Dark Matter Phenomenology of intersecting D6-branes with a Stückelberg portal

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String Phenomenology 2015
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In collaboration with Miguel Peiró and Pablo Soler,
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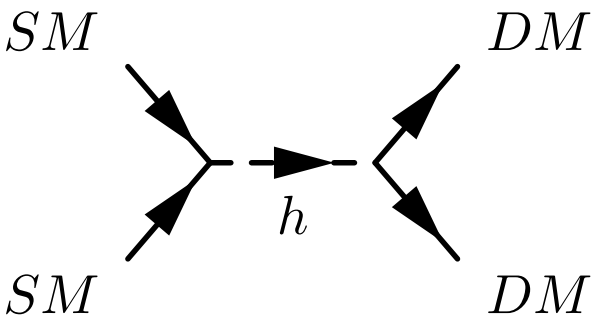
Introduction

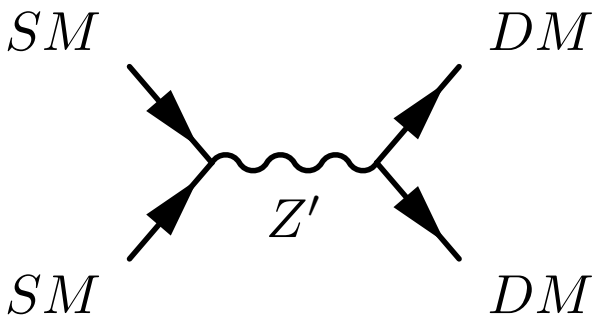
The SM and DM content could live in different sectors...

$$\underbrace{SU(3)_c \times SU(2)_L \times U(1)_{\mathsf{v}}^n}_{\text{SM}} \times \underbrace{U(1)_{\mathsf{h}}^m \times G_{\mathsf{h}}}_{\text{DM}},$$

...and be connected by some kind of portal

$$\text{SM} \longleftrightarrow \text{DM}$$
$$h, Z' ...$$





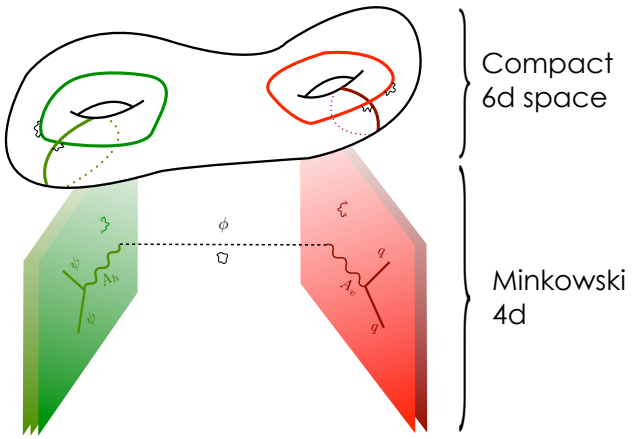
String Realization

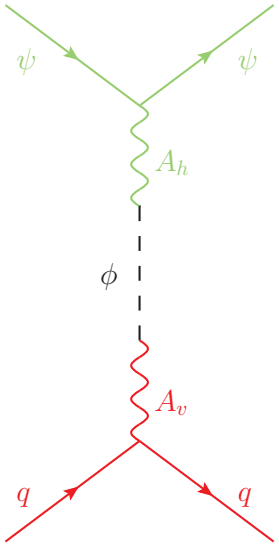
D6 brane type IIA string model

- A stack of N overlapping branes hosts a $U(N) \cong SU(N) \times U(1)$ gauge group.
- Visible and hidden gauge boson couples to RR axions (closed strings).

$$\mathcal{L} = -\frac{1}{2} G_{ij} (\partial \phi^i - k_a^i A^a)(\partial \phi^j - k_b^j A^b)$$

Stückelberg Mechanism





Wan-Zhe Feng, Gary Shiu, Pablo Soler, Fang Ye. PRL (2014)

Wan-Zhe Feng, Gary Shiu, Pablo Soler, Fang Ye. JHEP (2014)

String Realization

$$\underbrace{SU(3)_c \times SU(2)_L \times U(1)_{\mathsf{v}}^n}_{\text{SM}} \times \underbrace{U(1)_{\mathsf{h}}^m \times G_{\mathsf{h}},}_{\text{DM}}$$

$$\mathcal{L} = -\frac{1}{4}\vec{F}^T \cdot f \cdot \vec{F} - \frac{1}{2}\vec{A}^T \cdot M^2 \cdot \vec{A} + \sum_\alpha \overline{\psi}_\alpha \left(i\partial\!\!\!/ + \vec{Q}_\alpha^T \cdot \vec{A}\!\!\!/ \right) \psi_\alpha$$

In general f and M are non-diagonal. However we choose $f = \text{diag}(g_1^{-1} ... \, g_{n+m}^{-1})$. After two kind of transformations (canonical kinetic terms and diagonal mass matrix):

$$\mathcal{L} = -\frac{1}{4}F''^2_i - \frac{1}{2}m_i^2 A''^2_i + \sum_\alpha \overline{\psi}_\alpha \left(i\partial\!\!\!/ + \vec{g'}_\alpha^T \cdot \vec{A}\!\!\!/'' \right) \psi_\alpha$$

$$g'^{(i)}_\alpha = \vec{Q}_\alpha^T \cdot \vec{v}'_{(i)}$$

Wan-Zhe Feng, Gary Shiu, Pablo Soler, Fang Ye. PRL (2014)

Wan-Zhe Feng, Gary Shiu, Pablo Soler, Fang Ye. JHEP (2014)

String Realization

MADRID MODELS

Luis E. Ibanez, F. Marchesano, R.Rabadan. JHEP (2001)

$$\underbrace{U(3)_{\mathsf{A}} \times U(2)_{\mathsf{B}} \times U(1)_{\mathsf{C}} \times U(1)_{\mathsf{D}}}_{\text{SM}} \times \underbrace{U(1)^m_{\mathsf{h}} \times G_{\mathsf{h}},}_{\text{DM}}$$

Matter field	Q_A	Q_B	Q_C	Q_D	Y
Q_L	1	-1	0	0	1/6
q_L	1	1	0	0	1/6
U_R	-1	0	1	0	-2/3
D_R	-1	0	-1	0	1/3
L	0	-1	0	-1	-1/2
E_R	0	0	-1	1	1
N_R	0	0	1	1	0

$$Q^Y = \frac{1}{6}\left(Q_A - 3Q_C + 3Q_D\right)$$

$$g^Y_\alpha = e\, Q^Y_\alpha = \frac{e}{6}\left(Q_{\alpha A} - 3Q_{\alpha C} + 3Q_{\alpha D}\right)$$

$$g^{Z'}_\alpha = a\, Q_{\alpha A} + b\, Q_{\alpha B} + c\, Q_{\alpha C} + d\, Q_{\alpha D} + \sum_{i=1}^m h_i\, Q^{(h)}_{\alpha i}$$

String Realization

Madrid Models

Luis E. Ibanez, F. Marchesano, R.Rabadan. JHEP (2001)

$$\underbrace{U(3)_{\mathsf{A}}\times U(2)_{\mathsf{B}}\times U(1)_{\mathsf{C}}\times U(1)_{\mathsf{D}}}_{\text{SM}} \times \underbrace{U(1)^m_{\mathsf{h}}\times G_{\mathsf{h}}}_{\text{DM}},$$

$$C_u^V = g_{u_L}^{Z'} + g_{u_R}^{Z'} = (b+c)$$
$$C_d^V = g_{d_L}^{Z'} + g_{d_R}^{Z'} = (b-c)$$

$$C_t^V = (-b-c)$$
$$C_b^V = (-b+c)$$

$$C_u^A = g_{u_L}^{Z'} - g_{u_R}^{Z'} = (2a+b-c)$$
$$C_d^A = g_{d_L}^{Z'} - g_{d_R}^{Z'} = (2a+b+c)$$

$$C_t^A = (2a-b-c)$$
$$C_b^A = (2a-b+c)$$

$$C_\ell^V = (-b-c)$$
$$C_\ell^A = (-b+c-2d)$$

Isospin Violation from Stückelberg portals

Effective Lagrangian for SI interactions,

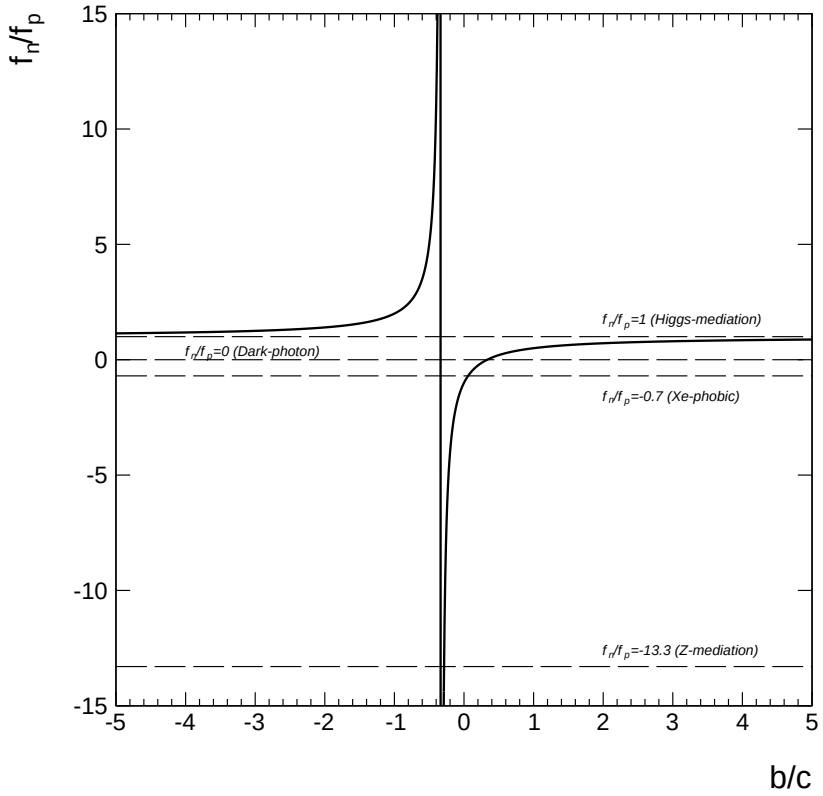
$$\mathcal{L}_{SI}^{V} = f_p(\bar{\psi}\gamma_\mu\psi)(\bar{p}\gamma^\mu p) + f_n(\bar{\psi}\gamma_\mu\psi)(\bar{n}\gamma^\mu n),$$

$$f_p = 2b_u + b_d, \quad f_n = b_u + 2b_d,$$

$$b_u = \frac{hC_u^V}{2m_{Z'}^2} = \frac{h}{2m_{Z'}^2}(b+c),$$

$$b_d = \frac{hC_d^V}{2m_{Z'}^2} = \frac{h}{2m_{Z'}^2}(b-c).$$

$$\frac{f_n}{f_p} = \frac{(3b-c)}{(3b+c)} = \frac{(3b/c-1)}{(3b/c+1)}.$$



Isospin Violation from Stückelberg portals

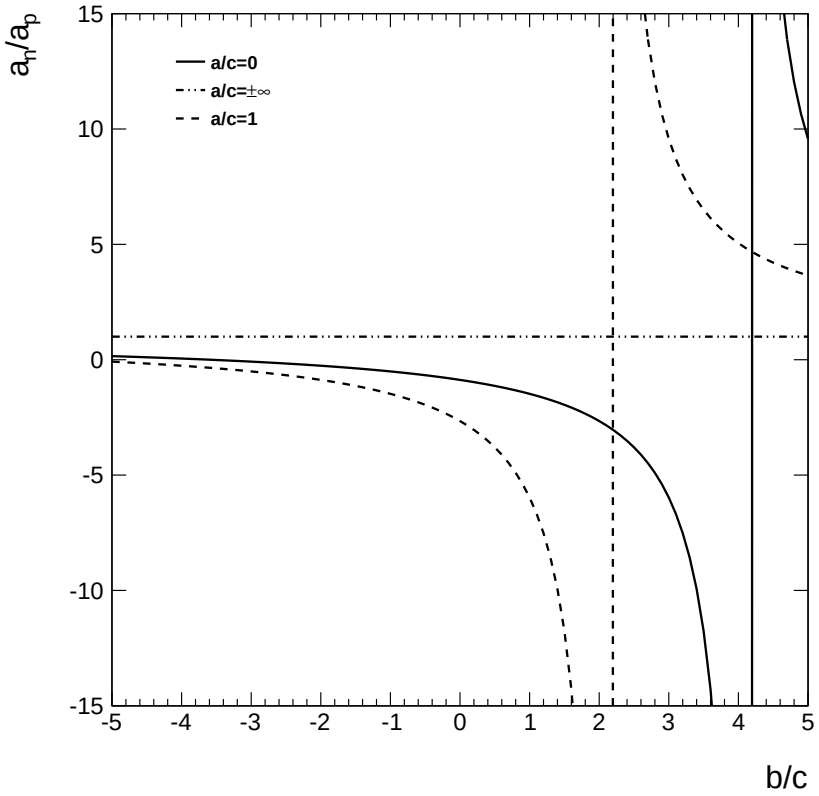
Effective Lagrangian for SD interactions,

$$\mathcal{L}_{SD} = a_p(\bar{\psi}\gamma_\mu\gamma_5\psi)(\bar{p}\gamma^\mu\gamma_5 p) + a_n(\bar{\psi}\gamma_\mu\gamma_5\psi)(\bar{n}\gamma^\mu\gamma_5 n),$$

$$a_p = \sum_{q=u,d,s} \frac{\alpha_q^A}{\sqrt{2}G_F}\Delta_q^p = \frac{h}{2\sqrt{2}G_F m_{Z'}^2}\left[C_u^A\Delta_u^p + C_d^A(\Delta_d^p + \Delta_s^p)\right],$$

$$a_n = \sum_{q=u,d,s} \frac{\alpha_q^A}{\sqrt{2}G_F}\Delta_q^n = \frac{h}{2\sqrt{2}G_F m_{Z'}^2}\left[C_u^A\Delta_u^n + C_d^A(\Delta_d^n + \Delta_s^n)\right]$$

$$\frac{a_n}{a_p} = \frac{\Delta_u^n + \frac{2a/c+b/c+1}{2a/c+b/c-1}(\Delta_d^n + \Delta_s^n)}{\Delta_u^p + \frac{2a/c+b/c+1}{2a/c+b/c-1}(\Delta_d^p + \Delta_s^p)}.$$



LHC and LUX: LUX

We have calculated LUX limits computing the number of events for a Xe-based detector.

$$\sigma_p^{SI} = \frac{4}{\pi}\mu_p^2 f_p^2 = \frac{\mu_p^2 h^2}{\pi m_{Z'}^4}\left(3b+c\right)^2,$$

$$\sigma_p^{SD} = \frac{24G_F^2}{\pi}\mu_p^2 a_p^2 = \frac{3\mu_p^2 h^2}{\pi m_{Z'}^4}[(2a+b-c)\Delta_u^p + (2a+b+c)(\Delta_d^p + \Delta_s^p)]^2.$$

To calculate the cross section in neutrons we multiply by the $(f_n/f_p)^2$ and $(a_n/a_p)^2$ factors respectively.

(Standard Isothermal Maxwellian velocity distribution, $v_0 = 220$ km/s, $v_{esc} = 544$ km/s, $\rho_0 = 0.3$ GeV/cm^3, the same as LUX)

LHC and LUX: LHC

Dilepton and dijet searches from ATLAS detector ($\sqrt{s} = 8$ TeV,$\mathcal{L} = 20.5$ fb^{-1}):

$$pp \to Z' \to \mu^+\mu^-(e^+e^-).$$

$$\sigma_{l^+l^-} \simeq \left(\frac{1}{3}\sum_q \frac{dL_{q\bar{q}}}{dm^2_{Z'}} \times \widehat{\sigma}(q\bar{q} \to Z')\right) \times \mathrm{BR}(Z' \to l^+l^-)\,,$$

$$\sigma_{l^+l^-} = \frac{\pi}{48s}\mathcal{W}_{Z'}\left(s, m^2_{Z'}\right) \times \mathrm{BR}(Z' \to l^+l^-)\,,$$

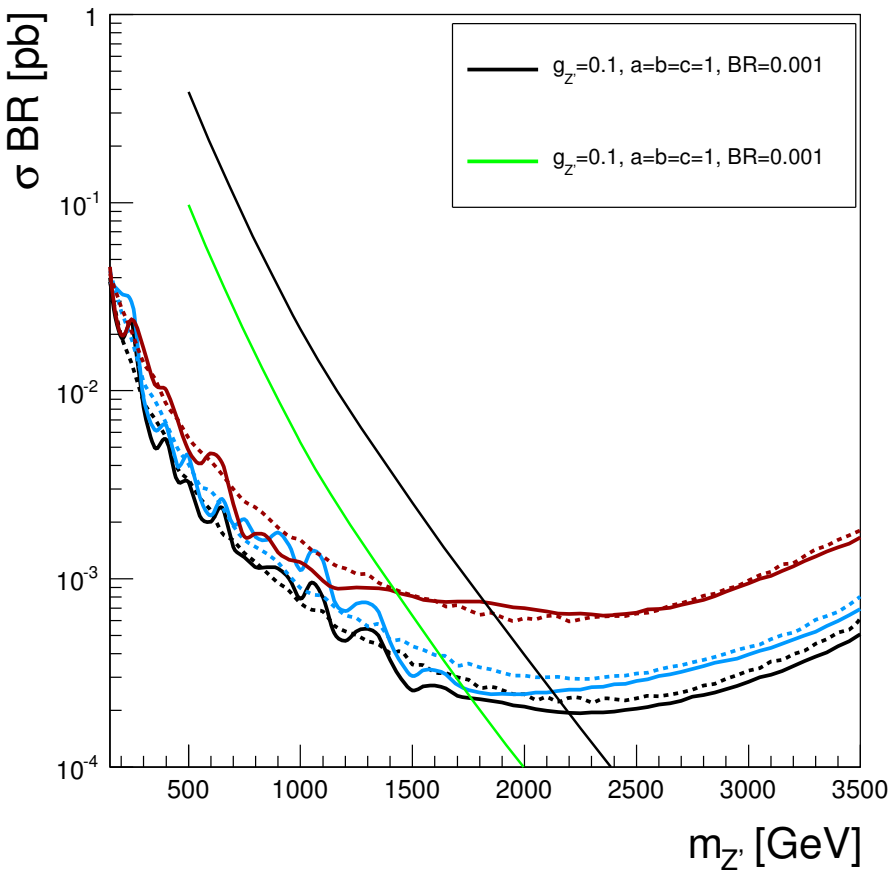
$$\mathcal{W}_{Z'} = \sum_{q=u,d,c,s} c_q\omega_q\left(s, m^2_{Z'}\right)\,.$$

$$\mathcal{W}_{Z'} = c_{up}\omega_{up}\left(s, m^2_{Z'}\right) + c_{down}\omega_{down}\left(s, m^2_{Z'}\right)\,.$$

$$\sigma^{LO}_{l^+l^-} = \left[c_{up}\tilde{\omega}_{up}\left(s, m^2_{Z'}\right) + c_{down}\tilde{\omega}_{down}\left(s, m^2_{Z'}\right)\right] \times \mathrm{BR}(Z' \to l^+l^-)\,.$$

LHC and LUX: Benchmark points

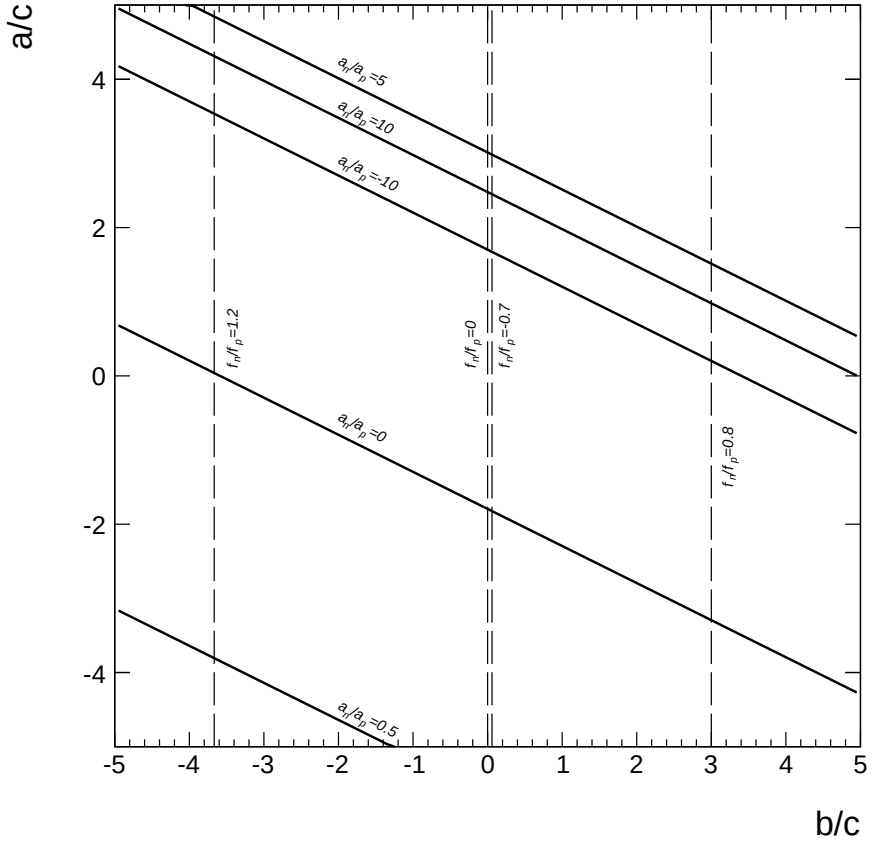
$$\sigma^{LO}_{l^+l^-} = \left[c_{up}\tilde{\omega}_{up}\left(s, m^2_{Z'}\right) + c_{down}\tilde{\omega}_{down}\left(s, m^2_{Z'}\right)\right] \times \mathrm{BR}(Z' \to l^+l^-)$$



$\tilde{\omega}_{up}$ and $\tilde{\omega}_{down}$ were calculated using CalcHEP 3.6.22 using the parton distribution function CTEQ6L as ATLAS does.

Benchmark Point

$$c = 0.1, \quad d/c = 3, \quad h = 0.5, \quad m_{DM} = 500\,\mathrm{GeV}, \quad m_{Z'} = 3\,\mathrm{TeV}$$



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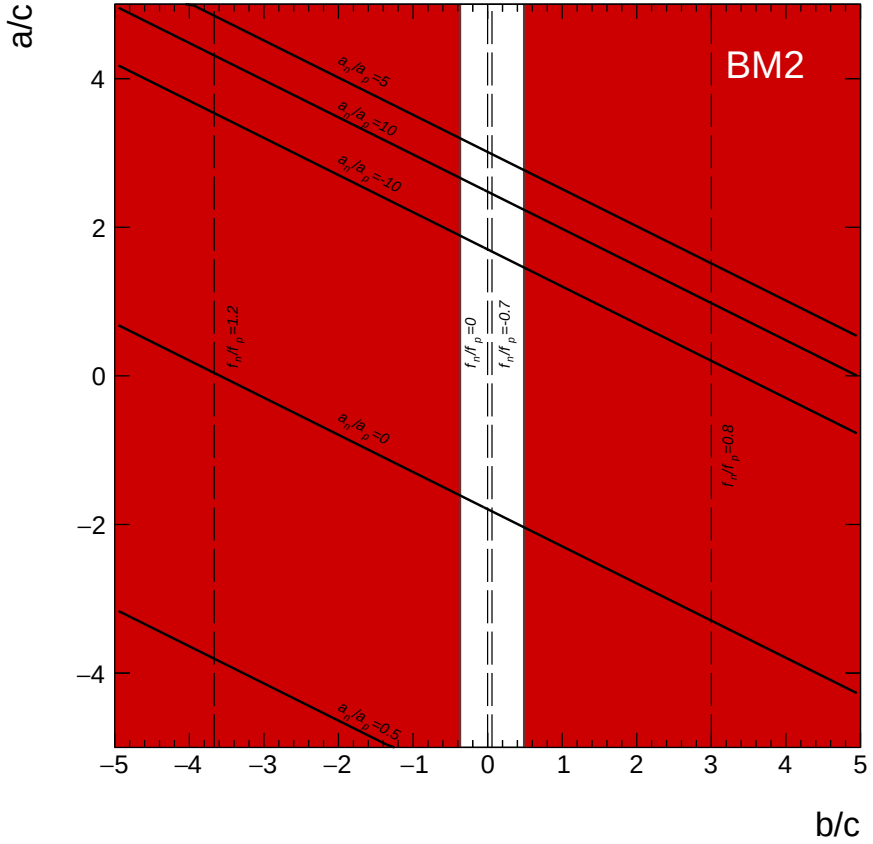

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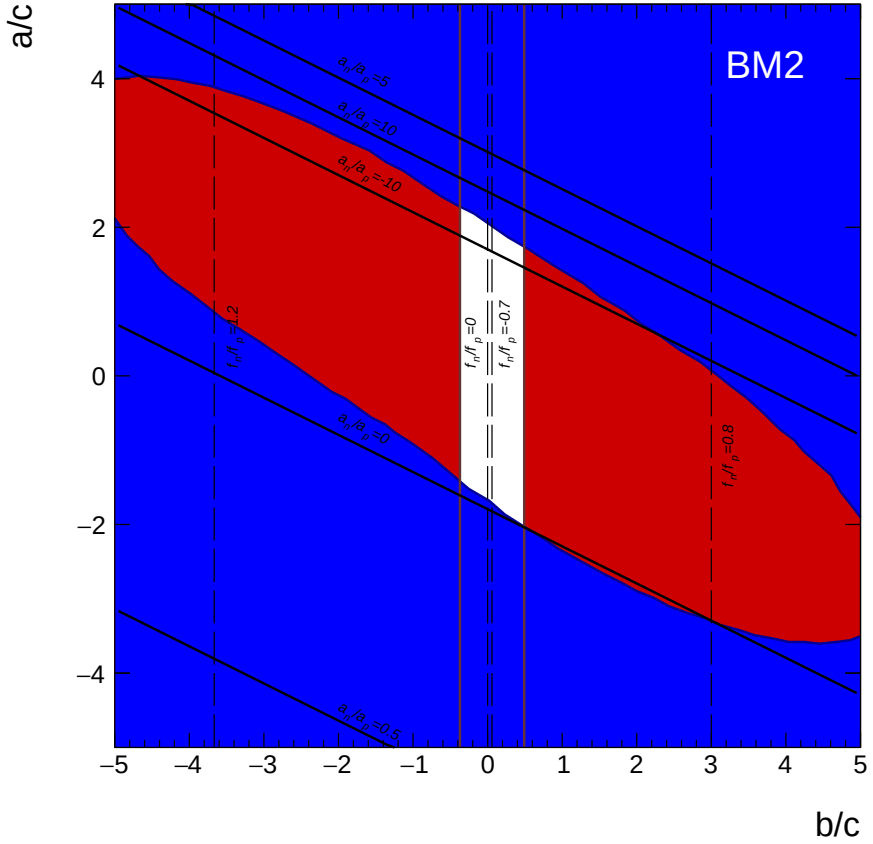

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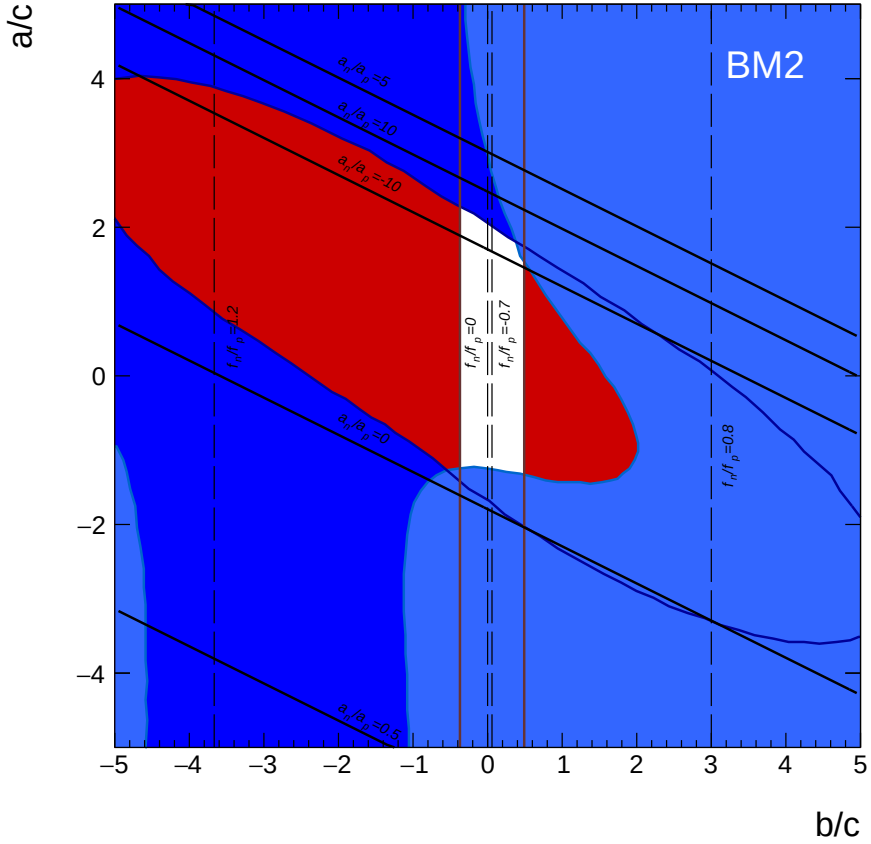
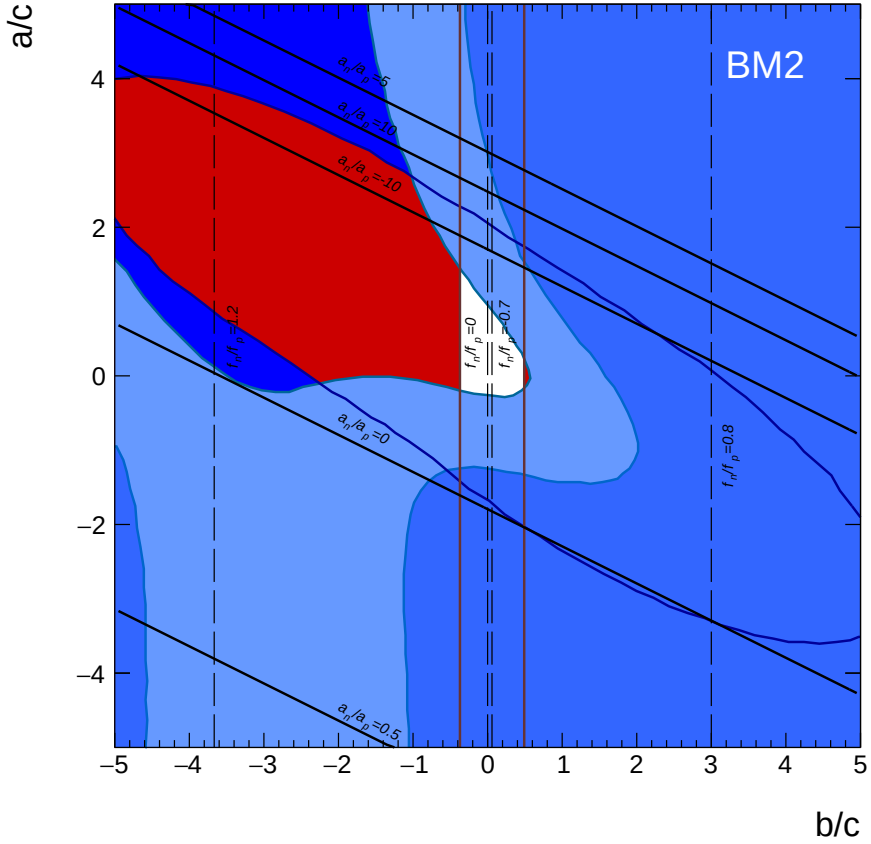


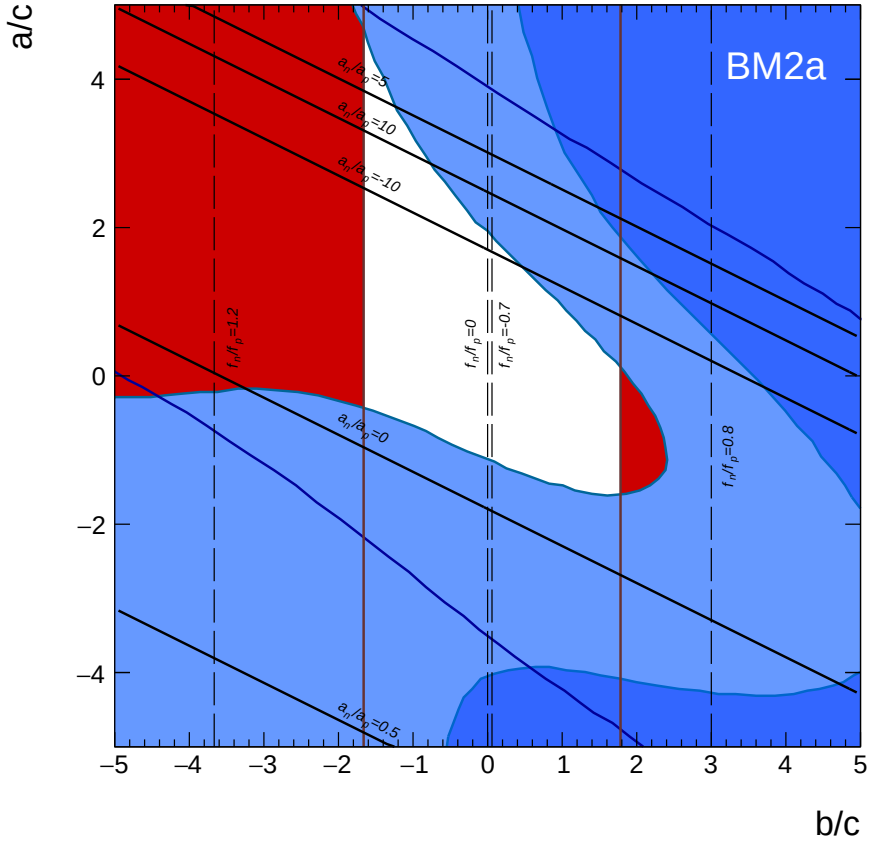
Benchmark Point

$$c = 0.1, \quad d/c = 3, \quad h = 0.5, \quad m_{DM} = 500\,\mathrm{GeV}, \quad m_{Z'} = 3\,\mathrm{TeV}$$



Benchmark Point 2

$$c = 0.05, \quad d/c = 5, \quad h = 0.25, \quad m_{DM} = 500\,\mathrm{GeV}, \quad m_{Z'} = 3\,\mathrm{TeV}$$



Conclusions

- The SM and the DM could live in different sectors
- Both sectors could communicate via portals
- D6-brane models provide Stückelberg (Z') portals
- This kind of portals has an interesting and a very characteristic phenomenology
- This kind of models are easily proven by LUX and the LHC
- More different aspects of the phenomenology to come (future work)

THANK YOU FOR YOUR ATTENTION