ArXiv:2207.00356 (Ulrich Haisch, LS, Stefan Schulte)

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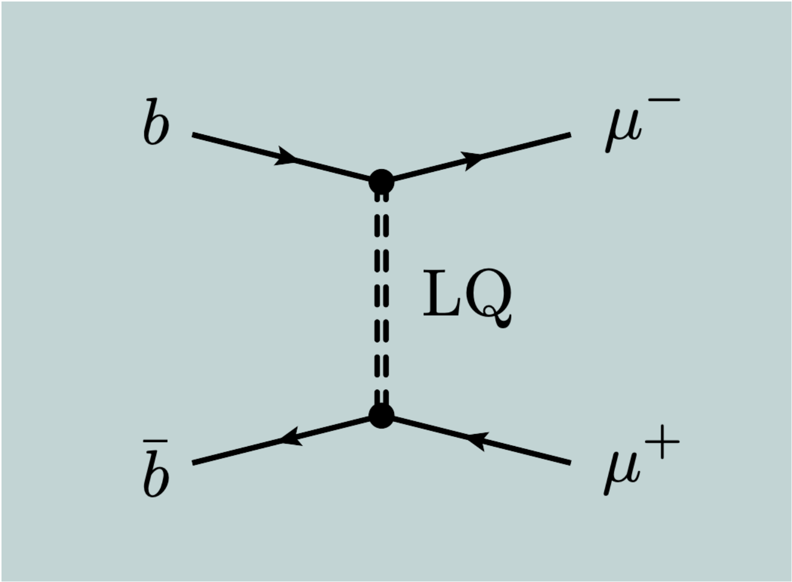
Technische Universität München

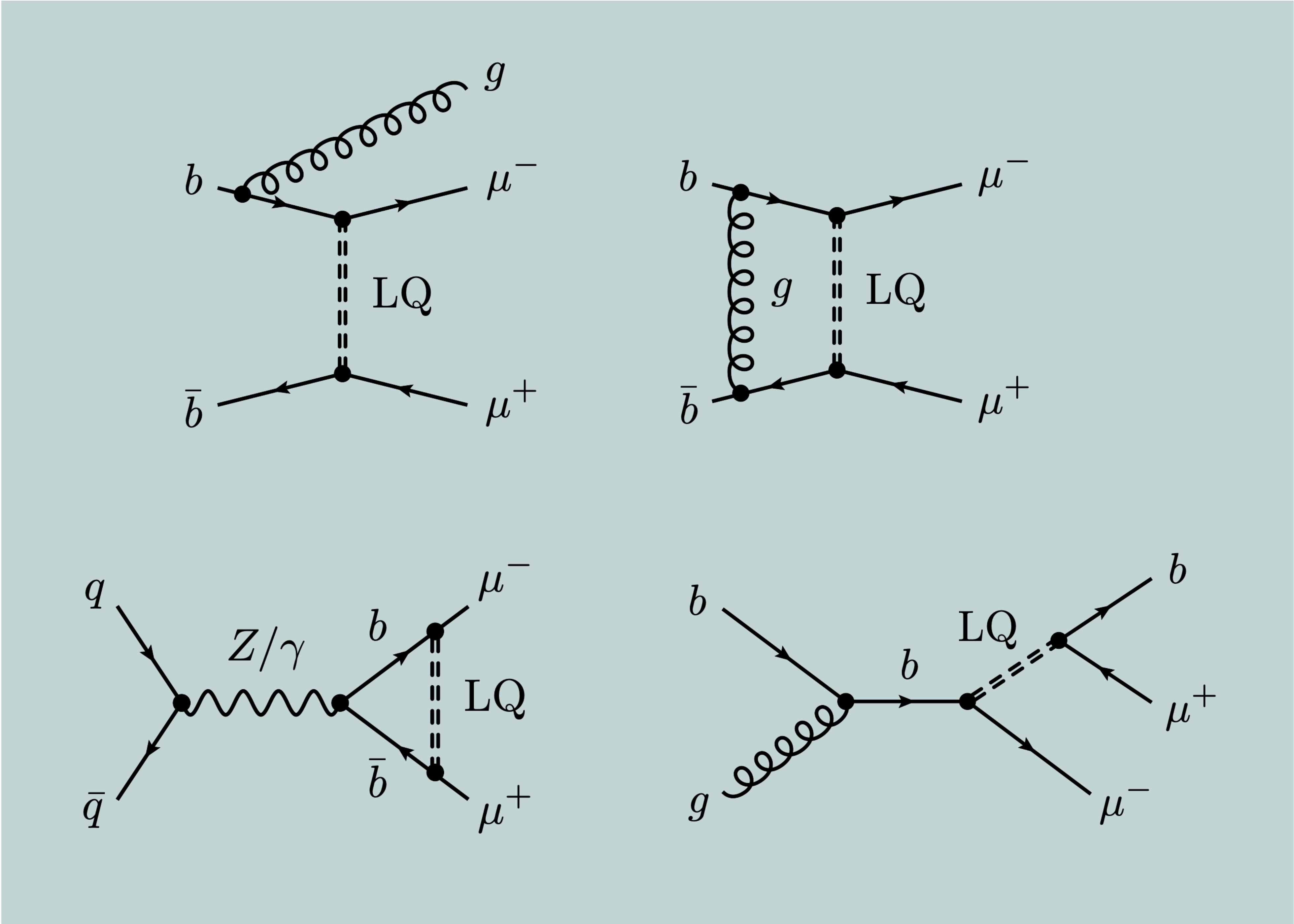
On Drell-Yan Production of Scalar Leptoquarks coupling to Heavy Quark Flavours

Luc Schnell

LF(U)V Workshop

July 4, 2022





1. Introduction

1.1 Motivation

1.2 Drell-Yan

1.3 Going beyond the leading order

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Hints for lepton flavour universality violation (LFUV)

$bs\mu\mu$ $bc\tau\nu$

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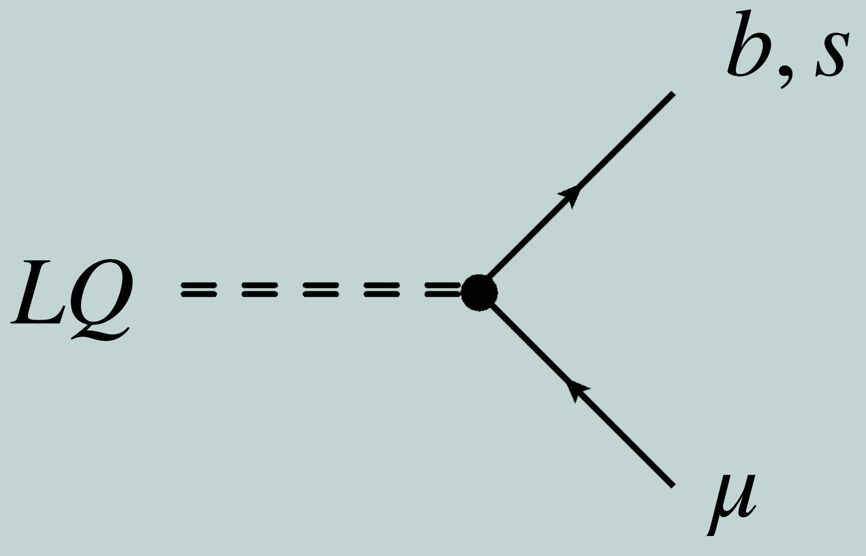

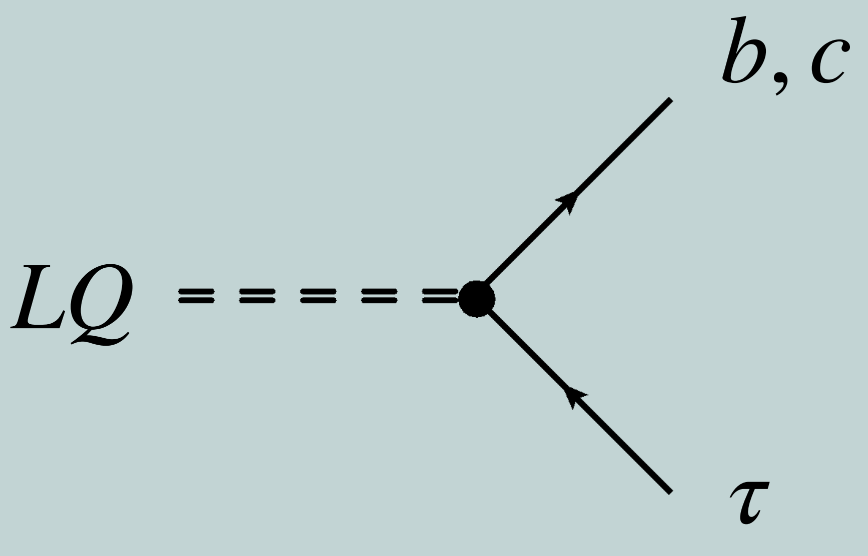

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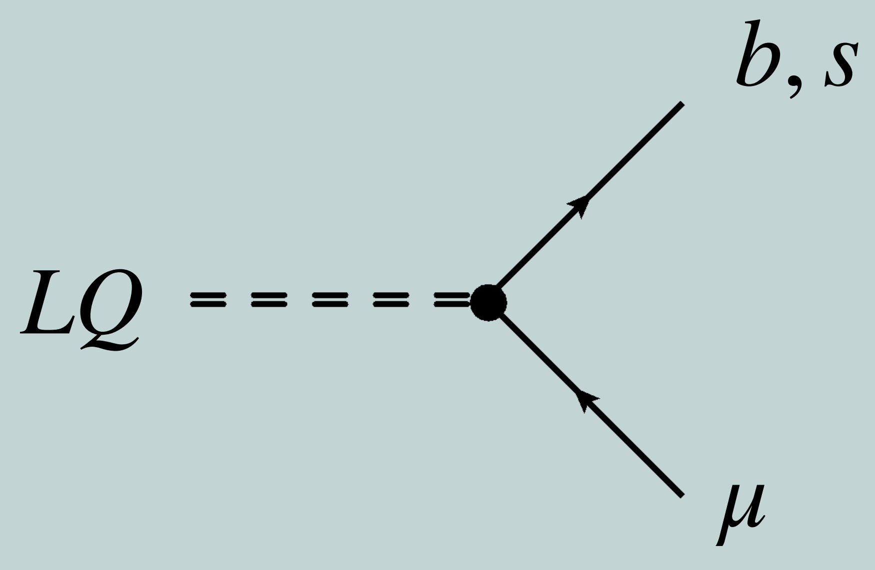

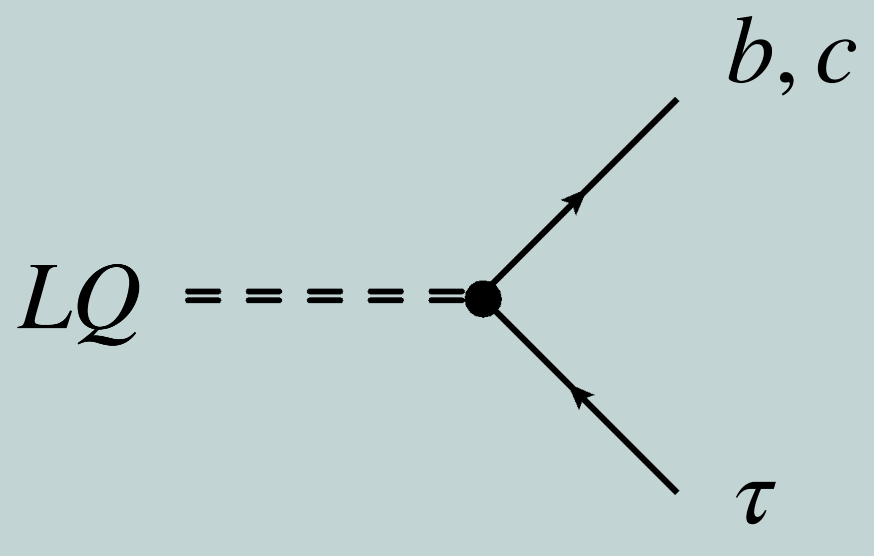

Low-energy precision observables

B physics, LFV, meson mixing, Z couplings to fermions, AMMs, EDMs, PV and many more.

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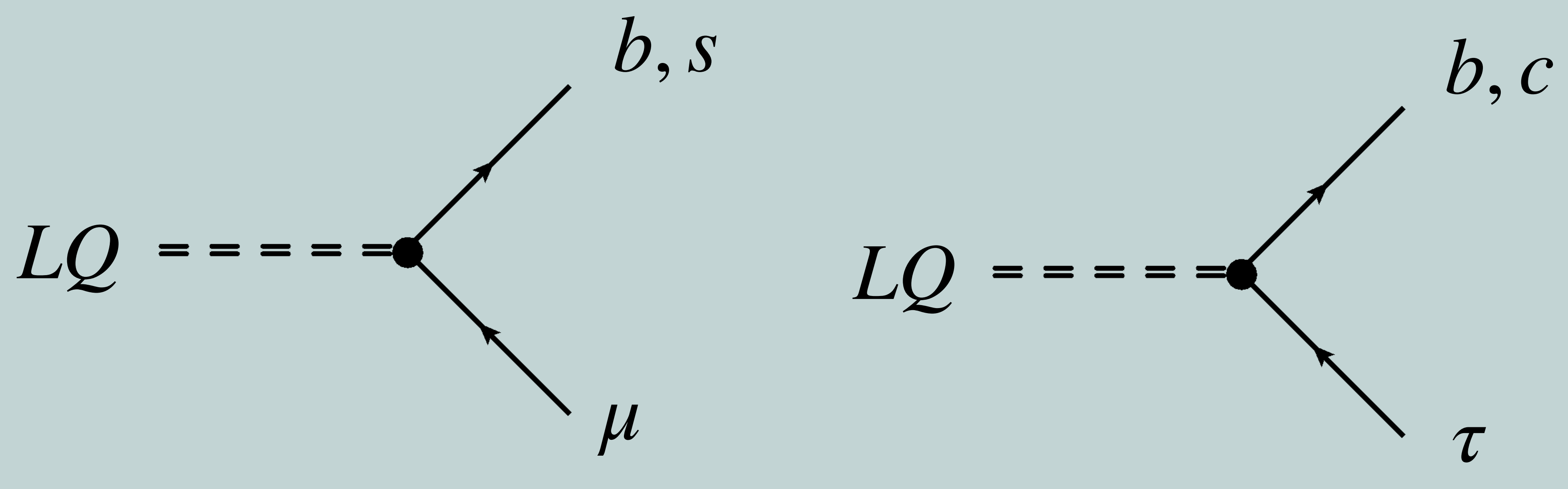

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High-energy searches at LHC

Pair production, single (resonant) production and **Drell-Yan**.

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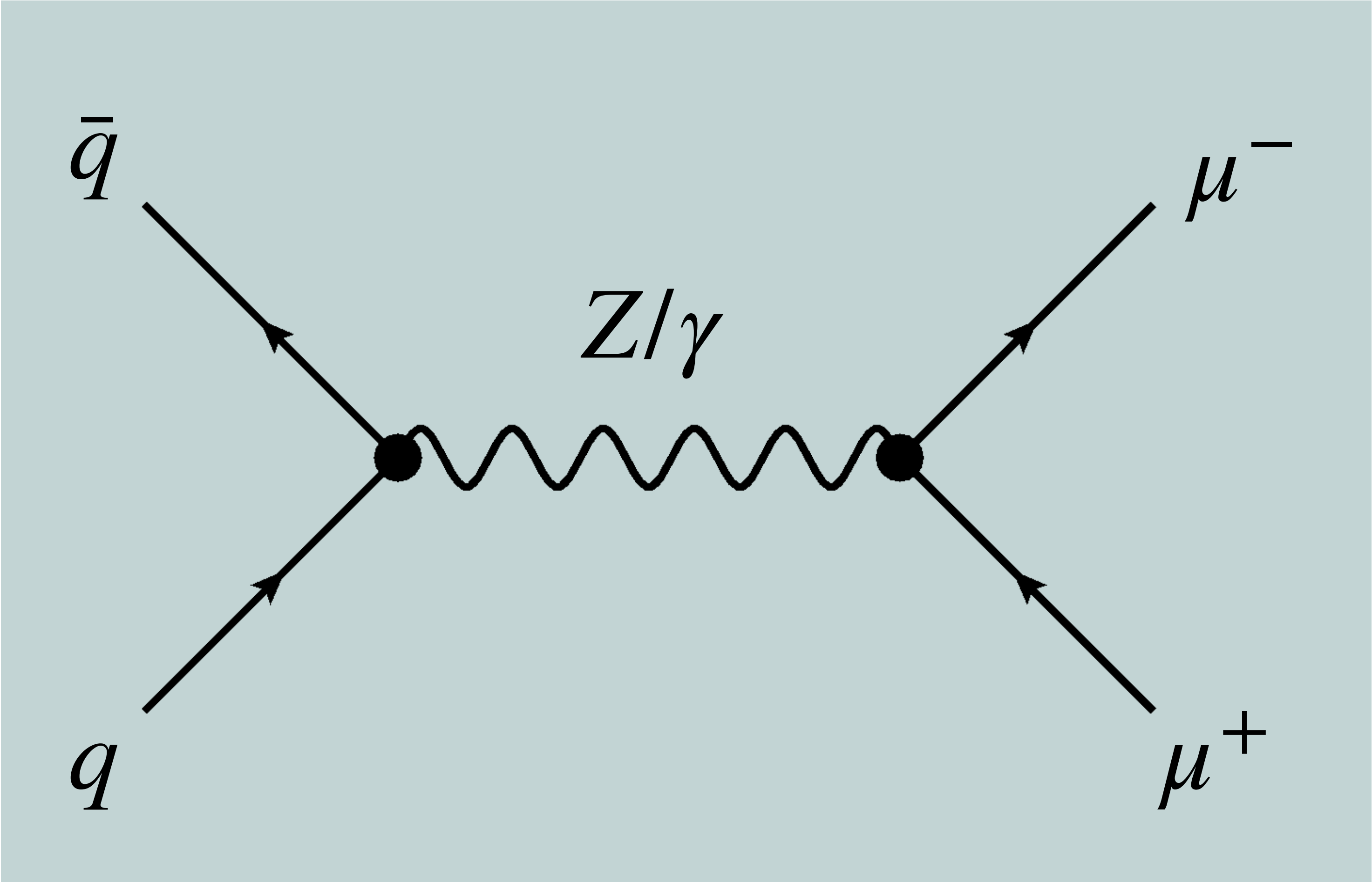
1.2 Drell-Yan



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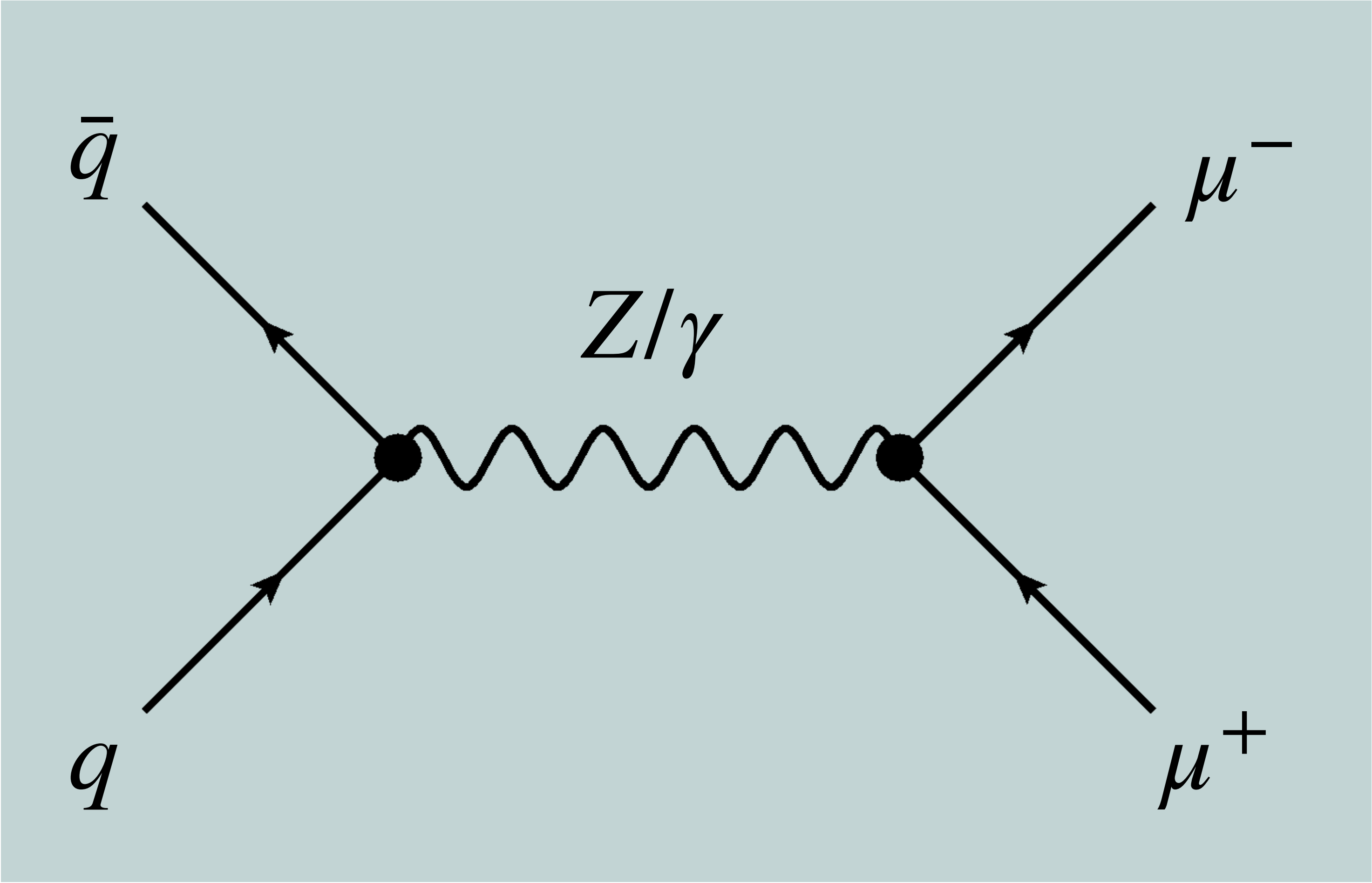

- **Clean** and **well-reconstructable** experimental signature with excellent detection efficiency.

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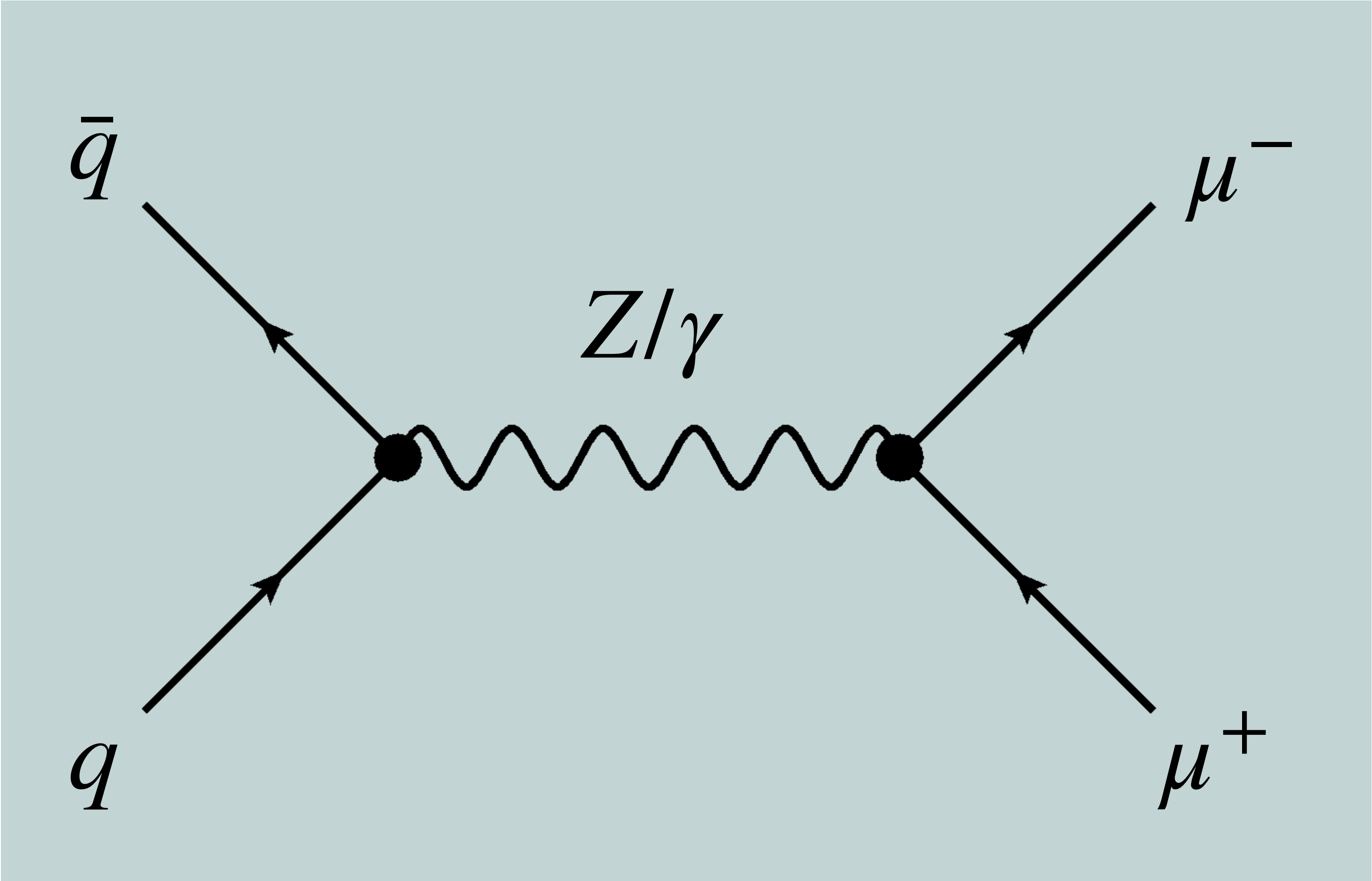

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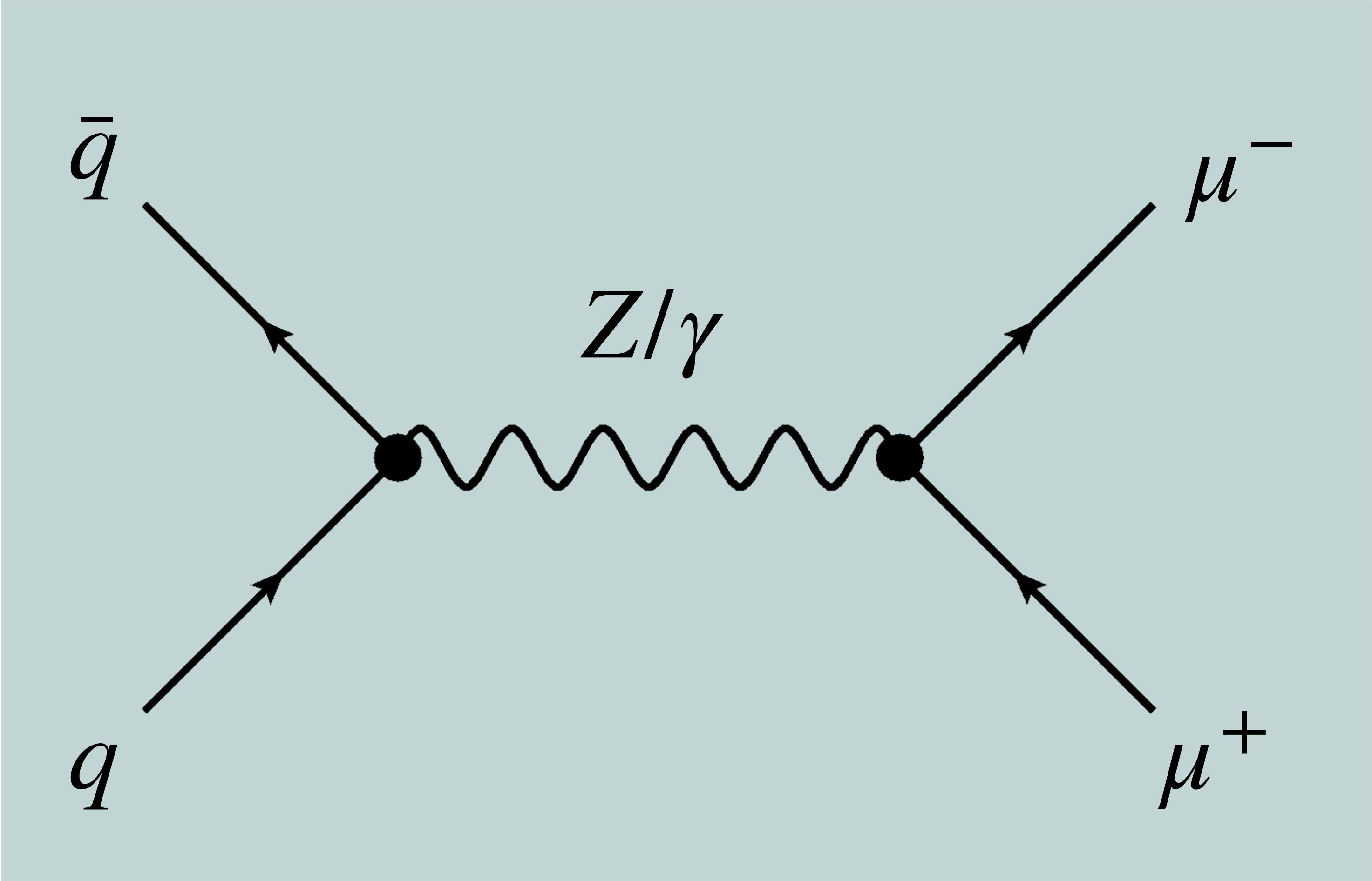

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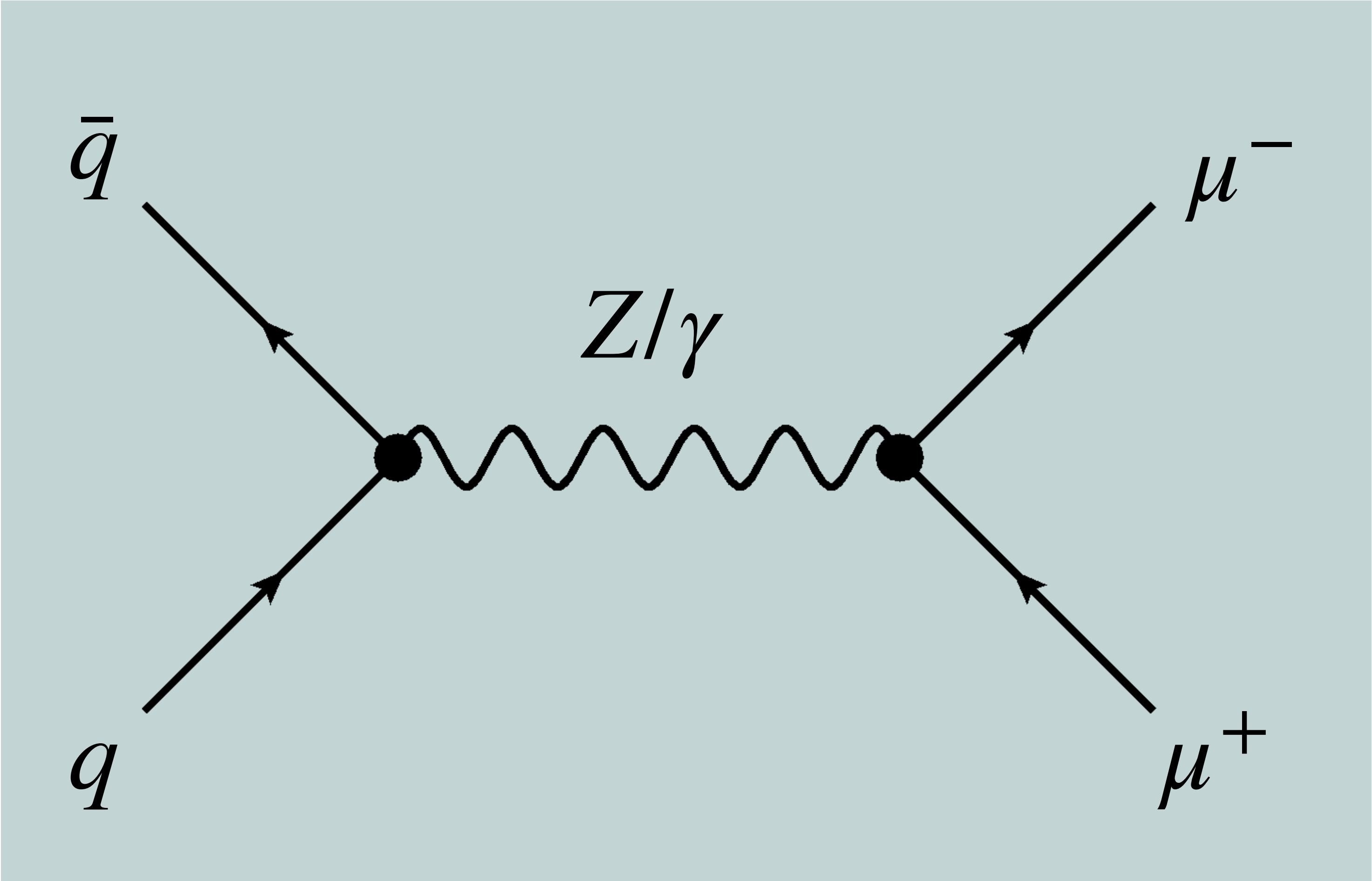

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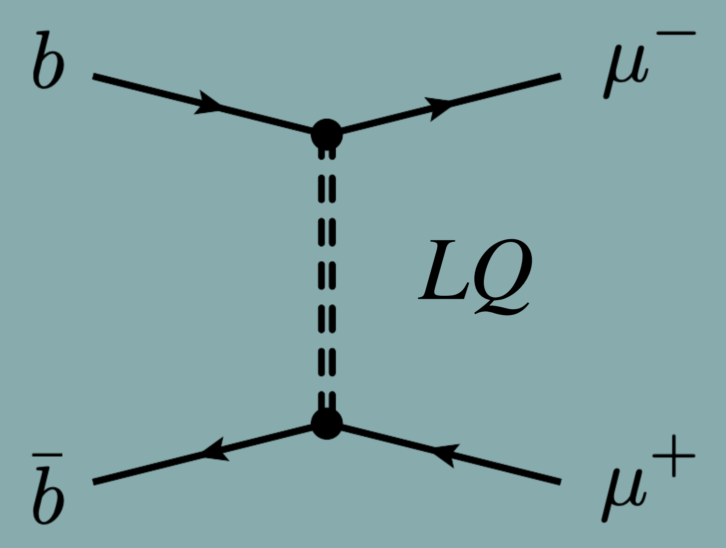
- LQs contribute at leading order via **non-resonant t-channel exchange**.



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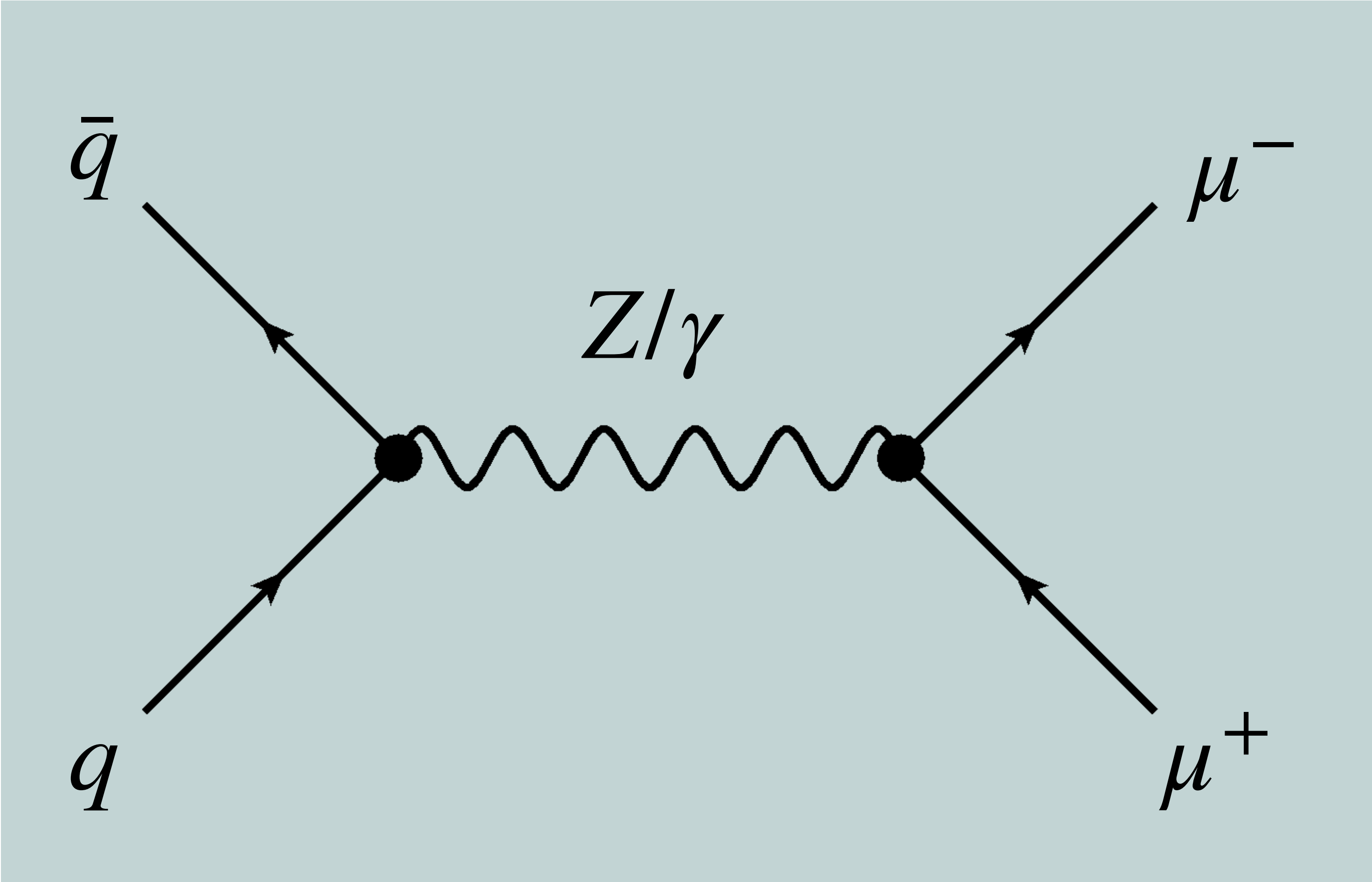

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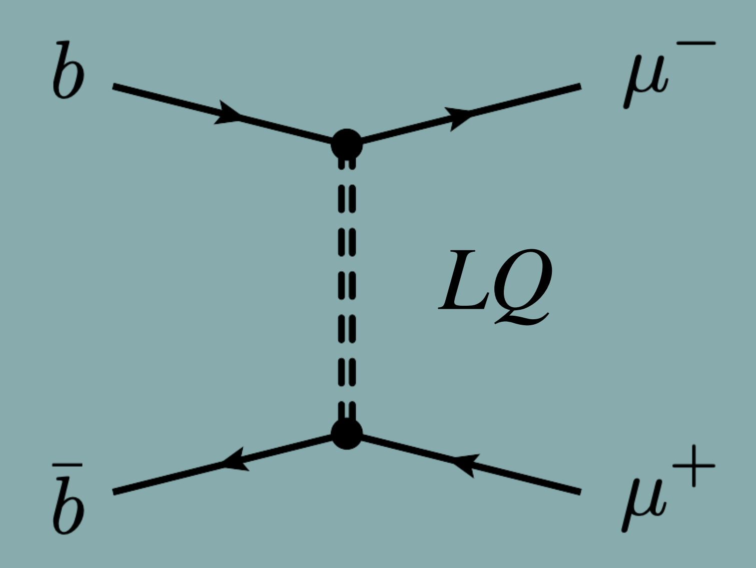

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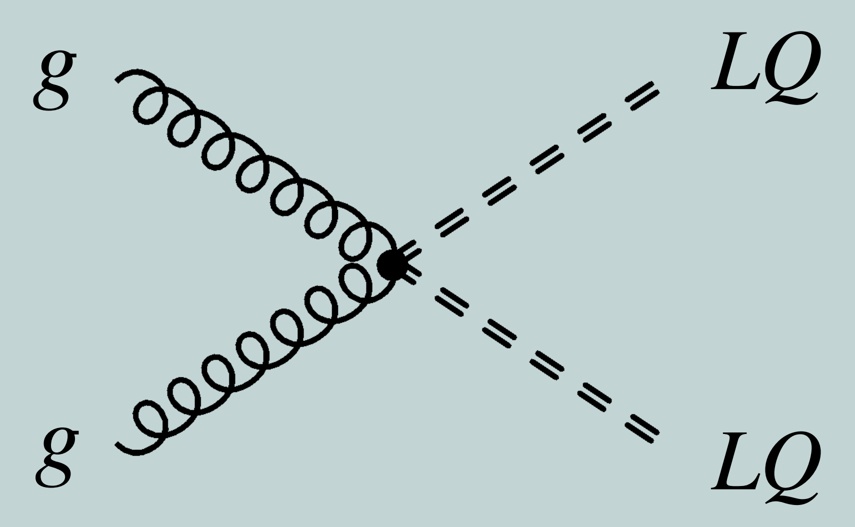

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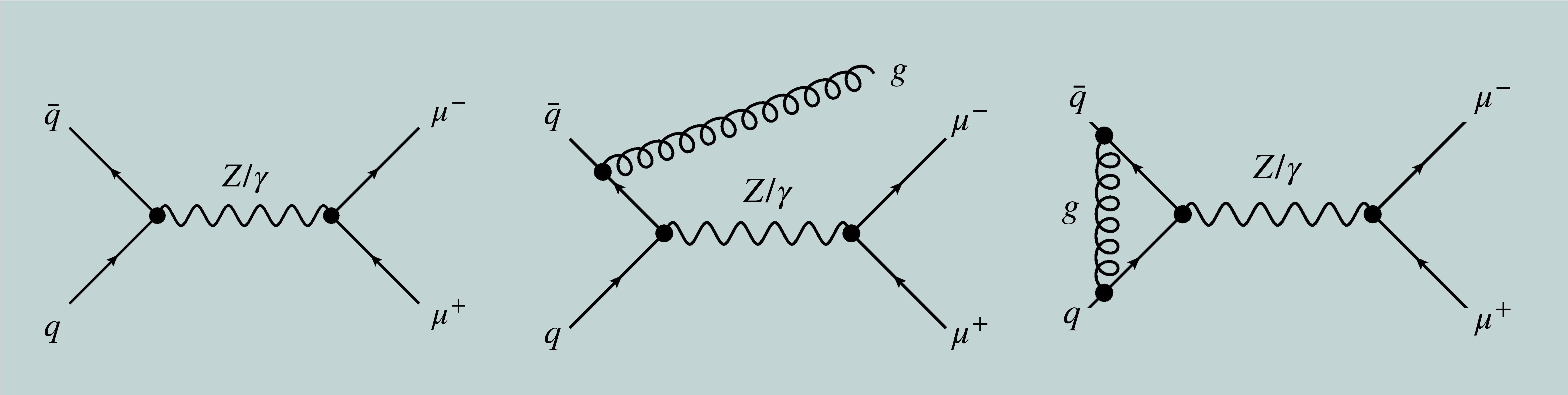

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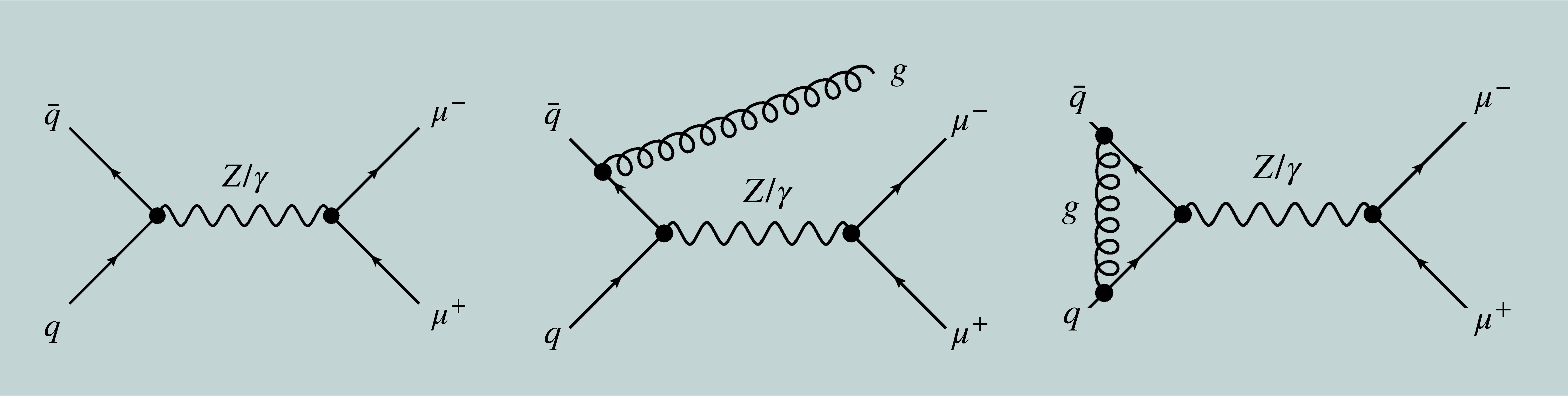

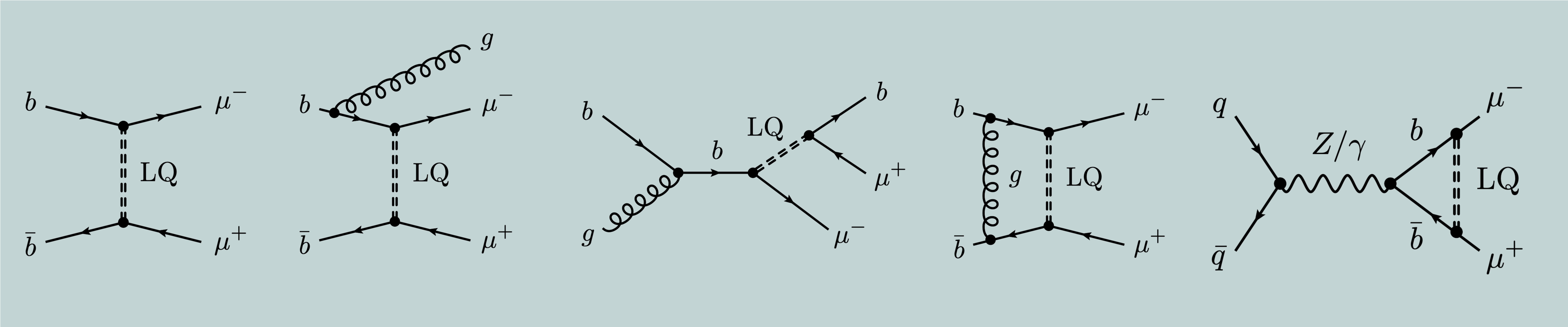

2. Theoretical framework and calculations

2.1 Simplified LQ model

2.2 Matrix elements

2.3 POWHEG-Box (in a nutshell)

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- We consider the **simplified LQ model**

$$\mathcal{L} \supset Y_{u\ell}\,\bar{u}^c\ell\,S_1^\dagger + Y_{d\ell}\,\bar{d}^c\ell\,\tilde{S}_1^\dagger + \mathrm{h.c.}\,,$$

involving the two $SU(2)_L$ singlets $S_1 \sim \left(\mathbf{3}, \mathbf{1}, -1/3\right)$ and $\tilde{S}_1 \sim \left(\mathbf{3}, \mathbf{1}, -4/3\right)$ coupling to right-handed fermions.

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- The size of the modifications in $pp \to \ell^+\ell^-$ primarily depends on the **flavour structure** and the **magnitude** of $Y_{u\ell}$, $Y_{d\ell}$.

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- The size of the modifications in $pp \to \ell^+\ell^-$ primarily depends on the **flavour structure** and the **magnitude** of $Y_{u\ell}$, $Y_{d\ell}$.

- The representation of the LQ plays a role only in the **interference** with the SM. S_1 ($\tilde{S}_1$) leads to destructive (constructive) interference, these interactions can therefore be used as a template to cover the **full space of scalar LQ models**.

2. Theoretical framework and calculations

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- Calculation of the tree-level, real emission and virtual correction matrix elements relying on the full **FeynRules+FeynArts+FormCalc** machinery.

- For the numerical evaluation, we used both the analytical expressions from **PackageX** and the Passarino-Veltman functions implemented in **LoopTools**, obtaining the same results.

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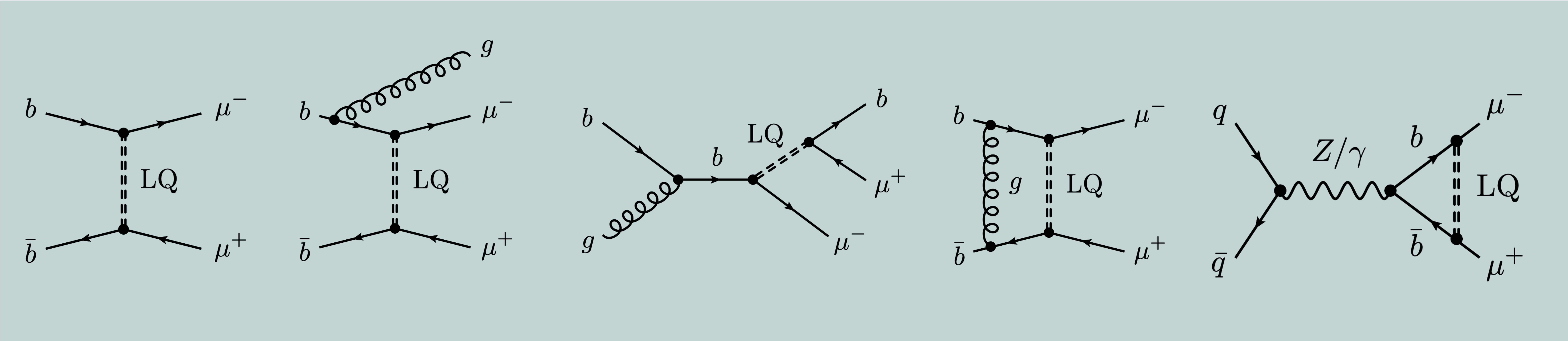

2. Theoretical framework and calculations

2.3 POWHEG-Box (in a nutshell)

See ArXiv:0709.2092 for detailed information.

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- In Monte Carlo (MC) simulations at NLO precision, two main issues need to be addressed:

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- The virtual and real matrix elements have infrared and collinear divergences:

$$\sigma_{\mathrm{NLO}} = \int d\mathbf{\Phi}_n \, \mathcal{L} \left[\mathcal{B}(\mathbf{\Phi}_n) + \mathcal{V}_{\mathrm{b}}(\mathbf{\Phi}_n) \right] + \int d\mathbf{\Phi}_{n+1} \, \mathcal{L} \, \mathcal{R}(\mathbf{\Phi}_{n+1})$$

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- These are cured by introducing appropriate counterterms and a clever subtraction of divergent terms in the singular regions of phase space (e.g. in the **FKS subtraction** scheme):

$$\begin{aligned} \bar{B}(\mathbf{\Phi}_n) &= B(\mathbf{\Phi}_n) + V(\mathbf{\Phi}_n) \\ &+ \left[\int d\Phi_{\mathrm{rad}} \left[R(\mathbf{\Phi}_{n+1}) - C(\mathbf{\Phi}_{n+1}) \right] + \int \frac{dz}{z} \left[G_{\oplus}(\mathbf{\Phi}_{n,\oplus}) + G_{\ominus}(\mathbf{\Phi}_{n,\ominus}) \right] \right]^{\bar{\mathbf{\Phi}}_n = \mathbf{\Phi}_n} , \end{aligned}$$

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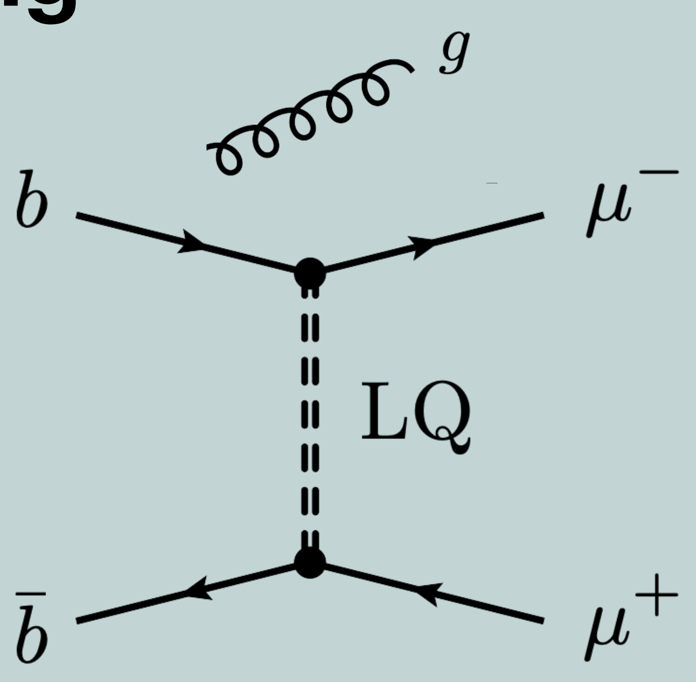
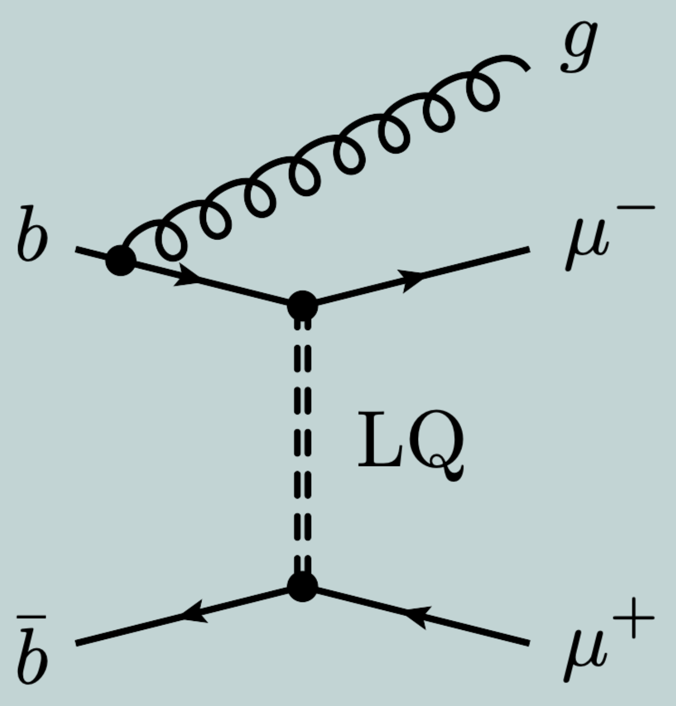
LO + PS





NLO

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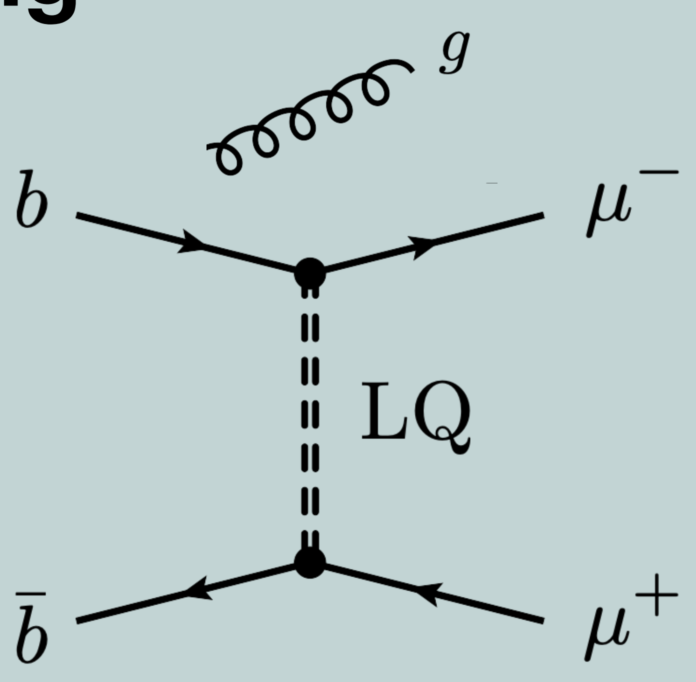

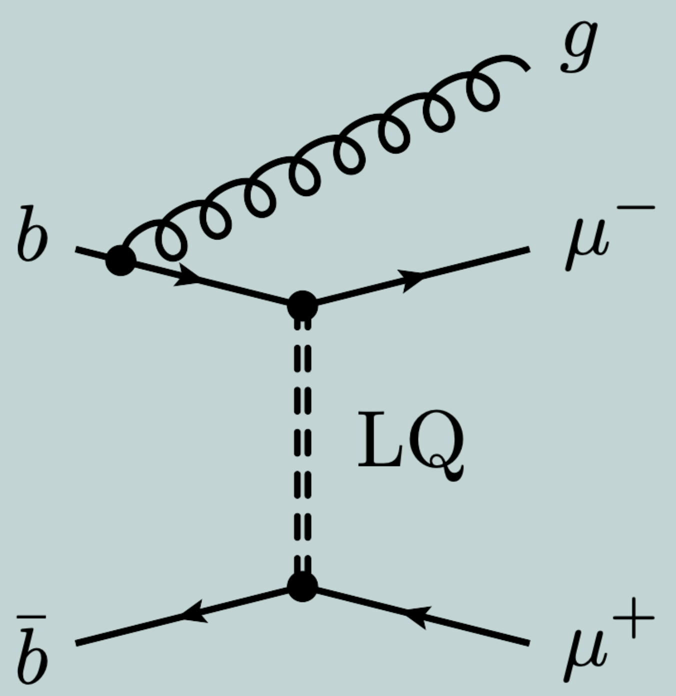

NLO

- **Jet-Matching:** generate tree-level and real emission events, run parton shower (PS) and reconstruct jets, veto jet if it cannot be matched to an underlying parton within some scale.
  $\rightarrow$ **unphysical matching scale**

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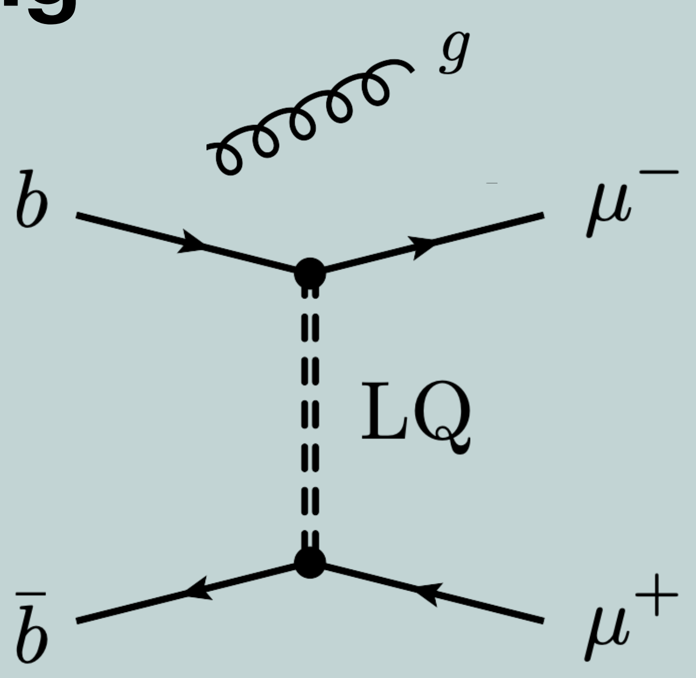

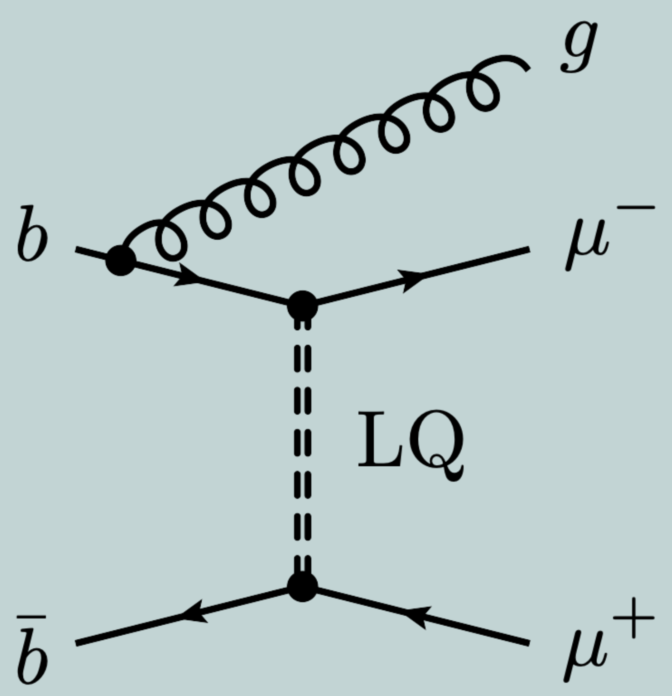

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- The POWHEG framework uses a different strategy, **generating hardest emission events using full NLO accuracy.**

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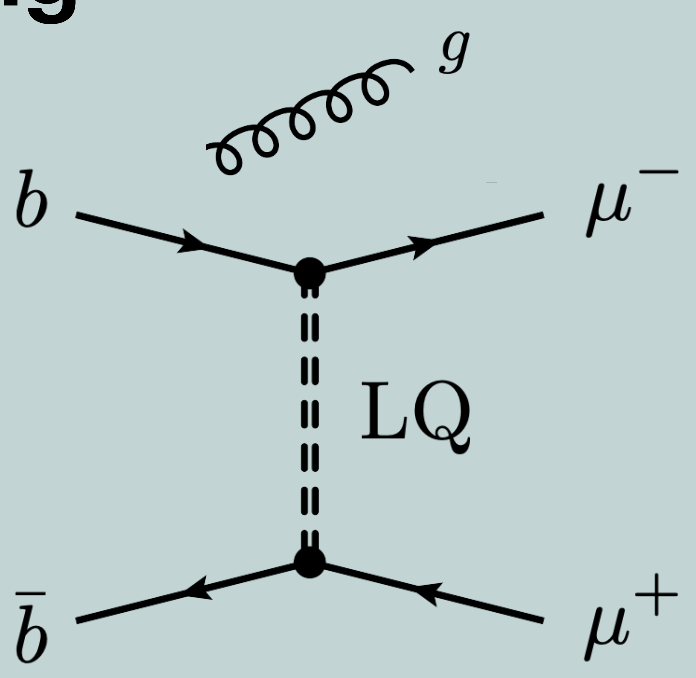

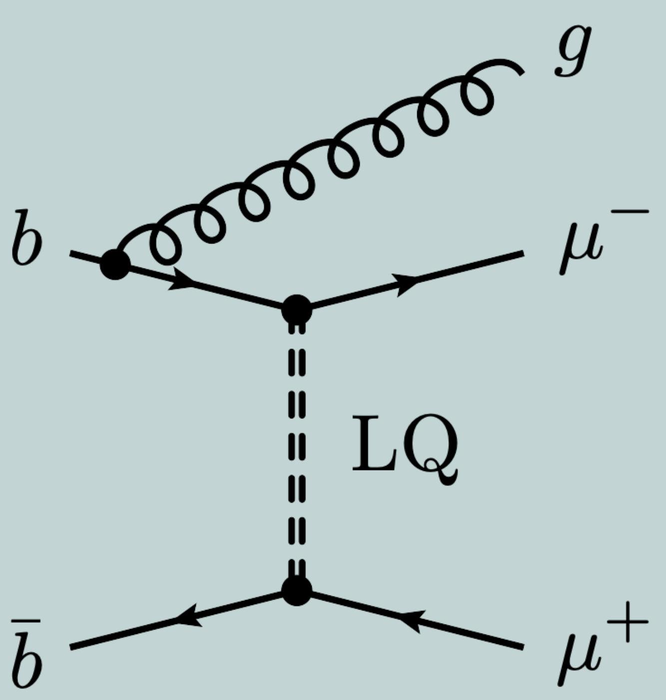

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- The POWHEG framework uses a different strategy, **generating hardest emission events using full NLO accuracy.**
- The **PS** is then only needed for emissions below p_T^{min}.

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2.3 POWHEG-Box (in a nutshell)

See ArXiv:1002.2581 for more information.

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Matrix elements

Born.f
real.f
virtual.f

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3. Phenomenology

3.1 Inclusive cross section

3.2 b-tags

3.3 Exclusion limits

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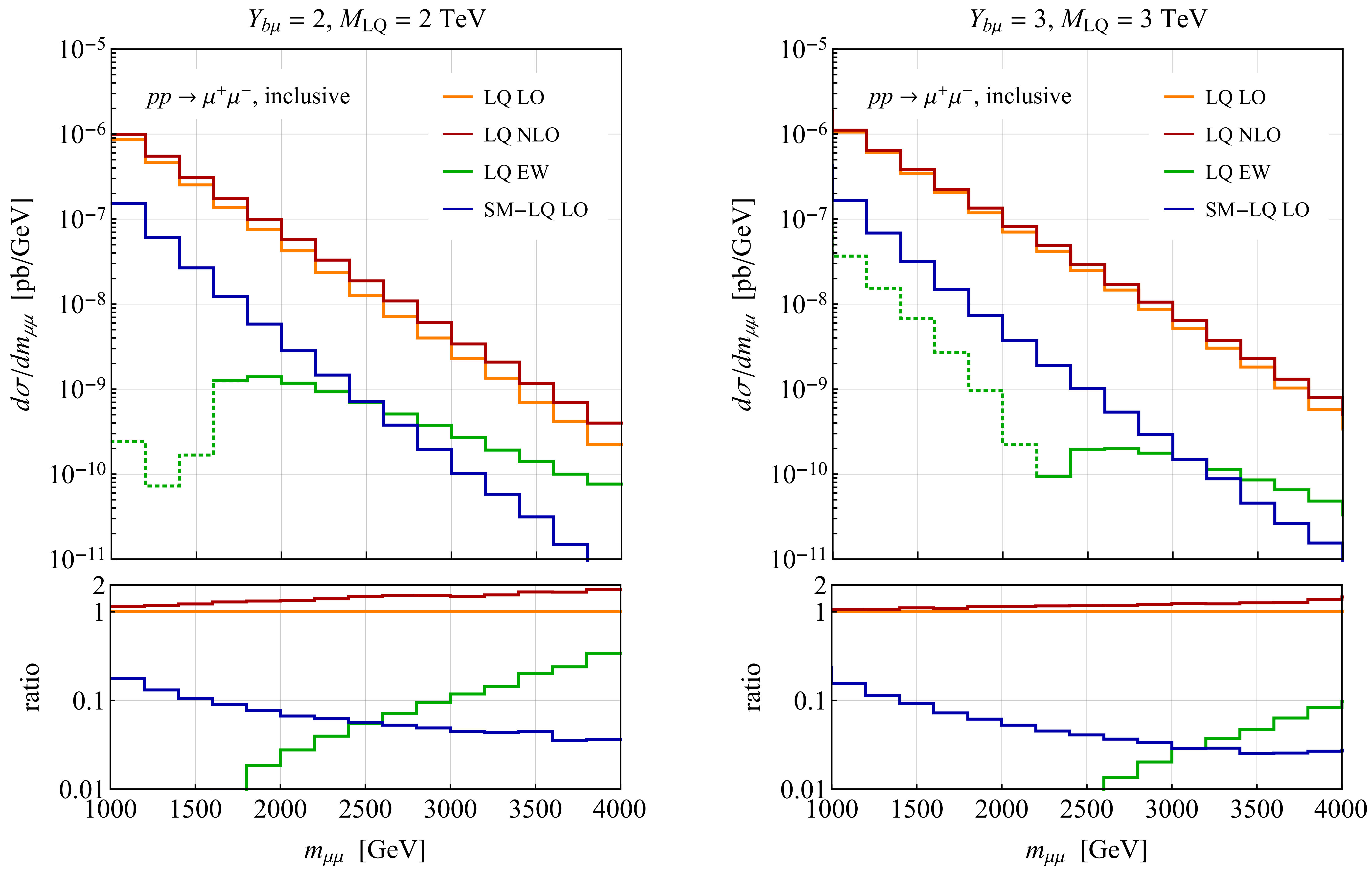

3. Phenomenology

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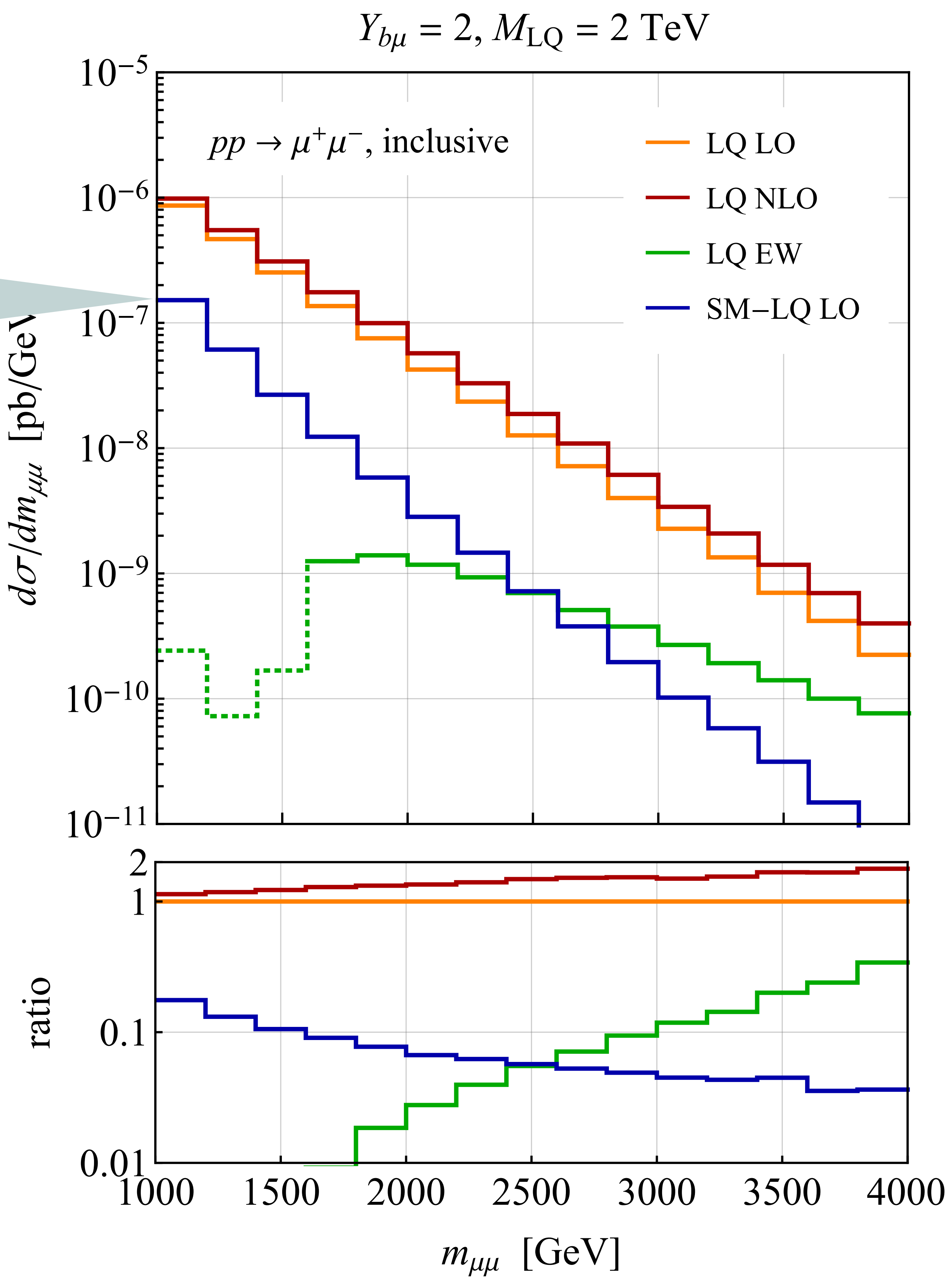
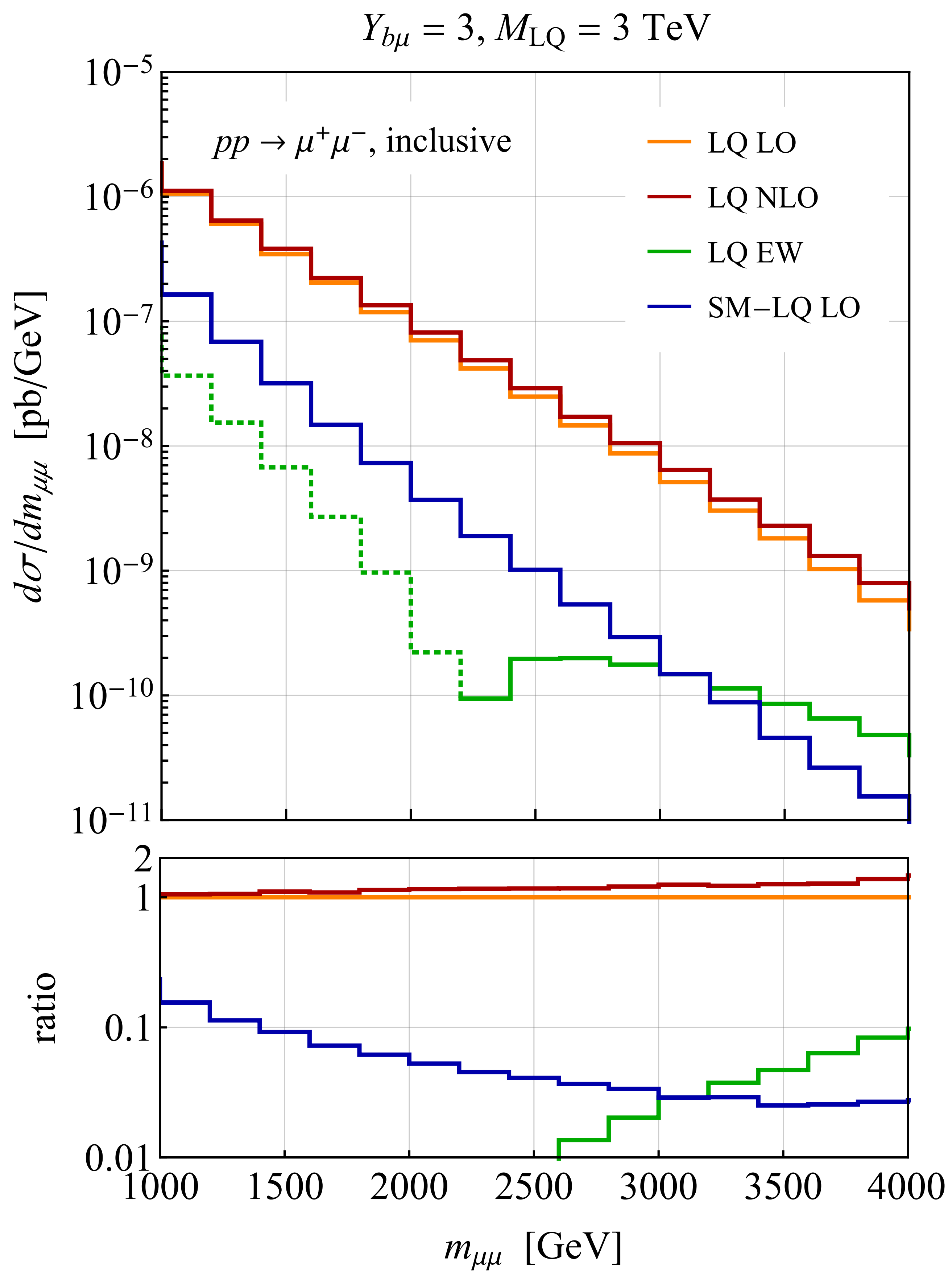
Interference effects become relevant only for low $m_{\mu\mu}$.





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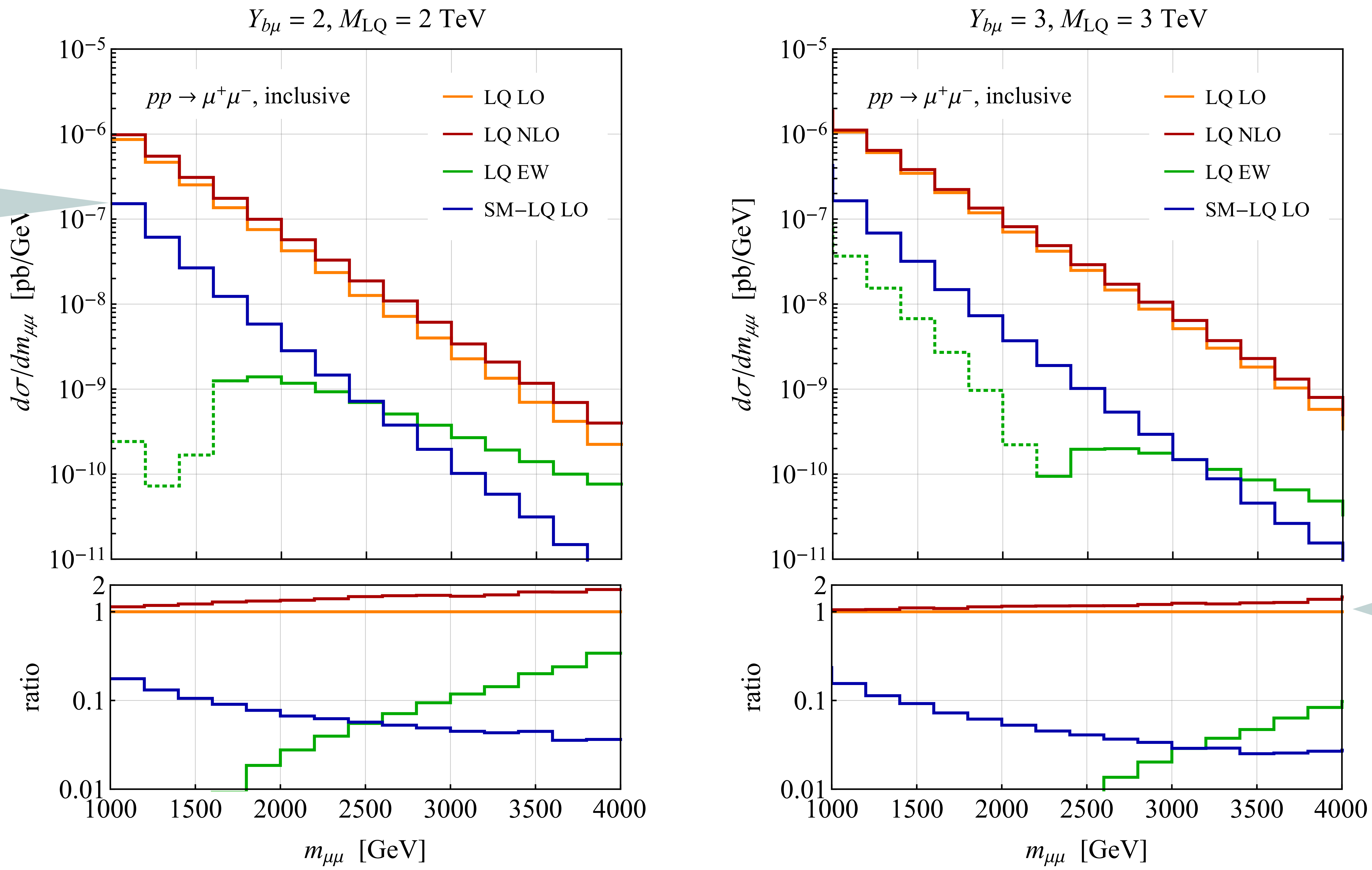

NLO corrections are important for obtaining precise predictions, especially at high $m_{\mu\mu}$.

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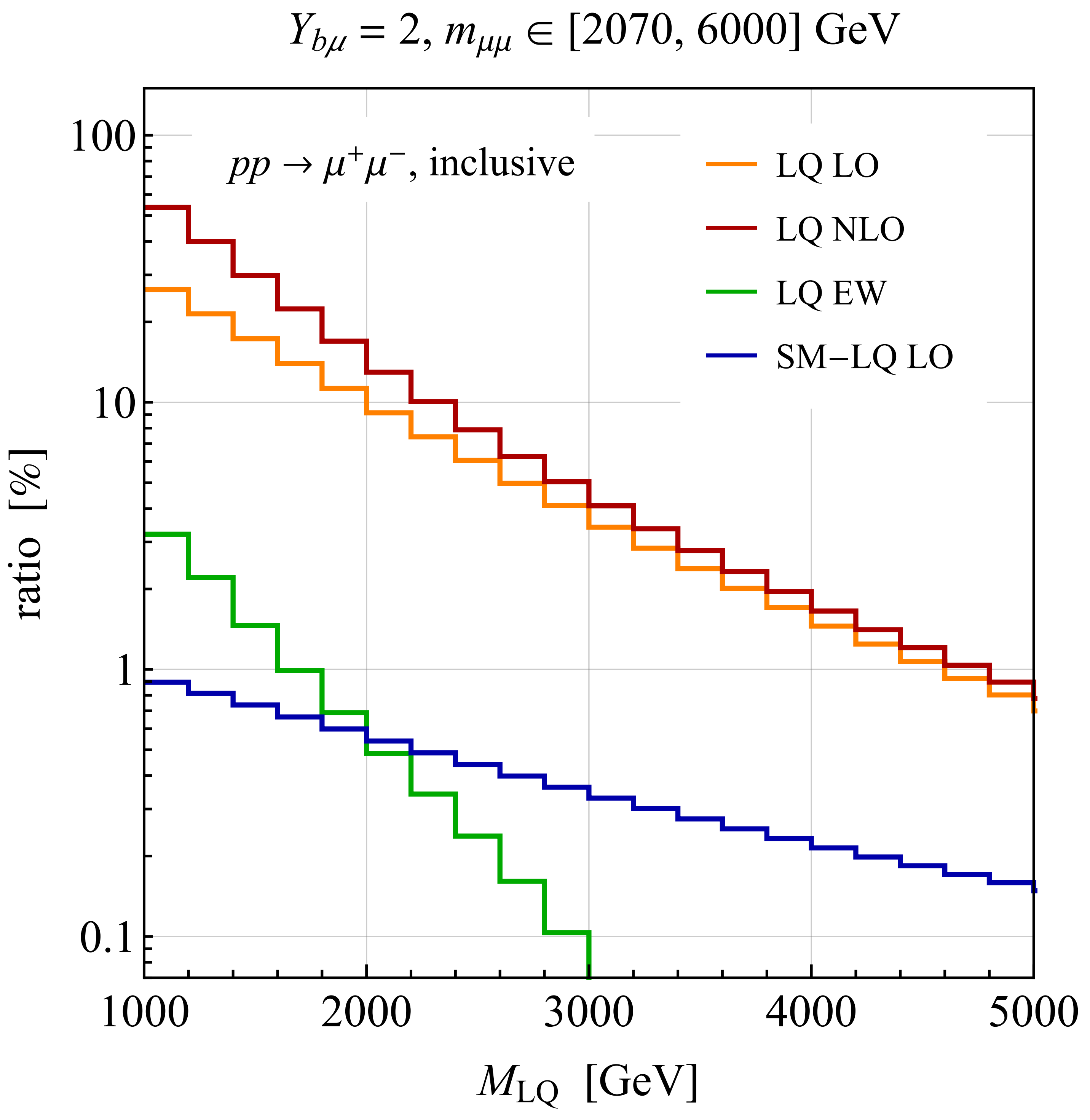

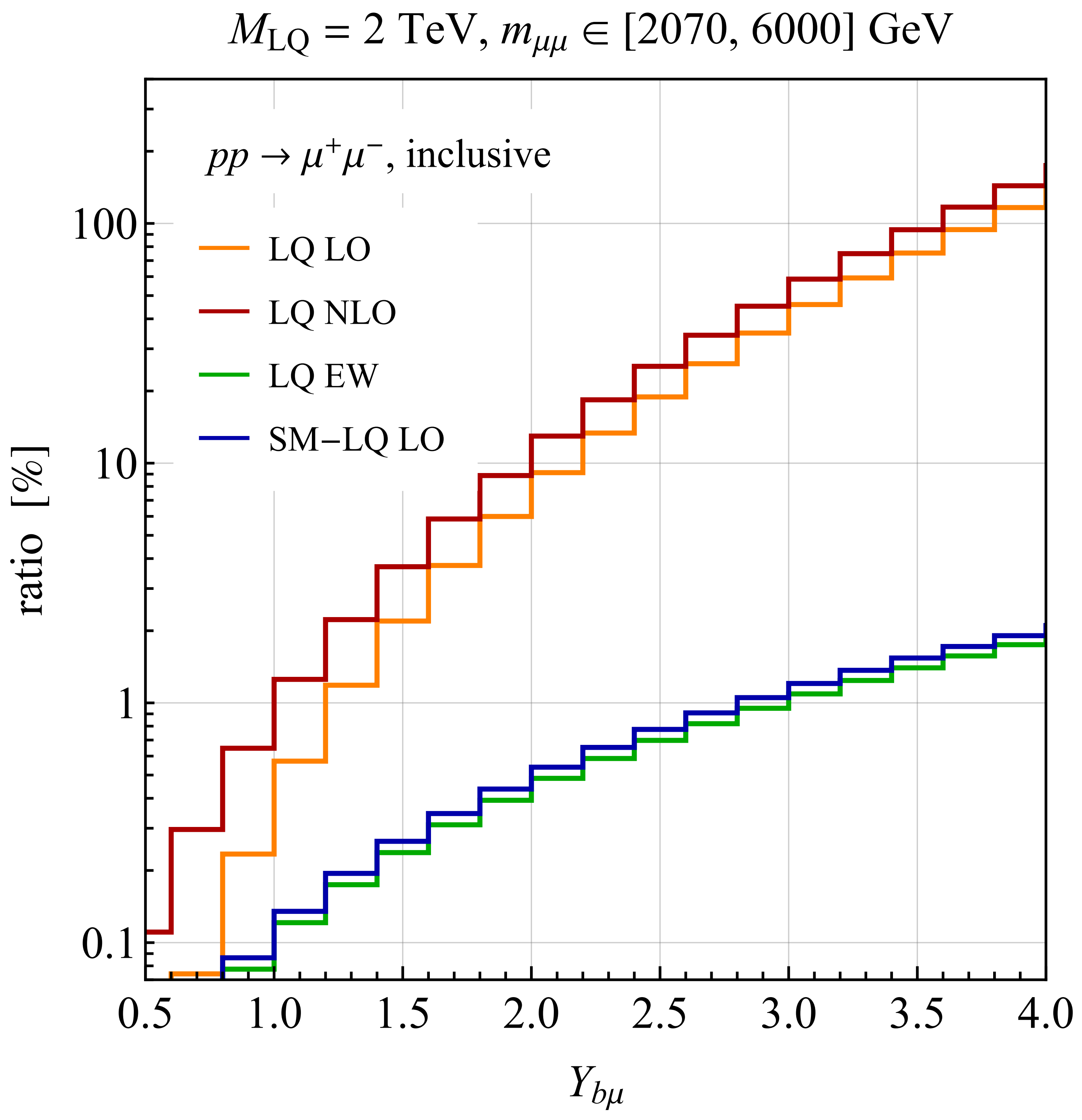

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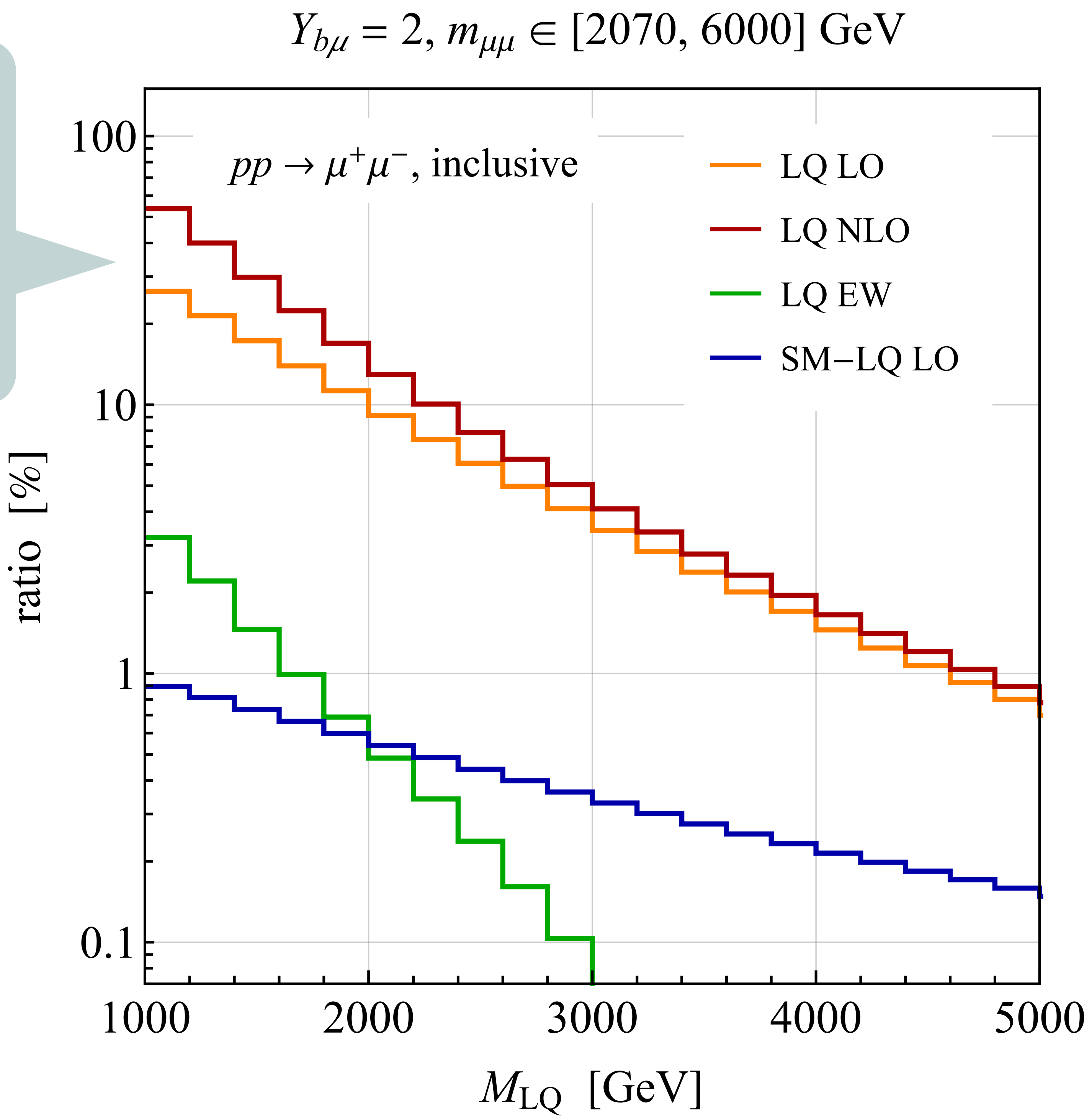
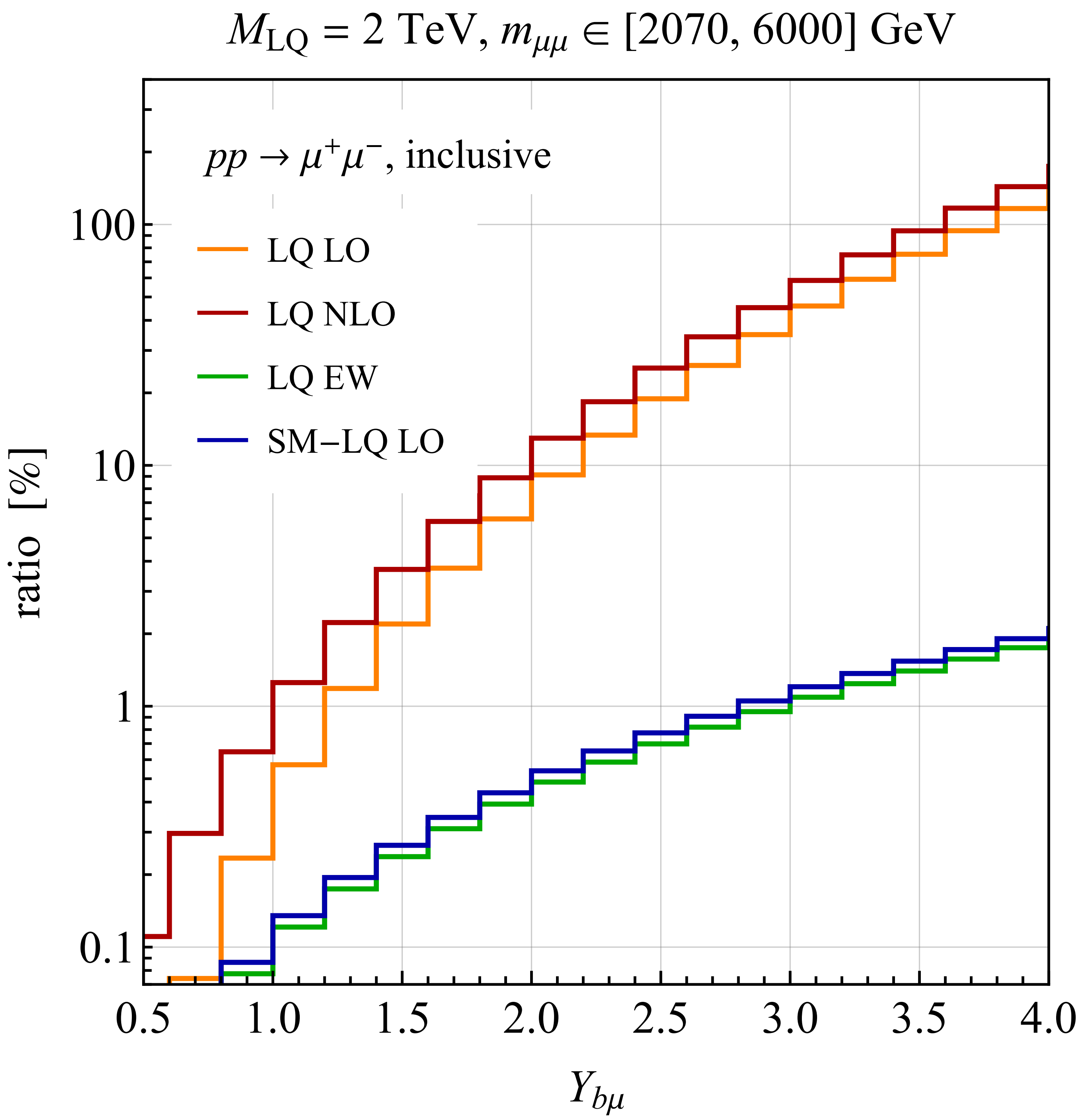
NLO corrections decrease as the **single LQ production** channel decouples.





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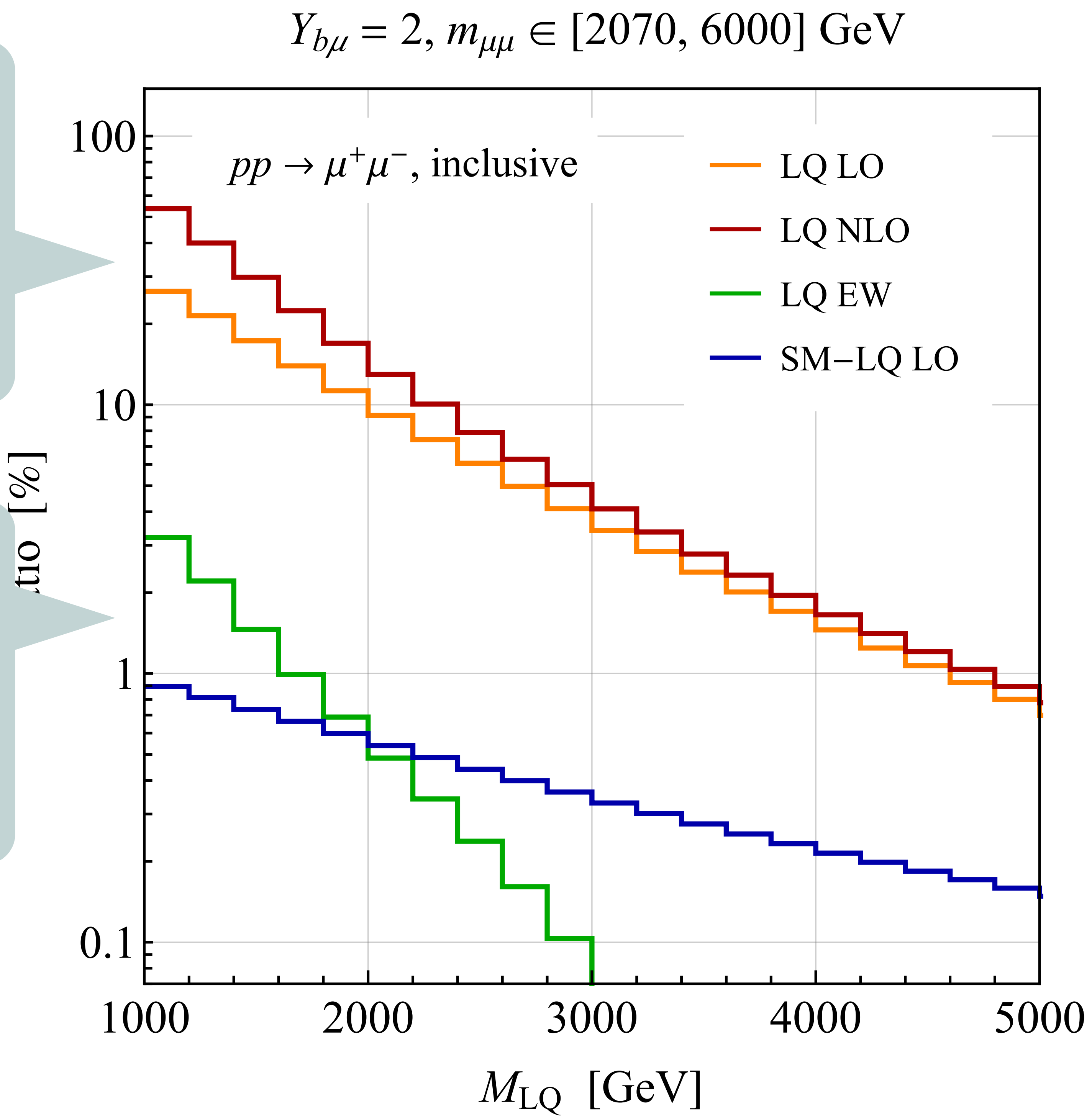
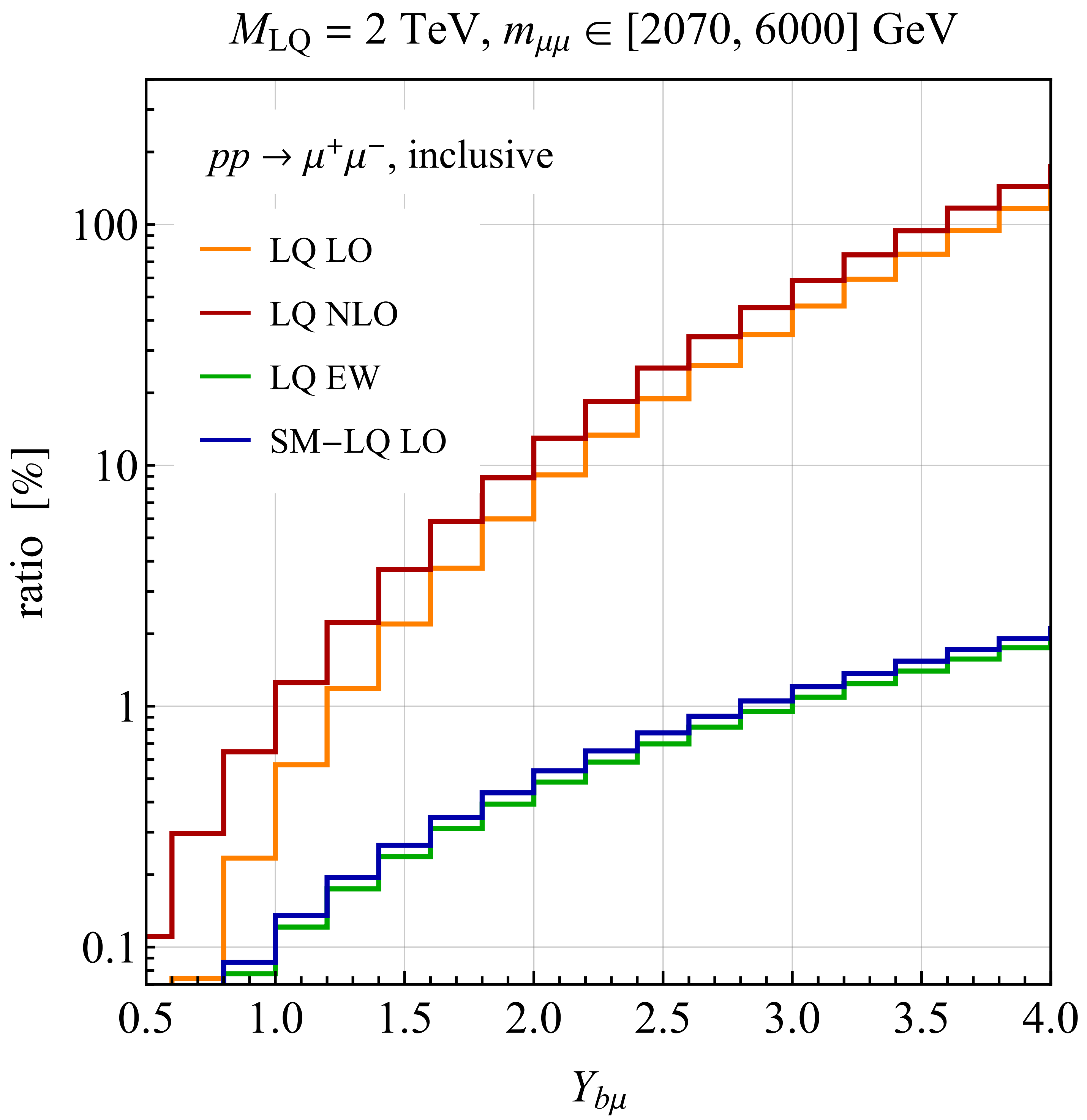
NLO corrections decrease as the **single LQ production** channel decouples.

Interference and EW effects are not relevant in the signal region considered by ATLAS.





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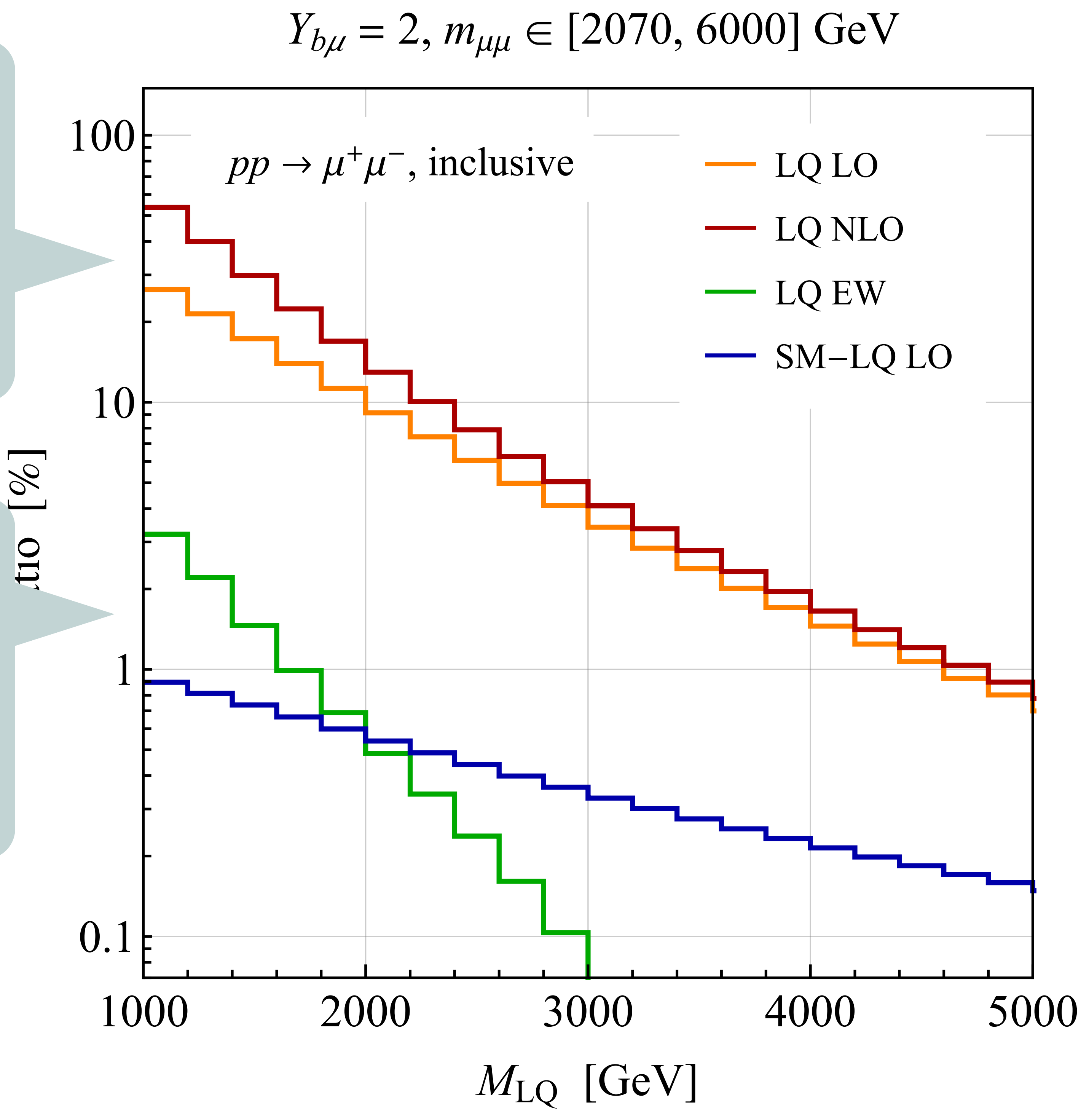

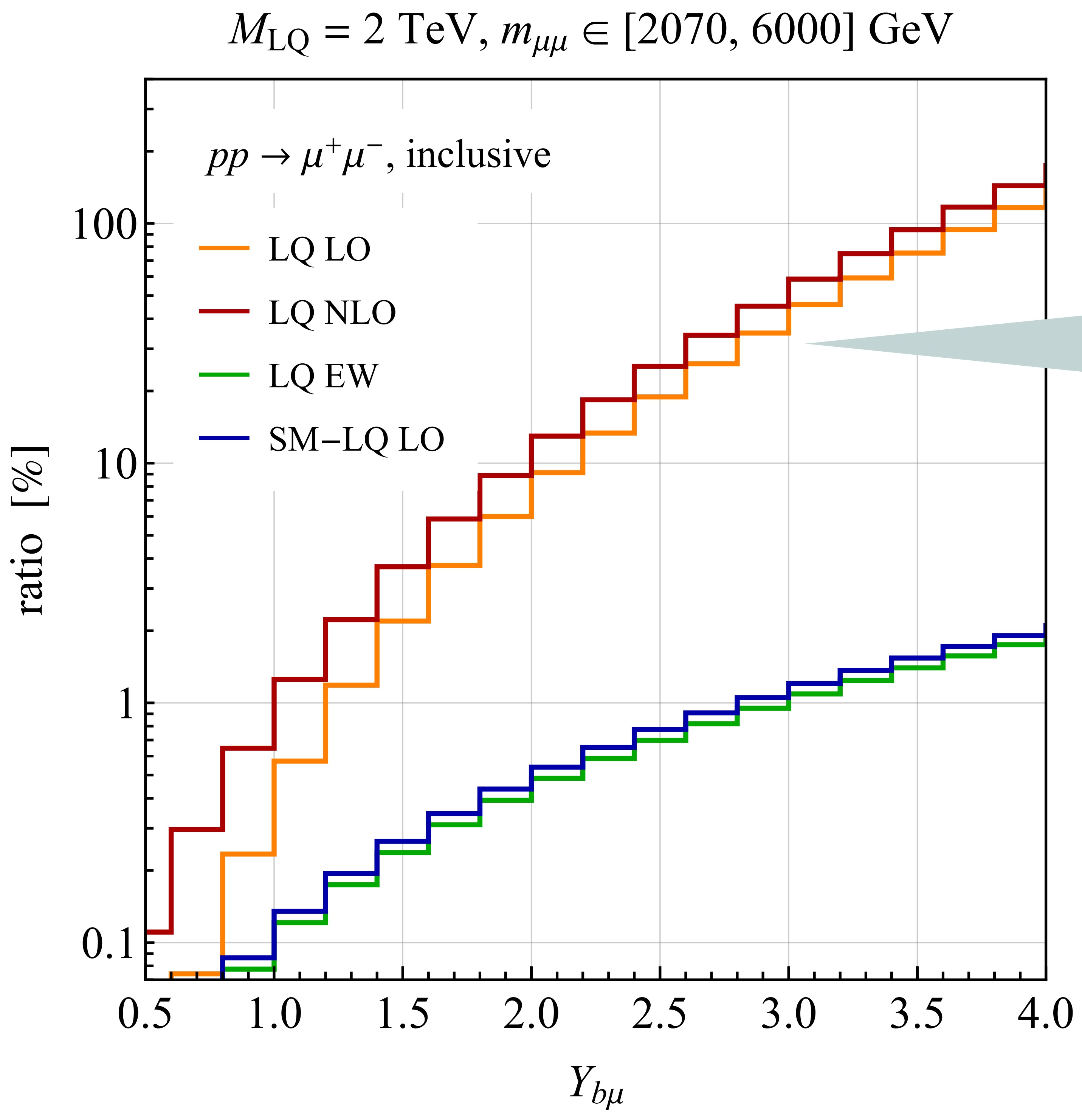

Single LQ production channel becomes less important for larger $Y_{b\mu}$, since it scales as $|Y_{b\mu}|^2$, whereas the tree-level contribution scales as $|Y_{b\mu}|^4$.

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Recasting their analysis using the full

Madanalysis5 + Delphes

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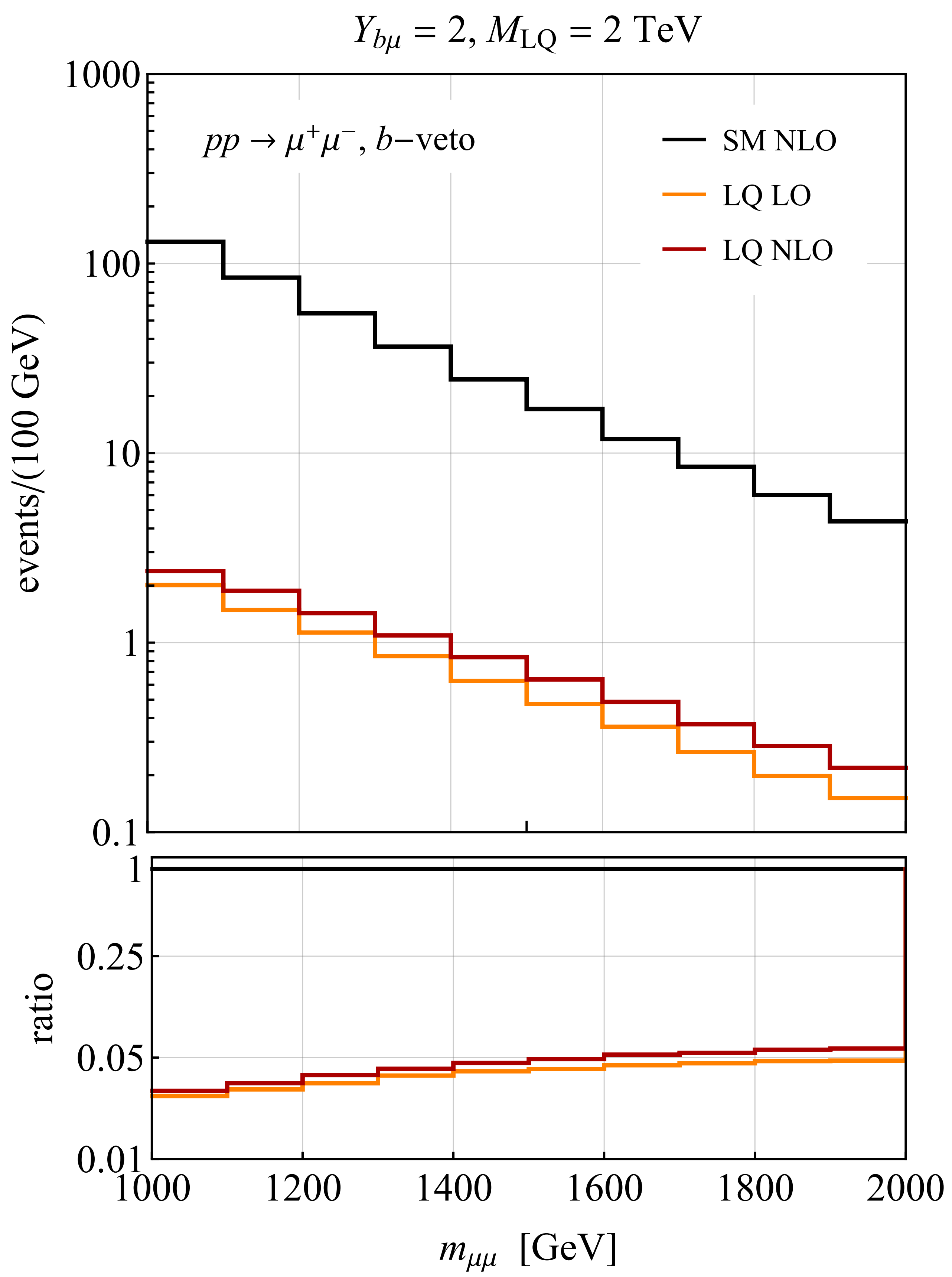

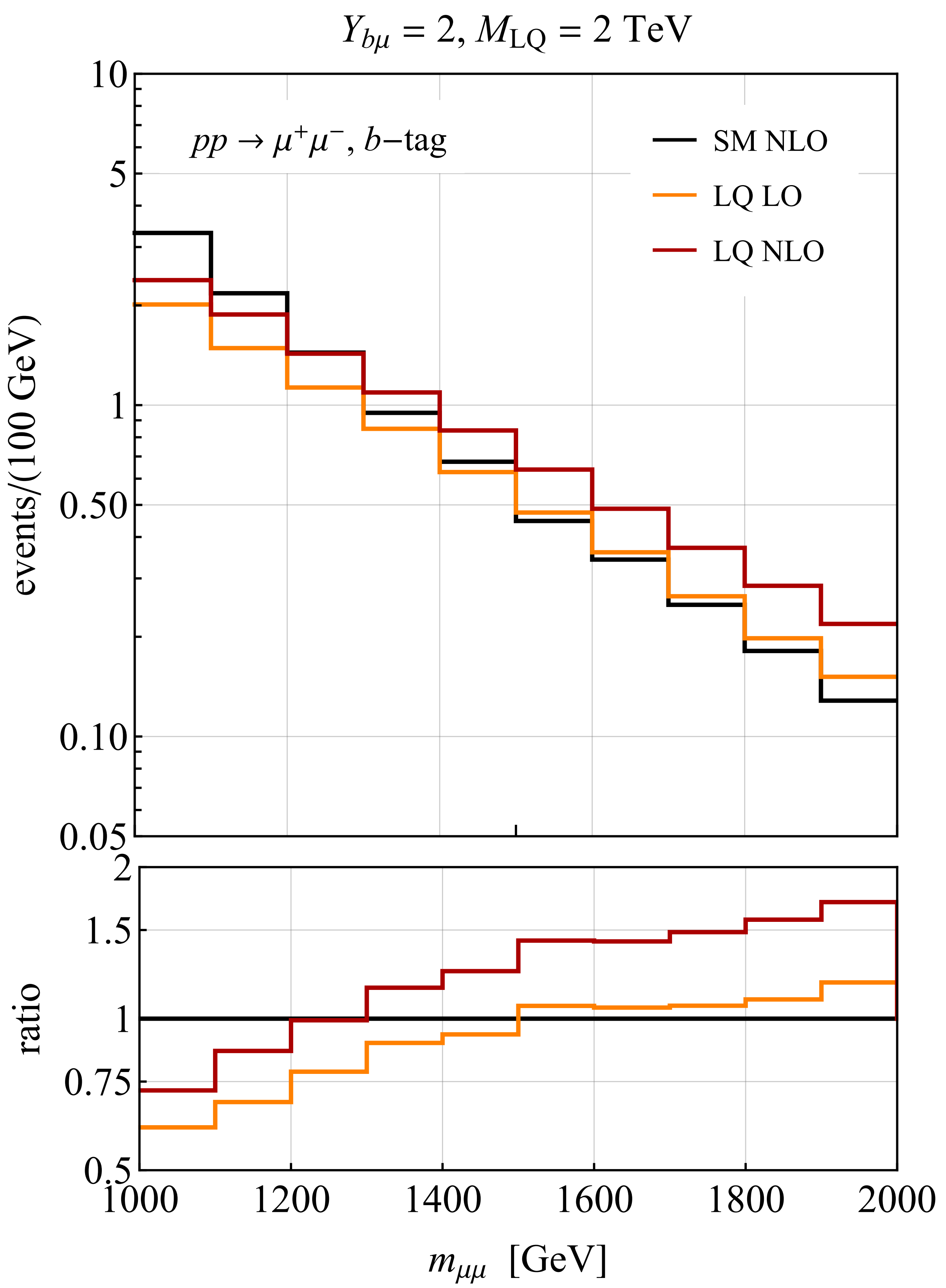

3. Phenomenology

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- ATLAS recently presented a **DY analysis for light-leptons** with and without **b-tags**.

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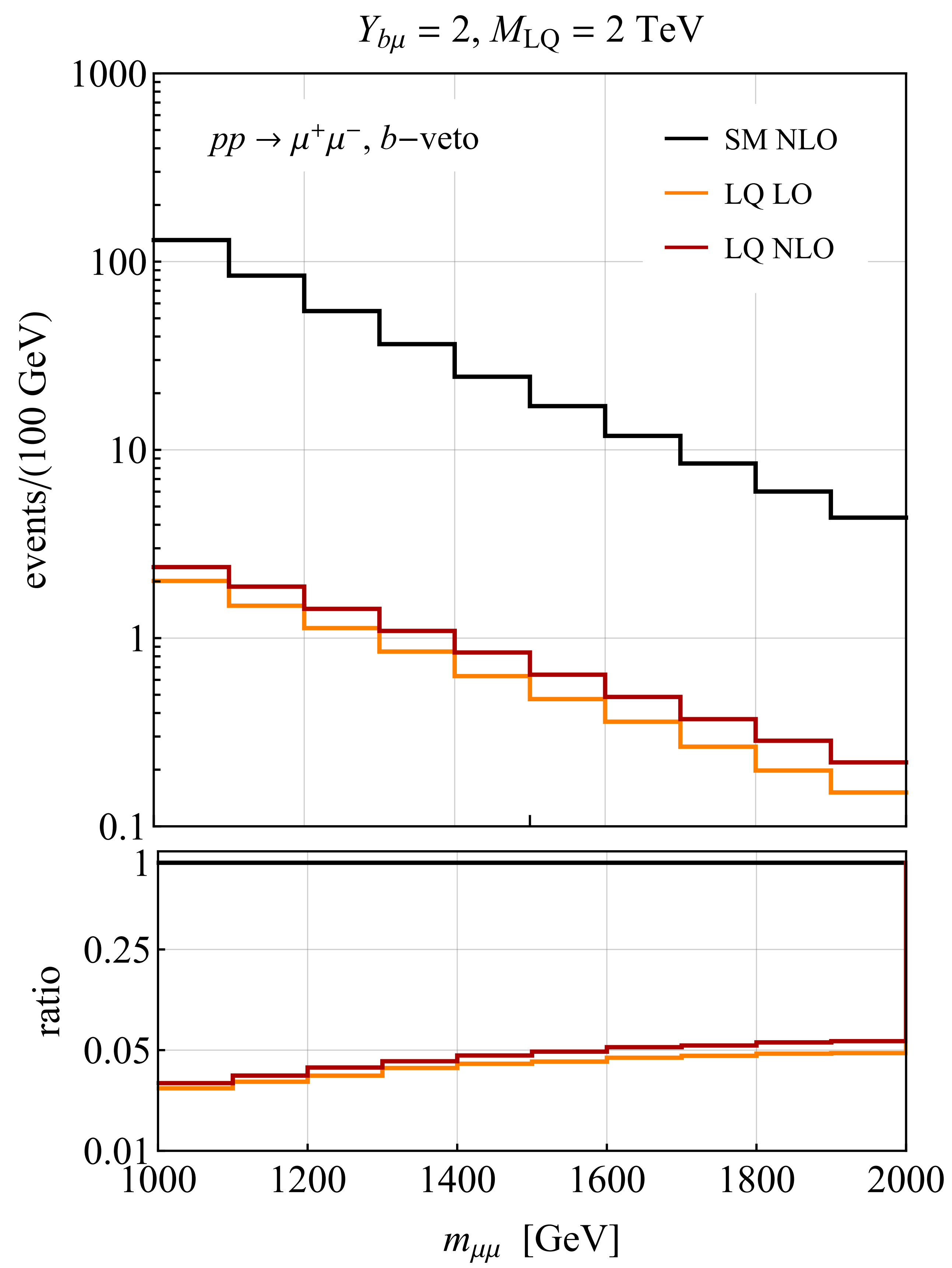

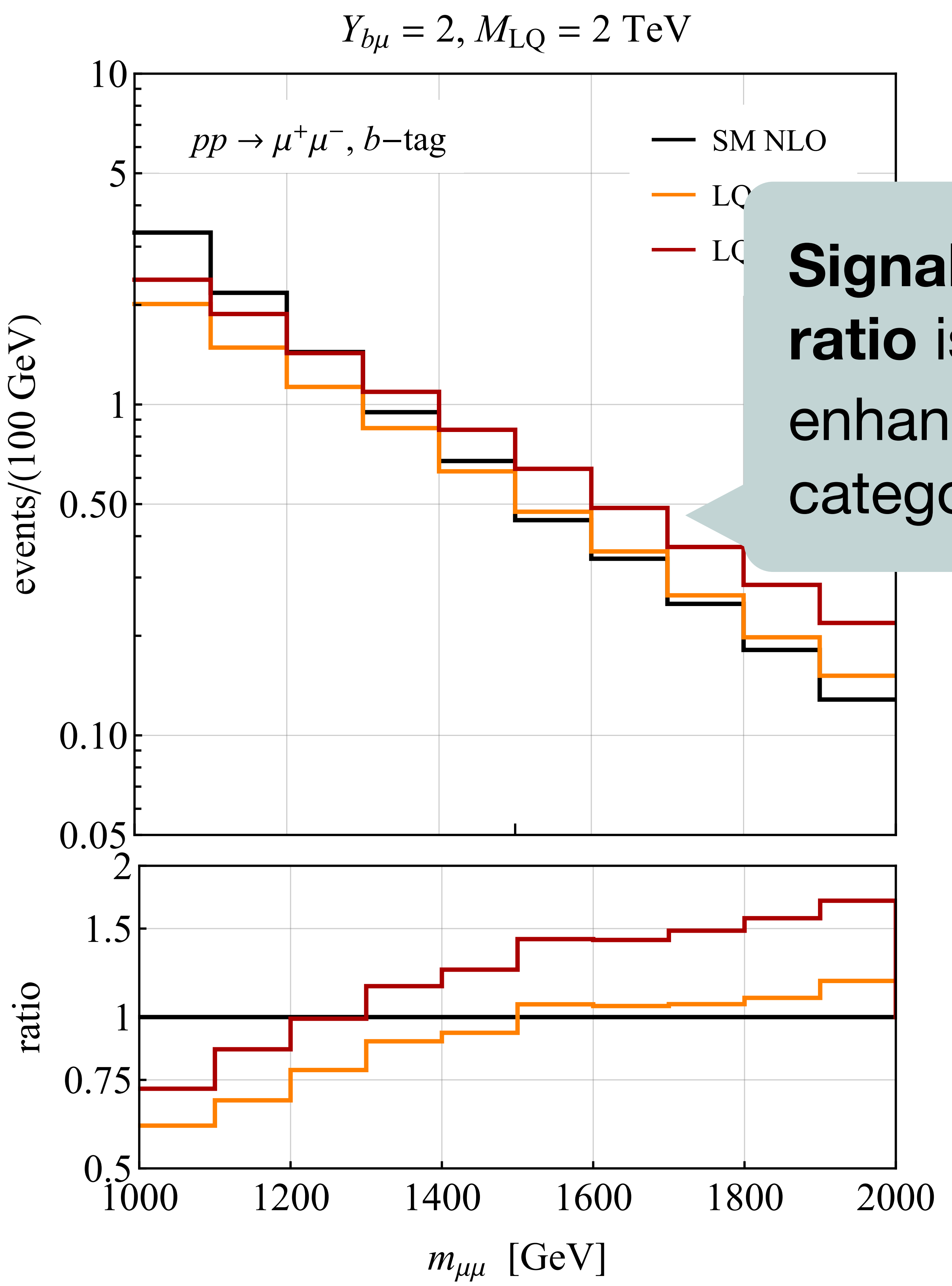

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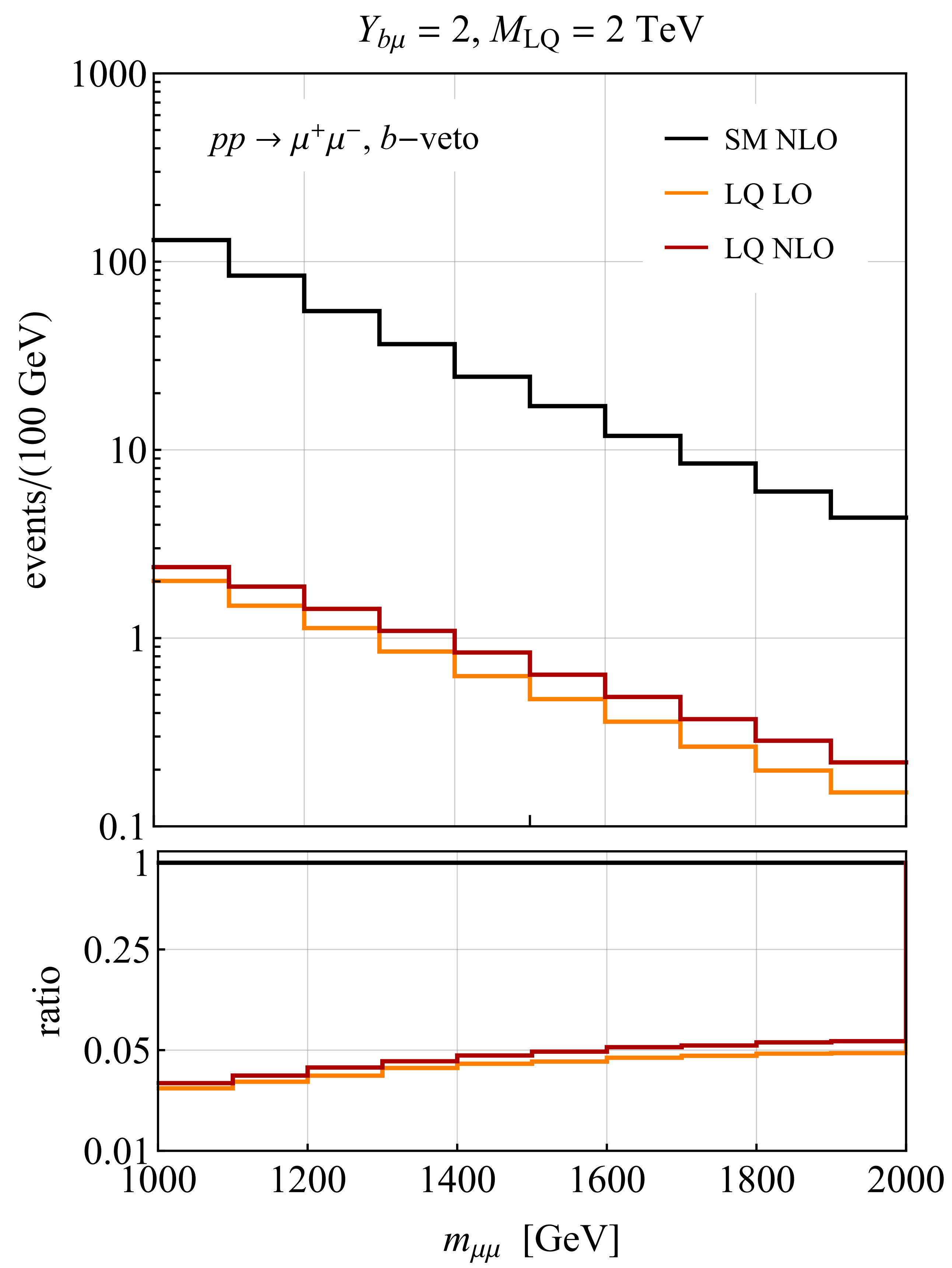

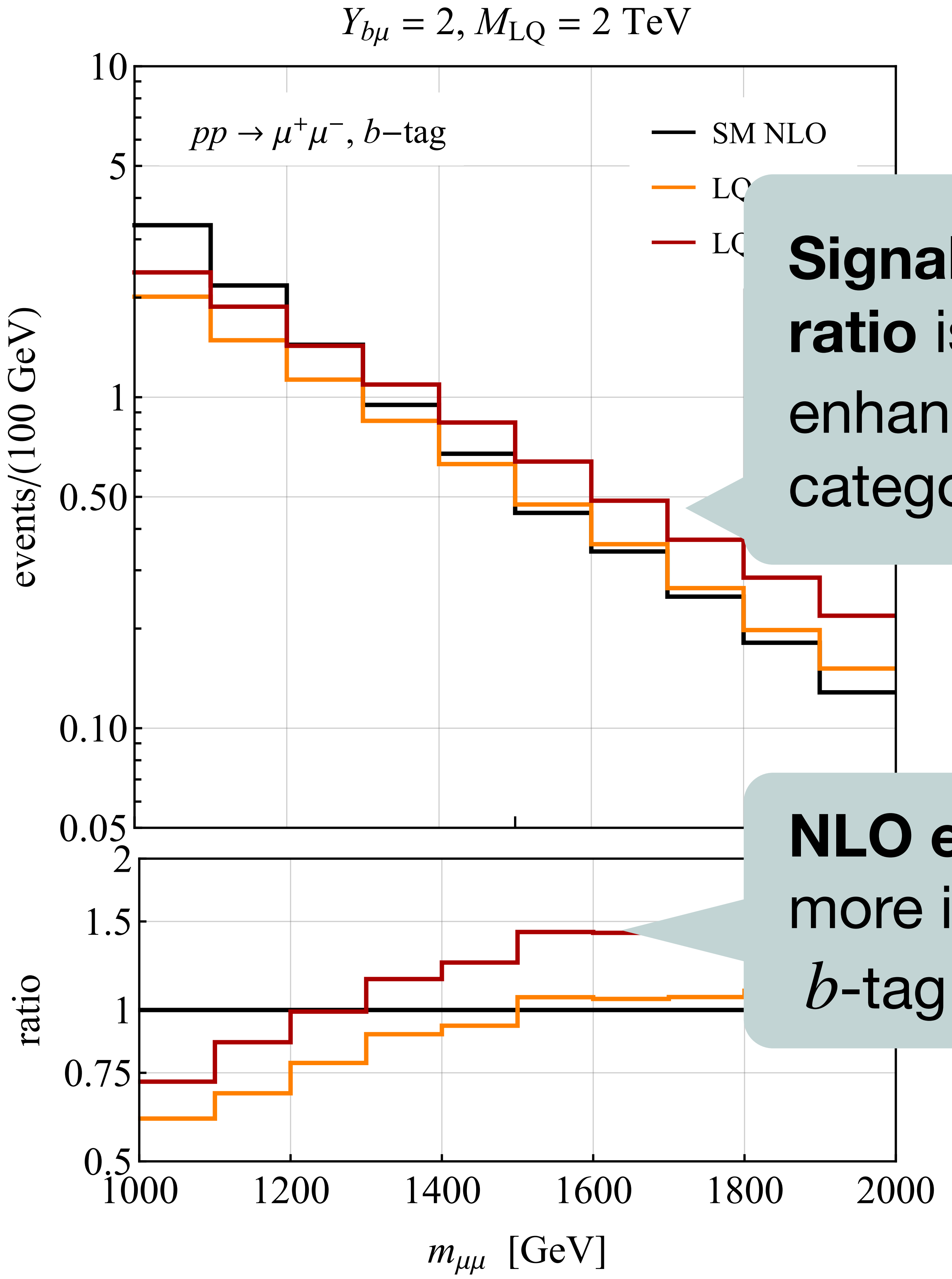

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NLO effects are even more important in the b-tag category.

3. Phenomenology

3.3 Exclusion Limits

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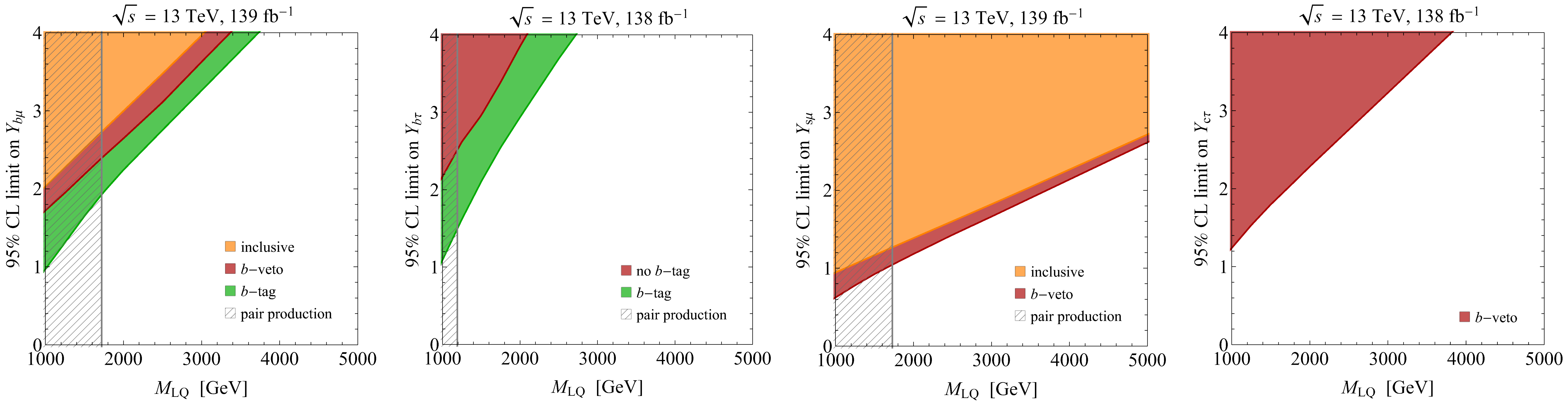

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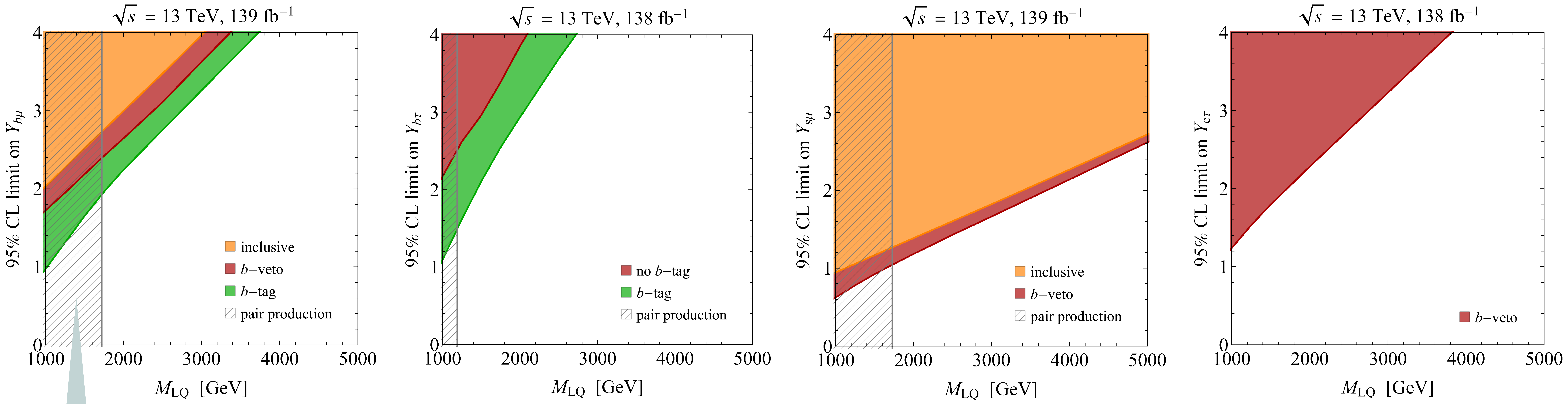

Improved exclusion limits due to NLO description and b-tagging.

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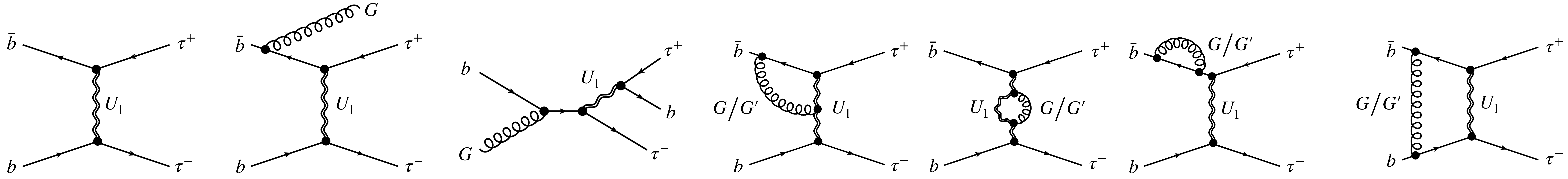
- We are working on a full NLO implementation of the U_1 **vector leptoquark** from third family gauge models.



5. Conclusions

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Thank you for your attention!

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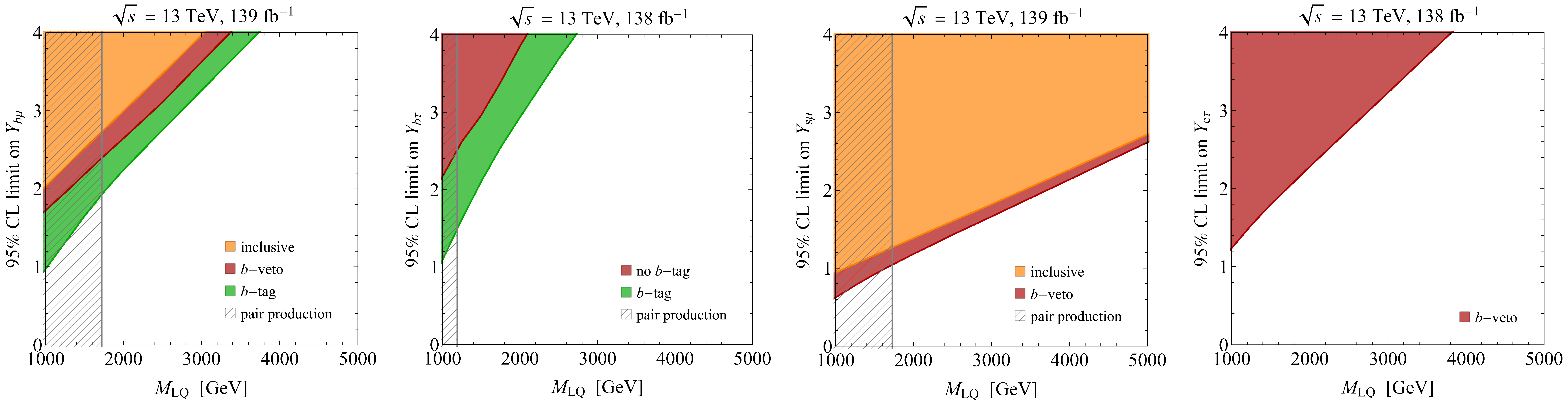

3. Phenomenology

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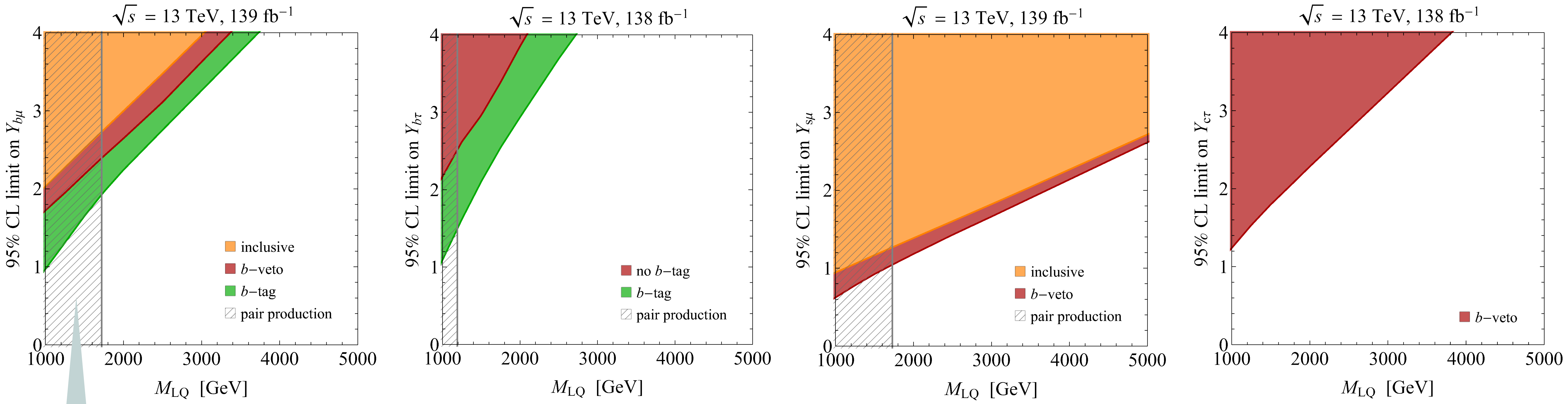

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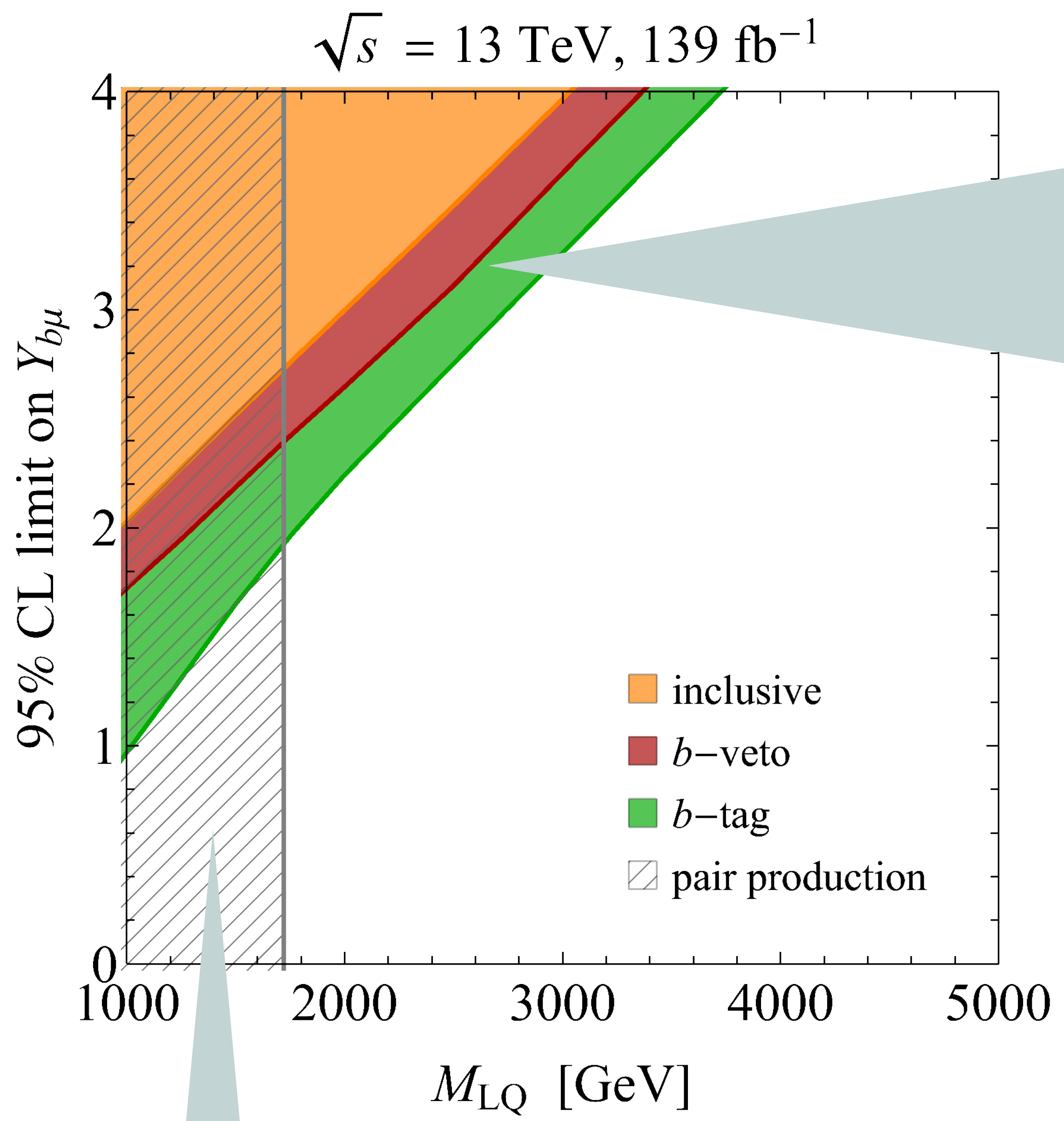

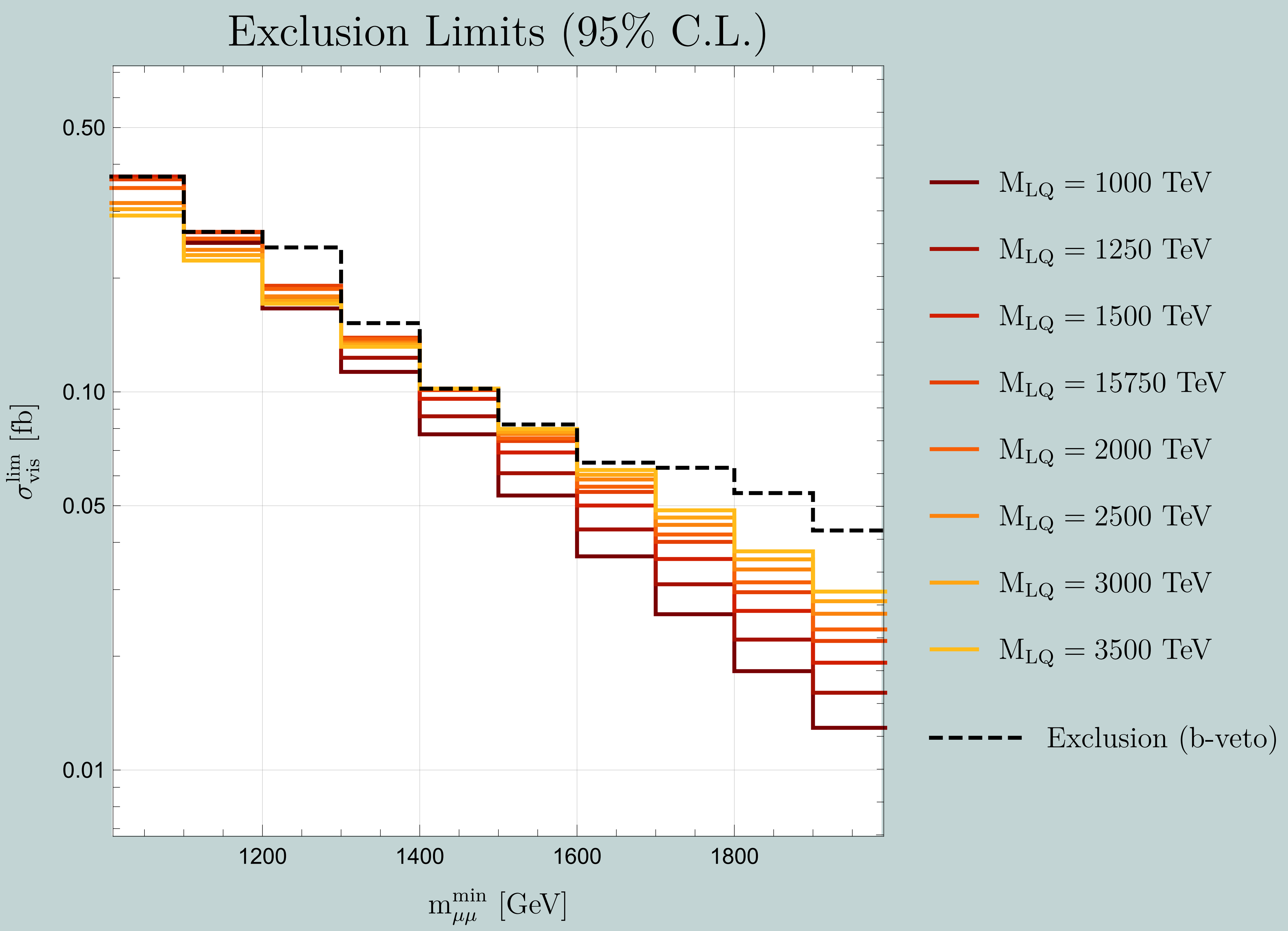

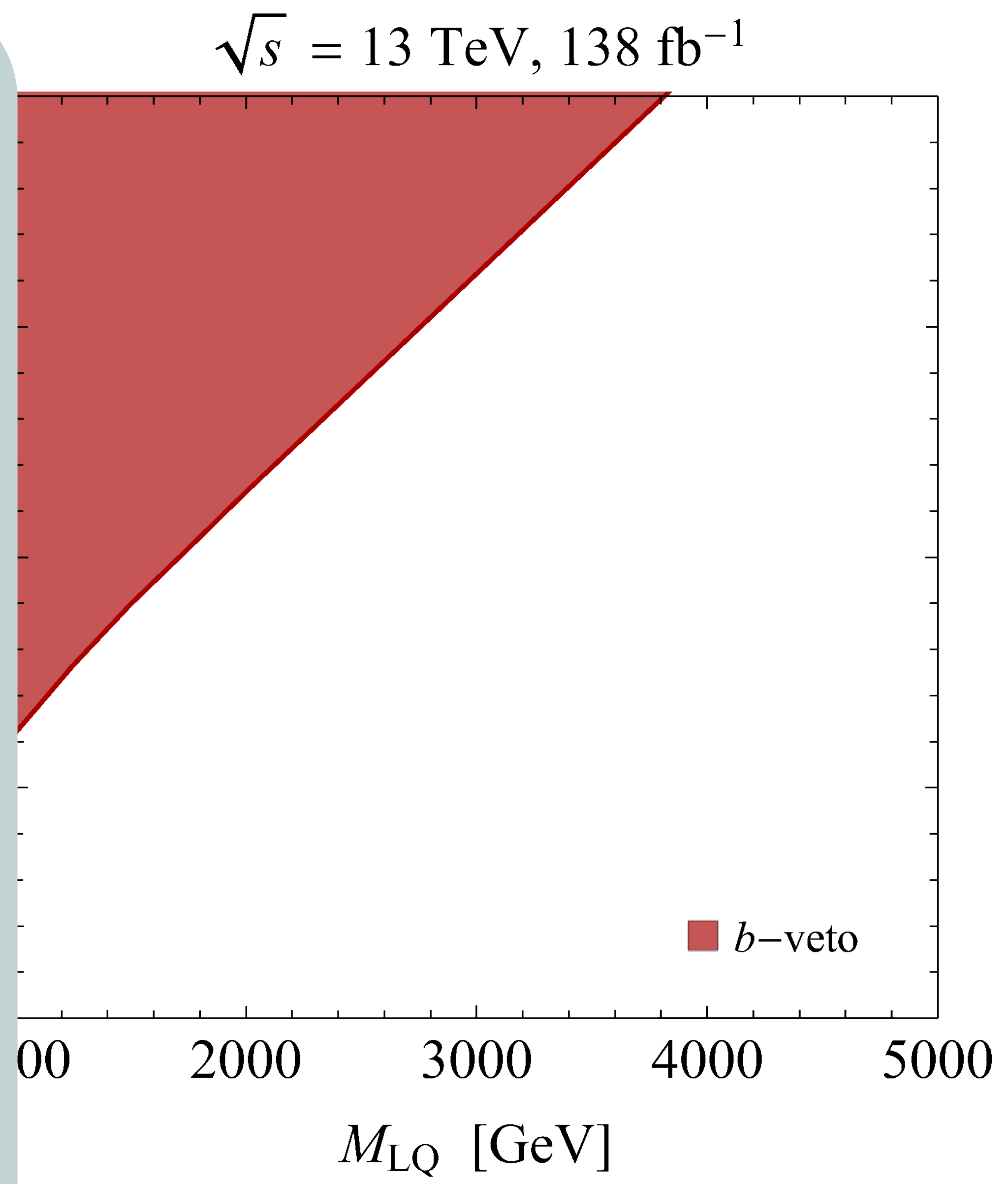

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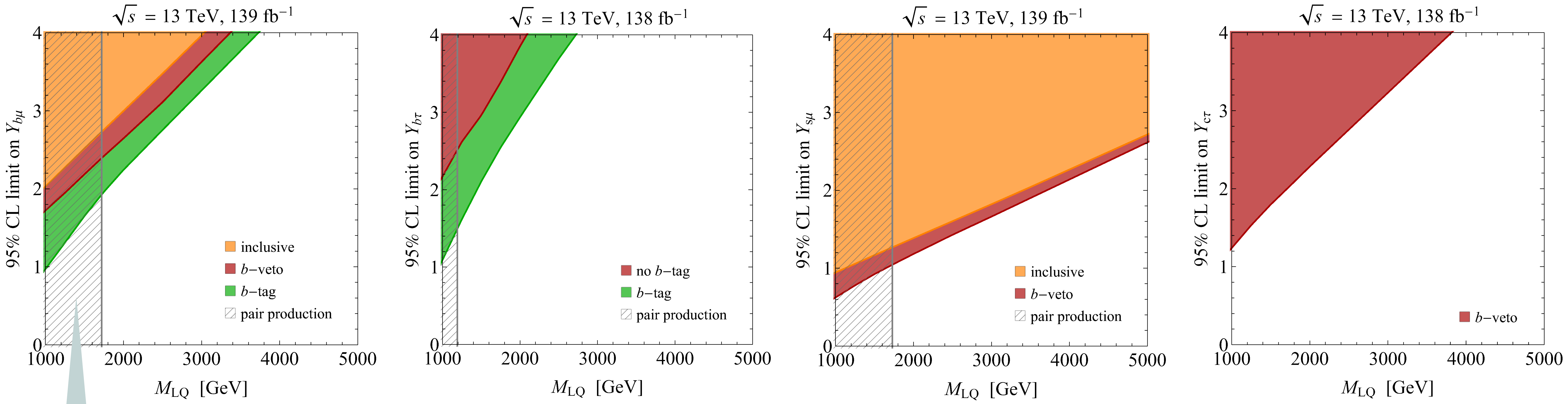

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2. Theoretical framework and calculations

2.3 POWHEG-Box (in a nutshell)

2. Avoiding double counting

See ArXiv:0709.2092 for detailed information.

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- The **PS** is then only needed for emissions below p_T^{min}.

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