ASTROPARTICLE PHYSICS 2014
A joint TeVPA/IDM conference

ICECUBE

1398

IceCube Dark Matter Searches Overview

Carsten Rott

rott@skku.edu

for the IceCube Collaboration

Sungkyunkwan University, Korea

Astroparticle Physics 2014
23-28 June 2014
Amsterdam

The IceCube Collaboration

International Funding Agencies

- Fonds de la Recherche Scientifique (FRS-FNRS)
- Fonds Wetenschappelijk Onderzoek-Vlaanderen (FWO-Vlaanderen)
- Federal Ministry of Education & Research (BMBF)
- German Research Foundation (DFG)
- Deutsches Elektronen-Synchrotron (DESY)
- Inoue Foundation for Science, Japan
- Knut and Alice Wallenberg Foundation
- Swedish Polar Research Secretariat
- The Swedish Research Council (VR)
- University of Wisconsin Alumni Research Foundation (WARF)
- US National Science Foundation (NSF)

Overview

This Talk

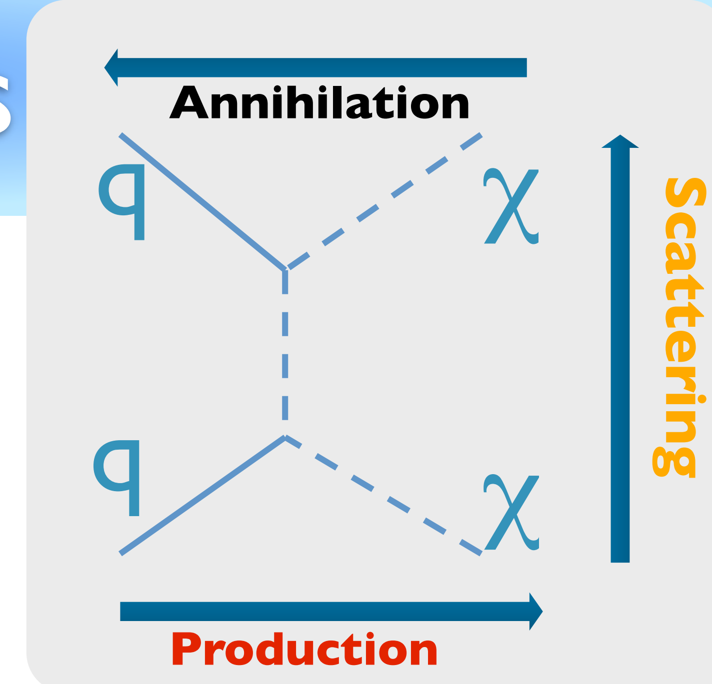
- Motivation
- Neutrino Signals from Dark Matter
- The IceCube Neutrino Telescope
- Overview of latest results
  - Dark Matter Self-annihilation cross section
  - WIMP Nucleon scattering cross section
- Future Prospects
- Conclusions

Following Talks

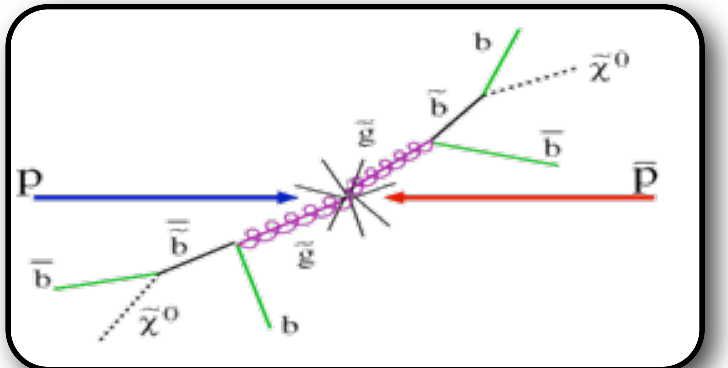
- Search for Dark Matter Annihilation in the Galactic Center with IceCube (*Martin Bissok*)
- Searching for annihilating dark matter in nearby galaxies and galaxy clusters with IceCube (*Meike deWith*)
- A search for Dark Matter in the centre of the Earth with the IceCube neutrino detector (*Jan Kunnen*)

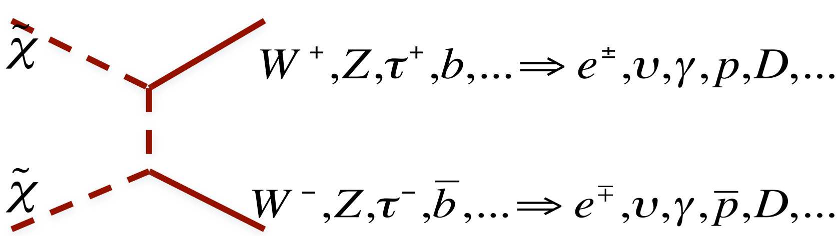
Motivation

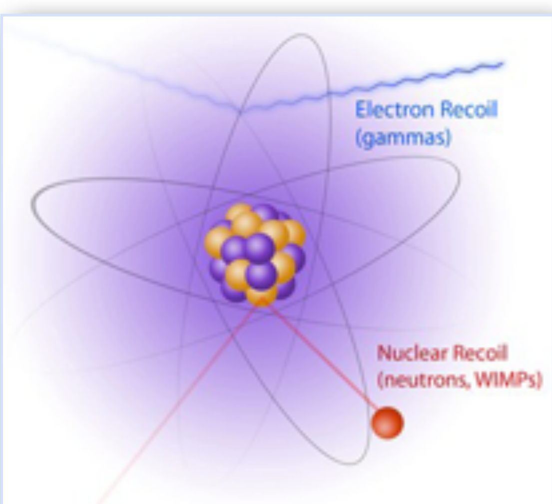
Role of Neutrinos



WIMP - Weakly Interacting Massive Particle







- **Production**
  - Colliders
- **Indirect Searches**
  - 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

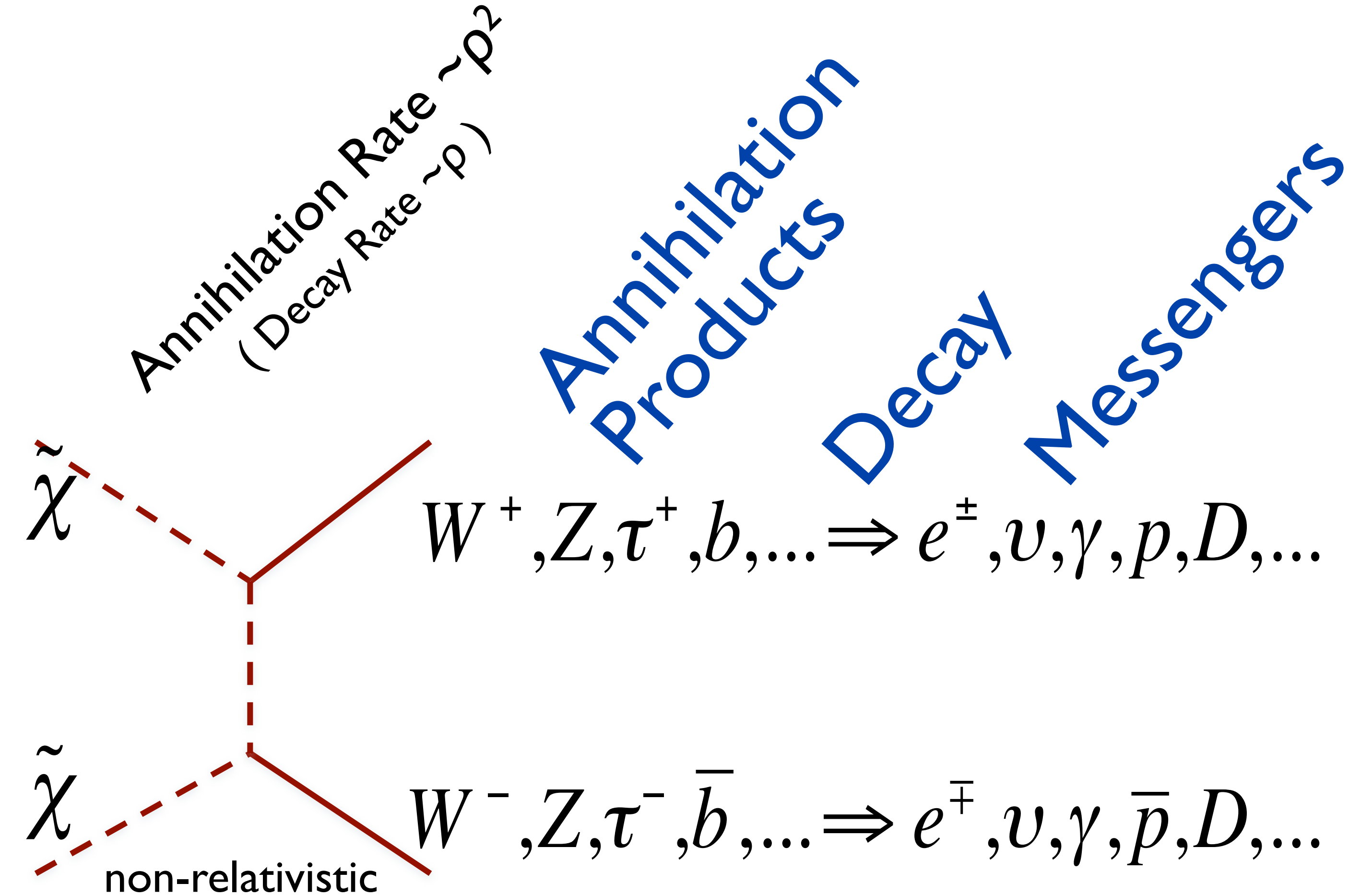
WIMP Self-annihilation cross section

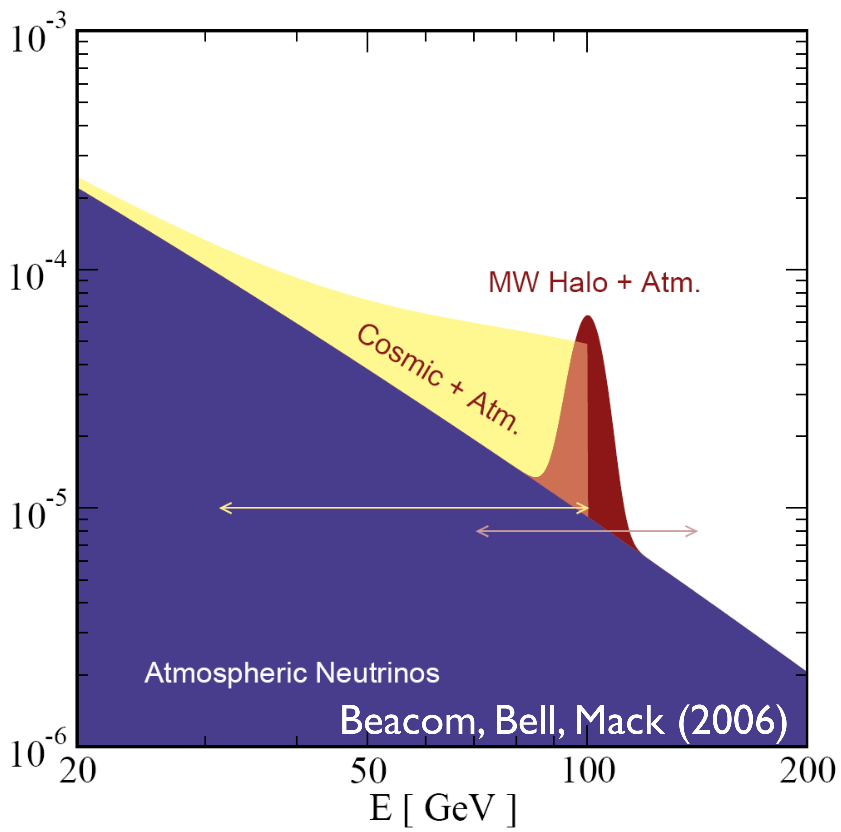
WIMP-Nucleon Scattering cross section

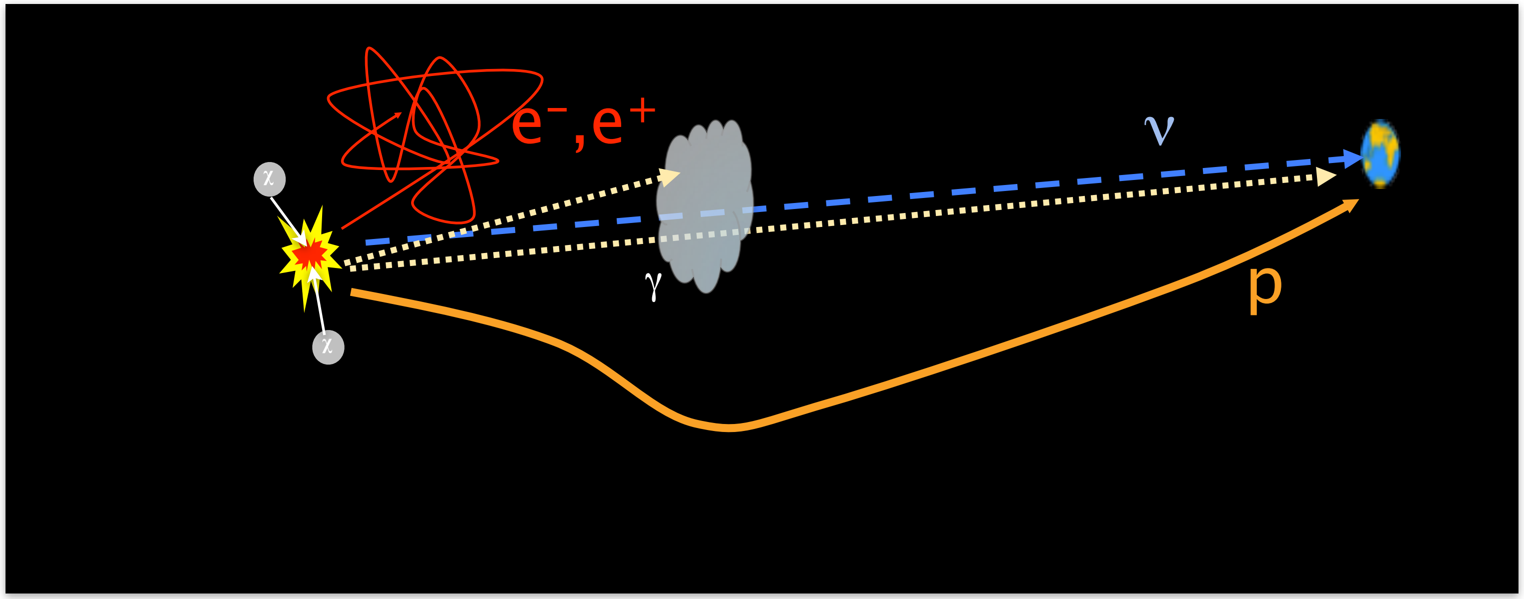
Dark Matter Annihilation Signals

- Identify overdense regions of 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







The IceCube Neutrino Telescope

Gigaton Neutrino Detector at the Geographic South Pole

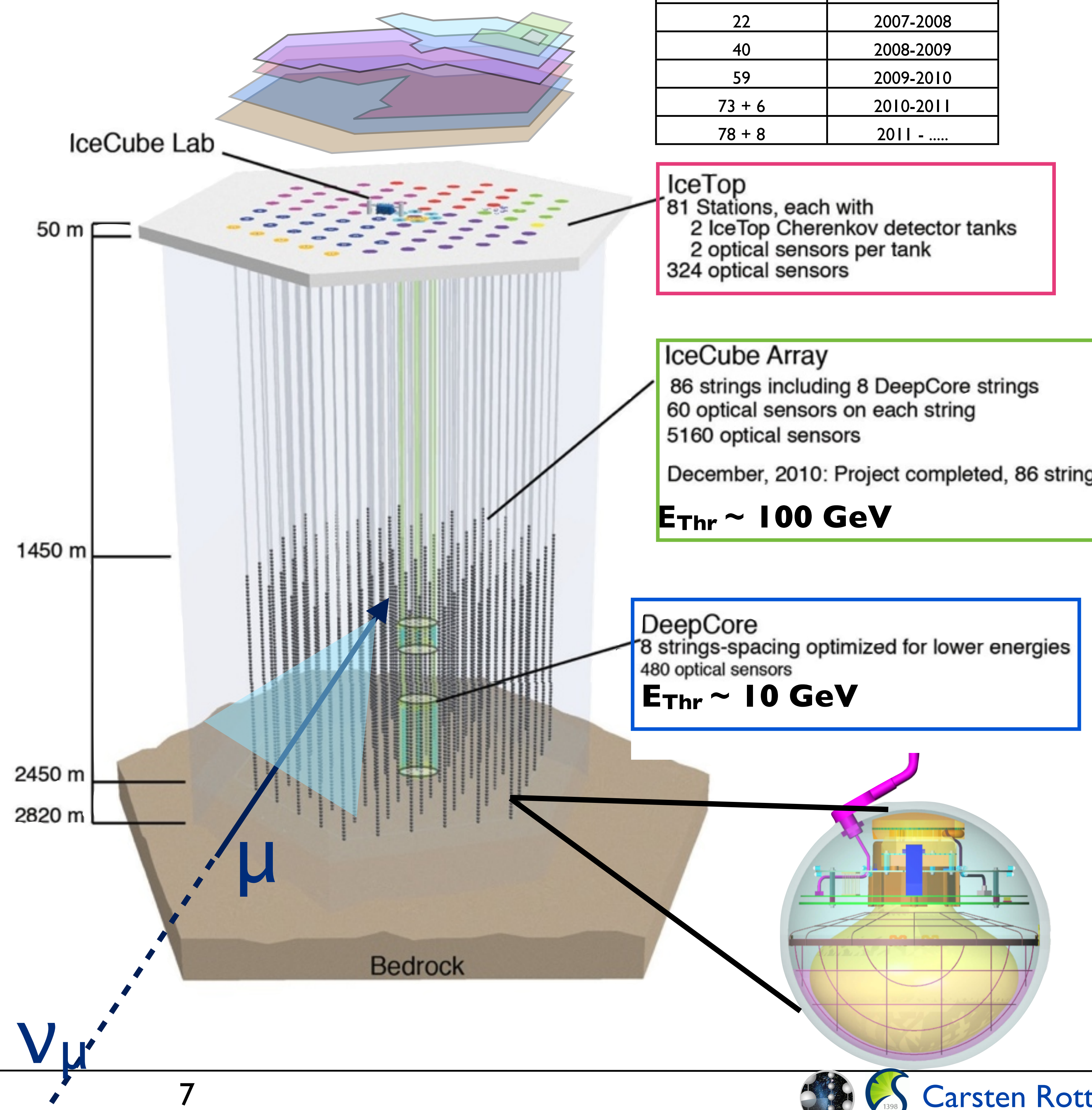
5160 Digital optical modules distributed over 86 strings

Completed in December 2010, start of data taking with full detector May 2011

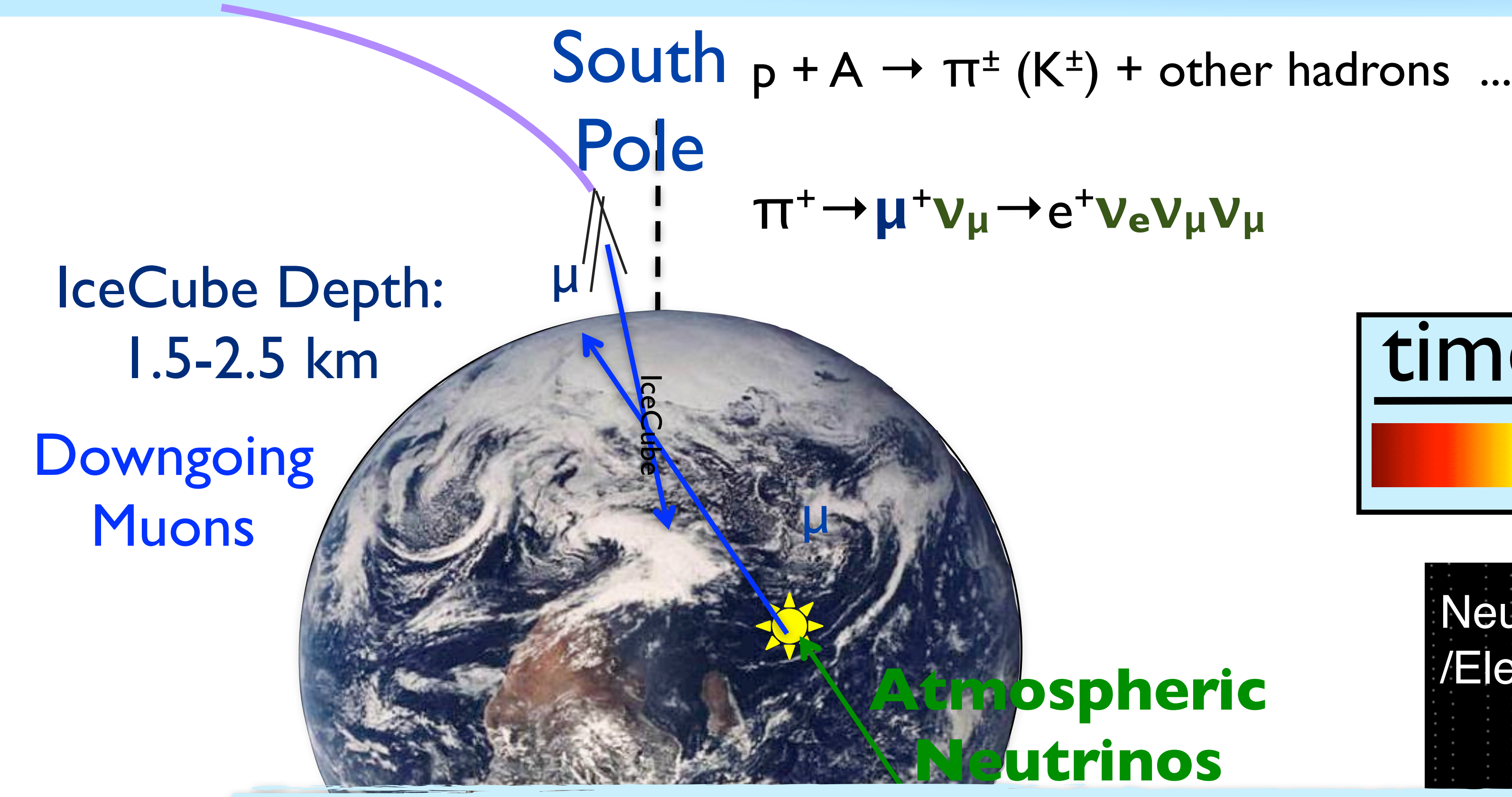
Data acquired during the construction phase has been analyzed

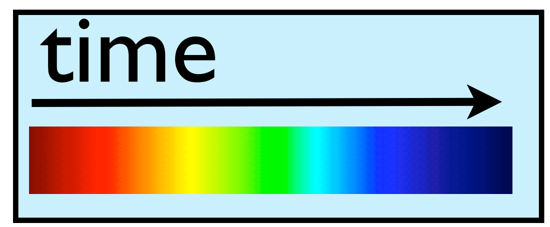
Neutrinos are identified through Cherenkov light emission from secondary particles produced in the neutrino interaction with the ice

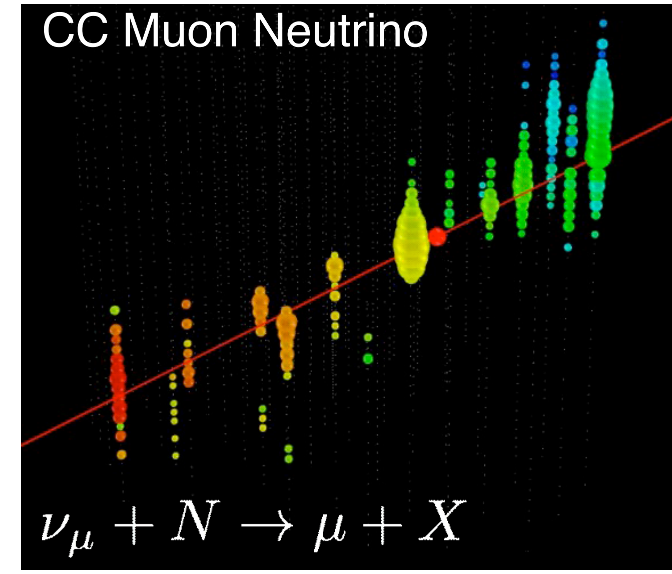
Strings	Dataset
1	2005-2006
9	2006-2007
22	2007-2008
40	2008-2009
59	2009-2010
73 + 6	2010-2011
78 + 8	2011 - .....

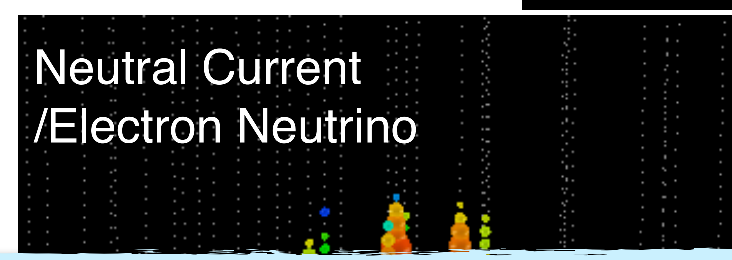


Signals in IceCube







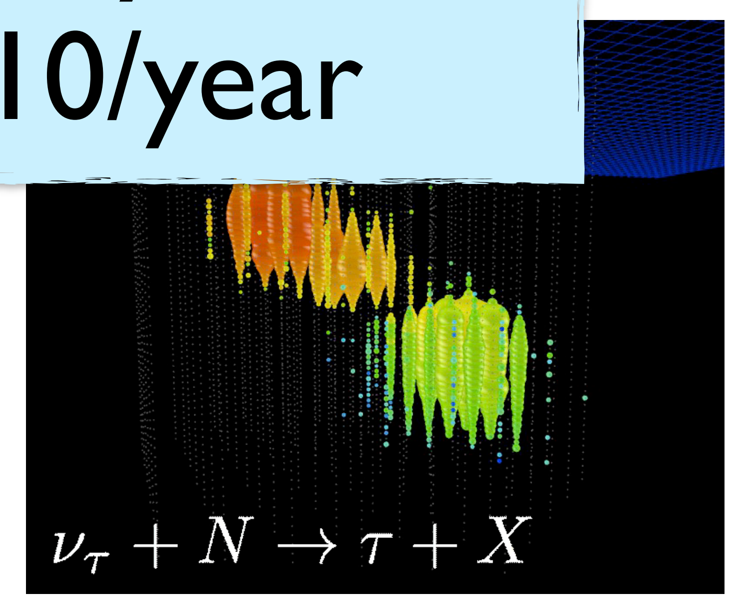


Atmospheric muons ~ 10^{11}/year

Atmospheric neutrinos ~ 10^5/year

Astrophysical neutrinos ~ >10/year

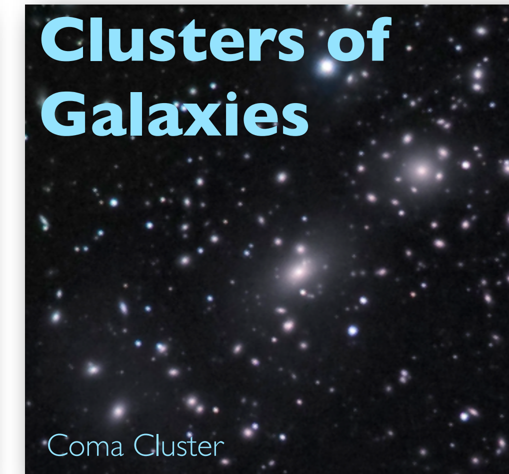
- Earth is used as muon filter
- Atmospheric neutrinos create irreducible neutrino background to extra terrestrial neutrino fluxes



Dark Matter Self-annihilations

$<\sigma_A v>$

Sources



Extra-galactic	Milky Way Halo	Galactic Center	Dwarf Spheroidal	Clusters of Galaxies
small halo model dependence, boost factors	Large DM content, nearby source, O(10) larger flux than extra-galactic	Very dense DM accumulation, nearby source	no astrophysical backgrounds	large DM content, high boost factors from sub structure
Diffuse flux, spectral feature	Anisotropy	Extended Source	Point source	Extended source
signal weak compared to Galactic signal	relatively independent from DM halo profile	very strong dependence on DM density profile	cored profiles favored, less flux	understanding of boost factors

see talk by Martin Bissok

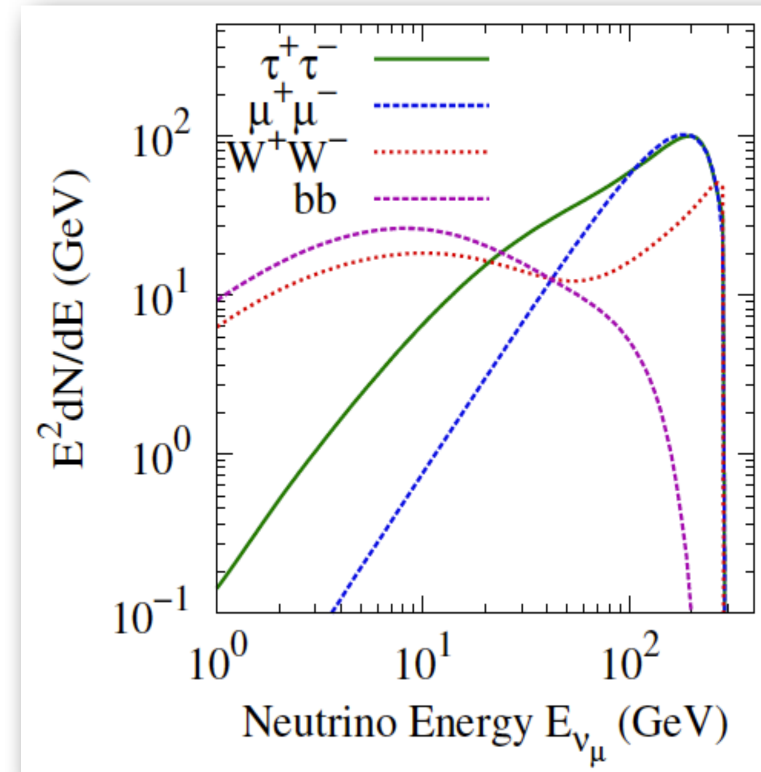
see talk by Meike de With

Dark Matter Annihilation

Measure Flux

Particle Physics

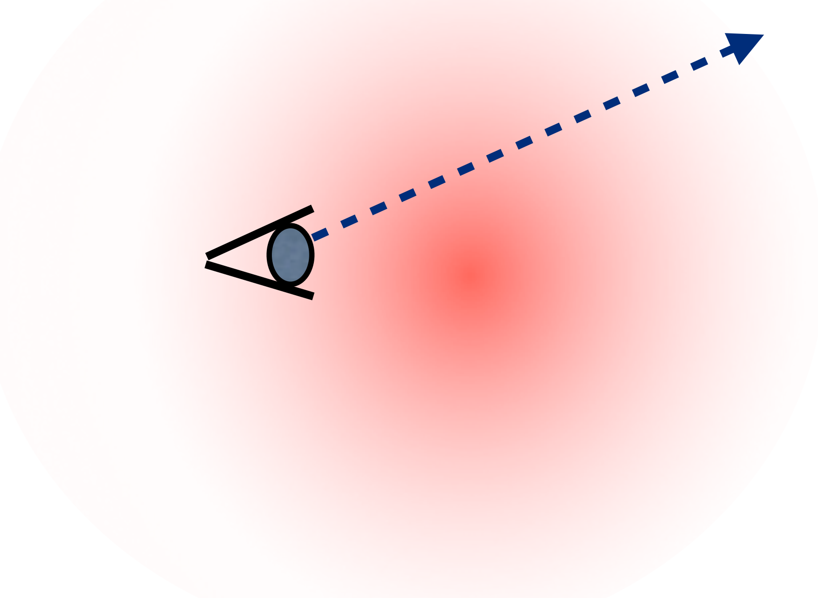
$$\frac{d\Phi}{dE}(E,\phi,\theta) = \frac{1}{4\pi}\frac{\langle\sigma_A v\rangle}{2m_\chi^2}\Sigma_f \frac{dN}{dE}B_f$$



x

Dark Matter Distribution

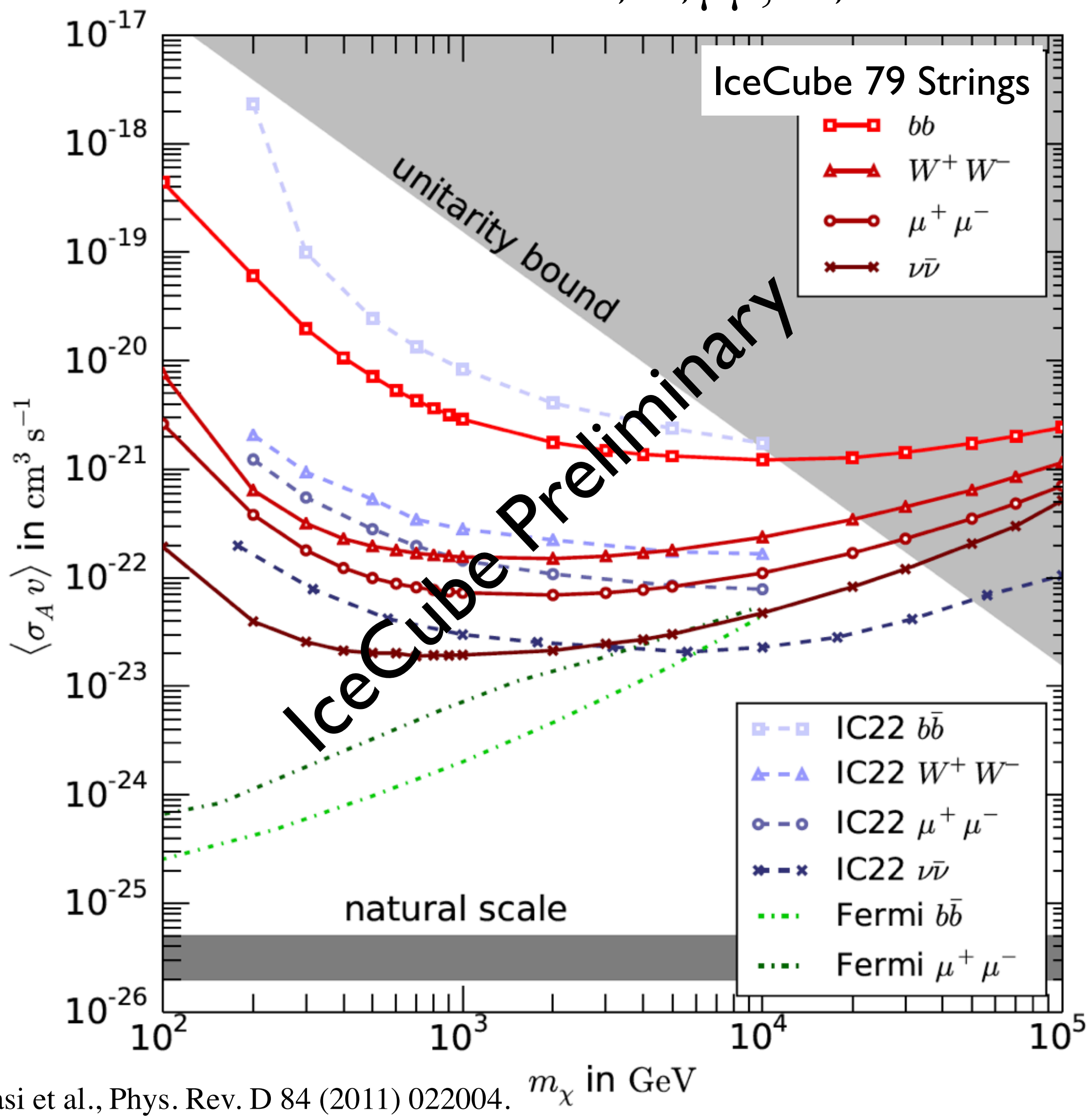
line of sight (los) integral



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

IceCube Anisotropies in the Galactic Halo

- Galactic Center (GC) on the southern hemisphere
  - large backgrounds from down-going muons
- Search for anisotropy on Northern hemisphere
  - high-purity neutrino sample (up-going muon events)
- Assume annihilation into νν, bb, μμ, ττ, WW

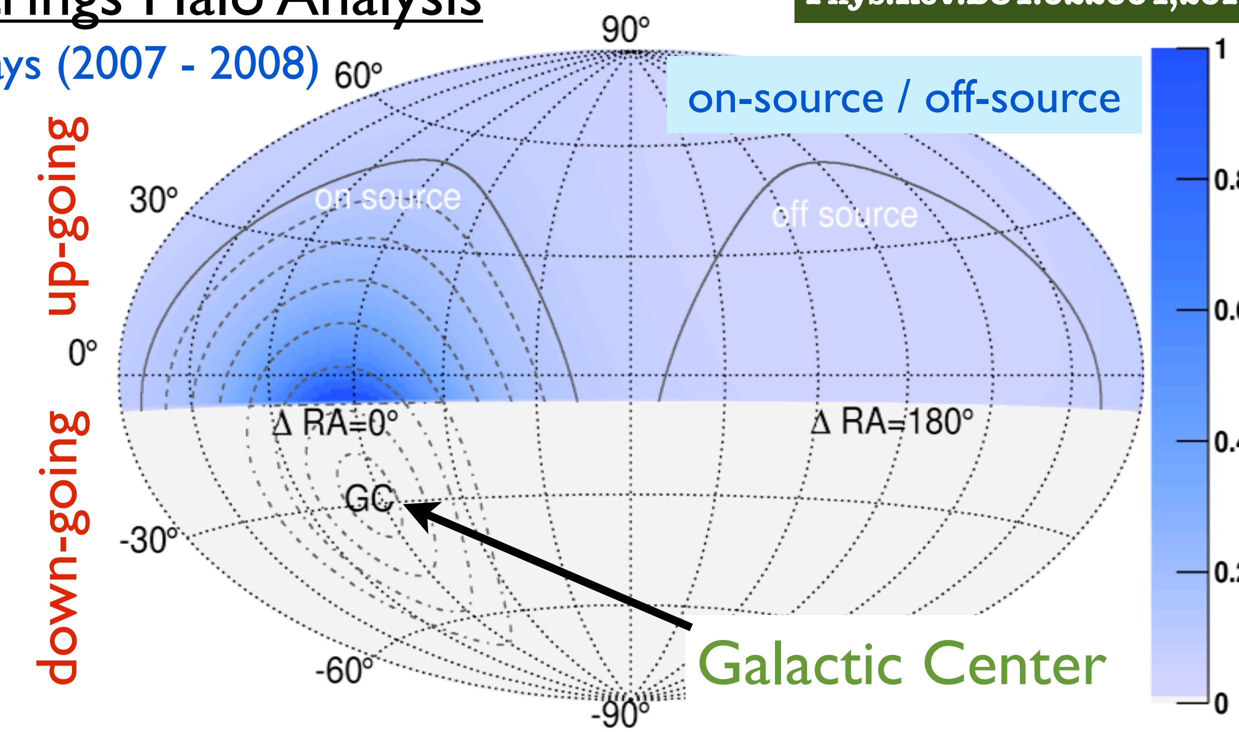


R. Abbasi et al., Phys. Rev. D 84 (2011) 022004.
M. Ackermann et al., Astrophys. J. 761 (2012) 91.

22-strings Halo Analysis

Phys.Rev.D84:022004,2011

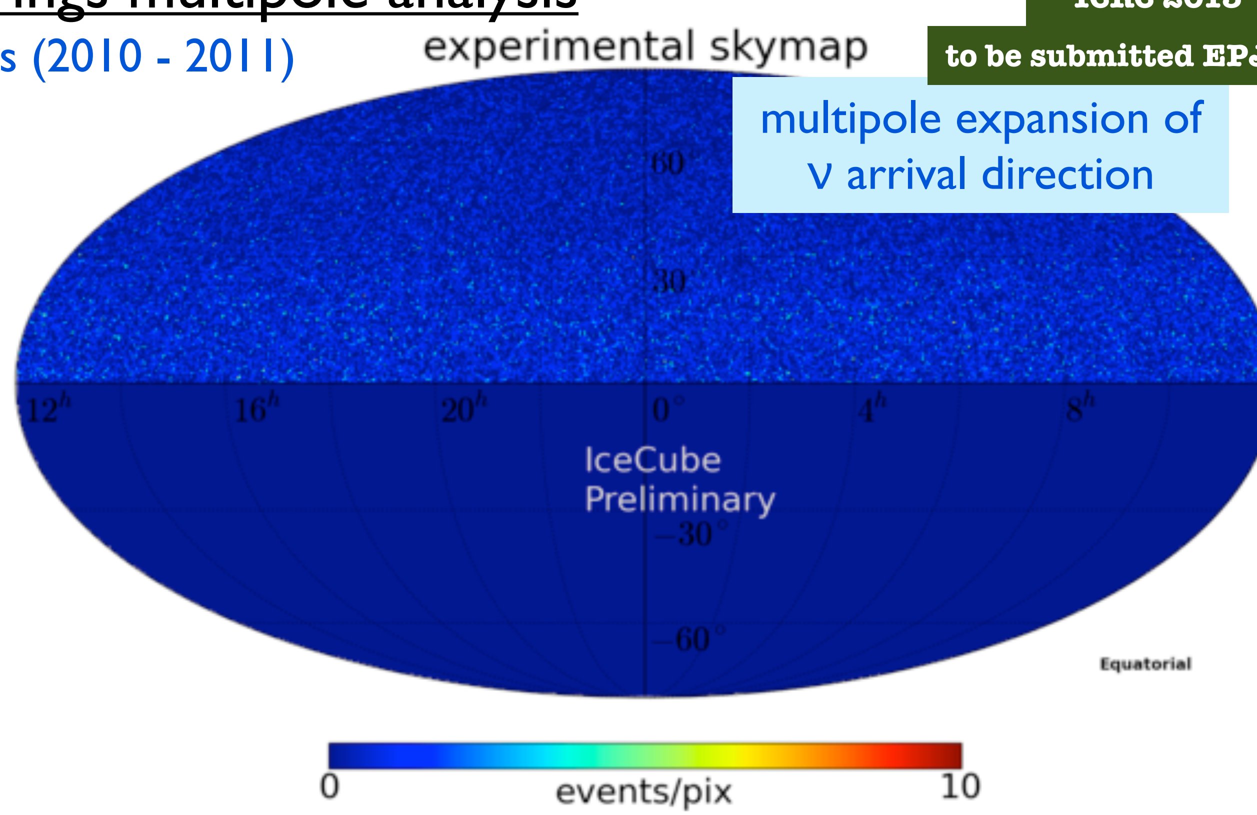
276 days (2007 - 2008)



79-strings multipole analysis

ICRC 2013
to be submitted EPJ

316 days (2010 - 2011)

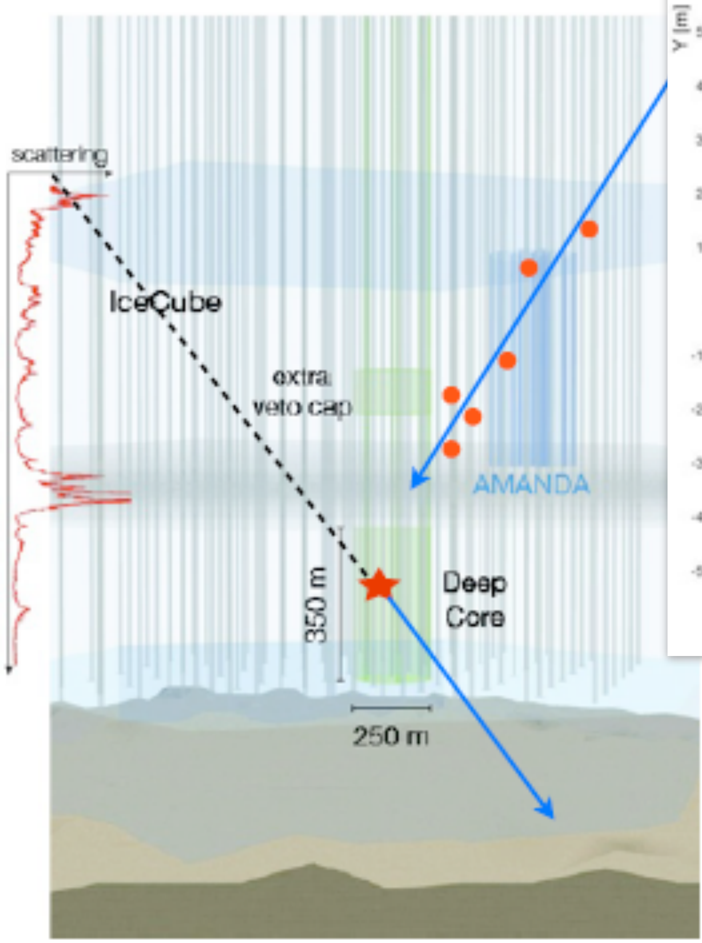


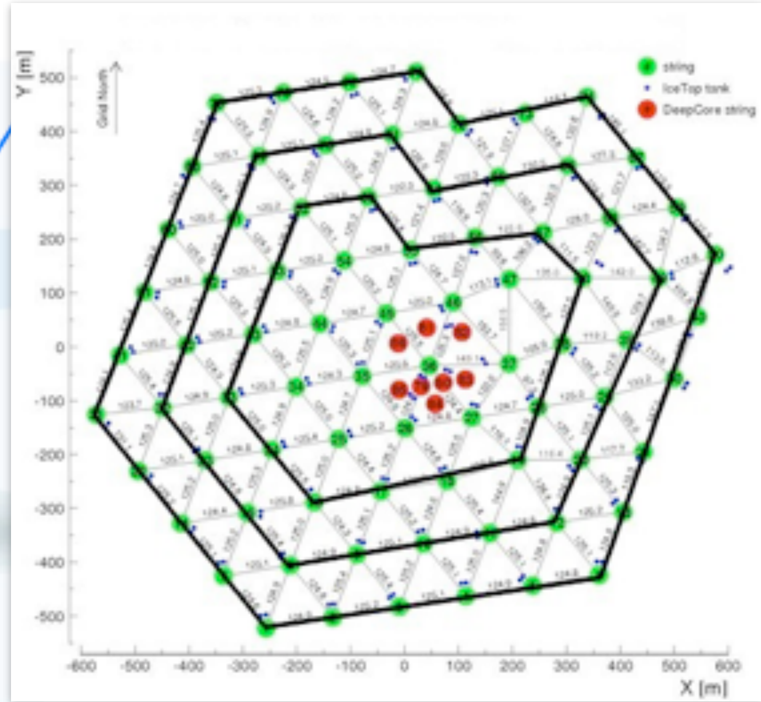
see talk by Martin Bissok

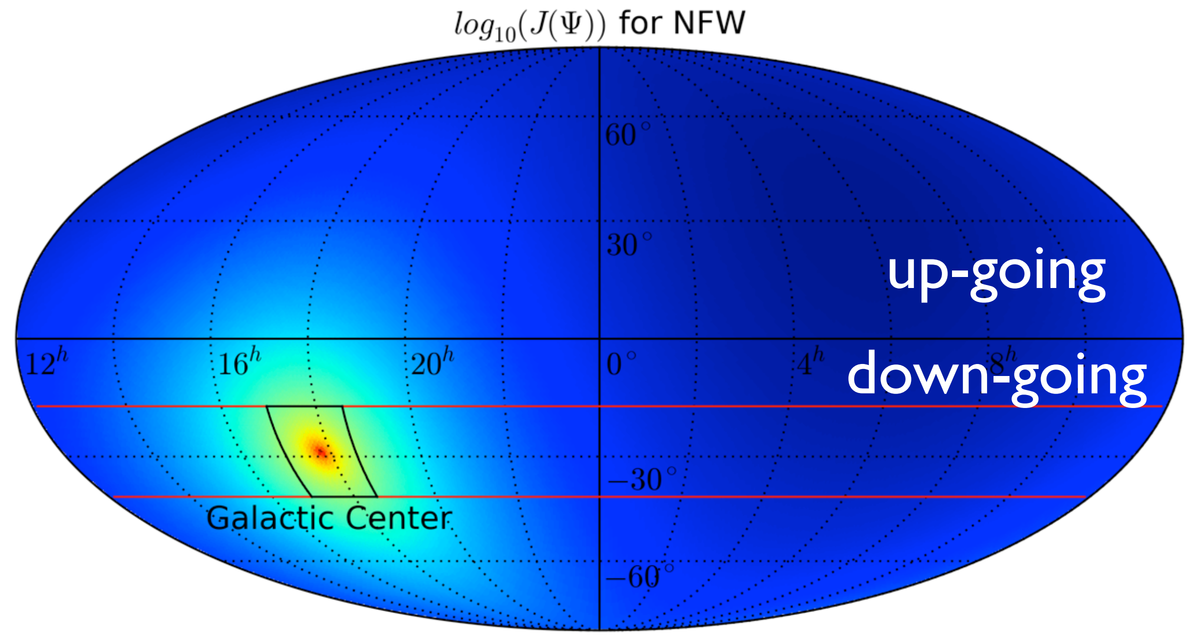
Galactic Center Search

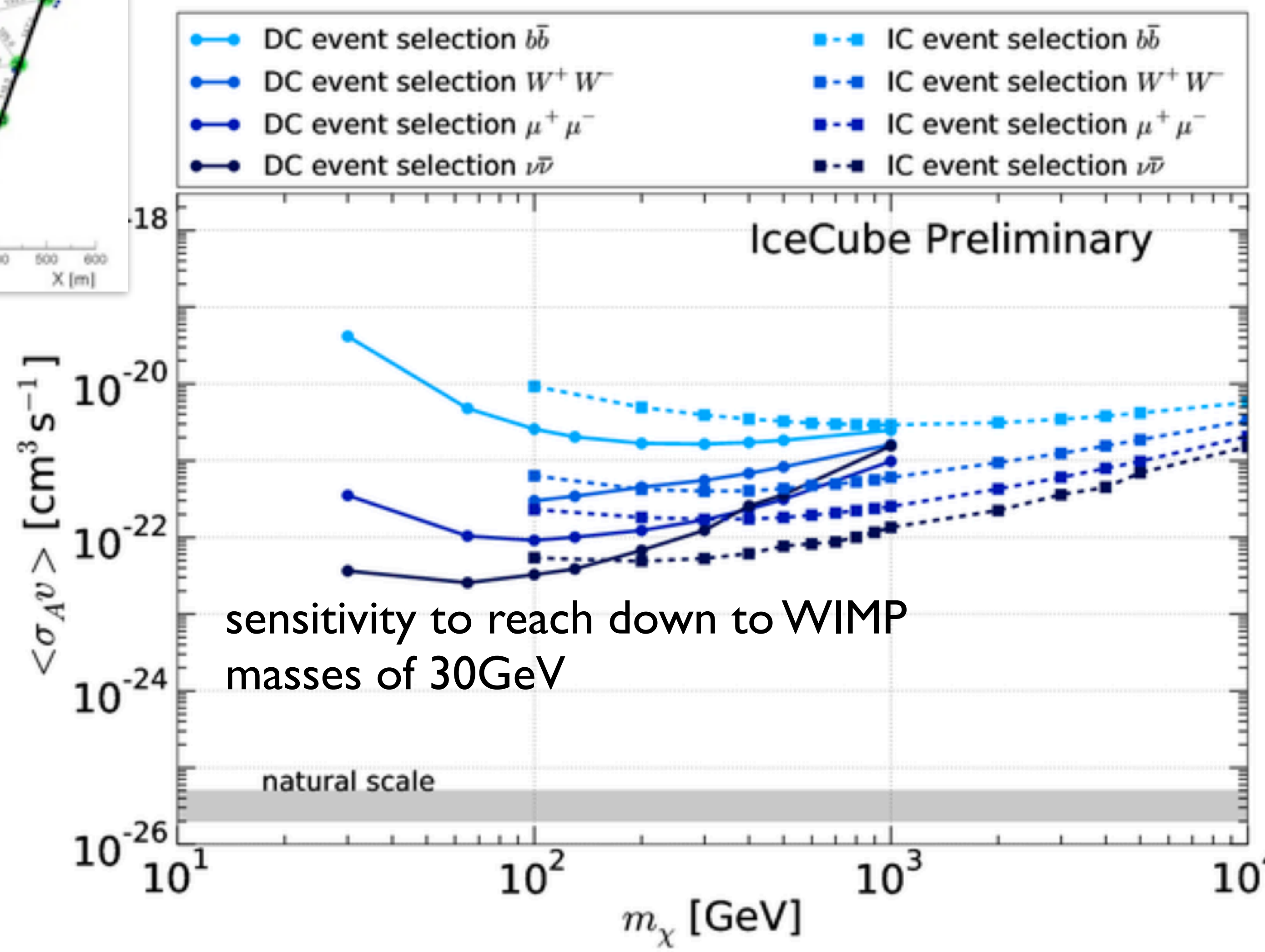
Use IceCube external strings as a veto:

- 3 complete layers around DeepCore (~ 375m)
- Full sky sensitivity: access to southern hemisphere



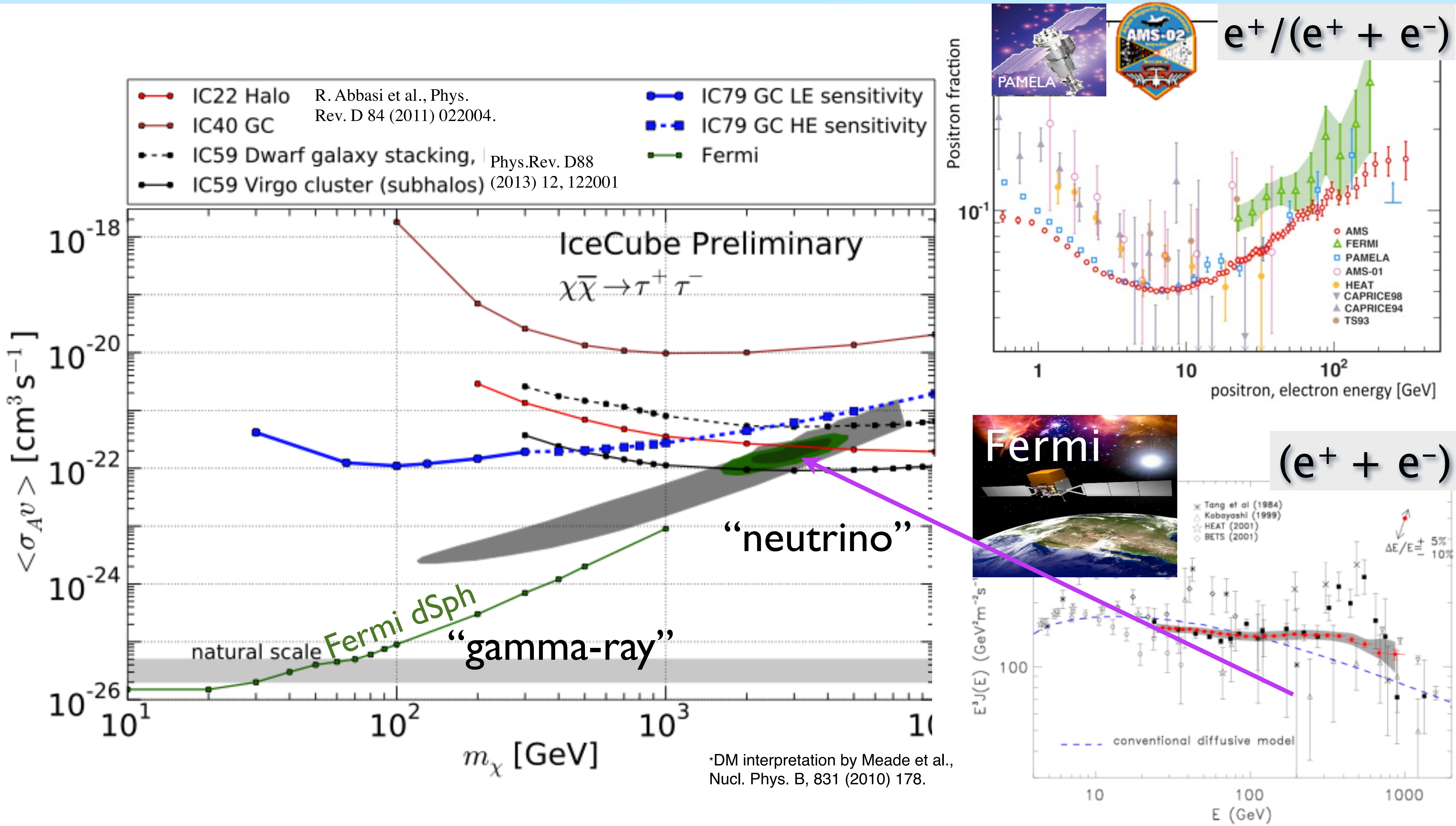






Separate Low energy and High energy optimizations:
GC is above the horizon
→ Fiducial volume in central strings
→ refined muon veto from surrounding layers
Use scrambled data for background estimation

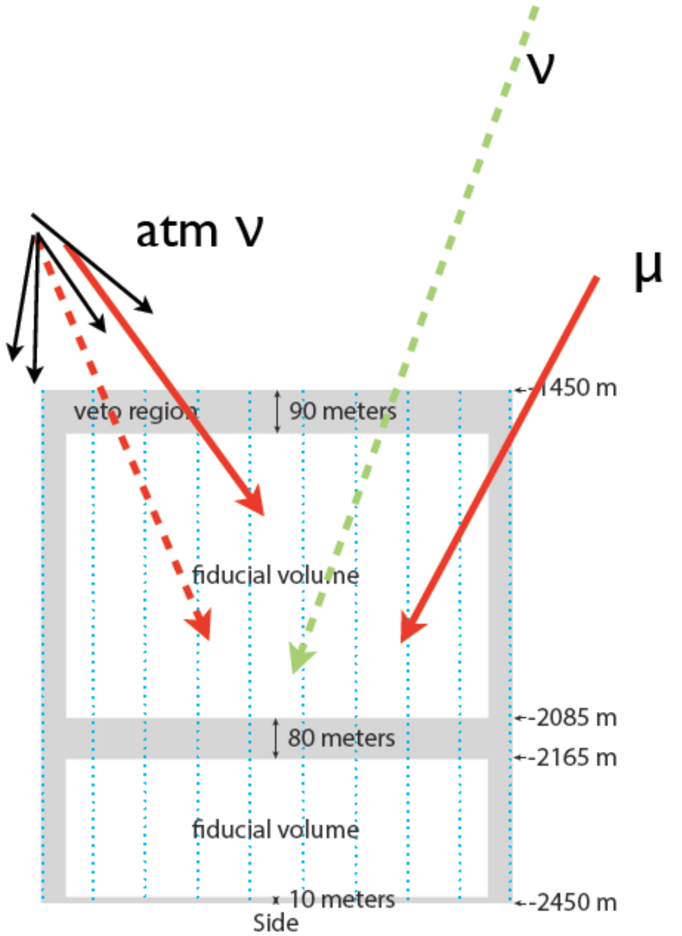
Neutrinos test lepton anomalies



IceCube can probe models motivated by the observed lepton anomalies

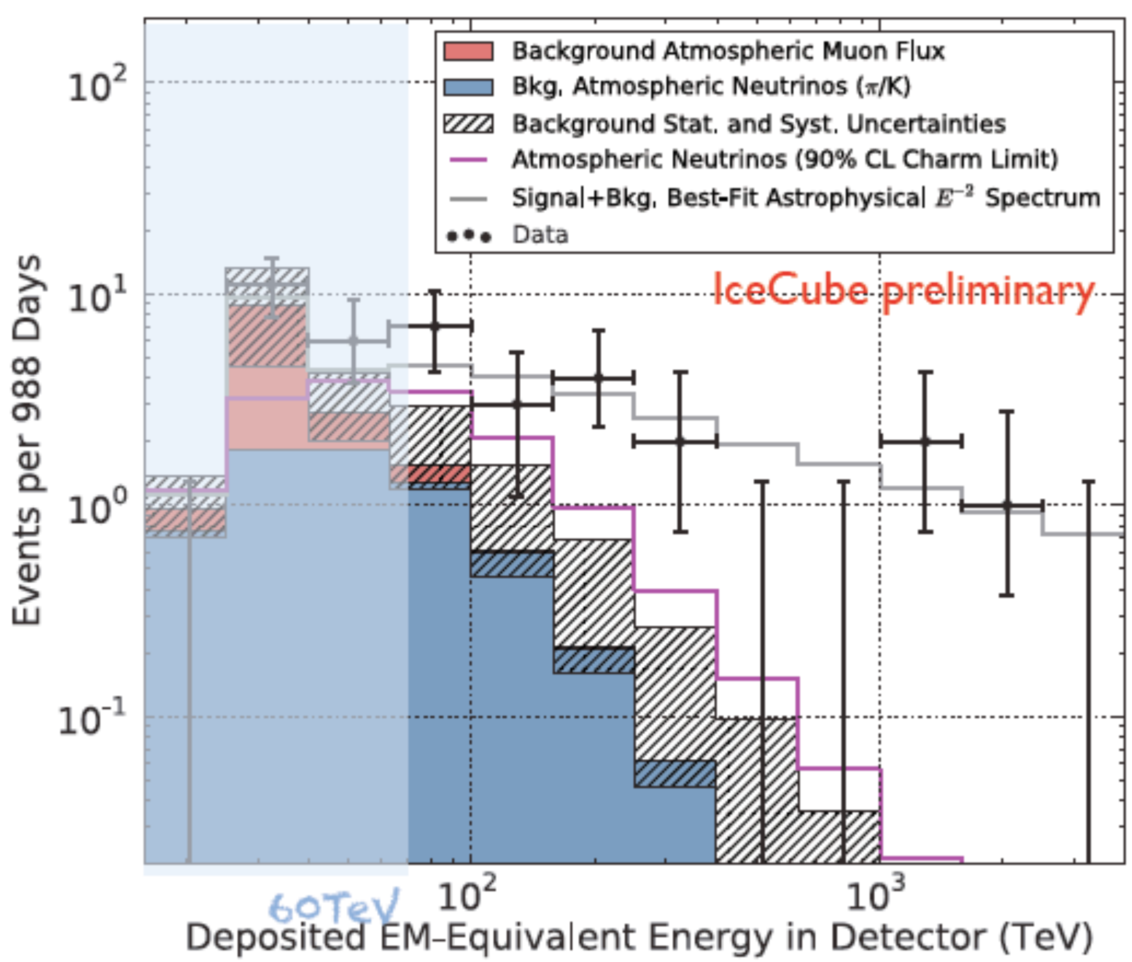
Dark Matter Decay - High Mass Dark Matter

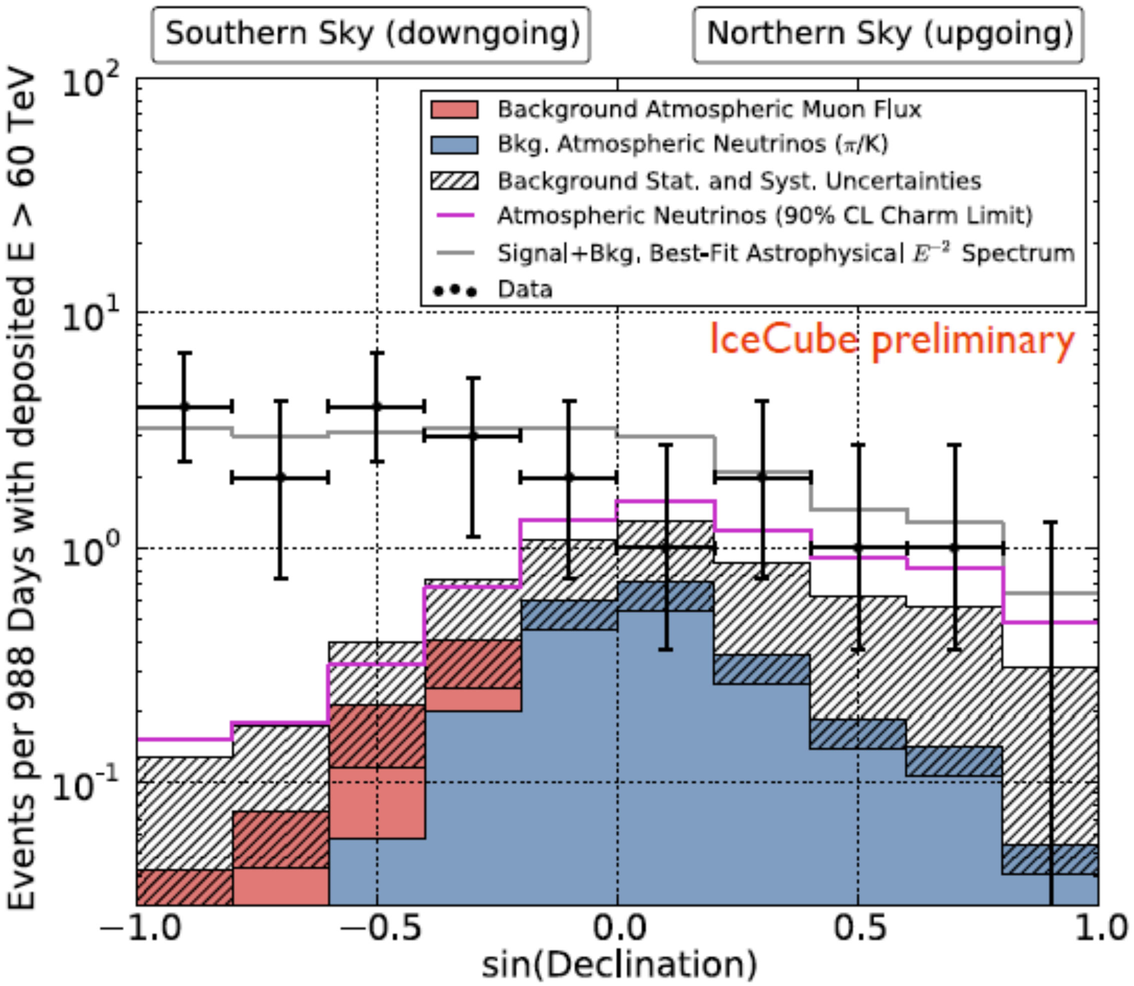
IceCube: High-energy neutrino events



IceCube Collaboration
arXiv:1405.5303v1

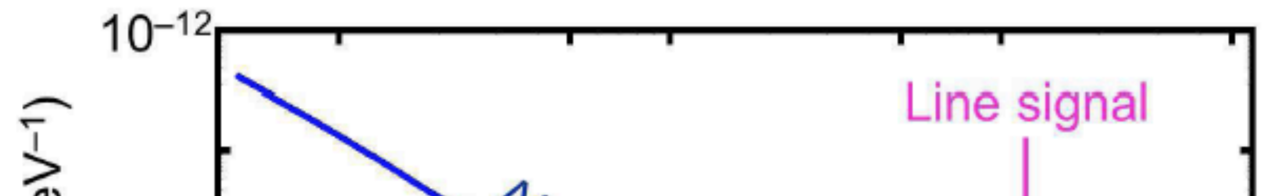
- 37 events observed (2010-2013)
  - 2 years analysis found 28 events Science 342, 1242856 (2013)
- energy spectrum >60TeV harder than background
- atmospheric origin rejected at 5.7σ





Heavy Dark Matter

- IceCube's high-energy cascade events triggered interest in high-mass dark matter models
  - Two events intriguingly close in energy
    - consistent with electron neutrino interactions at about 1PeV



Could this be dark matter ?

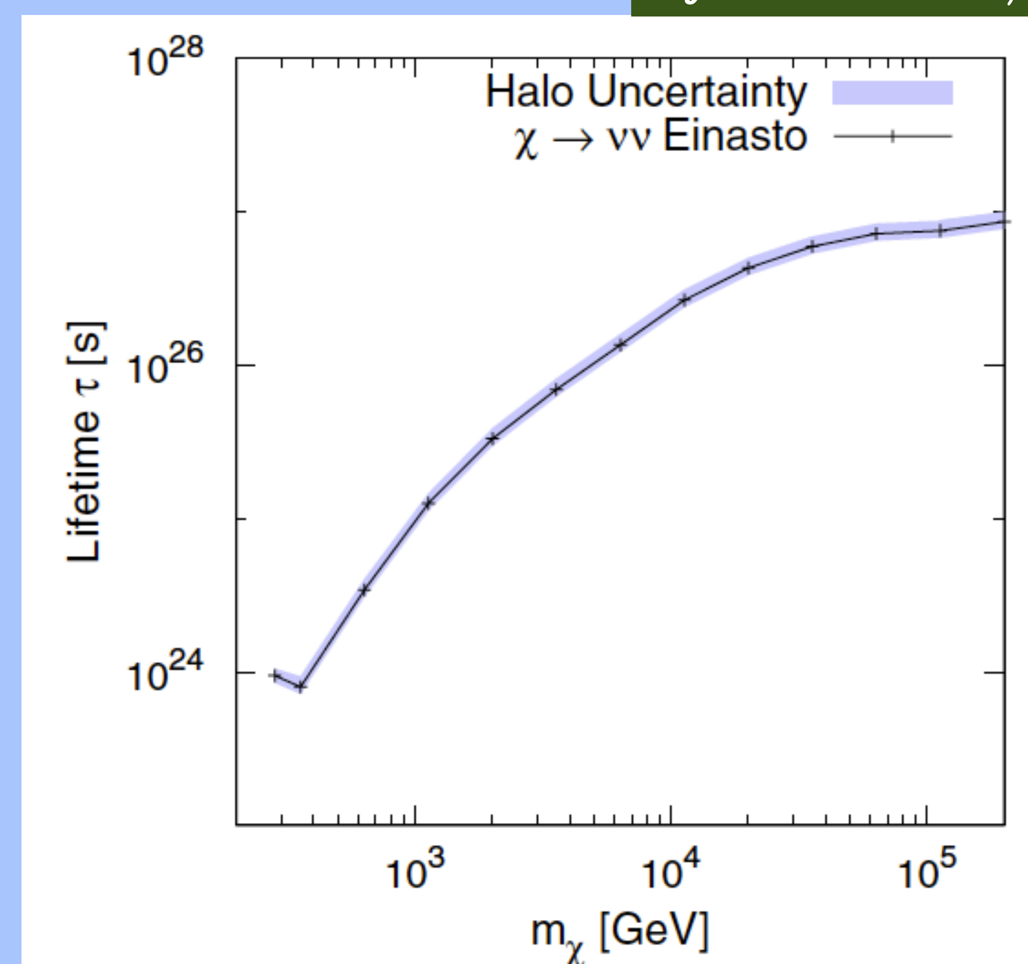
Evidence:
- ~2PeV Dark Matter Particle mass
- Flux can be related to the lifetime τ_{DM}

$$\tau_{DM} \simeq 1.9 N_\nu \times 10^{28} \text{ s}$$

- Models
  - Singlet fermion in an extra dimension
  - Hidden Sector Gauge Boson
  - Gravitino Dark Matter with R-Parity Violation

IceCube Bound on lifetime ~10^{27}s

Phys.Rev.D84:022004,2011



prep.)]

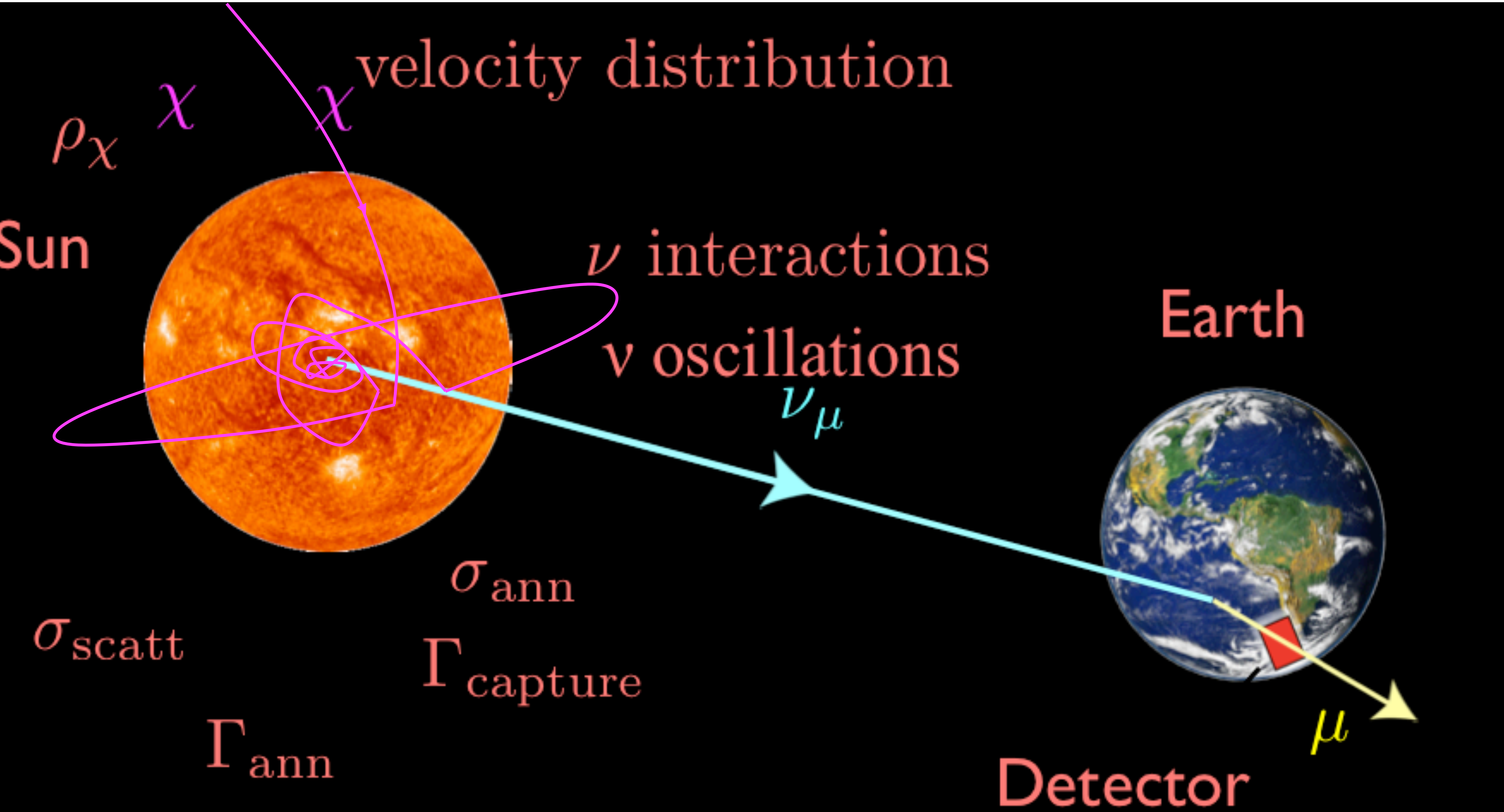
within 65°

within 25°

Solar WIMPs

σ_{scatt}

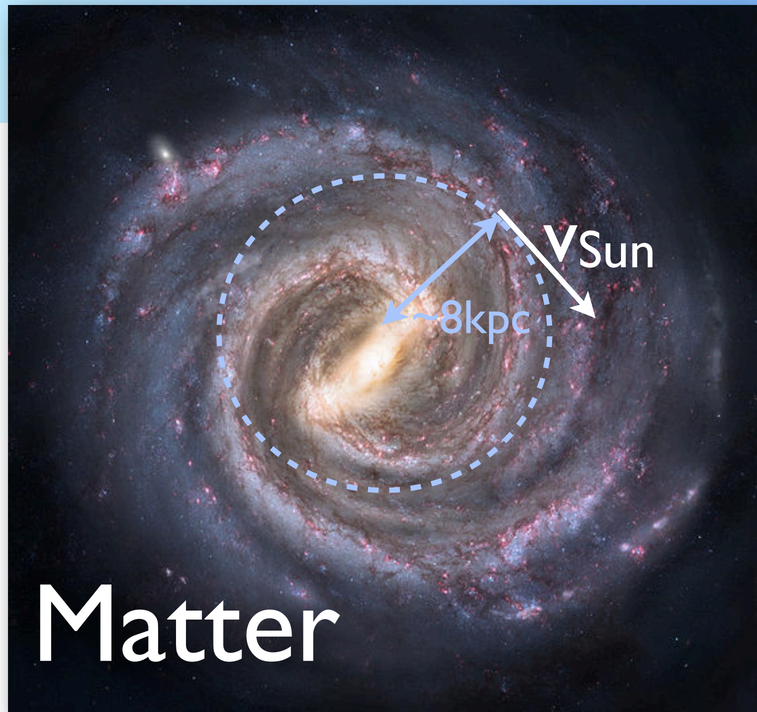
Solar WIMPs



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

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

Solar WIMP Capture



+

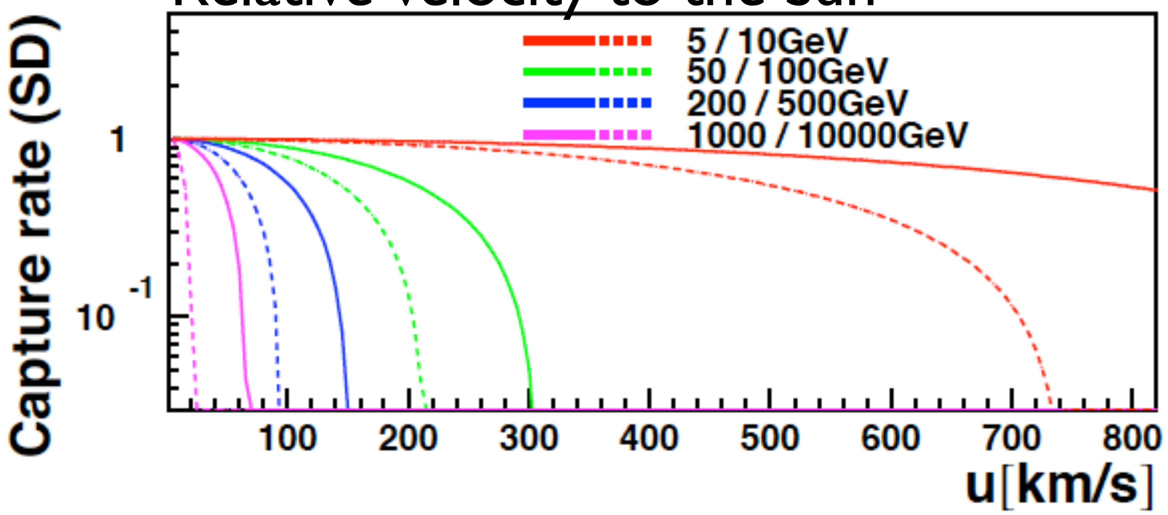
Standard assumption

DM isotropic with Maxwellian velocity distribution

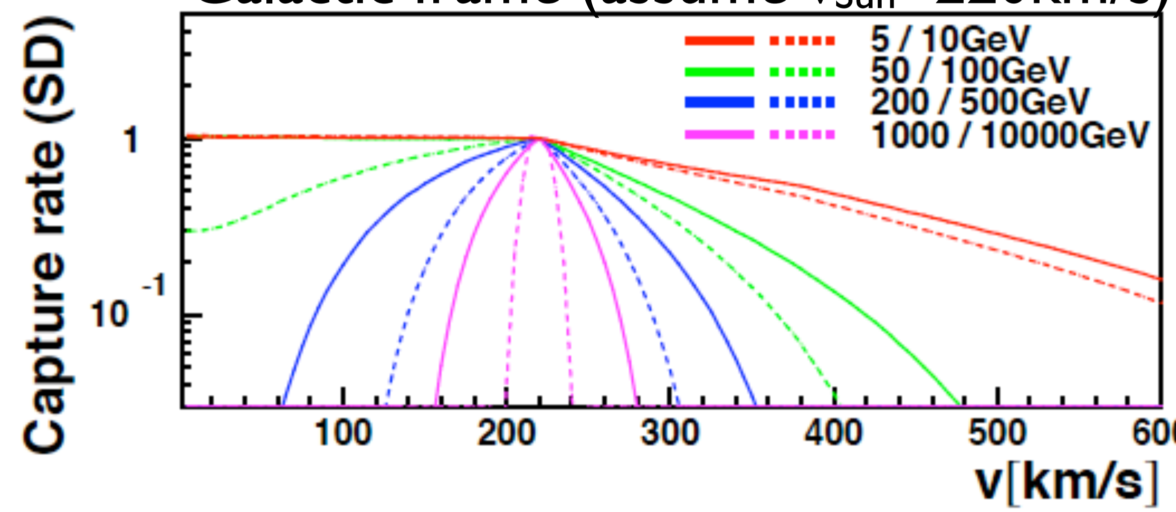
... consequence of a density profile $\rho(r) \propto r^{-2}$ of collisionless particles

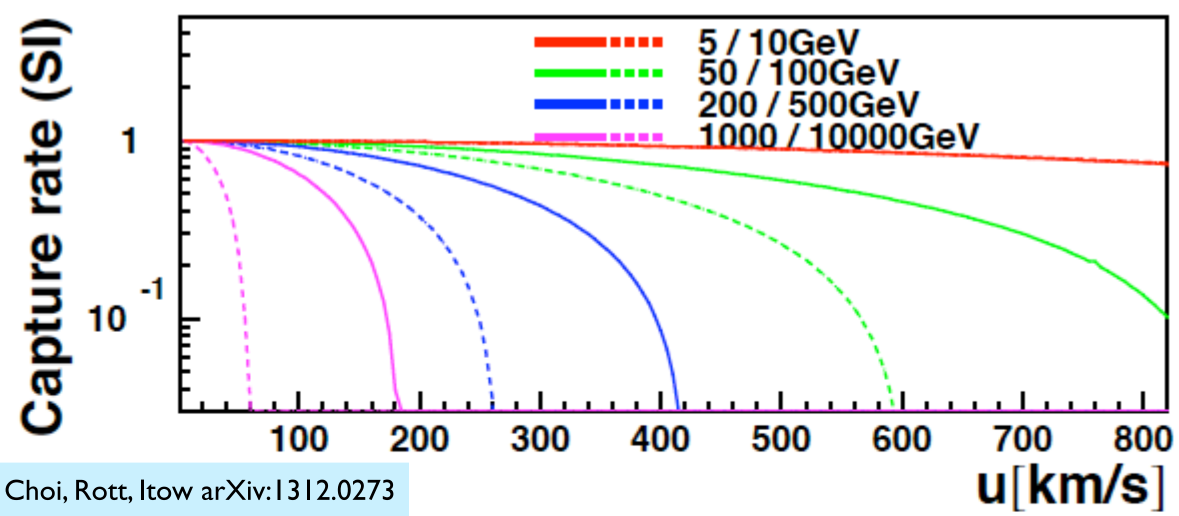
$$f(u) = \sqrt{\frac{3}{2\pi}}\frac{u}{v_\odot v_{\rm rms}}\left(\exp\left(-\frac{3(u-v_\odot)^2}{2v_{\rm rms}^2}\right) - \exp\left(-\frac{3(u+v_\odot)^2}{2v_{\rm rms}^2}\right)\right).$$

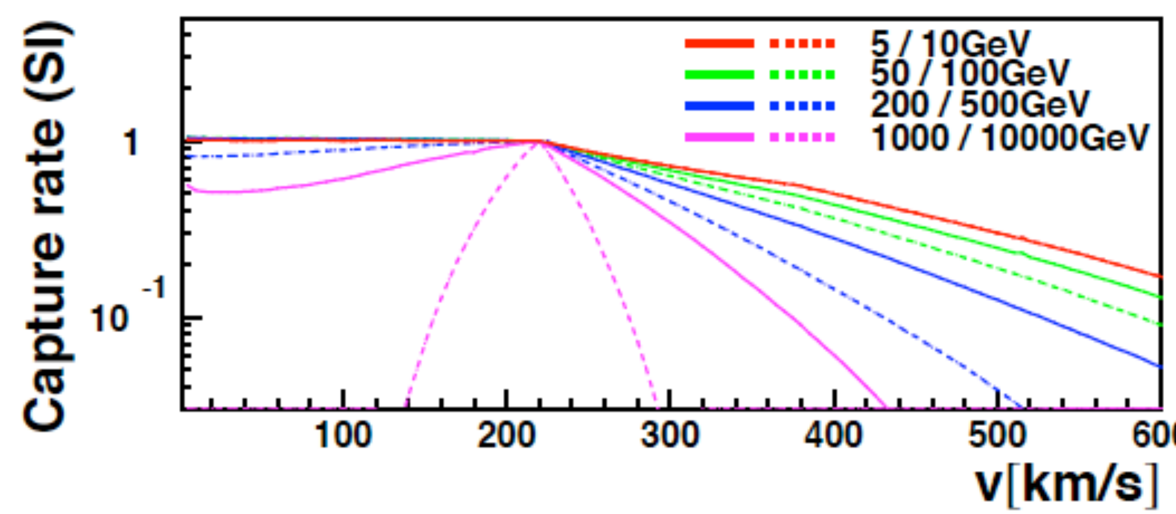
Relative velocity to the Sun



Galactic frame (assume v_{Sun}=220km/s)





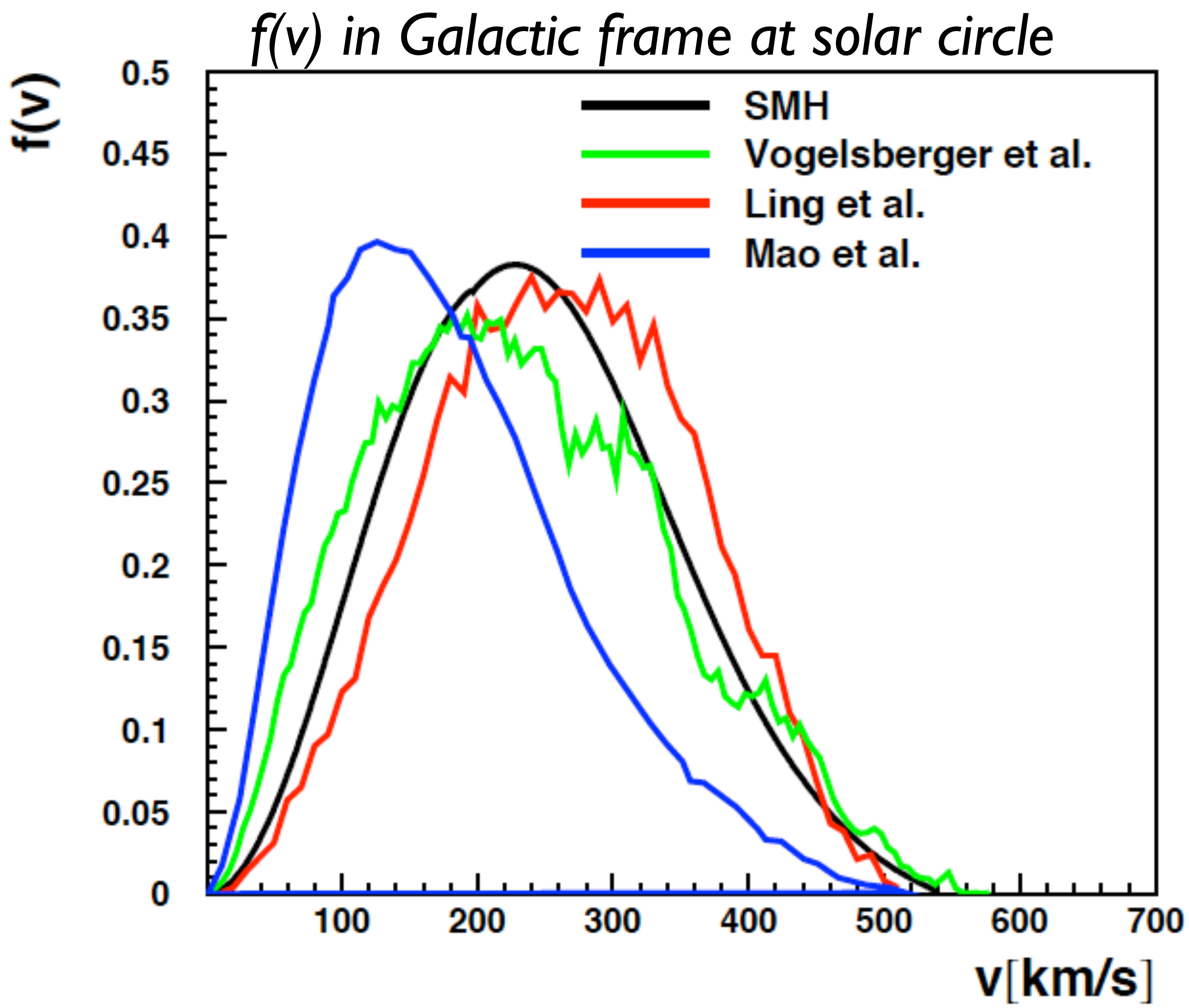


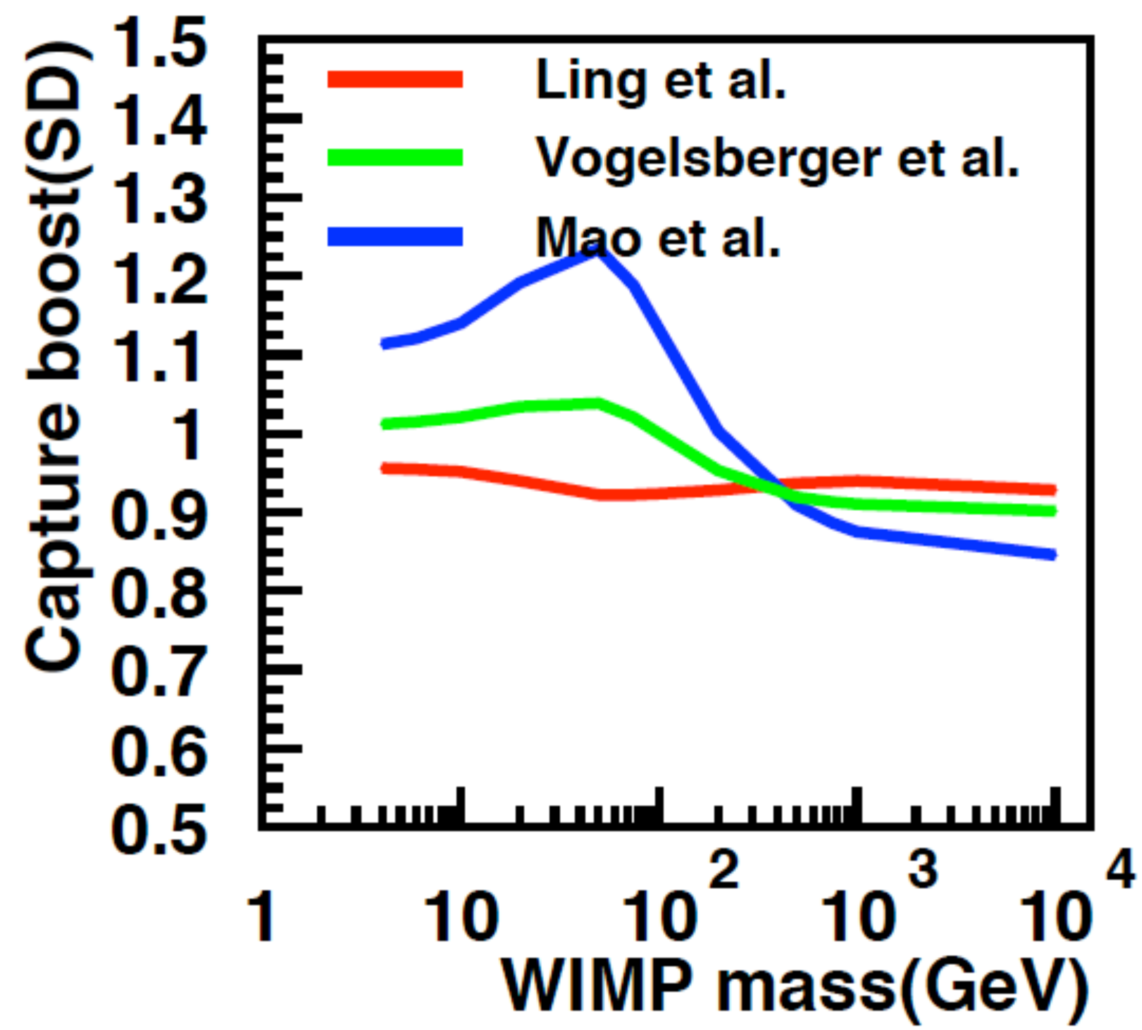
Choi, Rott, Itow arXiv:1312.0273

Impact of velocity distribution

- Explore the change in capture rate using different velocity distributions obtained from dark matter simulations

Choi, Rott, Itow JCAP 1405 (2014) 049





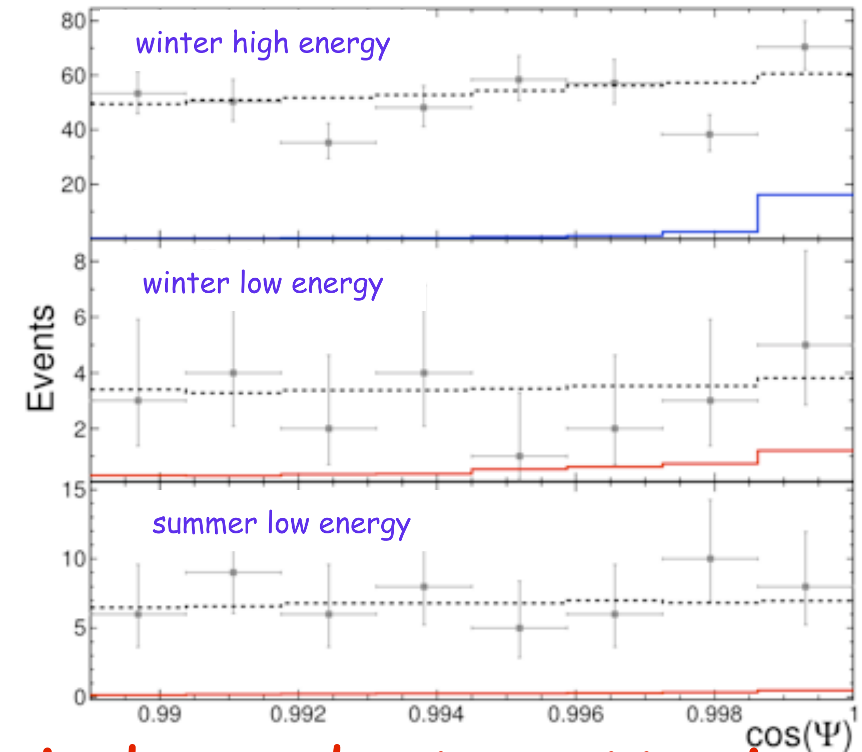
- A comparison of captures rates for different WIMP velocity distributions show that overall changes in the capture rate are smaller than 20%

IceCube Solar WIMP Limits

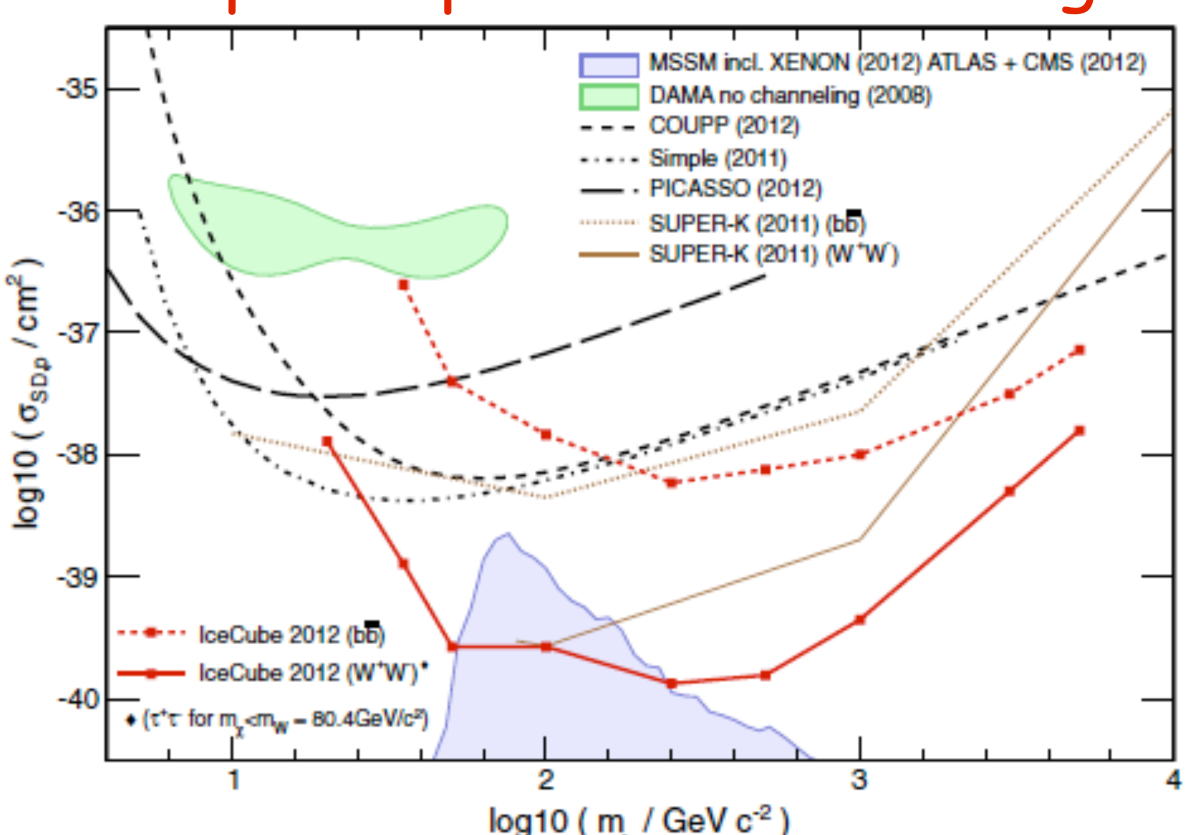
PRL 110, 131302 (2013)

- IceCube 79-strings configuration (partially completed DeepCore)
  - 318 days (May 2010 - May 2011)
- Search for an excess of events from the direction of the Sun
  - use track events for better pointing
- Separate summer and winter analysis
  - use outer detector to veto down-going muons for summer analysis

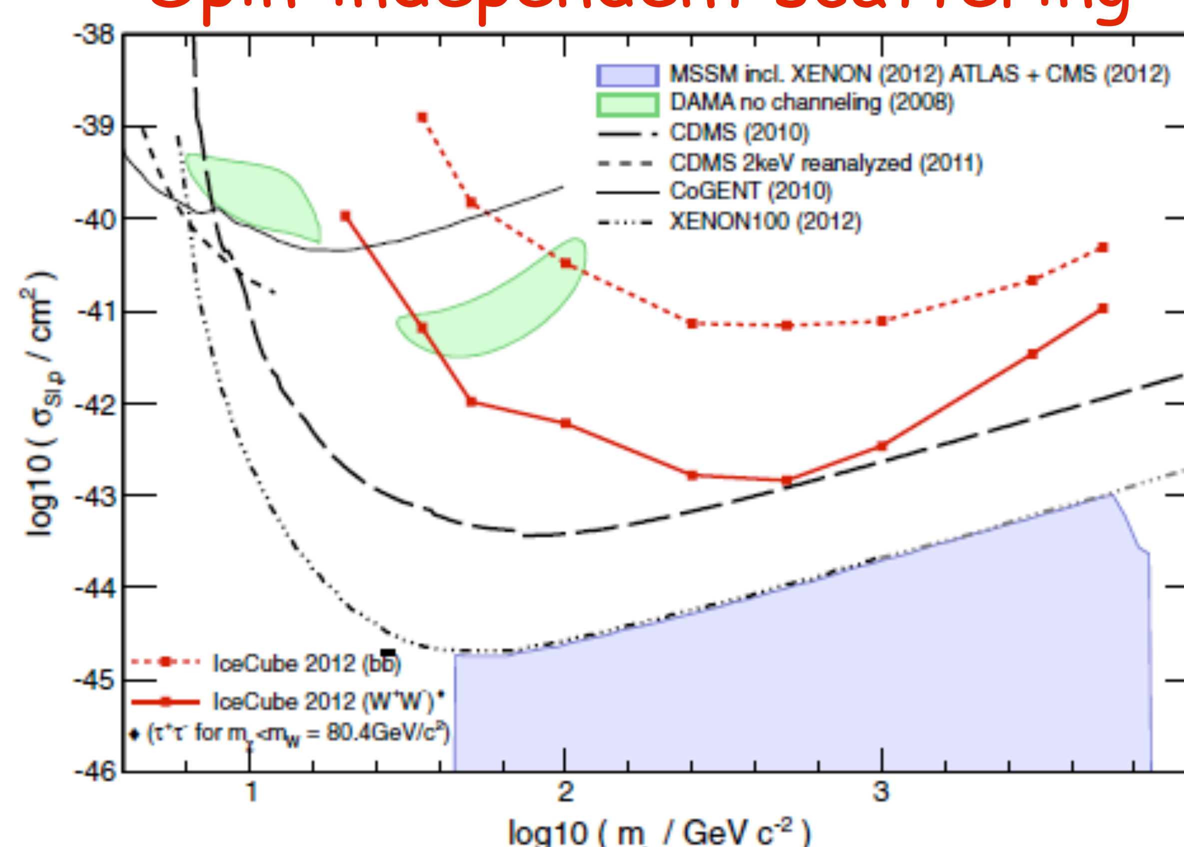
Observed events



Spin-dependent scattering

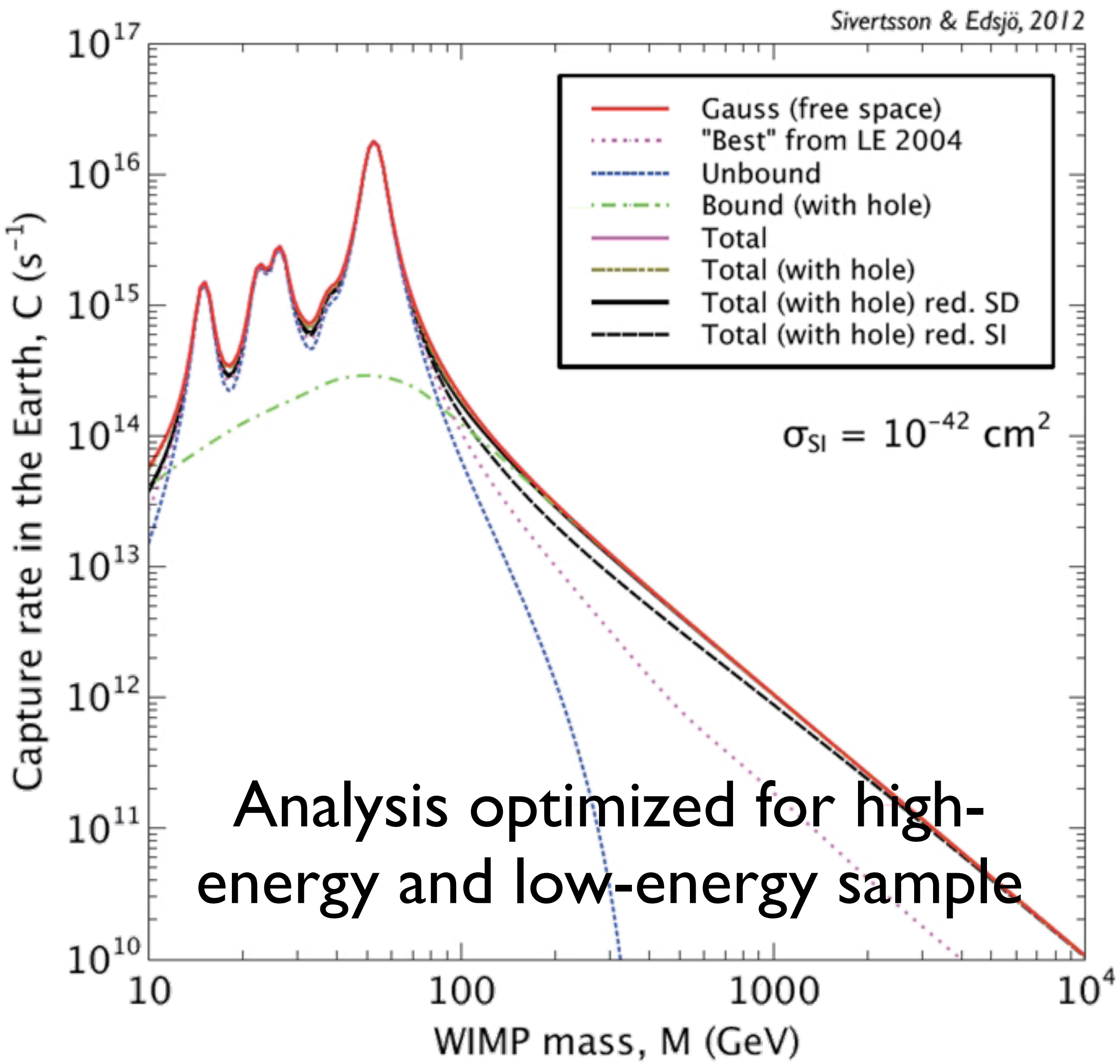


Spin-independent scattering

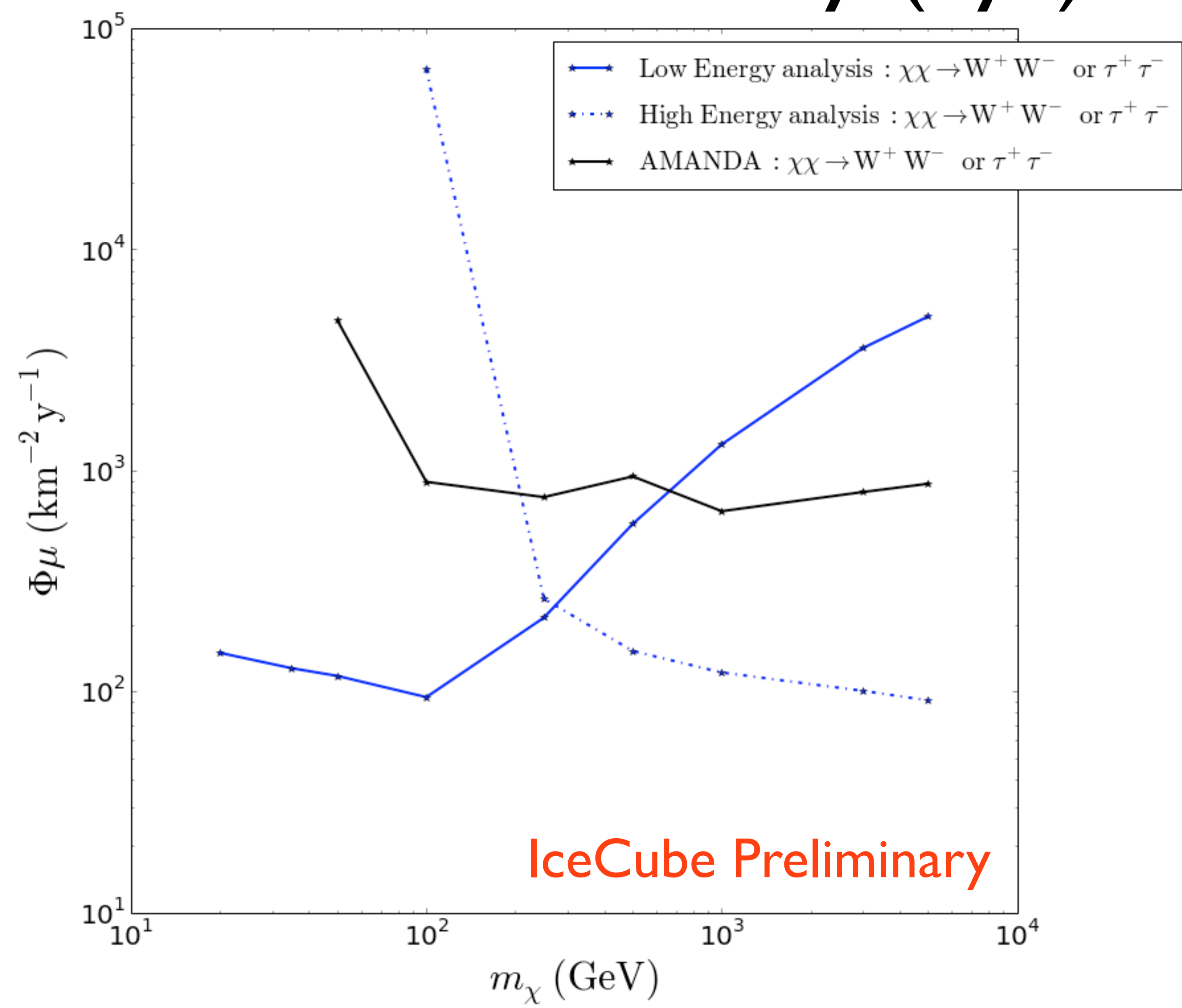


Earth WIMPs

Dark Matter Captured in the Earth -- Look for vertical up-going events from self-annihilating dark matter in the Earth's Core



IceCube Sensitivity (1yr)



see talk by Jan Kunnen

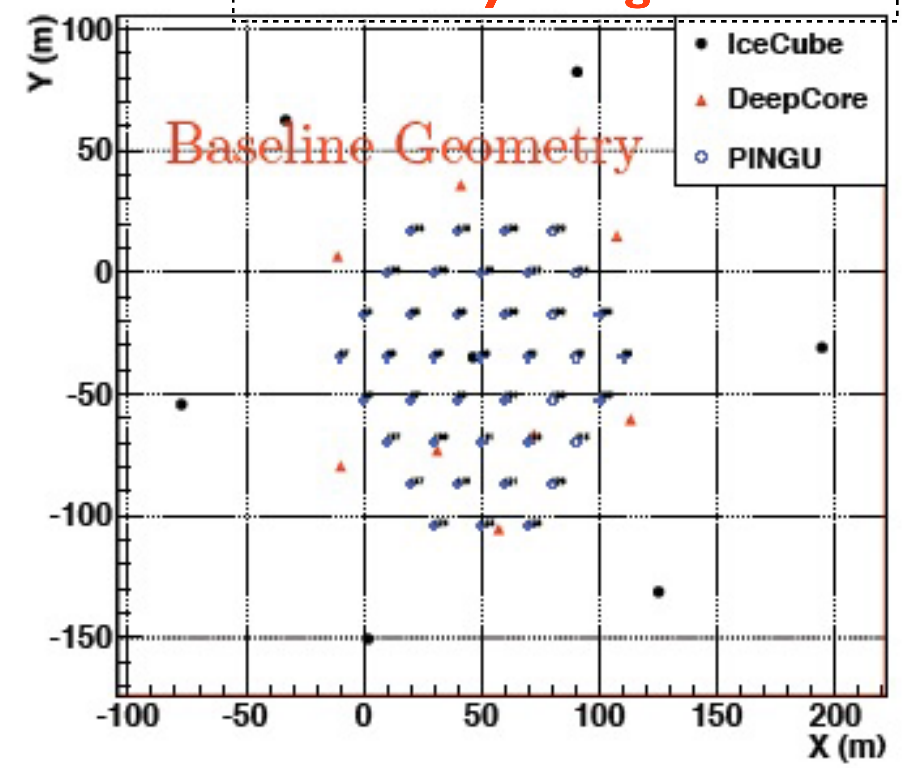
Future Prospects

PINGU Dark Matter Sensitivity

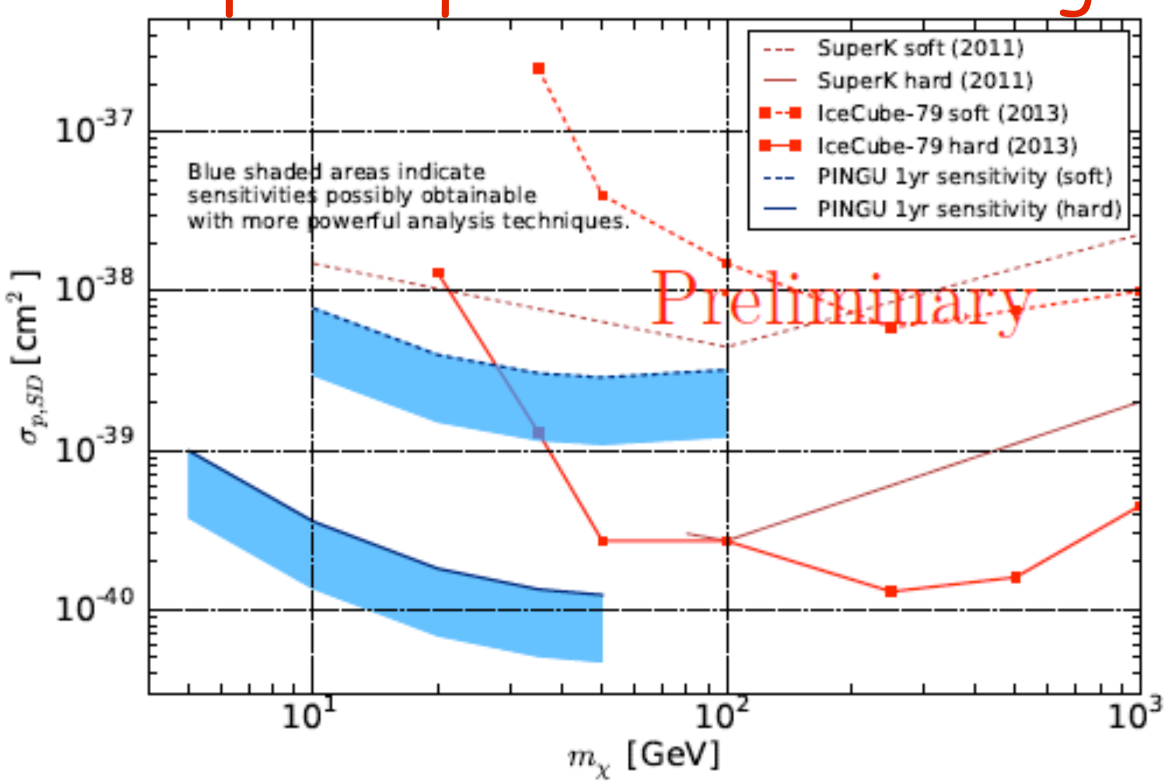
Precision **I**ce**C**ube **N**ext **G**eneration **U**pgrade

- High density instrumentation:
  - baseline geometry: 40 strings with 60 DOMs each)
  - Threshold ~ 1GeV
- Test low mass WIMP region -- capable to comfortably test DAMA/Libra

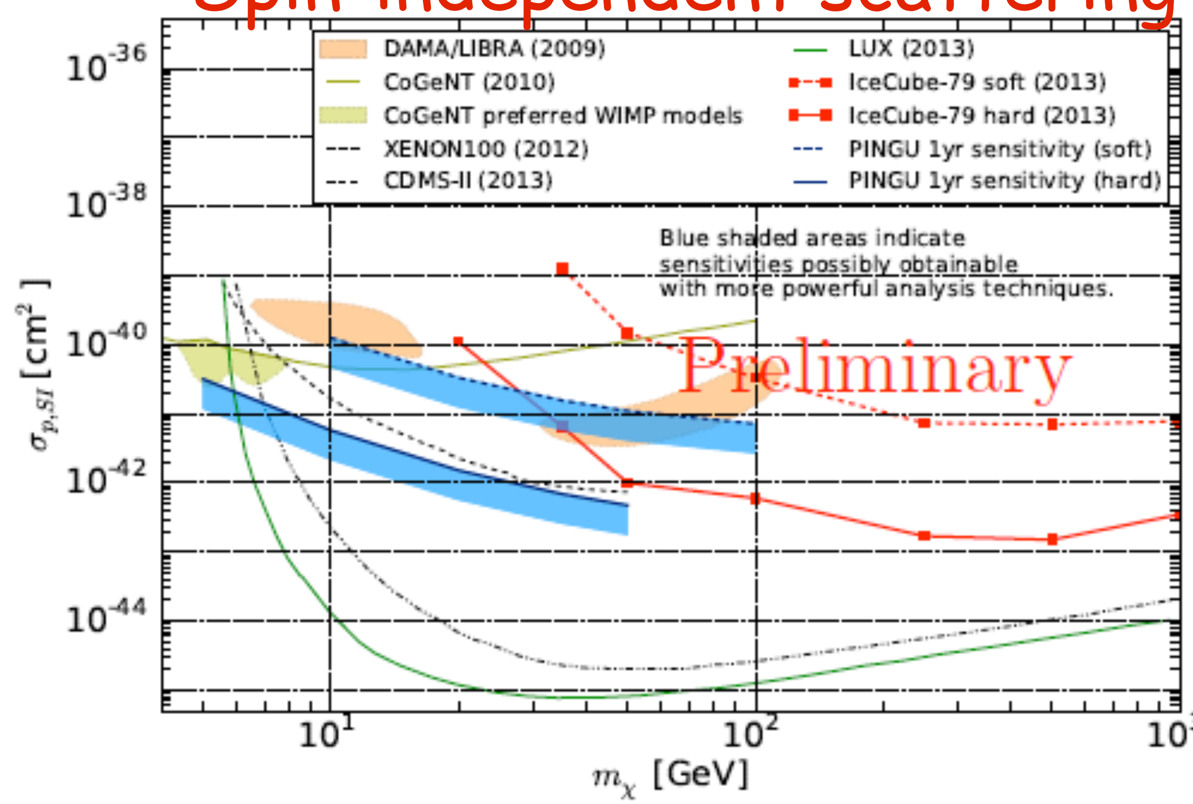
see talk by Doug Cowen



Spin-dependent scattering



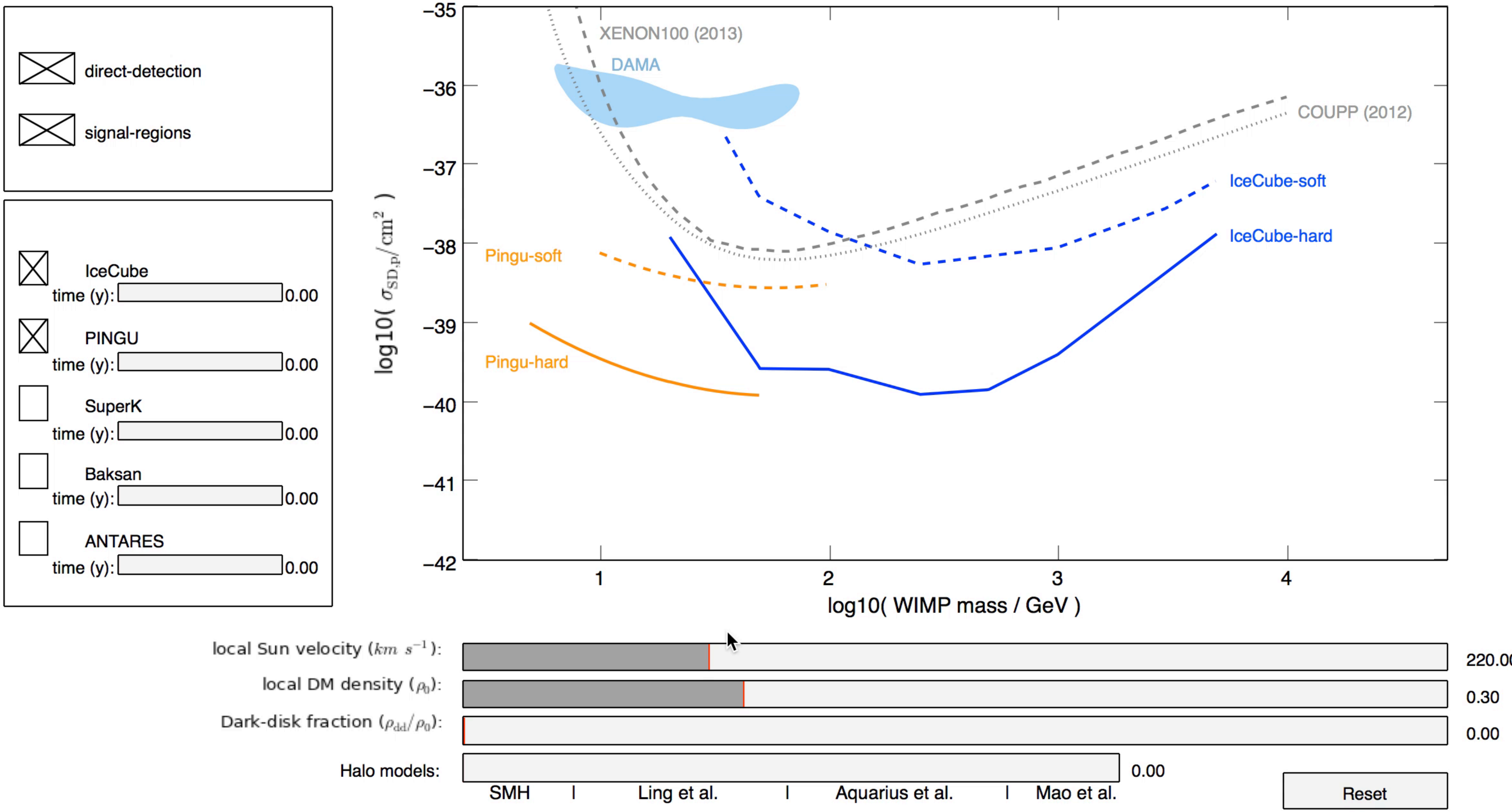
Spin-independent scattering



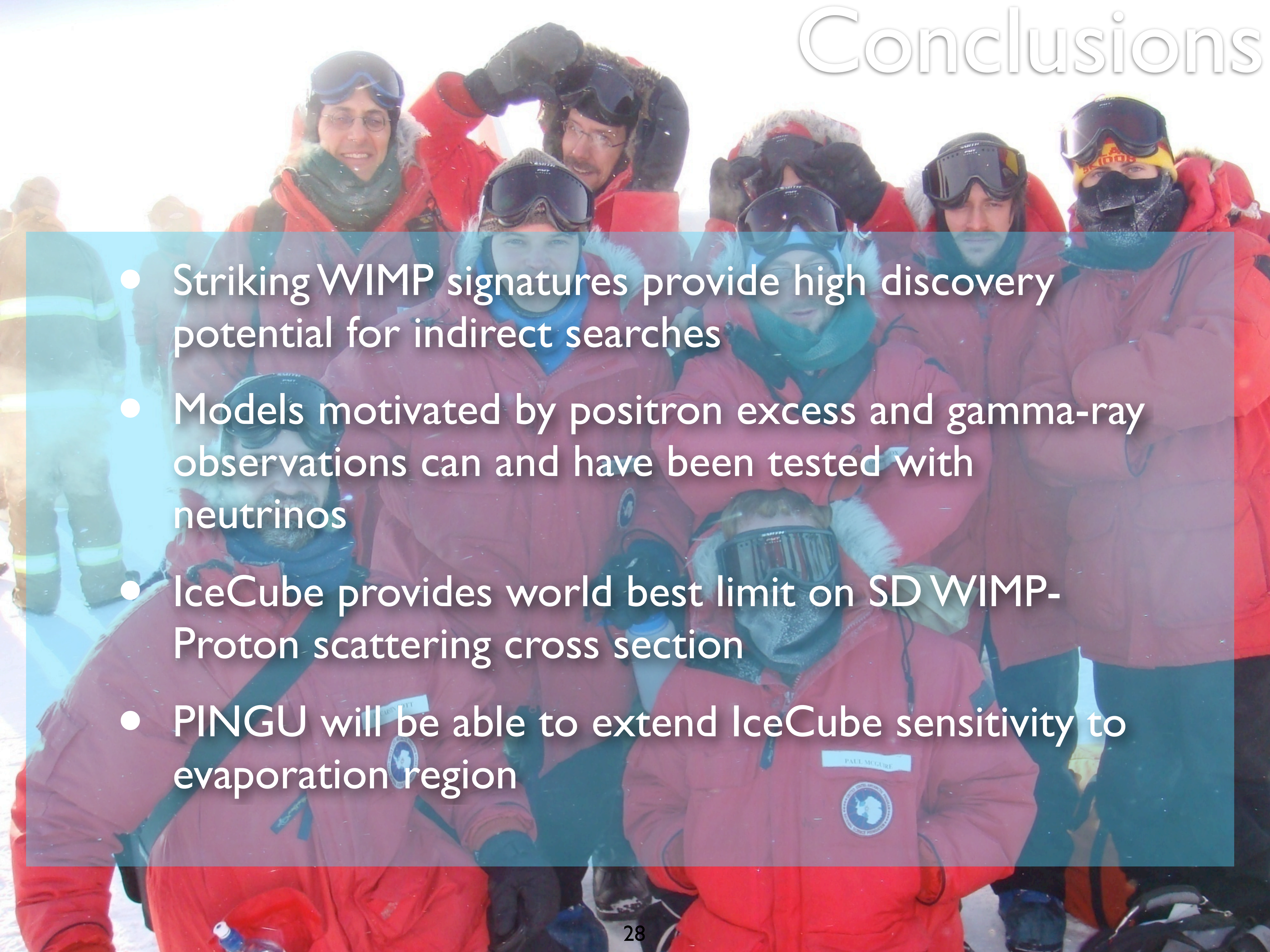
Impact of astrophysical uncertainties

M. Danninger & C. Rott "Solar WIMPs Unraveled" -- Invited Review for Physics of the Dark Universe (submitted)

interactive tool to study impact of astrophysical parameters



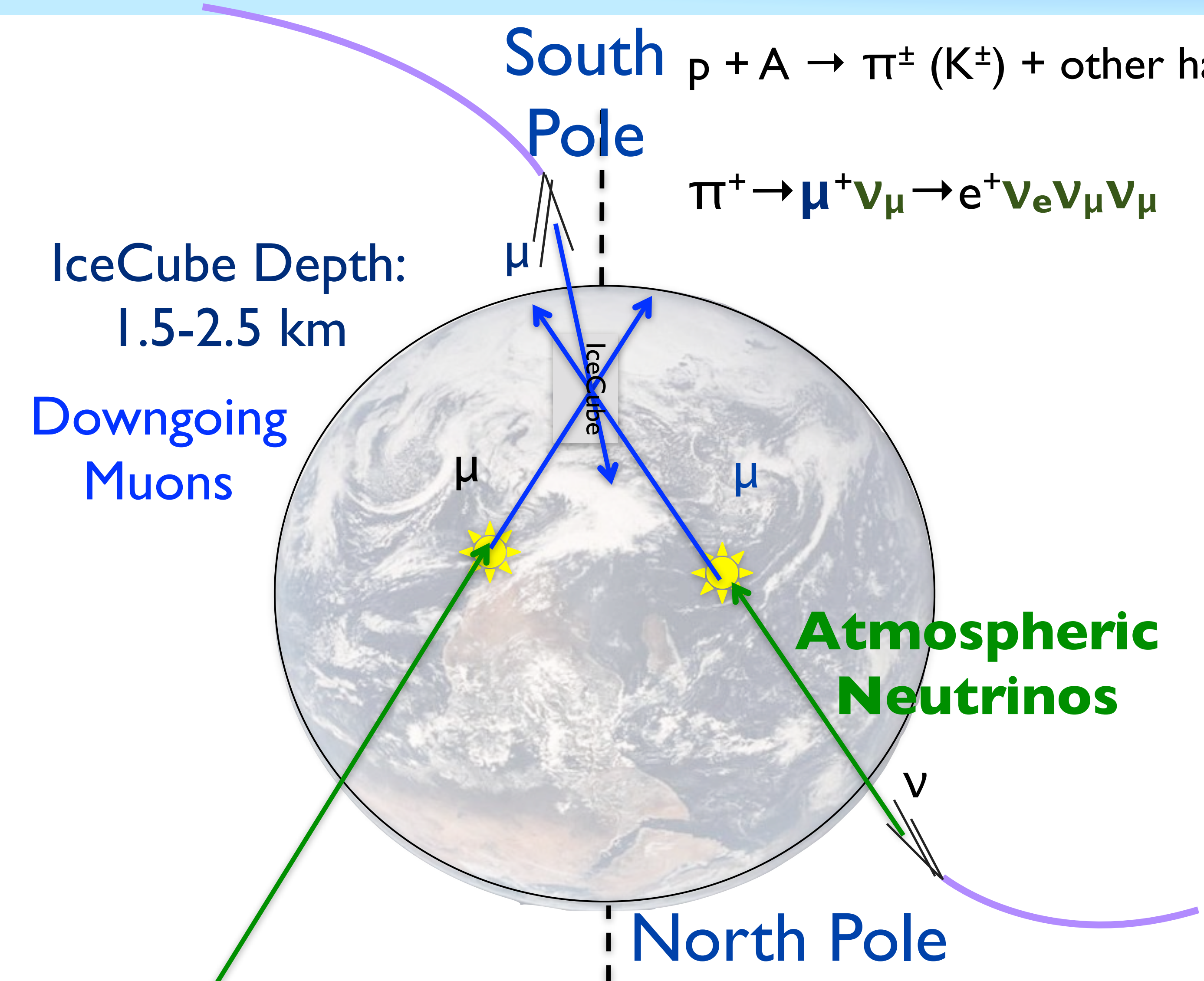
Conclusions



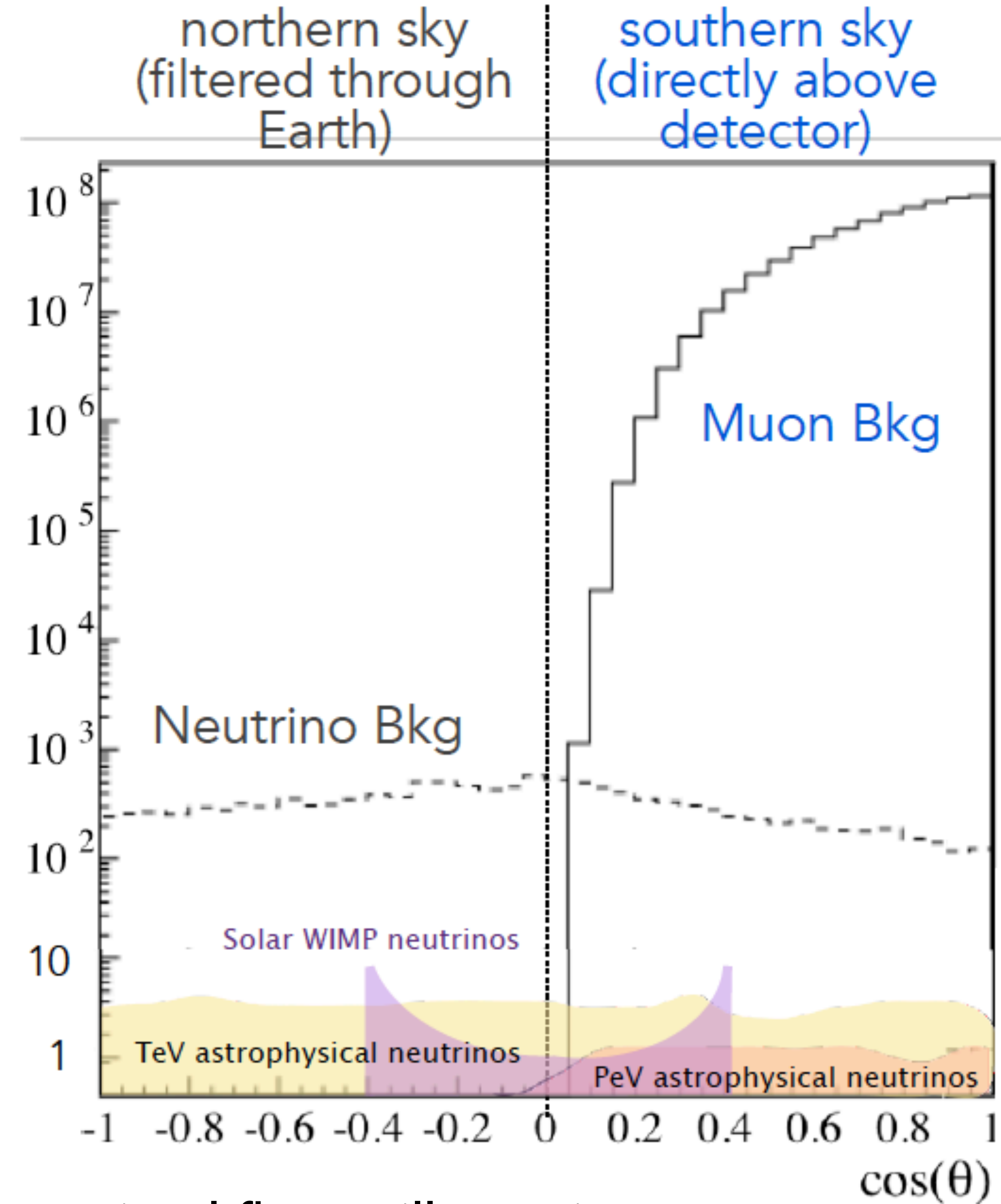
- Striking WIMP signatures provide high discovery potential for indirect searches
- Models motivated by positron excess and gamma-ray observations can and have been tested with neutrinos
- IceCube provides world best limit on SD WIMP-Proton scattering cross section
- PINGU will be able to extend IceCube sensitivity to evaporation region

Thanks !

Signals in IceCube



- Up-going events can be used to obtain "clean" neutrino sample
  - Earth is used as muon filter
- Atmospheric neutrinos create irreducible neutrino background to extra terrestrial neutrino fluxes



signal flux as illustration

Dark Matter in the Milky Way

IceCube Dwarf Spheriodal / Galaxy Clusters

- Dwarf spheriodal galaxies, clusters of galaxies, and large galaxies represent well defined sources of Dark Matter
  - Dark Matter distribution critical for optimization, assume conservative density profile

$$\frac{d\Phi_j(\Delta\Omega, E_j)}{dE_j} = \frac{\langle\sigma v\rangle}{2m_\chi^2}\frac{dN_j}{dE_j}J(\Delta\Omega)$$

Analysis performed with 340days of IceCube 59 string data

Event selection via Boosted Decision Tree

For robustness the search windows and cut values were **optimized for 5 TeV WIMPs** and used for all WIMP-masses.

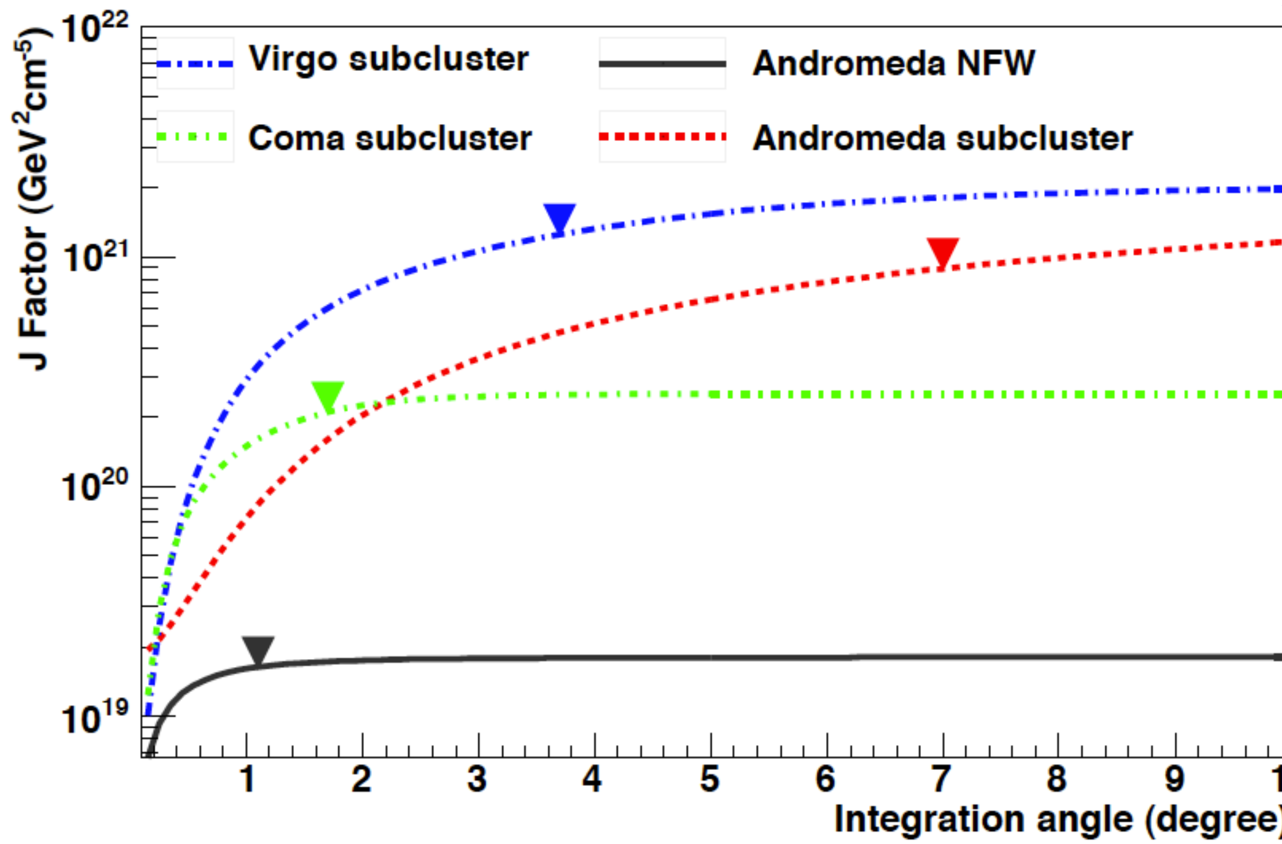
Source	declination	distance [kpc]	mass [$M_\odot$]	$\log_{10}J$ [GeV^2cm^{-5}]
Segue 1	+16°04'55"	23	1.58×10^7	19.6 ± 0.53
Ursa Major II	+63°07'48"	30	1.09×10^7	19.6 ± 0.40
Coma Berenices	+23°55'09"	44	0.72×10^7	19.0 ± 0.37
Draco	+57°54'55"	80	1.87×10^7	18.8 ± 0.13
M31	+41°16'09"	778	6.9×10^{11}	19.2 *
Virgo	+12°20'13"	22300	6.9×10^{14}	18.2 *
Coma	+27°56'20"	95000	1.3×10^{15}	17.1 *

J-factor source

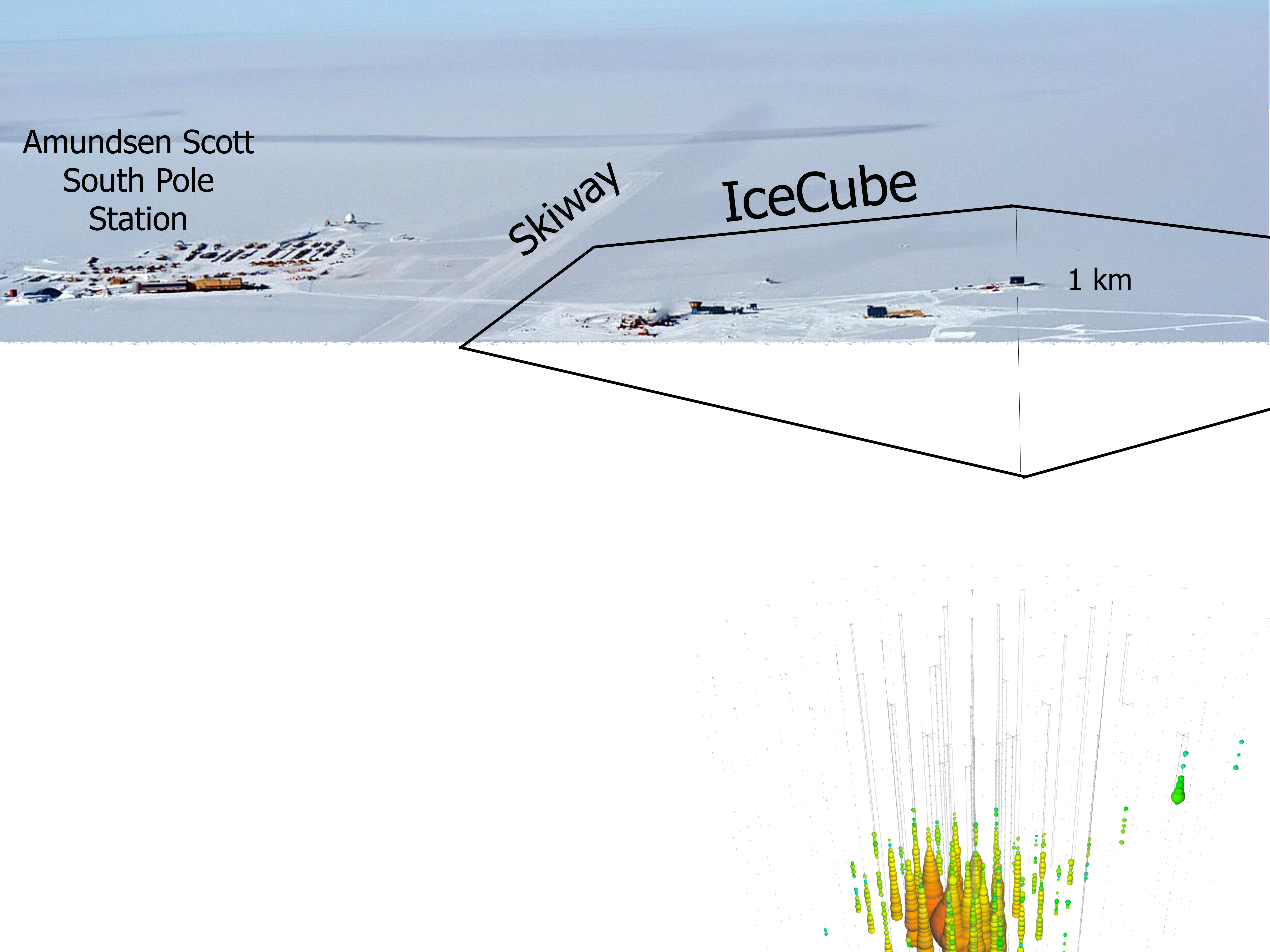
Phys. Rev. Lett. 107, 241302 (2011)

Temple et al. 0707.4374

Gao et al. Mon.Not.Roy.Astron.Soc. 419 (2012) 1721



Phys.Rev. D88 (2013) 122001
arXiv:1111.2738 [astro-ph.HE]


Amundsen Scott
South Pole
Station
Skiway
IceCube
1 km