Constraints on flavor-changing Z' models by B_s mixing, Z' production and $B_s \to \mu^+\mu^-$.

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Outline

- Motivation for flavor changing Z' models.
- A flavor-changing Z' model.
- Constraint from the new B_s mixing data.
- Range of parameters allowed by Z' production limits.
- Prediction for $B_s \to \mu^+\mu^-$.

Motivations for flavor changing Z' models

- Heavy extra gauge bosons may exist in many extensions of the SM, including GUT, extra dimensions, little Higgs, ...
- In some string-inspired models, the 3 families are generated differently in the extra dimensions. It may happen that the coupling strength to one of the families is different.
- So when rotating to the mass eigenbasis, flavor-changing couplings are induced.
- Thus, it will affect the FCNC processes.

A Flavor Changing Z' model

In some string-inspired models, it is possible to have family nonuniversal interactions, assuming flavor diagonal,

$$\mathcal{L} = -g_2 Z'_\mu \, \bar\psi_i \gamma^\mu \left(\epsilon_{L\,ij} P_L + \epsilon_{R\,ij} P_R \right) \psi_j$$

with $\epsilon_{L,R}$ being the chiral couplings of Z'.

- Assume

$$\epsilon^u_{L,R} = Q^u_{L,R}\,\mathbf{1}, \;\; \epsilon^e_{L,R} = Q^e_{L,R}\,\mathbf{1}, \;\; \epsilon^d_R = Q^d_R\,\mathbf{1},$$

and the only deviation from $\mathbf{1}$ is

$$\epsilon^d_L = Q^d_L \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & x \end{pmatrix}$$

with $x \sim O(1) \neq 1$.

• Rotate to the mass eigenbasis by $(V_d)_{L,R}$ (assume the up-sector is already diagonal.) So the only flavor changing effect is in the LH down-sector: ϵ_L^d:

$$\mathcal{L} = -g_2 Z'_\mu \left(\bar{d}, \bar{s}, \bar{b}\right)_m \gamma^\mu \left(V_{dL}^\dagger \epsilon_L^d V_{dL} P_L + Q_R^d \mathbf{1} P_R\right) \begin{pmatrix} d \\ s \\ b \end{pmatrix}_m$$

where

$$\begin{aligned} B_L^d &\equiv V_{dL}^\dagger \epsilon_L^d V_{dL} = V_{\rm ckm}^\dagger \epsilon_L^d V_{\rm ckm} \\ &= Q_L^d \begin{pmatrix} 1 & (x-1)V_{ts}V_{td}^* & (x-1)V_{tb}V_{td}^* \\ (x-1)V_{td}V_{ts}^* & 1 & (x-1)V_{tb}V_{ts}^* \\ (x-1)V_{td}V_{tb}^* & (x-1)V_{ts}V_{tb}^* & x \end{pmatrix} \end{aligned}$$

Note that the sizes of the flavor-changing couplings are given by the CKM and satisfy the hierarchy: $|B_L^{bs}| > |B_L^{bd}| > |B_L^{sd}|$.

Such couplings can give to observable FCNC.

B_s-$\overline{B}_s$ Meson Mixing

- As in the B_d system, the B_s-$\overline{B}_s$ system provides another testing ground for the SM CKM mechanism.
- The experimental ratio $\Delta M_d/\Delta M_s$ determines V_{td}/V_{ts} if assuming no new physics.
- In the SM, the ΔM_s is expected to be around 18 ps^{-1}, and the phase ϕ_s to be small.
- New physics contributions can play an important role in the B_s-$\overline{B}_s$ mixing because of the loop nature in the SM.

New Results from DØ and CDF

- The FCNC effect in the b-s sector of the SM was recently confirmed in the B_s meson mixing observed by DØ and CDF:

$$
\begin{aligned}
\text{CDF}: &\quad \Delta M_s = 17.33\,^{+0.42}_{-0.21}\,(\text{stat.}) \pm 0.07\,(\text{syst.})\,\text{ps}^{-1}\,, \\
\text{DØ}: &\quad \Delta M_s = 19.0 \pm 1.215\,\text{ps}^{-1}\,, \\
\text{Combined}: &\quad \Delta M_s^{\text{exp}} = 17.46\,^{+0.47}_{-0.30}\,\text{ps}^{-1} \qquad (1\sigma\ \text{range})
\end{aligned}
$$

- Within the SM, this implies

$$|V_{td}/V_{ts}| = 0.208\,^{+0.008}_{-0.007}$$

- In comparison, the latest Belle results on $b \to d\gamma$ and $b \to s\gamma$ gives 0.142 – 0.259 (95% C.L. range) for the ratio.

Treatment of the data

- We re-evaluate the B_s mass difference in the SM without referring to ΔM_d and before the recent Tevatron data:

$$\begin{aligned} \Delta m_{B_s}^{\rm SM} &= \frac{G_F^2}{6\pi^2} M_W^2 m_{B_s} f_{B_s}^2 (V_{tb}V_{ts}^*)^2 \eta_{2B} S_0(x_t) \\ &\times [\alpha_s(m_b)]^{-6/23} \left[1 + \frac{\alpha_s(m_b)}{4\pi} J_5\right] B_{B_s}(m_b) \\ &= 19.52 \pm 5.28 \ {\rm ps}^{-1} \ . \end{aligned}$$

- We have used

$$\eta_{2B} \simeq 0.551, \quad J_5 \simeq 1.627, \quad m_{B_s} = 5.3696 \pm 0.0024 \ {\rm GeV}$$

$$\tau_{B_s} = 1.466 \pm 0.059 {\rm ps}^{-1}, \quad f_{B_s}\sqrt{\hat{B}_{B_s}} = 0.262 \pm 0.035$$

  And we use the CKMfitter results after EPS 2005:

$$\lambda = 0.22622 \pm 0.00100, \ A = 0.825^{+0.011}_{-0.019}, \ \bar\rho = 0.207^{+0.036}_{-0.043}, \ \bar\eta = 0.340 \pm 0.023$$

- This is consistent with the experimental result. One can use it to constrain the parameters of the new physics models.

Z' Contributions and Constraints

- New physics contributions to $b \to s$ transition induce $|\Delta B| = |\Delta S| = 2$ operators that affects B_s mixing is (LL only)

$$\mathcal{L}_{\rm eff}^{Z'} = \frac{G_F}{\sqrt{2}} \left(\frac{g_2 M_Z}{g_1 M_{Z'}} B_L^{sb} \right)^2 O^{LL}(m_b) = \frac{G_F}{\sqrt{2}} \left(\rho_L^{sb} \right)^2 e^{2i\phi_L^{sb}} O^{LL}(m_b)$$

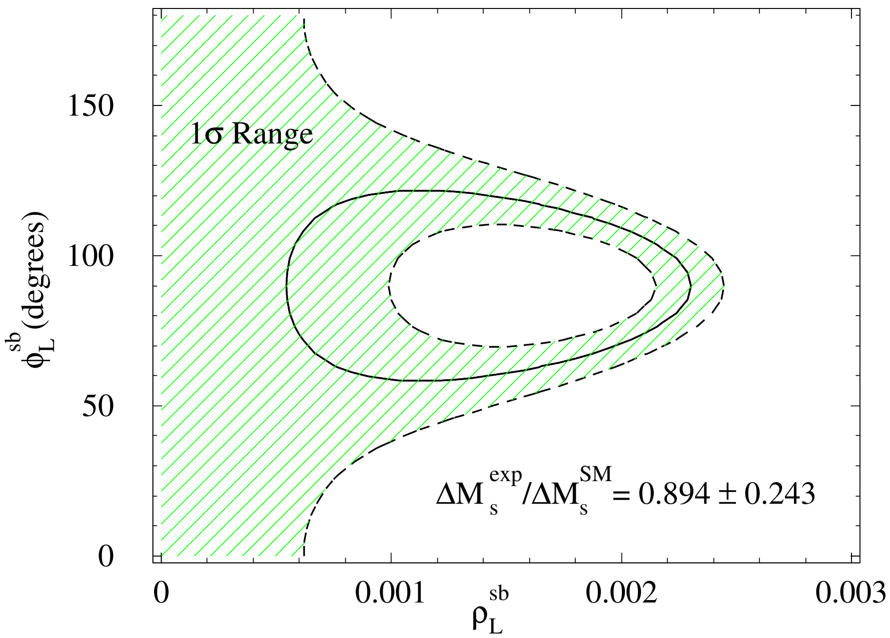
where $O^{LL} = [\bar{s}\gamma_\mu(1-\gamma_5)b]\,[\bar{s}\gamma^\mu(1-\gamma_5)b]$.

- The effect of the LH FCNC induced by Z' is

$$\frac{\Delta M_s^{\rm exp}}{\Delta M_s^{\rm SM}} = \left| 1 + 3.57 \times 10^5 \left(\rho_L^{sb} \right)^2 e^{2i\phi_L^{sb}} \right| = 0.894 \pm 0.243$$

- In the model that we are considering

$$\rho_L^{sb} \equiv \left| \frac{g_2 M_Z}{g_1 M_{Z'}} B_L^{sb} \right| = \left| \frac{g_2 M_Z}{g_1 M_{Z'}} (x-1) Q_L^d V_{tb} V_{ts}^* \right| , \quad \phi_L^{sb} = 180^\circ$$



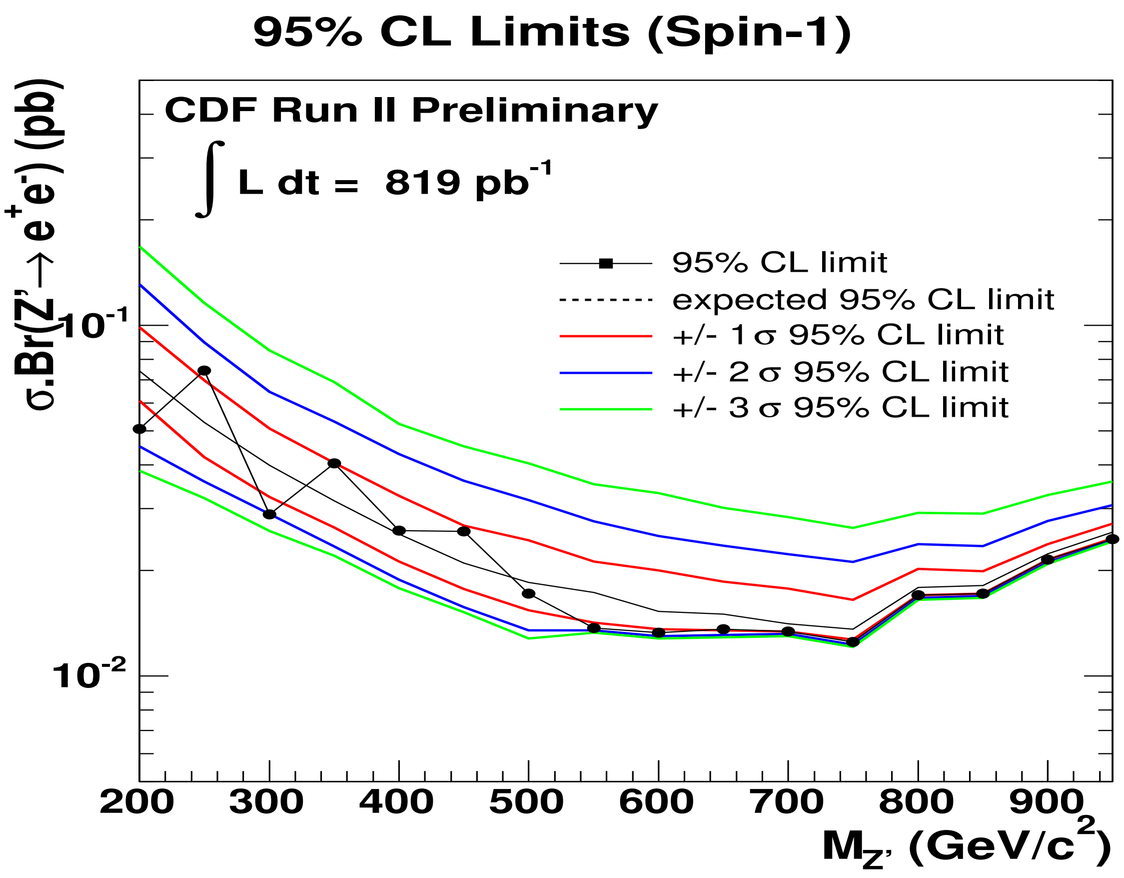
- For $\phi_L^{sb} = 0^\circ/180^\circ$, $\rho_L^{sb} < 6.20 \times 10^{-4}$.
- In more general models, ϕ_L^{sb} can be different. For $\phi_L^{sb} = 90^\circ$, $\rho_L^{sb} < 10^{-3}$.
- Note that there are regions where $\rho_L^{sb} > 10^{-3}$. E.g., at $\phi_L^{sb} = 90^\circ$, $2.15 \times 10^{-3} < \rho_L^{sb} < 2.45 \times 10^{-3}$. It corresponds to a larger Z' contribution than the SM one.

Z' production limit at the Tevatron

Drell-Yan process:

$$p\bar{p} \to \gamma,\ Z,\ Z' \to \mu^+\mu^-,\ \ e^+e^-$$

has been very useful in constraining Z' models.



95 % C.L. limits on $\sigma(Z') \cdot B(Z' \to e^+e^-)$ at the Tevatron.

$M_{Z'}$ (GeV)	$\sigma \cdot B^{95}$ (pb)	$M_{Z'}$ (GeV)	$\sigma \cdot B^{95}$ (pb)
200	0.0505	600	0.0132
250	0.0743	650	0.0136
300	0.0289	700	0.0134
350	0.0404	750	0.0126
400	0.0261	800	0.0171
450	0.0259	850	0.0172
500	0.0172	900	0.0215
550	0.0138	950	0.0246

Preliminary RunII 95% C.L. limits on $\sigma(Z') \cdot B(Z' \to e^+e^-)$.

Implied constraints on various Z' models

	Sequential Z	Z_{LR}	Z_χ	Z_ψ	Z_η
Q_L^u	0.3456	−0.08493	$\frac{-1}{2\sqrt{10}}$	$\frac{1}{\sqrt{24}}$	$\frac{-2}{2\sqrt{15}}$
Q_R^u	−0.1544	0.5038	$\frac{1}{2\sqrt{10}}$	$\frac{-1}{\sqrt{24}}$	$\frac{2}{2\sqrt{15}}$
Q_L^d	−0.4228	−0.08493	$\frac{-1}{2\sqrt{10}}$	$\frac{1}{\sqrt{24}}$	$\frac{-2}{2\sqrt{15}}$
Q_R^d	0.0772	−0.6736	$\frac{-3}{2\sqrt{10}}$	$\frac{-1}{\sqrt{24}}$	$\frac{-1}{2\sqrt{15}}$
Q_L^e	−0.2684	0.2548	$\frac{3}{2\sqrt{10}}$	$\frac{1}{\sqrt{24}}$	$\frac{1}{2\sqrt{15}}$
Q_R^e	0.2316	−0.3339	$\frac{1}{2\sqrt{10}}$	$\frac{-1}{\sqrt{24}}$	$\frac{2}{2\sqrt{15}}$
Q_L^ν	0.5	0.2548	$\frac{3}{2\sqrt{10}}$	$\frac{1}{\sqrt{24}}$	$\frac{1}{2\sqrt{15}}$

Implied constraints on various Z' models:

$$Z'_{\rm SM} > 845 \text{ GeV}, \quad Z'_\chi > 720 \text{ GeV}, \quad Z'_\psi > 690 \text{ GeV}, \quad Z'_\eta > 715 \text{ GeV},$$

Constraint on the present model by Z' production

- The production cross section of Z' followed by the leptonic decay is given by

$$\sigma(p\bar{p} \to Z' \to \ell^+\ell^-) = \frac{g_2^4}{144}\frac{1}{s}\frac{M_{Z'}}{\Gamma_{Z'}}\left({Q_L^\ell}^2 + {Q_R^\ell}^2\right) \times \sum_{q=u,d,s,c}\left({Q_L^q}^2 + {Q_R^q}^2\right)\int_r^1 \frac{dx}{x} f_q(x)\, f_{\bar{q}}\left(\frac{r}{x}\right)$$

where $\sqrt{s} = 1960$ GeV, $r = M_{Z'}^2/s$ and $\Gamma_{Z'}$ is the total width.
The partial width $Z' \to f\bar{f}$ is

$$\Gamma(Z' \to f\bar{f}) = \frac{N_f g_2^2 M_{Z'}}{48\pi}\sqrt{1-4\mu}\left[2\left(|Q_L^f|^2 + |Q_R^f|^2\right)(1-\mu) + 12\mu\, Q_L^f\, Q_R^f\right]$$

- In the present FCNC Z' model,

$$B_L^d = Q_L^d \begin{pmatrix} 1 & (x-1)V_{ts}V_{td}^* & (x-1)V_{tb}V_{td}^* \\ (x-1)V_{td}V_{ts}^* & 1 & (x-1)V_{tb}V_{ts}^* \\ (x-1)V_{td}V_{tb}^* & (x-1)V_{ts}V_{tb}^* & x \end{pmatrix}$$

one can translate the bound on $\rho_L^{sb} \equiv \left| \frac{g_2 M_Z}{g_1 M_{Z'}} B_L^{sb} \right| < 6.2 \times 10^{-4}$ to other elements in B_L^d. We obtain the upper limits on

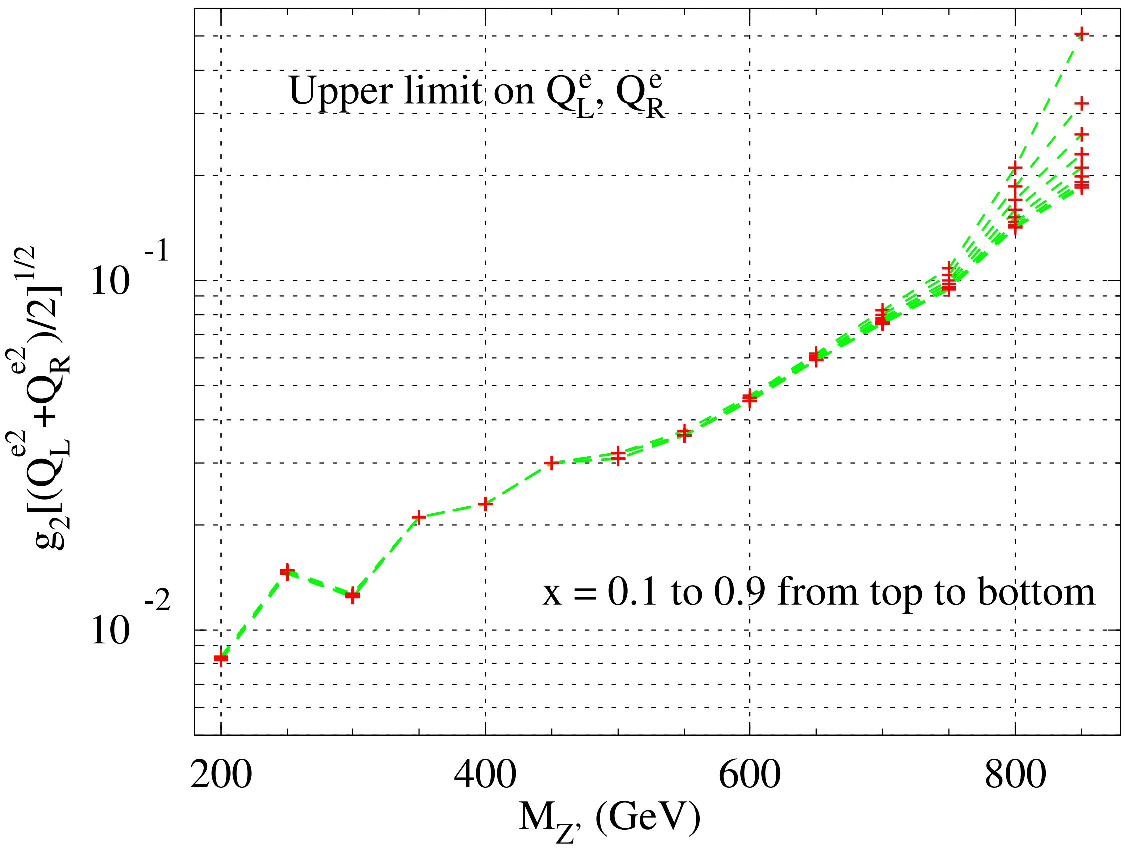
$$Z' - q - \bar{q}$$

- With the assumption

$$|Q_R^d| = |Q_L^d|\,, \qquad |Q_{L,R}^u| = |Q_{L,R}^d|\,.$$

then from the bound of ρ_L^{sb} we have the size of all $Z' - q - \bar{q}$ couplings. Then using the CDF $\sigma(Z') \cdot B(Z' \to e^+e^-)$ limits one can obtain upper limits on

$$g_2 \sqrt{({Q_L^e}^2 + {Q_R^e}^2)/2}$$



With $\rho_L^{sb} = 6.20 \times 10^{-4}$.

Constraints from $B_s \to \mu^+\mu^-$ data

- The decay rate in Z' model depends on $\rho^{sb,\mu}_{L,R}$:

$$B(B_s \to \mu^+\mu^-) = \tau(B_s)\frac{G_F^2}{4\pi} f_{B_s}^2 m_\mu^2 m_{B_s} \sqrt{1-\frac{4m_\mu^2}{m_{B_s}^2}}\,|V_{tb}^* V_{ts}|^2$$
$$\times \left\{ \left| \frac{\alpha}{2\pi \sin^2\theta_W} Y\left(\frac{m_t^2}{M_W^2}\right) + 2\frac{\rho_L^{bs}\rho_L^{\mu\mu}}{V_{tb}^* V_{ts}} \right|^2 + \left| 2\frac{\rho_L^{bs}\rho_R^{\mu\mu}}{V_{tb}^* V_{ts}} \right|^2 \right\}$$
$$\rho^{\mu\mu}_{L,R} = \frac{g_2 M_Z}{g_1 M_{Z'}} Q^e_{L,R}$$

- In the SM, by putting all $\rho_{L,R} = 0$:

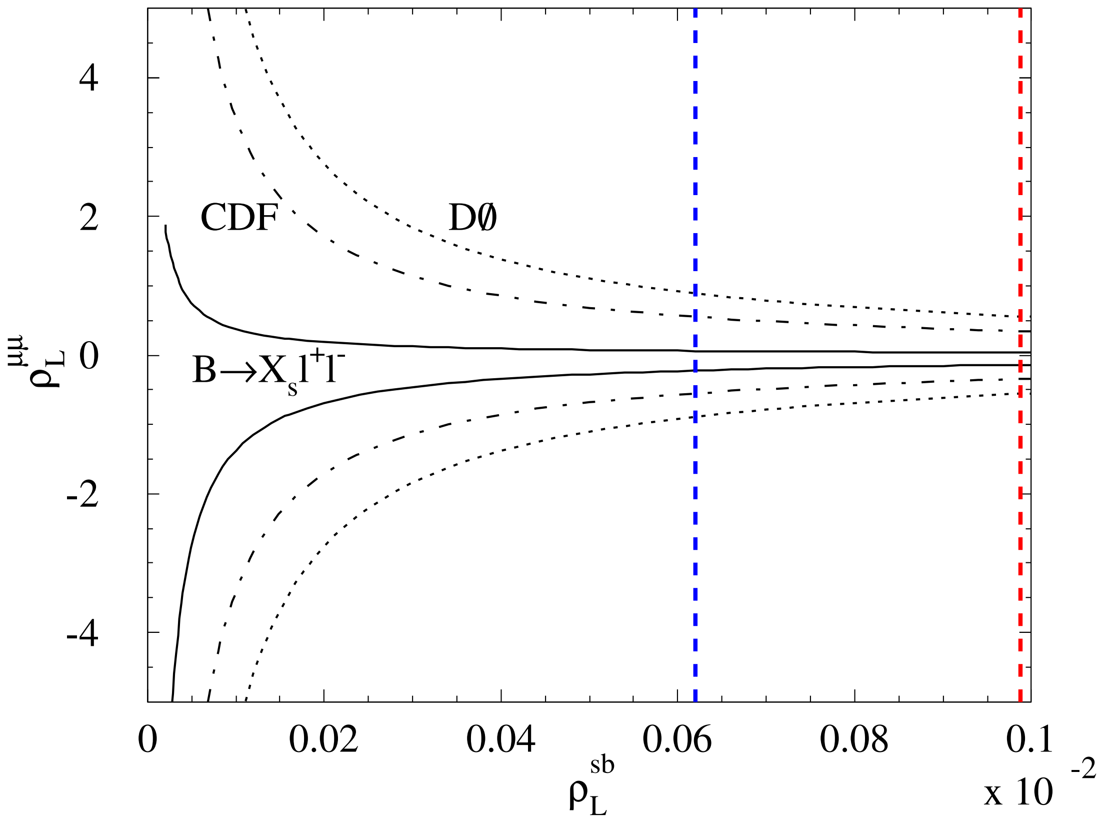
$$B(B_s \to \mu^+\mu^-) = 4.2 \times 10^{-9}$$

- The current upper limits from CDF and DØ

$$B(B_s \to \mu^+\mu^-) < 1.0 \times 10^{-7} \quad \text{(CDF)}$$
$$B(B_s \to \mu^+\mu^-) < 2.3 \times 10^{-7} \quad \text{(DØ)}\,.$$

In our Z' model $\rho_R^{sb} = 0$, $\phi_L^{sb} = 180^\circ$, and we set $\rho_R^{\mu\mu} = \rho_L^{\mu\mu}$.

We use $B_s \to \mu^+\mu^-$ data to constrain on the (ρ_L^{sb}-$\rho_{L,R}^{\mu\mu}$) plane.



Blue: $\rho_L^{sb} < 6.20 \times 10^{-4}$ for $\phi_L^{sb} = 180^\circ$.

- Note that ρ_L^{sb}-$\rho_{L,R}^{\mu\mu}$ is also constrained by the decay:

$$b \to s\,\ell^+\ell^-$$

- Using the latest average from BABAR and Belle

$$B(B \to X_s \ell^+\ell^-) = \left(4.50\,{}^{+\,1.03}_{-\,1.01}\right) \times 10^{-6}$$

- We obtain the constraint:

$$1 \le \left|1 + 2\times 10^4 \rho_L^{sb}\, \rho_L^{\mu\mu}\right| \le 1.75$$

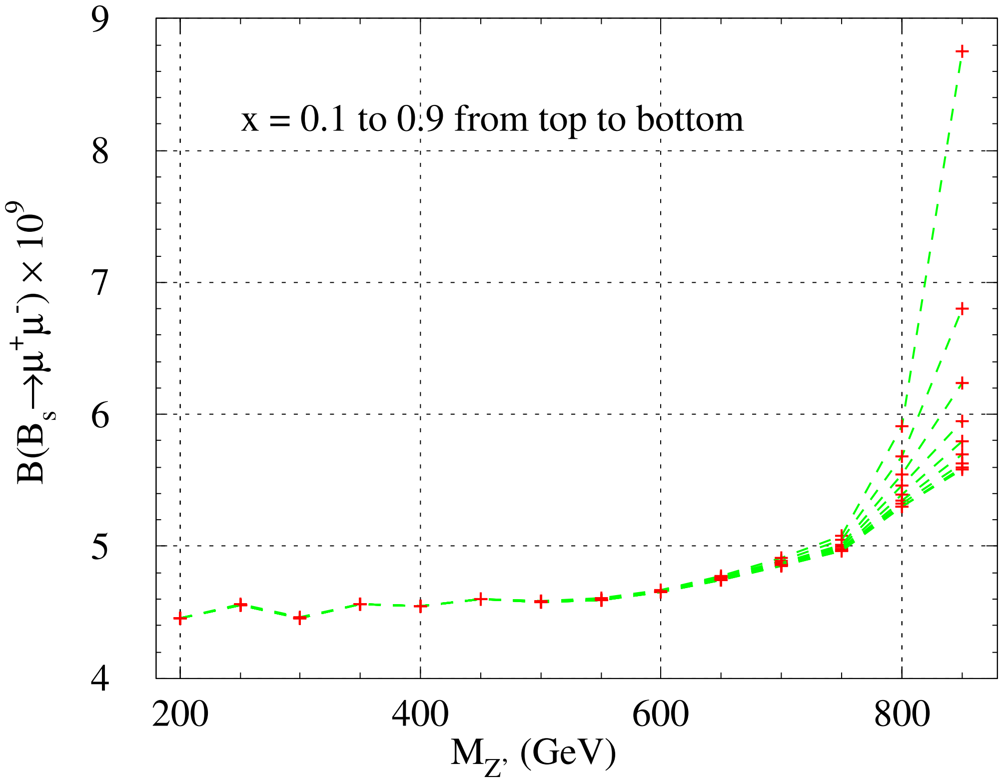
  This constraint is stronger than the CDF limit on $B(B_s \to \mu^+\mu^-)$.

- If we fixed $\rho_L^{sb} = 6.20 \times 10^{-4}$, the constraint on $\rho_L^{\mu\mu}$ from $b \to s\ell^+\ell^-$ is WEAKER than the direct Z' production.

With the upper limit of

- $\rho_L^{sb} = 6.20 \times 10^{-4}$ from B_s-$\overline{B}_s$ mixing,
- $g_2\sqrt{Q_L^{e2} + Q_R^{e2}}$ from Z' production

one can predict the maximal rates for $B_s \to \mu^+\mu^-$



Conclusions

- In many string-inspired models, each generation is created differently. We consider a Z' model that has family-nonuniversal interaction, though diagonal. It induces FCNC effects.

- The recent data on B_s-$\overline{B}_s$ mixing data constrained
  $\rho_L^{sb} \equiv \left| \frac{g_2 M_Z}{g_1 M_{Z'}} B_L^{sb} \right| < 6.2 \times 10^{-4}$.

- Once the upper limit of ρ_L^{sb} is fixed, the flavor-diagonal couplings Z'-q-q are also fixed. We used the direct $\sigma(Z') \cdot B(Z' \to e^+ e^-)$ to constrain on the Z'-e-e couplings.

- We found that the same constraint on Z'-ℓ-ℓ obtained from $B_s \to \mu^+\mu^-$ and $B \to X_s \ell^+ \ell^-$ are weaker than those from Z' production.

- We used the combined constraints $\rho_L^{sb} = 6.20 \times 10^{-4}$ from B_s-$\overline{B}_s$ mixing and $g_2 \sqrt{Q_L^{e2} + Q_R^{e2}}$ from Z' production to predict the maximally allowed $B_s \to \mu^+\mu^-$. It turns out the BR is less than 10^{-8}.