Constraining dark matter capture and annihilation cross sections by searching for neutrino signature from the Earth core

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Based upon work done with Fei-Fan Lee and Yue-Lin Sming Tsai

Outline:

a. Dark matter capture and annihilation in the Earth core
b. Calculation of neutrino signal and background event rates
c. Three scenarios on σ^{SI}_p and their implications on constraining $\langle\sigma v\rangle$
d. Summary

Capture and annihilation in the Earth core

$$\Gamma_A(t) = \frac{C_c}{2}\tanh^2\left(\frac{t}{\tau_A}\right)$$

$\Gamma_A(t)$: determines the neutrino flux

C_c: capture rate depends on σ^{SI}_p and gravitational potential of specific chemical element

$\tau_A \equiv 1/\sqrt{C_c C_A}$ equilibrium time scale with the annihilation coefficient $C_A = \frac{\langle\sigma v\rangle}{V_0}\left(\frac{m_\chi}{20GeV}\right)^{2/3}$

Hence neutrino flux depends on both σ^{SI}_p and $\langle\sigma v\rangle$

DM induced neutrino flux from the Sun is more sensitive to σ^{SD}_p

General Background

- Probing $\chi\chi \rightarrow \nu\bar{\nu}$ from Earth core with IceCube were discussed in I. F. M. Albuquerque, L. J. B. e Silva, and C. P. de los Heros, Phys. Rev. D 85, 123539 (2012), for large DM mass (few hundred GeV to TeV).
- Probing $\chi\chi \rightarrow \tau^+\tau^-$ from Earth Core with IceCube were also discussed in C. Delaunay, P. J. Fox, and G. Perez, J. High Energy Phys.05 (2009) 099 for large DM mass as well.
- We consider light DM mass as well and include DeepCore capability in our discussions. All possible annihilation channels are discussed.

DM signal and atmospheric background

$$N_{\text{signal}} = \int_{E^{\text{th}}}^{m_\chi} \sum_{i,k} \frac{d\Phi_{\nu_i}^{\text{DM}}}{dE_\nu} A_{\text{eff}}^{i,k}(E_\nu)\, dE_\nu\, d\Omega$$

$$\frac{\text{DM signal}}{\sqrt{\text{ATM background}}} = 2.0$$

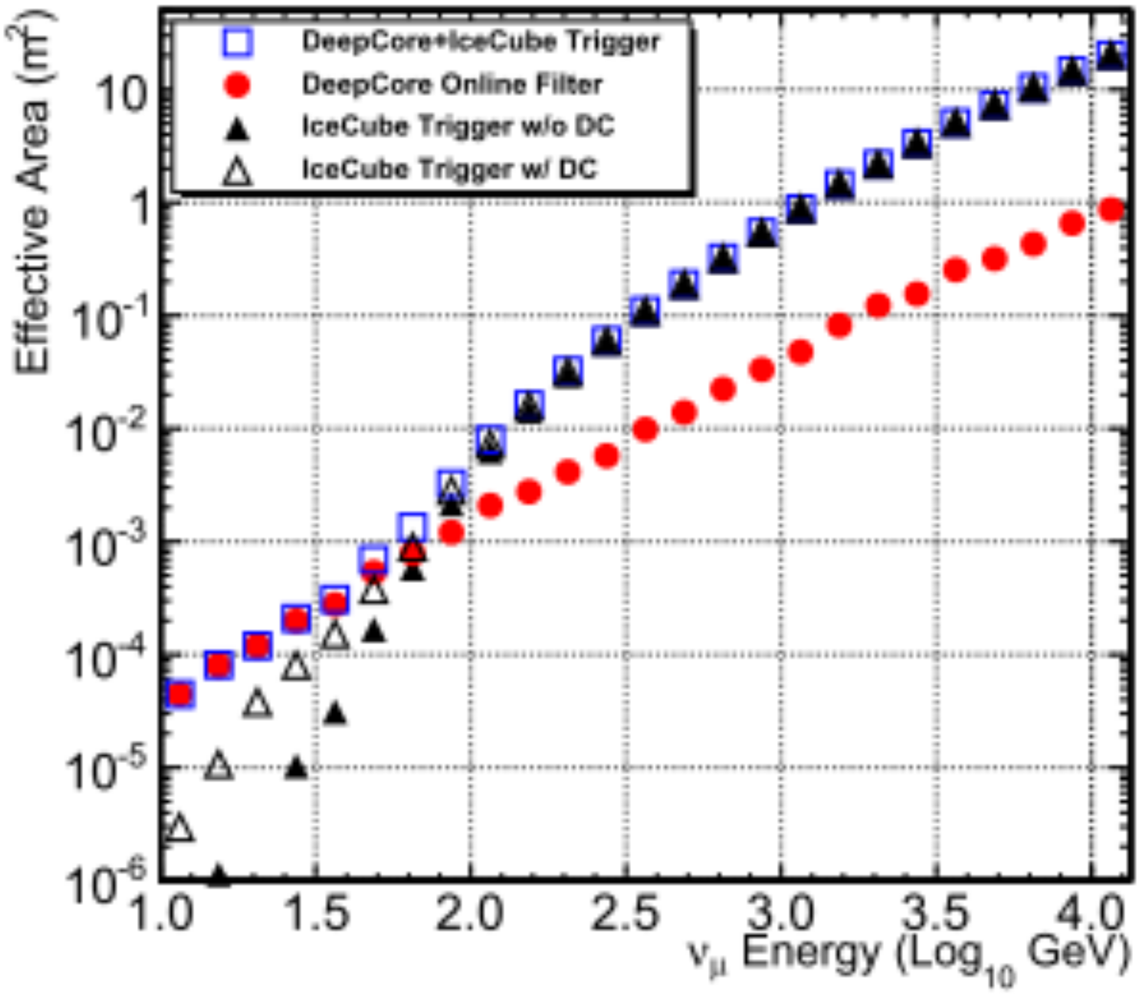
$$N_{\text{background}} = \int_{E^{\text{th}}}^{E_{\max}} \sum_{i,k} \frac{d\Phi_{\nu_i}^{\text{ATM}}}{dE_\nu} A_{\text{eff}}^{i,k}(E_\nu)\, dE_\nu\, d\Omega$$

2σ detection
Significance in
5 years

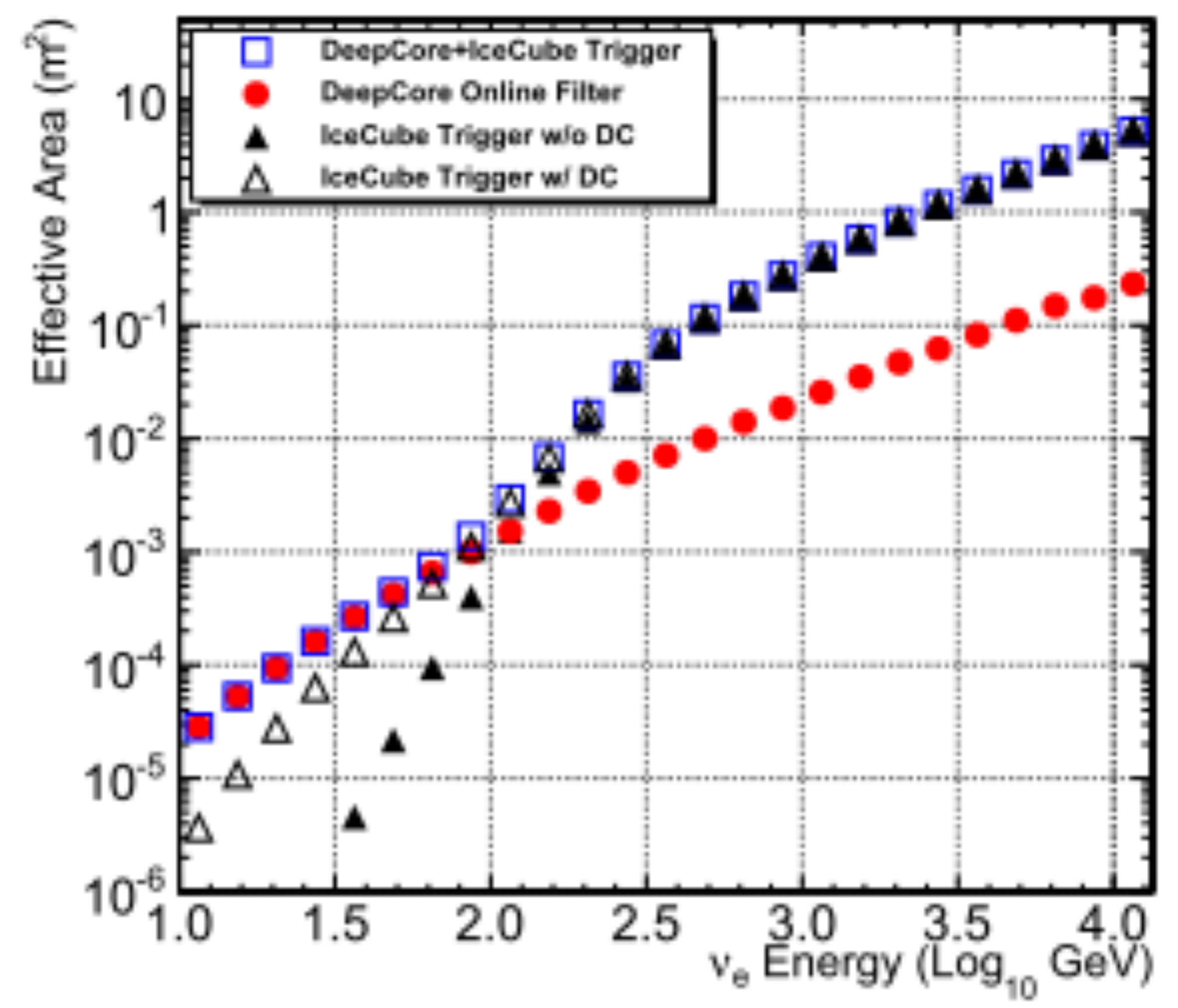
i: neutrino flavor, k: CC or NC interaction

Calculation done by WIMPSIM
M. Blennow, J. Edsjo and T. Ohlsson, JCAP 0801, 021 (2008)

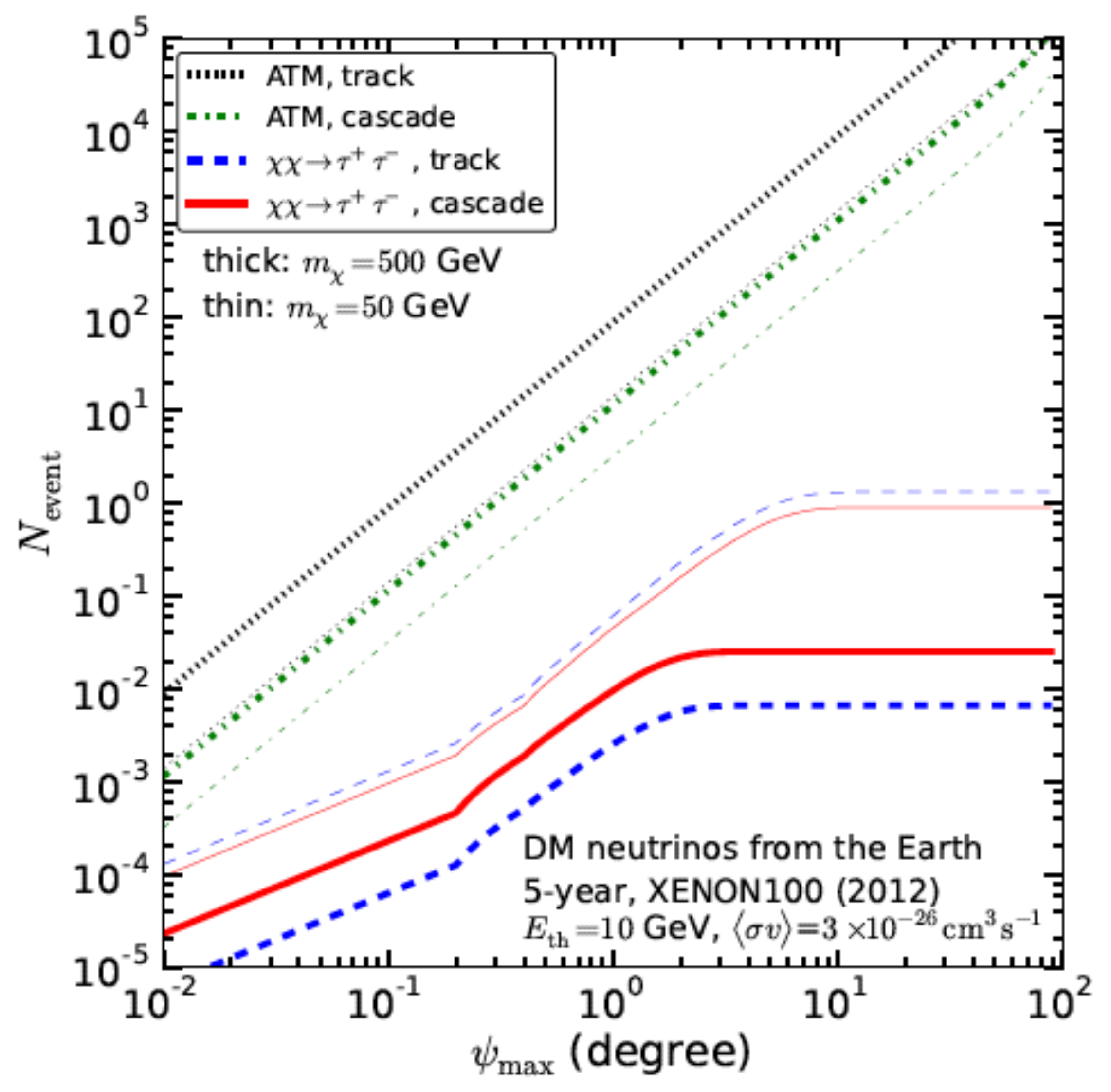
IceCube Effective Areas-Track Events



IceCube Effective Areas-Cascade Events

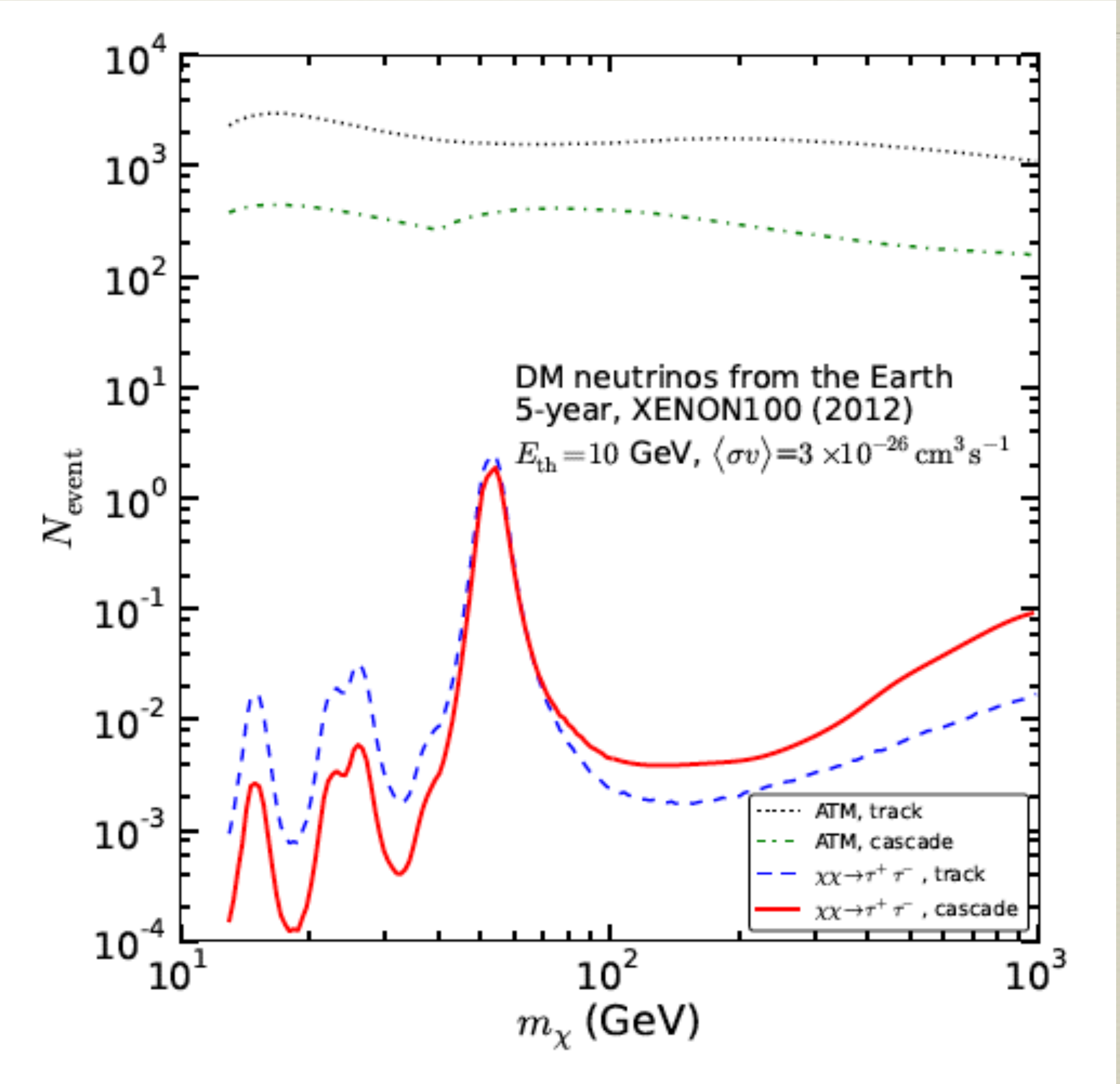


$\psi_{\max}$: observation open angle toward the Earth core



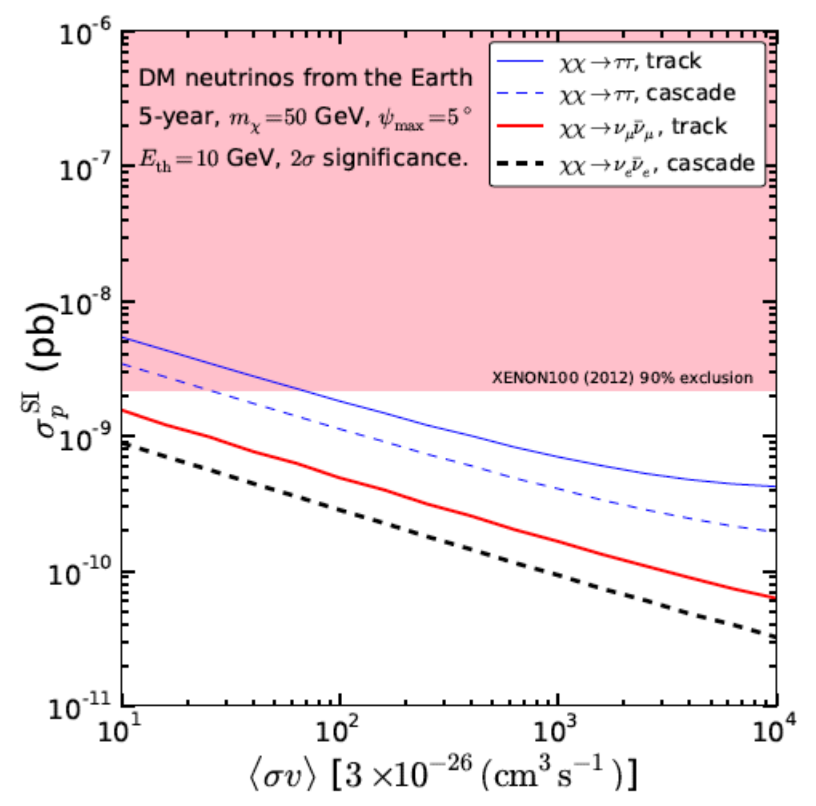
$\psi^{c}_{\max}$:

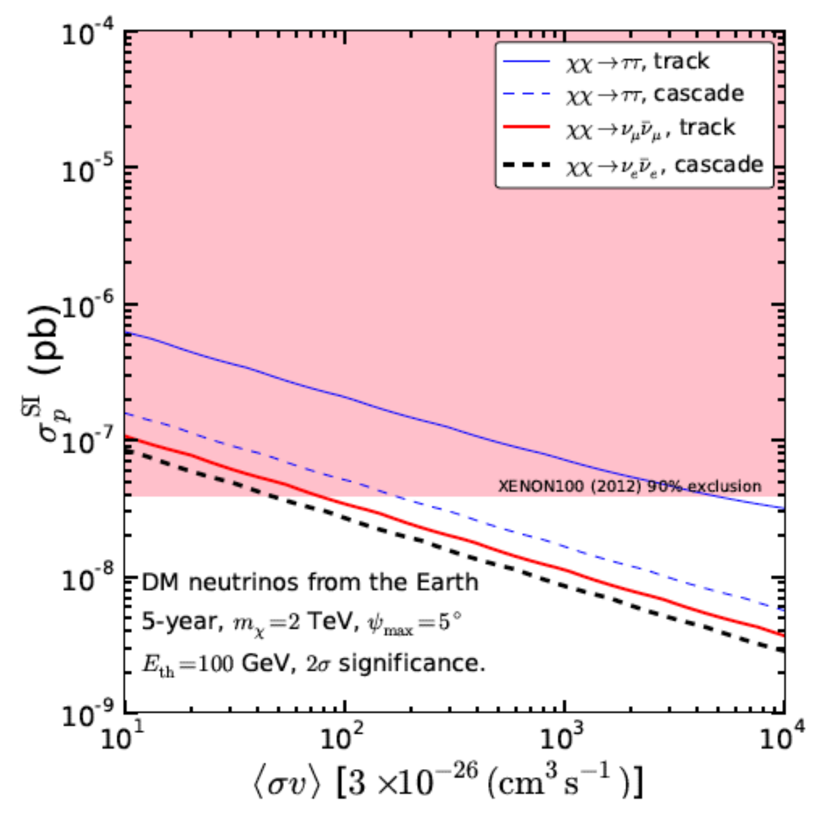
critical value of $\psi_{\max}$ when N_{event} no longer increases



Several resonance peaks for $N_{\rm event}$

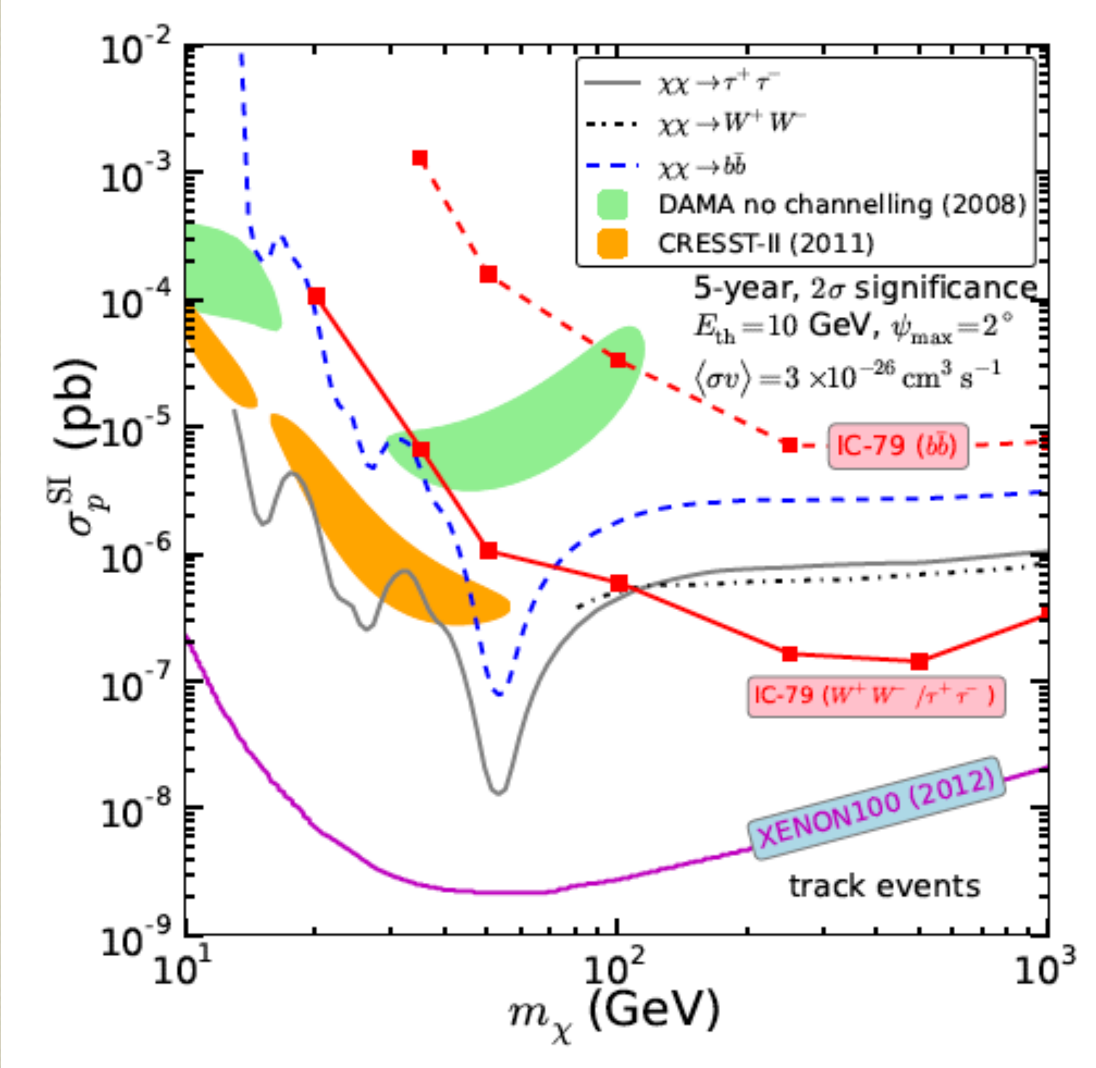
Comparison of small and large m_χ





- For larger m_χ, 2σ significance requires larger <σv>
- Sensitivity for each channel is derived by assuming dominant branching fraction for that particular channel.

Scenario A: Neutrino observation implied by DAMA and CRESST-II



- IC-79: IceCube 79 string result from the search for DM annihilation in the Sun

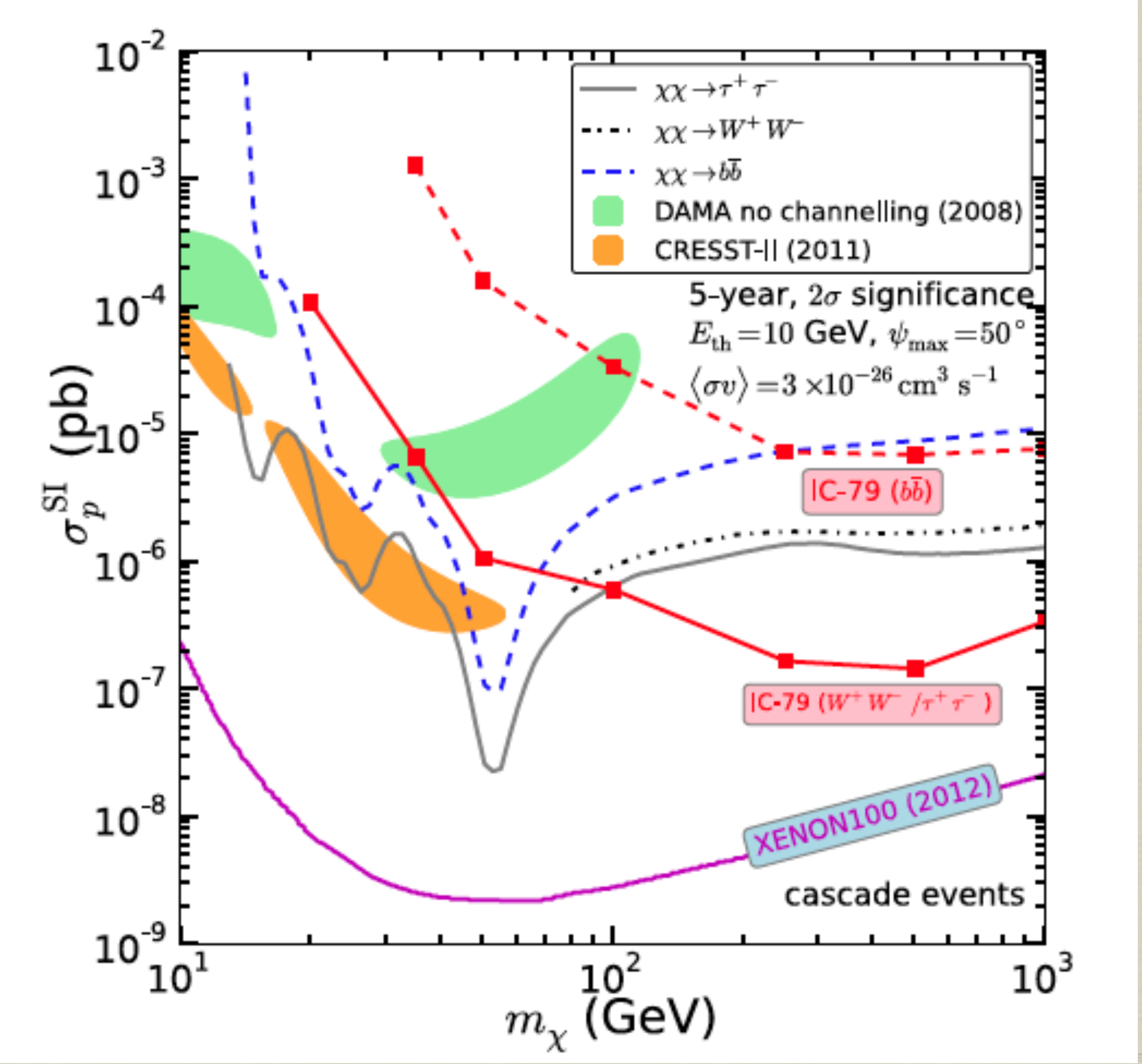
- M. G. Aartsen et al. [IceCube Collaboration], Phys. Rev. Lett. 110, 131302 (2013)

Track events

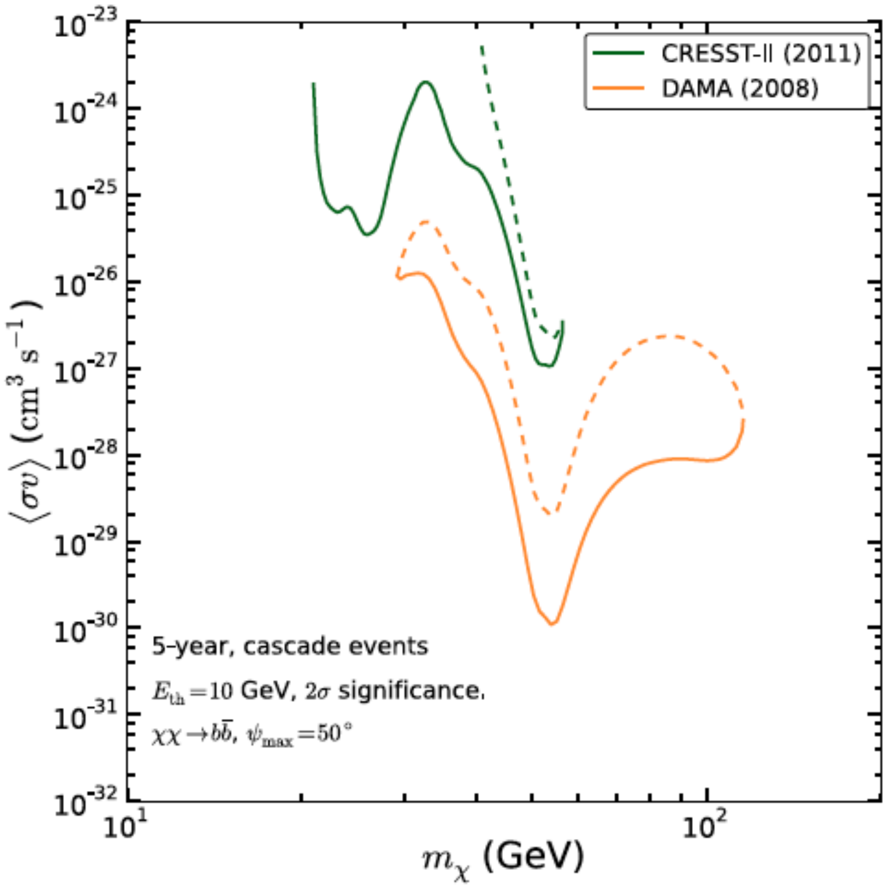
$\Psi_{\rm max}$=2°

$\langle\sigma v\rangle = 3\times10^{-26}\,{\rm cm^3 s^{-1}}$

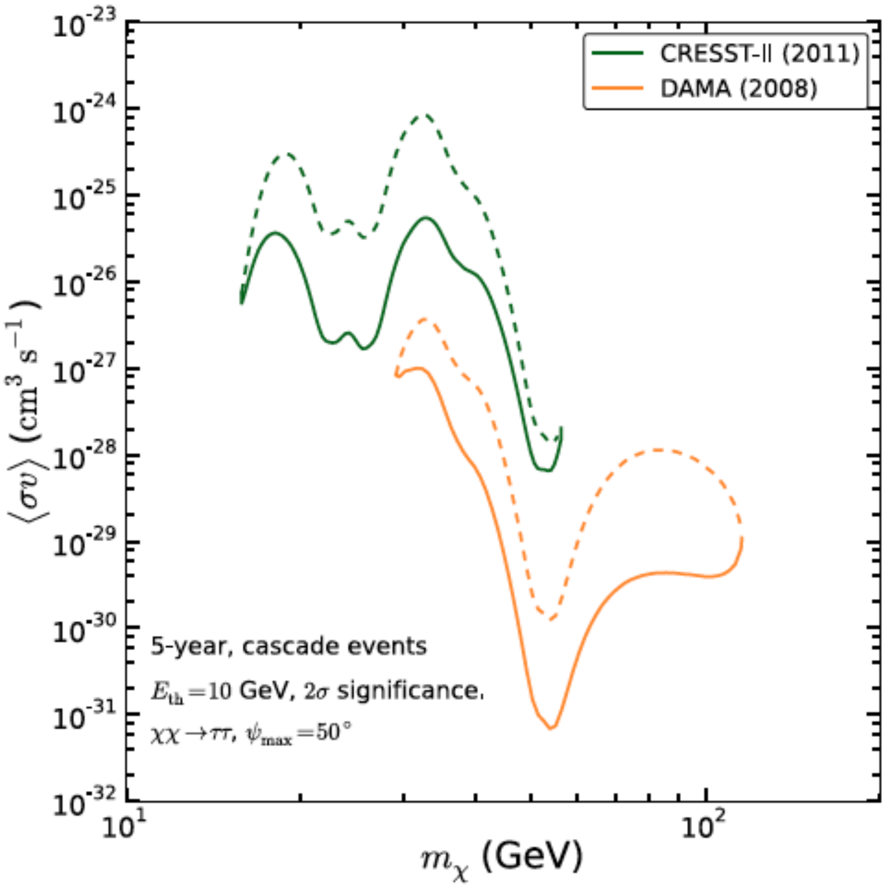
Cascade events Ψ_{max}=50°



One can probe <σv> to values much smaller than 3×10^{-26}cm^{3}s^{-1} if σ^{SI}_p js given by DAMA or CRESST-II

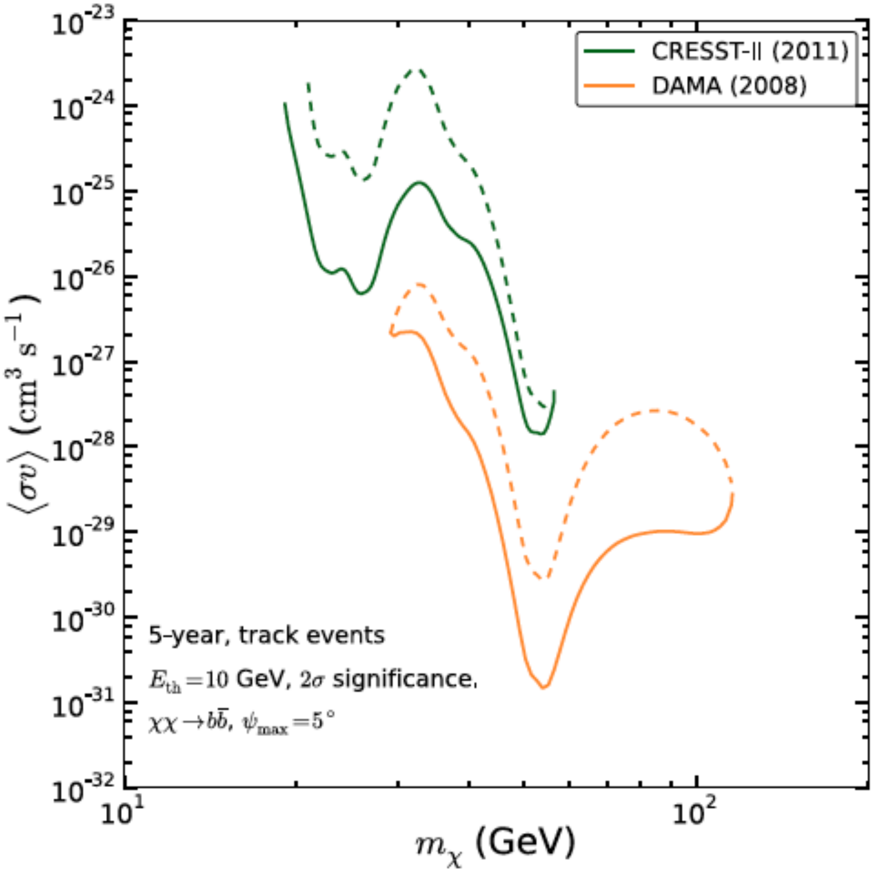


$b\bar{b}$ final state

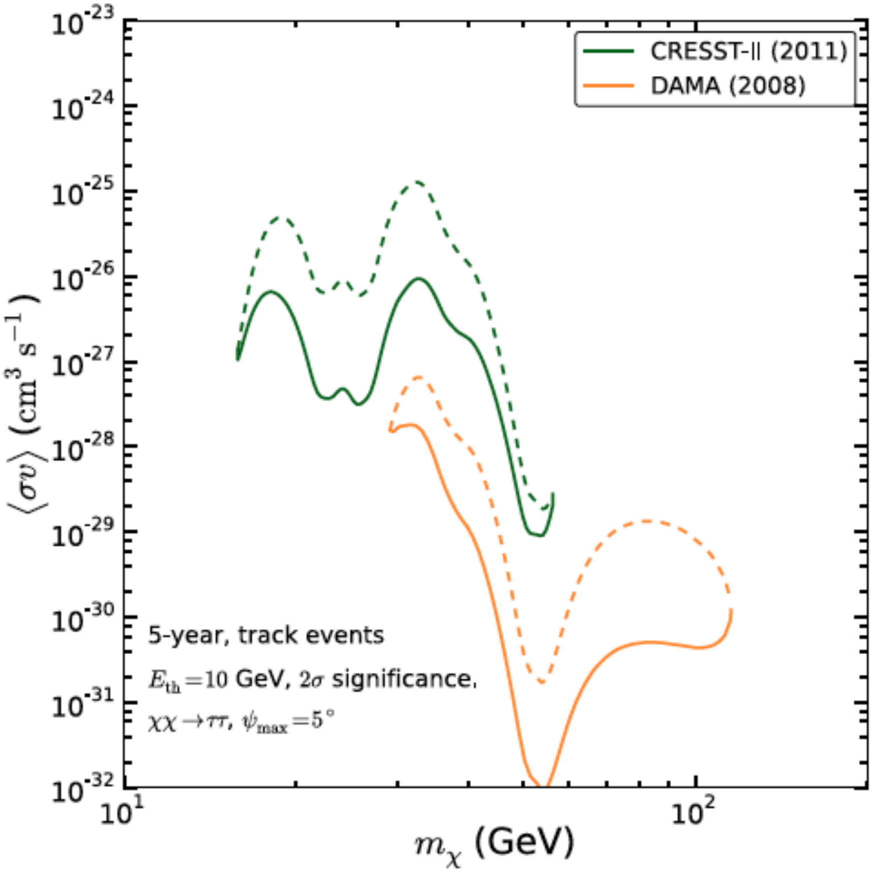


$\tau^+\tau^-$ final state

- Cascade events with ψ_{max}=50°
- Upper limits of <σv> with σ^{Si}_p ranges given by DAMA or CRESST-II



$b\bar{b}$ final state

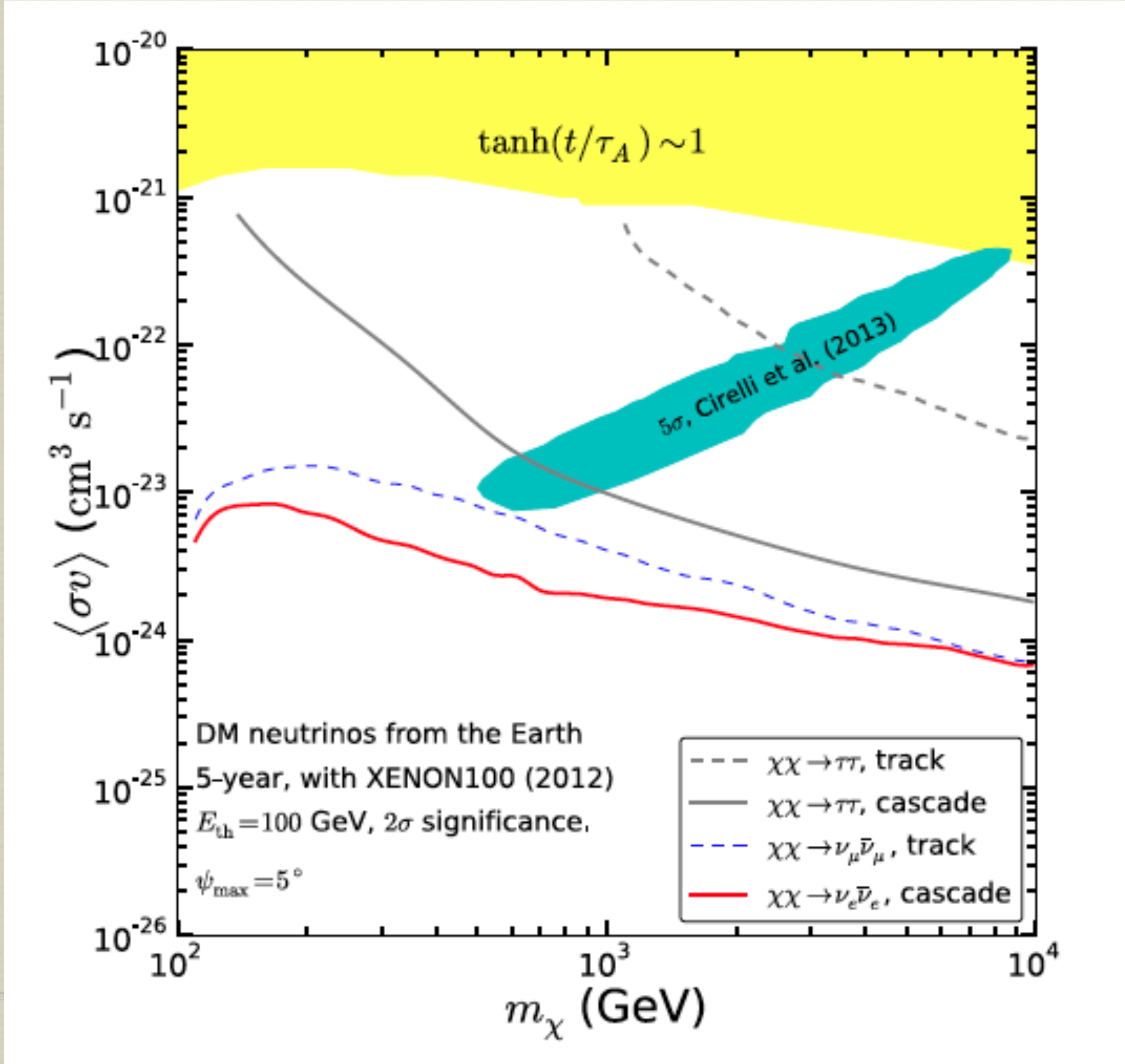


$\tau^+\tau^-$ final state

- Track events with ψ_{max}=5°

- Muon neutrinos in this mode comes from tau lepton decays or oscillations from tau neutrinos

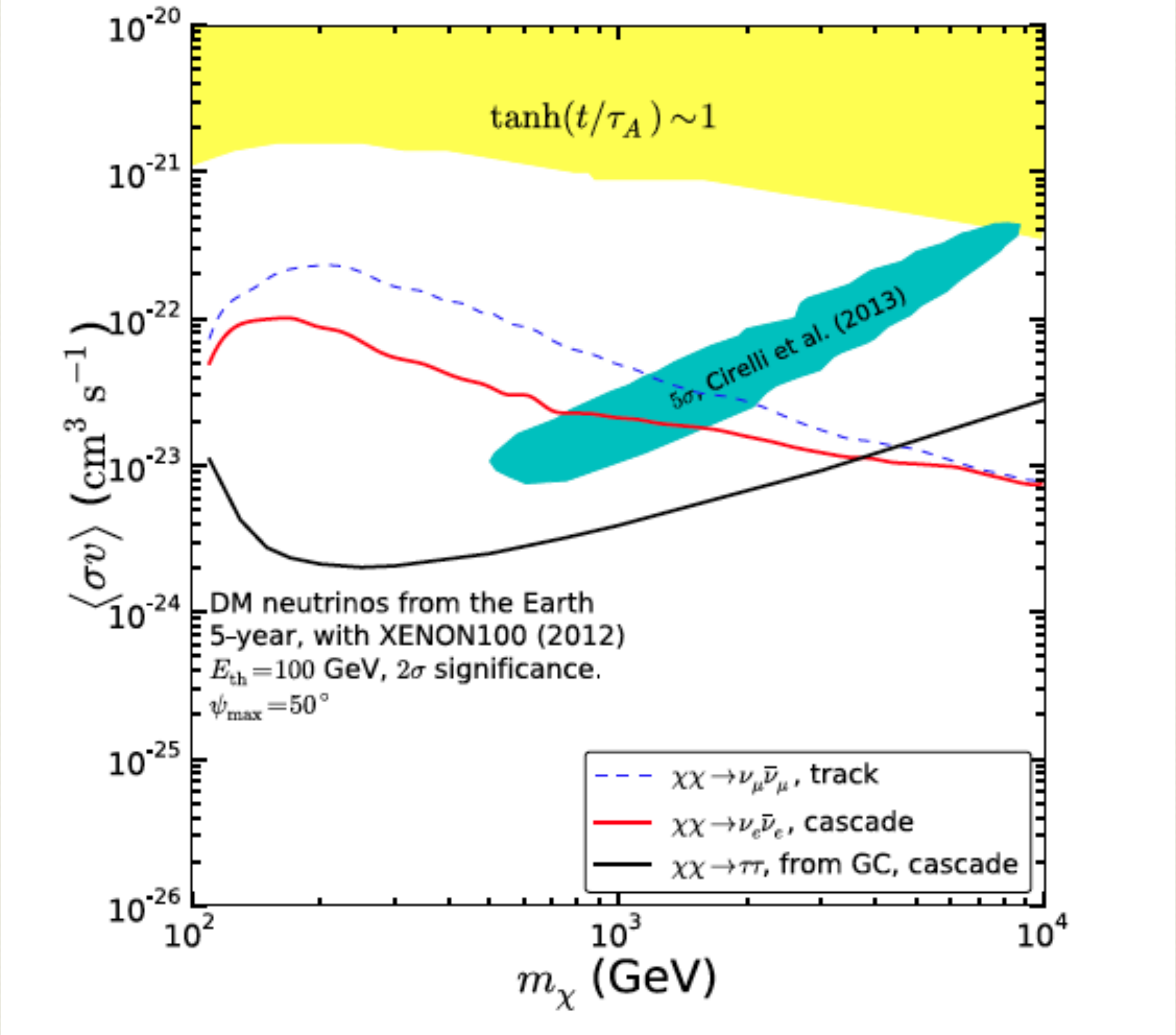
Scenario B: Probing <σv> with XENON100 bound on σ^{SI}_p as input



ψ_{max}=5°

- Challenging for cascade Events; however, see R. Auer, Nucl. Instrum. Methods Phys. Res., Sect. A 602,84 (2009).

- Green region: AMS02+ PAMELA preferred region

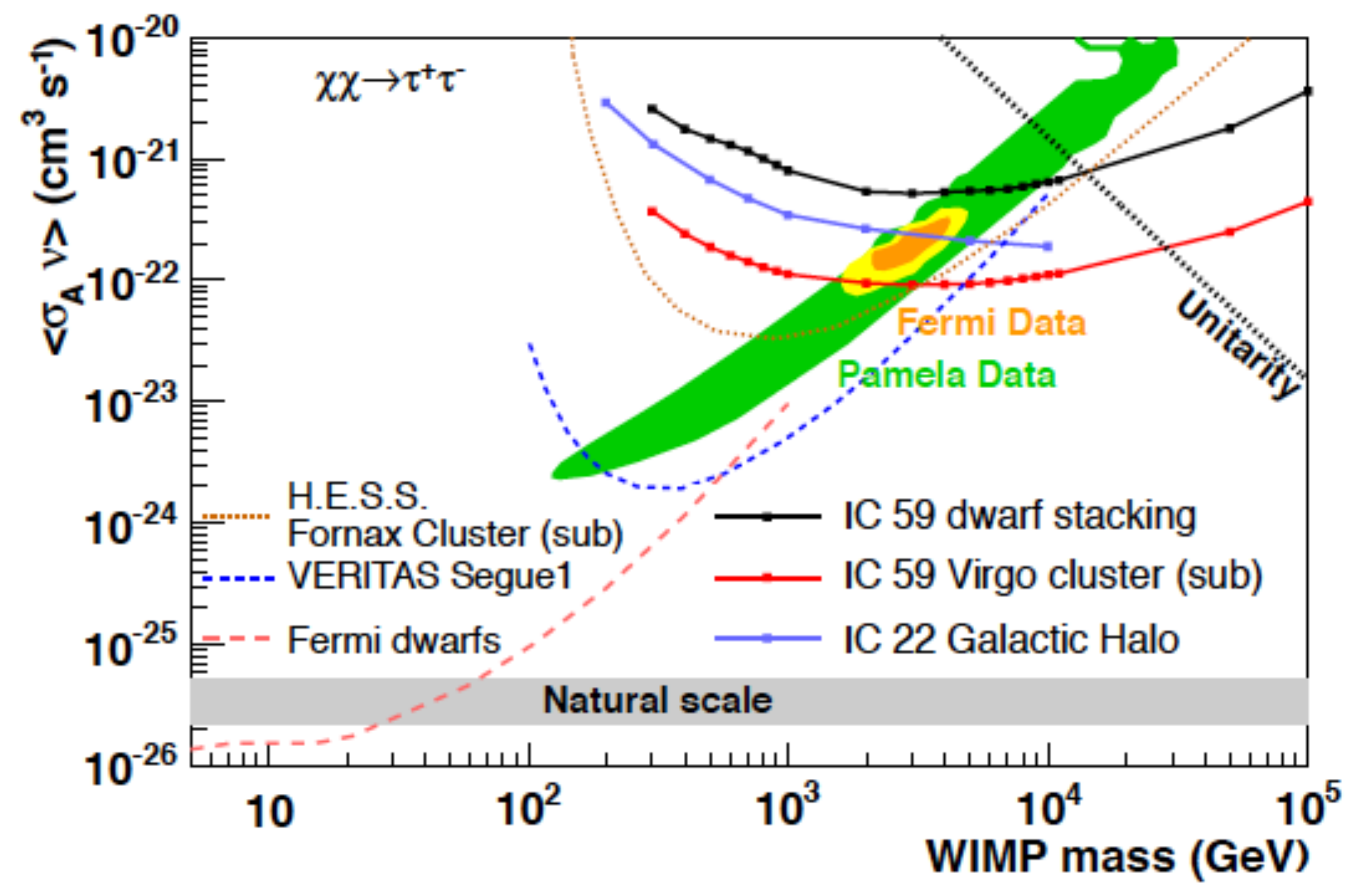


ψ_{max}=50°
Only monochromatic channels remain

$$\chi\chi \to \tau^+\tau^-$$

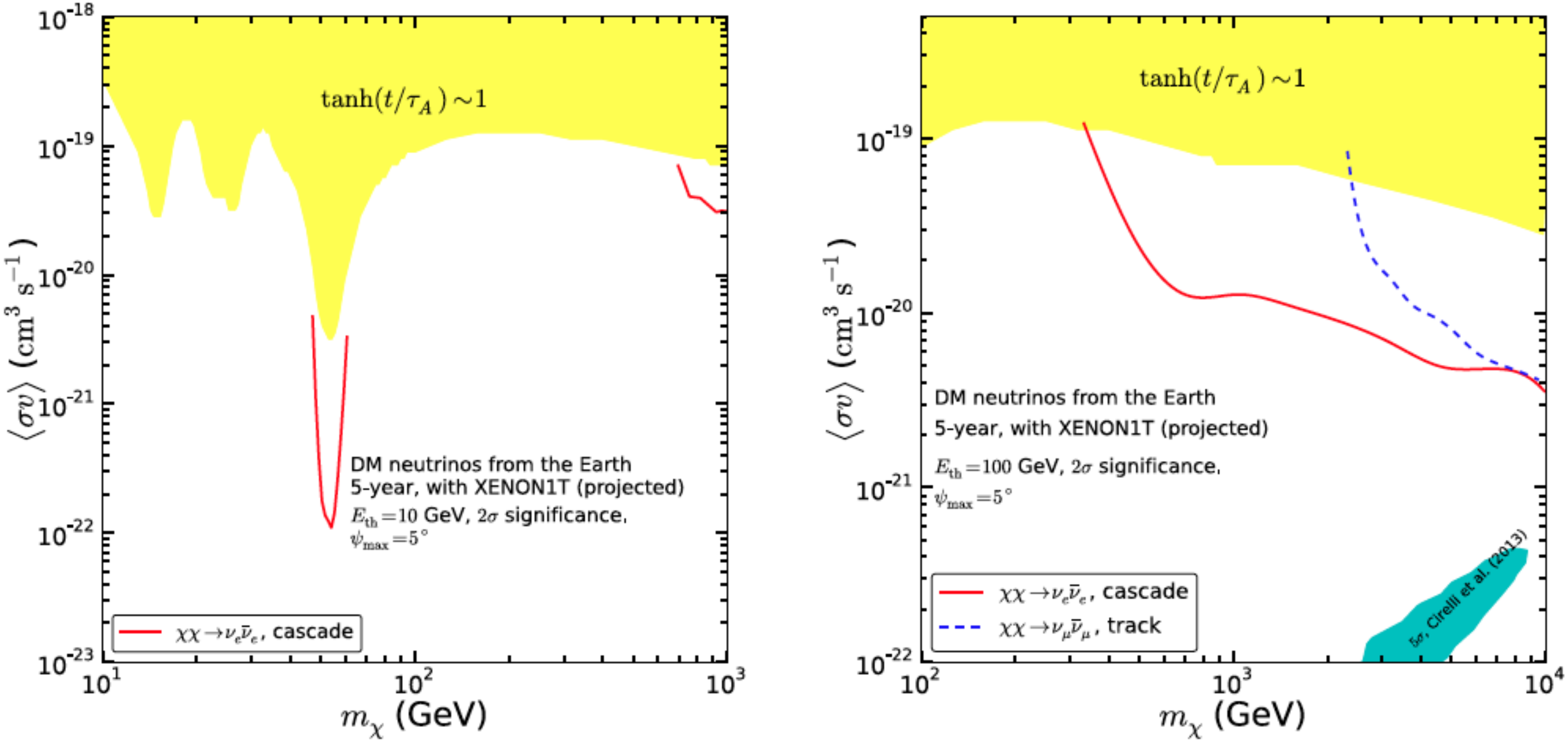
from galactic center produces cascade events— sensitive to AMS02+ PAMELA region

S. K. Mandal et al., Phys. Rev. D81, 043508 (2010)



IceCube new results on DM search
M. G. Aartsen *et al*., arxiv: 1307.3473 [astro-ph.HE]

Scenario C: assuming non-detection by XENON1T



$E_{\rm th}$=10 GeV

$\chi\chi \rightarrow \nu_\tau \bar{\nu}_\tau$ not shown

$E_{\rm th}$=100 GeV

Only monochromatic channels remain

Summary:

- With $\langle\sigma v\rangle=3\times10^{-26}$ cm^3s^{-1}, search for neutrinos produced by DM annihilation in the Earth core gives better limit on σ^{SI}_p than the current IC-79 search for DM induced neutrinos from the Sun.
- Taking DAMA and CRESST-II preferred regions as inputs for σ^{SI}_p, one can probe $\left\langle\sigma\left(\chi\chi\rightarrow\tau^+\tau^-\right)v\right\rangle$ to $10^{-32}cm^3s^{-1}$ and $\left\langle\sigma\left(\chi\chi\rightarrow b\bar{b}\right)v\right\rangle$ to $10^{-31}cm^3s^{-1}$ for m_χ at Iron resonance.
- Taking XENON100(2012) upper limit as input for σ^{SI}_p, one can probe $\left\langle\sigma\left(\chi\chi\rightarrow\tau^+\tau^-\right)v\right\rangle$ into the region favored by PAMELA and AMS02, but the limit is not as strong as the galactic search.

Summary:

- Taking XENON1T upper limit as input for σ^{SI}_{p} , one can only probe monochromatic channel $\langle\sigma(\chi\chi \rightarrow \nu\bar{\nu})v\rangle$