(Quark) Flavour Physics

A biased 2016 pick for Pierre

J. Orloff, LPC Clermont

Fayet Fest, Dec. 8 2016

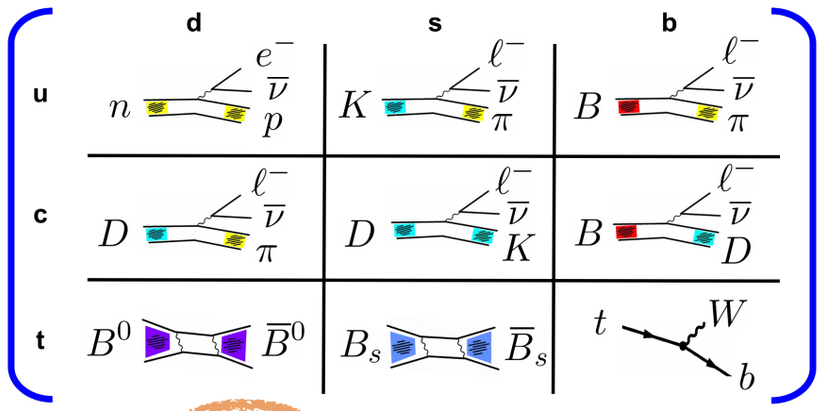
Overview

- CKM global fit status
- Tensions beyond the fit
- Models behind C_9^{NP}
- Organizing, with DM?

Latest CKM global fit

c.f. Perez@CKM'16, Mumbai

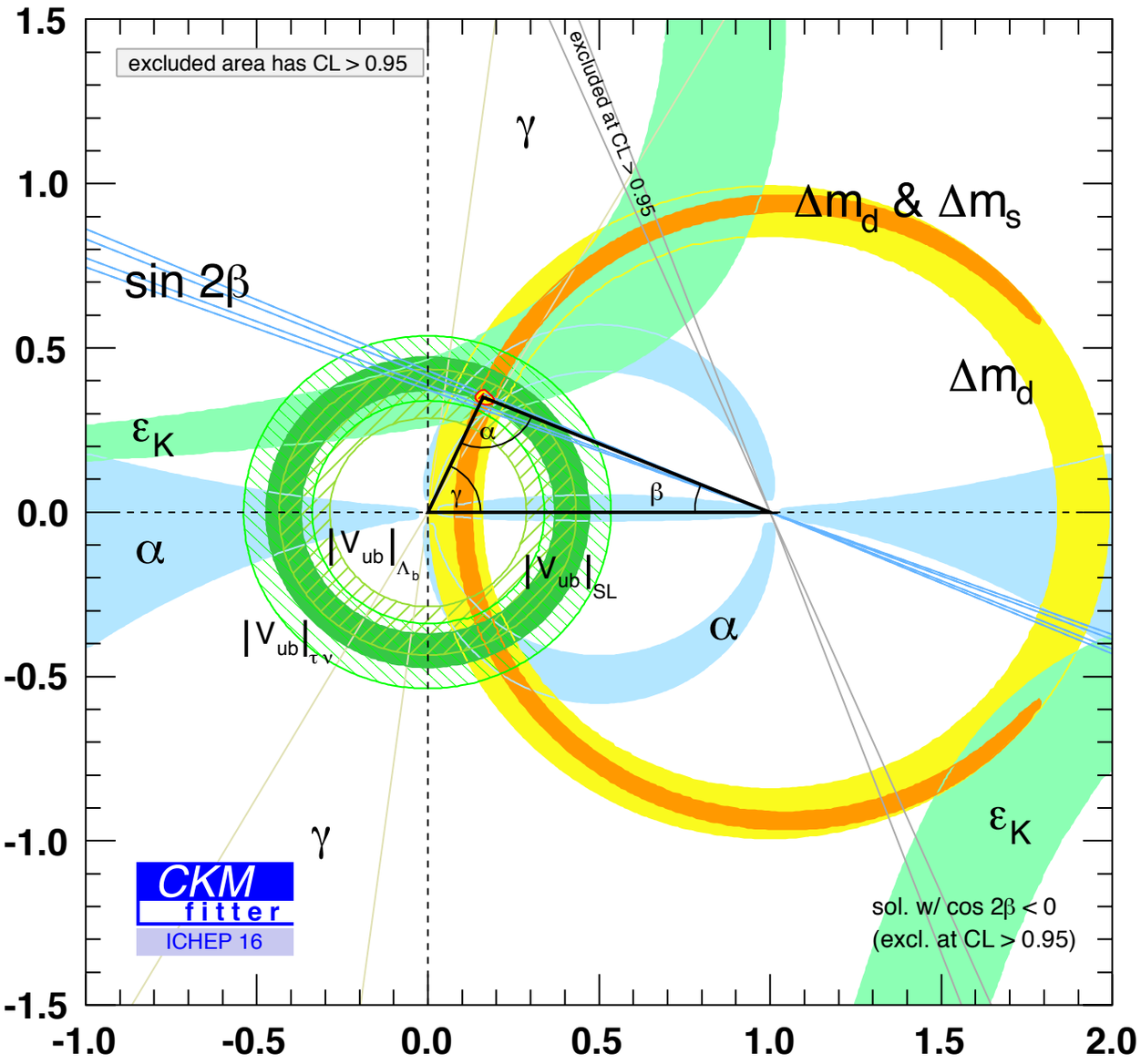
$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$



$$\lambda = \frac{|V_{us}|}{\sqrt{|V_{ud}|^2 + |V_{us}|^2}} = 0.22513^{+28}_{-31}$$

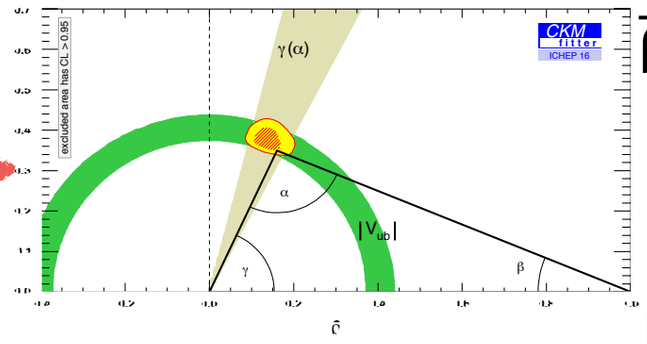
$$A = \frac{|V_{cb}|/\lambda^2}{\sqrt{|V_{ud}|^2 + |V_{us}|^2}} = 0.8250^{+56}_{-77}$$

$$\bar{\rho} + i\bar{\eta} = -\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}$$

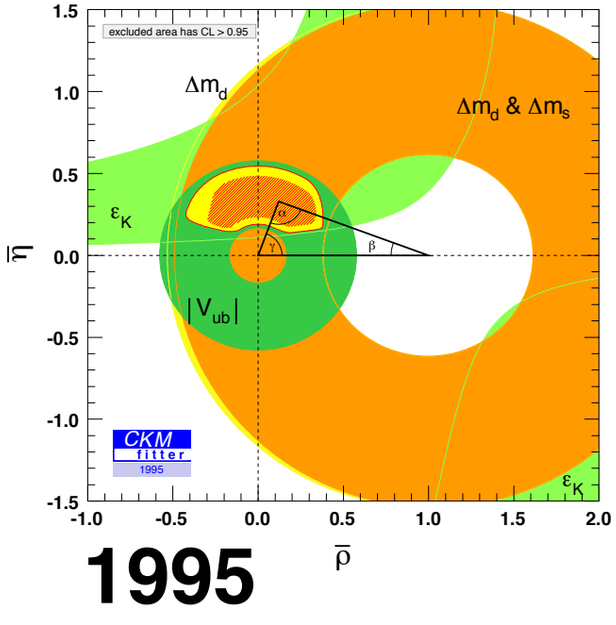


Remarkable consistence of :

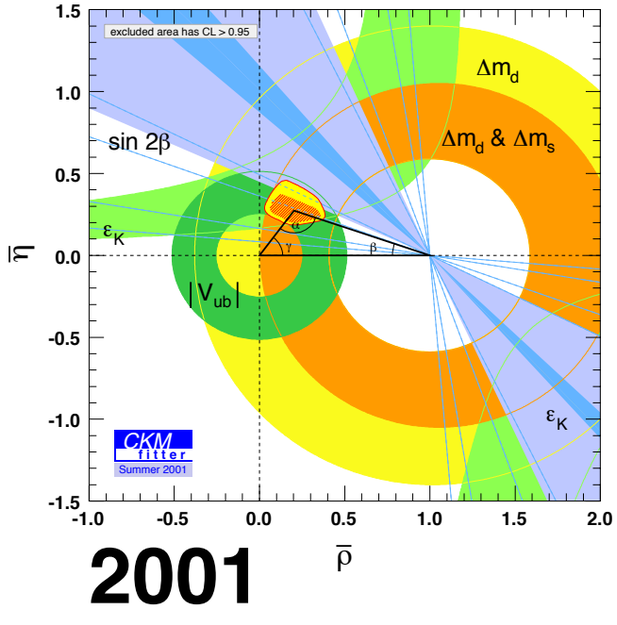
- CP-even vs CP-odd observables
- sizes vs angles
- loop vs tree (Pierre's favorite?):



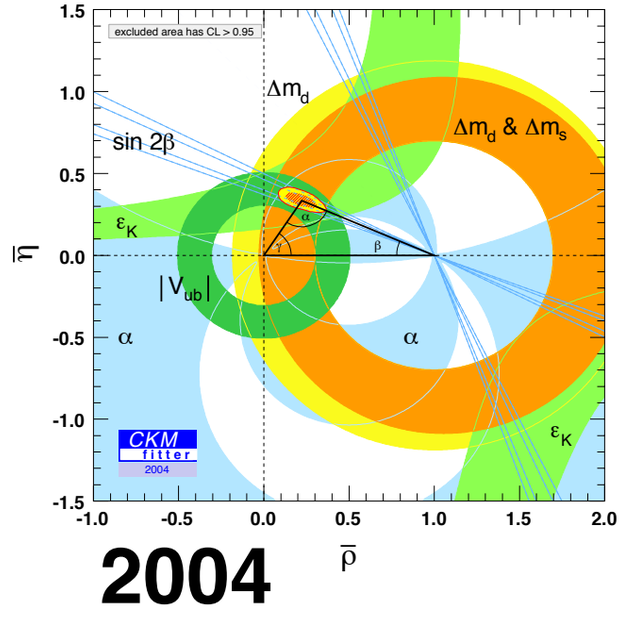
Irresistible 20 years progression



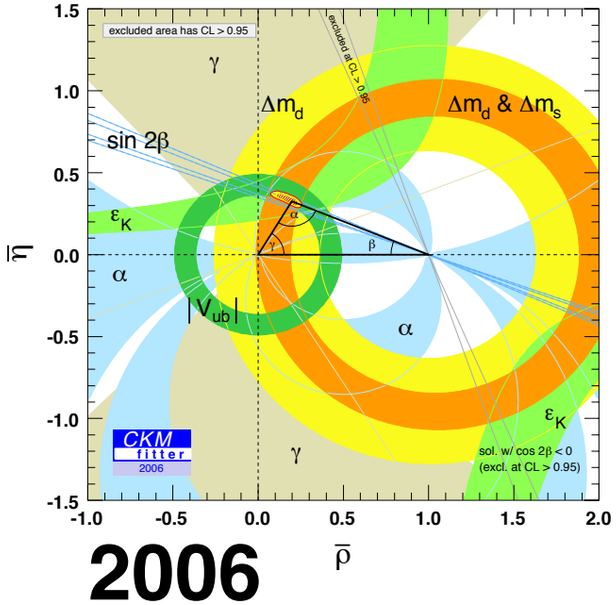
1995



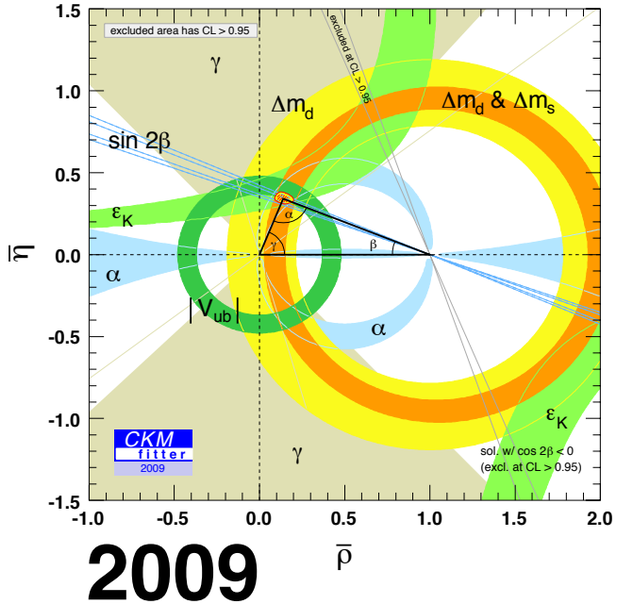
2001



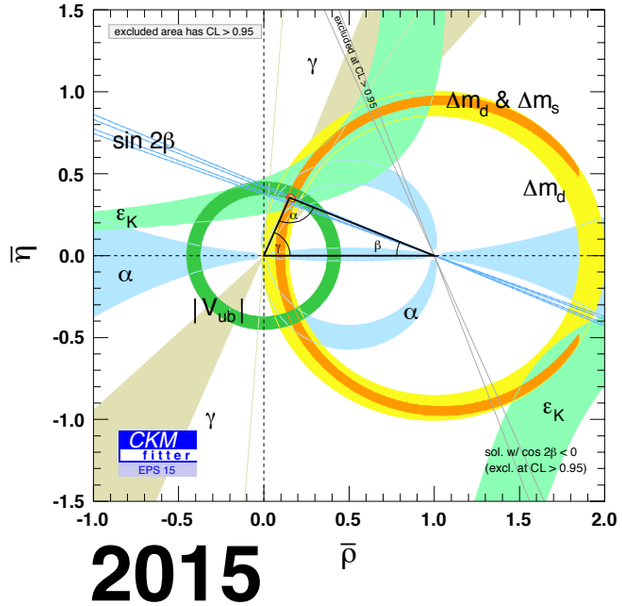
2004



2006



2009

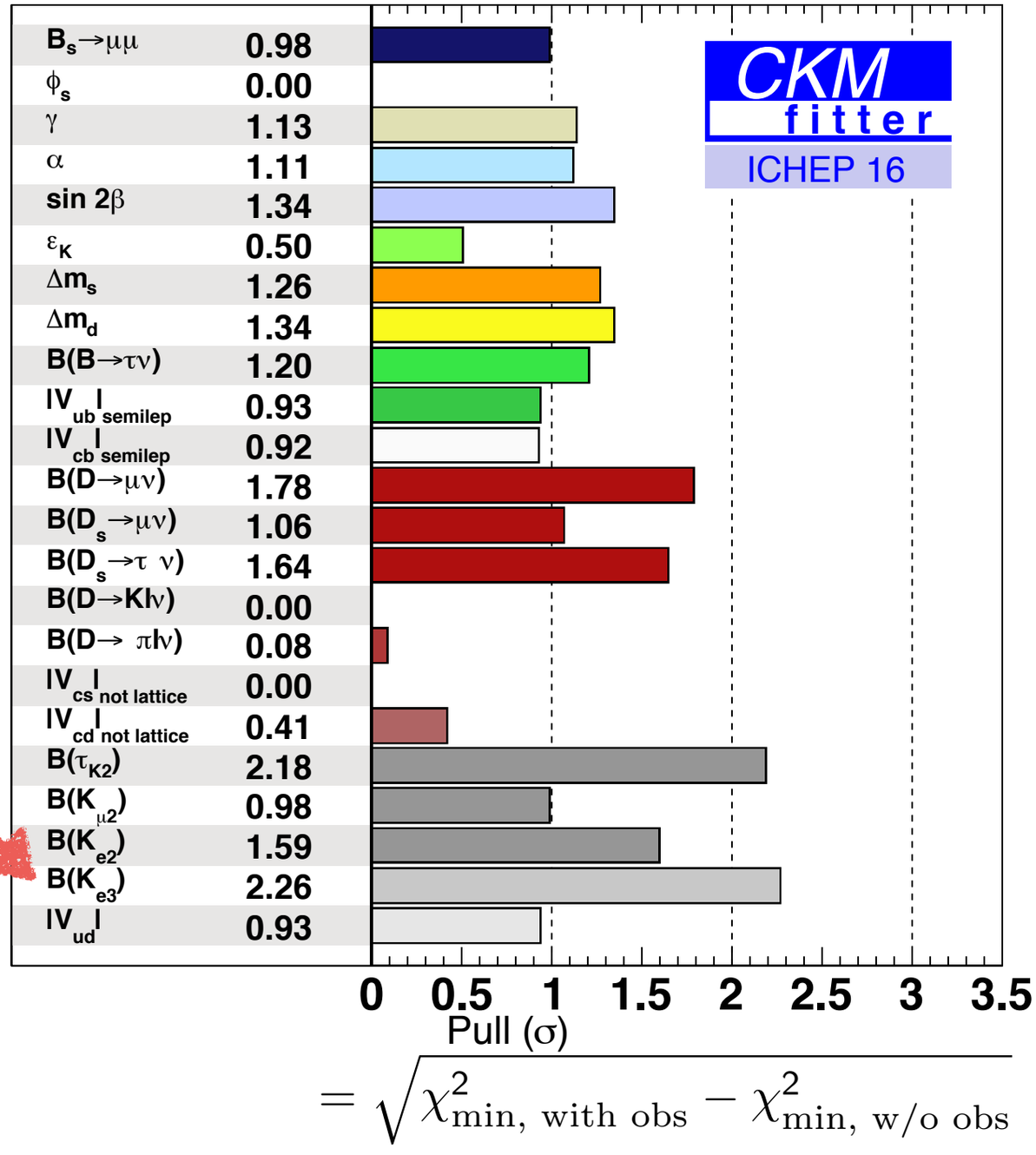


2015

Thanks to: LEP, KTeV, NA48, Babar/Belle, D0/CDF, LHCb/CMS

Pulls for various observables

- For uncorrelated gaussian errors, pulls should average to 0, with variance = 1
- But there are correlations, and Rfit non-gaussianities for th. uncertainties (→ pull = 0)
- New 2.3σ « tension » B(K→π eν): ~ welcome ! (from lattice new $f^{K\to\pi}(0)$)
- But there are more serious tensions (meaningless to include in global fit: require extra parameters)



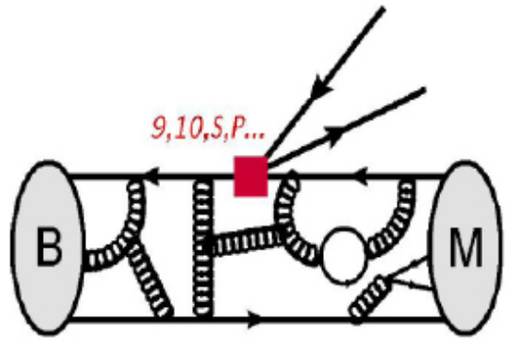
$$= \sqrt{\chi^2_{\text{min, with obs}} - \chi^2_{\text{min, w/o obs}}}$$

Anomalies beyond the global fit

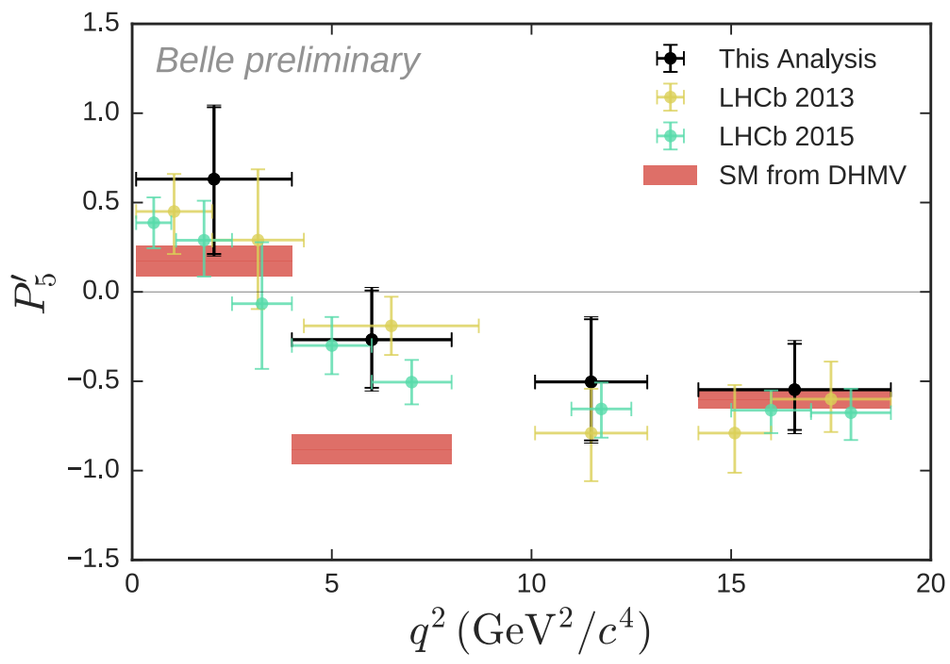
B→K*μμ

Exclusive b→s FCNC transition:

- requires delicate form factors, but
- offers many observables depending on dilepton invariant q^2 and angles (wrt K*→Kπ)



A specific angular variable (P'_5) displays a significant (2-3σ) deviation from SM (+FF!) in LHCb (2013,15) and Belle data.



arXiv:1609.01355

→ consider non-SM contributions C_9^{NP} to effective operators like

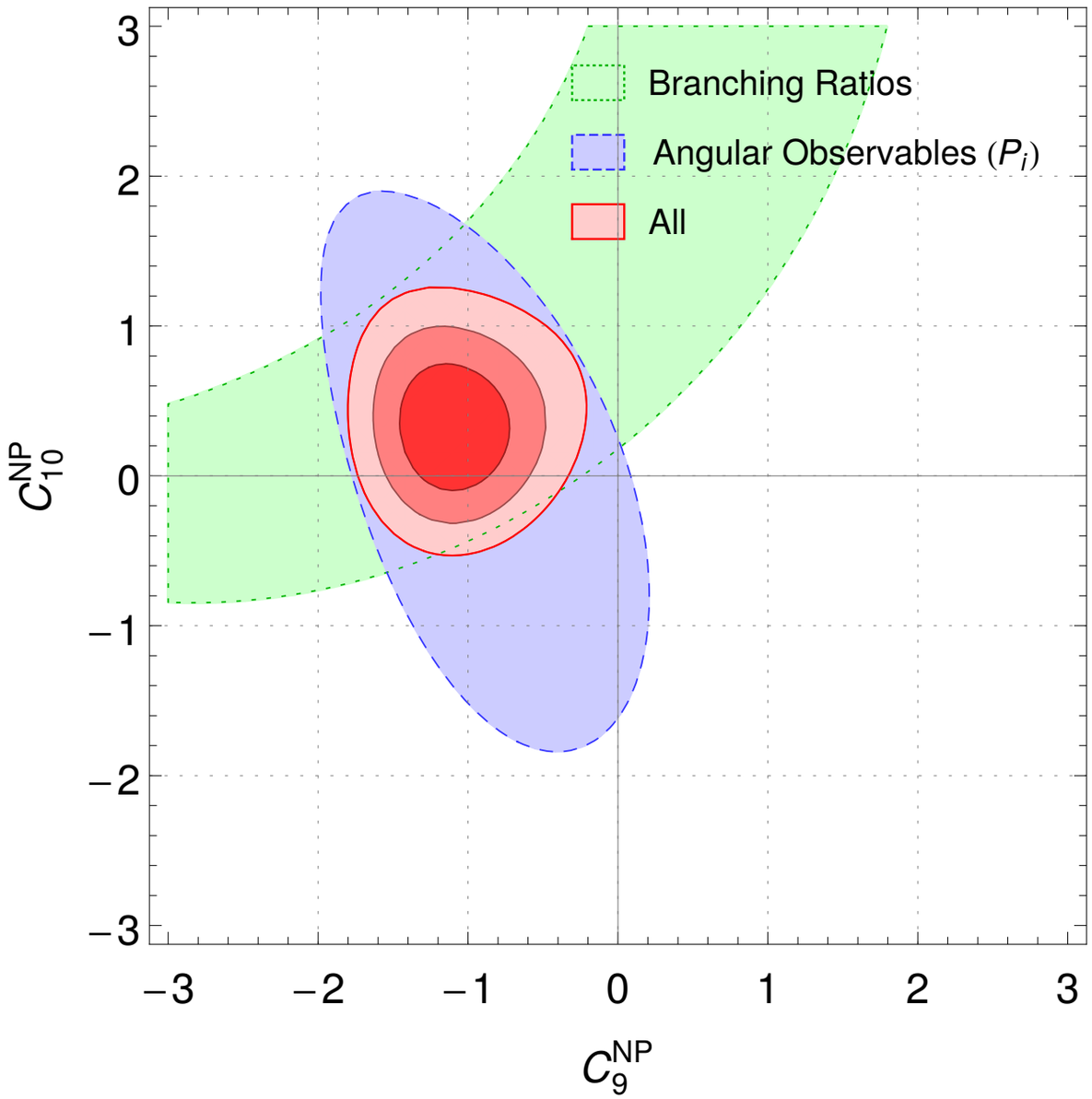
$$\mathcal{O}_9^{(\prime)} = \frac{\alpha}{4\pi}[\bar{s}\gamma^\mu P_{L(R)} b][\bar{\mu}\gamma_\mu \mu] \qquad C_9^{SM} = 4.07$$

$$\mathcal{O}_{10}^{(\prime)} = \frac{\alpha}{4\pi}[\bar{s}\gamma^\mu P_{L(R)} b][\bar{\mu}\gamma_\mu \gamma_5 \mu] \qquad C_{10}^{SM} = -4.31$$

Combining K*μμ observables

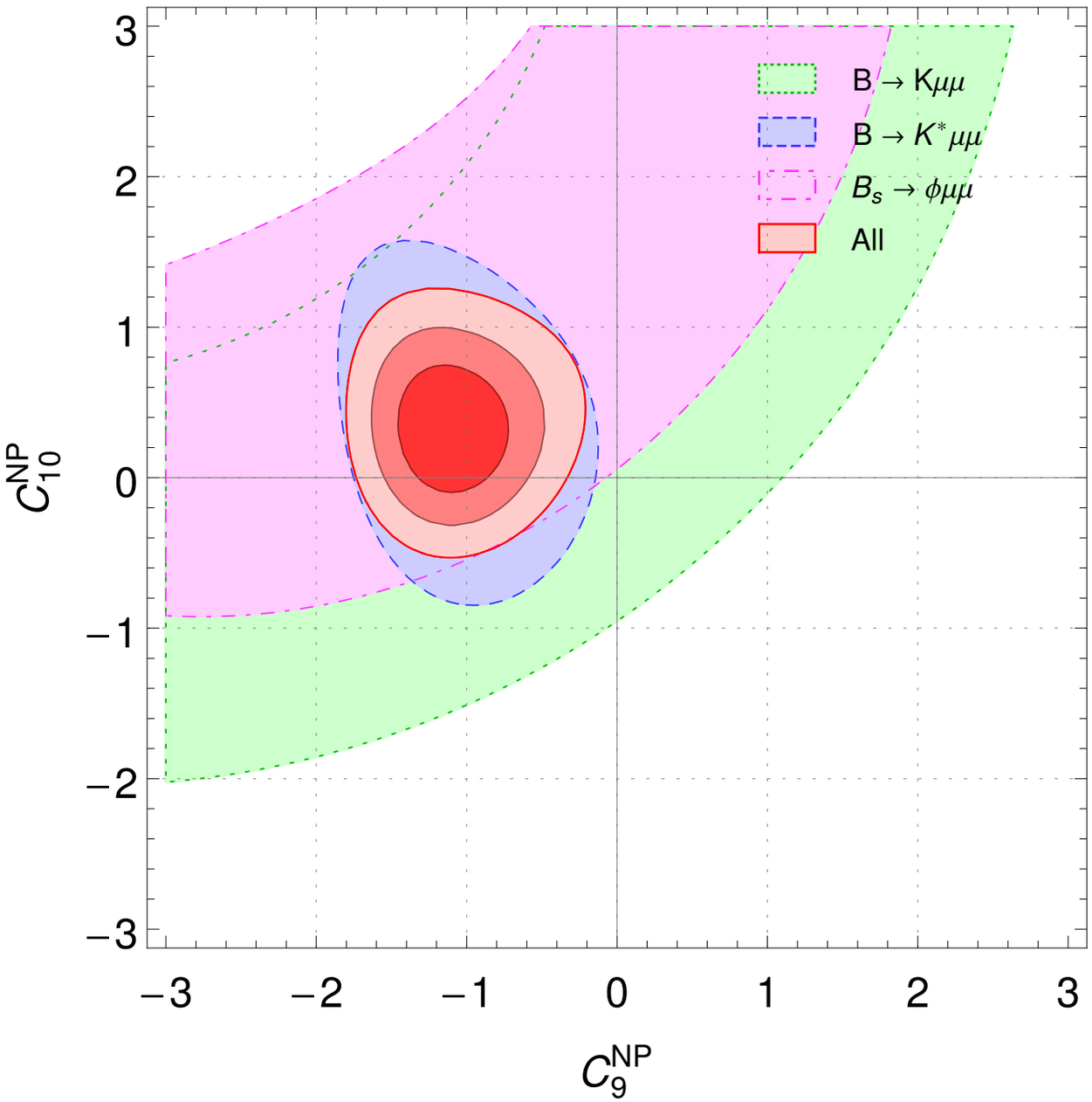
- Combining diff. q^2 bins for branching ratios and angular observables coherently adds up to **SM-pull of ~ 4.5σ**
- $C_9^{NP} \sim$ -1.1 alleviates this tension, without need for other NP contributions (or maybe $C_{10} = -C_9$)
- Alternatives:
  - Long distance cc contribution: could not be q^2-independent
  - More (over-?)conservative form factors uncertainties reduce →2σ (Camalich'1412.3183)

Descotes-Genon & al. 1510.04239



Other b→sμμ

- Other b→s BR compatible
- No other angles available yet…

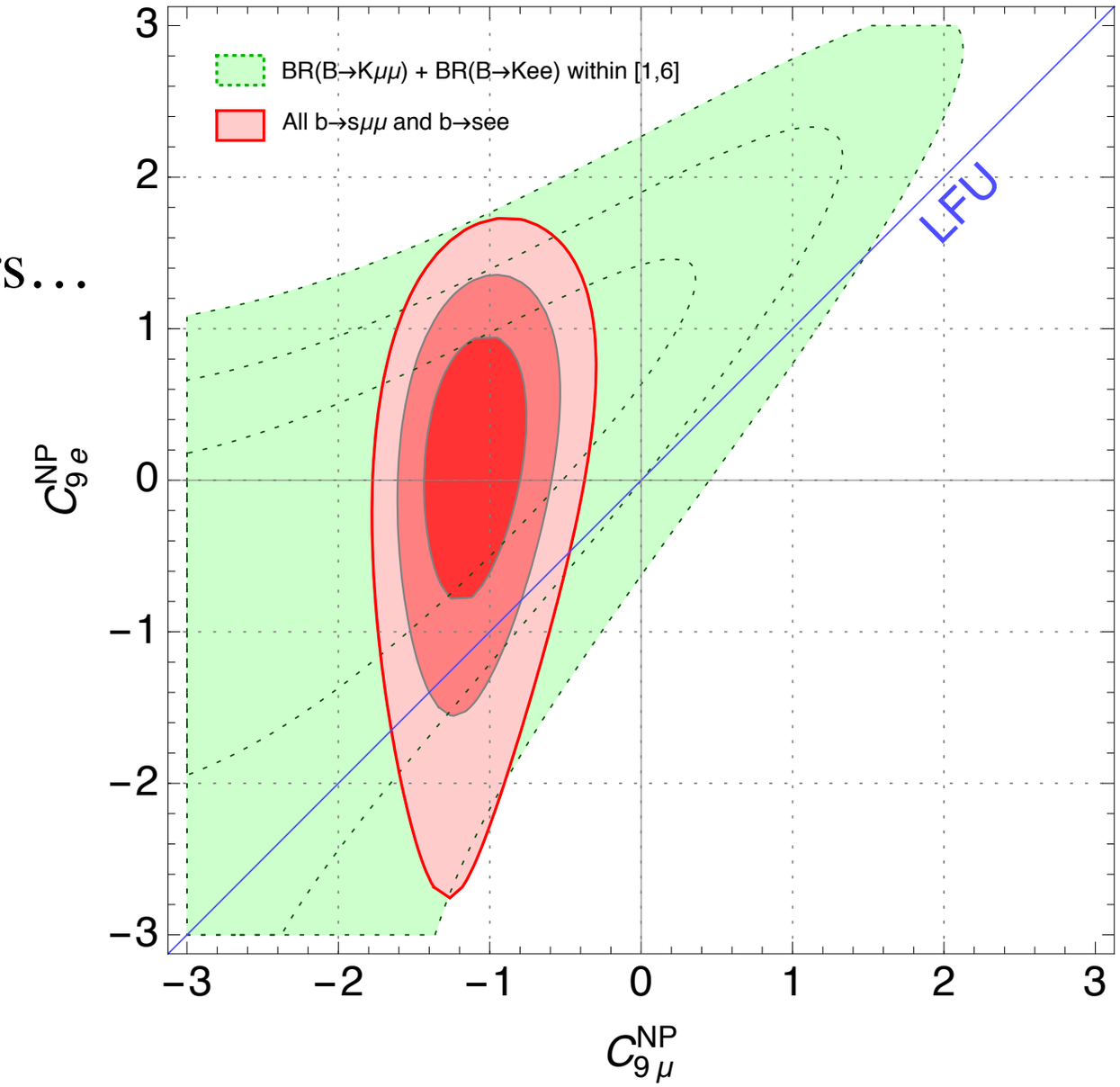


Adding b→s ee

- $R_K = \frac{\mathrm{Br}(B^+ \to K^+\mu^+\mu^-)}{\mathrm{Br}(B^+ \to K^+e^+e^-)} = 0.745^{+0.090}_{-0.074} \pm 0.036$

  while $R_K{}^{SM} = 1$
- → 2.3σ tension, by itself
- Insensitive to form factors, cc pairs…

- Adding such ee channels further increase the tension **up to ~ 4.9σ**
- Even if these σ's may need (some) renormalization, how to account for $C_9{}^{NP} = -1.1$ (? = $C_{10}{}^{NP}$)



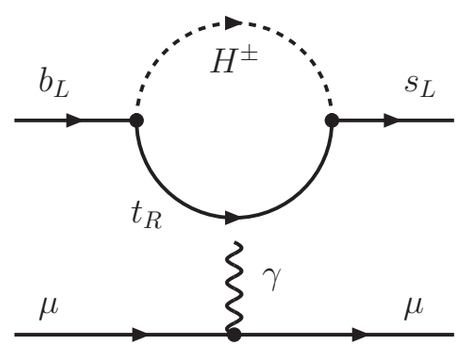
Models behind C_9^{NP}

C_9^{NP} = -1.1: not SUSY !

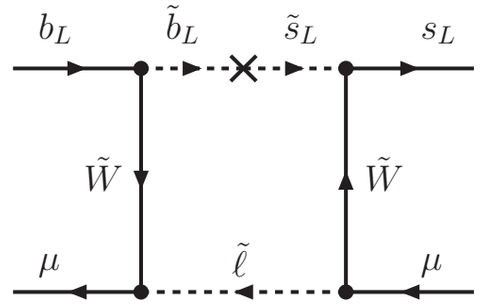
Altmannshofer & Straub
arXiv:1308.1501

SUSY contributions to C_9^{NP} << 1 (and/or wrong sign) :

- Z penguins suppressed by vector coupling of muons ~(1-4sw^2)~0.08
- photon penguins are too small:
  - $C_9^{H^\pm} \simeq -\frac{m_t^2}{m_{H^\pm}^2}\frac{1}{24}\,(\cot\beta)^2\; f_9^{H^\pm}\left(\frac{m_t^2}{m_{H^\pm}^2}\right) < 0.05$
  - higgsino loop only large if > 0
  - gluino and wino loops are only > 0.5 for m_{squark} < 300 GeV (!)



- boxes are even further suppressed by extra sfermion propagators



This cannot be SUSY (hence it's wrong?)

If confirmed, what then?

Example: Z'(L_μ-L_τ) model

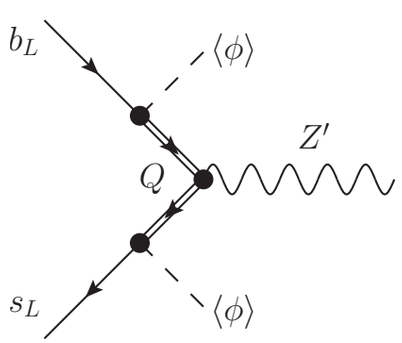
- C_9 = Vector current → *Z'*
- Anomaly free →
  - $U_1(L_\mu\text{-}L_\tau)$-coupling to leptons
  - broken by scalar ϕ
  - vector-like quarks-mediated effective coupling to quarks

Altmannshofer'1403.1269

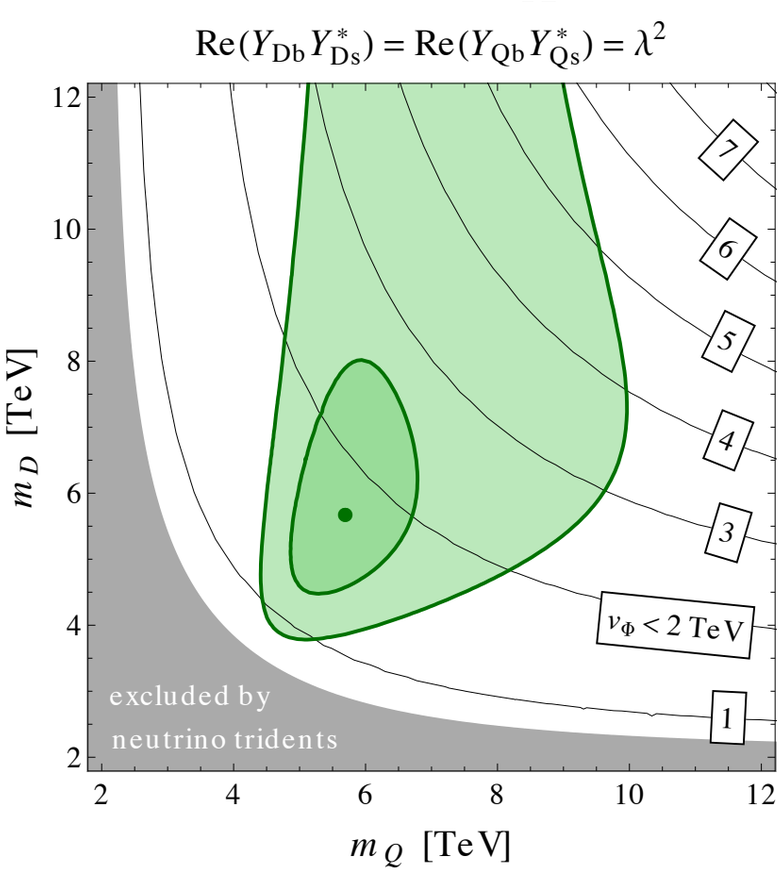
$$
\begin{aligned}
J^{\alpha\,(\mathrm{lep})}_{Z'} &= Q_\ell \Big(\bar{\ell}_2 \gamma^\alpha \ell_2 - \bar{\ell}_3 \gamma^\alpha \ell_3 \\
&\qquad + \bar{\mu}_R \gamma^\alpha \mu_R - \bar{\tau}_R \gamma^\alpha \tau_R \Big) \\
J^{\alpha\,(\mathrm{had})}_{Z'} &= \mathbb{R}^{(d)}_{ij} \bar{d}_i \gamma^\alpha P_R d_j + \mathbb{L}^{(d)}_{ij} \bar{d}_i \gamma^\alpha P_L d_j \\
&\quad + \mathbb{R}^{(u)}_{ij} \bar{u}_i \gamma^\alpha P_R u_j + \mathbb{L}^{(u)}_{ij} \bar{u}_i \gamma^\alpha P_L u_j \\
&\quad + \Phi^\dagger \bar{\tilde{U}}_L (Y_{Ut} t_R + Y_{Uc} c_R + Y_{Uu} u_R) \\
&\quad + \Phi^\dagger \bar{\tilde{D}}_L (Y_{Db} b_R + Y_{Ds} s_R + Y_{Dd} d_R)
\end{aligned}
$$

$$
\mathcal{L}_{\mathrm{dim6}} = (\Phi^* i \overleftrightarrow{D_\alpha} \Phi) \; \frac{\lambda^{(q)}_{ij}}{\Lambda^2} (\bar{q}^i_L \gamma^\alpha q^j_L)
$$

- $C_9 = \lambda^{(q)}_{bs} \dfrac{1}{\Lambda^2} = \dfrac{Y_{Qb} Y^*_{Qs}}{2 m_Q^2}$



- Other flavour constraints (B_s mixing,…)
- Proof of concept, but somewhat baroque…
- Notice : ad-hoc flavour structure…



Minimal renormalizable model

Gripaios'1509.05020

- Renormalizable blowing up of effective operators

$$\mathcal{O}_9^{(\prime)} = \frac{\alpha}{4\pi}[\bar{s}\gamma^\mu P_{L(R)} b][\bar{\mu}\gamma_\mu \mu]$$

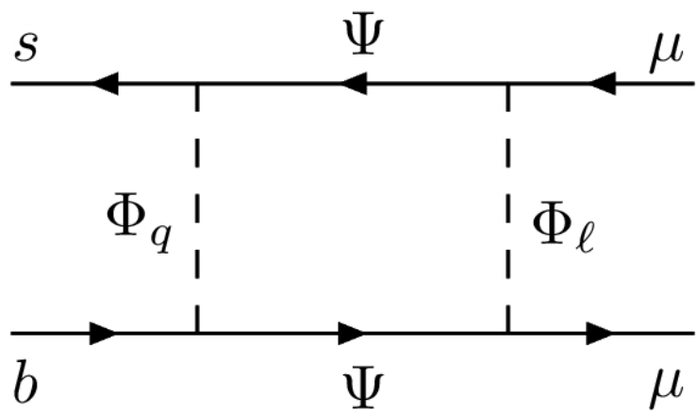
$$\mathcal{O}_{10}^{(\prime)} = \frac{\alpha}{4\pi}[\bar{s}\gamma^\mu P_{L(R)} b][\bar{\mu}\gamma_\mu \gamma_5 \mu]$$

requires at least 3 NP fields: « sfermions » ϕ_Q, ϕ_L, and « higgsino » ψ (but there is no SUSY…), in SU(2) representations to be chosen:

$$\alpha_i^q\, \overline{\Psi} Q_L^i \Phi_q + \alpha_i^\ell\, \overline{\Psi}^c L_L^i \Phi_\ell + \text{h.c.}$$

- Boxes then generate the effective operators, eg:

$$C_9^{\mu NP} = -C_{10}^{\mu NP} = \left(\frac{4G_F}{\sqrt{2}} V_{ts}^* V_{tb} \frac{\alpha}{4\pi}\right)^{-1} \frac{7}{576\pi^2} \frac{K(x_q, x_\ell)}{M_\Psi^2} \alpha_2^{q*} \alpha_3^q \left|\alpha_2^\ell\right|^2$$



- Can do the job, for ad-hoc flavour structures

Need for an organization (and DM?)

Need for flavour theory?

- 13 / 19 parameters of the vanilla SM are flavour related: quark mixings (4), masses (6), lepton masses (3)
- More (>7) with neutrinos (see tomorrow)
- Even more (>>???) if coping with b→s anomalies really needed

⇒ Can these all be wrapped up in one flavour model?

⇒ Can there be a (stable) DM candidate on the way?

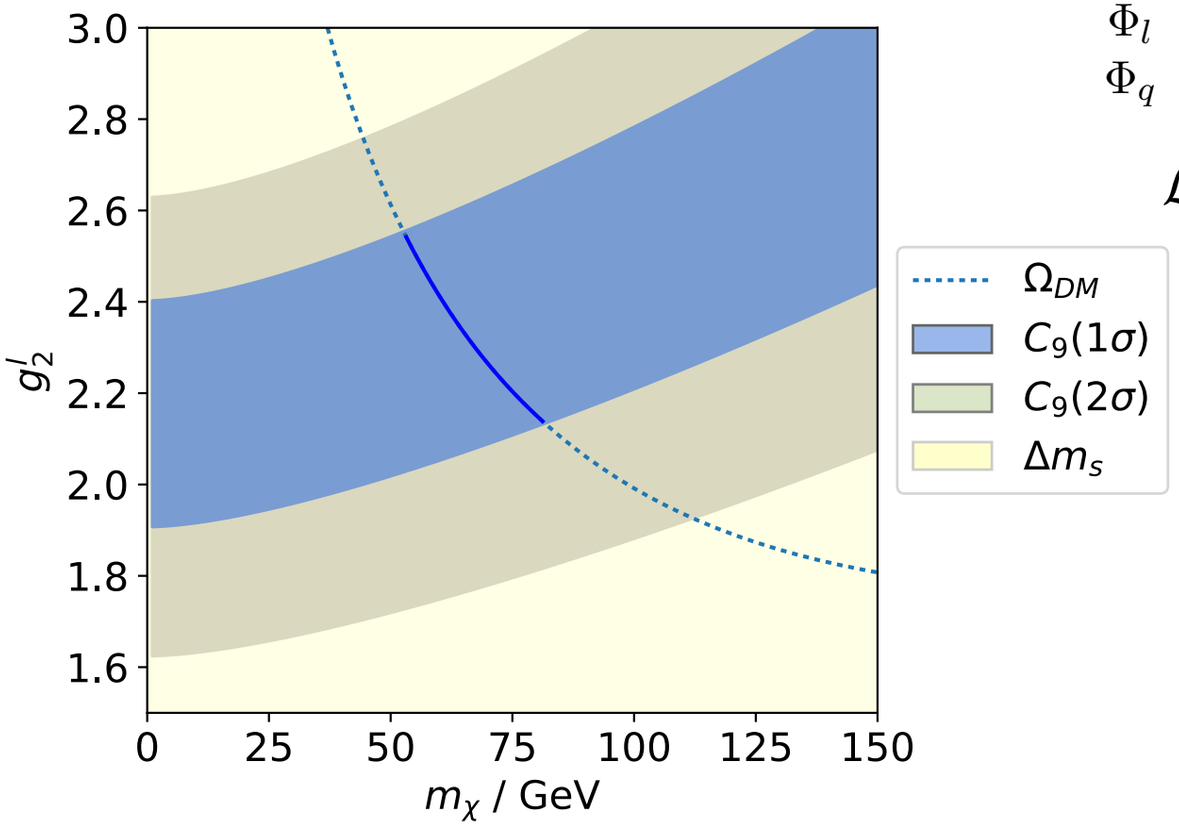
1st tentative with A_4

with G. Hiller, D. Skodras

- In the spirit of Altarelli'1205.5133, take the charge assignments:
- $\psi \to \chi$: DM candidate, stable thanks to $U(1)_\chi$
- For singlet DM, above direct limits: $M_l > 300$ GeV, $M_q > 700$ GeV

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	$(3,2,-\frac{1}{6})$	$(1,0,1)$	$(-\frac{1}{3},0,1)$

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



Very preliminary: to be refined…

Conclusions

- We might be witnessing a growing case for BSM, from $b \to s l^+ l^-$ transitions
- Further data should help settling QCD (FF, cc) uncertainties
- This is NOT Susy! (:-(
- It is >>>> ugglier!
- But taming the parameter zoo, DM « naturally » enters in the game…
- Would this be enough to attract Pierre into flavour issues???