B anomalies: a DM connection?

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B Anomalies and Lepton Universality

- $R_{K(*)}$ = BR($B \to K^{(*)}\,\mu\mu$) / BR($B \to K^{(*)}\,ee$) (= 1 for SM : « clean »)
- $B \to K^*\mu\mu$ angular observables
- BR($B_s \to \phi\mu\mu$)
- Most significant tensions reduced by a ~20% Lepton Flavour Universality Violating (LFUV) correction to SM contribution (e.g. « $C_{9\mu}$ »)

Capdevila'1704.05340

Largest pulls	$\langle P_5' \rangle_{[4,6]}$	$\langle P_5' \rangle_{[6,8]}$	$R_K^{[1,6]}$	$R_{K^*}^{[0.045,1.1]}$	$R_{K^*}^{[1.1,6]}$	$\mathcal{B}^{[2,5]}_{B_s\to\phi\mu^+\mu^-}$	$\mathcal{B}^{[5,8]}_{B_s\to\phi\mu^+\mu^-}$
Experiment	-0.30 ± 0.16	-0.51 ± 0.12	$0.745^{+0.097}_{-0.082}$	$0.66^{+0.113}_{-0.074}$	$0.685^{+0.122}_{-0.083}$	0.77 ± 0.14	0.96 ± 0.15
SM prediction	-0.82 ± 0.08	-0.94 ± 0.08	1.00 ± 0.01	0.92 ± 0.02	1.00 ± 0.01	1.55 ± 0.33	1.88 ± 0.39
Pull (σ)	-2.9	-2.9	+2.6	+2.3	+2.6	+2.2	+2.2
Prediction for $\mathcal{C}_{9\mu}^{\rm NP} = -1.1$	-0.50 ± 0.11	-0.73 ± 0.12	0.79 ± 0.01	0.90 ± 0.05	0.87 ± 0.08	1.30 ± 0.26	1.51 ± 0.30
Pull (σ)	-1.0	-1.3	+0.4	+1.9	+1.2	+1.8	+1.6

- PS: not addressing $R_{D(*)}$ = BR($B \to D^{(*)}\tau\nu$) / BR($B \to D^{(*)}\mu\nu$) here…

Wilson coefficients Fits

- FCNC $b \to s$ transitions in the SM mostly come from W-t-ν boxes, summarised by effective operators

$$\mathcal{H}_{\rm eff} = -\frac{4\,G_F}{\sqrt{2}} V_{tb}V_{ts}^* \frac{e^2}{16\pi^2} \sum_i (C_i O_i + C'_i O'_i) + \text{h.c.}$$

$$O_9 = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell)\,, \qquad O'_9 = (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \ell)\,,$$
$$O_{10} = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)\,, \quad O'_{10} = (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)\,.$$

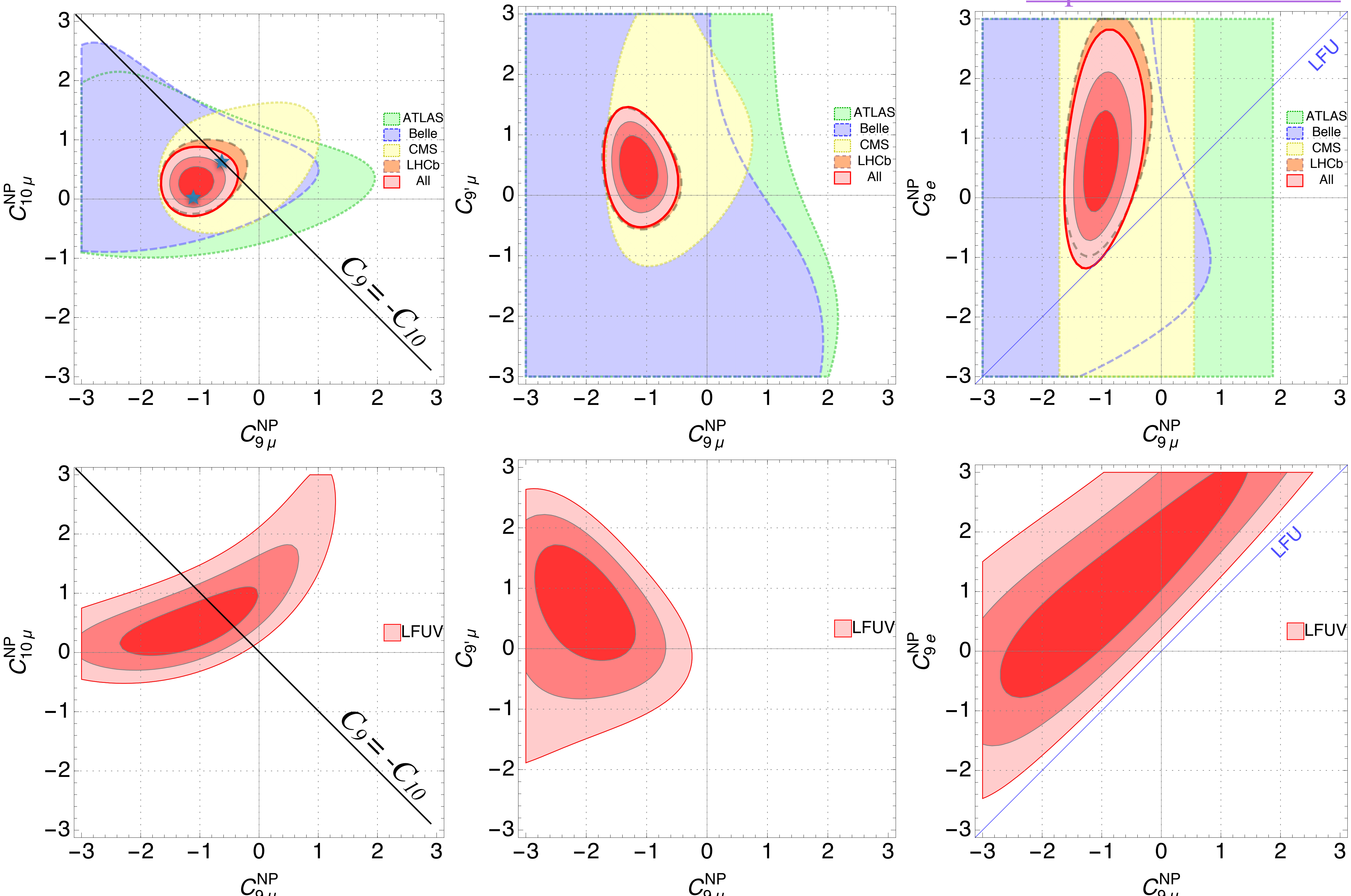
- In the SM, for all leptons, $C_9 \approx - C_{10} \approx 4.32$ & $C'_9 = - C'_{10} = 0$
- All fits (D'Amico'1704.05438, Capdevila'1704.05340, Altmannshofer'1703.09189, Geng'1704.05446) point in the same direction, with varying significance:

Capdevila'1704.05340

	All					LFUV				
1D Hyp.	Best fit	1 σ	2 σ	Pull_{SM}	p-value	Best fit	1 σ	2 σ	Pull_{SM}	p-value
$\mathcal{C}_{9\mu}^{\text{NP}}$	-1.10	$[-1.27, -0.92]$	$[-1.43, -0.74]$	5.7	72	-1.76	$[-2.36, -1.23]$	$[-3.04, -0.76]$	3.9	69
$\mathcal{C}_{9\mu}^{\text{NP}} = -\mathcal{C}_{10\mu}^{\text{NP}}$	-0.61	$[-0.73, -0.48]$	$[-0.87, -0.36]$	5.2	61	-0.66	$[-0.84, -0.48]$	$[-1.04, -0.32]$	4.1	78
$\mathcal{C}_{9\mu}^{\text{NP}} = -\mathcal{C}'_{9\mu}$	-1.01	$[-1.18, -0.84]$	$[-1.33, -0.65]$	5.4	66	-1.64	$[-2.12, -1.05]$	$[-2.52, -0.49]$	3.2	31
$\mathcal{C}_{9\mu}^{\text{NP}} = -3\mathcal{C}_{9e}^{\text{NP}}$	-1.06	[-1.23,-0.89]	[-1.39,-0.71]	5.8	74	-1.35	$[-1.82, -0.95]$	$[-2.38, -0.59]$	4.0	71

Wilson coefficients Fits (2)

Capdevila'1704.05340



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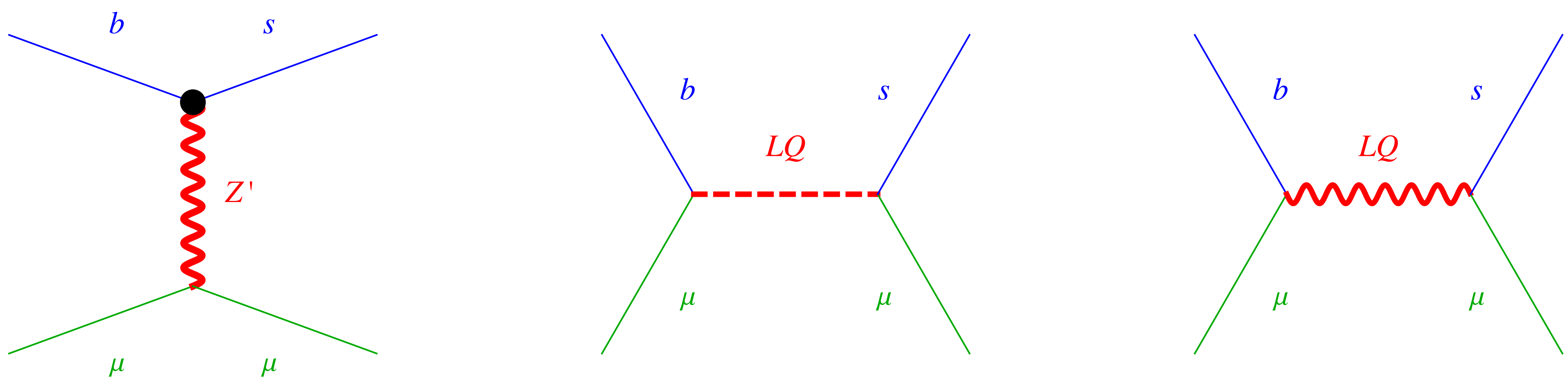
Tree Level Models

- Reasonable, to generate a large (~20%) correction to a SM-loop with a heavy particle
- Either s-channel Z' (Crivellin…), or t-channel leptoquark (Hiller…)



- But no DM connection, unless if *b-s-Z'* coupling is loop-generated (Bélanger'1507.06660). Bonus: g_μ-2 (another long standing issue…)

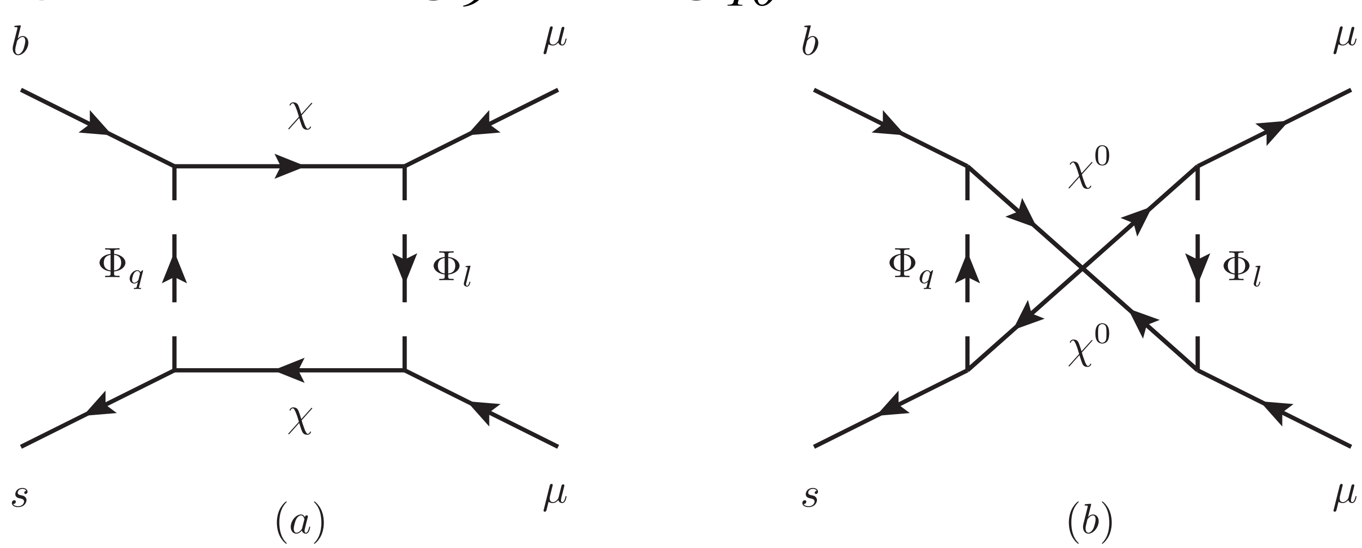
Minimal Loop Model

- See Gripaios'1412.1791 for an exhaustive list
- Minimal set of BSM fields: 1 « squark » Φ_q, 1 « slepton » Φ_l, 1 « neutralino » χ with Yukawa couplings:

$$\mathcal{L} = g_i^q \bar{\chi}_R Q_L^i \Phi_q + g_i^l \bar{\chi}_R L_L^i \Phi_l + \text{h.c.}$$

Field	$\mathcal{G}_{\text{SM}}$
Q_L^i	$(3,2,\frac{1}{6})$
U_R^i	$(3,1,\frac{2}{3})$
D_R^i	$(3,1,-\frac{1}{3})$
L_L^i	$(1,2,-\frac{1}{2})$
E_R^i	$(1,1,-1)$
H	$(1,2,\frac{1}{2})$
χ	$(1,1,0)$
	$(1,3,0)$
Φ_l	$(1,2,\frac{1}{2})$
Φ_q	$(3,2,\text{-}\frac{1}{6})$

- Generates $\Delta C_9 = -\Delta C_{10}$ via



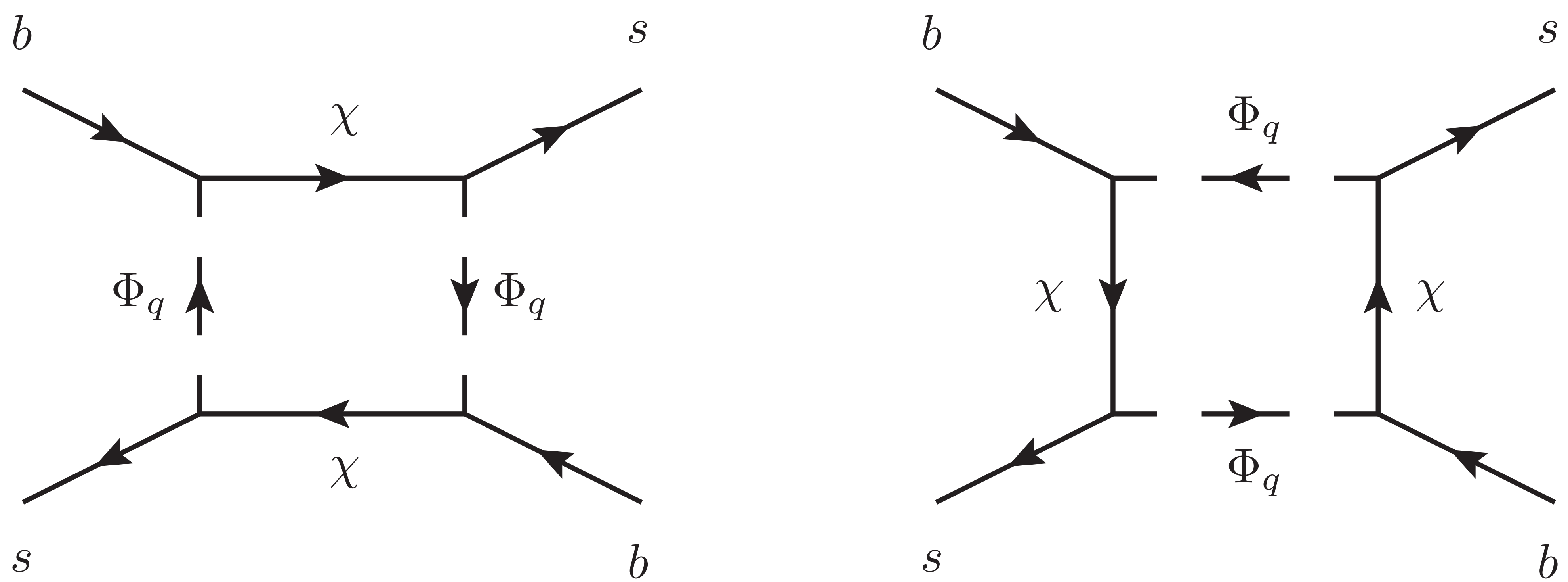
(poor man's Susy, with free Yukawas)

(Adding flavour symmetries)

- BSM new fields can be embedded into
  - Froggat-Nielsen construction for (s)quarks ($\rightarrow g^q{}_2\, g^q{}_3 = 0.04$)
  - $A_4 \times Z_3$ symmetry (Feruglio'1205.5133) for neutrino mixings
    ($\rightarrow$ only one g^l can differ from zero: « explains » LFUV)
- $U(1)_\chi$ (or $Z_{2\chi}$ if Majorana) stabilizes χ as DM candidate

Field	$\mathcal{G}_{\rm SM}$	$A_4 \times U(1)_{\rm FN} \times Z_3$	$U(1)_{B'} \times U(1)_{L'} \times U(1)_\chi$
Q_L^i	$(3,2,\frac{1}{6})$	$(1,\Upsilon_{Q_i},\omega)$	$(\frac{1}{3},0,0)$
U_R^i	$(3,1,\frac{2}{3})$	$(1,\Upsilon_{U_i},\omega^2)$	$(\frac{1}{3},0,0)$
D_R^i	$(3,1,-\frac{1}{3})$	$(1,\Upsilon_{D_i},\omega^2)$	$(\frac{1}{3},0,0)$
L_L^i	$(1,2,-\frac{1}{2})$	$(3,0,\omega)$	$(0,1,0)$
E_R^i	$(1,1,-1)$	$(1^{(\prime,\prime\prime)},\Upsilon_{E_i},\omega^2)$	$(0,1,0)$
H	$(1,2,\frac{1}{2})$	$(1,0,1)$	$(0,0,0)$
χ	$(1,1,0)$	$(1,0,\omega)$	$(0,0,1)$
	$(1,3,0)$	$(1,0,\omega)$	$(0,0,1)$
Φ_l	$(1,2,\frac{1}{2})$	$(1'',0,1)$	$(0,-1,1)$
Φ_q	$(3,2,-\frac{1}{6})$	$(1,0,1)$	$(-\frac{1}{3},0,1)$

Constraints: B_s mixing

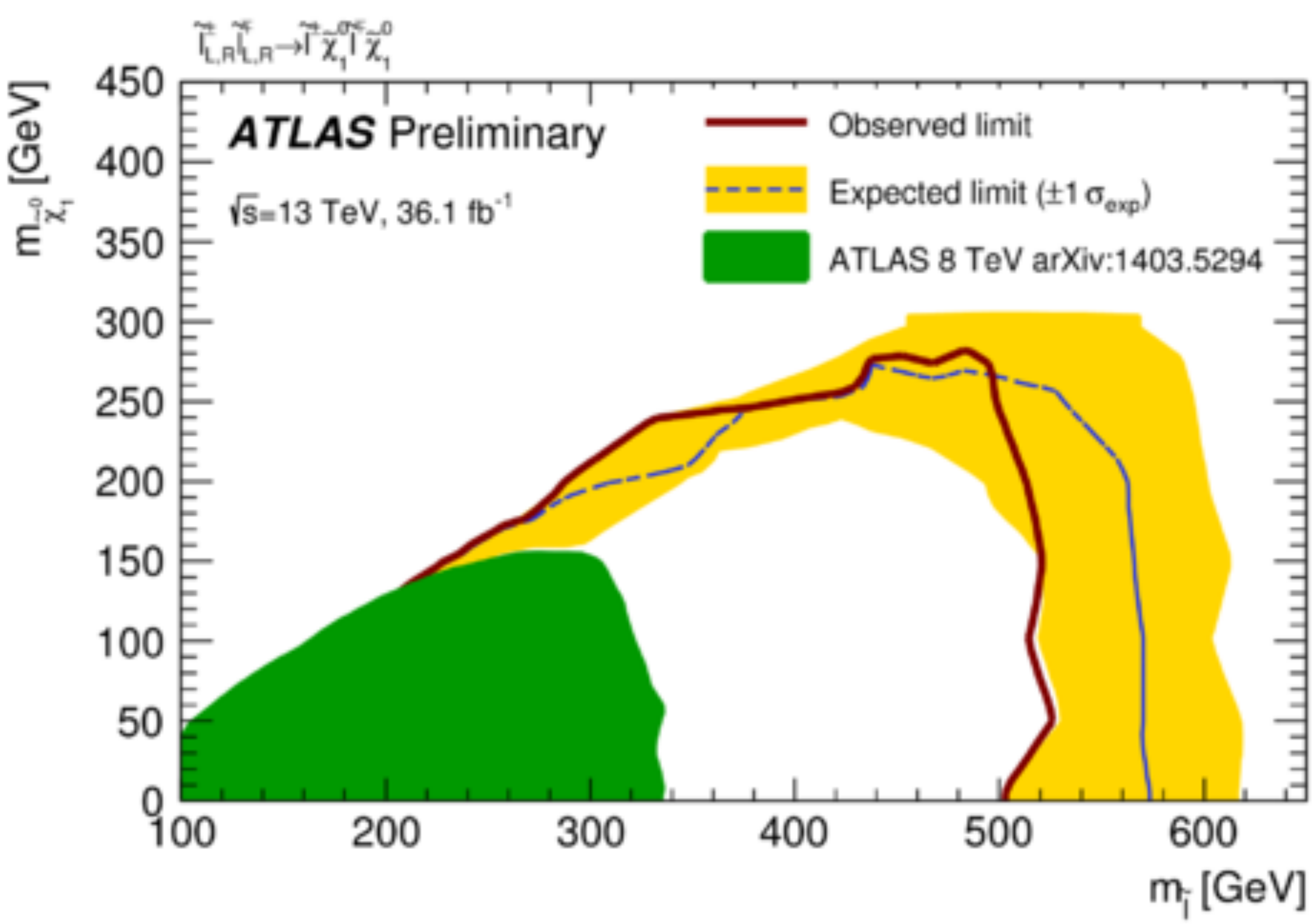


$$C^1_{B\bar{B}} = \frac{|g_2^{q*} g_3^q|^2}{m_\chi^2} \frac{1}{128\pi^2} \left(K'(x_q) + 2G'(x_q)\right)$$

- Δm_s forbids large values of g^q and/or low values of M_{Φ_q}
- For FN values of g^q and M_{Φ_q} >950 GeV, there is no constraint

Constraints: direct production @LHC

- We impose squark and slepton searches limits:
  $M_{\Phi q} > 950$ GeV (sbottom: ATLAS-CONF-2017-038)
  $M_{\Phi l} > 300$ GeV (slepton_l ATLAS'1403.5294, recently updated:
  $M_{\Phi l} > 500$ GeV (ATLAS-CONF-2017-039)



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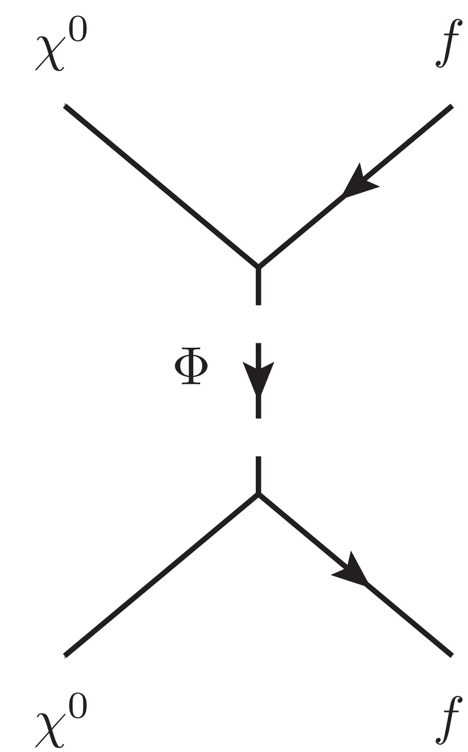
Relic density & Indirect detection

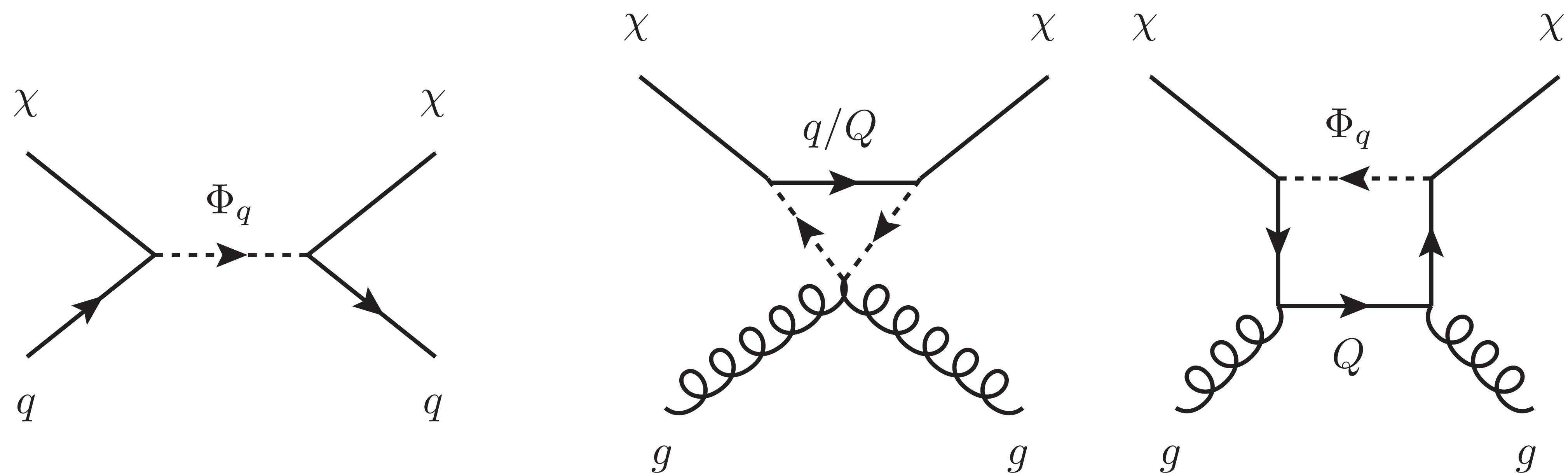
- Dominated by the tree annihilation into fermions (below WW threshold)
- Helicity suppression favours bb, but large slepton Yukawa wins

$$\langle \sigma v \rangle \left(\bar{\chi}^0 \chi^0 \to \bar{f} f\right) = \frac{N_c g_f^4}{32\pi m_\chi^2 \left(1 + x_f\right)^2} \left(\frac{m_f^2}{m_\chi^2} + \frac{2\left(1 + x_f^2\right)}{3\left(1 + x_f\right)^2} v^2 \right).$$



- $\to v^2$ term controls primordial annihilation, and no ID signal

Direct Detection

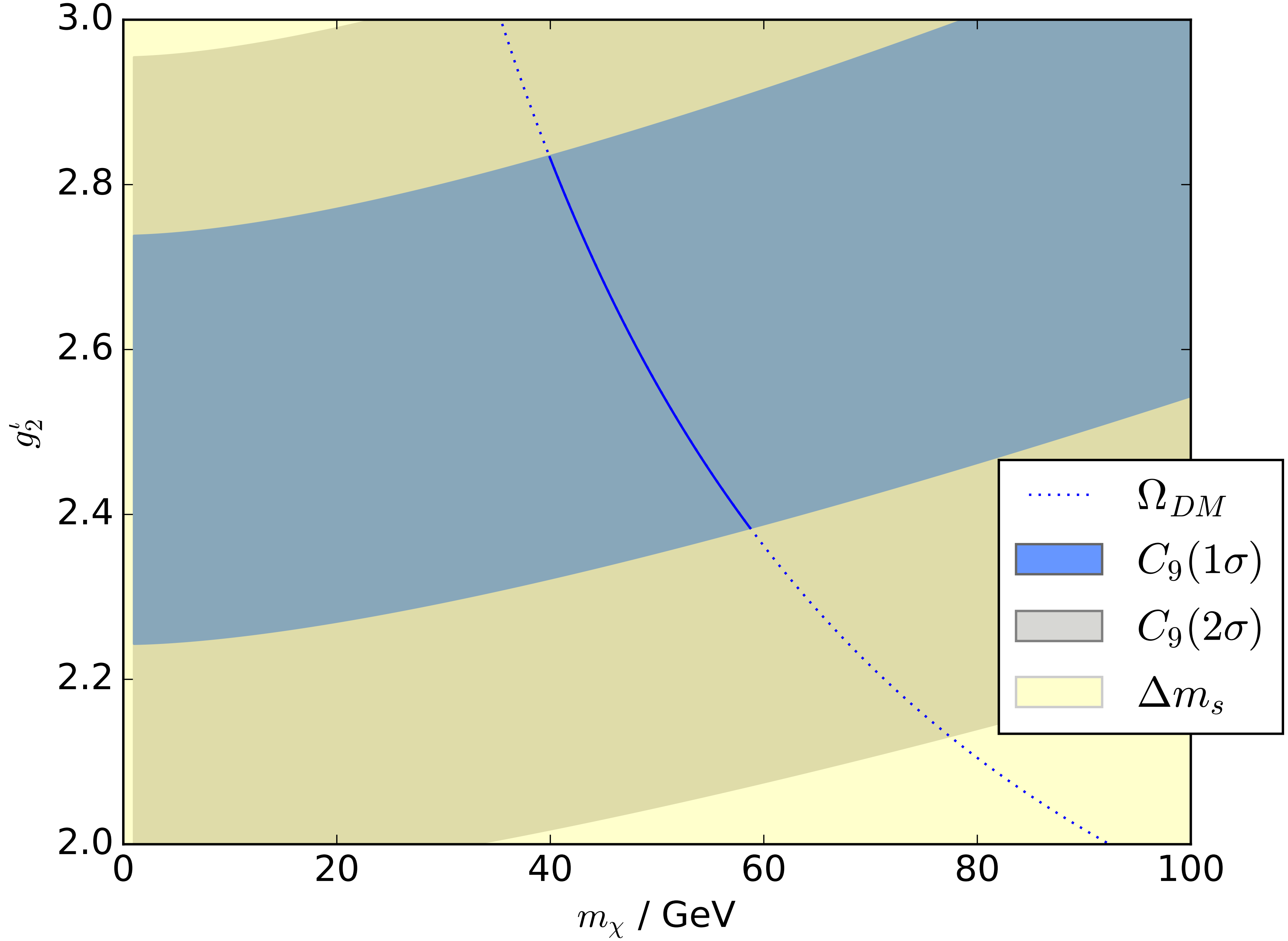


- Even including loop-interactions to gluonsdoesn't allow for more than ~10^{-49} cm^{-2} for 100 GeV neutralino and 1 TeV squark

$$\hat{\sigma}_N^{\mathrm{SI}} = \frac{4\mu_N^2}{\pi}\left(Z f_p + (A-Z) f_n\right)^2 \qquad\qquad \frac{f_N}{m_N} = \frac{m_\chi}{M_{\Phi_q}^4}\sum_{q,Q}|g^q|^2\left[\frac{f_{TG}}{108} + \frac{3}{12}\left(q(2)+\bar{q}(2)\right)\right].$$

→ no DD constraints in the near future

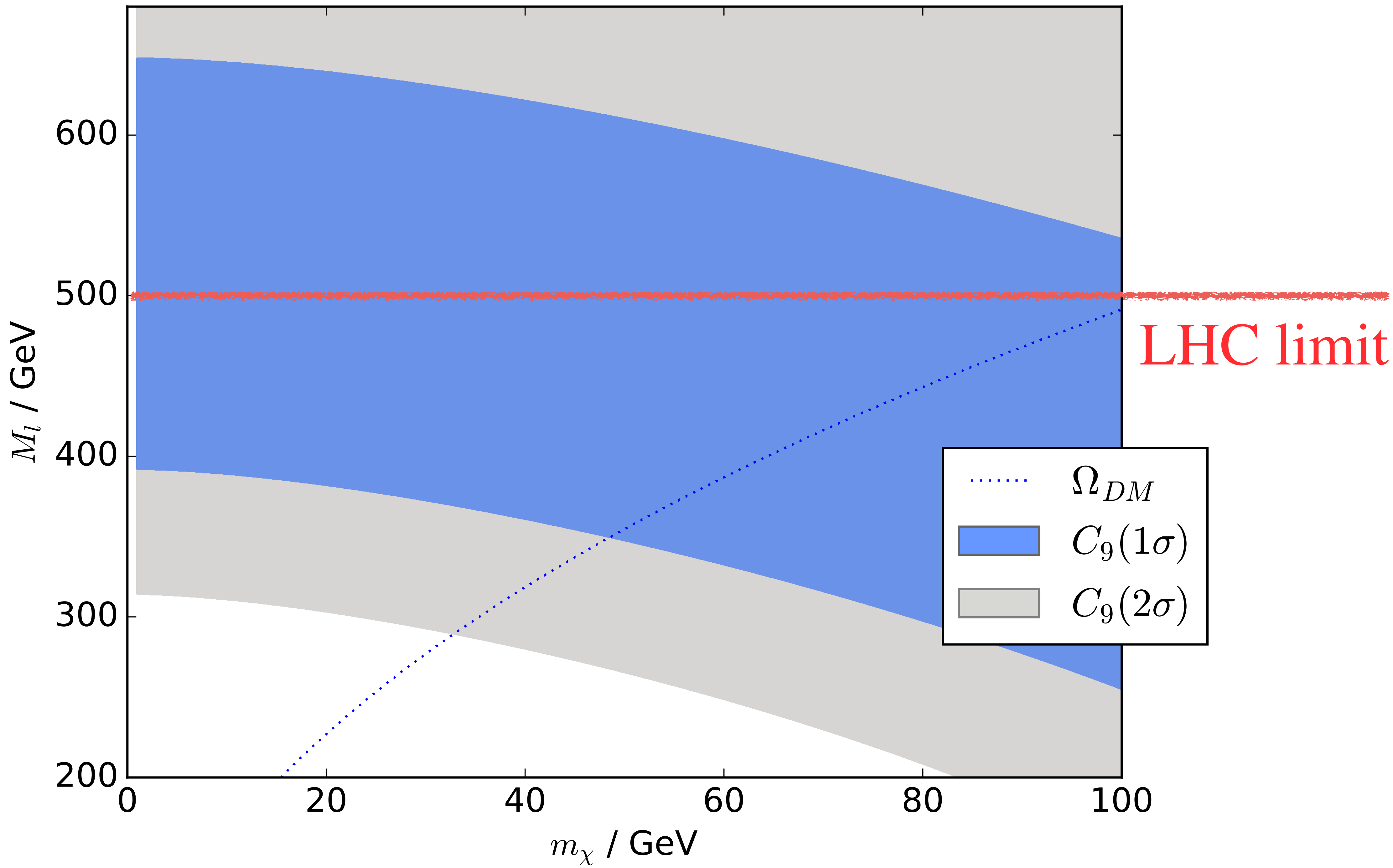
Relic density vs C_9 (m_χ - g^l)



Fixing $M_{\Phi q}$ = 950 GeV ; $M_{\Phi l}$ = 300 GeV

→ g^l is pushed close to non-perturbative upper limit (~3.5)

Relic density vs C_9 (m_χ - M_l)



Fixing $M_{\Phi q} = 950$ GeV ; $g^l = 3$

→ LHC M_l limit is pushing out of the C_9 1-σ band (! WW threshold)

Conclusion

- Loop models for $C_9 = - C_{10}$ explanations of B anomalies generically offer a DM candidate
- Relic density may (still…) be compatible,
- But DD an ID detection cannot be put to use.
- Instead, direct LHC searches seriously shrink the parameter space
- (most appealing model $(\chi, \Phi_l, \Phi_q) = (3,4,2)_{SU(2)}$ accomodating $(g\text{-}2)_\mu$ is already excluded; $(1,2,2)_{SU(2)}$ studied here only accounts for 20%)
- Maximal LFUV is compatible with flavour symmetries