# Top-flavored DM in DSMEFT

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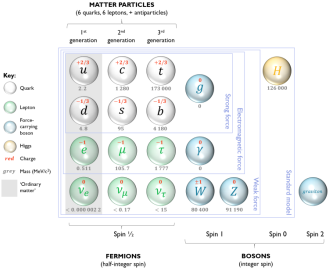
30 Nov. 2024

# Outline

# Motivation

M. Cirelli, A. Strumia and J. Zupan, arXiv:2406.01705
N. Aghanim *et al.* [Planck], arXiv:1807.06209

- Standard Model



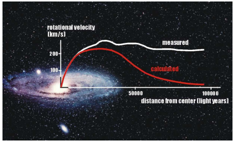
  - Why three generations of fermion?
  - What's dark matter made of?
  - ...

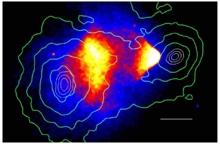
$\Rightarrow$ BSM

- Search for NP $\left\{ \begin{array}{l} \text{Direct: LHC} \\ \text{Indirect: Flavor physics} \end{array} \right.$

Flavor-Changing Neutral-Current (FCNC)

- Cosmological measurements
  - About $4\%$ ordinary matter
  - About $25\%$ dark matter



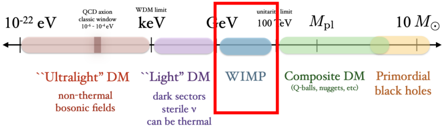


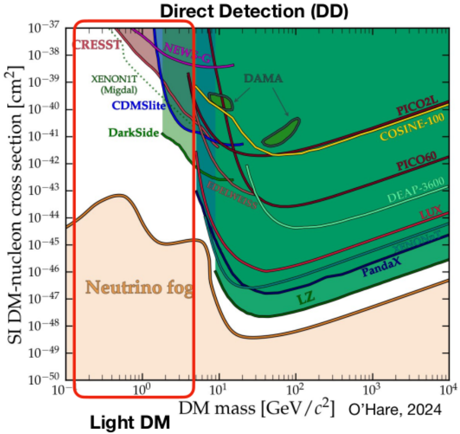
- Dark matter
  - WIMPs: good candidate
  - Assuming Big Bang, $\Omega h^2$
  - Electrically neutral
  - FC $\rightarrow \bar{q}_i q_i \phi$ or FCNC $\rightarrow \bar{q}_i q_j \phi (i \neq j)$

# Weakly interacting massive particles (WIMPs)

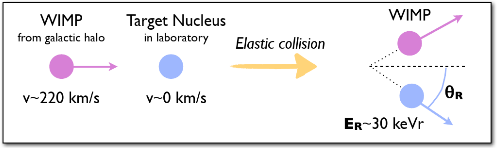
J. Cooley, SciPost Phys. Lect. Notes **55** (2022), 1. arXiv:2110.02359

- Mass spectrum





- Direct Detection

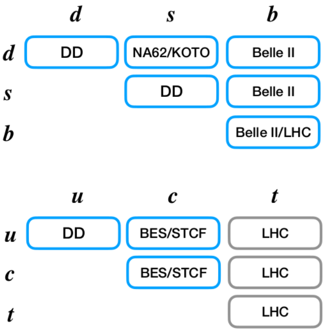


$$\frac{dR}{dE_R} = \frac{\rho_0}{m_\chi m_N} \int_{v_{min}}^{\infty} v f(\vec{v}) \frac{d\sigma_{\chi N}}{dE_R} d\vec{v}$$

# Light dark matter

Electrically neutral → FC: $\bar{q}_i q_i \phi$ or FCNC: $\bar{q}_i q_j \phi (i \neq j)$

B. Batell, T. Lin and L. T. Wang, arXiv:1309.4462
C. Kilic, M. D. Klimek and J. H. Yu, arXiv:1501.02202
M. Blanke and S. Kast, arXiv:1702.08457
J. Hermann and M. Worek, arXiv:2108.01089
E. Chalbaud, *et al.*, arXiv:2404.10852
… …

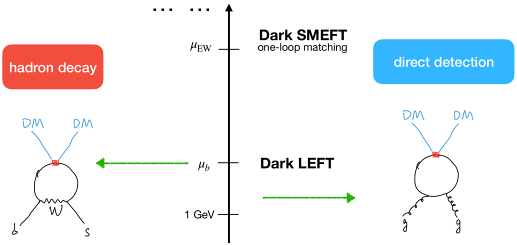


|  | ***d*** | ***s*** | ***b*** |
|---|---|---|---|
| ***d*** | DD | NA62/KOTO | Belle II |
| ***s*** |  | DD | Belle II |
| ***b*** |  |  | Belle II/LHC |

|  | ***u*** | ***c*** | ***t*** |
|---|---|---|---|
| ***u*** | DD | BES/STCF | LHC |
| ***c*** |  | BES/STCF | LHC |
| ***t*** |  |  | LHC |

▭ means related to the DM relic density

example:
$B^+ \to K^+ +$ DM + DM
$K^+ \to \pi^+ +$ DM + DM
$D^0 \to \pi^0 +$ DM + DM



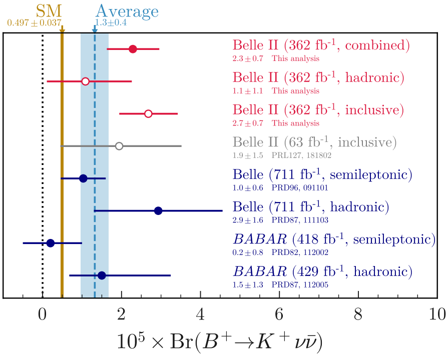
Exp: DM → Missing energy

SM: Missing energy → $\nu\bar{\nu}$

# $B$ decay: $b \to s + \text{inv}$

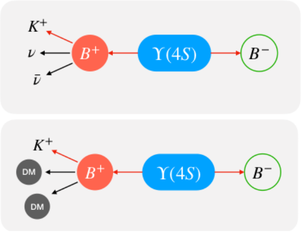
I. Adachi *et al.* [Belle-II], arXiv:2311.14647 (PRD)

- 2023 Aug Belle II



- Exp & SM $[10^{-6}]$

$$\left.\begin{aligned}\mathcal{B}(B^+ \to K^+ \nu\bar{\nu})_{\text{exp}} &= 23 \pm 7 \\ \mathcal{B}(B^+ \to K^+ \nu\bar{\nu})_{\text{SM}} &= 4.16 \pm 0.57\end{aligned}\right\} 2.7\sigma$$



Can it contribute to other $b \to s$ decay? $b \to d, s \to d$ decay?

# $B$ decay: $d_i \to d_j + \mathrm{DM}$

- $d_i \to d_j\phi\phi$
  C. Bird, *et al.*, arXiv:hep-ph/0401195
  J. F. Kamenik and C. Smith, arXiv:1111.6402
  G. Li, J. Y. Su and J. Tandean, arXiv:1905.08759
  X. G. He, *et al.*, arXiv:2005.02942
  C. Q. Geng and J. Tandean, arXiv:2009.00608
  G. Li, *et al.*, arXiv:2103.12921
  F. Kling, *et al.*, arXiv:2212.06186

- $d_i \to d_j\bar{\chi}\chi$
  J. F. Kamenik and C. Smith, arXiv:1111.6402
  J. Y. Su and J. Tandean, arXiv:1912.13507
  G. Li, *et al.*, arXiv:2004.10942
  T. Felkl, S. L. Li and M. A. Schmidt, arXiv:2111.04327

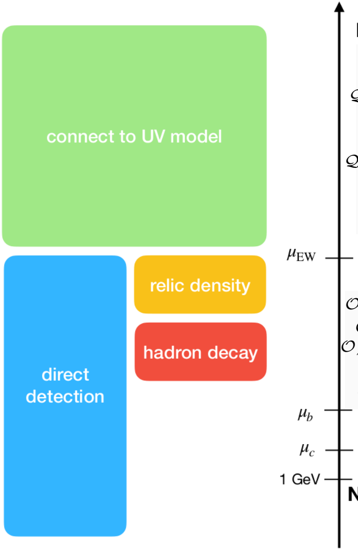
- $d_i \to d_jXX$
  J. F. Kamenik and C. Smith, arXiv:1111.6402
  G. Li, *et al.*, arXiv:2103.12921
  X. G. He, X. D. Ma and G. Valencia, arXiv:2209.05223

- $d_i \to d_ja$
  J. Martin Camalich, *et al.*, arXiv:2002.04623
  M. Bauer, *et al.*, arXiv:2110.10698
  A. W. M. Guerrera and S. Rigolin, arXiv:2211.08343

| Observable | unit | SM | EXP |
|---|---|---|---|
| $\mathcal{B}(B^+ \to K^+\nu\bar{\nu})$ | $10^{-6}$ | $(4.16 \pm 0.57)$ | $(23 \pm 7)$ |
| $\mathcal{B}(B^0 \to K^0\nu\bar{\nu})$ | $10^{-6}$ | $(3.85 \pm 0.52)$ | $< 26$ |
| $\mathcal{B}(B^+ \to K^{*+}\nu\bar{\nu})$ | $10^{-6}$ | $(9.70 \pm 0.94)$ | $< 61$ |
| $\mathcal{B}(B^0 \to K^{*0}\nu\bar{\nu})$ | $10^{-6}$ | $(9.00 \pm 0.87)$ | $< 18$ |
| $\mathcal{B}(B_s \to \phi\nu\bar{\nu})$ | $10^{-6}$ | $(9.93 \pm 0.72)$ | $< 5400$ |
| $\mathcal{B}(B^+ \to \pi^+\nu\bar{\nu})$ | $10^{-7}$ | $(1.40 \pm 0.18)$ | $< 140$ |
| $\mathcal{B}(B^0 \to \pi^0\nu\bar{\nu})$ | $10^{-8}$ | $(6.52 \pm 0.85)$ | $< 900$ |
| $\mathcal{B}(B^+ \to \rho^+\nu\bar{\nu})$ | $10^{-7}$ | $(4.06 \pm 0.79)$ | $< 300$ |
| $\mathcal{B}(B^0 \to \rho^0\nu\bar{\nu})$ | $10^{-7}$ | $(1.89 \pm 0.36)$ | $< 400$ |
| $\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu})$ | $10^{-11}$ | $(8.42 \pm 0.61)$ | $(10.6^{+4.0}_{-3.4} \pm 0.9)$ |
| $\mathcal{B}(K_L \to \pi^0\nu\bar{\nu})$ | $10^{-11}$ | $(3.41 \pm 0.45)$ | $< 300$ |
| $\mathcal{B}(B_s \to \mathrm{inv})$ | $10^{-4}$ | $\approx 0$ | $< 5.9$ |
| $\mathcal{B}(B^0 \to \mathrm{inv})$ | $10^{-4}$ | $\approx 0$ | $< 1.4$ |

# Effective Field Theory

approach to combine the various experimental searches, model-independent, complete operator basis



**Dark SMEFT** $SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$, all the SM particles

example

$$\mathcal{Q}_{u\phi^2} = (\bar{q}_p u_r \widetilde{H})\phi^2$$
$$\mathcal{Q}_{u\chi} = (\bar{u}_p \gamma_\mu u_r)(\bar{\chi}\gamma^\mu \chi)$$
$$\mathcal{Q}_{uX^2} = (\bar{q}_p u_r \widetilde{H}) X_\mu X^\mu$$
$$\mathcal{Q}_{qa} = (\bar{q}_p \gamma_\mu q_r)\partial^\mu a$$
$$\cdots$$

2011 Kamenik, Smith
2014 Duch, Grzadkowski, Wudka
2017 Brod, Gootjes-Dreesbach, Tammaro, Zupan
2021 Criado, Djouadi, Perez-Victoria, Santiago
2022 Aebischer, Altmannshofer, Jenkins, Manohar (basis@dim-6)
2023 Song, Sun, Yu (basis@dim-8)

Axion-like particle, see also H.Y.Cheng, Phys.Rept 1988

2020 Bauer, Neubert, Renner, Schnubel, Thamm
2023 Song, Sun, Yu (basis@dim-8)

**Dark LEFT** $SU(3)_C \otimes U(1)_{\rm em}$, $W, Z, h, t$ have been integrated out

$$\mathcal{O}_{u\phi^2} = (\bar{d}_p P_R d_r)\phi^2$$
$$\mathcal{O}_{u\chi} = (\bar{d}_p \gamma_\mu P_L d_r)(\bar{\chi}\gamma^\mu \chi)$$
$$\mathcal{O}_{uX^2} = (\bar{d}_p P_R d_r) X_\mu X^\mu$$
$$\mathcal{O}_{qa} = (\bar{d}_p \gamma_\mu P_L d_r)\partial^\mu a$$
$$\mathcal{O}_{g\phi} = G^a_{\mu\nu} G^{a,\mu\nu} \phi^2$$
$$\cdots$$

example

2022 Aebischer, Altmannshofer, Jenkins, Manohar (basis@dim-6)
2022 He, Ma, Valencia (basis@dim-6)
2023 Liang, Liao, Ma, Wang (basis@dim-8)

**NRET/HDMET/Chiral EFT**

$$\chi(x) = e^{-im_\chi v\cdot x}(\chi_v(x) + X_v(x))$$

2011 Hill, Solon
2012 Fitzpatrick, Haxton, Katz, Lubbers, Xu
2013 Hill, Solon
2013 Anand, Fitzpatrick, Haxton
2016 Bishara, Brod, Grinstein, Zupan

# Top-flavored DM

- Dark SMEFT with 3rd generation at $\mu_{\mathrm{EW}}$

$$\mathcal{Q}_{u\phi^2} = (\bar{q}_p u_r \widetilde{H})\phi^2, \quad \Longrightarrow \quad (\bar{t}_L t_R)\phi^2$$

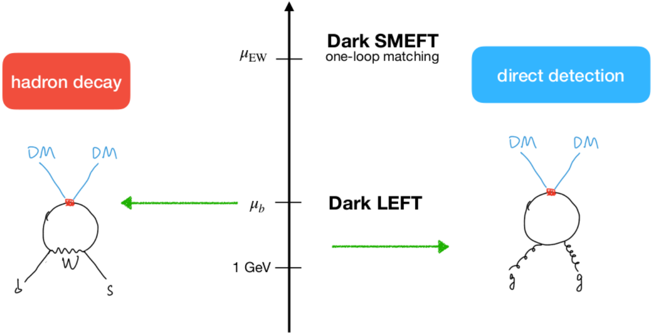
$$\mathcal{C} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix} \mathcal{C}_{33}$$

B. Batell, T. Lin and L. T. Wang, arXiv:1309.4462
I. Boucheneb, *et al.*, arXiv:1407.7529
C. Kilic, M. D. Klimek and J. H. Yu, arXiv:1501.02202
U. Haisch and E. Re, arXiv:1503.00691
M. Blanke and S. Kast, arXiv:1702.08457
U. Haisch, G. Polesello and S. Schulte, arXiv:2107.12389
J. Hermann and M. Worek, arXiv:2108.01089
E. Chalbaud, *et al.*, arXiv:2404.10852
… …
M. Aaboud *et al.* [ATLAS], arXiv:1903.01400

$$\mathcal{O}_{d\phi^2} = (\bar{d}_p P_R d_r)\phi^2$$
$$\mathcal{O}^{L}_{dXX} = (\bar{d}_p \gamma^\mu P_L d_r) X_{\mu\nu} X^\nu$$
$$\mathcal{O}^{V,LR}_{d\chi} = (\bar{d}_p \gamma_\mu P_L d_r)(\bar{\chi}\gamma^\mu\chi),$$

+ $\mathcal{O}(20)$ operators

$$\langle H_2 | \mathcal{O}_i | H_1 \rangle$$



$$\mathcal{O}_{g\phi} = G^a_{\mu\nu} G^{\mu\nu,a} \phi^2,$$
$$\mathcal{O}_{gX} = G^a_{\mu\nu} G^{\mu\nu,a} X_\rho X^\rho,$$
$$\mathcal{O}_{g\chi} = G^a_{\mu\nu} G^{\mu\nu,a} \bar{\chi}\chi$$

+ operators with $u, d, s$

$$\langle N | \mathcal{O}_j | N \rangle$$

# B decay in DSMEFT

J. Aebischer, *et al.*, JHEP **06** (2022), 086, arXiv:2202.06968
H. Song, H. Sun and J. H. Yu, JHEP **05** (2024), 103, arXiv:2306.05999

**Can DSMEFT operators explain the Belle II excess, while satisfy other $b \to s$ bounds ?**

| Observable | unit | SM | EXP |
|---|---|---|---|
| $\mathcal{B}(B^+ \to K^+ \nu\bar\nu)$ | $10^{-6}$ | $(4.16 \pm 0.57)$ | $(23 \pm 7)$ |
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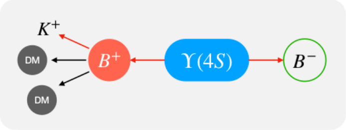
$$\mathcal{M} \propto L_i \cdot \langle H_2 | \mathcal{O}_i | H_1 \rangle$$

$$d\Gamma = \frac{1}{2E_{\text{CM}}} |\mathcal{M}|^2 d\Pi_n$$



$$\mathcal{L}_{\text{DSMEFT}} \supset \frac{1}{\Lambda^{d-4}} \sum_i \mathcal{C}_i \mathcal{Q}_i^{(d)}$$

$$\mathcal{L}_{\text{DLEFT}} \supset \frac{1}{v e v^{d-4}} \sum_i L_i \mathcal{O}_i^{(d)}$$

$\mu_{\text{EW}}$

**Dark SMEFT**

$$\begin{array}{llr}
\mathcal{Q}_{u\phi} = (\bar q_p u_r \widetilde H)\phi + \text{h.c.}, & \mathcal{Q}_{u\phi^2} = (\bar q_p u_r \widetilde H)\phi^2 + \text{h.c.}, & 4 \\
\mathcal{Q}_{q\chi} = (\bar q_p \gamma_\mu q_r)(\bar\chi \gamma^\mu \chi), & \mathcal{Q}_{u\chi} = (\bar u_p \gamma_\mu u_r)(\bar\chi \gamma^\mu \chi), & 3 \\
\mathcal{Q}_{uHX} = (\bar q_p \sigma_{\mu\nu} u_r \widetilde H) X^{\mu\nu} + \text{h.c.}, & \mathcal{Q}_{uX^2} = (\bar q_p u_r \widetilde H) X^\mu X_\mu + \text{h.c.}, & 1 + 13 \\
\mathcal{Q}_{qa} = (\bar q_p \gamma_\mu q_r)\partial^\mu a, & \mathcal{Q}_{ua} = (\bar u_p \gamma_\mu u_r)\partial^\mu a. & 2
\end{array}$$

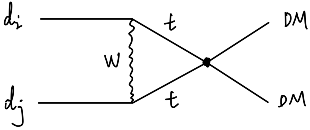
**Dark LEFT**

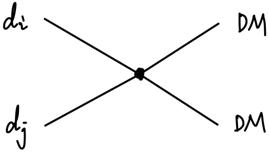
$\mu_b$

$$\begin{array}{llr}
\mathcal{O}_{d\phi} = (\bar d_p P_R d_r)\phi + \text{h.c.}, & \mathcal{O}_{d\phi^2} = (\bar d_p P_R d_r)\phi^2 + \text{h.c.}, & 4 \\
\mathcal{O}_{d\chi}^{V,RR} = (\bar d_p \gamma_\mu P_R d_r)(\bar\chi \gamma^\mu \chi), & \mathcal{O}_{d\chi}^{V,LR} = (\bar d_p \gamma_\mu P_L d_r)(\bar\chi \gamma^\mu \chi), & 5 \\
\mathcal{O}_{d\widetilde X}^{T} = (\bar d_p \sigma^{\mu\nu} P_R d_r)\widetilde X_{\mu\nu} + \text{h.c.}, & \mathcal{O}_{dX^2} = (\bar d_p P_R d_r) X_\mu X^\mu + \text{h.c.}, & 1 + 10 \\
\mathcal{O}_{da}^{L} = (\bar d_p \gamma_\mu P_L d_r)\partial^\mu a, & \mathcal{O}_{da}^{L} = (\bar d_p \gamma_\mu P_R d_r)\partial^\mu a, & 2 \\
\mathcal{O}_{g\phi} = G^a_{\mu\nu} G^{\mu\nu,a} \phi^2, & \mathcal{O}_{\phi\gamma} = F_{\mu\nu} F^{\mu\nu} \phi^2. & 8
\end{array}$$

# One-loop matching @ $\mu = m_W$

- Quark & DM operators
  - DSMEFT $\mathcal{Q}_{u\phi^2} = (\bar{q}_p u_r \widetilde{H})\phi^2 + \text{h.c.}$
  - LEFT $\mathcal{O}_{d\phi^2} = (\bar{d}_p P_R d_r)\phi^2 + \text{h.c.}$





$$\mathcal{M} \propto V_{ti}^* V_{tj} [\mathcal{C}_{u\phi^2}]_{33} S(m_k, \mu) \langle [\mathcal{O}_{d\phi^2}]_{ij} \rangle + \cdots$$

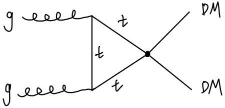
$$\mathcal{A} = [L_{d\phi^2}]_{ij} \langle [\mathcal{O}_{d\phi^2}]_{ij} \rangle$$

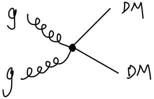
- Matching @ $\mu = m_W$

$$[L_{d\phi^2}]_{ij} = V_{ti}^* V_{tj} [\mathcal{C}_{u\phi^2}]_{33} S(m_i, \mu),$$

# Anomaly matching @ $\mu = m_W$

- Boson & DM operators
  - DSMEFT $\mathcal{Q}_{u\phi^2} = (\bar{q}_p u_r \widetilde{H})\phi^2 + \text{h.c.}$
  - DLEFT $\mathcal{O}_{g\phi^2} = G^a_{\mu\nu} G^{a,\mu\nu} \phi^2$





$$\frac{vev}{2\sqrt{2}}[\bar{t}(1+\gamma_5)t + \bar{t}(1-\gamma_5)t]\phi^2 = \frac{vev}{\sqrt{2}}\bar{t}t\phi^2$$

$$m_t \bar{t}t \to -\frac{\alpha_s}{12\pi} G^a_{\mu\nu} G^{a,\mu\nu}$$

M. A. Shifman, A. I. Vainshtein and V. I. Zakharov, Phys. Lett. B **78** (1978), 443-446

- WC @ $\mu = m_W$

$$m_t \bar{t}t\phi^2 \to \quad -\frac{\alpha_s}{12\pi} G^a_{\mu\nu} G^{a,\mu\nu}\phi^2$$

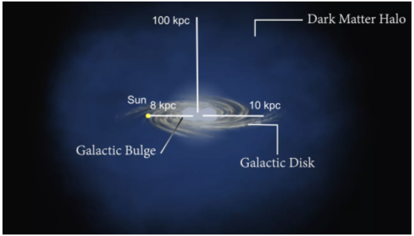
$$L_{g\phi^2} = -\frac{vev^2}{\Lambda^2}\frac{\alpha_s vev}{12\sqrt{2}\pi m_t}(\mathcal{C}_{u\phi^2})_{33}$$

# Where we start?

J. Cooley, SciPost Phys. Lect. Notes **55** (2022), 1. arXiv:2110.02359
J. I. Read, J. Phys. G **41** (2014), 063101. arXiv:1404.1938

## We know almost nothing about dark matter except for:

- Equation of state → Non-relativistic particles
- Total energy density
  - $25\%$ of the total energy density
  - About six times of the energy density of baryons
- Its velocity around the earth
  - About $200\ \mathrm{km/sec}$
- Energy density around the earth
  - $0.4\ \mathrm{GeV/cm^2} \rightarrow 22.4\mathrm{mol/L}^{\sim}1\mathrm{Pa}$



# Direct Detection

- Nucleon matrix

E. Del Nobile, arXiv:2104.12785

$$\langle N|\mathcal{O}_{d\phi^2}|N\rangle =\langle N|\bar{d}d|N\rangle\langle\phi^2\rangle = \frac{m_N}{m_d} f^N_{T_q}\langle\phi^2\rangle$$

$$\langle N|\mathcal{O}_{g\phi^2}|N\rangle = -\frac{9\alpha_s}{8\pi}\langle N|G^a_{\mu\nu}G^{a,\mu\nu}|N\rangle\langle\phi^2\rangle = m_N f^N_{T_G}\langle\phi^2\rangle$$

- For $N_f = 3$ quark flavors:

J. Hisano, R. Nagai and N. Nagata, JHEP **05** (2015), 037. arXiv:1502.02244.

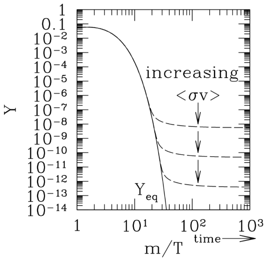
$$\Theta^\mu_\mu = -\frac{9\alpha_s}{8\pi}G^a_{\mu\nu}G^{a,\mu\nu} + \sum_{u,d,s} m_q\bar{q}q, \qquad m_N =\langle N|\Theta^\mu_\mu|N\rangle$$

$$f^N_{T_G} \equiv 1 - \Sigma_{q=u,d,s} f^N_{T_q}$$

- Differential event rate

$$\frac{dR}{dE_R} = \frac{\rho_0}{m_\chi m_N}\int_{v_{min}}^{\infty} v f(\vec{v})\frac{d\sigma_{\chi N}}{dE_R}d\vec{v}$$

# Relic density



- Boltzmann equation

$$\frac{dn}{dt} + 3Hn = -\langle \sigma v \rangle \left[ (n)^2 - (n^{eq})^2 \right],$$

$$\frac{dY}{dx} = -\frac{\lambda \langle \sigma v \rangle}{x^2} (Y^2 - Y_{eq}^2) \Longleftarrow \begin{cases} Y = n/s \\ x = m/T \end{cases}$$

- The thermal average cross section

G. Bertone, D. Hooper and J. Silk, Phys. Rept. **405** (2005), 279-390, arXiv:hep-ph/0404175

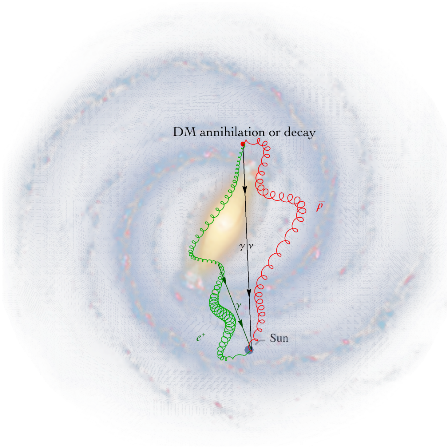
$$\langle \sigma v \rangle = \frac{4x}{K_2^2(x)} \int_0^\infty d\epsilon \epsilon \sqrt{1+\epsilon} K_1(2x\sqrt{1+\epsilon}) \sigma, \quad \epsilon = \frac{s - 4m^2}{4m^2}$$

- The DM abundance

J. Aebischer, *et al.*, JHEP **06** (2022), 086, arXiv:2202.06968
S. Navas *et al.* [PDG], Phys. Rev. D **110** (2024) no.3, 030001

$$\Omega h^2 = \frac{h^2 s_0}{\rho_{crit}} mY \Longleftarrow \begin{cases} \rho_{crit} = 1.053672(24) \times 10^{-5} h^2 \mathrm{GeV/cm^2} \\ s_0 = 2891.2(1.9)/\mathrm{cm}^3 \end{cases}$$

# Indirect Detection



K. K. Boddy and J. Kumar, Phys. Rev. D **92** (2015) no.2, 023533, arXiv:1504.04024

- The upper limit $\quad \mathrm{DM} + \mathrm{DM} \to \gamma\gamma$

$$\langle \sigma v \rangle \lesssim 3 \times 10^{-28} \left( \frac{m_{\mathrm{DM}}}{\mathrm{GeV}} \right) \ \mathrm{cm}^3/\mathrm{s}$$

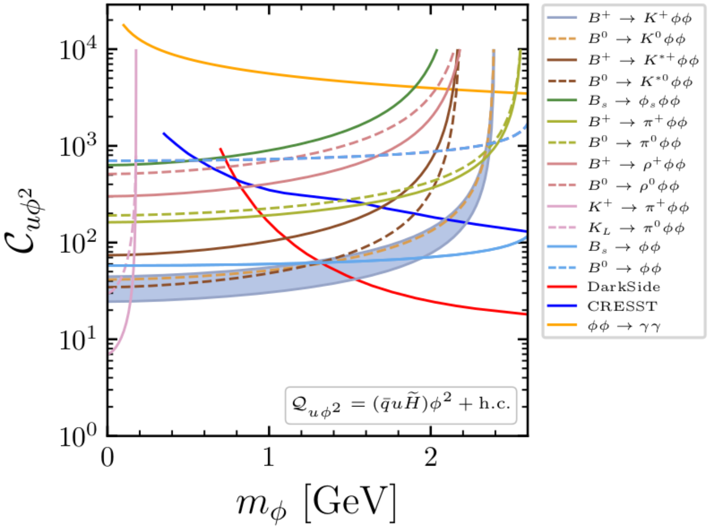
- The thermally averaged cross section

$$\langle \sigma v(\phi\phi \to \gamma\gamma) \rangle \simeq \frac{8}{\pi} \frac{m_\phi^2}{vev^4} |L_{\phi\gamma}|^2,$$

$$\langle \sigma v(XX \to \gamma\gamma) \rangle \simeq \frac{8}{3\pi} \frac{m_X^2}{vev^4} |L_{X\gamma}|^2,$$

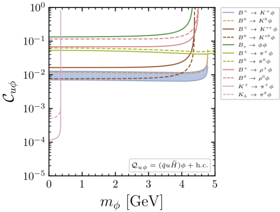
$$\langle \sigma v(\bar{\chi}\chi \to \gamma\gamma) \rangle \simeq \frac{1}{\pi} \frac{m_\chi^4}{vev^6} |L_{\chi\gamma}|^2.$$

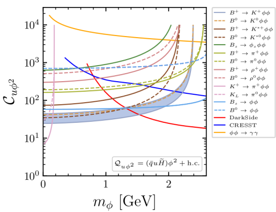
# Scalar DM

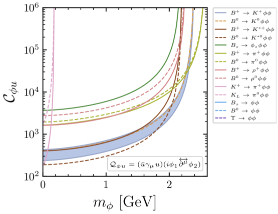


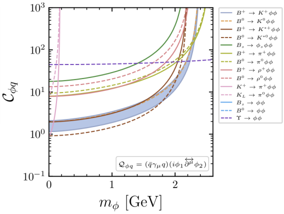
- Little mass
  - $B^0 \to K^{*0} + \text{inv}$
  - $K$ decay
- Large mass
  - $B_s \to \text{inv}$
- Direct detection
  - meson decay precision
  - stronger constraints

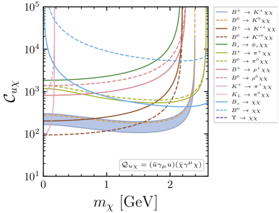
# Scalar or Fermionic DM

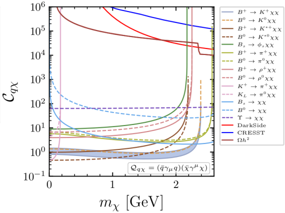


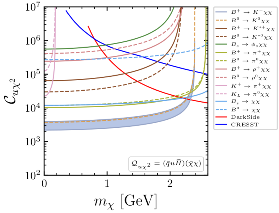




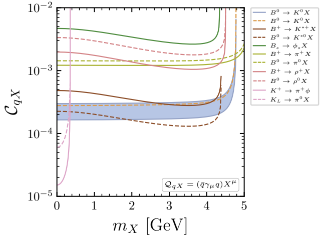




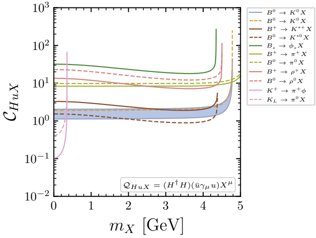




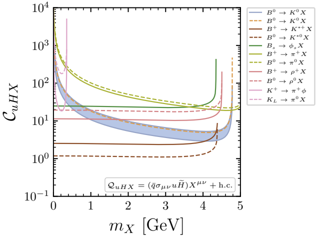
# Vector DM



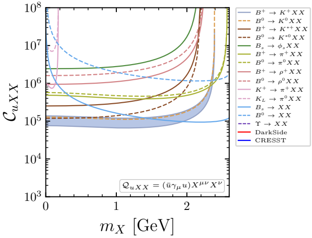
$10^{-2}$
$10^{-3}$
$10^{-4}$
$10^{-5}$
$\mathcal{C}_{qX}$
0
1
2
3
4
5
$m_X$ [GeV]
$\mathcal{Q}_{qX} = (\bar{q}\gamma_\mu q)X^\mu$
$B^0 \to K^0 X$
$B^0 \to K^0 X$
$B^+ \to K^{*+} X$
$B^0 \to K^{*0} X$
$B_s \to \phi_s X$
$B^+ \to \pi^+ X$
$B^0 \to \pi^0 X$
$B^+ \to \rho^+ X$
$B^0 \to \rho^0 X$
$K^+ \to \pi^+ \phi$
$K_L \to \pi^0 X$



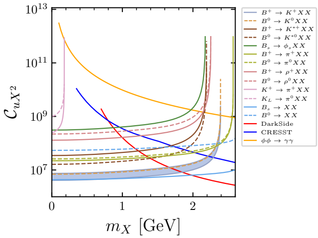
$10^{3}$
$10^{2}$
$10^{1}$
$10^{0}$
$10^{-1}$
$10^{-2}$
$\mathcal{C}_{HuX}$
0
1
2
3
4
5
$m_X$ [GeV]
$\mathcal{Q}_{HuX} = (H^\dagger H)(\bar{u}\gamma_\mu u)X^\mu$
$B^0 \to K^0 X$
$B^0 \to K^0 X$
$B^+ \to K^{*+} X$
$B^0 \to K^{*0} X$
$B_s \to \phi_s X$
$B^+ \to \pi^+ X$
$B^0 \to \pi^0 X$
$B^+ \to \rho^+ X$
$B^0 \to \rho^0 X$
$K^+ \to \pi^+ \phi$
$K_L \to \pi^0 X$



$10^{4}$
$10^{3}$
$10^{2}$
$10^{1}$
$10^{0}$
$10^{-1}$
$\mathcal{C}_{uHX}$
0
1
2
3
4
5
$m_X$ [GeV]
$\mathcal{Q}_{uHX} = (\bar{q}\sigma_{\mu\nu} u \tilde{H})X^{\mu\nu} + \text{h.c.}$
$B^0 \to K^0 X$
$B^0 \to K^0 X$
$B^+ \to K^{*+} X$
$B^0 \to K^{*0} X$
$B_s \to \phi_s X$
$B^+ \to \pi^+ X$
$B^0 \to \pi^0 X$
$B^+ \to \rho^+ X$
$B^0 \to \rho^0 X$
$K^+ \to \pi^+ \phi$
$K_L \to \pi^0 X$



$10^{8}$
$10^{7}$
$10^{6}$
$10^{5}$
$10^{4}$
$10^{3}$
$\mathcal{C}_{uXX}$
0
1
2
$m_X$ [GeV]
$\mathcal{Q}_{uXX} = (\bar{u}\gamma_\mu u)X^{\mu\nu}X^\nu$
$B^+ \to K^+ XX$
$B^0 \to K^0 XX$
$B^+ \to K^{*+} XX$
$B^0 \to K^{*0} XX$
$B_s \to \phi_s XX$
$B^+ \to \pi^+ XX$
$B^0 \to \pi^0 XX$
$B^+ \to \rho^+ XX$
$B^0 \to \rho^0 XX$
$K^+ \to \pi^+ XX$
$K_L \to \pi^0 XX$
$B_s \to XX$
$B^0 \to XX$
$\Upsilon \to XX$
DarkSide
CRESST



$10^{13}$
$10^{11}$
$10^{9}$
$10^{7}$
$\mathcal{C}_{uX^2}$
0
1
2
$m_X$ [GeV]
$B^+ \to K^+ XX$
$B^0 \to K^0 XX$
$B^+ \to K^{*+} XX$
$B^0 \to K^{*0} XX$
$B_s \to \phi_s XX$
$B^+ \to \pi^+ XX$
$B^0 \to \pi^0 XX$
$B^+ \to \rho^+ XX$
$B^0 \to \rho^0 XX$
$K^+ \to \pi^+ XX$
$K_L \to \pi^0 XX$
$B_s \to XX$
$B^0 \to XX$
DarkSide
CRESST
$\phi\phi \to \gamma\gamma$

# Summary

In DSMEFT framework,

- Combining meson decays with DD experiments by the top-DM couplings.
- Calculating the branching ratios of $b \to s, b \to d$ and $s \to d + \mathrm{inv}$ transitions.
- Constraining the corresponding WCs using experimental data.

Belle II measurement of $B^+ \to K^+ + \mathrm{inv}$ allow parameter regions:

- For most operators, $B^0 \to K^{*0} + \mathrm{inv}$ decay provides the strongest constraints.
- For some operators (e.g. $\mathcal{Q}_{u\phi^2}, \cdots$), $B_s \to \mathrm{inv}$ can exclude the large mass regions.
- For $\mathcal{Q}_{u\phi^2}, \mathcal{Q}_{u\chi^2}, \mathcal{Q}_{uX^2}$, DD experiments can further exclude the large mass regions.
- Indirect detection are far weaker than meson decay limits.

# Thank You !