Neutralino searches with the AMANDA and IceCube neutrino telescopes

D. Hubert for the IceCube Collaboration

dhubert@vub.ac.be

Vrije Universiteit Brussel - IIHE

IceCube

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Outline

- Indirect detection of SUSY dark matter
- The AMANDA/IceCube neutrino telescope
- AMANDA: analysis strategy, results and current efforts
  - Earth neutralinos (2001–2003 data)
  - Sun neutralinos (2001 data)
- IceCube: expected sensitivities (for 10 years operation)
  - IceCube
  - IceCube with low energy extension

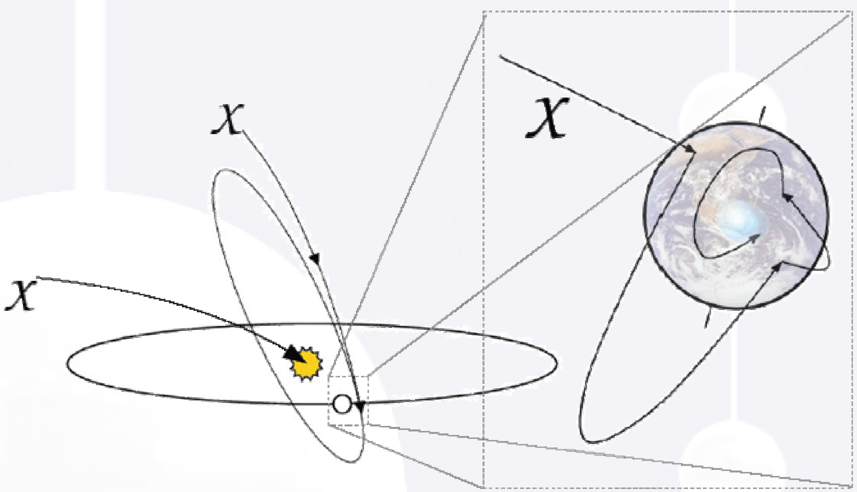
Neutralino dark matter detection…

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



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

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

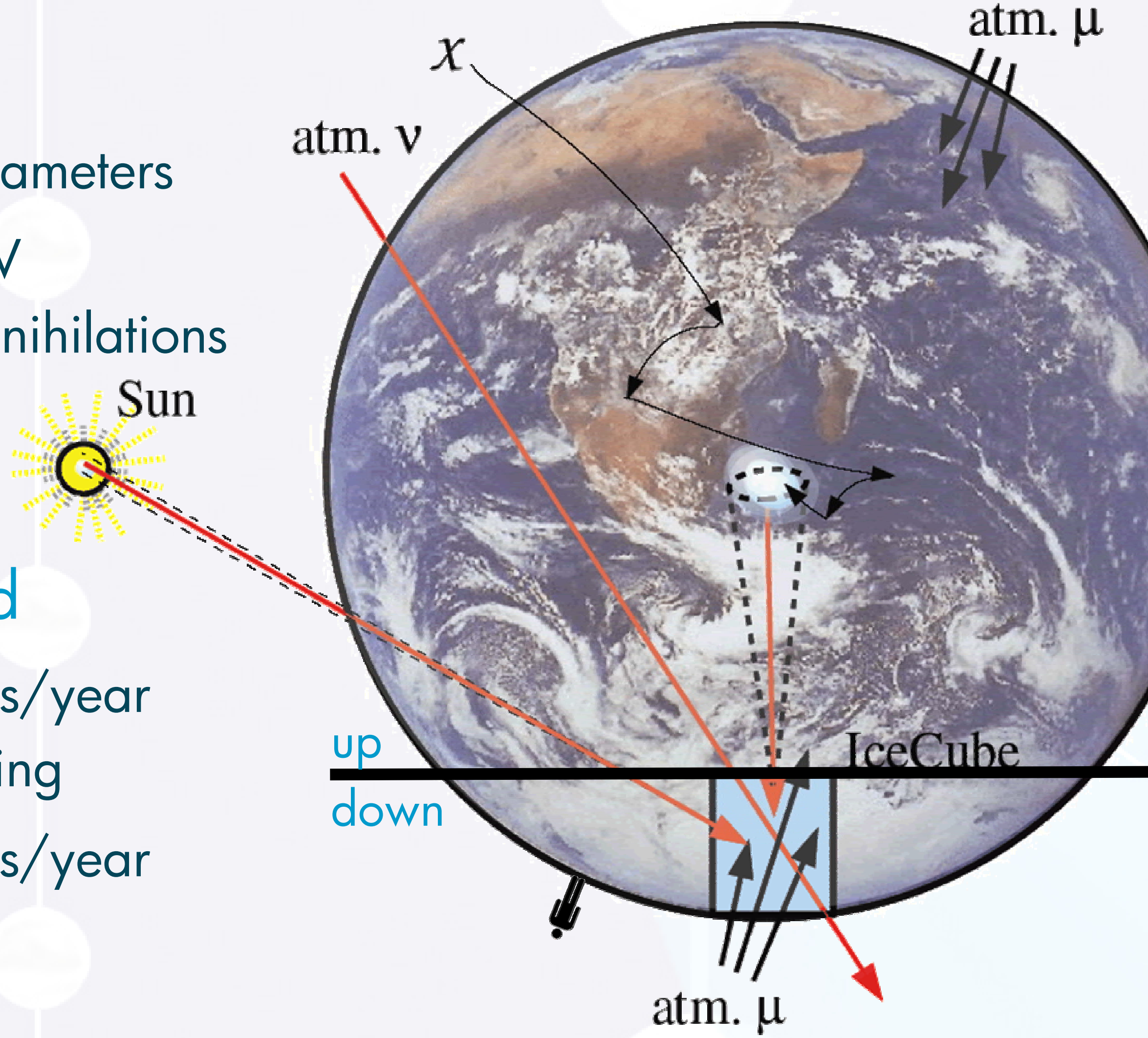
...with neutrinos

Neutralino signal

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

Atmospheric background

- muons ~$O(10^9)$ events/year
  downward going
- neutrinos ~$O(10^3)$ events/year
  all directions



The IceCube collaboration

University of Alaska, Anchorage
University of California, Berkeley
University of California, Irvine
Clark-Atlanta University
University of Delaware / Bartol Research Institute
University of Kansas
Lawrence Berkeley Natl. Laboratory
University of Maryland
Pennsylvania State University
Southern University and A&M College
University of Wisconsin, Madison
University of Wisconsin, River Falls

RWTH Aachen
DESY, Zeuthen
Universität Dortmund
MPIfK Heidelberg
Humboldt Universität, Berlin
Universität Mainz
BUGH Wuppertal

Stockholms Universitet
Uppsala Universitet

Vrije Universiteit Brussel
Université Libre de Bruxelles
Universiteit Gent
Université de Mons-Hainaut

Chiba University

University of Canterbury, Christchurch

Universiteit Utrecht

Oxford University

EPFL Lausanne

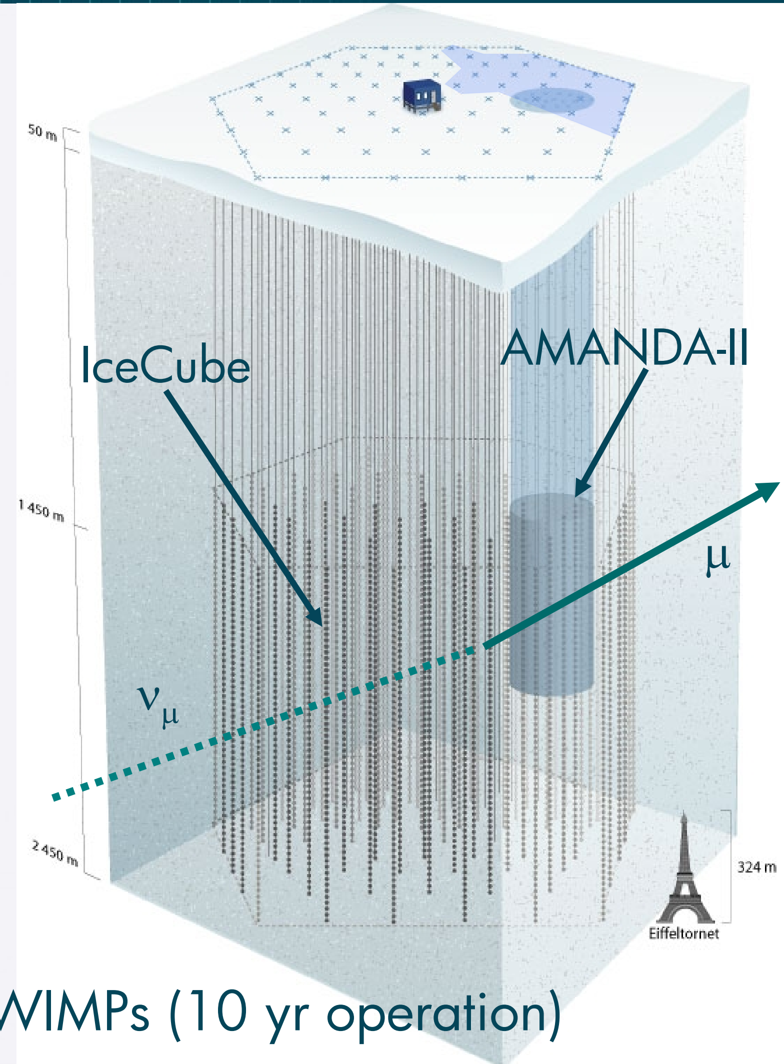
The AMANDA/IceCube neutrino telescope

AMANDA-II: 2000-...

- 677 OMs on 19 strings
- diameter ~200m, height ~500m

IceCube: 2005-...

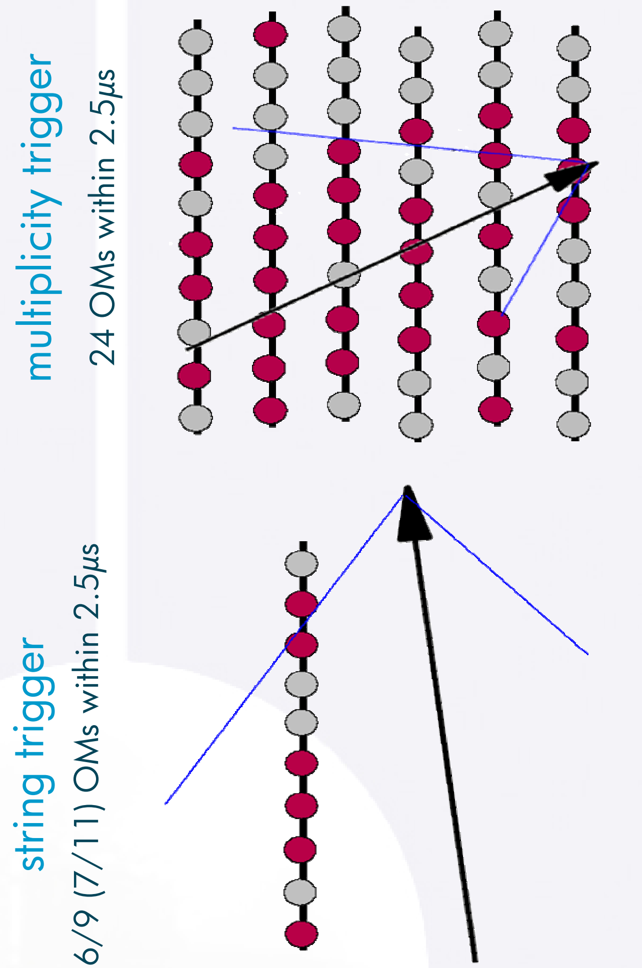
- Feb. 2007: 22/80 strings deployed
- diameter ~1000m, height ~1000m
- incorporates AMANDA-II since 2007

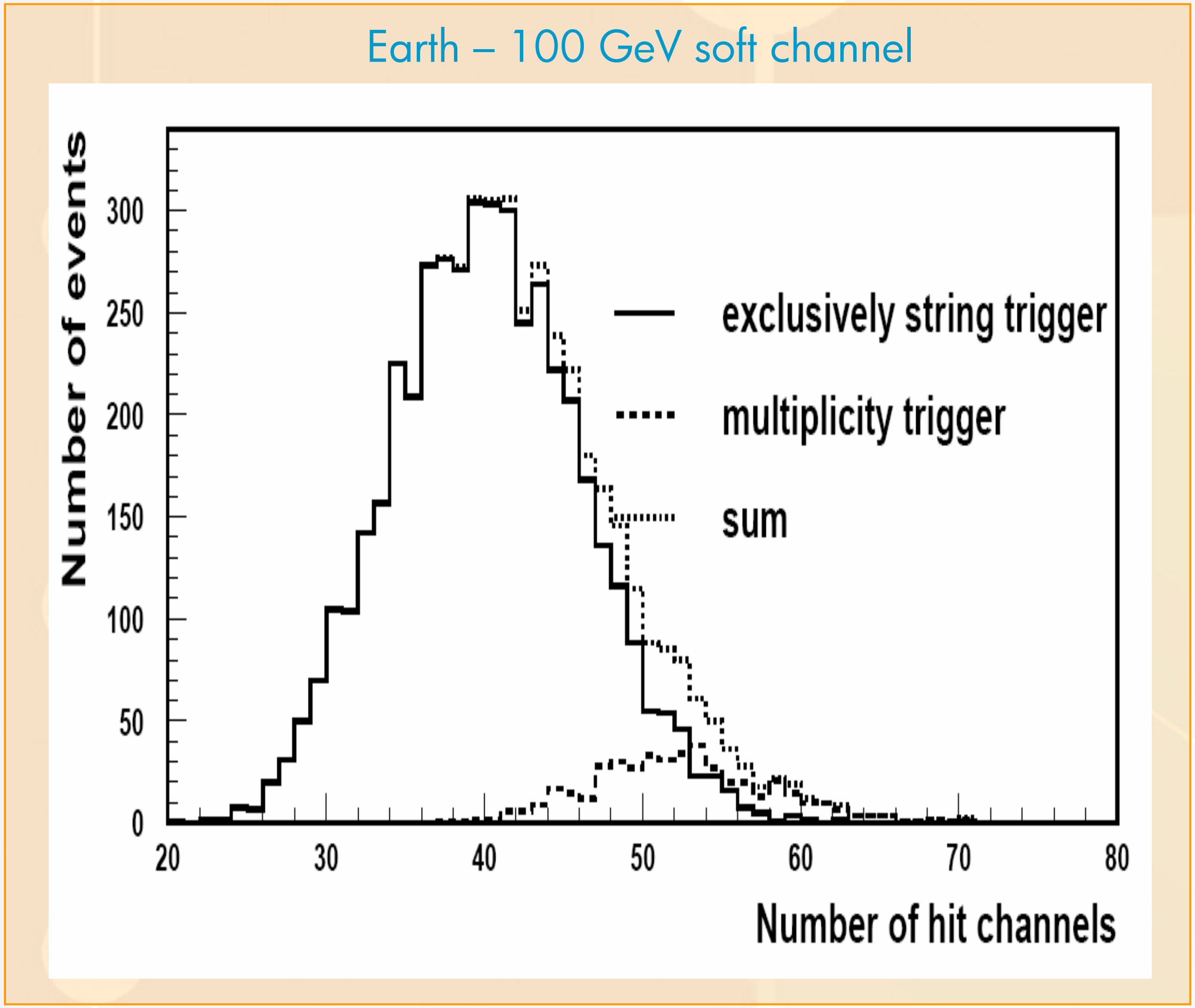


Neutralino searches

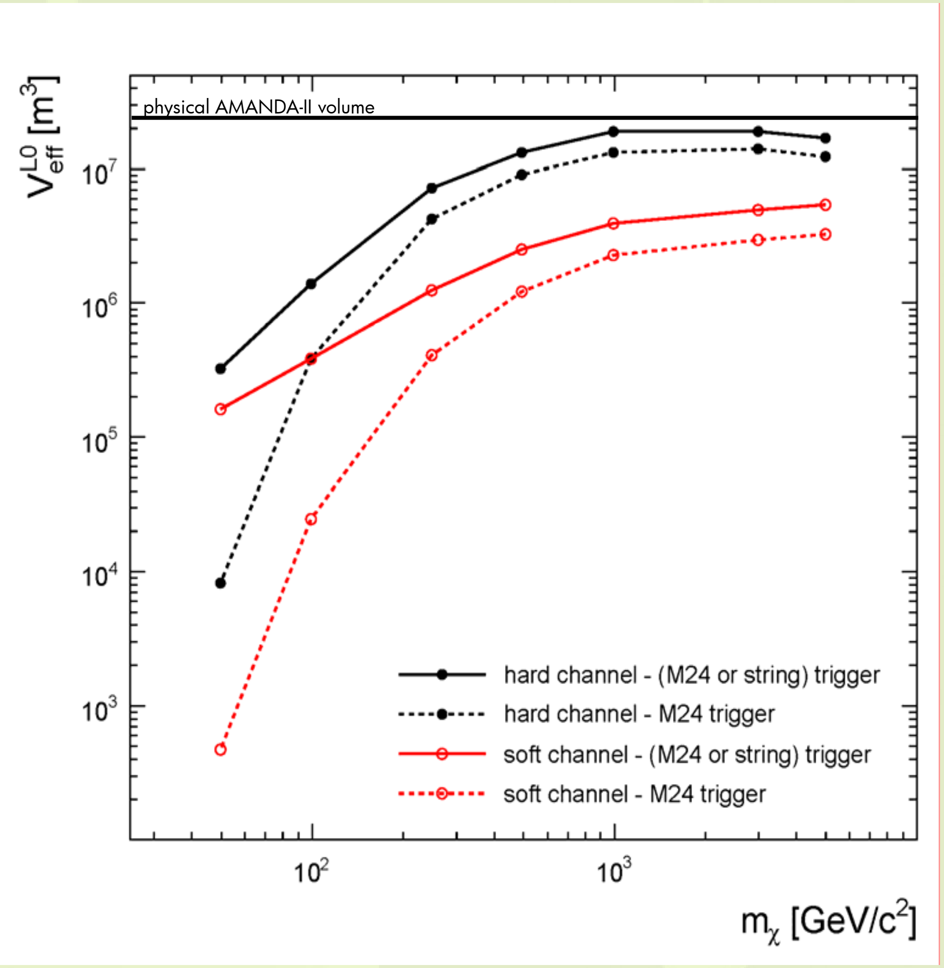
- Earth WIMPs 2001–2003 (prelim. results) 688.0 days, ~5x10^9 triggers
- Sun WIMPs 2001 (no low E sensitive trigger) 143.7 days, ~9x10^8 triggers
- IceCube (+low E ext.): sensitivities for Sun WIMPs (10 yr operation)

Additional low E trigger





Efficiency of the AMANDA triggers



Effective volume for solar χ

- At trigger level (L0)

$$V_{eff}^{L0} = \iint \frac{N_{L0}(E,\theta)}{N_{gen}(E,\theta)} V_{gen}(E,\theta)\, dE d\theta$$

- Low E trigger improves trigger efficiency by factor >10 for E_μ<100GeV
- Still 20-30% gain at higher energies

Neutralino analysis strategy

General analysis

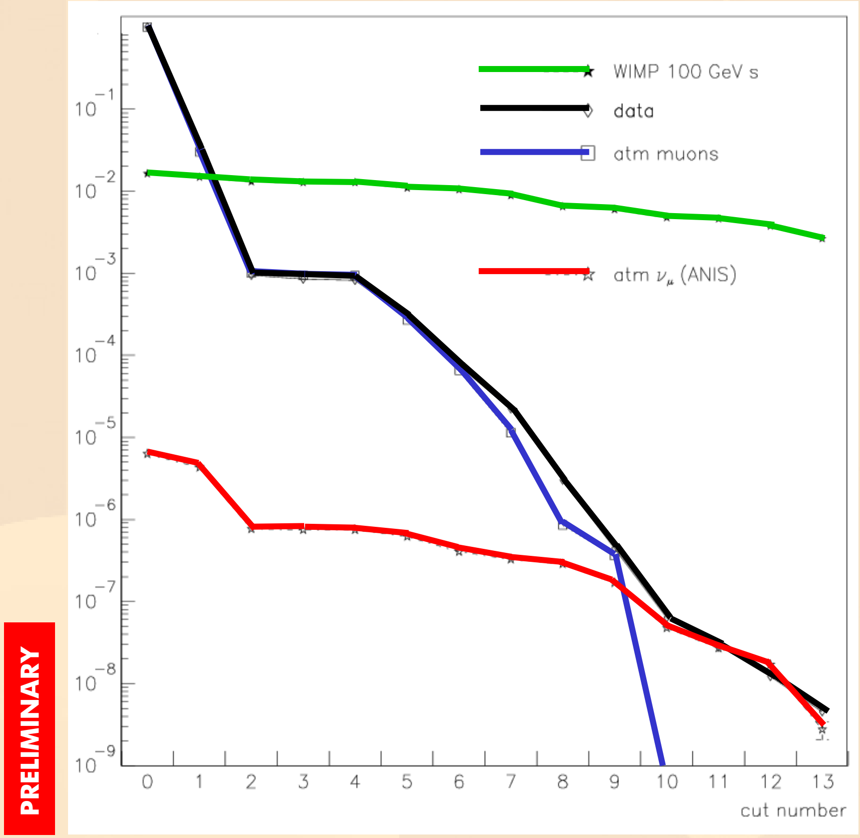
- optimize 6 to 14 neutralino models (3 to 7x mass, 2x channel) separately
  better sensitivity, especially for low energy models
- blind analysis
  subsample data (Earth) or randomize azimuth (Sun)

Filter steps

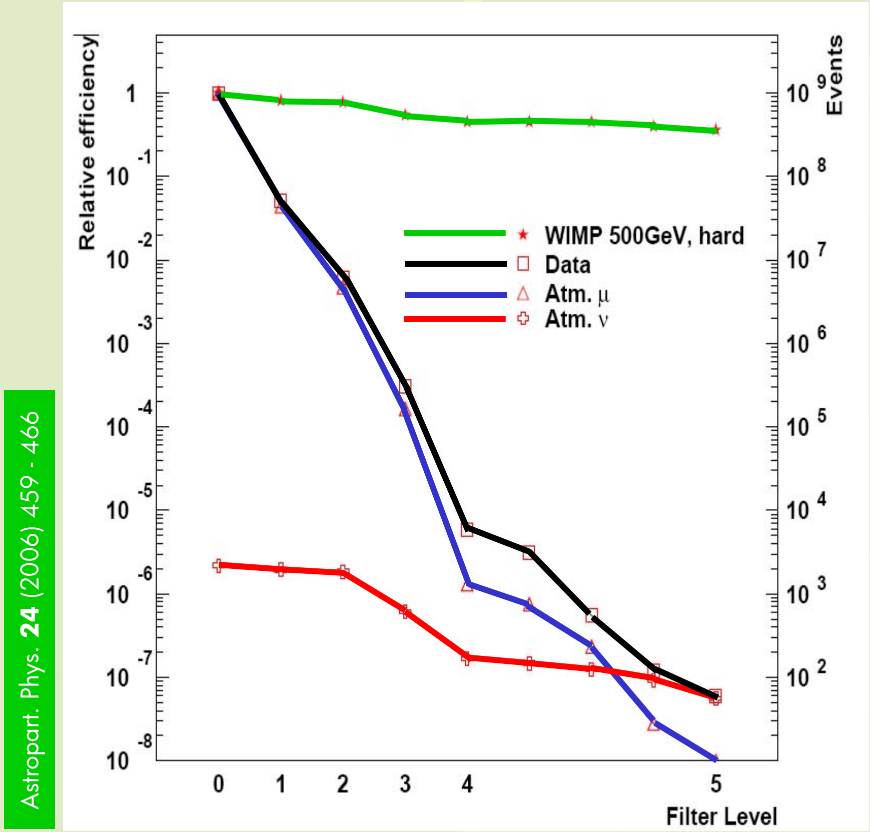
1. reject atmospheric muons ~O(10^9)
   direction, reconstruction quality, …
2. reduce atmospheric neutrinos ~O(10^3)
   final search bin
3. claim discovery or calculate limits
   estimate background from MC (Earth) or off-source data (Sun)

Selection efficiencies

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

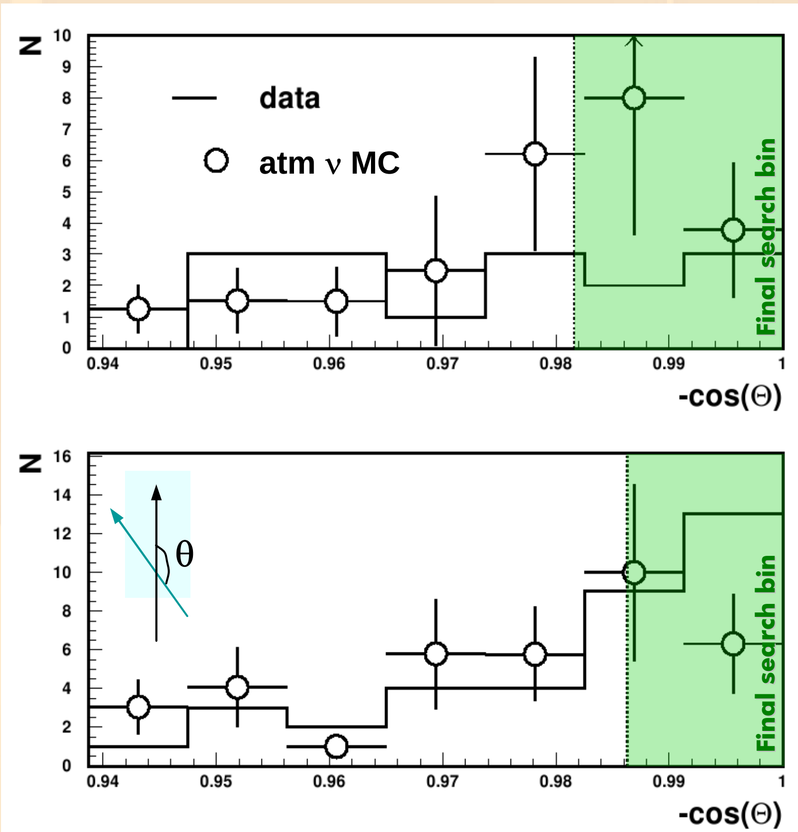


Sun – 1-dim cuts and multi-dim cut, using S/√B criterion



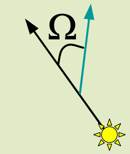
Data consistent with background

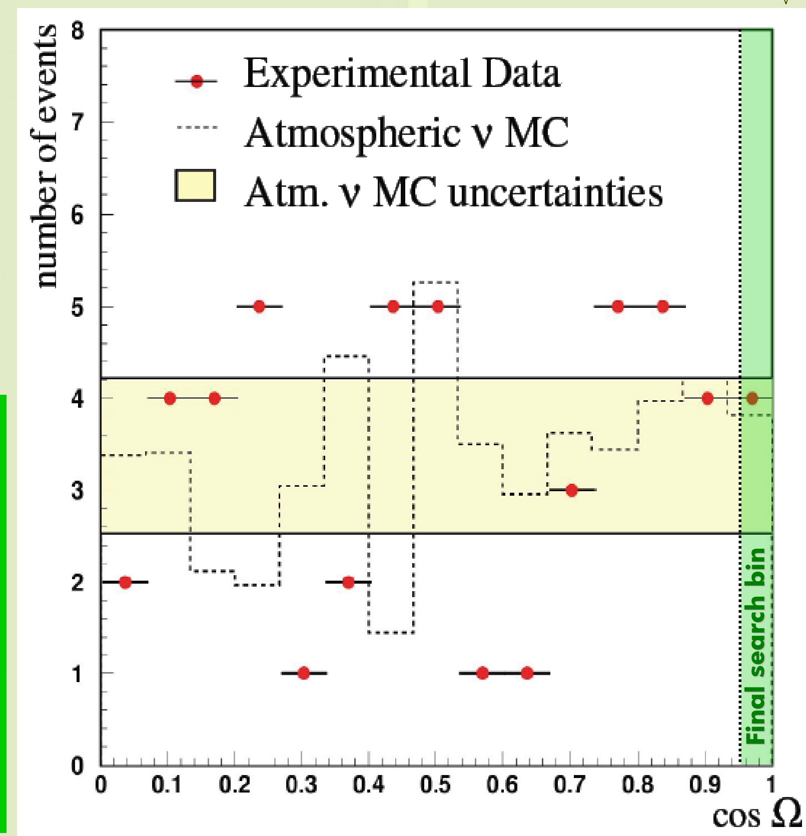
Earth – final event sample
50 GeV soft & hard channel



PRELIMINARY

Sun – final event sample
500 GeV hard channel





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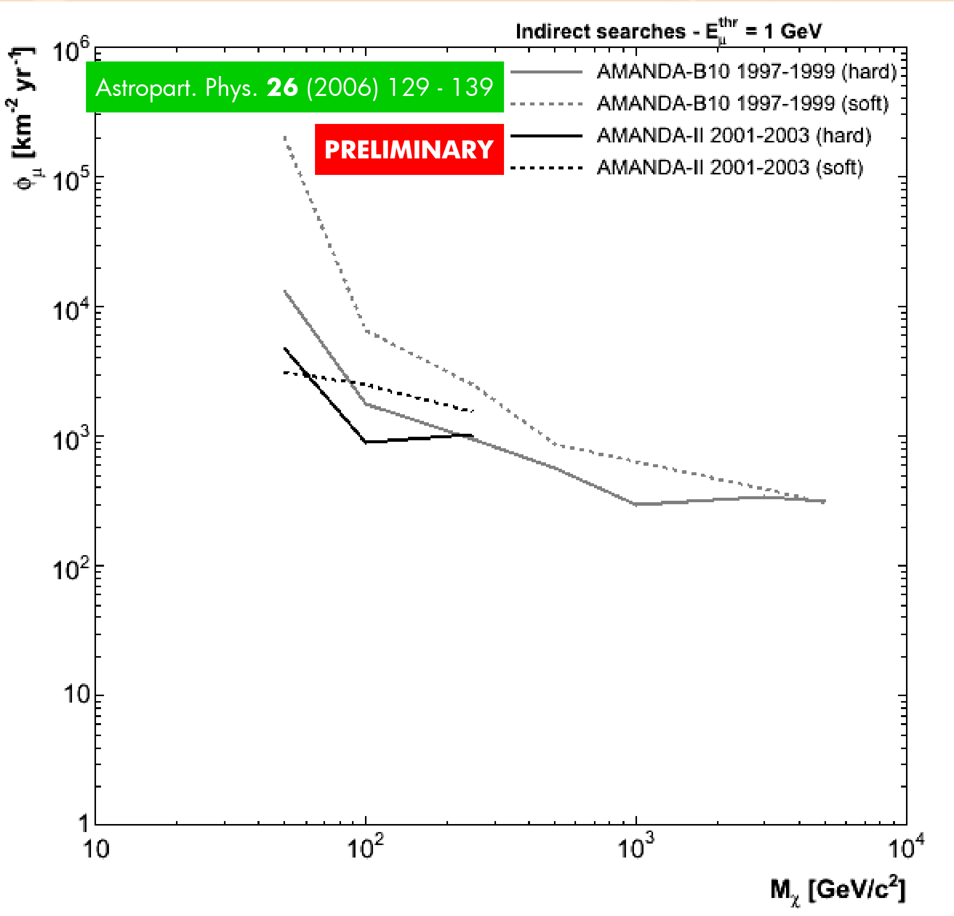
Muon flux limit – Earth 2001-2003



Preliminary results

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

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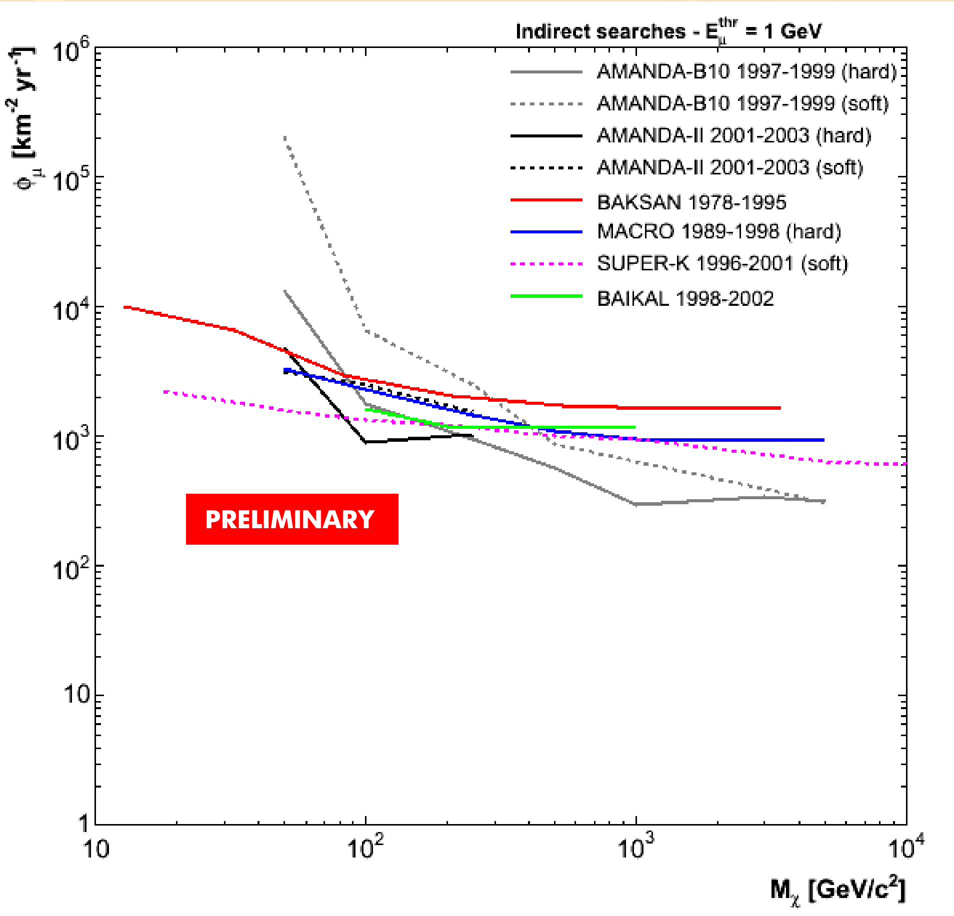

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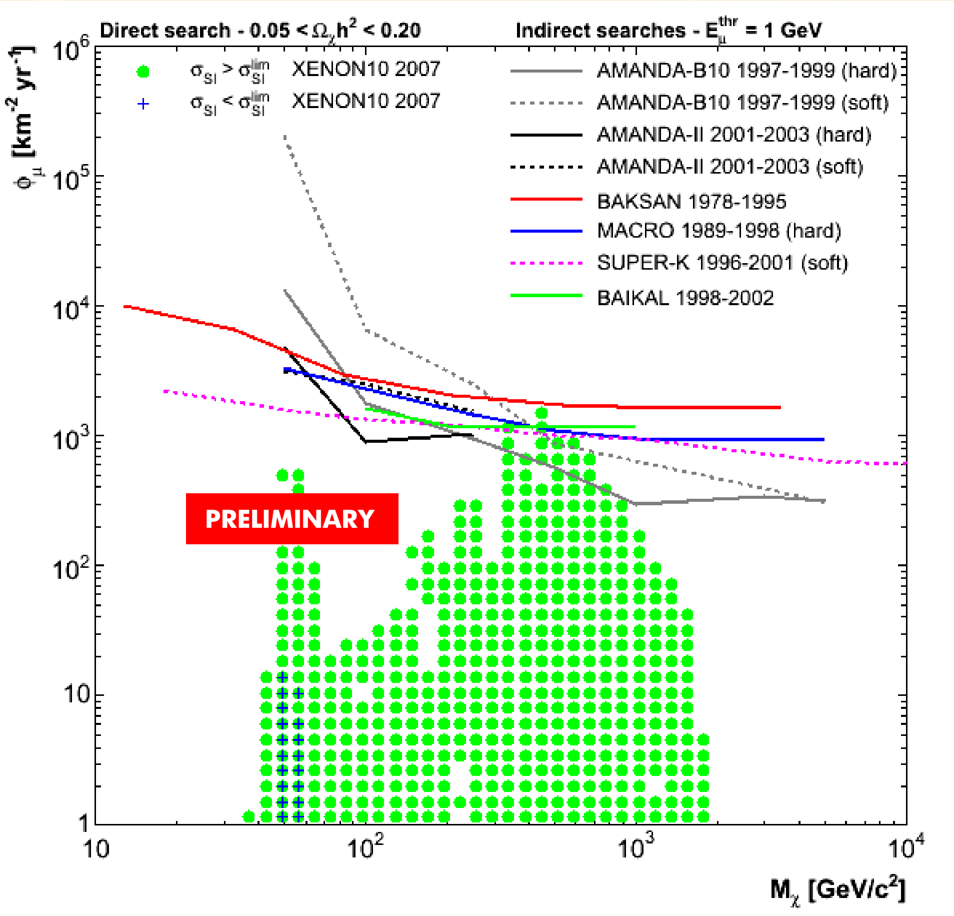

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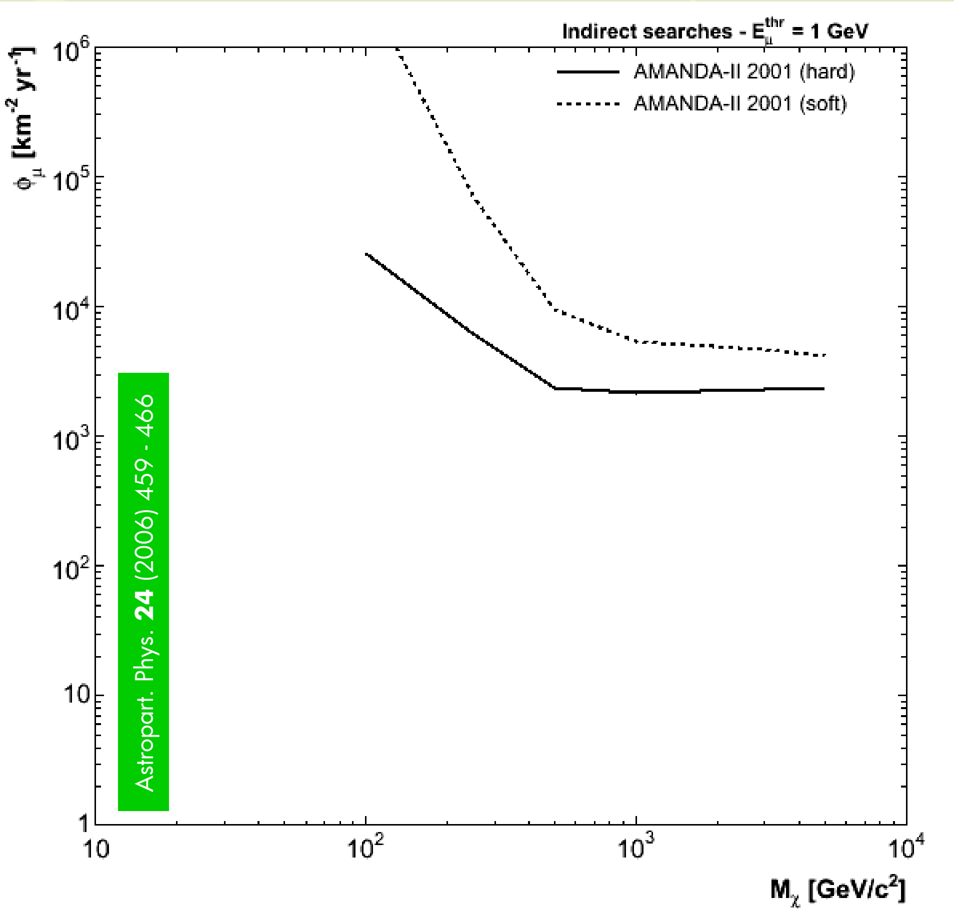
Outlook

- optimization for full mass range
- unblinding pending

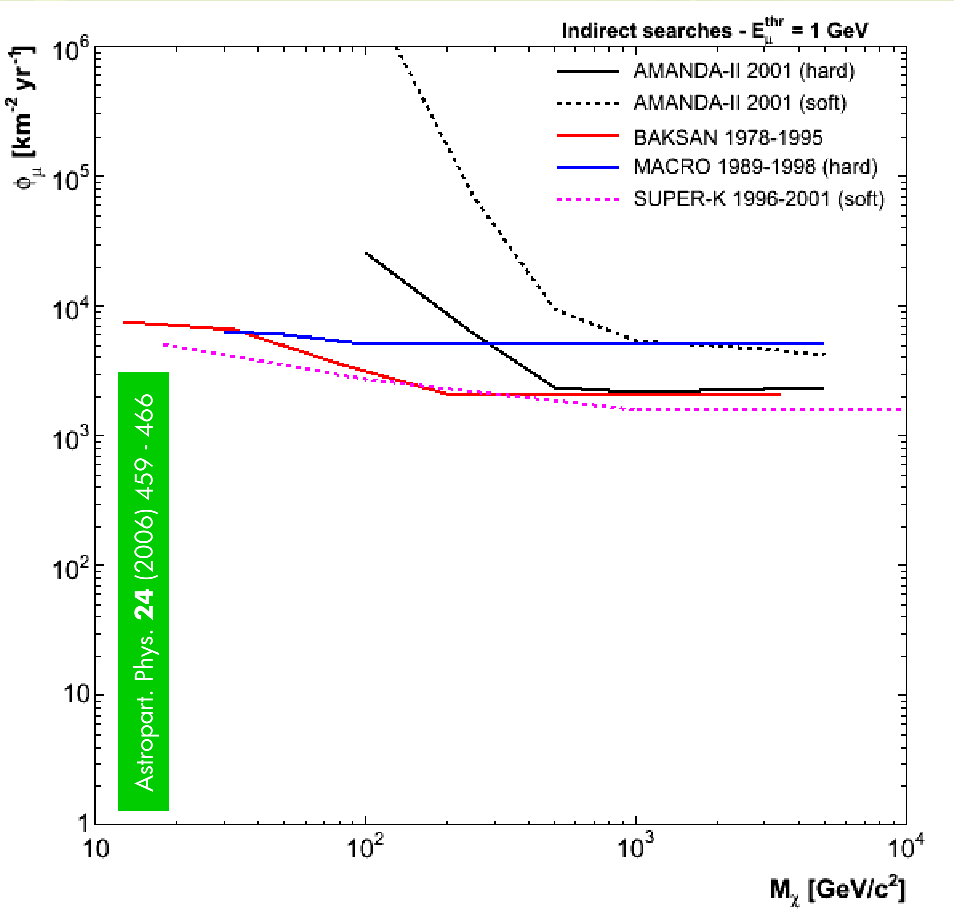
Muon flux limit – Sun 2001



Current results

- 1st AMANDA result
- no low E trigger

Muon flux limit – Sun 2001



Current results

- 1st AMANDA result
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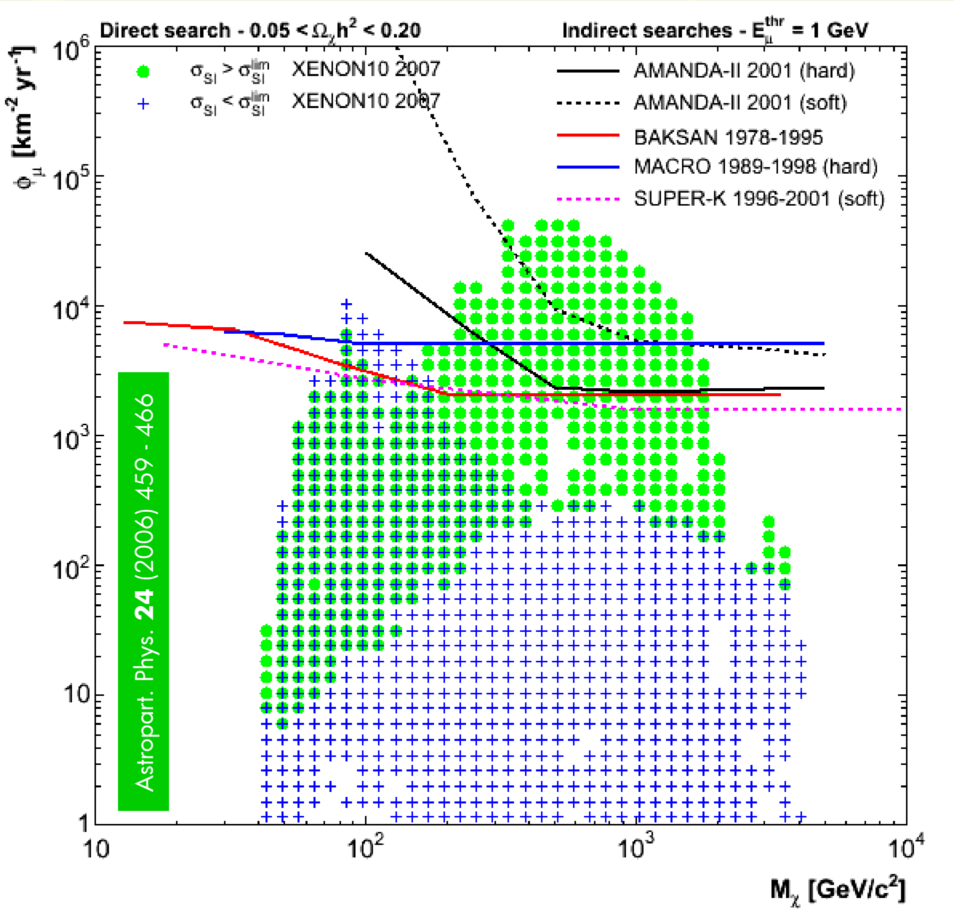
- competitive with 144 days of livetime

Muon flux limit – Sun 2001



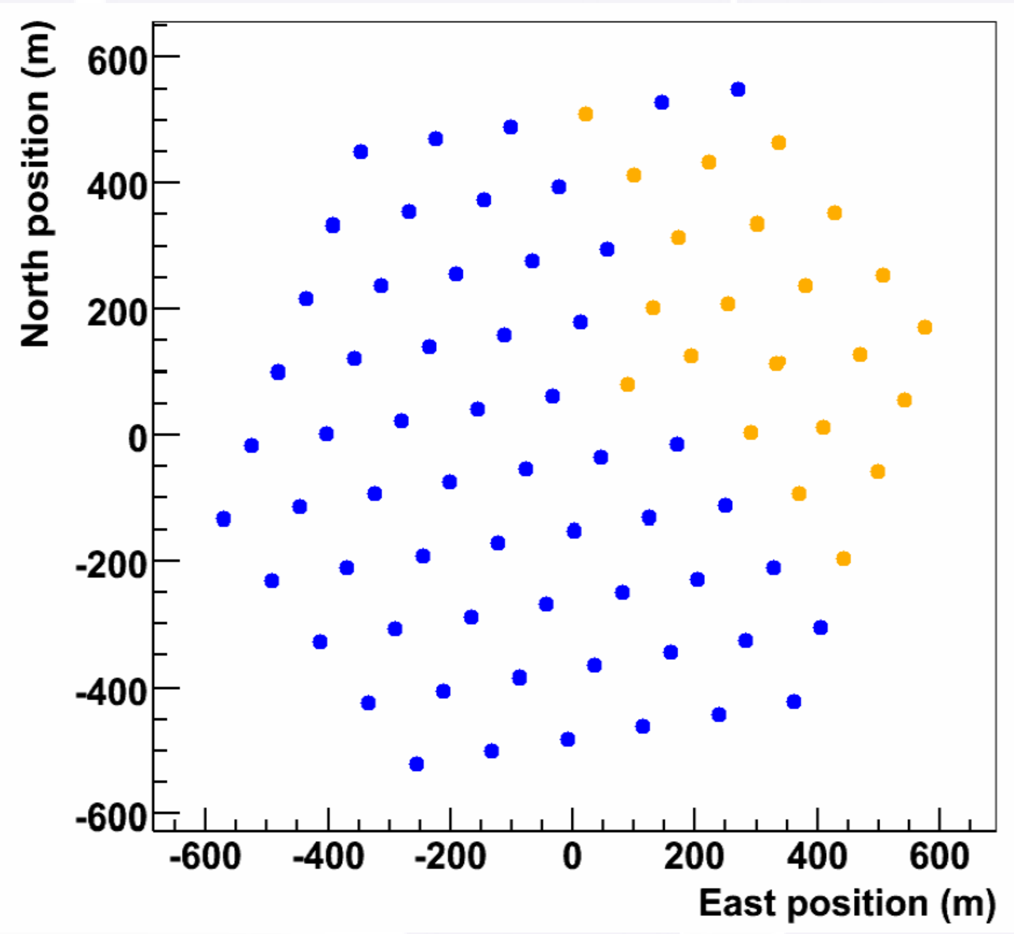
Current results

- 1^{st} AMANDA result
- no low E trigger
- competitive with 144 days of livetime

Outlook

- inclusion of low E triggers
- more statistics (2001–2005)
- improved analysis methods

IceCube-80 baseline geometry



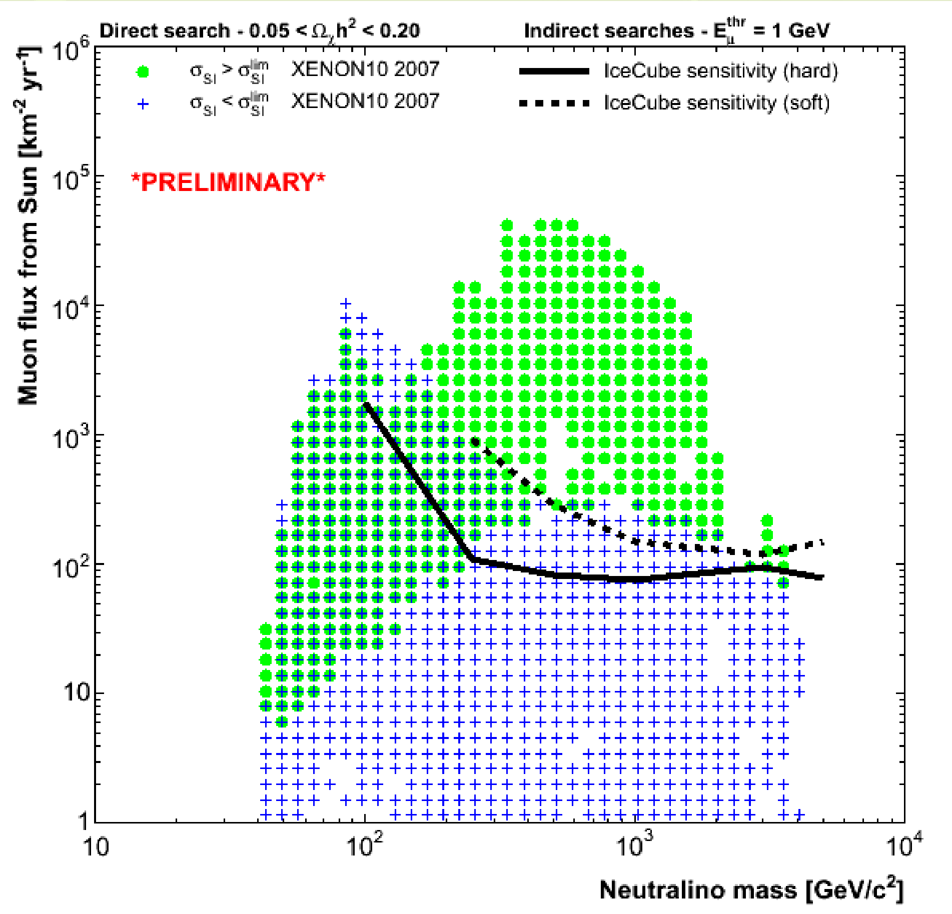
IceCube-80

- superior instrumentation (wrt AMANDA)
- up to 80 instrumented cables
- finished by 2011

Deployment status

- only during austral summer (Nov.-Feb.)
- IC-22 deployed and performs to specifications
- IC-(36-40) by Feb. 2008

Expected sensitivity IceCube-80



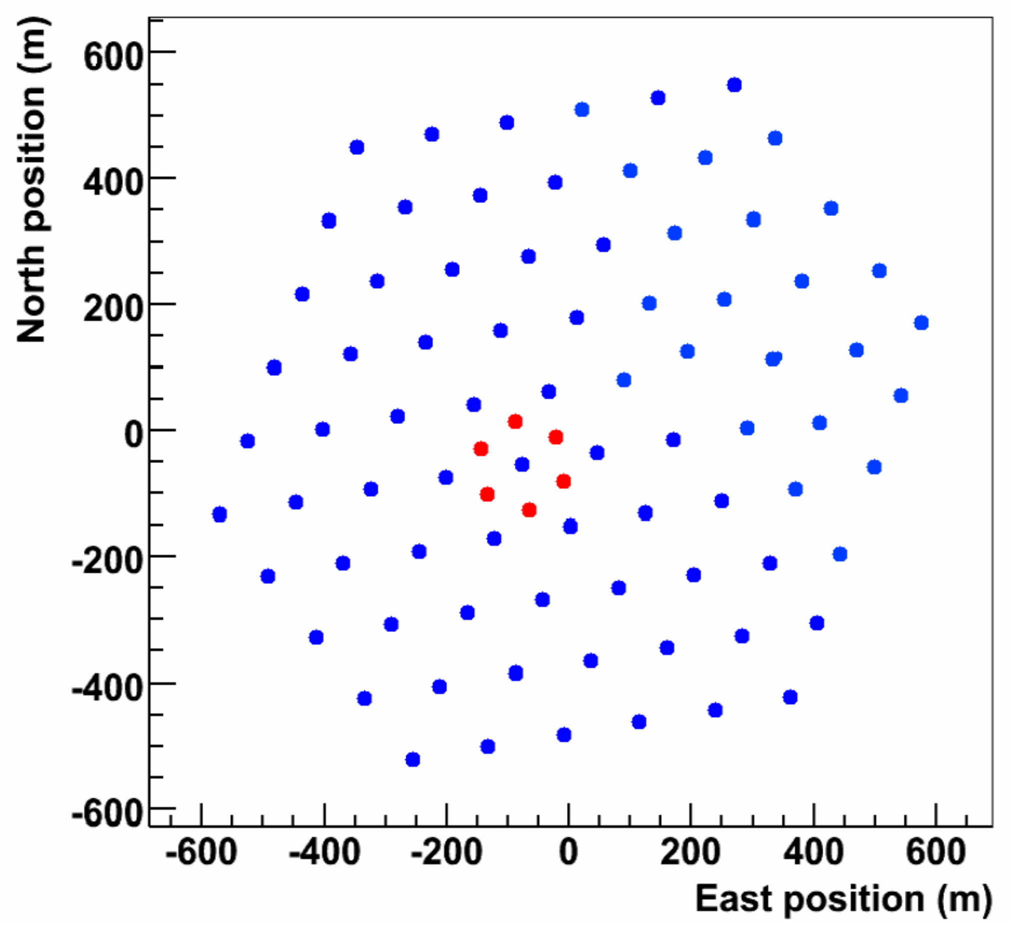
Analysis

- latest simulation and reconstruction tools
- BG: atm. μ and ν
- simple (suboptimal) filter

Sensitivity for

- Sun WIMPs
- 5 years livetime (=10 yr data taking)

Low energy extension IceCube-86



IceCube-86

- 6 additional *deep core* strings (funding requested for 6-12 strings)
- lower E_{thr}
  → increases signal efficiency
- use outer strings as μ veto
  → more efficient background rejection
- 4π detector for 10GeV-10TeV *always* live
- preliminary geometry

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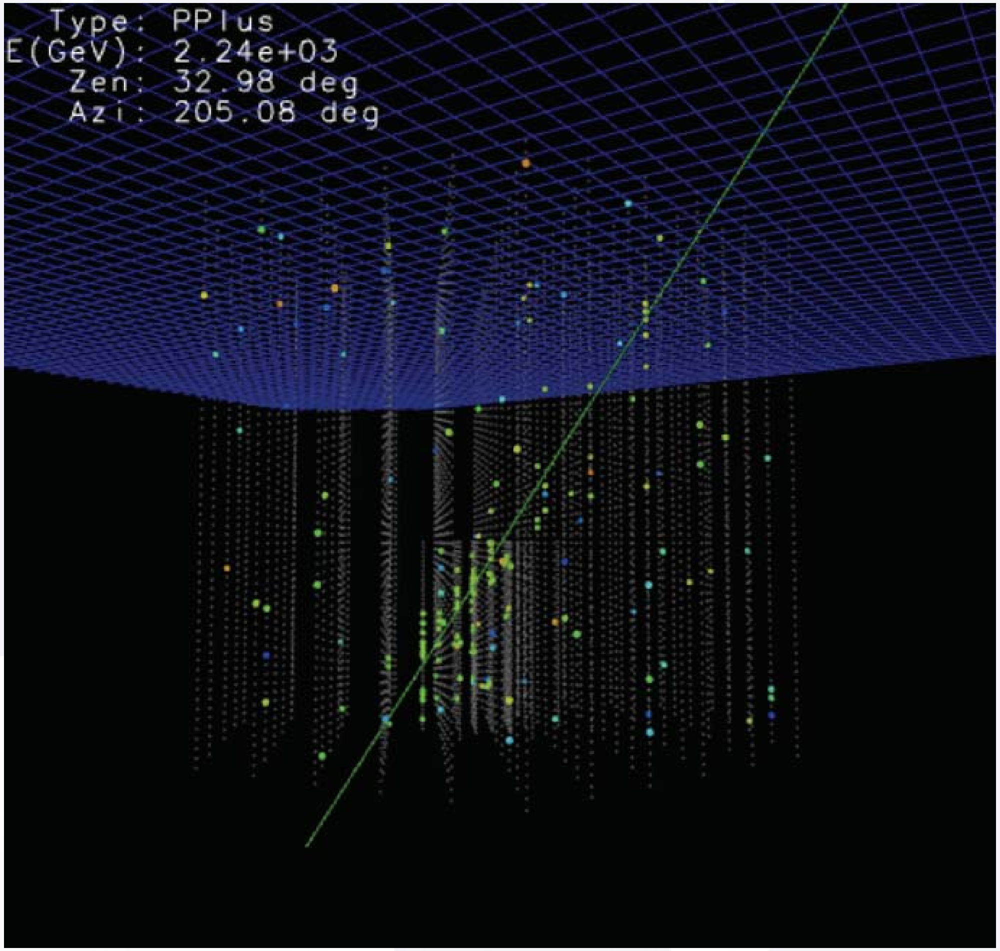

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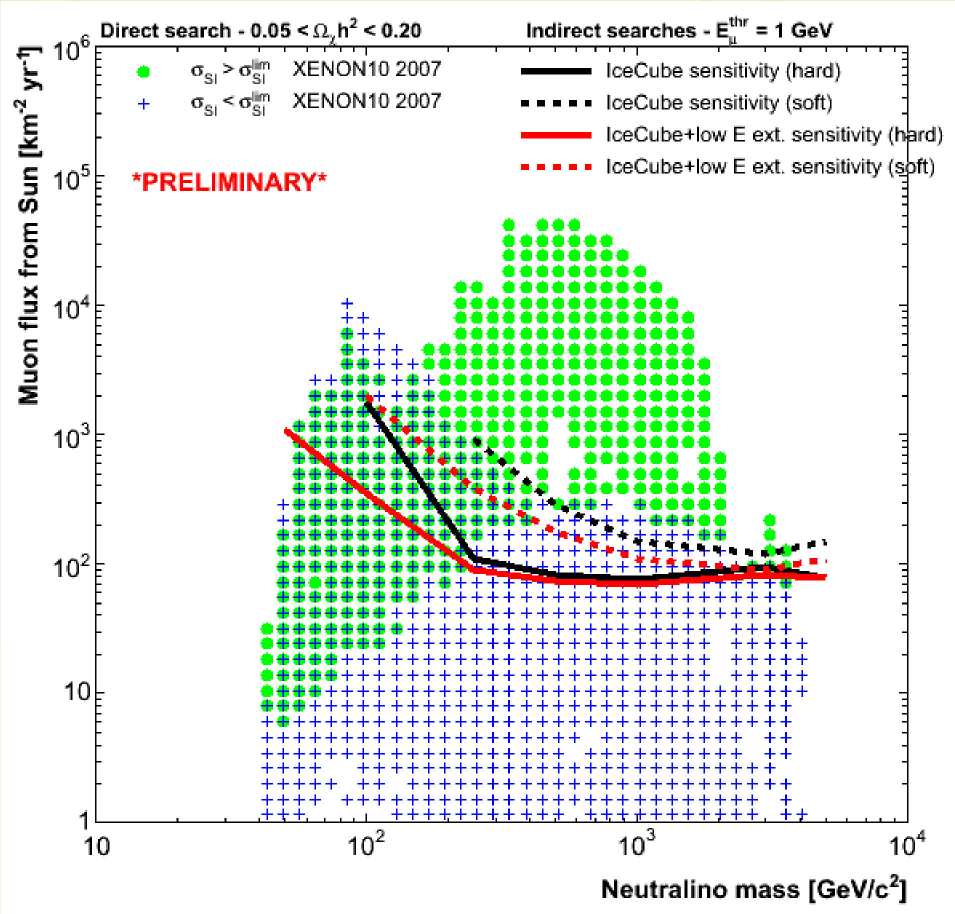


Sensitivity for

- Sun WIMPs
- 5 years livetime (=10 yr data taking)

Low energy extension

- essential for low masses (<250GeV)
- small gain for higher masses
- simple (suboptimal) filter
- even denser configuration possible if funding allows

Conclusion AMANDA

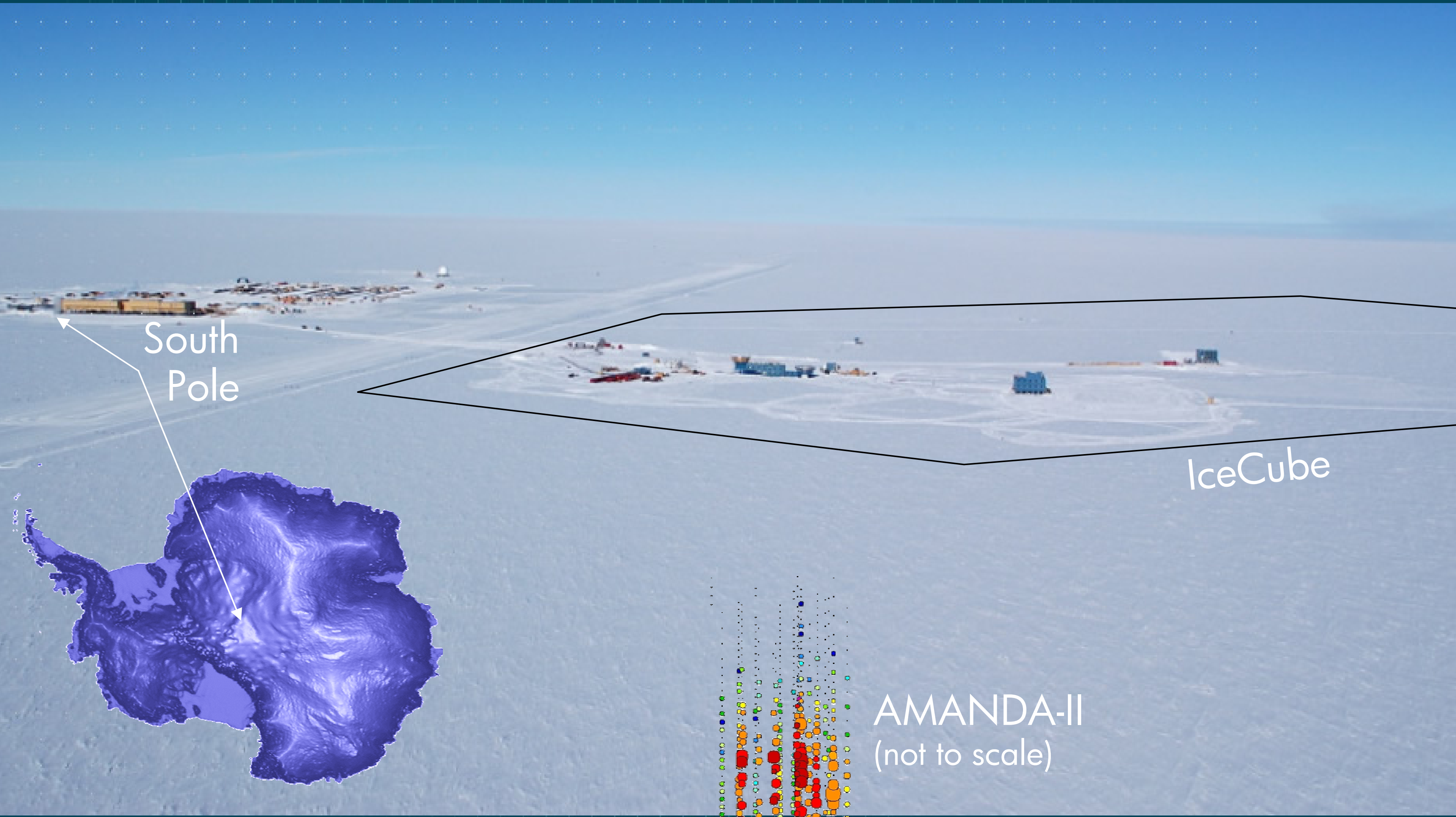
- No statistically significant excess of neutralino-induced neutrinos from the center of the Earth or the Sun observed
- AMANDA upper limits on the muon flux competitive with other indirect searches
- New trigger improves low E sensitivity by factor >10
- Final 2001–2005 results for Earth and Sun neutralinos follow soon

Conclusion IceCube

- IceCube deployment well underway, halfway by Feb. 2008
- IceCube sensitivities obtained with current analysis tools
- Low energy extension under investigation which improves sensitivity dramatically below M_χ<250GeV
- IceCube complementary with direct searches

Backup slides

Amundsen-Scott South Pole station



Experimental and simulated data

Experiment

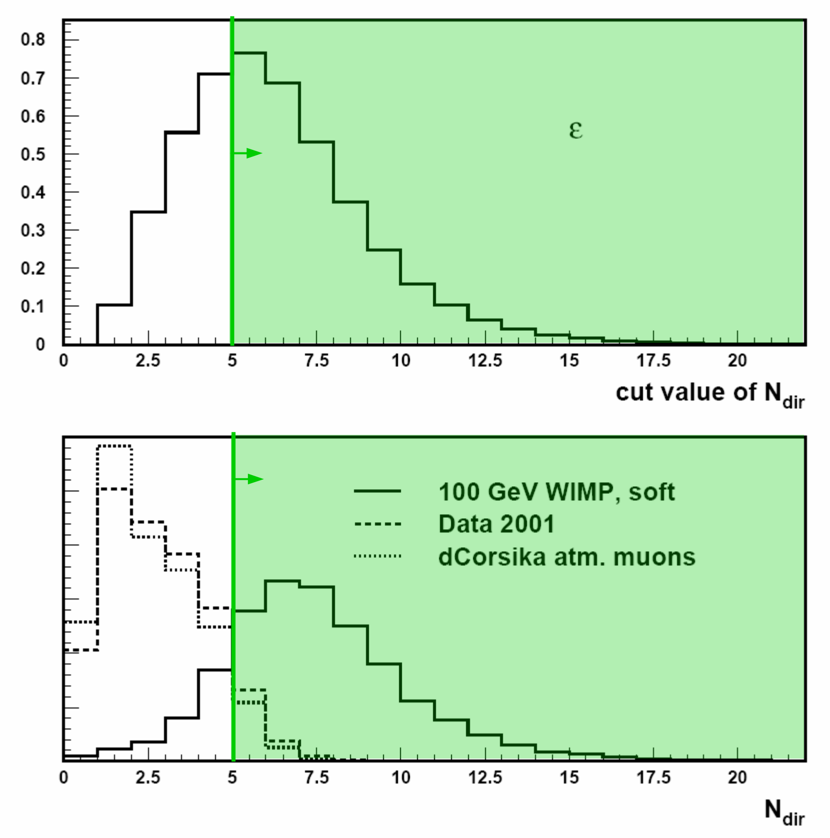
- 2001-2003: 5.3×10^9 events — 688.0 days eff. livetime
- 2001 (w/o string): 8.7×10^8 events — 143.7 days eff. livetime

Simulation

- neutralino: [DARKSUSY]
  - $50 \text{ GeV} < M_\chi < 5000 \text{ GeV}$
  - *hard* ($W^+W^-/\tau^+\tau^-$) and *soft* ($b\bar{b}$) ann. channel
  - $90° < \theta_\nu < 113°$ (Sun) — $\theta_\nu \sim 180°$ (Earth)
- atm. μ: [CORSIKA]
  - $600 \text{ GeV} < E_p < 10^{11} \text{ GeV}$ — $0° < \theta_{prim} < 90°$
- atm. ν: [ANIS]
  - $10 \text{ GeV} < E_\nu < 10^8 \text{ GeV}$ — $80° < \theta_\nu < 180°$

Rejection of atmospheric muons

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



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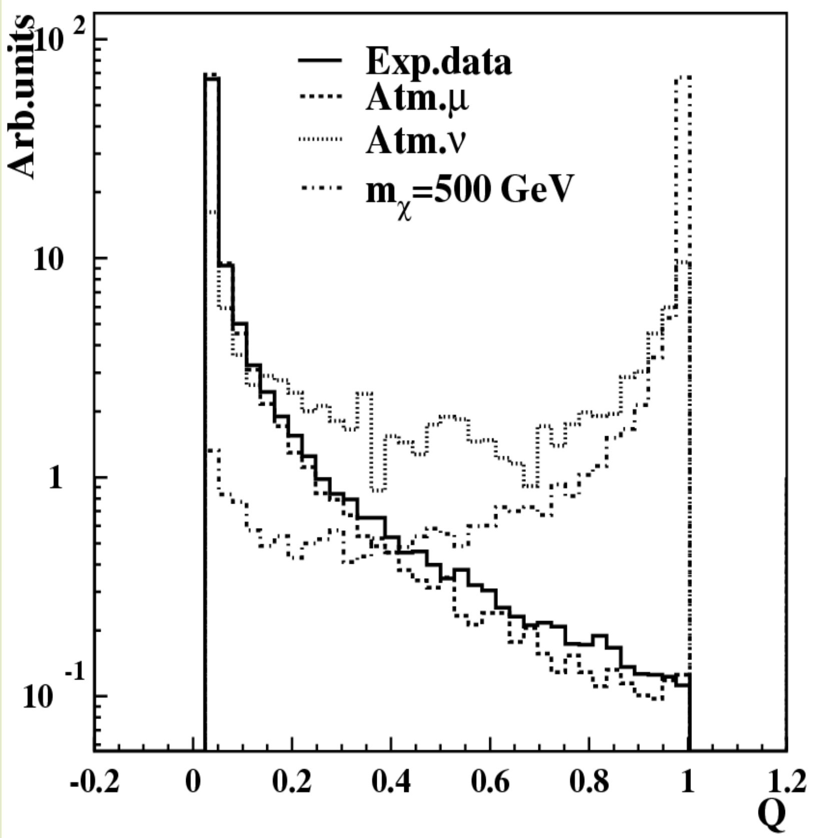
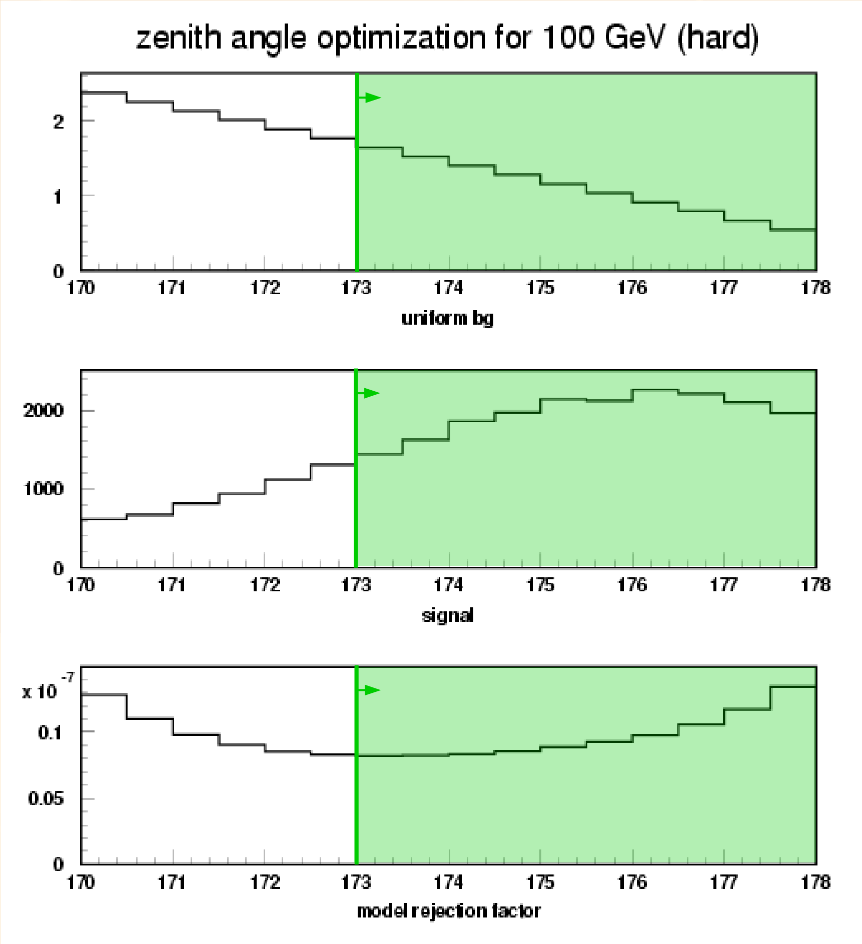


Optimizing search cone



Final search cone

- Assume isotropic atm. ν background in θ=160°-180°, 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