Title: Particle Physics with IceCube-DeepCore and Beyond

Date: Apr 24, 2012 01:00 PM

URL: http://pirsa.org/12040078

Abstract: The IceCube neutrino observatory is the world's largest high-energy neutrino telescope, utilizing the deep Antarctic ice as the Cherenkov detector medium. In December 2010 the last of the observatory's 86 strings of optical detectors was deployed, completing the approximate cubic-kilometer array.   With the addition of a low-energy extension, called DeepCore, the observatory has very high neutrino detection efficiency for energies ranging from ~10 GeV to a few EeV. The low-energy threshold establishes the first steps towards precision neutrino measurements in the Antarctic. Discussed will be early results from this emerging particle physics program as well as initial expectations from studies of potential future detector upgrades towards creating a multi-megaton neutrino detector with O(10 MeV) energy threshold.


Chooz/SNO/SuperK
Non-accelerator based

ICECUBE

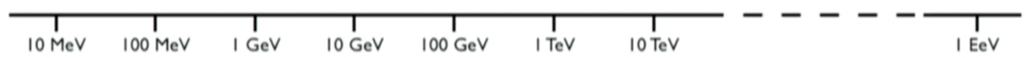
Particle physics with IceCube-DeepCore and beyond

Darren R. Grant
Department of Physics, Centre for Particle Physics
University of Alberta

Particle Physics Seminar - Perimeter Institute
Waterloo ON Canada

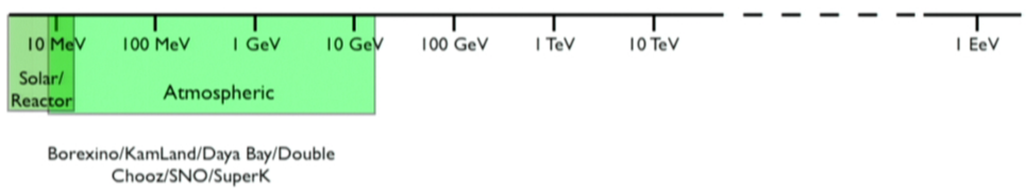
UNIVERSITY OF ALBERTA

The Neutrino Detector Spectrum



** boxes select primary detector physics energy regimes and are not absolute limits*

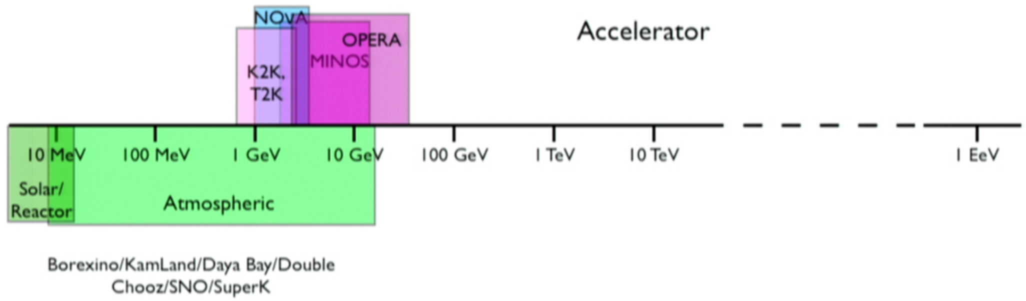
The Neutrino Detector Spectrum



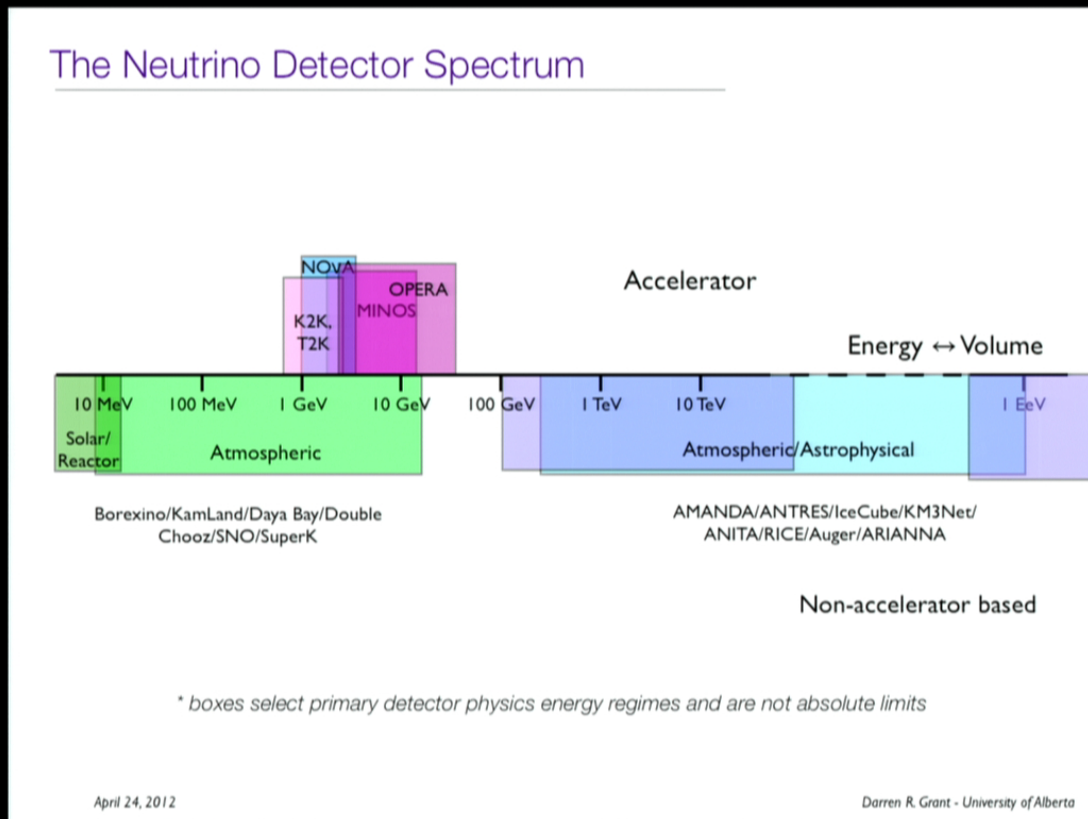
Non-accelerator based

* boxes select primary detector physics energy regimes and are not absolute limits

The Neutrino Detector Spectrum

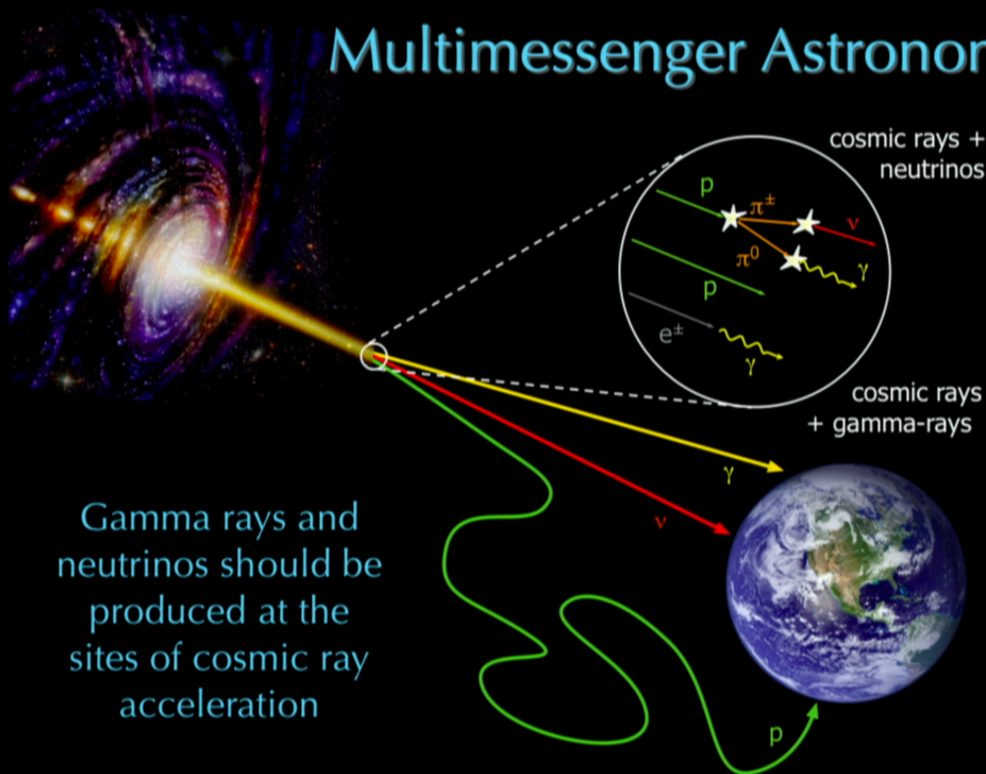


* boxes select primary detector physics energy regimes and are not absolute limits

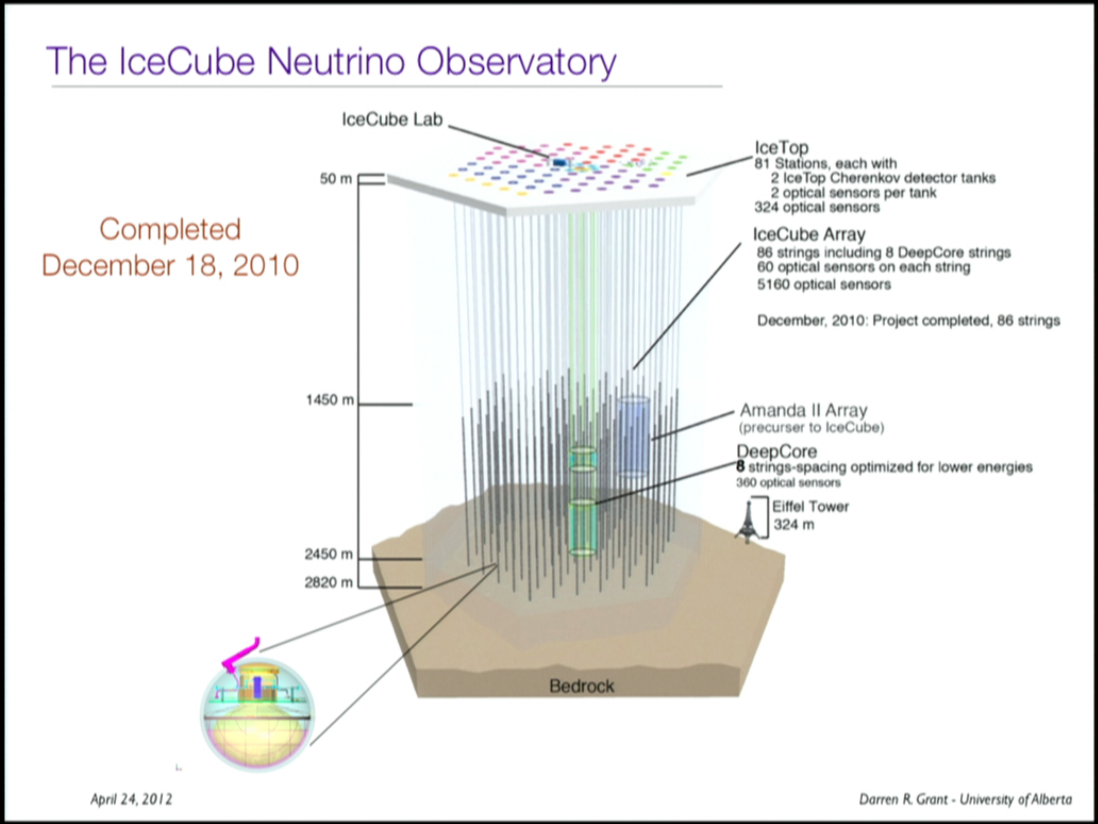


The Neutrino Detector Spectrum
NOvA
OPERA
MINOS
K2K,
T2K
Accelerator
Energy ↔ Volume
10 MeV
100 MeV
1 GeV
10 GeV
100 GeV
1 TeV
10 TeV
1 EeV
Solar/
Reactor
Atmospheric
Atmospheric/Astrophysical
Borexino/KamLand/Daya Bay/Double
Chooz/SNO/SuperK
AMANDA/ANTRES/IceCube/KM3Net/
ANITA/RICE/Auger/ARIANNA
Non-accelerator based
* boxes select primary detector physics energy regimes and are not absolute limits
April 24, 2012
Darren R. Grant - University of Alberta

Multimessenger Astronomy



Gamma rays and neutrinos should be produced at the sites of cosmic ray acceleration

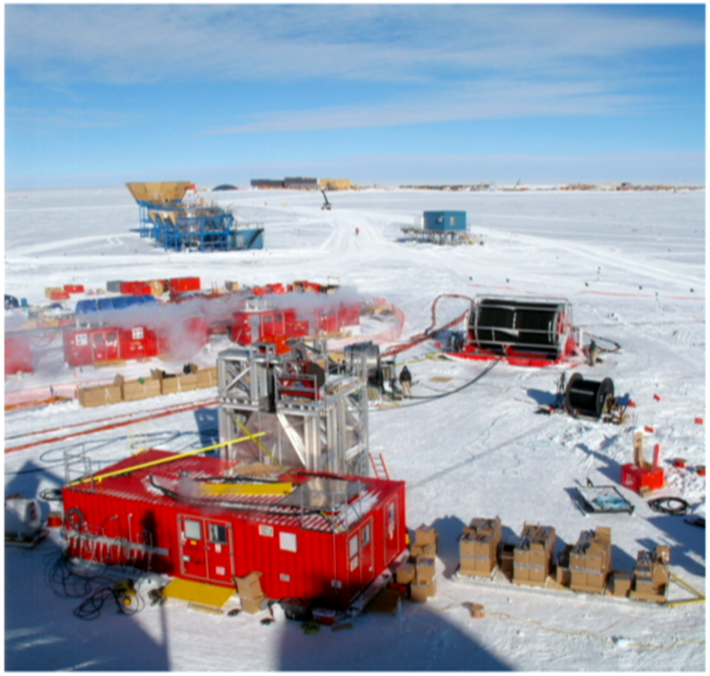

The IceCube Neutrino Observatory
Completed
December 18, 2010
IceCube Lab
50 m
1450 m
2450 m
2820 m
IceTop
81 Stations, each with
2 IceTop Cherenkov detector tanks
2 optical sensors per tank
324 optical sensors
IceCube Array
86 strings including 8 DeepCore strings
60 optical sensors on each string
5160 optical sensors
December, 2010: Project completed, 86 strings
Amanda II Array
(precurser to IceCube)
DeepCore
8 strings-spacing optimized for lower energies
360 optical sensors
Eiffel Tower
324 m
Bedrock
April 24, 2012
Darren R. Grant - University of Alberta

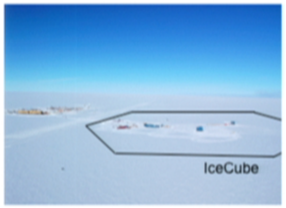
The IceCube Collaboration

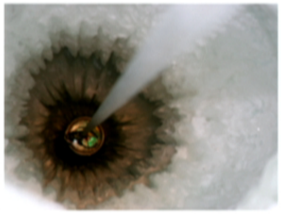
38 institutions - 4 continents - ~220 Physicists

April 24, 2012

Darren R. Grant - University of Alberta

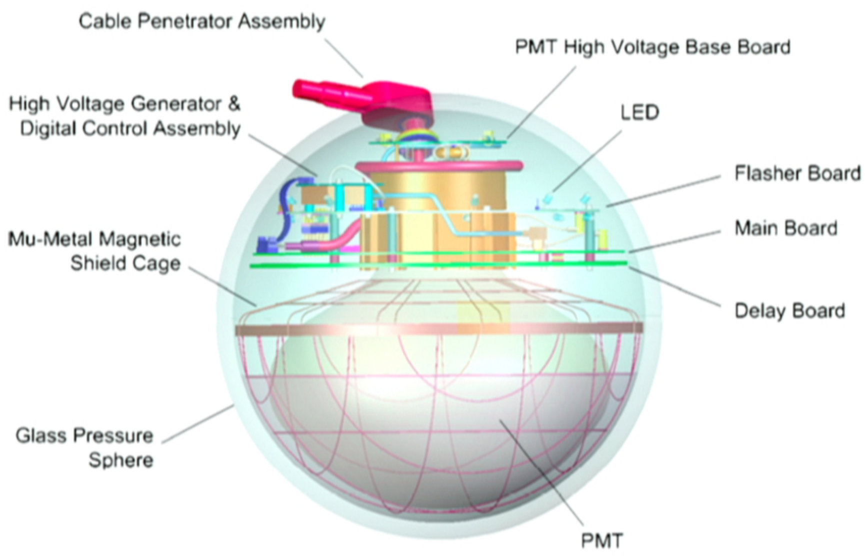






Amundsen-Scott South Pole Station, Antarctica

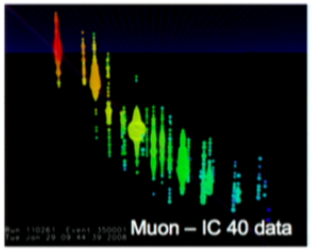
The Digital Optical Module (DOM)



April 24, 2012

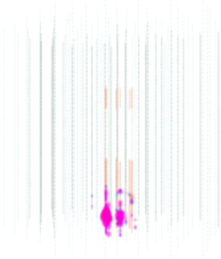
Darren R. Grant - University of Alberta

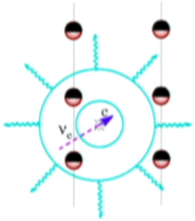
Neutrino Telescopes - Principle of Detection



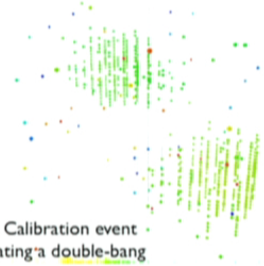
Tracks:
- through-going muons
- pointing resolution ~1°

Candidate IC79 Cascade



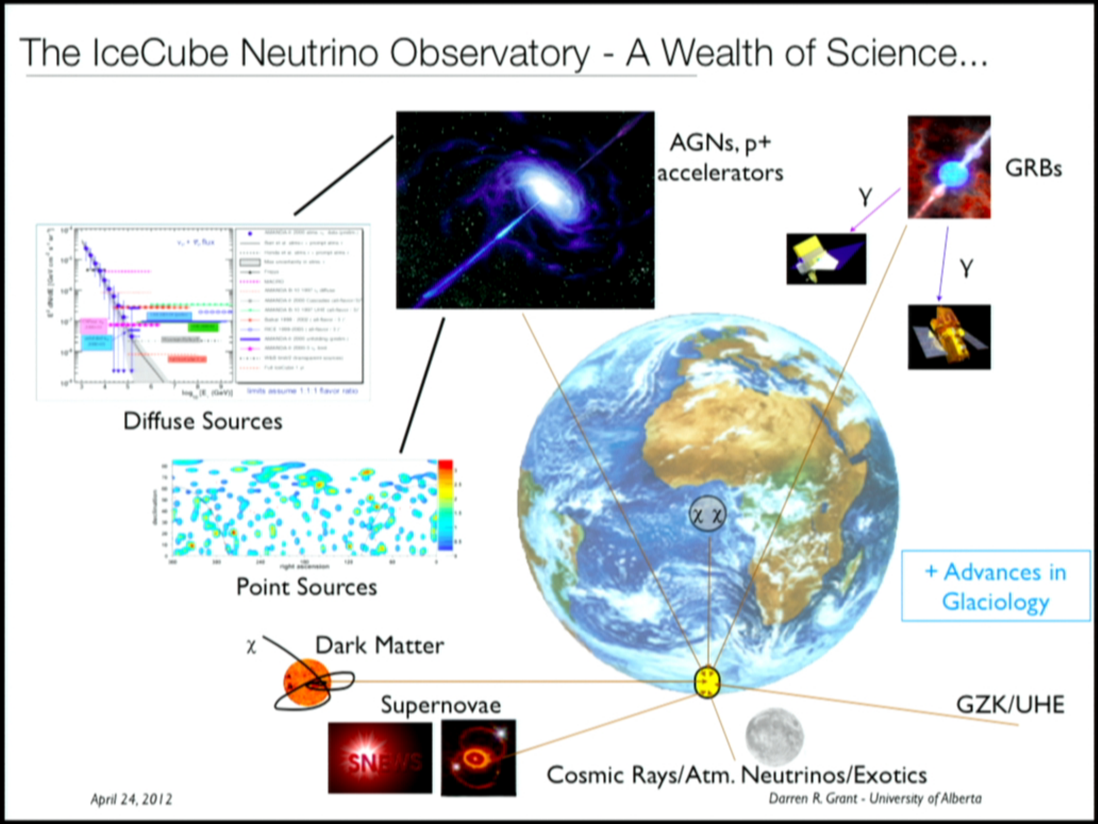


Cascades:
- Neutral current for all flavors
- Charged current for ν_e and low-E ν_τ
- Energy resolution ~10% in log(E)

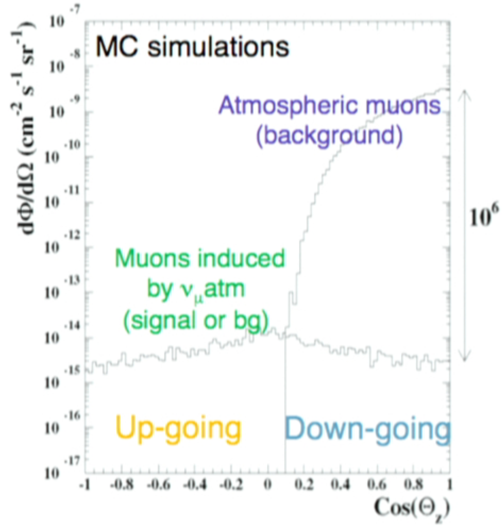


LED Calibration event simulating a double-bang

Composites:
- Starting tracks
- high-E ν_τ (Double Bangs)
- Good directional and energy resolution


The IceCube Neutrino Observatory - A Wealth of Science...
AGNs, p+ accelerators
GRBs
γ
γ
Diffuse Sources
Point Sources
+ Advances in Glaciology
χ
Dark Matter
χ χ
Supernovae
SNEWS
GZK/UHE
Cosmic Rays/Atm. Neutrinos/Exotics
April 24, 2012
Darren R. Grant - University of Alberta

Signal and Background considerations



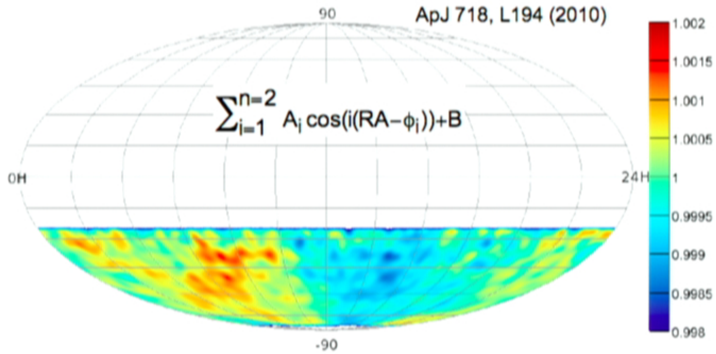
April 24, 2012

Darren R. Grant - University of Alberta

Cosmic ray anisotropy

An analysis of in-ice cosmic ray muons

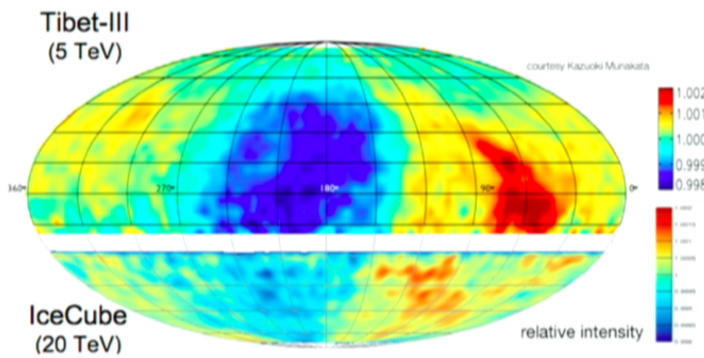
- 22-string IceCube detector had 4.3e9 well reconstructed muon tracks from cosmic rays.
- Mean angular resolution of 3 degrees and energy of 20 TeV
- Fit the relative intensity of the first and second harmonic.



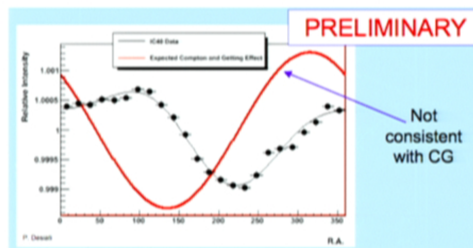
April 24, 2012

Darren R. Grant - University of Alberta

Cosmic ray anisotropy



- A first measurement of the southern hemisphere cosmic ray anisotropy
- Consistency found with previous northern hemisphere measurements
- Cause remains unknown; not consistent with Compton-Getting (relative motion about the Galactic Centre)



April 24, 2012

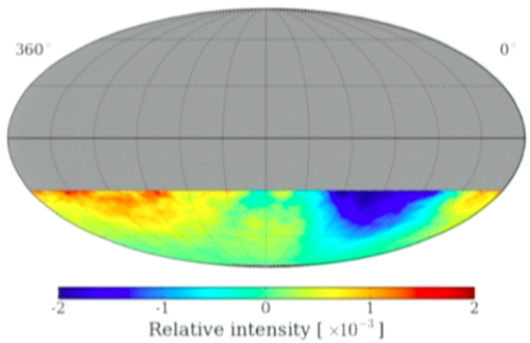
Darren R. Grant - University of Alberta

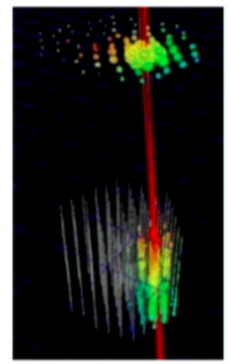
Cosmic ray anisotropies

[S. Benzvi, M. Santander, S. Toscano, S. Westerhoff et al., ICRC 2011]
[R. Abbasi, P. Desiati et al., ICRC 2001]

First significant observation of the anisotropy at 400 TeV in the southern sky.

IT59 + IT79
~ 10^8 events, ~ 400 TeV





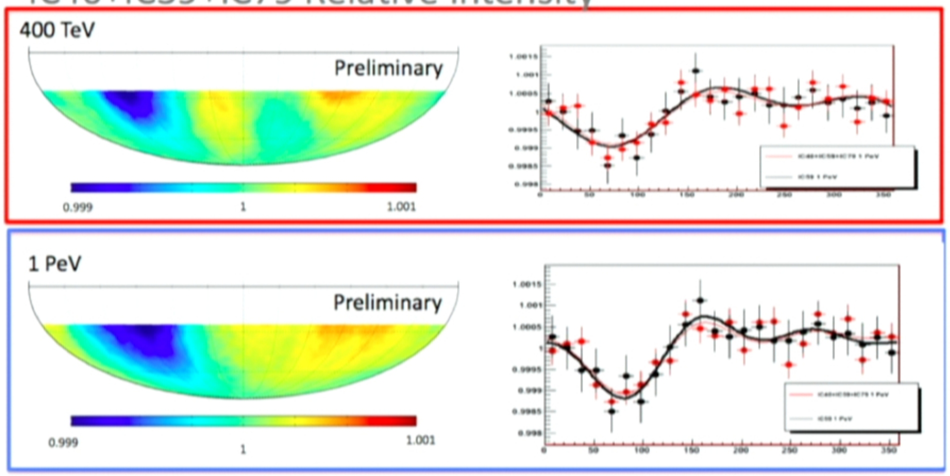
April 24, 2012

Darren R. Grant - University of Alberta

Cosmic ray anisotropies

- Anisotropy observed at 400 TeV persists significantly at 1 PeV
- The origin of the anisotropy is unknown:
  - not consistent with the Compton-Getting assuming the galactic cosmic rays closer to the knee.
  - interstellar magnetic field
  - reveals a new feature of the galactic cosmic ray distribution that must be put into the theories

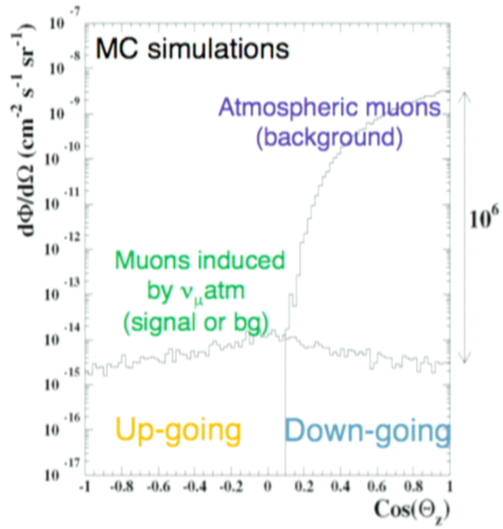
IC40+IC59+IC79 Relative Intensity



April 24, 2012

Darren R. Grant - University of Alberta

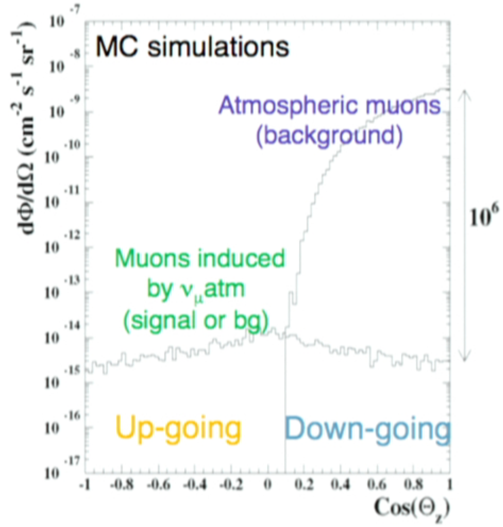
Background considerations



April 24, 2012

Darren R. Grant - University of Alberta

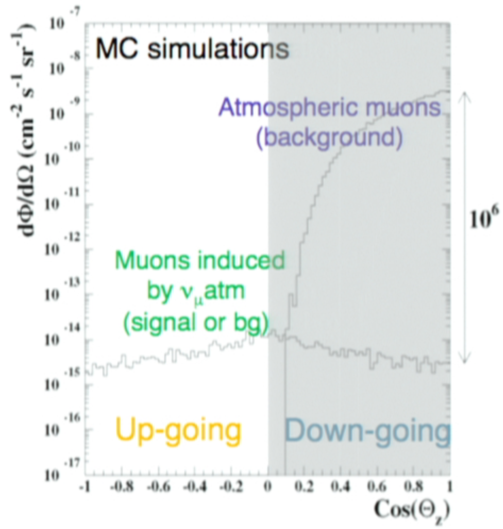
Background considerations



April 24, 2012

Darren R. Grant - University of Alberta

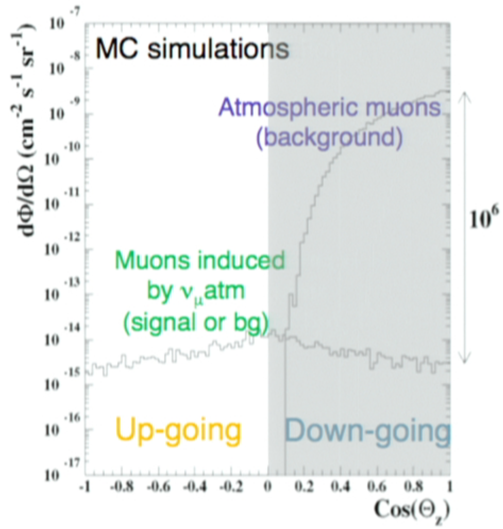
Background considerations

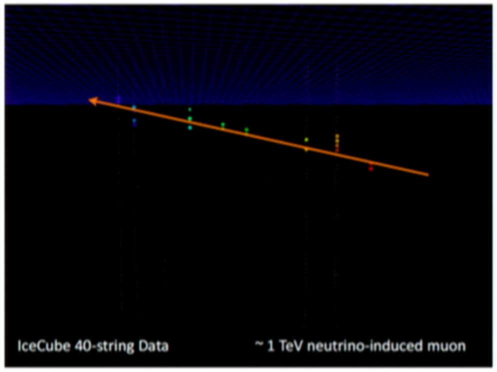


April 24, 2012

Darren R. Grant - University of Alberta

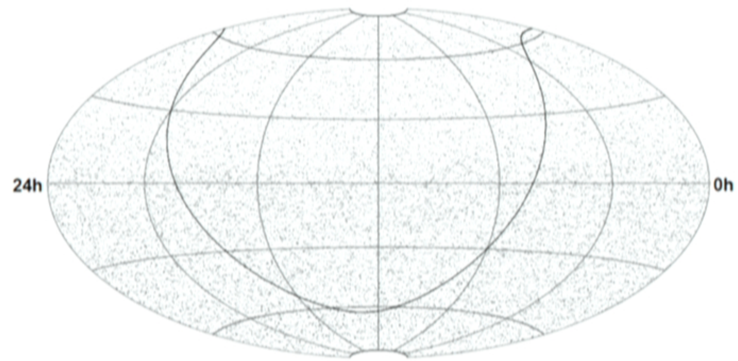
Background considerations





Identify and reconstruct your best candidates (IceCube 40-string Detector)

- Operated for 375.5 days
  - Northern sky - 14139 events
  - Southern sky - 23151 events
  - Search for clustering of events in direction and energy.

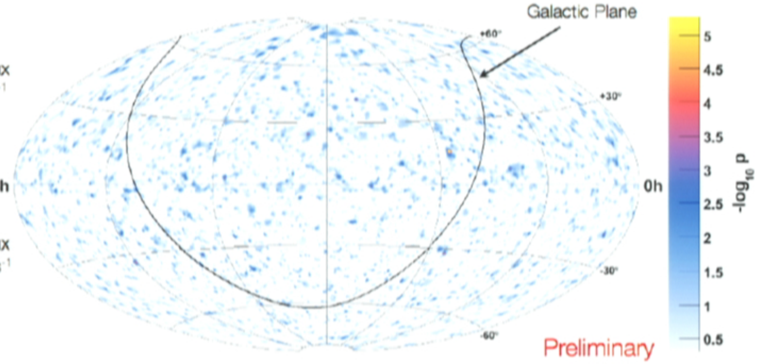


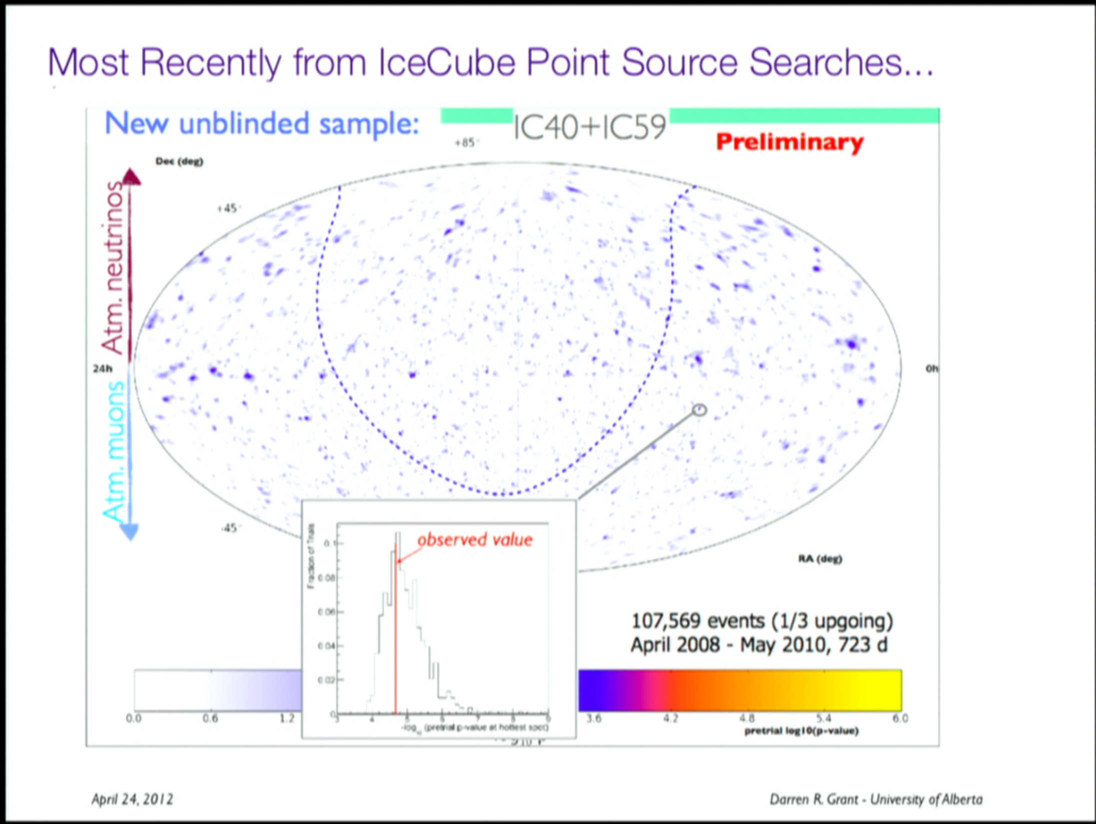
Perform the Point Source Search (IceCube 40-strings)

- Search for an excess of astrophysical neutrinos from a common direction over the atmospheric neutrino background
- All sky search with >37K neutrino candidates (~23k from southern hemisphere atmospheric neutrinos
- Hottest spot in the 40-string data set was not statistically significant (96% of scrambled sky maps have higher significance)

Northern Sky Limit for E^{-2} flux
$\Phi^{90} = 2\text{-}20 \times 10^{-12}$ TeV cm^{-2} s^{-1}
TeV-PeV sensitivity

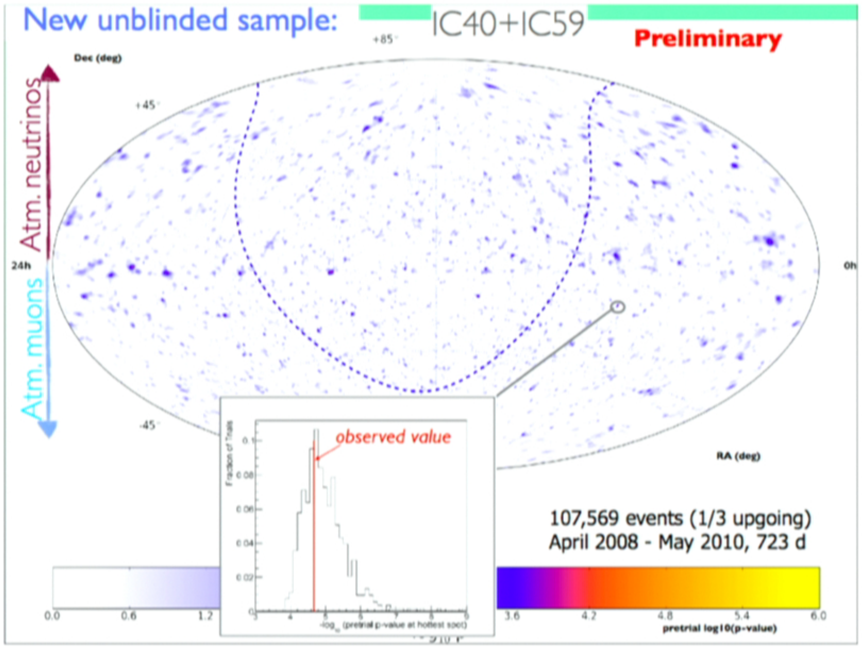
Southern Sky Limit for E^{-2} flux
$\Phi^{90} = 3\text{-}700 \times 10^{-12}$ TeV cm^{-2} s^{-1}
1 PeV < sensitivity





Most Recently from IceCube Point Source Searches...
New unblinded sample:
IC40+IC59
Preliminary
Dec (deg)
Atm. neutrinos
Atm. muons
24h
0h
+85
+45
-45
RA (deg)
observed value
107,569 events (1/3 upgoing)
April 2008 - May 2010, 723 d
pretrial log10(p-value)
April 24, 2012
Darren R. Grant - University of Alberta

Most Recently from IceCube Point Source Searches...



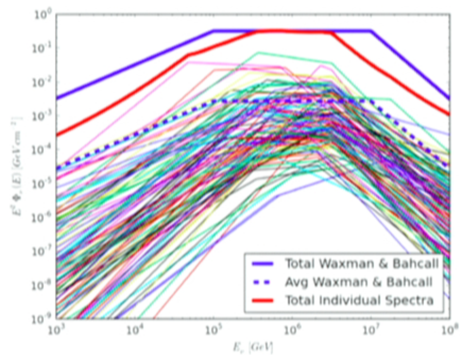
IceCube Searches for Gamma Ray Burst Neutrinos

- Search for events correlated in time and direction of observed GRBs.

- The small time/space window dramatically reduces backgrounds in the search

- In the IceCube 59-string dataset livetime there were 109 GRBs triggered by gamma ray observations (ie. Fermi) considering only those that would produce upward going events in the detector

- Each burst spectra is individually modeled and stacked

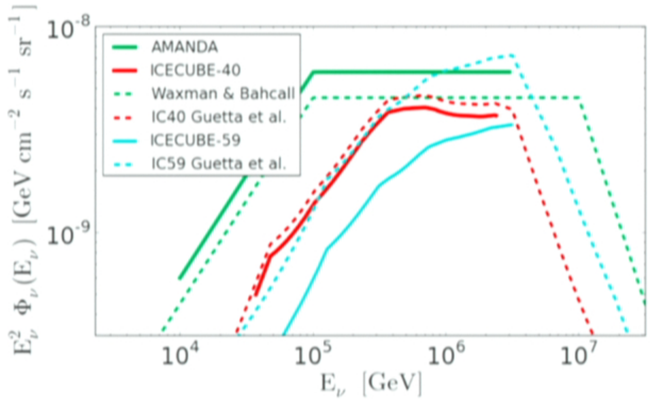


April 24, 2012

Darren R. Grant - University of Alberta

IceCube Searches for Gamma Ray Burst Neutrinos...sometimes a null result is a result!

- Search for events correlated in time and direction of observed GRBs.
- The small time/space window dramatically reduces backgrounds in the search
- In the IceCube 59-string dataset livetime there were 109 GRBs triggered by gamma ray observations (ie. Fermi) considering only those that would produce upward going events in the detector
- Each burst spectra is individually modeled and stacked....**No observed correlation!**



Long-standing GRB models are being stringently tested!

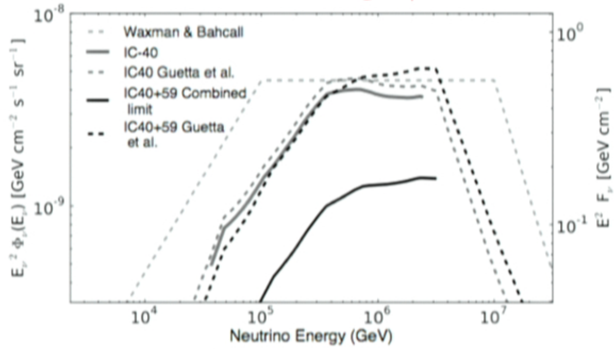
April 24, 2012

Darren R. Grant - University of Alberta

IceCube Searches for Gamma Ray Burst Neutrinos...sometimes a null result is a result!

- Search for events correlated in time and direction of observed GRBs.
- The small time/space window dramatically reduces backgrounds in the search
- In the IceCube 59-string dataset livetime there were 109 GRBs triggered by gamma ray observations (ie. Fermi) considering only those that would produce upward going events in the detector
- Each burst spectra is individually modeled and stacked....**No observed correlation!**

Nature 484, 351-354 (19 April 2012)



Updated for the IC40 + 59 datasets

Long-standing GRB models are being stringently tested!

April 24, 2012

Darren R. Grant - University of Alberta

IceCube Searches for Gamma Ray Burst Neutrinos...sometimes a null result is a result!

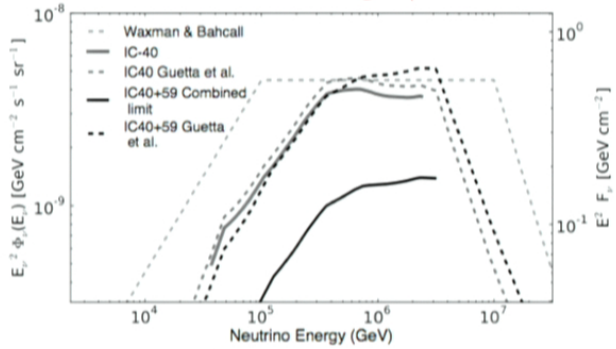
• Search for events correlated in time and direction of observed GRBs.

•The small time/space window dramatically reduces backgrounds in the search

• In the IceCube 59-string dataset livetime there were 109 GRBs triggered by gamma ray observations (ie. Fermi) considering only those that would produce upward going events in the detector

• Each burst spectra is individually modeled and stacked....**No observed correlation!**

Nature 484, 351-354 (19 April 2012)



Updated for the IC40 + 59 datasets

Long-standing GRB models are being stringently tested!

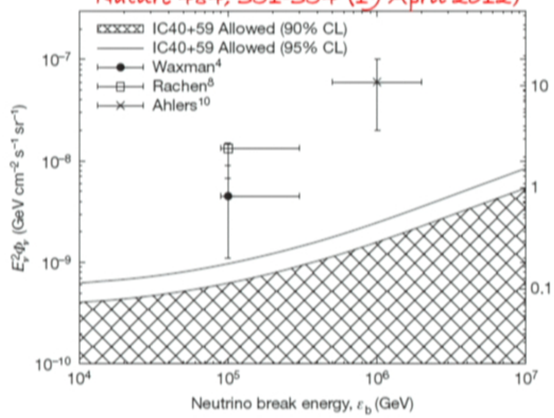
April 24, 2012

Darren R. Grant - University of Alberta

IceCube Searches for Gamma Ray Burst Neutrinos...sometimes a null result is a result!

- Search for events correlated in time and direction of observed GRBs.
- The small time/space window dramatically reduces backgrounds in the search
- In the IceCube 59-string dataset livetime there were 109 GRBs triggered by gamma ray observations (ie. Fermi) considering only those that would produce upward going events in the detector
- Each burst spectra is individually modeled and stacked....**No observed correlation!**

Nature 484, 351-354 (19 April 2012)

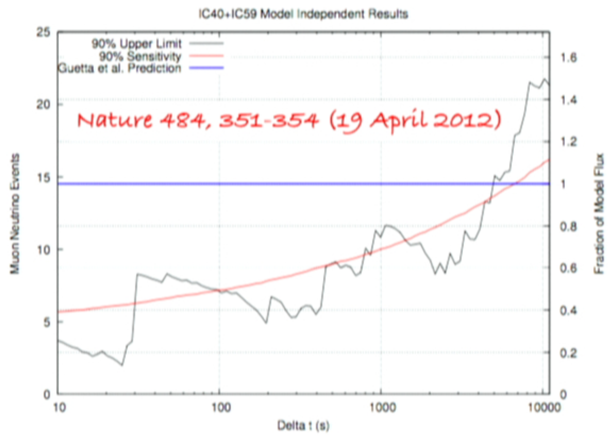


Long-standing GRB models are being stringently tested!

Darren R. Grant - University of Alberta

IceCube Searches for Gamma Ray Burst Neutrinos...Model Independent search

- High signal efficiency
- Unbinned weighting technique
- Wide variety of time scales for neutrino emission

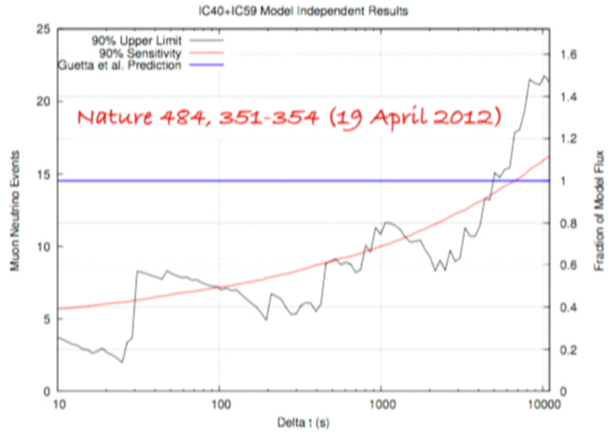


April 24, 2012

Darren R. Grant - University of Alberta

IceCube Searches for Gamma Ray Burst Neutrinos...Model Independent search

- High signal efficiency
- Unbinned weighting technique
- Wide variety of time scales for neutrino emission

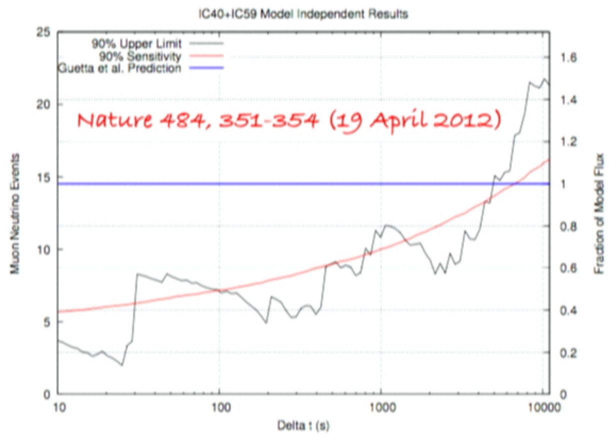


April 24, 2012

Darren R. Grant - University of Alberta

IceCube Searches for Gamma Ray Burst Neutrinos...Model Independent search

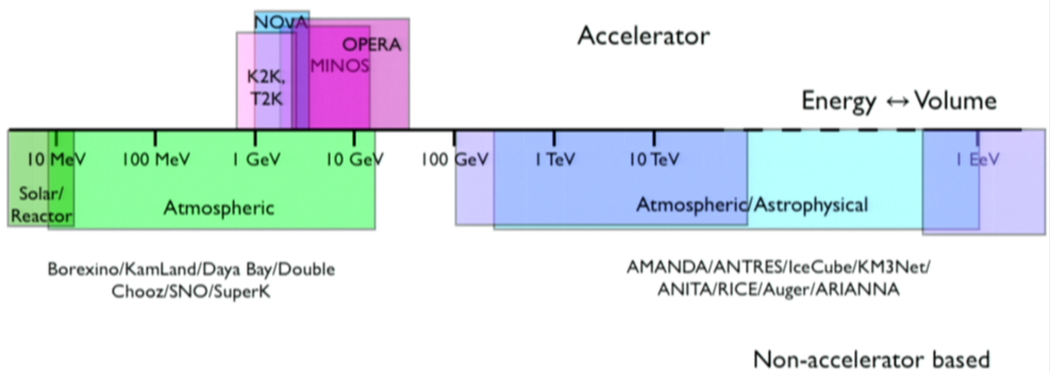
- High signal efficiency
- Unbinned weighting technique
- Wide variety of time scales for neutrino emission



April 24, 2012

Darren R. Grant - University of Alberta

The Neutrino Detector Spectrum

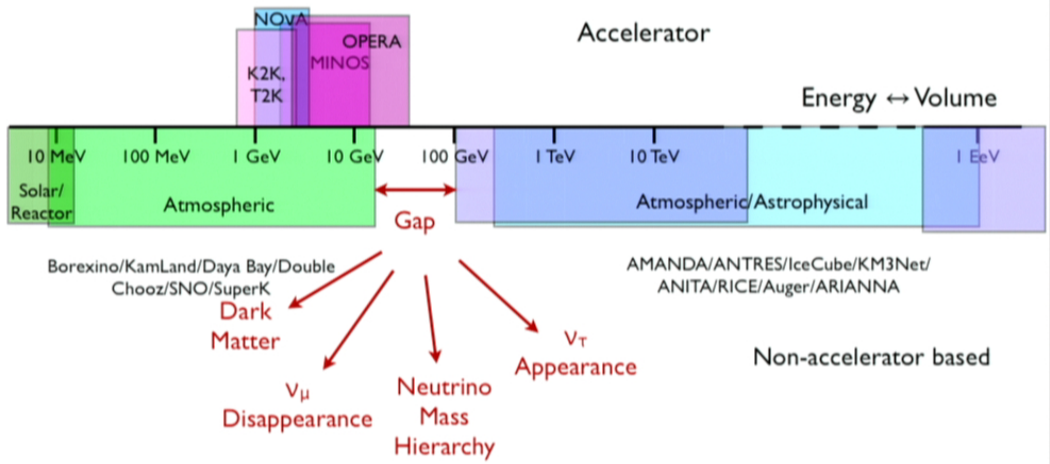


** boxes select primary detector physics energy regimes and are not absolute limits*

April 24, 2012

Darren R. Grant - University of Alberta

The Neutrino Detector Spectrum



* boxes select primary detector physics energy regimes and are not absolute limits

April 24, 2012

Darren R. Grant - University of Alberta

IceCube

IceCube

April 24, 2012

Darren R. Grant - University of Alberta

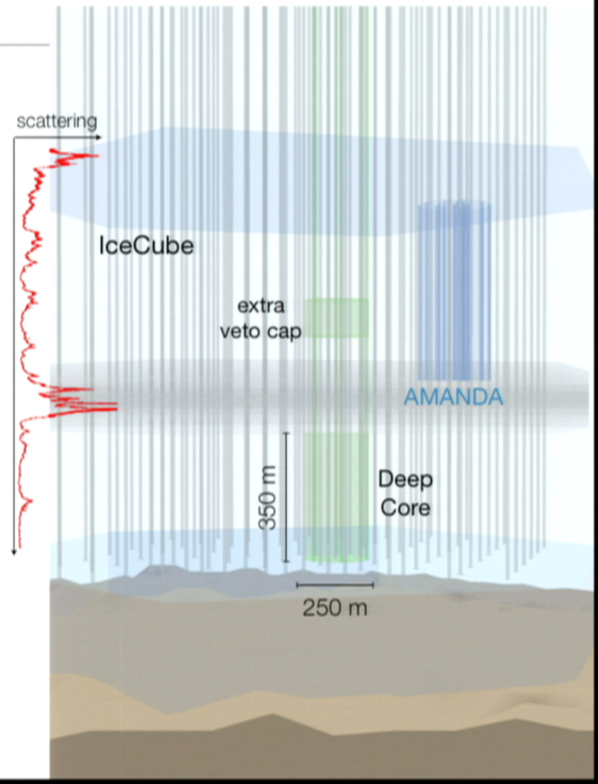
IceCube-DeepCore

IceCube DeepCore

Darren R. Grant - University of Alberta

DeepCore Design

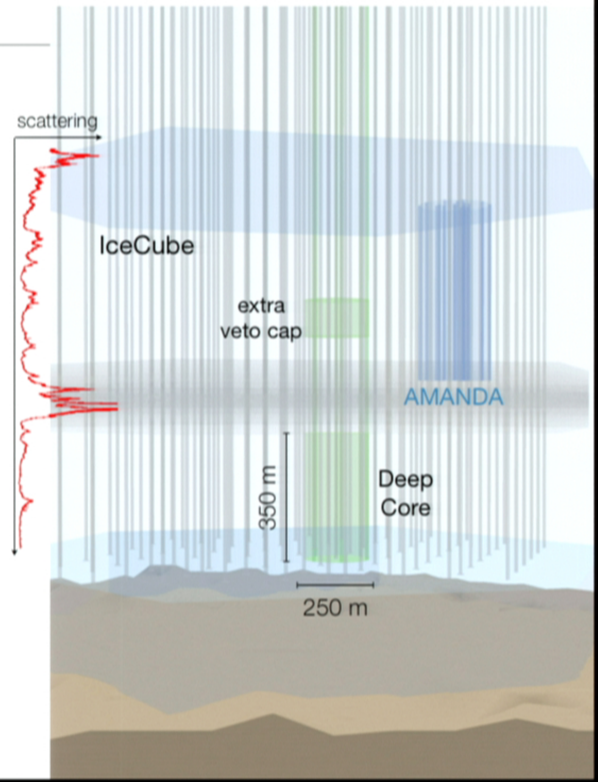
- Eight special strings plus seven nearest standard IceCube strings
- 72 m inter-string horizontal spacing (six with 42 m spacing)
- 7 m DOM vertical spacing
- ~35% higher Q.E. PMTs
- ~5x higher effective photocathode density
- Deployed mainly in the clearest ice, below 2100 m
- λ_{eff} > ~50 m
- Result: 30 MTon detector with ~10 GeV threshold, will collect O(100k) physics quality atmospheric ν/yr



April 24, 2012

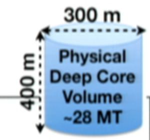
DeepCore Design

- Eight special strings plus seven nearest standard IceCube strings
- 72 m inter-string horizontal spacing (six with 42 m spacing)
- 7 m DOM vertical spacing
- ~35% higher Q.E. PMTs
- ~5x higher effective photocathode density
- Deployed mainly in the clearest ice, below 2100 m
- λ_{eff} > ~50 m
- Result: 30 MTon detector with ~10 GeV threshold, will collect O(100k) physics quality atmospheric ν/yr



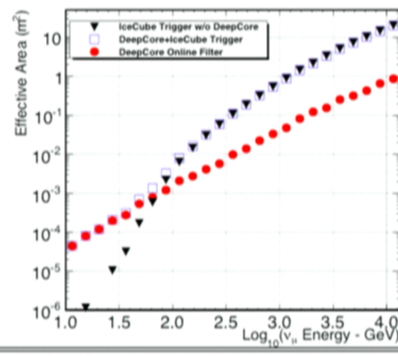
April 24, 2012

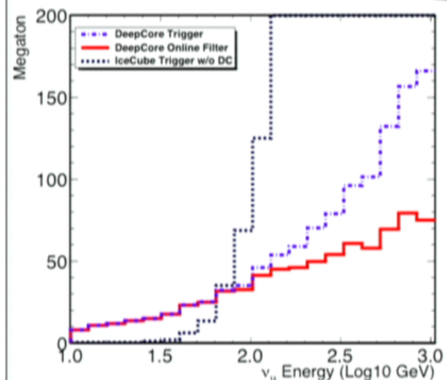
DeepCore Effective Area and Volume



Effective area for ν_μ at trigger level

Reconstruction efficiencies not included yet – relative effect likely to increase





Effective volume for muons from ν_μ interacting in Deep Core

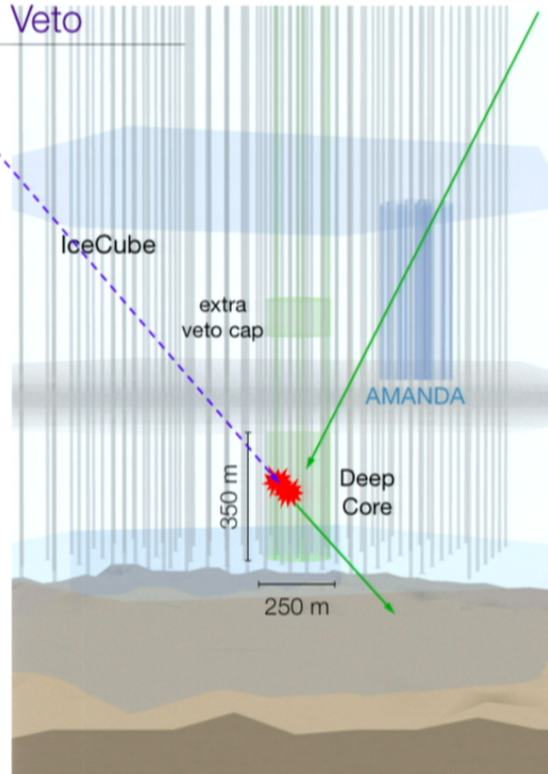
NB: full analysis efficiency *not* included yet

Trigger: ≥3 DOMs hit in 2.5μs;
Online Veto: No hits consistent with muons outside DeepCore volume

April 24, 2012 Darren R. Grant - University of Alberta

DeepCore Atmospheric Muon Veto

- Overburden of 2.1 km water-equivalent is substantial, but not as large as at deep underground labs
- However, top and outer layers of IceCube provide an active veto shield for DeepCore
- ~40 horizontal layers of modules above; 3 rings of strings on all sides
- Effective μ-free depth much greater
- Can use to distinguish atmospheric μ from atmospheric or cosmological ν
- Atm. μ/ν trigger ratio is ~10^6
- Vetoing algorithms expected to reach at least 10^6 level of background rejection

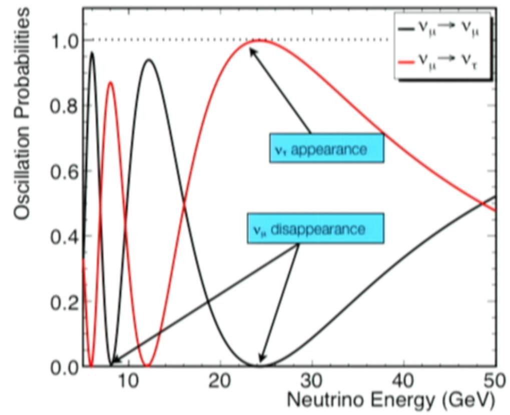


April 24, 2012

First from DeepCore - Observation of Atmospheric Cascades

- Disappearing ν_μ should appear in IceCube as ν_τ cascades
  - Effectively identical to neutral current or ν_e CC events
  - Could observe ν_τ appearance as a distortion of the energy spectrum, if cascades can be separated from muon background

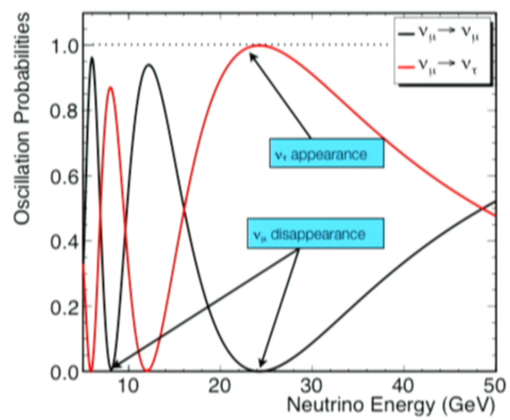
Mena, Mocioiu & Razzaque, *Phys. Rev.* D**78**, 093003 (2008)



First from DeepCore - Observation of Atmospheric Cascades

- Disappearing ν_μ should appear in IceCube as ν_τ cascades
  - Effectively identical to neutral current or ν_e CC events
  - Could observe ν_τ appearance as a distortion of the energy spectrum, if cascades can be separated from muon background

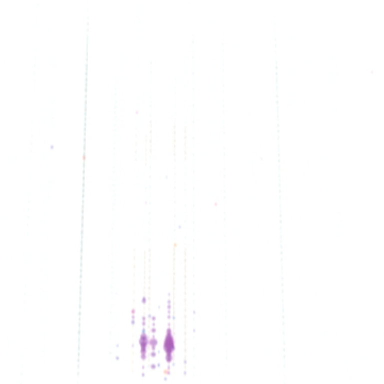
Mena, Mocioiu & Razzaque, *Phys. Rev.* D**78**, 093003 (2008)



First from DeepCore - Observation of Atmospheric Cascades

- Disappearing ν_μ should appear in IceCube as ν_τ cascades
  - Effectively identical to neutral current or ν_e CC events
  - Could observe ν_τ appearance as a distortion of the energy spectrum, if cascades can be separated from muon background
- First results from DeepCore are neutrino cascade events
  - The dominant background now is CC ν_μ events with short tracks

Preliminary



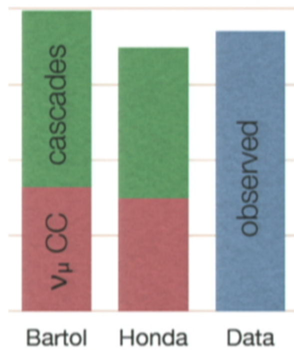
Candidate cascade event
Run 116020, Event 20788565, 2010/06/06

First from DeepCore - Observation of Atmospheric Cascades

- A substantial sample of cascades has been obtained, final data set ~60% cascade events
  - Events have a mean energy ~200 GeV (not sensitive to oscillations with these first cuts)
  - Atmospheric muon background is being assessed (expected to be small)
- The potential to discriminate between atmospheric neutrino models exists and thus measuring air shower physics

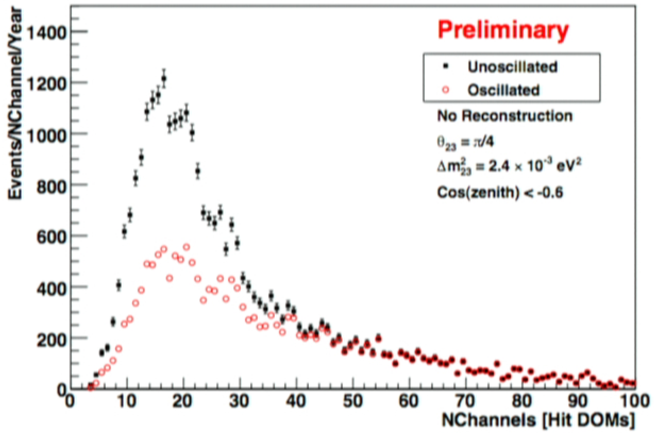
preliminary!

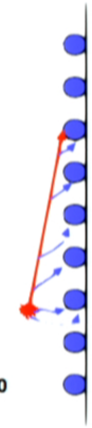
	Cascades	CC ν_μ	Total
Bartol	650	454	1104
Honda	551	415	966
Data			1029



Muon-neutrino disappearance

- Full detector simulation of signal
  - 3-flavor oscillations, PREM
  - 1 year DC
  - No BG
  - cos(θ)<-0.6



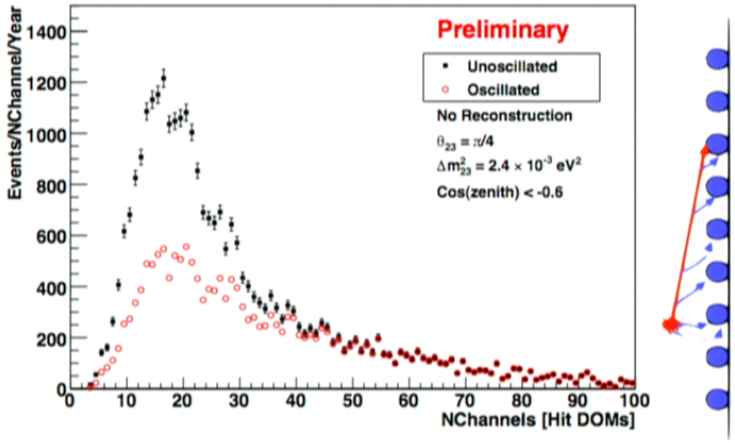


- Number of hit channels used as simple energy estimator

Darren R. Grant - University of Alberta

Muon-neutrino disappearance

- Full detector simulation of signal
  - 3-flavor oscillations, PREM
  - 1 year DC
  - No BG
  - cos(θ)<-0.6

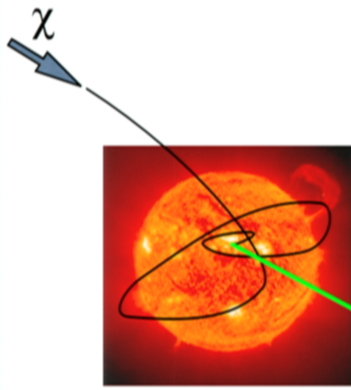


- Number of hit channels used as simple energy estimator

April 24, 2012

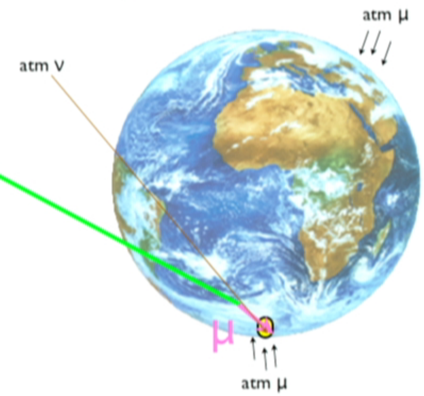
Darren R. Grant - University of Alberta

Indirect Dark Matter Searches



- Search for neutrinos produced in the annihilation of dark matter collected in massive astrophysical objects (Sun, centre of Earth...)
- Resultant neutrino energies of order GeV - TeV.

ν_μ



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

Silk, Olive and Srednicki, '85
Gaisser, Steigman & Tilav, '86
Freese, '86

Krauss, Srednicki & Wilczek, '86
Gaisser, Steigman & Tilav, '86

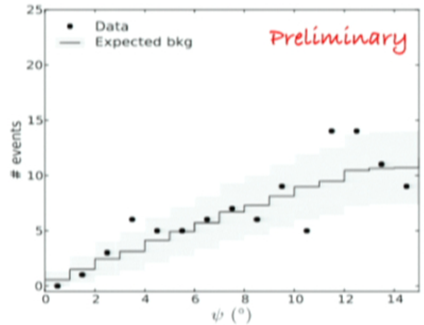
April 24, 2012

Darren R. Grant - University of Alberta

Indirect Dark Matter Searches

Solar WIMP search

- We utilize data when the Sun is below the horizon (March - September), resulting in near-horizontal muon tracks.
    - AMANDA-II (2001 - 2006)
    - IceCube 22 and 40-strings (2007-2009)
    - Total exposure 1065 days.
- Several levels of filtering are applied to remove atmospheric muon backgrounds.
- Signal selection efficiency order of 20%, dependent on the neutrino energy.
- Angular resolution:
    - AMANDA (<500 GeV) 4 - 5 degrees
    - IceCube-22 (>500 GeV) 3 degrees
- Examine angular distribution Ψ for Sun and muon track.

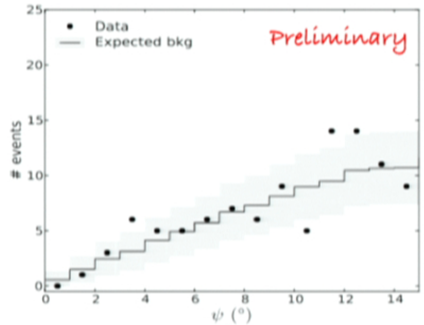


Observed flux in live days is consistent with background expectations.

Indirect Dark Matter Searches

Solar WIMP search

- We utilize data when the Sun is below the horizon (March - September), resulting in near-horizontal muon tracks.
    - AMANDA-II (2001 - 2006)
    - IceCube 22 and 40-strings (2007-2009)
    - Total exposure 1065 days.
- Several levels of filtering are applied to remove atmospheric muon backgrounds.
- Signal selection efficiency order of 20%, dependent on the neutrino energy.
- Angular resolution:
    - AMANDA (<500 GeV) 4 - 5 degrees
    - IceCube-22 (>500 GeV) 3 degrees
- Examine angular distribution Ψ for Sun and muon track.

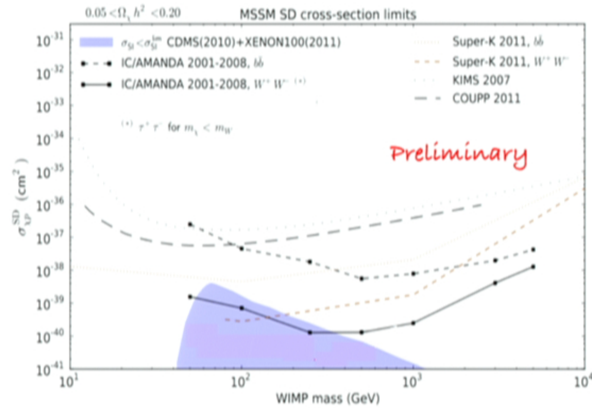


Observed flux in live days is consistent with background expectations.

Indirect Dark Matter Searches

Solar WIMP search

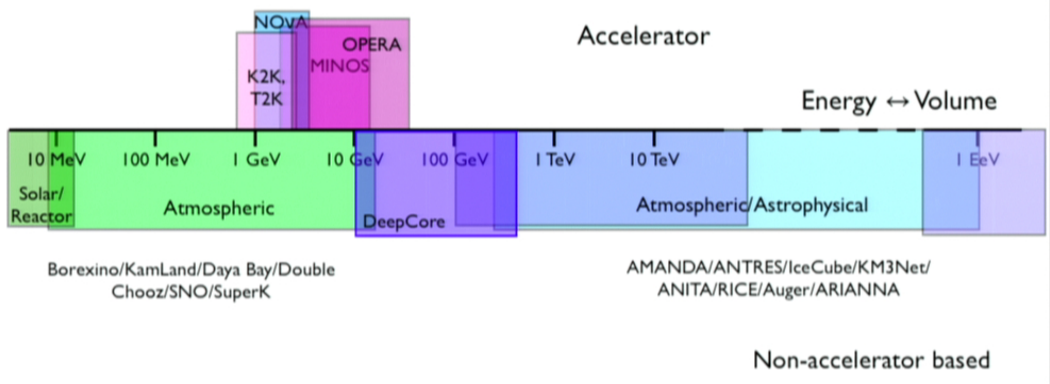
- Solar WIMP searches probe SD scattering cross section
  - SI cross section constrained well by direct search experiments
- Requires models of solar dark matter population distributions, annihilation modes



April 24, 2012

Darren R. Grant - University of Alberta

The Neutrino Detector Spectrum



** boxes select primary detector physics energy regimes and are not absolute limits*

April 24, 2012

Darren R. Grant - University of Alberta

IceCube-DeepCore

IceCube-DeepCore-PINGU

IceCube DeepCore PINGU/MICA

April 24, 2012

Darren R. Grant - University of Alberta

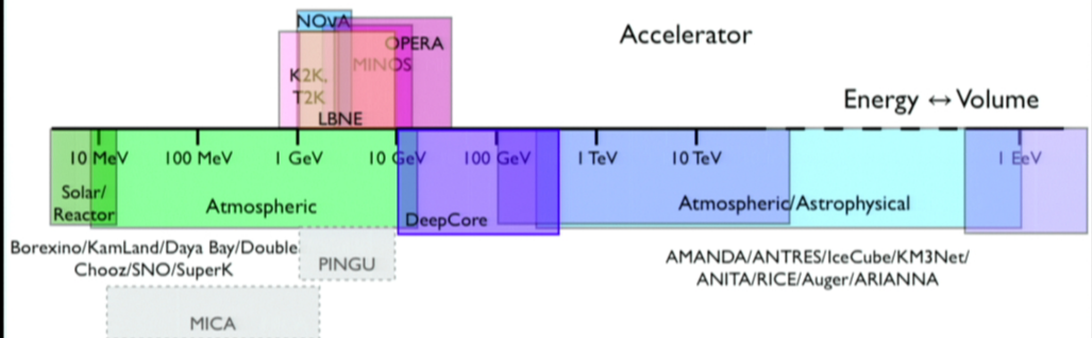
IceCube-DeepCore-PINGU

April 24, 2012

Darren R. Grant - University of Alberta

PINGU/MICA

(Precision IceCube Next Generation Upgrade/Multimegaton Ice Cherenkov Array)



~70 active members in feasibility studies:

- IceCube, KM3Net, Several neutrino experiments
- Photon detector developers
- Theorists

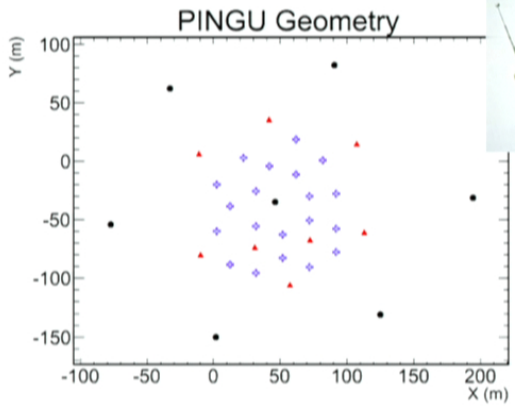
PINGU - Possible detector configurations

- First stage ("PINGU")
- Add ~20 in-fill strings to DeepCore to extend energy reach to ~1 GeV
    - improves WIMP search, neutrino oscillation measurements, other low energy physics
    - test bed for physics signals addressed by next stage
- Use mostly standard IceCube technology
- Include some new photon detection technology as R&D for next step

- Second stage ("MICA")
- Using new photon detection technology, build detector that can reconstruct Cherenkov rings for events well below 1 GeV
    - proton decay, supernova neutrinos, PINGU topics
- Comparable in scope (budget/strings) to IceCube, but in a much smaller volume

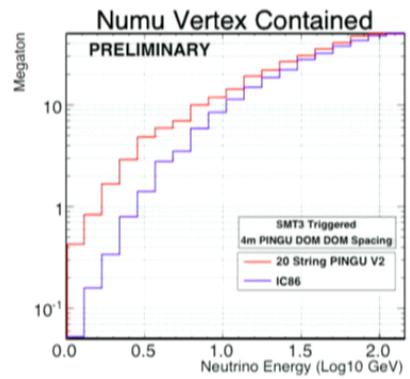
PINGU: Possible Geometry

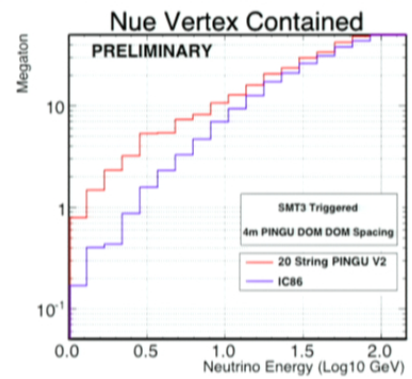
- Could continue to fill in the DeepCore volume
  - E.g., an additional 20 strings (~1200 DOMs) in the 30 MTon DeepCore volume
  - Could reach O(GeV) threshold in inner 10 MTon volume



- Price tag would likely be around $25M

PINGU: Effective Volumes

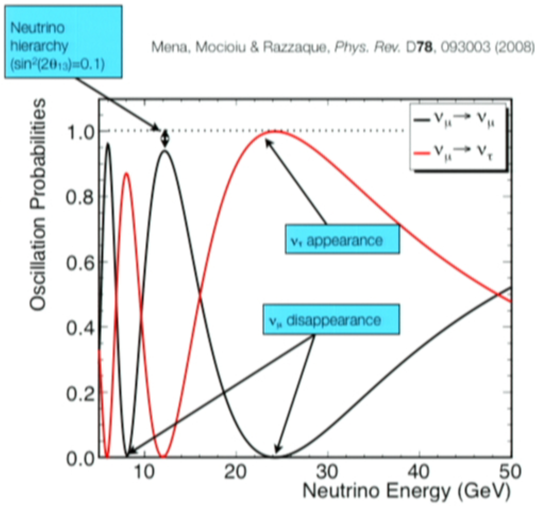




- Increased effective volume for energies below ~15 GeV
- Nearly and order of magnitude increase at 1 GeV (100s of kTon)
- Expected improvement over DeepCore > 10x despite above does not yet include analysis efficiencies

PINGU Physics

- Probe lower mass WIMPs
- Gain sensitivity to second oscillation peak/trough
  - will help pin down $(\Delta m_{23})^2$
  - enhanced sensitivity to neutrino mass hierarchy
- Gain increased sensitivity to supernova neutrino bursts
  - Extension of current search for coherent increase in singles rate across entire detector volume
  - Only 2±1 core collapse SN/century in Milky Way
    - need to reach out to our neighboring galaxies
- Gain depends strongly on noise reduction via coincident photon detection (e.g., in neighbor DOMs)
- Begin initial in-situ studies of sensitivity to proton decay
- Extensive calibration program
- Pathfinder technological R&D for MICA



April 24, 2012

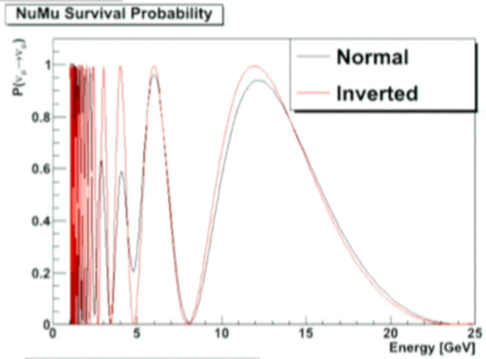
Darren R. Grant - University of Alberta

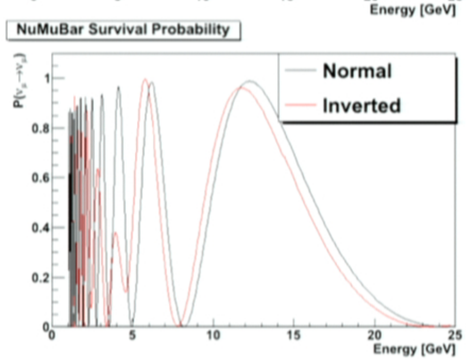
PINGU Neutrino Mass Hierarchy

Possible sensitivity to neutrino mass hierarchy via matter effects if θ_{13} is large

- Exploit asymmetries in the neutrino/anti-neutrino cross section, kinematics
- Effect is largest at energies below 5 GeV (for Earth diameter baseline)
- Control of systematics will be crucial

Recent results suggest that nature may be kind and provide a sufficiently large θ_{13}





April 24, 2012

Darren R. Grant - University of Alberta

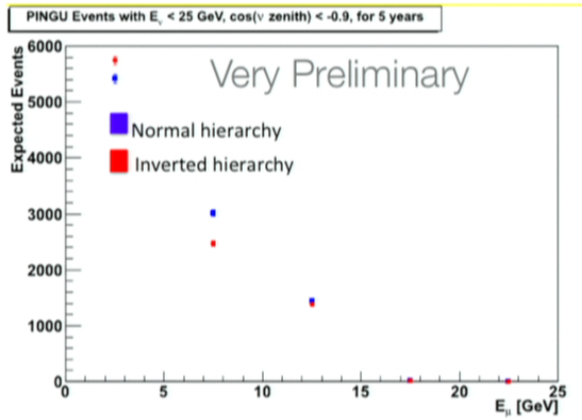
PINGU Neutrino Mass Hierarchy

Simulations of 20-string PINGU with 5 years of data and $\sin^2(2\theta_{13}) = 0.1$

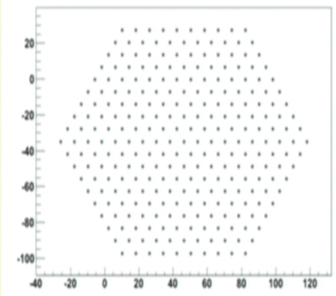
Assumes perfect background rejection, selecting events within 25 degrees of vertical

Up to 20% (10 sigma) effects in several energy/angular bins

The signal is potentially there **if** the systematics can be controlled



MICA Conceptual Detector



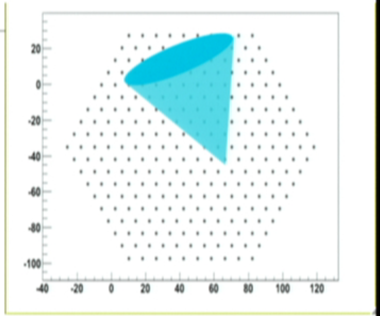
- O(few hundred) strings of “linear” detectors within DeepCore fiducial volume
- Goals: ~5 MTon scale with energy sensitivity of:
  - O(10 MeV) for bursts
  - O(100 MeV) for single events
- Physics extraction from Cherenkov ring imaging in the ice
- IceCube and DeepCore provide active veto
- No excavation necessary: detection medium is the support structure

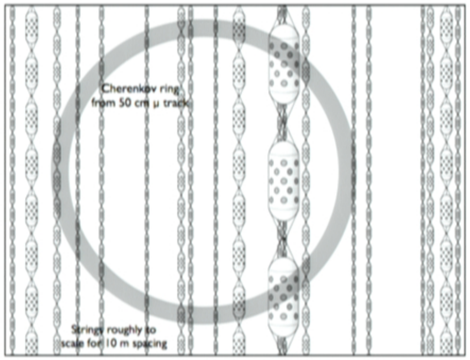
April 24, 2012

Darren R. Grant - University of Alberta

MICA Conceptual Detector

- O(few hundred) strings of "linear" detectors within DeepCore fiducial volume
- Goals: ~5 MTon scale with energy sensitivity of:
  - O(10 MeV) for bursts
  - O(100 MeV) for single events
- Physics extraction from Cherenkov ring imaging in the ice
- IceCube and DeepCore provide active veto
- No excavation necessary: detection medium is the support structure



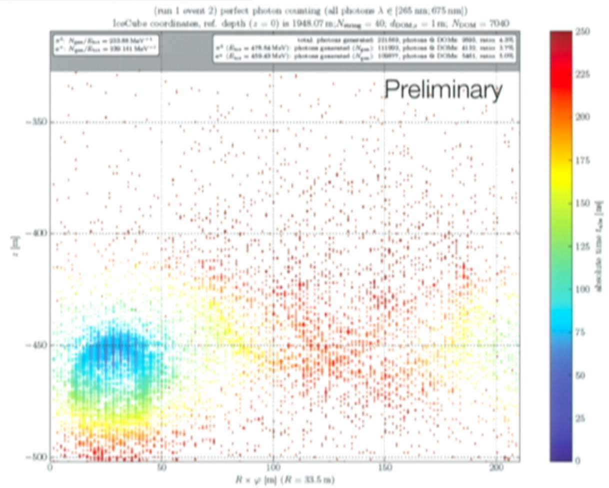


MICA Physics

- Proton decay
  - Studying sensitivity to p -> $\pi^0 + e^+$ channel
  - Requires energy threshold of ~100's of MeV
  - Background limited - depends on energy resolution, particle ring ID
- Supernova neutrinos
  - Need to reach well beyond our galaxy to get statistical sample of SN neutrinos
  - Background levels may be too high for a ~10 MeV threshold for individual events, but still allows for observation of bursts of events
- Plus improvements for WIMP, oscillation analyses over PINGU & DeepCore

MICA Proton Decay

- For fiducial volume of 1.5 MT (5×10^{35} protons) with 10 MeV energy threshold
- investigating $p \rightarrow \pi^0 + e^+$ channel as first step; clearly others to be studied
- Current predictions of SU(5) - 10^{36} yr sensitivity probe minimal realistic theory and SUSY SU(5) - 10^{36} yr would rule out MSSM defined for $M_{GUT} << M_{Planck}$
- Backgrounds will be key
- MC studies needed to understand:
  - energy resolution in a volume detector
  - possibilities for e/μ ID from Cherenkov rings
  - required photocathode coverage

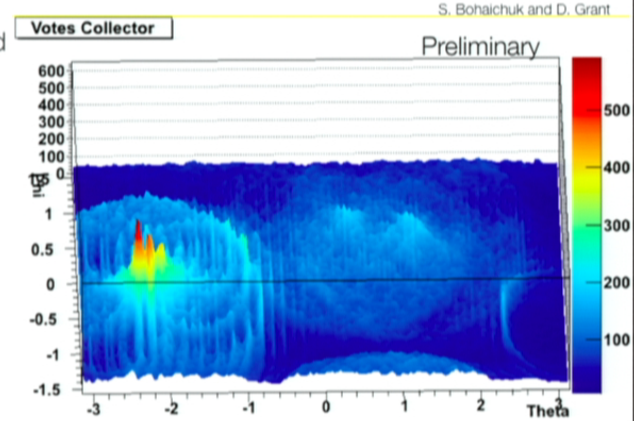


- First simulations underway. Above from very simple strawman geometry using DOMs
- ~240 photons per MeV deposited energy. 4-5% photons detected (assuming complete acceptance)

MICA Proton Decay

- For fiducial volume of 1.5 MT (5×10^{35} protons) with 10 MeV energy threshold
- investigating $p \rightarrow \pi^0 + e^+$ channel as first step; clearly others to be studied
- Current predictions of SU(5) - 10^{36} yr sensitivity probe minimal realistic theory and SUSY SU(5) - 10^{36} yr would rule out MSSM defined for $M_{GUT} << M_{Planck}$
- Backgrounds will be key
- MC studies needed to understand:
  - energy resolution in a volume detector
  - possibilities for e/μ ID from Cherenkov rings
  - required photocathode coverage

S. Bohaichuk and D. Grant



- First simulations underway. Above from very simple strawman geometry using DOMs
- ~240 photons per MeV deposited energy. 4-5% photons detected (assuming complete acceptance)

MICA SuperNovae

- With a large-scale detector, O(5MT), designed for proton decay, you essentially confer sensitivity out to O(10 Mpc).
  - Background constraints for proton decay are much larger than for supernova neutrinos (3000 photons per supernova neutrino with a 3% effective coverage = 100 photons/SN neutrino detected)
- Within the detector design ensure 10 MeV events detectable in burst mode.
- Caveat: LOTS of uncertainties (reconstruction, particle ID,...)

http://arxiv.org/abs/0810.1959v2

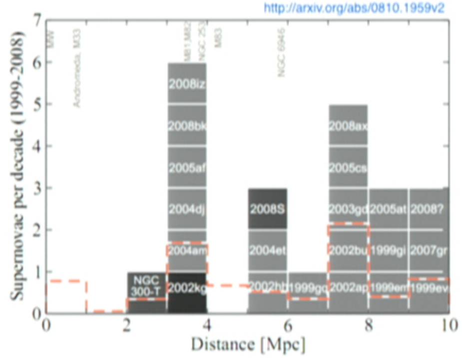
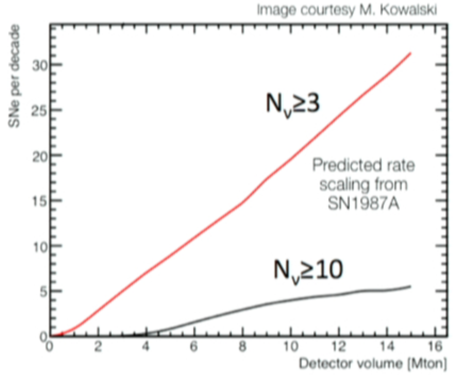


Image courtesy M. Kowalski



April 24, 2012

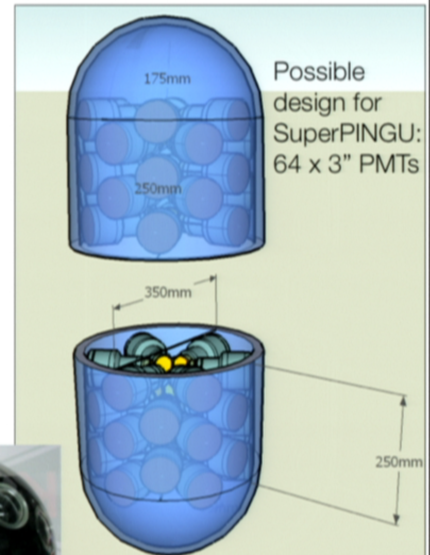
Darren R. Grant - University of Alberta

MICA Detector R&D

Courtesy E. de Wolf & P. Kooijman

Composite Digital Optical Module

- Glass cylinder containing 64 3" PMTs and associated electronics
    - Effective photocathode area >5x that of a 10" PMT
    - Diameter comparable to IceCube DOM so (modulo much tighter vertical spacing) drilling requirement would also be similar
    - Single connector
- Might enable Cherenkov ring imaging in the ice



Summary

- IceCube completed construction in December 2010 on schedule and within budget.
- The detector is exceeding the initial performance goals. It is now has sensitivity to neutrinos of all flavors in a very wide energy range (10 GeV to 10^9 GeV) in both hemispheres. Recent results have started stringently testing the models for astrophysical neutrinos.
- DeepCore has been running for >2 year and is taking data in its final configuration. First results are now appearing!
- Expect significant improvement in sensitivity to dark matter, potential for neutrino oscillations. Preliminary analysis suggests we may have detected atmospheric electron neutrinos for the first time in a high-energy telescope.
- Towards the future, South Pole ice may be prove to be an attractive alternative for large-scale precision neutrino detectors (and direct detection dark matter with DM-Ice). Feasibility studies now underway.

April 24, 2012

Darren R. Grant - University of Alberta