Fermion WIMPless dark matter at DeepCore and IceCube

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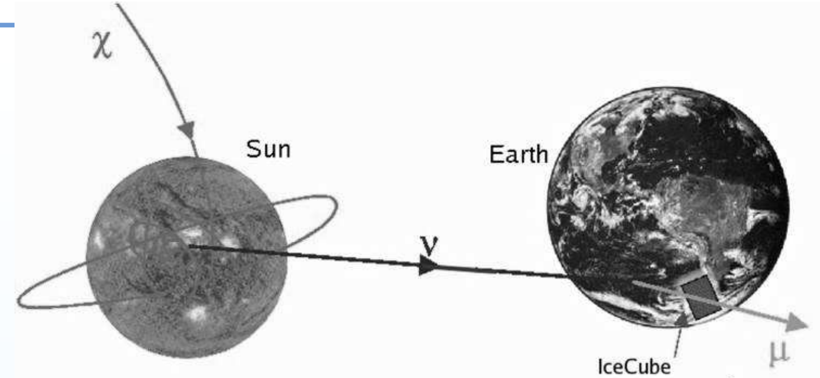
Based on

V. Barger, J. Kumar, D. Marfatia and E.M. Sessolo, arXiv: 1004.4573 [hep-ph

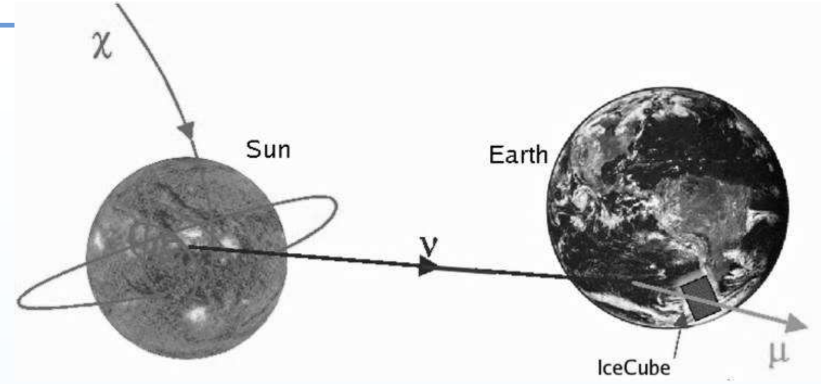
DM capture and annihilation



Indirect detection (ID) by neutrino telescopes:

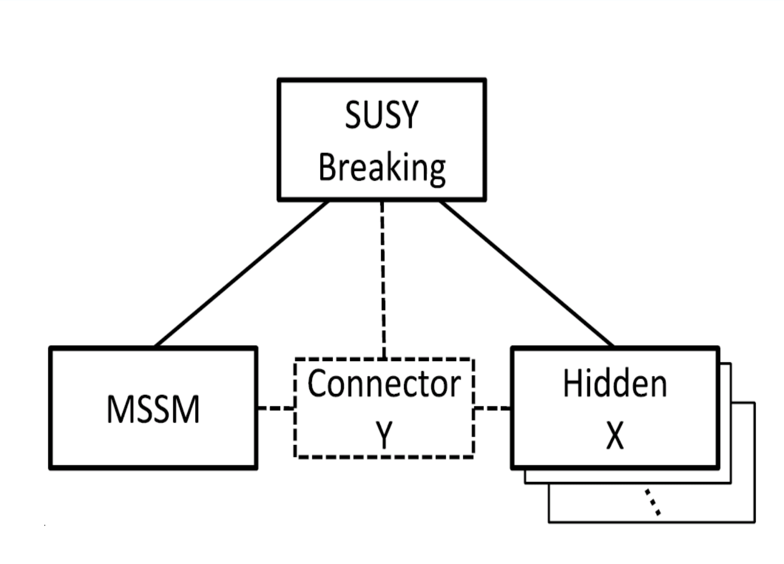
- DM can be captured by the Sun if particles lose enough kinetic energy through collisions
- Enhanced number N of DM particles at the center $\Rightarrow$ Annihilation to MSSM products that decay to neutrinos
- Flux of high-energy neutrinos to the Earth
- Neutrinos can be detected by IceCube (DeepCore)
- At equilibrium ($t_{Sun} \gg \tau$), we have annihilation rate (Γ_A) $\rightarrow$ half capture rate $C_\odot/2$

DM capture and annihilation



- If annihilation rate $\propto$ capture rate $\Rightarrow$ astrophysical uncertainties cut out
- Capture rate $C_\odot \propto \rho_{halo}, v_{halo}, m_\chi, \sigma_{SI} + \sigma_{SD}$
- Can compare with direct detection
- If $\sigma_{SD} \sim \sigma_{SI} \Rightarrow$ Bounds from neutrino detectors surpassed by direct detection
- Current direct detection experiment more sensitive to σ_{SI}
- Indirect detection advantageous for $m_\chi \sim 1 - 10$ GeV
- Indirect detection advantageous for $\sigma_{SD} \gg \sigma_{SI}$

WIMPless dark matter

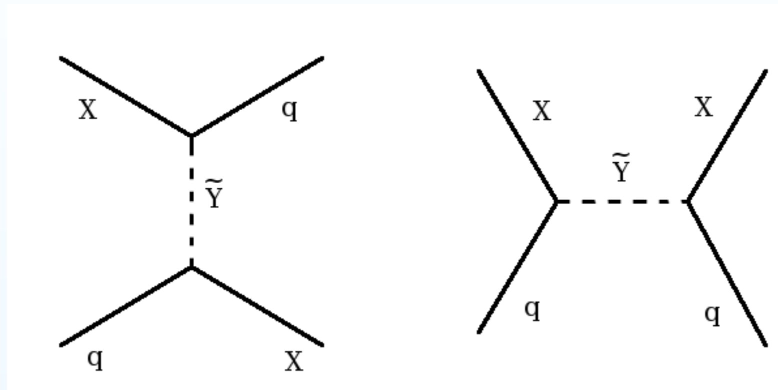


GMSB can provide candidate for ID through WIMPless scenario
(J. L. Feng and J. Kumar, arXiv:0803.4196 [hep-ph], see J. Kumar's talk tomorrow)

If VEV in SUSY-breaking, $\langle \hat{S} \rangle = \langle \mathcal{S} \rangle + \theta^2 \langle F_S \rangle \equiv M + \theta^2 F_S$,

$$\frac{g_X^4}{m_X^2} \sim \frac{g_{weak}^4}{m_{weak}^2} \propto \left(\frac{M}{F_S} \right)^2 \Rightarrow \frac{g_{weak}^4}{m_{weak}^2} \sim \langle \sigma v \rangle \simeq 1 \text{ pb. "WIMP miracle"}$$

Fermionic model



Superpotential:

$$
\begin{aligned}
W \quad = \quad & \lambda_{Li}\hat{X}_L\hat{Y}_L\hat{Q}_{Li} + \lambda_{Ri}\hat{X}_R\hat{Y}_R\hat{Q}_{Ri} + m_Y\hat{Y}_L\hat{Y}_R \\
& +\lambda'_{Lj}\hat{X}_L\hat{Y}_L^{lep.}\hat{L}_{Lj} + \lambda'_{Rj}\hat{X}_R\hat{Y}_R^{lep.}\hat{L}_{Rj} + m_{Y^{lep.}}\hat{Y}_L^{lep.}\hat{Y}_R^{lep.}
\end{aligned}
$$

We consider Majorana DM

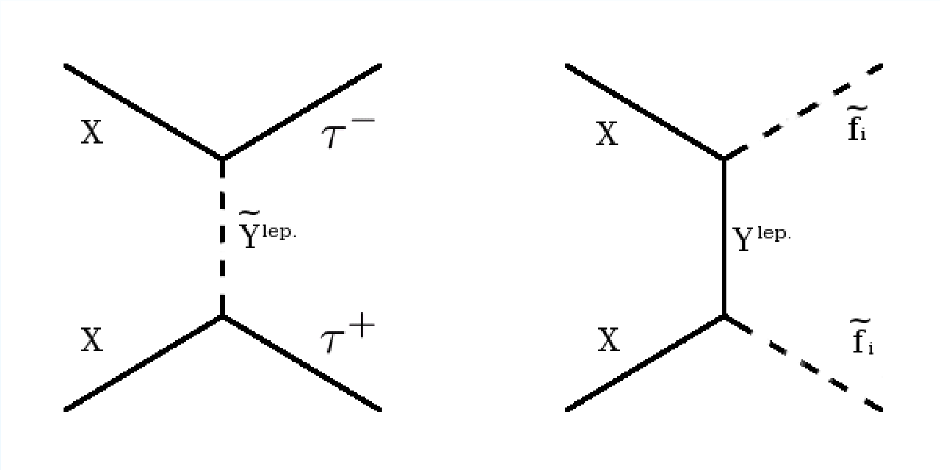
(Only axial-vector contributions to effective operators)

If DM is Majorana, *only spin-dependent scattering to hydrogen present!* $\longrightarrow$ evade direct detection bounds

Properties of our fermionic model

- $\sigma_{SD} \propto [\sum_i (\lambda_{Li}^2 + \lambda_{Ri}^2)/(m_{\tilde{Y}}^2 - m_X^2)]^2$
- We must have $m_X < m_Y < 600$ GeV because X is the lightest particle *under stabilizing symmetry*.
- If one couples DM to more than one quark generation then flavor-changing NCs $\Rightarrow$ only one generation
- Since DM Majorana, annihilation to light quarks is chirality-suppressed
- If hidden sector vectors/scalars $\Rightarrow$ then $\langle \sigma v \rangle \sim 1$ pb to hidden sector.
- To get comparable $\langle \sigma v \rangle$ to MSSM $\Rightarrow$ couple to τ, $\tilde{l}_{L,R}$, $\tilde{u}_{L,R}$ and $\tilde{d}_{L,R}$
- To have annihilation $m_X > m_{\tilde{q}} \Rightarrow$ Not natural in GMSB and cascade dependent $\Rightarrow$ Neglect coupling to squarks

Fermionic model



ANNIHILATION CROSS-SECTION ADMITS BOTH SM AND SUSY FINAL STATES!

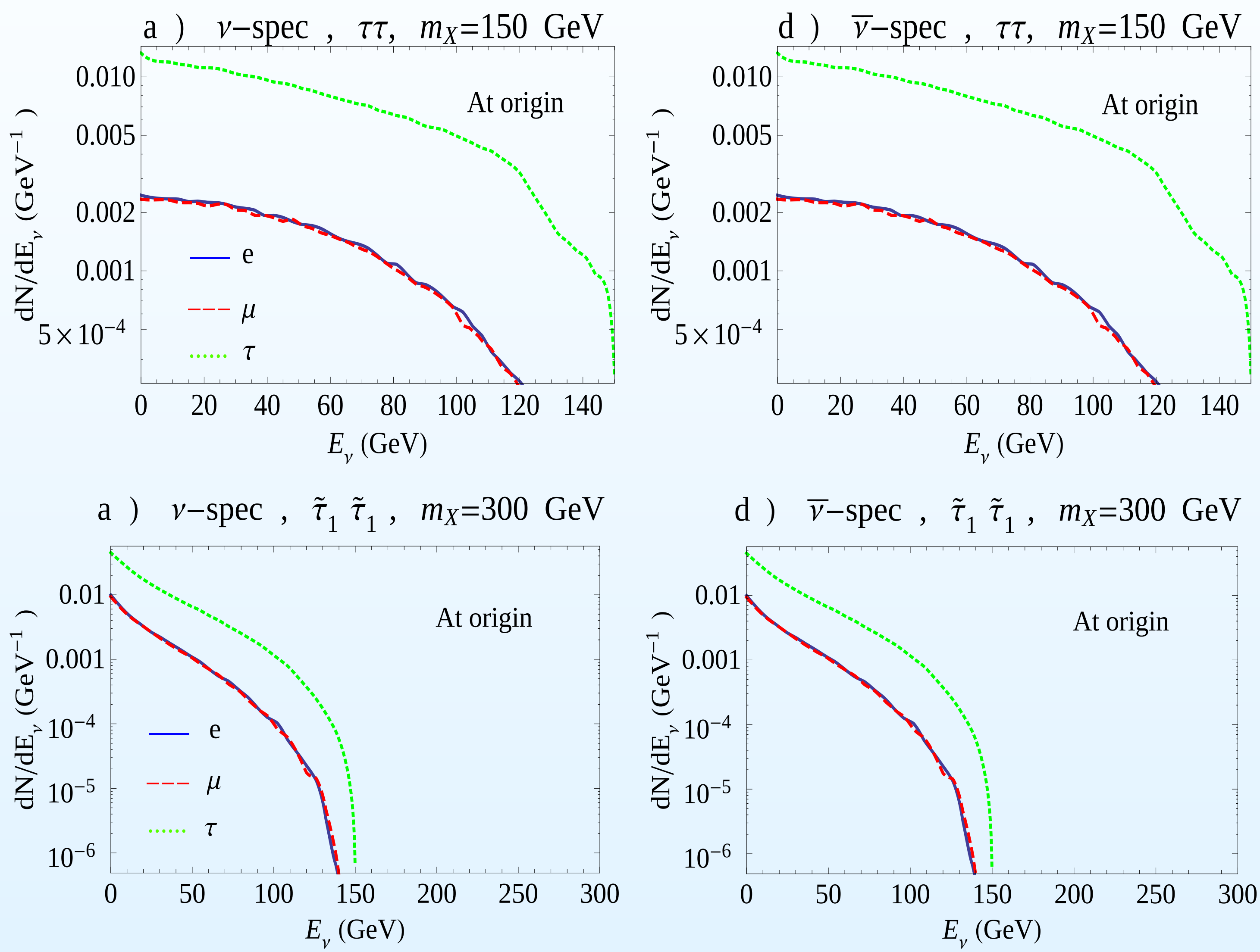
$m_X = 150, 300, 400$ GeV

Ann. to taus with BF=1

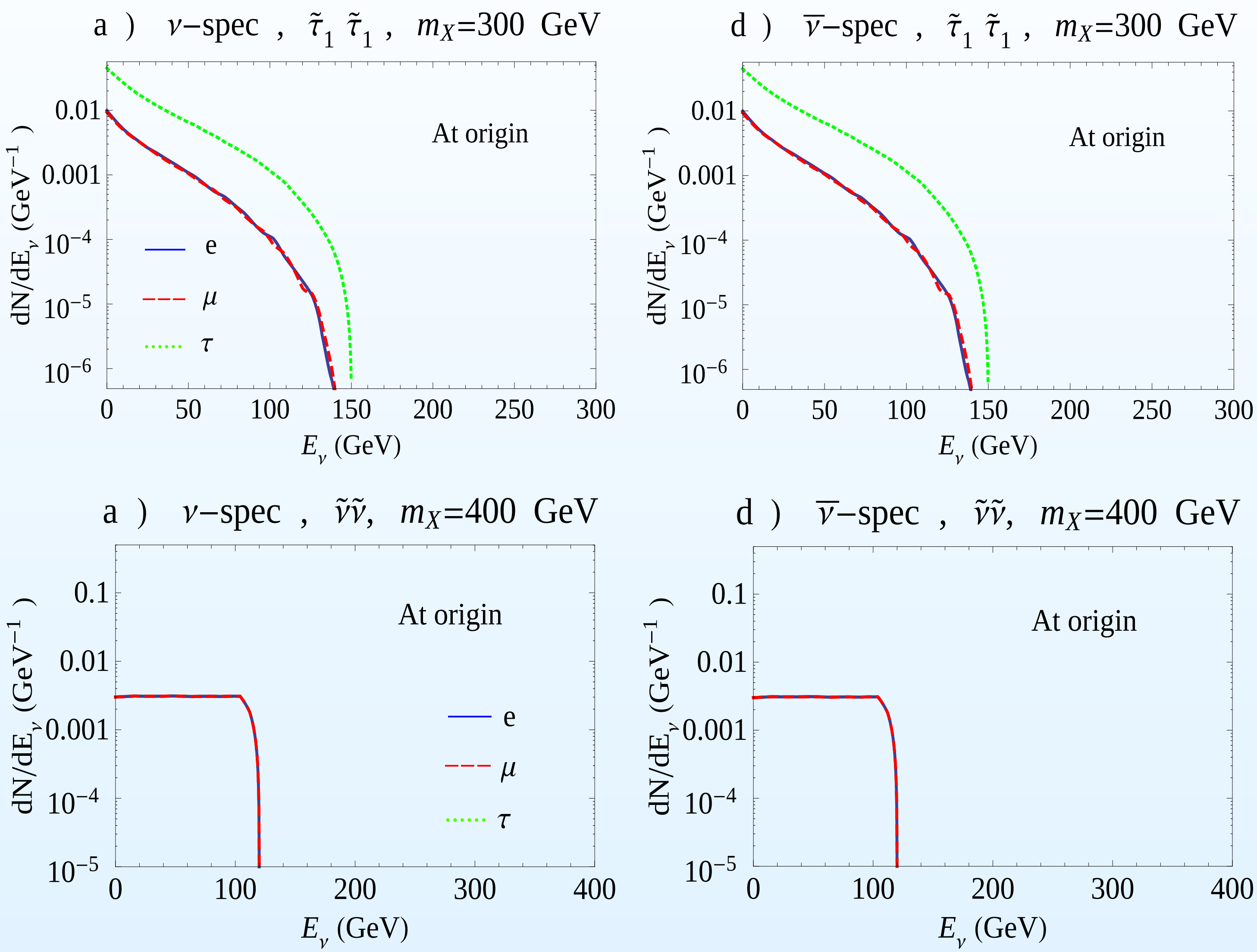
Ann. to staus NNLSP (BF=1) and sneutrinos NNLSP (BF=0.33)

Cascade products and neutrino spectra obtained with PYTHIA

Neutrino Spectra



Neutrino Spectra



Propagation through the Sun

Density matrix formalism:

$$\frac{d\rho}{dr} = -i[\mathbf{H}, \rho] + \left.\frac{d\rho}{dr}\right|_{NC} + \left.\frac{d\rho}{dr}\right|_{CC} + \left.\frac{d\rho}{dr}\right|_{in}$$

Hamiltonian we use:

$$\mathbf{H} = \frac{1}{2E_\nu}\mathbf{U}\text{diag}(0, \Delta m^2_{21}, \Delta m^2_{31})\mathbf{U}^\dagger + \text{diag}(\sqrt{2}G_F N_e, 0, 0)$$

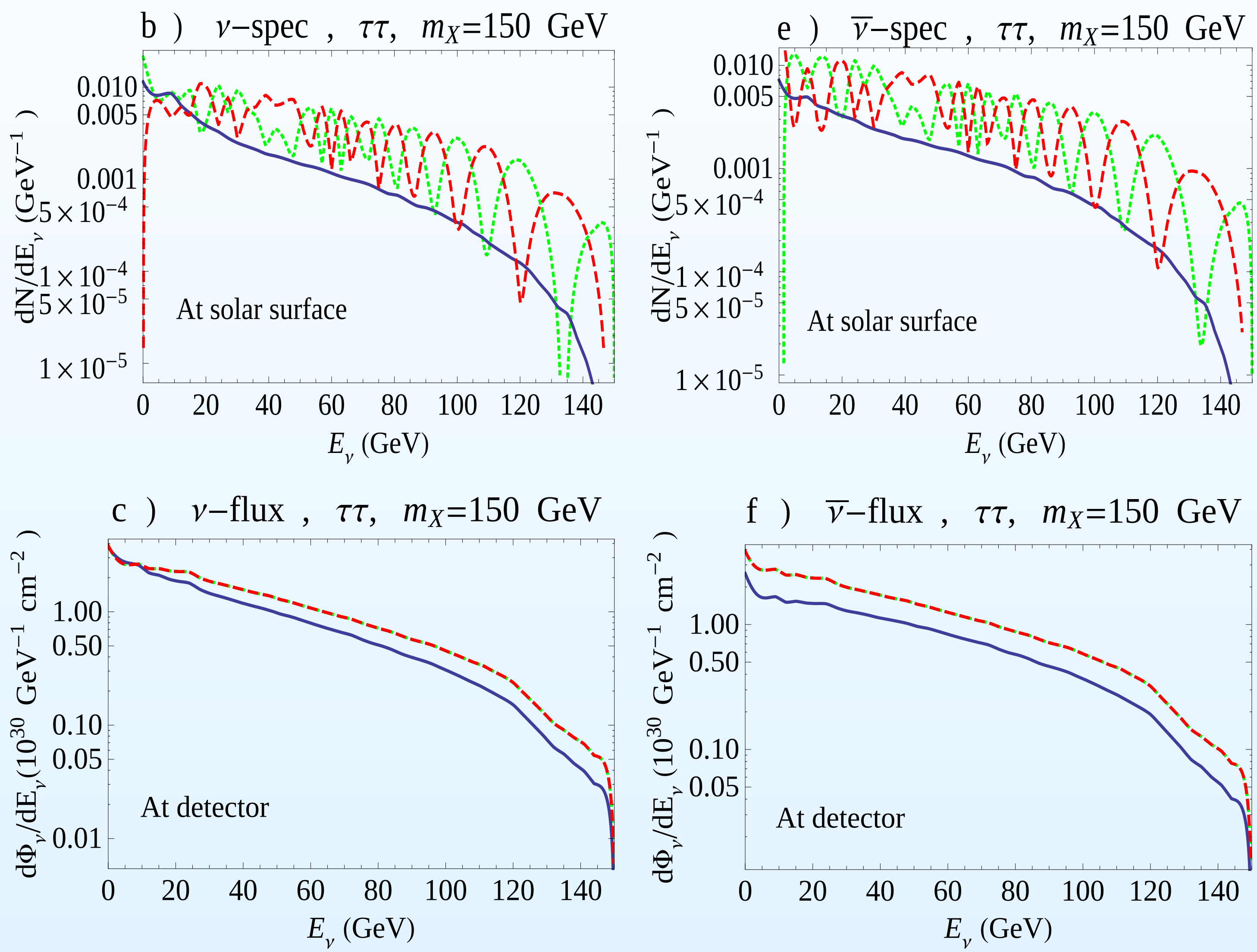
with parameters:
$\Delta m^2_{21} = 8.1 \times 10^{-5}$ eV^2 $\Delta m^2_{31} = 2.2 \times 10^{-3}$ eV^2 $\theta_{12} = 33.2^\circ$
$\theta_{23} = 45^\circ$ $\theta_{13} = 0$

Injection term diagonal in the flavor basis.

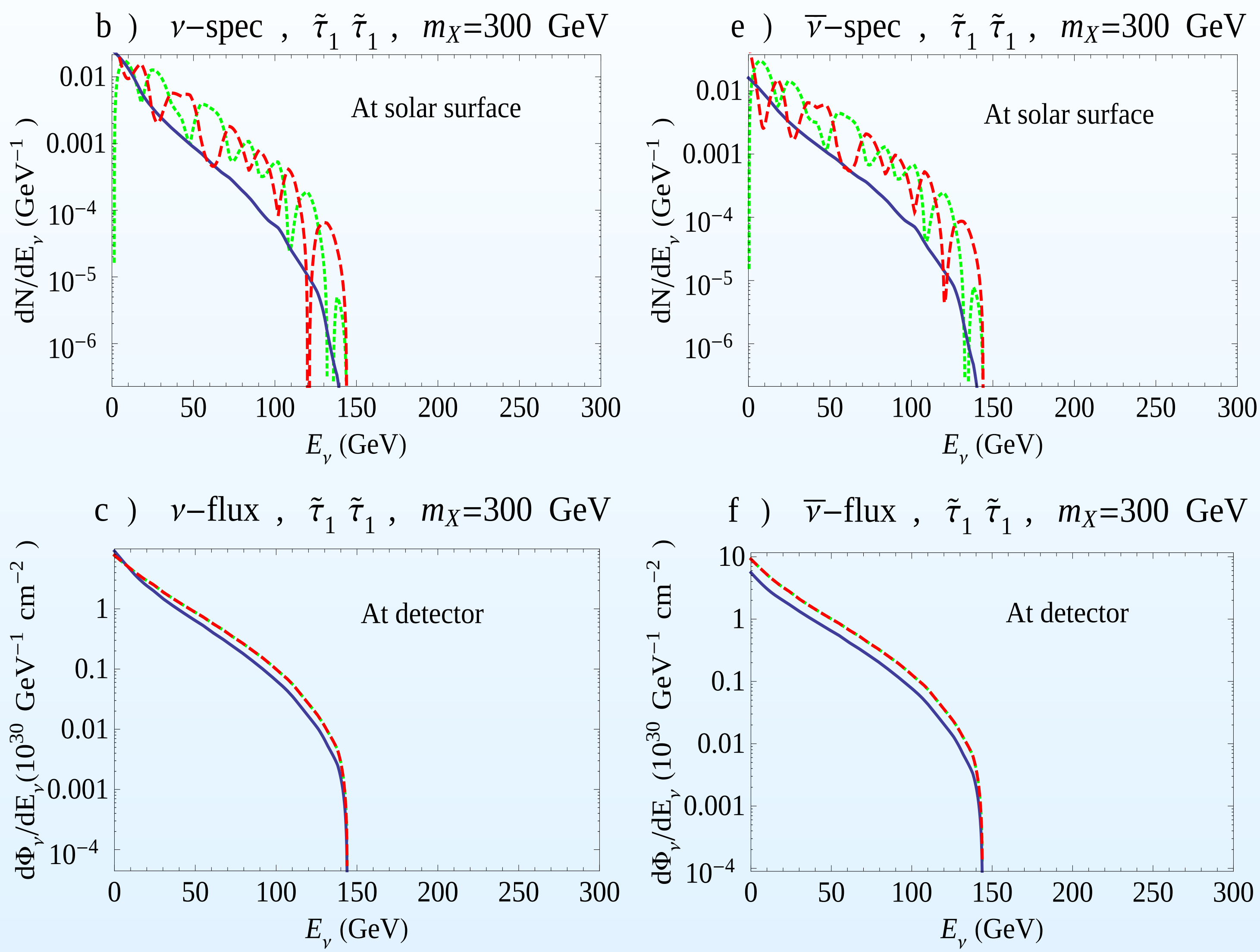
NC, CC and tau regeneration included.

Modulation averaged out at detector.

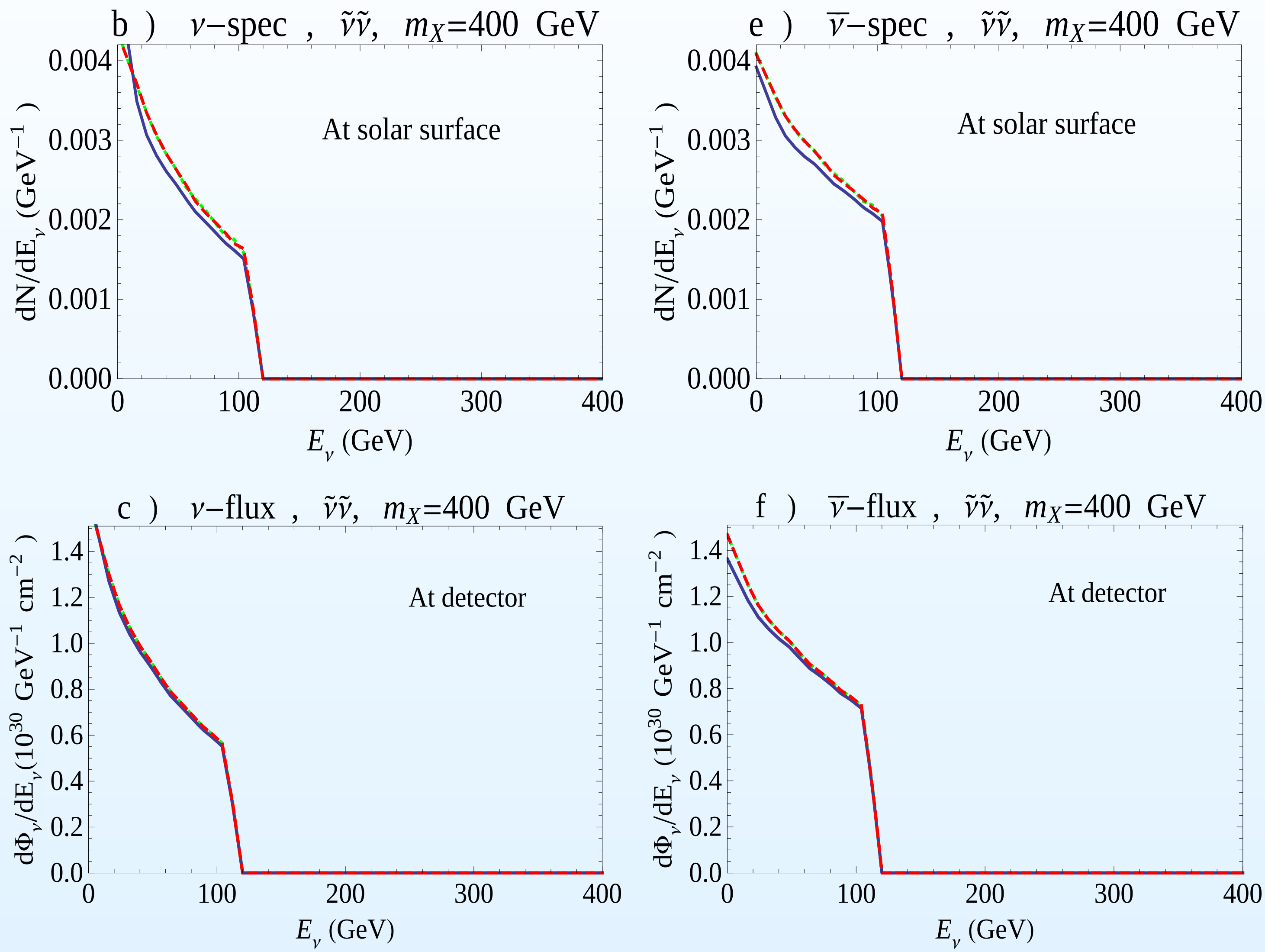
Neutrino Spectra



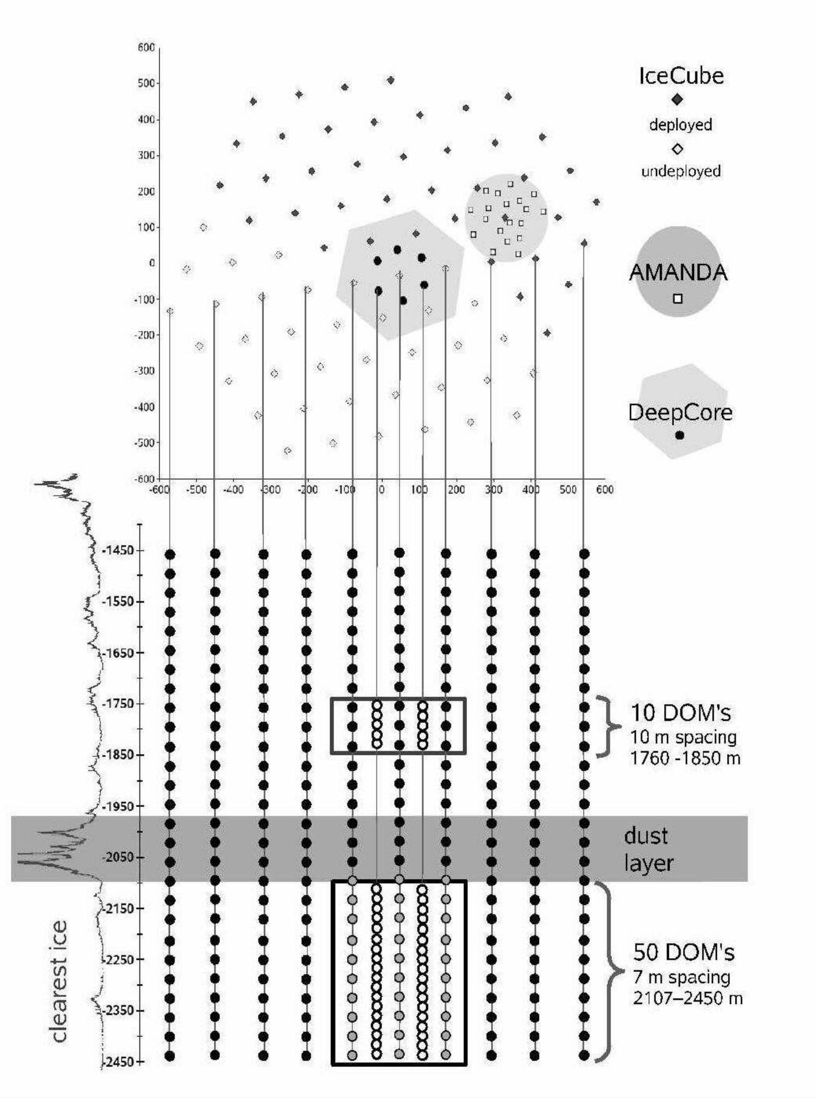
Neutrino Spectra



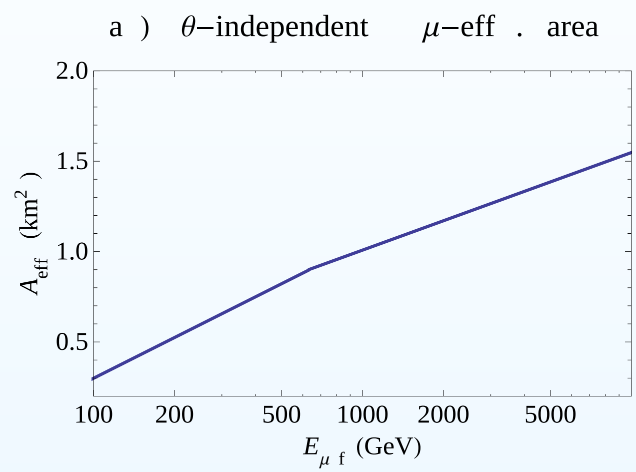
Neutrino Spectra



The IceCube and DeepCore detectors



Muon rates at IceCube, evaluation

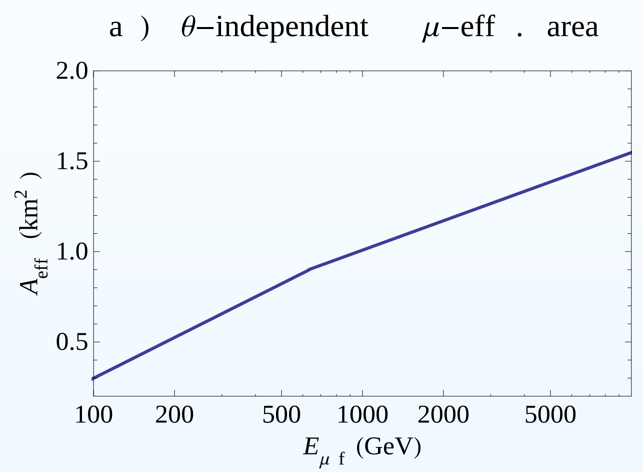


We divide event topologies into *upward* and *contained*.

Upward:

- μ-neutrino CC-scatter with a nucleus in ice
- Average range over which energy losses due to *ionization*, *bremsstrahlung*, *pair production* and *photonuclear effects* force the muon energy below detector threshold
- Muon survival probability
- Muon *effective area* for IceCube

Muon rates at IceCube, evaluation



We divide event topologies into *upward* and *contained*.

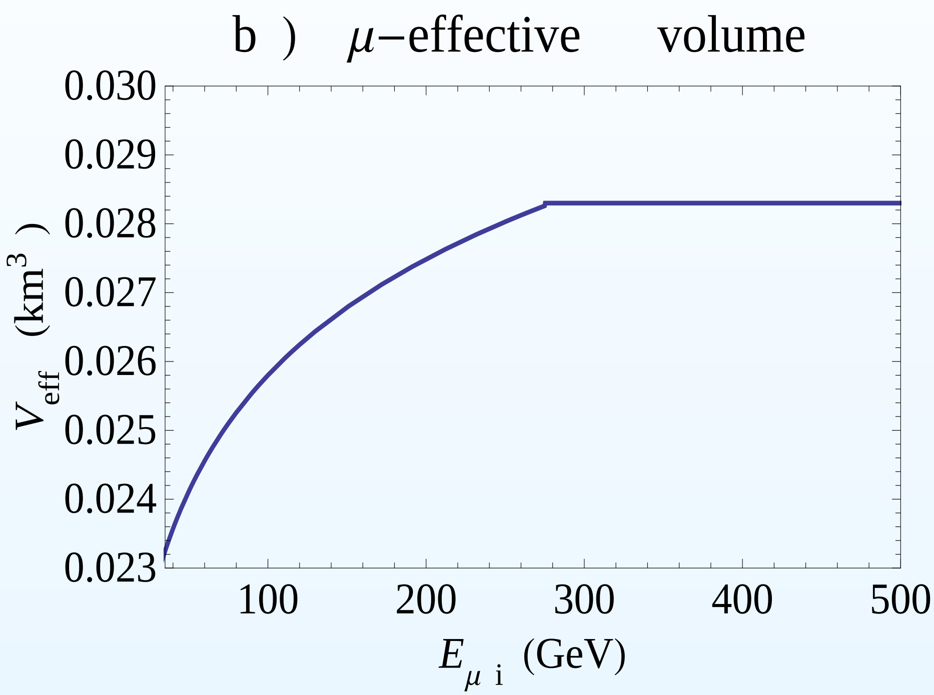
Contained:

- Neutrinos interact within detector volume
- No energy loss in $L \sim 1$ km
- $A_{eff} = 1$ km^2
- $E_{thr} = 100$ GeV

For *contained* and *upward* events we track the sun below horizon

- Atmospheric background in a cone of 1° opening

Muon rates at DeepCore

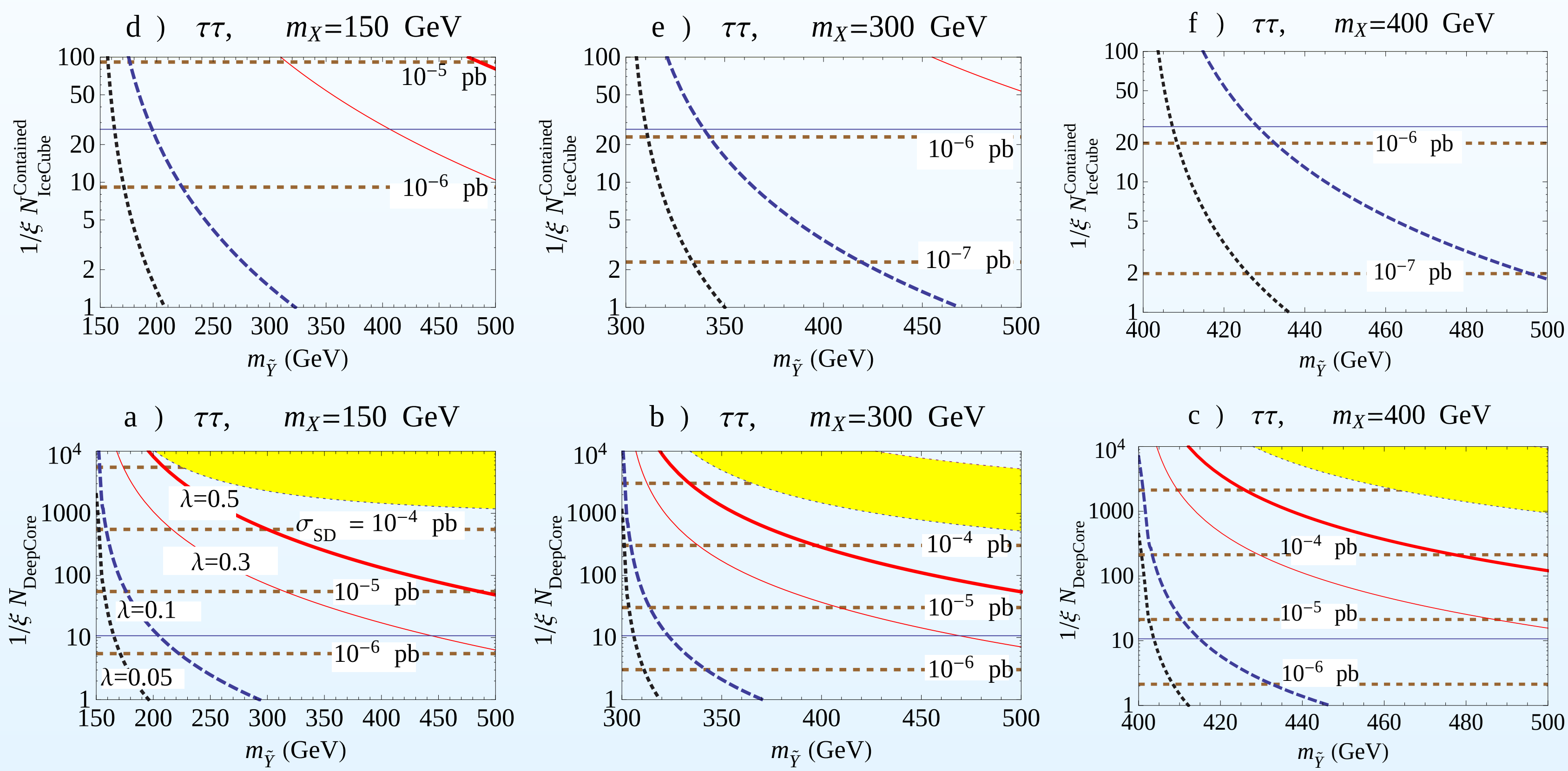


- IceCube instrum. vol. used to veto muon events from above the horizon
- Contained events
- Muon *effective volume* for DeepCore
- $E_{min} = 35$ GeV
- Sun above *and* below horizon

Results

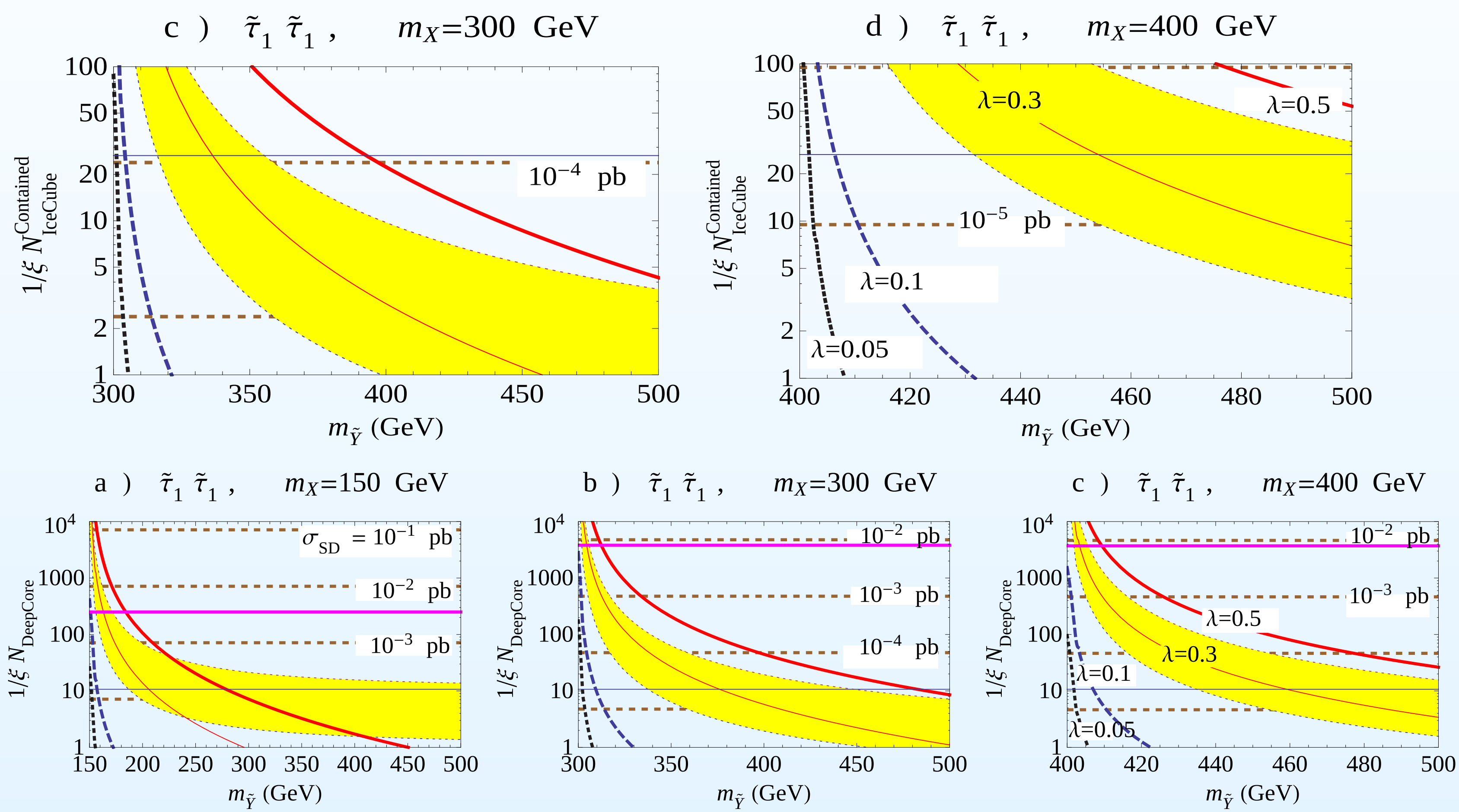
IceCube contained and DeepCore

Number of events in five years of observation in the $\tau^-\tau^+$-channel for varying choices of $\lambda = \lambda_{(L,R)(u,d)}$



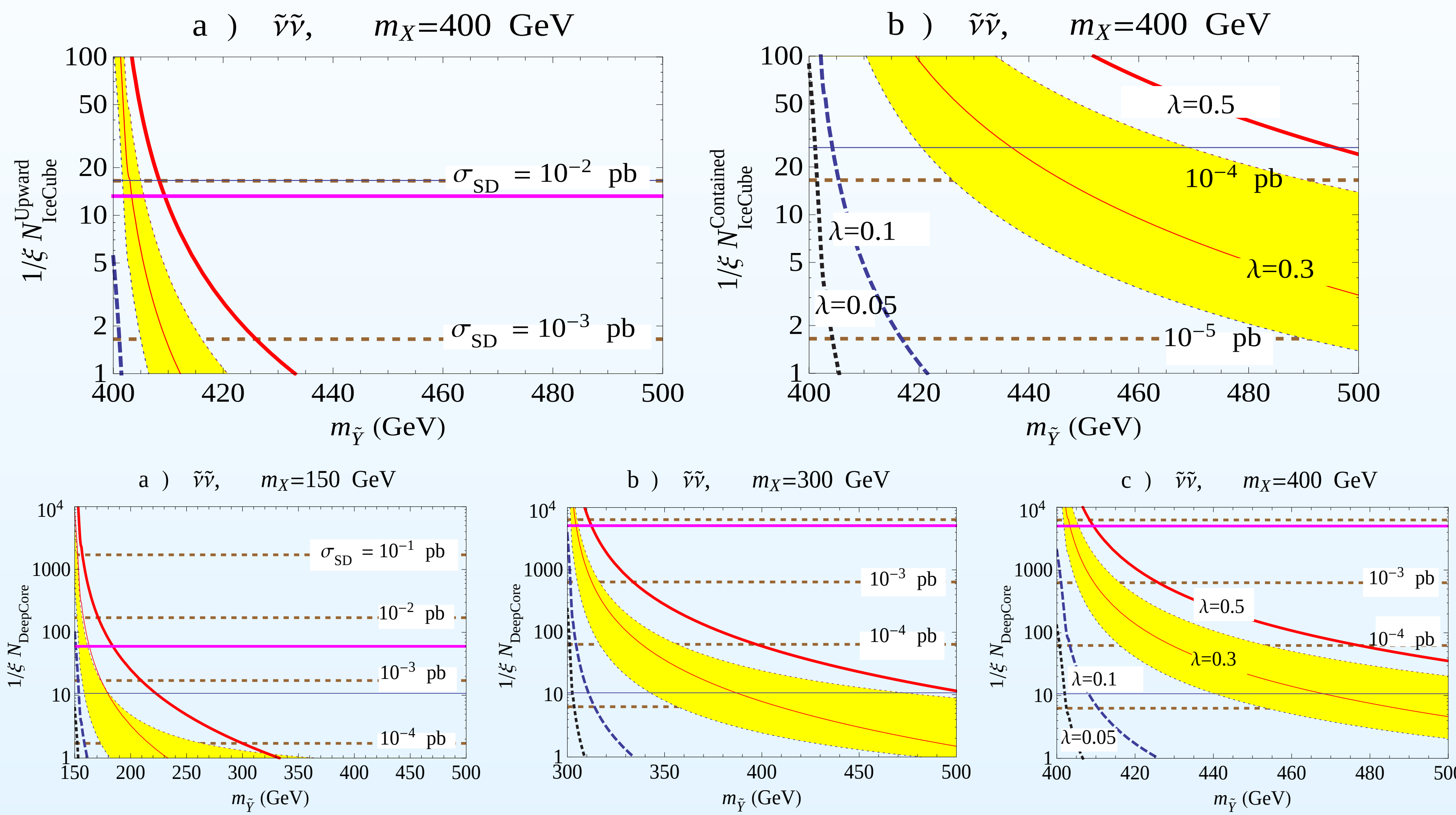
Results

Stau-channel: IceCube contained and DeepCore



Results

Sneutrino-channel:



Summary

- Investigate indirect detection of WIMPless fermion DM at IceCube and DeepCore
- Interesting in the context of IceCube/DeepCore because
only spin-dependent nuclear scattering
- Annihilation channels are taus, staus and sneutrinos
- Neutrino spectra propagated with attention to oscillations, NC, CC
and tau-regeneration
- Muon event rates at detector modelled
- Given the background, a five year 3σ discovery in upward or contained events
at IceCube disfavored in the stau and sneutrino channels
for $m_X \lesssim 150$ GeV
- DeepCore can comfortably produce discovery in any analyzed channel
- Good prospects for Majorana fermion WIMPless DM at IceCube and DeepCore