Phenomenology of Inclusive $\overline{B} \to X_s \ell\ell$ for the Belle II Era
[2007.04191]

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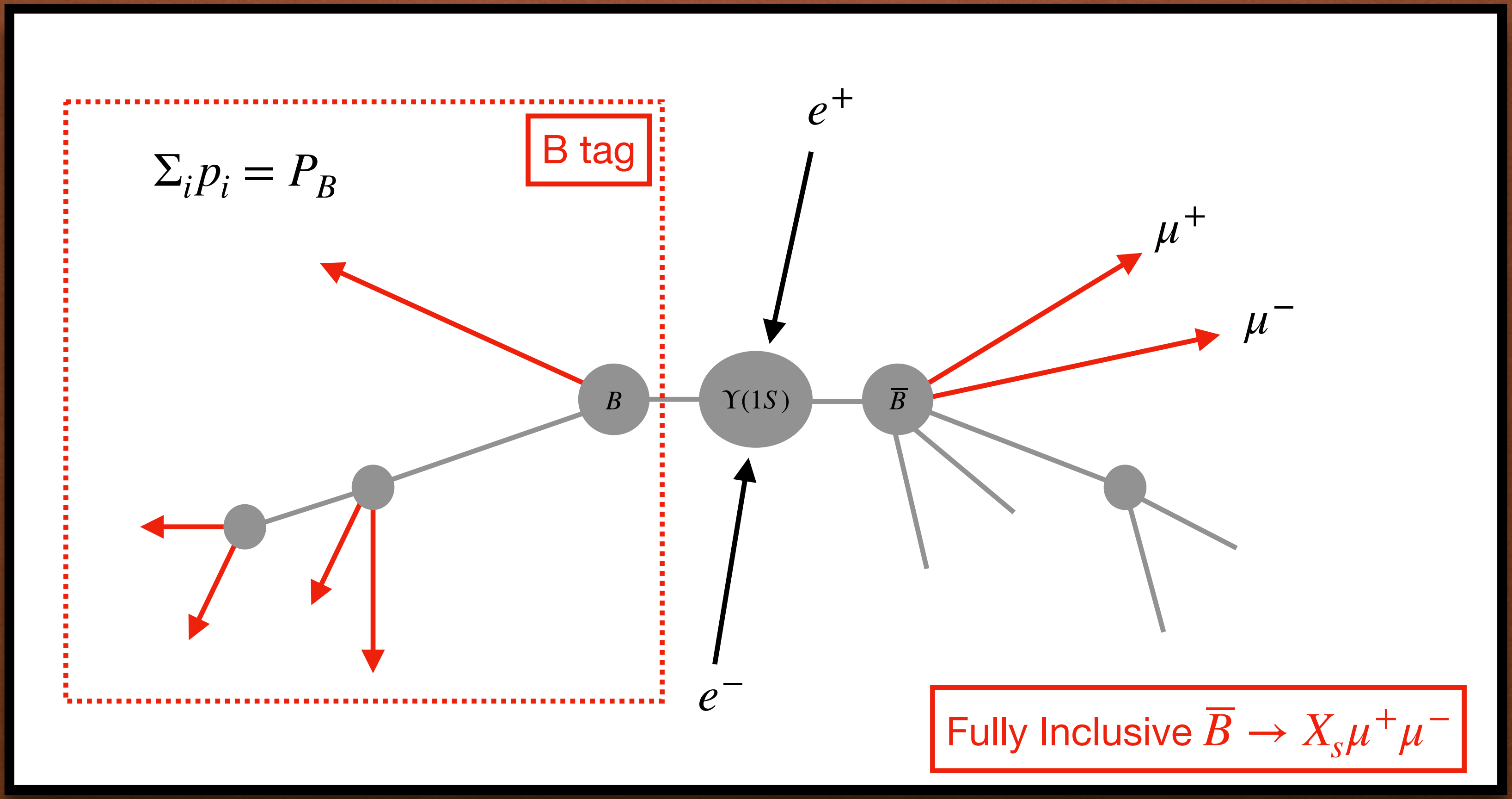
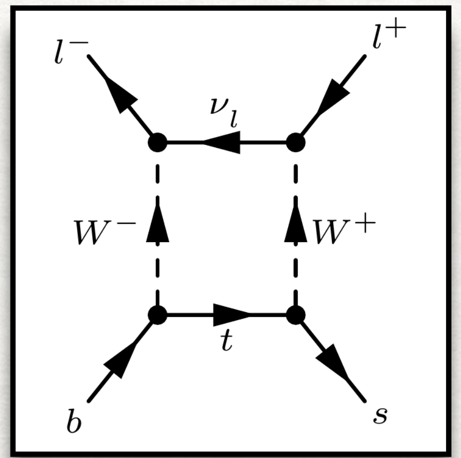
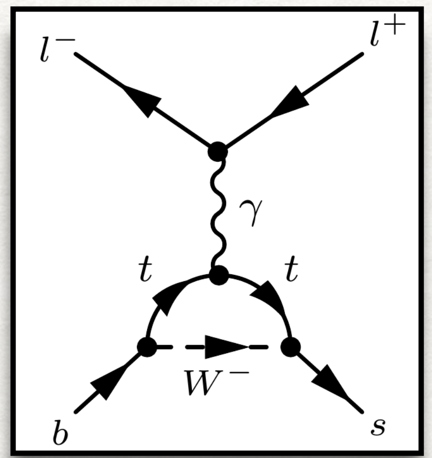


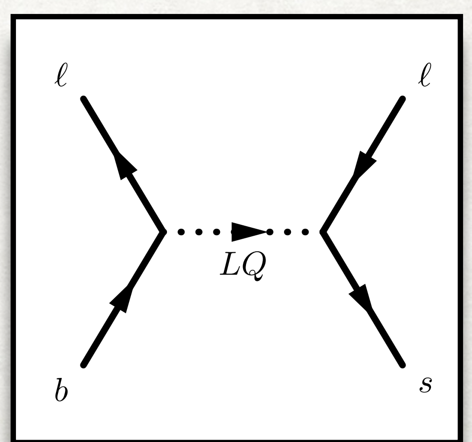
Effective Theory

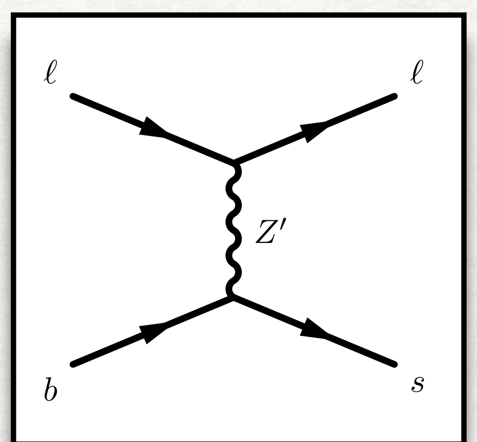
- Standard model "selection rule": flavor changing neutral currents go through loops





- New physics can enter at tree level





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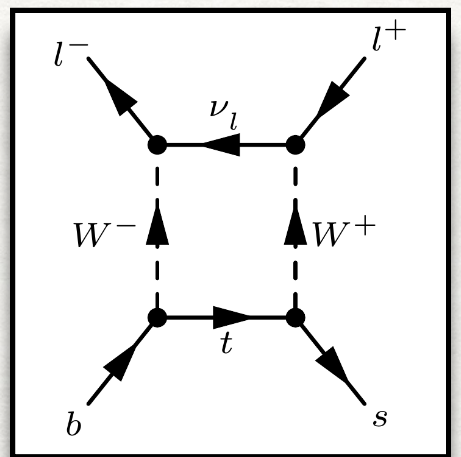

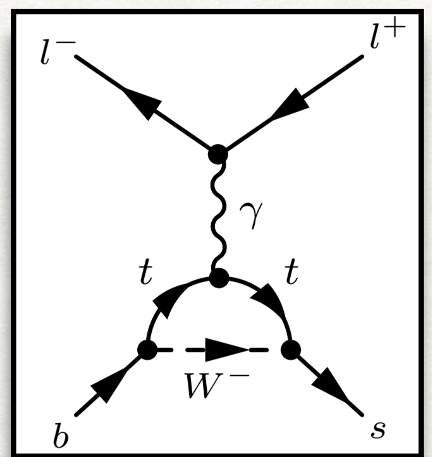

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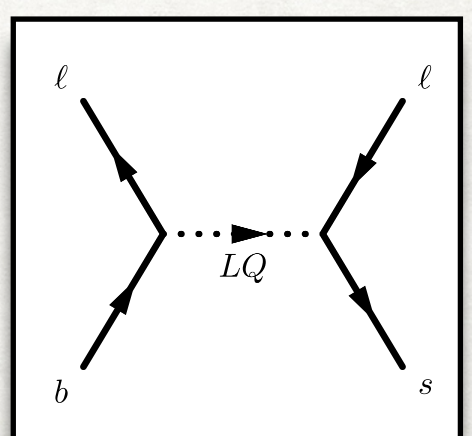
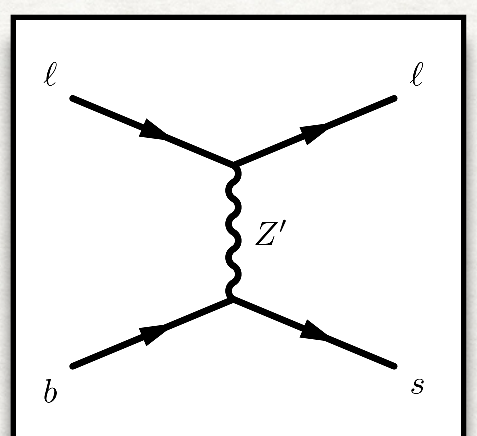


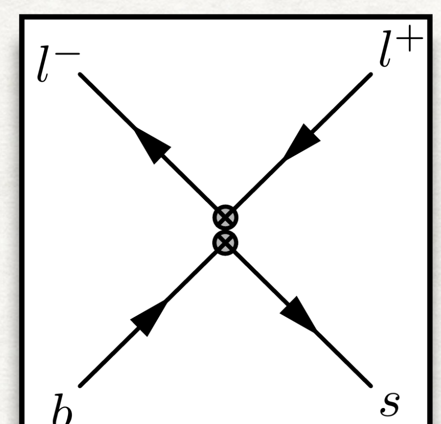


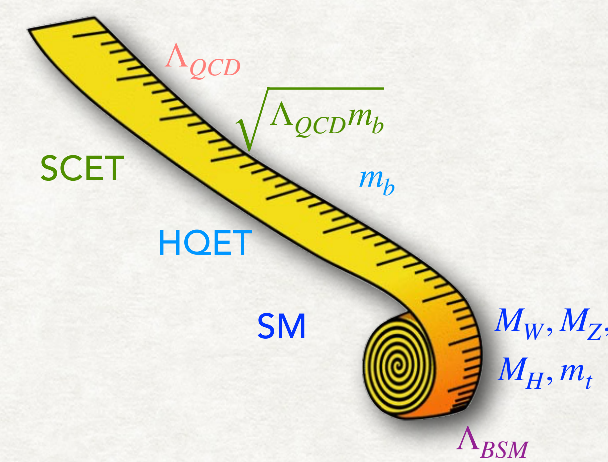
- Use an EFT to separate the electroweak scale from dynamical scales

- Matching is performed at $\mu \sim M_W$, and the Wilson coefficients run with RGEs to $\mu \sim m_b$

$$\mathscr{L} = \frac{4G_F^2}{\sqrt{2}} V_{ts}^* V_{tb} \sum_i C_i(\mu) Q_i$$

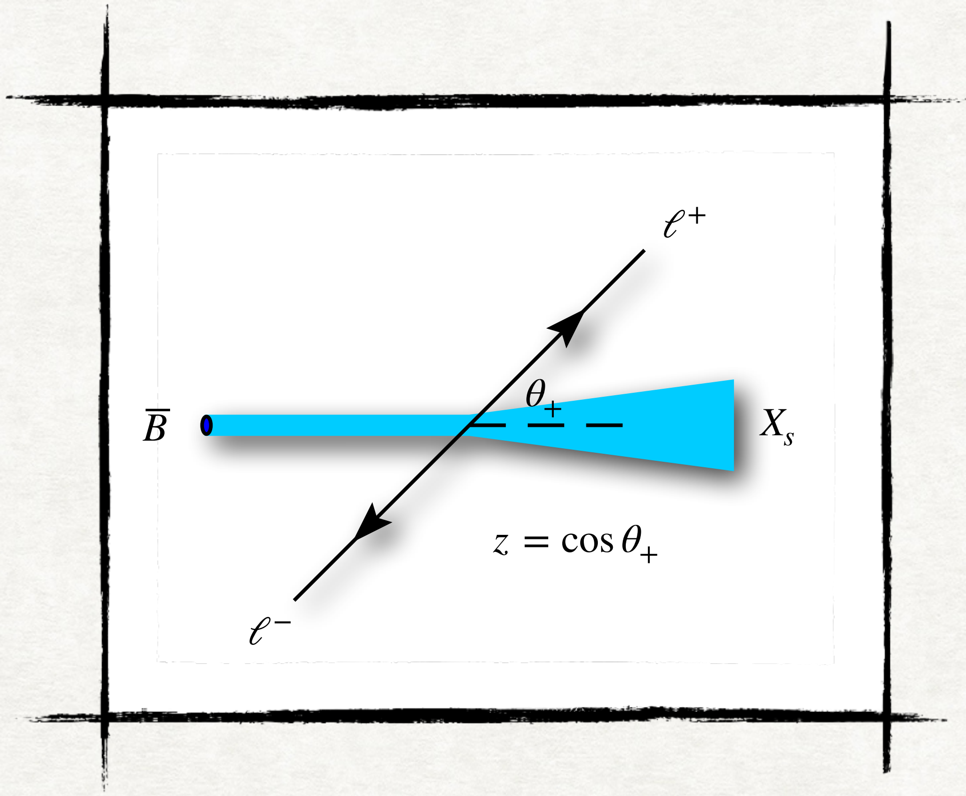
$$Q_9 = (\bar{b}\gamma_\mu P_L s)(\bar{\ell}\gamma^\mu \ell), \quad Q_{10} = (\bar{b}\gamma_\mu P_L s)(\bar{\ell}\gamma^\mu \gamma_5 \ell)$$





- Strategy: extract the Wilson coefficients of these operators from all available data -> SM null test

Inclusive Kinematics



- Three invariants: $(M_X\,, q^2\,, z)$
- Focus is on the low-q^2 region ($q^2 = [1{,}6]\,\text{GeV}^2$) below narrow $c\bar{c}$ resonances ($M_\psi^2 = 9.6\,\text{GeV}^2$, $M_{\psi'}^2 = 13.6\,\text{GeV}^2$)
- Integrate over hadronic mass: smear over $K\,, K\pi\,, K\pi\pi\ldots$
- Partial wave decomposition in z:

$$\frac{d^2\Gamma}{dq^2 dz} = \frac{3}{8}\left[(1+z^2)\,H_T(q^2) + 2z\,H_A(q^2) + 2(1-z^2)\,H_L(q^2)\right]$$

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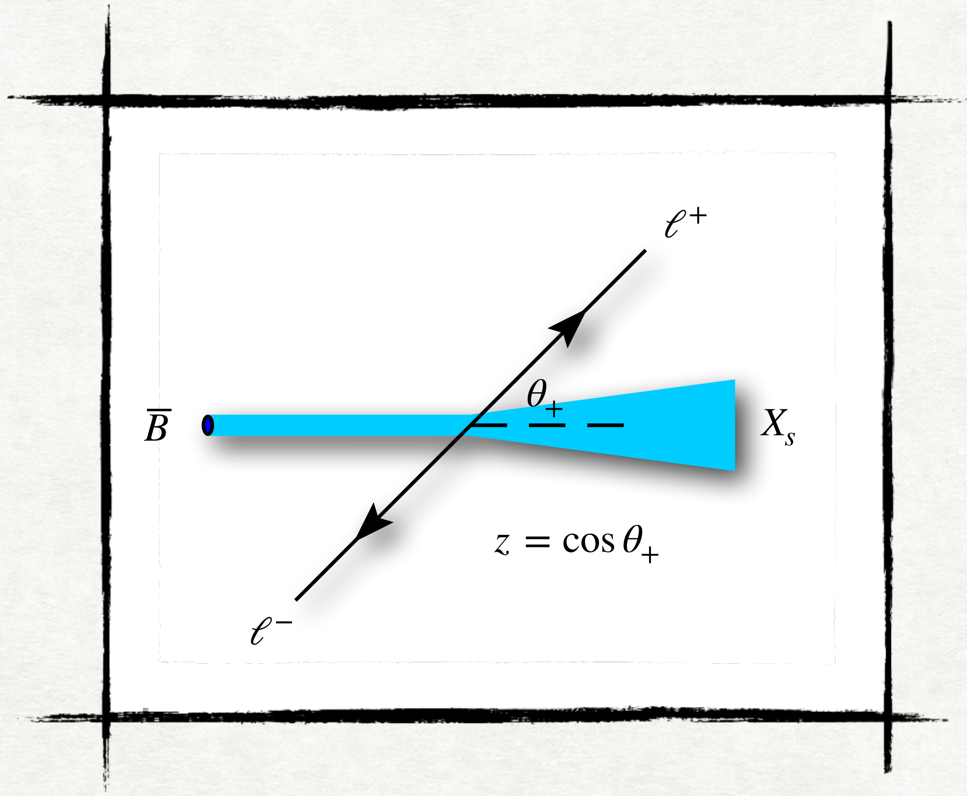

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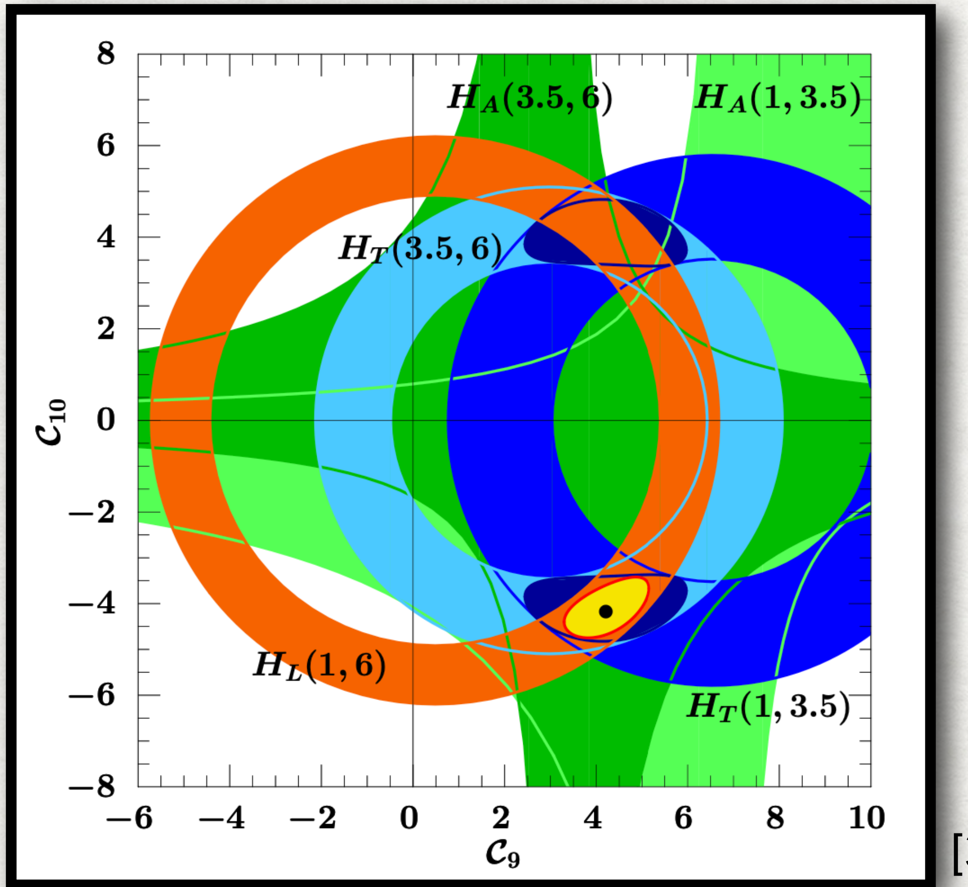
- $H_{T,A}$ are polluted by C_7 as $q^2 \to 0$ (photon pole)

$$H_T \sim (4/q^2)C_7^2 + 4C_7C_9 + q^2(C_9^2 + C_{10}^2)$$

$$H_A \sim (2C_7 + q^2C_9)C_{10}$$

$$H_L \sim 4C_7^2 + 4C_7C_9 + C_9^2 + C_{10}^2$$

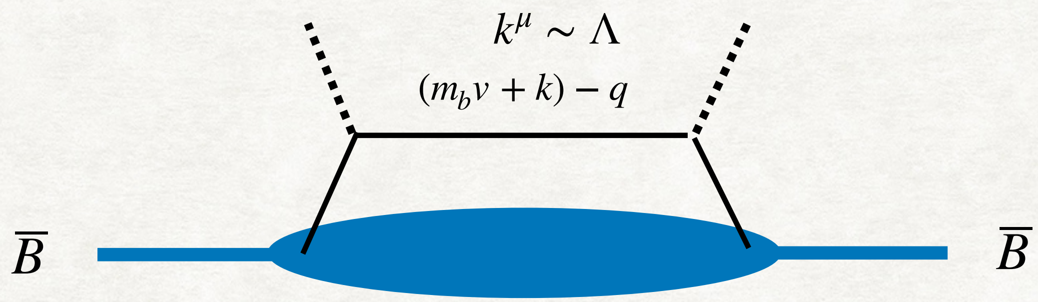
- Lee, Ligeti, Stewart and Tackmann [3]: split the statistics of $H_{T,A}$ into two bins



[3]

High q^2

- In the high q^2, $M_X^2 \sim \Lambda m_b$ (forced small by kinematics) and therefore the rate is sensitive to heavy quark pdfs:



$$[(m_b v + k) - q]^2 = \underbrace{(m_b v - q)^2 + 2k_+ \cdot (m_b v - q)_-}_{\mathcal{O}(\Lambda m_b)} + \mathcal{O}(\Lambda^2)$$

- One component k_+ of the residual momentum enters at leading power

$$S(k^+) = \frac{1}{2}\left\langle \overline{B}_v \,|\, \bar{b}_v\, \delta(in \cdot D - k^+)\, b_v \,|\, \overline{B}_v \right\rangle$$
$$= \delta(k^+) - \frac{1}{6}\lambda_1 \delta''(k^+) + \cdots$$

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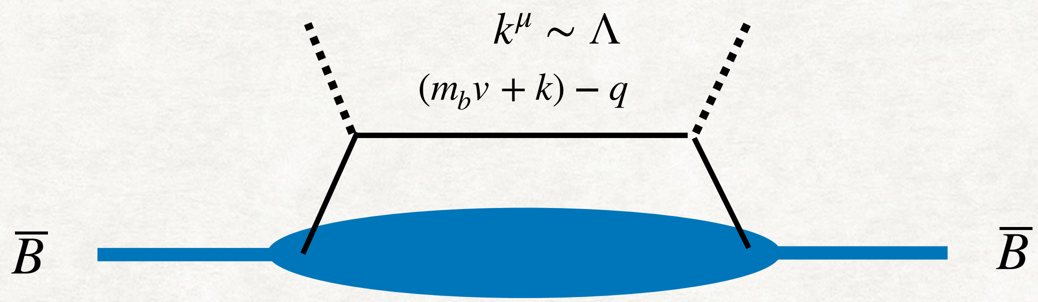

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- Two HQET matrix elements parameterize the leading corrections to the parton model

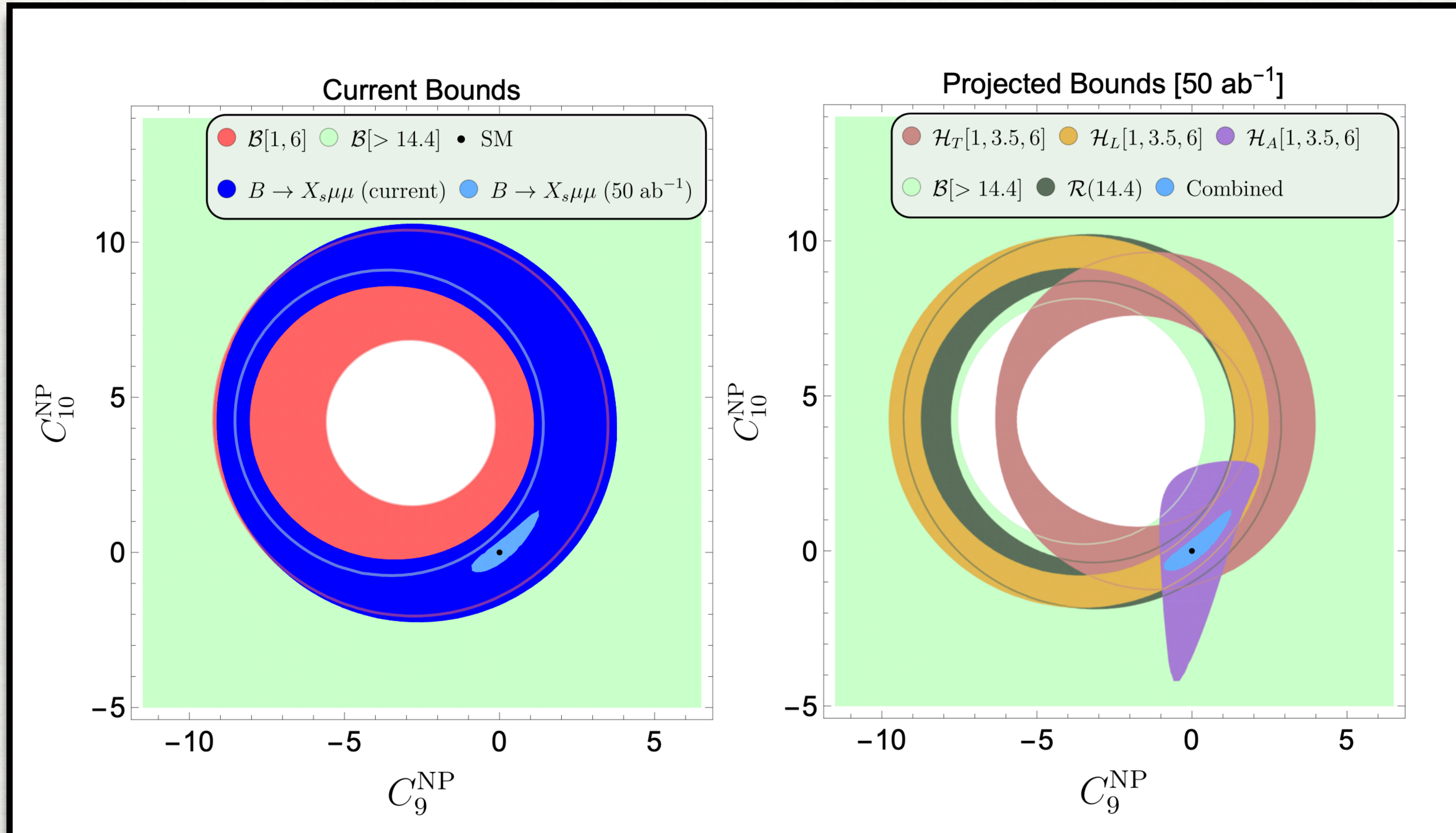
$$\lambda_1 = \left\langle \overline{B}_v \right| \bar{b}_v D^2 b_v \left| \overline{B}_v \right\rangle \qquad \text{[Fermi motion]}$$
$$\lambda_2(\mu) = \left\langle \overline{B}_v \right| \bar{b}_v \sigma_{\mu\nu}[G^{\mu\nu}] b_v \left| \overline{B}_v \right\rangle \qquad [M_B^* - M_B]$$

- Ligeti and Tackmann [4]: normalizing to $\overline{B} \to X_u \ell \nu$ reduces uncertainty from power corrections

$$\mathcal{R}(q_0^2) = \frac{\int_{q_0^2}^{M_B^2} dq^2\, [d\Gamma_s/dq^2]}{\int_{q_0^2}^{M_B^2} dq^2\, [d\Gamma_u/dq^2]}$$

$$\boxed{\begin{aligned}\mathcal{B}(14.4)_{\mu\mu} &= 2.38(87) \times 10^{-7} \\ \mathcal{R}(14.4)_{\mu\mu} &= 2.53(19) \times 10^{-3}\end{aligned}} \quad [1]$$

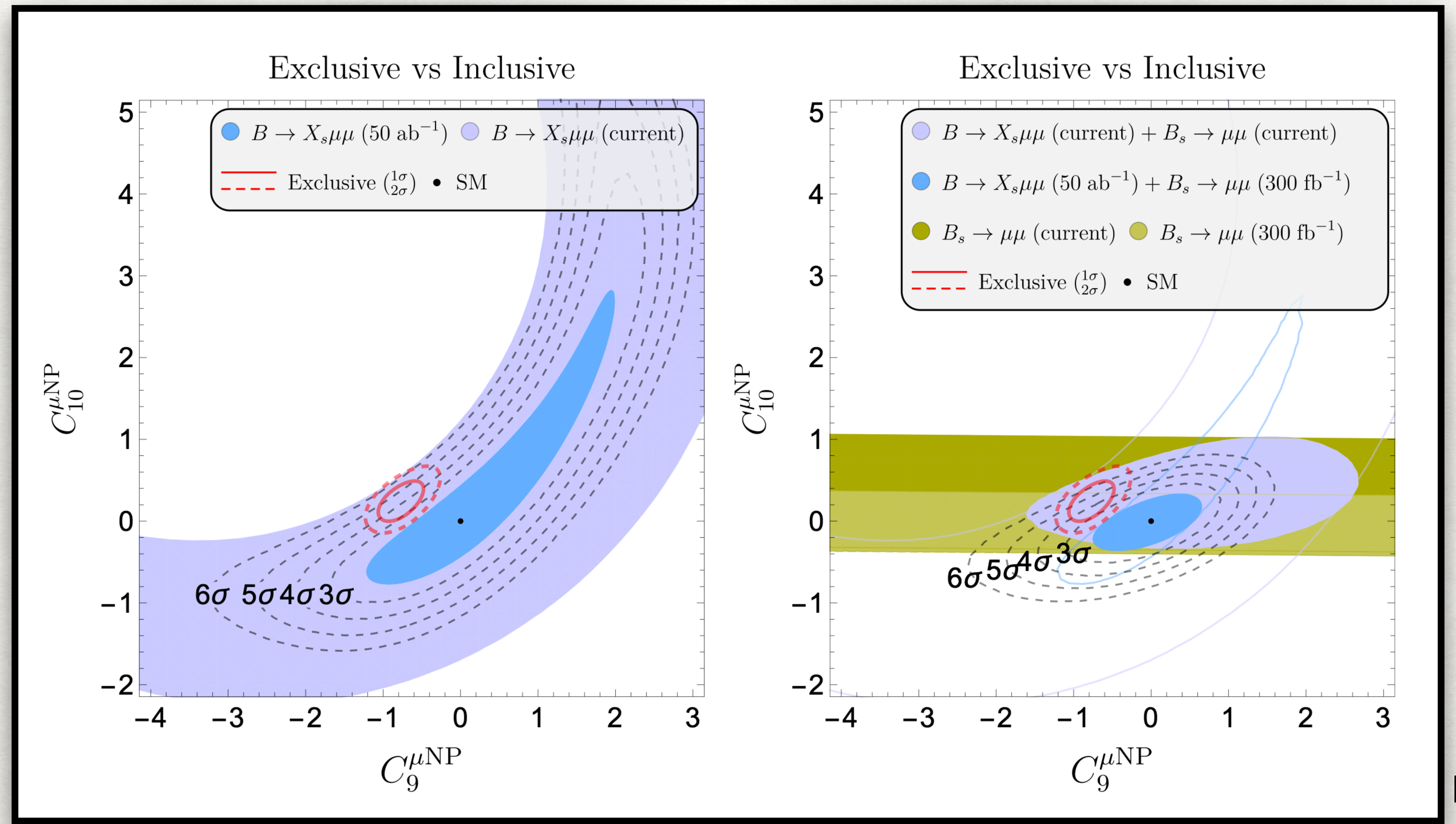
Belle II Projections



[1]

Comparison with exclusive decays

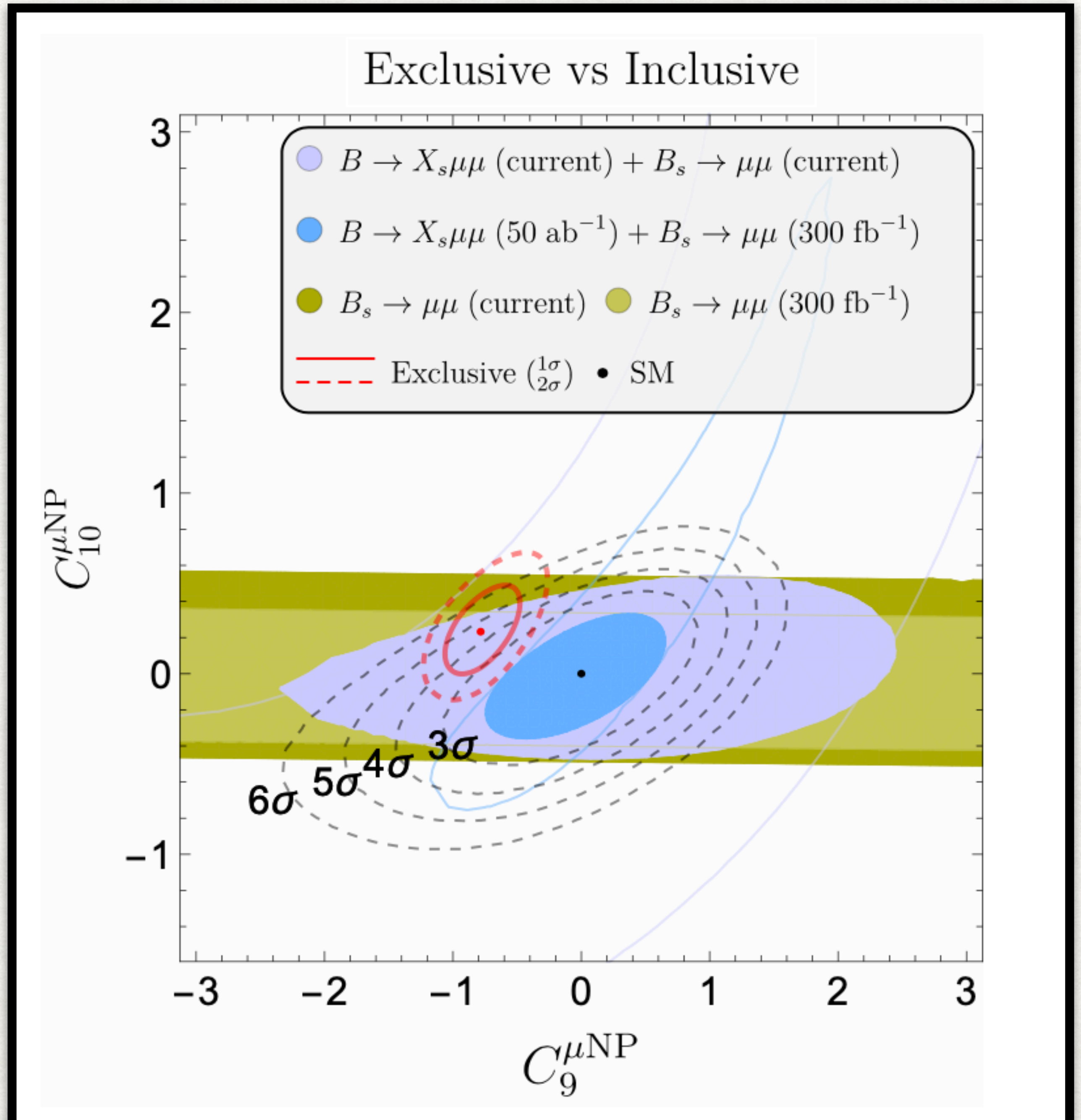
- The inclusive analysis benefits from an additional constraint from $\overline{B}_s \to \mu\mu$
- If $b \to s\ell\ell$ is SM-like, the inclusive measurement at Belle II is projected to exclude the central value of the global exclusive fits at 5σ



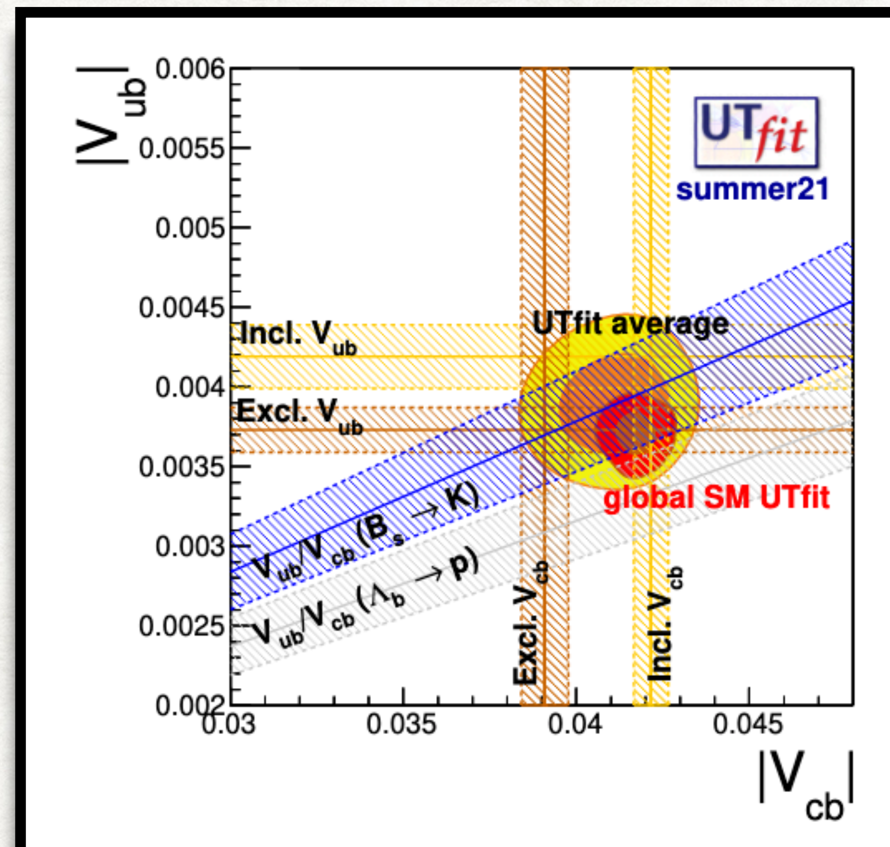
[1]

Comparison with exclusive decays

Updated $\overline{B}_s \to \mu\mu$ measurement

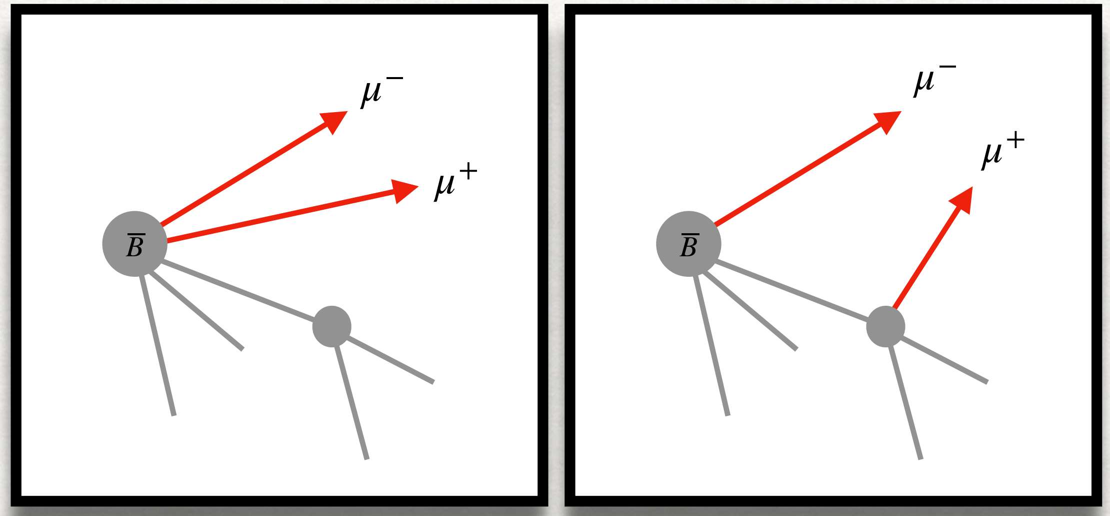


- Historically: inclusive/exclusive comparisons **increase** uncertainties (in conservative approach)



Low q^2: hadronic mass cut

- Large backgrounds from double semileptonic decay $\overline{B} \to (X_c \to X_s \ell^+ \nu)\ell^- \nu$



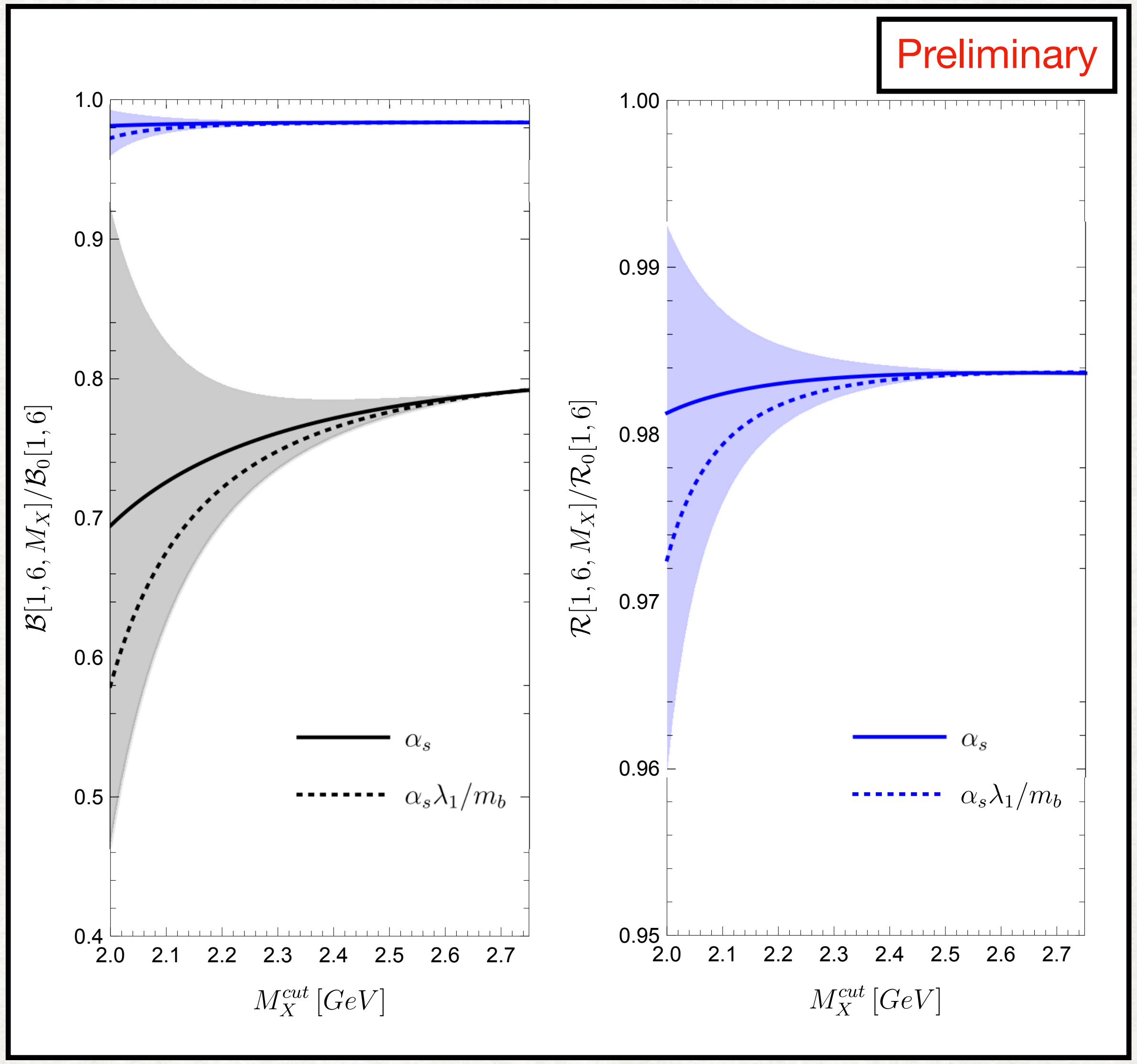
- Can be reduced with a cut $M_X < M_D$ but extrapolation above this cut comes with $\sim 20\,\%$ model uncertainty

- Normalizing to $\overline{B} \to X_u \ell \nu$ reduces uncertainty from power corrections:

$$\mathcal{R}(q_1^2, q_2^2, M_X^{cut}) = \frac{\int_{q_1^2}^{q_2^2} dq^2 \int_0^{M_X^{cut}} dM_X \, [d^2\Gamma_s/dq^2 dM_X]}{\int_{q_1^2}^{q_2^2} dq^2 \int_0^{M_X^{cut}} dM_X \, [d^2\Gamma_u/dq^2 dM_X]}$$

- Huber, Hurth, Jenkins, Lunghi: calculation of the triple differential $\overline{B} \to X_s \ell\ell$ spectrum (M_X, q^2, z) at order α_s/m_b^2 [to be released soon!]

- Bands indicate the size of the power corrections not yet calculated



References

- Phenomenology papers:
  - [1] arXiv:2007.04191 [2] arXiv:1908.07507
- Angular decomposition:
  - [3] arXiv:hep-ph/0612156
- Normalization to $\overline{B} \to X_u \ell \nu$
  - [4] arXiv:hep-ph/0512191v2
- Hadronic mass cut effects:
  - [5] arXiv:hep-ph/0512191 [6] arXiv:0812.0001