Z' Models for B Anomalies at the LHC

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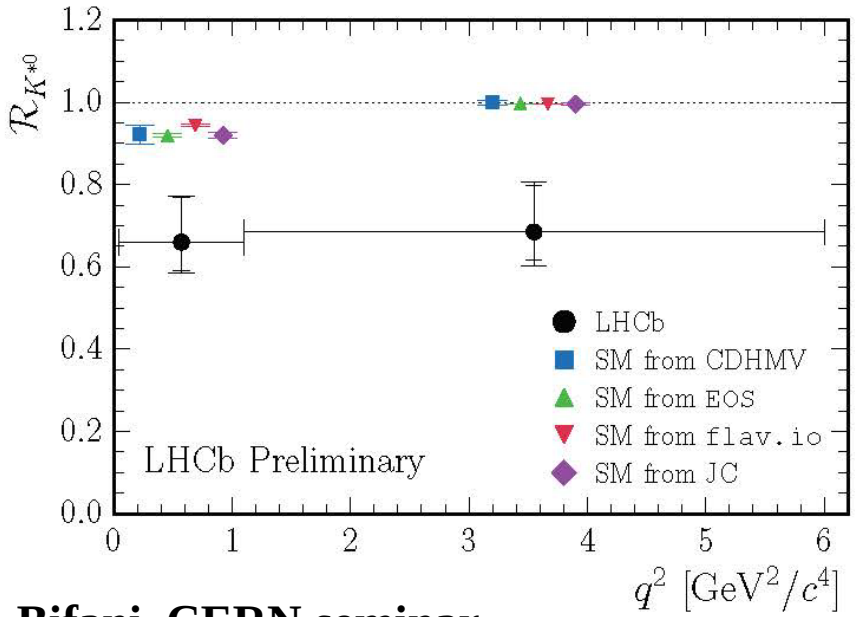
arXiv:1707.07016

Recent Results

$$R_K = \frac{\mathcal{B}(B \to K\mu^+\mu^-)}{\mathcal{B}(B \to Ke^+e^-)}\,,\quad R_{K^*} = \frac{\mathcal{B}(B \to K^*\mu^+\mu^-)}{\mathcal{B}(B \to K^*e^+e^-)}$$



S. Bifani, CERN seminar

$$R_K^{[1,6]} = 0.745^{+0.090}_{-0.074} \pm 0.036\,,$$

~ 2.6 σ

$$R_{K^*}^{[0.045,1.1]} = 0.660^{+0.110}_{-0.070} \pm 0.024$$

$$R_{K^*}^{[1.1,6]} = 0.685^{+0.113}_{-0.069} \pm 0.047$$

~ 2.4 - 2.5 σ

Global fits to b—> s l^+l^- observables: ~ 4 σ deviation from the SM

Altmannshofer, Stangl, Straub, 2017, G. D'Amico et al 2017, Capdevilla et al, 2017

Operators and New Physics

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

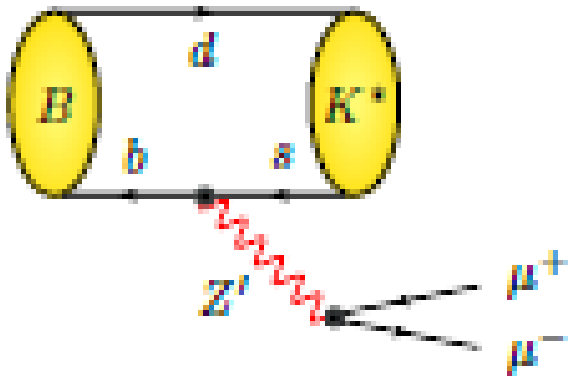
Best fit to B-anomalies: New contributions to C_9^μ, C_{10}^μ

C_9^μ and C_{10}^μ are associated with the following operators:

$$O_9 = (\bar{s}\gamma_\alpha P_L\, b)(\bar{\mu}\gamma^\alpha \mu) \qquad O_{10} = (\bar{s}\gamma_\alpha P_L\, b)(\bar{\mu}\gamma^\alpha \gamma^5 \mu)$$

The new contributions to these operators can arise in BSM theories

E.g.,



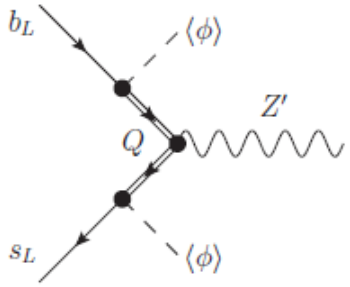
Simple Model

Minimal Lagrangian:

$$L \supset Z'_\mu \left[g^V_\mu \bar{\mu} \gamma^\alpha \mu + (g_b \; \delta^L_{bs} \bar{s} \gamma^\alpha P_L \; b + h.c.) \right]$$

$$V_{tb} V^*_{ts} \frac{e^2}{16\pi^2} C_9 = g_b \; \delta^L_{bs} g^V_\mu \frac{v^2}{2M^2_{Z'}}$$

Many models can generate this Lagrangian, e.g., using Vector-like quarks (Q)

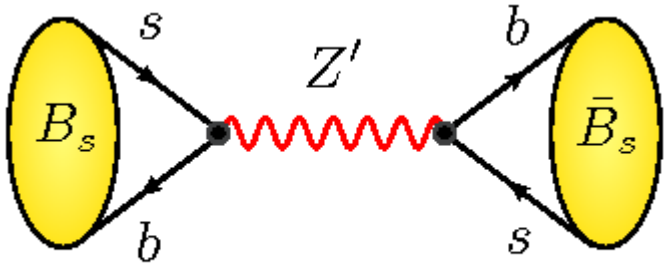


E.g., Altmanshofer, Yavin, 2015, Many more refs (see , arXiv:1707.07016 for a full list)

$$L \supset Z'_\mu \left[g^V_\mu \bar{\mu} \gamma^\alpha \mu + g^V_\mu \bar{\nu}_\mu \gamma^\alpha P_L \; \nu_\mu + g_b \sum_{q=t,b} \bar{q} \gamma^\alpha P_L \; q + (g_b \; \delta^L_{bs} \bar{s} \gamma^\alpha P_L \; b + h.c.) \right]$$

Avoid first generation coupling to Z': strong constraint O(few TeV)

Some Constraints



$$\Delta_{B_s} \simeq 5857 \left(g_b^2 \, \delta_{bs}^2 \left(\frac{\text{TeV}}{m_{Z'}} \right)^2 \right) \left(1 - 0.029 \ln \frac{m_{Z'}}{\text{TeV}} \right)$$

Δ_{BS} =0.07 ± 0.09

Allanach, Querioz, Strumia, Sun, 2016

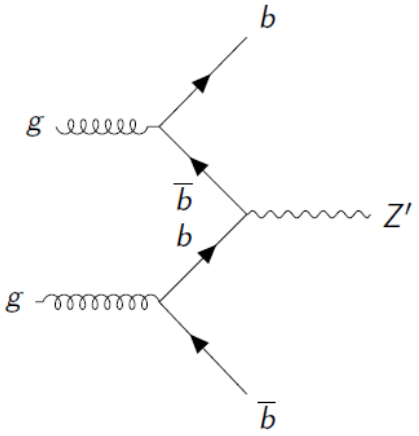
Weak constraints from neutrino trident production and contributions to muon g-2

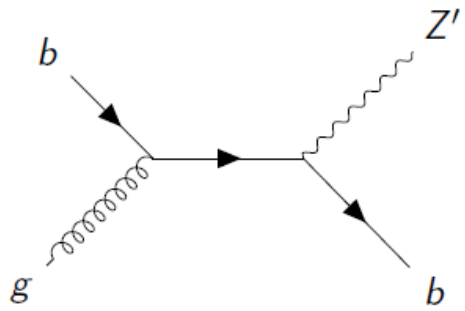
Probing at the LHC

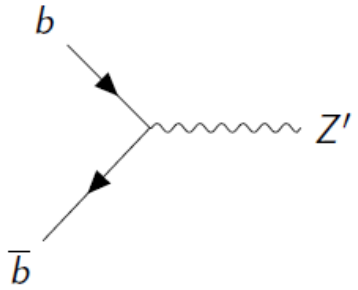
Via b-fusion

$$\sigma(pp \to Z' \to \mu\,\mu) \sim \frac{2\,g_b^2\,g_\mu^{V\,2}}{6\,g_b^2 + 3g_\mu^{V\,2}}$$

$$\sigma(pp \to Z' \to b\,\bar{b}) \sim \frac{3\,g_b^4}{6\,g_b^2 + 3g_\mu^{V\,2}}$$





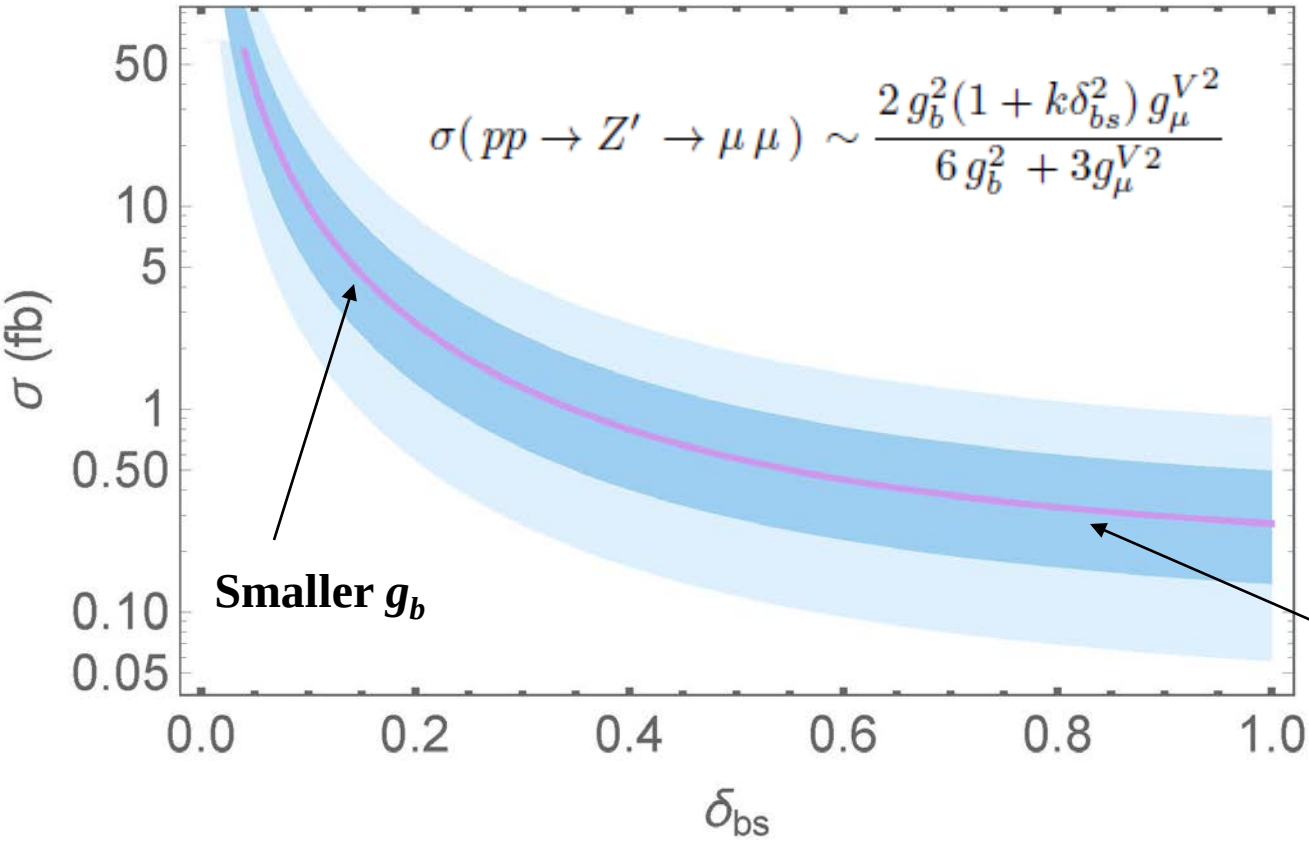


We call it BFF: Bottom Fermion Fusion

$m_{Z'}$	$\sigma(pp \to Z'bb)$ pb	$\sigma(pp \to Z'b(b))$ pb	$\sigma(pp \to Z')$ pb
200 GeV	$322.8\ (g_b)^2$	$150.7\ (g_b)^2$	$295.62\ (g_b)^2$
350 GeV	$38.88\ (g_b)^2$	$18.88\ (g_b)^2$	$35.06\ (g_b)^2$
500 GeV	$7.57\ (g_b)^2$	$4.27\ (g_b)^2$	$7.93\ (g_b)^2$

LHC

The Z' production cross-section has a range after satisfying B-anomalies:



fit for B anomalies:

$$\frac{g_b \delta_{bs} g_\mu^V}{M_{Z'}^2}$$

$M_{Z'}$ =350 GeV

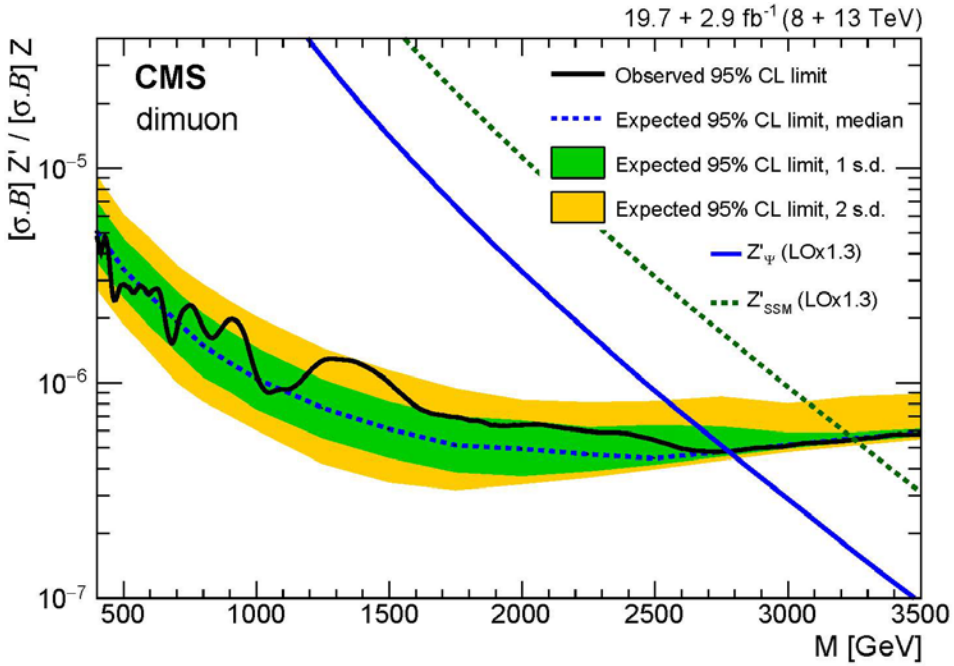
σ **depends on g_b, for larger g_b (b b fusion): final state 2 b + 2 μ +jets**

σ depends on g_b δ_{bs}, **for smaller g_b (b s fusion): final state 1 b + 2 μ +jets**

Constraints

Z' is produced by b-fusion

Current constraint: Inclusive di-muon resonance search



- SM background becomes dominant for $M_{Z'}$ <500 GeV
- Di-jet, t tbar resonance searches produce weaker limits
- Below 500 GeV, Di-muon resonance + ≥ 1 b tagged jet

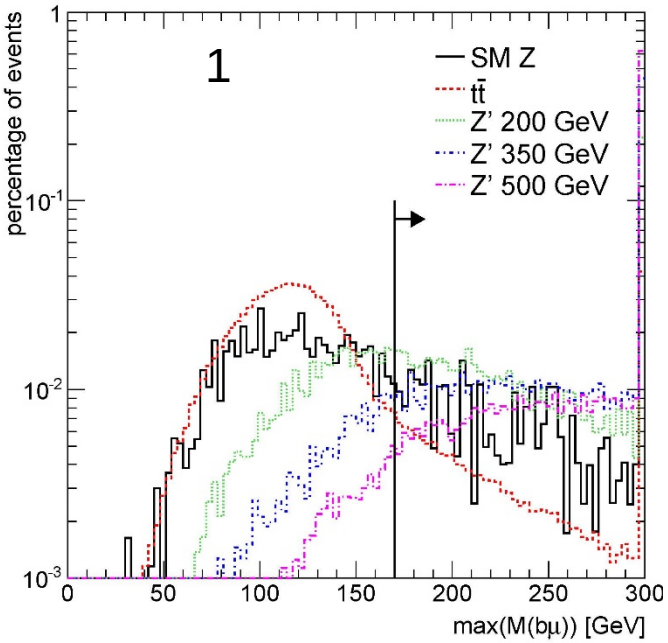
LHC

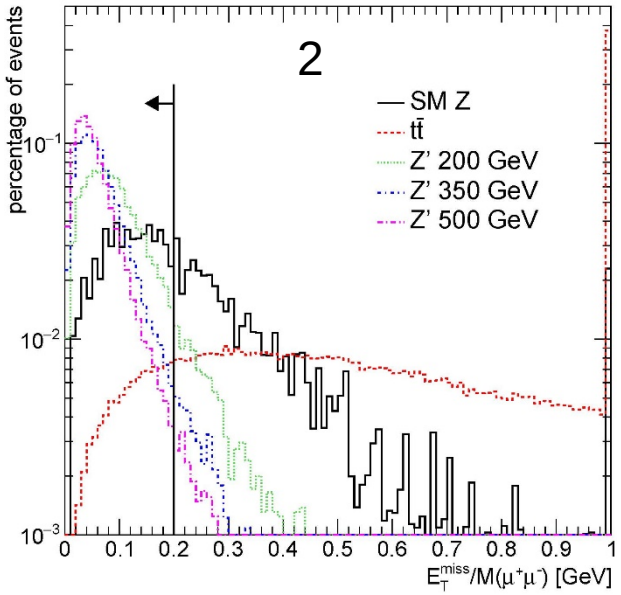
Selection criteria:
Di-muon resonance + ≥ 1 b tagged jet

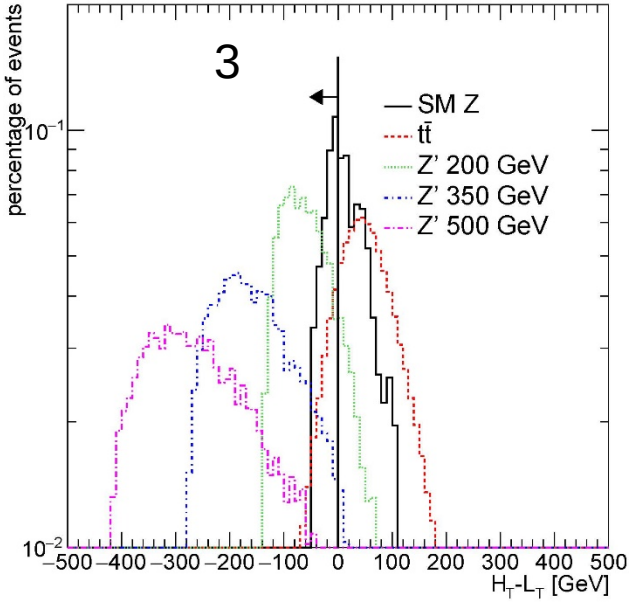
1. **Top mass bound: $M_{b\mu}$ >170 GeV**

2. **Normalized missing transverse energy: $E_T^{miss}/m_{\mu\mu}$<0.2**

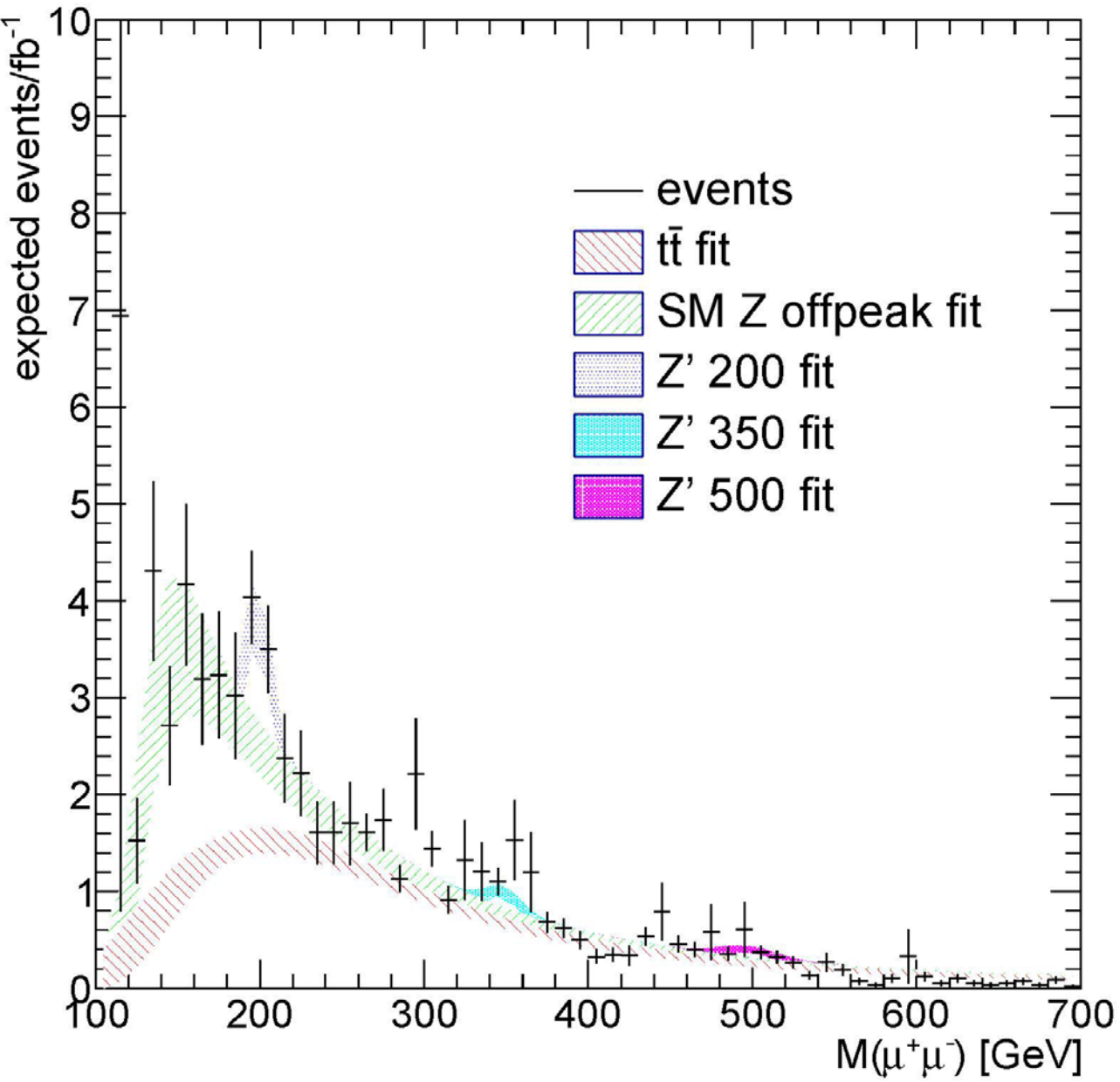
3. **Leptonic vs hadronic activity (H_T-L_T)**





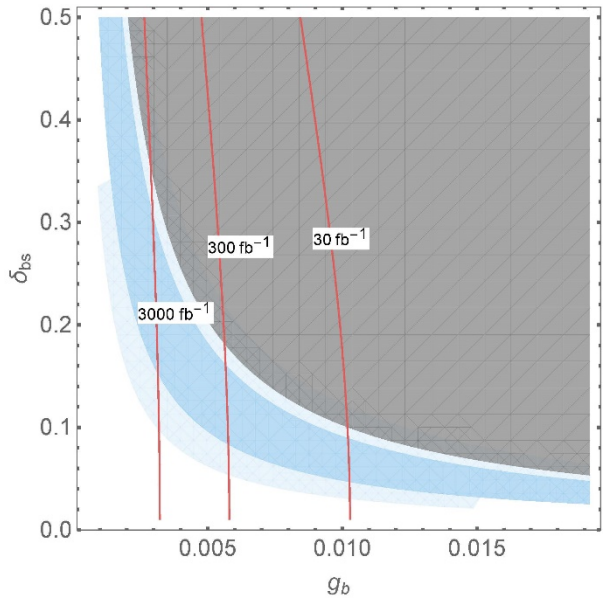


LHC

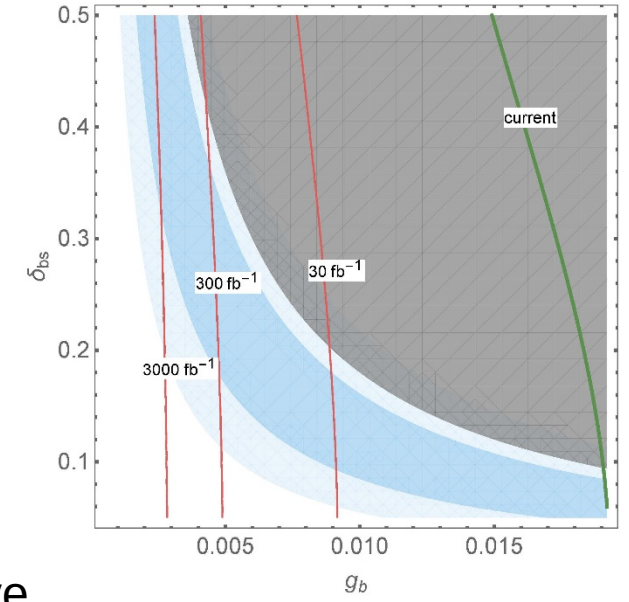


- g_μ=1 for calculating Z' decay width
- The significance increases for smaller g_μ

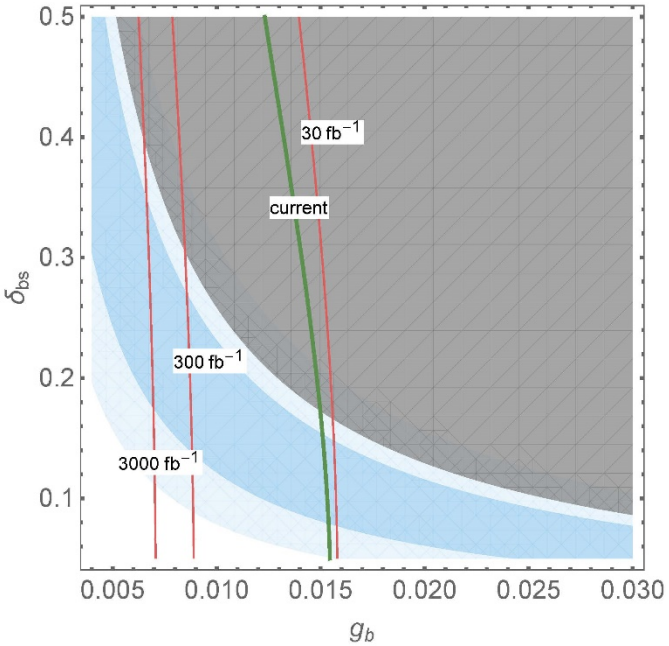
LHC: Current & Future



g_b-δ_{bs} : allowed parameter space: Blue regions

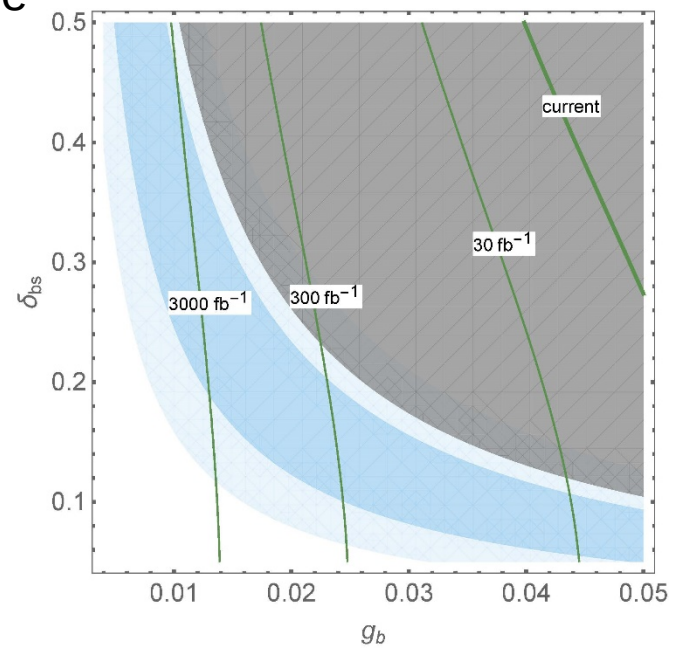


Green contours: Inclusive di-muon resonance



Red contours: di-muon resonance + ≥ 1 b

Grey regions: excluded by B_s mixing



Conclusion

- **B anomalies are explained if Z' couples to b, s and muons**
- **Z' coupling to third generations can be probed using b-fusion at the LHC**
- **Flavor violating b-s- Z' coupling introduces a minimum production cross-section at the LHC**
- **The existing inclusive di-muon search limit can be applied to these model parameter space**
- **The reach can be improved by utilizing di-muon + ≥ 1 b**