Neutrinos from cosmic ray interactions in the Sun

Carl Niblaeus

astro-ph/1704.02892

with Joakim Edsjö[a], Jessica Elevant[a], Rikard Enberg[b]

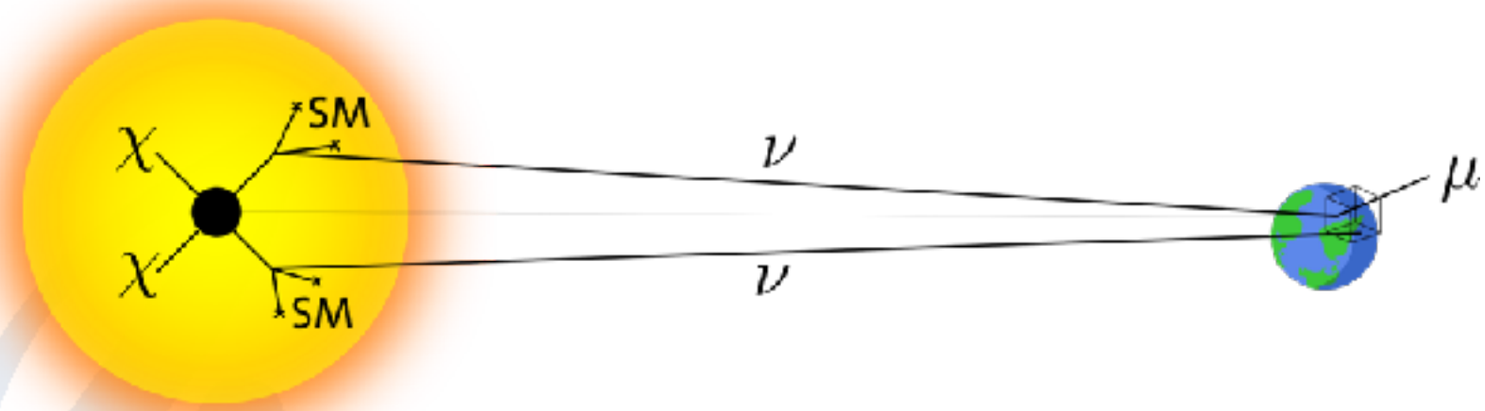
[a]Stockholm University & OKC, [b]Uppsala University

Stockholm University

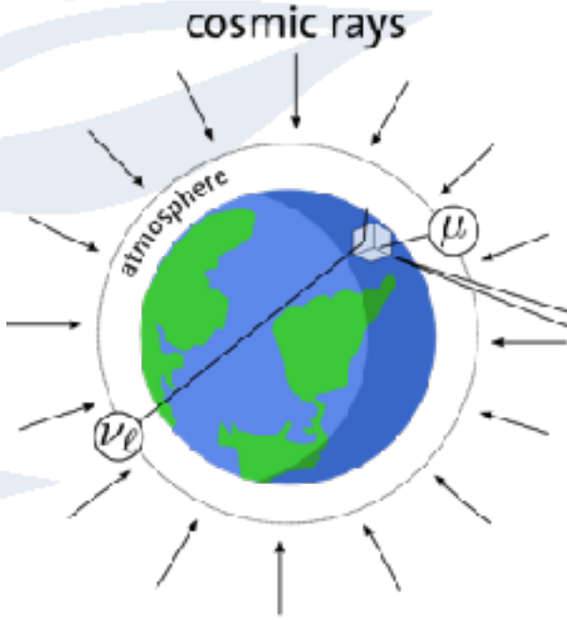
Oskar Klein centre

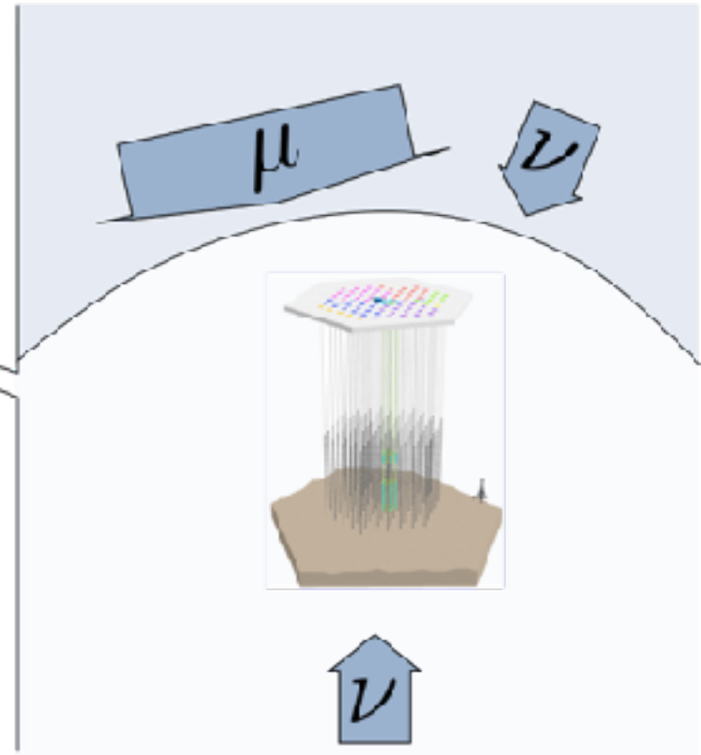
When solar WIMP searches become more sensitive, an additional background source becomes relevant

The signal



The main background





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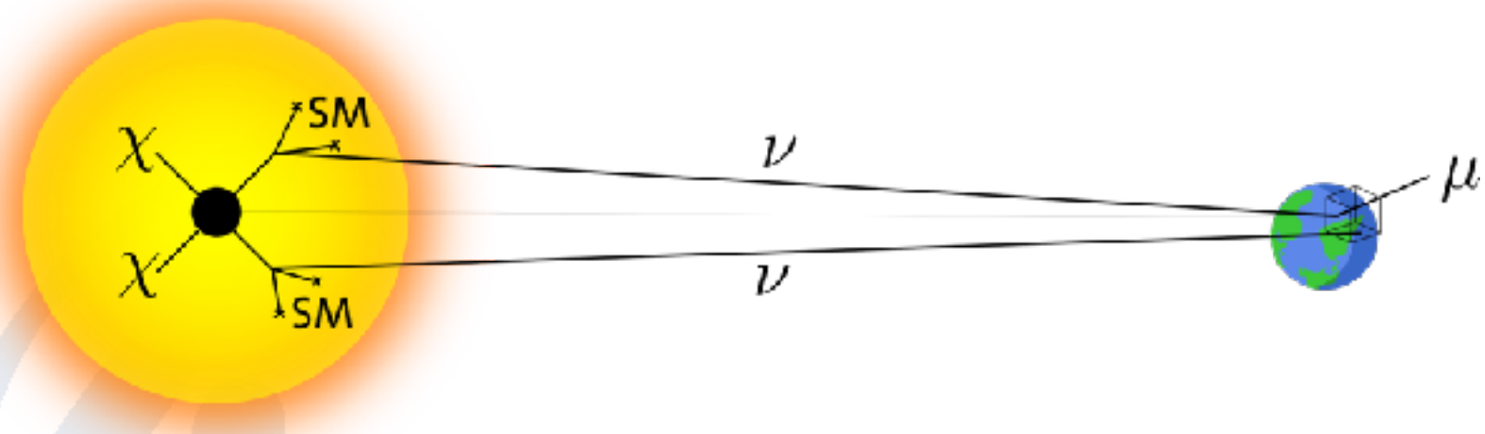

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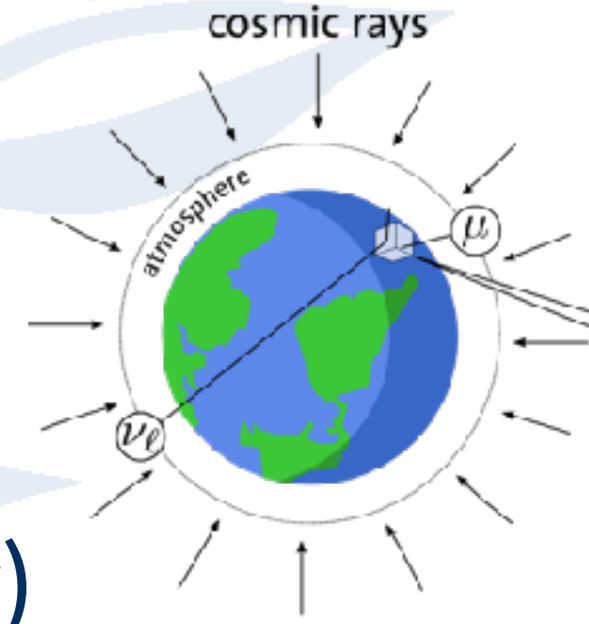
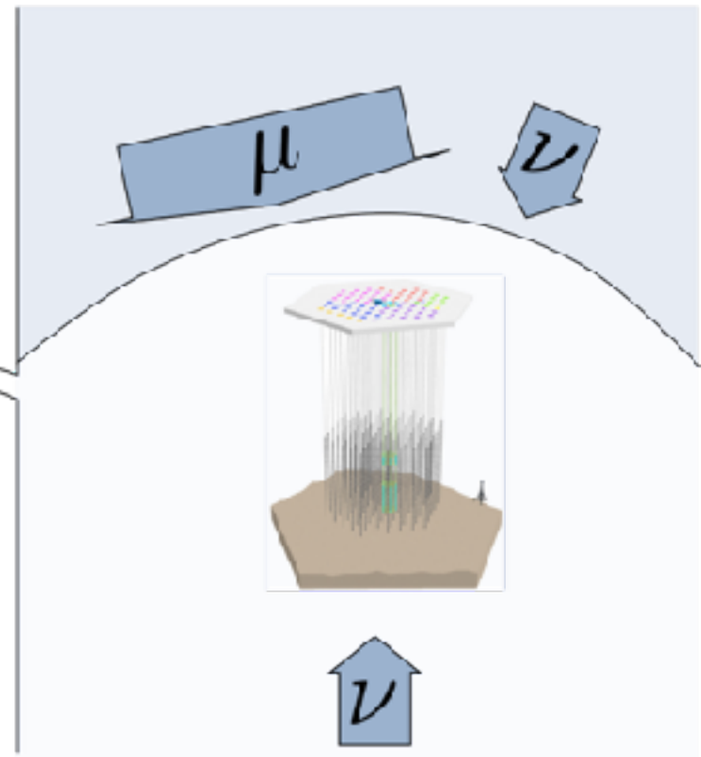
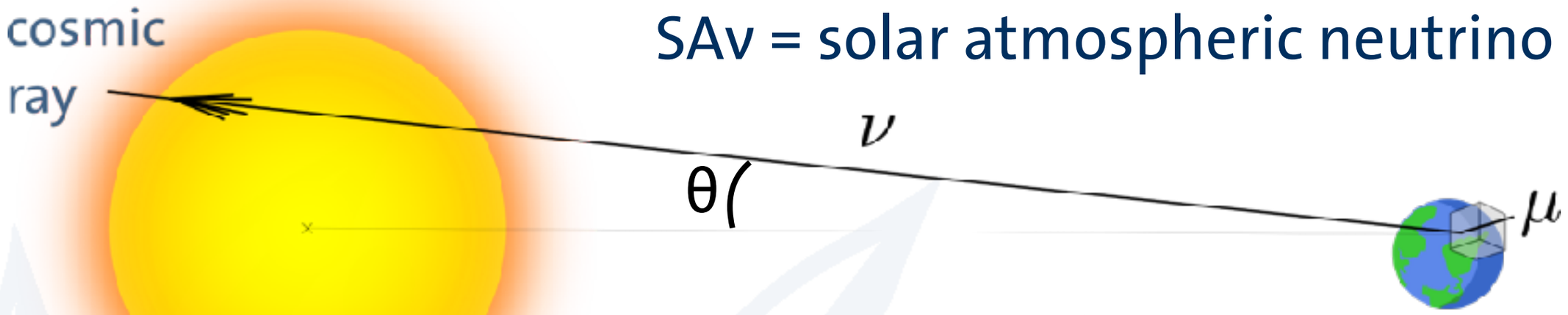




… but also

solar atmospheric ν (SAν)

We calculate the SAν flux at Earth and study impact on solar WIMP searches



SAν = solar atmospheric neutrino

Moskalenko (1991)

Seckel et al. (1991)

Ingelman, Thunman (1996)

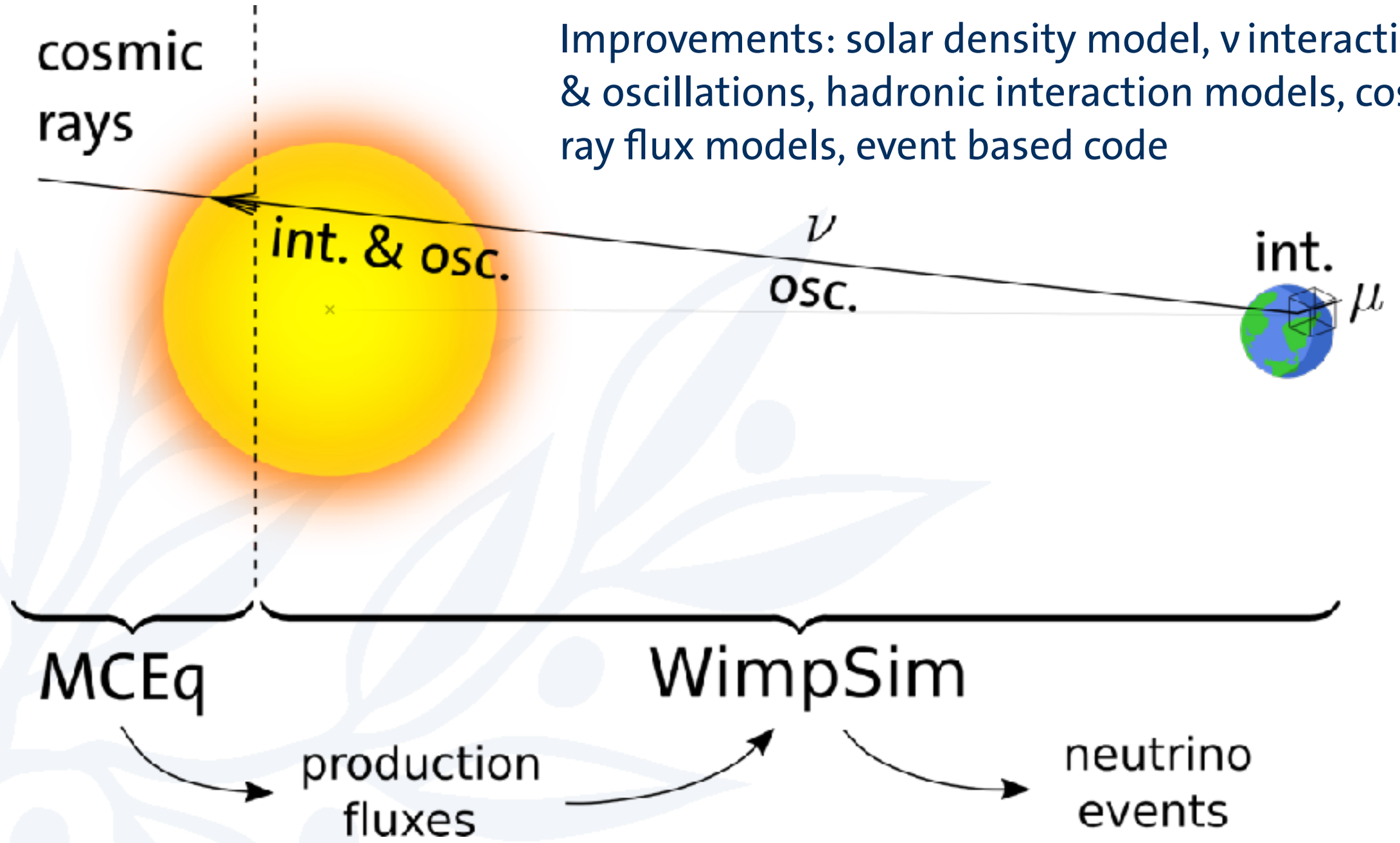
Argüelles et al. (2017)

The SAν flux is quite small (2-3 events/year) but generally larger than Earth atm. flux per solid angle

Potentially tricky background in solar WIMP searches

We have calculated the SAν flux at Earth with MCEq & WimpSim

Improvements: solar density model, ν interactions & oscillations, hadronic interaction models, cosmic ray flux models, event based code



https://github.com/afedynitch/MCEq

http://wimpsim.astroparticle.se

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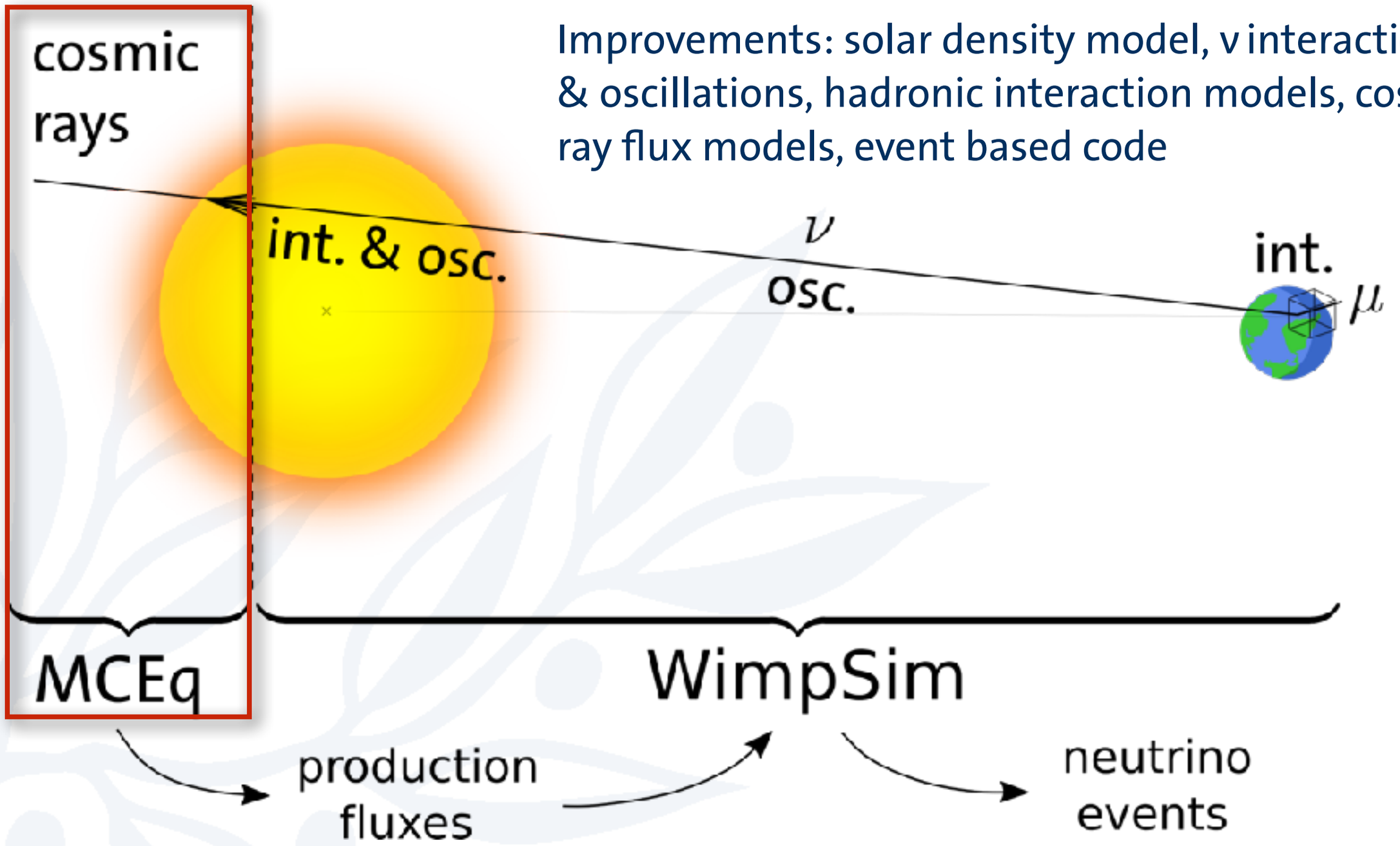


https://github.com/afedynitch/MCEq

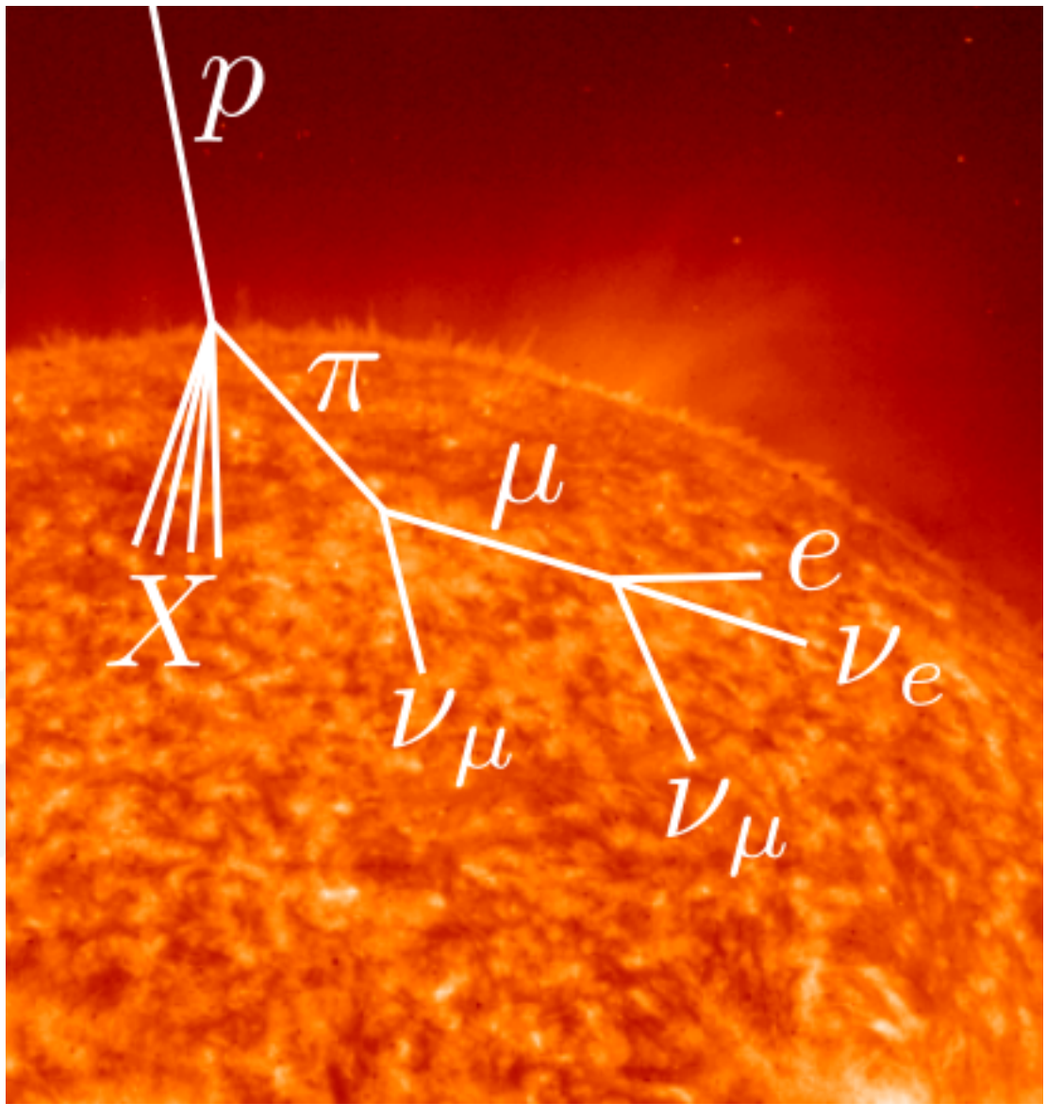
http://wimpsim.astroparticle.se

Neutrinos mainly come from decays in cosmic ray induced cascades

We use MCEq* for calculation of ν production fluxes

More ν produced when hadron/muon decay preferred over interaction

Flavour ratio at production
$\nu_e+\bar{\nu}_e : \nu_\mu+\bar{\nu}_\mu : \bar{\nu}_\tau+\nu_\tau \approx 1 : 2 : 0$



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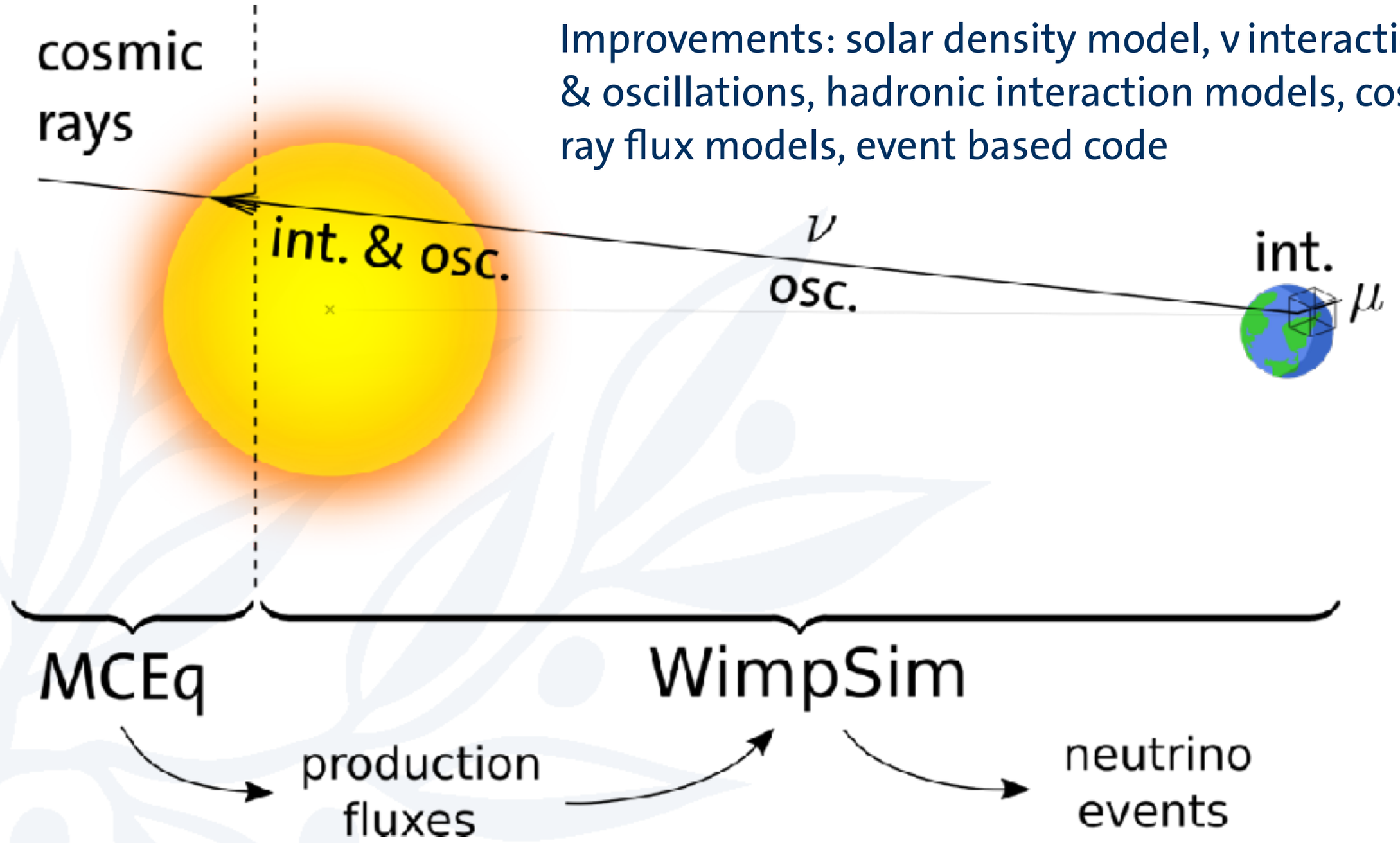

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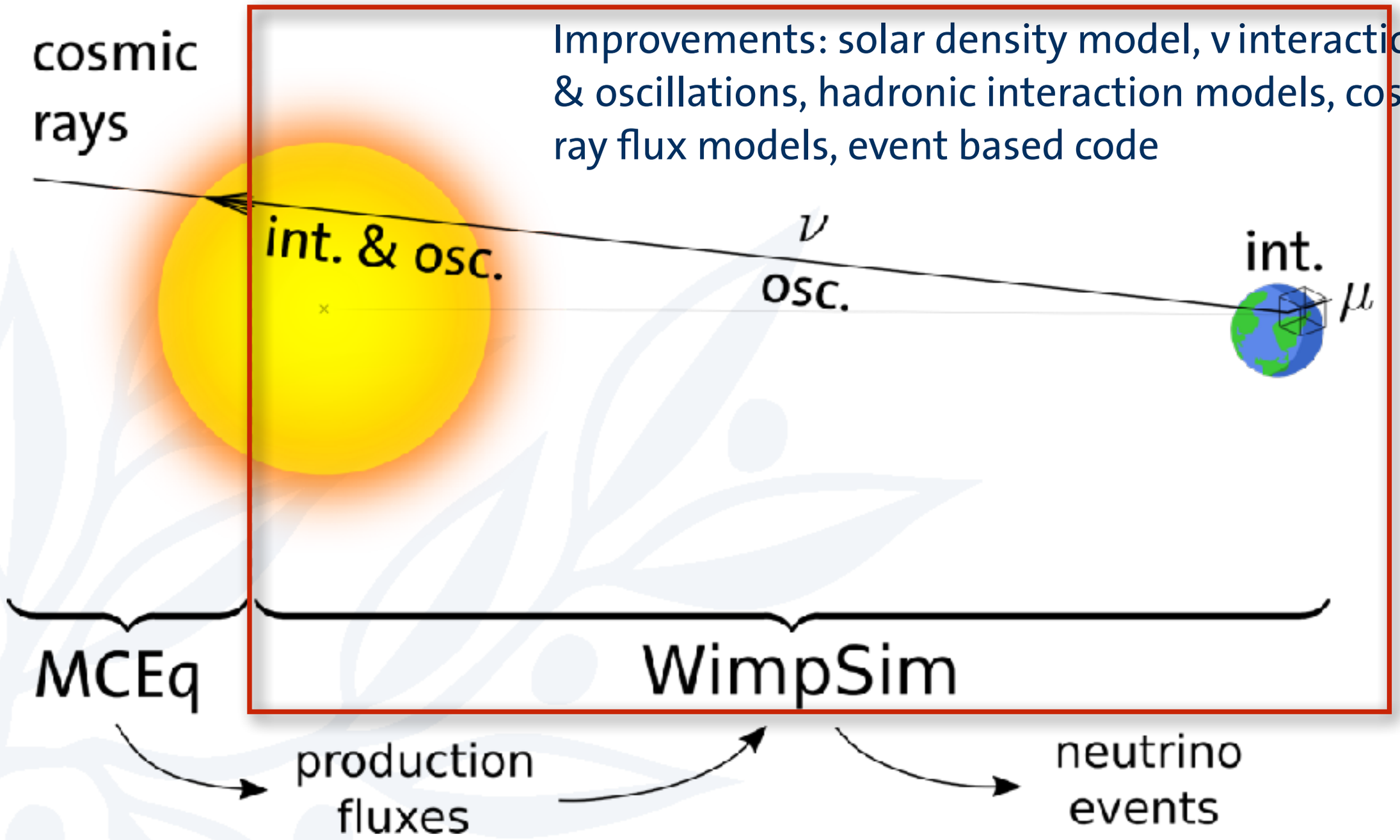

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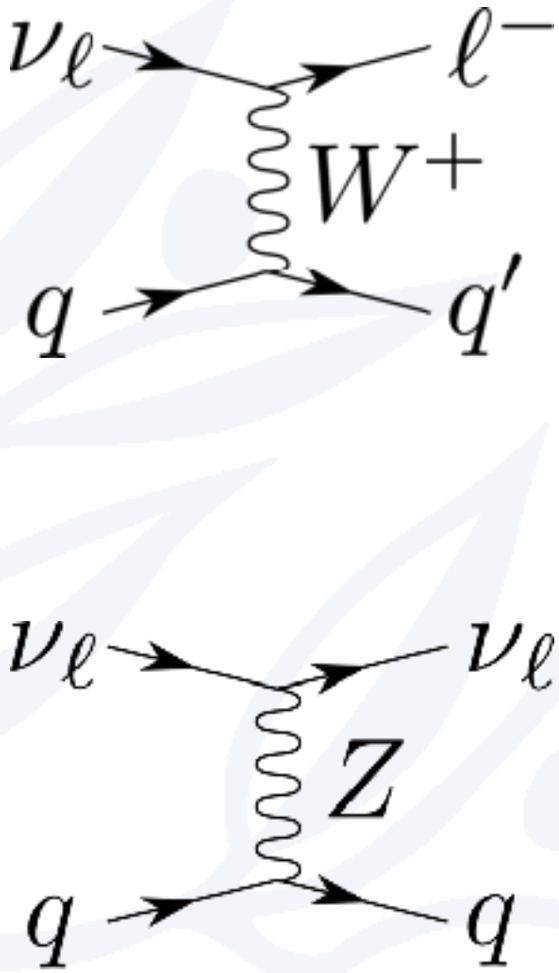
The neutrinos interact on their way through the Sun

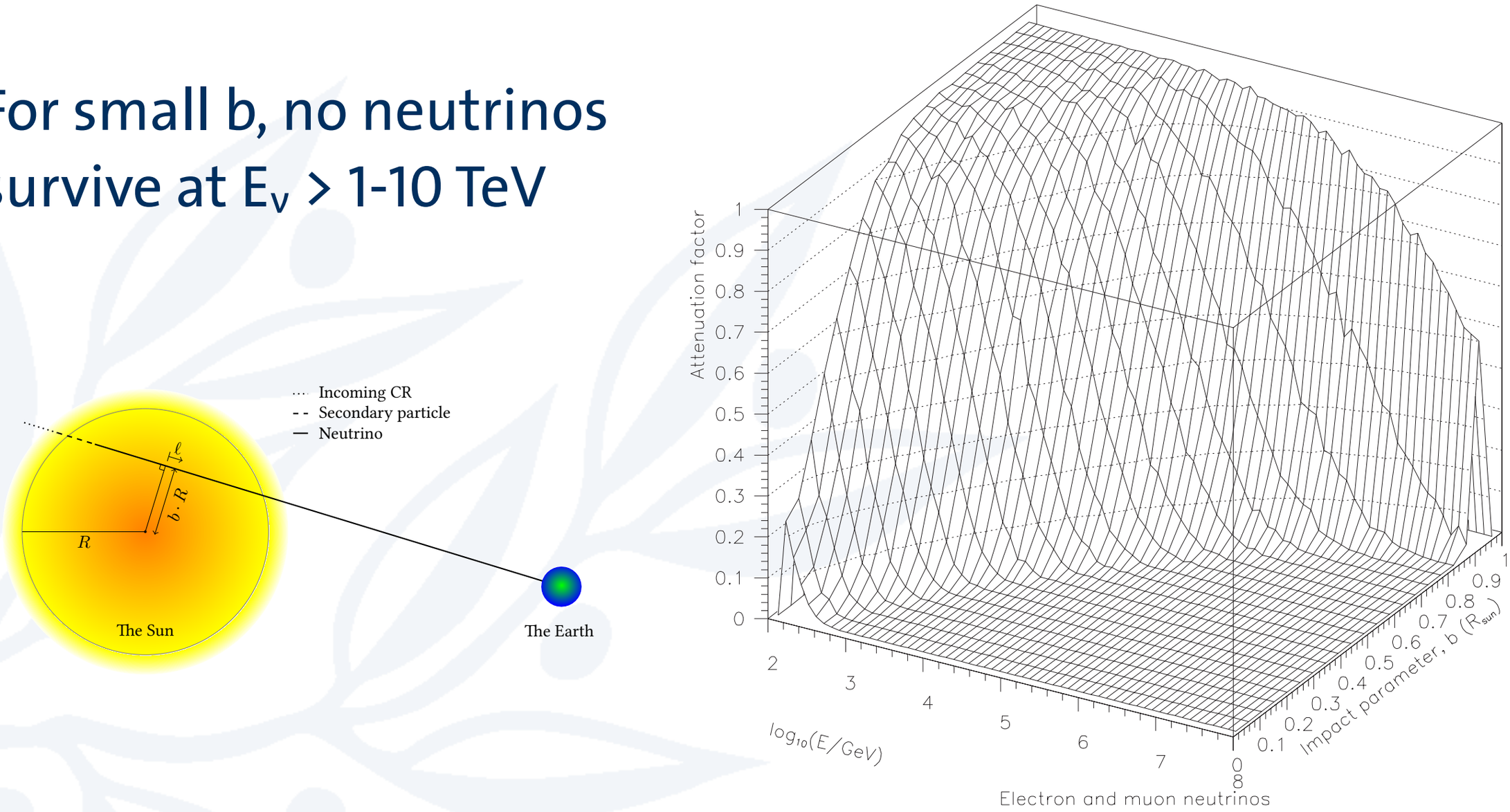


Neutrino flux attenuated

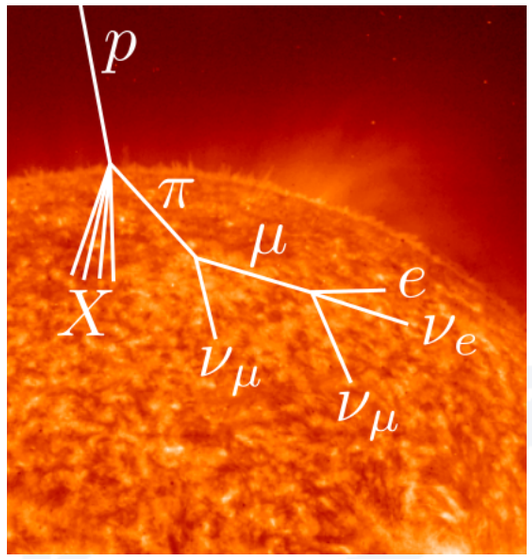
Neutrino flux shifted to lower E

The fraction of surviving electron and muon neutrinos

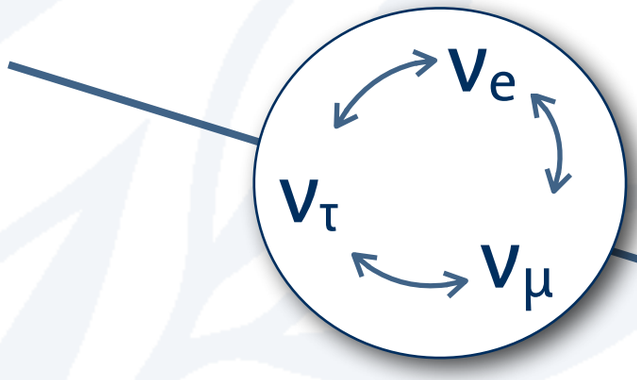
For small b, no neutrinos survive at E_ν > 1-10 TeV



Oscillations in the Sun and on the way to Earth change flavour ratio



At production: $\nu_e+\bar{\nu}_e : \nu_\mu+\bar{\nu}_\mu : \bar{\nu}_\tau+\nu_\tau \approx 1 : 2 : 0$



At Earth: $\approx 1 : 1 : 1$

Fogli et al. hep-ph/0608321
Mannheim et al. hep-ph/9910208

Differences compared to Earth atmospheric flux

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The solar atmosphere is **less dense** than the Earth's, higher fraction of decays than interactions

- larger SAν flux than EAν flux per solid angle
- SAν flux shifted to higher energy

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SAv interact in Sun and oscillate in propagation to Earth

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- SAv flux shifted to higher energy

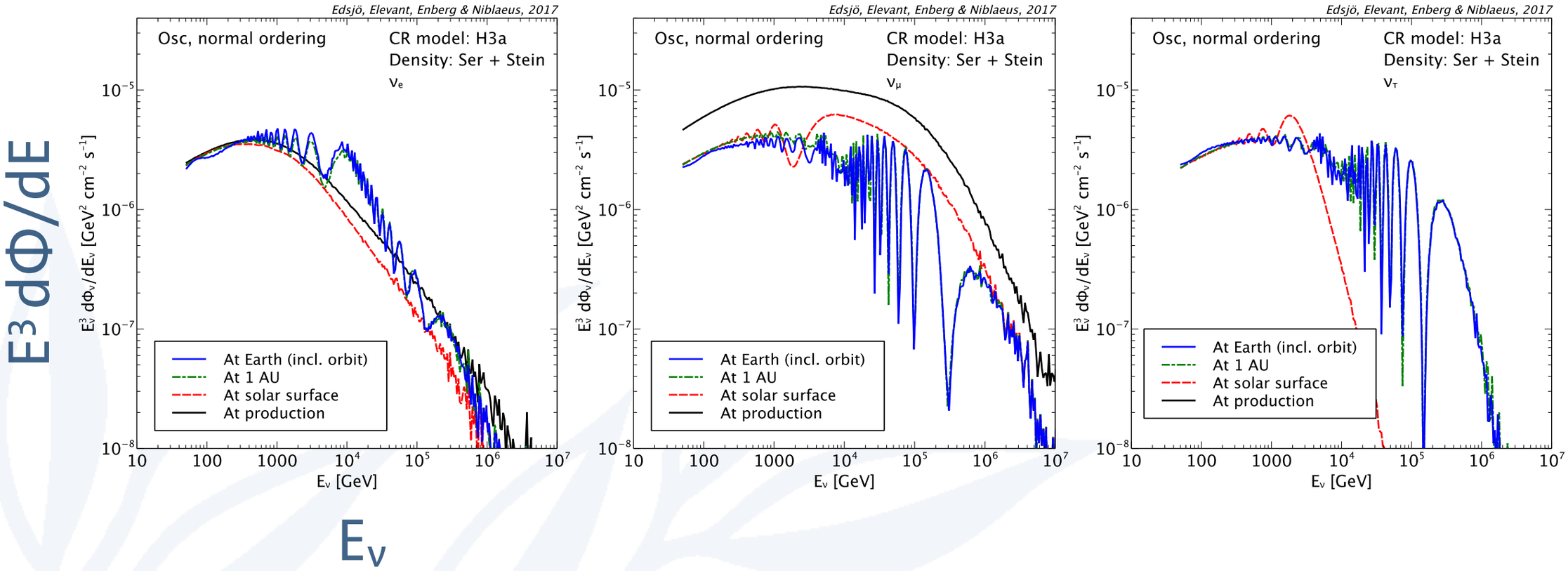
SAv interact in Sun and oscillate in propagation to Earth

Solar magnetic field will affect charged particles in cascades

- important for lower energies below ~100 GeV
- neglected in our calculation

We predict a few events per year from the SAν flux

ν_e ν_μ ν_τ



$E_\nu^3\, d\Phi/dE$

E_ν

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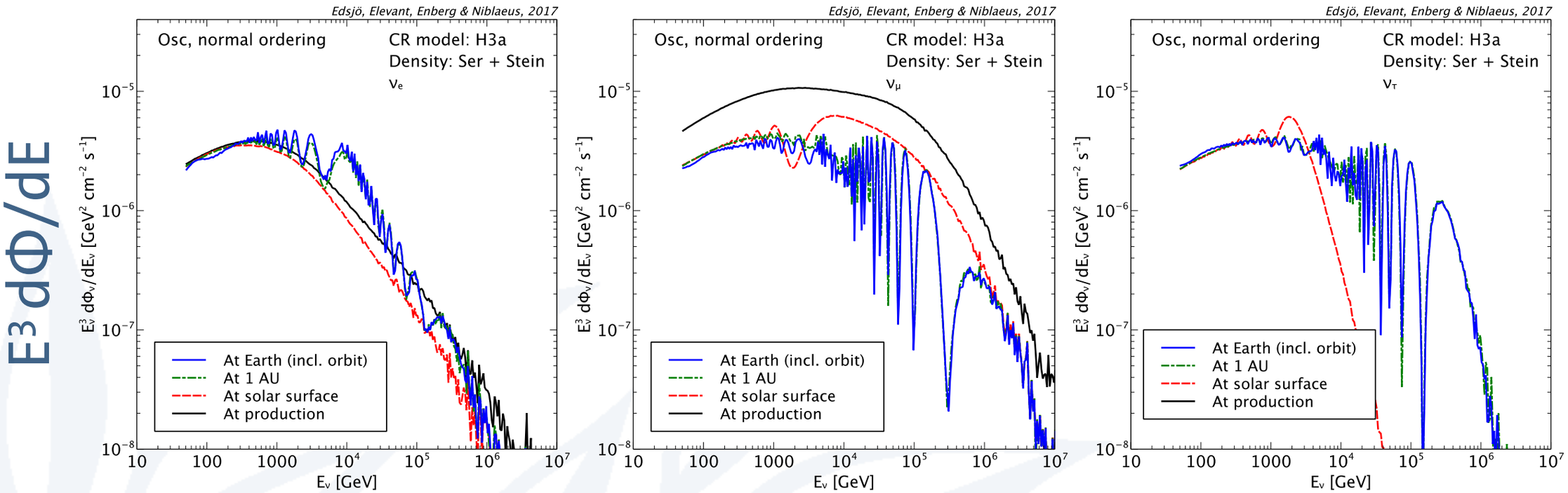

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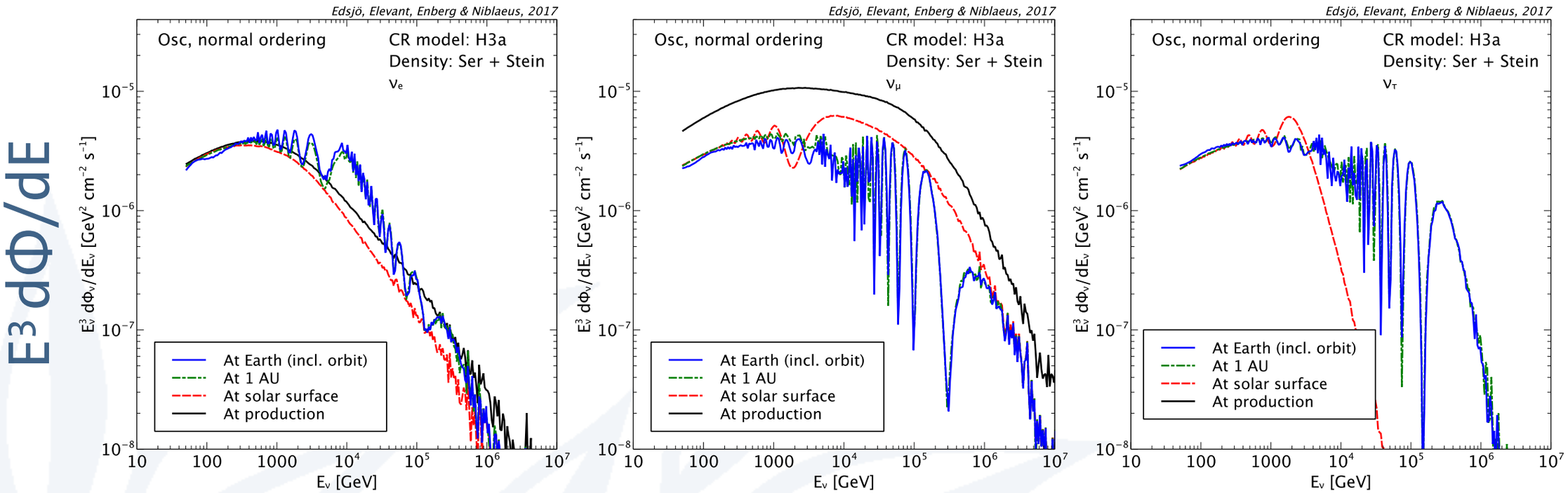

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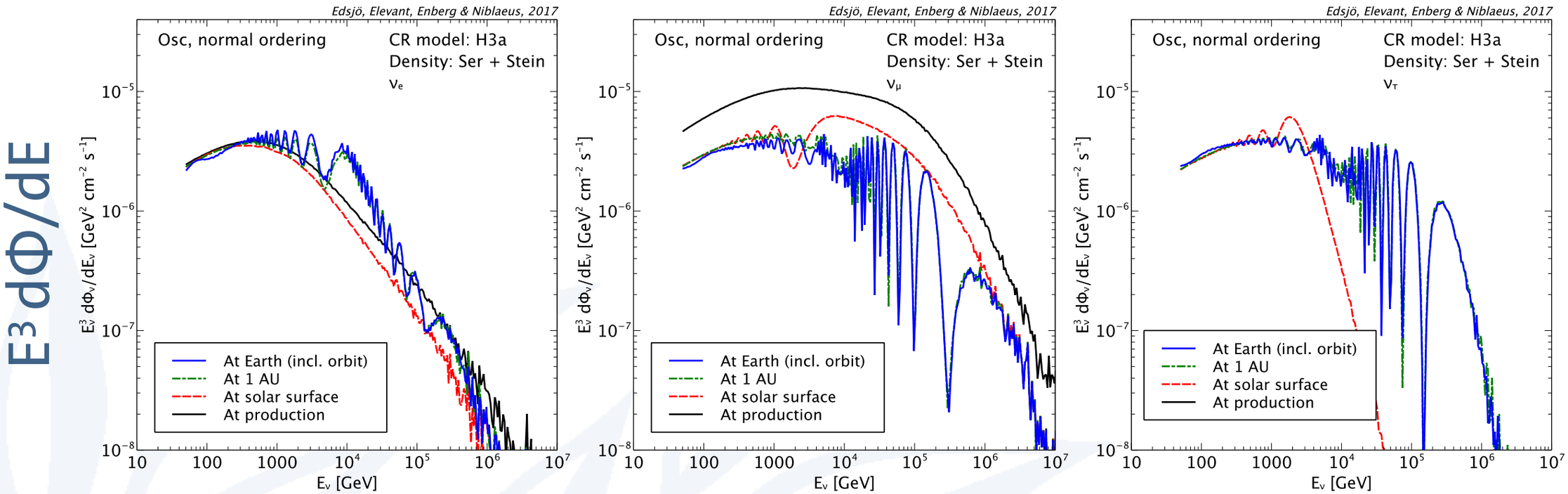


E_ν

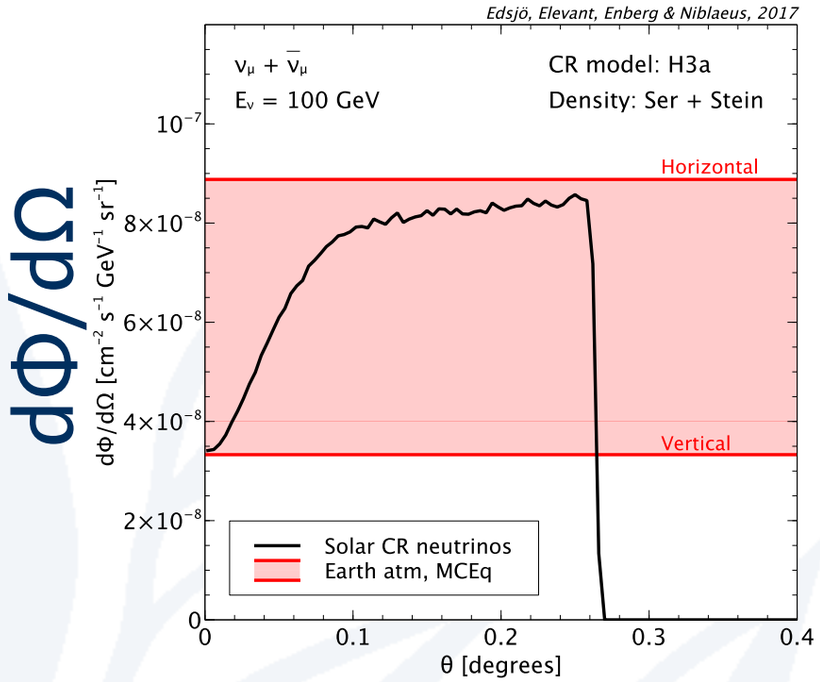
$$\int A_{\text{eff}}(E)\frac{d\Phi}{dE}(E)\,dE$$

$\Rightarrow$ 2-3 events/year

A_{eff} from IceCube [1612.05949]

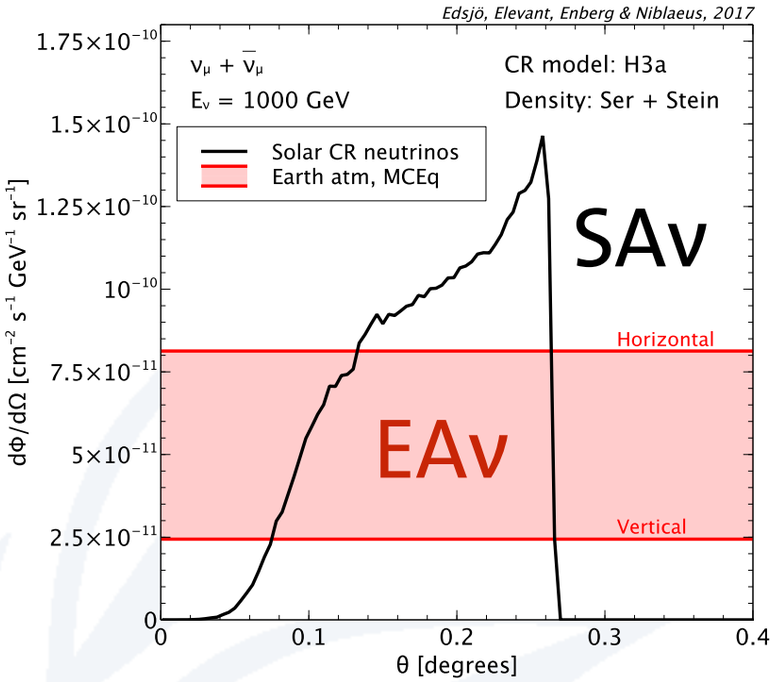
The SAν flux can be larger than the Earth atmospheric per solid angle

E_ν=100 GeV

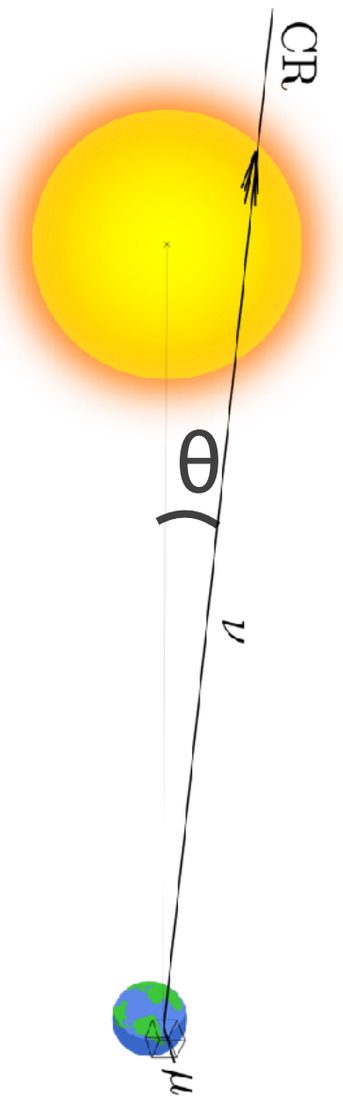


θ

E_ν=1000 GeV



Solar radius: 0.26°



Smeared in ν telescope by:

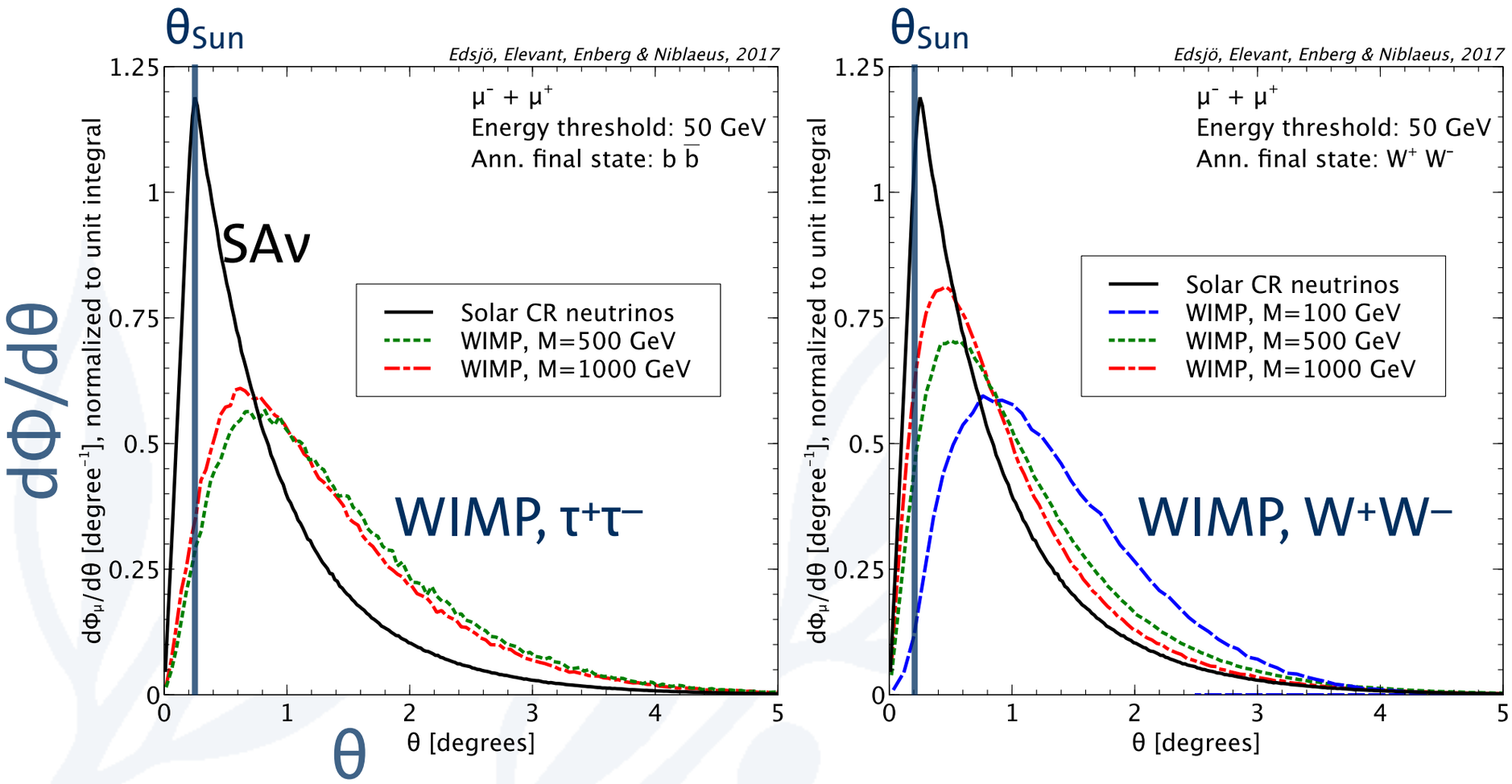
(i) neutrino-muon scattering angle

(ii) multiple Coulomb scattering

(iii) angular resolution

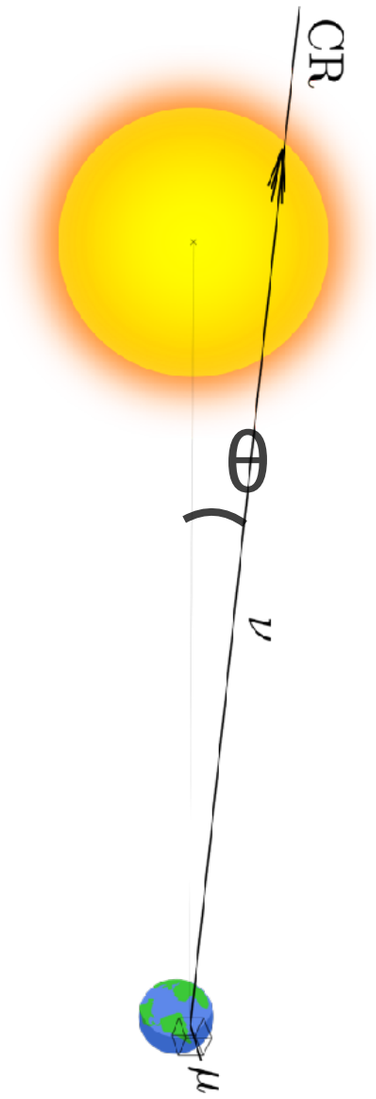
The SAν flux can be tough do distinguish from WIMP-induced neutrinos

The neutrino-induced muon flux (normalised to unit integral):



IC ang. resolution:

- 6° for E_ν=100 GeV
- 2° for E_ν=1000 GeV



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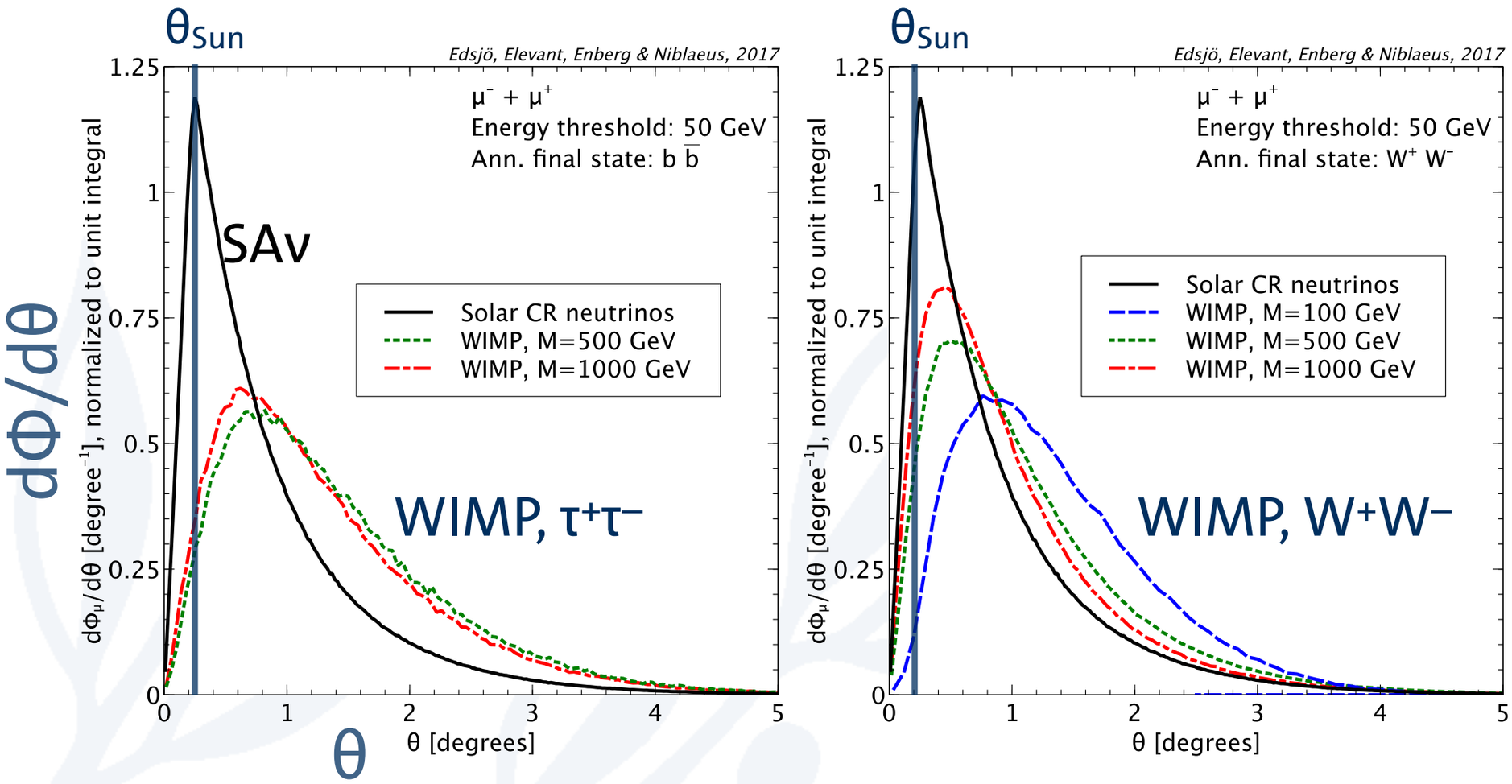

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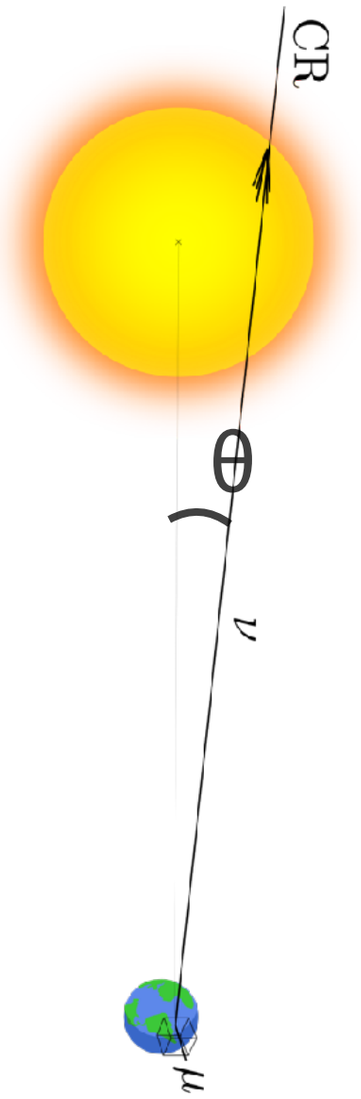

Energy spectra are different (power-law vs bump) but energy estimate for muons is poor at these energies

This results in a sensitivity floor for solar WIMP searches

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Equilibrium of capture and decay: N_{evt}(WIMP ann.) given by $\sigma_{\chi p}^{SD}$

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Define floor as the $\sigma_{\chi p}^{SD}$ where N_{evt}(WIMP ann.) = N_{evt}(SAν), i.e. S=B

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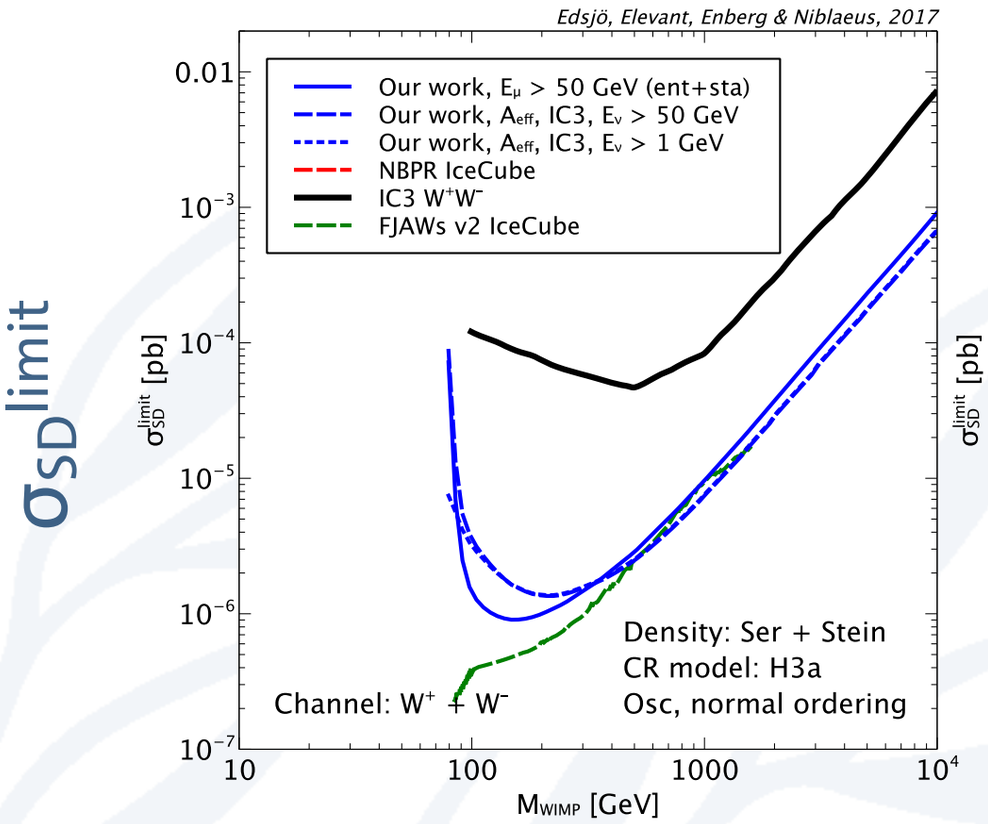
Caveats:

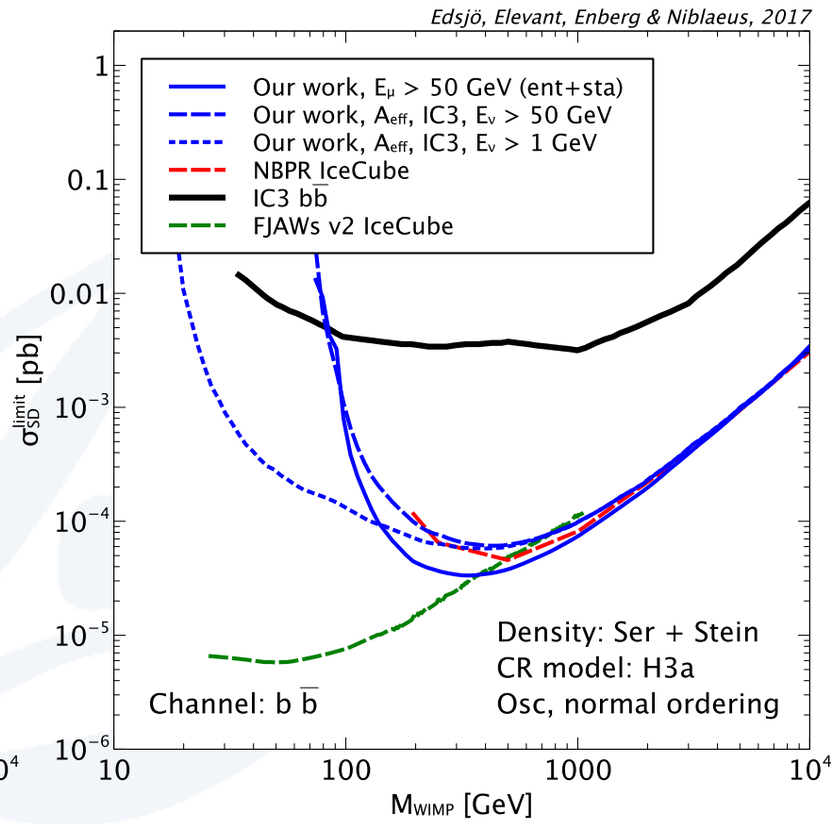
- crude analysis, proper statistical analysis and detector simulation needed
- for low m_χ highly affected by how N_{evt} calculated

SAν dominate below this sensitivity floor for the WIMP-proton cross section

W⁺W⁻



bb̄



M_{WIMP}

$\sigma_{\chi p}^{SD,limit}$ defined by N_{evt}(WIMP ann.) = N_{evt}(SAν)

NBPR: astro-ph/1703.10280 FJAWs v2: astro-ph/1703.07798

Review

Neutrino telescopes look for a neutrino flux from DM annihilations in the Sun

SAv, created by cosmic ray interactions in the Sun is a background that is currently neglected

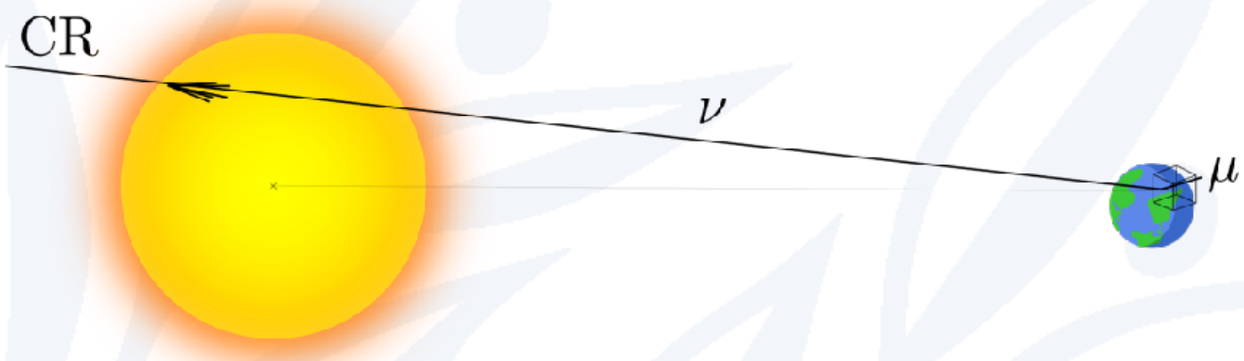
We have calculated the SAv flux at Earth

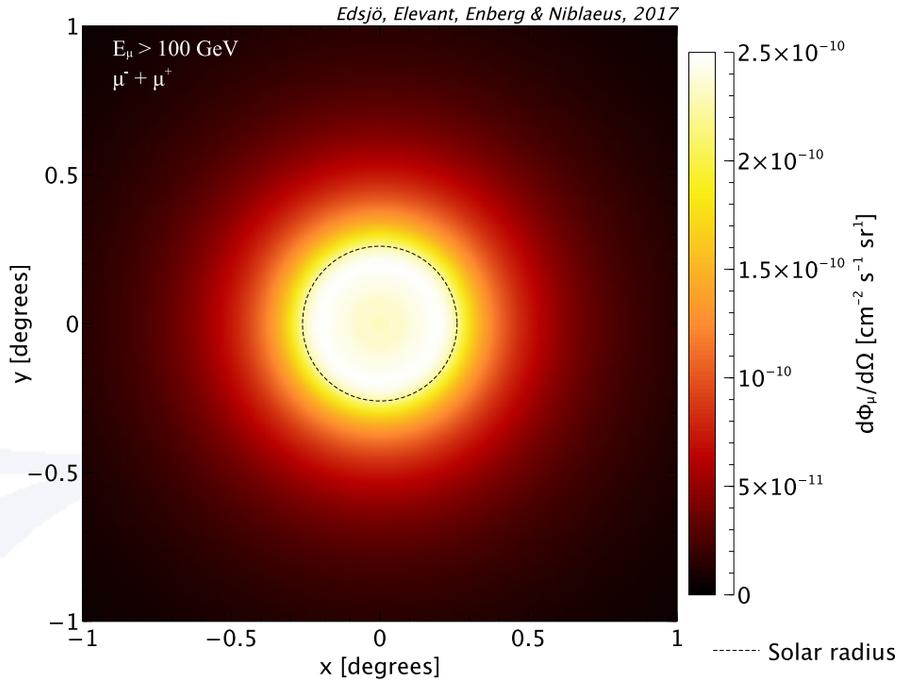
It can be tough to distinguish a dark matter signal from the SAv

We have calculated the flux of solar atmospheric neutrinos and studied the effect on dark matter searches

astro-ph/1704.02892

code: http://wimpsim.astroparticle.se





Future prospects:

More detailed studies of detection possibilities

Refined modeling of e.g. magnetic fields

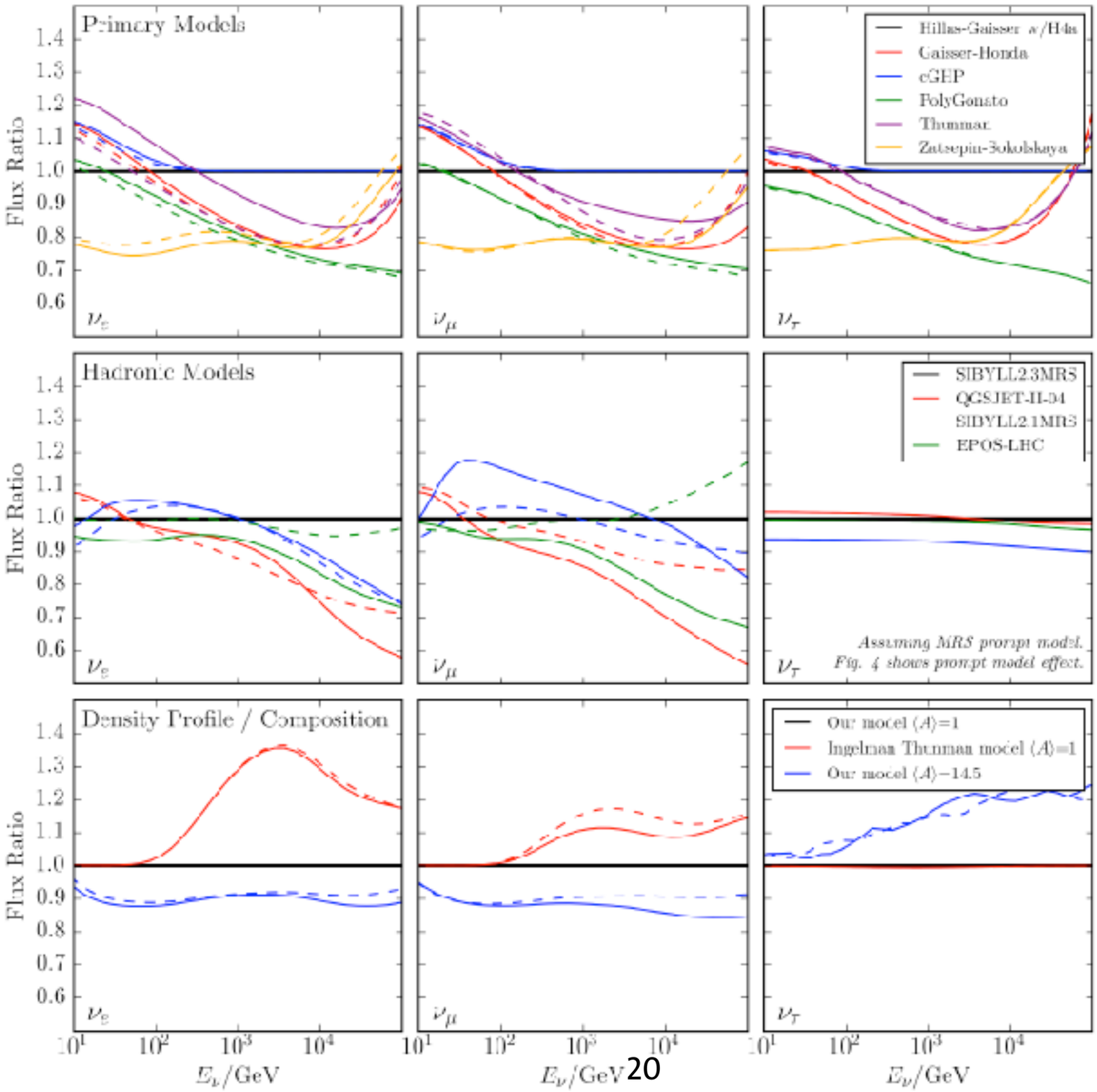
Extra

Systematics on production fluxes from Argüelles et al., astro-ph/1703.07798

CR flux model

Hadr. int. model

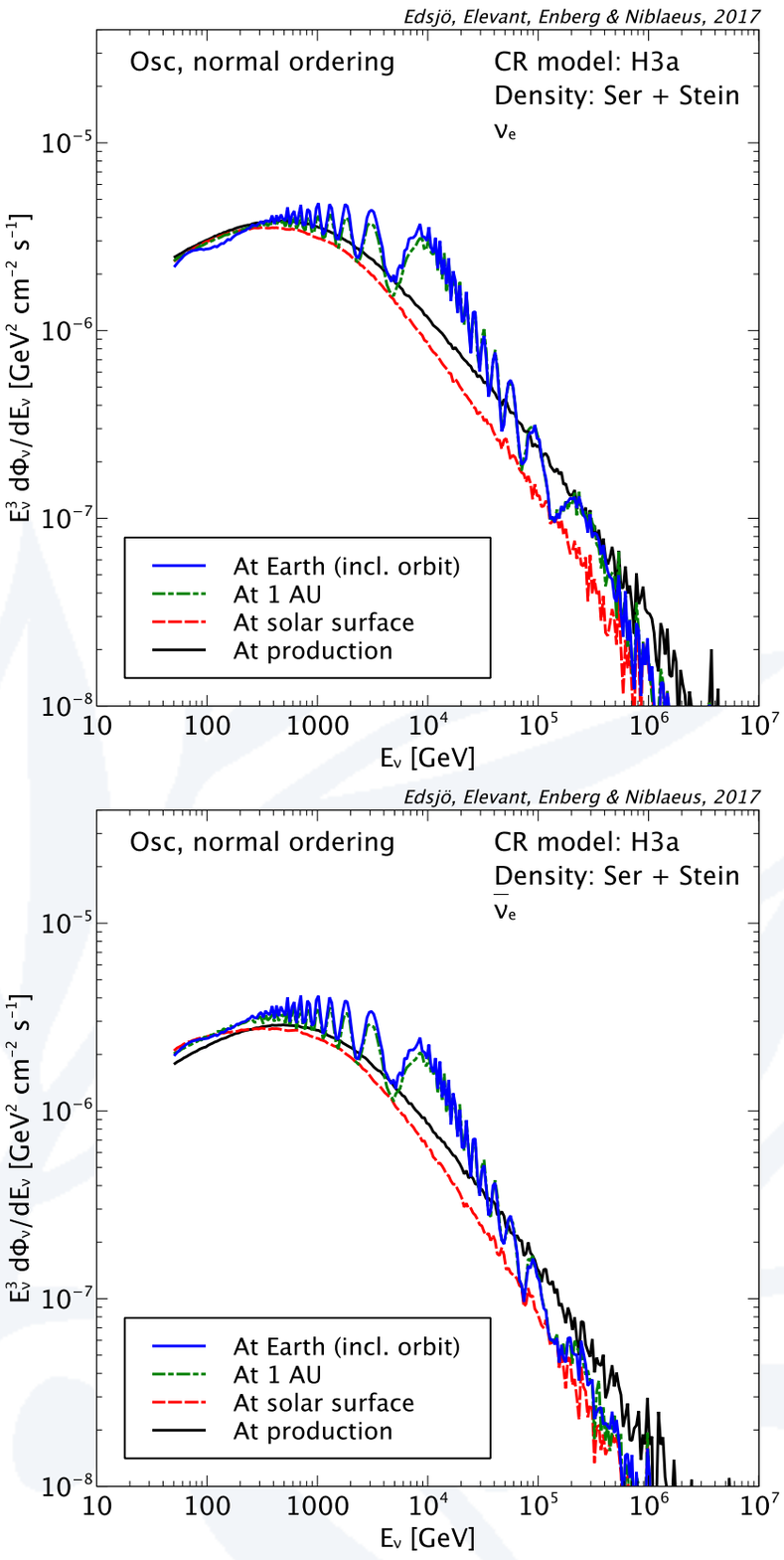
Density profile

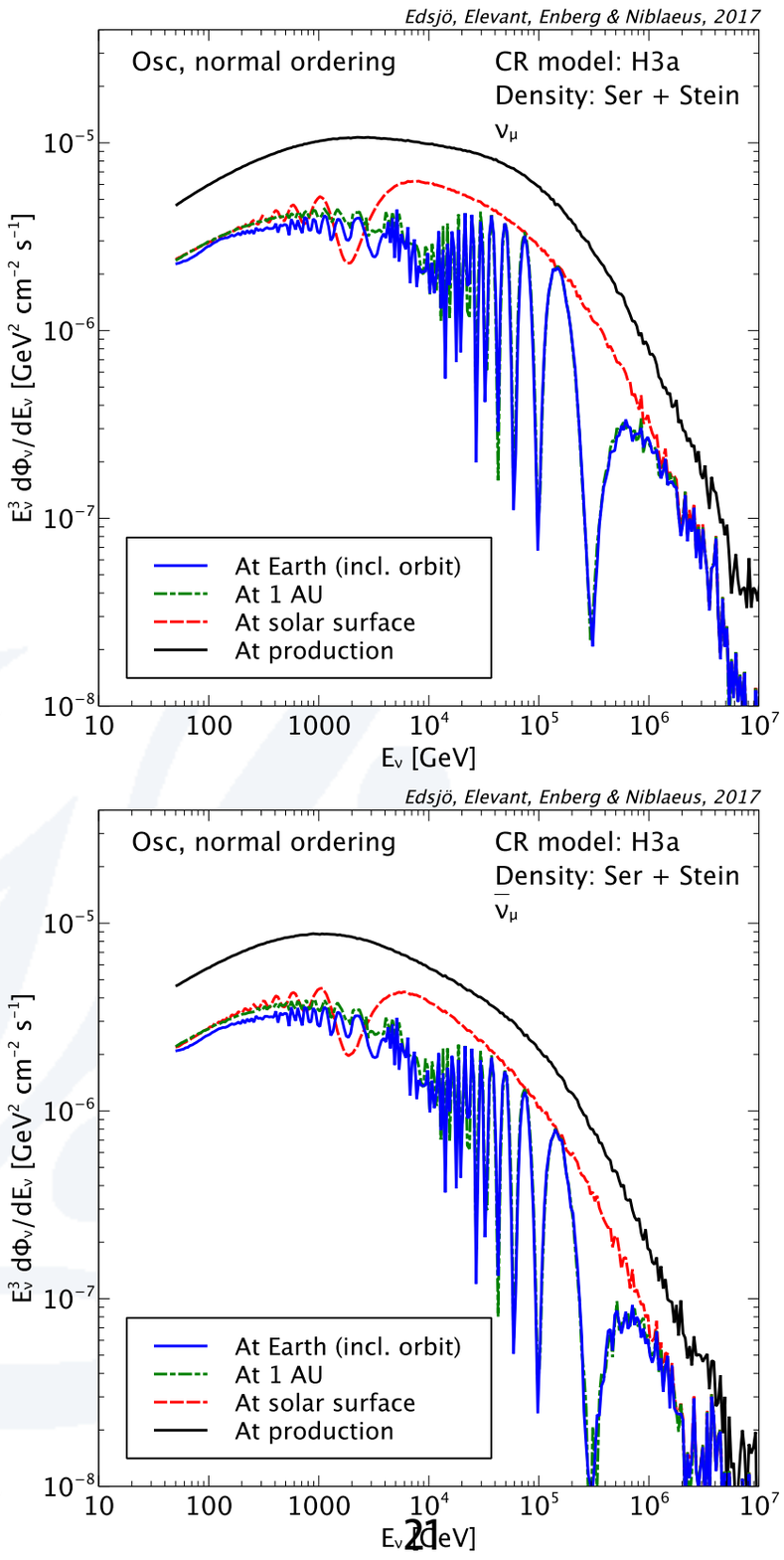


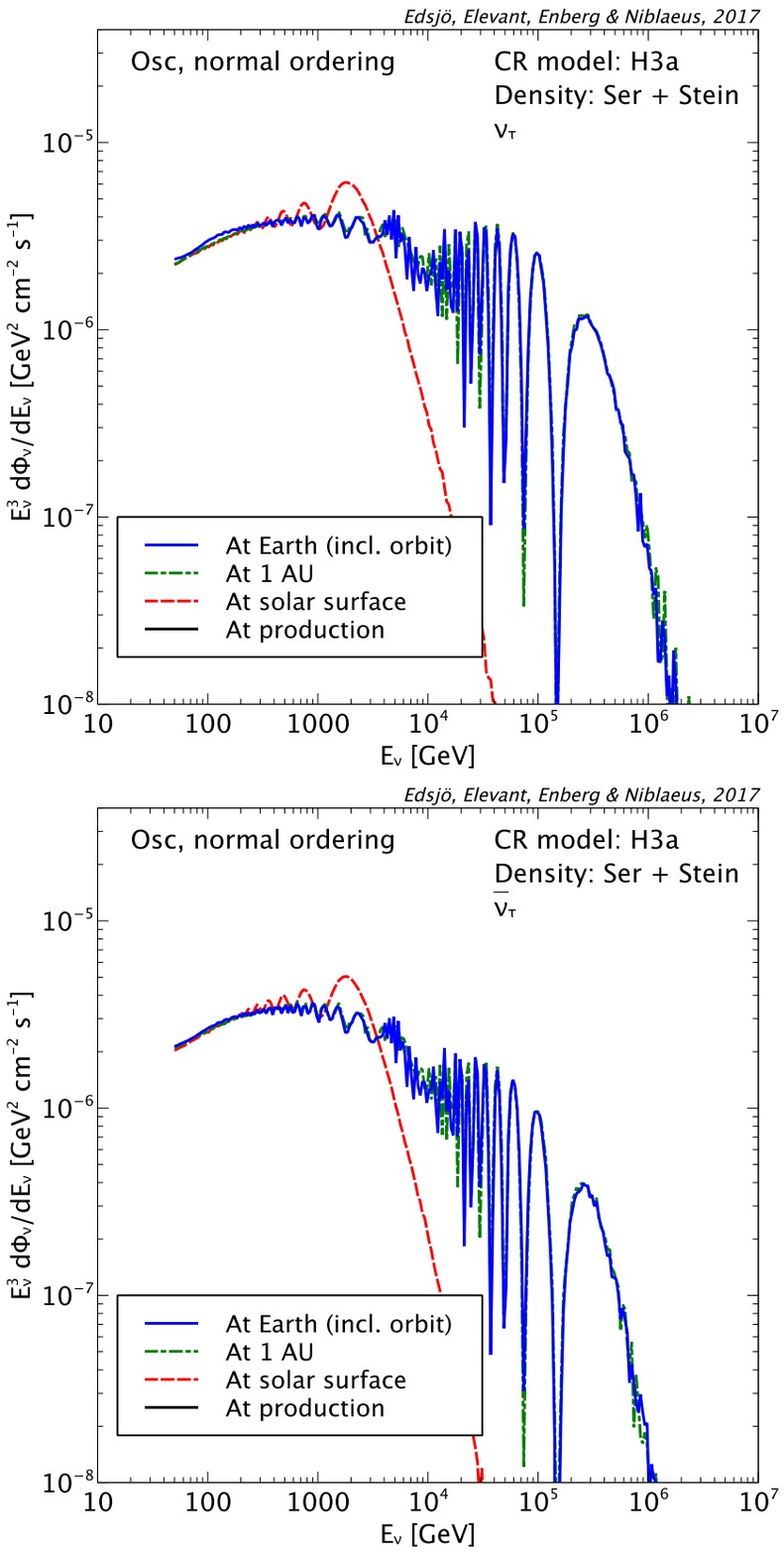
Final effect: factor≈2

Magnetic field neglected

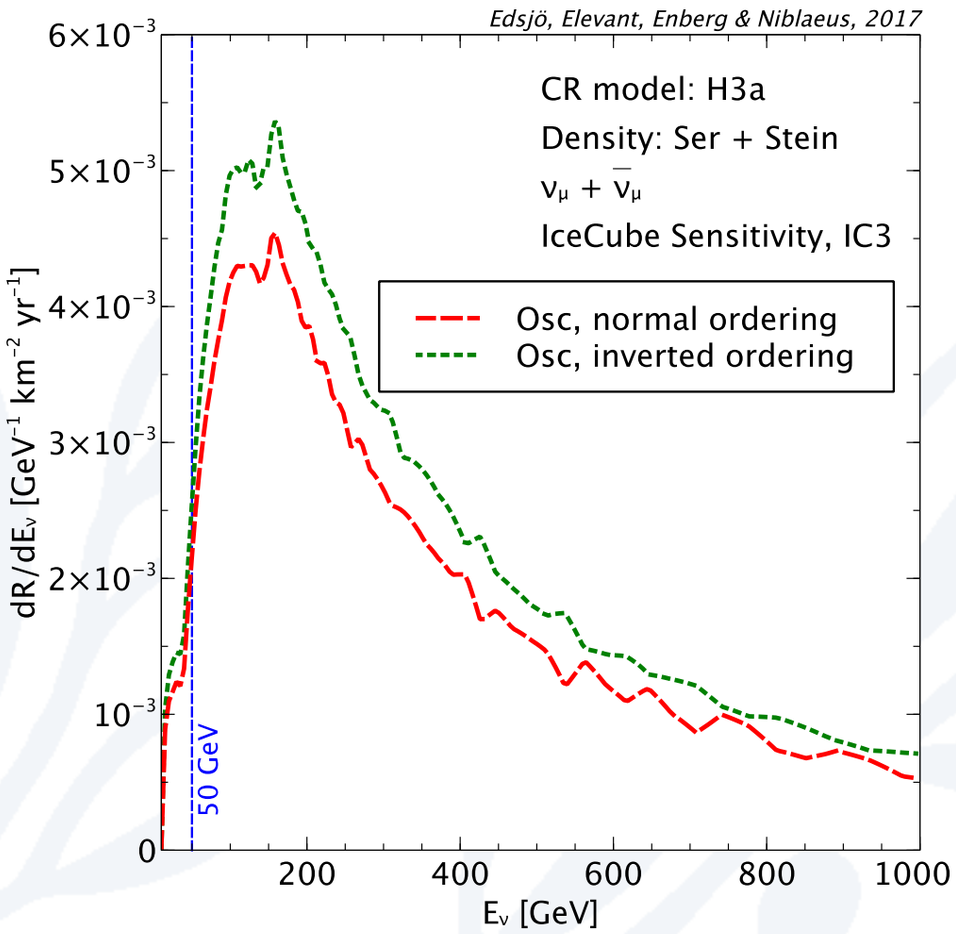
Fluxes for all flavours



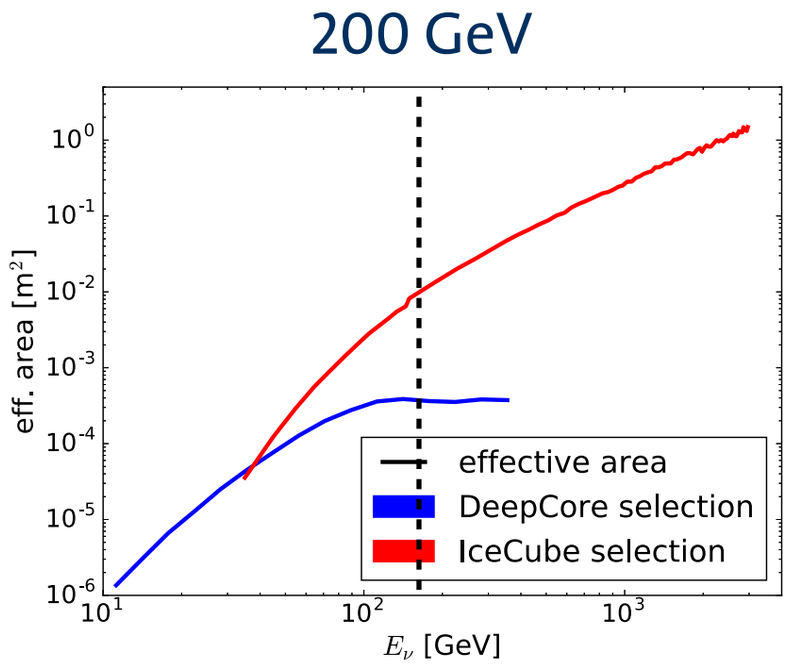




The event rate is dominated by neutrino energies around 150 GeV



$$\frac{dR}{dE} = A_{\text{eff}}(E)\frac{d\Phi}{dE}$$



IC 3y analysis, astro-ph/1612.05949

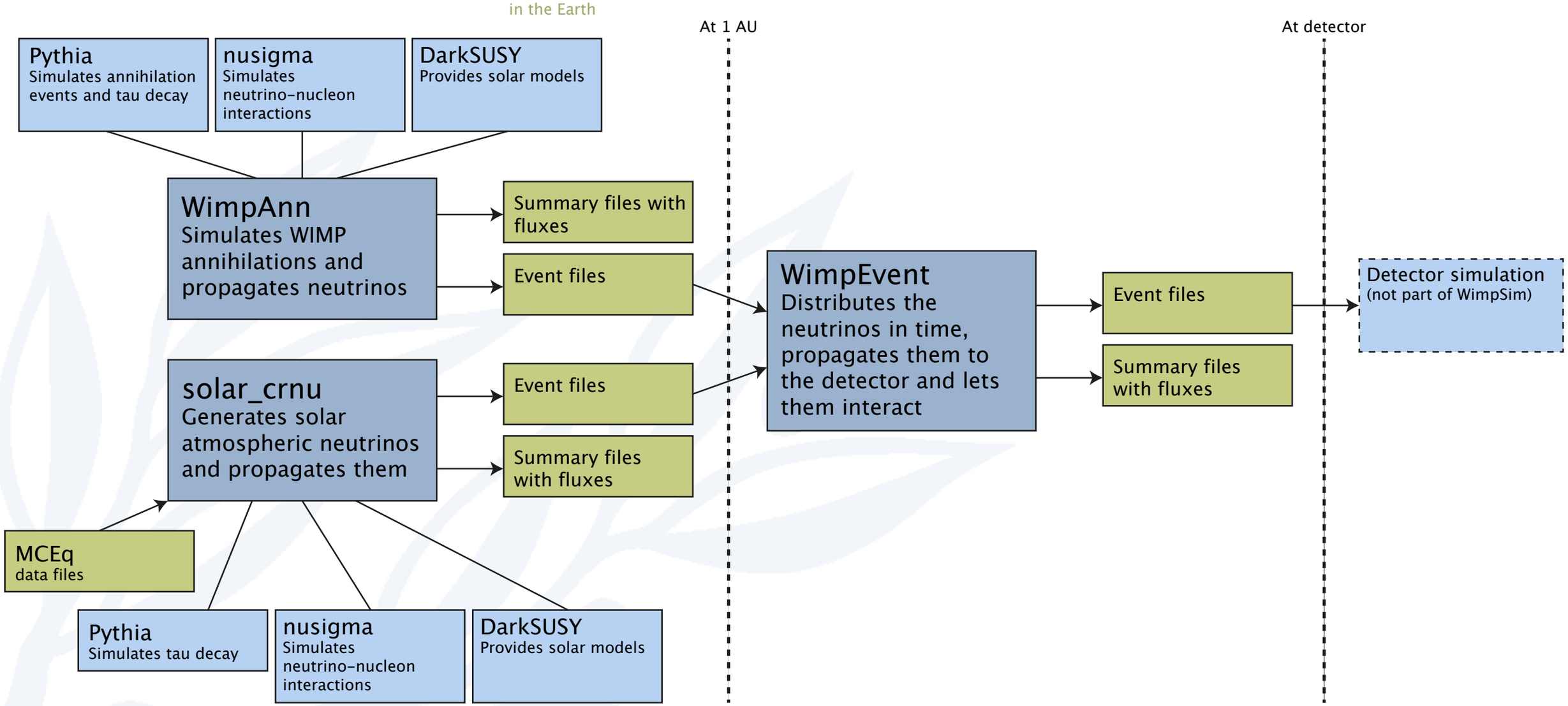
Effective area drops faster than flux increases as energy is lowered below 100 GeV

WimpSim code layout

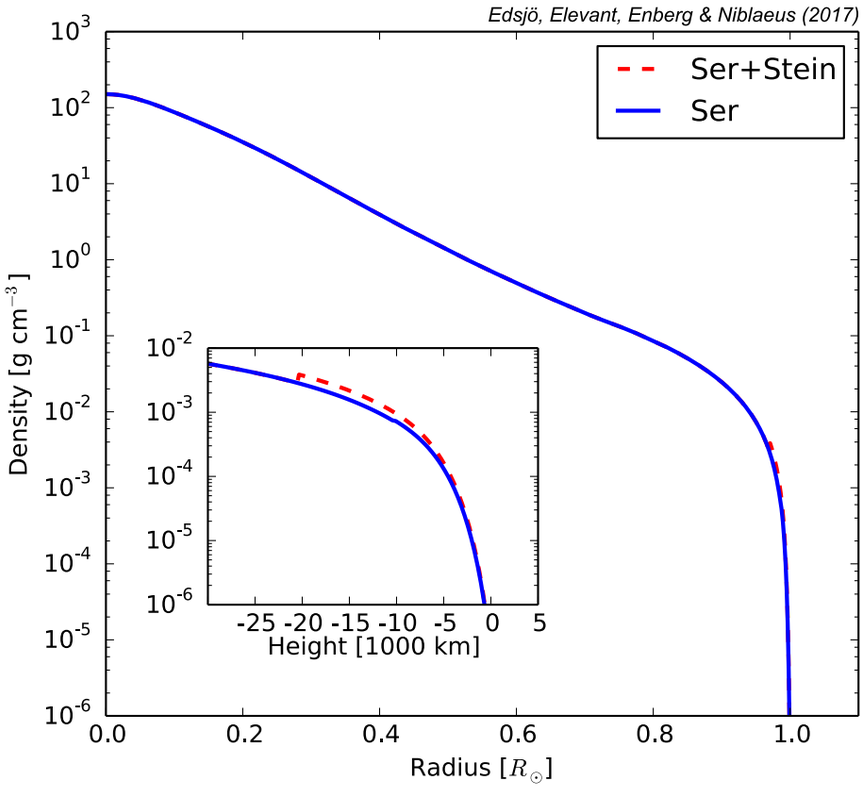
In the Sun*

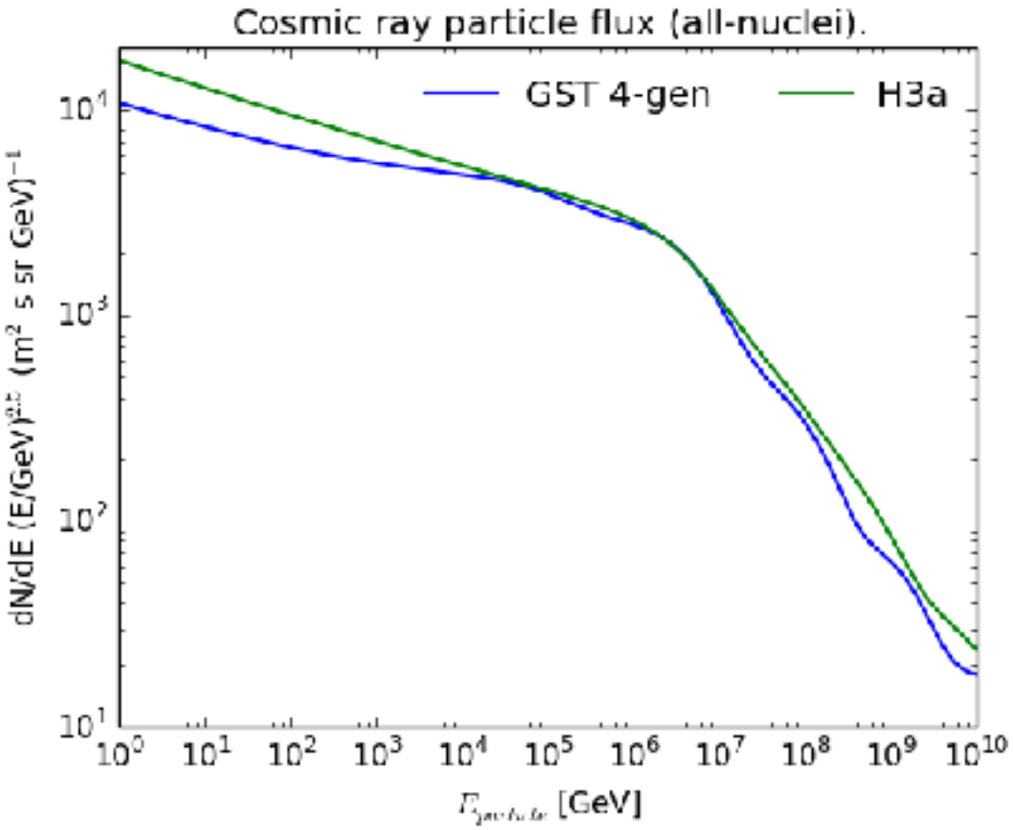
*) WimpAnn can also be run for annihilations in the Earth

At the Earth



We have varied density profile, CR flux model and neutrino mass hierarchy

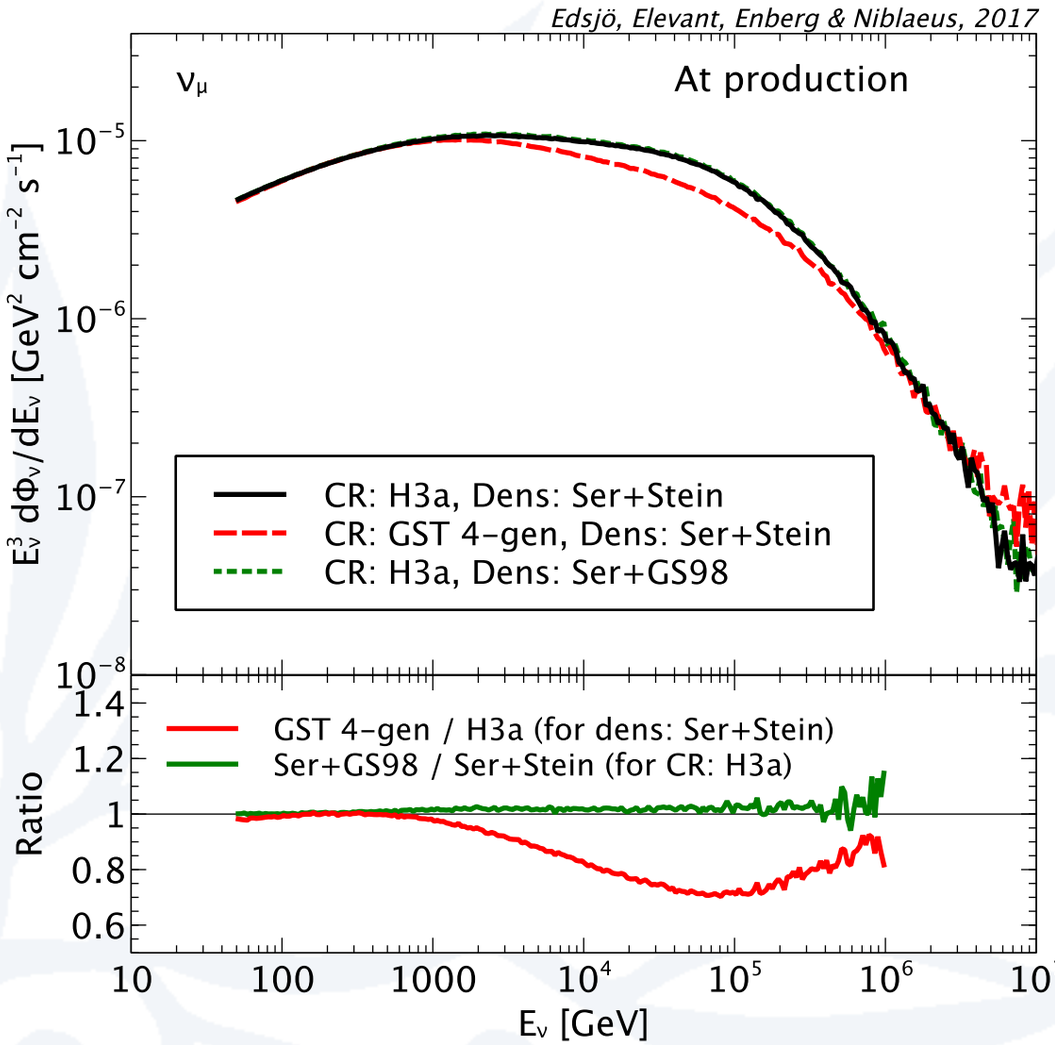




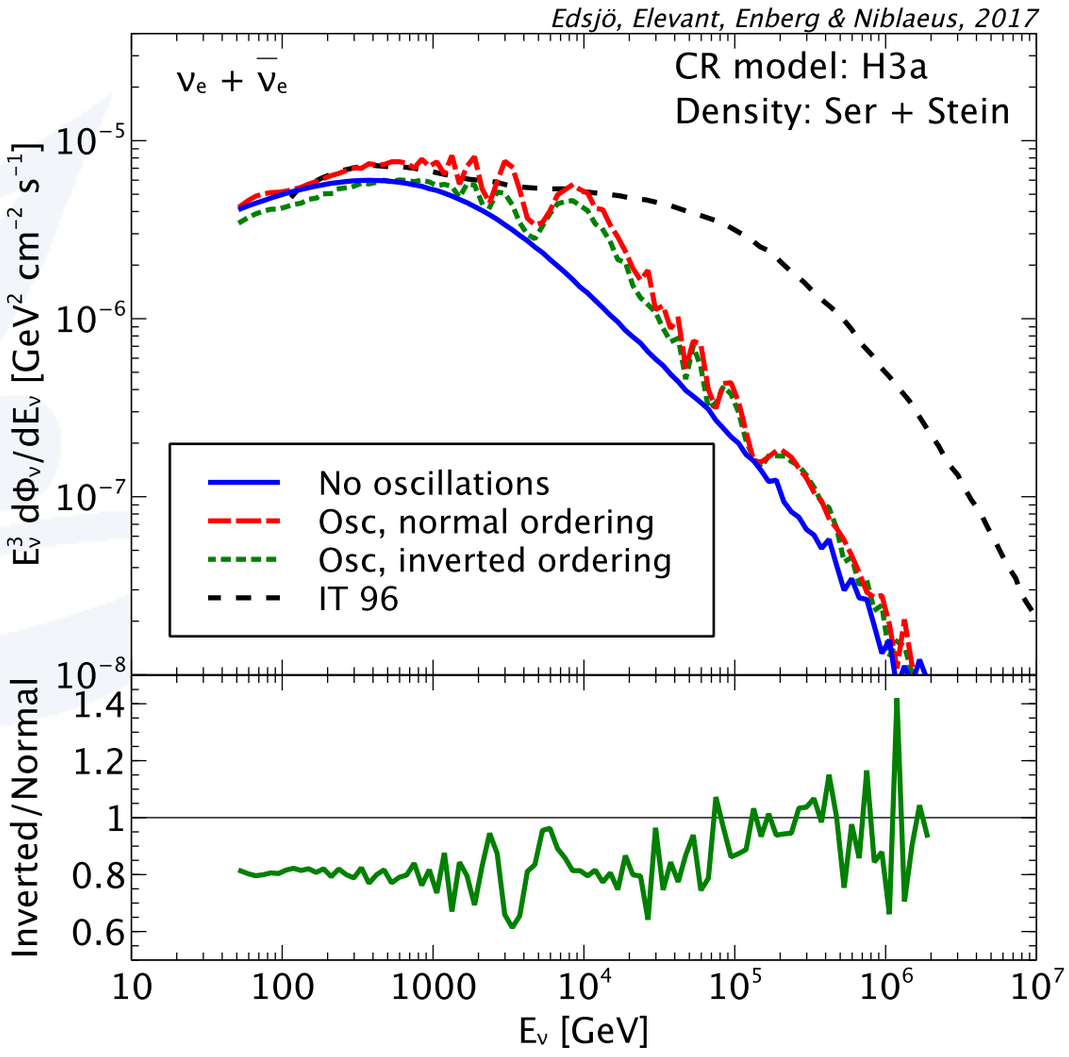
Mass hierarchy affects matter oscillations and best-fit values of oscillation parameters

Resulting flux differences are rather small

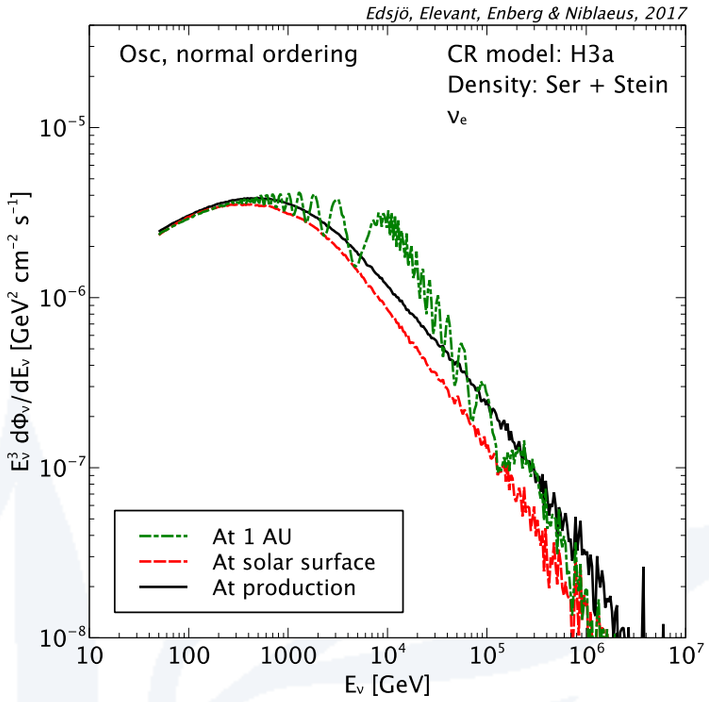
Density/CR model

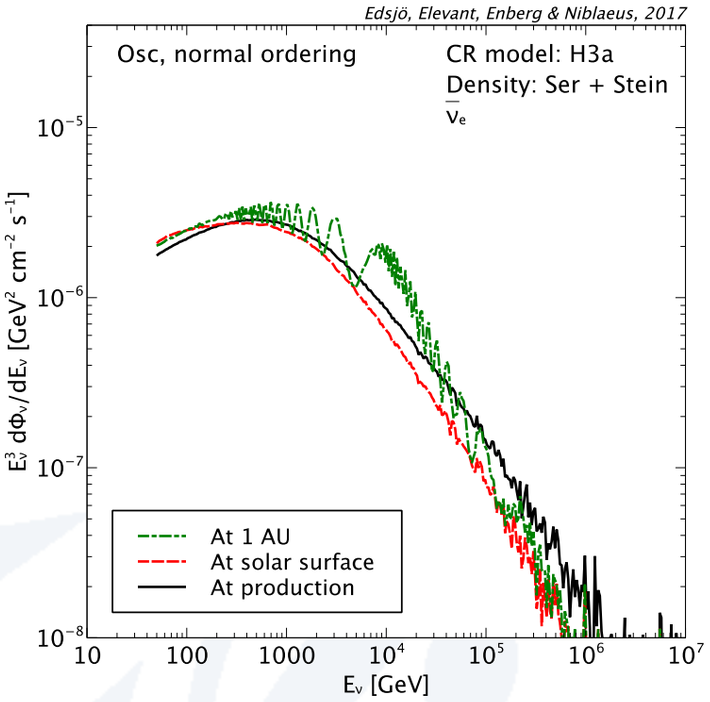


Mass hierarchy

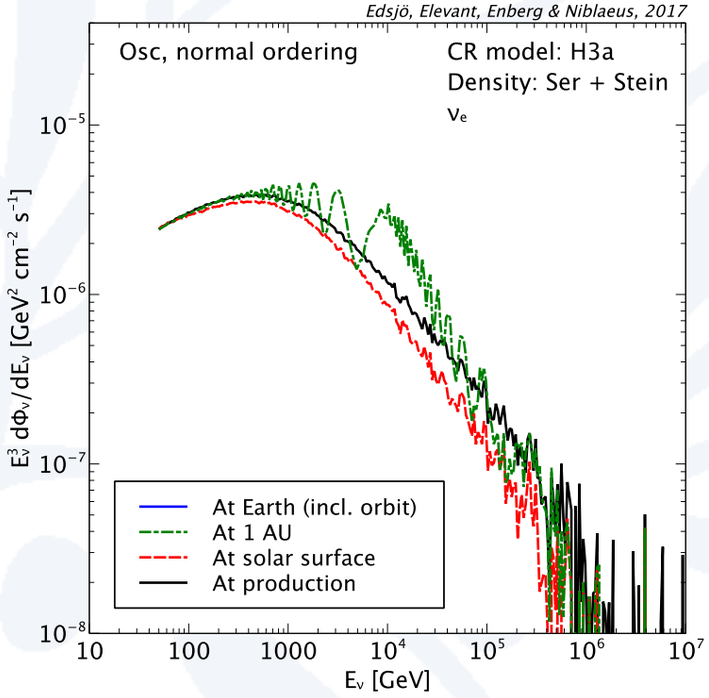


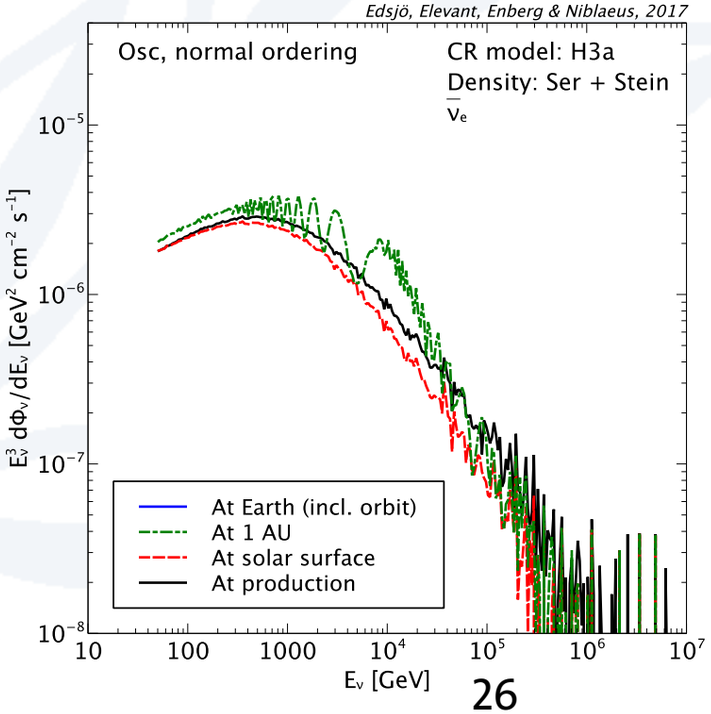
Matter oscillation effects (MSW) are small





Standard





No MSW effect