Dark 2009

Christchurch, NZ

Jan. 18 - 24, 2009

Recent Results & Status of IceCube

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(Stockholm Univ.)

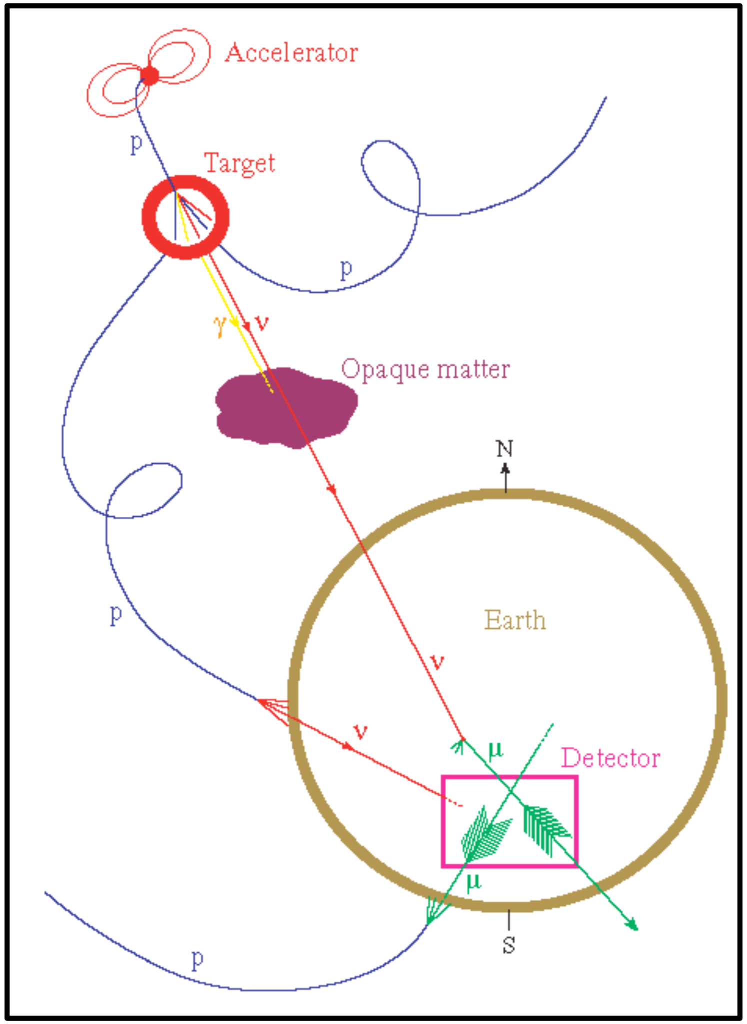
for IceCube Collaboration

Outline

- Introduction
- The IceCube Detector
- Recent Results
- Current Status
- Future: Deep Core
- Conclusion

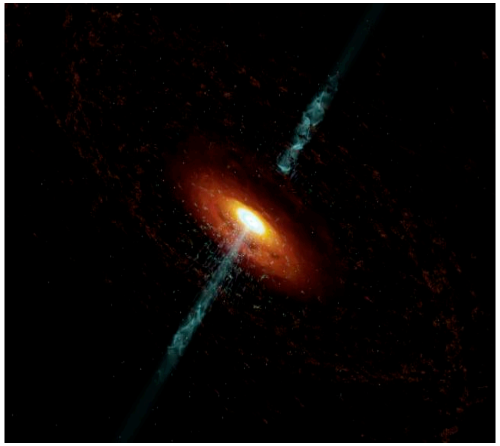
Science cover: 2007
Vol. 315, issue 5818

Nature-produced High E Particles



At earth we observe:

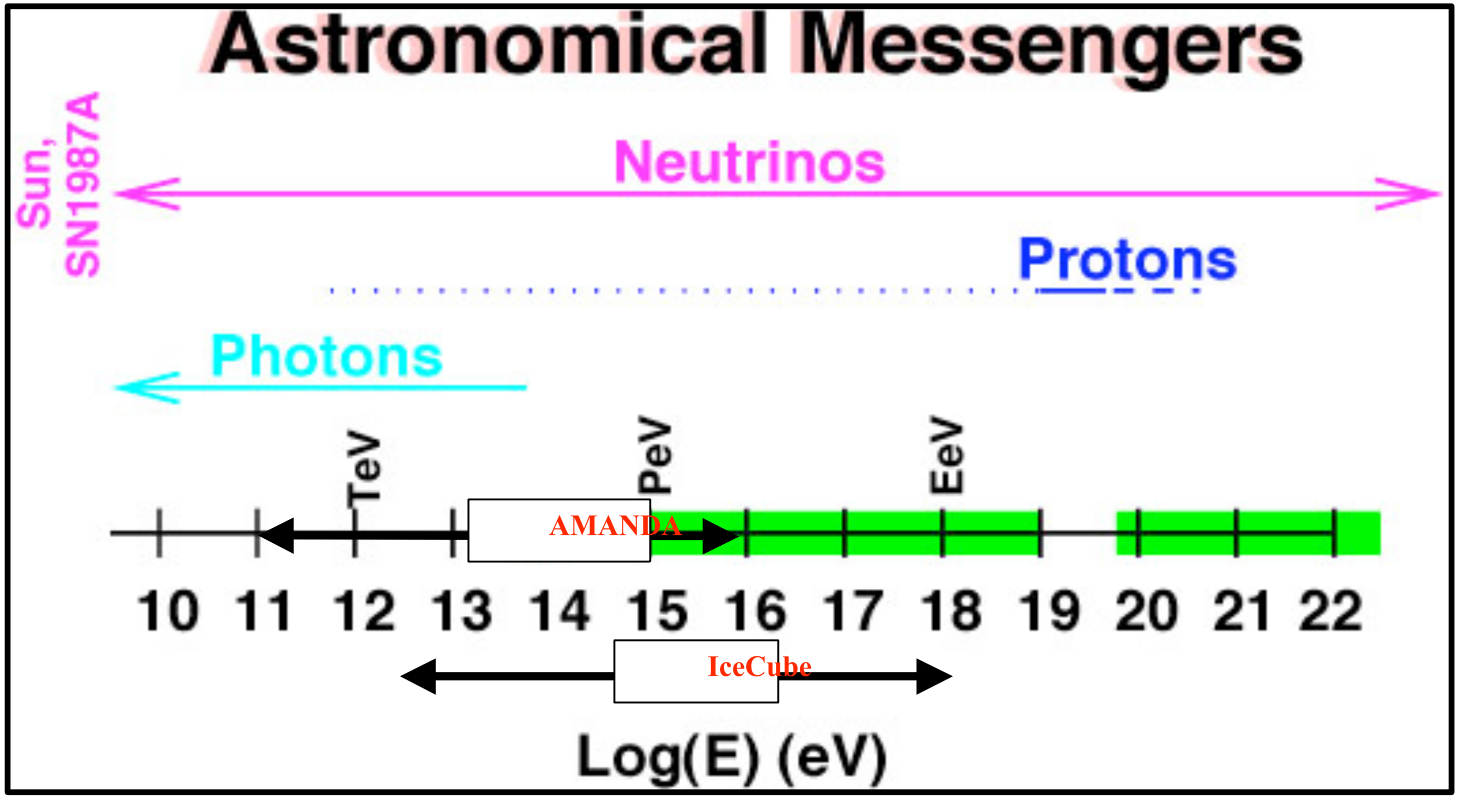
-- Cosmic rays (~80% protons)
-- Photons
-- Neutrinos



We would like to answer:

-- What are the sources?
-- What's the physics at/near the sources?

Detecting Astrophysical Particles



- Photons get absorbed (or pair-production) above 50 TeV.
- Protons get bent below 10 EeV and strongly attenuated above 50 EeV (GZK cut-off).
- Neutrinos cover all energy range, point back, but hard to detect.

Neutrino Telescope

Requirements:

-- Large detection volume to compensate for small cross section and small flux of neutrinos

-- Optically transparent medium: water, ice

Detectors:

-- Water: DUMAND, Baikal, ANTARES, NESTOR, NEMO, KM3Net

-- Ice: AMANDA, IceCube (successor of AMANDA)

Medium	Water	Ice
Location	Northern	Southern
Deployment	Mostly year-round	austral summer
PMT noise rate	~ 40 KHz	~0.5 KHz
Scattering length	> 100 m @466nm	~ 20 m @ 400 nm
Absorption length	~ 60 m @466 nm	~110 m @ 400 nm
Detector geometry	Unstable	Stable

The IceCube Collaboration

USA (15):
- Bartol Research Institute, Delaware
- Pennsylvania State University
- UC Berkeley
- UC Irvine
- Clark-Atlanta University
- University of Maryland
- University of Wisconsin-Madison
- University of Wisconsin-River Falls
- Lawrence Berkeley National Lab.
- University of Kansas
- Southern University and A&M College, Baton Rouge
- University of Alaska, Anchorage
- University of Alabama
- Georgia Tech University
- Ohio State University

Sweden (2):
- Stockholm University
- Uppsala University

UK (1):
- Oxford University

Netherlands (1):
- Utrecht University

Switzerland (1):
- EPFL, Lausanne

Germany (7):
- Universität Mainz
- DESY-Zeuthen
- Universität Dortmund
- Universität Wuppertal
- Humboldt Universität
- MPI Heidelberg
- RWTH Aachen

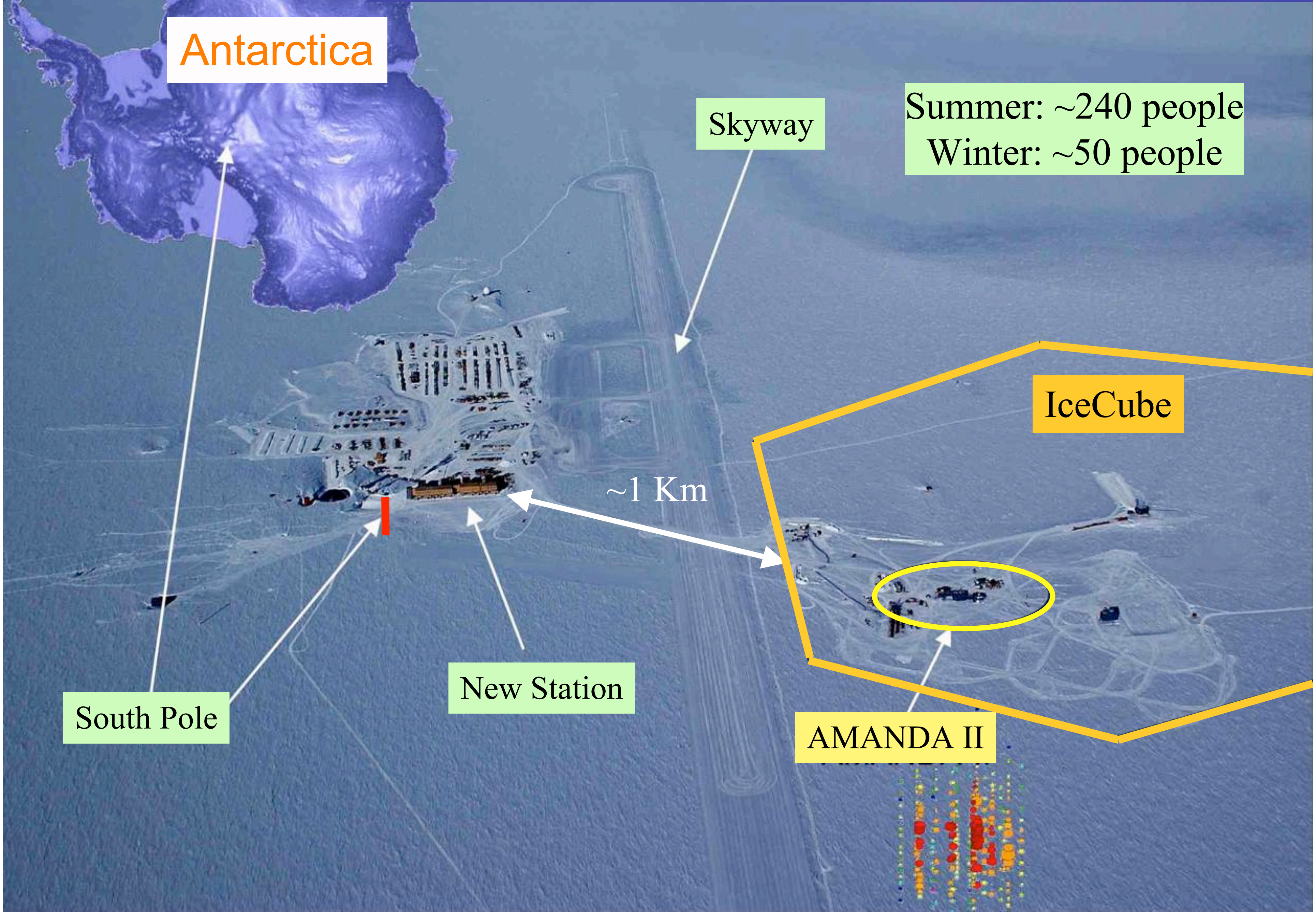
Belgium (4):
- Université Libre de Bruxelles
- Vrije Universiteit Brussel
- Universiteit Gent
- Université de Mons-Hainaut

Japan (1):
- Chiba University

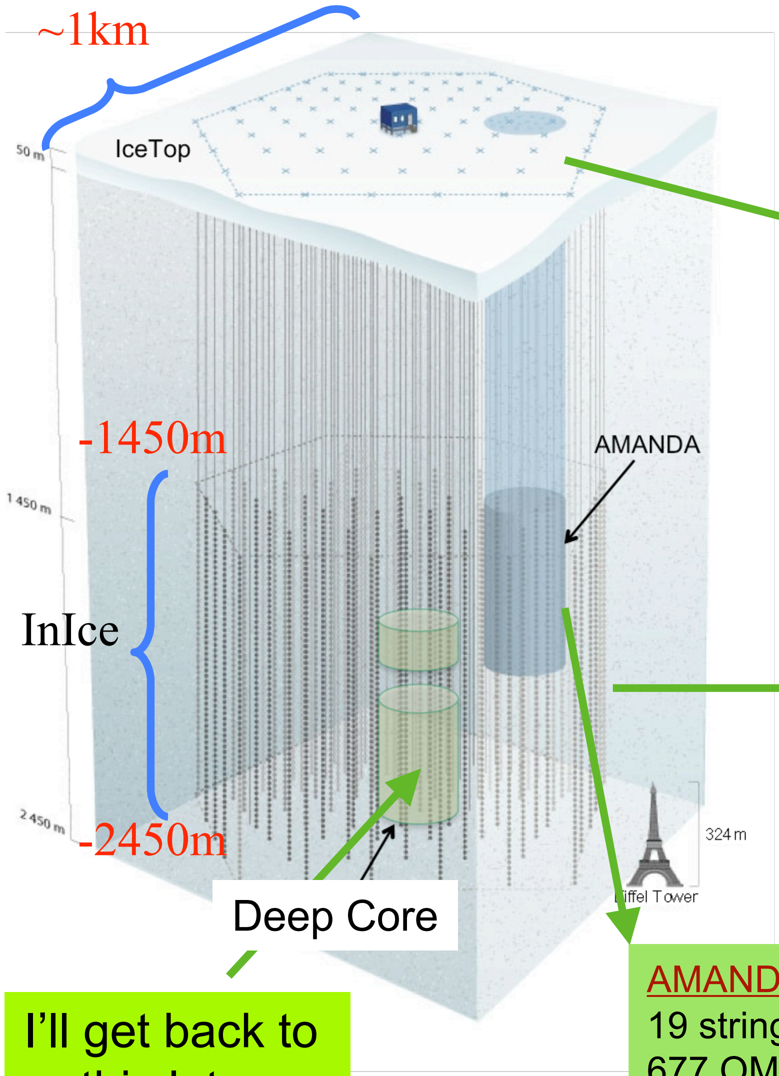
New Zealand (1):
- University of Canterbury

~250 members
33 institutions
9 countries

Amundsen-Scott South Pole Station

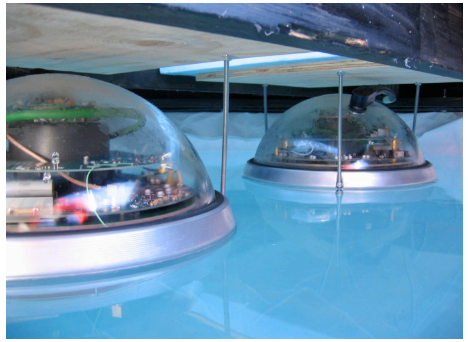


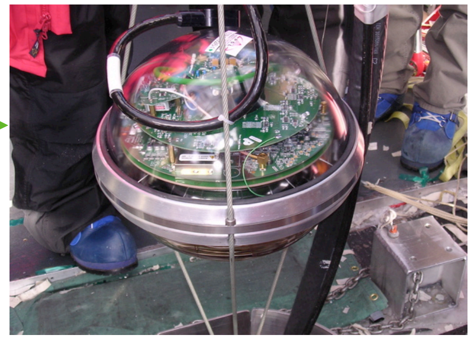
The IceCube Detector



I'll get back to this later.

IceTop (air shower array):
80 stations
2 frozen-water tanks / station
2 DOMs / tank



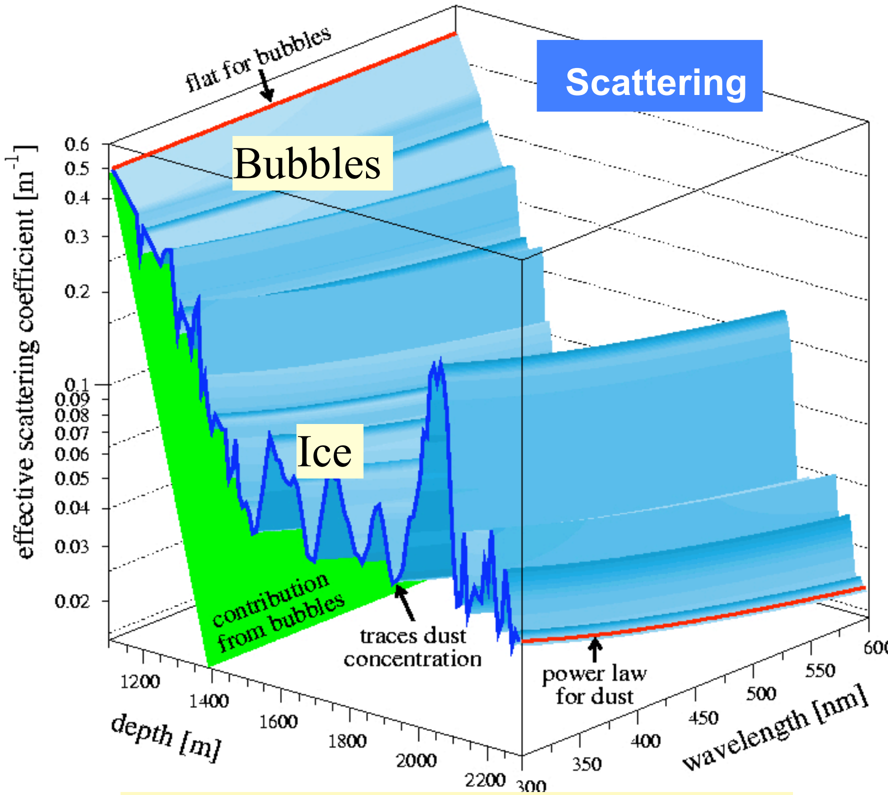


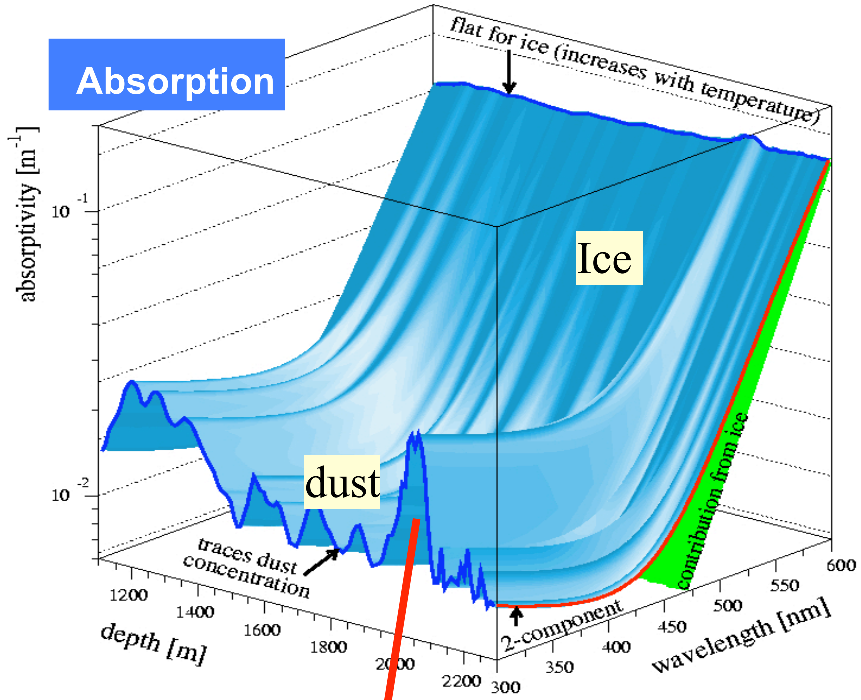
AMANDA: 1996 - 2008
19 strings
677 OMs total
10-20 m vertical spacing
~40 m between strings

InIce:
80 strings
60 DOMs / string
17 m vertical spacing
125 m between strings

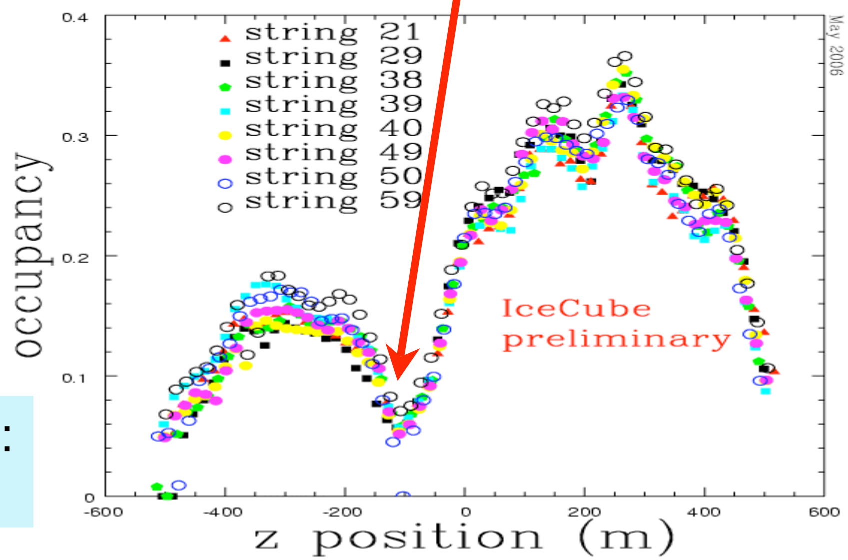
String Deployment

Ice Properties



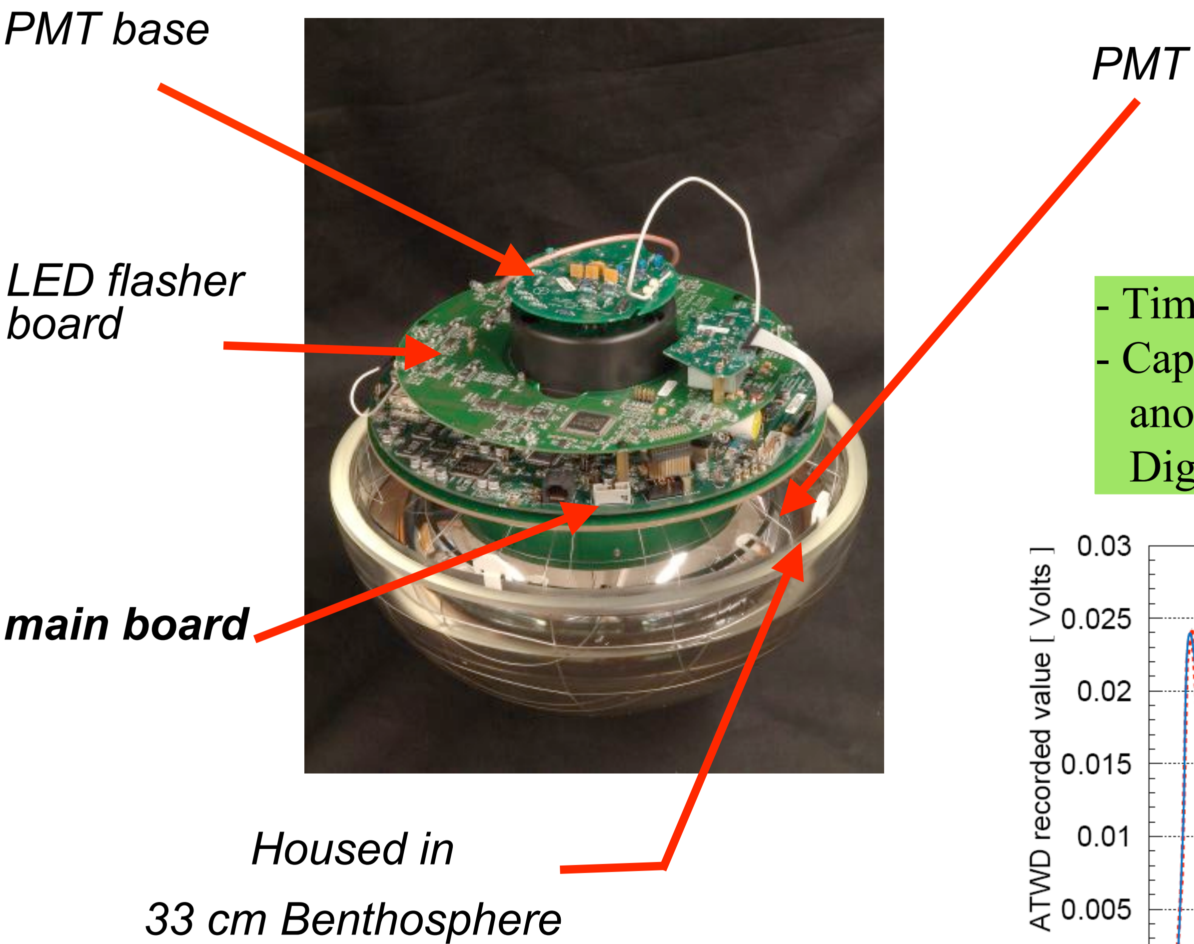


Average optical parameters:
λ_{abs} ~ 110 m @ 400 nm
λ_{sca} ~ 20 m @ 400 nm



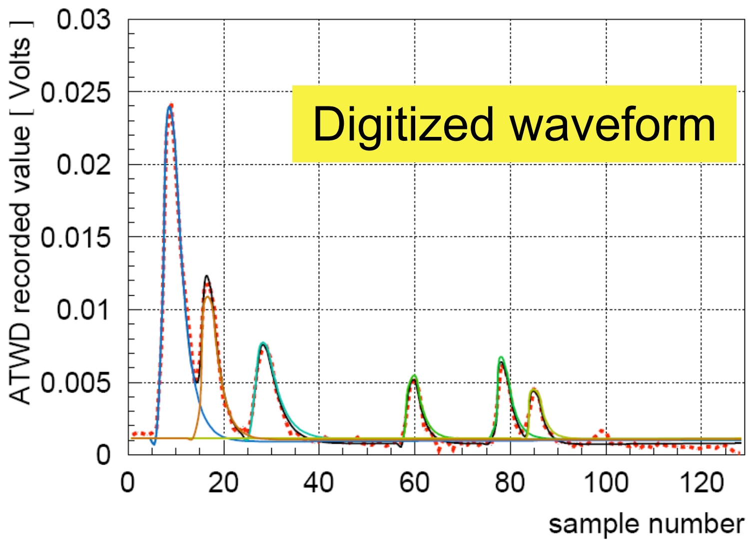
At bottom half of detector (very clear ice):
λ_{abs} ~ 220 m, λ_{sca} ~ 40 m @ 400 nm

Digital Optical Module (DOM)



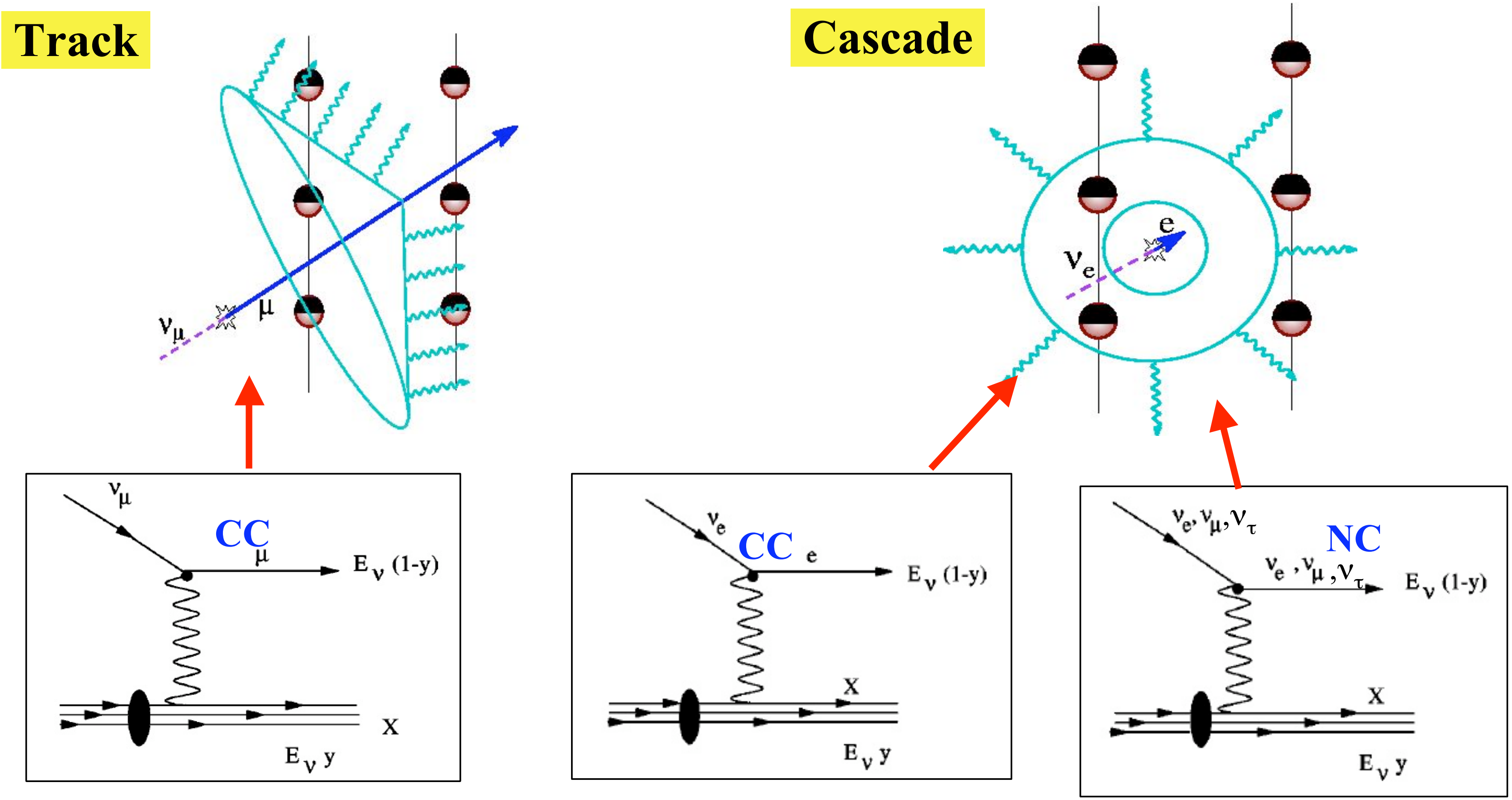
Hamamatsu R7081-02
(10”, 10-stage, 10^7 gain)

- Time-stamp at the DOM
- Capture complex waveforms at PMT anode with Analog Transient Waveform Digitizer (ATWD) & fADC



Neutrino Detection

Method: detect Cherenkov light from secondary particles produced
by neutrino interaction



Dark09, Christchurch,
New Zealand

IceCube Talk
Seo, Stockholm Univ.

ν Detection Quality

Track

	IceCube-80	AMANDA
Angular resolution	< 1°	2° ~ 3°
E resolution $\log_{10}(E/GeV)$	~ 50%	~ 50%
Time resolution	~ 3 nsec	5 ~ 7 nsec

Cascade

Angular resolution	---	---
E resolution $\log_{10}(E/GeV)$	~ 20%	~ 20%
Time resolution	~ 3 nsec	5 ~ 7 nsec

Event Rates

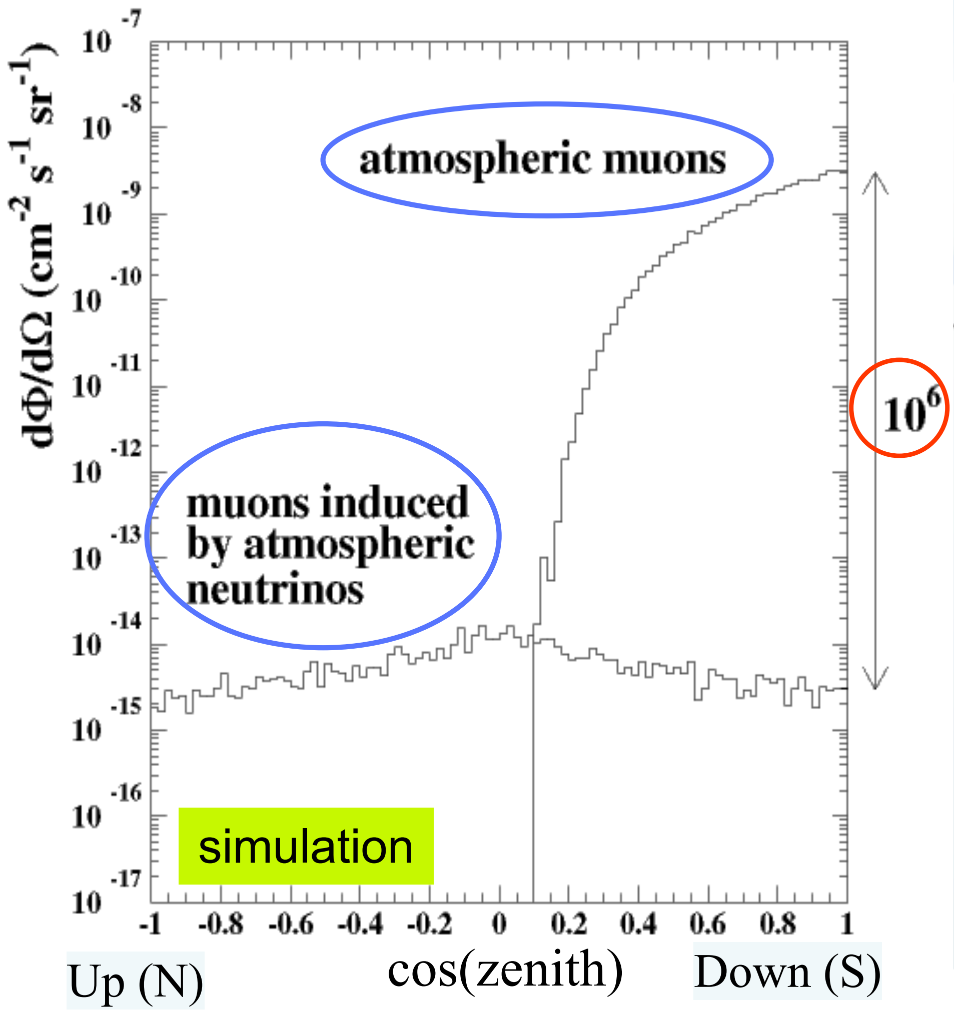
Year	#Strings	Run Length	Trigger Rate	ν rate	CR μ Rate
2005	IC1	-	-	2	-
2006	IC9	137 days	150 Hz	~ 1.5/day	80 Hz
2007	IC22	319 days	670 Hz	~ 20/day	550 Hz
2008	IC40	~ 1year	1400 Hz		1000 Hz
2011	IC80	10 years	TBD	~ 200/day	1650 Hz

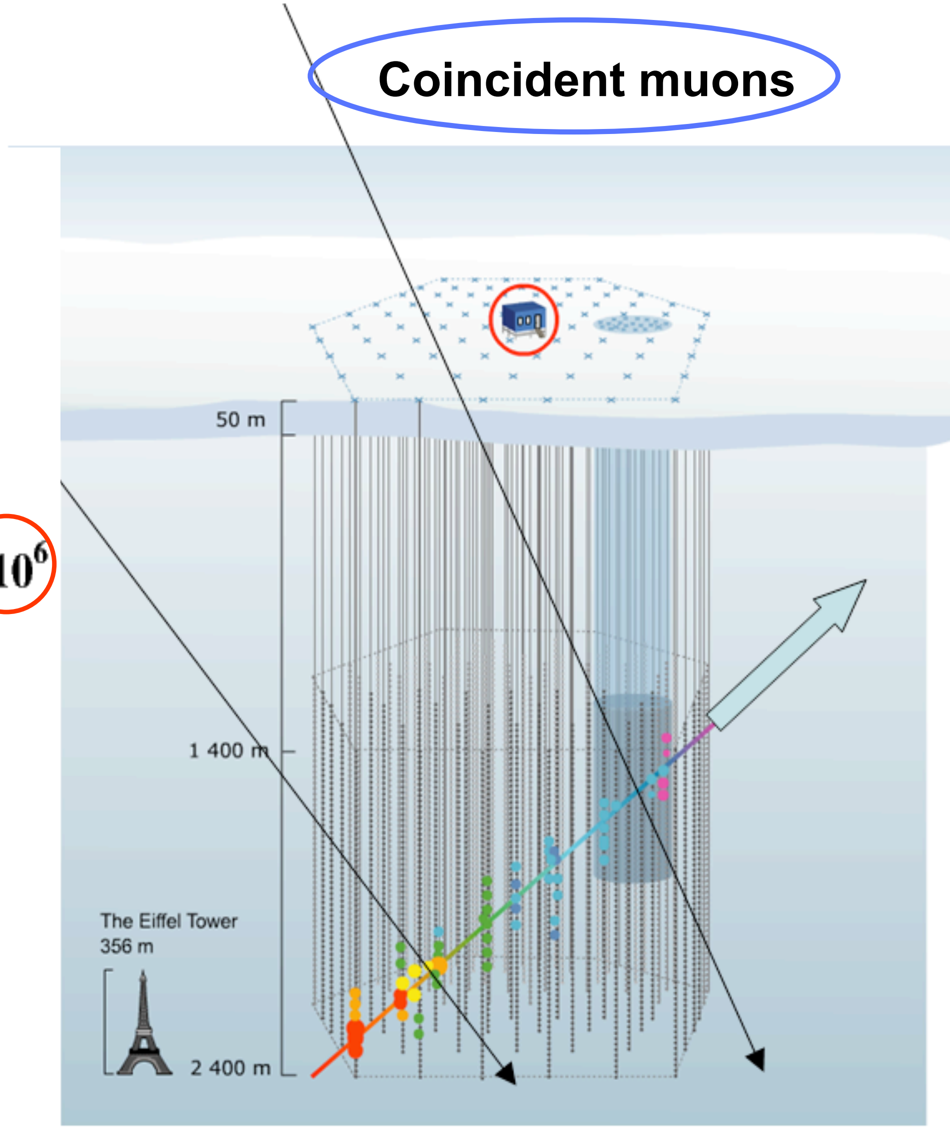
Data Transfer

-- Satellite: ~32.5 GB/day (Y2008), (pre-scaled) filtered events

-- Ship: once a year for all filtered events in tapes

Backgrounds





IceCube Physics Reach

Astronomy/Astrophysics:

-- point source search: GRB, AGN, etc...

-- diffuse search

Cosmic ray physics:

-- compositions, energy spectrum

HEP:

-- neutrino oscillations over cosmologically long baseline

-- atmospheric neutrino oscillations

-- charm production from high energy atmospheric neutrinos

-- etc…

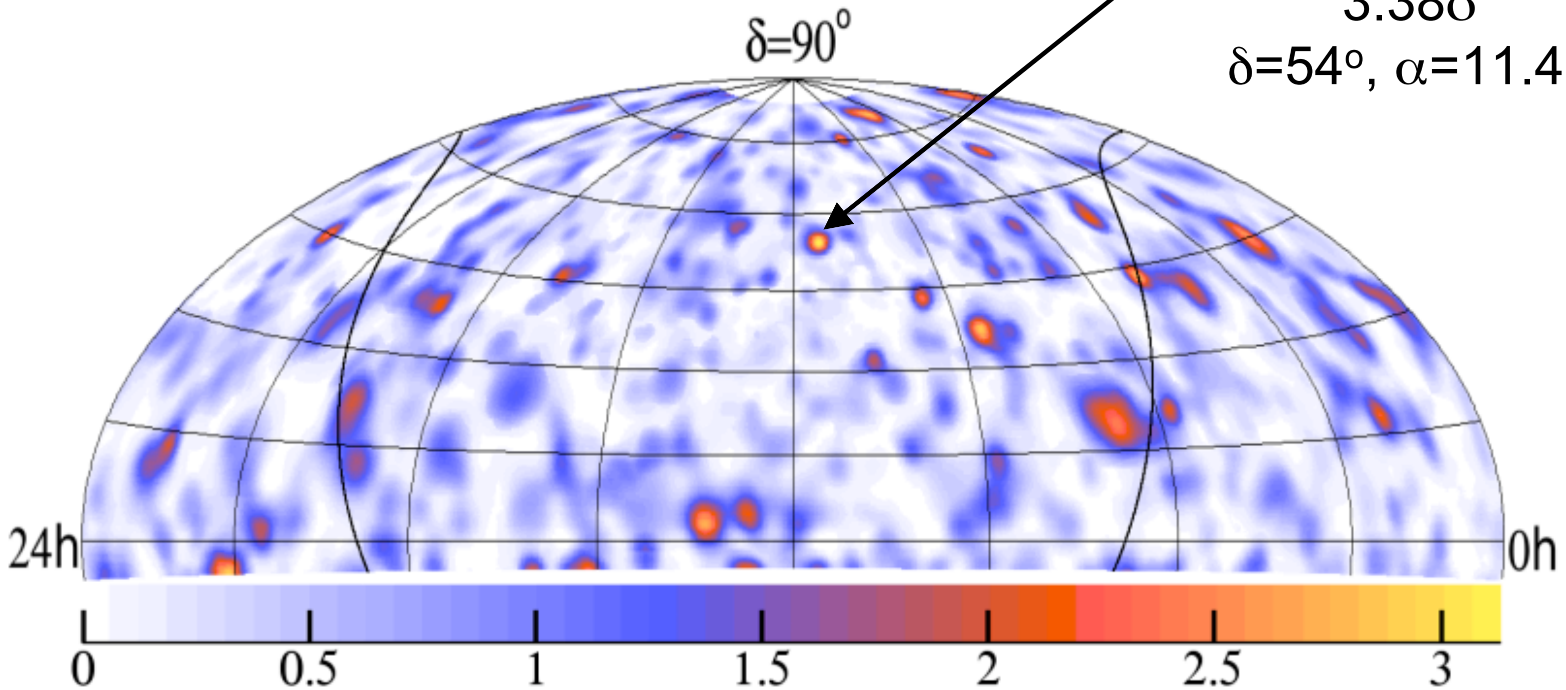
New physics:

-- **WIMPs**, (GUT) monopoles, nuclearites, Q-balls, stau pairs

-- violation of Lorentz invariance, etc…

AMANDA Sky Map

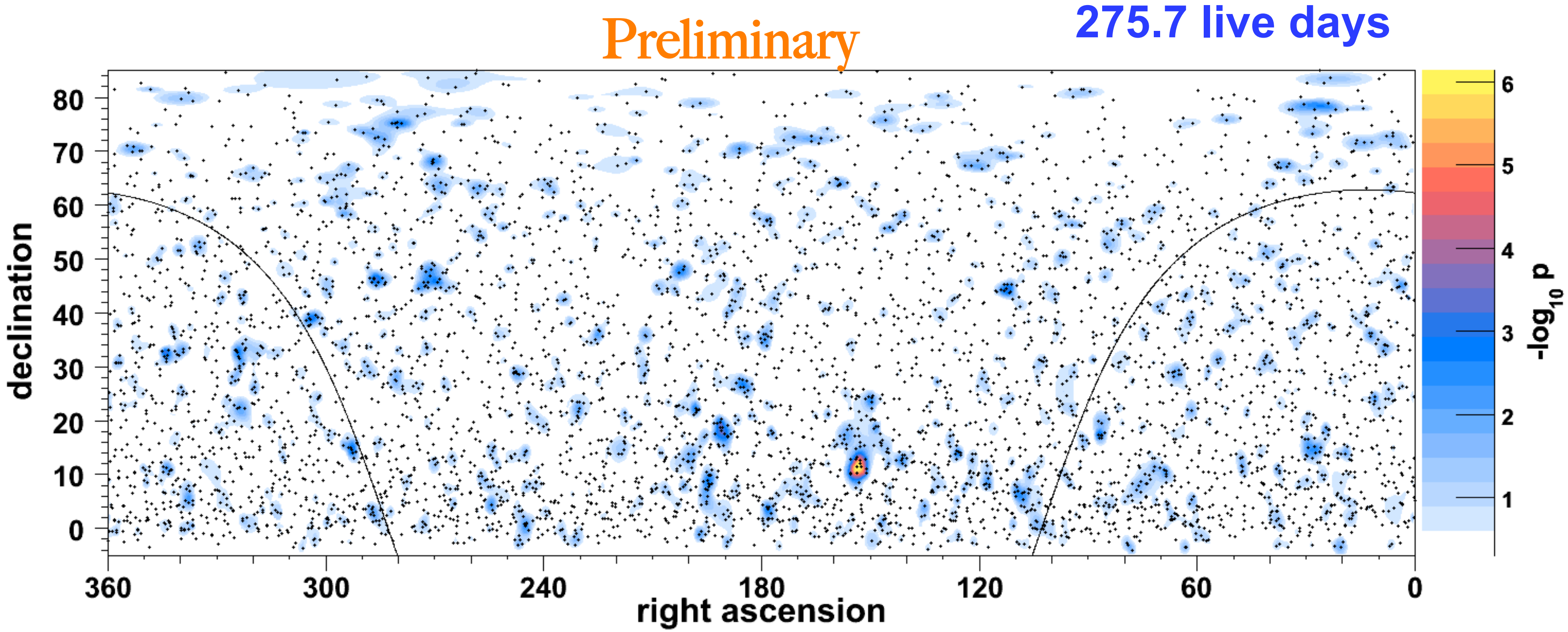
Max. significance
3.38σ
$\delta=54^o$, $\alpha=11.4h$



significance

-- 3.8 years livetime data of AMANDA
-- Max. significance is 3.38σ
-- However, 95% of randomized data sets showed significance of 3.38σ or greater.

IceCube 22 string Sky Map

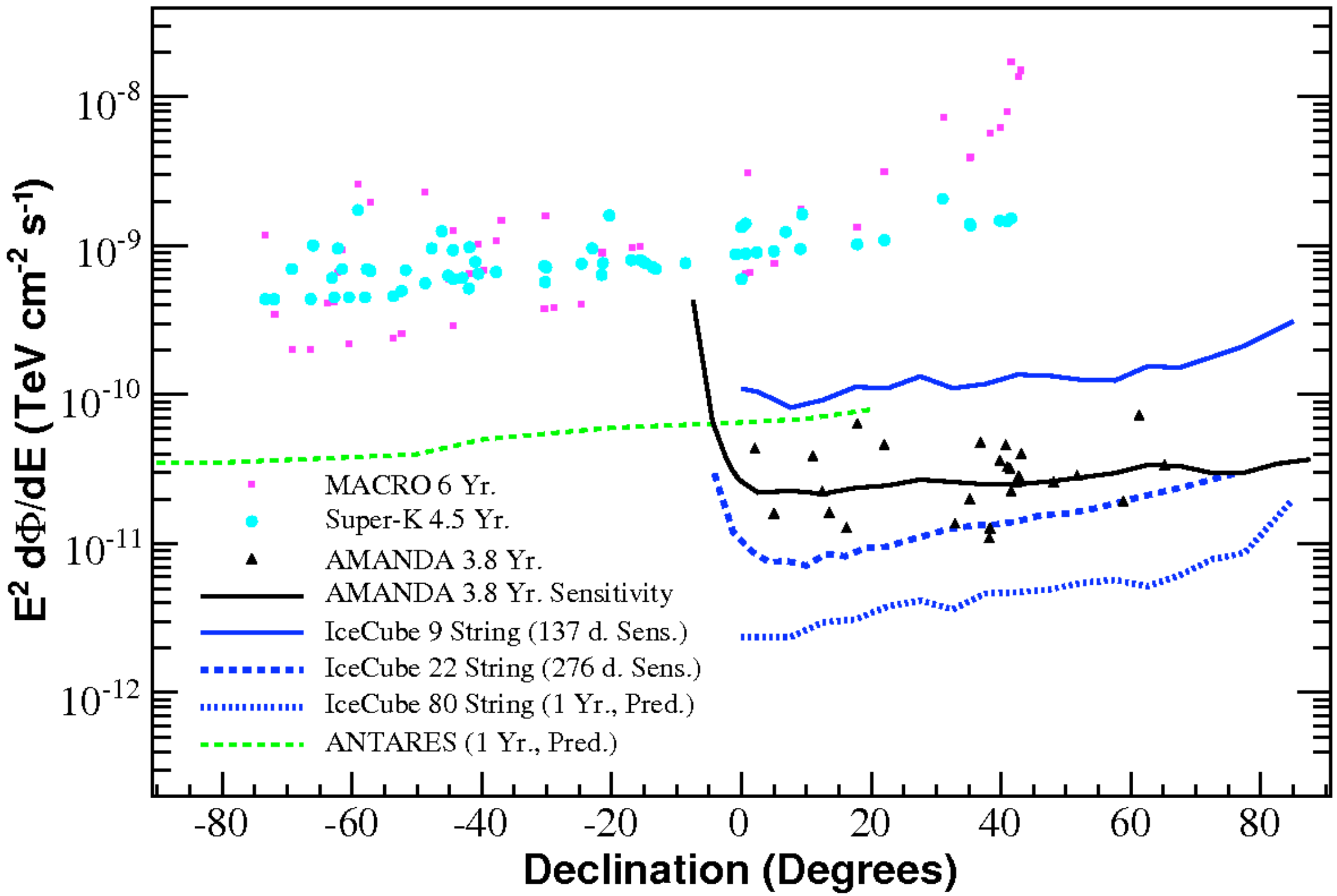


Location: Ra: 153.375° , Dec: 11.375°

Estimated pre-trial significance (p-value): -log10(p): 6.13995

p-value of post-trials: ~1.34%

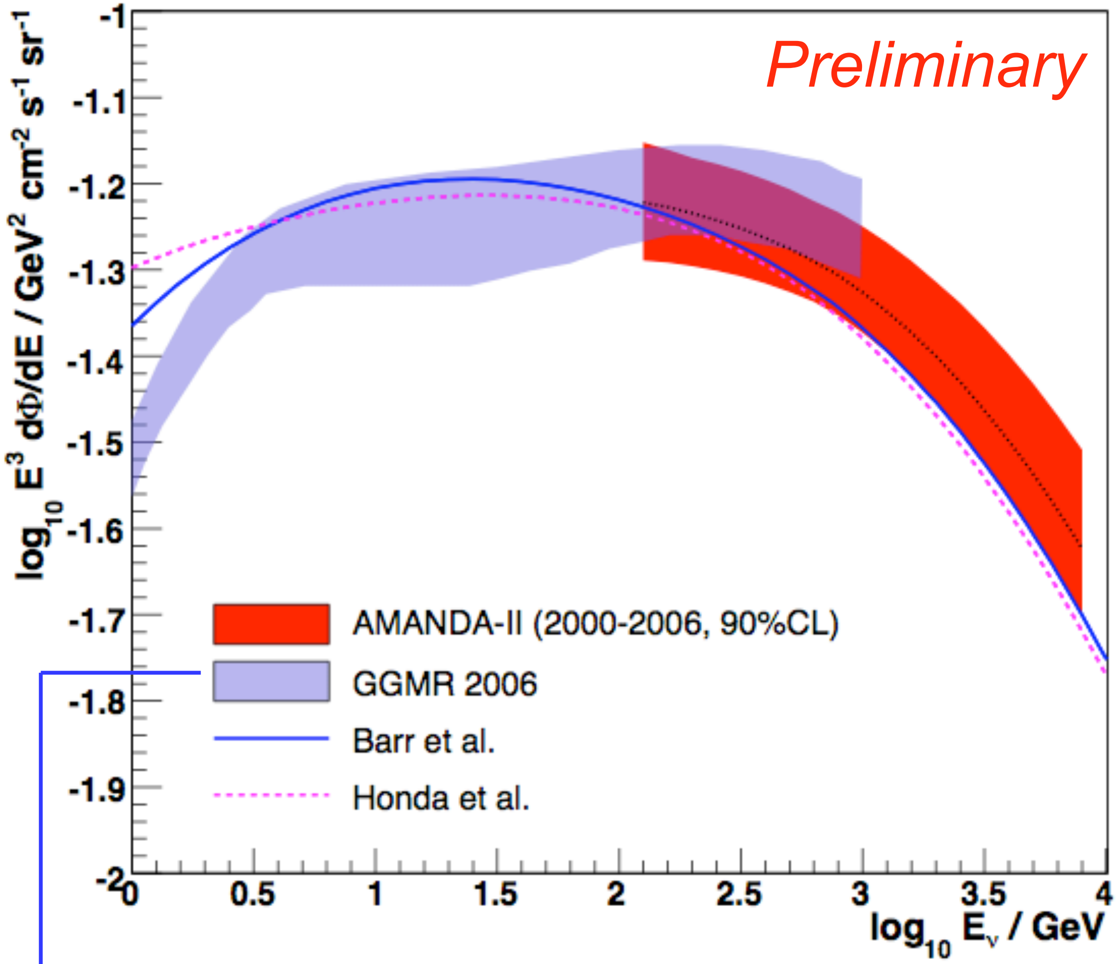
Astrophysical ν Diffuse Flux Limit



AMANDA 3.8 yr limit : 10^{-11} ~ 10^{-10} $E^2 d\Phi/dE$ ($TeVcm^{-2}s^{-1}$)

Expected IceCube80 (1 yr) sensitivity: 10^{-12} ~ 10^{-11} $E^2 d\Phi/dE$ ($TeVcm^{-2}s^{-1}$)

Atmospheric ν



SuperK data,
González-García, Maltoni, & Rojo,
JHEP 0610 (2006) 075

-- atmospheric ν are irreducible BG.

-- AMANDA measurement is similar to the two popular atm. ν models.

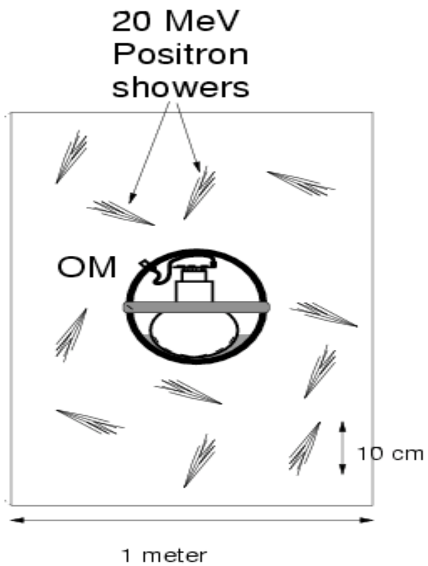
Super Nova Monitoring

SNEWS (SuperNova Early Warning System) is a collaborative effort among Super-K, SNO, LVD, KamLAND, AMANDA, BooNE and gravitational wave experiments

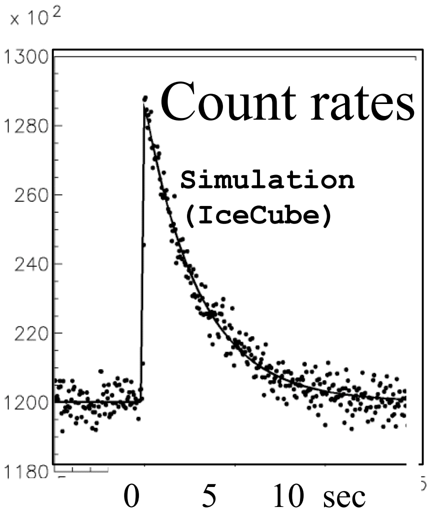
Bursts of low-energy (MeV) neutrinos from core collapse supernovae

$$\bar{\nu}_e + p \rightarrow n + e^+$$

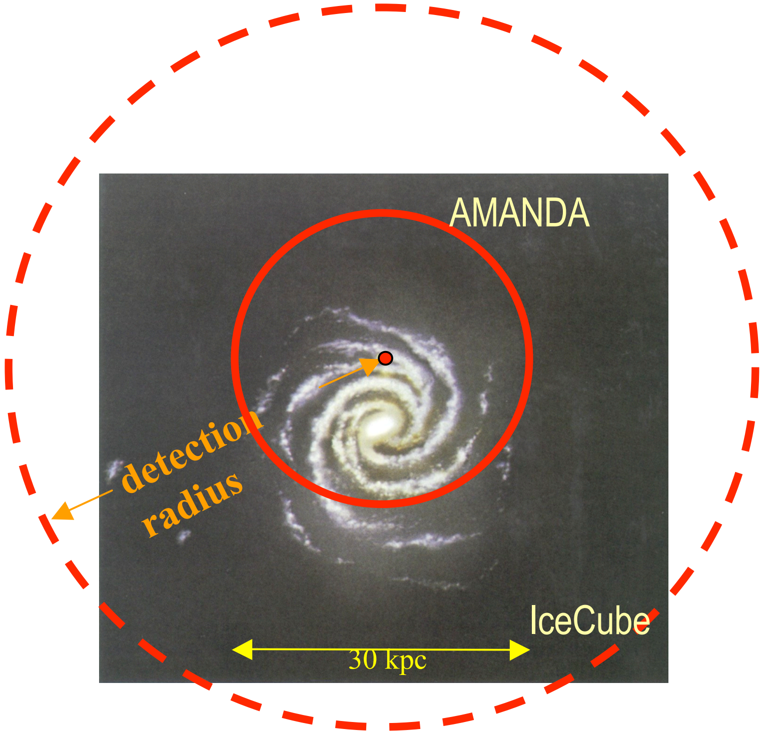
The produced positron is emitted almost isotropically



O(10cm) long tracks

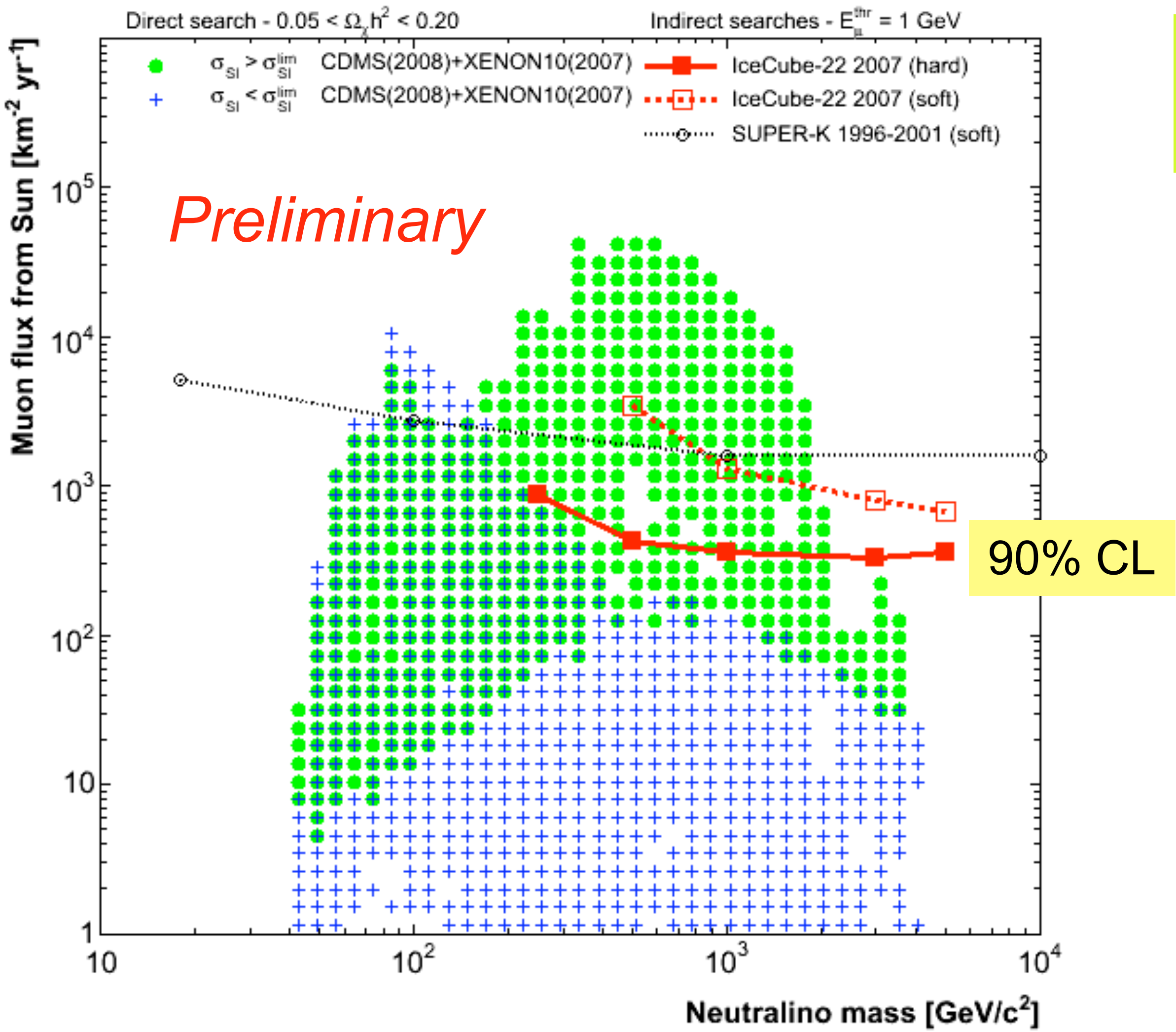


Rate increase
on top of dark noise



- AMANDA sees 90% of the galaxy
- IceCube will see out to the LMC (Large Magellanic Cloud, ~50 kpc)

IceCube WIMP Search: Indirect



looking for excess ν_μ in the Sun direction

-- No excess was observed w/ 22 strings.

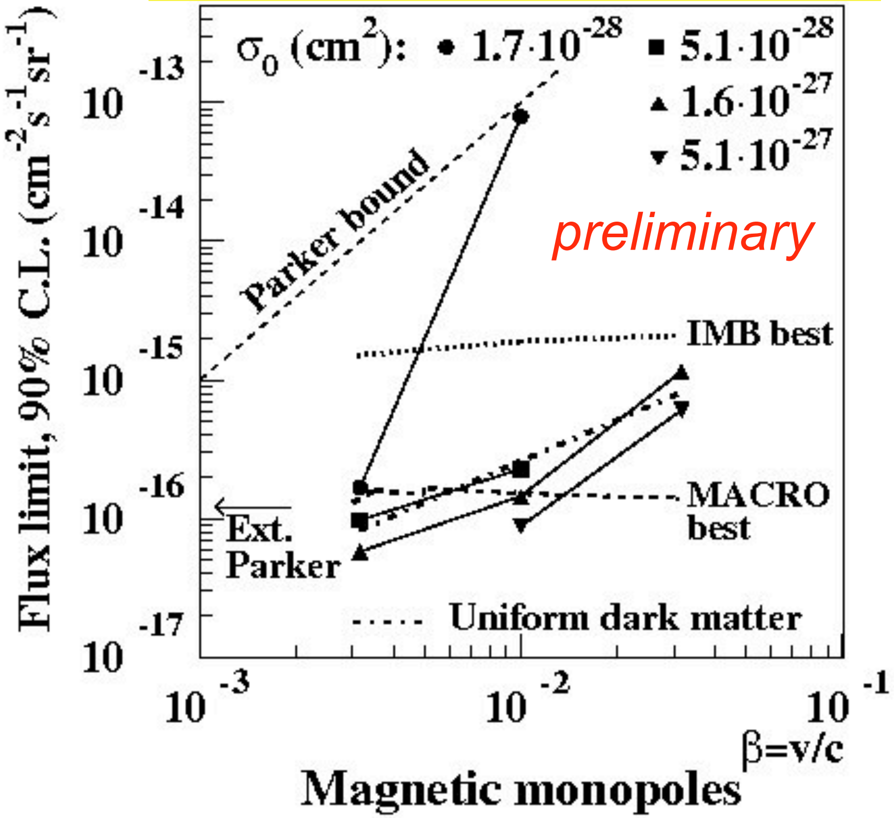
-- We set 90% CL on the muon flux from Sun.

-- We also set current best limit on SD x-section.

See A. Rizzo's talk!

Sub-relativistic Monopoles

AMANDA 2001 (64 live days)



m_M >= $\sim 10^{16}$ GeV (GUT)

M + p → M + e⁺ + π⁰(2γ) → em shower

-- catalysis of nucleon decay by GUT magnetic monopoles (**σ = ~ 10^{-56}cm²**)

-- baryon & lepton number violation

Rubakov-Callan mechanism:

$$\sigma = \frac{\sigma_0}{\beta^n} \cdot F(\beta), \quad n = 1 \text{ or } 2$$

(for $\beta < 10^{-3}$)

$\sigma_0 =$ typical strong int. x-section

$F(\beta) =$ suppression factor (smaller for higher Z atom & lower β)

Hydrogen:

$$\sigma = 0.18 \frac{\sigma_0}{\beta^2}$$

Oxygen:

$$\sigma = \frac{\sigma_0}{\beta_{nucl}}$$

← **Nucleon velocity ~ 0.1**

*** We also have preliminary flux limits on **relativistic monopole search** w/ AMANDA.

Violation of Lorentz Invariance

Violation of Lorentz Invariance (VLI): *Living Rev. Relativity*, 8, 5

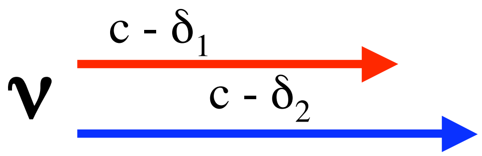
-- one of the aspects in quantum gravity

-- natural in Planck scale (~10^{19} GeV)

-- but also feasible in much lower energy

-- can be tested in, for example,

(A) neutrino oscillation (different from mass osc.):
different osc. prob. (velocity eigen state),
no ν mass dependence but L/E



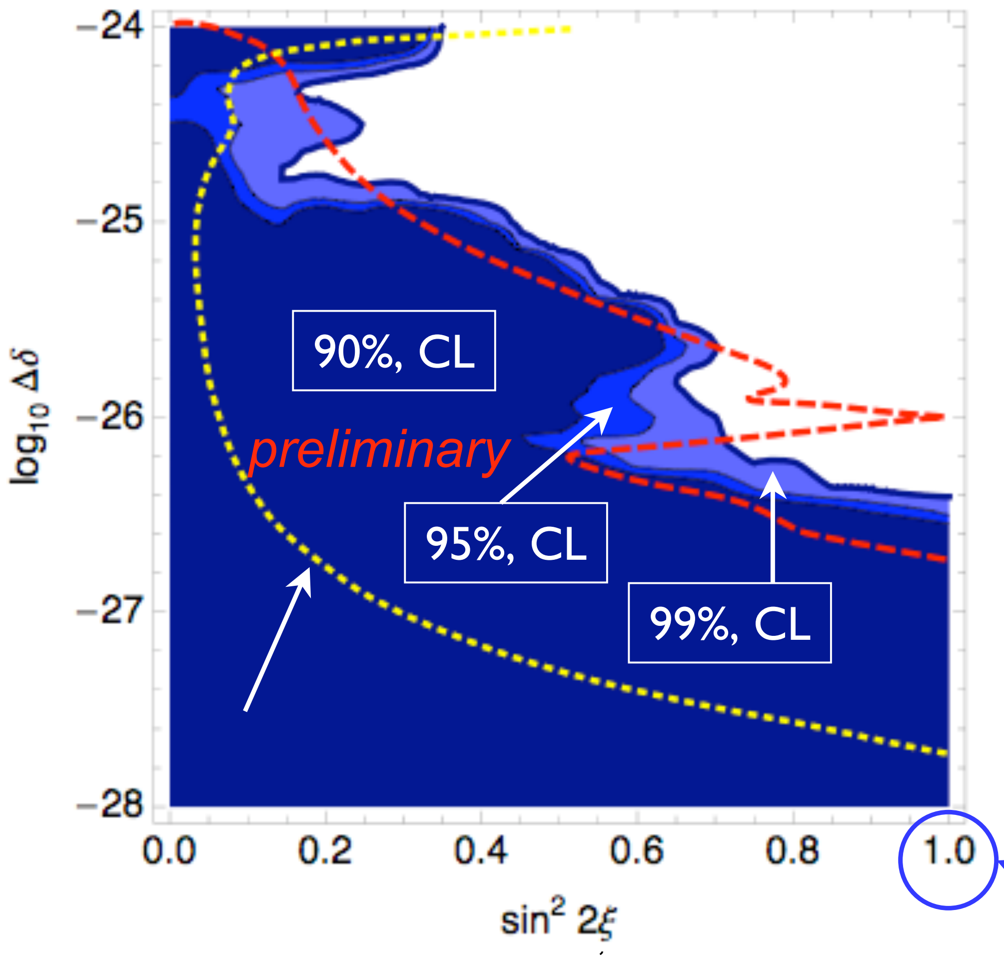
(B) observing higher UHE ν flux than that of WB bound:
E_{thresh} for ν interactions can be modified by VLI

VLI Preliminary Result

--- AMANDA data (3.8 live years) showed **no evidence** for ν osc. Induced by VLI

--- $\delta c/c < 2.8 \times 10^{-27}$ (90%CL) with $\boldsymbol{P}_{\nu\mu\text{-->}\nu\mu}$(maximal mixing)

cf. SuperK + K2K limit: $\delta c/c < 1.9 \times 10^{-27}$ (90%CL)



ξ: VLI mixing angle in 2 flavor system

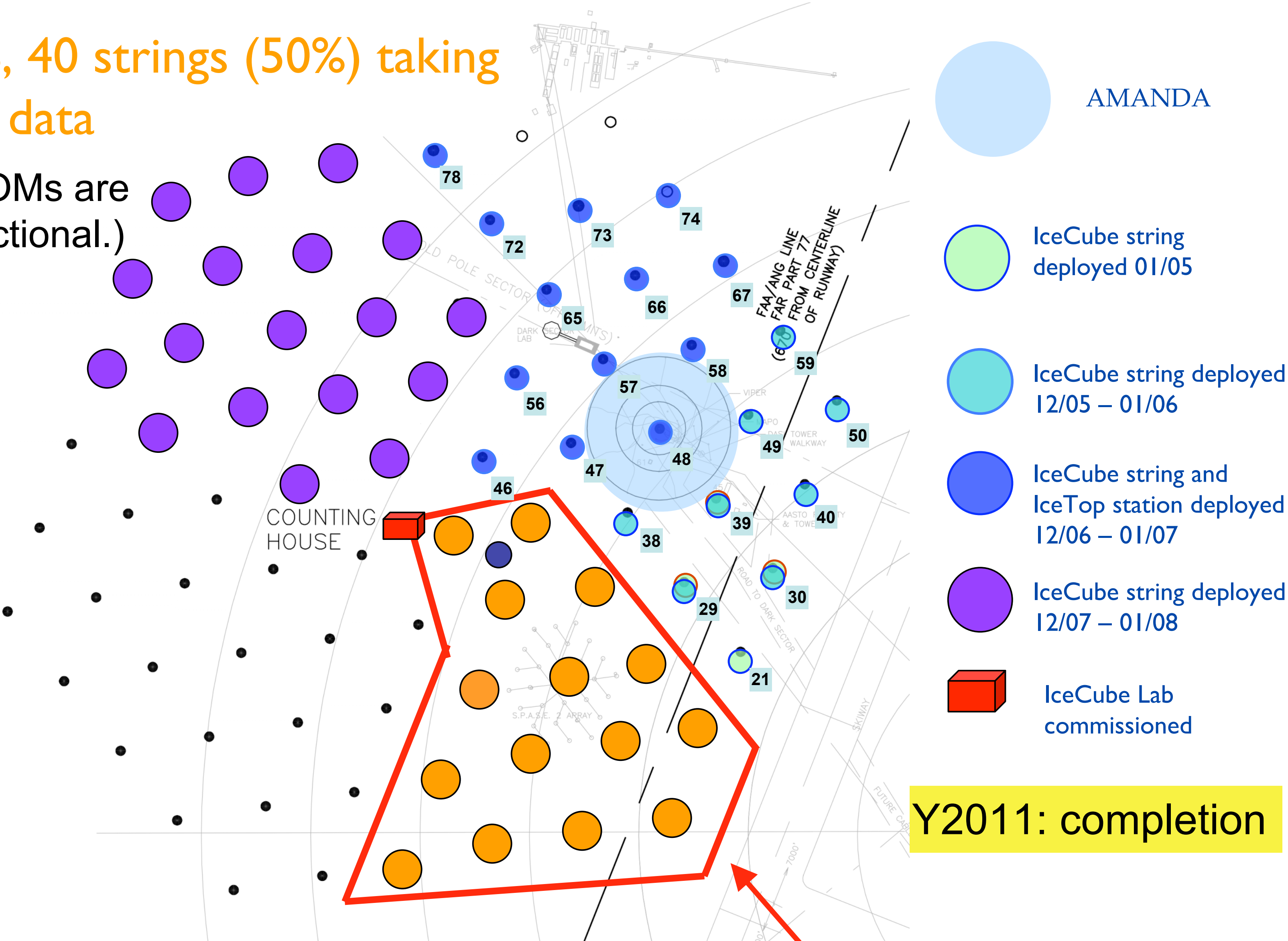
$\Delta\delta = \delta c/c$

Maximal mixing

IceCube Deployment Status

In 2008, 40 strings (50%) taking physics data

(98% DOMs are fully functional.)



Y2011: completion

Deployed 15+1 strings in 2008/09

Dark09, Christchurch, New Zealand

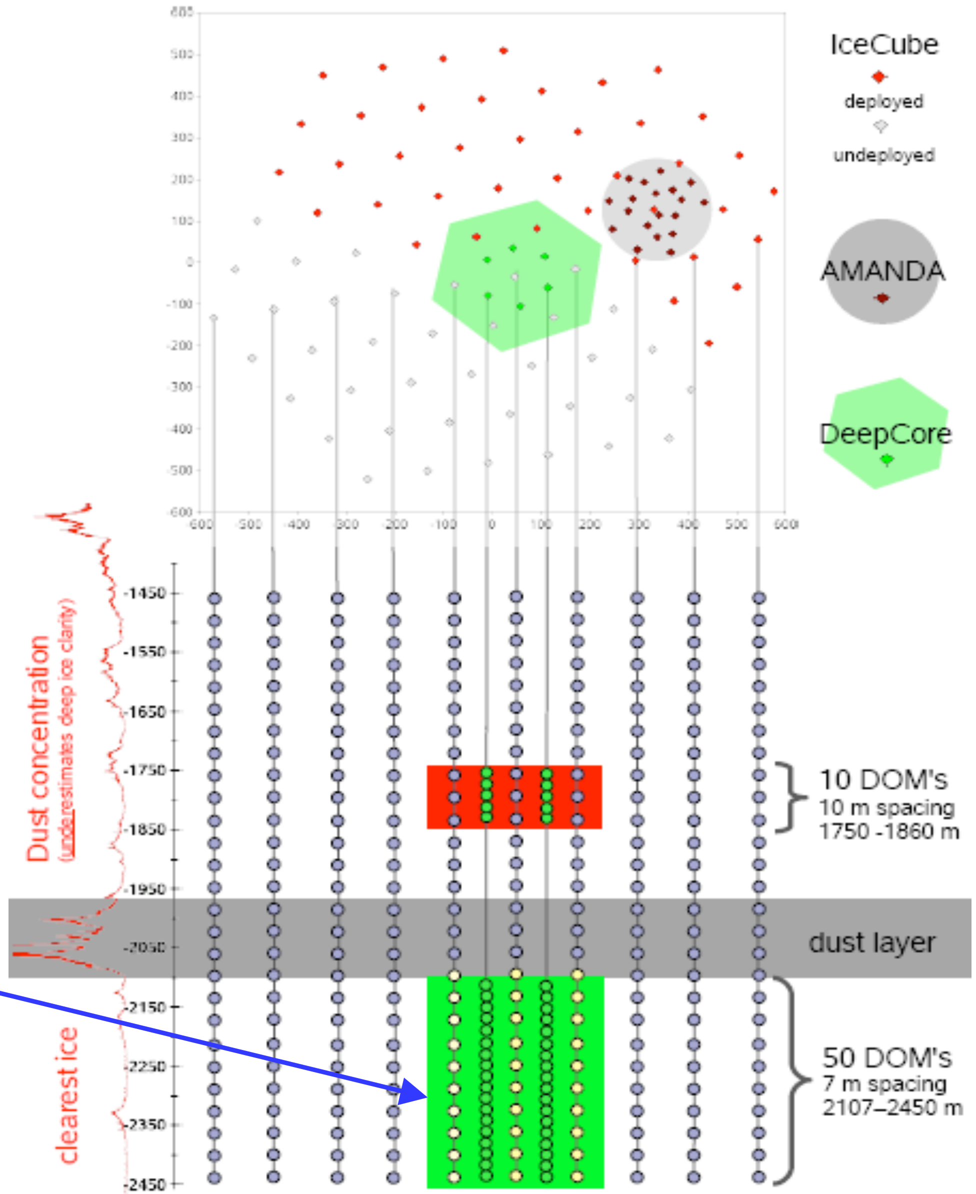
Future: Deep Core

- *To improve **low E event efficiency***
  -- indirect DM search, atm. ν osc, etc..

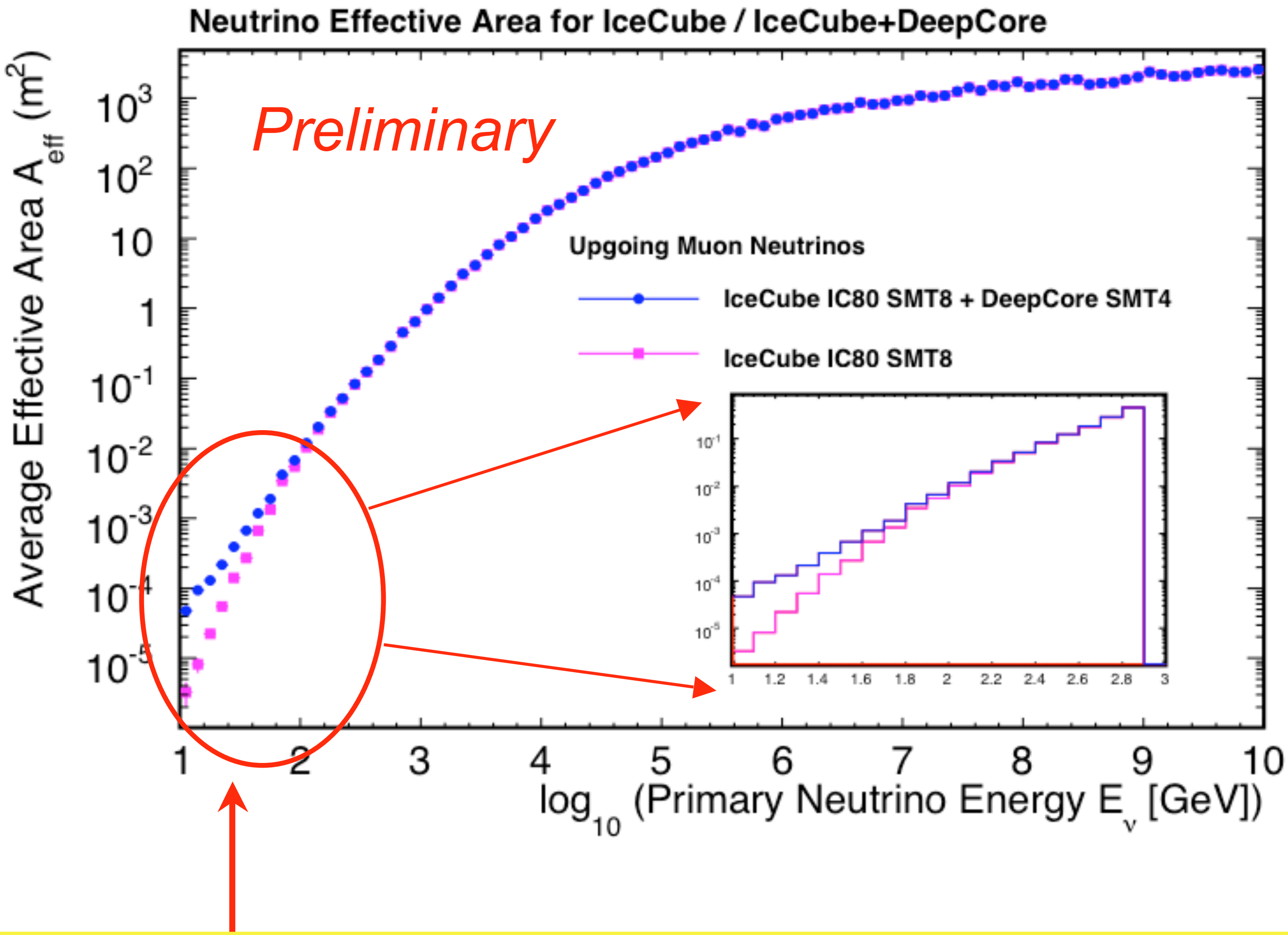
- *total 6 strings (75 m apart)*
  cf. nominal strings: 125 m apart

- *60 DOMs/string*
  -- **high QE DOMs**
  (~ 35% more light yield)
  -- DOMs are densely spaced

- ***4 π detector:***
  -- veto surrounding bottom inner core (6 DC + 7 IC)
  -- explore southern sky as well as Galactic Center



ν Effective Area Comparison



ν effective area increased by deep core in low E region

Conclusion

- IceCube has been taking data smoothly w/ > 50% detector: 100% detector is expected in 2011.
- We have very interesting results with IceCube 22 strings and complete AMANDA 7 years data, which will be published soon.
- However we have no evidence for a source of extra-terrestrial neutrinos yet.
- IceCube deep core will play a critical role in low E physics including indirect Dark Matter search.
- Future extensions optimized for EHE neutrinos are being considered.

Swedish ice breaker


LC-130 Hercules landing at SPole

Thank you!


IceCube Counting House

Myself

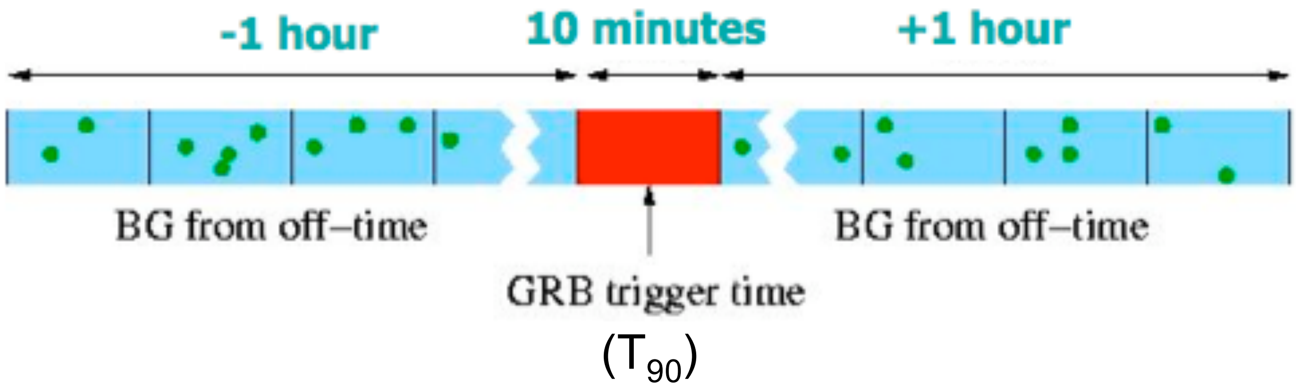
Backup slides

Search for ν from GRB

Time window search:

--- search around GRB duration (T_{90}): this reduces BG significantly.

--- use GRB trigger info from other exp. (BATSE, Swift, Fermi, etc…)

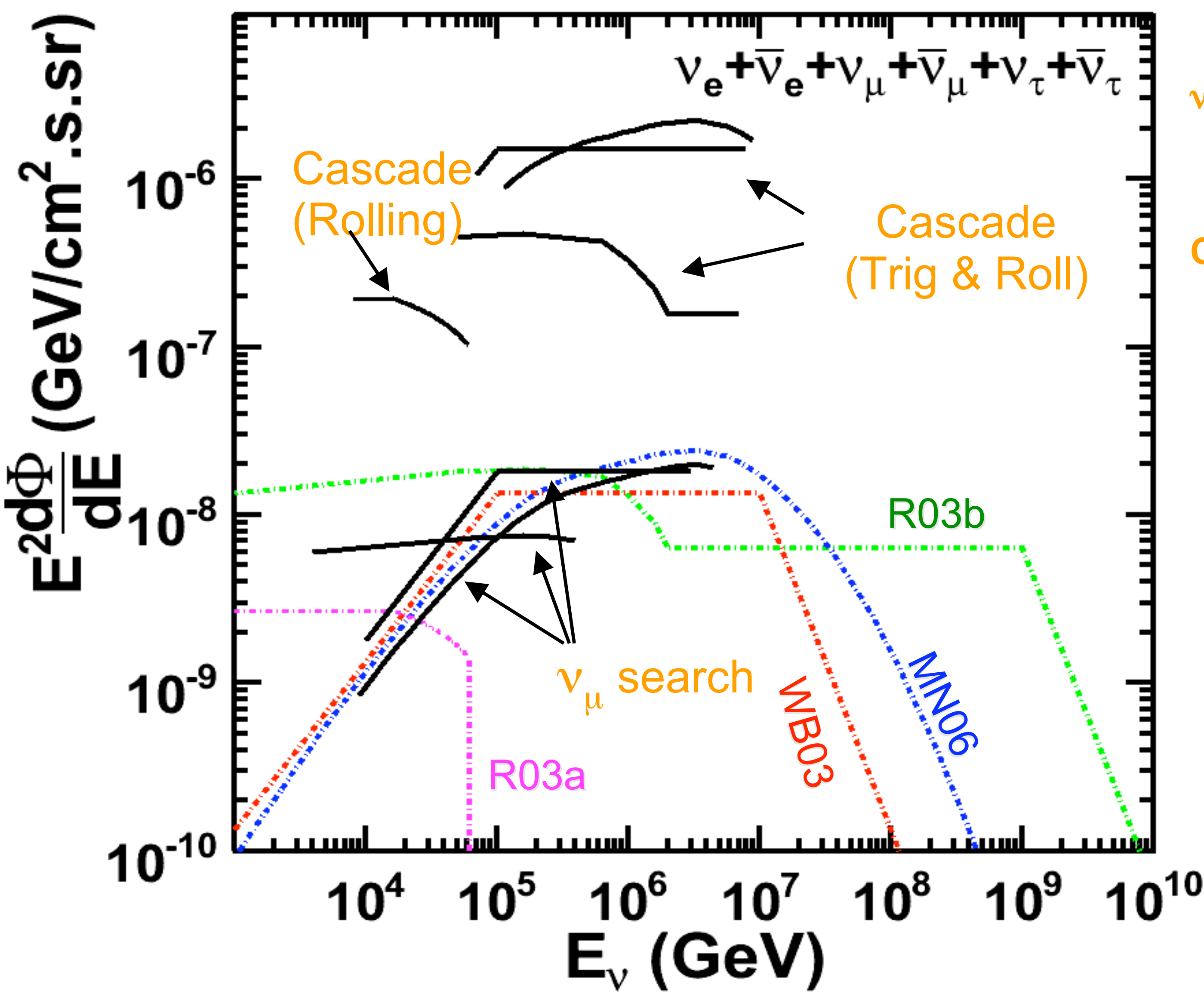


Rolling search:

--- scan through all the data in a given year and search for a statistically significant signal within a fixed time duration.

ν Flux Limits from GRB

All flavor limits by AMANDA

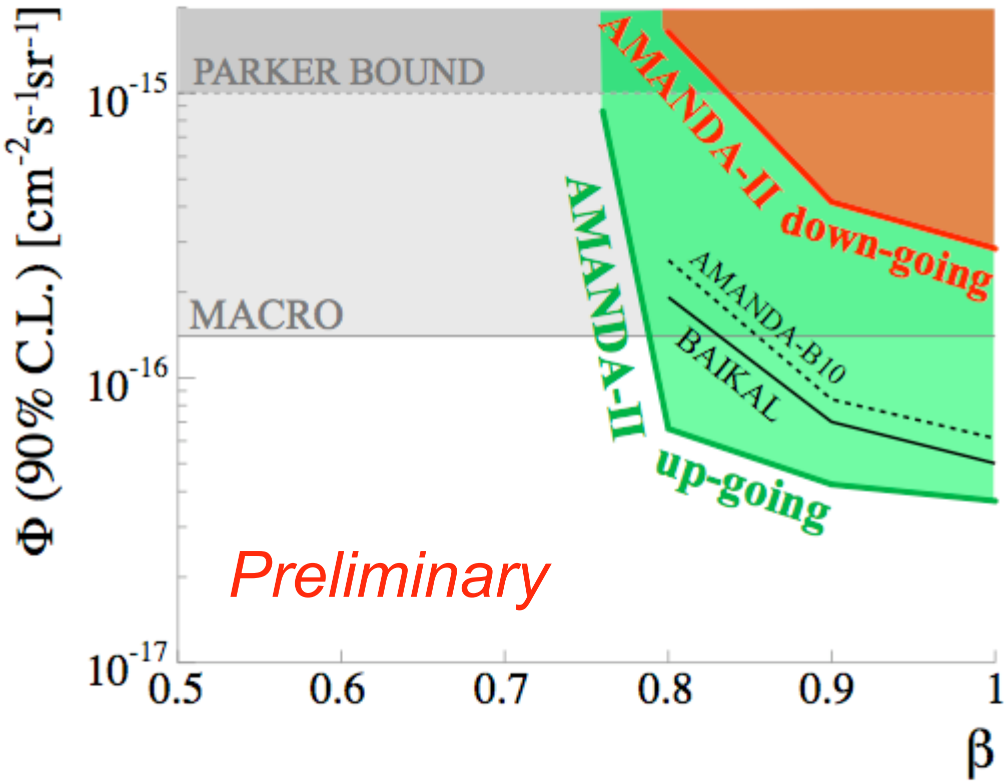


ν_μ search:
Over 400 Northern Hemisphere GRBs

Cascade search
Trigger search with 73 GRBs
Rolling seach for 2001-2003

--R03b: Supranova model
--WB03: Waxman-Bahcall model
--R03a: Choked Burst model
--MN06: Murase Nagataki model

Relativistic Monopoles



-- Relativistic monopoles will leave very bright track in ice medium:

~ 8300 x muon

($g^2 = [n*e/(2*\alpha)]^2$ = ~8300 e^2 for n = 1.33)

-- Slowly moving (down to $\beta \sim 0.5$) monopoles can be detected via δ electrons generated along the monopole path.

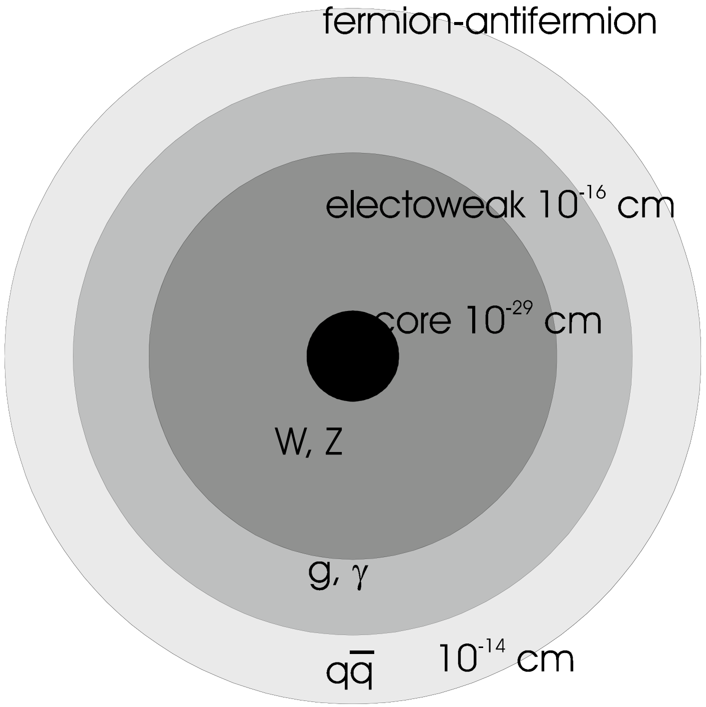
-- IceCube will be large improvement

- Bigger effective area

-- IceCube will push limit towards

~10^{-19} cm^{-2} s^{-1} sr^{-1}

GUT Magnetic Monopole



- grand unification core
  - virtual X-bosons (10^{-29} cm)
- electroweak unification
  - virtual W, Z, γ, g (10^{-16} cm)
- confinement region
  - g, γ (10^{-13} cm)
- condensate
  - fermion-antifermion pairs ($r \sim m_f^{-1}$)