Massachusetts Institute of Technology

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

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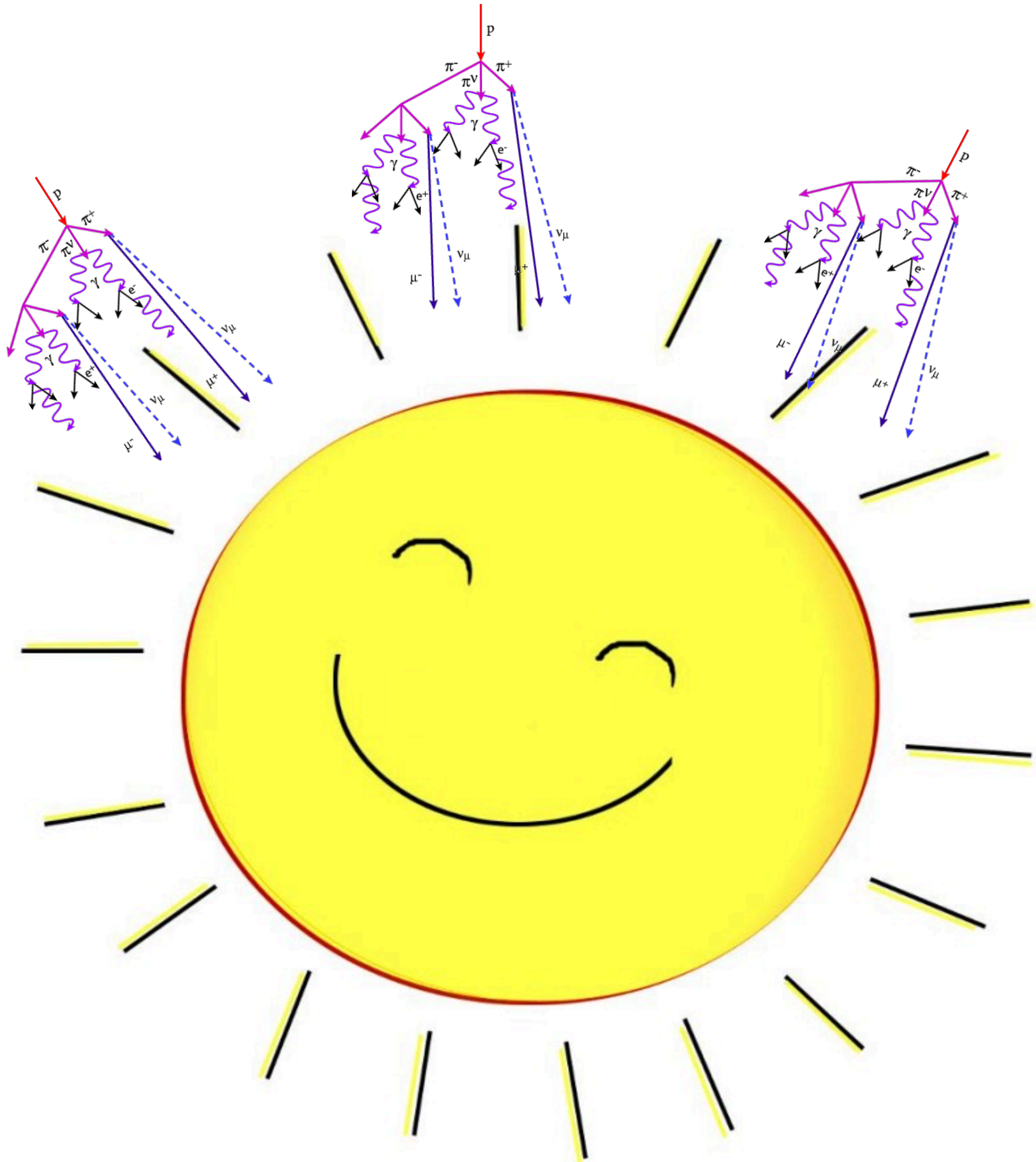
in collaboration with Gwen de Wasseige, Anatoli Fedynitch, and Ben Jones

Based on JCAP07 (2017) 024 (arXiv:1703.07798)

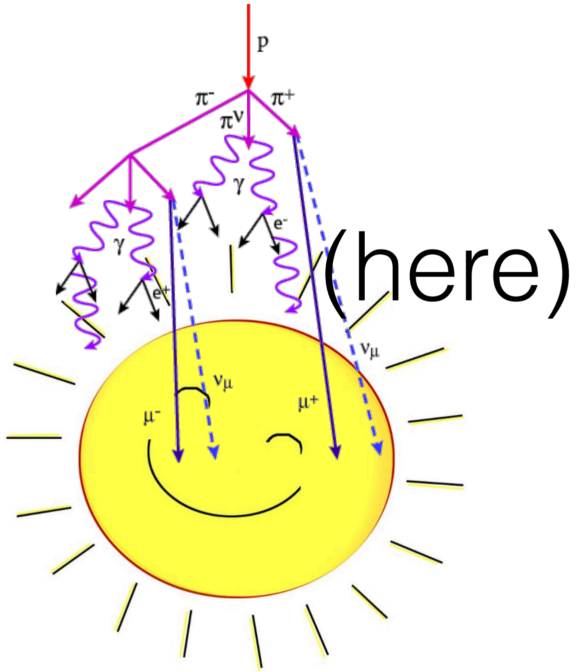
VRIJE UNIVERSITEIT BRUSSEL



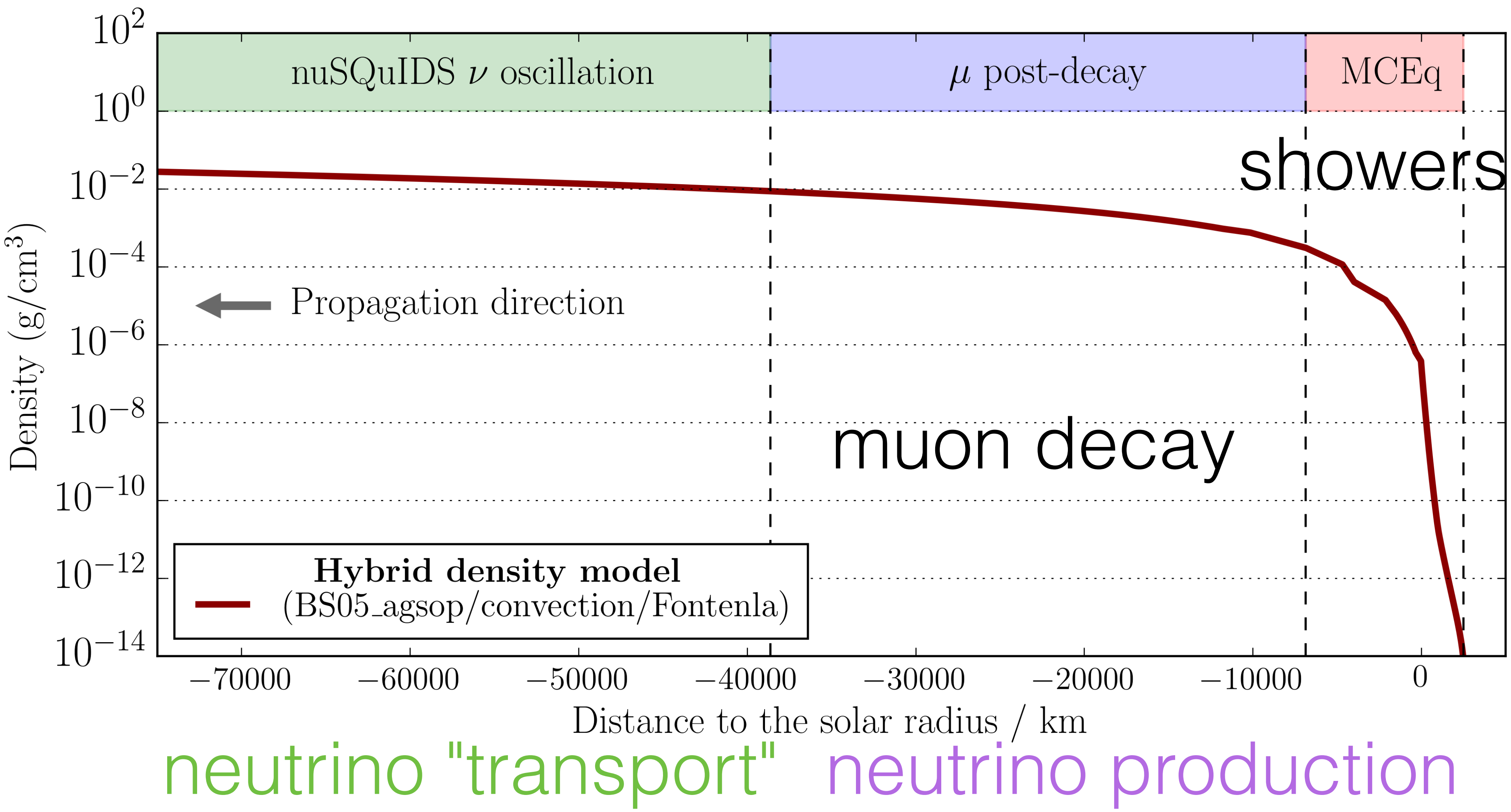
Like in the Earth the Sun is bombarded by CR, which shower in the solar atmosphere producing neutrinos

Recipe for a Solar-Atmospheric neutrino flux calculation

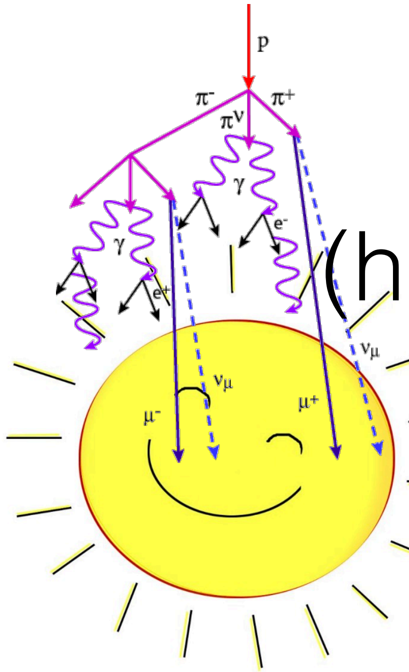
- ✤Cosmic ray incident flux
- ✤Model of the solar atmosphere
- ✤Hadronic model for particle interaction showers
- ✤Cascade equation code
  https://github.com/afedynitch/MCEq
- ✤Neutrino transport code
  https://github.com/arguelles/nuSQuIDS



Where are the neutrinos produced?



- Showers occur in the outer part of the Sun.
- Very boosted muons decay in after shower region.



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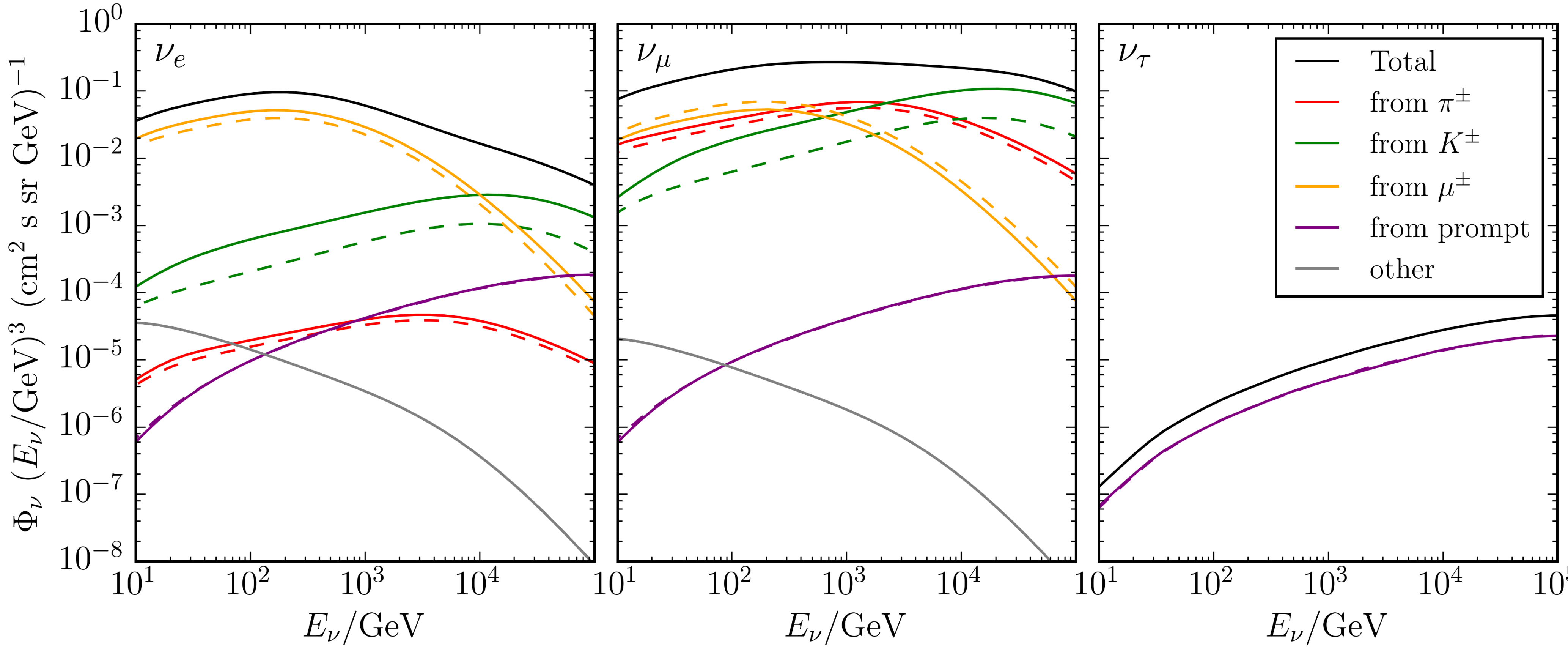
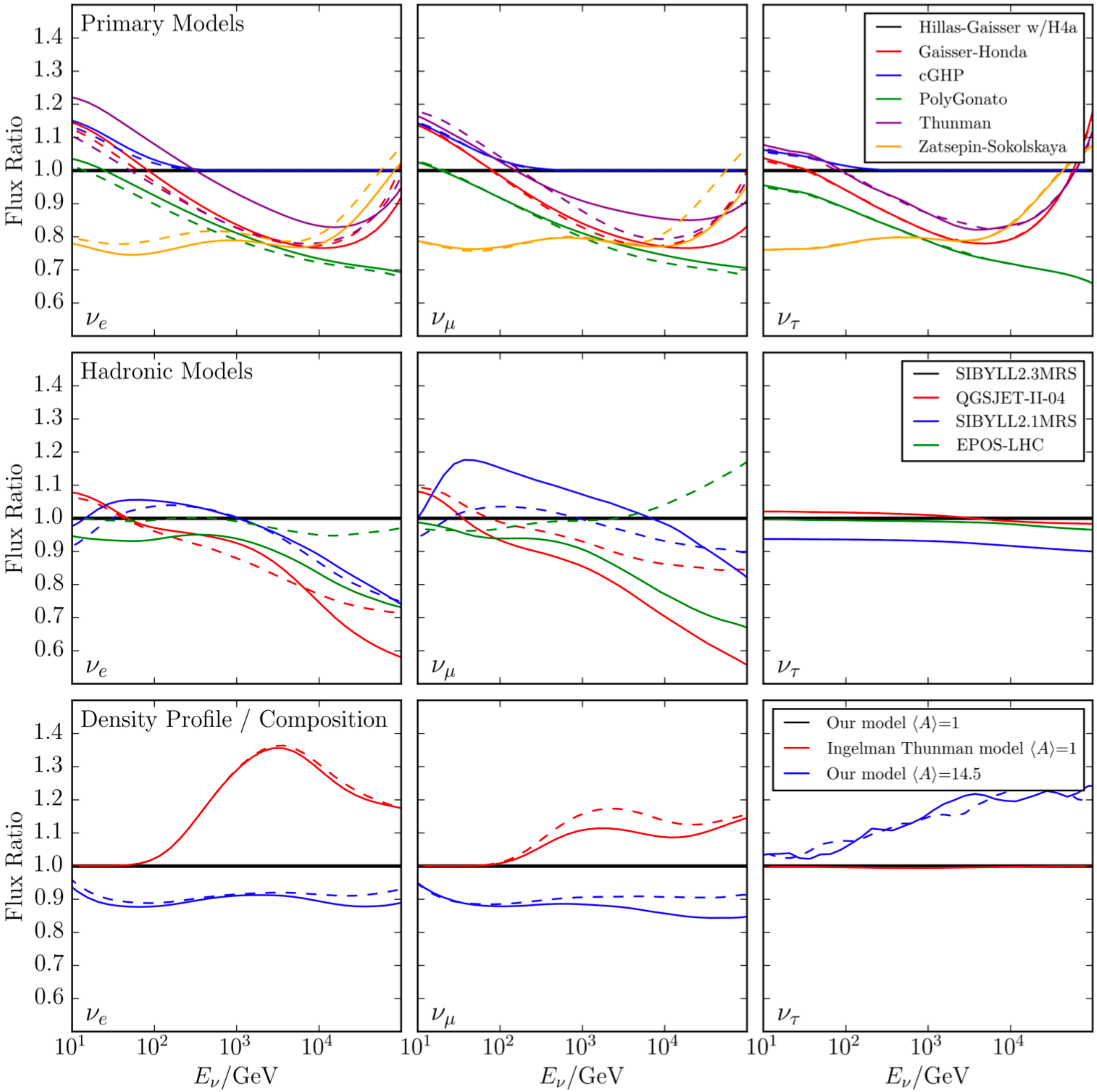
Flux decomposed



(Cosmic ray model: Gaisser-Honda with H4a and hadronic model Sibyll2.3)

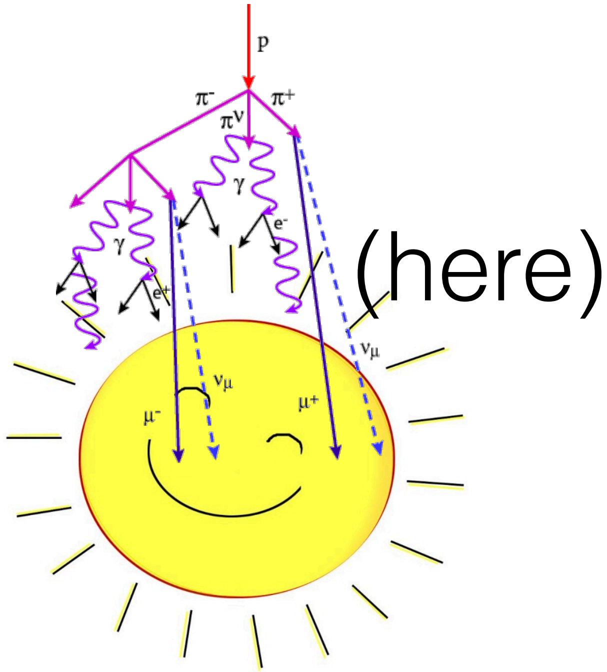
- ✤ Electron/Muon neutrinos dominated from muon decays and K.
- ✤ Tau neutrinos only present from charmed component (prompt)



We consider uncertainties due to cosmic ray models, hadronic models, and solar atmosphere modeling.

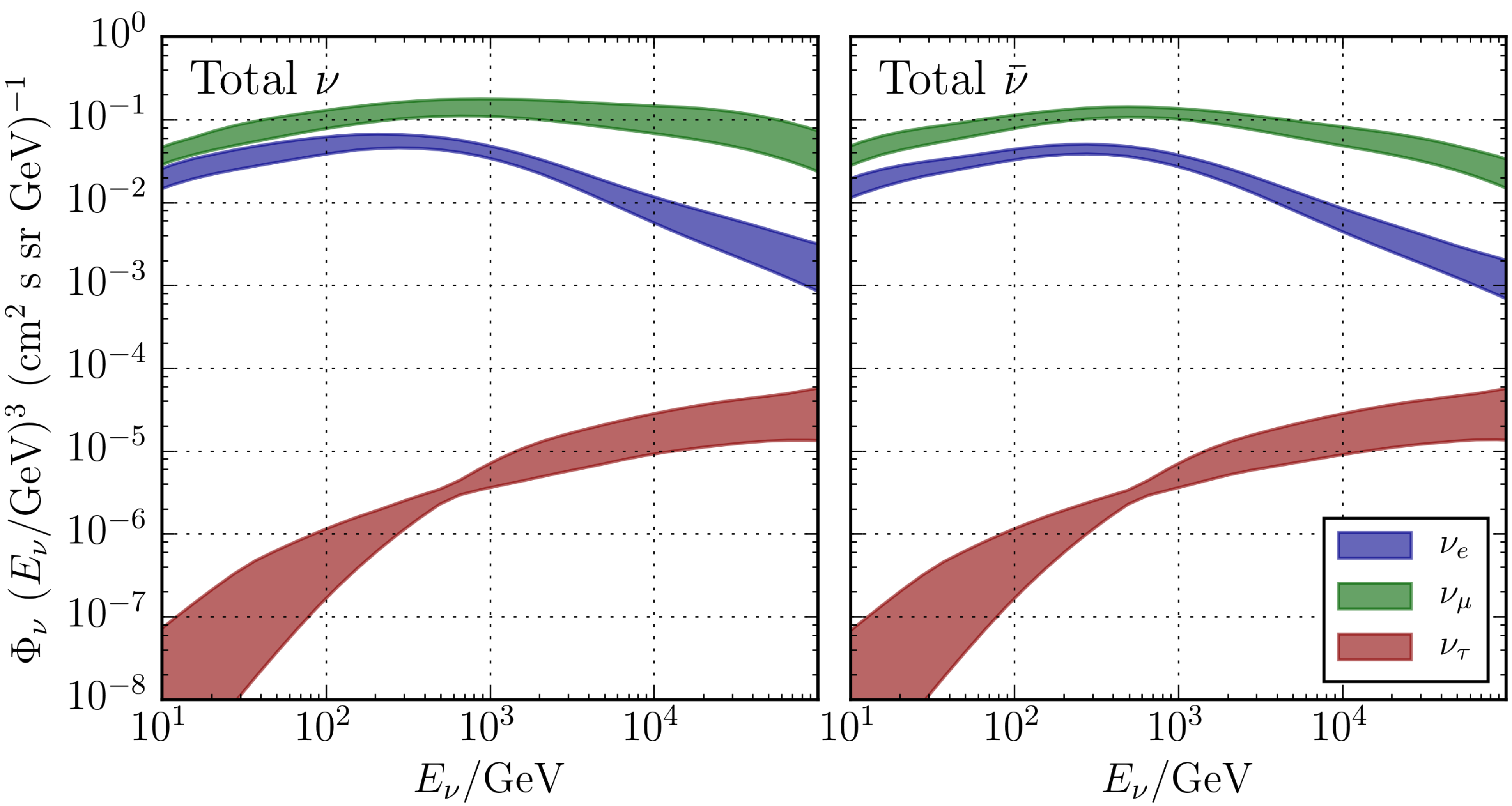
Total Uncertainty ~ 30%

(*except nu_tau-prompt)

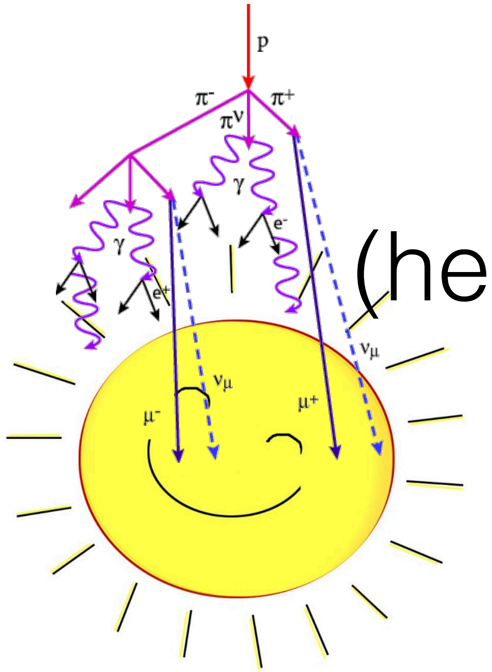


Our flux calculation after showering with uncertainties

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



Neutrino transport



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oscillations **absorption**

$$\frac{dF_\nu(E)}{dx} = -i[\mathrm{H}, \mathrm{F}_\nu(\mathrm{E})] - \sum_\alpha \frac{1}{2\lambda^\alpha(E)}\{\Pi_\alpha, F_\nu(E)\}$$

nc-“regeneration”

$$+\int_{E'} \frac{1}{\lambda_{\mathrm{NC}}(E')} \sum_\alpha \{\Pi_\alpha, F_\nu(E')\} NC(E', E)$$

$$+\int_{E'} \frac{1}{\lambda^\tau(E')} F_\tau(E') CC_\tau(E', E) \Pi_\tau$$

$$+\mathrm{Br}_\mu \int_{E'} \frac{1}{\lambda^\tau(E')} \bar{F}_\tau(E') CC_\tau(E', E) \Pi_\mu \,,$$

$$+\mathrm{Br}_e \int_{E'} \frac{1}{\lambda^\tau(E')} \bar{F}_\tau(E') CC_{\bar{\tau}}(E', E) \Pi_e$$

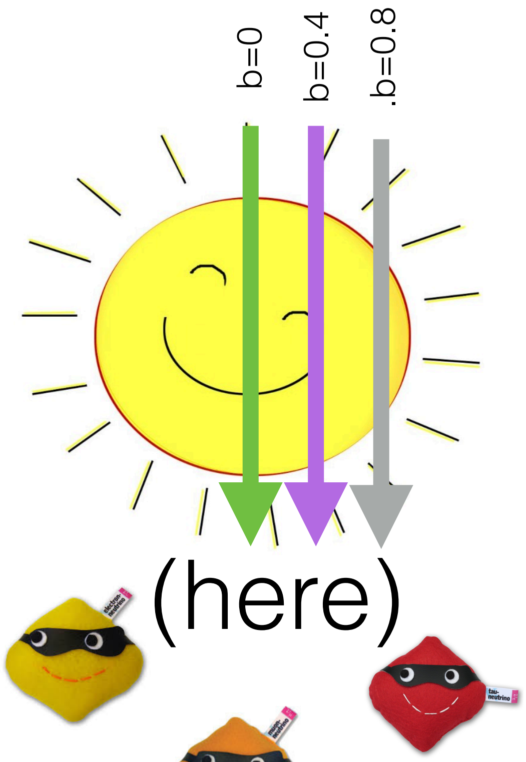
tau-“regeneration”

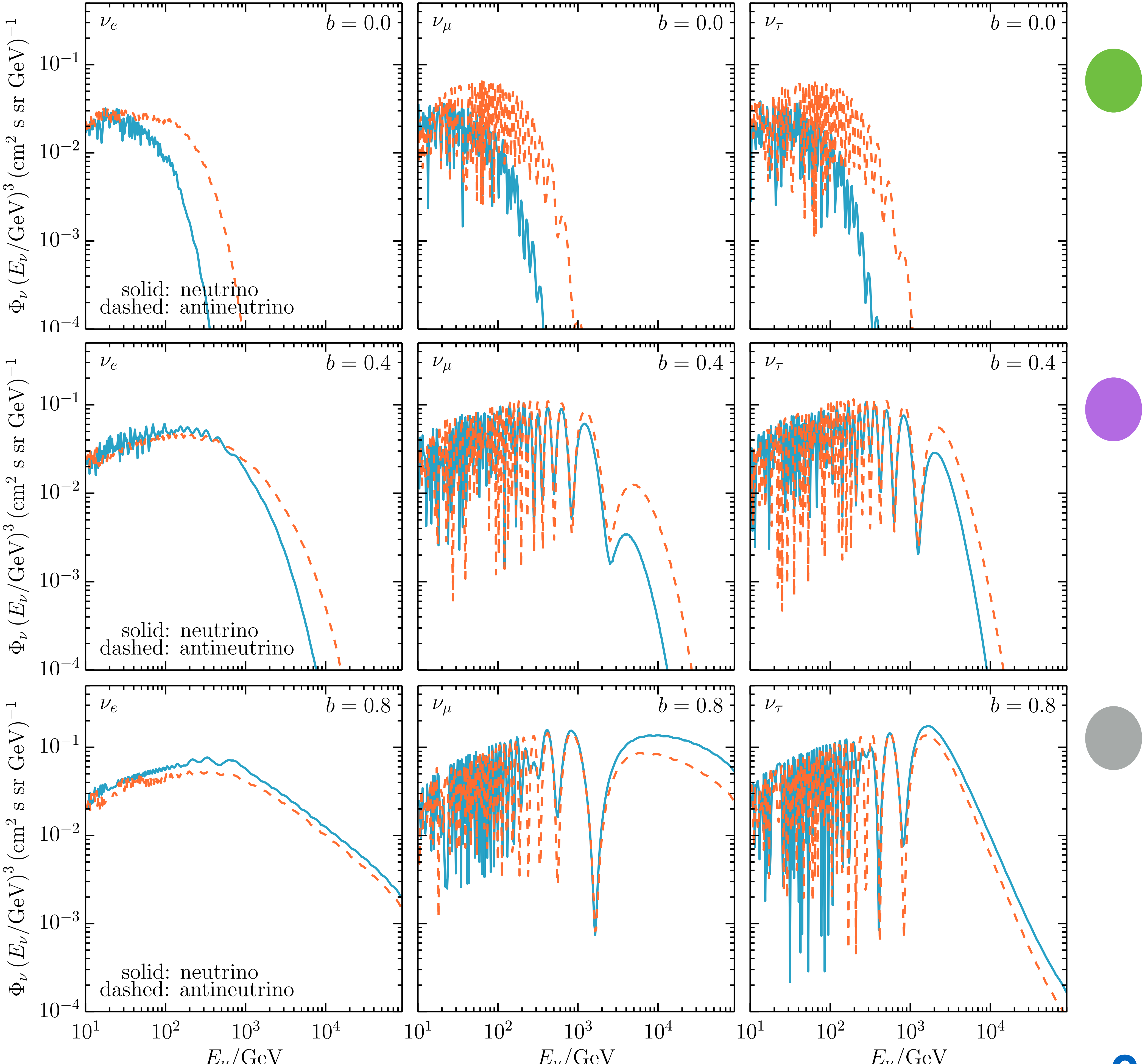
Neutrino propagation accounts for CC, NC, oscillations, and tau regeneration. Code is fast: 15-30 min per calculation.

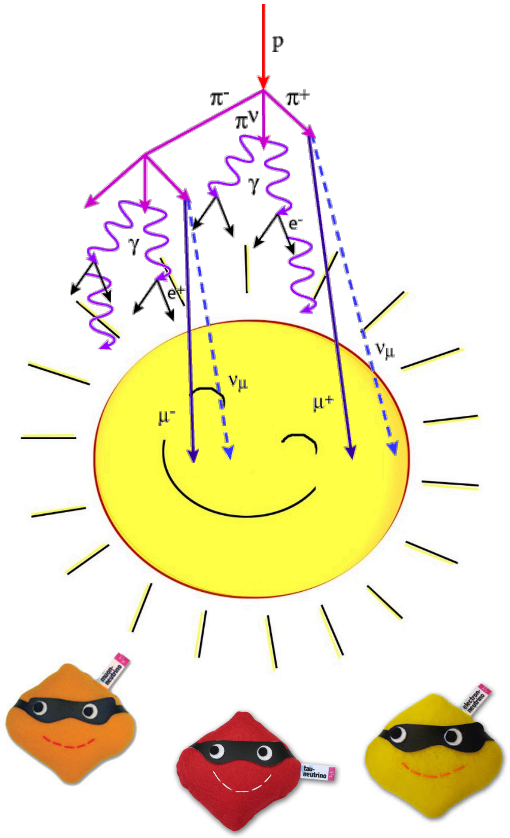
Get it here:

https://github.com/jsalvado/SQuIDS

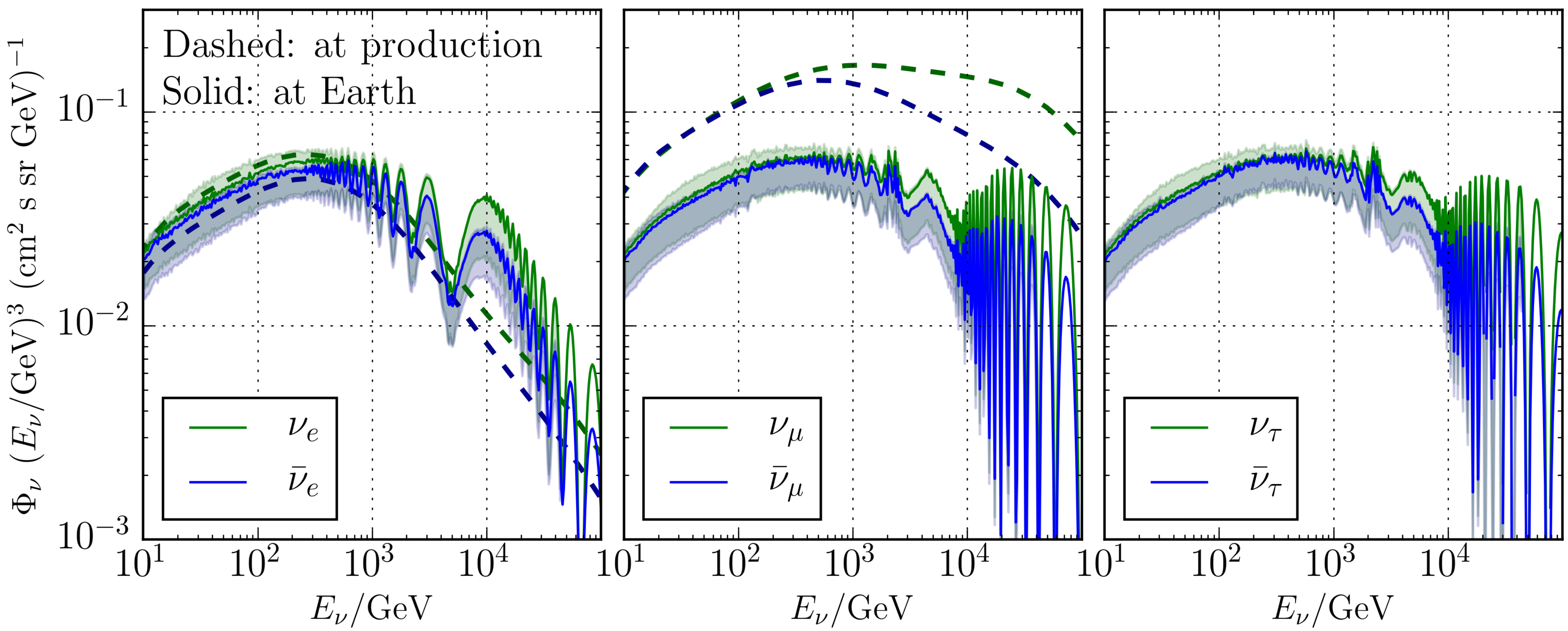
https://github.com/arguelles/nuSQuIDS


b=0
b=0.4
b=0.8
(here)


ν_e
ν_μ
ν_τ
$b = 0.0$
$b = 0.4$
$b = 0.8$
solid: neutrino
dashed: antineutrino
$\Phi_\nu \, (E_\nu/\mathrm{GeV})^3 \, (\mathrm{cm}^2 \text{ s sr GeV})^{-1}$
E_ν/GeV
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^1
10^2
10^3
10^4



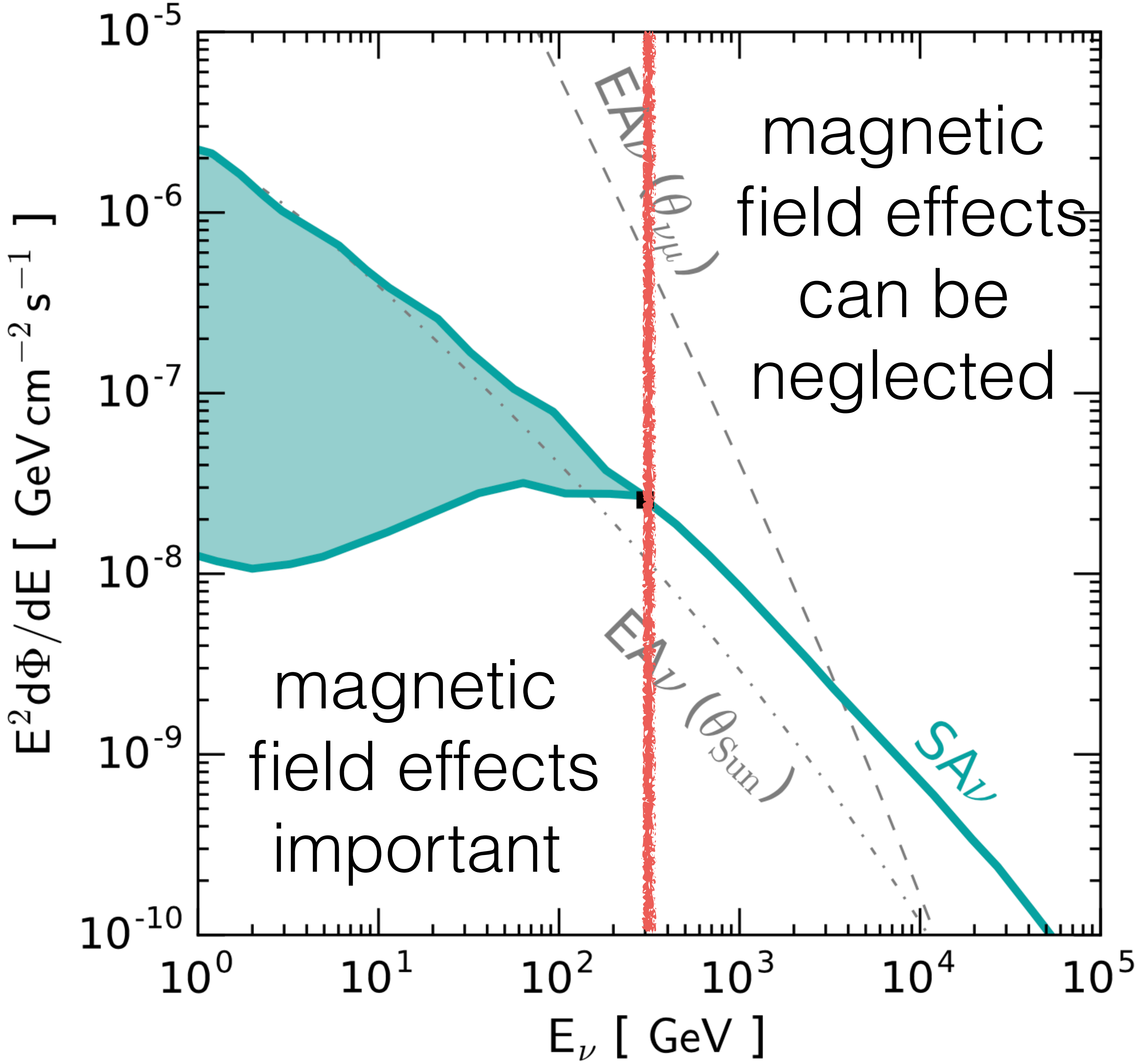
Averaging Oscillations to Earth!



- 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.

$$\bar{\Phi}_\alpha(E_\nu) = \frac{1}{T} \sum_\beta \int_0^T dt \; P_{osc}^{\beta,\alpha}(r(t), E_\nu) \Phi_{b,\beta}(E_\nu)$$

Caveat: magnetic fields



- ✤Ng et al. (1703.10280) use previous calculation by Ingelman-Thunman (Phys.Rev.D54:4385-4392,199) above 300 GeV and use Seckel et al. model below it.
- ✤**Our calculation assumes neglects magnetic field effects.**

Seckel et al. (1991)

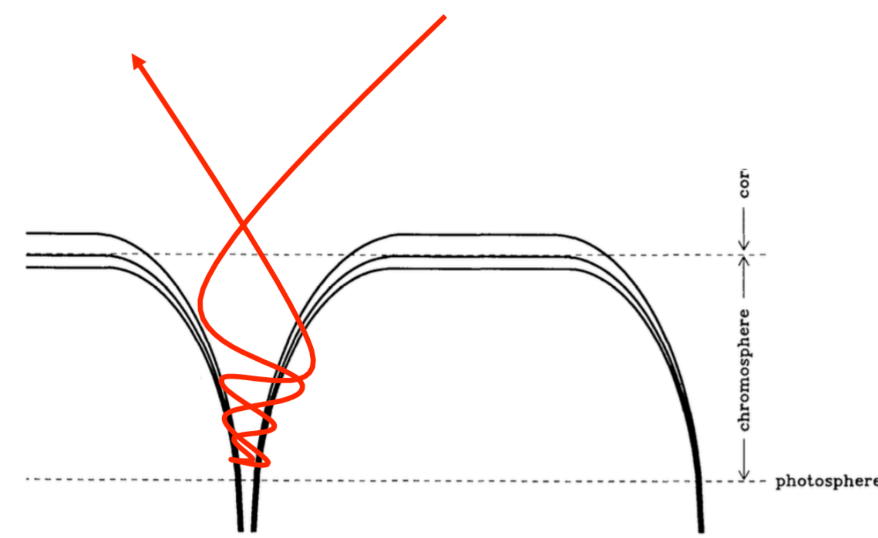
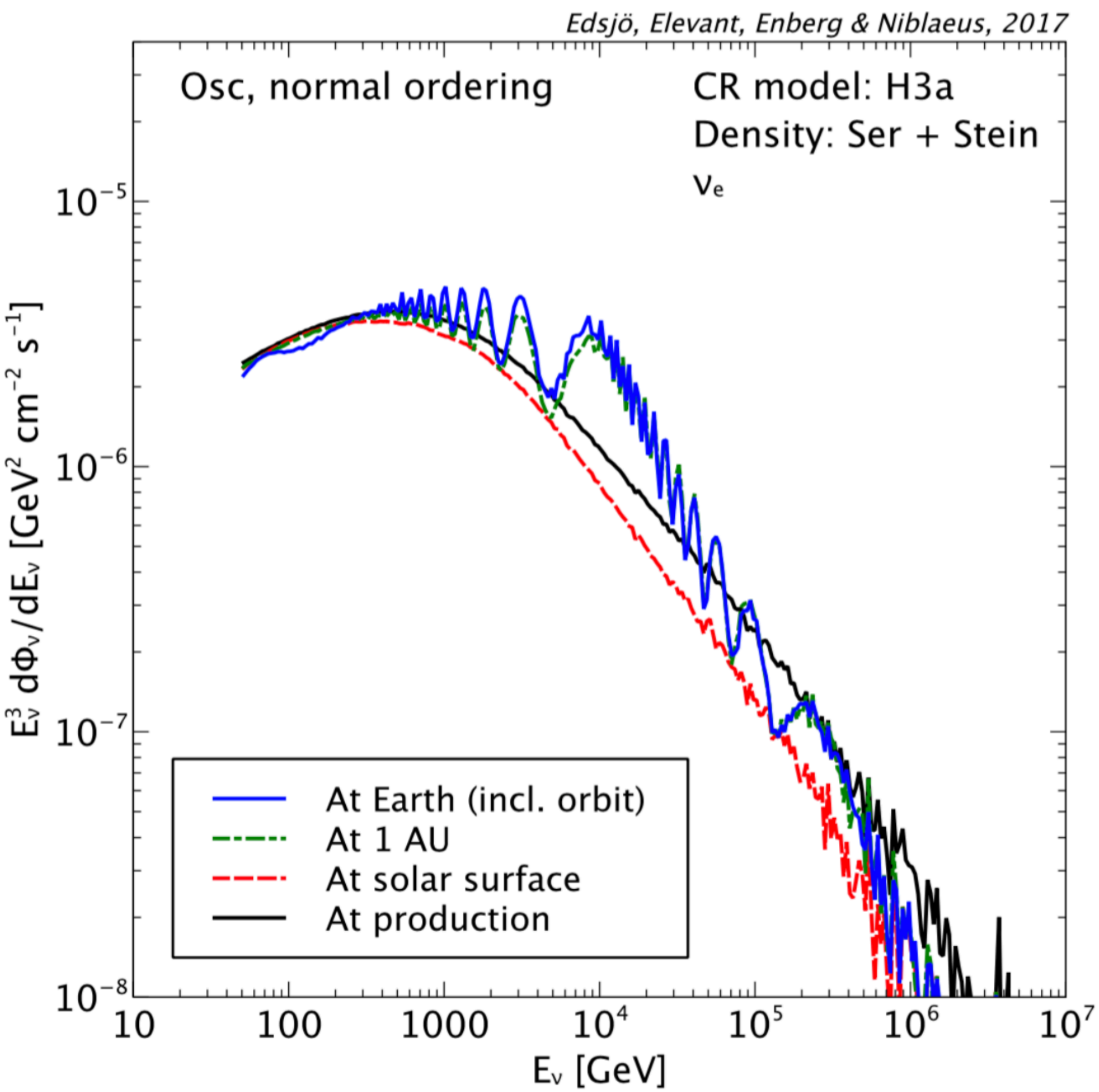


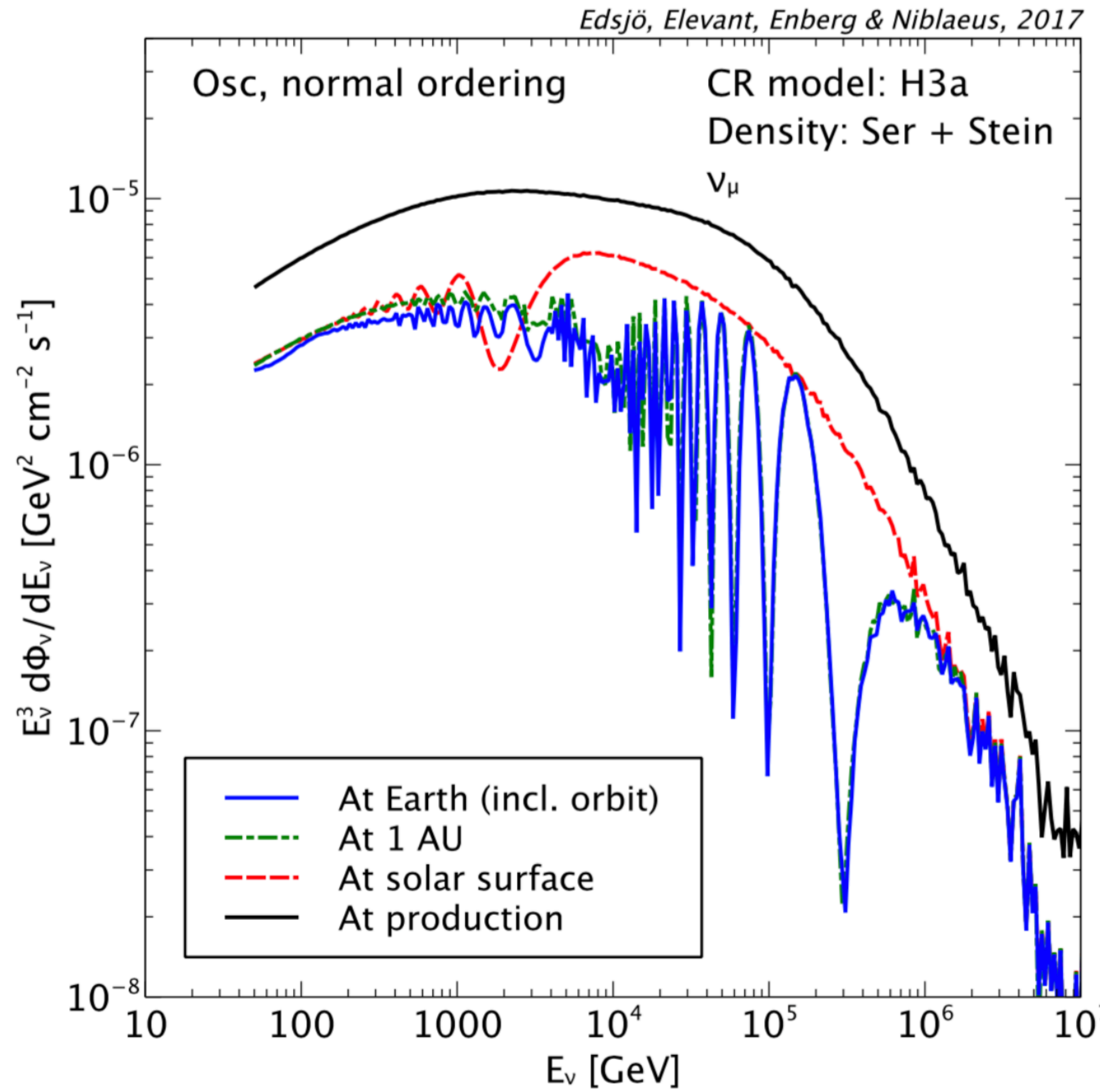
FIG. 2.—Schematic representation of solar magnetic fields near the photosphere.

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

Edsjö et al. recent calculation

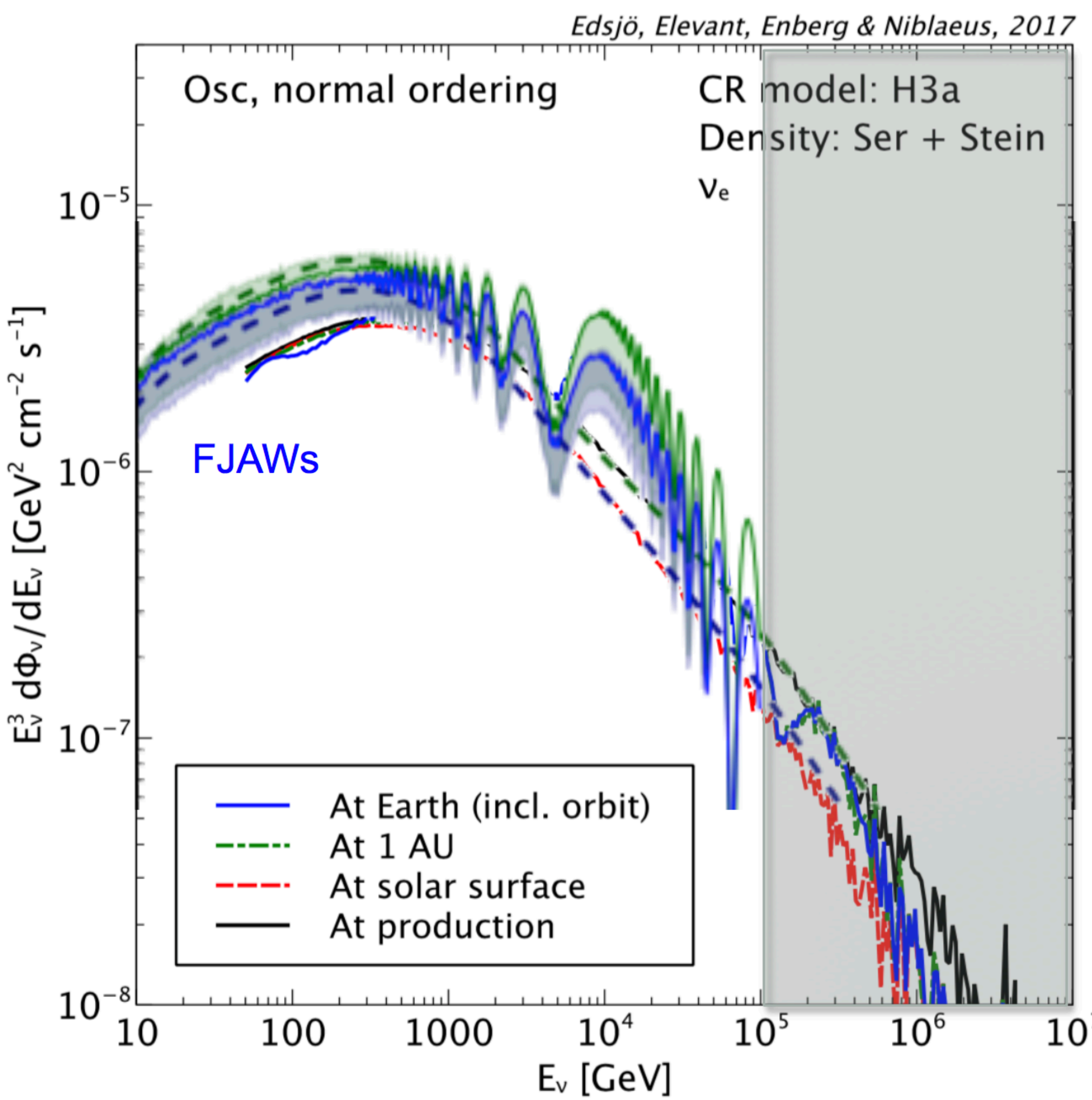
Edsjö et al. (1704.02892) recalculate the flux (using MCeq too!), but different solar atmosphere and using a MC method for neutrino transport.

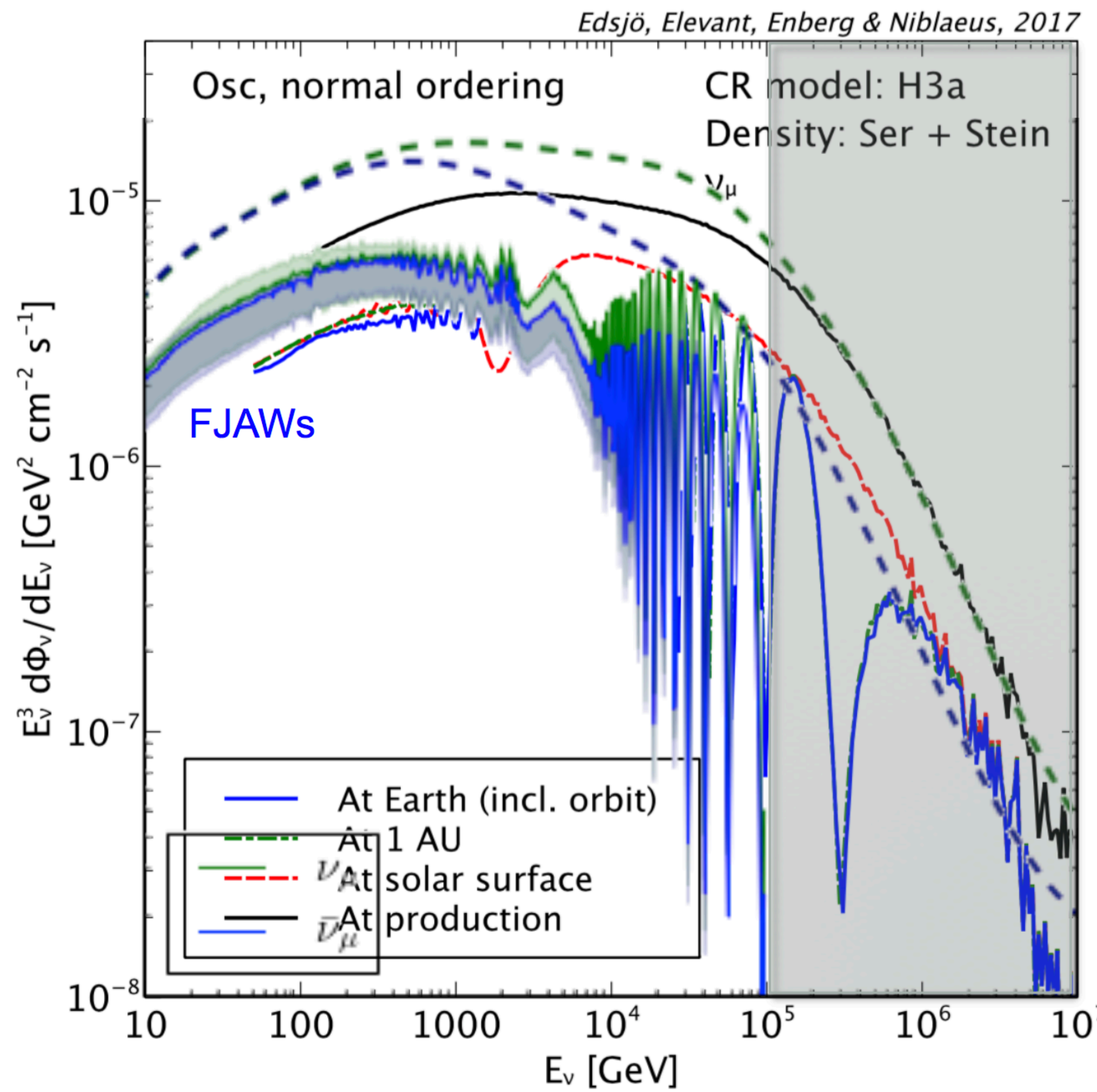




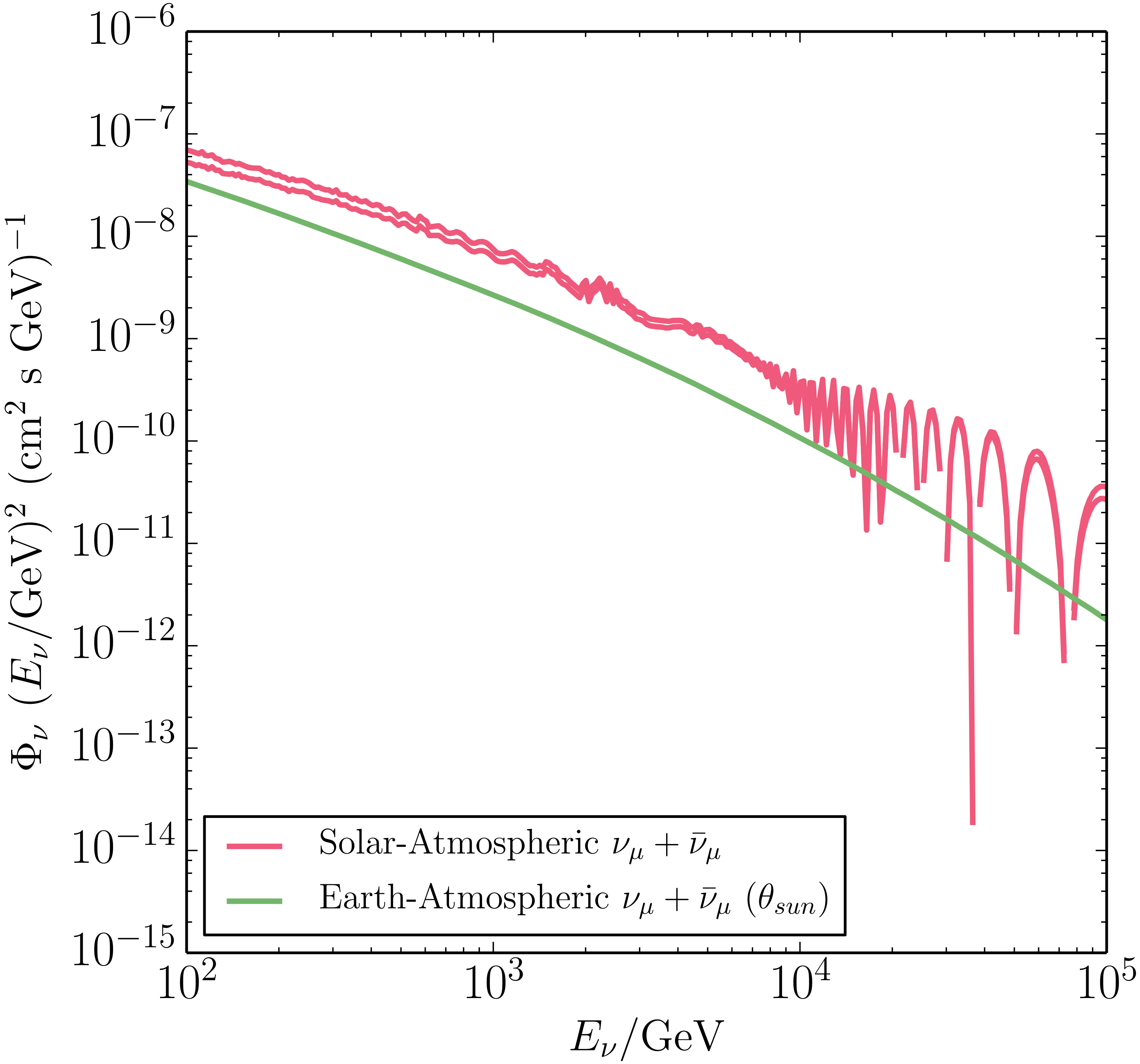
Comparison with Edsjö et al.

Edsjö et al. (1704.02892) recalculate the flux (using MCeq too!), but different solar atmosphere and using a MC method for neutrino transport.



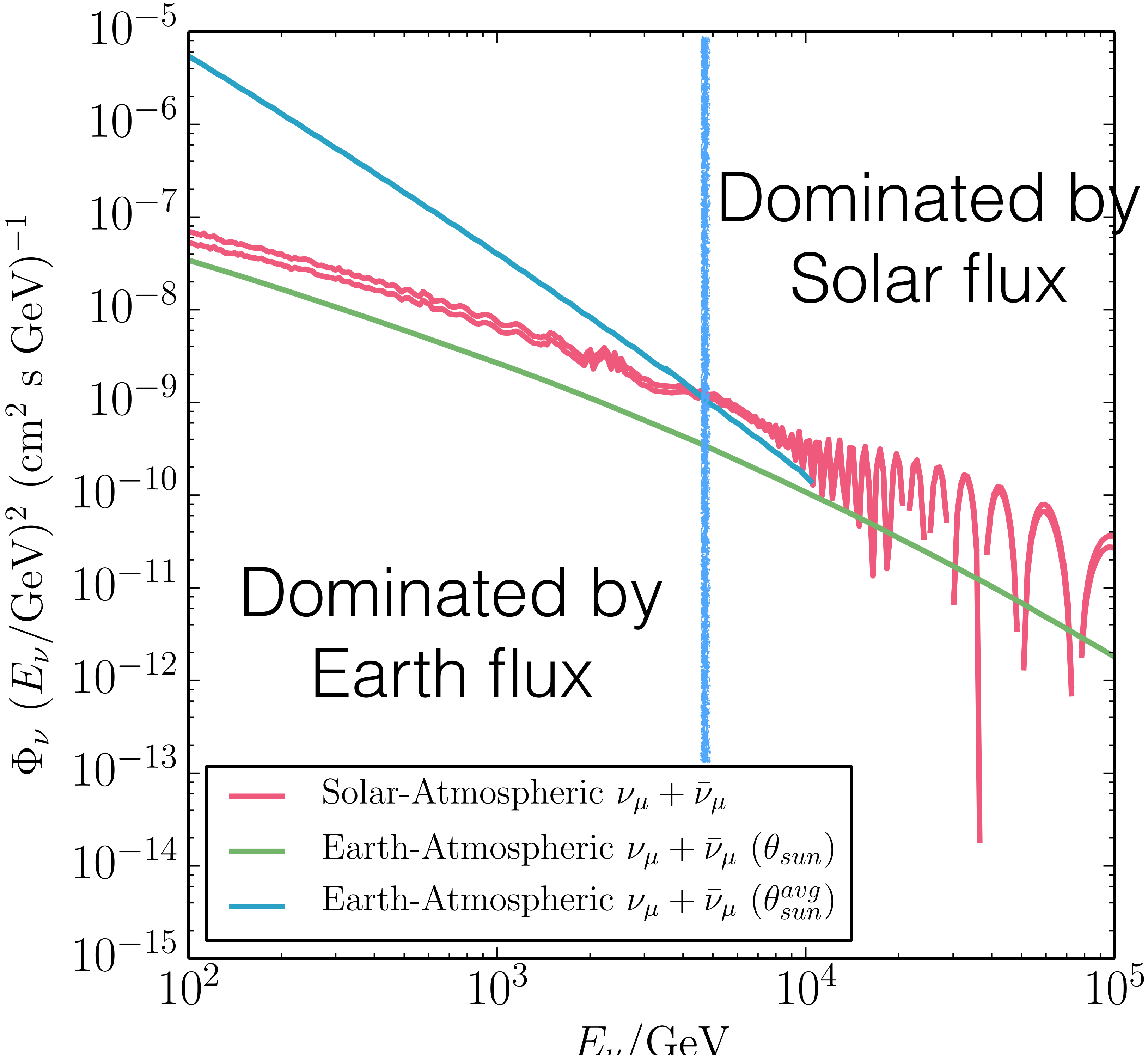


Comparison with Earth-Atmospheric flux



- At the Sun position the solar flux is greater than the conventional atmospheric flux!

Comparison with Earth-Atmospheric flux



- ✤ At the Sun position the solar flux is greater than the conventional atmospheric flux!
- ✤ But what matters is the integrated flux considering the angular separation between muon-neutrino

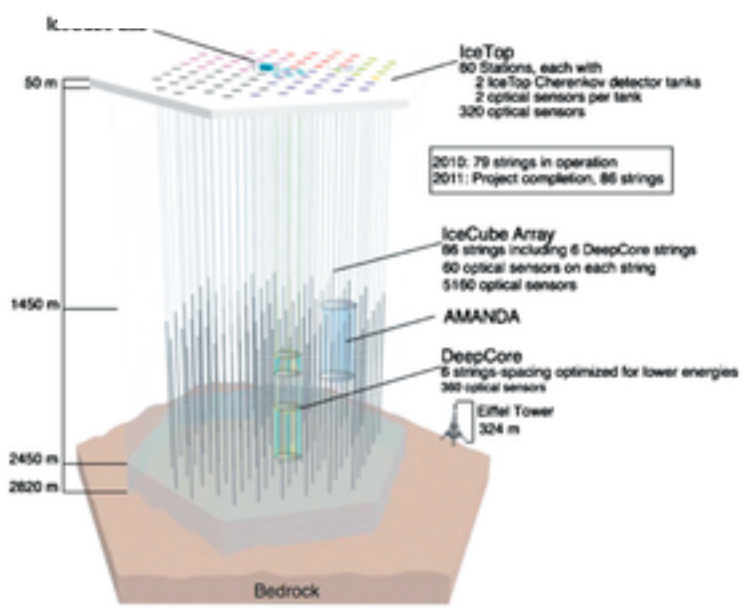
$$\theta_{\nu\mu} \approx 1^o \sqrt{E_\nu/\mathrm{TeV}}$$

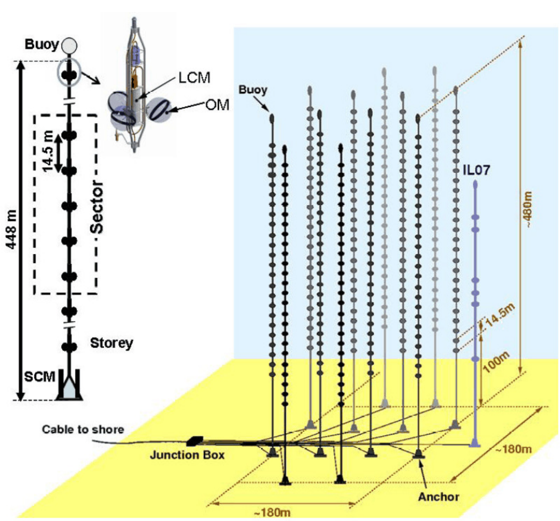
Ng et al. (2017), arXiv:1703.10280

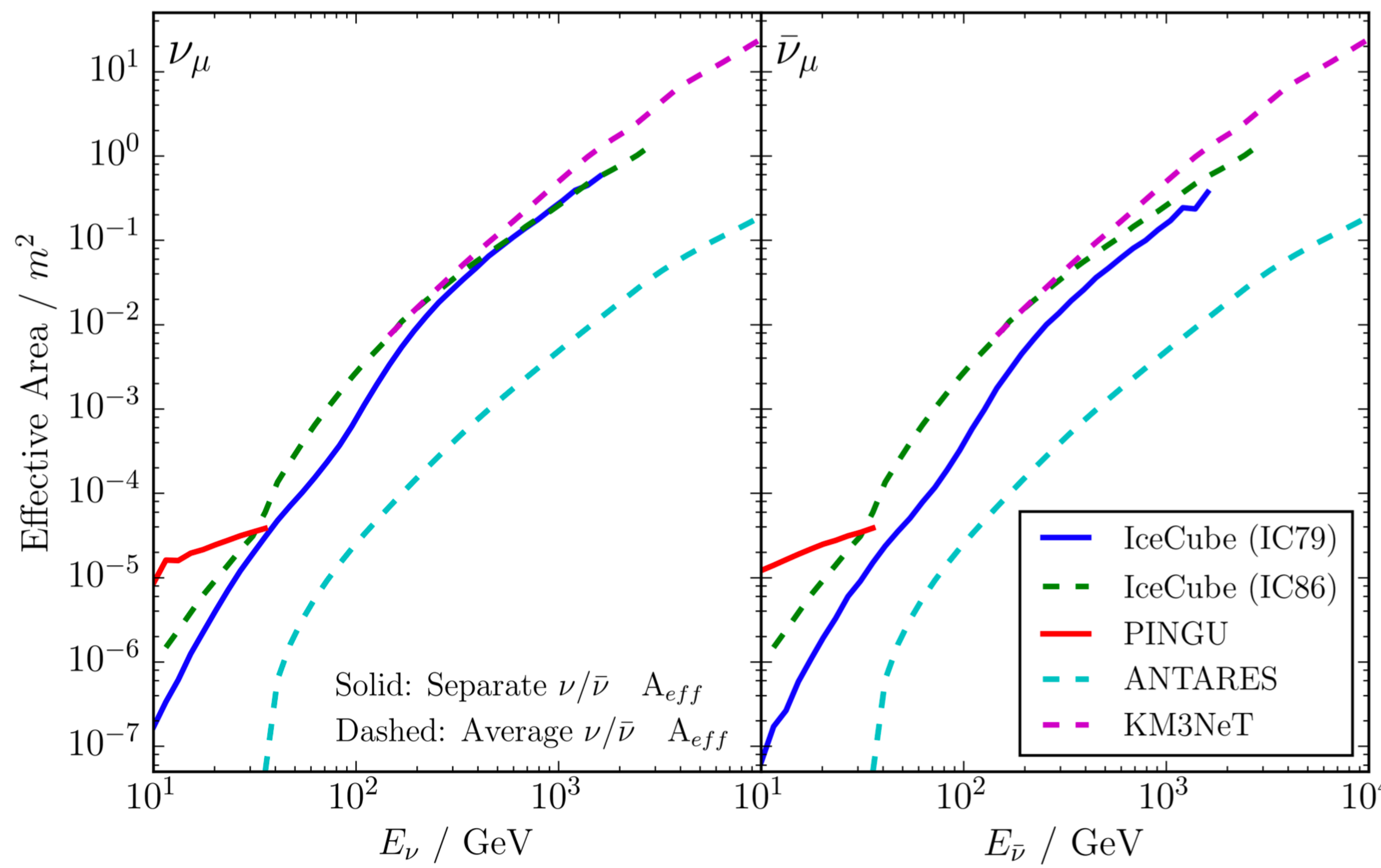
Rates!

(*used average nu+nubar effective area)

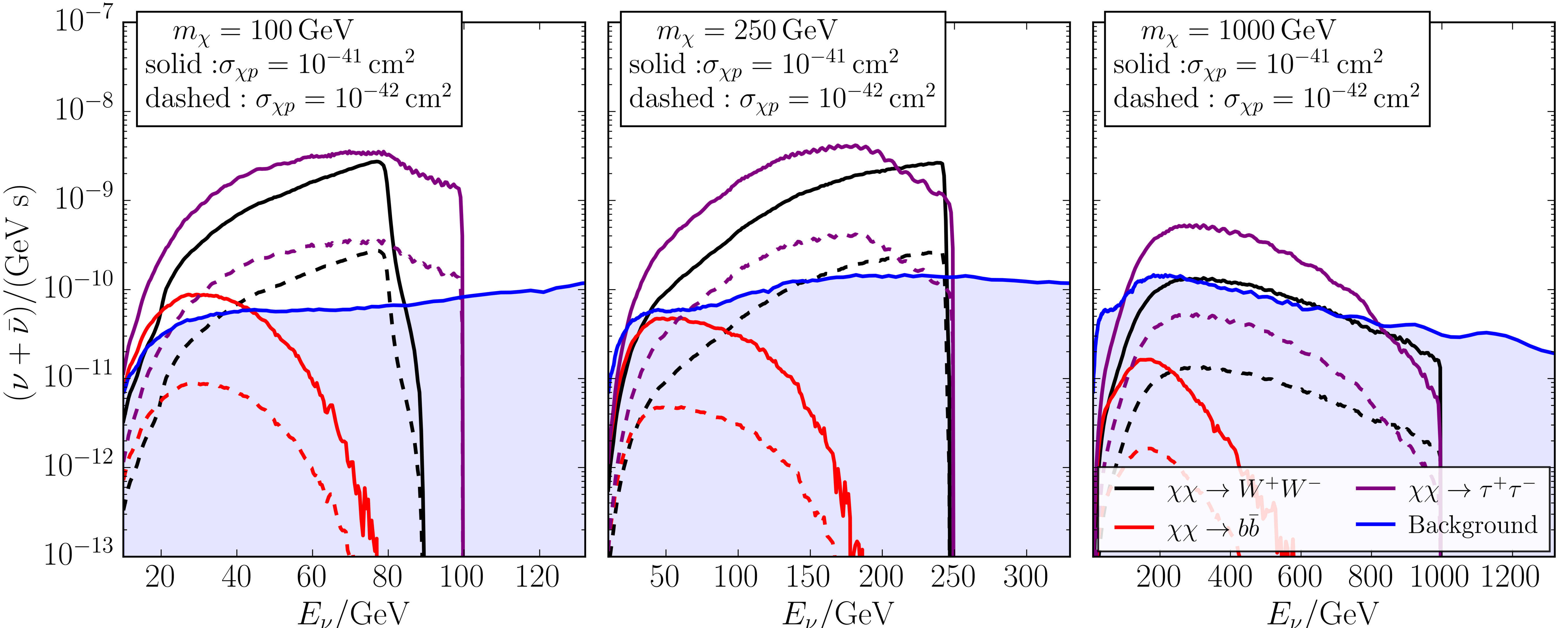
Experiment	Expected ν_μ rate R (evts / yr)	Expected $\bar{\nu}_\mu$ rate R (evts / yr)
IceCube (IC79)	$1.36 < R < 2.17$	$0.73 < R < 1.17$
IceCube (IC86)*	$2.05 < R < 3.29$	$1.97 < R < 3.16$
ANTARES*	$0.032 < R < 0.053$	$0.030 < R < 0.049$
IceCube+PINGU	$1.42 < R < 2.26$	$0.79 < R < 1.26$
KM3NeT*	$3.02 < R < 4.95$	$2.78 < R < 4.53$

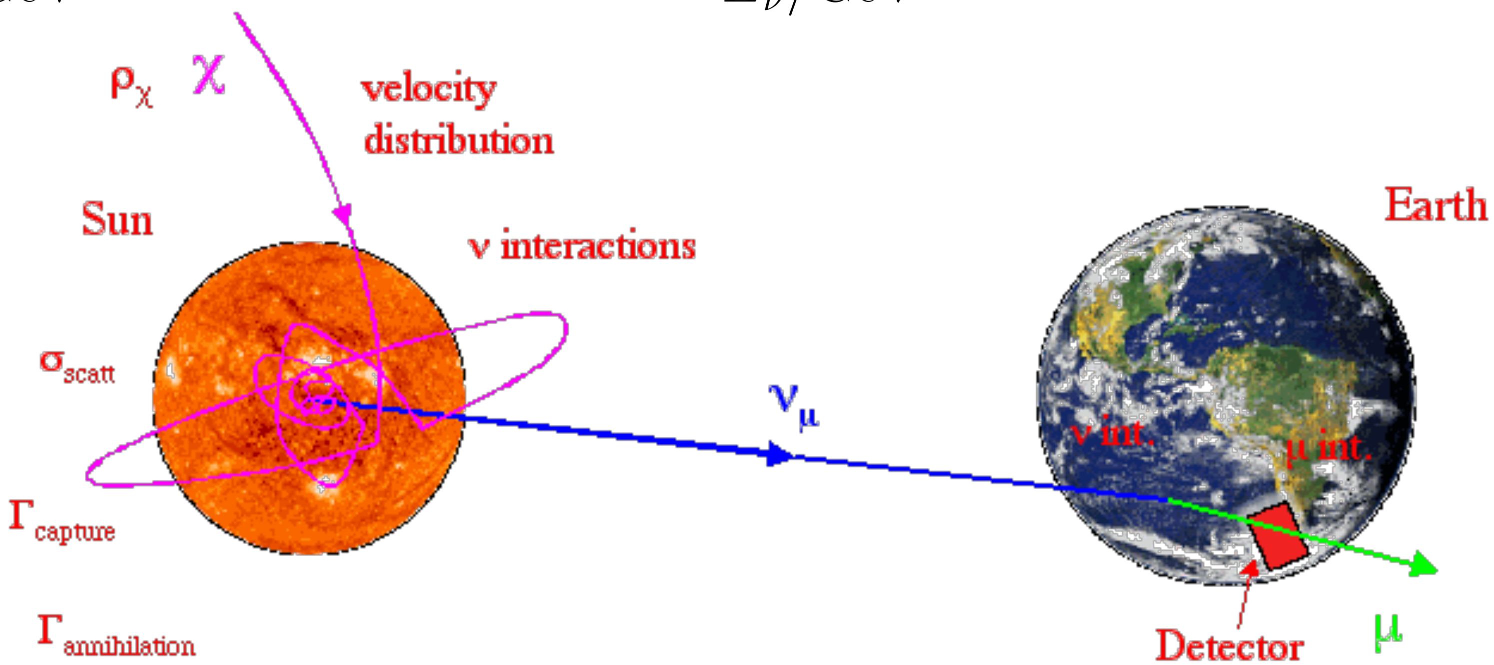




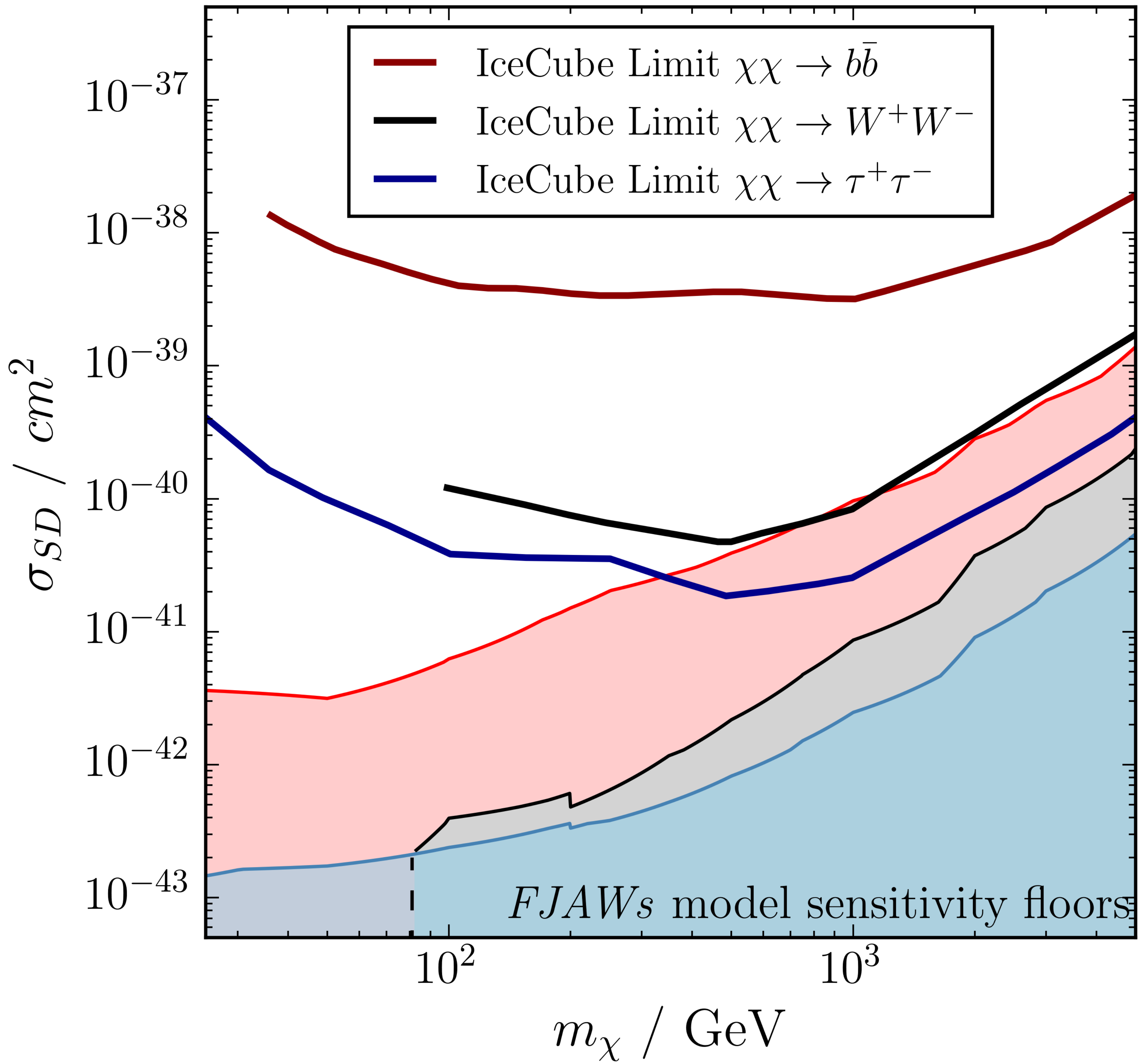


Solar-Atmospheric neutrinos as a DM background





The Neutrino Floor



- ✤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.
- ✤Good agreement with Ng. Et al. and Edsjö et al. (2017).

Floor: S ~ B.

Take home message

✤We are getting closer to detecting Solar-Atmospheric neutrinos!

✤**Three** new independent calculations have recently predicted Solar-Atmospheric neutrino flux: **good agreement**. See CA et al (**1703.07798**), Ng et al (**1703.10280**), and Edjö et al. (**1704.02892**).

✤Next step: add magnetic field modeling.

✤**Fluxes for all variants and at several stages available online.**

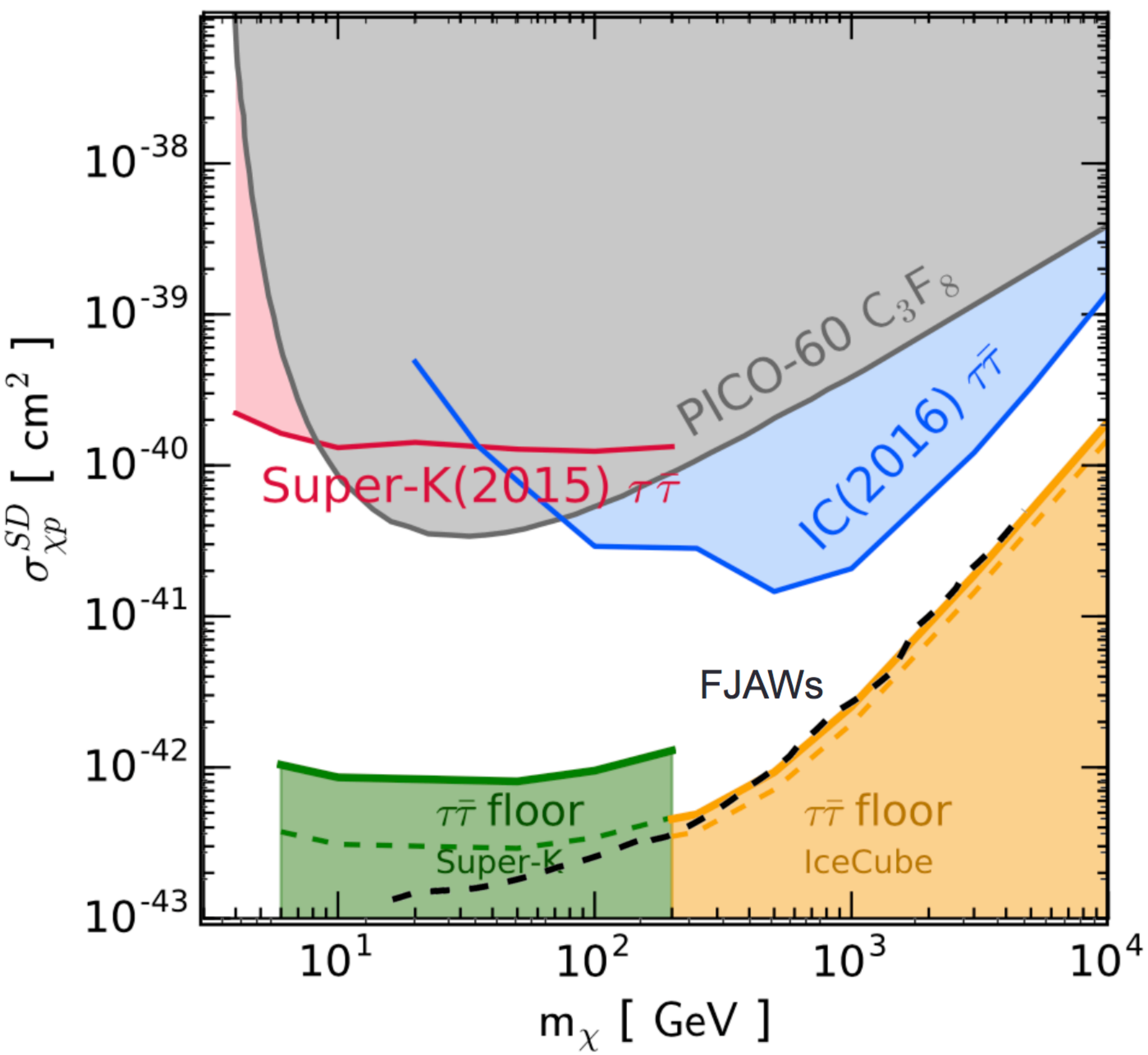
THANKS!

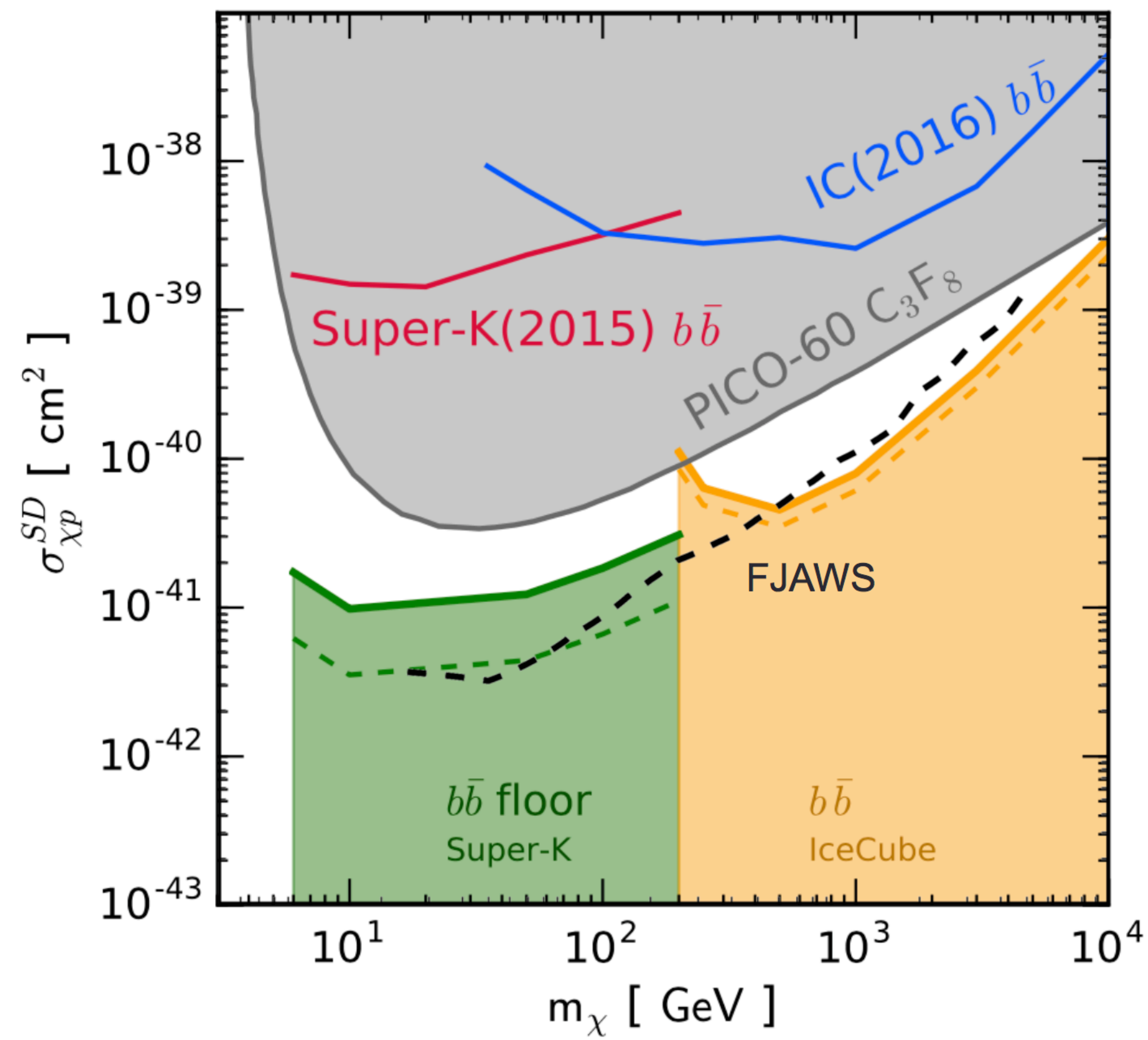
*Fluxes available here https://dspace.mit.edu/handle/1721.1/108394

BONUS SLIDES!

Floor comparison with Ng et al.

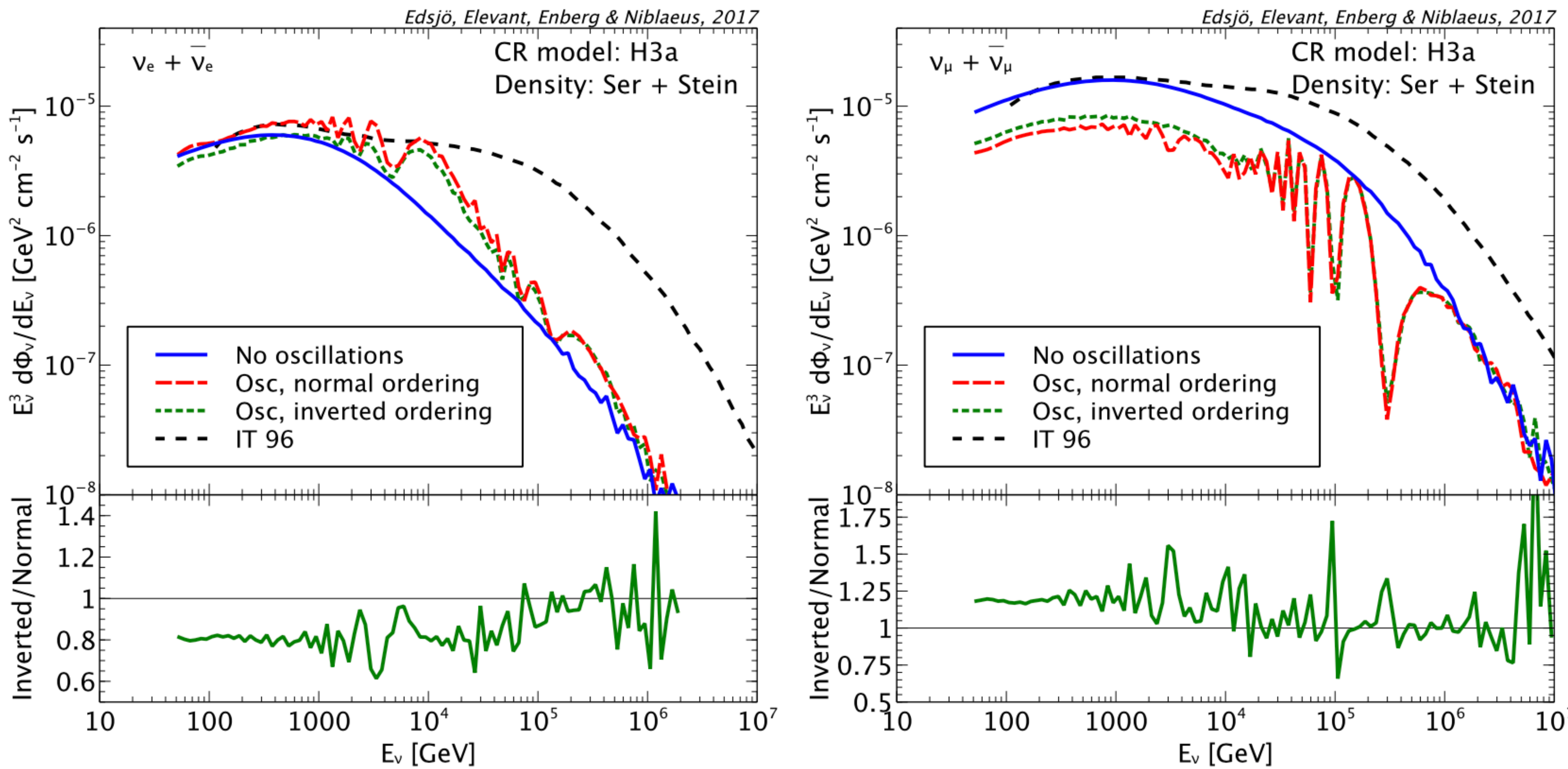
✤Ng et al. (1703.10280) use previous calculation by Ingelman-Thunman. Modification of the flux at low energies due to magnetic field effects accounted in their calculation.





Differences in the floor due to detector modeling.

Effect of neutrino ordering



Edsjö et al. (1704.02892)

Solar density profile