Flavor Physics from high-p_T tails at the LHC

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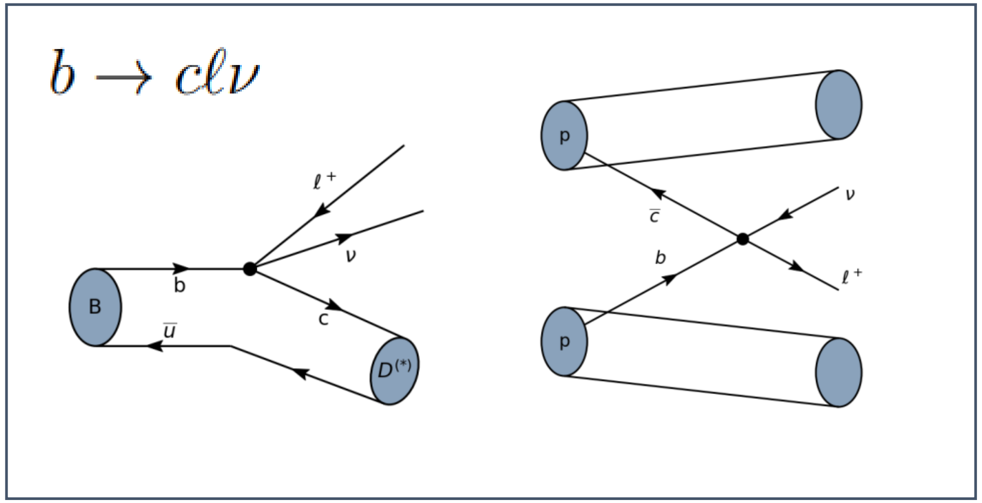
Based on D. Becirevic, S. Fajfer, D. Faroughy, F. Jaffredo, N.Kosnik and O.Sumensari *(in preparation)*

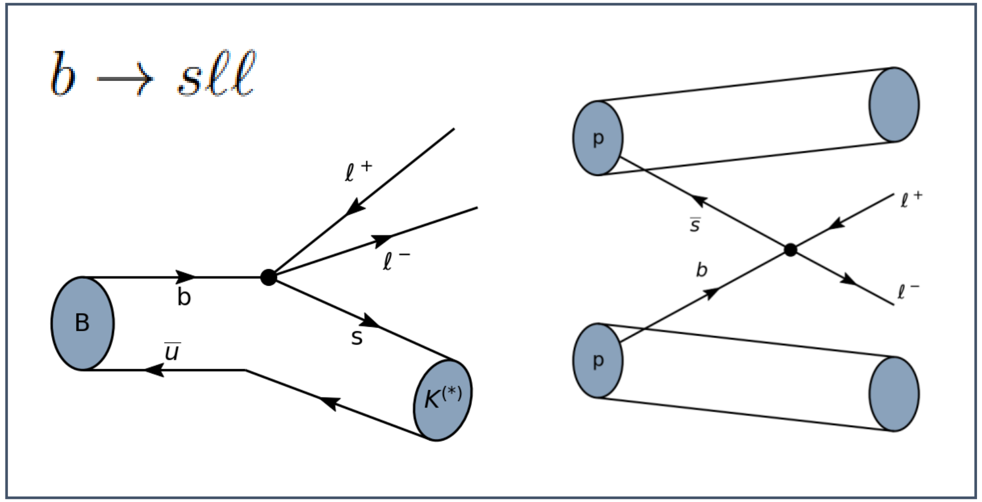
Motivations

- Hints of Lepton Flavor Universality Violation (LFUV) in $b \to s\ell\ell$ and $b \to c\ell\nu$ transitions from LHCb and B-factories.

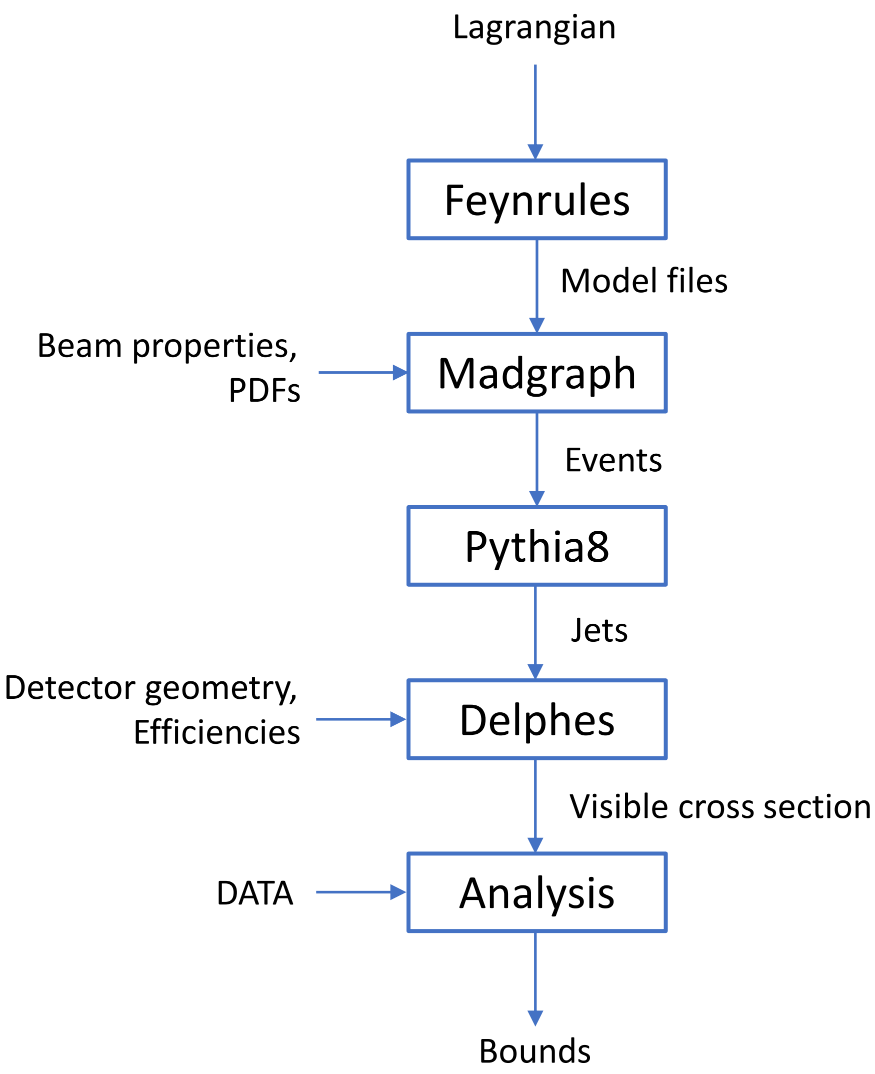
$$R_{D^{(*)}} = \frac{\mathcal{B}\left(B \to D^{(*)}\tau\nu\right)}{\mathcal{B}\left(B \to D^{(*)}\mu\nu\right)} \qquad R_{K^{(*)}} = \left.\frac{\mathcal{B}\left(B \to K^{(*)}\mu^+\mu^-\right)}{\mathcal{B}\left(B \to K^{(*)}e^+e^-\right)}\right|_{q^2 \in [q^2_{\rm min}, q^2_{\rm max}]}$$

- The relevant semileptonic transitions can also be probed in pp collisions but in a different energy regime.
- Non-resonant interactions: search of "fat" tails in di-lepton production

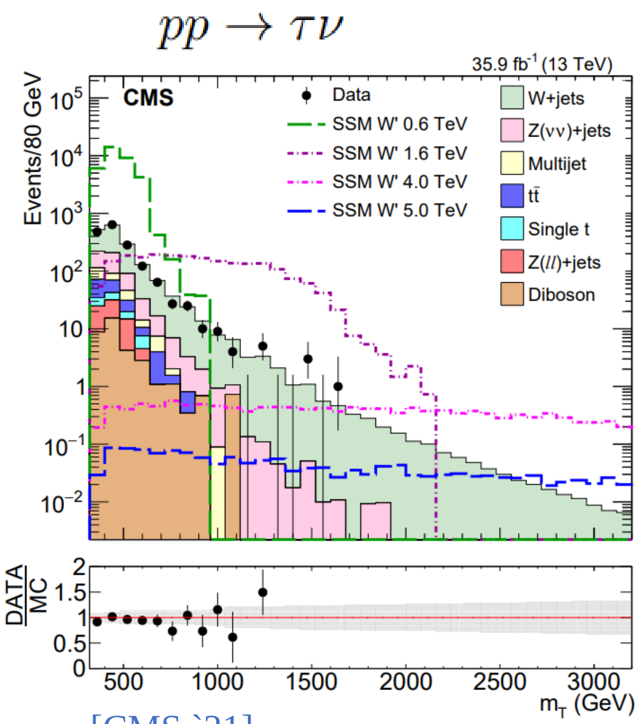




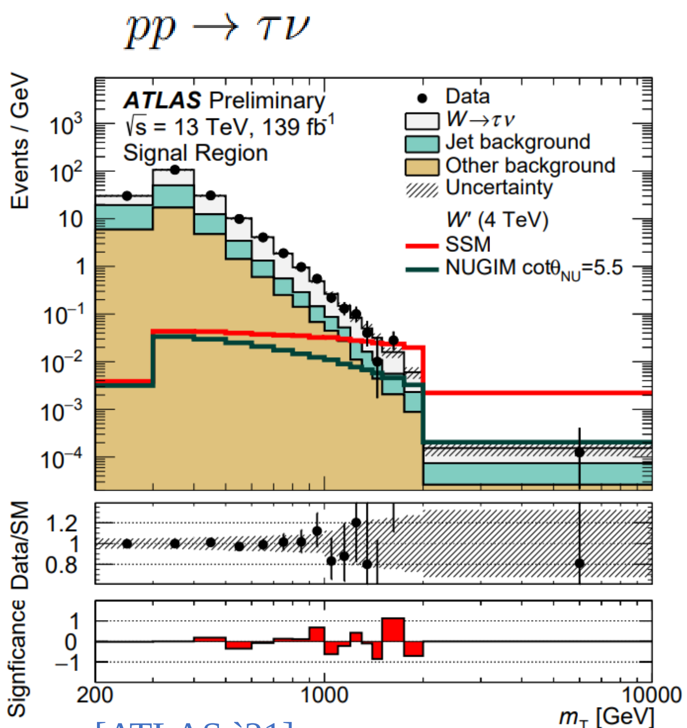
Constraining new physics using collider observables



- Parameters can be constrained by comparing the results of pseudo-experiments to data.
- Hard task : evaluate uncertainties



[CMS `21]



[ATLAS `21]

EFT example: $bc \to \ell\nu$

- EFT at the $\mathcal{O}(\text{TeV})$ scale can accommodate the charged current anomaly. [Di Luzio, Nardecchia `17]
- Lagrangian defined in term of 5 Wilson Coefficients:

$$\mathcal{L}_{NP} = -\frac{4G_f V_{ij}}{\sqrt{2}}\Big[g^{ij}_{V_{LL}}(\bar{u}_i\gamma_\mu P_L d_j)(\bar{\tau}\gamma^\mu P_L \nu_\tau) + g^{ij}_{V_{RL}}(\bar{u}_i\gamma_\mu P_R d_j)(\bar{\tau}\gamma^\mu P_L \nu_\tau)$$
$$+ g^{ij}_{S_L}(\bar{u}_i P_L d_j)(\bar{\tau} P_L \nu_\tau) + g^{ij}_{S_R}(\bar{u}_i P_R d_j)(\bar{\tau} P_L \nu_\tau) + g^{ij}_{T}(\bar{u}_i \sigma_{\mu\nu} P_L d_j)(\bar{\tau}\sigma^{\mu\nu} P_L \nu_\tau)\Big] + h.c.,$$

- Full cross section obtained by convoluting with PDFs $\longrightarrow$ Suppressed for heavy quarks

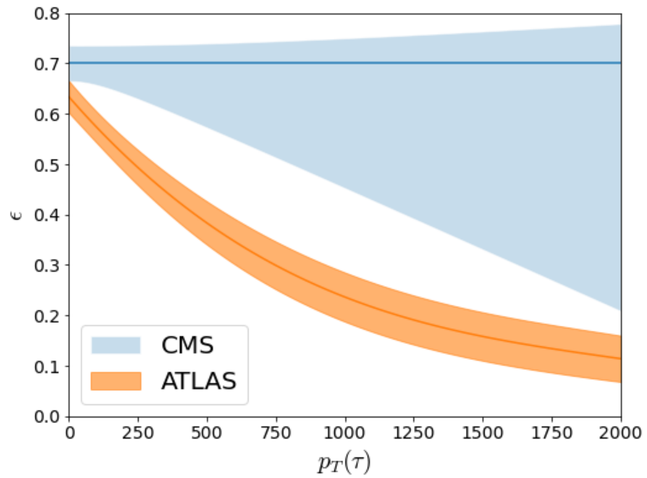
$$\hat{\sigma}(\hat{s}) \simeq \frac{|V_{cb}|^2 G_F^2 \hat{s}}{18\pi}\left[|g_{V_{LR}}|^2 + |g_{V_{RL}}|^2 + \frac{3}{4}|g_{S_L}|^2 + \frac{3}{4}|g_{S_R}|^2 + 4|g_T|^2\right]$$

$\downarrow$ Energy enhanced

$$\sigma(pp \to \tau^+\nu) = \sum_{ij}\int \frac{d\tau}{\tau}\mathcal{L}_{q_i\bar{q}_j}(\tau)\,[\hat{\sigma}(\tau s)]_{ij}\,,$$

$$\mathcal{L}_{q_i\bar{q}_j} = \tau\int_\tau^1 \frac{dx}{x}\left(f_{q_i}(x,\mu_F) f_{\bar{q}_j}(\tau/x,\mu_F) + q_i \leftrightarrow \bar{q}_j\right).$$

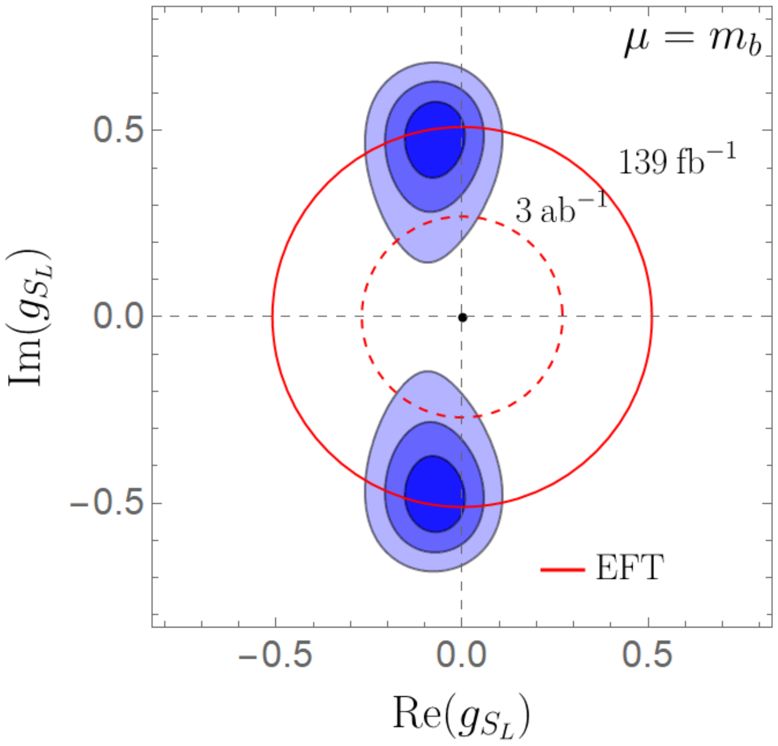
EFT example: $bc \to \ell\nu$



[CMS `21]
[ATLAS `21]

- Bounds of the same order than flavor !
- ATLAS at 139 fb^{-1} strangely equivalent to CMS at 36 fb^{-1}.

  $\longrightarrow$ Systematics on the tau reconstruction efficiency cannot be ignored.



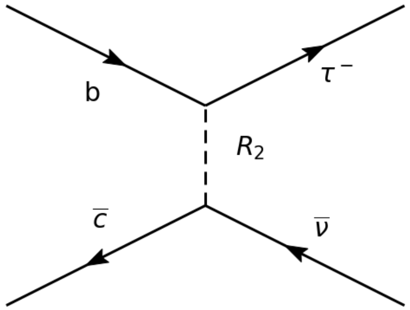
$$g_{S_L} = 4 g_{T}\big|_{\mu = 1\text{TeV}} \Rightarrow \boxed{\left|g_{S_L}\big|_{\mu = m_b}\right| < 0.5}$$

[Marzocca, Min, Son, `20]
[Greljo, Camalich, Ruiz-Alvarez, `18]
[this work]

- Can we really trust the EFT at such high scales ?

Example of full model: R_2

$$\mathcal{L}_{R_2} = y^R_{ij}\bar{Q}_i R_2 l_{Rj} + y^L_{ij}\bar{u}_{Ri}\widetilde{R}_2^\dagger L_j + \text{h.c.}$$



See [Becirevic et al. `18] for full model.

- We take $m_{R_2} = 1.3\ \text{TeV}$ and a particular Yukawa structure that can explain the charged current anomalies.
- The total cross section is ~30% smaller than the EFT cross section after matching.

$$\hat{\sigma}\left(c\bar{b} \to \tau^+\nu_\tau\right) = \frac{1}{128 N_c \pi s}\frac{\left|y^L_{c\tau}\right|^2 \left|y^R_{b\tau}\right|^2 \hat{u}^2}{\left(\hat{u} - m^2_{R_2}\right)^2}$$

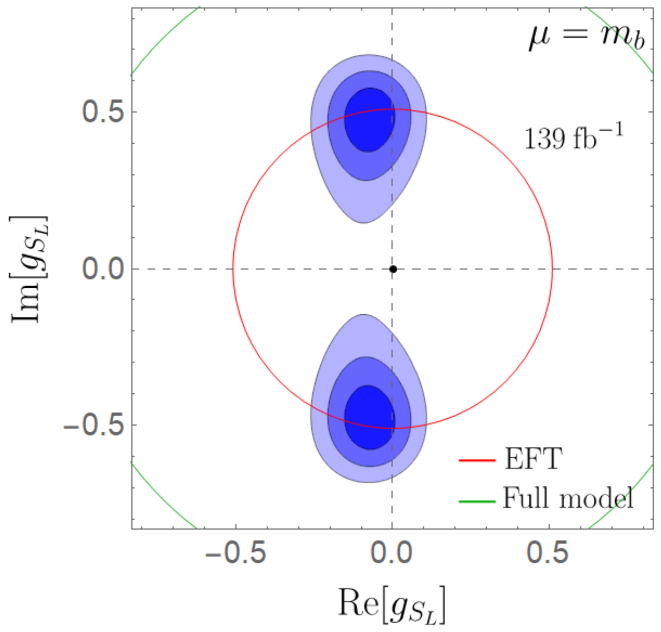
Because $$\frac{1}{u - m^2_{R_2}} \simeq -\frac{1}{m^2_{R_2}}\left(1 + \frac{u}{m^2_{R_2}} + \dots\right), \qquad u \in [-s, 0]$$

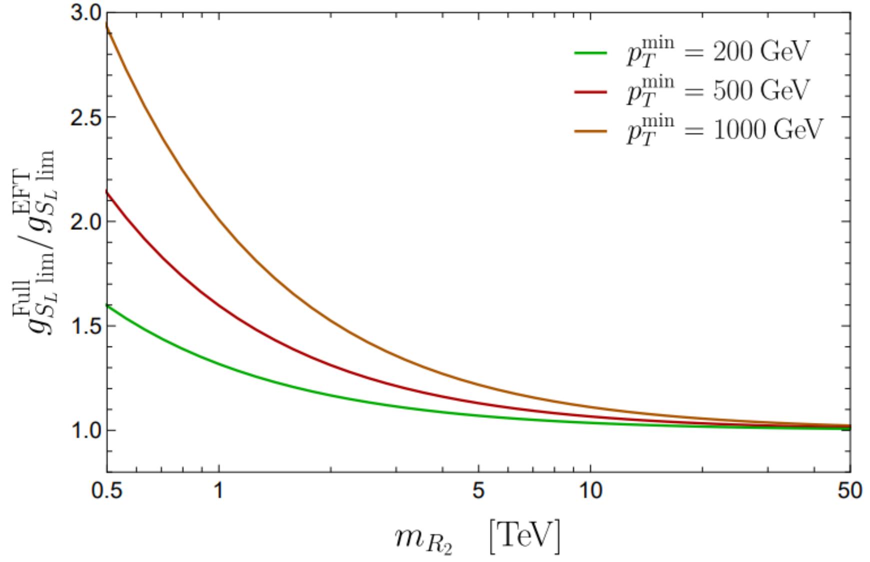
$$g_S^{\mu=m_{R_2}} = 4 g_T^{\mu=m_{R_2}} = \frac{y^L_{c\tau}\left(y^R_{b\tau}\right)^*}{4\sqrt{2} m^2_{R_2} G_F V_{cb}}$$

$$\boxed{\left(\left|y^L_{c\tau}\right|^2 + \left|y^L_{c\mu}\right|^2\right)\left|y^R_{b\tau}\right|^2 < 8.31}$$

- We can plug the constraint back into the matching.

Example of full model: R_2





- The 30% difference in cross section only holds for the full cross section
- In general, it is a function of $\hat{s}$!
- The validity of the EFT depends on cut of the analysis.
- Even without p_T cut, Bin 3 dominates in the analysis $\longrightarrow$ Effective cut.

- 2 solutions:
  - Restrict the EFT fit to low p_T $\longrightarrow$ Loses significance
  - Require the mass of NP to be high enough

    $\longrightarrow$ Focus on the cases of the larger mass scale of NP

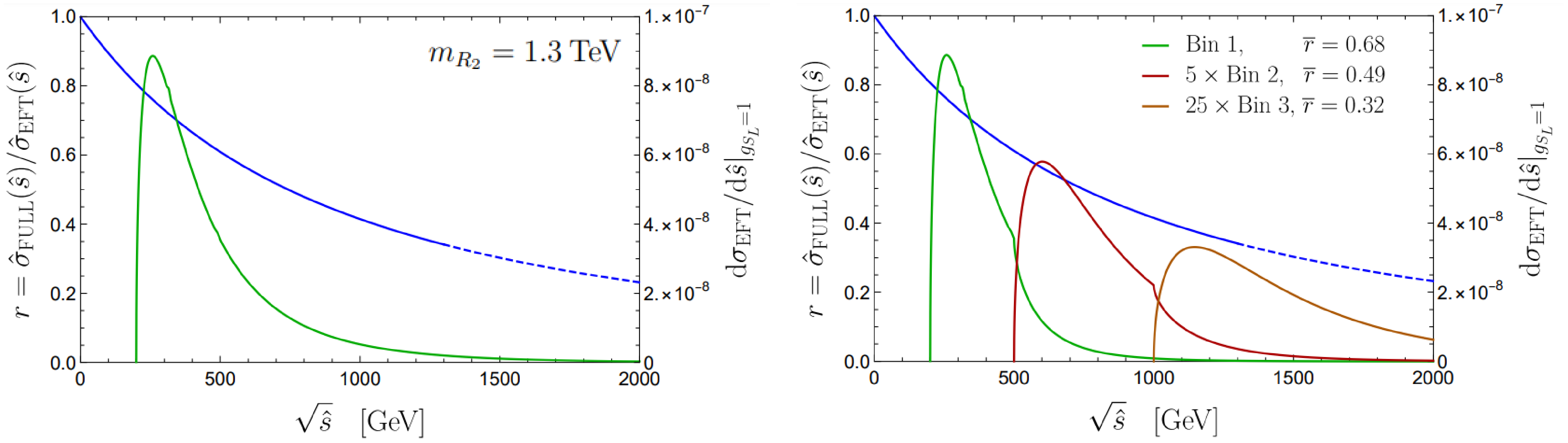
See also [Iguro, Takeuchi and Watanabe `21]

Conclusion

- Hints of LFUV in B decays strongly support the presence of NP.
- Since the cross section increases with energy, NP signatures could be seen at high-p_T.
- Hight-p_T searches can be competitive with flavor observables.
- The usual EFT approach can be used, but special care must be taken when interpreting the obtained results if the hight-p_T and NP scales are not sufficiently separated.
- Easy to over constrain the NP (tau efficiency, real cross-section smaller than the EFT)
- Inclusion of the propagation of the mediator in the simulation leads to more conservative but more reliable bounds.

Thank you !

Backup



Bin 1: $p_T \in [0.2, 0,5]$ TeV
Bin 2: $p_T \in [0.5, 1.0]$ TeV
Bin 3: $p_T > 1.0$ TeV