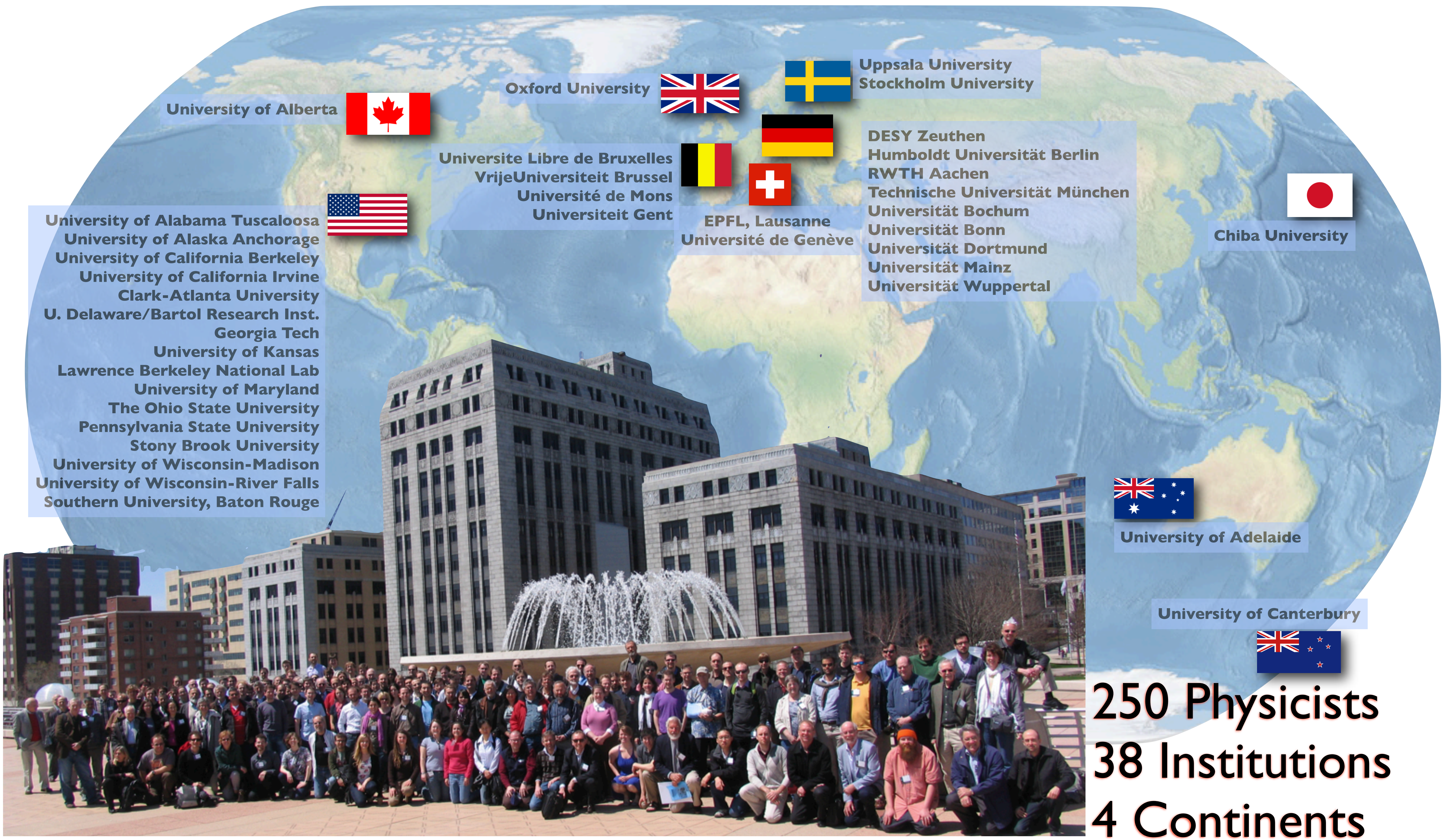
Dark Matter Searches with IceCube

Carsten Rott

for the IceCube Collaboration

Center for Cosmology and AstroParticle Physics (CCAPP)
The Ohio State University

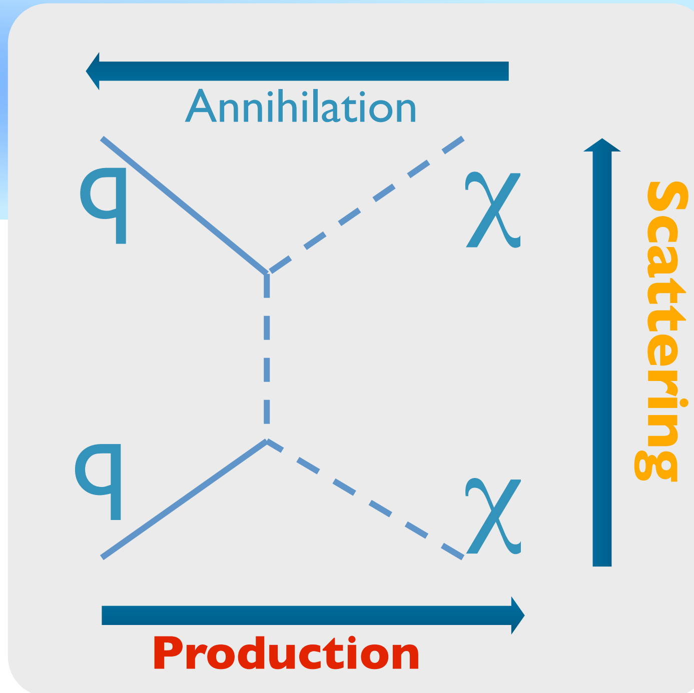
The IceCube Collaboration



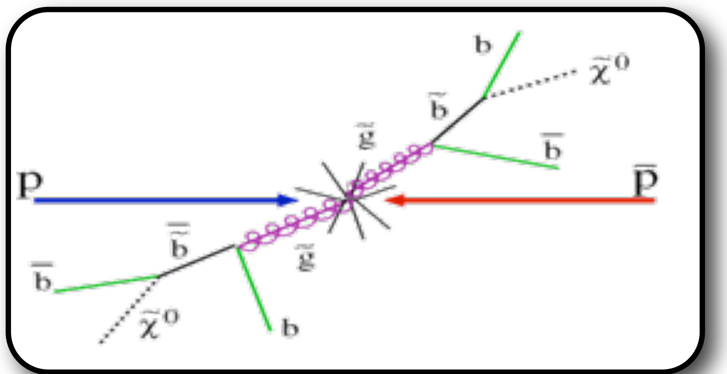
Overview

- Motivation
- IceCube Detector
- Latest Results
- Future Plans
- Conclusions

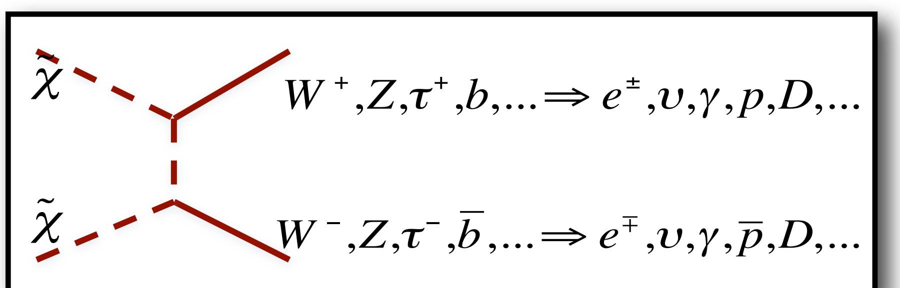
Strategies for WIMP Detection

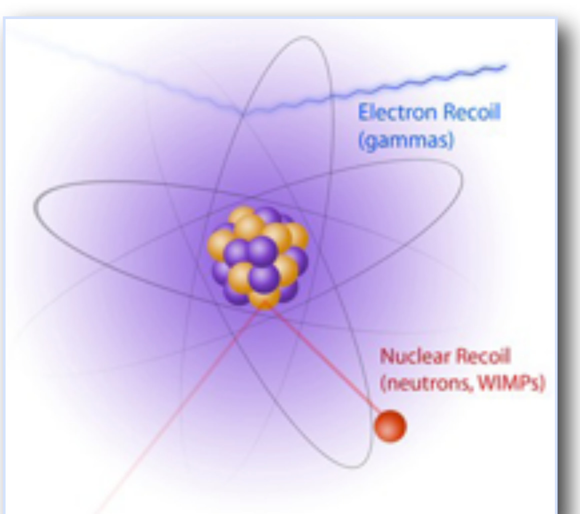


WIMP - Weakly Interacting Massive Particle



- **Production**
  - Colliders
- **Indirect Searches**
  - Annihilation of Dark Matter in Galactic Halo, ...
    - Gamma-rays, electrons, neutrinos, anti-matter, ...
  - Annihilation signals from WIMPs captured in the Sun (or Earth)
    - Neutrinos
- **Direct Searches**
  - WIMP scattering of nucleons → Nuclear recoils



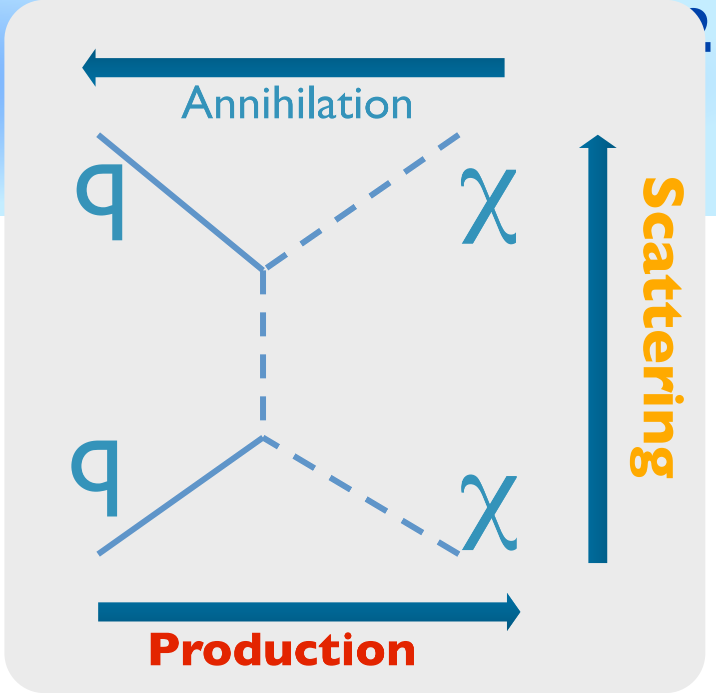


WIMP Self-annihilation cross section

WIMP-Nucleon Scattering cross section

Strategies for WIMP Detection

IceCube



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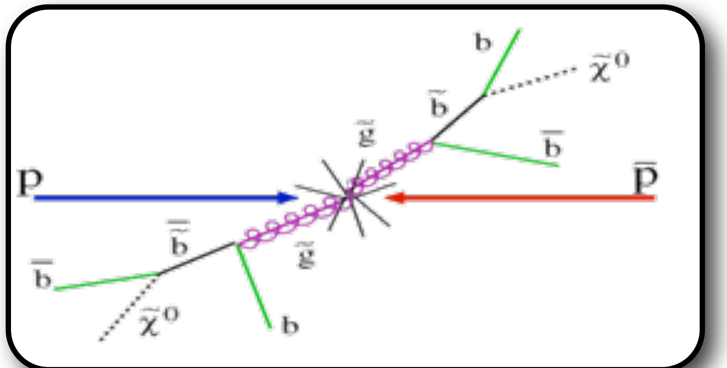

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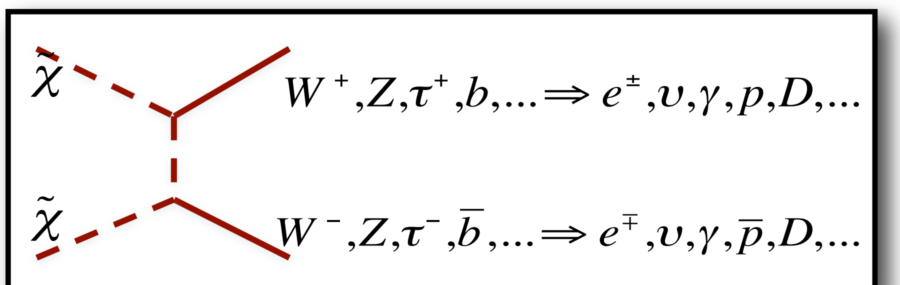
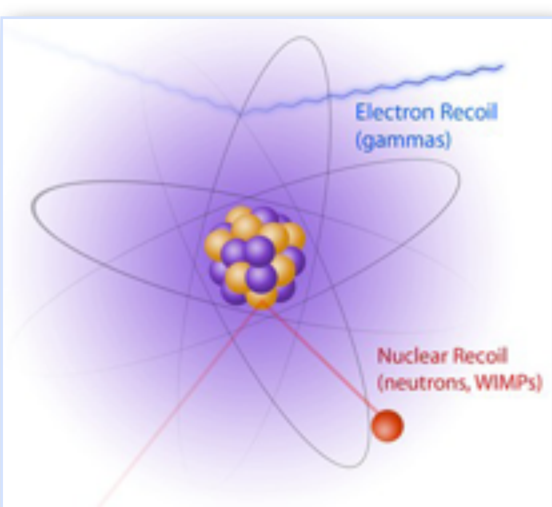
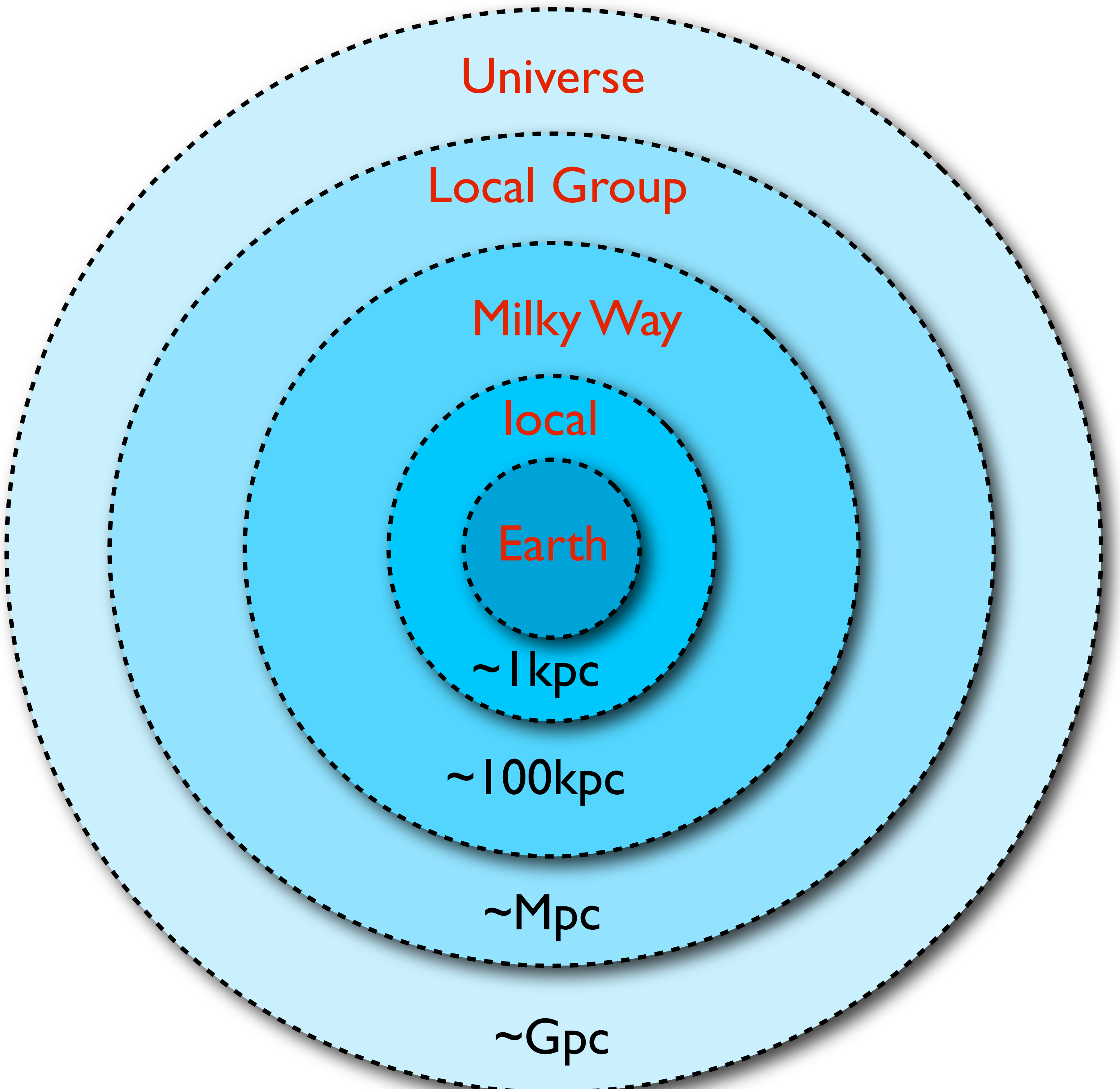




Dark Matter at all scales



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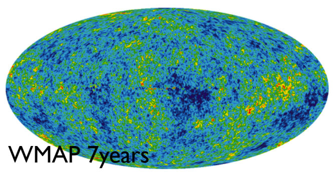
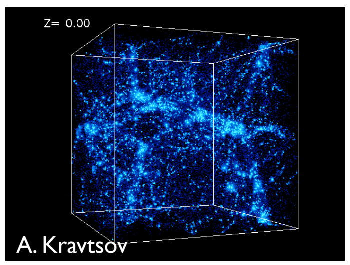
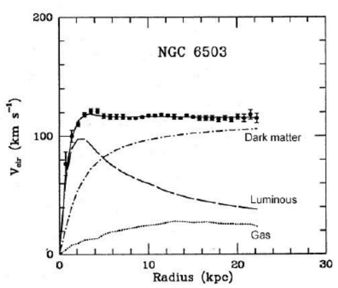
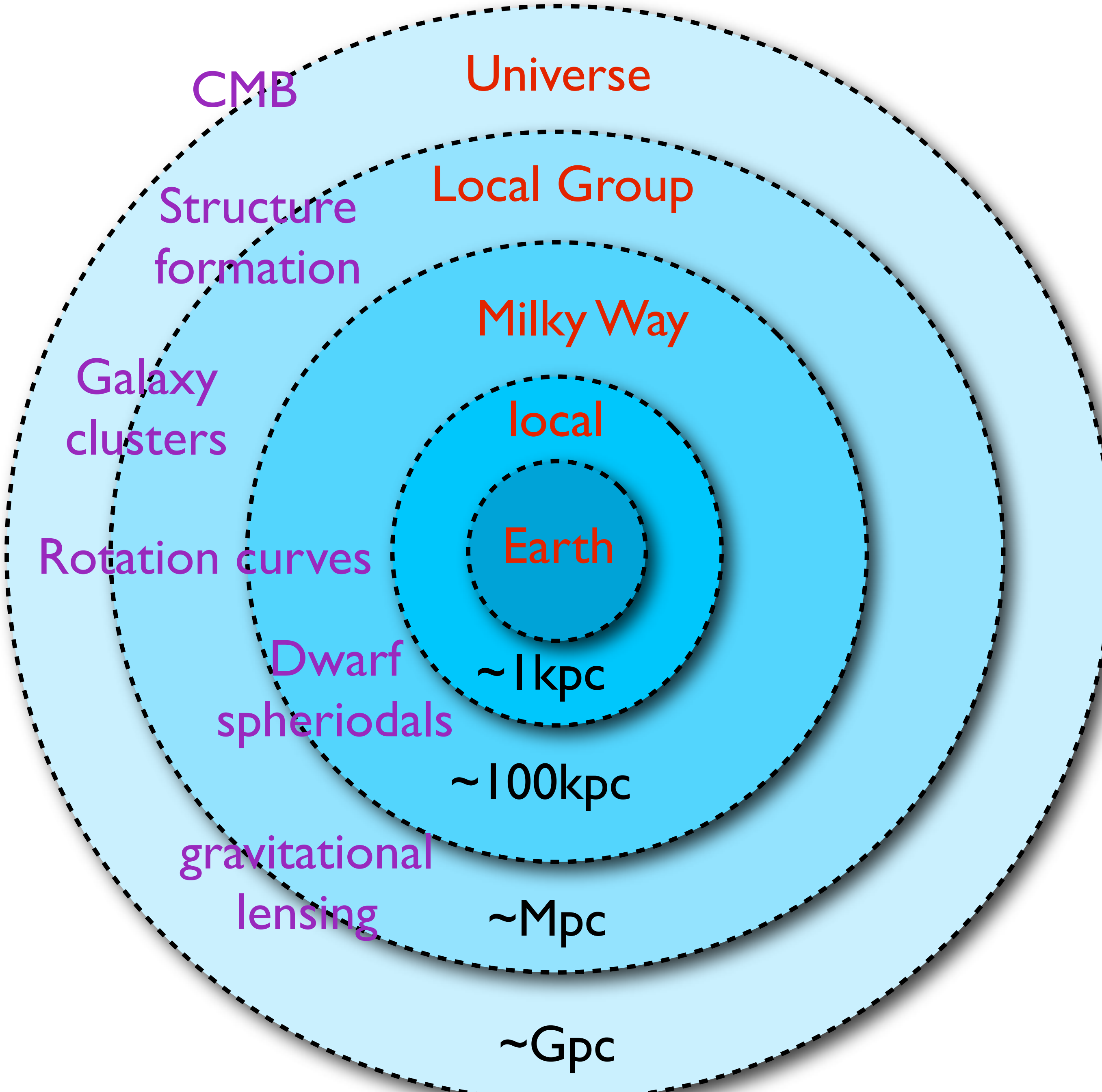






Begeman, Broels & Sanders (1991)



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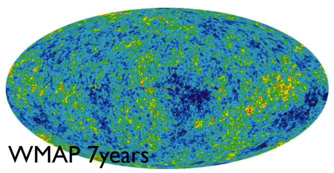

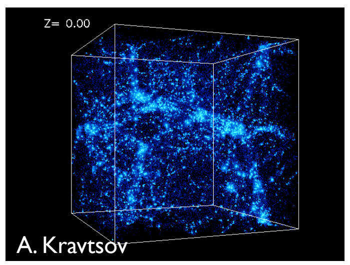

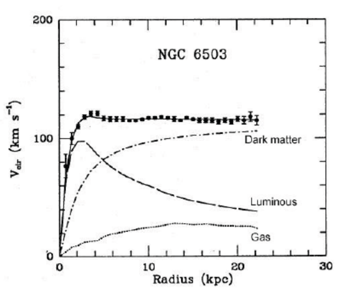

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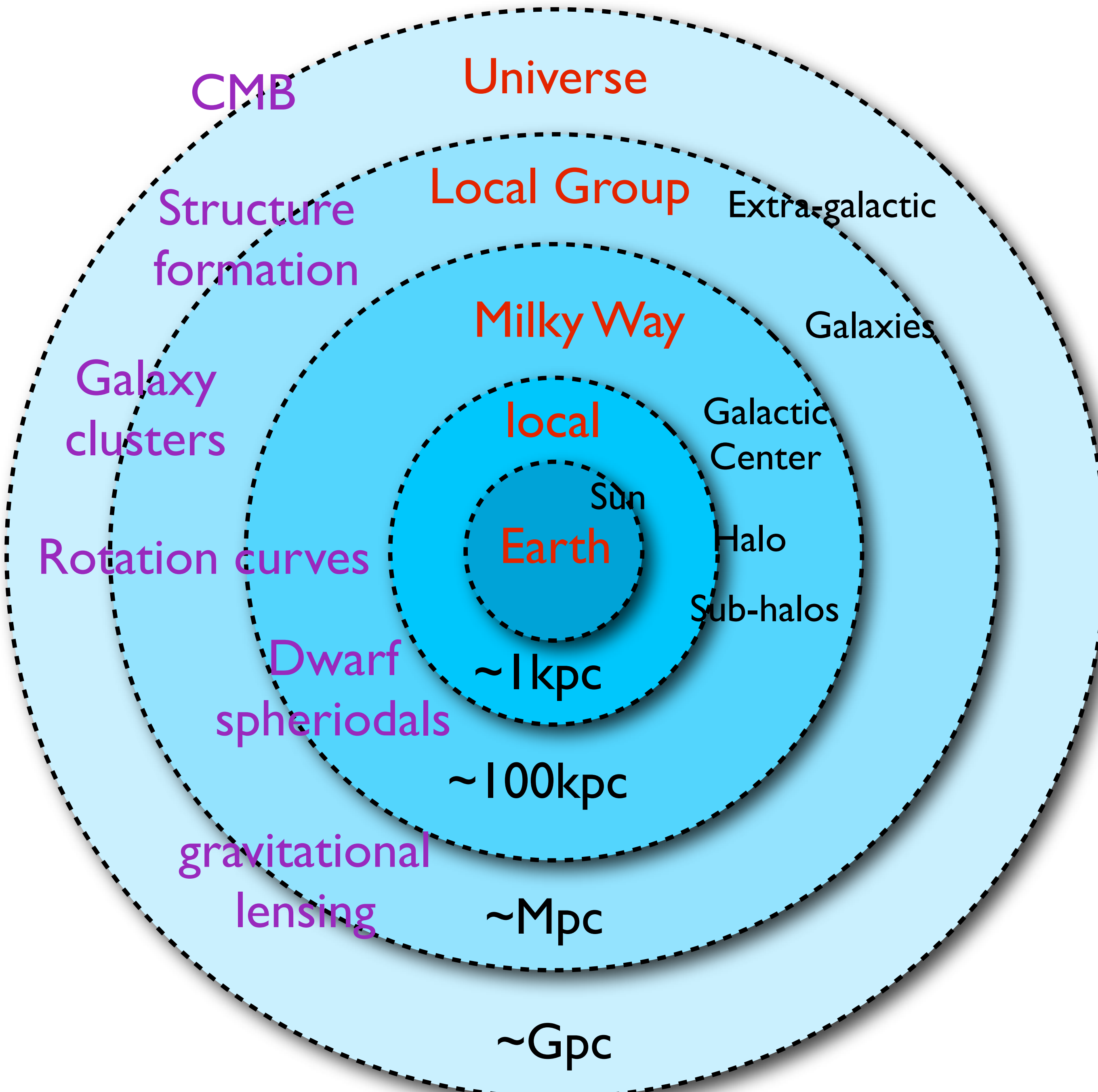

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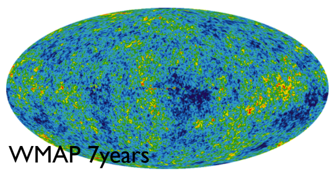

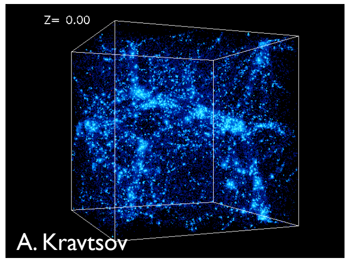

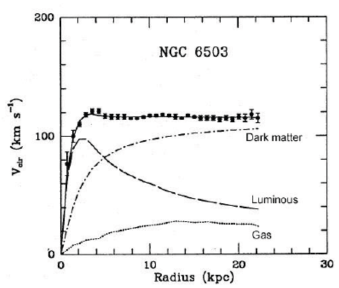

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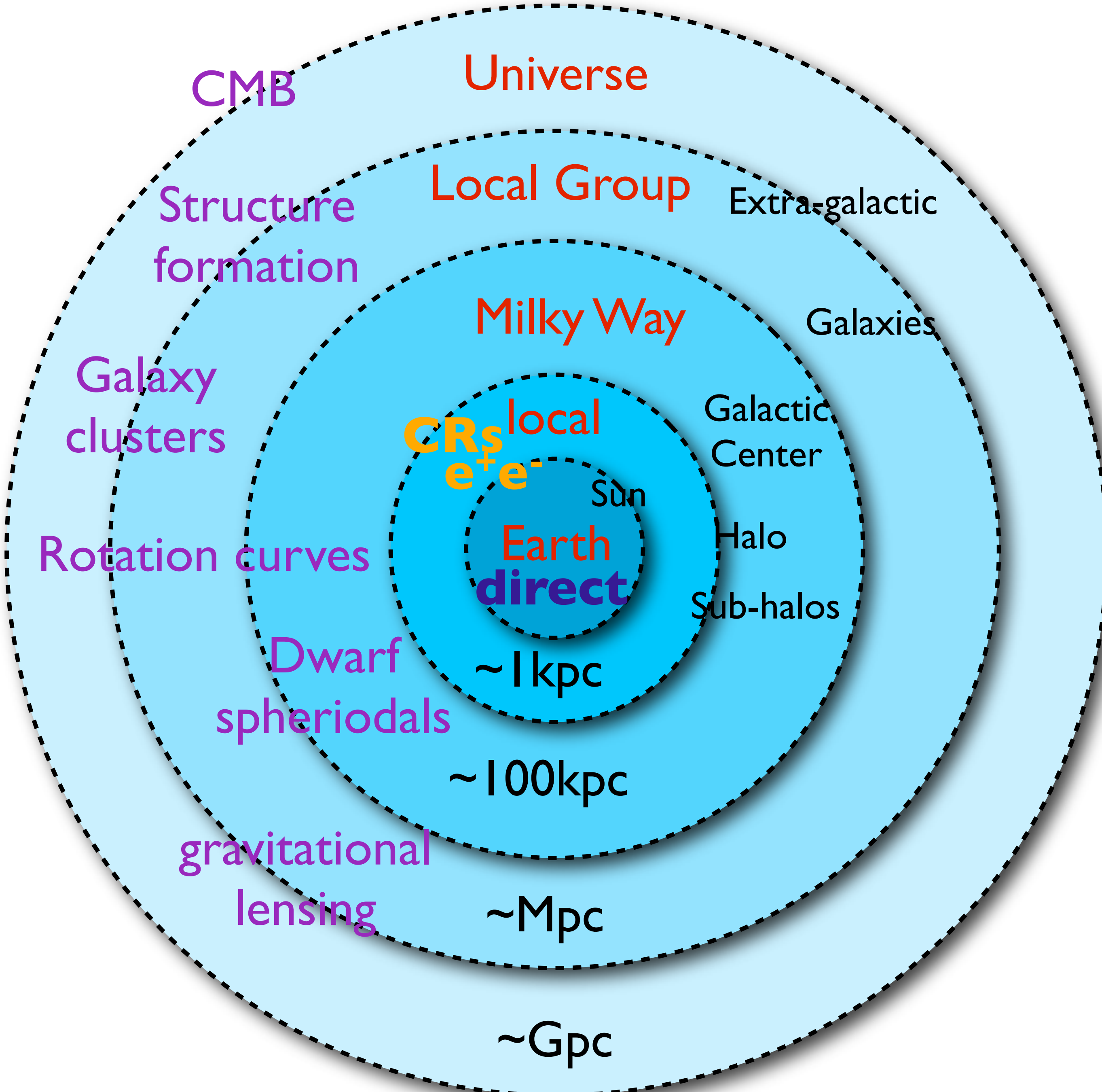

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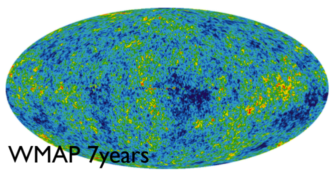

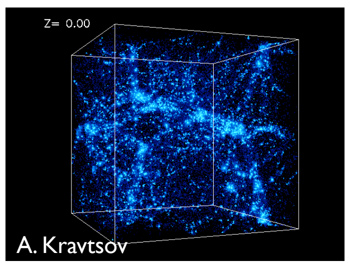

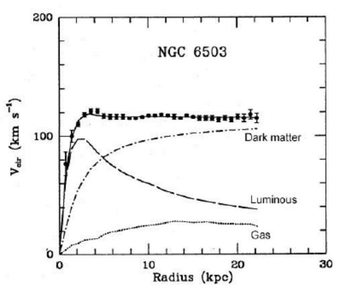

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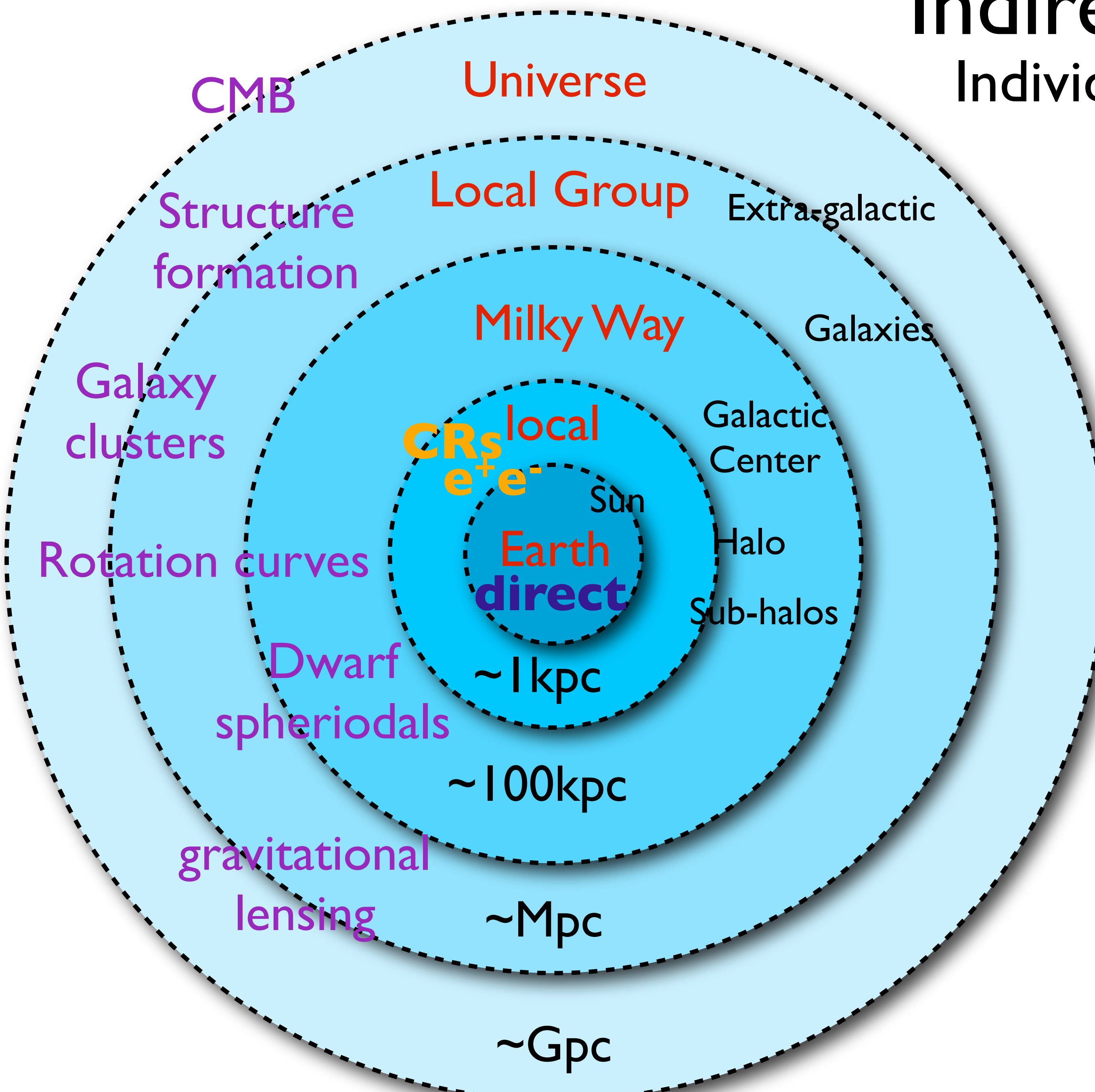
“Indirect Targets” for ν

Individual sources and diffuse



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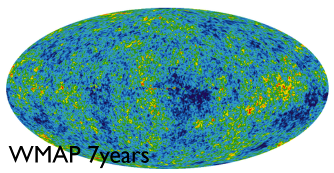

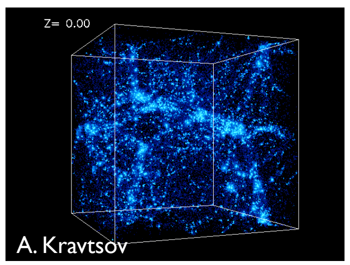

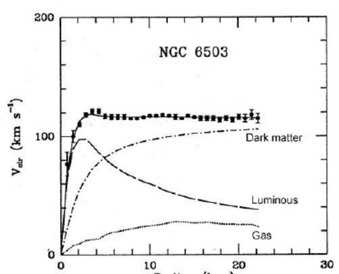

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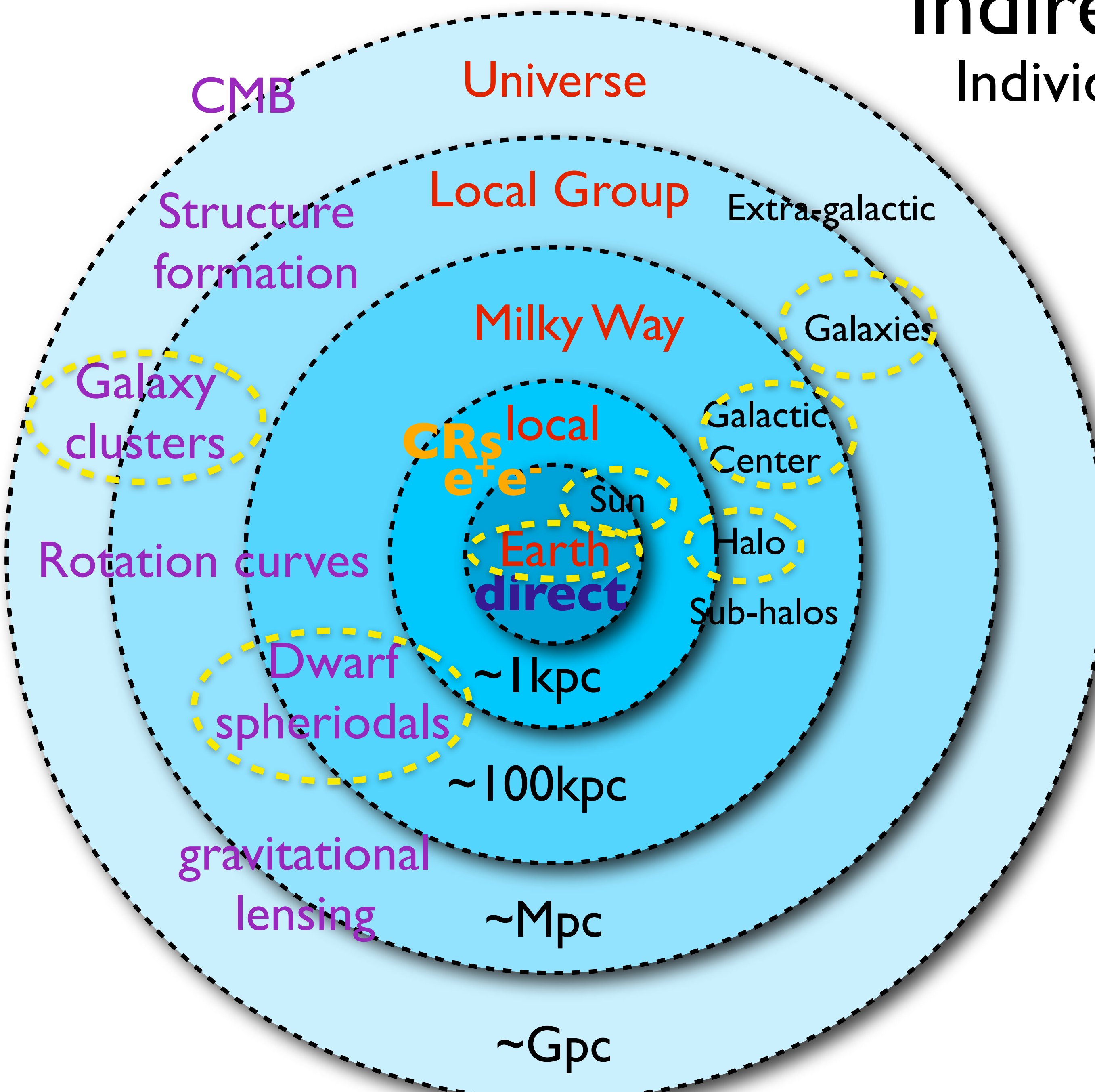


"Indirect Targets" for ν

Individual sources and diffuse

IceCube Analyses:

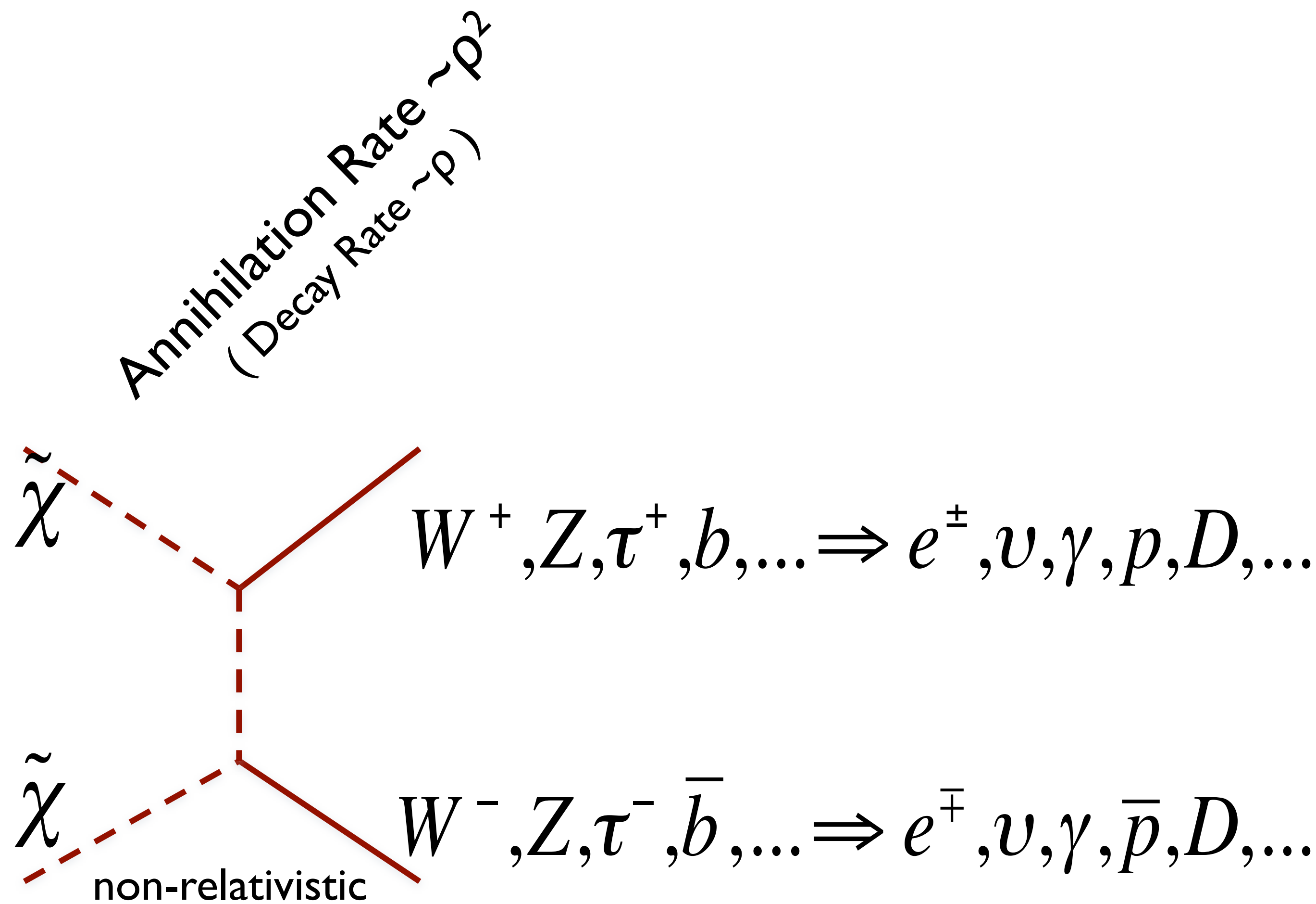
Galactic Halo:
Limits from IceCube-22
Galactic Center:
Limits from IceCube-40
Various channels, including line

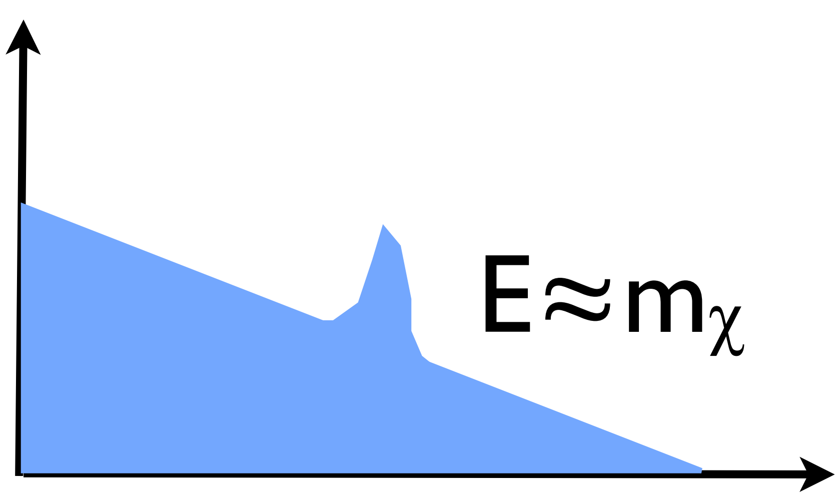
Dwarf Galaxies:
→ Search with IceCube-59
Clusters of Galaxies:
→ Search with IceCube-59

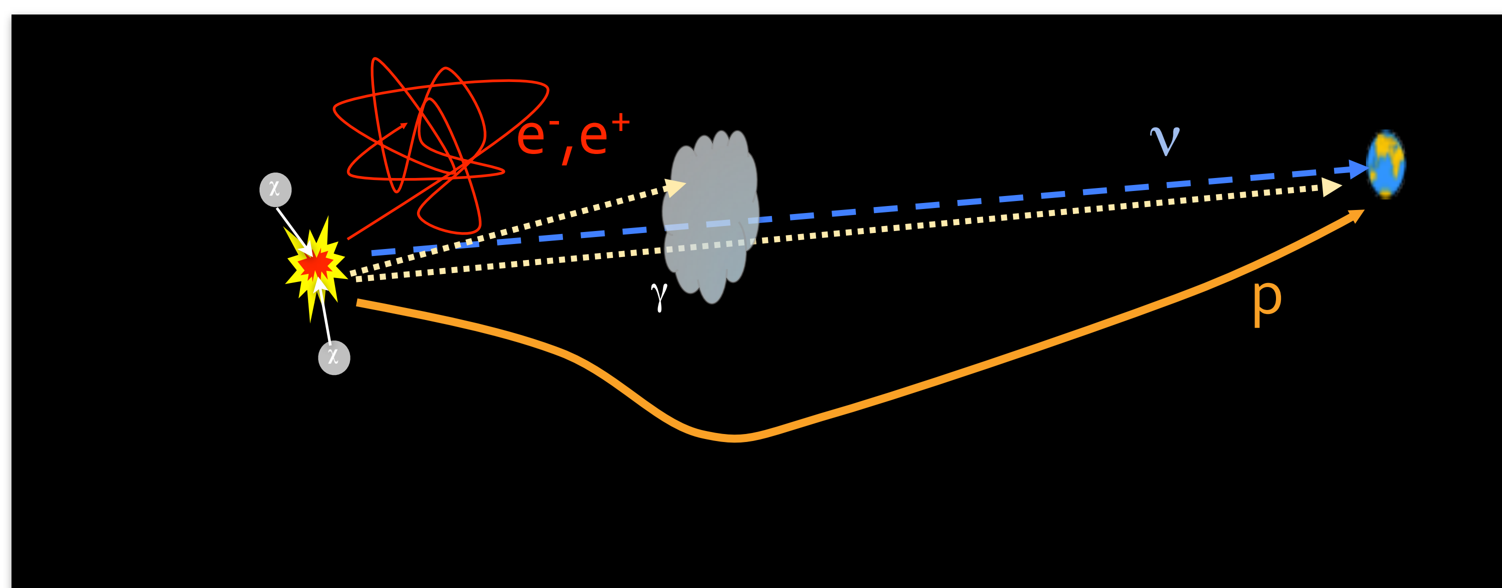
Sun:
Combined Limits form AMANDA, IC22, IC40+AMANDA
→ Search with IceCube-79
Searches beyond " standard" SUSY:
→ Secluded dark matter sector
Earth:
Limits from AMANDA, IceCube analysis in progresss

Dark Matter Annihilation Signals

- Interactions that determine the WIMP relic abundance also lead to self-annihilations in the present epoch
    - Identify overdense regions of Dark Matter ⇒self-annihilation can occur at significant rates
- Pick prominent Dark Matter target
- Understand backgrounds
- Features in the signal enhance to chance distinguish backgrounds
    - Line / End-point







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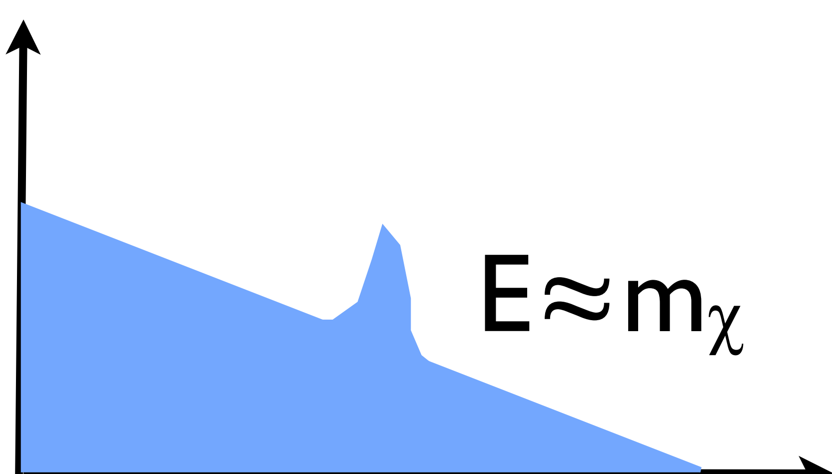
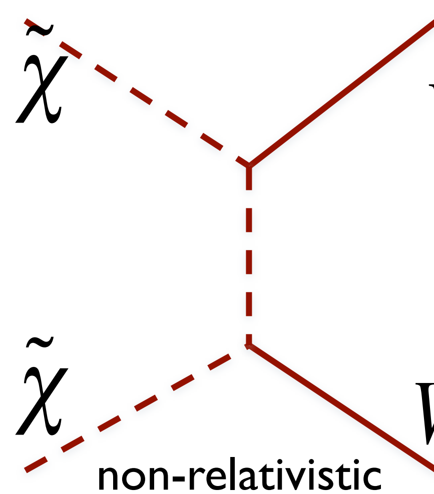


Annihilation Rate ~ρ^2
(Decay Rate ~ρ)

Annihilation Products

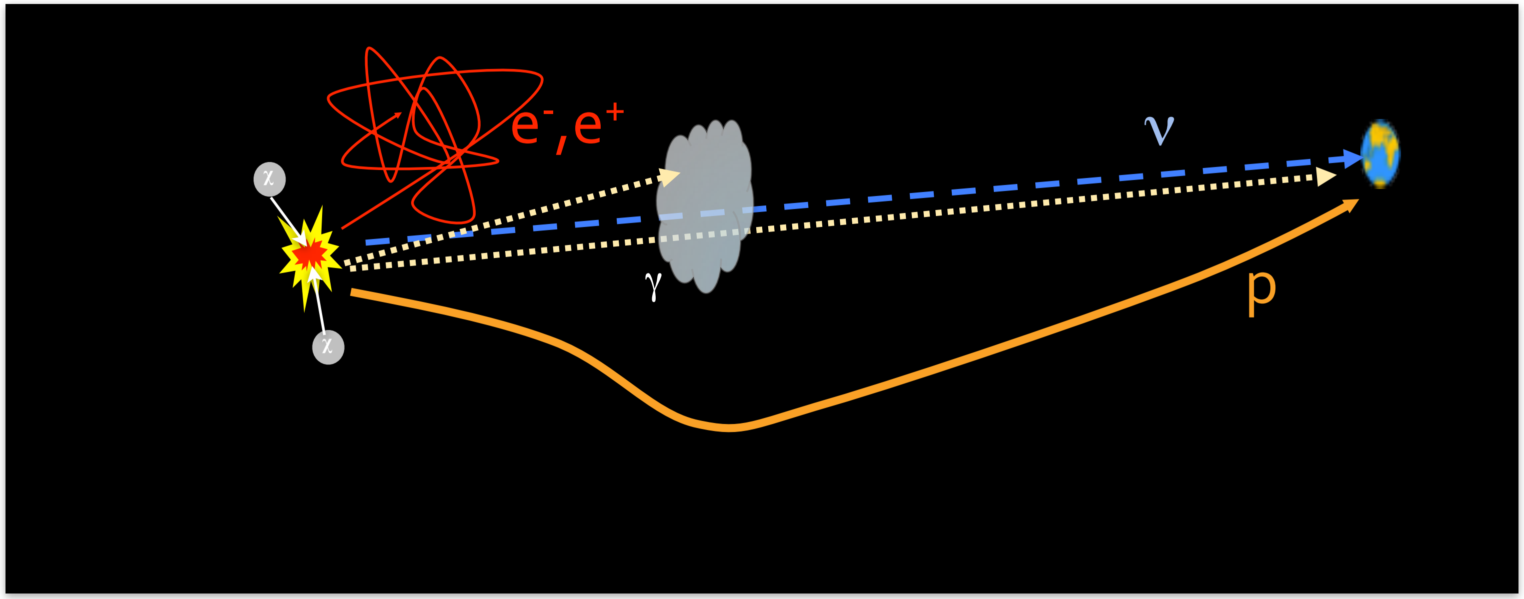
Decay

Messengers



$$W^+, Z, \tau^+, b, \ldots \Rightarrow e^\pm, \upsilon, \gamma, p, D, \ldots$$

$$W^-, Z, \tau^-, \bar{b}, \ldots \Rightarrow e^\mp, \upsilon, \gamma, \bar{p}, D, \ldots$$



The IceCube Neutrino Telescope

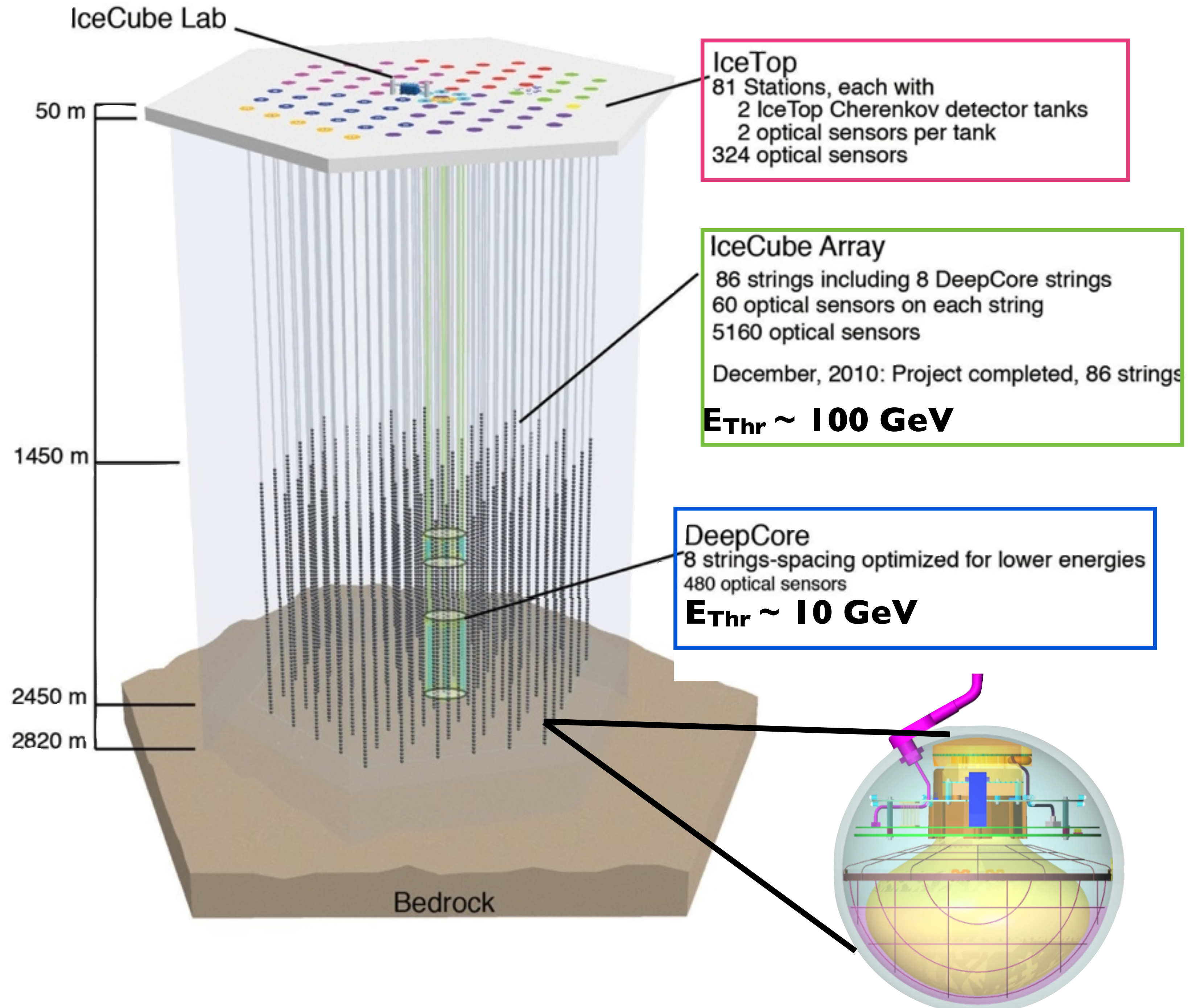
Gigaton Neutrino Detector at the Geographic South Pole

5160 Digital optical modules distributed over 86 strings

Completed in December 2010, start of data taking with full detector May 2011

Data acquired during the construction phase has been analyzed

Neutrinos are identified through Cherenkov light emission from secondary particles produced in the neutrino interaction with the ice



The IceCube Neutrino Telescope

Strings	Dataset
1	2005-2006
9	2006-2007
22	2007-2008
40	2008-2009
59	2009-2010
73 + 6	2010-2011
78 + 8	2011 - .....

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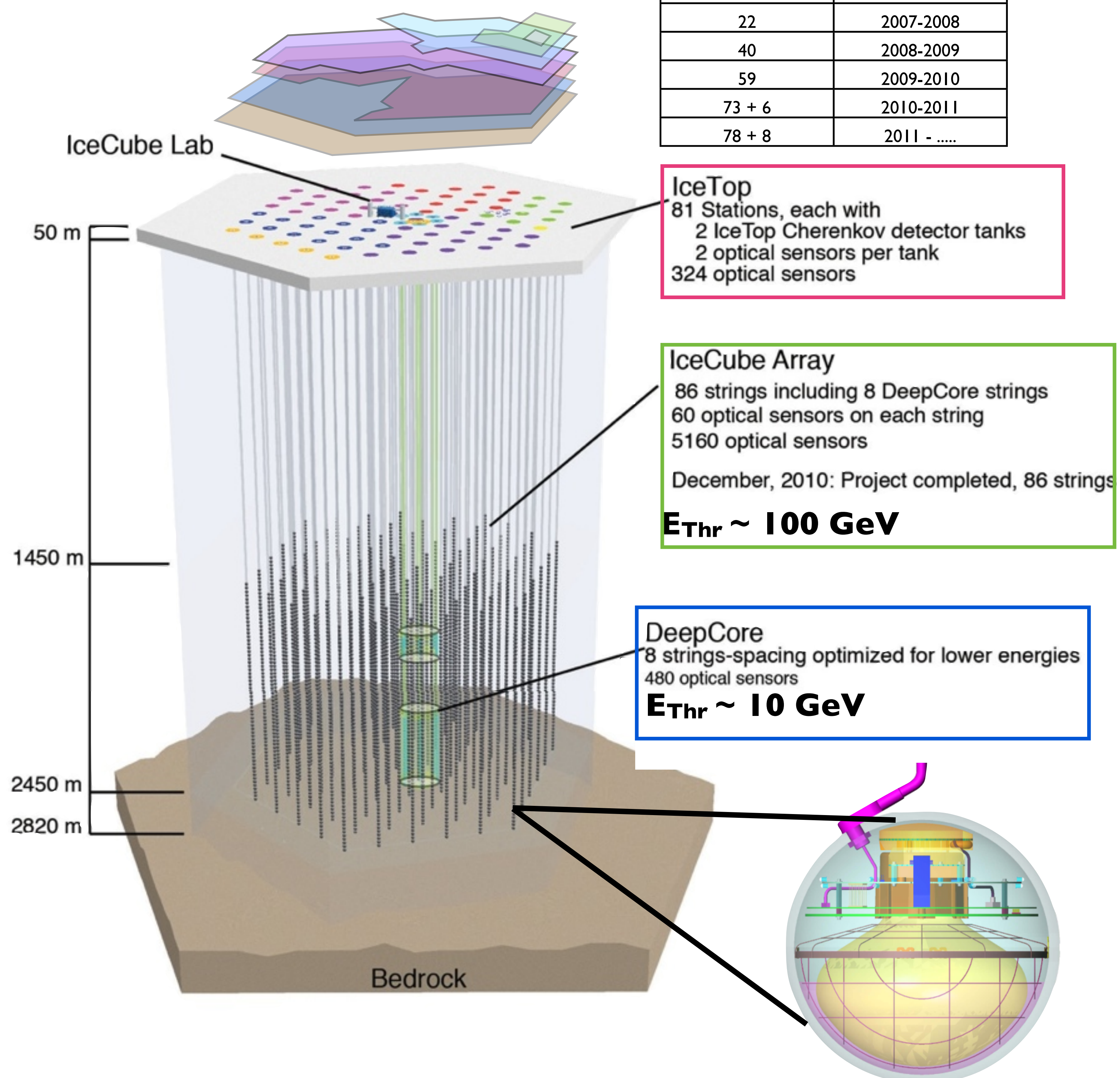

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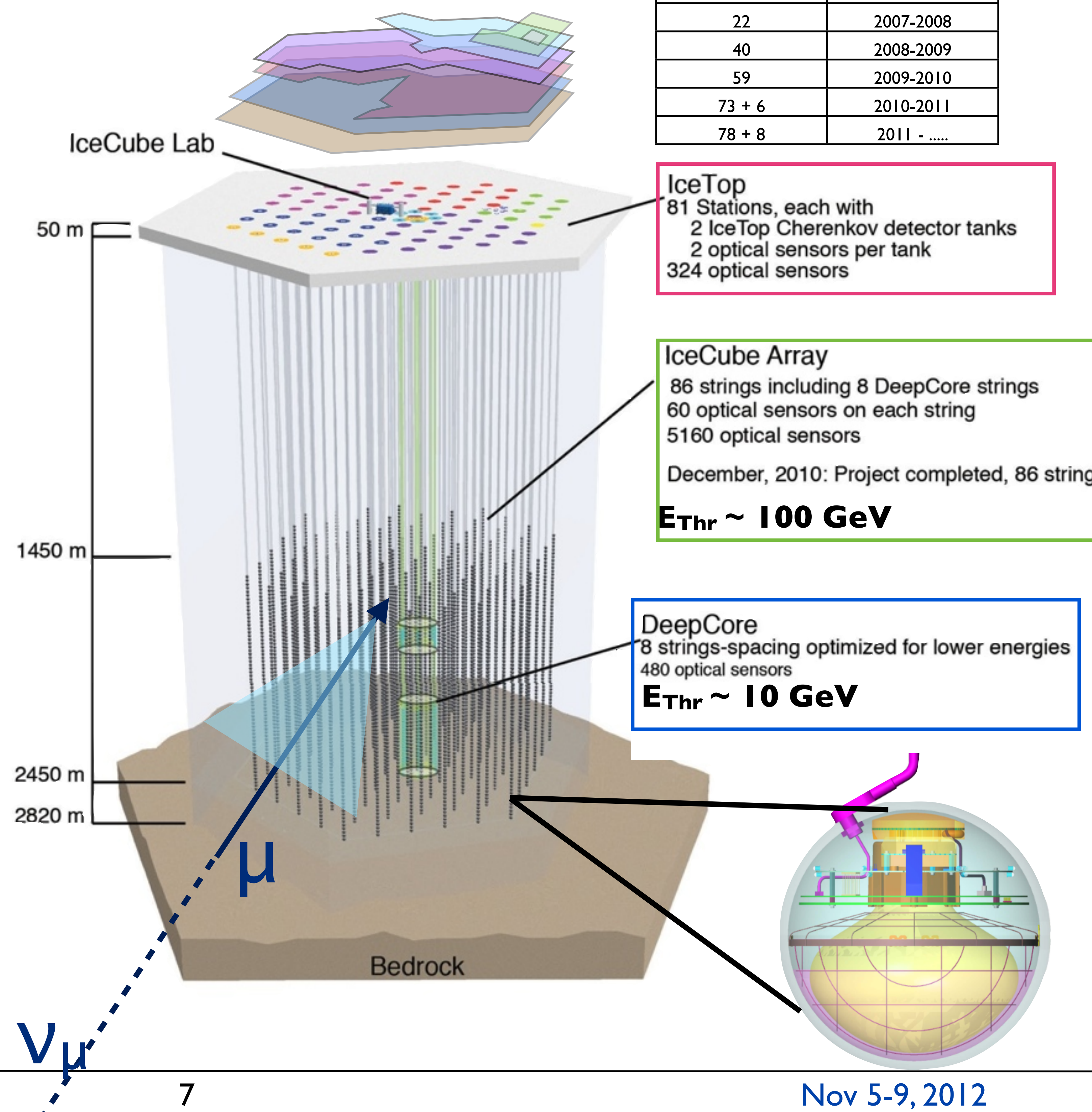


Signals in IceCube

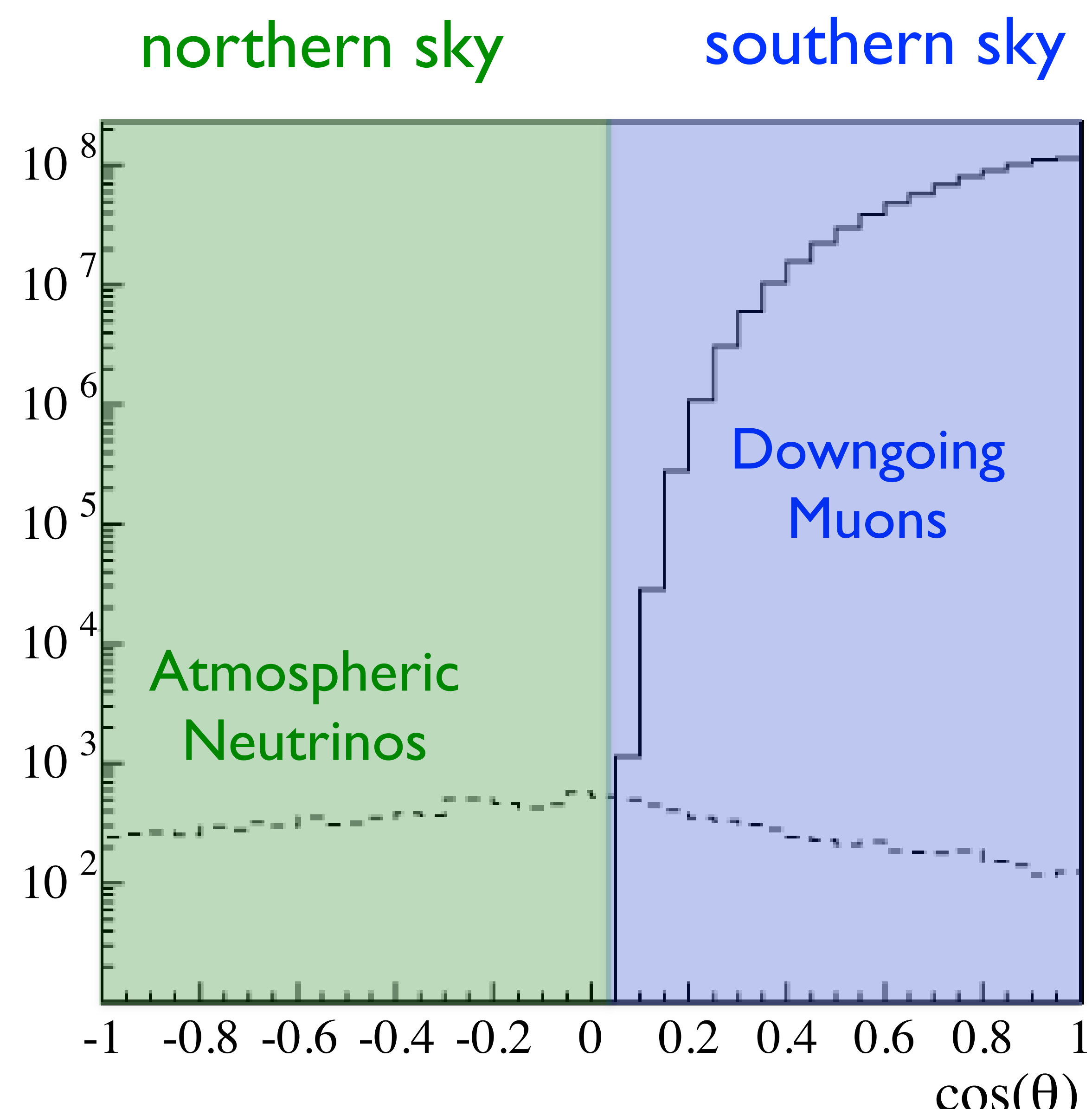
South Pole

$p + A \rightarrow \pi^{\pm}\ (K^{\pm})$ + other hadrons ... $\pi^{+} \rightarrow \mu^{+}\nu_{\mu} \rightarrow e^{+}\nu_{e}\nu_{\mu}\nu_{\mu}$

IceCube Depth: 1.5-2.5 km

Downgoing Muons

North Pole



Atmospheric backgrounds for extra-terrestrial neutrino searches at the depth of IceCube

- Up-going events can be used to obtain "clean" neutrino sample
  - Earth is used as muon filter
- Atmospheric neutrinos create irreducible neutrino background to extra terrestrial neutrino fluxes

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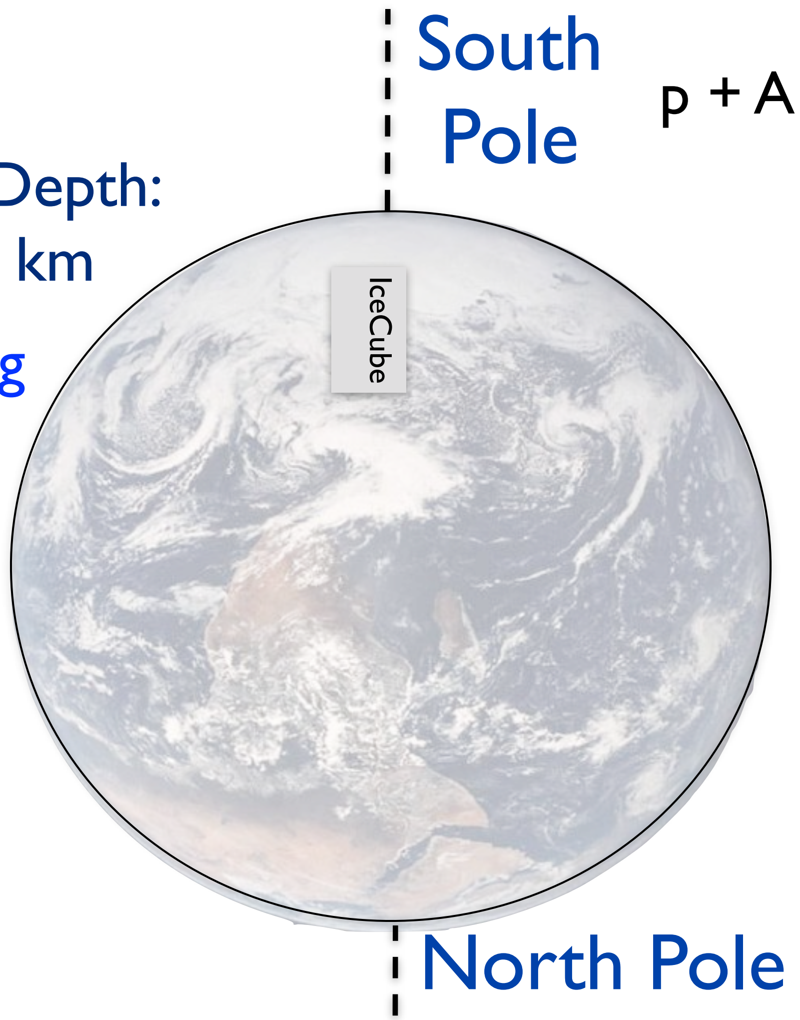

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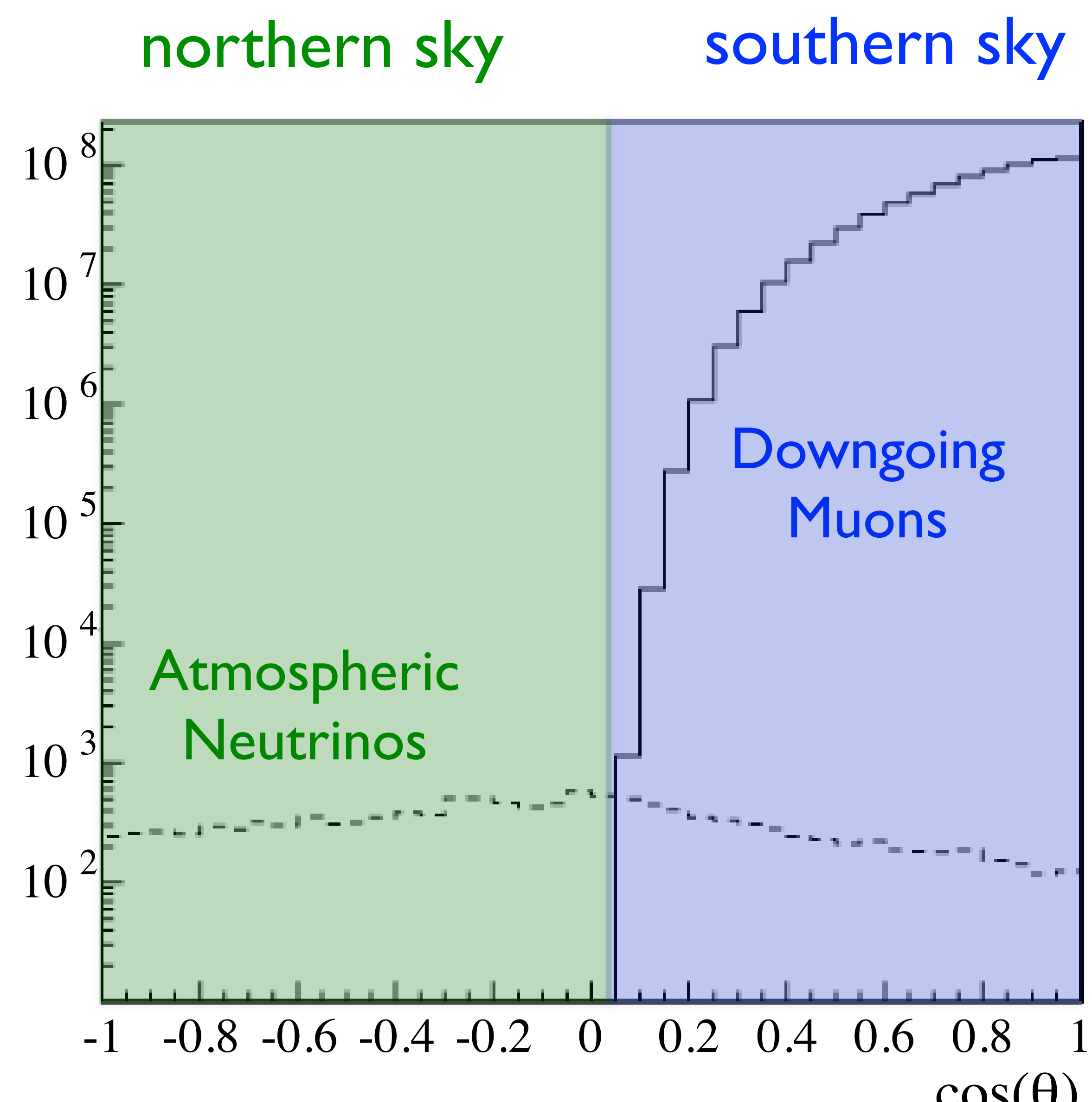

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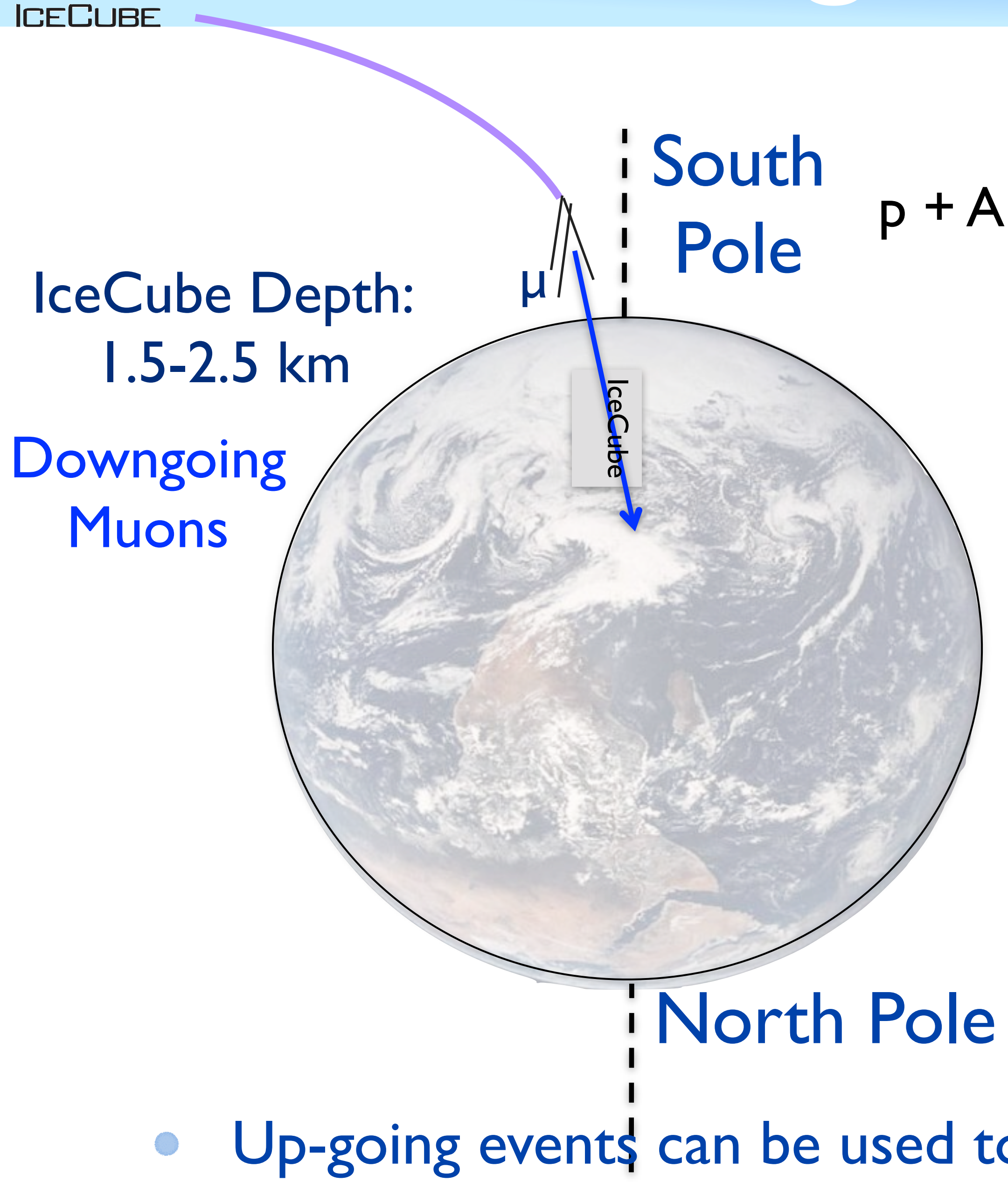

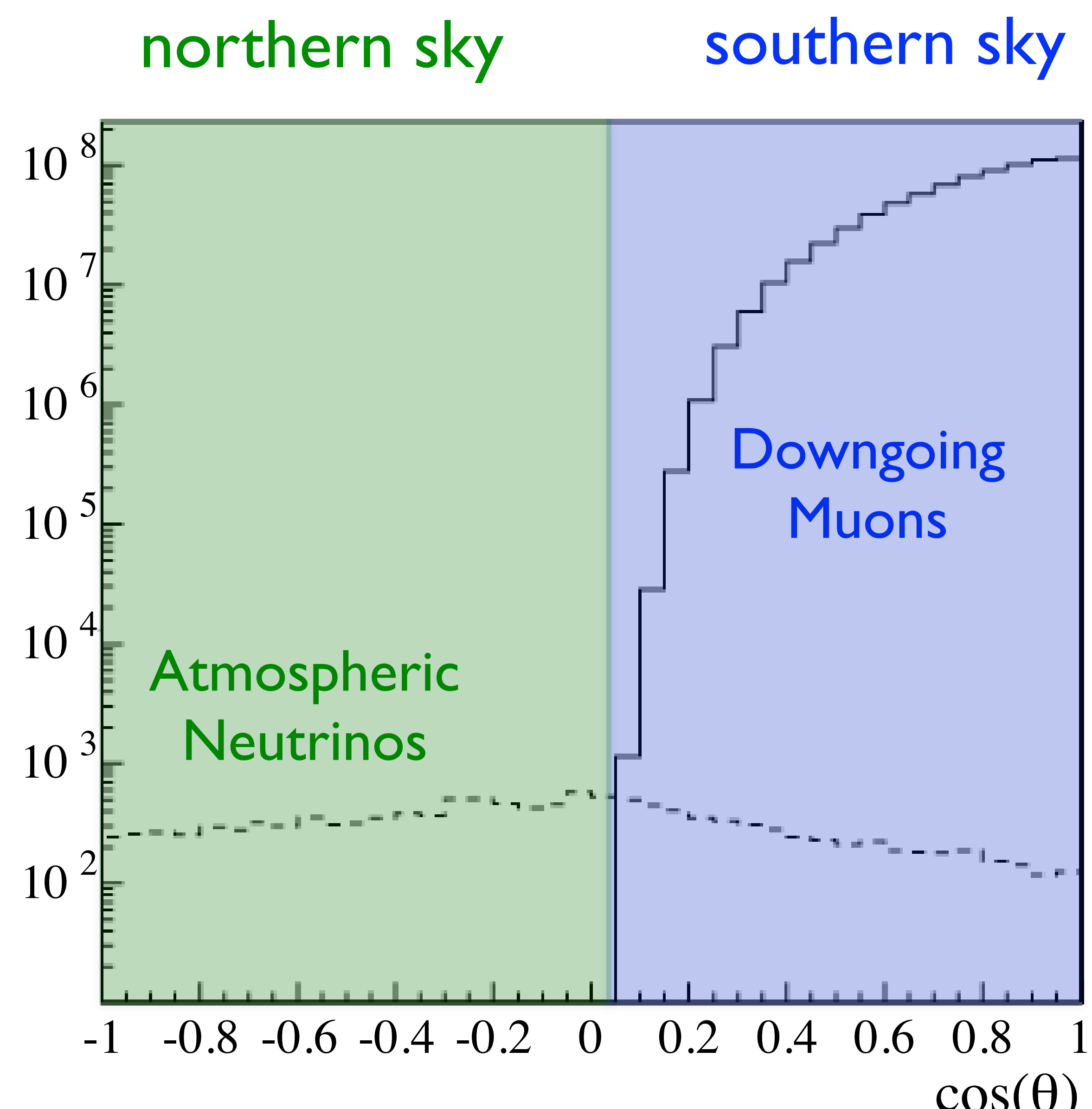

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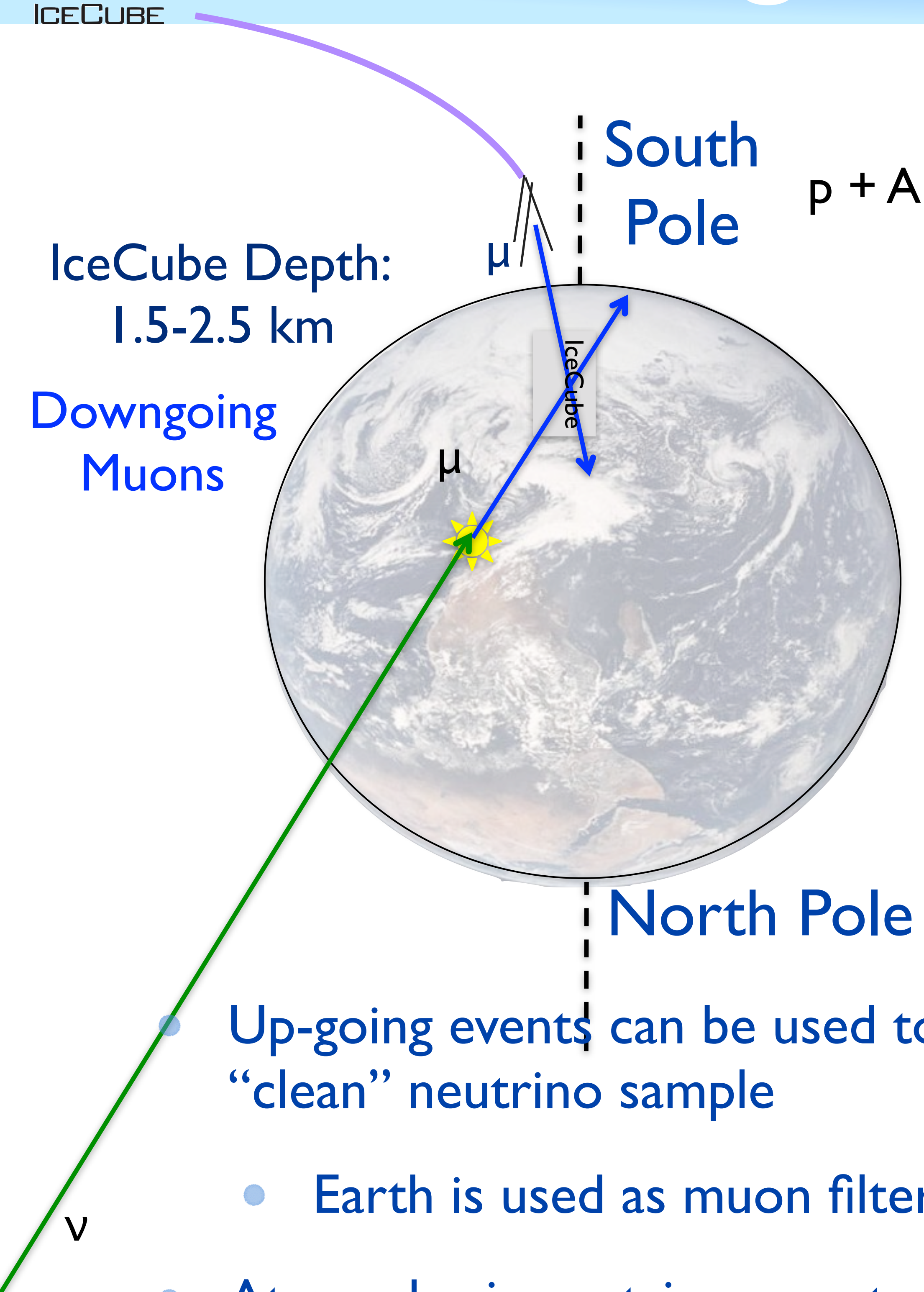

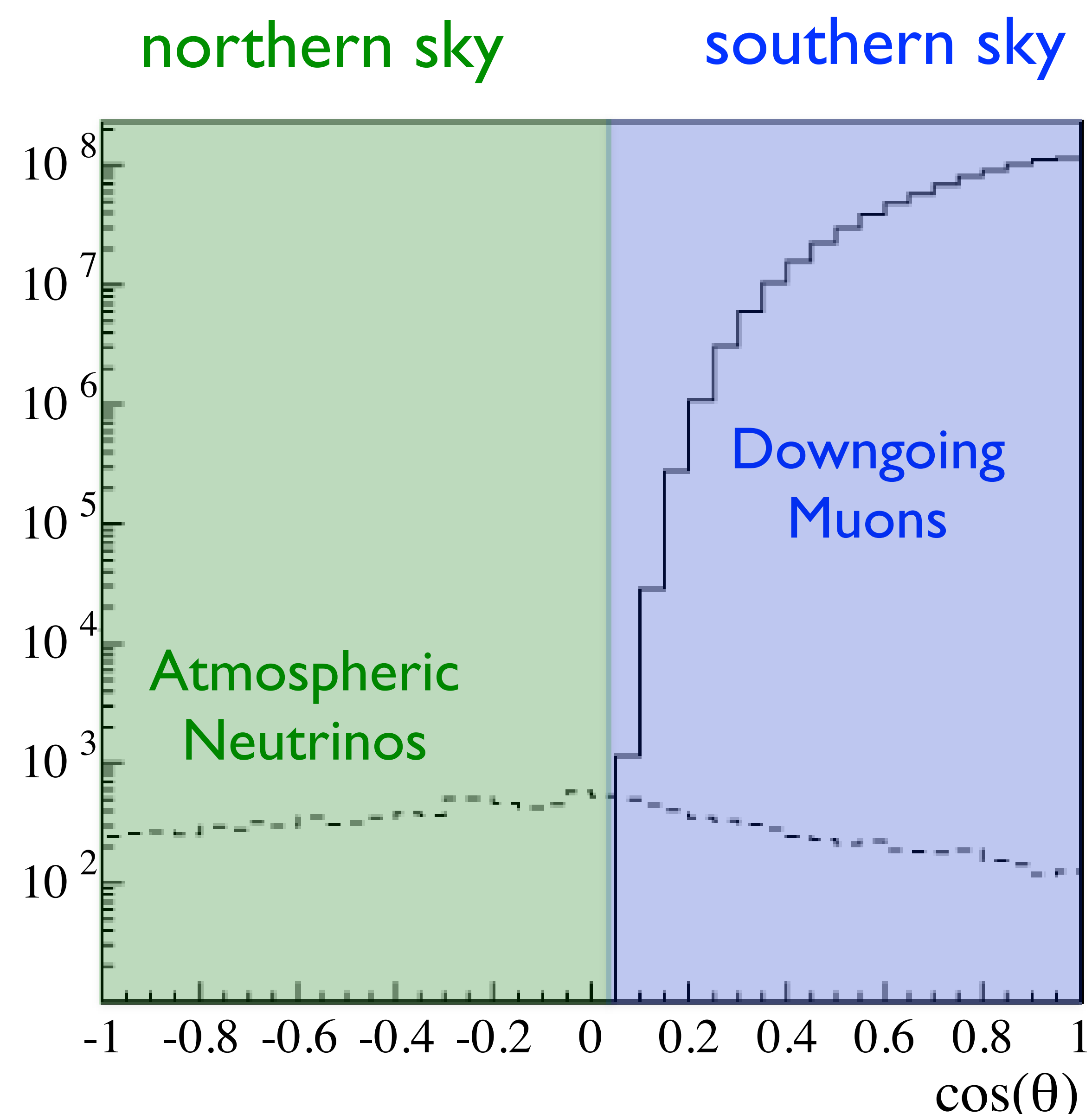

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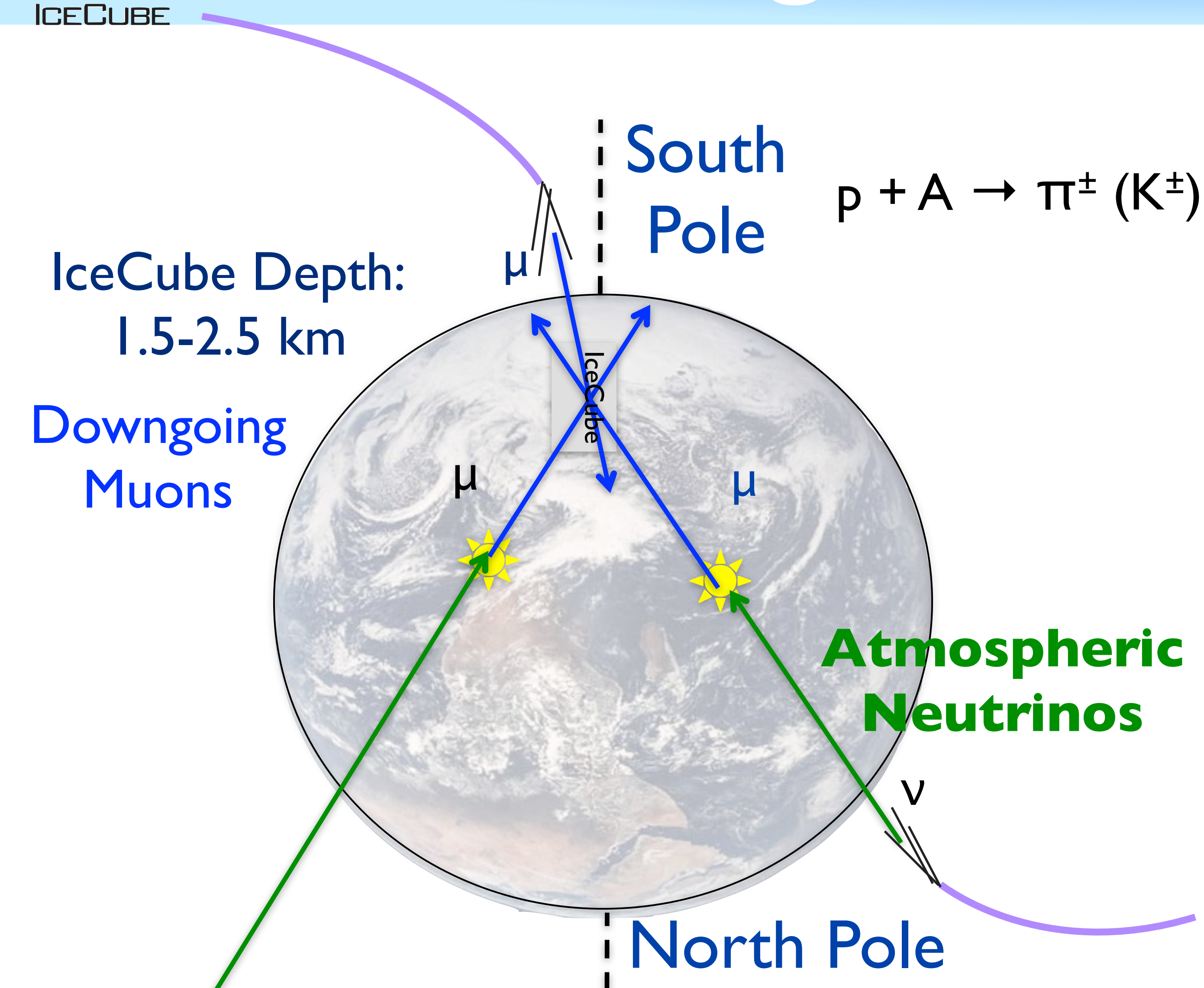

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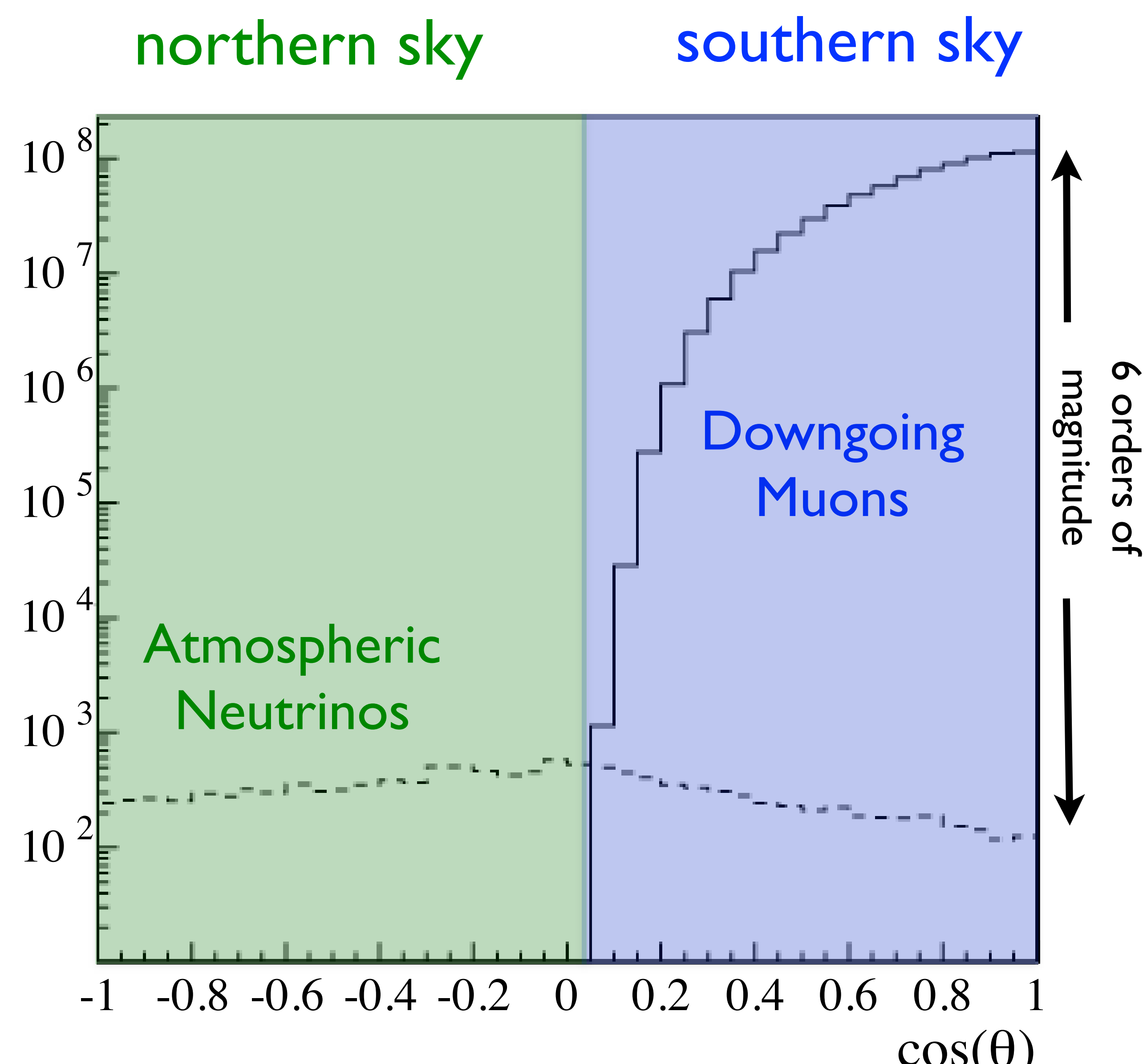

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Signals in IceCube

South Pole

IceCube Depth: 1.5-2.5 km

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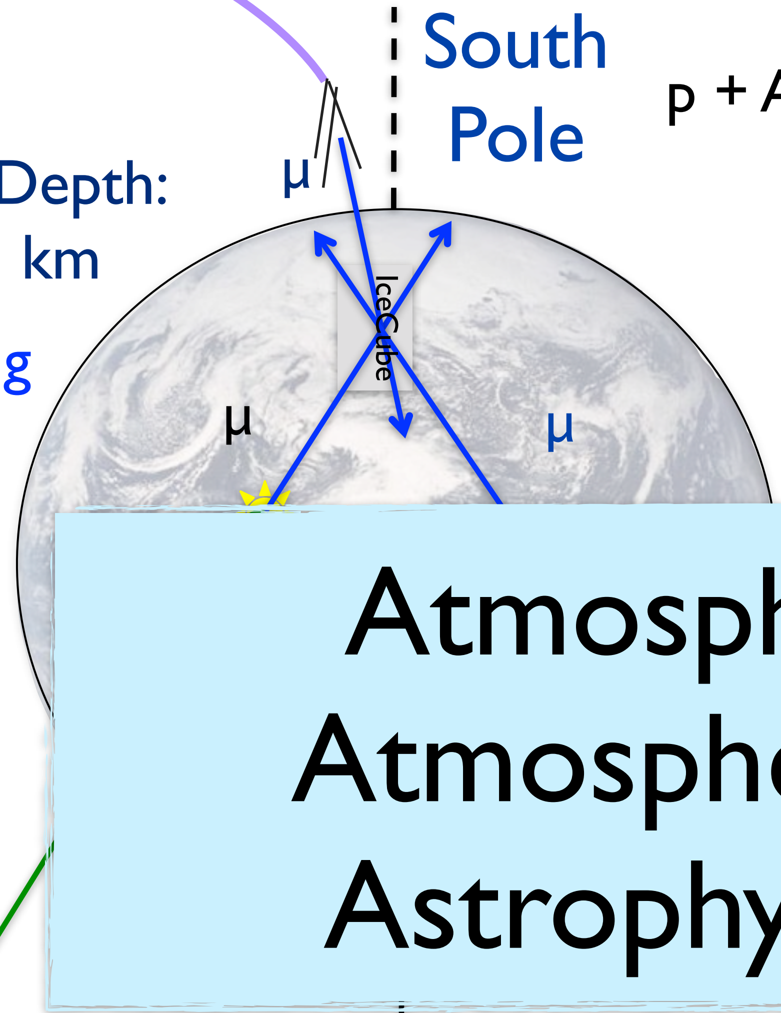

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Atmospheric muons ~ 10^{11}/year

Atmospheric neutrinos ~ 10^{5}/year

Astrophysical neutrinos ~ ??/year

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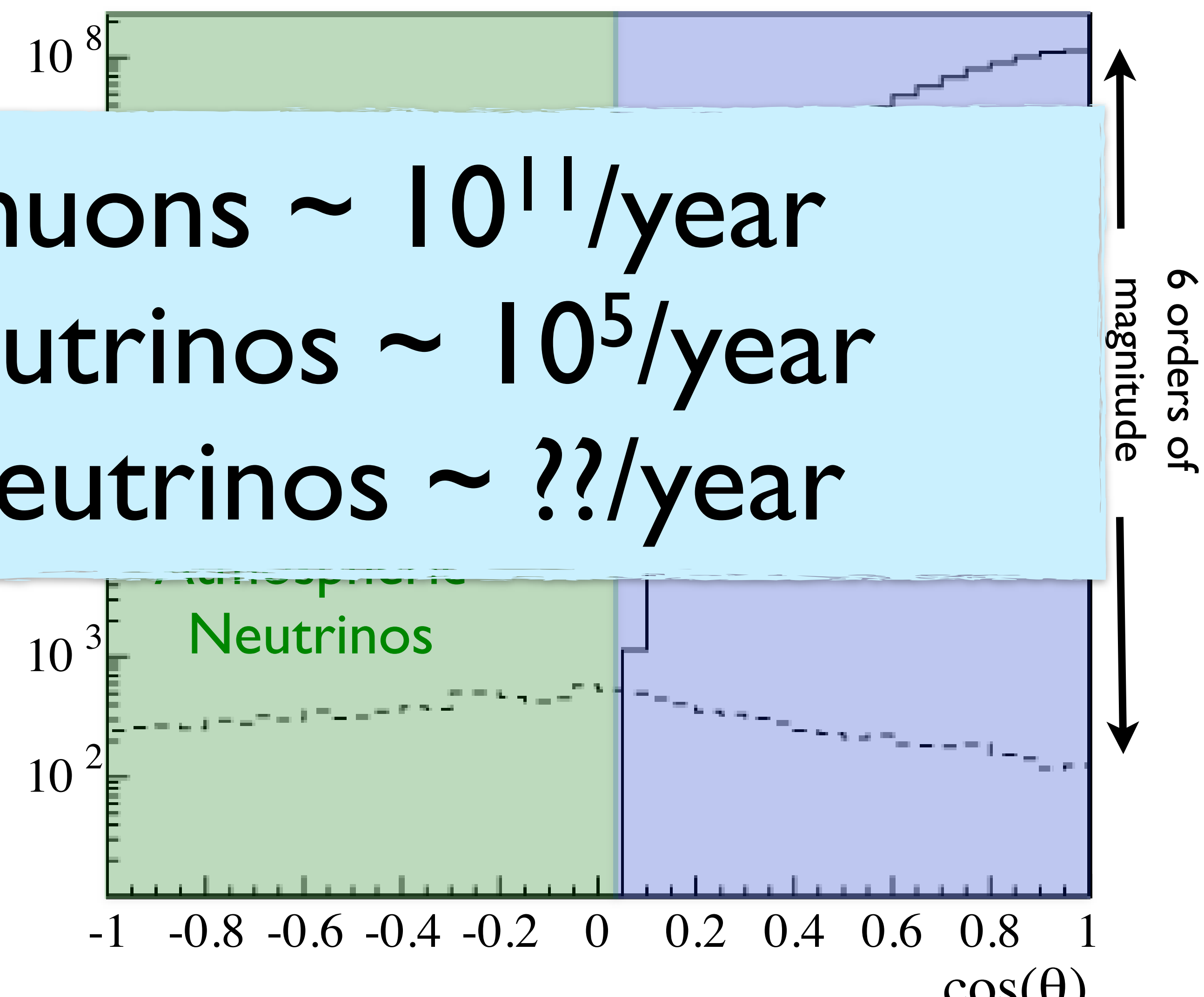
northern sky

southern sky

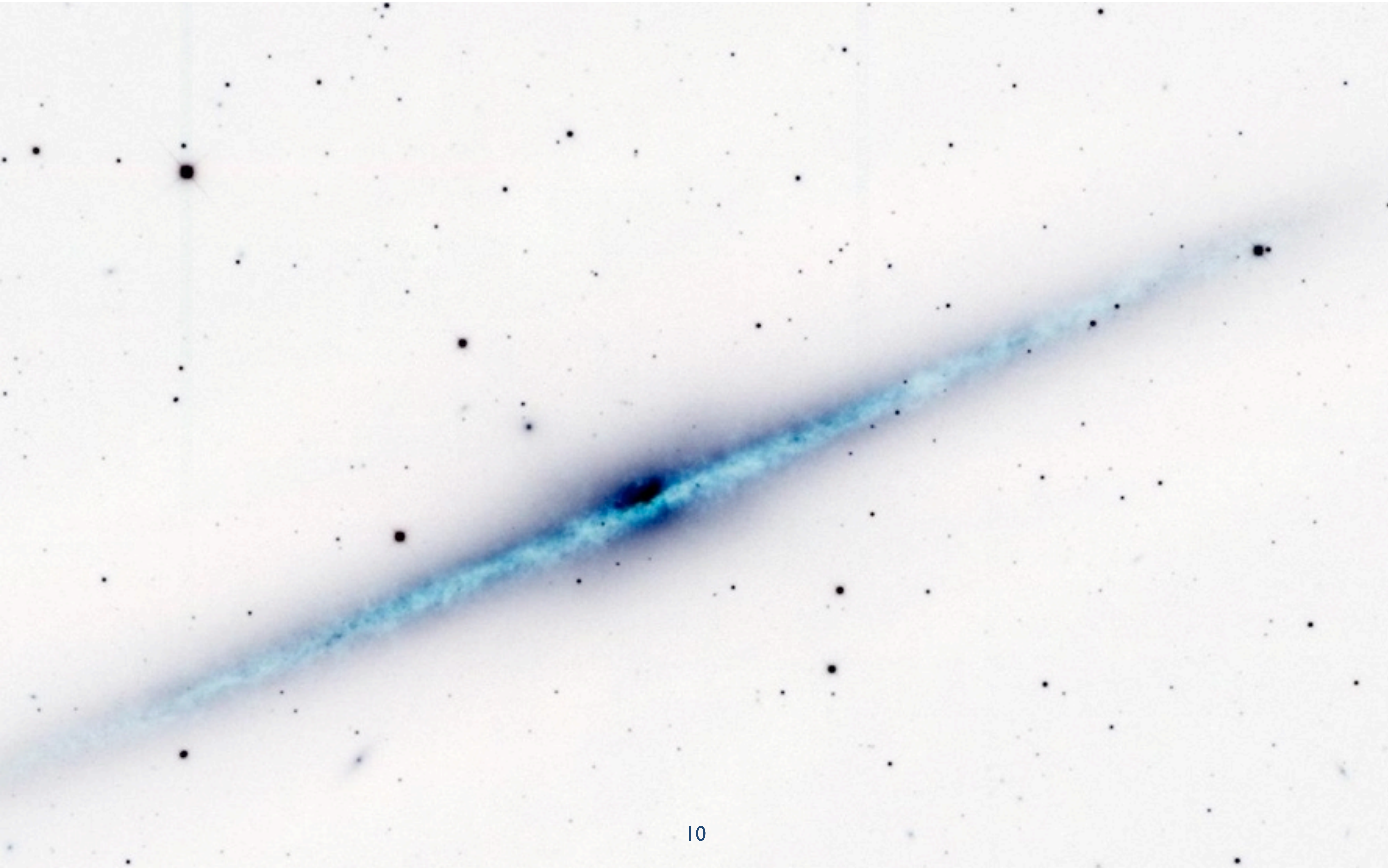


Atmospheric backgrounds for extra-terrestrial neutrino searches at the depth of IceCube

Galactic Center, Halo, Dwarfs, Clusters of Galaxies

Dark Matter in the Milky Way

Dark Matter in the Milky Way



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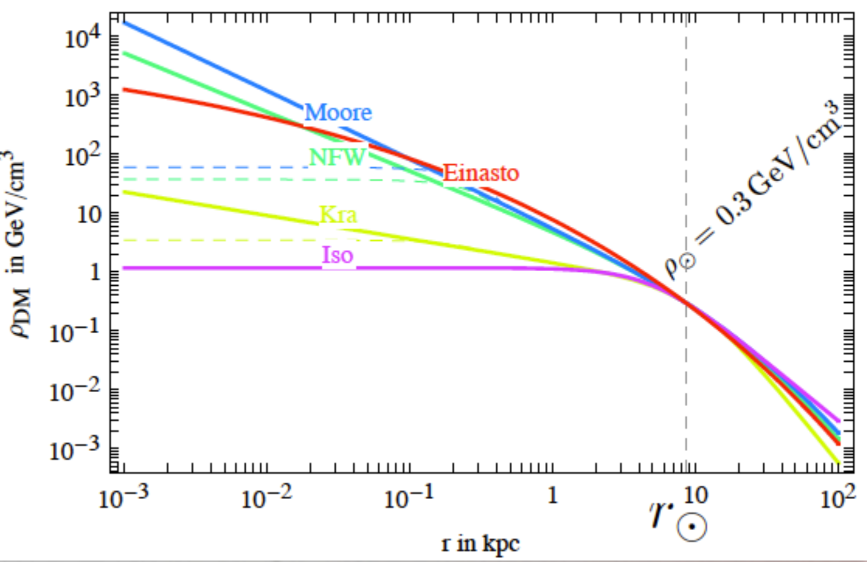

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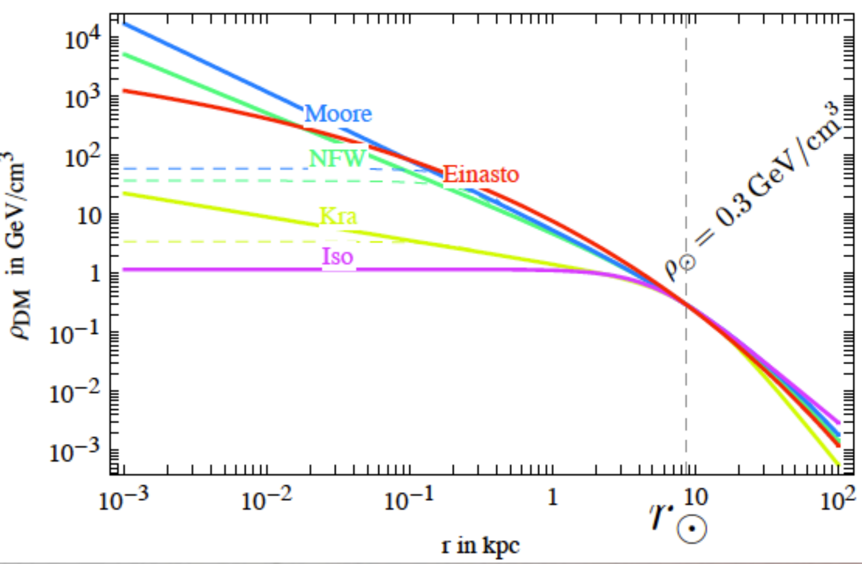

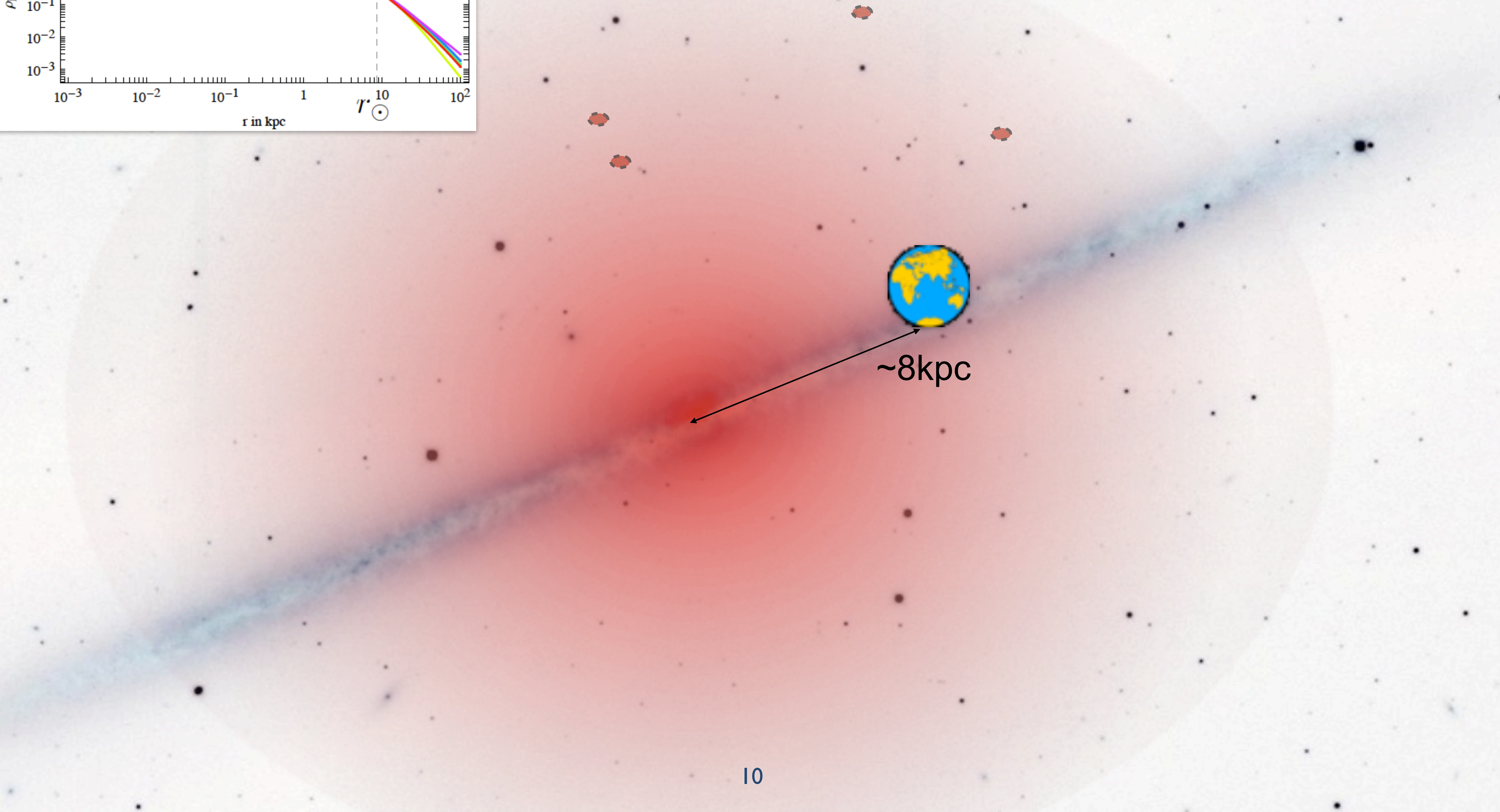

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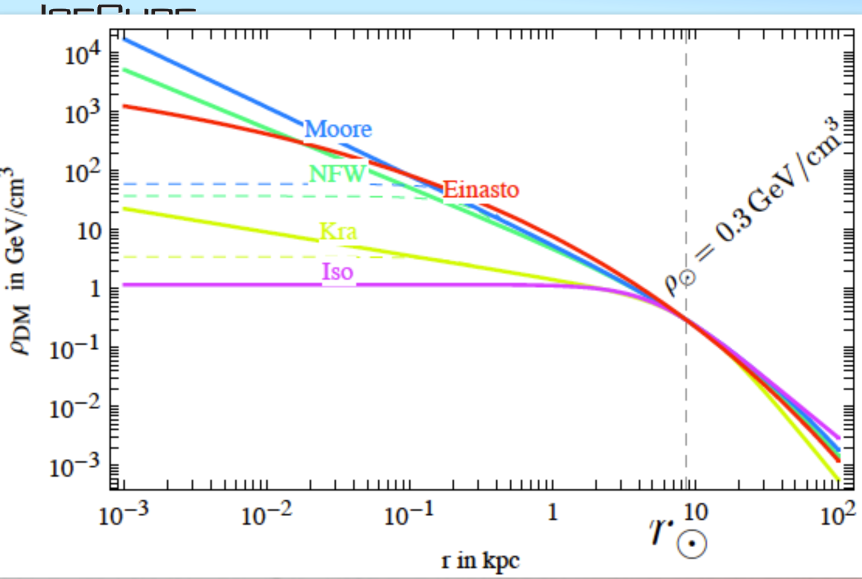
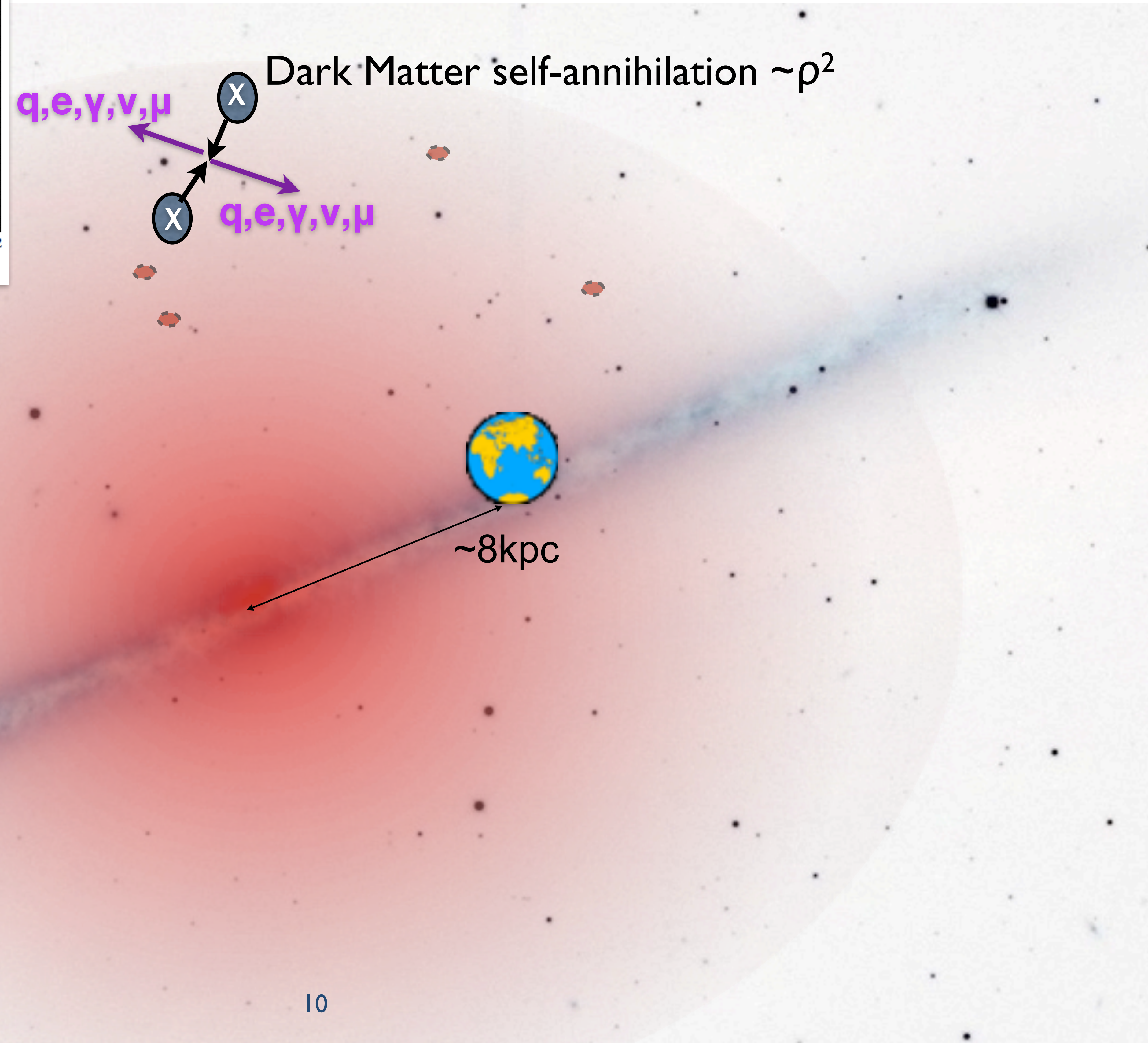
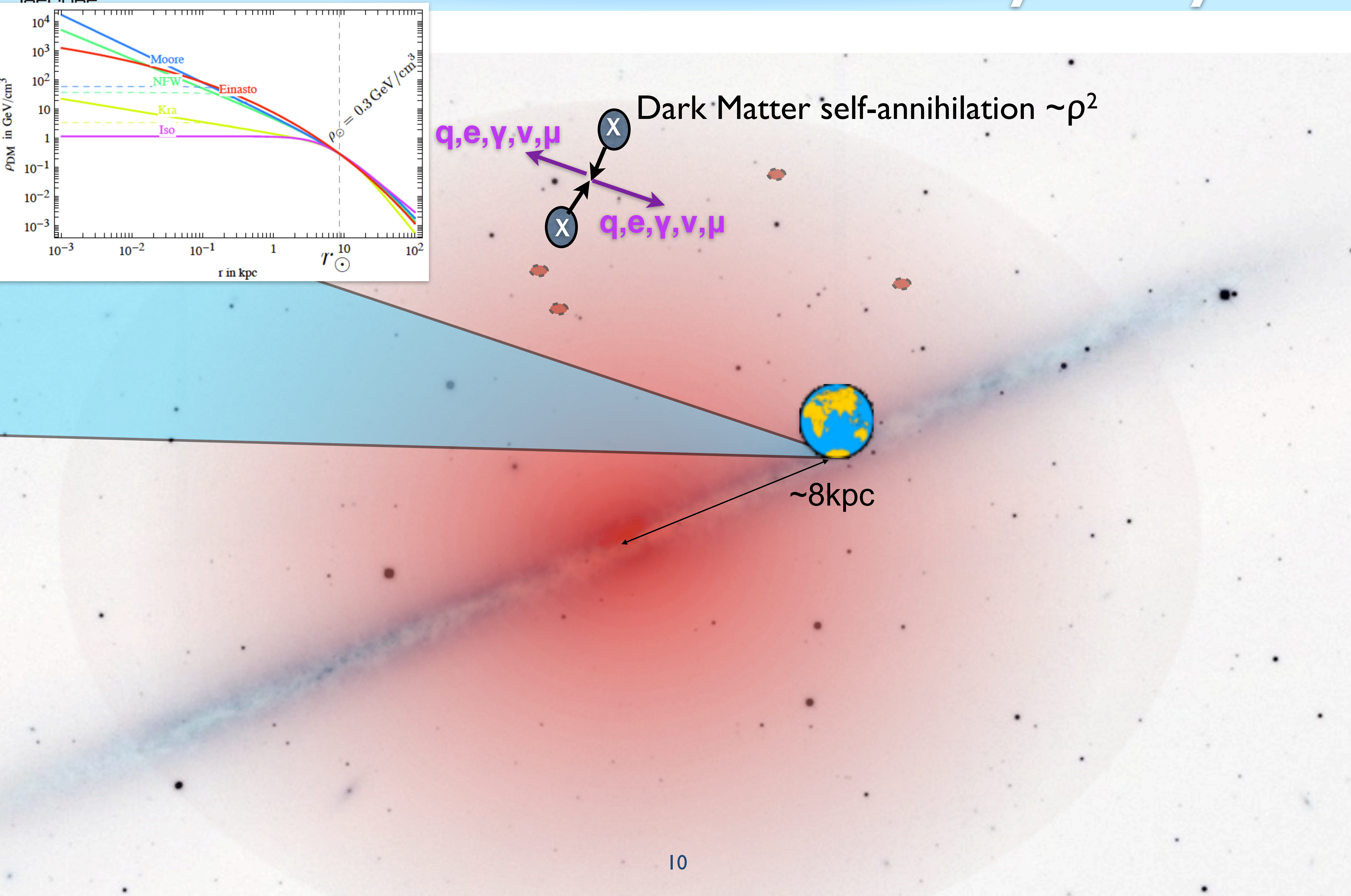
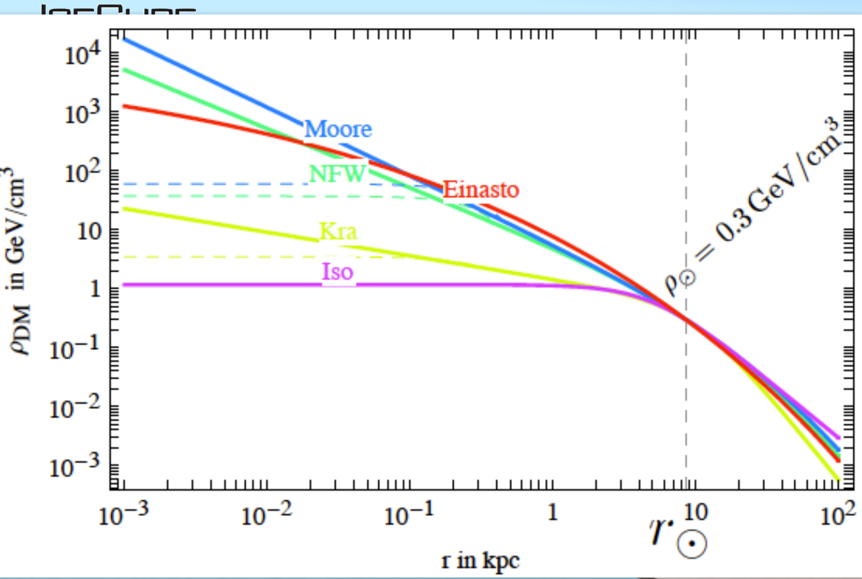


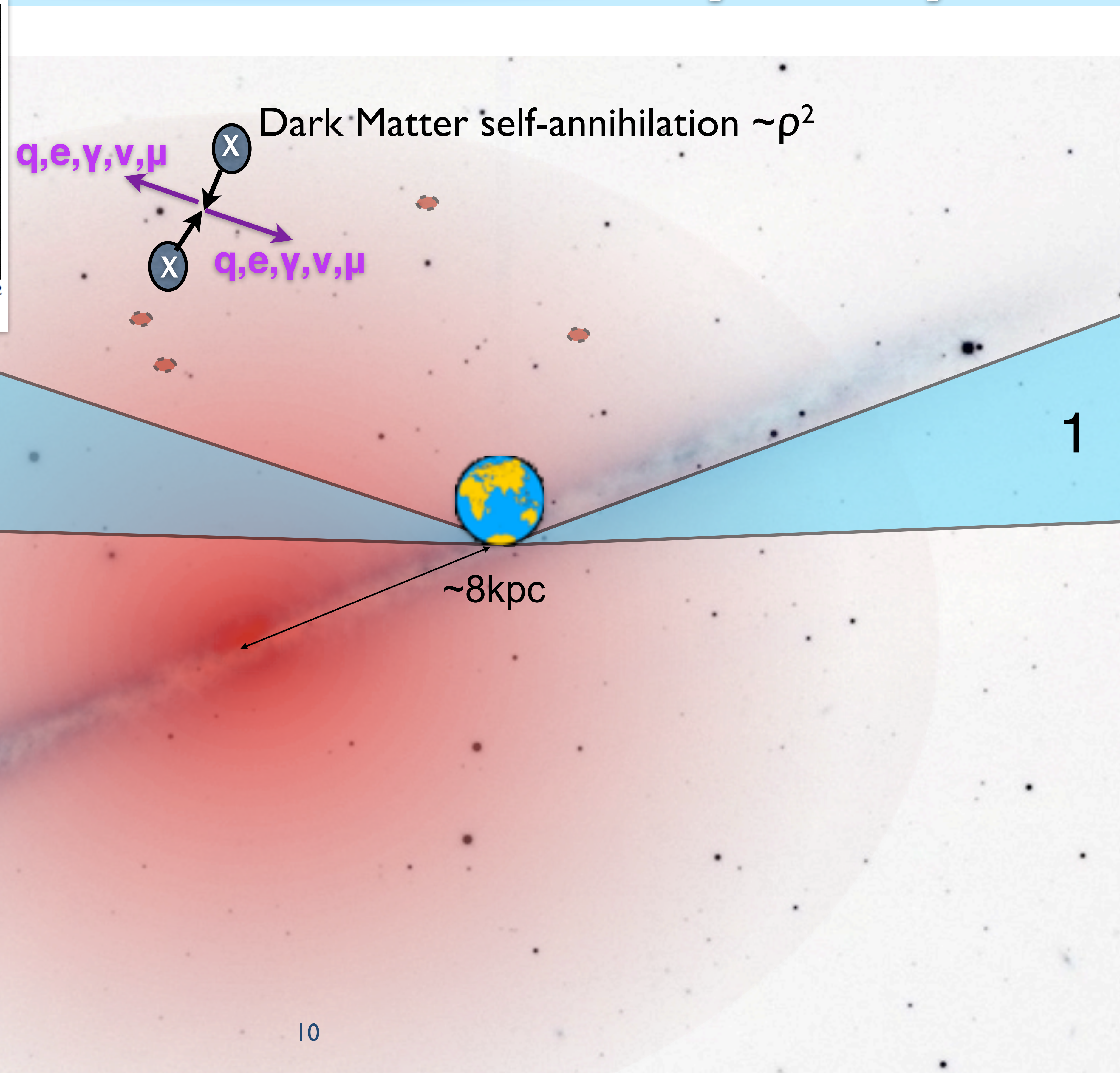


Dark Matter in the Milky Way

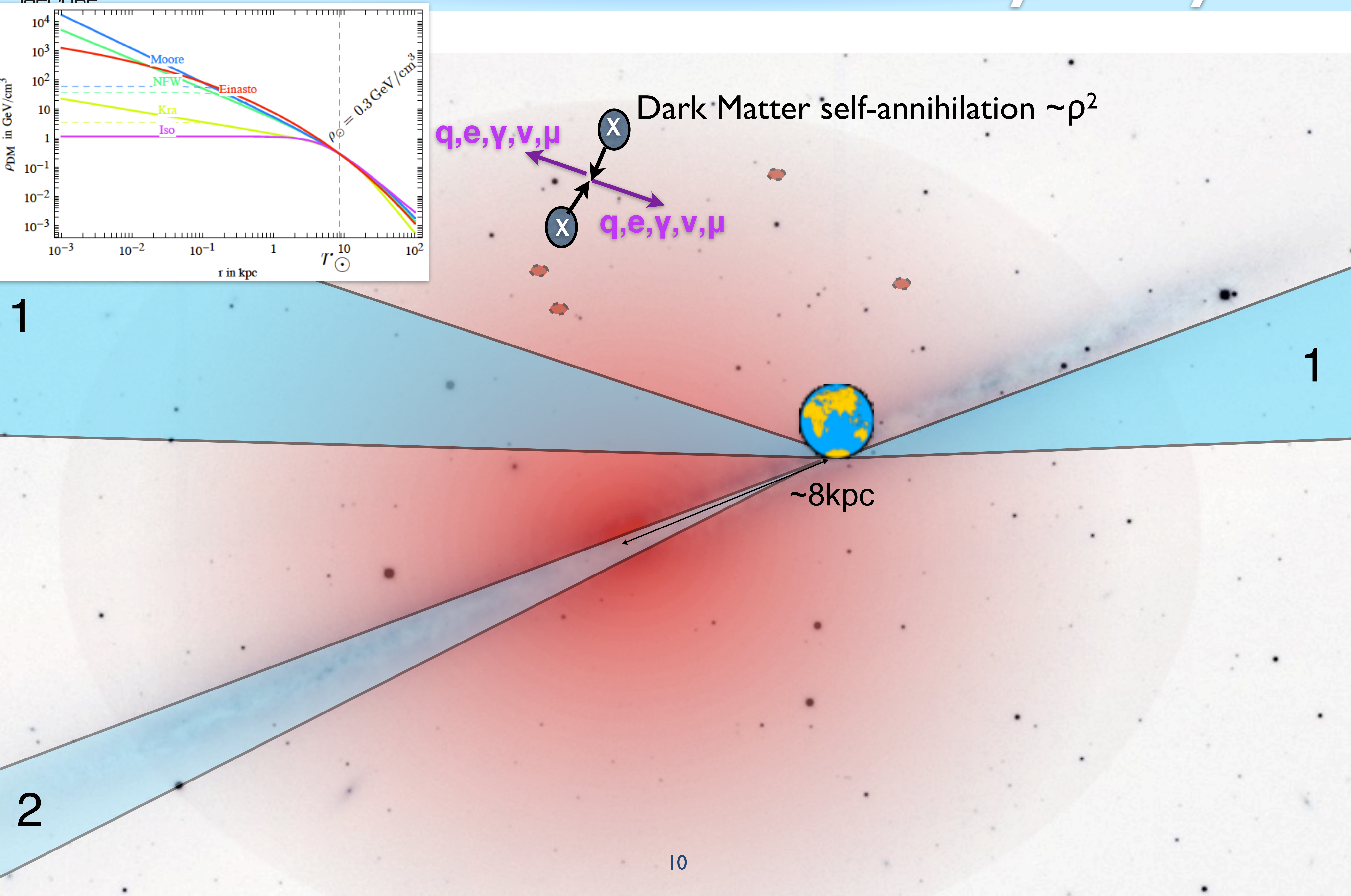


Dark Matter in the Milky Way

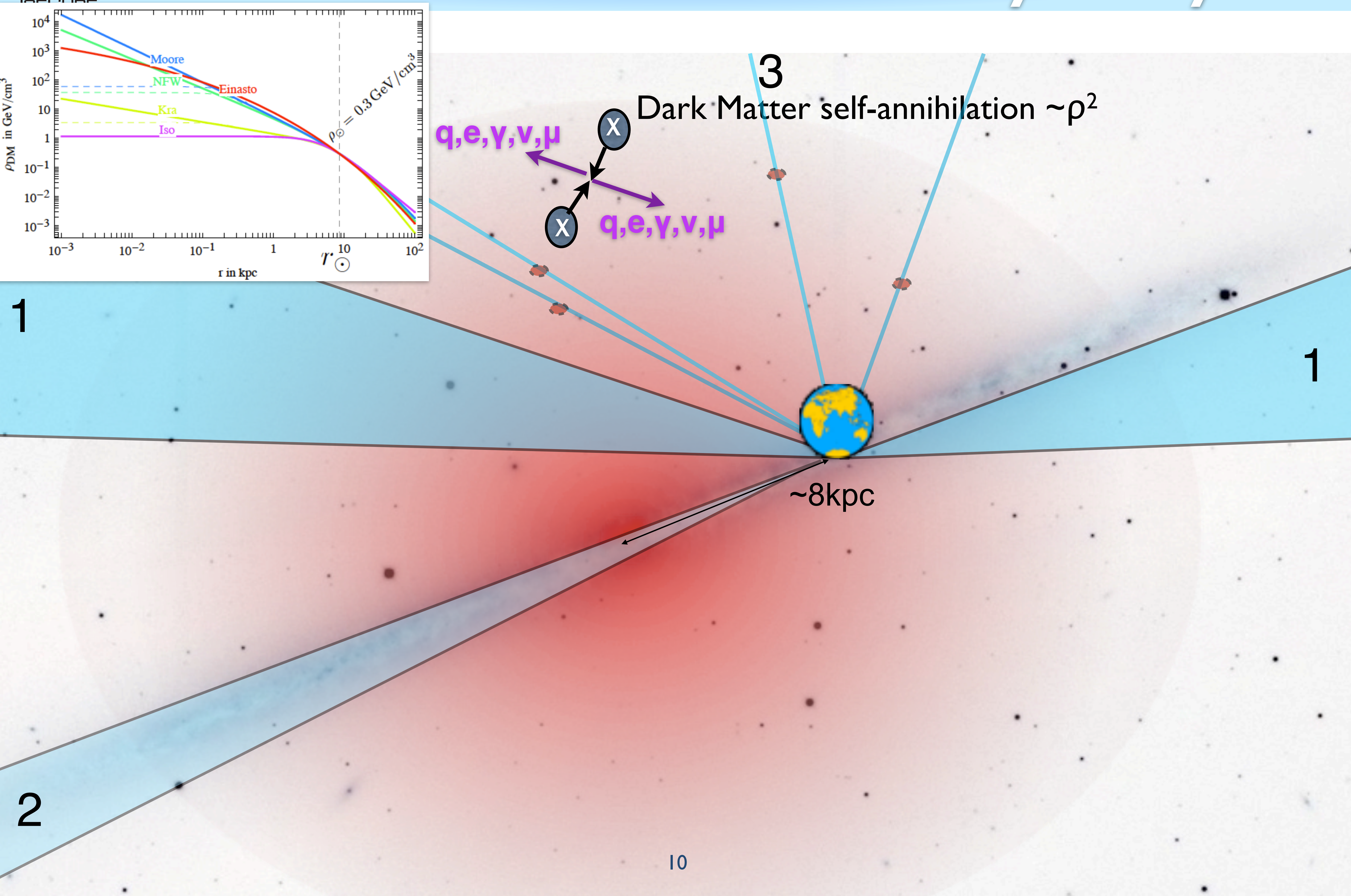




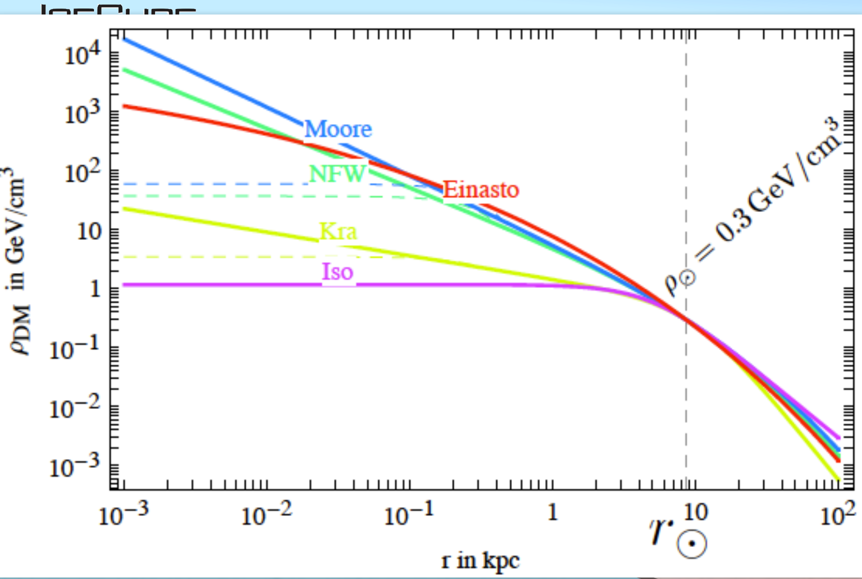
Dark Matter in the Milky Way

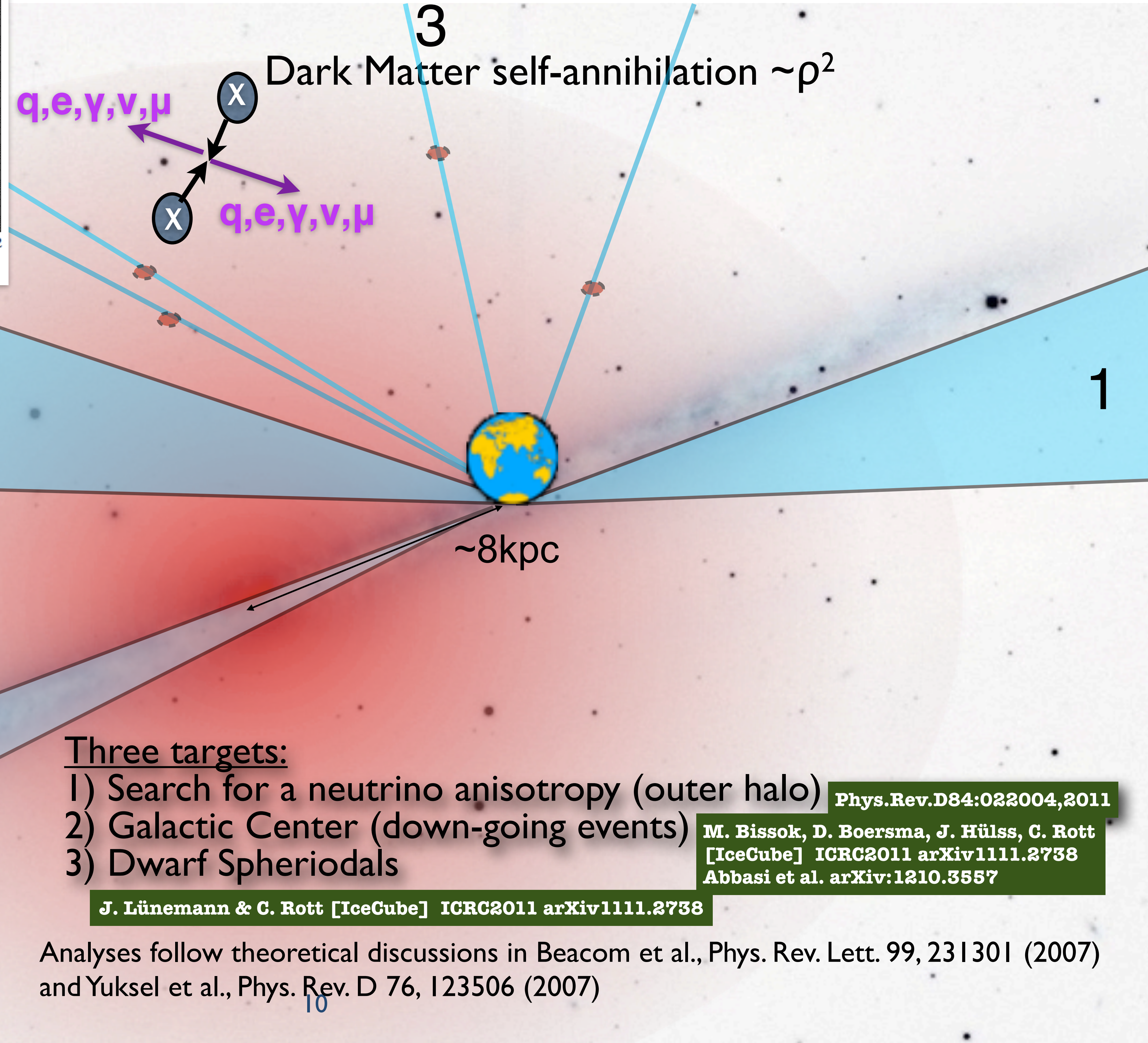


Dark Matter in the Milky Way



Dark Matter in the Milky Way





Three targets:

1) Search for a neutrino anisotropy (outer halo) **Phys.Rev.D84:022004,2011**

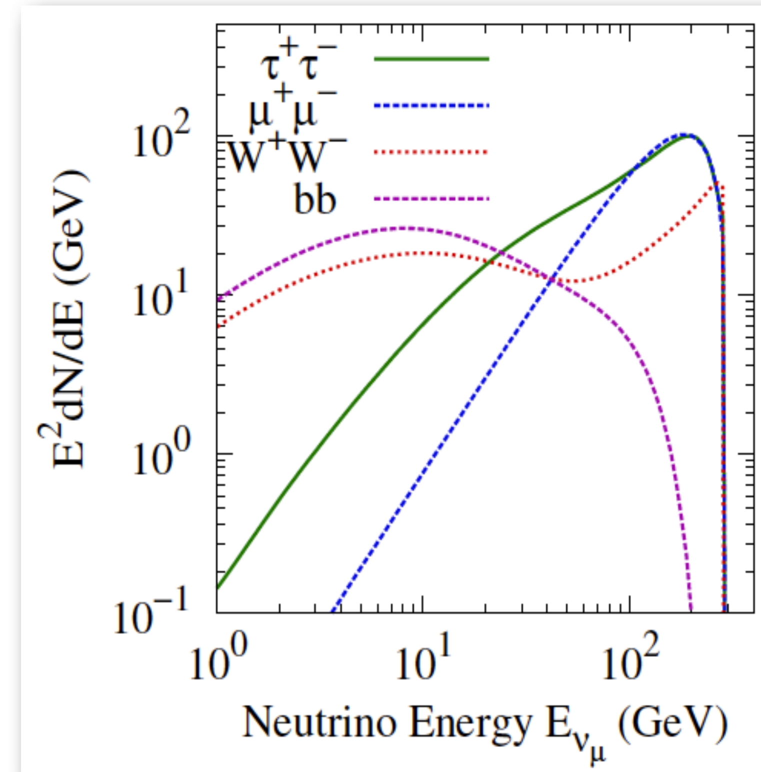
2) Galactic Center (down-going events) **M. Bissok, D. Boersma, J. Hülss, C. Rott [IceCube] ICRC2011 arXiv1111.2738 Abbasi et al. arXiv:1210.3557**

3) Dwarf Spheriodals

J. Lünemann & C. Rott [IceCube] ICRC2011 arXiv1111.2738

Analyses follow theoretical discussions in Beacom et al., Phys. Rev. Lett. 99, 231301 (2007) and Yuksel et al., Phys. Rev. D 76, 123506 (2007)

Dark Matter Annihilation



Measure Flux = **Particle Physics**

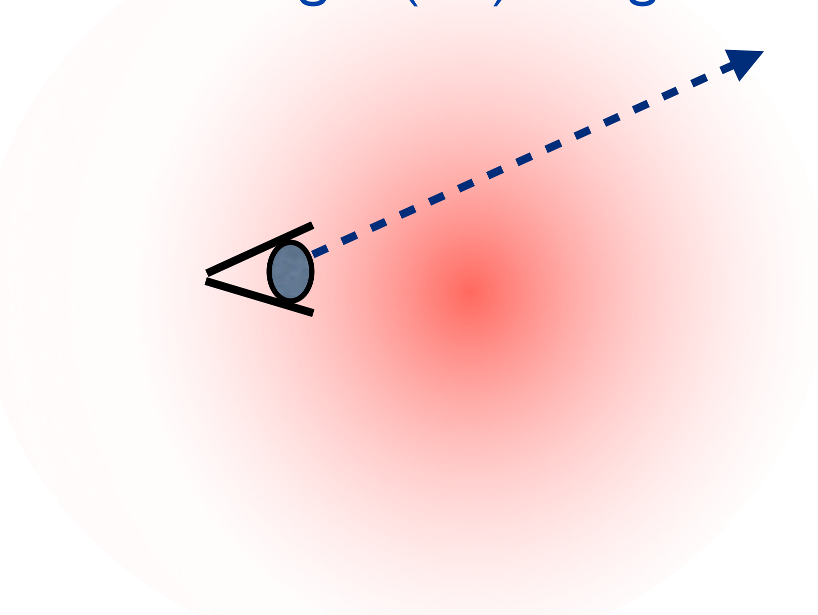
$$\frac{d\Phi}{dE}(E,\phi,\theta) = \frac{1}{4\pi}\frac{\langle\sigma_A v\rangle}{2m_\chi^2}\Sigma_f\frac{dN}{dE}B_f$$

x

Dark Matter Distribution

$$\int_{\Delta\Omega(\phi,\theta)} d\Omega' \int_{\mathrm{los}} \rho^2(r(l,\phi'))dl(r,\phi')$$

line of sight (los) integral

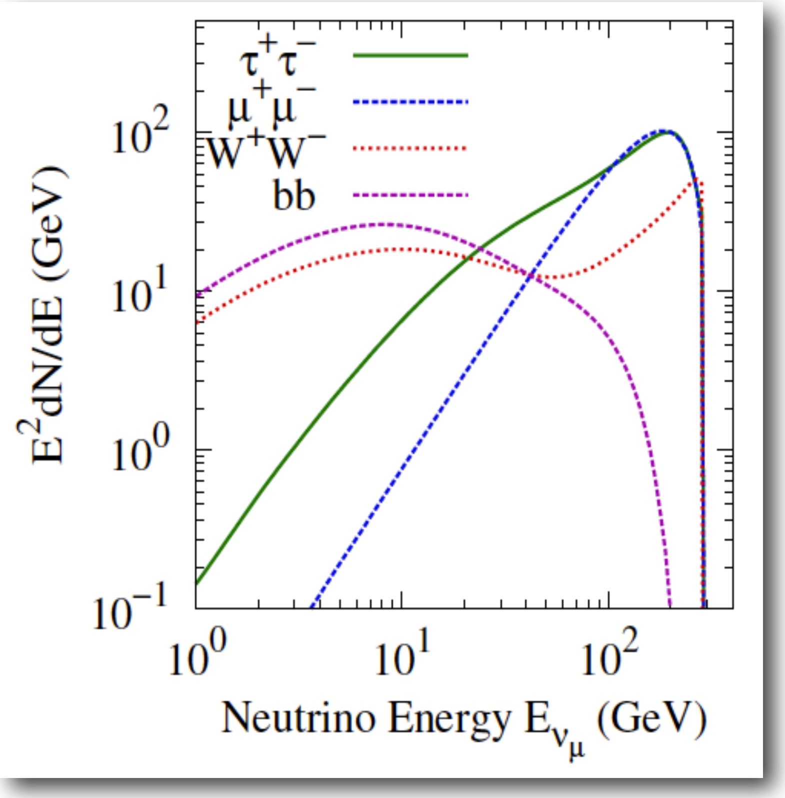


Dark Matter Annihilation

Measure Flux

$$\frac{d\Phi}{dE}(E,\phi,\theta) = \frac{1}{4\pi}\frac{\langle\sigma_A v\rangle}{2m_\chi^2}\Sigma_f\frac{dN}{dE}B_f$$

Particle Physics



x

Dark Matter Distribution

$$\int_{\Delta\Omega(\phi,\theta)} d\Omega' \int_{\text{los}} \rho^2(r(l,\phi'))dl(r,\phi')$$

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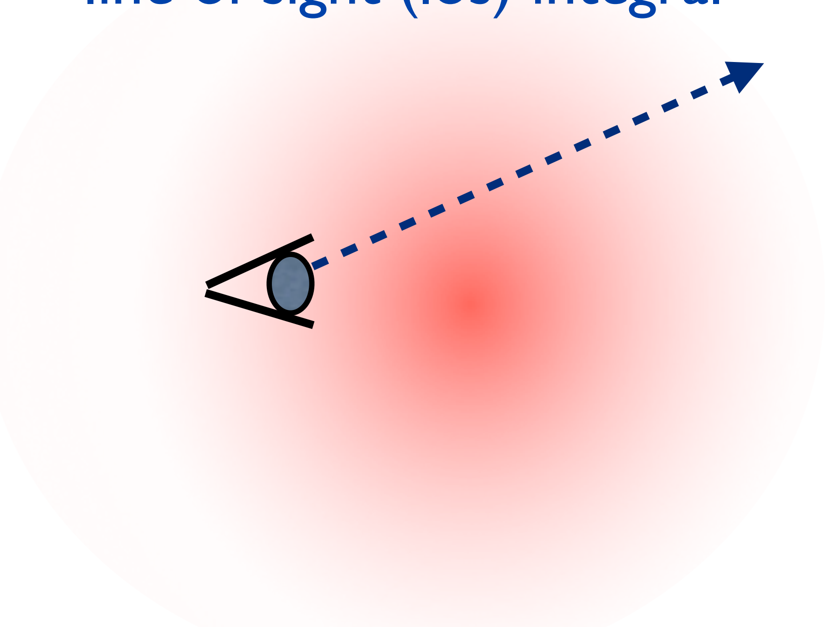
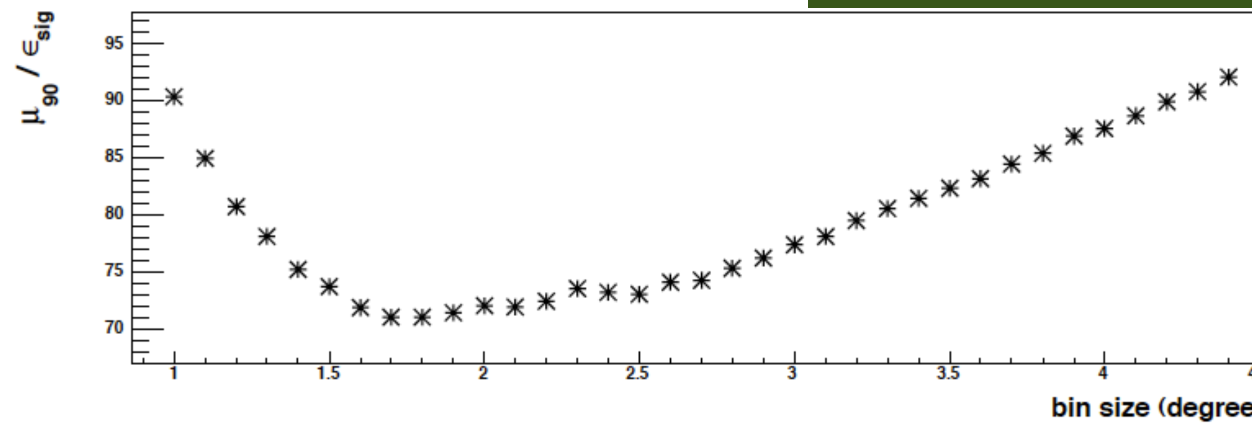


Dwarf Analysis

J. Luenemann & C.Rott ICRC2011
arXiv:1111.2738 [astro-ph.HE]

- Northern hemisphere well covered
- Well defined targets
- Can be regarded as point sources
- Dominated by few close objects
- Neutrino detectors continuously operating, but large effort for IACTs



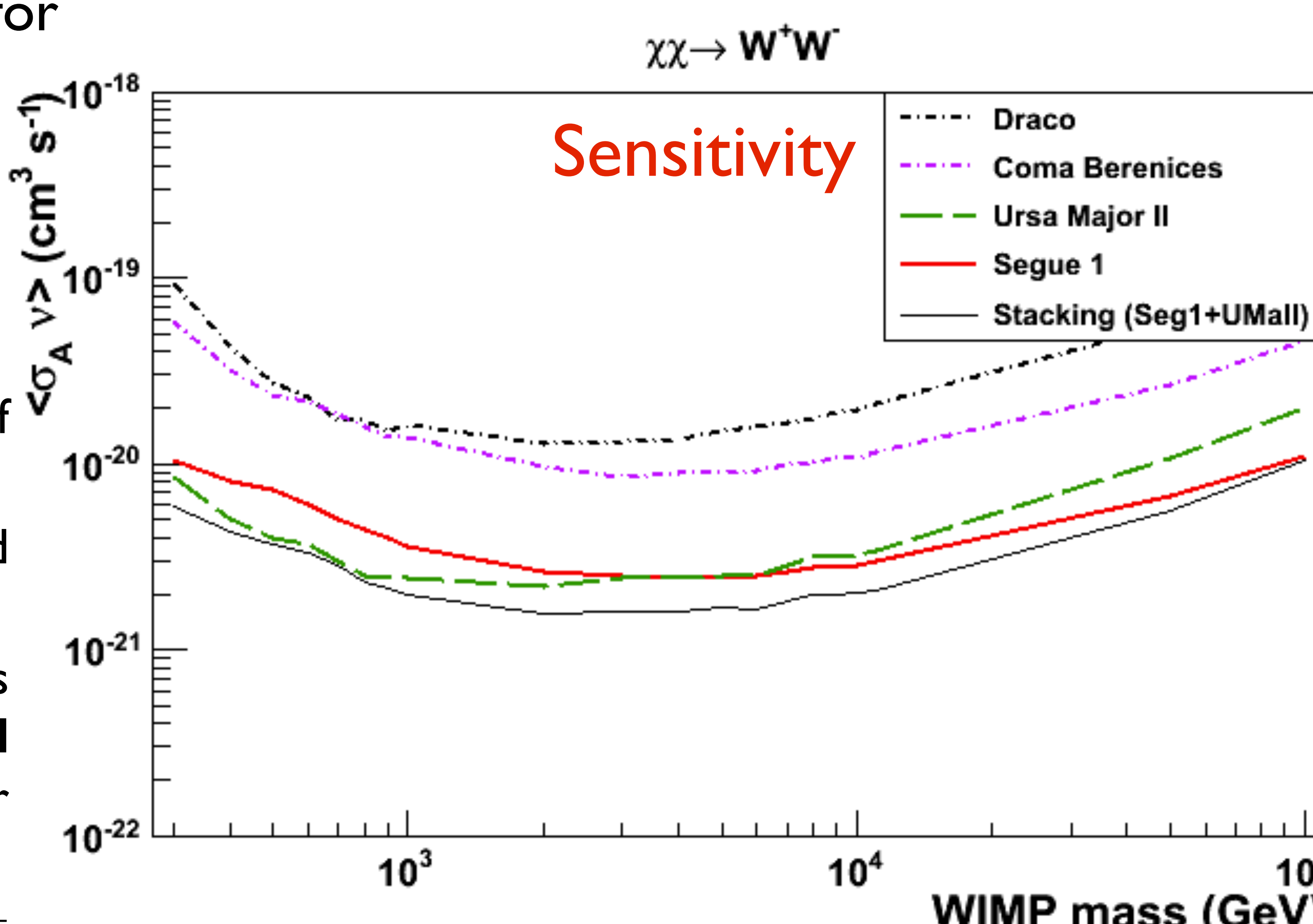
$$\frac{d\Phi_j(\Delta\Omega, E_j)}{dE_j} = \frac{\langle\sigma v\rangle}{2m_\chi^2}\frac{dN_j}{dE_j}J(\Delta\Omega)$$

J–factors from
Phys. Rev. Lett. 107, 241302 (2011)

Analysis performed with 340days of IceCube 59 string data

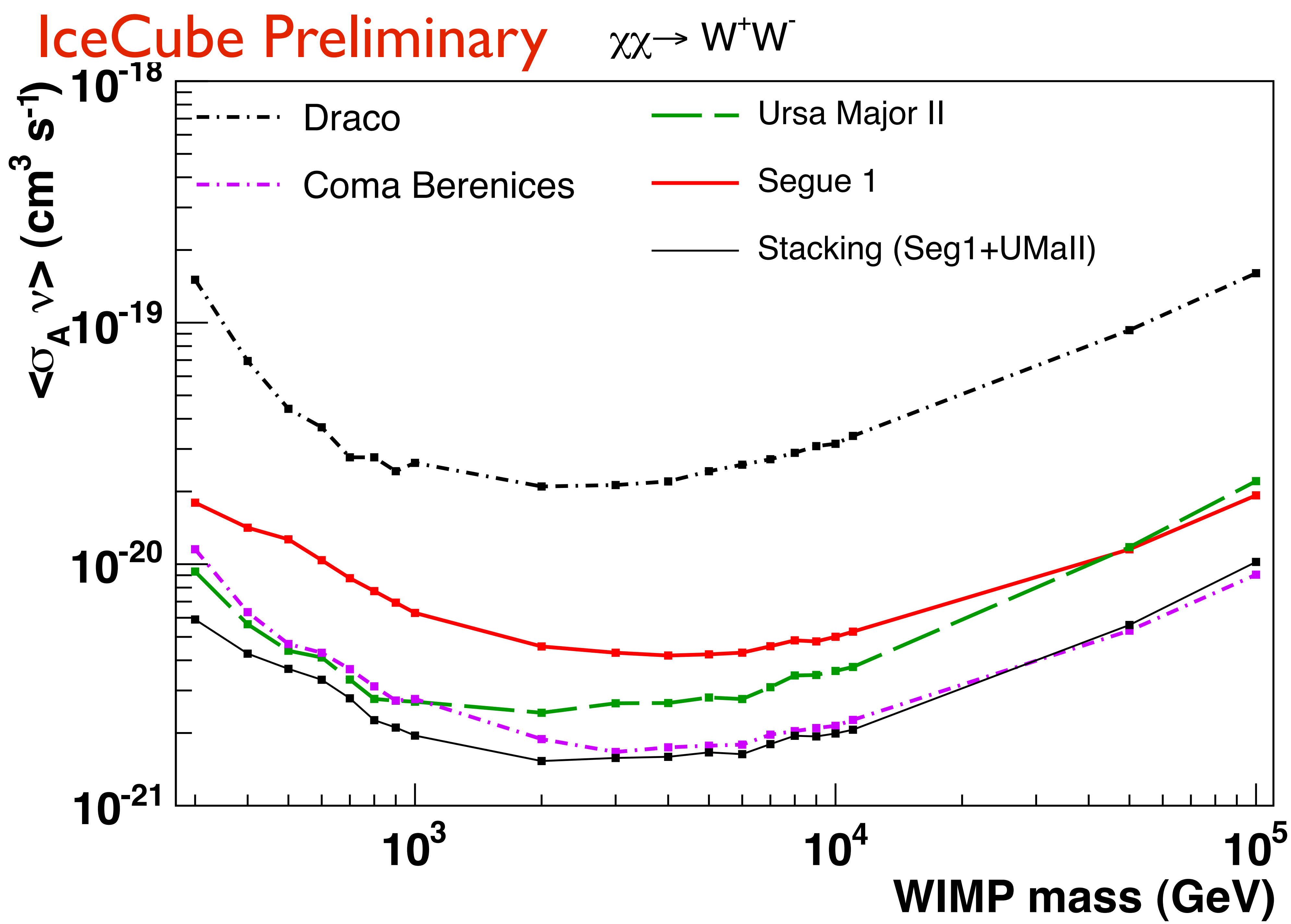
Event selection via Boosted Decision Tree

For robustness the search windows and cut values were **optimized for 5 TeV WIMPs** and used for all WIMP-masses.

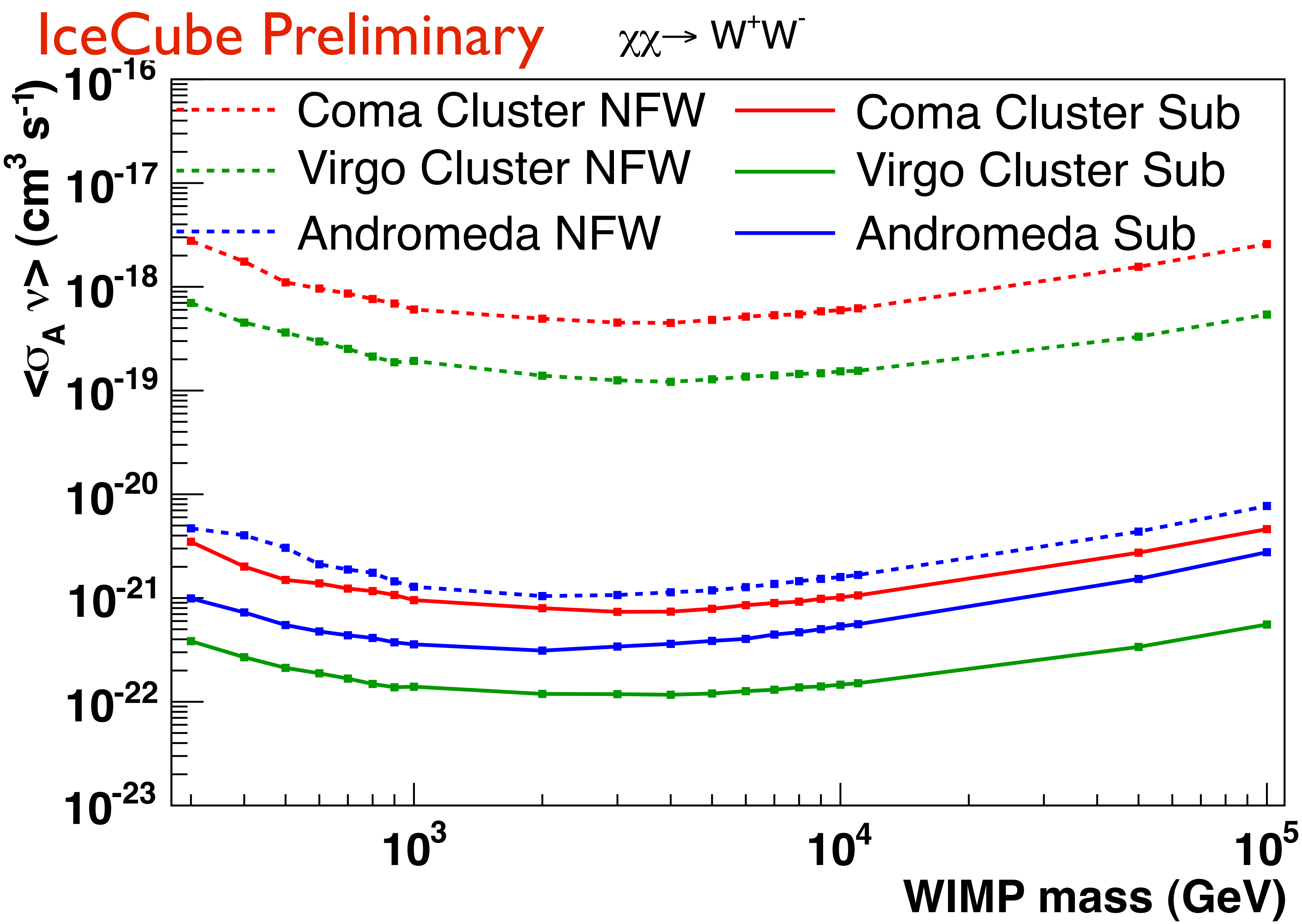


Dwarfs Limits

Limits computed at **90% C.L.** as function of WIMP mass assuming branching fraction of 100% WW and NFW profile



Clusters of Galaxies



J-factors from
Han et al. 1201.1003
Temple et al. 0707.4374

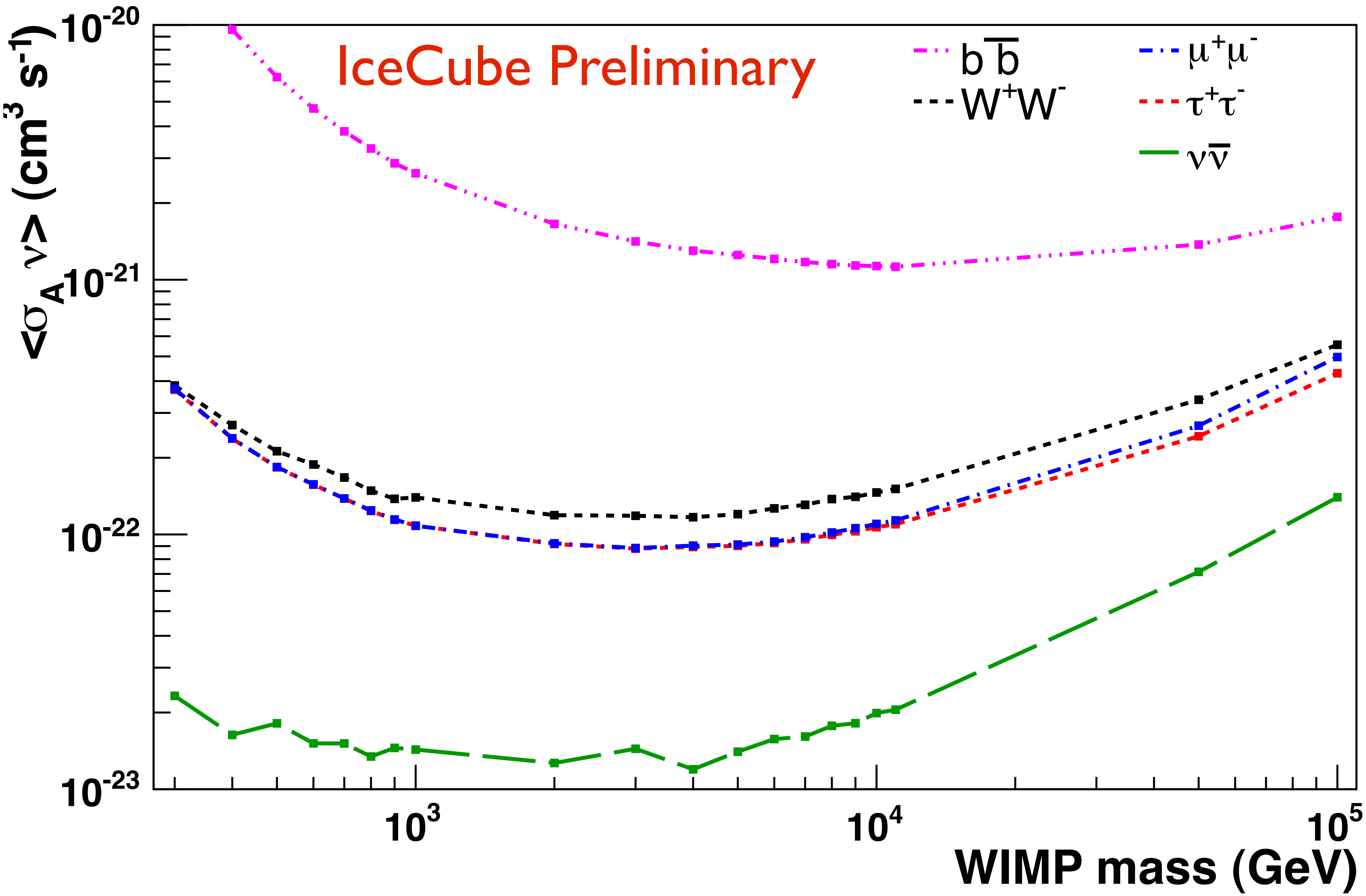
Extended sources

Optimized size of search window

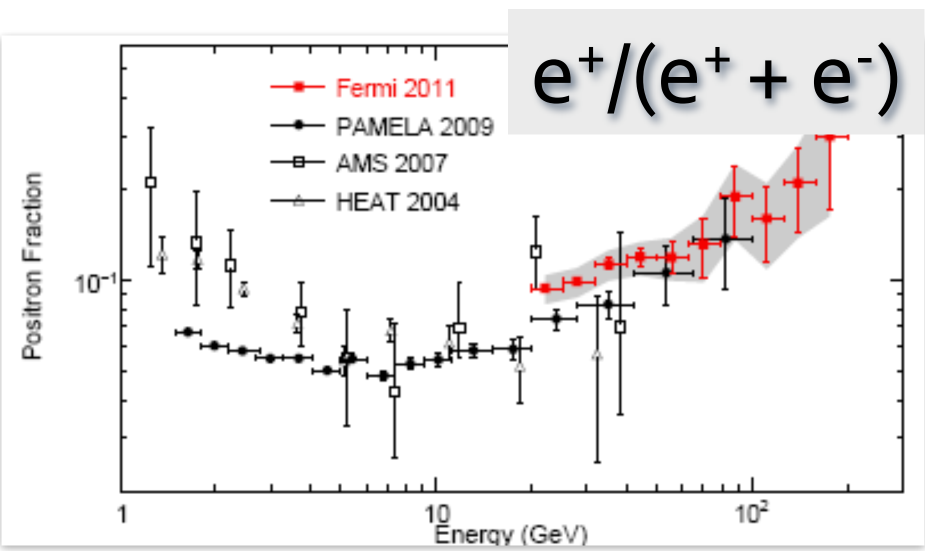
Substructures taken into account

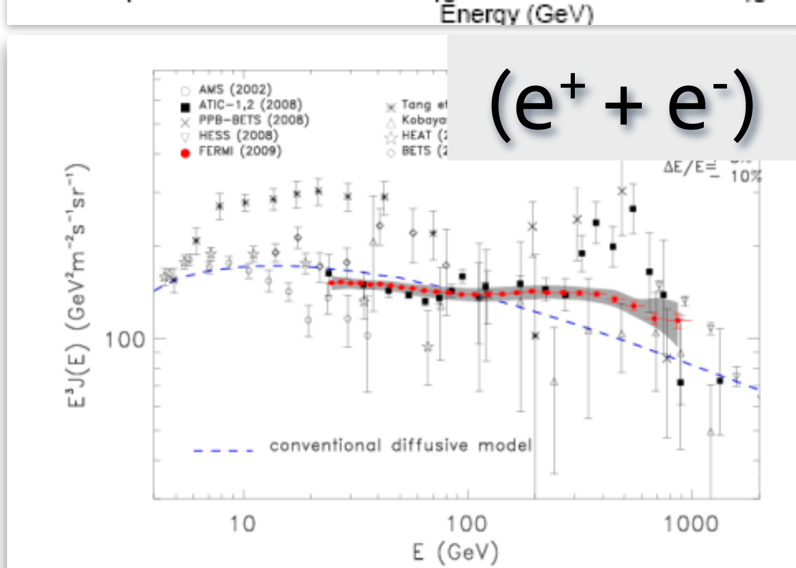
- Best Limit obtained for Virgo Cluster

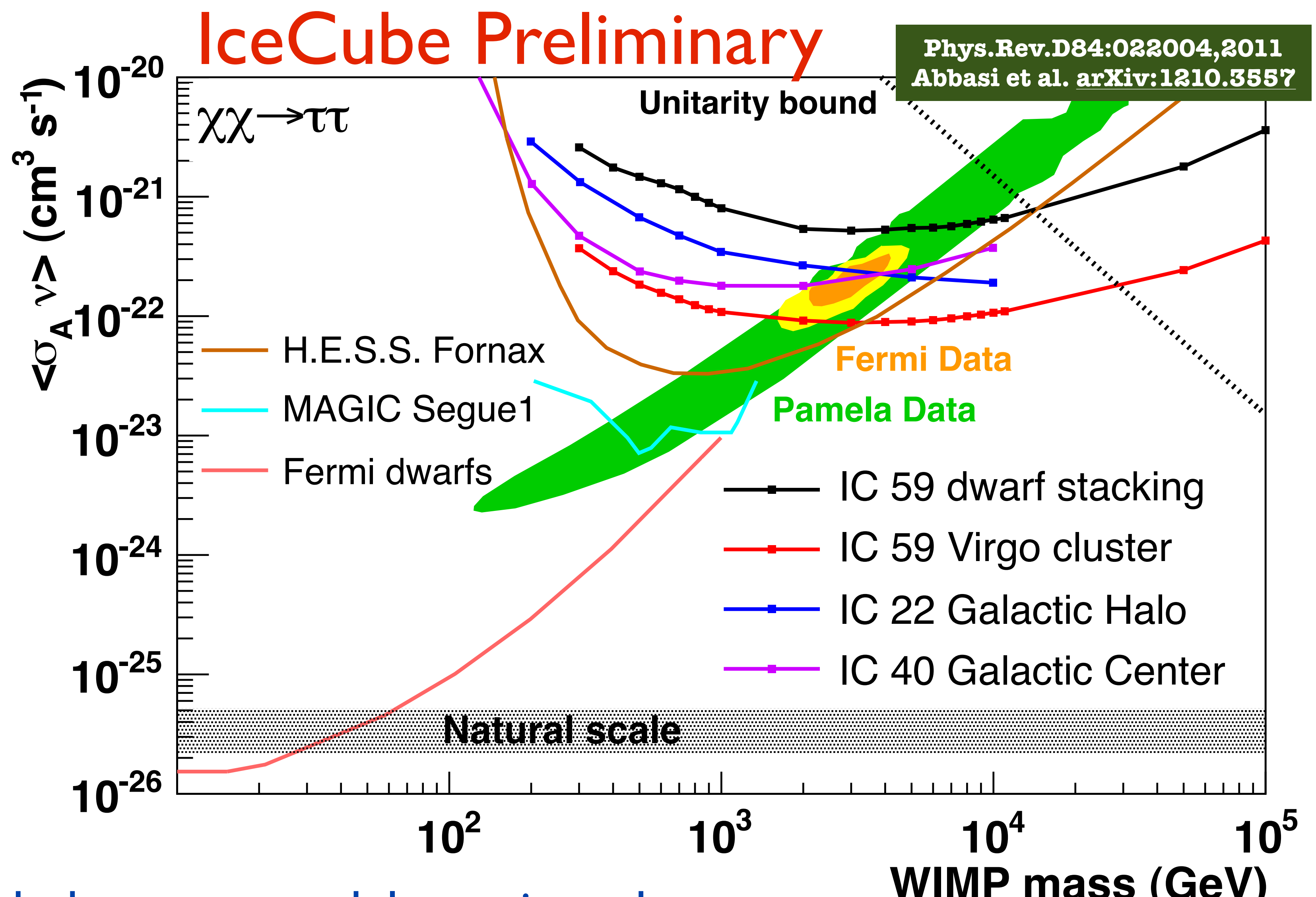
Virgo Cluster (with subclusters)



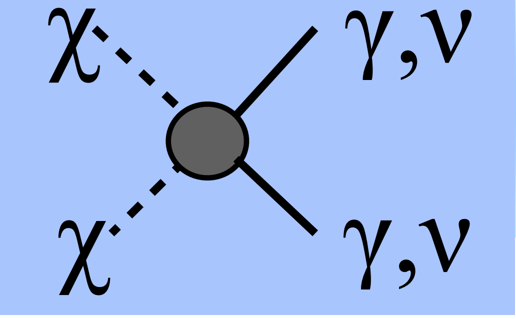
Results







Indirect searches / IceCube can test dark matter models motivated by PAMELA and Fermi-LAT electron data (e.g. Meade et al. 2008)



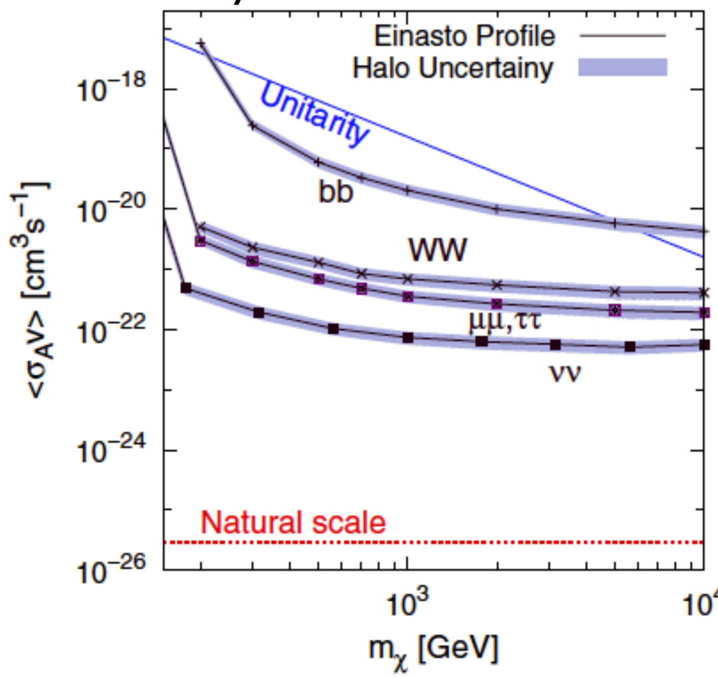
Neutrino Line Search

- Neutrinos set conservative upper limit on the total self-annihilation cross section using the line channel $\chi\chi \rightarrow \nu\nu$

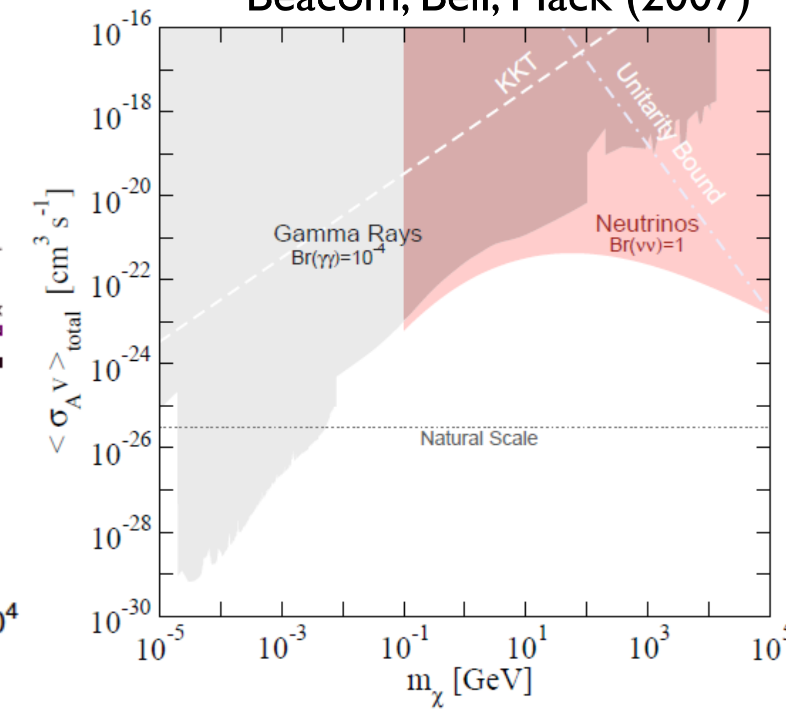
  Beacom, Bell, Mack (2007)

- IceCube has published limits for line channel for large WIMP masses m_χ
- $m_\chi \approx 100$GeV match well contained events in DeepCore

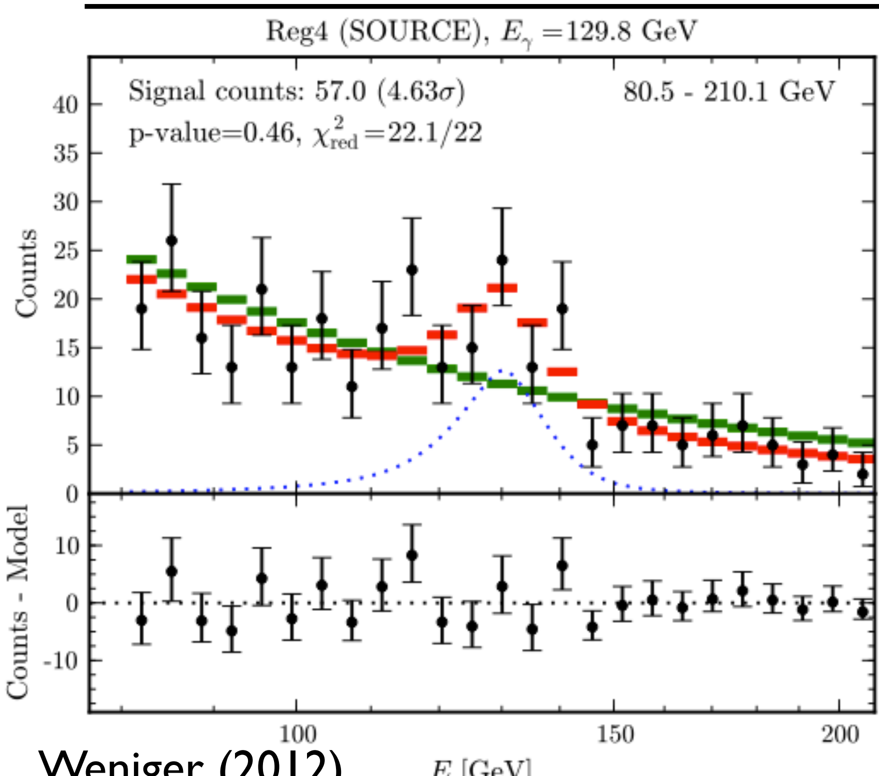
Phys.Rev.D84:022004,2011



Beacom, Bell, Mack (2007)

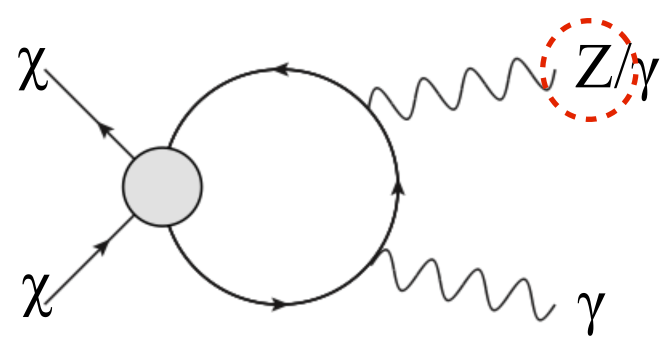


Neutrinos can also check predictions from gamma-ray lines:



Weniger (2012)

$$\langle\sigma v\rangle_{\gamma\gamma} \sim 10^{-27}\ \mathrm{cm}^3/\mathrm{s}$$

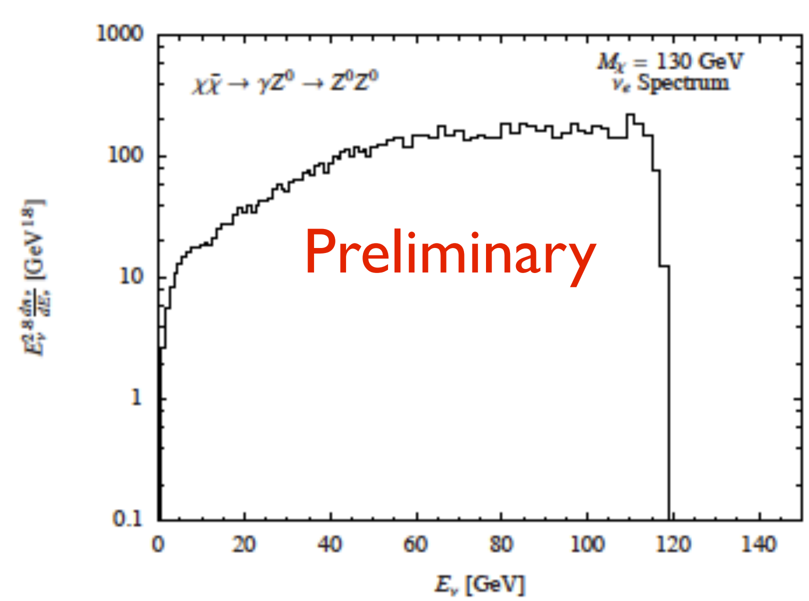


Cohen et al. arXiv:1207.0800v3

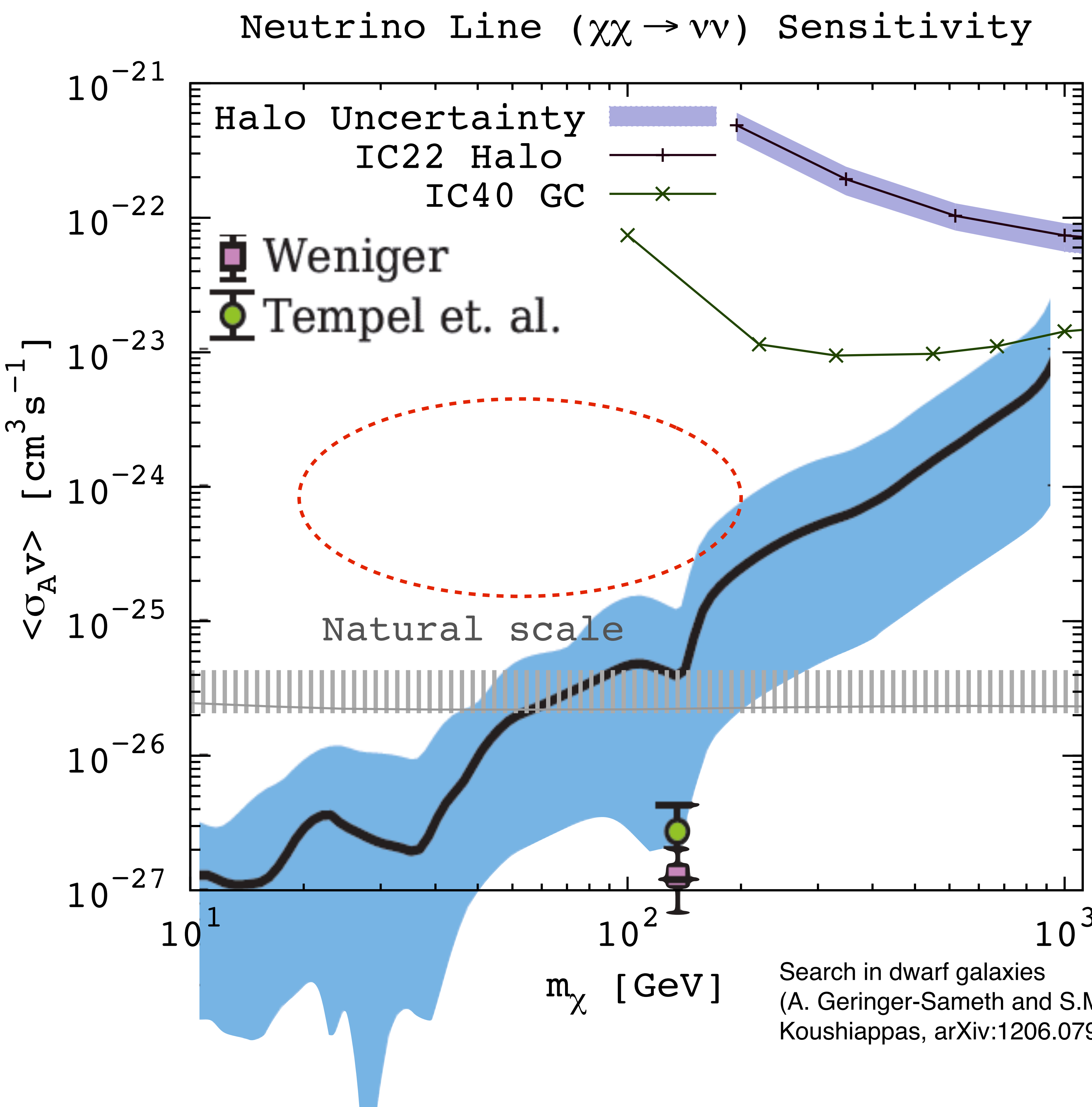
see talk by C.Weniger (this session)

Dedicated analysis focuses on Neutrino lines in the energy range 20-200GeV

A. Z^0Z^0 Channel



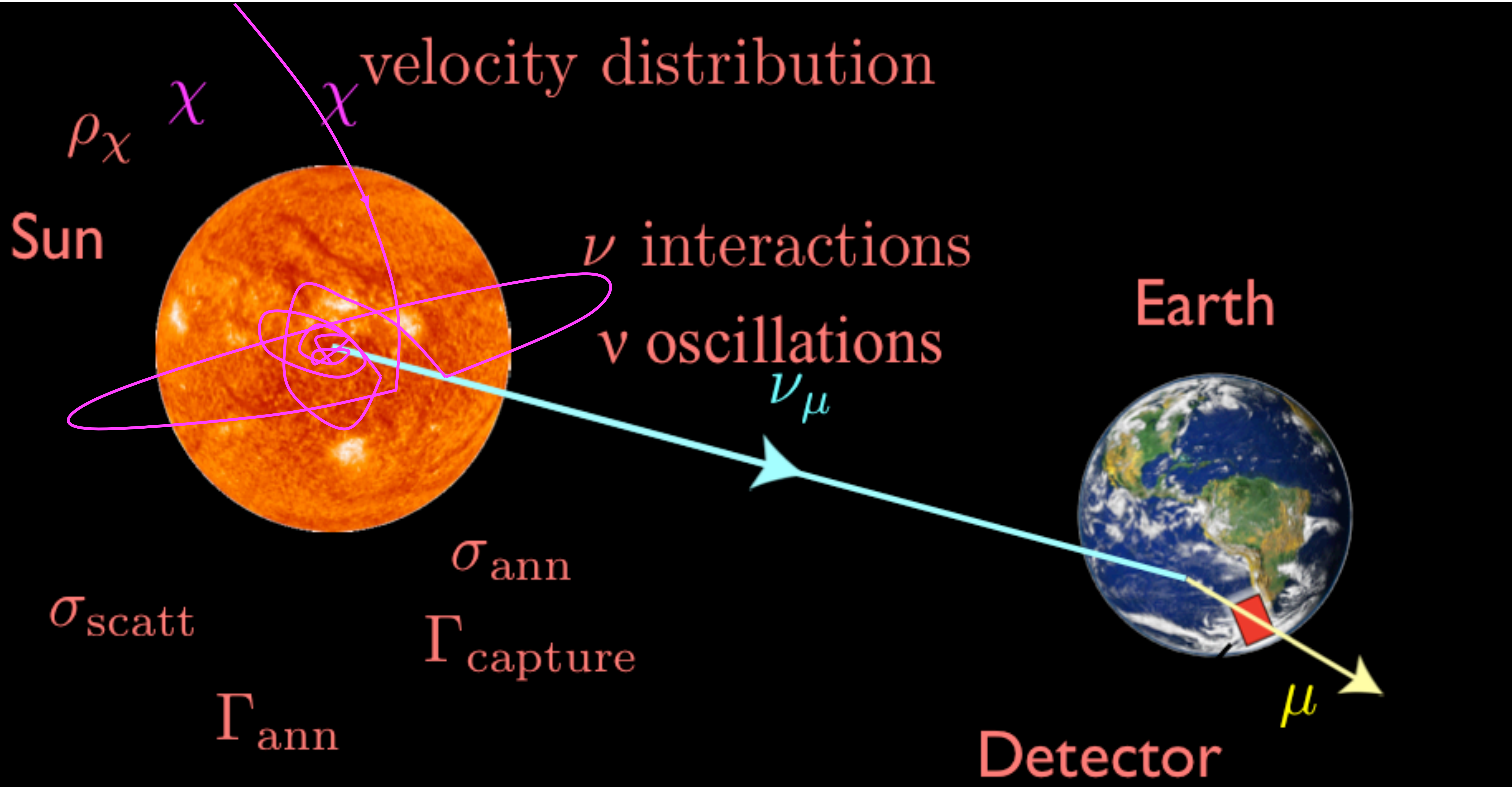
Neutrino lines



Search in dwarf galaxies (A. Geringer-Sameth and S.M. Koushiappas, arXiv:1206.0796)

Dark Matter in the Sun

Solar WIMP Signal



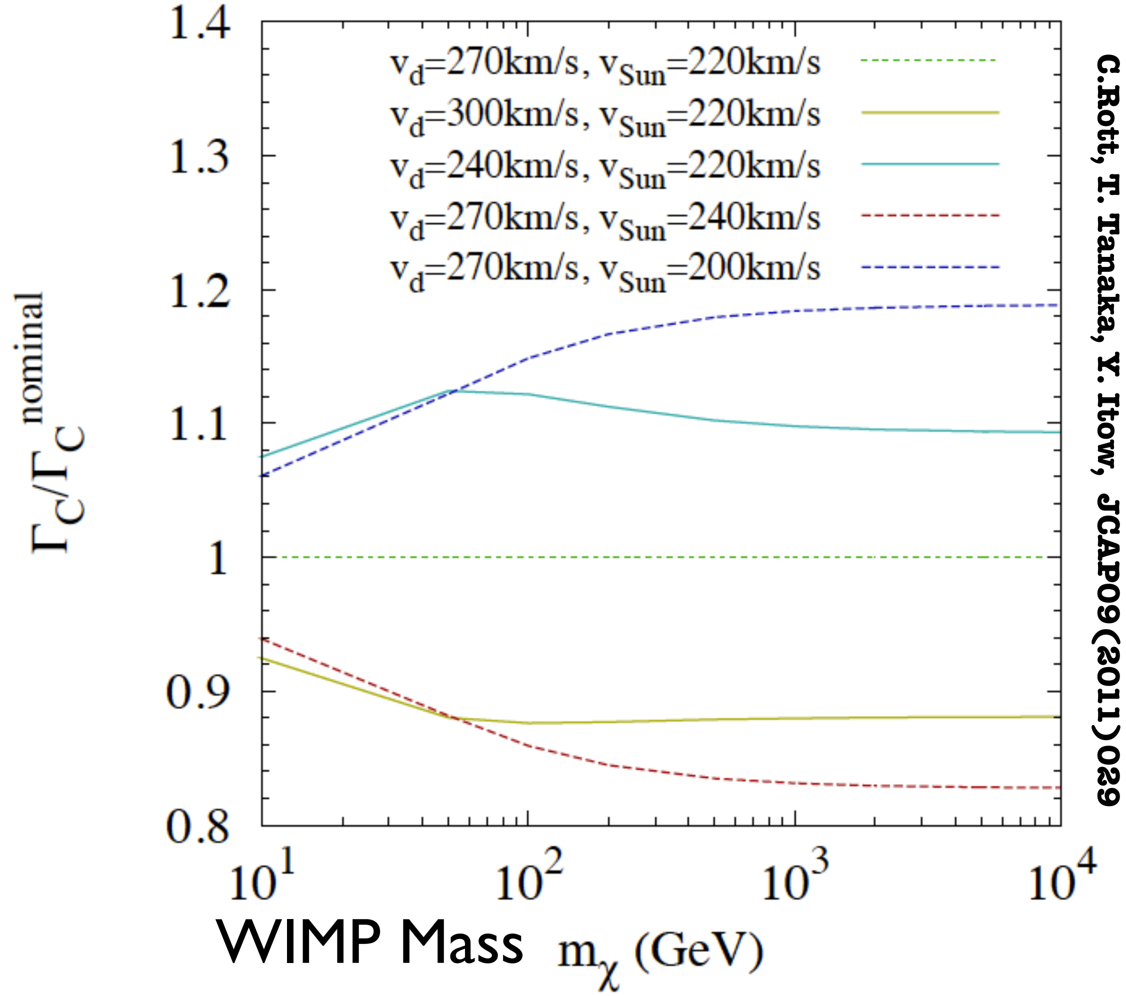
Freese '86
Krauss, Srednicki & Wilczek '86
Gaisser, Steigman & Tilav '86

Silk, Olive and Srednicki '85
Gaisser, Steigman & Tilav '86

Solar WIMP Capture

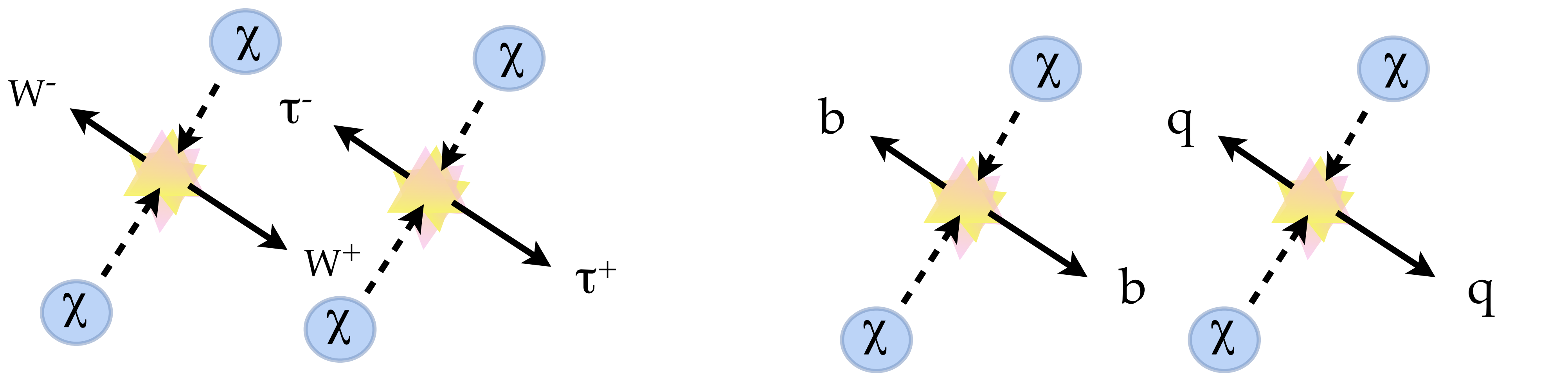
- WIMPs can get gravitationally captured by the Sun
  - Capture rate, Γ_C ,depends on WIMP-nucleon scattering cross section
- Dark Matter accumulates and starts annihilating
  - → Only neutrinos can make it out
- Equilibrium: The capture rate regulates the annihilation rate ($\Gamma_A=\Gamma_C/2$)
  - The neutrino flux only depends on the WIMP-Nucleon scattering cross section

Effect on Capture Rate Γ_C



Astrophysical uncertainties well under control + use conservative local dark matter density (0.3GeV/cm³) in our analysis

Dark Matter Annihilation in the Sun



high energy neutrinos from annihilation / decay products

$\nu\nu$ $W^- W^+$ $\tau^- \tau^+$ bb qq e^+e^-

highest energy neutrinos

fewest neutrinos

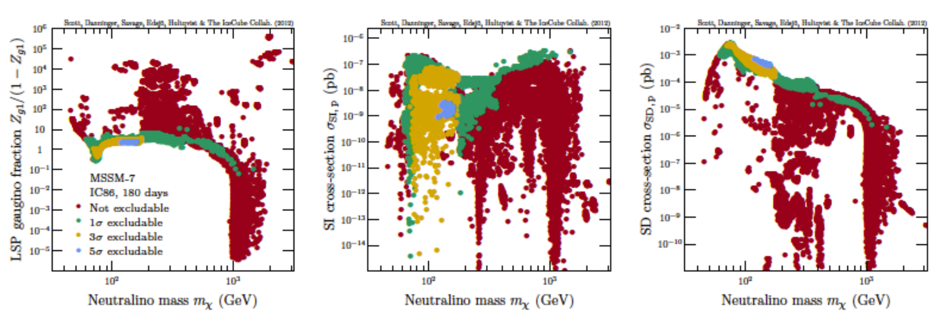
Benchmarks
Br 100%

Hard channel

Soft channel

Specific Model

$$\mathcal{L}_{\text{total}}(n_{\text{tot}}, \Xi|\psi) = \mathcal{L}_{\text{num}}(n_{\text{tot}}|\psi) \prod^{n_{\text{tot}}} \mathcal{L}_{\text{ang},i}(\phi'_i|\psi)\, \mathcal{L}_{\text{spec},i}(N_i|\psi)$$



see: Scott, Savage, Edsjo and IceCube Collaboration "Use of event-level neutrino telescope data in global fits for theories of new physics" arXiv1207.0810

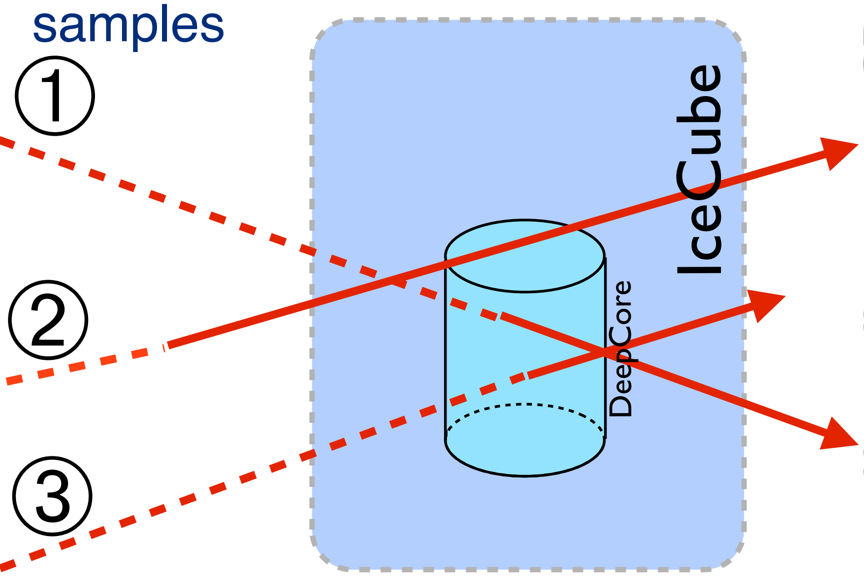
low energy neutrinos from hadronic shower

see: Rott, Siegal-Gaskins, Beacom arXiv1208.0827

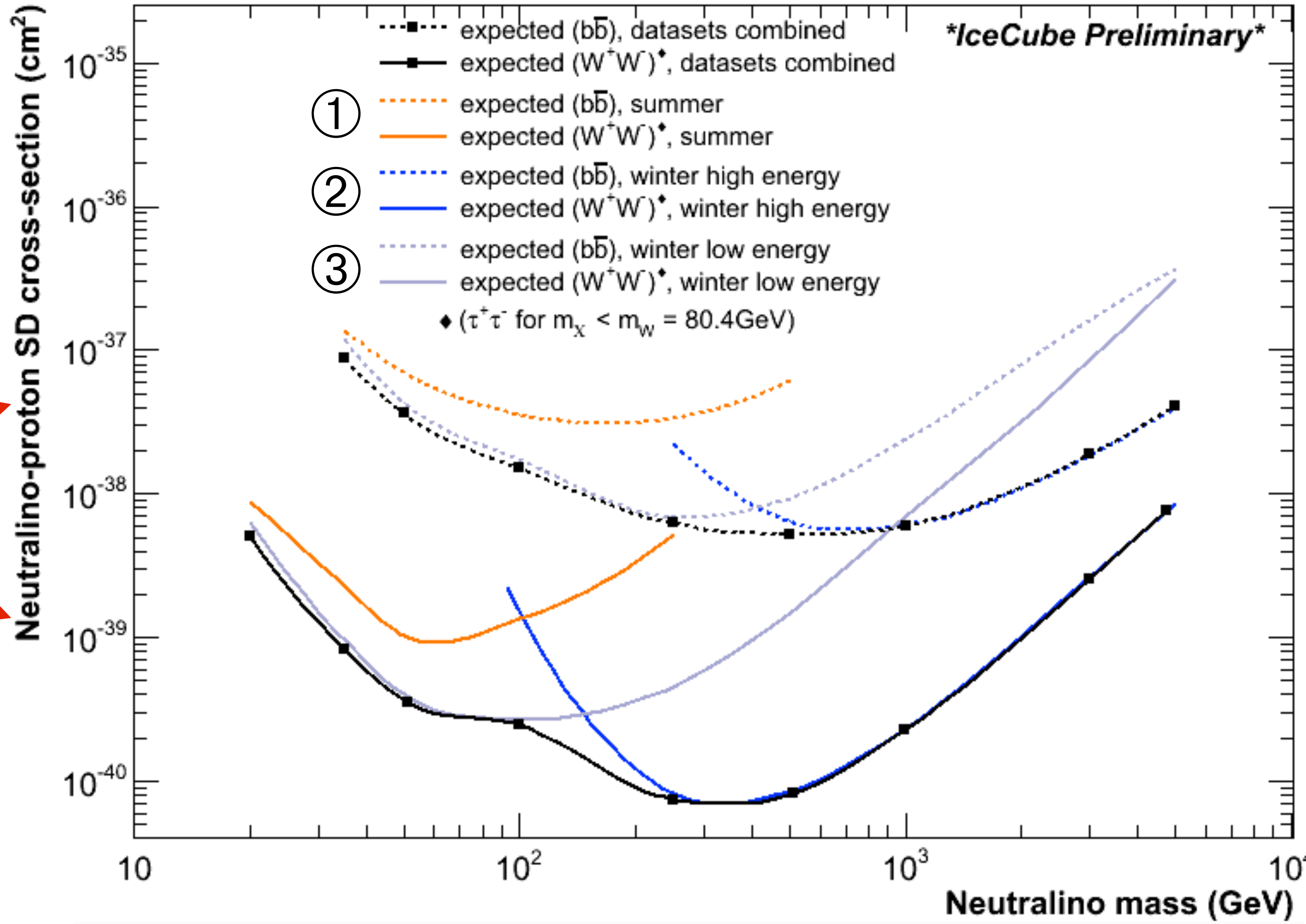
DeepCore Solar WIMP Sensitivity

IceCube 79-string 318days (May 2010 - May 2011)

Analysis performed separately for austral summer (Sun above horizon) and austral winter (Sun below horizon) - 3 independent samples



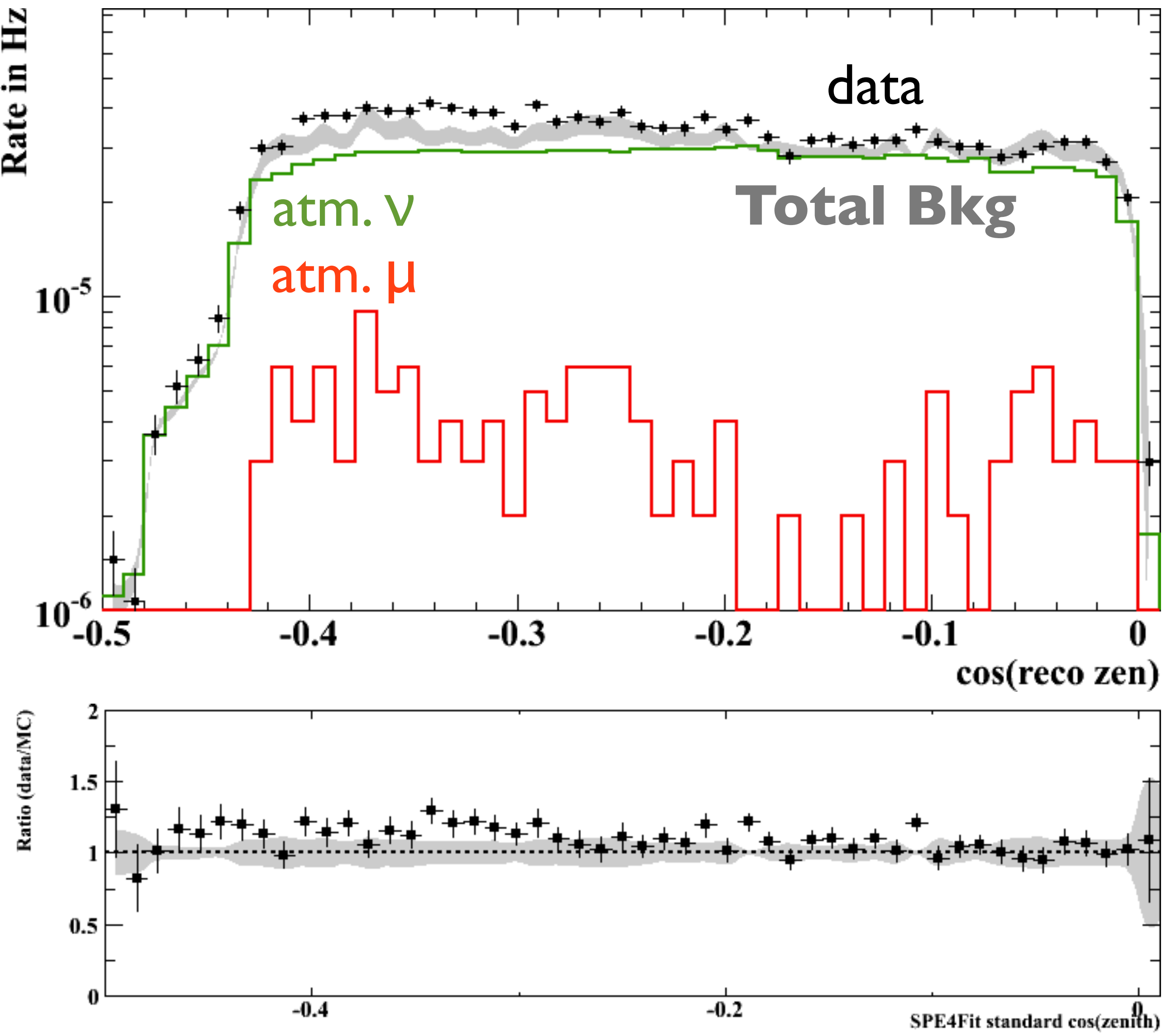
Compare distribution of the final sample to these PDFs of background and signal to determine most likely signal content and combine likelihoods, weighted by relative livetime



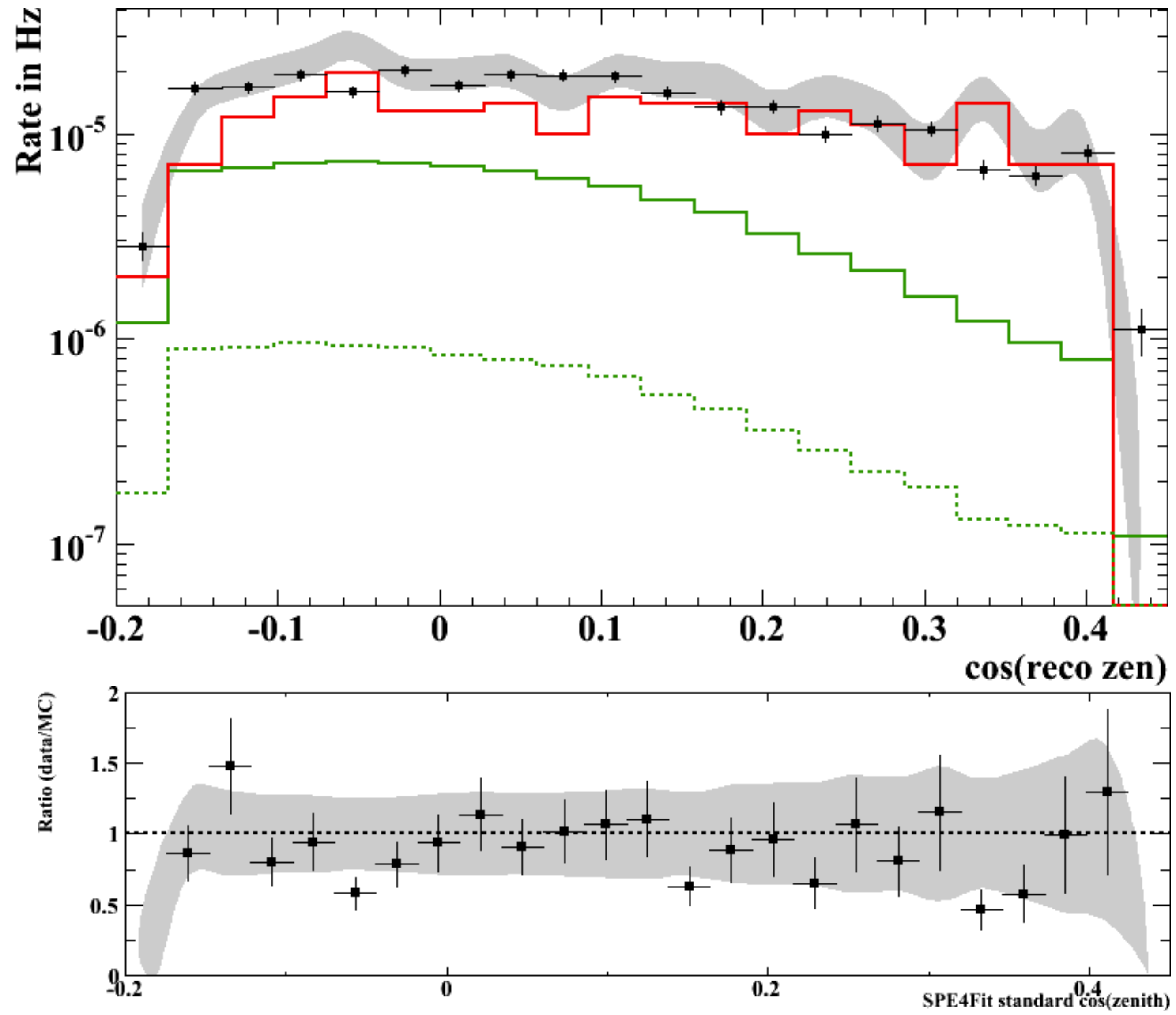
$$\mathcal{L}(\mu) = \prod_i^{n_{obs}} f(\Psi_i|\mu), \quad \text{where} \quad f(\Psi|\mu) = \frac{\mu}{n_{obs}} f_s(\Psi) + (1 - \frac{\mu}{n_{obs}}) f_{bg}(\Psi)$$

IC79 Solar WIMP

② Event Selection (Winter, High energy, 151days)



① Event Selection (Summer, Low energy, 166days)



- Event selection with separate Boosted Decision Tree (BDT)
- Training on off-source data + signal simulation
- Optimized final cut on BDT output
  - run llh-analysis for various selection criteria to determine best sensitivity

IC79 Solar WIMP

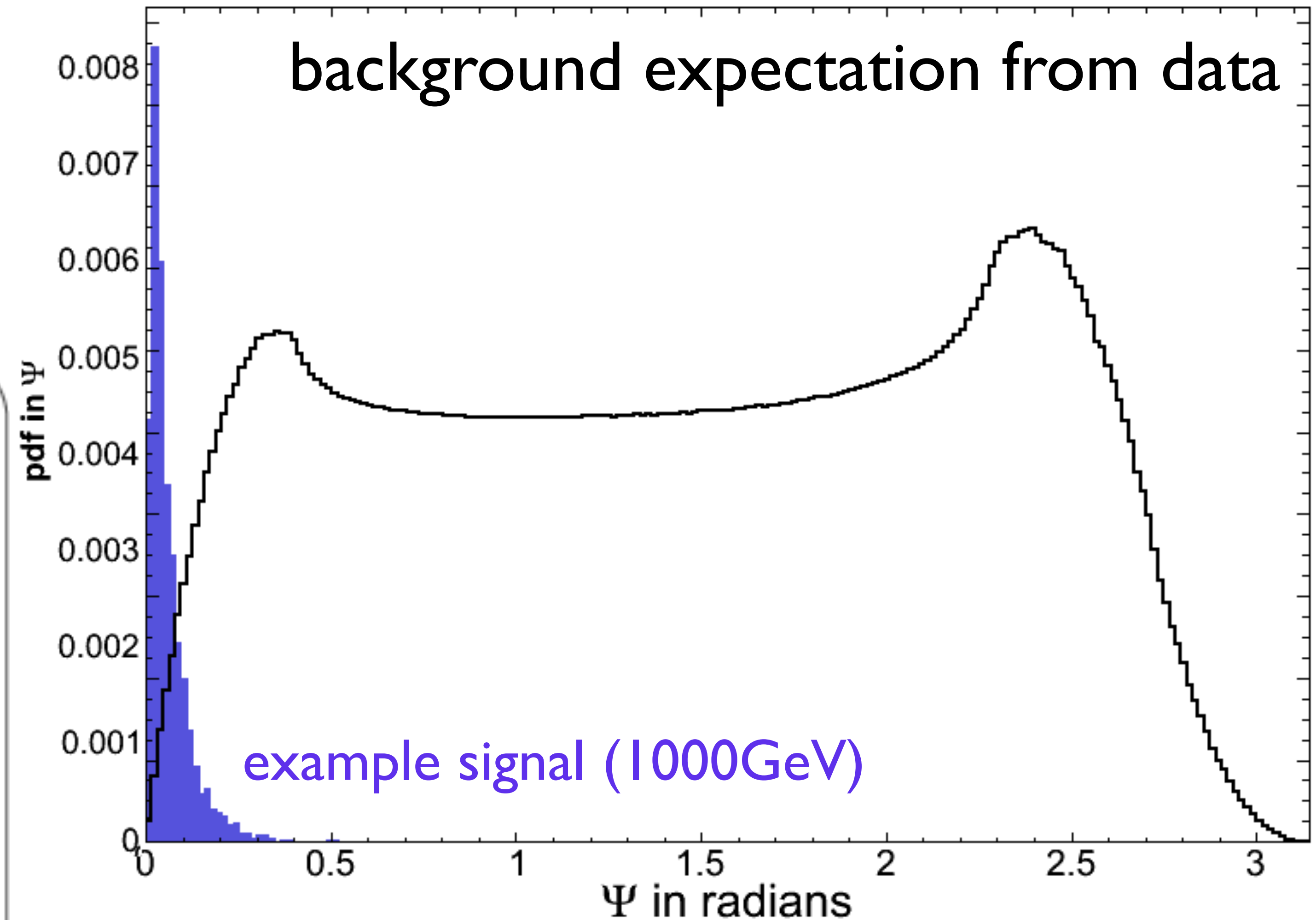
The observed angle to the Sun is fitted with *signal* and *background* pdf:s

How many signal events can be consistent with the *observation*?

Evaluate shape fit with log-likelihood rank (Feldman-Cousins) to construct confidence regions for the number of signal events μ_s

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

where ***L*** is the pdf product over the final sample



Angle between event track and direction from the Sun

$$\mu_j = \mu \frac{T^j_{\text{live}} V^j_{\text{eff}}}{T^1_{\text{live}} V^1_{\text{eff}} + T^2_{\text{live}} V^2_{\text{eff}}}$$

IC79 Solar WIMP

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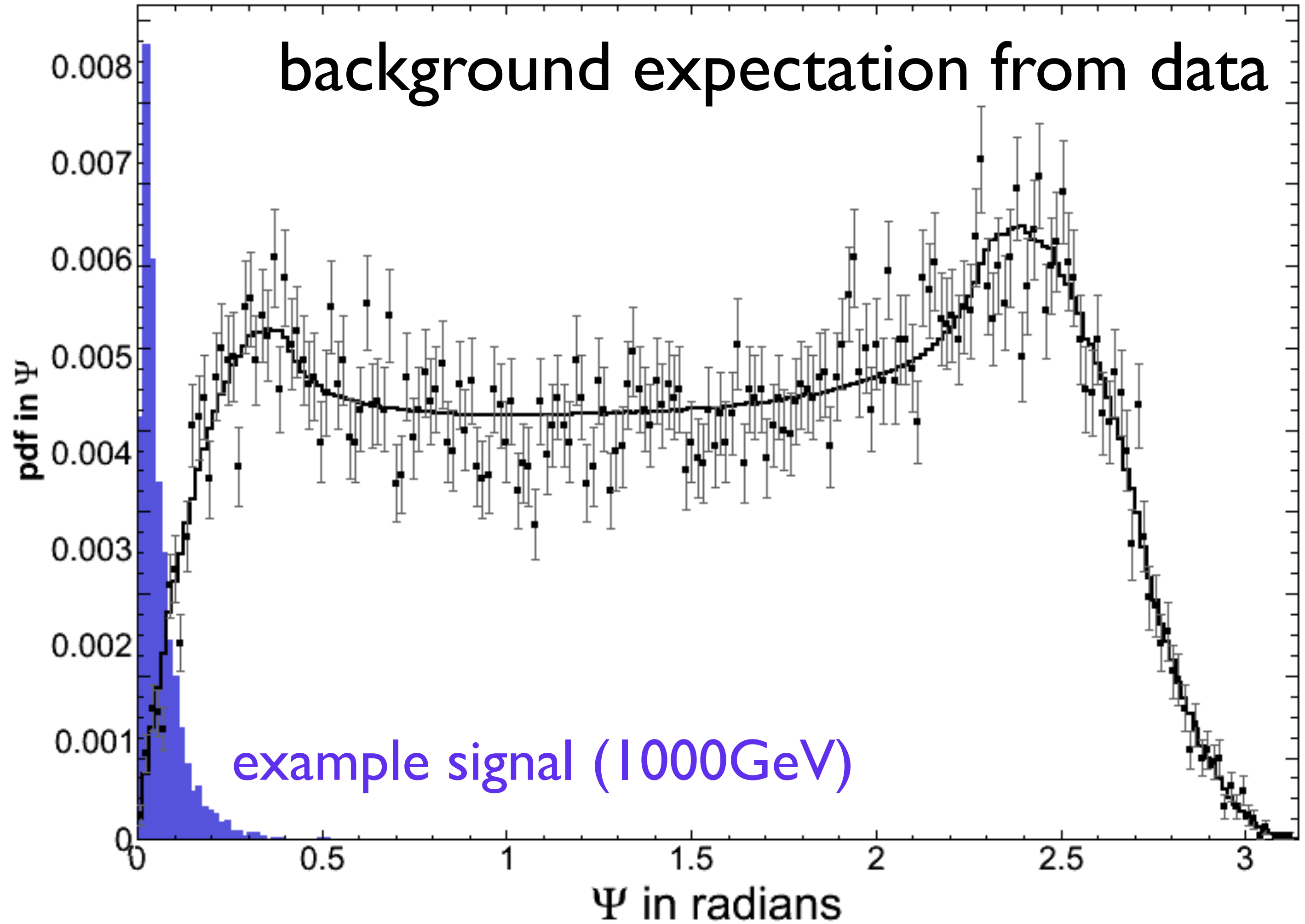
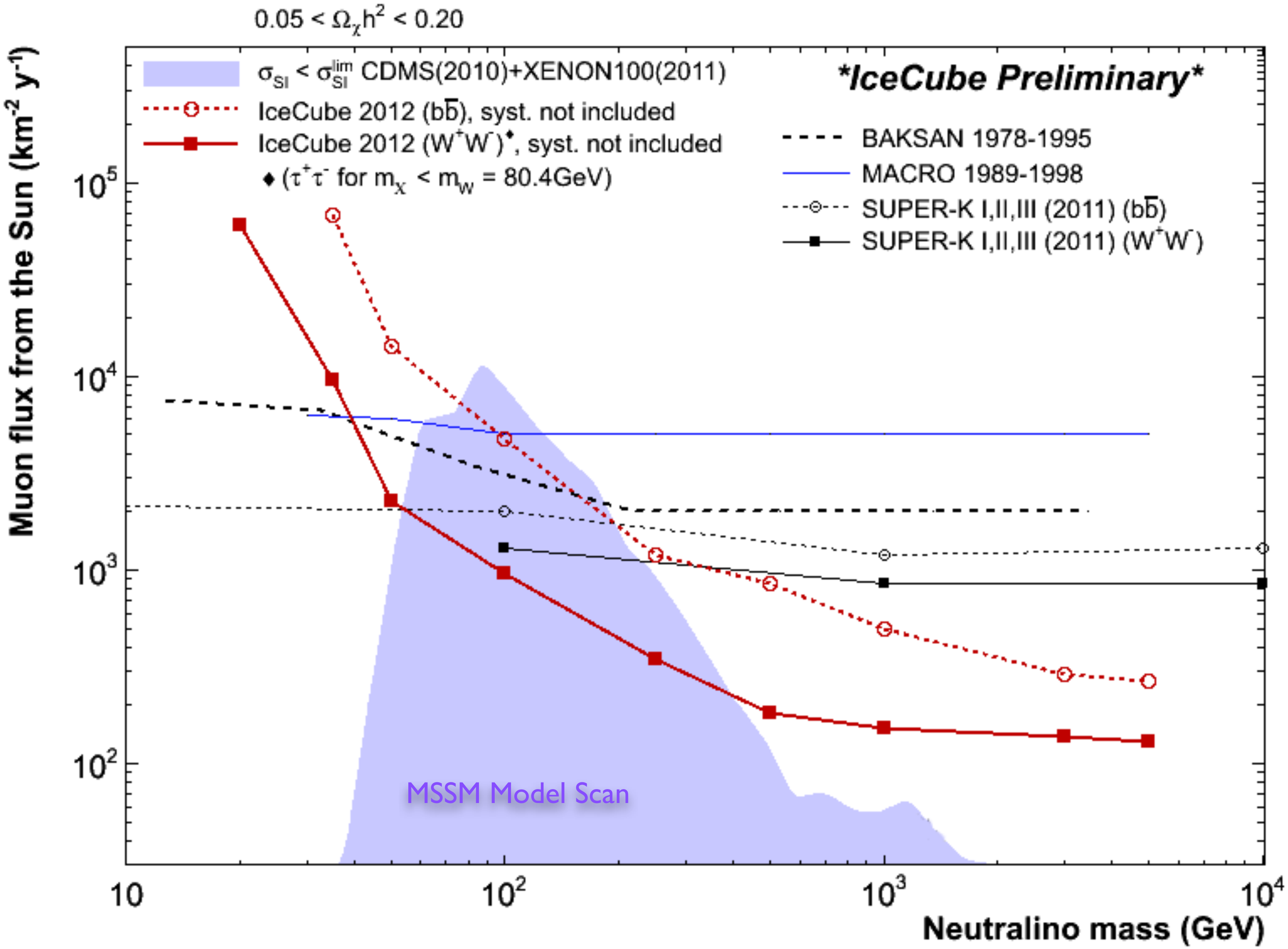


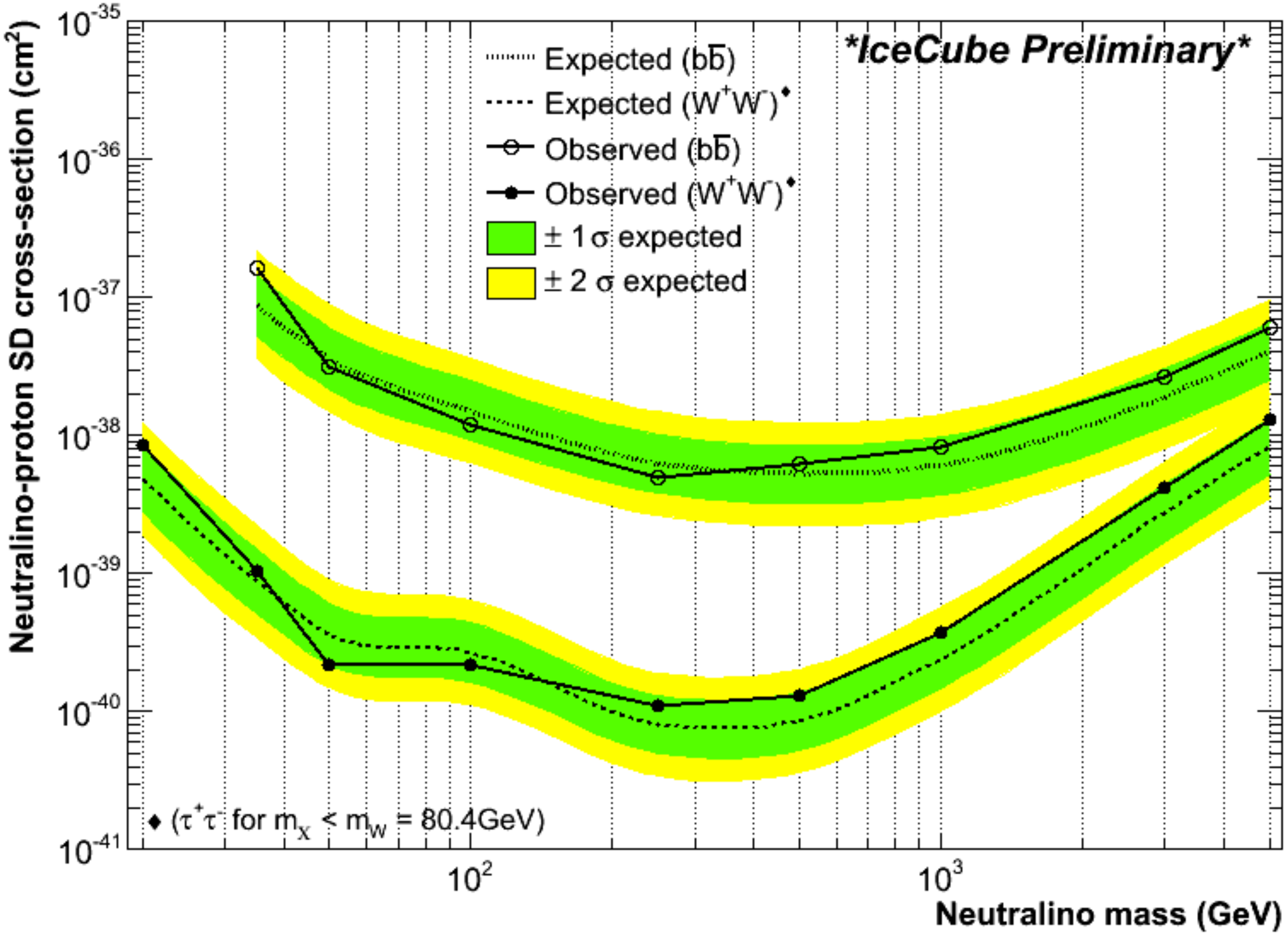
Angle between event track and direction from the Sun

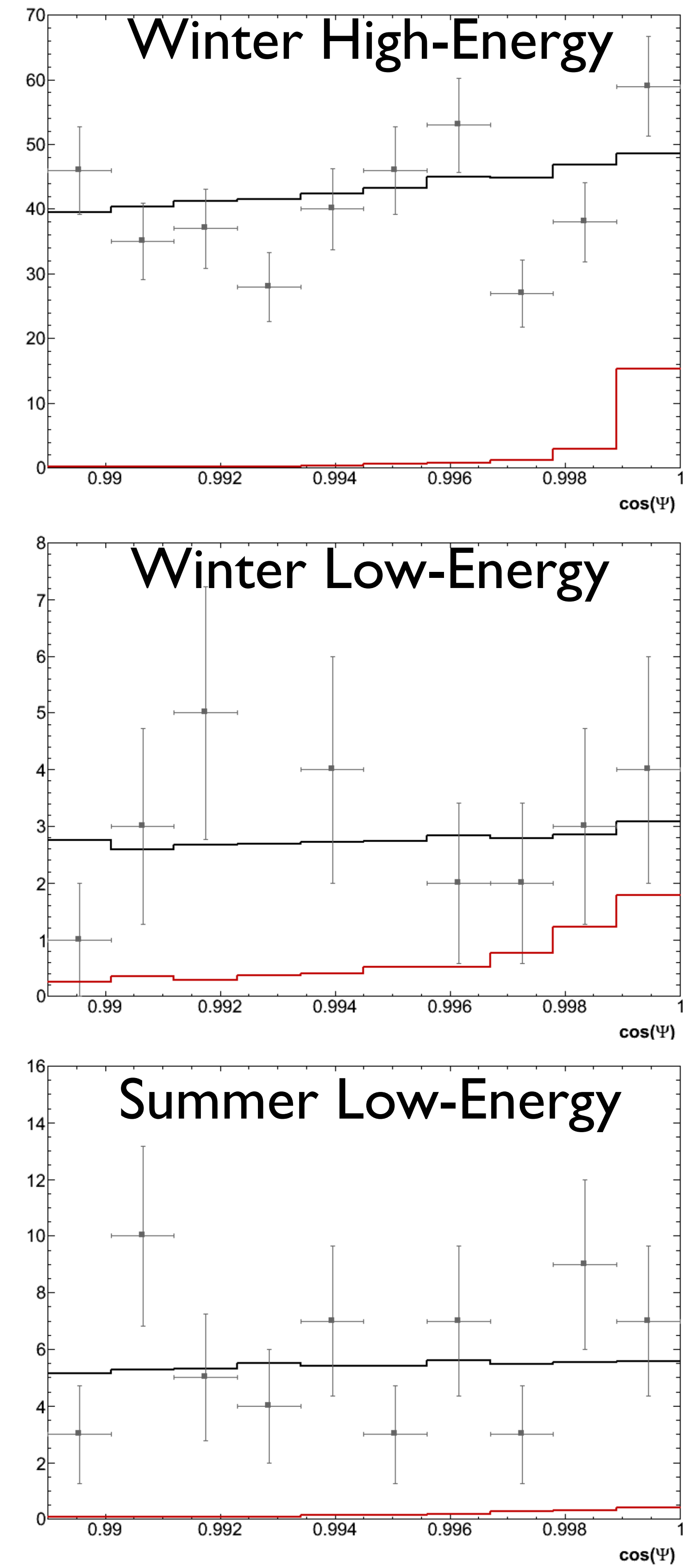
$$\mu_j = \mu \frac{T^j_{\mathrm{live}} V^j_{\mathrm{eff}}}{T^1_{\mathrm{live}} V^1_{\mathrm{eff}} + T^2_{\mathrm{live}} V^2_{\mathrm{eff}}}$$

Muon Flux Limit

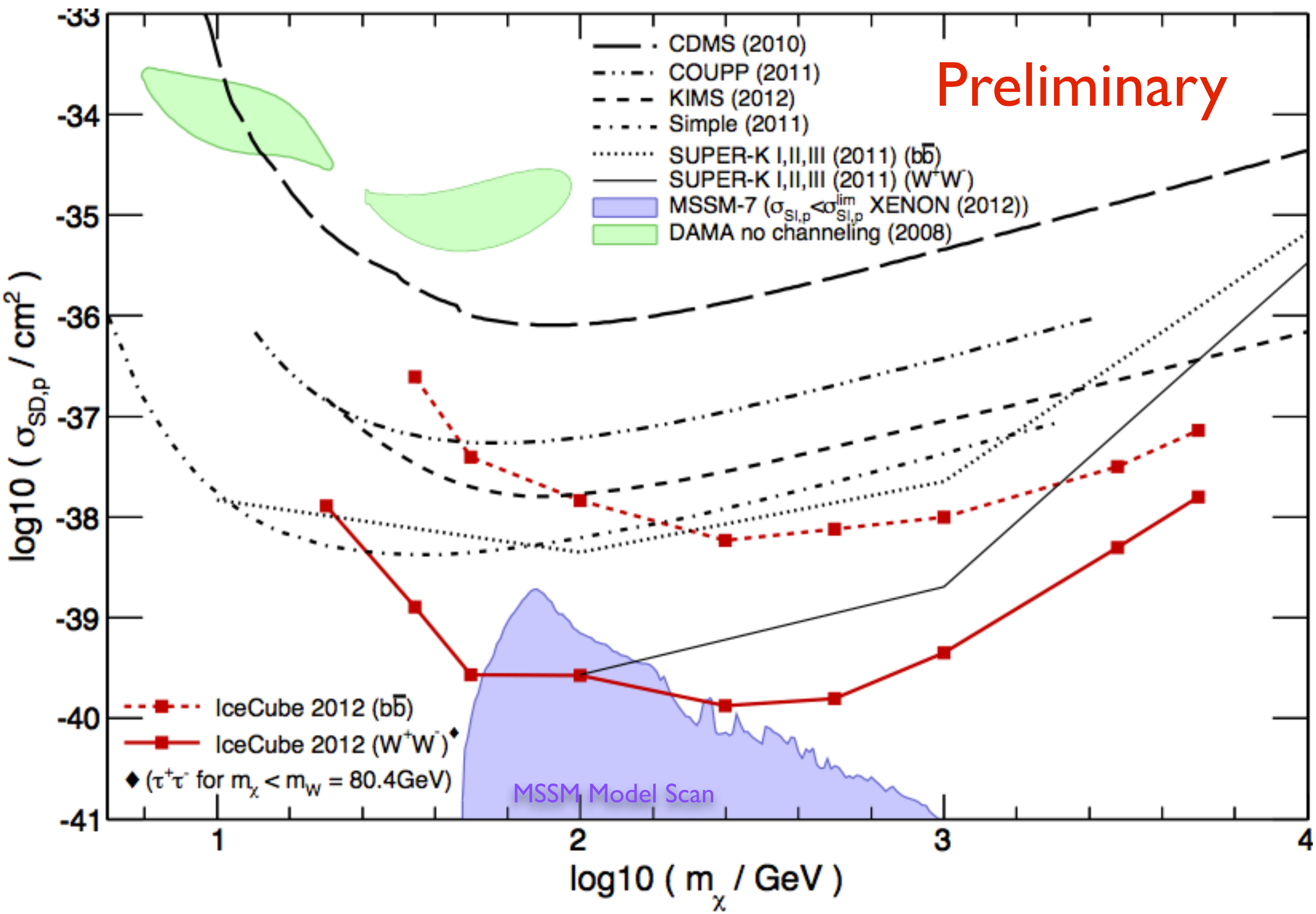


Results


IceCube Preliminary
Expected ($b\bar{b}$)
Expected (W^+W^-)♦
Observed ($b\bar{b}$)
Observed (W^+W^-)♦
± 1 σ expected
± 2 σ expected
♦ ($\tau^+\tau^-$ for m_χ < m_W = 80.4GeV)
Neutralino-proton SD cross-section (cm²)
Neutralino mass (GeV)

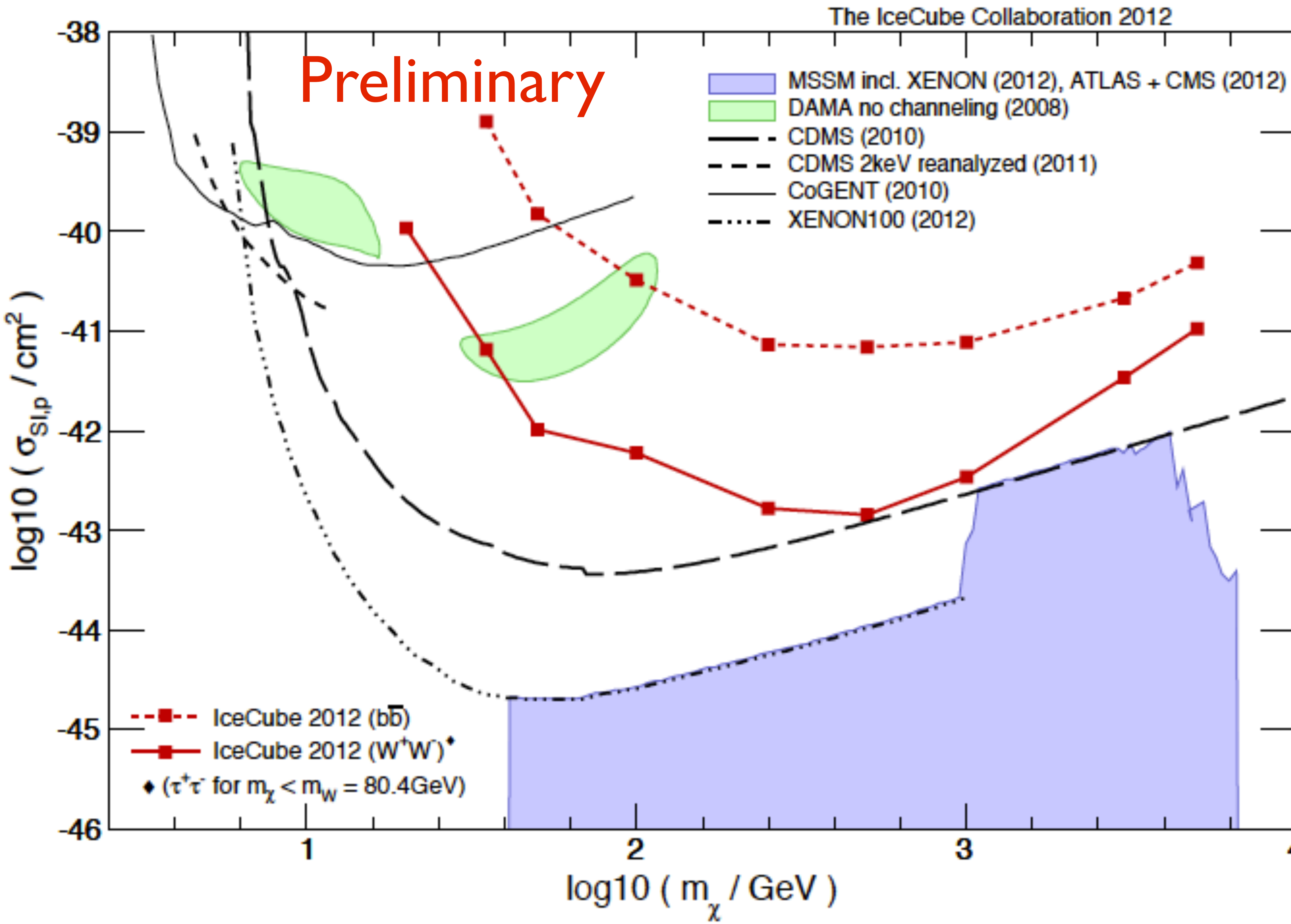

Winter High-Energy
Winter Low-Energy
Summer Low-Energy
cos(Ψ)

SD Limit Solar WIMPs



PRL in preparation

SI Limit Solar WIMPs

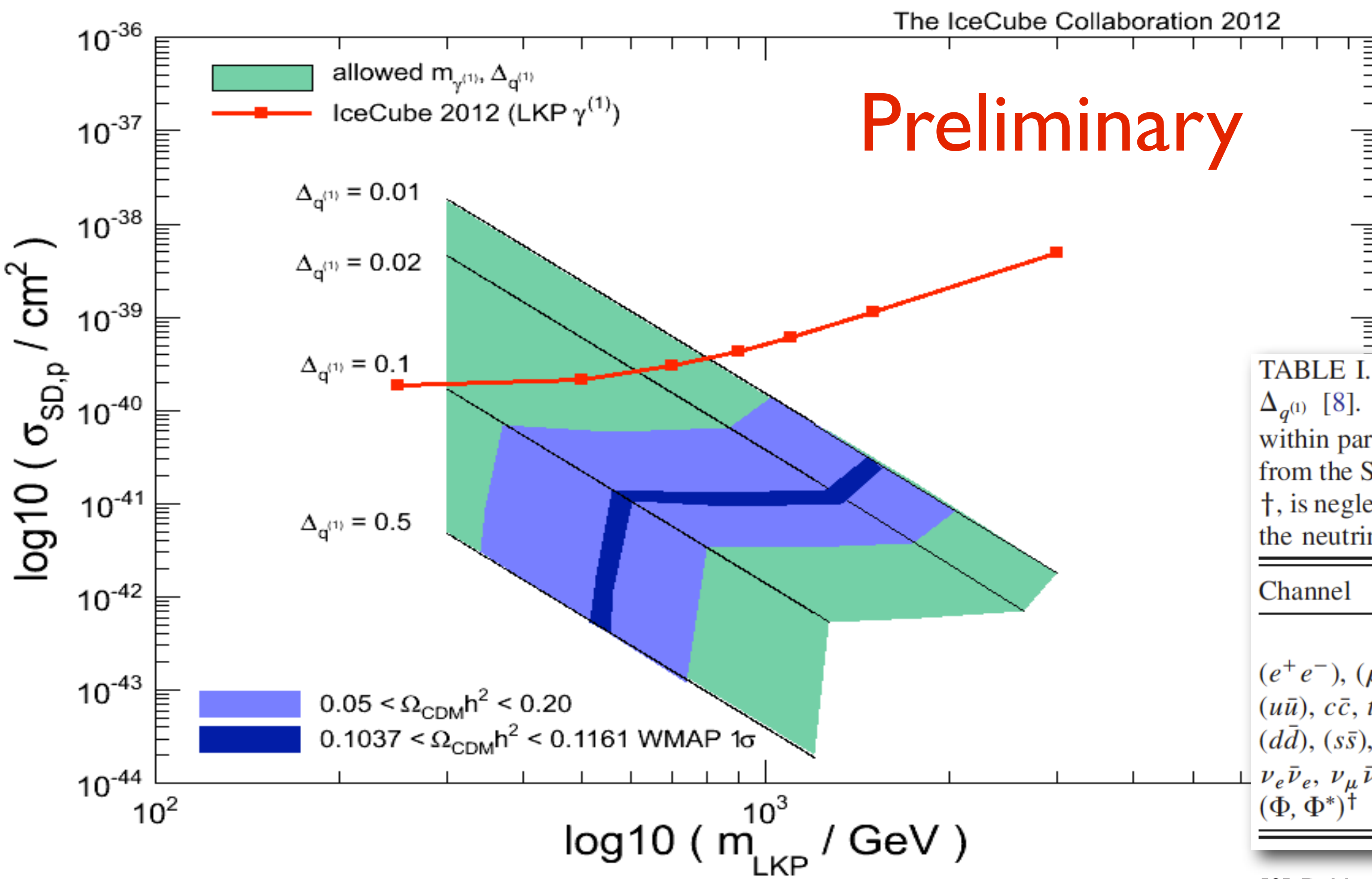


PRL in preparation

Kaluza Klein Dark Matter *New*

Consider universal extra dimension (UED) scenario with five space time dimensions
WIMP is LKP -- $\gamma^{(1)}$
Model described by two parameters: $\mathbf{\Delta_q}$ and $\mathbf{M_{LKP}}$
Limits on SD WIMP-proton cross section using 1yr of **IceCube 79-string** data

$$\text{mass splitting } \Delta_{q^{(1)}} \equiv (m_{q^{(1)}} - m_{\gamma^{(1)}})/m_{\gamma^{(1)}}$$



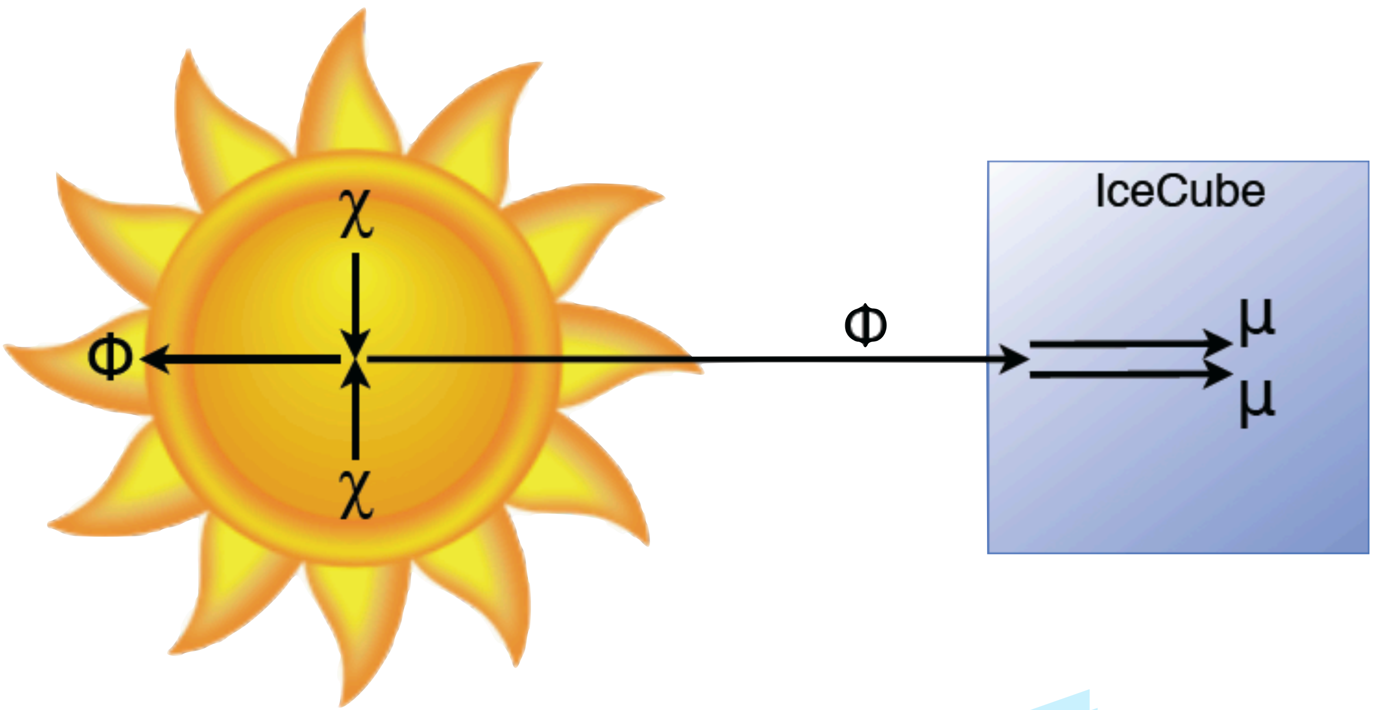
Abbasi et al. PHYSICAL REVIEW D 81, 057101 (2010)

TABLE I. LKP annihilation branching ratios for two values of $\Delta_{q^{(1)}}$ [8]. Ratios are not summed over generations. Channels within parenthesis give negligible contribution to a neutrino flux from the Sun. The Higgs-field annihilation channel, marked with †, is neglected, due to large uncertainty and small contribution to the neutrino flux.

Channel	Branching ratio	
	$\Delta_{q^{(1)}} = 0$	$\Delta_{q^{(1)}} = 0.14$
(e^+e^-), $(\mu^+\mu^-)$, $\tau^+\tau^-$	0.20	0.23
$(u\bar{u})$, $c\bar{c}$, $t\bar{t}$	0.11	0.077
$(d\bar{d})$, $(s\bar{s})$, $b\bar{s}$	0.007	0.005
$\nu_e\bar{\nu}_e$, $\nu_\mu\bar{\nu}_\mu$, $\nu_\tau\bar{\nu}_\tau$	0.012	0.014
$(\Phi, \Phi^*)^\dagger$	0.023	0.027

[8] D. Hooper and G. D. Kribs, Phys. Rev. D 67, 055003 (2003).

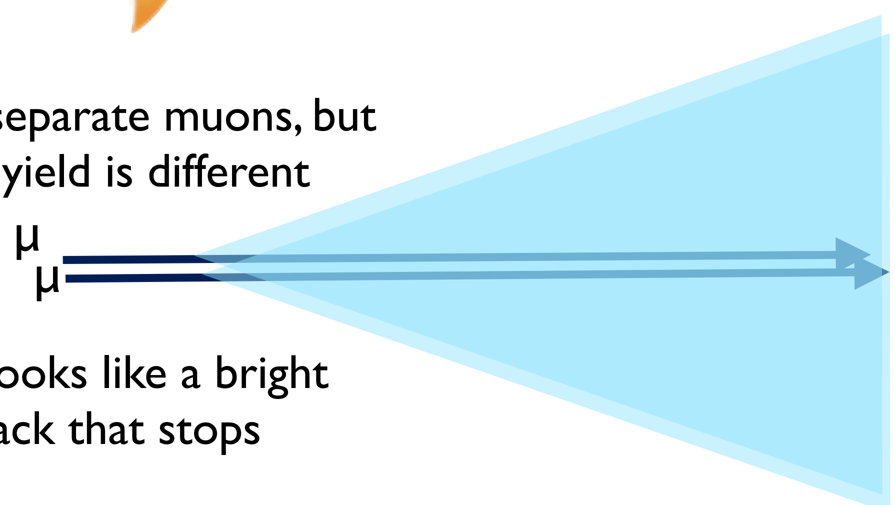
Secluded Dark Matter



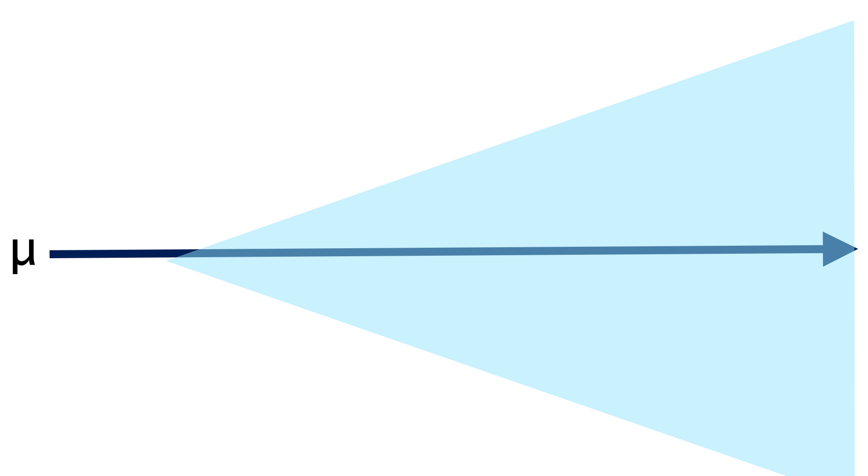
Secluded WIMPs / dark hidden sector WIMPs annihilate with a weak-scale rate to metastable mediators, Φ, which are in turn very weakly coupled to the SM.

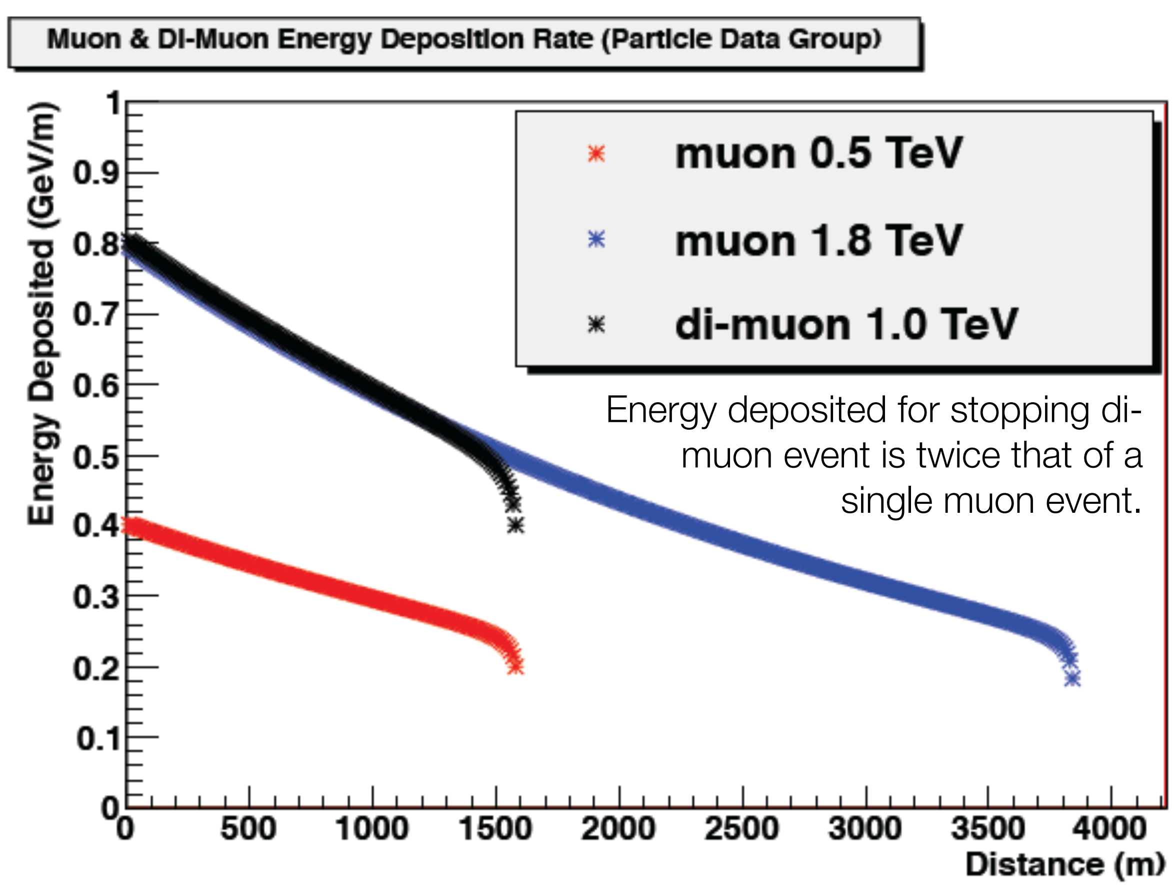
If lifetime of mediator is large, it could decay at significant rates at distances from the Sun ~ 1A.U.

do not separate muons, but light yield is different

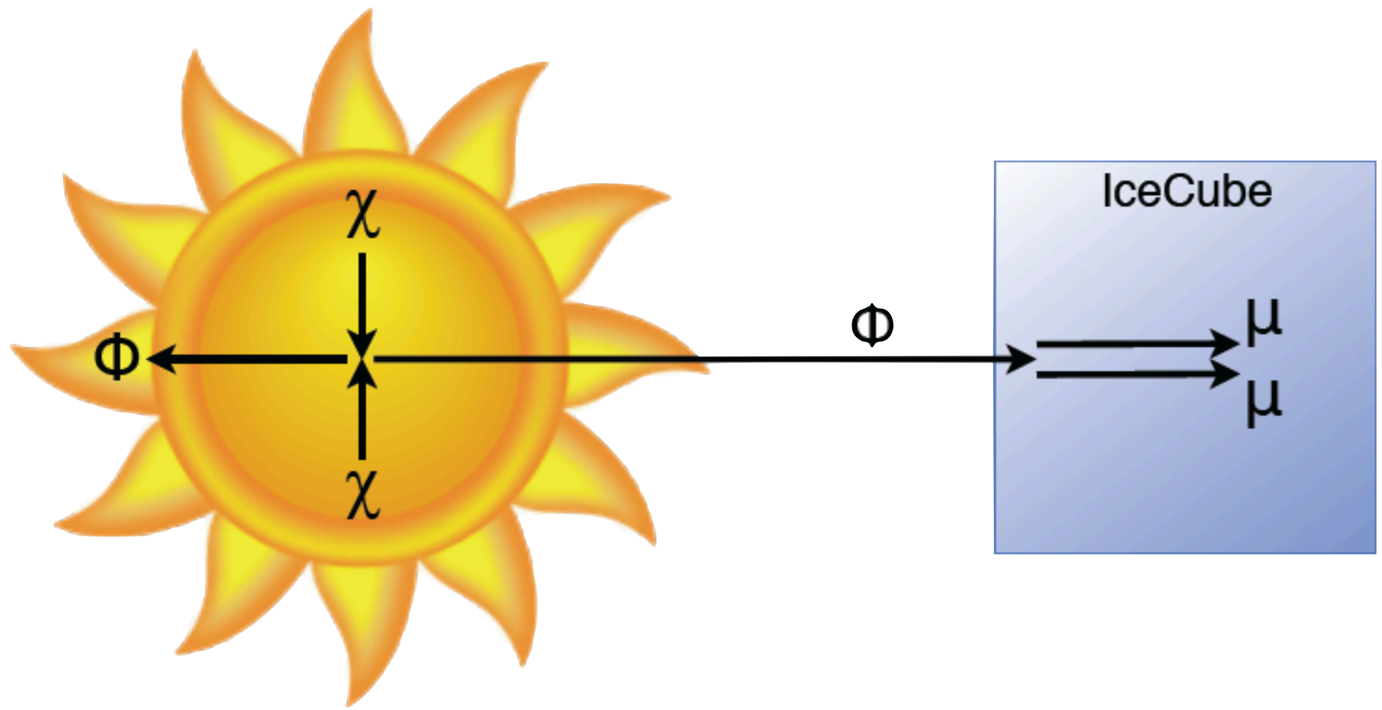


This looks like a bright track that stops





Secluded Dark Matter



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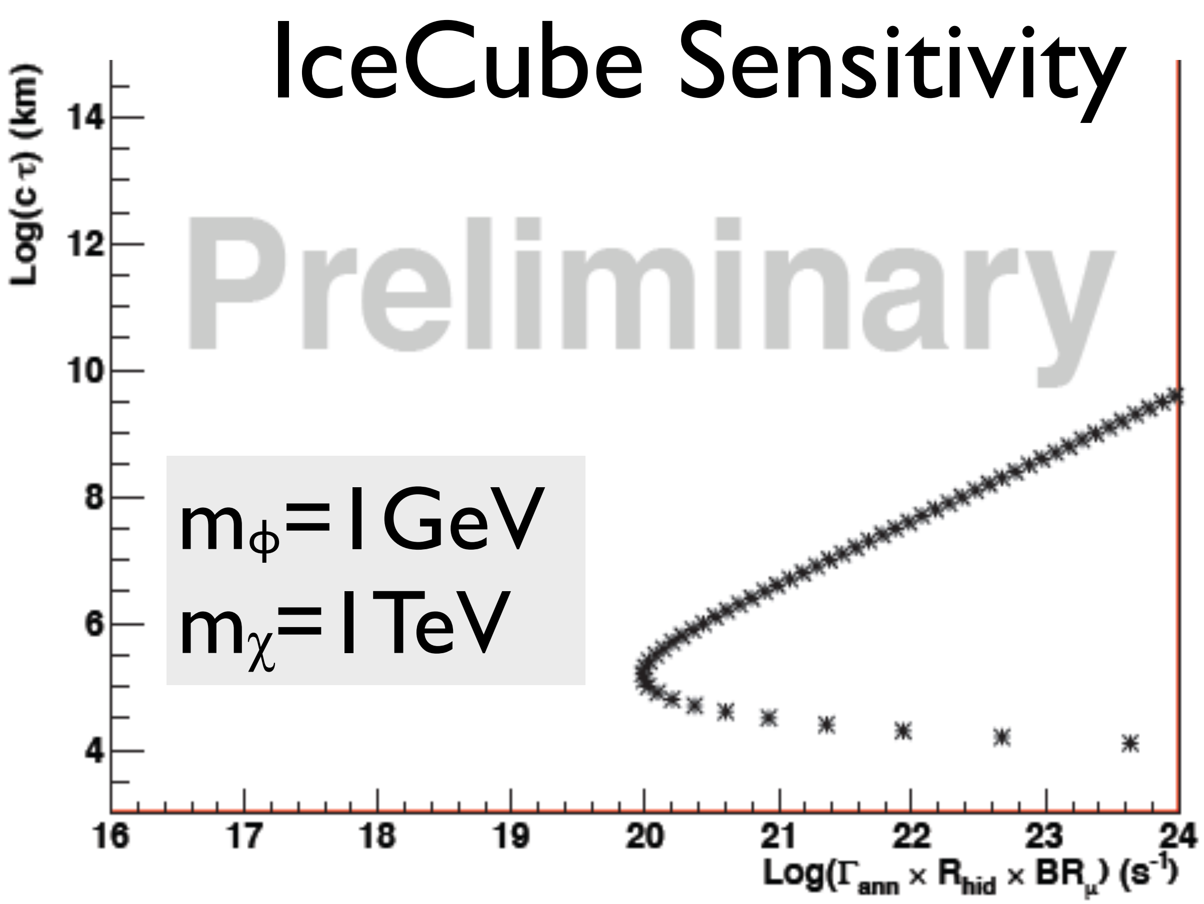
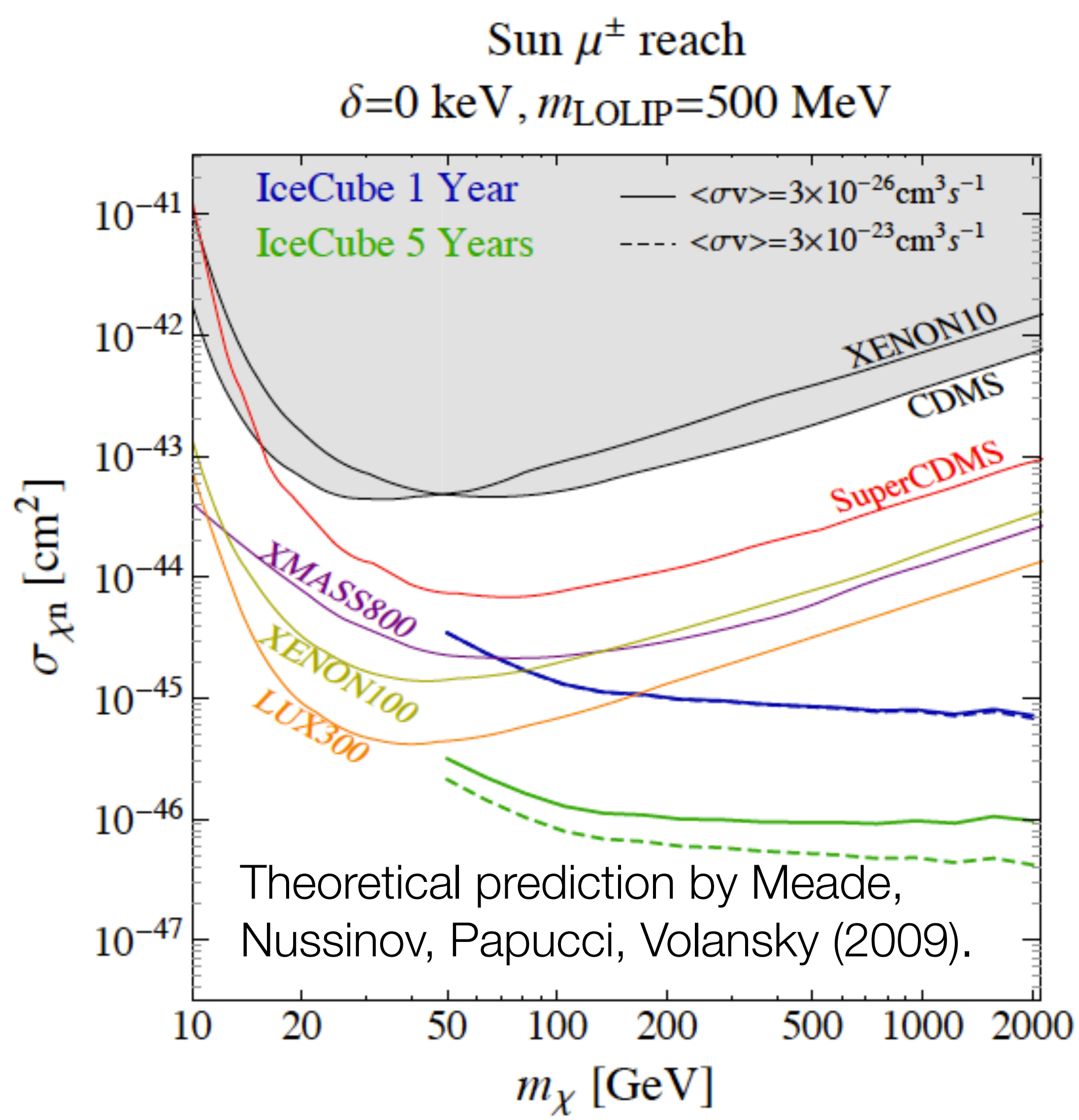
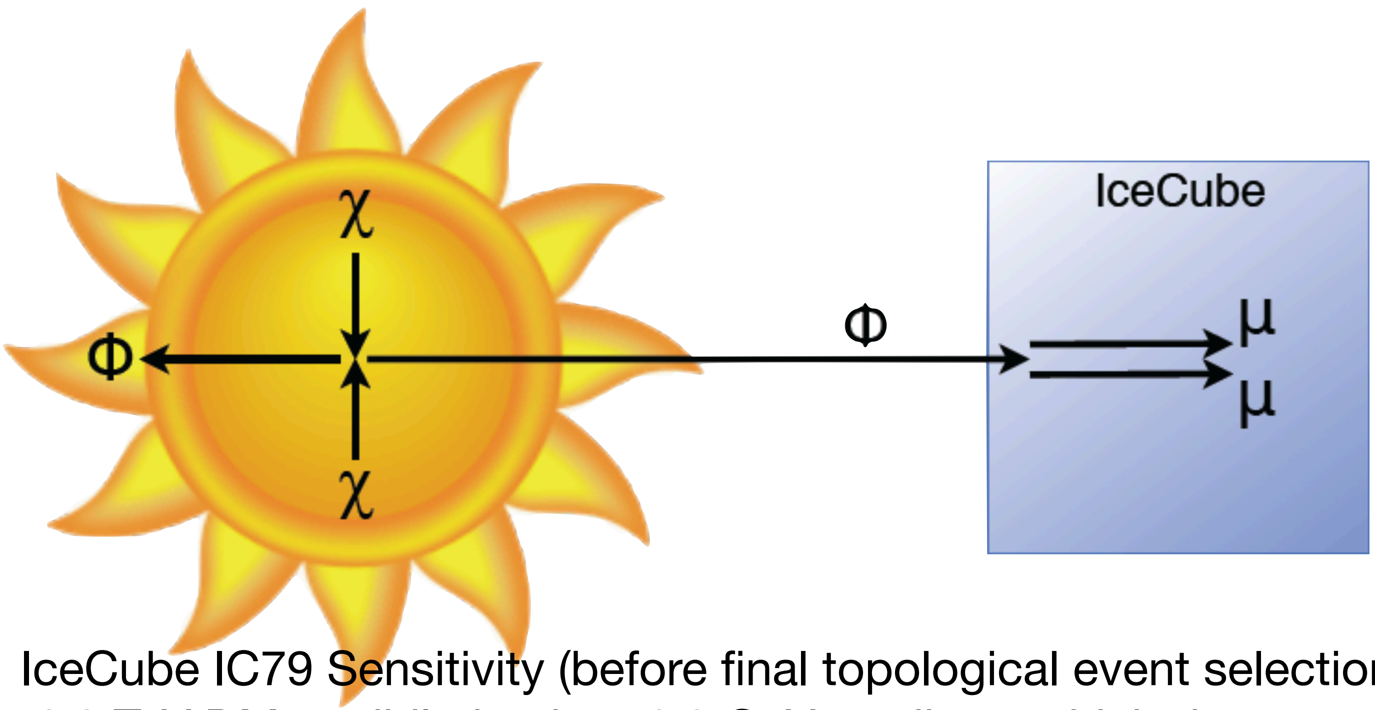
If lifetime of mediator is large, it could decay at significant rates at distances from the Sun ~ 1A.U.





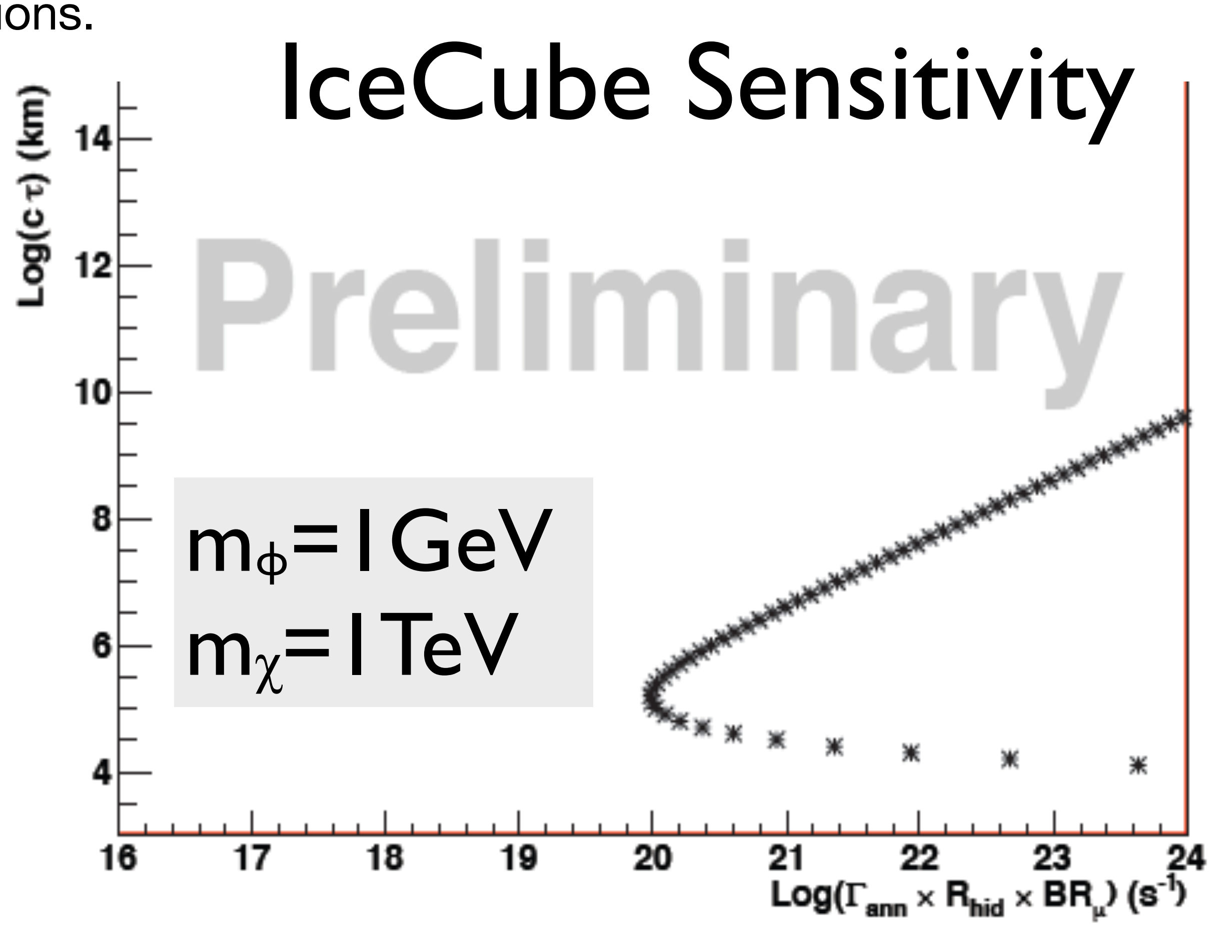
Secluded Dark Matter

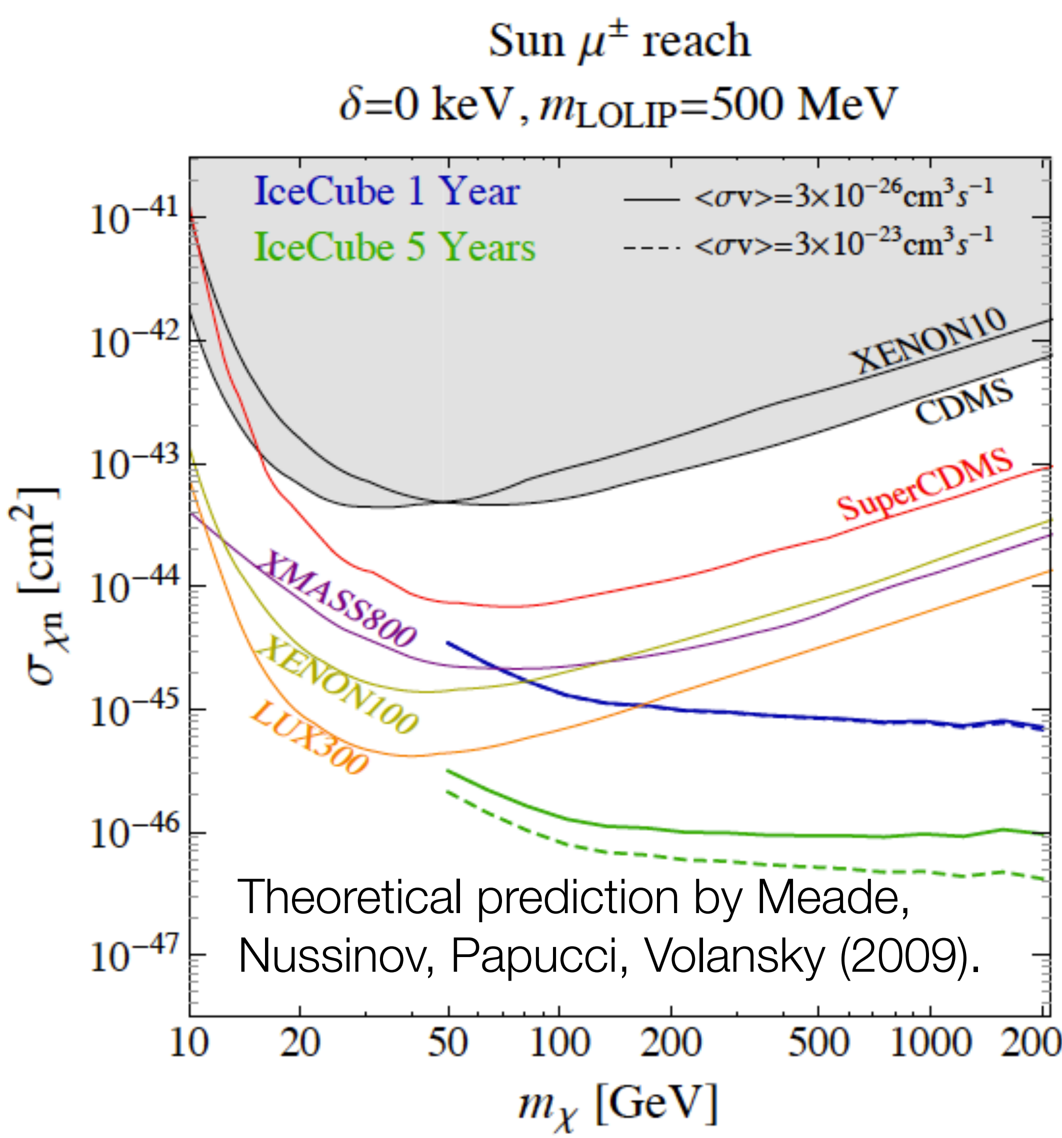


Secluded WIMPs / dark hidden sector WIMPs annihilate with a weak-scale rate to metastable mediators, Φ, which are in turn very weakly coupled to the SM.

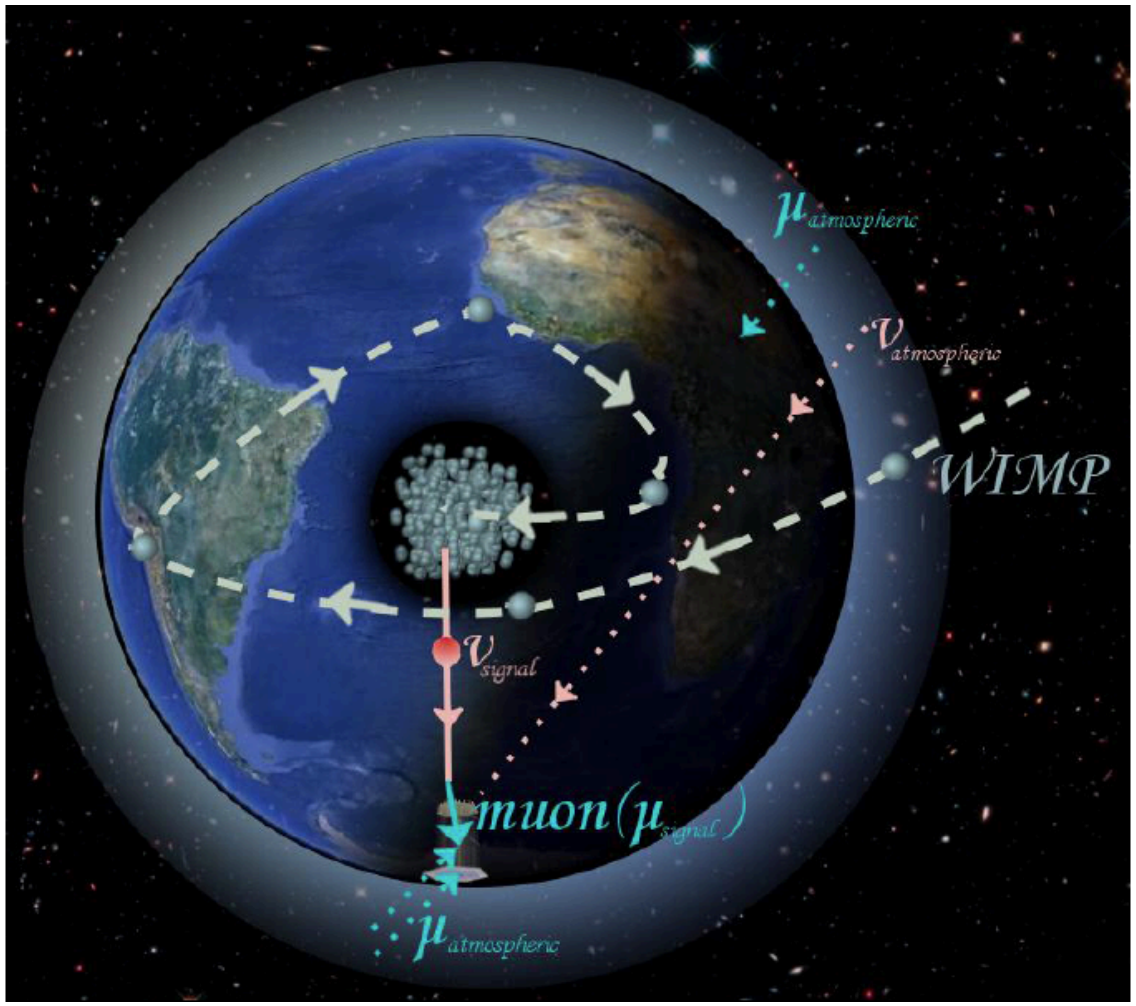
If lifetime of mediator is large, it could decay at significant rates at distances from the Sun ~ 1A.U.

IceCube IC79 Sensitivity (before final topological event selection):
1.0 TeV DM annihilating into 1.0 GeV mediator which decays to two muons.

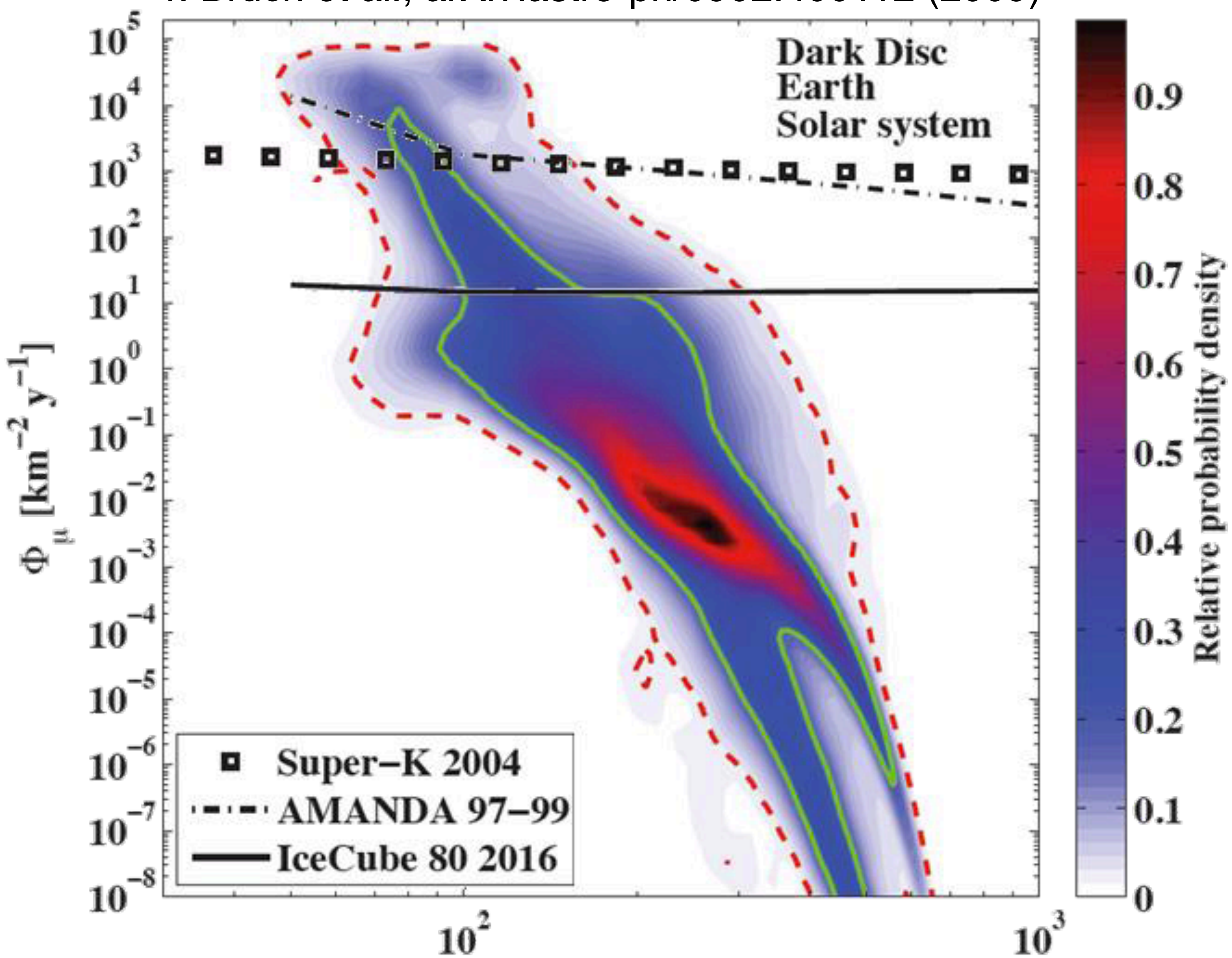




Earth WIMPs



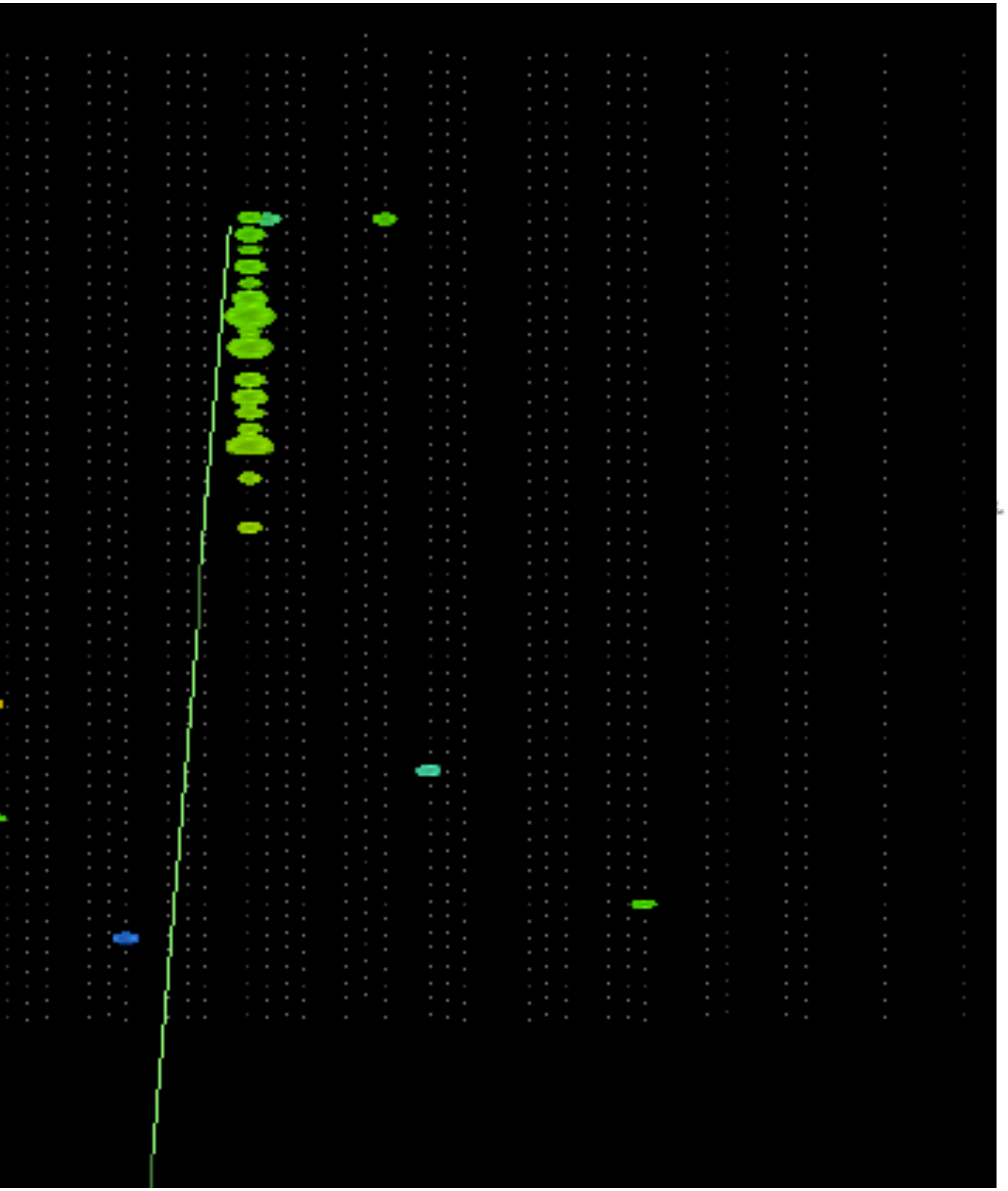
T. Bruch et al., arXiv:astro-ph/0902.4001v2 (2009)



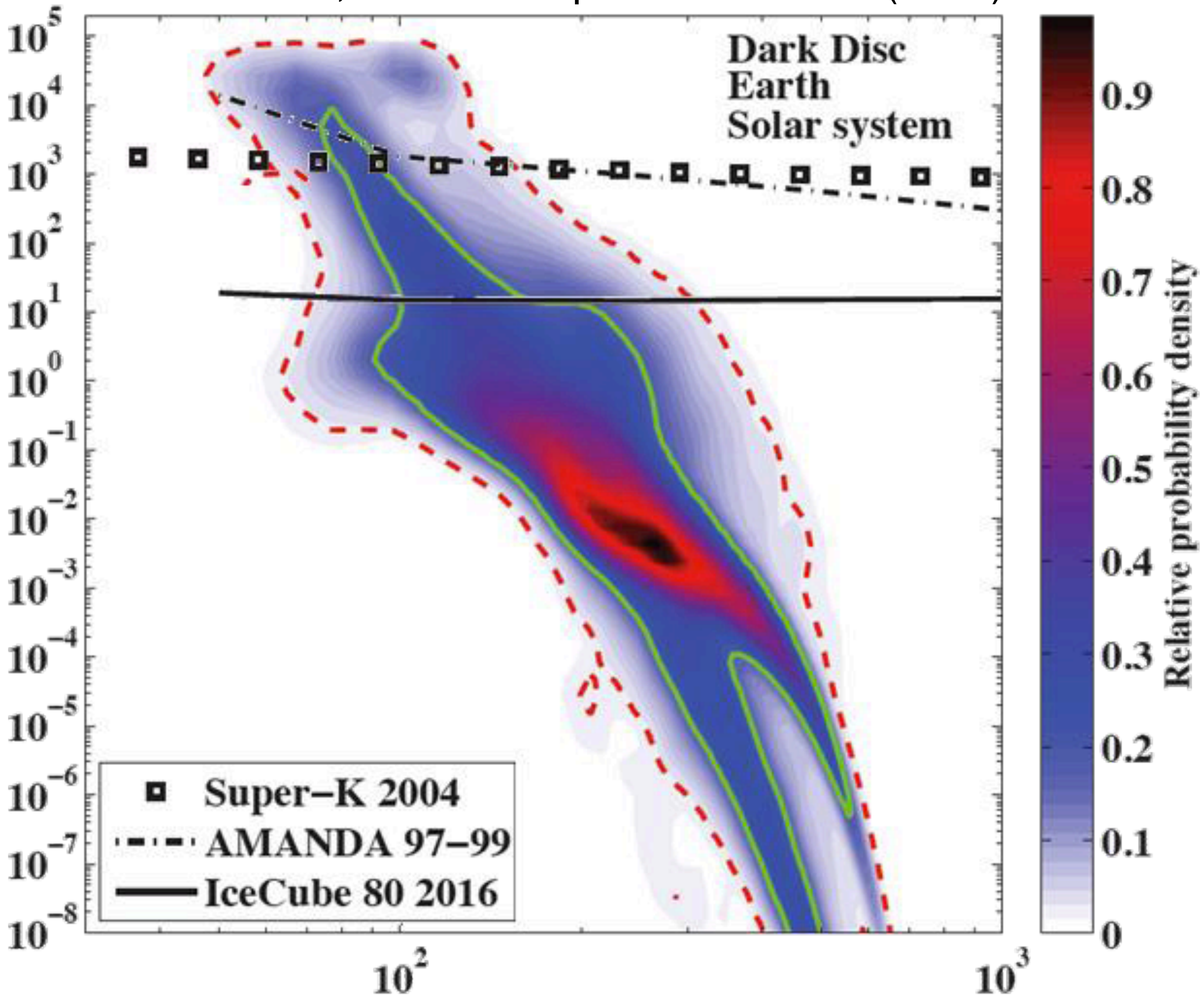
Dedicated Earth WIMP filer active since IC22 detector

Analysis now focusing on full IceCube detector

Earth WIMPs



T. Bruch et al., arXiv:astro-ph/0902.4001v2 (2009)



Dedicated Earth WIMP filer active since IC22 detector

Analysis now focusing on full IceCube detector

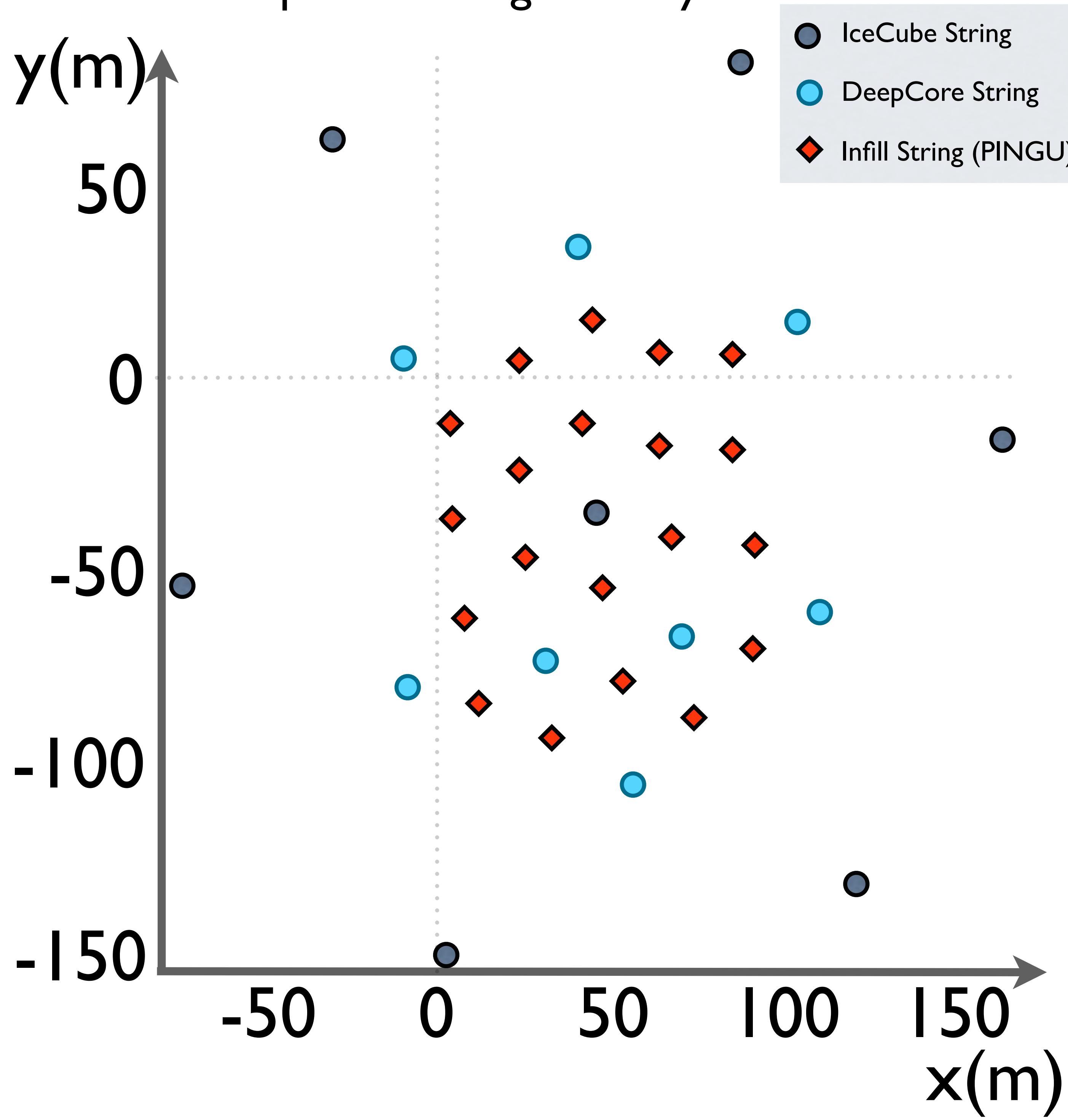
PINGU

PINGU - Precision IceCube Next Generation Upgrade

© [2011] The Pygos Group

- Test low mass WIMPs and precision measurements of neutrino oscillations
  - Needs energy threshold of few GeV
- Developing a proposal to further in-fill DeepCore, called PINGU
  - Instrument a volume of about 10MT with ~20 strings each containing 50-60 optical module
  - Rely on well established drilling technology and photo sensors
  - Create platform for calibration program and test technologies for future detectors

An example PINGU geometry



© [2011] The Pygos Group

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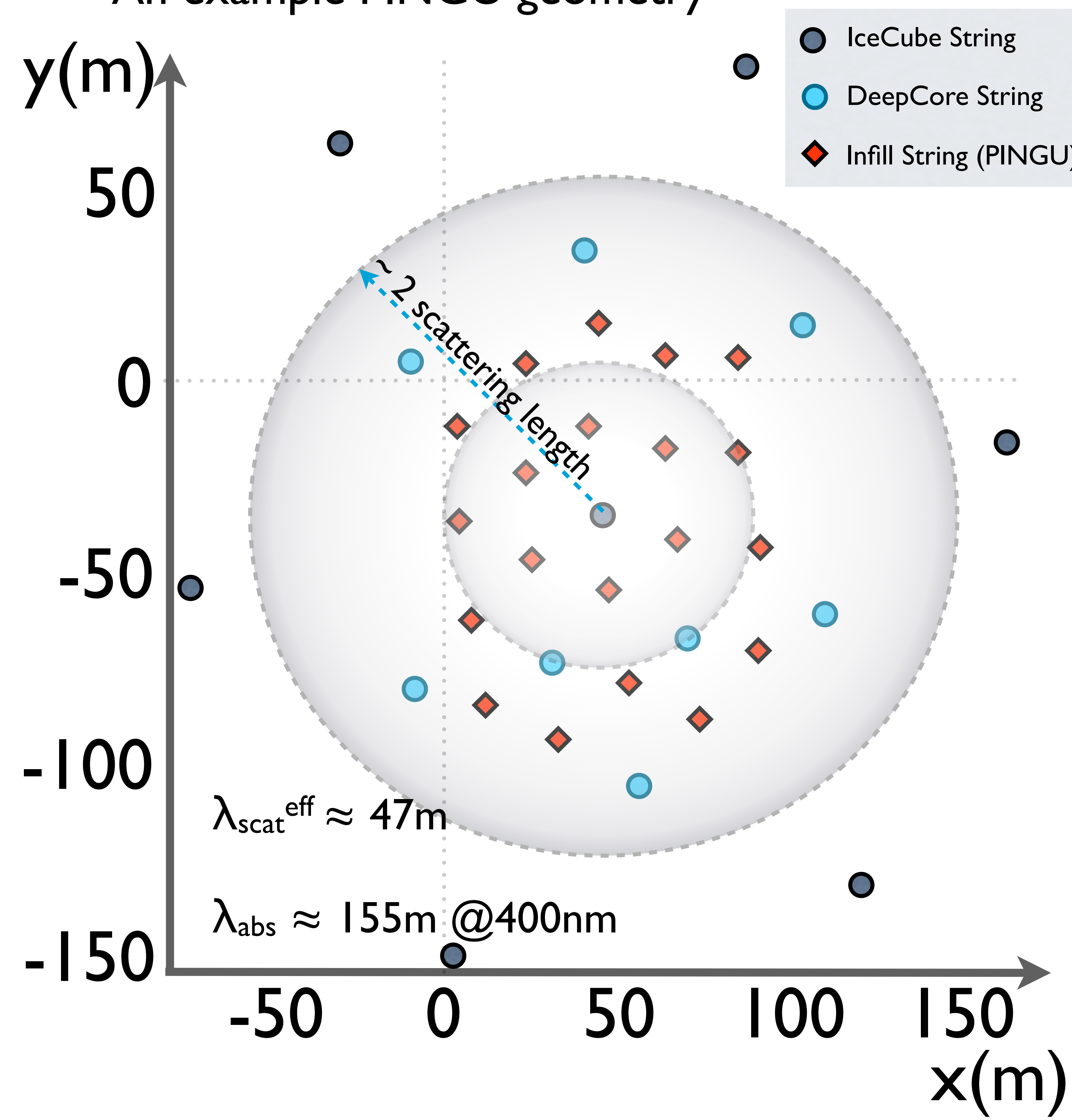
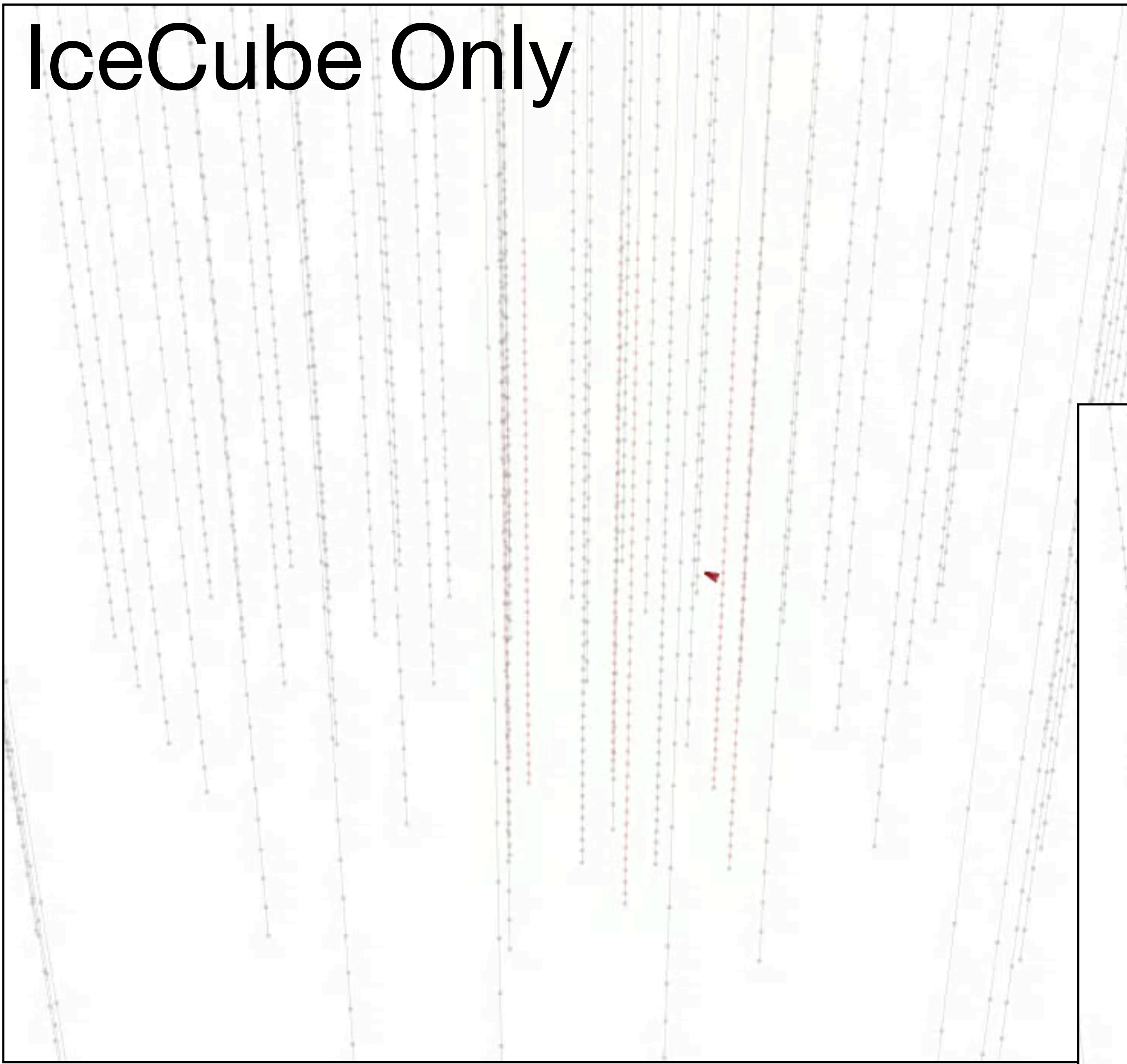


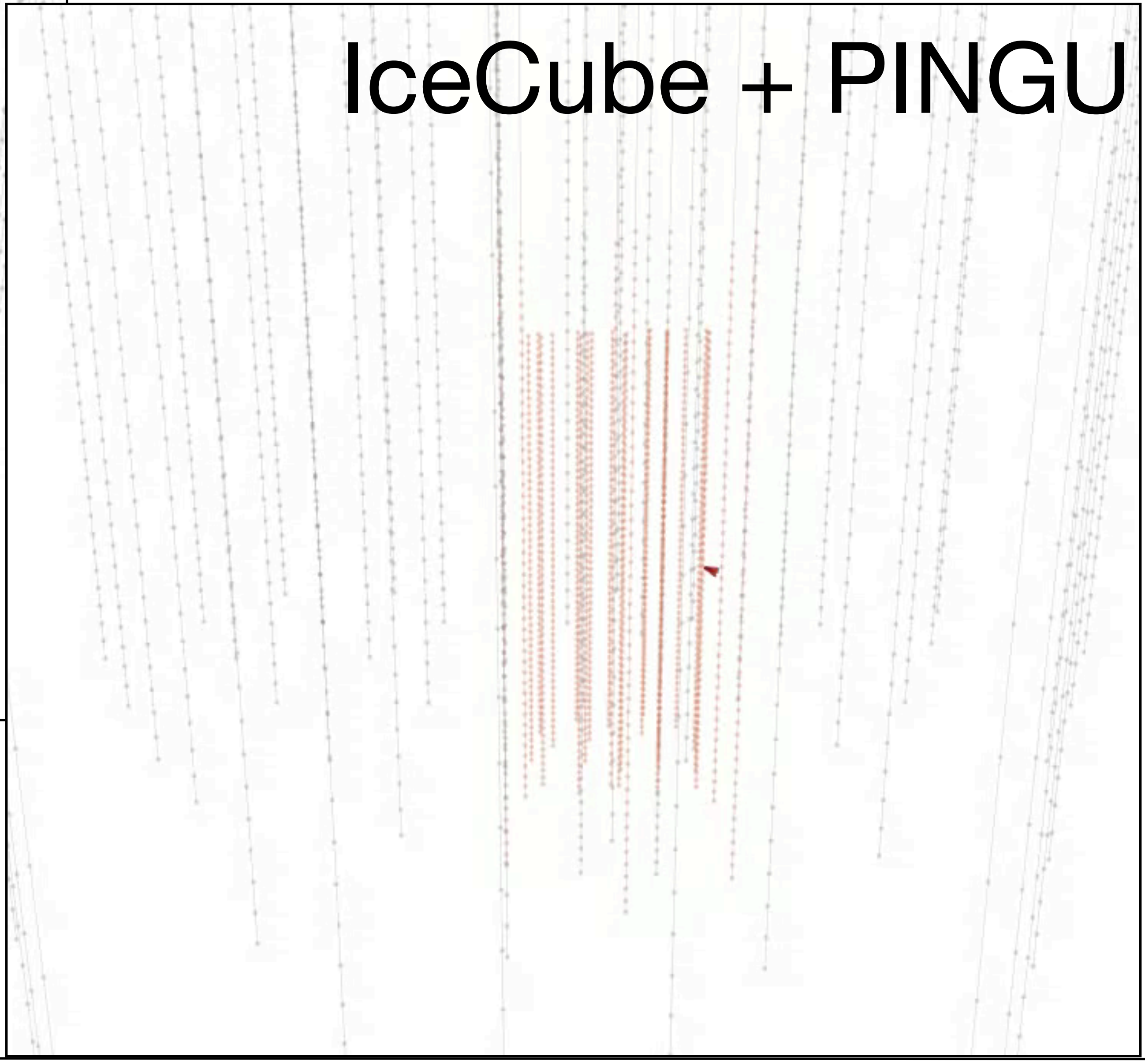
Example Event (simulation)

© [2011] The Pygos Group



- 9 GeV muon neutrino (physics only hits)

[~4.9GeV muon / ~4.5GeV shower]



20 ⇒ 50 hit modules

PINGU and Solar WIMPs

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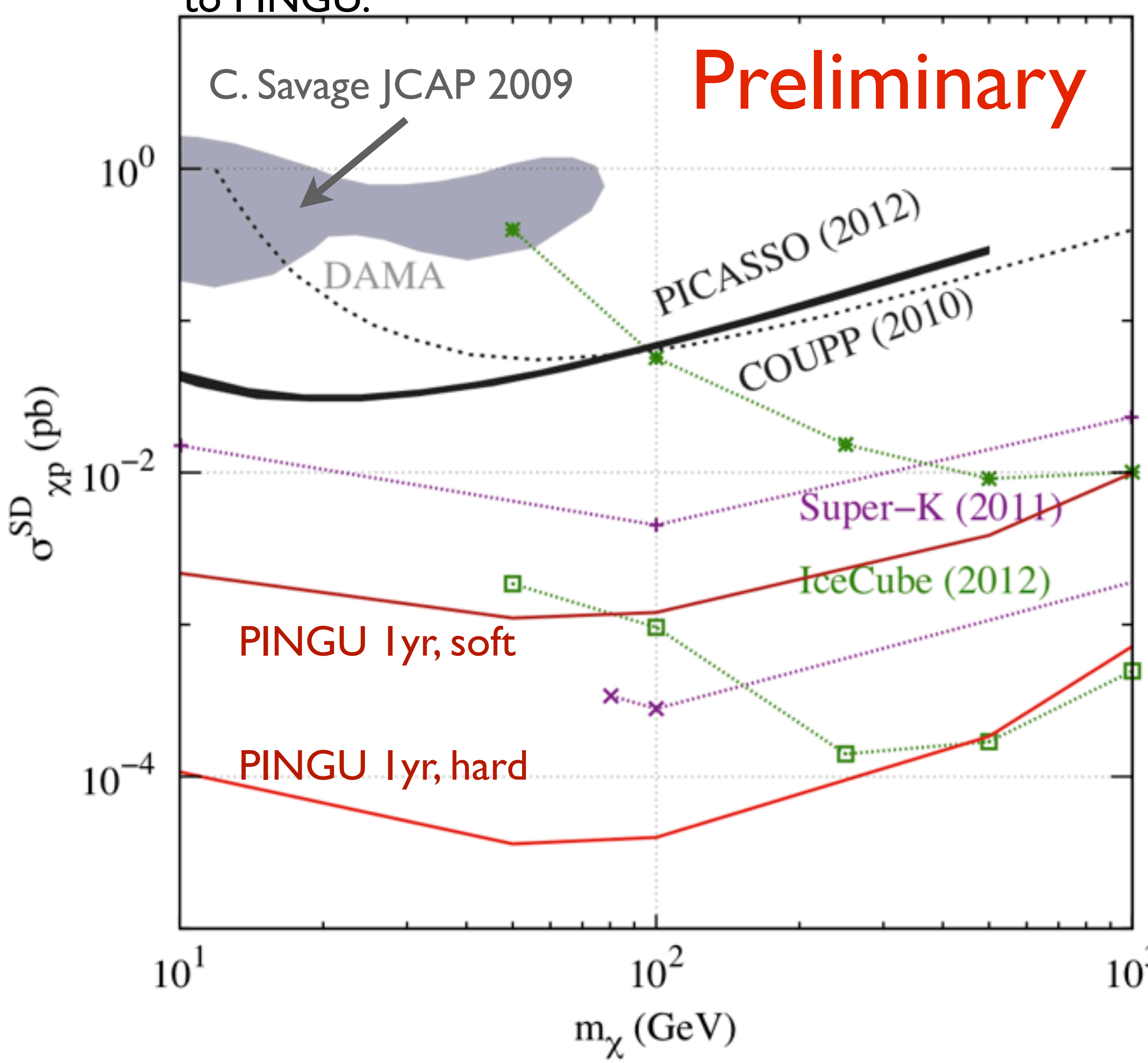
- Preliminary solar WIMP sensitivity based PINGUs effective volume
- Assume that atmospheric muon backgrounds can be effectively rejected (not included in the sensitivity)

- Low-mass WIMP scenarios well testable
- Next steps:
  - Detailed study with full PINGU simulation
  - More sophisticated event reconstruction
  - Check atmospheric muon background

Adapted **Rott, Tanaka, Itow JCAP09(2011)029** to PINGU.

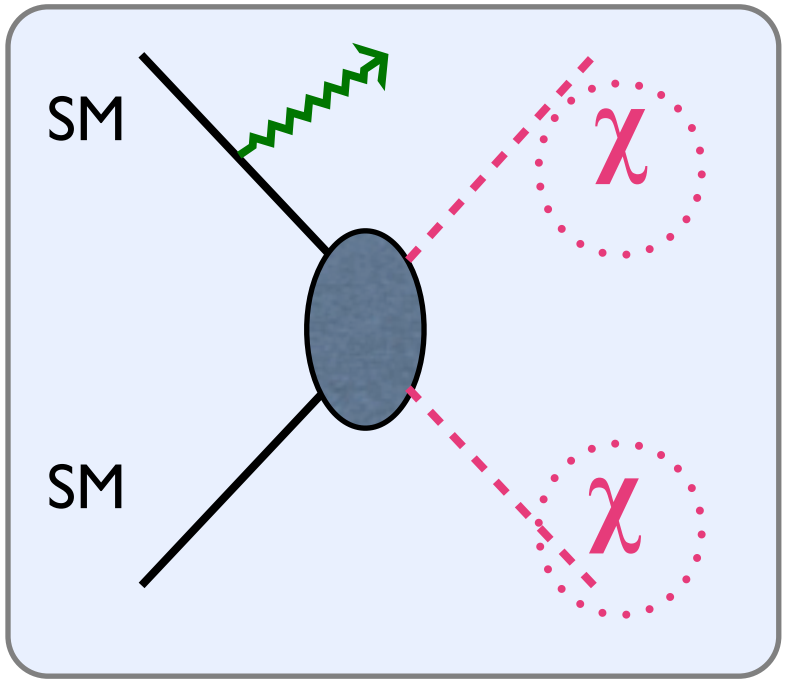


Conclusions

- IceCube completed December 2010
  - Limits dark matter self-annihilation cross section at the level of $10^{-22}cm^3s^{-1}$ to $10^{-23}cm^3s^{-1}$ achieved from Galactic Center / Halo
- Latest Results
  - First experimental neutrino results on Clusters of Galaxies and Dwarfs Spheriodals
    - Very competitive limit on DM self-annihilation cross section for high WIMP masses
  - First full year-round IceCube + DeepCore solar Dark Matter search
    - Most stringent limits in large parts of WIMP mass range on SD scattering
- Next
  - 2yrs of DeepCore data waiting for analysis
  - Very diverse indirect dark matter search program starting with full IceCube + DeepCore
    - Earth WIMPs, Solar WIMPs, Secluded Dark Matter, ...
  - Exploring the potentially great dark matter prospects with future extensions (PINGU)

Backup

LHC - Indirect - Direct Connection



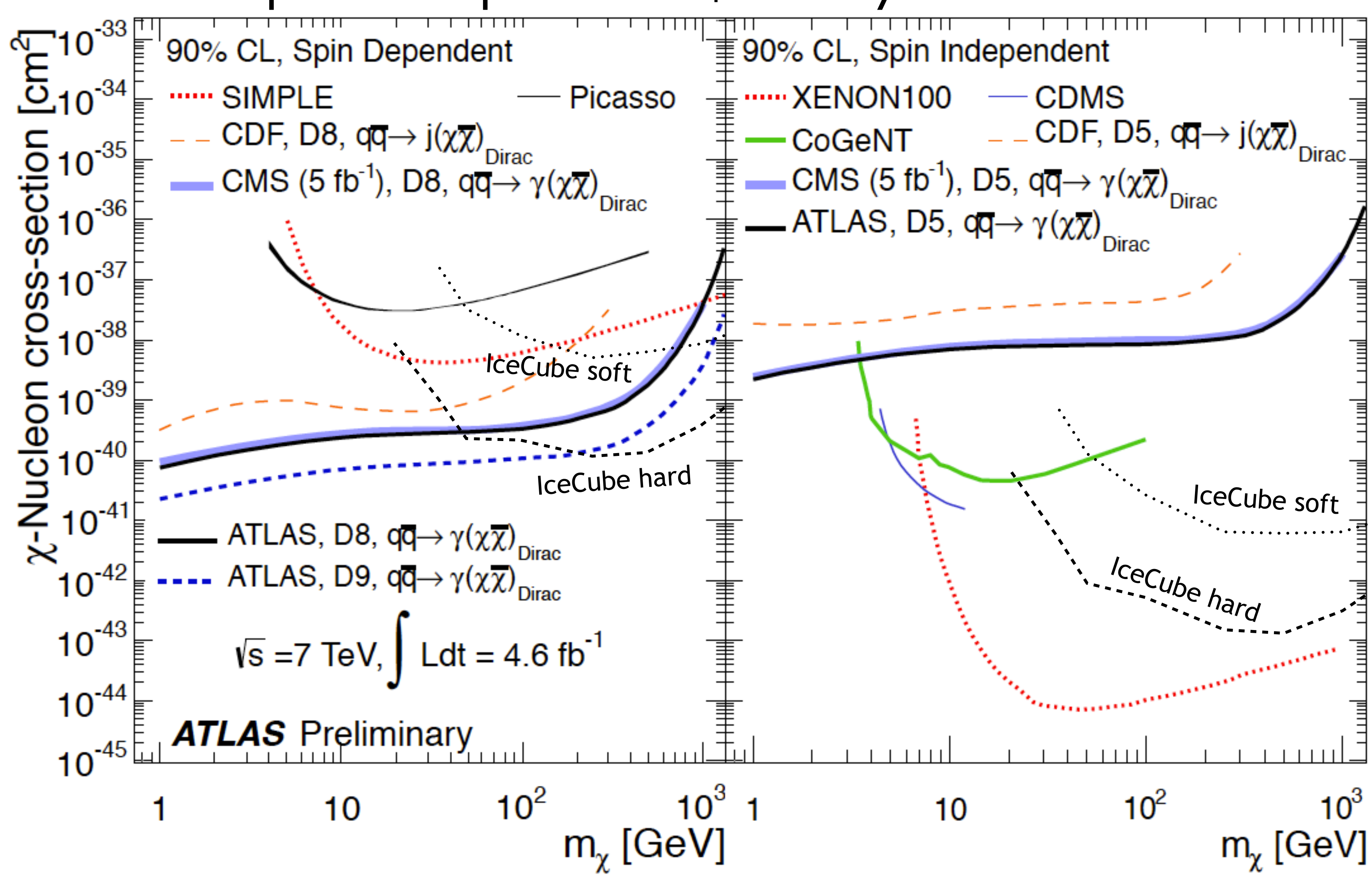
WIMPs at LHC:

WIMPs expected to interact with Standard Model (SM) particle via new interaction

Assume mediating particles too heavy to be produced directly

→ effective field theory (contact interaction)

Example: mono-photon + E_T^{miss} analysis



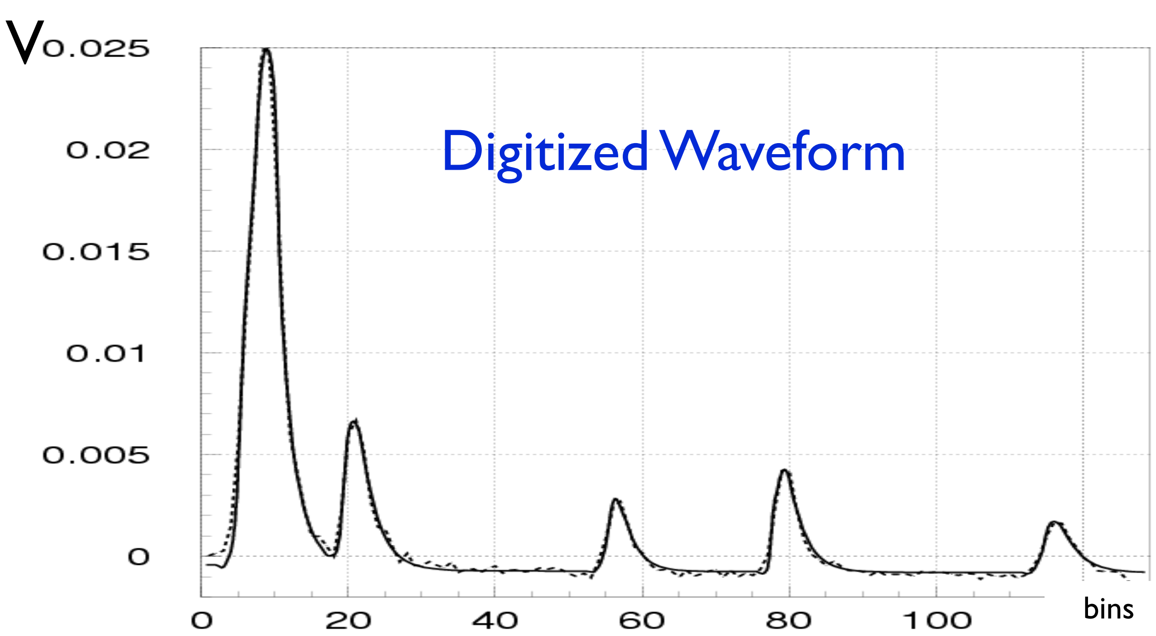
Observation of a indirect WIMP signal

→ combined with LHC search start probing underlying theory

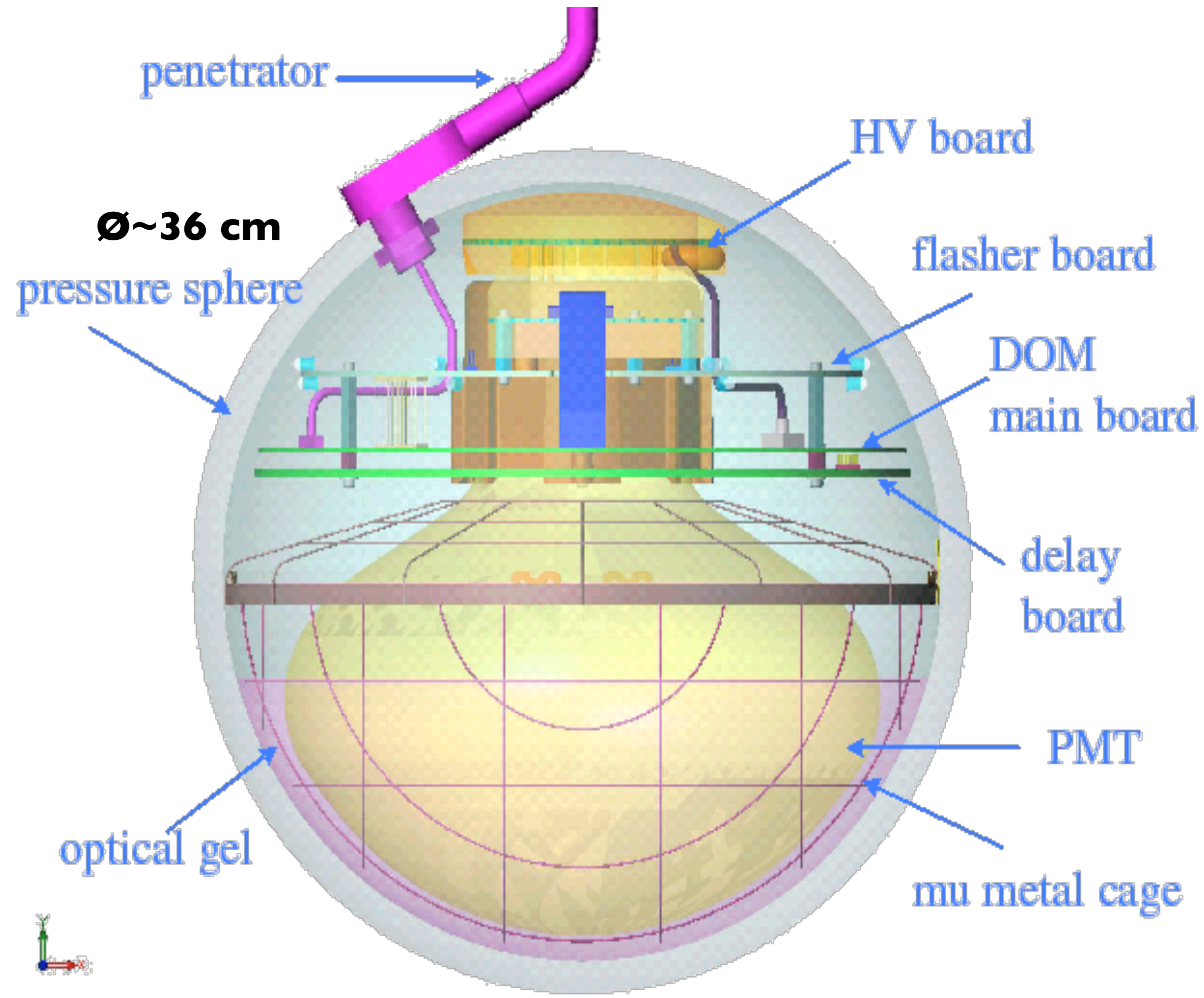
Digital Optical Module (DOM)

Measure individual photon arrival time:

- 2 ping-ponged four-channel ATWDs:
  - Analog Transient Waveform Digitizer
  - 200-700 Megasamples/s
  - 400 ns range
  - 400 pe / 15 ns
- fADC (fast 'ADC'):
  - 40 Megasamples/s
  - 6.4 μs range



10 inch Hamamatsu PMT (R-7081-02)



- Dark Noise rate ~ 350 Hz
- Local Coincidence rate ~ 15 Hz
- Deadtime < 1%
- Timing resolution ≤ 2 ns

Kaluza Klein Dark Matter

- Consider universal extra dimension (UED) scenario with five space time dimensions
- WIMP is LKP -- $\gamma^{(1)}$ First excitation of the KK photon
- Model described by two parameters: **Δ_q** and **M_{LKP}**
- Limits on SD WIMP-proton cross section **IceCube 22-string** and **AMANDA 6-year**

PHYSICAL REVIEW D 81, 057101 (2010) arXiv:0910.4480

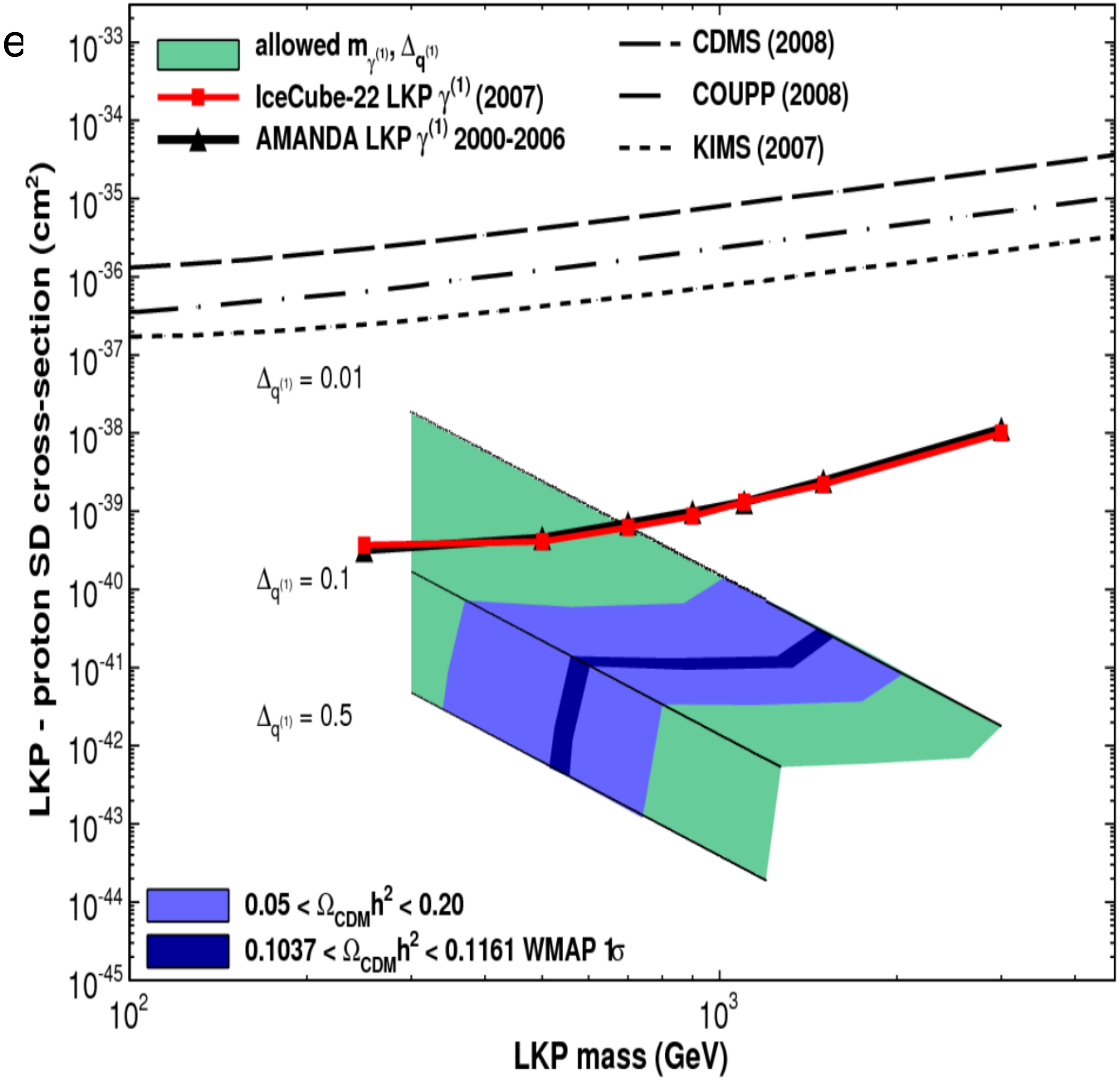
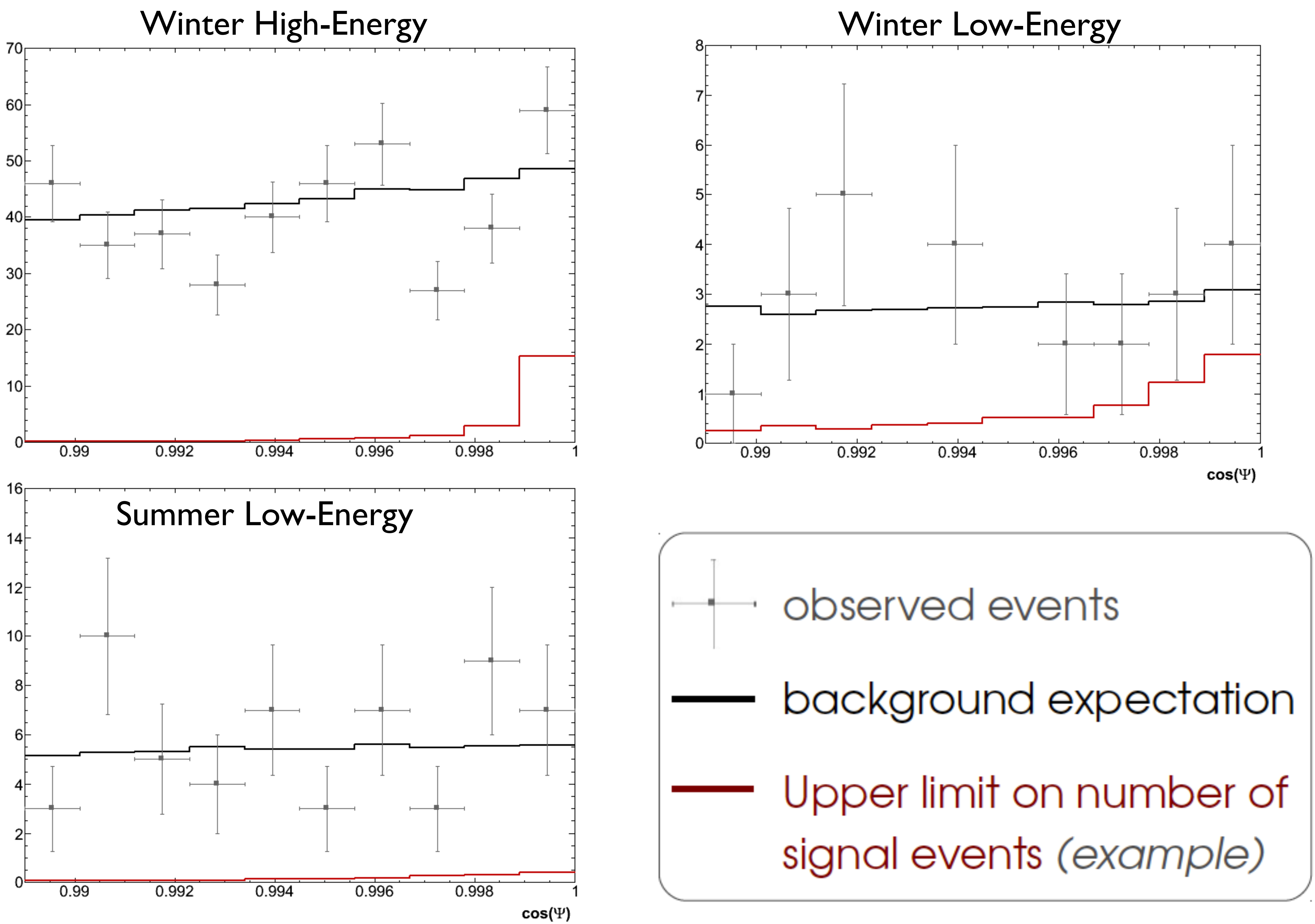


TABLE I. LKP annihilation branching ratios for two values of $\Delta_{q^{(1)}}$ [8]. Ratios are not summed over generations. Channels within parenthesis give negligible contribution to a neutrino flux from the Sun. The Higgs-field annihilation channel, marked with †, is neglected, due to large uncertainty and small contribution to the neutrino flux.

Channel	Branching ratio $\Delta_{q^{(1)}} = 0$	Branching ratio $\Delta_{q^{(1)}} = 0.14$
(e^+e^-), $(\mu^+\mu^-)$, $\tau^+\tau^-$	0.20	0.23
$(u\bar{u})$, $c\bar{c}$, $t\bar{t}$	0.11	0.077
$(d\bar{d})$, $(s\bar{s})$, $b\bar{s}$	0.007	0.005
$\nu_e\bar{\nu}_e$, $\nu_\mu\bar{\nu}_\mu$, $\nu_\tau\bar{\nu}_\tau$	0.012	0.014
$(\Phi, \Phi^*)^\dagger$	0.023	0.027

[8] D. Hooper and G. D. Kribs, Phys. Rev. D 67, 055003 (2003).

IC79 Solar WIMP Unblinding



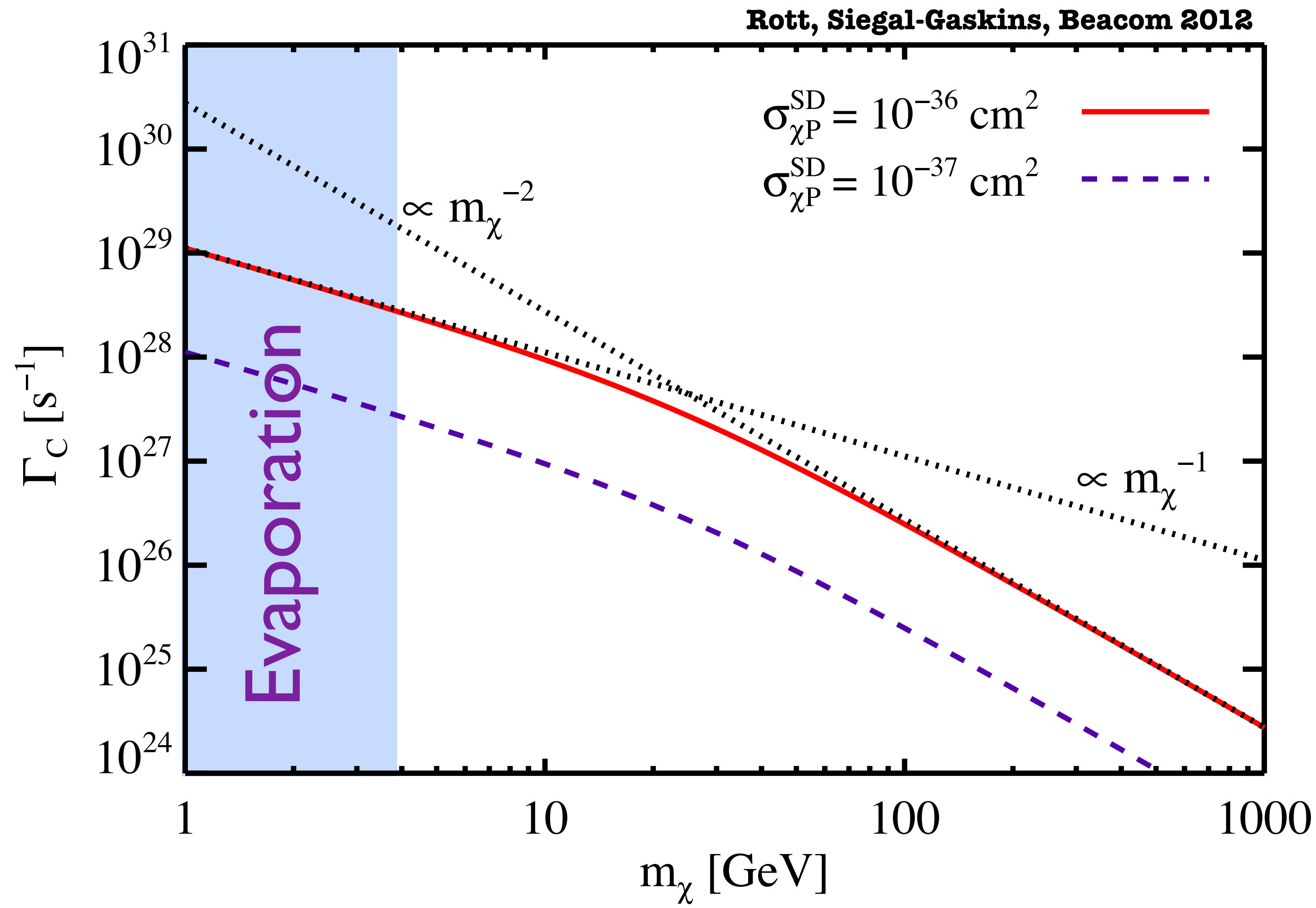
IC79 Solar WIMPs

TABLE II. Systematic errors on signal flux expectations in percent. Masses in GeV, Class-II uncertainties marked *

Source	benchmark masses		
	< 35	35 - 100	> 100
ν oscillations	6	6	6
ν-nucleon cross-section	7	5.5	3.5
μ-propagation in ice	<1	<1	<1
Time, position calibration	5	5	5
DOM sensitivity spread*	6	3	10
Photon propagation in ice*	15	10	5
Absolute DOM efficiency*	50	20	15
Total uncertainty	54	25	21

Solar WIMP Capture

- WIMPs can get gravitationally captured by the Sun
  - Capture rate, Γ_C ,depends on WIMP-nucleon scattering cross section
- Dark Matter accumulates and starts annihilating
  - → Only neutrinos can make it out
- Equilibrium: The capture rate regulates the annihilation rate ($\Gamma_A=\Gamma_C/2$)
  - The neutrino flux only depends on the WIMP-Nucleon scattering cross section



The capture rates scales as:

$\Gamma_C \sim \rho_\chi m_\chi^{-1} \sigma_A$ for $m_\chi \sim m_A$

$\Gamma_C \sim \rho_\chi m_\chi^{-2} \sigma_A$ for $m_\chi >> m_A$

number density + kinematic suppression

m_A - is the target mass