Search for neutralino dark matter with the AMANDA neutrino telescope

D. Hubert and A. Davour for the IceCube Collaboration

dhubert@vub.ac.be
Vrije Universiteit Brussel, Belgium
Outline

• Indirect detection of dark matter
• The AMANDA neutrino telescope
• Analysis strategy, results and current efforts
  – Earth neutralinos (2001–2003 data)
  – Sun neutralinos (2001 data)
• Conclusion
Neutralino dark matter detection…

Neutralinos
if lightest SUSY particle: stable, weakly interacting, massive (GeV-TeV scale)
→ possibly main (dark) matter component of Universe

Indirect detection
accumulation in heavy objects (Earth, Sun, Galactic Center)
detection through annihilation products

\[ \chi\chi \rightarrow \left\{ \begin{array}{c} q\bar{q} \\ l^+l^- \\ W, Z, H \\ \ldots \end{array} \right\} \rightarrow \left\{ \begin{array}{c} \bar{p}, e^+ \\ \gamma \\ \nu \\ \ldots \end{array} \right\} \]

\[ \langle E_\nu \rangle \approx \frac{M_\chi}{3} \ldots \frac{M_\chi}{2} = O(\text{GeV-TeV}) \]
Neutralino signal

- rate depends on SUSY parameters
- $50 \text{ GeV} < M_\chi < 5000 \text{ GeV}$
- hard ($W^+W^-$) & soft ($b\bar{b}$) annihilations
- vertically upward (Earth)
  ~horizontal (Sun)

Atmospheric background

- muons $\sim O(10^9)$ events/year downward going
- neutrinos $\sim O(10^3)$ events/year all directions
The AMANDA/IceCube neutrino detector

AMANDA-II: 2000-...
- 677 OMs on 19 strings
- diameter ~200m, height ~500m

IceCube: 2005-...
- Feb. 2007: 22 strings deployed
- diameter ~1000m, height ~1000m
- incorporates AMANDA-II since 2007

Neutralino searches
- Earth WIMPs 2001–2003 (prelim. results)
  688.0 days, ~5x10^9 events
- Sun WIMPs 2001 (no low E sensitive trigger)
  143.7 days, ~9x10^8 events
- AMA-Ice3: poster by Gustav Wikström (HE3.3)
Additional low E trigger

Earth – 100 GeV soft channel

- Multiplicity trigger: 24 OMs within 2.5µs
- String trigger: 6/9 (7/11) OMs within 2.5µs

Graph showing number of events vs. number of hit channels for:
- Exclusively string trigger
- Multiplicity trigger
- Sum

30th International Cosmic Ray Conference
Merida, Yucatan, Mexico, July 3rd – 11th 2007

Daan Hubert for the IceCube Collaboration
Vrije Universiteit Brussel, Belgium
Neutralino analysis strategy

General analysis

• optimize 6 to 14 neutralino models (3 to 7x mass, 2x channel) separately
  better sensitivity, especially for low energy models

• blind analysis
  subsample data (Earth) or randomize azimuth (Sun)

Filter steps

1. reject atmospheric muons $\sim O(10^9)$
  direction, reconstruction quality, …

2. reduce atmospheric neutrinos $\sim O(10^3)$
  final search bin

3. claim discovery or calculate limits
  estimate background from MC (Earth) or off-source data (Sun)
Selection efficiencies

Earth – sequential 1-dim cuts, optimized with soft criterion

Sun – 1-dim cuts and multi-dim cut, using S/\sqrt{B} criterion
Data consistent with background

**Earth** – final event sample
50 GeV soft & hard channel

**Sun** – final event sample
500 GeV hard channel

Muon flux limit – Earth 2001-2003

Preliminary results
- optimized 6 low E models
- additional trigger lowers E threshold
- x60 improvement for 50 soft!
Preliminary results

- optimized 6 low E models
- additional trigger lowers E threshold
- x60 improvement for 50 soft!
Muon flux limit – Earth 2001-2003

Preliminary results
• optimized 6 low E models
• additional trigger lowers E threshold
• x60 improvement for 50 soft!

Outlook
• optimization for full mass range
• unblinding pending
Muon flux limit – Sun 2001

Current results
• 1st AMANDA result
• competitive with 144 days of livetime
• no string trigger

[Graph showing indirect searches with $E_{\mu}^\text{st} = 1$ GeV]
Current results

- 1\textsuperscript{st} AMANDA result
- competitive with 144 days of livetime
- no string trigger
Muon flux limit – Sun 2001

Current results
- 1st AMANDA result
- competitive with 144 days of livetime
- no string trigger

Outlook
- inclusion of low E triggers
- more statistics (2001–2003 data)
- improved analysis methods
Conclusion

• No statistically significant excess of neutralino-induced neutrinos from the center of the Earth or the Sun observed
• AMANDA upper limits on the muon flux competitive with other indirect searches
• New trigger improves low E sensitivity by factor $>$10
• Final 2001–2003 results for Earth and Sun neutralinos follow soon
Amundsen-Scott South Pole station

South Pole

IceCube

AMANDA-II
(not to scale)
Experimental and simulated data

Experiment

- 2001-2003: \(5.3 \times 10^9\) events, 688.0 days eff. livetime
- 2001 (w/o string): \(8.7 \times 10^8\) events, 143.7 days eff. livetime

Simulation

- neutralino: \(50\) GeV \(< M_\chi \leq 5000\) GeV
  - [DARKSUSY]: hard \((W^+W^-/\tau^+\tau^-)\) and soft \((b\bar{b})\) ann. channel
  - \(90^\circ < \theta_\nu < 113^\circ\) (Sun), \(\theta_\nu \sim 180^\circ\) (Earth)
- atm. \(\mu\): \(600\) GeV \(< E_p < 10^{11}\) GeV, \(0^\circ < \theta_{\text{prim}} < 90^\circ\)
  - [CORSIKA]
- atm. \(\nu\): \(10\) GeV \(< E_\nu < 10^8\) GeV, \(80^\circ < \theta_\nu < 180^\circ\)
  - [ANIS]
Rejection of atmospheric muons

Earth – sequential 1-dim cuts, optimized with soft criterion

Sun – 1-dim cuts and multi-dim cut, using $S/\sqrt{B}$ criterion
Optimizing search cone

Final search cone

- Assume isotropic atm. $\nu$ background in $\theta = 160^\circ - 180^\circ$, normalized to total MC expectation in same bin
- Optimize model rejection factor

$$MRF = \frac{\bar{\mu}_{90}(n_b)}{n_s}$$

MRF leads on average to “best upper limit” in N repeated experiments
Efficiency of the AMANDA triggers

Effective volume for solar $\chi$

- At trigger level (L0)
  \[ V_{\text{eff}}^{L0} = \frac{N_{L0}}{N_{\text{gen}}} \times V_{\text{gen}} \]
- String trigger improves trigger efficiency by factor $>10$ for $E_{\mu}<100\text{GeV}$
- Still 20-30% gain at higher energies