Results from Low-Energy Neutrino searches for Dark Matter in the Galactic Center with IceCube

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Dark Matter Working Group Meeting
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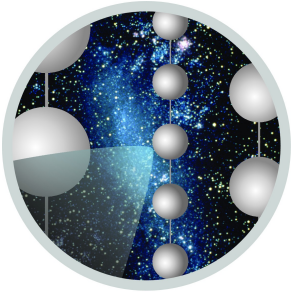
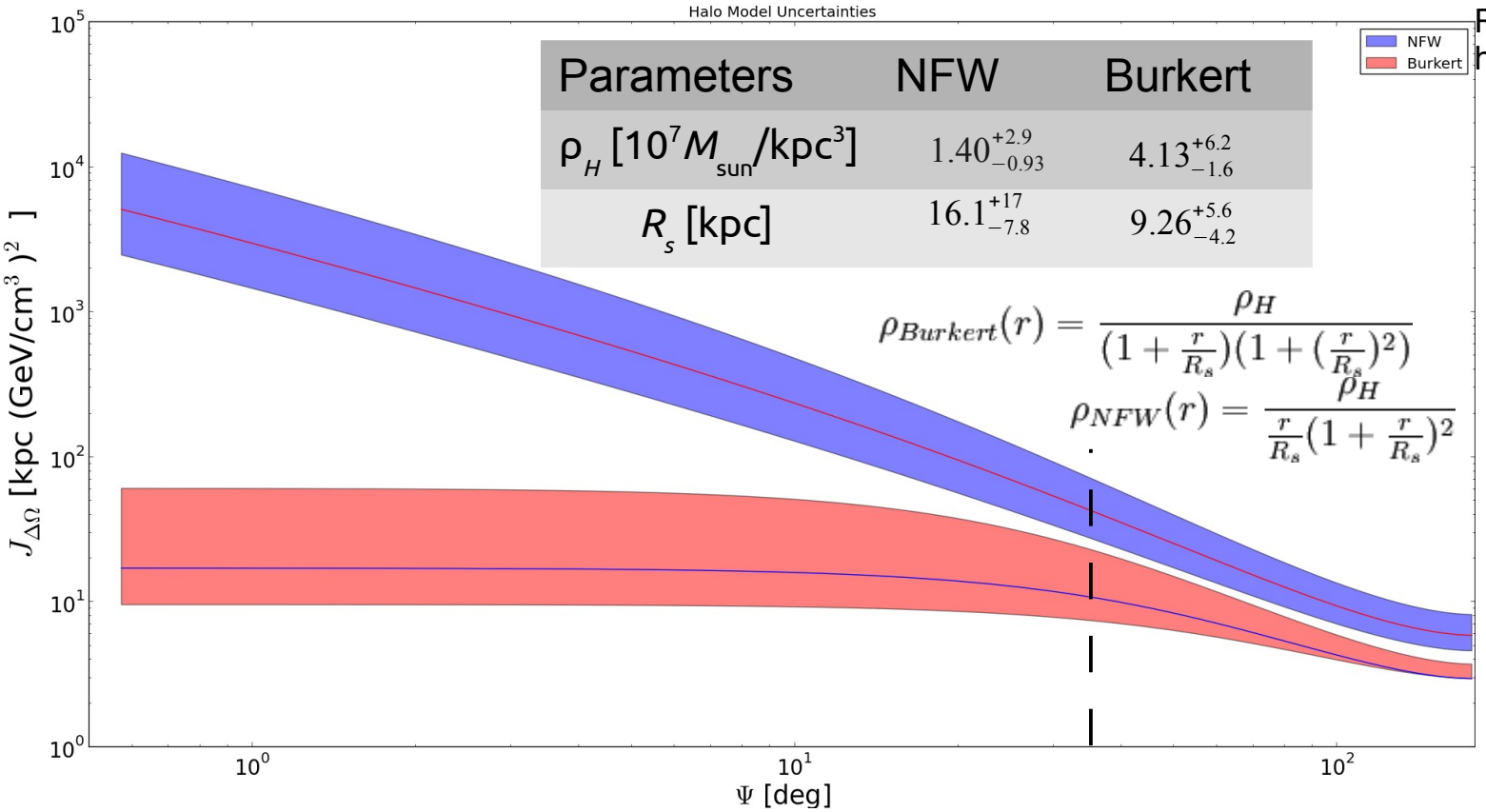


Halo Model Uncertainties

- **Burkert**
  - Fits observations best
  - Flattest profile
- **NFW**
  - Still not excluded
  - The 'standard' one



Ref: Salucci et al.
http://arxiv.org/abs/1304.5127

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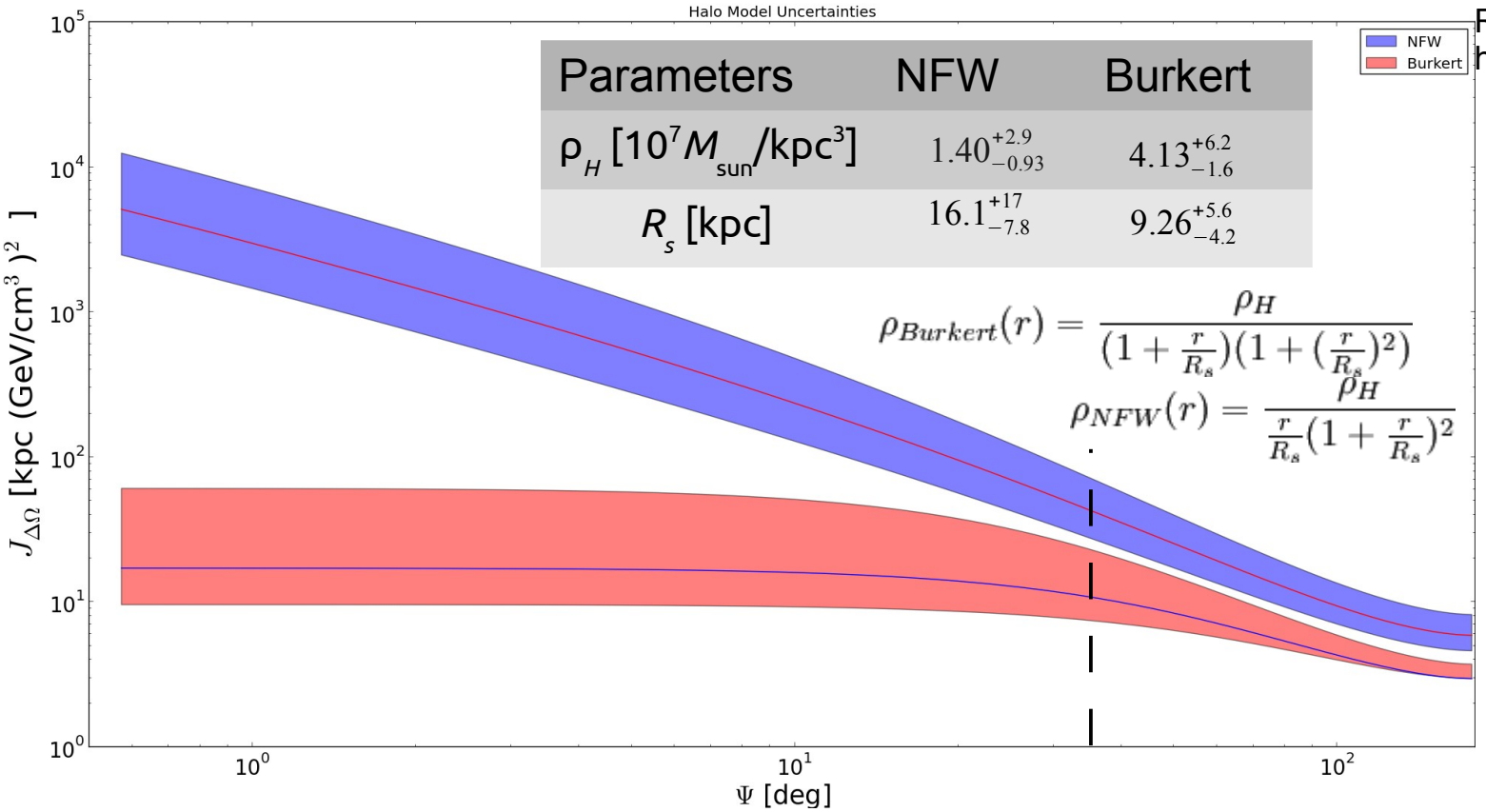

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Outline

- Introduction
- IceCube
- Analysis
- Results

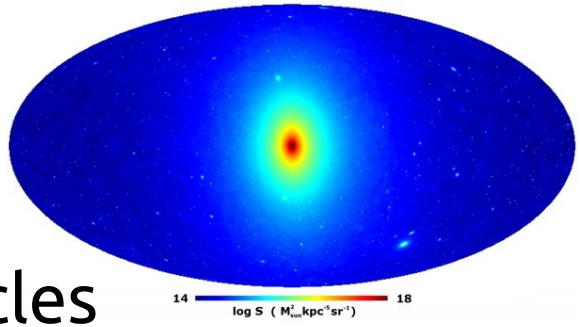
Introduction

Looking for:

- Neutrino signal from the Galactic Center

From what?

- Annihilating Dark Matter (WIMPs)
  - Assumption: WIMPs annihilate to SM particles which in turn decay to neutrinos



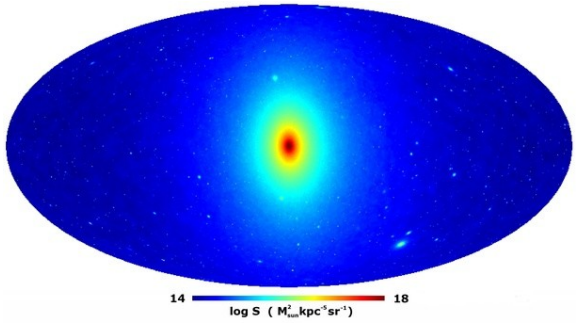
Millenium simulation

Measuring or putting a limit on the averaged velocity cross-section

$$\frac{\mathrm{d}\,\Phi_\nu}{\mathrm{d}\,E} = \frac{\langle \sigma v \rangle}{2} J(\Psi) \frac{R_{sc}\,\rho_{sc}^2}{4\pi\, m_\chi^2} \frac{\mathrm{d}\,N_\nu}{\mathrm{d}\,E}$$

Introduction

We believe that the Milky Way is embedded in a dark matter halo. Dark matter density depends on the distance from the center.

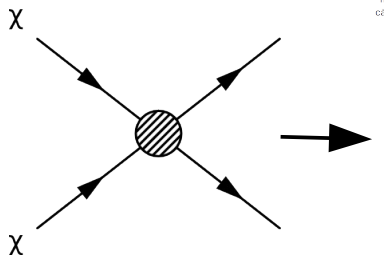


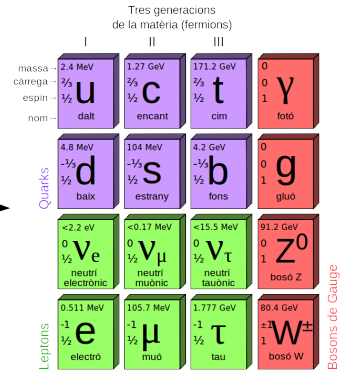
Millenium simulation

$J(\Psi)$ is the line of sight integral
Usually described analytically by different halo models.

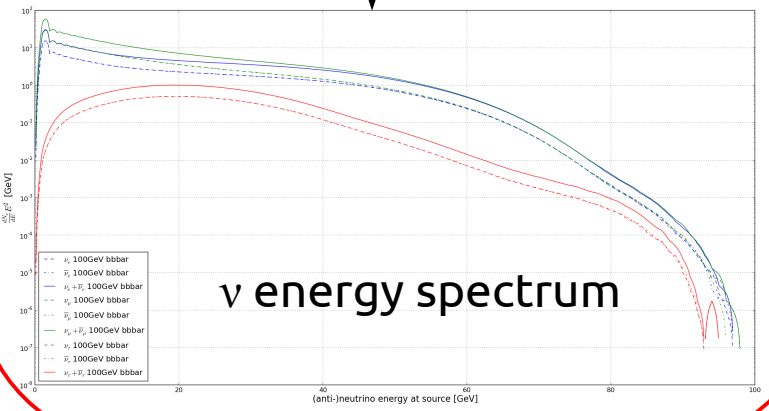
$$\frac{\mathrm{d}\Phi_\nu}{\mathrm{d}E} = \frac{\langle \sigma v \rangle}{2} J(\Psi) \frac{R_{sc}\rho_{sc}^2}{4\pi m_\chi^2} \frac{\mathrm{d}N_\nu}{\mathrm{d}E}$$

WIMPs: Weakly Interacting Massive Particles, χ .
If majorana → Self annihilation.



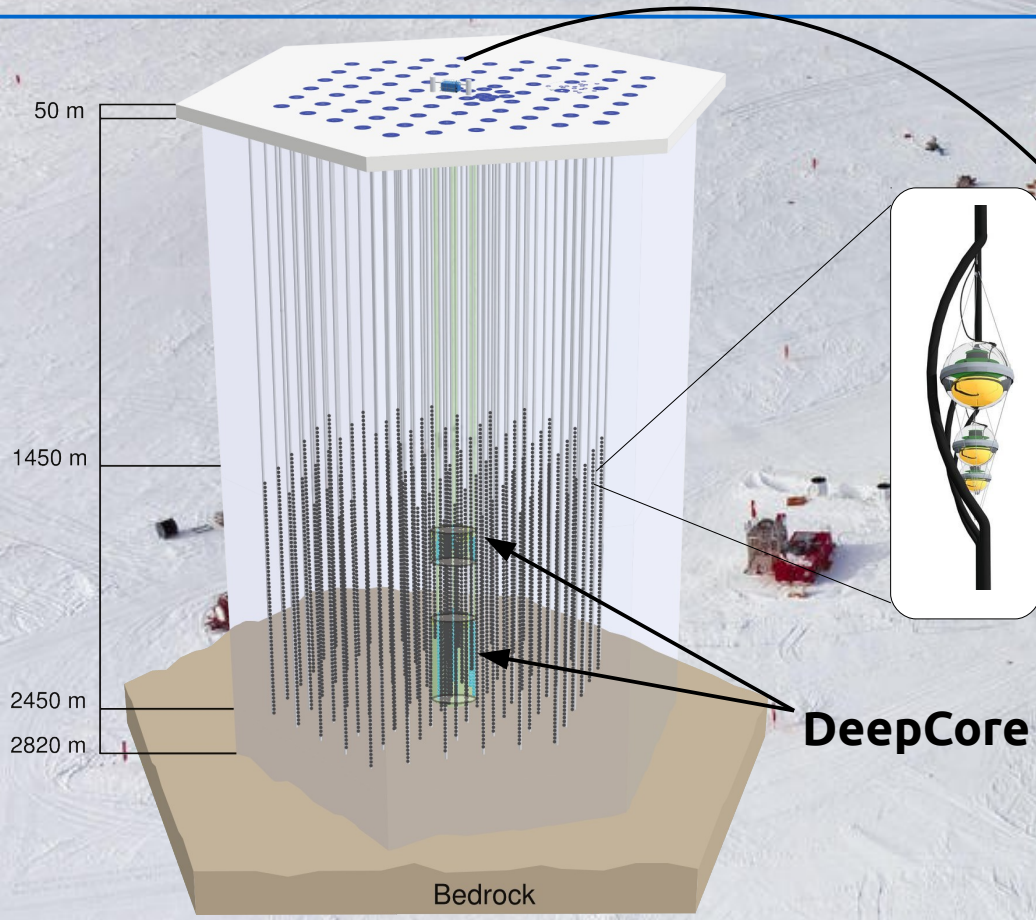


SM particles decay to neutrinos



ν energy spectrum

IceCube detector



1.5 km - 2.5 km deep

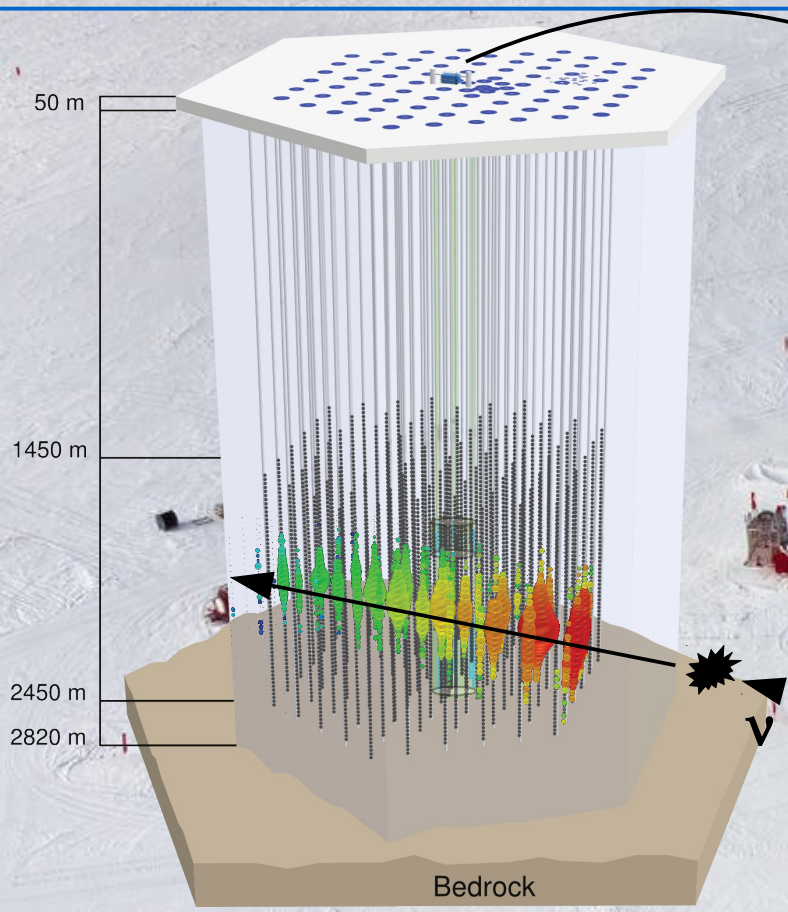
typically 125 m spacing between strings (~70 m in DeepCore)

60 Optical modules per string

1 km³ – 1 Gton instr. volume

- Located at the South Pole
- 38 institutions world wide participate in the experiment
- Around 250 scientists

IceCube detector



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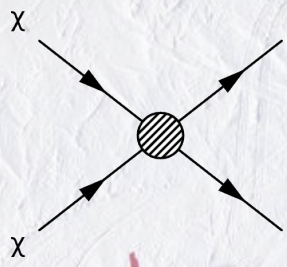
IceCube lab

O(km) μ tracks from ν_μ CC

O(10m) cascades from ν_e CC, low energy ν_τ CC, and νx NC

Cherenkov radiation detected by 3D array of optical modules



Searching for dark matter annihilations is in the low energy regime for IceCube. ~10 GeV-TeV

Analysis

Strategy

- **Event selection**
  - Reduce the number of events to a manageable amount
  - Select events with good quality
- **Analysis**
  - Maximum likelihood analysis

Analysis - event selection

Signal:

Low energy Neutrinos from WIMP annihilations:

-Down-going neutrino events.
-Neutrino energy :10 GeV – 1 TeV
-Rate: ??< ~4μHz [based on limits]

Backgrounds:

Atmospheric Muons:

-Dominating but reducible
-Down-going
-Rate: ~3kHz (300 million per day)

Atmospheric neutrinos:

-Irreducible
-Almost isotropic
-Rate: 0.01Hz (~1000 per day)

At the South Pole the Galactic Center is always seen at a zenith of 61°

Event Selection: Strategies

- Down-going events
- Starting events (inside DeepCore)
- Linear cuts
- Vetos
- Split sample (high and low energy)
  - Two BDTs (Boosted Decision Trees)

Analysis - event selection

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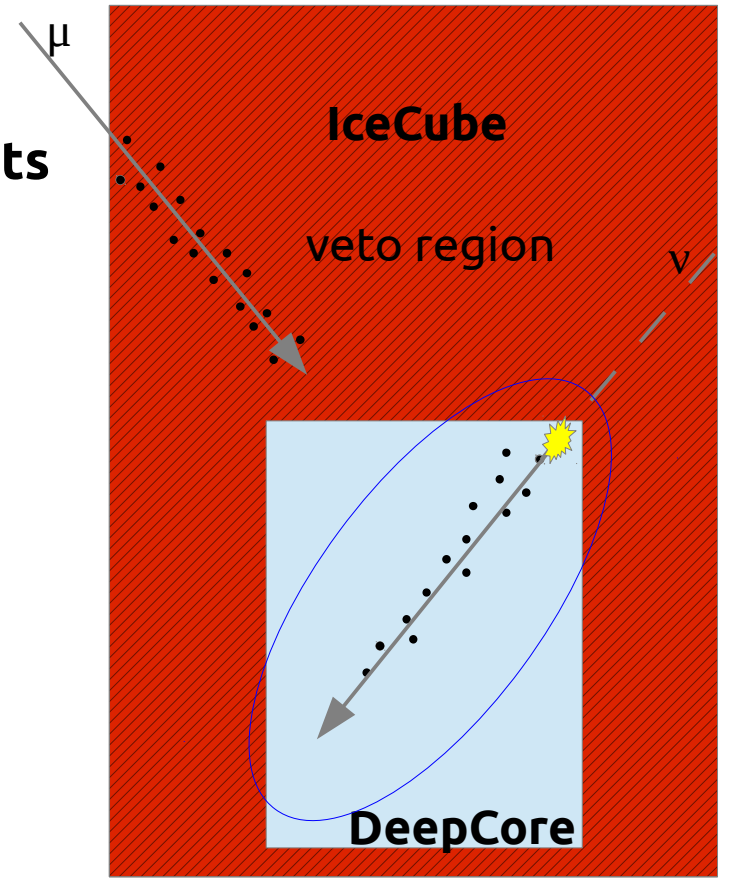
Starting Events



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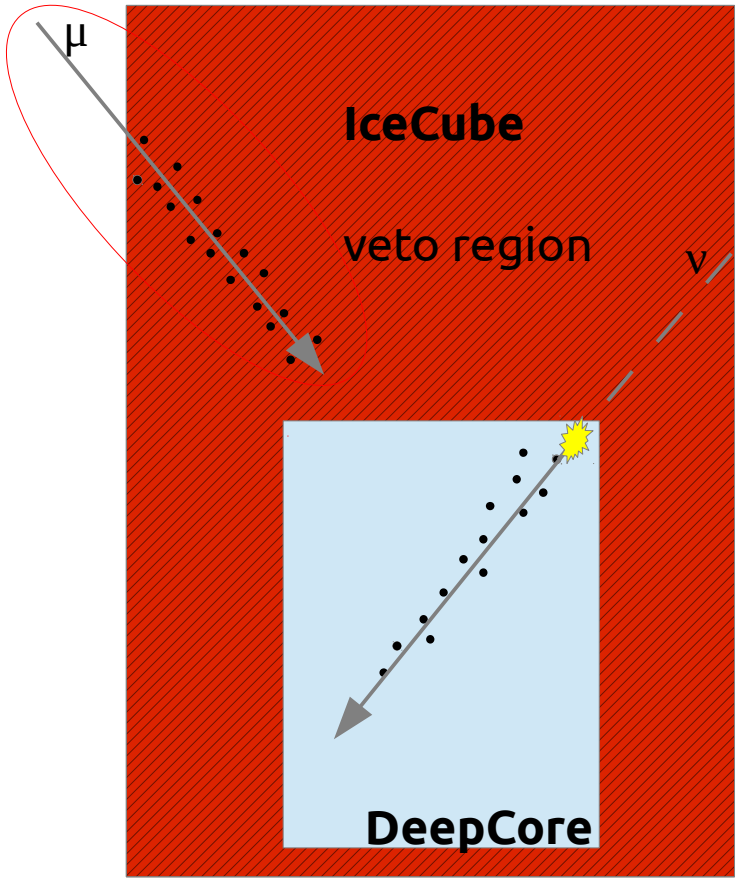
Vetoing incoming atmospheric muons

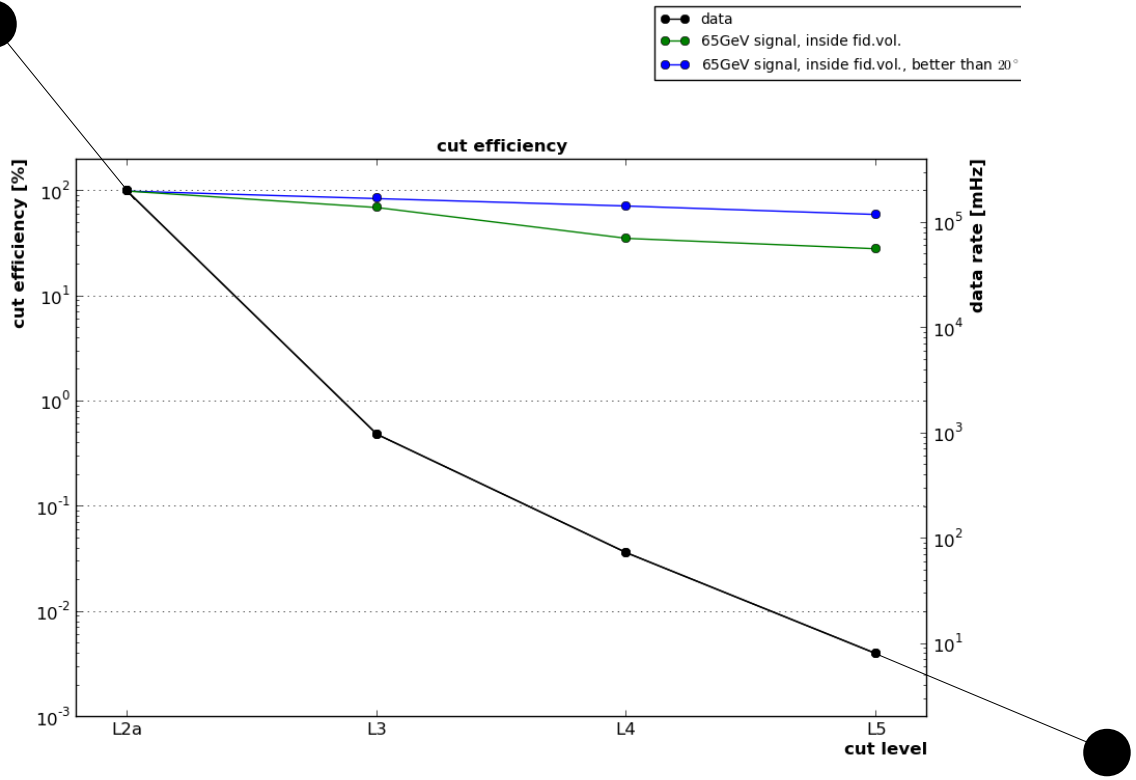


Analysis - event selection

Trigger level : ~250Hz

Two BDTs trained:
- On low energy signal
- On high energy signal

BDT cut is determined by the sensitivity of the ML-analysis
For each annihilation channel and WIMP mass the BDT with the best sensitivity is chosen.



Final selection after BDT: ~1mHz

Analysis- Maximum Likelihood

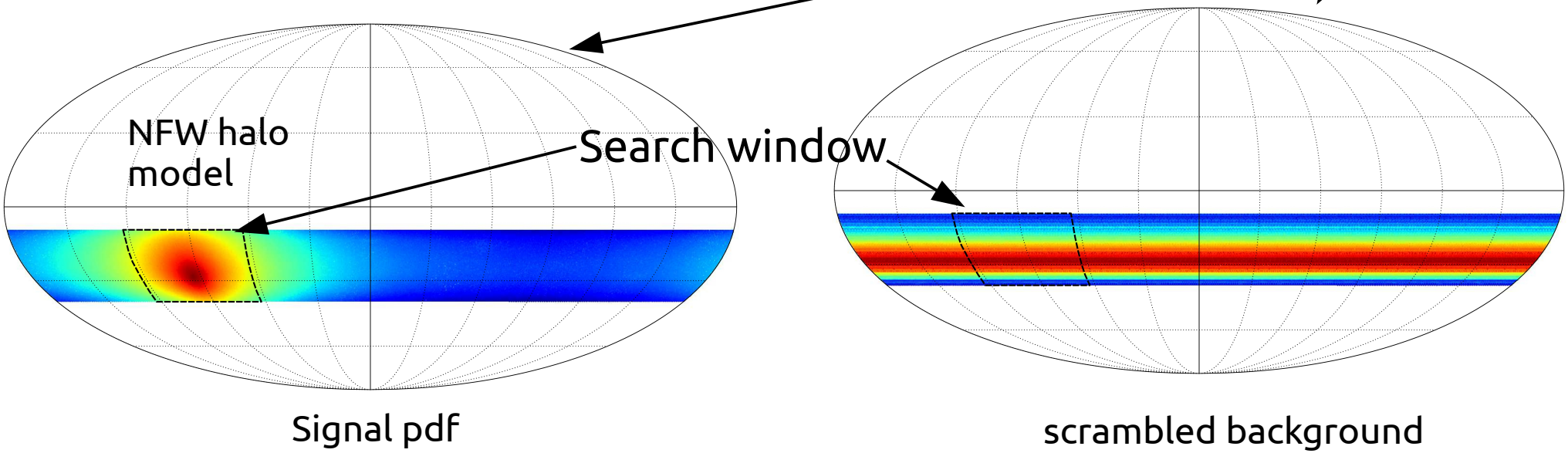
A ML analysis is performed incorporating the shape and the number of events in the search window.

b_{exp} expected background
n number of observed events
μ number of signal events

Likelihood formulation

$$L(\mu) = \frac{(b_{exp}+\mu)^n}{n!} e^{-(b_{exp}+\mu)} \prod_{i=1}^{n} \left(\frac{\mu}{n} f_s(x_i) + \frac{(n-\mu)}{n} f_{bg}(x_i) \right)$$

Signal shape strongly depends on the halo model.



Signal pdf

scrambled background

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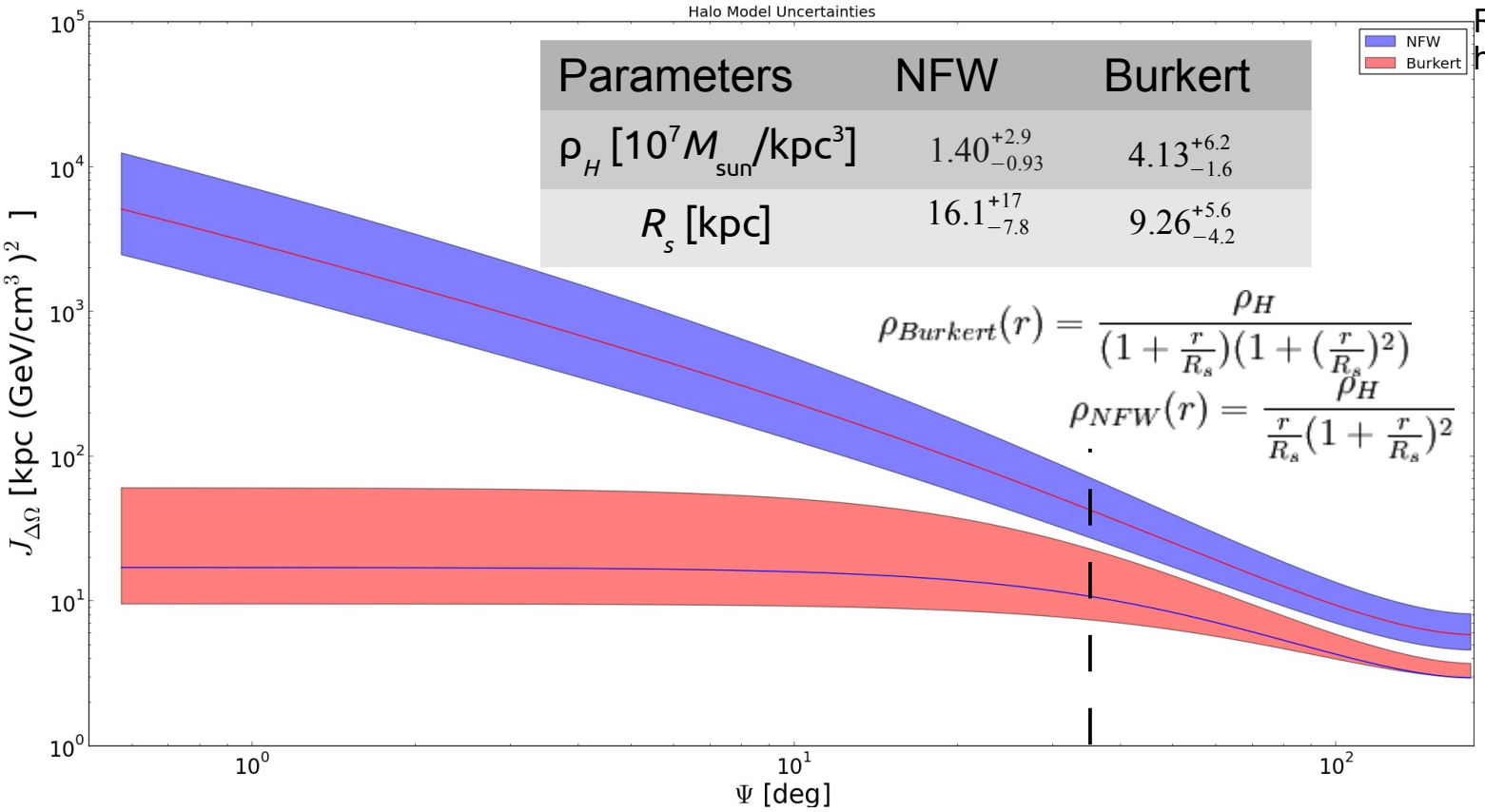

Parameters	NFW	Burkert
ρ_H [$10^7 M_{sun}$/kpc^3]	$1.40^{+2.9}_{-0.93}$	$4.13^{+6.2}_{-1.6}$
R_s [kpc]	$16.1^{+17}_{-7.8}$	$9.26^{+5.6}_{-4.2}$

$$\rho_{Burkert}(r) = \frac{\rho_H}{(1+\frac{r}{R_s})(1+(\frac{r}{R_s})^2)}$$

$$\rho_{NFW}(r) = \frac{\rho_H}{\frac{r}{R_s}(1+\frac{r}{R_s})^2}$$

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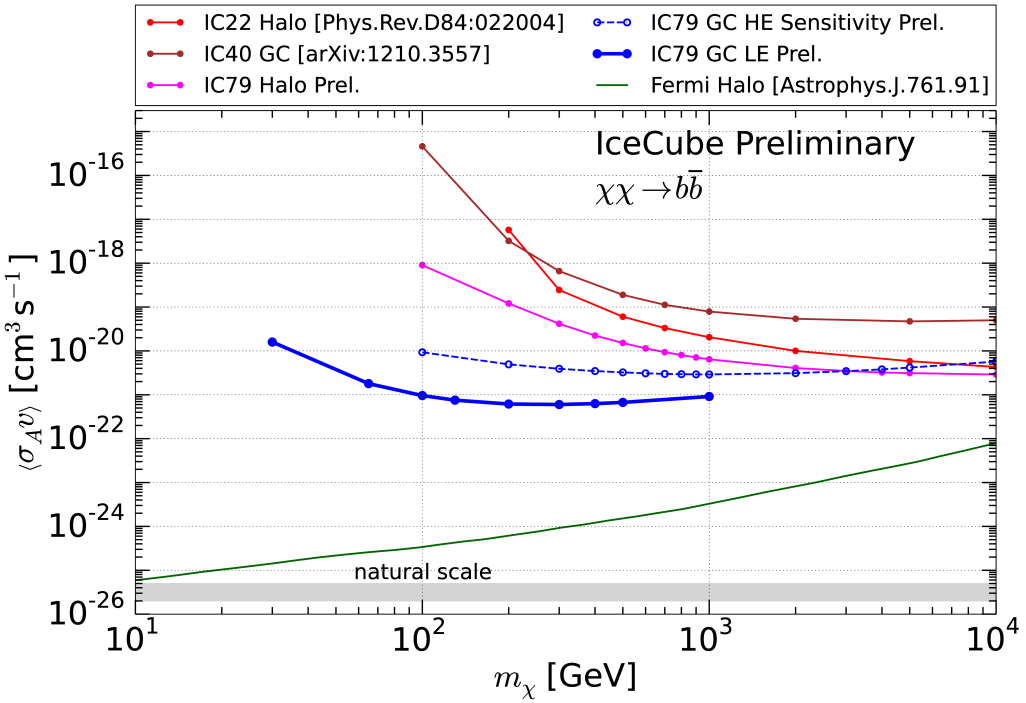
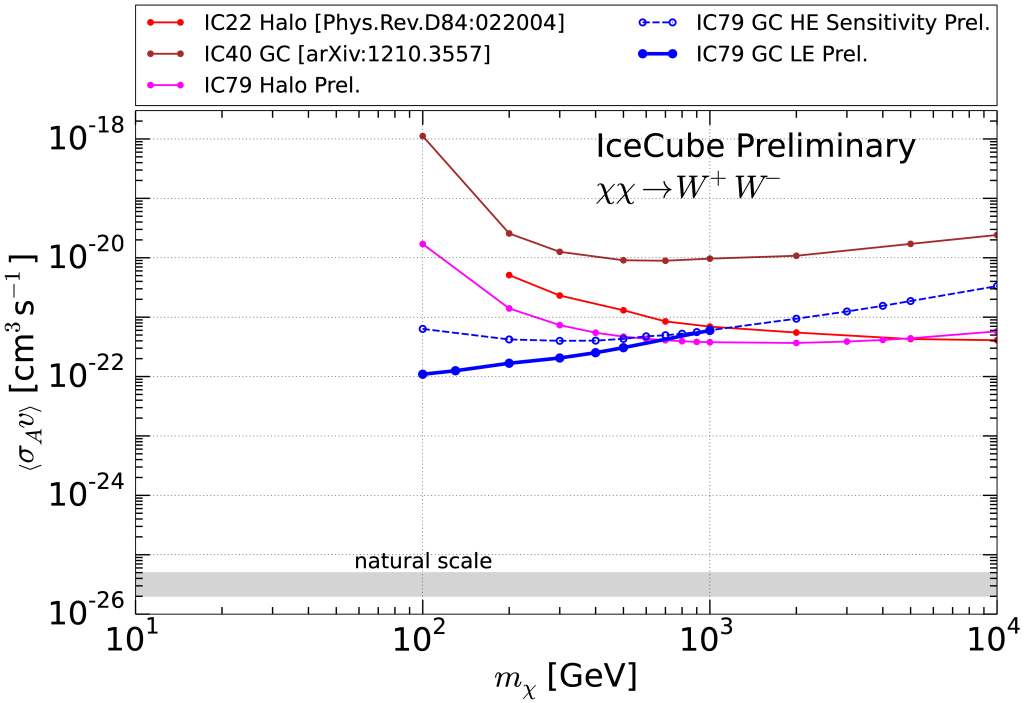
Results

Limits at 90% CL using Feldman Cousins procedure
Note: no systematic errors included





Most competitive among IceCube analyses for soft channels and low ν-energies

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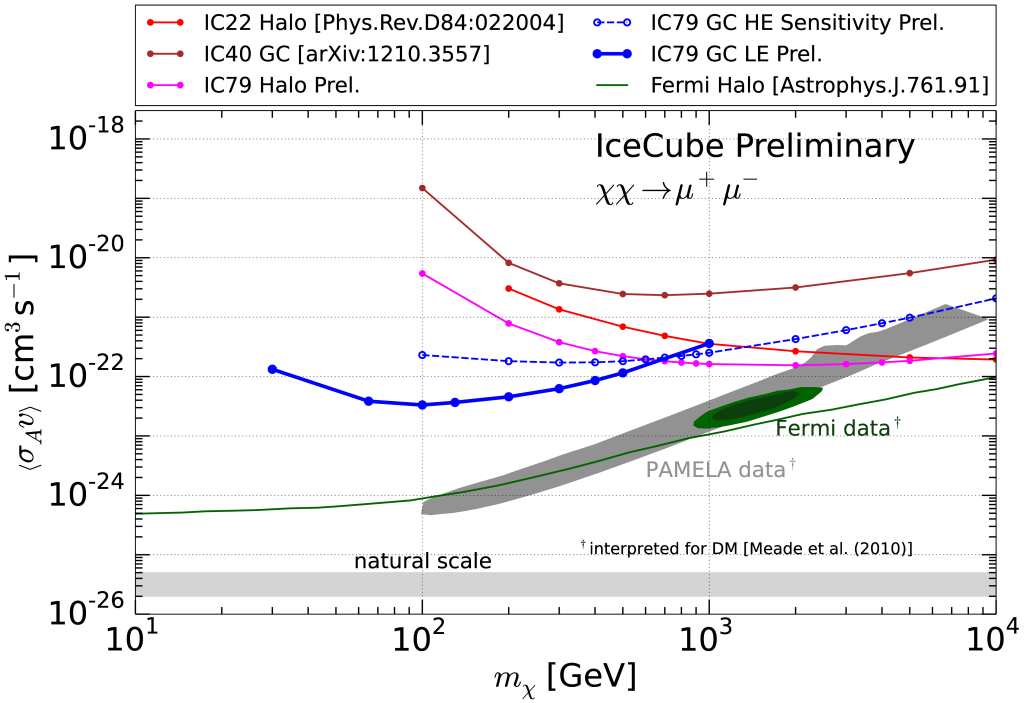

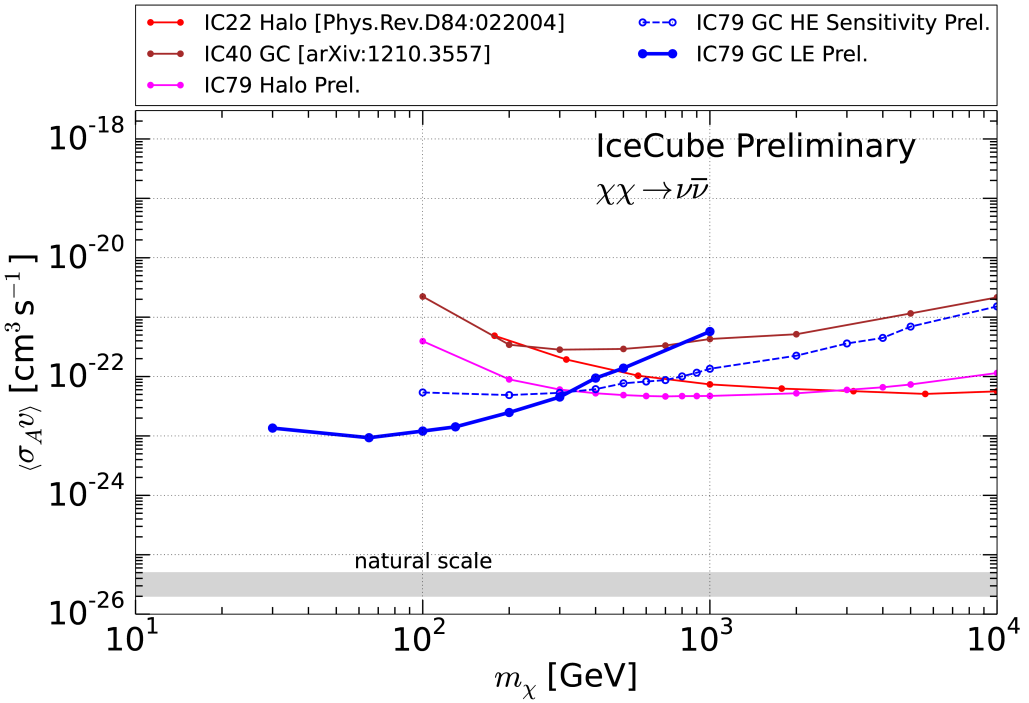

Most competitive among IceCube analyses for soft channels and low ν-energies

Summary

- First IceCube analysis looking at Galactic Center for low WIMP masses (<100 GeV)
- Sensitivity has improved up to 4 orders of magnitude compared to previous IceCube analyses.
- New methods developed to reject atmospheric muon background.
- Systematic studies almost finished.
- High energy analysis completed soon.
  - Limits of the two analyses will be combined.

Thank You

Thank You
for your attention!