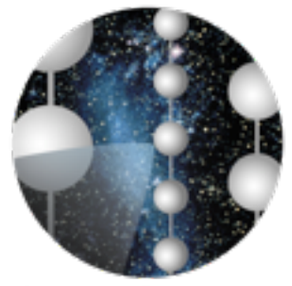
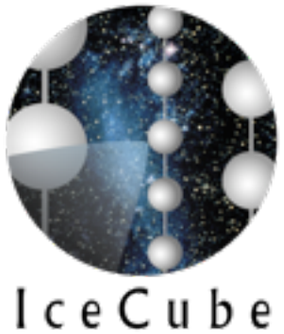
Searches for Dark Matter with IceCube



Tyce DeYoung
Department of Physics, Center for Particle Astrophysics
Pennsylvania State University
for the IceCube Collaboration

Indirect and Direct Detection of Dark Matter
Aspen Center for Physics
February 6, 2011

The IceCube Collaboration



University of Alabama
University of Alaska, Anchorage
University of California, Berkeley
University of California, Irvine
Clark-Atlanta University
Bartol Research Institute, University of Delaware
Georgia Institute of Technology
University of Kansas
Lawrence Berkeley Natl. Laboratory
University of Maryland
Ohio State University
Pennsylvania State University
Southern University and A&M College
University of Wisconsin, Madison
University of Wisconsin, River Falls

RWTH Aachen
Ruhr-Universität Bochum
Universität Bonn
DESY, Zeuthen
Universität Dortmund
MPIfK Heidelberg
Humboldt Universität, Berlin
Universität Mainz
BUGH Wuppertal

Stockholms Universitet
Uppsala Universitet

Vrije Universiteit Brussel
Université Libre de Bruxelles
Universiteit Gent
Université de Mons

University of Alberta

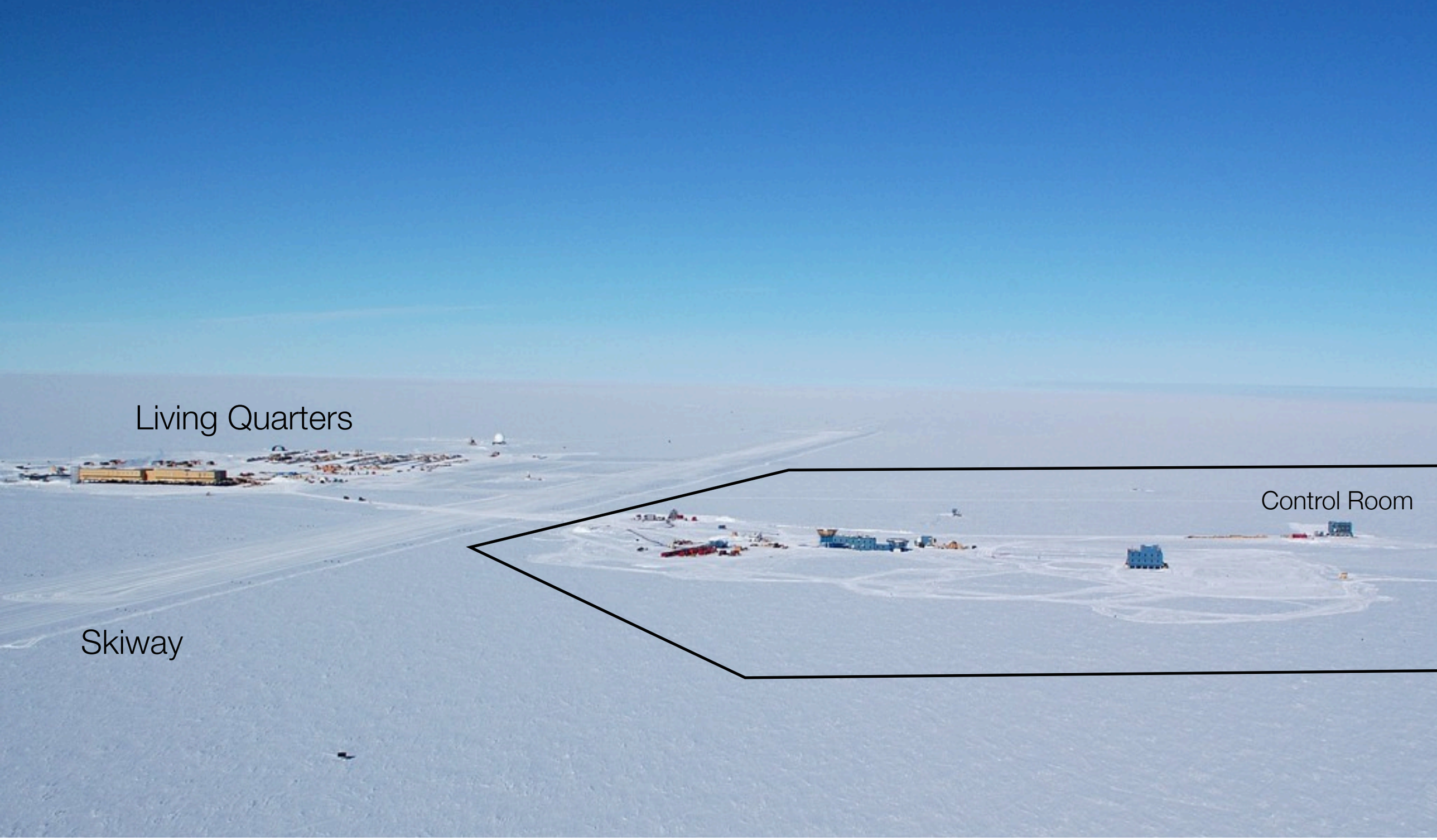
Chiba University

University of Canterbury

EPF Lausanne

Oxford University

University of the West Indies



IceCube

One km^3 of extremely transparent polar ice
Buried 1.5 - 2.5 km below the surface of the ice cap
Amundsen-Scott South Pole Station

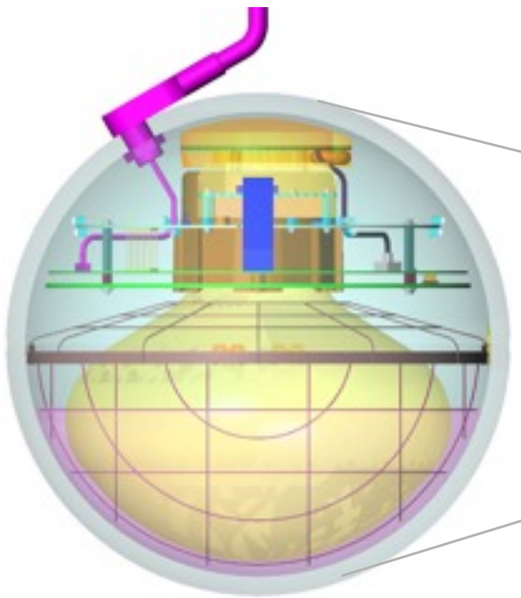
IceCube

5160 DOMs on 86 strings

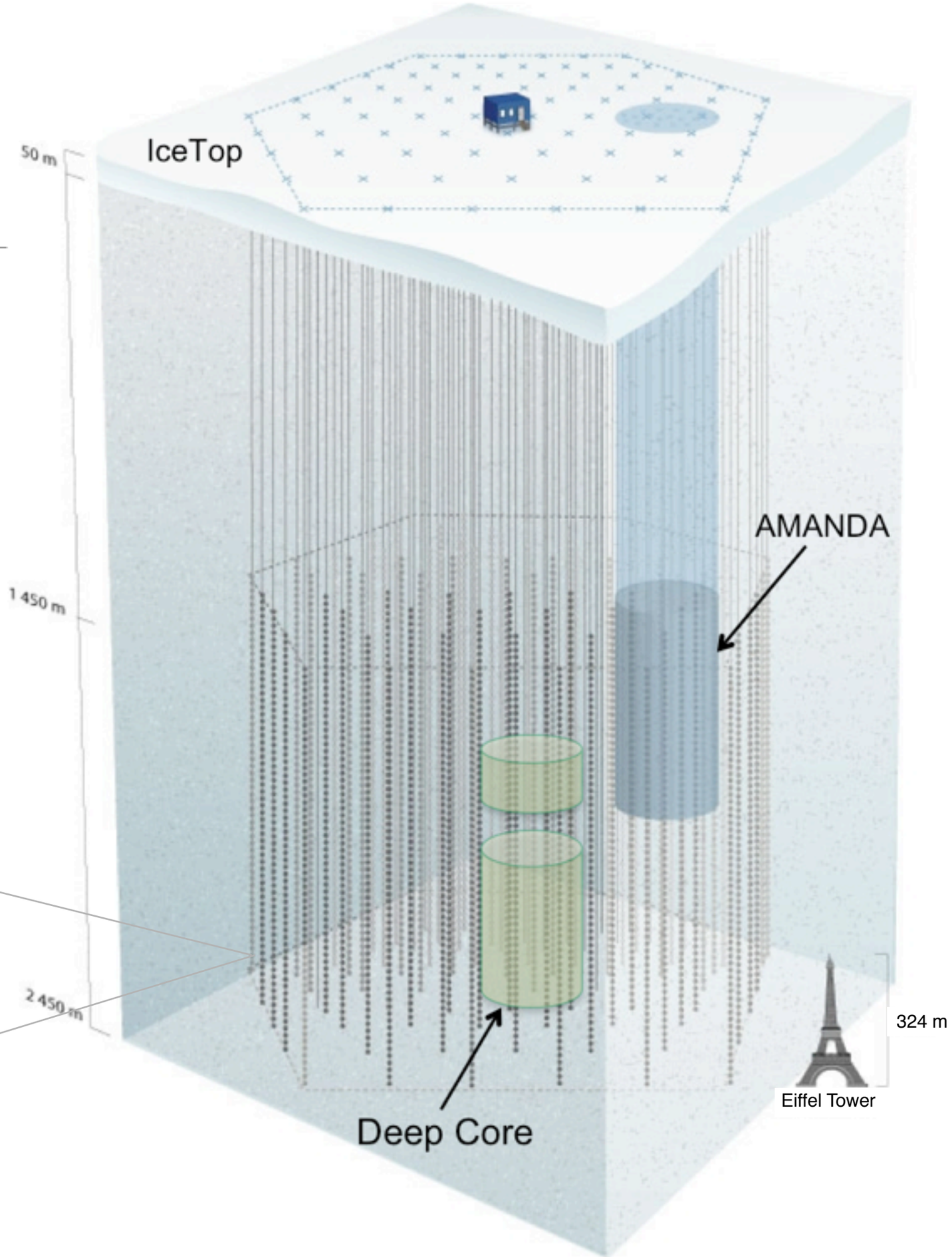
160 tank ice-Cherenkov surface air shower array (IceTop)

Includes DeepCore infill array (sensitivity to lower energies)

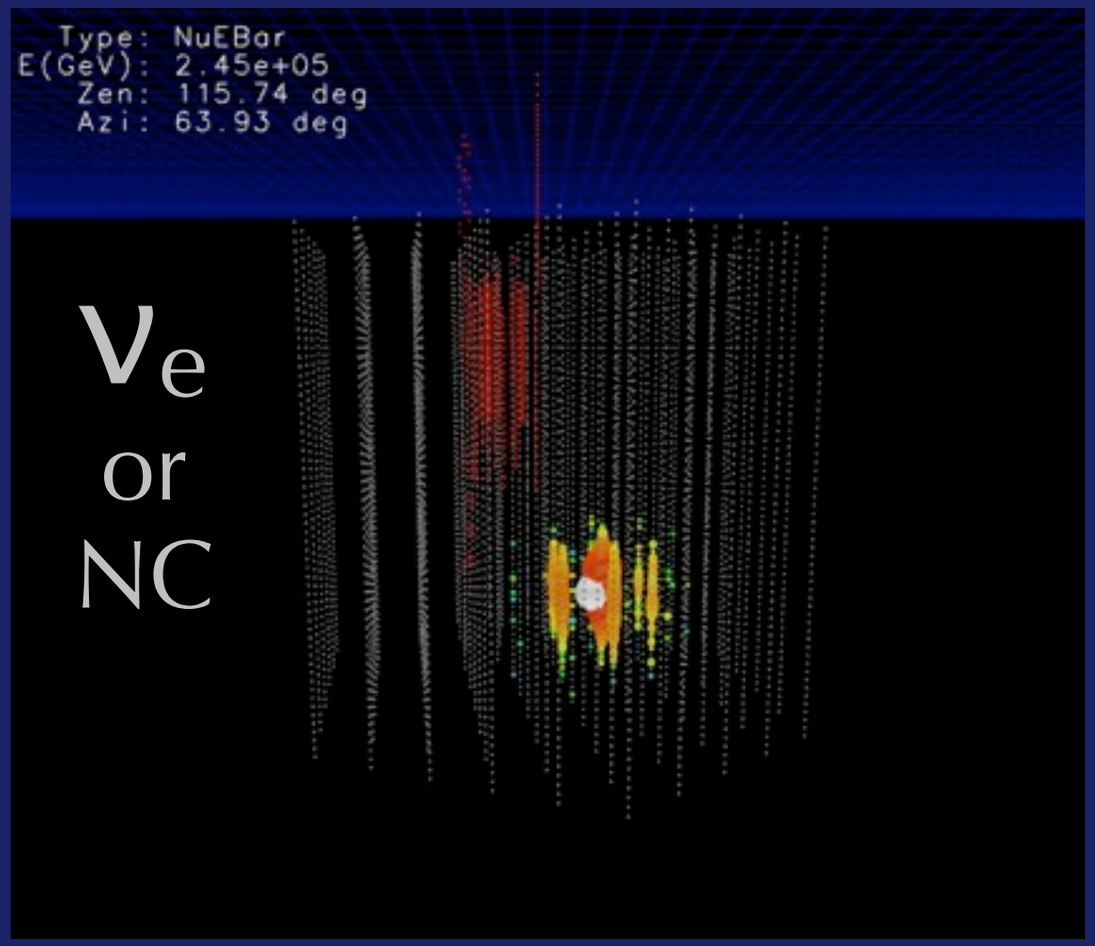
All strings now deployed after 7 construction seasons

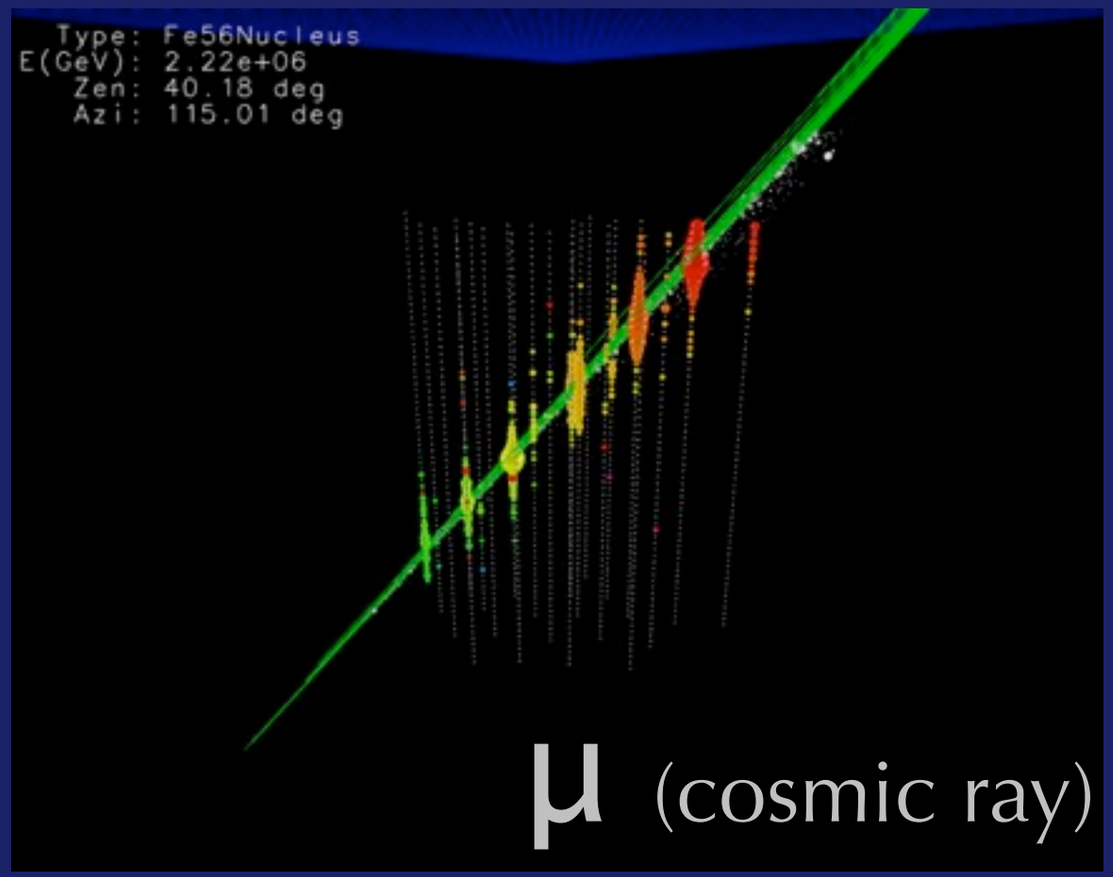


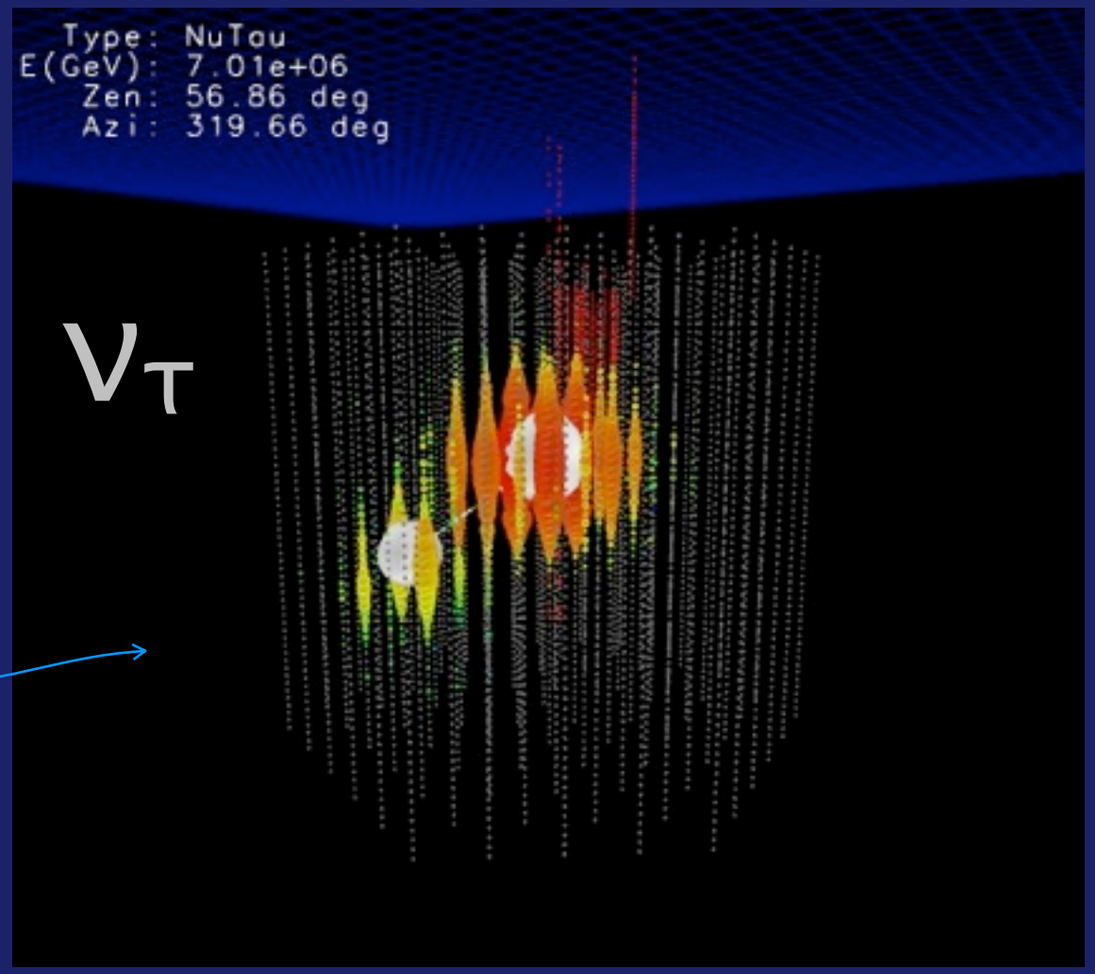
Digital Optical Module (DOM)



Neutrino Signatures



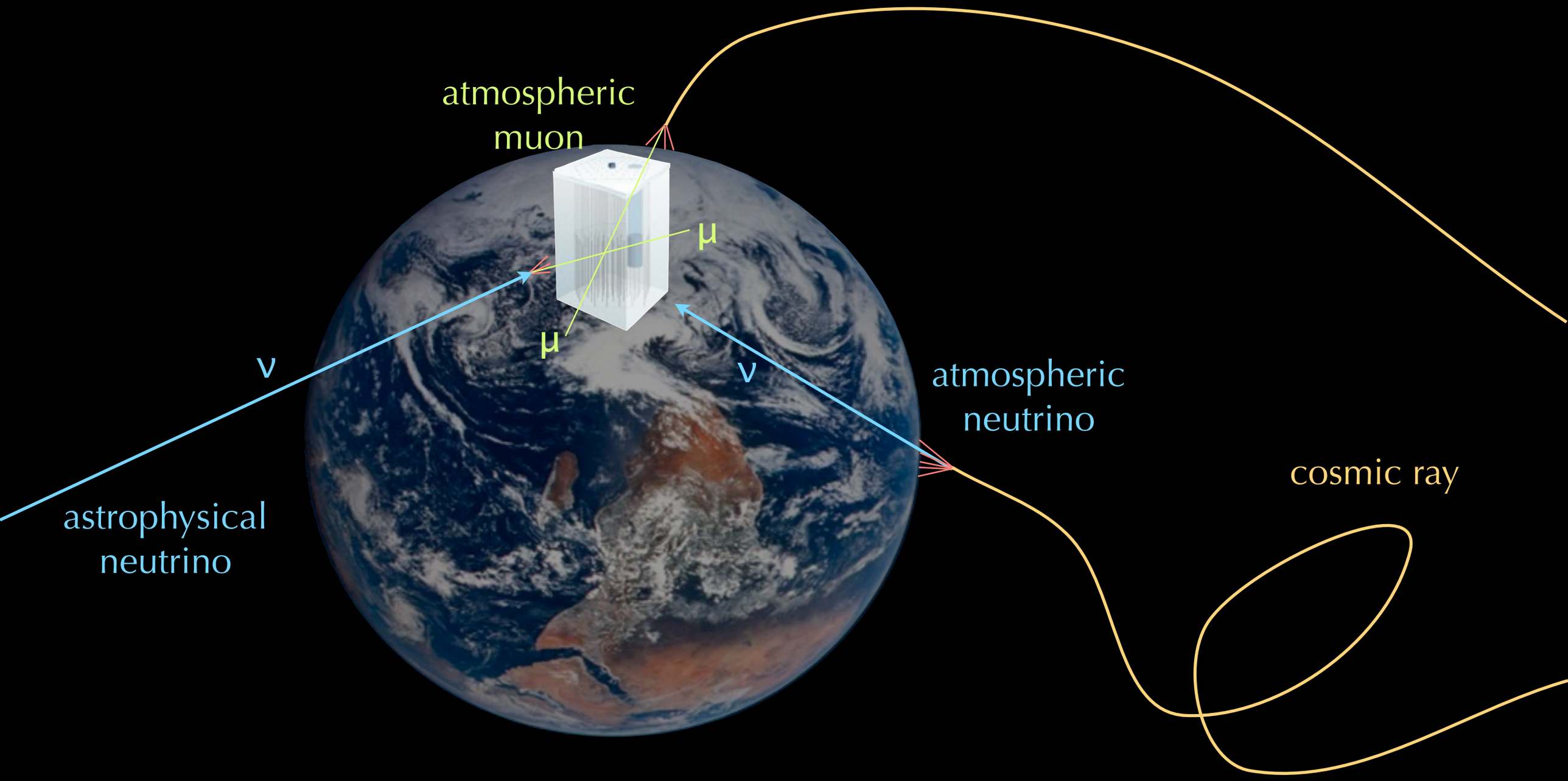




"Double Bang":
One of several tau signatures : lollipop, inverted lollipop, etc…

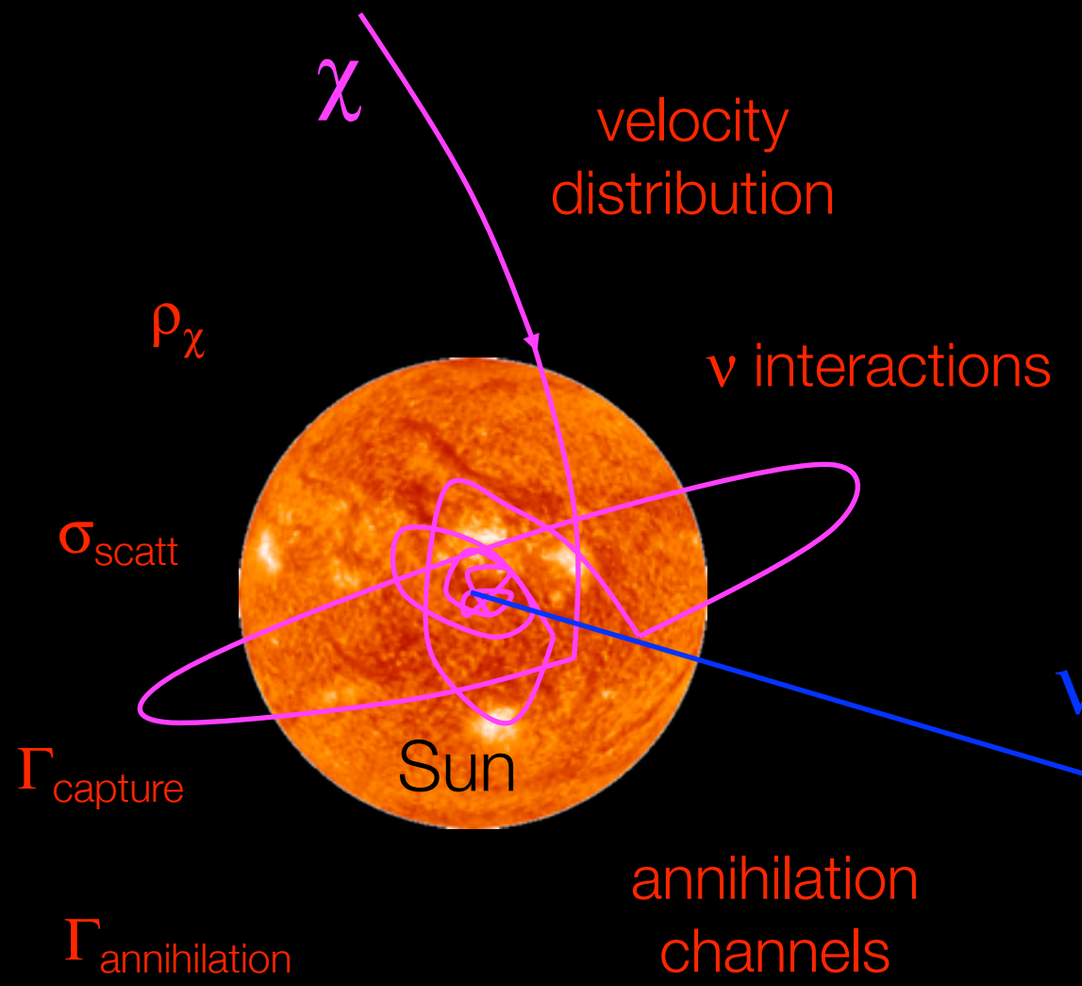
(Learned & Pakvasa, Beacom et al.,…)

Signals and Backgrounds

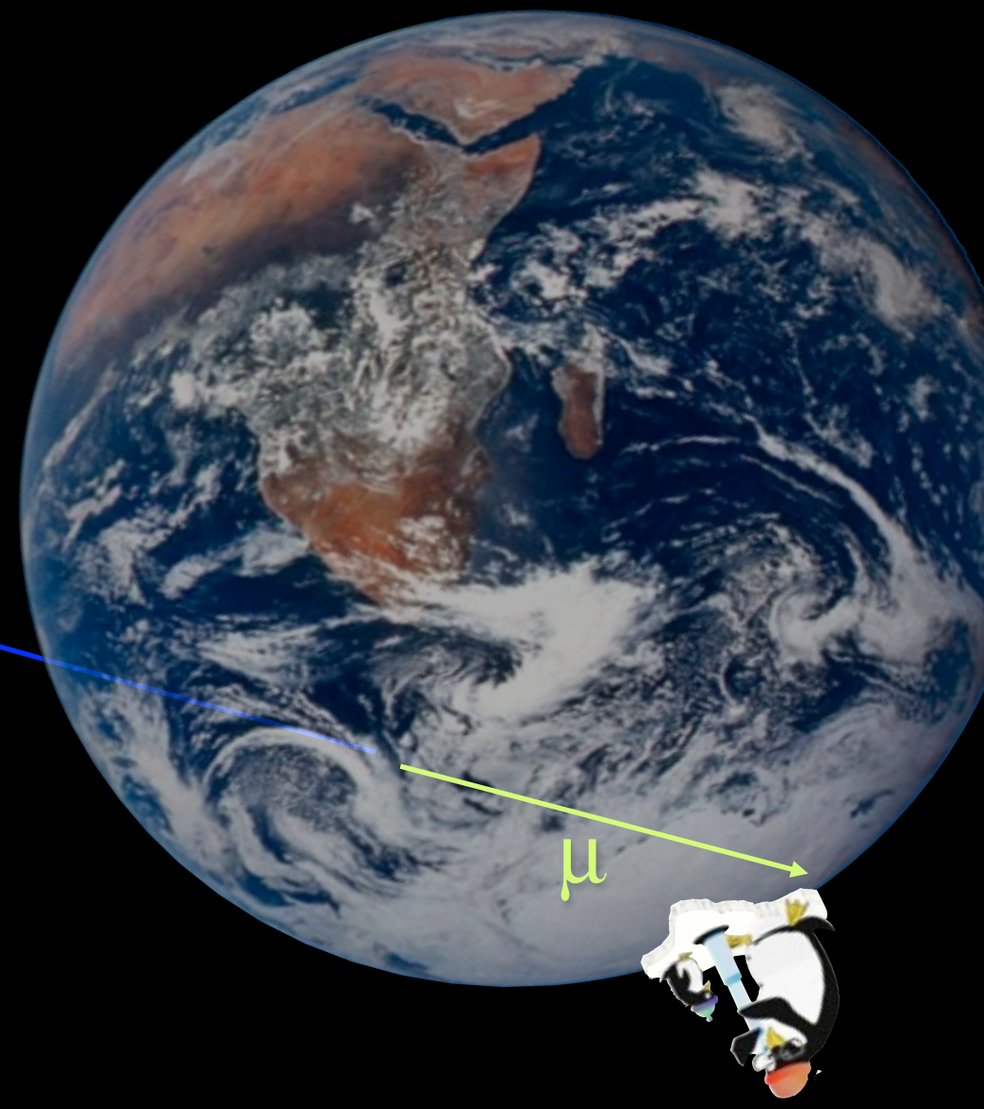


Reconstruct muon track from pattern of Cherenkov light,
assume muon is aligned with primary neutrino

Indirect Detection of Dark Matter



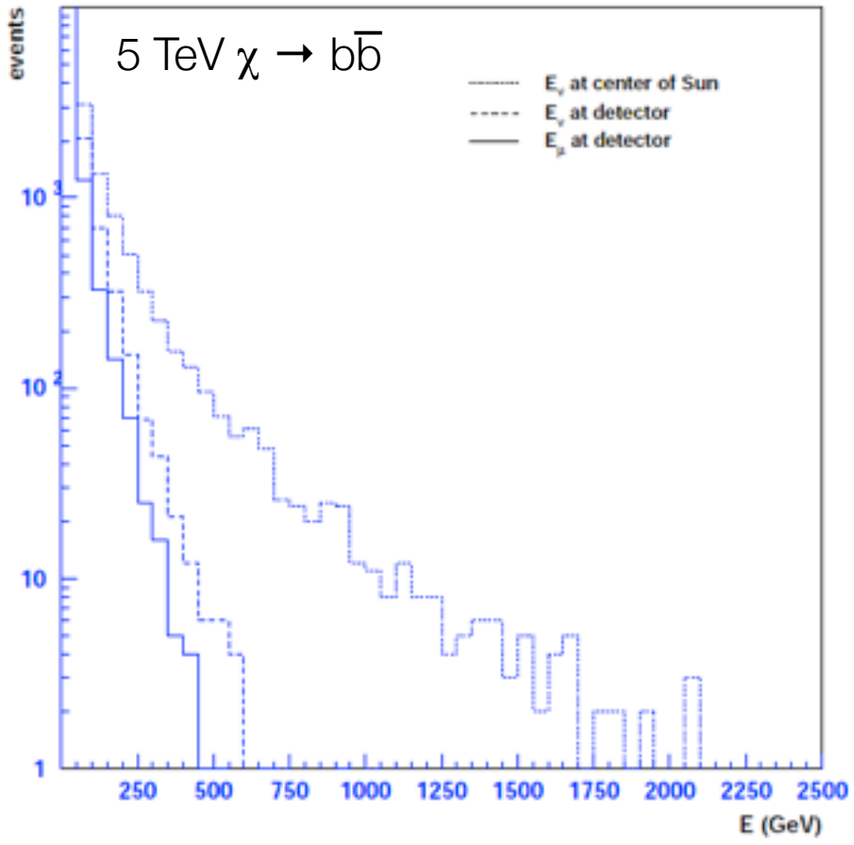
Similar accumulation in Galactic and terrestrial gravitational wells, dwarf spheroidals

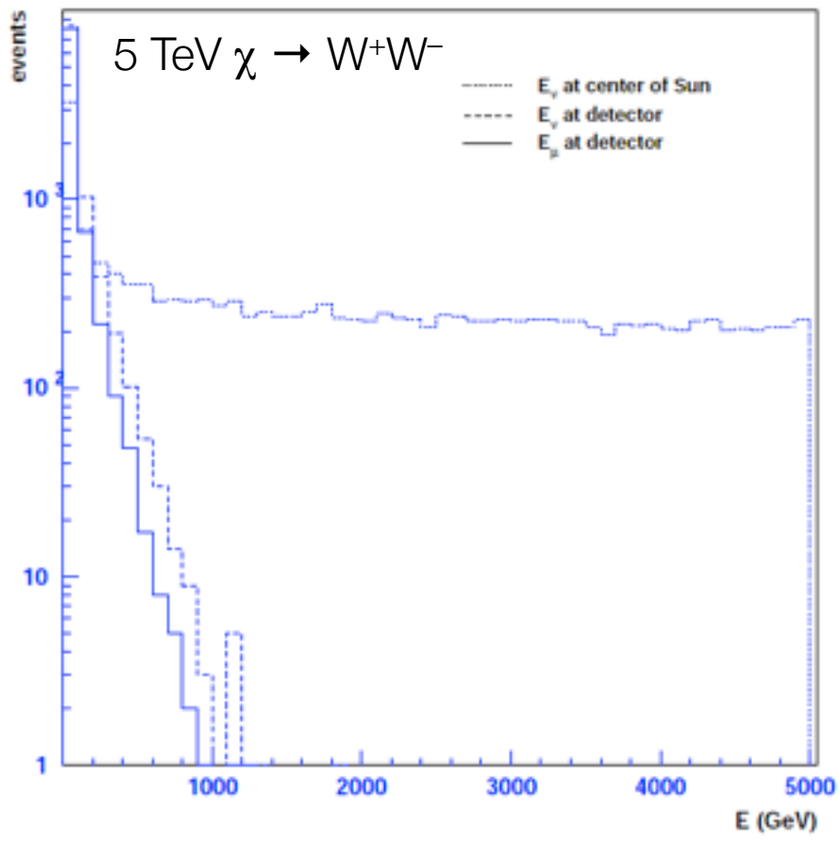


Silk, Olive and Srednicki, ’85
Gaisser, Steigman & Tilav, ’86
Freese, ’86
Krauss, Srednicki & Wilczek, ’86
Gaisser, Steigman & Tilav, ’86
et alia

IceCube can also probe dark matter decay models, other types of dark matter

Expected Neutrino Energy Spectrum



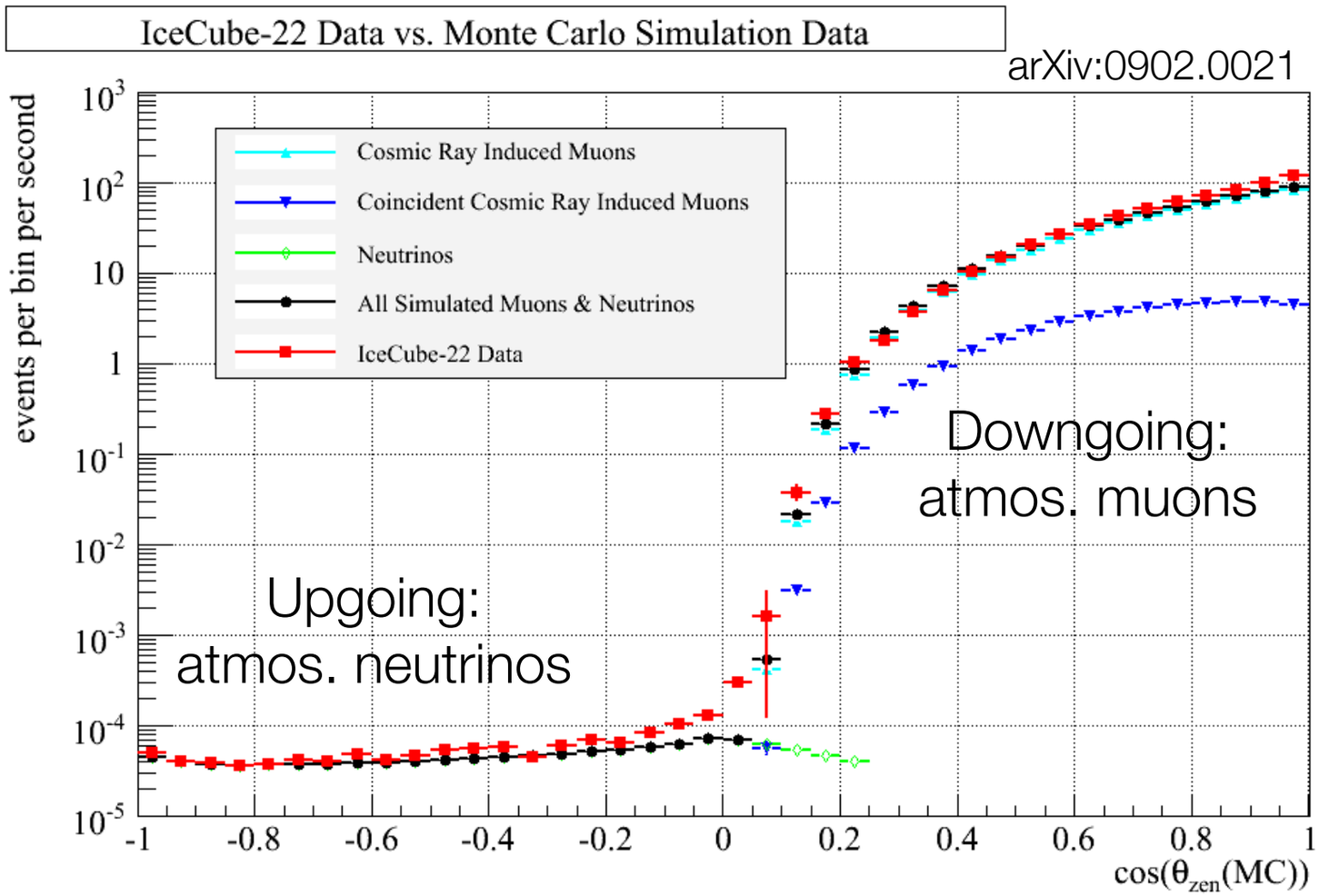


- All neutrinos from the Sun are low energy for IceCube (few hundred GeV), even for the highest dark matter masses
- For Galactic and Earth searches, no significant neutrino energy losses in dense medium, so higher energy neutrinos possible

Background Rejection

- Event quality parameters and multivariate methods used to reject misreconstructed atmospheric muons

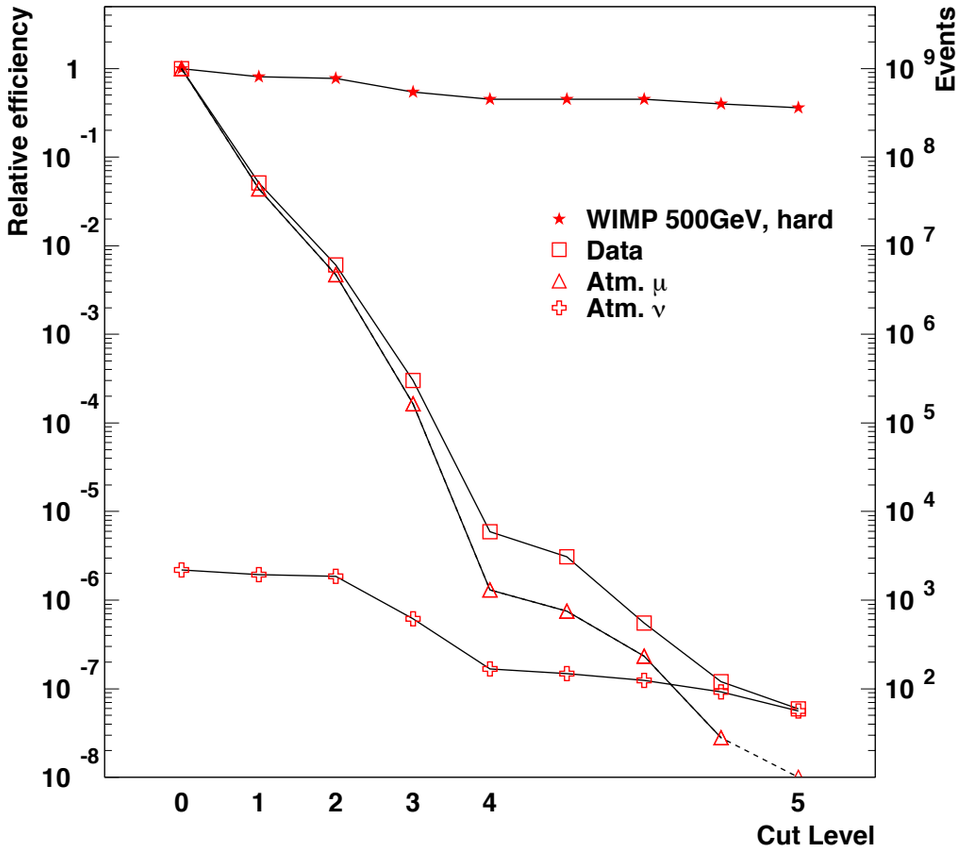
- Search for low energy tracks from below horizon (March – Sept.)



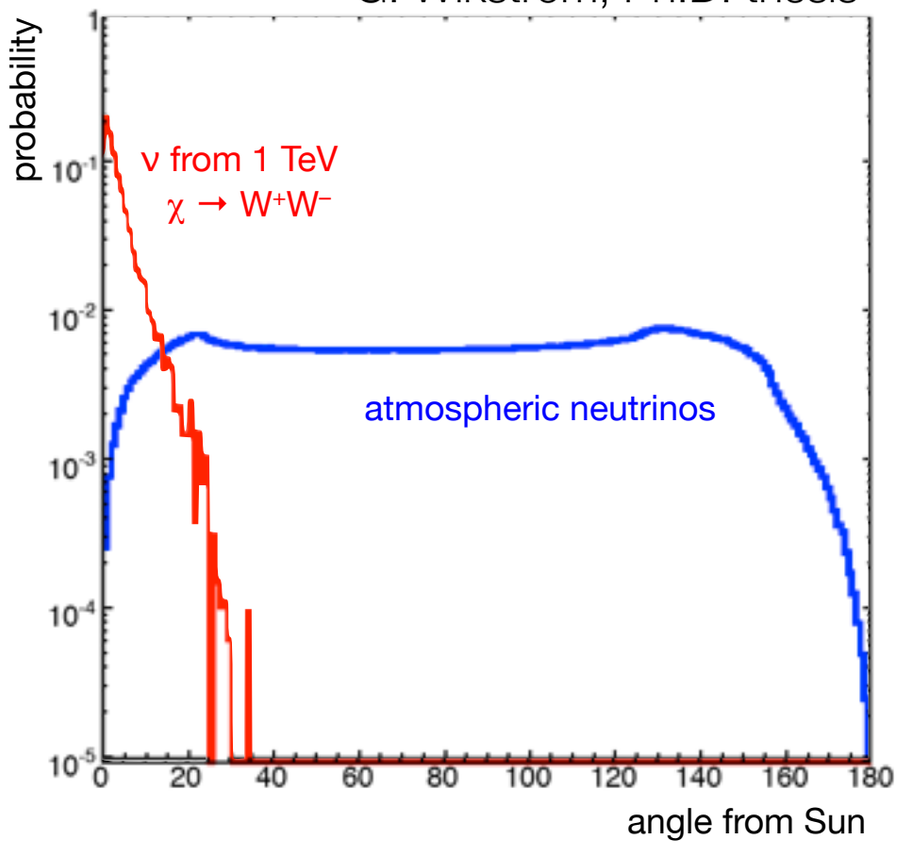
- Analyses of 22-string IceCube data set from 2007 and AMANDA 2000-06 data set (preliminary) will be shown
  - Most restrictive limits shown; IceCube more sensitive at higher masses

Signal Selection

Astropart. Phys. 24. 459 (2006)



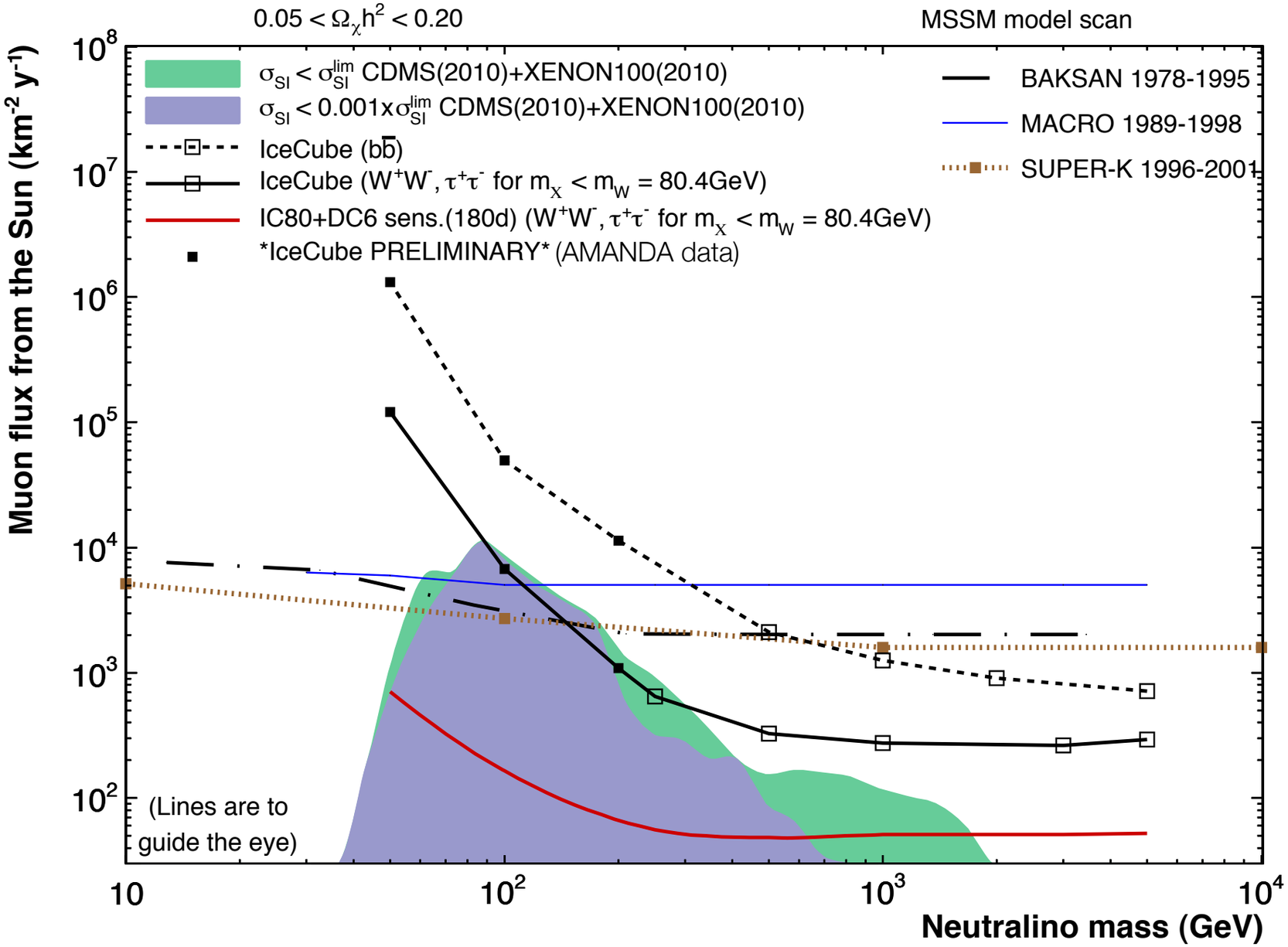
G. Wikström, Ph.D. thesis



- Signal selection efficiency typically $\mathcal{O}(20\%)$
- Remaining data set dominated by atmospheric neutrinos
- Look for excess coming from direction of the Sun, use shape analysis to limit flux due to dark matter

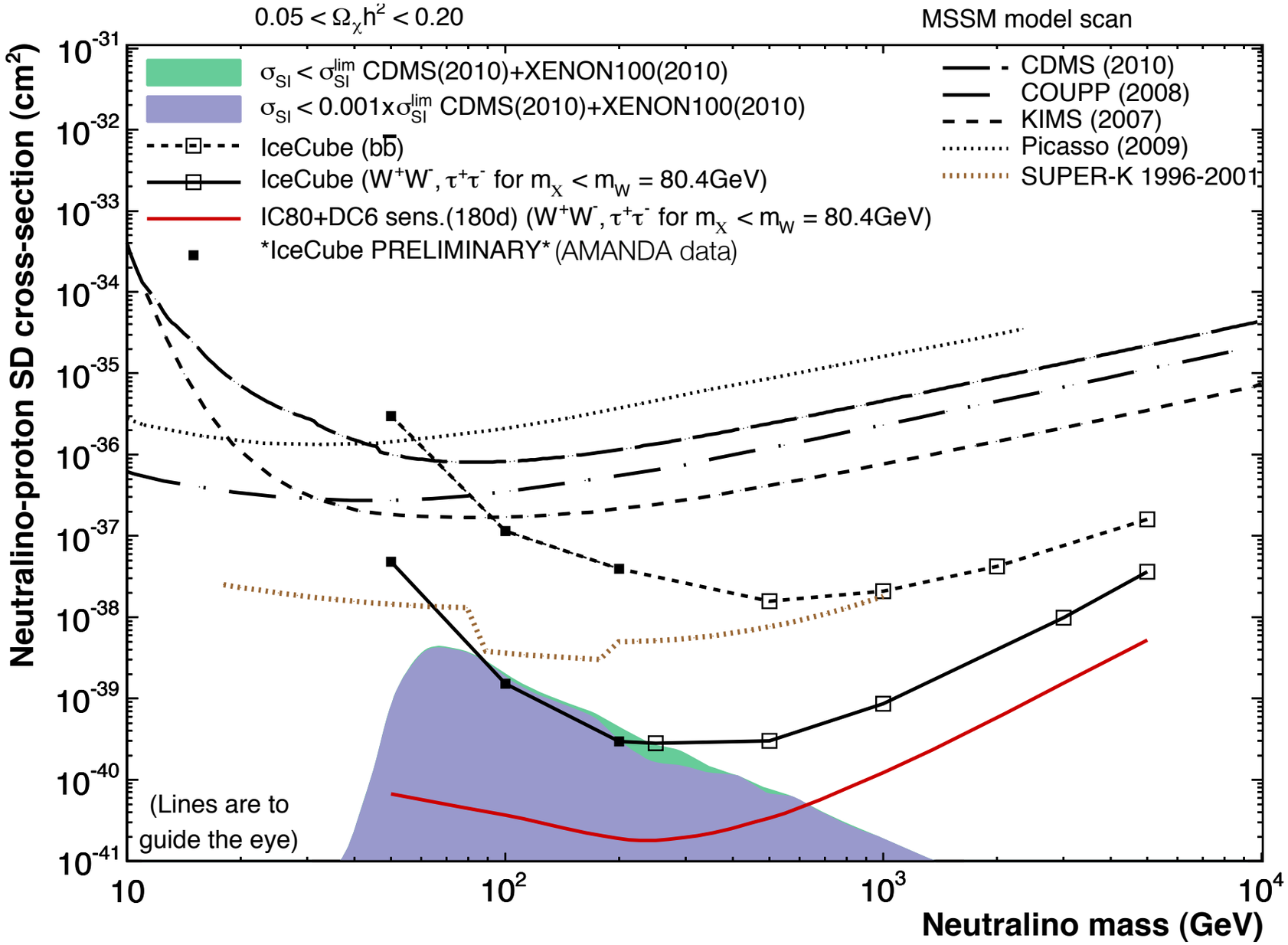
Limits on Muon Flux

Phys. Rev. Lett. 102, 201302 (2009)



For given MSSM parameters, use DarkSUSY and detector simulation to predict muon flux – depends on WIMP mass and branching ratios ($\chi\chi \rightarrow X$)

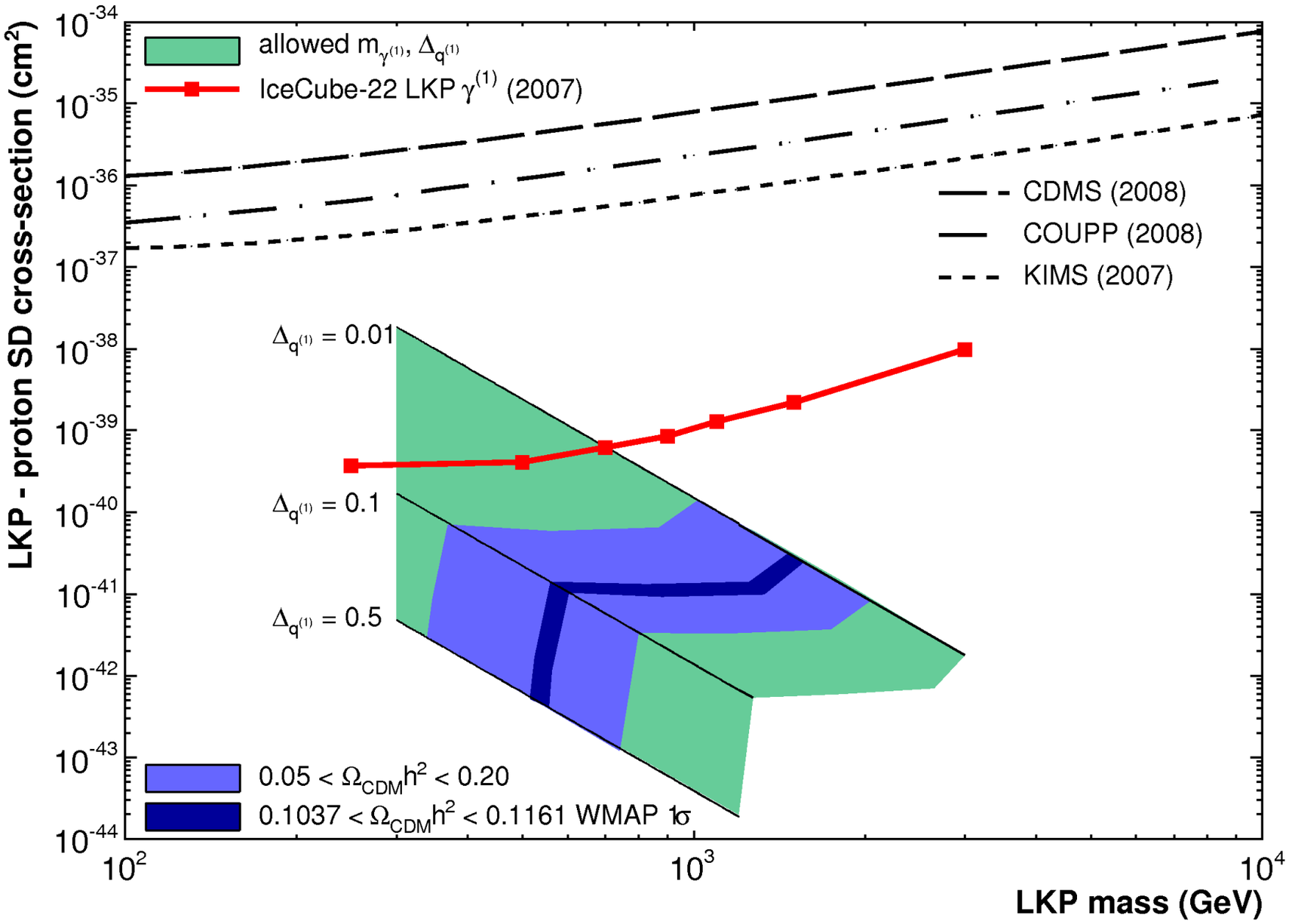
Limits on Scattering Cross Section



Assume equilibrium between capture and annihilation in Sun, capture rate dominated by spin-dependent scattering (can also limit SI scattering)

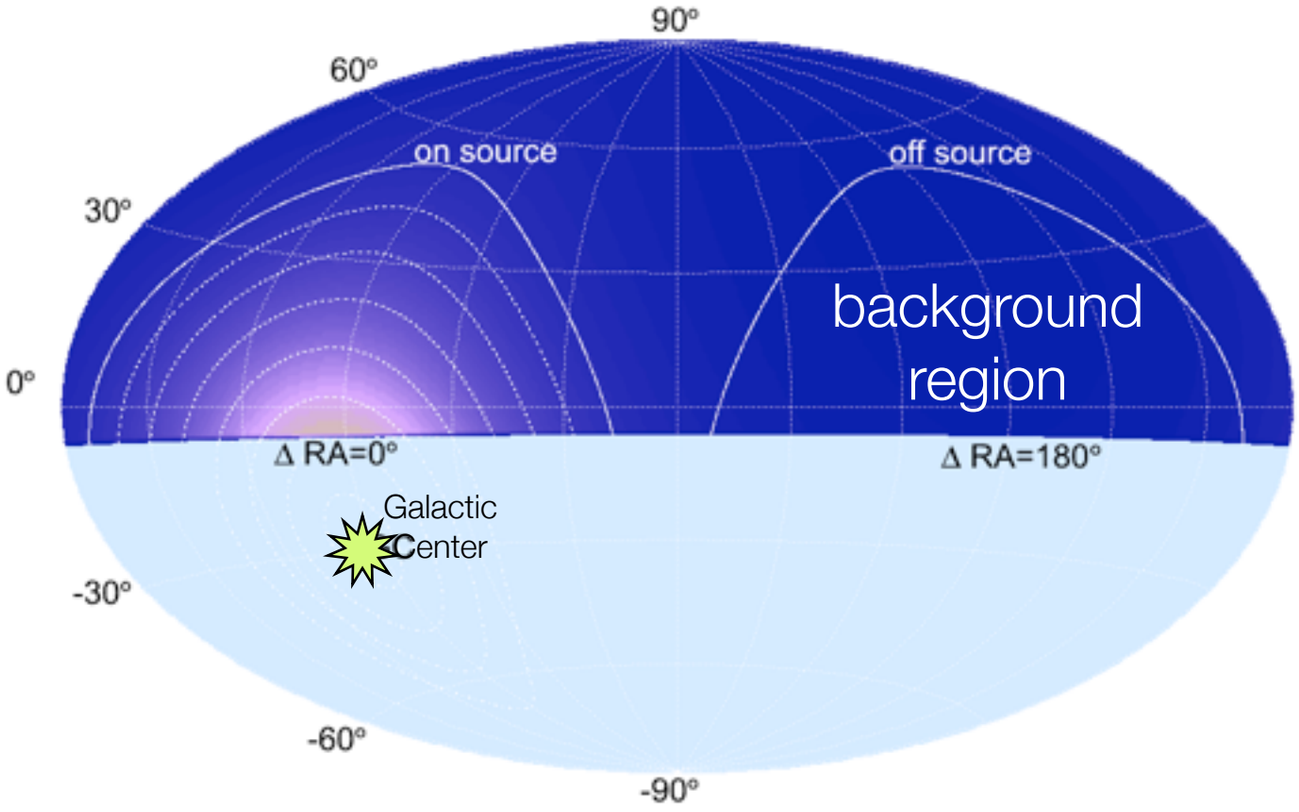
Kaluza-Klein Particles

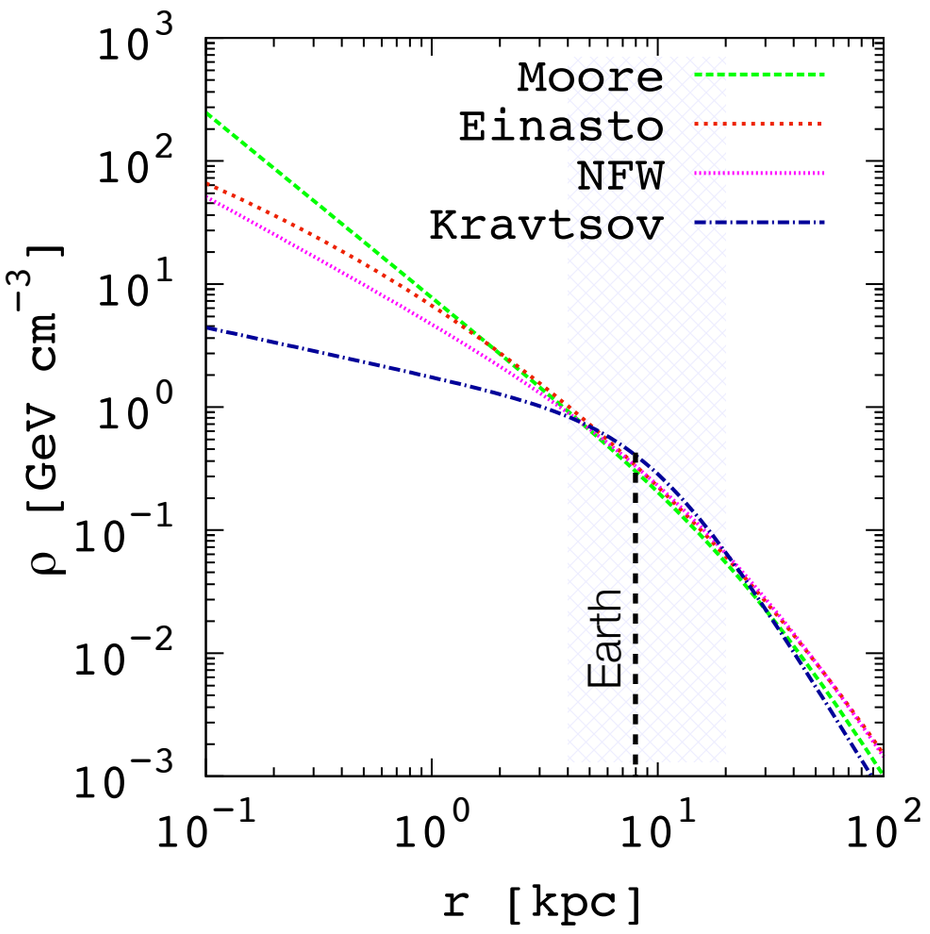
Phys. Rev. D81, 057101 (2010)



Can reinterpret limit by calculating expected muon flux in models of universal extra dimensions to limit LKP scattering cross section

Dark Matter in the Galactic Halo

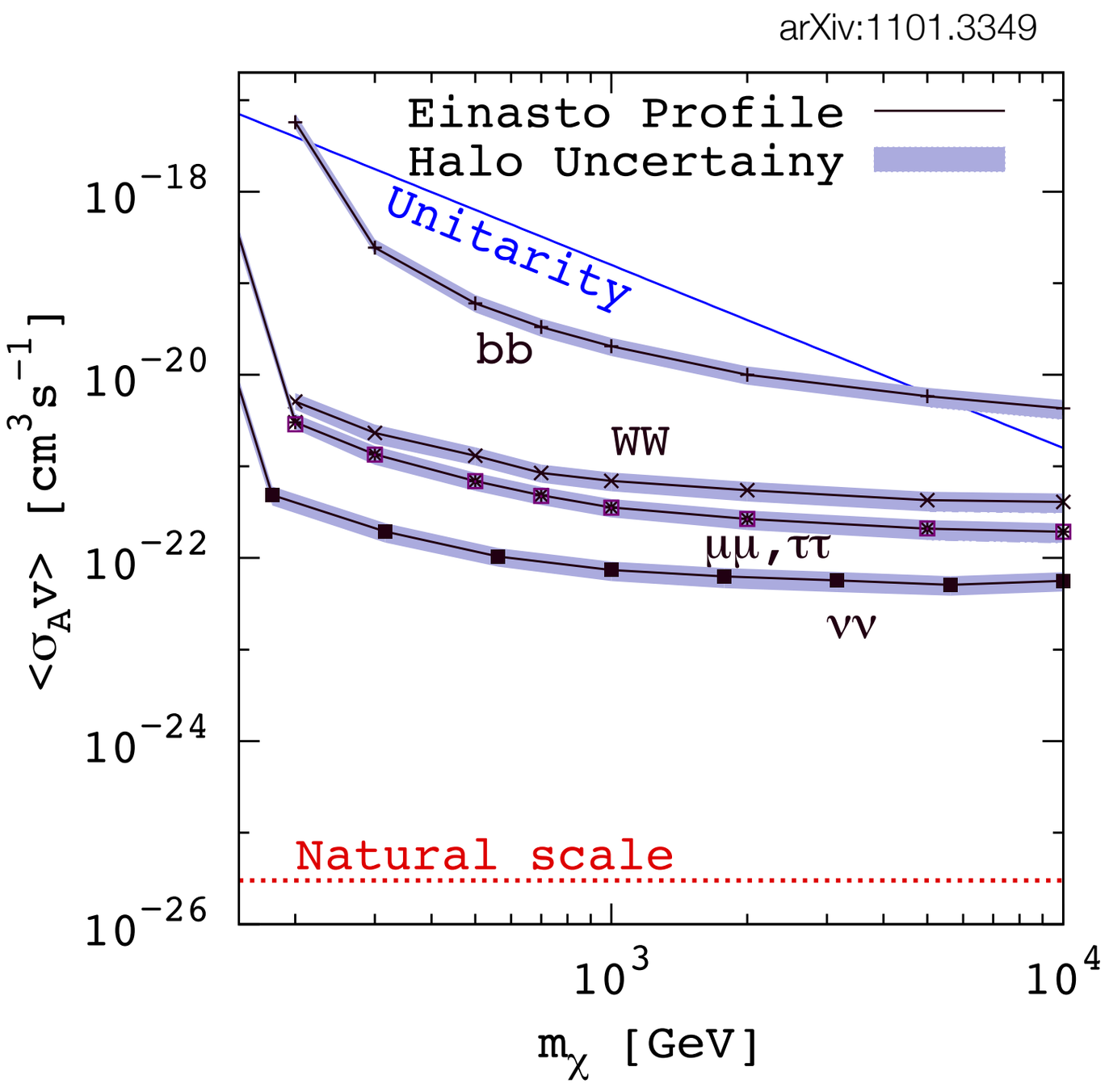




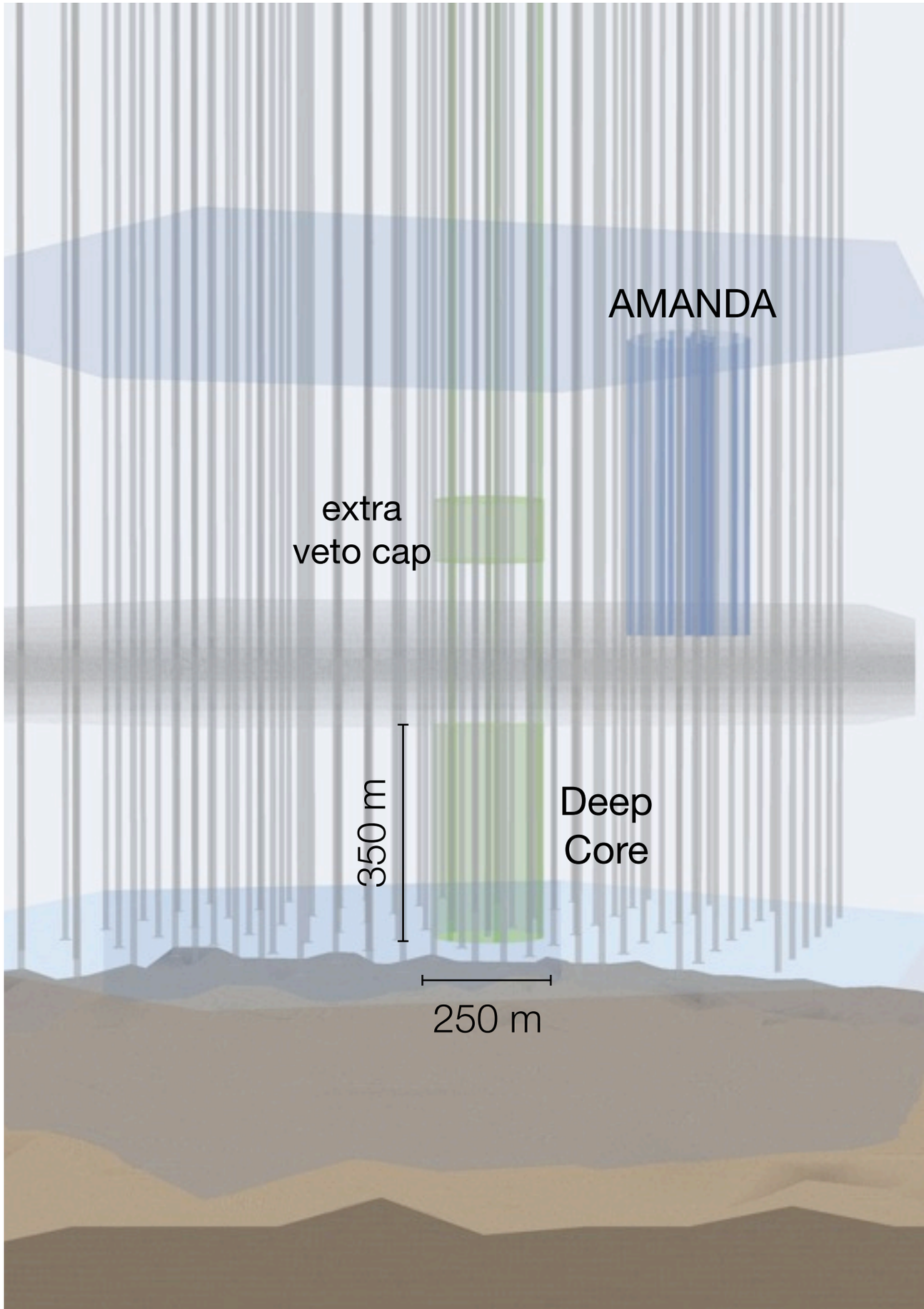
- Look for spatially-extended excess neutrino flux from the halo using the point source sky map
  - Galactic Center in Southern sky – above horizon for IceCube
- Weak dependence on halo distribution when looking so far away from GC

Limits on Annihilation in the Halo

- Probes $\langle\sigma_A v\rangle$ rather than $\sigma_{\chi N}$
- Cleaner analysis than for Solar dark matter
  - No neutrino energy losses after WIMP annihilation
  - No dependence on χN scattering assumptions
- Present limits in physically relevant region but still well above natural scale

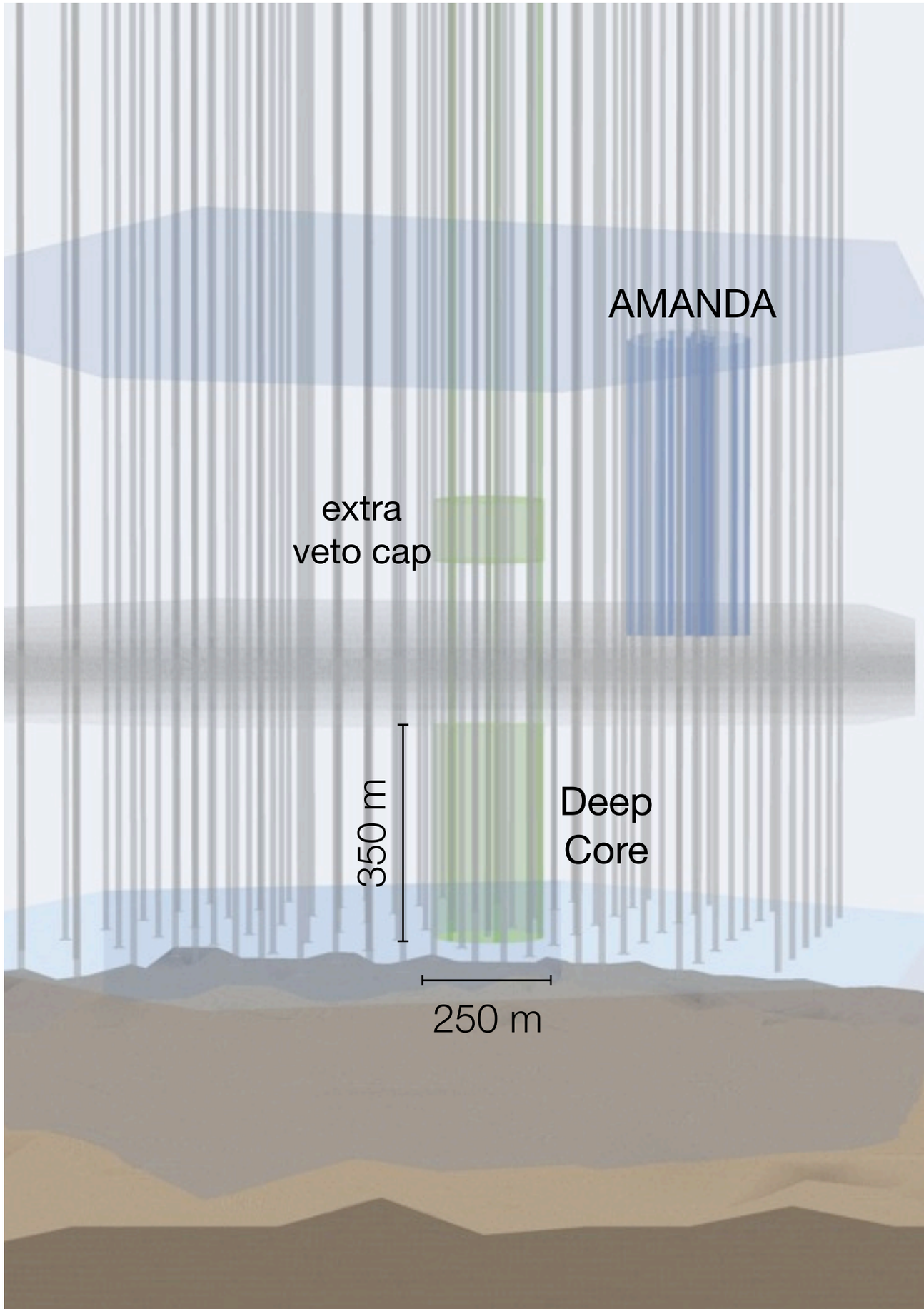


IceCube DeepCore



IceCube DeepCore

- Eight special strings plus 7 nearest standard IceCube strings
  - 72 m interstring spacing
  - 7 m DOM spacing
  - High Q.E. PMTs
  - ~5x higher effective photocathode density



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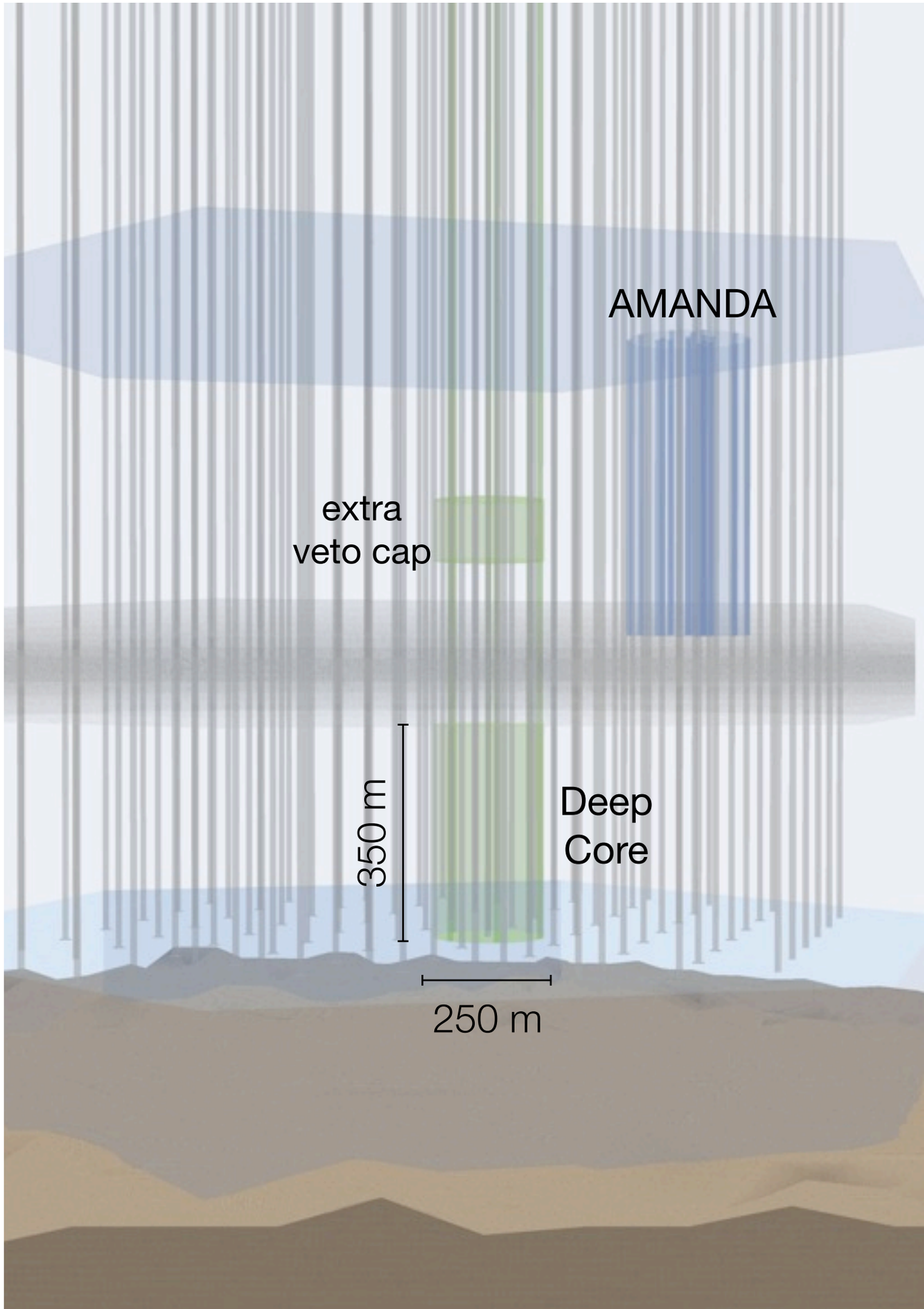
- In the clearest ice, below 2100 m
  - $\lambda_{atten} \approx$ 40-50 m (cf. 20-25 m in shallower ice)



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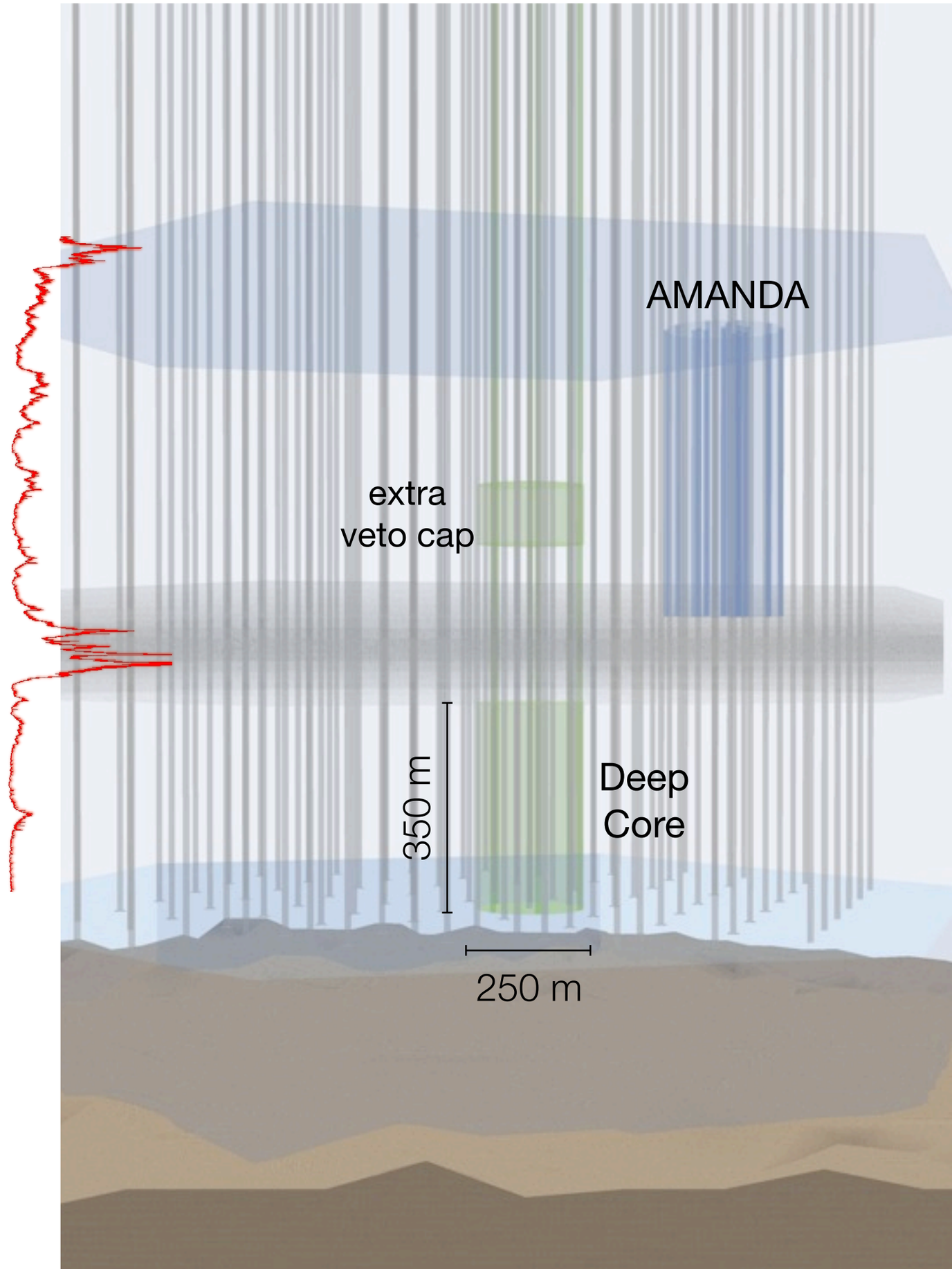
  - $\lambda_{atten} \approx$ 40-50 m (cf. 20-25 m in shallower ice)
- Up to an order of magnitude increase in event rate at energies down to 10 GeV

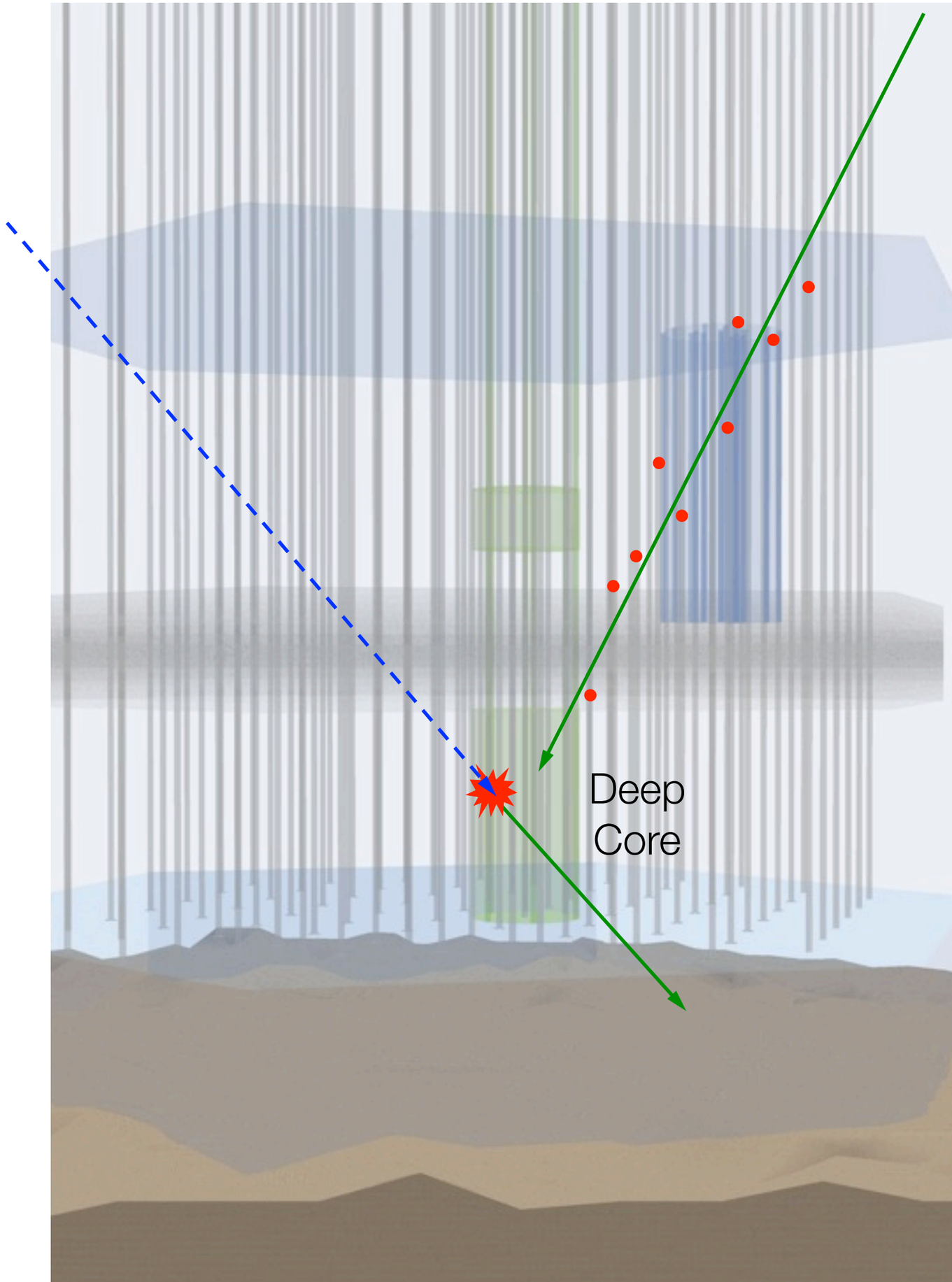


Atmospheric Muon Veto

- Top and outer layers of IceCube can be used to detect and veto atmospheric muon background

- Should provide access to neutrinos from the full sky (4π)
  - Sensitivity to Galactic Center, full-year Solar search

- Initial stage of background rejection provides 8 x 10^{-3} muon rejection with 99% signal efficiency in ~30 MTon volume
  - Further background rejection being optimized, final signal efficiency not yet known



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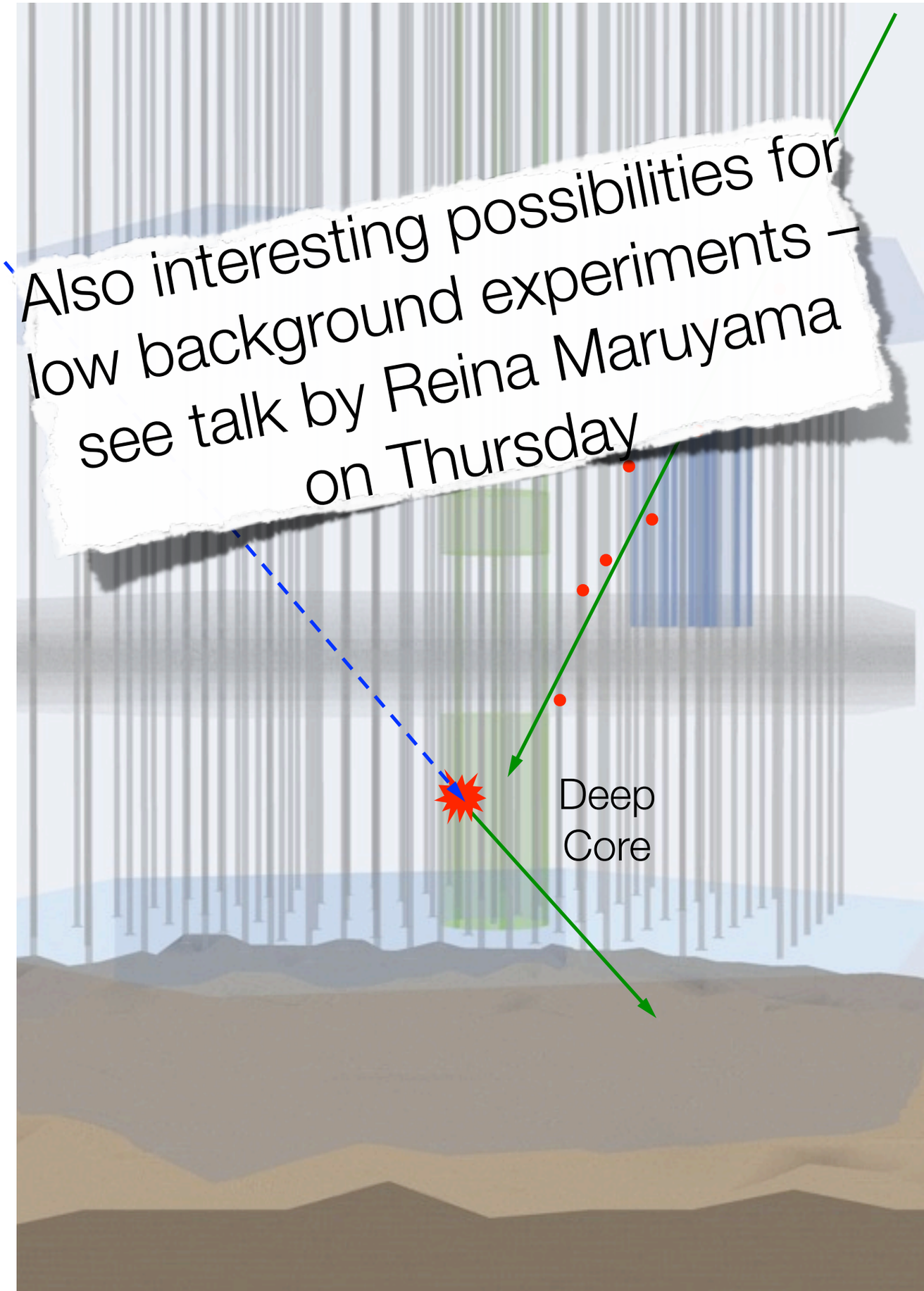
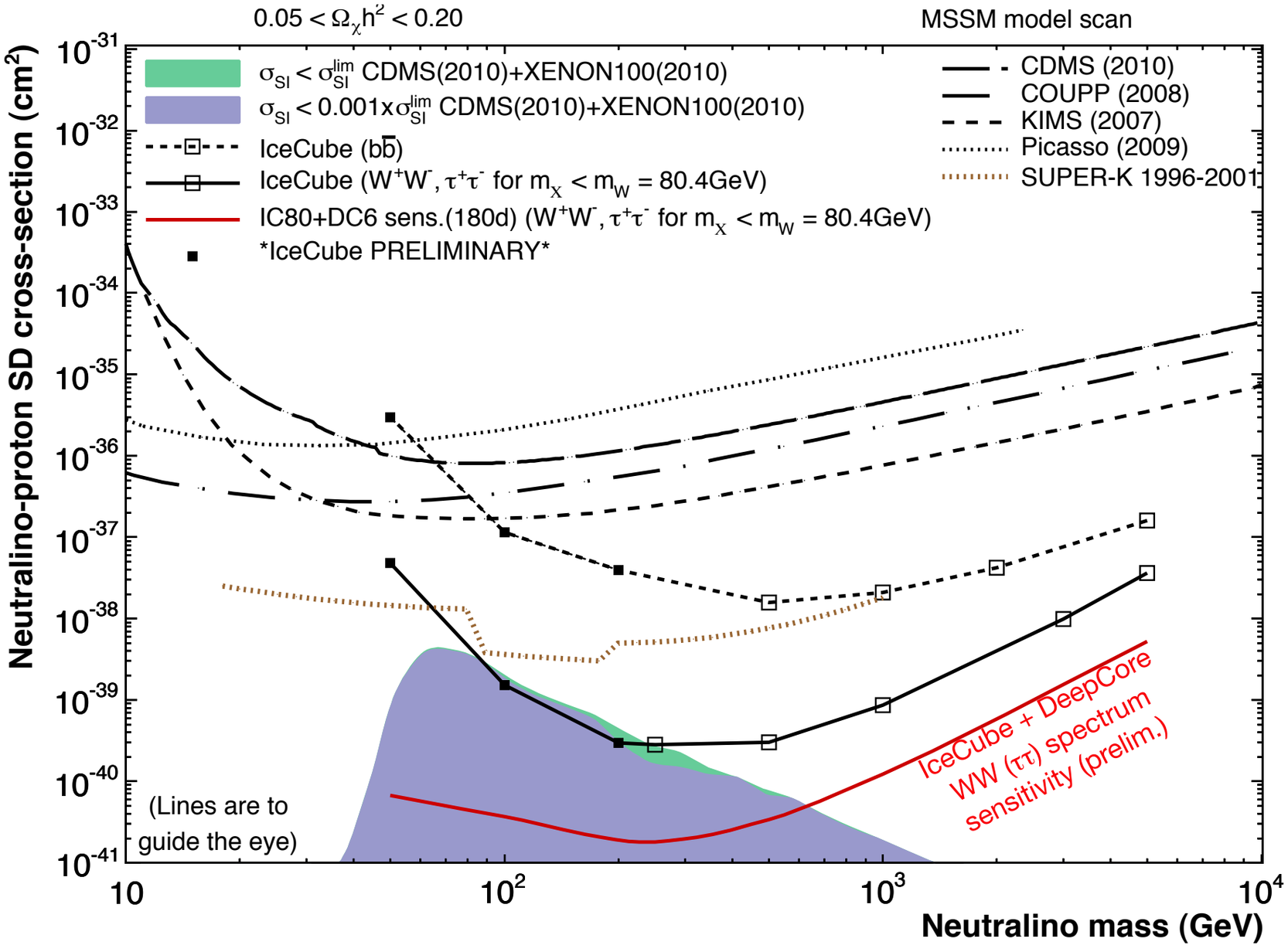
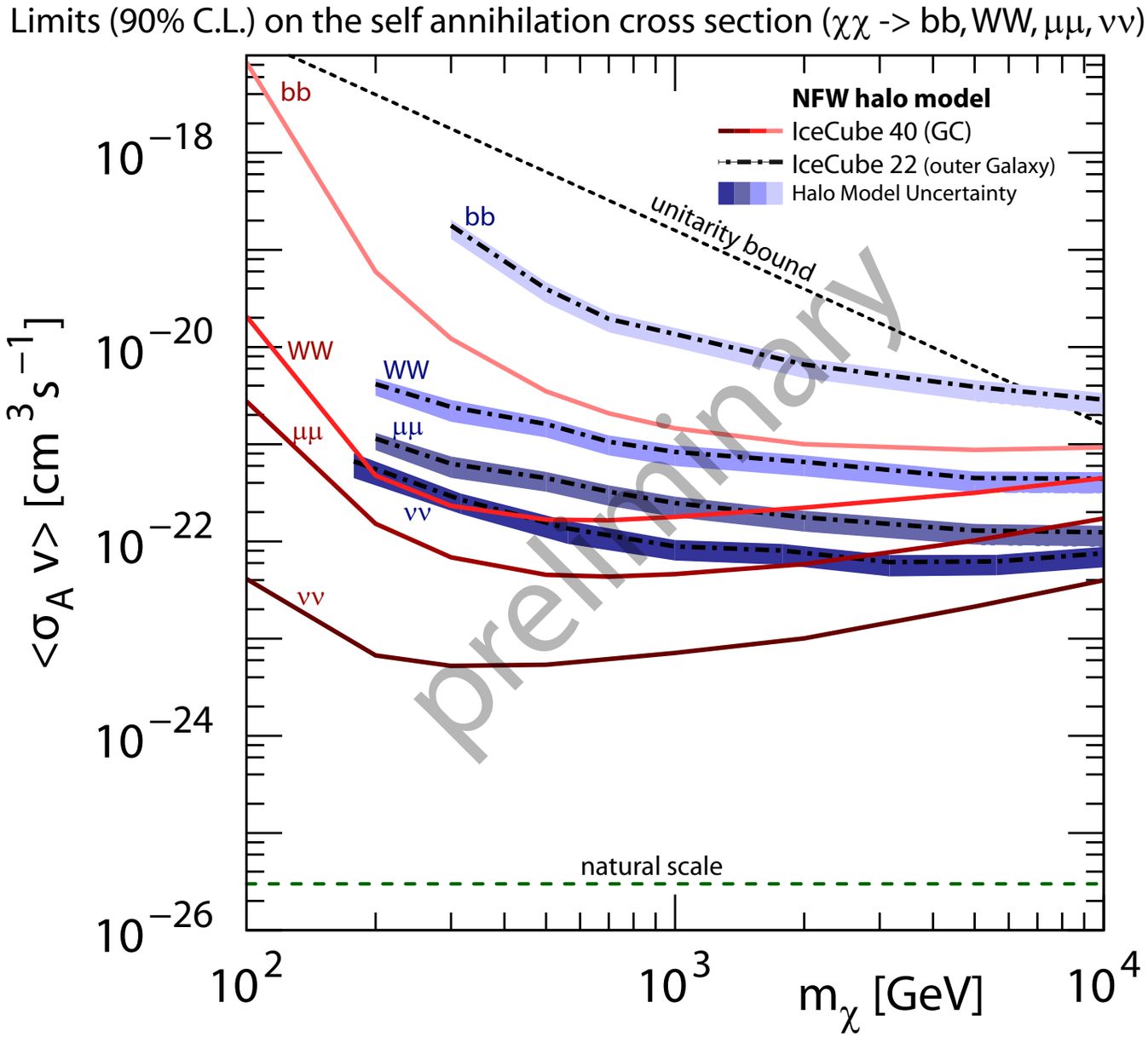


Limits on Solar Dark Matter



Preliminary estimate suggests sensitivity to an interesting range of parameter space, depending on assumed branching ratios

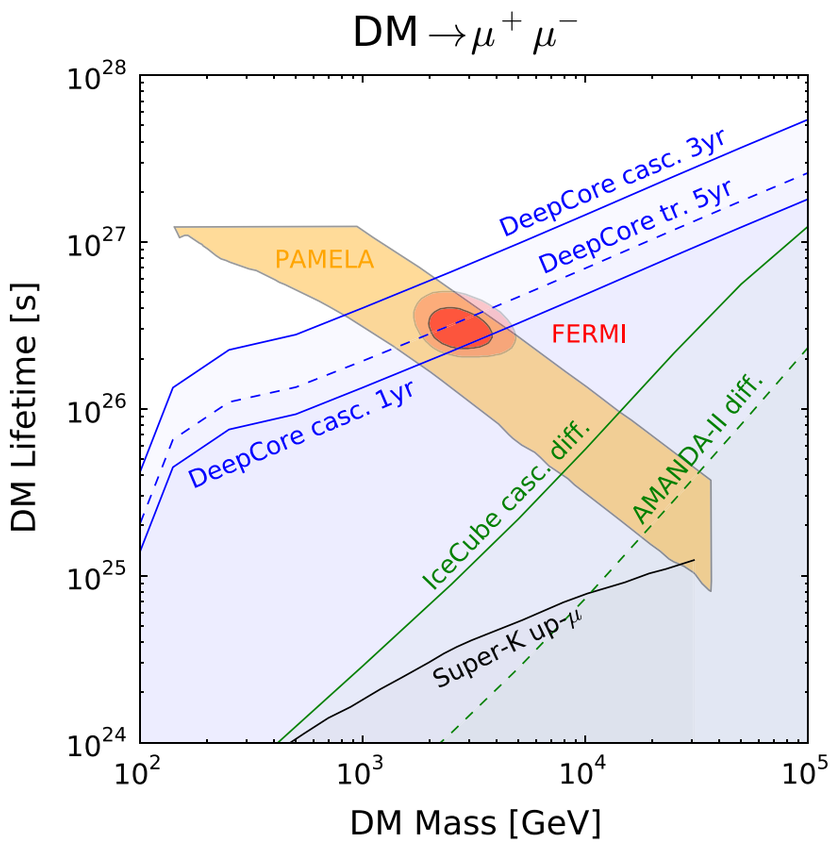
Limits on Annihilation in the Galactic Center

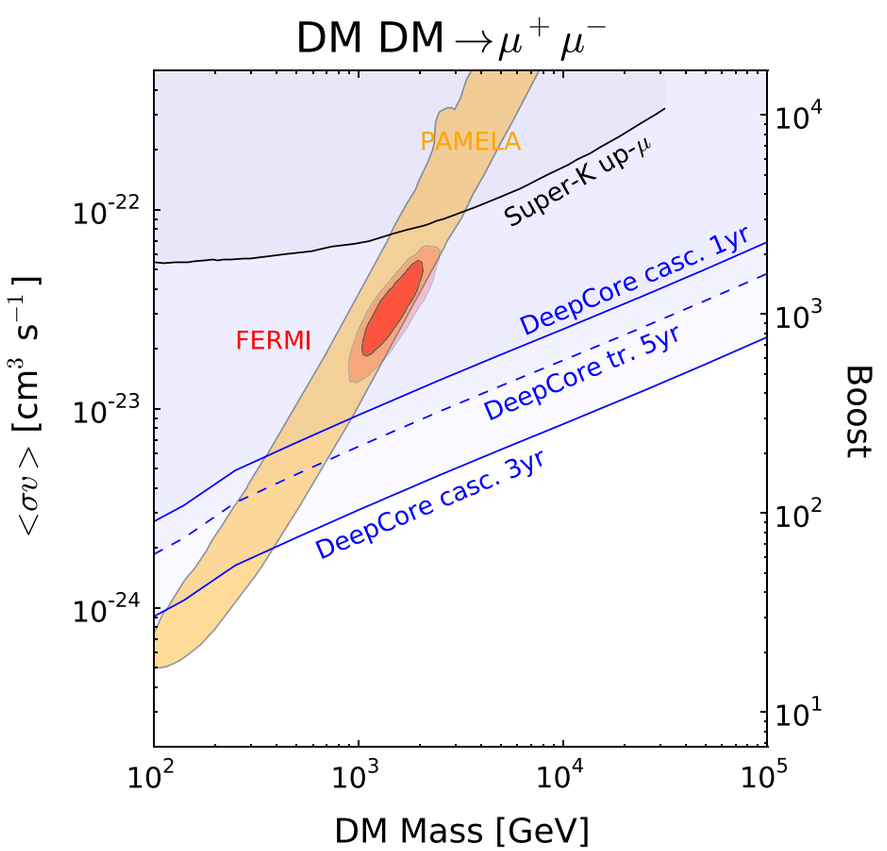


Sensitivity to Galactic Center allows us to probe regions of higher WIMP density (with strong dependence on halo distribution model)

Limits on Other Dark Matter Models

Mandal, Buckley, Freese, Spolyar & Murayama, *Phys. Rev.* D81 (2010)





- Projected DeepCore sensitivity to leptophilic dark matter decay or annihilation, motivated by PAMELA / Fermi results
  - N.B.: not official IceCube predictions
- Many other discussions of how IceCube / DeepCore can probe various dark matter scenarios – lots to do!

Conclusions

- IceCube is now completely deployed, data taking with full 86-string detector will begin within a few months

- Indirect searches underway for dark matter in the Sun, Galactic Center, outer halo, dwarf spheroidals
  - Initial results from the 2008 and 2009 (22, 40 string) configurations, and final results from AMANDA, are appearing now

- Sensitivity to some types of dark matter competitive with or better than direct searches, complementary to other indirect methods
  - IceCube is beginning to probe physically relevant regions of parameter space

- DeepCore deployed and taking data for the last 8 months
  - Will expand sensitivity to Sun & Galactic Center, lower DM masses