PARIS

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Towards excluding a Light Z' explanation of $b \to s\ell^+\ell^-$ anomalies

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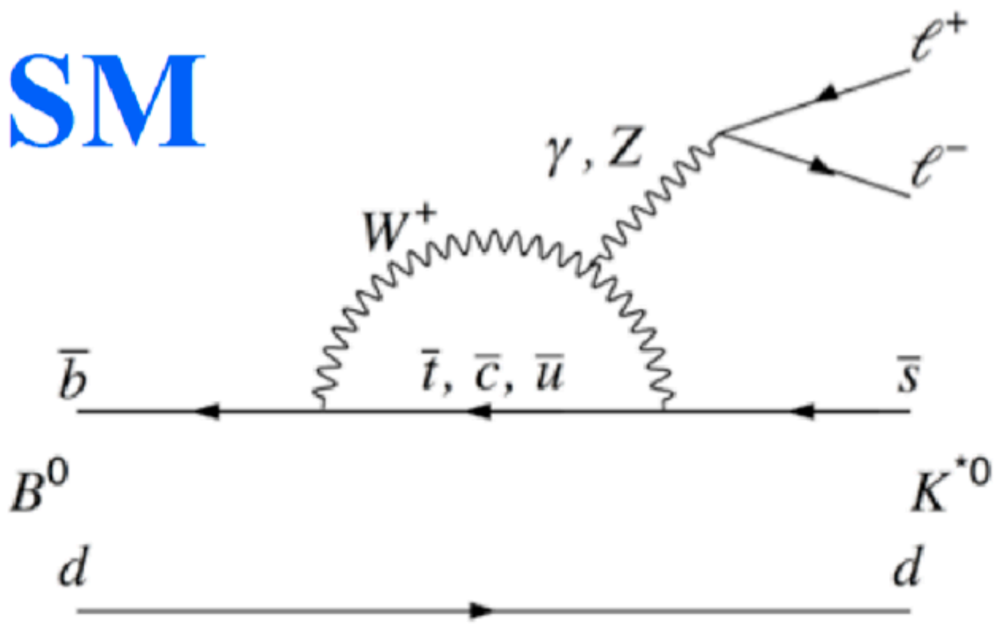
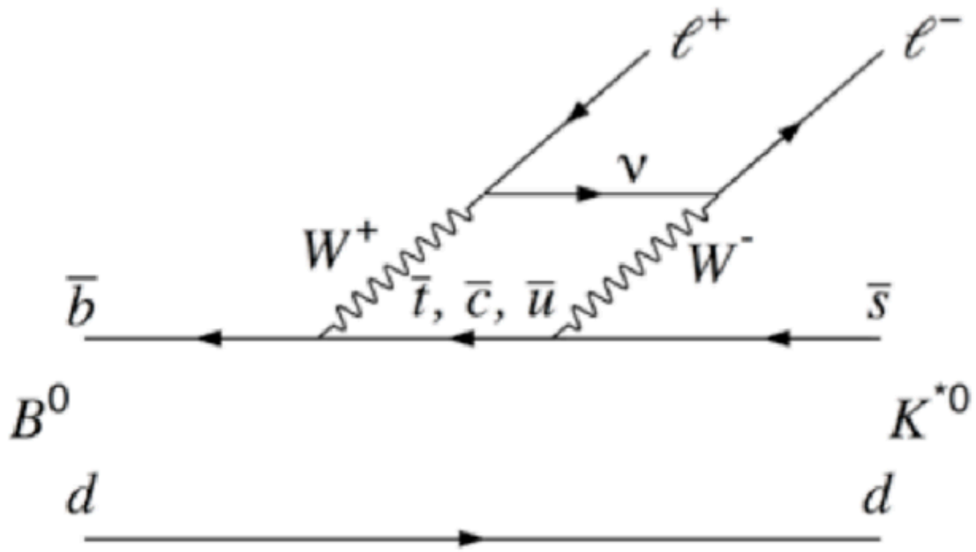
Neutral Current B Decays

Neutral Current B Decays

Many observables with the underlying process $b \to s\ell^+\ell^-$ exhibit deviations from SM expectations.





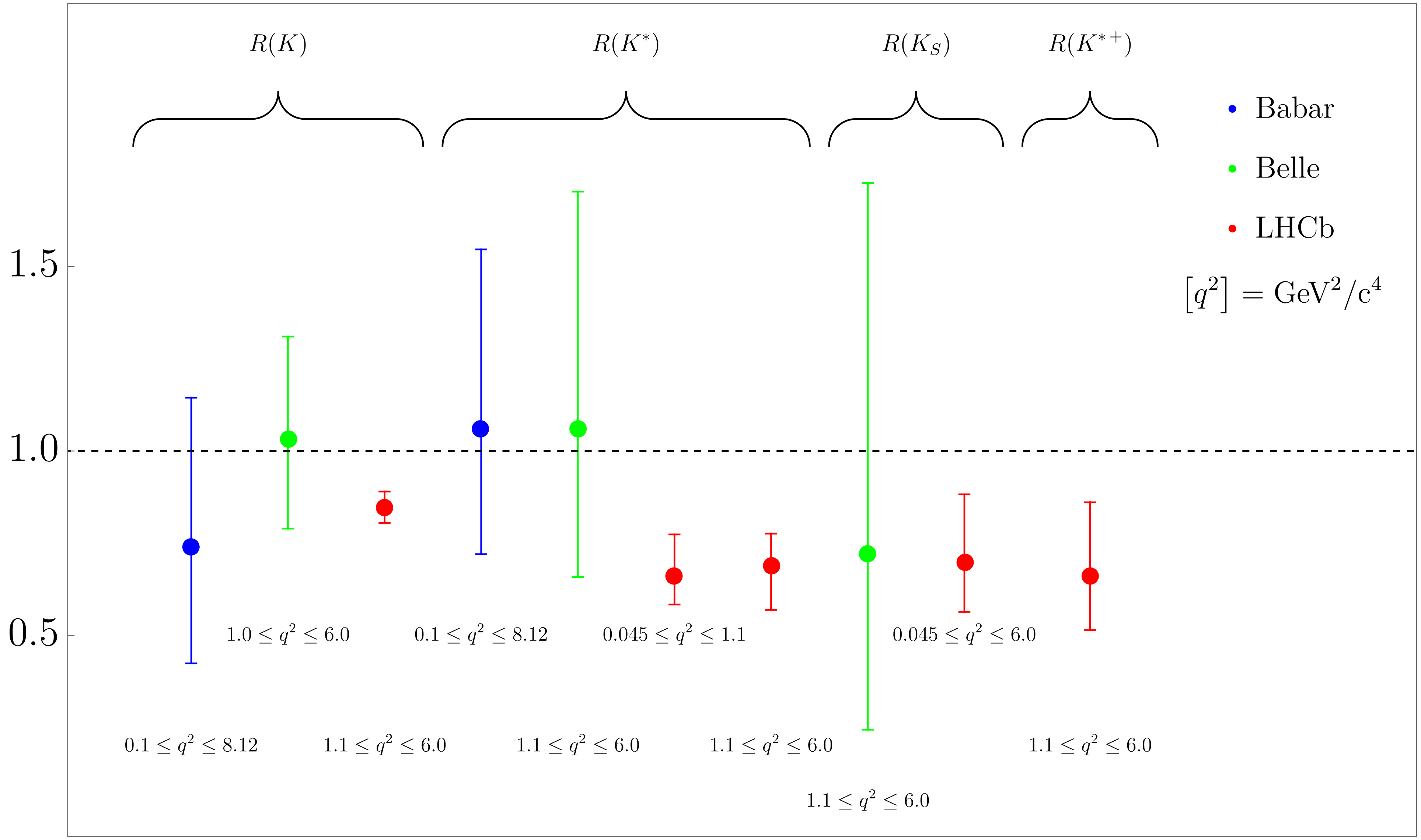
Due to their suppression in the SM, they have a high sensitivity to potential NP contributions.

Neutral Current B Decays

$b \to s\mu^+\mu^-$ vs $b \to se^+e^-$

Huge experimental effort from LHCb and Belle

$$R(A) = \frac{\int \frac{d\mathcal{B}}{dq^2}(B \to A\mu^+\mu^-)dq^2}{\int \frac{d\mathcal{B}}{dq^2}(B \to Ae^+e^-)dq^2}$$



There is a coherent pattern of deviations from the SM

Other Observables show coherent discrepancies with the SM

$B_s \to \mu^+\mu^-$ theoretically very clean but chirality suppress

Angular Observables: P_5' ,... theoretically less clean

Neutral Current B Decays

To perform a global fit to all data we work within the model-independent approach of the effective Hamiltonian:

$$H_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i C_i O_i$$

$$O_9 = \frac{e}{16\pi^2}(\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell)\,, \qquad O_9' = \frac{e}{16\pi^2}(\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \ell)\,,$$

$$O_{10} = \frac{e}{16\pi^2}(\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)\,, \qquad O_{10}' = \frac{e}{16\pi^2}(\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)\,,$$

$$O_S = \frac{e}{16\pi^2}(\bar{s} P_R b)(\bar{\ell}\ell)\,, \qquad O_S' = \frac{e}{16\pi^2}(\bar{s} P_L b)(\bar{\ell}\ell)\,,$$

$$O_P = \frac{e}{16\pi^2}(\bar{s} P_R b)(\bar{\ell}\gamma_5 \ell)\,, \qquad O_P' = \frac{e}{16\pi^2}(\bar{s} P_L b)(\bar{\ell}\gamma_5 \ell)\,.$$

This approach works also for a light Z': $C_i(q^2)$!

Good Fit requires effects in the muon channel: C_9^μ, $C_9^\mu = -C_{10}^\mu$, …

2103.13370
2103.12738
2104.08921

Light Z'

https://inspirehep.net/literature/2039365

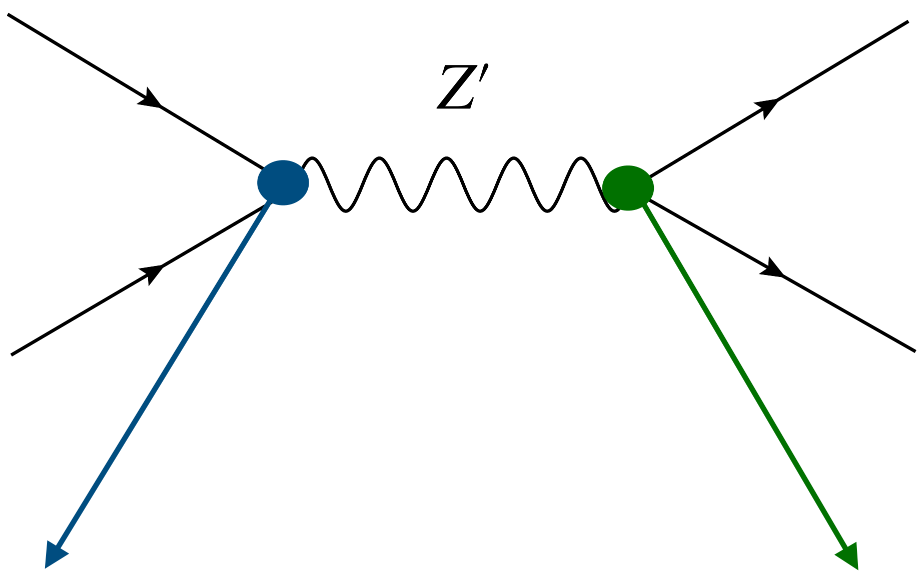
W. Altmannshofer, A. Crivellin, C.A.M., G. Inguglia, P. Feichtinger, J.M. Camalich

Light Z'

$m_{Z'} \lesssim 6$ GeV

We want to investigate whether a solution to $b \to s\ell^+\ell^-$ can be excluded

What are the minimal ingredients we need?

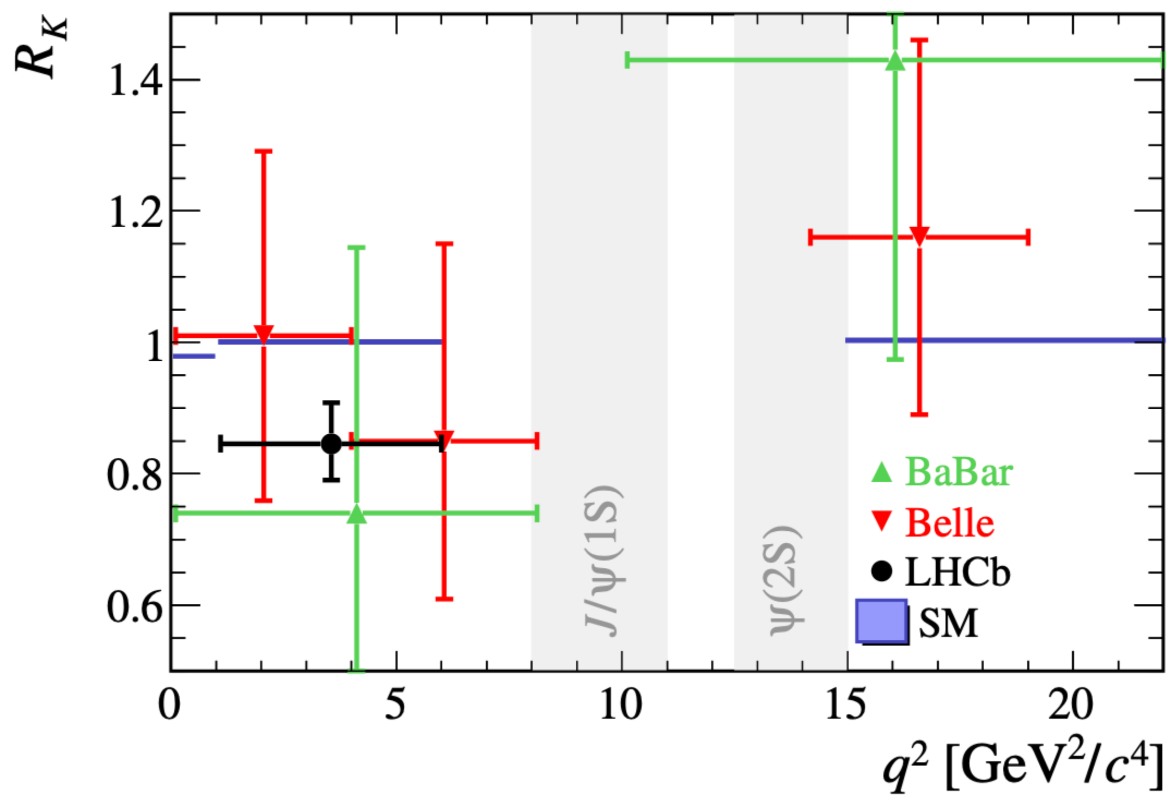


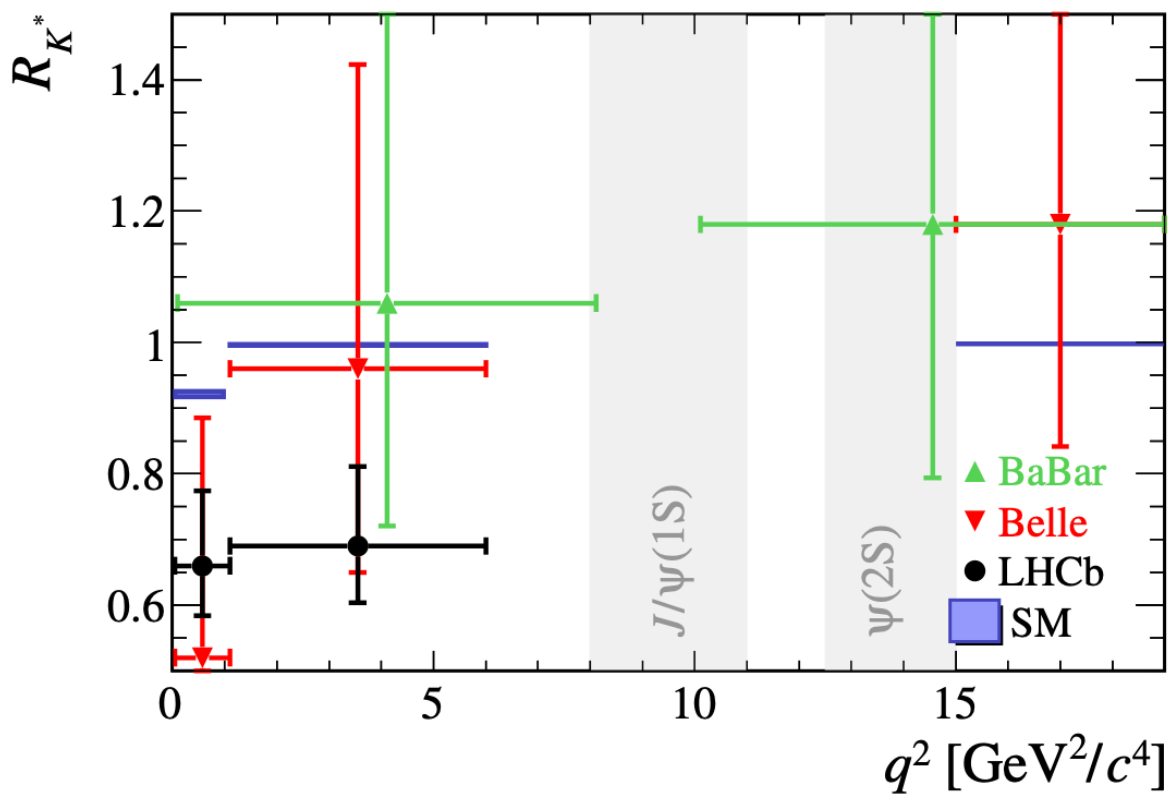
$b - \bar{s}$ coupling

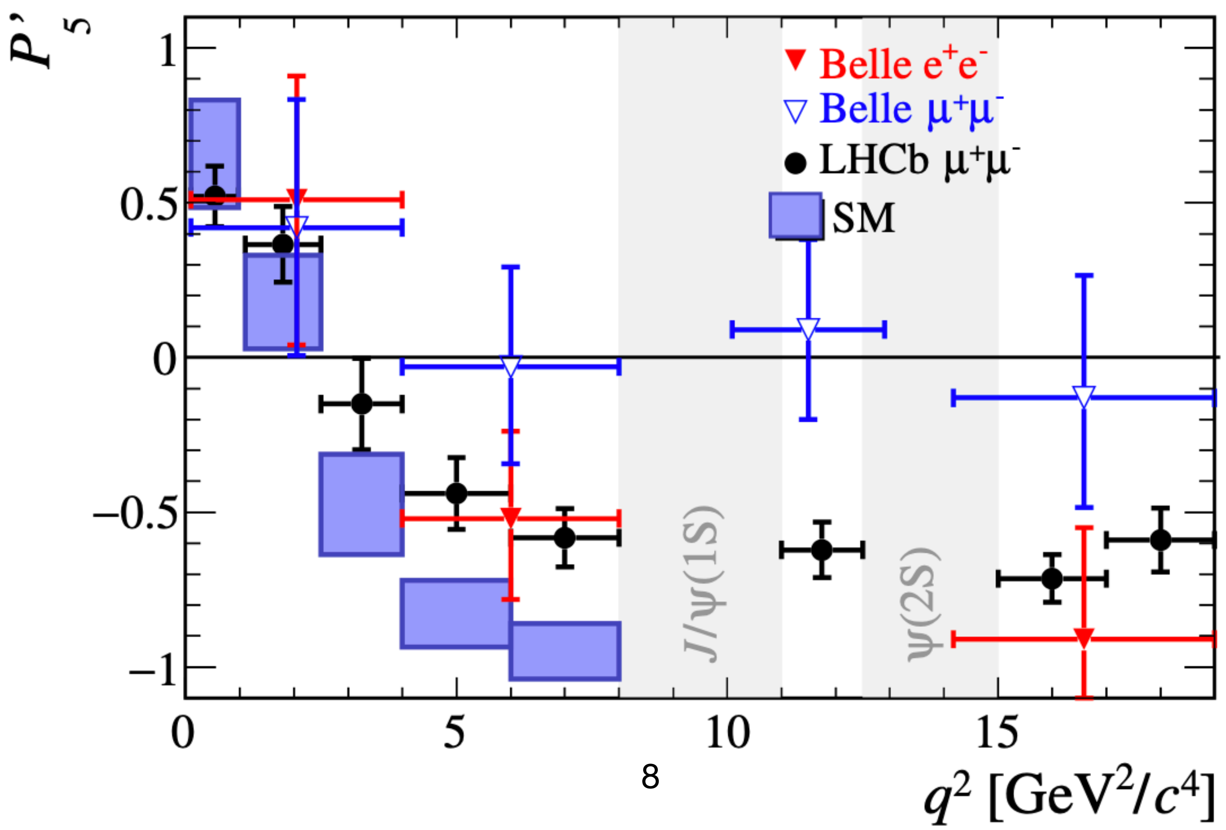
$\mu - \bar{\mu}$ coupling

Light Z'

$m_{Z'} \lesssim 6$ GeV







Light Z'

Setup

$m_{Z'} \lesssim 6$ GeV

$$\mathscr{L}_{Z'} \supset \left[\bar{\mu}\left(g^V_{\mu\mu}\gamma^\mu + g^A_{\mu\mu}\gamma^\mu\gamma_5\right)\mu + g^L_{sb}\bar{s}\gamma^\mu P_L b + g_\chi \bar{\chi}\gamma^\mu\chi\right] Z'_\mu$$

Observables

- $b \to s\ell^+\ell^-$
- $B \to K^{(*)}$ + invisible
- $B_s - \bar{B}_s$ mixing
- $(g-2)_\mu$
- $pp \to \mu^+\mu^-$ + invisible
- $e^+e^- \to \mu^+\mu^-$ + invisible

Light Z'

$b \to s\ell^+\ell^-$ & $(g-2)_\mu$

$m_{Z'} \lesssim 6$ GeV

$$\mathcal{L}_{Z'} \supset \left[\bar{\mu}\left(g^V_{\mu\mu}\gamma^\mu + g^A_{\mu\mu}\gamma^\mu\gamma_5\right)\mu + g^L_{sb}\bar{s}\gamma^\mu P_{L,R} b + g_\chi \bar{\chi}\gamma^\mu\chi\right] Z'_\mu$$

$b \to s\ell^+\ell^-$

$(g-2)_\mu$

$$C_9 = \frac{g^L_{sb} g^V_{\mu\mu}}{q^2 - m^2_{Z'} + i m_{Z'}\Gamma_{Z'}}$$

$$C_{10} = \frac{g^L_{sb} g^A_{\mu\mu}}{q^2 - m^2_{Z'} + i m_{Z'}\Gamma_{Z'}}$$

$$\Delta a_\mu = \frac{m^2_\mu}{12\pi^2 M^2_{Z'}} \mathrm{Re}\left[(g^V_{\mu\mu})^2 - 5(g^A_{\mu\mu})^2\right]$$

$$g_V = -\sqrt{5} g_A$$

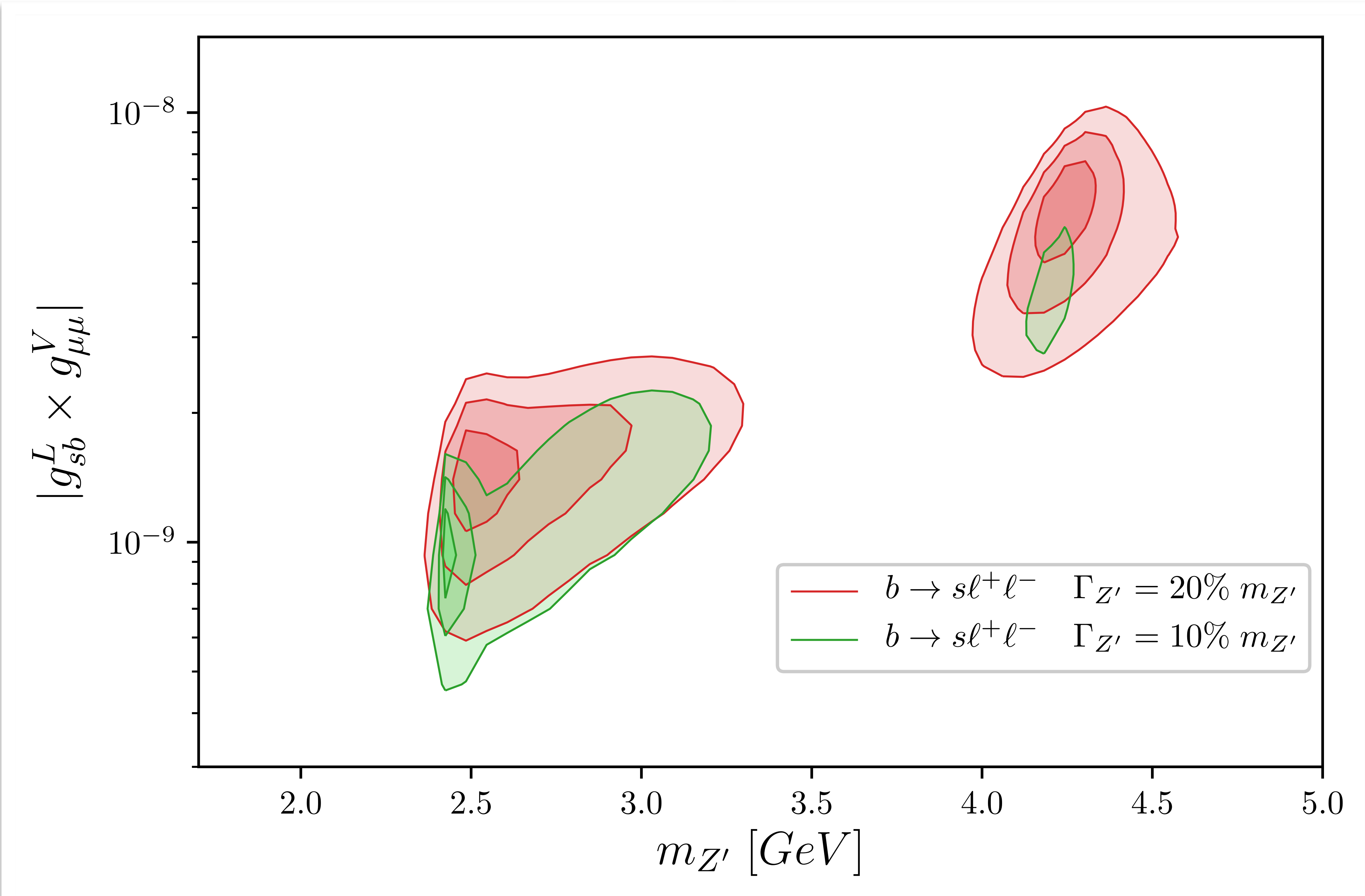
$m_{Z'} \gtrsim 2.5$ GeV

F. Sala, D. Straub hep/1704.06188.pdf

Light Z'

$b \to s\ell^+\ell^-$

$C_9 = -\sqrt{5}C_{10}$



Light Z'

$B \to K^{(*)} \nu\nu$

$$\mathscr{B}(B \to K^{(*)}\chi\bar{\chi}) = \mathscr{B}(Z' \to \bar{\chi}\chi) \int_{s_{\min}}^{s_{\max}} ds\, \Gamma_{Z'}(s)\, \mathrm{BW}(s)\, \mathscr{B}(B \to K^{(*)}Z')(s)$$

$$s_{\min} = 4m_\chi^2$$

$$s_{\max} = \left(m_B - m_{K^{(*)}}\right)^2$$

$$\mathrm{BW}(s) = \frac{\sqrt{s}}{\pi} \frac{1}{(s - m_{Z'}^2)^2 + \Gamma_{Z'}(s)^2 m_{Z'}^2}$$

$$\Gamma_{Z'}(s) = \frac{g_\chi^2}{12\pi\sqrt{s}} \sqrt{1 - 4\frac{m_\chi^2}{s}}\,(s + 2m_\chi^2)$$

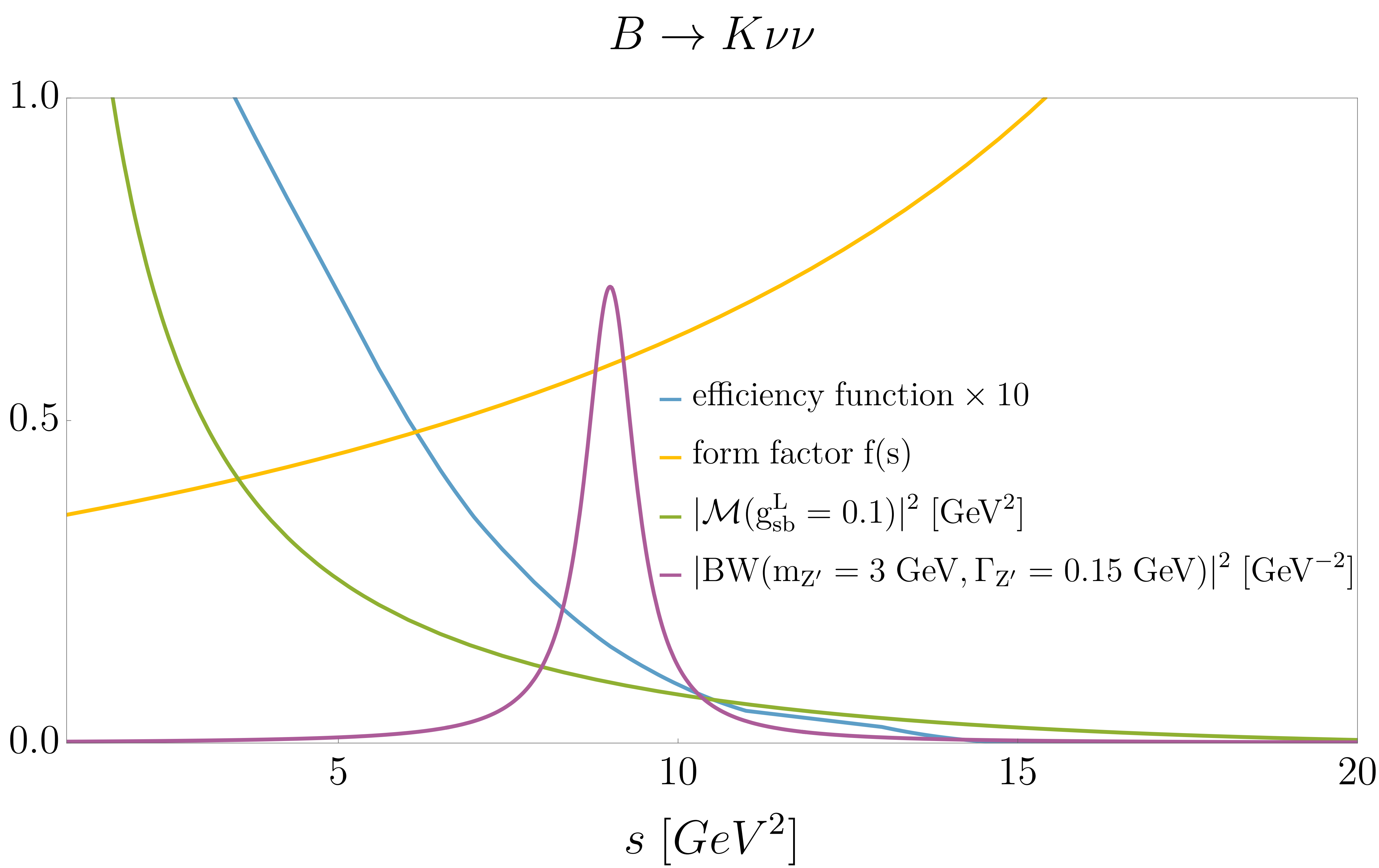
Belle II:

$\mathscr{B}(B^+ \to K^+\nu\bar{\nu}) < 4.1 \times 10^{-5}$

Others: Babar, Belle

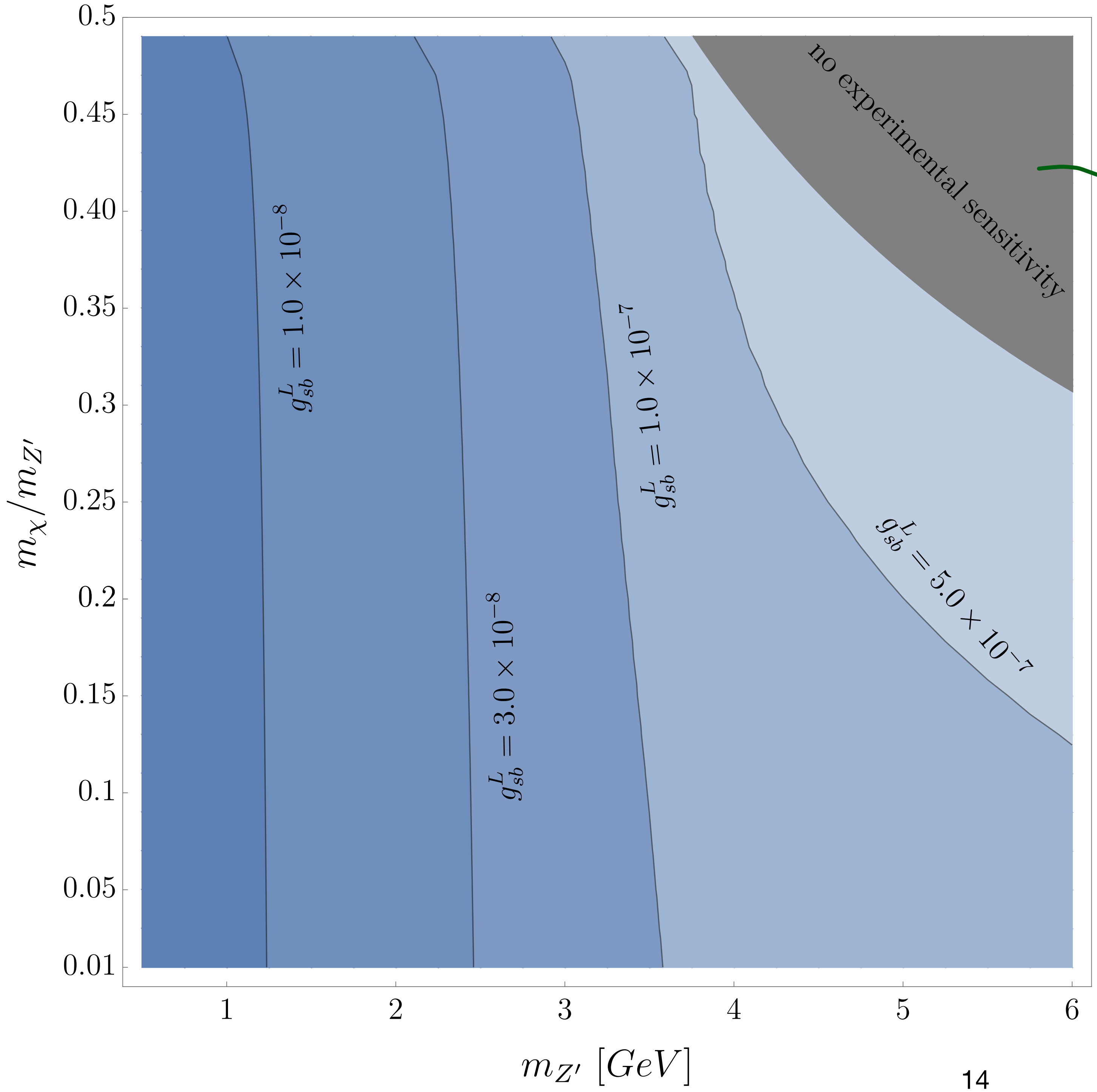
Light Z'

$B \to K^{(*)}\nu\nu$



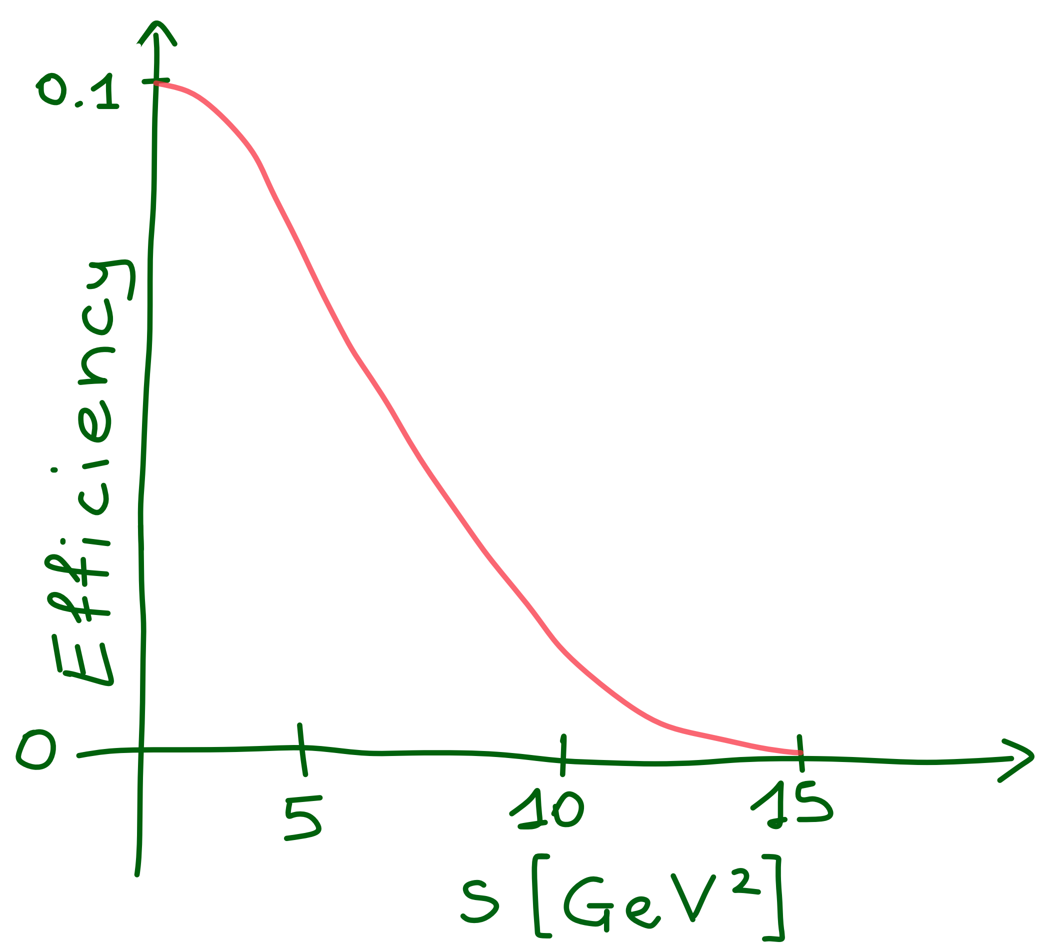
Light Z'

Recasted Belle II analysis



- A large m_χ weakens the bounds on g_{sb}^L

$$s_{\text{min}} = 4m_\chi^2$$



Light Z'

Other bounds

$B_s - \bar{B}_s$ mixing

- Light Z' masses: OPE in $m_{Z'}/m_B$ $\rightarrow$ weaker than $B \rightarrow K^{(*)}\nu\nu$
- For $m_{Z'} \sim m_B$: no reliable treatment yet

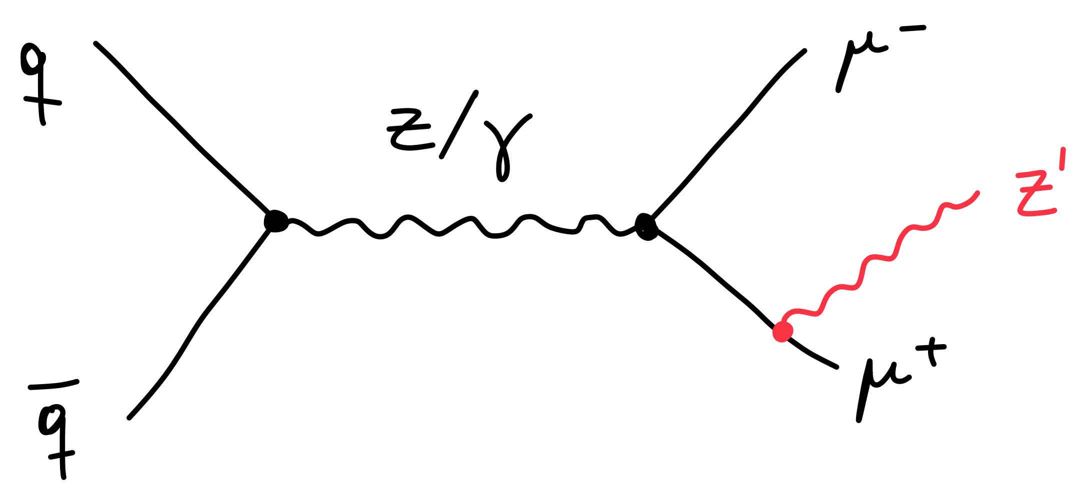
$e^+e^- \rightarrow \mu^+\mu^- + \text{invisible}$

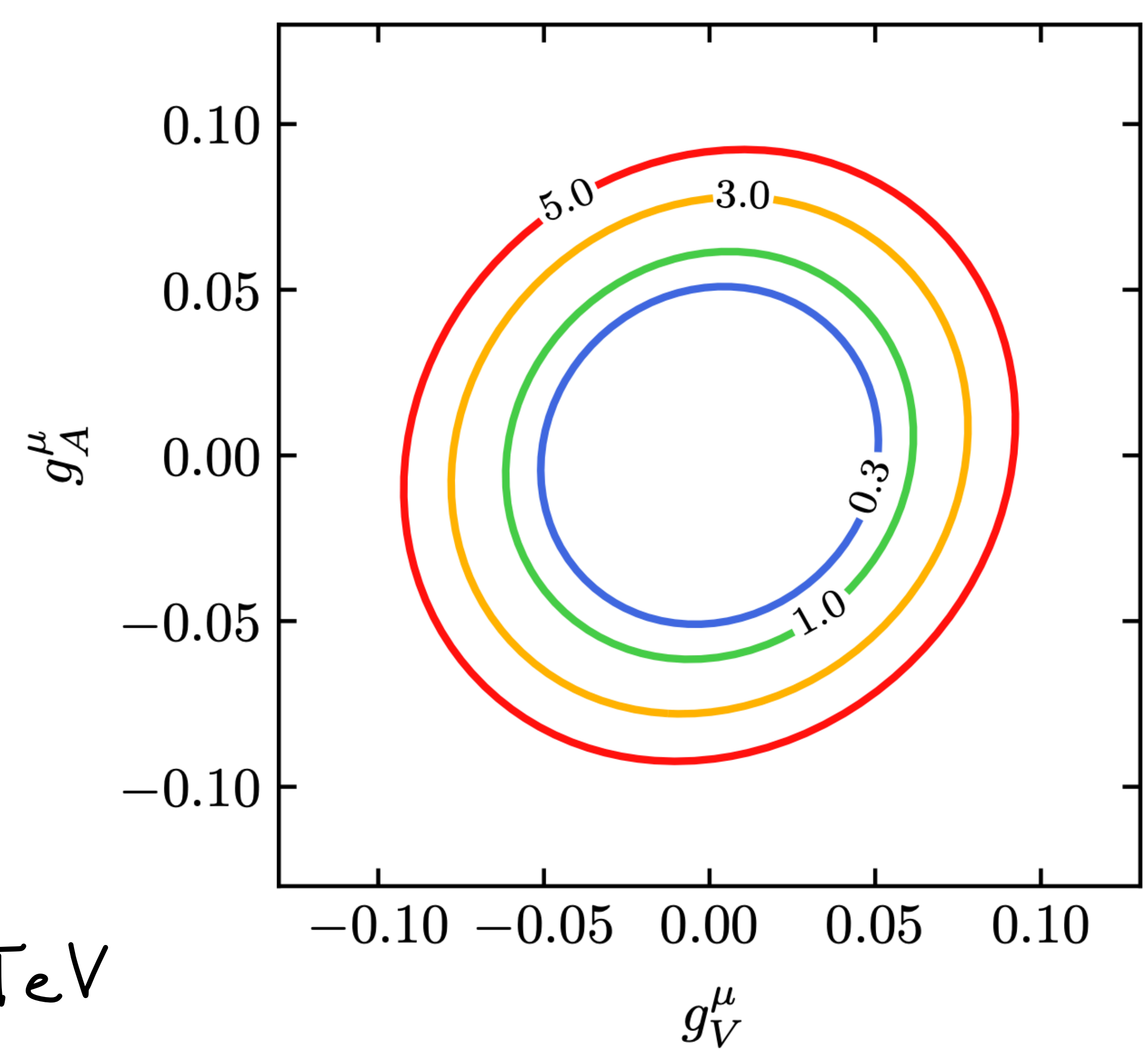
- Recasted Belle II analysis for a sizeable Z' width:
  - $276\ \text{pb}^{-1}$ hep/1912.11276
  - $50\ \text{fb}^{-1}$
  - $5\ \text{ab}^{-1}$

Limits on $g^V_{\mu\mu}$ of the order $10^{-1} - 10^{-2}$

$pp \rightarrow \mu^+\mu^- + \text{invisible}$

F. Bishara, U. Haisch, P.F. Monni hep/1705.03465

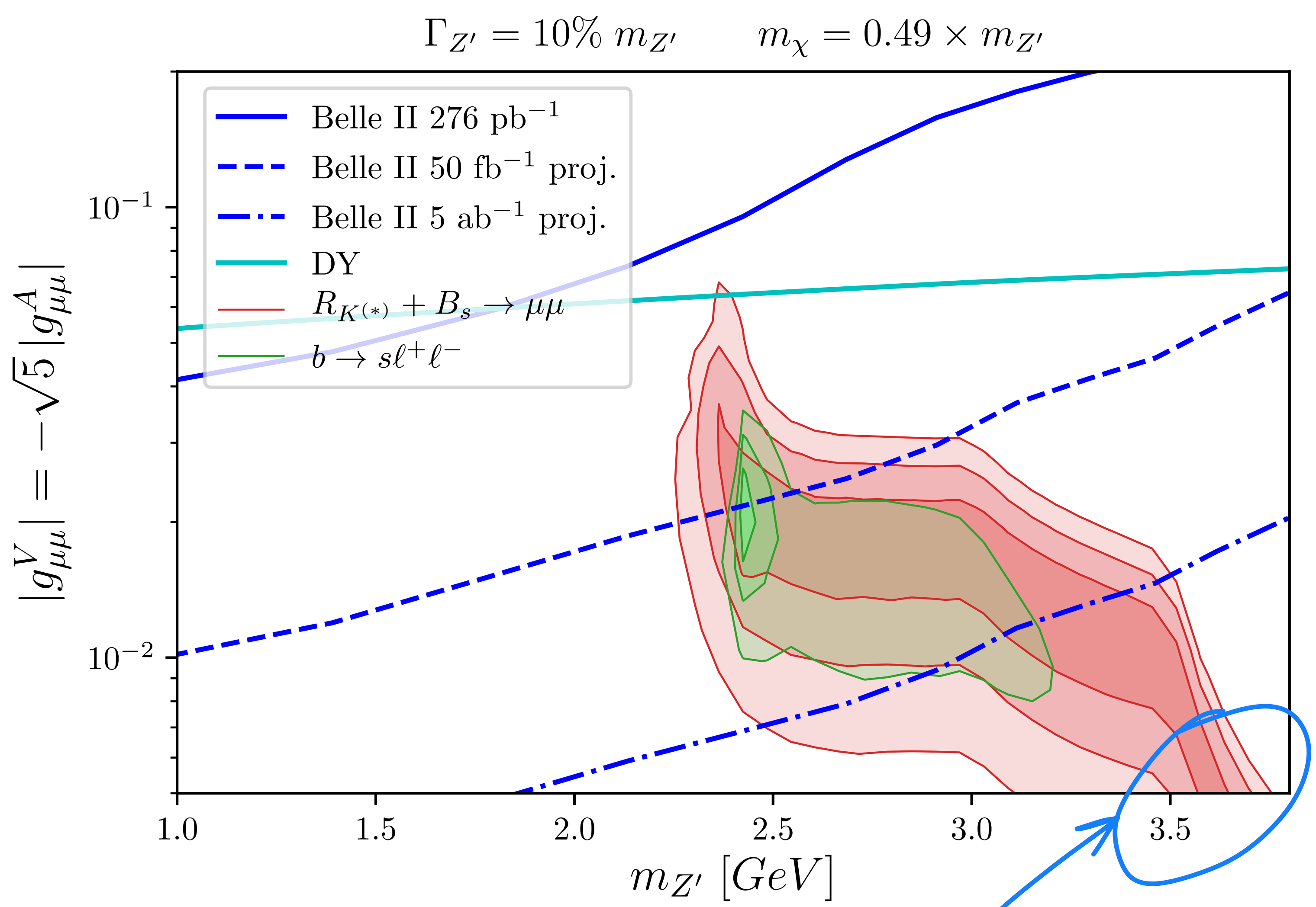




ATLAS 3.2 fb^{-1} $\sqrt{s} = 13$ TeV

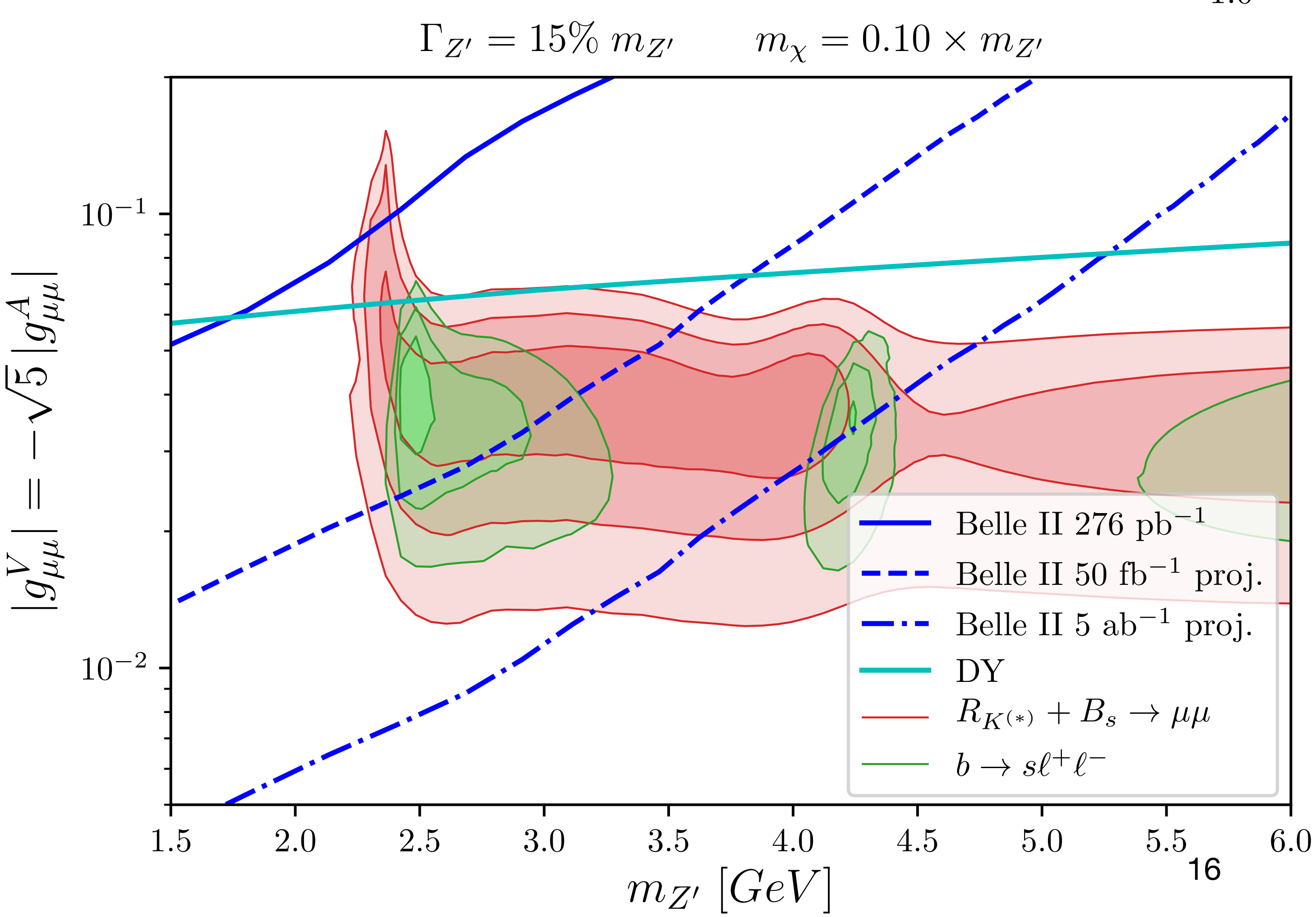
Light Z'

Bounds on $g^V_{\mu\mu}$



Maximum g^L_{bs} allowed by $B \to K^{(*)}\nu\nu$

Cannot exclude a light Z' yet



Belle efficiency drops

$\Longrightarrow g^L_{bs}$ can be very large

- **Future Belle II analysis can exclude**

  $m_{Z'} \sim 2.5$ GeV

- $m_{Z'} \sim 4$ GeV **would not lead to**

  $R(K^{(*)}) > 1$ **in high-q^2 bins**

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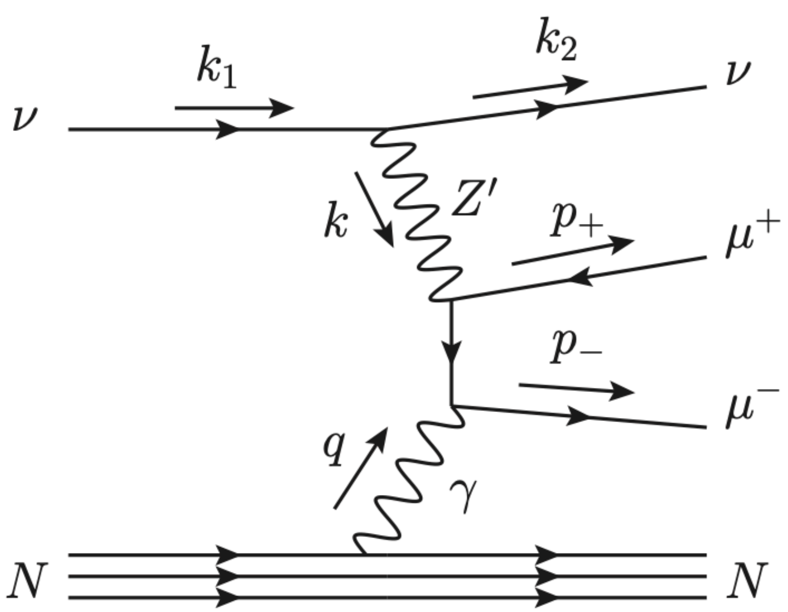
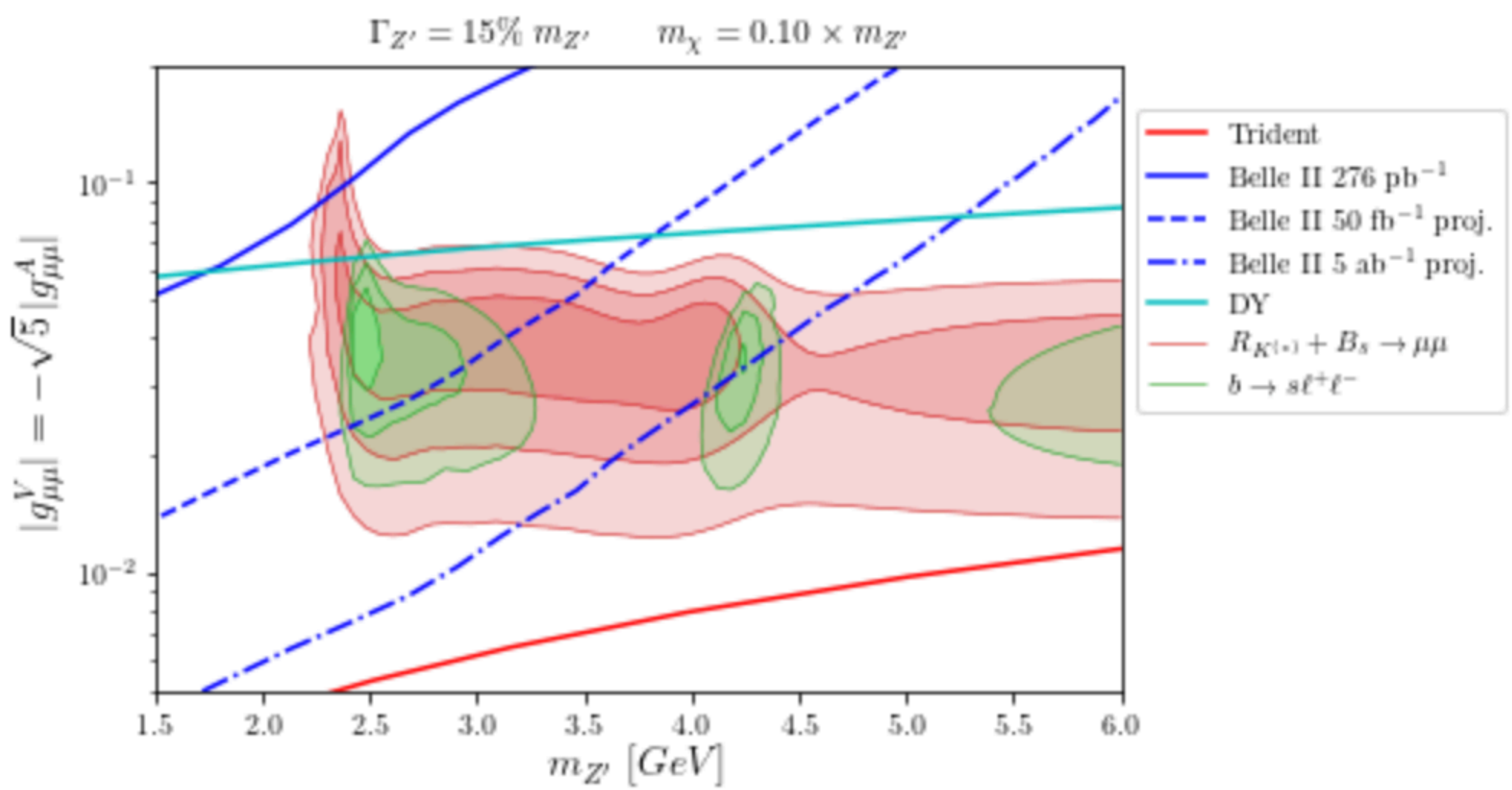
Light Z'

Bounds on $g^V_{\mu\mu}$

What about Neutrino Trident Production?

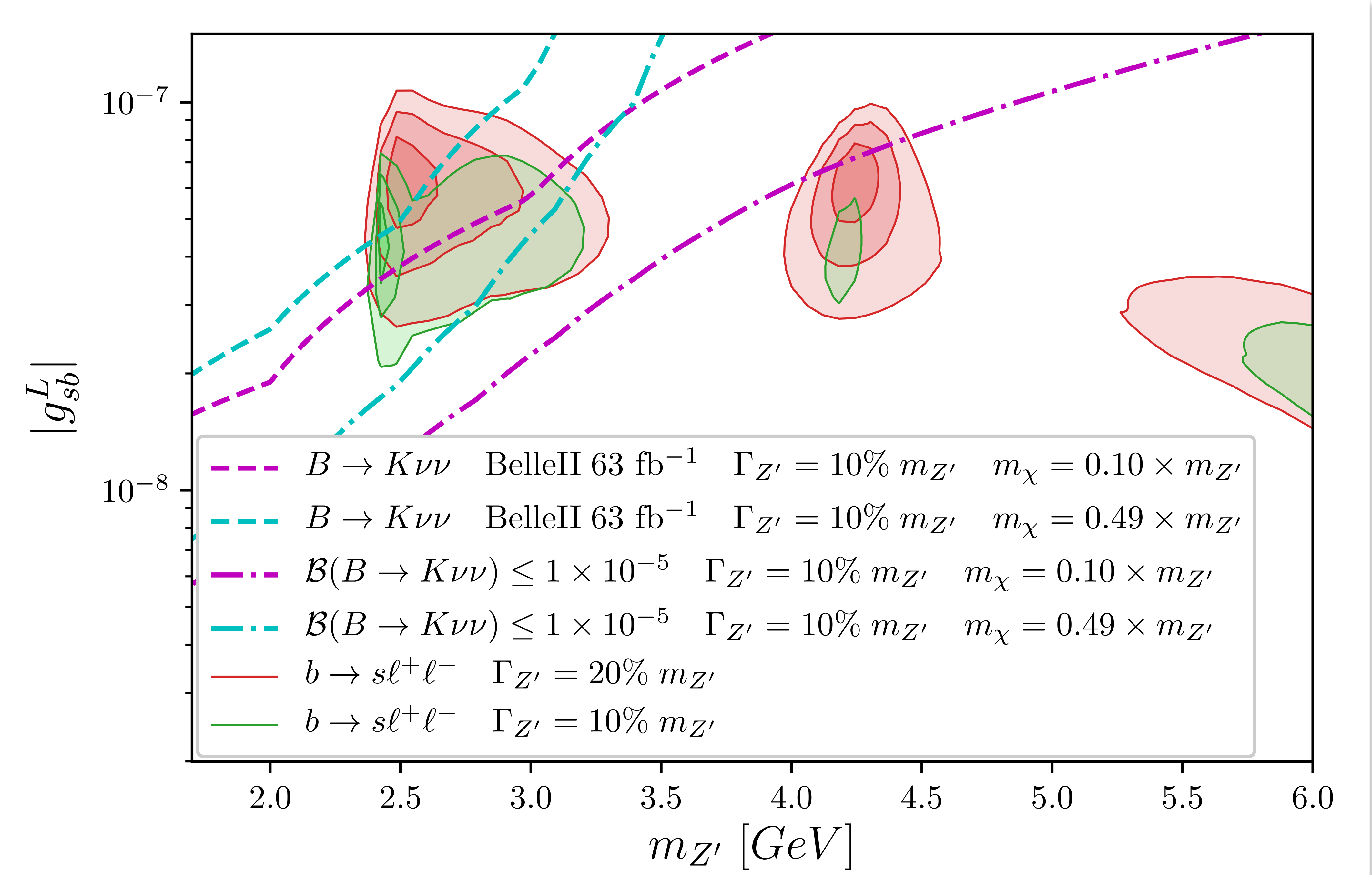




Light Z'

Bounds on g_{sb}^L

Alternatively we can maximize $g_{\mu\mu}^V$ from $e^+e^- \to \mu^+\mu^- + \text{invisible}$



Thank you for your attention!

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