Flavor violation at 13 TeV LHC in $(\mu^+\tau^- + b\text{-jet})$ events

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Presentation Outline

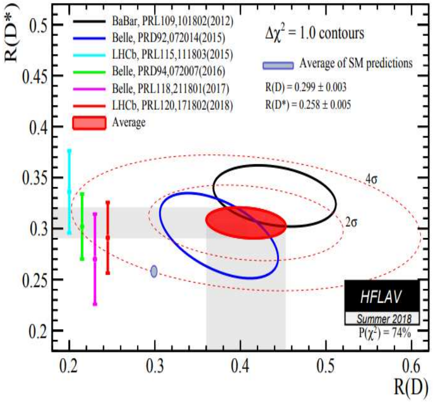
Motivation

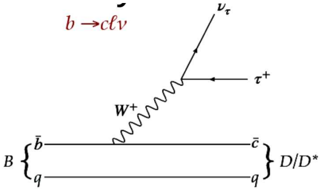
- The property that distinguishes the fundamental fermions from one another is called *flavor*.
- In SM, the universality of lepton flavor (LFU) is an accidental symmetry, broken only by Yukawa interactions.
- LFU violation observed in tree-level $b \to c\ell\nu$ and loop-level $b \to s\ell\ell$ FCNC.(Belle, BABAR, LHCb)
- Anomalies indicate towards BSM, NP models predicts particles with different couplings to q and ℓ.
- Motivated by Models with Z', leptoquark etc...
  Model independent approach → Effective Operators
- Flavor violating signatures at LHC
  (ATLAS 1607.08079, 1807.06573)

Presentation Outline

Charged current decay at tree level $b \to c\ell\nu$

$$\frac{4G_F}{\sqrt{2}} V_{cb} \left(1 + C^{\rm NP}\right) \left[(c,b)(\tau,\nu_\tau)\right]$$



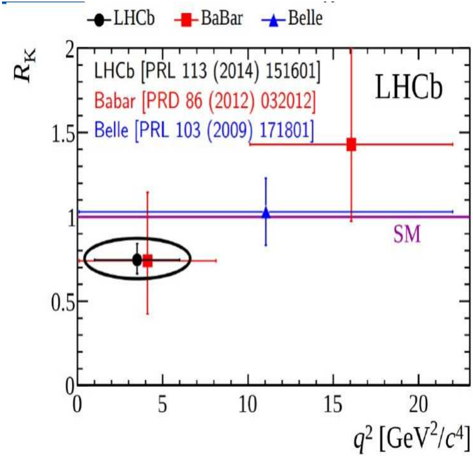


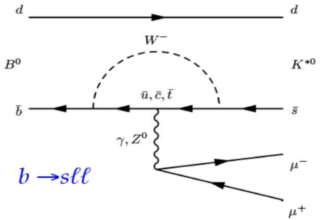
- $R(D^{(*)}) \equiv \dfrac{\mathrm{BR}(B \to D^{(*)}\tau\nu)}{\mathrm{BR}(B \to D^{(*)}\ell\nu)}$
- $R_{J/\psi} \equiv \dfrac{\mathrm{BR}(B_c \to J/\psi\tau\nu)}{\mathrm{BR}(B_c \to J/\psi\mu\nu)}$

The observed values lie above the SM predictions ($\sim 2\sigma$)

Neutral current decay at loop level $b \to s\ell\ell$

$$\frac{-4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i C_i(\mu)\mathcal{O}_i(\mu)$$





- $R_{K^{(*)}} \equiv \frac{\mathrm{BR}(B \to K^{(*)}\mu\mu)}{\mathrm{BR}(B \to K^{(*)}ee)}$
- $\mathrm{Br}(B \to \phi\mu\mu)$

The observed values lie below the SM predictions

Other Observables

- The $B_s \to \mu\mu$ agrees well with SM prediction.

$$\mathrm{BR}\ (B_s \to \mu\mu)_{exp} = 3.0 \pm 0.6 \times 10^{-9}$$
$$\mathrm{BR}\ (B_s \to \mu\mu)_{SM} = 3.65 \pm 0.23 \times 10^{-9}$$

- Strong constrain to NP.
- Hard to explain all together in one Model.
- Minimal Model $\to$

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Presentation Outline

Minimal Model

- Phenomenological Model$\to$ less parameters
- Assume coupling with the third generation of lepton only.

$$\mathcal{H}^{\rm NP} = A_1\left(\overline{Q}_{2L}\gamma_\mu Q_{3L}\right)\left(\overline{L}_{3L}\gamma^\mu L_{3L}\right) + A_1\left(\overline{Q}_{2L}\gamma_\mu L_{3L}\right)\left(\overline{L}_{3L}\gamma^\mu Q_{3L}\right)$$

$$+ A_2\left(\overline{Q}_{2L}\gamma_\mu Q_{3L}\right)\left(\overline{\tau}_R\gamma^\mu \tau_R\right)$$

- A rotation from the flavor basis to mass basis induces the couplings with the 2nd generation of leptons.

$$\tau = \cos\theta\,\tau' + \sin\theta\,\mu' \qquad \nu_\tau = \cos\theta\,\nu'_\tau + \sin\theta\,\nu'_\mu$$

$\to$ $(bs)(\mu\mu)$ will be suppressed by $(\sin\theta)^2$

- Better χ^2 w.r.t SM, allowing all LFV observables.

Presentation Outline

Processes

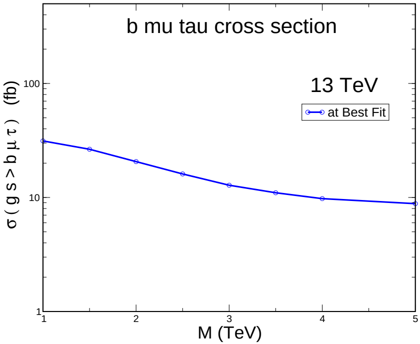
- Best Fit $A_1 = -3.88$, $A_2 = -2.62$, $|\sin\theta| = 0.016$, $\theta_L = \theta_R$
- Effective Coupling: $\lambda^2 \sim M^2 \times$ Coupling
- $(3A_1/4)(s,b)(\tau\tau)$ at Best-fit, with some normalization:

Mass basis	λ	λ at M=1 TeV
$(3A_1/4)\cos^2\theta(s,b)(\tau'\tau')$	$\sqrt{2M^2(3A_1/4)\cos^2\theta)}$	2.41
$(3A_1/4)\sin^2\theta(s,b)(\mu'\mu')$	$\sqrt{2M^2(3A_1/4)\sin^2\theta)}$	0.039
$(3A_1/4)\sin 2\theta(s,b)(\mu'\tau')$	$\sqrt{2M^2(3A_1/4)\sin 2\theta)}$	0.431

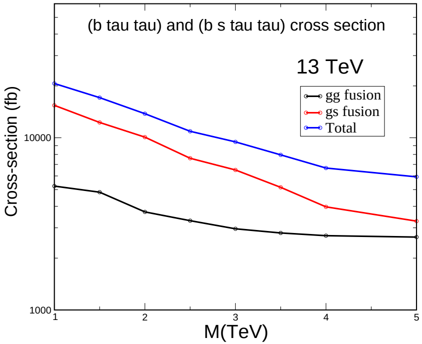
- $gg \to (s,b)(\mu'\mu')$, $gs \to b(\mu'\mu')$ is studied in (1805.11402)
- We study $gg \to (s,b)(\tau'\tau')$, $gs \to b(\tau'\tau')$ via Z' mediator
- Also $gg \to (s,b)(\mu'\tau')$, $gs \to b(\mu'\tau')$

Cross Sections

$(s, b)(\mu\tau)$

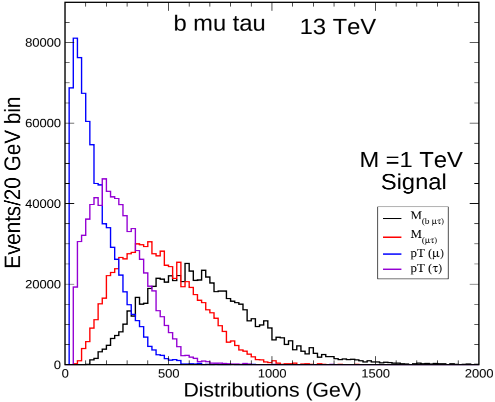


$(s, b)(\tau\tau)$



We study the final state with a oppositely charged mu tau pair and a b-jet, coming from tau tau pair and bjet, allowing one tau to decay leptonically

Signal Distributions

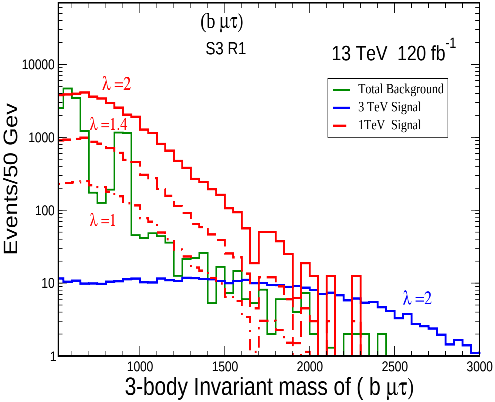


Selections (GeV) :

- $M_{(\mu,\tau)} > 100$
- Region 1 ($R1$):
  - $p_T(\mu) > 50$
  - $p_T(\tau) > 100$
  - $M_{(b\mu,\tau)} > 500$
- Region 2 ($R2$):
  - $p_T(\mu) > 100$
  - $p_T(\tau) > 150$
  - $M_{(b\mu,\tau)} > 800$

Two Signal Regions to probe different NP scale

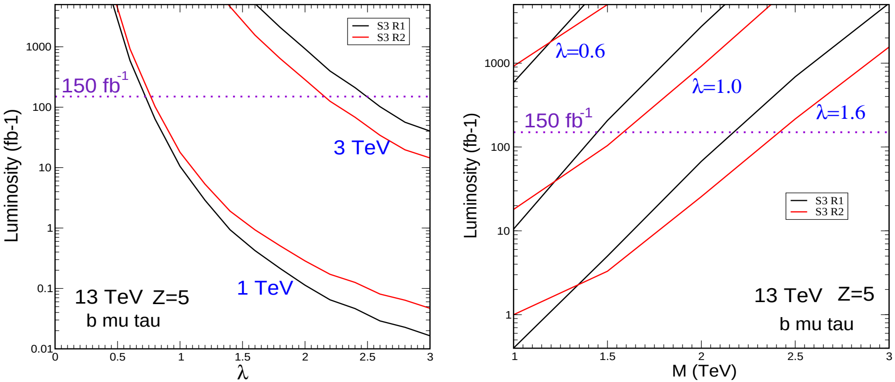
Backgrounds



Major Backgrounds:

- $t\bar{t}$
- Diboson
- W+jets
- Z+jets
- Single top

Results



- Both Signal Regions are useful.
- Effective Coupling $\lambda^2 = 0.53$ and $\lambda^2 = 0.25$ can be probed with $150 fb^{-1}$ and $3000 fb^{-1}$ luminosity.

Presentation Outline

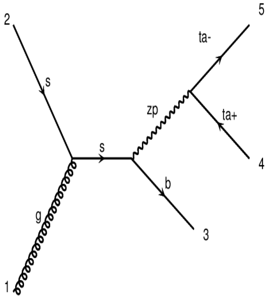
Conclusion

- Discovery prospect with current and future LHC data looks promising.
- Analysis is in progress. More than one tau in the final state can be studied.
- Exclusion limits on effective coupling at 13 TeV.
- Background uncertainty.
- Flavor violating signatures at LHC are complementary to Belle, BABAR, LHCb. With higher luminosity smaller couplings can be probed indirectly at LHC.

Thank you..

$$\mathcal{H}^{\rm eff} = \frac{4G_F}{\sqrt{2}} V_{cb} \left(1 + C^{\rm NP}\right) [(c,b)(\tau,\nu_\tau)] \qquad \mathcal{H}^{\rm eff} = \frac{-4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i C_i(\mu)\mathcal{O}_i(\mu) \tag{1}$$

$$Z = \sqrt{2[(s+b)\ln(1+s/b) - s]}. \tag{2}$$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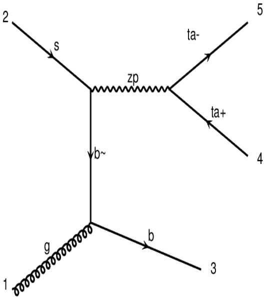
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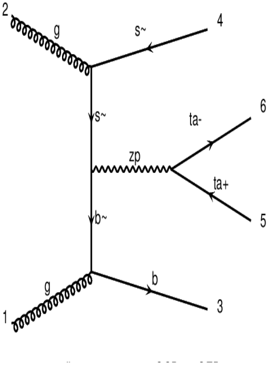
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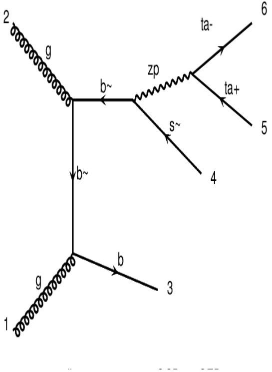
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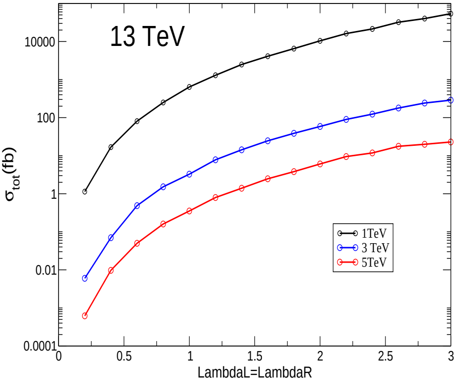
13 TeV
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1
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2
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3
LambdaL=LambdaR
σtot(fb)
1TeV
3 TeV
5TeV

Table : Background cross sections to pass the selections at 13 TeV p-p collision. The contributions will be combined later.

Background	cross section (fb)	$S2$ (fb)	$S3 - R1$ (fb)	$S3 - R2$ (fb)
$pp \to ZZ$	17×10^3	0.83	0.017	0.017
$pp \to WW$	130×10^3	3.38	0.52	0.13
$pp \to WZ$	49×10^3	2.40	0.049	0.049
$pp \to t\bar{t}$	831×10^3	403.71	10.00	0.75
$pp \to llj$	760×10^3	31.08	0.38	0.08
$pp \to lljj$	394×10^3	97.32	2.36	0.39
$pp \to Wjj$	27.3×10^6	3849.3	109.2	19.11
$pp \to Wj$	69.0×10^6	275.3	6.88	0.69
$pp \to WWjj$	23×10^3	5.84	0.80	0.16
$pp \to WWbb$	75	0.186	0.0050	0.00046
$pp \to WWj$	40×10^3	4.89	0.37	0.07
$pp \to WWb$	16×10^3	36.69	9.45	3.09
$pp \to Wt$	71.7×10^3	20.51	1.73	0.33
Total		4731.42	141.77	24.86

Table : Signal cross section to pass the selections in final states with $\mu^+\tau^- b$ at 13 TeV p-p collision. Cross sections are calculated from best-fit values.

BP	M (TeV)	σ_{tot} (pb)	$S2$(fb)	$S3 - R1$(fb)	$S3 - R2$(fb)
1	1	20.66	1022.67	633.44	214.04
2	1.5	17.1	871.985	664.39	406.52
3	2	13.79	700.601	551.39	403.46
4	2.5	10.9	533.25	411.58	315.53
5	3	9.46	438.66	318.55	245.60
6	3.5	7.954	0	0	0
7	4	6.67	261.08	143.49	94.54
8	5	6.93	249.75	111.56	60.00