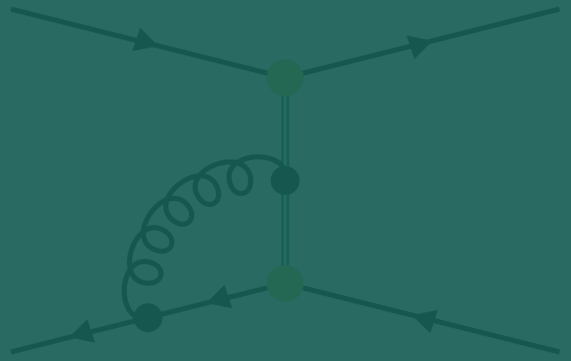
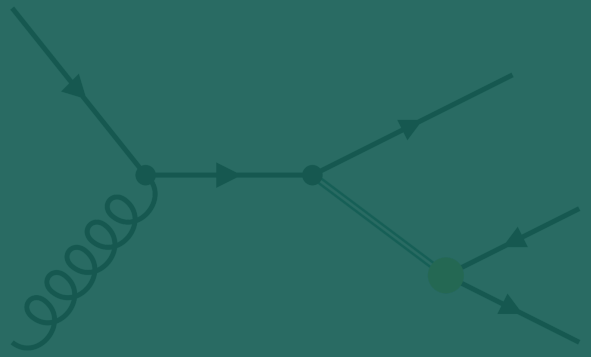
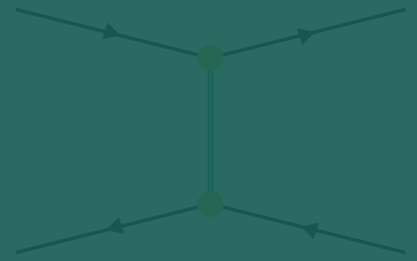




Inclusive Drell-Yan Production with Leptoquarks: Simulating NLO Effects in non-resonant Dilepton Searches

Based on arXiv:2207.00356 and arXiv:2209.12780
In collaboration with Ulrich Haisch and Luc Schnell

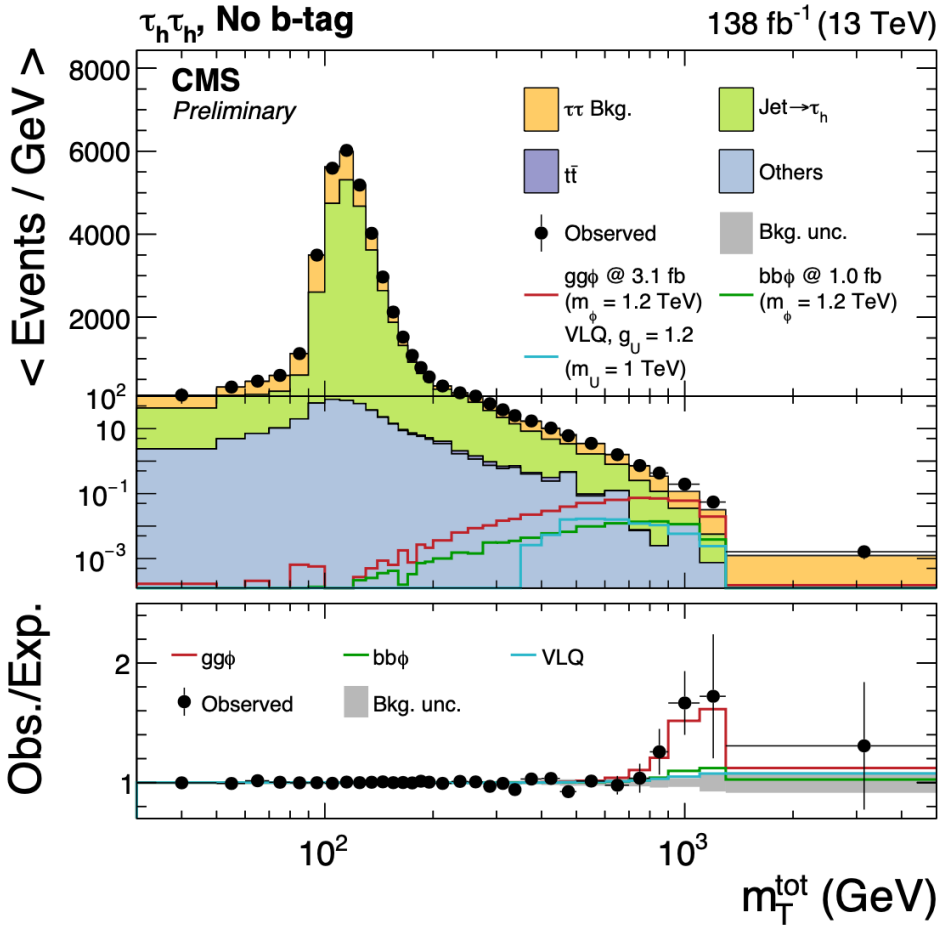
Stefan Schulte

DESY Theory Workshop „Higgs, Flavor and beyond“| Sep 27 – Sep 30, 2022

MAX-PLANCK-INSTITUT FÜR PHYSIK

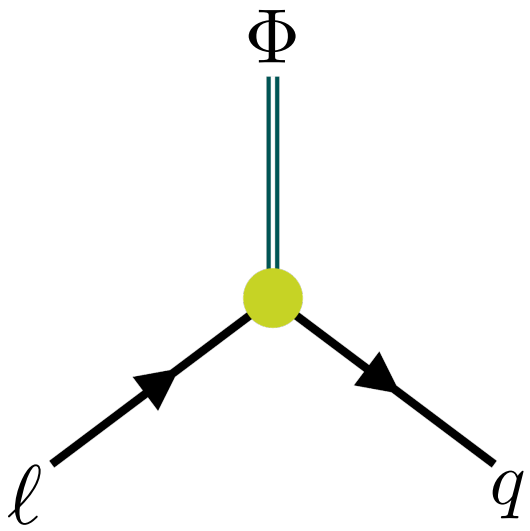
Flavor Anomalies: Hints for New Physics?

- $R_{D^{(*)}}$ and $R_{K^{(*)}}$ anomalies
- Muon anomalous magnetic moment
- Excesses in $pp \longrightarrow \tau^+\tau^-$ spectra in the high mass tail reported by CMS

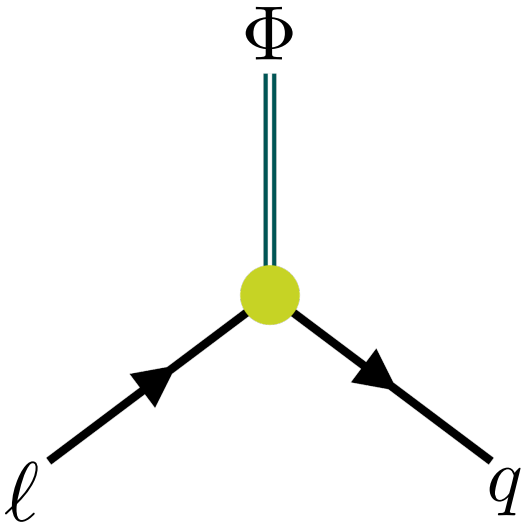


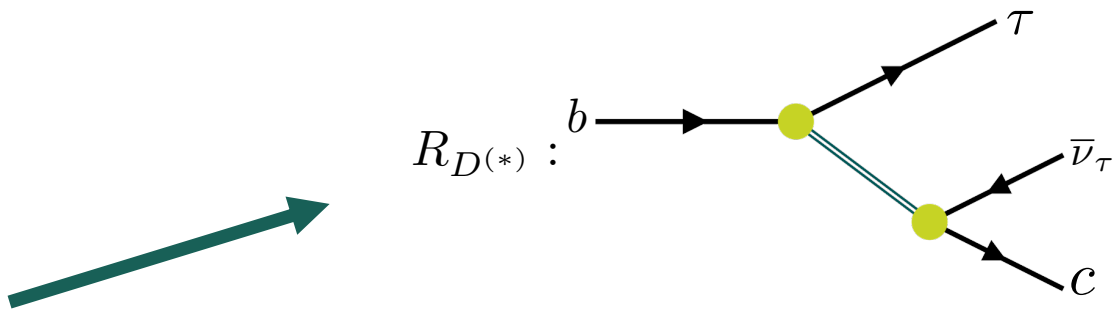
taken from CMS PAS HIG-21-001

Explaining anomalies with Leptoquarks

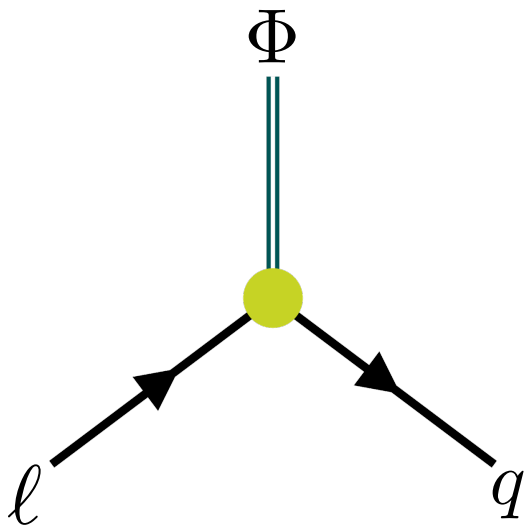


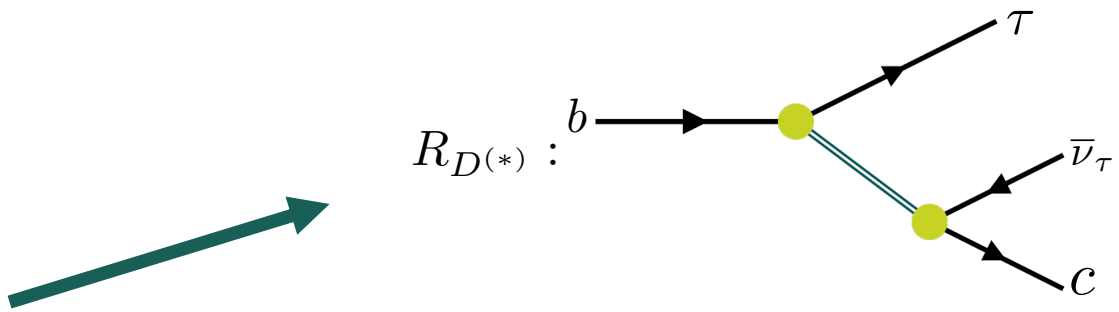
Explaining anomalies with Leptoquarks

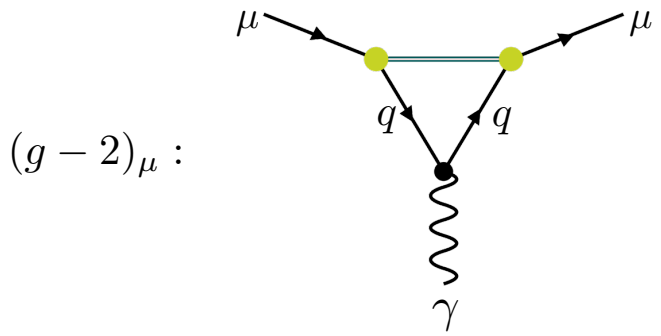




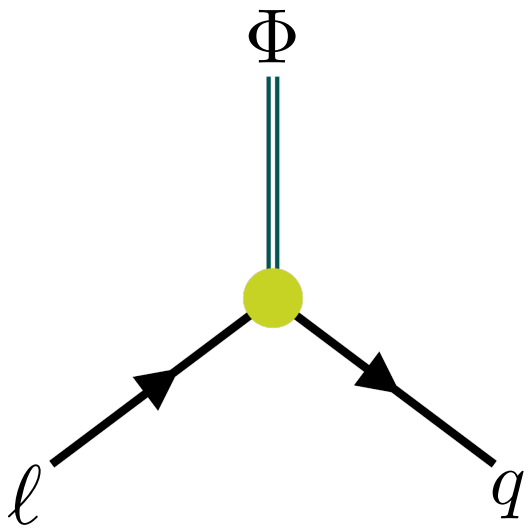
Explaining anomalies with Leptoquarks



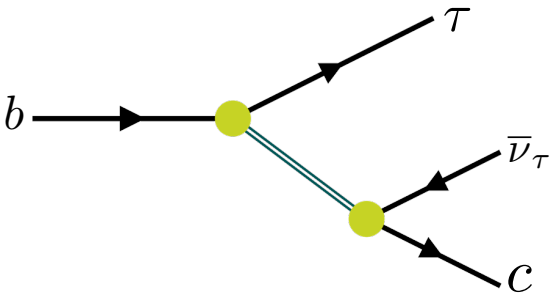




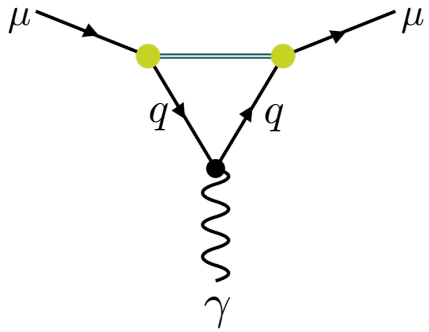
Explaining anomalies with Leptoquarks



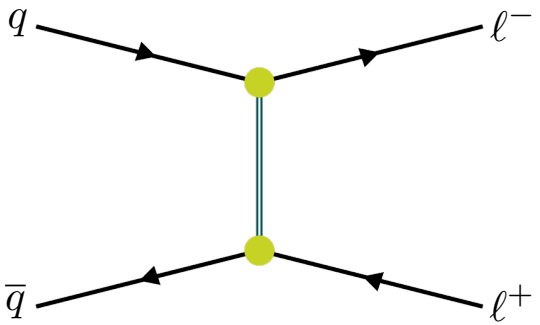
$R_{D^{(*)}}$:



$(g-2)_\mu$:



$\ell^+\ell^-$:



LQ Representations under consideration

Scalar case: $S_1 \sim (3, 1, -1/3)$ & $\tilde{S}_1 \sim (3, 1, -4/3)$

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

- Simplest LQ extensions of SM
- Serves as basis for more involved LQ scalar models

Vector case: $U \sim (3, 1, 2/3)$

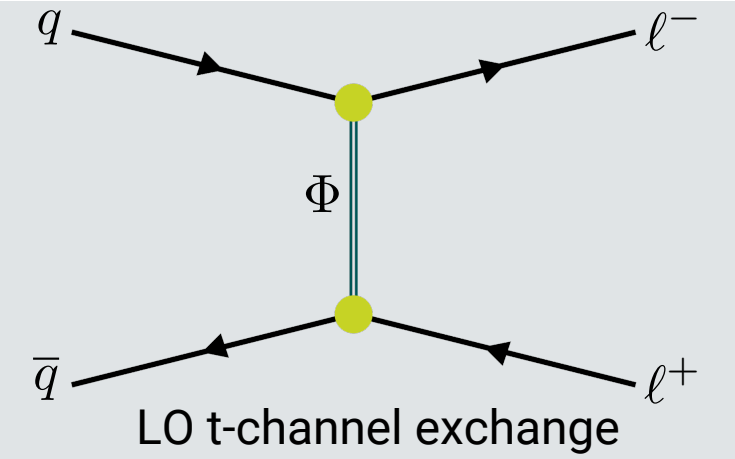
$$\mathcal{L}_{4321} \supset \frac{g_4}{\sqrt{2}}\, \bar{\psi}_q^a\, \gamma_\mu\, \psi_\ell\, U^{\mu,a} + \text{h.c.} + g_s\, \bar{\psi}_q\, \gamma_\mu T^a\, \psi_q\, G^{\mu,a} + c_3\, g_4\, \bar{\psi}_q\, \gamma_\mu T^a\, \psi_q\, G'^{\mu,a}$$

- 4321 model minimal UV complete gauge vector LQ model explaining LFU violations in semi-leptonic B decays
- Further complications: coloron $G' \sim (8, 1, 0)$, additional Ghosts & Goldstone modes

Goals and Strategy

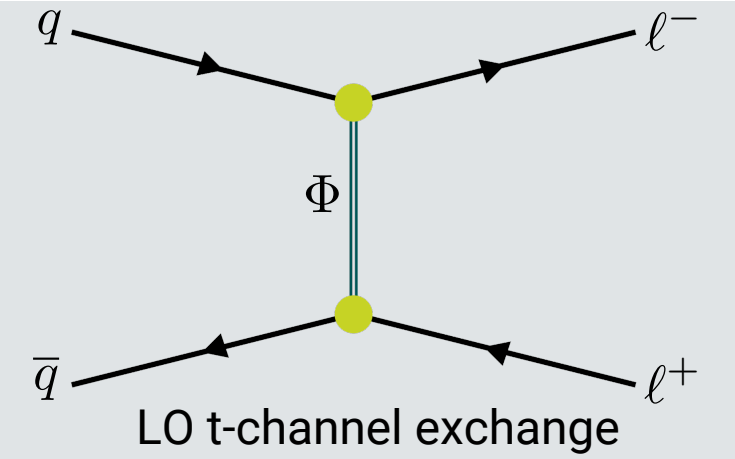
- Compute all relevant LQ contributions (using **FeynRules, FeynArts, FormCalc, LoopTools & Package-X**)
- Implementation of dilepton production via LQs into the **POWHEG-BOX** (linked to **PYTHIA**) for **NLO+PS accuracy** in QCD
- Study impact of
  - adding **b-jet tagging** to signal regions
  - **Coloron mass** in the vector case
  - **Interference** with the SM and **electroweak effects**
- Recast of ATLAS & CMS studies to derive exclusion limits (using **MadAnalysis & Delphes**)

Drell-Yan Process and LQ contributions

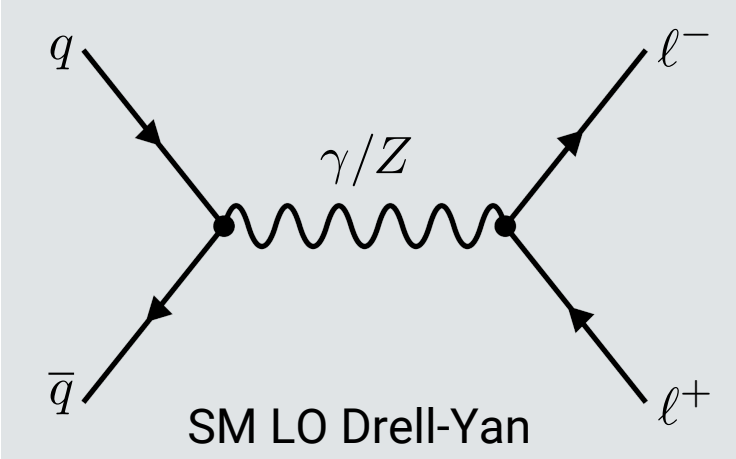


LO t-channel exchange

Drell-Yan Process and LQ contributions

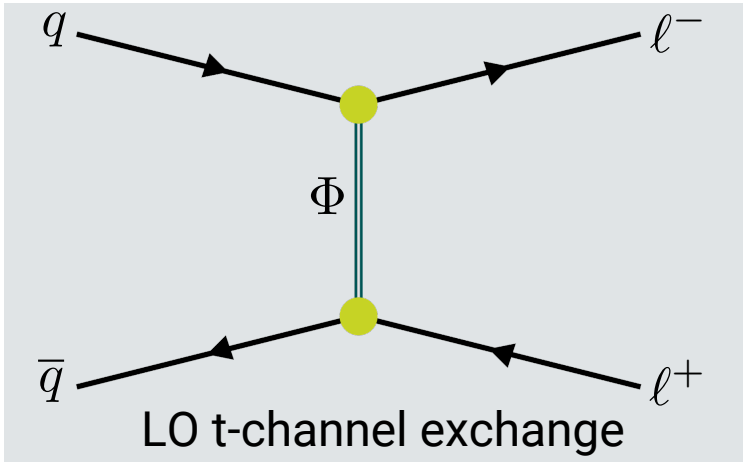


LO t-channel exchange

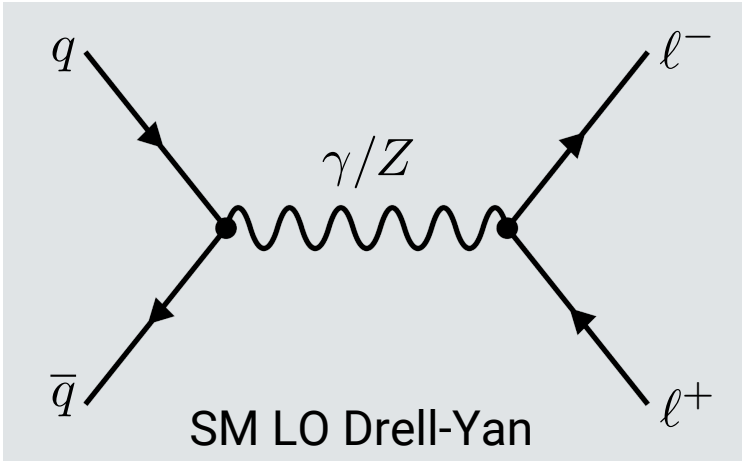


SM LO Drell-Yan

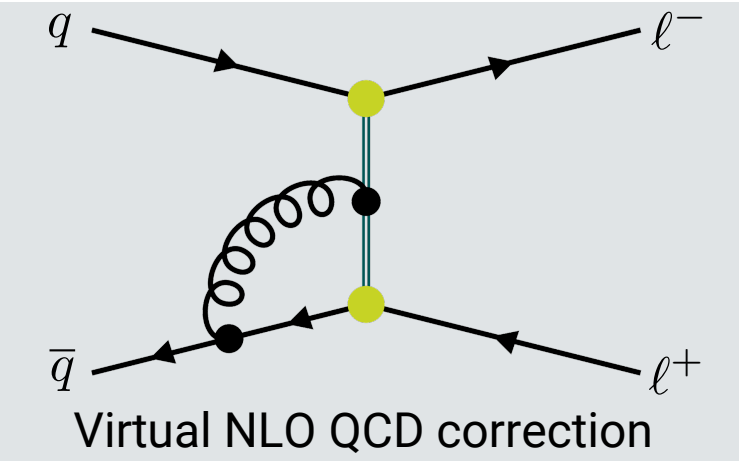
Drell-Yan Process and LQ contributions



LO t-channel exchange

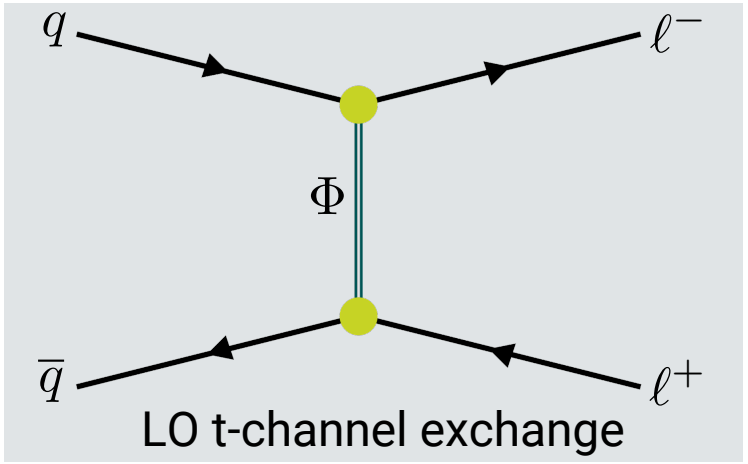


SM LO Drell-Yan

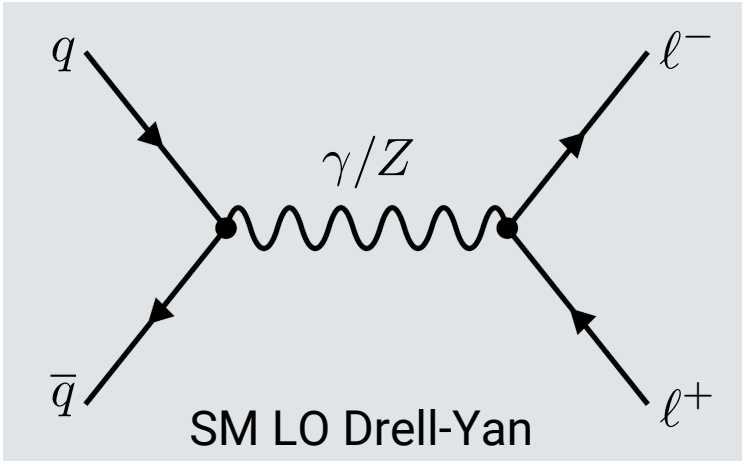


Virtual NLO QCD correction

Drell-Yan Process and LQ contributions



LO t-channel exchange



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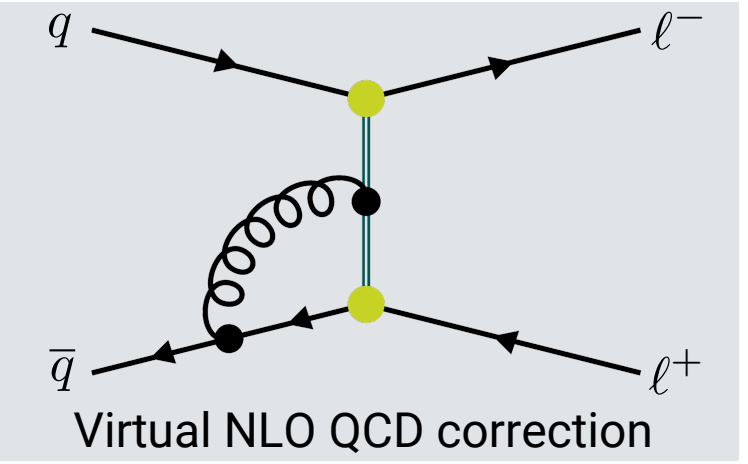
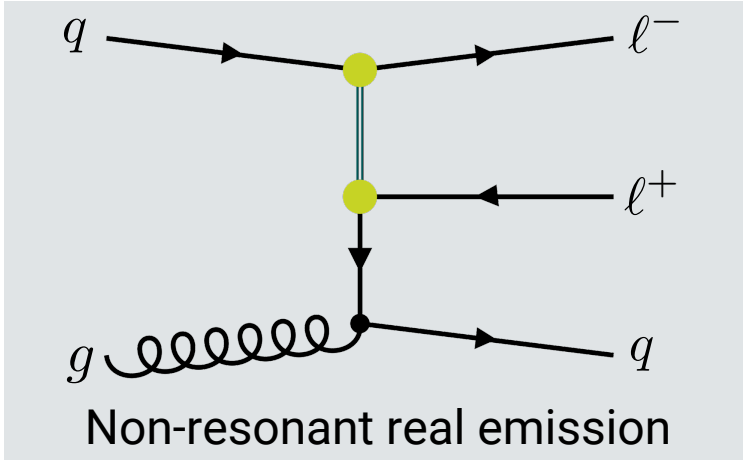
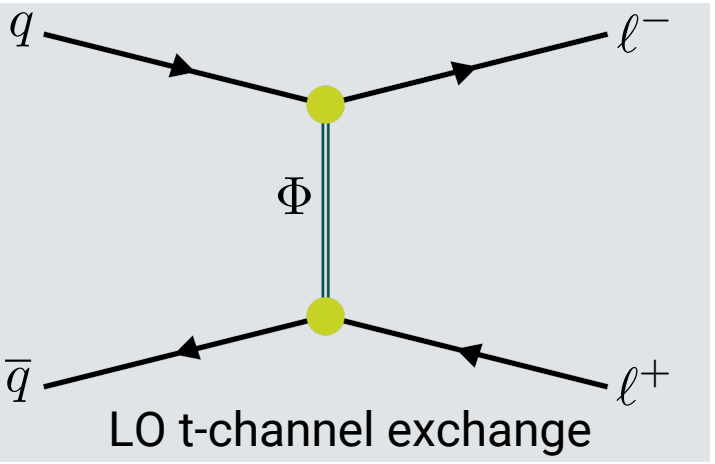


Virtual NLO QCD correction



Non-resonant real emission

Drell-Yan Process and LQ contributions



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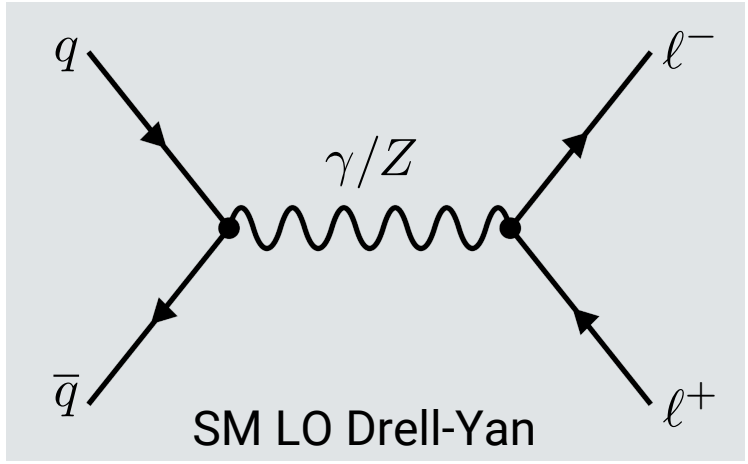

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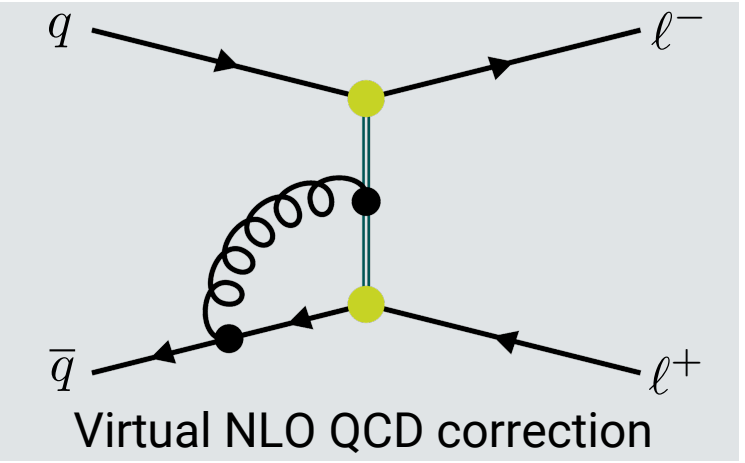
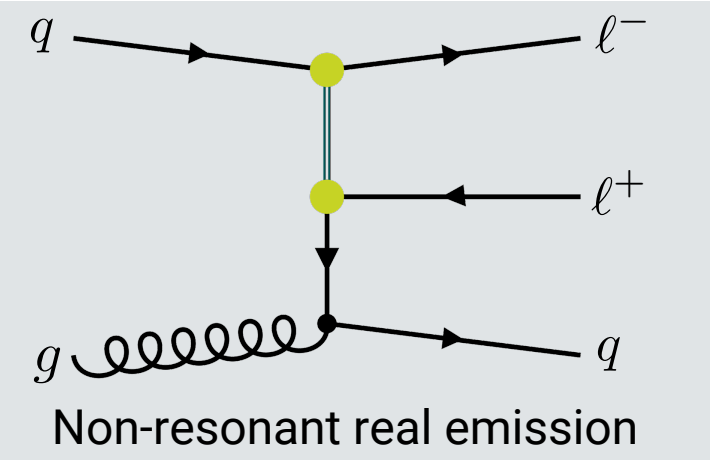
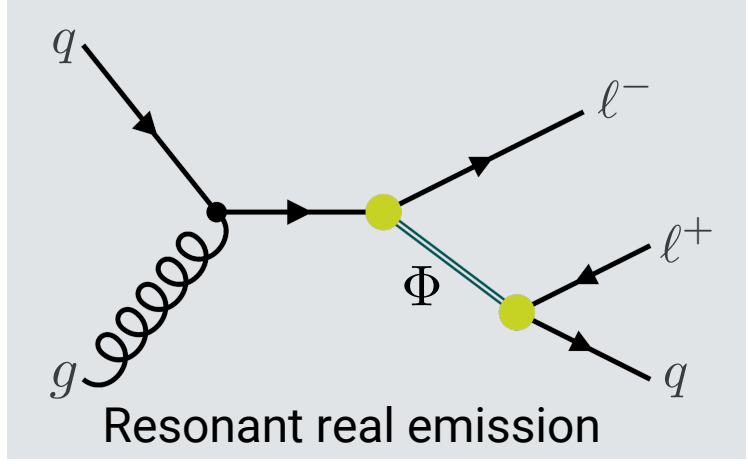


Virtual NLO QCD correction

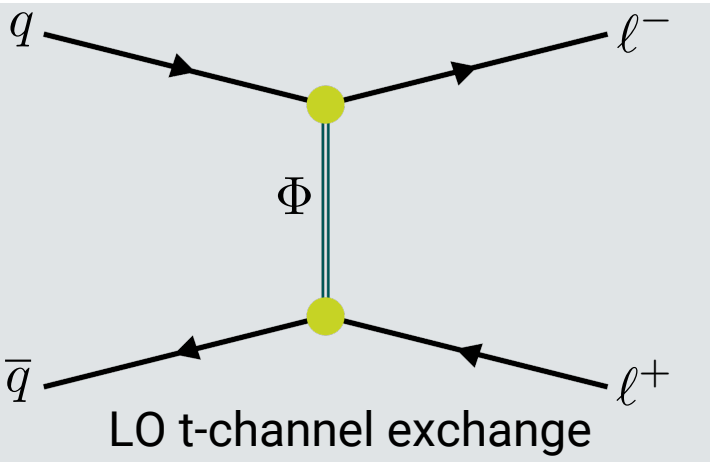


Non-resonant real emission

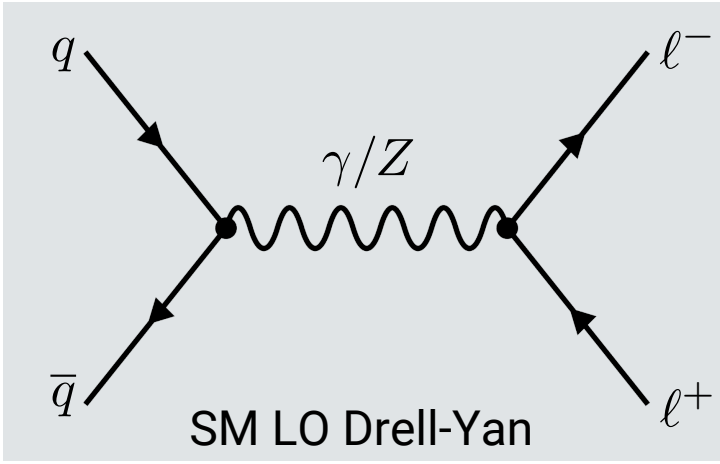


Resonant real emission

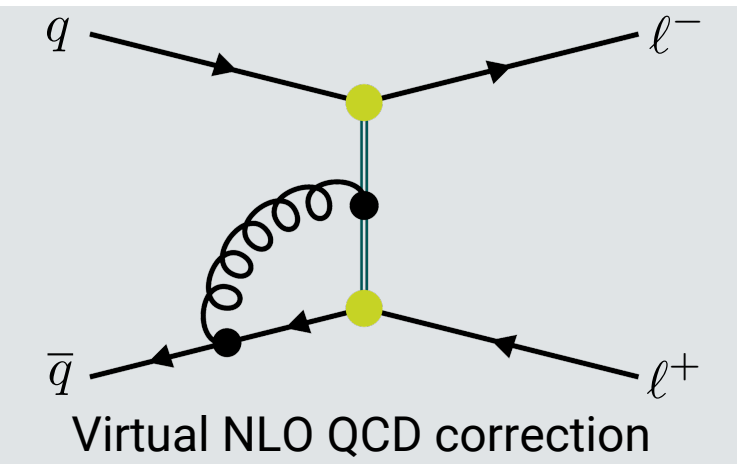
Drell-Yan Process and LQ contributions



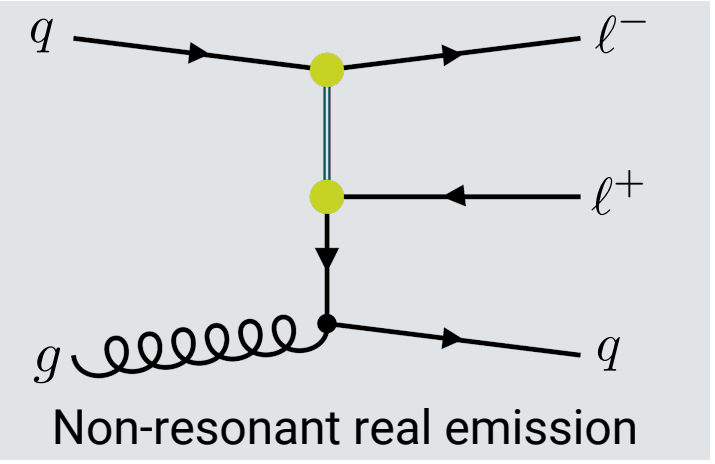
LO t-channel exchange



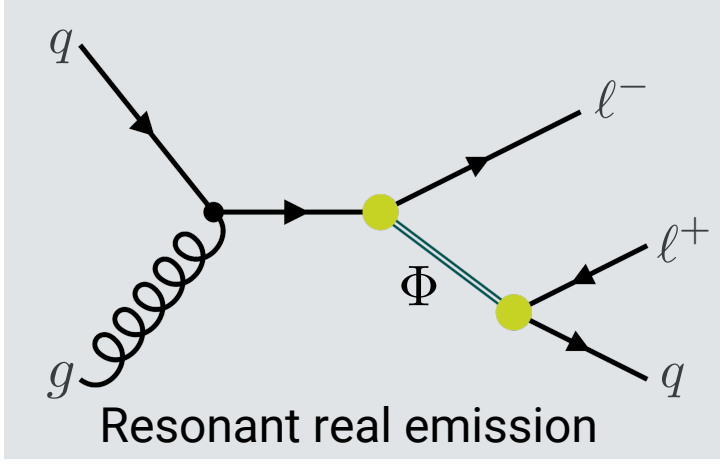
SM LO Drell-Yan



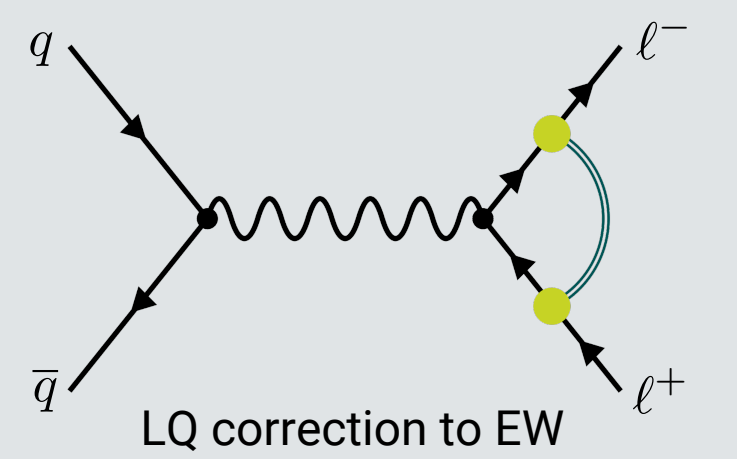
Virtual NLO QCD correction



Non-resonant real emission



Resonant real emission

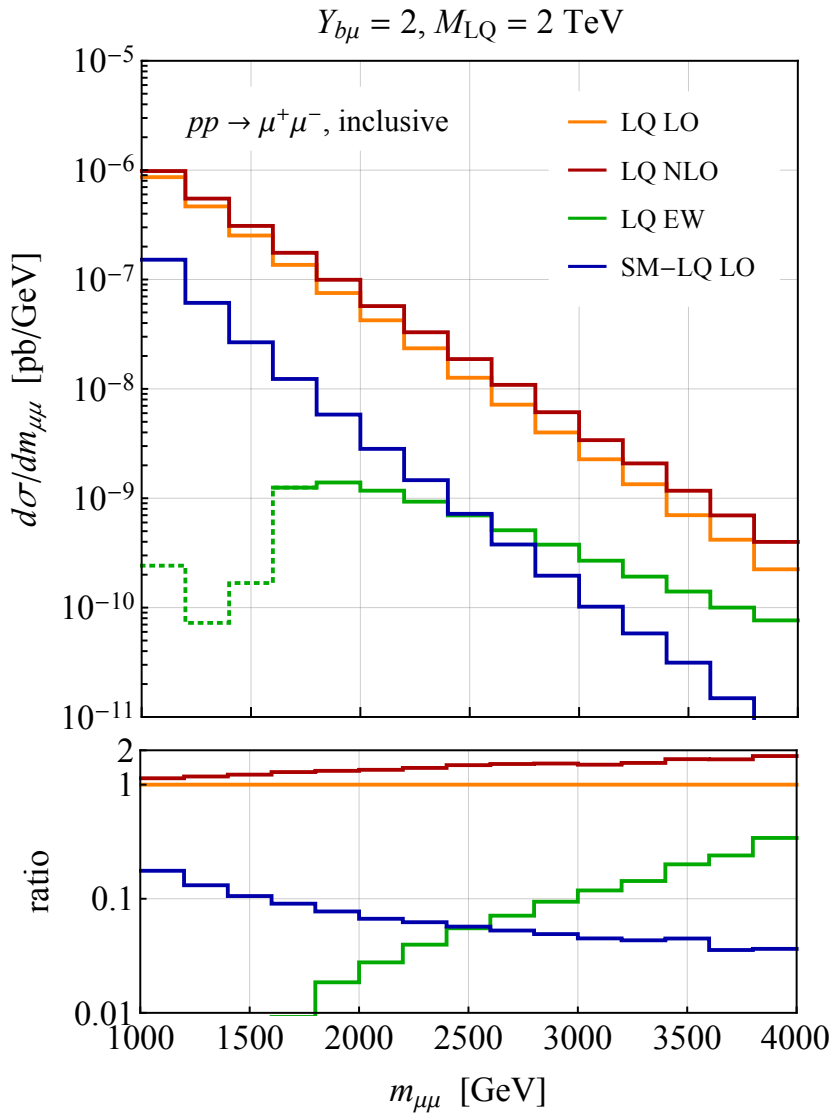


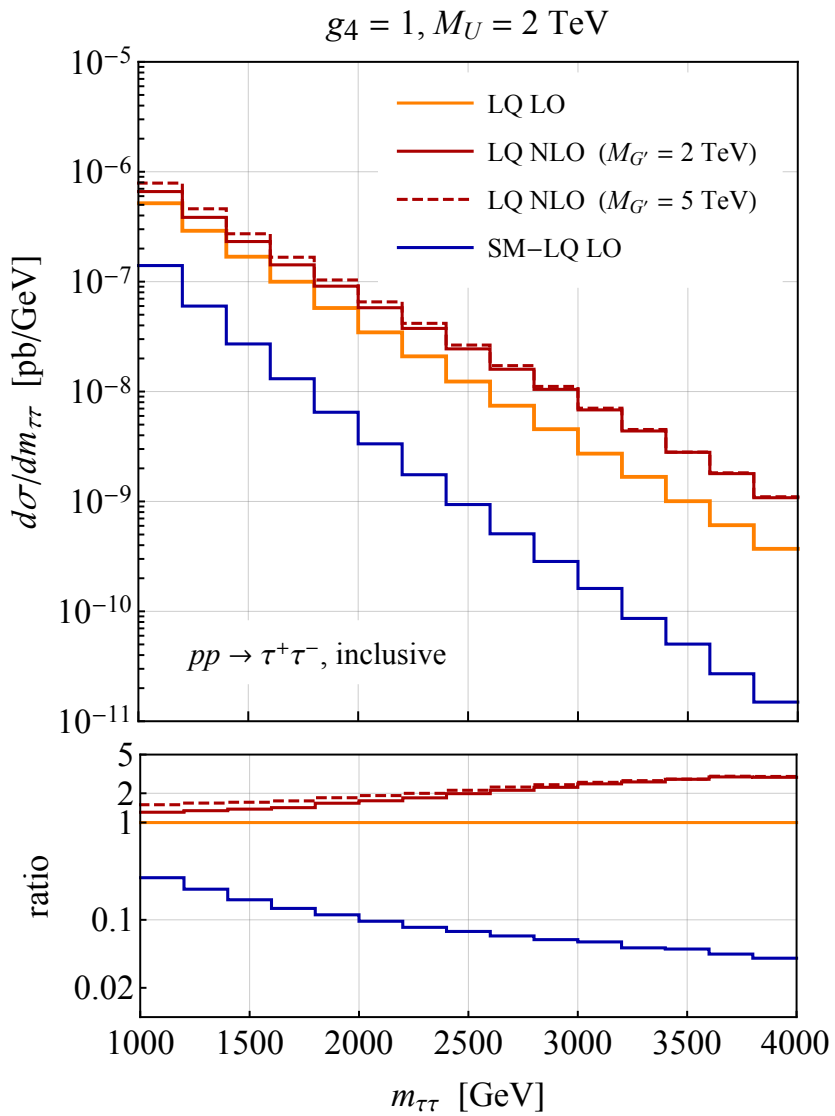
LQ correction to EW

Comparing the different LQ contributions I

Interference effects only relevant for small invariant masses

EW corrections increasingly important due to presence of Sudakov logarithms

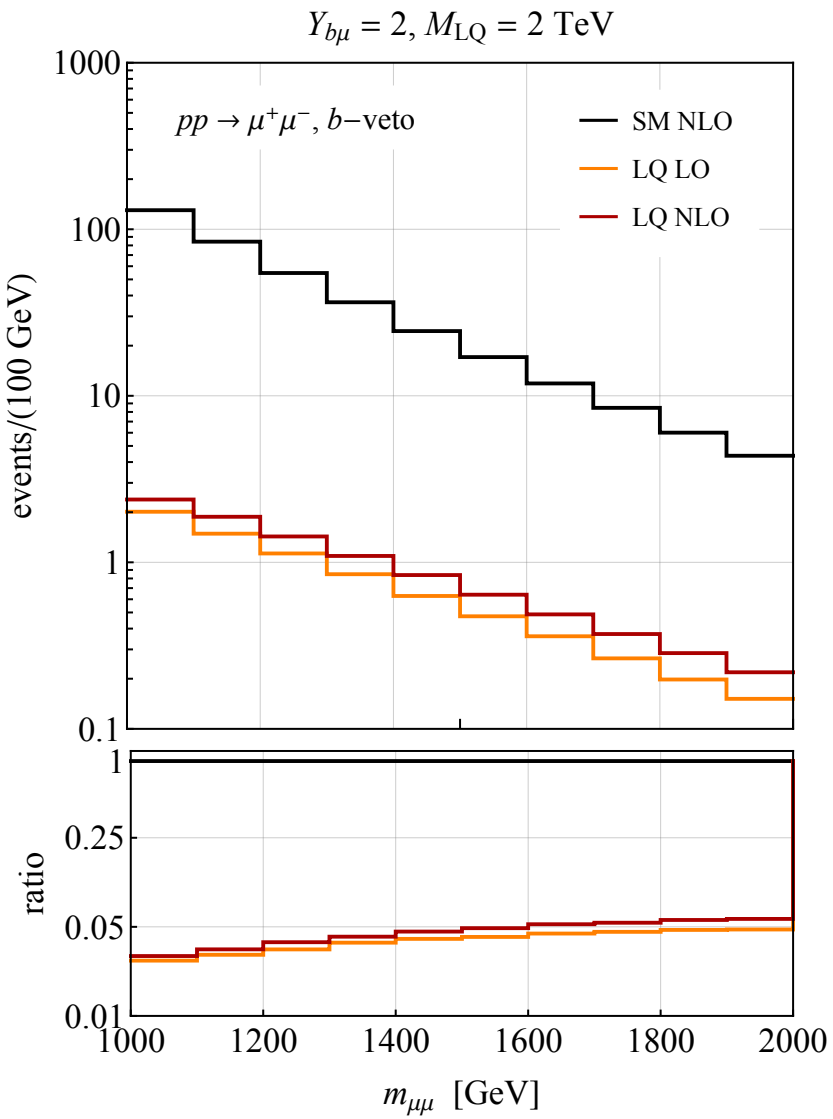


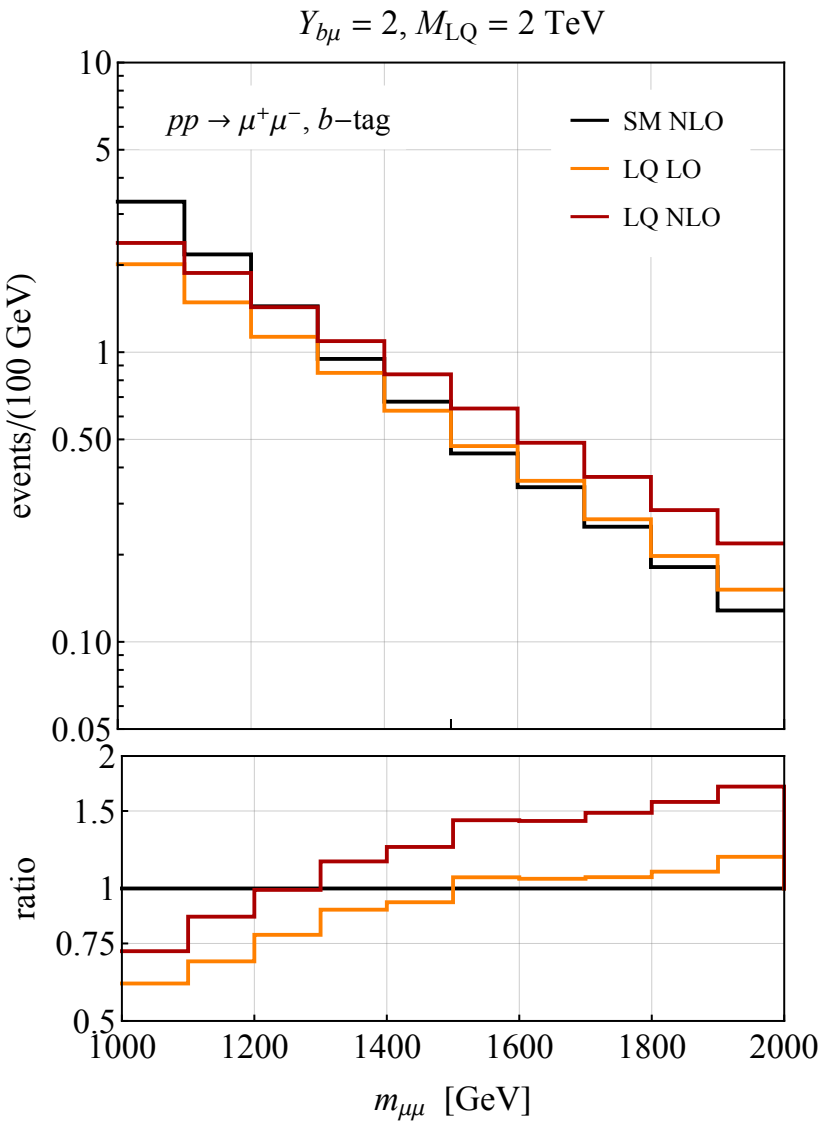


Coloron mass less important for large invariant masses

NLO accuracy in QCD crucial for non-resonant searches

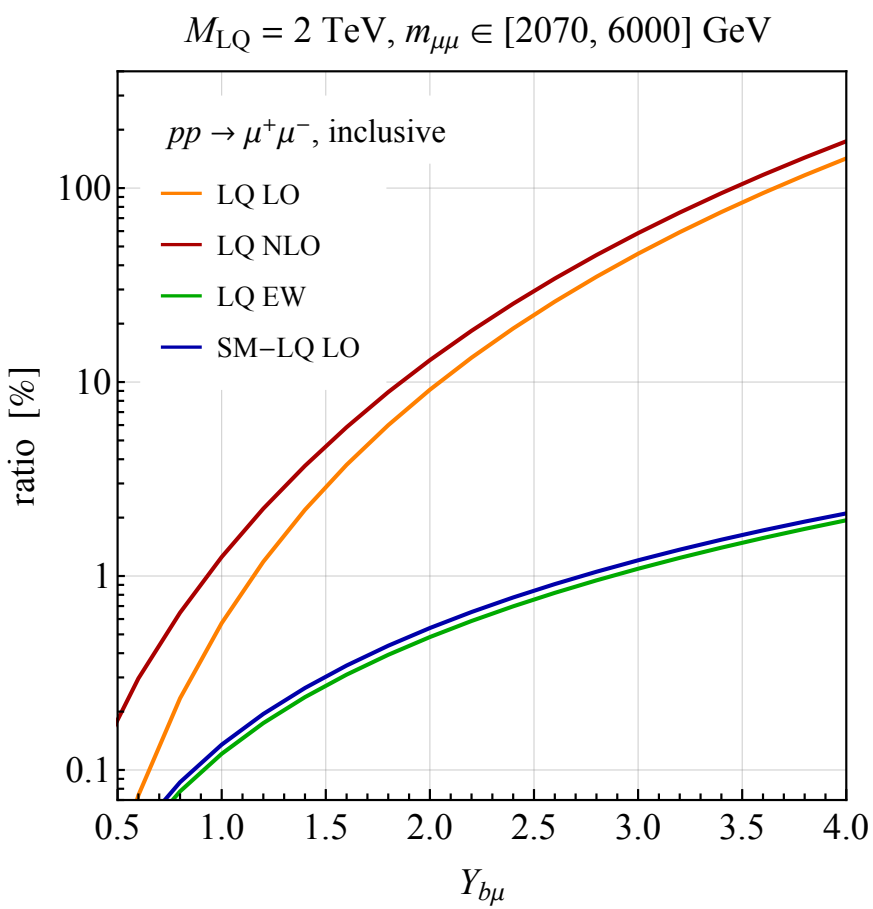
Scalar case: Impact of b-tagging

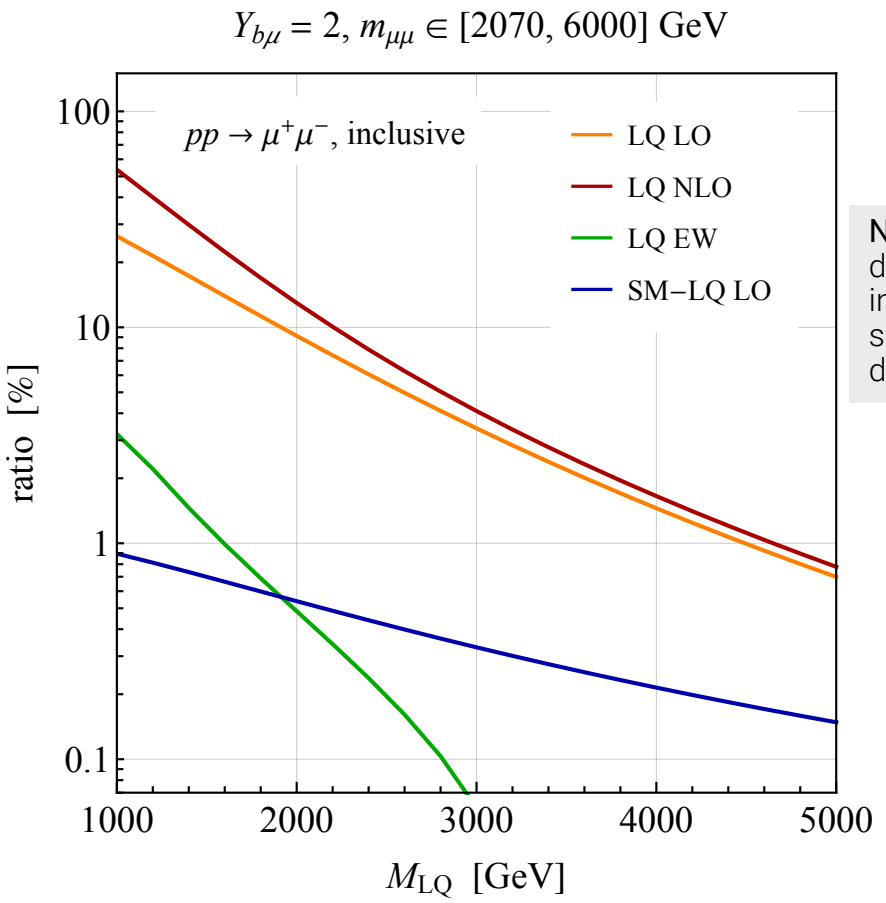




Comparing the different LQ contributions II

NLO QCD corrections decrease for increasing coupling since resonant real corrections decouple faster: Single LQ production ~coupling^2, but tree-level ~coupling^4



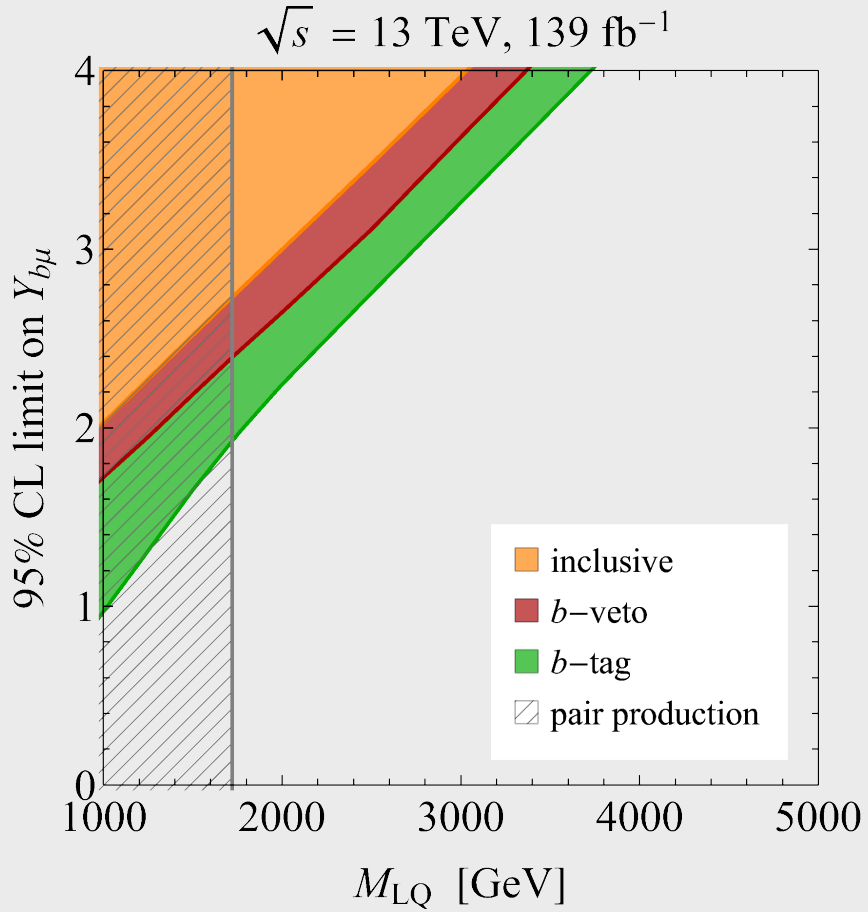


NLO QCD corrections decrease for increasing mass as single LQ production decouples

EW effects and interference of minor importance

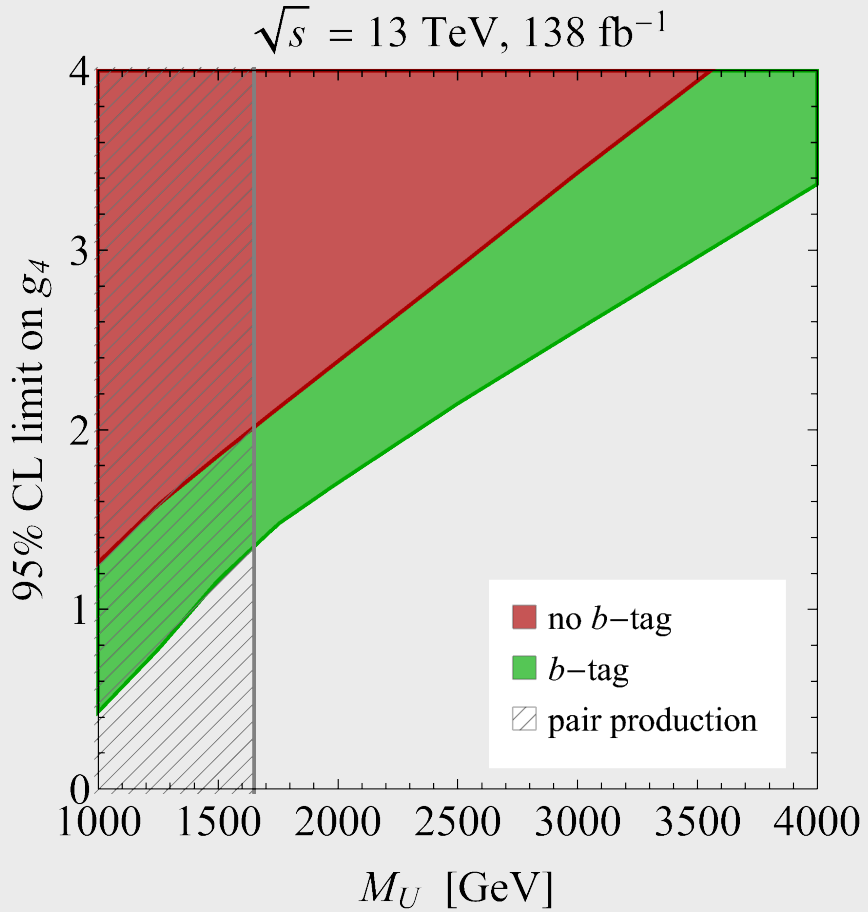
Exclusion Limits

Scalar Case



Based on Aad et al. (ATLAS) JHEP 11, 005 (2020) and Phys. Rev. Lett. 127, 141801 (2021)

Vector Case



Based on Sirunyan et al. (CMS), arXiv:2208.02717 [hep-ex]

Conclusion

- Non-resonant dilepton searches main avenue to probe LQs with high masses
- **NLO modelling** of LQ signal crucial for accurate exclusion limits
- NLO MC event generator for scalar & vector LQ contribution to dilepton production (about to be) **published in the POWHEG framework**
- Additional **b-tagging** can significantly improve sensitivity of non-resonant dilepton searches
- Minor impact of EW corrections, SM-LQ interference & coloron mass

Thank you for your attention!