EPS-HEP 2015, Vienna
23 July 2015

Violation of lepton flavour universality in composite Higgs models

Presented by Peter Stangl

Junior Research Group "New Physics"
Excellence Cluster Universe, Munich

Deviation from SM in $B^+ \to K^+ \ell^+ \ell^-$

R_K from LHCb measurement

The measured ratio R_K has a 2.6σ deviation from the SM:

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

LHCb, arXiv:1406.6482

If confirmed this would be an evidence for violation of lepton flavour universality (LFU).

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Explanation by new physics models

- possible in models with spin-0 or spin-1 leptoquarks or a heavy neutral gauge boson mediating $b \to s\,\ell^+\ell^-$ arXiv:1403.1269, 1408.1627, 1409.0882, 1409.4557, 1411.0565, 1411.3161, 1411.4773, 1412.7164, 1501.00993 ,1501.05193, 1503.03477, 1505.03079, ... see talk by Javier Fuentes-Martin
- not possible in the MSSM Altmannshofer, Straub, arXiv:1411.3161
- possible in composite Higgs models (CHMs) with composite leptoquarks Gripaios, Nardecchia, Renner, arXiv:1412.1791
- more simple CHMs: presented here, based on C. Niehoff, PS, D. Straub [arXiv:1503.03865]

Parametrization of $b \to s\,\ell^+\ell^-$ transition

Operators in the weak effective Hamiltonian

Transition $b \to s\,\ell^+\ell^-$ parametrized by Wilson coefficients C_9^ℓ, ${C'}_9^\ell$, C_{10}^ℓ and ${C'}_{10}^\ell$ associated with the operators

$$O_9^\ell = (\bar{s}\,\gamma_\mu\,P_L\,b)\left(\bar{\ell}\,\gamma^\mu\,\ell\right) \qquad {O'}_9^\ell = (\bar{s}\,\gamma_\mu\,P_R\,b)\left(\bar{\ell}\,\gamma^\mu\,\ell\right)$$

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Constraints from recent fits

Recent fits have shown that the data prefers either

- a negative shift in C_9^μ only: $\delta C_9^\mu < 0$
- or a shift in C_9^μ and C_{10}^μ with $-\delta C_9^\mu = \delta C_{10}^\mu > 0$

Altmannshofer, Straub, arXiv:1411.3161

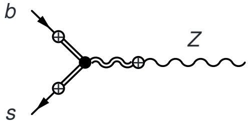
Heavy resonances in CHMs

- CHMs predict heavy resonance partners of SM fields that transform under a global symmetry $G \supset G_{SM}$.
- SM fields mix with heavy partners

e.g.

- Amount of mixing is called "degree of compositeness" (composite mass eigenstates from mixing)
- Mixing may modify SM couplings

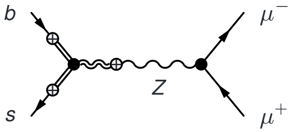
e.g.



(tree-level FCNC)

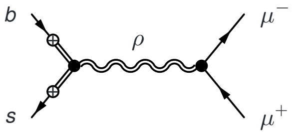
Possible contributions to δC_9^μ and δC_{10}^μ in CHMs

Z exchange

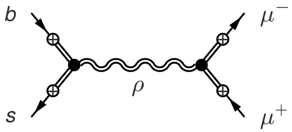


Tree-level flavour-changing Z coupling from mixing of b,s and Z with heavy resonances

Heavy vector resonance ρ exchange



ρ-muon coupling which is approximately equal to Z-muon coupling



ρ-muon coupling from mixing of muons with heavy resonances

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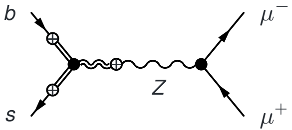

Tree-level flavour-changing Z coupling from mixing of b,s and Z with heavy resonances,
gives a contribution $\delta C_{10}^\mu \gg \delta C_9^\mu$ due to the small vector coupling of Z to leptons and is lepton flavour universal.

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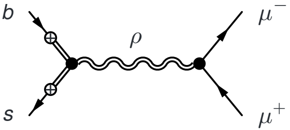

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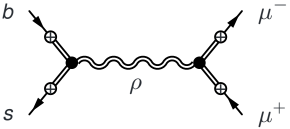

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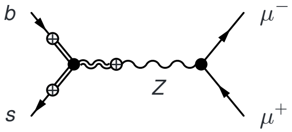

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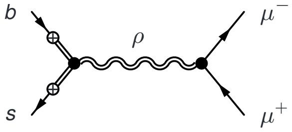
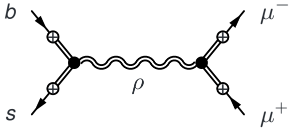


ρ-muon coupling which is approximately equal to Z-muon coupling,
has the same problem as the Z exchange.



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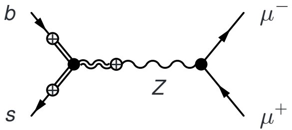

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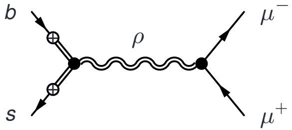

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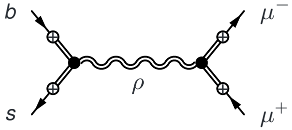
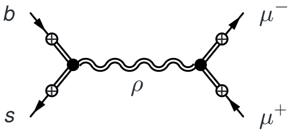


ρ-muon coupling from mixing of muons with heavy resonances,
might give the expected contribution if degree of compositeness s_μ is big enough.

Composite muons



Handedness of composite muons

- shift in only C_9^μ requires sizable left- and right-handed degrees of compositeness s_{μ_L} and s_{μ_R}.
- $\delta C_{10}^\mu = -\delta C_9^\mu$ would require only sizable s_{μ_L}.

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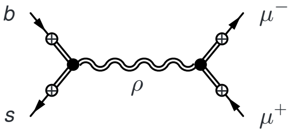

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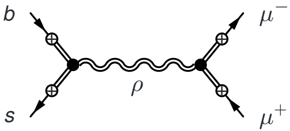

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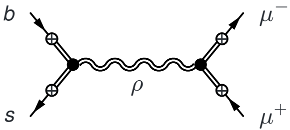

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Lower bound on degree of compositeness

- Constraints from B_s-$\bar{B}_s$ mixing require not too large b-s-ρ coupling.
- To get an effect in R_K, one thus needs a degree of compositeness of

$$s_{\mu_L} \gtrsim 0.17 \cdot \sqrt{f/v}$$

Electroweak constraints

Constraints on $Z\mu_L\mu_L$ coupling

- s_{μ_L} would shift Z coupling to left-handed muons which is strongly constrained by LEP.
- This can be avoided by a custodial protection of the Z-muon coupling using a discrete P_{LR} symmetry! Agashe et al., arXiv:hep-ph/0605341, Agashe, arXiv:0902.2400
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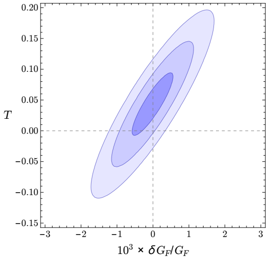
Contribution to Fermi constant

- Charged current coupling $W^+\mu_L^-\nu_{\mu_L}$ not protected.
- Shift of Fermi constant: $\frac{\delta G_F}{G_F} \approx -\frac{v^2}{4f^2}\, s_{\mu_L}^2$
- Constraints on G_F are correlated with constraints on T parameter: $s_{\mu_L} \lesssim 0.08\frac{f}{v}$



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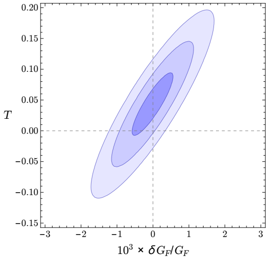


The $Z\nu_{\mu L}\nu_{\mu L}$ coupling

- Neutral current coupling to neutrinos also not protected.
- The correction can explain the LEP 2σ deficit in the invisible Z width. This *improves* the agreement with the data!

Results

Result for R_K

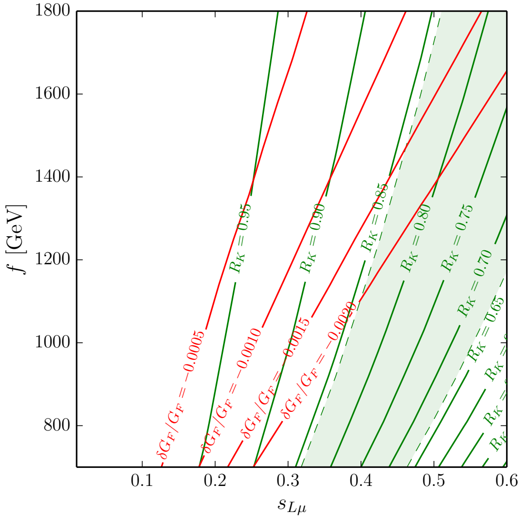
Assuming a 10% correction to ΔM_s in B_s-$\bar{B}_s$ mixing, one can express R_K by s_{μ_L} and f only:

$$1 - R_K \approx 0.14 \left[\frac{1.3\,TeV}{f}\right] \left[\frac{s_{\mu_L}}{0.4}\right]^2$$

Lower bounds for f & s_{μ_L}

Using all previous assumptions:

$$f \gtrsim 1.3\,TeV \quad s_{\mu_L} \gtrsim 0.4$$



Conclusions

Left handed muons with a sizable degree of compositeness can explain the departure from LFU measured by LHCb.

Predictions

- Explanation needs $\delta C_{10}^{\mu} = -\delta C_{9}^{\mu}$. Can be tested with more precise measurements.
- Violation of LFU in other modes expected.
- Sizable effect in B_s mixing testable with higher precision of CKM parameters.