Phenomenology of Kaluza-Klein gluon in warped extra dimension

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(Ochanomizu U.)

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in collaboration with Y. Kanehata (0902.3322[hep-ph])

Y. Kanehata, N. Maru, K. Yoneyama (in progress)

- b-quark coupling w/ Z-boson may be one of the good stages to look for the implications of physics beyond the SM

- In this talk, I report an interpretation on a ‘puzzle’ in the Zbb coupling in the framework of Warped Extra Dimension model

Plan

- Introduction: summary of electroweak data
- Puzzles(?) in EW data: b-jet asymmetry
- KK gluon in Warped Extra Dimension model
- Summary

Introduction

- LEP exp. @CERN (1st phase:1989-1995)
  - electron-positron collision on the Z-pole
  - 17 million Z decays
  - precise study of fermion pair production processes in Z decay
  - Test of the Standard Model
  - Window looking for physics beyond the SM

	data	SM prediction	SM pull
LEP 1			
line-shape & FB asym.:			
Γ_Z (GeV)	2.4952 ± 0.0023	2.4957	−0.23
σ_h^0(nb)	41.540 ± 0.037	41.477	1.69
R_l	20.767 ± 0.025	20.744	0.92
$A_{\rm FB}^{0,l}$	0.01714 ± 0.00095	0.01648	0.69
τ polarization:			
$A_l(P_\tau)$	0.1465 ± 0.0032	0.14825	−0.54
b and c quark results:			
R_b	0.21629 ± 0.00066	0.21586	0.65
R_c	0.1721 ± 0.0030	0.172225	−0.04
$A_{FB}^{0,b}$	0.0992 ± 0.0016	0.10393	−2.95
$A_{FB}^{0,c}$	0.0707 ± 0.0035	0.07432	−1.03
jet charge asymmetry:			
$\sin^2\theta_{\rm eff}^{\rm lept}$	0.2324 ± 0.0012	0.23137	0.86
SLC			
$A_l(SLD) = A_{LR}^0$	0.1513 ± 0.0021	0.14825	1.47
A_b	0.923 ± 0.020	0.9350	−0.59
A_c	0.670 ± 0.027	0.6684	−0.06
Tevatron + LEP 2			
m_W (GeV)	80.398 ± 0.025	80.380	0.74
Γ_W (GeV)	2.1400 ± 0.060	2.0916	0.81
Numerical inputs			
m_Z (GeV)	91.18756 ± 0.00021	91.18737	0.90
$G_F(10^{-5}{\rm GeV}^{-2})$	1.16637 ± 0.00001	1.16637	—
Parameters			
$\Delta\alpha_{\rm had}^{(5)}$	0.02768 ± 0.00022	0.02772	−0.17
$\alpha_s(m_Z)$	0.118 ± 0.002	0.118	−0.25
m_t (GeV)	172.5 ± 2.7	171.1	0.51
m_H (GeV)	—	70.2	—
$\chi^2_{\rm tot}$ (d.o.f. = 19 − 5)			18.095

summary of EW precision data
(*Phys.Rept.427:257,2006*)

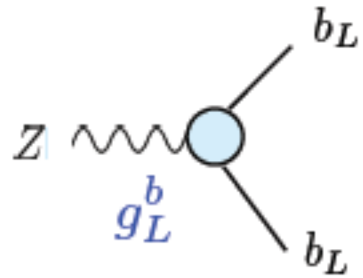
in the SM, there are four parameters which are determined from the data

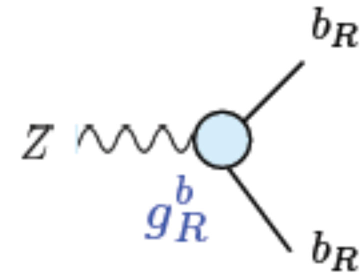
Puzzles(?) in EW data

SM is mostly good, but...

LEP electroweak working group, Phys. Rept. **427**, 257 (2006)

	data	SM	
LEP1		best fit	pull
line-shape & FB asym.:			
Γ_Z(GeV)	2.4952 ± 0.0023	2.4965	-0.57
σ_h^0(nb)	41.540 ± 0.037	41.481	1.59
R_l	20.767 ± 0.025	20.739	1.12
A_{FB}^l	0.0171 ± 0.0010	0.01642	0.79
b and c quark results:			
R_b	0.21629 ± 0.00066	0.21562	1.01
R_c	0.1721 ± 0.0030	0.1723	-0.07
A_{FB}^b	0.0992 ± 0.0016	0.1037	-2.8
A_{FB}^c	0.07072 ± 0.0035	0.07428	-1.02
SLC			
A_{LR}	0.1513 ± 0.0021	0.1480	1.51
A_b	0.923 ± 0.020	0.9346	-0.58
A_c	0.6702 ± 0.027	0.6683	0.07



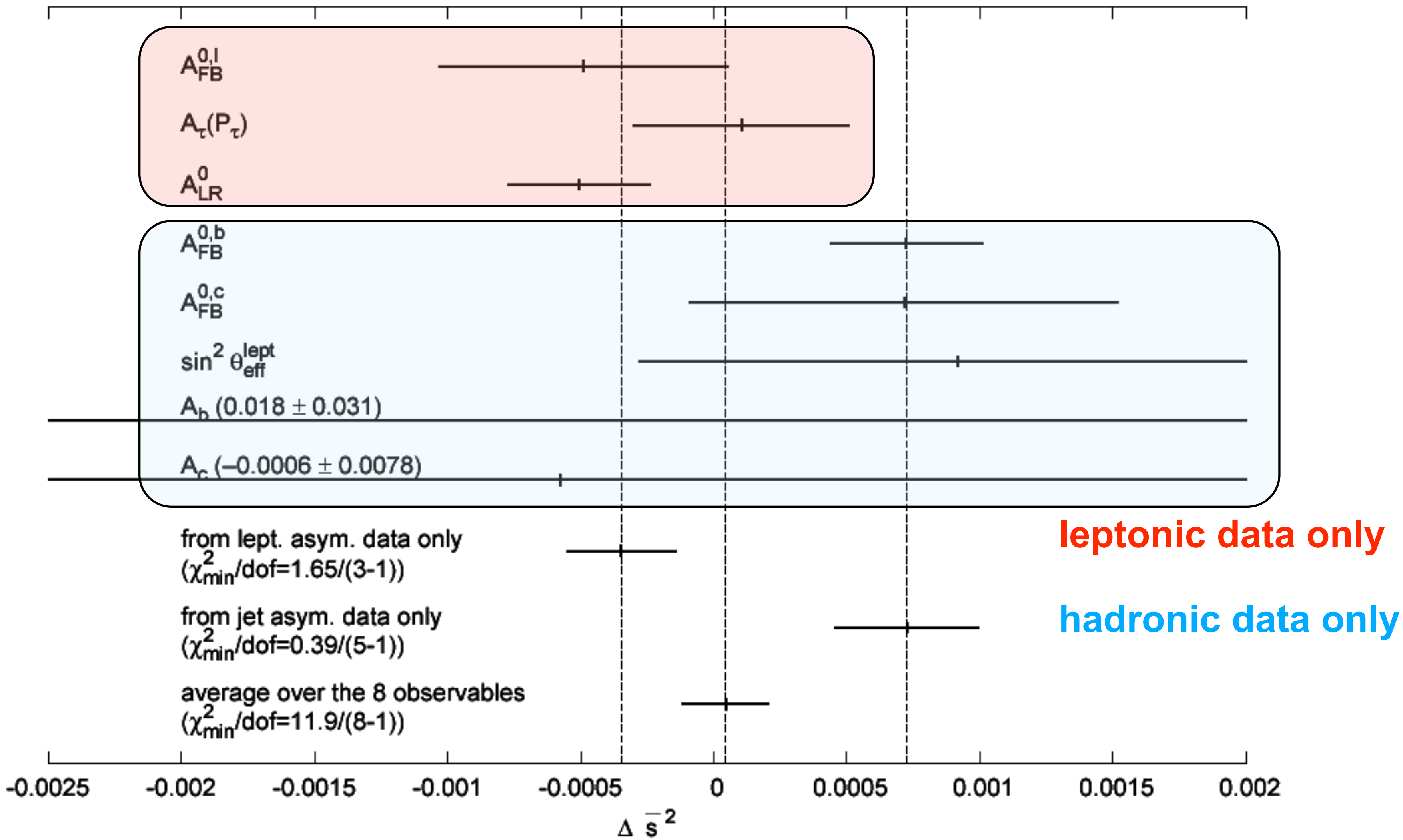


$$A_{FB}^b(\mathrm{exp.}) = 0.0992 \pm 0.0016$$
$$A_{FB}^b(\mathrm{SM}) = 0.1037$$

2.8σ deviation

$$A_{FB}^b(new\ phys.) = A_{FB}^b(SM) - 0.0326\Delta g_L^b - 0.1789\Delta g_R^b$$
$$\delta A_{FB}^b = -0.0326\Delta g_L^b - 0.1789\Delta g_R^b = -(45 \pm 16) \times 10^{-4}$$

effective Weinberg angle vs. jet-asymmetry data



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\sigma_h^0[\text{nb}] &= 41.481 + .047\Delta\bar{g_Z}^2 + 3.878\Delta\bar{s}^2 + 16.41\Delta g_L^b - 2.880\Delta g_R^b - .016x_s, \\
R_l &= 20.738 - .008\Delta\bar{g_Z}^2 - 17.474\Delta\bar{s}^2 - 20.734\Delta g_L^b + 3.638\Delta g_R^b + .020x_s, \\
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A_{FB}^{0,l} &= 0.01628 + .000440\Delta\bar{g_Z}^2 - 1.7565\Delta\bar{s}^2, \\
A_{FB}^{0,b} &= 0.10326 + .0014\Delta\bar{g_Z}^2 - 5.612\Delta\bar{s}^2 - .0326\Delta g_L^b - .1789\Delta g_R^b, \\
A_{FB}^{0,c} &= 0.0738 + .0011\Delta\bar{g_Z}^2 - 4.34\Delta\bar{s}^2, \\
A_l &= 0.14731 + .0020\Delta\bar{g_Z}^2 - 7.894\Delta\bar{s}^2, \\
A_b &= 0.93463 + .000027\Delta\bar{g_Z}^2 - .6372\Delta\bar{s}^2 - .2929\Delta g_L^b - 1.608\Delta g_R^b, \\
A_c &= 0.6680 + .0005\Delta\bar{g_Z}^2 - 3.468\Delta\bar{s}^2, \\
\sin^2\theta_{\text{eff}}^{\text{lept}} &= 0.23148 - .00025\Delta\bar{g_Z}^2 + 1.0033\Delta\bar{s}^2, \\
m_W &= 80.365 - .137x_H - .019x_H^2 + .018x_t - .005x_\alpha - .002x_s.
\end{aligned}
$$

$\Delta\bar{g}_Z^2$ and $\Delta\bar{s}^2$ (also Δg_L^b and Δg_R^b) include the radiative corrections not only in the SM but also new physics

an interpretation of A^b_{FB} data

LEP electroweak working group, Phys. Rept. **427**, 257 (2006)

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$$A^b_{FB}(new\ phys.) = A^b_{FB}(SM) - 0.0326\Delta g^b_L - 0.1789\Delta g^b_R$$

$$\delta A^b_{FB} = -0.0326\Delta g^b_L - 0.1789\Delta g^b_R = -(45 \pm 16) \times 10^{-4}$$

FB asymmetry can be expressed using LR asymmetry

$$A^b_{FB} = \frac{3}{4} A_e A_b$$

But b-quark LR asym.(@SLD) looks consistent with SM

Thus, reason may be

(1) A_e (=A_LR)?
(2) b-tagging@LEP?
(3) statistics?

or ***NEW PHYSICS*** in b-quark coupling

Example: MSSM (gluino contribution)

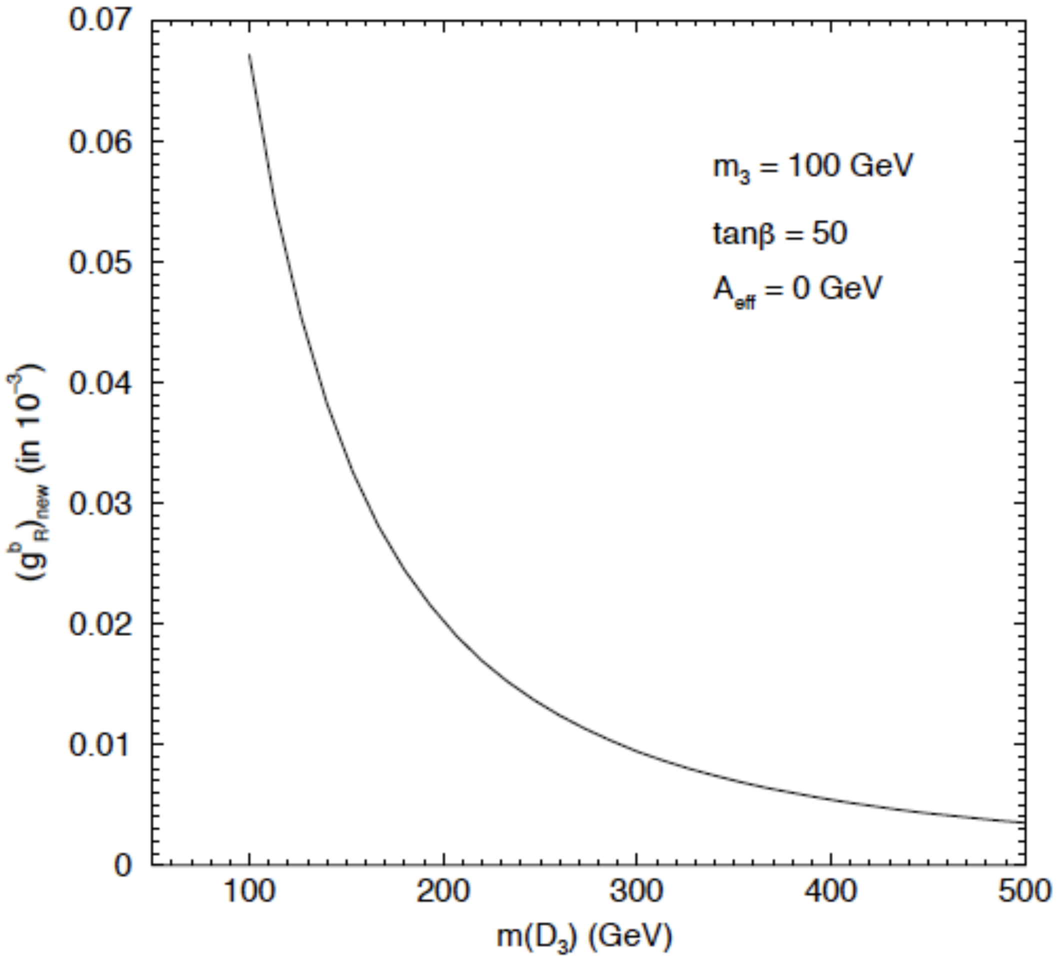


Figure 4: The gluino contribution to $(g_R^b)_{\rm new}$.

GCC, Hagiwara (2000)

relative sign of g_b^R is good, but size is too small to explain the puzzle

other new physics approach:

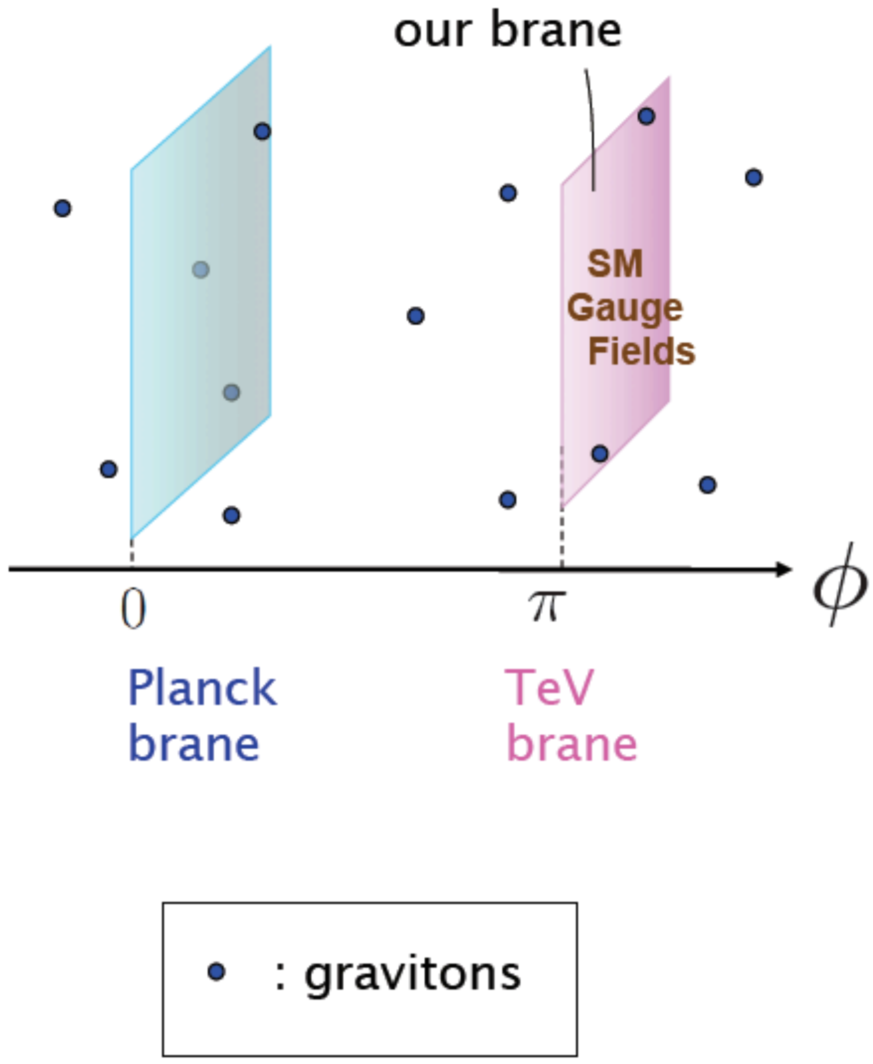
extra gauge boson
(He etal, 2002)

extra vector-like quark
(Choudhury etal, 2002, etc)

KK gluon
in Warped Extra Dimension model

Warped extra dimension (RS model)
- one of the solutions to the hierarchy problem

Randall and Sundrum, PRL83,3370('90)



Set up:
Two 3-branes with $\Lambda(<0)$ in the bulk
& 5D metric:

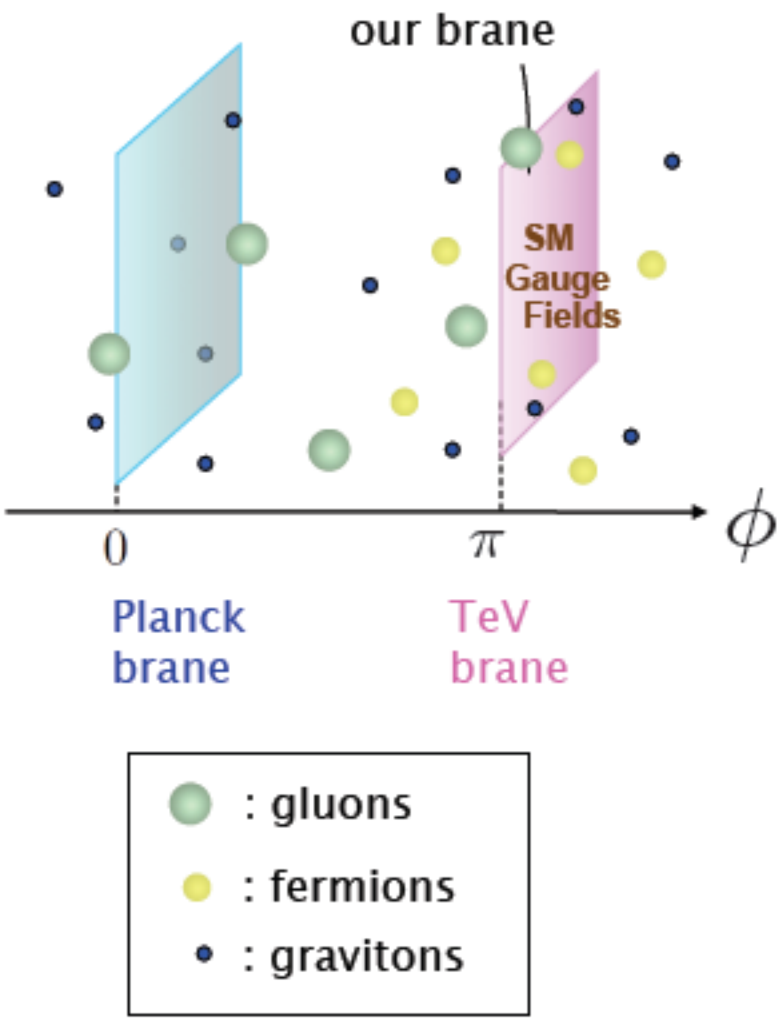
$$ds^2 = e^{-2k|y|}\eta_{\mu\nu}dx^\mu dx^\nu - dy^2$$

electroweak scale:

$$\begin{aligned} v \sim O(100\mathrm{GeV}) &= e^{-kr_c\pi} \times v_0 \\ &= e^{-kr_c\pi} \times 10^{18}\mathrm{GeV} \end{aligned}$$

the hierarchy between Planck and
EW scales is stable if $kr_c = 11 - 12$

Extension of RS model



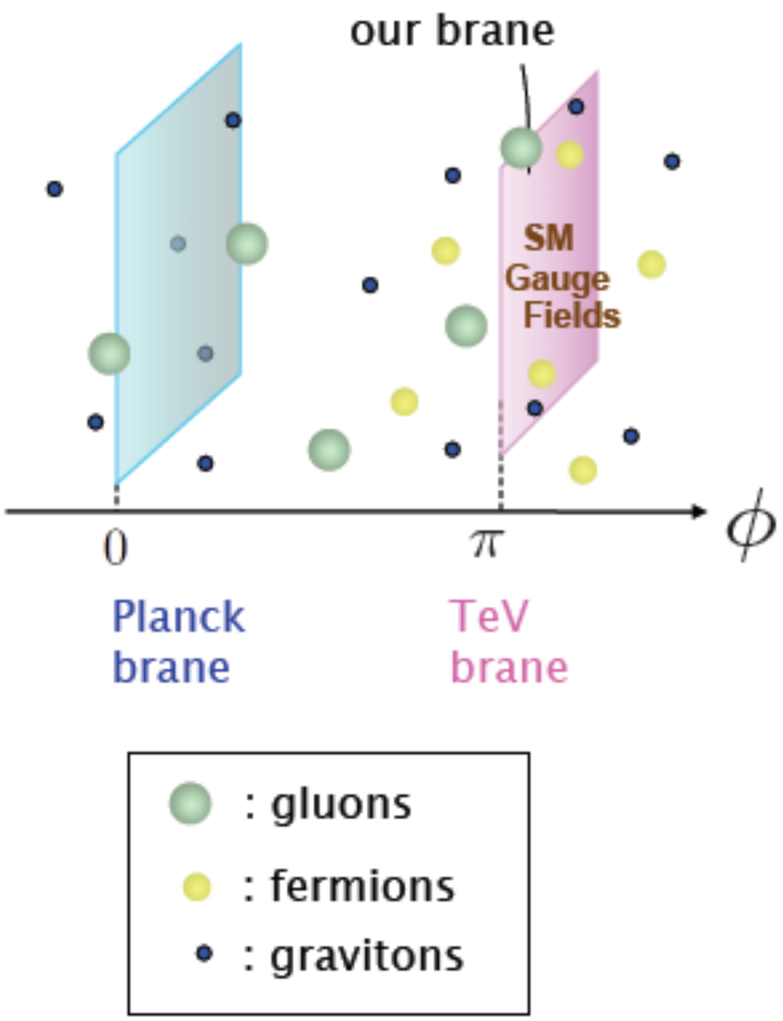
allow that fermions and gauge boson propagate into the bulk

KK(Kaluza-Klein) decomposition

$$A_\mu(x,\phi) = \sum_{n=0}^{\infty} A_\mu^{(n)}(x) \frac{\chi_A^{(n)}(\phi)}{\sqrt{r_c}}$$

$$\Psi_{L,R}(x,\phi) = \sum_{n=0}^{\infty} \psi_{L,R}^{(n)}(x) \frac{e^{2\sigma(\phi)}}{\sqrt{r_c}} \hat{f}_{L,R}^{(n)}(\phi)$$

Extension of RS model



- KK EW gauge bosons gives too large oblique corrections (corrections to gauge boson propagators) so that the scale of KK mass is strongly constrained as ~O(10TeV)

- further arrangement on the model is required

Davoudiasl et al, PLB473, 43('00)
Pomarol, PLB486,153('00)
Csaki etal, PRD66, 064021('02)

possiblity of Kaluza-Klein gluon

- no interaction with EW gauge boson → constraints from the oblique corrections are expected to be negligible
- couples only to quarks (not to leptons)
- (KK) gluon may resolve A_fb^b puzzle w/o conflicting the agreement of the lepton sector between exp. and SM
- comments: difficulty from model building (suppression of KK of W, Z?)

possiblity of Kaluza-Klein gluon

$$A_\mu(x,\phi) = \sum_{n=0}^{\infty} A_\mu^{(n)}(x) \frac{\chi_A^{(n)}(\phi)}{\sqrt{r_c}}$$

$$\Psi_{L,R}(x,\phi) = \sum_{n=0}^{\infty} \psi_{L,R}^{(n)}(x) \frac{e^{2\sigma(\phi)}}{\sqrt{r_c}} \hat{f}_{L,R}^{(n)}(\phi)$$

interaction of KK gluon and fermions

$$g_{mnq}^{ffA} \sim \int_{-\pi}^{\pi} d\phi e^{\sigma} \hat{f}_L^{(m)*} \hat{f}_L^{(n)} \chi_A^{(q)}$$

overlapping of wave functions in 5th D

it depends on the bulk mass term of fermion

$$S_f = \int d^4x \int d\phi r_c \sqrt{G} \left[V_n^M \left(\frac{i}{2} \bar{\Psi} \gamma^n \partial_M \Psi + h.c. \right) - \mathrm{sgn}(\phi) m_\Psi \bar{\Psi} \Psi \right]$$

$$m_\Psi = \nu_\Psi k \epsilon(y)$$

Grossman and Neubert, PLB474,361('00)

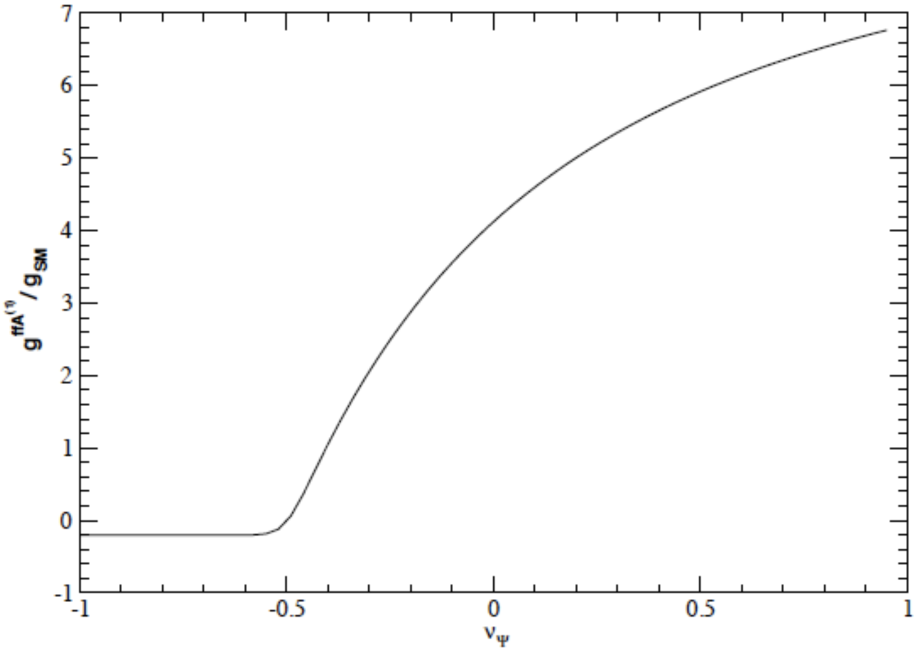
the bulk femion mass terms have been used to explain the hierarchy of Yukawa couplings

Agashe etal, (2003)

flavor dependent coupling

$$\xi = \frac{g_{001}^{ffA}}{g_{\mathrm{SM}}} \sim \int_{-\pi}^{\pi} d\phi e^{\sigma} \hat{f}_L^{(m)*} \hat{f}_L^{(n)} \chi_A^{(q)}$$

$$\approx \begin{cases} -0.2 & (\nu_\Psi < -0.5) \\ 4.0 + 5.2\nu_\Psi - 4.6\nu_\Psi^2 & (\nu_\Psi > -0.5) \end{cases}$$



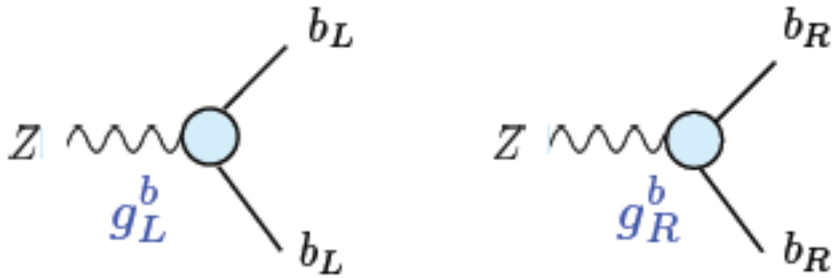
flavor dependent coupling of quarks with KK gluon

the coupling of KK gluon could be a few times larger than the QCD coupling

recall A^b_{FB} puzzle

$$
\begin{aligned}
A^b_{FB}(\text{exp.}) &= 0.0992 \pm 0.0016 \\
A^b_{FB}(\text{SM}) &= 0.1037
\end{aligned}
$$

$$\delta A^b_{FB} = -45 \pm 16 \quad (\times 10^{-4})$$

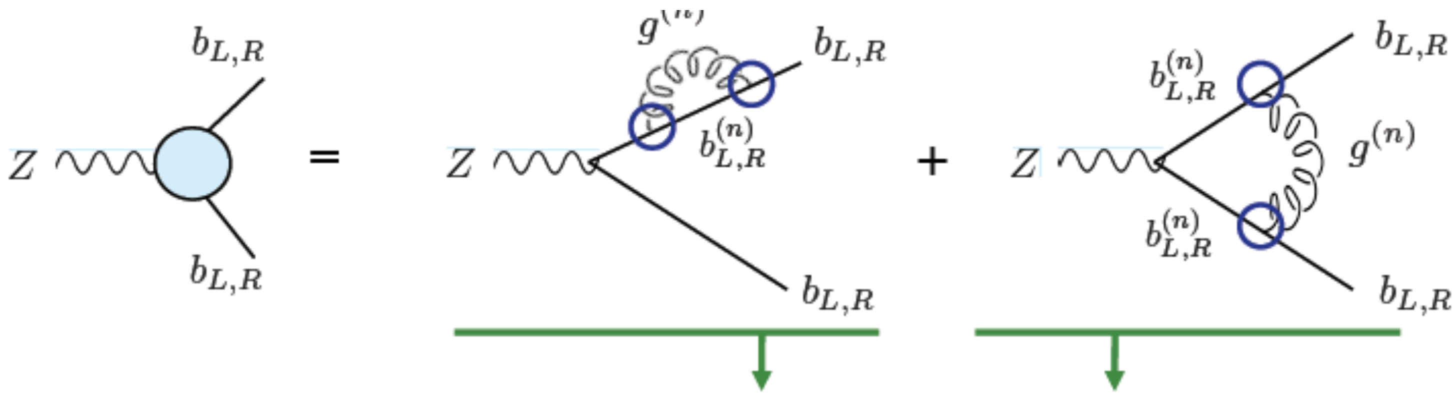


$$g^b_\alpha = g^b_\alpha(\text{SM}) + \Delta g^b_\alpha \quad (\alpha = L, R)$$

$$
\begin{aligned}
A^b_{FB} &= A^b_{FB}(\text{SM}) + \delta A^b_{FB} \\
&= A^b_{FB}(\text{SM}) - 0.0326\Delta g^b_L - 0.1789\Delta g^b_R
\end{aligned}
$$

evaluate KK gluon
contribution to Zbb couplings

KK gluon contribution in 1-loop



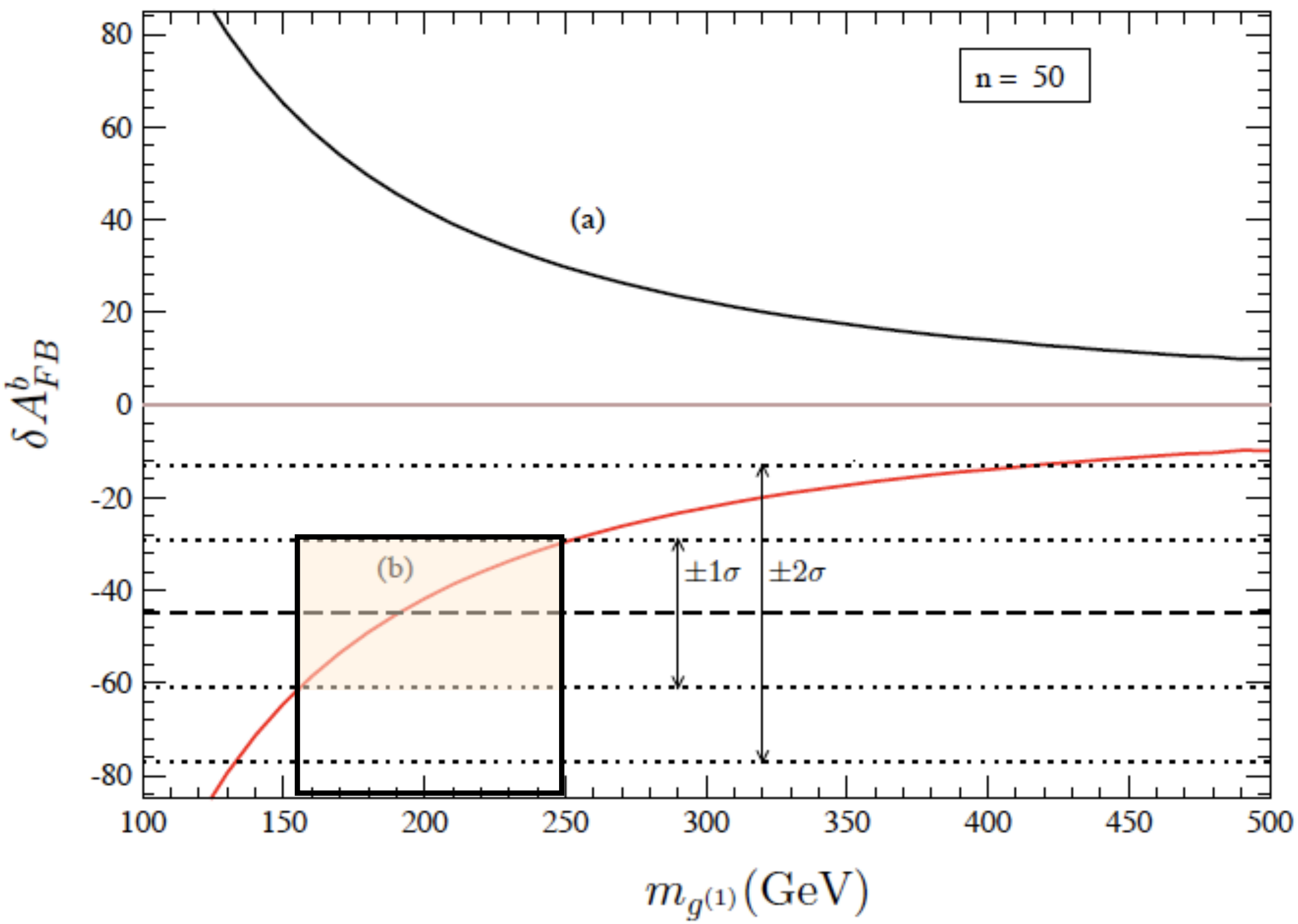
$$\Delta g^b_{L,R}(m_{g^{(n)}},\xi) = \frac{1}{\sqrt{4\sqrt{2}G_F m_z^2}} \left(g^{bbZ}_{L,R}\Sigma'(0) - \Gamma(m_z^2) \right)$$

(Note)
UV divergence of loop integral → cancel between two diagrams
However, infinity comes from sum of infinite KK towers.
The following result is obtained for n=50

$$A^b_{FB} = A^b_{FB}(\mathrm{SM}) + \delta A^b_{FB}$$
$$= A^b_{FB}(\mathrm{SM}) - 0.0326\Delta g^b_L - 0.1789\Delta g^b_R$$

$(\mathrm{a}) : (\xi_L, \xi_R) = (6, 0.2)$

$(\mathrm{b}) : (\xi_L, \xi_R) = (0.2, 6)$



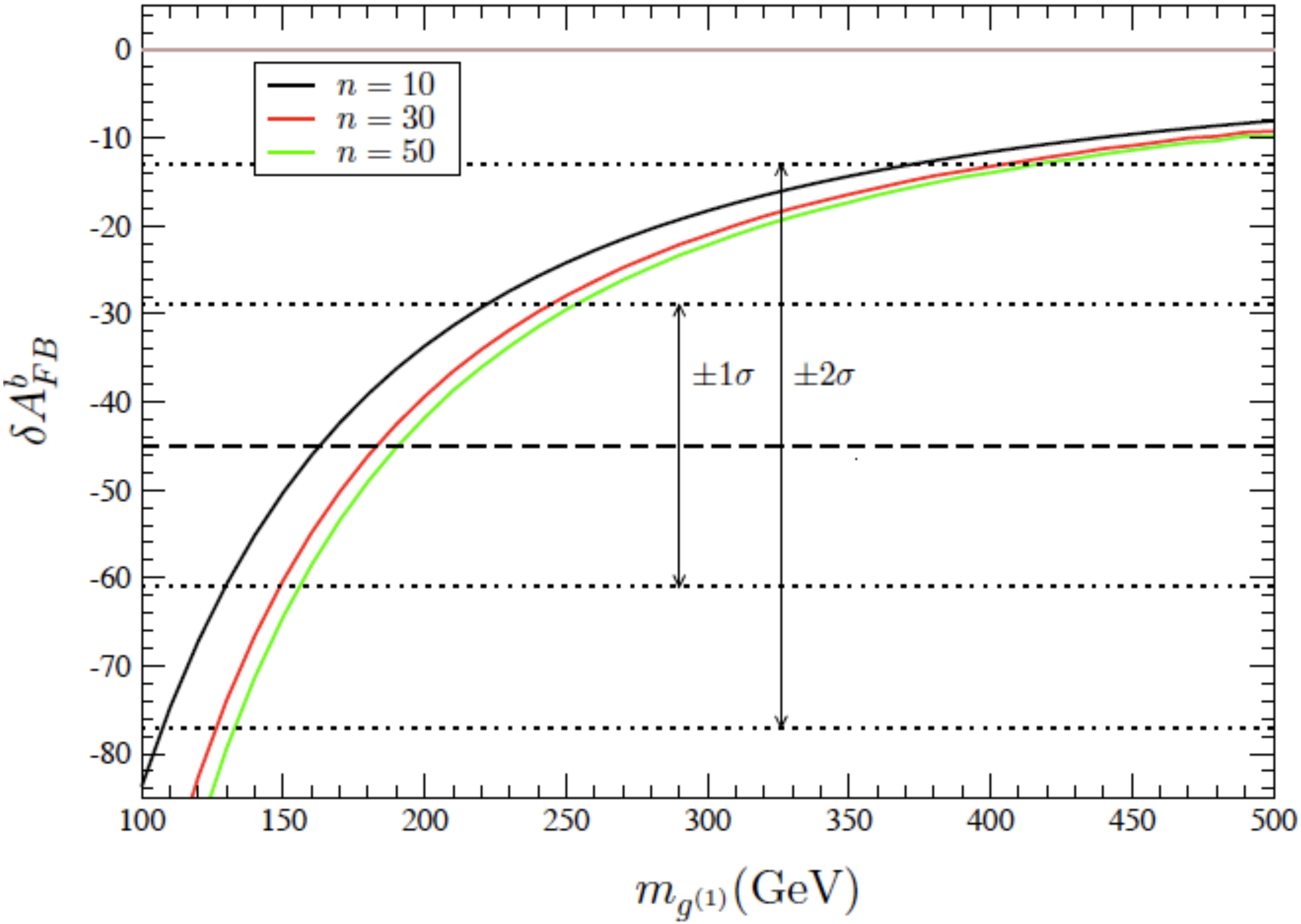
$$g^b_\alpha \sim I_{3b} - Q_b \sin^2\theta_W$$
$$g^b_L < 0, \quad g^b_R > 0$$

favored scenario:
right-handed b-quark couples strongly to KK gluon

KK gluon w/ m~200GeV explains A_FB^b puzzle in 1-σ level

mass of KK mode (for n=50) ~13 TeV

KK mode dependence



Correlation w/ other obs.

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$$\begin{aligned} A^b_{FB}(\mathrm{NP}) &= [A^b_{FB}]_{\mathrm{SM}} - 0.0326\Delta g^b_L - 0.1789\Delta g^b_R \\ R_b(\mathrm{NP}) &= [R_b]_{\mathrm{SM}} - 0.78\Delta g^b_L + 0.14\Delta g^b_R \\ A_b(\mathrm{NP}) &= [A_b]_{\mathrm{SM}} - 0.30\Delta g^b_L - 1.63\Delta g^b_R \end{aligned}$$

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\end{aligned}
$$

	A^b_{FB}	R_b	A_b	χ^2
pull(SM)	-2.8	1.0	-0.6	9.7
	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$
pull	-1.0	-2.4	0.7	7.5

$m_{g^{(1)}} \simeq 250\mathrm{GeV}$ for $\xi_R = 6$

phenomenology at hadron colliders

- KK gluon couples to (only) left-handed (t,b) quarks
- production process: $b\bar{b} \to g^{(1)}$
- no gluon fusion channel

more detail, see Yoneyama's talk
(next)

compare

$$\sigma_0 \equiv \sigma(p\bar{p} \to g^{(1)} + X) \times \mathrm{Br}(g^{(1)} \to b\bar{b}) \quad (\xi_L, \xi_R) = (0.2, 6)$$

and Tevatron results

(CDF) arXiv: 0812.4036, 0808.3347

Tevatron constraints

lower bound in 2σ

$$m_{g^{(1)}} > 157\mathrm{GeV}$$

→consistent with A_{FB}^{b} in 1-σ

3 jets event@LEP2 may increase the lower bound

more detail, see Yoneyama's talk (next)

GCC, Kanehata, Maru, Yoneyama, in preparation

Summary

- a possibility to explain b-jet asymmetry data within the framework of Warped Extra Dim.
- Enhancement of right handed b-quark coupling is favored from the data
- 3rd gen. quarks could strongly couple to KK gluon
- KK gluon w/ m~200 GeV is favored
- safe from Tevatron bound since production in p-pbar collision is suppressed (Yoneyama's talk)
- signal at LHC?

Back up

cut-off

- Naive Dimensional Analysis (NDA)

Manohar and Georgi (1984)

  - cut-off Λ → limit of energy scale where 4D gauge couplings are not perturbative

- in case of RS model

$$\begin{aligned} \Lambda &\sim 24\pi^2/g_5^2 \\ g_5 &= g_4\sqrt{\pi r_c} \\ g_4^2 &\approx 16\pi^2 \\ \Lambda &\approx 1/r_c \sim k/10 \end{aligned}$$

interval of mass

$$m_n \simeq n\pi k e^{-\pi k r_c}$$

number of KK mode

$$\sharp = \Lambda/m_n \sim 10^{15}$$

number of KK mode is another model parameter (we take n=50)

2. Framework

- EW observables in Z decay experiments can be expressed in terms of the effective couplings

$$g_\alpha^f = a_\alpha^f + b_\alpha^f \Delta \bar{g}_Z^2 + c_\alpha^f \Delta \bar{s}^2 + \Delta g_\alpha^f$$

f: flavor,   α: chirality

$\bar{g}_Z^2, \bar{s}^2$: obtained from the gauge boson propagator corrections

Δg_α^f : vertex corrections

Δ: shift from the SM reference values

$$(m_t, m_H, \Delta\alpha^{(5)}_{\mathrm{had}}(m_Z^2), \hat{\alpha}_s(m_Z)) = (172, 100, 0.0277, 0.118)$$

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$$g_\alpha^f = a_\alpha^f + b_\alpha^f \Delta \bar{g}_Z^2 + c_\alpha^f \Delta \bar{s}^2 + \Delta g_\alpha^f$$

e.g.,

$$g_L^\nu = 0.50199 + 0.45250 \Delta \bar{g}_Z^2 + 0.00469 \Delta \bar{s}^2$$

$$(g_L^f \sim I_3 - Q_f \sin^2 \theta_W)$$

$$
\begin{aligned}
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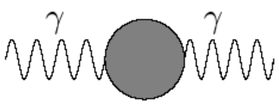
A_{FB}^{0,b} &= 0.10326 + .0014\Delta\bar{g_Z}^2 - 5.612\Delta\bar{s}^2 - .0326\Delta g_L^b - .1789\Delta g_R^b, \\
A_{FB}^{0,c} &= 0.0738 + .0011\Delta\bar{g_Z}^2 - 4.34\Delta\bar{s}^2, \\
A_l &= 0.14731 + .0020\Delta\bar{g_Z}^2 - 7.894\Delta\bar{s}^2, \\
A_b &= 0.93463 + .000027\Delta\bar{g_Z}^2 - .6372\Delta\bar{s}^2 - .2929\Delta g_L^b - 1.608\Delta g_R^b, \\
A_c &= 0.6680 + .0005\Delta\bar{g_Z}^2 - 3.468\Delta\bar{s}^2, \\
\sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}} &= 0.23148 - .00025\Delta\bar{g_Z}^2 + 1.0033\Delta\bar{s}^2, \\
m_W &= 80.365 - .137x_H - .019x_H^2 + .018x_t - .005x_\alpha - .002x_s.
\end{aligned}
$$

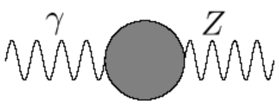
$\Delta\bar{g}_Z^2$ and $\Delta\bar{s}^2$ (also Δg_L^b and Δg_R^b) include the radiative corrections not only in the SM but also new physics

summary of radiative corrections

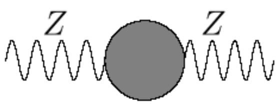
gauge boson propagator corrections



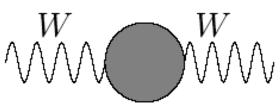
$\sim \bar{e}^2(q^2) = \hat{e}^2[1-\mathrm{Re}\overline{\Pi}^{\gamma\gamma}_{T,\gamma}(q^2)]$



$\sim \bar{s}^2(q^2) = \hat{s}^2[1+\frac{\hat{c}}{\hat{s}}\mathrm{Re}\,\overline{\Pi}^{\gamma Z}_{T,\gamma}(q^2)]$



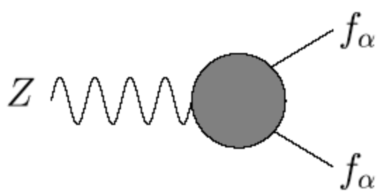
$\sim \bar{g}_Z^2(q^2) = \hat{g}_Z^2[1-\mathrm{Re}\overline{\Pi}^{ZZ}_{T,Z}(q^2)]$



$\sim \bar{g}_W^2(q^2) = \hat{g}^2[1-\mathrm{Re}\overline{\Pi}^{WW}_{T,W}(q^2)]$

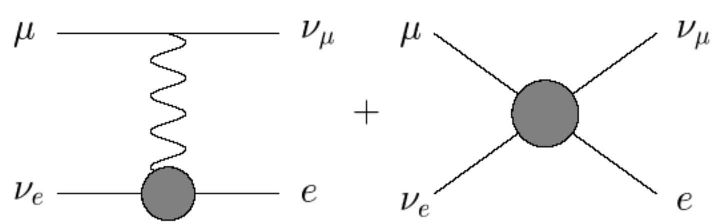
Hagiwara, Haidt, Kim, Matsumoto (1994)

Zff vertex corrections



$\sim \Delta g^f_\alpha$

vertex/box corrections in muon decay



$\sim \Delta\bar{\delta}_G$

independent of external fermions

(process independent corrections)

process dependent corrections

gauge boson propagator corrections

$\bar{g}_Z^2, \bar{s}^2 \leftrightarrow S, T, U$ parameters (Peskin-Takeuchi, 1990)

$$\begin{aligned} \Delta\bar{g}_Z^2 &= 0.00412\Delta T_Z \\ \Delta\bar{s}^2 &= 0.00360\Delta S_Z - 0.00241\Delta T_Z + 0.00011x_\alpha \end{aligned}$$

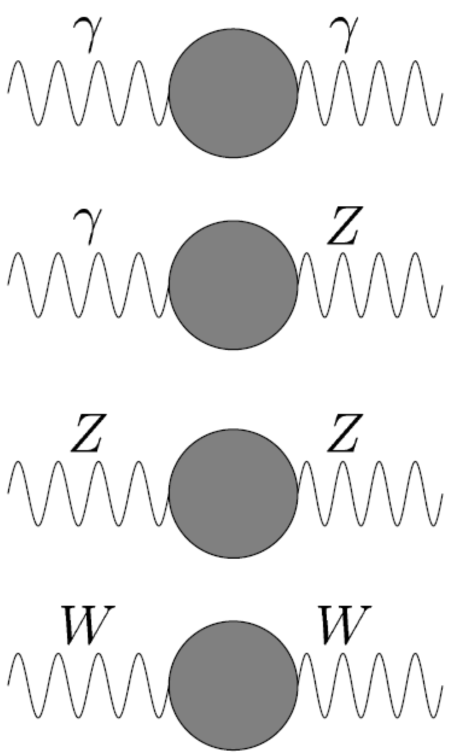
$$\begin{aligned} T_Z &= T + 1.49R - \frac{\Delta\bar{\delta}_G}{\alpha} \\ S_Z &= S + R - 0.064x_\alpha \end{aligned}$$

$$\frac{4\pi}{\bar{g}_Z^2(m_Z^2)} - \frac{4\pi}{\bar{g}_Z^2(0)} = -\frac{1}{4}R$$

G.C.C, Hagiwara ('98)

gauge boson propagator corrections

(overview of Peskin-Takeuchi's formalism (1990))



- there are four form factors (function of momentum transfar q^2)
- at q^2 = 0 and mZ^2, eight form factors in total
- at q^2=0, two form factors including photon leg vanish due to the gauge invariance
- three of six form factors could be replaced by (α, mZ, G_F)

- then, gauge boson propagator corrections can be evaluated by three parameters (S,T,U)

gauge boson propagator corrections

(overview of Peskin-Takeuchi's formalism (1990))

assuming the running of the pi-functions between $q^2 = 0$ and $q^2 = m_Z^2$ can be described by the SM, and the scale of new physics is much larger than m_Z, the three independent parameters can be chosen as follows

$$
\begin{aligned}
S &= 16\pi \mathrm{Re}\left[\Pi_{T,\gamma}^{3Q}(m_Z^2) - \Pi_{T,Z}^{33}(0)\right] \\
T &= \frac{4\sqrt{2}G_F}{\alpha}\left[\Pi_T^{33}(0) - \Pi_T^{11}(0)\right] \\
U &= \left[\Pi_{T,Z}^{33}(0) - \Pi_{T,W}^{11}(0)\right]
\end{aligned}
$$

gauge boson propagator corrections

$\bar{g}_Z^2, \bar{s}^2 \leftrightarrow S, T, U$ parameters (Peskin-Takeuchi, 1990)

$$\begin{aligned} \Delta\bar{g}_Z^2 &= 0.00412\Delta T_Z \\ \Delta\bar{s}^2 &= 0.00360\Delta S_Z - 0.00241\Delta T_Z + 0.00011x_\alpha \end{aligned}$$

$$\begin{aligned} T_Z &= T + 1.49R - \frac{\Delta\bar{\delta}_G}{\alpha} \\ S_Z &= S + R - 0.064x_\alpha \end{aligned}$$

$$\frac{4\pi}{\bar{g}_Z^2(m_Z^2)} - \frac{4\pi}{\bar{g}_Z^2(0)} = -\frac{1}{4}R$$

- the parameter "R" accounts for the new physics contributions to the running of Z-boson self energy between 0 and mZ
- SUSY contributions to R is important

$$m_W = 80.402 - 0.288\Delta S + 0.418\Delta T + 0.337\Delta U + 0.012x_\alpha - 0.126\frac{\Delta\bar{\delta}_G}{\alpha}$$

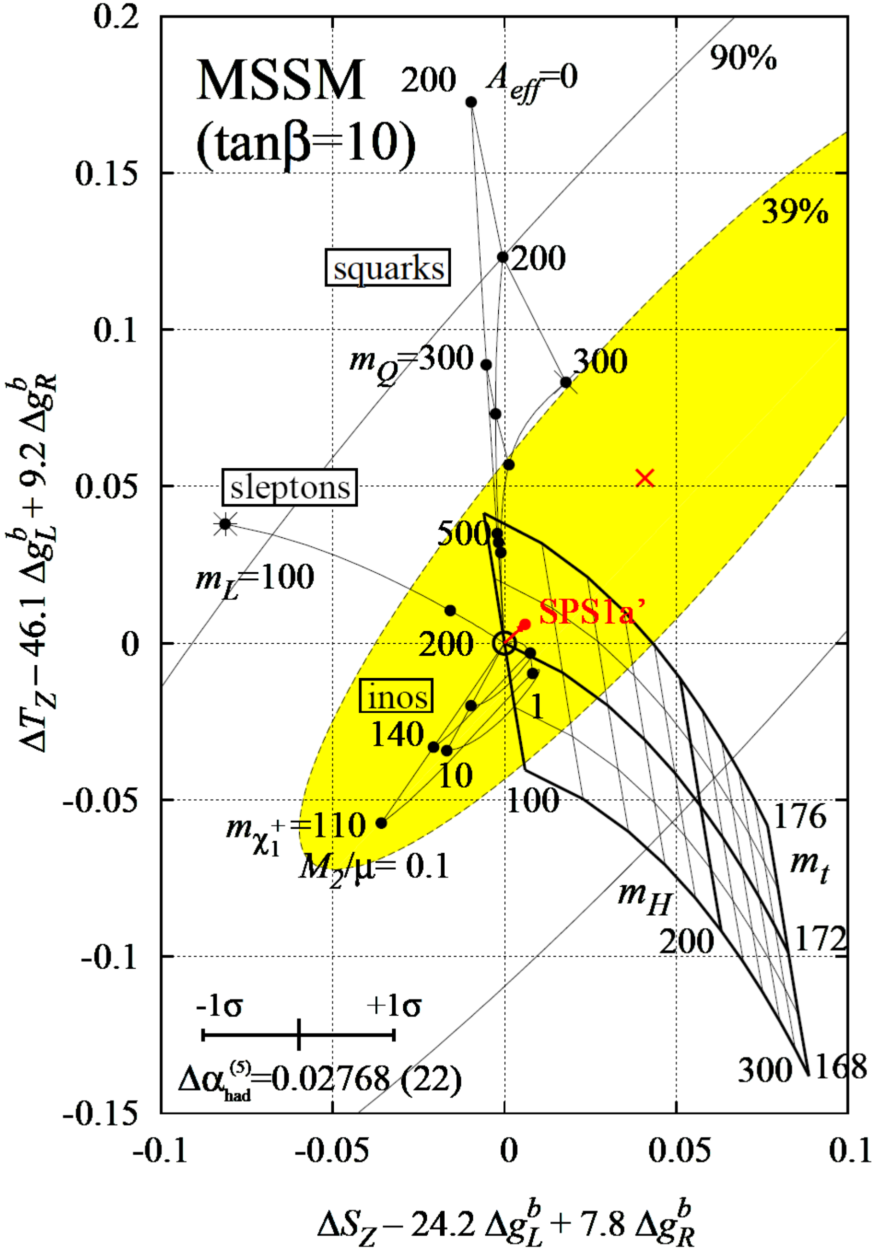
G.C.C, Hagiwara ('98)

- we can perfom model independent analysis using (Sz, Tz and Zbb vertex corrections) and mW.

$$S_Z, T_Z, g_L^b, g_R^b$$

$$\left.\begin{array}{rcl} \Delta S_Z &=& 0.041 + 24.2\Delta g_L^b - 7.8\Delta g_R^b \pm 0.101 \\ \Delta T_Z &=& 0.053 + 46.1\Delta g_L^b - 9.2\Delta g_R^b \pm 0.125 \end{array}\right\}, \quad \rho_{\mathrm{corr}} = 0.90$$

$$\chi^2_{\min} = 15.7 + (\text{squared term of } \Delta g_L^b, g_R^b)$$



yellow: 1-sigma allowed region of (S_Z, T_Z, g^b_L, g^b_R)

(1)SM prediction (mt, mH)

(2)light squarks gives significantly large Tz

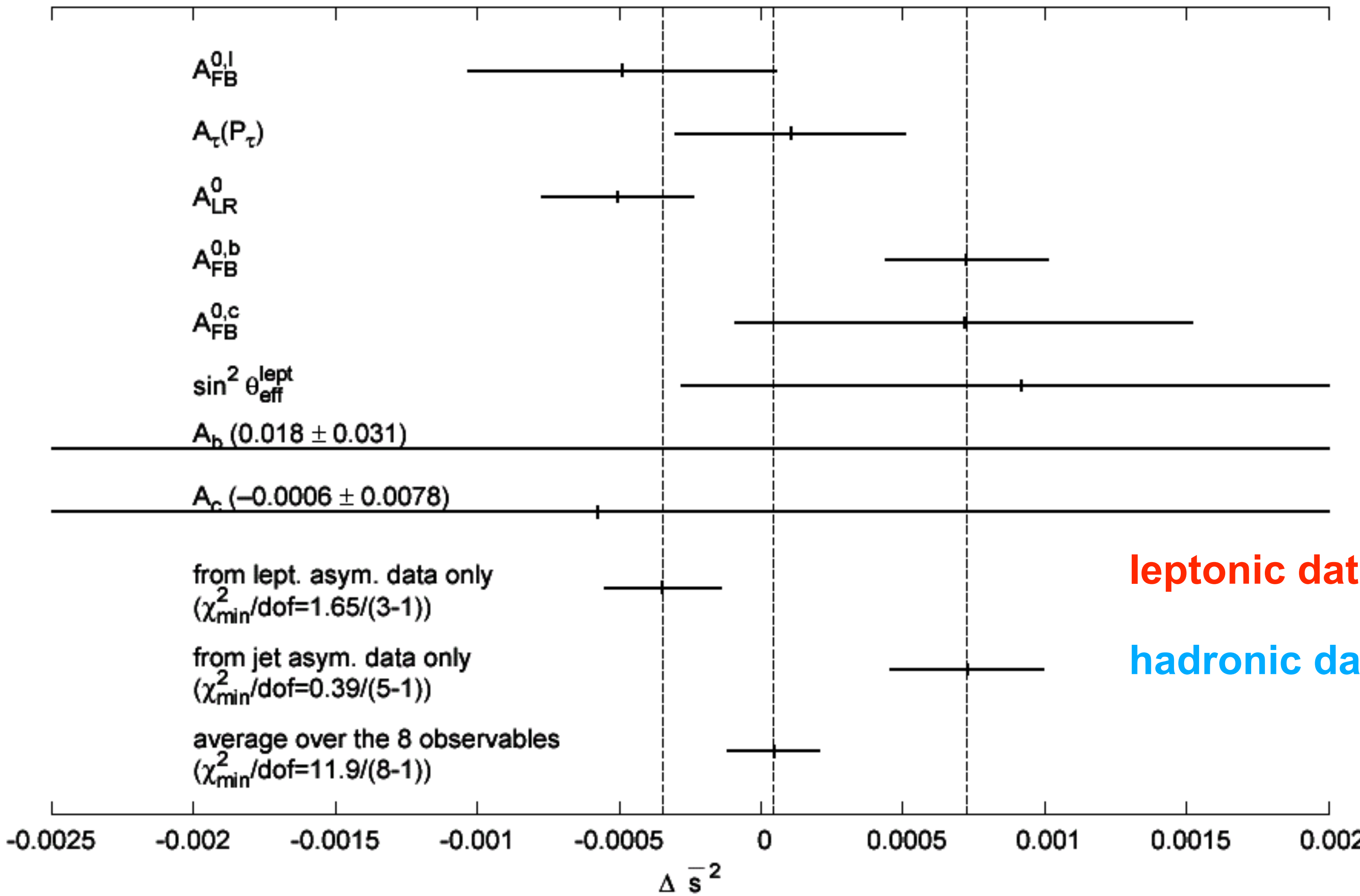
(3)sleptons (~100GeV) gives large Sz

(4)chargino-neutralino

* SPS1a' →a SUSY parameter set (benchmark) used in the linear collider community

GCC, Hagiwara, Matsumoto, Nomura (2008)

effective Weinberg angle vs. jet-asymmetry data



leptonic data only

hadronic data only