FFF:
Freeze out
Freeze in
and The Flavon

2307.14972 with Rusa Mandal

Dedicated to Invisibles 23 workshop

One model working at two scales

directed by

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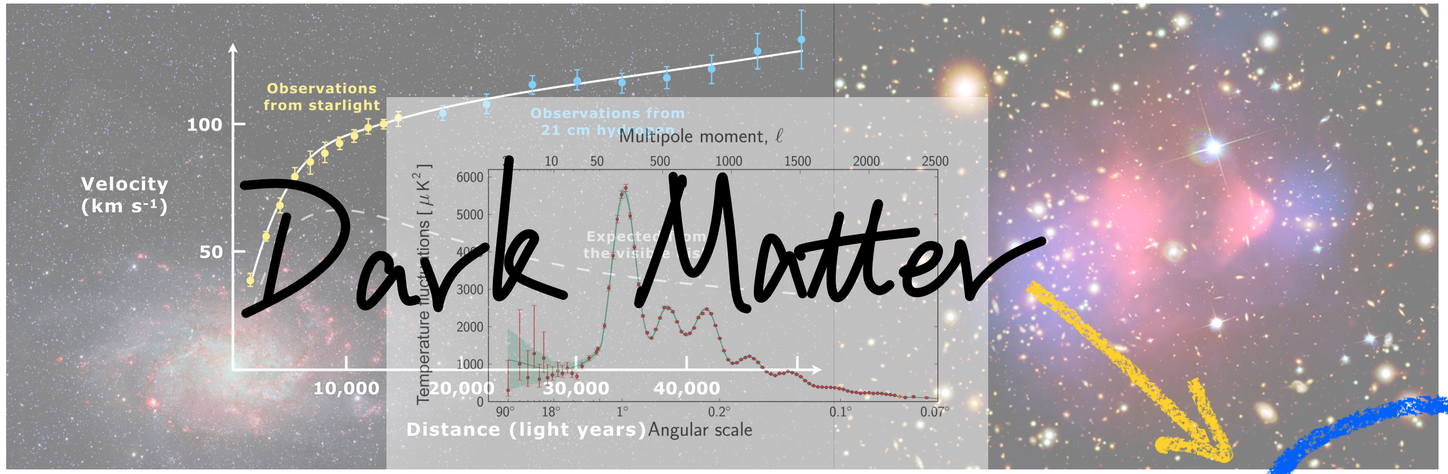
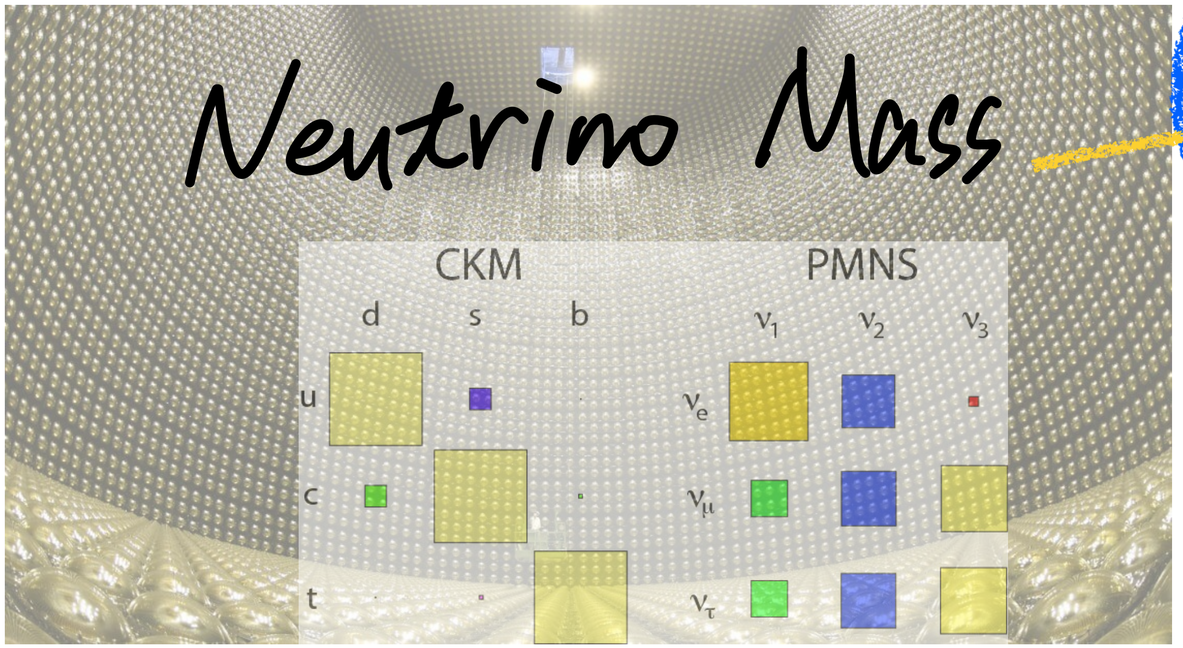
Naturwissenschaftlich Technische Fakultät

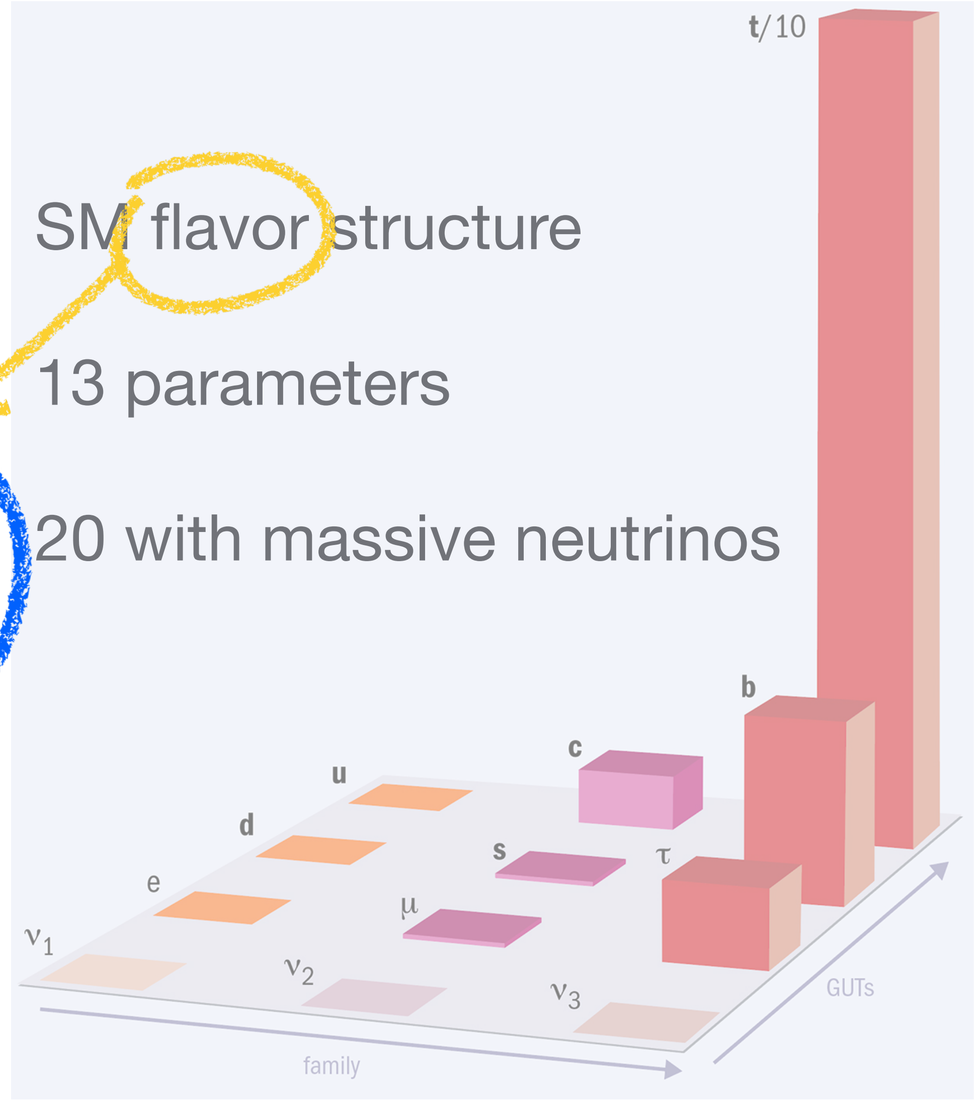
Evidence of new physics





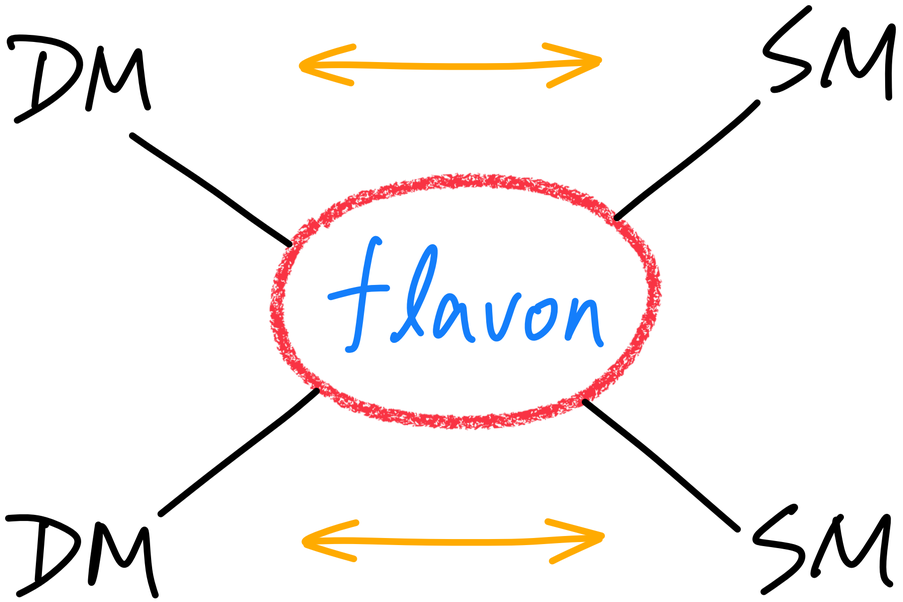
Mystery of flavor

- SM flavor structure
- 13 parameters
- 20 with massive neutrinos



Summary for the impatient

"THAT'S THE END OF MY PRESENTATION. ANY QUESTIONS?"



- ✓ Freeze-out WIMP
- ✓ Freeze-in FIMP

Thanks for watching !

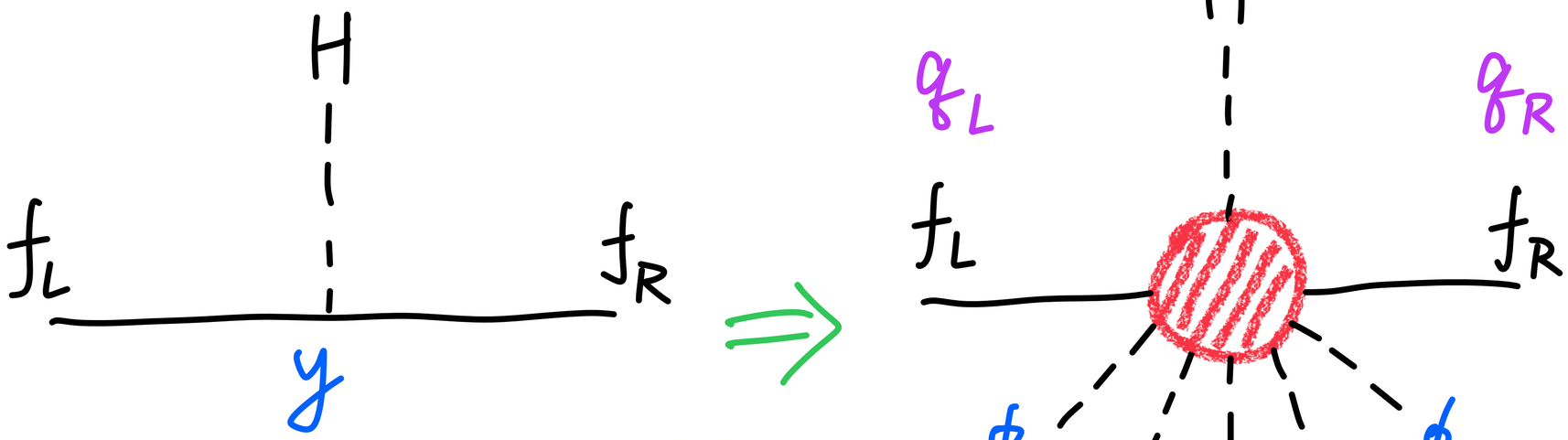
Hierarchy in fermion mass

$$\frac{m_e}{m_t} \approx 3 \times 10^{-6}$$

Top Yukawa $y_t \approx 1$

$$\text{Log}_{10}\left(\frac{\text{Mass}\begin{bmatrix} e & u & \tau \\ d & s & b \\ u & c & t \end{bmatrix}}{m_t}\right) \approx -\begin{bmatrix} 5.5 & 3.2 & 2 \\ 4.5 & 3.2 & 1.6 \\ 4.8 & 2.1 & 0 \end{bmatrix}$$

Global U(1) Froggatt-Nielsen symmetry



Flavon

$$y\,\bar{f}_L H f_R \Longrightarrow c\left(\frac{\phi}{M}\right)^n \bar{f}_L H f_R$$

$$y \sim \varepsilon^n$$

$$\begin{cases} c \sim O(1) \\ \dfrac{\phi \to v_\phi}{M} = \varepsilon \\ q_L - q_R = n \end{cases}$$

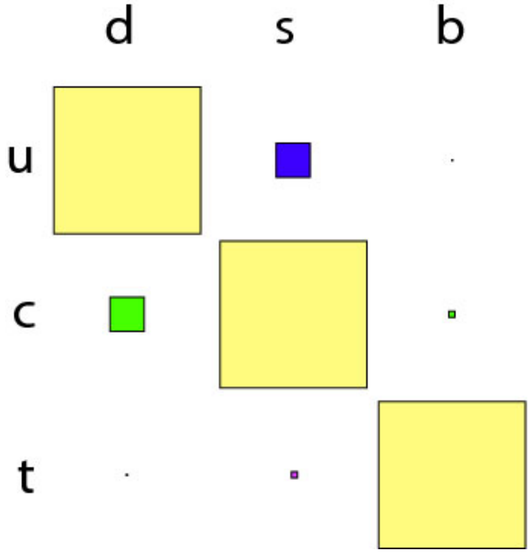
Froggatt-Nielsen charges

$$\varepsilon = \frac{V_\phi}{M} \approx V_{us} \approx 0.23$$

$$n_u^{ij} = \begin{pmatrix} 8 & 4 & 3 \\ 7 & 3 & 2 \\ 5 & 1 & 0 \end{pmatrix}, \quad n_d^{ij} = \begin{pmatrix} 7 & 6 & 6 \\ 6 & 5 & 5 \\ 4 & 3 & 3 \end{pmatrix}, \quad n_e^{ij} = \begin{pmatrix} 9 & 6 & 4 \\ 8 & 5 & 3 \\ 8 & 5 & 3 \end{pmatrix}$$

$y \sim \varepsilon^n$

CKM

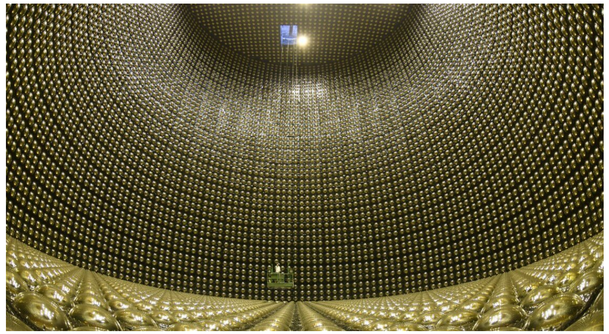


$$\begin{pmatrix} q_{Q_1} & q_{Q_2} & q_{Q_3} \\ q_u & q_c & q_t \\ q_d & q_s & q_b \end{pmatrix} = \begin{pmatrix} 3 & 2 & 0 \\ -5 & -1 & 0 \\ -4 & -3 & -3 \end{pmatrix}$$

q_L q_R

$$\begin{pmatrix} q_{L_1} & q_{L_2} & q_{L_3} \\ q_e & q_\mu & q_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ -8 & -5 & -3 \end{pmatrix}$$

$$\begin{cases} c \sim O(1) \\ \dfrac{\phi \to V_\phi}{M} = \varepsilon \\ q_L - q_R = n \end{cases}$$



Right-handed neutrino and DM

$\{ N_1 \quad N_2 \quad N_3 \}$

Heavy

Z_2 symmetry

DM

$C_\nu \left(\frac{\phi}{M}\right)^{n_\nu} \bar{L} \tilde{H} N_{2,3}$

Yukawa : 3 x 2 matrix

$$\begin{pmatrix} x & x \\ x & x \\ x & x \end{pmatrix}$$

$\frac{1}{2} C_N \left(\frac{\phi}{M}\right)^{n_N} M \bar{N} N$

Majorana : 3 x 3 matrix

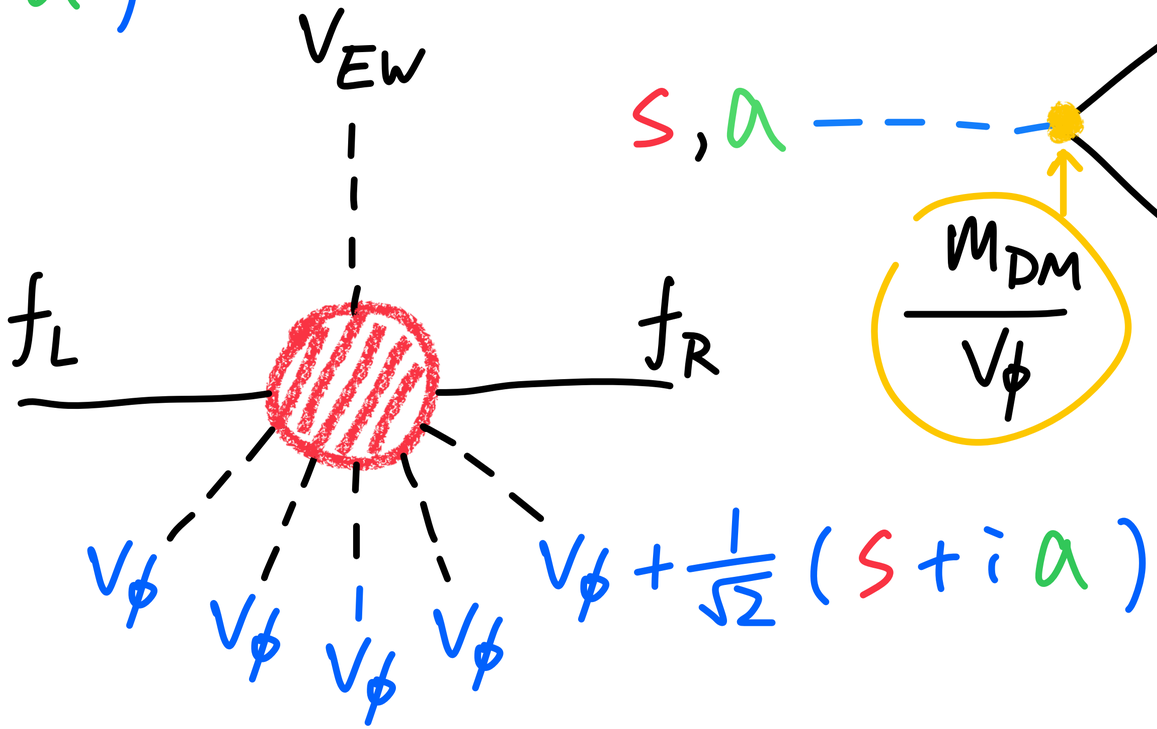
$$\begin{pmatrix} x & 0 & 0 \\ 0 & x & x \\ 0 & x & x \end{pmatrix}$$

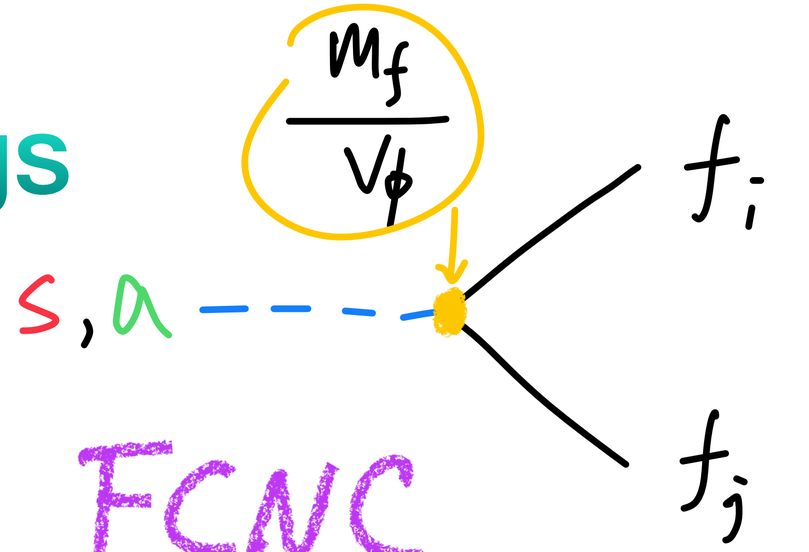
Flavon couplings

$$H \to v_{EW} + \frac{1}{\sqrt{2}}(h + i G_0)$$

$$\phi \to v_\phi + \frac{1}{\sqrt{2}}(s + i a)$$

$$\begin{cases} m_s \sim v_\phi \\ 10\,\text{GeV} \leqslant m_a \ll m_s \end{cases}$$

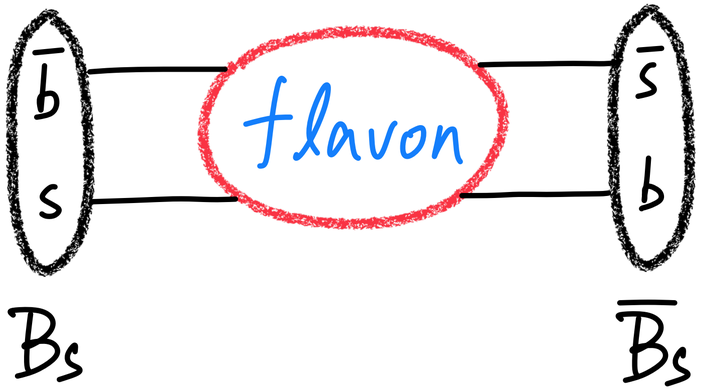




FCNC

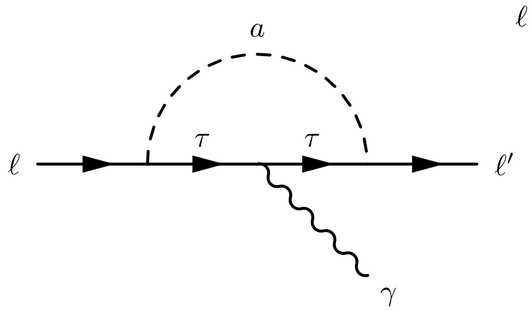
Experimental constraints

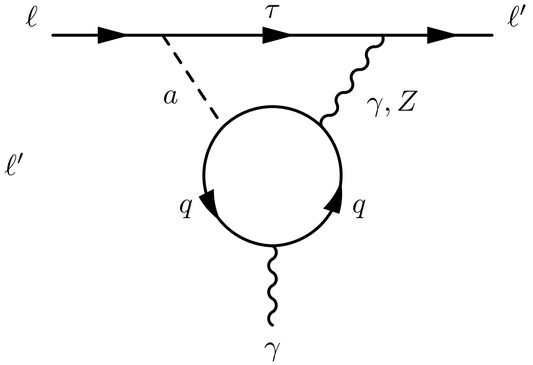
B-meson mixing



$$\left(\frac{m_a}{\text{GeV}}\right) \times \left(\frac{v_\phi}{\text{TeV}}\right) \gtrsim 180$$

$\mu \to e\gamma$ (MEG)



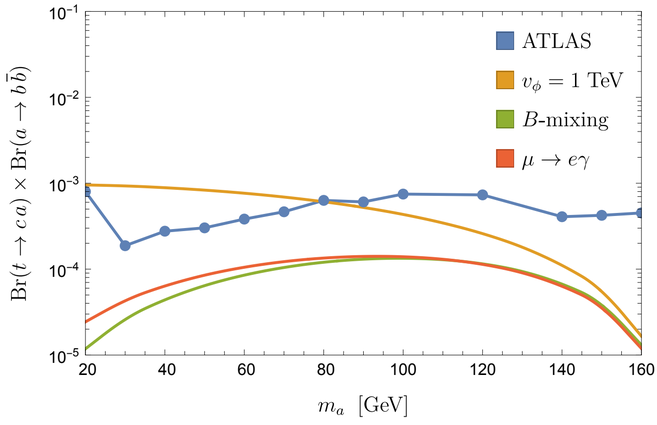


$$\left(\frac{m_a}{\text{GeV}}\right) \times \left(\frac{v_\phi}{\text{TeV}}\right) \gtrsim 190^*$$

*For $m_a \lesssim 100$ GeV

Top decay ATLAS

$$\text{Br}(t \to c a) \times \text{Br}(a \to b\bar{b})$$

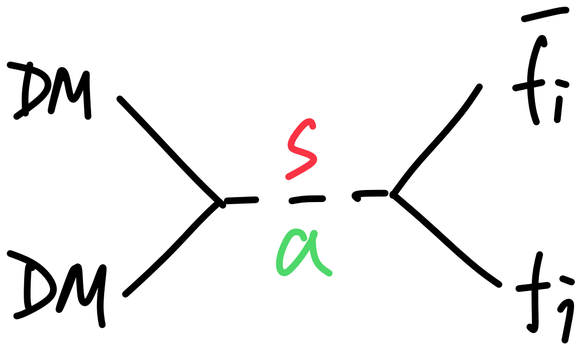


EFT... wait, at what scale? $V_\phi = ?$

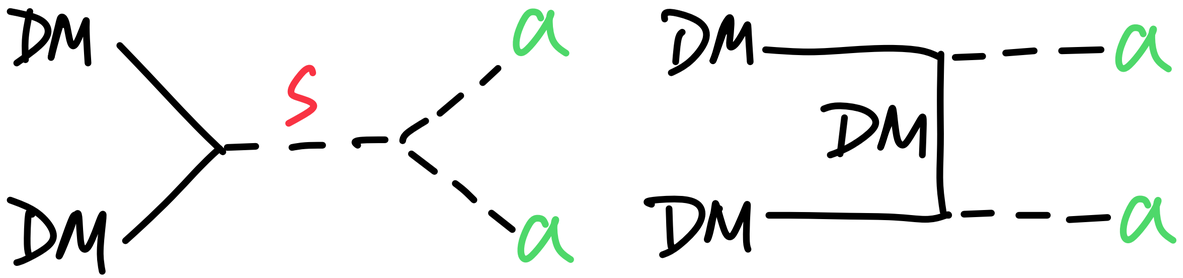
TeV scale: freeze out

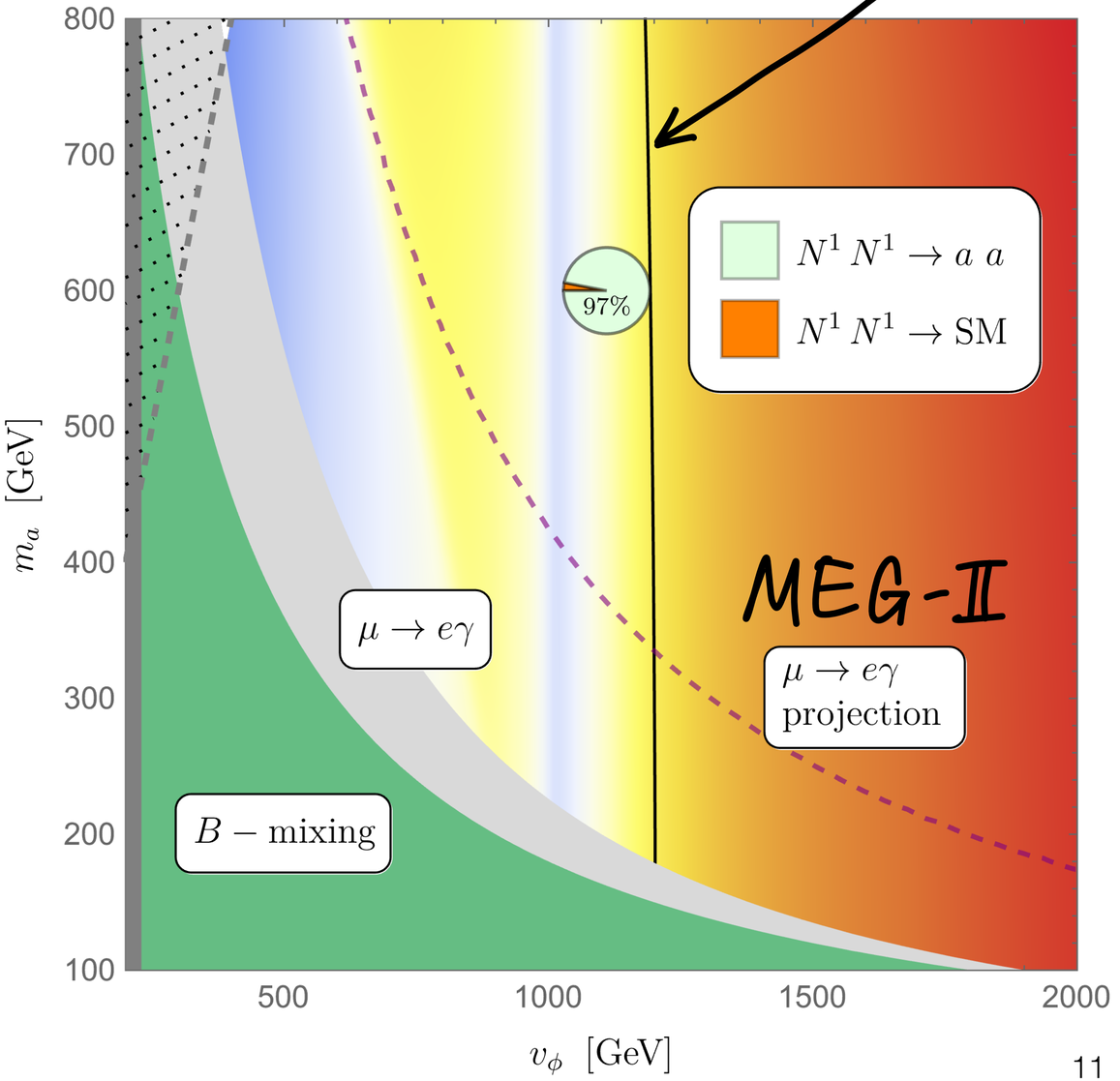
m_a vs V_ϕ

$$\left(\frac{m_a}{\text{GeV}}\right) \times \left(\frac{V_\phi}{\text{TeV}}\right) \geq \begin{cases} 180 & B_s \\ 190^* & \mu \to e\gamma \end{cases}$$

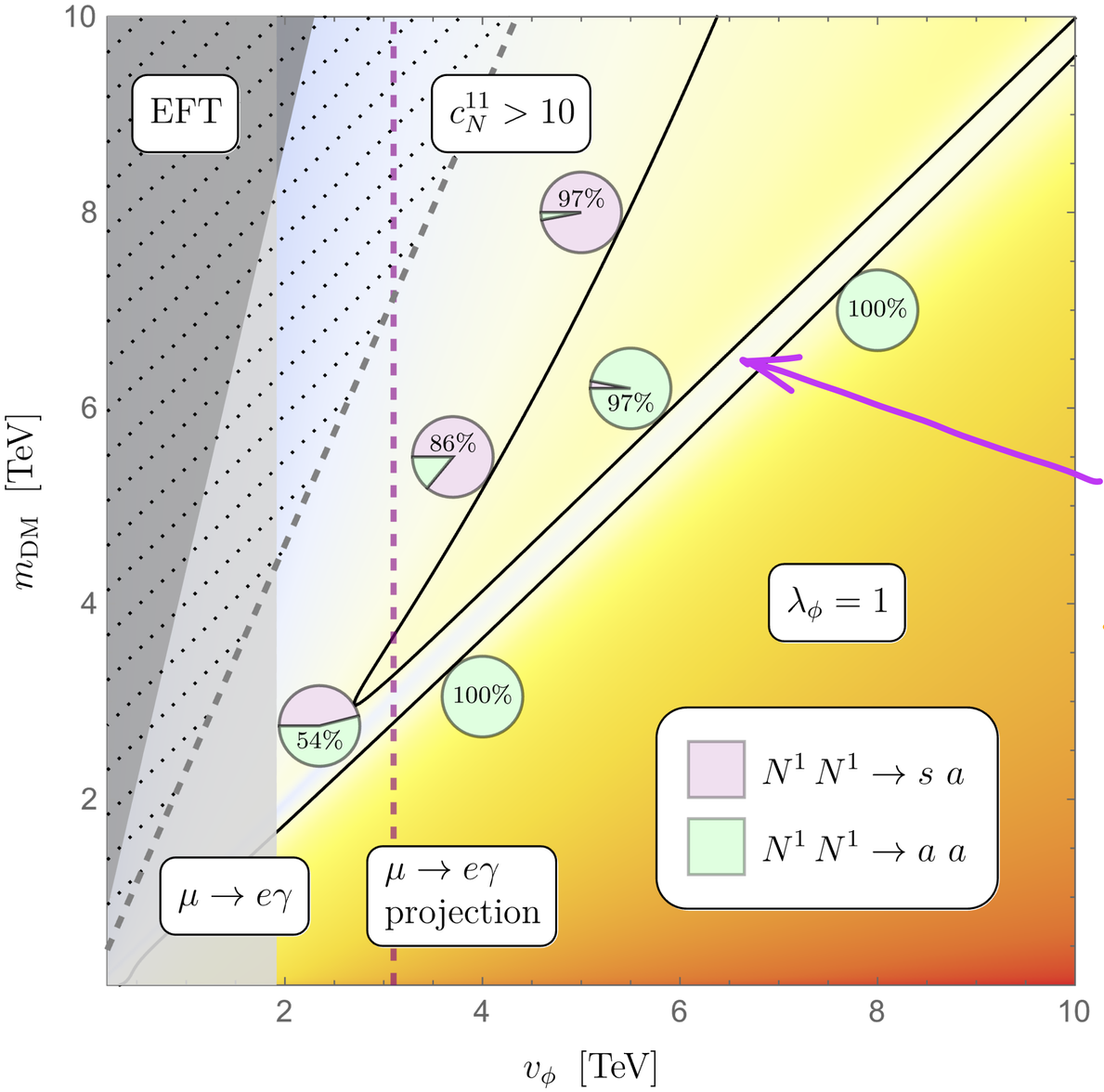


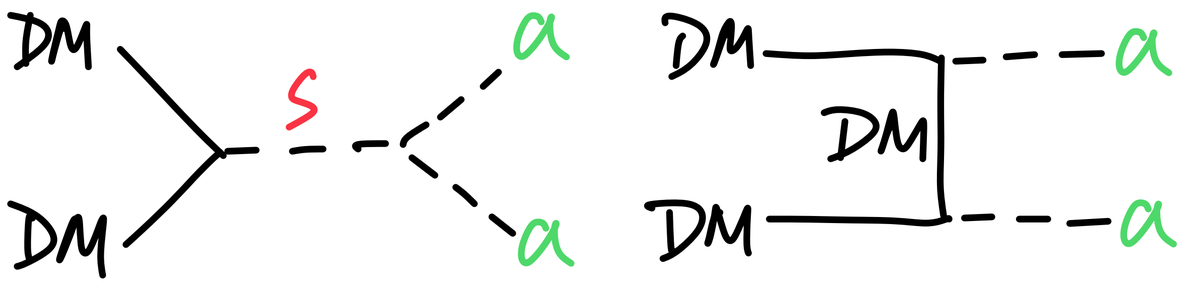
$M_{DM} = 1\,\text{TeV}$



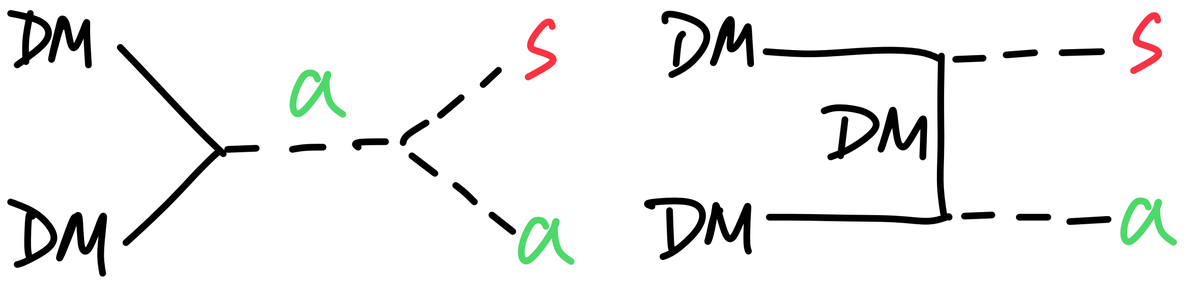


TeV scale: freeze out m_{DM} vs V_ϕ

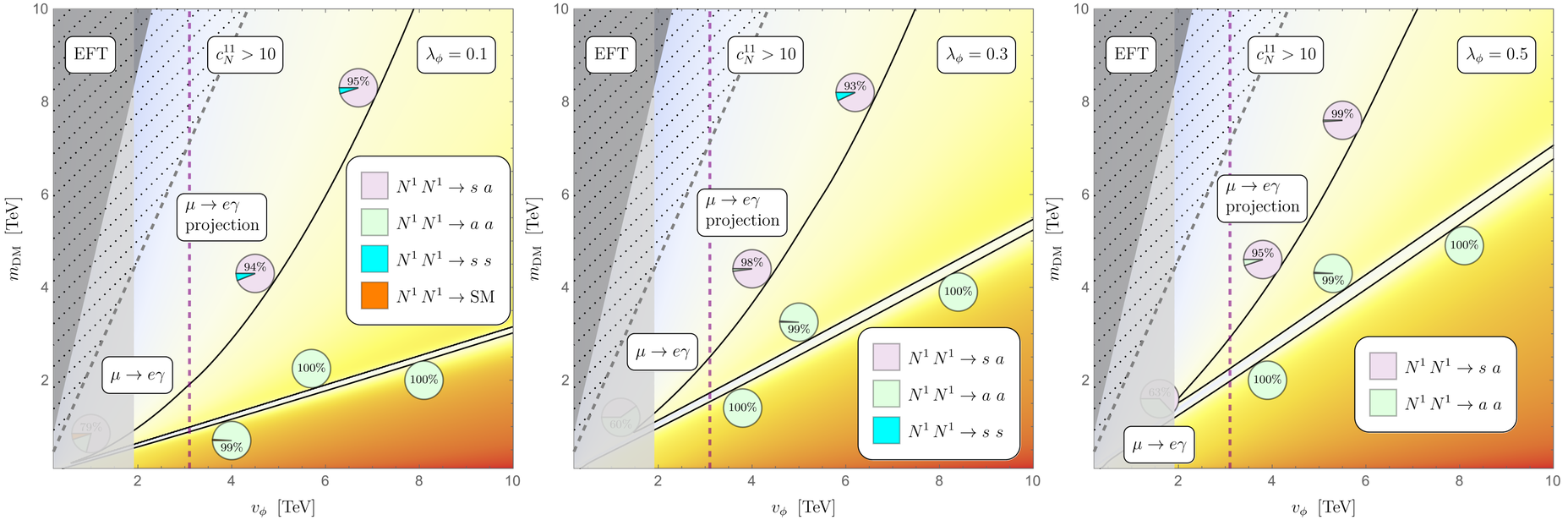


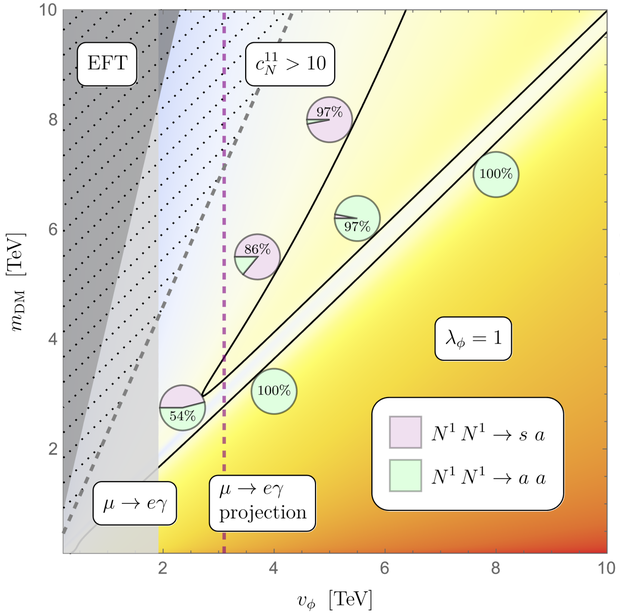


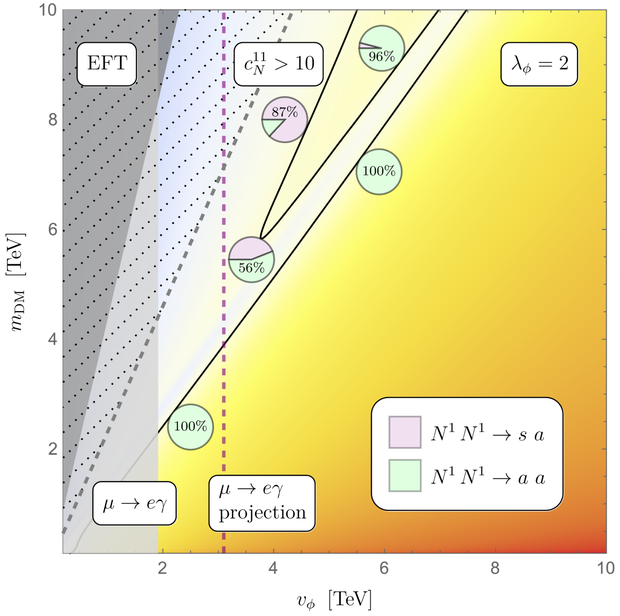
Resonance ! $m_s = 2V_\phi$

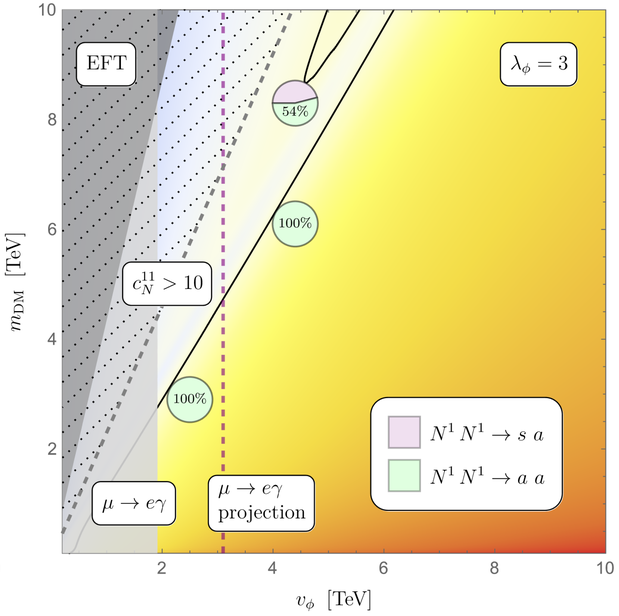


TeV scale: freeze out with various λ_ϕ

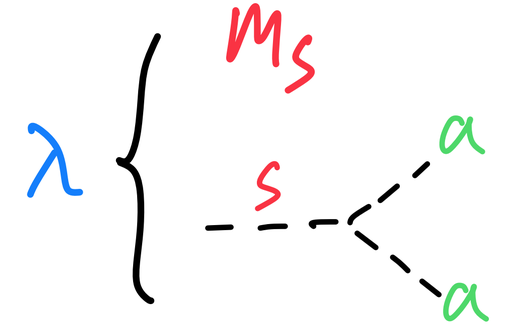


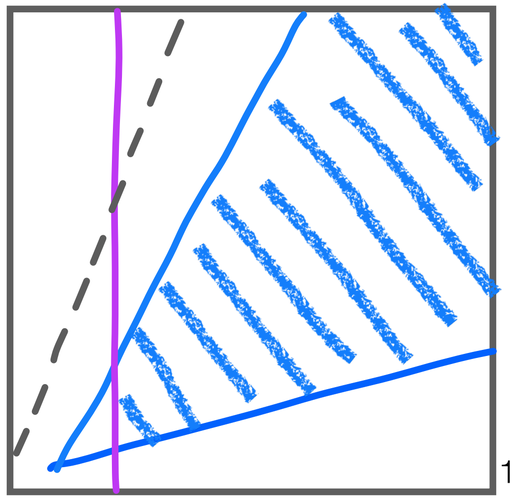




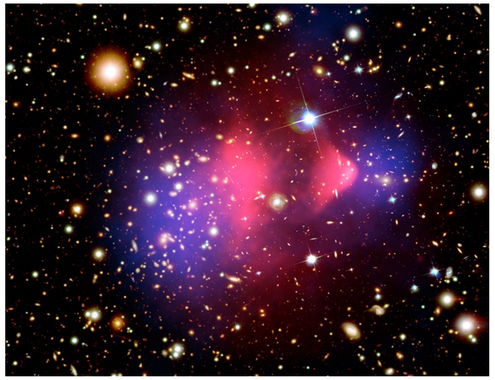


$\lambda\phi^4$ term in flavon potential

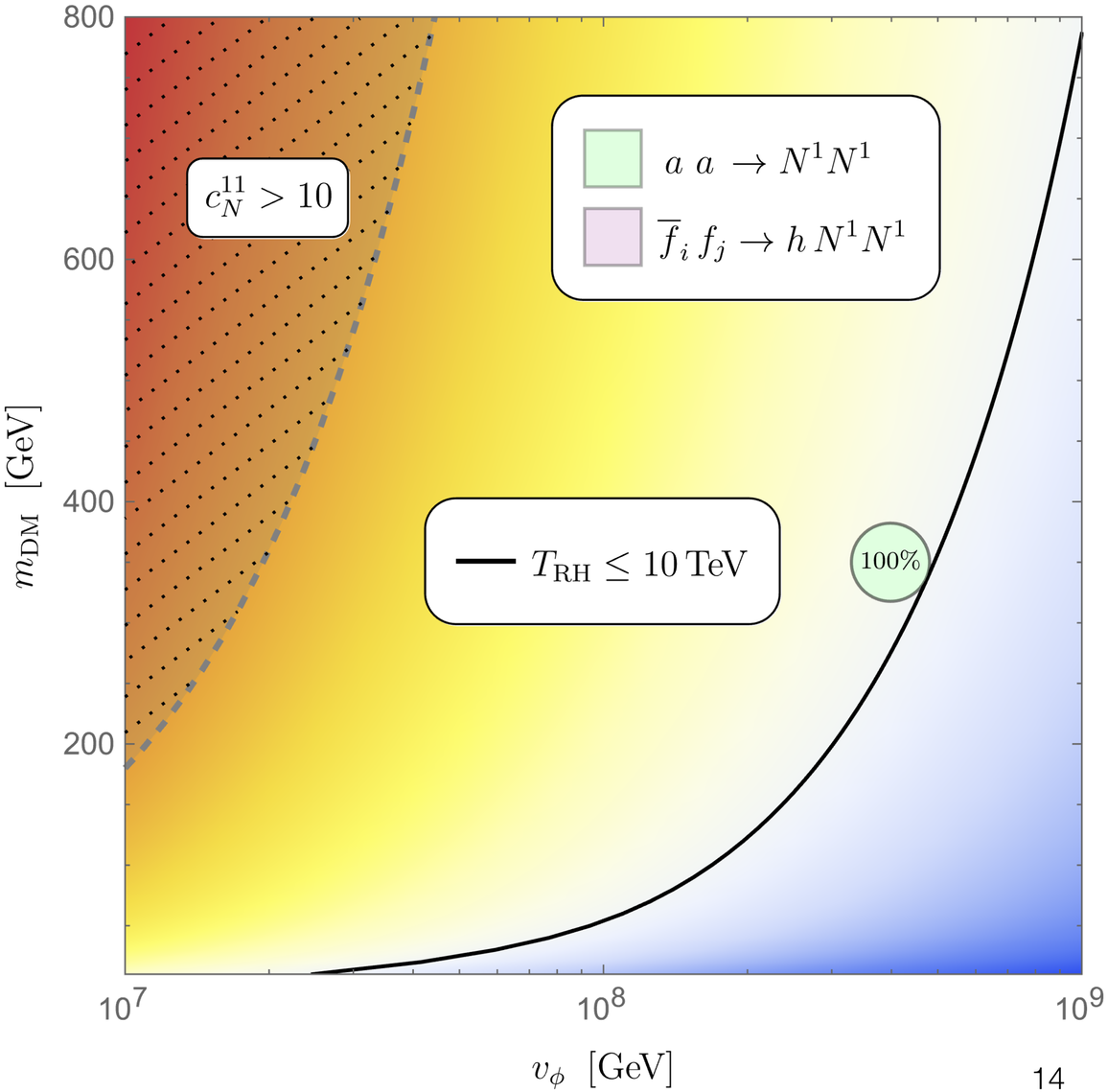




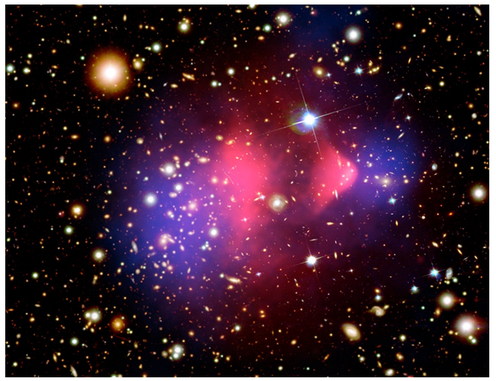
High scale: (IR) freeze in m_{DM} vs V_ϕ

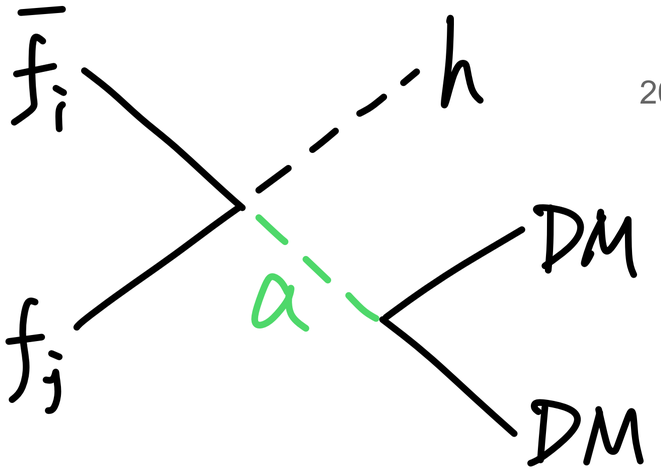


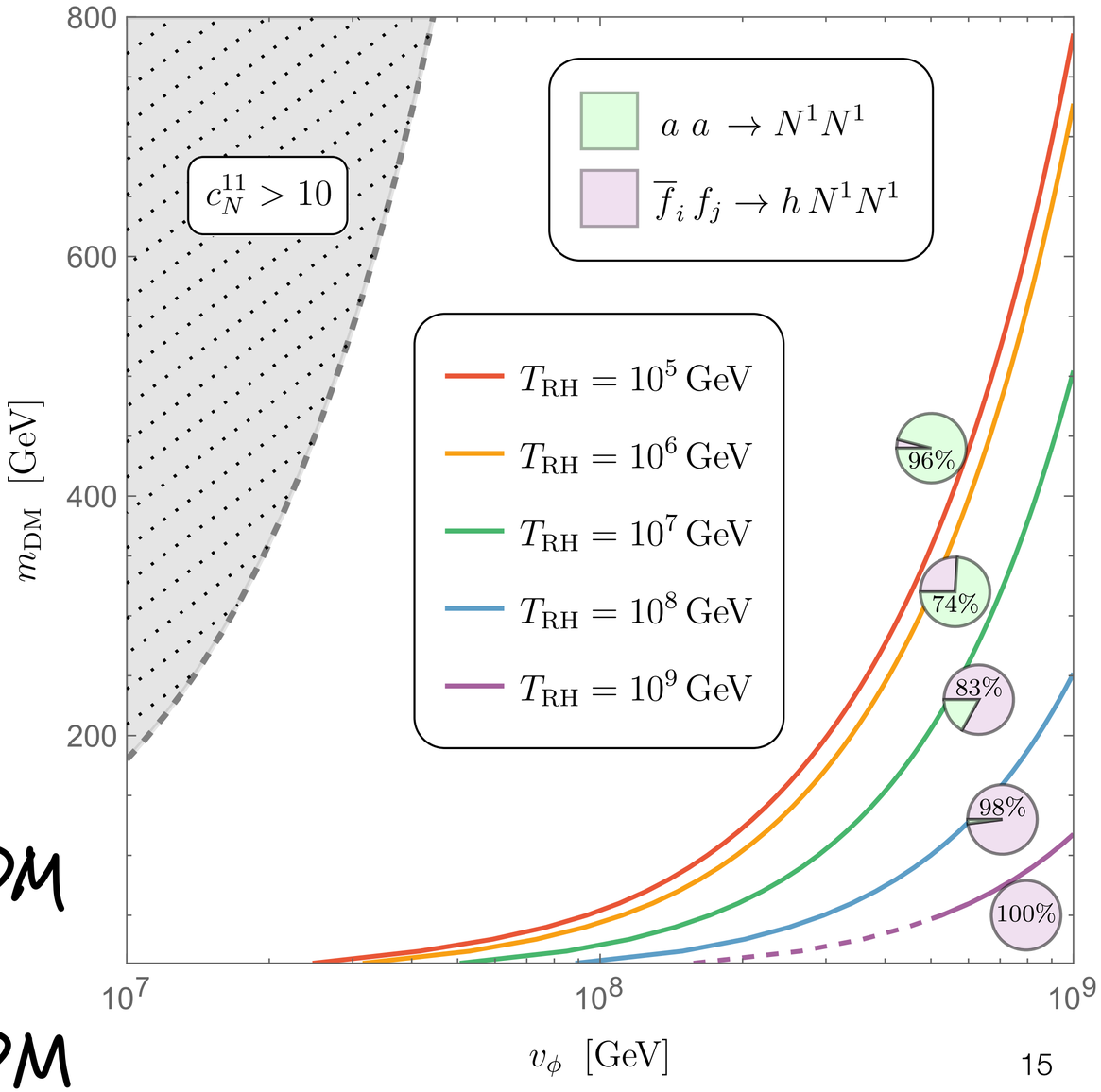
"Low" T_{RH}



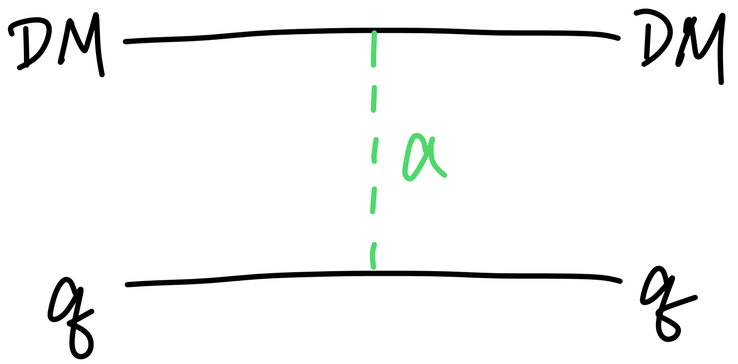
High scale: (UV) freeze in m_{DM} vs V_ϕ







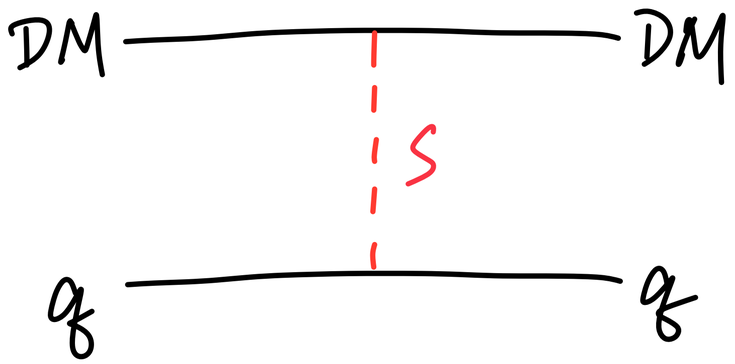
Direct detection

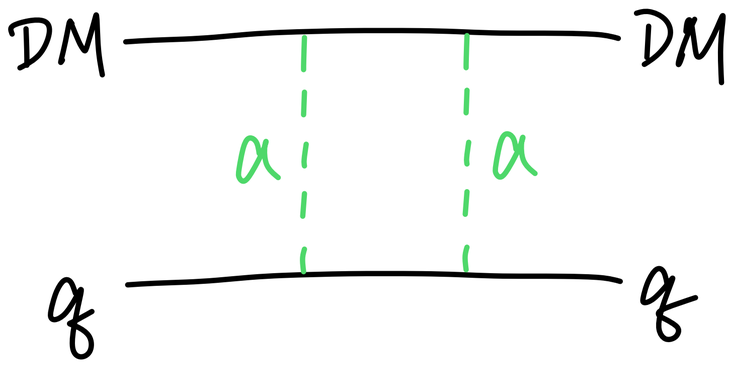


Spin-dependent σ

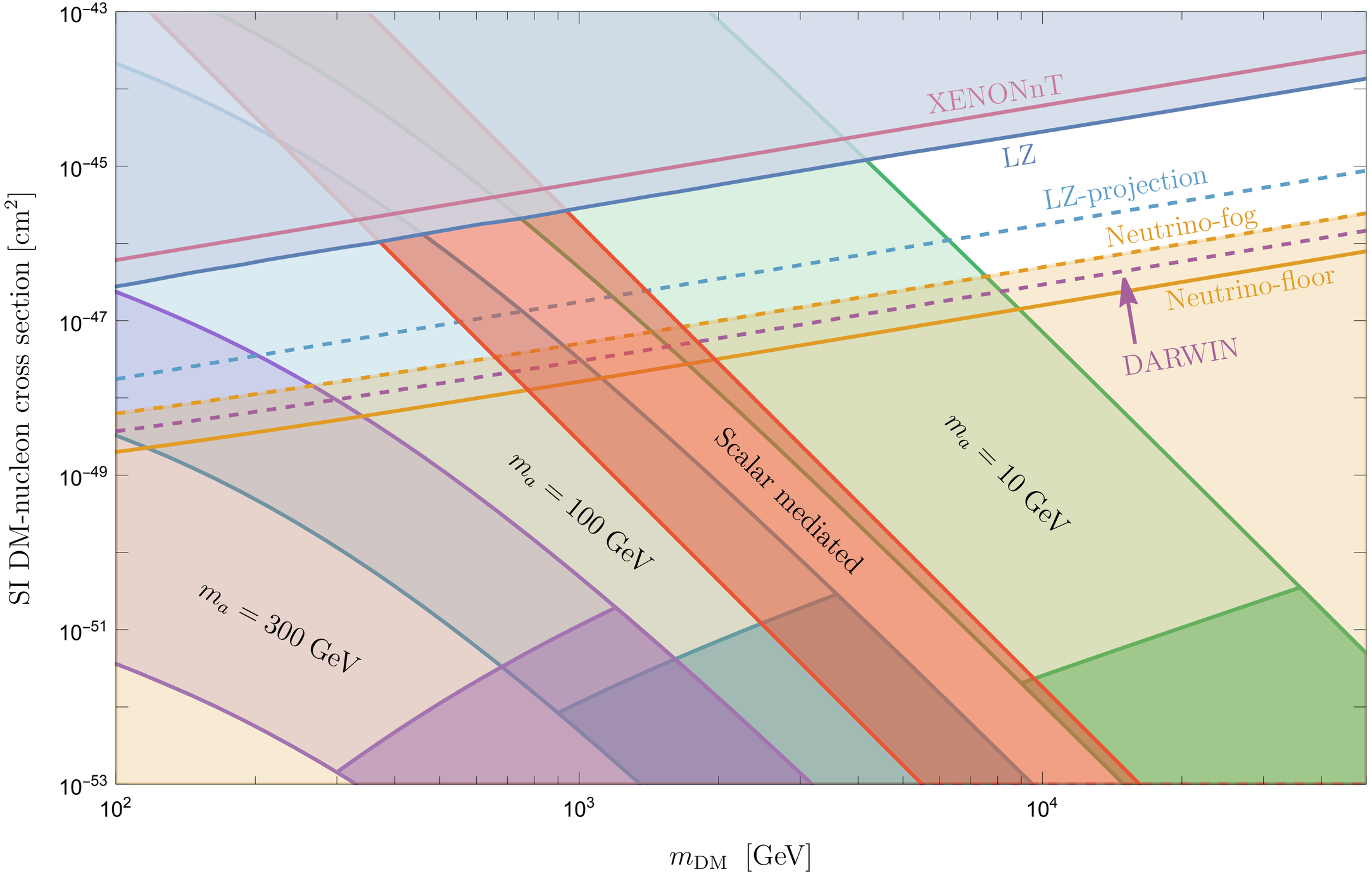
Momentum suppressed

10^5 too small !

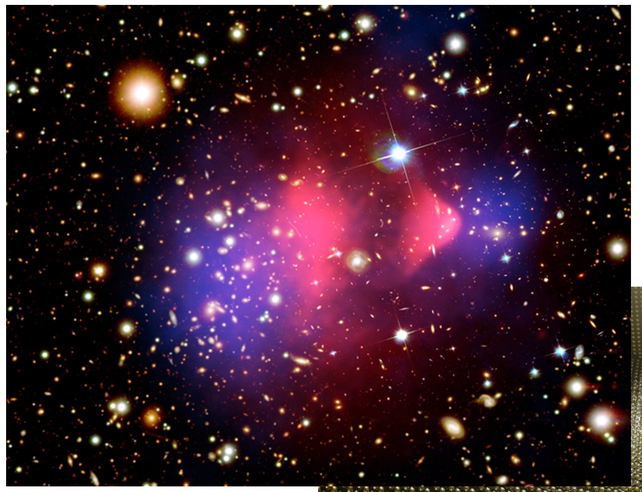


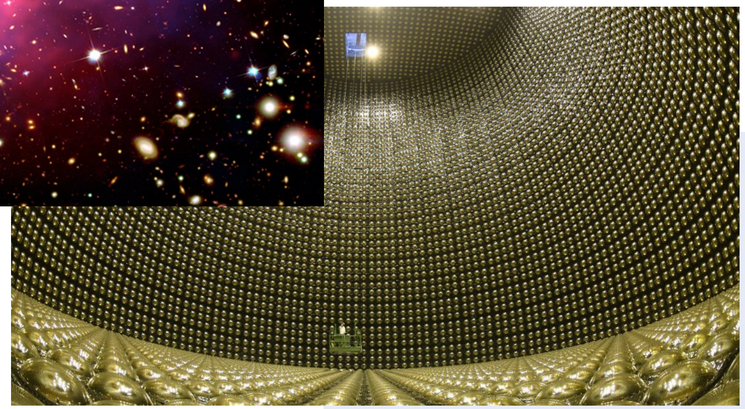


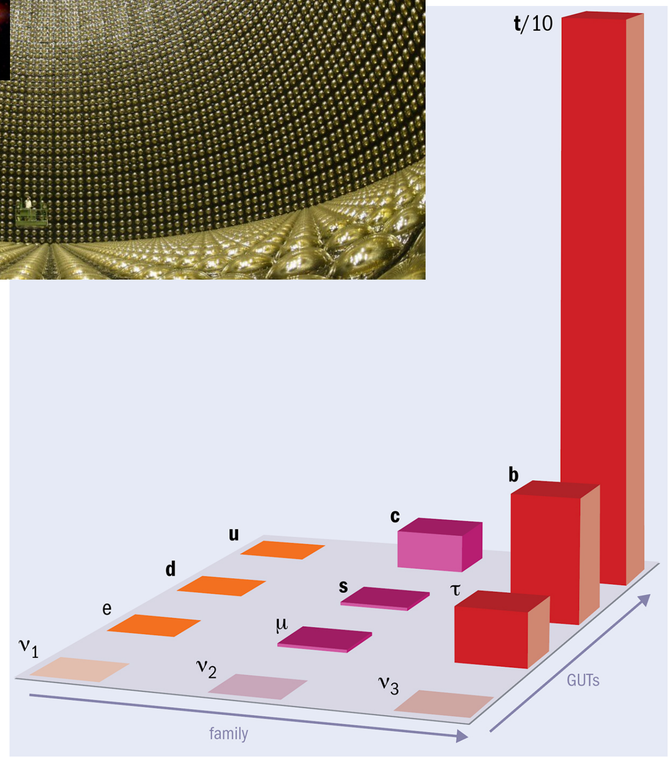
Spin-independent σ

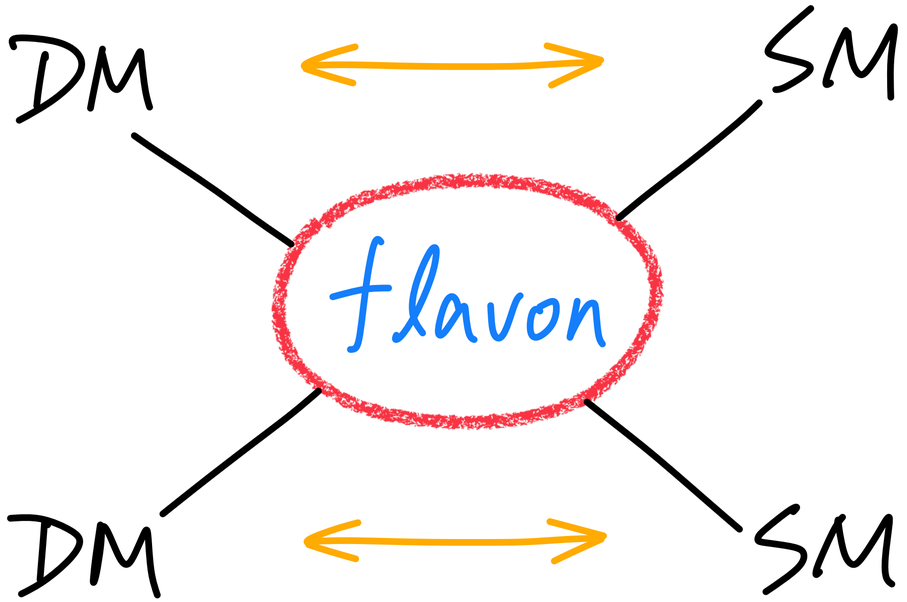

XENONnT
LZ
LZ-projection
Neutrino-fog
Neutrino-floor
DARWIN
Scalar mediated
$m_a = 10$ GeV
$m_a = 100$ GeV
$m_a = 300$ GeV
SI DM-nucleon cross section [cm^2]
10^{-43}
10^{-45}
10^{-47}
10^{-49}
10^{-51}
10^{-53}
10^2
10^3
10^4
$m_{\rm DM}$ [GeV]

Summary for the ~~im~~patient









Next :

Baryogenesis

- ✓ Freeze-out WIMP
- ✓ Freeze-in FIMP