Galactic Dark Matter Signature in IceCube DeepCore

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Cross Strait Meeting

F.-F. Lee and G.-L. Lin, Phys. Rev D85, 023529 (2012)

F.-F. Lee G.-L Lin and Sming Tsai, in preparation

Outline

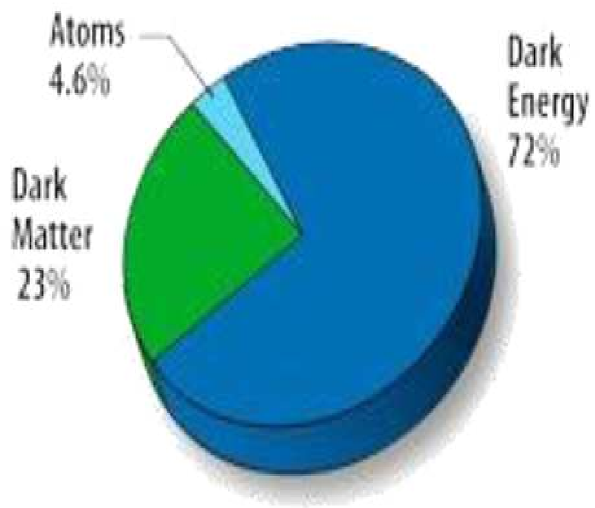
- Introduction
- IceCube 22-string search for galactic dark matter
- Detection sensitivity in IceCube+DeepCore—phenomenological analysis
- Constraints from gamma ray observations
- Summary

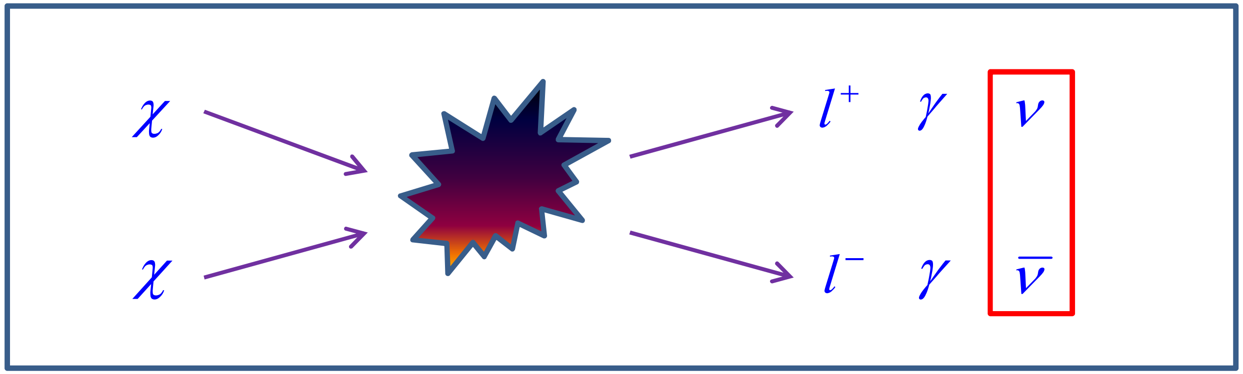
Dark Matter

◆ An unknown type of matter does neither emit nor reflect EM radiation.

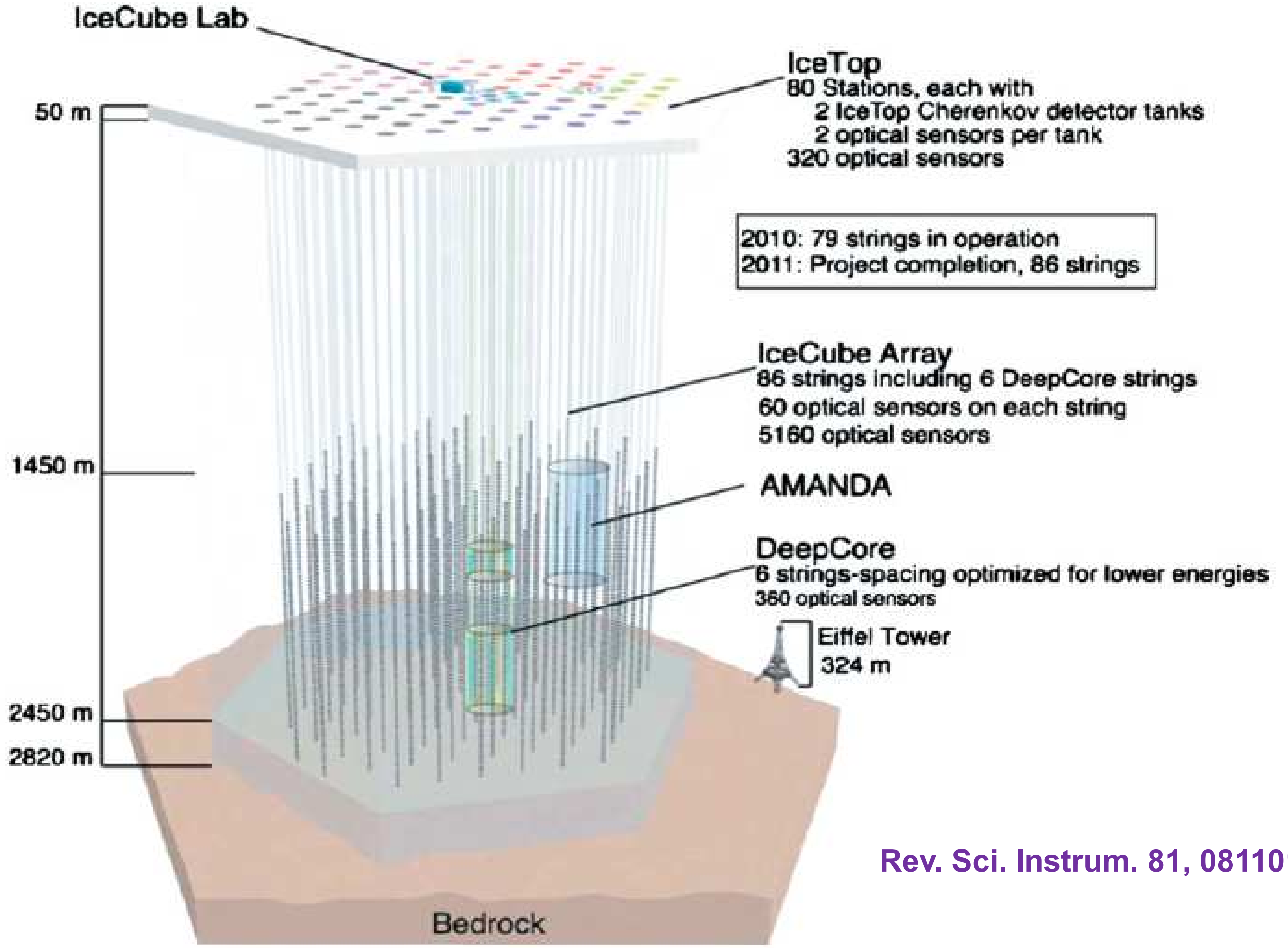
◆ Weakly Interacting Massive Particles (WIMPs) are one of the leading candidates for DM.

◆ WIMPs are theoretically well motivated and capable of producing the correct relic density.





IceCube Neutrino Observatory



Rev. Sci. Instrum. 81, 081101 (2010)

Detection threshold energy of **Iceube** > **100GeV**

Detection threshold energy of **Iceube + DeepCore** ~ **10GeV**

Track Events & Cascade Events

Track Events

Charged-Current ν_μ interaction : $\nu_\mu + N \rightarrow \mu^- + X$

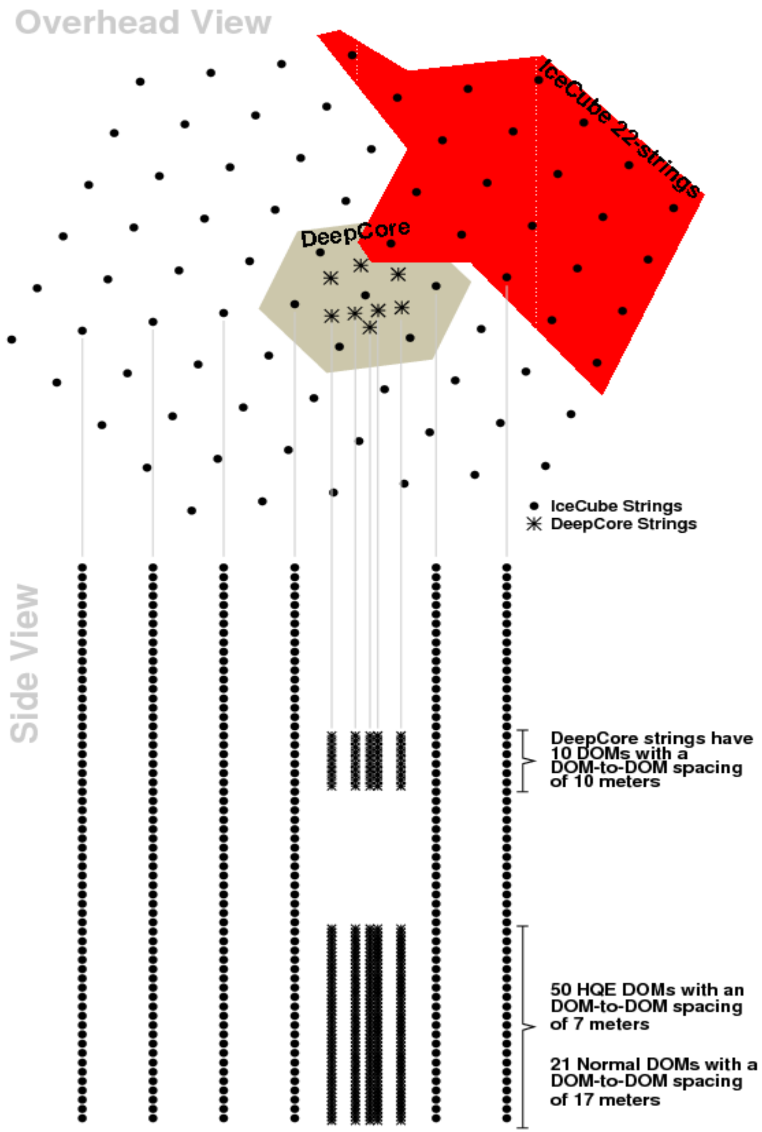
Cascade Events

Neutral-Current ν_l interaction : $\nu_l + N \rightarrow \nu_l + X\,(\text{Hadronic})$

Charged-Current ν_e interaction : $\nu_e + N \rightarrow e^-(\text{EM}) + X\,(\text{Hadronic})$

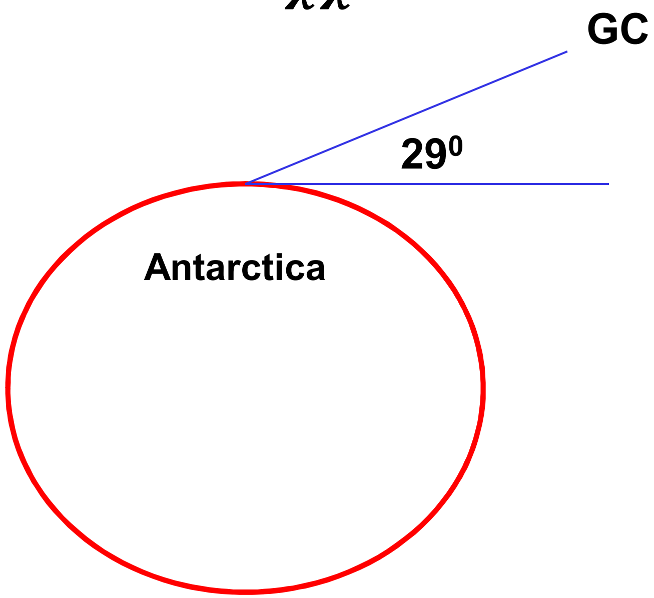
Charged-Current ν_τ interaction : $\nu_\tau + N \rightarrow \tau^- + X$

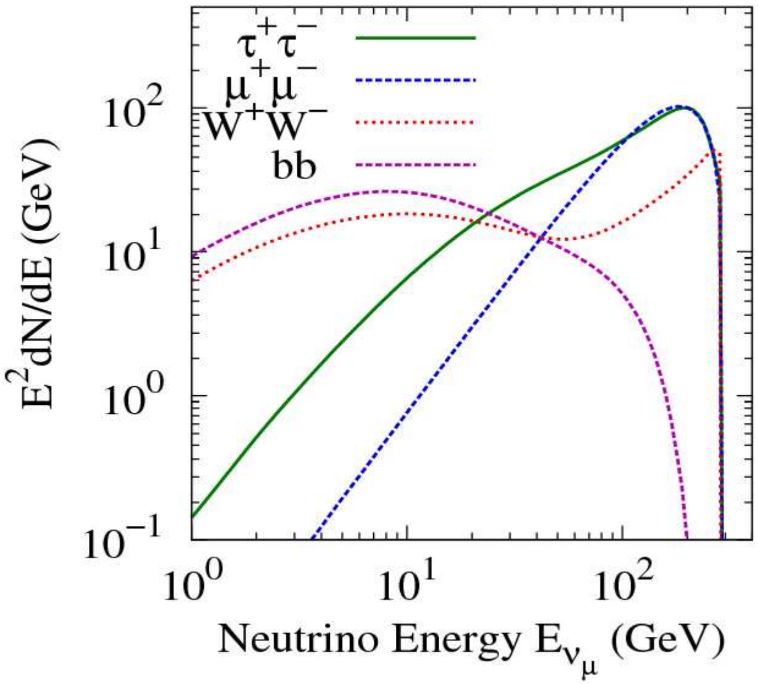
IceCube 22 String Result

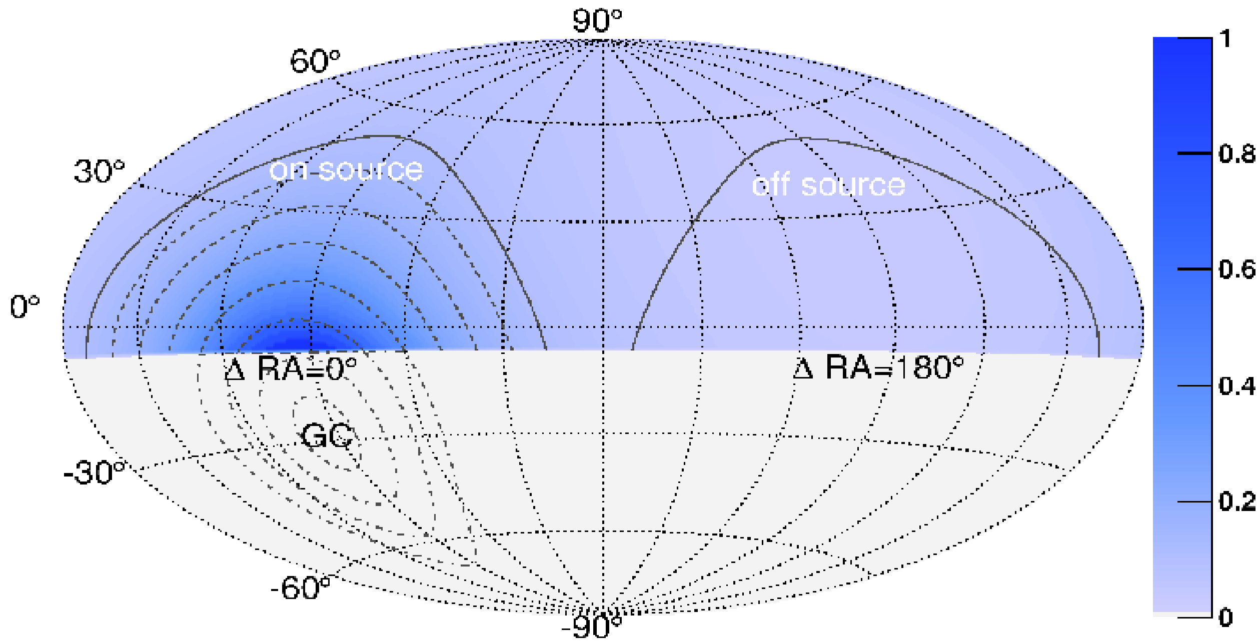


Phys. Rev. D 84, 022004 (2011)
2007~2008, 276 days of data

Also includes $\chi\chi \rightarrow \nu\bar{\nu}$

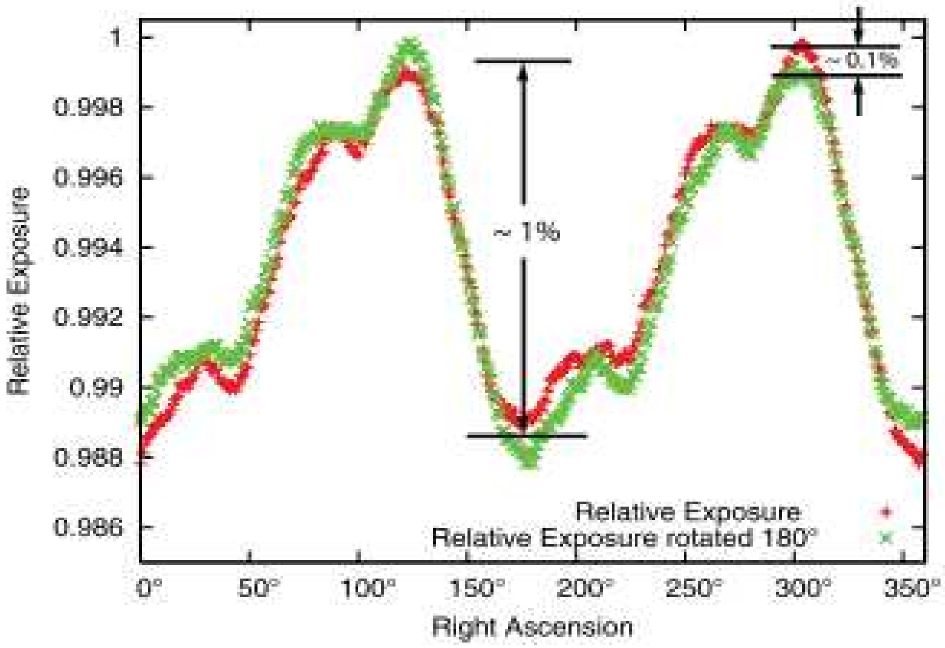






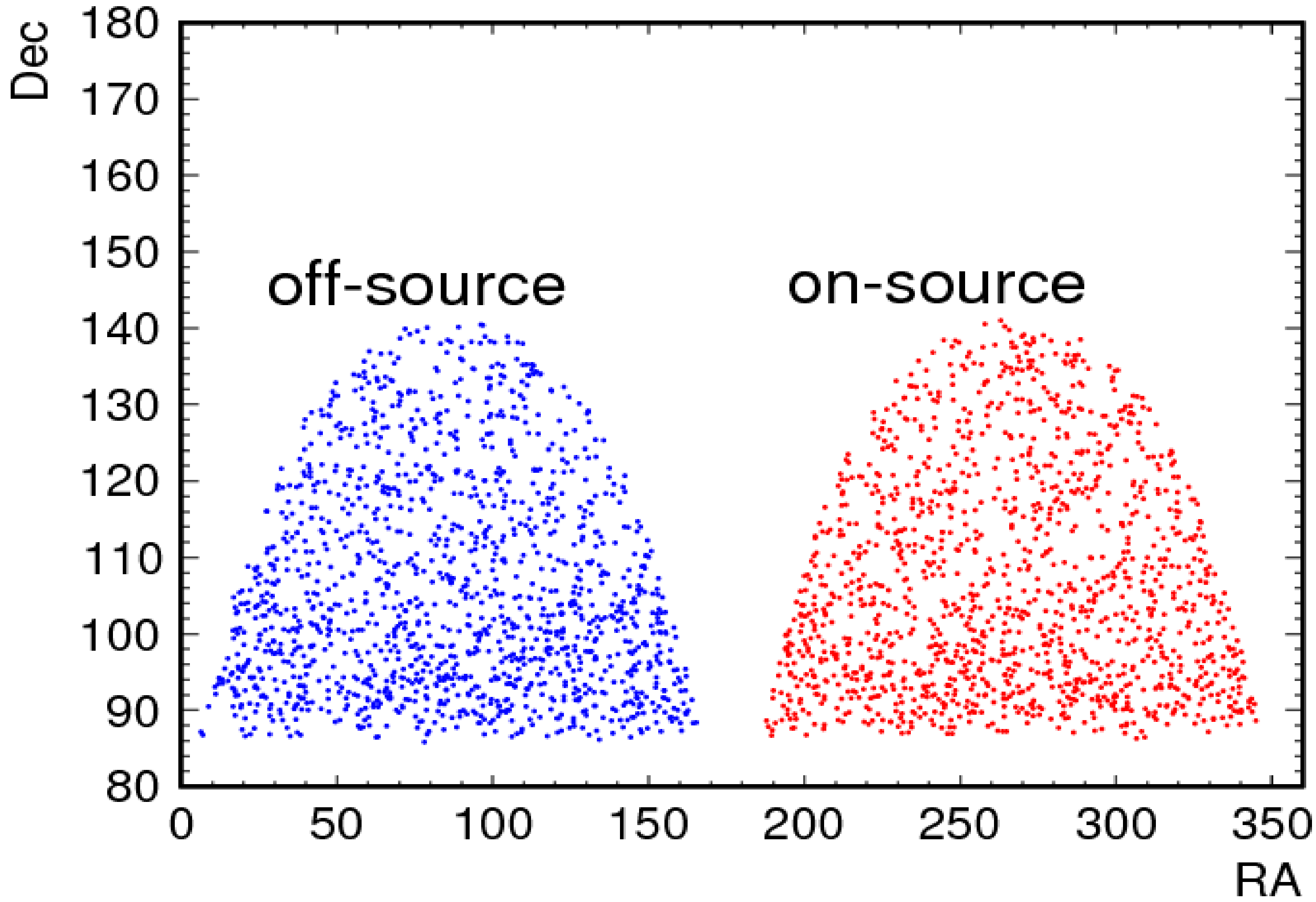
GC is located at
266° right ascension (RA)
And -29^0 declination.

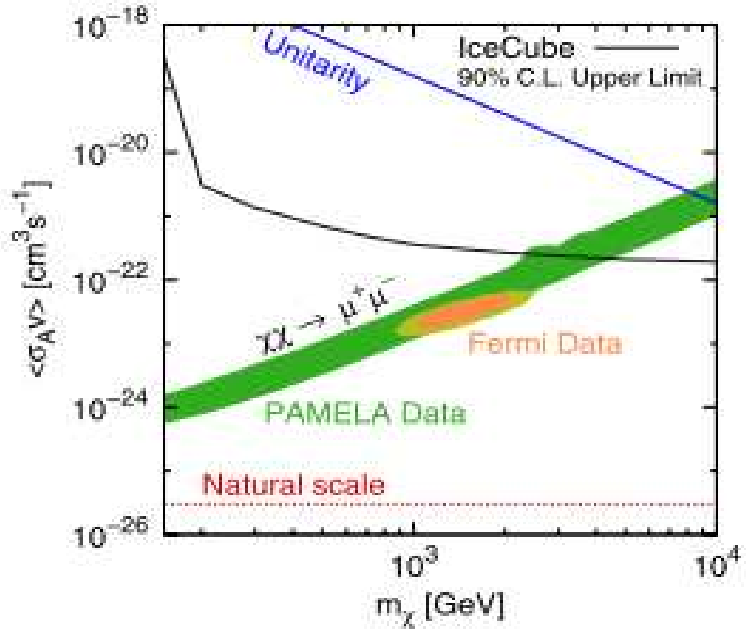
Select muon track events from -5^0 to 85^0 in declination.

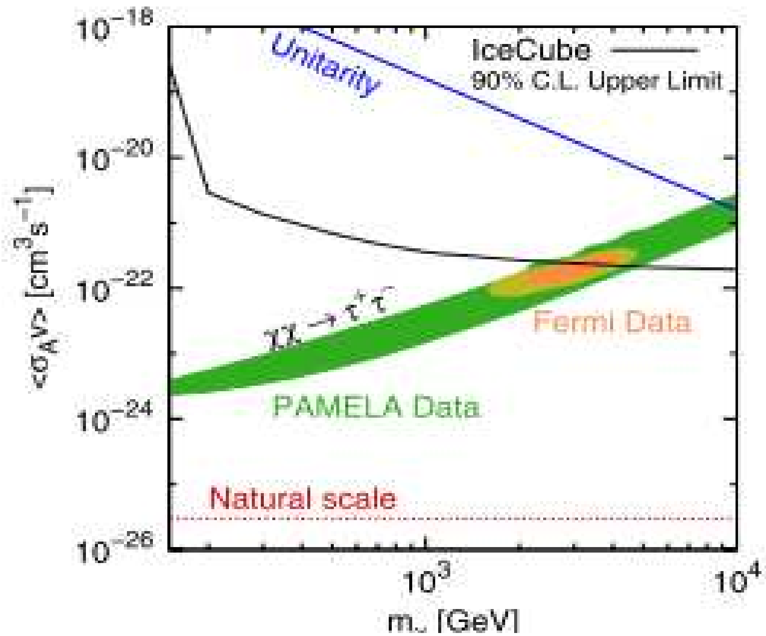


Measure $\Delta N=(N^{bkg}_{on}+N^{sig}_{on})-(N^{bkg}_{off}+N^{sig}_{off}) \approx \Delta N^{sig}$

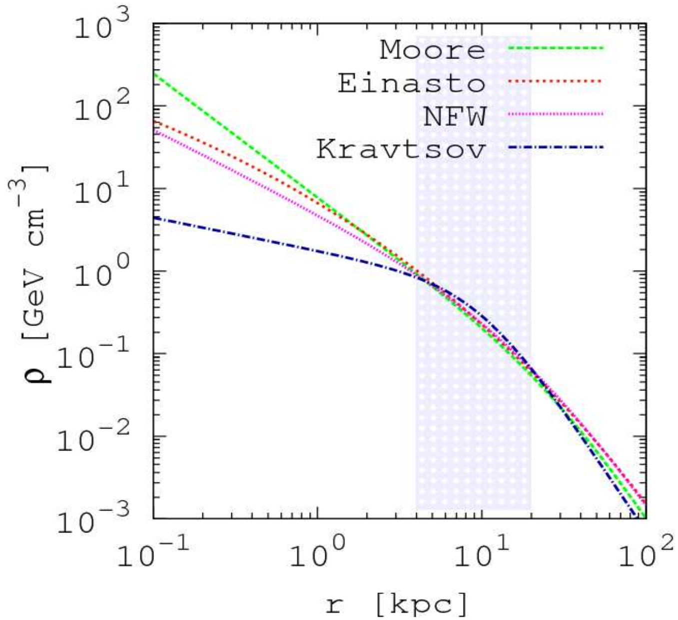
Search results







This result is almost independent of galactic halo model

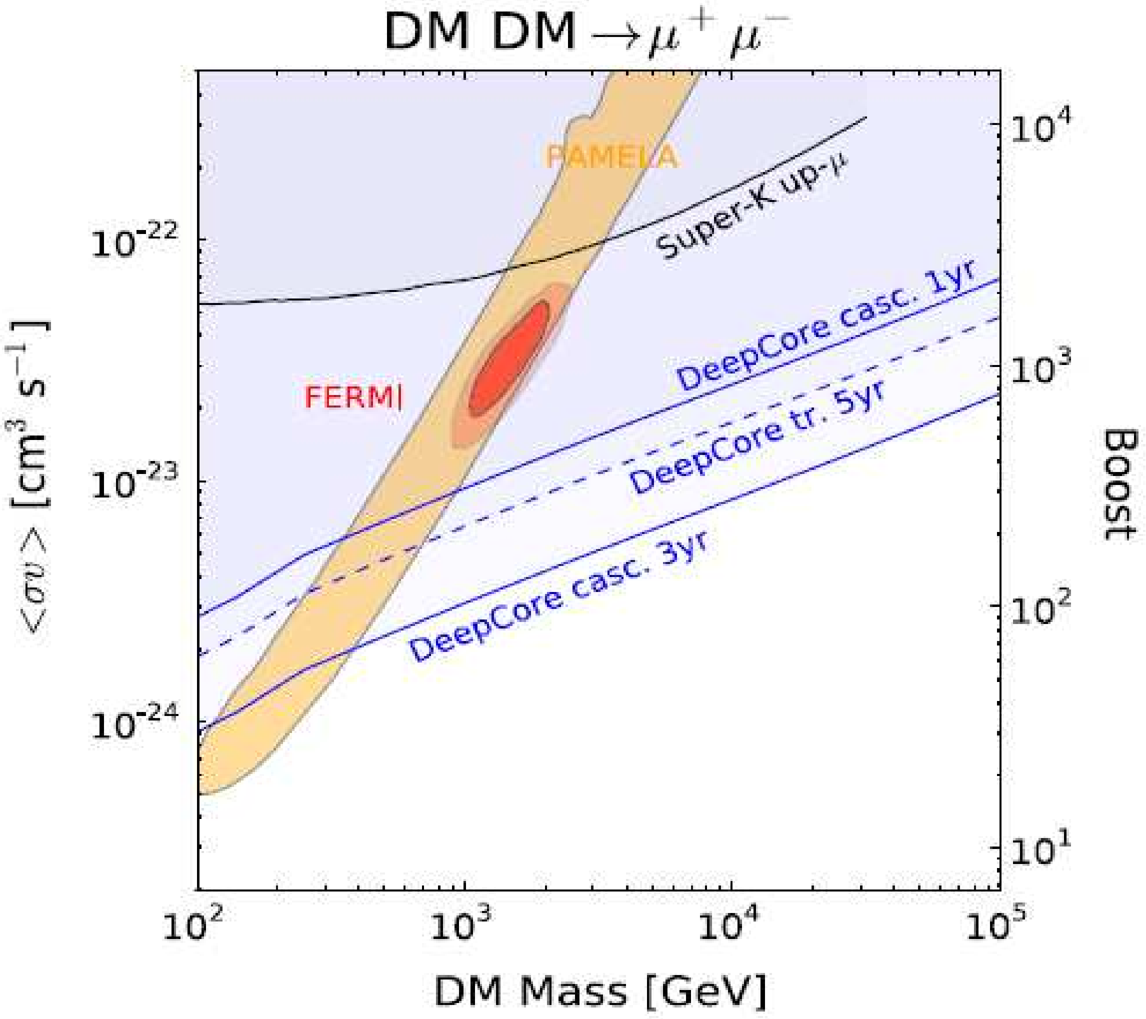


PAMELA: GeV positron excess
Fermi: electron spectra

Constraints for annihilation to $\mu^+\mu^-$

S. K. Mandal et al. Phys. Rev. D81, 2010

P. Meade et al. Nucl. Phys. B 831, 2010

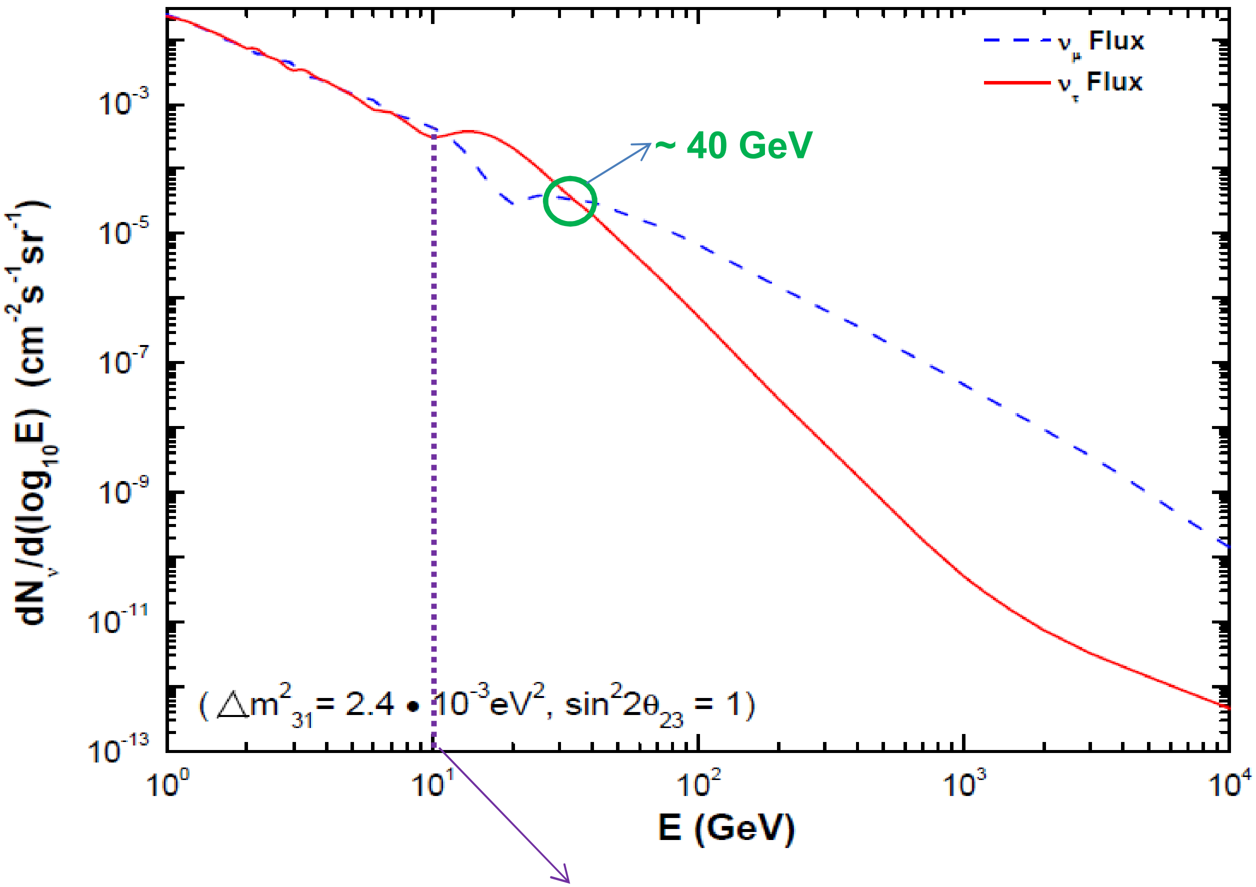


- Constraints are expected to Improve with DeepCore data
- Look for downward going neutrinos from GC, in additional to upward going events
  - E^{th} =40 GeV

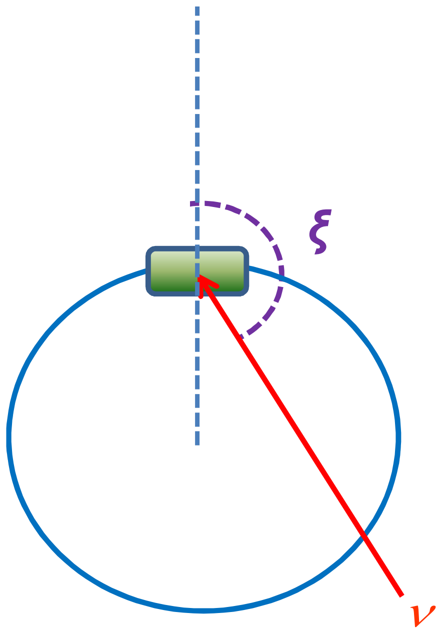
We are interested in low DM mass case
Consider 10 GeV energy threshold for track and shower

Atmospheric neutrino fluxes averaged for $-1 \leqq \cos\xi \leqq -0.4$

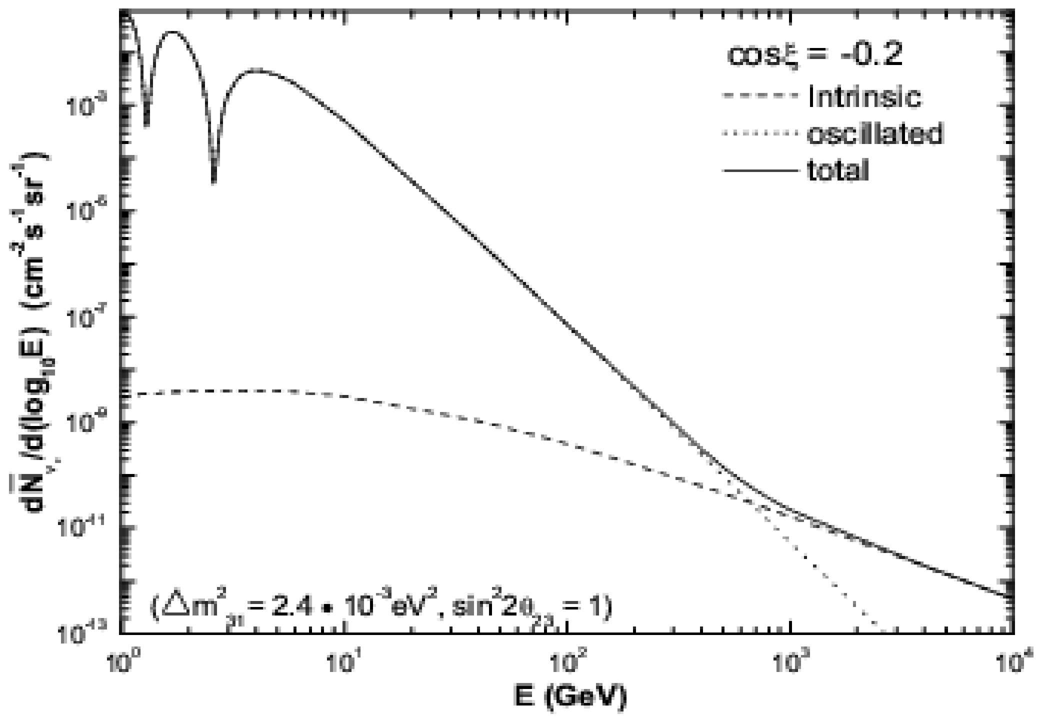
F. F. Lee, G. L. Lin, Astropart. Phys. 25, 2006



Detection threshold energy of Iceube + DeepCore

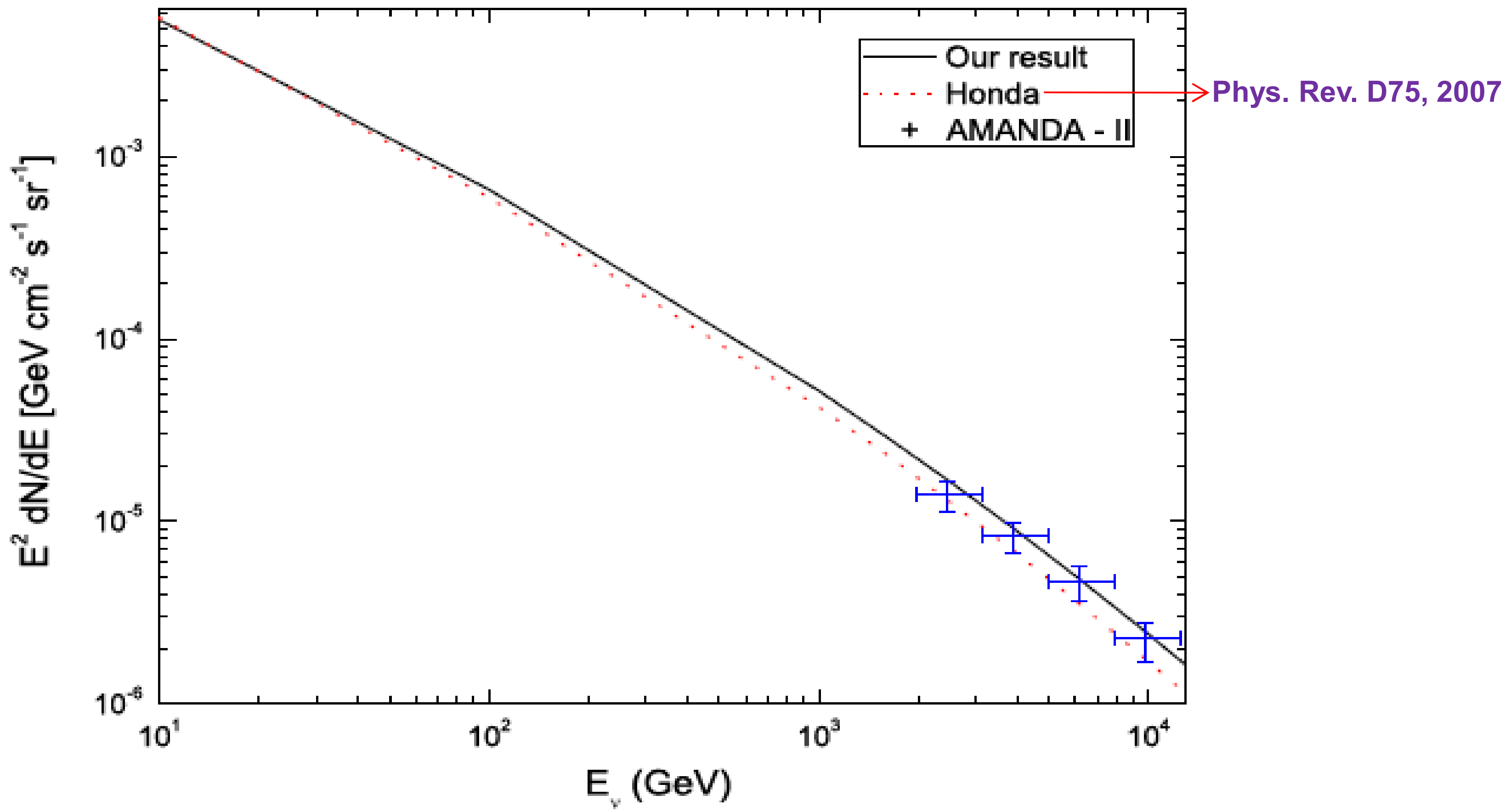


ν_τ flux $\cos\xi = -0.2$



Angle-averaged atmospheric muon neutrino flux for 0 ≦ cosξ ≦ 1

(without oscillations)



Comparison with Honda flux and AMANDA-II measurement

Neutrino flux from DM decay in the galactic halo

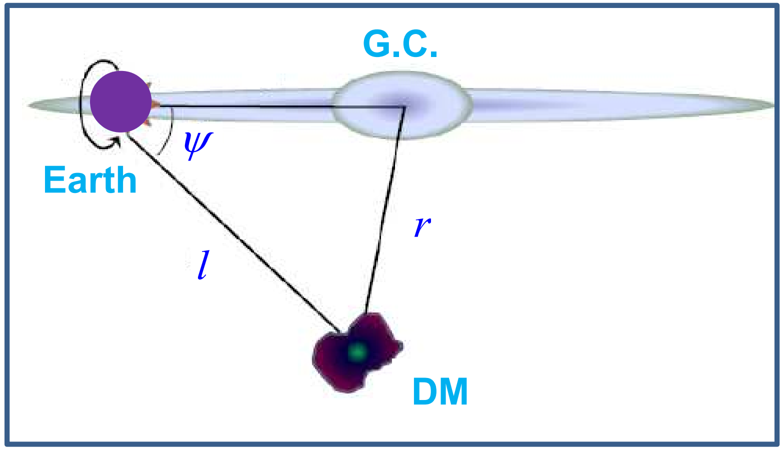
$$\frac{d\Phi_{\nu_i}}{dE_{\nu_i}} = \frac{\Delta\Omega}{4\pi}\frac{1}{m_\chi \tau_\chi}\left(\sum_F B_F \frac{dN^F_{\nu_i}}{dE}\right) R_\oplus \rho_\oplus \times J_1(\Delta\Omega) \quad \propto \frac{\rho}{m_\chi \tau_\chi}$$

- $R_\oplus = 8.5\,\mathrm{kpc}$: distance from the galactic center to the solar system
  $\rho_\oplus = 0.3\,\mathrm{GeV/cm^3}$: DM density in the solar neighborhood
  $dN^F_{\nu_i}/dE$: neutrino spectrum per decay for a given decay channel F
  τ_χ : DM lifetime
- $J_1(\Delta\Omega)$ is the DM distribution integrated over the line-of-sight (l.o.s) for decay and averaged over a solid angle $\Delta\Omega = 2\pi(1 - \cos\psi_{max})$

$$J_1(\Delta\Omega) = \frac{1}{\Delta\Omega}\int_{\Delta\Omega} d\Omega \int_{l.o.s} \frac{dl}{R_\oplus}\left(\frac{\rho(r(l,\psi))}{\rho_\oplus}\right)^1$$

Navarro-Frenk-White (NFW) DM density profile

$$\rho(r) = \rho_s\left(\frac{R_s}{r}\right)\left(\frac{R_s}{R_s + r}\right)^2$$



Neutrino flux from DM annihilation in the galactic halo

$$\frac{d\Phi_{\nu_i}}{dE_{\nu_i}} = \frac{\Delta\Omega}{4\pi}\frac{\langle\sigma\upsilon\rangle}{2m_\chi^2}\left(\sum_F B_F \frac{dN_{\nu_i}^F}{dE}\right) R_\oplus \rho_\oplus^2 \times J_2(\Delta\Omega) \quad \propto \frac{\rho^2\langle\sigma\upsilon\rangle}{2m_\chi^2}$$

- $<\sigma v>$ is the thermally averaged annihilation cross section

$$\langle\sigma\upsilon\rangle = B\langle\sigma\upsilon\rangle_0$$

B : boost factor . $<\sigma v>_0 = 3 \times 10^{-26}\ cm^3 s^{-1}$: typical cross section for DM relic density.

- $J_2(\Delta\Omega)$ is the line-of-sight (l.o.s) integral for annihilation

$$J_2(\Delta\Omega) = \frac{1}{\Delta\Omega}\int_{\Delta\Omega} d\Omega \int_{l.o.s} \frac{dl}{R_\oplus}\left(\frac{\rho(r(l,\psi))}{\rho_\oplus}\right)^2$$

Neutrino fluxes on Earth

$$\begin{pmatrix} \Phi_{\nu_e} \\ \Phi_{\nu_\mu} \\ \Phi_{\nu_\tau} \end{pmatrix} = \begin{pmatrix} P_{ee} & P_{e\mu} & P_{e\tau} \\ P_{\mu e} & P_{\mu\mu} & P_{\mu\tau} \\ P_{\tau e} & P_{\tau\mu} & P_{\tau\tau} \end{pmatrix} \begin{pmatrix} \Phi^0_{\nu_e} \\ \Phi^0_{\nu_\mu} \\ \Phi^0_{\nu_\tau} \end{pmatrix} = P \begin{pmatrix} \Phi^0_{\nu_e} \\ \Phi^0_{\nu_\mu} \\ \Phi^0_{\nu_\tau} \end{pmatrix}$$

J. G. Learned, Astropart. Phys. 3, 1995
H. Athar et al. Phys. Rev. D62, 2000
L. Bento et al. Phys. Lett. B476, 2000
K. C. Lai et al. Phys. Rev. D82, 2010

- $\Phi^0_{\nu_\alpha}$: neutrino flux at the astrophysical source
- Φ_{ν_α} : neutrino flux measured on the Earth
- $P_{\alpha\beta}$: probability of the oscillation $\nu_\beta \to \nu_\alpha$

- In the tribimaximal limit of neutrino mixing angles: $\sin^2\theta_{23} = 1/2, \sin^2\theta_{12} = 1/3, \sin^2\theta_{13} = 0$

$$P = \begin{pmatrix} \frac{5}{9} & \frac{2}{9} & \frac{2}{9} \\ \frac{2}{9} & \frac{7}{18} & \frac{7}{18} \\ \frac{2}{9} & \frac{7}{18} & \frac{7}{18} \end{pmatrix}$$

$\Rightarrow$

$$\begin{cases} \Phi_{\nu_e} = \frac{5}{9}\Phi^0_{\nu_e} + \frac{2}{9}\Phi^0_{\nu_\mu} + \frac{2}{9}\Phi^0_{\nu_\tau} \\ \Phi_{\nu_\mu} = \Phi_{\nu_\tau} = \frac{2}{9}\Phi^0_{\nu_e} + \frac{7}{18}\Phi^0_{\nu_\mu} + \frac{7}{18}\Phi^0_{\nu_\tau} \end{cases}$$

- with recently measured θ_{13} value: $\sin^2 2\theta_{13} = 0.092$

Dayabay best fit, PRL108, 171803(2012)

See also

Double Chooz, PRL108, 131801 (2011)

RENO arXiv:1204.0626

$$P = \begin{pmatrix} 0.53 & 0.26 & 0.21 \\ 0.26 & 0.37 & 0.37 \\ 0.21 & 0.37 & 0.42 \end{pmatrix}$$

Event Rates

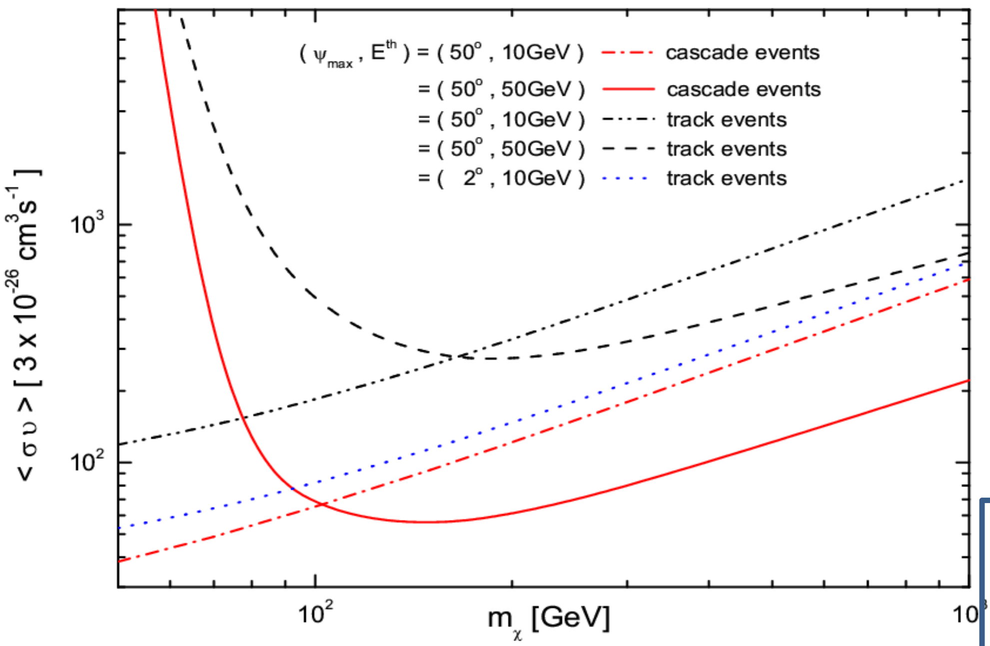
$$\Gamma_{\text{track}} = \int_{E_\mu^{\text{th}}}^{E_{\max}} \mathrm{d}E_\mu \int_{E_\mu}^{E_{\max}} \mathrm{d}E_{\nu_\mu} N_A \rho_{\text{ice}} V_{\text{tr}} \times \frac{\mathrm{d}\Phi_{\nu_\mu}}{\mathrm{d}E_{\nu_\mu}} \cdot \frac{\mathrm{d}\sigma^{CC}_{\nu_\mu N}\left(E_{\nu_\mu}, E_\mu\right)}{\mathrm{d}E_\mu} + (\nu \rightarrow \bar{\nu})$$

$$\Gamma_{\text{cascade}} = \int_{E_{\text{shower}}^{\text{th}}}^{E_{\max}} \mathrm{d}E_{\text{shower}} \int_{E_{\text{Shower}}}^{E_{\max}} \mathrm{d}E_\nu N_A \rho_{\text{ice}} V_{\text{casc}} \times \frac{\mathrm{d}\Phi_\nu}{\mathrm{d}E_\nu} \cdot \frac{\mathrm{d}\sigma_{\nu N}\left(E_\nu, E_{\text{shower}}\right)}{\mathrm{d}E_{\text{shower}}} + (\nu \rightarrow \bar{\nu})$$

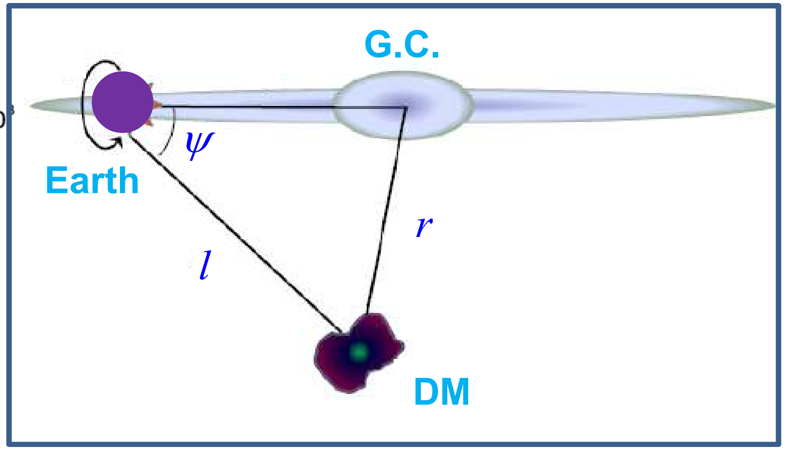
→ $(\nu_e N)_{\text{CC}}$, $(\nu_e N)_{\text{NC}}$, $(\nu_\mu N)_{\text{NC}}$, $(\nu_\tau N)_{\text{CC}}$, $(\nu_\tau N)_{\text{NC}}$

- $\rho_{\text{ice}} = 0.9\ \text{g cm}^{-3}$ is the density of ice ; $N_A = 6.022 \times 10^{23}\ \text{g}^{-1}$ is Avogadro's number
- $V_{\text{tr}} \approx 0.04\ \text{km}^3$ is the effective volume of IceCube DeepCore array for muon track events
  $V_{\text{casc}} \approx 0.02\ \text{km}^3$ is the effective volume of IceCube DeepCore array for cascade events
- $E_{\max}$ is taken as m_χ for DM annihilatoin ; $E_{\max}$ is taken as $\frac{m_\chi}{2}$ for DM decay
- $\frac{\mathrm{d}\Phi_{\nu_e}}{\mathrm{d}E_{\nu_e}}$ is taken from **M. Honda et al. Phys. Rev. D75, 2007**

Constraints for DM annihilation cross section

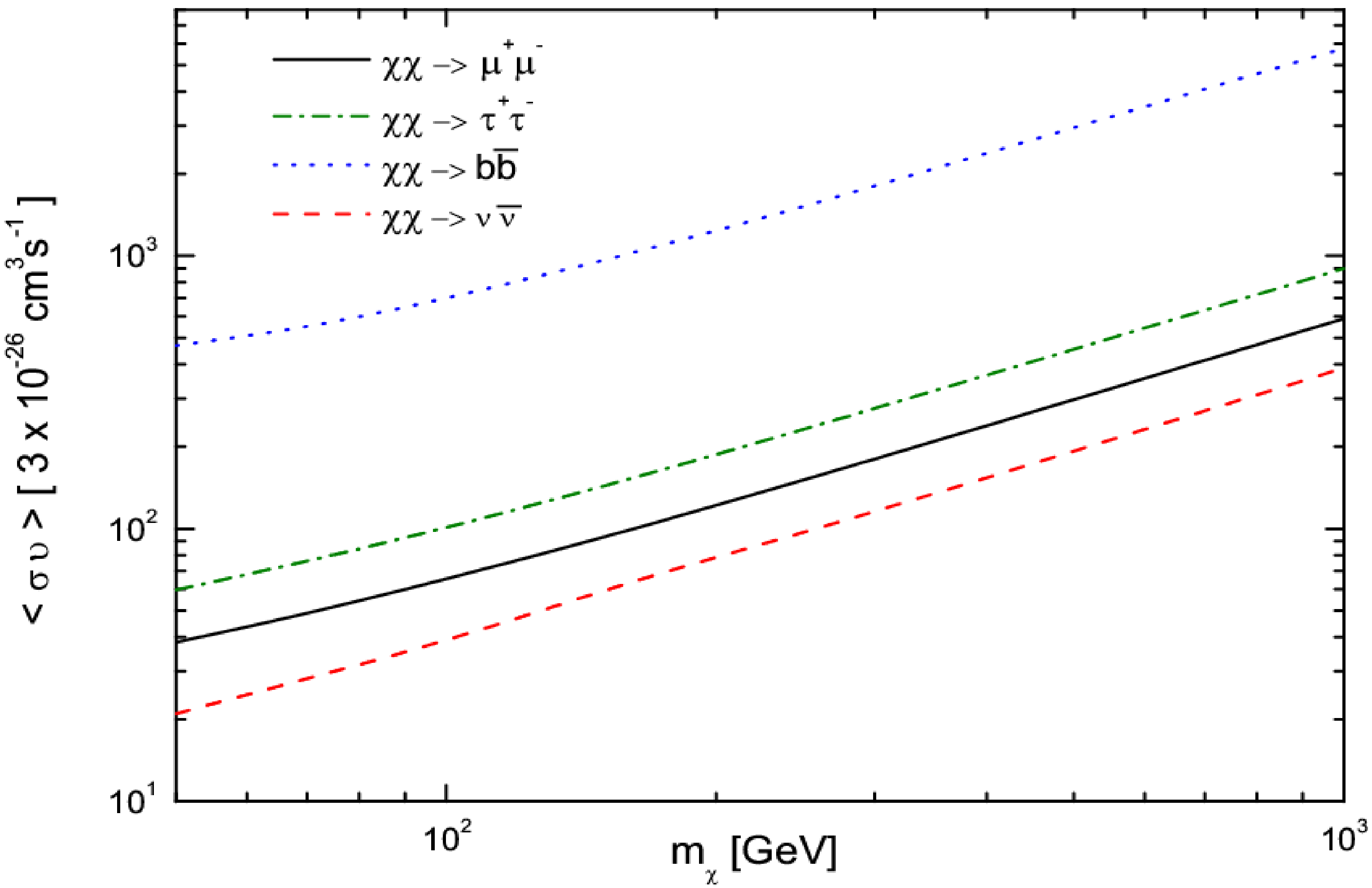


2σ in 5 years



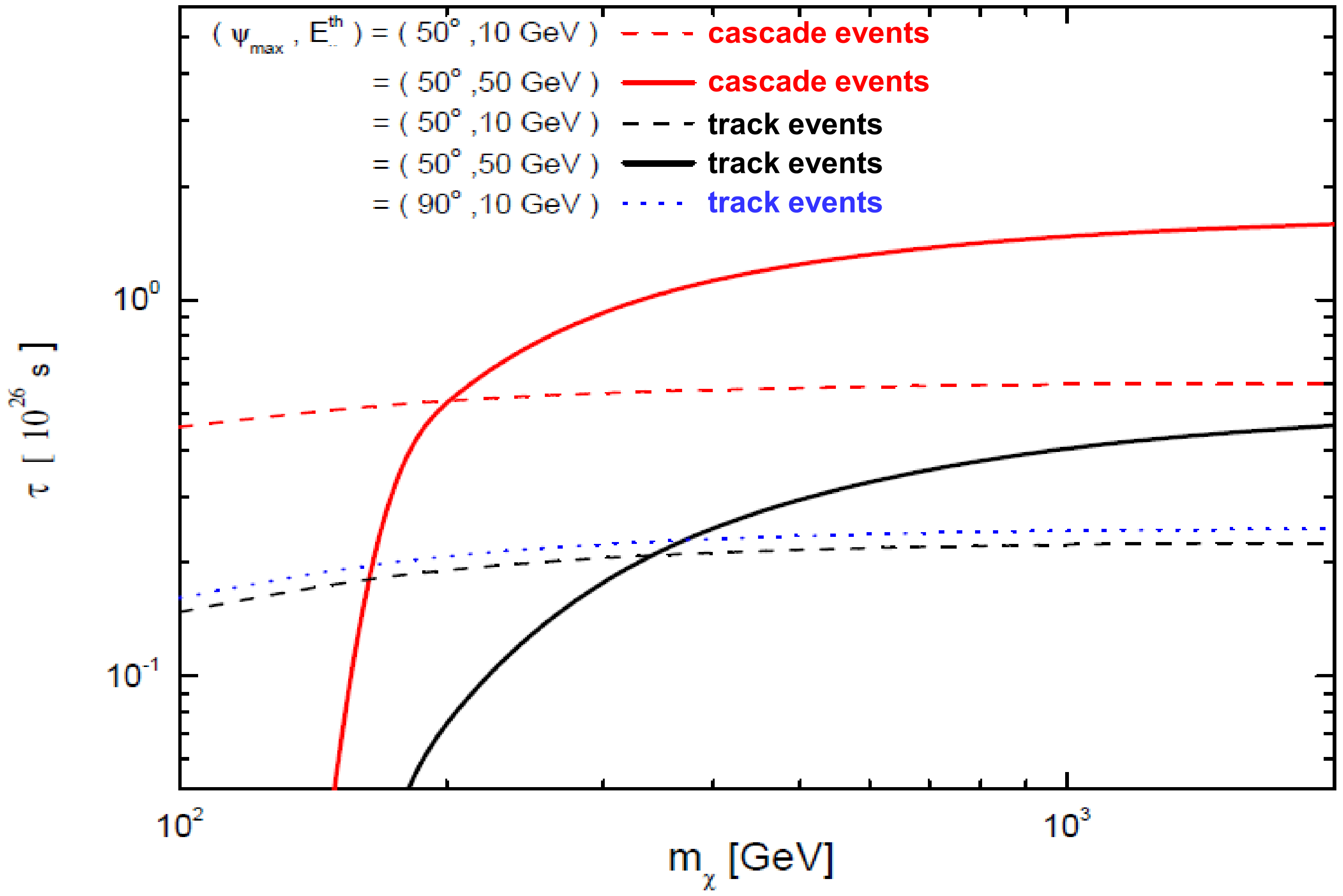
$\chi\chi \rightarrow \mu^+\mu^-$

50 GeV threshold from A. E. Erkoca, M. H. Reno, I. Sarcevic, Phys. Rev. D82, 2010

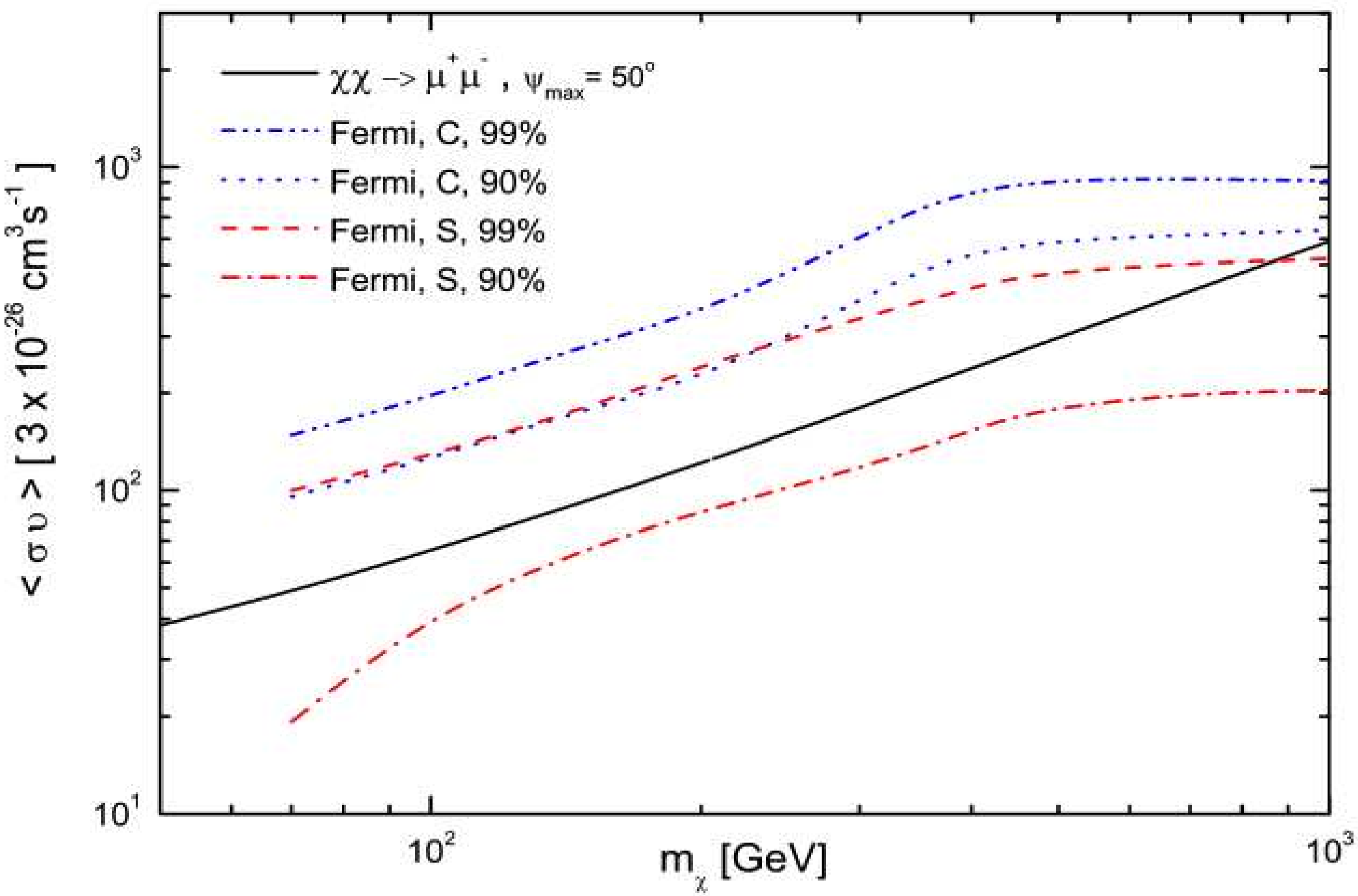


Constraints on various modes

Constraints for DM decay $\chi \to \mu^+ \mu^-$ (track & cascade)



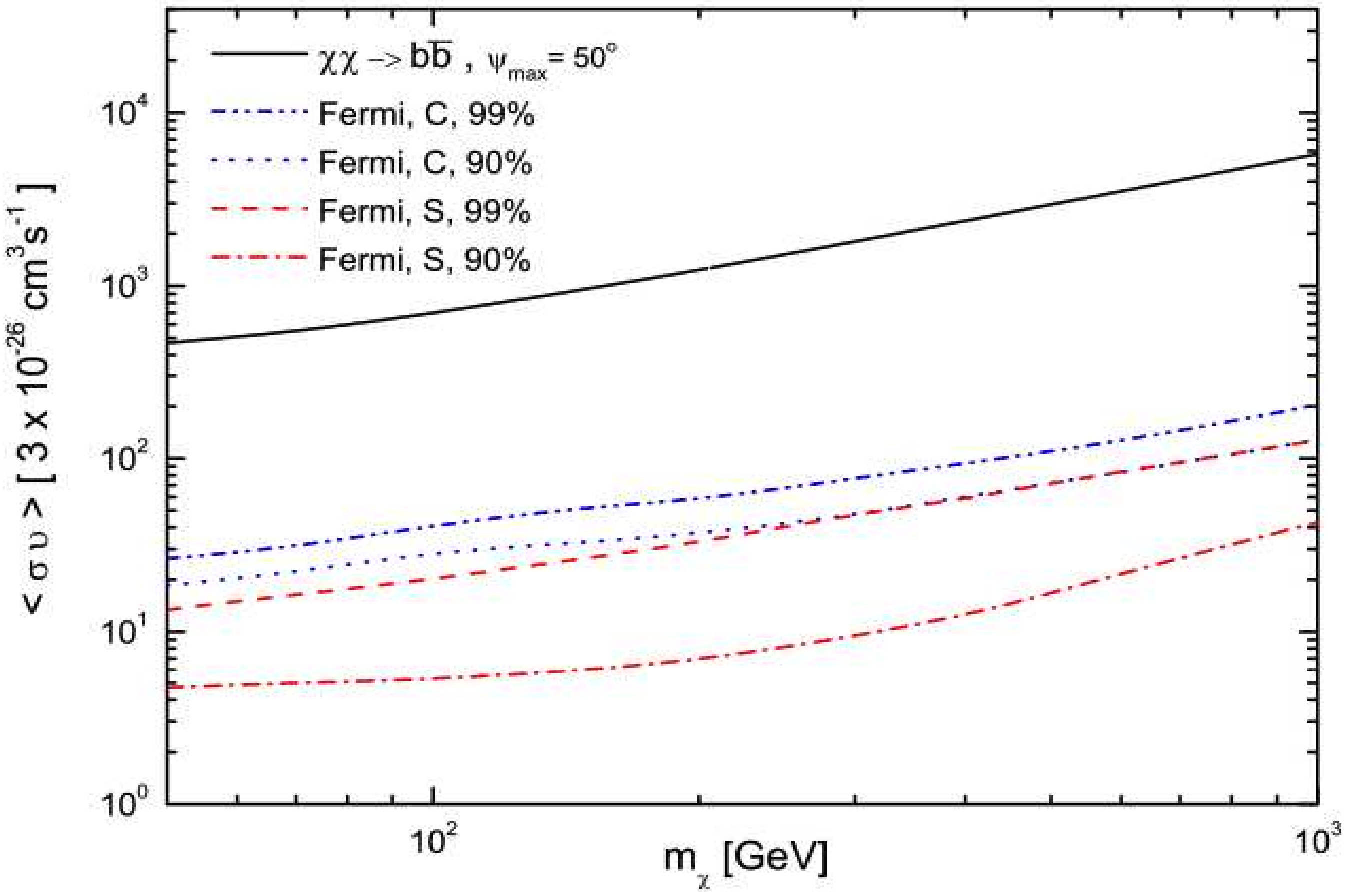
Compare with Fermi-LAT constraints
Detecting extragalactic isotropic gamma-ray



99.999% (4.3 σ) actually **A.A. Abdo et al., JCAP04 (2010) 014**

20 MeV to 300 GeV

Compare with Fermi-LAT constraints



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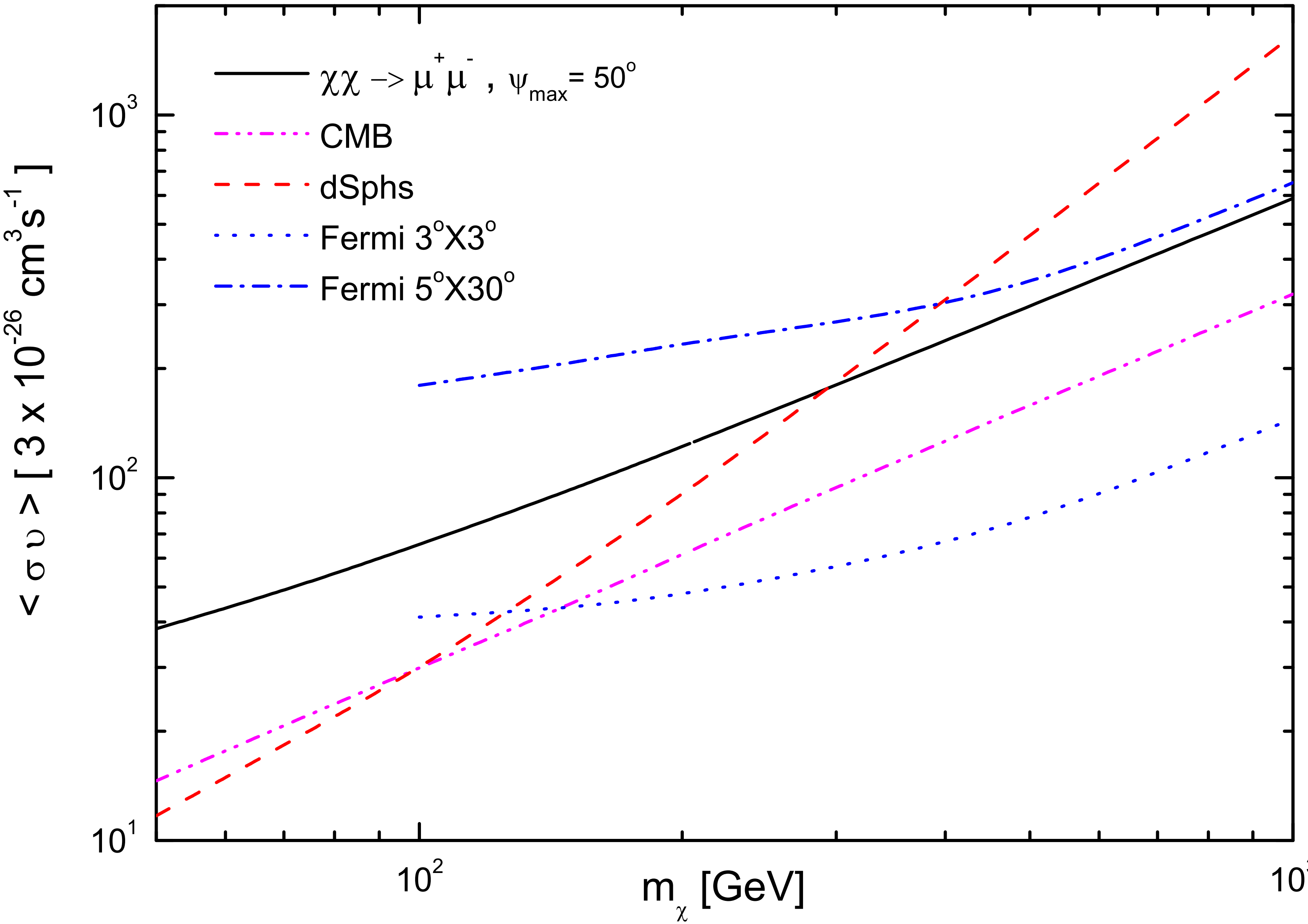
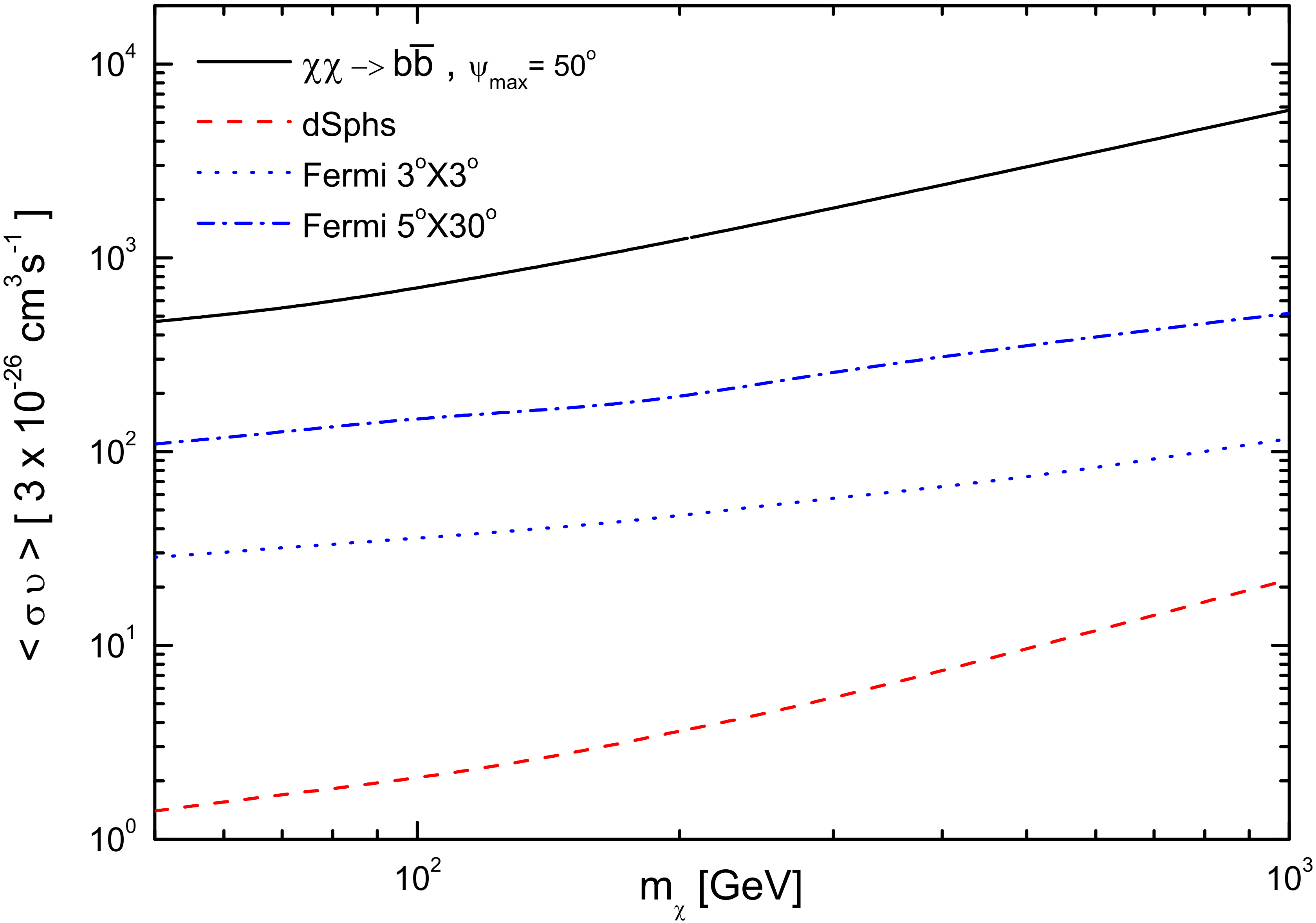
More comparisons



More comparisons



Direct neutrino production not constrained by gamma ray

Summary

(1) We employ NFW DM profile to calculate the track and cascade event rates in IceCube DeepCore due to neutrino fluxes from WIMP annihilations and decays in the galactic halo.

(2) We take into account neutrino oscillations and calculate the event rates due to atmospheric neutrino background.

(3) Cascade events provide stronger constraints on DM annihilation cross section and DM decay time than the corresponding constraints provided by track events with the same threshold energy.

(4) Fermi_LAT gamma ray constraints are generally more stringent than those expected at IceCube DeepCore. On the other hand, DM annihilating directly into neutrino pair is not constrained by gamma ray.

Summary

(5) KM3NeT situated in northern hemisphere could provide better sensitivity on DM annihilation cross section.

http://www.km3net.org/TDR/TDRKM3NeT.pdf