Title: WIMPless Dark Matter and Meson Decays with Missing Energy

Date: Apr 20, 2010 12:30 PM

URL: http://pirsa.org/10040111

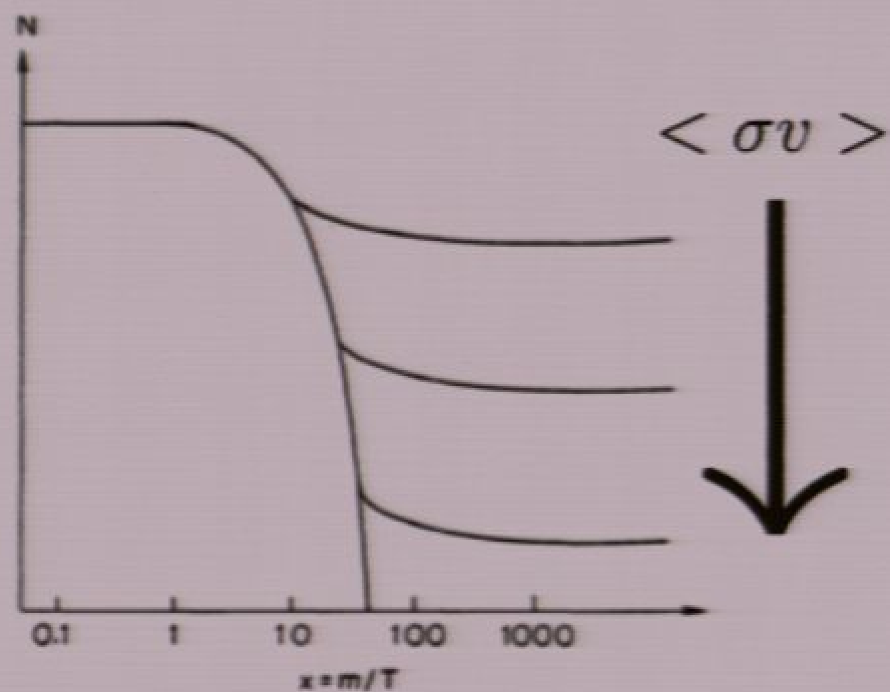
Abstract: WIMPless dark matter offers an attractive framework in which dark matter can be very light. We investigate the implications of such scenarios on invisible decays of bottomonium states for dark matter with a mass less than around $5 {\rm GeV}$. We relate these decays to measurements of nucleon-dark matter elastic scattering. We also investigate the effect that a coupling to s quarks has on flavor changing $b\to s$ processes involving missing energy.

Outline

- arXiv:0903.4982, PRD 79, 114001 ('09)
- WIMP(less) Dark Matter, GMSB
- Connector between SM and Hidden Sector
- $\chi b0$ decays
- b-s mixing Δm_s
  $B^+ \to K^+ + \mathrm{inv.}$

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

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

Gauge Mediated SUSY Breaking (GMSB)

- Couple Chiral Superfield S (singlet) to Messenger Superfields (charged under SM)

$$W = \lambda \bar{\bar{\Phi}}_m S \Phi_m$$

- Chiral Superfield acquires VEV, breaks SUSY

$$< S >= M + \theta^2 F$$

- Transmitted to SM fields and superpartners via messenger fields which couple to SM gauge fields

$$M_m = \lambda M, \ F_m = \lambda F$$

GMSB (cont'd)

- Generates Superpartner Masses:

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

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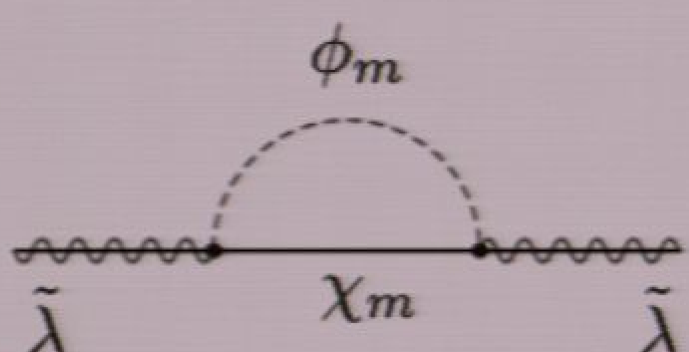

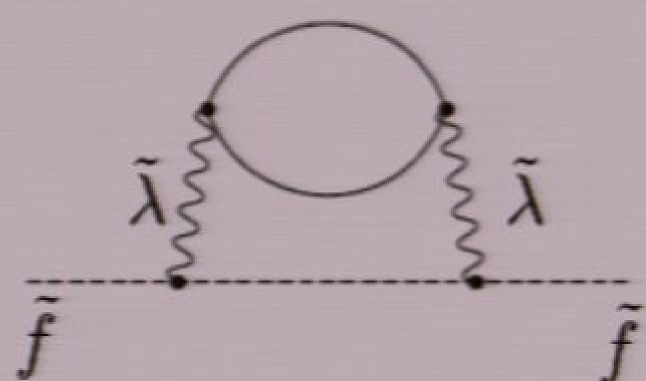

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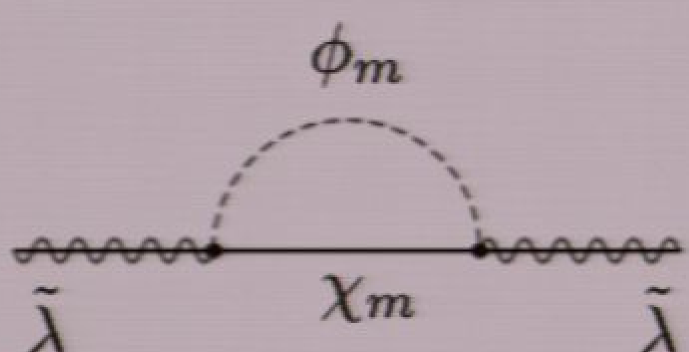
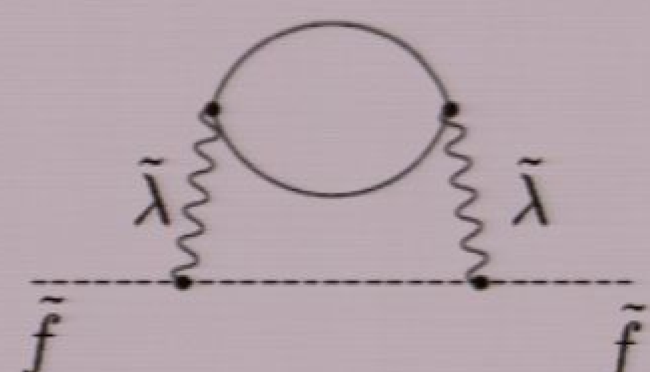




GMSB (cont'd)

- Flavor blind: FCNCs suppressed
- But Gravitino Problem due to suppressed Yukawa couplings, eg. $m_e \ll m_W$

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

GMSB & Additional Hidden Sector

- Introduce a hidden sector and couple it to S with hidden sector messengers

$$W = \lambda_X \bar{\Phi}_{mX} S \Phi_{mX}$$

- SUSY Breaking transmitted to hidden sector by hidden sector messenger M and F terms

$$M_{mX} = \lambda_X F,\ F_{mX} = \lambda_X F$$

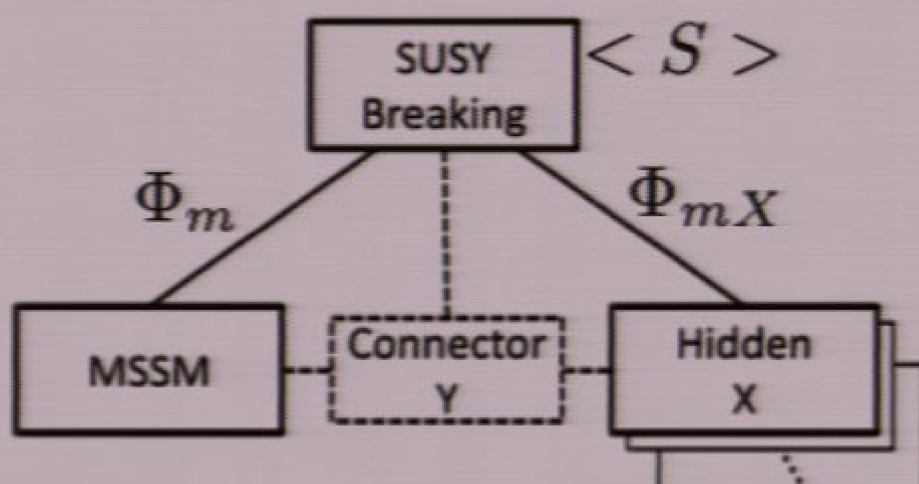
J. L. Feng and J. Kumar, arXiv:0803.4196

GMSB & Additional Hidden Sector (cont'd)

- Generates hidden Superpartner Masses

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

- Hidden thermal relic may be stable



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WIMPless "Miracle"

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

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

- 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

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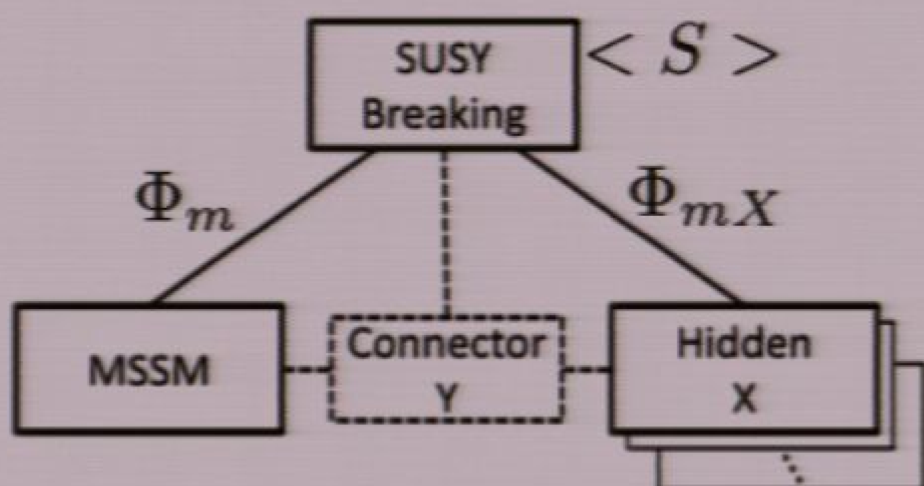

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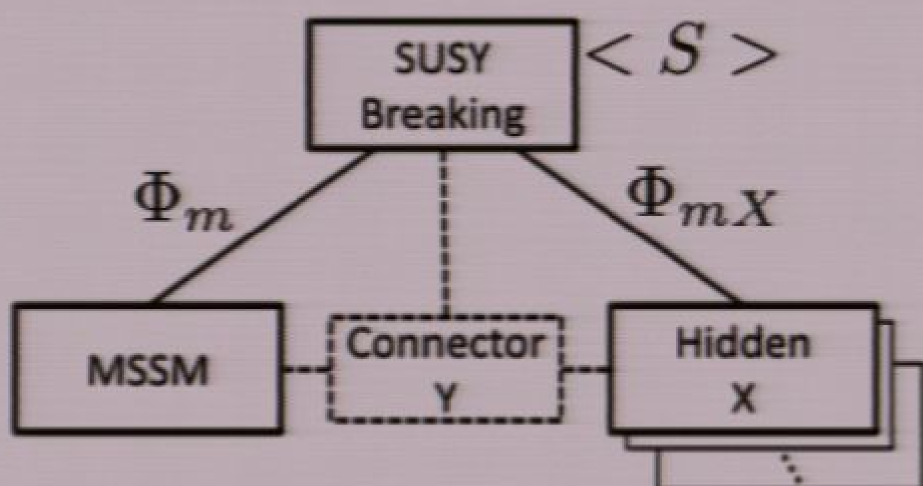

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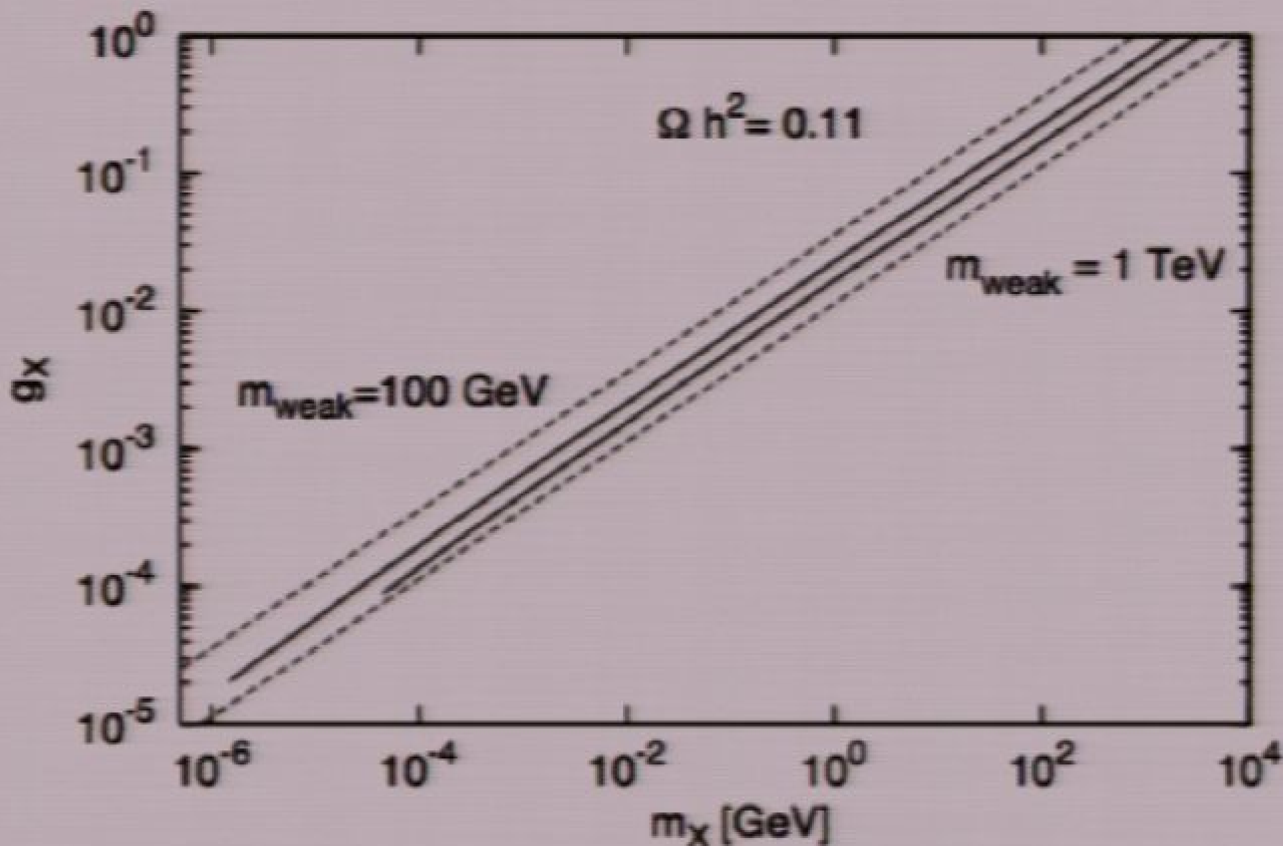
Why?

- Several anomalous experimental results
- Why not?

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
- "Large" hidden sector requires slightly lower reheat temperature

Feng, Tu, and Yu, JCAP 0810, 043 ('08)



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

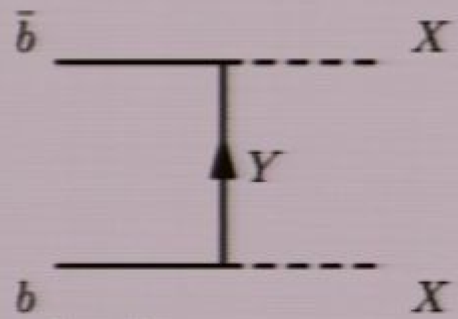
"4th Gen. quark" Connector & Scalar DM

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

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

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

Invisible Bottomonium Decays



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

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

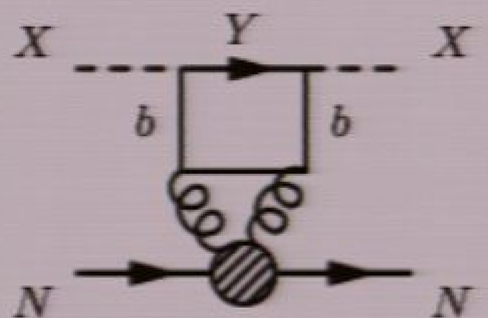
$$\mathcal{B}(\Upsilon(2S) \to \gamma\chi_{b0}(1P) \to \gamma XX) \simeq (4.9 \pm 0.5) \times 10^{-6}\lambda_b^4 \left(\frac{400 \text{ GeV}}{m_Y}\right)^2 \sqrt{1 - \frac{4m_X^2}{M_{\chi_{b0}}^2}}$$

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

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

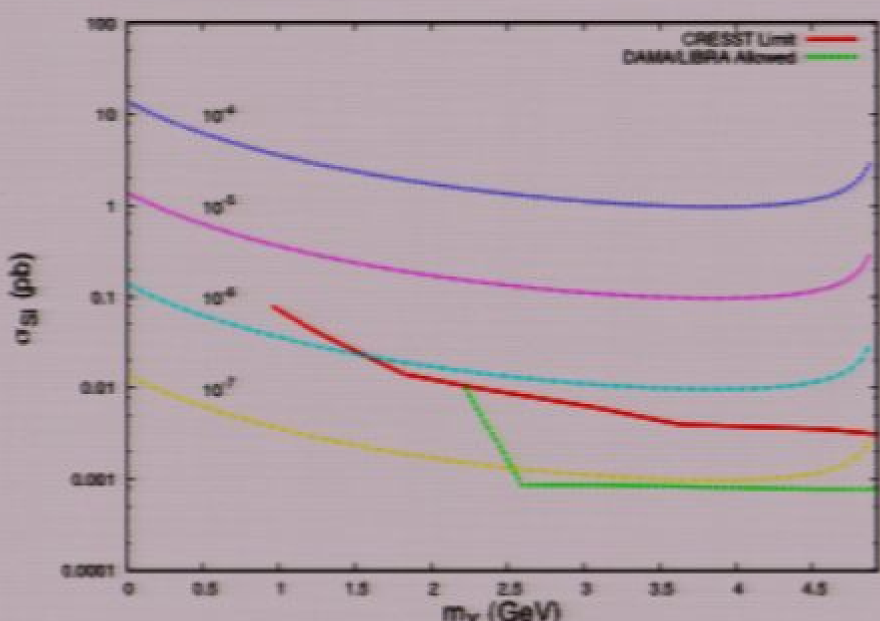
$$\lambda_b^2 \sim 4,\ m_X = 1 \text{ GeV},\ m_Y = 400 \text{ GeV}$$

Direct Detection

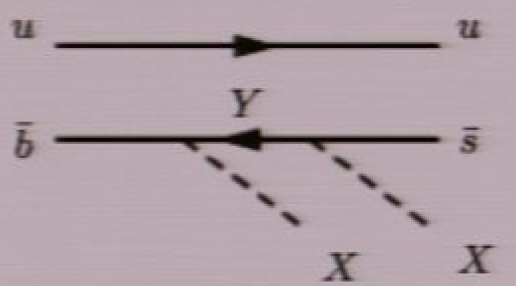


$$\sigma_{\rm SI} = \frac{\lambda_b^4}{4\pi} \frac{m_N^2 \left[Z B_b^p + (A-Z) B_b^n \right]^2}{A^2 \left(m_N + m_X \right)^2 \left(m_Y - m_X \right)^2}$$

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



Strange quarks too?



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

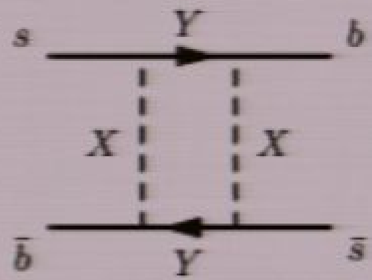
$$\mathcal{B}\left(B^+ \to K^+ X X\right) = \left(1.0 \times 10^5\right) |\rho|^2 F\left(m_X\right)$$

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

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

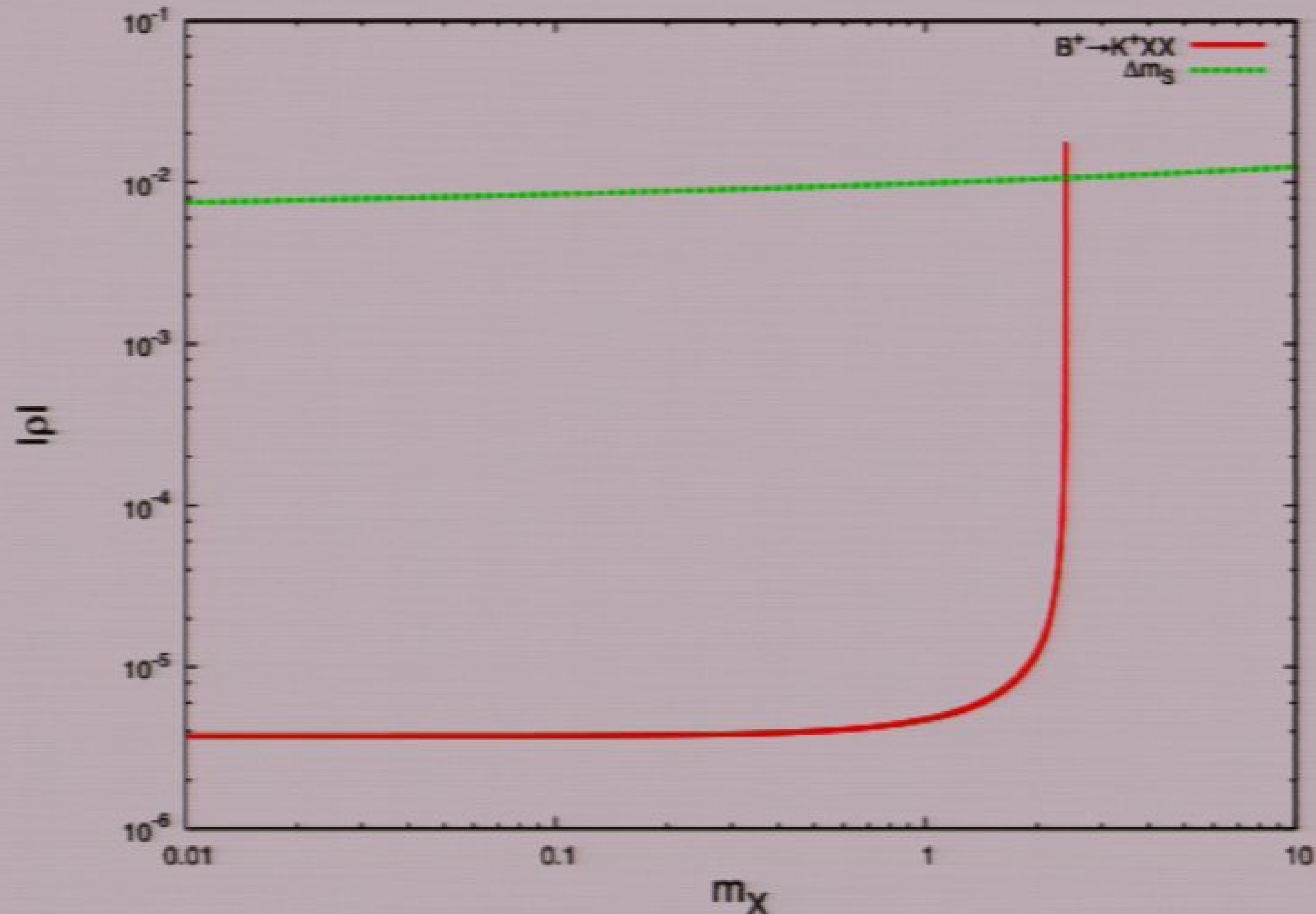
$$\mathcal{B}\left(B^+ \to K^+ \bar{\nu}\nu\right) < 1.4 \times 10^{-5}$$

Δm_s



$$\Delta m_s \simeq -\frac{(\lambda_b \lambda_s^*)^2}{288\pi^2 m_Y^2} \log\left(\frac{m_X^2}{m_Y^2}\right) f_{B_s}^2 M_{B_s} \left[8 + 5\left(\frac{M_{B_s}}{m_b + m_s}\right)^2\right]$$
$$\simeq (1.82 \pm 0.12 \times 10^5 \text{ ps}^{-1})\, \rho^2 \left\{1 - 0.08 \log\left[\left(\frac{m_X}{1 \text{ GeV}}\right)^2 \left(\frac{400 \text{ GeV}}{m_Y}\right)^2\right]\right\}$$

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



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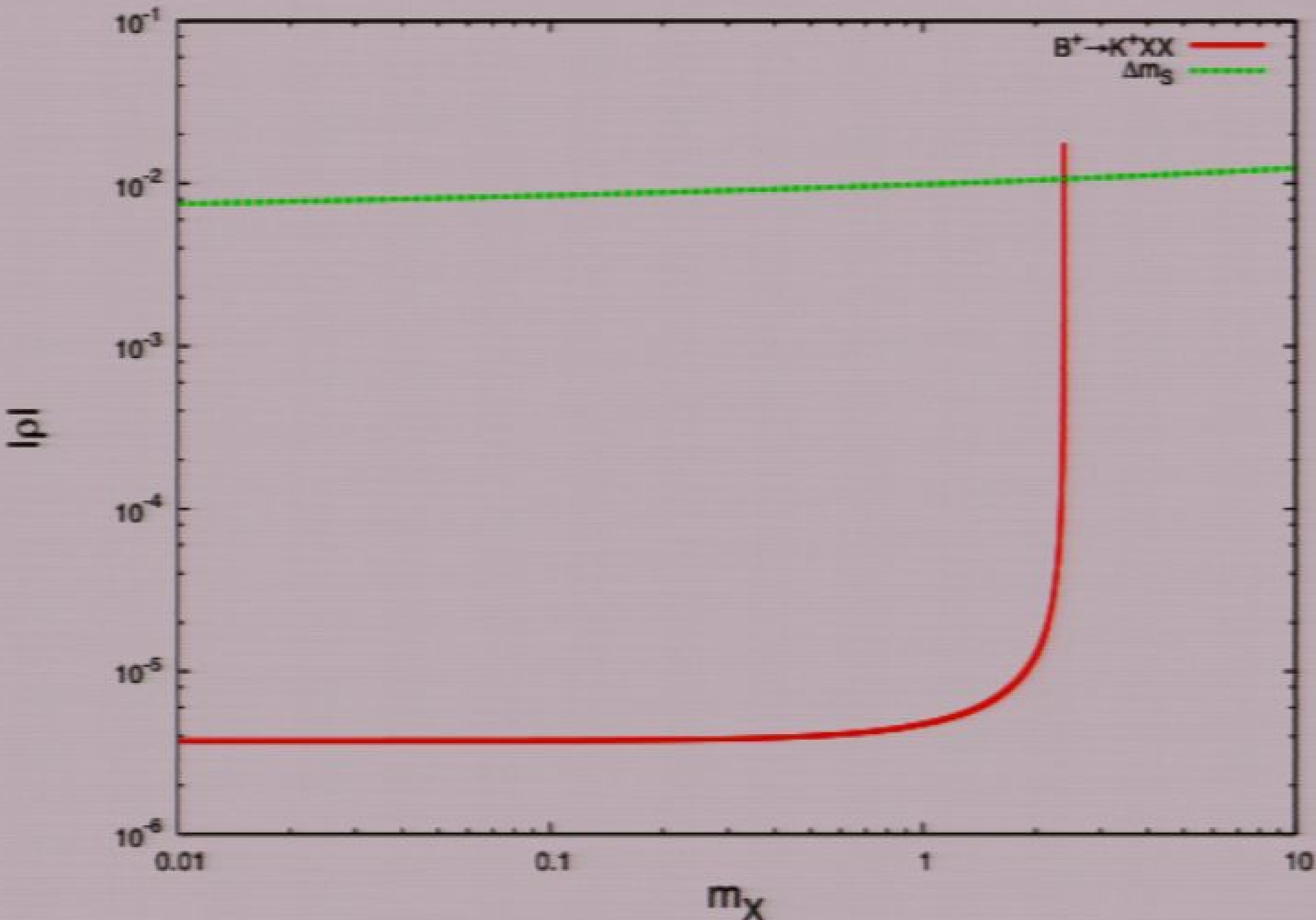
b-s coupling

- 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 $B_s^0 \to J/\psi\phi$?



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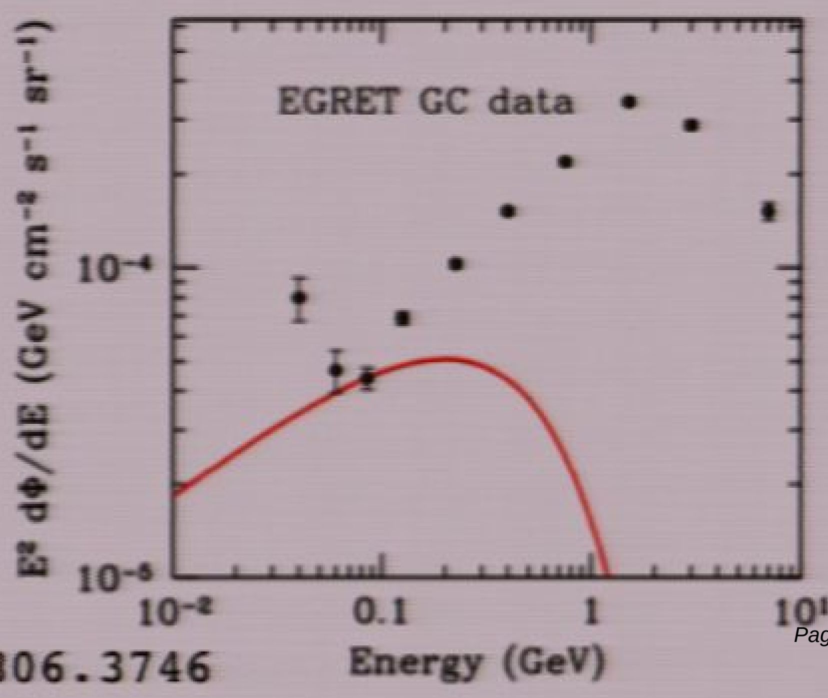
Indirect Detection

$$XX \to \bar{b}b$$

- Enhanced for small masses due to increased number density

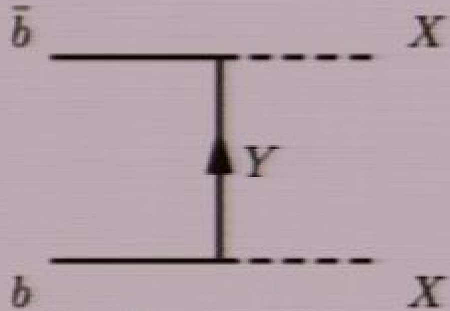


Feng, Kumar, Strigari, arXiv:0806.3746

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?

Invisible Bottomonium Decays



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