Searches for Dark Matter with the IceCube Neutrino Telescope

Rencontres de Moriond 2010
Cosmology Session

Erik Strahler
Vrije Universiteit Brussel
For the IceCube Collaboration
15/03/2010
Neutrino Detection Principles

- Interaction in/near detector
  - Tracks (~km) (CC $\nu_\mu$)
  - Cascades (CC $\nu_e$, $\nu_\tau$ / NC $\nu_\mu$)
- Cherenkov radiation emitted by daughter lepton
- Optical sensors record arrival time and intensity of photons for reconstruction
The IceCube Neutrino Telescope

- Antarctic glacier provides large, extremely clear medium for propagation of Cherenkov photons
The IceCube Neutrino Telescope

- Large Hybrid Detector
  - ~km³ instrumented volume
- IceTop
  - Surface air shower array
  - ~300 TeV threshold
- AMANDA-II
  - Precursor Array
  - Decommissioned May 2009
- IceCube-DeepCore
  - 79 of 86 strings deployed
  - Complete in 2011
More on DeepCore

• 6 string sub-array
  – More densely instrumented
  – Closer string spacing
  – High quantum efficiency PMTs
  – Deployed in the deepest, clearest ice

• Extend sensitivity to ~10 GeV
  – Dark Matter Searches
  – Neutrino Oscillation

• Use of IceCube as a veto extends searches to the southern sky
  – More sources including the Galactic Center
Reconstruction

- Tracks / Cascades reconstructed based on Cherenkov photon arrival times and intensities.

Better Pointing Resolution

Better Energy Resolution

Better Background Rejection
Detection Challenges

- Down-going muons from Cosmic Ray showers dominate by 6 orders of magnitude
Detection Challenges

• Down-going muons from Cosmic Ray showers dominate by 6 orders of magnitude
  – Restrict Searches to Northern Sky
Detection Challenges

- **Down-going muons from Cosmic Ray showers dominate by 6 orders of magnitude**
  - Restrict Searches to Northern Sky
- **Mis-reconstructed muons dominate by 3 orders of Magnitude**
  - Especially troublesome are coincident muons
- **Atmospheric Neutrinos typically dwarf potential signals**
  - Isotropically distributed
IceCube Analyses

- Cosmic Ray Composition
- Supernovae Neutrinos
- Atmospheric Neutrinos
- Indirect Dark Matter Searches
- Diffuse Astrophysical Neutrinos
- GZK Neutrinos
- Time Integrated Point Sources
- Transient Point Sources
MSSM Neutralino Dark Matter

- With R-parity conservation, the neutralino is stable
- Collected in Massive Objects (Sun, Galactic Halo, …)
- Self-annihilation leads to SM particles and then neutrinos

\[ \chi\chi \rightarrow b\bar{b}, \tau^+\tau^-, W^+W^-, ... \rightarrow \nu S \]

- Event rates and energies depend on MSSM model parameters and astrophysics (relative velocities, galactic density profile)
  - few to \(10^3\) events per year
  - GeV to TeV energies
Solar WIMPs

- DM swept up from the halo by the Sun’s passage over its history
- Scattering with protons leads to capture
- Measurement of the neutrino flux probes the scattering cross-section

\[ \chi \rightarrow \nu \]
Solar WIMPs

- DM swept up from the halo by the Sun’s passage over its history
- Scattering with protons leads to capture
- Measurement of the neutrino flux probes the scattering cross-section

- Stringent event selection reduces the muon and atmospheric neutrino backgrounds
Limits on Neutralinos in the Sun

- Determine the muon flux from the direction of the sun
- Limit the neutrino-induced muons from WIMP annihilation
Limits on Neutralinos in the Sun

- Calculate the corresponding limit on the SD WIMP-nucleon scattering cross-section
- Compare hard and soft annihilation channels

Corresponding $\sigma_{SI}$ within factor $10^3$ of current direct limits

Corresponding $\sigma_{SI}$ more than factor $10^3$ below current direct limits
UED Kaluza-Klein Dark Matter

- In single extra dimension model, first KK excitation of $B^{(1)}$ can be a stable LKP.

- SI scattering cross-sections are small, but SD can be large enough to probe

- Limits calculated using same analysis as for neutralino DM search
Dark Matter from the Galactic Halo

- Select halo density profile
- Select SUSY model to neutrino spectrum
- Measure flux at Earth to constrain the self annihilation cross-section

\[
\frac{d\Phi}{dE} = \frac{\langle \sigma_A \nu \rangle}{2} J(\psi) \frac{R_{sc} \rho_{sc}^2}{4\pi m^2_\chi} \frac{dN}{dE}
\]

Measure Constrain Halo SUSY

15 March 2010 DM Detection with IceCube - Rencontres de Moriond 2010
Dark Matter from the Galactic Halo

- Initial limits for various annihilation channels shown in blue
- Method improved using 40-string dataset (red)
  - Specially filtered to look at GC
  - Hint of improvements to come with DeepCore
Conclusions and Outlook

- DeepCore installation complete, IceCube nearing Completion
  - In commissioning phase. 79 string data taking to begin in April
- Final AMANDA-II analyses nearing completion, first results from partial IceCube configurations have been published
  - Strong limits on MSSM spin-dependent WIMP scattering cross-sections
  - IC40 and IC59 analyses are underway

- DeepCore opportunities
  - Reduce threshold to ~10 GeV
  - Increase reach for low mass dark matter
  - Extend searches to southern sky using veto techniques. (GC, etc.)