Solar Atmospheric Neutrinos and the Sensitivity Floor for Solar Dark Matter Annihilation Searches

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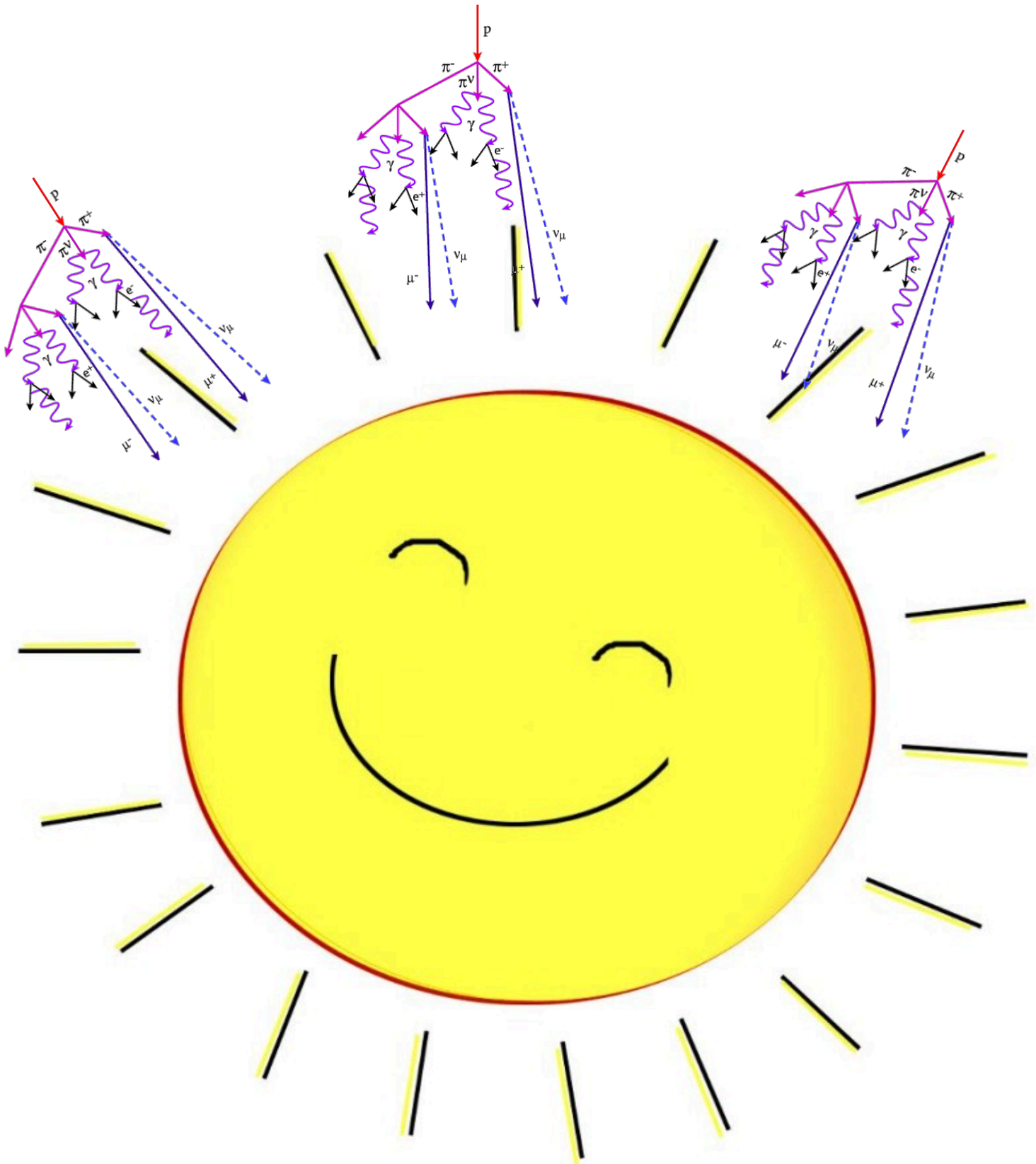
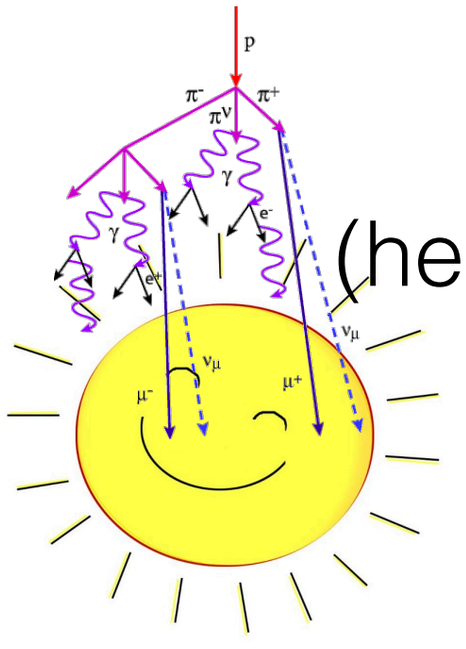
DESY



Like in the Earth the Sun is bombarded by CR, which shower in the solar atmosphere



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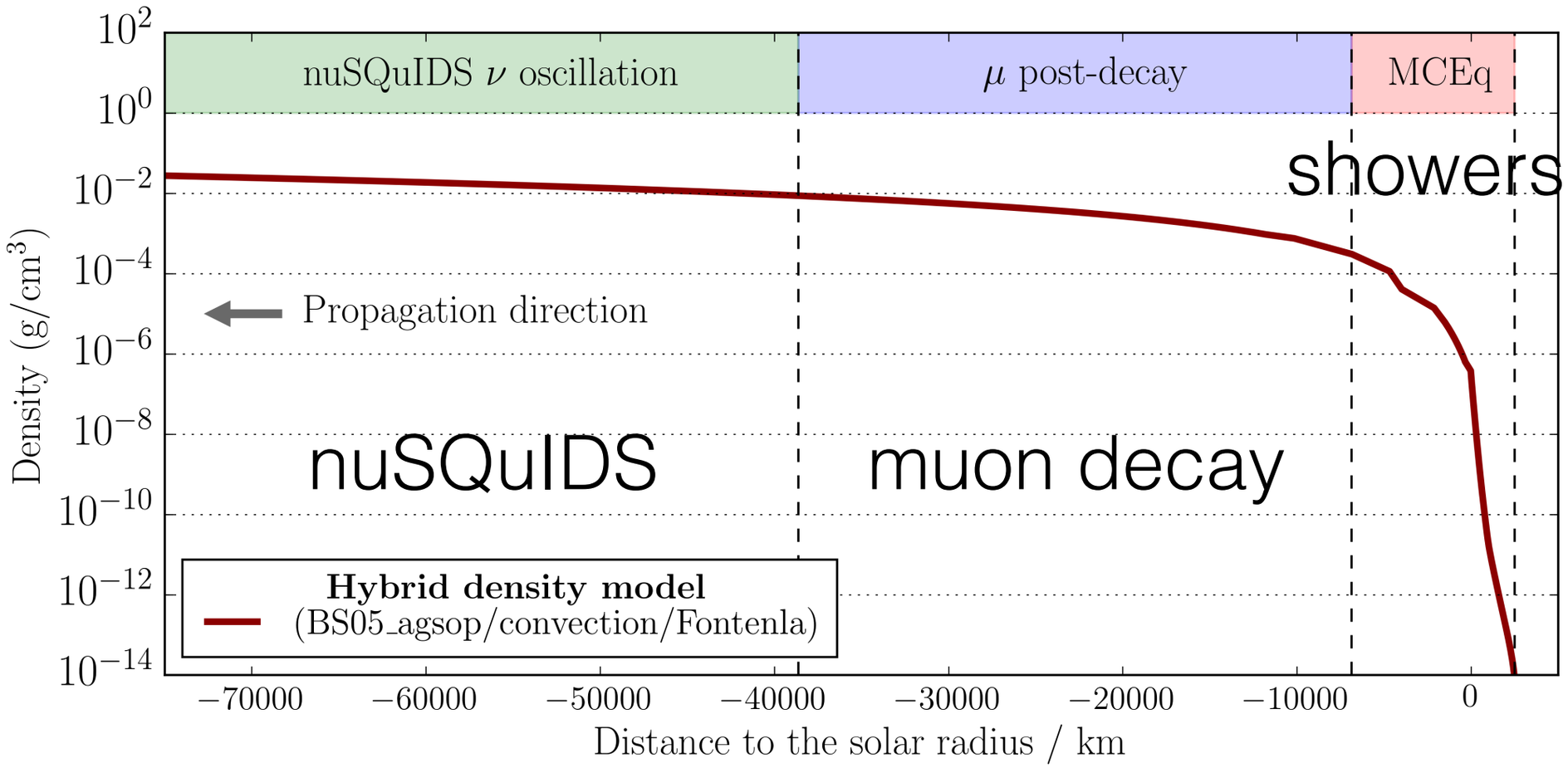
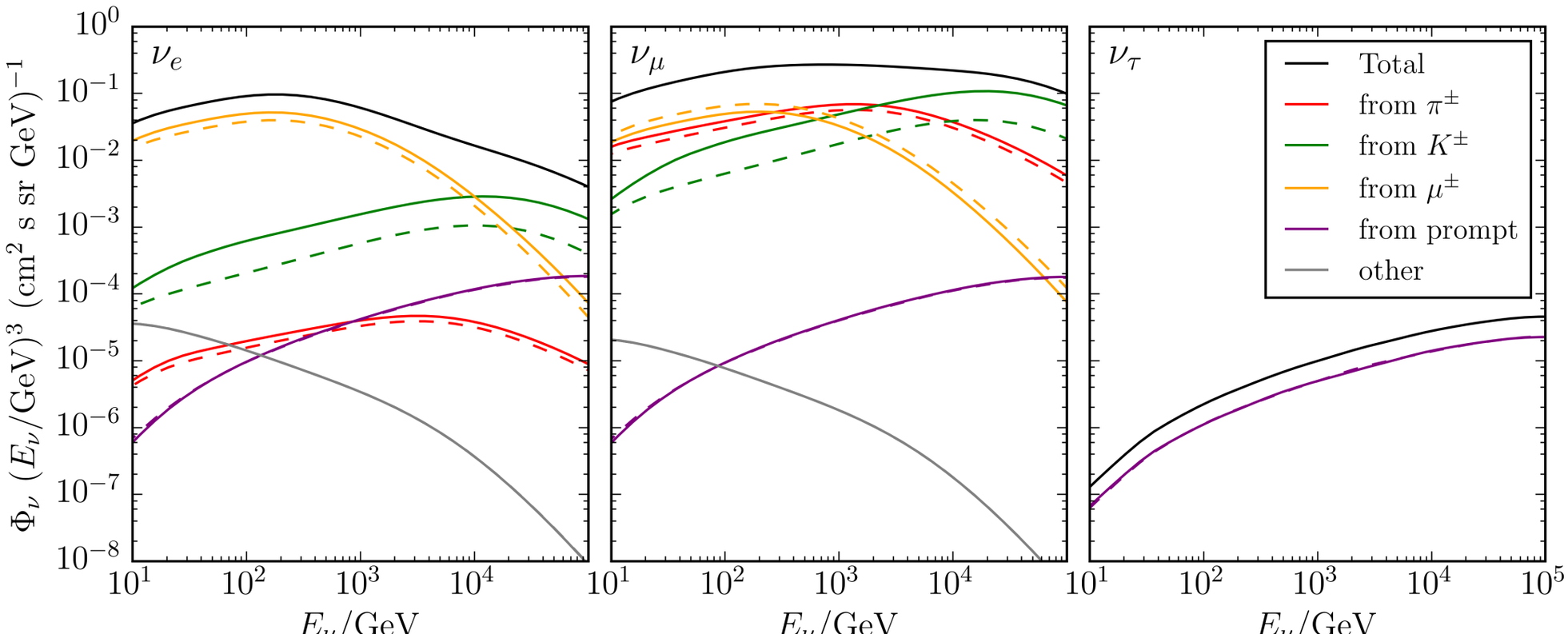
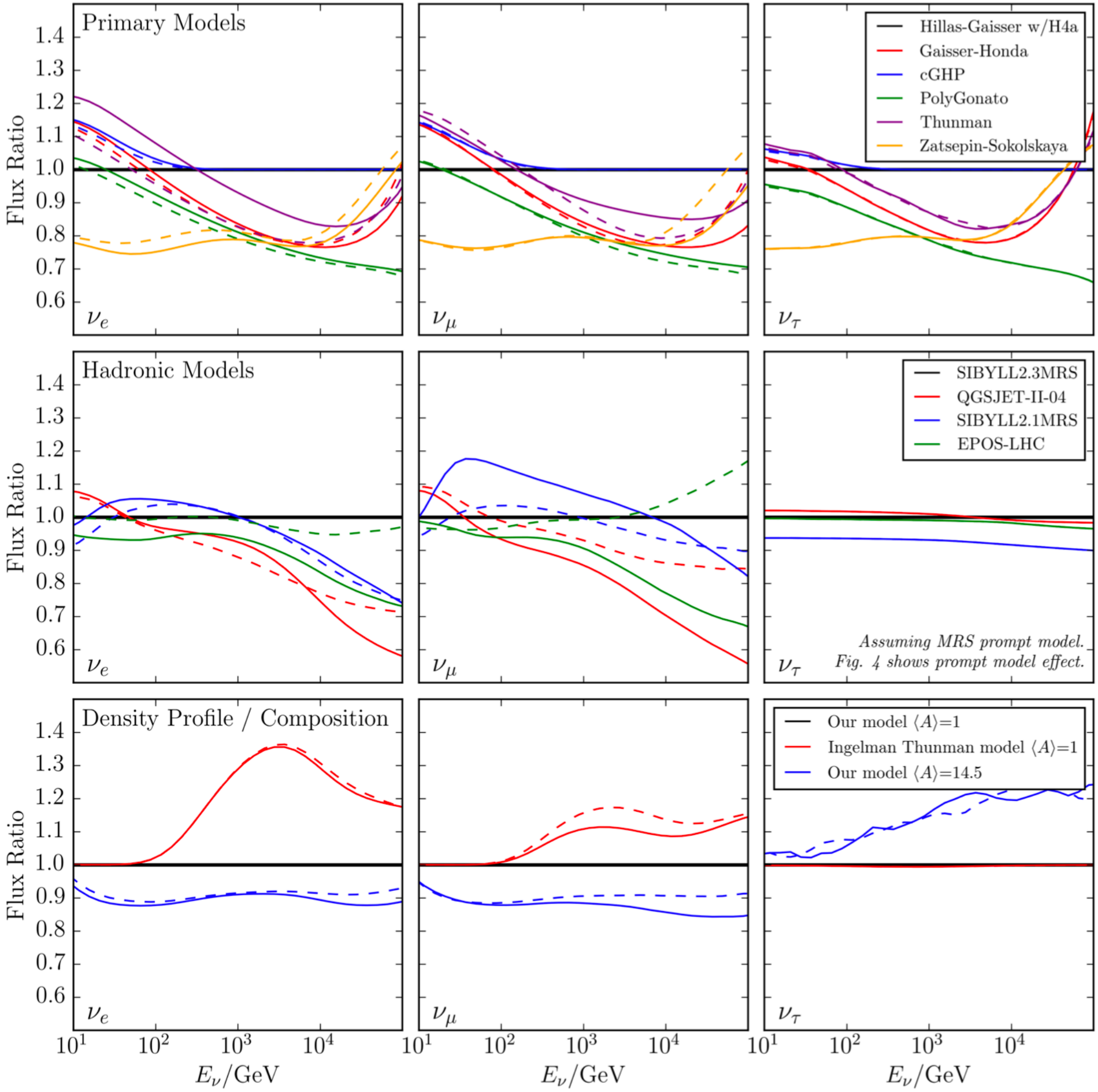
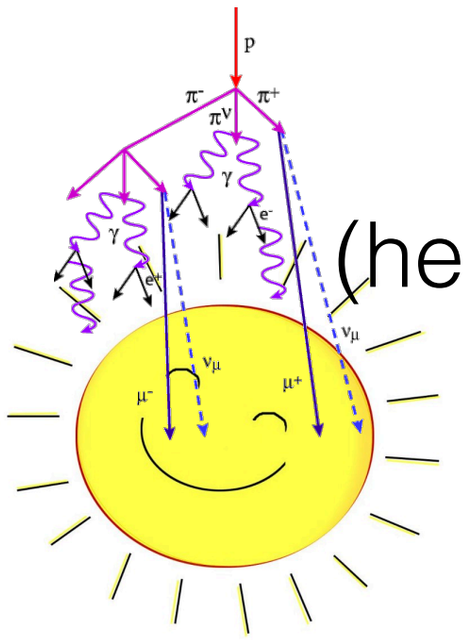




(MCEq., our solar atmosphere model, and Sibyll2.3)



We study CR, hadronic, atmosphere model uncertainties



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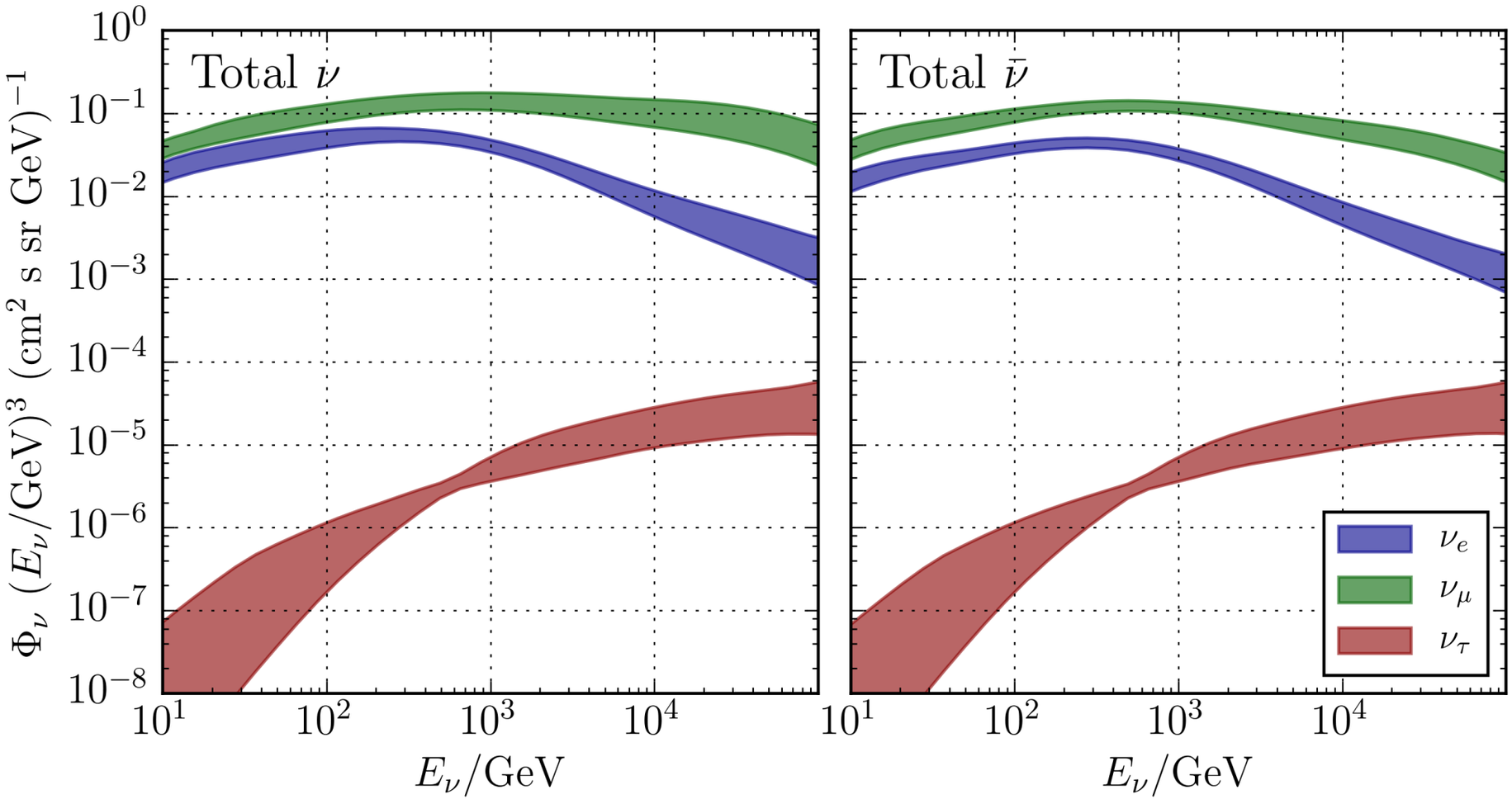
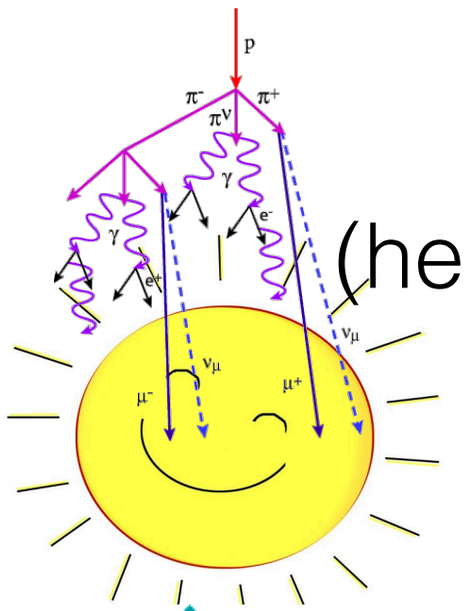
- These error bands account for cosmic ray, hadronic, and atmospheric model uncertainties





For neutrino propagation we use the nuSQuIDS package.

(here)

$$\frac{\partial \rho(E,x)}{\partial x} = -i[H_1(E,x),\rho(E,x)] - \{\Gamma(E,x),\rho(E,x)\} + F\left[\rho,\bar{\rho};E,x\right]$$

$$\bar{F}\left[\rho,\bar{\rho};E,x\right] = \sum_\alpha \bar{\Pi}_\alpha(E,x)\int_E^\infty \mathrm{Tr}\left[\bar{\Pi}_\alpha(E_{\bar{\nu}_\alpha},x)\bar{\rho}(E_{\bar{\nu}_\alpha},x)\right]\frac{1}{\bar{\lambda}^\alpha_{\mathrm{NC}}(E_{\bar{\nu}_\alpha},x)}\frac{\partial \bar{N}^\alpha_{\mathrm{NC}}(E_{\bar{\nu}_\alpha},E)}{\partial E}dE_{\bar{\nu}_\alpha}$$

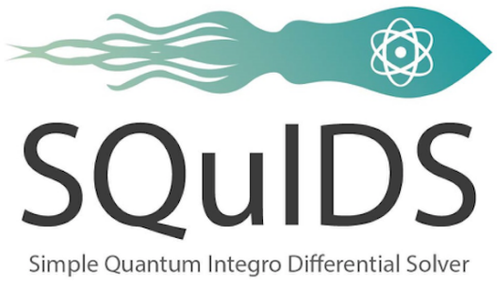
$$+\bar{\Pi}_\tau(E,x)\int_E^\infty\int_{E_\tau}^\infty \mathrm{Tr}\left[\bar{\Pi}_\tau(E_{\bar{\nu}_\tau},x)\bar{\rho}(E_{\bar{\nu}_\tau},x)\right]$$

$$\times\frac{1}{\bar{\lambda}^\tau_{\mathrm{CC}}(E_{\nu_\tau},x)}\frac{\partial \bar{N}^\tau_{\mathrm{CC}}(E_{\bar{\nu}_\tau},E_\tau)}{\partial E_\tau}\frac{\partial \bar{N}^{\mathrm{all}}_{\mathrm{dec}}(E_\tau,E)}{\partial E}dE_{\bar{\nu}_\tau}dE_\tau$$

$$\cdot\left(\mathrm{Br}_e\bar{\Pi}_e(E,x)+\mathrm{Br}_\mu\bar{\Pi}_\mu(E,x)\right)\int_E^\infty\int_{E_\tau}^\infty \mathrm{Tr}\left[\Pi_\tau(E_{\nu_\tau},x)\rho(E_{\nu_\tau},x)\right]$$

$$\times\frac{1}{\lambda^\tau_{\mathrm{CC}}(E_{\nu_\tau},x)}\frac{\partial N^\tau_{\mathrm{CC}}(E_{\nu_\tau},E_\tau)}{\partial E_\tau}\frac{\partial N^{\mathrm{lep}}_{\mathrm{dec}}(E_\tau,E)}{\partial E}dE_{\nu_\tau}dE_\tau \qquad (10b)$$

$$+\left(\sum_\alpha \bar{\Pi}_\alpha(E,x)\right)\int_E^\infty \mathrm{Tr}\left[\bar{\Pi}(E_{\bar{\nu}_e},x)\bar{\rho}(E_{\bar{\nu}_e},x)\right]\frac{1}{\bar{\lambda}_{\mathrm{GR}}(E_{\bar{\nu}_e},x)}\frac{\partial \bar{N}^e_{\mathrm{GR}}(E_{\bar{\nu}_e},E)}{\partial E}dE_{\bar{\nu}_e}$$

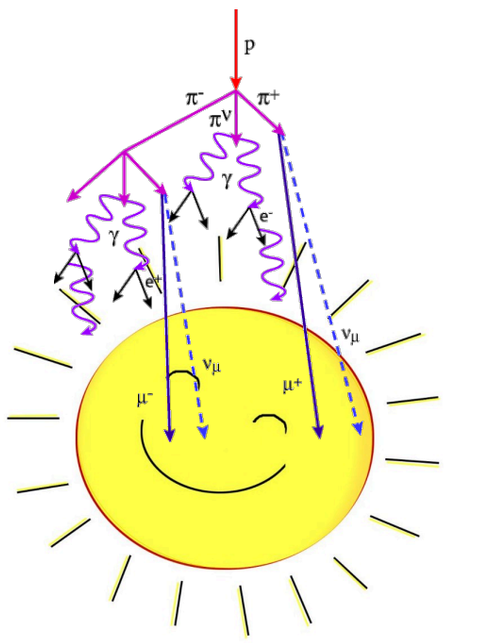


Neutrino propagation accounts for CC, NC, oscillations, and tau regeneration. Code is fast: 15-30 min per calculation.

Get it here:

https://github.com/jsalvado/SQuIDS

https://github.com/arguelles/nuSQuIDS



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ν_e $b = 0.0$ | ν_μ $b = 0.0$ | ν_τ $b = 0.0$

ν_e $b = 0.4$ | ν_μ $b = 0.4$ | ν_τ $b = 0.4$

ν_e $b = 0.8$ | ν_μ $b = 0.8$ | ν_τ $b = 0.8$

solid: neutrino
dashed: antineutrino

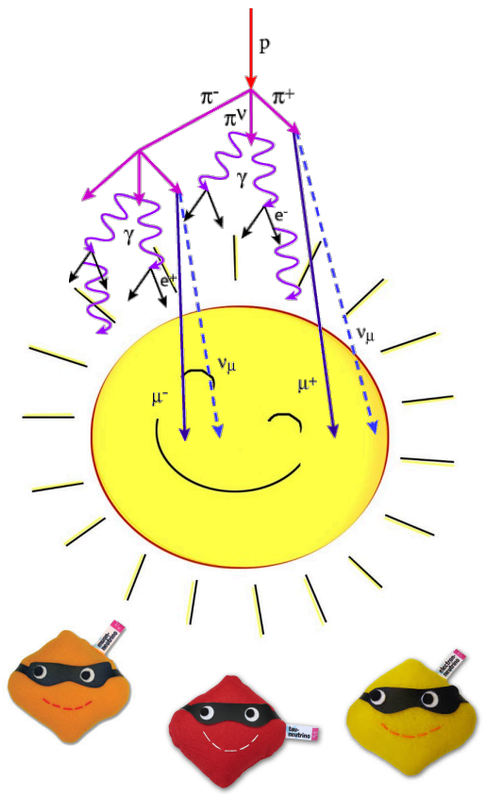
$\Phi_\nu\,(E_\nu/\mathrm{GeV})^3\,(\mathrm{cm}^2\ \mathrm{s\ sr\ GeV})^{-1}$

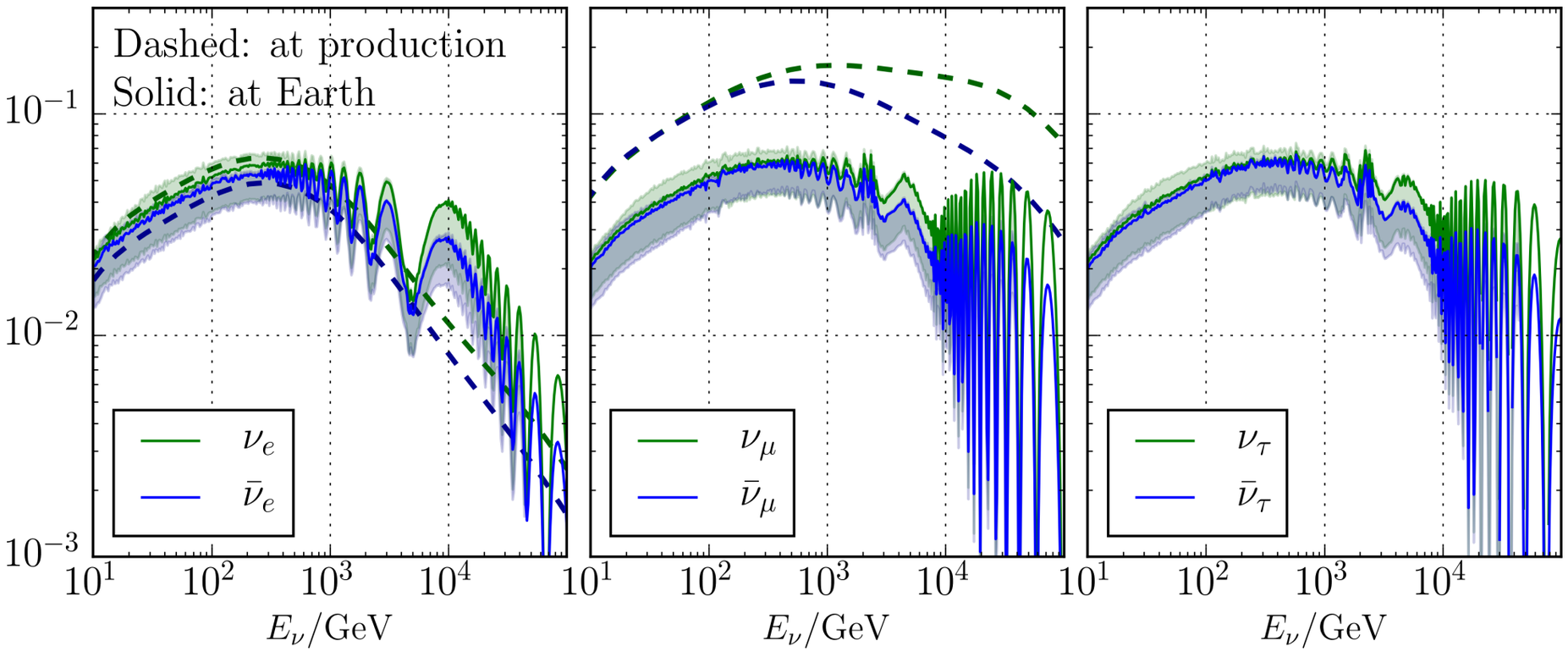
10^{-1} 10^{-2} 10^{-3} 10^{-4}

10^1 10^2 10^3 10^4

E_ν/GeV

Expected flux at Earth





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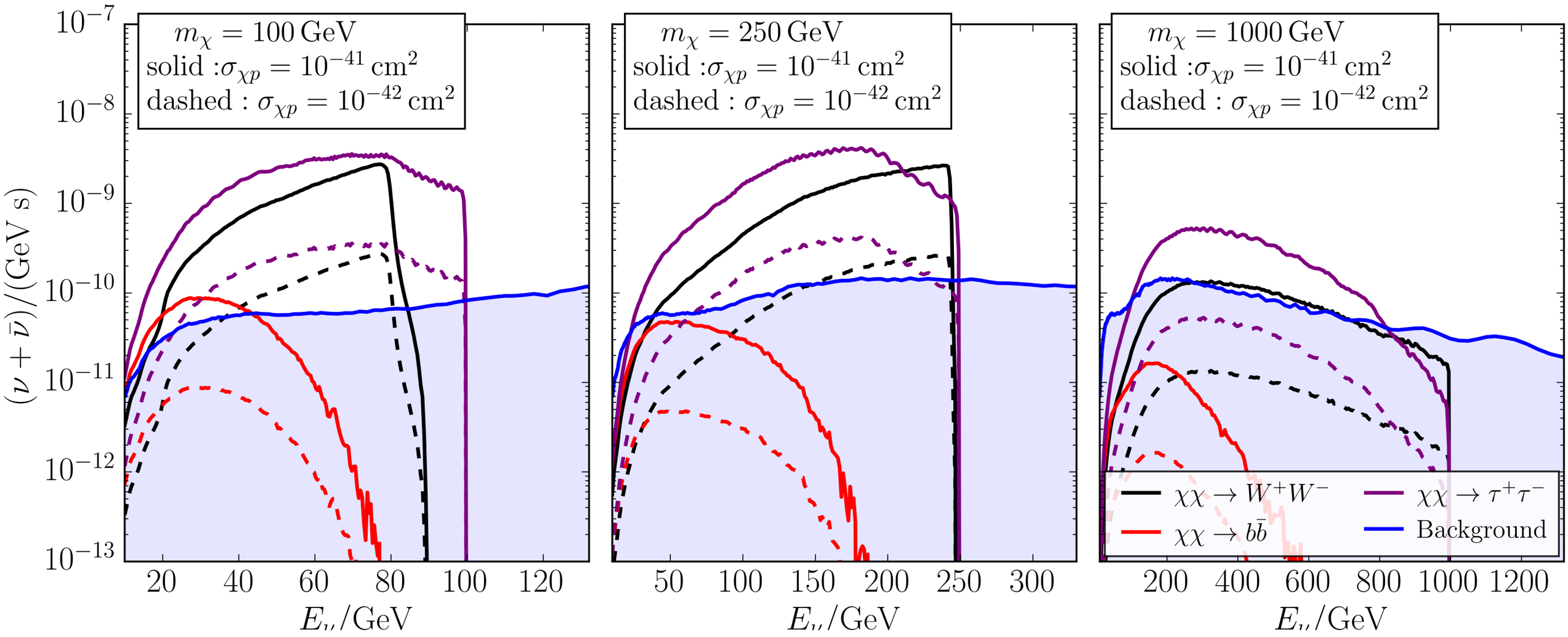
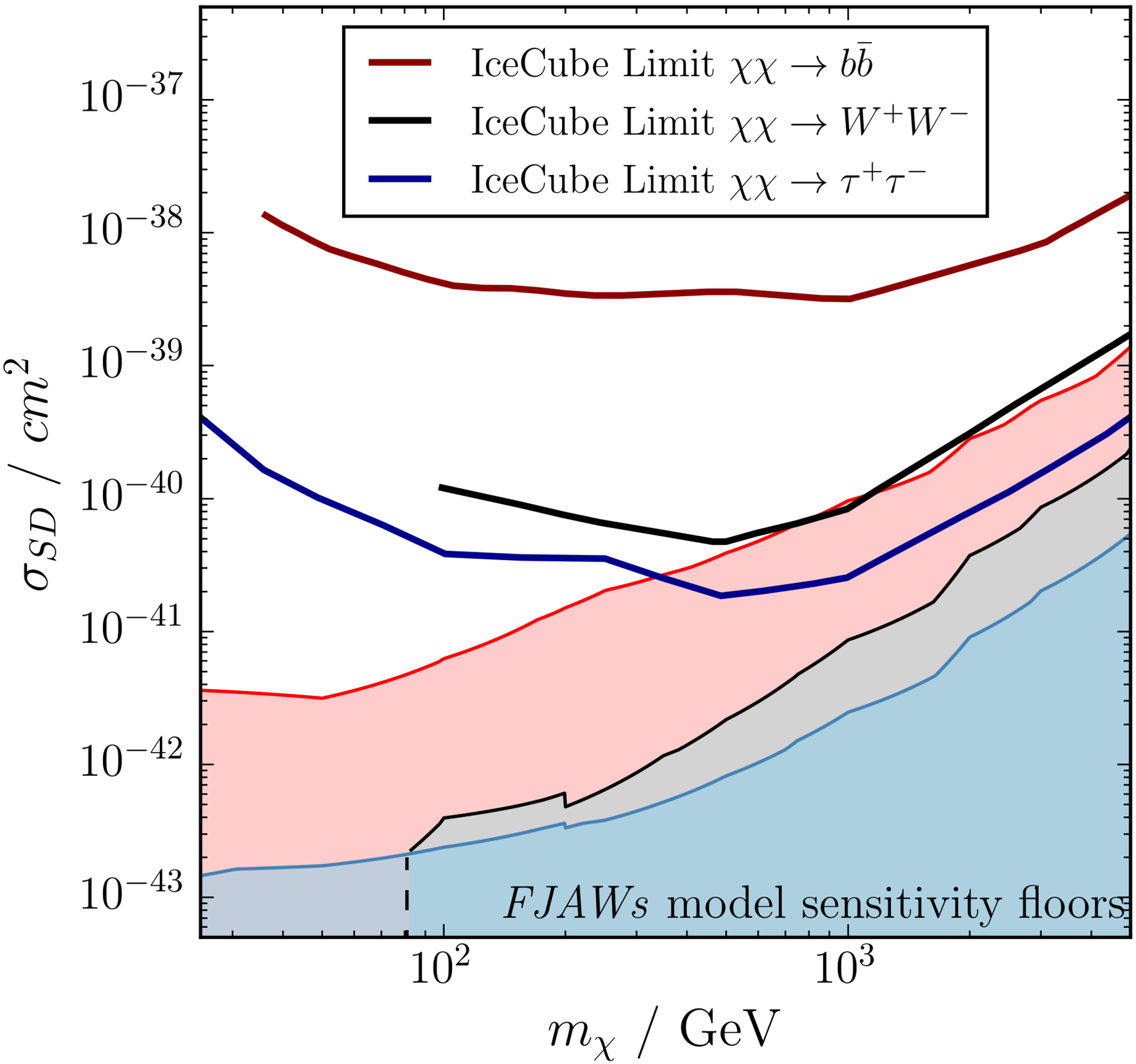
- At these high energies neutrino coherence is maintained.
- Low energy fast oscillation are average out due to vacuum oscillation through the year:
  - Aphelion to perihelion distance difference is ~ 4 million km.
  - Oscillation length at 100 GeV is ~ 1% of this distance.
  - Oscillation length is comparable at 10 TeV.

Comparison of DM rates with solar neutrinos



Experiment	Expected ν_μ rate R (evts / yr)	Expected $\bar{\nu}_\mu$ rate R (evts / yr)
IceCube (IC79)	$1.33 < R < 2.12$	$0.70 < R < 1.11$
IceCube (IC86)*	$2.04 < R < 3.28$	$1.91 < R < 3.07$
ANTARES*	$0.032 < R < 0.053$	$0.029 < R < 0.047$
IceCube+PINGU	$1.39 < R < 2.22$	$0.77 < R < 1.23$
KM3NeT*	$3.00 < R < 4.94$	$2.67 < R < 4.36$

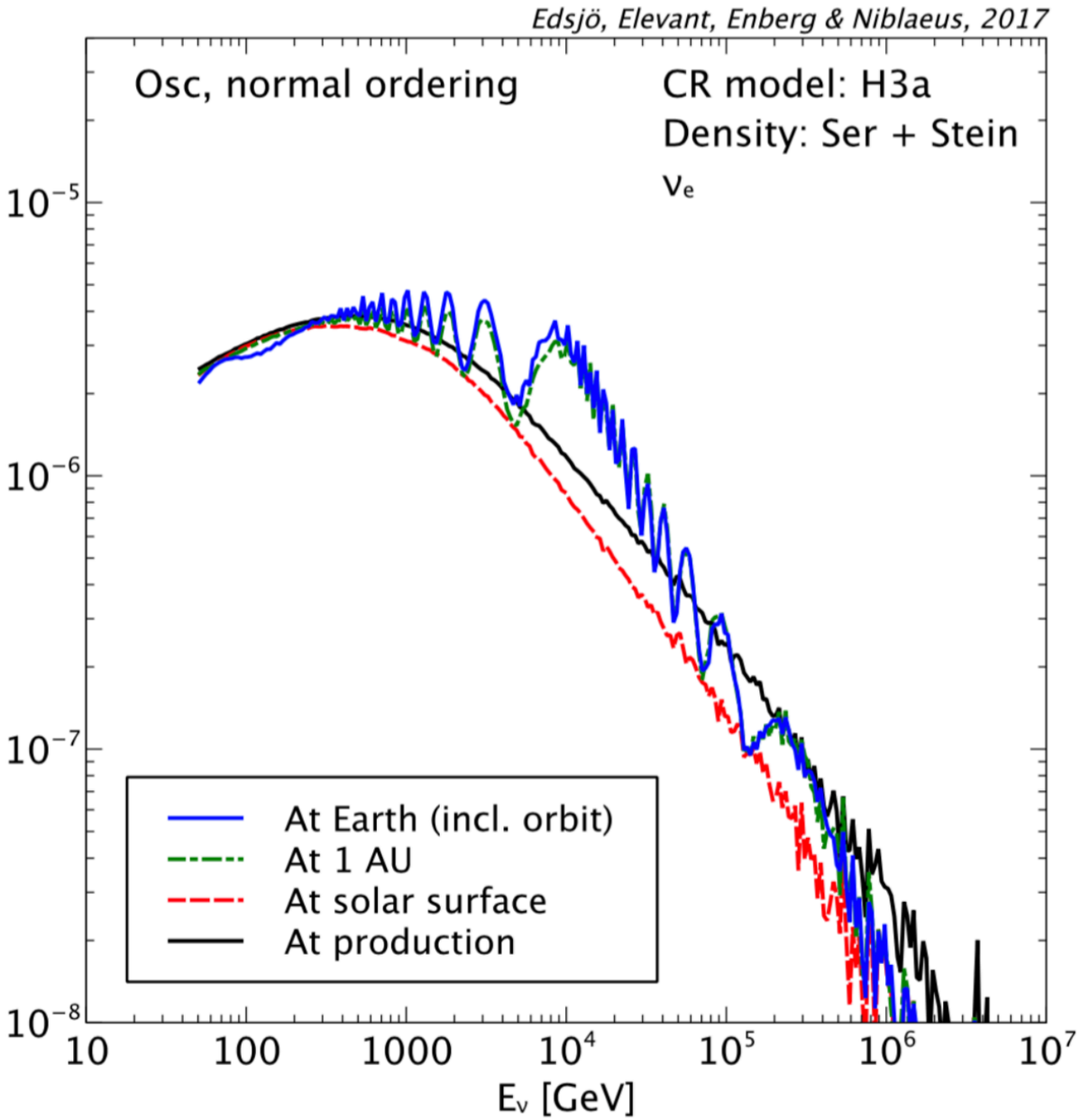
Money plot!

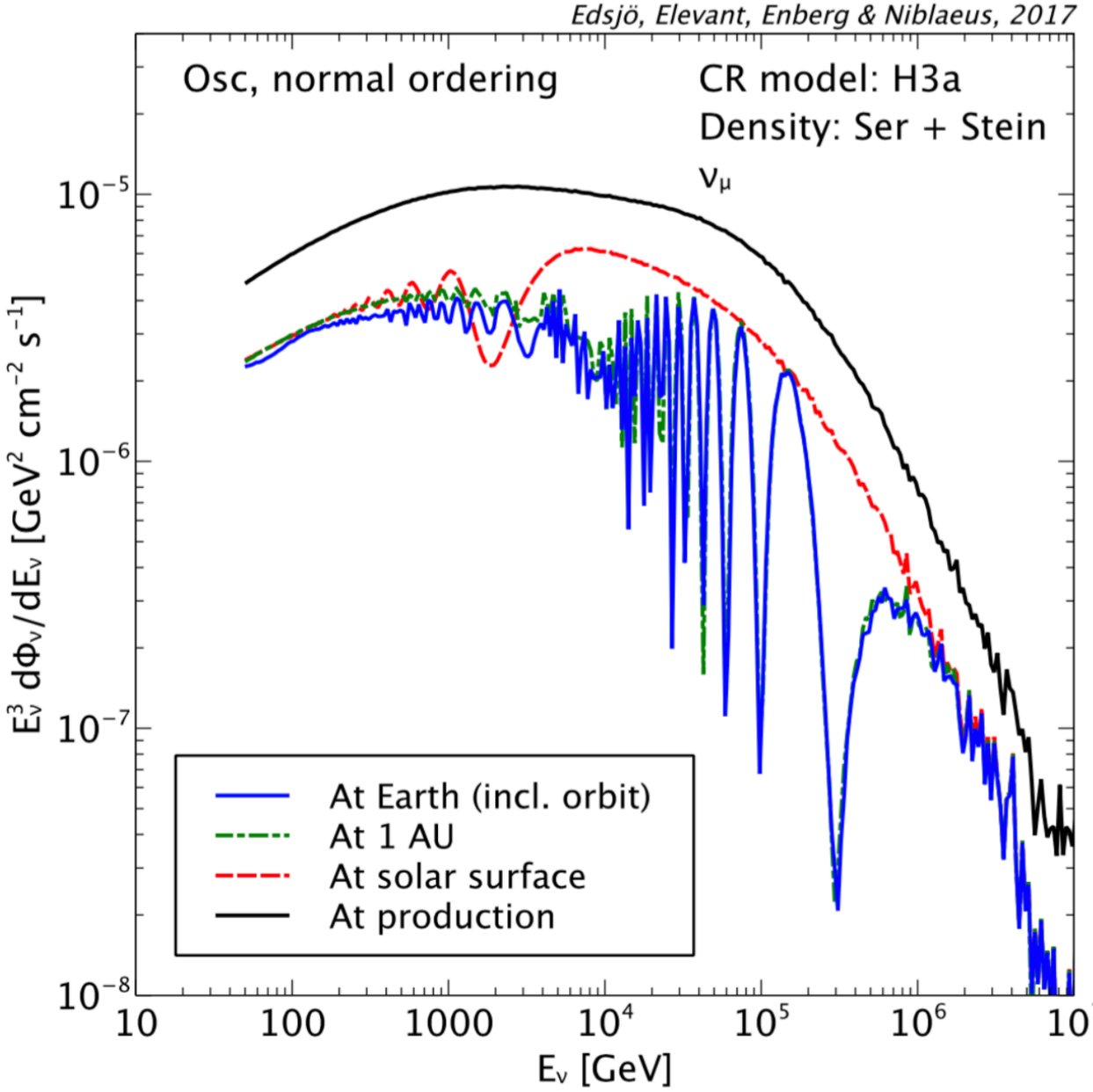


- For each DM mass and cross section we calculate the energy region of interest (ERI) where 90% of the DM-neutrino events are.
- We calculate in the ERI the number of expected atmospheric solar neutrinos.
- Floor: S ~ B.

Comparison with recent results!

✤Edsjö et al. (1704.02892) recalculate the flux (using MCeq too!). Good agreement in fluxes and floor.





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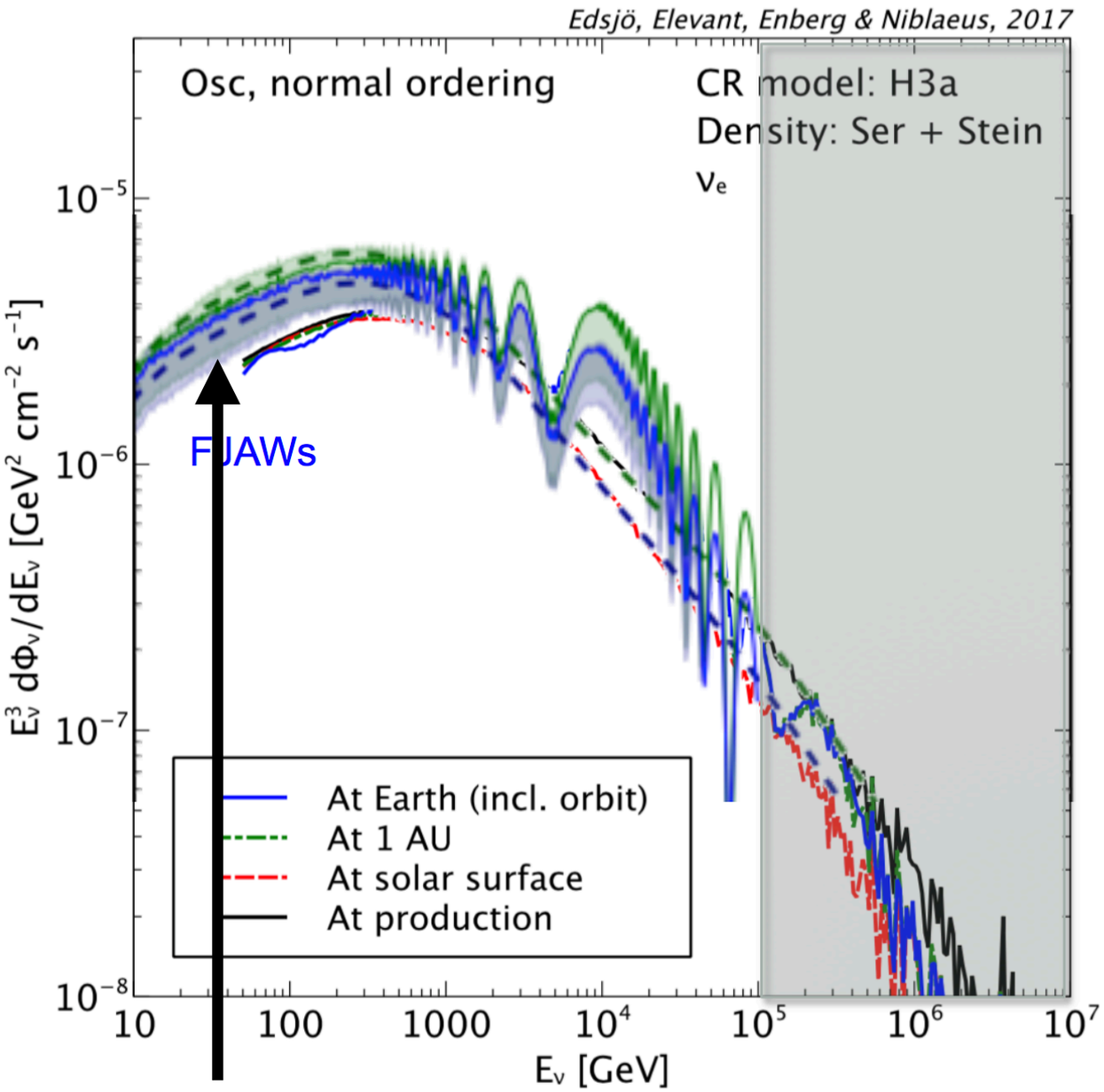
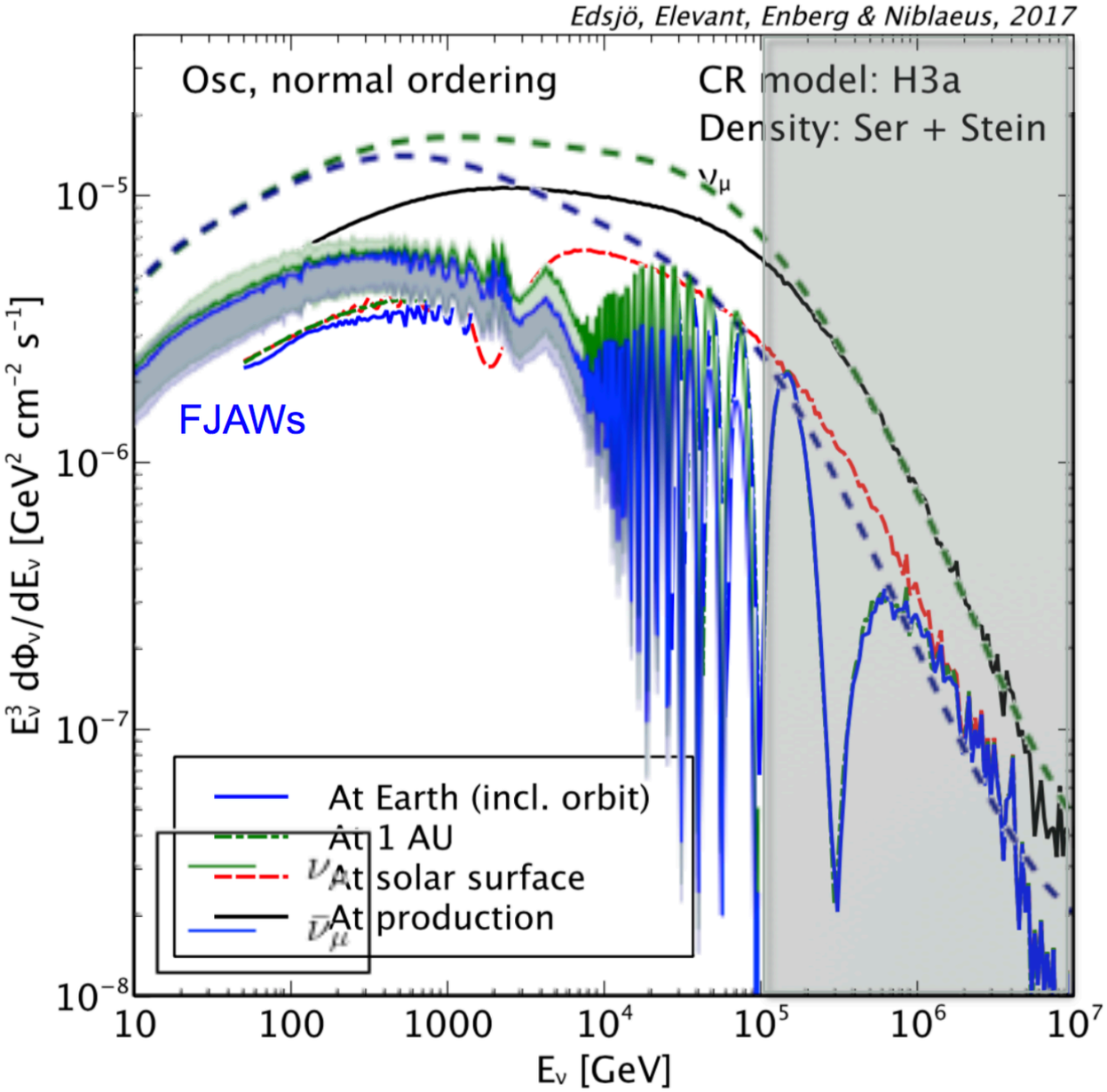
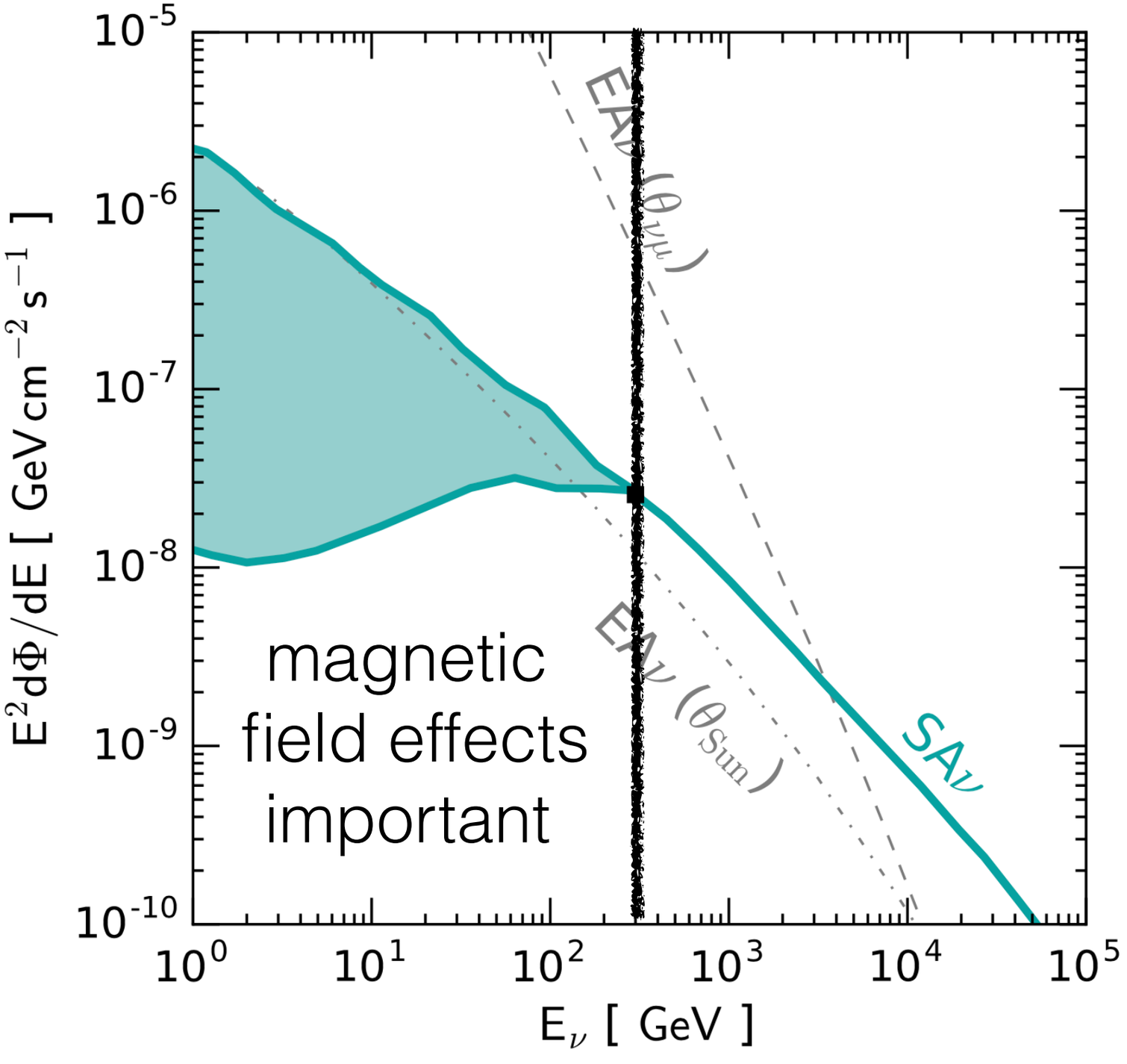




low energy disagreements: muon decay implementation?

Comparison with recent results!



- Ng et al. (1703.10280) use previous calculation by Ingelman-Thunman above 300 GeV and use Seckel et al. model below it.
- **Our calculation assumes neglects magnetic field effects.**

Seckel et al. (1991)

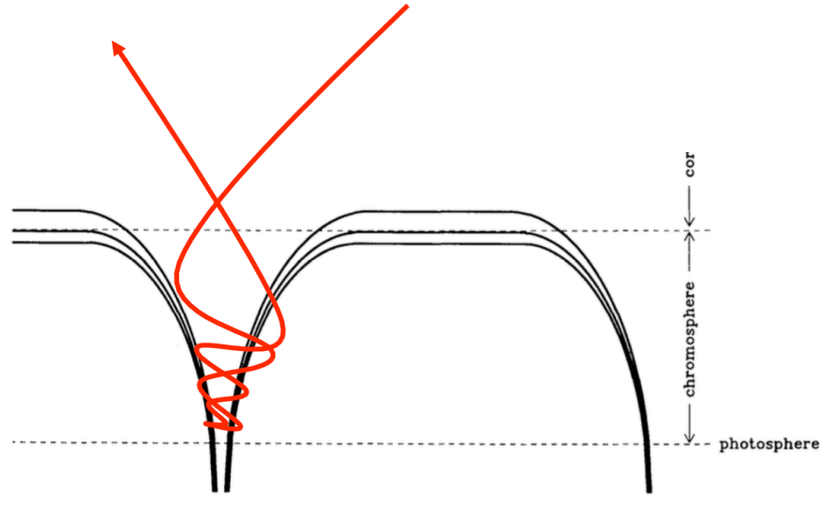
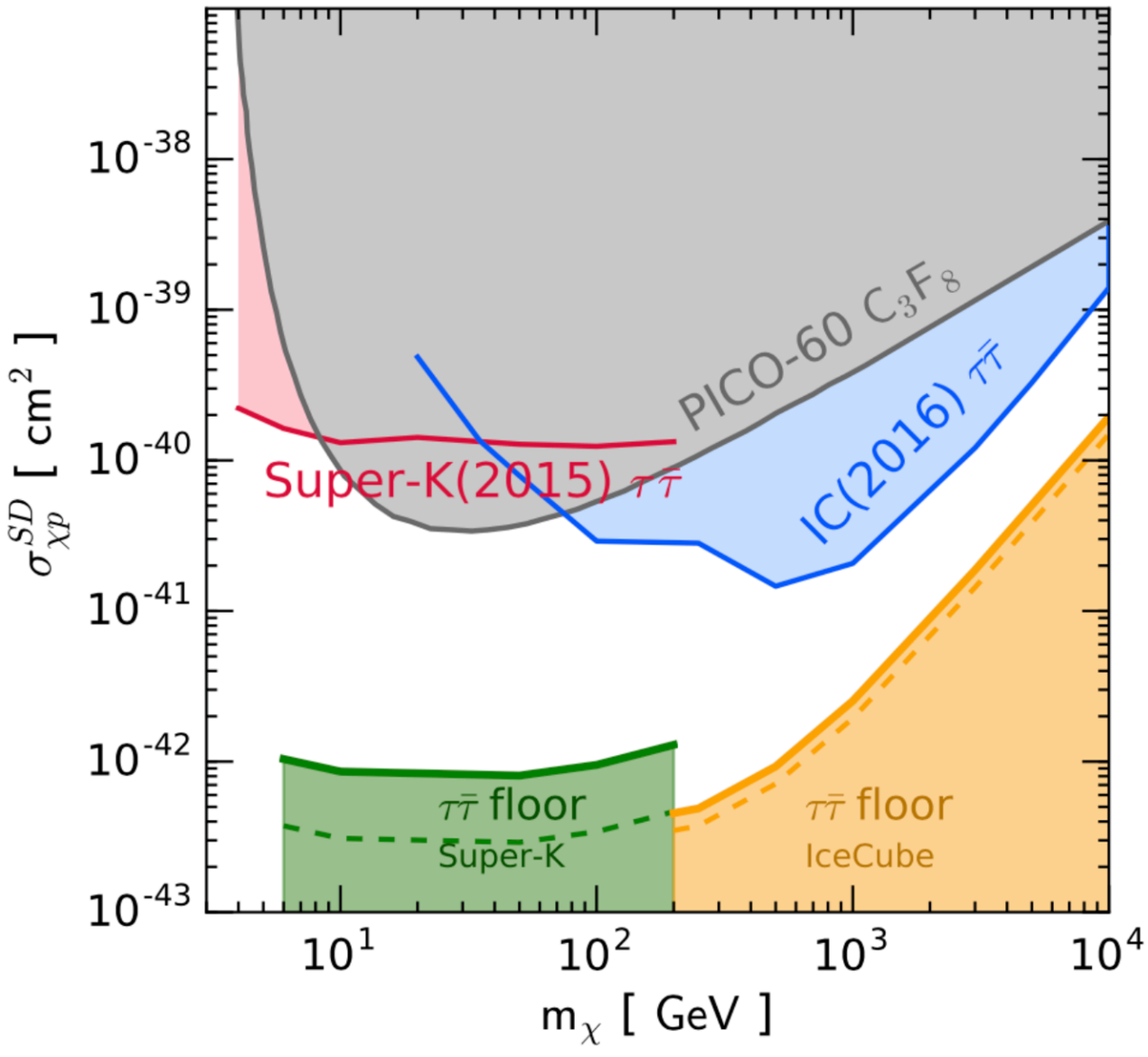


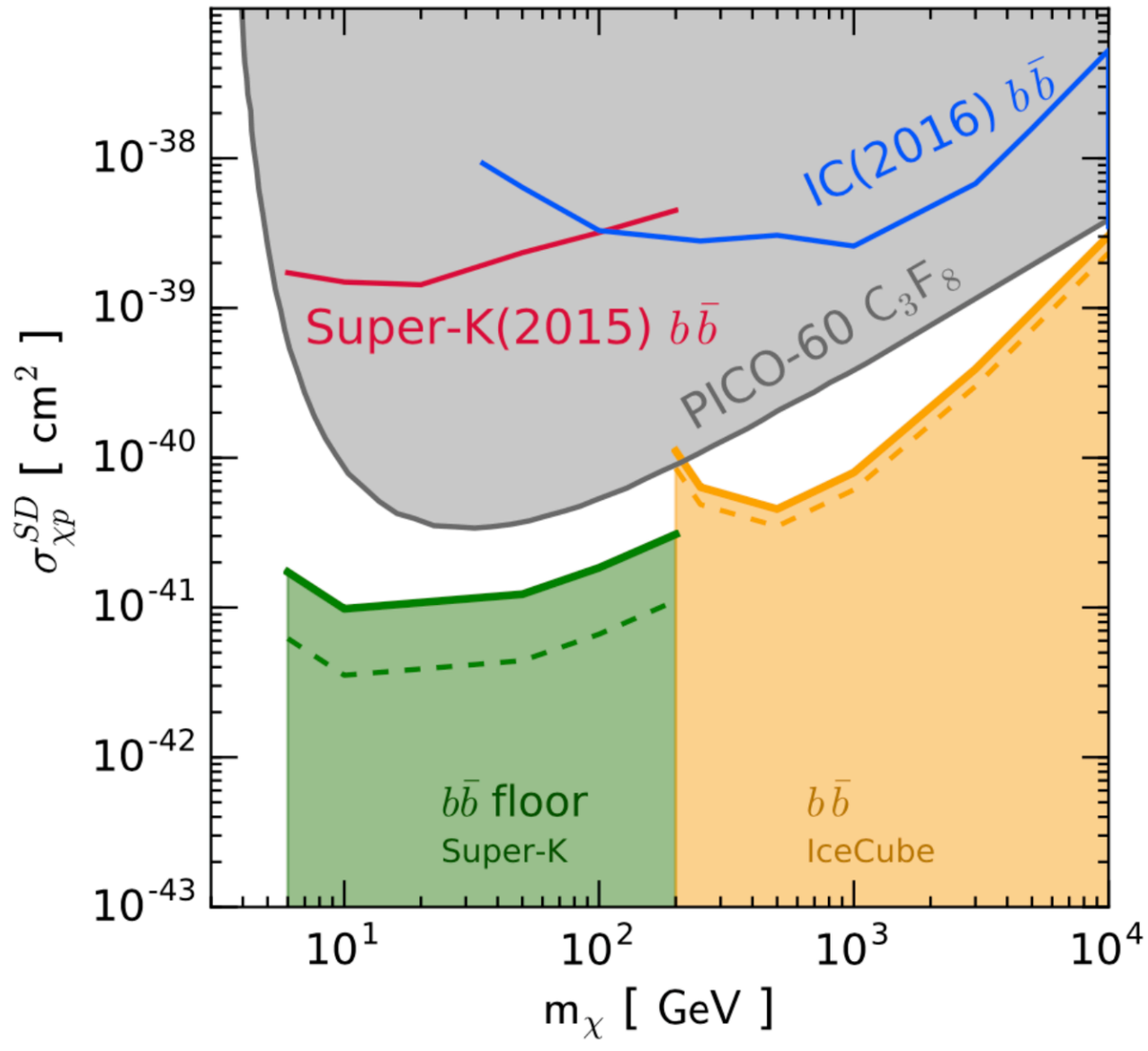
FIG. 2.—Schematic representation of solar magnetic fields near the photosphere.

*Ingeman-Thunman calculation in good agreement with new calculations up to ~ 1 TeV.

Comparison with recent results!

✤Ng et al. (1703.10280) use previous calculation by Ingelman-Thunman. Modification of the flux at low energies due to magnetic field effects accounted in their calculation.





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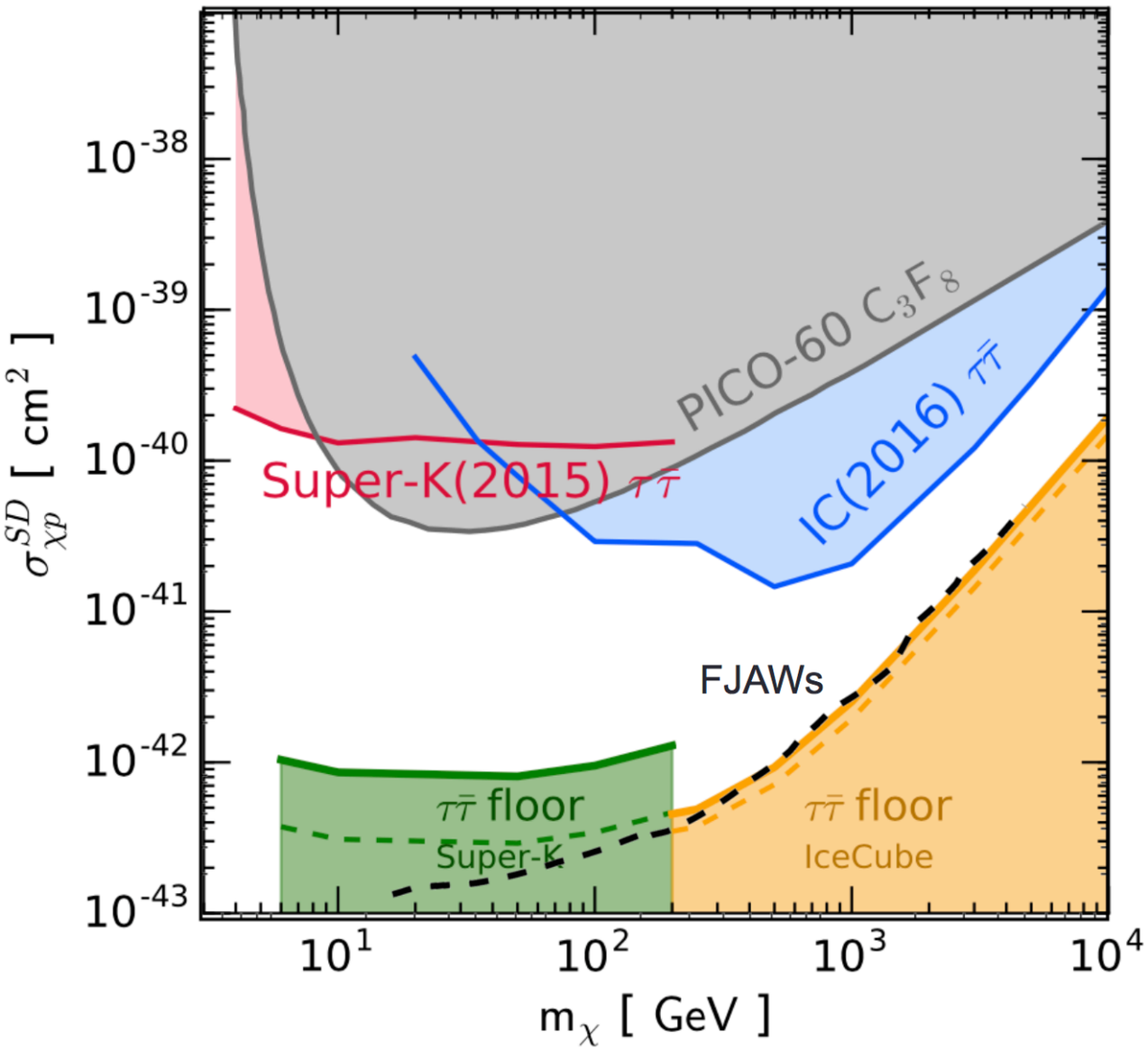
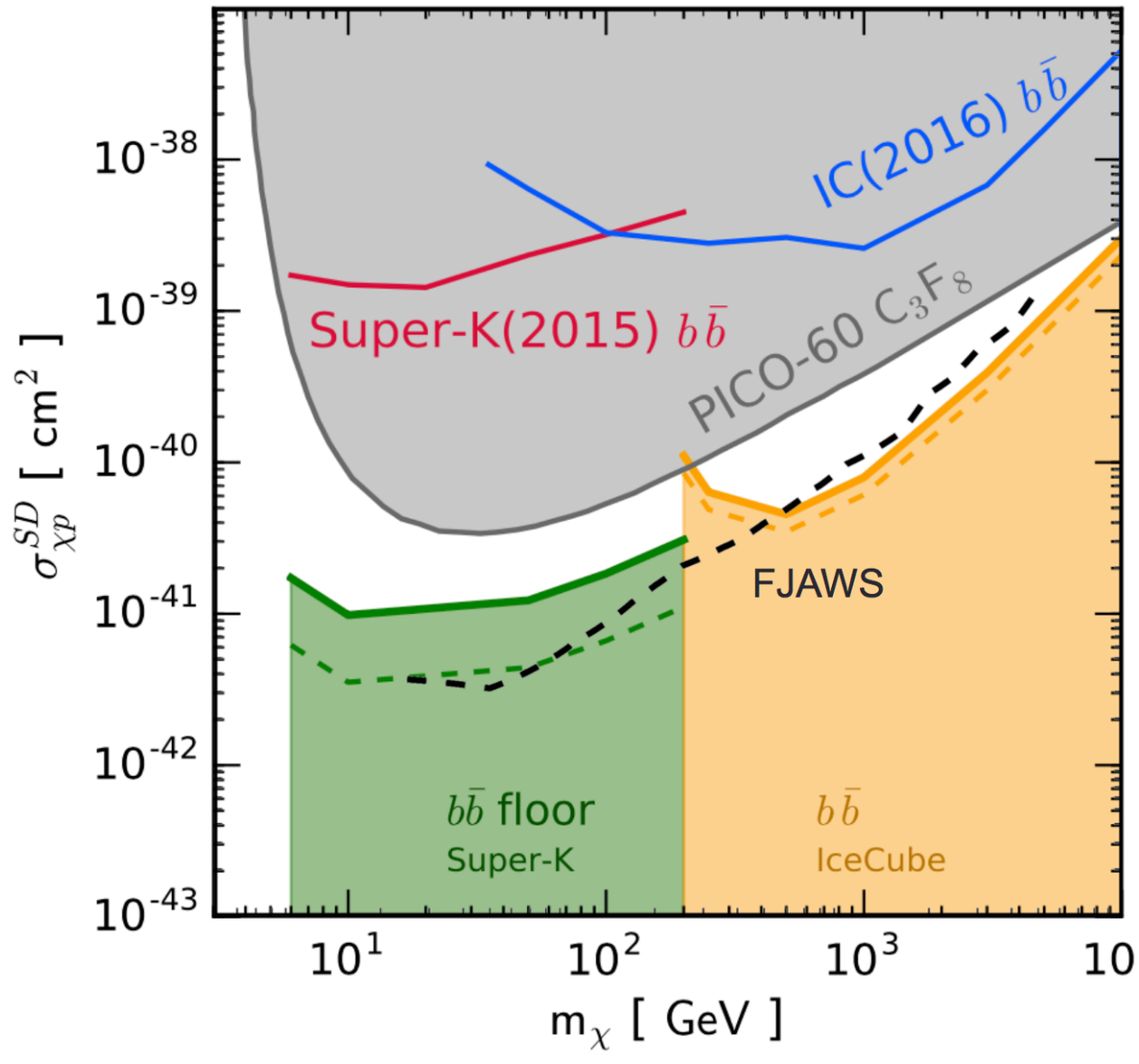




Take home message

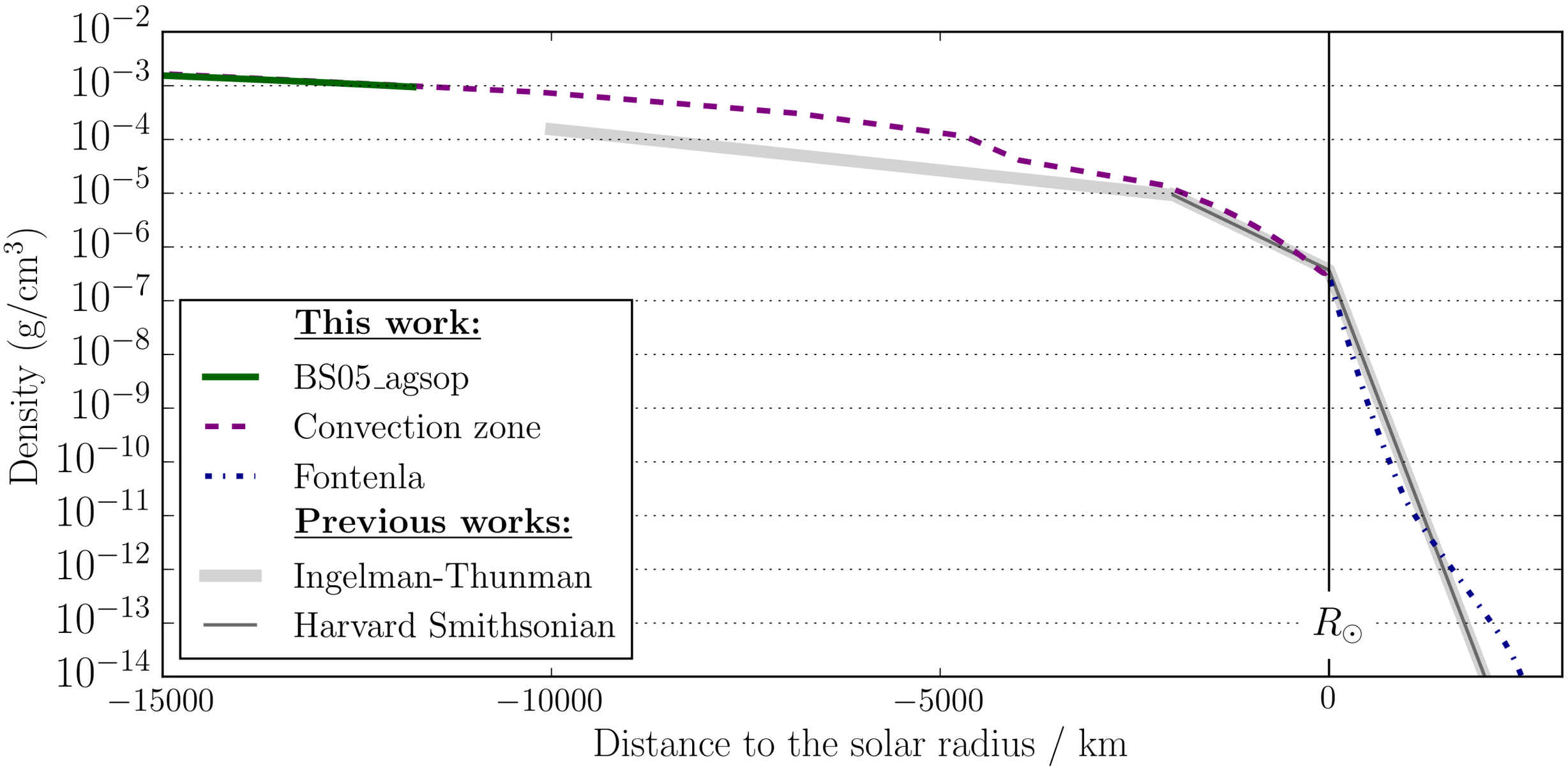
- We are getting closer to detecting Solar-Atmospheric neutrinos!
- **Three** new independent calculations of the predicted Solar-Atmospheric neutrino flux: good agreement. See **1703.07798**, **1703.10280**, and **1704.02892**.
- **Fluxes for all variants and at several stages available online.**

THANKS!

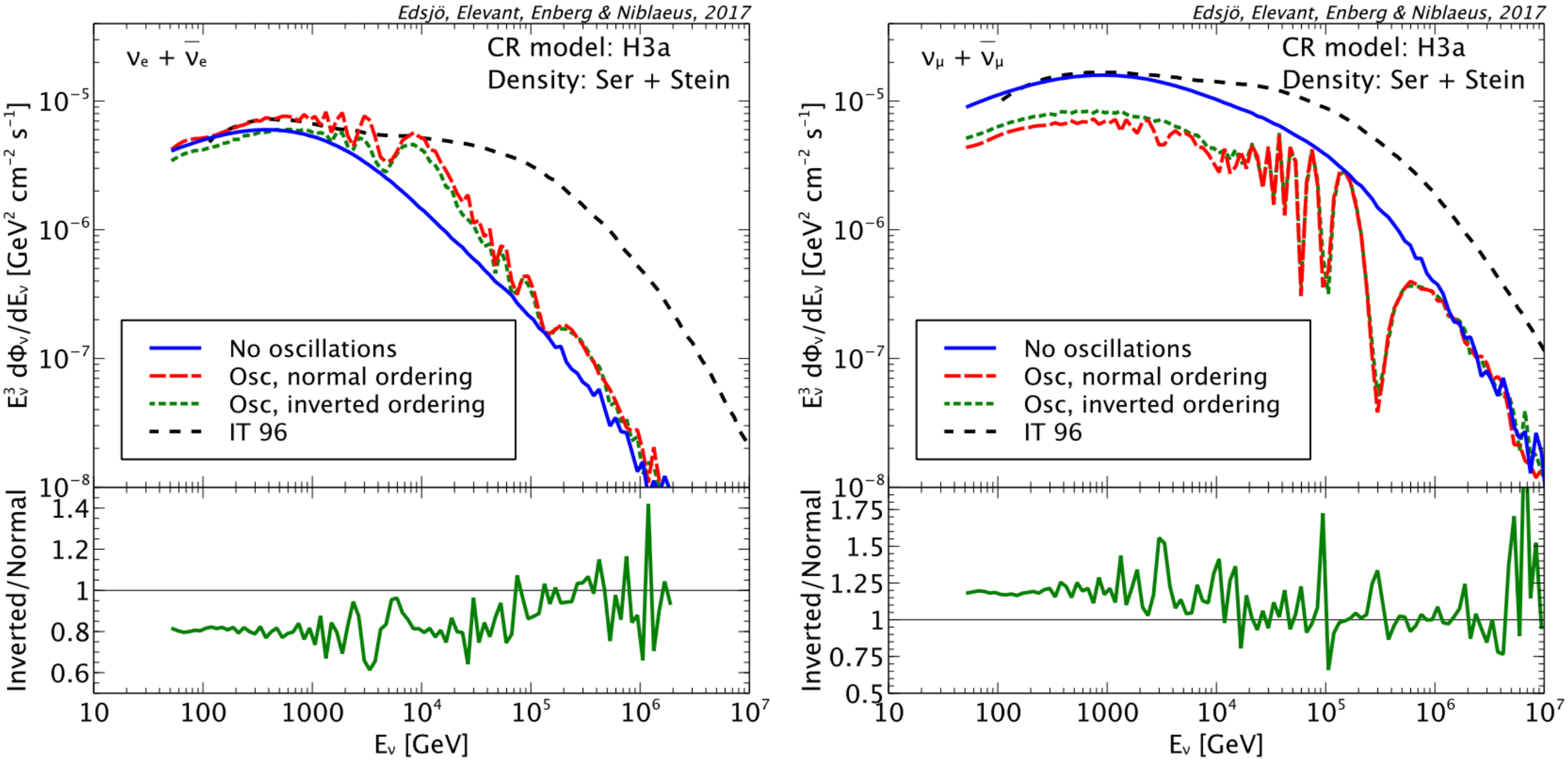
*Fluxes available here
https://dspace.mit.edu/handle/1721.1/108394

BONUS SLIDES!

Atmospheric model detail



Comparison with Ingelman-Thunman



Edsjö et al. (1704.02892)