Impact of Z' near the Z-pole and flavor violating couplings

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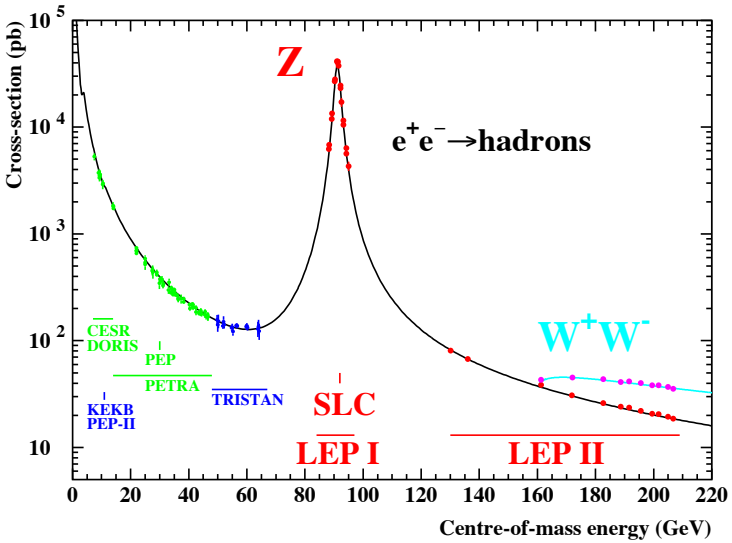
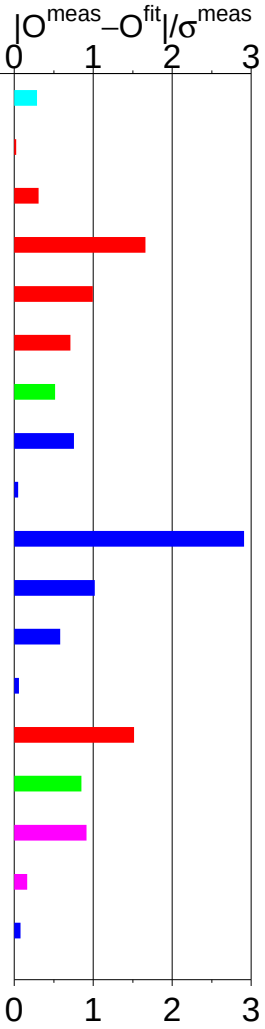
Outline

1. Motivation
2. Z' near the Z pole
3. Flavor violating Z' coupling and muon g-2
4. Summary



	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02750 ± 0.00033	0.02759
m_Z [GeV]	91.1875 ± 0.0021	91.1874
Γ_Z [GeV]	2.4952 ± 0.0023	2.4959
σ^0_{had} [nb]	41.540 ± 0.037	41.478
R_l	20.767 ± 0.025	20.742
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01646
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1482
R_b	0.21629 ± 0.00066	0.21579
R_c	0.1721 ± 0.0030	0.1722
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1039
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0743
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1482
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.399 ± 0.023	80.378
Γ_W [GeV]	2.085 ± 0.042	2.092
m_t [GeV]	173.20 ± 0.90	173.27



July 2011

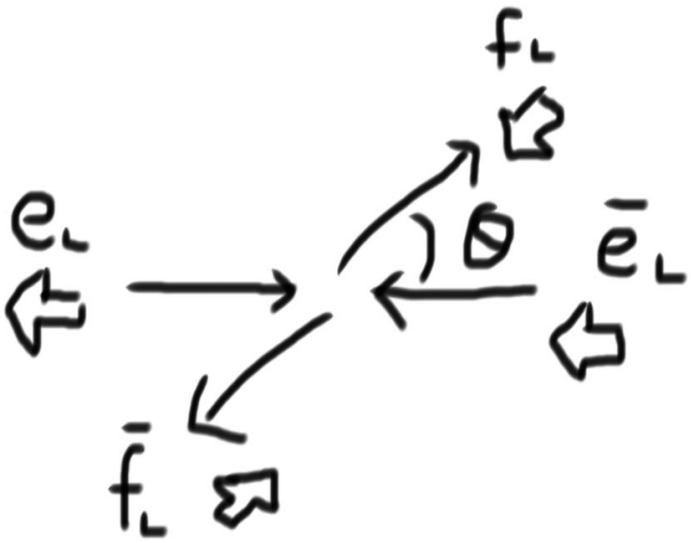
Several ideas

- Modifying g_R^b
  - Radiative correction with extended Higgs Haber-Logan 2000
  - Mixing of the b quark with heavy exotics Choudhury-Tait-Wagner 2002
  - LR models that single out the third generation He-Valencia 2002
- Scaler neutrino resonance Erler-Feng-Polonsky 1997
- Heavy Z' with family non universal couplings

  Erler-Langacker 2000 Langacker-Plumacher 2000
- Degenerate Z and Z' Caravaglios-Ross 1994

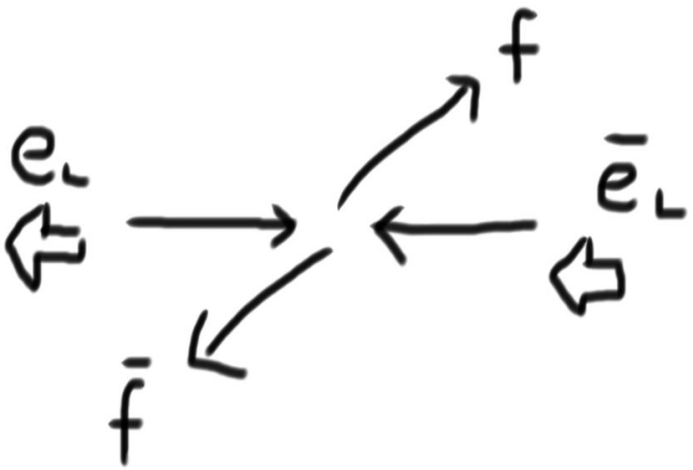
Forward-barckward asymmetry

$$
\begin{aligned}
A^b_{FB} &\equiv \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} \\
&\propto \frac{\hat{\sigma}^b_{LL} - \hat{\sigma}^b_{LR} - \hat{\sigma}^b_{RL} + \hat{\sigma}^b_{RR}}{\hat{\sigma}^b_{LL} + \hat{\sigma}^b_{LR} + \hat{\sigma}^b_{RL} + \hat{\sigma}^b_{RR}} \xrightarrow{Z\ only} \frac{g_L^{e\,2} - g_R^{e\,2}}{g_L^{e\,2} + g_R^{e\,2}} \frac{g_L^{b\,2} - g_R^{b\,2}}{g_L^{b\,2} + g_R^{b\,2}}
\end{aligned}
$$



Left-right asymmetry

$$
\begin{aligned}
A_{LR} &\equiv \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} \\
&\propto \frac{\hat{\sigma}^b_{LL} + \hat{\sigma}^b_{LR} - \hat{\sigma}^b_{RL} - \hat{\sigma}^b_{RR}}{\hat{\sigma}^b_{LL} + \hat{\sigma}^b_{LR} + \hat{\sigma}^b_{RL} + \hat{\sigma}^b_{RR}} \xrightarrow{Z\ only} \frac{g_L^{e\,2} - g_R^{e\,2}}{g_L^{e\,2} + g_R^{e\,2}}
\end{aligned}
$$



A rough sketch

$\mathrm{Obs}\left(\begin{smallmatrix}\text{(Ex-SM)/SM}\\ |\Delta\text{Ex/Ex}|\end{smallmatrix}\right)$ cf. PDG2010

$$A^b_{FB}\left(\begin{smallmatrix}-4\%\\ |1\%|\end{smallmatrix}\right) \propto \frac{\hat\sigma^b_{LL}-\hat\sigma^b_{LR}-\hat\sigma^b_{RL}+\hat\sigma^b_{RR}}{\hat\sigma^b_{LL}+\hat\sigma^b_{LR}+\hat\sigma^b_{RL}+\hat\sigma^b_{RR}} \xrightarrow{\text{Z only}} \frac{g_L^{e\,2}-g_R^{e\,2}}{g_L^{e\,2}+g_R^{e\,2}}\frac{g_L^{b\,2}-g_R^{b\,2}}{g_L^{b\,2}+g_R^{b\,2}}$$

$$A^b_{LR}\left(\begin{smallmatrix}3\%\\ |1\%|\end{smallmatrix}\right) \propto \frac{\hat\sigma^b_{LL}+\hat\sigma^b_{LR}-\hat\sigma^b_{RL}-\hat\sigma^b_{RR}}{\hat\sigma^b_{LL}+\hat\sigma^b_{LR}+\hat\sigma^b_{RL}+\hat\sigma^b_{RR}} \xrightarrow{\text{Z only}} \frac{g_L^{e\,2}-g_R^{e\,2}}{g_L^{e\,2}+g_R^{e\,2}}$$

$$A^b_{LRFB}\left(\begin{smallmatrix}-1\%\\ |2\%|\end{smallmatrix}\right) \propto \frac{\hat\sigma^b_{LL}-\hat\sigma^b_{LR}+\hat\sigma^b_{RL}-\hat\sigma^b_{RR}}{\hat\sigma^b_{LL}+\hat\sigma^b_{LR}+\hat\sigma^b_{RL}+\hat\sigma^b_{RR}} \xrightarrow{\text{Z only}} \frac{g_L^{b\,2}-g_R^{b\,2}}{g_L^{b\,2}+g_R^{b\,2}}$$

$$R_b\left(\begin{smallmatrix}.3\%\\ |.3\%|\end{smallmatrix}\right) \propto \frac{\hat\sigma^b_{LL}+\hat\sigma^b_{LR}+\hat\sigma^b_{RL}+\hat\sigma^b_{RR}}{\hat\sigma^5_{LL}+\hat\sigma^5_{LR}+\hat\sigma^5_{RL}+\hat\sigma^5_{RR}} \xrightarrow{\text{Z only}} \frac{g_L^{b\,2}+g_R^{b\,2}}{g_L^{5\,2}+g_R^{5\,2}}$$

A rough sketch

- Modifying $g_R^{b\,2} \to g_R^{b\,2} + \delta g_R^{b\,2}$

$$A_{FB}^b + \delta A_{FB}^b \sim (g_L^{b\,2} - g_R^{b\,2})(1 - \frac{\delta g_R^{b\,2}}{g_L^{b\,2} - g_R^{b\,2}}) \sim (g_L^{b\,2} - g_R^{b\,2})(1 - \frac{\delta g_R^{b\,2}}{g_L^{b\,2}})$$

$$R^b + \delta R^b \sim (g_L^{b\,2} + g_R^{b\,2})(1 + \frac{\delta g_R^{b\,2}}{g_L^{b\,2} + g_R^{b\,2}}) \sim (g_L^{b\,2} + g_R^{b\,2})(1 + \frac{\delta g_R^{b\,2}}{g_L^{b\,2}})$$

- Scaler resonance

  No angular dependence, i.e., $-\delta A_{FB}^b / A_{FB}^b \sim \delta R^b / R^b$

  No interference, i.e., $\delta R^b > 0$ (cf. $R^b_{\text{LEPII ave.}} \sim -2.1\sigma$)

=> Vector boson resonance near Z-pole

A rough sketch

$$A^b_{FB}\left(\begin{smallmatrix}-4\% \\ |1\%|\end{smallmatrix}\right) \propto \frac{\hat{\sigma}^b_{LL} - \hat{\sigma}^b_{LR} - \hat{\sigma}^b_{RL} + \hat{\sigma}^b_{RR}}{\hat{\sigma}^b_{LL} + \hat{\sigma}^b_{LR} + \hat{\sigma}^b_{RL} + \hat{\sigma}^b_{RR}}$$

$$A^b_{LR}\left(\begin{smallmatrix}3\% \\ |1\%|\end{smallmatrix}\right) \propto \frac{\hat{\sigma}^b_{LL} + \hat{\sigma}^b_{LR} - \hat{\sigma}^b_{RL} - \hat{\sigma}^b_{RR}}{\hat{\sigma}^b_{LL} + \hat{\sigma}^b_{LR} + \hat{\sigma}^b_{RL} + \hat{\sigma}^b_{RR}}$$

$$A^b_{LRFB}\left(\begin{smallmatrix}-1\% \\ |2\%|\end{smallmatrix}\right) \propto \frac{\hat{\sigma}^b_{LL} - \hat{\sigma}^b_{LR} + \hat{\sigma}^b_{RL} - \hat{\sigma}^b_{RR}}{\hat{\sigma}^b_{LL} + \hat{\sigma}^b_{LR} + \hat{\sigma}^b_{RL} + \hat{\sigma}^b_{RR}}$$

$$R_b\left(\begin{smallmatrix}.3\% \\ |.3\%|\end{smallmatrix}\right) \propto \frac{\hat{\sigma}^b_{LL} + \hat{\sigma}^b_{LR} + \hat{\sigma}^b_{RL} + \hat{\sigma}^b_{RR}}{\hat{\sigma}^5_{LL} + \hat{\sigma}^5_{LR} + \hat{\sigma}^5_{RL} + \hat{\sigma}^5_{RR}}$$

A rough sketch

$$A^b_{FB}\left(\begin{smallmatrix}-4\% \\ |1\%|\end{smallmatrix}\right) \propto \frac{\hat{\sigma}^b_{LL} - \hat{\sigma}^b_{LR} - \hat{\sigma}^b_{RL} + \hat{\sigma}^b_{RR}}{\hat{\sigma}^b_{LL} + \hat{\sigma}^b_{LR} + \hat{\sigma}^b_{RL} + \hat{\sigma}^b_{RR}}$$

$$A^b_{LR}\left(\begin{smallmatrix}3\% \\ |1\%|\end{smallmatrix}\right) \propto \frac{\hat{\sigma}^b_{LL} + \hat{\sigma}^b_{LR} - \hat{\sigma}^b_{RL} - \hat{\sigma}^b_{RR}}{\hat{\sigma}^b_{LL} + \hat{\sigma}^b_{LR} + \hat{\sigma}^b_{RL} + \hat{\sigma}^b_{RR}}$$

$$A^b_{LRFB}\left(\begin{smallmatrix}-1\% \\ |2\%|\end{smallmatrix}\right) \propto \frac{\hat{\sigma}^b_{LL} - \hat{\sigma}^b_{LR} + \hat{\sigma}^b_{RL} - \hat{\sigma}^b_{RR}}{\hat{\sigma}^b_{LL} + \hat{\sigma}^b_{LR} + \hat{\sigma}^b_{RL} + \hat{\sigma}^b_{RR}}$$

$$R_b\left(\begin{smallmatrix}.3\% \\ |.3\%|\end{smallmatrix}\right) \propto \frac{\hat{\sigma}^b_{LL} + \hat{\sigma}^b_{LR} + \hat{\sigma}^b_{RL} + \hat{\sigma}^b_{RR}}{\hat{\sigma}^5_{LL} + \hat{\sigma}^5_{LR} + \hat{\sigma}^5_{RL} + \hat{\sigma}^5_{RR}}$$

A rough sketch

$$g_L^e \sim -0.27,\ g_R^e \sim 0.23,\ g_L^b \sim -0.42,\ g_R^b \sim 0.08$$

$$A_{FB}^b\left(\begin{smallmatrix}-4\% \\ |1\%|\end{smallmatrix}\right) \propto \frac{\hat{\sigma}_{LL}^b - \hat{\sigma}_{LR}^b - \hat{\sigma}_{RL}^b + \hat{\sigma}_{RR}^b}{\hat{\sigma}_{LL}^b + \hat{\sigma}_{LR}^b + \hat{\sigma}_{RL}^b + \hat{\sigma}_{RR}^b} \quad (\sim 0.10)$$

$$A_{LR}^b\left(\begin{smallmatrix}3\% \\ |1\%|\end{smallmatrix}\right) \propto \frac{\hat{\sigma}_{LL}^b + \hat{\sigma}_{LR}^b - \hat{\sigma}_{RL}^b - \hat{\sigma}_{RR}^b}{\hat{\sigma}_{LL}^b + \hat{\sigma}_{LR}^b + \hat{\sigma}_{RL}^b + \hat{\sigma}_{RR}^b} \quad (\sim 0.15)$$

$$A_{LRFB}^b\left(\begin{smallmatrix}-1\% \\ |2\%|\end{smallmatrix}\right) \propto \frac{\hat{\sigma}_{LL}^b - \hat{\sigma}_{LR}^b + \hat{\sigma}_{RL}^b - \hat{\sigma}_{RR}^b}{\hat{\sigma}_{LL}^b + \hat{\sigma}_{LR}^b + \hat{\sigma}_{RL}^b + \hat{\sigma}_{RR}^b} \quad (\sim 0.9)$$

$$R_b\left(\begin{smallmatrix}.3\% \\ |.3\%|\end{smallmatrix}\right) \propto \frac{\hat{\sigma}_{LL}^b + \hat{\sigma}_{LR}^b + \hat{\sigma}_{RL}^b + \hat{\sigma}_{RR}^b}{\hat{\sigma}_{LL}^5 + \hat{\sigma}_{LR}^5 + \hat{\sigma}_{RL}^5 + \hat{\sigma}_{RR}^5}$$

Outline

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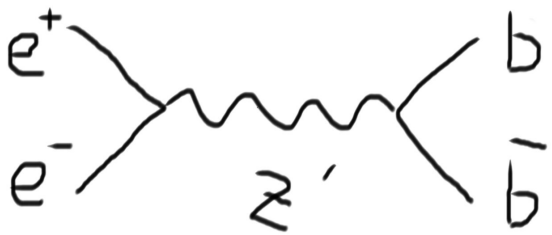
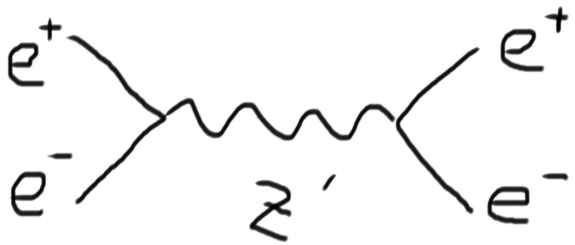
Z' which couples only to e and b

$$\mathcal{L}_{Z'} \supset \bar{e}\gamma^\mu(g_L'^e P_L + g_R'^e P_R)eZ'_\mu + \bar{b}\gamma^\mu(g_L'^b P_L + g_R'^b P_R)bZ'_\mu$$





$A_{FB}^{b(-2)}$, $A_{FB}^{b(\mathrm{pk})}$, $A_{FB}^{b(+2)}$, $A_{LR}^{e(\mathrm{had})}$

$R_b^{(-2)}$, R_b^0, $R_b^{(+2)}$, σ_{had}^0, A_b

$A_{FB}^{0,e}$, R_e^0, $A_{LR}^{e(\mathrm{lept})}$

*For now, we assume no Z-Z' mixing and any exotic field

Minimize the function of

$$\chi^2 = \sum_{i=1}^{12} \left(\frac{\mathcal{O}^i_{Ex} - \mathcal{O}^i_{SM+Z'}(g_{SM}, m_{Z'}, g'^e_L, g'^e_R, g'^b_L, g'^b_R)}{\Delta \mathcal{O}^i_{Ex}} \right)^2$$

i = { $A_{FB}^{b(\mathrm{pk},\pm 2)}$, $A_{LR}^{e(\mathrm{had})}$, $R_b^{(0,\pm 2)}$ σ^0_{had}, A_b $A_{FB}^{0,e}$, R_e^0, $A_{LR}^{e(\mathrm{lept})}$ }

using

- MINUIT

where

- $\mathcal{O}^i_{SM+Z'}$ are calculated by ZFITTER 6.43 and ZEFIT 6.10

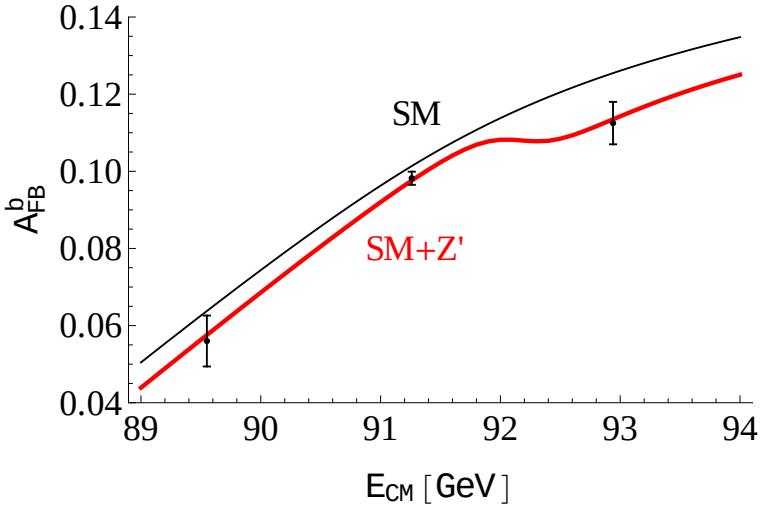
  $m_Z = 91.1875$ GeV $\quad \Delta\alpha^{(5)}(m_Z^2) = 0.02758$
  $\alpha_S(m_Z^2) = 0.118 \quad m_t = 173.3$ GeV $\quad m_H = 117$ GeV.

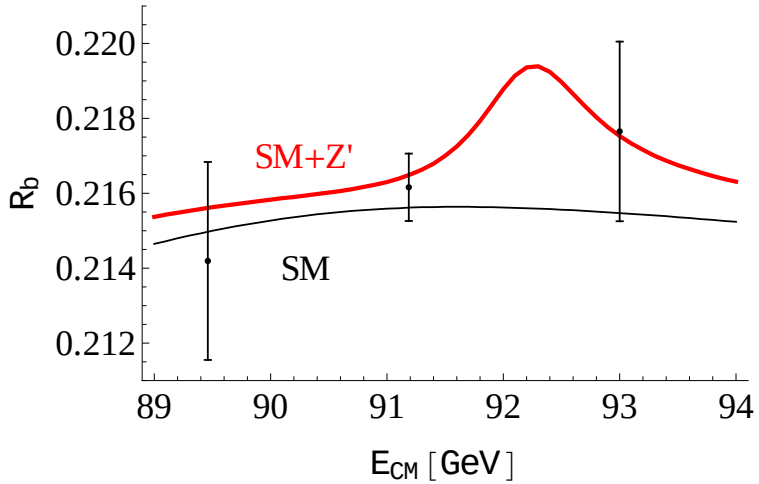
Best fit

$m_{Z'} = 92.2$ GeV $(\Gamma_{Z'} = 1.1$ GeV$)$
$g_L'^e = 5.9 \times 10^{-3}$ $g_R'^e = 7.3 \times 10^{-3}$ $g_L'^b = 4.0 \times 10^{-2}$ $g_R'^b = -5.4 \times 10^{-1}$

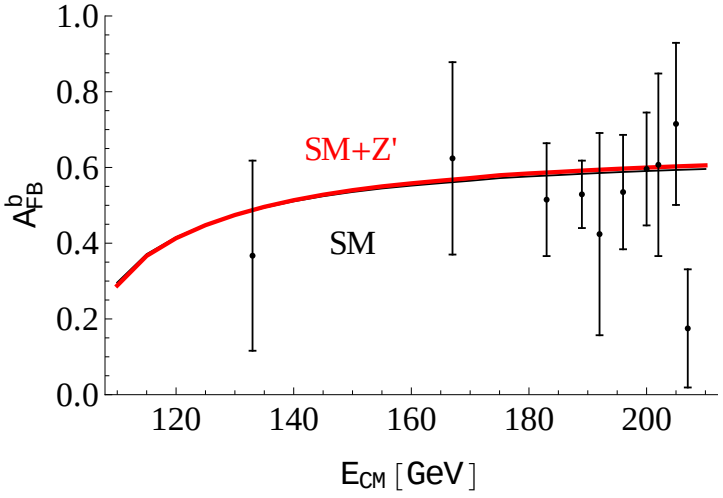
Quantity	Exp. value	SM	χ^2_{SM}	Z'	$\chi^2_{Z'}$
$\sigma^0_{\rm had}$ [nb]	41.541(37)	41.481	**2.6**	41.529	**0.1**
$R_b(-2)$	0.2142(27)	0.2150	0.1	0.2156	0.3
R^0_b	0.21629(66)	0.21580	0.6	0.21670	0.4
$R_b(+2)$	0.2177(24)	0.2155	0.8	0.2177	0.0
$A^b_{FB}(-2)$	0.0560(66)	0.0638	**1.4**	0.0577	**0.1**
$A^b_{FB}(\rm pk)$	0.0982(17)	0.1014	**3.5**	0.0979	**0.0**
$A^b_{FB}(+2)$	0.1125(55)	0.1255	**5.6**	0.1136	**0.0**
A_b	0.923(20)	0.9346	0.3	0.9237	0.0
R^0_e	20.804(50)	20.737	1.8	20.765	0.6
$A^{0,e}_{FB}$	0.0145(25)	0.0165	0.7	0.0174	1.4
$A_e(\rm LR-had.)$	0.15138(216)	0.14739	**3.4**	0.15014	**0.3**
$A_e(\rm LR-lept.)$	0.1544(60)	0.1473	1.4	0.1473	1.4
total χ^2			**22.1**		**4.6**

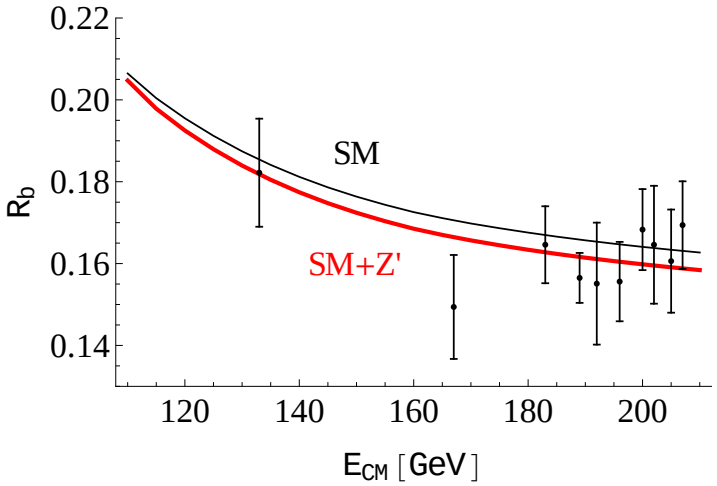
Near Z-pole behavior





Off Z-pole behavior





Other fit

- Only two non-zero couplings $g_L'^e$ and $g_R'^b$
  - $m_{Z'} = 92.1$ GeV $\quad g_L'^e = 4.8 \times 10^{-3} \quad g_R'^b = -4.7 \times 10^{-1}$
  - $\underline{\chi^2 = 6.4}$

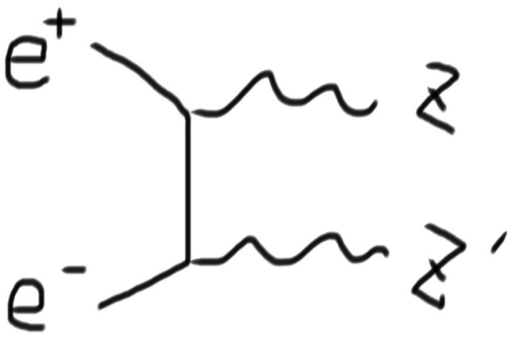
- Fixed $m_{Z'} = 95$GeV
  - $g_L'^e = 2.7 \times 10^{-2} \quad g_R'^e = 1.3 \times 10^{-2}$
    $g_L'^b = 8.0 \times 10^{-2} \quad g_R'^b = -4.9 \times 10^{-1}$
  - $\underline{\chi^2 = 9.3}$

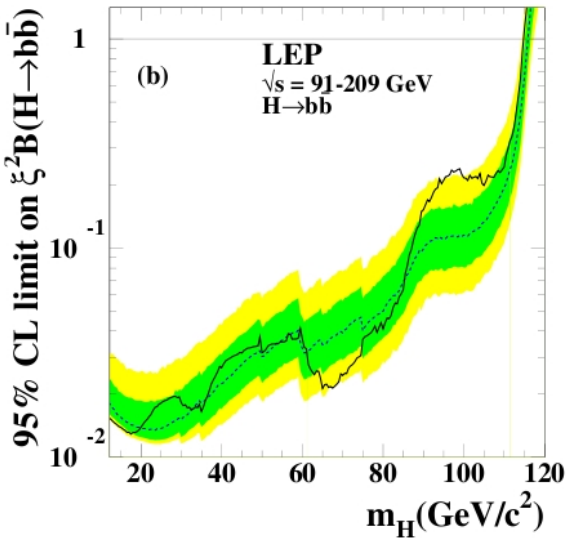
Some features

χ^2	$m_{Z'}$	$\Gamma_{Z'}$	$g_L'^e$	$g_R'^e$	$g_L'^b$	$g_R'^b$
4.6	92.2	1.1	5.9 $\times 10^{-3}$	7.3 $\times 10^{-3}$	4.0 $\times 10^{-2}$	-5.4$\times 10^{-1}$
6.4	92.1		4.8 $\times 10^{-3}$			-4.7$\times 10^{-1}$
9.3	95	1.6	2.7 $\times 10^{-2}$	1.3 $\times 10^{-2}$	8.0 $\times 10^{-2}$	-4.9$\times 10^{-1}$

- $m_{Z'} \sim m_Z$
- $g_R'^b > g_L'^b > g_L'^e, g_R'^e$
- $\mathrm{Br}(Z' \to b\bar{b}) \approx 100\%$
- $\sigma(e^+e^- \to Z'Z')$: negligible
- $\sigma(e^+e^- \to ZZ' \to Zb\bar{b})$ => next slide

$e^+e^- \to ZZ' \to Zb\bar{b}$ at LEP



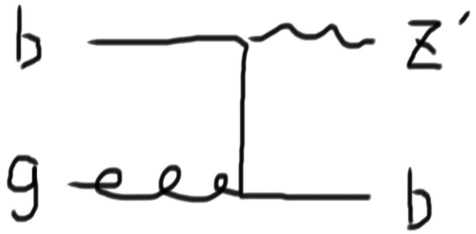


- $\sigma(e^+e^- \to ZZ' \to Zb\bar{b})$
  - $\sim$ 5 fb in "the best fit"
  - $\sim$ 36 fb in the fit with fixed $m_{Z'} = 95$ GeV

    *This is about 10% of $\sigma(e^+e^- \to ZH(H \to bb))$

    cf. 2.3σ excess at $m_{b\bar{b}} \sim$ 90-105 GeV at LEP Higgs search

$gb \to Z'b$ At Tevatron and LHC



- Predicted cross section
  $\sigma(p\bar{p} \to Z'b) \simeq$ 20 - 30 pb
- Current constraint
  $\sigma(p\bar{p} \to Hb) \times B(H \to b\bar{b}) <$ 26 - 32 pb for $m_H \simeq$ 90-100 GeV CDF 2.6fb^{-1} data (2011)
- At the LHC the $Z'b$ cross section is two orders of magnitude larger Campbell-Ellis-Maltoni-Willenbrock 2003

=> constraint on $g_R'^b$ and/or Br($Z' \to b\bar{b}$)

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Current deviation

$$\Delta a_\mu = a_\mu^{\rm exp} - a_\mu^{\rm SM} = 261(80) \times 10^{-11} (3.3\sigma)$$

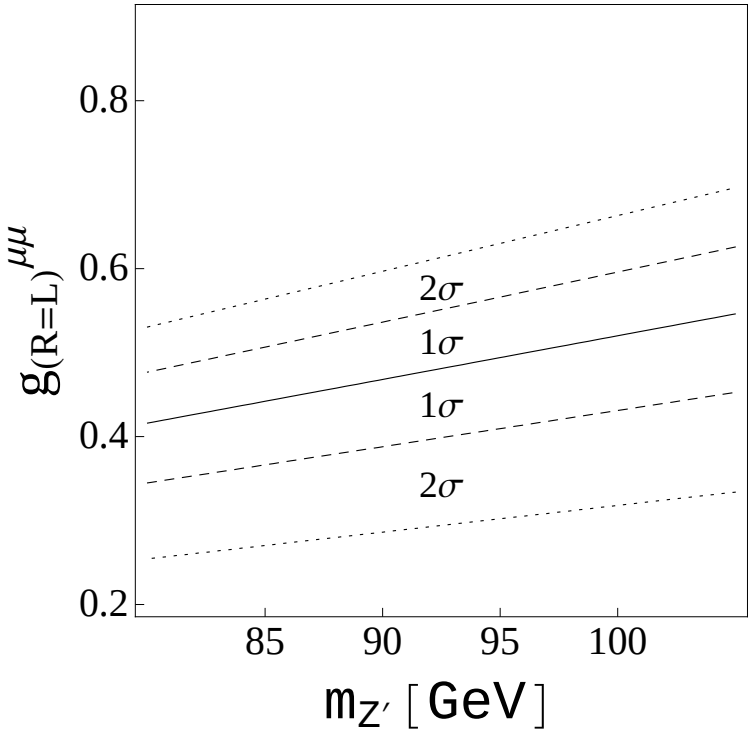
Hagiwara-Liao-Martin-Nomura-Teubner 2011

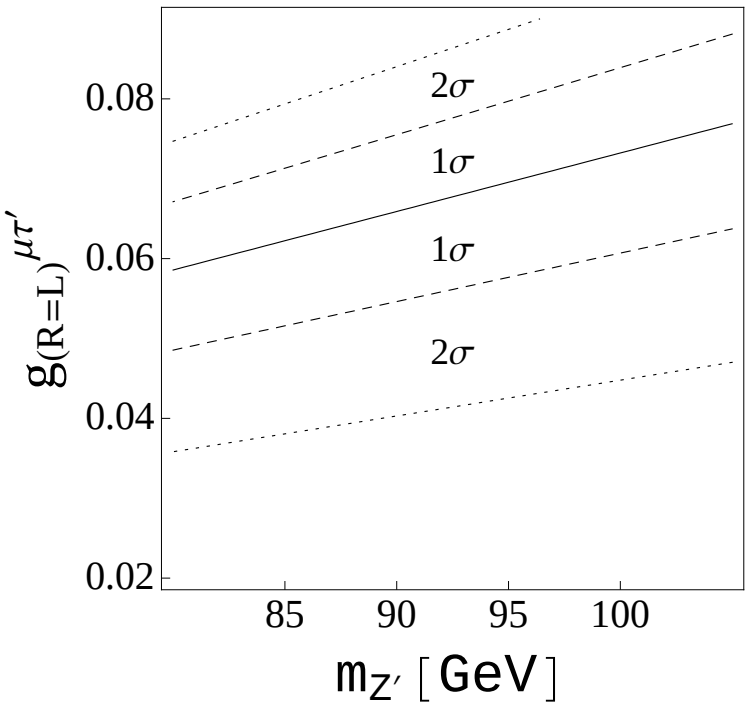
$$a_\mu^{EW}(Z) \sim -200 \times 10^{-11}$$

Z' contribution to $a_\mu^{Z'}$

Huang-Lin-Shan-Zhang, Choudhury-Mukhopadhyaya-Rakshit, Murakami etc.

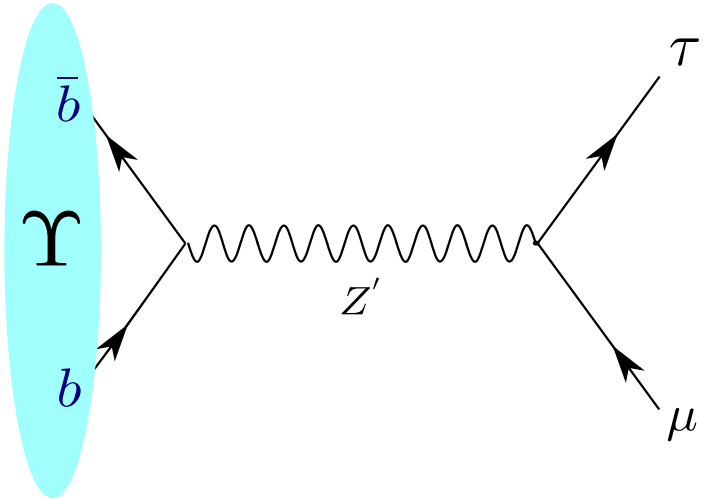
$$a_\mu^{Z'} = -\frac{1}{(4\pi)^2} \frac{m_\mu}{m_Z'^2} \frac{4}{3} [m_\mu ((g_L'^{\mu\mu})^2 + (g_R'^{\mu\mu})^2) - 3 m_{\tilde{f}} g_L'^{\mu\tilde{f}} g_R'^{\mu\tilde{f}}]$$

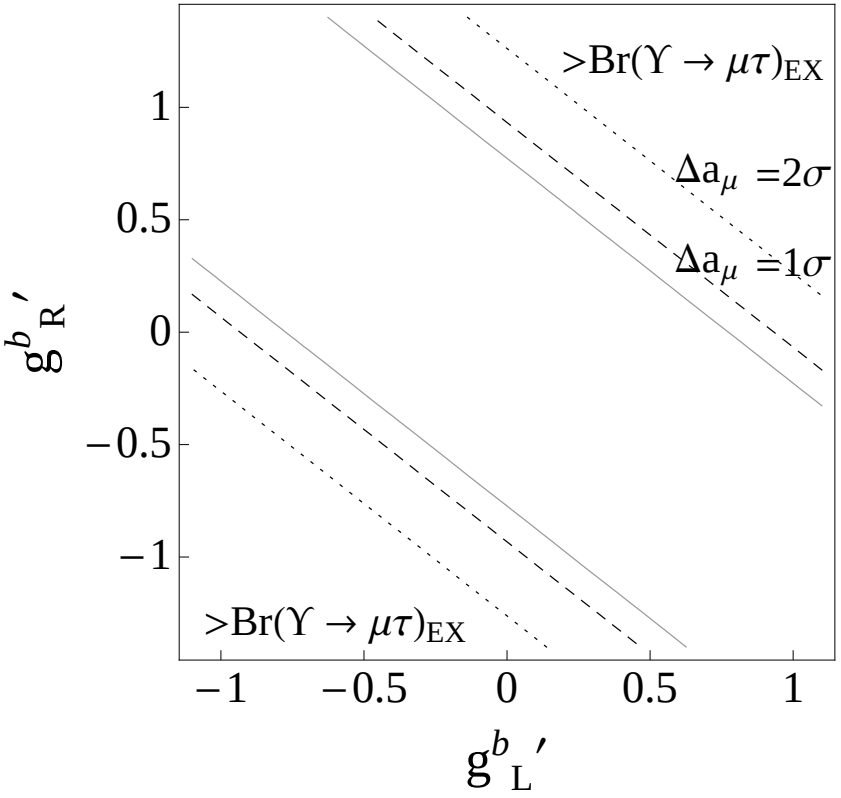

0.8
0.6
0.4
0.2
85
90
95
100
$g_{(R=L)}^{\mu\mu}$
$m_{Z'}$ [GeV]
2σ
1σ
1σ
2σ


0.08
0.06
0.04
0.02
85
90
95
100
$g_{(R=L)}^{\mu\tau'}$
$m_{Z'}$ [GeV]
2σ
1σ
1σ
2σ

$\Upsilon \to \mu\tau$ constraint

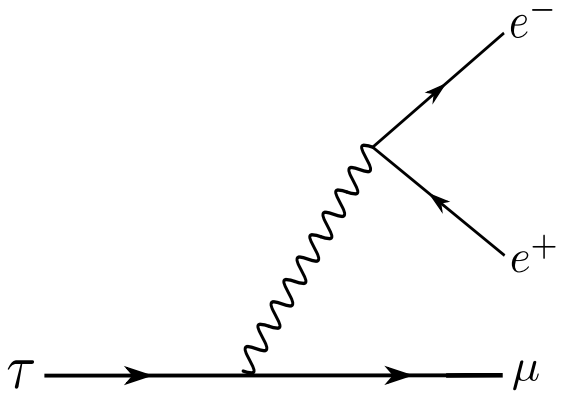
$\mathrm{Br}(\Upsilon(2S) \to \tau^{\pm}\mu^{\mp}) < 3.3\times10^{-6}$ (90% C.L.) Babar 2010
$\mathrm{Br}(\Upsilon(3S) \to \tau^{\pm}\mu^{\mp}) < 3.1\times10^{-6}$ (90% C.L.) Babar 2010

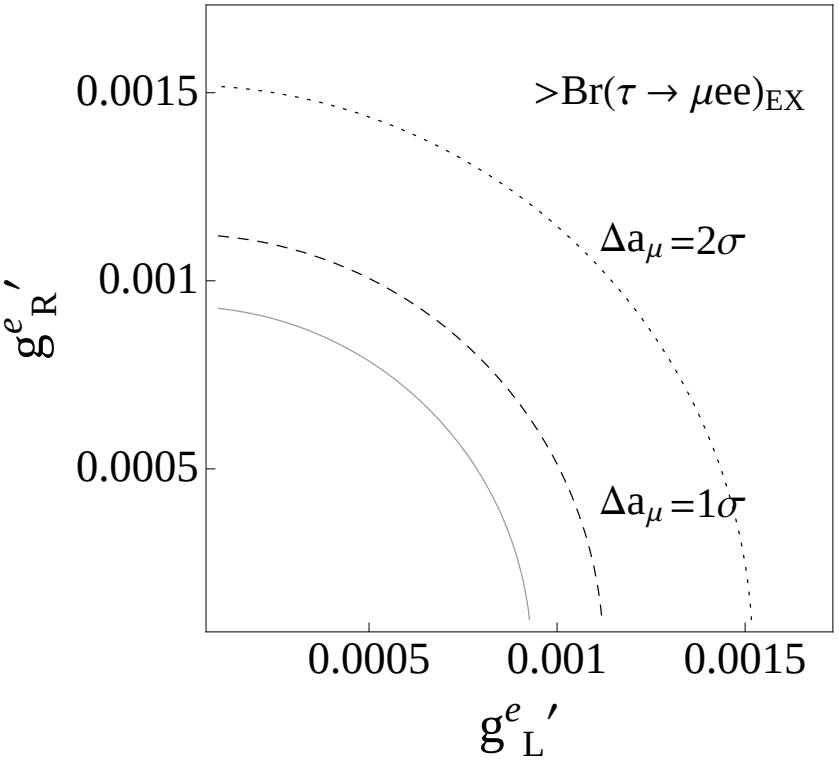




$\tau \to \mu ee$ constraint

$\mathrm{Br}(\tau \to \mu ee) < 1.8 \times 10^{-8}$ (90% C.L.) Belle 2010

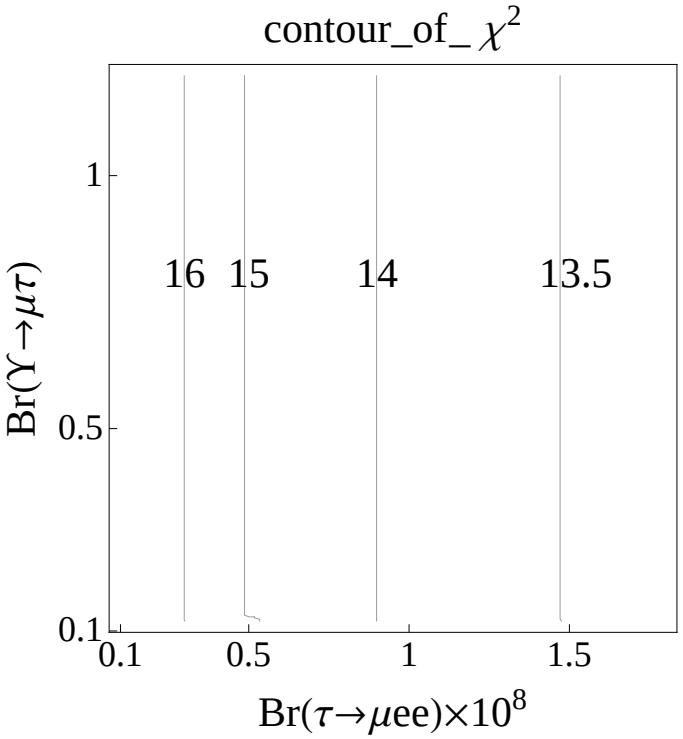




Best fit

$m_{Z'}$	$\Gamma_{Z'}$	$g_L'^e$	$g_R'^e$	$g_L'^b$	$g_R'^b$	$g'^{\mu\tau}$
91.2	0.1	7.9×10^{-4}	5.0×10^{-4}	5.0×10^{-4}	-1.5×10^{-1}	6.6×10^{-2}

- χ^2 =13.4 (=35 SM) for 13 obs.
- all the contributions to χ^2 are less than 2 except $A_{FB}^{b(+2)} \sim 5$



Outline

1. Motivation
2. Z' near the Z pole
3. Flavor violating Z' coupling and muon g-2
4. Summary

Summary

- The Z' boson near the Z-pole can fix the deviations of A_{FB}^{b} and $A_{LR}^{e(\mathrm{had})}$ and improve many other relevant observables.
- $g'^{\mu\tau}$ coupling can fix the deviations of g-2
- New data from Tevatron and LHC will soon exclude or constrain allowed parameters