Neutrinos at the Energy Frontier

Steve Barwick, UC Irvine
The energy frontier has traditionally led to tremendous breakthroughs in our understanding of how the universe operates.

- We hope to exploit EHE ν provided by nature (EHE = extremely high energy)
Messengers of Astronomy

- The neutrino window begins at energies above $10^{13}$ eV
- Era of multi-messenger astronomy
Motivation: GZK neutrinos are a guaranteed source

- **Ultra-high energy cosmic rays:**
  - From where??! And How??

- **Standard Model:**
  - Ordinary charged particles accelerated by distant sources: AGN, GRBs…

- **If so: GZK neutrinos are the signature**
  - Probably necessary and sufficient to confirm standard GZK model
• Two predictions
  – 1. There is a brick wall for the highest energy cosmic rays. We should observe energies below about $10^{20}$ eV.

  – 2. The reactions that limit the cosmic ray energies produce neutrinos as a by-product

GZK neutrinos are probably the 2nd most likely source of high energy neutrinos!
Recent work suggests GZK cutoff observed -or not

Observed by HiRes

\[ \chi^2/DOF = 40.5/32 \]
\[ \chi^2 \text{ Norm} = 2.7(9) \]
\[ \chi^2 \gamma = 2.47(9) \]
\[ \text{G Norm} = 2.2(4) \]
\[ G \gamma = 3 \]

Not consistent with AGASA data
Models of diffuse EHE Neutrinos

Required exposure to measure 10 events/decade at $E^2(dF/dE) = 10^{-7}$
EHE Neutrinos Explore Higher Dimensions

Friess, Hooper & Han astro-ph/0204112
The AMANDA-II Collaboration

- Bartol Research Institute, University of Delaware
- BUGH Wuppertal, Germany
- Universite Libre de Bruxelles, Brussels, Belgium
- DESY-Zeuthen, Zeuthen, Germany
- Dept. of Technology, Kalmar University, Kalmar, Sweden
- Lawrence Berkeley National Laboratory, Berkeley, USA
- Dept. of Physics, UC Berkeley, USA
- Dept. of Physics and Astronomy, UC-Irvine, USA
- Institute of Physics, University of Mainz, Mainz, Germany
- University of Mons-Hainaut, Mons, Belgium
- Fysikum, Stockholm University, Stockholm, Sweden
- Dept. of Physics, University of Alabama, USA
- Vrije Universiteit Brussel, Brussels, Belgium
- Dept. Fisica, Univ. Simon Bolivar, Caracas, Venezuela
- Dept. of Physics and Astronomy, Penn State University, College Station, USA
- Dept. of Astronomy, Dept. of Physics, University of Wisconsin, Madison, USA
- Physics Department, University of Wisconsin, River Falls, USA
- Division of High Energy Physics, Uppsala University, Uppsala, Sweden

Institutions: 8 US, 9 European, 1 South American
AMANDA-II with TWR

South Pole 2km Deep Ice

- AMANDA-II now reporting 97-00 data.
- Demonstrated technology after R&D period on ice properties and prototypes (10 years from start to finish)

http://amanda.uci.edu
Drill Camp - 1997
Deploying an AMANDA sensor at -40C.

Going down the hole
The Cherenkov Effect
Traditional way to detect neutrinos in AMANDA-II

Look for upward going tracks
Science Potential/Opportunities of AMANDA-II

New technique

$\nu$传统方式

$\nu_\mu$ 传统方式

S. Barwick
ICRC, Aug 2001
AMANDA-II Search for HE ν from Point Sources

No clustering, so flux limits

Submitted to PRL
astro-ph/0309585
At EHE energies, neutrinos cannot penetrate the earth, so expect most events from horizon.
Main background: muon “bundles”
- Comparable $N_{\text{PMT}}$ but smaller $N_{\gamma}$
- Calibrate with *in-situ* $N_2$ laser
- Still evaluating systematic uncertainties

At EHE energies, AM-II is nearly 0.3 km$^2$

**Preliminary Limit**

Submitted to PRL
ICECUBE

Perhaps First Km³ Neutrino Detector ~2010

First funds 2002

- 80 strings,
  60 PMT’s each;
  4800 optical modules total

- $V \approx 1 \text{ km}^3,$
  $E_{th} \sim 0.5-1\text{TeV}$

Ideally suited for $E_\nu < 10 \text{ PeV}$
ANITA
ANtarctic Impulsive Transient Antenna

S. Barwick (UCI), J. Beatty (PSU), J. Clem (Bartol), S. Coutu, D. Cowen (PSU), M. DuVernois (U Minn.), P. Evenson (Bartol), P. Gorham (Hawaii), K. Liewer (JPL), D. Saltzberg (UCLA), D. Seckel (Bartol), G. Varner (U Hawaii), K. Woschnagg (UCB)

Collaborators:
D. Besson (U Kansas), F. Halzen (Wisconsin), D. Kieda (Utah), J. Learned, S. Matsuno (UH)

Red= worked at pole
ANtarctic Impulsive Transient Antenna

- NASA funding started 2003 for first launch in 2006
- Phase A approval for SMEX ToO mission, >2006

www.ps.uci.edu/~anita
ANITA concept

cascade produces UHF-microwave EMP

antenna array on payload

earth

0.1–100 EeV neutrinos

refracted RF

ice

cascade

1–3 km

56° Cherenkov cone
Noise Tests at South Pole

- Ambient noise on the high plateau

Log-Periodic Antenna
RF emission from ice

Initial Results from Polar Studies

- It looks good so far

Nadir–Zenith noise, 1/26/03 South Pole ski hut at 6 km

![Graph showing antenna noise temperature vs. frequency](image)
What’s Next? ANITA-lite

2 Receiver Horns

Electronics

Piggyback on TIGER
Launch Dec ‘03

RF Survey of Antarctica
Why is ANITA a good idea?

- Frontier Science and very exciting
  - Win-win with GZK neutrinos
- Scans ice over 600km radius, and enormous detector volume!
- Radio signal can be calculated precisely and has been measured at high energy lab - unique signature!
- Energy resolution is relatively good
- Antenna can be absolutely calibrated by man-made radio transmitter embedded in deep hole (eg. Vostok)
- Clean signal
  - Linearly polarized, must originate in ice, distinct few ns time structure of pulse, “beam-off” in directions over water
- Balloon flight path is far from sources of confusing background

Revolutionary concept in EHE neutrino detection!
High Energy Neutrino Roadmap

projection by Christian Spiering, 10/02
Outlook

• With AMANDA-II, the requisite tools to inaugurate multi-messenger astronomy are available.

• To probe the neutrino fluxes at highest energies, new techniques are being developed based on radio cherenkov detection.

• ANITA extends search volume to $10^6$ m$^3$. 
EeV (10^{18} eV) Science Goals

• GZK from p+γ_{CMB}
  – Detection would confirm highest energy cosmic rays are extragalactic and composed of ordinary stuff like protons, helium
  – Provides neutrinos to study predictions of Grand Unified Models, the Holy Grail of Particle Physics
  – Non-detection would be great surprise

• Supermassive Black Hole/ AGN models
  – Compared to searches at 1-100 TeV, probes a complementary set of models
  – Salamon and Stecker (‘95), Protheroe(‘97), Mannheim(‘95), Halzen and Zas(‘97)

• Exotic sources - physics of the early Universe
  – Topological defects, Heavy Boson decay, Z-burst, micro-Blackholes
EHE Detection Guidelines

\((E > 10^{16} \text{ eV})\)

EHE ν do not penetrate earth

EHE events very bright; many PMTs detect multiple photons

\(R_\mu \geq 10 \text{ km}\)

bright horizontal MC track
\textbf{ANITA} 

Shower profile observed by radio (~2GHz)

- Measured pulse field strengths follow shower profile very closely
- Charge excess also closely correlated to shower profile (EGS simulation)
- Polarization completely consistent with Cherenkov

\begin{itemize}
  \item Measured pulse field strengths follow shower profile very closely
  \item Charge excess also closely correlated to shower profile (EGS simulation)
  \item Polarization completely consistent with Cherenkov
\end{itemize}
Ice transparency

Loss tangent a strong function of temperature

For cold ice, UHF (0.1-1GHz) best

Antarctic data approaches pure ice values

\[ L_\alpha = \lambda \left[ \pi n \left( \varepsilon''/\varepsilon' \right) \right]^{-1} \sim 6 \text{ km at 300 MHz & -60C (pure ice)} \]
New results—SLAC T460 June 2002

Follow up experiment to SLAC T444, with rock-salt target

• Much wider energy range covered:
  – <1PeV up to 10 EeV

• Radio Cherenkov observed over 8 orders of magnitude in radio pulse power
$\mu$-Flux Limits for Point Sources
AMANDA-II Search for HE $\nu$ from GRBs

Green’s Function Fluence Limit

(K. Kuehn, TAUP’03)

<table>
<thead>
<tr>
<th>Year</th>
<th>Detector</th>
<th>$N_{\text{Bursts}}$</th>
<th>$N_{\text{BG, Pred}}$</th>
<th>$N_{\text{Obs}}$</th>
<th>Event U.L.</th>
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<td>1997</td>
<td>B-10</td>
<td>78 (BT)</td>
<td>0.06</td>
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<td>2.41</td>
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<td>94 (BT)</td>
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<tr>
<td>1999</td>
<td>B-10</td>
<td>96 (BT)</td>
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<td>0.83/0.40</td>
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<tr>
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<td>A-II</td>
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</table>

BT = BATSE Triggered  BNT = BATSE Non-Triggered  New = IPN & GUSBAD

382 GRBs examined!