

Probing New Physics Effects in $b \rightarrow s l l'$ transitions

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Plan of the talk

- Introduction
- Some relevant results
- $b \rightarrow s l l'$ processes
- New Physics prospects
- Outlook

Motivation for New Physics

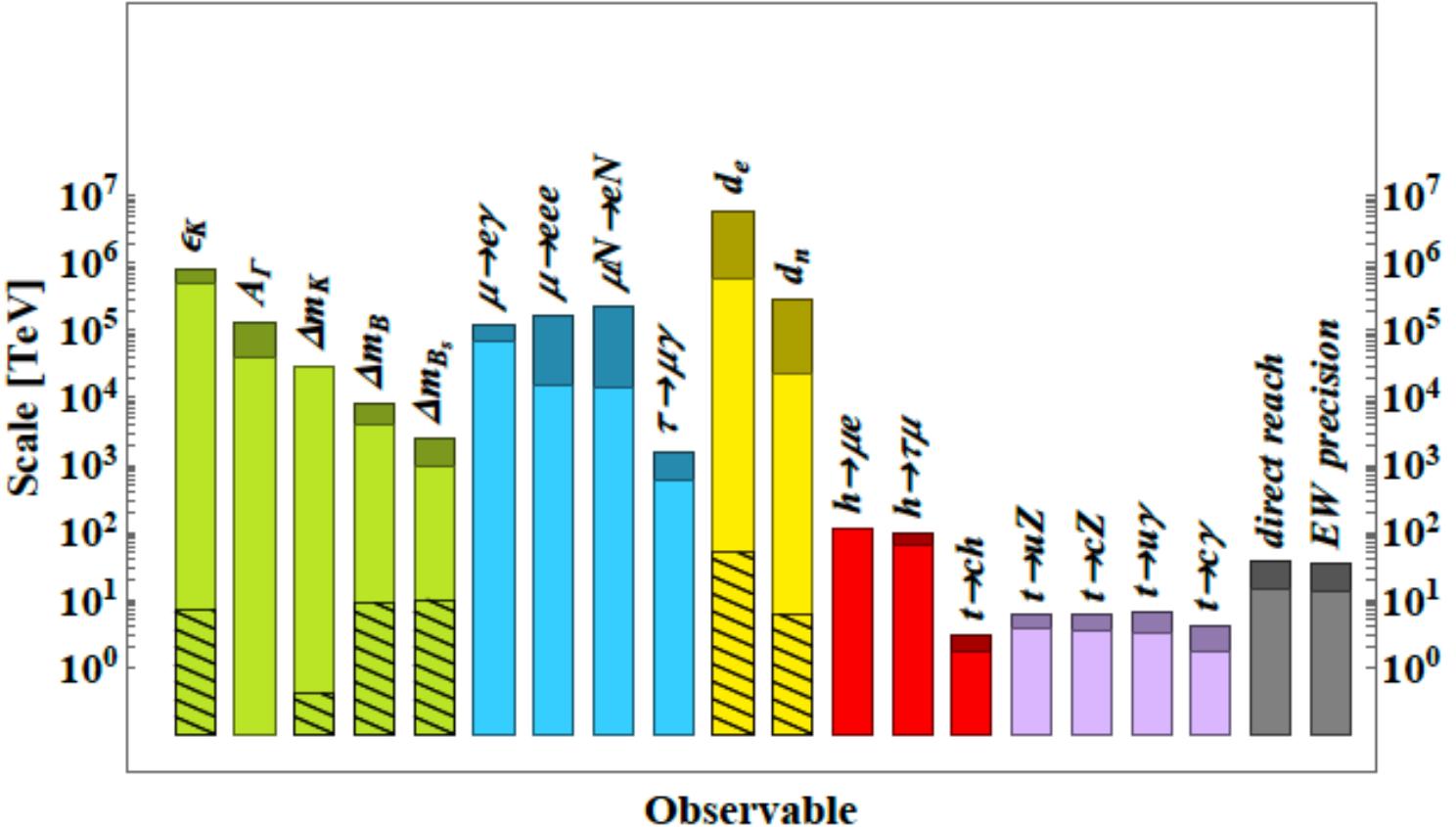
- Standard Model is exceptionally Successful
- 5 decades of matching results and growing!
- Observation of Neutrino Oscillation
- Baryon Asymmetry of the Universe
- Dark Matter and Dark Energy
- -> There should be something beyond SM
- Flavor Physics: indirect probe of NP beyond direct collider reach

Motivation

- R_D and R_{D^*} tension
- P_5' in $B \rightarrow K^* \mu^+ \mu^-$ is another avenue
- BR in $B_s \rightarrow \varphi \mu^+ \mu^-$ has deviation from SM
- 1-2 sigma deviations seen in few observables
- Two popular models (Z' and LQ)
- We consider $b \rightarrow s l l'$ with Z' model

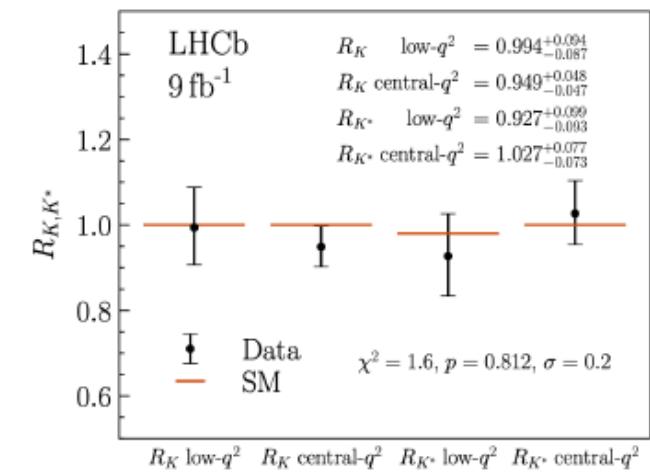
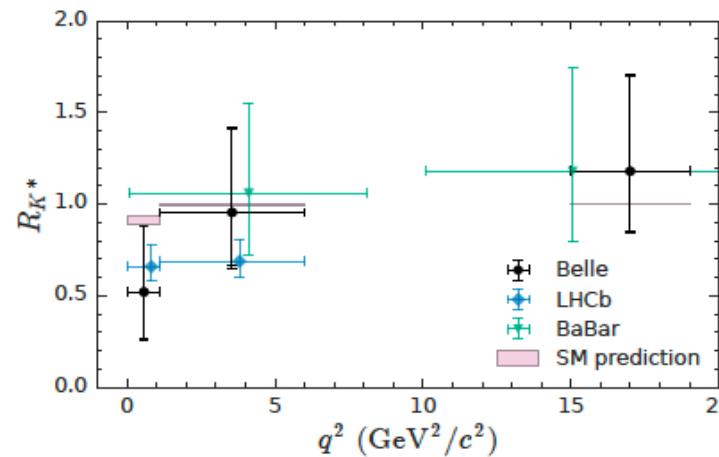
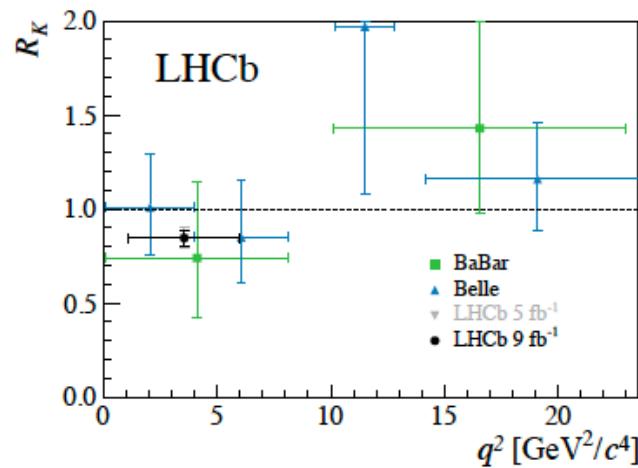
[See talks: Ben Allanach LP-2023
: Matteo Rama LP 2023]

Indirect high scale physics signature



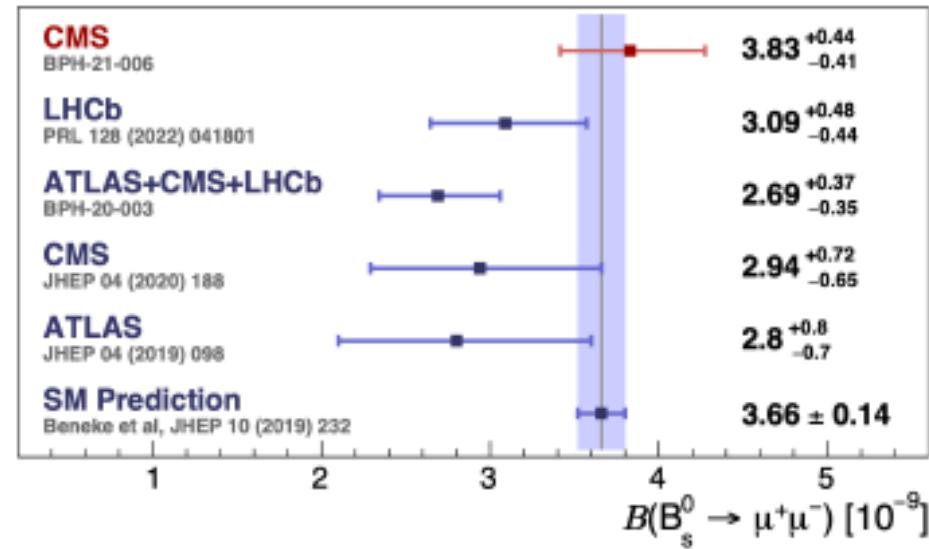
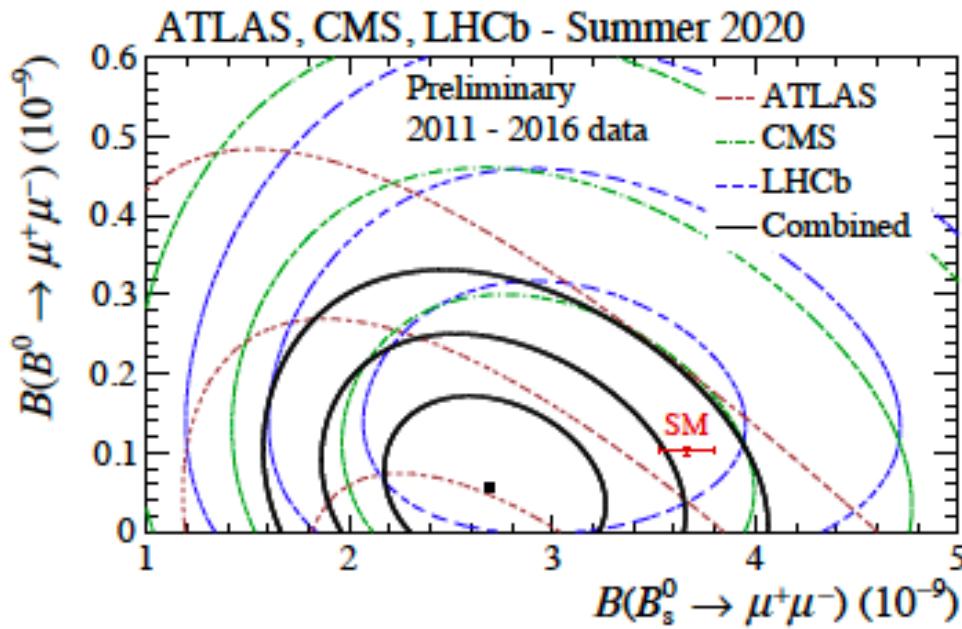
$R_K, R_{K^*} \dots$

- Some B measurements deviate by $1-2\sigma$ from SM predictions
- Branching ratios of $B \rightarrow K\mu^+\mu^-$, $B \rightarrow K^*\mu^+\mu^-$, and $B_s \rightarrow \phi\mu^+\mu^-$
- Angular observables in $B \rightarrow K^*\mu^+\mu^-$



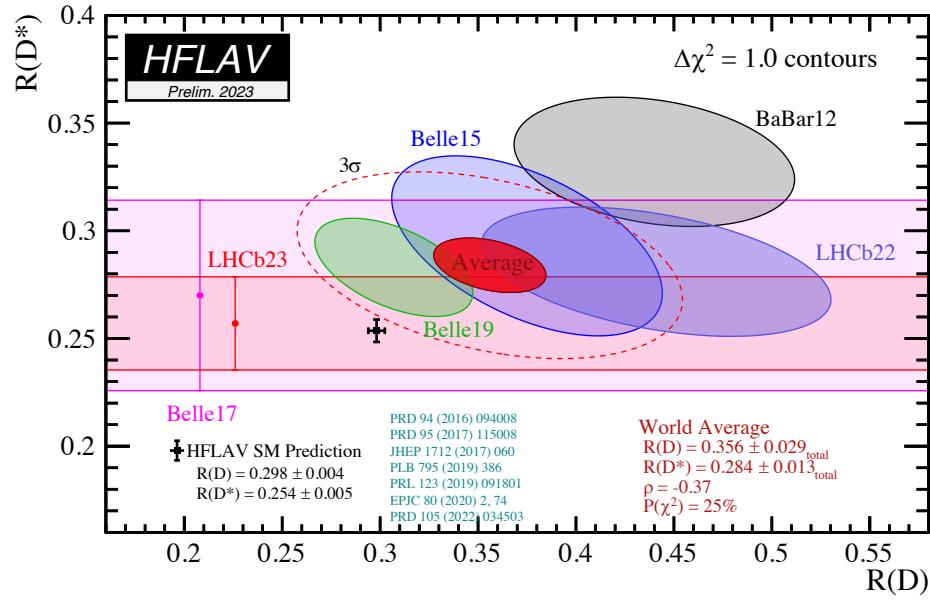
Still 10-15 % NP allowed [Ben Allanach]

The case of $B_{s(d)} \rightarrow \mu^+ \mu^-$



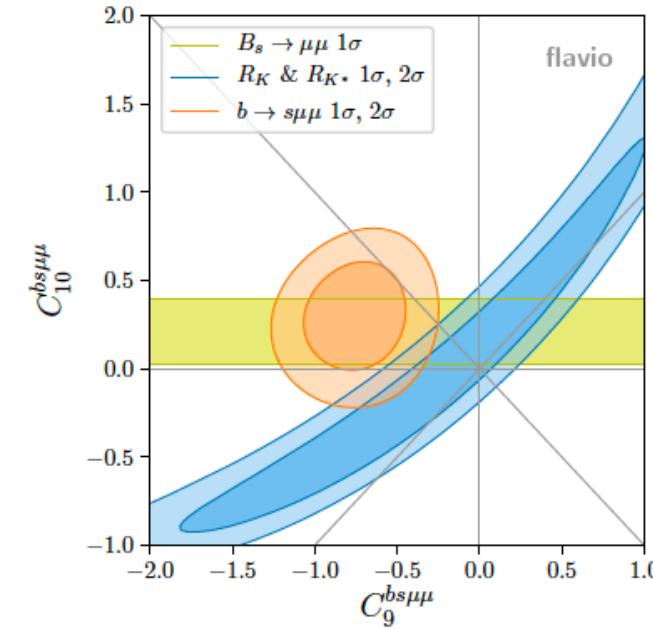
Still 5-10 % NP possible (Ben Allanach's talk)

$R_D - R_{D^*}$



Although current average is about 3 sigma away from SM

Rare $b \rightarrow s\ell\ell$ WET fit



A Greljo et al.: arxiv: 2212.10497

$$\tau \rightarrow \mu\mu\mu \quad < 3.2 \times 10^{-8}$$

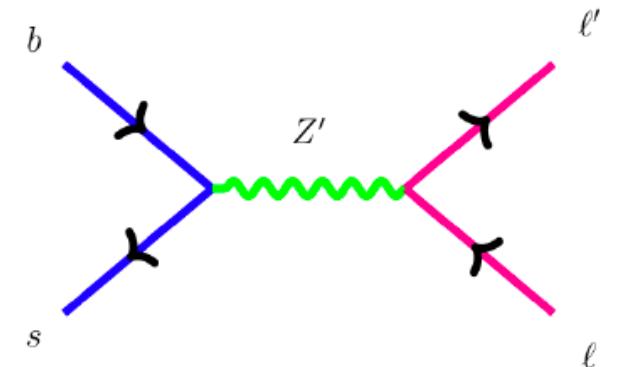
$$\tau \rightarrow eee \quad < 3.6 \times 10^{-8}$$

$$\mu^+ \rightarrow e^+e^+e^- \quad < 1.0 \times 10^{-12}$$

We have considered, Z' -b-s coupling to be real

Z' to ll coupling SM like

LFV leptonic decays are sources of new physics [
talk by Y Kuno LP 2023]



Observables

Forward-backward asymmetry

$$A_{\text{FB}}(q^2) = \frac{1}{d\Gamma/dq^2} \left(\int_0^1 d \cos \theta_\ell \frac{d\Gamma}{d \cos \theta_\ell dq^2} - \int_{-1}^0 d \cos \theta_\ell \frac{d\Gamma}{d \cos \theta_\ell dq^2} \right)$$

Longitudinal polarization

$$\langle \mathcal{F}_L \rangle = \frac{\int_{q_{low}^2}^{q_{high}^2} dq^2 \frac{d\Gamma_L}{dq^2}}{\int_{q_{low}^2}^{q_{high}^2} dq^2 \frac{d\Gamma}{dq^2}}$$

Ratio of BR

$$R_{K\ell}^{\ell\ell'} = \frac{\mathcal{B}(\bar{B} \rightarrow \bar{K}\ell\ell')}{\mathcal{B}(\bar{B} \rightarrow \bar{K}\ell\ell)},$$

$$R_{V\ell}^{\ell\ell'} = \frac{\mathcal{B}(\bar{B} \rightarrow \bar{V}\ell\ell')}{\mathcal{B}(\bar{B} \rightarrow \bar{V}\ell\ell)}, (V = K^*, \phi),$$

$$R_{Kl}^{\ell\ell'} = \frac{\mathcal{B}(\bar{B} \rightarrow \bar{T}\ell\ell')}{\mathcal{B}(\bar{B} \rightarrow \bar{T}\ell\ell)}, (T = K_2^*, f_2')$$

$$B \rightarrow K^* \ell \ell' \text{ and } B_s \rightarrow \phi \ell \ell'$$

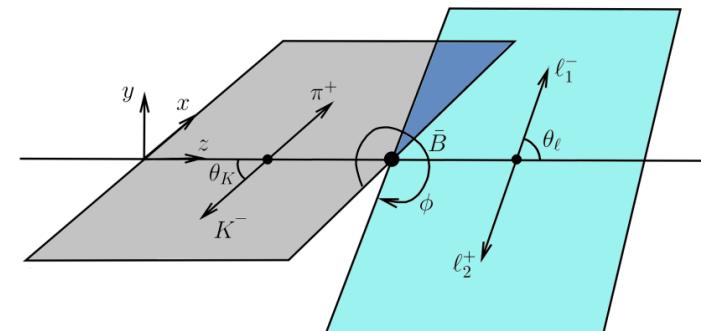
$$\begin{aligned} \langle \bar{K}^*(k) | \bar{s} \gamma^\mu (1 - \gamma_5) b | \bar{B}(p) \rangle &= \varepsilon_{\mu\nu\rho\sigma} \varepsilon^{*\nu} p^\rho k^\sigma \frac{2V(q^2)}{m_B + m_{K^*}} - i\varepsilon_\mu^*(m_B + m_{K^*}) A_1(q^2) \\ &\quad + i(p+k)_\mu (\varepsilon^* \cdot q) \frac{A_2(q^2)}{m_B + m_{K^*}} + iq_\mu (\varepsilon^* \cdot q) \frac{2m_{K^*}}{q^2} [A_3(q^2) - A_0(q^2)], \end{aligned} \quad (10)$$

$$\begin{aligned} \langle \bar{K}^*(k) | \bar{s} \sigma_{\mu\nu} q^\nu (1 - \gamma_5) b | \bar{B}(p) \rangle &= 2i\varepsilon_{\mu\nu\rho\sigma} \varepsilon^{*\nu} p^\rho k^\sigma T_1(q^2) + [\varepsilon_\mu^*(m_B^2 - m_{K^*}^2) - (\varepsilon^* \cdot q)(2p - q)_\mu] T_2(q^2) \\ &\quad + (\varepsilon^* \cdot q) \left[q_\mu - \frac{q^2}{m_B^2 - m_{K^*}^2} (p+k)_\mu \right] T_3(q^2) \end{aligned}$$

$$I(q^2, \theta_\ell, \theta_K, \phi) = I_1^s(q^2) \sin^2 \theta_K + I_1^c(q^2) \cos^2 \theta_K + [I_2^s(q^2) \sin^2 \theta_K + I_2^c(q^2) \cos^2 \theta_K] \cos 2\theta_\ell$$

$$\begin{aligned} &\quad + I_3(q^2) \sin^2 \theta_K \sin^2 \theta_\ell \cos 2\phi + I_4(q^2) \sin 2\theta_K \sin 2\theta_\ell \cos \phi \\ &\quad + I_5(q^2) \sin 2\theta_K \sin \theta_\ell \cos \phi + [I_6^s(q^2) \sin^2 \theta_K + I_6^c(q^2) \cos^2 \theta_K] \cos \theta_\ell \\ &\quad + I_7(q^2) \sin 2\theta_K \sin \theta_\ell \sin \phi + I_8(q^2) \sin 2\theta_K \sin 2\theta_\ell \sin \phi \\ &\quad + I_9(q^2) \sin^2 \theta_K \sin^2 \theta_\ell \sin 2\phi. \end{aligned}$$

$$\frac{d\mathcal{B}}{dq^2} = \frac{1}{4} [3I_1^c(q^2) + 6I_1^s(q^2) - I_2^c(q^2) - 2I_2^s(q^2)]$$



$$B \rightarrow T\{K_2^*, f'_2\} \ell\ell'$$

The transition matrix elements are:

$$\langle K_2^*(k, \epsilon^*) | \bar{s} \gamma^\mu b | \bar{B}(p) \rangle = -\frac{2V(q^2)}{m_B + m_{K_2^*}} \epsilon^{\mu\nu\rho\sigma} \epsilon_{T\nu}^* p_\rho k_\sigma,$$

$$\begin{aligned} \langle K_2^*(k, \epsilon^*) | \bar{s} \gamma^\mu \gamma_5 b | \bar{B}(p) \rangle &= 2im_{K_2^*} A_0(q^2) \frac{\epsilon_T^* \cdot q}{q^2} q^\mu + i(m_B + m_{K_2^*}) A_1(q^2) \left[\epsilon_T^{*\mu} - \frac{\epsilon_T^* \cdot q}{q^2} q^\mu \right] \\ &\quad - iA_2(q^2) \frac{\epsilon_T^* \cdot q}{m_B + m_{K_2^*}} \left[(p+k)^\mu - \frac{m_B^2 - m_{K_2^*}^2}{q^2} q^\mu \right] \end{aligned}$$

$J^{PC} = 2^{++}$ tensor meson (T)

$$F^{B_{(s)}T}(q^2) = \frac{F^{B_{(s)}T}(0)}{1 - a_T(q^2/m_{B_q}^2) + b_T(q^2/m_{B_q}^2)^2} \quad F = V, A_{0,1,2} \text{ and } T_{1,2,3}$$

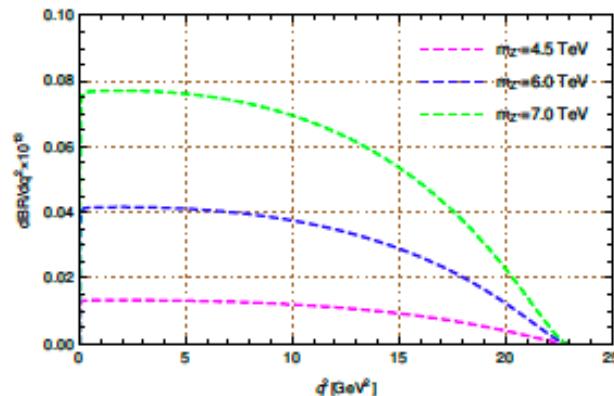
Inputs/ Scenarios

P_5' , $B \rightarrow K^*(*)\ell\bar{\ell}$, $B_s \rightarrow \varphi \mu\mu$, $B_s \rightarrow \mu\mu$

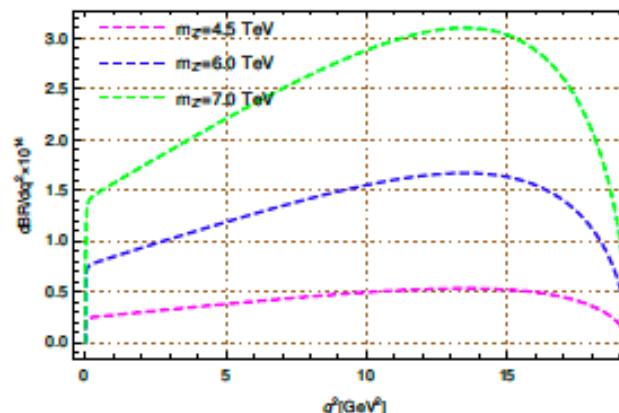
We consider two scenarios:

- S-I : $C_9^{\text{NP}} \neq 0$
- S-II : $C_9^{\text{NP}} = -C_{10}^{\text{NP}}$
- Taken $m_{Z'} = 4.5 \text{ TeV}, 6 \text{ TeV} \text{ and } 7 \text{ TeV}$ (3 values)
(Using latest bounds from ATLAS, CMS)

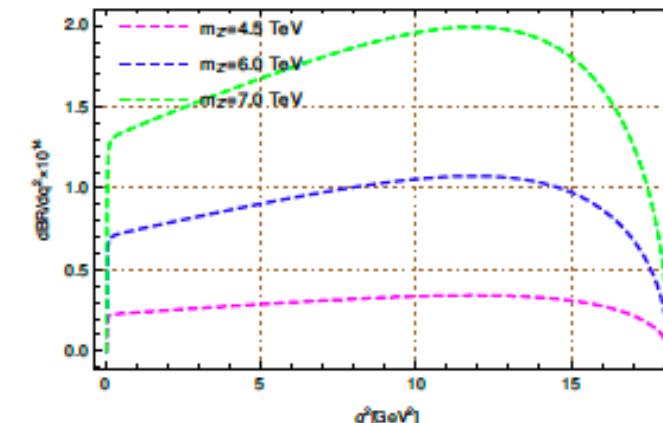
Differential BR ($B \rightarrow X \mu e$)



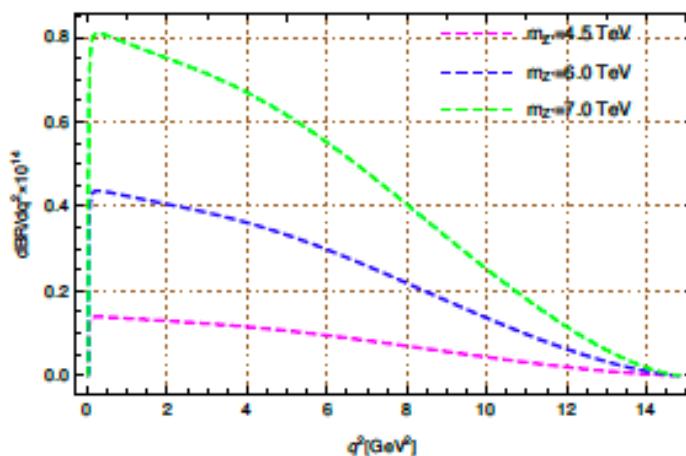
K



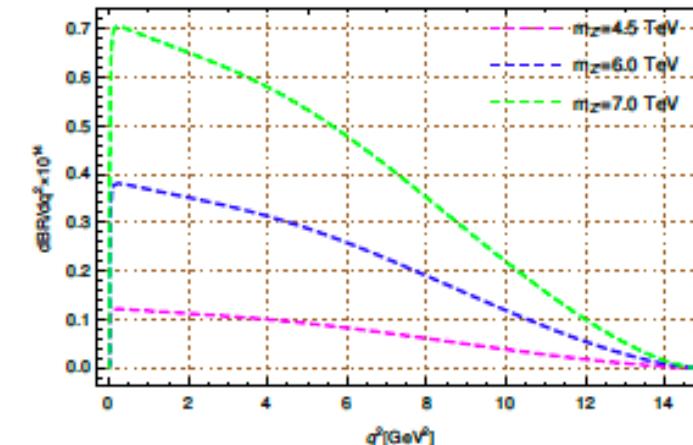
K^*



ϕ

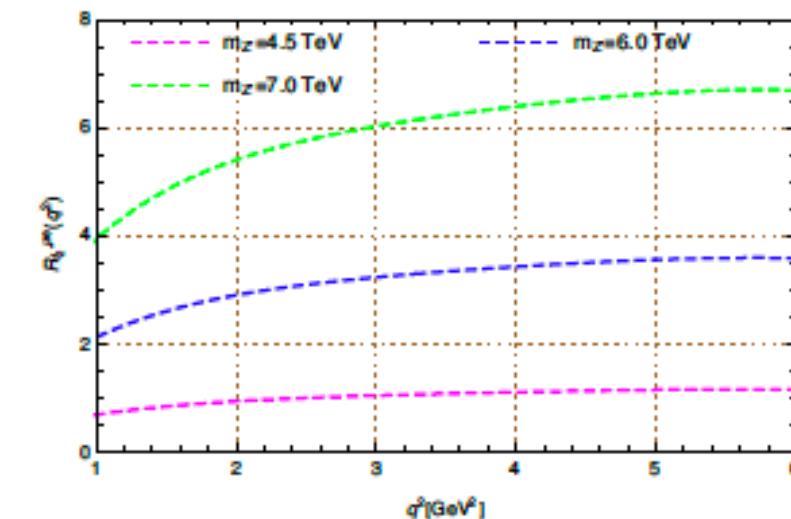
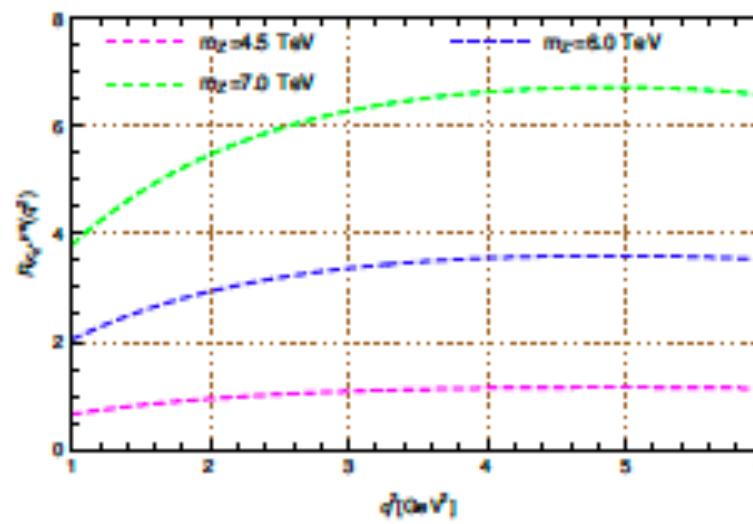
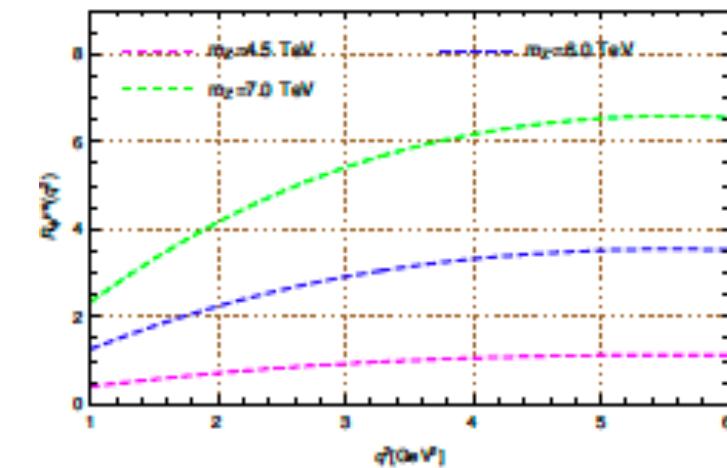
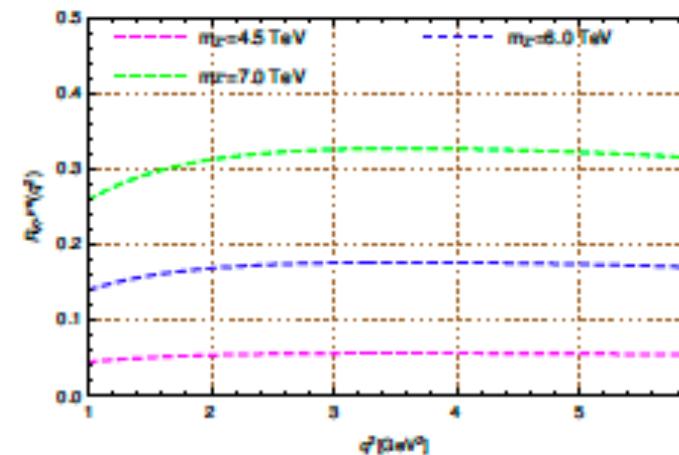
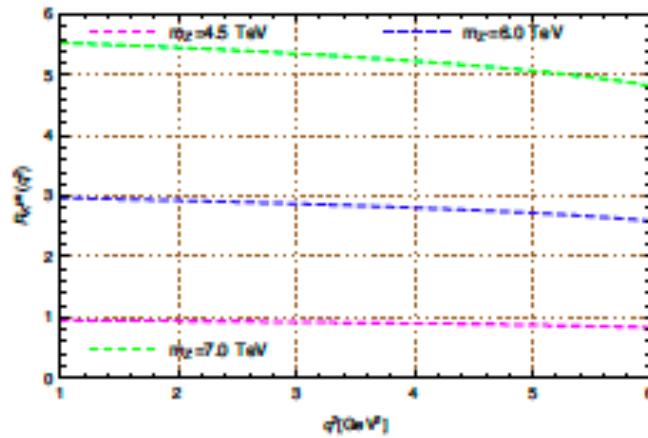


K_{2*}

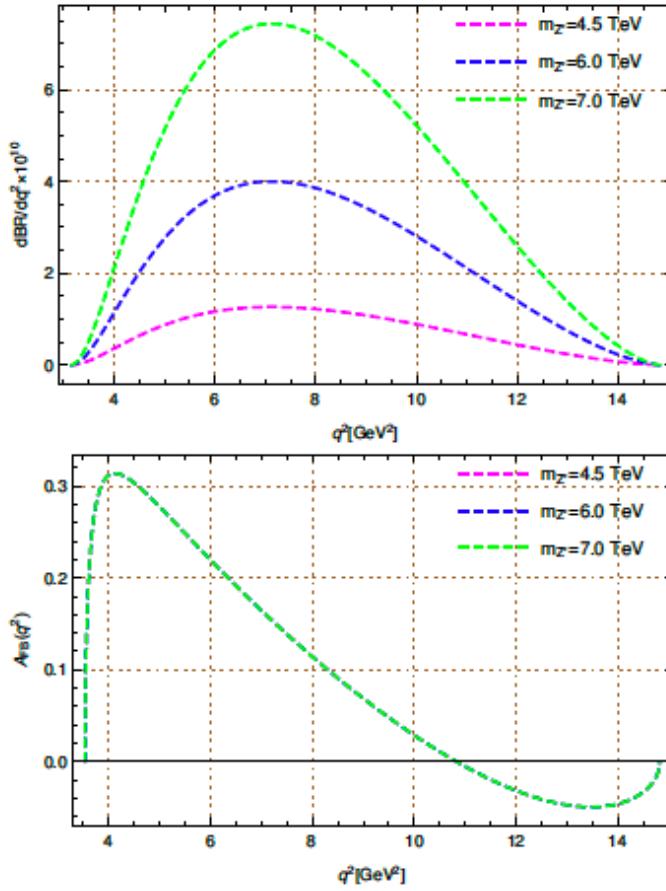


f_2'

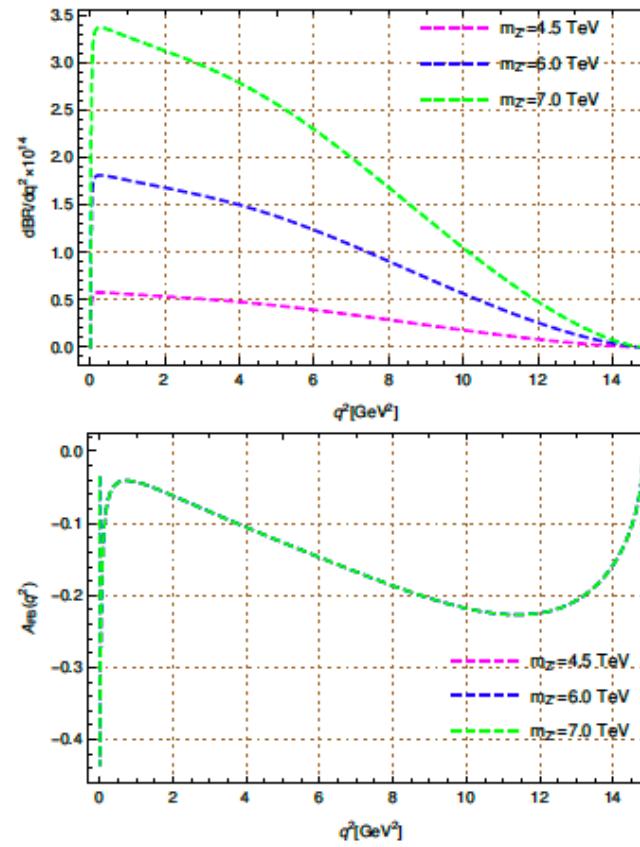
$$\mathcal{R}_{K,K^*,\phi,K_2^*,f_2'}^{\mu e}$$



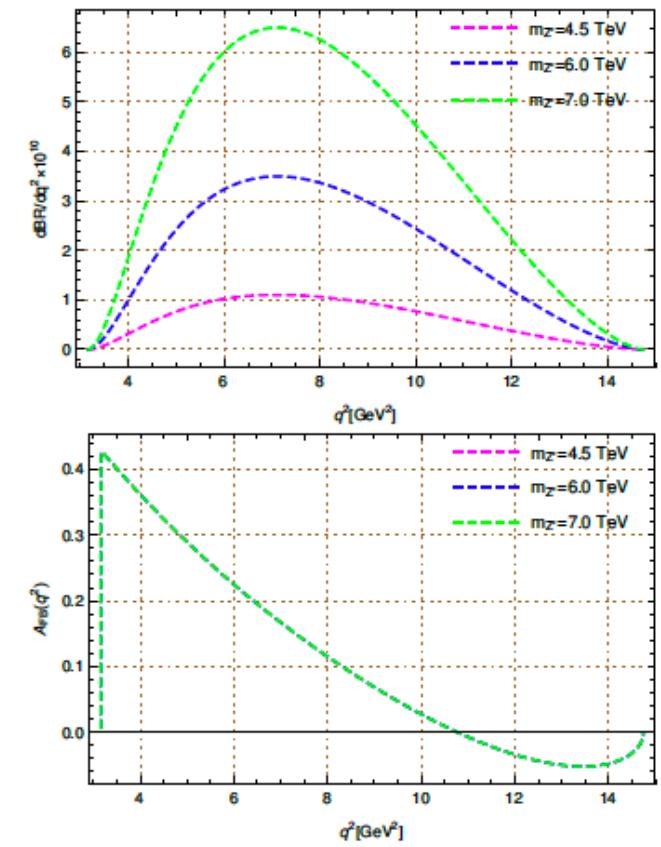
$$B \rightarrow T(K_2^*, f'_2) \ell \ell'$$



$$B \rightarrow K_2^* \tau \mu$$

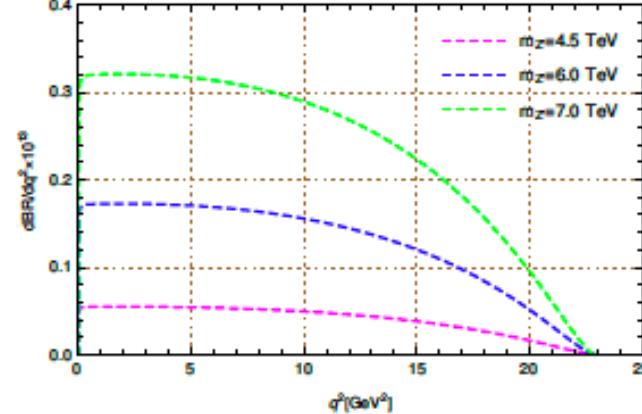
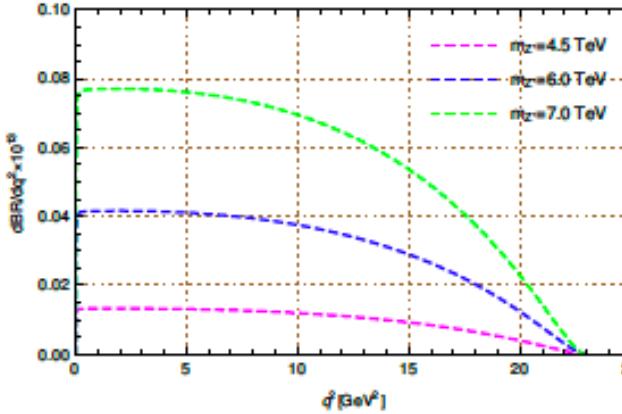
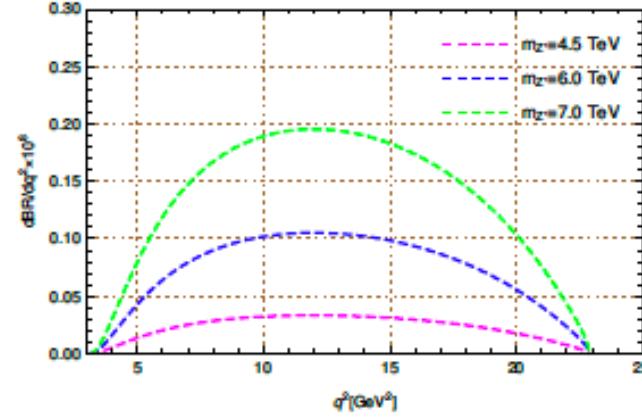
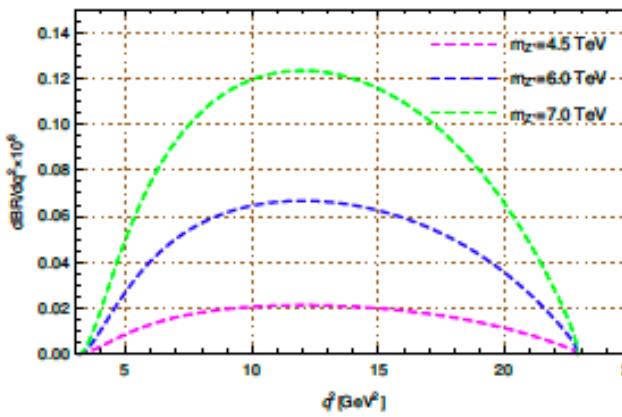
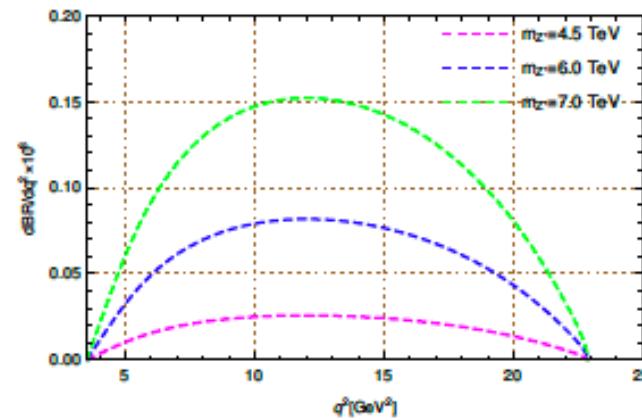
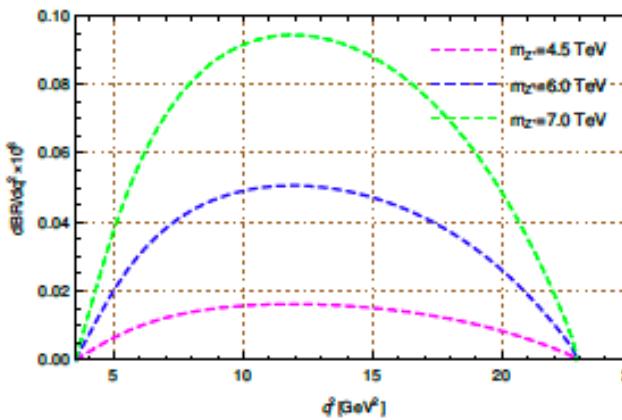


$$B \rightarrow K_2^* \mu e$$

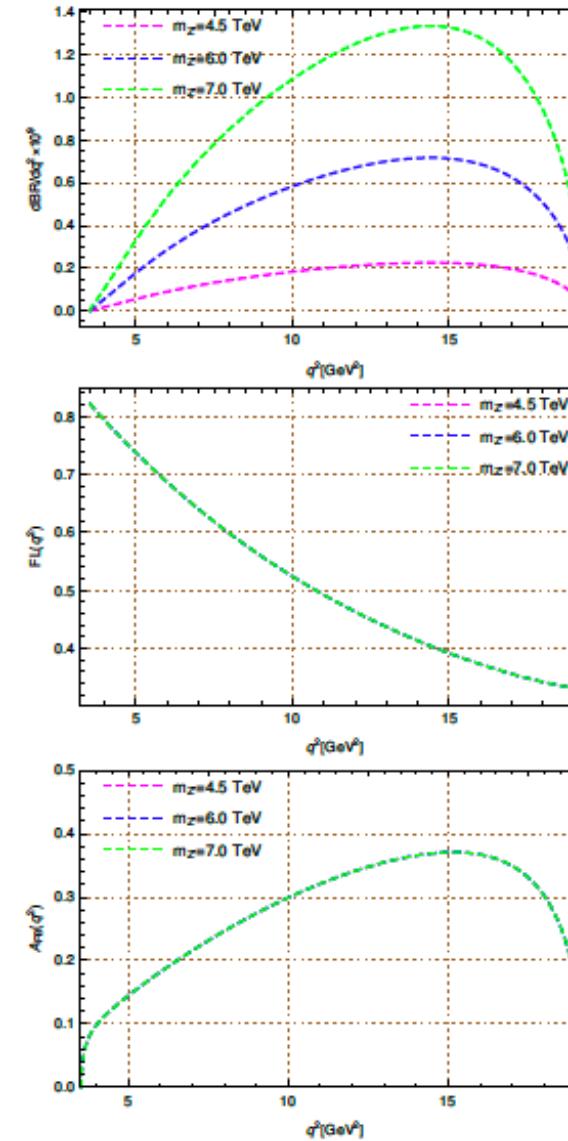
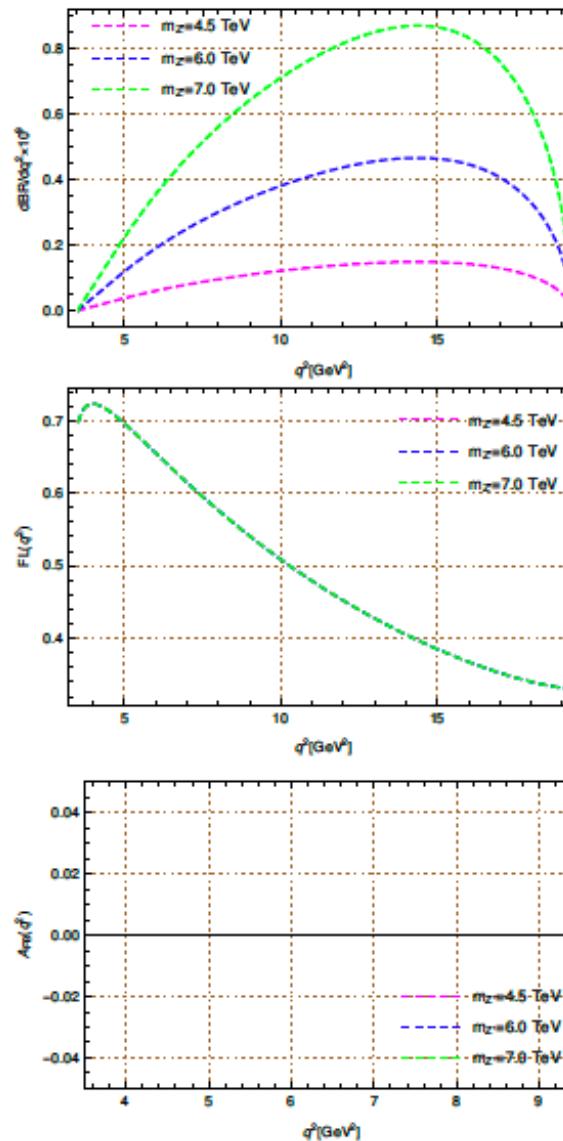


$$B \rightarrow f'_2 \tau e$$

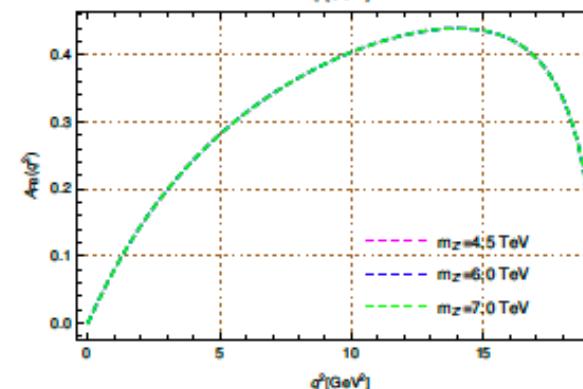
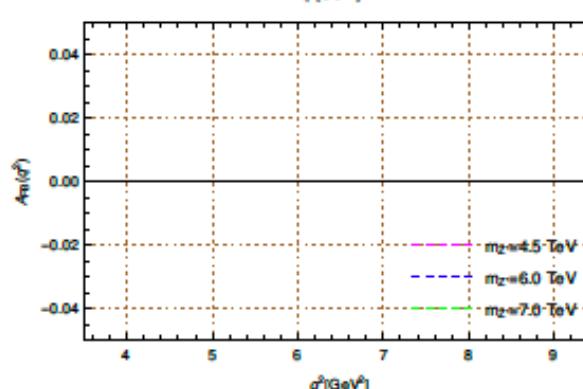
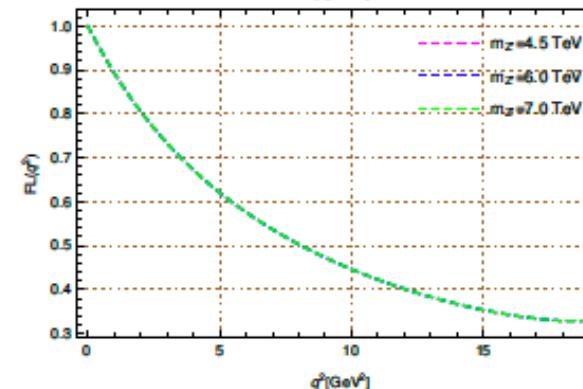
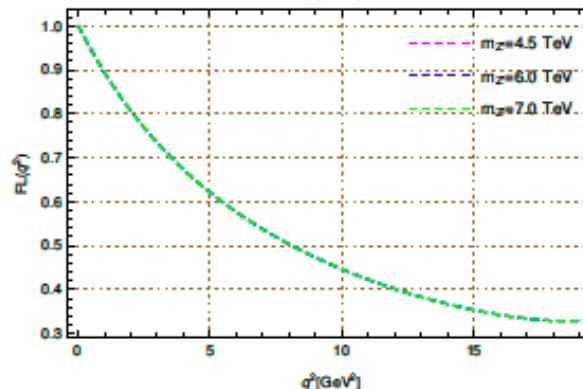
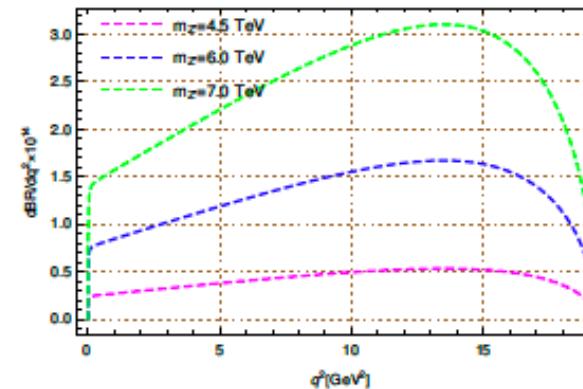
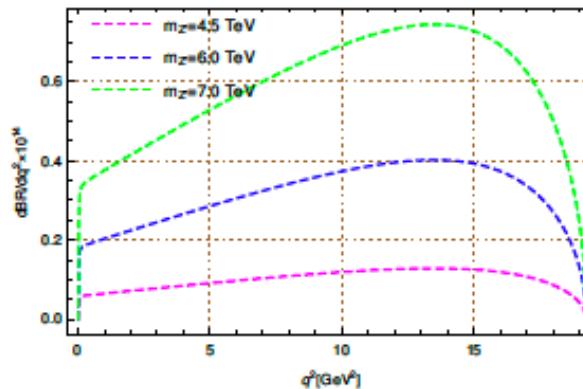
$B \rightarrow K\tau\mu$ (top), $B \rightarrow K\tau e$ (middle), $B \rightarrow K\mu e$



$B \rightarrow K^*\tau\mu$: $d\mathcal{B}/dq^2, F_L(q^2)$ and $A_{FB}(q^2)$



$d\mathcal{B}/dq^2$, $F_L(q^2)$ and $A_{FB}(q^2)$ of $B \rightarrow K^*\mu e$



Predictions for $B \rightarrow (K_2^*, f_2') \ell \ell'$ processes

Observable		$m_{Z'} = 4.5$ TeV	$m_{Z'} = 6.0$ TeV	$m_{Z'} = 7.0$ TeV	$m_{Z'} = 4.5$ TeV	$m_{Z'} = 6.0$ TeV	$m_{Z'} = 7.0$ TeV
		$B_s \rightarrow K_2^* \ell \ell' (Z' \text{ contribution})$				$B \rightarrow f_2' \ell \ell' (Z' \text{ contribution})$	
$\mathcal{B}_{\mu e} \times 10^{-12}$	$\mathcal{S} - I$	0.010	0.034	0.063	0.009	0.029	0.054
	$\mathcal{S} - II$	0.044	0.141	0.262	0.037	0.117	0.218
$\mathcal{B}_{\tau \mu} \times 10^{-9}$	$\mathcal{S} - I$	0.420	1.316	2.455	0.365	1.144	2.133
	$\mathcal{S} - II$	0.630	2.003	3.727	0.549	1.743	3.243
$\mathcal{B}_{\tau e} \times 10^{-9}$	$\mathcal{S} - I$	0.525	1.655	3.063	0.457	1.440	2.666
	$\mathcal{S} - II$	0.823	2.609	4.851	0.716	2.271	4.222
$\mathcal{A}_{FB}^{\mu e}$	$\mathcal{S} - I$	-0.009	-0.009	-0.009	-0.010	-0.010	-0.010
	$\mathcal{S} - II$	-0.120	-0.120	-0.120	-0.123	-0.123	-0.123
$\mathcal{A}_{FB}^{\tau \mu}$	$\mathcal{S} - I$	0.231	0.231	0.231	0.233	0.233	0.233
	$\mathcal{S} - II$	0.122	0.122	0.122	0.122	0.122	0.122
$\mathcal{A}_{FB}^{\tau e}$	$\mathcal{S} - I$	0.247	0.247	0.247	0.248	0.248	0.248
	$\mathcal{S} - II$	0.128	0.128	0.128	0.129	0.129	0.129

TABLE V: Upper limit values of $B \rightarrow (K_2^*, f_2') \ell \ell'$ processes in Z' model

Outlook

- Small deviations observed in Flavor sector
- No clear evidence for BSM
- LFV measurements will be key
- Precision Flavor Physics
- Exciting time ahead