Searching for Dark Matter with IceCube

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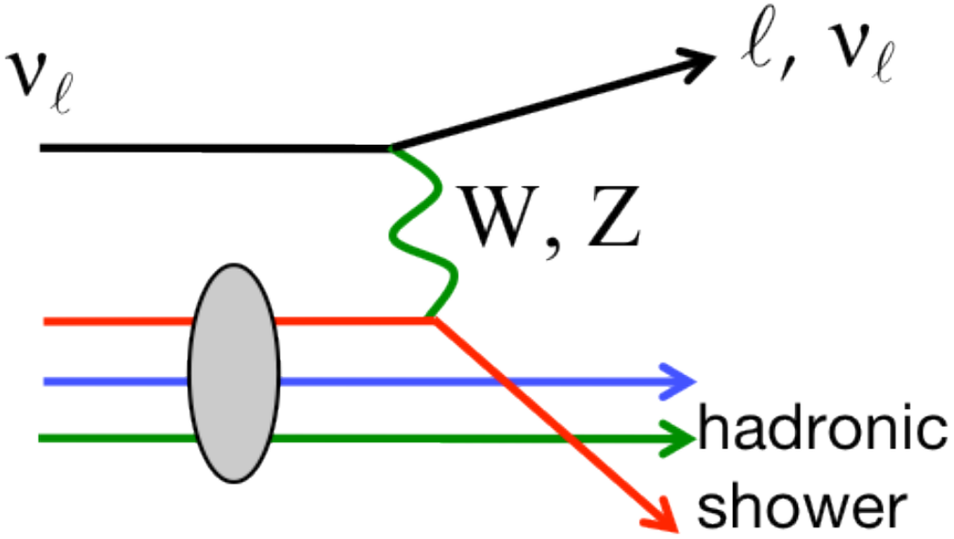
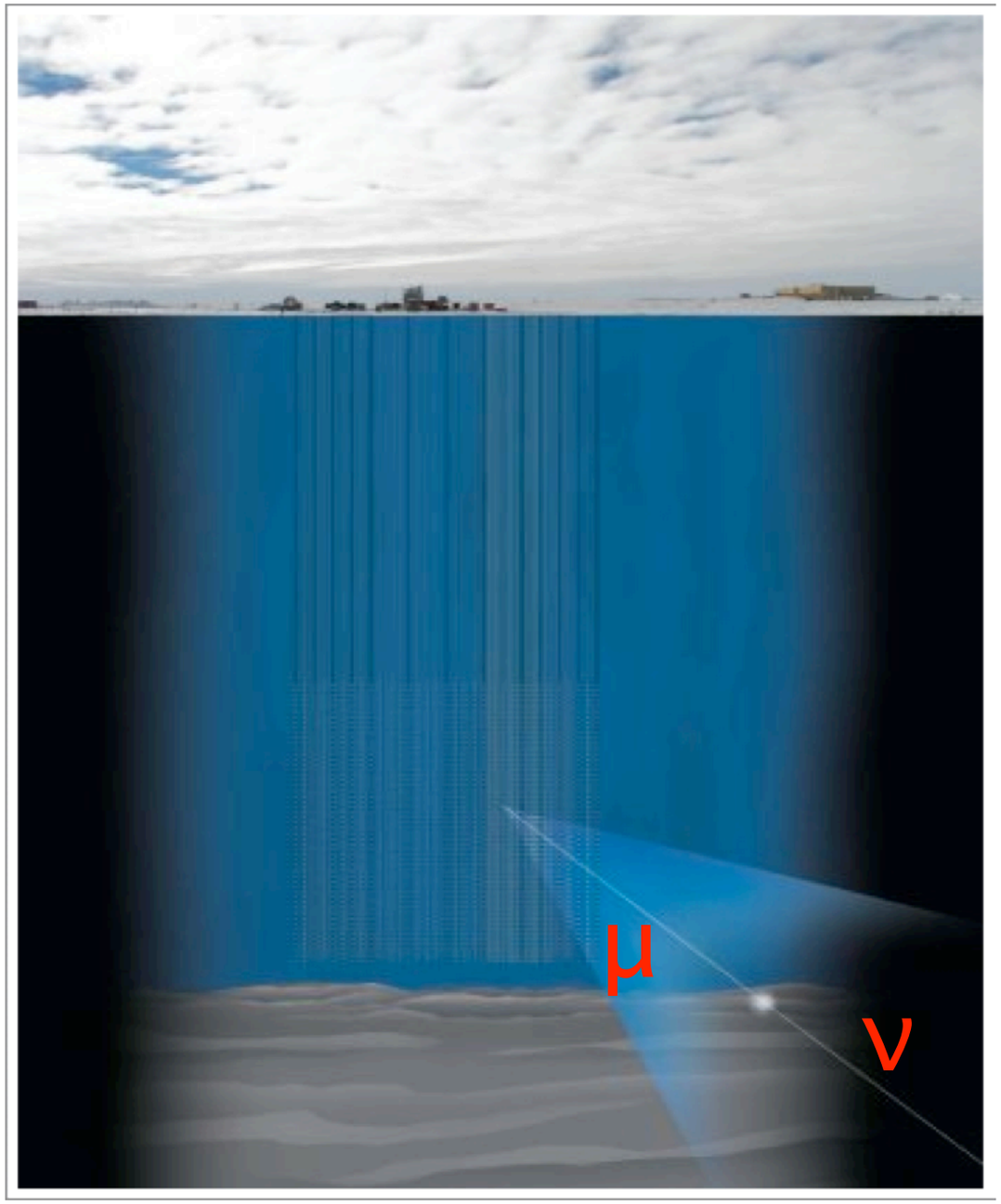
Aspen Winter Conference
22 Jan 2010

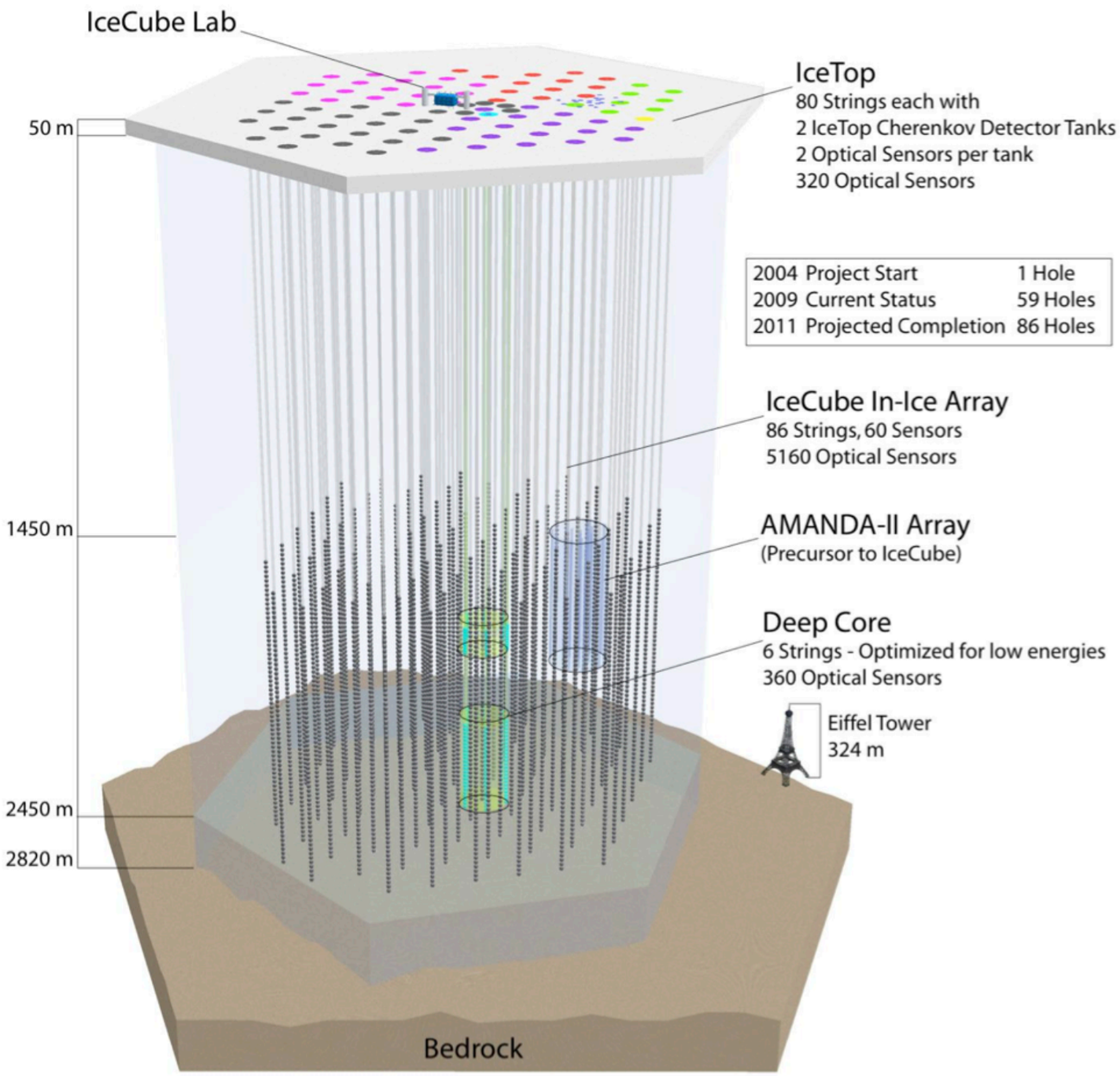
Detection Principle





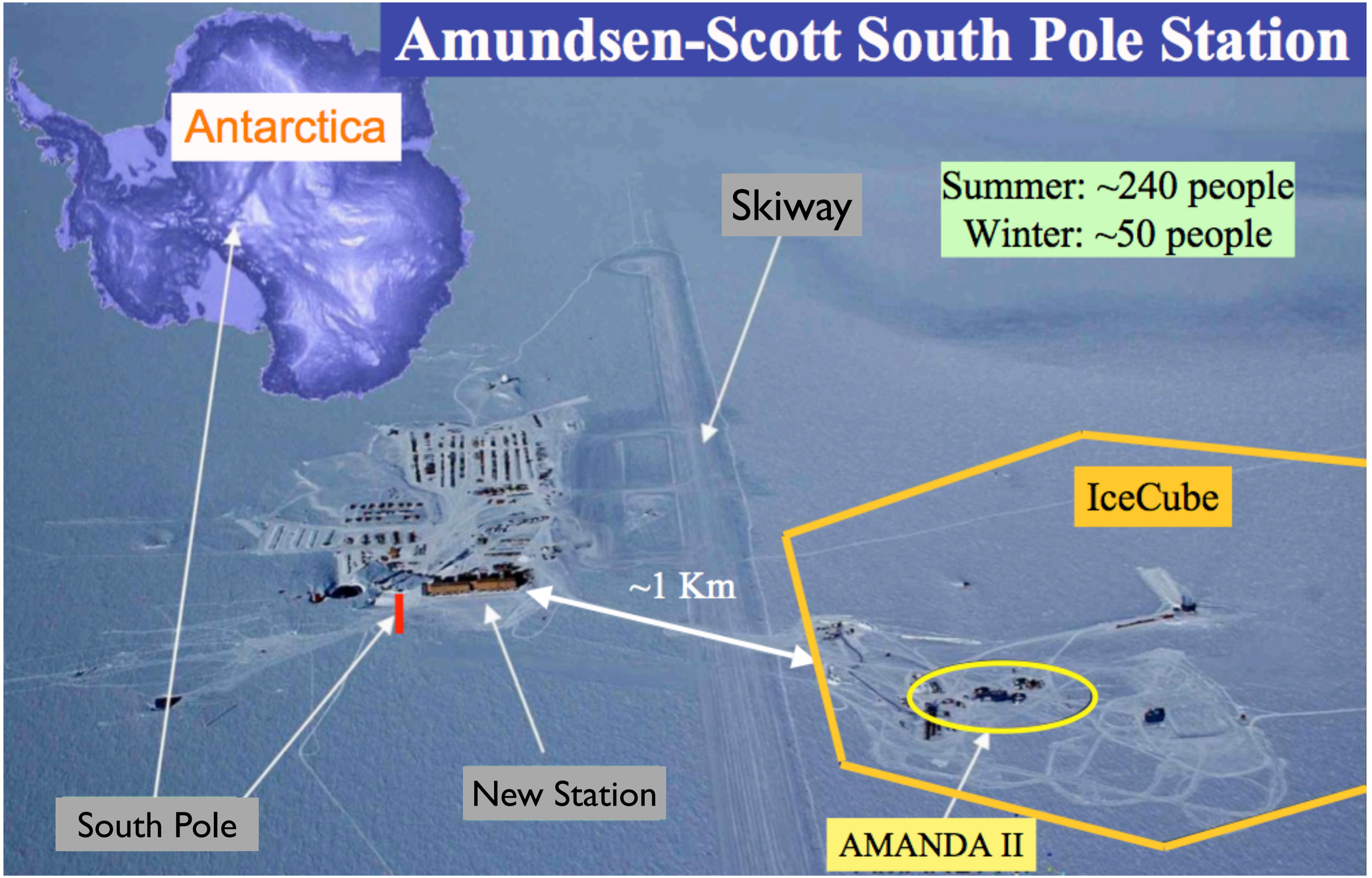
- *0*(km) muon track from ν_μ CC
- *0*(10 m) cascade from ν_e CC, low E ν_T CC, and all NC
- Cherenkov radiation detected by 3D array of optical modules (OMs)

The IceCube Detector



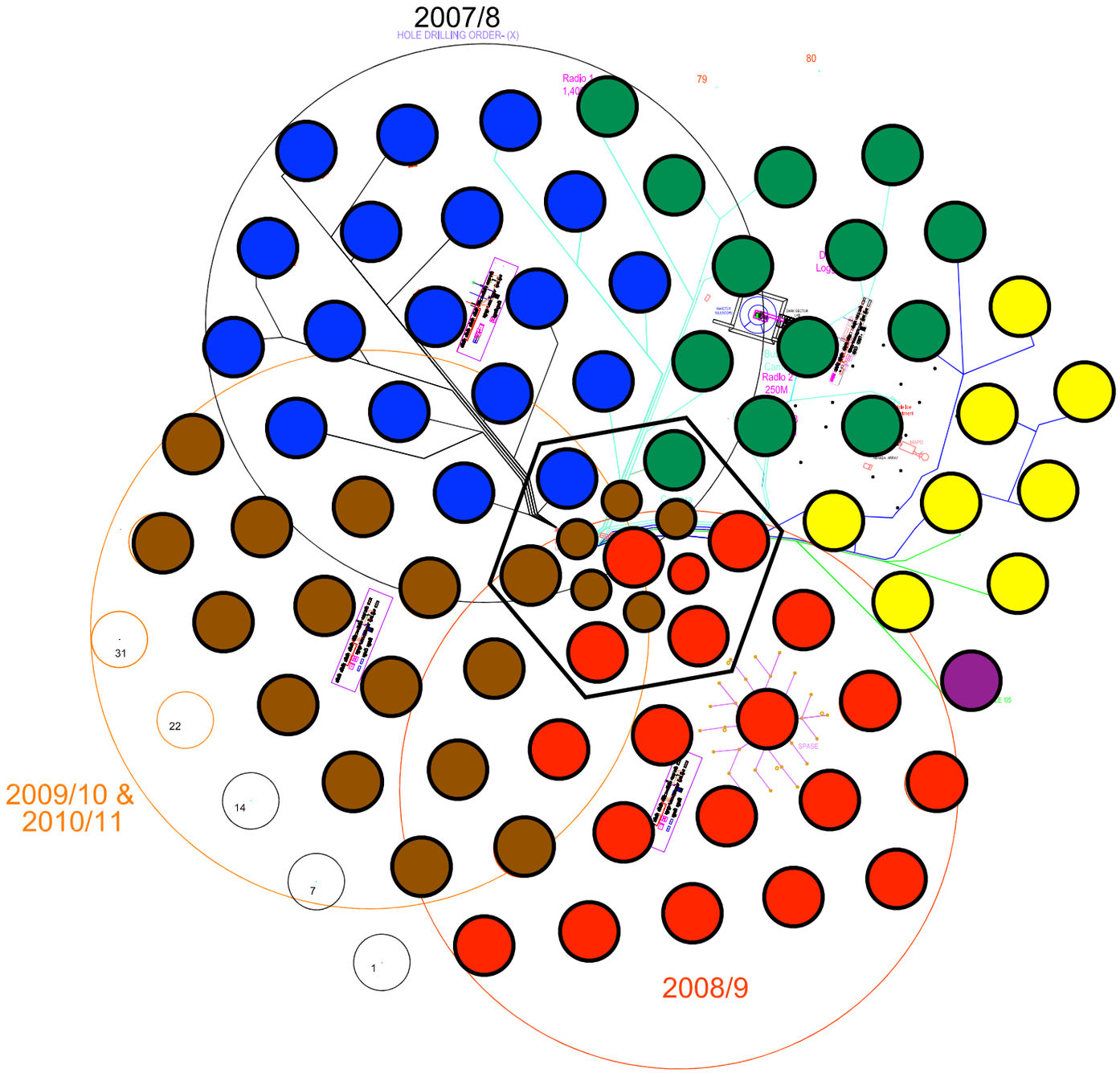
- Cubic km of instrumented ice at a depth b/w 1450 and 2450 m
  - 125 m b/w strings, 17 m b/w sensors
- AMANDA: now decommissioned
- DeepCore: closer spacing of sensors in cleanest ice, surrounded by IceCube veto
  - 70 m b/w strings, 7 m b/w sensors
  - High QE PMTs
- IceTop: Surface Cosmic Ray detector

Amundsen-Scott South Pole Station

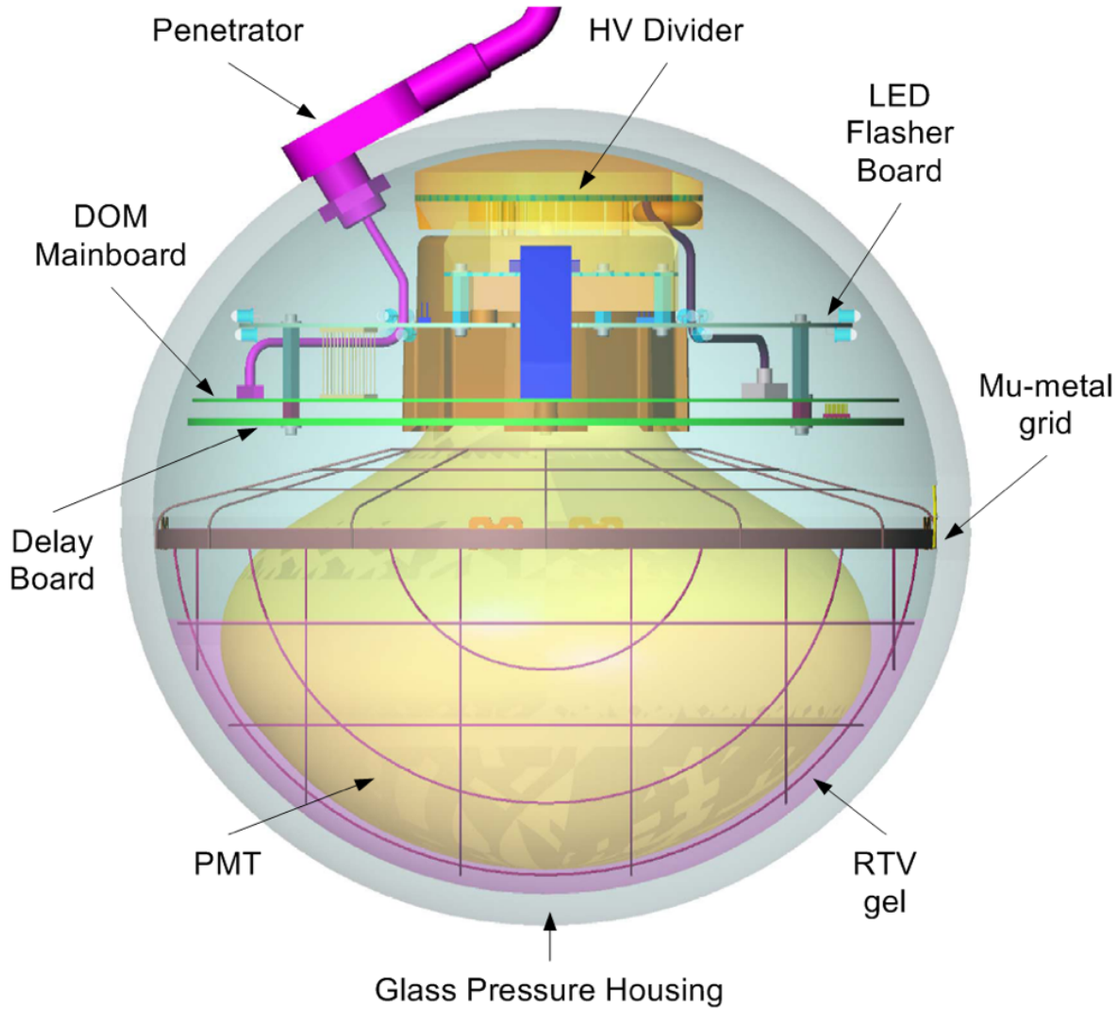


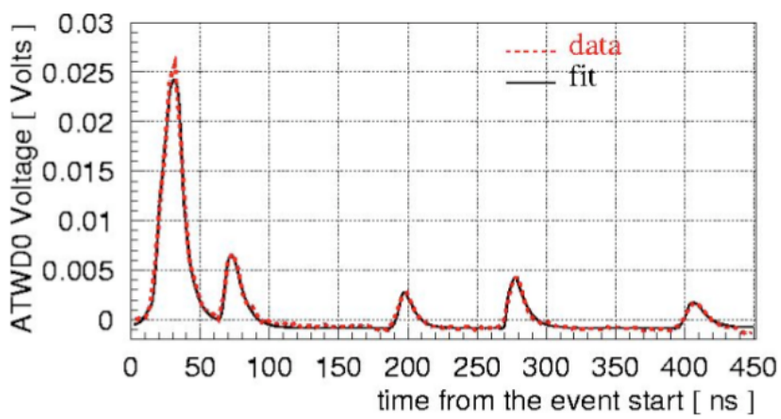
Deployment Timeline

Year	Deploy	Total
2004/5	1	1
2005/6	8	9
2006/7	13	22
2007/8	18	40
2008/9	18+1	58+1
2009/10	15+5	73+6



Digital Optical Module (DOM)





PMT:

- 10” Hamamatsu
- QE ~25% @ 390 nm

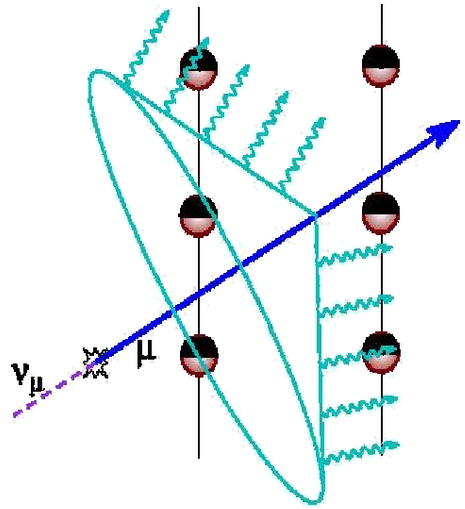
Digitizers:

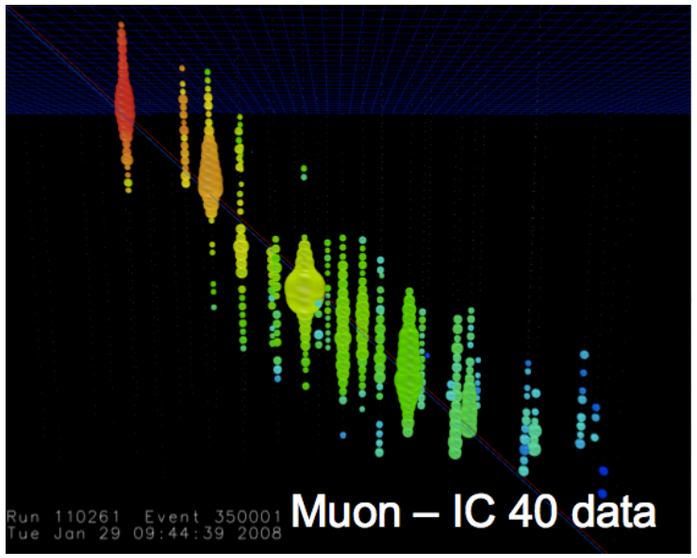
- ATWD
  - 3 Gain Channels
  - Sampled @ 300 MSPS
  - Record 400 ns
- ADC
  - Sampled @ 40 MSPS
  - Record 6.4 μs

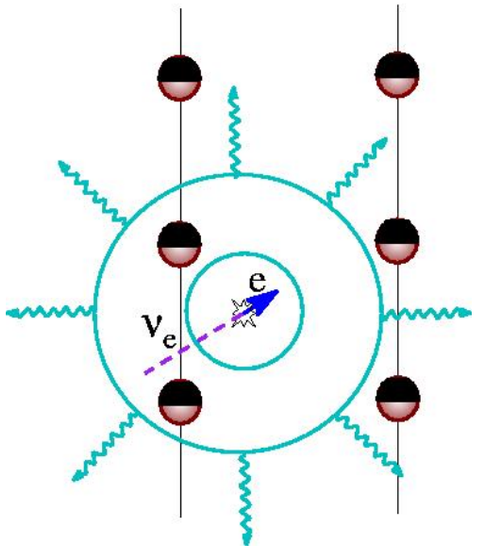
Neutrino Signatures

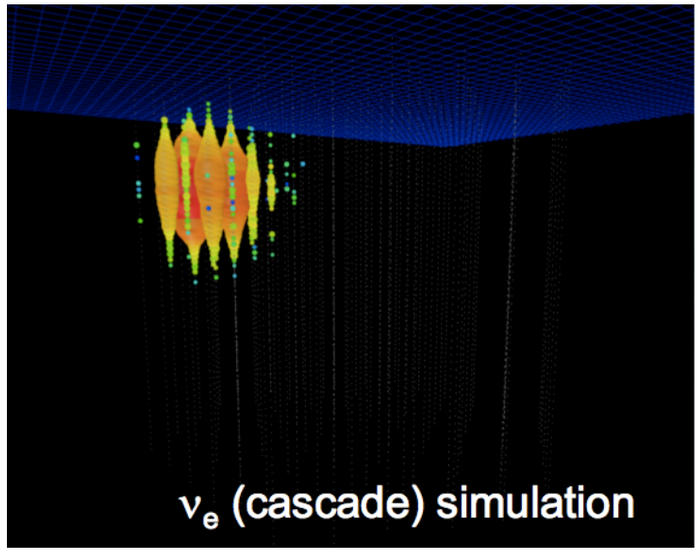
Tracks:

- Through-going muons
- Pointing resolution ~ 1°







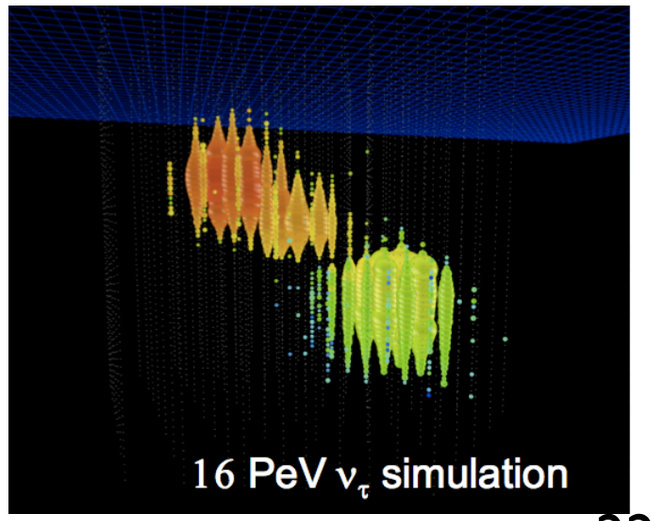


Cascades:

- Neutral Current for all flavors
- Charged Current for ν_e and low E ν_T
- Energy resolution ~ 10% in Log(E)

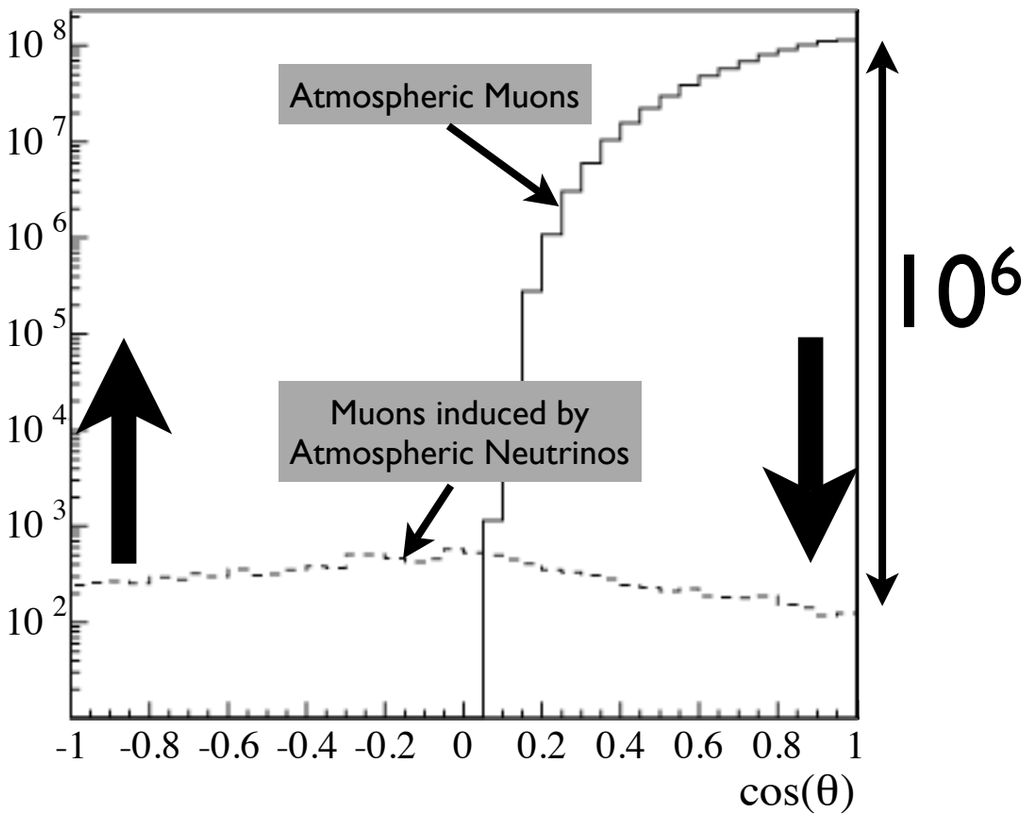
Composites:

- Starting tracks
- Tau Double Bangs
- Good directional and energy resolution



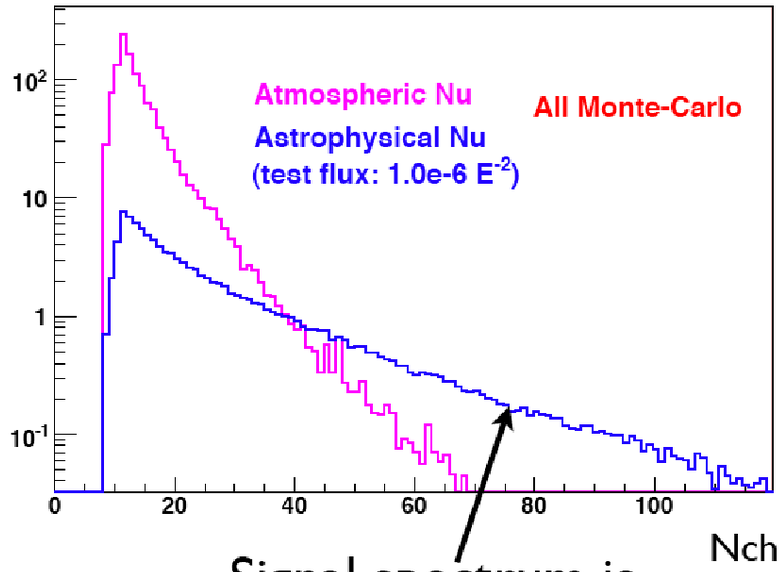
Backgrounds

Direction

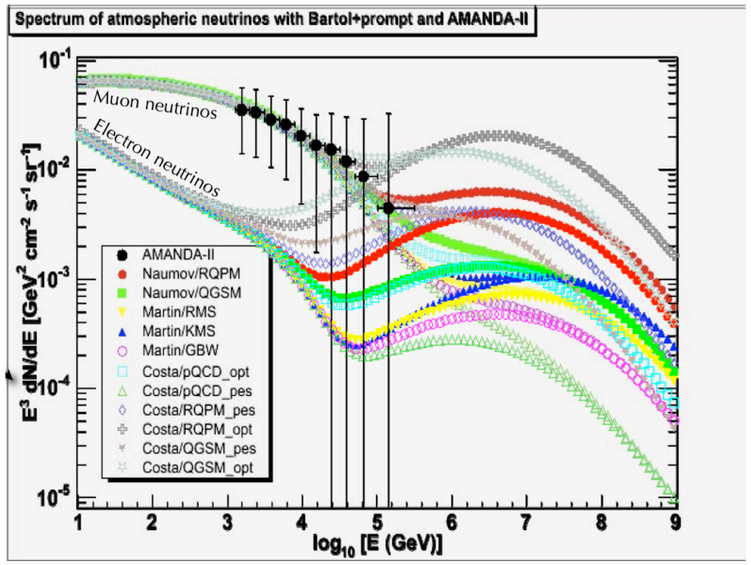


- Atmospheric muons from above
- Atmospheric neutrinos from all directions

Energy

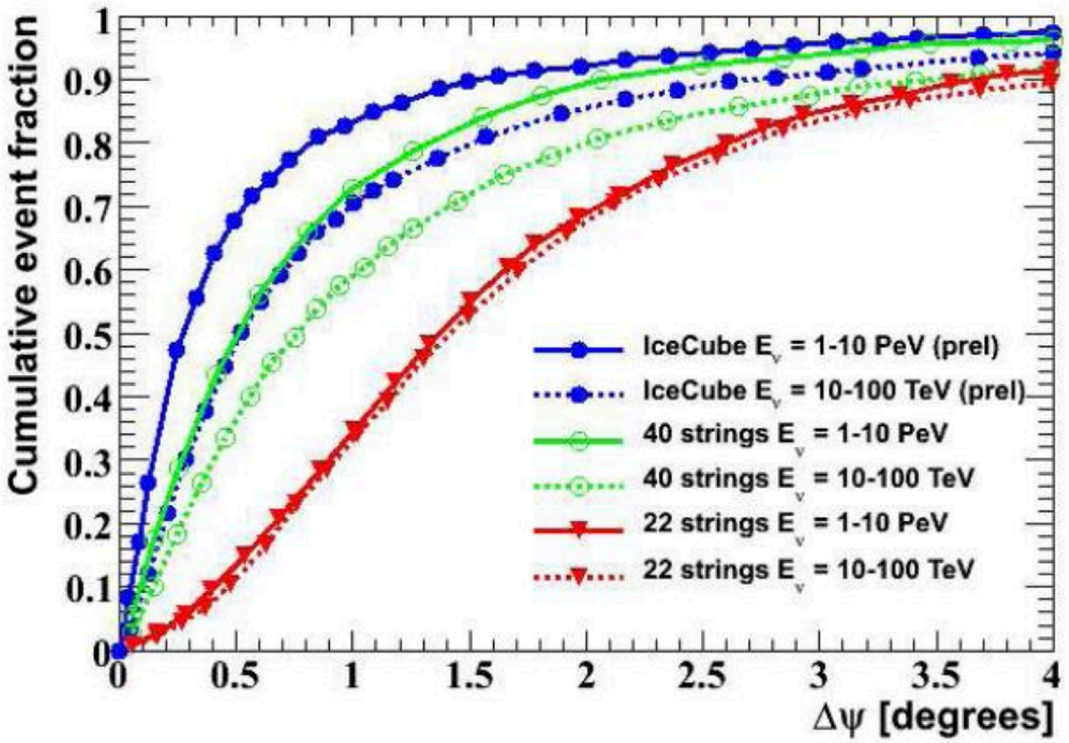


Signal spectrum is harder than Atms.Neutrino



But there's Charm...

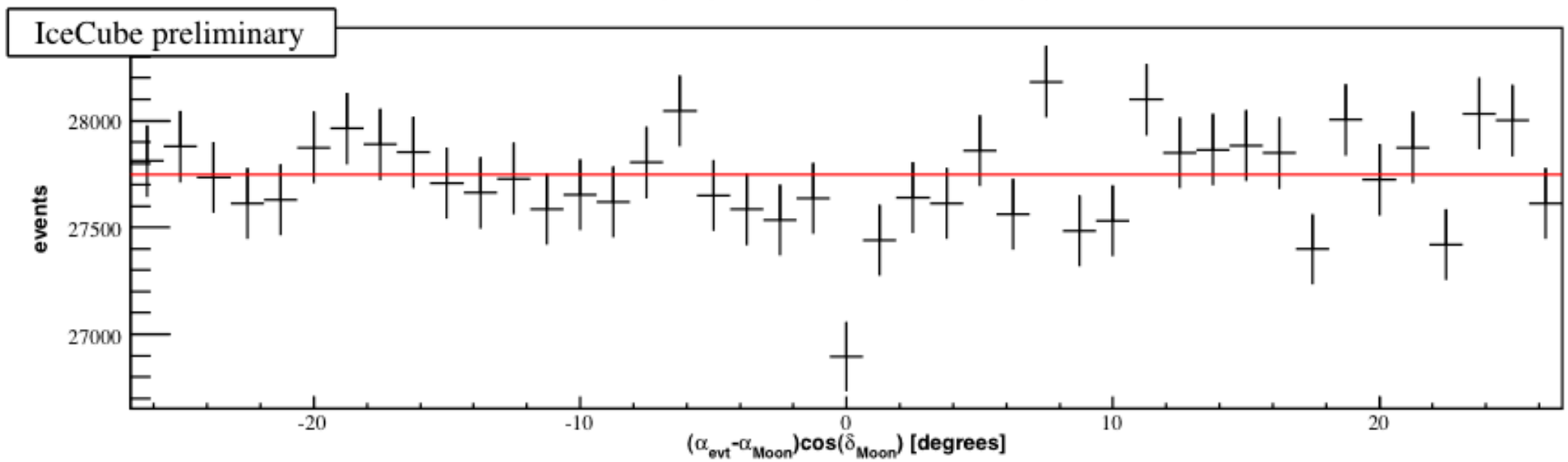
Pointing Resolution



Median angular error:

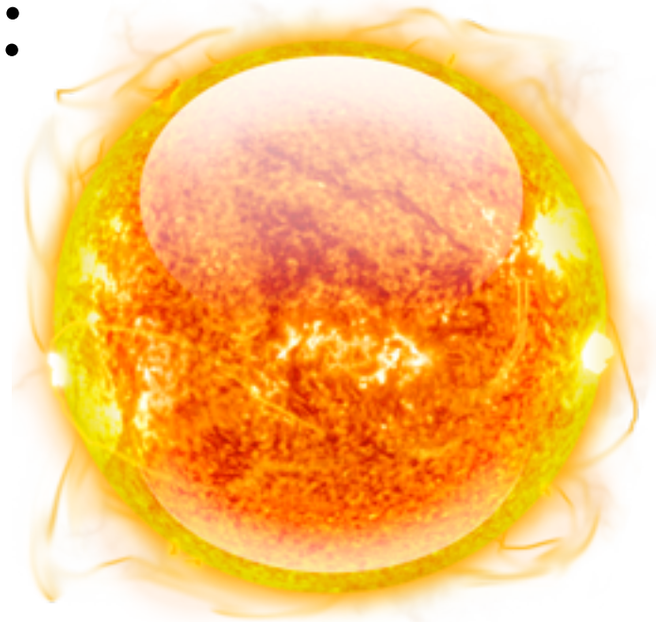
- IC22: ~ 1.5°
- IC40: < 1.0°
- IC80: < 0.5°

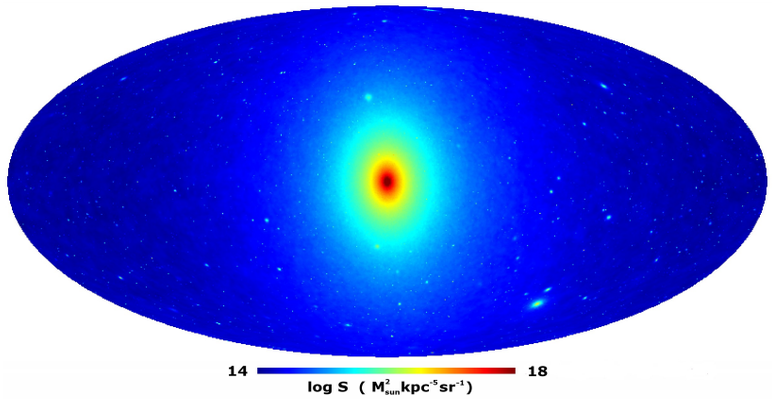
Moon Shadow



Dark Matter Searches

Look for neutrinos from annihilation of WIMPs in:

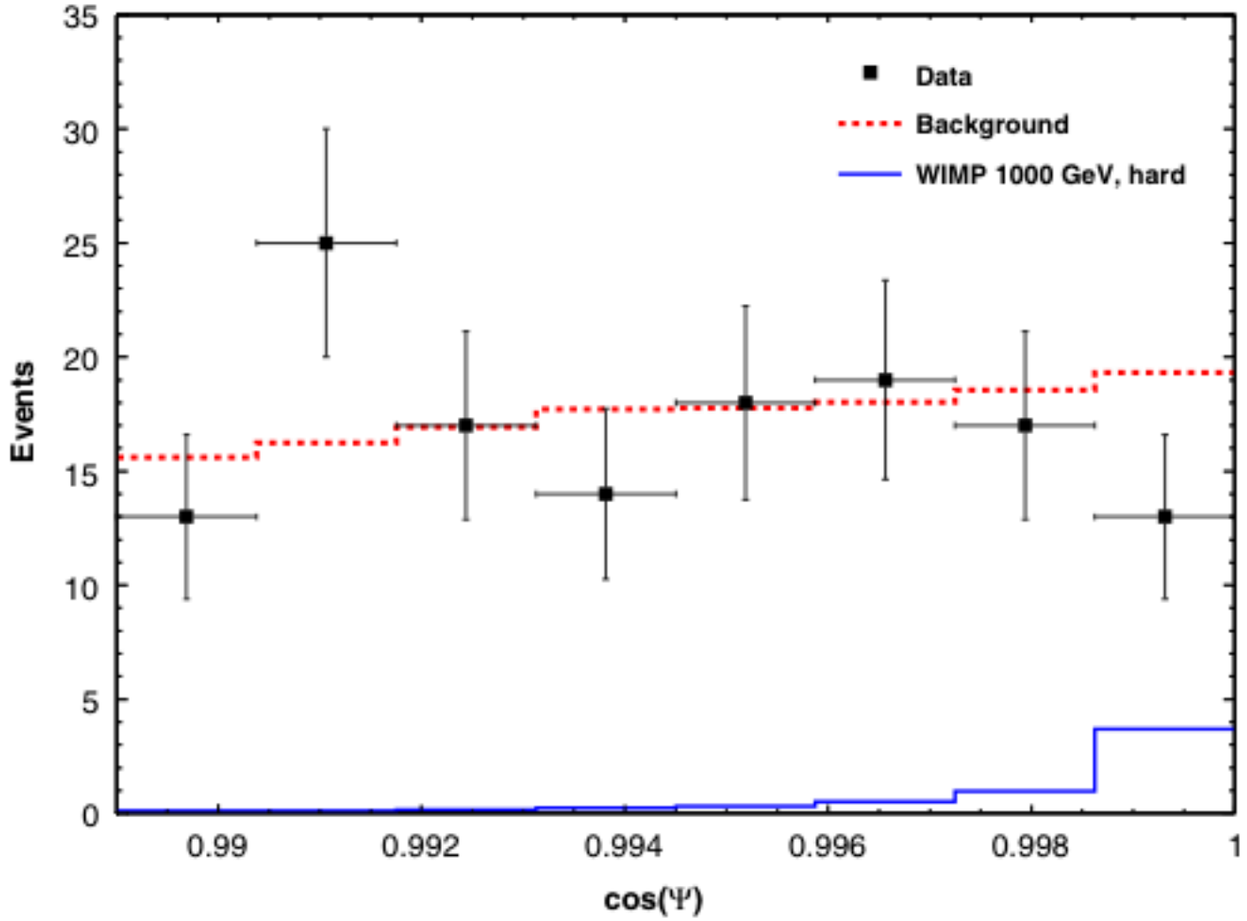




- Solar WIMPs: MSSM χ and UED LKP
- Earth WIMPs: MSSM χ
- Galactic Halo: MSSM χ

IC22 Solar WIMPs

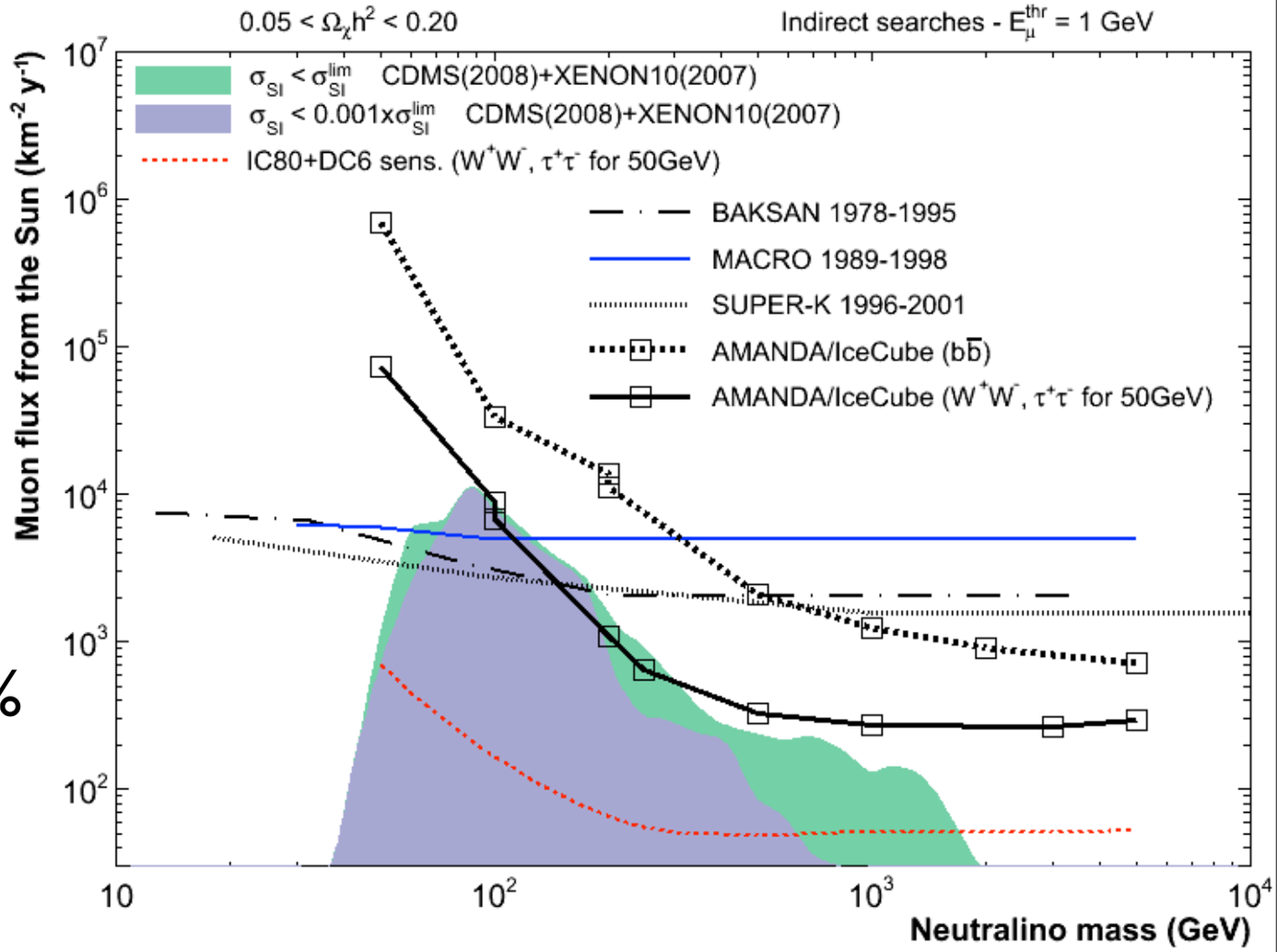
- Blind analysis: Hide Sun azimuth
- Select events with zenith: 90°-120° when Sun is below horizon
- Background cuts: SVM trained on 12 observables
- 6946 events in 104.3 days of live time
- Simulation predicts 56% atmospheric ν_μ and 44% misreconstructed atmospheric μ



- Calculate angular distance to the Sun
- Consistent with BG expectation

Muon Flux Limit

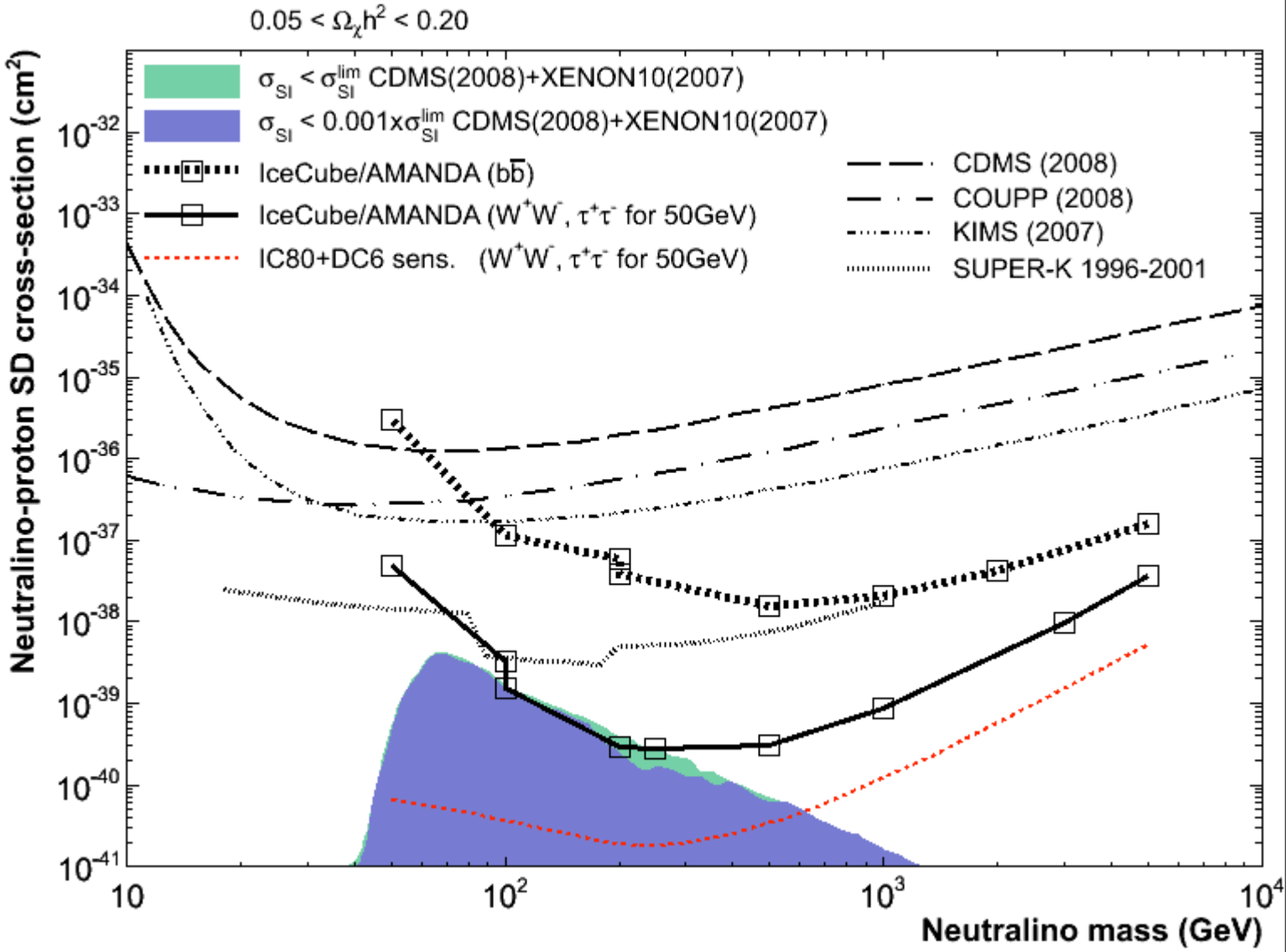
- Fit observed Ψ distribution with sum of simulated signal and expected BG
- Signal: MSSM neutralino
- BG: data with randomized azimuth
- 90% CL upper limit on signal between 6.4 - 8.5 events
- Largest systematic error: Photon propagation and DOM efficiency ~ 20%
- Translate upper limit on signal count into upper limit on flux



PRL 102, 201302 (2009)

Neutralino SD Cross-section

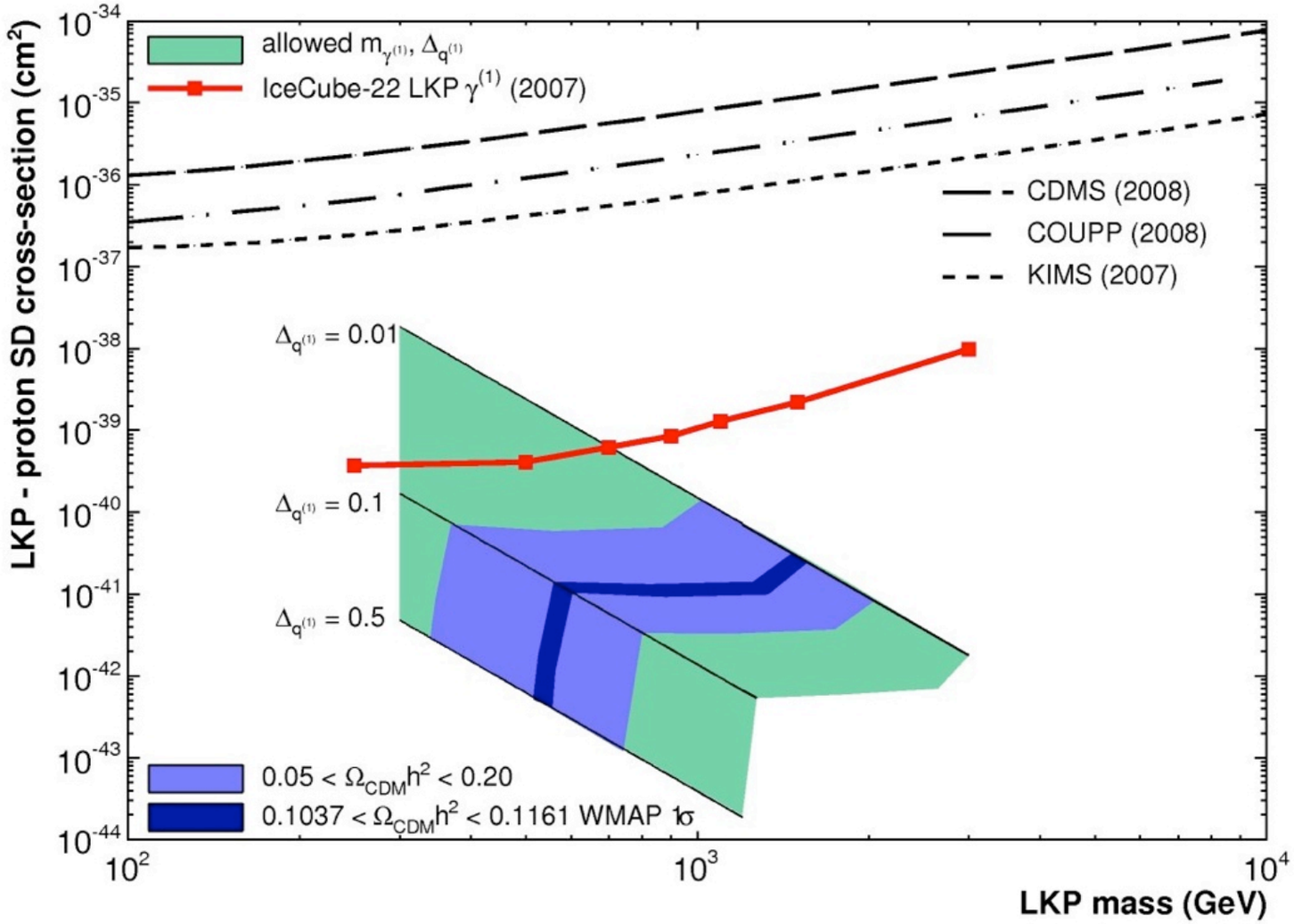
- Convert muon flux limit to cross-section limits
- Assumes equilibrium: $\Gamma_A = \frac{1}{2} C_C$
- Take two extreme annihilation channels: $W^+W^-, b\bar{b}$
- 3-flavor oscillations
- Neutrino cross-sections
- Muon energy loss in ice



JCAP 04, 009 (2009)

Kaluza-Klein DM

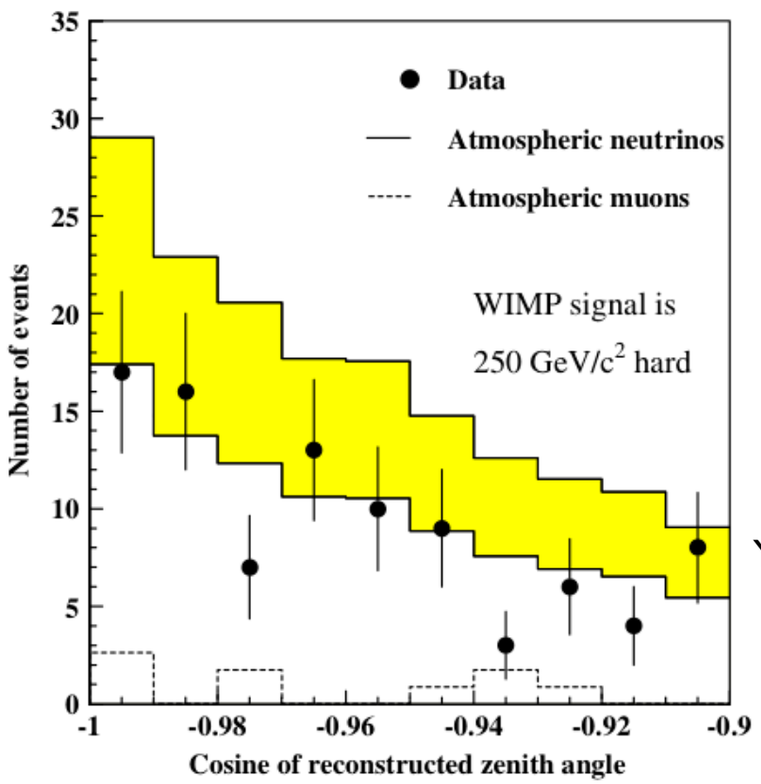
- Use same data
- UED in 5 spacetime dimensions
- LKP is KK photon
- Allowed mass: 300 GeV to a few TeV
- Model has two parameters: Δ_q and M_{LKP}
- In equilibrium in the Sun
- Annihilate to SM particles → ν's



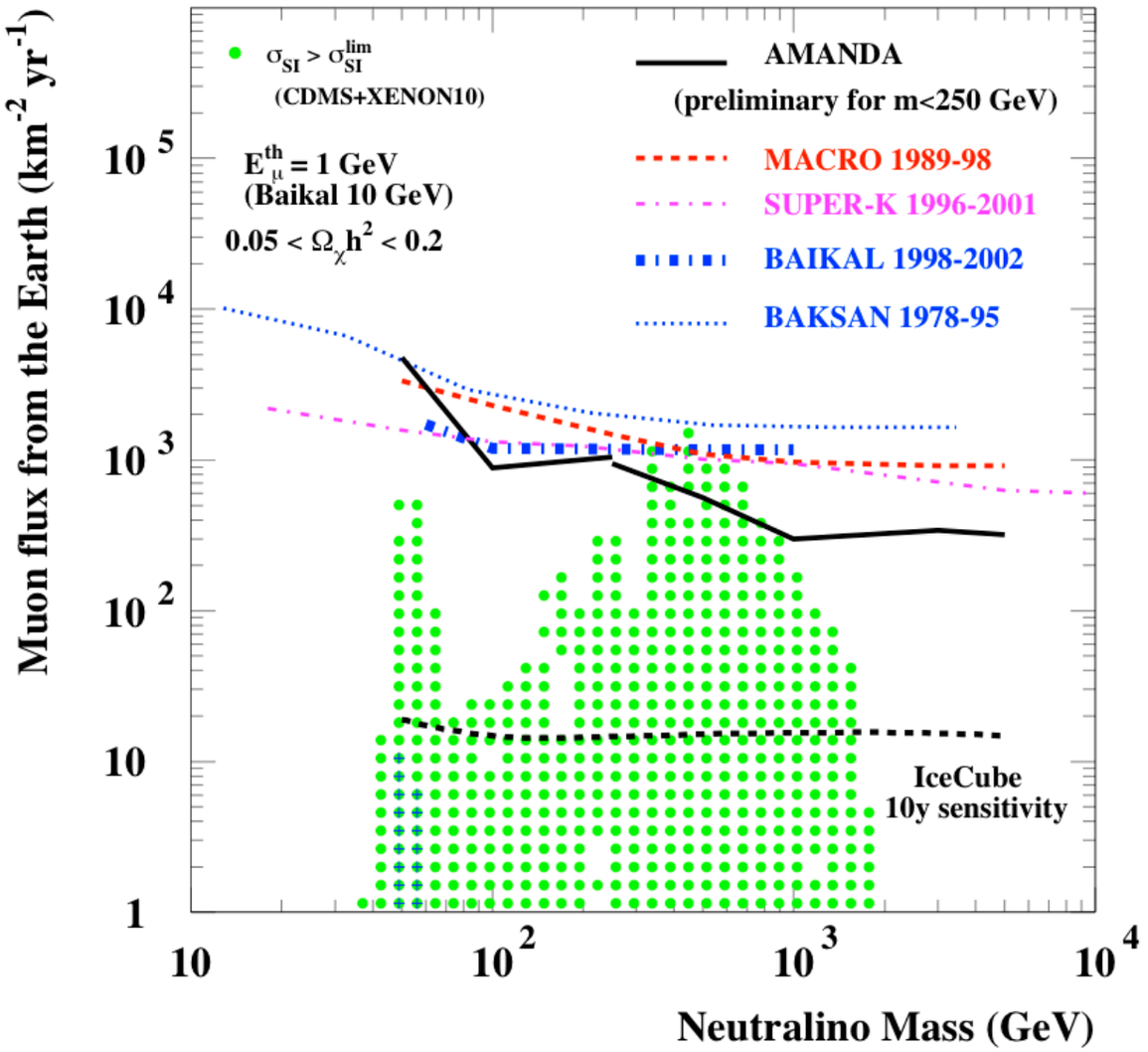
arXiv:astro-ph/0910.4480v1 (23 Oct 2009)

AMANDA Earth WIMPs

- 421.9 days of live time between 1997-99
- Similar to Solar analysis except look for vertical events

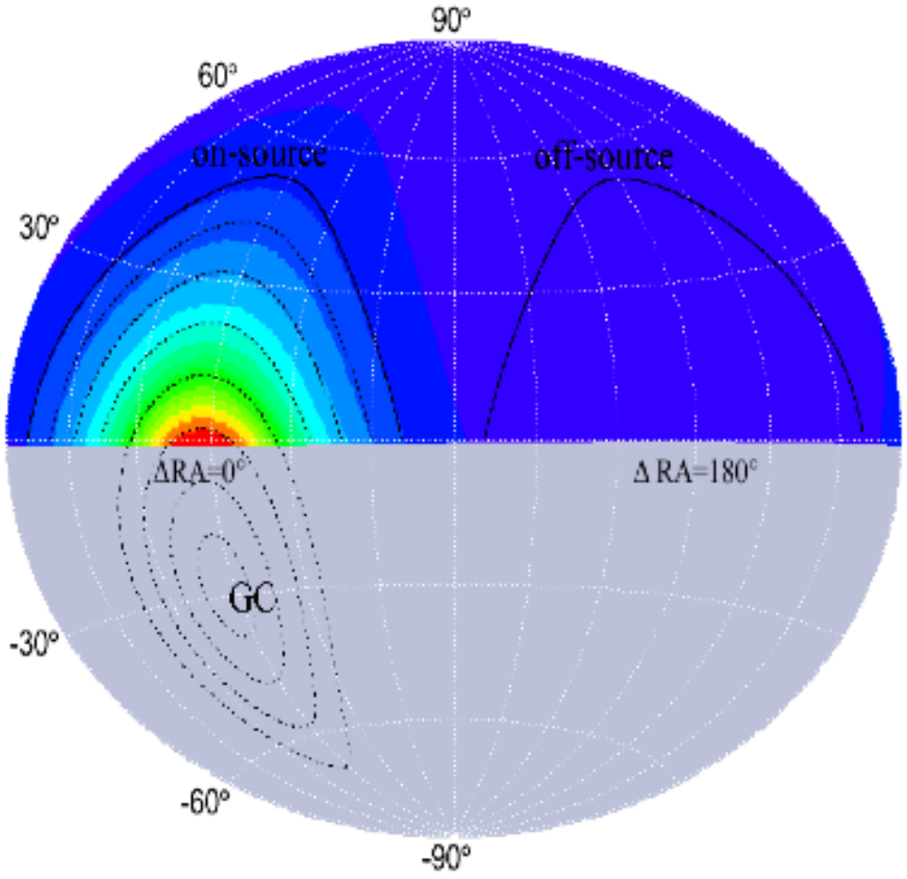


Yellow band = Systematic error



Astropart. Phys. 26 (2006) 129-139

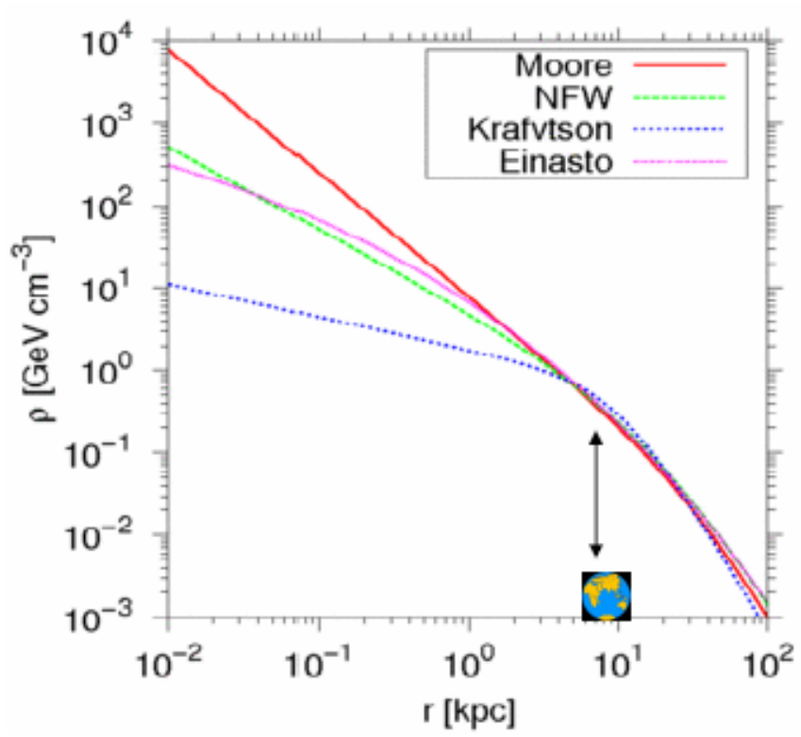
IC22 Galactic Halo



- Galactic Center is above the horizon
- Compare equal areas of on-source and off-source
- Pick halo and SUSY models, measure flux, constrain annihilation cross-section

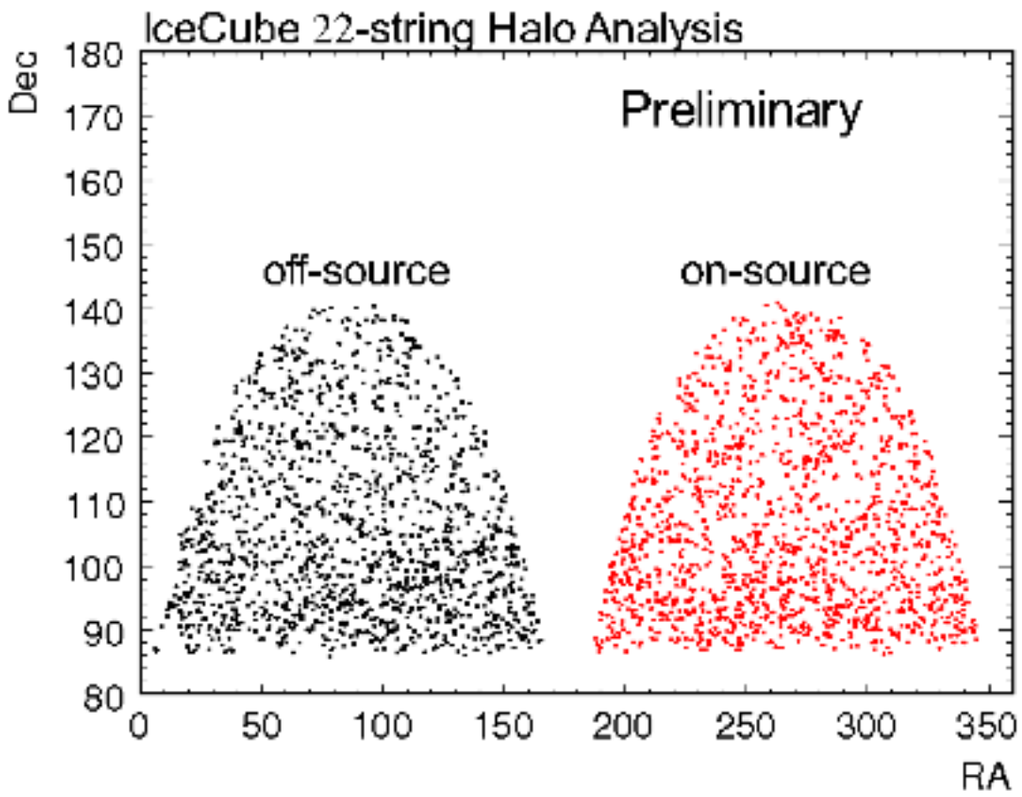
$$\frac{d\Phi}{dE} = \frac{<\sigma_A v>}{2} J(\psi) \frac{R_{sc}\rho_{sc}^2}{4\pi m_\chi^2} \frac{dN}{dE}$$

Measure — Constrain — Halo — SUSY

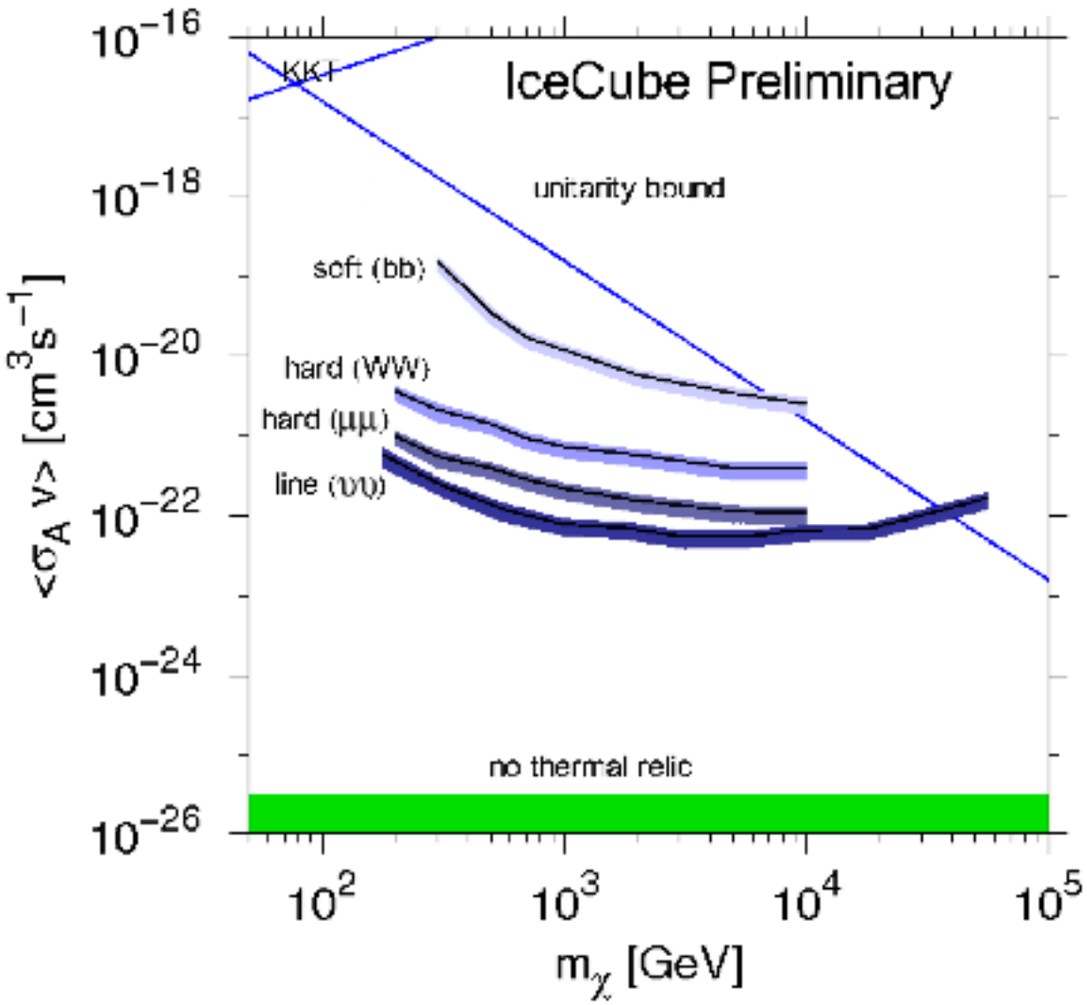


Galactic Halo Limit

- Observe N_{on} = 1367, N_{off} = 1389
- 90% CL upper limit on signal = 46

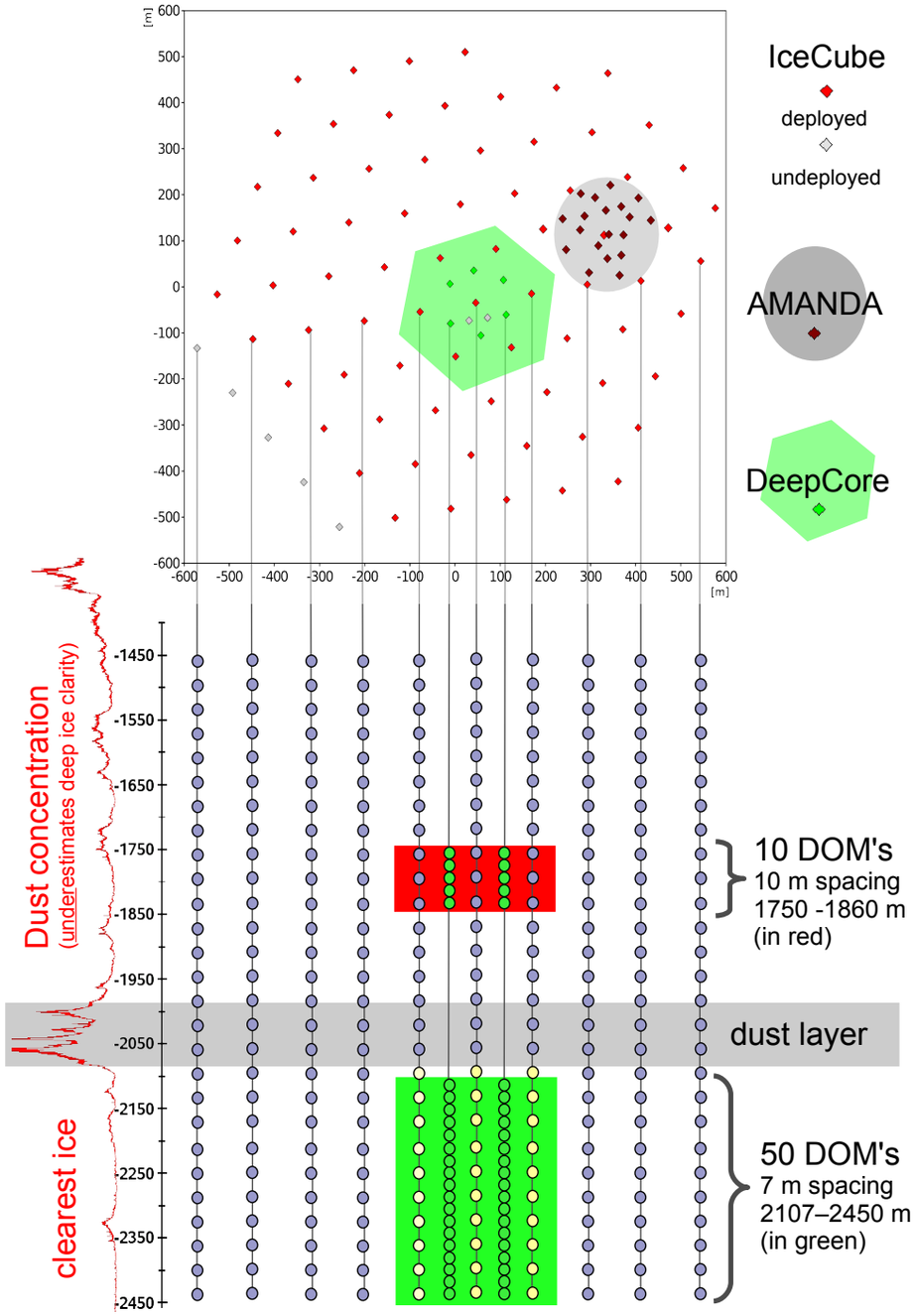


Systematic errors not included



arXiv:astro-ph/0912.5183v1 (30 Dec 2009)

DeepCore

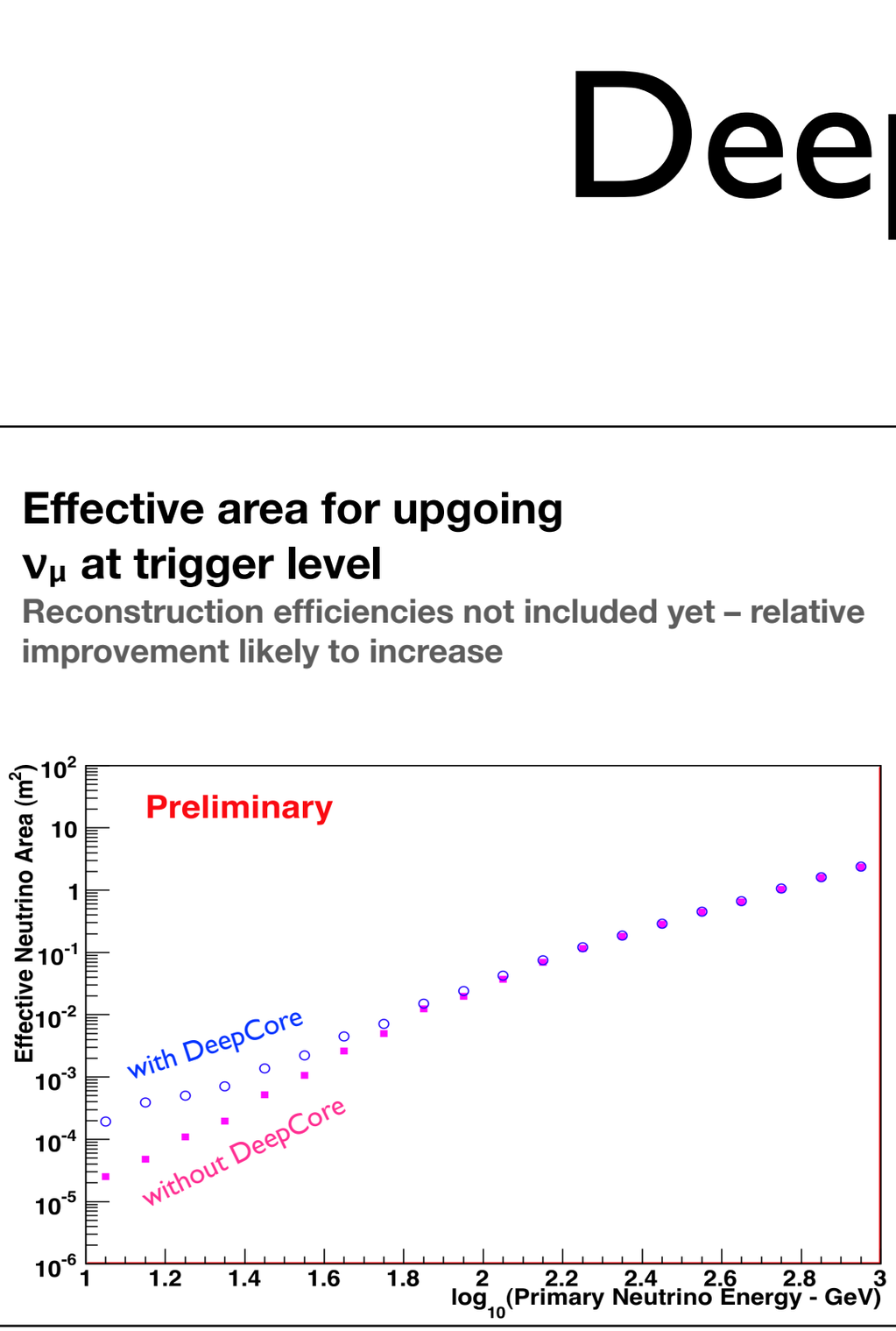


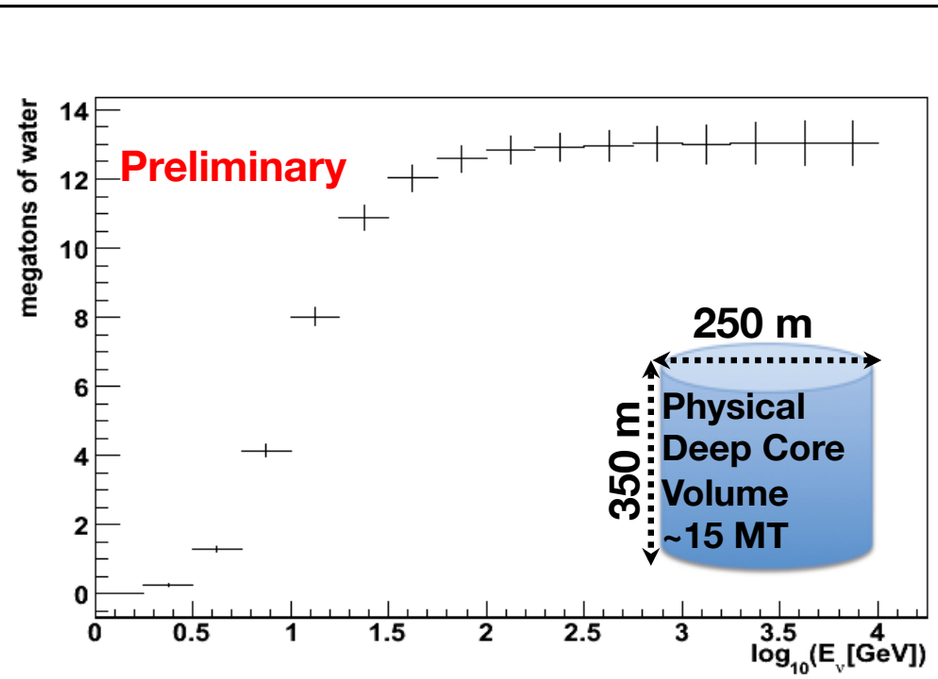
- Surrounded by IceCube → Active veto
- Simulation predicts background rejection ~ 10^6
- Opens up the Southern Sky, Galactic Center
- Cleanest ice, denser spacing →Better reconstructions
- Better cascade identification

DeepCore

Effective area for upgoing ν_μ at trigger level

Reconstruction efficiencies not included yet – relative improvement likely to increase





Effective volume for downgoing ν_μ interacting in Deep Core

Trigger level, reconstruction efficiencies not included yet

DeepCore Enhanced Physics

- Dark Matter (Discussed in this talk)
- Southern Sky Point Sources (IceCube Veto)
- Atmospheric Neutrinos (High Statistics)
  - Lorentz invariance
  - Quantum decoherence
- Neutrino Oscillations (Low Energy)
  - ν_μ disappearance
  - ν_τ appearance
  - Mass hierarchy

Conclusions

- Most stringent limits on SD neutralino cross-sections for masses > 100 GeV
- Starting to reject models still allowed by direct detection experiments
- IceCube construction ends next year
- IC79 + DeepCore physics run starts soon
- IC40 WIMP analyses are underway and IC59 data available soon
- DeepCore will greatly improve WIMP sensitivities near WIMP masses of 100 GeV