Indirect Searches for Dark Matter with Deep Core

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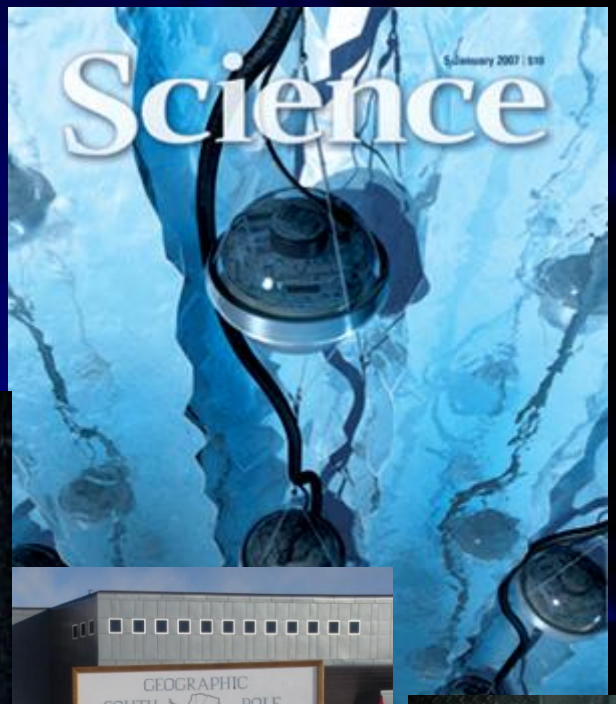
Outline

- Motivation
- Overview of signatures
- Analysis / Methods
  - Solar
  - Earth
  - Halo
- Conclusions



IceCube - Deep Core Neutrino Telescope

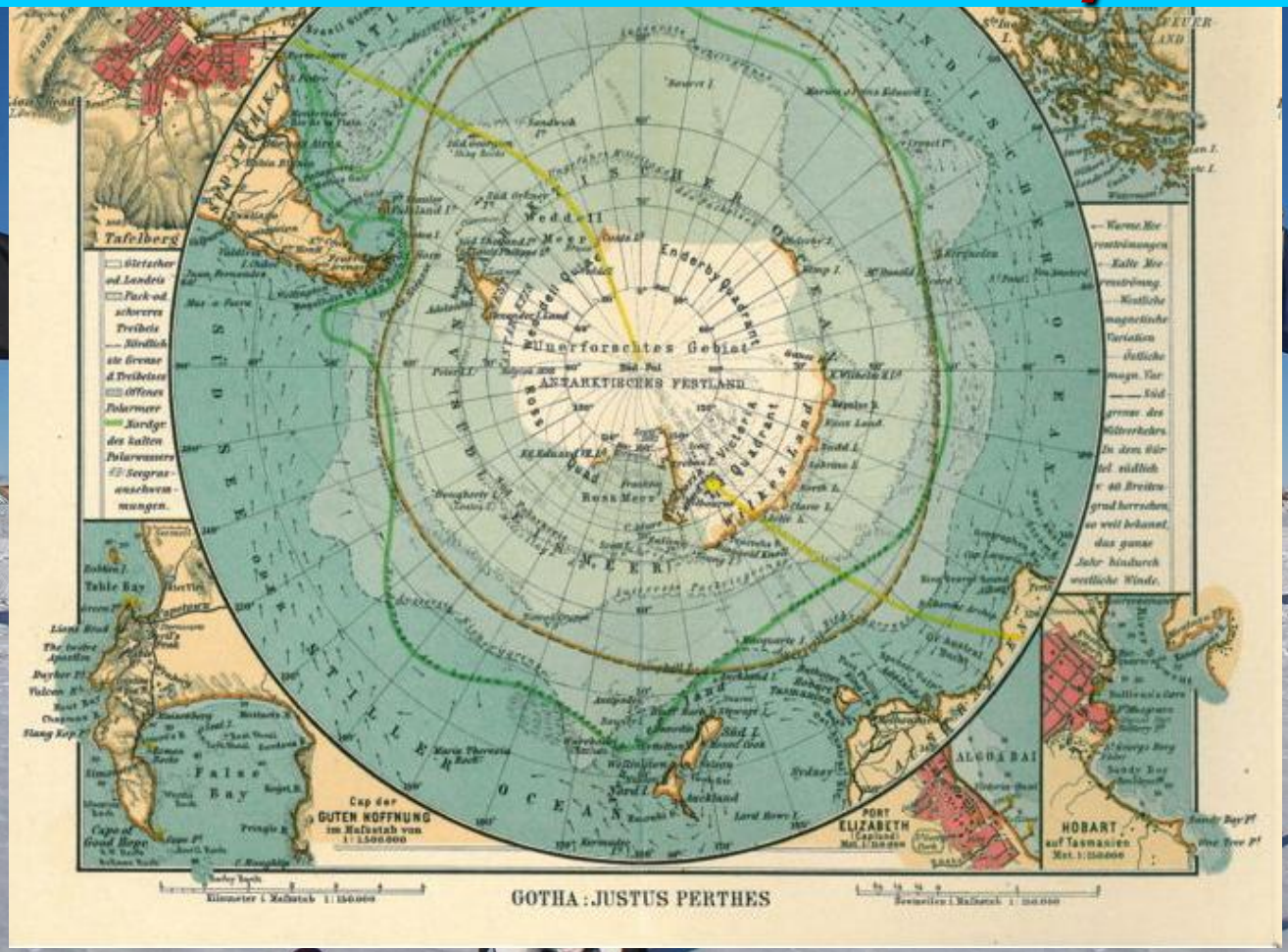


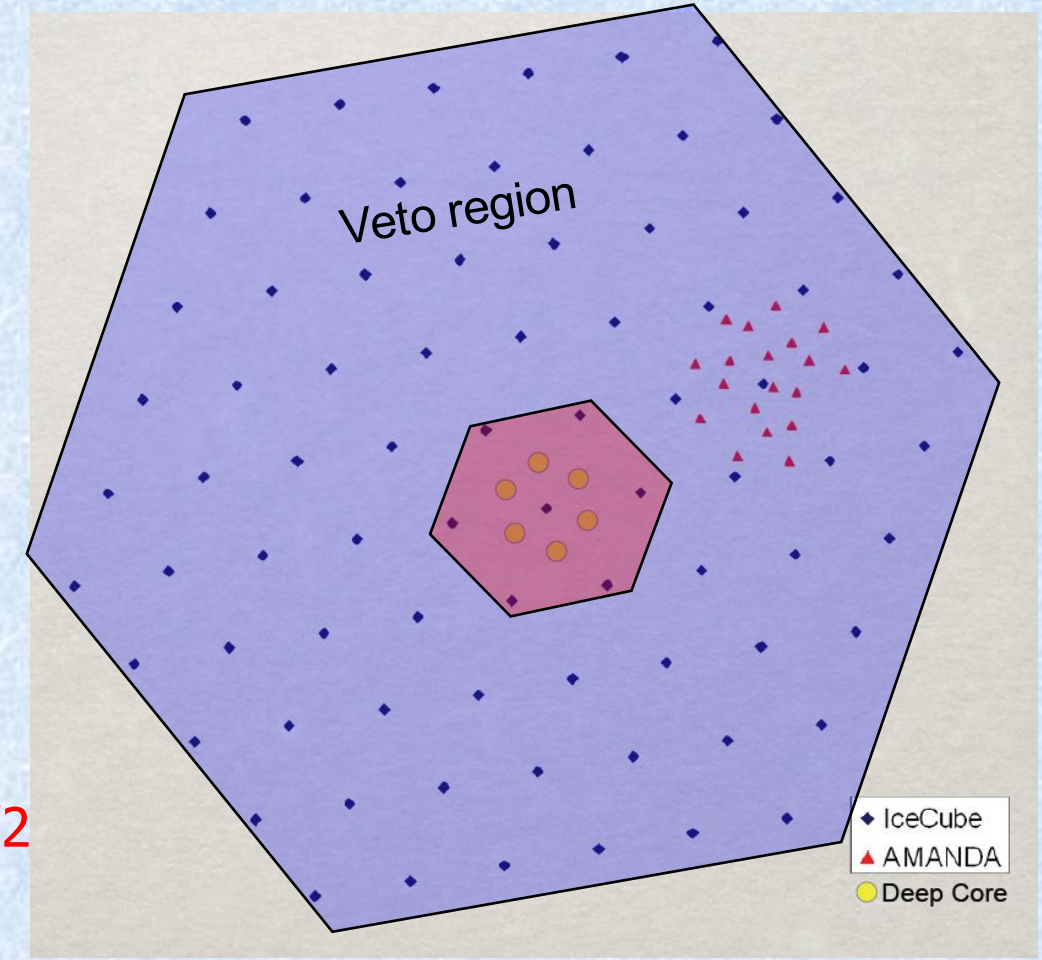
Photo: Cynthia Chiang

Deep Core Low Energy Extension

- Effective Veto against down-going muons from surrounding strings and DOMs above ($\sim 10^5$ reduction in background)
- Large veto region allows for 4π steradians (all sky) analysis
  - Southern Sky
  - Year around sun
- **IceCube:**

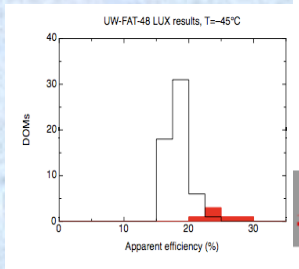
  $D_{scatter}$=20m<< ½*$D_{interstring}$ =125m/2
- **Deep Core:**

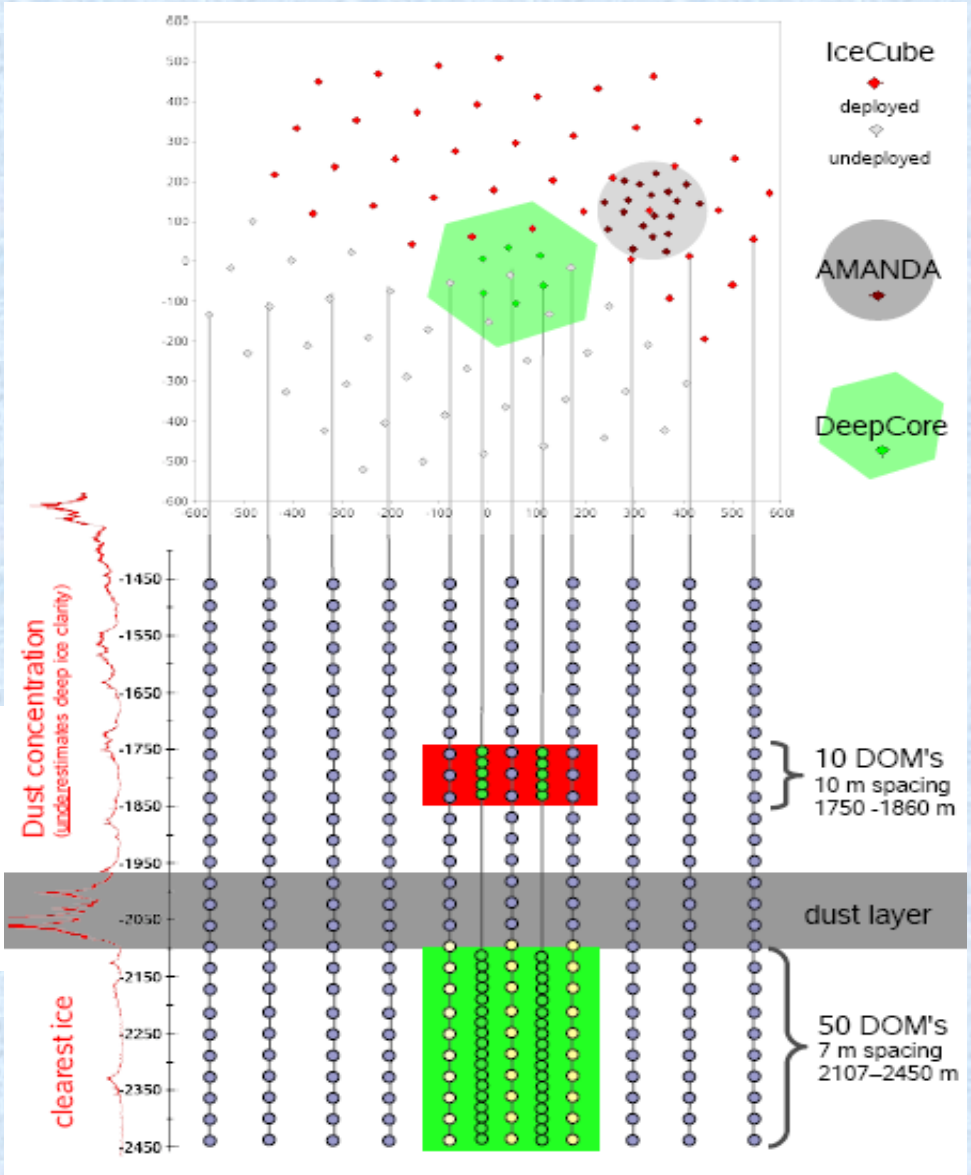
  $D_{scatter}$=40m ~ ½ *$D_{interstring}$ =72m/2
  - direct light



Deep Core Extension

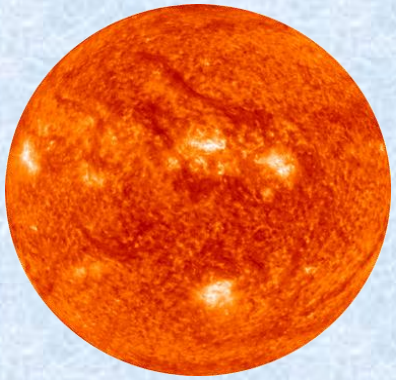
- Deep Core Strings
  - 6 strings with high quantum efficiency PMTs, densely spaced
  - 7 "standard" IceCube strings
- located in best ice (below 2100 m exceptionally clear)
- Interstring spacing 72m
- Uses high Quantum Efficiency PMTs, that have about 40% higher efficiency
- Located in the deep ice
  - Lower atmospheric muon background
  - Larger scattering length ~40m

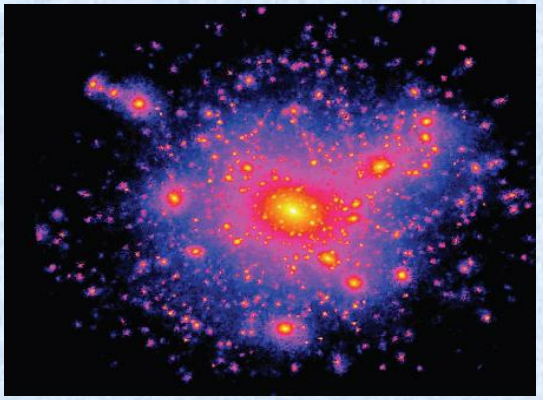




Indirect Searches for Dark Matter

Searches Overview



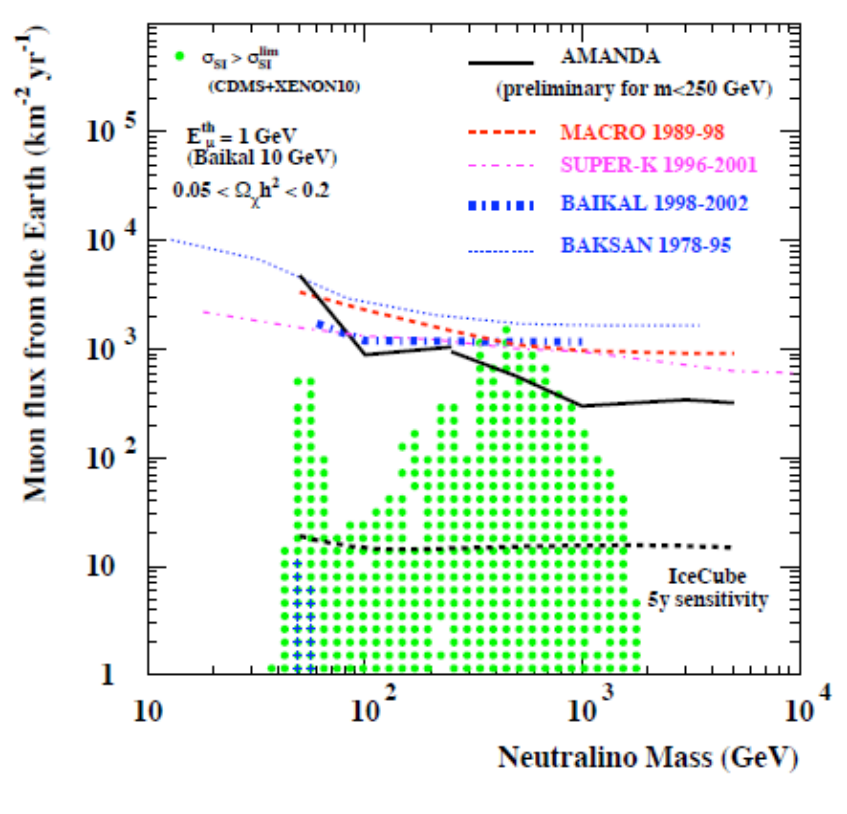


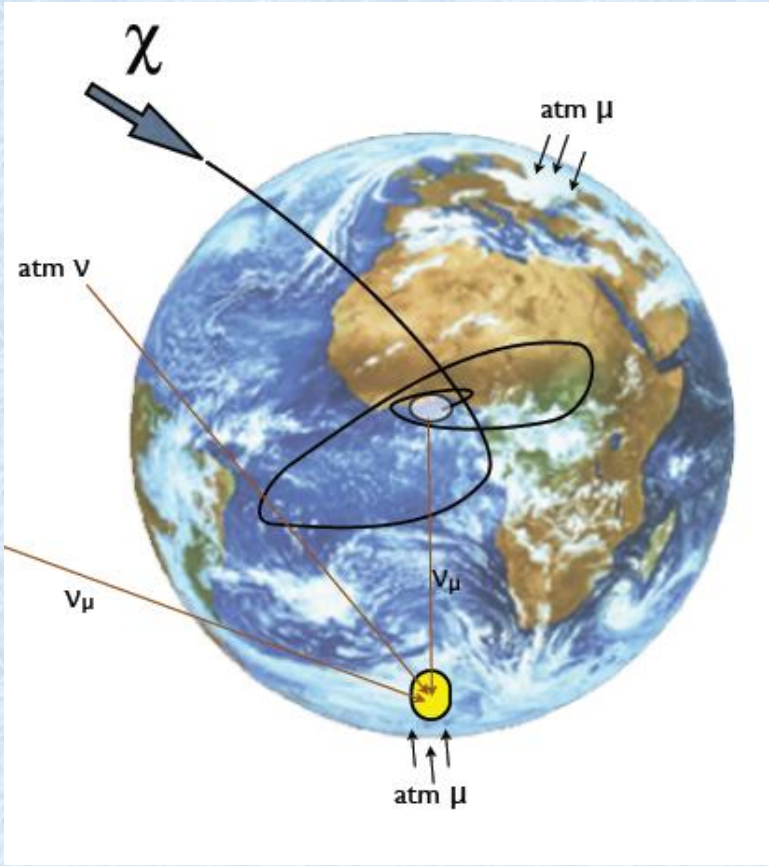
Solar	Earth	Halo
Background off-source on-source	Background simulations	Background off-source on-source
Muon neutrinos	Muon neutrinos	**Cascades**, Muon neutrinos
Neutrino Flux, **Scattering cross-section**	Neutrino Flux, ?	Neutrino Flux**, Self-annihilation cross-section**
Excess	Excess	**Anisotropy**, Spectrum
IceCube (+ Deep Core)	**IceCube** (+ Deep Core)	**DeepCore** (+ IceCube)

Earth WIMPs

Earth Wimps

- Place 90%C.L. limit on muon flux from the center of the Earth



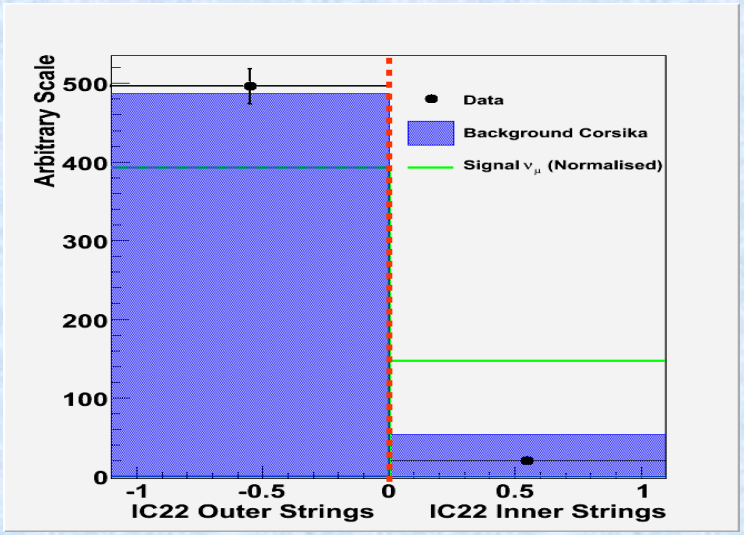


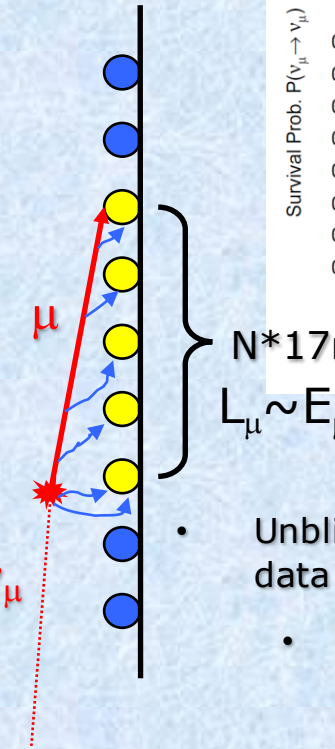
- Understanding of low energy vertical tracks extremely important (relates closely to oscillation analysis)

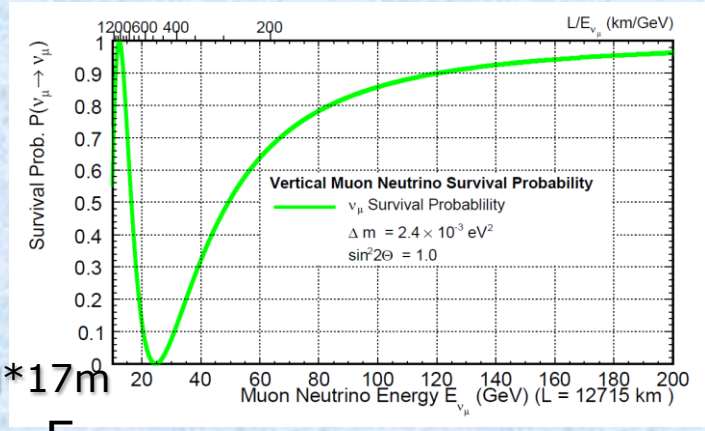
Some experience with Oscillations

arXiv:0810.3698

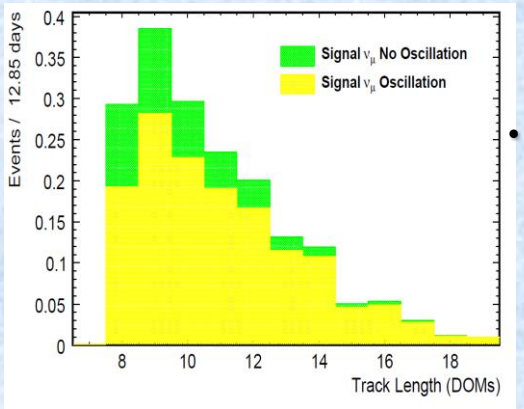
- IceCube's lowest energy threshold is realized in vertical events (due to its geometry)
- Can we see atmospheric neutrino oscillations ?
- Expected results of χ^2 test using the track length as energy estimator (under the assumption that remaining background can be rejected)







- Unblineded a small subset of the IC22 data for validation purposes:
  - Expected:
    - Signal (Muon Neutrinos): 1.81 (no-osc) / 1.42 (osc)
    - Background: 0.0 +/- 20.3
  - Observed three events



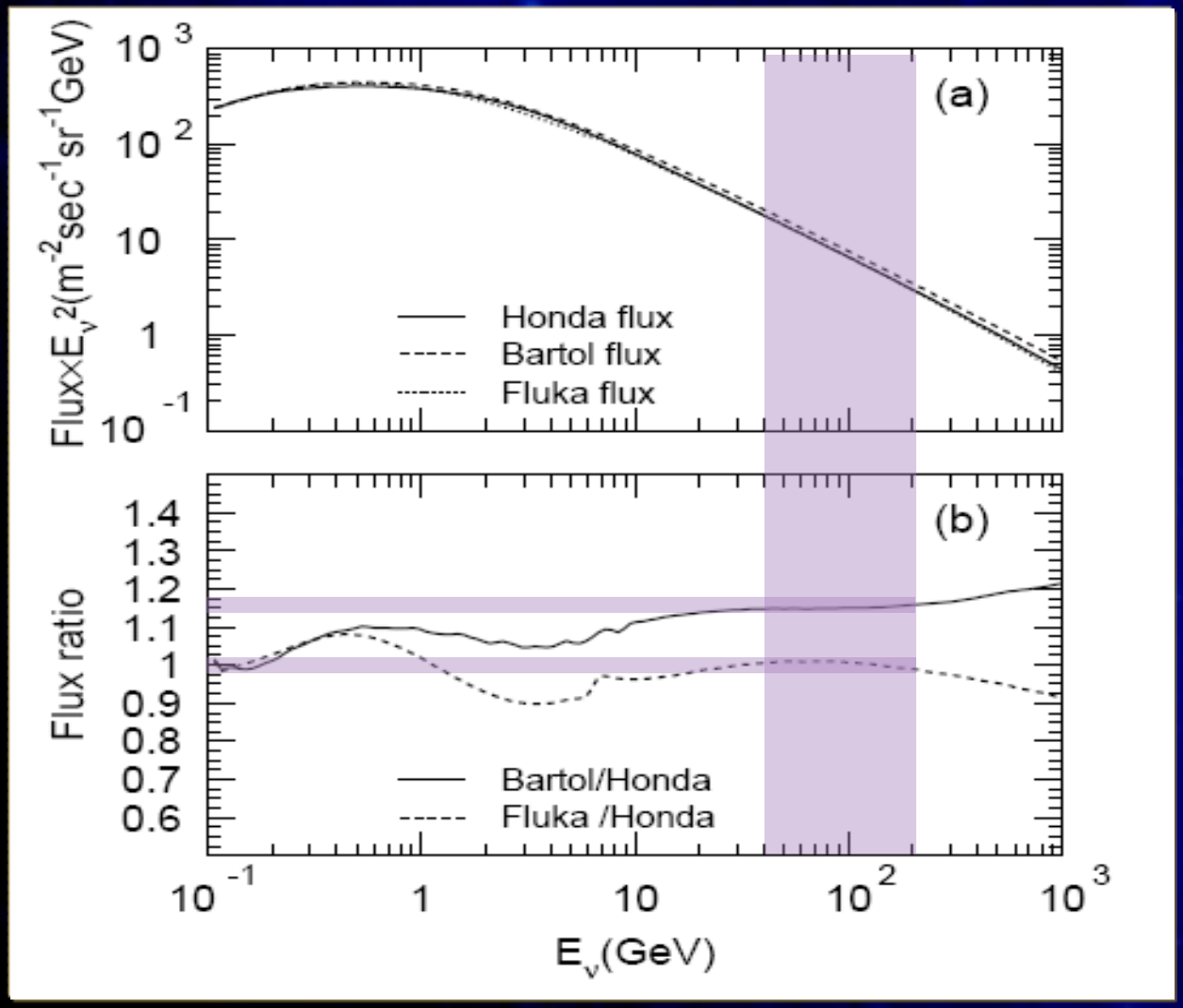
Larger MC background dataset is currently studied

-> Same background as for Earth WIMPs

-> Need to understand osc. Before looking for Earth WIMPs

Systematic Uncertainties

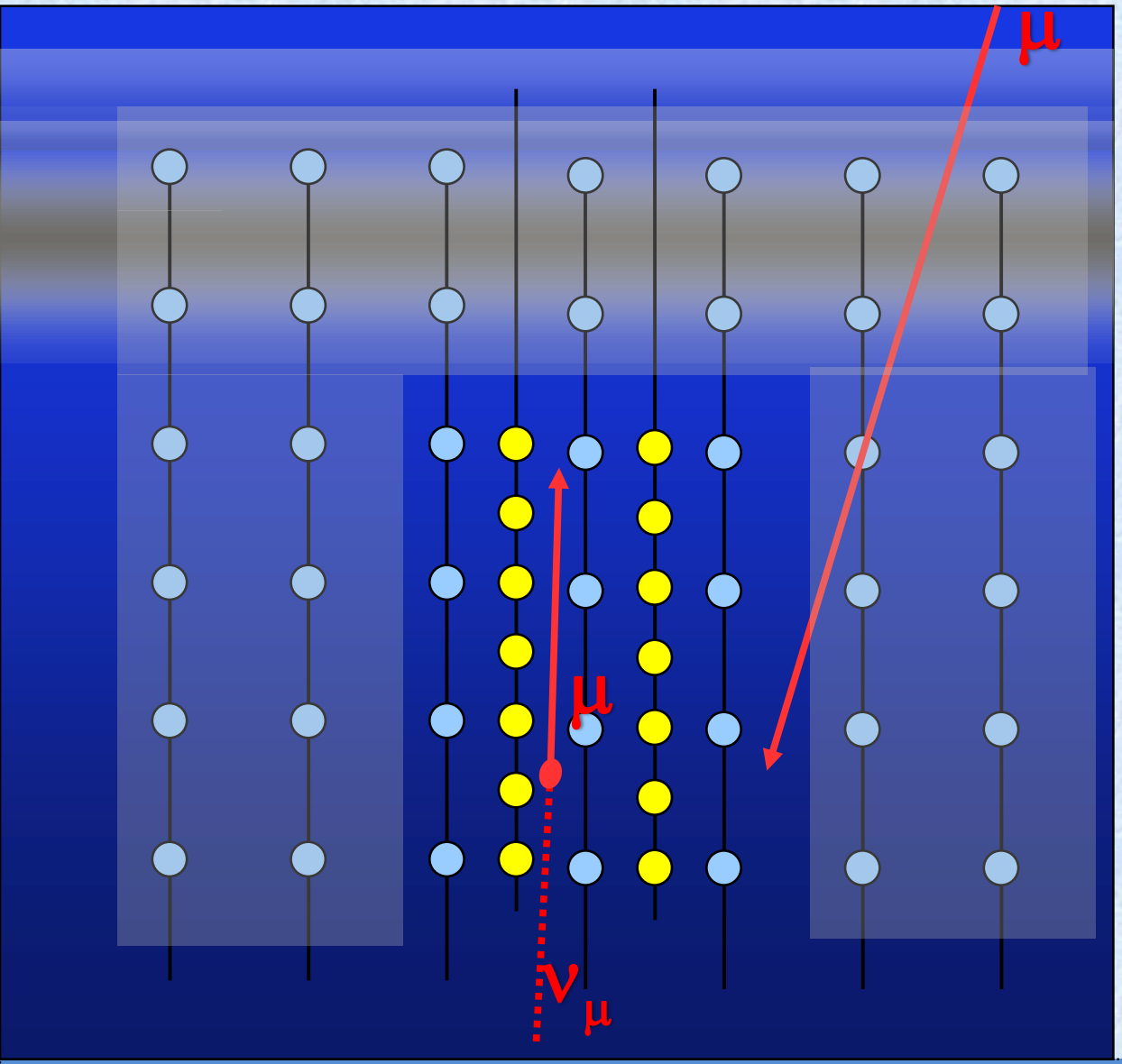
Neutrino Flux Uncertainty



[Super K **Phys.Rev.D71:112005,2005**]

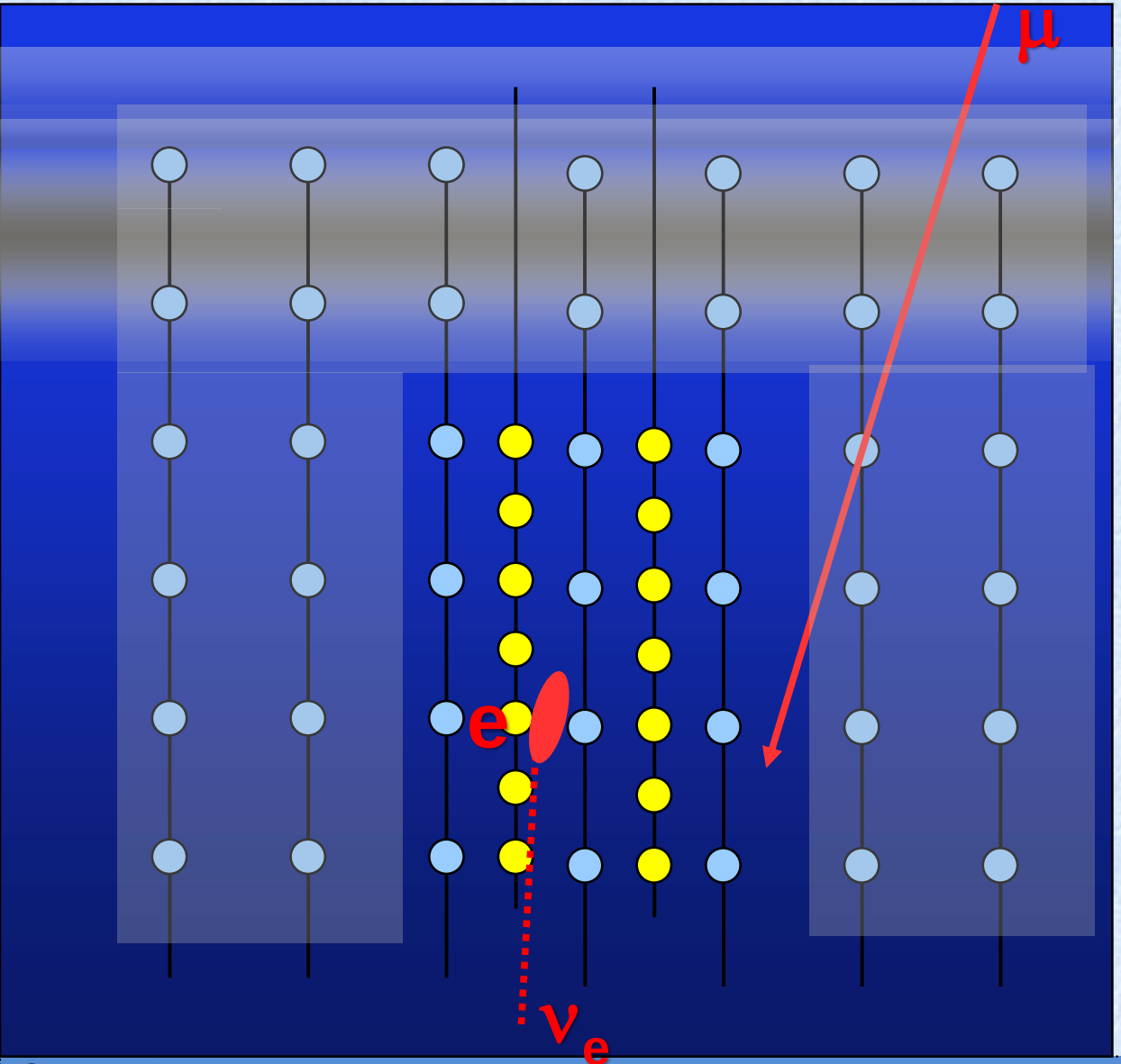
- Uncertainties on the atmospheric muon neutrino flux have a direct impact on the oscillation analysis
- Important is the variation in the flux ratio of different flux models as function of energy, in the energy range considered
- Expected uncertainty on the neutrino flux of about ~5-10%

What to look for



- Deep Core Impact:
  - Lower Energy Threshold, more stat. for 50-200GeV Neutrinalinos
  - Low-energy vertical events are in IceCube predominately single-string events, but Multi-string events in DeepCore
    - Background estimation in IceCube relies more heavily in MC (no control region !) … but inclined multi-string tracks in DeepCore can be used
    - Down-going fully contained events might be useable for normalization purpose (similar as for the oscillation analysis)

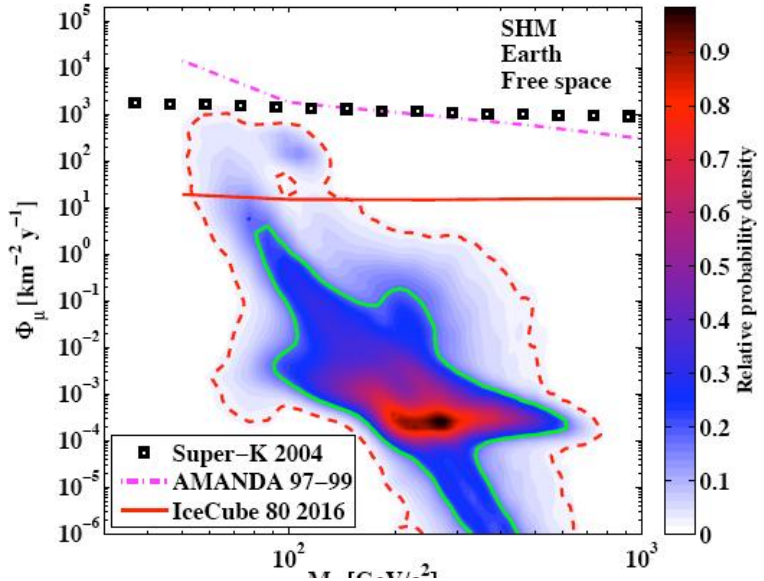
What about cascades ?

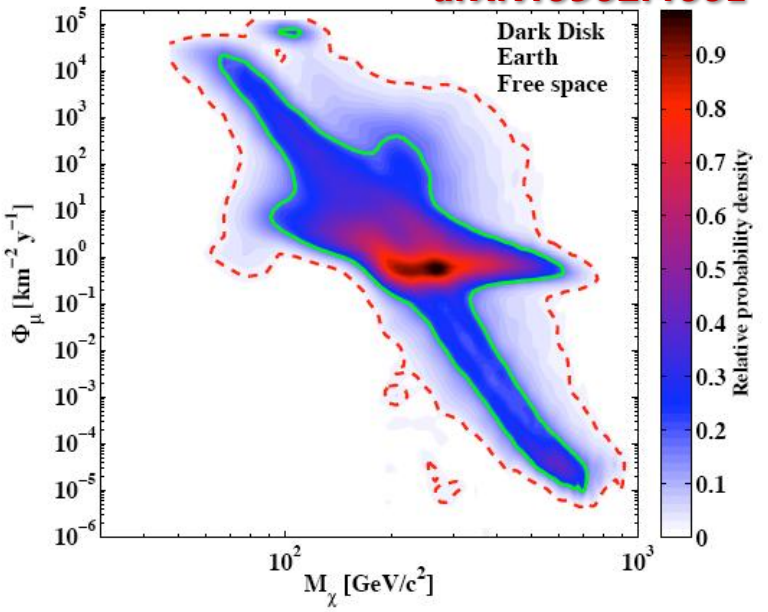


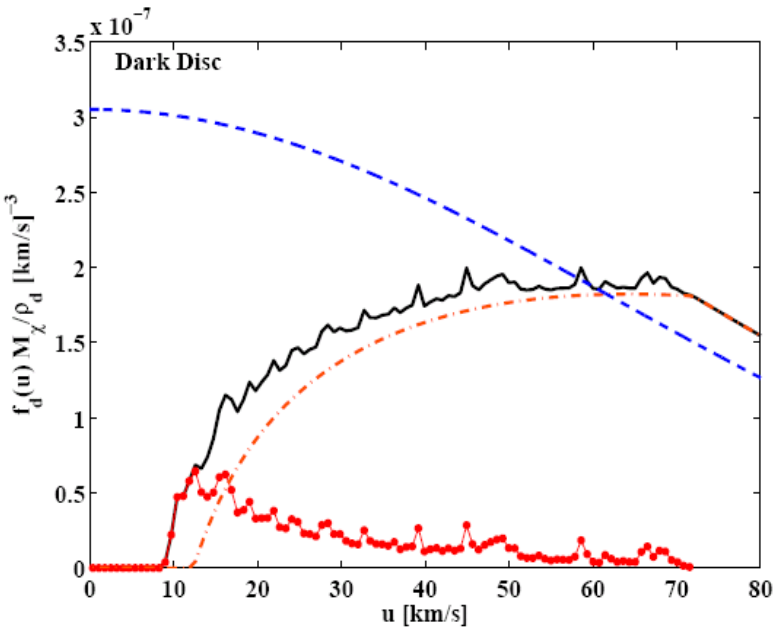
- Can one benefit from cascades ?
  - Help to determine WIMP mass in light of uncertainties in the atm. neutrino background flux.
  - Problem: cascade angular resolution likely not good enough

Earth WIMPs

arXiv:0902.4001





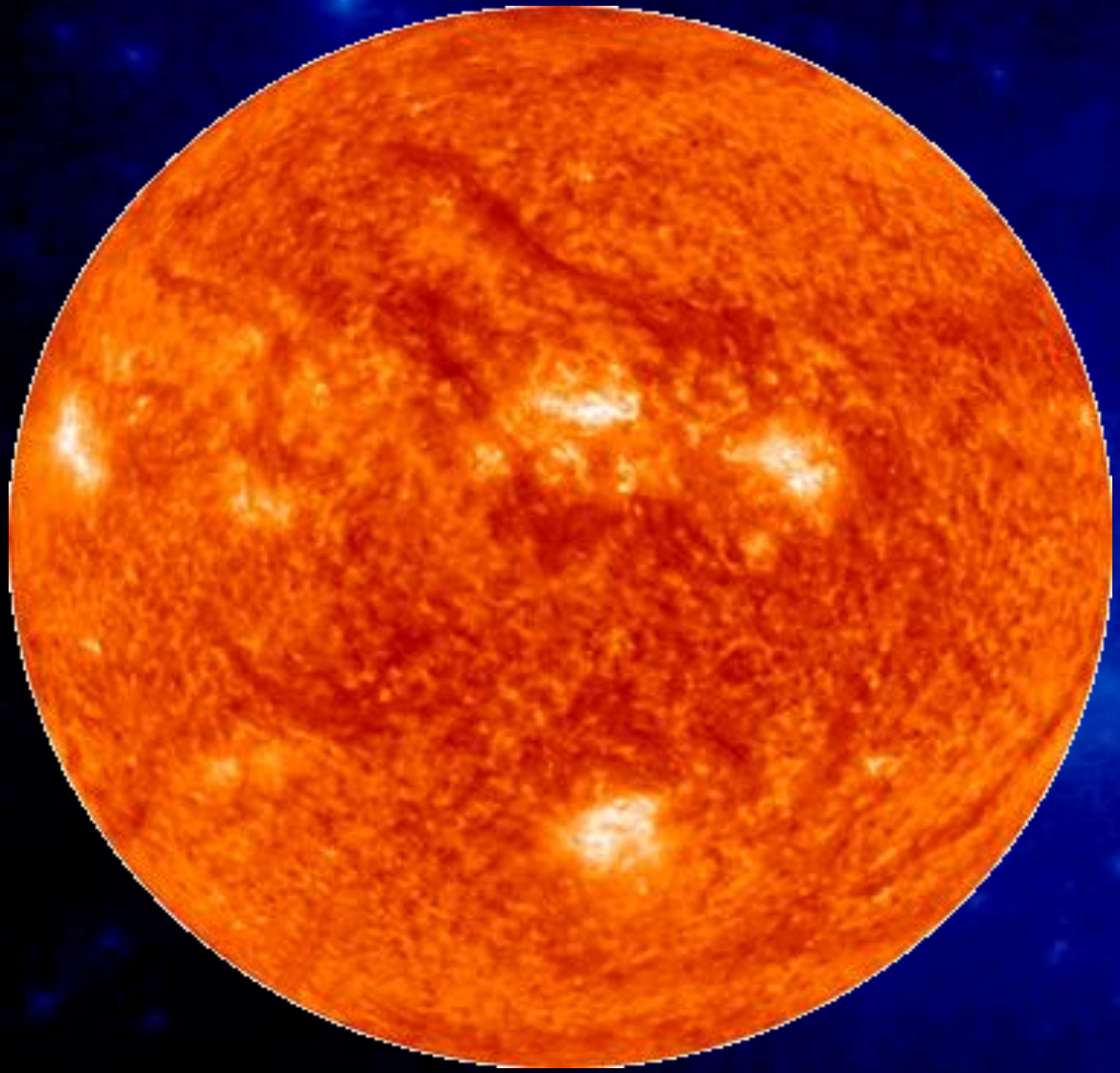


Earth typically not in equilibrium

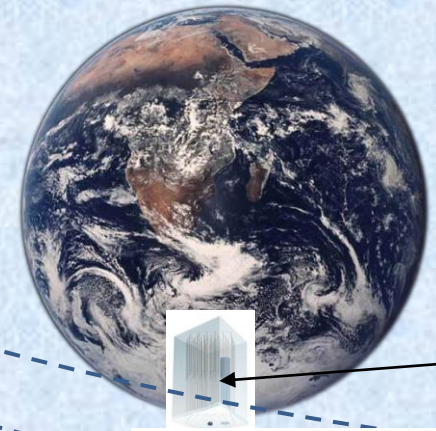
Annihilation rate extremely sensitive to capture conditions

Dark Disk – Merge events in the history of the galactic halo can enhance the expected neutrino flux from the Earth WIMPs annihilation by orders of magnitude.

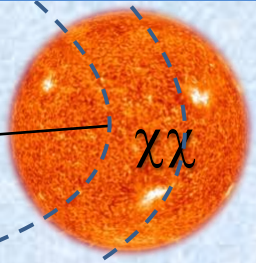
Solar WIMPs



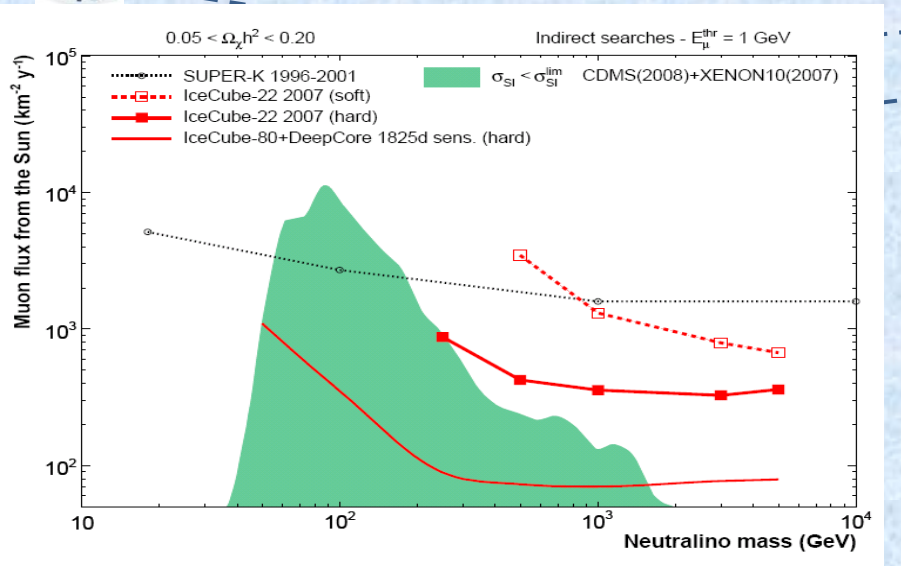
IceCube-22 Solar WIMPs



Solar WIMPs

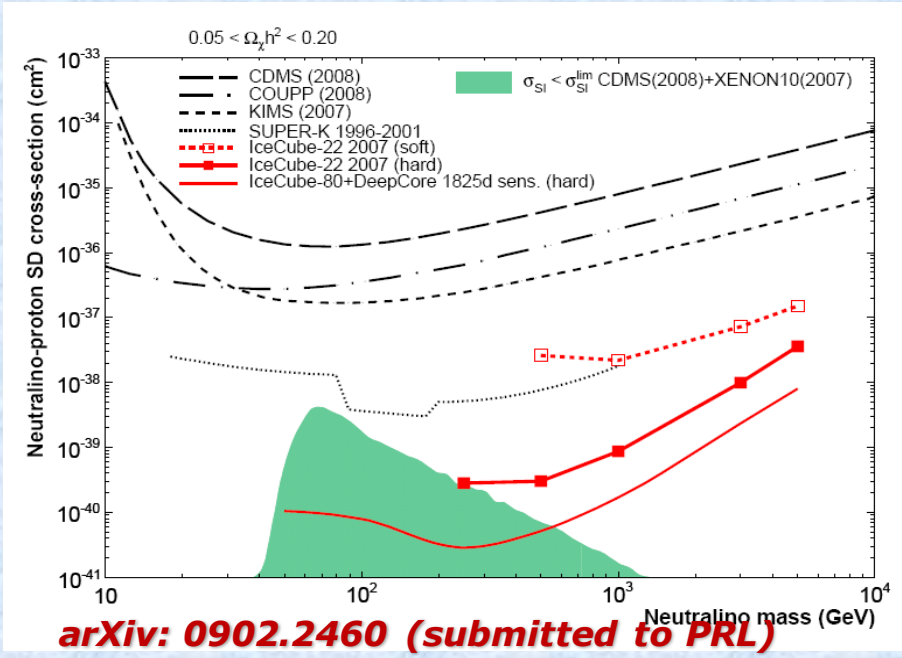


Direction of the sun remains scrambled until selections are finalized (blind)



- Look for an excess of neutrinos in the direction of the sun
- No evidence for a signal observed
- Upper limits on muon flux from neutralino annihilations in the Sun

- Under the assumption of equilibrium condition in the Sun, a limit on the WIMP-Nucleon cross-section can be obtained
- For spin-dependent couplings, IceCube's sensitivity is about 2-orders of magnitude better than direct searches



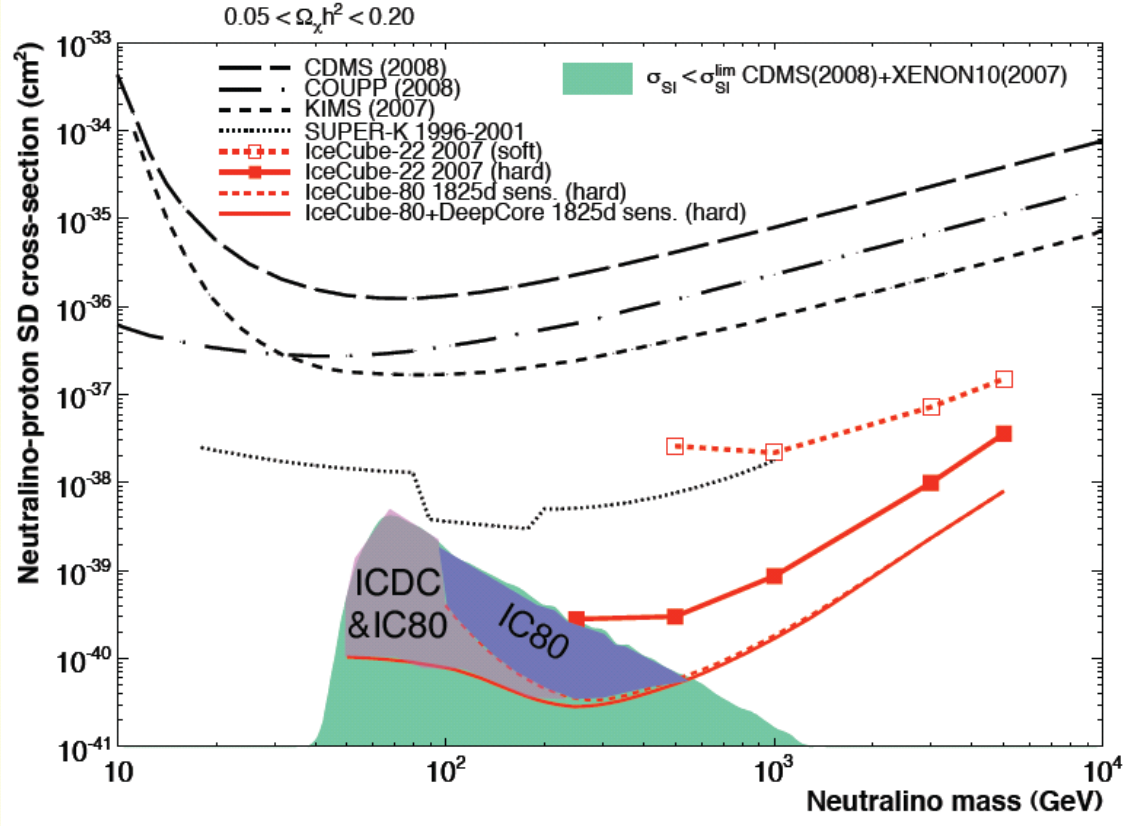
arXiv: 0902.2460 (submitted to PRL)

Solar WIMPS Outlook

- WIMPs all year around
- 50-100GeV Neutralinos can be probed
- Significant improvement in sensitivity to Neutralinos with masses below 200GeV

– Hard: $\chi\chi \rightarrow W^+W^- \rightarrow \nu\,\nu$

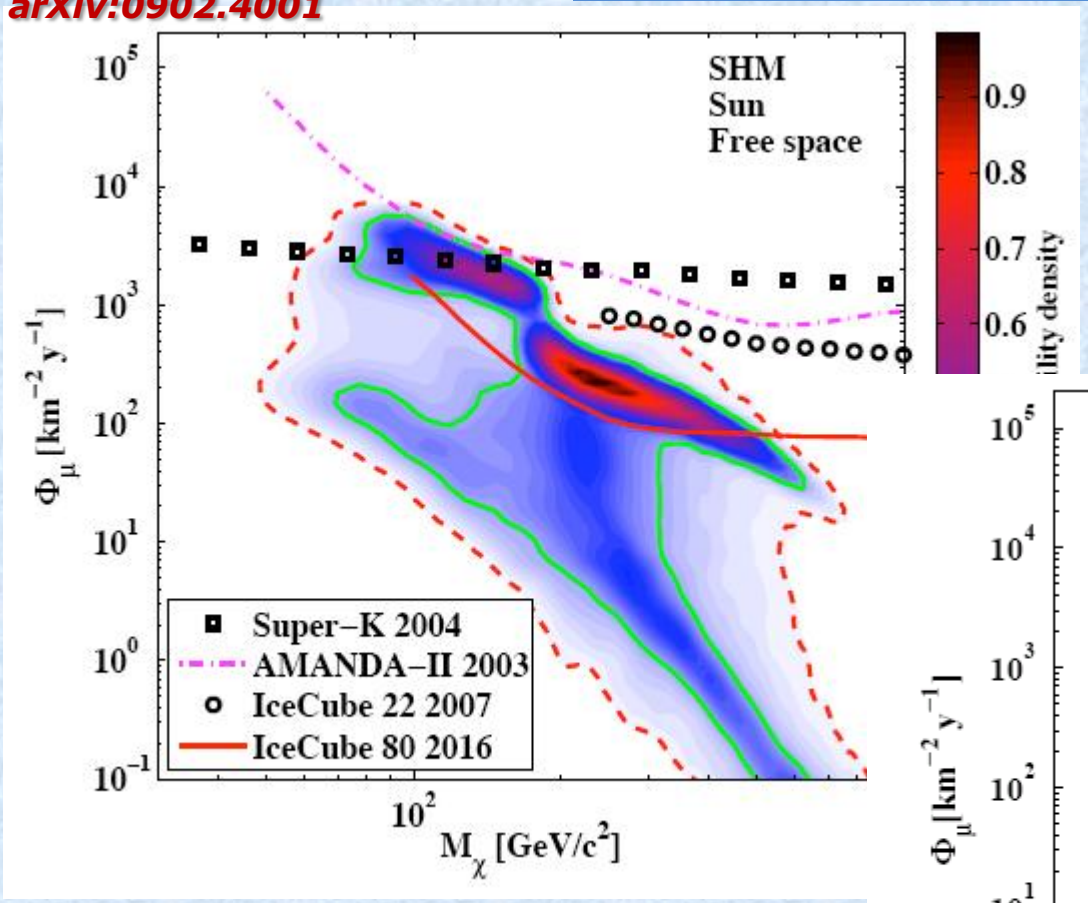
– Soft: $\chi\chi \rightarrow bb \rightarrow \nu\,\nu$

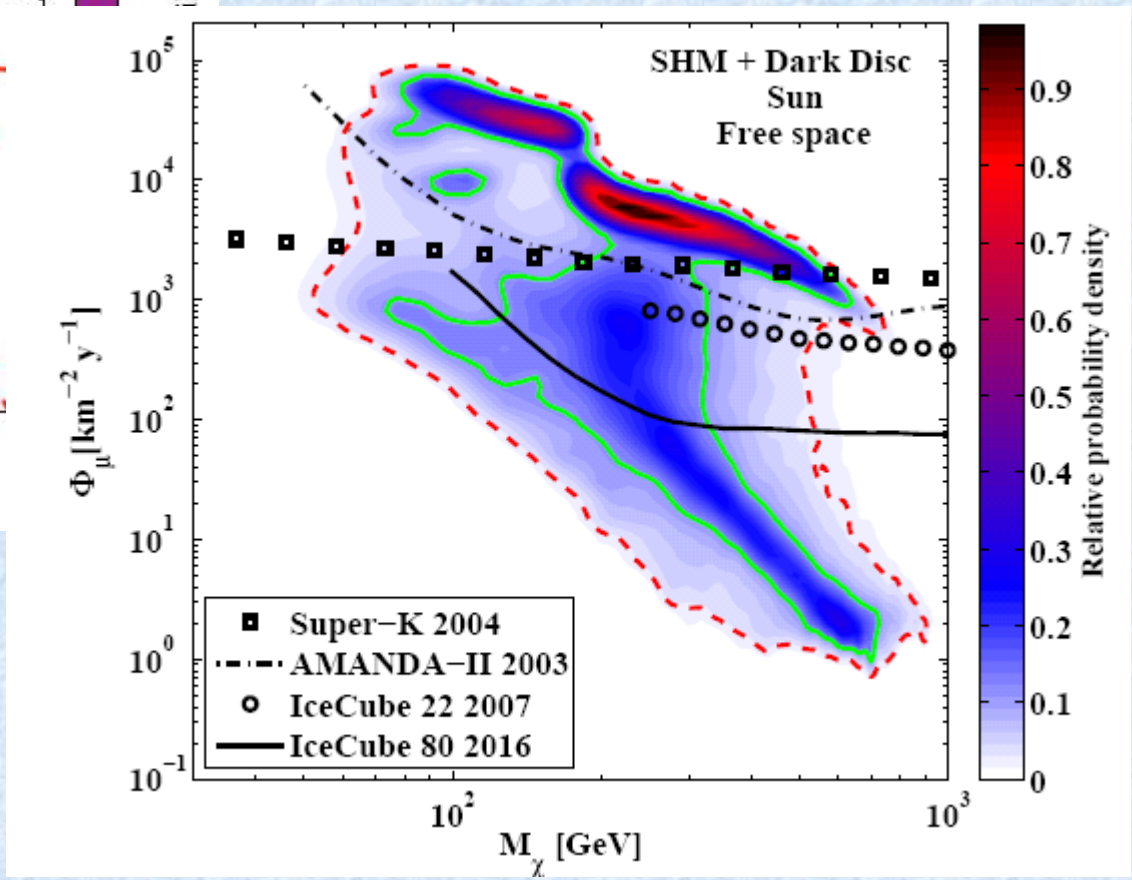


- Sensitivity shown for DeepCore is conservative (using an older less optimized DeepCore geometry)

Solar WIMPs Outlook

arXiv:0902.4001

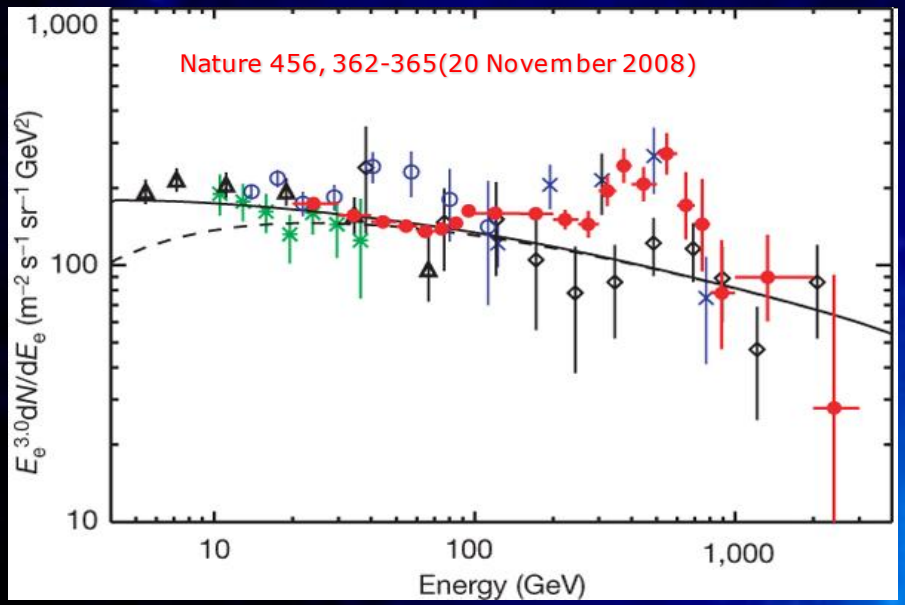


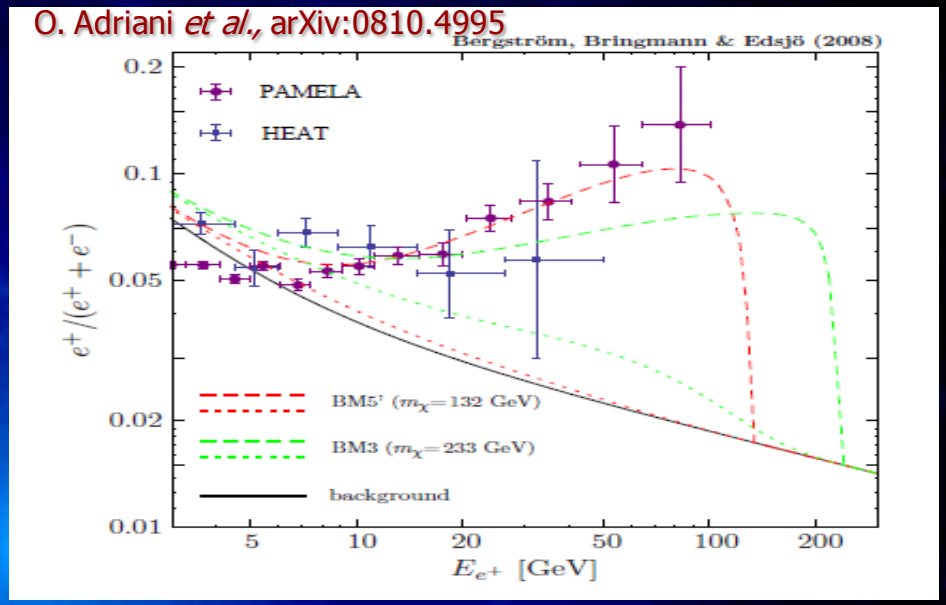


- Deep Core will be able to test a large number of allowed CMSSM parameter space

Halo WIMPs

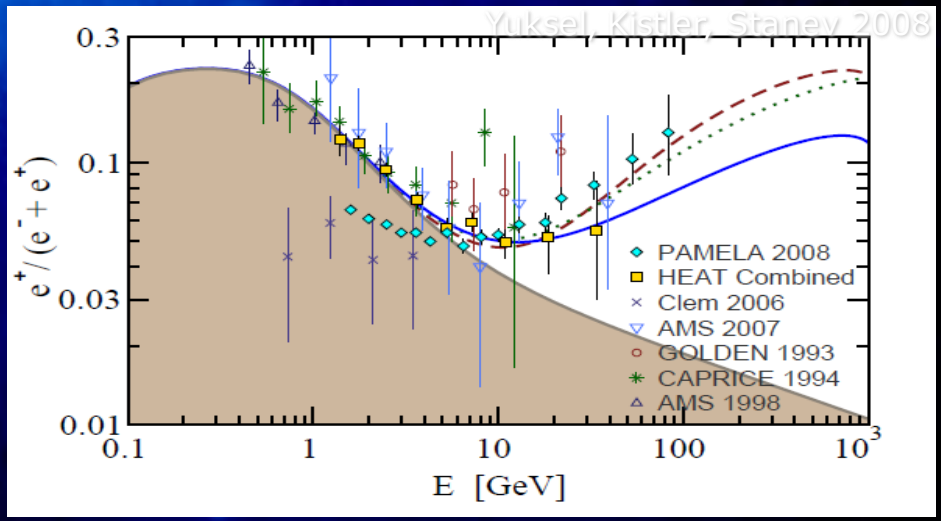
Recent Excitement





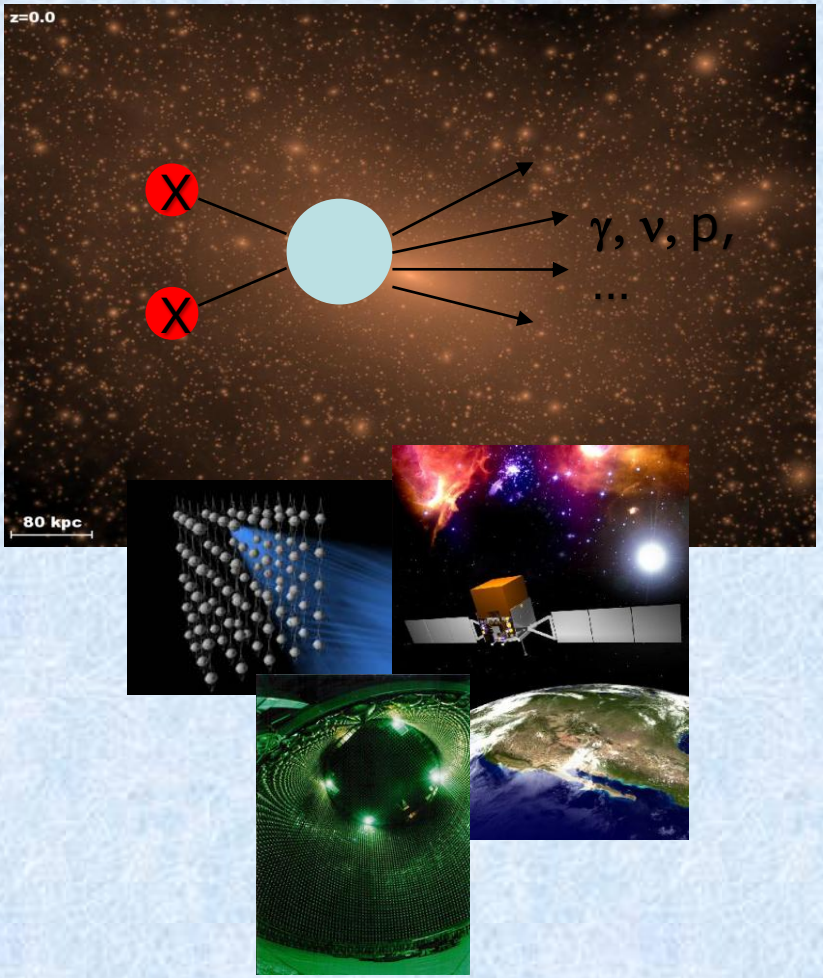
Problems
… steeply falling spectra
… energy calibration
… backgrounds
… local sources ?

Conclusion:
Might entirely consistent with astrophysical sources, but if it is really DM then much higher than expected boost factors are needed



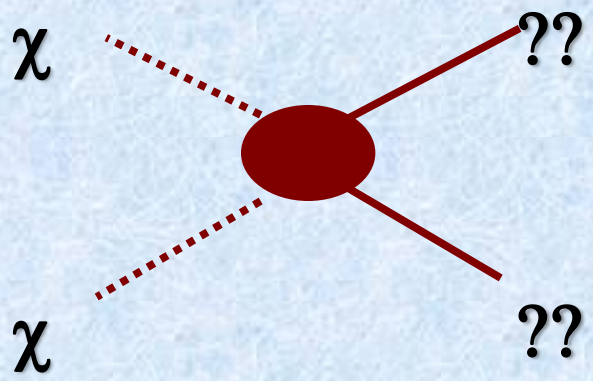
Motivation

- Strong observational evidence for the existence of dark matter halos
  - We should look for dark matter annihilation/decay signals from galactic halos
  - Such a search is complementary to searches for annihilation signals from the Sun and Earth



Delectability of "invisible"

- One might think that the DM halo is more detectable with "visible" annihilation products
  - if other final states are more detectable, then we can set the most stringent limit with invisible states (neutrinos)
  - IceCube is big because we look for "invisible" states
  - To understand the properties of DM we need a multi-wavelength approach anyway



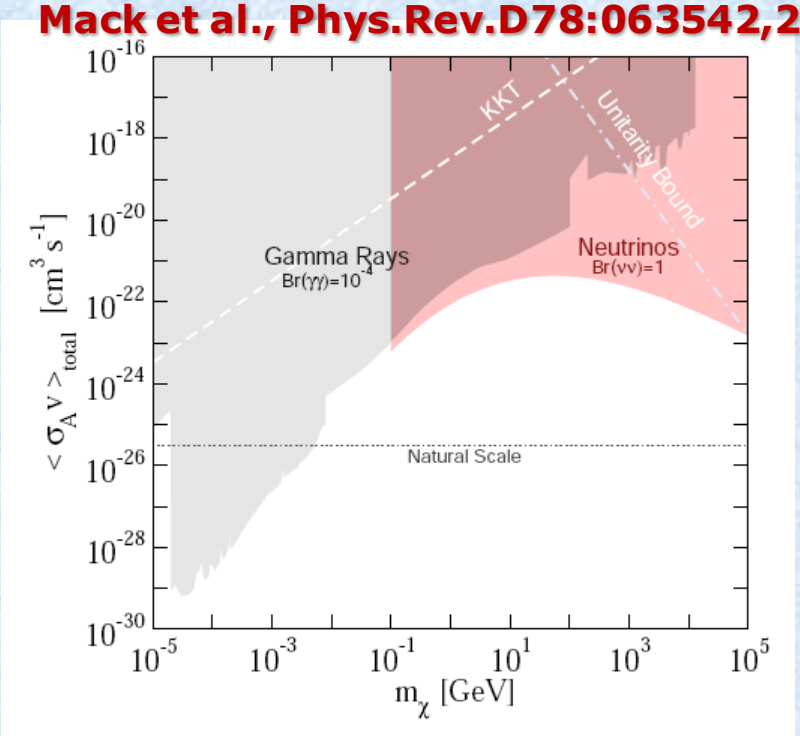
"visible" SM particles:
WW, bb, qq, γγ, …

"invisible" SM particles:
νν

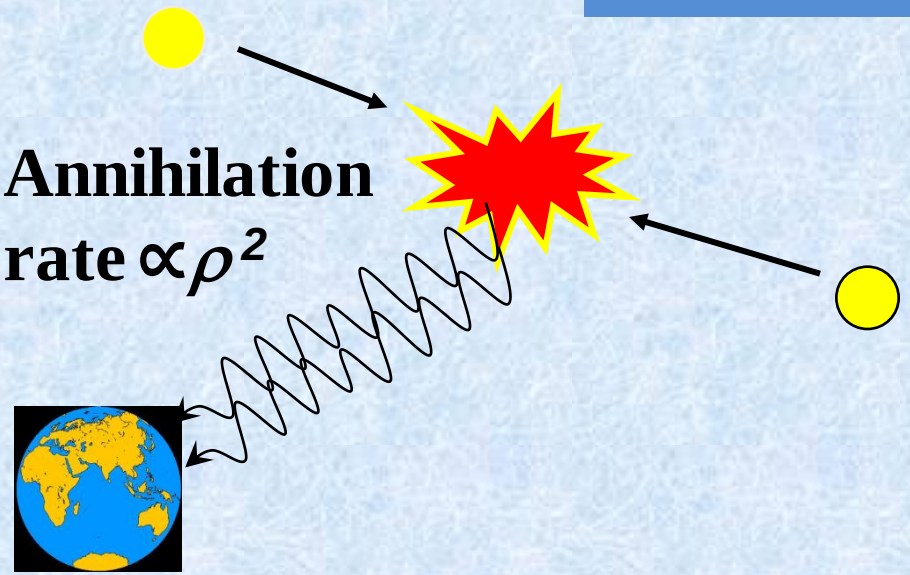
Galactic Center and Halo

- Galactic Center signal strongly depends on the uncertain cuspiness of the underlying halo profile
- Galactic Center signal has severe disadvantages
- Galactic Center is on the Southern hemisphere and therefore events are down-going in IceCube
- Other "neutrino source" might be present at the GC region
  - This of course means we absolutely should still look at the GC as soon as instrumentally / analytically possible

Mack et al., Phys.Rev.D78:063542,2008.

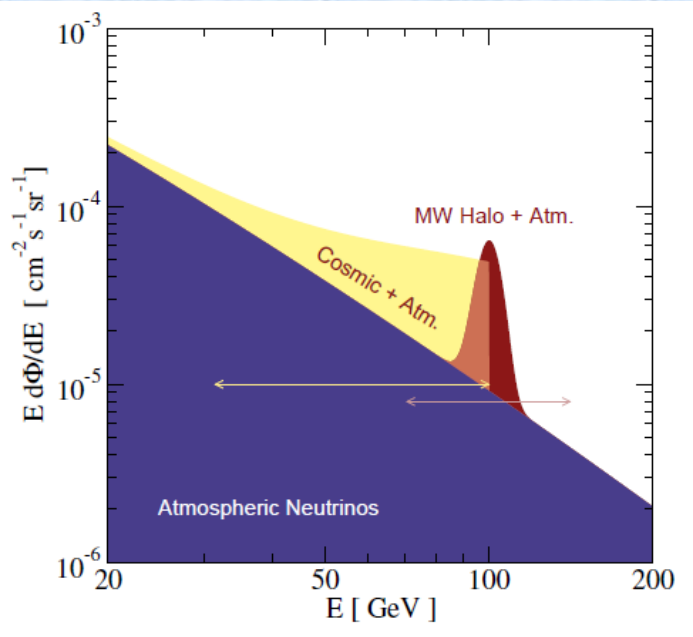


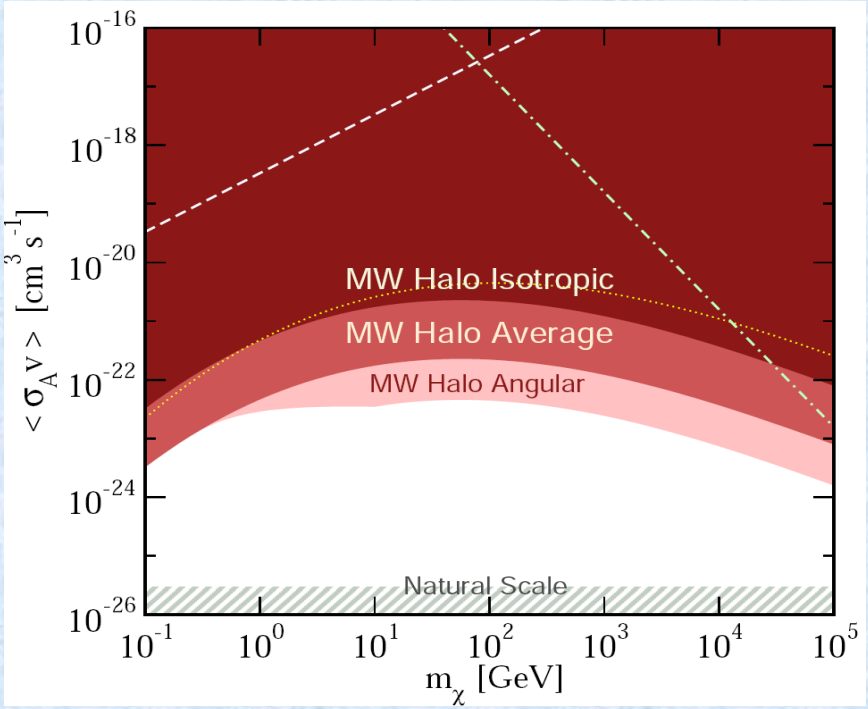
Halo WIMPs



Galactic Center on Southern hemisphere -30°
- Deep Core is needed

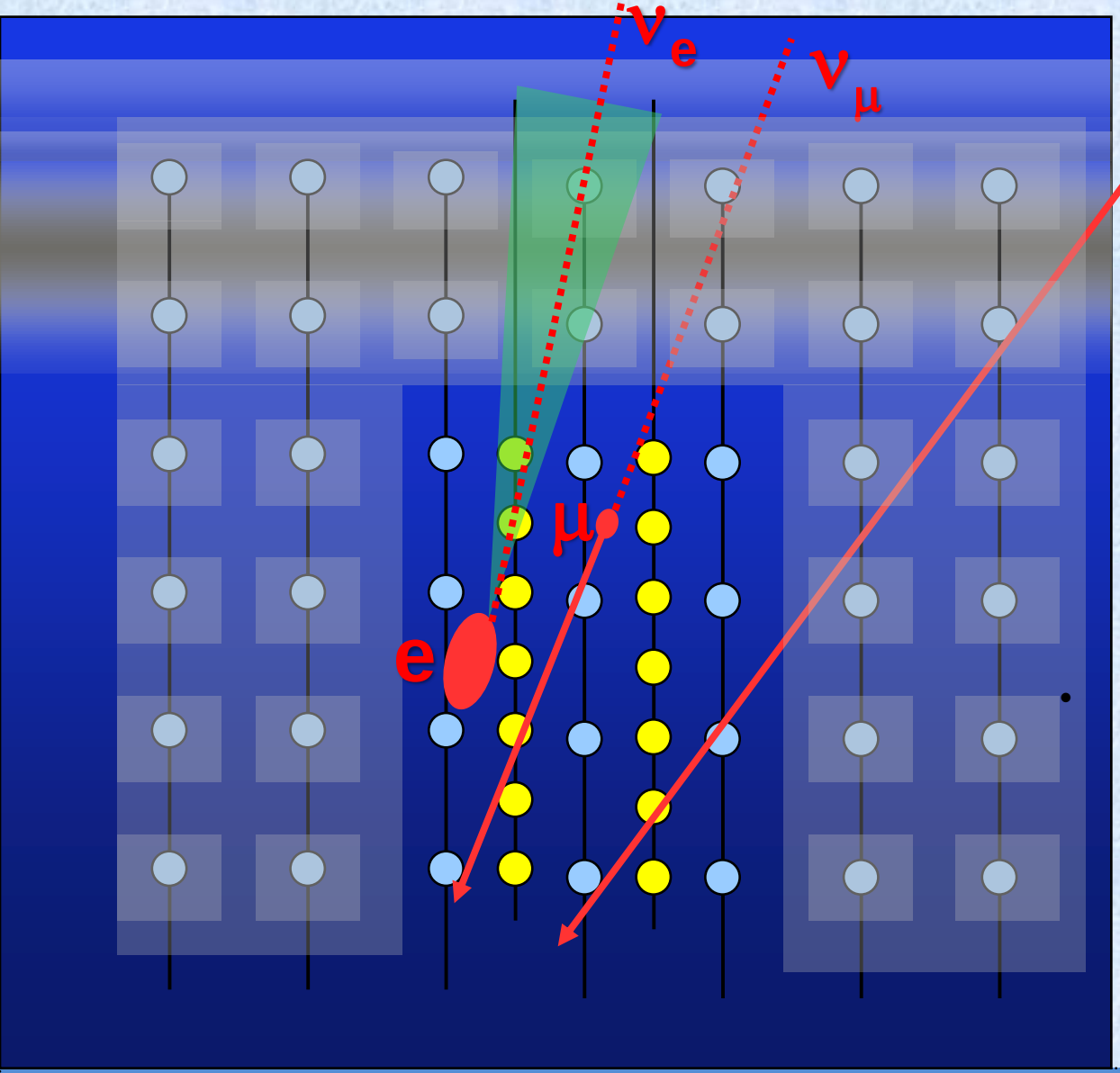
Neutrino signal "least detectable", hence allows to set conservative limit on the total self-annihilation cross-section



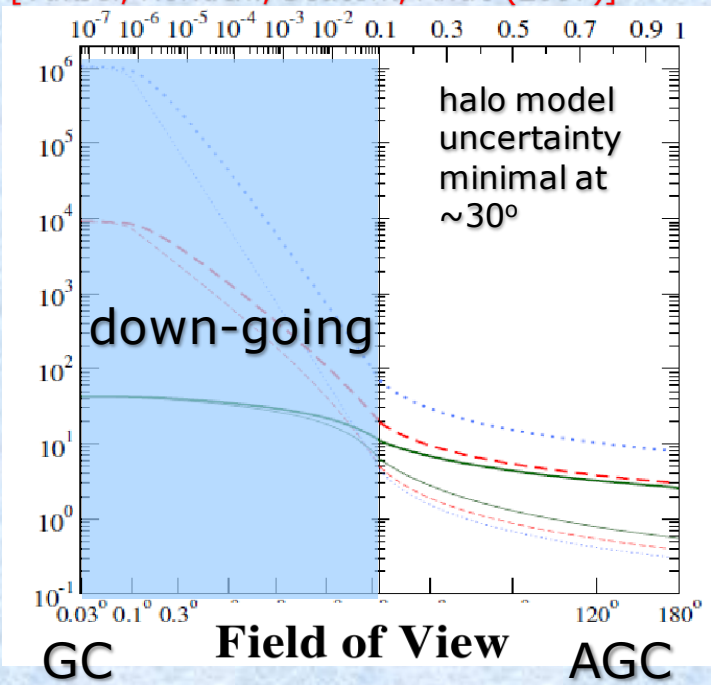


[Yuksel, Horiuchi, Beacom, Ando (2007)]

Veto



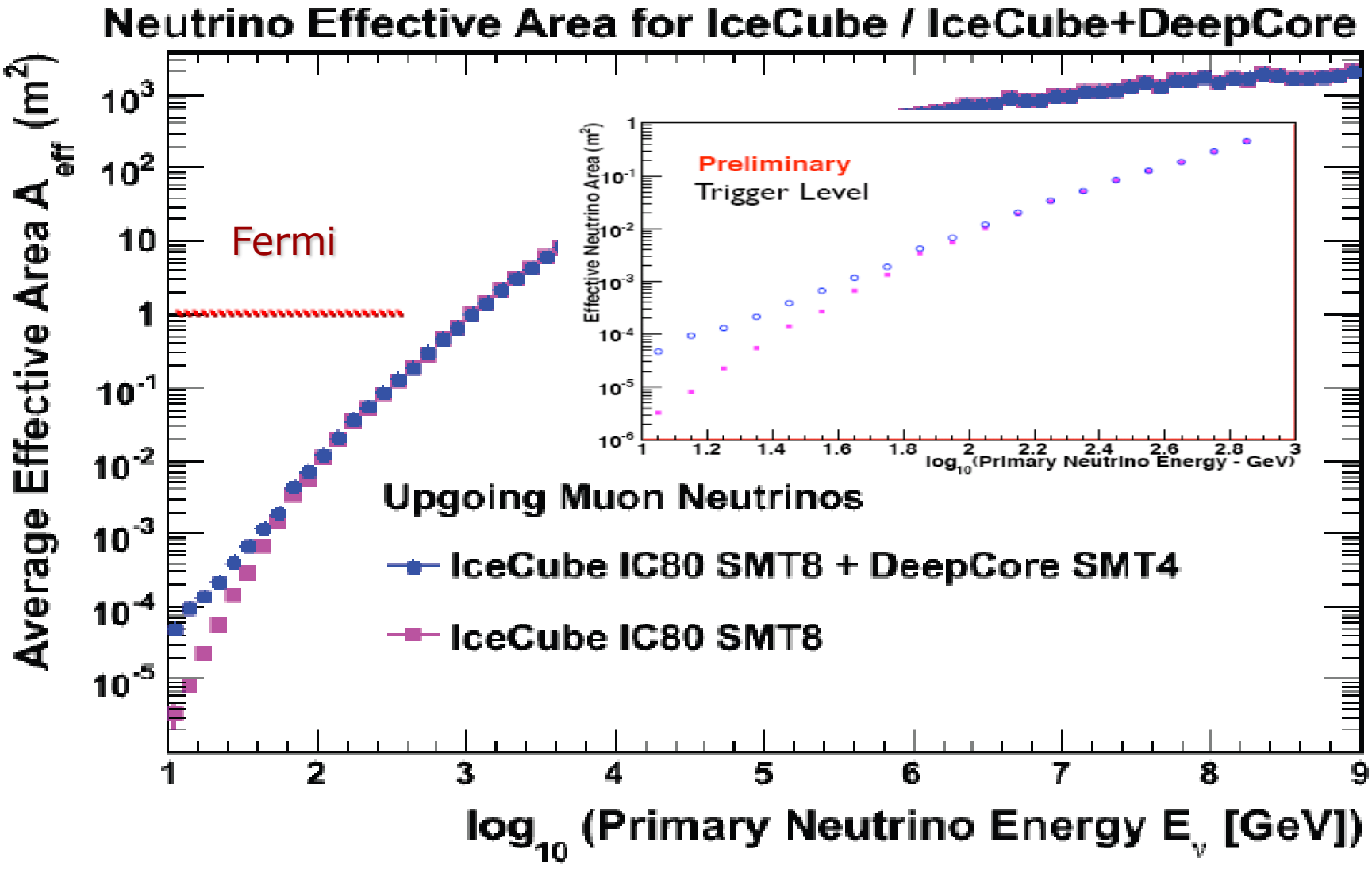
[Yuksel, Horiuchi, Beacom, Ando (2007)]



Cascades are ideal:

- Lower atm. background
- Large scale distribution, anglular resolution of 30deg is more than enough
- Eventually contributions from "known" neutrino point sources could still be subtracted based on the measured flux muon neutrino flux

Effective Area



arXiv:0810.3698

Systematic Uncertainties and Deep Core

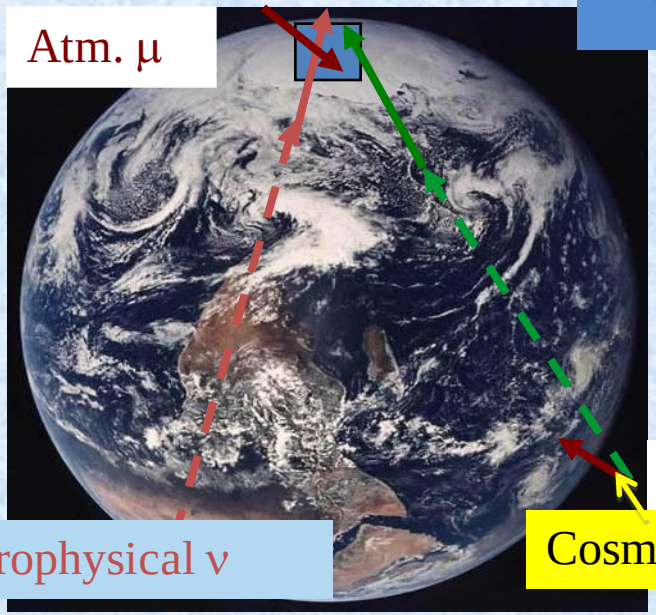
- Example Solar WIMP Analysis
  - Quantum efficiency of optical sensors ~30%
    - Potential to be improved ...
  - Light propagation in the ice (ice properties) ~20%
    - Potential to be improved ... naturally as simulation matures
  - Timing and geometry calibration ~10%
    - Could become more important for Deep Core !

Conclusions

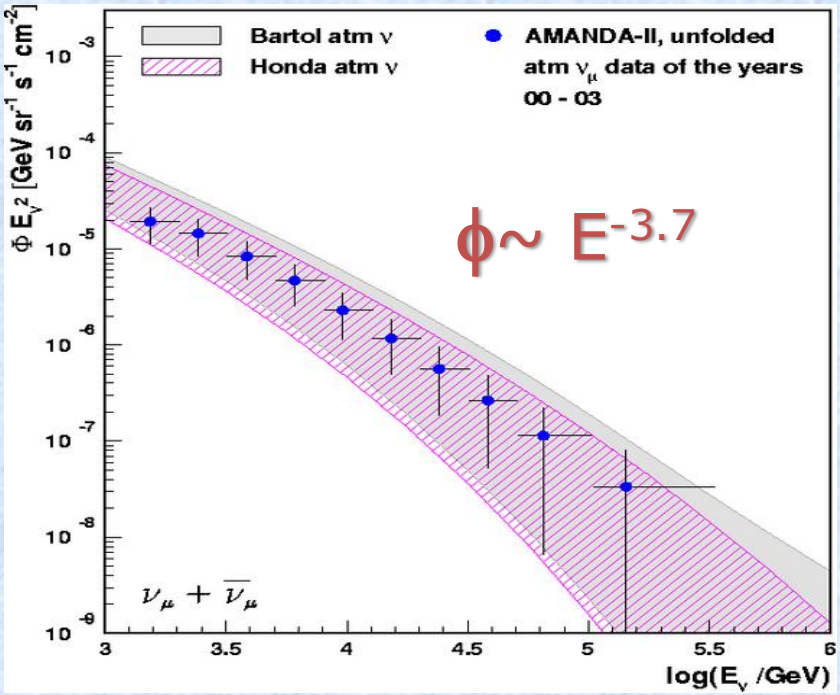
- Significant increase in sensitivity to WIMPs with masses below 200GeV
- Diffuse cascade fluxes (such as for the halo analysis) require a tight veto ring
- Searches are Complimentary and very completive to direct searches
- Outlook for Dark Matter Searches with Deep Core is bright
- See also material from (for more details):
  - **Novel Searches for Dark Matter with Neutrino Telescopes [Nov 17-Nov19, 08]**
    - **http://ccapp.osu.edu/program_dark.html**

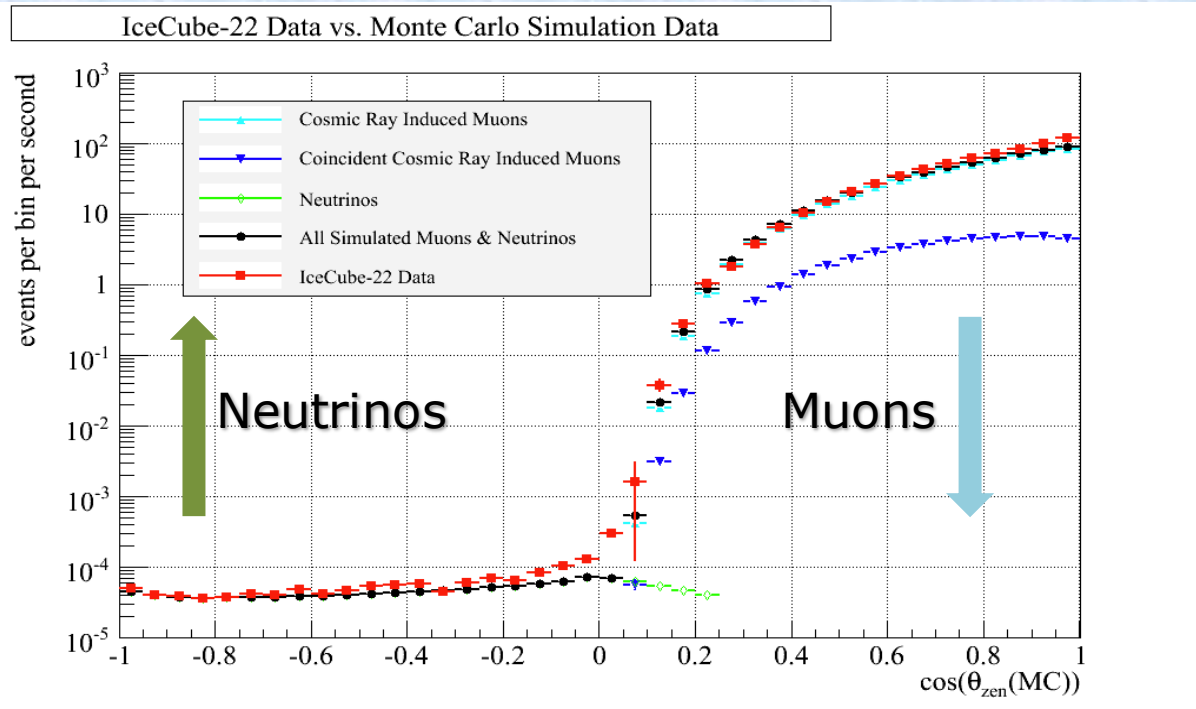
Backup Slides

Atmospheric Neutrinos

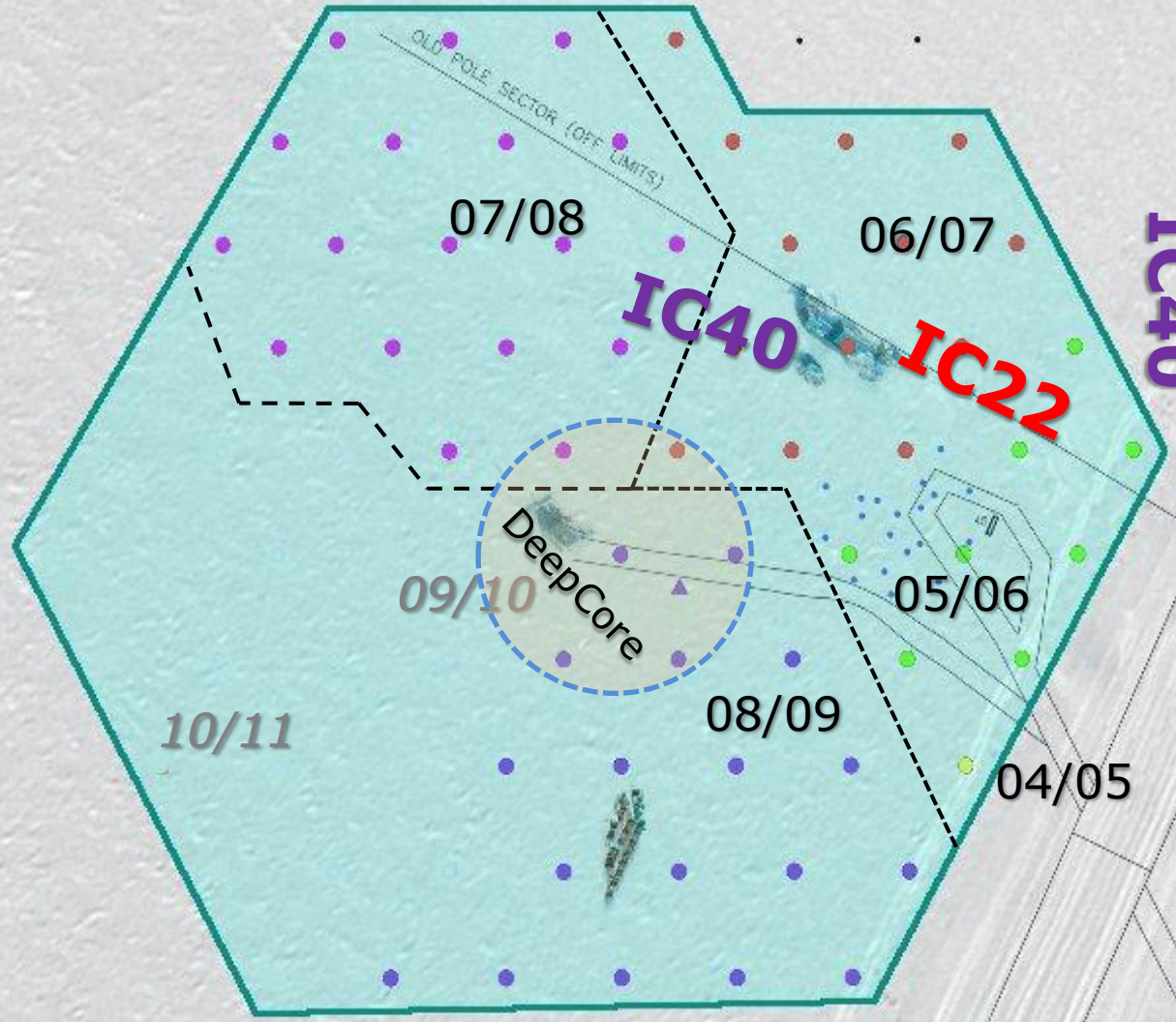


Strings	μ rate	ν rate
AMANDA	~80 Hz	~4.8 / day
IC22	~550 Hz	~28 / day
IC40	~1000 Hz	~110 / day
IC80*	~1650 Hz	~220 / day





IceCube Detector Status



Season	Deployed
2004-2005	1 string
2005-2006	8 strings
2006-2007	13 strings
2007-2008	18 strings
2008-2009	18+1 strings

IC40

IC22