IceCube Solar **Dark Matter** search

&

Global SUSY fits with IceCube data

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The Oscar Klein Centre for Cosmoparticle Physics, Stockholm

Spaatind 2 - 7 January 2012

Ways to search for Dark Matter

1) Accelerators (Production)

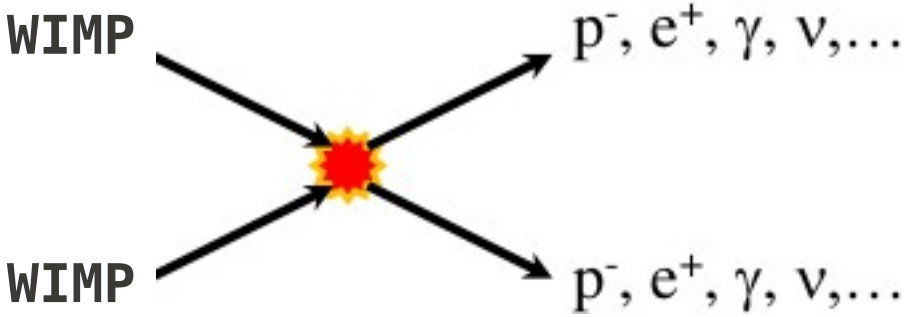
2) Direct Detection (Scattering)

3) Indirect Detection (Annihilation)

Indirect Detection (Annihilation)

- Annihilation rate scales as square of DM density:
  → look for high density regions
  - Galactic Center
  - Dwarf galaxies
  - WIMPs trapped in stars

- Annihilation products
  - Produced at different rates
  - Propagate differently
  - Different backgrounds



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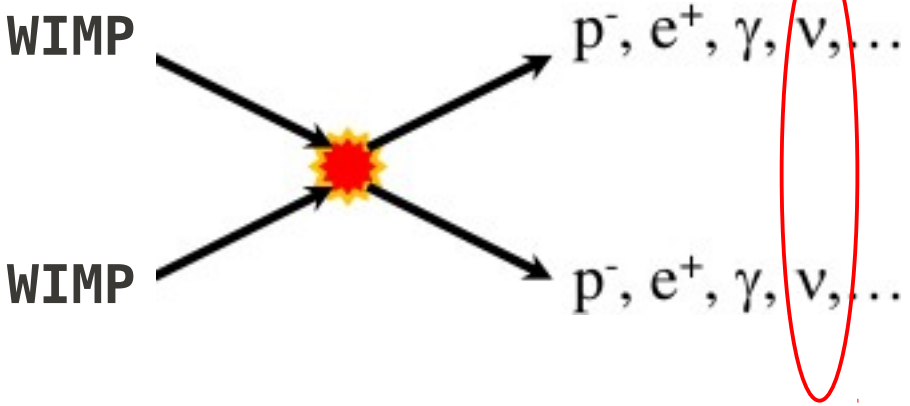
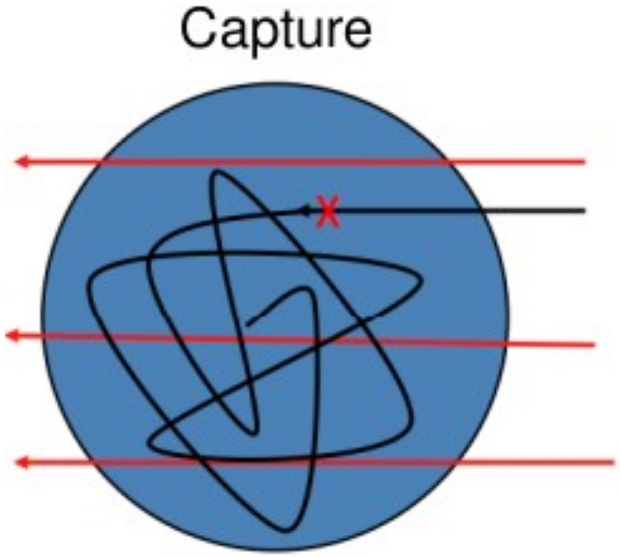
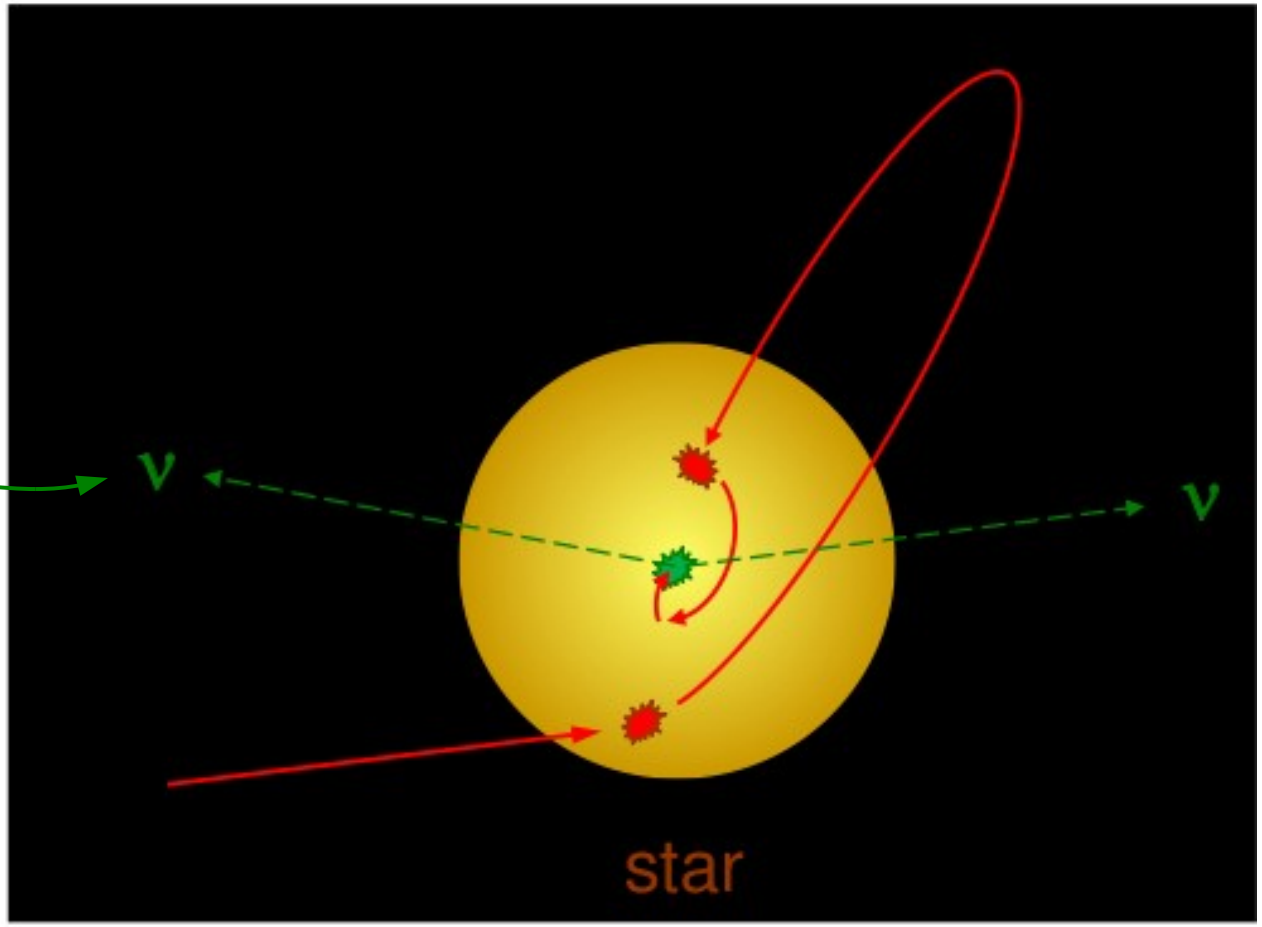


Indirect Search with IceCube





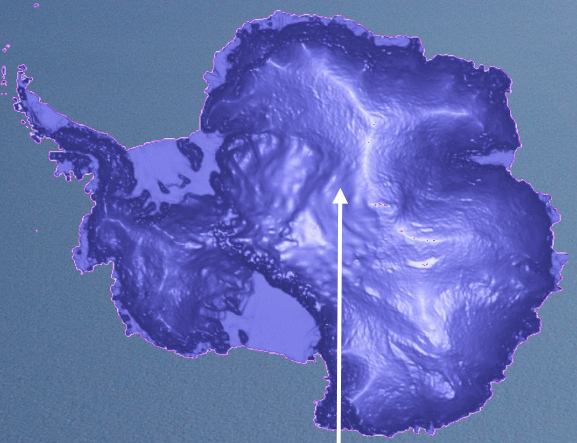
Propagate+oscillate their way to the South Pole, **convert into muons** in **CC** interactions

Look for **Cerenkov radiation** from the **μ**

IceCube detector

Neutrinos interact so weakly that a large volume of detecting material is needed

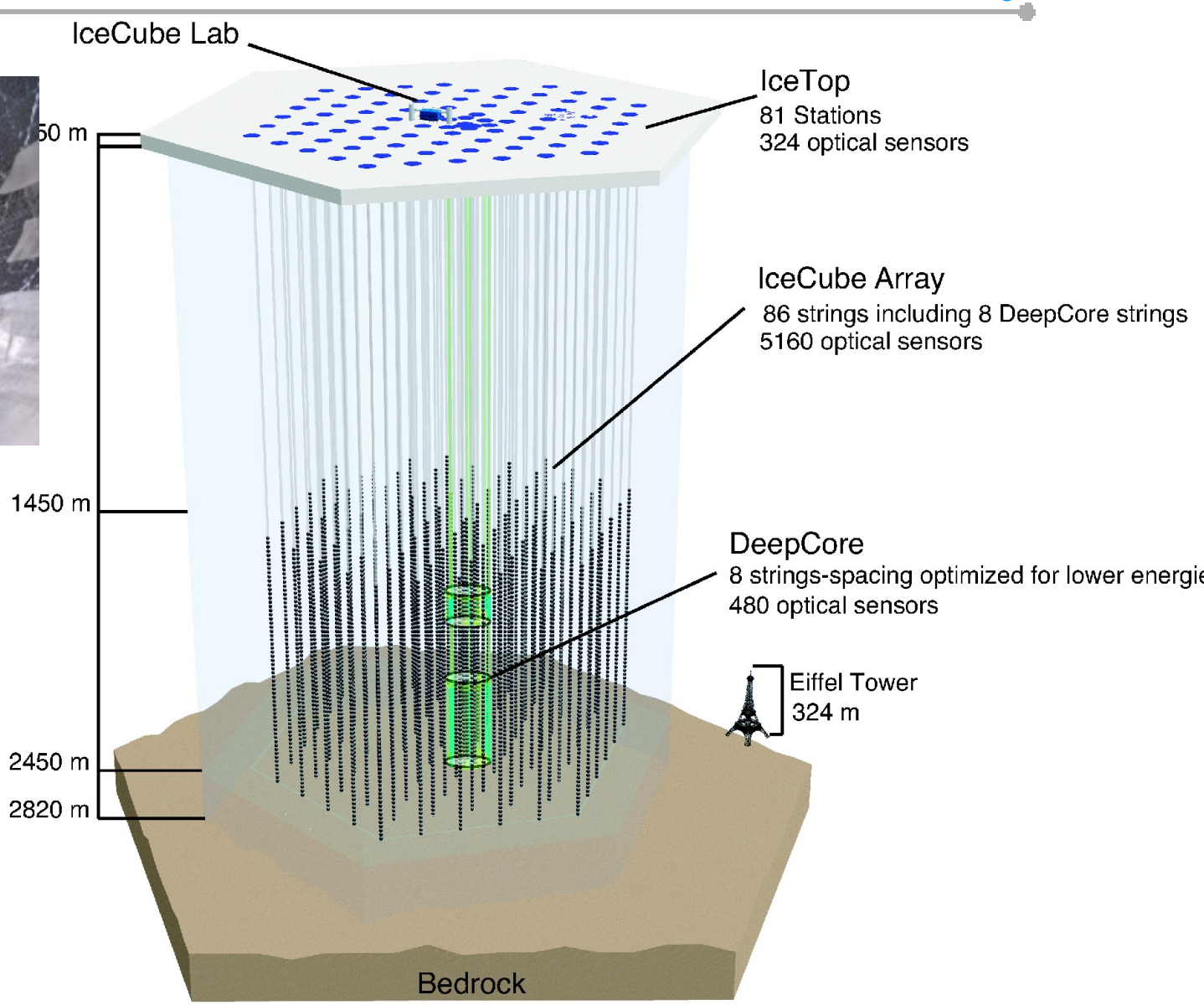
IceCube uses the Antarctic ice



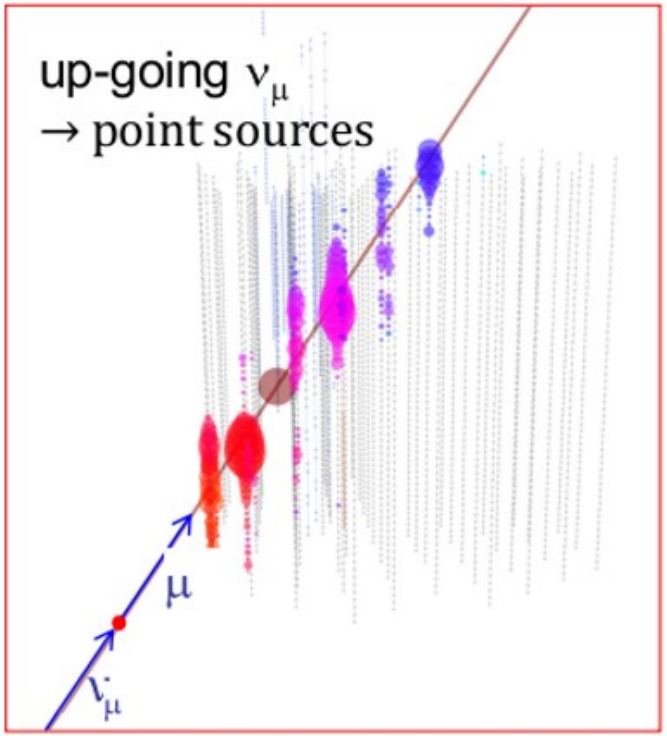
South Pole

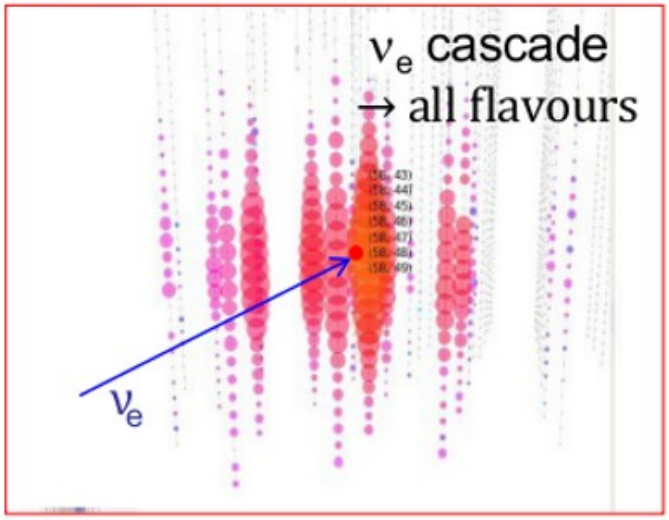
IceCube

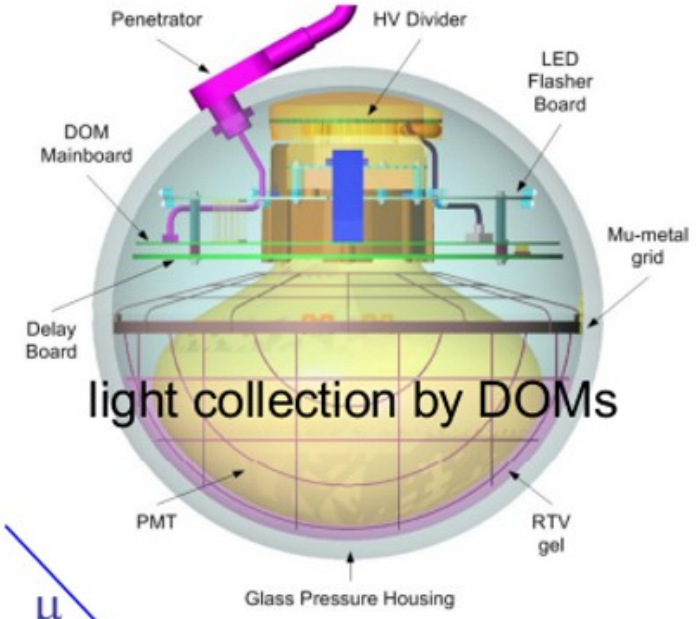
IceCube detector

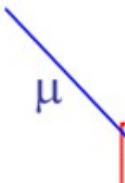


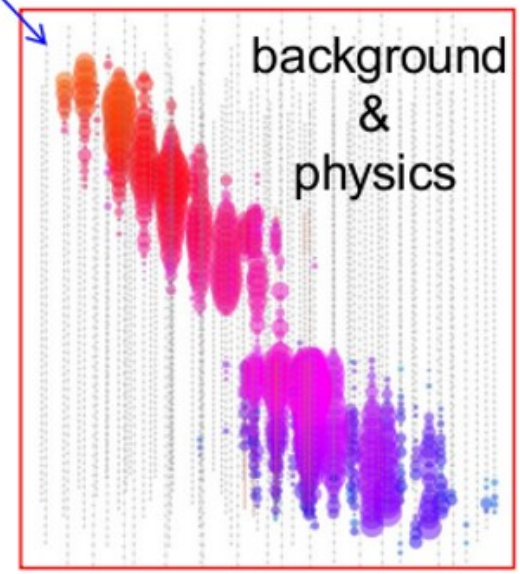
IceCube event signatures

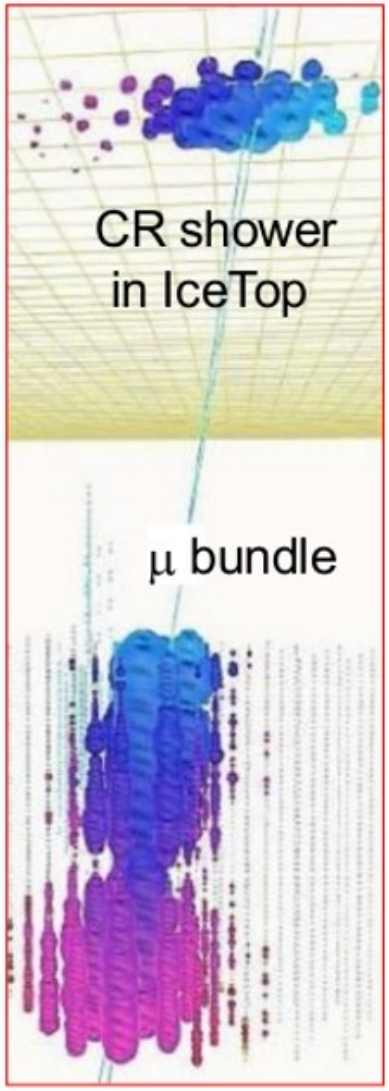








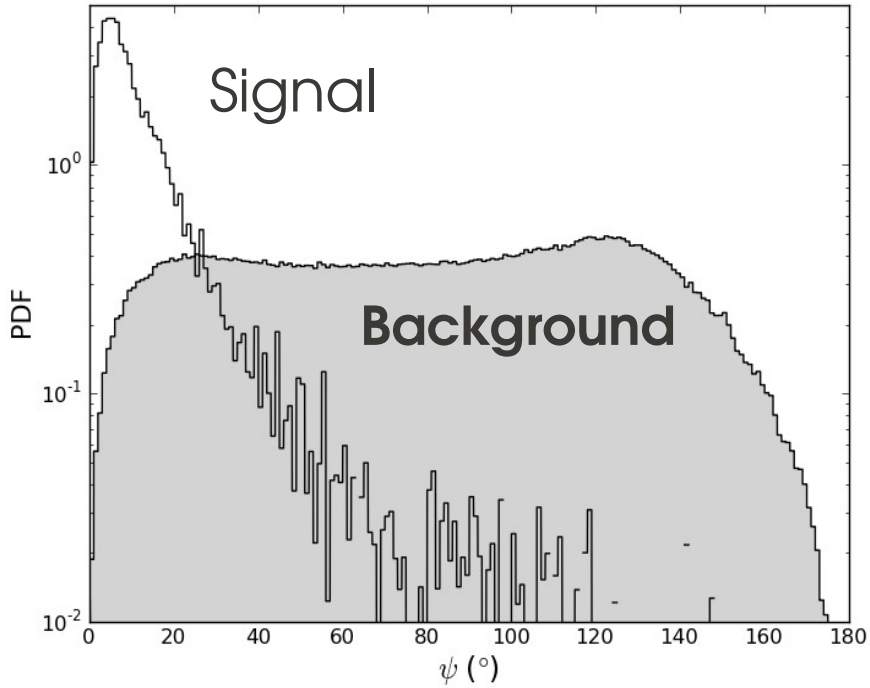




Dark Matter Searches from the Sun

Analysis strategy: Blind analysis with respect to true azimuthal direction

- ✗ 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
- ✗ **DM searches directional:** good additional handle on event selection
  → distribution-shape analysis (maximum LLH analysis)



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

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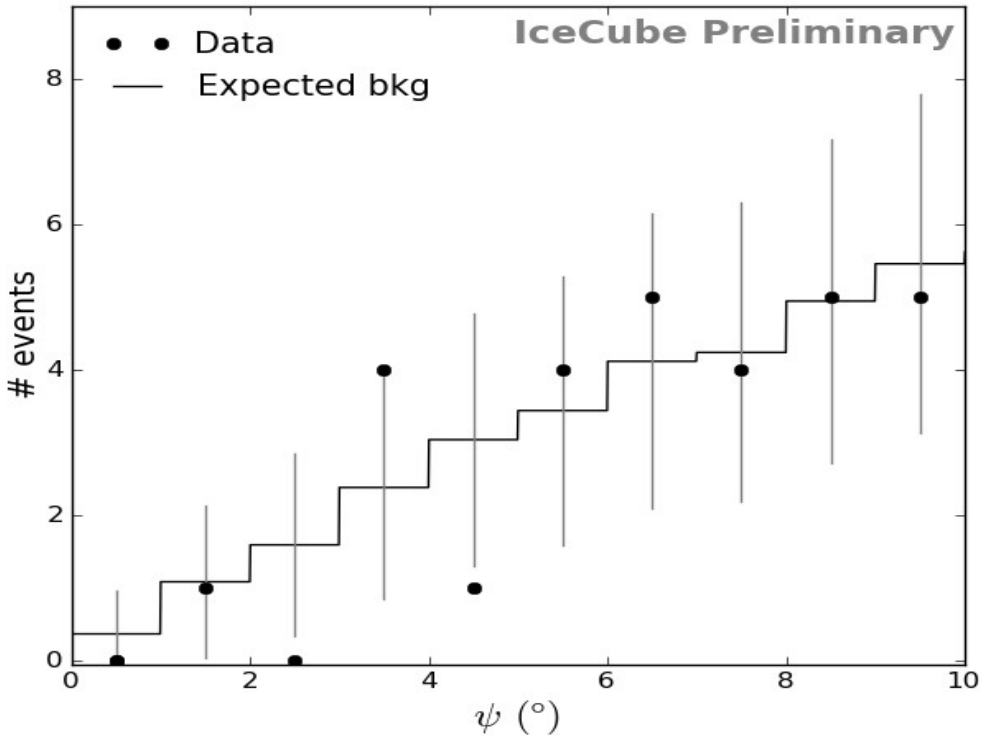
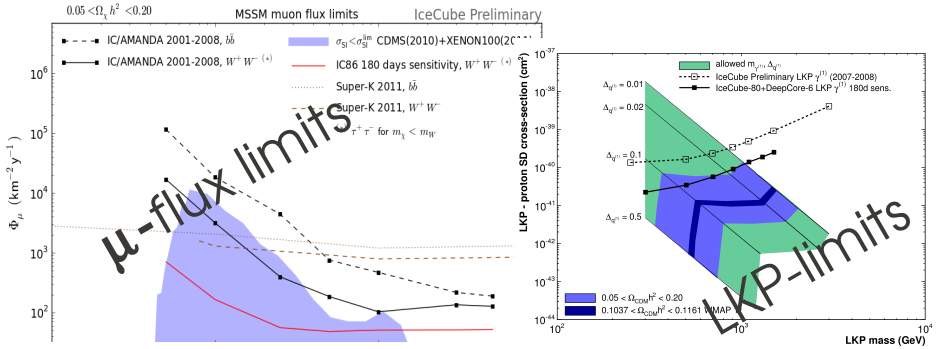


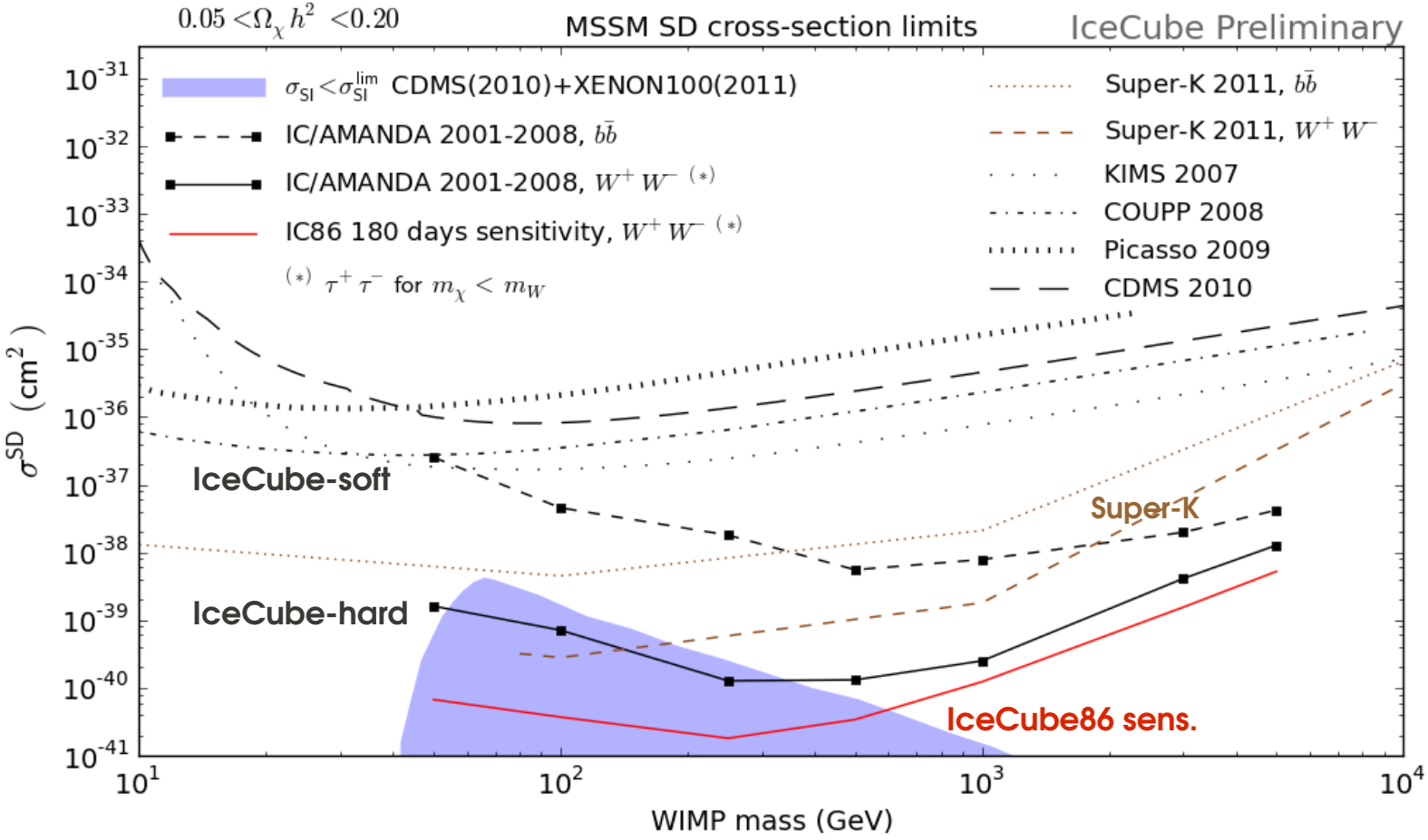
Events close to the direction of the Sun

Analysis Results from the Sun

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

Total livetime of 1065 days





New SUSY analysis with IceCube

What can the muon signal tell me?

IceCube Coll. together with:
Pat Scott, Chris Savage, Joakim Edsjö

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

Global SUSY analysis with IceCube

More information comes from a global statistical fit.

→ **parameter estimation exercise**

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)**

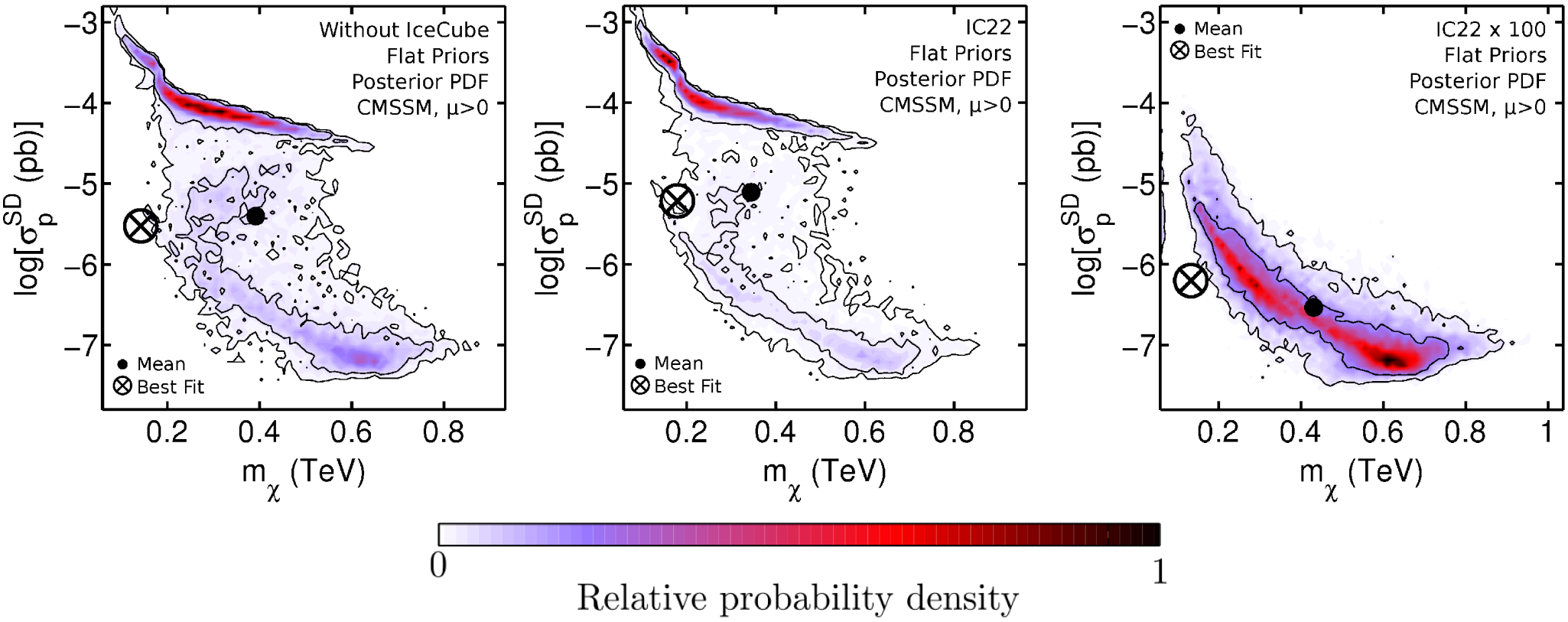
+ IceCube

unbinned likelihood

$$\mathcal{L} = \prod_{j=1}^{n_{\mathrm{bins}}} \left[\mathcal{L}_{\mathrm{N},j} \prod_{i=1}^{n_{\mathrm{tot},j}} \mathcal{L}_{\mathrm{A},ij} \mathcal{L}_{\mathrm{E},ij} \right]$$

Global SUSY analysis with IceCube

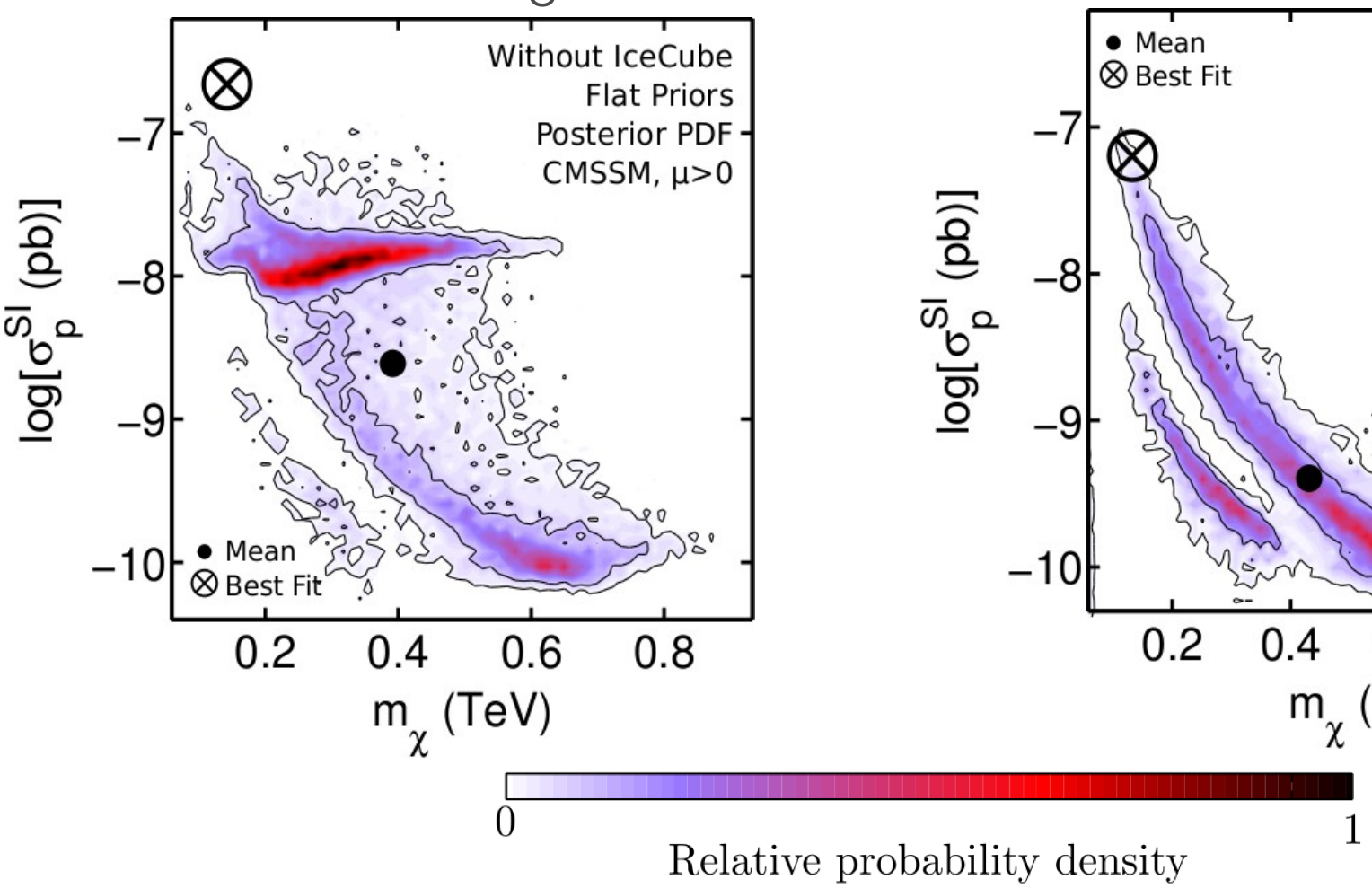
SD nuclear scattering cross-section in the CMSSM with IceCube-22 events



- ✗ Contours indicate 1σ and 2σ credible regions
- ✗ Shading+contours indicate relative probability only, not overall goodness of fit
- ✗ Scans performed with modified SuperBayes 1.5.1 and unreleased DarkSUSY

Global SUSY analysis with IceCube

SI nuclear scattering cross-section in the CMSSM with IceCube-22 events



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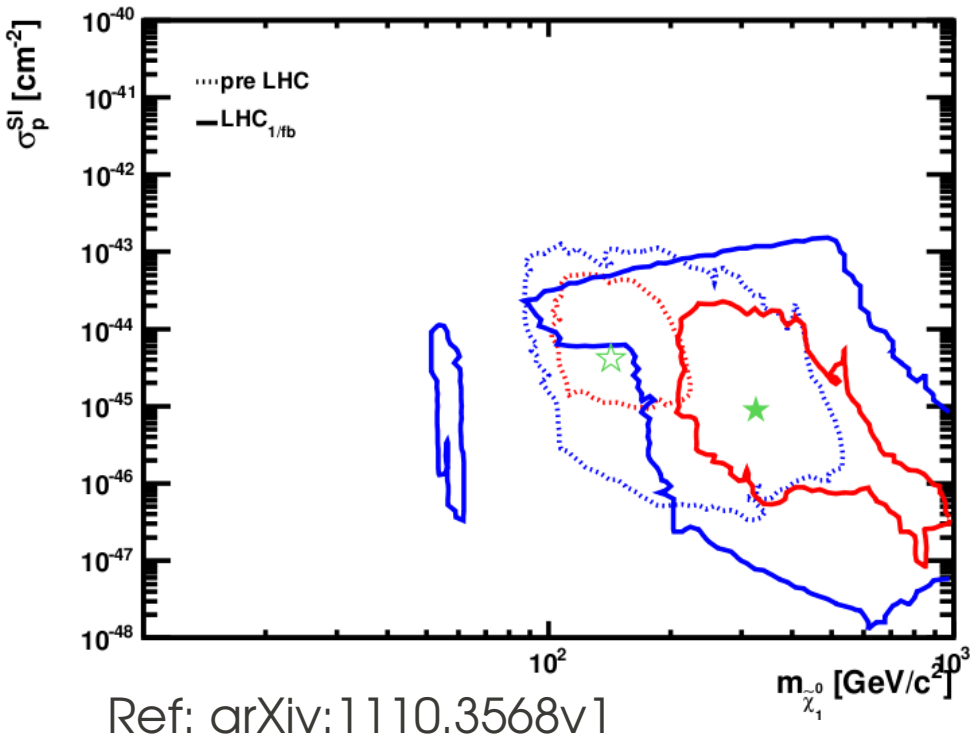
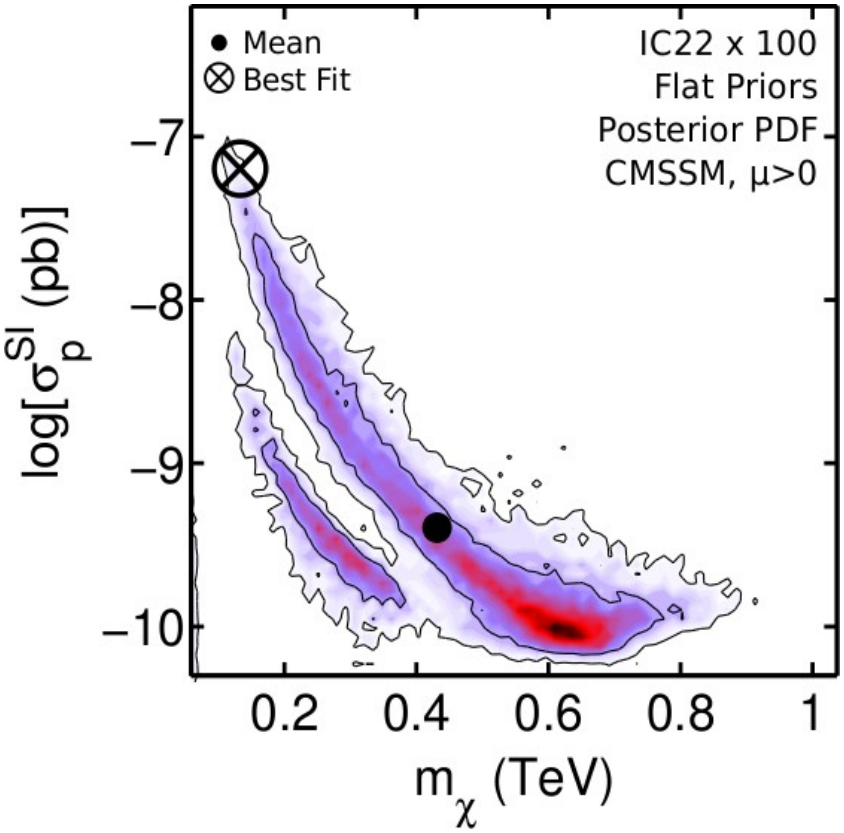


Ref: arXiv:1110.3568v1



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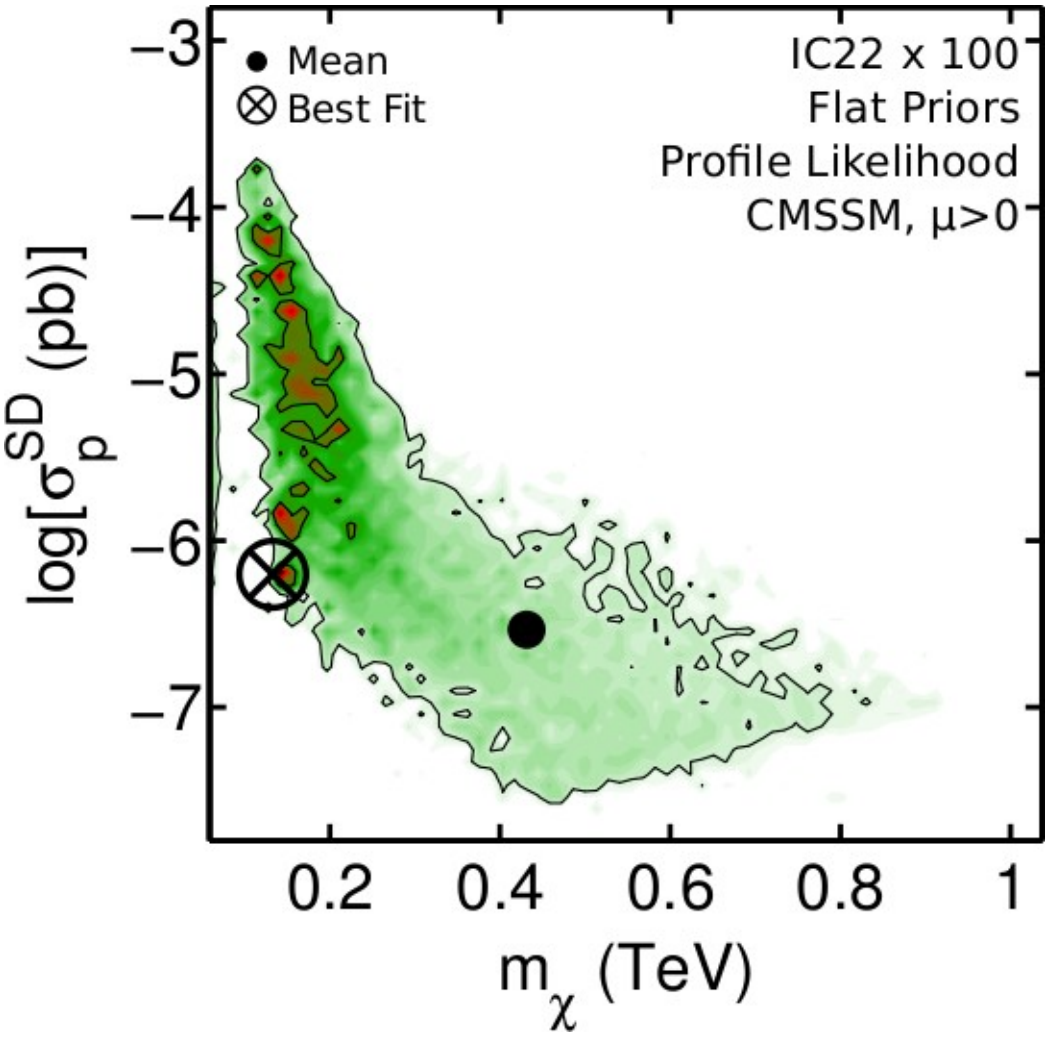
Thank You

More Material



SUSY model exclusion analysis

DarkSUSY for computing neutrino fluxes:

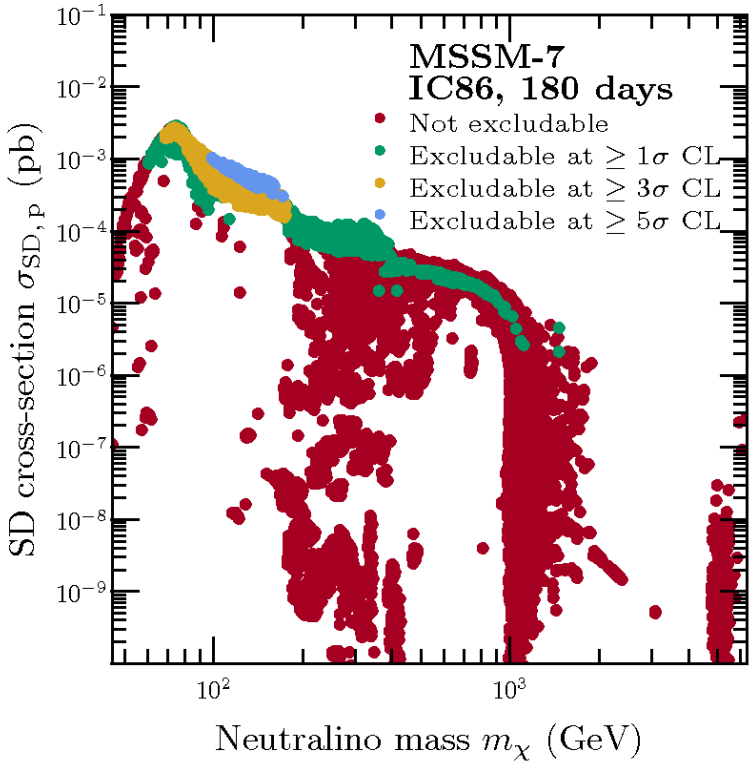
- ✗ No assumption of equilibrium between capture & annihilation, or ann. final state
- ✗ Inclusion of perturbations to WIMP orbits by Jupiter
- ✗ Full numerical capture, SD and SI scattering on many more isotopes than just ^{1}H
- ✗ Full neutrino production, propagation and oscillation via tabulated WIMPSim results
- ✗ Explicit example models - lightest neutralino in SUSY (**MSSM-7** and **CMSSM**)

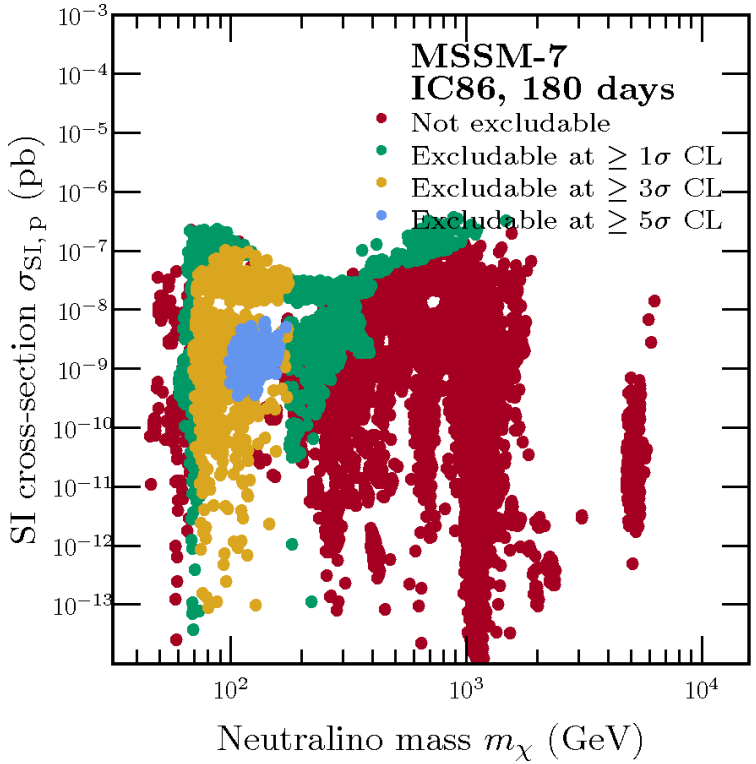
Compare **observed** number of events and **predicted** number for each model, taking into account systematic uncertainties and construct p-values

→ **Model exclusion analysis**

Global SUSY analysis with IceCube

Assuming preliminary (conservative) estimate of IC-86 effective area





- ✗ Only partial goodness of fit, no measure of convergence, no idea how to generalise to regions or whole space.
- ✗ Frequency/density of models in IN/OUT scans means essentially nothing.

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** their way to the South Pole, **convert into muons** in CC interactions

(6) Look for **Cerenkov radiation** from the μ

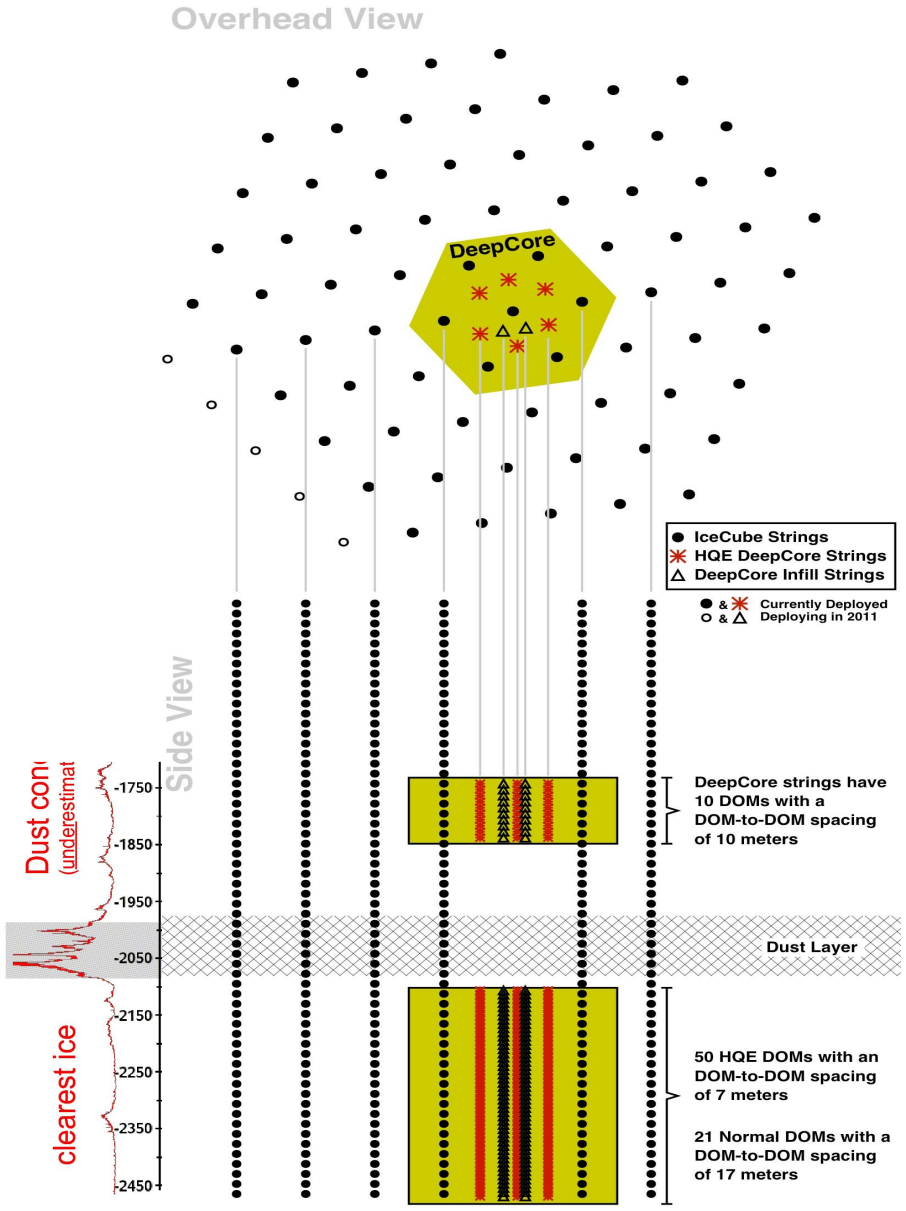
WIMP candidates:

- **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]

DeepCore sub-array

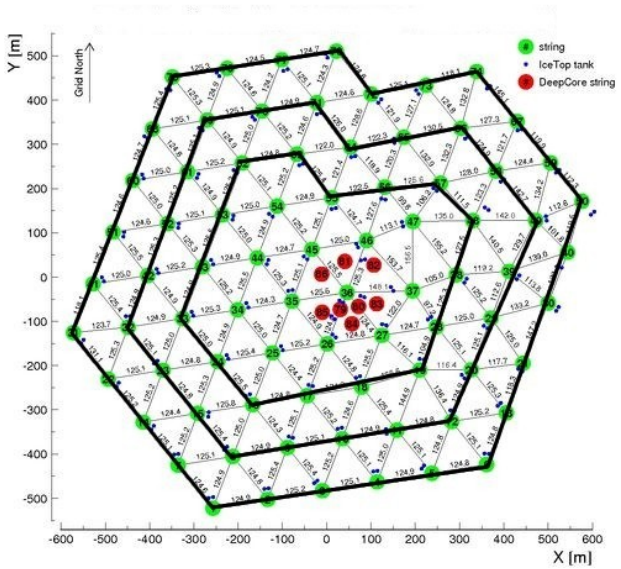
- 6 additional strings – 60 High Quantum Efficiency PMTs (deployed in deep ice)
- 7m DOM spacing (17m standard), 72m inter-string spacing.

  → focus energies (few GeV~1TeV)
- 4π detector using IceCube as an active veto. Southern sky sources (GC) and year round observation for the Sun.



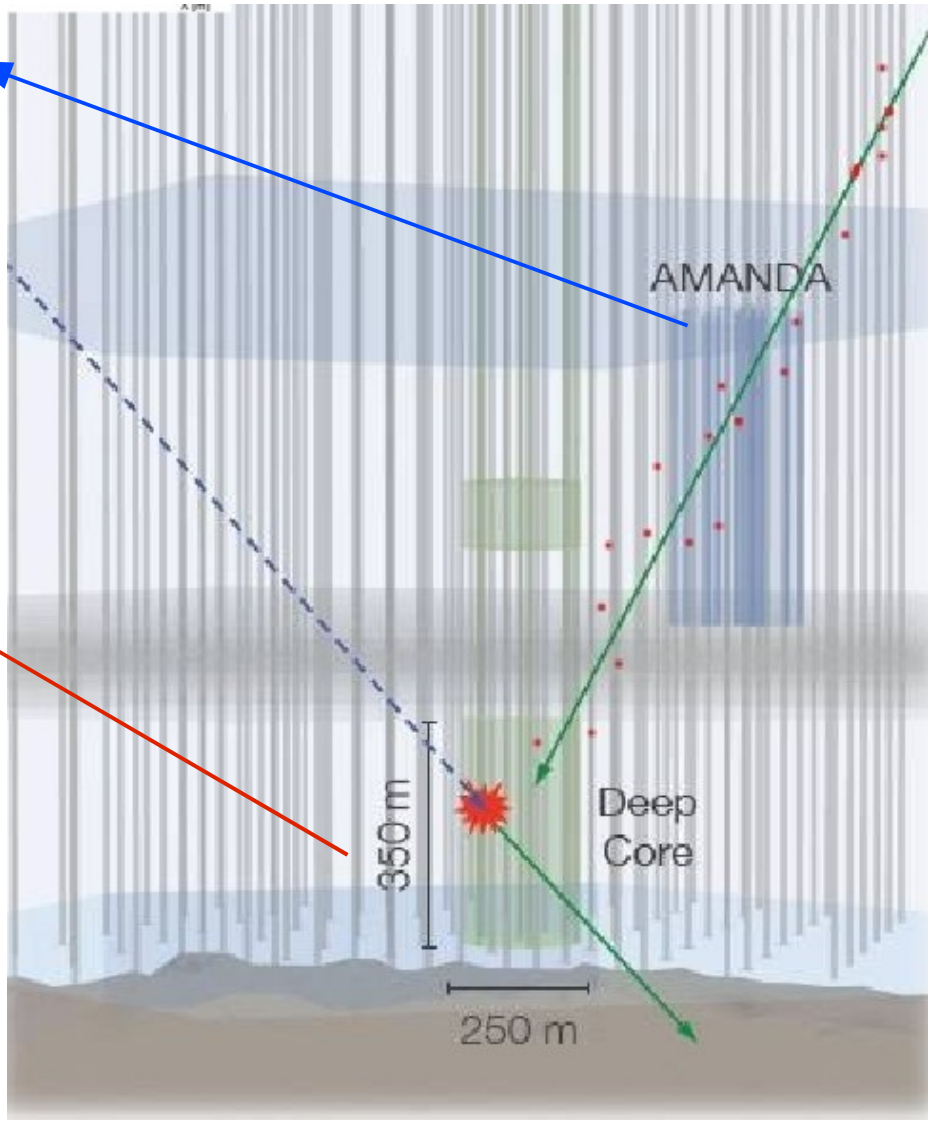
IceCube detector

IceCube 86-strings



AMANDA
19 strings
Until 2009

DeepCore
8 add. densely instrumented strings



- ✗ 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)

IceCube detection principle

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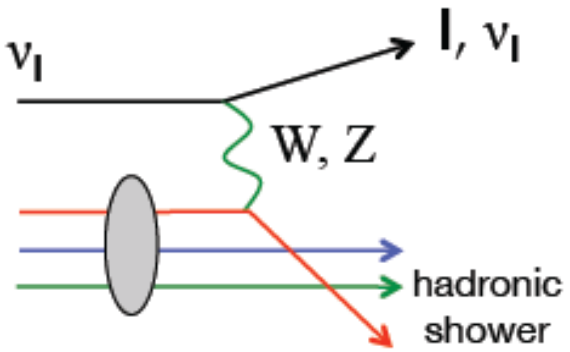
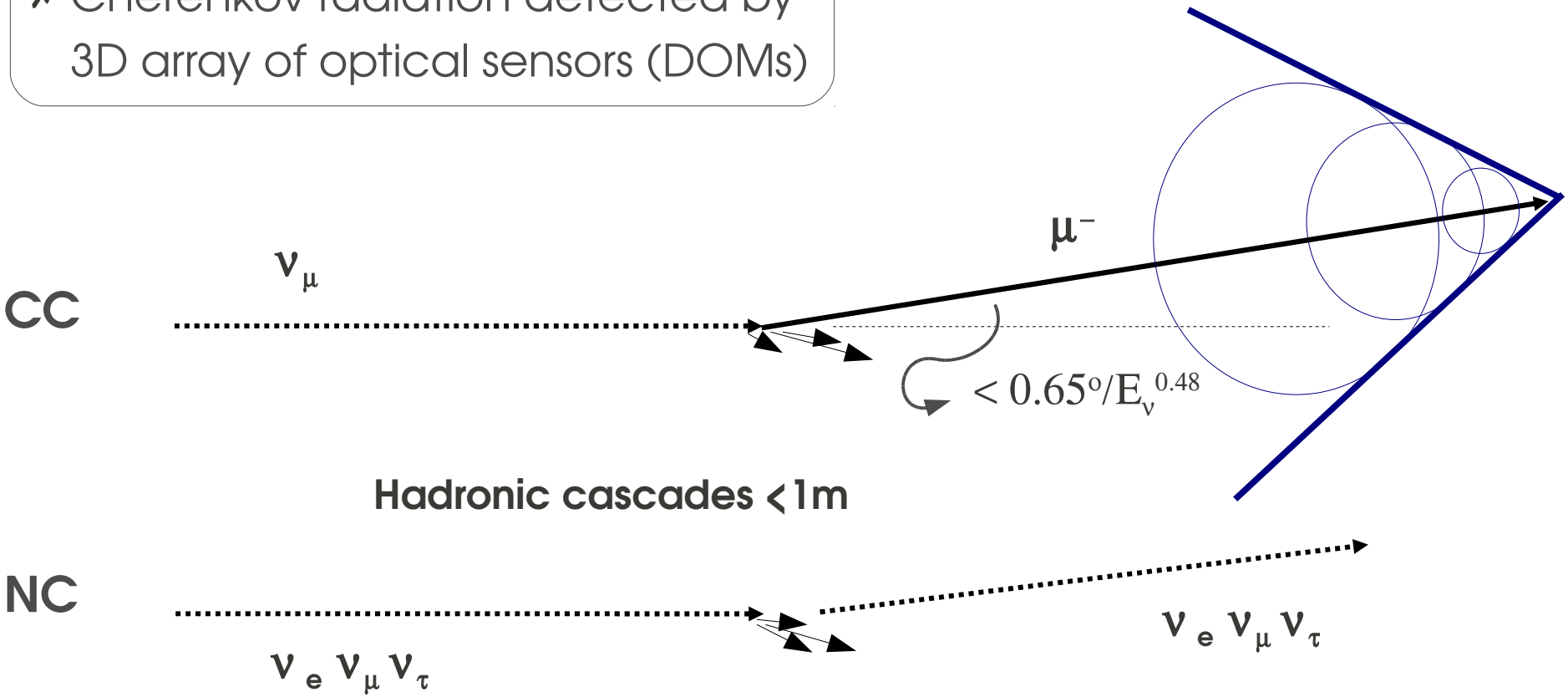
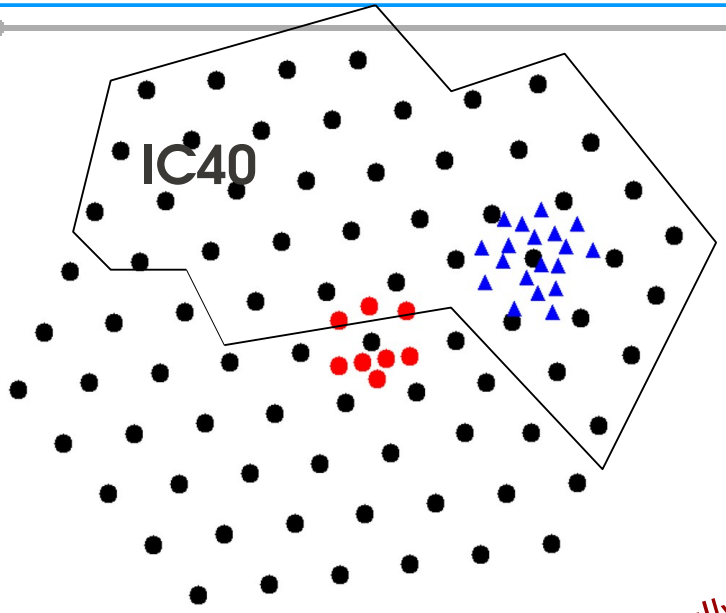




Dark Matter Searches from the Sun



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

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

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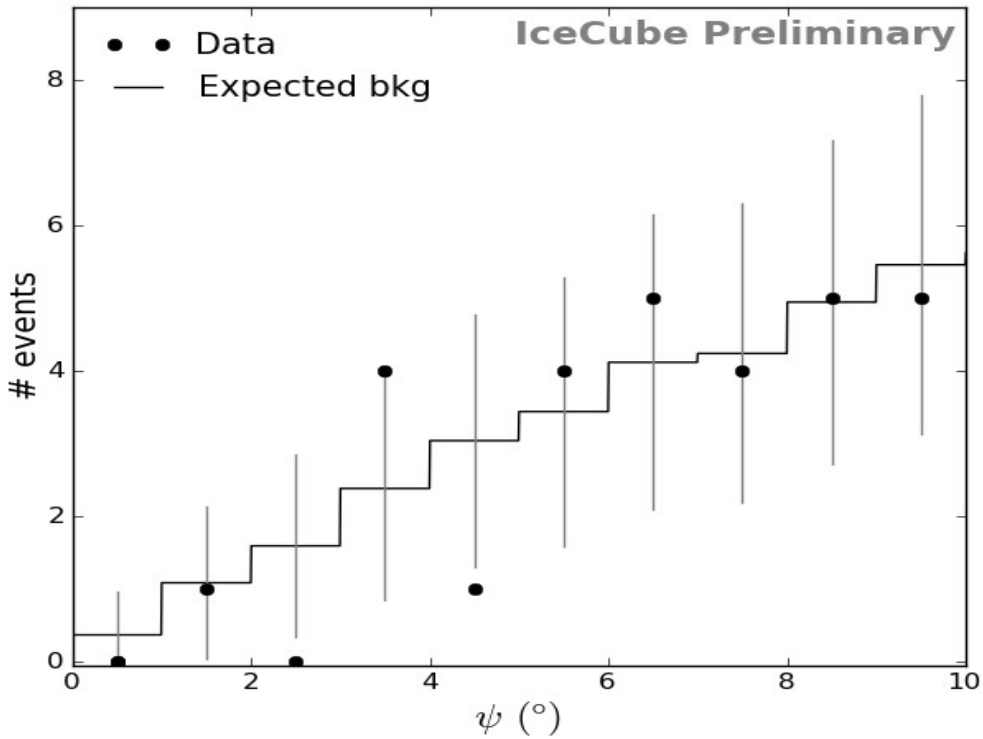
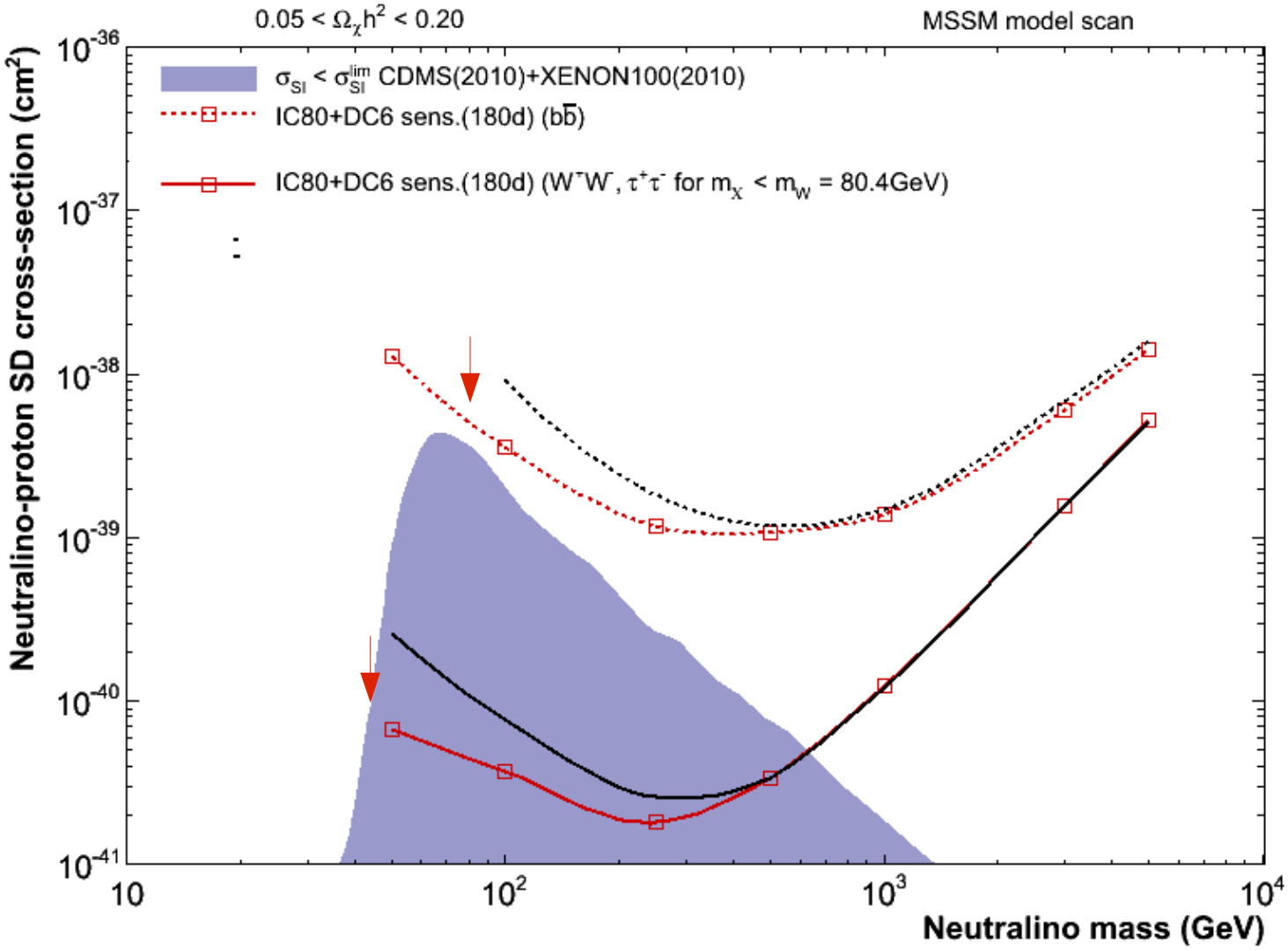


Events close to the direction of the Sun

Analysis prospects from the Sun

(I) Sensitivity improves by factor of 10

(II) Addition of DeepCore (6 strings)



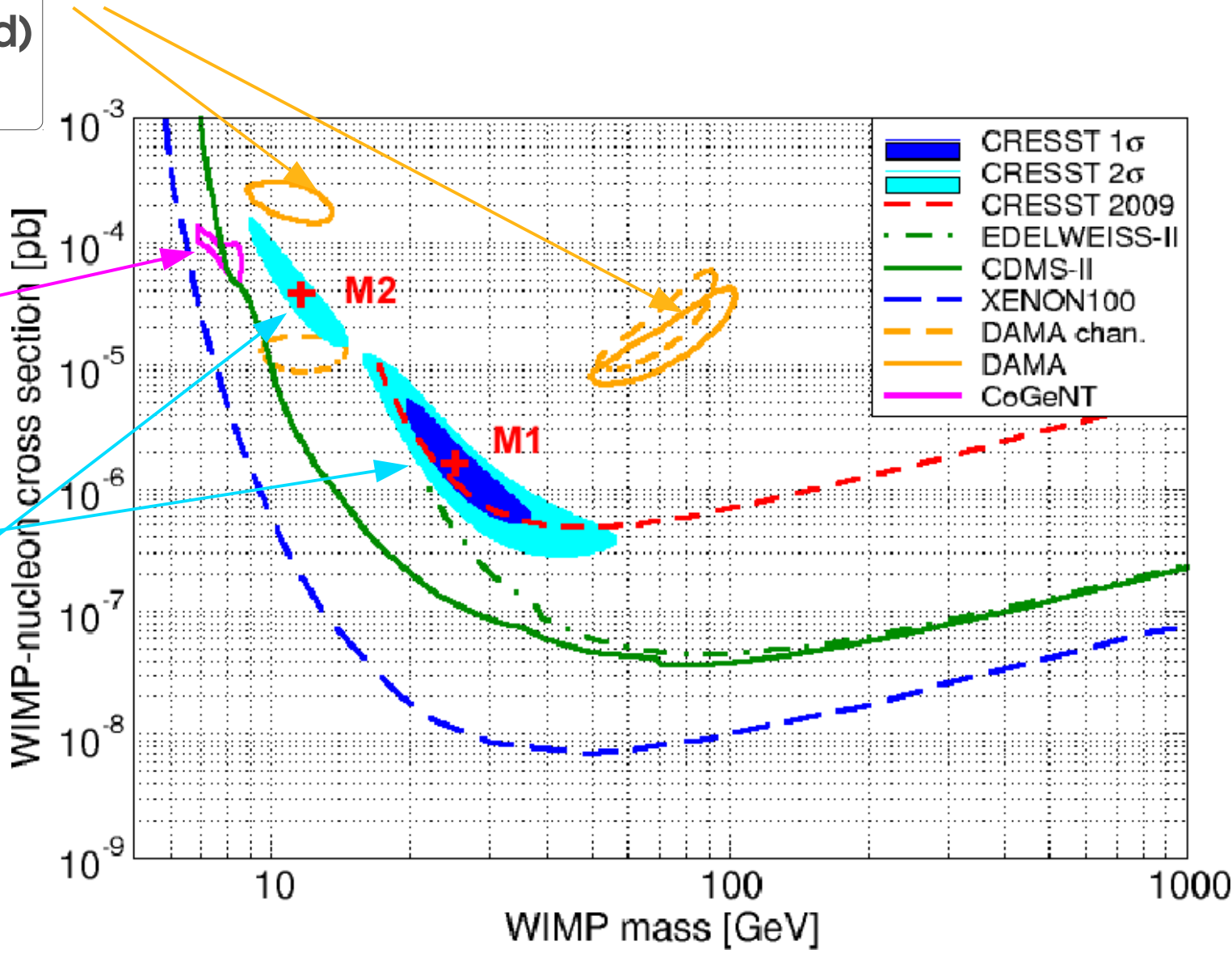
Analysis prospects from the Sun

DAMA-Libra (ann. mod)
(~8-sigma)

CoGeNT (ann. mod)
(~2.8-sigma)

CRESST
M1 (~4.7-sigma)
M2 (~4.2-sigma)

No indication:
XENON 100
CDMS-II



Analysis prospects from the Sun

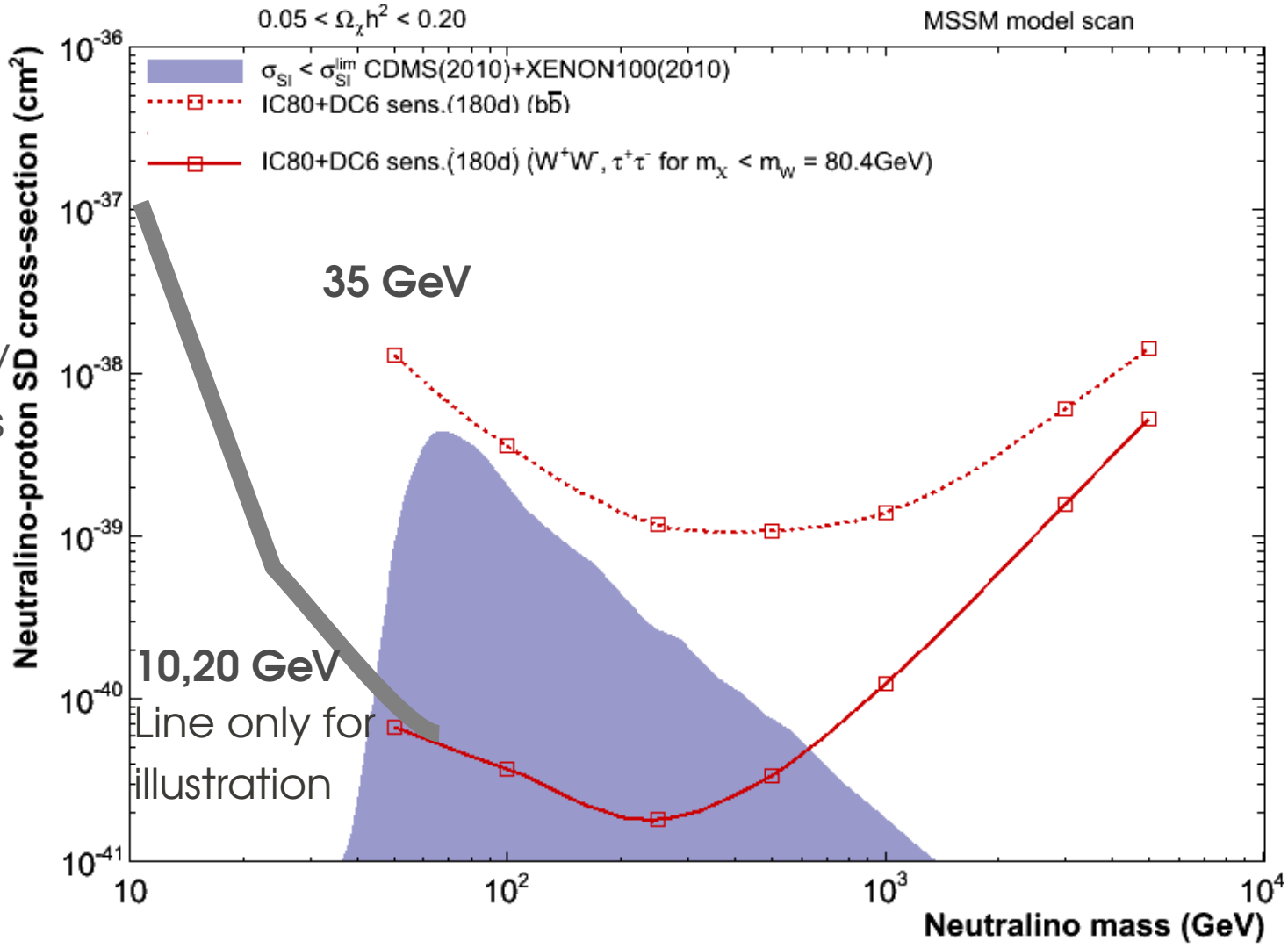
(I) Sensitivity improves by factor of 10

(II) Addition of DeepCore (6 strings)

(III) probe down to 35GeV for both ann.channels

(IV) try to push down to a WIMP mass of 10GeV

(V) use IceCube as veto for DeepCore events and do **all year solar** search



Analysis Results from the Sun

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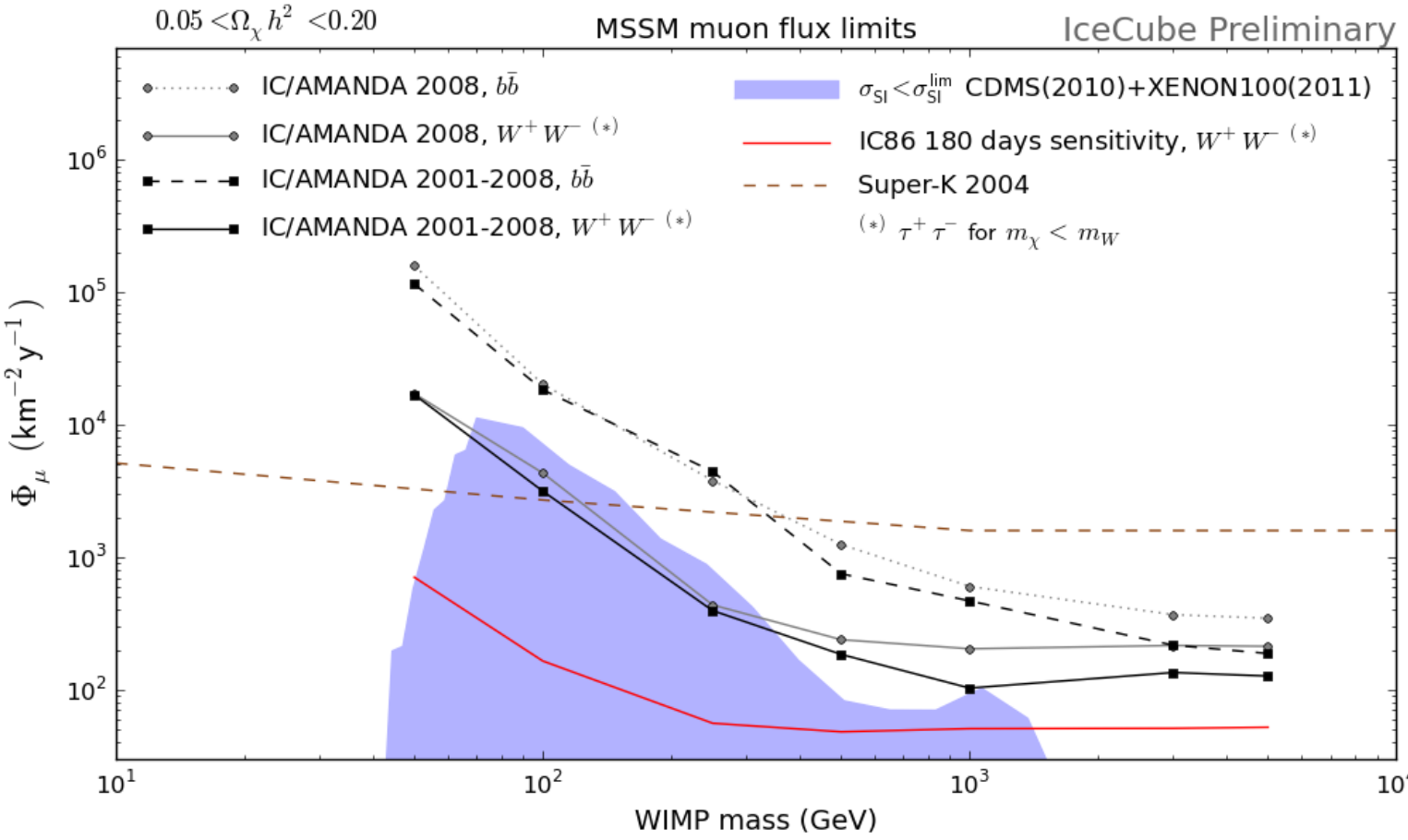

limits & sensitivity:

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:

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

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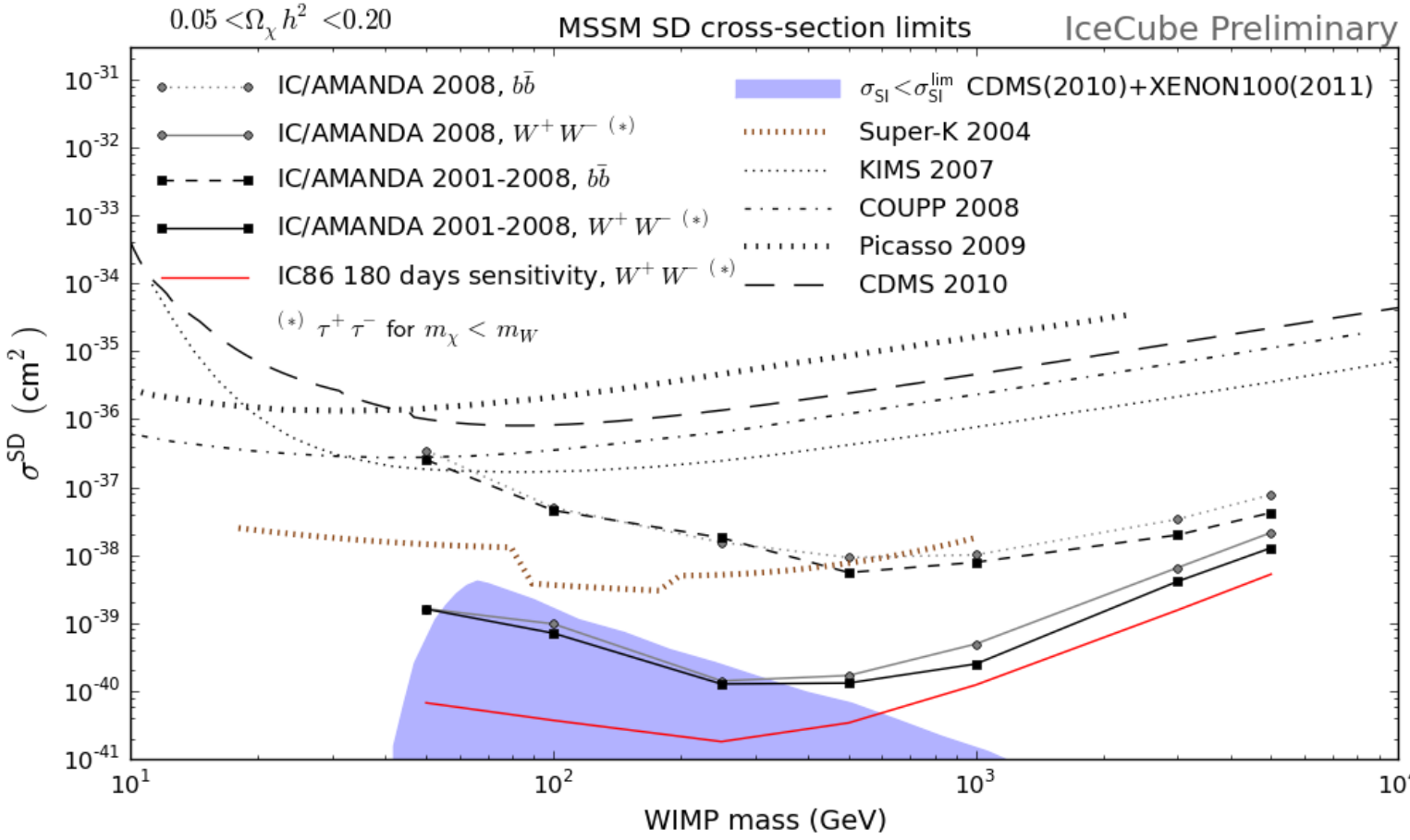

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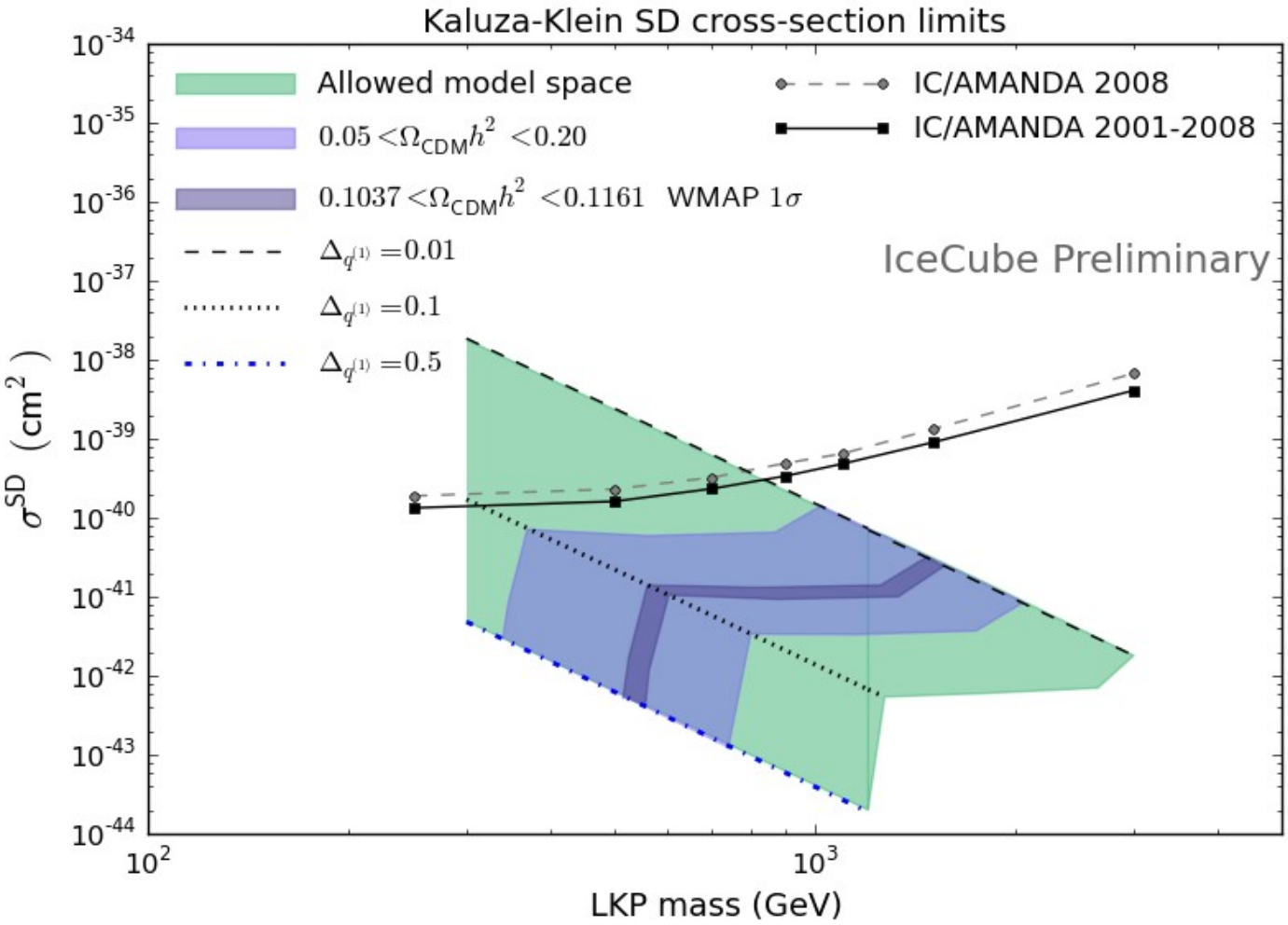

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