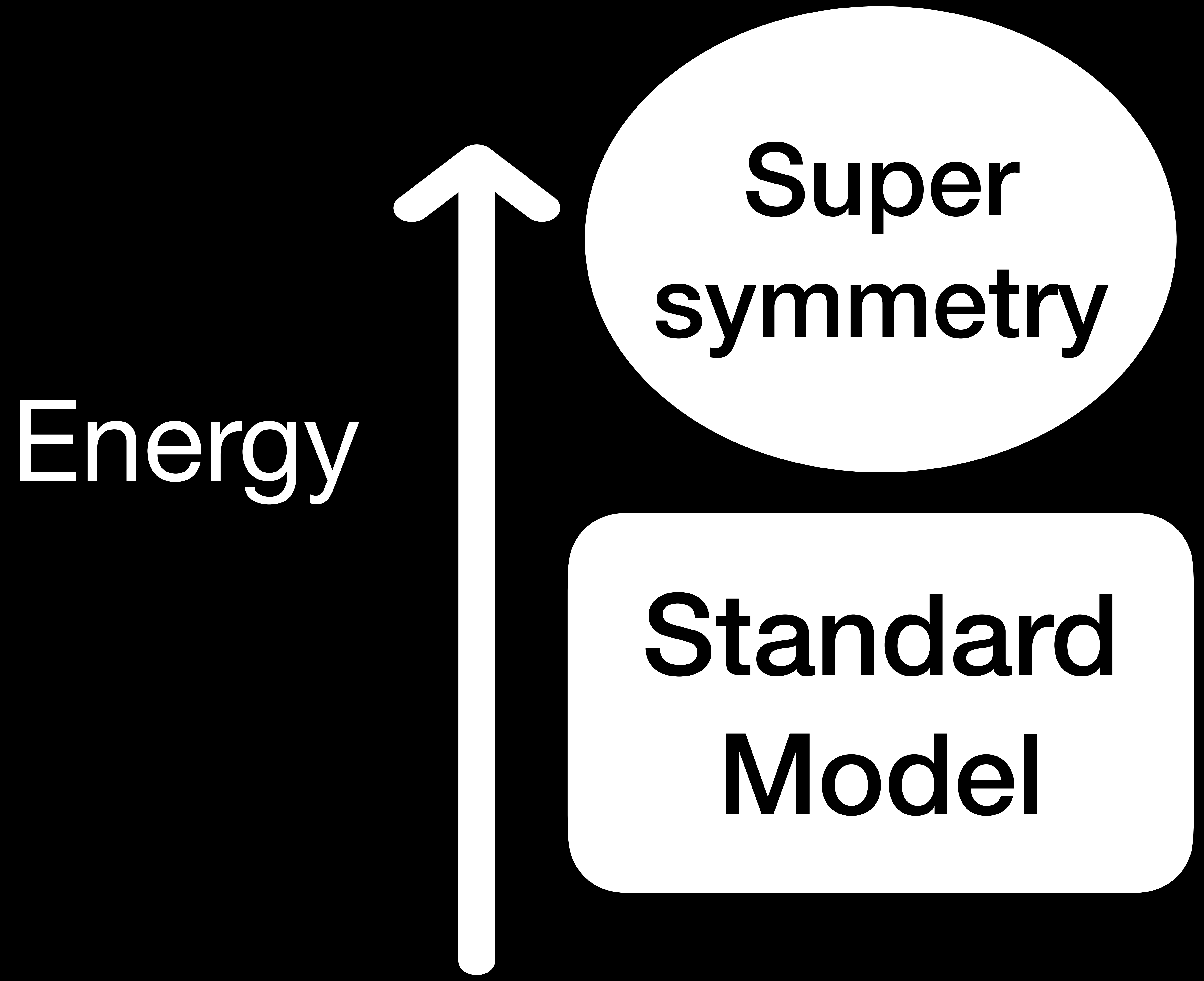
DARK GMSB

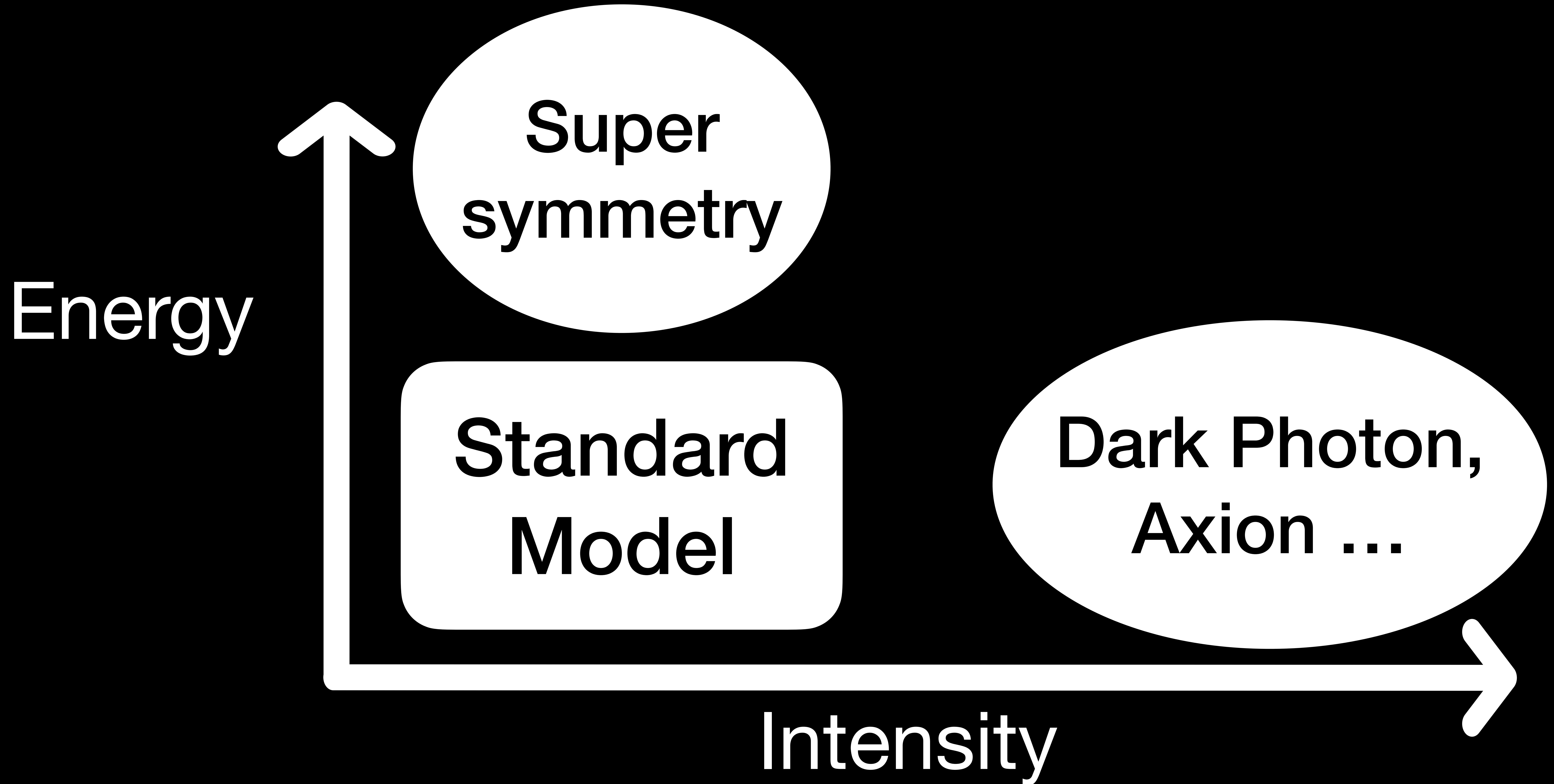
(On going work… to appear soon)

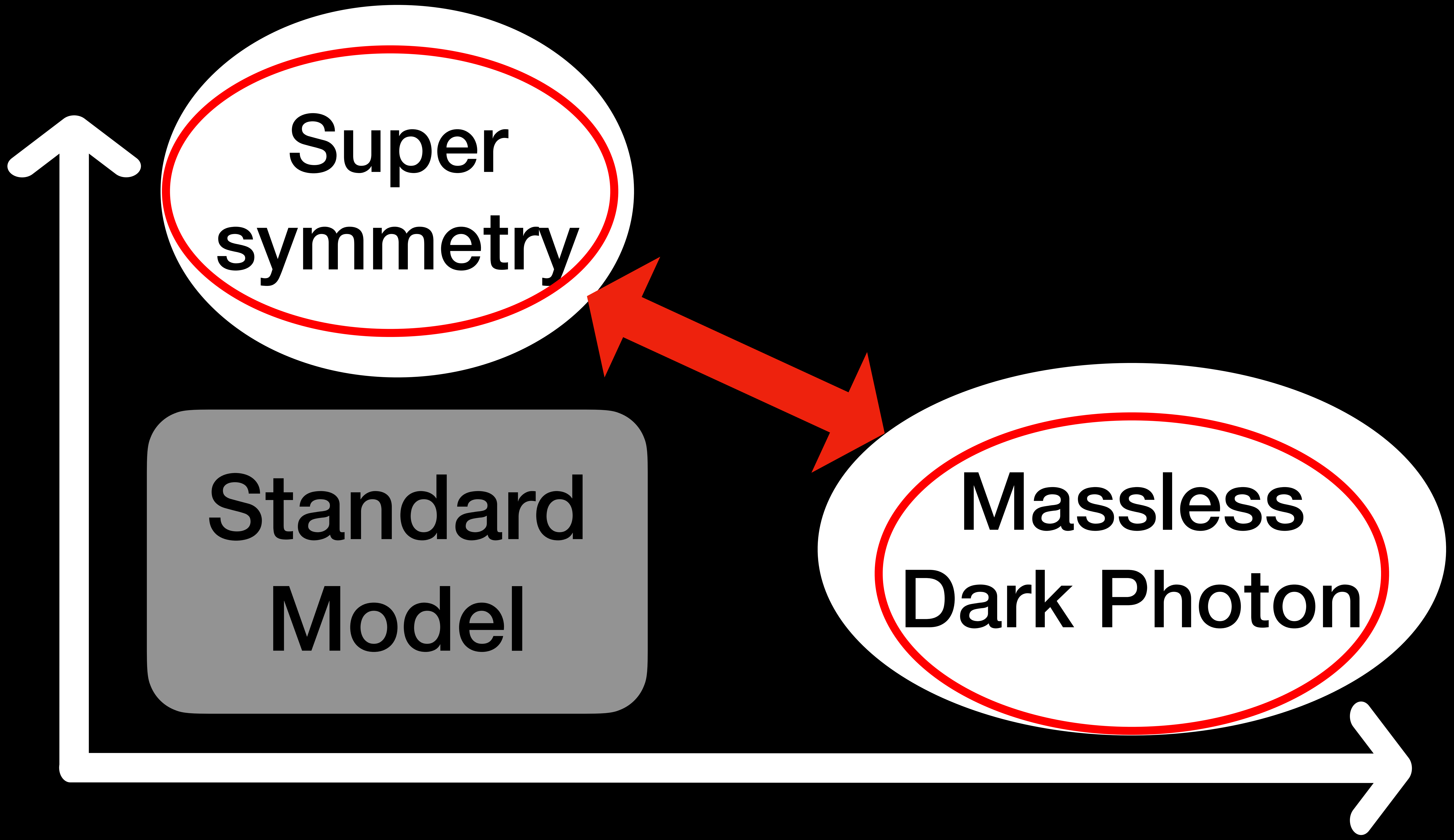
Jiheon Lee
KAIST

in collaboration with
Brian Batell, Yechan Kim, Hye-Sung Lee

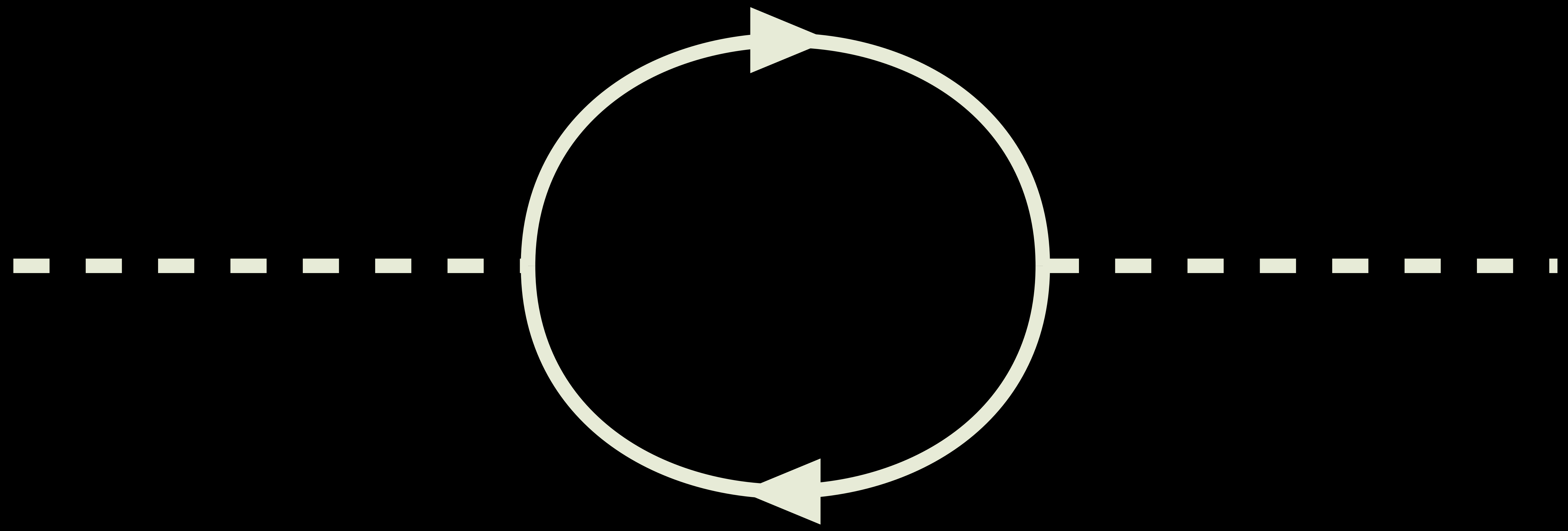
Standard
Model


Energy
Super symmetry
Standard Model

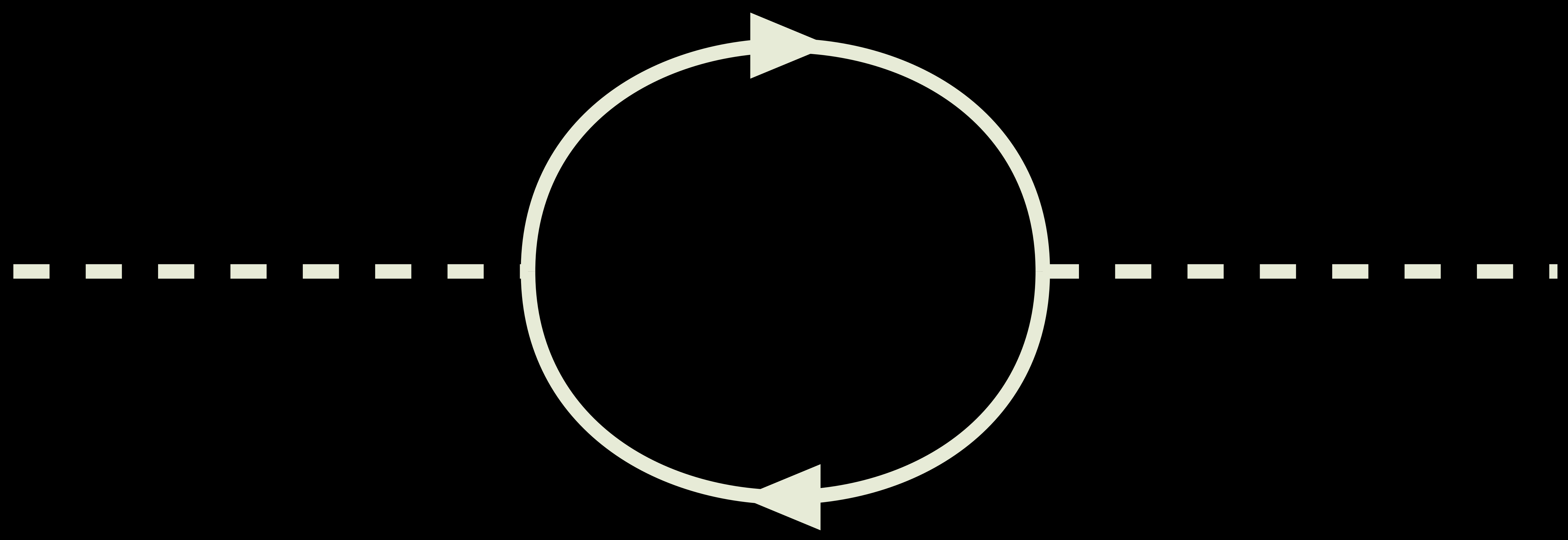

Super
symmetry
Energy
Standard
Model
Dark Photon,
Axion …
Intensity


Super
symmetry
Standard
Model
Massless
Dark Photon

Supersymmetry
(SUSY)



$$\Delta m_h^2 = -\frac{|\lambda_f|^2}{8\pi^2}\Lambda_{\mathrm{UV}}^2 + \ldots$$



$$\Delta m_h^2 = -\frac{|\lambda_f|^2}{8\pi^2}\Lambda_{\mathrm{UV}}^2 + ...$$

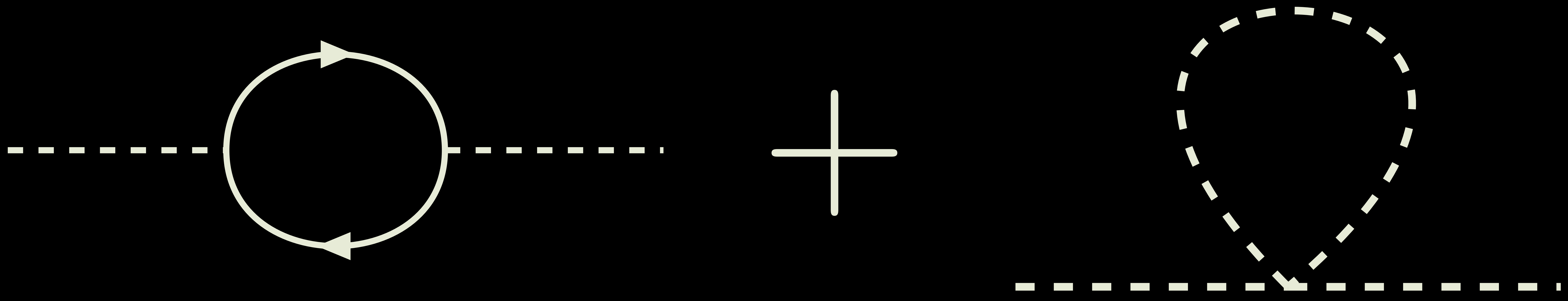
But why $(m_h \sim 100\mathrm{GeV}) \ll (M_{\mathrm{Pl}} \sim 10^{18}\mathrm{GeV})$

Fermion

f

Boson

$\tilde{f}$



$$\Delta m_h^2 = (\text{Safe terms})$$

Fermion

f

Boson

$\tilde{f}$

Same quantum number

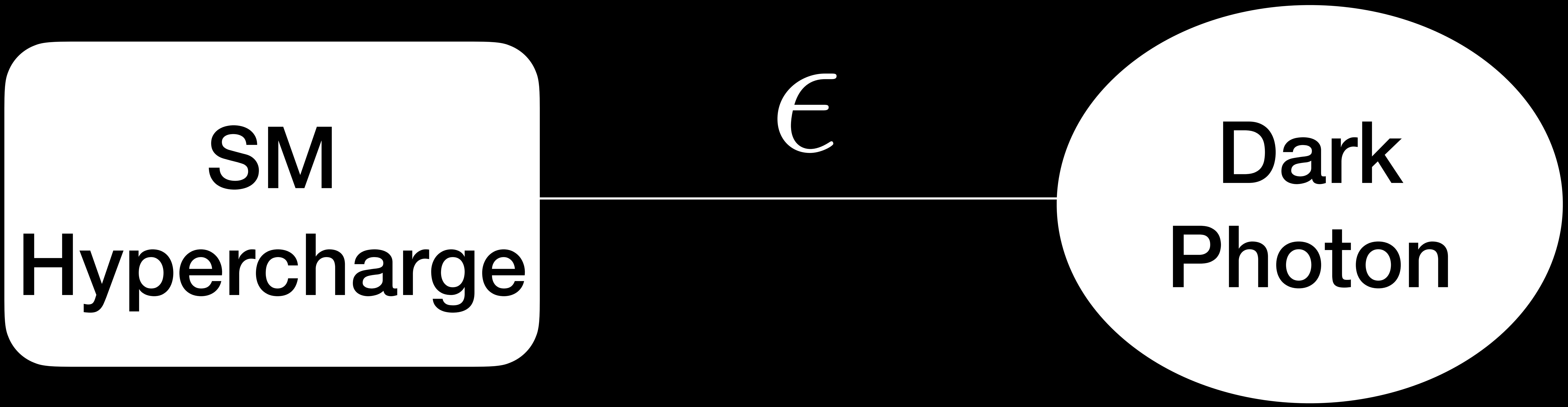
Same mass

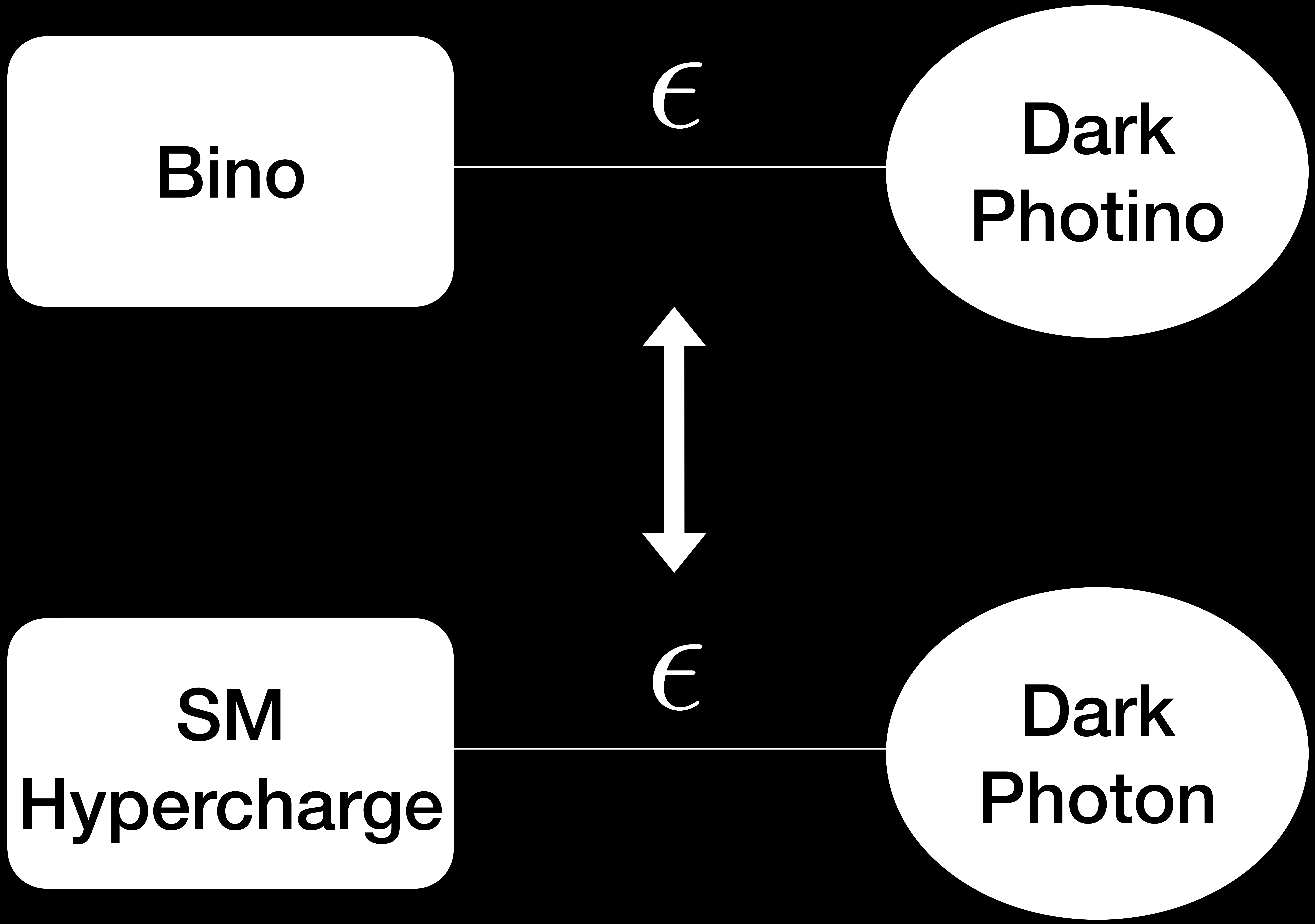
Supersymmetry must be broken

Dark Photon and Supersymmetry

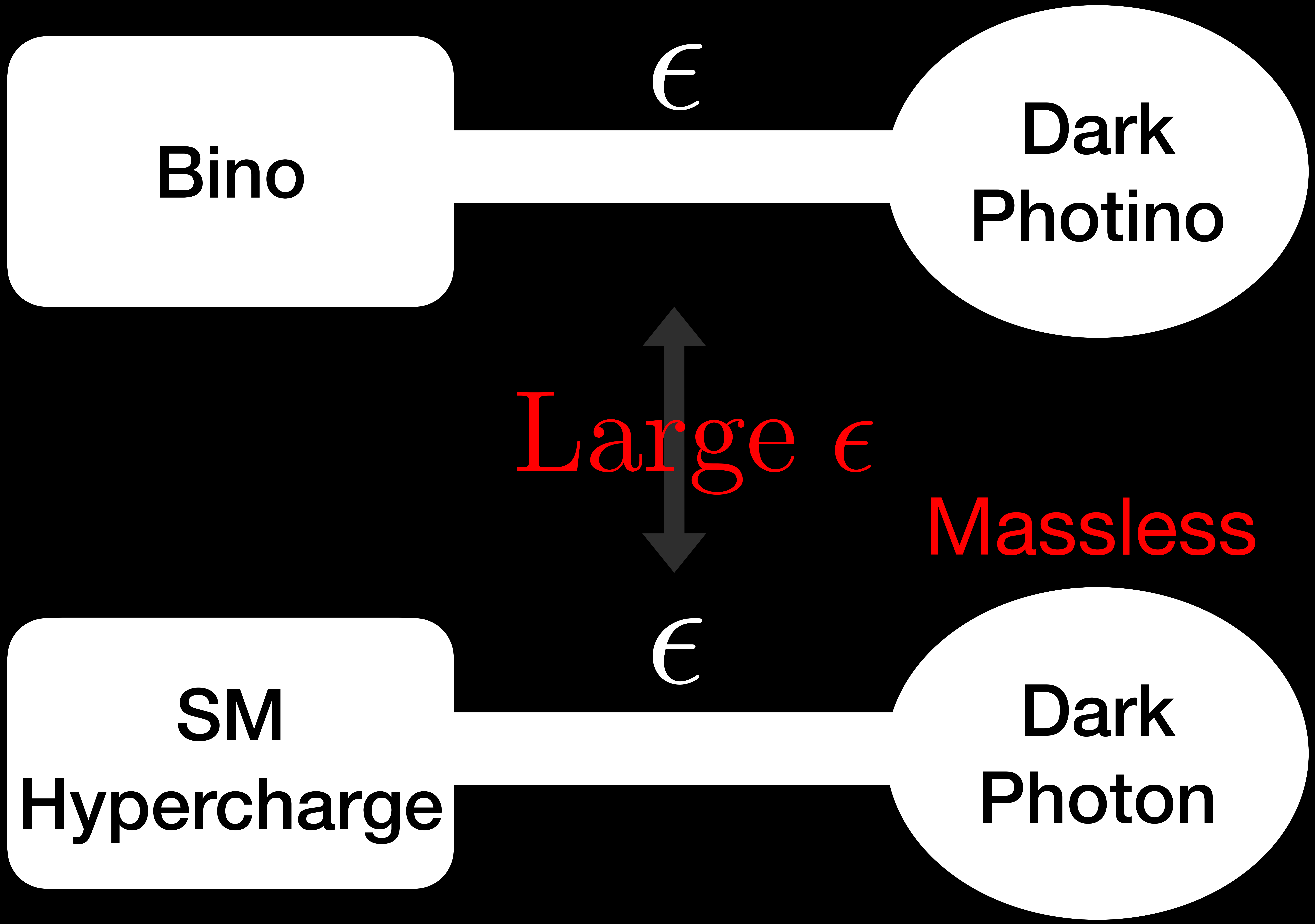
Diens, Kolda, Russel (1997); Ibarra, Ringwald, Weniger (2009); Chun, Park (2009); …

$$\frac{\epsilon}{2} B_{\mu\nu} X^{\mu\nu}$$





Bino
ϵ
Dark Photino
SM Hypercharge
ϵ
Dark Photon


Bino
ϵ
Dark
Photino
Large ϵ
Massless
SM
Hypercharge
ϵ
Dark
Photon

$$\mathcal{L} \supset \int d^2\theta \left(\frac{1}{4}\hat{\mathcal{W}}_{\mathbb{B}}\hat{\mathcal{W}}_{\mathbb{B}} + \frac{1}{4}\hat{\mathcal{W}}_{\mathbb{X}}\hat{\mathcal{W}}_{\mathbb{X}} + \frac{\epsilon}{2}\hat{\mathcal{W}}_{\mathbb{B}}\hat{\mathcal{W}}_{\mathbb{X}} \right) + h.c.$$

Gauge bosons: $-\frac{1}{4}\mathbb{B}_{\mu\nu}\mathbb{B}^{\mu\nu} - \frac{1}{4}\mathbb{X}_{\mu\nu}\mathbb{X}^{\mu\nu} - \frac{\epsilon}{2}\mathbb{B}_{\mu\nu}\mathbb{X}^{\mu\nu}$

Gauginos : $i\tilde{\mathbb{B}}^\dagger\sigma^\mu\partial_\mu\tilde{\mathbb{B}} + i\tilde{\mathbb{X}}^\dagger\sigma^\mu\partial_\mu\tilde{\mathbb{X}} + (i\epsilon\tilde{\mathbb{B}}^\dagger\sigma^\mu\partial_\mu\tilde{\mathbb{X}} + h.c.)$

$$\mathcal{L} \supset \int d^2\theta \left(\frac{1}{4}\hat{\mathcal{W}}_{\mathbb{B}}\hat{\mathcal{W}}_{\mathbb{B}} + \frac{1}{4}\hat{\mathcal{W}}_{\mathbb{X}}\hat{\mathcal{W}}_{\mathbb{X}} + \frac{\epsilon}{2}\hat{\mathcal{W}}_{\mathbb{B}}\hat{\mathcal{W}}_{\mathbb{X}} \right) + h.c.$$

Gauge bosons: $-\frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}X_{\mu\nu}X^{\mu\nu}$

Gauginos : $i\tilde{B}^\dagger\sigma^\mu\partial_\mu\tilde{B} + i\tilde{X}^\dagger\sigma^\mu\partial_\mu\tilde{X}$

$$\hat{\mathcal{W}}_{\mathbb{B}} = \hat{\mathcal{W}}_B/\sqrt{1-\epsilon^2} \quad \text{and} \quad \hat{\mathcal{W}}_{\mathbb{X}} = \hat{\mathcal{W}}_X - \epsilon\hat{\mathcal{W}}_B/\sqrt{1-\epsilon^2}$$

$$\mathcal{L} \supset \int d^2\theta \left(\frac{1}{4} \hat{\mathcal{W}}_{\mathbb{B}} \hat{\mathcal{W}}_{\mathbb{B}} + \frac{1}{4} \hat{\mathcal{W}}_{\mathbb{X}} \hat{\mathcal{W}}_{\mathbb{X}} + \frac{\epsilon}{2} \hat{\mathcal{W}}_{\mathbb{B}} \hat{\mathcal{W}}_{\mathbb{X}} \right) + h.c.$$

Gauge bosons: $-\frac{1}{4} B_{\mu\nu} B^{\mu\nu} - \frac{1}{4} X_{\mu\nu} X^{\mu\nu}$

Gauginos : $i\tilde{B}^\dagger \sigma^\mu \partial_\mu \tilde{B} + i\tilde{X}^\dagger \sigma^\mu \partial_\mu \tilde{X}$

$$\hat{\mathcal{W}}_{\mathbb{B}} = \hat{\mathcal{W}}_B / \sqrt{1-\epsilon^2} \quad \text{and} \quad \hat{\mathcal{W}}_{\mathbb{X}} = \hat{\mathcal{W}}_X - \epsilon \hat{\mathcal{W}}_B / \sqrt{1-\epsilon^2}$$

$$\begin{pmatrix} \hat{\mathbb{X}} \\ \hat{\mathbb{B}} \end{pmatrix} = \begin{pmatrix} \frac{1}{\sqrt{1-\epsilon^2}} & 0 \\ -\frac{\epsilon}{\sqrt{1-\epsilon^2}} & 1 \end{pmatrix} \begin{pmatrix} \cos\omega & -\sin\omega \\ \sin\omega & \cos\omega \end{pmatrix} \begin{pmatrix} \hat{X} \\ \hat{B} \end{pmatrix}$$

Gauge interaction vertices

$$\mathcal{L} \supset g'_{\rm Y} Y J^{\mu}_{Y} \mathbb{B}_{\mu} + g_D D J^{\mu}_{D} \mathbb{X}_{\mu}$$

$$= \left[-\frac{g_D \epsilon}{\sqrt{1-\epsilon^2}} D J^{\mu}_{D} + g_Y Y J^{\mu}_{Y} \right] B_{\mu} + g_D D J^{\mu}_{D} X_{\mu},$$

Gauge interaction vertices

$$\mathcal{L} \supset g'_{Y} Y J^{\mu}_{Y} \mathbb{B}_{\mu} + g_D D J^{\mu}_{D} \mathbb{X}_{\mu}$$

$$= \left[-\frac{g_D \epsilon}{\sqrt{1-\epsilon^2}} D J^{\mu}_{D} + g_Y Y J^{\mu}_{Y} \right] B_{\mu} + g_D D J^{\mu}_{D} X_{\mu},$$

SM fermions only interact with “B”

Gaugino’s cosmological constraint on ϵ : Ibarra, Ringwald, Weniger (2009)

Gauge interaction vertices

$$\mathcal{L} \supset g'_{\rm Y} Y J^\mu_{\rm Y} \mathbb{B}_\mu + g_D D J^\mu_D \mathbb{X}_\mu$$

$$= \left[-\frac{g_D \epsilon}{\sqrt{1-\epsilon^2}} D J^\mu_D + g_Y Y J^\mu_Y \right] B_\mu + g_D D J^\mu_D X_\mu ,$$

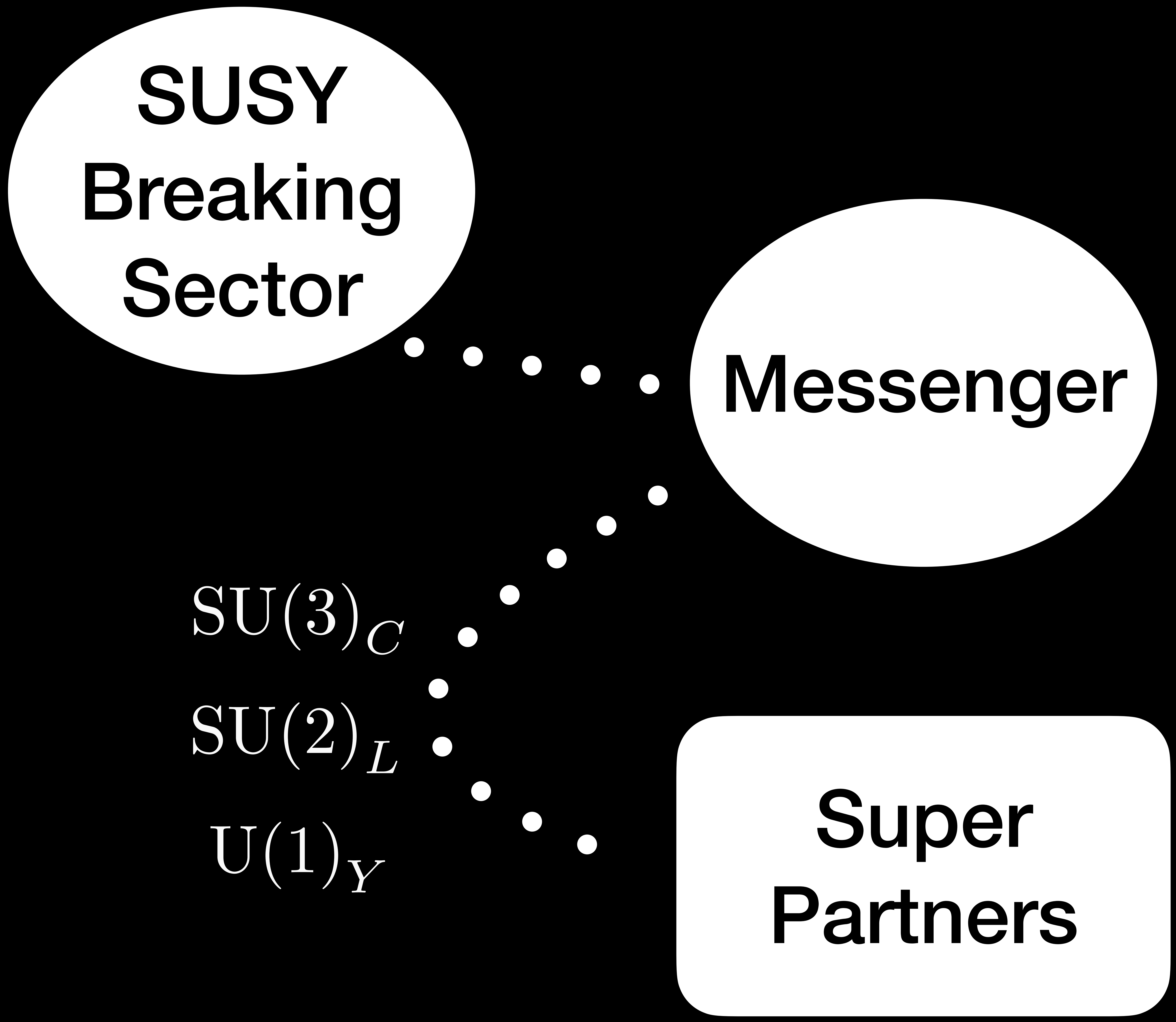
SM fermions only interact with "Photons"

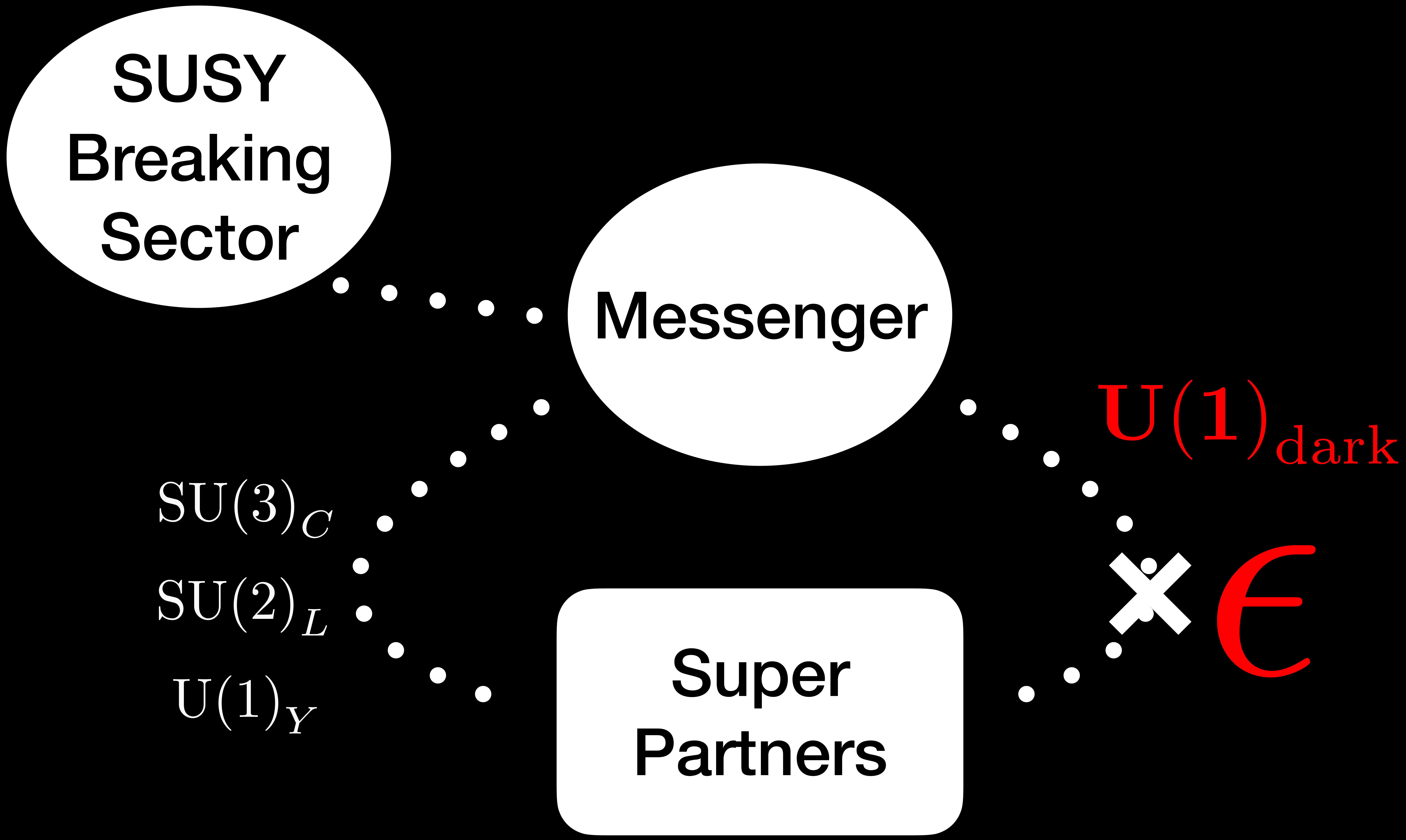
Fractional charge from the dark charge

Gaugino's cosmological constraint on ϵ : Ibarra, Ringwald, Weniger (2009)

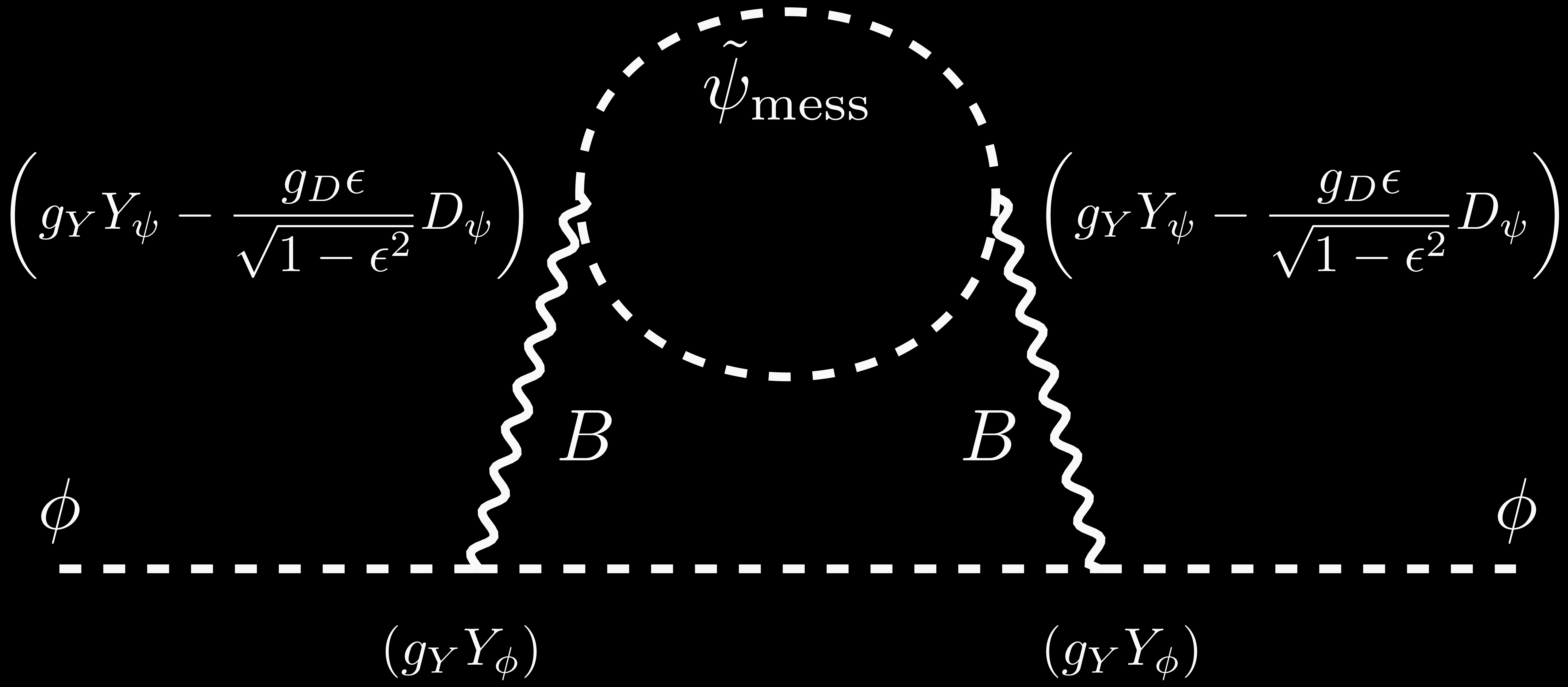
Dark Gauge Mediation SUSY Breaking

(Dark GMSB)


SUSY Breaking Sector
Messenger
$\mathrm{SU}(3)_C$
$\mathrm{SU}(2)_L$
$\mathrm{U}(1)_Y$
Super Partners

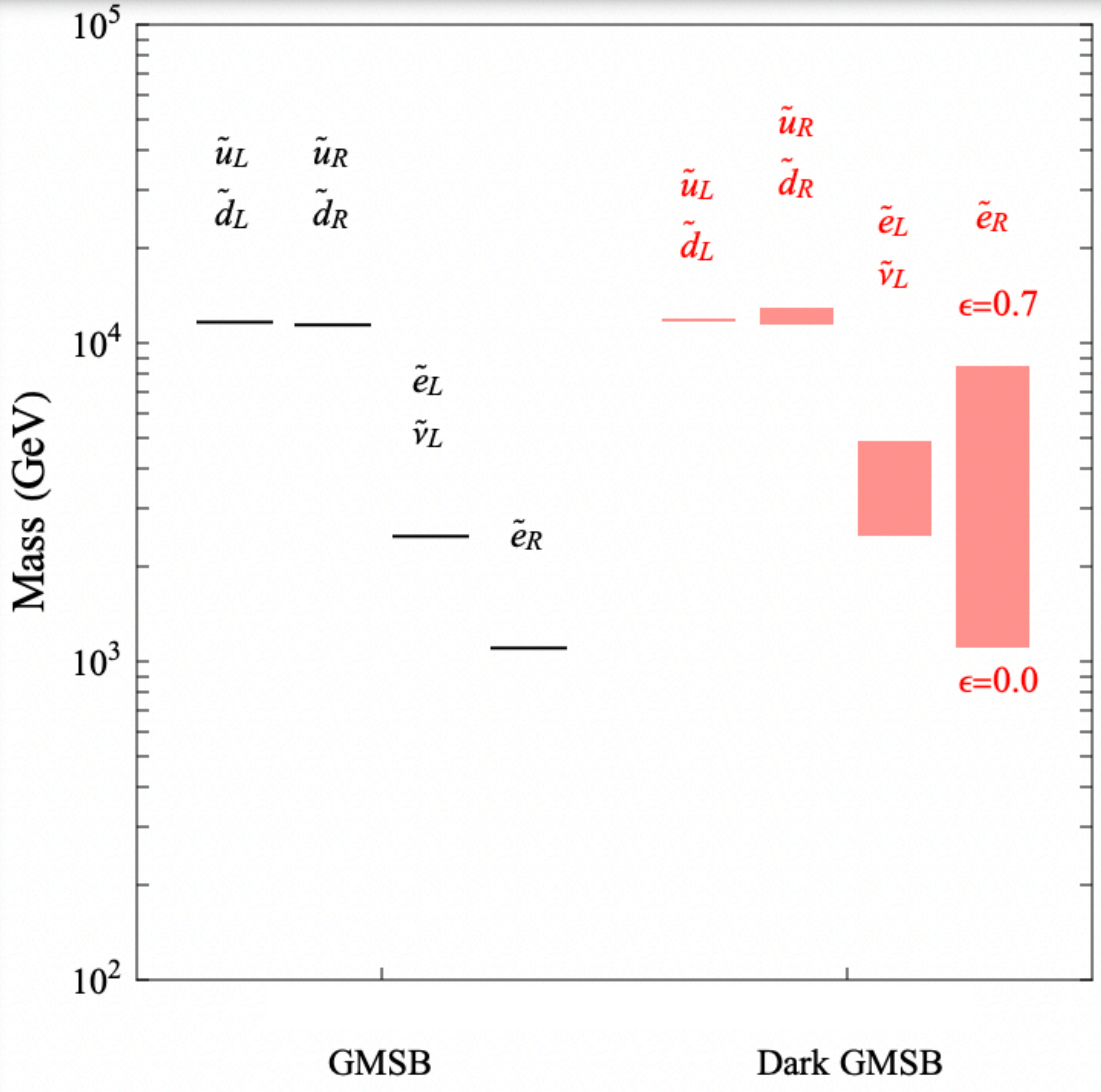

SUSY Breaking Sector
Messenger
$\mathrm{SU}(3)_C$
$\mathrm{SU}(2)_L$
$\mathrm{U}(1)_Y$
$\mathrm{U}(1)_{\mathrm{dark}}$
$\times\,\epsilon$
Super Partners

Scalar masses

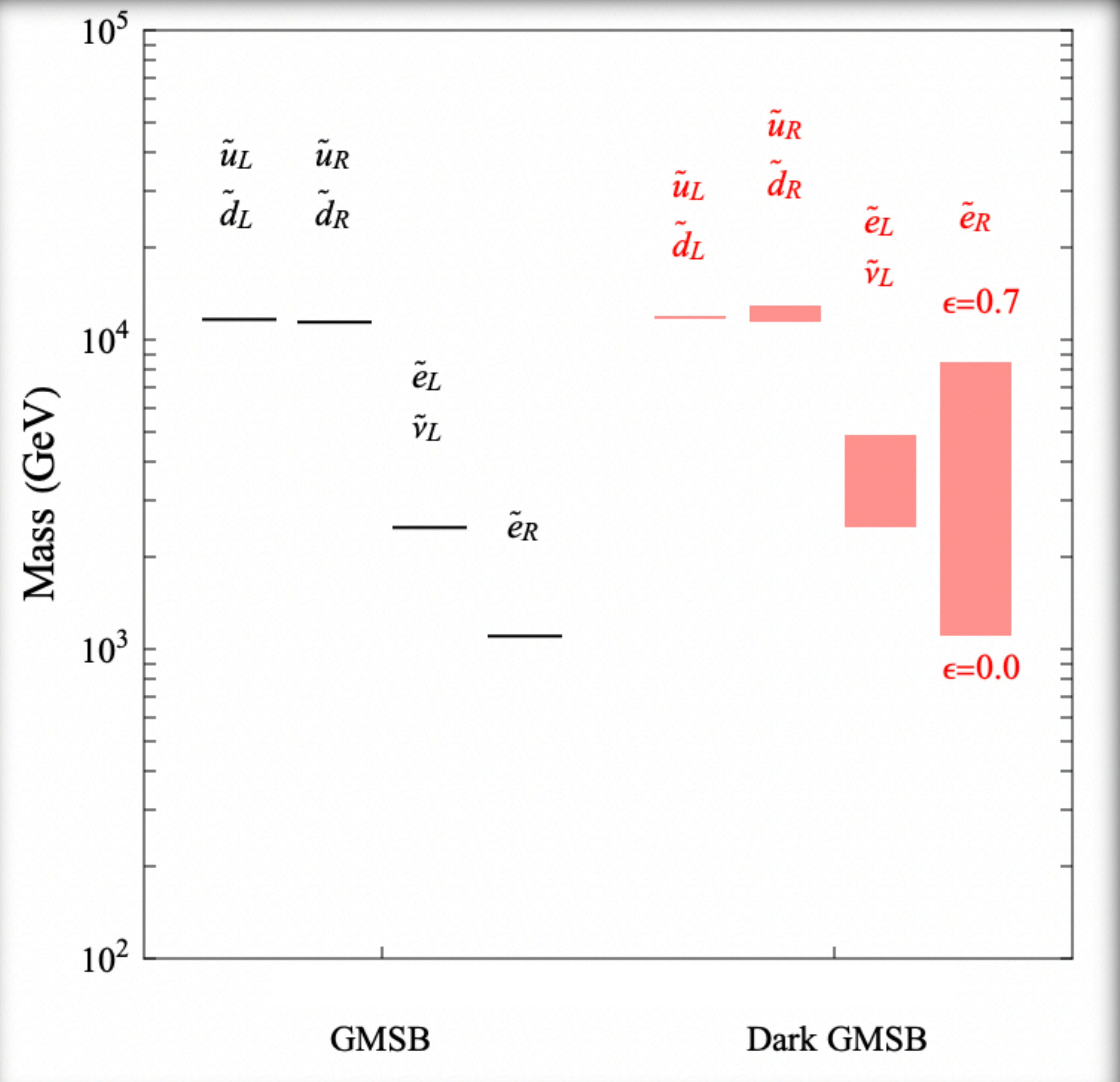


$$(g_Y Y_\phi)^2 (g_Y Y_\psi)^2 \rightarrow (g_Y Y_\phi)^2 \left(g_Y Y_\psi - \frac{g_D \epsilon}{\sqrt{1-\epsilon^2}} D_\psi\right)^2$$

Sfermion spectrum



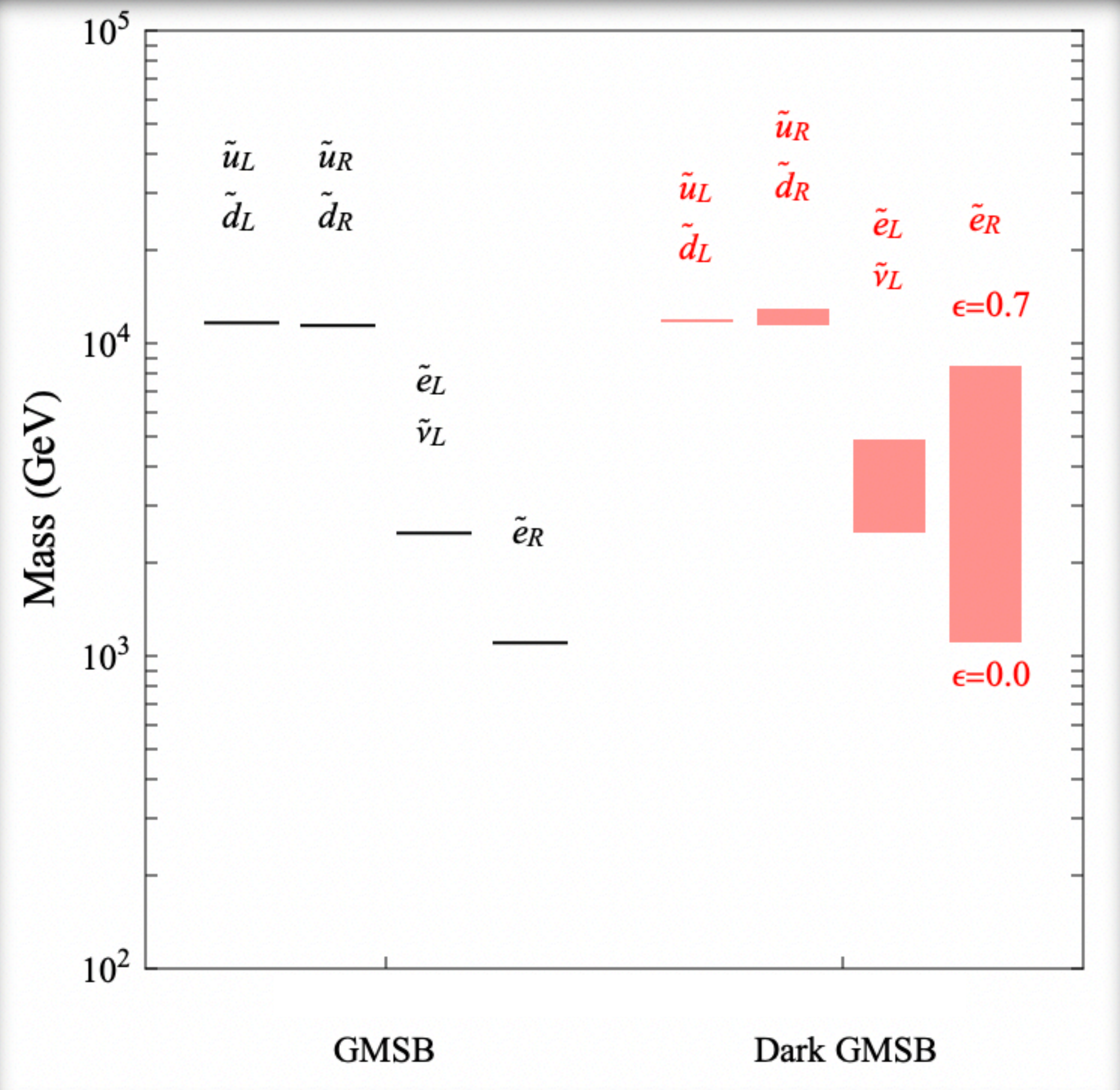
Sfermion spectrum



$$m_{\tilde{q}}^2(\epsilon) = \sum_{\Psi} \tilde{M}_{\text{mess},2}^2 \left[\frac{2g_3^4}{3} + \frac{3g_2^4}{8} + g_1^2 Y_{\tilde{q}}^2 \left(g_1 Y_\Psi - \frac{g_D \epsilon D_\Psi}{\sqrt{1-\epsilon^2}} \right)^2 \right],$$

$$Y_{\tilde{q}_L} = \frac{1}{6} \qquad Y_{\tilde{u}_R} = \frac{2}{3} \qquad Y_{\tilde{d}_R} = -\frac{1}{3}$$

Sfermion spectrum



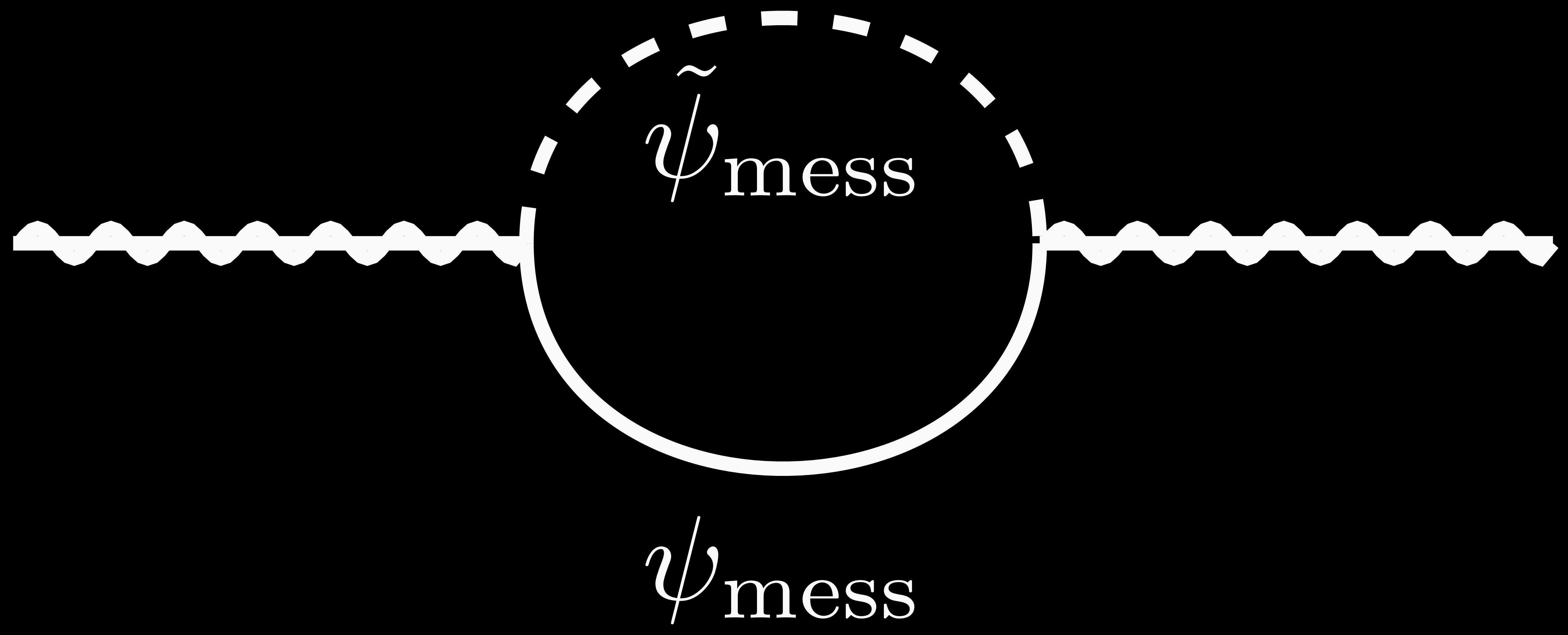
$$m_{\tilde{q}}^2(\epsilon) = \sum_{\Psi} \tilde{M}^2_{\text{mess},2} \left[\frac{2g_3^4}{3} + \frac{3g_2^4}{8} + g_1^2 Y_{\tilde{q}}^2 \left(g_1 Y_\Psi - \frac{g_D \epsilon D_\Psi}{\sqrt{1-\epsilon^2}} \right)^2 \right],$$

$$m_{\tilde{\ell}_L}^2(\epsilon) = \sum_{\Psi} \tilde{M}^2_{\text{mess},2} \left[\frac{3g_2^4}{8} + g_1^2 Y_{\tilde{\ell}_L}^2 \left(g_1 Y_\Psi - \frac{g_D \epsilon D_\Psi}{\sqrt{1-\epsilon^2}} \right)^2 \right],$$

$$m_{\tilde{e}_R}^2(\epsilon) = \sum_{\Psi} \tilde{M}^2_{\text{mess},2} \left[g_1^2 Y_{\tilde{e}_R}^2 \left(g_1 Y_\Psi - \frac{g_D \epsilon D_\Psi}{\sqrt{1-\epsilon^2}} \right)^2 \right],$$

$$Y_{\tilde{q}_L} = \frac{1}{6} \qquad Y_{\tilde{u}_R} = \frac{2}{3} \qquad Y_{\tilde{d}_R} = -\frac{1}{3} \qquad Y_{\tilde{\ell}_L} = -\frac{1}{2} \qquad Y_{\tilde{e}_R} = -1$$

Dark photino/ Bino masses



$$\mathrm{M}^{2\times 2}_{\tilde{N}} = \begin{pmatrix} M_D & M_K \\ M_K & M_1 \end{pmatrix}$$

$$M_D = \sum_\Psi g_D^2 D_\Psi^2 \tilde{M}_{\rm mess,1},$$

$$M_K = \sum_\Psi g_D D_\Psi \left(g_1 Y_\Psi - \frac{g_D \epsilon D_\Psi}{\sqrt{1-\epsilon^2}} \right) \tilde{M}_{\rm mess,1},$$

$$M_1 = \sum_\Psi \left(g_1 Y_\Psi - \frac{g_D \epsilon D_\Psi}{\sqrt{1-\epsilon^2}} \right)^2 \tilde{M}_{\rm mess,1},$$

Neutralino mass matrix

$$\begin{pmatrix} \tilde{X} & \tilde{B} & \tilde{W}^3 & \tilde{H}_d^0 & \tilde{H}_u^0 \end{pmatrix}$$

$$\begin{pmatrix} M_D & M_K & 0 & 0 & 0 \\ M_K & M_1 & 0 & -c_\beta s_W m_Z & s_\beta s_W m_Z \\ 0 & 0 & M_2 & c_\beta c_W m_Z & -s_\beta c_W m_Z \\ 0 & -c_\beta s_W m_Z & c_\beta c_W m_Z & 0 & -\mu \\ 0 & s_\beta s_W m_Z & -s_\beta c_W m_Z & -\mu & 0 \end{pmatrix}$$

EW breaking condition

$$V \supset (|\mu|^2 + m_{H_u}^2)|H_u^0|^2 + (|\mu|^2 + m_{H_d}^2)|H_d^0|^2$$

$$|\mu(\alpha_{\rm eff})|^2 = -\frac{m_Z^2}{2} - \frac{m_{H_u}^2(\alpha_{\rm eff}) + m_{H_d}^2(\alpha_{\rm eff})}{2} + \frac{m_{H_u}^2(\alpha_{\rm eff}) - m_{H_d}^2(\alpha_{\rm eff})}{2\cos(2\beta)}.$$

$$\left(\alpha_{\rm eff} \equiv \frac{\epsilon^2}{1-\epsilon^2}\frac{g_D^2}{4\pi}\right)$$

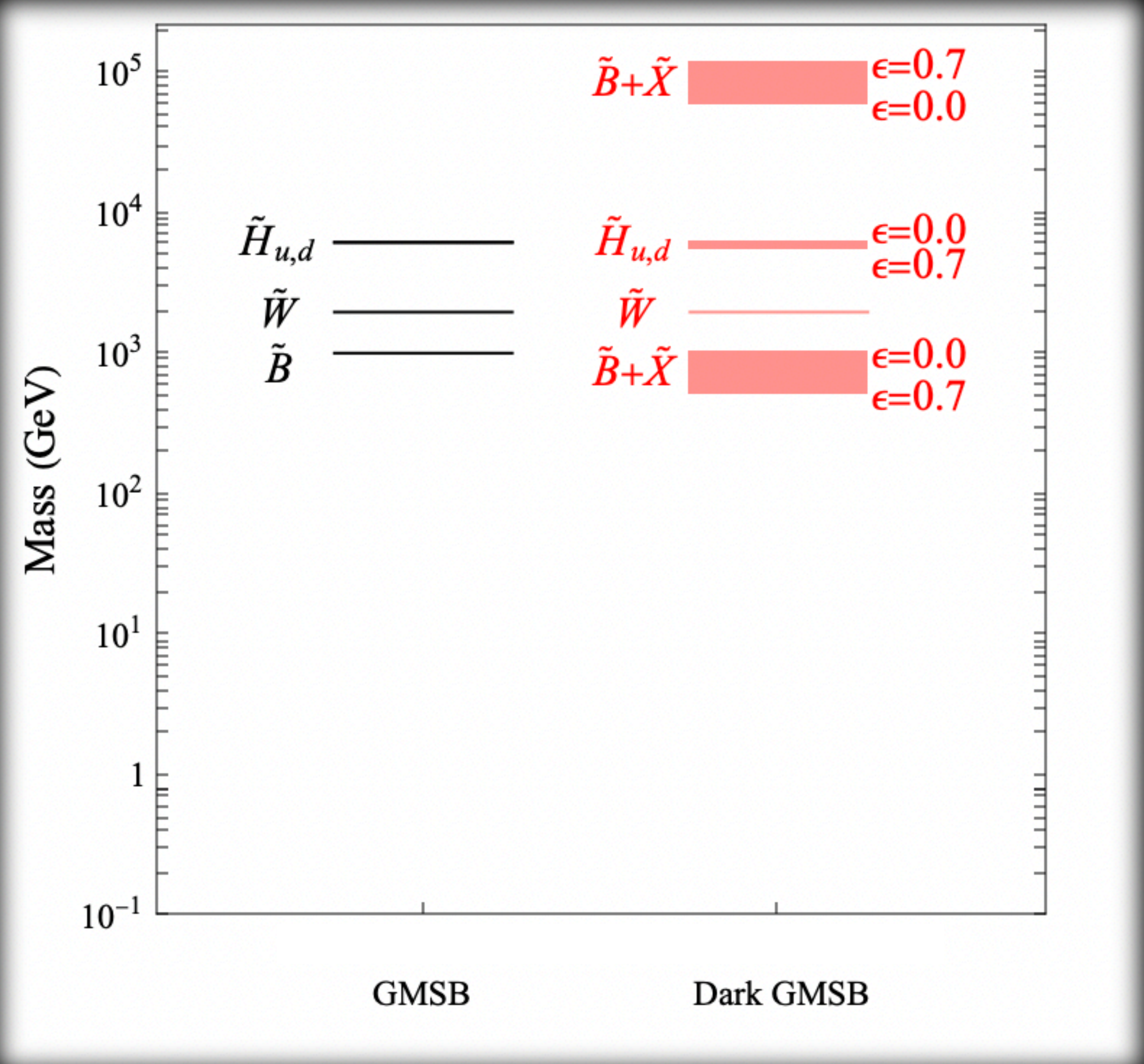
Neutralino mass matrix

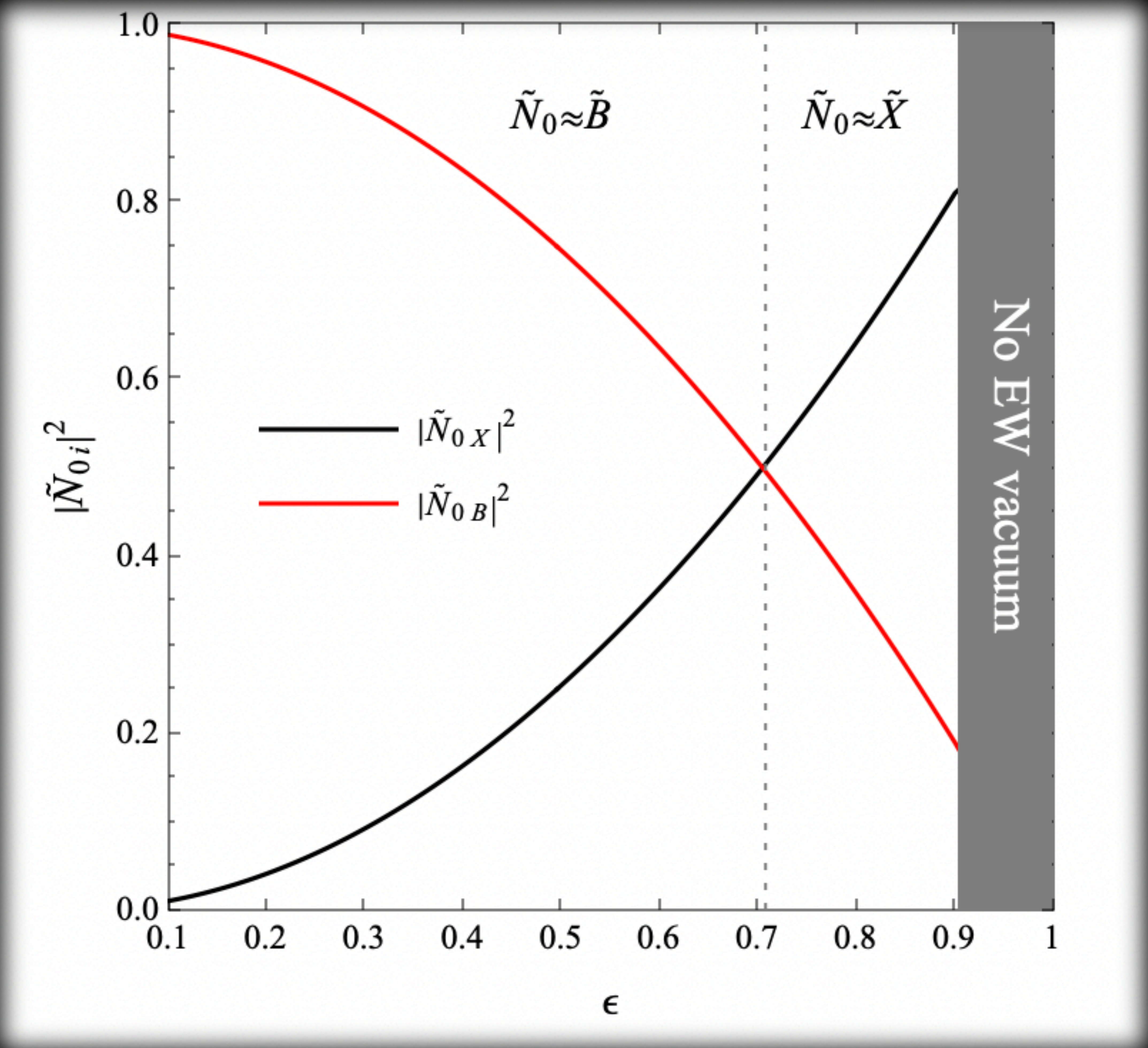
$$\begin{pmatrix} \tilde{X} & \tilde{B} & \tilde{W}^3 & \tilde{H}_d^0 & \tilde{H}_u^0 \end{pmatrix}$$

$$\begin{pmatrix} M_D & M_K & 0 & 0 & 0 \\ M_K & M_1 & 0 & -c_\beta s_W m_Z & s_\beta s_W m_Z \\ 0 & 0 & M_2 & c_\beta c_W m_Z & -s_\beta c_W m_Z \\ 0 & -c_\beta s_W m_Z & c_\beta c_W m_Z & 0 & -\mu \\ 0 & s_\beta s_W m_Z & -s_\beta c_W m_Z & -\mu & 0 \end{pmatrix}$$

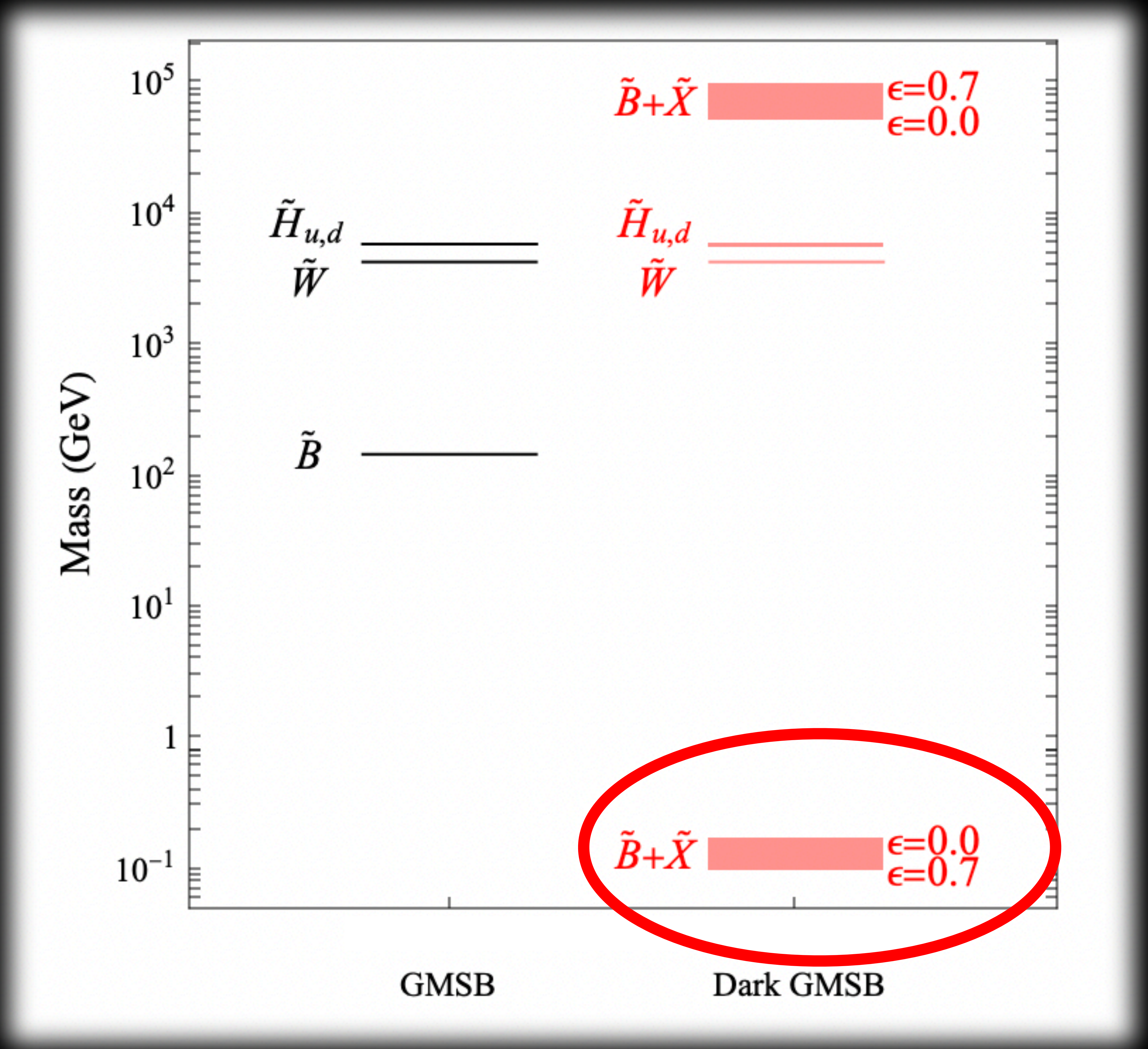
$$\Psi_1 = (3, 1, -1/3, 1)$$
$$\Psi_2 = (2, 1, 1/2, 1)$$

$$(SU(3)_C, SU(2)_L, U(1)_Y, U(1)_D)$$





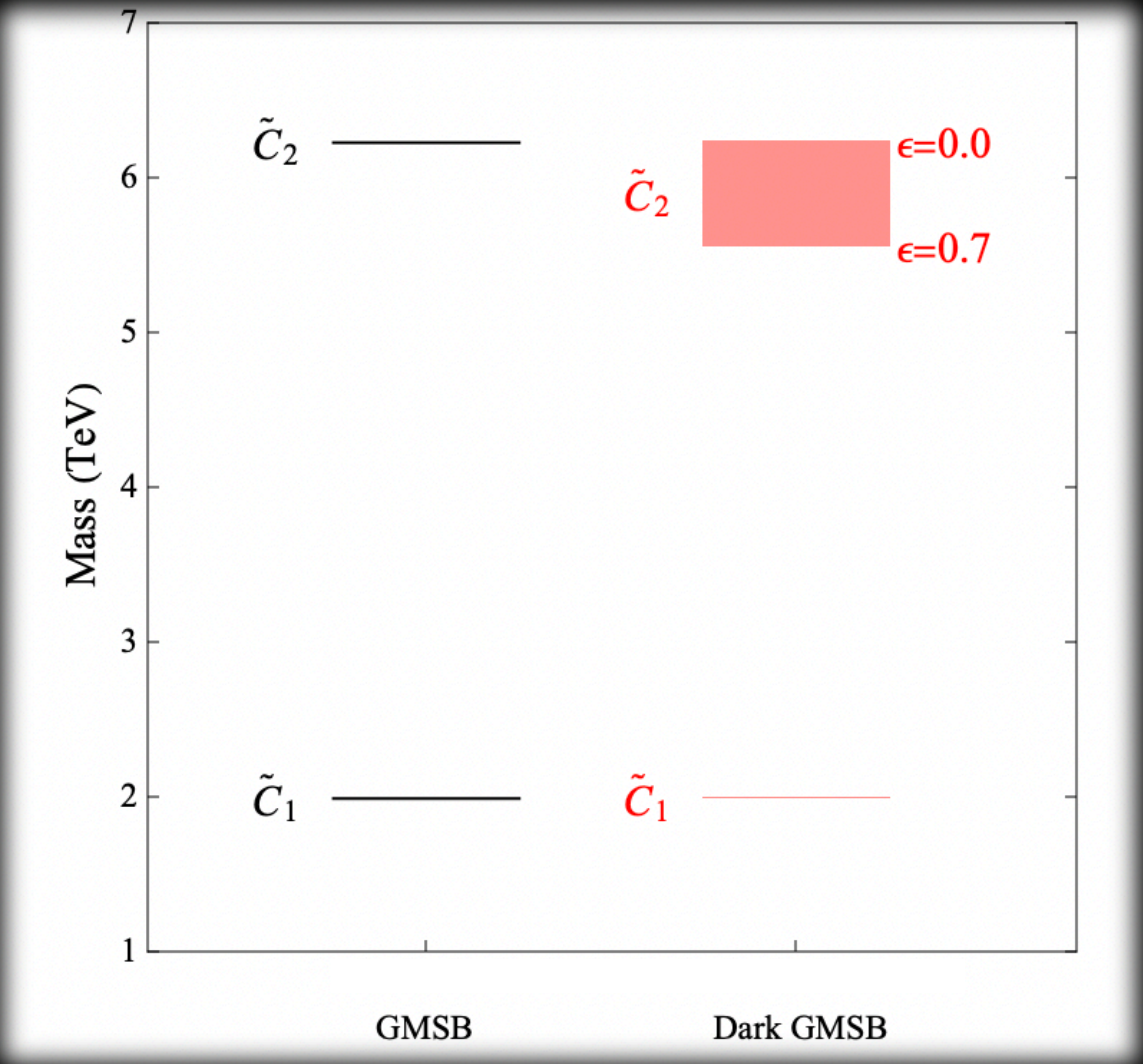
$$\Psi_1 = (3, 2, 1/6, 1)$$



$$\mathbf{M}^{2\times 2}_{\tilde{N}} = \begin{pmatrix} M_D & M_K \\ M_K & M_1 \end{pmatrix}$$

$$\mathrm{Det}\left[M^{2\times 2}_{\tilde{N}}\right] = 0$$

Chargino mass spectrum



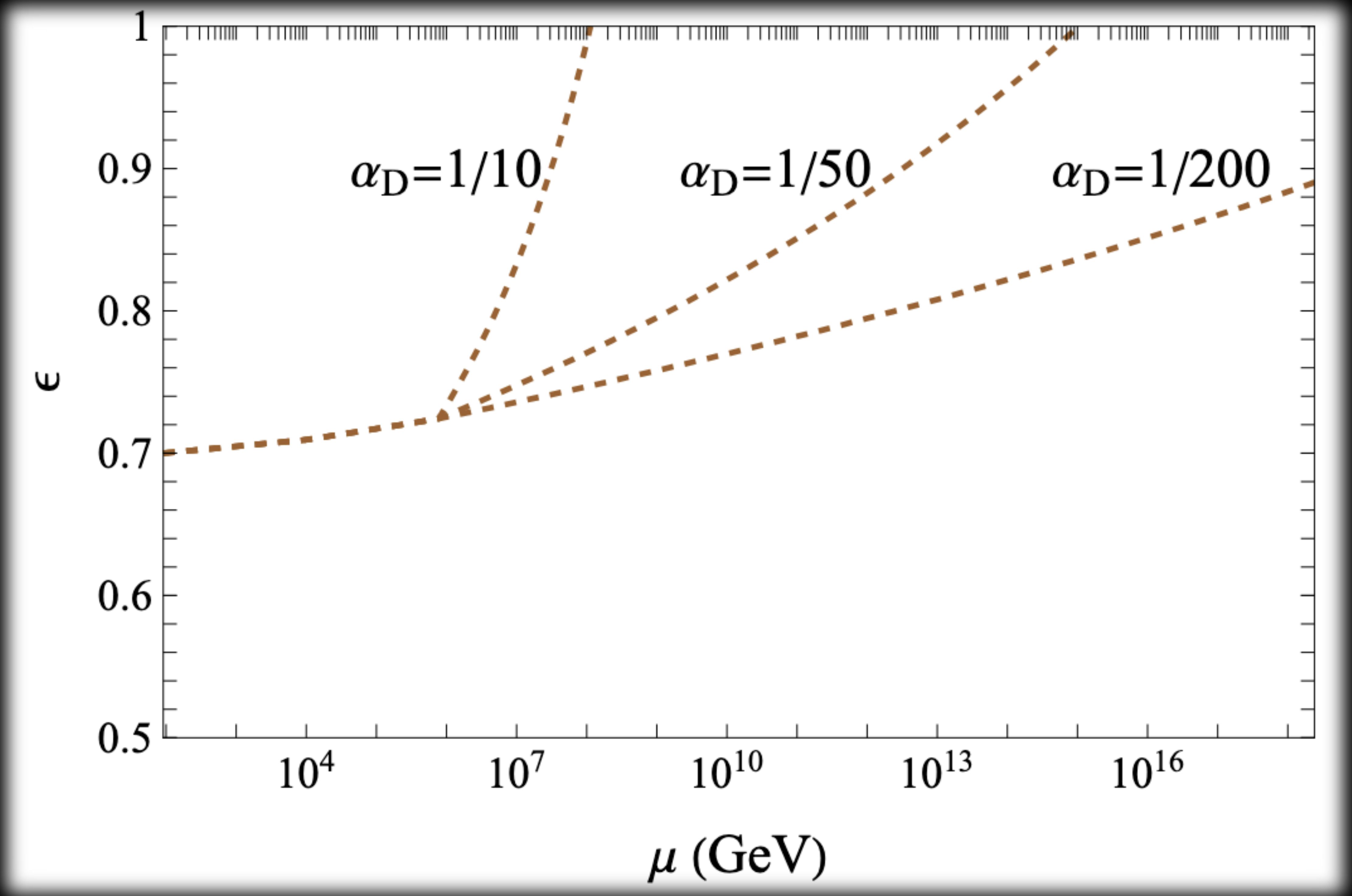
$$m_{\tilde{C}_2} \simeq |\mu|$$

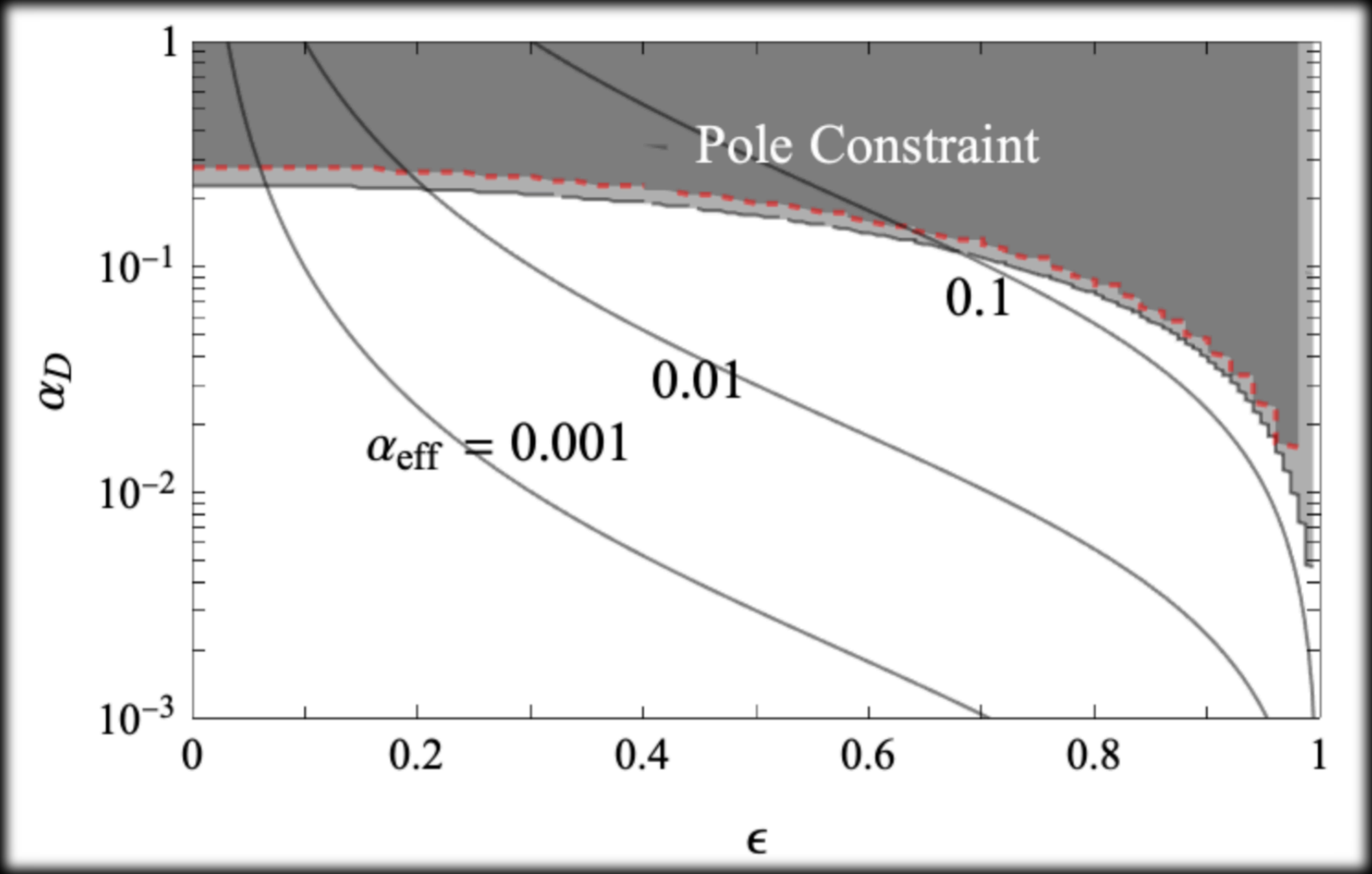
$$m_{\tilde{C}_1} \simeq M_2$$

How large?

$$\alpha_D \equiv \frac{g_D^2}{4\pi},$$

$$\left(\alpha_{\rm eff} \equiv \frac{\epsilon^2}{1-\epsilon^2}\frac{g_D^2}{4\pi}\right)$$





Summary and outlook

- Dark GMSB can affect the spectra of supersymmetric particles

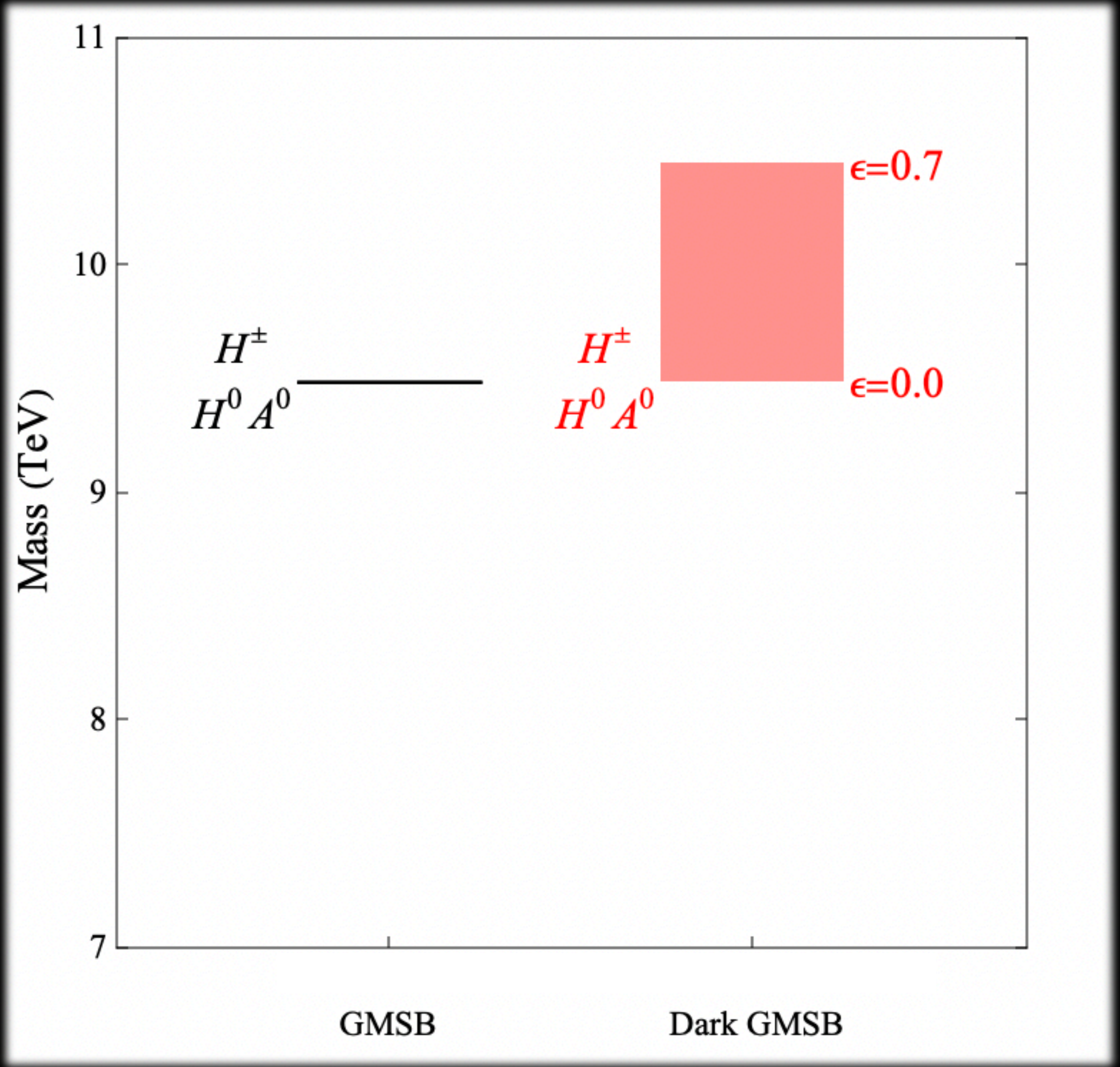
  (Significant changes occur for sleptons)

- Large kinetic mixing can be constrained by the Landau pole

- We are working on the RG running of the spectra, and phenomenologies of the model

Stay tuned

Heavy Higgs spectrum

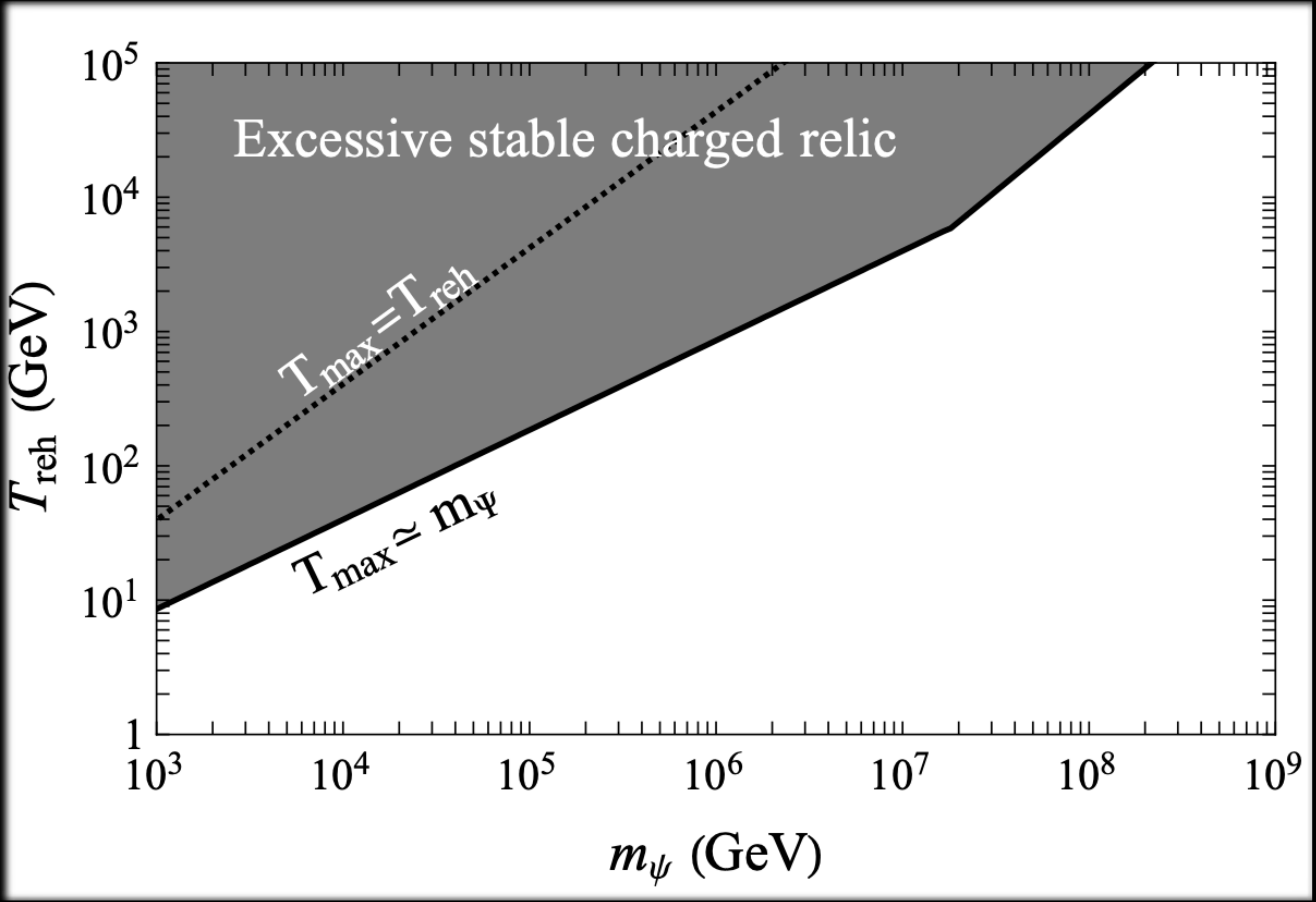


$$m^2_{H_u}(\alpha_{\rm eff})|_{m_{\tilde t}} = m^2_{H_u}(\alpha_{\rm eff})|_{M_{\rm mess}} - \frac{3y_t^2}{4\pi^2} m^2_{\tilde t}(\alpha_{\rm eff}) \left(\ln \frac{M_{\rm mess}}{m_{\tilde t}(\alpha_{\rm eff})} + \frac{3}{2} \right)$$

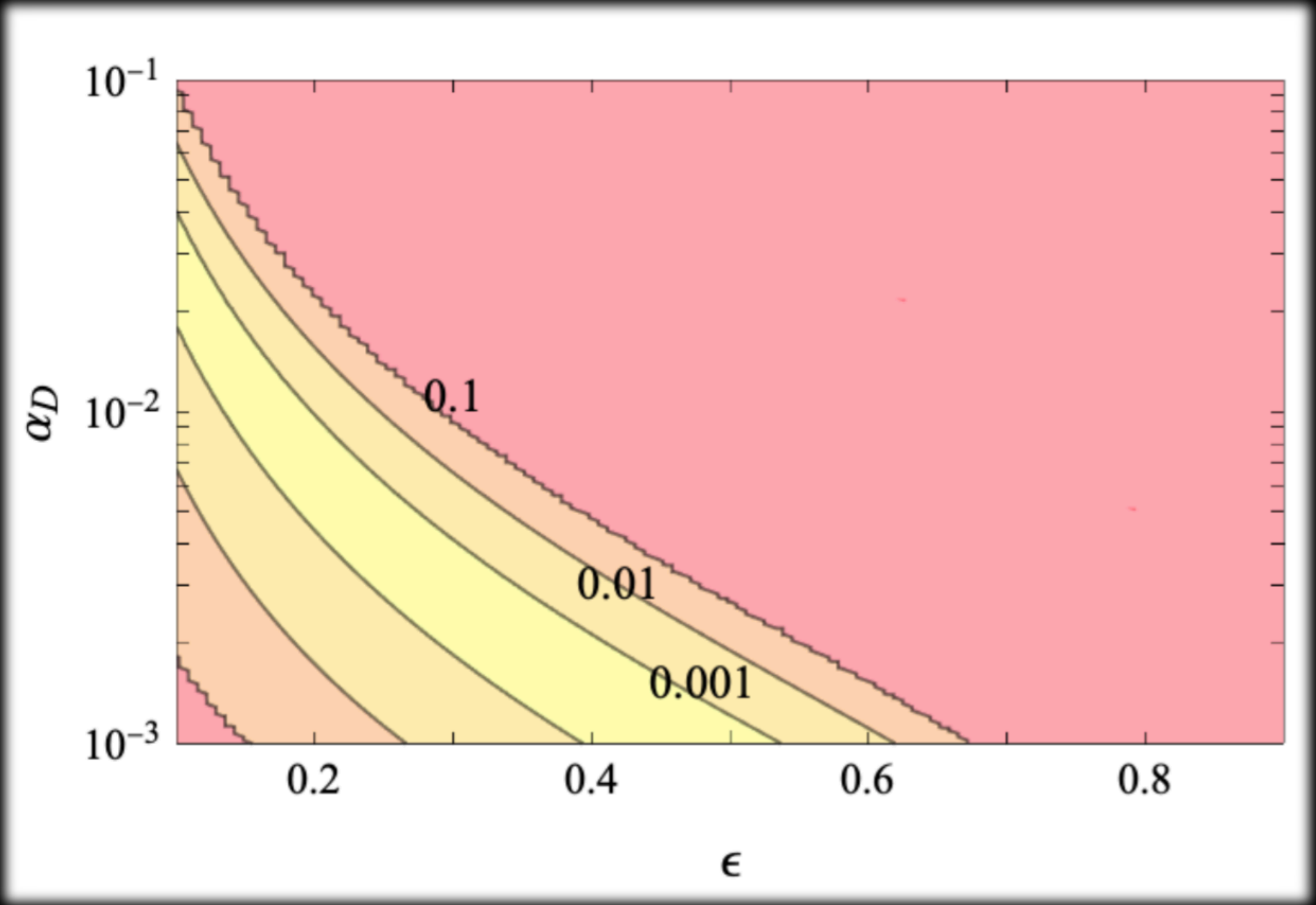
$$m^2_{A^0}(\alpha_{\rm eff}) = 2|\mu_{\rm eff}(\alpha_{\rm eff})|^2 + m^2_{H_u}(\alpha_{\rm eff}) + m^2_{H_d}(\alpha_{\rm eff})$$

$$m^2_{H^\pm, H^0, A^0} \simeq \frac{3y_t^2}{4\pi^2} m^2_{\tilde t}(\alpha_{\rm eff}) \left(\ln \frac{M_{\rm mess}}{m_{\tilde t}(\alpha_{\rm eff})} + \frac{3}{2} \right) \left(1 - \frac{1}{\cos(2\beta)} \right)$$

Relic messengers



Relic gravitinos

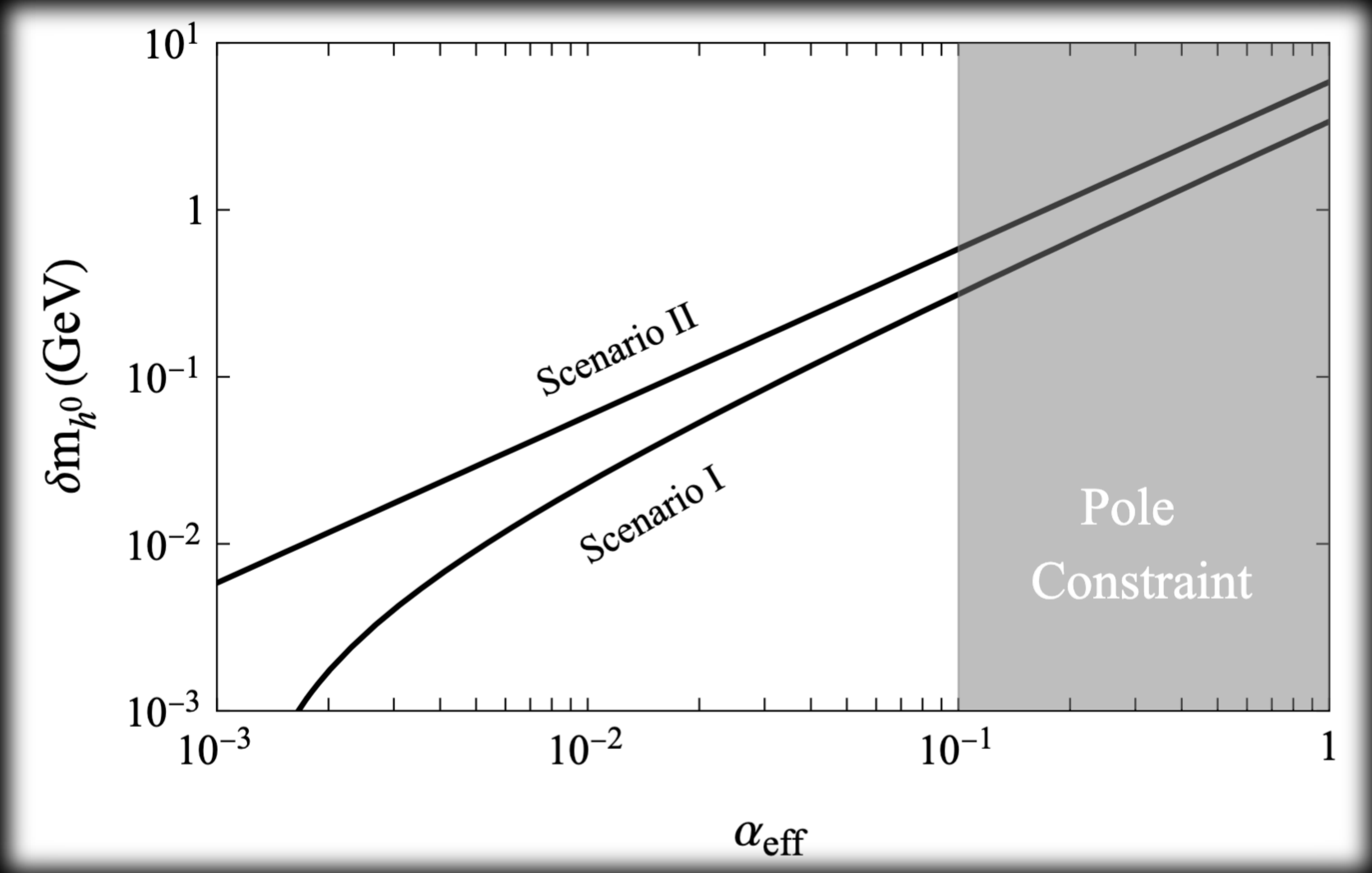


SM Higgs mass

$$m_{h^0}^2(\epsilon) \simeq m_Z^2 \cos^2 2\beta + \frac{3m_t^4}{4\pi^2 v^2} \ln\left(\frac{M_s^2(\epsilon)}{m_t^2}\right)$$

$$M_s(\epsilon) = \sqrt{m_{\tilde{t}_1}(\epsilon) m_{\tilde{t}_2}(\epsilon)}$$

$$\delta m_{h_0}^2(\epsilon) \simeq \frac{17 m_t^4}{64\pi^2 v^2} \frac{\sum_\Psi g_1^2 g_{\text{eff}} D_\Psi \left(-2 g_1 Y_\Psi + g_{\text{eff}} D_\Psi\right)}{\sum_\Psi g_3^4}$$



Higgs decay to neutralinos