(Indirect) Dark Matter Searches with IceCube

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DJURÖNÄSET
KONFERENS • HOTELL

ICECUBE

UPPSALA UNIVERSITET

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Preamble

- The slides contain various references to ICRC proceedings. The official publication of the proceedings will probably take another few months, but the IceCube contributions will be published soon (in September) on arXive (in 6 bundles of 5-10 papers each, organized by topic).
- These PDF slides contain a few animations. It seems that these animations rely on javascript support, which is apparently not available in all PDF viewers. On my linux laptop they are correctly displayed only in `acroread`; programs like `evince` will only display the first frame.
- During the presentation I showed a few movies of IceCube simulations. The movie files are too big to embed in the slides.

Outline I

1. IceCube
    - IceCube Neutrino Observatory
    - Cherenkov light
    - Detector medium
    - Neutrino interactions
    - Track reconstruction
    - Cosmic rays
    - Anatomy of an IceCube Analysis
    - Recent results
2. Scattering cross section
    - Gravitational capture (recap)
    - Earth
    - Sun
3. Annihilation cross section
    - Annihilation of DM in galaxies (recap)
    - Galactic halo
    - Dwarf galaxies and galaxy clusters
4. DM-ice
    - DM-ice collaboration
    - DM-ice idea
5. Outlook
    - Outlook

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The IceCube Collaboration

International Funding Agencies

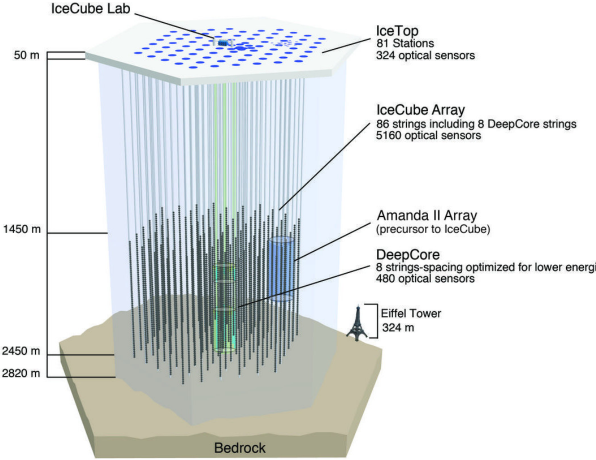
Fonds de la Recherche Scientifique (FRS-FNRS)
Fonds Wetenschappelijk Onderzoek-Vlaanderen (FWO-Vlaanderen)
Federal Ministry of Education & Research (BMBF)
German Research Foundation (DFG)
Deutsches Elektronen-Synchrotron (DESY)
Inoue Foundation for Science, Japan
Knut and Alice Wallenberg Foundation
Swedish Polar Research Secretariat
The Swedish Research Council (VR)
University of Wisconsin Alumni Research Foundation (WARF)
US National Science Foundation (NSF)

IceCube Neutrino Observatory

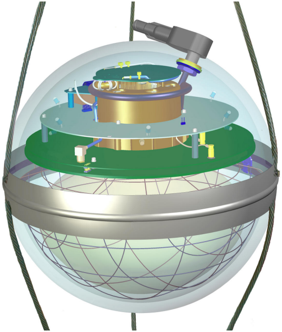
at Amundsen Scott South Pole Station

- Energy range:
  - IceTop: $\sim$ 300 TeV - EeV
  - In-ice array: $\sim$ 100 GeV - EeV
  - DeepCore: $\sim$ 10 GeV - TeV
- Trigger rate: 3 kHz
- Reliability:
  - 98.5% live DOMs
  - 99% uptime

More info:
http://icecube.wisc.edu



Digital Optical Module (DOM)



- 10 inch PMT in glass sphere (basket ball size)
- QE: 25% for DeepCore DOMs, 20% for others.
- dark noise 300-500 Hz
- digitization:
  - ATWD: 128 $\times$ 3.3 ns large dynamic range (good for close hits)
  - FADC: 256 $\times$ 25 ns modest dynamic range (good for remote hits)
- calibration:
  - $\mathcal{O}(1ns)$ timing accuracy:
    - Pulse unfolding from waveform
    - Clock synchronization between DOMs
  - 12 LED flashers on each DOM
    - inter-string timing
    - geometry checks
    - ice optical properties

More info: *Physics **26** (2006) 155-173, or* `arXiv:astro-ph/0604450`

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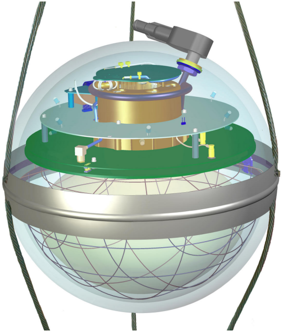

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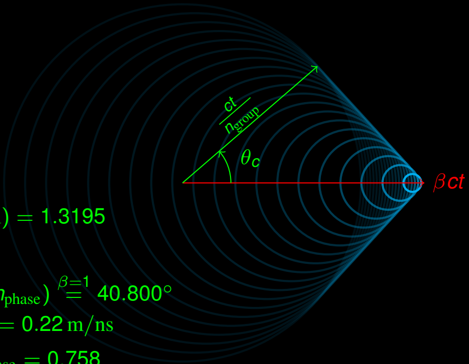
$\beta = 1.0$



$n_{\mathrm{phase}}(\lambda = 400\,\mathrm{nm}) = 1.3195$

$n_{\mathrm{group}} = 1.35634$

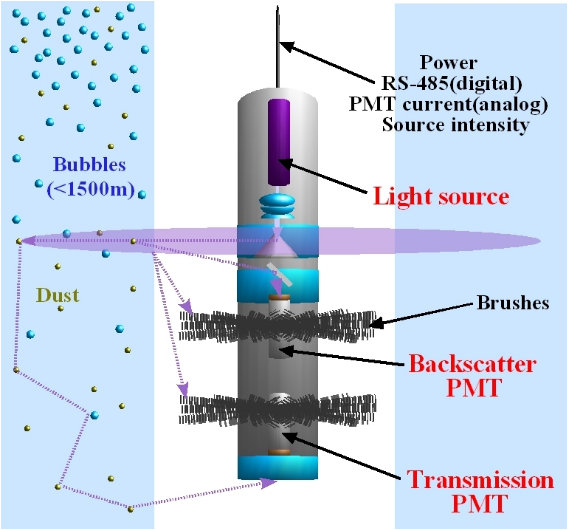
$\theta_c = \arccos(1/\beta n_{\mathrm{phase}}) \overset{\beta=1}{=} 40.800°$

$c_{ice} = c_{\mathrm{vac}}/n_{\mathrm{group}} = 0.22\,\mathrm{m/ns}$

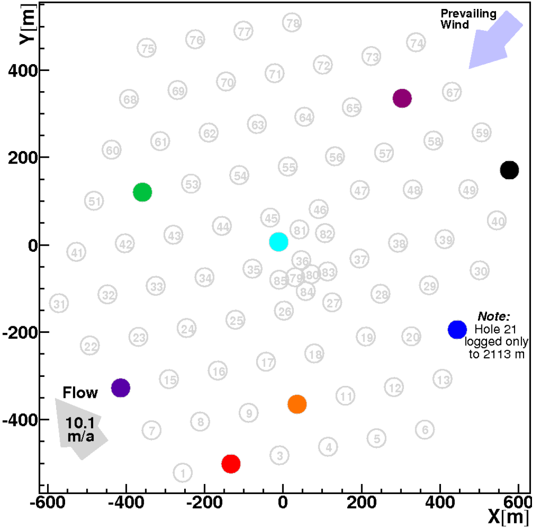
$\beta_{threshold} = 1/n_{\mathrm{phase}} = 0.758$

$\beta = 1.0$

Detector medium: dust logger data



Detector medium: dust logger data



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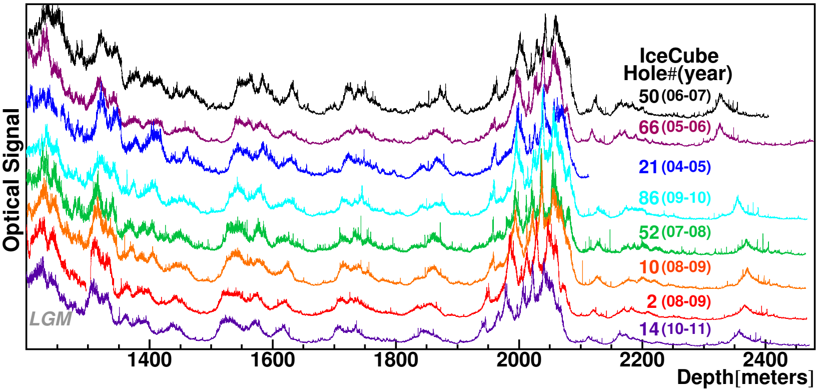

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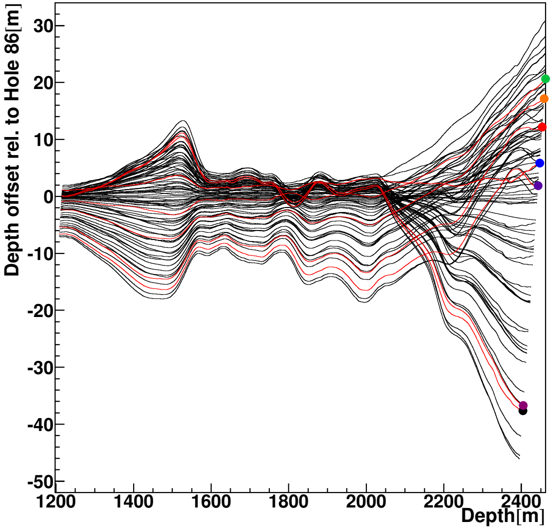

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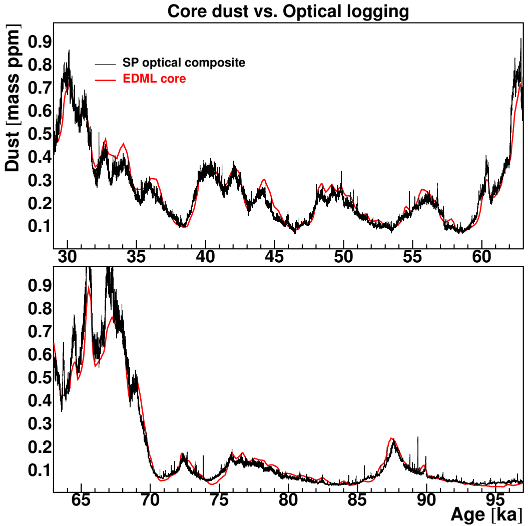
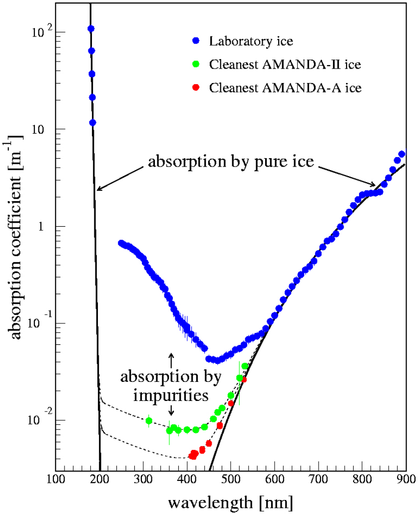


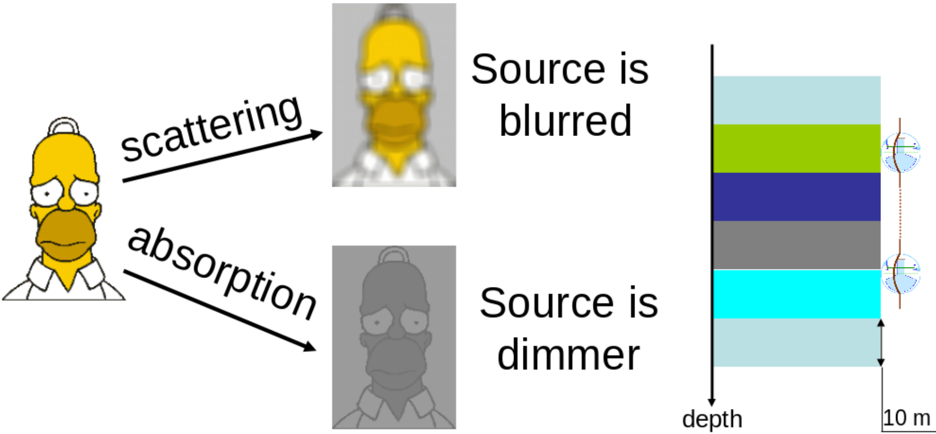
Optical properties

dust concentration $\neq$ optical properties
(but there is a strong correlation between the two)

South Polar ice is the cleanest ice we know



Scattering and Absorption of Light in Ice

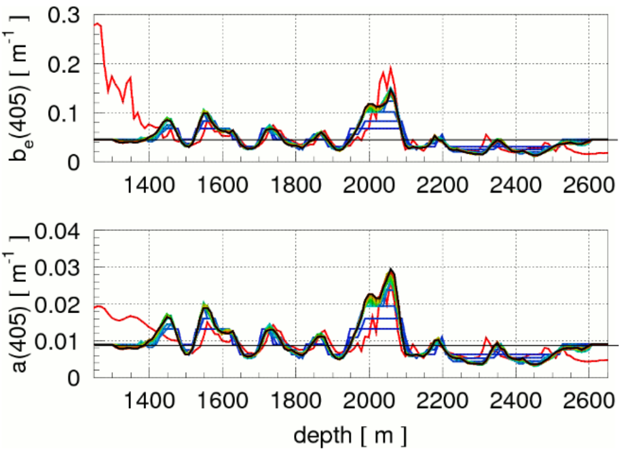


a = inverse absorption length ($1/\lambda_{abs}$)
b = inverse scattering length ($1/\lambda_{sca}$)

200+ parameters

(Slide stolen from Dima Chirkin)

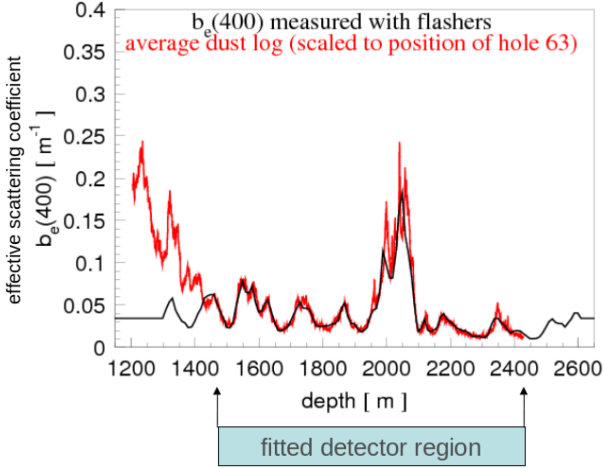
SPICE: South Pole Ice model



- Start with the bulk ice of reasonable scattering and absorption
- At each step of the minimizer compare the simulation of all flasher events at all depths to the available data set
- do this for many ice models, varying the properties of one layer at a time → select the best one at each step
- converge to a solution!

(Slide stolen from Dima Chirkin)

Correlation with dust logger data



(Slide stolen from Dima Chirkin)

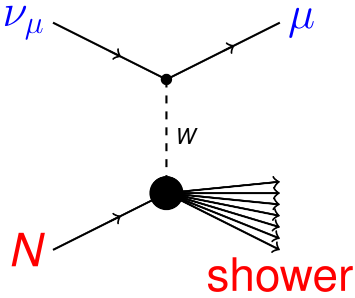
More info on dust logging:

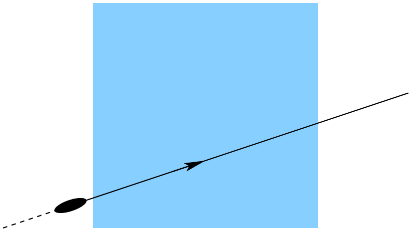
- *Geophysical Research Letters **32** (2005) L21815 1-4*
- New paper submitted to Journal of Glaciology, coming out soon
- Ryan Bay's dust map website:
  `http://icecube.berkeley.edu/~bay/dustmap/`

More info on optical aspects of the ice:

- *NIM **A711** (2013) 73-89, or* `arXiv:1301.5361 [astro-ph.IM]]`
- *Journal Of Geophysical Research **Vol. 111** (2006) D13203*

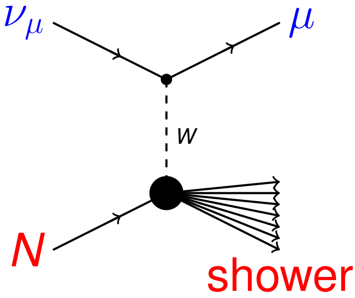
Neutrino interactions: CC ν_μ

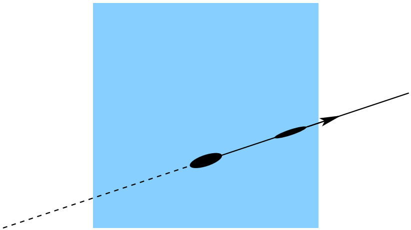




(ν_μ starting outside of IceCube array)

Neutrino interactions: CC ν_μ





(ν_μ starting inside the array)

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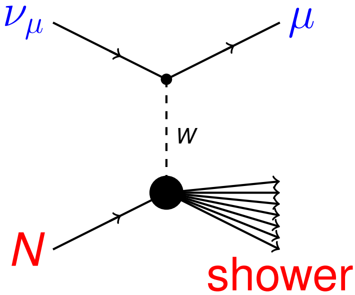
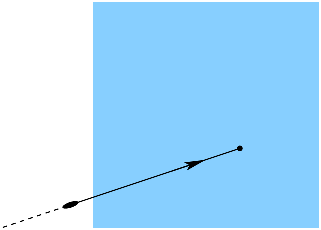
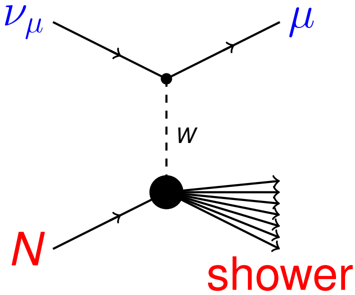
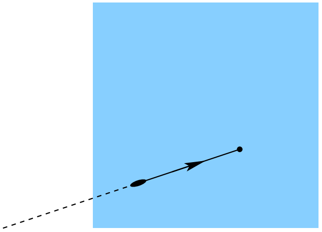




(ν_μ with μ stopping inside the array) (LE ν_μ with μ contained inside the array)

Neutrino interactions: CC ν_μ





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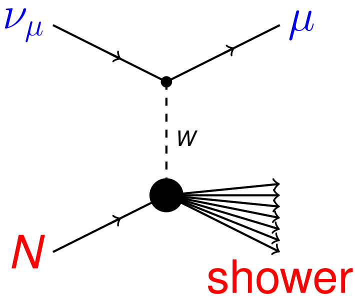
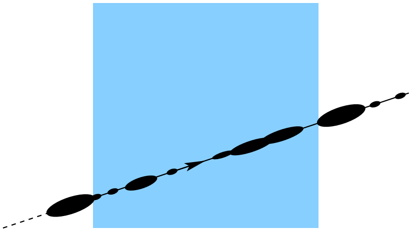
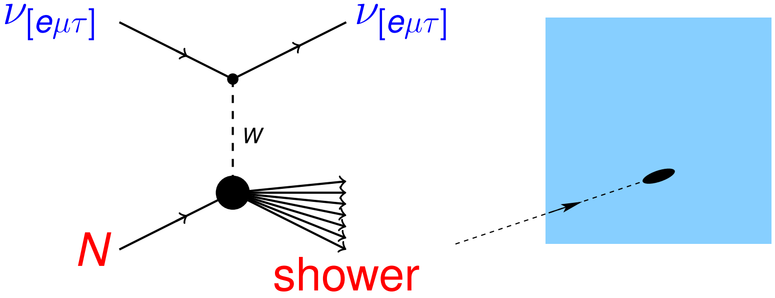




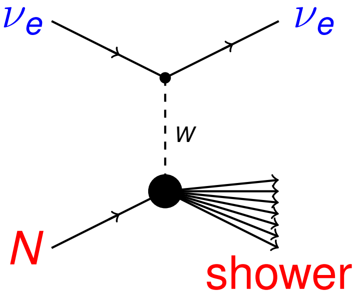
(HE ν_μ, with stochastic showers)

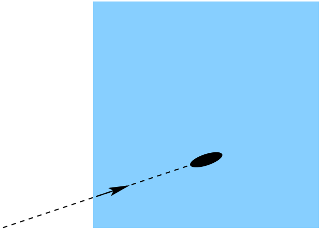
Neutrino interactions: NC $\nu_{[e\mu\tau]}$



($\nu_{[e\mu\tau]}$ interacting (NC) inside the array)

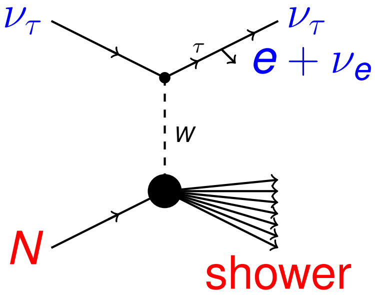
Neutrino interactions: CC ν_e

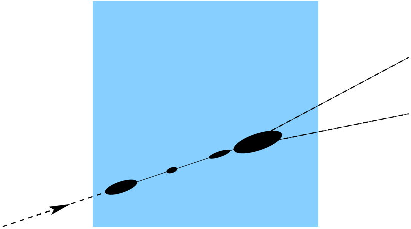




(ν_e interacting (CC) inside the array)

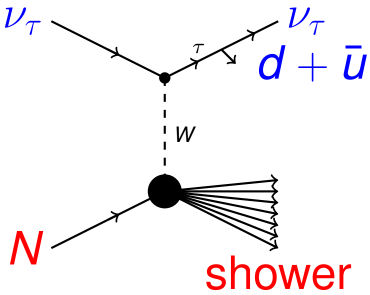
Neutrino interactions: CC ν_τ

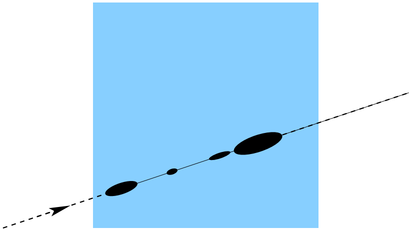




("double bang")

Neutrino interactions: CC ν_τ





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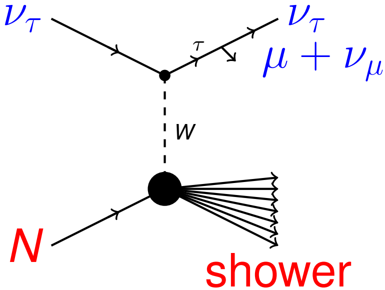
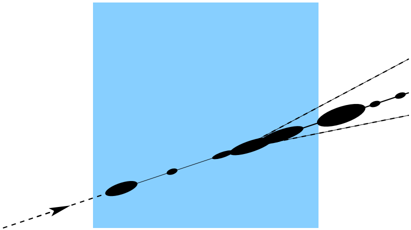
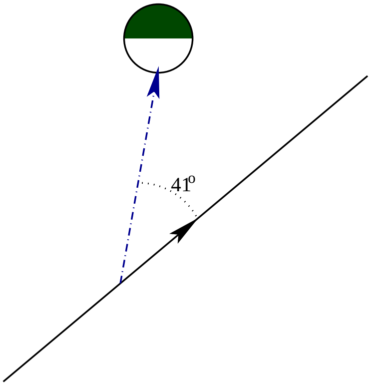




(faint HE tau decaying into bright HE muon)

Light & Photoelectrons



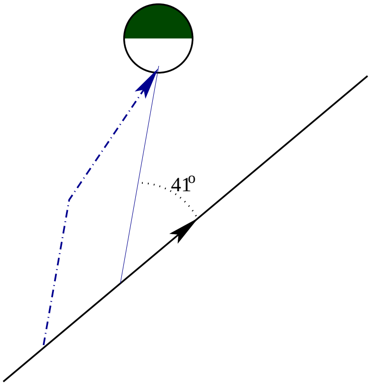
To be modeled:

- Light Emission
- Scattering, absorption
- Time residual
- Arrival time distribution
- Jitter, noise
- Expected total number of PE

Available solutions:

- Analytic: Pandel
- Tabulated raytracing: Photonics

Light & Photoelectrons



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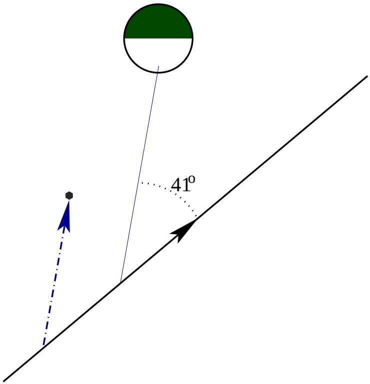

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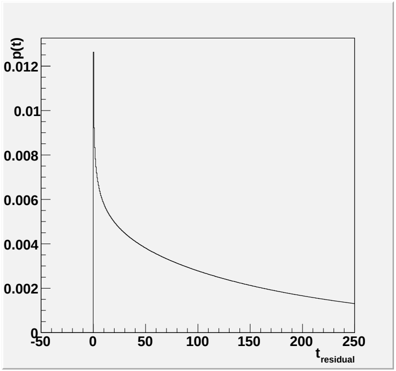

$$t_{residual} = t_{pulse} - t_{direct}$$

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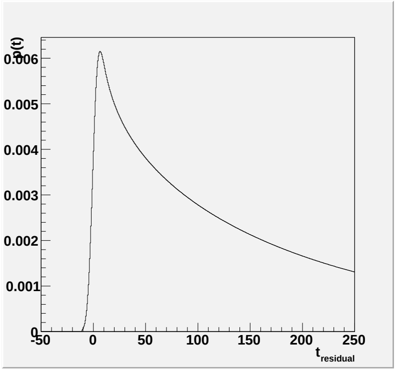

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Light & Photoelectrons

$$p(\xi, \rho, t) = \frac{\rho^{\xi} t^{\xi - 1}}{\Gamma(\xi)} e^{-\rho t}$$

$\xi = R/\lambda$
$\rho = \frac{1}{\tau} + \frac{c}{\lambda_a}$

$$\mathcal{F}_{\sigma}(\xi, \rho, t) = \int_{-\infty}^{+\infty} p(\xi, \rho, t') g_{\sigma}(t' - t, \sigma) dt'$$

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Light & Photoelectrons

(photonics movie)

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Track and energy reconstruction

(interactively on the whiteboard)

Cosmic rays

- both a dominant background and an interesting signal
- too big a topic to cover here!

Anatomy of an IceCube Analysis I

1. Events are selected by a trigger and saved by the DAQ (3kHz).
   - simple multiplicty triggers
   - single string triggers
   - slow partile triggers
   - fixed rate
2. Processing and Filtering
   - Computing farm at Pole: 400 cores
   - Calibrate waveforms, extract pulse times & charges
   - Simple event splitting
   - Fast reconstructions
   - Two dozen filters flag various types of "interesting events", e.g. upgoing muons, cascade candidates, events from the direction of the Moon/Sun/GC, extremely bright events, events starting in DeepCore.
3. Transmission by satellite of filtered events "to the North"
   - Available bandwidth $\sim$ 90 GiB/day
   - All raw data are written to tape but read only in very exceptional cases.
   - Starting with IC86, most events are transmitted with compressed event data (digitized pulses instead of full waveforms).
4. "Level 2" processing:
   - (usually minor) changes in detector status information
   - more elaborate event reconstructions
   - common to (almost) all analyses
5. Define blindness strategy

Anatomy of an IceCube Analysis II

- depends on analysis
- E.g.: randomize event time for point source searches

6. "Level 3" processing:
   - channel-specific: muon, cascade, WIMP, ...
   - event selection (passing rate 1-10%)
   - more elaborate event reconstructions, including angular error estimates
7. Final event selection:
   - straight cuts or multivariate analysis methods (BDT, random forest)
   - typical observables:
     - multiplicity (total charge, number of hit strings/DOMs)
     - track fit likelihood and error estimate
     - quantities derived from "direct hits" (hits from almost unscattered photons)
8. Unblinding review
   - The entire analysis must be defined before looking at the final level data
   - If possible: define procedure for all conceivable outcomes
9. Unblind
10. Compute results, evaluate, troubleshoot
11. Publish
12. `goto 1`

Recent results

- Point source search: nothing found so far, limits going down...
  - Steady point source search: e.g. ICRC 2013 paper 550
  - Transient point source search: e.g. *Nature* ***484*** *(2012) 351-354, or* *`arXiv:1204.4219 [astro-ph.HE]`*
- IceCube confirms neutrino oscillation parameters
  - E.g. ICRC 2013 papers 848 (and 450, 455, 460)
- High Energy Starting Events: 4σ excess!
  - E.g. ICRC 2013 paper 650
  - Paper submitted to Science

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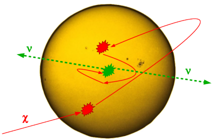
Gravitational capture (recap)



(M. Danninger)

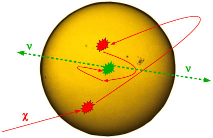
- WIMPs may scatter elastically
  - in the Sun
  - in the Earth
- and lose enough E_{kin} such that $v_\chi < v_{esc}$
- lose more E_{kin}, accumulate in center
- annihilate into SM particles, including neutrinos
- detection of escaping neutrinos:
  - effectively a specialized point source search
  - on/off-source regions "easy" for Solar WIMP searches
  - no good off-source regions for Earth WIMP searches
  - insensitive to $\langle \sigma_A v \rangle$ (as long as it is large enough)
  - dependencies, assumptions:
    - WIMP mass m_χ
    - velocity distribution
    - local DM density ("dark disc"?)
    - ...

$$\frac{dN}{dt} = C_C - C_A N^2 - C_E(M_\chi) N$$

$$\tau = 1/\sqrt{C_C C_A}$$

$$\Gamma_A(t_\odot) = \frac{1}{2} C_C \tanh^2\left(\frac{t_\odot}{\tau}\right) \overset{t_\odot \gg \tau}{=} \frac{1}{2} C_C$$

Gravitational capture (recap)



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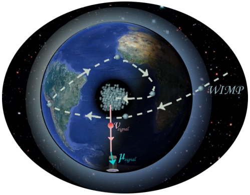
Gravitational capture (recap)



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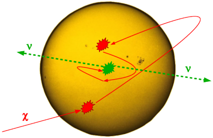

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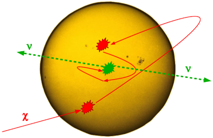

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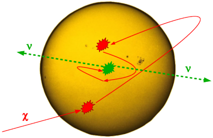

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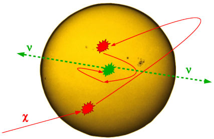

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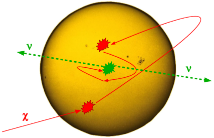

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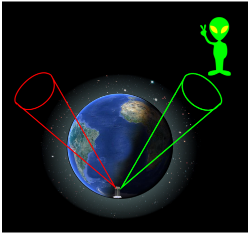

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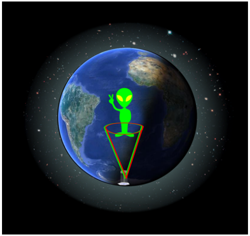

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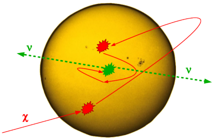

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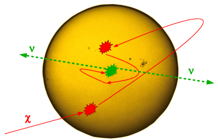

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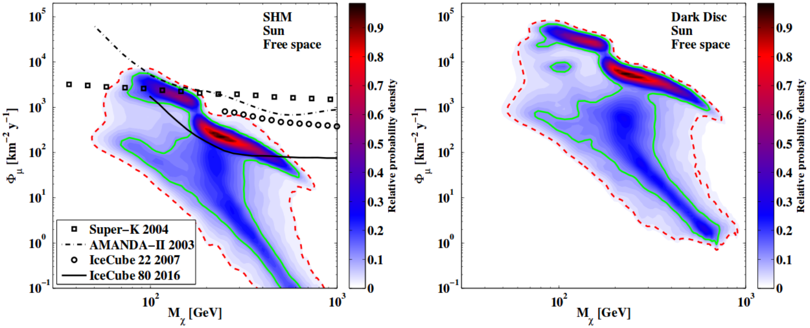
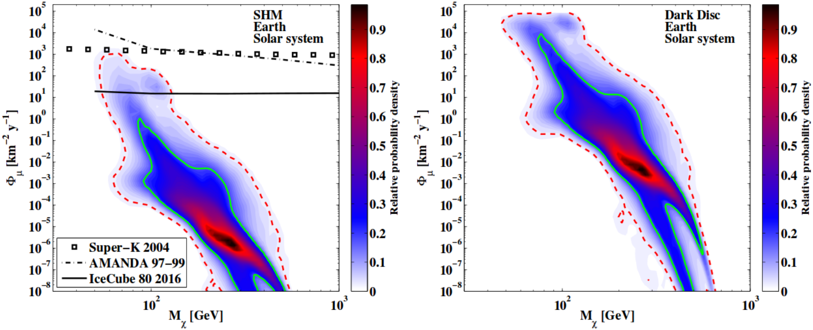
Dark disc? Effect on Φ_μ from Sun



Bruch et al., arXiv:0902.4001

However: *Pestaña & Eckhart*, arXiv:1009.0925, *Bidin et al.*, arXiv:1011.1289, *Sanchez-Salcedo et al.*, arXiv:1103.4356, *Bidin et al.*, arXiv:1204.3924

Dark disc? Effect on Φ_μ from Earth center



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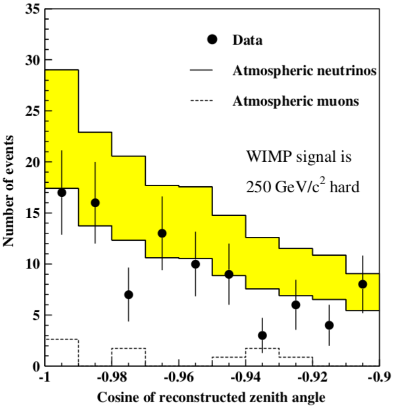
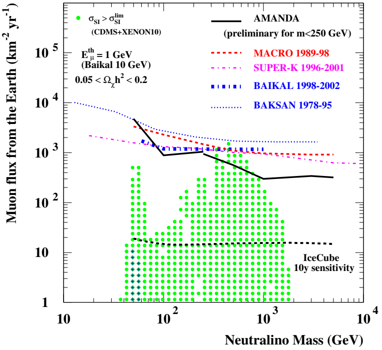
Earth WIMPs: AMANDA result

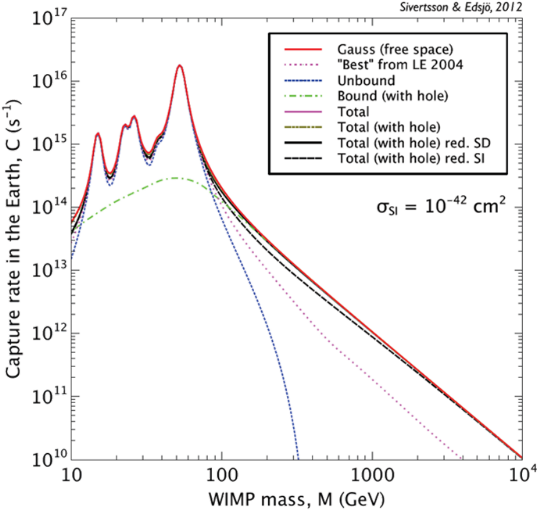
Data from AMANDA-B10 (1997-1999) and AMANDA 2001-2003





Achterberg et al., Astropart. Phys. ***26*** *(2006) 129*

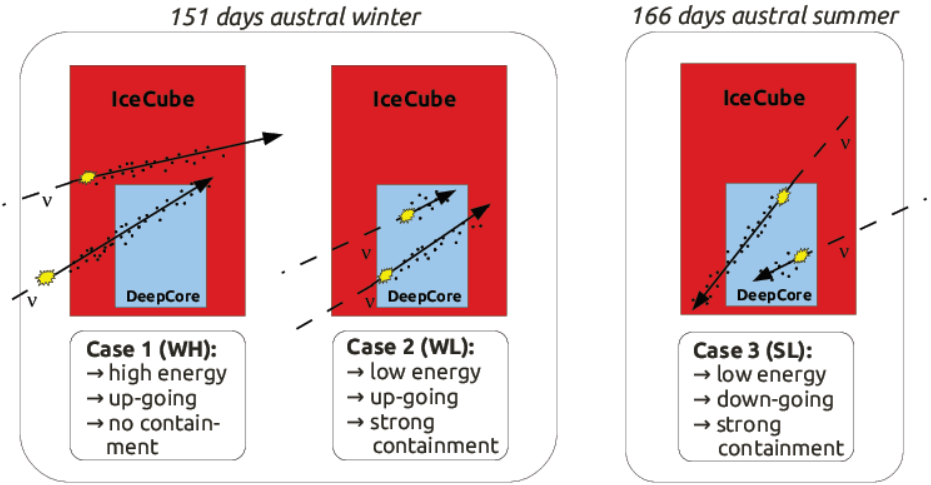
Earth WIMPs: capture rates



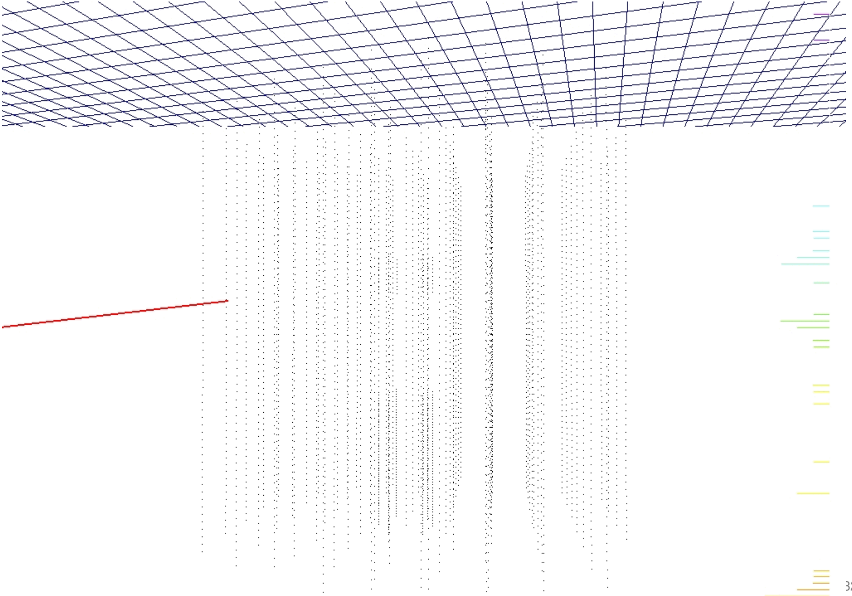
Sivertsson & Edsjö, Phys. Rev. ***D85*** *(2012) 123514, or* `arXiv:1201.1895 [astro-ph.HE]`

IceCube-79 string analysis details

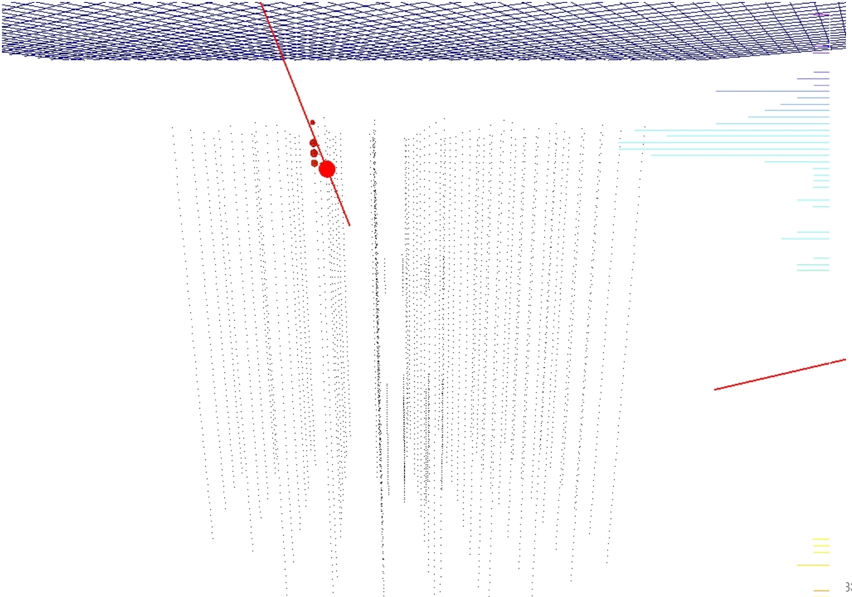
- Analysis for the whole year! Used 317 days livetime
- With DeepCore, analysis reaches neutrino energies of *10-20GeV*



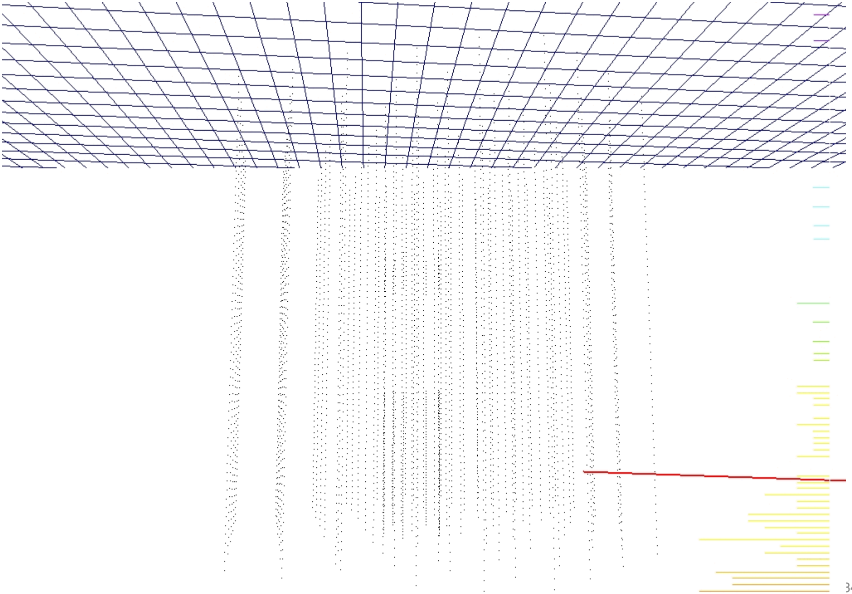
Single event example



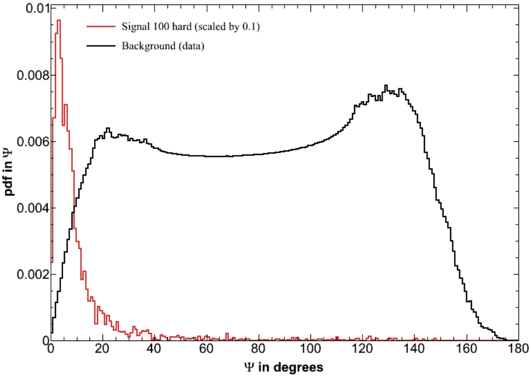
Coincident event example



Event starting in DeepCore example



Analysis method



Ψ is the angle between the reconstructed track and the Sun

Analysis method

1. Construction of PDFs:
   - Determine $f_s(\Psi)$ from MC for (all signal models) $\times$ (4 event selections)
     - Sun direction = neutrino direction
   - Determine $f_{BG}(\Psi)$ from data for all (4) event selections
     - Sun direction is computed from scrambled event time
2. Define likelihood for μ signal events per N event in the final event selection:

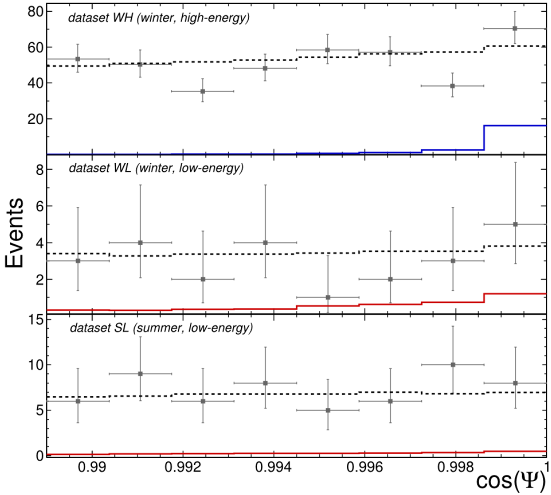
$$
\begin{aligned}
f(\mu, \Psi) &= \frac{\mu}{N} f_s(\Psi) + \left(1 - \frac{\mu}{N}\right) f_{BG}(\Psi) \\
\mathcal{L}(\mu) &= \prod_{i=1}^{N} f(\mu, \Psi_i)
\end{aligned}
$$

3. Let $\hat{\mu}$ be the value of μ that maximizes $\mathcal{L}$; then

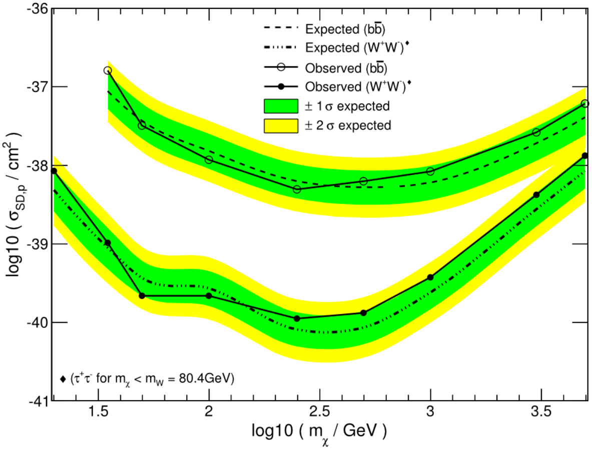
$$
\mathcal{R}(\mu) = \frac{\mathcal{L}(\mu)}{\mathcal{L}(\hat{\mu})}
$$

4. Feldmann-Cousins 90% confidence interval construction

Angle between neutrino and the Sun

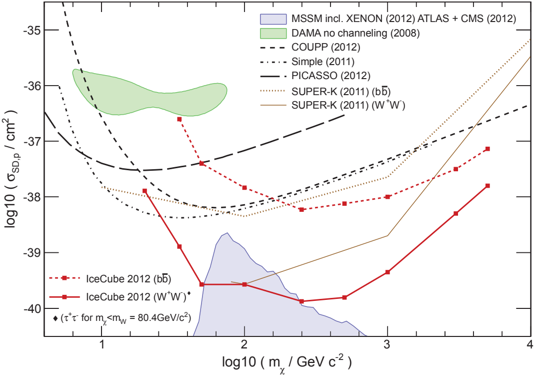


SD limits with expected sensitivity



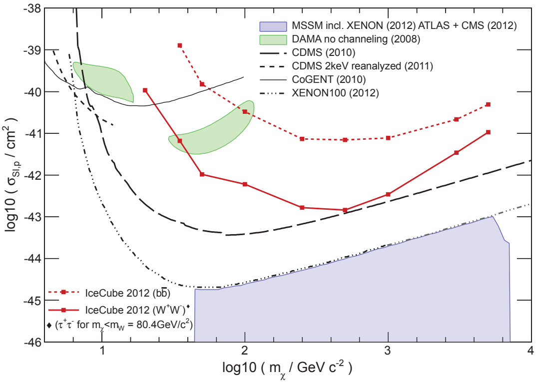
R. Abbasi et al., Phys. Rev. ***D81*** *(2010) 057101, or* `arXiv:0910.4480 [astro-ph.CO]`

SD Limits



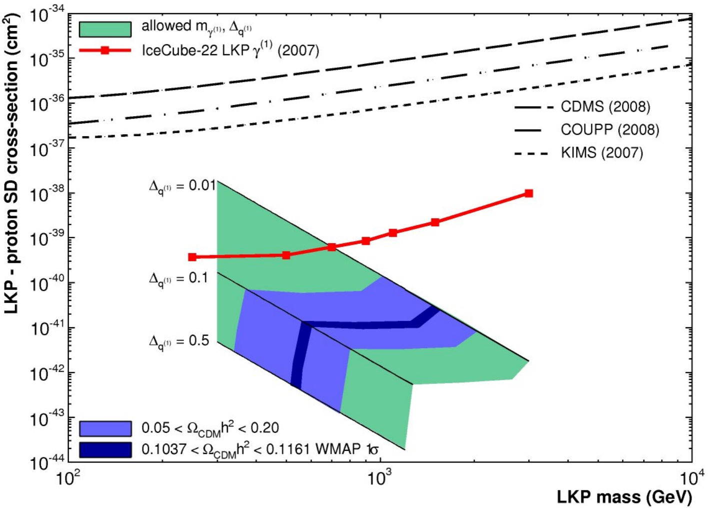
R. Abbasi et al., Phys. Rev. ***D81*** *(2010) 057101, or* `arXiv:0910.4480 [astro-ph.CO]`

SI Limits



R. Abbasi et al., Phys. Rev. ***D81*** *(2010) 057101, or* `arXiv:0910.4480 [astro-ph.CO]`

Kaluza-Klein dark matter

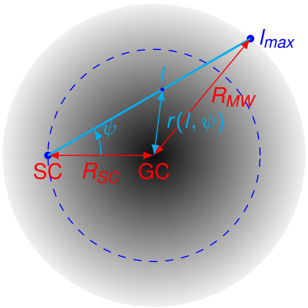


R. Abbasi et al., Phys. Rev. ***D81*** *(2010) 057101, or* `arXiv:0910.4480 [astro-ph.CO]`

Outline

1. IceCube
   - IceCube Neutrino Observatory
   - Cherenkov light
   - Detector medium
   - Neutrino interactions
   - Track reconstruction
   - Cosmic rays
   - Anatomy of an IceCube Analysis
   - Recent results
2. Scattering cross section
   - Gravitational capture (recap)
   - Earth
   - Sun
3. Annihilation cross section
   - Annihilation of DM in galaxies (recap)
   - Galactic halo
   - Dwarf galaxies and galaxy clusters
4. DM-ice
   - DM-ice collaboration
   - DM-ice idea
5. Outlook
   - Outlook

Annihilation (and decay) of DM in galaxies (recap)



$$r(l,\psi) = \sqrt{R_{SC}^2 - 2lR_{SC}\cos\psi + l^2}$$

$$J_A(\psi) = \int_0^{l_{\max}} \left(\frac{\rho(r(l,\psi))}{\rho_{SC}}\right)^2 \frac{dl}{R_{SC}}$$

$$J_D(\psi) = \int_0^{l_{\max}} \frac{\rho(r(l,\psi))}{\rho_{SC}} \frac{dl}{R_{SC}}$$

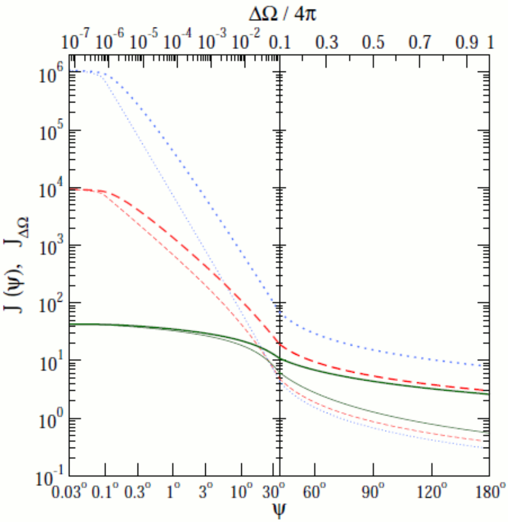
Neutrino flux in IceCube:

$$d\phi_A/dE_\nu\,(\psi) = \frac{1}{2}\langle\sigma_A v\rangle J_A(\psi)\frac{R_{SC}\rho_{SC}^2}{4\pi m_\chi^2} d\mathcal{N}_{A,\nu}/dE_\nu$$

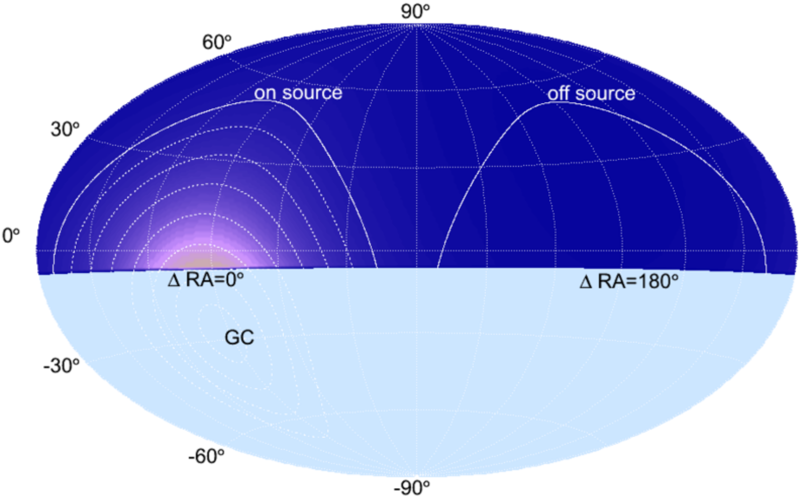
$$d\phi_D/dE_\nu\,(\psi) = \frac{1}{2\tau_\chi} J_D(\psi)\frac{R_{SC}\rho_{SC}}{4\pi m_\chi} d\mathcal{N}_{D,\nu}/dE_\nu$$

More info: *Phys. Rev.* ***D76*** *(2007) 123506, or* `arXiv:0707.0196 [astro-ph]`

Line of sight integral (annihilation)



Galactic halo (IC22)



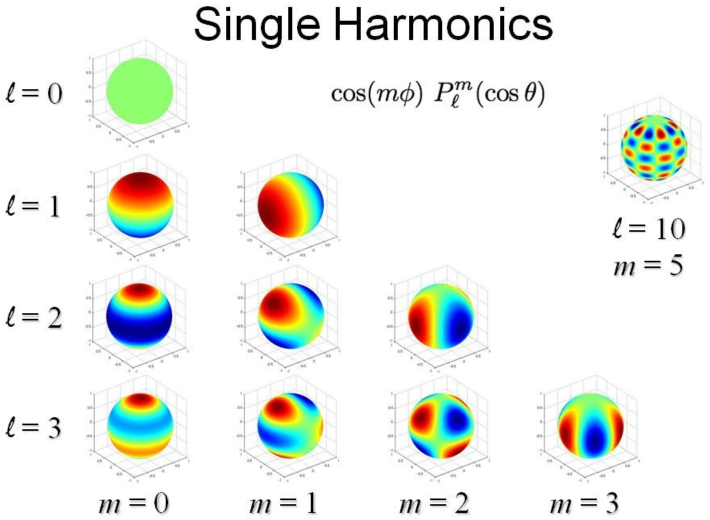
Galactic halo (IC22)

- Start with pure neutrino sample (from IC22 point source analysis)
- Measure $\Delta N = N_{on} - N_{off}$
- Determine 90% confidence interval
- Sensitivity:

$$\langle \sigma v \rangle = \Delta N_{90} \frac{\langle \sigma v \rangle_0}{N_{sig,on} \langle \sigma v \rangle - N_{sig,off} \langle \sigma v \rangle}$$

More info: *Phys. Rev.* ***D84*** *(2011) 022004, or* `arXiv:1101.3349 [astro-ph.HE]`

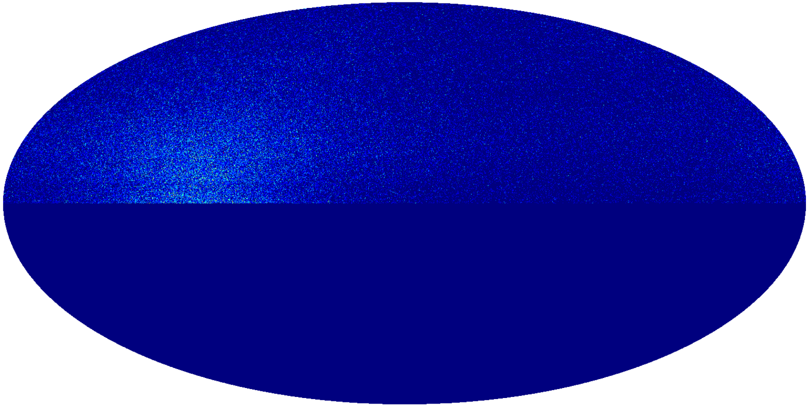
Galactic halo (IC79)



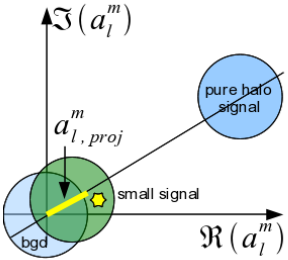
Galactic halo (IC79)

pure signal:

Pure Signal Skymap



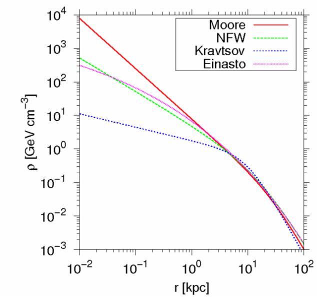
Galactic halo (IC79)

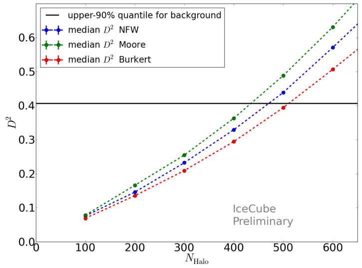


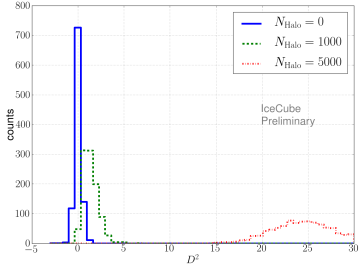
$$D^2 = \frac{1}{\sum w_l^m} \sum_{l=1}^{l_{max}} \sum_{m=1}^{m=l} sign(a^m_{l,proj}) \cdot w_l^m \cdot \left(\frac{a^m_{l,proj} - \left\langle a^m_{l,proj,atm} \right\rangle}{\sigma(a^m_{l,proj,atm})} \right)^2$$

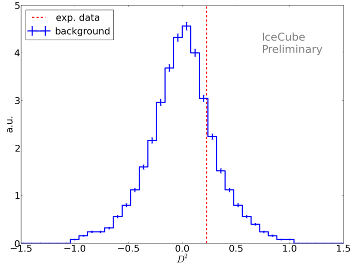
$$w_l^m = \left\| \frac{a^m_{l,proj,halo} - \left\langle a^m_{l,proj,atm} \right\rangle}{\sigma(a^m_{l,proj,atm})} \right\|$$

Galactic halo (IC79)

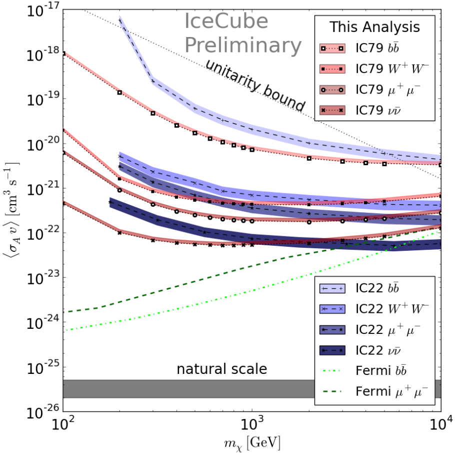








Galactic halo results (IC22 and IC79)

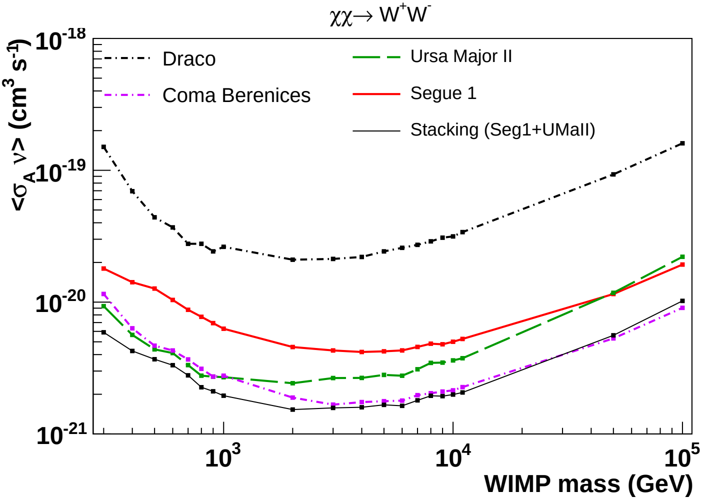


More info: R. Reimann for the IceCube collaboration, ICRC 2013 paper 0451

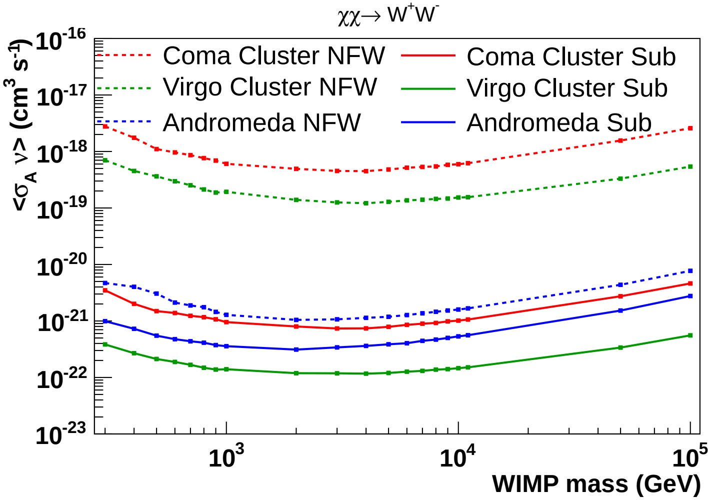
Dwarf galaxies and galaxy clusters

- Search a neutrino annihilation signal from dwarf spheroidals and galaxy clusters
- IC59 data (event selection optimized for this analysis: not standard point source sample)
- Use same assumptions as were done for Fermi LAT analysis of these objects
- No signal found $\rightarrow$ 90% upper limits

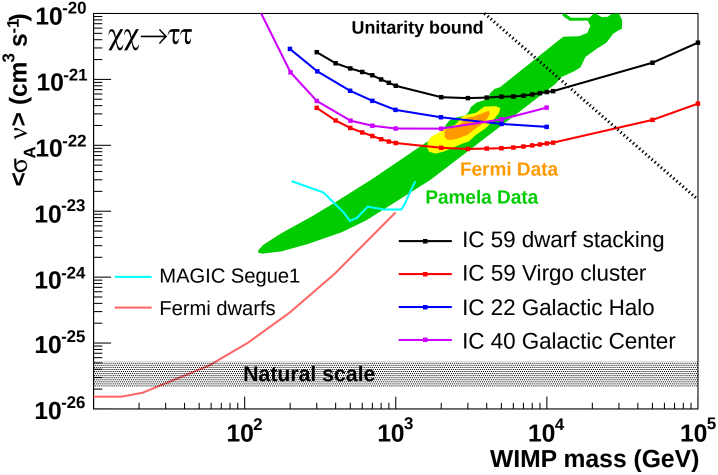
Dwarf galaxies



Galaxy clusters



Dwarf galaxies and galaxy clusters



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1. IceCube
   - IceCube Neutrino Observatory
   - Cherenkov light
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   - Dwarf galaxies and galaxy clusters
4. DM-ice
   - DM-ice collaboration
   - DM-ice idea
5. Outlook
   - Outlook

DM-ice collaboration

NOTE: DM-ice $\cap$ IceCube $\neq \phi$ but DM-ice $\not\subseteq$ IceCube!

- University of Wisconsin at Madison (USA)
  Reina Maruyama, Francis Halzen, Karsten Heeger, Albrecht Karle, Carlos Pobes, Walter Pettus, Zachary Pierpoint, Antonia Hubbard, Bethany Reilly, Matthew Kauer
- University of Sheffield (UK)
  Neil Spooner, Vitaly Kudryavtsev, Dan Walker, Matt Robinson, L. Thompson, Sam Telfer, Calum McDonald
- University of Alberta (Canada)
  Darren Grant
- University of Illionois at Urbana-Champain (USA)
  Liang Yang
- Fermilab (USA)
  Lauren Hsu
- Shanghai Jiao Tang University (China)
  Xiangdong Ji, Changbo Fu
- Penn State (USA)
  Doug Cowen, Ken Clark
- NIST Gaithersburg (USA)
  Pieter Mumm
- University of Stockholm (Sweden)
  Chad Finley, Per Olof Hulth, Klas Hultqvist, Christian Walck
- DigiPen Institute of Technology (USA)
  Charles Duba, Erik Mohrmann
- Boulby Underground Science Facility (UK)
  Sean Paling
- SNOLAB (Canada)
  Bruce Cleveland

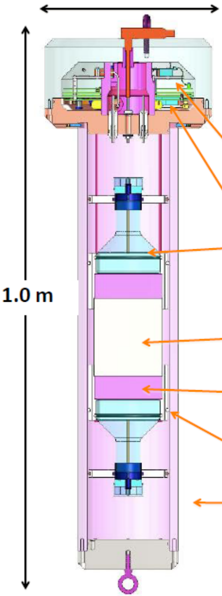
DM-ICE

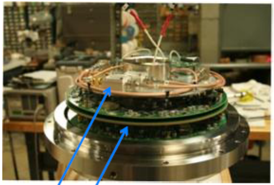
DM-ice overview

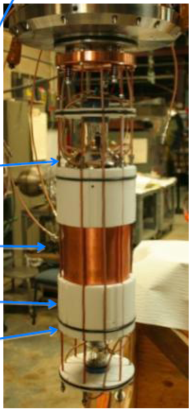
- Idea: Repeat DAMA/Libra experiment within IceCube
- Why? Because:
  - The phase of the signal should remain the same for both experiments, while systematic errors should be very different; in particular, the CR muon background should have the opposite phase.
    - (However: *Eur. Phys. J.* ***C72*** *(2012) 2064, or* `arXiv:arXiv:1202.4179 [astro-ph.GA]`)
  - The radioactive background in South Pole ice is very low.
    - South Pole ice at 2500 m depth (2200 m w.e.) is 100,000 years old.
    - Vulcanic ash: $\sim$ 0.1 ppm, U: $\sim$ 0.1 ppt, Th: $\sim$ 0.1 ppt, K: $\sim$ 100 ppt.
    - No lead/copper shielding necessary.
    - Ice moderates neutrons.
    - No worries about radon gas.
    - $\sim$ 85 $\mathrm{muons}/\mathrm{m}^2/$*day* at 2500 m, can be reduced by $\sim$ 1-2 orders of magnitude by using IceCube as a veto.
  - Temperature of deep ice is very constant
  - Existing infrastructure
    - NSF-run Amundsen-Scott South Pole Station
    - Ice drilling technique developed by IceCube
    - Use IceCube for readout electronics, data handling, remote operation
- Status:
  - DM-ice-17 prototype ($2 \times 8.5\,\mathrm{kg}$ crystals)
    - installed in December 2010
    - taking data since Spring 2011
    - performance studies will be published soon
  - DM-ice-250 in design (see paper)
- More info:
  - DM-ice website: `http://dm-ice.physics.wisc.edu/index.html`
  - *Astroparticle Physics* ***35*** *(2012) 749-754, or* `arXiv:arXiv:1106.1156 [astro-ph.HE]`

DM-Ice17 (prototypes)

(Slide stolen from Matthew Kauer!)

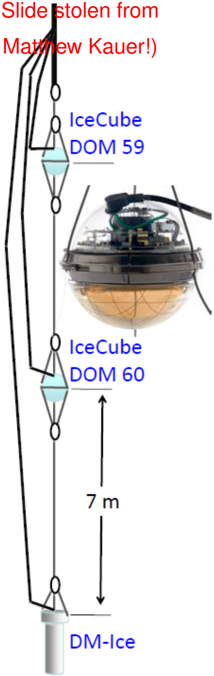






Prototype x2

- 2 HV control boards
- 2 IceCube mainboards
- PMTs: 5” ETL 9390-UKB
- NAIAD NaI Crystal (Ø 5.5” x 6”, 8.5 kg)
- 5 cm quartz lightguides (Suprasil B)
- PTFE light reflectors
- Stainless Steel Pressure Vessel



Background rates in DM-ice-17

From arXiv:1106.1156

Table 1: Assumed concentrations of ^{238}U, ^{232}Th and ^{nat}K, in ppb for major components of a NaI assembly and the surrounding ice. Details on the estimate for contamination in Antactic ice are in the text.

Material	^{238}U	^{232}Th	^{nat}K
drill ice [27]	0.076±0.046	0.47±0.14	<262
Antarctic ice	10^{-4}	10^{-4}	0.1
PMT [26]	30	30	60000
steel PV [27]	0.2	1.6	442
NaI	0.005	0.005	10

Table 2: Shown are the estimated contribution to event rate from 1-10 keV$_{ee}$ in a single 8 kg NaI crystal. The first three items are calculated using the Geant4 simulation of a simple 8 kg assembly. The internal NaI contamination is taken from [18] where the energy spectrum of events from radioactivity was simulated for the DAMA experiment assuming radioisotope concentrations reported in [32].

Material	event rate in NaI (cpd/kg/keV$_{ee}$)
drill ice	0.8
Antarctic ice	< 0.001
photomultiplier tubes	0.01-0.02
steel PV	0.2-0.6
NaI crystal	~0.3

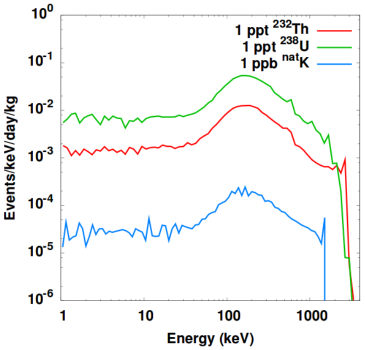


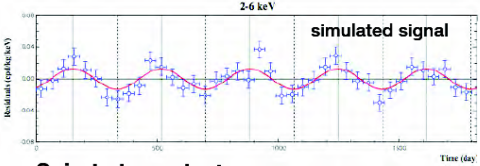
Figure 2: The histograms show the simulated activity in NaI crystals due to uniform radioactivity in the ice surrounding the detector assembly.

(Slide stolen from Reina Maruyama!)

DM-Ice Sensitivity and a DAMA-Like Signal

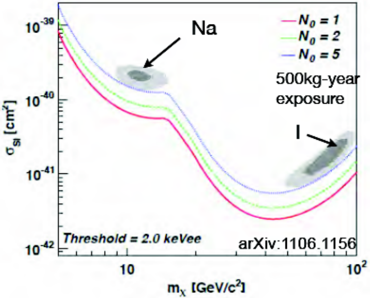
Sensitivity

Model-Independent: Assume DAMA-like signal, statistics



		2 NAIAD	NAIAD size	DAMA size
	Years	17.0 kg	44.5 kg	250 kg
NAIAD background	1	0.45	0.72	1.71
	3	0.77	1.25	2.96
	5	1.00	1.61	3.82
	7	1.18	1.91	4.52
50% NAIAD background	1	0.63	1.02	2.42
	3	1.09	1.77	4.18
	5	1.41	2.28	5.40
	7	1.67	2.70	6.39
Double DAMA background	1	0.85	1.37	3.26
	3	1.47	2.38	5.64
	5	1.90	3.07	7.29
	7	2.25	3.64	8.62
DAMA background	1	1.20	1.94	4.61
	3	2.08	3.37	7.98
	5	2.69	4.35	10.31
	7	3.18	5.14	12.19
1/10 DAMA background	1	3.80	6.15	14.57
	3	6.58	10.65	25.24
	5	8.50	13.75	32.59
	7	10.06	16.27	38.56

Spin-Independent



- 5-σ detection of DAMA-like signal with a 250-kg / 2-year running time (2 - 4 keV) and comparable backgrounds to DAMA

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  - Several GC analyses with IC86 data
- GC *decaying* DM search
- Secluded dark matter search (based on IC79 solar WIMP search)
- Solar WIMP analysis will be continued with IC86 data sets
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