Reappraisal of minimally flavoured Z´ scenario

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Anomalies 2021
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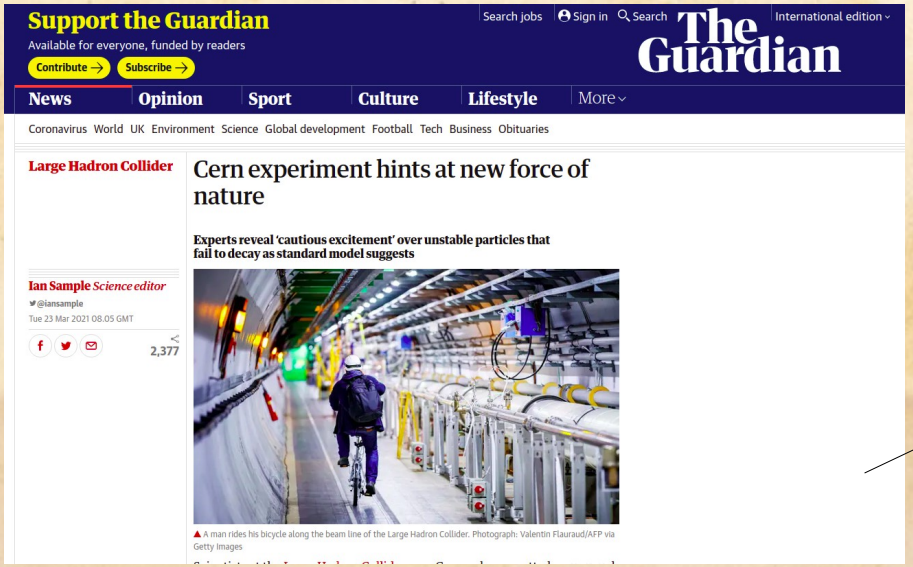
2021 is really promising for *New* Physics



(22/03/2021)

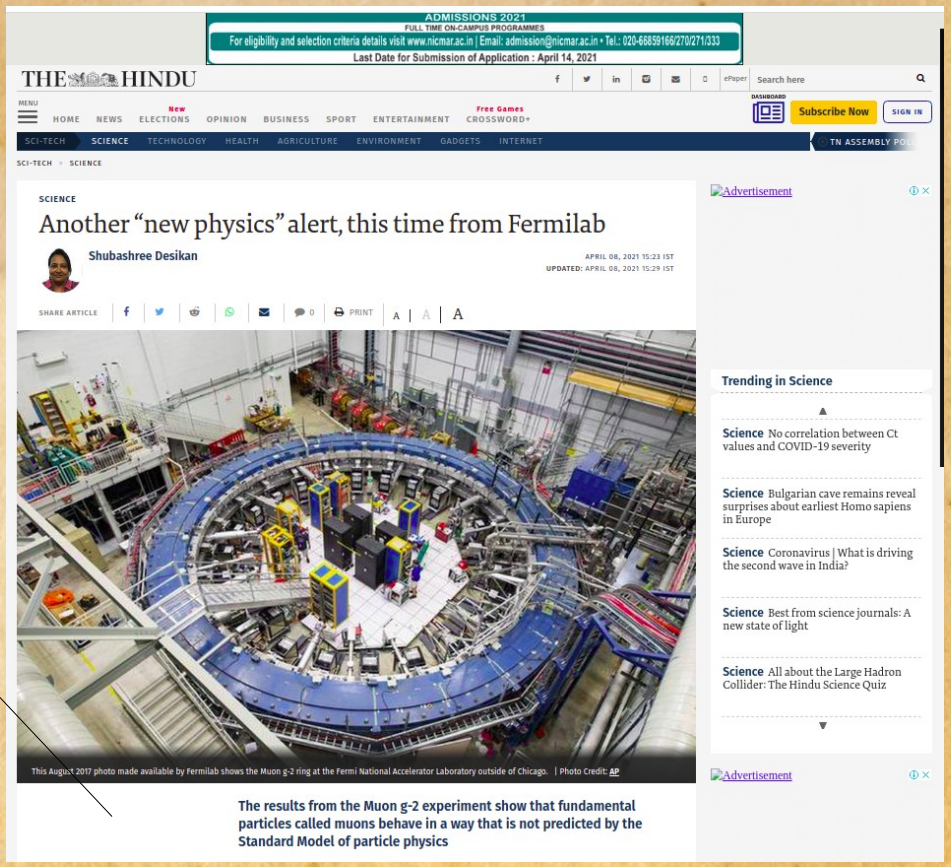
LHCb detector at CERN's **Large Hadron Collider** presents evidence for the breaking of **lepton universality in B-meson decays**, with a significance of 3.1 standard deviations

arXiv : 2103.11769

(07/04/2021)

The first result from the **Muon g-2** experiment at **Fermilab** confirms the result from the experiment performed at Brookhaven National Lab two decades ago. The result shows 4.2 standard deviations from the SM prediction

Phys. Rev. Lett. **126** (2021) 141801



Some Other Observables

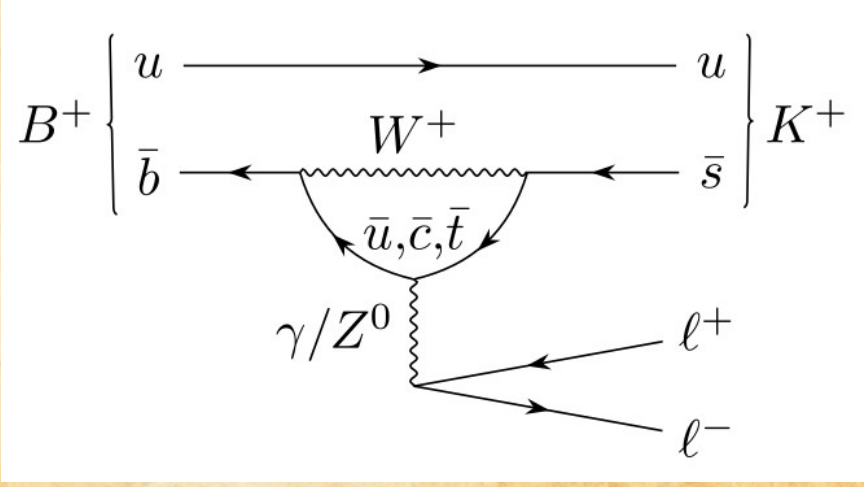
- In this category, there exist some other experimental data e.g., $(g-2)_e$, R_{K^*}, etc. which also provide different opportunities to study BSM physics
- The data of angular observables (e.g., P_2, P'_5) of the decay mode $B^+ \longrightarrow K^{+*}\mu^+\mu^-$ (Phys.Rev.Lett. **126** (2021) 16) show discrepancy from the SM prediction
- Overall these experimental results strongly indicate the presence of ***New Physics***

$b \to s\ \ell^+\ell^-$ flavour physics observables: R_K is one of them

$$R_K = \frac{\mathrm{Br}\,(B^+ \to K^+\mu^+\mu^-)}{\mathrm{Br}\,(B^+ \to K^+e^+e^-)}$$

In SM it's value should be ≈ Unity.
Recent experimental data is $0.864^{+0.044}_{-0.041}$.
This shows the violation of lepton flavour universality

- At the quark level the decays are governed by $b \to s\ \ell^+\ell^-$ transitions
- In SM it does not arise at tree level but occur at one loop level and hence they are highly suppressed and a good probe for new physics
- For R_K: in general required Wilson Coefficients (WCs) are C_9, C_{10} etc



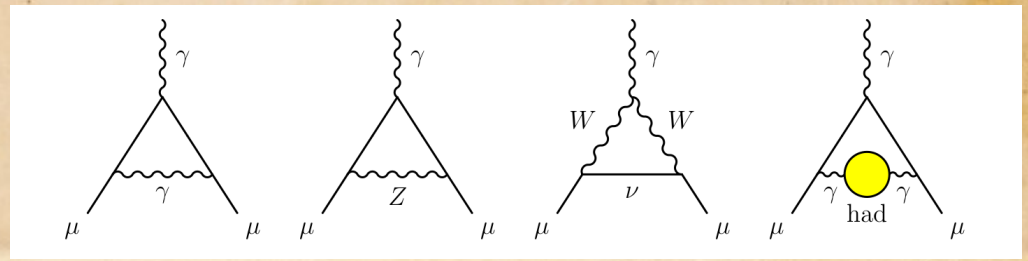
Anomalous magnetic moment of muon

The Dirac equation predicts a muon magnetic moment

$$\vec{M} = g_\mu \frac{e}{2m_\mu}\vec{S}$$

Quantum loop effects lead to a small calculable deviation from gyromagnetic ratio g_μ (= 2), parameterized by the ***anomalous magnetic moment***

$$a_\mu \equiv \frac{g_\mu - 2}{2}$$



SM prediction = $(116591810 \pm 43)\times 10^{-11}$, over the 20 Years it deviates from experimental data by 3.5σ

Recent data (world average) of muon g-2 is = $(116592061 \pm 41)\times 10^{-11}$. It deviates by 4.2σ from SM prediction and the deviation is

$$\Delta a_\mu = (251 \pm 59)\times 10^{-11}$$

Effective Z' scenario approach

- We have proposed some effective field theoretical frameworks containing a neutral Z' boson which has flavour violating couplings with ordinary leptons and quarks

- Type-I: Electron and muon have only the vectorial interaction with the Z' boson

$$\mathcal{L} \in \bar{l}\gamma^{\alpha}(a^{l}_{Z'})l \; Z'_{\alpha}$$

- Type-II: Electron and muon have both the vectorial and axial vectorial interaction (but different in strengths) with the Z' boson

$$\mathcal{L} \in \bar{l}\gamma^{\alpha}(a^{l}_{Z'} + \gamma^{5}b^{l}_{Z'})l \; Z'_{\alpha}$$

- Type-III: Electron has axial vectorial (with strength $b^{e}_{Z'}$) and muon has vectorial interaction (with strength $a^{\mu}_{Z'}$) with Z' boson. Moreover, in order to resolve the $b \to s \; \ell^{+}\ell^{-}$ anomalies we have introduced a tree level interaction b-s-Z' with coupling strength g_{bs}

$$\mathcal{L} \in \left[g_{bs}(\bar{b}\gamma^{\alpha}P_{L}s) + \bar{\mu}\gamma^{\alpha}a^{\mu}_{Z'}\mu + \bar{e}\gamma^{\alpha}\gamma^{5}b^{e}_{Z'}e\right] Z'_{\alpha}$$

New Physics Contributions

NP contribution to $(g-2)_l$ is

$$\Delta a_l^{Z'} = \frac{1}{8\pi^2}\left((a^l_{Z'})^2 F_{a^l_{Z'}}(R_{Z'}) - (b^l_{Z'})^2 F_{b^l_{Z'}}(R_{Z'}) \right)$$

with $R_{Z'} \equiv M^2_{Z'}/m^2_l$

and

$$F_{a^l_{Z'}}(R_{Z'}) = \int_0^1 dx \, \frac{2x(1-x)^2}{(1-x)^2 + R_{Z'}x}$$

$$F_{b^l_{Z'}}(R_{Z'}) = \int_0^1 dx \, \frac{2x(1-x)(3+x)}{(1-x)^2 + R_{Z'}x}$$

New Physics Contributions

Effective Hamiltonian for $b \to s l^+ l^-$ transition

$$\mathcal{H}_{\rm eff}(b \to s l^+ l^-) = -\frac{G_F}{\sqrt{2}} V_{ts}^* V_{tb} \left[C_{9V}(\mathcal{M})(\bar{s}\gamma^\alpha P_L b)(\bar{l}\gamma_\alpha l) + C_{10A}(\mathcal{M})(\bar{s}\gamma^\alpha P_L b)(\bar{l}\gamma_\alpha \gamma_5 l) \right]$$

For $b \to s\, \mu^+ \mu^-$ transition, the NP contribution to the WC C_9 is

$$C_9^{\rm NP} = \frac{\sqrt{2}\pi}{G_F \alpha V_{ts}^* V_{tb}} \frac{g_{bs} a_{Z'}^{\mu}}{M_{Z'}^2}$$

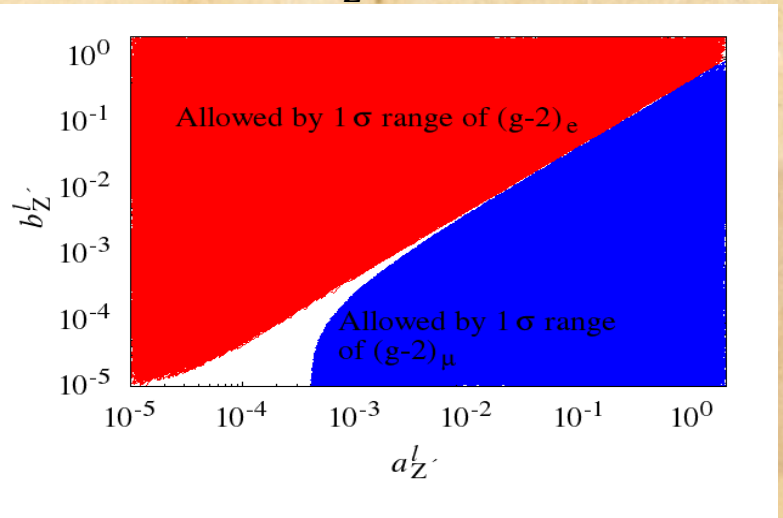
For $b \to s\, e^+ e^-$ transition, the NP contribution to the WC C_{10} is

$$C_{10}^{\rm NP} = \frac{\sqrt{2}\pi}{G_F \alpha V_{ts}^* V_{tb}} \frac{g_{bs} b_{Z'}^{e}}{M_{Z'}^2}$$

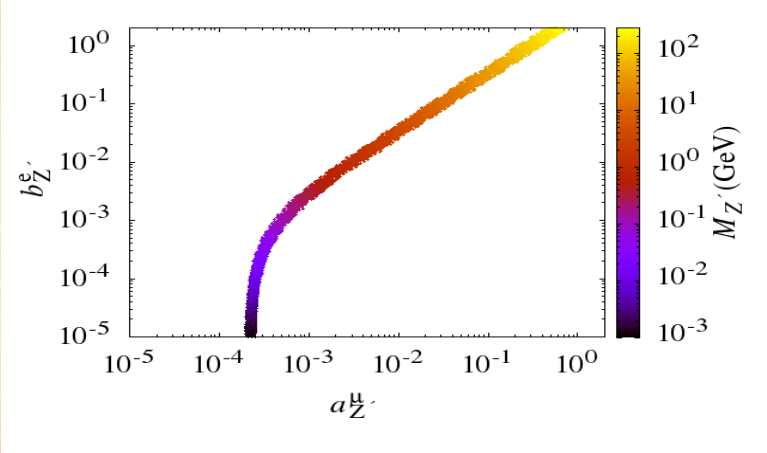
With these WCs and appropriate form factors we evaluate the respective decay widths, and consequently we calculate NP contribution to several observables

Models and Results

- Type-I: Can't satisfy $(g-2)_\mu$ and $(g-2)_e$ with negative value of Δa_e simultaneously
- Type-II: Can't satisfy $(g-2)_\mu$ and $(g-2)_e$ with negative value of Δa_e simultaneously with same values of $a^\mu_{Z'}$ and $b^e_{Z'}$



- Type-III: Can satisfy $(g-2)_\mu$ and $(g-2)_e$ with negative value of Δa_e simultaneously

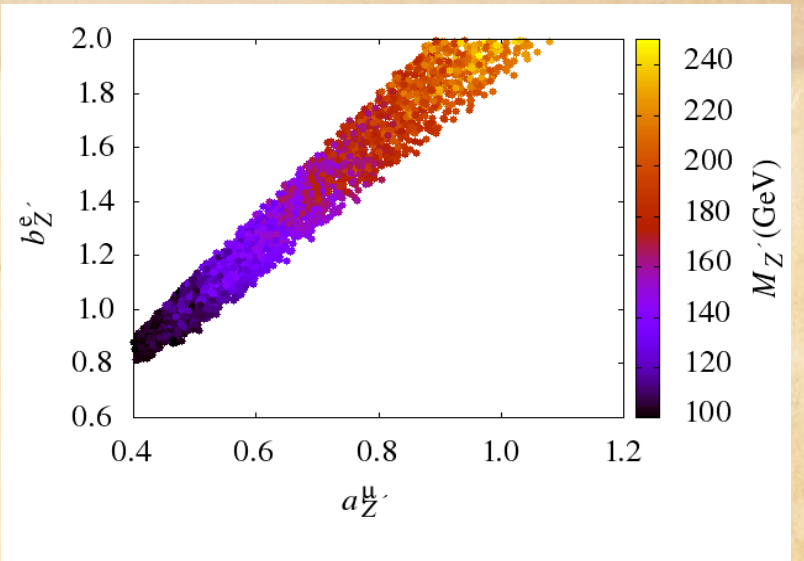


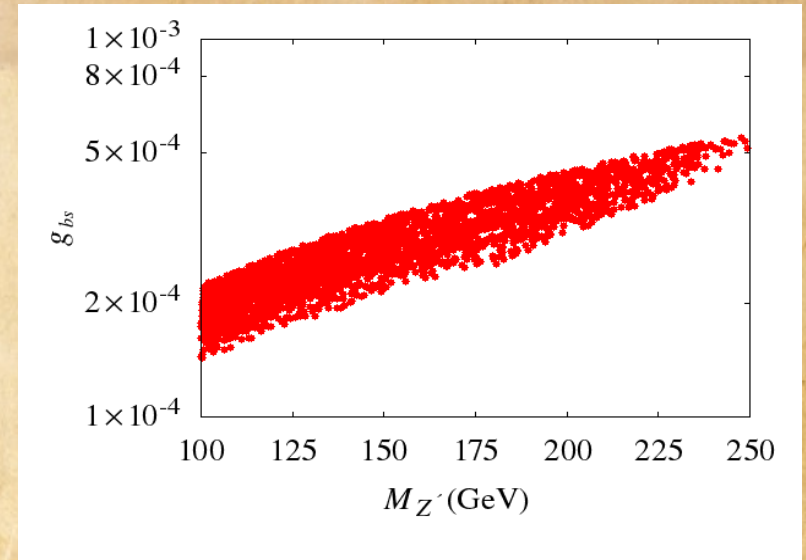
$b \to s\, \ell^+\ell^-$ anomalies in Type-III scenario

In Type-III scenario we can easily explain $R_{K^{(*)}}$ including angular observables (P_2 and P'_5) of the decay mode $B^+ \to K^{+*}\mu^+\mu^-$ simultaneously

Due to the presence of tree level coupling b-s-Z' we consider the constraint from $B_s^0 - \bar{B}_s^0$ oscillation data

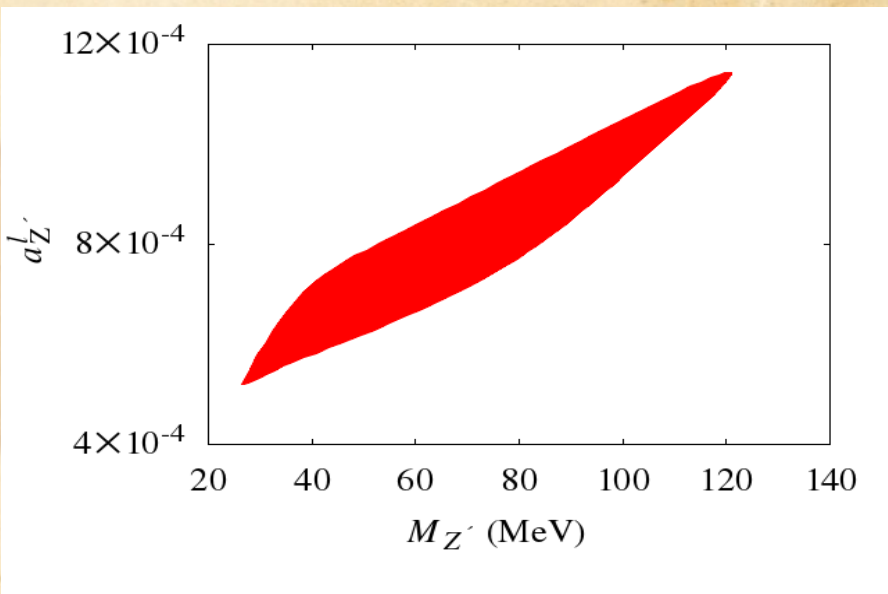
Considering all these experimental data we have the allowed parameter space in the following

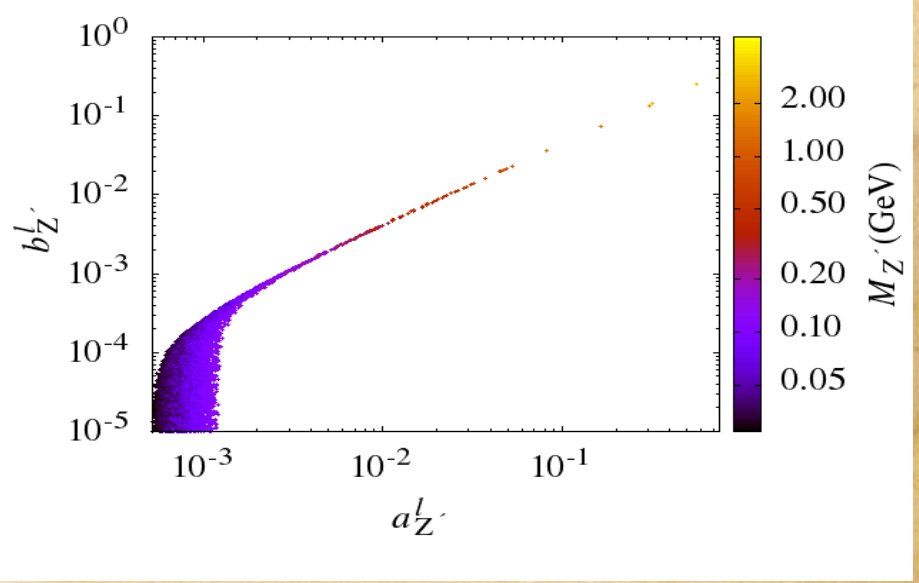




$(g\text{-}2)_e$ with positive value of Δa_e

- The most economic scenario namely Type-III will not work in this case
- Other two scenarios, Type-I and Type-II can explain the $(g-2)_e$ with positive value of Δa_e and $(g-2)_\mu$ simultaneously





- In this case, the allowed values of masses of Z' are restricted within a very small value ($M^2_{Z'} << q^2$)
- We can not obtain the required WCs that are mandatory for the $b \to s\ \ell^+\ell^-$ anomalies

Summary

- We consider minimally flavoured effective field theoretical approach with minimum independent parameters
- Z' has flavour violating interaction with ordinary quarks and leptons
- After imposing all possible constraints, a particular scenario (namely Type-III) can explain $(g-2)_\mu$, $(g-2)_e$ with negative value of Δa_e, $R_{K^{(*)}}$, and angular observables (P_2 and P'_5) of the decay mode $B^+ \to K^{+*} \mu^+ \mu^-$ within a restricted region of parameter space

Thank You