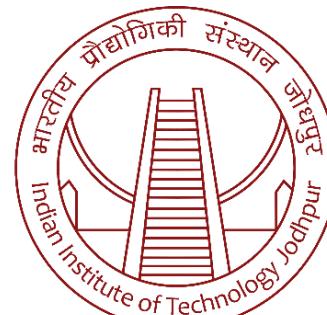


Lepton Flavor Violating $B \rightarrow K_2^* \mu^\pm \tau^\mp$ Decays

Juhi Vardani
IIT Jodhpur



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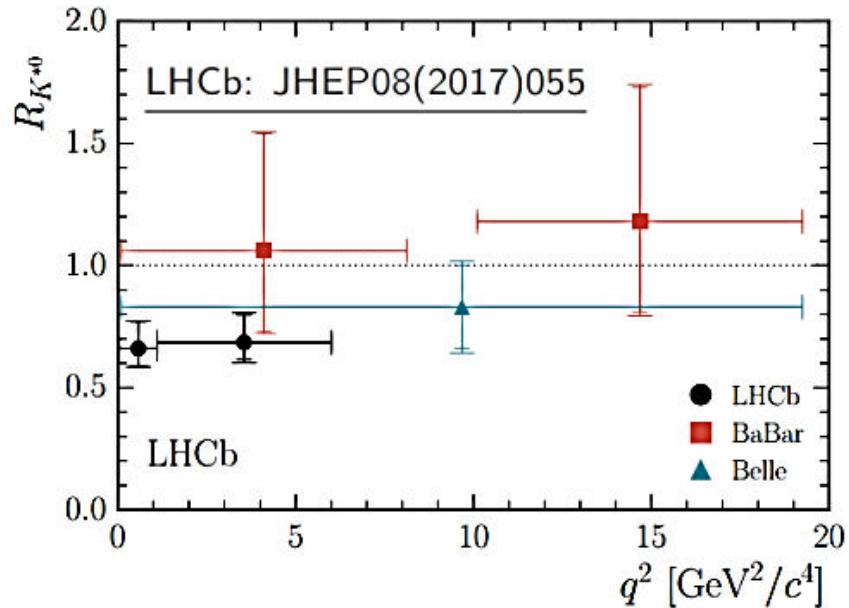
In Collaboration with Suman Kumbhakar (Univ of Montreal), Ria Sain (IIT Guwahati)

Vietnam Flavour Physics Conference 2022

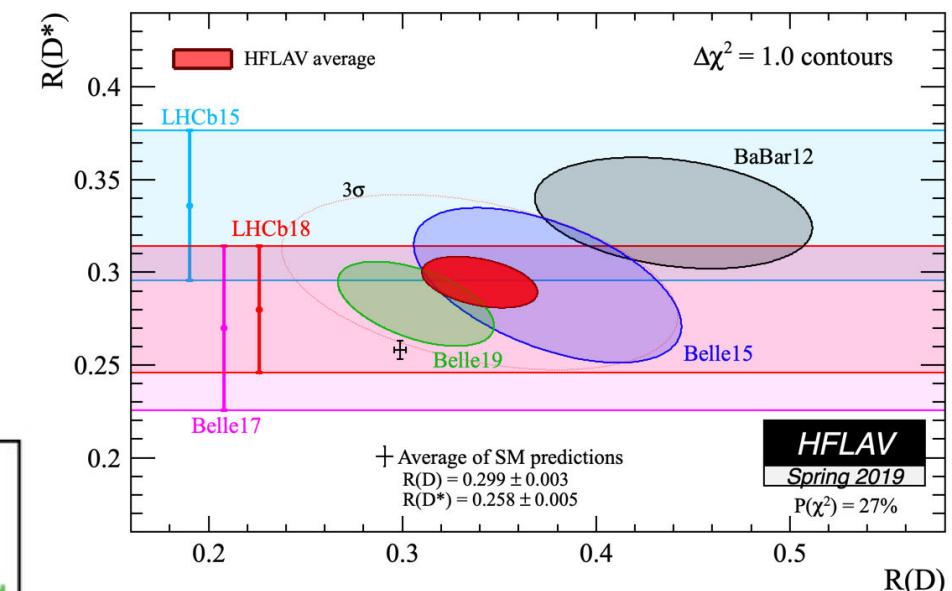
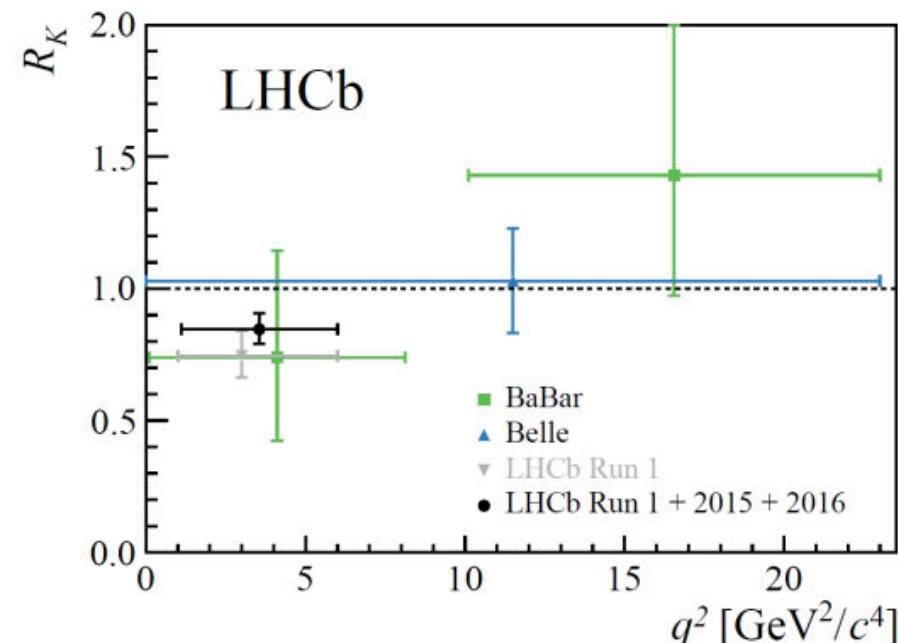
Plan of Talk :

- ❖ Motivation
- ❖ Angular analysis of $B \rightarrow K_2^* l_1^+ l_2^-$ decay
- ❖ U1 Leptoquark Model
- ❖ Results

B anomalies:



$$R_{K^{(*)}} = \frac{B \rightarrow K^{(*)} \mu^+ \mu^-}{B \rightarrow K^{(*)} e^+ e^-}$$



$$R_{D^{(*)}} = \frac{B \rightarrow D^{(*)} \tau \bar{\nu}}{B \rightarrow D^{(*)} l \bar{\nu}}$$

Theoretical Analysis

- The decay amplitude for $B \rightarrow K_2^* l_1^+ l_2^-$ consists of both short and long distance physics.
- The new physics effective Hamiltonian for the $b \rightarrow s l_1^+ l_2^-$ transition is :

$$H_{eff} = -\frac{\alpha_{em} G_F}{\sqrt{2}\pi} V_{ts}^* V_{tb} \sum_{i=V,A,S,P} (C_i(\mu) \mathcal{O}_i(\mu) + C'_i(\mu) \mathcal{O}'_i(\mu)) \quad (1).$$

Where $C_i^{(')}$ ($i=V,A,S,P$) are new physics coupling coefficients and $\mathcal{O}_i^{(')}$ are :

$$\mathcal{O}_V^{(')} = [\bar{s} \gamma^\mu P_{L(R)} b] [l_2 \gamma_\mu l_1] \quad \mathcal{O}_A^{(')} = [\bar{s} \gamma^\mu P_{L(R)} b] [l_2 \gamma_\mu \gamma_5 l_1]$$

$$\mathcal{O}_S^{(')} = [\bar{s} P_{L(R)} b] [l_2 l_1] \quad \mathcal{O}_P^{(')} = [\bar{s} \gamma^\mu P_{L(R)} b] [l_2 \gamma_5 l_1]$$

Form Factor :

The matrix elements are parametrized by the following form factors:

$$\begin{aligned}\langle K_2^*(k, \epsilon^*) | \bar{s} \gamma^\mu b | \bar{B}(p) \rangle &= -\frac{2V(q^2)}{m_B + m_{K_2^*}} \epsilon^{\mu\nu\rho\sigma} \epsilon_{T\nu}^* p_\rho k_\sigma, \\ \langle K_2^*(k, \epsilon^*) | \bar{s} \gamma^\mu \gamma_5 b | \bar{B}(p) \rangle &= 2im_{K_2^*} A_0(q^2) \frac{\epsilon_T^* \cdot q}{q^2} q^\mu + i(m_B + m_{K_2^*}) A_1(q^2) \left[\epsilon_T^{*\mu} - \frac{\epsilon_T^* \cdot q}{q^2} q^\mu \right] \\ &\quad - iA_2(q^2) \frac{\epsilon_T^* \cdot q}{m_B + m_{K_2^*}} \left[(p+k)^\mu - \frac{m_B^2 - m_{K_2^*}^2}{q^2} q^\mu \right], \\ \langle K_2^*(k, \epsilon^*) | \bar{s} \gamma_5 b | \bar{B}(p) \rangle &= -\frac{2im_{K_2^*} A_0(q^2)}{m_b + m_s} (\epsilon_T^* \cdot q).\end{aligned}\tag{2.}$$

Angular Analysis

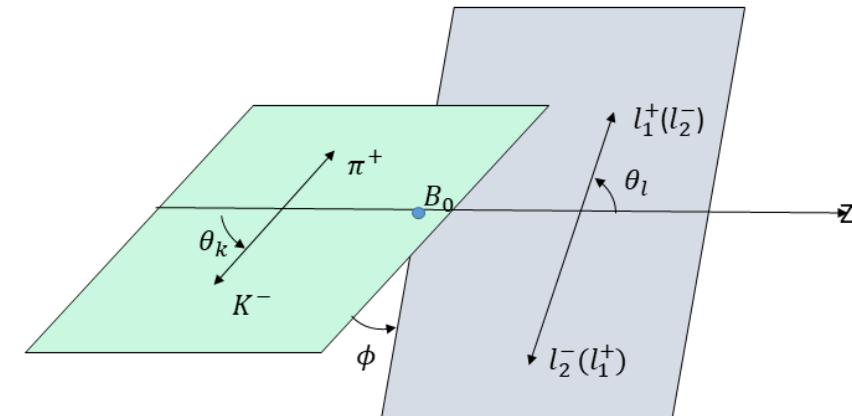
The two fold distribution for $B \rightarrow K_2^* l_1^+ l_2^-$ will be :

$$\frac{d^2\Gamma}{dq^2 d \cos \theta_\ell} = A(q^2) + B(q^2) \cos \theta_\ell + C(q^2) \cos \theta_\ell^2 \quad (3).$$

$$A = \frac{3}{4} \left\{ \frac{1}{4} \left[\left(1 + \frac{m_+^2}{q^2} \right) \beta_-^2 + \left(1 + \frac{m_-^2}{q^2} \right) \beta_+^2 \right] \left(|A_L^\parallel|^2 + |A_L^\perp|^2 + (L \rightarrow R) \right) \right. \\ + \frac{1}{2} (\beta_+^2 + \beta_-^2) (|A_L^0|^2 + |A_R^0|^2) \\ + \frac{4m_1 m_2}{q^2} \text{Re} \left[\left(A_R^0 A_L^{0*} + A_R^\parallel A_L^{\parallel*} + A_R^\perp A_L^{\perp*} \right) - (A_L^t A_R^{t*} + A_R^t A_L^{t*}) \right] \\ + \frac{1}{2} (\beta_-^2 + \beta_+^2 - 2\beta_-^2 \beta_+^2) (|A_L^t|^2 + |A_R^t|^2) + 2 (|A_{SP}|^2 \beta_-^2 + |A_S|^2 \beta_+^2) \\ \left. - \frac{2m_-}{\sqrt{q^2}} \beta_+^2 \text{Re} [A_S (A_L^t + A_R^t)^*] - \frac{2m_+}{\sqrt{q^2}} \beta_+^2 \text{Re} [A_{SP} (A_L^t - A_R^t)^*] \right\}.$$

$$C = \frac{3}{8} \beta_+ \beta_- \left\{ \left(|A_L^\parallel|^2 + |A_L^\perp|^2 - 2|A_L^0|^2 \right) + (L \rightarrow R) \right\}, \\ B = \frac{3}{4} \beta_- \beta_+ \left\{ \text{Re} \left[A_L^{\perp*} A_L^\parallel - (L \rightarrow R) \right] + \frac{m_+ m_-}{q^2} \text{Re} [A_L^{0*} A_L^t + (L \rightarrow R)] \right. \\ \left. - \frac{m_+}{\sqrt{q^2}} \text{Re} [A_S^* (A_L^0 + A_R^0)] - \frac{m_-}{\sqrt{q^2}} \text{Re} [A_{SP}^* (A_L^0 - A_R^0)] \right\},$$

$$\text{Here } m_\pm = (m_1 \pm m_2), \beta_\pm = \sqrt{1 - \frac{m_1 \pm m_2}{q^2}}$$



Observables

- The two fold distribution for $B \rightarrow K_2^* l_1^+ l_2^-$ will be :

$$\frac{d^2\Gamma}{dq^2 d \cos \theta_\ell} = A(q^2) + B(q^2) \cos \theta_\ell + C(q^2) \cos^2 \theta_\ell$$

- Integrating over the angle θ_ℓ gives differential branching ratio

$$\frac{dB}{dq^2} = \frac{1}{\Gamma_{total}} \left[2A(q^2) + \frac{2}{3}C(q^2) \right] \quad (4).$$

- Normalized forward-backward asymmetry $A_{fb}(q^2) = \frac{\int_0^1 d \cos \theta_\ell \frac{d\Gamma}{dq^2 d \cos \theta_\ell} - \int_{-1}^0 d \cos \theta_\ell \frac{d\Gamma}{dq^2 d \cos \theta_\ell}}{\int_0^1 d \cos \theta_\ell \frac{d\Gamma}{dq^2 d \cos \theta_\ell} + \int_{-1}^0 d \cos \theta_\ell \frac{d\Gamma}{dq^2 d \cos \theta_\ell}}$

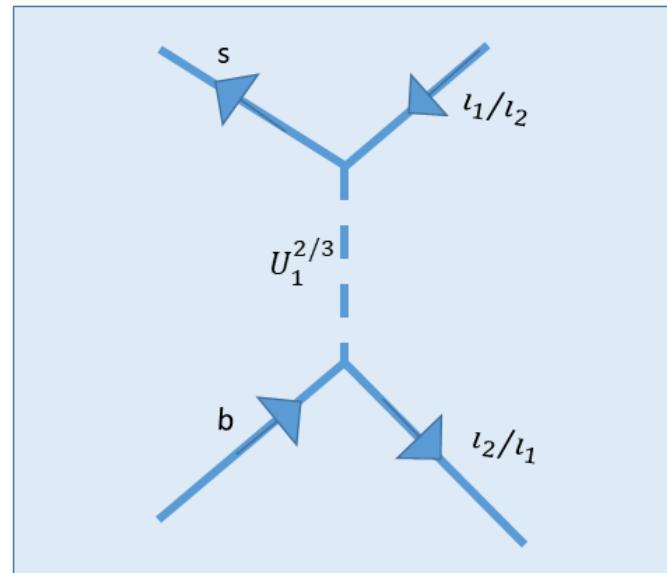
$$A_{fb}(q^2) = \frac{B(q^2)}{2A(q^2) + \frac{2}{3}C(q^2)} \quad (5).$$

Vector Leptoquark Model

The interaction Langrangian between the U_1 Leptoquark (LQ) and Standard Model (SM) fermion is:

$$\mathcal{L}_{U_1^{2/3}} = h_L^{ij} \bar{Q}_{iL} \gamma_\mu L_{jL} U_1^\mu + h_R^{ij} \bar{d}_{iR} \gamma_\mu l_{jR} U_1^\mu + \text{h.c.} \quad (6).$$

Here : $h_{L,R}^{ij}$ is LQ couplings , $Q_L(L_L)$ is the SM left –handed quark (lepton) doublet & $d_R(l_R)$ is right -handed down quark (lepton) singlet.



New Physics Analysis

- The SM Wilson Coefficient for $b \rightarrow sl_i^+ l_j^-$ and for $b \rightarrow cl_i \vartheta_j$, $C_n^{ij} = 0$ for $i \neq j$
- The New Physics (NP) Wilson Coefficient for $b \rightarrow sl_i^+ l_j^-$ transition in the presence of $U_1^{2/3}$ LQ will be

$$C_V^{ij} = -C_A^{ij} = \frac{\pi h_L^{2i} h_L^{3j*}}{\sqrt{2} G_f V_{ts}^* V_{tb} M_U^2}$$

- Whereas for $b \rightarrow c\tau\vartheta$

$$C_{V_L} = \frac{1}{2\sqrt{2} G_f M_U^2} h_L^{33*} [h_L^{33} + \left(\frac{V_{cs}}{V_{cb}}\right) h_L^{23}]$$

- We are working with $h_R^{ij} = 0$, $M_{LQ} = 1TeV$

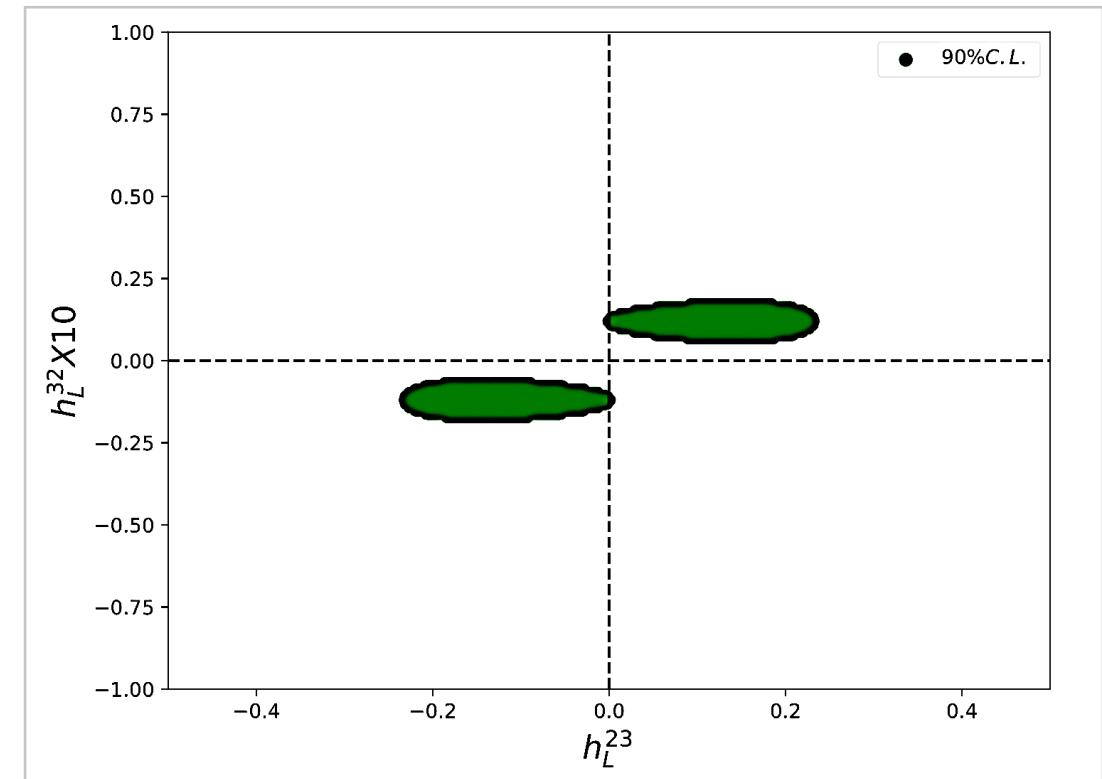
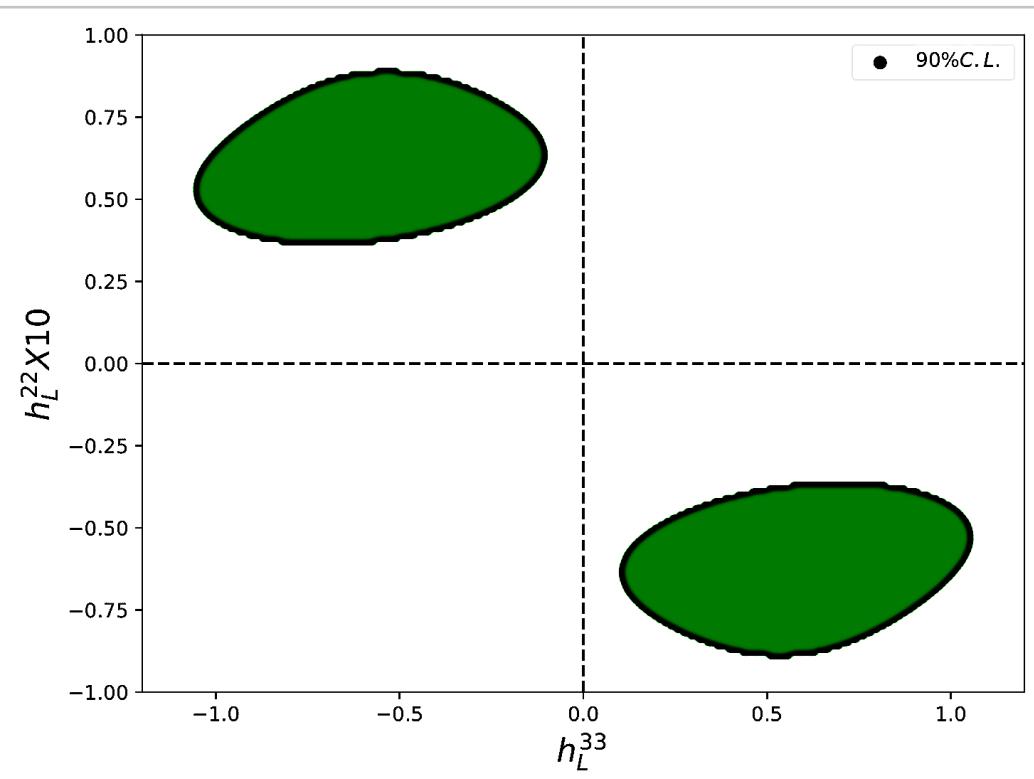
Observable Table :

Sector	Observable	Measurement
$b \rightarrow s\mu^+\mu^-$	All $b \rightarrow s\mu^+\mu^-$	$C_9^{\mu\mu} = -C_{10}^{\mu\mu} = -0.49 \pm 0.07$
$b \rightarrow c\tau\bar{\nu}$	R_D	$0.340 \pm 0.027 \pm 0.013$
	R_D^*	$0.295 \pm 0.011 \pm 0.008$
	$R_{J/\psi}$	$0.71 \pm 0.17 \pm 0.18$
		LHCb, <i>PRL</i> 120 (2018) 12, 121801
LFV	$B(B^+ \rightarrow K^+\tau^+\mu^-)$	$< 2.8 \times 10^{-5}$, 90% C.L.
	$B(B^+ \rightarrow K^+\tau^-\mu^+)$	$< 4.5 \times 10^{-5}$, 90% C.L.
	$B(\gamma \rightarrow \tau^\pm \mu^\mp)$	$< 3.3 \times 10^{-6}$, 90% C.L.
	$B(\tau \rightarrow \mu \varphi)$	$< 8.4 \times 10^{-8}$, 90% C.L.
		BaBar, <i>PRL</i> 104 (2010) 1511802

Methodology

- We performed a χ^2 - fit to fit all $b \rightarrow s\mu^+\mu^-$, $b \rightarrow c\tau\vartheta$ and Lepton Flavor Violating observables to find parameter space allowed by current flavour data.

$$\chi^2(h_L^{ij}) = \sum_k \frac{(o_k^{theory}(h_L^{ij}) - o_k^{expt})^2}{\sigma_{total,K}^2}$$



Results:

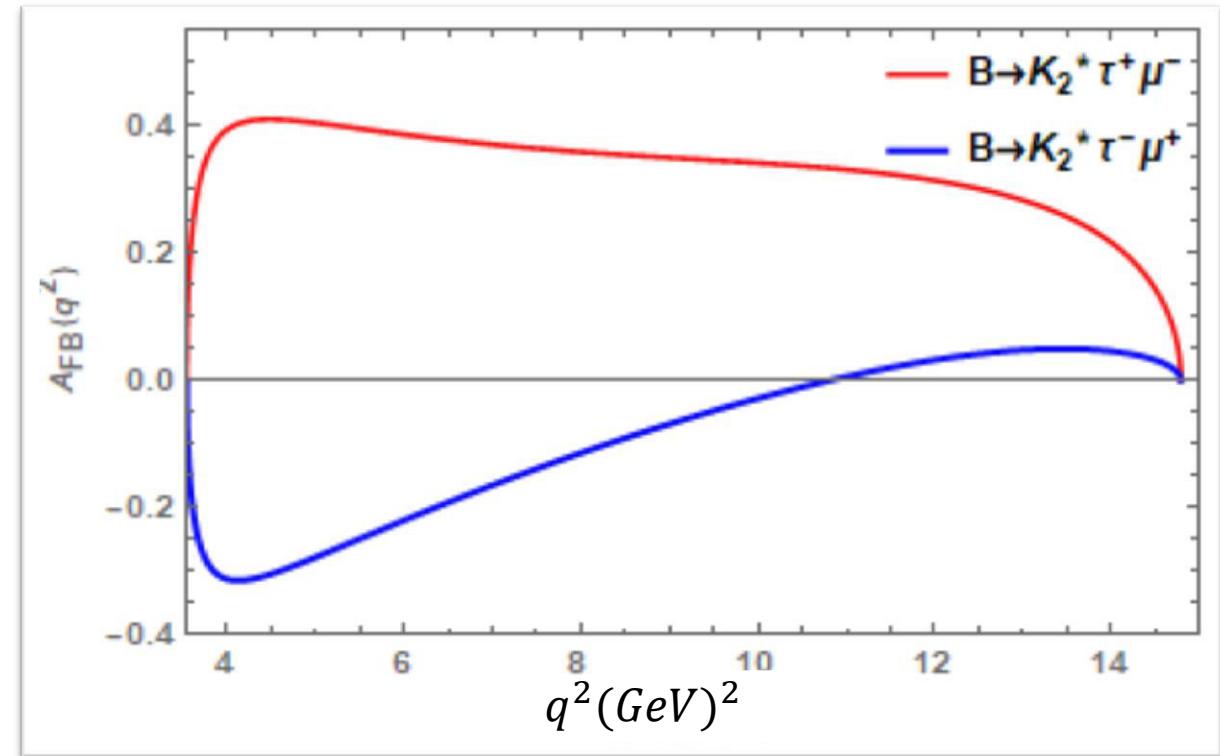
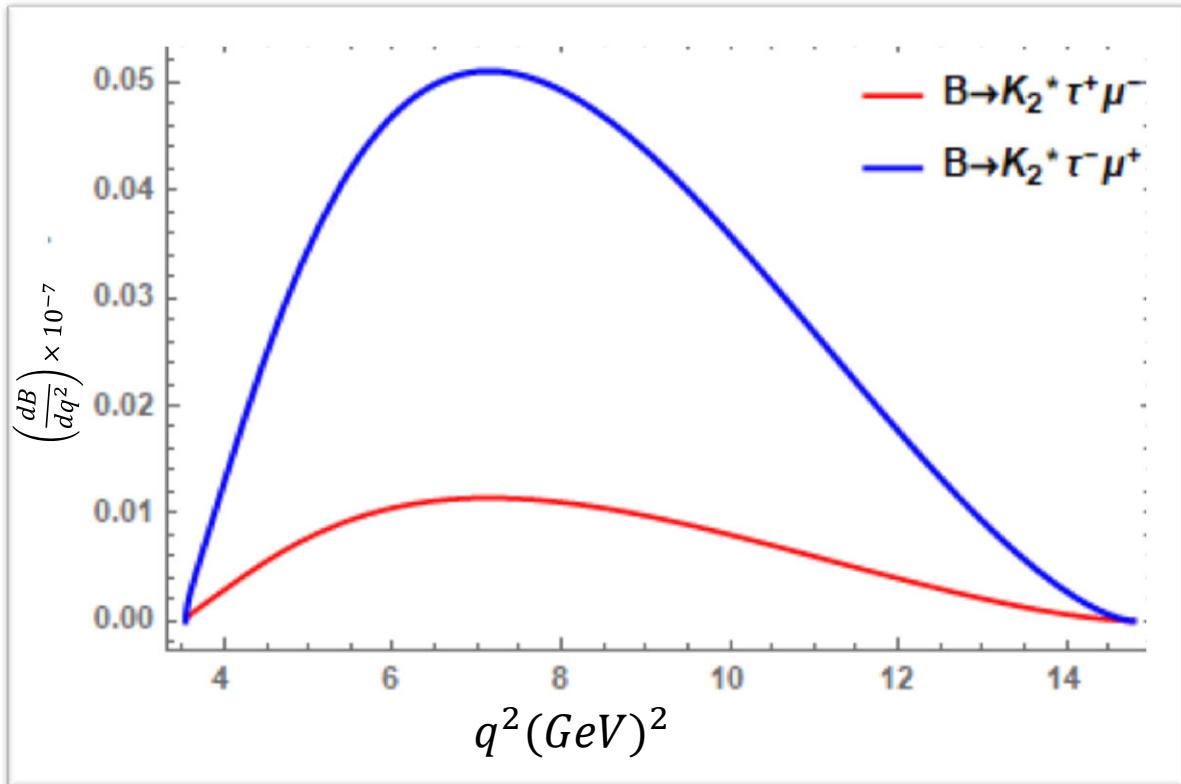
- Integrated maximum Branching Ratio and Forward -Backward Asymmetry(A_{fb}) for $B \rightarrow K_2^* \mu^- \tau^+$ (at 90% confidence level)

$$h_L^{23} \cdot h_L^{32} = 0.033, \text{ Br} \leq 0.074 \times 10^{-7}, A_{fb} \leq 0.358$$

- Integrated maximum Branching Ratio and Forward -Backward Asymmetry (A_{fb}) for $B \rightarrow K_2^* \mu^+ \tau^-$ (at 90% confidence level)

$$h_L^{22} \cdot h_L^{33} = -0.0070, \text{ Br} \leq 0.329 \times 10^{-7}, A_{fb} \leq -0.122$$

Results:



The plots on the left and right panels represent the differential branching ratio and the forward-Backward asymmetry (A_{fb}) as a function of q^2 .

Summary

- The measurements of the lepton flavor universality violation in semileptonic $b \rightarrow s$ and $b \rightarrow c$ transitions hint towards a possible role of NP in both sectors.
- Motivated by these anomalies, we investigated the lepton flavor violating $B \rightarrow K_2^*(1430)\mu^\pm\tau^\mp$ decays.
- These decays are forbidden in the SM and hence any hint of these decays would imply a smoking gun signal of BSM.
- We calculate the two-fold angular distribution of this decay in the presence of vector, axial-vector, scalar and pseudo-scalar new physics.
- We calculated the upper limit for Branching Fraction and Forward Backward Asymmetry for this decay in $U_1^{2/3}$ LQ Model.

Thank You

Backup : Transversity Amplitude

The vector and axial-vector transversity amplitudes can be expressed as

$$\begin{aligned}
 A_{0L,R} &= N \frac{\sqrt{\lambda}}{\sqrt{6}m_B m_{K_2^*}} \frac{1}{2m_{K_2^*}\sqrt{q^2}} \left[(C_{V-} \mp C_{A-}) \left[(m_B^2 - m_{K_2^*}^2 - q^2)(m_B + m_{K_2^*})A_1 - \frac{\lambda}{m_B + m_{K_2^*}} A_2 \right] \right], \\
 A_{\perp L,R} &= -\sqrt{2}N \frac{\sqrt{\lambda}}{\sqrt{8}m_B m_{K_2^*}} \left[(C_{V+} \mp C_{A+}) \frac{\sqrt{\lambda}V}{m_B + m_{K_2^*}} \right], \\
 A_{\parallel L,R} &= \sqrt{2}N \frac{\sqrt{\lambda}}{\sqrt{8}m_B m_{K_2^*}} [(C_{V-} \mp C_{A-})(m_B + m_{K_2^*})A_1], \\
 A_{Lt} &= N \frac{\sqrt{\lambda}}{\sqrt{q^2}\sqrt{6}m_B m_{K_2^*}} [\sqrt{\lambda}(C_{V-} - C_{A-})A_0], \\
 A_{Rt} &= N \frac{\sqrt{\lambda}}{\sqrt{q^2}\sqrt{6}m_B m_{K_2^*}} [\sqrt{\lambda}(C_{V-} + C_{A-})A_0],
 \end{aligned}$$

where $C_{V\pm} = (C_V \pm C'_V)$, and $C_{A\pm} = (C_A \pm C'_A)$. The transversity amplitudes for scalar, pseudoscalar interactions can be written as

$$\begin{aligned}
 A_S &= 2N \frac{\sqrt{\lambda}}{\sqrt{6}m_B m_{K_2^*}} [\sqrt{\lambda}(C_S - C_{S'})A_0], \\
 A_{SP} &= 2N \frac{\sqrt{\lambda}}{\sqrt{6}m_B m_{K_2^*}} [\sqrt{\lambda}(C_P - C_{P'})A_0].
 \end{aligned}$$

The normalization constant N is given by

$$N = \left[\frac{G_F^2 \alpha_e^2}{3 \cdot 2^{10} \pi^5 m_c^3} |V_{tb} V_{ts}^*|^2 q^2 \beta_+ \beta_- \lambda^{1/2} \mathcal{B}(K_2^* \rightarrow K\pi) \right]^{\frac{1}{2}}.$$

Leptoquark (LQ)

- LQ are hypothetical particle couple to both quark and lepton.
- LQ carries SU(3) color, fractional electric charge, baryon (B) and lepton (L) numbers.
- LQ are classified by Fermion number, spin and charge.
- As fermion number (F) = $3B+L$ for LQ it can be 0,2.
- LQ can have spin zero (Scalar) or spin one (Vector).
- Charge can have $\pm \frac{1}{3}, \pm \frac{2}{3}, \frac{-4}{3}, \frac{-5}{3}$.
- $U_1^{2/3}$ LQ can mediate both charge and neutral current interactions.

<https://doi.org/10.48550/arXiv.1603.04993>

LeptoQuark (LQ)

$SU(3) \times SU(2) \times U(1)$	Spin	Symbol	Type	$3B + L$
(3, 3, 1/3)	0	S_3	$LL(S_1^L)$	-2
(3, 2, 7/6)	0	R_2	$RL(S_{1/2}^L), LR(S_{1/2}^R)$	0
(3, 2, 1/6)	0	\tilde{R}_2	$RL(\tilde{S}_{1/2}^L), \overline{LR}$	0
(\bar{3}, 1, 4/3)	0	\tilde{S}_1	$RR(\tilde{S}_0^R)$	-2
(\bar{3}, 1, 1/3)	0	S_1	$LL(S_0^L), RR(S_0^R), \overline{RR}$	-2
(\bar{3}, 1, -2/3)	0	\bar{S}_1	\overline{RR}	-2
(3, 3, 2/3)	1	U_3	$LL(V_1^L)$	0
(\bar{3}, 2, 5/6)	1	V_2	$RL(V_{1/2}^L), LR(V_{1/2}^R)$	-2
(\bar{3}, 2, -1/6)	1	\tilde{V}_2	$RL(\tilde{V}_{1/2}^L), \overline{LR}$	-2
(3, 1, 5/3)	1	\tilde{U}_1	$RR(\tilde{V}_0^R)$	0
(3, 1, 2/3)	1	U_1	$LL(V_0^L), RR(V_0^R), \overline{RR}$	0
(3, 1, -1/3)	1	\bar{U}_1	\overline{RR}	0