Phenomenological work : assess astrophysical uncertainties on DS20k's exclusion limits

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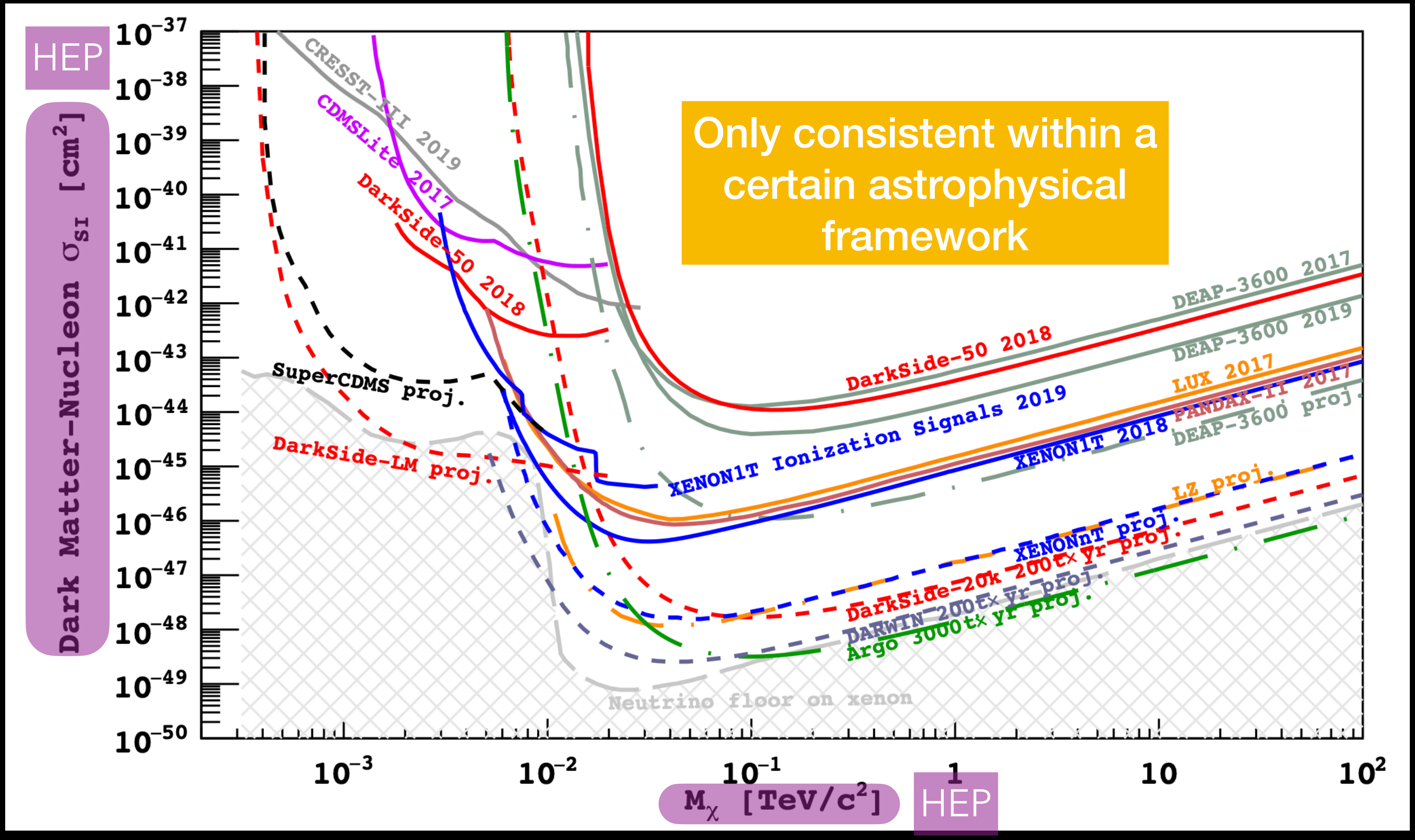
Phenomenology : goal of the current study



HEP Astro

Y-Axis

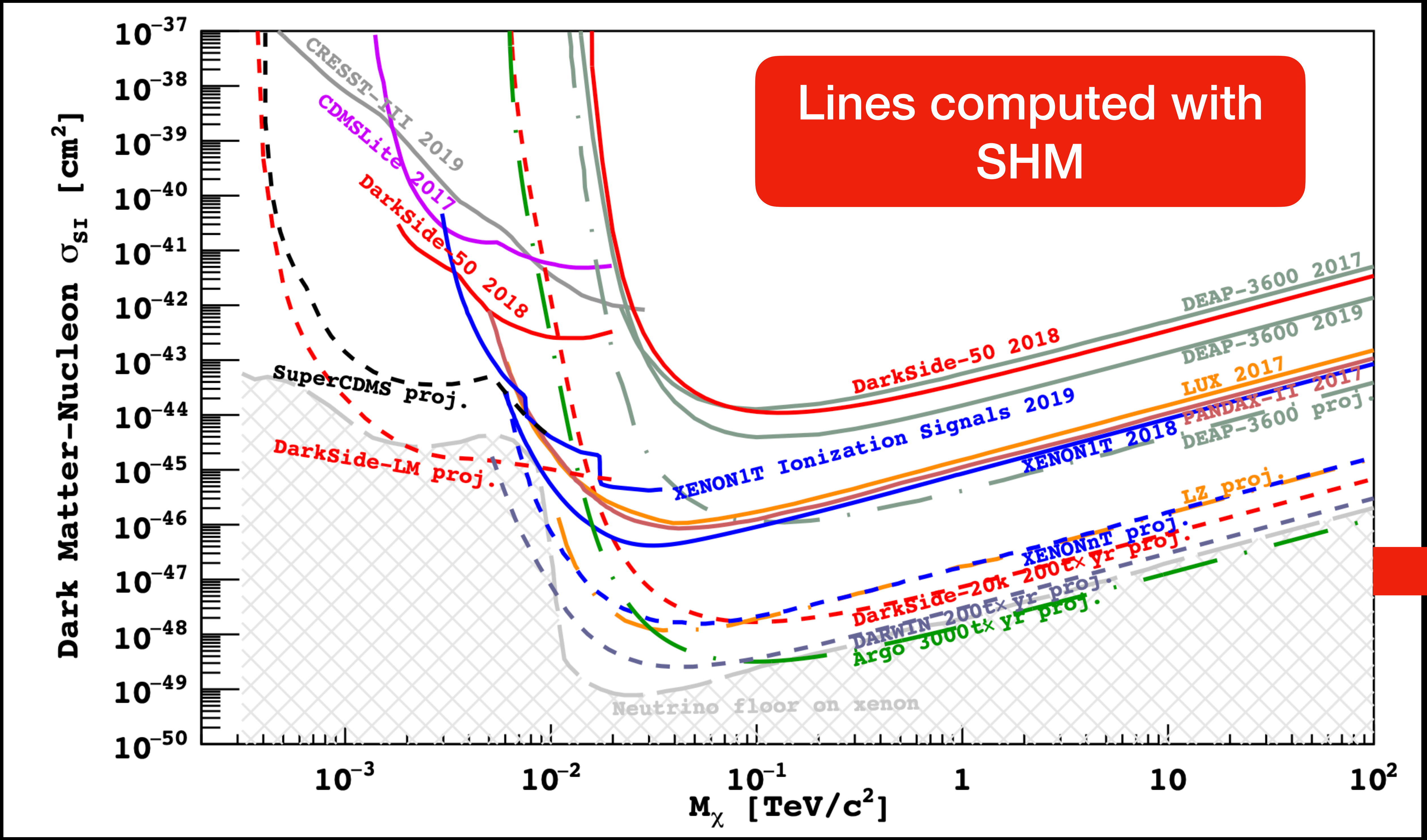
- $$\frac{dR}{dE_R} = \frac{\rho_0}{m_\chi m_N}\int_{v_{min}}^{v_{esc}} \frac{f(v)}{v}\frac{d\sigma}{dE_R}\, d\vec{v}$$

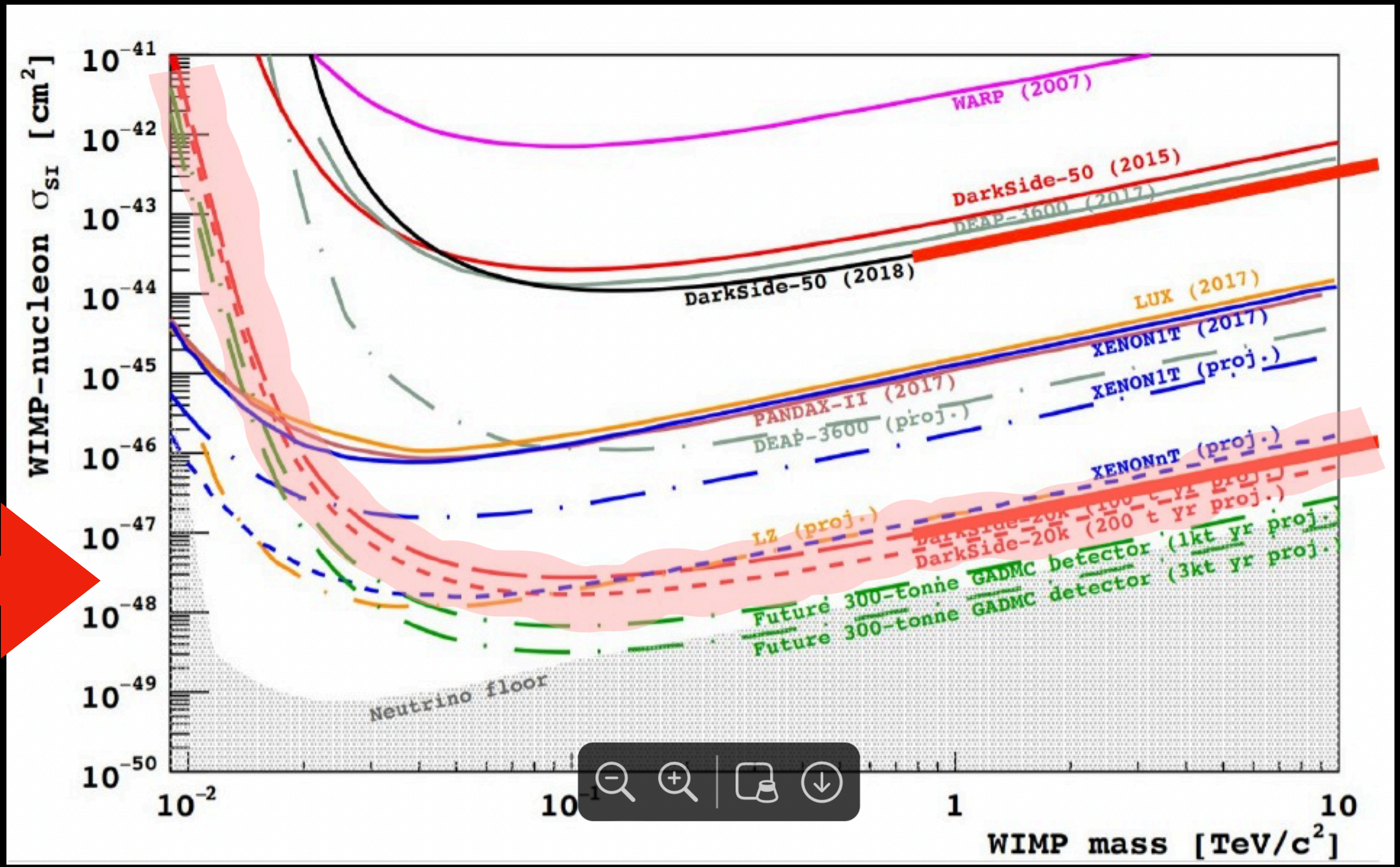
X-Axis

- Parameters at stake : $v_0, v_c, v_{esc}, \rho_0$ & f(v)
- Changing these parameters will affect the exclusion limits
- Goal: assess astrophysical uncertainties on DS-20k exclusion limit by considering more realistic and complex assumptions for the dark matter distribution

Velocity distributions of DM

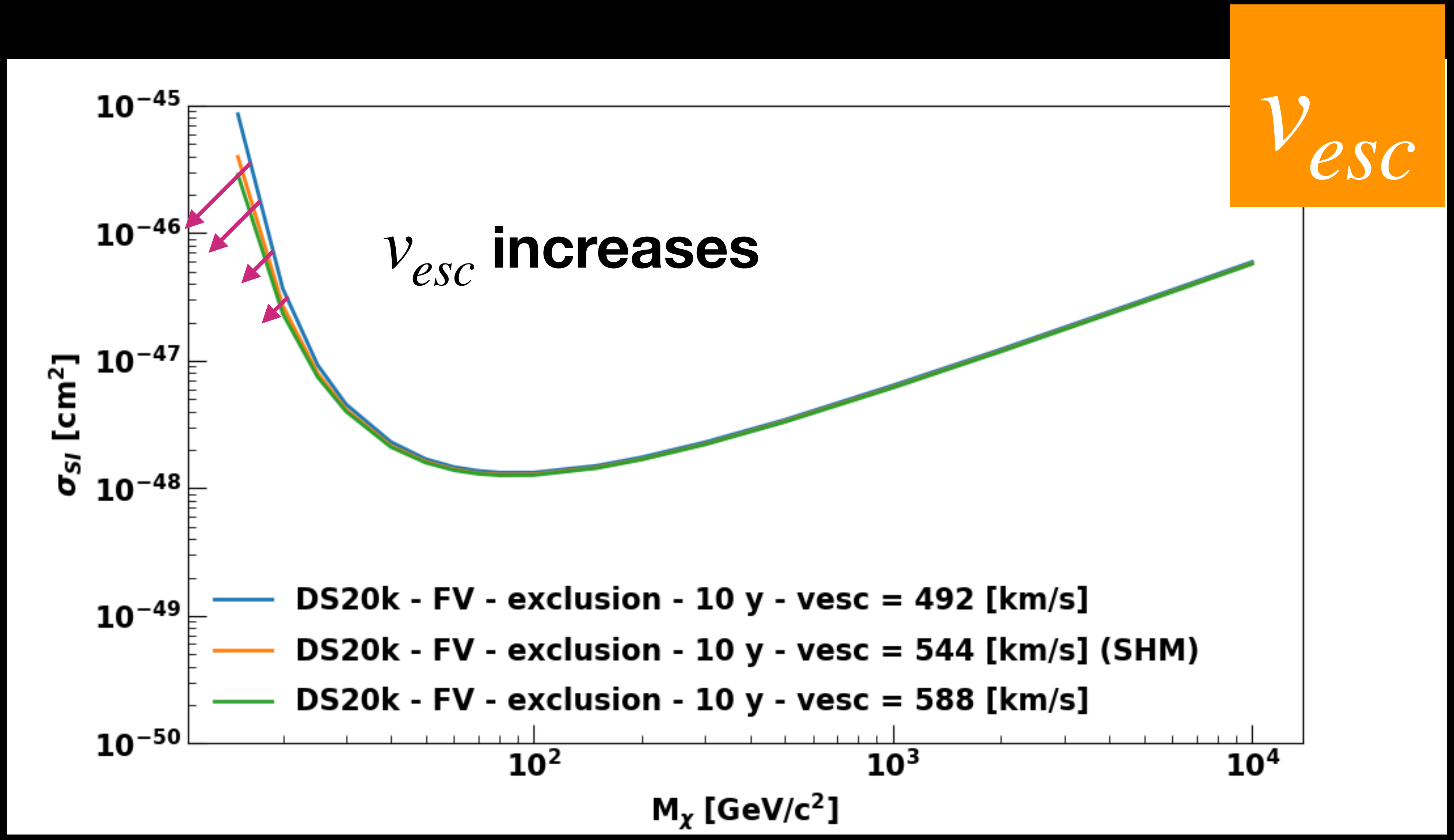
Lines computed with SHM

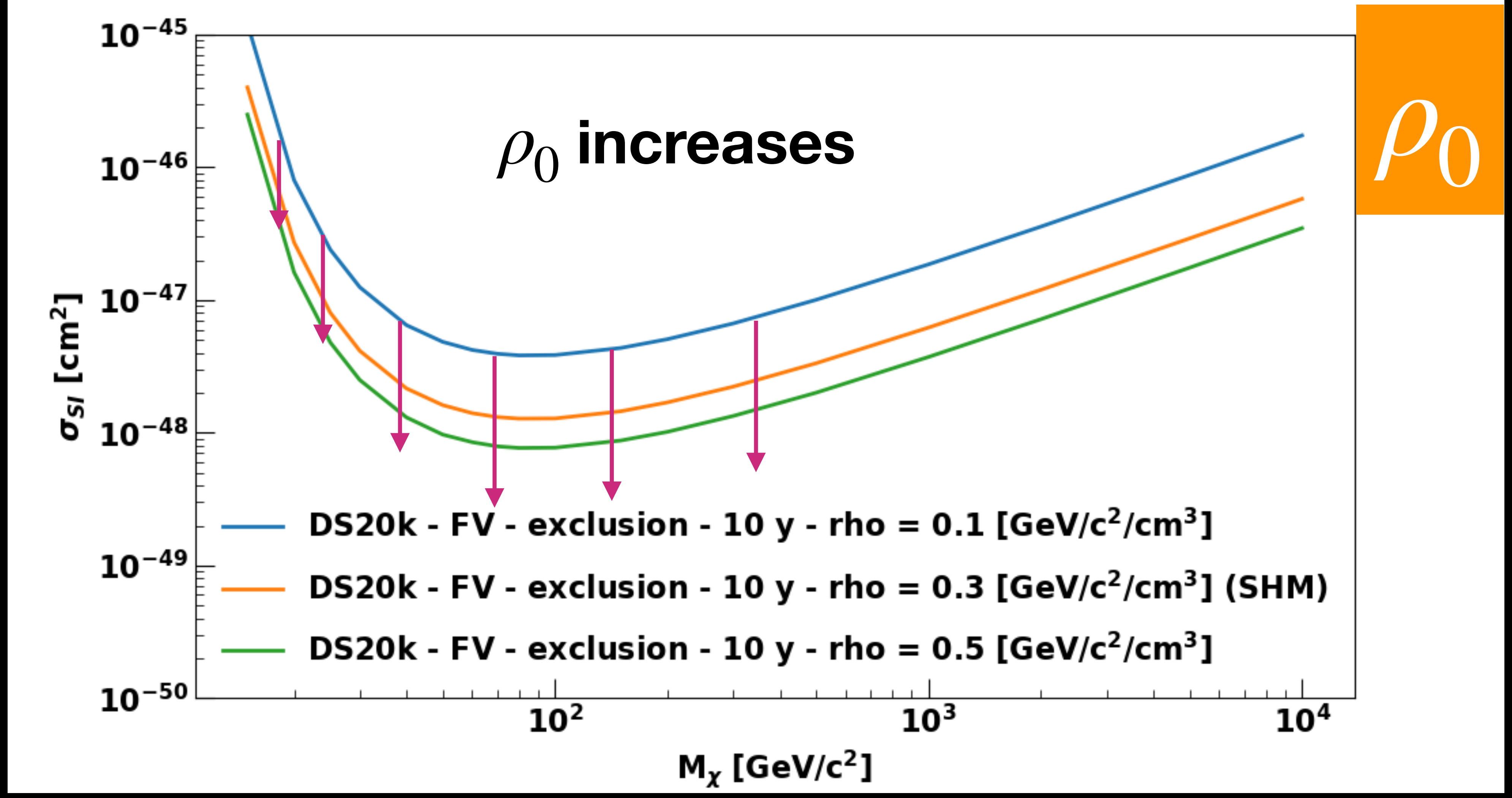




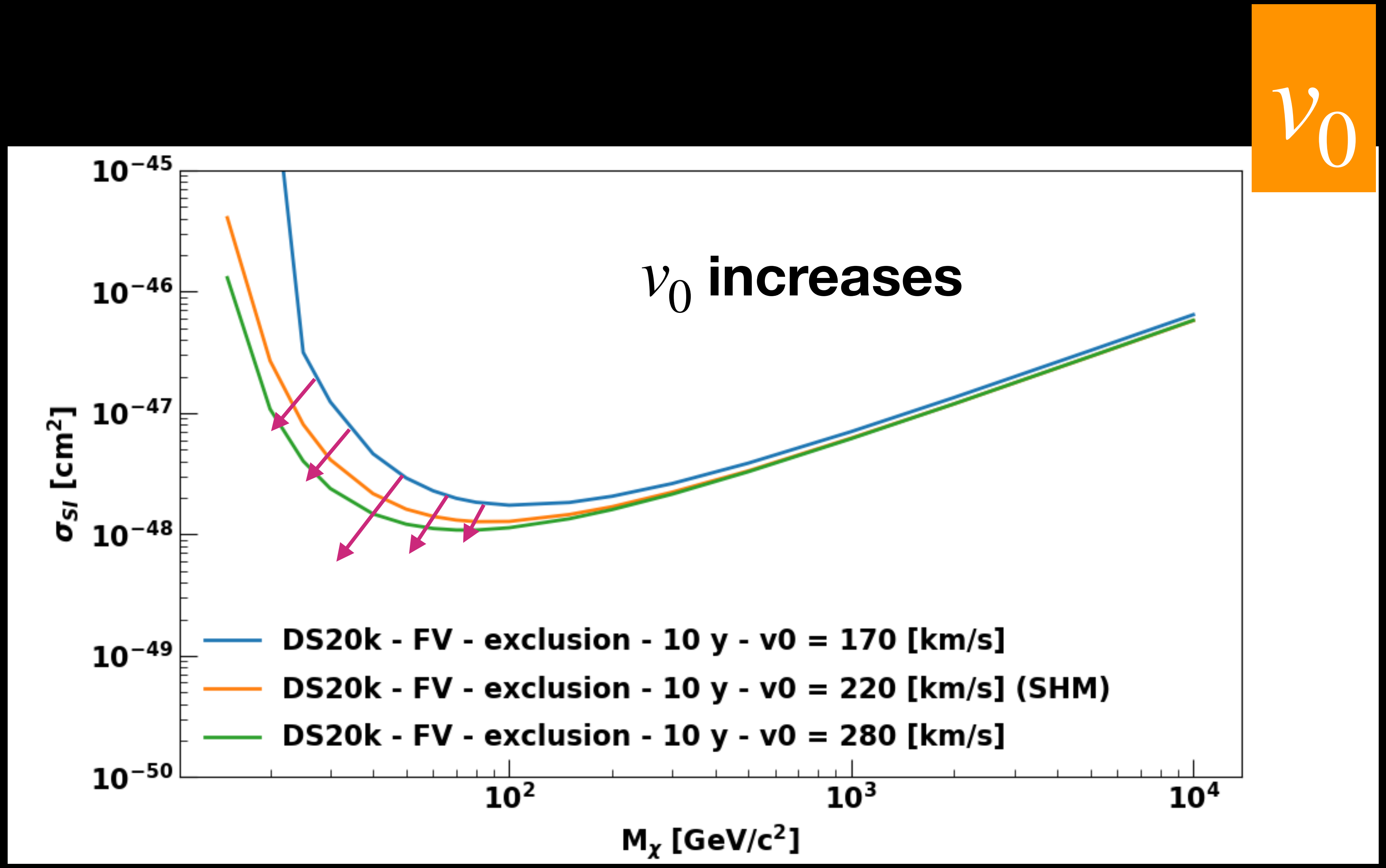
How does the overall code works ?

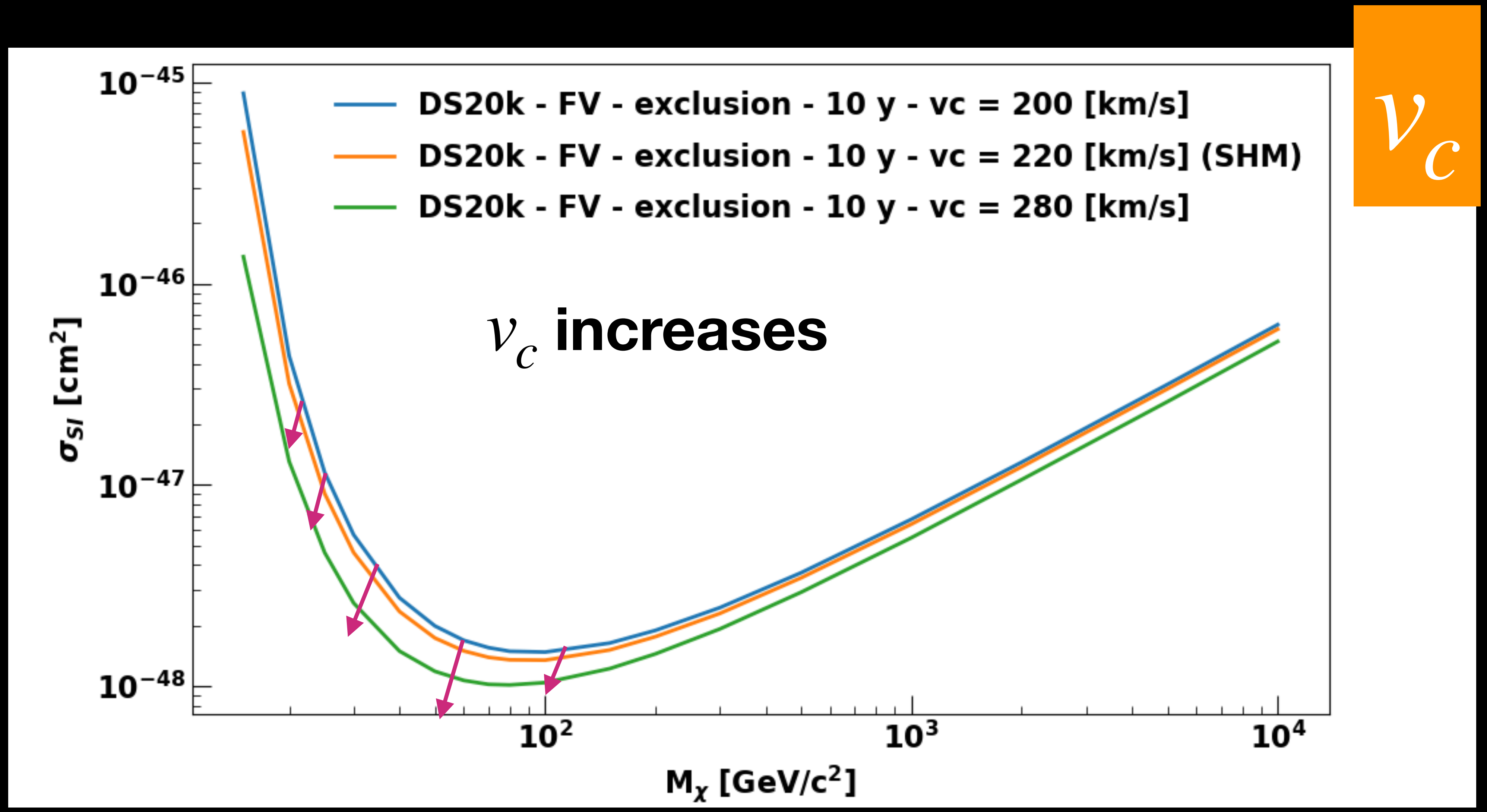
First goal : keep SHM and modify $v_{esc}, v_0, v_c, \rho_0$





Reproduction of effects seen by <u>Stefano Magni</u>

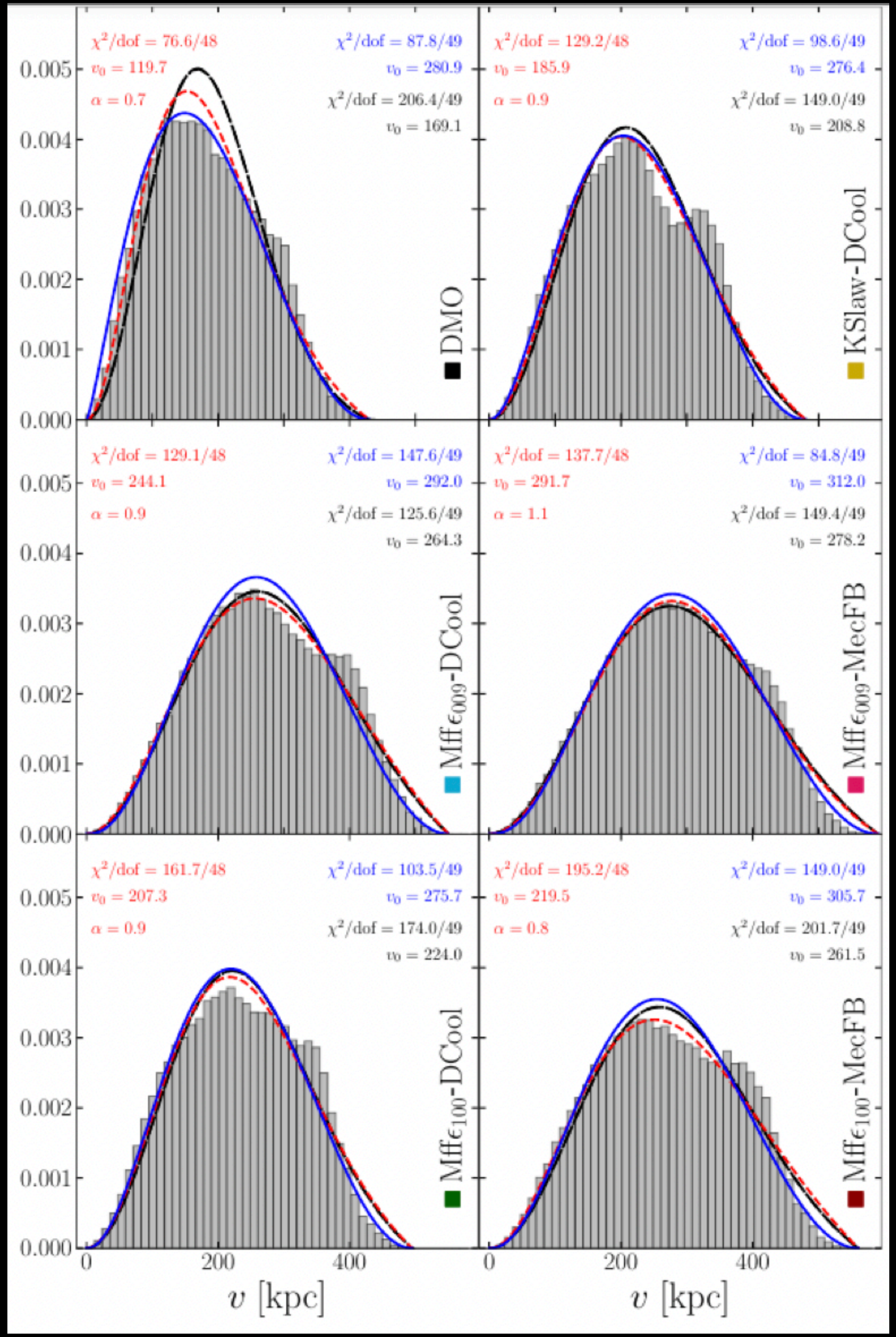




Second goal : change f(v) to use more relevant velocity distributions

More relevant ?

Histo		Simulations
Fit		Maxwellian
Fit		Generalised Maxwellian
Fit		Tsallis



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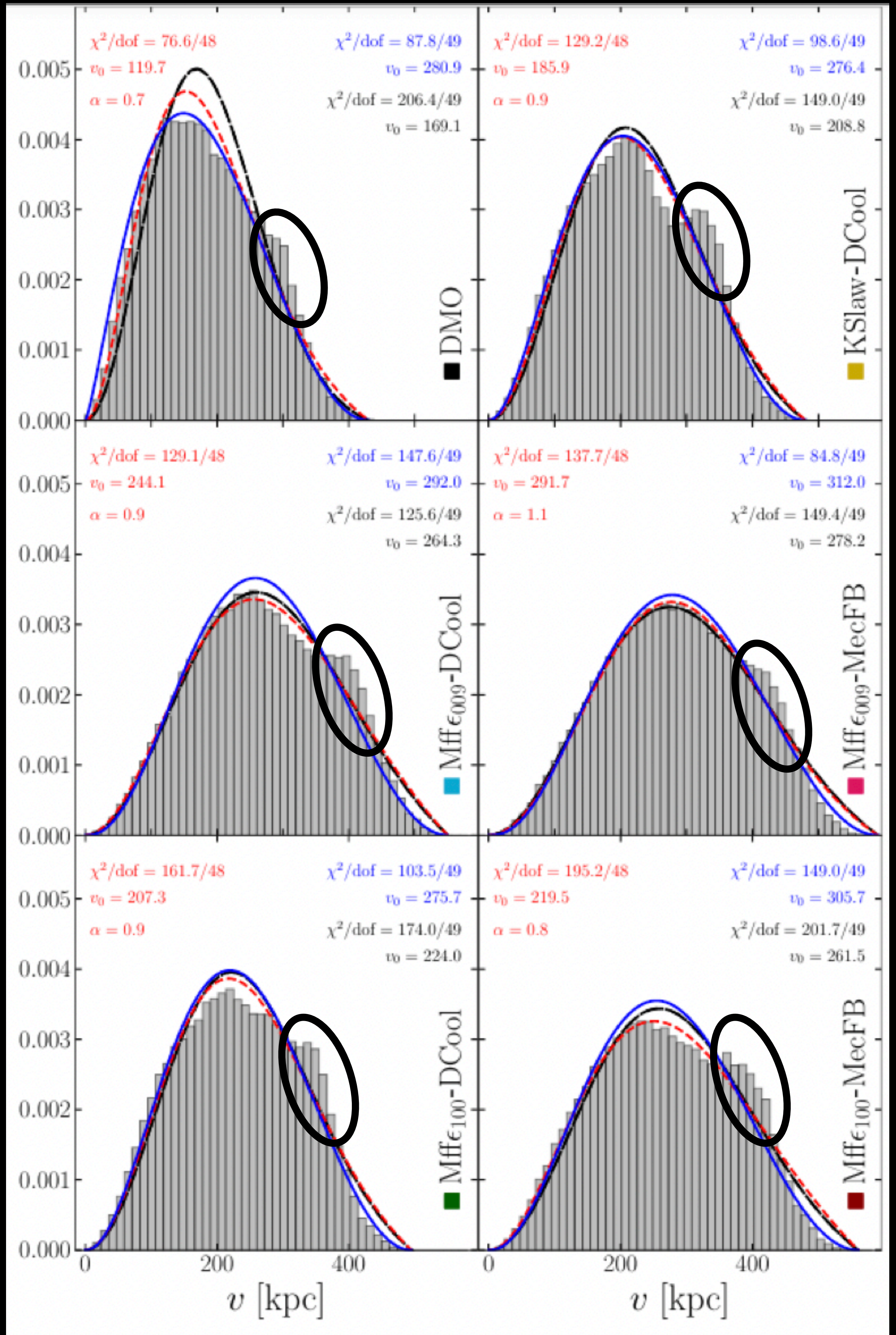


Clumps and streams : prospective study

The theory

- Astrophysical concepts

  - The WIMPs have a velocity distribution modeled inside the Milky Way

    - $$f_{gal}(\overrightarrow{v}) =_{e.g.} \frac{1}{2\pi^{3/2}v_0^3} e^{-|\overrightarrow{v}|^2/v_O^2}$$

  - But, in DMDD, we try to detect them on Earth -> need to express the velocity distributions on Earth

    - $$f_{\oplus}(\overrightarrow{v'}) = f_{gal}(\overrightarrow{v'} + \overrightarrow{v_{\oplus}}(t)) = \int_0^{2\pi}\int_0^{\pi} f_{\oplus}(v') \cdot v'^2 \cdot sin(\theta)d\theta d\phi$$

The collaboration code originally uses analytical results of SHM only, no numerical integrations/computations -> need to create a numerical module that is adaptable to different models

The functions

- I want to plot these functions at some point : need to focus on $f_{\oplus}(v')$ (not on $f_{\oplus}(\overrightarrow{v'})$)
    - The function takes in entry v' = | $\overrightarrow{v'}$ |
    - It computes | $\overrightarrow{v'}$ + $\overrightarrow{v_{\oplus}}$ | = $|\overrightarrow{v'}|^2 + |\overrightarrow{v_{\oplus}}|^2 + 2\,|\overrightarrow{v'}|\,|\overrightarrow{v_{\oplus}}|$ cos (θ)
    - It evaluates $f_{gal}(v) = f_{gal}(|\overrightarrow{v}|)$ at | $\overrightarrow{v'}$ + $\overrightarrow{v_{\oplus}}$ | by integrating on cos(θ) and * 2π (= $\int_0^{2\pi} d\phi$)
        - Only accurate in isotropic models
- Needed for prospective studies (study of simulations with clumps, streams, <u>« direct » study of anisotropies</u>) : perform the same but integrating on θ and ϕ
    - The function takes in entry v' = | $\overrightarrow{v'}$ |
    - It computes $v'_x = vcos(\phi)sin(\theta), v'_y = vsin(\phi)sin(\theta), v'_z = vcos(\theta)$
    - It computes | $\overrightarrow{v'}$ + $\overrightarrow{v_{\oplus}}$ | ² = $(v'_x + v_{\oplus,x})^2 + (v'_y + v_{\oplus,y})^2 + (v'_z + v_{\oplus,z})^2$
    - It evaluates $f_{gal}(v) = f_{gal}(|\overrightarrow{v}|)$ at | $\overrightarrow{v'}$ + $\overrightarrow{v_{\oplus}}$ | by integrating on θ and ϕ

For now :

SHM sharp cut

$$f_{gal}(\overrightarrow{v}) =_{e.g.} \frac{1}{2\pi^{3/2}v_0^3} e^{-|\overrightarrow{v}|^2/v_0^2}$$

if v < v_{esc}, else 0

SHM smooth cut

$$f_{gal}(\overrightarrow{v}) =_{e.g.} \frac{1}{2\pi^{3/2}v_0^3}\left(e^{-|\overrightarrow{v}|^2/v_0^2} - e^{-v_{esc}^2/v_0^2}\right)$$

if v < v_{esc}, else 0

1st step: reproduce the analytical velocity distribution and η function with my own numerical code

$$f_{gal}(v) = \frac{1}{N_{esc}} \cdot \frac{2}{\pi^{1/2} v_0^3} \cdot v^2 \cdot e^{-\frac{|\vec{v}|^2}{v_0^2}}$$ if v < v_{esc}

SHM

$$f_{gal}(\vec{v}) \rightarrow f_{\oplus}(\vec{v'}) = f_{gal}\left(\vec{v'} + \vec{v_{\oplus}}(t)\right)$$

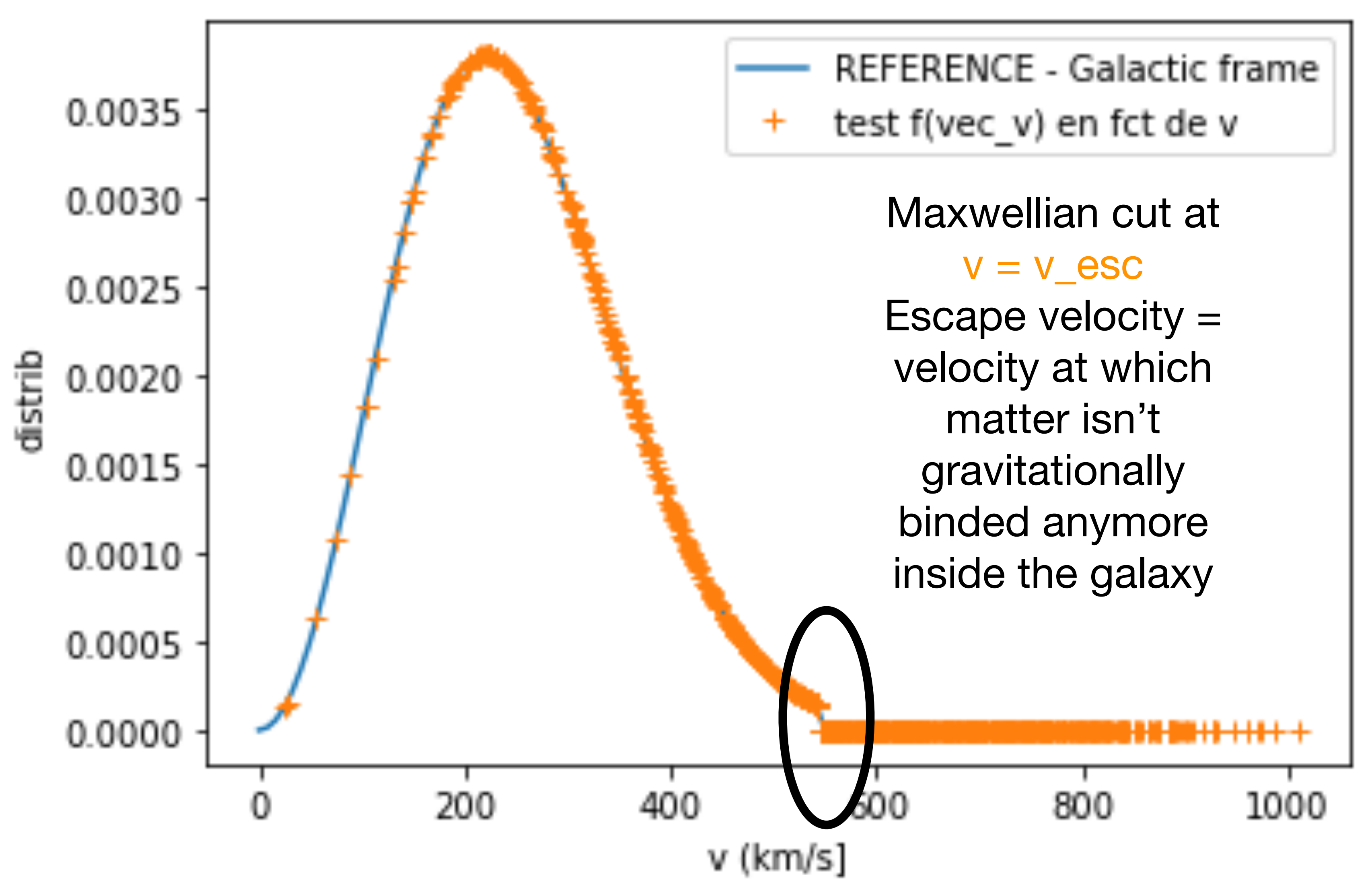
$$\vec{v} \rightarrow \vec{v'} + \vec{v_{\oplus}}(t)$$

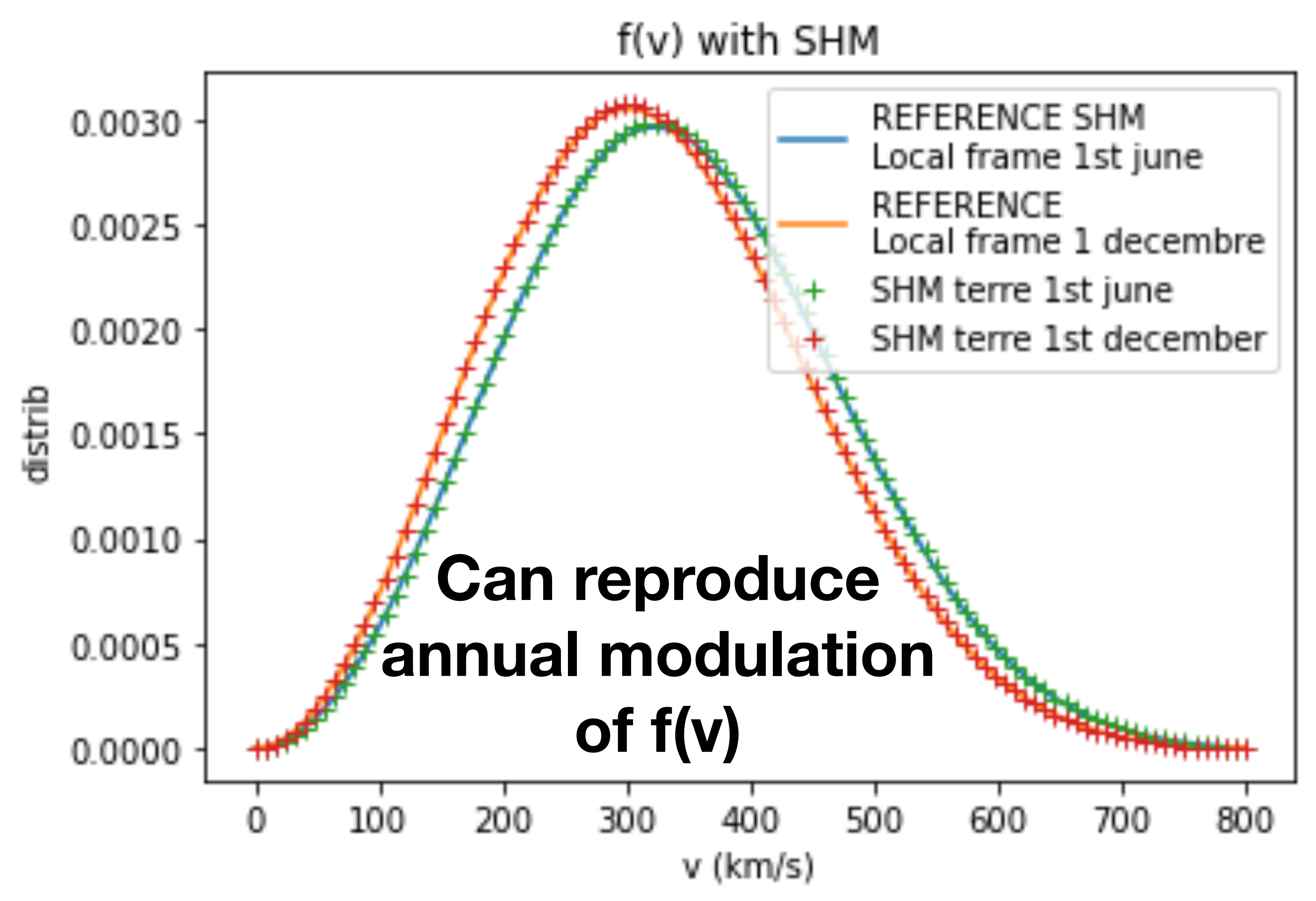
$$\frac{dR}{dE_R} = \frac{\rho_0}{m_\chi m_N} \underbrace{\int_{v_{min}}^{v_{esc}} d\vec{v} \frac{f(v)}{v}}_{\eta} \overbrace{\frac{d\sigma}{dE_R}}^{\approx \text{ cste}}$$

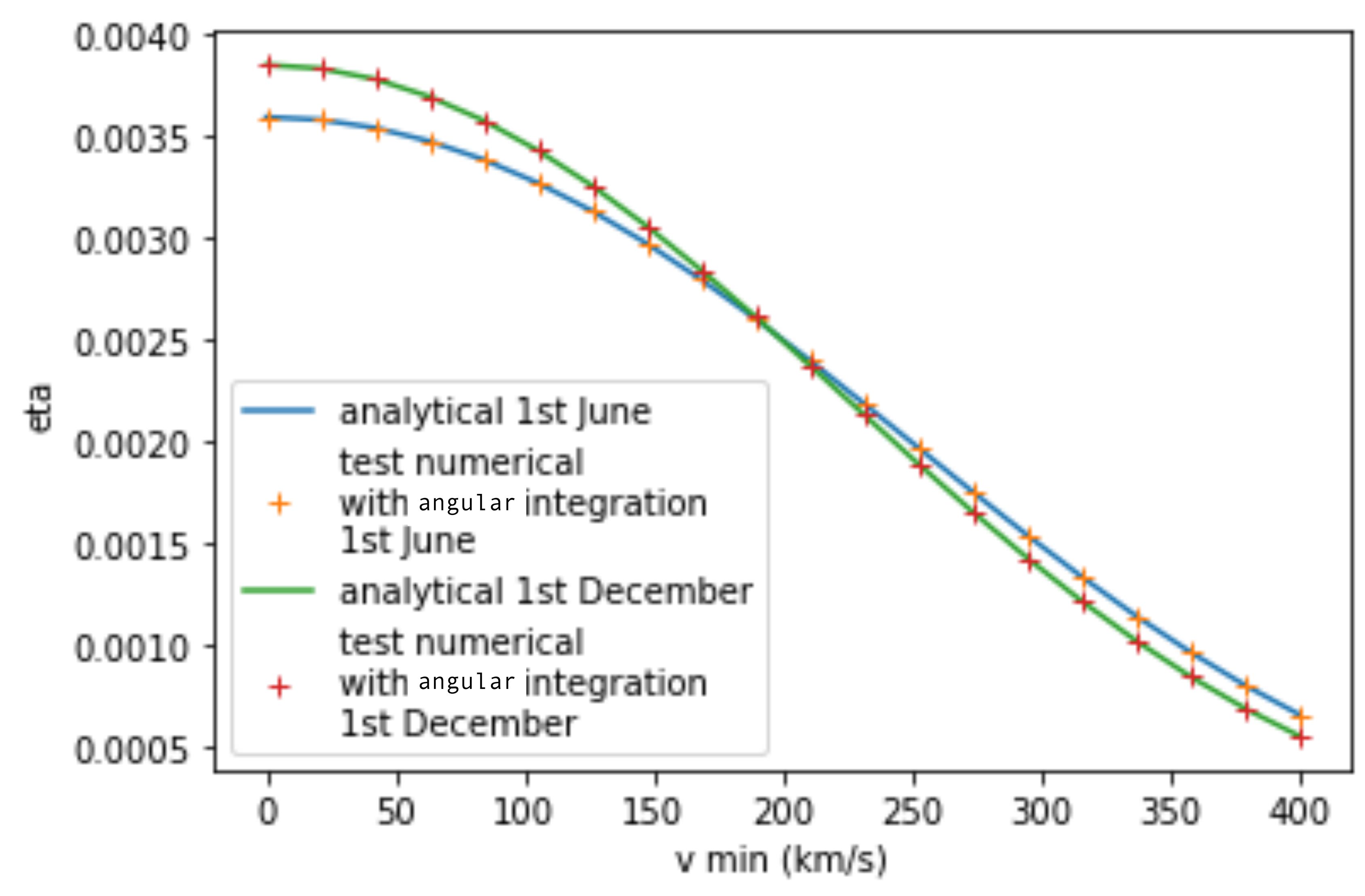
$$\eta = \int_{v_{min}}^{v_{esc}} \frac{f_{\oplus}(\vec{v'})}{v'} d\vec{v'}$$

In the galactic rest frame (= DM rest frame)

On Earth







v_{esc} = **544 km/s**

1st step: reproduce the analytical velocity distribution and η function with my own numerical code

$$f_{gal}(v) = \frac{1}{N_{esc}} \cdot \frac{2}{\pi^{1/2} v_0^3} \cdot v^2 \cdot e^{-\frac{|\vec{v}|^2}{v_0^2}} \text{ if v < } v_{esc}$$

SHM

$$f_{gal}(\vec{v}) \;->\; f_{\oplus}(\vec{v'}) = f_{gal}\left(\vec{v'} + \vec{v_{\oplus}}(t)\right)$$

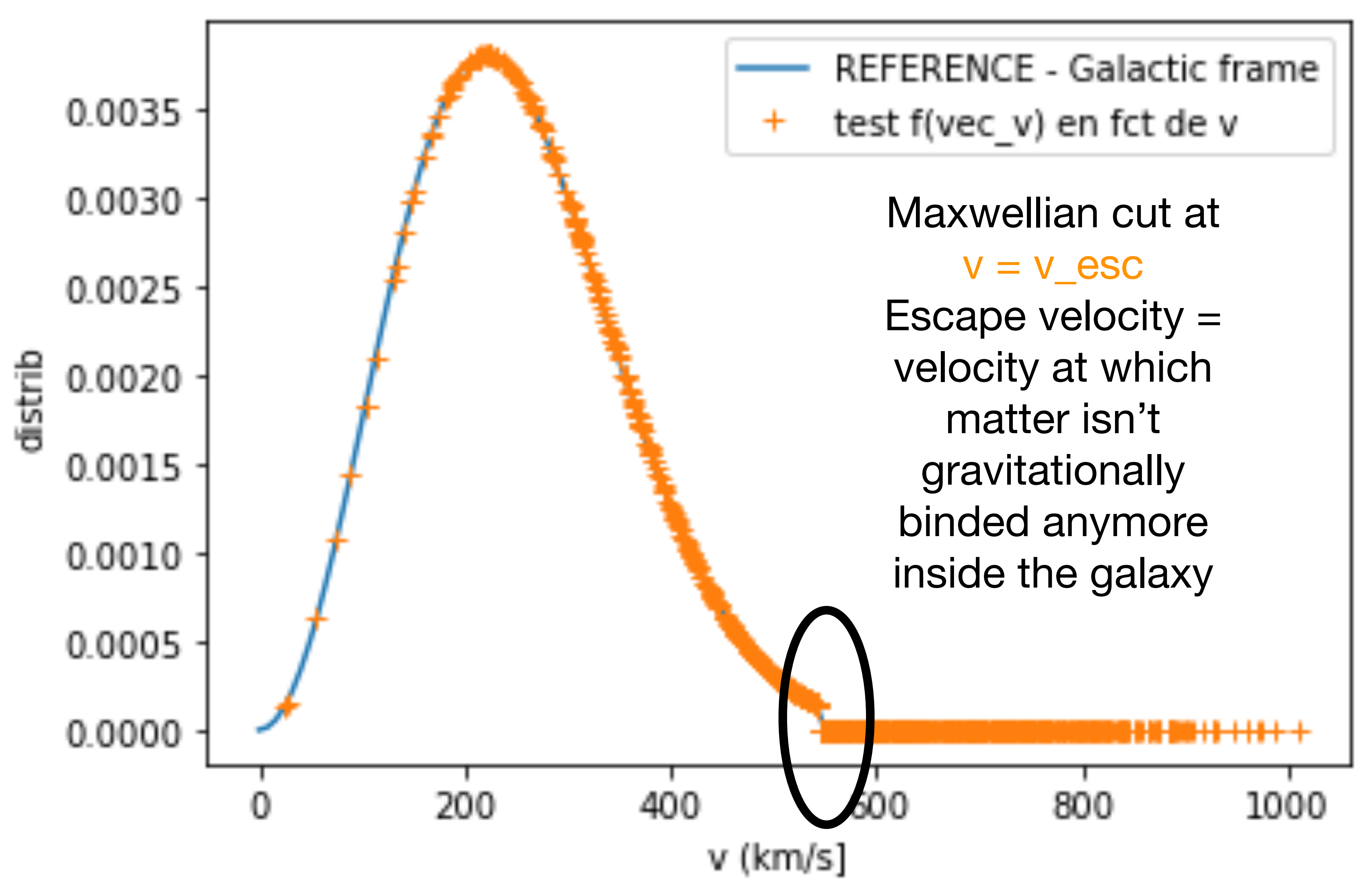
$$\vec{v} \;->\; \vec{v'} + \vec{v_{\oplus}}(t)$$

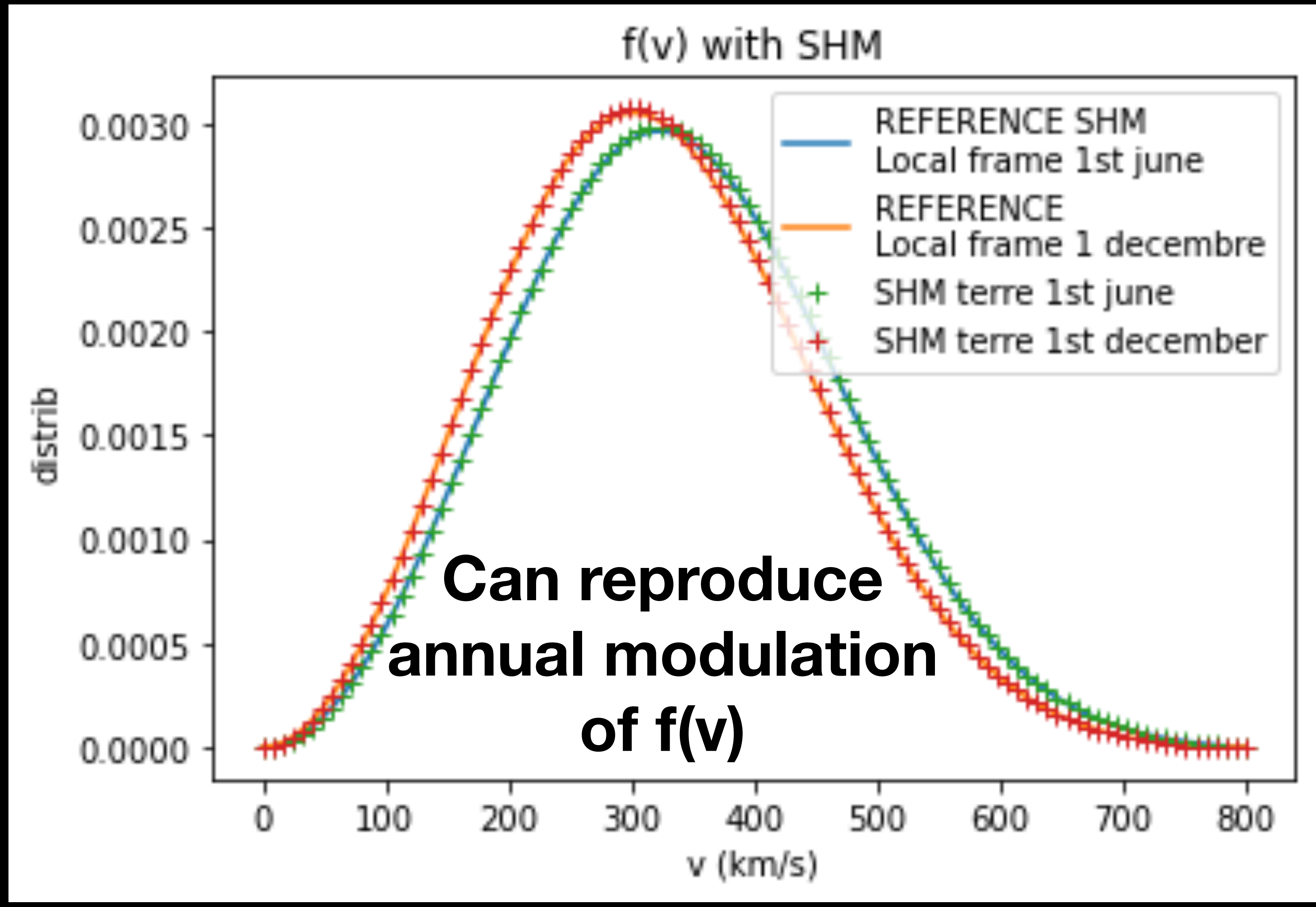
$$\frac{dR}{dE_R} = \frac{\rho_0}{m_\chi m_N} \underbrace{\int_{v_{min}}^{v_{esc}} d\vec{v}\, \frac{f(v)}{v}}_{\eta} \overbrace{\frac{d\sigma}{dE_R}}^{\approx \text{ cste}}$$

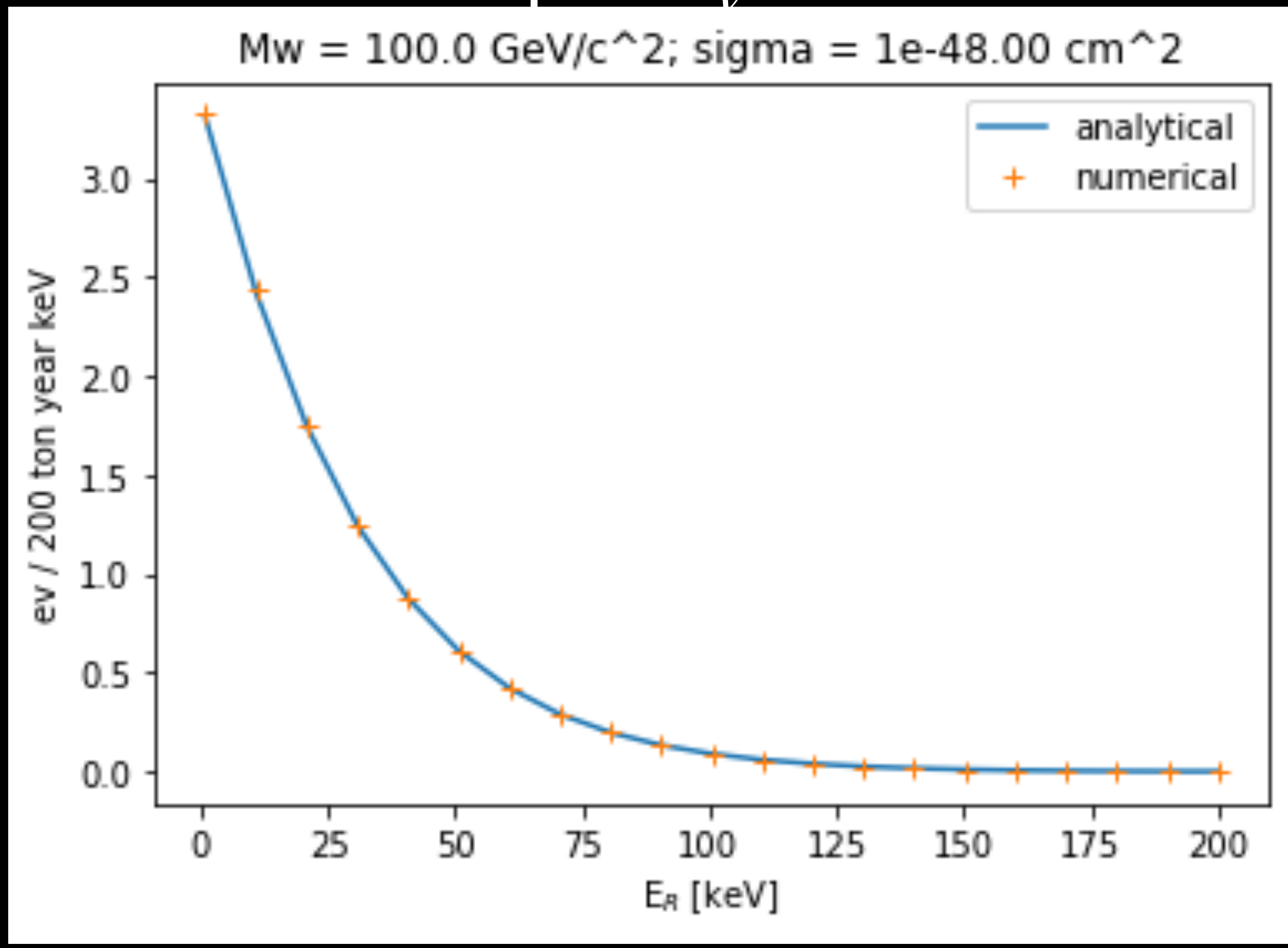
$$\eta = \int^{v_{esc}} \frac{f_{\oplus}(\vec{v'})}{v'} d\vec{v'}$$

In the galactic rest frame (= DM rest frame)

On Earth



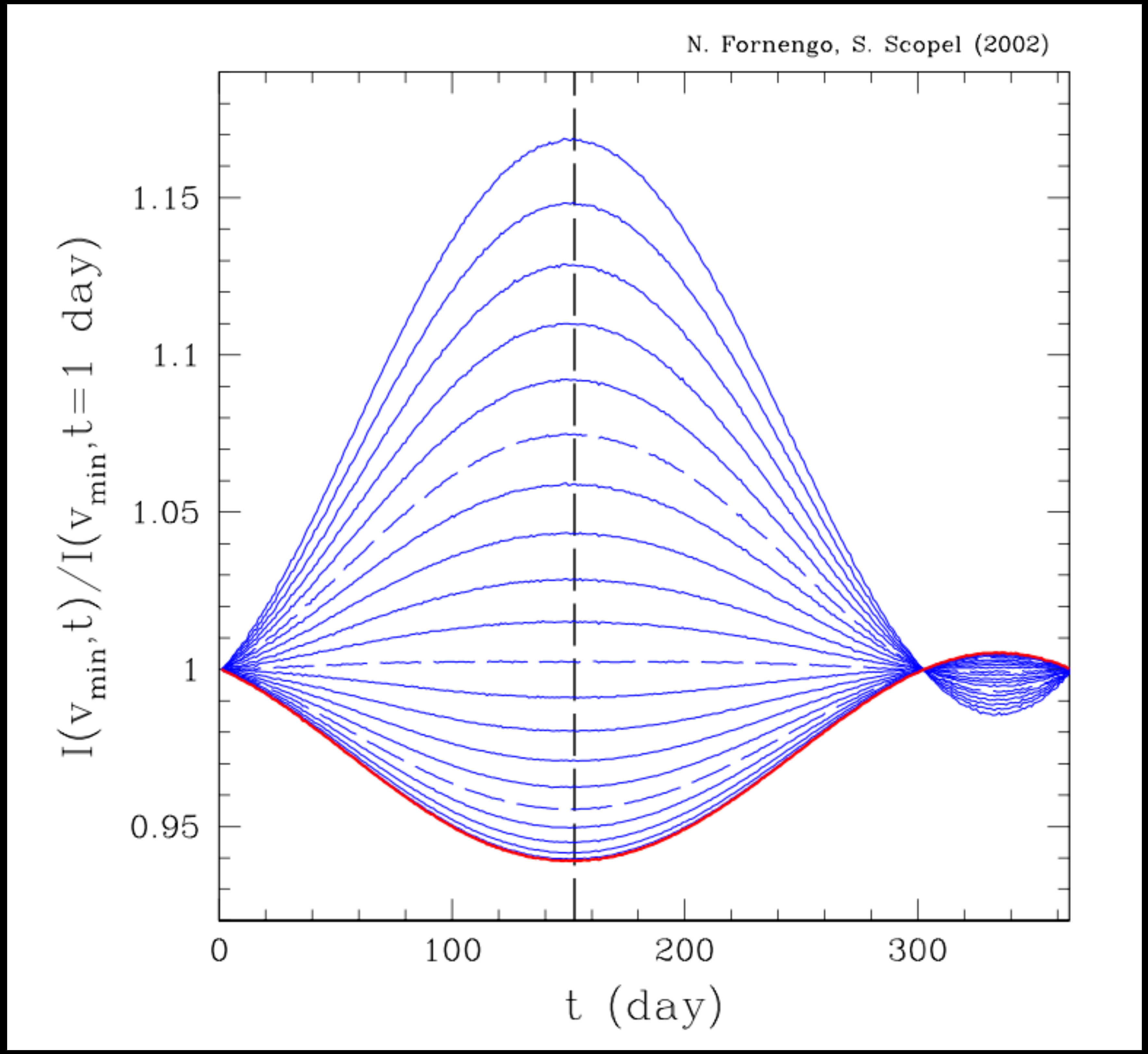


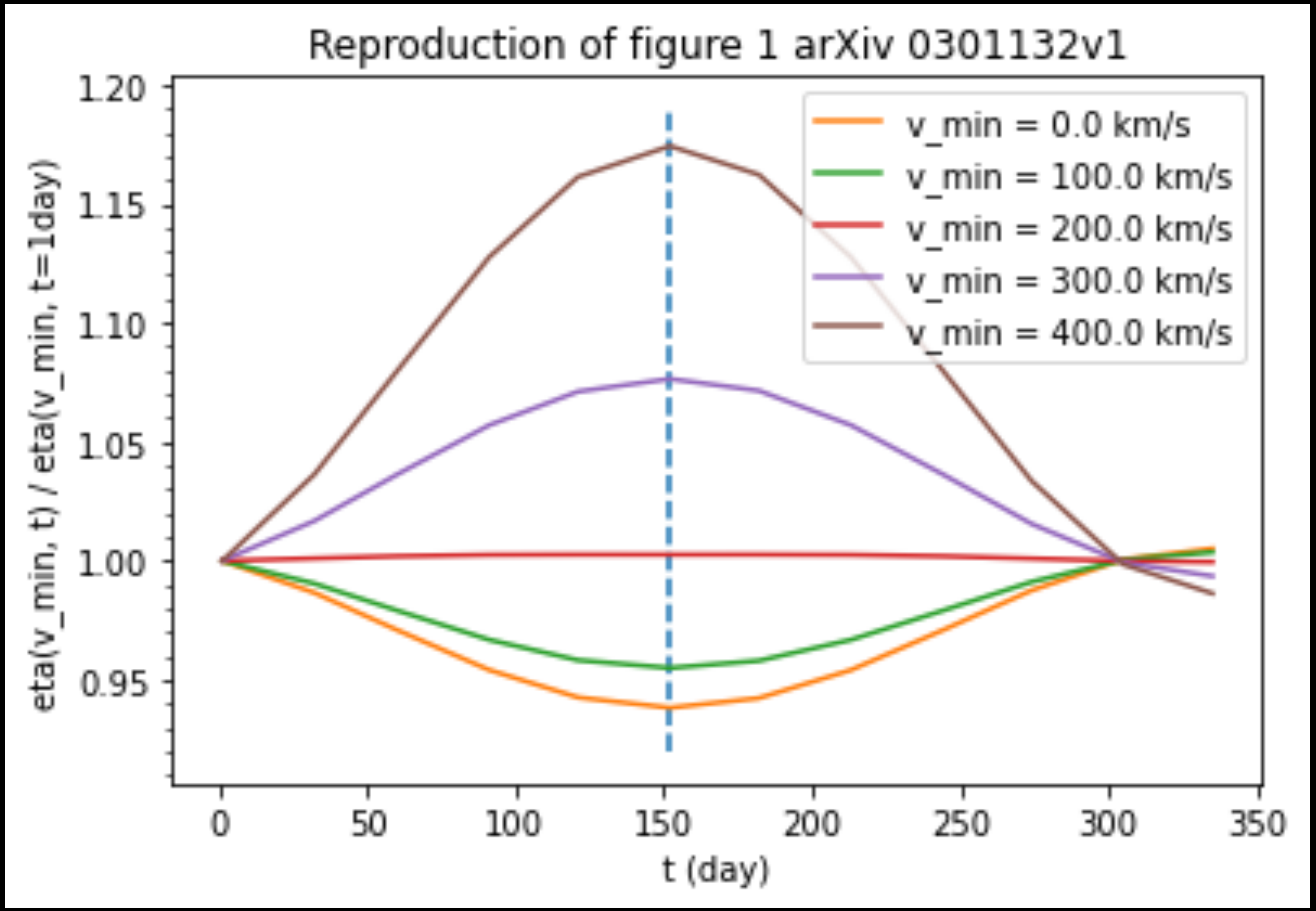


v_{esc} = **544 km/s**

1st step- bis: reproduce a figure of a paper

SHM - arXiv 0301132v1





Thus, with this preliminary study, I am convinced that my numerical tools are working properly

2nd step: play with different velocity distributions

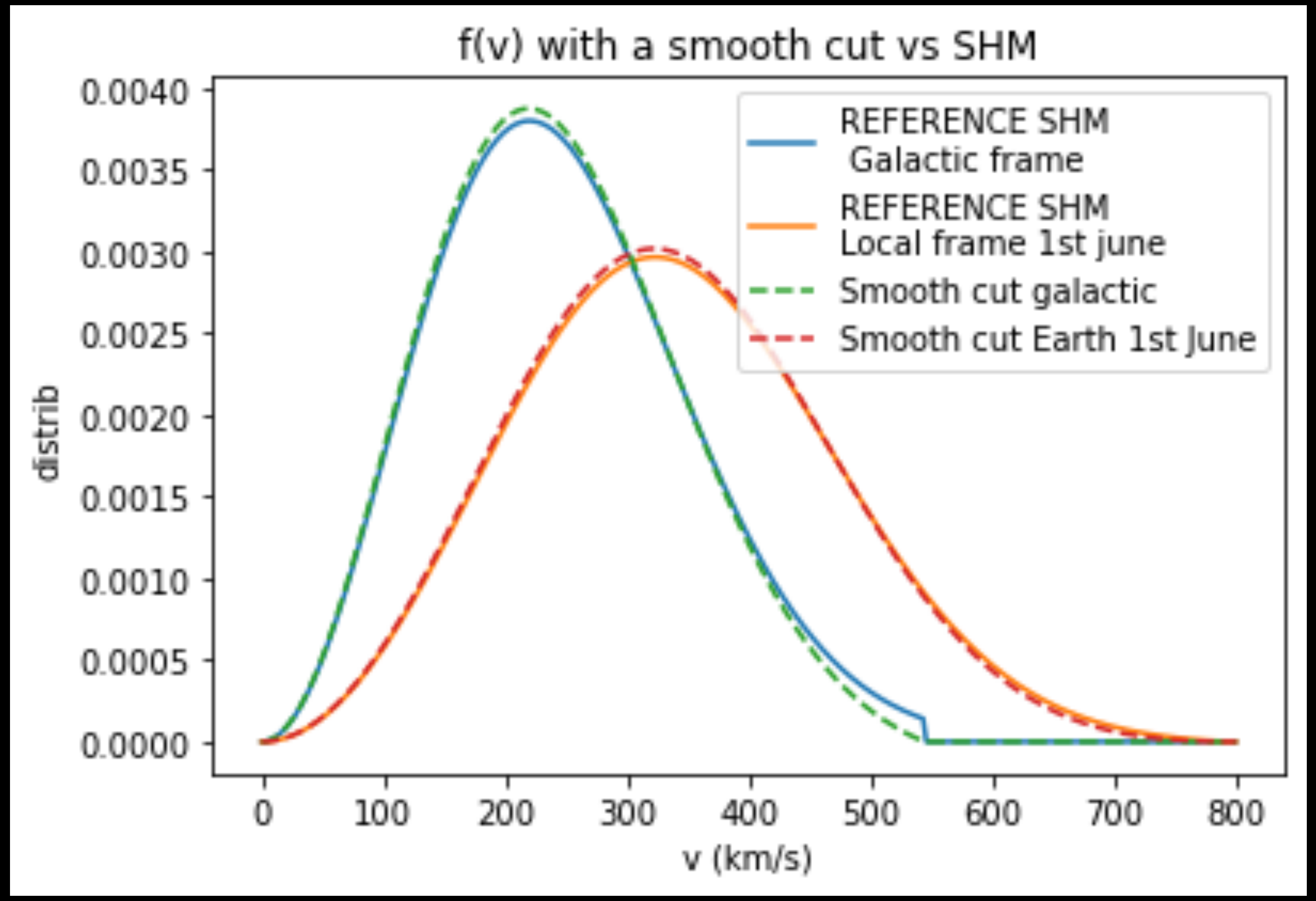
SHM - smooth cut -> to be more physical

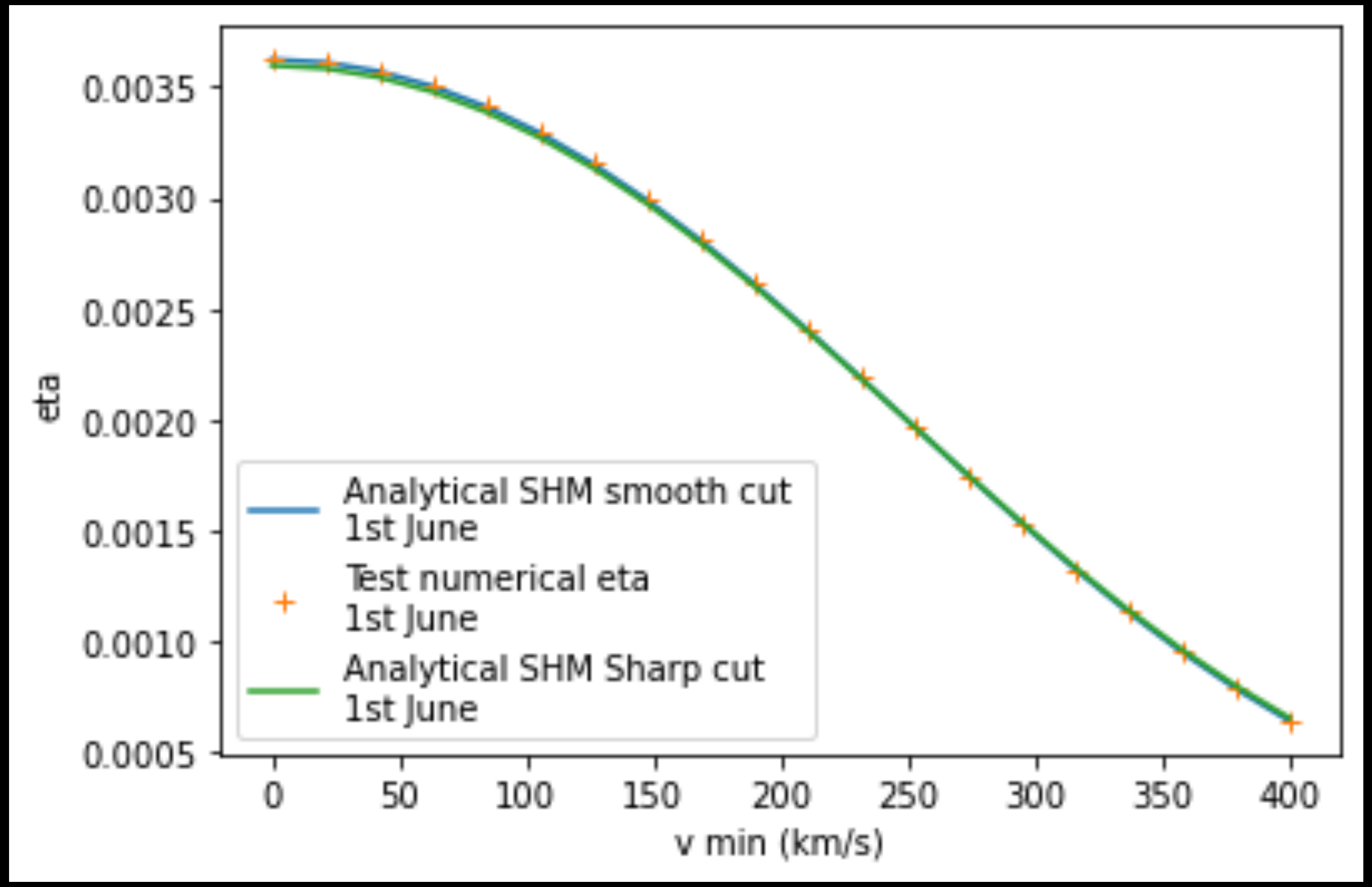
$$f(v) = \frac{1}{N_{esc}} \cdot \frac{2}{\pi^{1/2} v_0^3} \cdot v^2 \cdot \left(e^{-\frac{|\vec{v}|^2}{v_0^2}} - e^{-\frac{v_{esc}^2}{v_0^2}} \right) \text{ if v < } v_{esc}$$

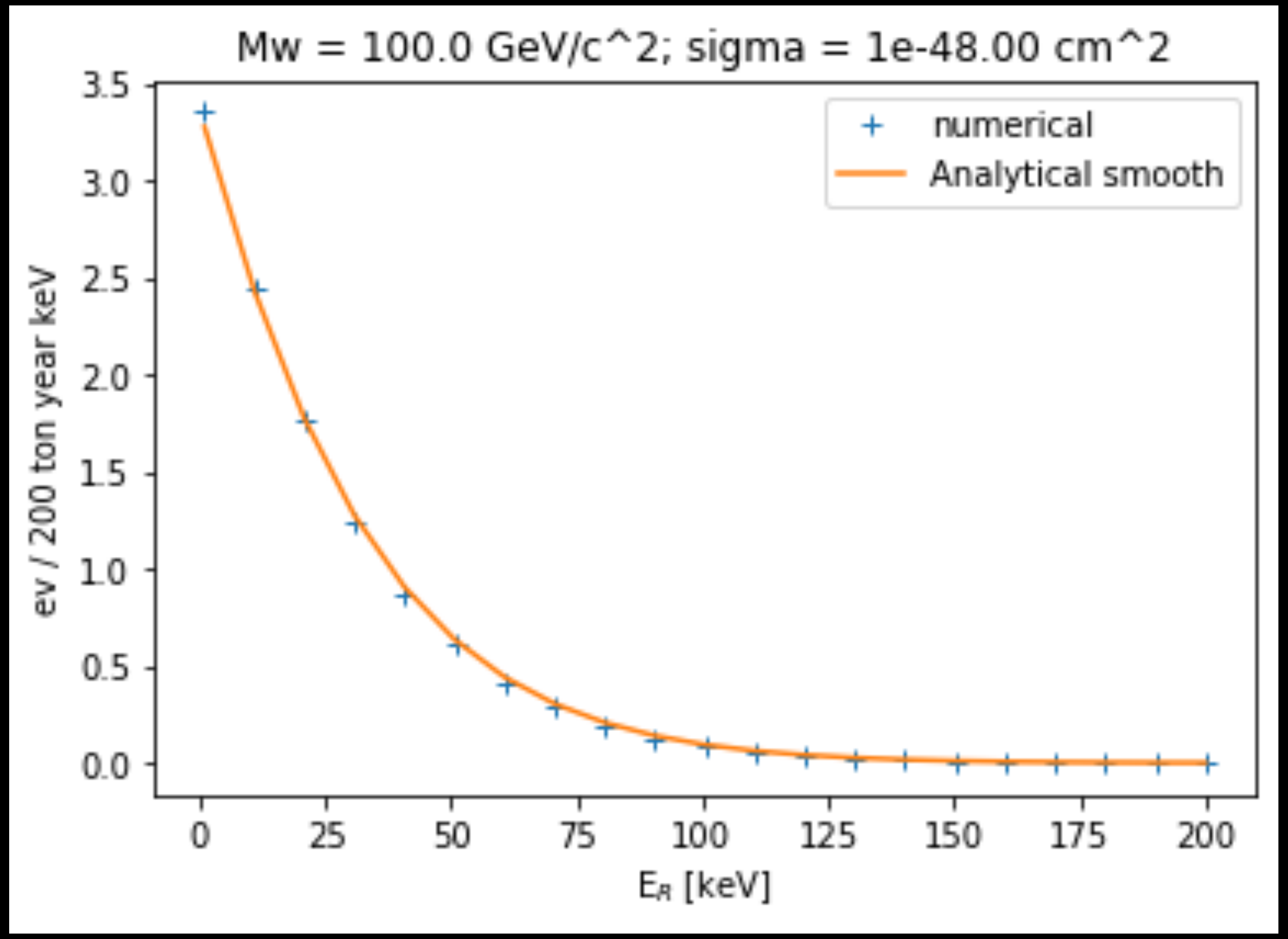
$$\eta = \int_{v_{min}}^{v_{esc}} \frac{f(\vec{v})}{v} d\vec{v}$$

Comparison SHM / SHM + smooth cut

Rate of events



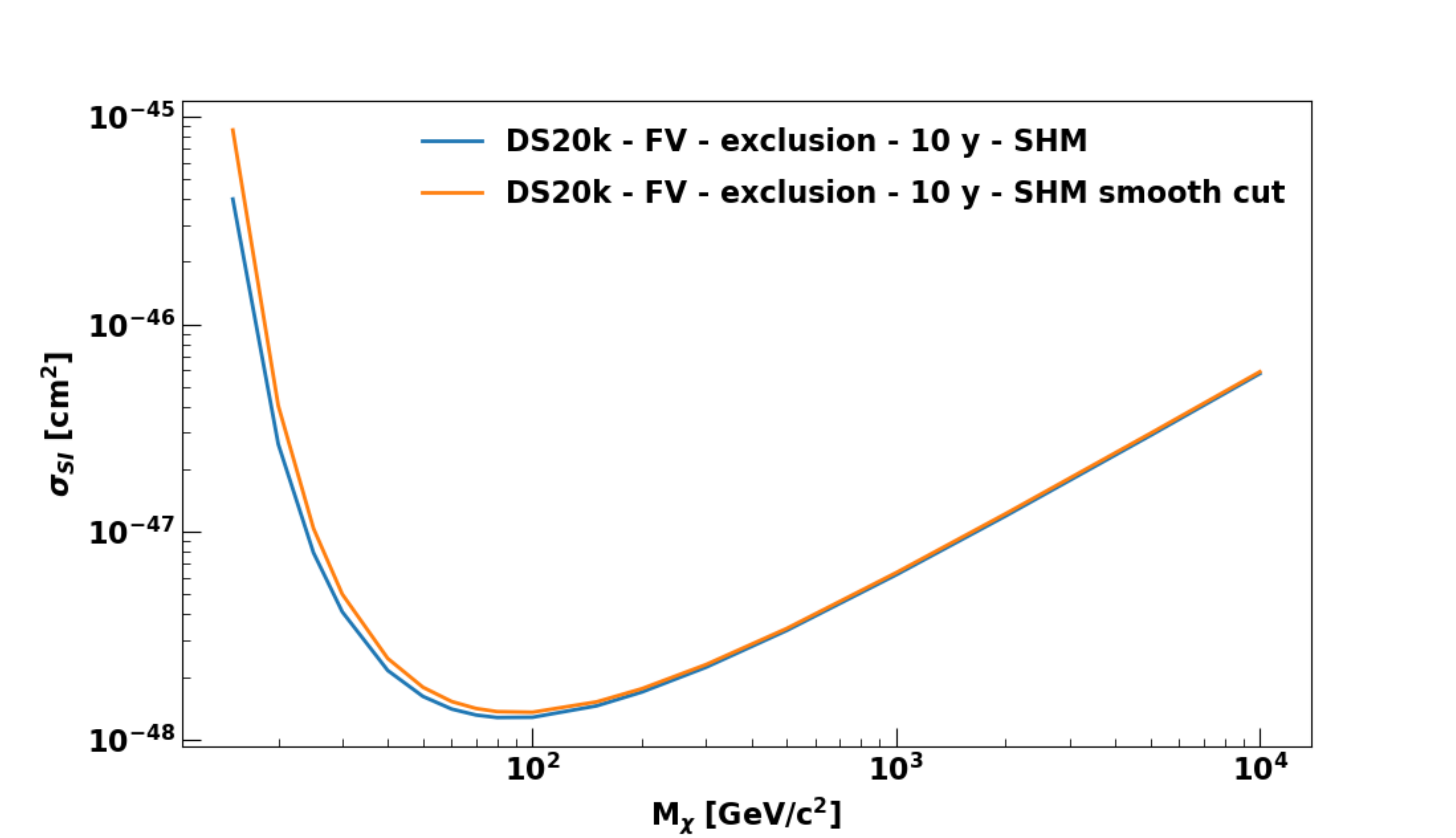




Effect on exclusion limits

Effect at low mass because the smooth cut affects the high velocities and the way the velocity drops before it

According to S. Magni's PhD, the Wimp mass threshold is determined by v_{esc}, v_c and $V_\odot$
-> Changing how the distribution drops at v_{esc} is kind of equivalent to change v_{esc} thus the Wimp mass detection threshold



Future

- Tsallis distribution $f(v) = \frac{2\pi}{N_q} \cdot v^2 \cdot \left(1 - (1-q) \cdot \frac{|\overrightarrow{v}|^2}{v_0^2} \right)$

- Anisotropic velocity distributions $f(\overrightarrow{v}) = Nexp\left(-\frac{v_x^2}{2\sigma_x^2} - \frac{v_y^2}{2\sigma_y^2} - \frac{v_z^2}{2\sigma_z^2} \right)$

- Start from density distributions (instead of velocity distributions)

- Instead of taking modeled velocity distribution, take simulation data