Other Workshop Summary

- **Second Workshop on "Low Energy" Neutrino Physics and Astrophysics with IceCube's DeepCore Sub-Array**
  - Held at Penn State last week (July 1-2)
  - Sponsor: Penn State’s Institute for Gravitation and the Cosmos and the Center for Particle Astrophysics
- Focused on physics potential of DeepCore with sensitivity to neutrinos with $E_\nu$ as low as 10 GeV
- Talks will be posted soon at [http://gravity.psu.edu/events/DeepCoreNeutrinoWorkshop/](http://gravity.psu.edu/events/DeepCoreNeutrinoWorkshop/)

Background: Aurora Australis
Photo credit: Jonathan Berry/NSF
Welcome | Doug Cowen | Penn State | 10 | 8:50-9:00
DeepCore Design & Initial Performance | Per Olof Hult | U. Stockholm | 20 | 9:00-9:20

**Dark Matter** (Convener: Per Olof Hult)

- Overview of SUSY Dark Matter | Pearl Sandick | UT-Austin | 30 | 9:25-9:55
- Dark Matter in IceCube | Doug Spolyar | Fermilab | 20 | 10:00-10:20
- Dark Matter in DeepCore | Sourav Mandal | UC-Berkeley | 20 | 10:25-10:45
- Coffee Break (20 min)

- Searches for Dark Matter in IceCube | Erik Strahler | U. Brussels | 20 | 11:05-11:25
- Prospects for Dark Matter Searches with DeepCore | Matthias Danninger | U. Stockholm | 15 | 11:30-11:45
- DeepCore and Galactic Center WIMPs | Carsten Rott | Ohio State U. | 15 | 11:50-12:05

**Fundamental neutrino properties** (Convener: Doug Cowen)

- Atmospheric v Oscillations & v_e in Ice | Gerardo Giordano | Penn State | 15 | 2:00-2:15
- Neutrino Cross Sections at 5-50 GeV | Hallie Reno | U. of Iowa | 30 | 2:20-2:50
- Coffee Break (20 min)
- Reactor Neutrino Experiments | Karsten Heeger | UWI-Madison | 30 | 3:10-3:40
- Accelerator Neutrino Experiments | Ed Kearns | Boston U. | 30 | 3:45-4:15
- Oscillation Prospects for DeepCore | Jason Koskinen | Penn State | 20 | 4:20-4:40

**Future Directions** (Convener: Tyce DeYoung)

- DeepCore Extensions and Other Ideas | Darren Grant | U. Alberta | 30 | 10:50-11:20
- Neutrino Mass Hierarchy and Mixing: Long-baseline Msmts. w/ IceCube | Laura Bodine | U. Washington | 15 | 11:25-11:40

**Neutrino Point Source Searches** (Convener: Tyce DeYoung)

- Fermi observations of selected Galactic sources | Julie McEnery | NASA/Goddard | 30 | 2:00-2:30
- 10 GeV Neutrinos from Fermi sources | Soeb Razzaque | Naval Research Laboratory | 30 | 2:35-3:05
- Transient Source Searches with DeepCore | Ignacio Taboada | Georgia Tech | 30 | 3:10-3:40
- Coffee Break (20 min)
- Steady Soft-Spectrum Source Searches with DeepCore | Claudine Colnard | MPI-Heidelberg | 30 | 4:00-4:30

Open Discussion; Adjourn
# 2nd DeepCore Workshop Agenda

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**Friday, July 2, 2010**

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## Focus here on DeepCore and...
- fundamental neutrino properties
- exotic physics
- point source searches
- future directions
Fundamental $\nu$ Properties with DeepCore

- Underlying neutrino oscillation physics
  - Current state of affairs summarized by Karsten Heeger (reactors) and Ed Kearns (accelerators)
  - Jason Koskinen reported that with DeepCore,
    - expect to have sensitivity to $\nu_\mu$ disappearance
    - hope to have sensitivity to $\nu_\tau$ appearance

- Neutrino cross sections at $E_\nu = 5$-50 GeV
  - Hallsie Reno pointed out that between 5-15 GeV there’s substantial uncertainty due to the mix of contributing processes: deep inelastic and quasi-elastic scattering, and single pion production
Neutrino Cross Sections @ 5-15 GeV

• Deep inelastic scattering
• Quasi-elastic scattering
• Single pion production

Typical separation of contributions.

Previous formula is the DIS term.

Qel and pion production can be approx. 25% of the cross section at 5 GeV.

Lipari, Lusignoli and Sartogo, PRL 74 (1994)
Target & Tau Mass Corrections also Important

- Target mass correction grows to about 5% at $E_\nu = 10$ GeV
- Tau mass correction is substantial for $\nu_\tau$ interactions throughout energy range of interest
- Anti-neutrino uncertainties are larger than for neutrinos due to lower $Q$ values
Neutrino Oscillations with DeepCore

- Jason Koskinen reminded us that standard neutrino oscillations predicts a “sweet spot” for DeepCore near $E_{\nu} = 25$ GeV

- DeepCore has greater sensitivity than IceCube
**Neutrino Oscillations with DeepCore**

- Critical to reject downgoing muon background
  - Online: Already achieve 8e3 rejection with 99% signal retention
  - Offline: Expect to do much better with more sophisticated algorithms
- Optimistic predicted $\nu_\mu$ disappearance signal (1 yr data, no background, no reconstruction!)
- Tau neutrino appearance prospects are also encouraging
- Additional 2 DeepCore infill strings in 2010/2011 will improve things on all fronts

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**Preliminary $\nu_\mu$ disappearance**

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<tr>
<td>1400</td>
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- Unoscillated
- Oscillated

No Reconstruction

$\theta_{23} = \pi/2$

$\Delta m_{23}^2 = 2.4 \times 10^{-3}$ eV

$\cos(\text{zenith}) < -0.6$

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Alternative Neutrino Oscillation Detector

- Failsafe technique employs dedicated postdoc observational capabilities at Pole
Alternative Neutrino Oscillation Detector

- Failsafe technique employs dedicated postdoc observational capabilities at Pole
Exotica

• Markus Ahlers gave theoretical overview of exotic signatures and discussed how DeepCore might help
  • Exotic Cherenkov signals
    • relativistic monopoles have 8300x standard dE/dx; slower monopoles can catalyze proton decay, leaving GeV-scale depositions along its track
      • DeepCore can search for dimmer, slower monopoles
    • charged massive particles (CHAMPs), next-lightest SUSY particle (NLSP): e.g. supersymmetric taus (staus) producing double-muon tracks
      • DeepCore can help separate di-muons better than IceCube alone
  • Exotic flavor compositions
    • DeepCore may help detect sub-dominant effects
  • Neutral long-lived particles (LOLIPs)
    • DeepCore can get us down to lower mass LOLIPs
Exotica: Monopole Signature in IceCube

Movement of a GUT Monopole/Q-Ball through IceCube

- **PM signal muon**
- **PM signal of a 2nd muon**
- **relativistic muon**
- **t=0 µsec**
- **t=0.5 µsec**
- **SLOP Filter passes events w/ lengths greater than 33µs**
- **t=500 µsec**
- **β = 10^{-3}**
- **Monopole (Q-ball)**
- **PM signal GUT monopole**

- **1 GeV cascades from p-decay**
- **High catalysis cross section**
- **Low catalysis cross section**

DESY (Zeuthen) - L. Benabderrahmane, C. Spiering
Aachen - T. Gluesenkamp, C. Weibusch

Friday, July 2, 2010

Penn State Low Eν Workshop Summary D. Cowen
Alex Olivas showed that DeepCore can help with the detection of slow monopoles. Analysis technique looks for long events, but if time gap between detected monopole interactions is too long, IceCube trigger will split it, making monopole harder to detect. DeepCore’s higher density of modules allows us to detect more interactions for a given monopole speed.
Neutrino Point Sources

- Soeb Razzaque was optimistic about low $E_\nu$ from novae (e.g., V407 Cygni found by Fermi LAT with $E_\gamma = 4$ GeV)
  - “symbiotic” white dwarf and red giant, 30/yr in galaxy, recur every 10-100 yrs
- Julie McEnery reported recent (and very impressive) Fermi results. Of particular interest for neutrino hunters:
  - detected >500 sources with $E_\gamma > 10$ GeV
  - discovered numerous TeV-emitting pulsar wind nebulae

- GeV supernova remnant population growing
  - pion decay scenarios (which would produce neutrinos) favored for mid-aged SNR (but leptonic scenarios not ruled out)

Neutrino Point Sources

- Ignacio Taboada reported on his recent result* on “choked” GRBs (jets inside core-collapse supernovae)
  - DeepCore gives added reach at low energies
    - SN at 10 Mpc gives 4 DeepCore events
  - DeepCore can also be used to reduce accidental background rate from atmospheric neutrinos:
    - In 100s search window, with 100k events in IceCube and 100k in DeepCore per year, requiring
      - 1 IceCube $\nu_\mu$ + 3 DeepCore $\nu_\mu$
      gives 1.4 accidentals/yr

Neutrino Point Sources

- Claudine Colnard reported some initial simulation results using the “atmospheric neutrino veto”*
  - using a veto and requiring numu events to start inside fiducial volume, expect clean neutrino signal from southern sky sources above ~30 TeV
  - test case using SNR RXJ 1713.7 3946 worked well (no background, but signal would have been too small to see)

*Schoenert et al., PRD79 043009, 2009
Darren Grant observed that the DeepCore program is very rich, but he humbly offered for consideration a quote by Gordon Gecko: “Greed is good.”

What other physics can we do in the ice that
- leverages on the presence of IceCube & DeepCore
- uses the intrinsically clean & quiet deep ice environment
- benefits from existing infrastructure to do interesting physics “on the cheap”? 
Future Directions

- A high-statistics, precision, low-energy neutrino particle physics experiment
  - Get 10 MT fiducial volume with a few GeV $E_\nu$ threshold for a modest $\$25M$
  - Improved WIMP sensitivity at low $\chi_0$ mass
  - Can see two $\nu_\mu$ disappearance minima and one maximum
- Laura Bodine described how the $\nu$ hierarchy could be determined, even if $\theta_{13}=0$:
  - Point an adjustable narrow-band beam at IceCube
  - Count $\nu_\mu$’s at energies as low as 100 MeV

Current IceCube: Brown
Current DeepCore: Blue+Green
Improved DeepCore: Red

Image courtesy A. Karle
Future Directions

- Or, if we see hint for dark matter with current configuration
  - Build 70 MT fiducial volume with 10 GeV $E_\nu$ threshold, again for a modest $25M$

Current IceCube: Brown
Current DeepCore: Blue+Green
Improved DeepCore: Red

Image courtesy A. Karle
Future Directions

- DM-Ice: repeat DAMA/LIBRA experiment in southern hemisphere location (at South Pole)
- Advantages:
  - if DAMA modulation is due to seasonal effects, not relative motion of earth in “WIMP ether”
    - DM-Ice will see the same modulation, but phase-shifted by 180 degrees
  - ice is radioactively very quiet
  - depth and surrounding IceCube array dramatically increase “effective depth”
  - no surrounding rock for cosmic rays to make neutrons with
- 2 prototypes will be deployed this winter on 2 IceCube strings using well-characterized NAIAD crystals
  - proof-of-principle
- Next steps: ultra-pure NaI crystals; scale up to few hundred kg
Future Directions

- **1 MT 10 MeV threshold ring-imaging Cherenkov detector in the ice**
  - photocathode coverage density comparable to proposed 100 kton “Hyper-K” detectors
- **Physics reach**
  - proton decay
    - rigorous test of GUT prediction
  - ~1 SN/yr at few Mpc
  - hep solar ν’s, $\theta_{23}$
- **$300M$ cost**
  - dominated by PMTs
  - about 1/3 the cost of proposed water Cherenkov options

Images courtesy T. DeYoung
Conclusions

- DeepCore has great discovery potential over a wide range of exciting physics topics
  - Dark Matter
  - Neutrino properties
  - Neutrino point source detection
  - Exotica
- Groups are forming to exploit the tantalizing opportunities for new experiments that leverage
  - the ice’s wonderful properties as a detection medium
  - the south pole infrastructure that includes a highly efficient cosmic ray veto: IceCube
- Join us, come up with your own idea(s), or both!