R_K and future

$b \to s\ell\ell$ BSM opportunities†

(†What tells a muon from an electron?)

based on works with Martin Schmaltz arXiv:1408.1627, Phys. Rev. D 90, 054014 (2014).

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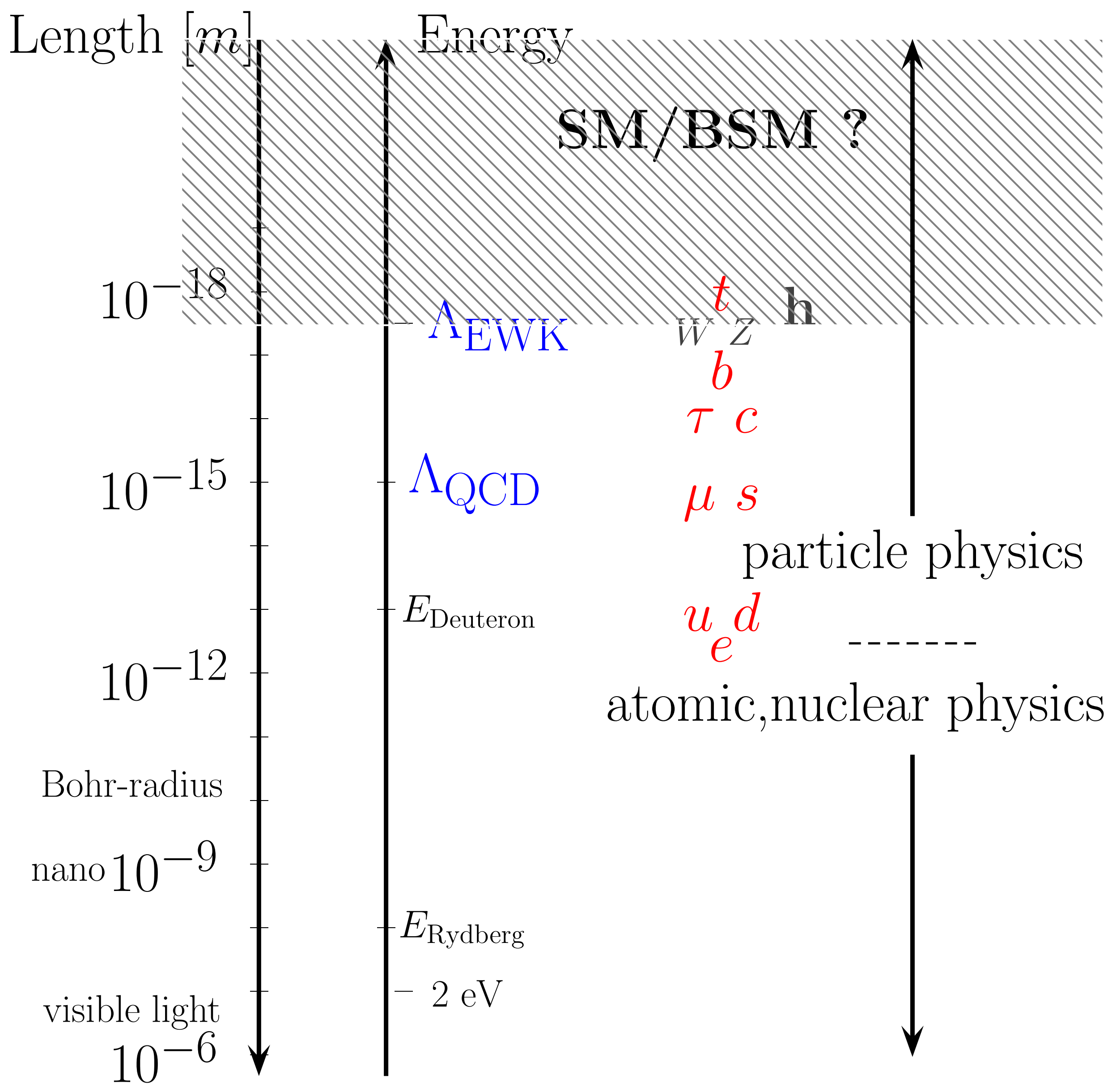
Exploring Physics at Highest Energies



FCNCs are suppressed in SM by i) weak loop, ii) CKM and iii) GIM. These suppression do not have to be at work in BSM, so FCNCs are great place to look for BSM effects.
Different sectors and different couplings presently probed:

$s \to d$: $K^0 - \bar{K}^0$, $K \to \pi\nu\bar{\nu}$

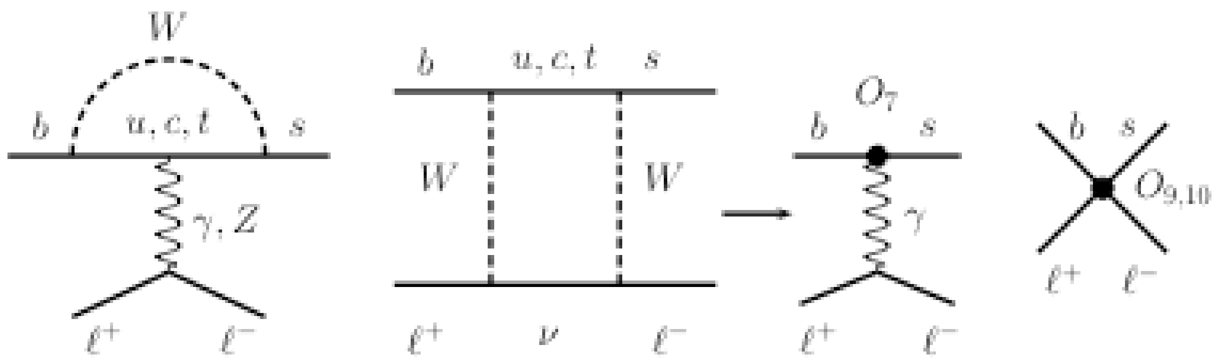
$c \to u$: $D^0 - \bar{D}^0$, ΔA_{CP}

$b \to d$: $B^0 - \bar{B}^0$, $B \to \rho\gamma$, $b \to d\gamma$, $B \to \pi\mu\mu$

$b \to s$: $B_s - \bar{B}_s$, $b \to s\gamma$, $B \to K_s\pi^0\gamma$, $b \to sll$, $B \to K^{(*)}ll$ (precision, angular analysis,R_K), $B_s \to \mu\mu$

$t \to c, u$, $l \to l'$: not observed

in red: mentioned lated



Construct EFT $\mathcal{H}_{\text{eff}} = -4\frac{G_F}{\sqrt{2}} V_{tb}V_{ts}^* \sum_i C_i(\mu)O_i(\mu)$ at dim 6

V,A operators $\mathcal{O}_9 = [\bar{s}\gamma_\mu P_L b]\,[\bar{\ell}\gamma^\mu \ell]\,, \quad \mathcal{O}_9' = [\bar{s}\gamma_\mu P_R b]\,[\bar{\ell}\gamma^\mu \ell]$

$\mathcal{O}_{10} = [\bar{s}\gamma_\mu P_L b]\,[\bar{\ell}\gamma^\mu \gamma_5 \ell]\,, \quad \mathcal{O}_{10}' = [\bar{s}\gamma_\mu P_R b]\,[\bar{\ell}\gamma^\mu \gamma_5 \ell]$

S, P operators $\mathcal{O}_S = [\bar{s}P_R b]\,[\bar{\ell}\ell]\,, \quad \mathcal{O}_S' = [\bar{s}P_L b]\,[\bar{\ell}\ell]\,,$ ONLY O_9, O_{10} in SM, all other BSM

$\mathcal{O}_P = [\bar{s}P_R b]\,[\bar{\ell}\gamma_5 \ell]\,, \quad \mathcal{O}_P' = [\bar{s}P_L b]\,[\bar{\ell}\gamma_5 \ell]$

and tensors $\mathcal{O}_T = [\bar{s}\sigma_{\mu\nu} b]\,[\bar{\ell}\sigma^{\mu\nu}\ell]\,, \quad \mathcal{O}_{T5} = [\bar{s}\sigma_{\mu\nu} b]\,[\bar{\ell}\sigma^{\mu\nu}\gamma_5 \ell]$

lepton specific $C_i O_i \to C_i^\ell O_i^\ell$, $\ell = e, \mu, \tau$

Probing Lepton e vs μ universality with R_K

Lepton-universal effects – including hadronic ones – drop out in ratios of branching fractions GH,Krüger'03

$$R_K = \frac{\mathcal{B}(\bar{B} \to \bar{K}\mu\mu)}{\mathcal{B}(\bar{B} \to \bar{K}ee)}$$

$$R_K^{LHCb} = 0.745 \pm^{0.090}_{0.074} \pm 0.036\,,$$ 1406.6482 hep-ex

2.6σ: if taken at face value this implies lepton-nonuniversal new physics in flavor sector. : $B \to K\mu\mu$: ~ 1226 events, $B \to Kee$: ~ 172 events

$R_K^{SM} = 1$ up to kinematic corrections $\mathcal{O}(m_\mu^2/m_b^2)$ and electromagnetic logs (depending on exp. cuts) $\mathcal{O}(\frac{\alpha_e}{4\pi} Log(m_e/m_b))$ permille level.

R_K -interpretations

$R_K = 0.745 \pm^{0.090}_{0.074} \pm 0.036$ implies suppressed muons or enhanced electrons.

model-independent interpretations with V,A interactions: arXiv:1408.1627, 1406.6681

$$0.7 \lesssim \mathrm{Re}[X^e - X^\mu] \lesssim 1.5\,,$$
$$X^\ell = C_9^{\mathrm{NP}\ell} + C_9'^\ell - (C_{10}^{\mathrm{NP}\ell} + C_{10}'^\ell)\,, \quad \ell = e, \mu\,.$$

BSM in electrons, or muons, or both. This is almost an order 1 effects, $C_9^{SM} \simeq -C_{10}^{SM} \simeq 4.2$ and identical for e and μ.

Ongoing precision fits in $B \to K^{(*)}\ell\ell$ decays dominated from hadron colliders hence essentially μ-constraints.

Assume new physics above the weak scale to be $SU(2)_L$-invariant; suggests to rewrite

$$\mathcal{O}^\ell_{LL} \equiv (\mathcal{O}^\ell_9 - \mathcal{O}^\ell_{10})/2\,, \quad \mathcal{O}^\ell_{LR} \equiv (\mathcal{O}^\ell_9 + \mathcal{O}^\ell_{10})/2\,, \tag{1}$$

$$\mathcal{O}^\ell_{RL} \equiv (\mathcal{O}'^\ell_9 - \mathcal{O}'^\ell_{10})/2\,, \quad \mathcal{O}^\ell_{RR} \equiv (\mathcal{O}'^\ell_9 + \mathcal{O}'^\ell_{10})/2\,, \tag{2}$$

$$C^\ell_{LL} = C^\ell_9 - C^\ell_{10}\,, \quad C^\ell_{LR} = C^\ell_9 + C^\ell_{10}\,, \tag{3}$$

$$C^\ell_{RL} = C'^\ell_9 - C'^\ell_{10}\,, \quad C^\ell_{RR} = C'^\ell_9 + C'^\ell_{10}\,. \tag{4}$$

If we assume new physics in muons alone

$$0.0 \lesssim \mathrm{Re}[C^\mu_{LR} + C^\mu_{RL} - C^\mu_{LL} - C^\mu_{RR}] \lesssim 1.9\,, \quad (BR(B_s \to \mu\mu))$$

$$0.7 \lesssim -\mathrm{Re}[C^\mu_{LL} + C^\mu_{RL}] \lesssim 1.5\,. \quad (R_K)$$

$$\mathcal{B}(\bar{B}_s \to ee)^{\rm exp} < 2.8 \cdot 10^{-7} \,, \tag{5}$$

$$\mathcal{B}(\bar{B}_s \to \mu\mu)^{\rm exp} = (2.9 \pm 0.7) \cdot 10^{-9} \,, \tag{6}$$

$$\mathcal{B}(\bar{B}_s \to ee)^{\rm SM} = (8.54 \pm 0.55) \cdot 10^{-14} \,, \tag{7}$$

$$\mathcal{B}(\bar{B}_s \to \mu\mu)^{\rm SM} = (3.65 \pm 0.23) \cdot 10^{-9} \tag{8}$$

resulting in

$$\frac{\mathcal{B}(\bar{B}_s \to ee)^{\rm exp}}{\mathcal{B}(\bar{B}_s \to ee)^{\rm SM}} < 3.3 \cdot 10^{6} \,, \tag{9}$$

$$\frac{\mathcal{B}(\bar{B}_s \to \mu\mu)^{\rm exp}}{\mathcal{B}(\bar{B}_s \to \mu\mu)^{\rm SM}} = 0.79 \pm 0.20 \,. \tag{10}$$

$\mathcal{B}(\bar{B}_s \to \mu\mu)$ currently suppressed w.r.t SM. This isolates $C^{\mu}_{LL} \simeq -1$ as a single operator (particle) interpretation of R_K. Note: this is V-A current. iff $\mathcal{B}(\bar{B}_s \to \mu\mu)$ would be enhanced this would isolate $C^{\mu}_{RL} \simeq -1$, RH currents!.

Other model-independent explanations (all other excluded):

i) V,A muons

ii) V,A electrons

iii) S,P electrons (disfavored at 1 σ and requires cancellations, testable with $\bar{B} \to \bar{K}ee$ angular distributions)

i and *ii* can be realized in leptoquark models. We find parameters of the (scalar) leptoquarks as

$$1\,\text{TeV} \lesssim M \lesssim 48\,\text{TeV}$$
$$2 \cdot 10^{-3} \lesssim |\lambda_{se}\lambda^*_{be}| \lesssim 4$$
$$4 \cdot 10^{-4} \lesssim |\lambda_{qe}| \lesssim 5$$

A LL muon leptoquark model

$$\mathcal{L} = -\lambda_{b\mu}\,\varphi^*\,q_3\ell_2 - \lambda_{s\mu}\,\varphi^*\,q_2\ell_2, \qquad \varphi(3,3)_{-1/3}$$

$$\mathcal{H}_{\text{eff}} = -\frac{\lambda^*_{s\mu}\lambda_{b\mu}}{M^2}\left(\tfrac{1}{4}[\bar{q_2}\tau^a\gamma^\mu P_L q_3]\,[\bar{\ell}_2\tau^a\gamma_\mu P_L\ell_2] + \tfrac{3}{4}[\bar{q_2}\gamma^\mu P_L q_3]\,[\bar{\ell}_2\gamma_\mu P_L\ell_2]\right)$$

gives $C_9^{\mathrm{NP}\mu} = -C_{10}^{\mathrm{NP}\mu} = \frac{\pi}{\alpha_e}\frac{\lambda^*_{s\mu}\lambda_{b\mu}}{V_{tb}V^*_{ts}}\frac{\sqrt{2}}{2M^2G_F} \simeq -0.5$

$SU(2)$ implies corresponding effects in $b \to s\nu\nu$ (only muon-neutrinos affected, signal diluted over 3 species).
$Br(B \to K^{(*)}\nu\nu$ enhanced by 3 %; Further correlation with B_s mixing, $b \to s\gamma$, and direct searches.
Decay modes of φ-triplet:

$$\begin{aligned} \varphi^{2/3} &\to t\,\nu \\ \varphi^{-1/3} &\to b\,\nu\,,\; t\,\mu^- \\ \varphi^{-4/3} &\to b\,\mu^- \end{aligned}$$

- If LHCb's measurement of R_K substantiates it implies that there is more difference between a muon and an electron than their mass. Lepton-universality, a feature of the $SU(3)_C \times SU(2)_L \times U(1)_Y$ SM appears to be violated in $b \to s$ FCNC transitions.

- Current data allow for model-independent explanations, as well as model frameworks such as leptoquarks.

- Explanations imply correlations with other FCNC processes as well as predictions for direct searches, that can be tested in the future.

STAY TUNED