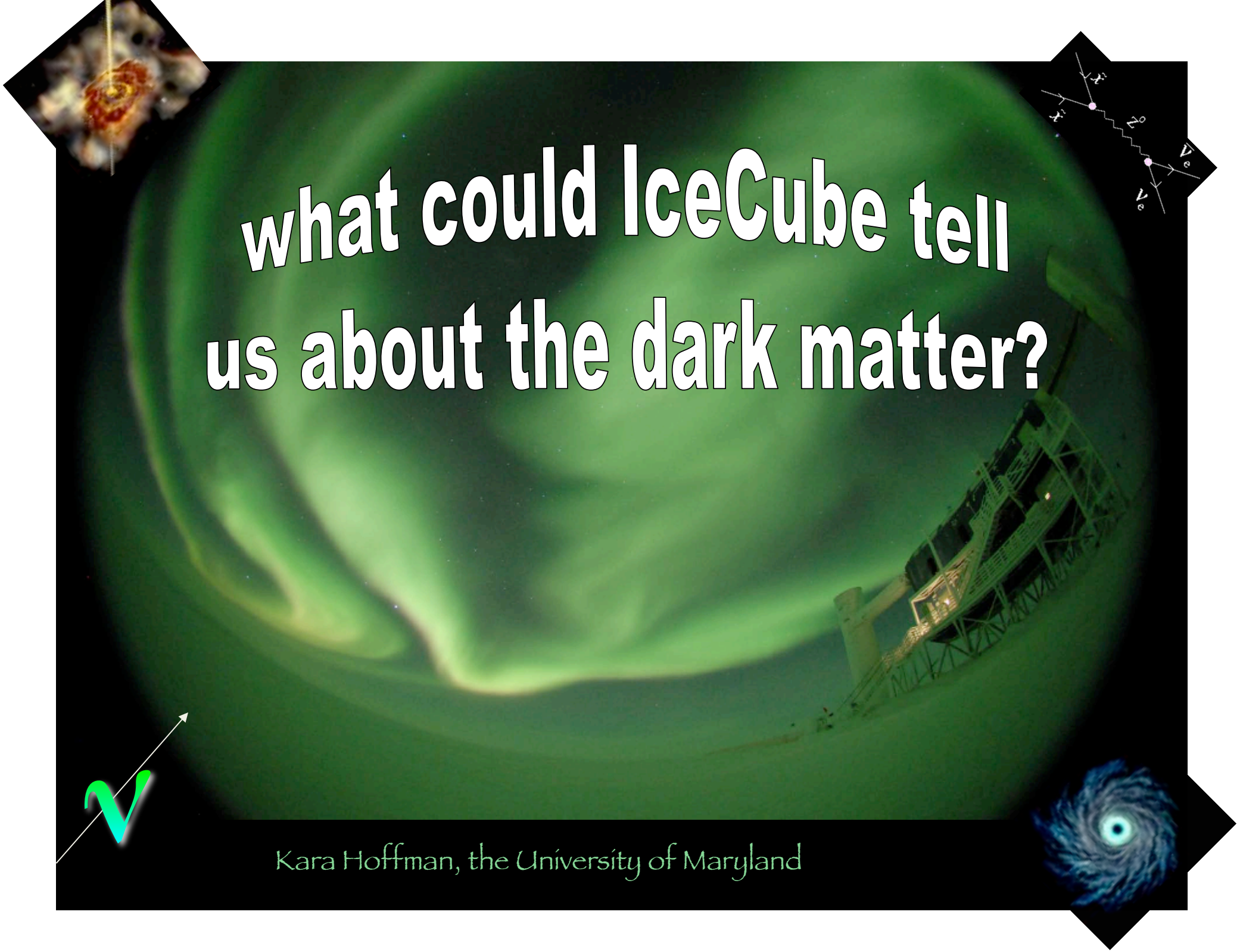
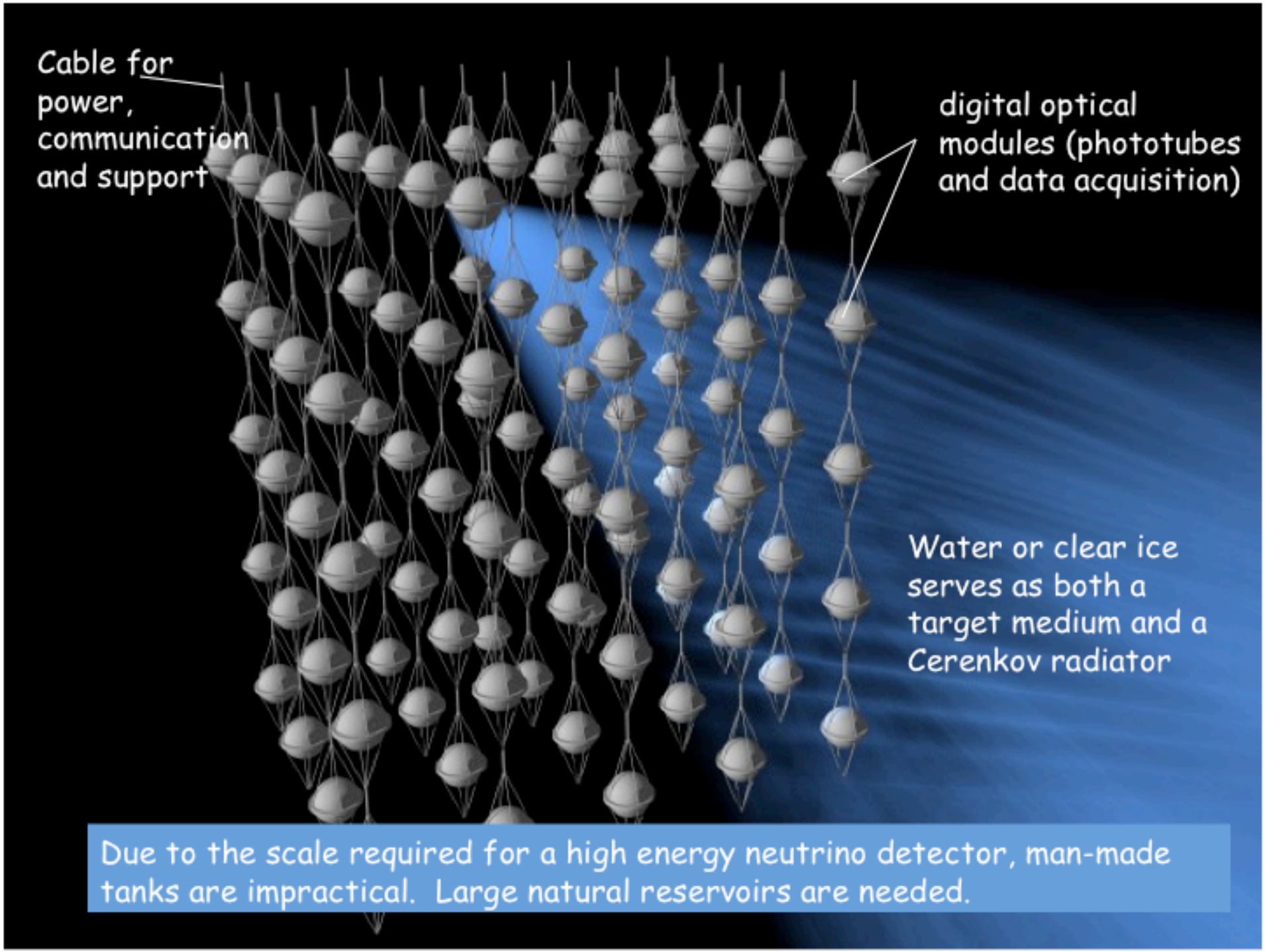
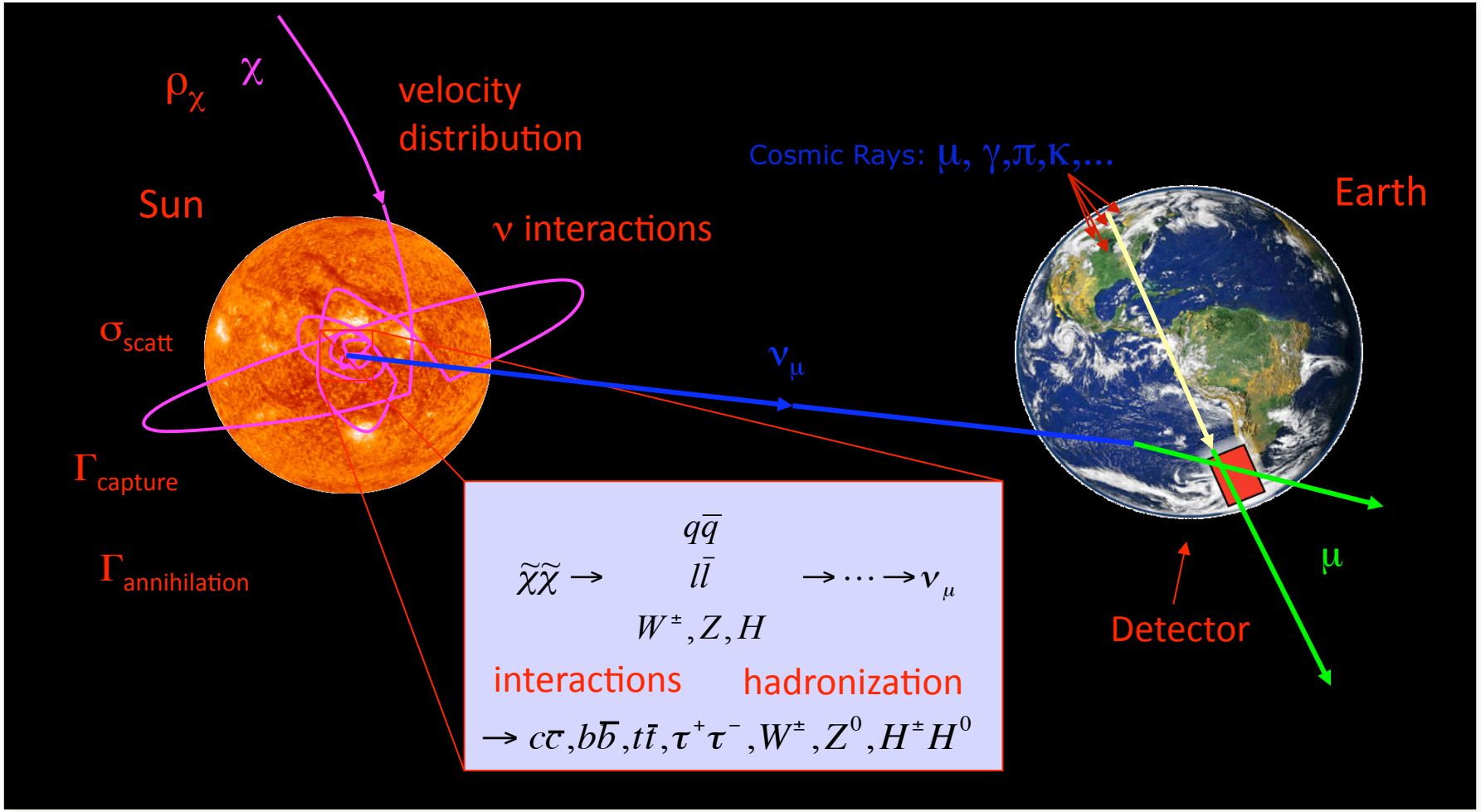

what could IceCube tell us about the dark matter?
Kara Hoffman, the University of Maryland


Cable for power, communication and support
digital optical modules (phototubes and data acquisition)
Water or clear ice serves as both a target medium and a Cerenkov radiator
Due to the scale required for a high energy neutrino detector, man-made tanks are impractical. Large natural reservoirs are needed.

WIMP detection by South Pole Neutrino telescopes



The Sun sinks maximally 23° below the horizon at the south pole

Horizontal events very important!

Also look for Wimps trapped in the gravity well of the earth. They will appear to come from the center of the earth.

Indirect vs. Direct Detection

Briefly…

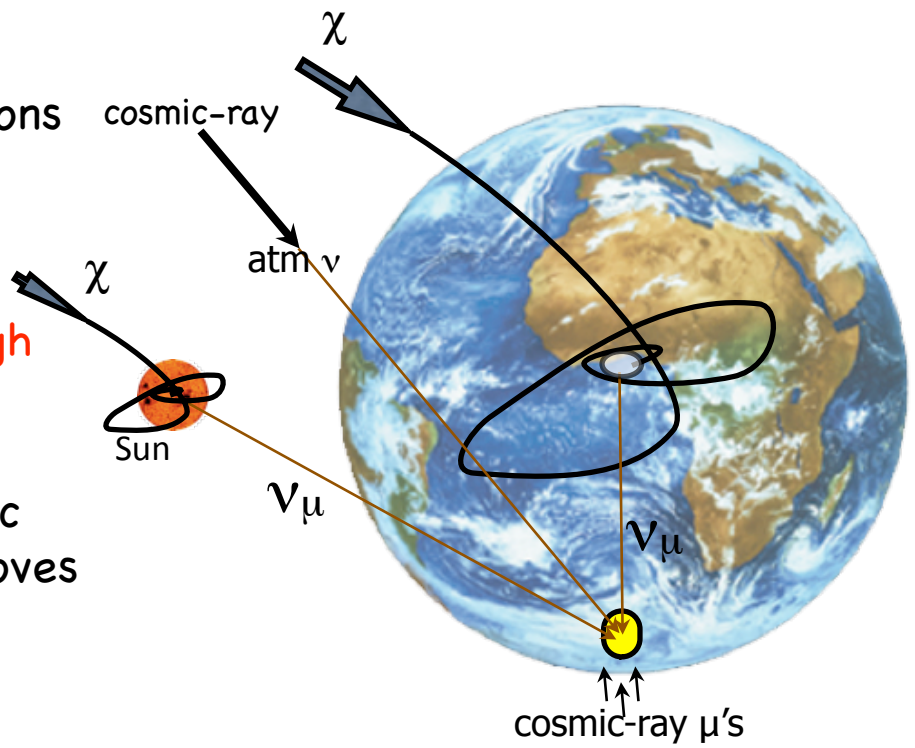
Indirect detection is:

•more sensitive to spin-dependent detection
(the sun is a huge proton target for which spin dependent interaction is important)

•less sensitive to spin-independent interactions
(A^2 coherence not present in hydrogen)

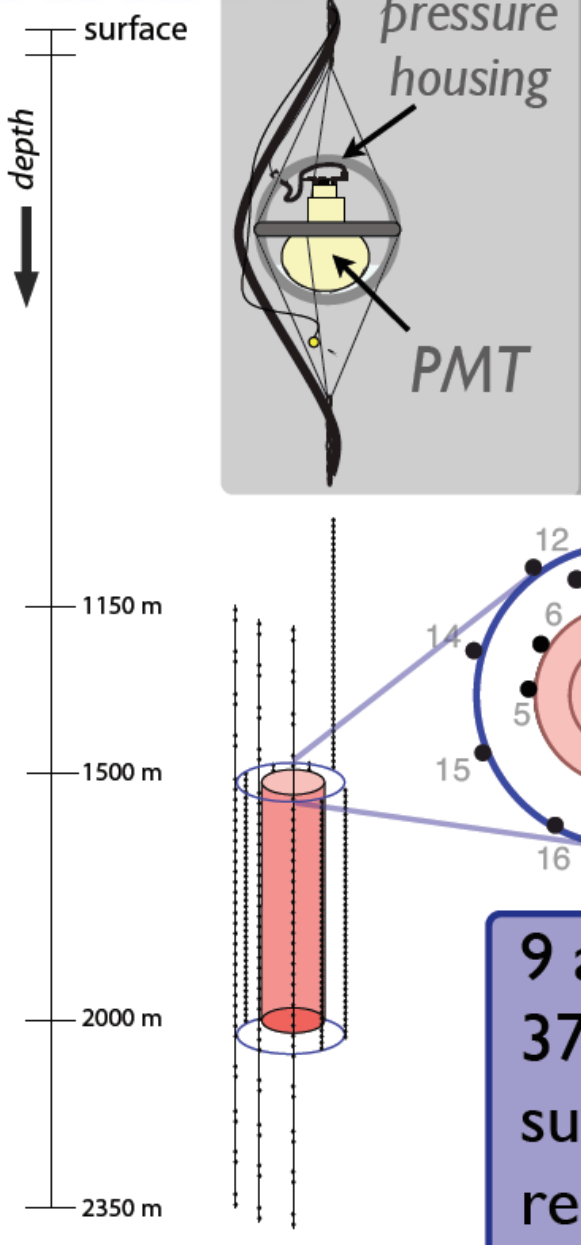
•more sensitive to low WIMP velocities
(efficient gravitational trapping whereas high velocity produce larger nuclear recoils)

•may sample regions with higher WIMP relic density as gravitational well (Sun, Earth) moves in space and time



AMANDA

the Antarctic Muon and Neutrino Array



The AMANDA-II Detector

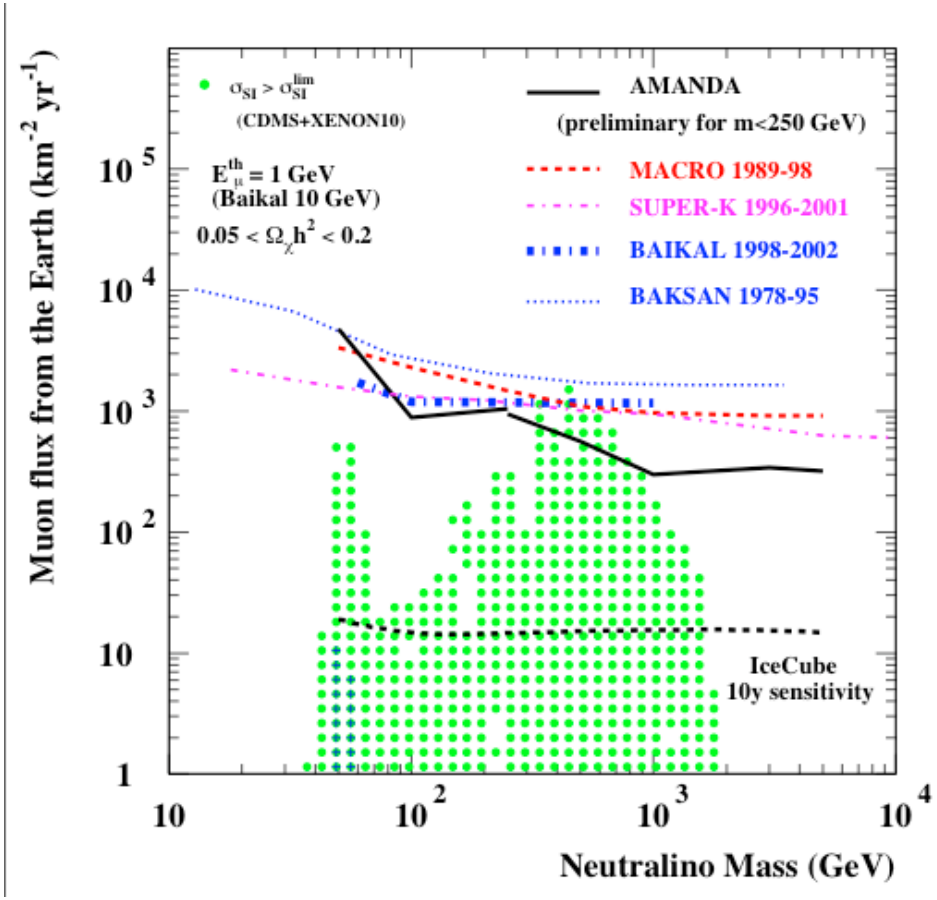
677 light sensitive Optical Modules embedded in Antarctic ice sheet deployed on 19 "strings" @ depths ~1500-2000m

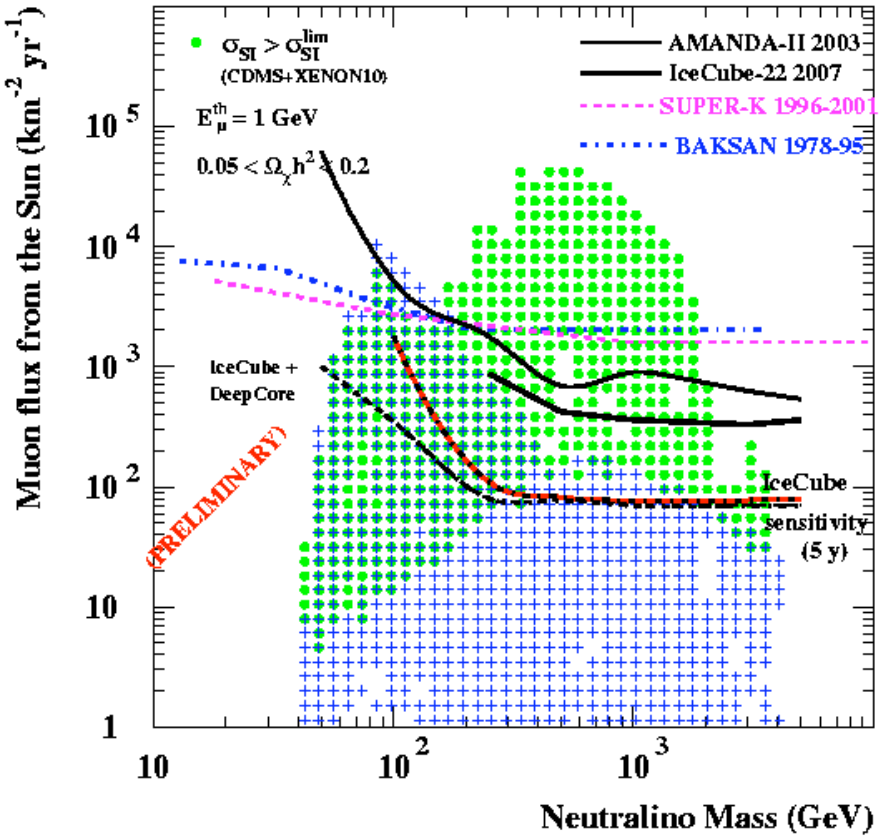
"AMANDA-B10" (10 strings)
302 OMs read out via *coaxial* or *twisted-pair electrical* cables

9 additional strings
375 OMs read out via *optical fibers*
superior timing- and double pulse resolution

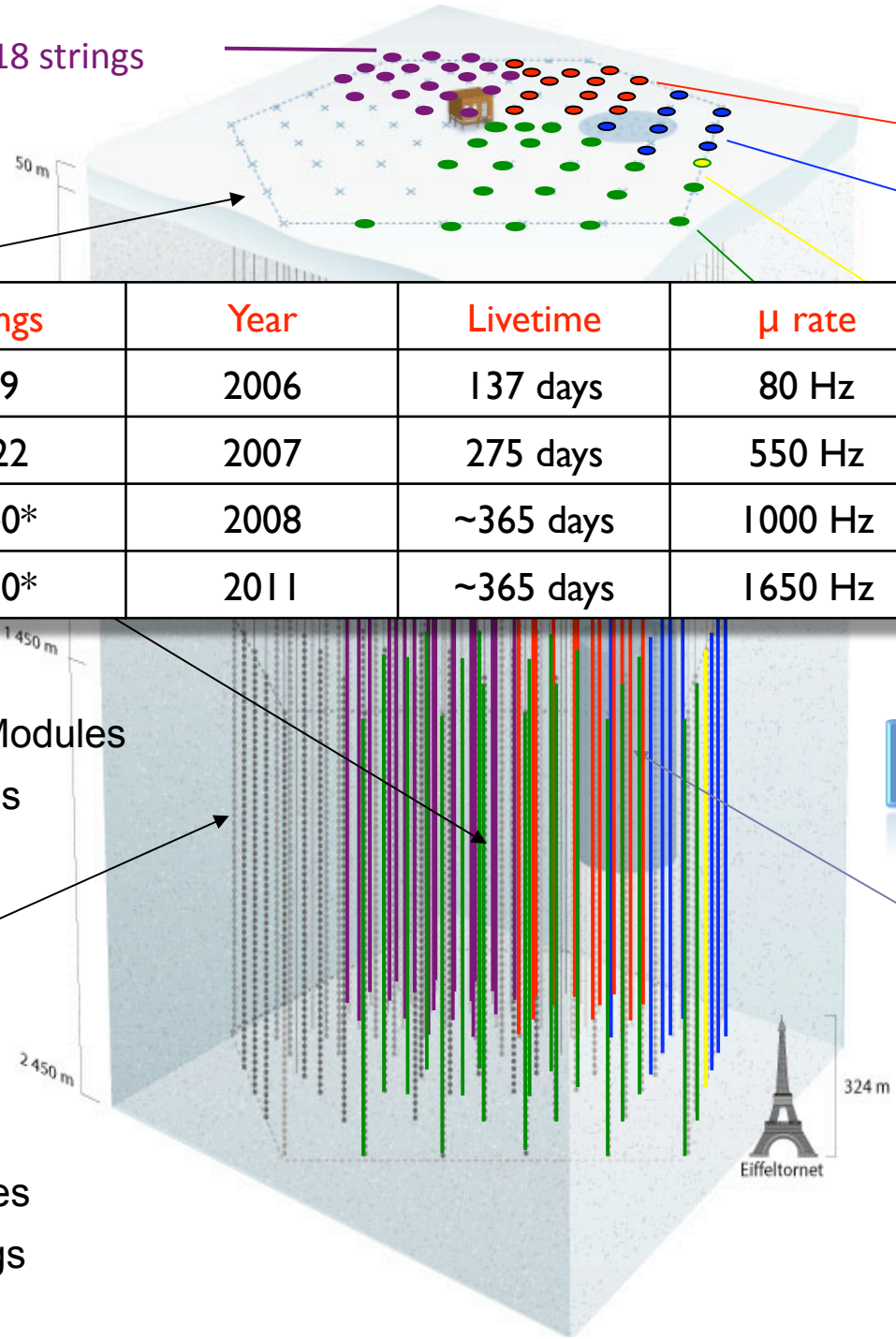
Earth WIMPs

Solar WIMPs





o Excluded by CDMS + XENON10
+ allowed by CDMS + XENON10



IceTop

Air shower d

threshold ~

DeepC

6 additional strings ,

60 Optical Modules

7 or 10 m between Modules

72 m between Strings

InIce

70-80 Strings ,

60 Optical Modules

17 m between Modules

125 m between Strings

Strings	Year	Livetime	μ rate	ν rate
IC9	2006	137 days	80 Hz	1.7 / day
IC22	2007	275 days	550 Hz	28 / day
IC40*	2008	~365 days	1000 Hz	110 / day
IC80*	2011	~365 days	1650 Hz	220 / day

ing

rings

ings

operating

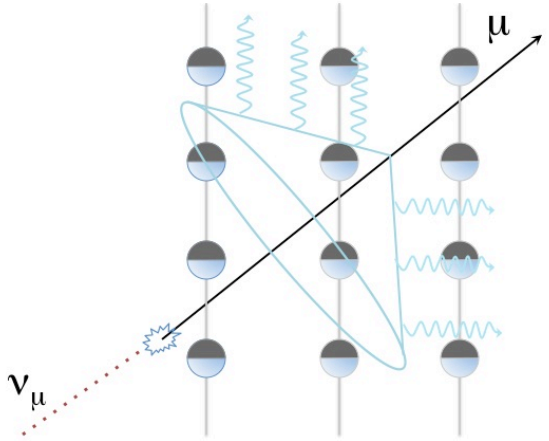
ICECUBE

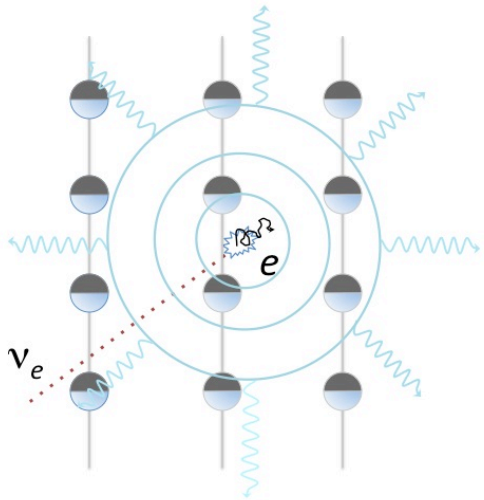
AMANDA

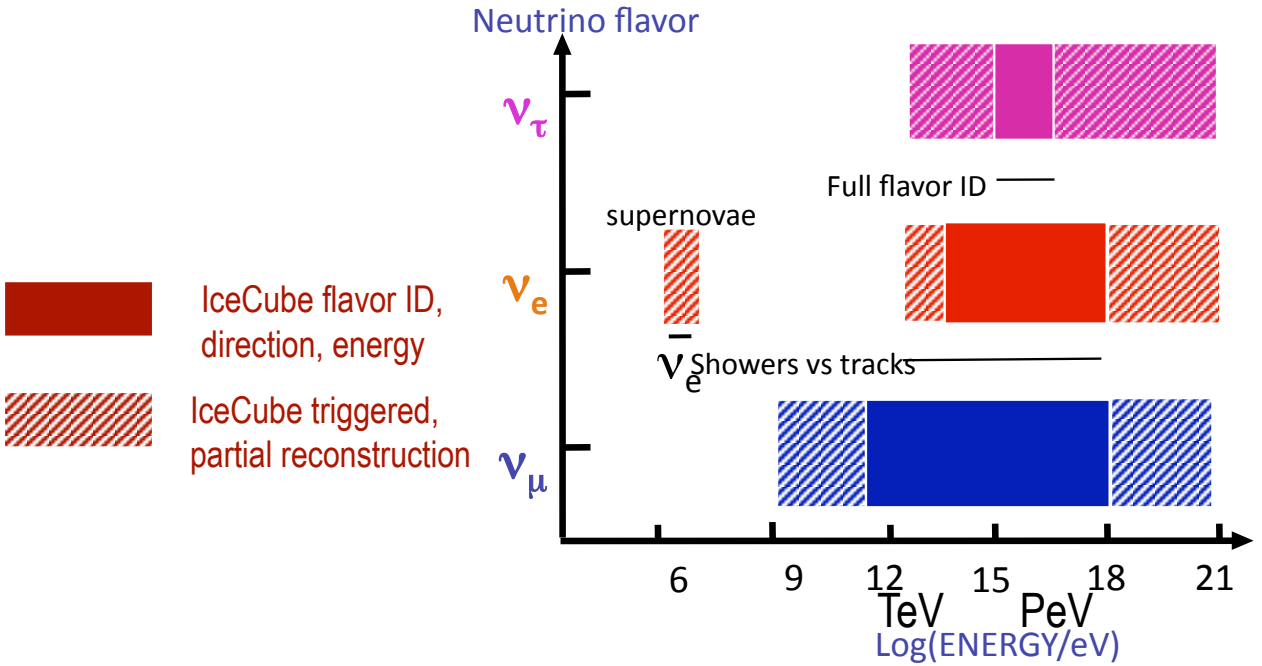
19 Strings

677 Modules

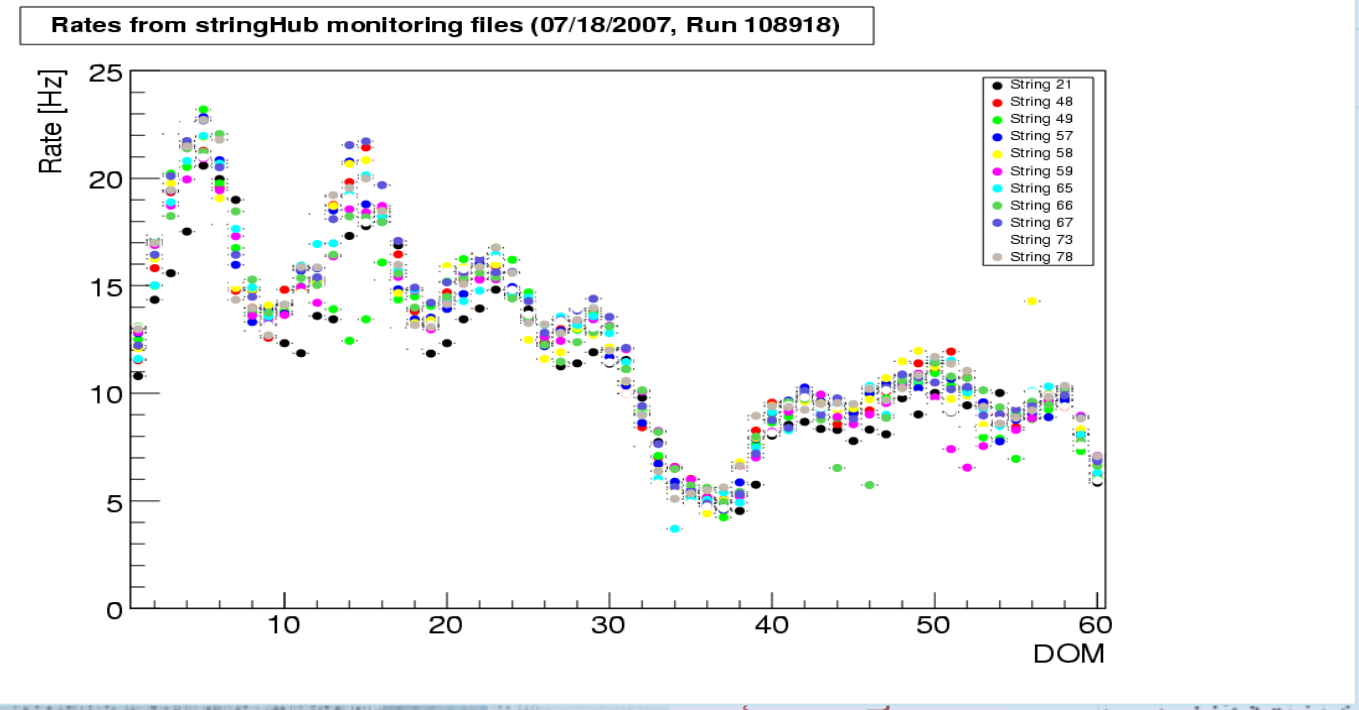
Energy and directional reconstruction







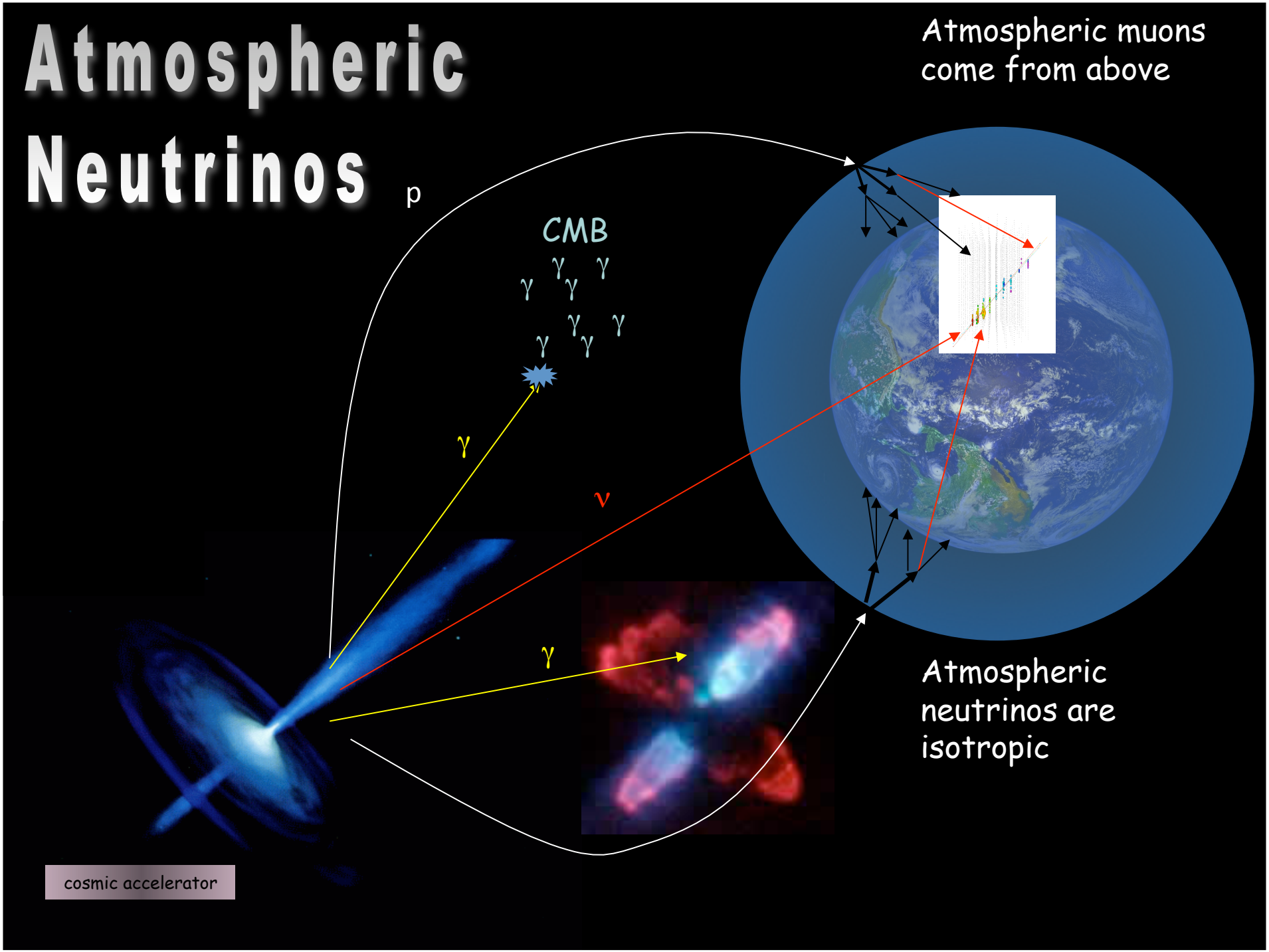
Ice Properties



500 TeV

Very clear ice

Atmospheric Neutrinos

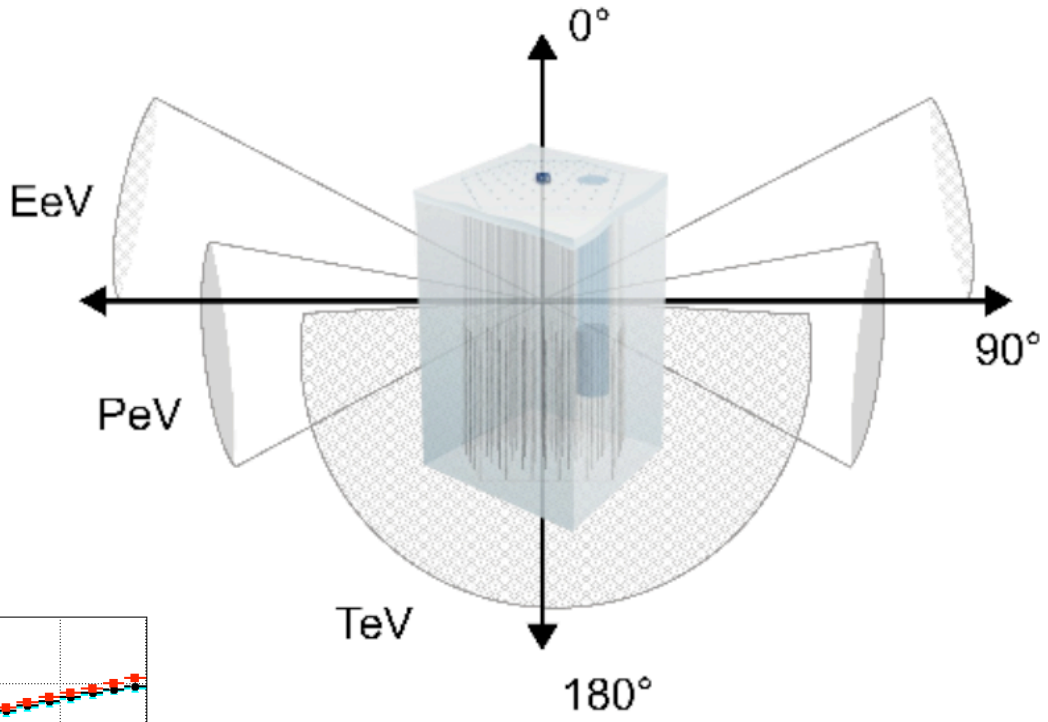


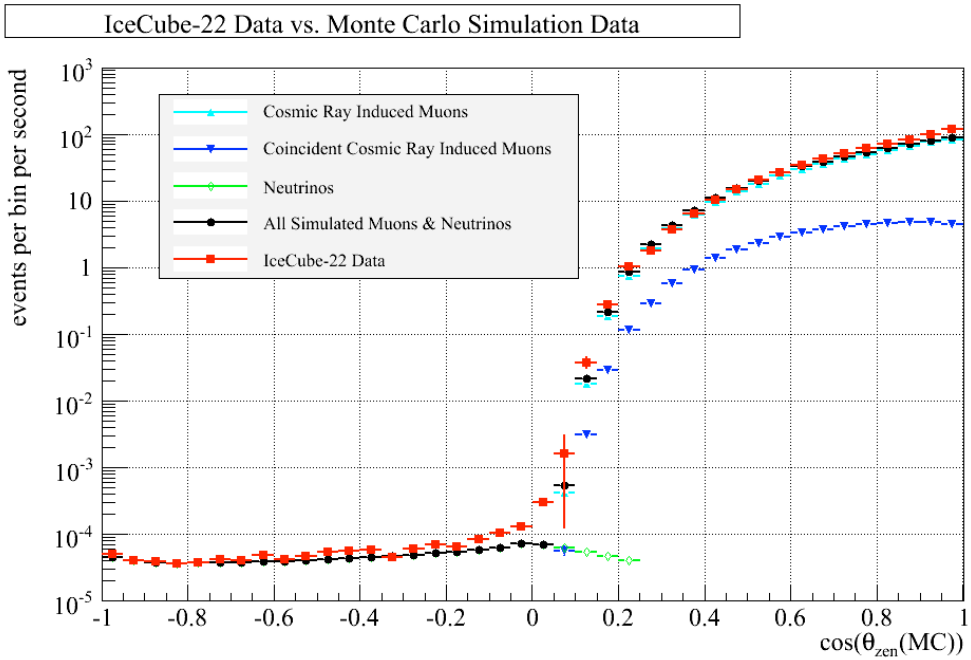
IceCube images the Northern Hemisphere!

•High flux from atmospheric muons inhibits search above horizon.

•Background from atmospheric neutrinos irreducible over all sky.

•Use energy related variables to discriminate against softer atmospheric spectrum for high energy phenomena.





•Muon energies of interest for WIMP searches are 50-500 GeV.

•Limited to searches below the horizon.

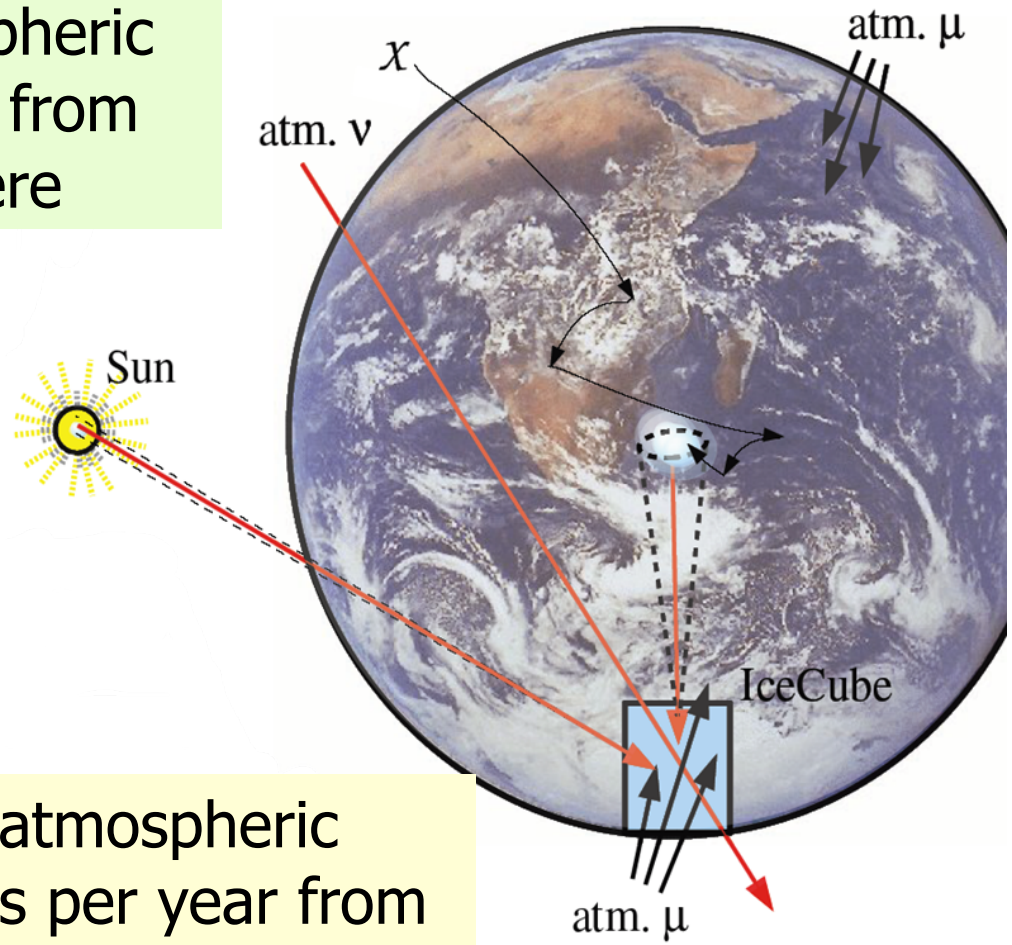
Backgrounds for WIMPs

BG

A few 1000 atmospheric neutrinos per year from northern hemisphere

signal

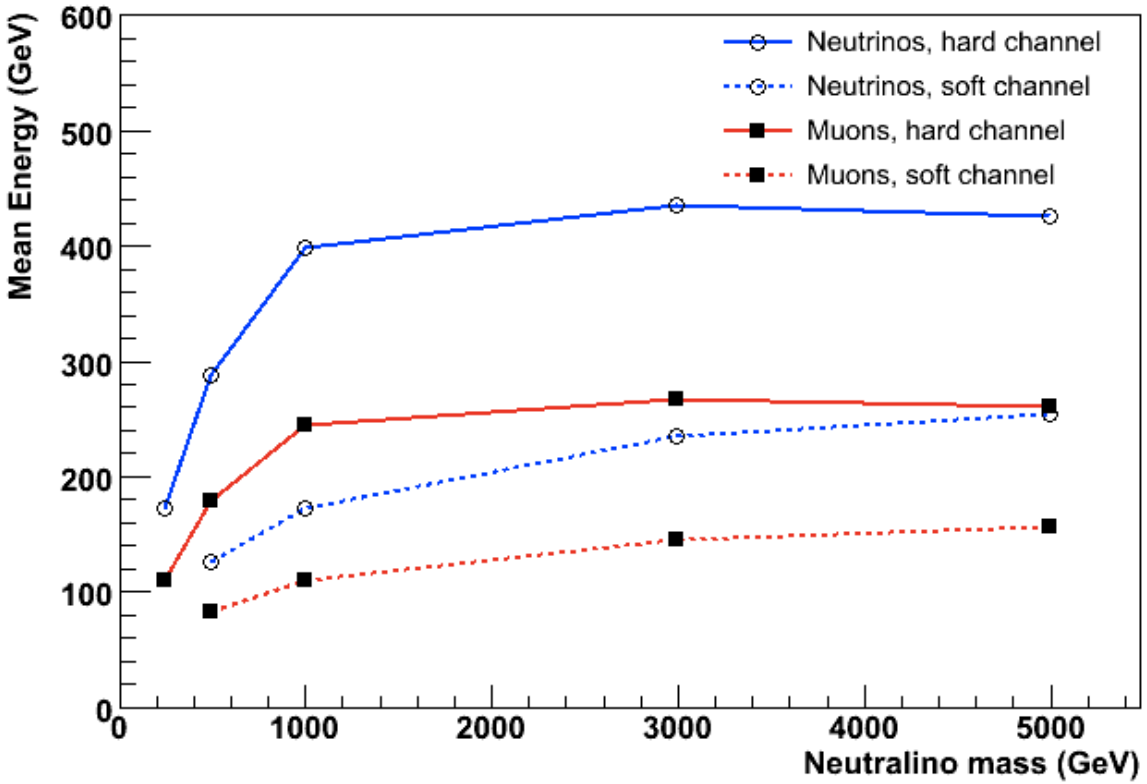
Max. a few neutrinos per year from WIMPs



BG

~10^9 atmospheric muons per year from southern hemisphere

Solar WIMP signal



Soft: $E_\mu \sim 0.01M_\chi$-$0.06M_\chi$

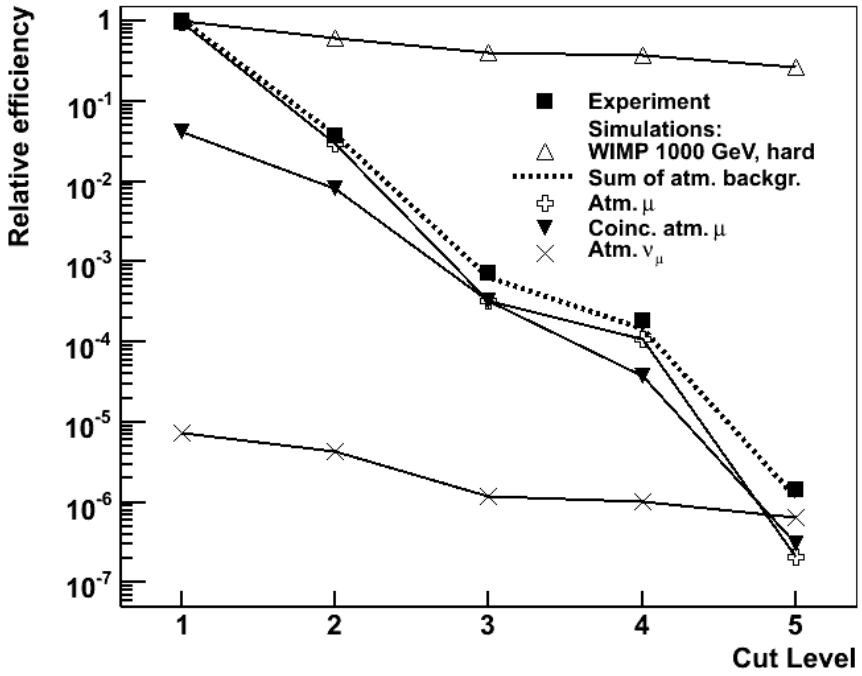
Hard: $E_\mu \sim 0.03M_\chi$-$0.3M_\chi$

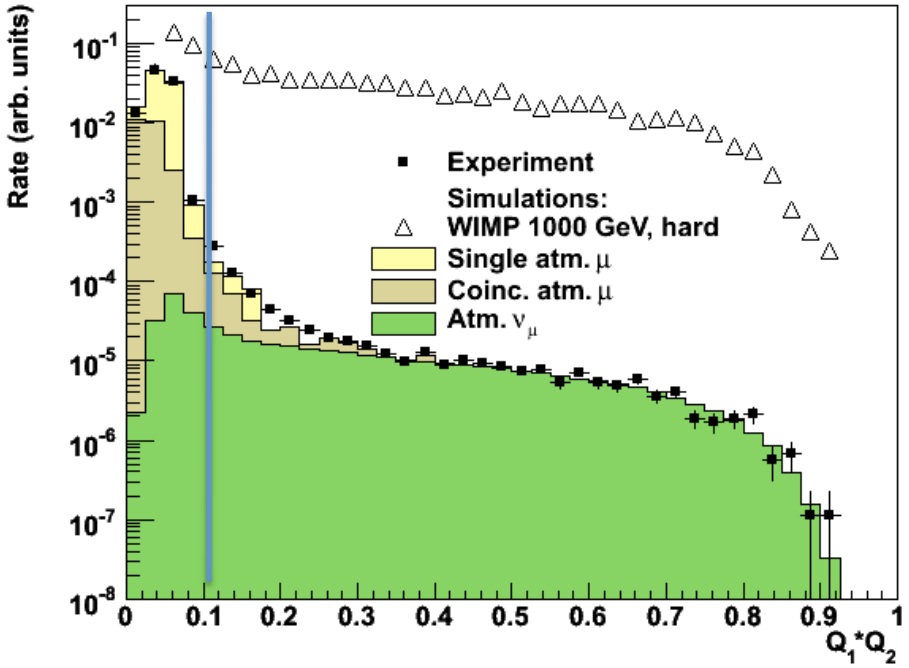
- signals simulated with WIMPSIM (Blennow, Edsjo, Ohlsson 2008) based on DarkSUSY
- 5 masses considered: 250, 500, 1000, 3000 and 5000 GeV
- 2 annihilation channels considered
  - Hard W+W-
  - $b\bar{b}$ from secondaries
- full propagation through the Sun is simulated, absorption in the Sun important above a few hundred GeV
- 3 flavor oscillations are accounted for
- IceCube optimized for E_ν>1 TeV

IceCube analysis with 22 string configuration

- data taken from April 2007-April 2008
- look for excess of muons from WIMP annihilations in the Sun
- requirement that Sun be below horizon limits analysis to 104 days livetime

- 10^6 background rejection needed





tightening cuts

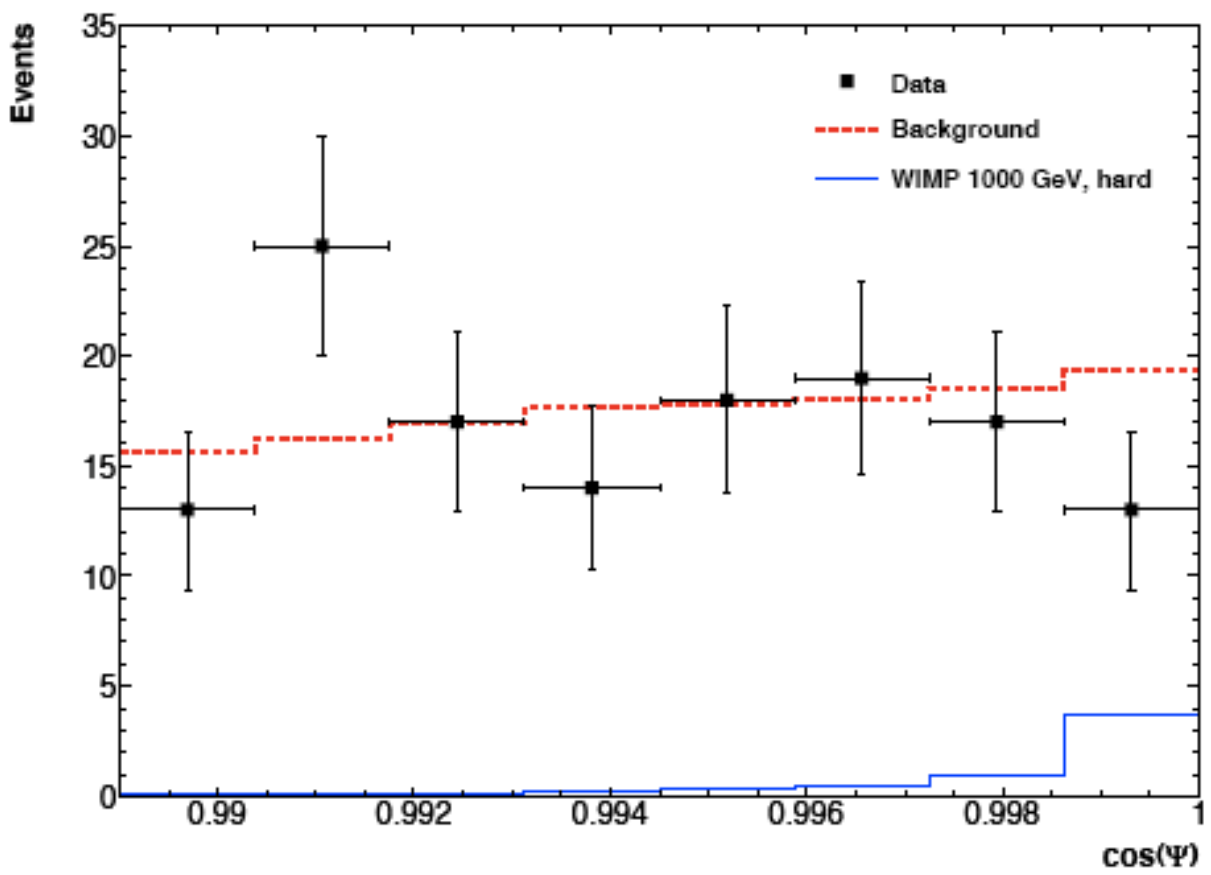
Take pure neutrino sample and look for excess above irreducible atmospheric neutrino background.

- search in bins in space angle from the direction of the Sun

- angular resolution important

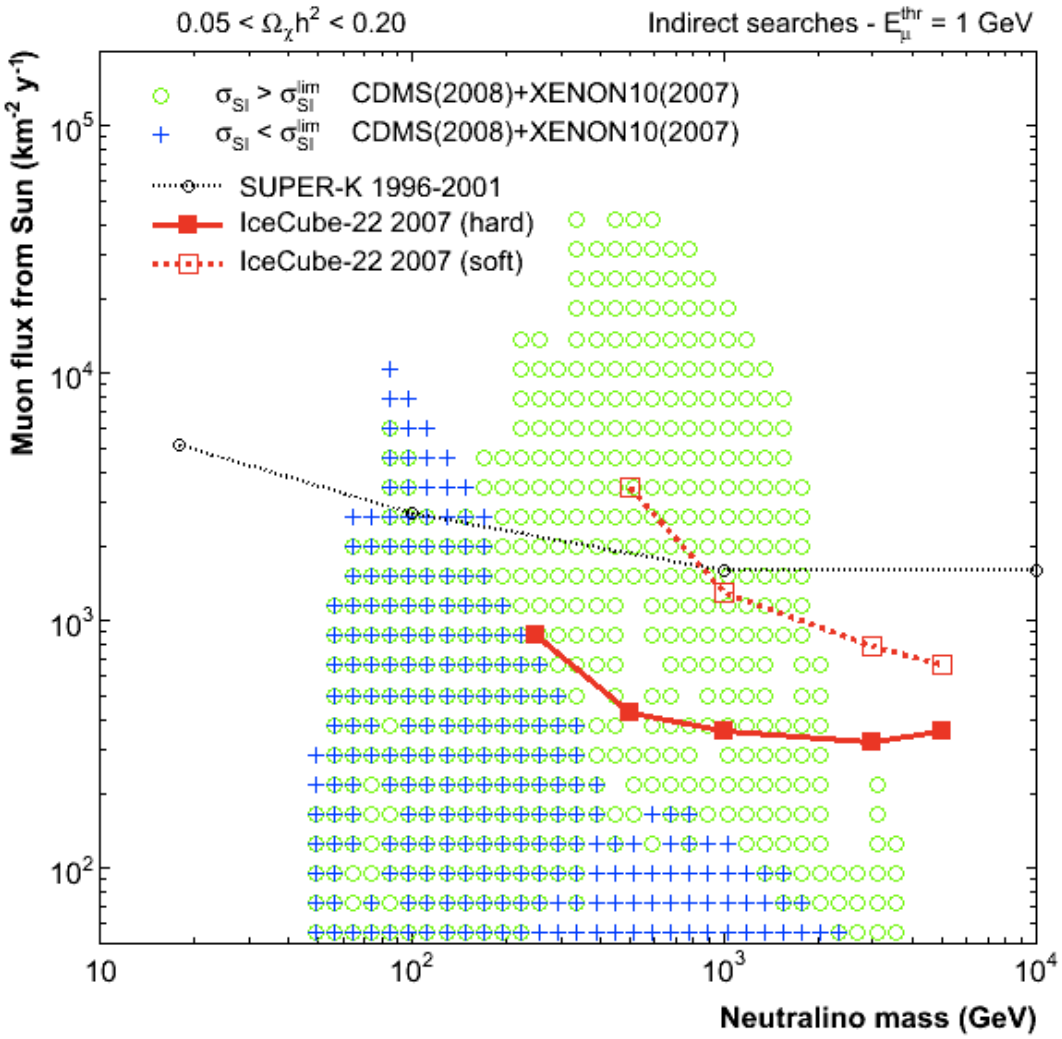
- 3° angular resolution >500 GeV for IC22 (better for IC40 and at higher energies)

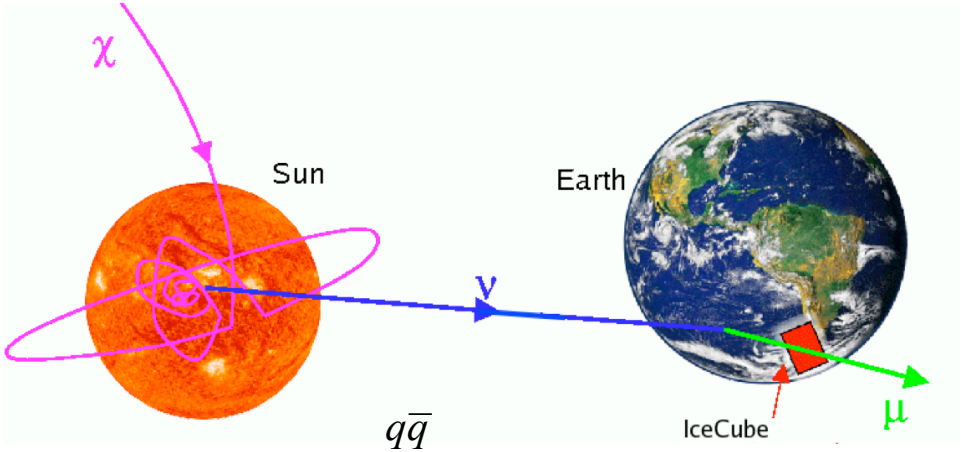
- was 4°-5° in AMANDA for tracks below 500 GeV



Muon Flux limits from the Sun

from IceCube 22



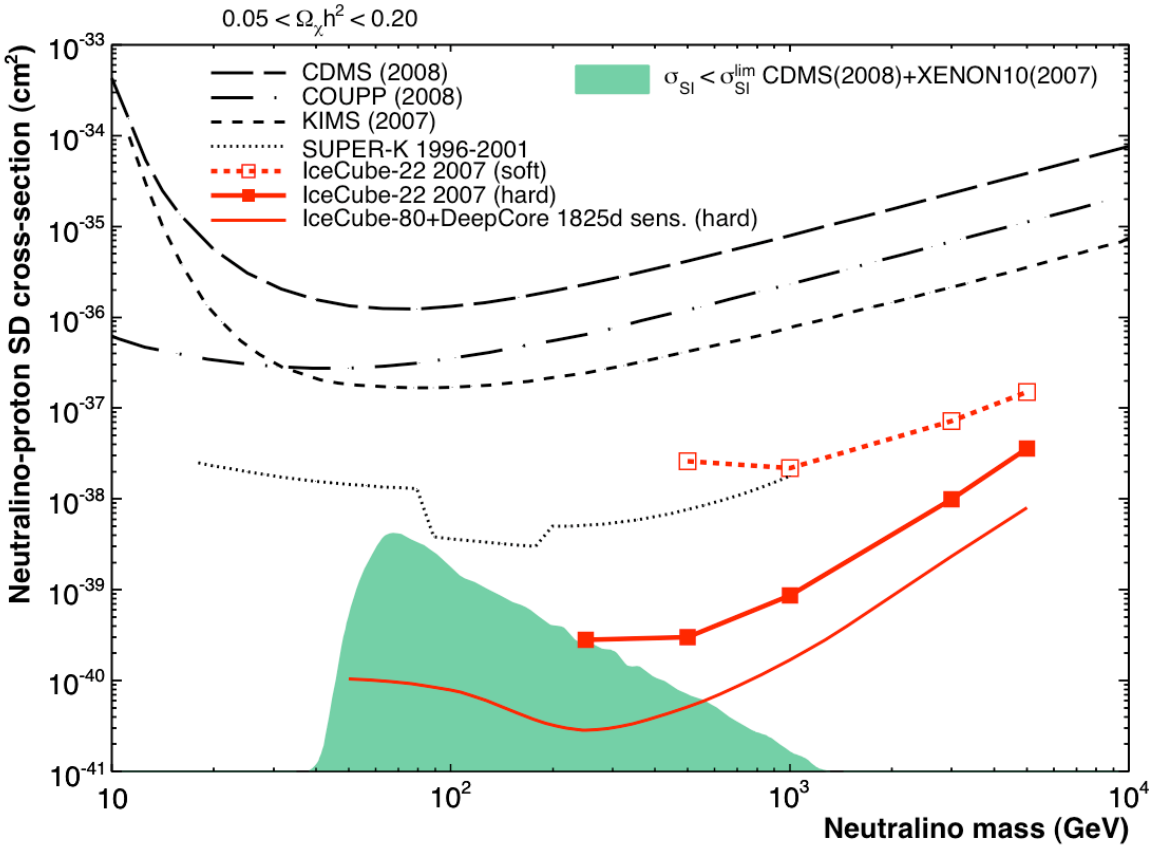


$$\tilde{\chi}\tilde{\chi} \rightarrow \begin{matrix} q\bar{q} \\ l\bar{l} \\ W^{\pm}, Z, H \end{matrix} \rightarrow \cdots \rightarrow \nu_{\mu}$$

WIMPs

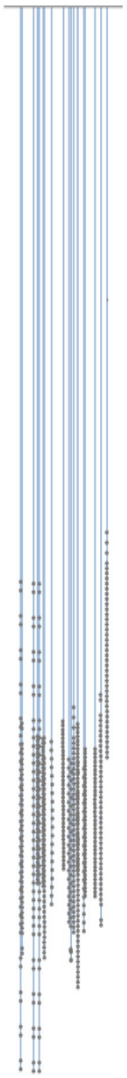
- *annihilating in the gravity well of the Sun*
- *indirect detection*
- *limits shown are spin dependent*

- Set limit on σ_{SD} by assuming $R_{annih} = R_{capture}$, local ρ_{WIMP} = 0.3GeV/cm^3 and Maxwellian v_{WIMP}
- See astro-ph 0903.2986 (Wikstrom and Edsjo) for method of converting muon flux to cross section limit.
- Deep core enhancement under construction will greatly enhance sensitivity.

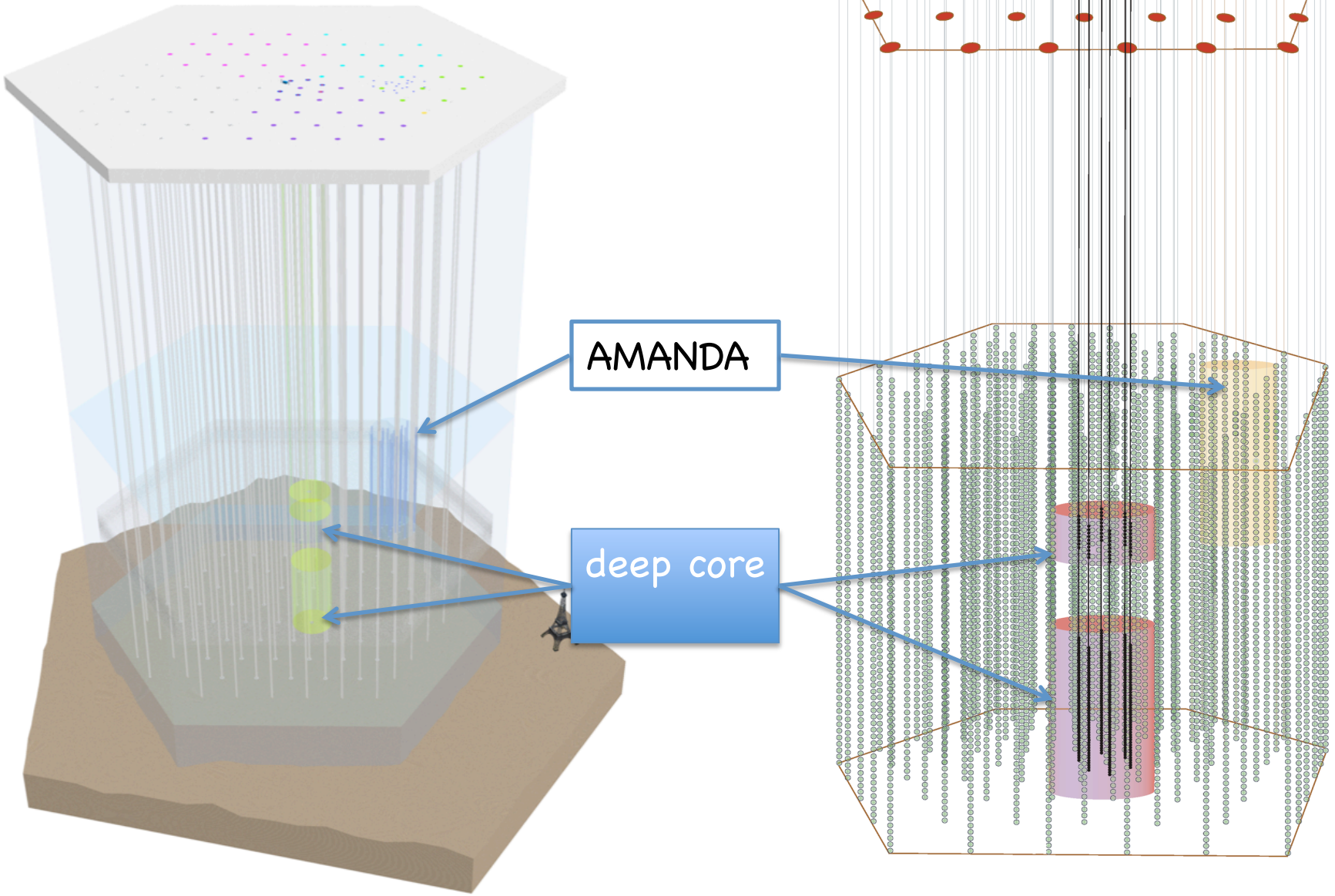


The role of AMANDA in IC WIMP analyses

- AMANDA has denser string spacing.
- AMANDA strongly improves the low energy physics in IceCube (e.g. Wimps, atm neutrinos)
- work has been done to synchronize the triggering and clocks of IceCube and AMANDA
- Combined analyses being done with 22 string and 40 string IceCube plus AMANDA data to increase sensitivity and extend low energy threshold (50 GeV?).
- BUT
  - Old and different hardware compared with IceCube
  - Not placed in the centre of IceCube
  - Placed quite shallow at 1500-2000 m
  - Counting house threatened by drifting snow
  - AMANDA needs 20 KW (1/3 of IceCube)
  - Needs special maintenance for both hardware and software



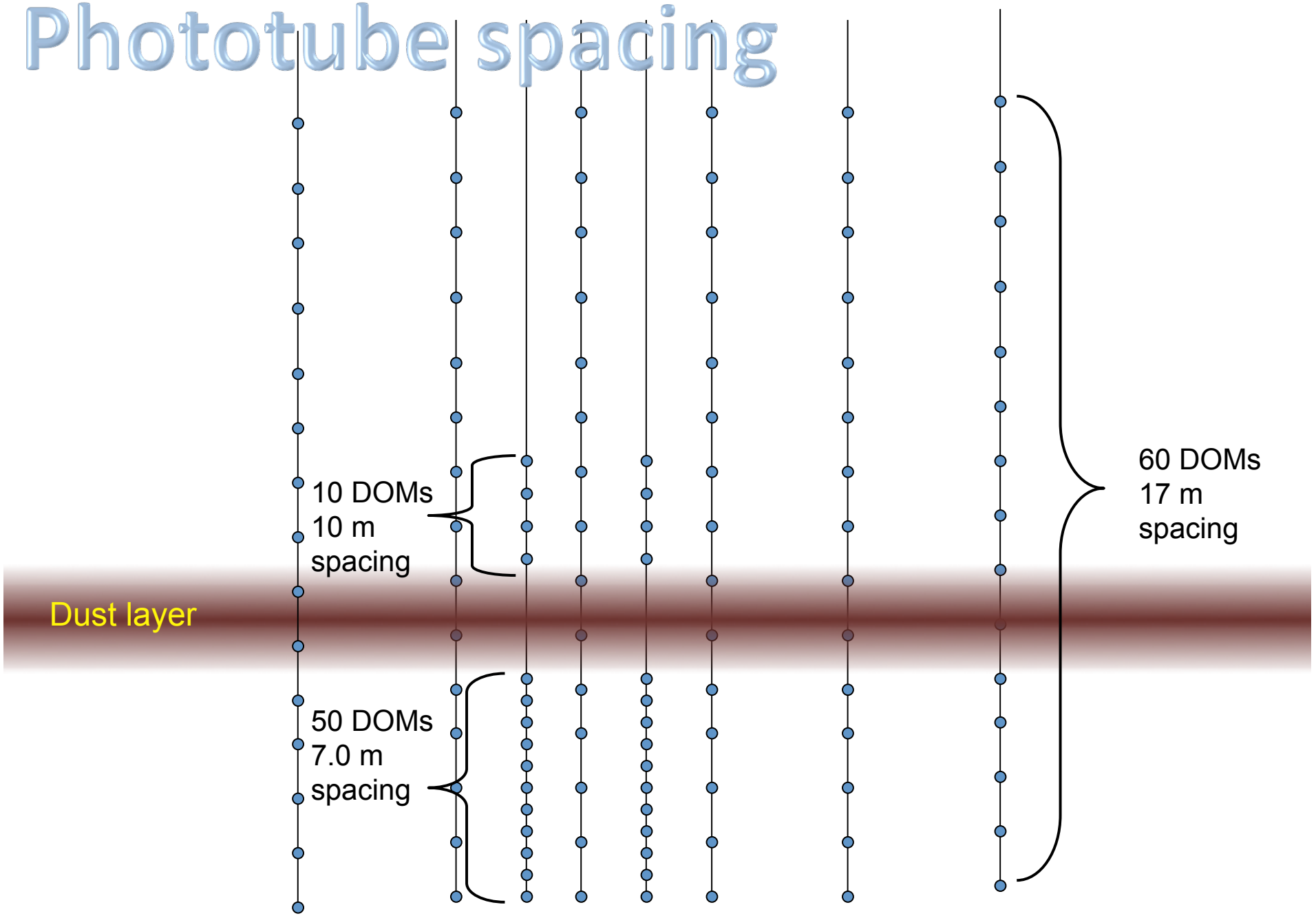
THE DEEP CORE



History (brief!) of the Deep Core

- Idea presented to the IceCube collaboration in April 2007.
- The low energy workshop in Aachen decides to prioritize Deep Core over AMANDA Sept. 07.
- IceCube supports Deep Core application in October 2007.
- Swedish apply for funding to Wallenberg foundation October 2007.
- Approval for six strings with 40 optical sensors November 2007 by Wallenberg foundation (2.8 M$).
- Additional funding from Belgium and Germany (1 M€) allow denser instrumentation.
- Deep Core workshop in Stockholm March 2008.
- First string already deployed in December 2008!
- The remaining strings to be deployed 2009/2010.

Phototube spacing

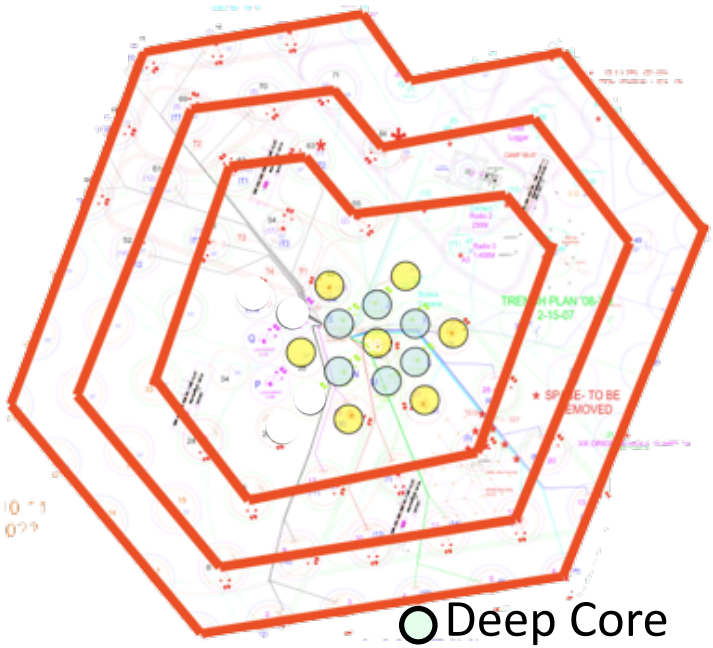


IceCube as an atmospheric muon veto

Rejection rate

$$\phi(\mu) / \phi(\nu_{atm}) \simeq 10^6$$

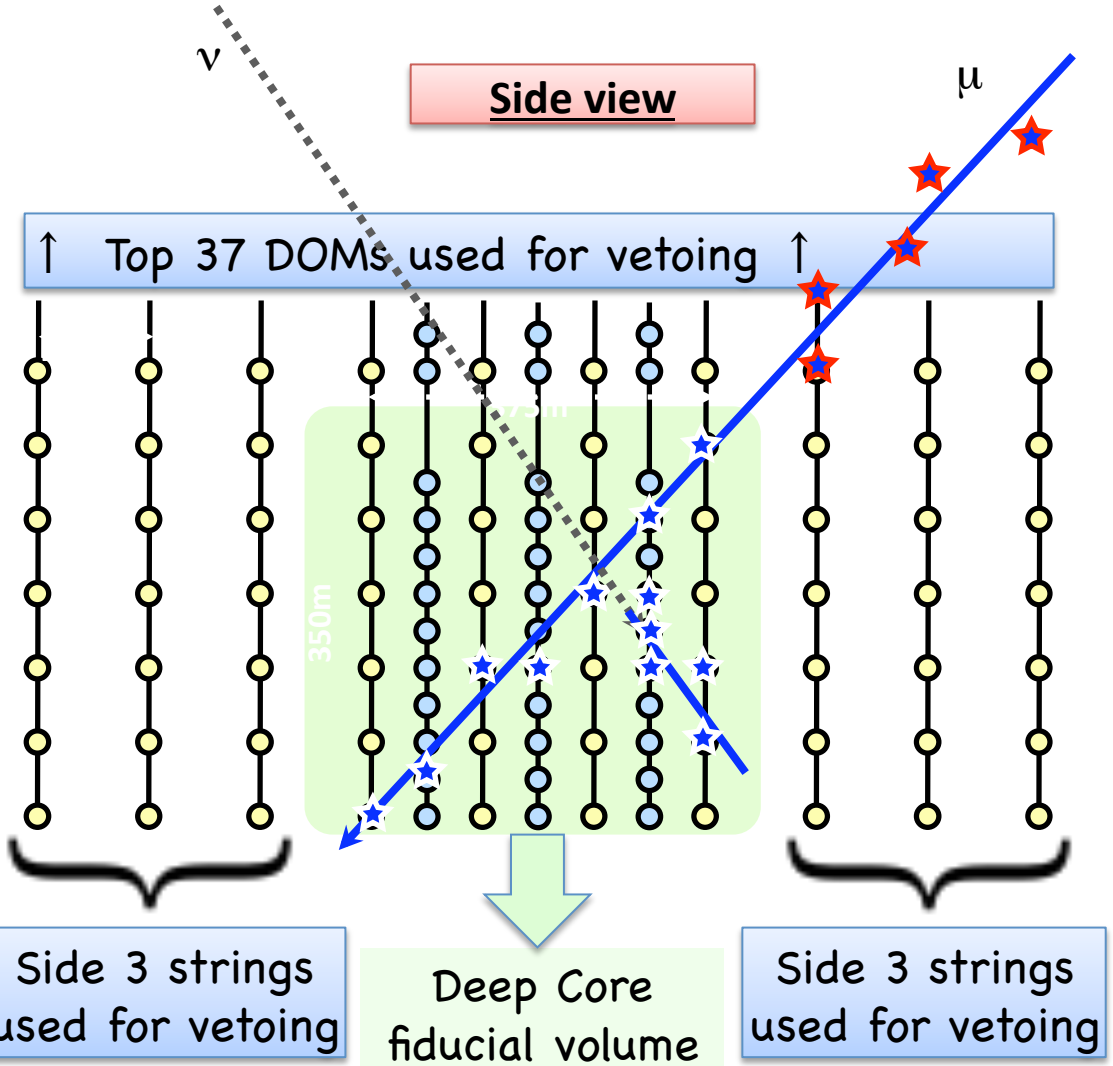
Top view



375 m thick active veto:
3 full IceCube string
layers surround Deep Core

veto allows searches above horizon!

Side view

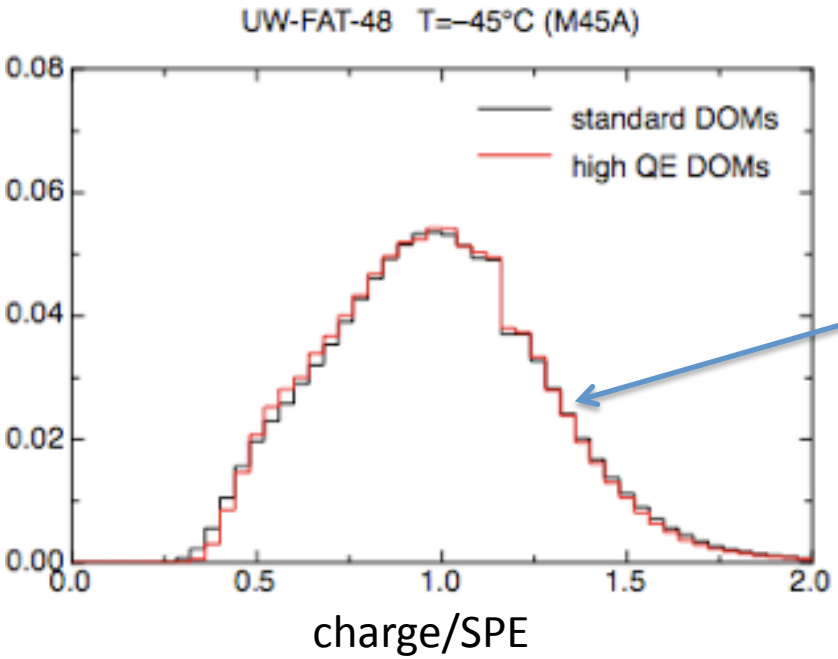


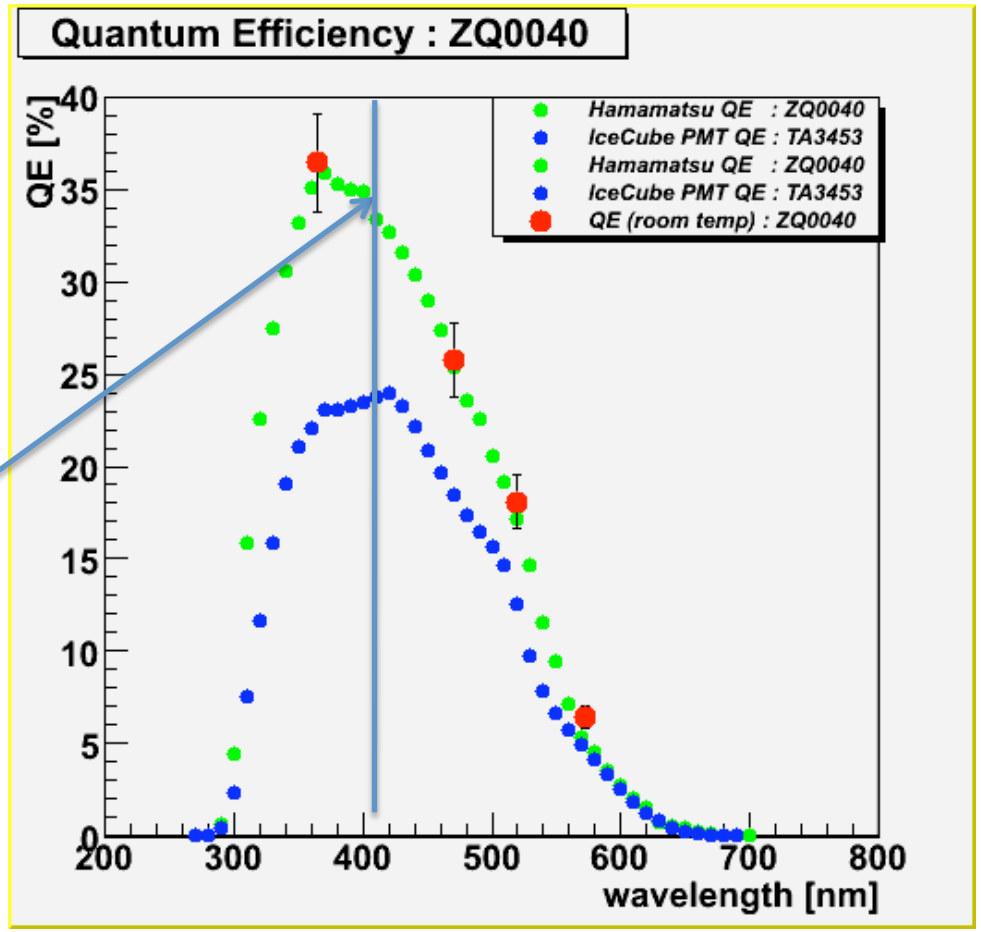
Hardware

•New (pricey) high quantum efficiency photomultiplier tubes feature new proprietary photocathode material

•40% higher efficiency at 405 nm wavelength

•...but also higher noise rate



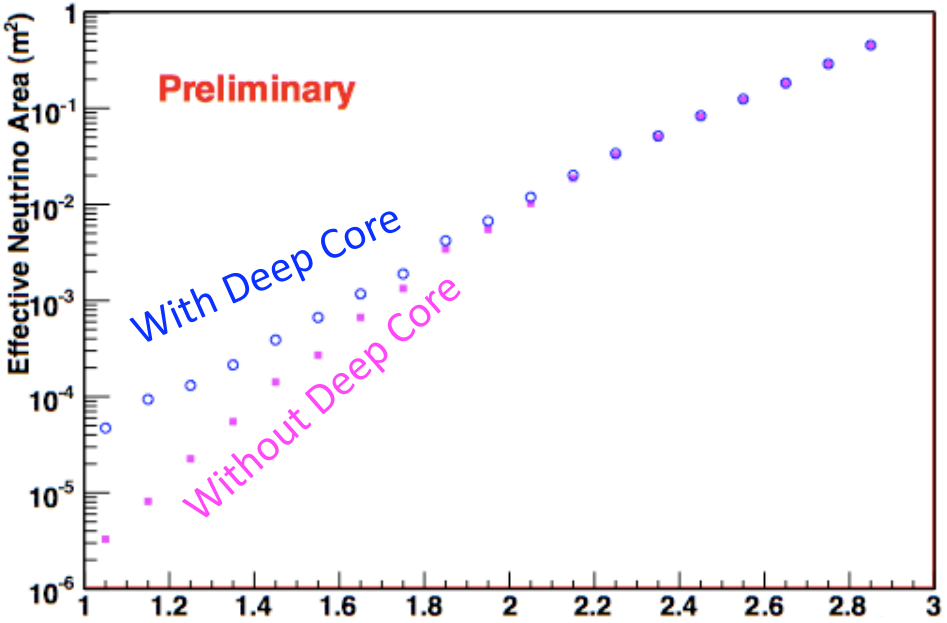


•charge response same as for standard PMTs

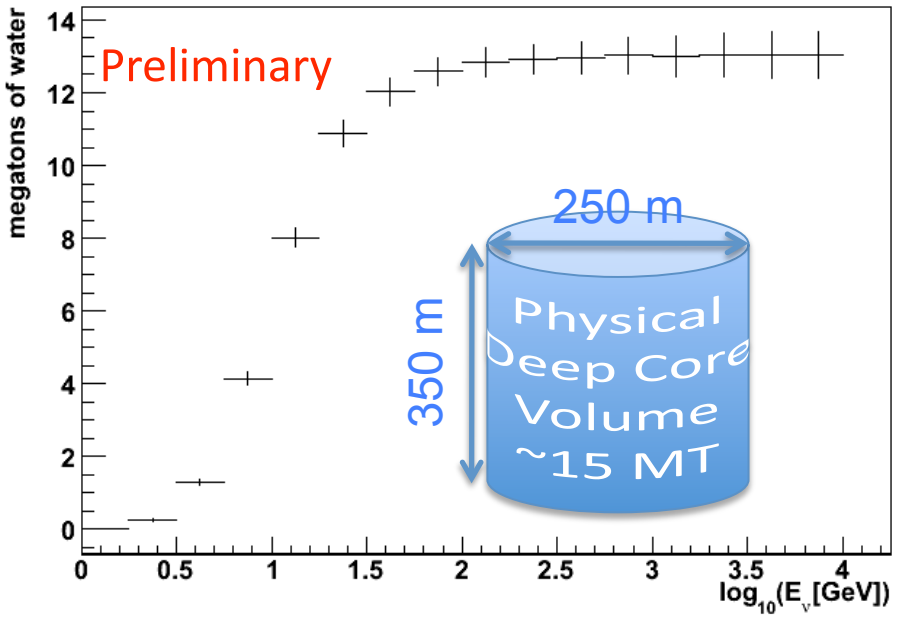
•In situ measurements with the first deployed string (08-09 season) are underway and so far validate lab measurements

Effective area and volume of the deep core

A_{eff}: For downgoing muon neutrinos following E^{-2} spectrum that trigger the detector (4 hit phototubes to trigger, no reconstruction efficiencies included yet!)



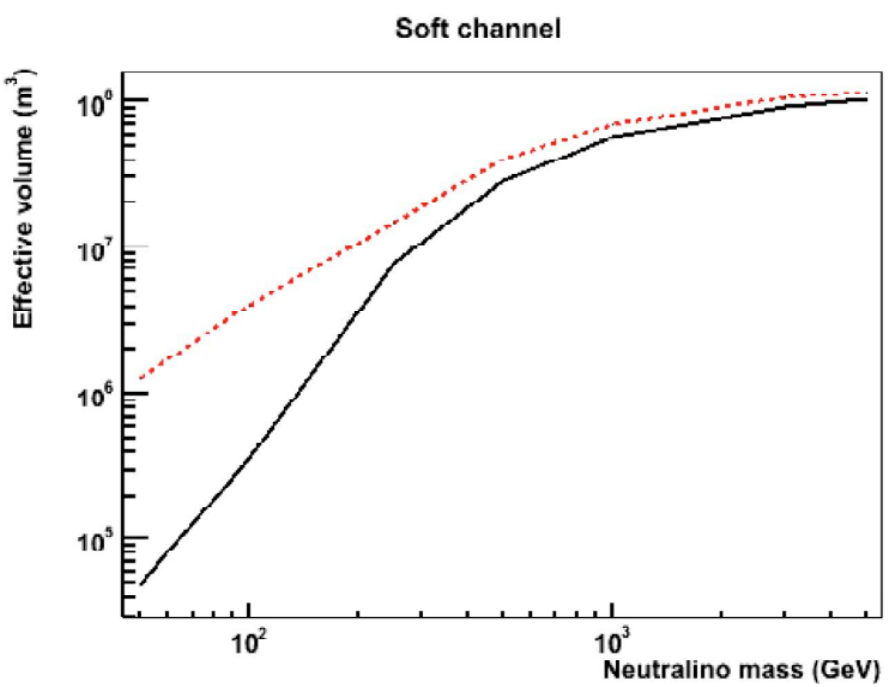
V_{eff}: For contained downgoing muon neutrinos that interact in the fiducial volume and trigger the detector (4 hit phototubes to trigger, no reconstruction efficiencies included yet!)

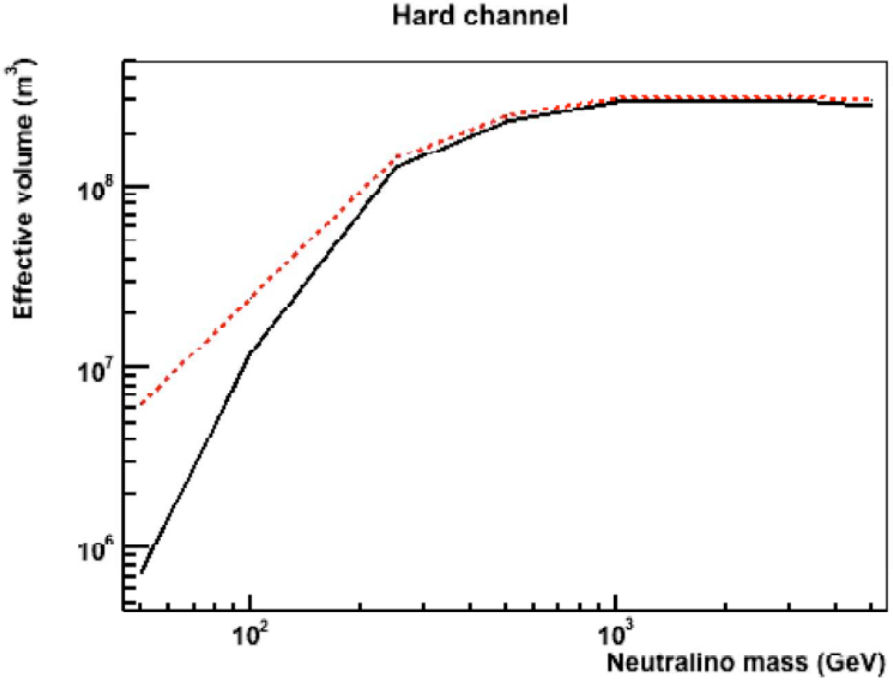


Increase in effective volume for WIMPs

…for IceCube versus IceCube & DeepCore

- gains mostly at low WIMP masses (50-500 GeV)
- decreases energy threshold and allows low energy searches when the Sun is above horizon
- opens up other low energy physics searches as well (Southern sky low energy neutrino emission, neutrino oscillation studies, exotics, etc.)

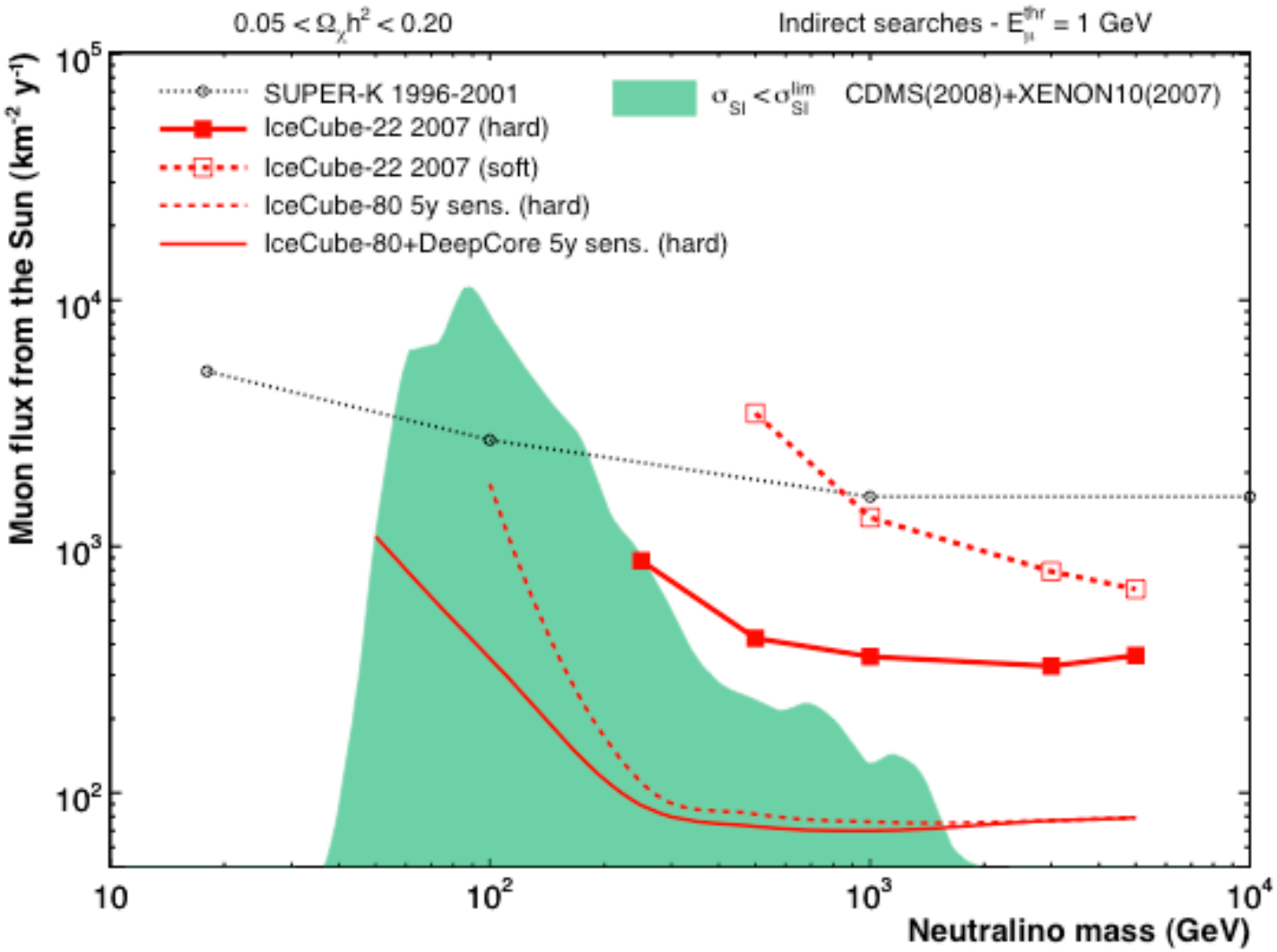




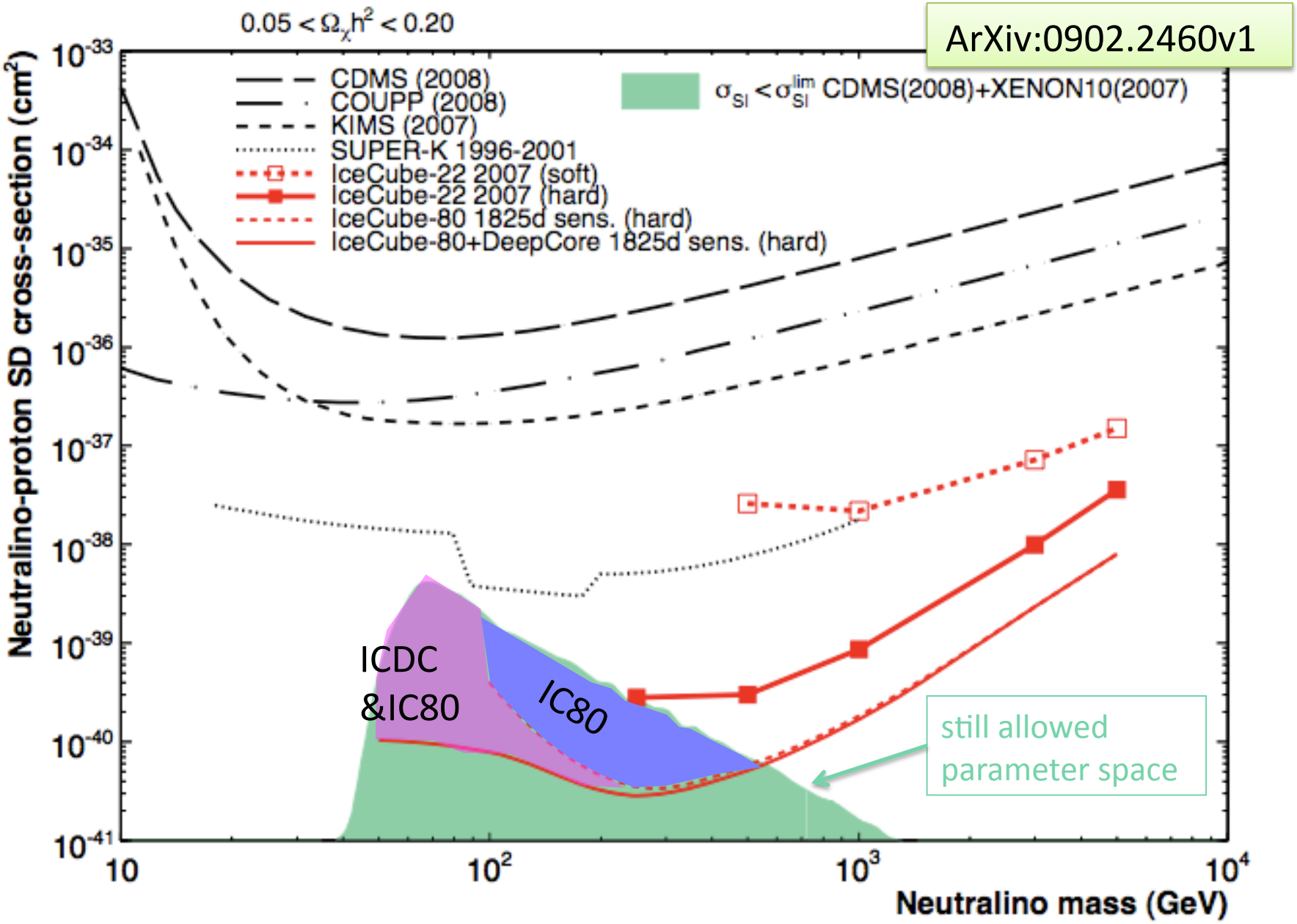
Muon flux limits

…from the Sun

80 string IceCube and IceCube Deep Core compared 22 string IceCube



Deep Core & IceCube (5 year) sensitivity!



Summary and Outlook

•Construction of IceCube on schedule, and the addition of 19 new IceCube strings in the austral summer of 2008-2009 brings the total to 59.

•Many analyses of the 22 string configuration, including the first solar WIMP analysis, are already complete, thanks to data filtering at the Pole and subsequent satellite transmission. IceCube 22 sets best limit on WIMP annihilation.

• Analyses using 40 strings and a factor of 3 improvement in sensitivity will be available shortly.

•1 cubic kilometer (80 strings) will be instrumented by 2011.

•IceCube indirect dark matter searches will be competitive with direct searches in a few years.

•Plans for a low energy enhancement have progressed quickly and construction has already commenced.

01.15.2006

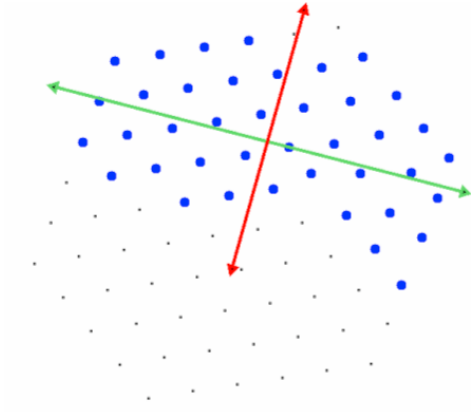
Backup Slides

Angular resolution

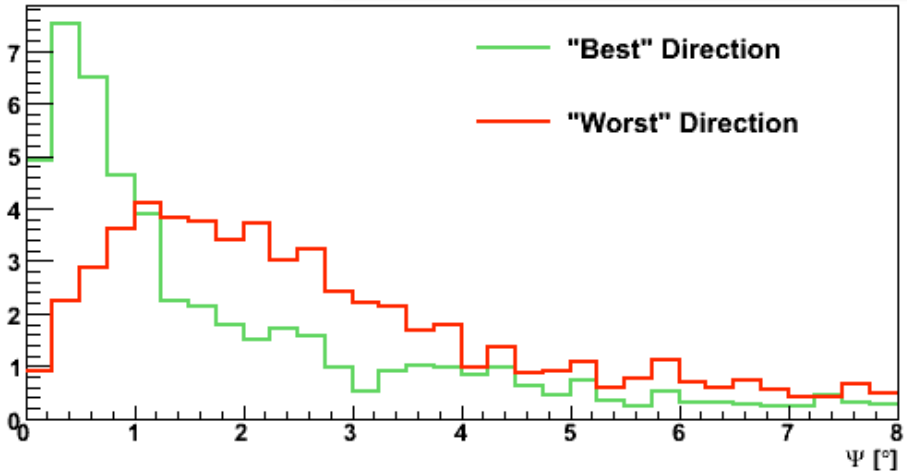
Filter level- 40 string configuration

•Angular resolution improves with detector size.

•More sophisticated filtering includes a single iteration of a likelihood.

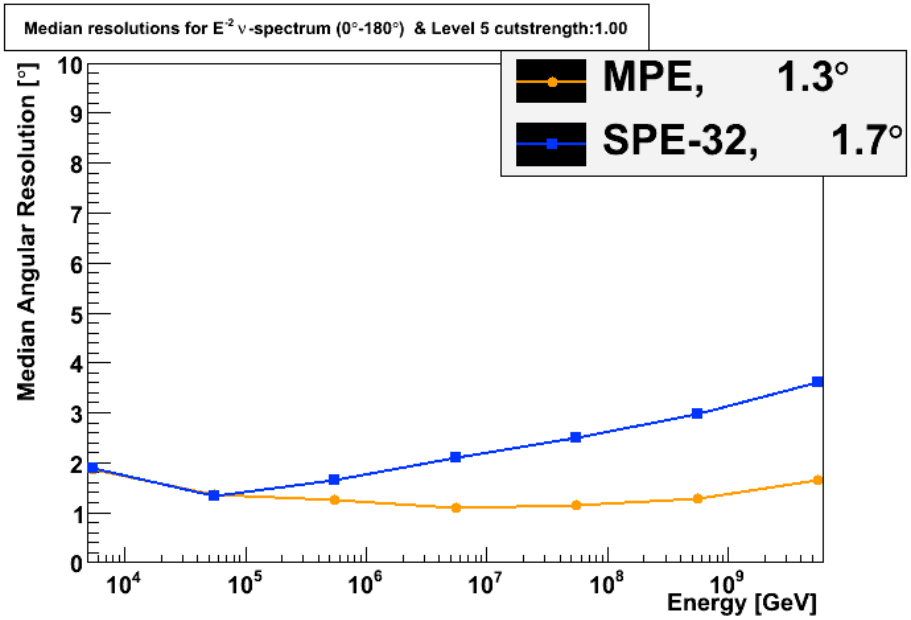


Point Spread Function

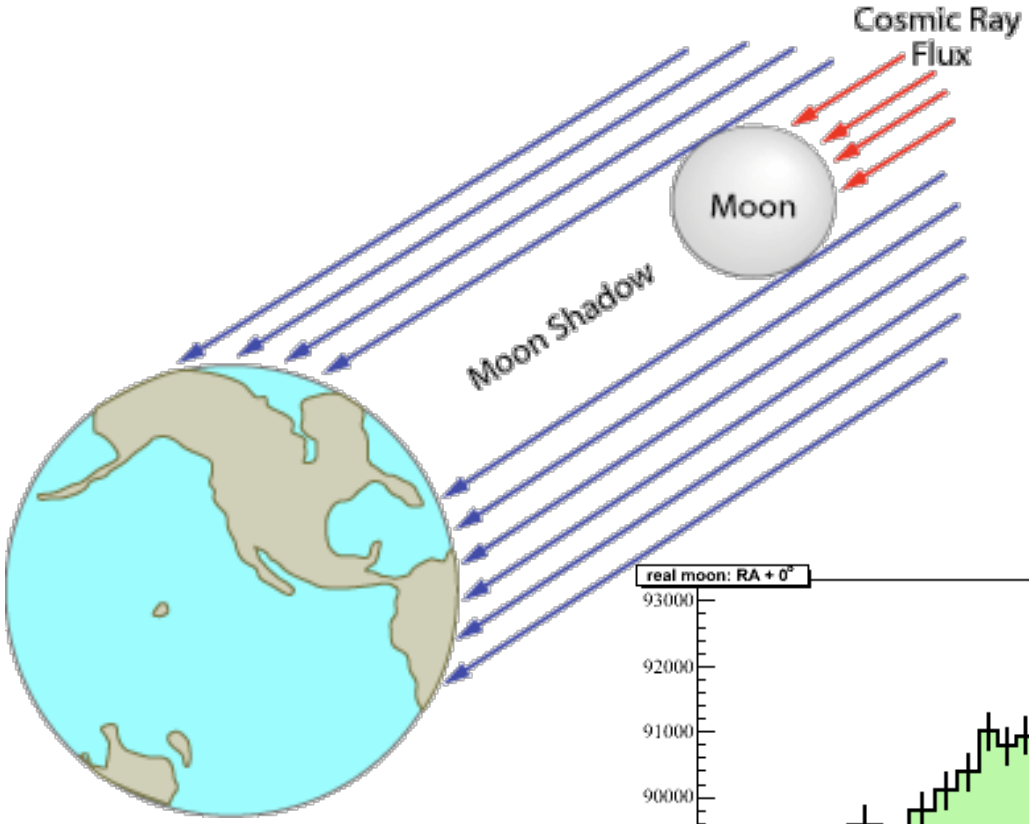


•Improved techniques improve angular resolution at high energies.

Median angular resolution:
(zenith angle averaged) **MPE SPE**
E-1.5 *ν – spectrum:* ***1.2° 2.4°***
E-2 *ν – spectrum:* ***1.3° 1.7°***

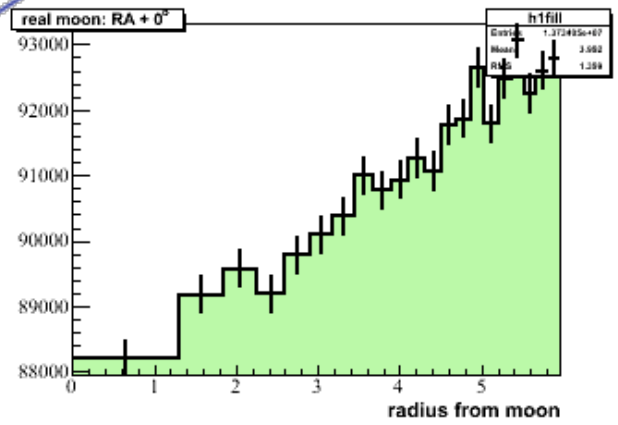


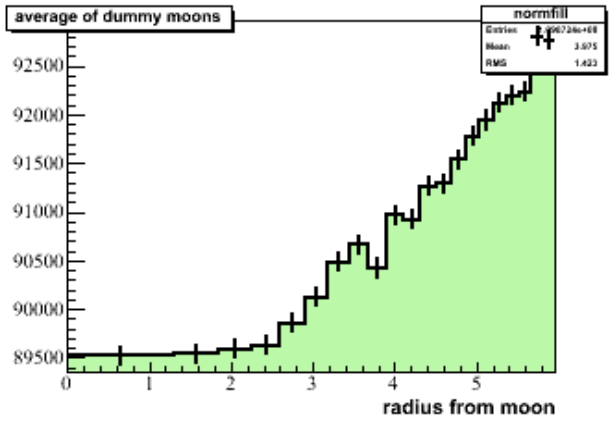
Moon Shadow

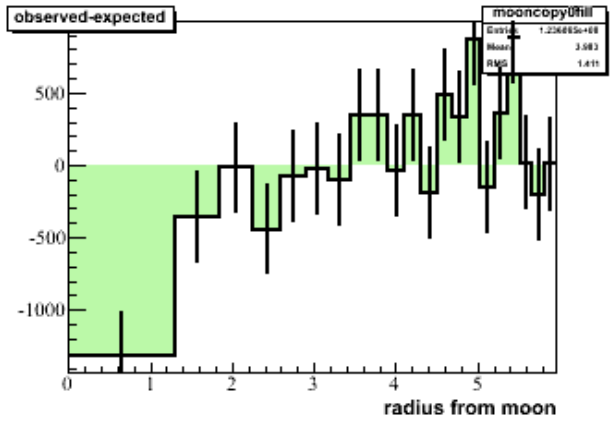


Existence of the moon confirmed!

4.2σ deficit of events from direction of moon in the IceCube 40-string detector (3 months of data) confirms pointing accuracy.







Validates pointing capabilities:

Angular resolution:
– IceCube 22 < 1.5°
– IceCube 80 < 1°

observed: 88202 events

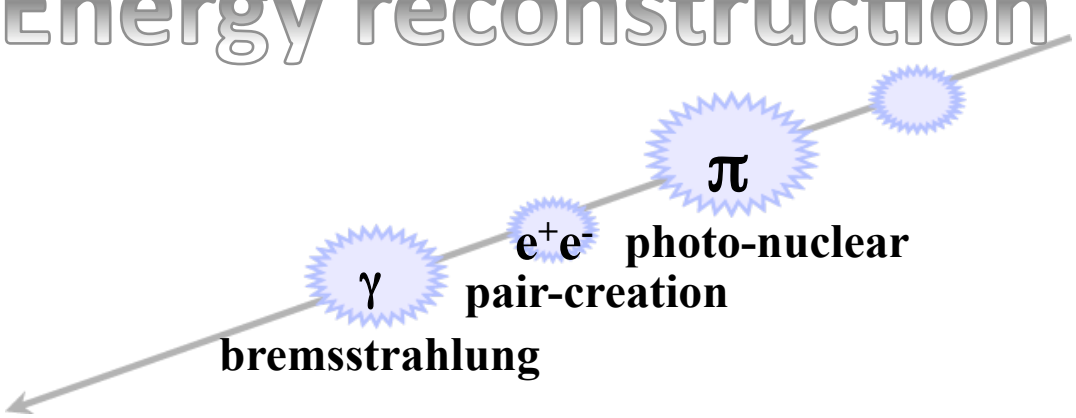
expected: 89521.6 events

deficit: -1319.62 events

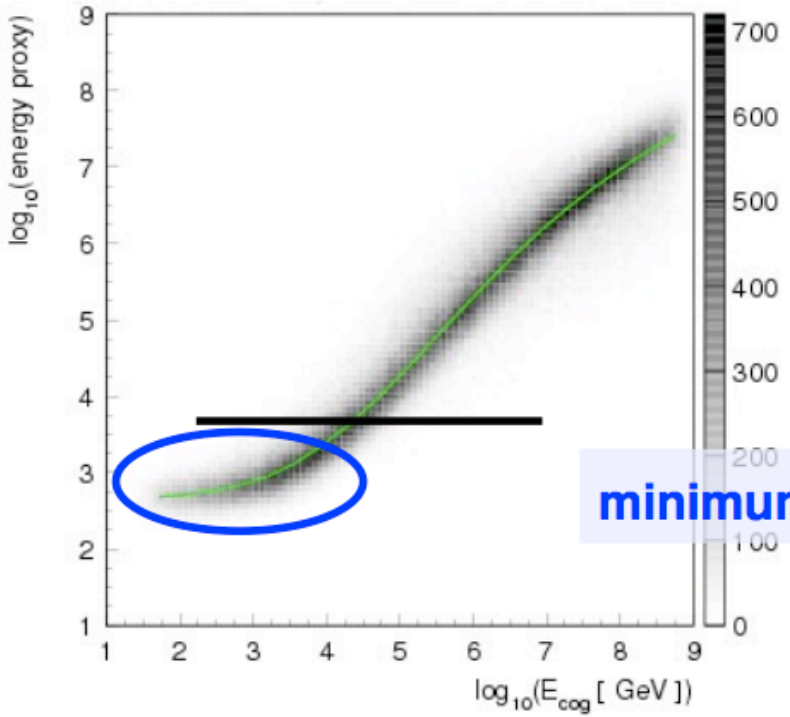
error: 315.265 events

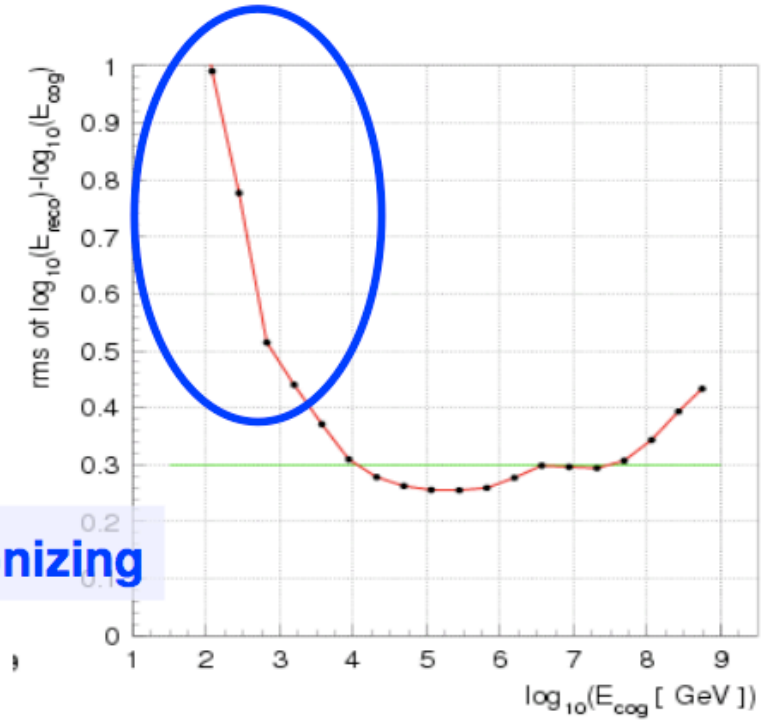
significance: -4.18576 σ

Energy reconstruction

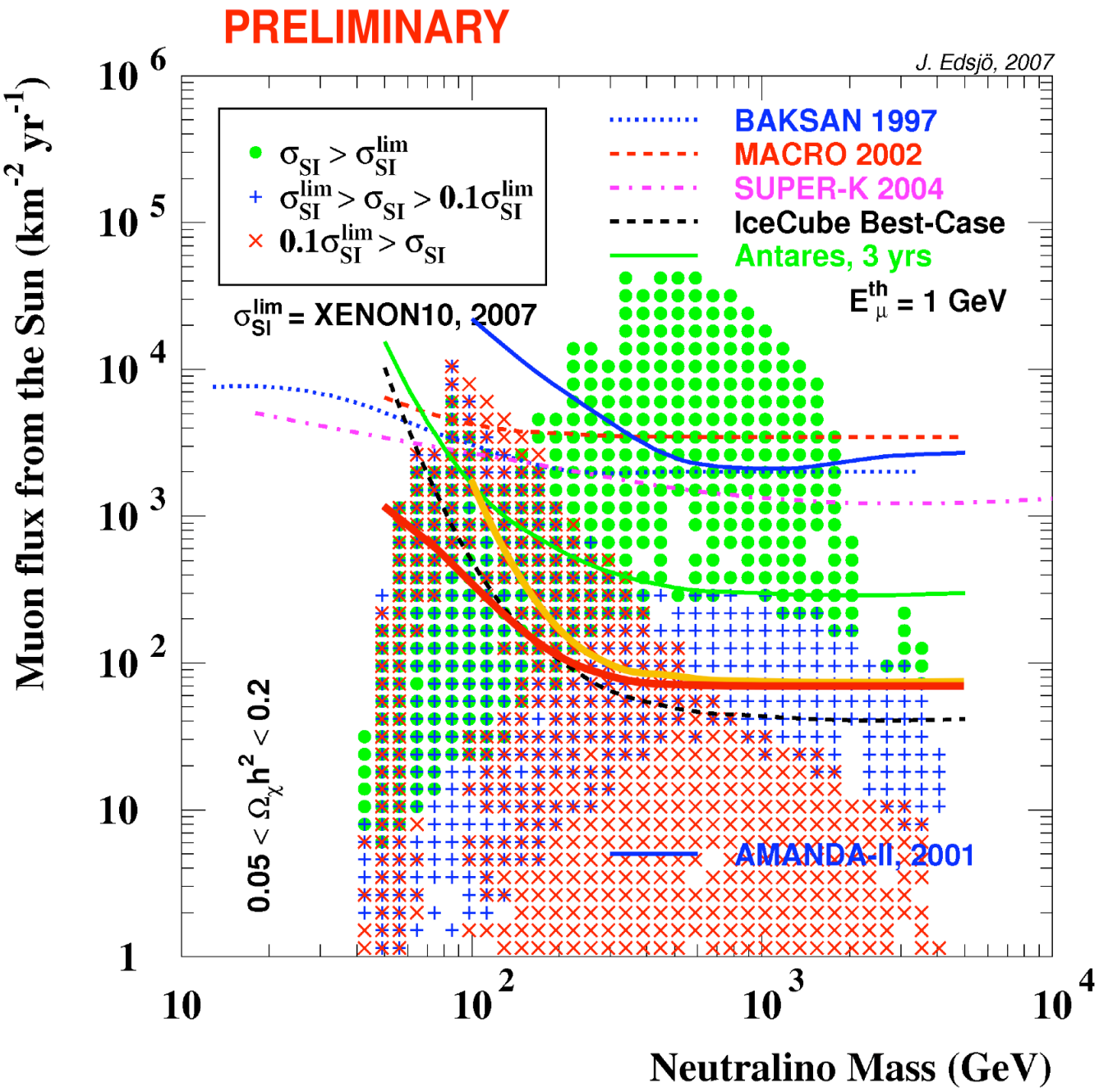


- New variables are a stronger function of energy.
- Use information contained in the waveform instead of simply counting the number of hit phototubes.





Energy Resolution
$\sigma(\log_{10}E) \sim 0.3$


PRELIMINARY
J. Edsjö, 2007
Muon flux from the Sun (km^{-2} yr^{-1})
Neutralino Mass (GeV)
$\sigma_{SI} > \sigma_{SI}^{lim}$
$\sigma_{SI}^{lim} > \sigma_{SI} > 0.1\sigma_{SI}^{lim}$
$0.1\sigma_{SI}^{lim} > \sigma_{SI}$
σ_{SI}^{lim} = XENON10, 2007
BAKSAN 1997
MACRO 2002
SUPER-K 2004
IceCube Best-Case
Antares, 3 yrs
E_{μ}^{th} = 1 GeV
AMANDA-II, 2001
$0.05 < \Omega_{\chi} h^2 < 0.2$

Irreducible atmospheric neutrino background