Latest Results on Searches for Dark Matter from IceCube

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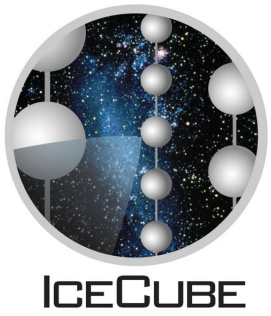
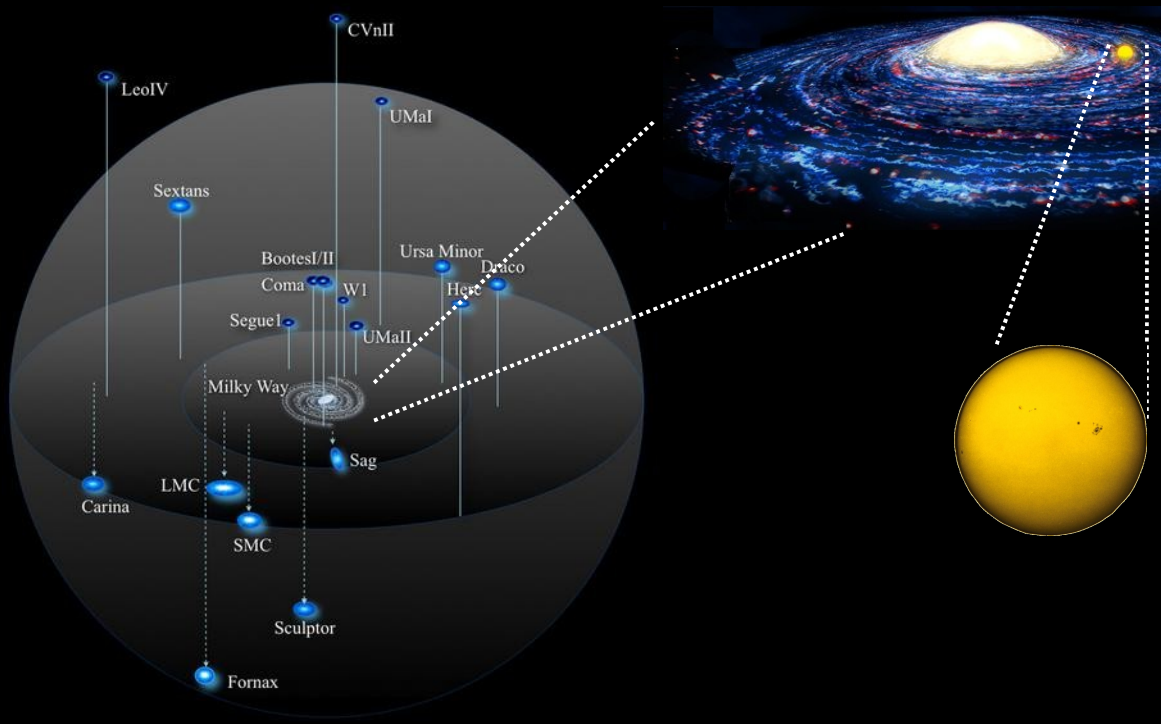
The Oscar Klein Centre for Cosmoparticle Physics, Stockholm University

36th International Conference on High Energy Physics



Indirect Search with IceCube

Look for potential sources that are well defined and have low or understood astrophysical backgrounds



Galactic Halo:
Limits from IceCube-22
Galactic Center:
Limits from IceCube-40

Local sources:
Sun:
Combined Limits form AMANDA, IC22, IC40+AMANDA
→ IceCube-79 final sensitivity *new

Searches beyond "standard" SUSY:
→ secluded dark matter sector *new

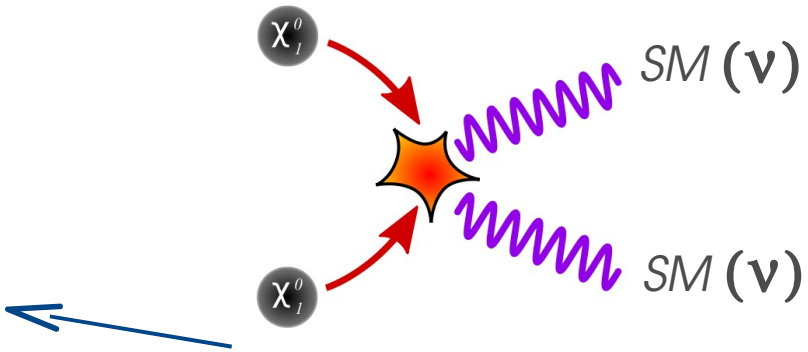
Earth:
Limits from AMANDA
(new analysis with IceCube-86 ongoing)

Dwarf spheroidal Galaxies:
→ IceCube-59 sens. *new
Clusters of Galaxies:
→ IceCube-59 sens. *new

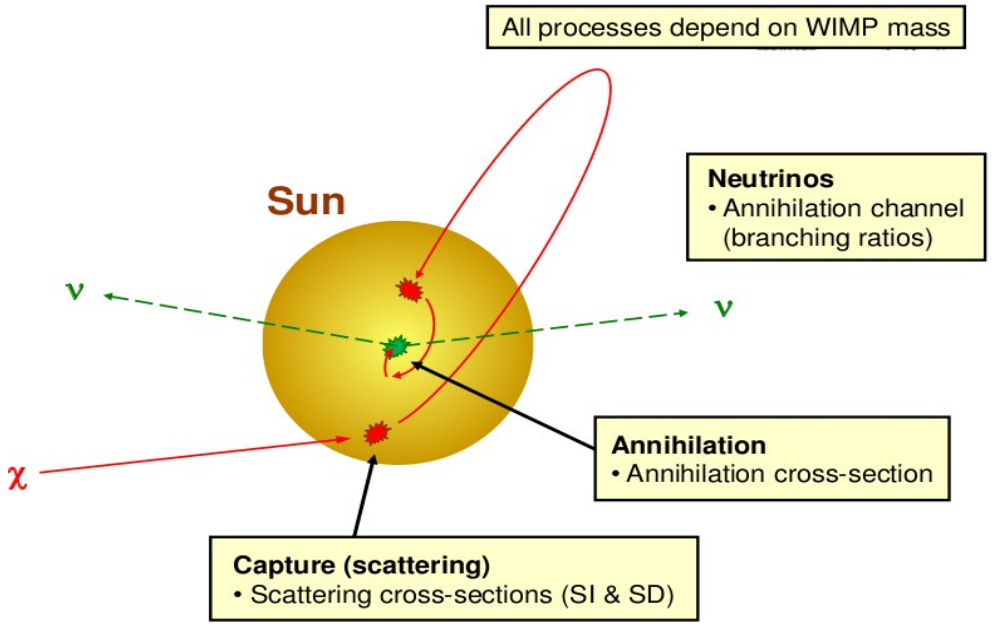
Indirect Search with IceCube

Very brief recap:

(1) **Halo WIMPs scatter** on nuclei in the ***Sun/Earth***
(2) Some lose enough energy in the scatter to be **gravitationally bound**
(3) Scatter some more, sink to the **core**
(4) **Annihilate** with each other, **producing neutrino**
(5) **Propagate+oscillate** to the South Pole, **convert into muons** in CC interactions
(6) Look for **Cerenkov radiation** from the μ



Galactic searches
(GC, halo, dwarf galacies, etc.)
→ constrain self-annihilation x-section



WIMP candidates:

- **MSSM**: (LSP) neutralino, m(χ^0_1)[35 GeV – 5 TeV]
  Hard channel ($\tau^+\tau^-$ / W^+W^-)
  Soft channel (**b b**)
- **UED**: (LKP), $B^{(1)}$ or $\gamma^{(1)}$
  fixed branching ratios: m($\gamma^{(1)}$) [250 GeV–3TeV]
- New model independent method for theories of new physics (later in talk)

IceCube detector

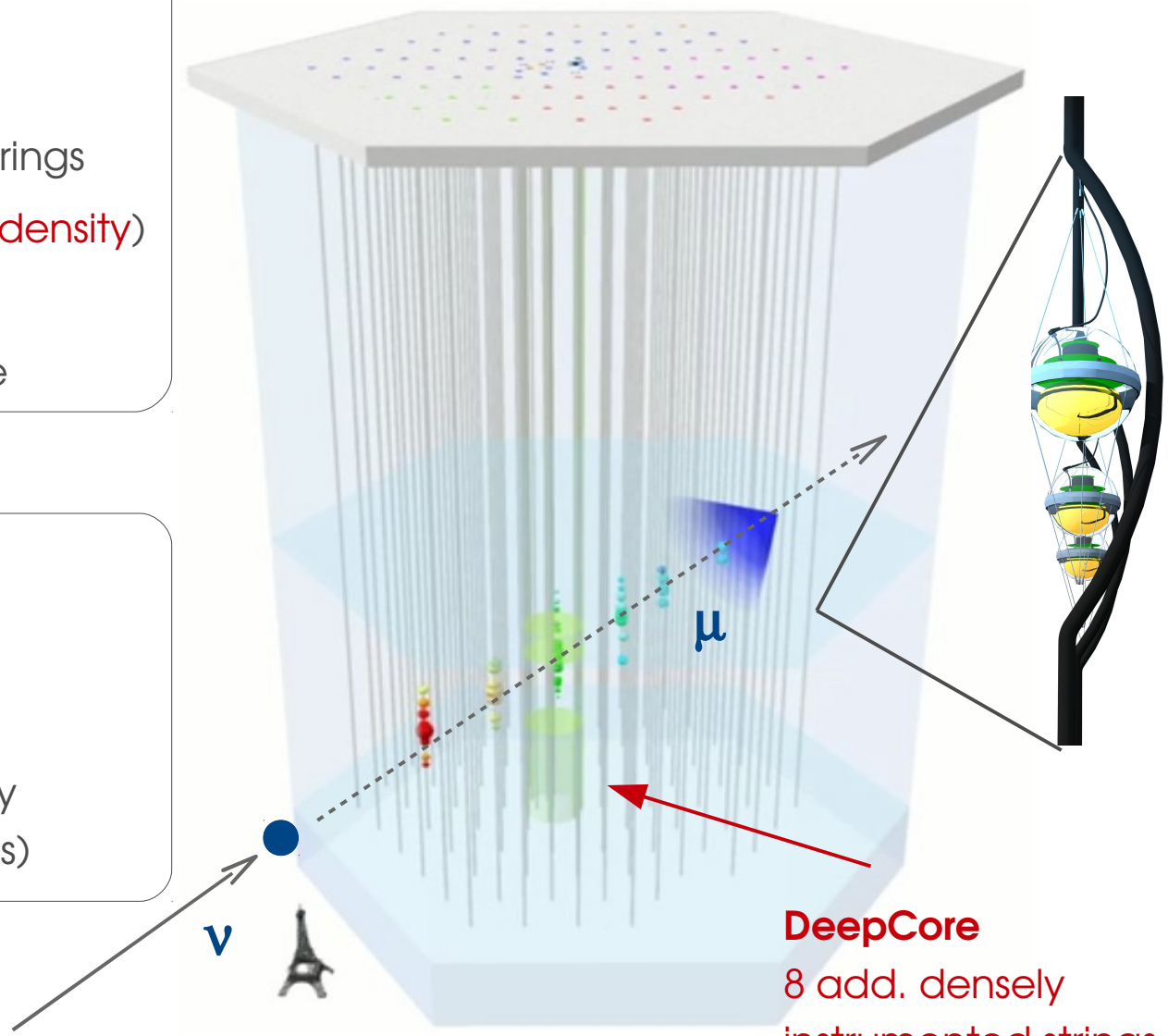
IceCube 86-strings

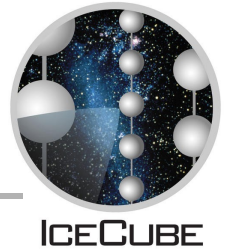
- 1.5 km - 2.5 km deep
- typically 125 m spacing between strings

(~70 m in DeepCore, 10x higher DOM density)

- 60 Modules per string
- 1 km -- 1 Gton instrumented volume

- O(km) muon tracks from ν_μ CC
- O(10m) cascades from ν_e CC, low energy ν_τ CC, and ν_x NC
- Cherenkov radiation detected by 3D array of optical sensors (DOMs)

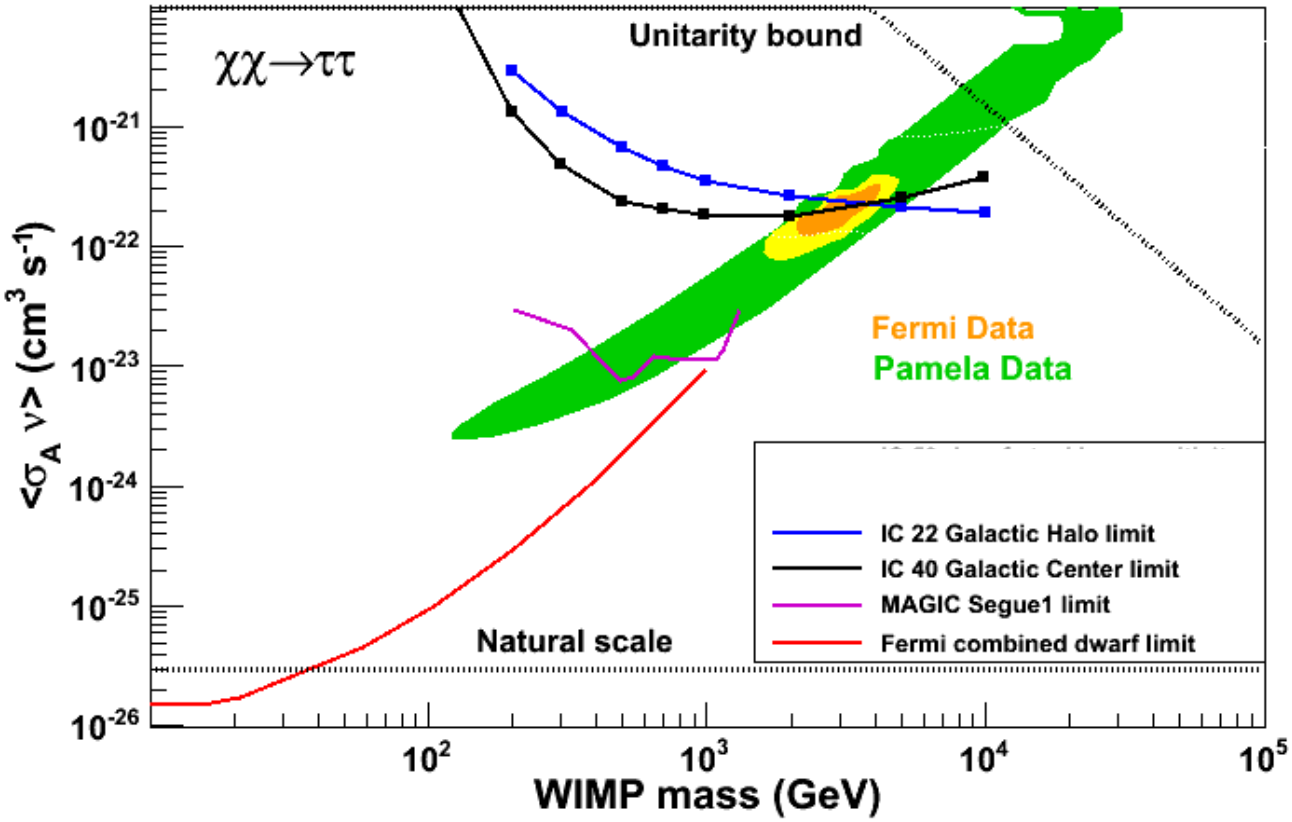




Galactic searches, dwarf spheroidal galaxies & nearby clusters of galaxies

Galactic & galaxy cluster limits

Limits computed at **90% C.L.** as function of WIMP mass and for various annihilation channels assuming branching fractions of 100%



multi-wavelength approach to dark matter searches:
IceCube can test DM models motivated by PAMELA & Fermi data (e.g. Meade et al. 2008)

Galactic & galaxy cluster limits

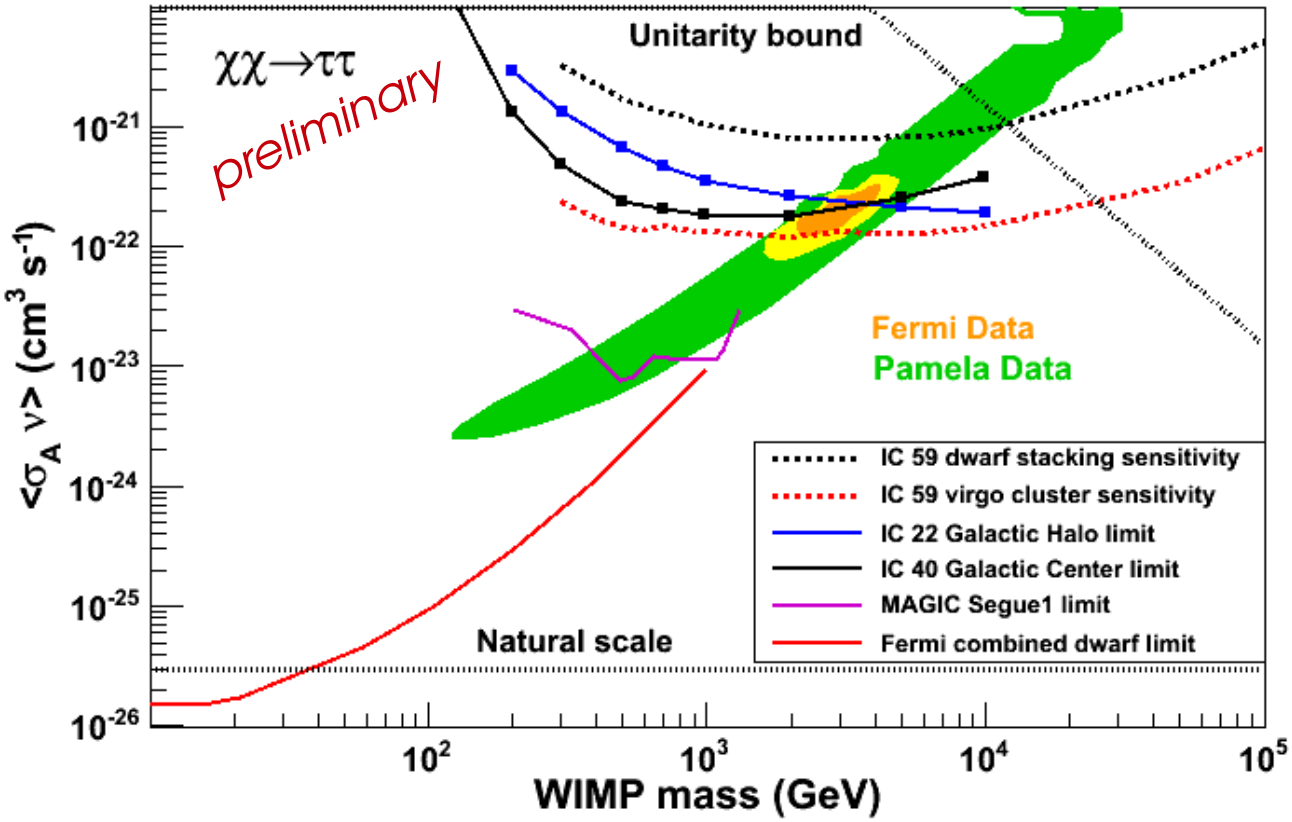
Limits computed at **90% C.L.** as function of WIMP mass and for various annihilation channels assuming branching fractions of 100%

Dwarf galaxies:

- Source stacking analysis
- Optimized size of search window
- NFW profile assumed

Galaxy clusters:

- Extended point source search
- Optimized size of search window
- Substructures taken into account



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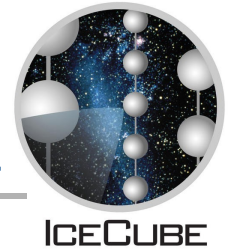
Solar Dark Matter searches

Analysis Results from the Sun



More details on limits

Abbasi et al., ***PRL*. 102**, 201302 (2009) (IC22)
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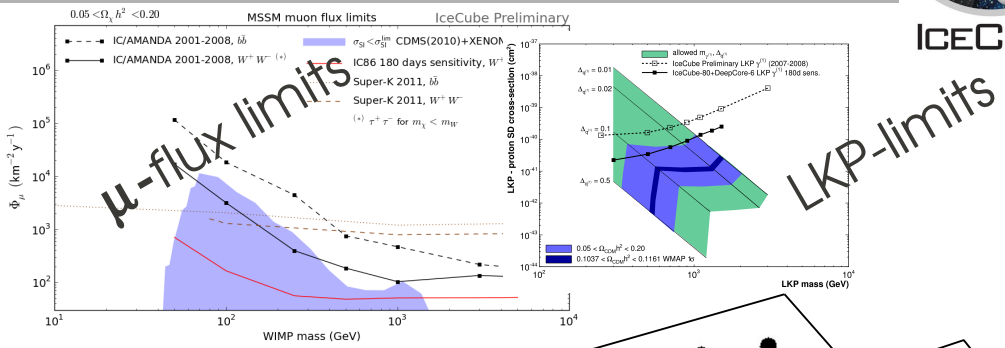
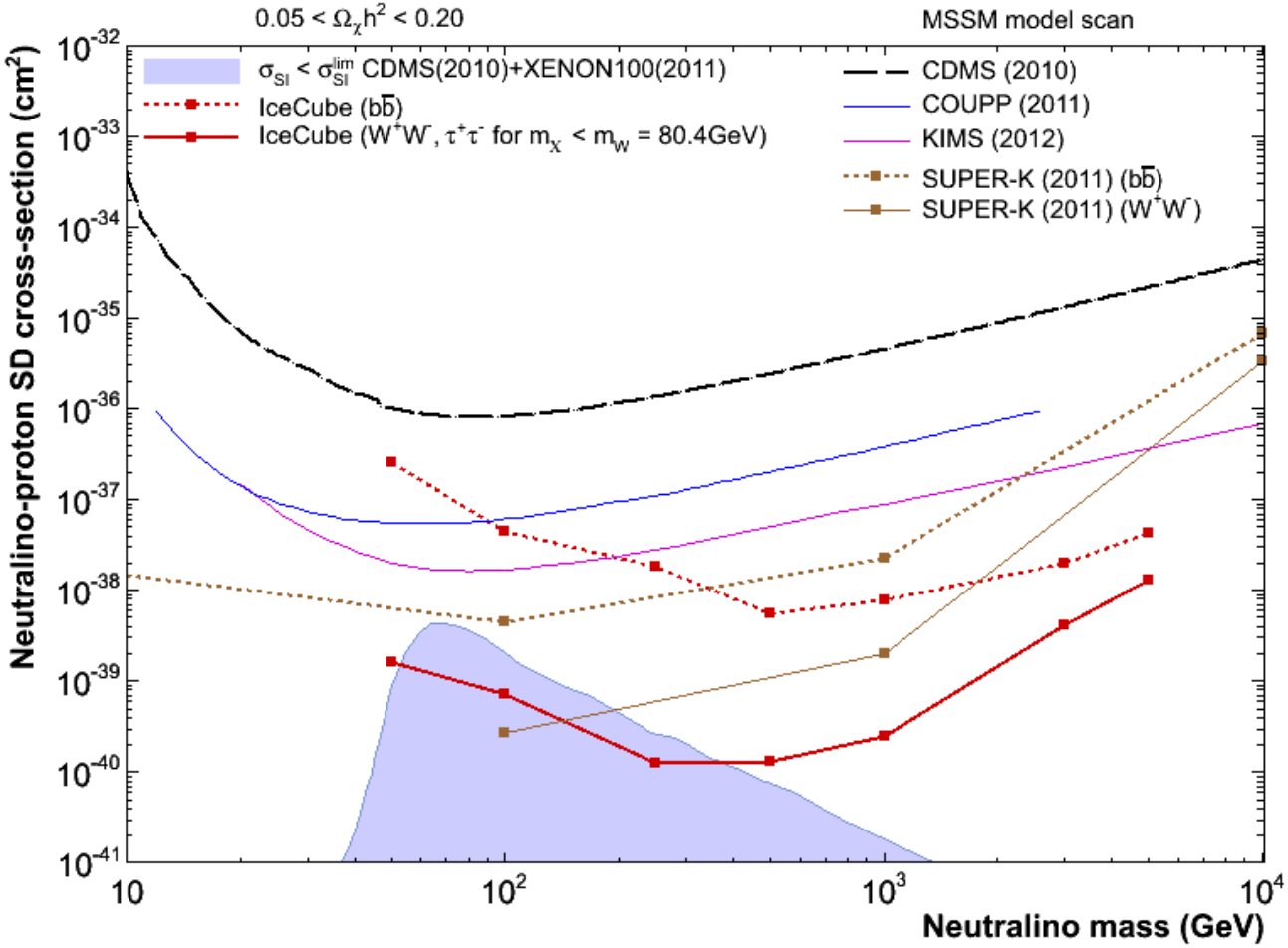
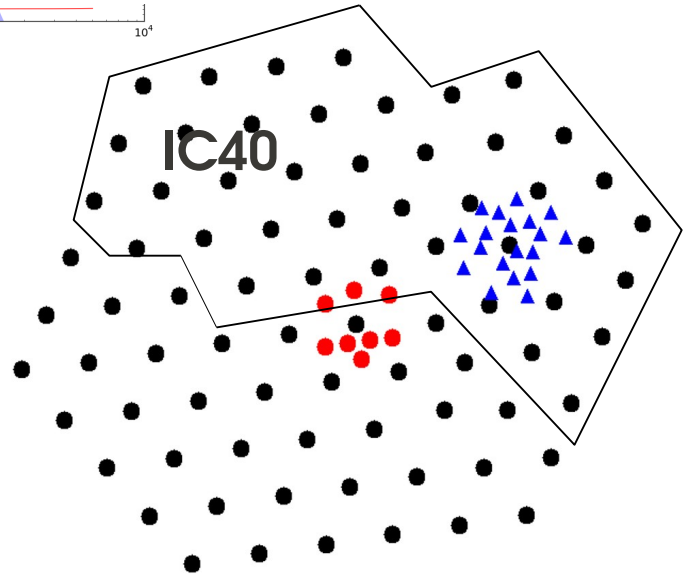






Combined multi-year limit from AMANDA, IceCube-22 and IceCube-40+AMANDA data
Total livetime of 1065 days

IceCube 79 string analysis

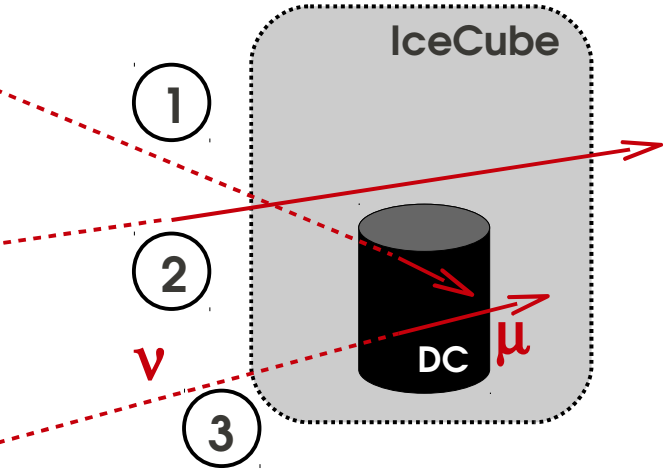
Solar WIMP analysis with 79 strings *(sensitivity)*

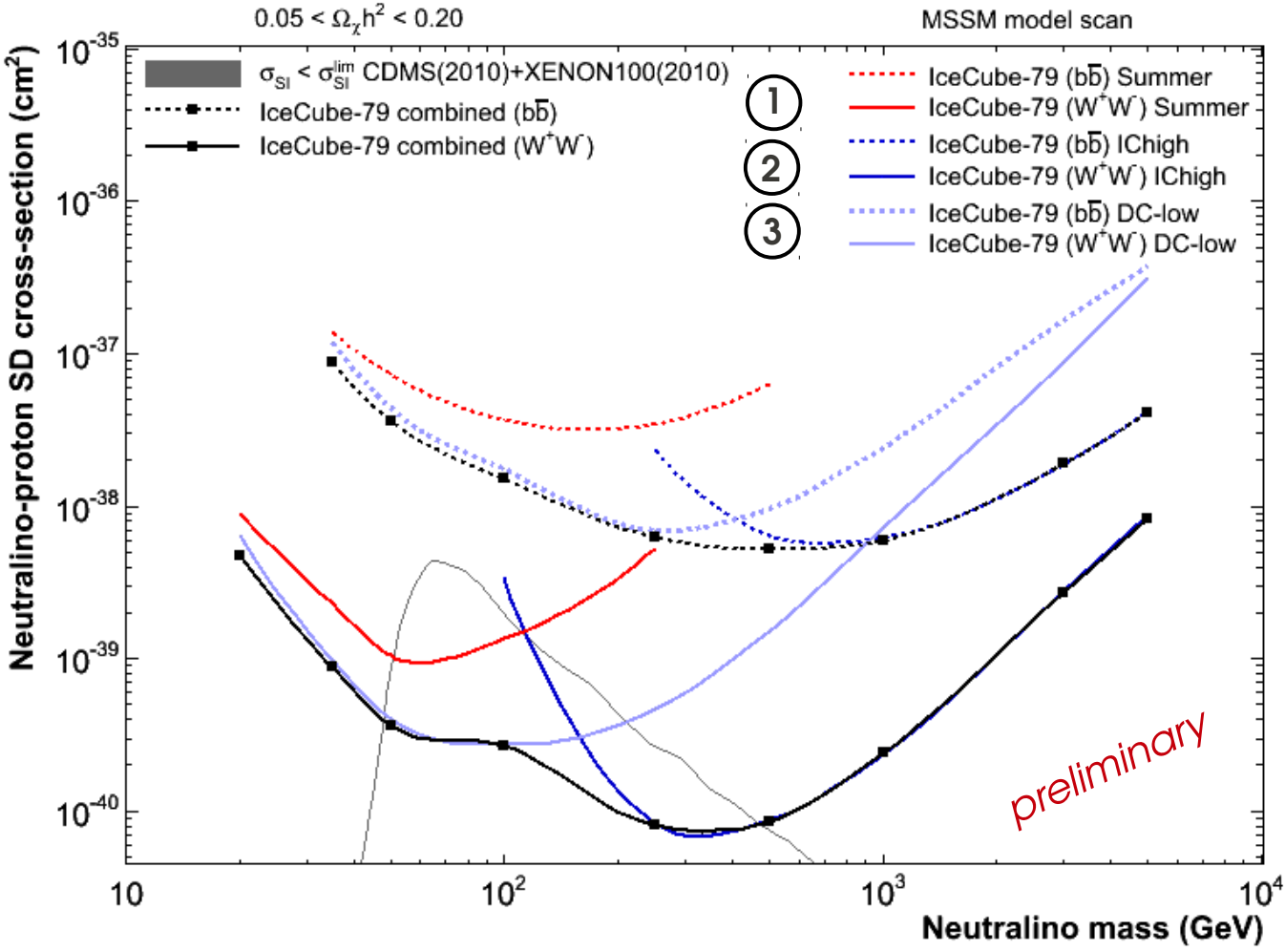
- Incl. DeepCore
- Performed separately for austral winter & summer (152d +167d livetime)
- Low energies (look for contained or partially contained events)

Analysis performed separately for;
austral summer (Sun above horizon)

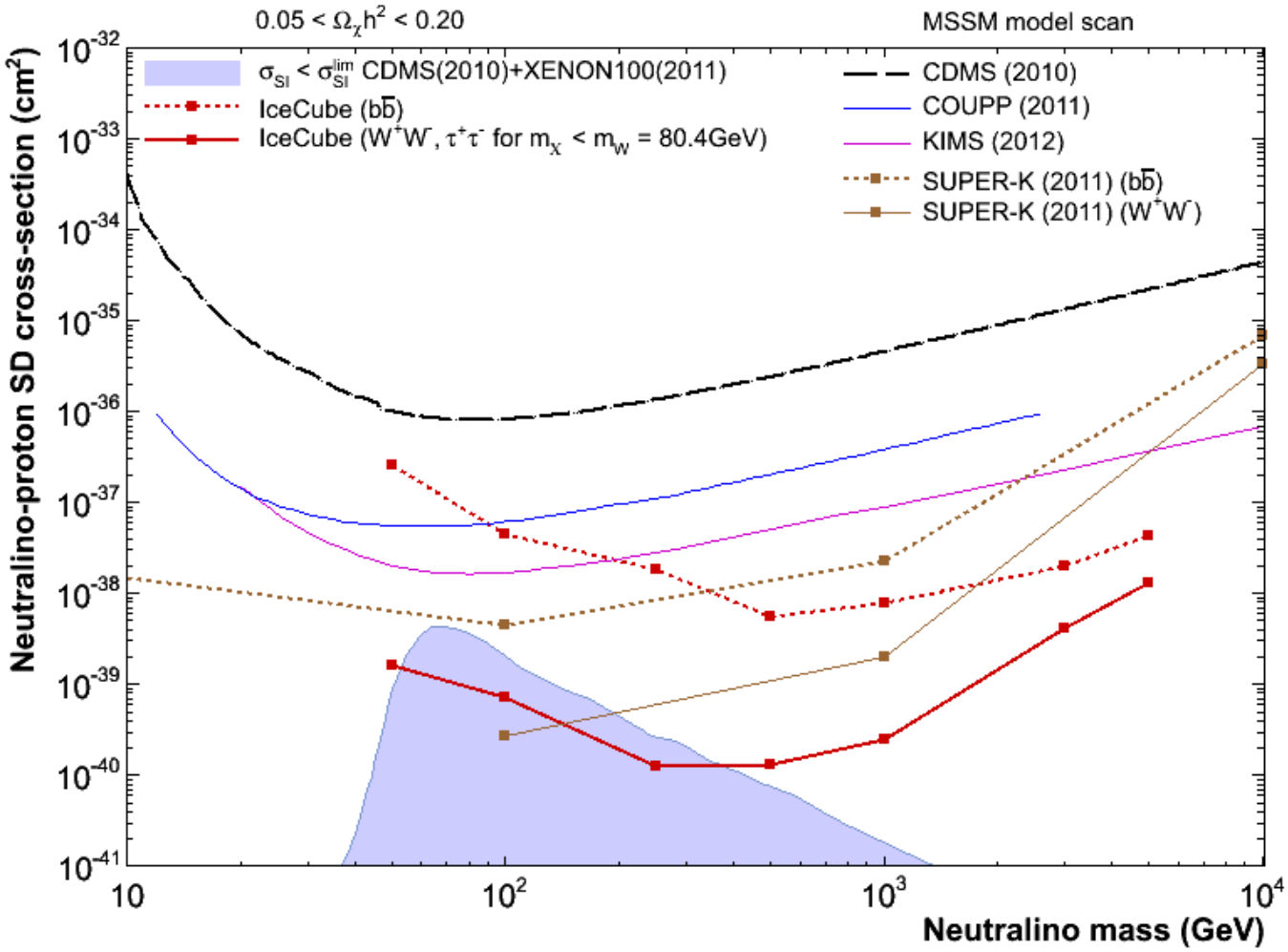
&

austral winter (Sun below horizon)





IceCube 79 string sensitivity



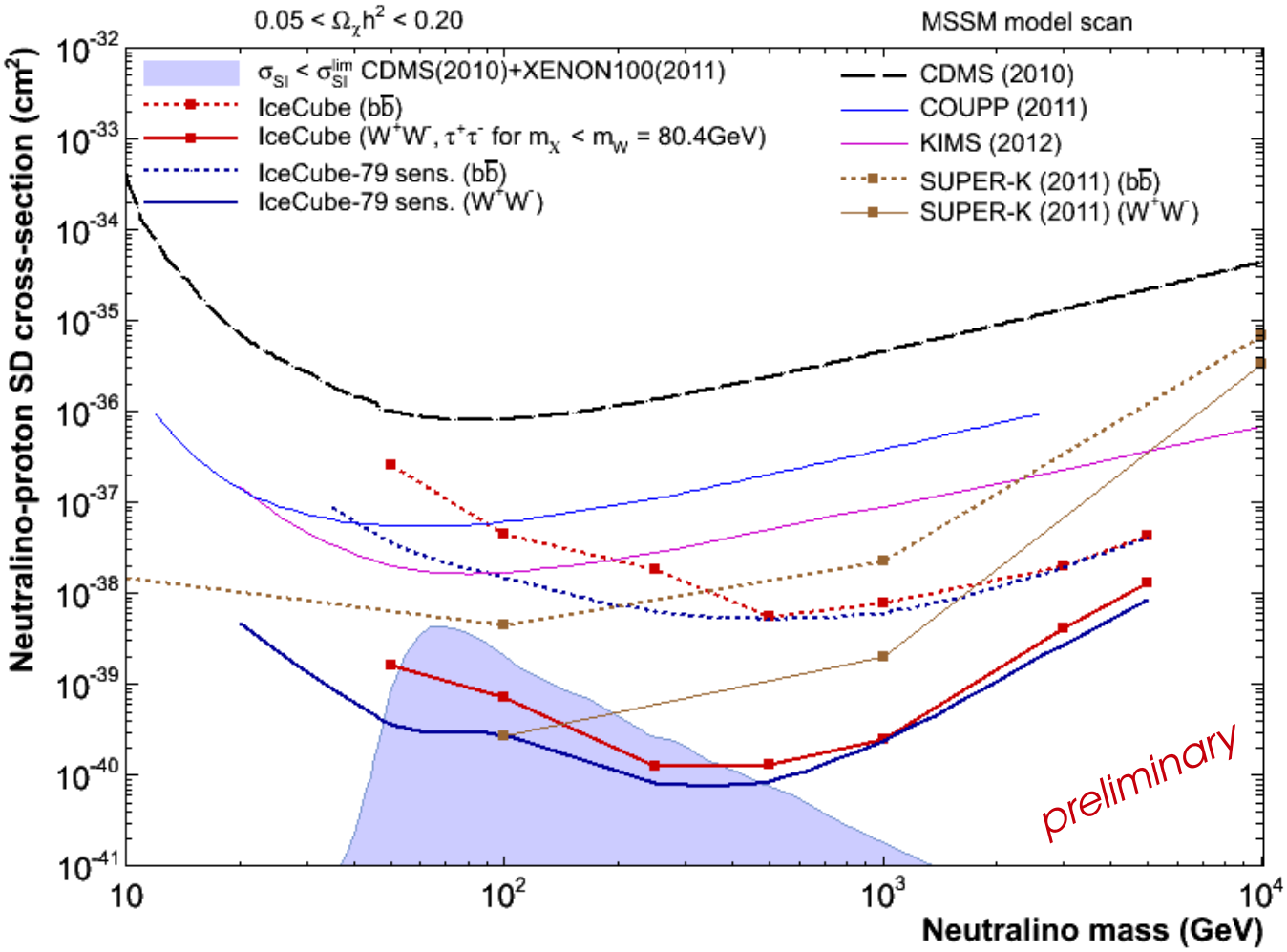
IceCube 79 string sensitivity

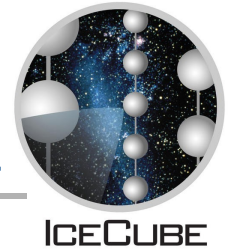
Sensitivity extends to WIMP masses of 20 GeV

Only 1 year of data

Data unblinding soon!

also search for UED models (not shown here)

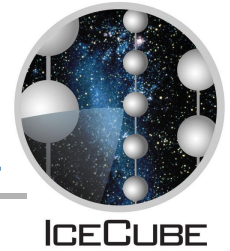




New model independent method for theories of new physics

(Solar Dark Matter searches)

Global SUSY analysis with IceCube



More details: P.Scott, C.Savage, J. Edsjö & the IceCube Collaboration, arXiv:1207.0810

Include IceCube event level data in a global statistical fit.

→ *parameter estimation rather than model exclusion*

Composite likelihood made up of observations from all over:

- Dark matter relic density from WMAP
- Precision electroweak tests at LEP & LEP limits on sparticle masses
- B-factory data (rare decays, b → sγ)
- Muon anomalous magnetic moment
- LHC searches, direct detection *(not yet included in examples)*

+ IceCube unbinned likelihood

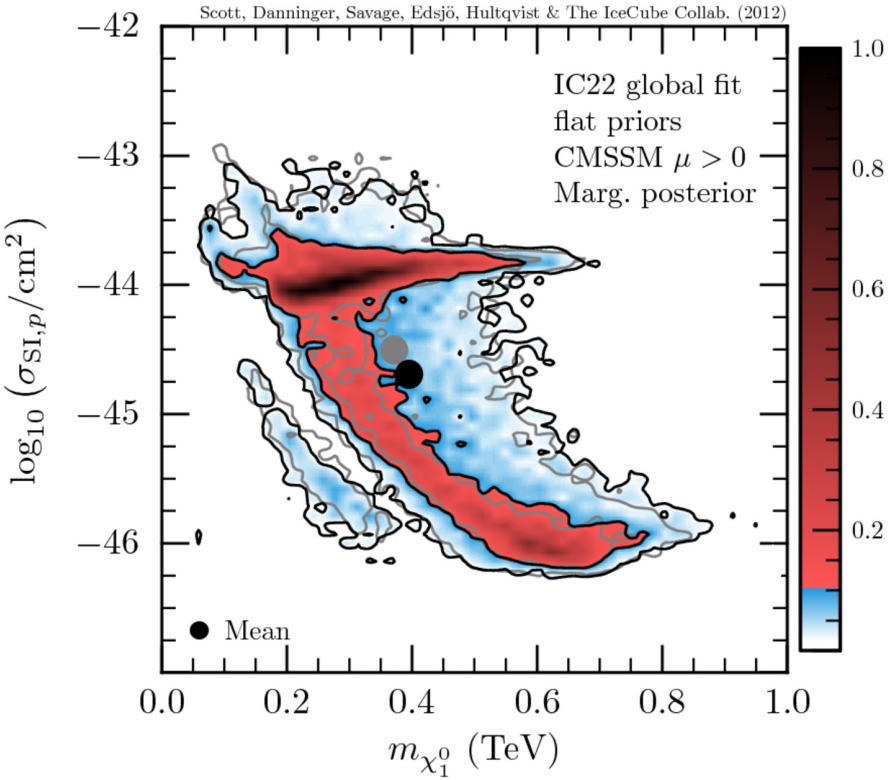
$$\mathcal{L}_{\mathrm{IC}}(\Theta) = \mathcal{L}_{\mathrm{IC}}(n \mid \theta_s(\Theta) + \theta_b) \prod_{k=1}^{n} \mathcal{L}_{\mathrm{spec}}(E_k \mid \Theta)\, \mathcal{L}_{\mathrm{ang}}(\cos\phi_k \mid \Theta)$$

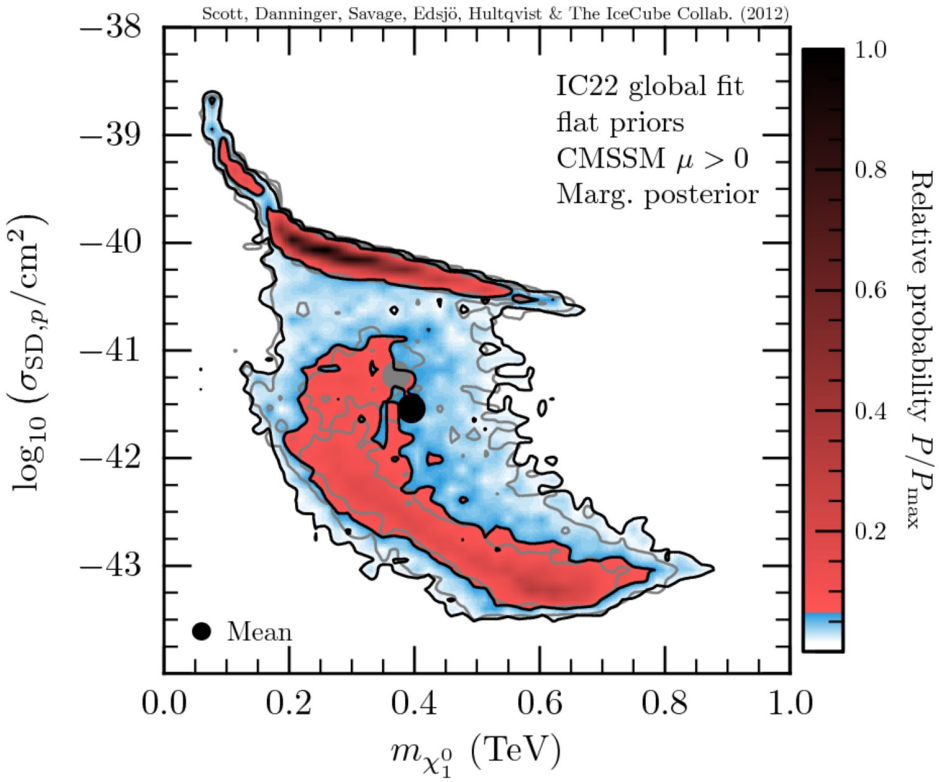
- Θ: WIMP or SUSY parameters
- n: **Number** of muon events
- E_k: Muon **energy**
- $\cos\phi_k$: Muon **angle** from Sun

Global SUSY analysis with IceCube

More details: P.Scott, C.Savage, J. Edsjö & the IceCube Collaboration, arXiv:1207.0810

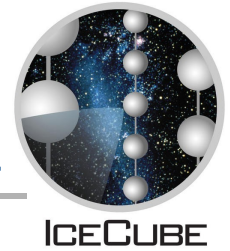
CMSSM, IceCube-22





- ✗ Contours indicate 1σ and 2σ credible regions
- ✗ Grey contours correspond to fit *without* IceCube data
- ✗ Shading+contours indicate *relative* probability only, not overall goodness of fit

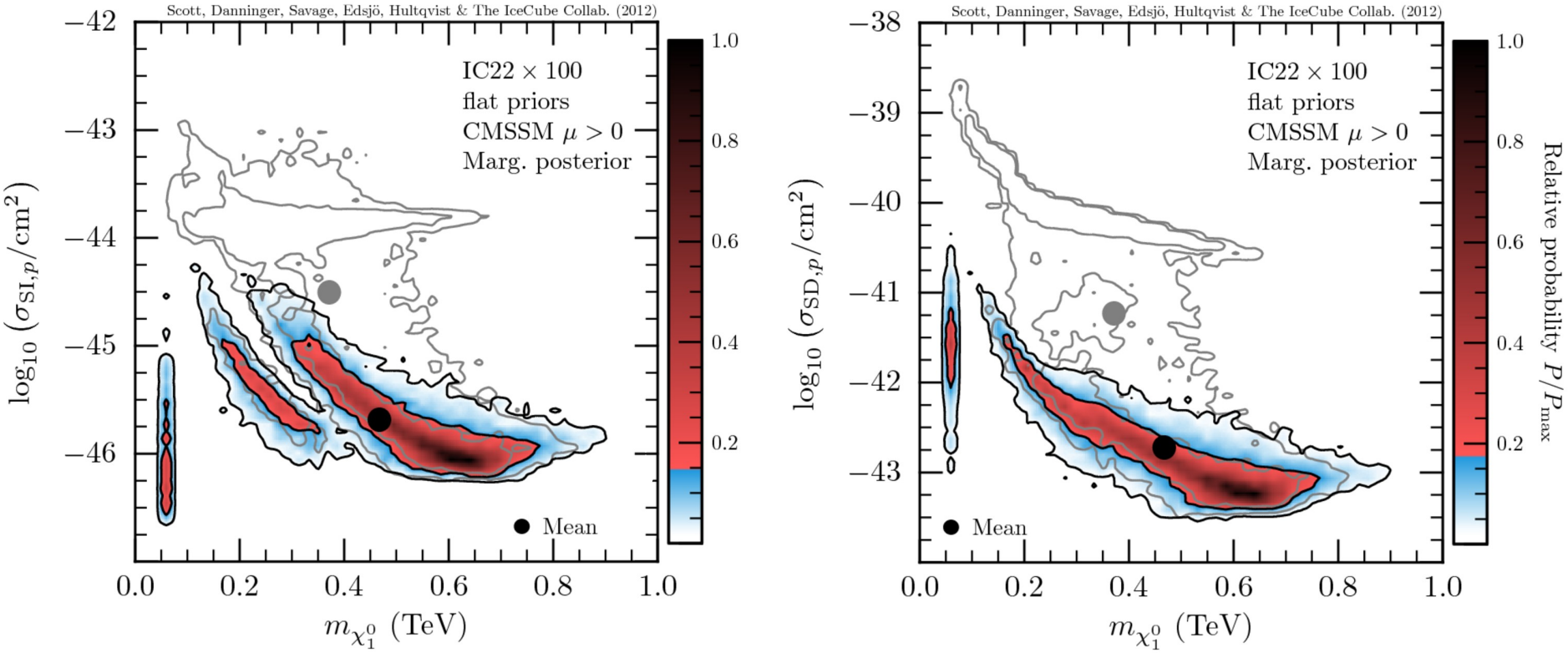
Global SUSY analysis with IceCube



More details: P.Scott, C.Savage, J. Edsjö & the IceCube Collaboration, arXiv:1207.0810

CMSSM, IceCube-22 with 100x boosted effective area

(indication for IceCube-79 and 86-string prospects)



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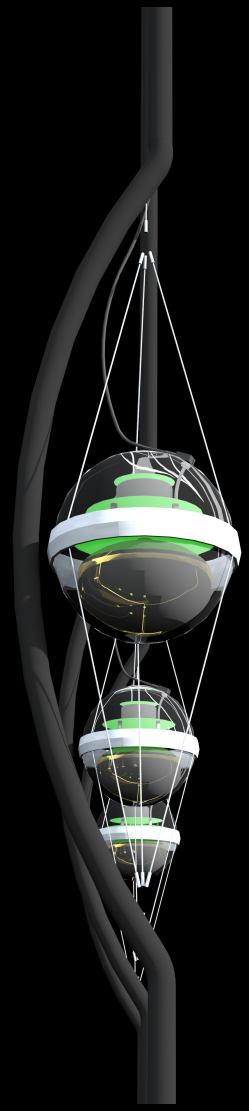
Closing remarks



- IceCube is extending Dark Matter searches, including new sources
  → dwarf spheroidal galaxies & nearby galaxy clusters
- IceCube already provides world best limits on SD WIMP-proton scattering cross-section for $m_\chi > 200$ GeV
- Solar WIMP Analysis on 79 strings to be unblinded soon....
  → Incl. DeepCore (6 densely instrumented strings)
  → **4π detector** → full year-round DM searches
  → improved sensitivity for low-mass WIMPs

improved at low m_χ

- New framework for **directly comparing event-level IceCube data** to **individual** points in theory **parameter spaces** is in place
  → requisite tools available in new DarkSUSY release (version 5.0.6)
  → **Event data will be released** in a form digestible by the tools
  → SUSY analyses of IC79 data are on the way

Additional slides

New SUSY analysis with IceCube

What can the muon signal tell me?

More details: P.Scott, C.Savage, J. Edsjö & the IceCube Collaboration, arXiv:1207.0810

Roughly:

- ✗ **Number** – how much annihilation is going on in the Sun
  ⇒ info on σ_{SD} , σ_{SI} and $\langle\sigma v\rangle$
- ✗ **Spectrum** – sensitive to WIMP mass m_χ and branching fractions **BF** into different annihilation channels χ
- ✗ **Direction** – how likely it is that they come from the Sun

In model-independent analyses a lot of this information is either discarded or not given with final limits

Goal:

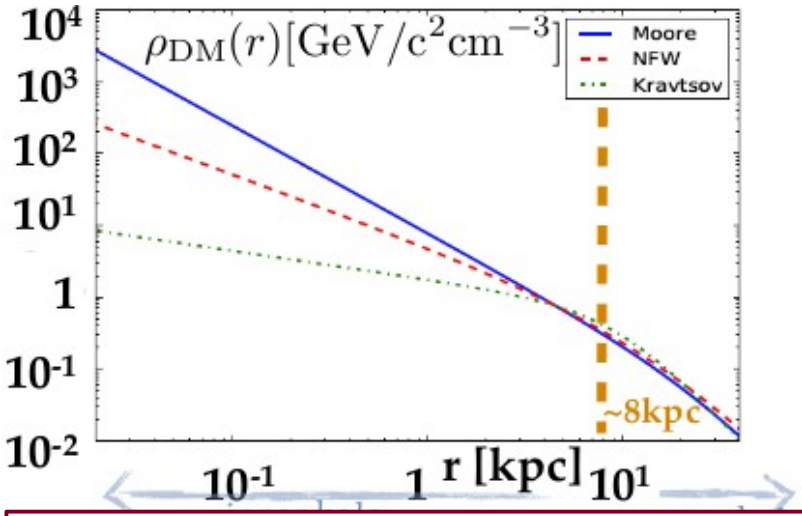
Use as much of this information on σ_{SD} , σ_{SI} , $\langle\sigma v\rangle$, m_χ and **BF** (χ) as possible to directly constrain specific points and regions in WIMP model parameter spaces

Galactic-Center and Halo search

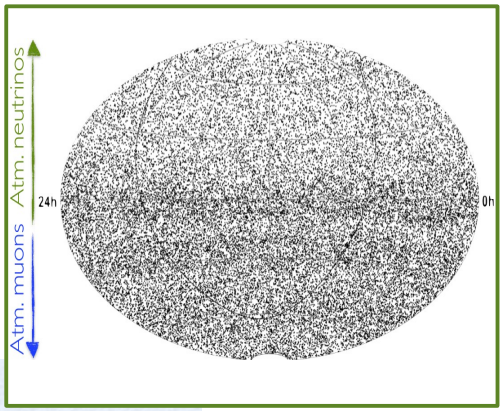
Dark Matter in the Milky Way:

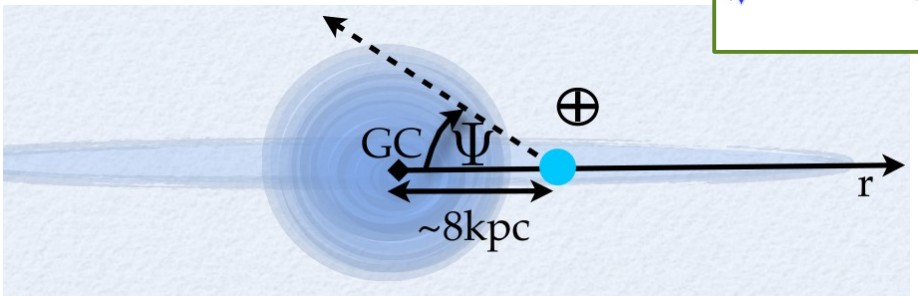
- ✗ Outer halo relatively well understood
- ✗ inner halo still subject of debates (cusp/core structure)
- ✗ Can probe DM **self-annihilation cross section**

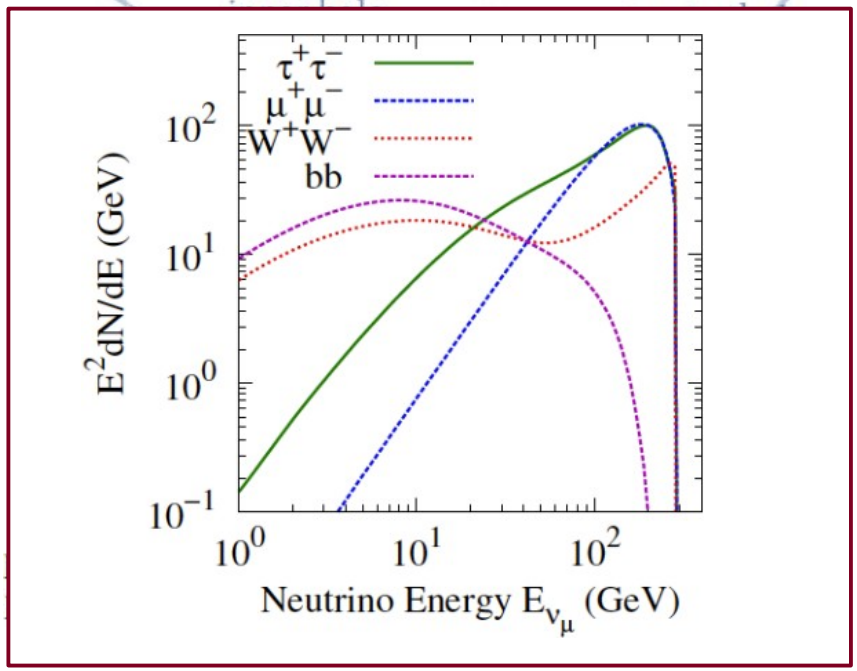
$$\frac{d\phi_\nu}{dE} = \frac{\langle\sigma_A v\rangle}{2} J_a(\Psi) \frac{R_{sc}\rho_{sc}^2}{4\pi m_\chi^2} \frac{dN}{dE}$$



- ✗ **Halo distribution**
- ✗ **SUSY** ($\chi\chi \rightarrow \mu^+\mu^-, \tau^+\tau^- \ldots$)
- ✗ **Measurement**
  e.g. IC40 event map



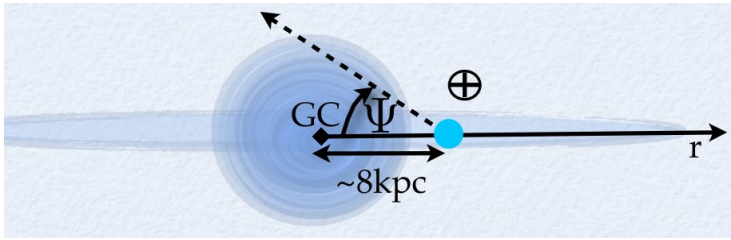




Galactic-Center and Halo search

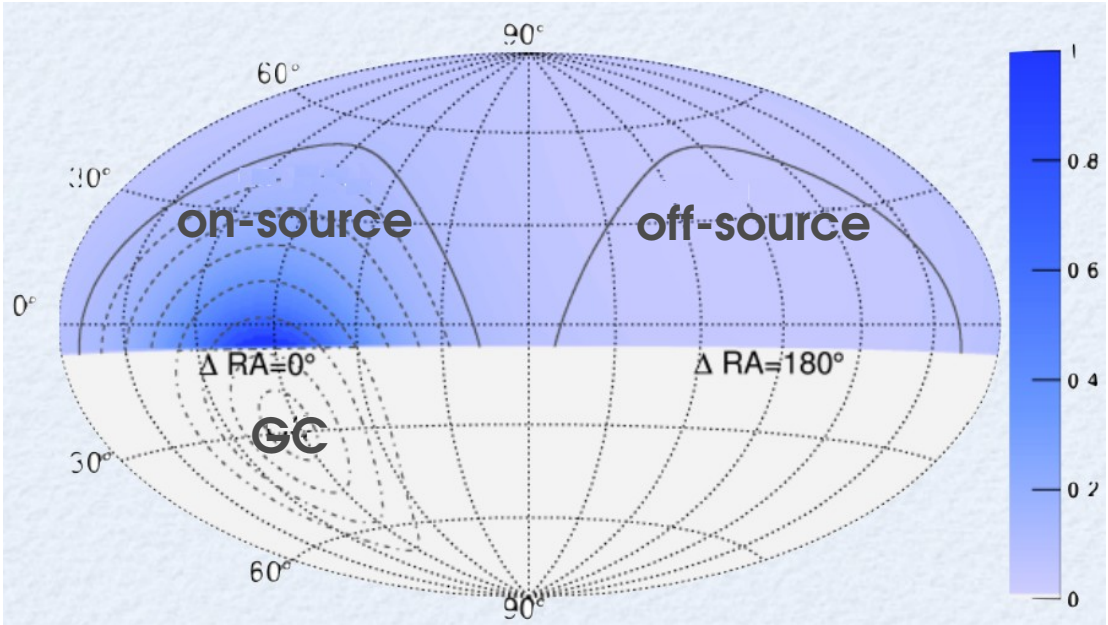
Analysis strategy:

Look for an excess of events in the on-source region w.r.t. the off-source



Galactic Center:

- ✗ on-source region above the horizon
- ✗ need to veto downgoing muons.
- ✗ Use central strings of detector as fiducial volume, surrounding layers as veto.



IC22 (Halo analysis – 275 days):
observed on-source: **1367** evts
observed off-source: **1389** evts
Event selection dominated by atm. **ν**

IC40 (G-Center analysis – 367 days):
observed on-source: **798842** evts
predicted from off-source: **798819** evts
Event selection dominated by atm. **μ**

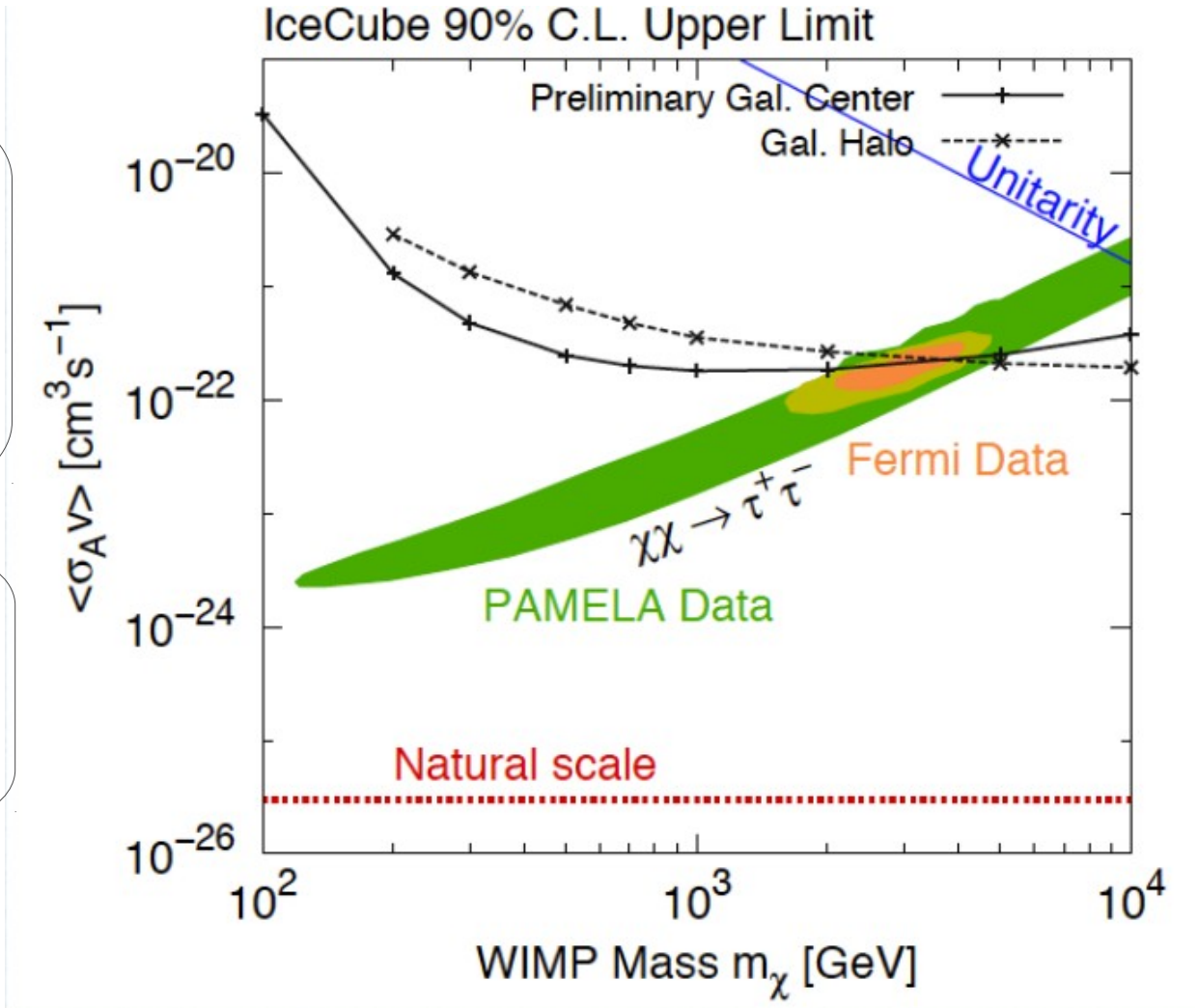
Observations in both analyses were consistent with background-only expectations

Galactic-Center and Halo limits

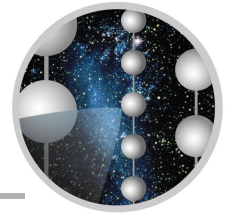
Limits computed at **90% C.L.** as function of WIMP mass and for various annihilation channels assuming branching fractions of 100%

multi-wavelength approach to dark matter searches:
IceCube can test DM models motivated by PAMELA & Fermi data (e.g. Meade et al. 2008)

For more details on analysis and systematics discussions:
Phys. Rev. D 84, 022004 (2011) (IC22)
ICRC 2011 (2011) (IC40)



Solar Dark Matter searches

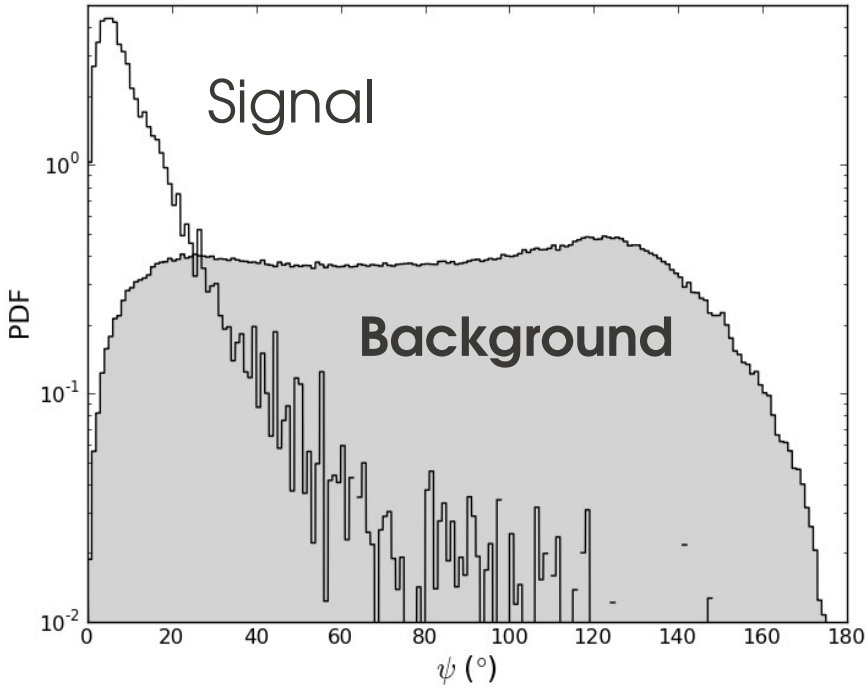


Blind analysis with respect to true azimuthal direction

Analysis strategy:

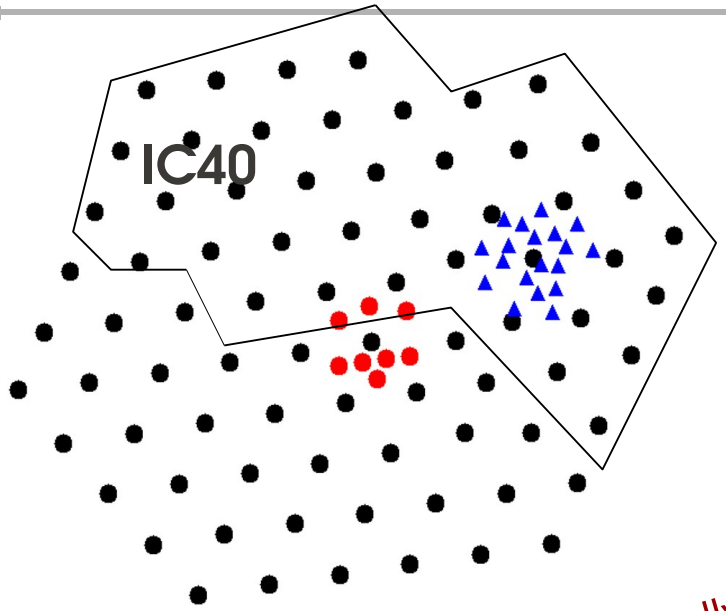
- ✗ Remove atmospheric muon events until data sample is dominated by atmospheric neutrino events
- ✗ signal events within IceCube may have low mean muon energy in detector
  → short tracks with few hits
- ✗ cut on quality and reconstruction parameters, maximizing horizontal low energy muon track selection **(linear** cuts & **multivariate** cuts**)**
- ✗ final data selection
  → determine **Veff & Aeff**
- ✗ **DM searches directional:** good additional handle on event selection

  → distribution-shape analysis



Signal & background pdf's of Ψ: angle between reconstructed track and direction of the Sun

Dark Matter Searches from the Sun



$$\Gamma_{\nu\mu} \leqslant \frac{N_{90}}{V_{\text{eff}} \cdot t}$$

Experimentally obtained quantity

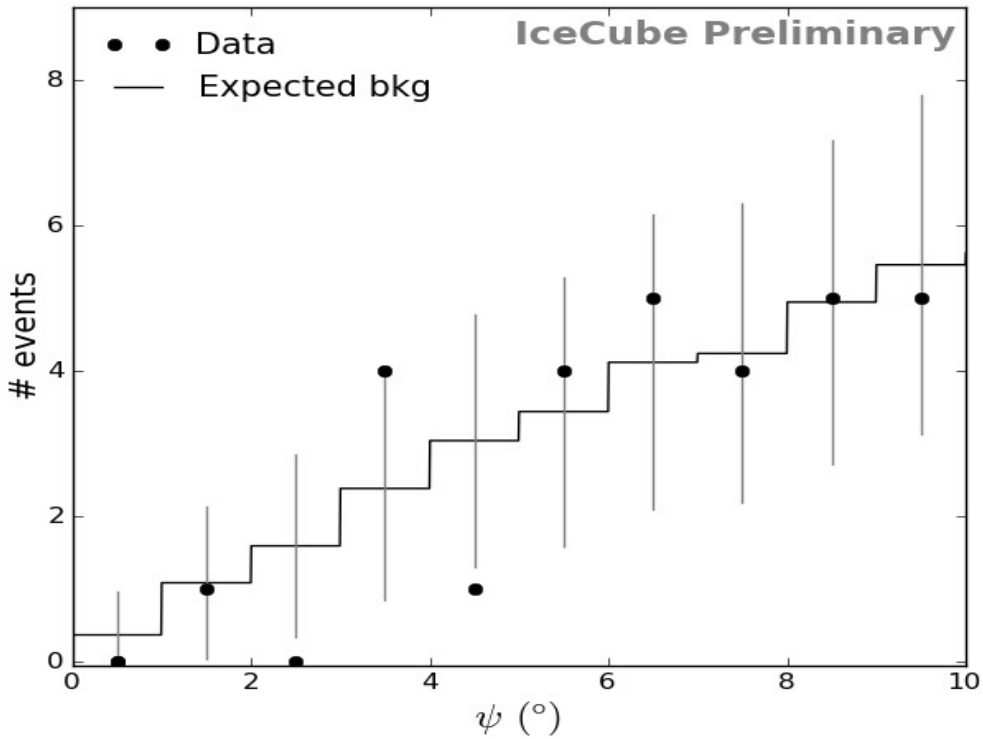
Γ_A

Φ_μ

$C_c \sim \sigma_{SD}$

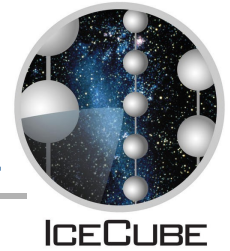
Combined multi-year limit from AMANDA, IceCube-22 and IceCube-40+AMANDA data

Total livetime of 1065 days



Events close to the direction of the Sun

Analysis Results from the Sun



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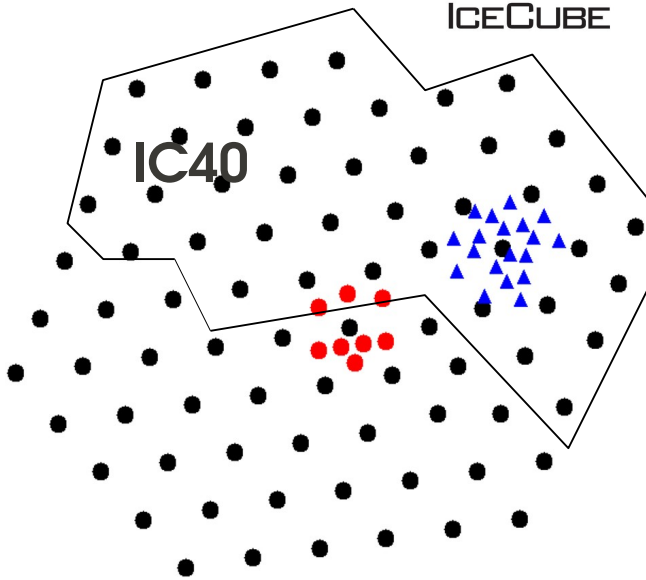

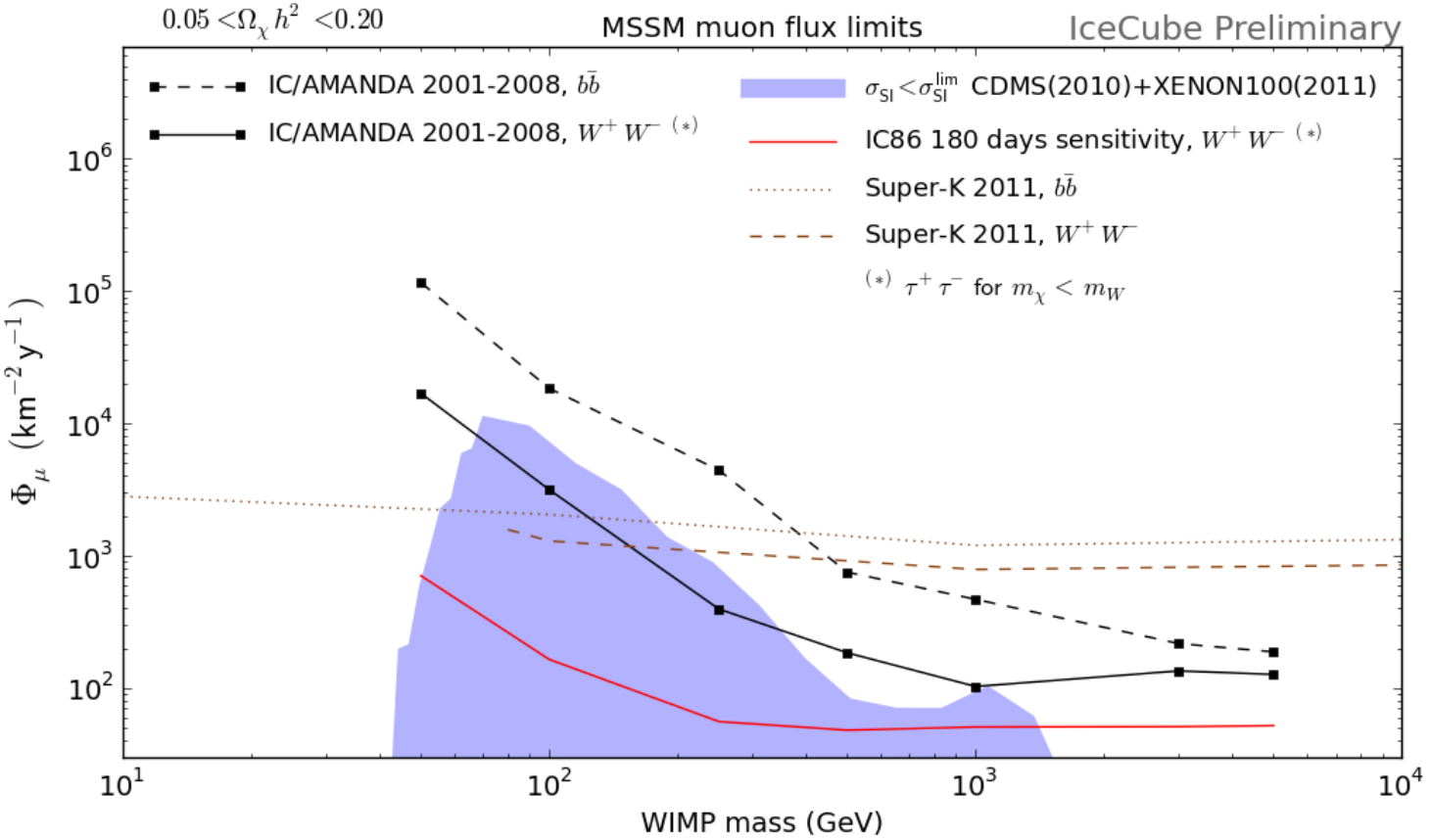

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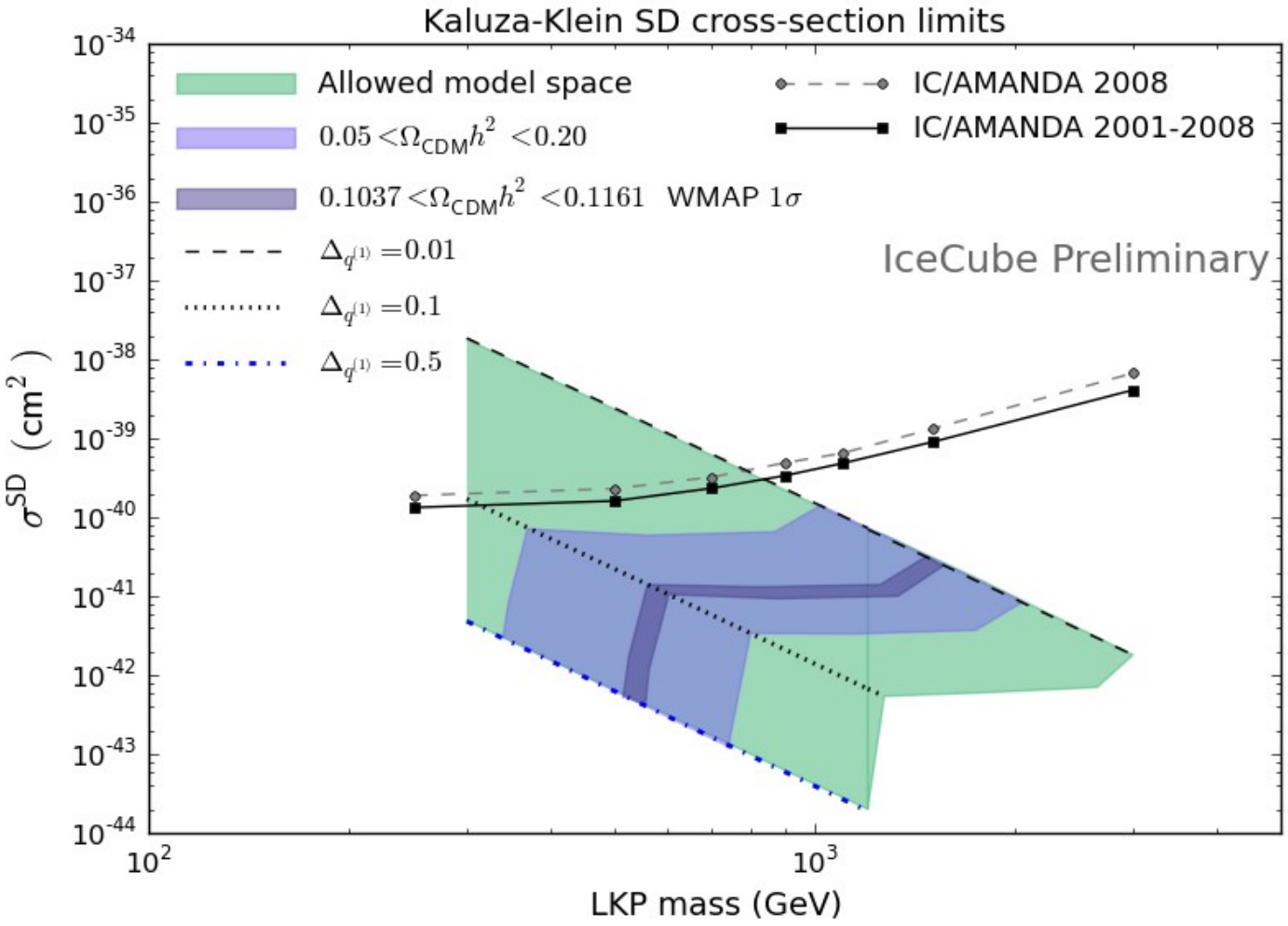


limits & sensitivity:

Only data, when Sun is below the horizon

main syst. uncertainty:

Photon propagation in the ice & absolute DOM efficiency (~20%)

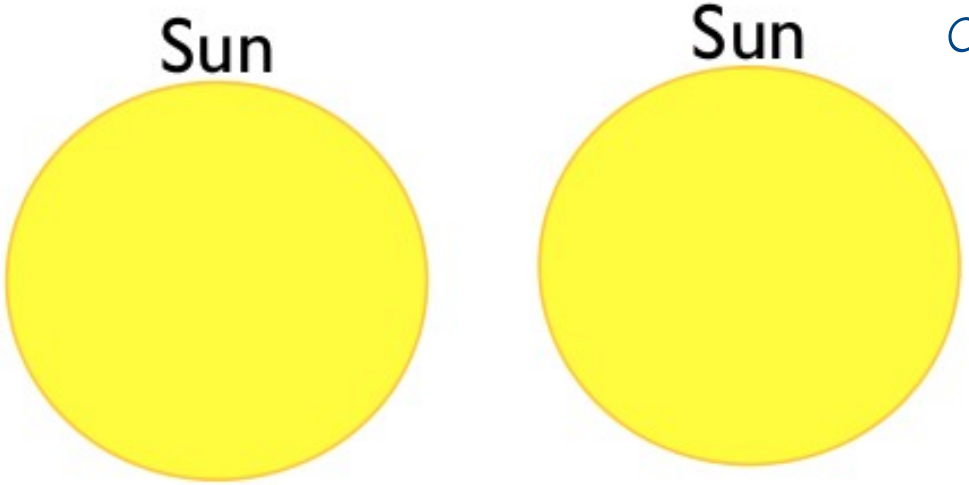
relate muon flux and WIMP - nucleon cross–section:

$$\Gamma_A = \frac{1}{2} C_C .$$

Solar WIMP Equilibrium

Slide taken from Carsten Rott (Neutrino 2012)

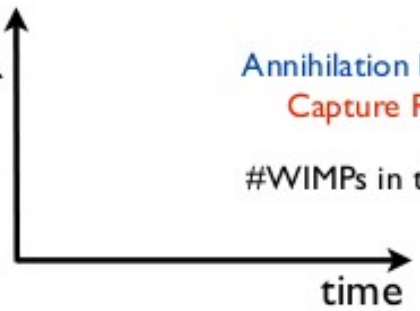
- Dark Matter accumulates and starts annihilating → Neutrinos are the only particles that can make it out
- At equilibrium ($\Gamma_A = 1/2\Gamma_C$) the neutrino flux does not depend on the self annihilation cross section !



	Universe 1	Universe 2
Self-annihilation cross section:	**large**	**small**
WIMP-Nucleon scattering:	same in both (capture rates are identical)	

$$\frac{dN}{dt} = C_C - C_A N^2 - C_E N$$

N = #WIMPs; Capture Rate (Γ_C); Annihilation Rate (Γ_A); Evaporation



Carsten Rott 26 Indirect WIMP Searches

Solar WIMP Equilibrium

Slide taken from Carsten Rott (Neutrino 2012)

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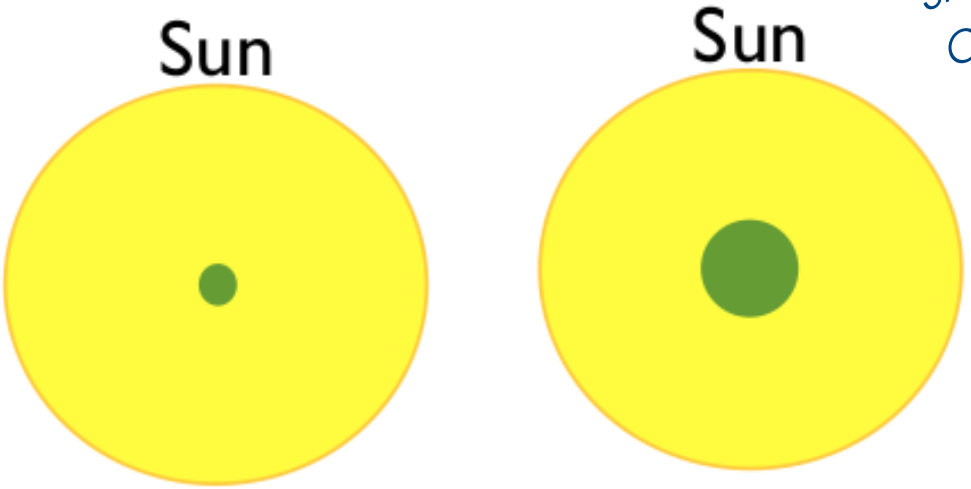

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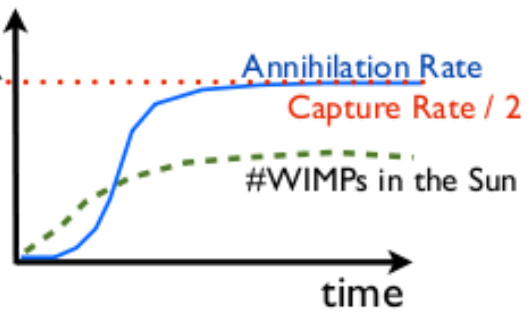

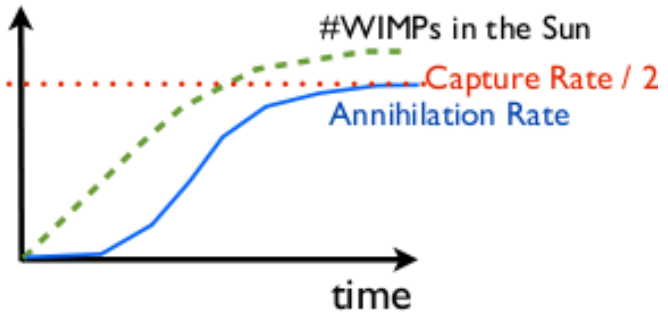

IceCube detector