R_K prediction in the MSSM

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Outline

1. The Effective theory
2. The R_K in the MSSM
3. Direct/Indirect Searches
4. Final Results
5. Conclusions

Motivation

- MSSM has many attractive features, e.g. *gauge coupling unification, solution to the hierarchy problem, dark matter candidate*
- Can the MSSM explain the current tensions in B-Physics?
- Analytically understand the MSSM prediction for R_K.
- Numerically estimate the maximal effect of the MSSM in the R_K.

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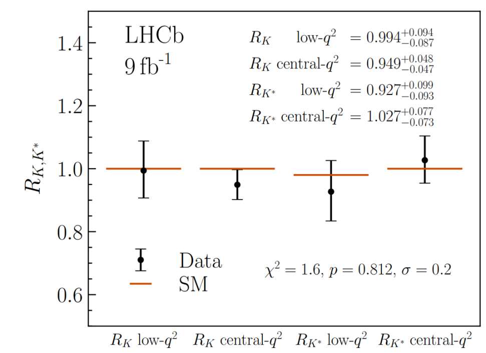
- ~~Can the MSSM explain the current tensions in B-Physics?~~ [LHCb: 2212.09153]



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Outline

The EFT Description

EFT characteristics:

- Relevant scale of the EFT at m_b, integrated out everything above 4 GeV.
- We call this EFT either *Weak Effective Theory (WET)* or *Low Energy Effective Theory (LEFT)*.
- Suitable EFT to study $b \to s\ell\ell$ transition.

Wilson coefficients:

- SM mainly contributes to 3 operators at the scale $\mu_b = 4.8$ GeV are

$$C_7^{\mathrm{SM}}(\mu_b) = -0.29 \qquad C_9^{\mathrm{SM}}(\mu_b) = 4.2 \qquad C_{10}^{\mathrm{SM}}(\mu_b) = -4.2$$

- Vector operators are dominant for the process $b \to s\ell\ell$.
- The Wilson coefficient C_7 contributes mostly to radiative decays.

Basis and Observables

- We define a chiral basis:

$$\mathcal{L}_{\text{eff}} = -\frac{1}{16\pi^2} \sum_{X,Y=L,R} C_{VXY}\, O_{VXY}$$

$\mathcal{O}^{IJKL}_{VXY} = \left(\bar{q}^J \gamma^\mu P_X q^I\right)\left(\bar{\ell}^L \gamma_\mu P_Y \ell^K\right)$: semileptonic operators.

- Measure of lepton flavor universality violation (LFUV)

$$R_K = \frac{\text{Br}(B^+ \to K^+ \mu^+ \mu^-)}{\text{Br}(B^+ \to K^+ e^+ e^-)}, \quad R_{K^*} = \frac{\text{Br}(B \to K^* \mu^+ \mu^-)}{\text{Br}(B \to K^* e^+ e^-)} .$$

- In terms of WCs the two ratios are: [Hiller, Schmaltz: 1411.4773]

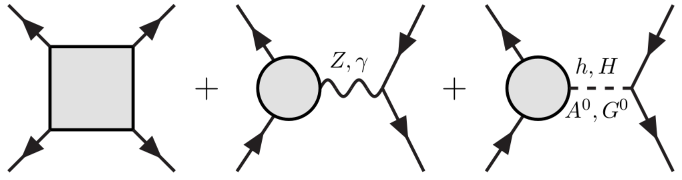
$$R_K \simeq 1 + \Delta_+, \qquad R_{K^*} \simeq 1 + p(\Delta_- - \Delta_+) + \Delta_+ ,$$

with $\Delta_\pm = 2\,\text{Re}\left[\frac{C^\mu_{VLL} \pm C^\mu_{VRL}}{C^{\text{SM}}_{VLL}} \; - \; (\mu \to e)\right]$

Outline

Strategy of the Calculation

- Relevant Feynman diagrams in the MSSM:



- All contributions have been calculated (boxes, Z,γ-penguins and Higgses), in the mass basis. [Dedes, Rosiek, Tanedo: 0812.4320]

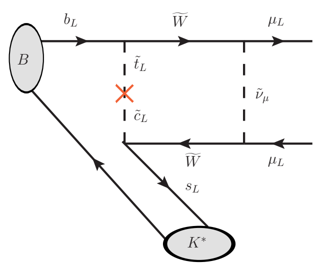
- Translate WCs from *mass basis* to *flavor basis* using FET to obtain the Mass Insertion (MI) approximation. [Dedes, *et al.*: 1504.00960]

- Analytically work out dominant contributions in the R_K, under NMFV assumptions.

- Verify numerically using `SUSY_FLAVOR`, while evading *direct* and *indirect* bounds. [J. Rosiek *et al.*: 1203.5023]

The R_K in the MSSM

- Z and γ - penguins are LFU and **drop out** of the calculation
- After FET, the dominant supersymmetric contribution is the box diagram



- To a good approximation in the MSSM

$$R_K \approx R_{K^*} \approx 1 + \Delta_+$$

- Major contribution from chargino-stop-muon sneutrino and the MI parameter $(\delta_U)^{23}_{LL}$

Semi-analytic expression for R_K

$$R_K(\chi^\pm)|_{\rm MSSM} \approx 1 - \underbrace{\left(\frac{v}{M_{\rm SUSY}}\right)^2 0.02}_{\rm MFV} - \underbrace{\left(\frac{v}{m_{\tilde{t}}}\right)^2 0.4(\delta_U)^{23}_{LL}}_{\rm NMFV}$$

Back of the envelope calculation

- Wino and stop masses close to the EW scale.
- Large mass hierarchy between muon-sneutrino and electron-sneutrino
- The dominant MI, $(\delta_U)^{23}_{LL} \sim \mathcal{O}(1)$.
- A very first rough estimate:

$$|\Delta R_K|_{\text{MSSM}} \approx 42\%$$

Reality check

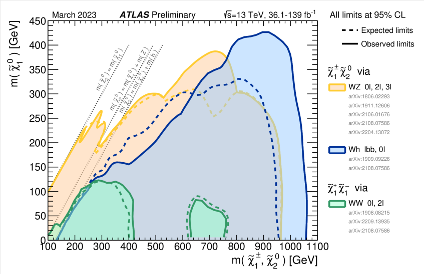
How much of this contribution remains after imposing contraints from **direct** and **indirect** searches?

Outline

Direct Searches

Direct production of $\chi_1^{\pm}\chi_2^0$ via SM bosons

- χ_1^0: pure Bino $\Rightarrow$ $M_1 = 200$ GeV
- χ_2^0 and $\chi_1^{\pm}$ degenerate, pure Wino states $\Rightarrow$ $M_2 = 300$ GeV



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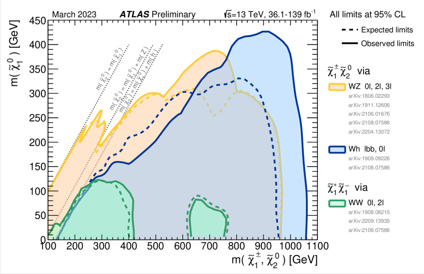

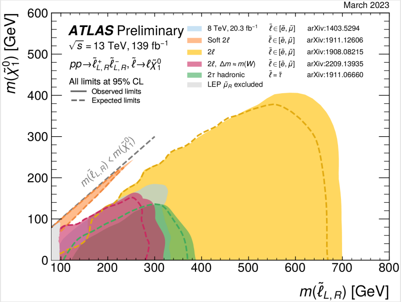

Smuon direct production,

- Bino mass at 200 GeV, $\Rightarrow$ $\tilde{\mu} \sim 220$ GeV
- Heavy mass scales ~ 3 TeV for other sleptons.

Direct Searches

Various gluino decays into lightest neutralino

- Gluino mass: $\Rightarrow M_G > 2.4$ TeV

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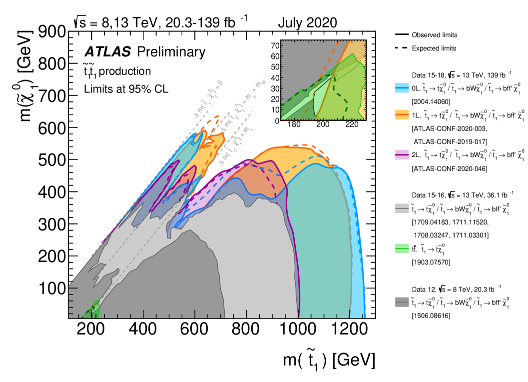
Direct stop production

- Lightest stop mass: $\Rightarrow m_{\tilde{t}_1} > 1.25$ TeV.
- Common mass scales at ~ 2.5 TeV for all squarks.
- OR tune the masses at $m_{\tilde{\chi}_1^0} \sim 400$ GeV and $m_{\tilde{t}_1} \sim 600$ GeV.



Indirect Searches

- $B - \bar{B}$ mixing: where we allow

$$\frac{\Delta M_s^{\text{MSSM}}}{\Delta M_s^{\text{SM}}} \equiv \Delta M_s^{\text{NP}} \leq 20\%$$

- Radiative decay of the B-meson:

$$Br(B \to X_s \gamma) = (3.32 \ \pm \ 0.15) \times 10^{-4}$$

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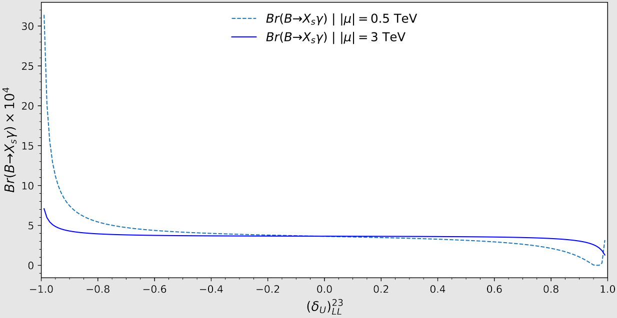

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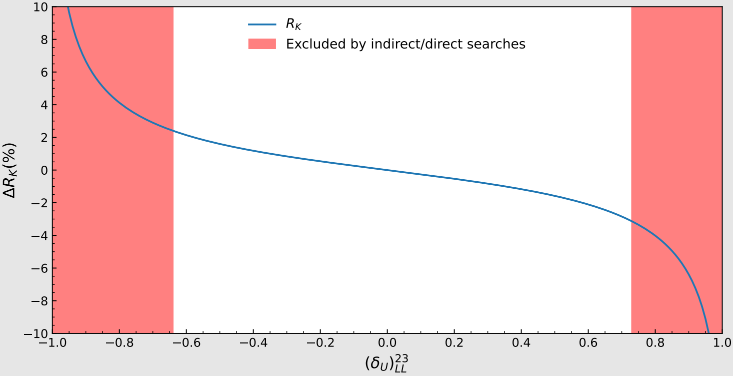
Final results I

Finally, after considering both **direct** and **indirect** bounds and for $\mathbf{m_{\tilde{t}_1}} \geq 1.25$ TeV:

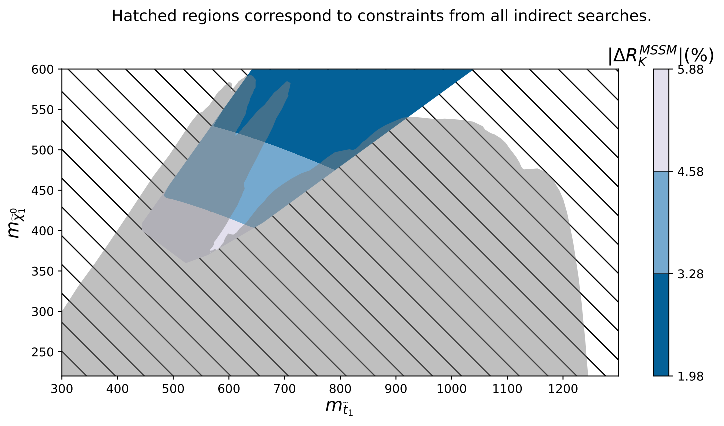


Numerically,

$$|\mathbf{\Delta R_K}|_{\mathrm{MSSM}} < \mathbf{4}\%$$

Final Results II

For the **ATLAS gap** scenario the final results is given by the contour plot:



Numerically,

$$|\mathbf{\Delta R_K}|_{\mathrm{MSSM}} \leq \mathbf{5}\%$$

Outline

Conclusions

- Analytically tried to understand R_K contributions in the NMFV scenarios using FET.
- Identified the most dominant contribution coming from chargino boxes and the leading MI $(\delta_U)^{23}_{LL}$.
- Applied direct and indirect bounds on the relevant MSSM parameters.
- Numerically estimated the SUSY prediction for $0.95 \leq R_K^{\text{MSSM}} \leq 1.05$.

Thank you!