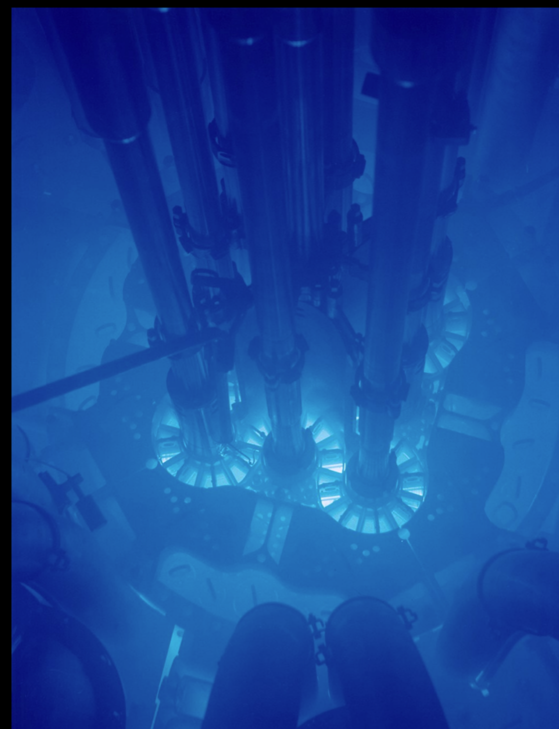
Astrophysical Neutrinos and New Physics with Water Cherenokov detectors



Kenny, Chun Yu Ng (吴震宇)
Weizmann Institute of Science

WEIZMANN INSTITUTE OF SCIENCE
Croucher Foundation

tme WCP2018

Neutrinos Astro-particle physics

Astro -------------------------- Particle

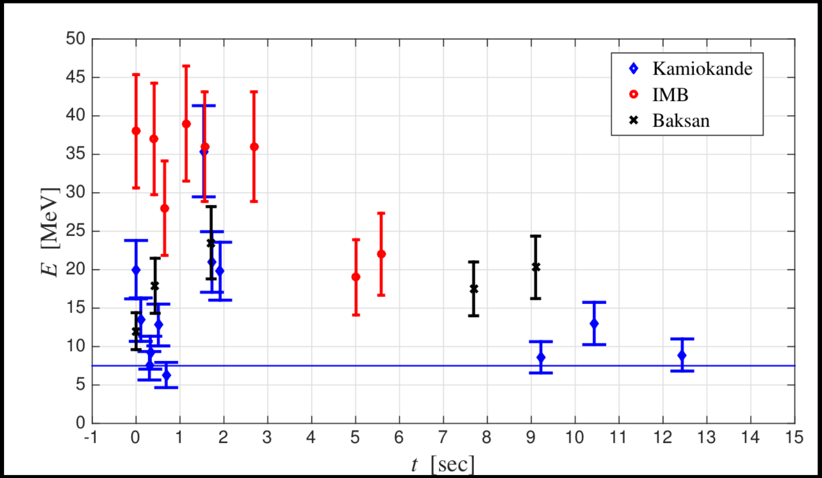
- Reveal concealed astrophysical sites
  - Solar, Supernova 
  - AGN
- Ideal messenger
- Cosmic hadron accelerator
  - 100 year CR problem

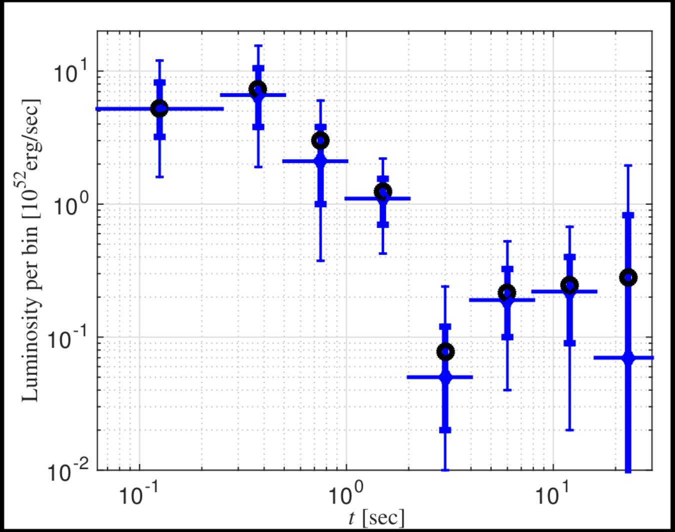
- Neutrino mass 
  - Dirac mass, why so small? -> Sterile neutrino!
  - Majorana mass?
  - Both?
- New physics portals?
  - Dark matter
  - Secret interactions

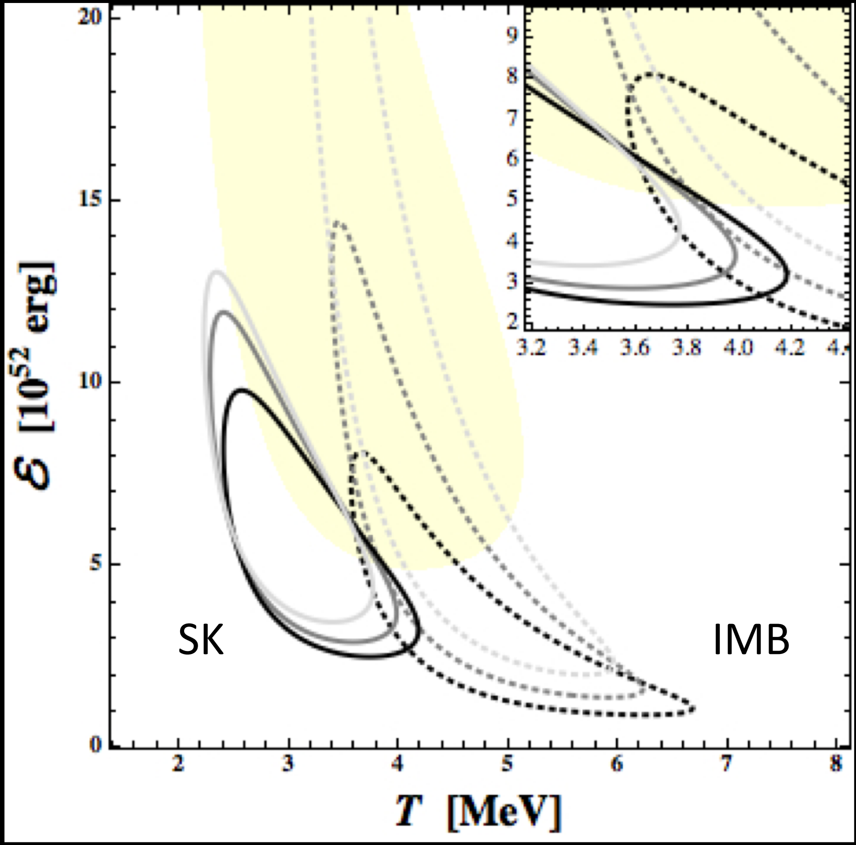
Supernova Neutrinos

Galactic Supernova

- SN1987A





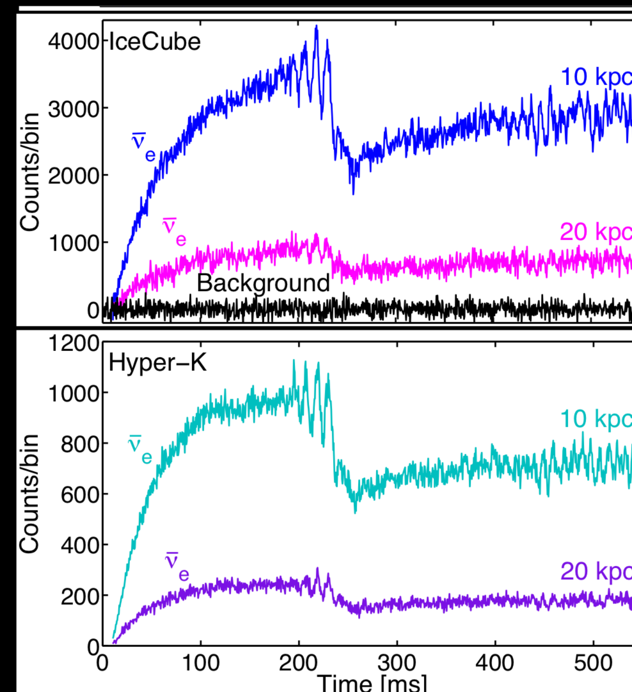


Vissani 2015

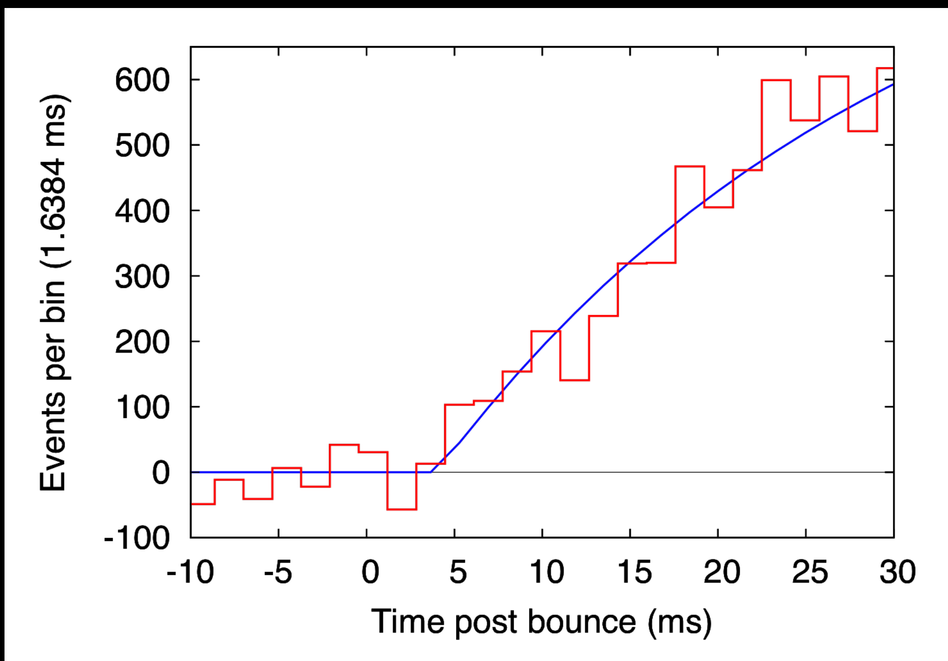
Blum Kushnir 2016

Galactic Supernova

Tamborra+2013

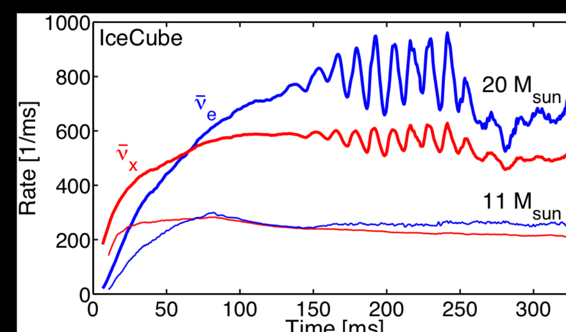


- IceCube



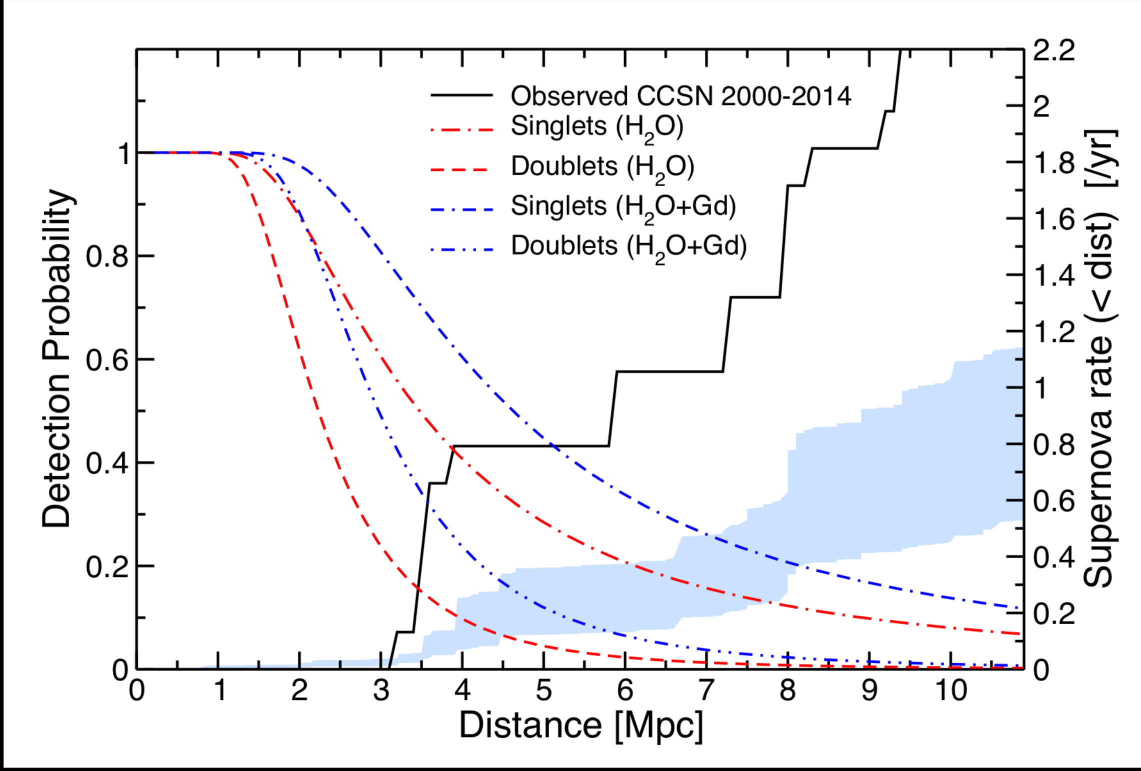
Halzen Raffelt 2009

- Bounce time ± 3.5ms -> GW



Nearby Supernova

- Can we see nearby supernova?
  - Local Overdensity?
- 1/year <6Mpc
- Singles (+ optical)
  - 30%
- 10 years
  - 1- P(no det.) > 97%!

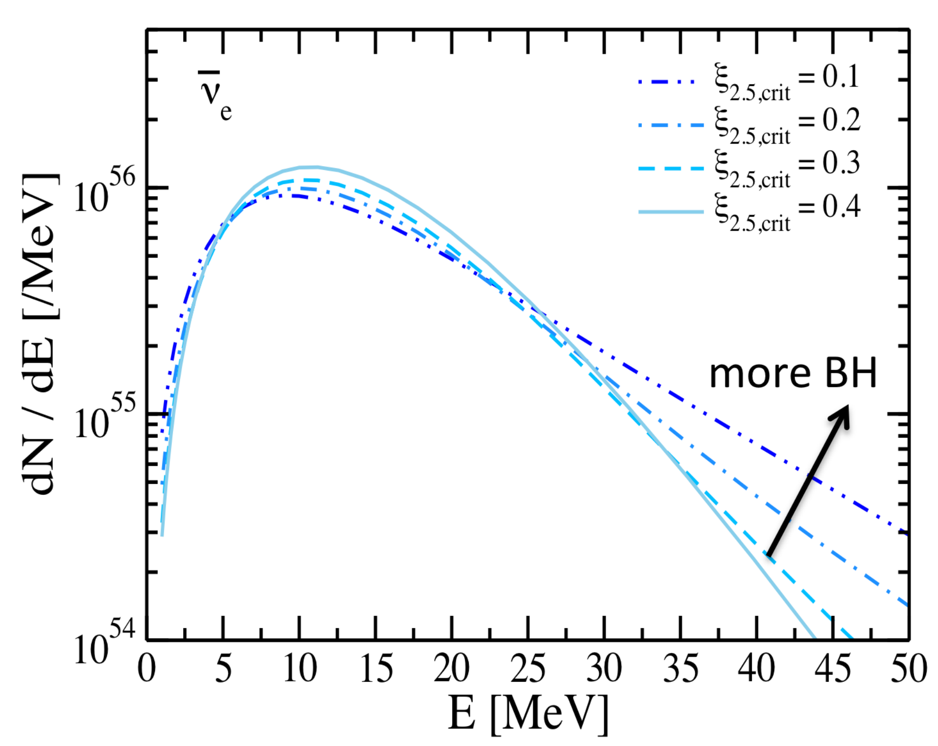


Nakamura et al 2016

Diffuse supernova neutrino background

Average neutrino emission

- Use >100 simulations to characterize progenitor dependence of neutrinos
- Include collapse to black holes, characterized by critical compactness

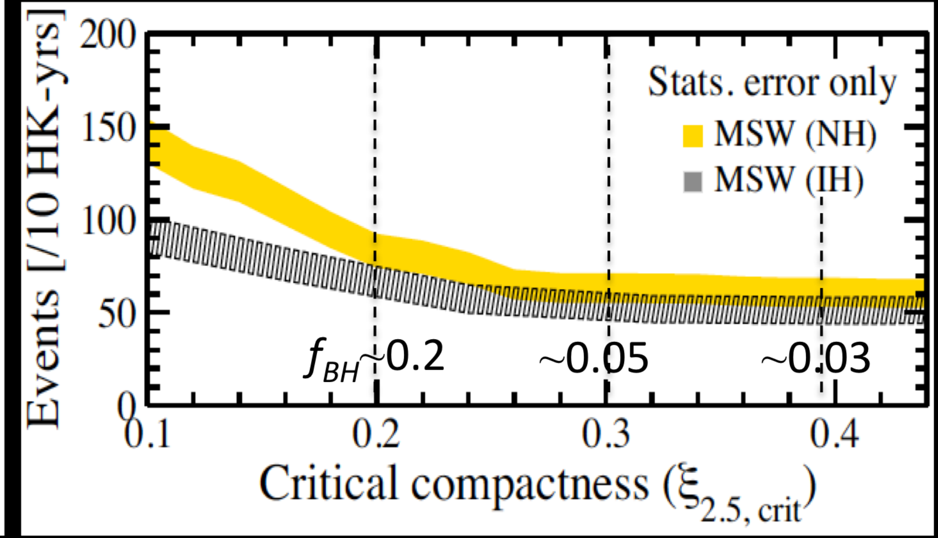


reviews by Beacom (2010), Lunardini (2010)

Event rate predictions

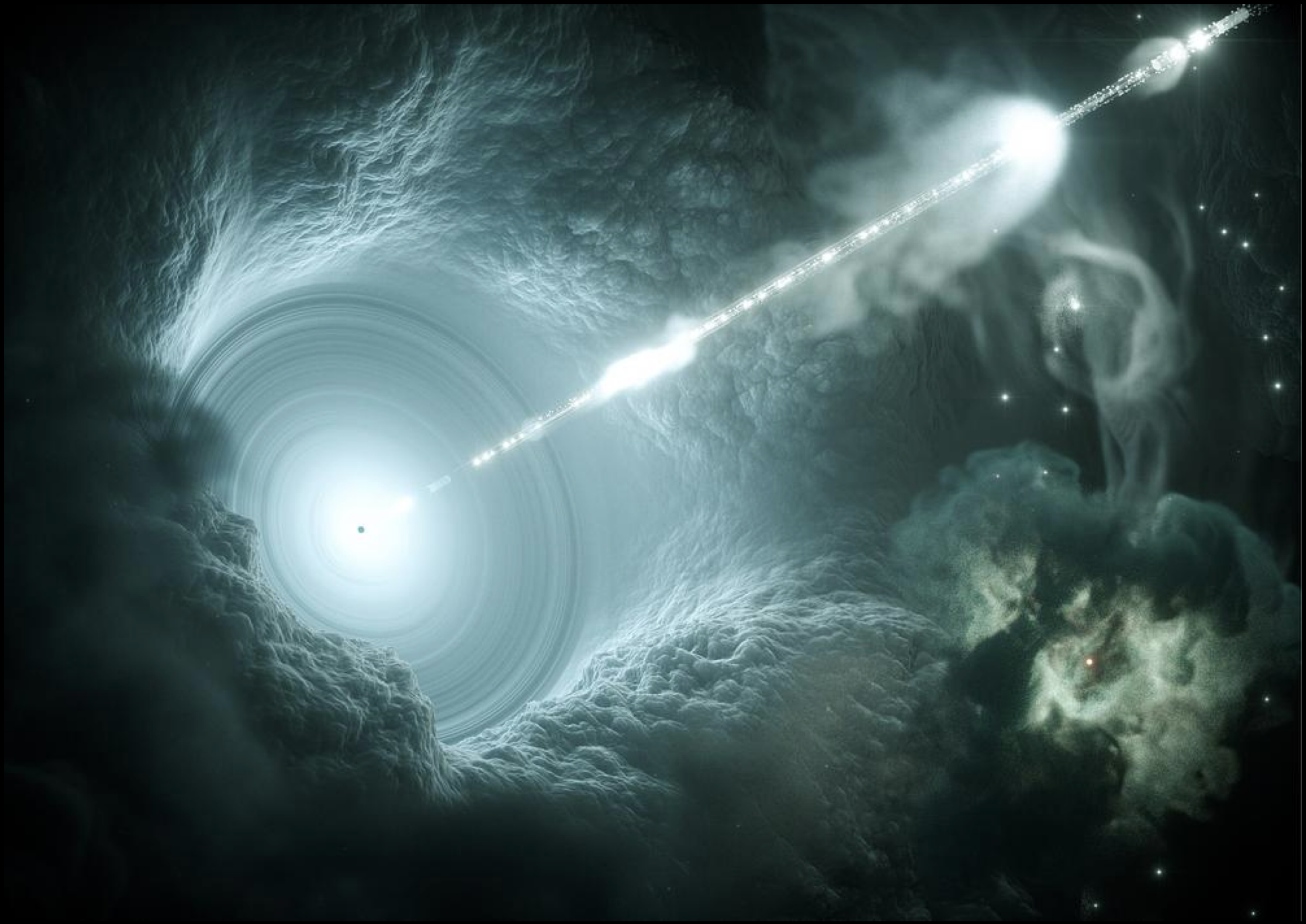
Hyper-K sensitive to small compactness ($\xi_{2.5}$ < 0.2, or f_{BH} > 0.2)

Spectrum	SK + Gd (>10MeV) [/yr]
4 MeV	1.8 +/- 0.5
4 MeV+BH	< 2.5
SN1987A	1.7 +/- 0.5



Horiuchi et al (2018); see also Lunardini (2009), Lien et al (2010), Moller et al (2018)

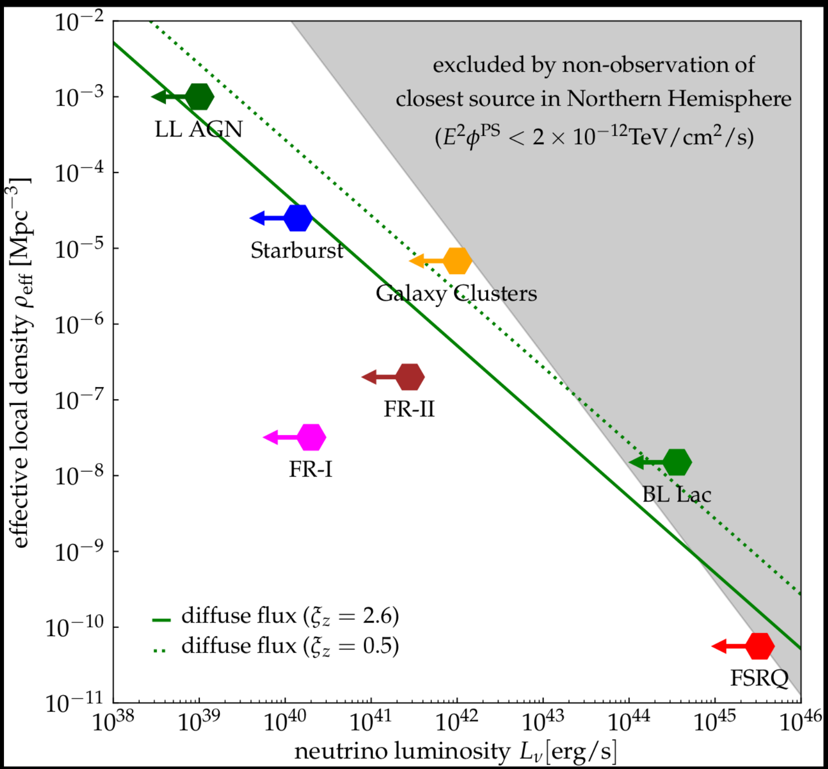
Astrophysical Neutrinos



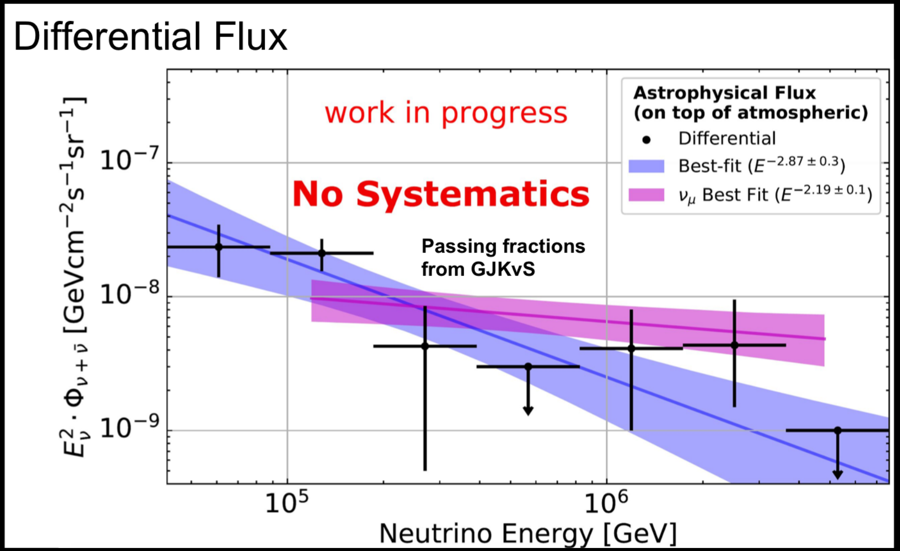
DESY: science communication lab

Diffuse Astrophysical Neutrinos

- IceCube HESE and ν_μ
- $E^{-2.2}$ vs $E^{-2.9}$?
- Two components?

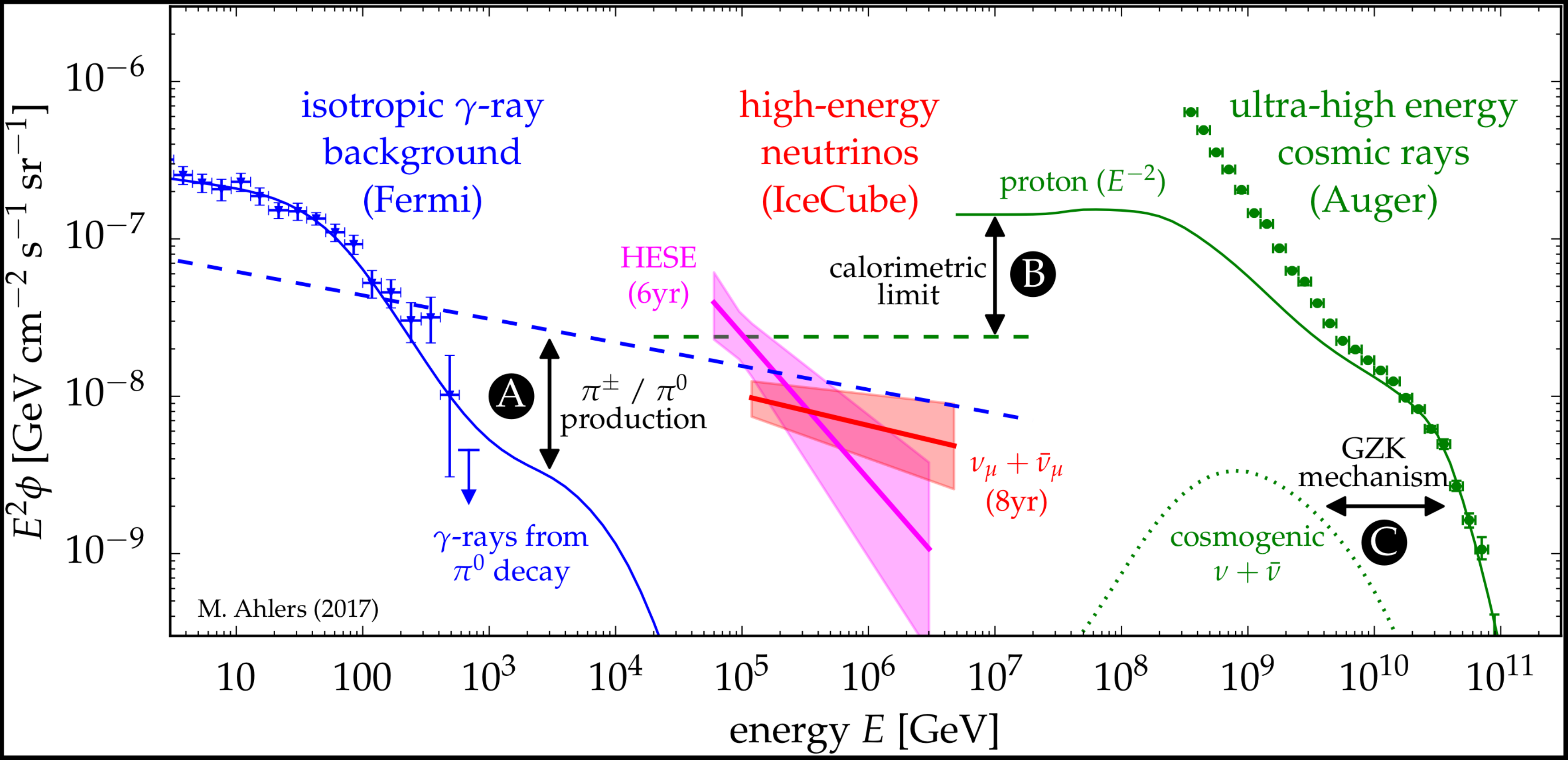


Schneider TeVPA2018



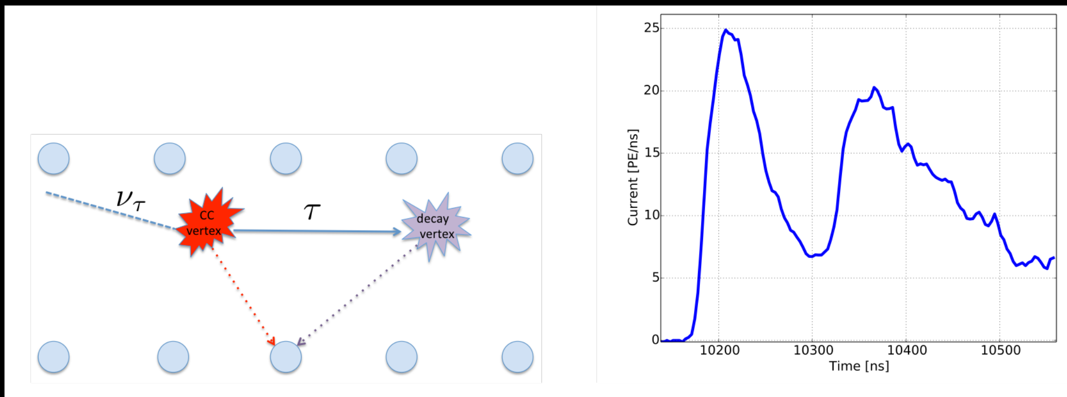
- Source cannot be rare and bright
- Or maybe hidden?

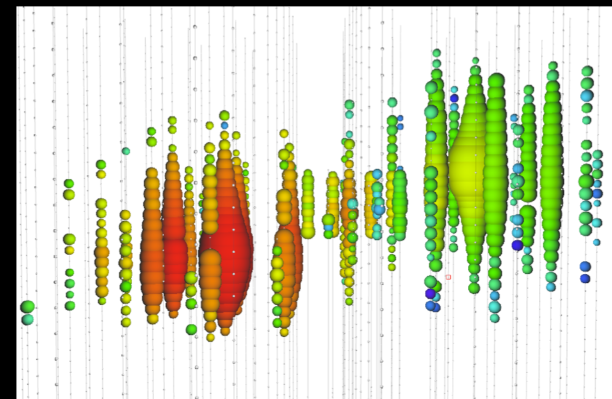
Multi-messenger Connection



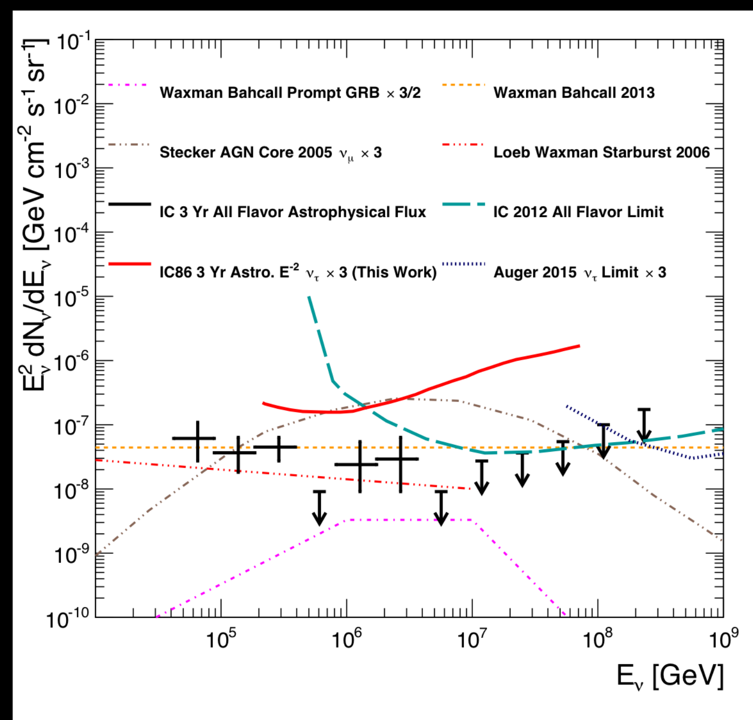
Ahlers, Halzen 2018

Where are the Taus?





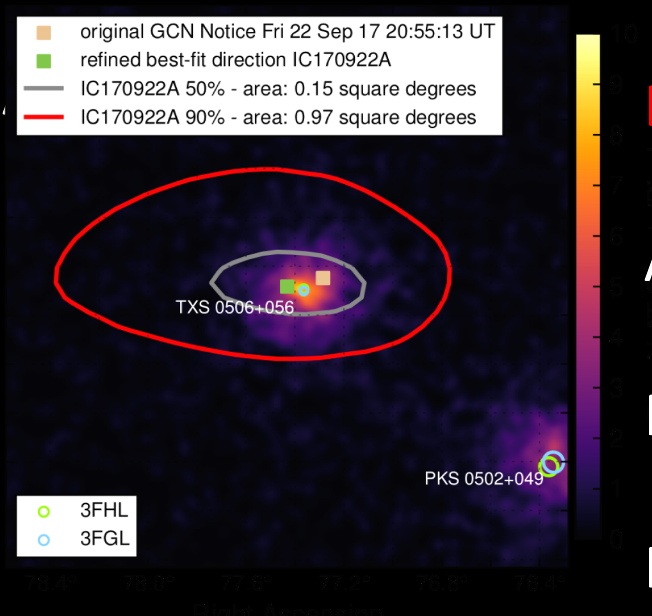
- Double Bang
- Double Pulse



IceCube 2015
3 years

Point source astrophysical Neutrinos

- Era of multimessenger astronomy with TXS events

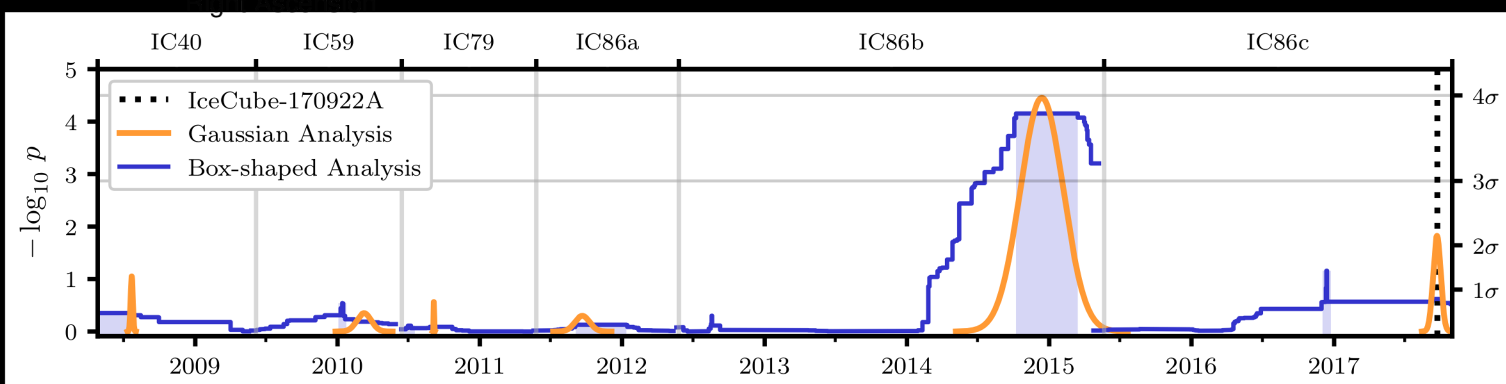


Blazar as a hadronic accelerator!

Association ~3 sigma

Neutrino flare ~3.5 sigma

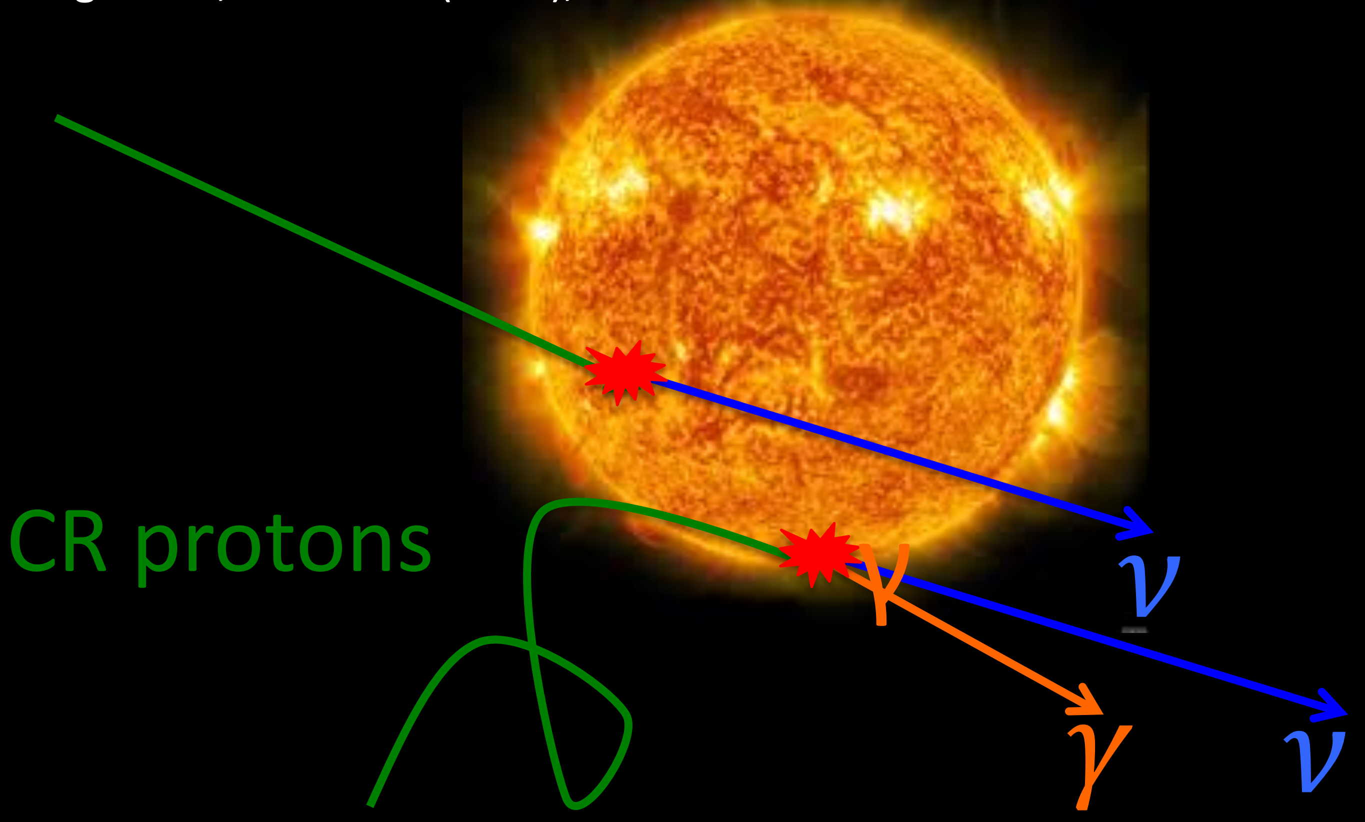
Need more of these!

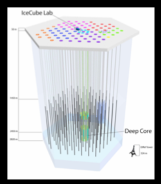


Sun – Cosmic-ray beam dump

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

Low density atmosphere
-> long interaction length
-> more decays
-> Higher flux, higher energy





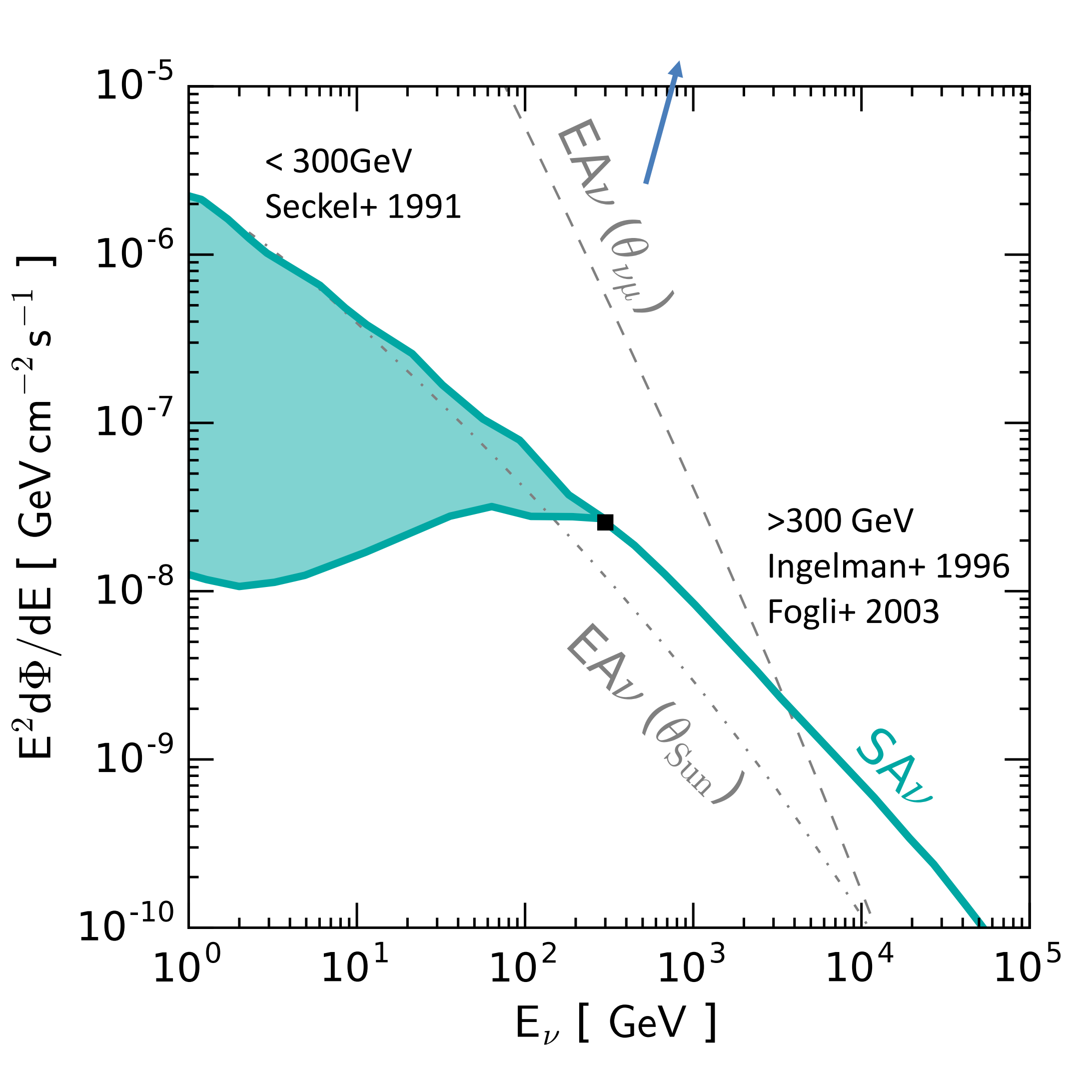
Neutrino Flux

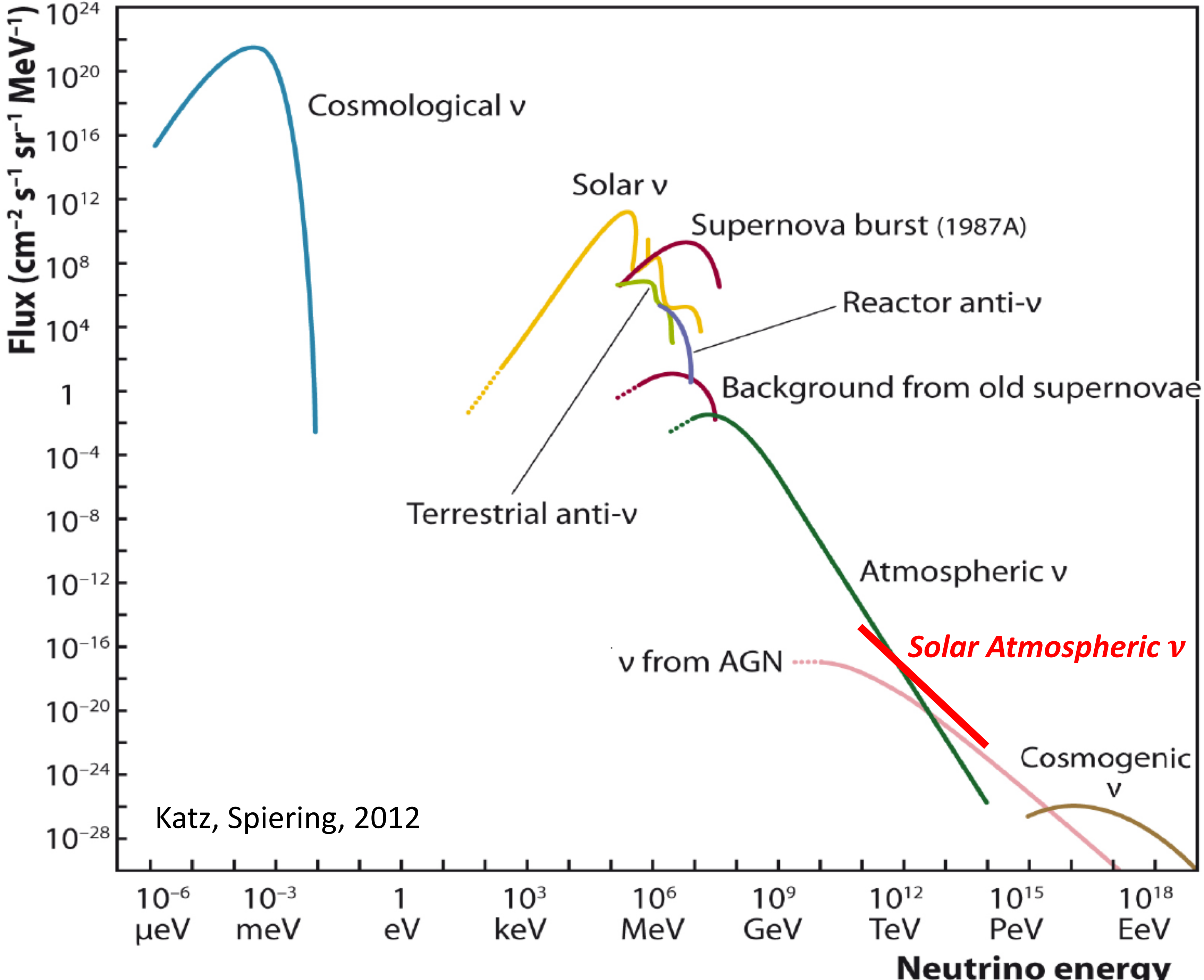
- Showers: $\nu_{e,\tau} CC, \nu_X NC$
- Tracks: $\nu_\mu CC$

- $\nu_\mu CC$ for directionality
  - kinematic angle

- Above ~3 TeV, greater than Earth ATM background

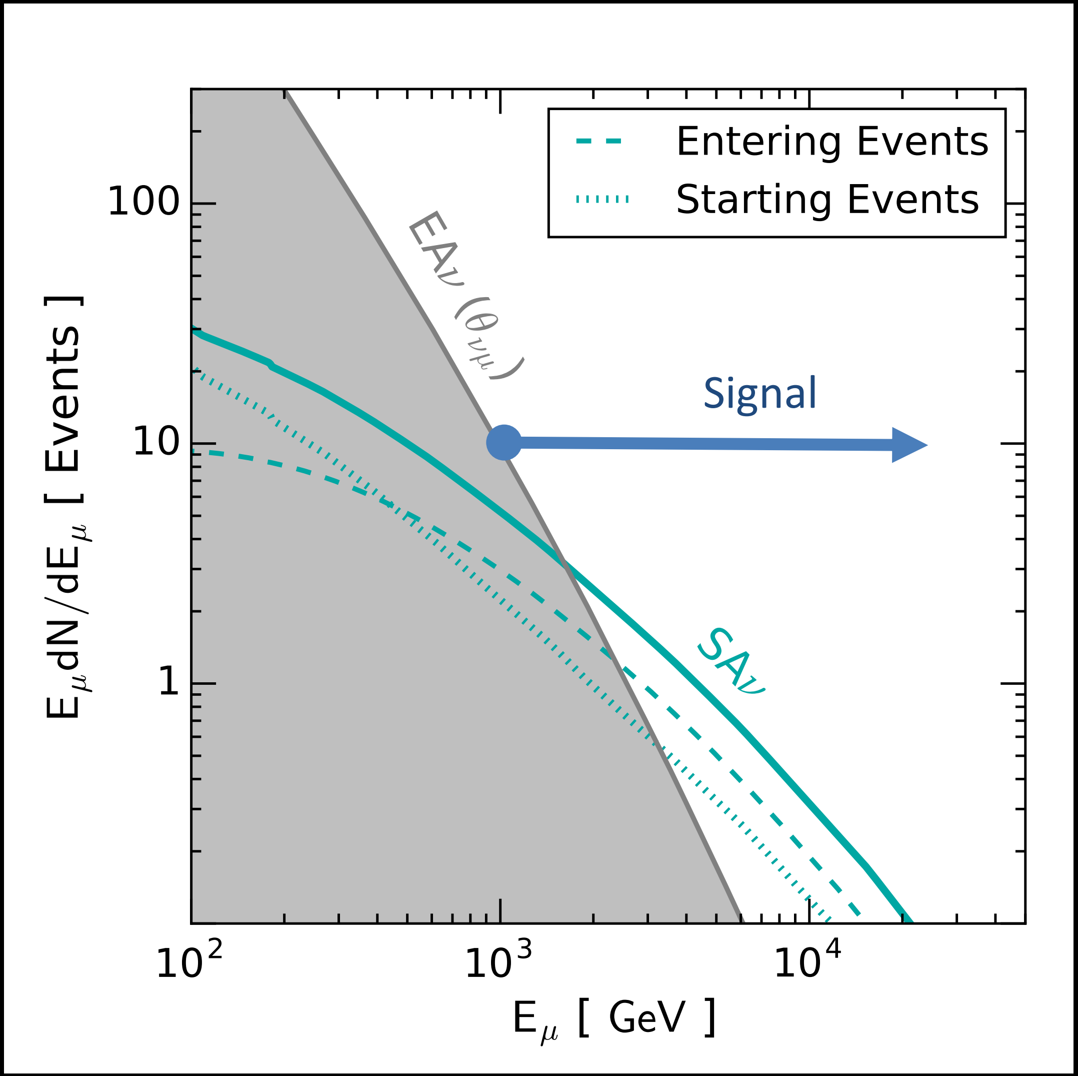
- Unclear how solar magnetic fields change the prediction



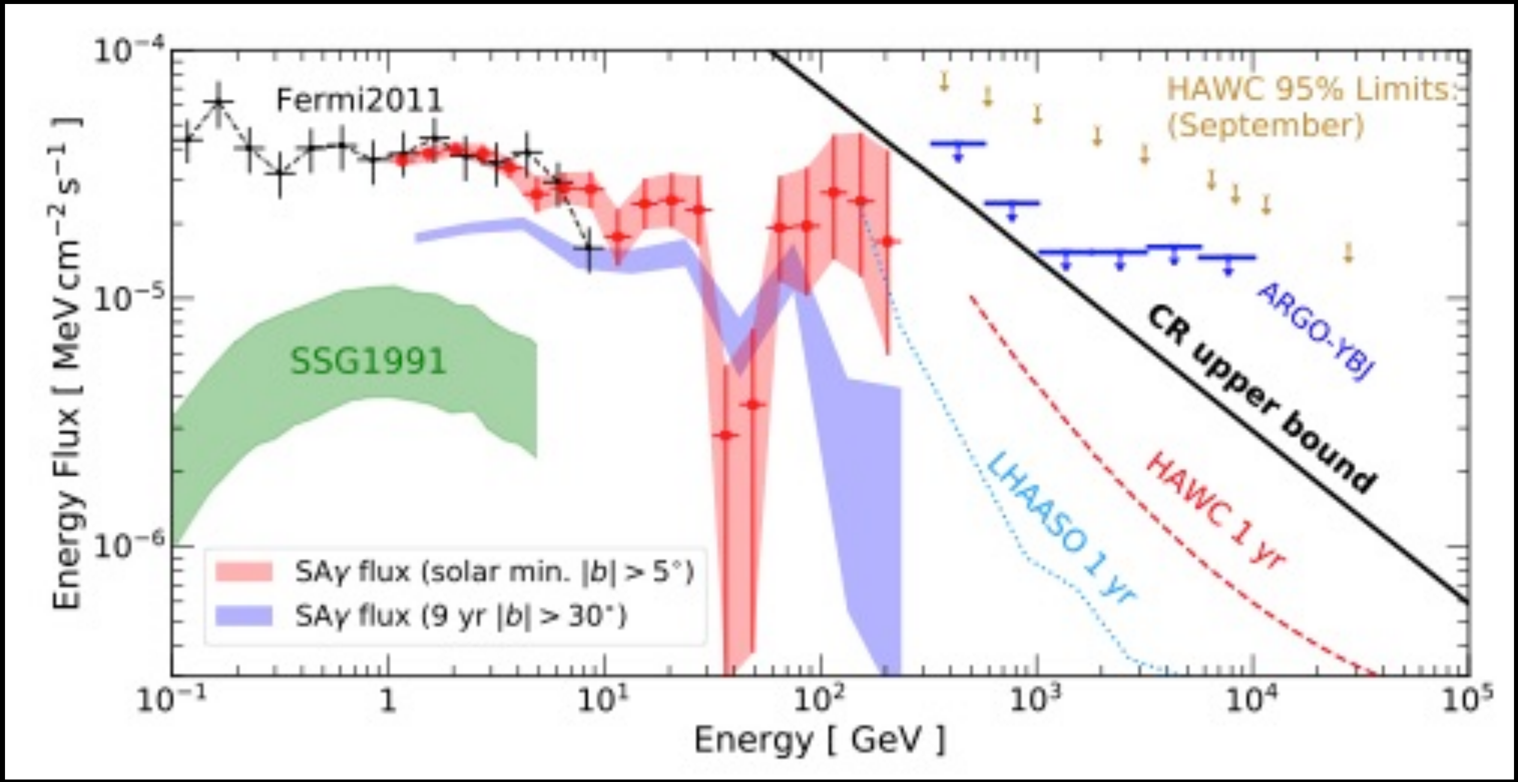

Flux (cm⁻² s⁻¹ sr⁻¹ MeV⁻¹)
10^24
10^20
10^16
10^12
10^8
10^4
1
10^−4
10^−8
10^−12
10^−16
10^−20
10^−24
10^−28
Cosmological ν
Solar ν
Supernova burst (1987A)
Reactor anti-ν
Background from old supernovae
Terrestrial anti-ν
Atmospheric ν
Solar Atmospheric ν
ν from AGN
Cosmogenic ν
Katz, Spiering, 2012
10^−6 µeV
10^−3 meV
1 eV
10^3 keV
10^6 MeV
10^9 GeV
10^12 TeV
10^15 PeV
10^18 EeV
Neutrino energy

SAν as a Signal

- Muon (>1TeV)
  - Energy resolution via energy loss
- ~ 5 signal events in 10 years (4 bkg)
- ~~1st~~ Another high-energy neutrino source?
- Common source for IceCube + KM3NeT



Solar Atmospheric gamma rays



Neutrinos could help understand the gamma rays

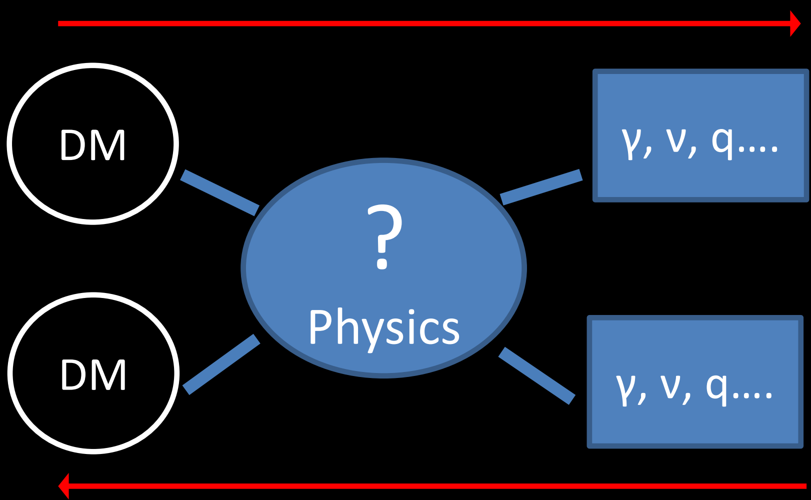
Tang et al 2018

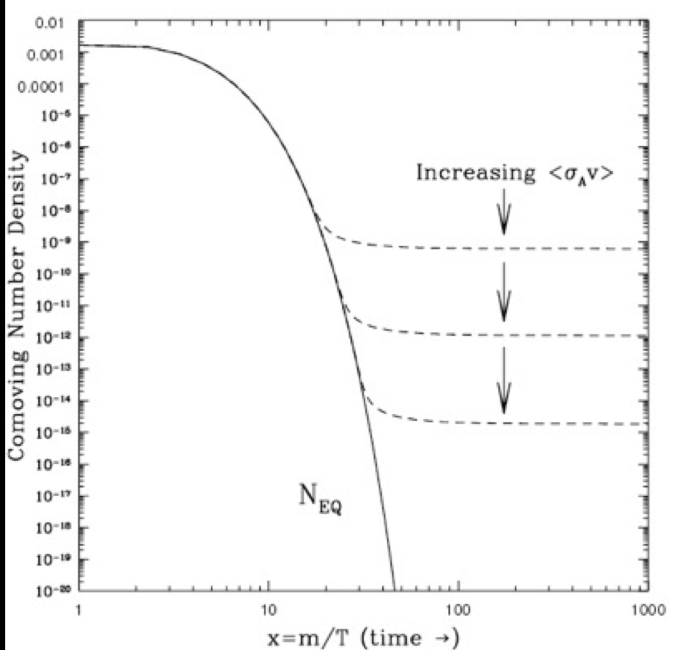
- Time variation
- Hard spectrum
- Large flux

Dark Matter and New physics

Dark Matter

- Weakly Interacting Massive Particles (WIMPs)



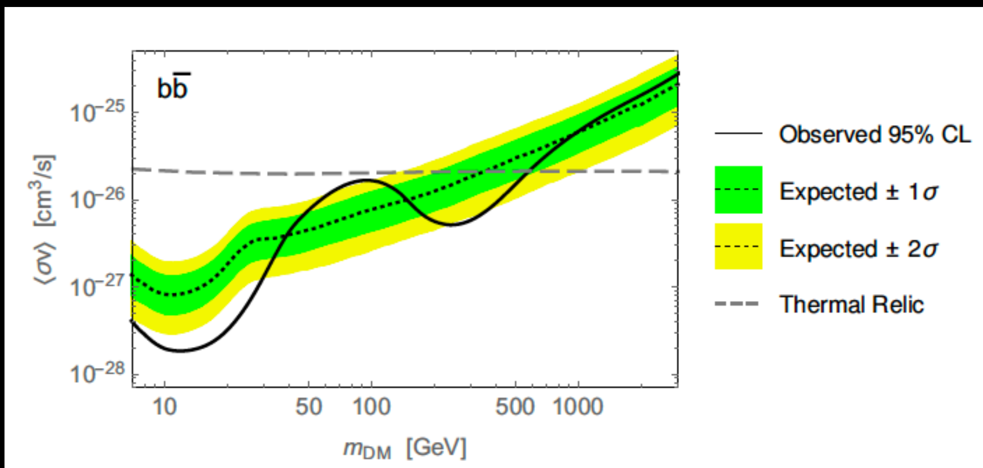


Jungman *et al* hep-ph/9506380

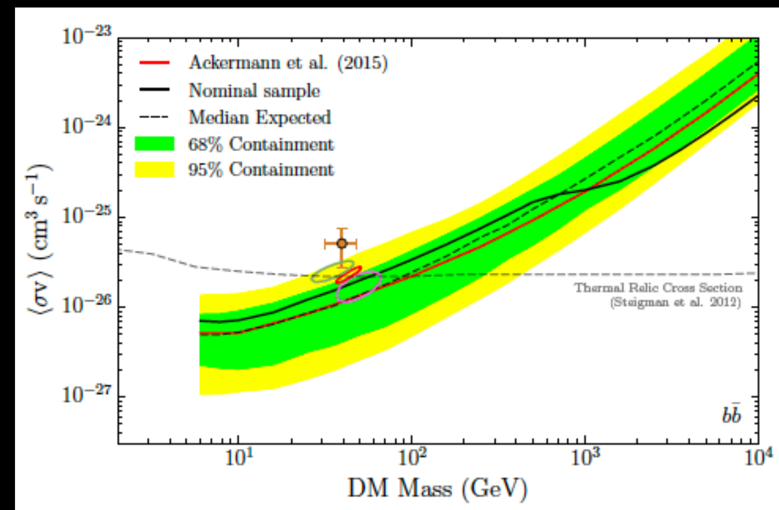
- Abundance <-> ***Total*** Cross section!
- $\frac{\Omega_{DM}\, h^2}{0.1} \approx \frac{3\times10^{-26}\mathrm{cm}^3\mathrm{s}^{-1}}{<\sigma v>}$

Dark Matter Annihilation

Antiproton, Reinert & Winkler 2018



Gamma rays, Fermi collab. 2017



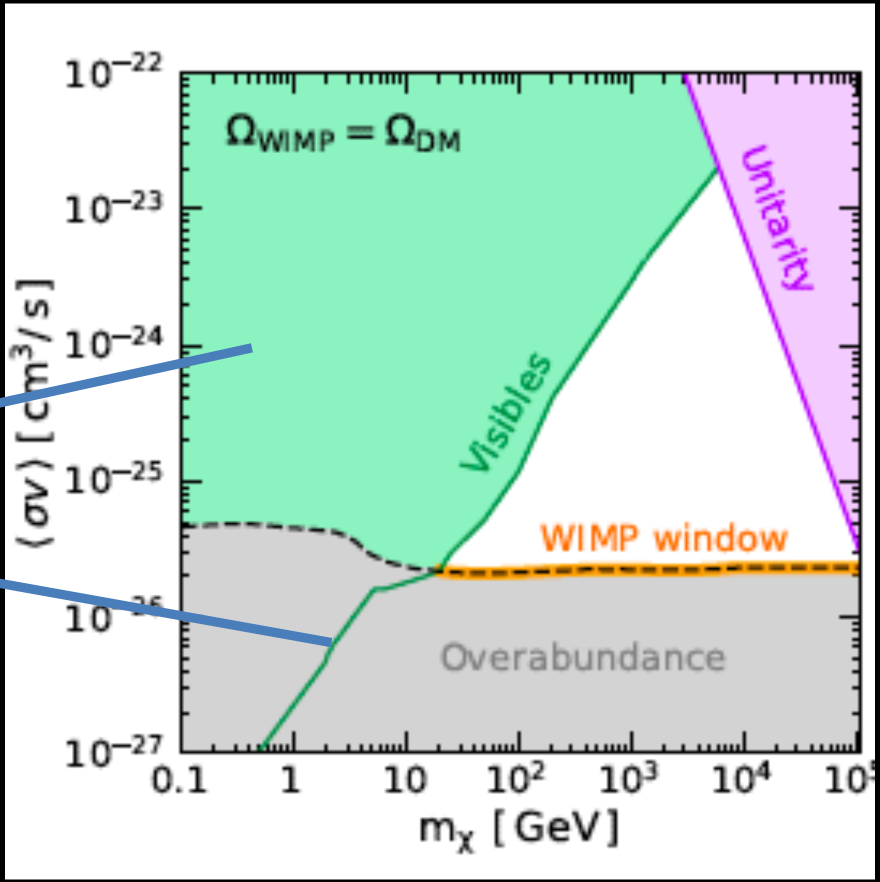
- Specific channels or models

The simplest WIMP hypothesis

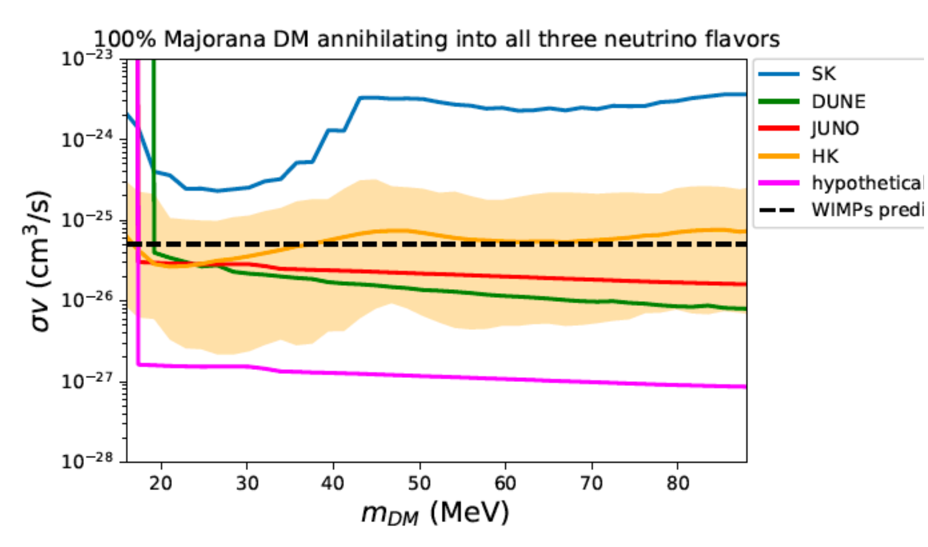
- Total cross section constraint
  - Arbitrary, mixed channel (mixed spectrum)
  - Fermi dwarf, AMS positron, Planck CMB
- New physics for large xsec
- Sub DM thermal relics

- All visible channels except Neutrinos!

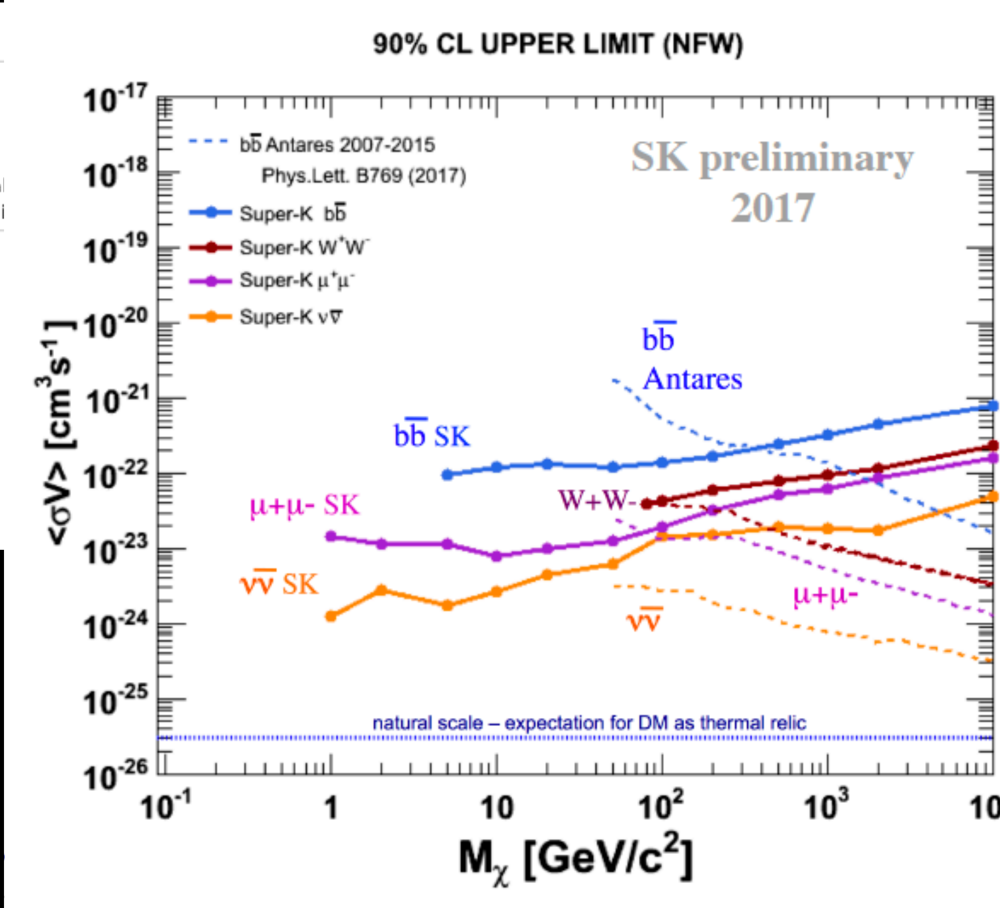
Leane, Slatyer, Beacom, KCYN, 2018



Neutrino Channel



Klop Ando 1809.00671
Also see
Olivares-Del Campo, Palomares-Ruiz, Pascoli 1805.09830

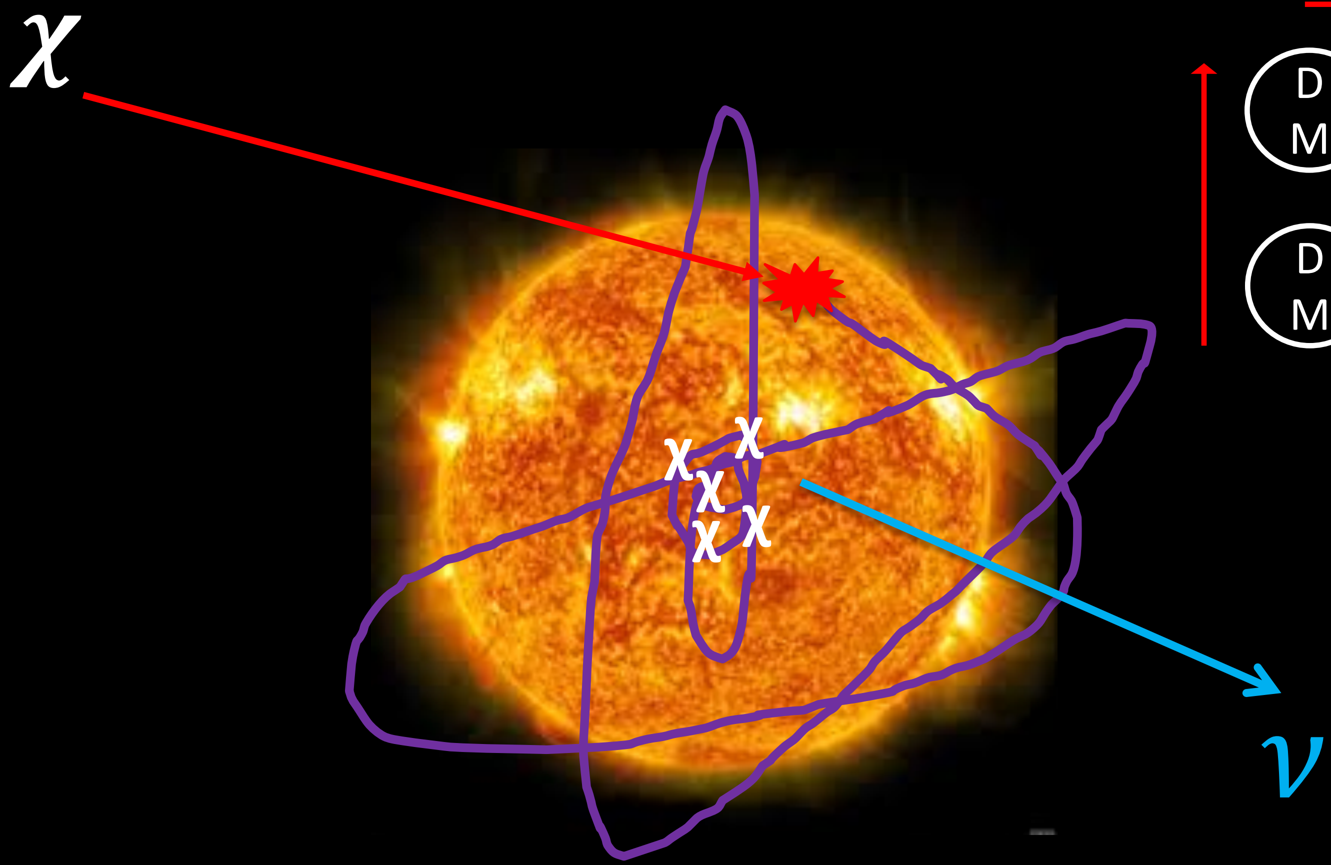


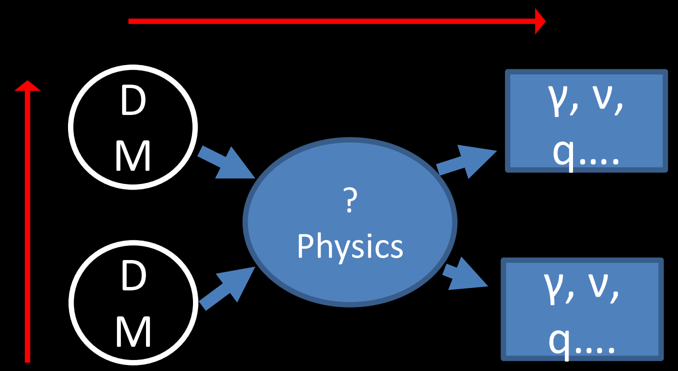
Mijakowski TAUP 2017

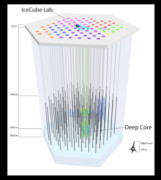
- Reaching thermal?
  - A significant milestone for testing WIMPs

Dark Matter

- Weakly Interacting Massive Particles

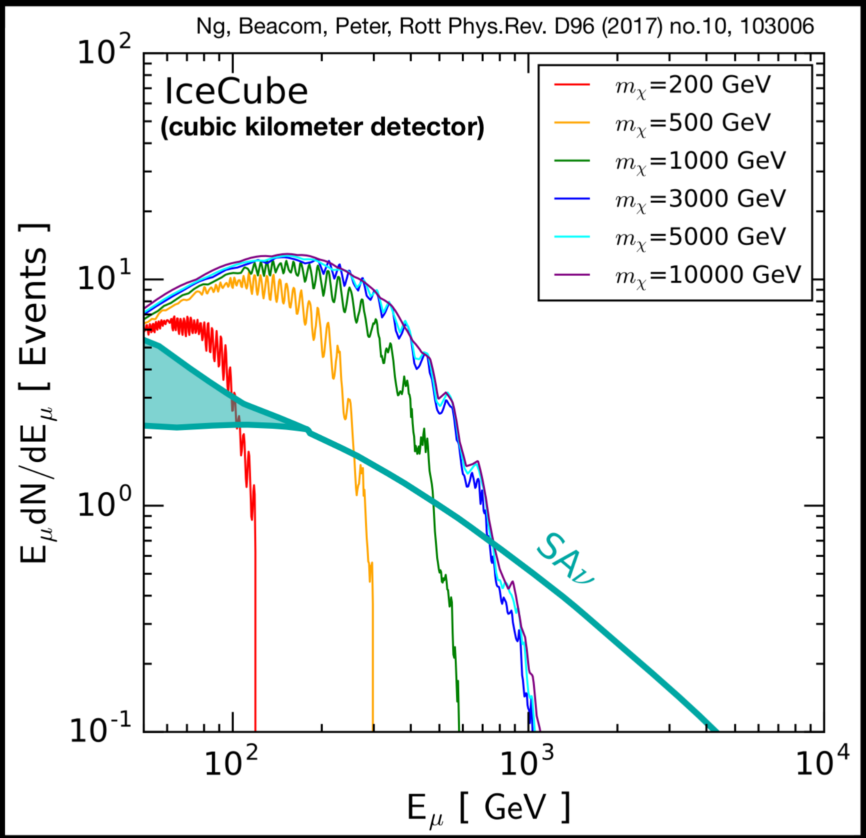


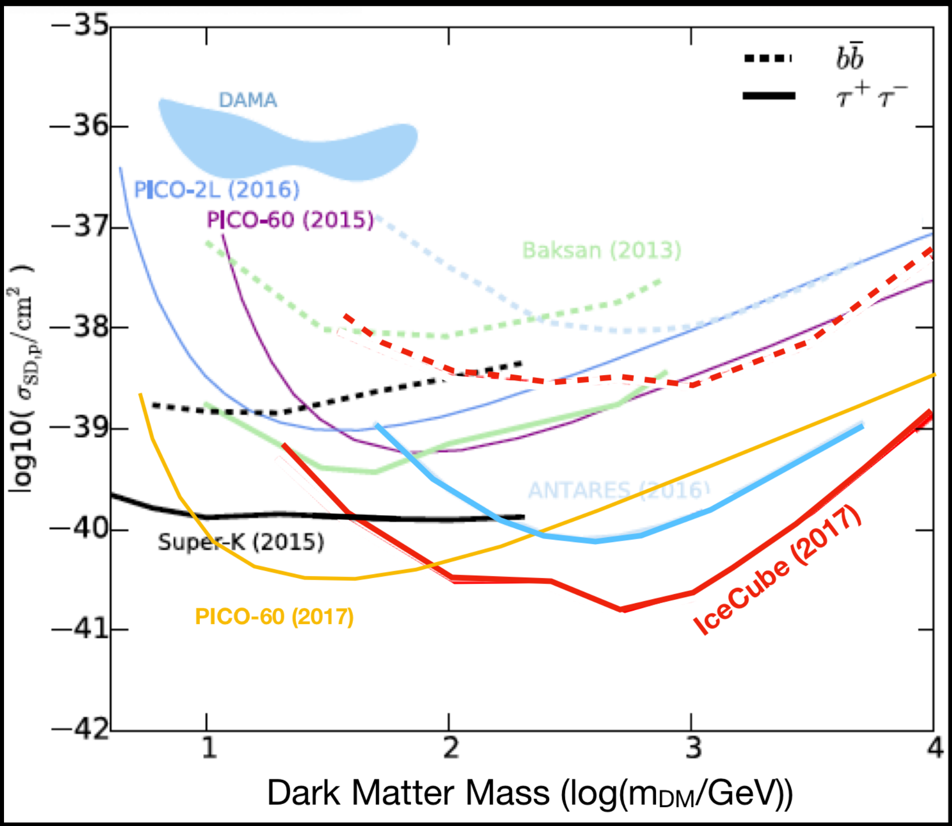




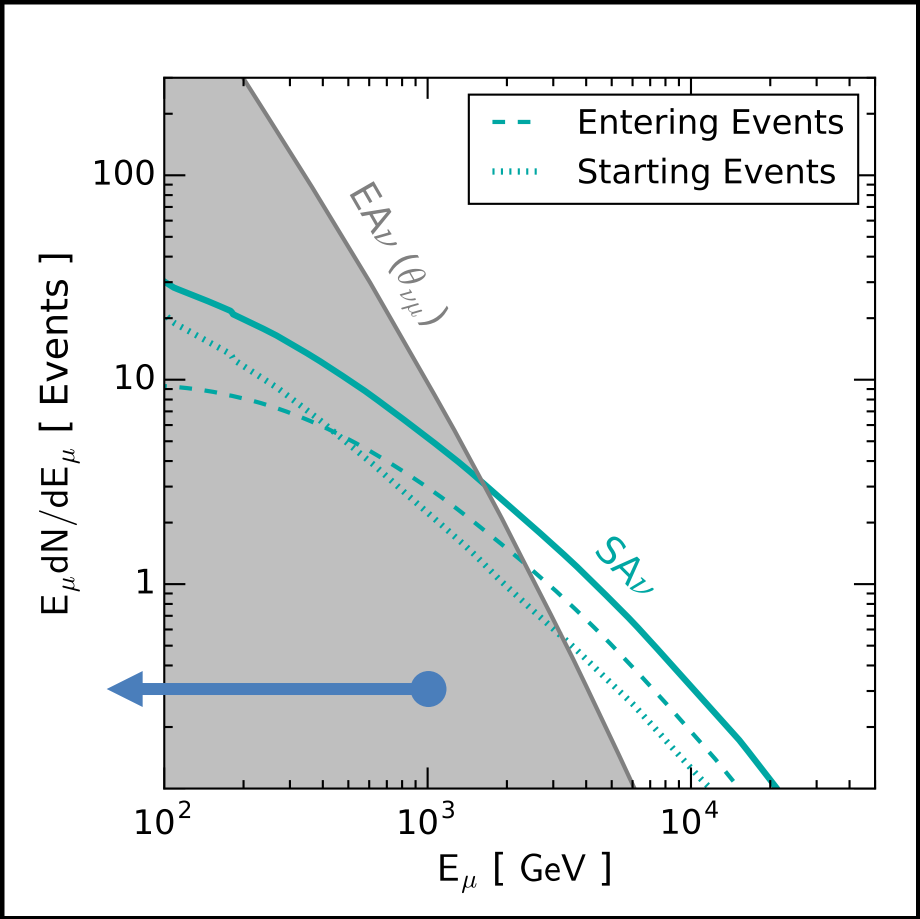
Dark Matter Search from the Sun

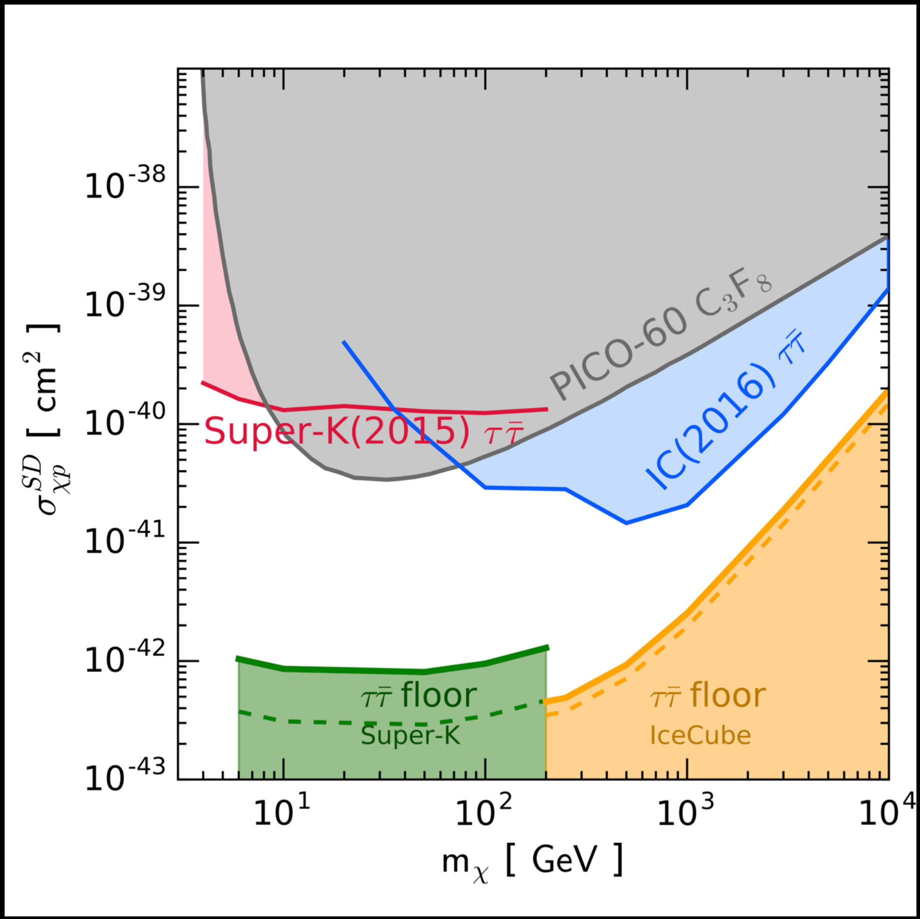
Rott, NOW 2018





Solar ATM neutrino – indirect detection Neutrino Floor





No B-field effect are considered

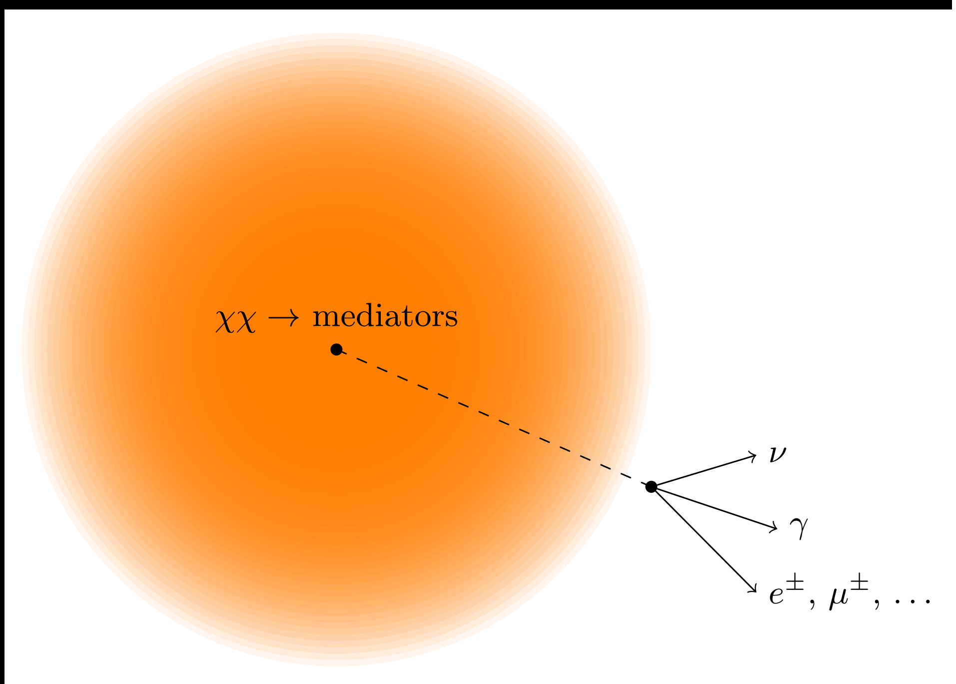
IceCube Search ongoing [S. In & C. Rott ICRC17 (965)]

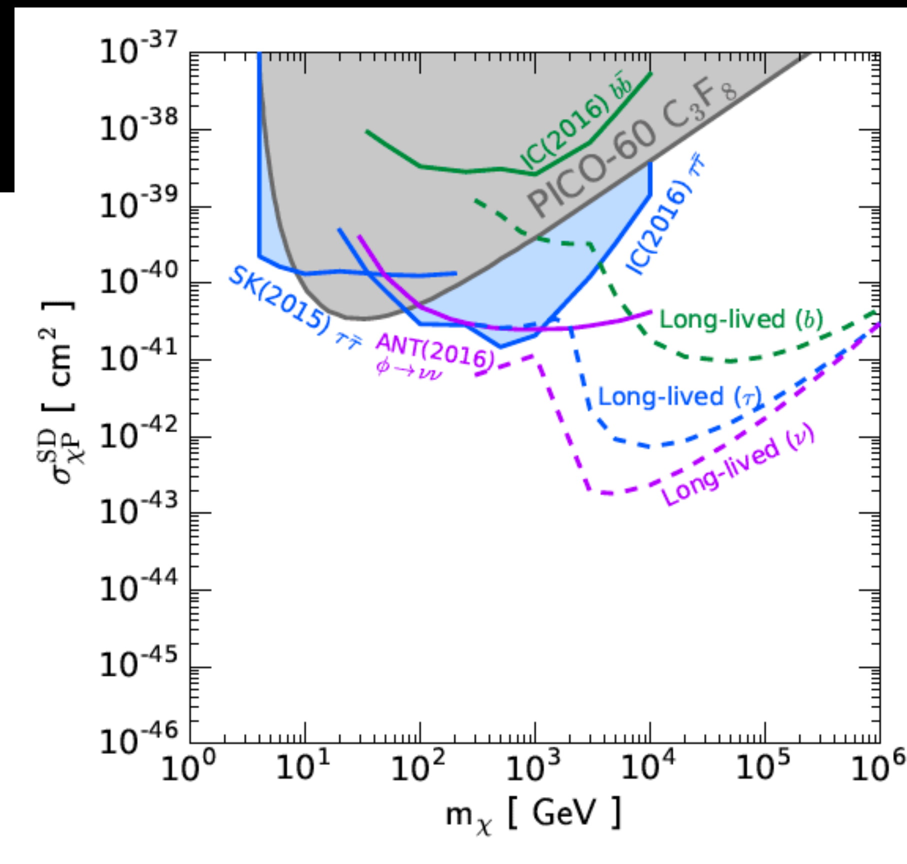
KCYN, Beacom, Peter, Rott, 1703.10280
See also
Arguelles+ 1703.07798
Edsjo+ 1704.02892

Dark Matter with long-lived mediators

Leane, KCYN, Beacom 1703.04629

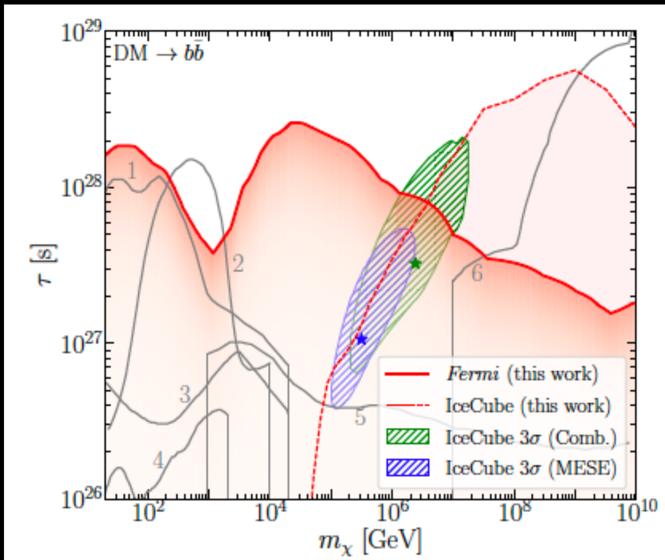
- No neutrino absorption
- + EM signatures!



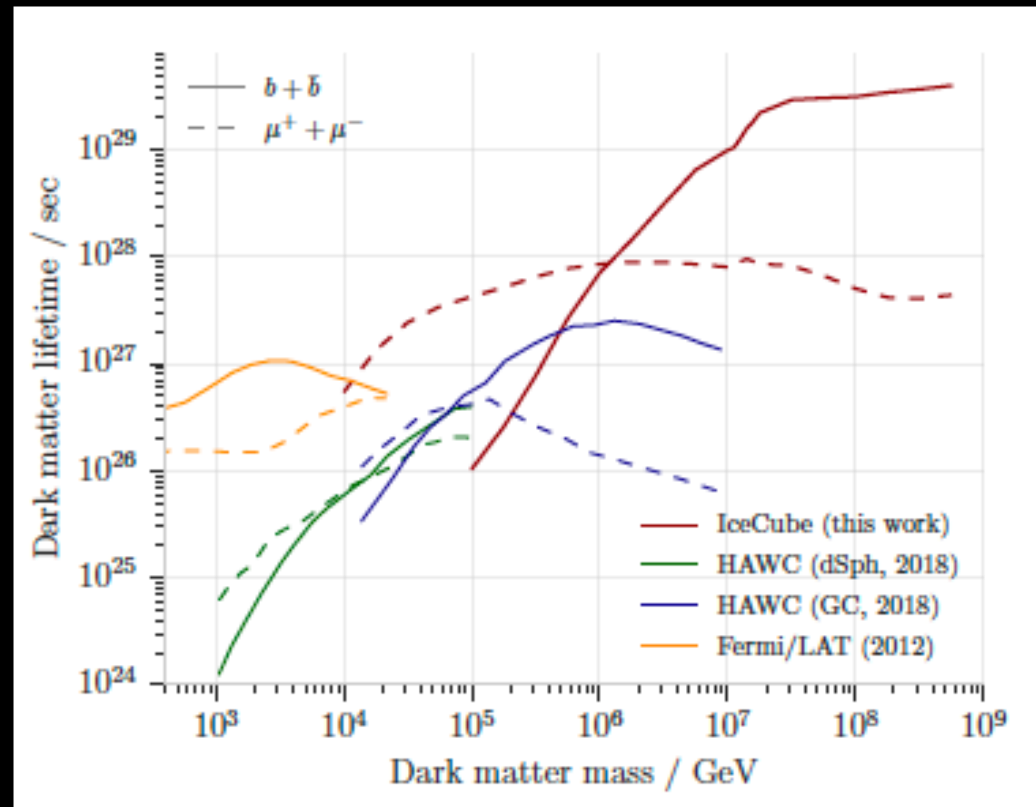


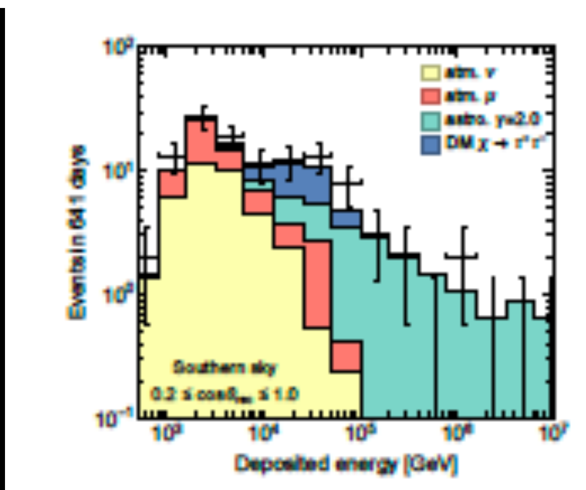
Dark Matter Decay

Cohen, Murase, Rodd, Safdi, Soreq 2017



IceCube Collab, 2018



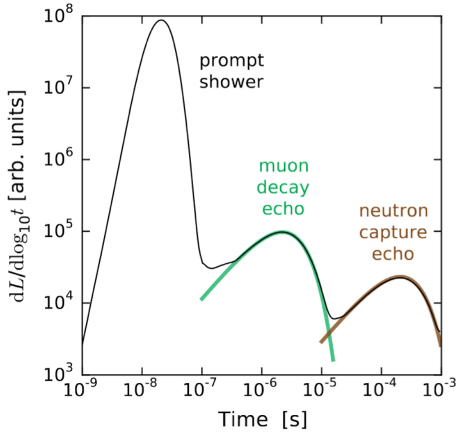


Chianese, Miele, Morisi 2017

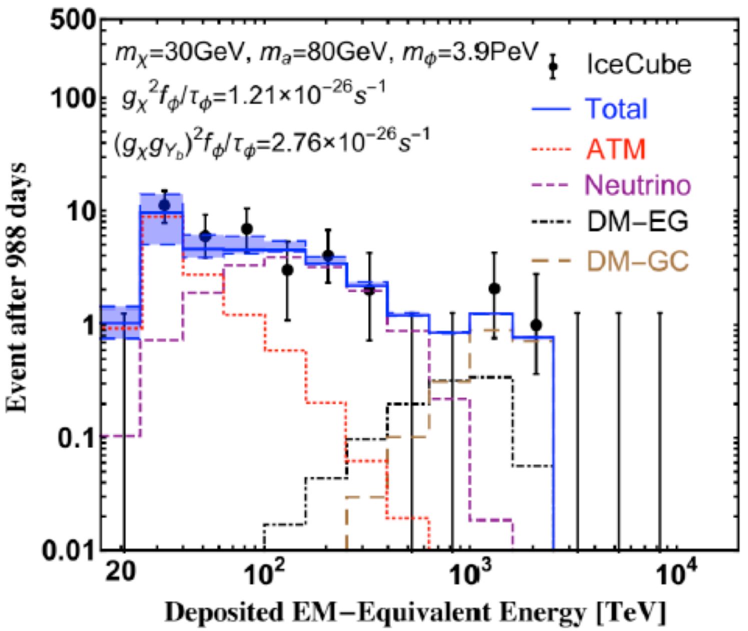
IceCube Boosted Dark Matter

Following search proposed by Kopp, Liu, Wan (2015)

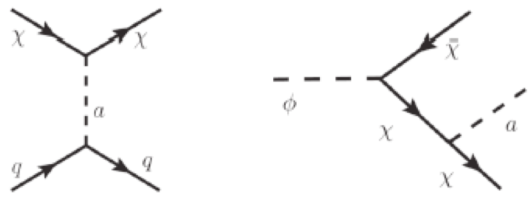
using "Echo Technique" Li, Bustamante, Beacom (2016)



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



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



Recoil (only hadronic cascades)

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

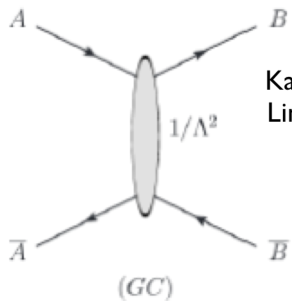
"Echo Technique" holds prospects to individually tag high-energy NC and CC interactions !

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

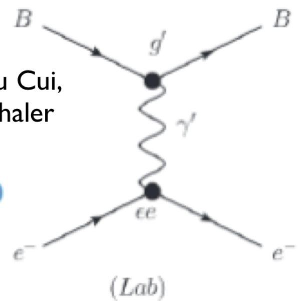
see also A. Steuer, L. Koepke [IceCube] PoS(ICRC2017)1008

C. Kachulis et al [Super-K] Phys.Rev.Lett. 120 (2018) no.22, 221301 [arXiv:1711.05278]

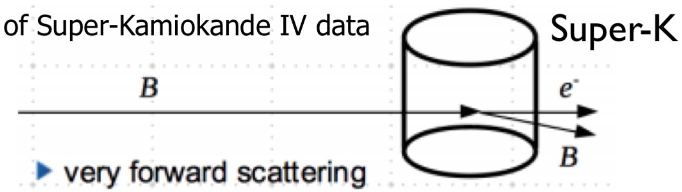
Super-K Boosted Dark Matter



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

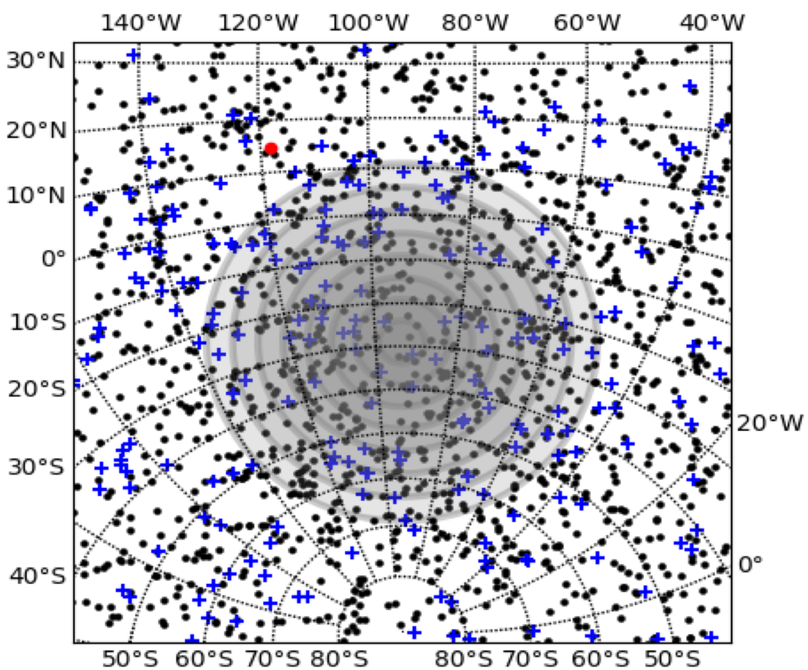


161.9 kiloton-years of Super-Kamiokande IV data



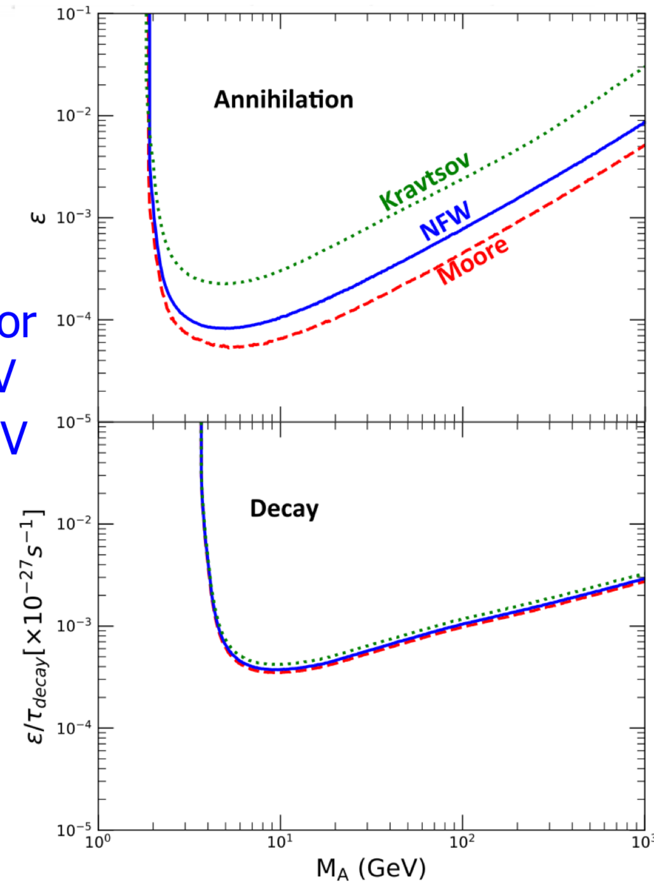
- very forward scattering
- electromagnetic shower
- no hadrons → no decay e, no neutrons

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



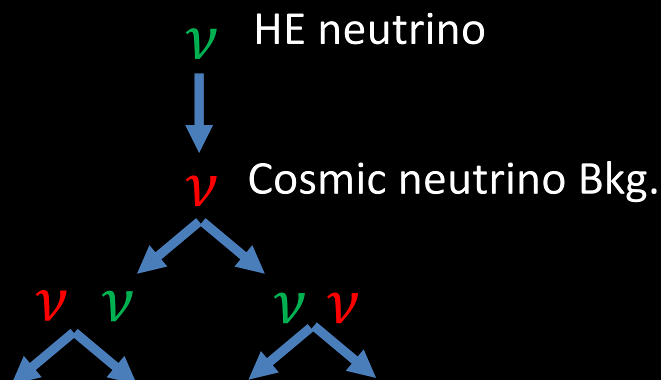
• < 1.33 GeV + 1.33 GeV-20 GeV • >20 GeV

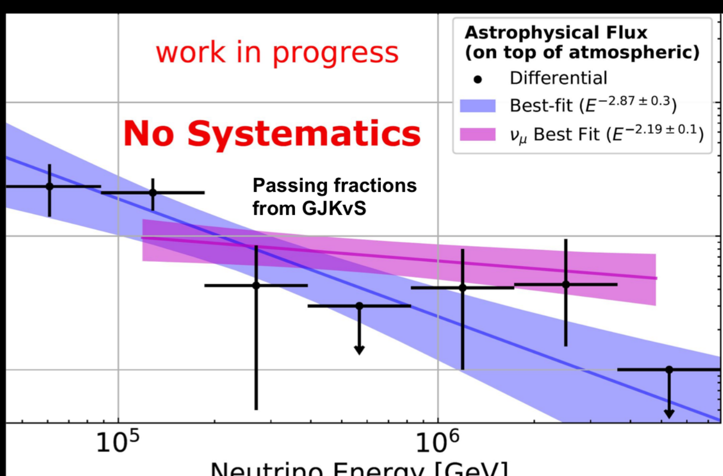
90% limits for
$m_{\gamma'}$=20 MeV
m_B=200 MeV
g'=0.5

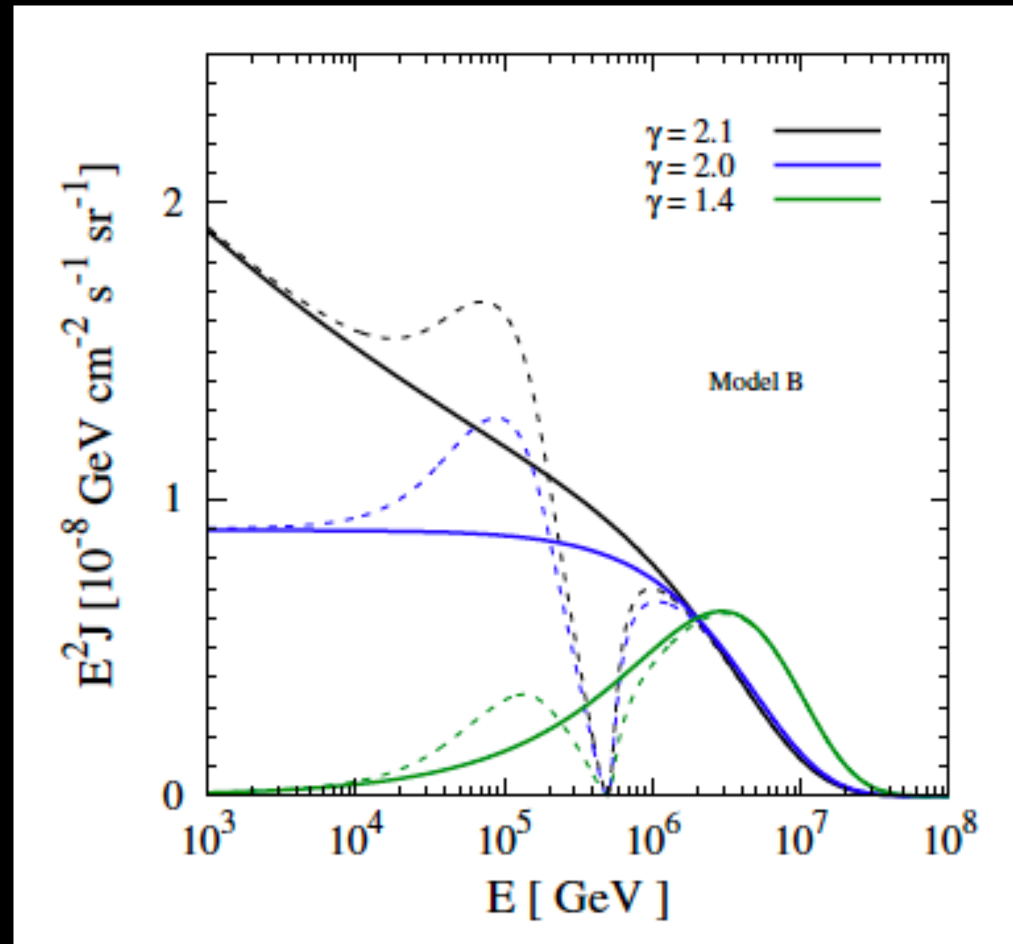


Cosmic neutrino cascades

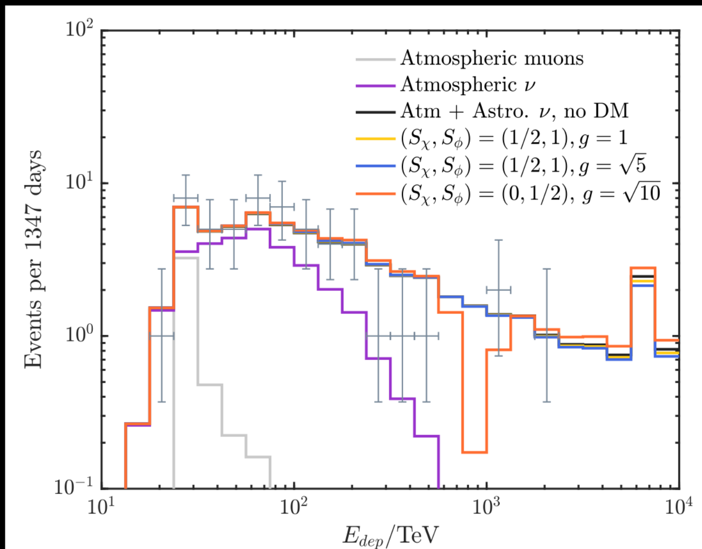
- Secret neutrino interactions

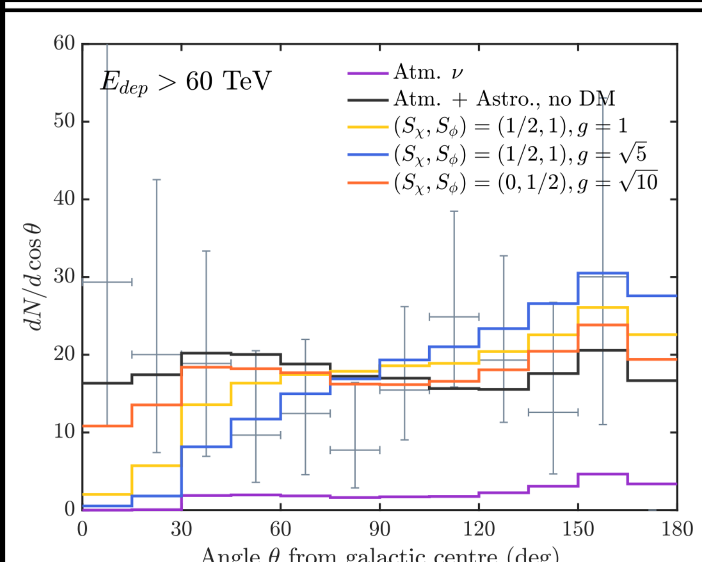


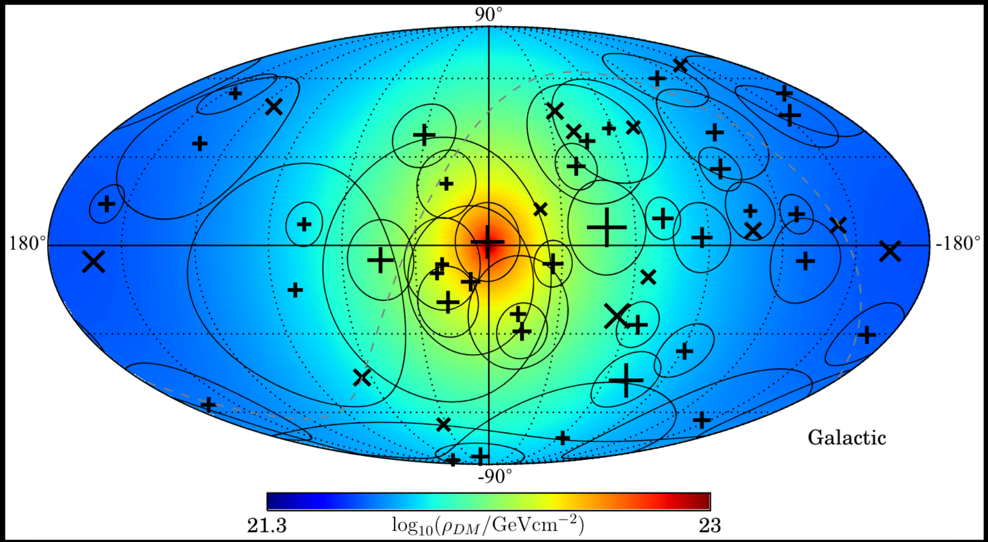




Neutrino Dark Matter Interaction

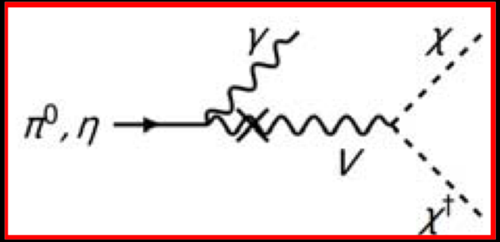


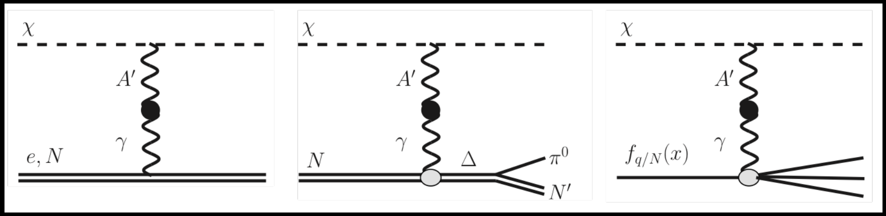


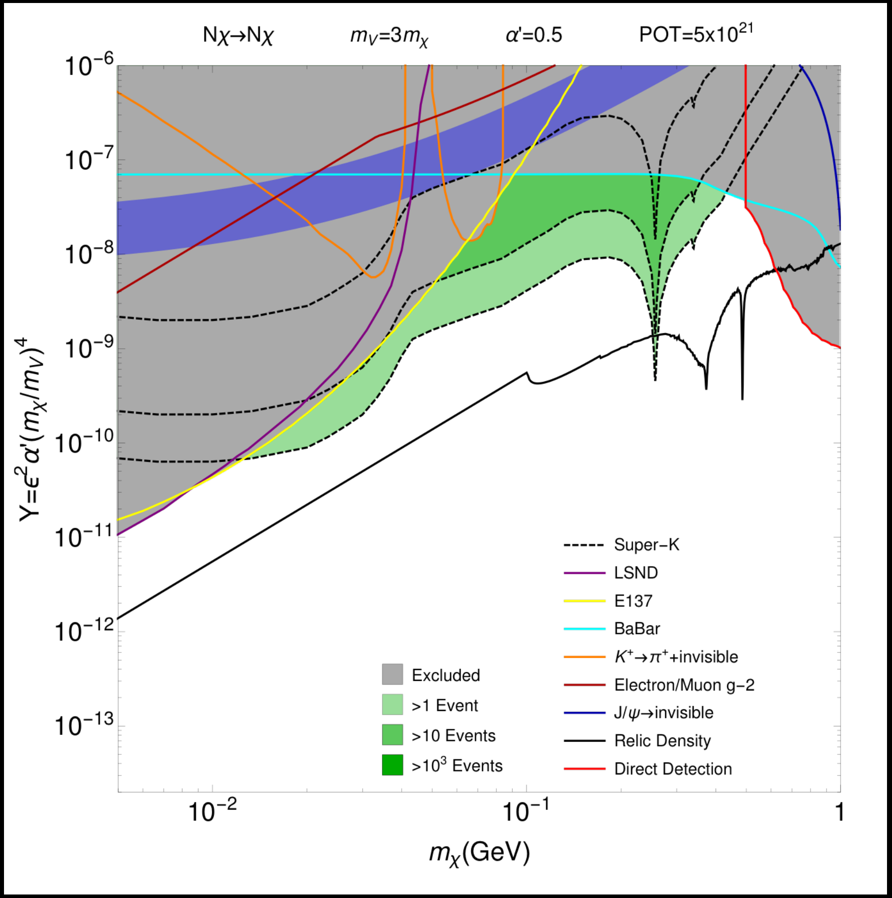


Argu¨elles, Kheirandish , Vincent, 2017

Dark Matter Beam (T2K)







deNiverville et al, 2017

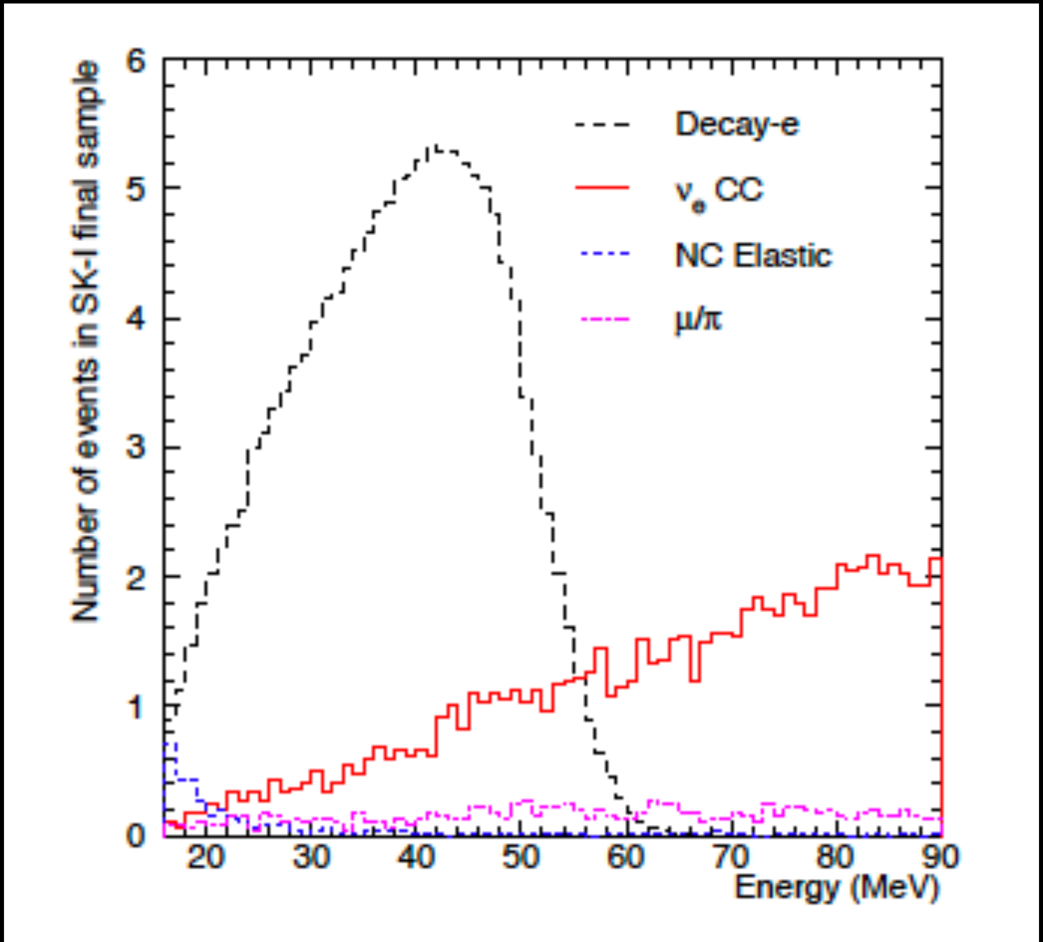
Summary

- Rich astroparticle phyiscs, many can only be done with water Cherenkov detectors

- Exciting times ahead for new detectors and maybe new techniques

Thanks!

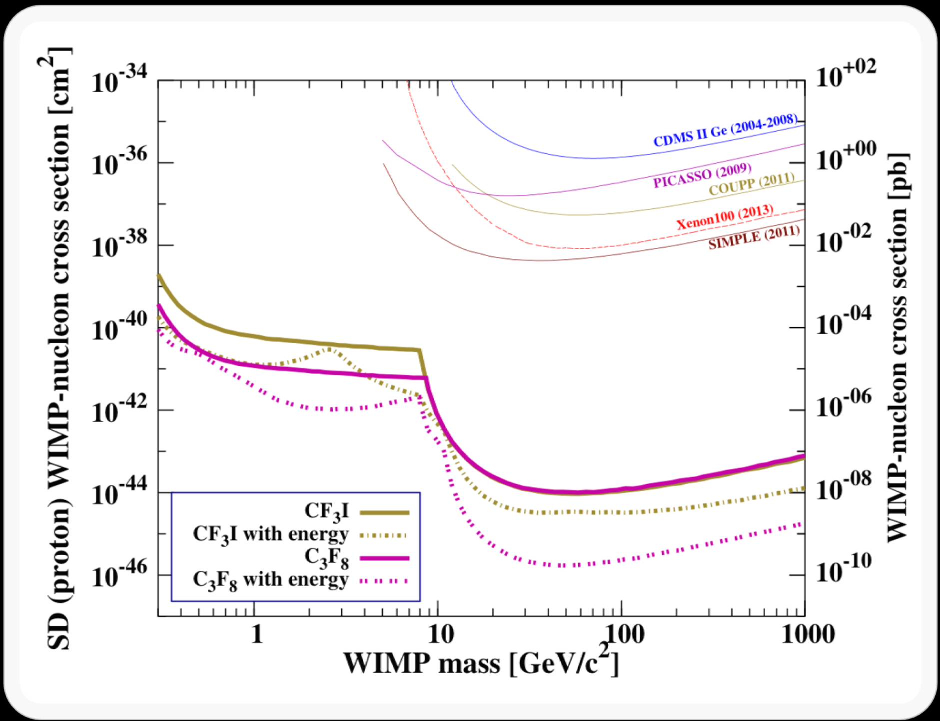
Backup slides



Decay-e
ν_e CC
NC Elastic
μ/π
Number of events in SK-I final sample
Energy (MeV)
0
1
2
3
4
5
6
20
30
40
50
60
70
80
90

Solar Atmospheric Neutrino Floor

- Large direct detection experiments are needed to reach 10^{-44} cm^2



Solar, diffuse supernova, atmospheric neutrinos
Ruppin et al. 2014