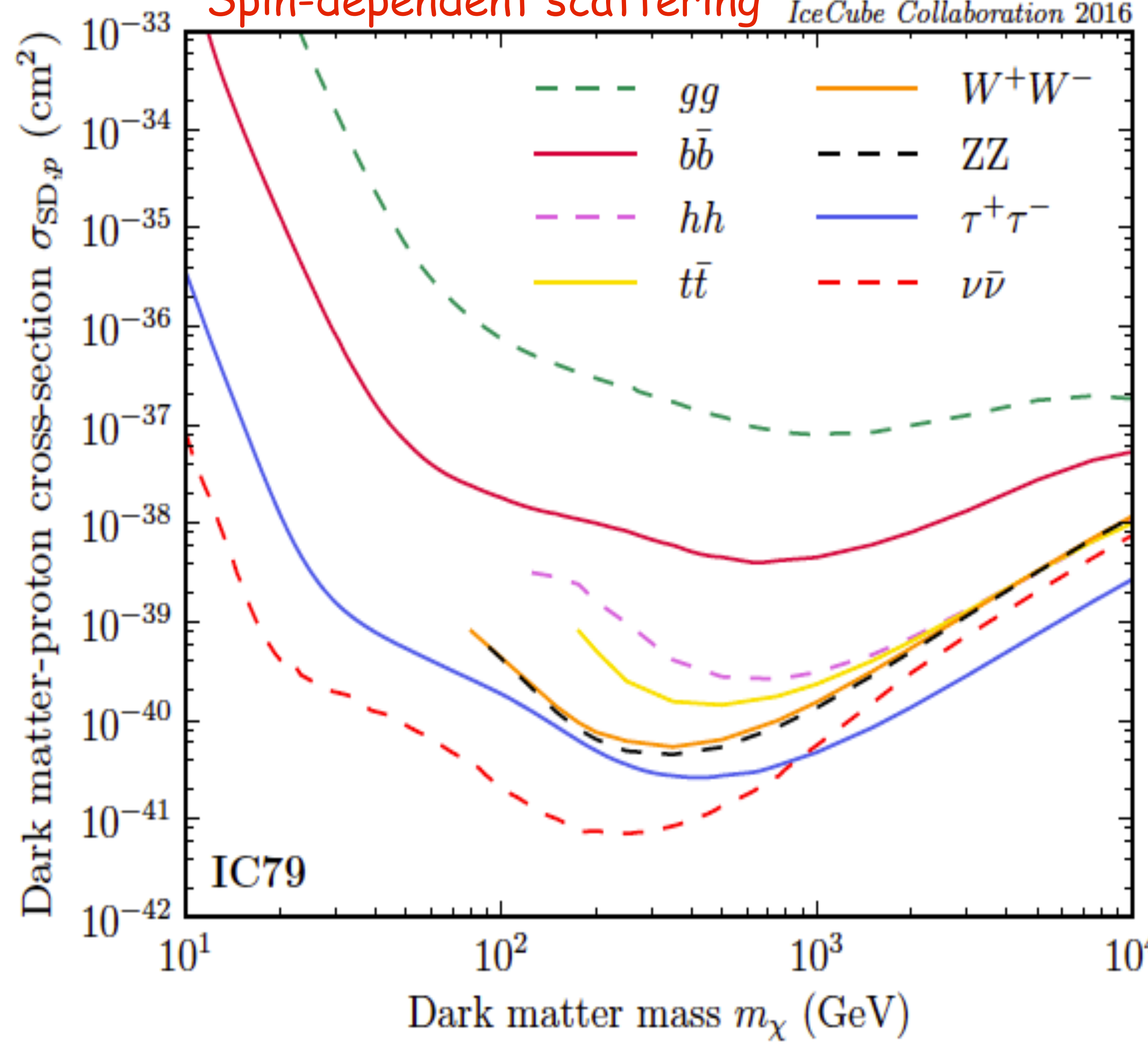
JCAP 04 (2016) 022 / http://arxiv.org/pdf/1601.00653.pdf

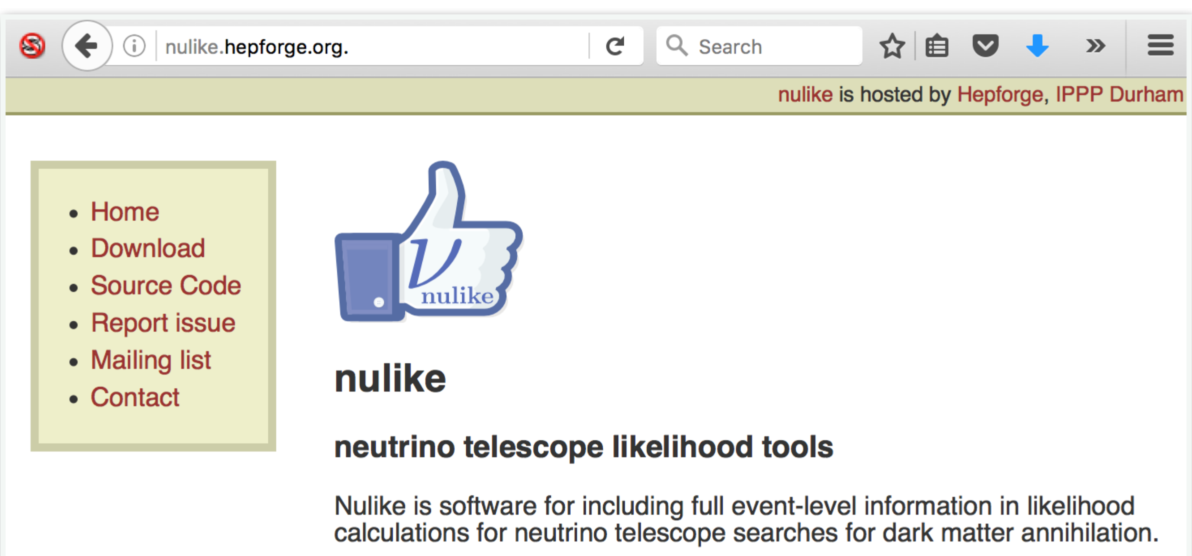
Availability of data

Spin-dependent scattering



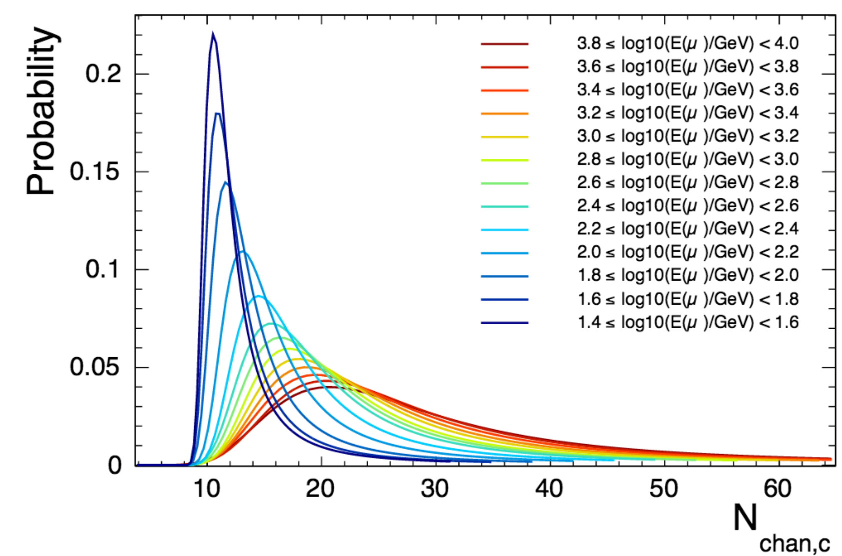
Spin-dependent scattering





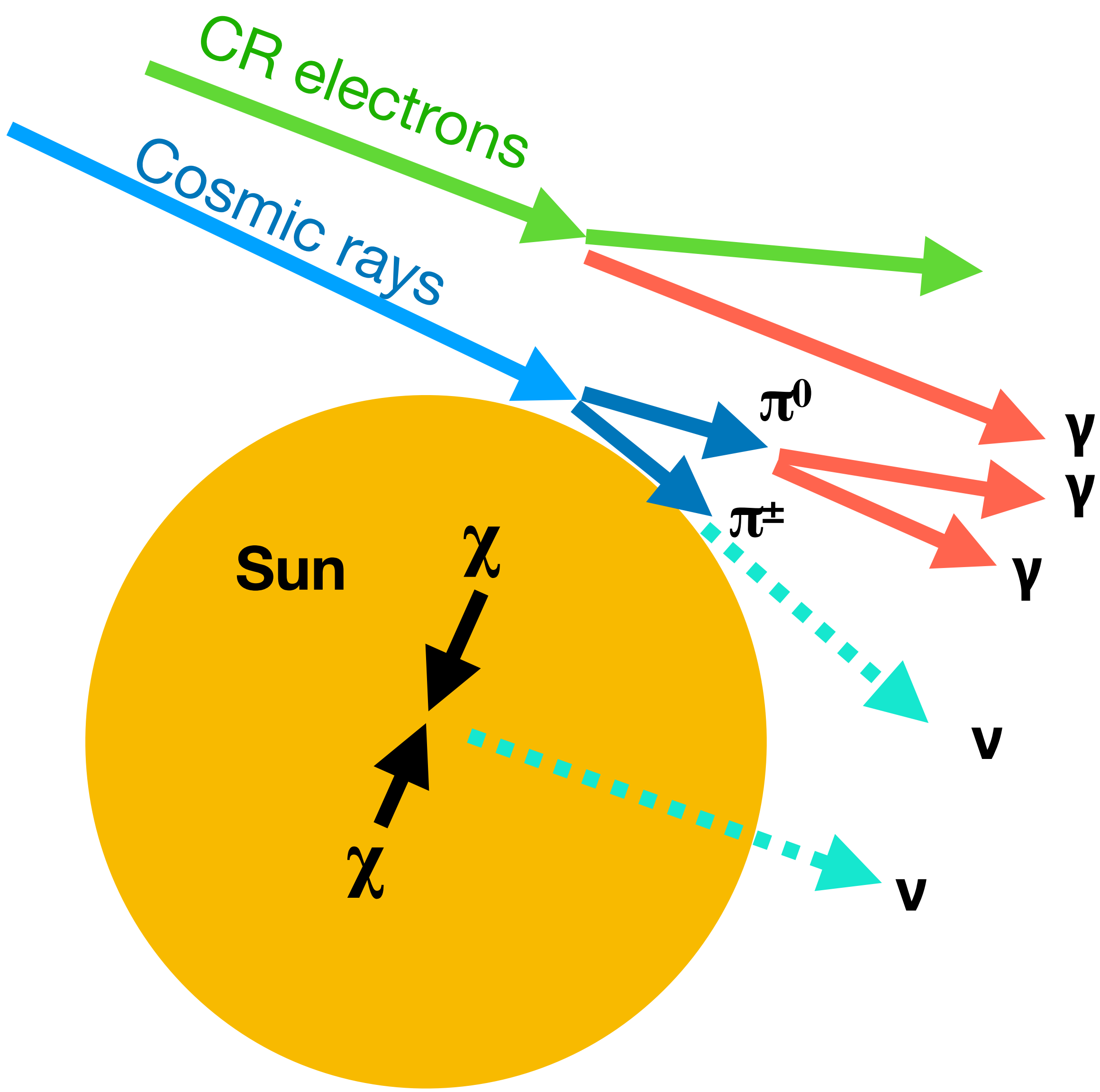
software to test your own model (cross section/ branching ratios)
- IceCube data released

- Likelihood includes:
  - energy and directional information

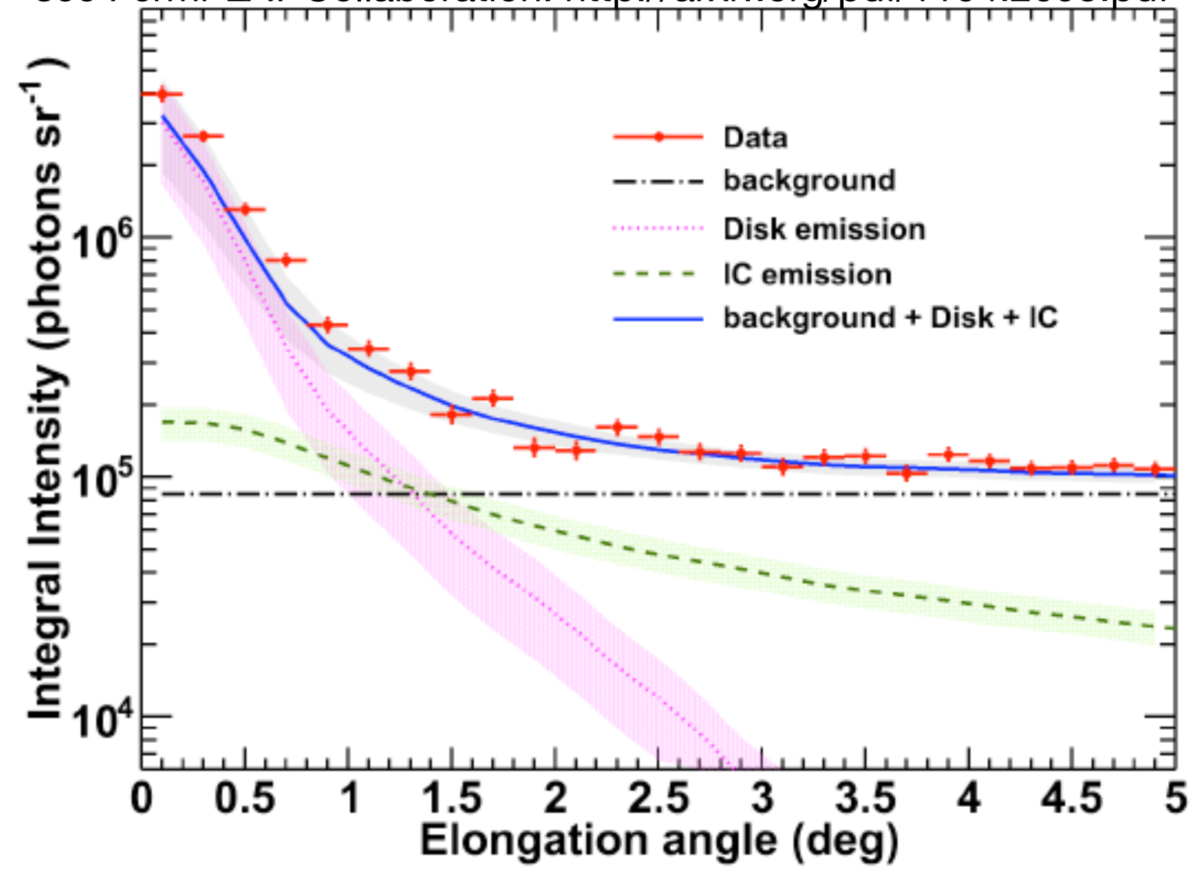


Solar Atmospheric Neutrino Floor

Cosmic ray interactions with the Sun



see Fermi-LAT Collaboration: http://arxiv.org/pdf/1104.2093.pdf



- Cosmic ray interactions in the Solar atmosphere produce gamma-rays and neutrinos
- Background to dark matter searches from the Sun, that soon will be relevant (and could result in the first high-energy neutrino point source)

Leptonic

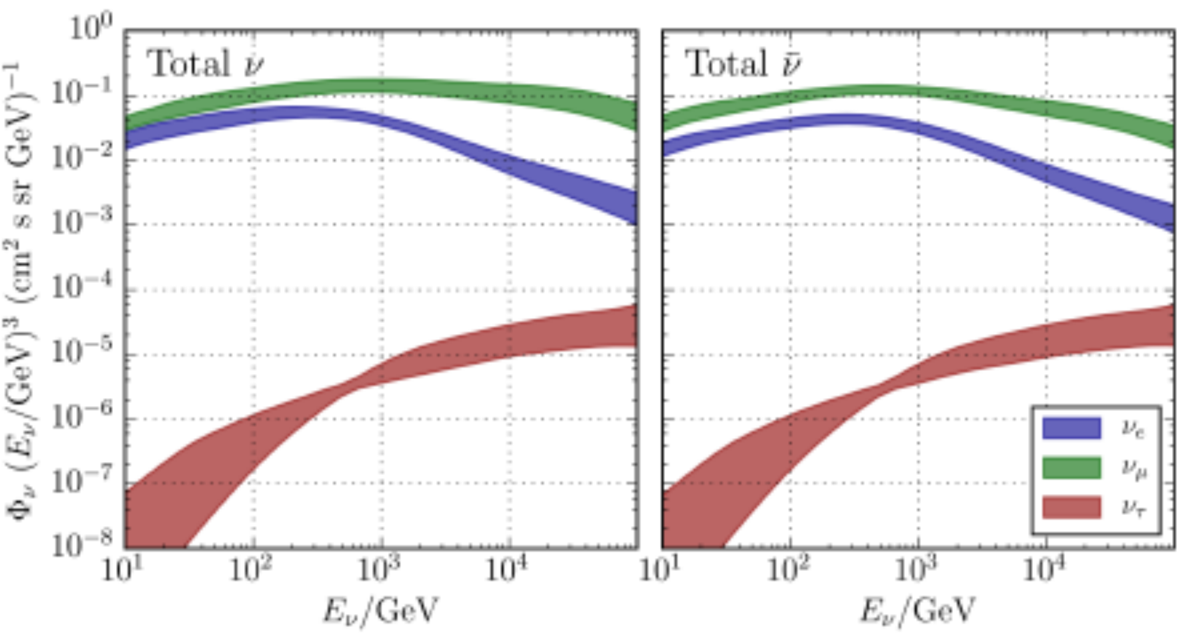
- Moskalenko, Porter, Digel (2006)
- Orlando, Strong (2007)

Hadronic

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

Solar Atmospheric Neutrino Flux

- The solar atmospheric neutrino spectrum is predicted to be harder compared to the Earth atmospheric background.



- Flux predictions vary by <30%, based on
  - primary models
  - hadronic and composition models
  - extremal solar density and composition models

C. Argüelles, G. de Wasseige, A. Fedynitch, B. Jones **JCAP 1707 (2017) no.07, 024** [arXiv:1703.07798]

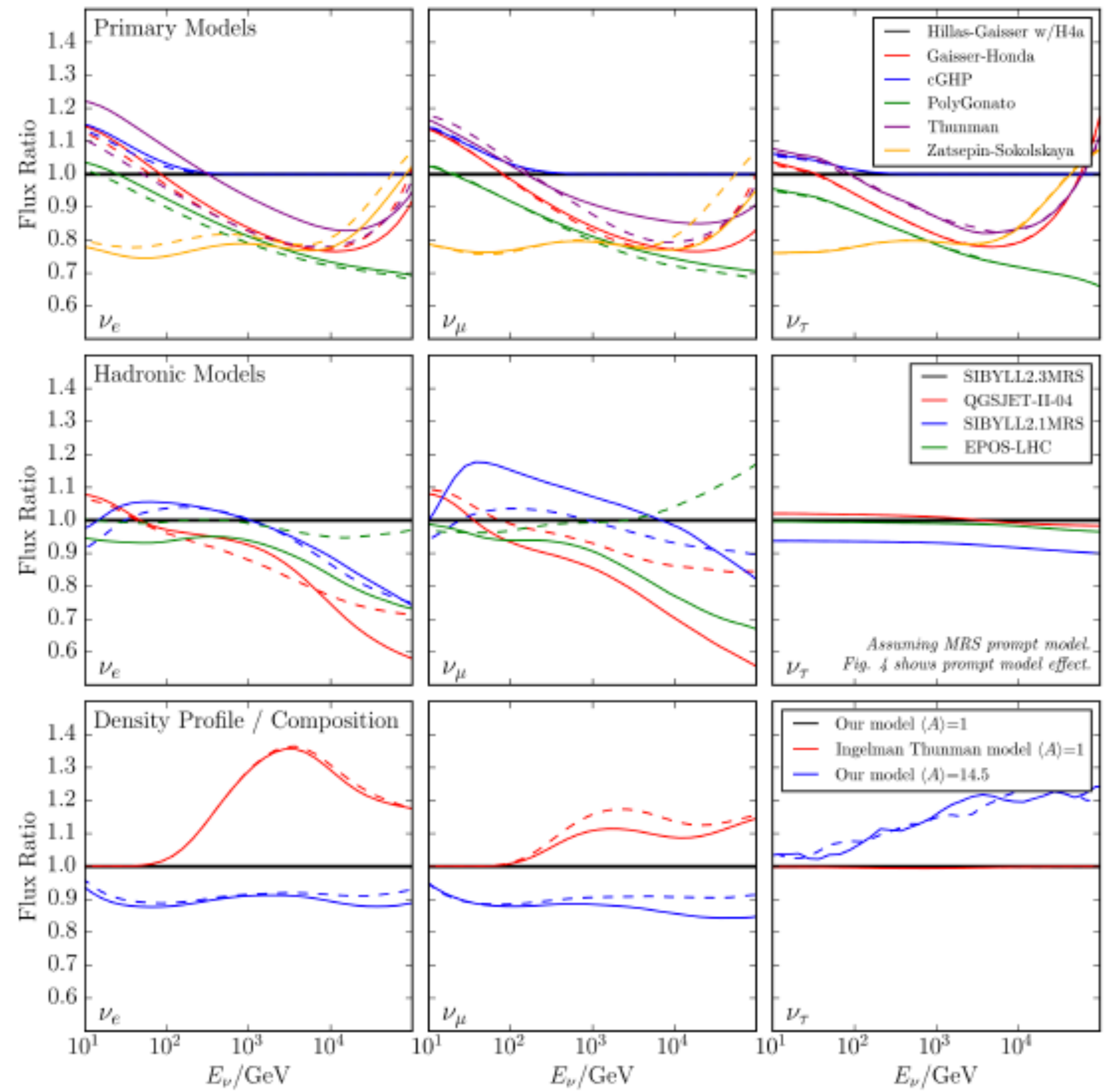
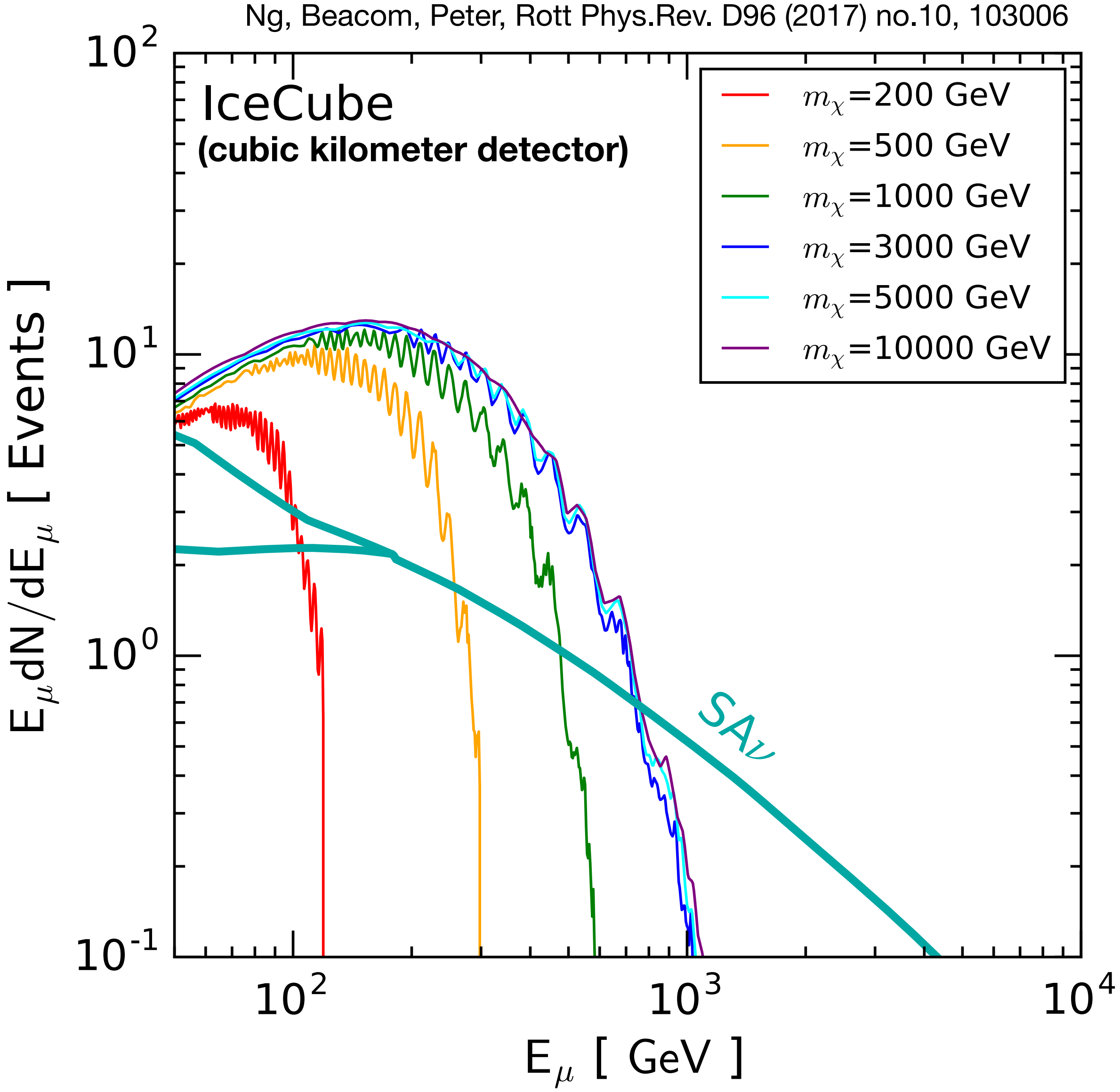


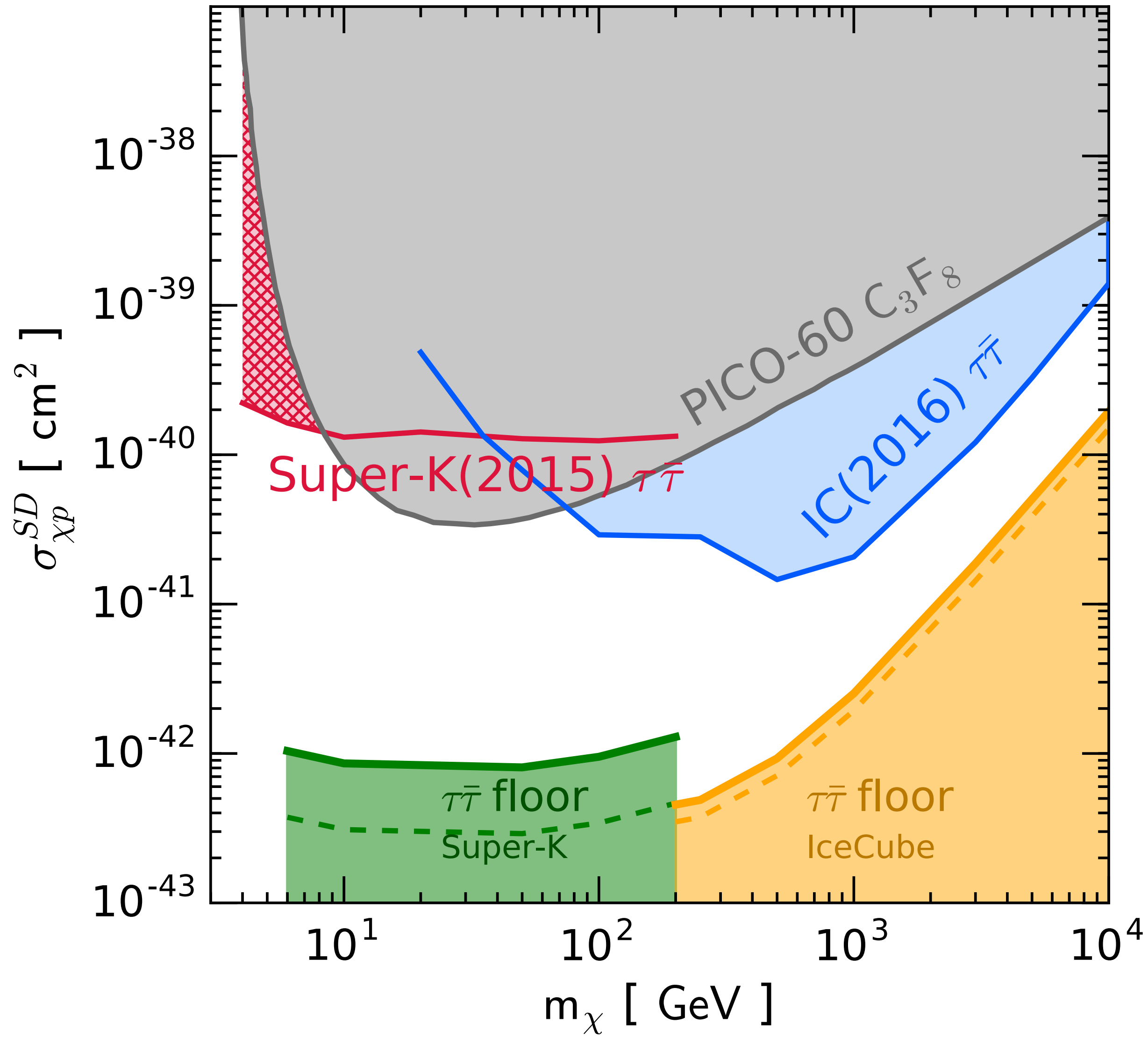
Figure 3. Effects of different models on our flux prediction, for impact parameter b=0. The top row shows various primary models; the second row, hadronic and composition models; the third row, extremal solar density and composition models. See text for more information and references.

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

Expect ~2events per year at cubic kilometer detector

Recent works on the Solar Atmospheric Neutrinos / Atmospheric Neutrino Floor

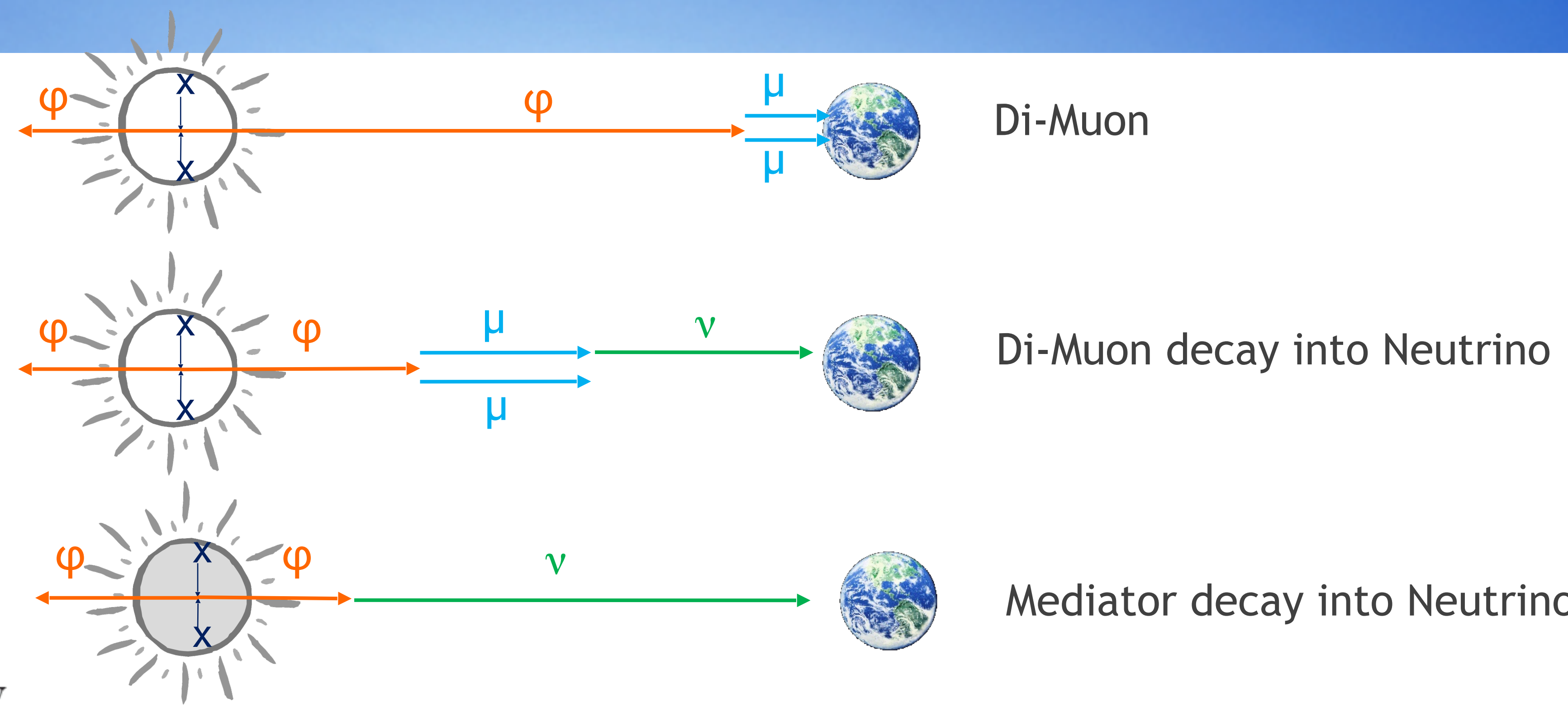
- C. Argüelles, G. de Wasseige, A. Fedynitch, B. Jones **JCAP 1707 (2017) no.07, 024** [arXiv:1703.07798]
- K. Ng, J. Beacom, A. Peter, C. Rott **Phys.Rev. D96 (2017) no. 10, 103006** [arXiv:1703.10280]
- J. Edsjö, J. Elevant, R. Enberg, and C. Niblaeus, **JCAP 2017 . 06 (2017), p. 033**, arXiv: 1704.02892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

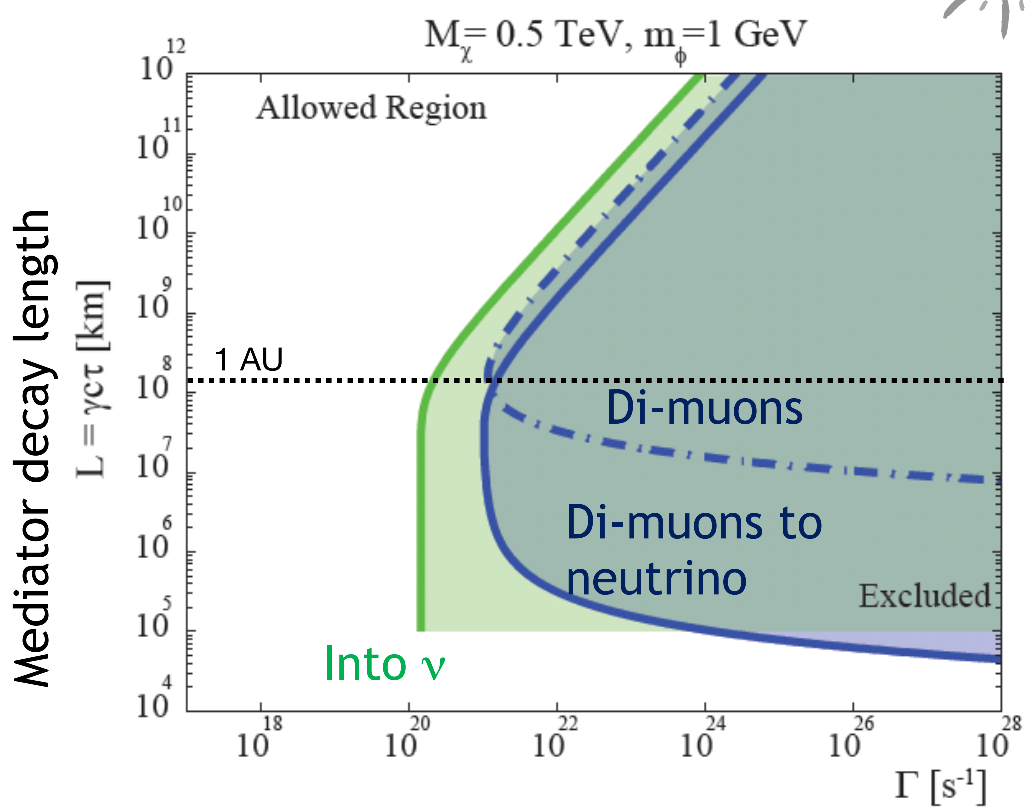
Secluded Dark Matter

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

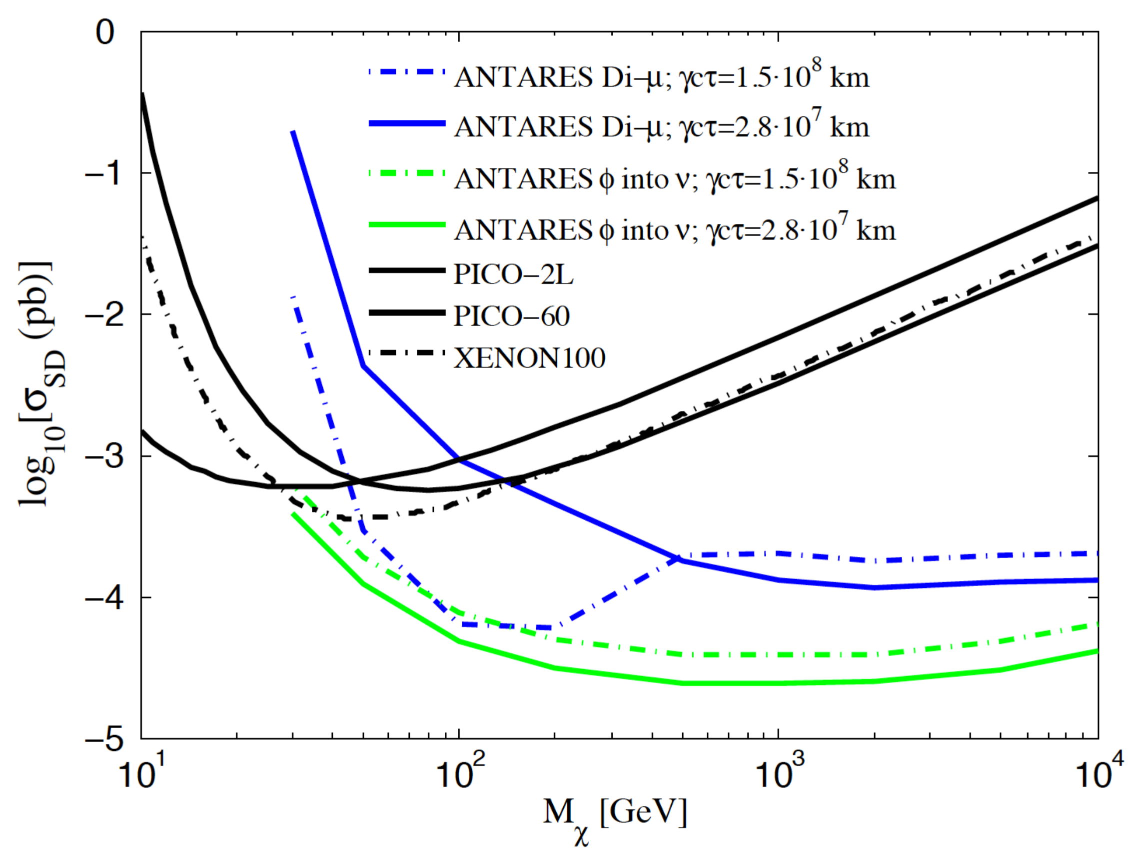
ANTARES Secluded Dark Matter

- 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)





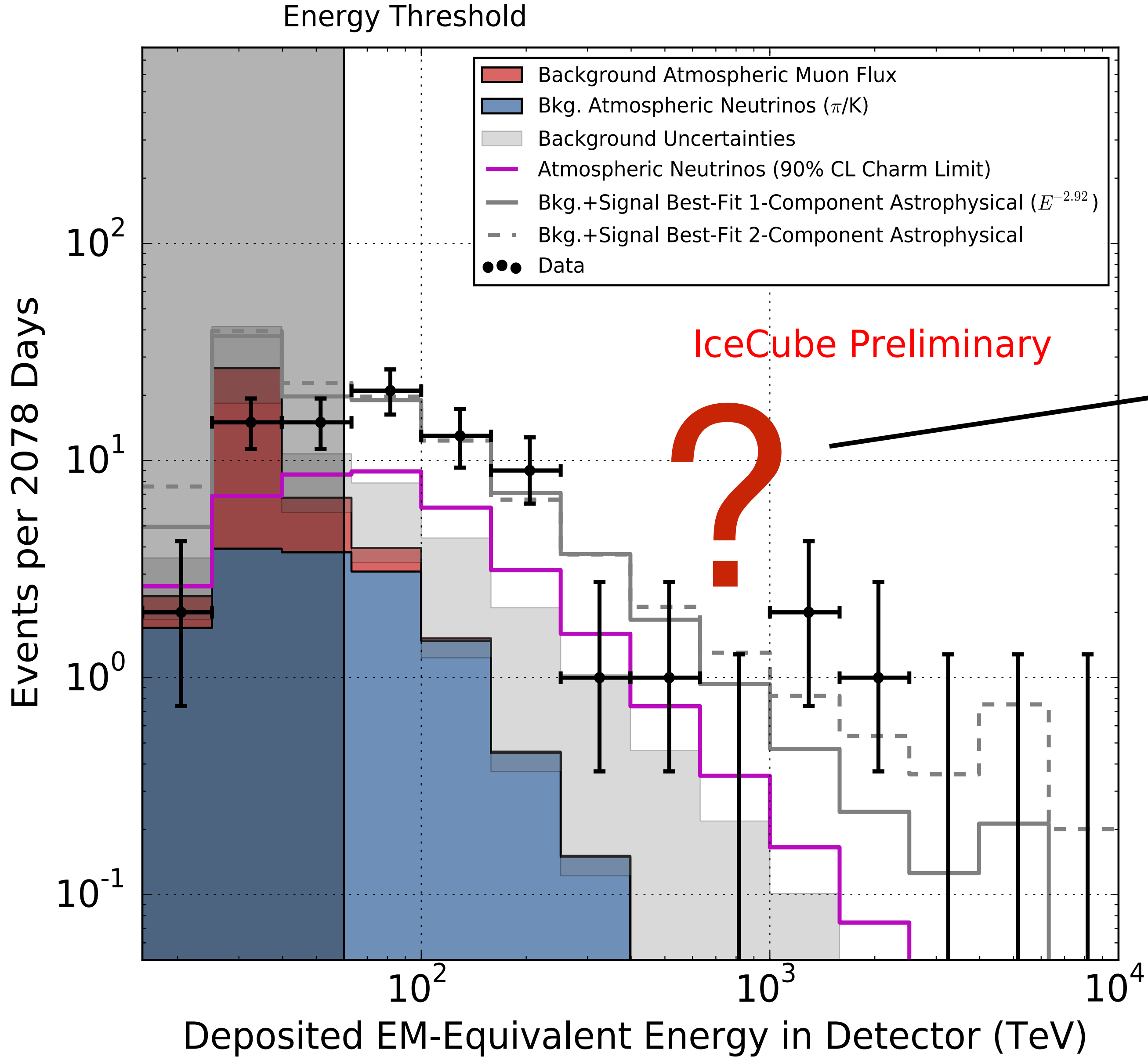
Annihilation of DM in the Sun x Branching ratio



- 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

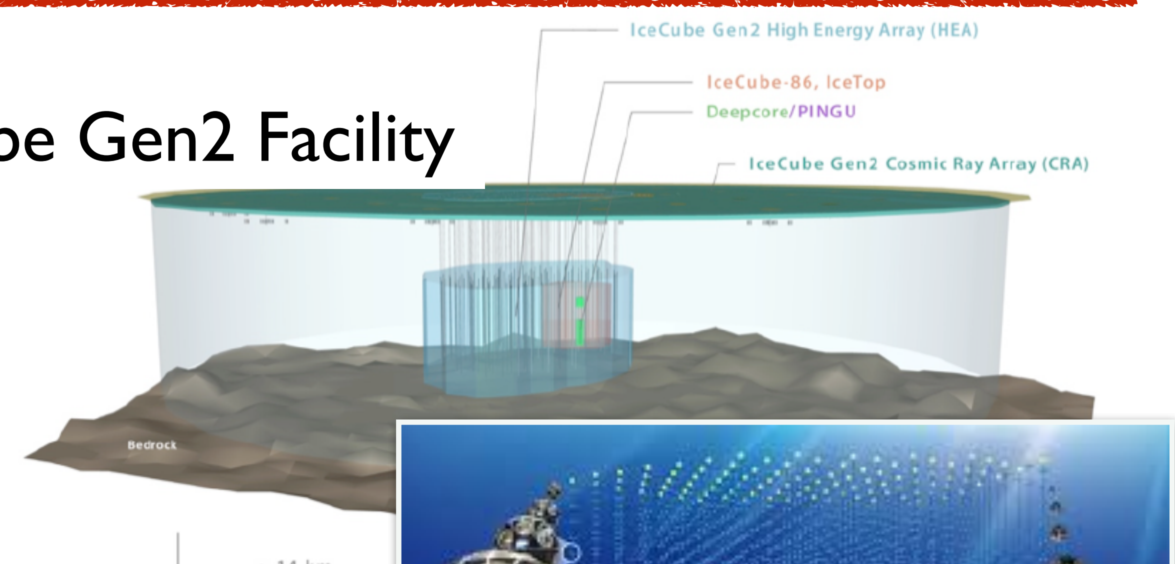
Outlook

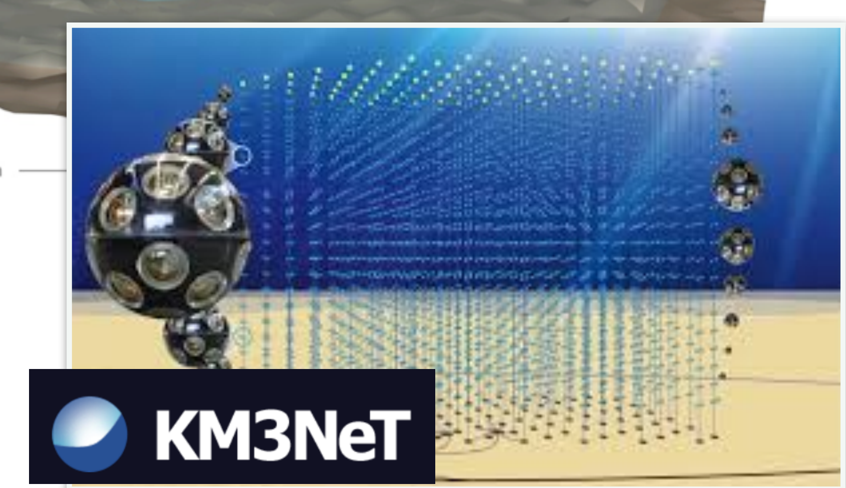
Beyond Standard Model Physics at the PeV scale



- PeV Scale Right Handed Neutrino Dark Matter
- Super Heavy Dark Matter
- Neutrino Portal Dark Matter
- Right-handed neutrino mixing via Higgs portal
- Heavy right-handed neutrino dark matter
- Leptophilic Dark Matter
- PeV Scale Supersymmetric Neutrino Sector Dark Matter
- Dark matter with two- and many-body decays
- Shadow dark matter
- Boosted Dark Matter
- …

IceCube Gen2 Facility



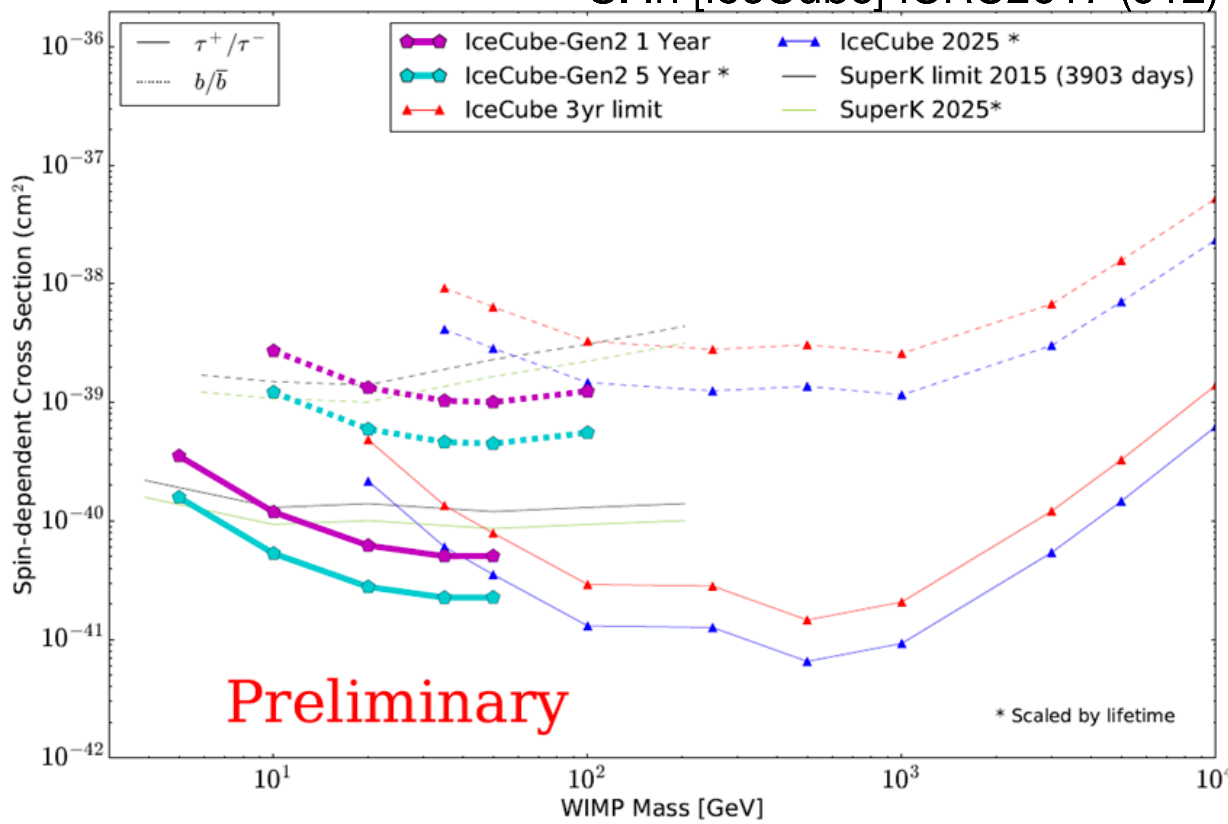


- Intense interest in high-energy neutrino region
  - Observations defy any simple explanation from a single generic source class
    - Multiple sources classes ?
    - Hints of new physics ?

Next generation neutrino detectors

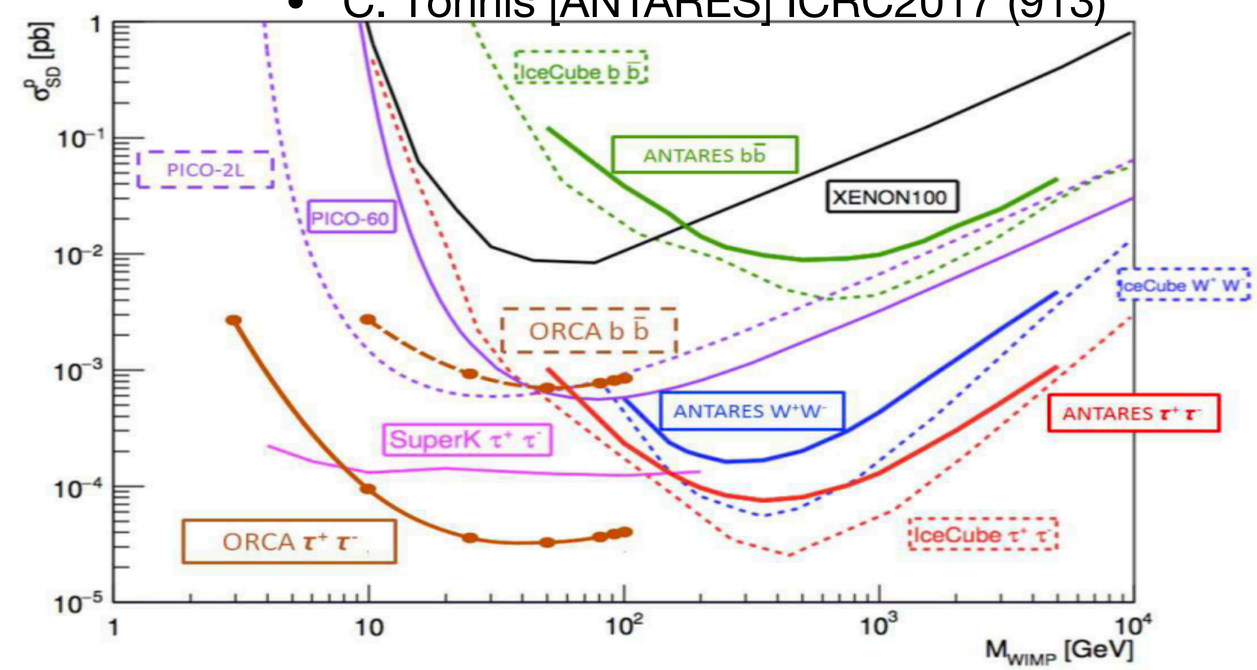
IceCube-Gen2 (PINGU fill in)

S. In [IceCube] ICRC2017 (912)

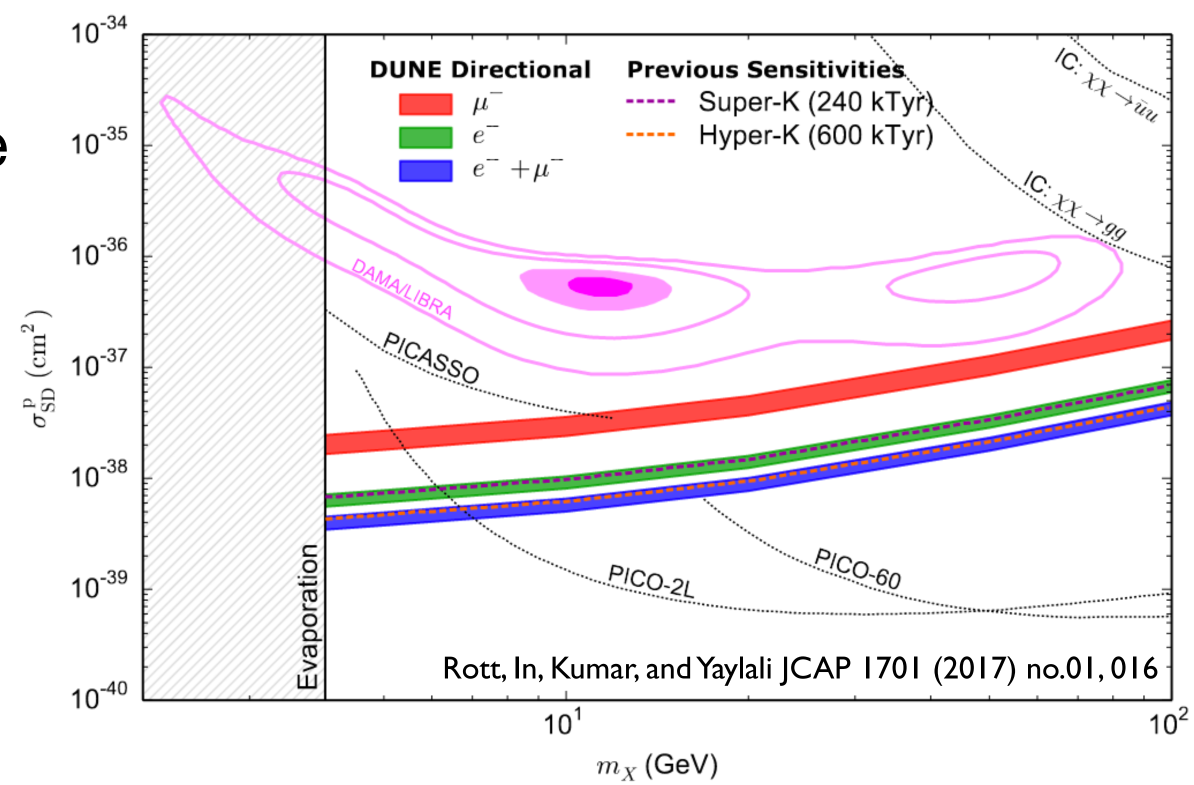


ORCA

- C. Tönnis [ANTARES] ICRC2017 (913)



- ORCA and IceCube-Gen2 (PINGU infill) have unique capability to explore DM between 4-50GeV in indirect solar wimp searches
  - This will also be an interesting region for Hyper-K / DUNE
- KM3NeT and IceCube-Gen2 extremely competitive for high-mass DM decay



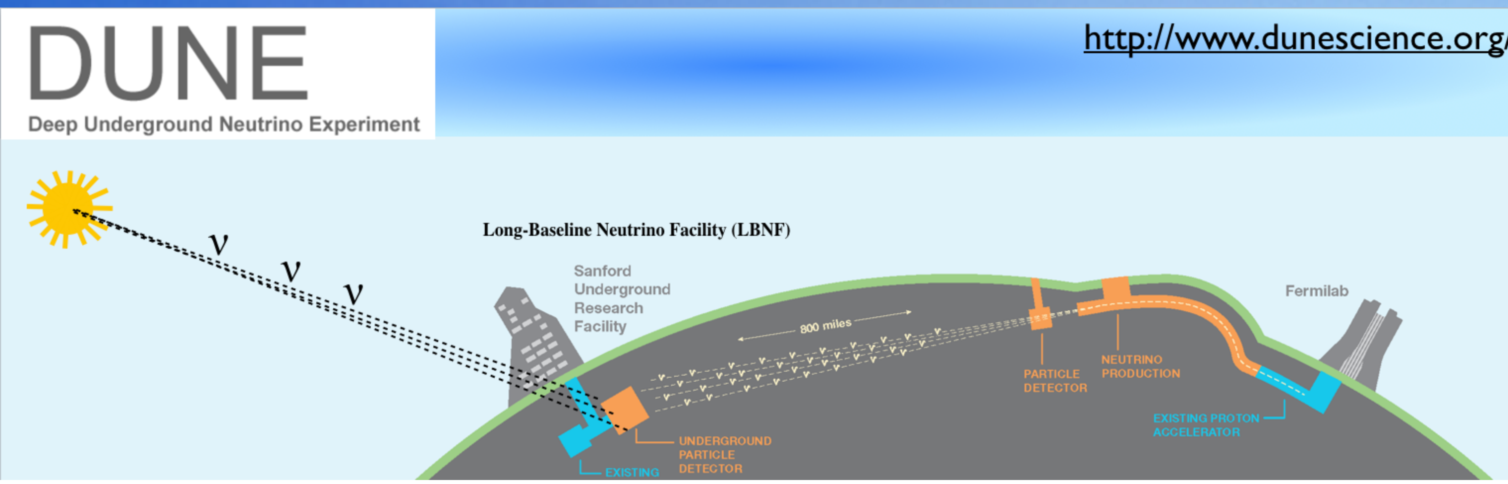
(see also talk on boosted DM sensitivities by Joshua Berger - Friday Feb 23)

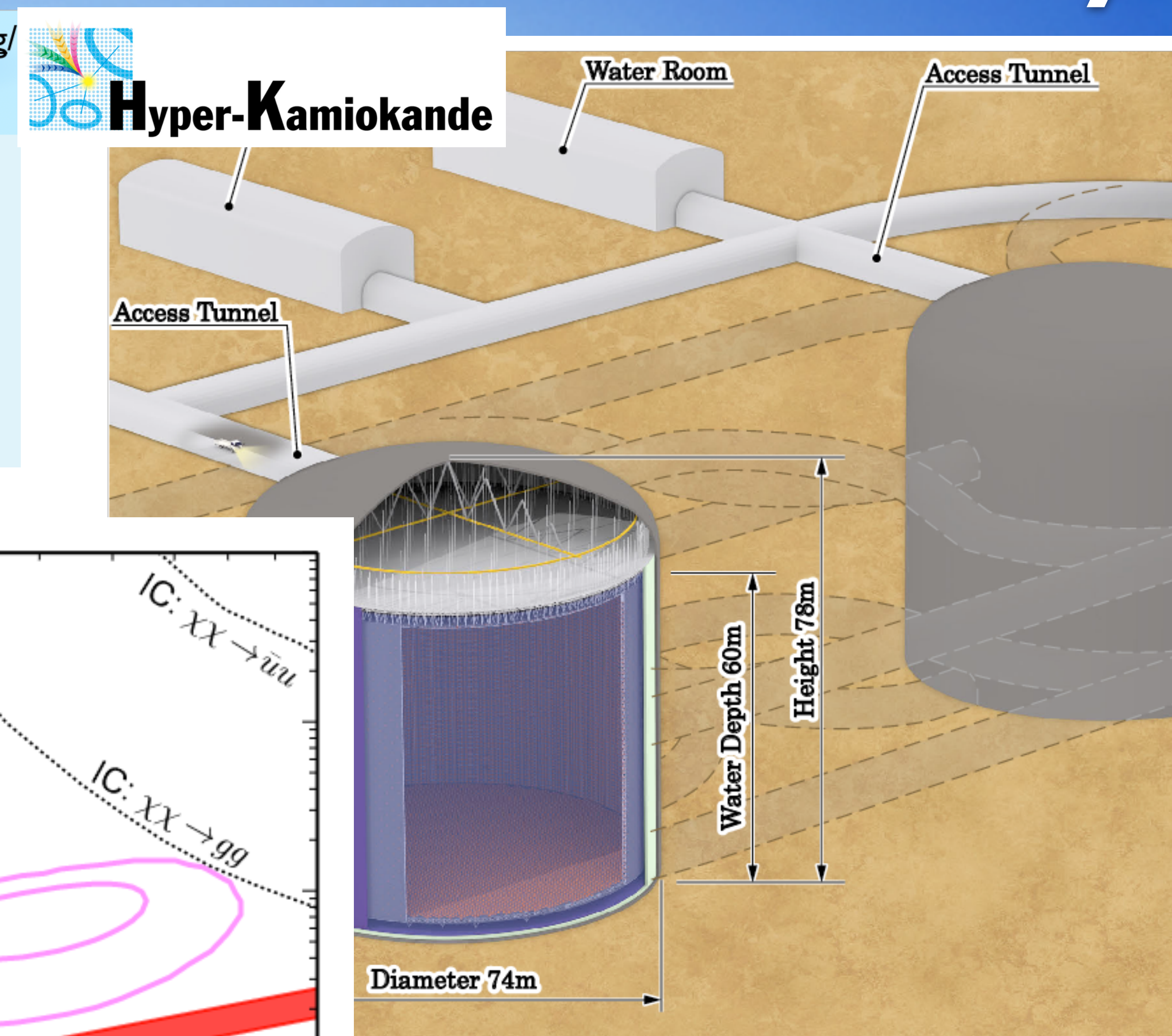
Conclusions

- Striking DM signatures might provide high discovery potential for indirect searches
- Models motivated by positron excess and gamma-ray observations can and have been tested with neutrino telescopes
- Lifetimes of heavy decaying dark matter can be constrained to 10^{28}s using neutrino signals
- Neutrino Telescopes provide world best limits on SD Dark Matter-Proton scattering cross section
- The new neutrino floor for solar dark matter searches has been calculated
- Neutrinos extremely sensitive to test low-mass Dark Matter scenarios at current and future detectors
- Efforts underway to expand searches beyond WIMP hypothesis …

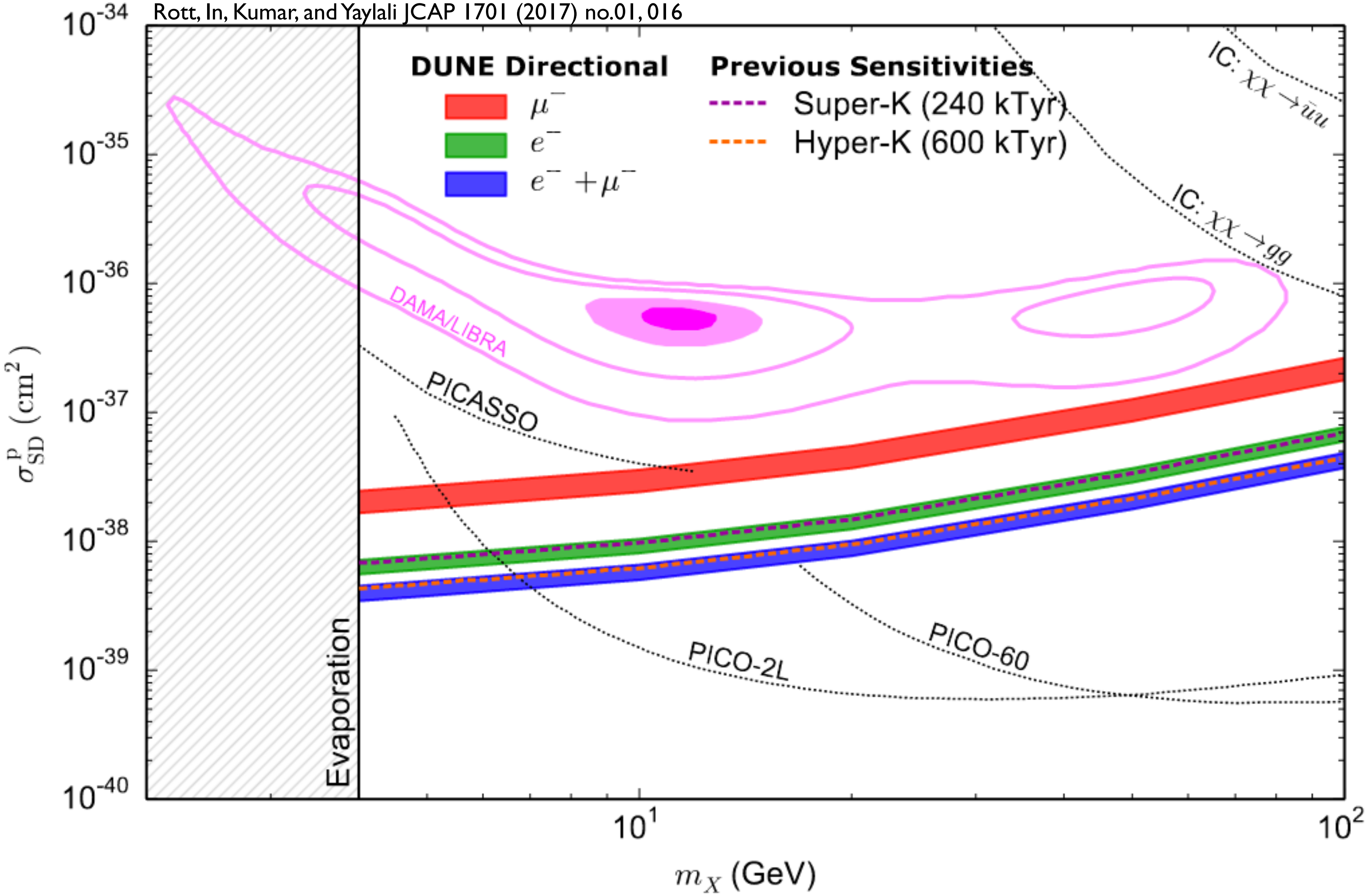
Thanks !

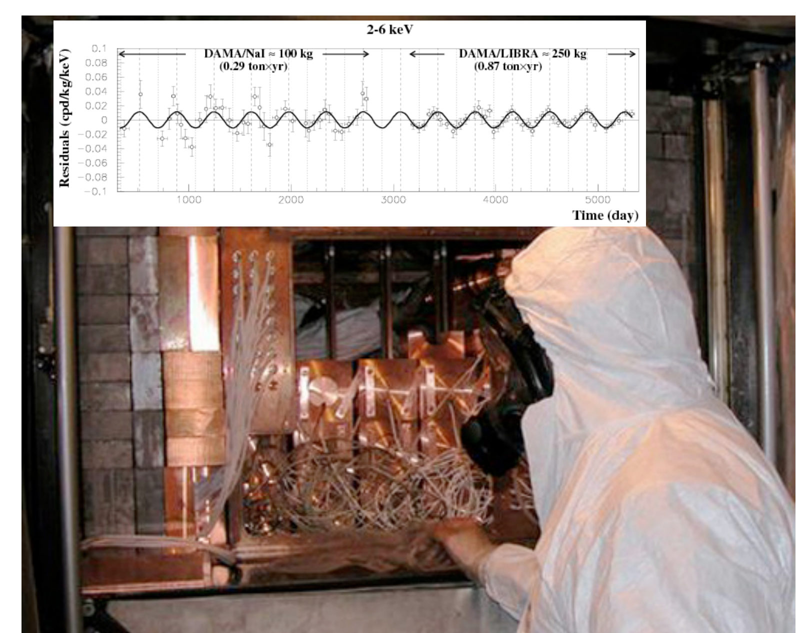
Sensitivity





Rott, In, Kumar, and Yaylali JCAP 1701 (2017) no.01, 016





Low-Energy Neutrinos from the Sun

Possible annihilation channels:

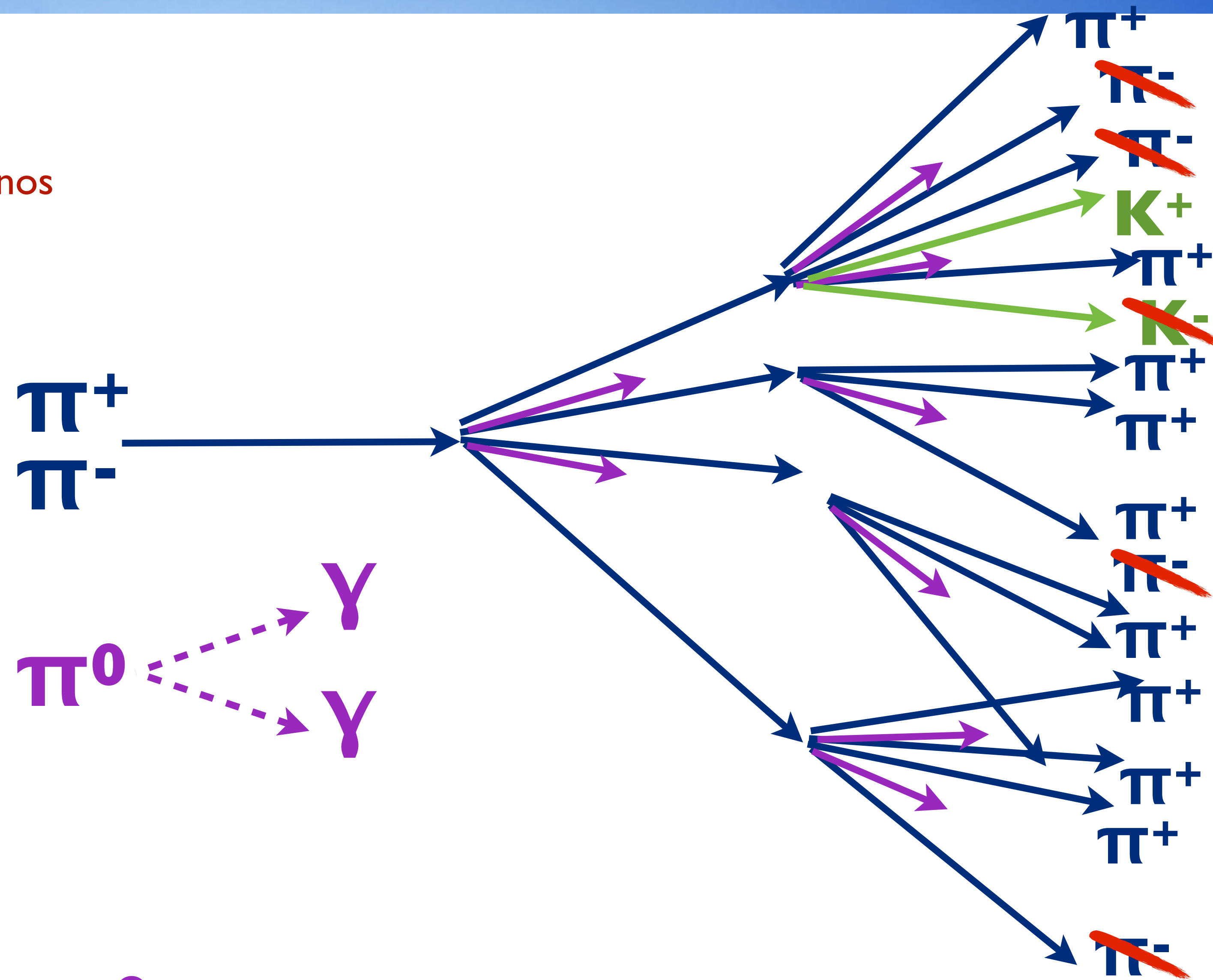
qq,gg,cc,ss,bb,tt,W^+W^-, ZZ, $\tau^+\tau^-$,$\mu^+\mu^-$, $\nu\nu$, e^+e^-,$\gamma\gamma$

few neutrinos

some "high energy" neutrinos in decays

⇒ basis of present day searches

dominant decay into hadrons



Charged pions and kaons decay at rest producing mono-energetic neutrinos

$\pi^+ \rightarrow \mu^+\nu_\mu$ E_ν= 29.8MeV

$K^+ \rightarrow \nu_\mu\ \mu^+$ E_ν=235.5MeV

$\mu^+ \rightarrow e^+\nu_e\bar{\nu}_\mu$

C. Rott, J. Siegal-Gaskins, J.F.Beacom Physical Review D 88, 055005 (2013) (arXiv1208.0827)
Bernal, Martín-Albo, Palomares-Ruiz JCAP 1308 (2013) 011
C.Rott, S.In, J.Kumar, D.Yaylali JCAP11(2015)039

π^0

- Lifetime too short to interact

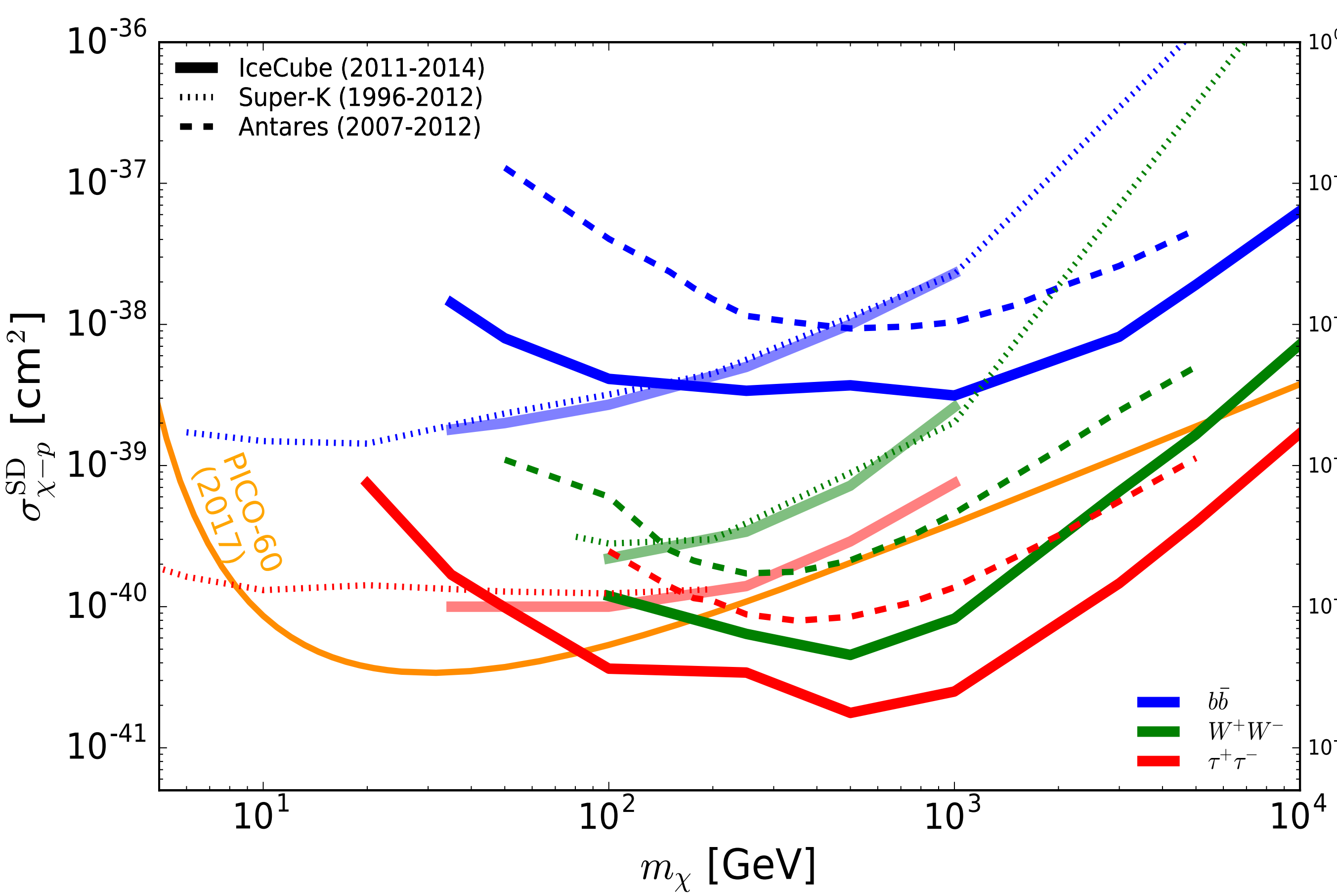
π^-

- Interaction length short compared to losses
- Produces secondary particles in collision with protons
- Dominant energy loss term is π^0 production

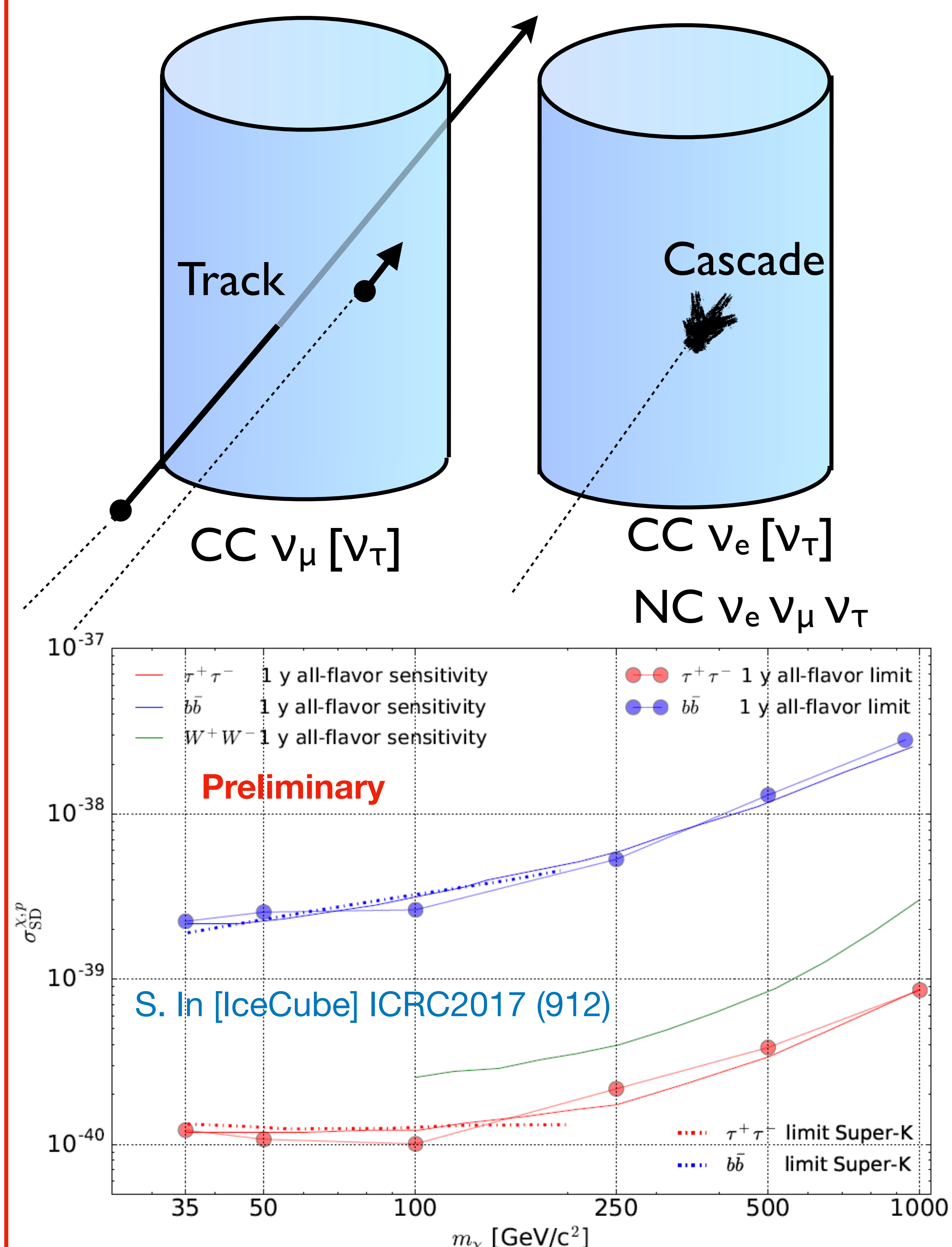
Solar Dark Matter - IceCube/ANTARES

- Convert neutrino flux limit into limit on WIMP-nucleon scattering cross section

IceCube Eur.Phys.J. C77 (2017) no.3, 146



All flavor Solar WIMP - IceCube



Solar WIMPs

- ANTARES - Phys.Lett. B759 (2016) 69-74
- IceCube Eur.Phys.J. C77 (2017) no.3, 146
- S. In and K. Wiebe [IceCube] ICRC2017 (912)

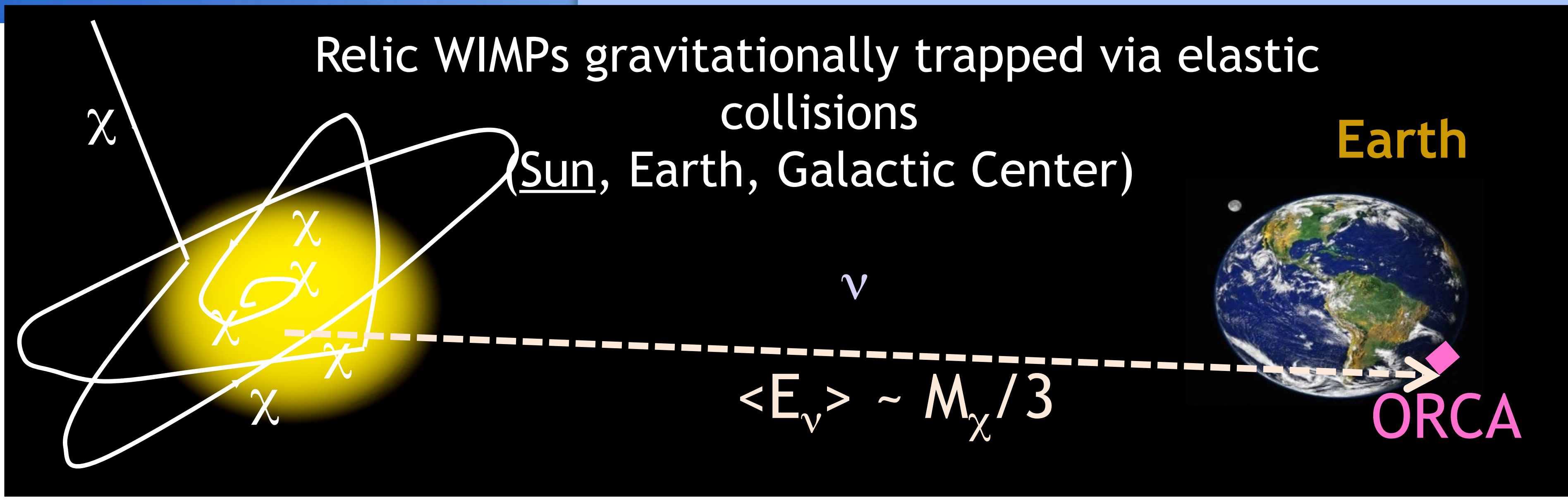
Impact of astrophysical uncertainties

M. Danninger & C. Rott "Solar WIMPs Unraveled" -- Physics of the Dark Universe (Nov 2014)

Interactive tool to study impact of astrophysical parameters

https://mdanning.web.cern.ch/mdanning/public/Interactive_figures/

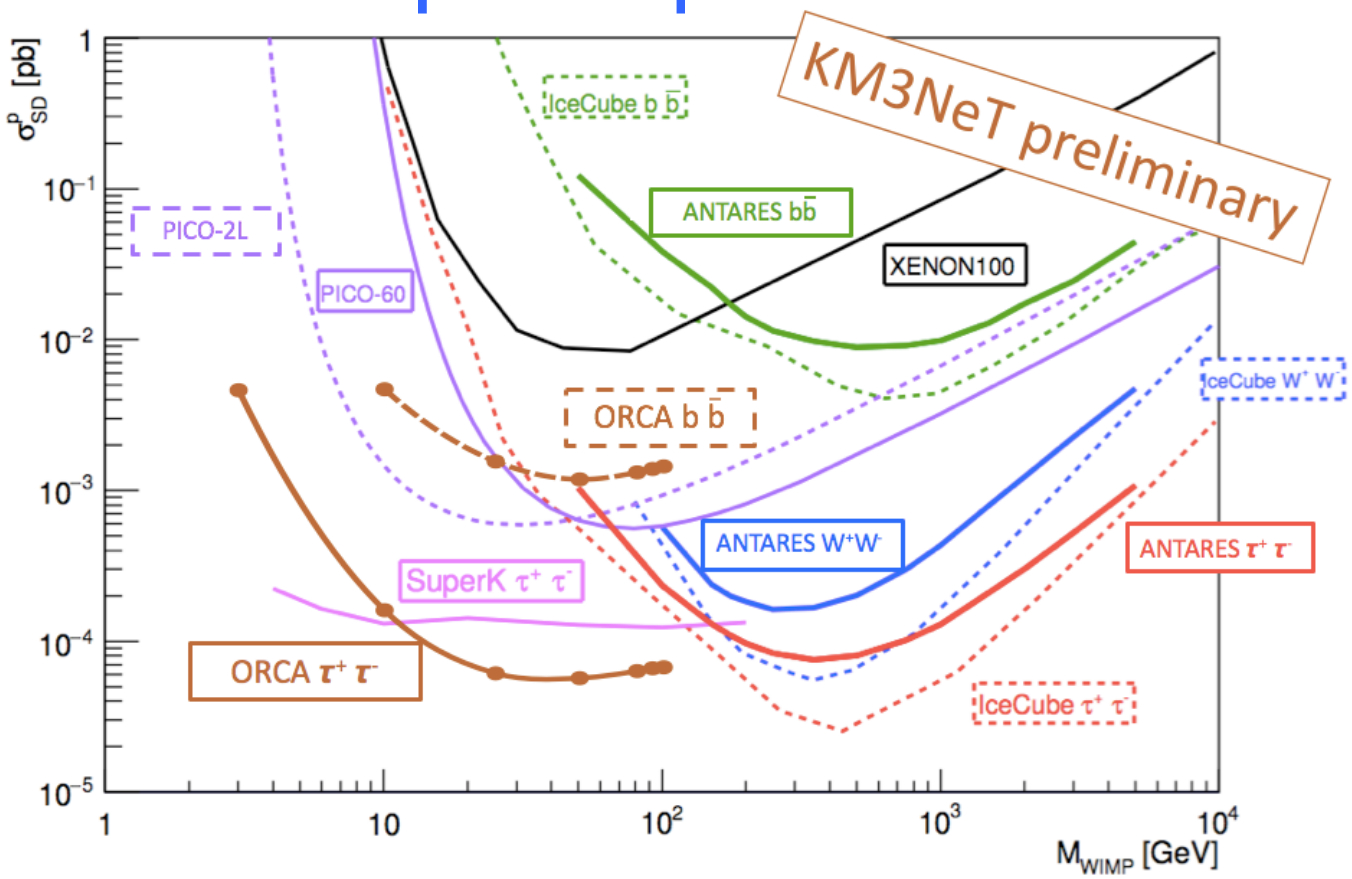
Indirect Detection of Dark Matter



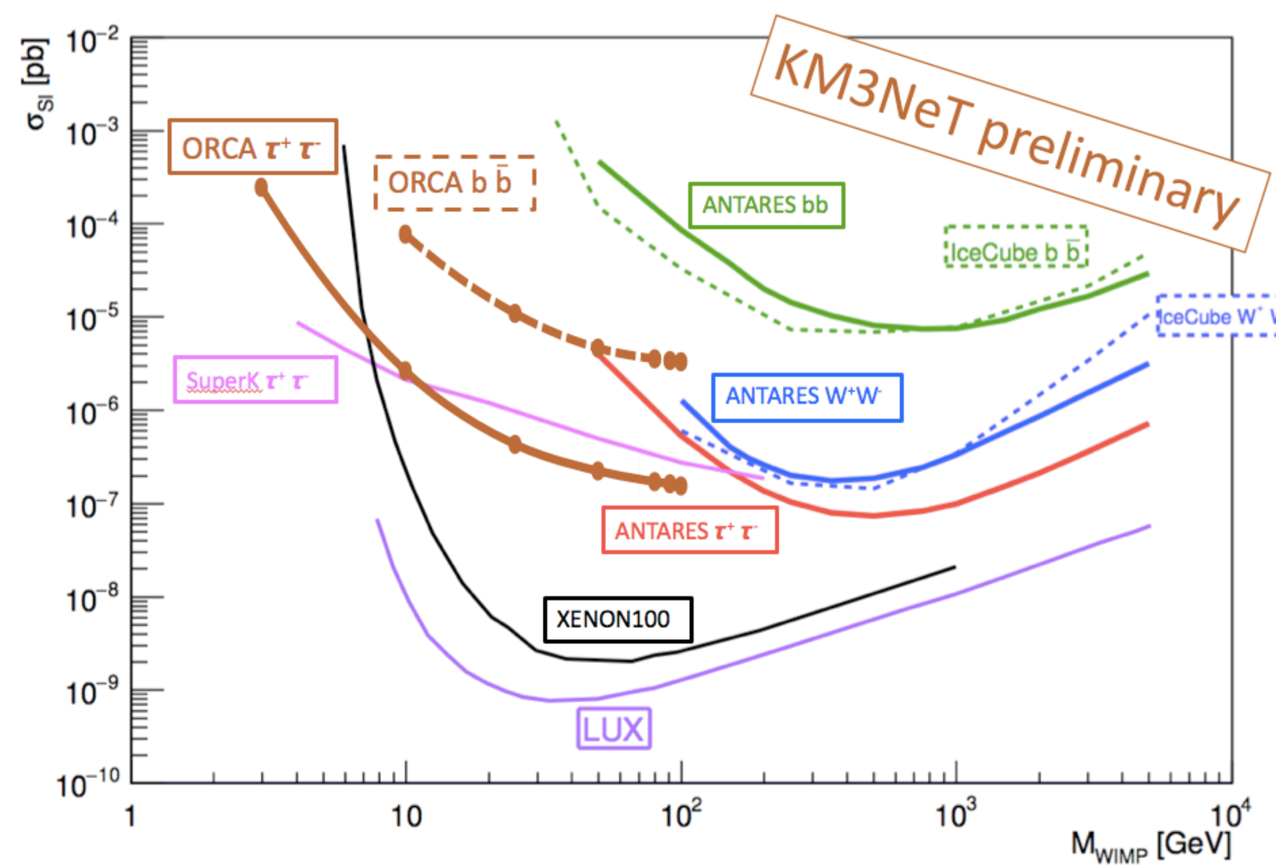
ORCA Schedule

- **Phase 1:**
  - **7 strings (funded)**
  - **operational by 2017/2018**
- **Phase 2:**
  - **115 strings (funding request ongoing)**
  - **operation by 2020**

Spin Dependent



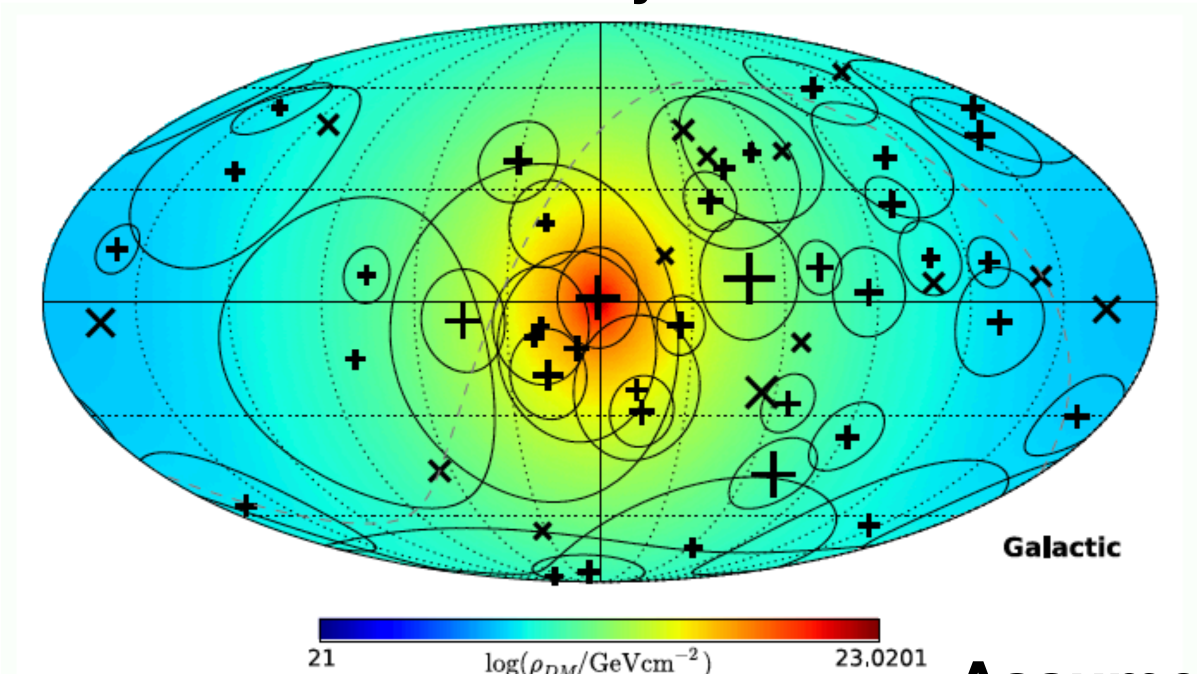
Spin Independent



ORCA 3 years - tracks+showers

Imaging Galactic Dark Matter with IceCube's High-Energy Cosmic Neutrinos

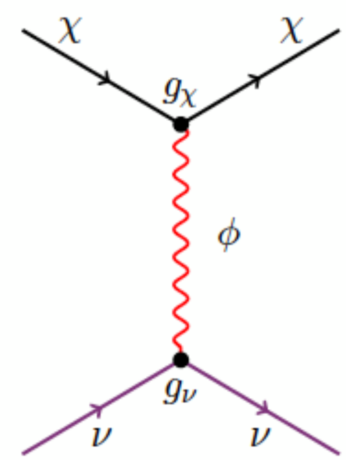
Dark Matter Column Density* as seen from Earth



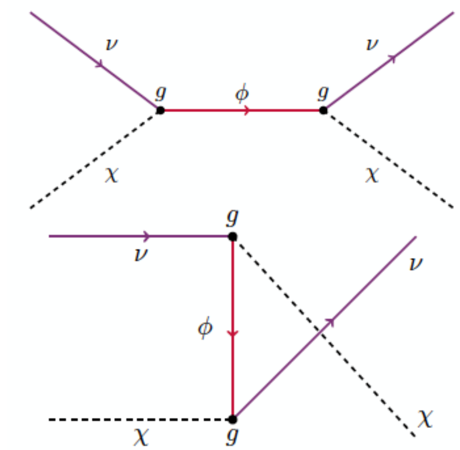
***Einasto Profile**

Dark Matter - Neutrino Interaction

(1) Fermion DM, vector mediator

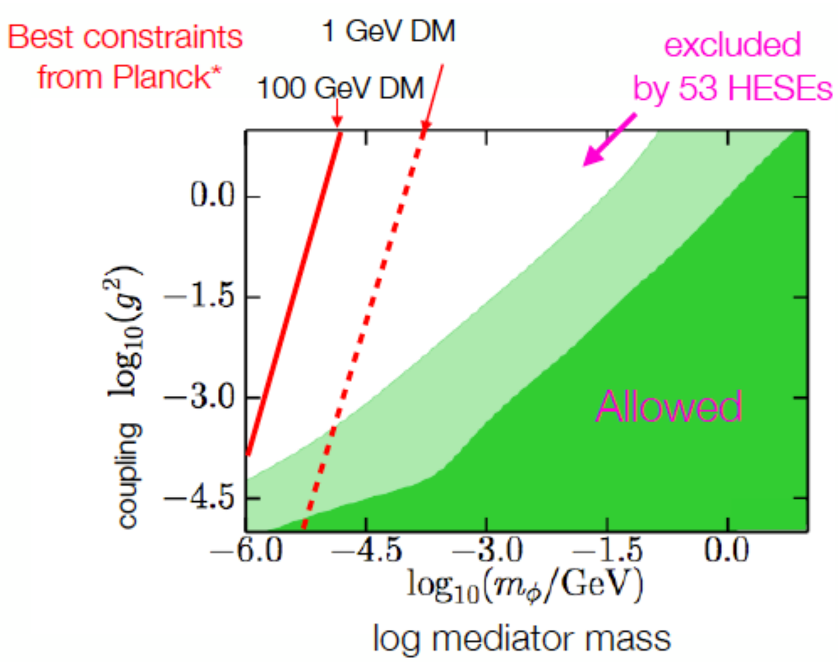


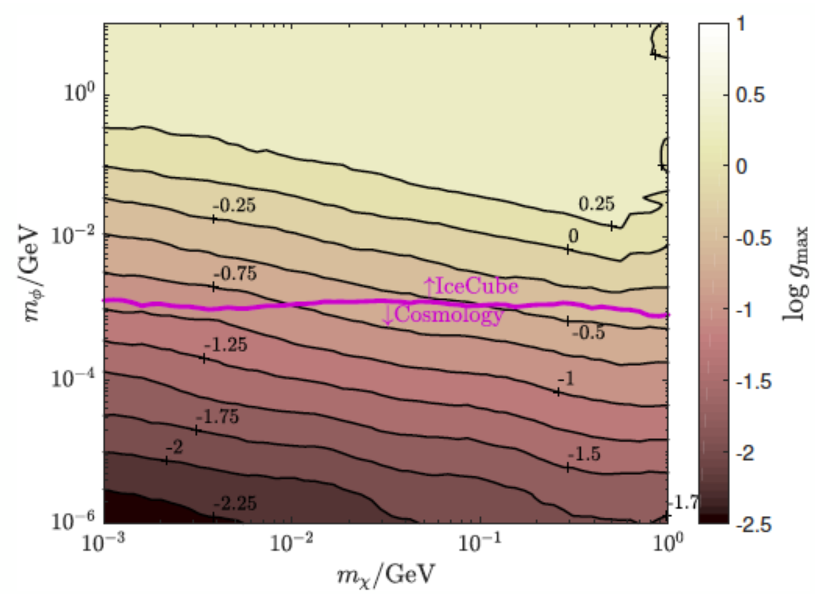
(2) Scale DM, ferminonic mediator

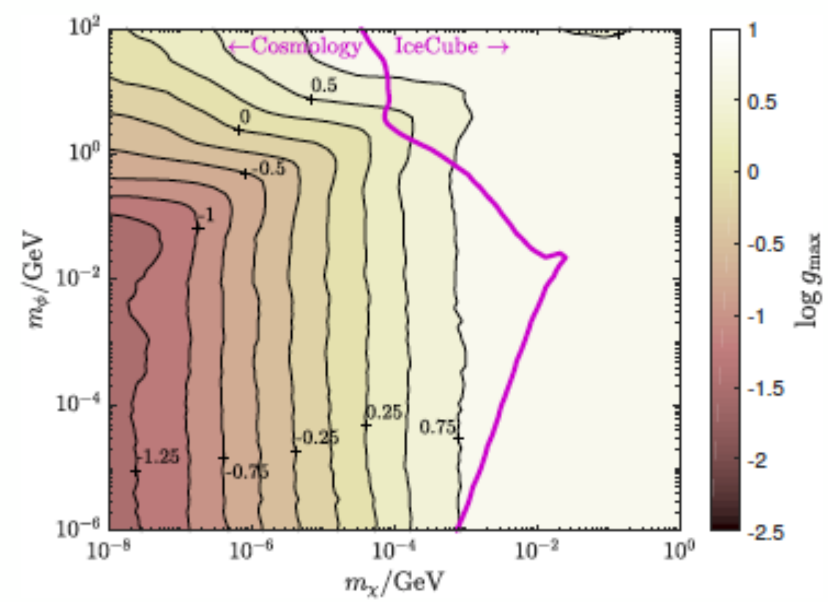


Assume:

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



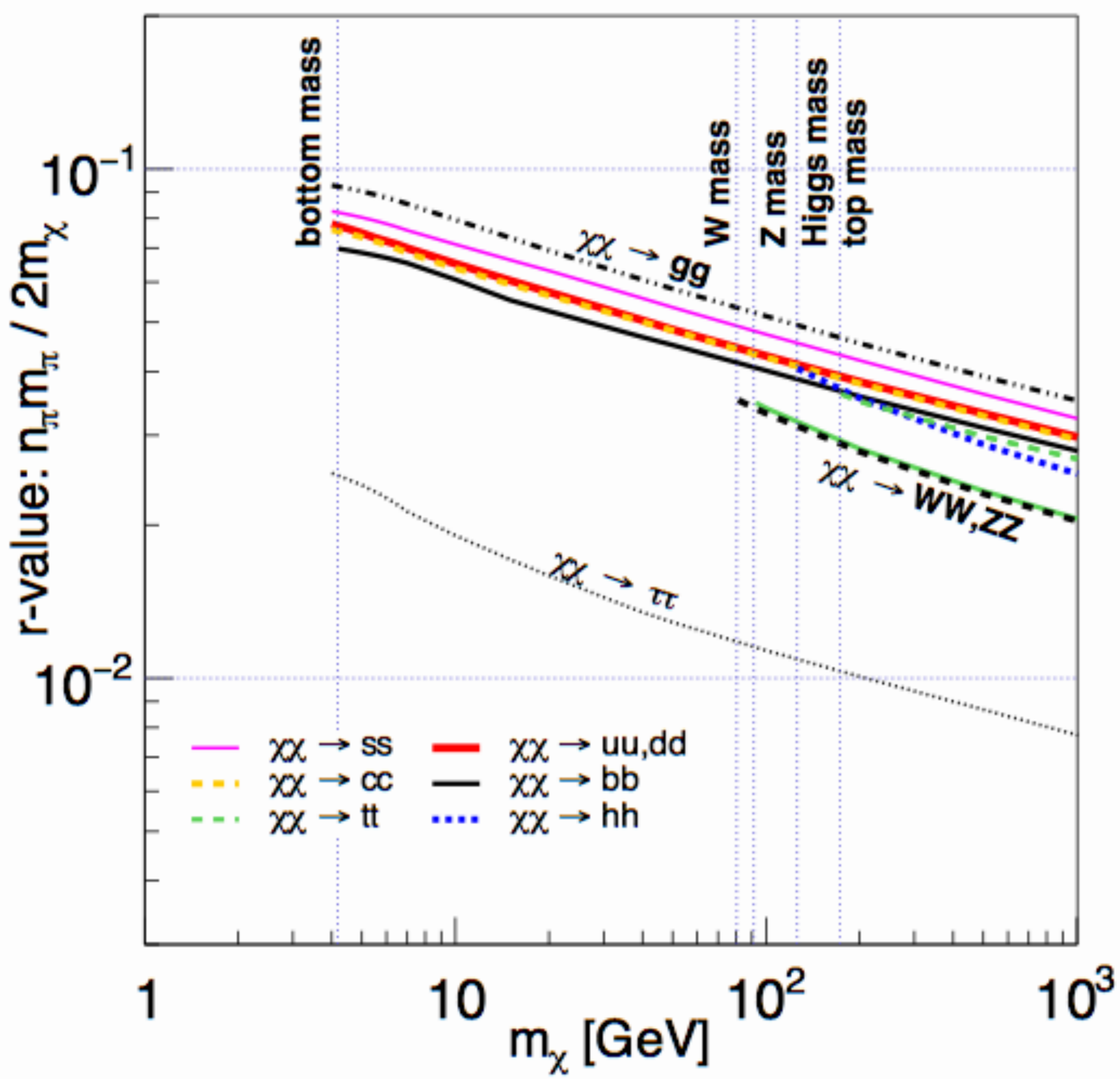




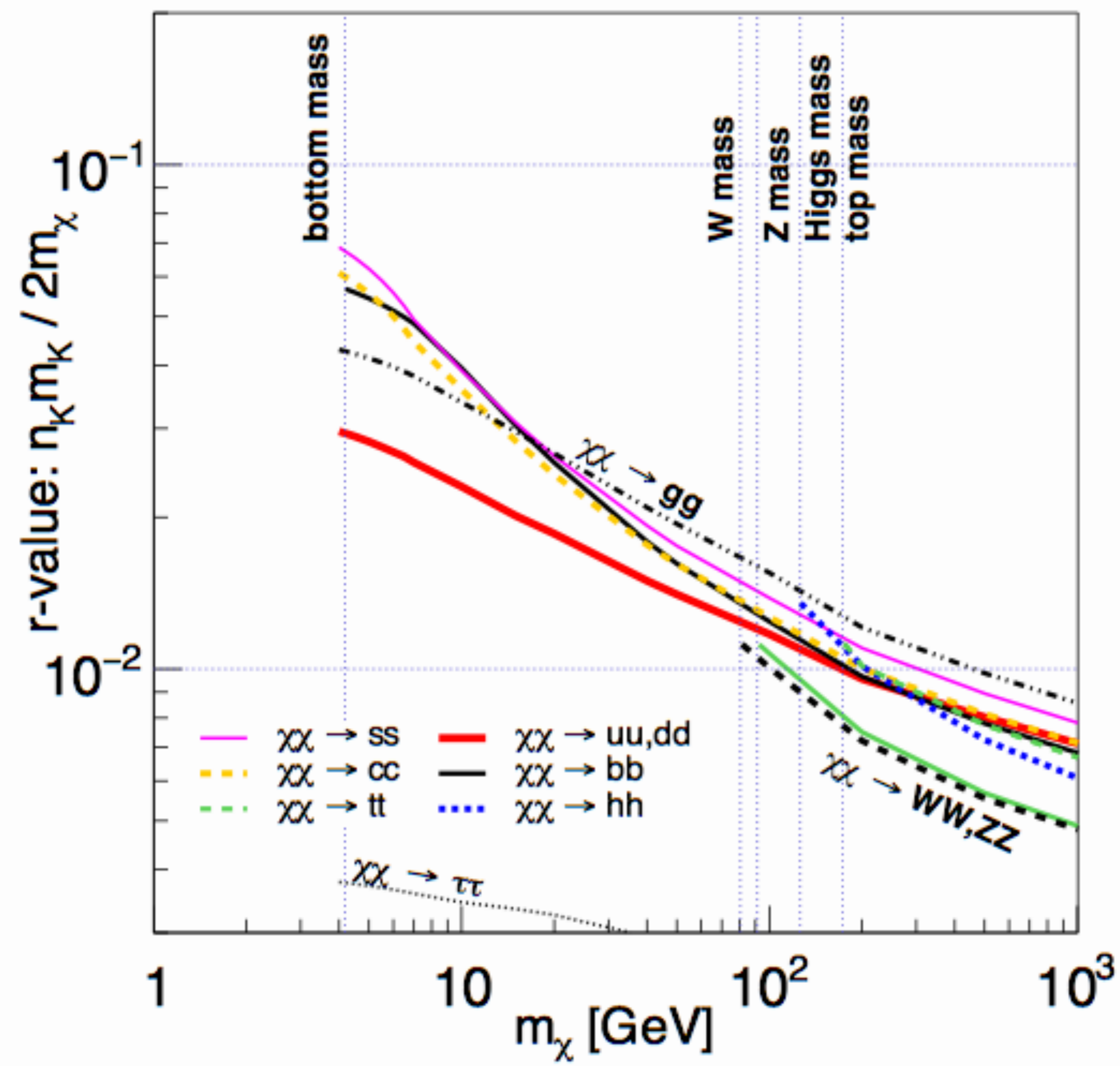
Low Energy Neutrinos from the Sun

Pion and Kaon yields

π^+ r-value - fraction of center-of-mass energy which goes into π^+

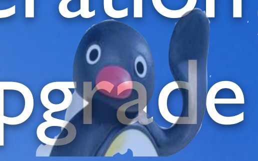


K^+ r-value - fraction of center-of-mass energy which goes into K^+



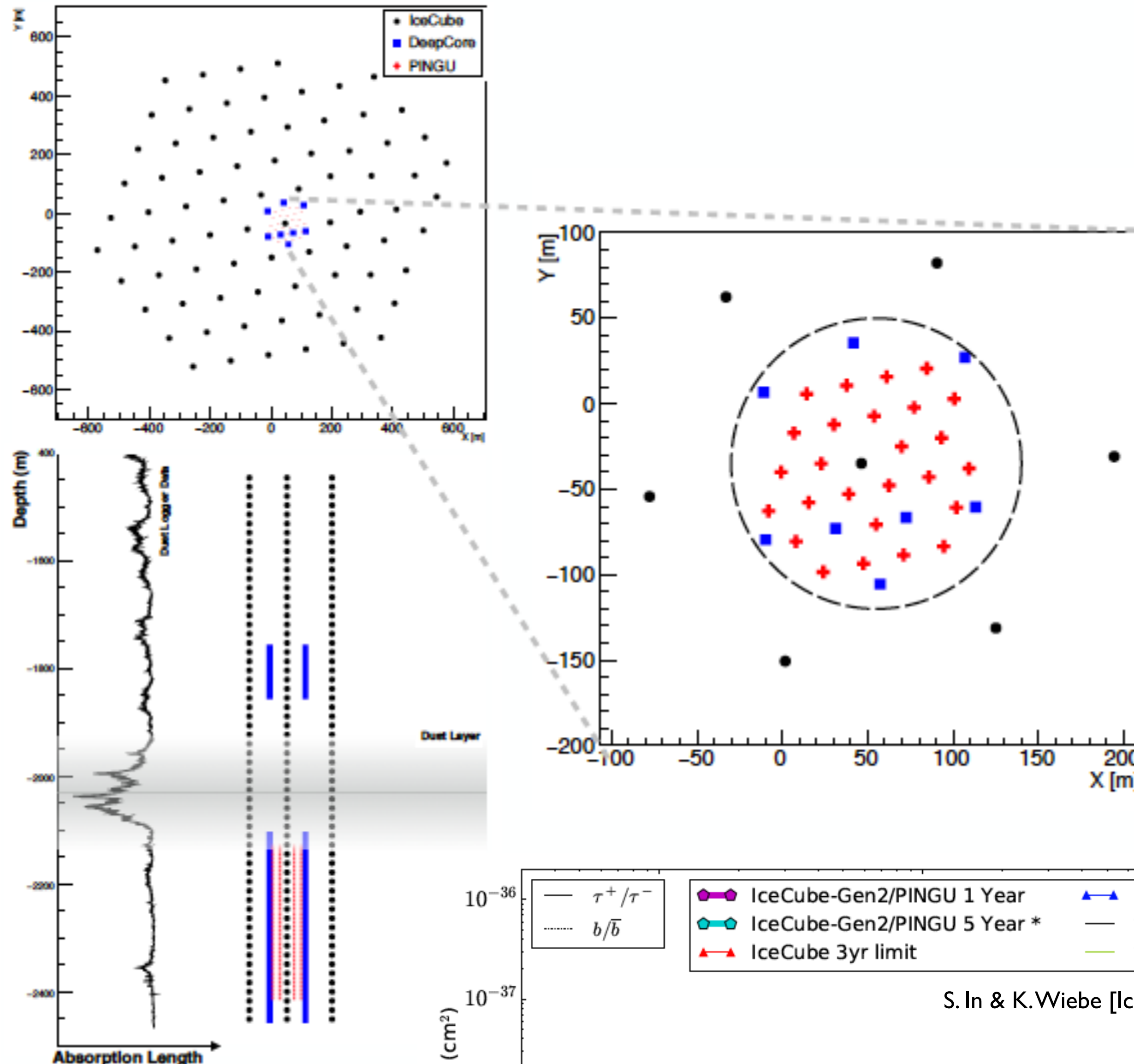
For low dark matter masses difference between flux from stopped pion and kaon decay at rest can be used to disentangle annihilation final states

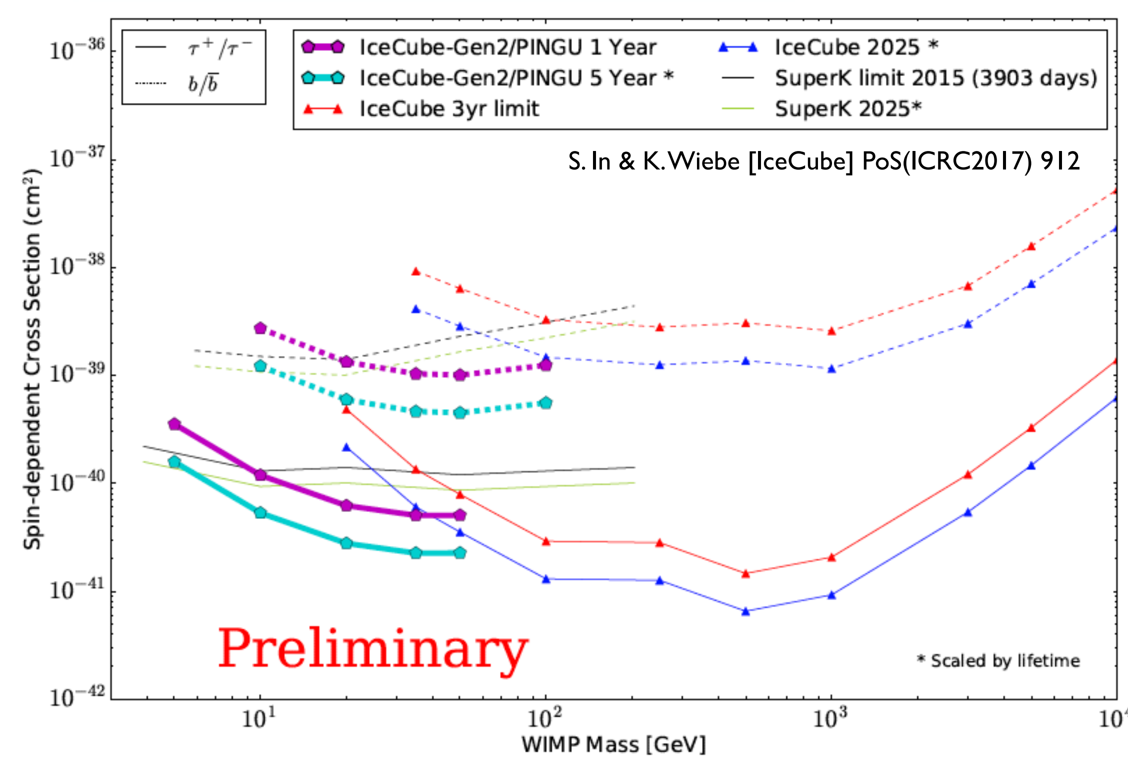
PINGU - Precision IceCube Next Generation Upgrade



IceCube PINGU Collaboration arXiv:1401.2046
Short version https://arxiv.org/pdf/1607.02671.pdf

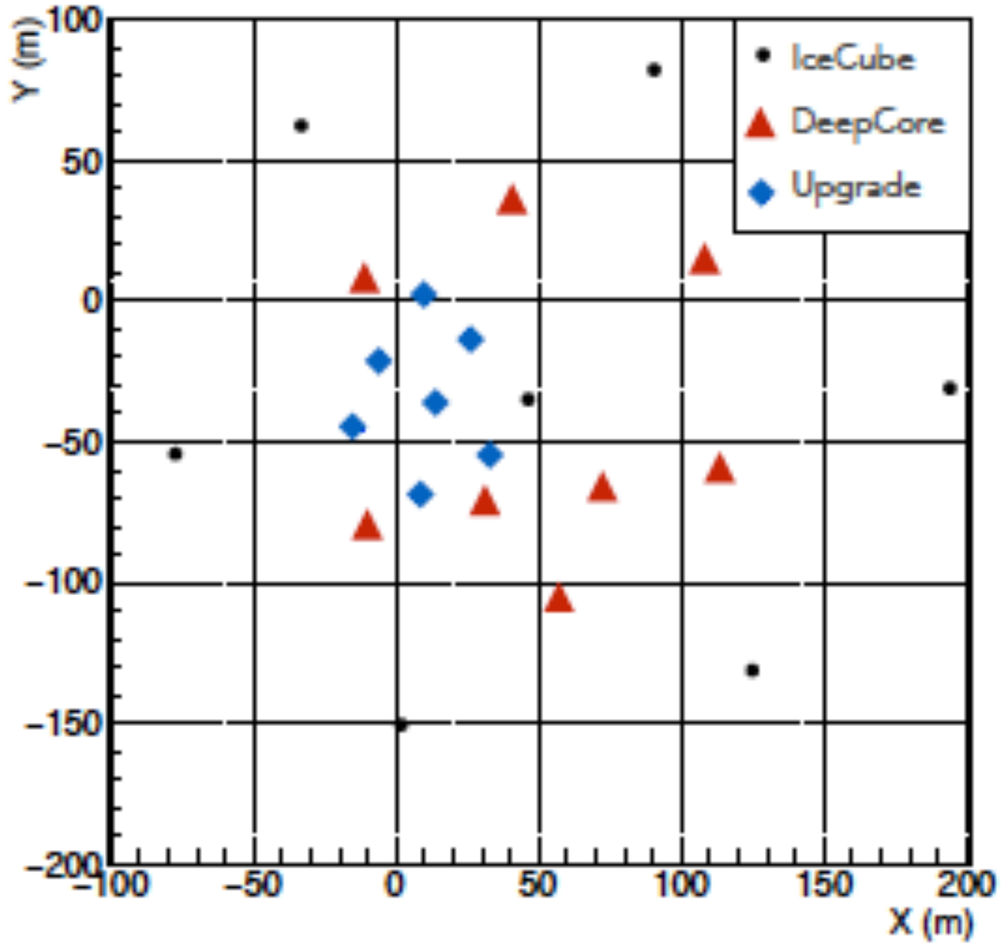
- PINGU upgrade plan
  - Instrument a volume of about 5MT with 20-26 strings
  - Rely on well established drilling technology and photo sensors
  - Create platform for calibration program and test technologies for future detectors
- Physics Goals:
  - Precision measurements of neutrino oscillations (mass hierarchy, ...)
  - Test low mass dark matter models

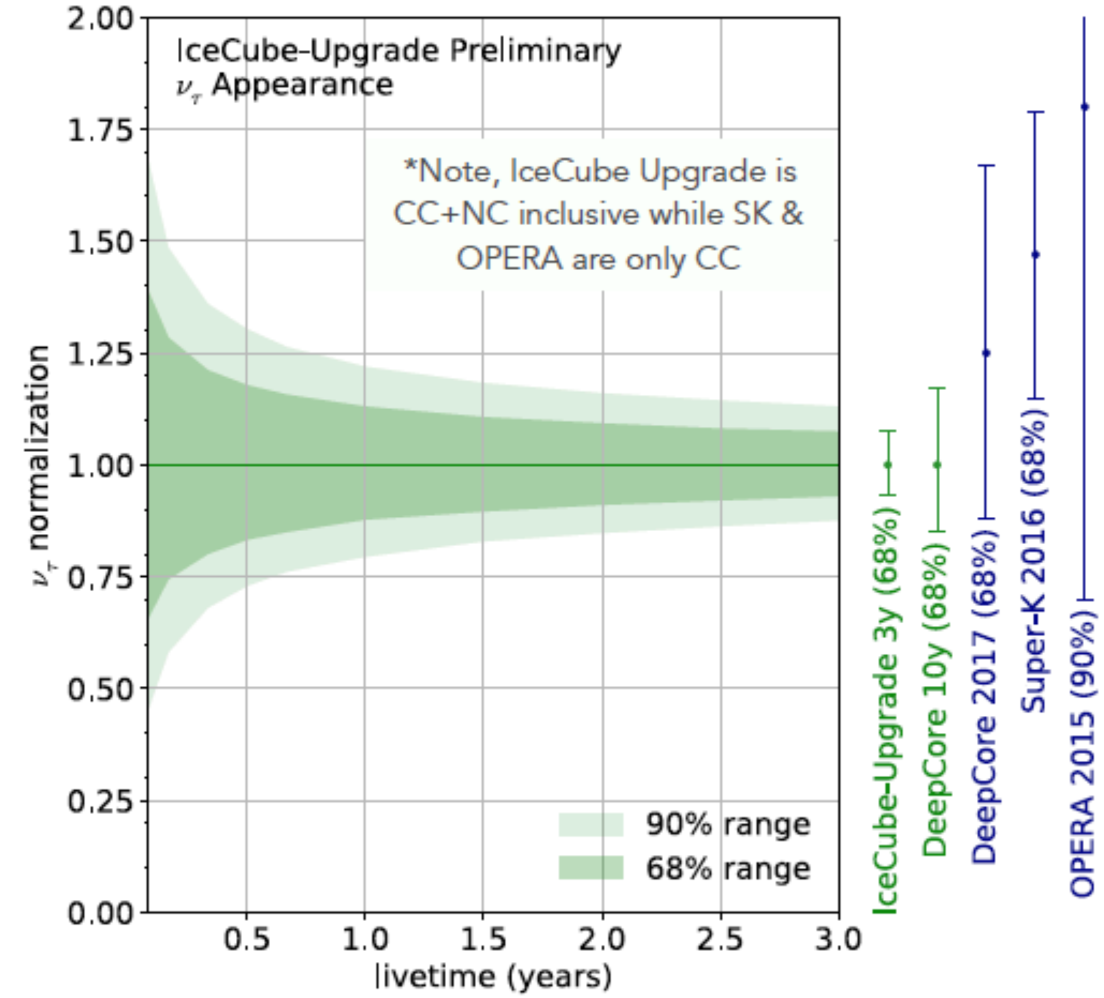




The IceCube Upgrade

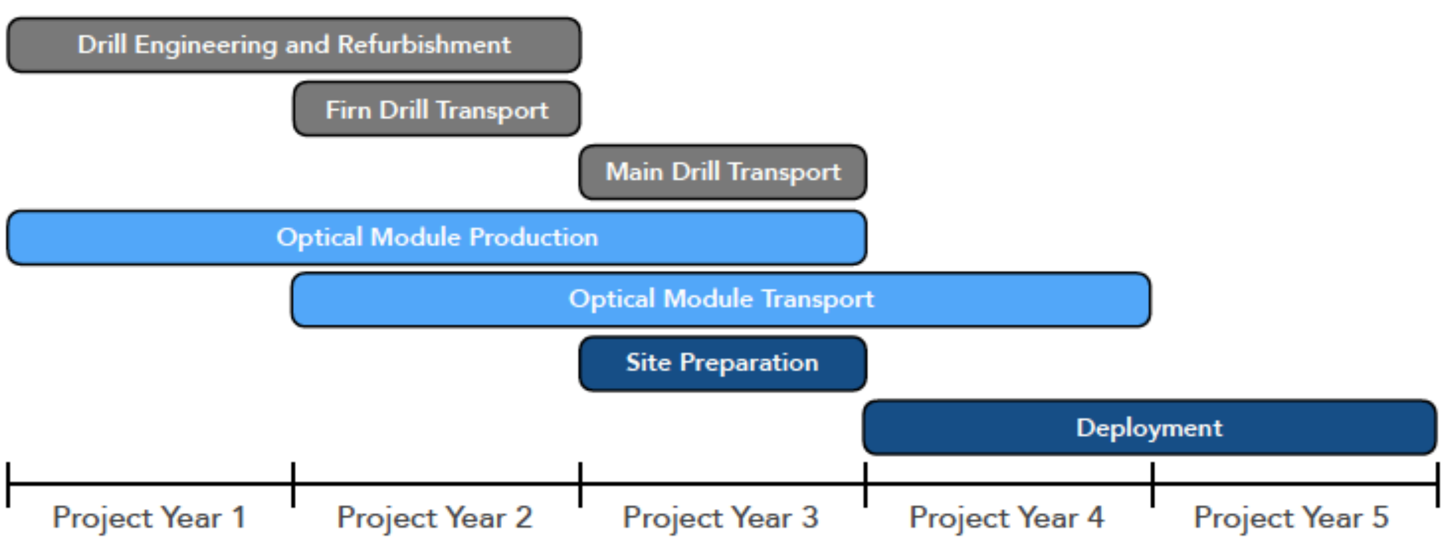
"The IceCube Upgrade" ~7strings





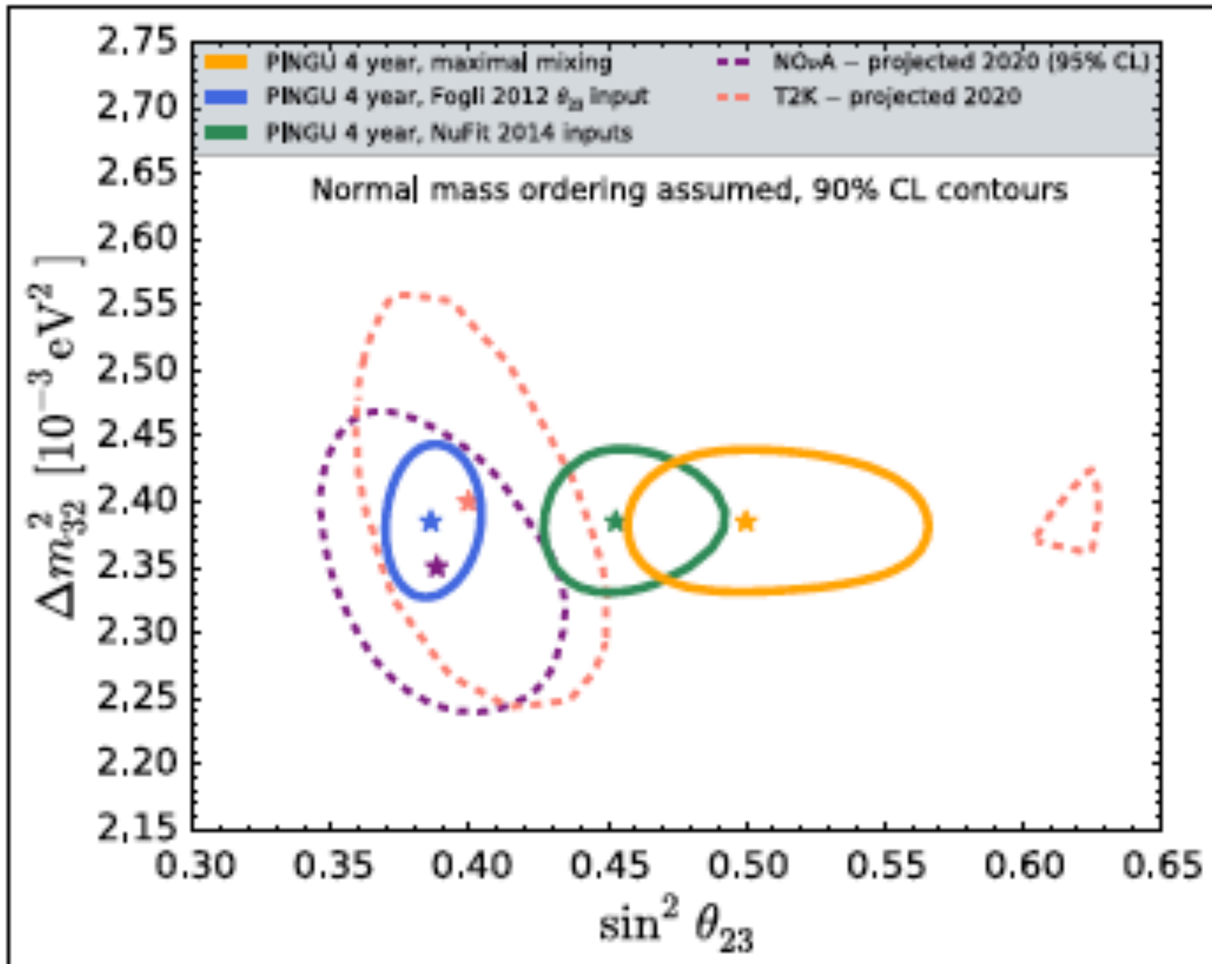
First step to restart South Pole activities

- Tau neutrino appearance
- Calibration devices
- Platform to test new technologies



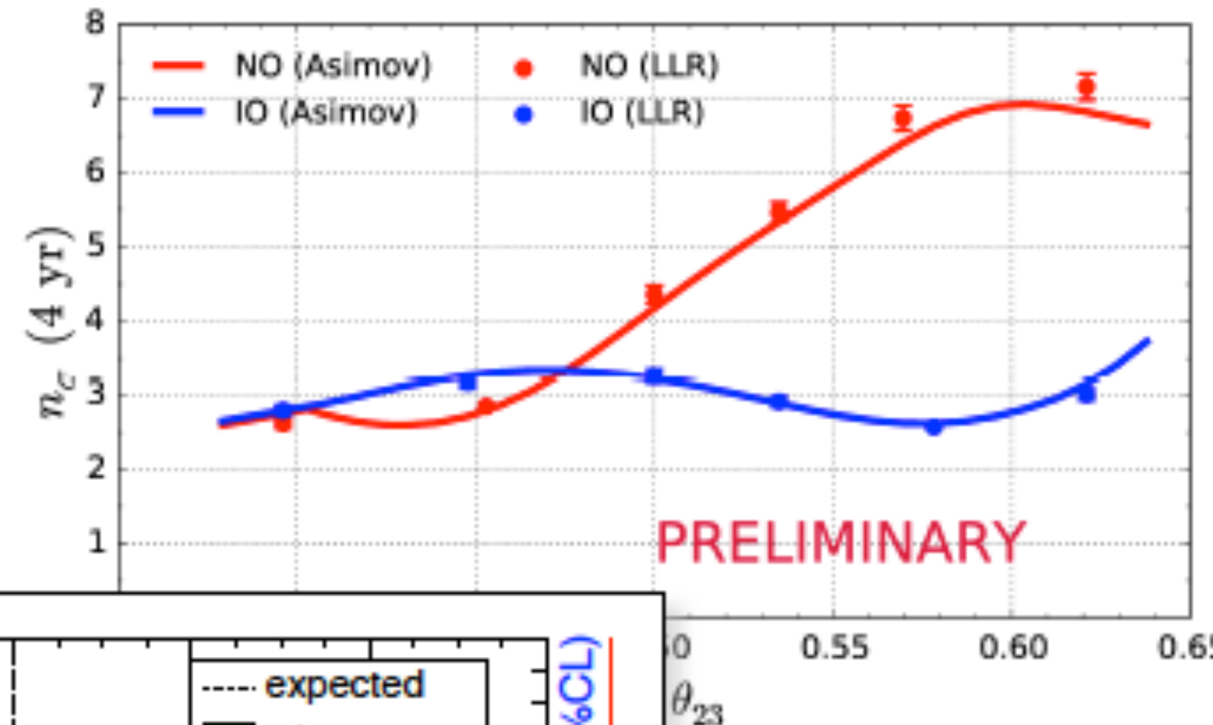
see also:
- PINGU LOI arXiv:1412.5106

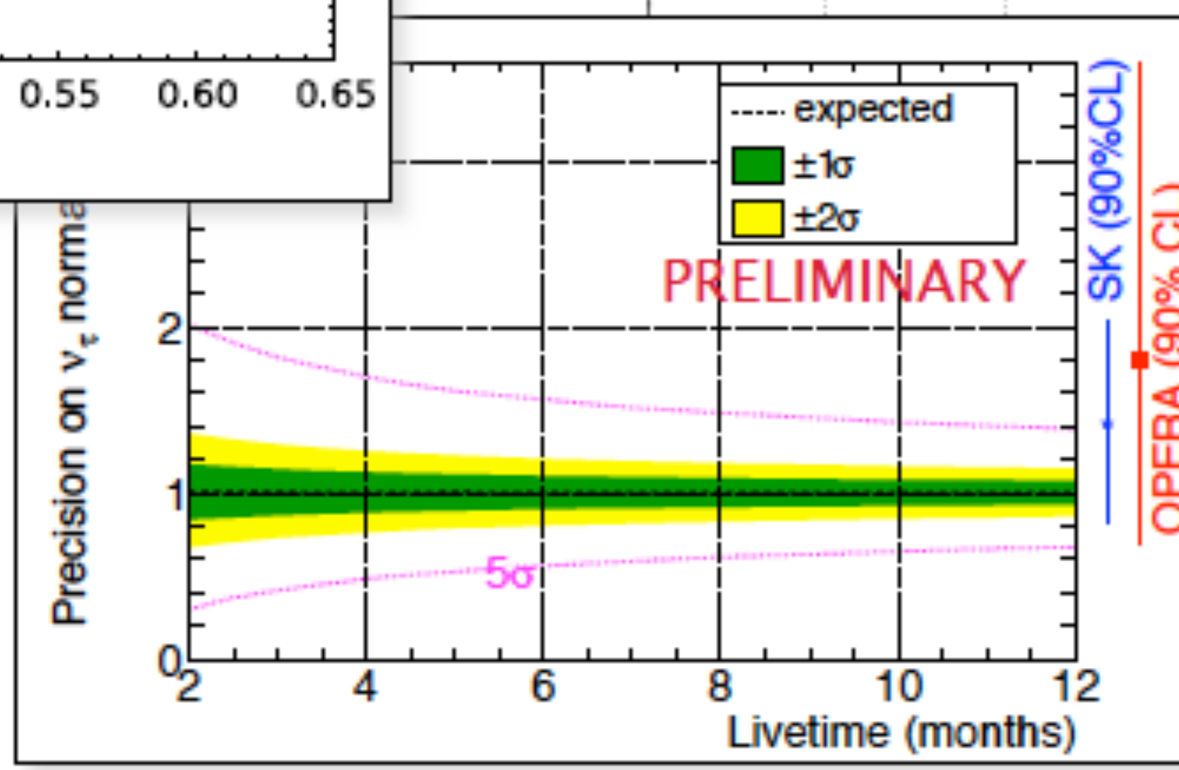
Neutrino Physics with PINGU



Measurement of mixing parameters with different method/energy range – Excellent sensitivity to octant of θ_{23}

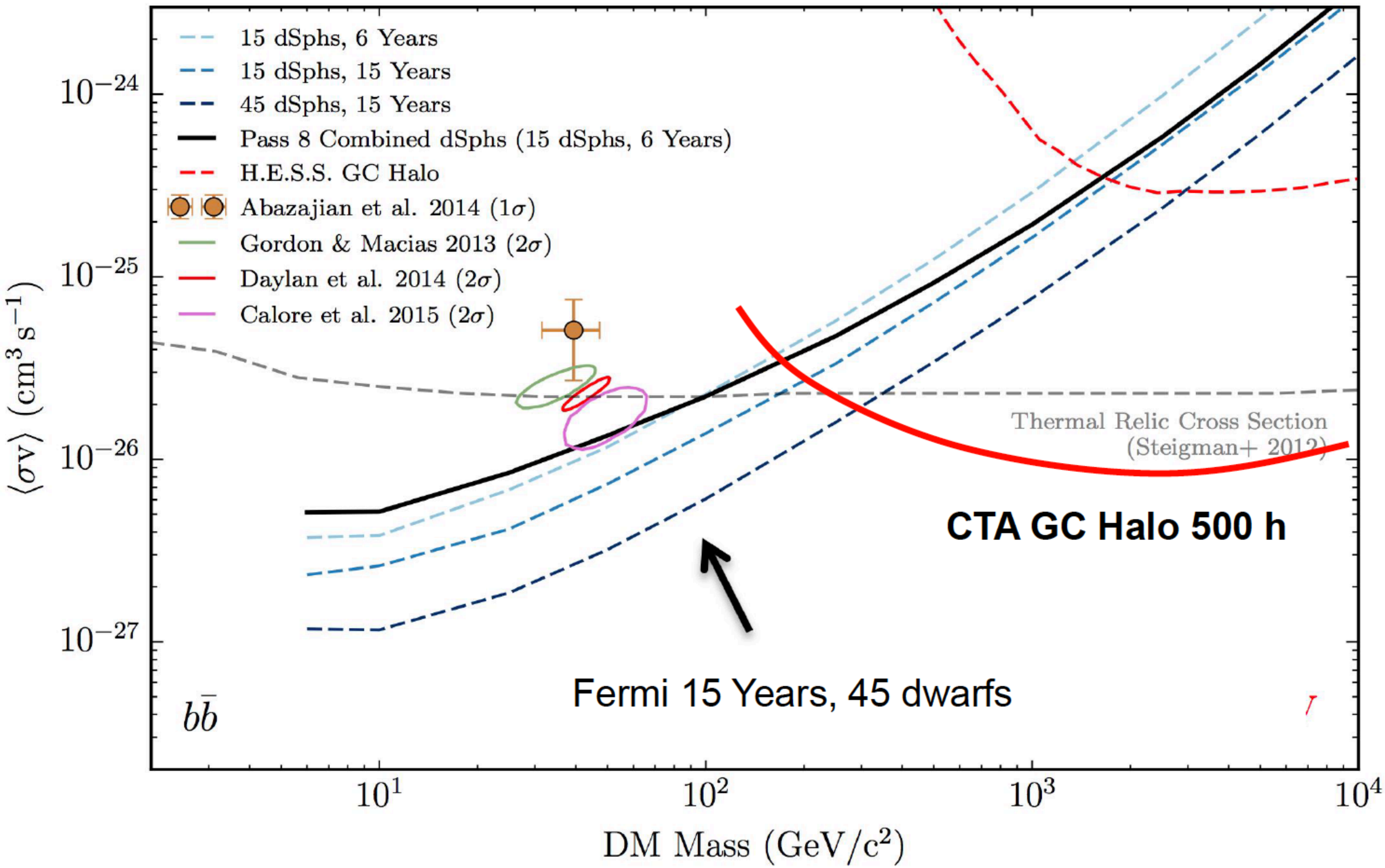
Determination of the neutrino mass ordering





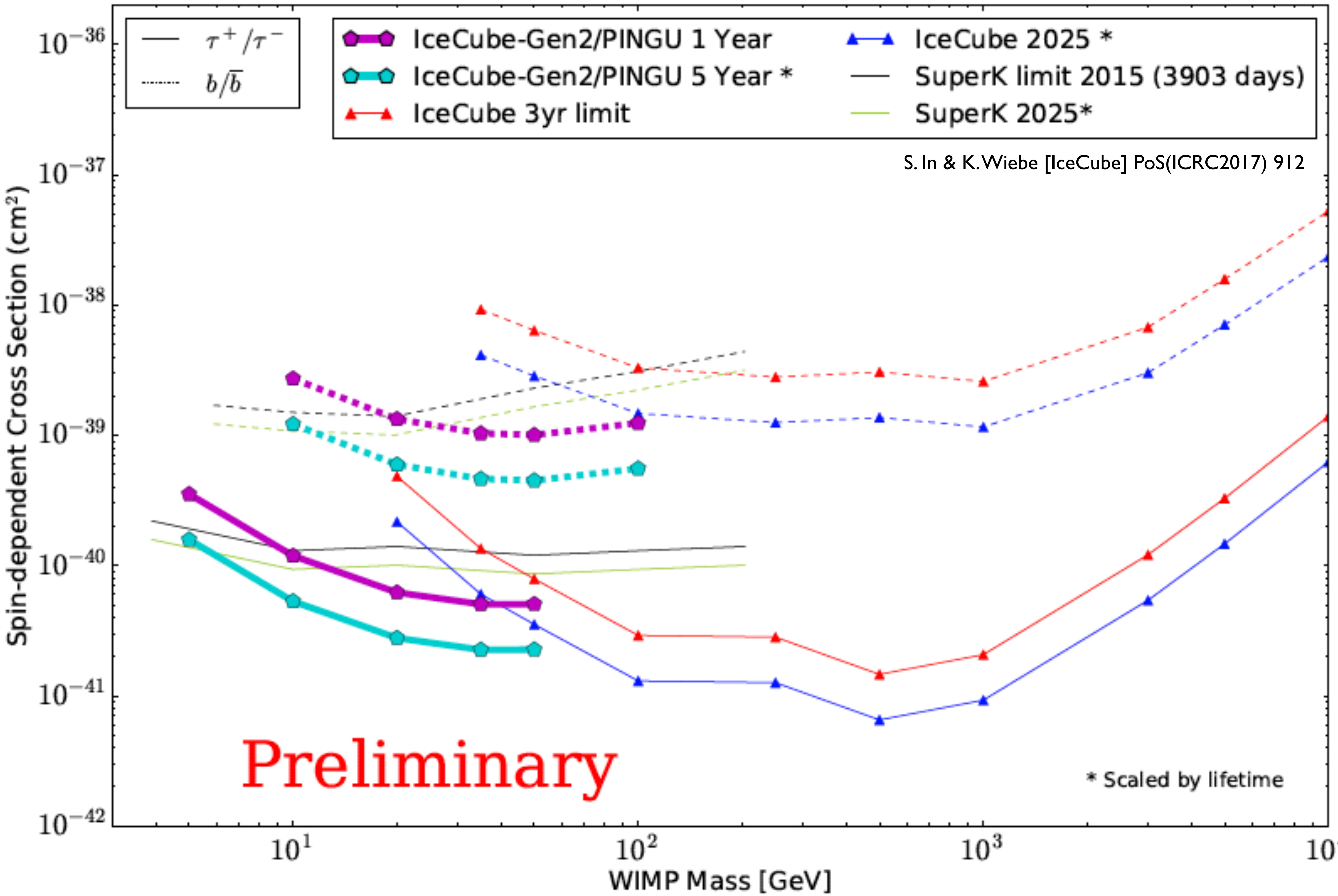
Precision measurement of ν_τ appearance – probe unitarity of PMNS matrix

CTA



15 dSphs, 6 Years
15 dSphs, 15 Years
45 dSphs, 15 Years
Pass 8 Combined dSphs (15 dSphs, 6 Years)
H.E.S.S. GC Halo
Abazajian et al. 2014 (1σ)
Gordon & Macias 2013 (2σ)
Daylan et al. 2014 (2σ)
Calore et al. 2015 (2σ)
Thermal Relic Cross Section
(Steigman+ 2012)
CTA GC Halo 500 h
Fermi 15 Years, 45 dwarfs
$b\bar{b}$
$\langle \sigma v \rangle$ (cm^3 s^{-1})
10^{-24}
10^{-25}
10^{-26}
10^{-27}
10^1
10^2
10^3
10^4
DM Mass (GeV/c^2)

PINGU DM Sensitivity



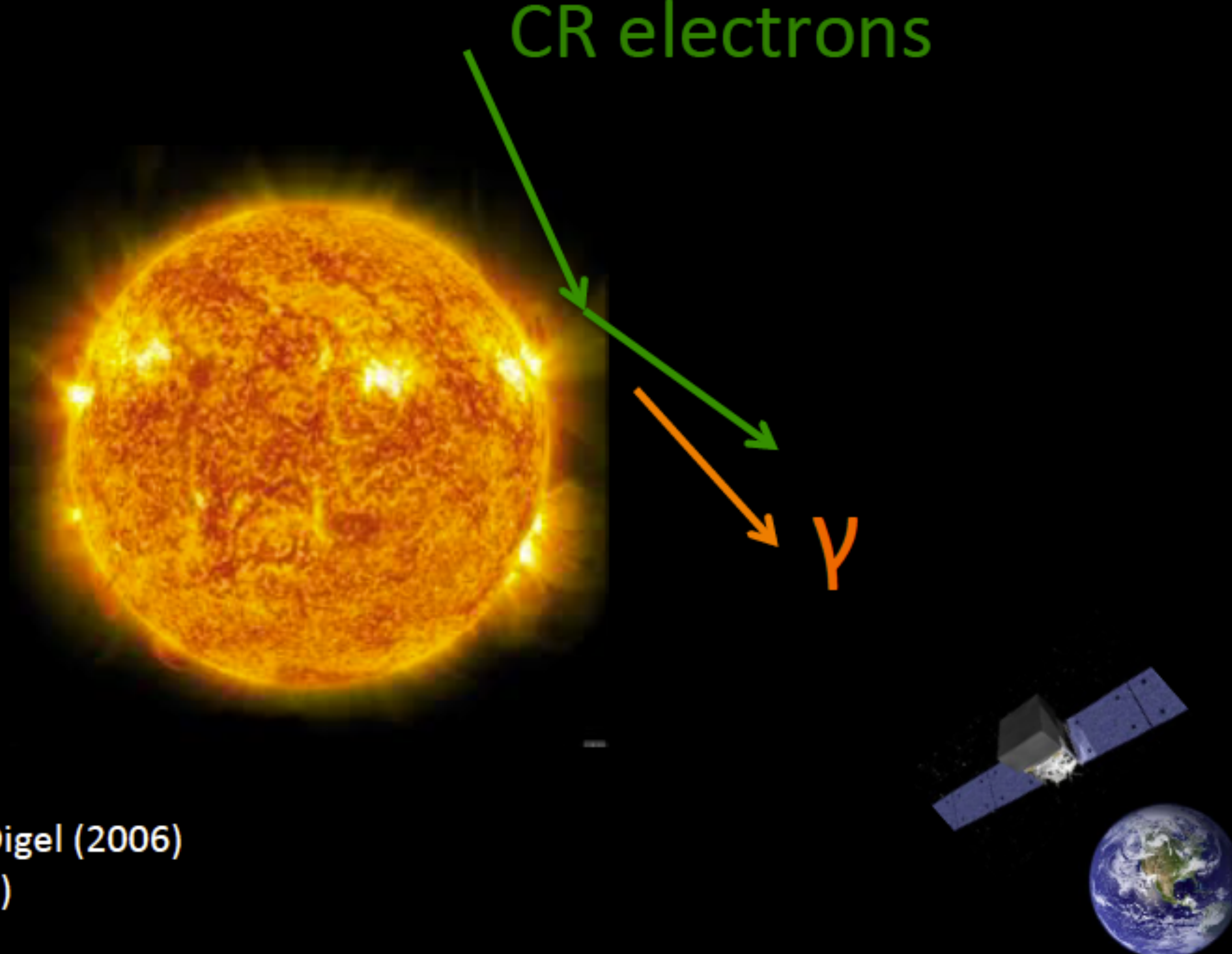
Solar Neutrino Floor

see K. Ng, J. Beacom, A. Peter, C. Rott PRD 2016

In preparation Ng, Beacom, Peter, Rott

Sun – Cosmic-Ray Beam Dump

- Leptonic

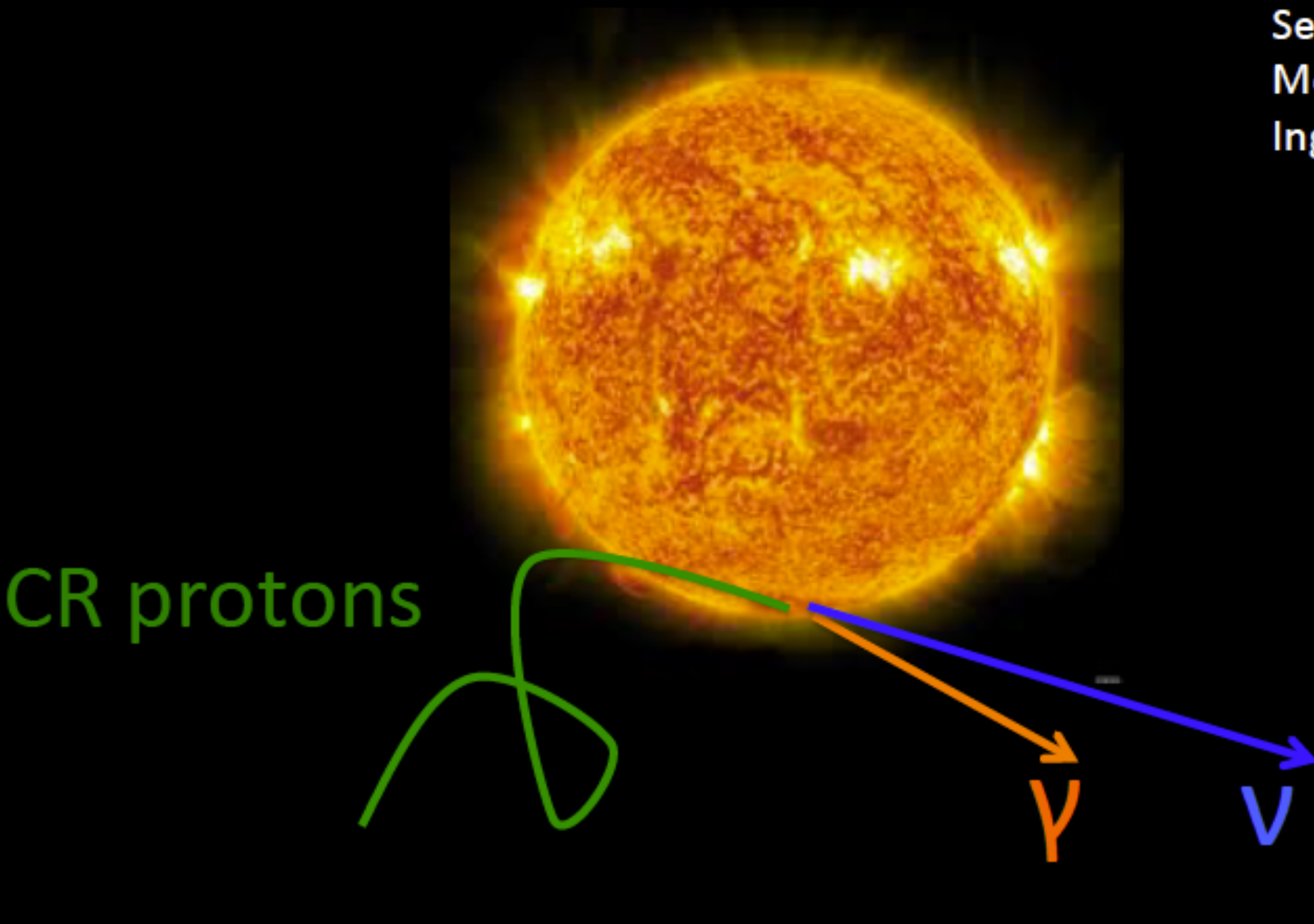


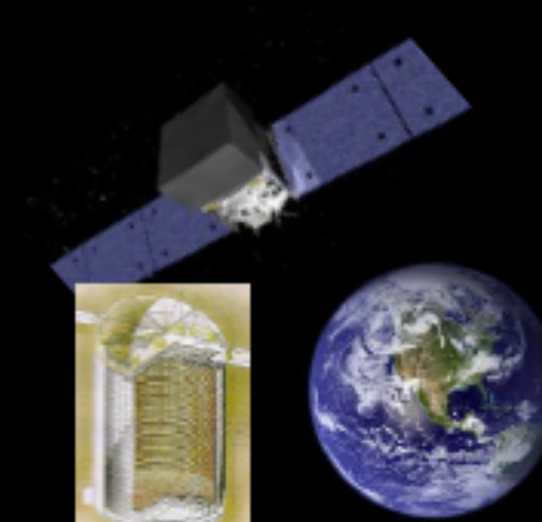
Moskalenko, Porter, Digel (2006)
Orlando, Strong (2007)

Sun – Cosmic-Ray Beam Dump

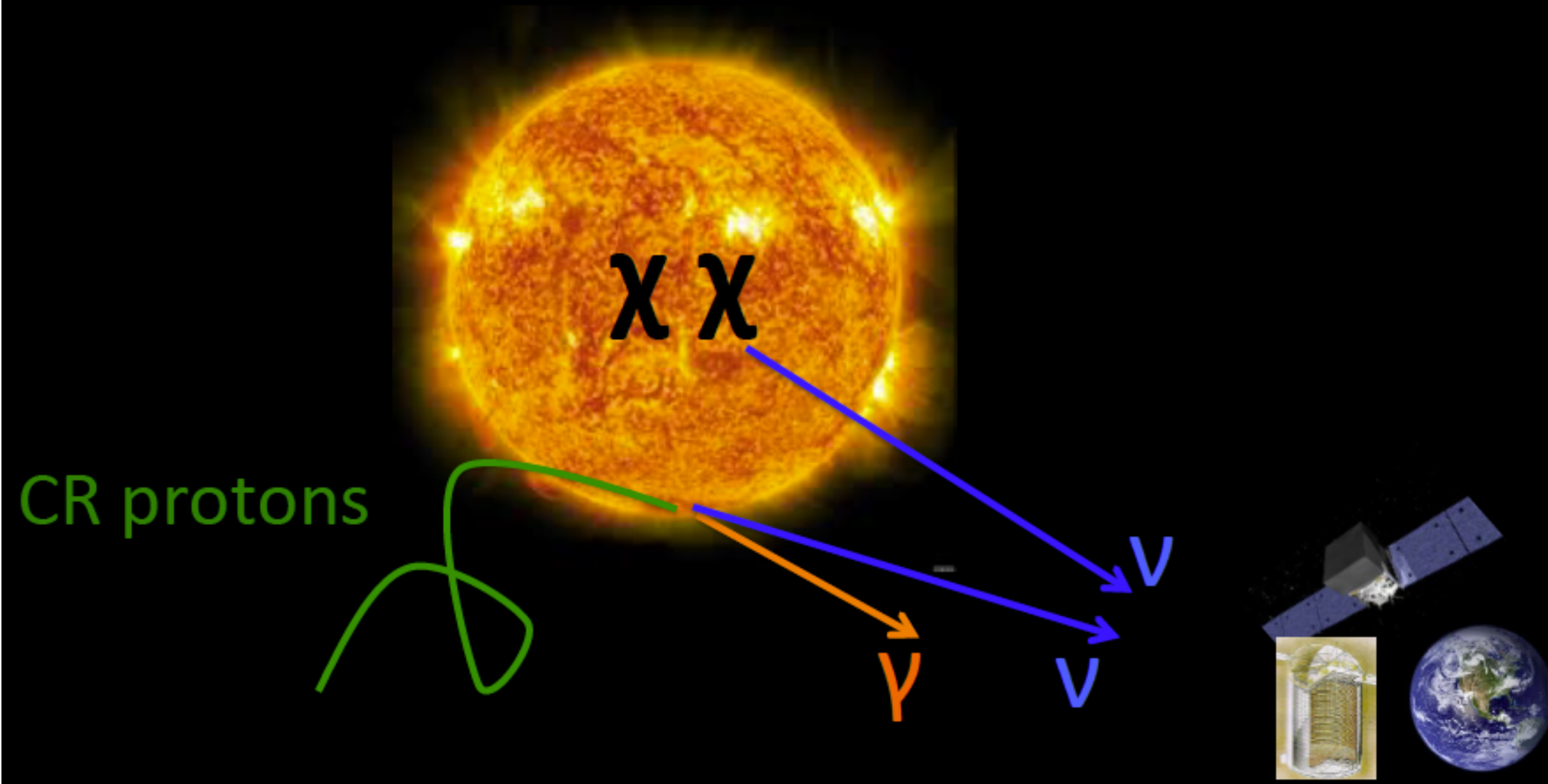
- Hadronic

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



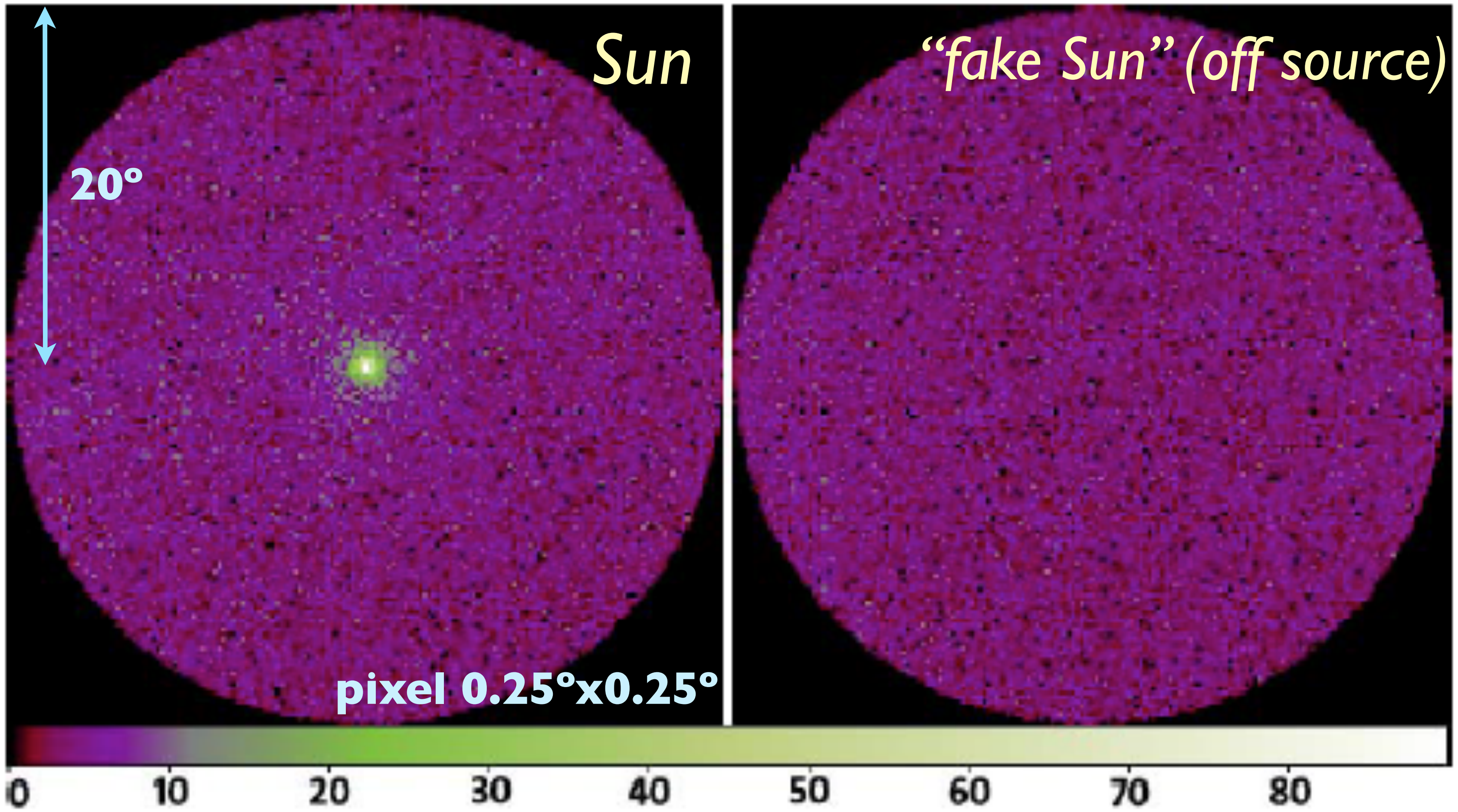


Cosmic Rays vs Dark Matter

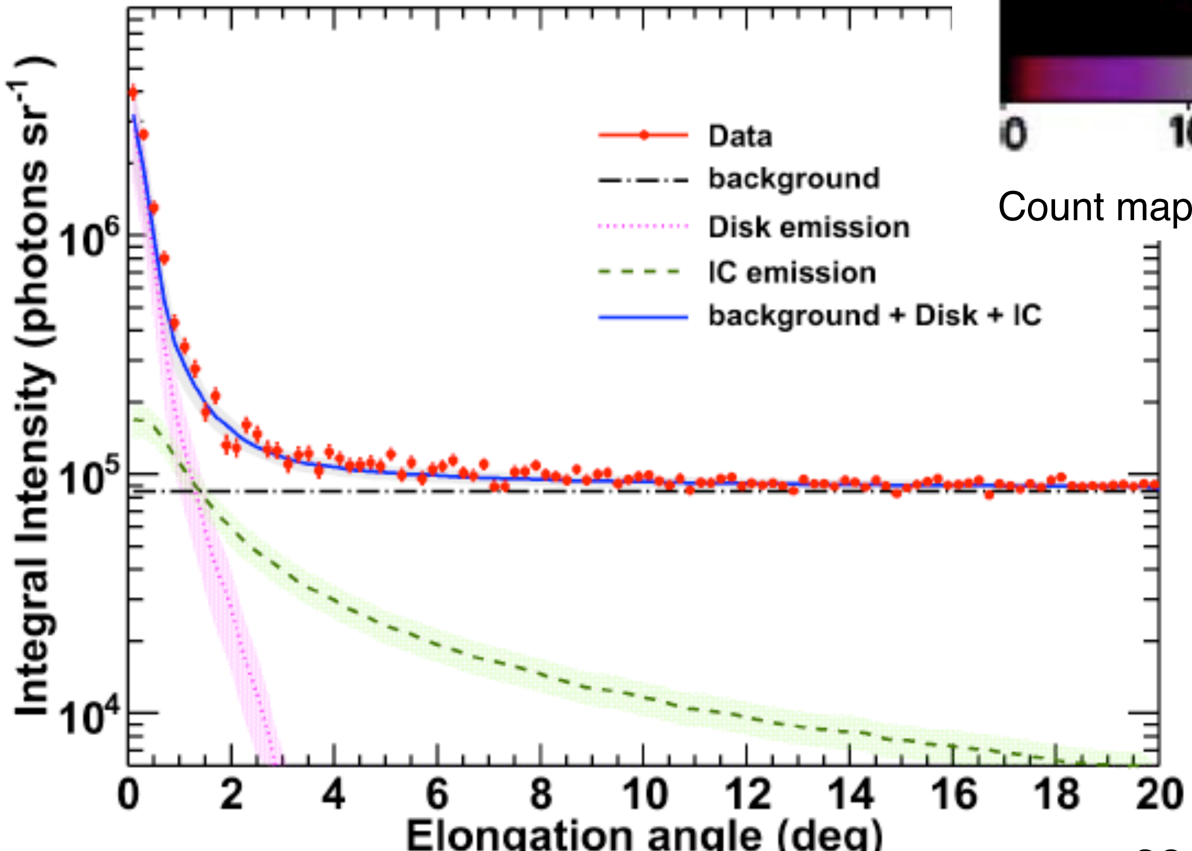


Gamma-ray's from the Sun

- 1.5 yrs of data during solar minimum
  - Aug 2008 - Feb 2010
- Standard Fermi analysis selection criteria



Count maps for events >100 MeV taken between August 2008 and February 2010

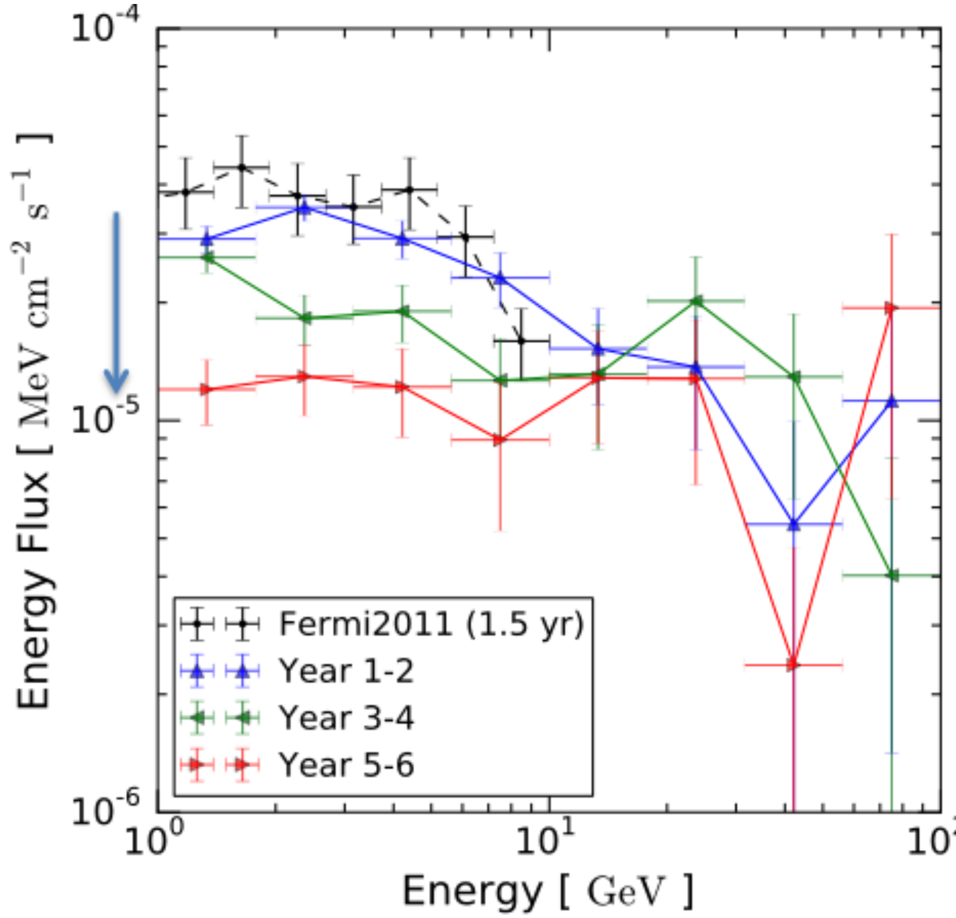


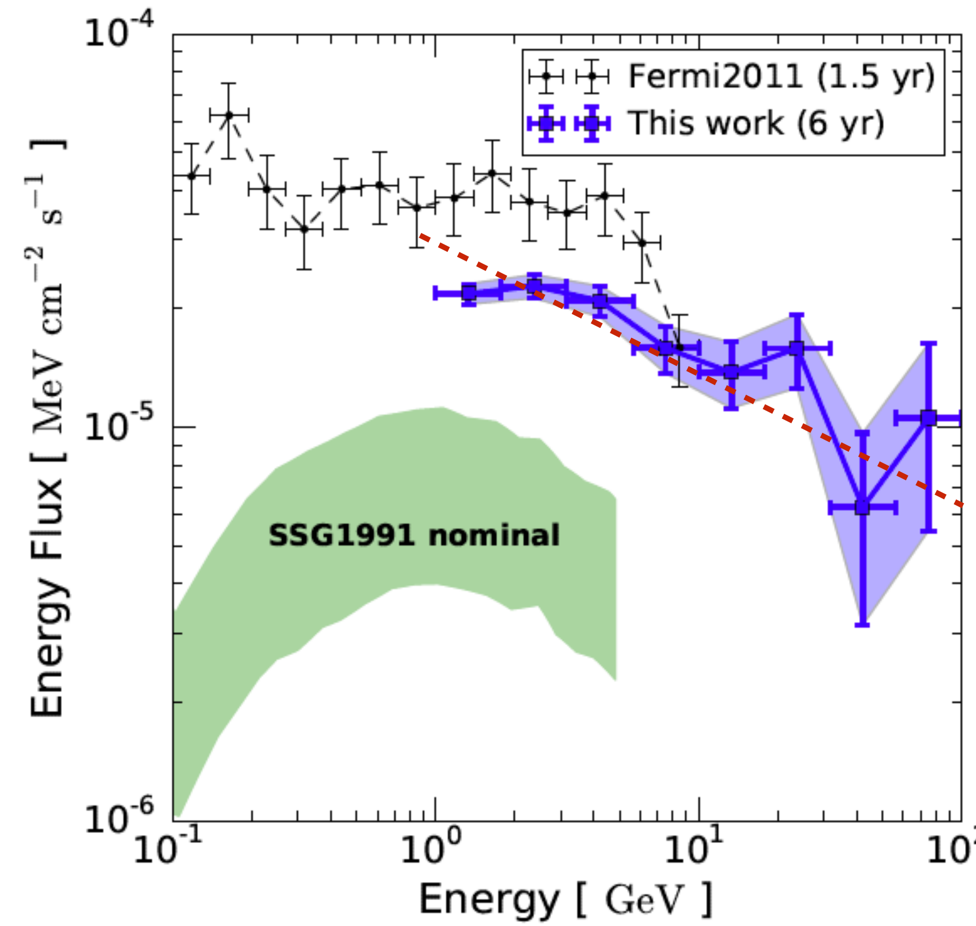
- Extended and disk emission is observed

see Fermi-LAT Collaboration: http://arxiv.org/pdf/1104.2093.pdf

Gamma-ray's from the Sun

- 6 yrs of data
  - Aug 2008 - Aug 2014
- Fermi science tools version v9r33p0

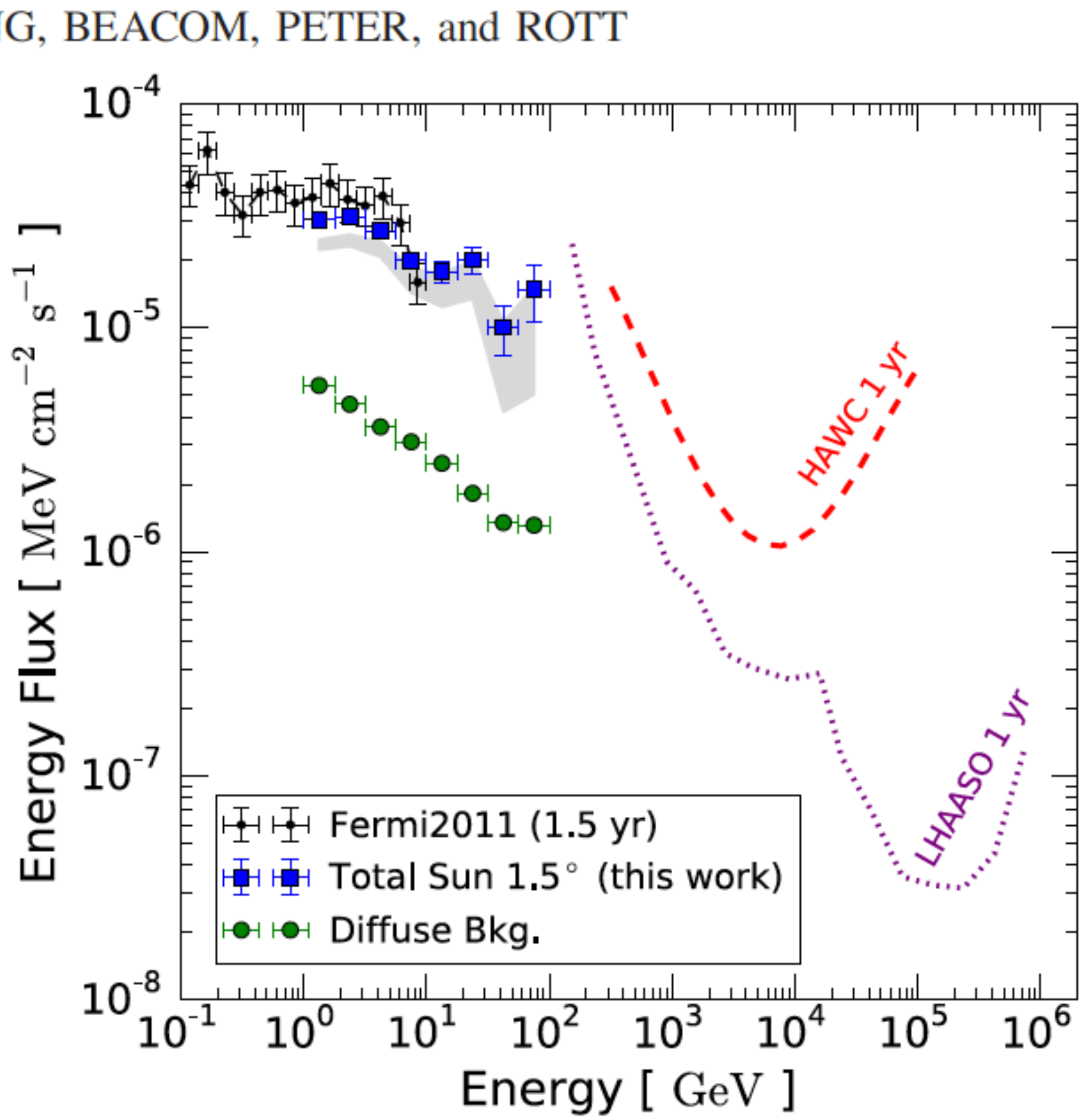


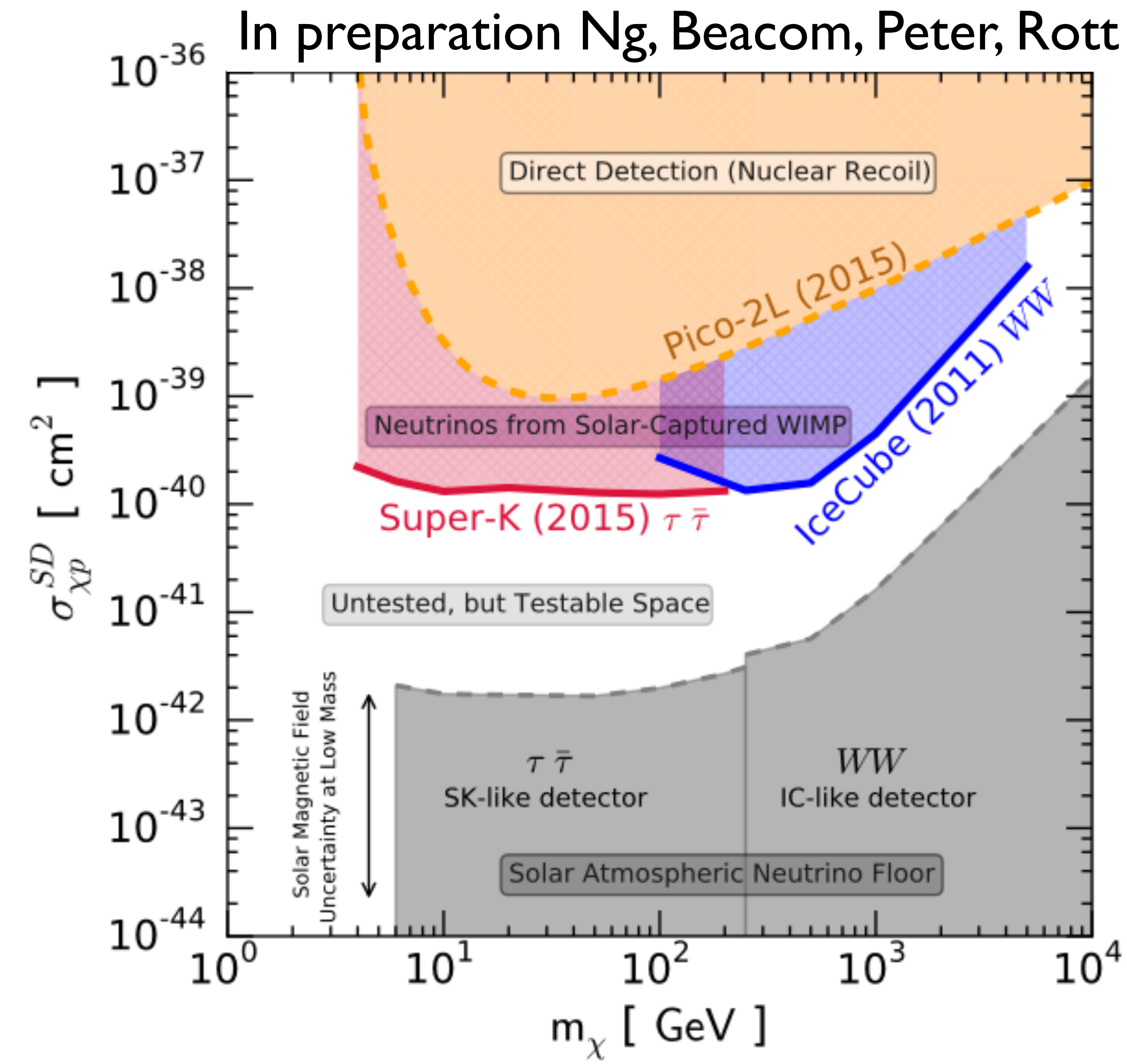


- Observed gamma-ray flux cannot be described by current models
- Significant time variation in solar-disk gamma-rays observed (<10GeV)
- Gamma-ray flux from the Sun extends beyond 100GeV

see K. Ng, J. Beacom, A. Peter, C. Rott PRD 2016

Gamma-ray's from the Sun





- Sun is a promising source for ground-based high altitude water Cherenkov detectors
- Background to dark matter search from the Sun, that soon will be relevant (and first high-energy neutrino point source ??)

see K. Ng, J. Beacom, A. Peter, C. Rott PRD 2016