On the bottom quark contribution to dark matter spin-dependent detection

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Exploring the Dark Sector
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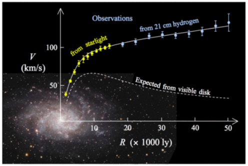
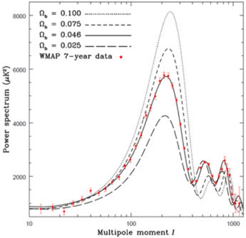
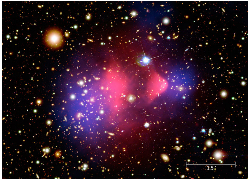
Dark Matter direct detection

The existence of DM:

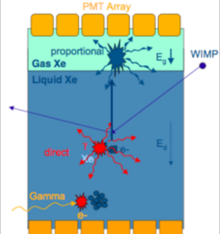






Direct detection:

(XENON website)



In the nonrelativistic limit

- Scalar interaction couples DM to the mass of nucleus.
- Axial-vector interaction couples DM to the spin of nucleus.

DM-nucleus SD interaction

DM-parton effective spin-spin interaction

$$\mathcal{L}_{\chi-q} = d_q \bar{\chi}\gamma^\mu\gamma_5\chi\bar{q}\gamma_\mu\gamma_5 q$$

Spin content of the nucleon

$$\langle n|\bar{q}\gamma_\mu\gamma_5 q|n\rangle = 2s_\mu^{(n)}\Delta q^{(n)}$$

$$\Delta s^{(p)} = \Delta s^{(n)} = -0.02, \quad \Delta u^{(p)} = \Delta d^{(n)} = 0.84, \quad \Delta d^{(p)} = \Delta u^{(n)} = -0.43$$

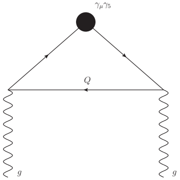
DM-nucleus effective interaction

$$\mathcal{L}_{\chi-n} = \bar{\chi}\gamma^\mu\gamma_5\chi\bar{n}s_\mu n \sum_{q=u,d,s} 2d_q\Delta q^{(n)}$$

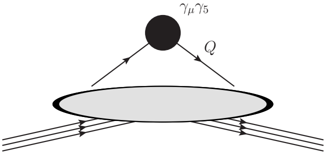
$$\sigma_{\text{SD}}^n = \frac{12}{\pi}\left(\frac{m_\chi m_n}{m_\chi + m_n}\right)^2 \Big|\sum_{q=u,d,s} d_q\Delta q_n\Big|^2$$

Axial charge of heavy quark

Axial anomaly:
gluon contribution to the proton spin



LO approximation:
heavy quark contribution to the proton spin

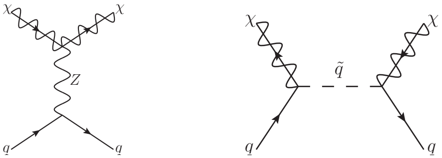


In the limit of small momentum transfer, bottom quark contribution to the neutral- current axial-charge

S.Bass et.al. (2002)

$$\Delta b \sim -6.6 \times 10^{-3}$$

Contribution to Z bosom mediated process



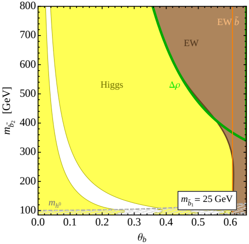
For Z mediated process, the contribution from Δb can only change the scattering rate:

$$\left(\frac{\Delta_u^{(p)} - \Delta_b^{(p)} - \Delta_s^{(p)} - \Delta_b^{(p)}}{\Delta_u^{(p)} - \Delta_b^{(p)} - \Delta_s^{(p)}}\right)^2 \sim 1.01$$

Enhanced bottom contribution

- Natural SUSY ⇒ A light sbottom
- Loose bound at collider (precision electroweak data and Higgs measurements)

B. Batell et.al. arXiv: 1312.2590



- Flavored dark matter models, where DM dominantly couples to bottom quark, is motivated by GCE.

Effective lagrangian in MSSM

Given the lagrangian

$$\mathcal{L} = \bar{q}(a_q + b_q\gamma_5)\chi\tilde{q} + c\bar{q}\gamma^\mu\gamma^5 q Z_\mu + d\bar{\chi}\gamma^\mu\gamma_5\chi Z_\mu$$

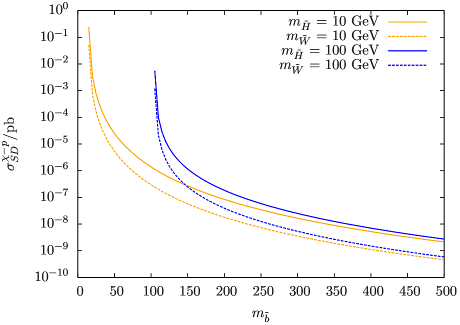
The DM-quark effective axial interaction

$$d_q = \frac{cd}{m_Z^2} - \sum_q \frac{1}{4}\frac{a^2 + b^2}{m_{\tilde{q}}^2 - (m_\chi + m_q)^2}$$

Sbottom s-channel mediation

$$\sigma_{\text{SD}}^{\tilde{b}-\tilde{W}} = \frac{12}{\pi}(\frac{m_\chi m_p}{m_\chi + m_p})^2(-\frac{g^2(T_{3b}Z_{\tilde{b}}^L)^2}{4(m_{\tilde{b}}^2 - (m_\chi + m_b)^2)}\Delta_b^{(p)})^2$$

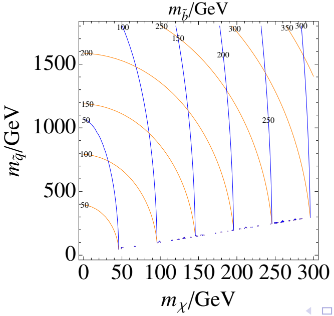
$$\sigma_{\text{SD}}^{\tilde{b}-\tilde{H}} = \frac{12}{\pi}(\frac{m_\chi m_p}{m_\chi + m_p})^2(-\frac{0.5Y_b^2(Z_N^{31})^2}{4(m_{\tilde{b}}^2 - (m_\chi + m_b)^2)}\Delta_b^{(p)})^2$$



Comparing with first generation squarks contributions (Gaugino DM)

$$\frac{\sigma_{\rm SD}^{\tilde b-\tilde W}}{\sigma_{\rm SD}^{\tilde q_{u,d}-\tilde W}} = \frac{(Z_{\tilde b}^L)^2|\Delta_b^{(p)}|}{m_{\tilde b}^2-(m_\chi+m_b)^2} \Big/ \frac{\Delta_u^{(p)}+\Delta_d^{(p)}}{m_{\tilde q_{u,d}}^2-m_\chi^2}$$

$$\frac{\sigma_{\rm SD}^{\tilde b-\tilde B}}{\sigma_{\rm SD}^{\tilde q_{u,d}-\tilde B}} = \frac{(a^2+b^2)_{\tilde b_1}}{m_{\tilde b}^2-(m_\chi+m_b)^2} \Big/ \frac{\sum_{\tilde u_{L,R}}(a^2+b^2)\Delta_u^{(p)}+\sum_{\tilde d_{L,R}}(a^2+b^2)\Delta_d^{(p)}}{m_{\tilde q_{u,d}}^2-m_\chi^2}$$

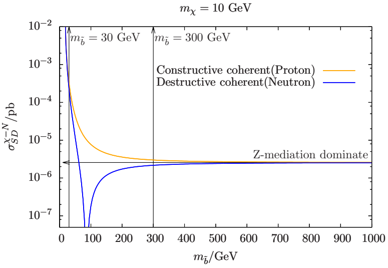


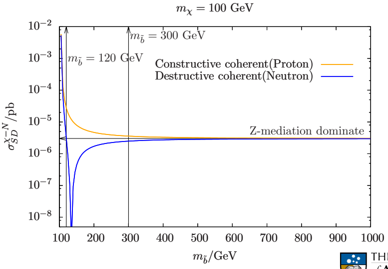
Comparing with Z boson contribution and coherent effects

$$\sigma_{\text{SD}}^{\chi-(p,n)} = \frac{12}{\pi}\left(\frac{m_\chi m_p}{m_\chi + m_p}\right)^2 \times$$

$$\left(\left(\frac{g^2((Z_N^{41})^2 - (Z_N^{31})^2)}{8m_W^2}\right)(T_{3u}\Delta_u^{(p,n)} + T_{3d}\Delta_d^{(p,n)} + T_{3s}\Delta_s^{(p,n)}) - \frac{0.5Y_b^2(Z_N^{31})^2}{4(m_{\tilde{b}}^2 - (m_\chi + m_b)^2)}\Delta_b^{(p,n)} \right)^2$$

In the heavy gaugino limit (assuming $Z_N^{41} \simeq 1.01 Z_N^{31}$) :





Constraint from DM spin-independent detection

Given an effective lagrangain

$$\mathcal{L}_{\mathrm{SI}} = \sum_q (f_q m_q \bar{\chi}\chi\bar{q}q + \frac{g_q^{(1)}}{m_\chi}\bar{\chi}i\partial^\mu\gamma^\nu\chi\mathcal{O}^q_{\mu\nu} + \frac{g_q^{(2)}}{m_\chi^2}\bar{\chi}(i\partial^\mu)(i\partial^\nu)\chi\mathcal{O}^q_{\mu\nu})$$

The SI DM-nucleus scattering cross section

$$\sigma_{\mathrm{SI}}^{\chi-p} = \frac{4}{\pi}(\frac{m_\chi m_N}{m_\chi + m_N})^2(f_N)^2$$

where

$$\begin{aligned}\frac{f_N}{m_N} &= \sum_{q=u,d,s} f_q f_{T_q} + \sum_{q=u,d,s,c,b}\frac{3}{4}(q(2)+\bar{q}(2))(g_q^{(1)}+g_q^{(2)}) - \frac{8\pi}{9\alpha_s}f_{T_G}f_G \\ &\sim \sum_{q=u,d,s} f_q f_{T_q} + \sum_{q=u,d,s,c,b}\frac{3}{4}(q(2)+\bar{q}(2))(g_q^{(1)}+g_q^{(2)}) + \frac{2}{27}\sum_{Q=c,b,t} f_{T_G} f_Q\end{aligned}$$

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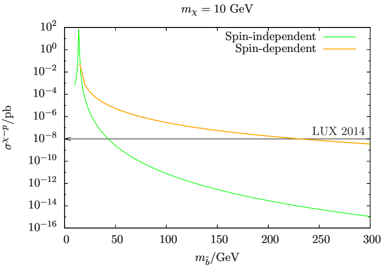
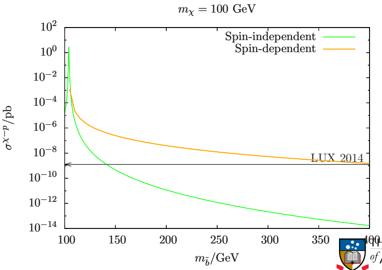
Wino dark matter

$$f_N = m_p\left(\frac{3}{4}(b(2)+\bar{b}(2))(g_b^{\tilde{b}_L-\tilde{W}}) + \frac{2}{27} f_{T_G} f_b^{\tilde{b}_L-\tilde{W}}\right)$$

where

$$f_b^{\tilde{b}_L-\tilde{W}} = \frac{g^2 m_\chi}{32}\frac{1}{(m_{\tilde{b}}^2 - m_\chi^2)^2}, \qquad g_b^{\tilde{b}_L-\tilde{W}} = \frac{g^2 m_\chi}{8}\frac{1}{(m_{\tilde{b}}^2 - m_\chi^2)^2}$$





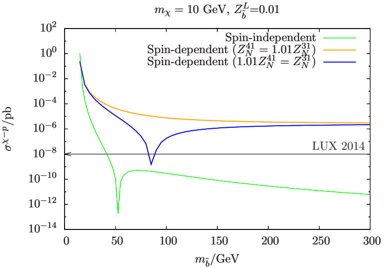
Higgsino dark matter

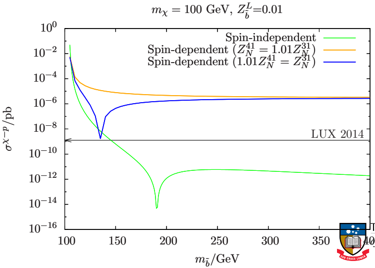
$$f_N = m_p\left(\frac{3}{4}(b(2)+\bar{b}(2))(g_b^{\tilde{b}_1-\tilde{H}}) + \frac{2}{27} f_{TG} f_b^{\tilde{b}_1-\tilde{H}}\right)$$

where

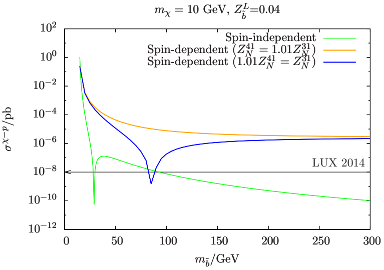
$$f_b^{\tilde{b}_1-\tilde{H}} = \frac{m_\chi}{(m_{\tilde{b}}^2-(m_\chi+m_b)^2)^2}\frac{0.5Y_b^2(Z_N^{31})^2}{8} - \frac{1}{m_b(m_{\tilde{b}}^2-(m_\chi+m_b)^2)}\frac{Y_b^2(Z_N^{31})^2 Z_{\tilde{b}}^L Z_{\tilde{b}}^R}{4},$$

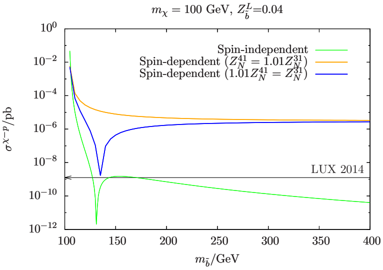
$$g_b^{\tilde{b}_1-\tilde{H}} = \frac{m_\chi}{(m_{\tilde{b}}^2-(m_\chi+m_b)^2)^2}\frac{0.5Y_b^2(Z_N^{31})^2}{2}$$



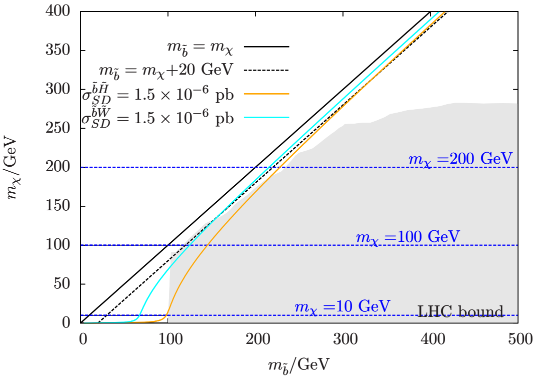


Different sbottom mixing



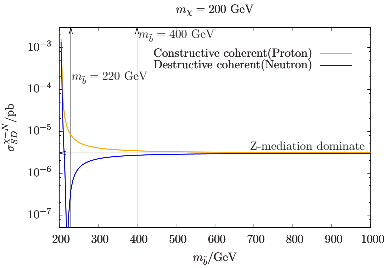


Constraints from collider



Several ways to get around

- Validate our calculation for smaller mass splitting between $\tilde{b}$ and χ by using higher order calculation.
- For $m_\chi \lesssim 100$ GeV: a more general framework, where the dark matter does not have any charged partners.
- For $m_\chi \sim 100$ GeV: more complicate decay mode for sbottom
- Heavier DM:



Conclusion

- Large bottom spin contribution to dark matter direct detection can be implemented.
- Those scenarios are still consistent with current experimental results.

Backup slides

Feynman rules

$$a_u = i\frac{Z_{\tilde{u}}^L}{2}(\frac{-g}{\sqrt{2}c_w}(\frac{1}{3}Z_N^{11}s_w + Z_N^{21}c_w) - Y_u Z_N^{41}) + i\frac{Z_{\tilde{u}}^R}{2}(\frac{2\sqrt{2}gs_w}{3c_w}Z_N^{11} - Y_u Z_N^{41}) \quad (1)$$

$$b_u = i\frac{Z_{\tilde{u}}^L}{2}(\frac{g}{\sqrt{2}c_w}(\frac{1}{3}Z_N^{11}s_w + Z_N^{21}c_w) - Y_u Z_N^{41}) + i\frac{Z_{\tilde{u}}^R}{2}(\frac{2\sqrt{2}gs_w}{3c_w}Z_N^{11} + Y_u Z_N^{41}) \quad (2)$$

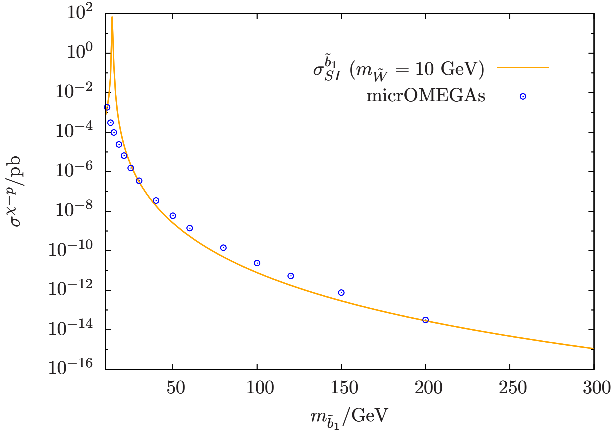
$$a_d = i\frac{Z_{\tilde{d}}^L}{2}(\frac{-g}{\sqrt{2}c_w}(\frac{1}{3}Z_N^{11}s_w - Z_N^{21}c_w) + Y_d Z_N^{31}) + i\frac{Z_{\tilde{d}}^R}{2}(\frac{-\sqrt{2}gs_w}{3c_w}Z_N^{11} + Y_d Z_N^{31}) \quad (3)$$

$$b_d = i\frac{Z_{\tilde{d}}^L}{2}(\frac{g}{\sqrt{2}c_w}(\frac{1}{3}Z_N^{11}s_w - Z_N^{21}c_w) + Y_d Z_N^{31}) + i\frac{Z_{\tilde{d}}^R}{2}(\frac{-\sqrt{2}gs_w}{3c_w}Z_N^{11} - Y_d Z_N^{31}) \quad (4)$$

$$c = \frac{i}{2}\frac{g}{c_w}T_{3q} \quad (5)$$

$$d = -\frac{i}{4}\frac{g}{c_w}((Z_N^{41})^2 - (Z_N^{31})^2) \quad (6)$$

Validation



$\sigma_{SI}^{\tilde{b}_1}$ ($m_{\tilde{W}} = 10$ GeV)
micrOMEGAs
$\sigma_{\chi-p}$/pb
$m_{\tilde{b}_1}$/GeV
10^{2}
10^{0}
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
10^{-16}
50
100
150
200
250
300