WIMPless Dark Matter and Meson Decays with Missing Energy

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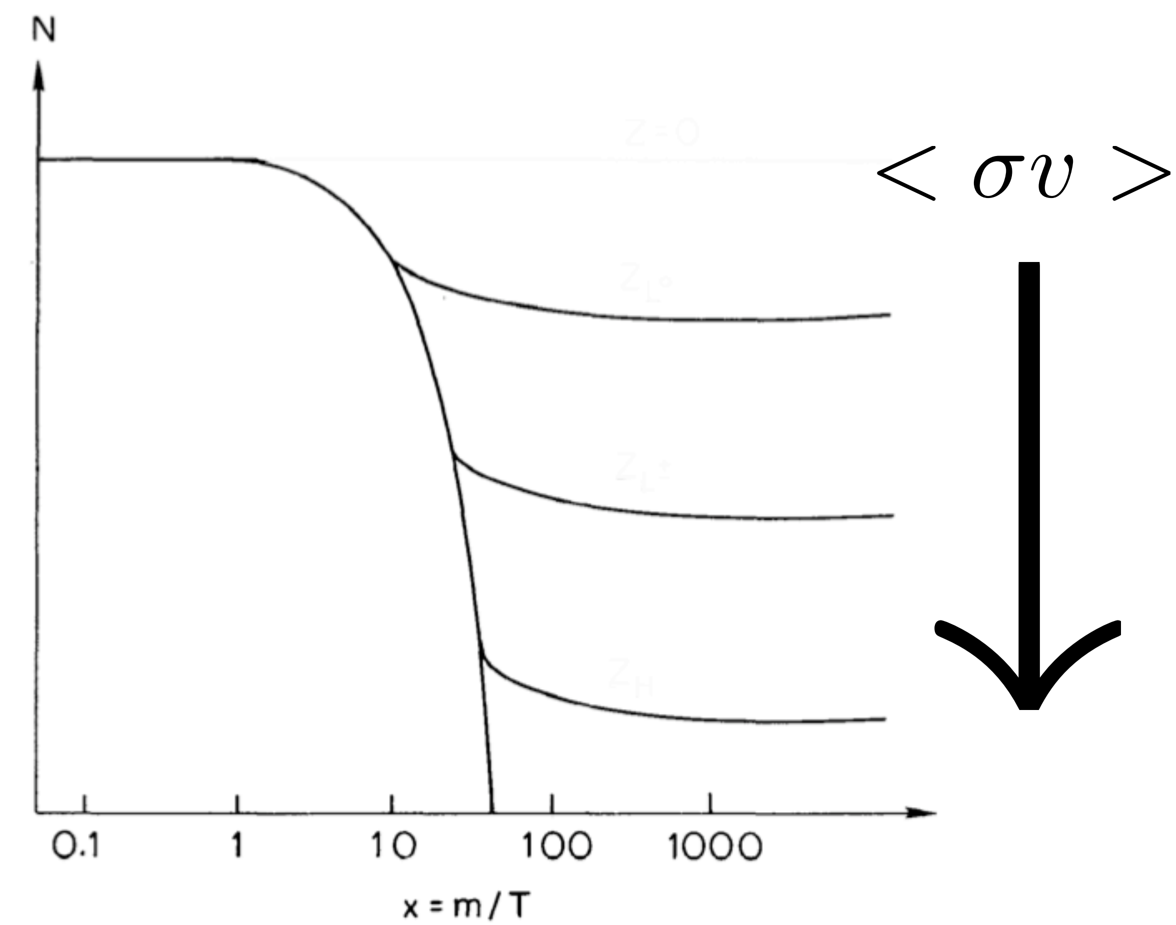
Outline

- WIMP(less) Dark Matter
- Phenomenological connector between SM and Hidden Sector
- χ_{b0} decays
- b-s coupling Δm_s
  $B^+ \to K^+ + \text{inv.}$

based on arXiv:0903.4982

Dark Matter

- Dark Matter accounts for ~25% of the Universe's energy density
- For Thermal Relics: $\Omega \simeq 0.23 \left(\frac{1 \text{ pb}}{< \sigma v >} \right) \sim \frac{m^2}{g^4}$



WIMP “Miracle”

- For weak scale masses and couplings we find a relic density that’s approximately correct

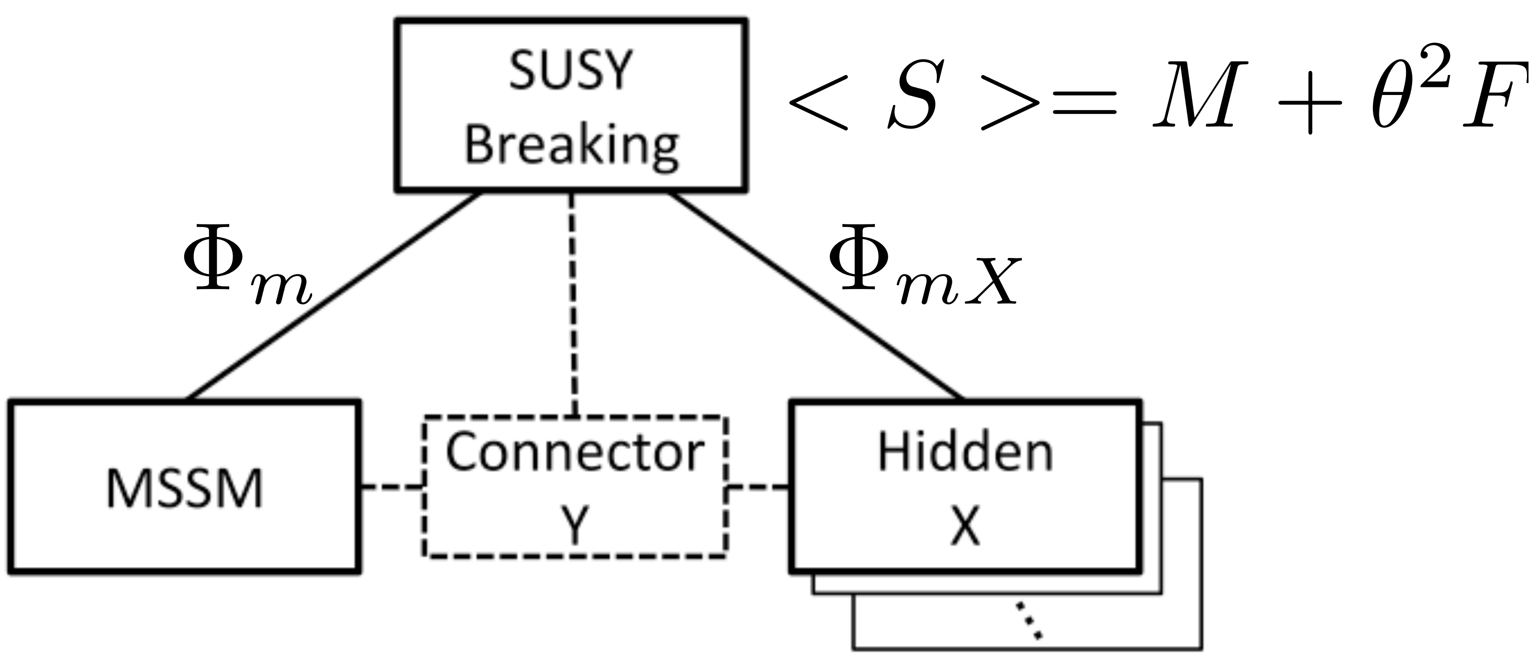
$$< \sigma v > \simeq 1 \text{ pb} \Rightarrow \Omega \simeq 0.25$$

J. L. Feng and J. Kumar,arXiv:0803.4196

WIMPless DM

$$W = \lambda \bar{\Phi}_m S \Phi_m + \lambda_X \bar{\Phi}_{mX} S \Phi_{mX}$$

$$M_m = \lambda M,\ F_m = \lambda F \quad M_{mX} = \lambda_X F,\ F_{mX} = \lambda_X F$$



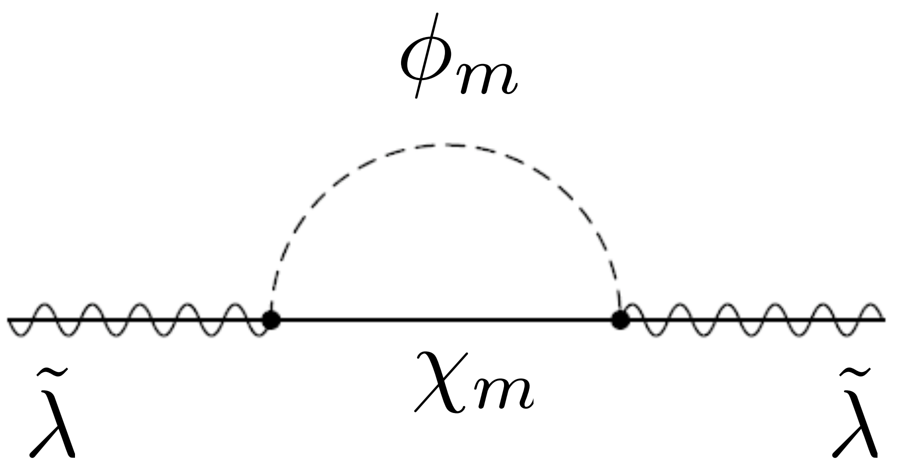
J. L. Feng and J. Kumar,arXiv:0803.4196

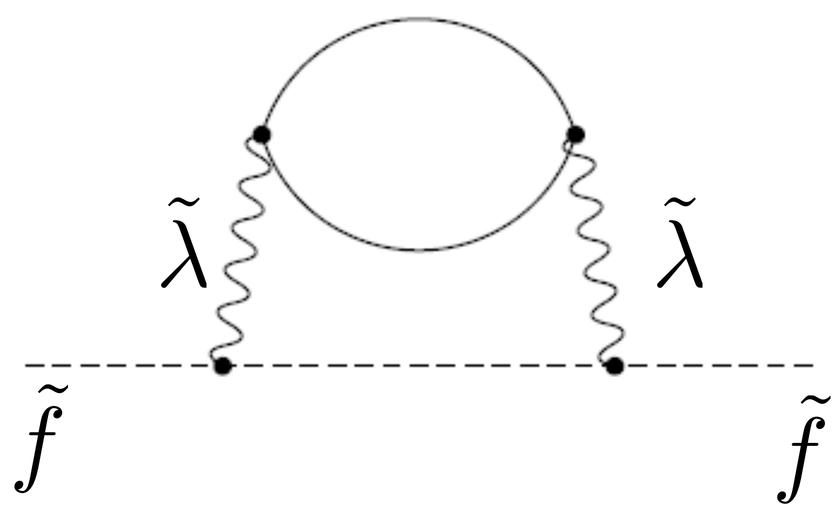
WIMPless "Miracle"

$$m \sim \frac{g^2}{16\pi^2}\frac{F_m}{M_m} = \frac{g^2}{16\pi^2}\frac{F}{M} \sim m_W$$

$$m_X \sim \frac{g_X^2}{16\pi^2}\frac{F_{mX}}{M_{mX}} = \frac{g_X^2}{16\pi^2}\frac{F}{M}$$

$$\frac{m^2}{g^4} \sim \frac{m_X^2}{g_X^4} \Rightarrow \Omega_X \sim 0.25$$





J. L. Feng and J. Kumar, arXiv:0803.4196

WIMPless "Miracle"

- Easy to imagine scenarios with no gravitino problem--an "accident" in MSSM
- They can account for dark matter:

$$\Omega_X \sim \frac{g_X^4}{m_X^4} \sim 0.25$$

- Their mass is not tied to the weak scale--can account for dark matter with a wide range of masses (~10 MeV-10 TeV) and couplings

Works in Practice?

- Shown by Feng, Tu, Yu in JCAP **0810**, 043 ('08) that hidden sector, single flavor, copy of SM with O(1) Yukawas satisfies BBN, relic density constraints
- Hidden "stau" DM -- no problem from hidden Compton scattering if hidden coupling g_X not too large
- See Hai-Bo Yu's talk

J. L. Feng and J. Kumar, arXiv:0803.4196

Connectors between SM and Hidden Sector

- Interaction between SM and Hidden Sector could be enhanced by particles with quantum numbers in both sectors
- “Generic” in string-inspired intersecting brane models
- Phenomenologically interesting

J. L. Feng and J. Kumar, arXiv:0803.4196

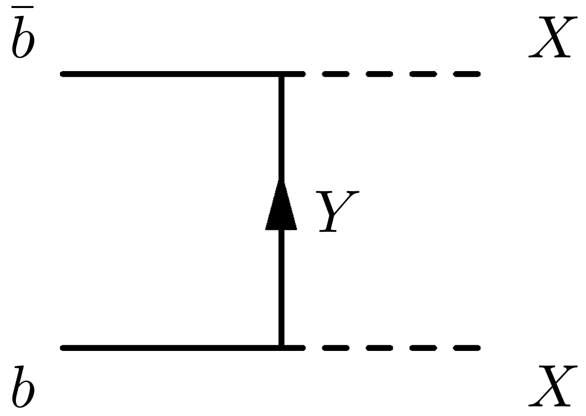
"4th Gen. quark" Connector & Scalar DM

- Couple fermion Y to hidden sector DM particle X and SM fermion f

$$\mathcal{L}_{\rm int} = \lambda_f X \bar{Y}_L f_L + \lambda_f X \bar{Y}_R f_R - m_Y \bar{Y}_L Y_R$$

- Consider only the coupling to bottom quarks for now $\Big($Kribs, Plehn, Spannowsky, Tait, ArXiv:0706.3718 $\Rightarrow m_Y > 258$ GeV$\Big)$
- Generates invisible bottomonium decays and spin-indep. cross section for scattering off a nucleon--direct detection

Invisible Bottomonium Decays



$$i\mathcal{M}(b\bar{b} \to XX) \quad \simeq -\frac{2i\lambda_b^2}{m_Y}\bar{v}(p')u(p)$$

- Induces $\chi_{b0} \to XX$

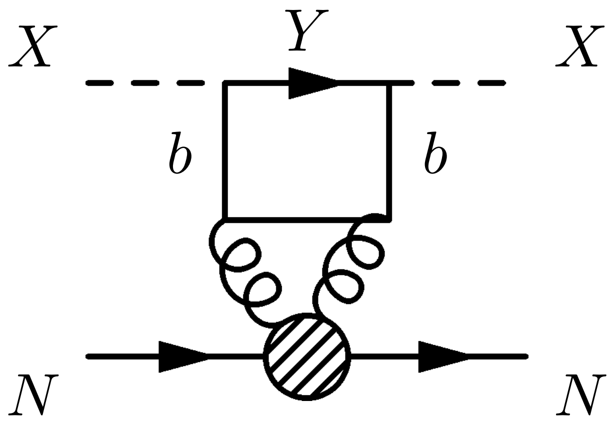
$$\mathcal{B}(\Upsilon(2S) \to \gamma\chi_{b0}(1P) \to \gamma XX) \simeq (4.9 \pm 0.5) \times 10^{-6}\lambda_b^4 \left(\frac{400\ \mathrm{GeV}}{m_Y}\right)^2 \sqrt{1 - \frac{4m_X^2}{M_{\chi_{b0}}^2}}$$

- About (1/fb) at CLEO on Y(2S). Background? Radiative Bhabha: $\frac{d\sigma}{d\cos\theta} \simeq (75\ \mathrm{pb}) \left[\frac{1+\cos^2\theta}{(1-\cos^2\theta)^2}\right]$

- Can probe $\mathcal{B}(\Upsilon(2S) \to \gamma XX) \sim 10^{-4}$

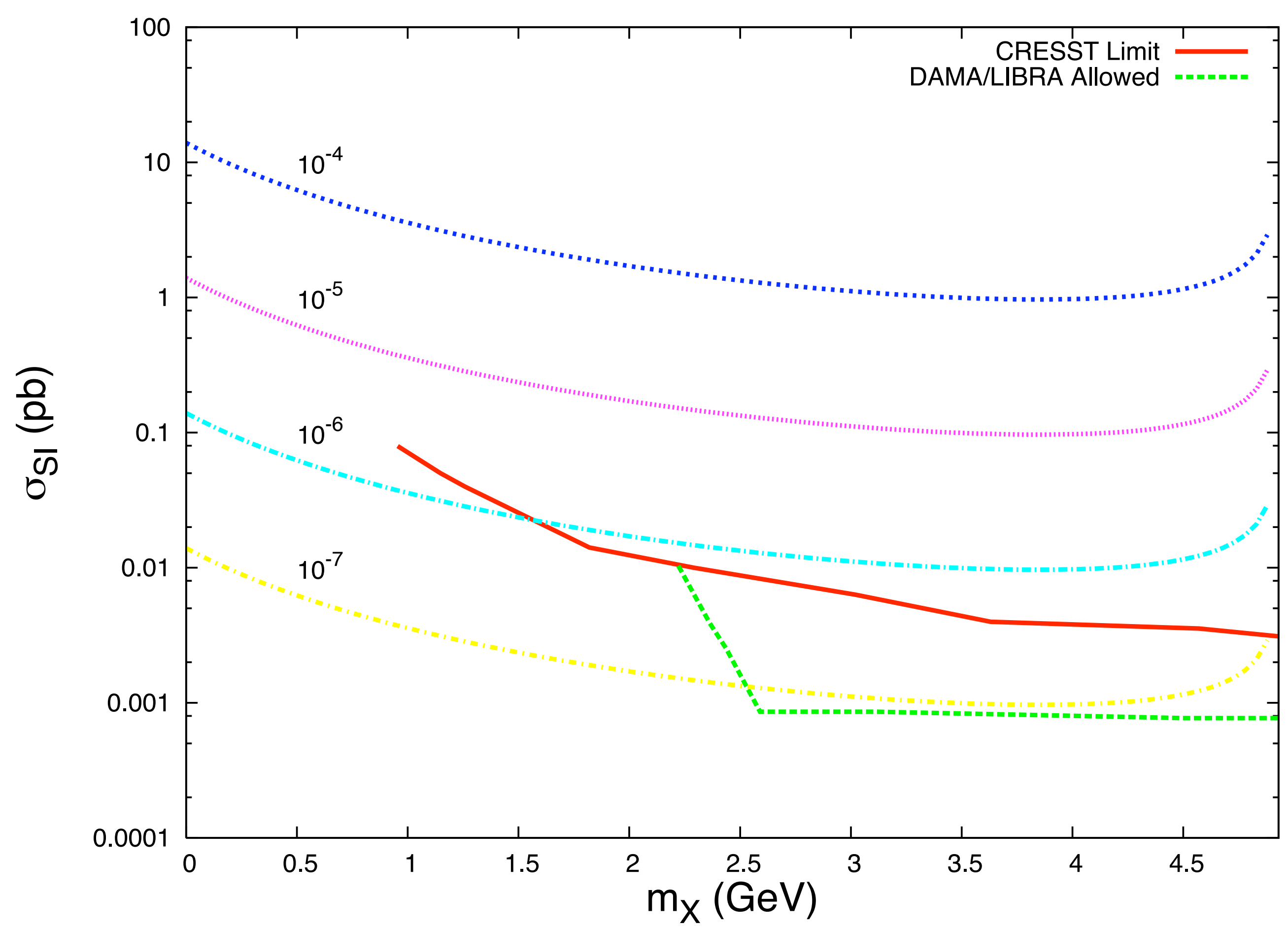
$$\lambda_b^2 \sim 4,\ m_X = 1\ \mathrm{GeV},\ m_Y = 400\ \mathrm{GeV}$$

Direct Detection

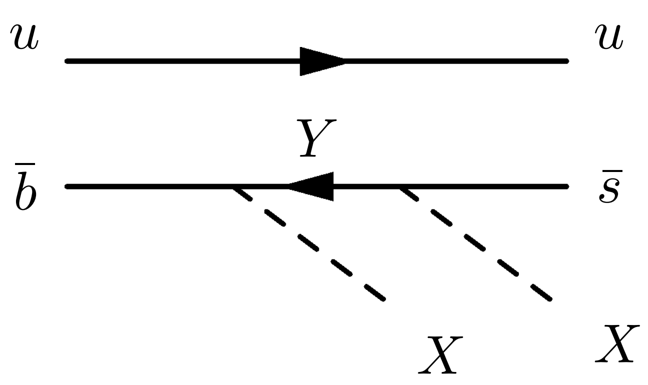


$$\sigma_{\rm SI} = \frac{\lambda_b^4}{4\pi} \frac{m_N^2 \left[Z B_b^p + (A-Z) B_b^n \right]^2}{A^2 \left(m_N + m_X \right)^2 \left(m_Y - m_X \right)^2}$$

$$B_b^{p,n} = (2/27) m_N f_g^{p,n} / m_b$$



Strange quarks too?



$$B^+ \to K^+ X X$$

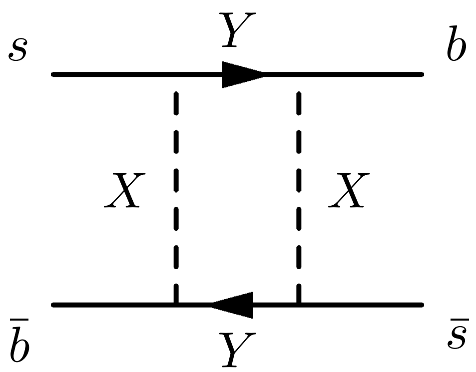
$$\mathcal{B}\left(B^+ \to K^+ X X\right) = \left(1.0 \times 10^5\right) |\rho|^2 \, F\left(m_X\right)$$

$$\rho = \lambda_b \lambda_s^* \left(\frac{400 \text{ GeV}}{m_Y}\right)$$

- BELLE-PRL **99**, 221802 ('07):

$$\mathcal{B}\left(B^+ \to K^+ \bar{\nu}\nu\right) < 1.4 \times 10^{-5}$$

Δm_s

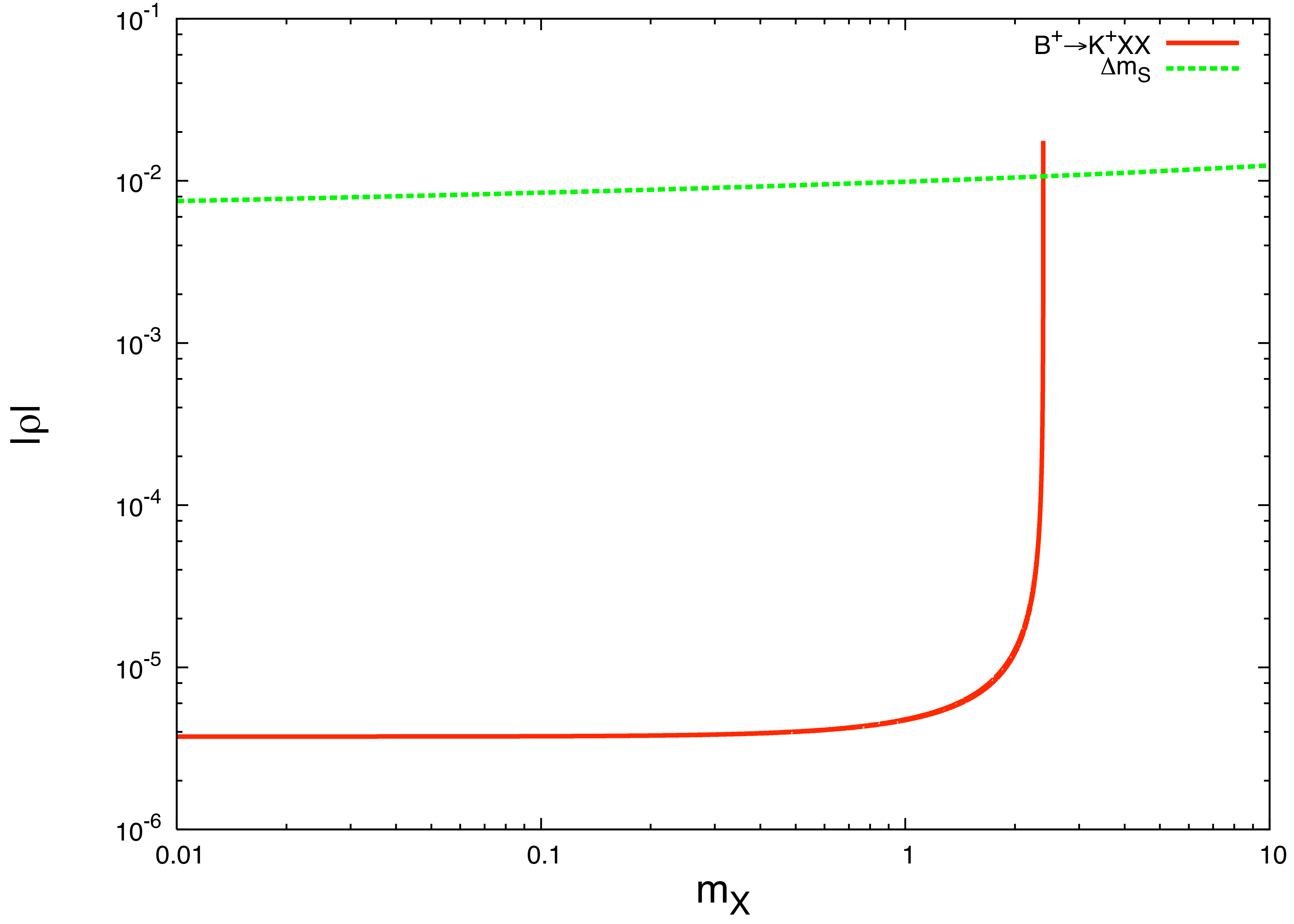


$$\Delta m_s \simeq -\frac{(\lambda_b \lambda_s^*)^2}{288\pi^2 m_Y^2} \log\left(\frac{m_X^2}{m_Y^2}\right) f_{B_s}^2 M_{B_s} \left[8 + 5\left(\frac{M_{B_s}}{m_b + m_s}\right)^2\right]$$

$$\simeq \left(1.82 \pm 0.12 \times 10^5 \ \mathrm{ps}^{-1}\right) \rho^2 \left\{1 - 0.08 \log\left[\left(\frac{m_X}{1 \ \mathrm{GeV}}\right)^2 \left(\frac{400 \ \mathrm{GeV}}{m_Y}\right)^2\right]\right\}$$

- Require that this is less than CDF measurement $\Delta m_s = 17.77 \pm 0.12 \ \mathrm{ps}^{-1}$

$$\rho = \lambda_b \lambda_s^* \left(\frac{400\ \mathrm{GeV}}{m_Y} \right)$$



b-s coupling

- Limit on coupling to strange quarks several orders of magnitude more stringent than that to bottom quarks
- Cabibbo-like suppression--not unexpected
- Could misalignment of phases be responsible for deviation from SM in $B_s^0 \to J/\psi\phi$?

Conclusions

- WIMPless DM offers natural scenarios where DM is not connected to the weak scale
- Interesting particle physics implications if there is a connector between hidden sector and SM
- More?