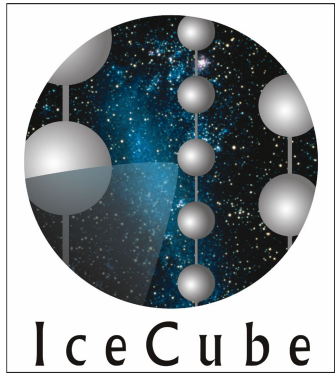
Search for Neutrinos from the Galactic Dark Matter Halo with IceCube

Jan-Patrick Hülß for the IceCube Collaboration
III. Physikalisches Institut B



Content

Dark Matter:
indirect detection

Galactic Halo:
Neutrinos from the Galactic Halo

IceCube:
Observation of Neutrinos

Northern Sky Observation:
Outer Galaxy, Analysis principle

Galactic Center Observation:
Southern Sky, Analysis principle

Results:
Limits on the annihilation cross section

Dark Matter Detection

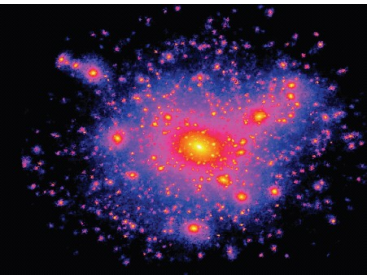
production at colliders
|
LHC

indirect detection

direct detection
|
Xenon, CDMS (Dama/Libra?)

annihilation in the galactic halo or center

annihilation in massive bodies



DM in halo annihilates

rate depends on:
- DM-DM x-section
- DM density square

extended source

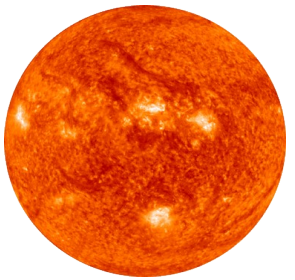
γ – Fermi, ...

e, p - PAMELA, ATIC, Fermi, HESS, AMS,...

$\bar{D}$ – (GAPS), ...

$\nu,\bar{\nu}$ – IceCube, (Km3Net), Super-K., ...

next Talk: M. Danninger
Searches for Dark Matter Annihilations in the Sun and Earth with IceCube and DeepCore



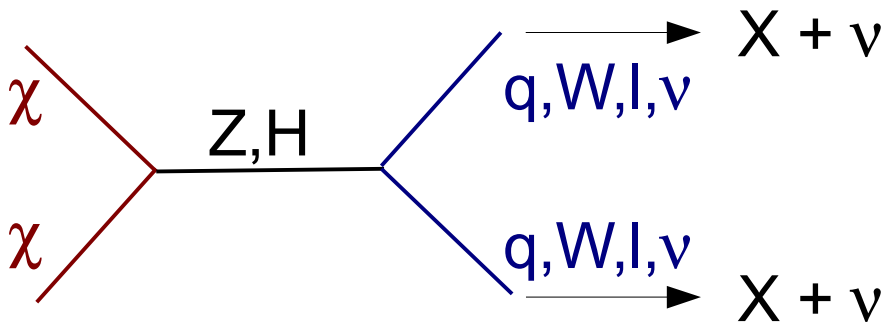
e.g. Sun captures DM

equilibrium with annihilation

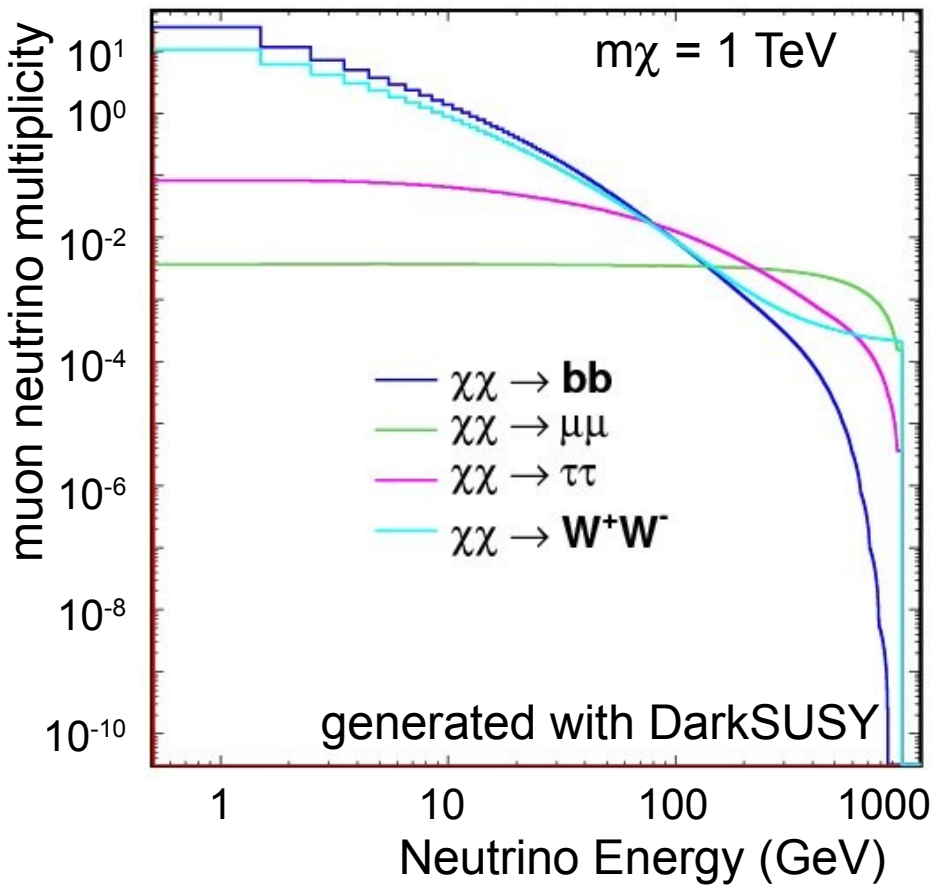
rate depends on:
- DM-nucleus x-section
- DM and Sun density

Neutrinos from DM

- WIMPs (χ) annihilate in a weak interaction
- Z, H can decay into any pair of particle & anti particle
- Branching ratios depend on SUSY model



- Chose two decays:
  - low energetic ν ($\chi\chi \rightarrow$ bb)
  - ($\chi\chi \rightarrow \tau\tau$ if not enough energy to produce bb)
  - high energetic ν ($\chi\chi \rightarrow \mu\mu$)
  - ($\chi\chi \rightarrow$ WW if produced in matter)
- All predictions by models are in between
- Expect neutrinos with E < TeV



The DM distribution in the halo

- n-body simulations

  Navarro-Frenk-White profile:
  astro-ph/9508025

  $\rho(r) = \rho_0 (r/a)^{-1}(1+r/a)^{-2}$

  a = 20 kpc

- empirical equation

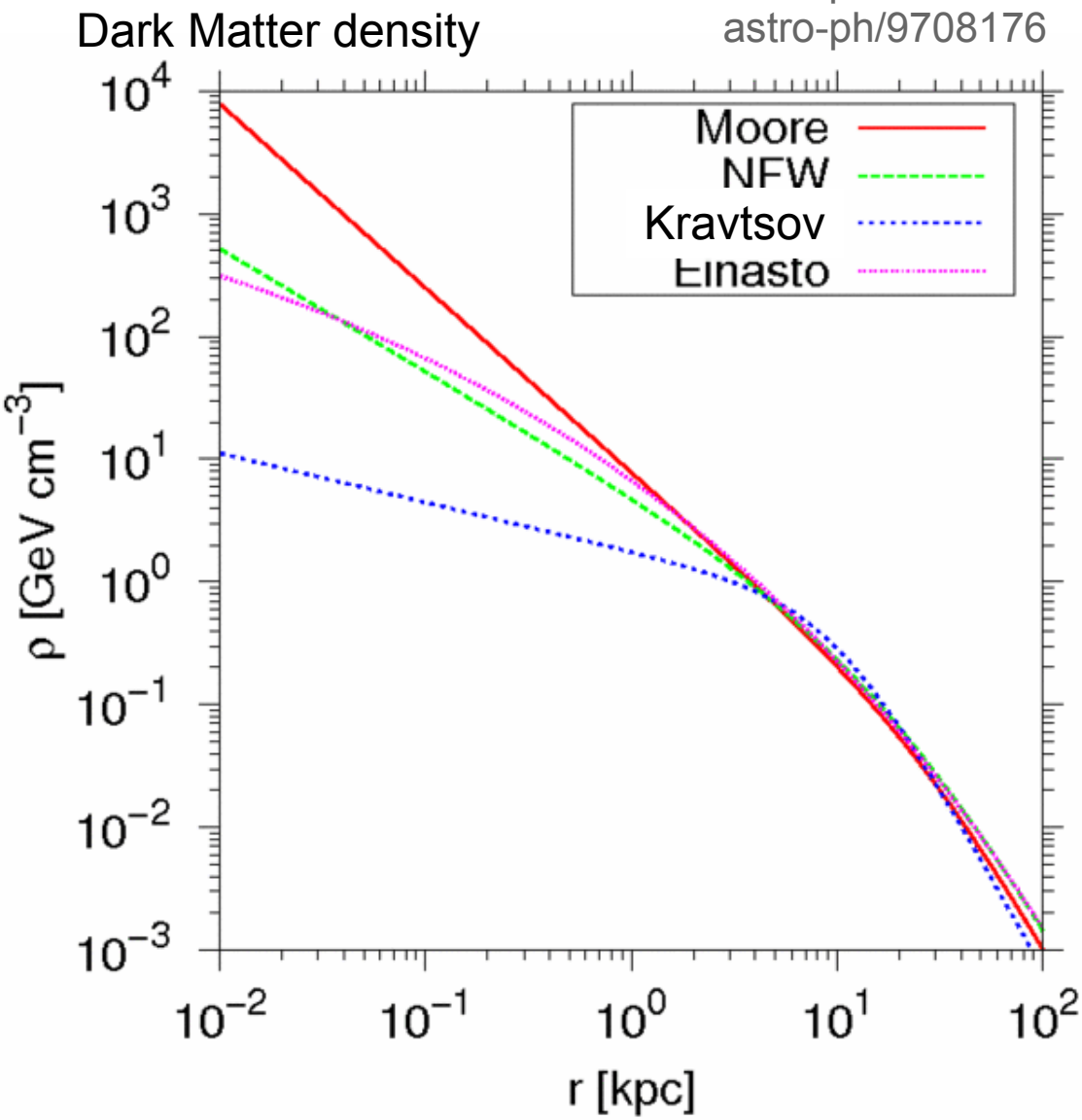
  Einasto profile:
  astro-ph/0509417

  $\rho(r) = \rho_0 \exp[-\alpha(r/\mathrm{kpc})^n]$

  a = 7.07

  n = 0.17

astro-ph/9903164
astro-ph/9708176



Fix normalization at solar circle: $\rho(8.5\mathrm{kpc}) = 0.3$ GeV cm^{-3}

expected neutrino flux

- Neutrino flux depends on Dark Matter in the line of sight

$$J(\psi) = R^{-1}\rho_0^{-2}\int_0^L \rho^2(r(l,\psi))\, dl$$

$$r(l,\psi) = (R^2 - 2lR\cos(\psi) + l^2)^{1/2}$$

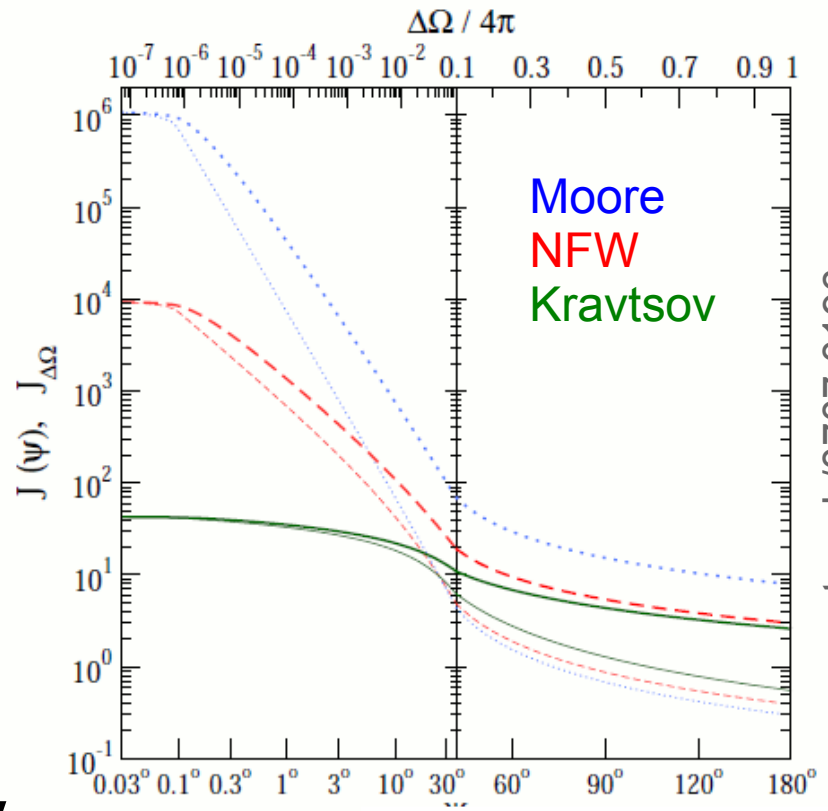
- Expected neutrino flux is:

$$d\phi/dE = 0.5 \langle\sigma v\rangle m_\chi^{-2} J(\psi) R^1 \rho_0^2 (4\pi)^{-1} dN/dE$$

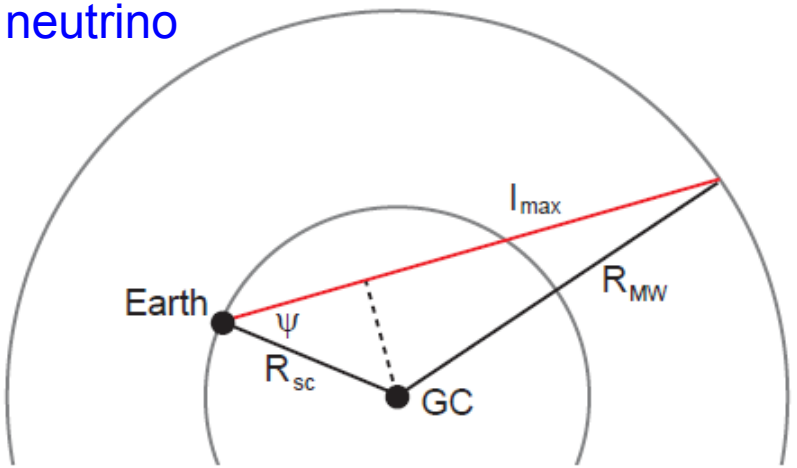
WIMP interaction: self annihilation cross section factor ½ for being its own antiparticle

Isotropic radiation

Particle physics: generated neutrino spectrum



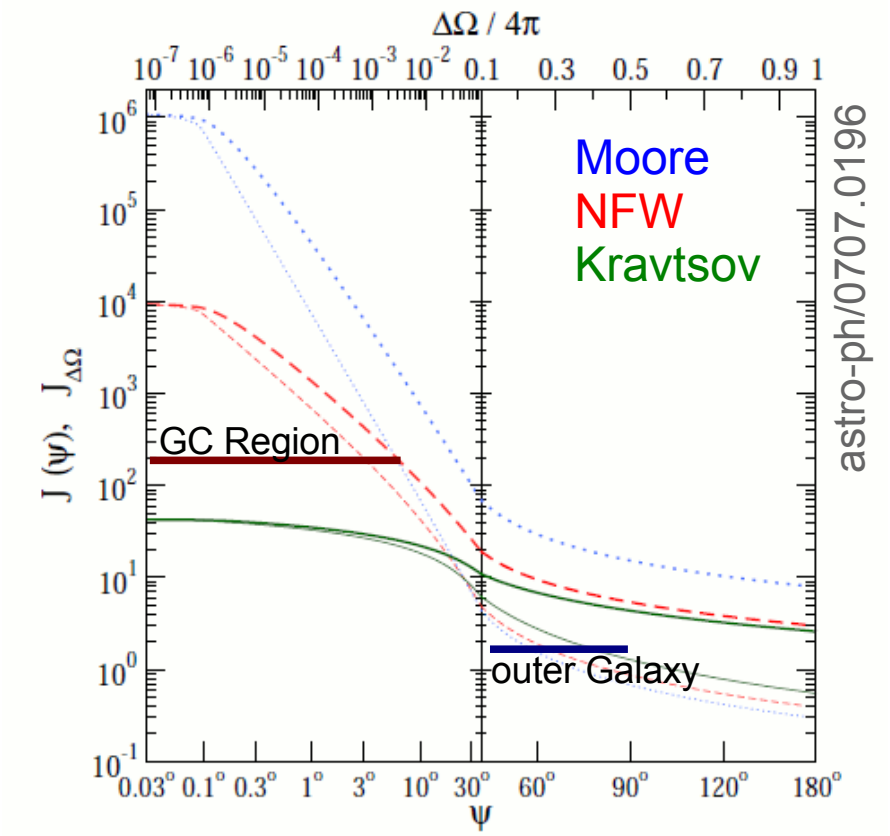
astro-ph/0707.0196

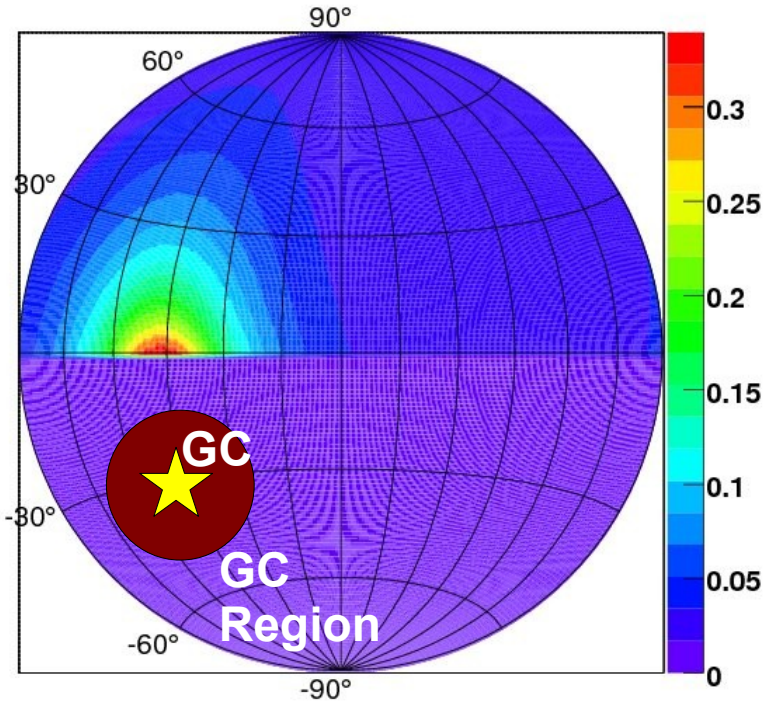


- highest flux expected from the direction of the galactic center
- some flux from every direction

How to observe a Flux from the DM halo?

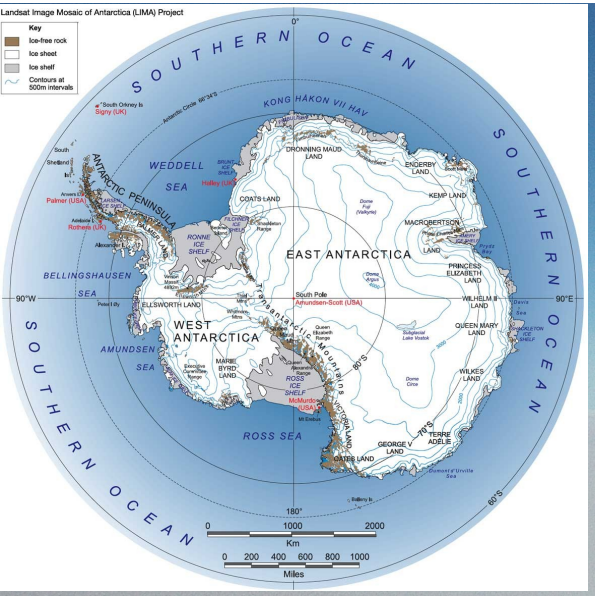
2 independent methods





- Observe the outer region of the Galaxy
  - DM density less model dependant
  - weak neutrino flux
  - nearly background free for IceCube (Northern hemisphere)
- Observe the GC Region
  - stronger neutrino flux
  - Depends on halo model
  - Huge background of atmospheric muons (Southern hemisphere)

IceCube Telescope



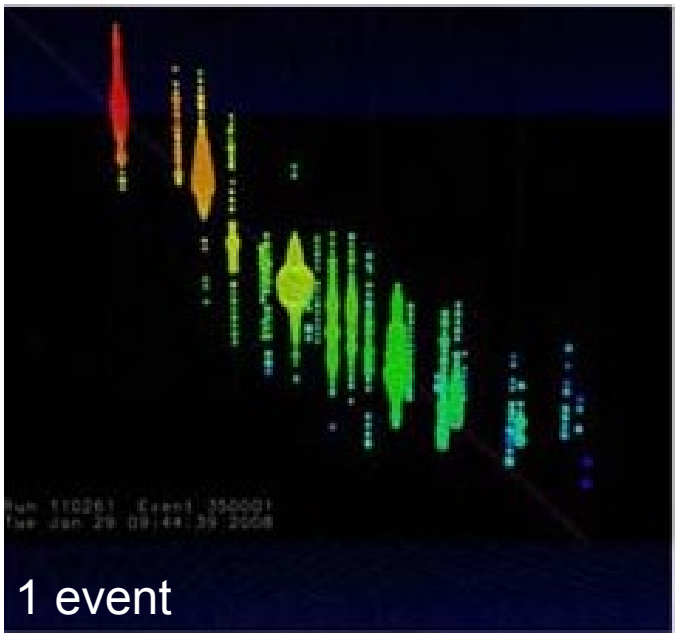
The IceCube Detector

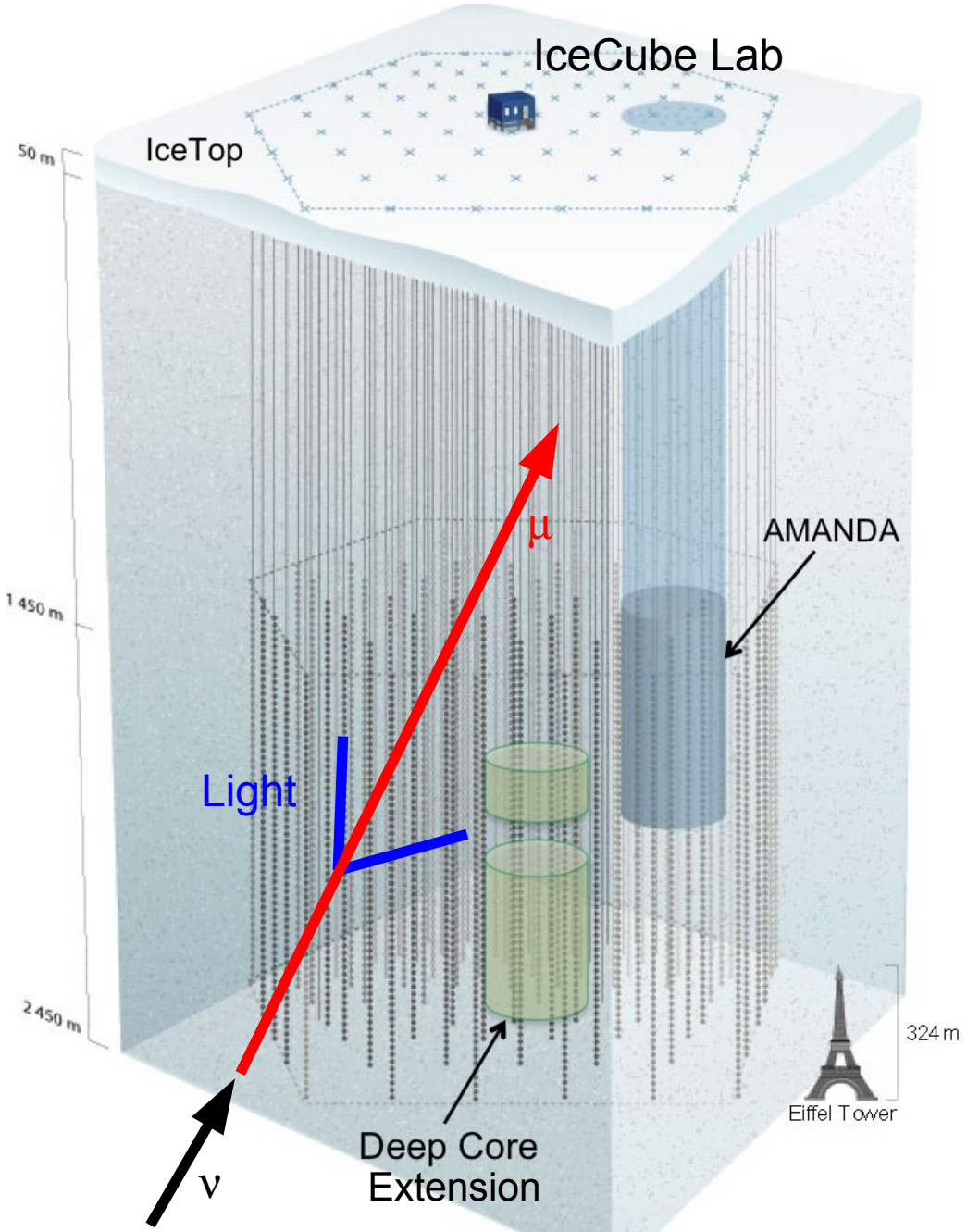
IceCube
1 km^3 with about 5000 sensors (DOMs)
78 cable with 60 sensors

DeepCore Extension
8 cables with 60 sensors in the deep ice

Detection Principle:
neutrino ν produces a muon μ
μ produces Cherenkov light in the ice

$$\nu + N \rightarrow \mu + X$$





Tu 12.10: D. Williams, Status of the IceCube Neutrino Observatory

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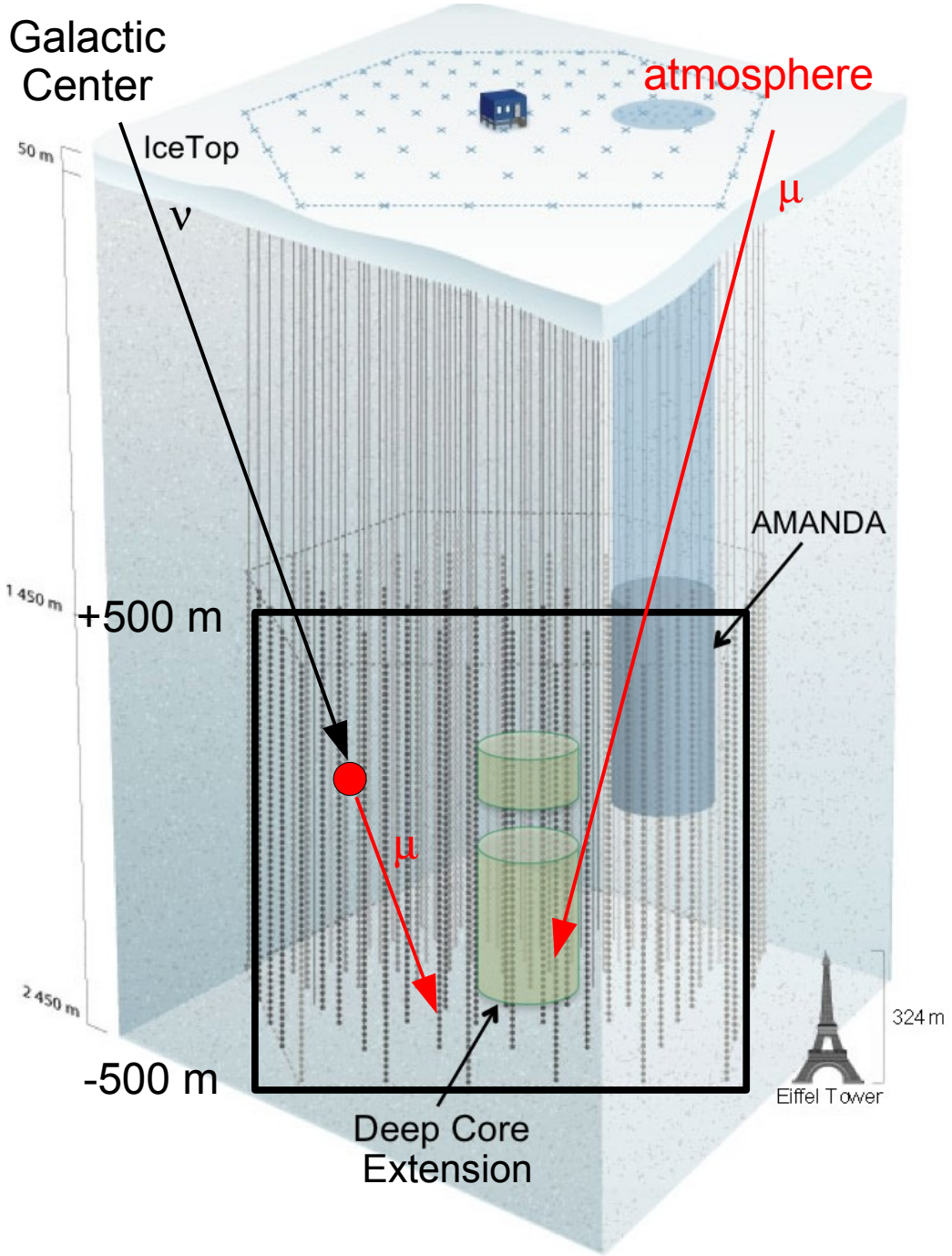
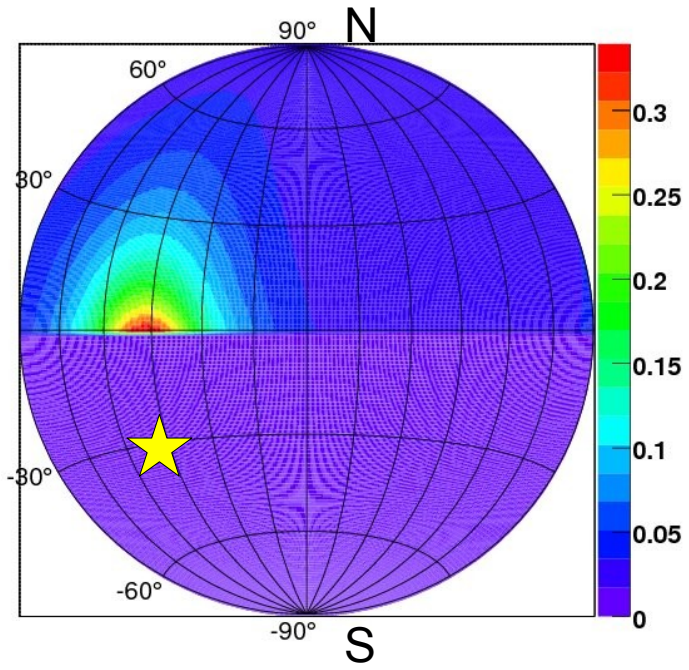
Background:
μ produced in the atmosphere

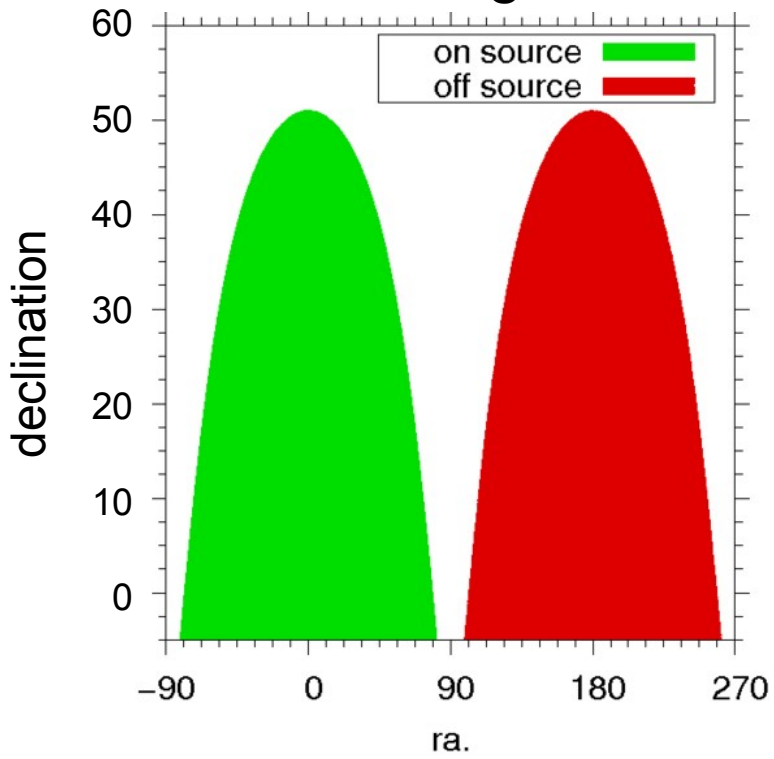
Signal from above (southern sky):
ν interacts in the detector
light signal starts inside the detector



Outer Galaxy Observation

- IceCube 22 data from 2007
  - point source sample, Northern Sky
- signature: large scale anisotropy
- compare the amount of events in an on- and off- source region
  - Removes systematic effects of the background simulation
  - Off-source region is not completely signal free
- on-source region:
  - All events closer than 80 deg to the GC
- off-source region:
  - same as on-source but rotated 180 deg in ra.





Systematic Uncertainties

Effect	Sys. Uncertainty
Cosmic-ray anisotropy	0.2%
Exposure	0.1%
Total Background	0.3%
Ice properties	25%
Reco. DOM Efficiency	4%
Muon propagation	3%
Bedrock uncertainty	3%
Neutrino cross section	2%
Exposure	1%
Total Signal Acceptance	26%

preliminary

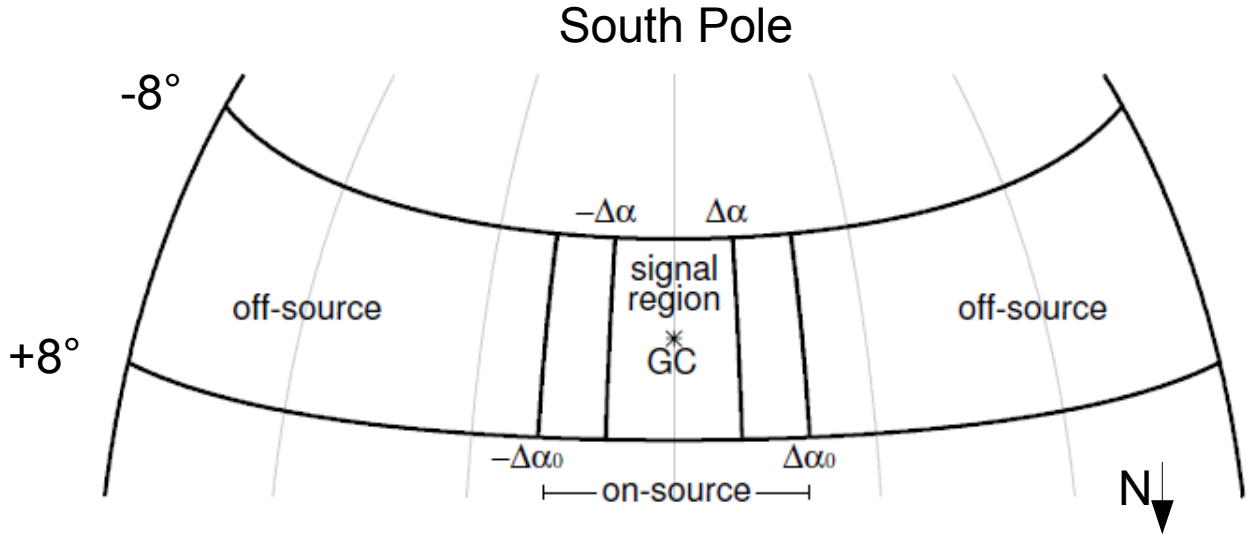
reliable background estimate due to on-/off-source method
- only other large scale structures could affect this

signal simulation is the dominant source of uncertainties

modeling of the optical ice properties

Galactic Center observation

- Galactic Center is one spot in the sky
  - ➔ use on/off source method
    reduce systematic uncertainties due to simulations
  - ➔ stick to one zenith band
  - ➔ large off source area A_{off}
    reduces statistic uncertainties



→ **use IceCube and Deep Core**
allows the identification of starting events

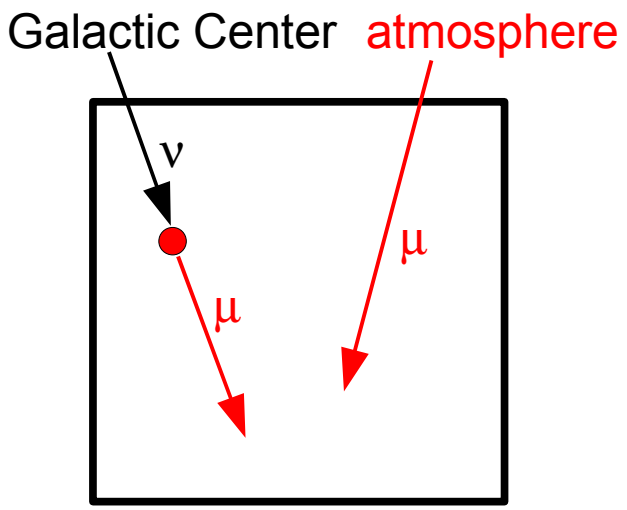
expected background $\langle N \rangle = N_{off} \frac{A_{sig}}{A_{off}}$

uncertainty $\Delta N = \sqrt{N_{off} \frac{A_{sig}}{A_{off}}}$

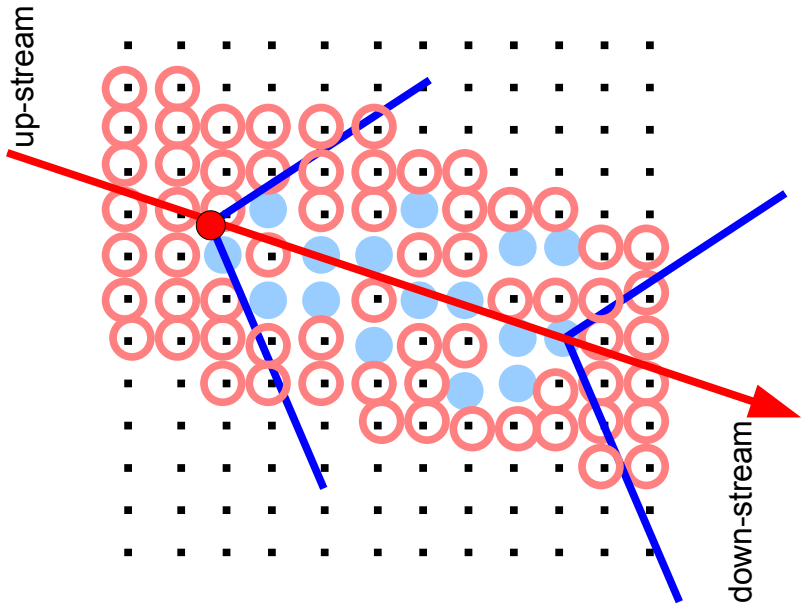
→ **no DeepCore data available up to now**
dedicated search with IC40
→ data from April 2008 to May 2009
→ first application of algorithms for DC

Identification of starting ν tracks

- identification of ν by starting tracks
- huge amount of atmospheric μ



- use the upstream DOMs without signal to identify these starting tracks
  - DOMs without signal could indicate a ν
- Challenge:
  - DOM spacing: 16 m vertical , 125 m horizontal
  - probability for a signal decreases rapidly with distance between DOM and track
  - in IceCube 40 isolated hits are removed
    - reduced chance to observe hits



Identification of Starting Events

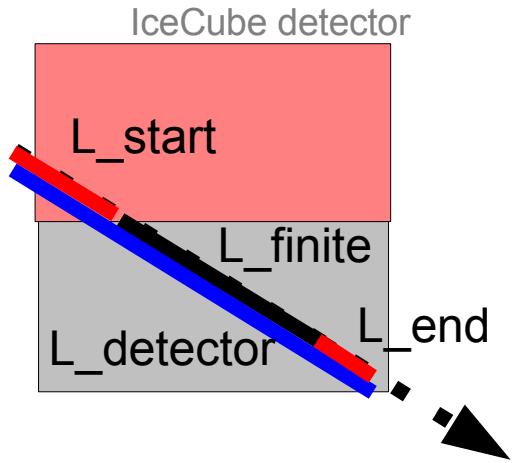
- quality selections
- selection of starting event
  - ➔ TopVeto : upper 30 DOMs of each string are used as veto
  - ➔ SideVeto: first hit has to be on an inner string
  - ➔ reconstructed start point has to be inside the detector

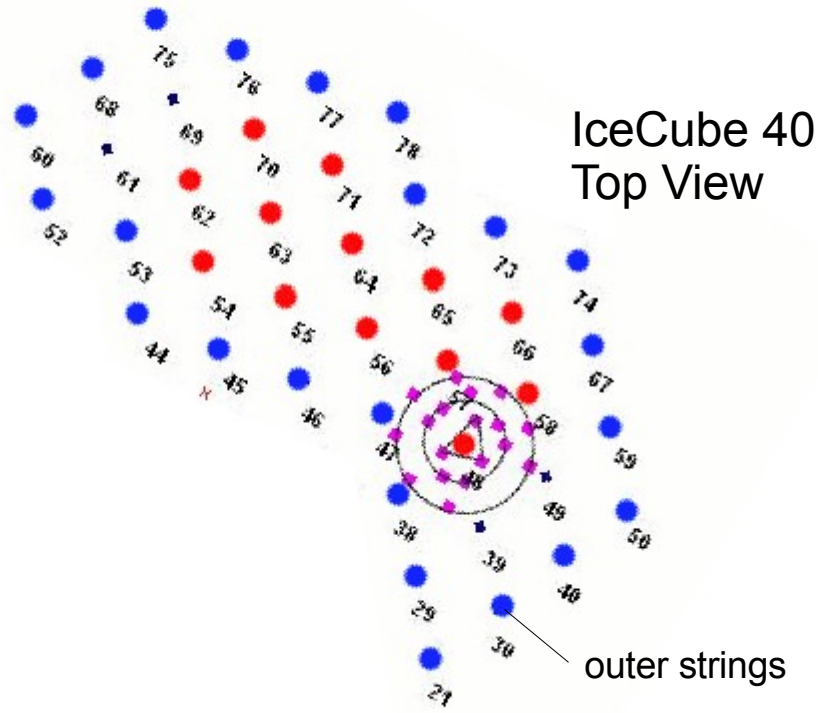
L_start/ L_detector > 0.1

angular resolution: ~2.5°

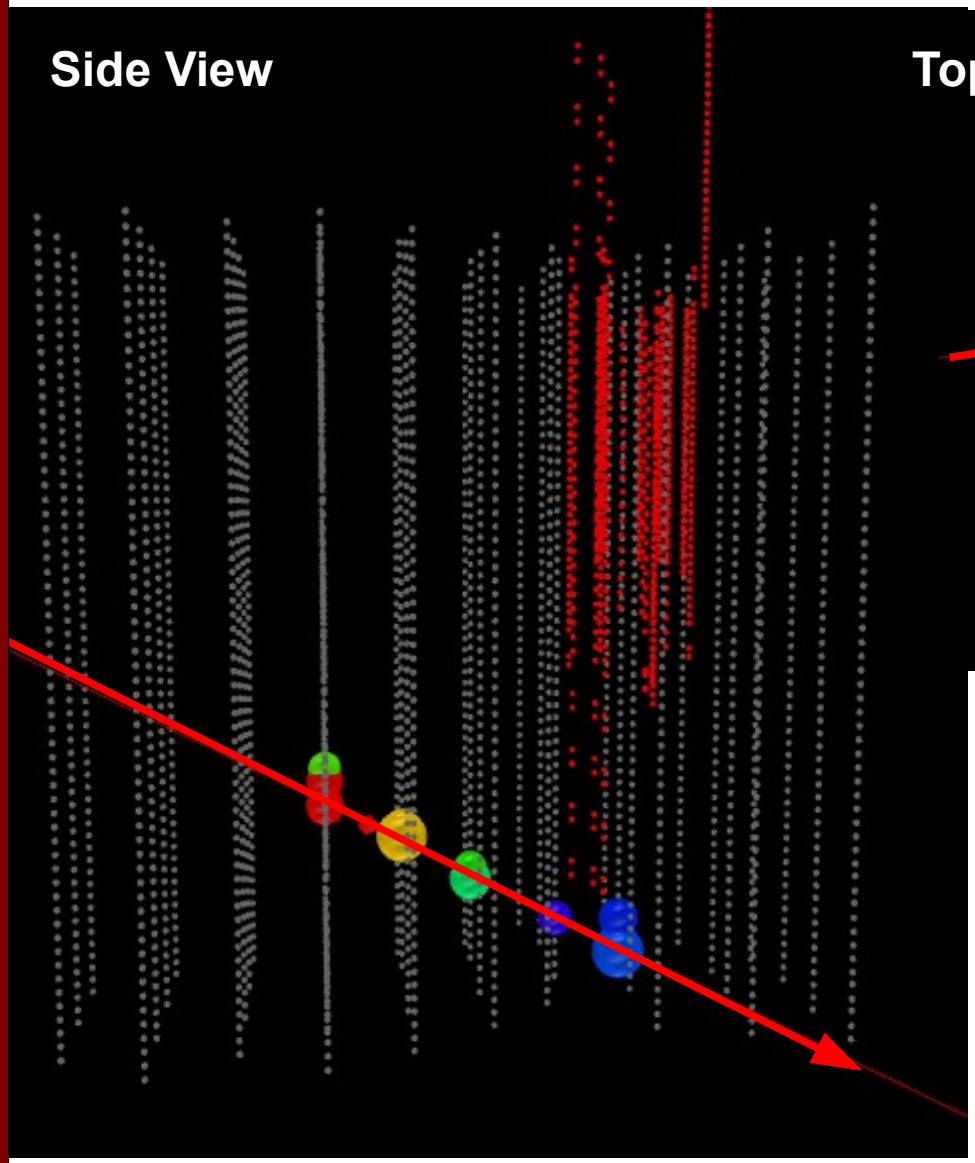
background passing: 0.02%
remaining background events: ~800k
(signal region)

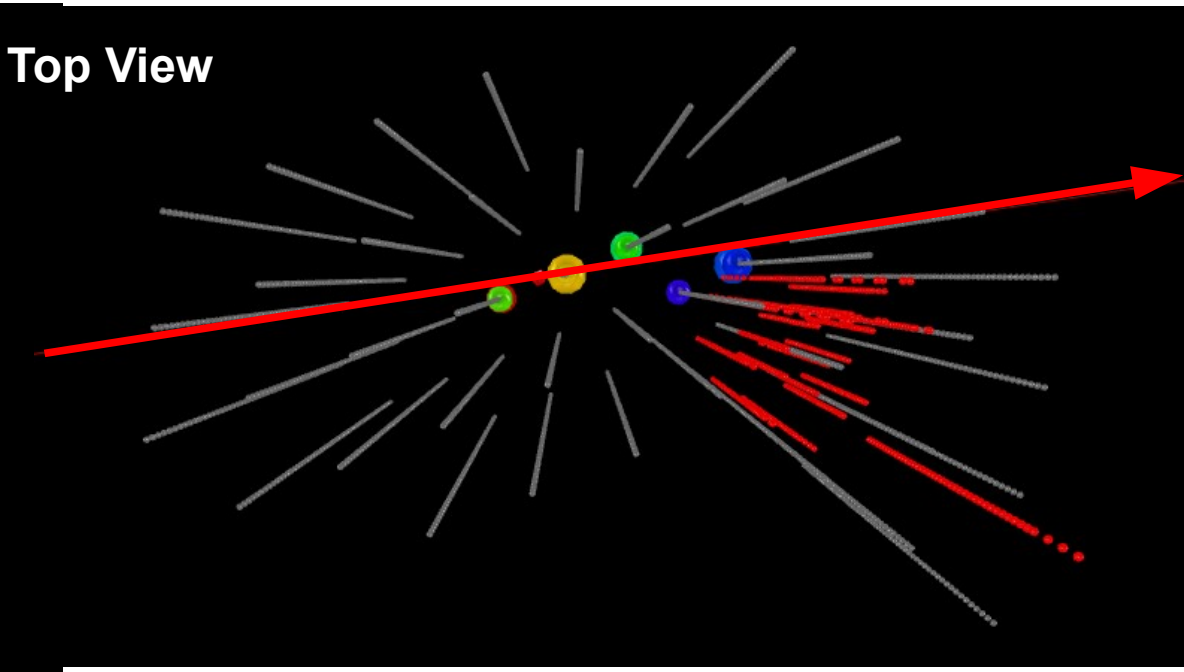
IceCube + DeepCore Filtering:
→ dedicated data stream for GC
→ keep larger detector volume for signal (smaller veto)
→ keep single hit DOMs for the analysis





Typical problematic background event





This simulated muon:
- passes 3 layers of strings,
- starts in the middle of the detector,
- is a long track leaving at the bottom

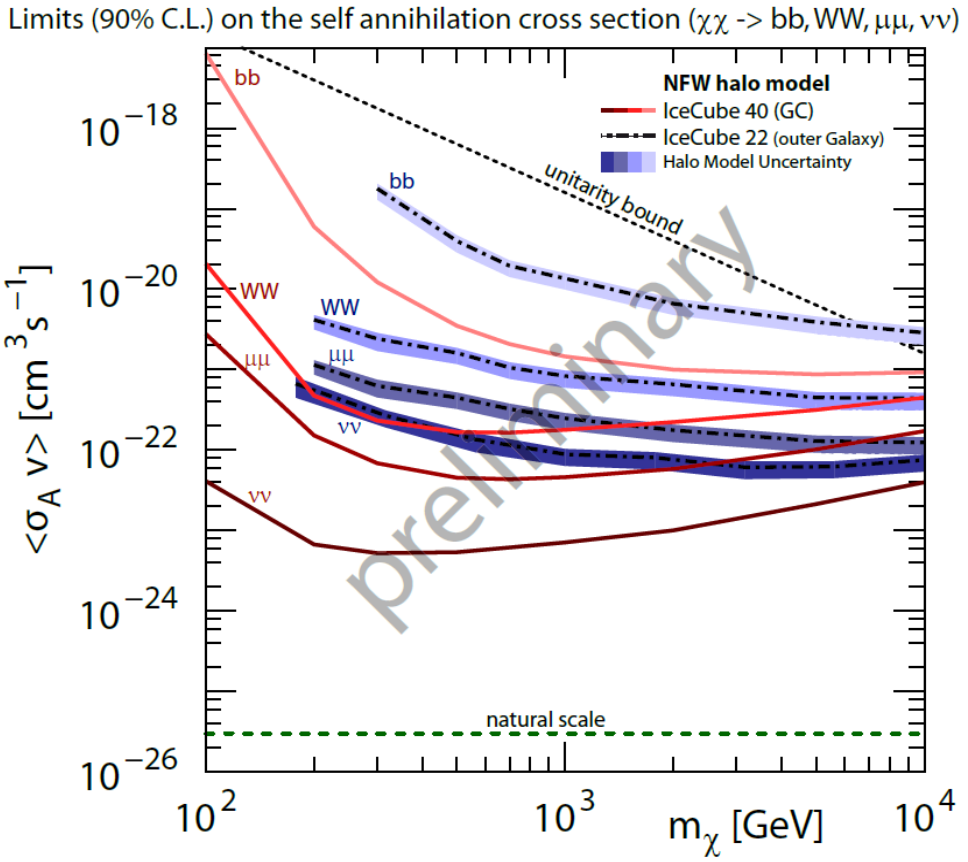
→ irreducible background
could be removed by energy cuts
but not for DM signal below 1 TeV

GC limit for self annihilation x-section

- No excess of events in the on source region in both analyses

events	IC22 outer G	IC40 GC
expected	1389	798.8 e3
observed	1367	798.8 e3
difference	22	23
limit (90% CL)	<49	<1168
J(ψ) (NFW)	~2	240

- limit WIMP self annihilation x-section
  - Limits by GC analysis more restrictive
    - but halo model dependent
  - Outer Galaxy analysis more sensitive for large WIMP masses
    - best for large WIMP masses
    - about halo model independent



Field of view

$$d\phi/dE = 0.5 \langle\sigma v\rangle m_\chi^{-2} J(\psi) R^1 \rho_0^2 (4\pi)^{-1} dN/dE$$

WIMP interaction | **Isotropic radiation** | **Particle physics**

Summary

- possible Neutrino Flux from Dark Matter in the Galactic Halo
  - depends on the extension of the standard model
  - depends on the Dark Matter distribution
- IceCube is sensitive to this signal
  - two complementary approaches:
  - observation of the outer galaxy: low halo model uncertainties, low background
  - observation of the GG: larger flux, sensitive to Dark Matter Density (halo model)
- no neutrino signal found
  - limits on self annihilation cross section
- observation of neutrinos from the southern hemisphere
  - identification is challenging with IceCube 40
  - full IceCube (including DeepCore) will improve the sensitivity significantly