Karlsruhe Institute of Technology

Institute for Theoretical Physics

Electroweak Corrections to Higgs Boson Pair Production: The light quark case

Marco Bonetti, Gudrun Heinrich, **Philipp Rendler**, William J. Torres Bobadilla | December 4, 2025

Overview

1. Motivation

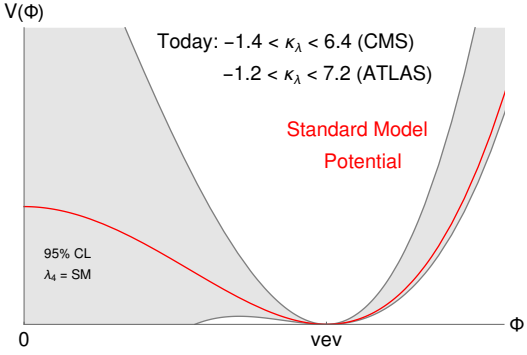
2. Computational Techniques

3. Results

4. Conclusion and Outlook

The Trilinear Higgs Coupling

$$\mathcal{L}_{\text{Higgs}} = \frac{1}{2}\left(\partial_\mu H\right)\left(\partial^\mu H\right) + \frac{1}{2}m^2H^2 + \lambda_3 H^3 + \lambda_4 H^4$$



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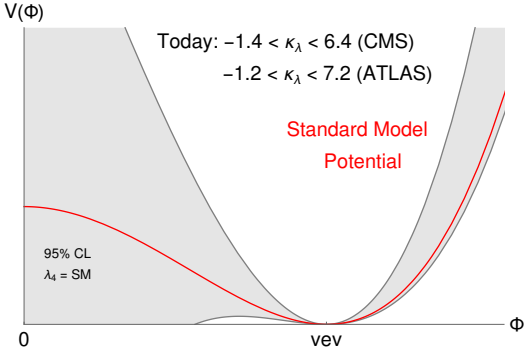

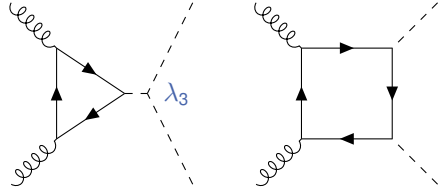

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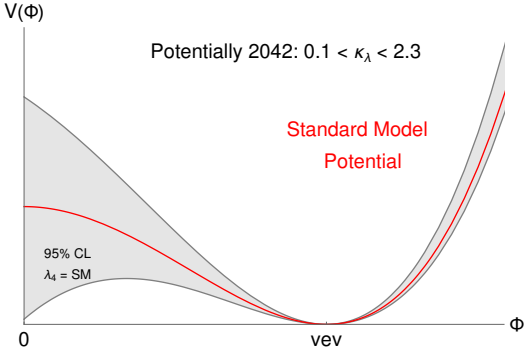
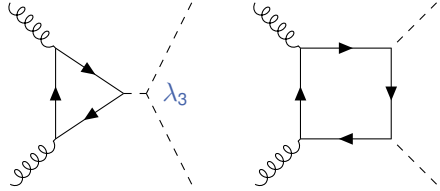
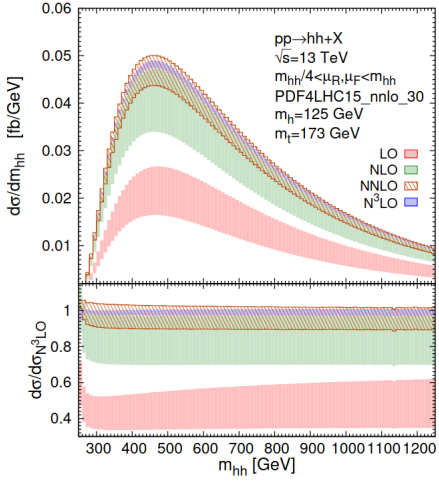




Theoretical Uncertainties



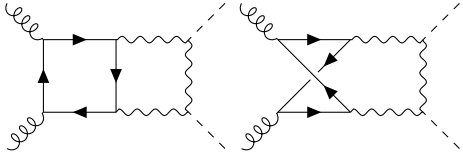
- QCD corrections:
  - NLO with full m_t [Borowka, Greiner, Heinrich, Jones, Kerner, Schlenk, Zirke (2016)] [Baglio, Campanario, Glaus, Mühlleitner, Spira, Streicher (2018)]
  - $\text{NNLO}_{\text{FTapprox}}$ [Grazzini, Heinrich, Jones, Kallweit, Kerner, Lindert, Mazzitelli (2018)]
  - $\text{N}^3\text{LO}_{\text{HTL}}$ [Chen, Li, Shao, Wang (2019)]
  - $\text{N}^3\text{LO}_{\text{HTL}}+\text{N}^3\text{LL}$ [Ajjath, Shao (2022)]

  $\Rightarrow$ QCD scale uncertainty $< 1\%$
- Effort in Reducing **top mass renormalization unertainty**:
  - Resummation of corresponding logarithms in SCET [Jaskiewicz, Jones, Szafron, Ulrich (2025)]
  - NNLO virtual corrections in the forward limit [Davies, Schönwald, Steinhauser (2025)]

$\Rightarrow$ Electroweak corrections are relevant

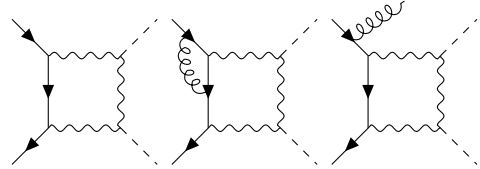
Higgs Pair Production through Light Quarks

Gluon initiated case [Bonetti, PR, Torres Bobadilla (2025)]



- Part of the Full EW Corrections [Bi, Huang, Huang, Ma, Yu (2023)]
- Gauge invariant and finite

Quark initiated case [Bonetti, Heinrich, PR, Torres Bobadilla (soon)]

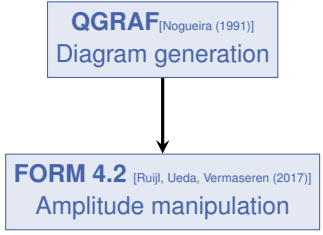


- **Full LO and NLO QCD** apart from suppressed $b\bar{b}$ contribution

Workflow

QGRAF[Nogueira (1991)]
Diagram generation

Workflow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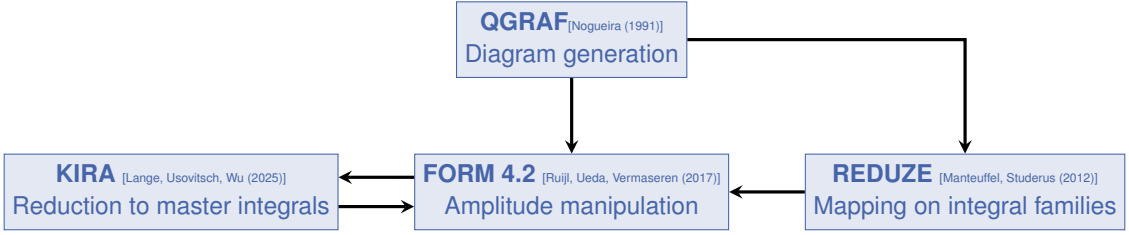
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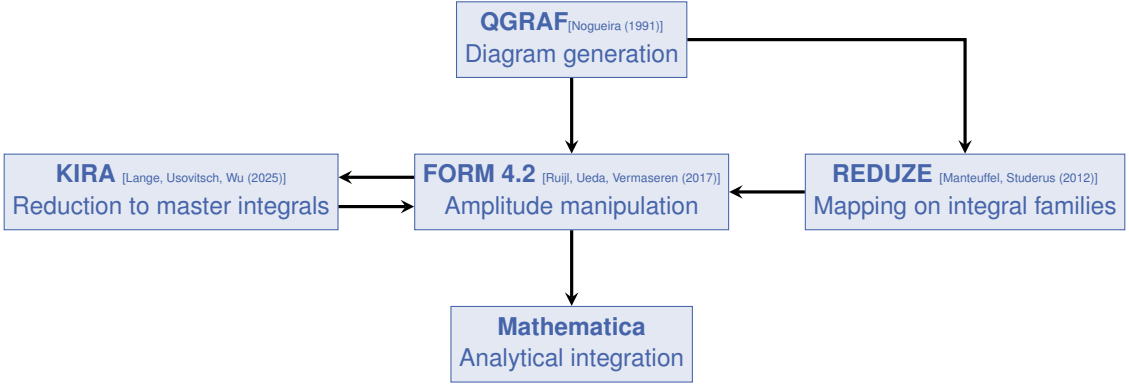
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Mapping on integral families
Mathematica
Analytical integration

Differential Equations

DEs in Canonical Form [Henn (2013)]

$$\mathrm{d}\mathbf{J} = \varepsilon \sum_{i=1}^{77} \mathbb{A}_i \, \mathrm{dlog}(\alpha_i) \, \mathbf{J} \qquad \mathbf{J}\text{: Master integrals}$$

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Solution: Chen Iterated Integrals

$$\mathbf{J} = \sum_n \varepsilon^n \mathbf{J}^{(n)}$$

$$\mathbf{J}^{(n)} = \int \sum_{i=1}^{77} \mathbb{A}_i \, \mathrm{dlog}(\alpha_i) \, \mathbf{J}^{(n-1)} + \mathbf{C}^{(n)}$$

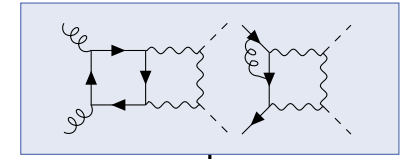
Boundary Conditions

We generate boundary functions with the **large mass expansion** $m_V^2 \to \infty$.

Example: Large Mass Expansion

$$m_V^6 \quad \xrightarrow[m_V^2 \to \infty]{} \quad m_V^6 \quad = \quad -\frac{2}{\varepsilon^2} - \frac{10}{\varepsilon} + (-20 - \pi^2) + \mathcal{O}(\varepsilon)$$

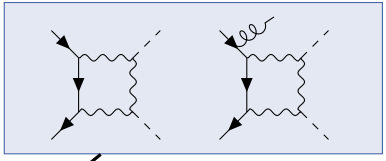
Implementation into POWHEG-BOX-V2



DIFFEXP [Hidding (2020)]

Grids: $\mathcal{O}(20000)$ points

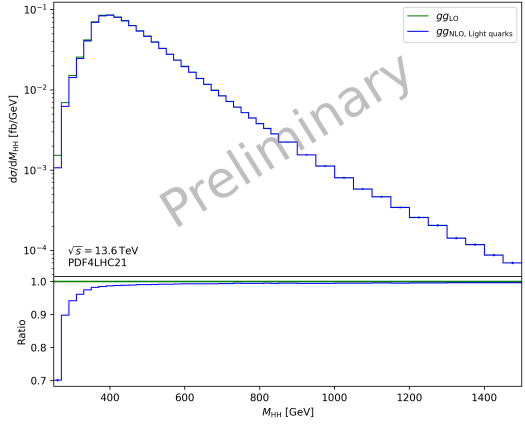
Interpolation

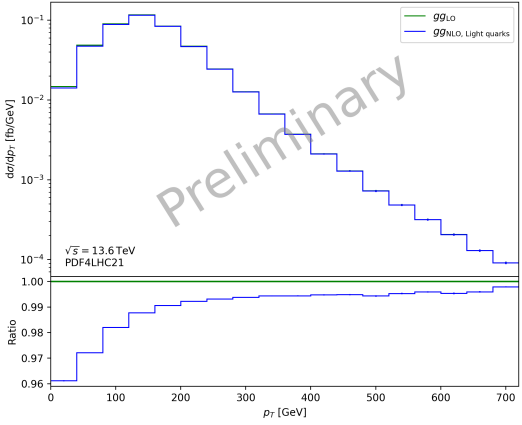


GOSAM-3
[Braun, Campillo Aveleira, Heinrich, Höfer, Jones, Kerner, Lang, Magerya (2025)]

POWHEG BOX V2 [Alioli (2010)]

Results: $gg \to HH$





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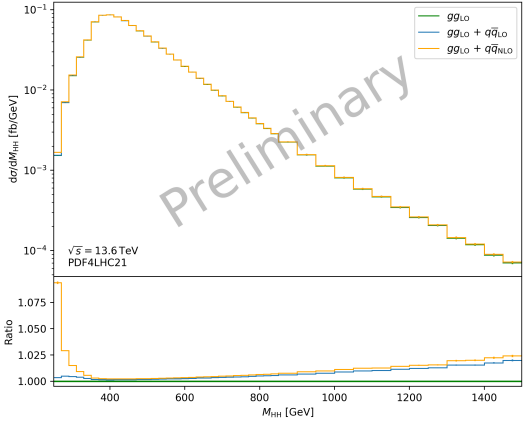
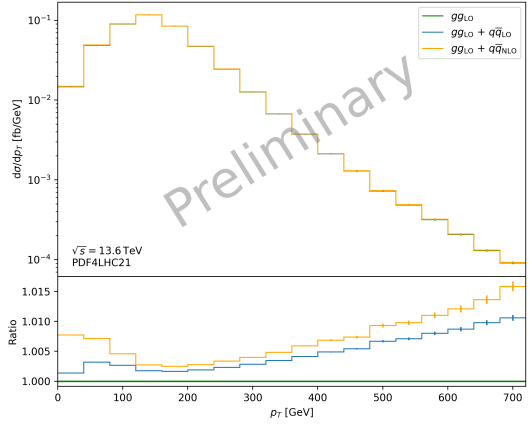
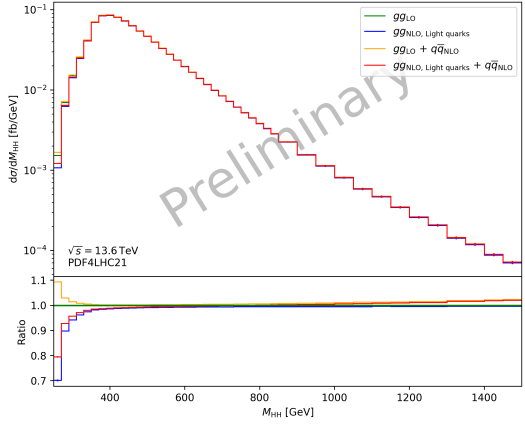
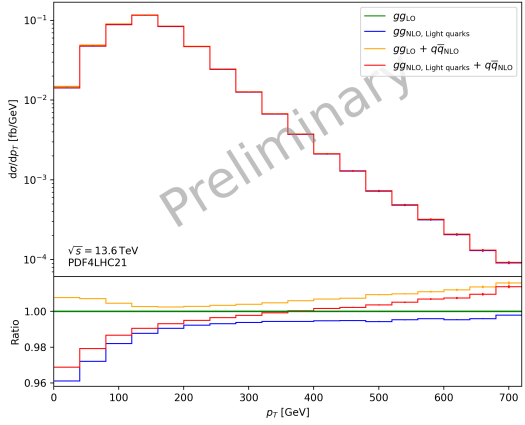




Results: Combined





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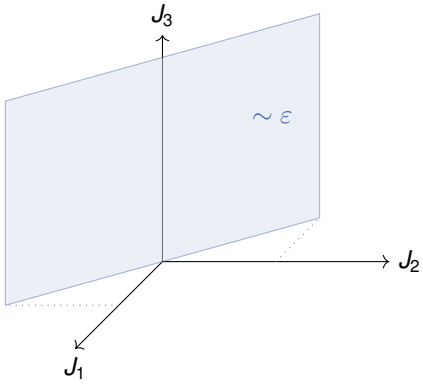
- Public release of the light quark corrections within `POWHEG-BOX-V2`
- Extension to a consistent EFT framework

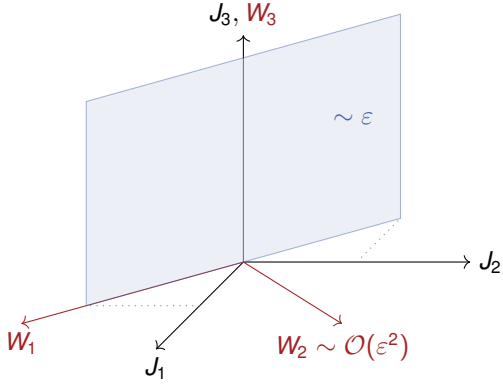
Thank you!

Backup Slides

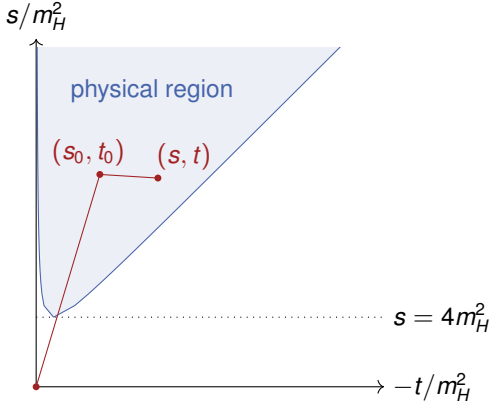
Rotation of Canonical Basis



$\mathbf{J} \longrightarrow \mathbf{W} = R\,\mathbf{J}$



Numerical Evaluation



We decompose the rotated basis into **independent functions**,

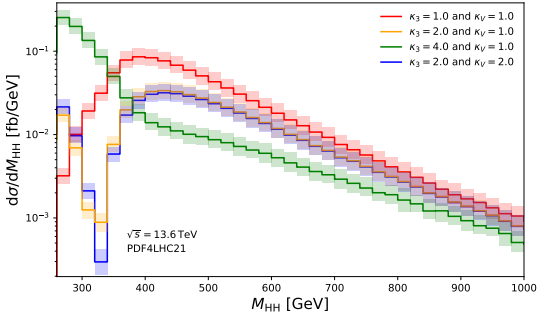
$$W_i(x) = \sum_j \varepsilon^j w_i^{(j)}(x)\,.$$

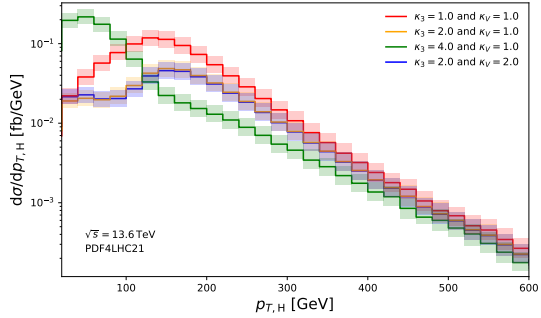
Then, we construct **differential equations**,

$$\mathrm{d}w_i^{(j)} = \sum_k \mathrm{d}\Omega_{i,k}\, w_k^{(j-1)}\,,$$

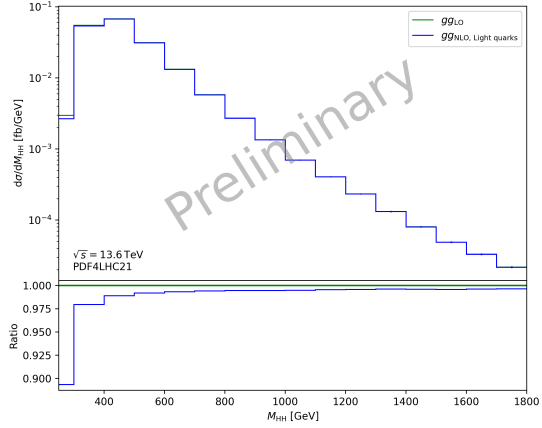
which we solve with DIFFEXP [2006.05510].

Results: Varying couplings





Results: $gg \to HH$: 100 GeV bins



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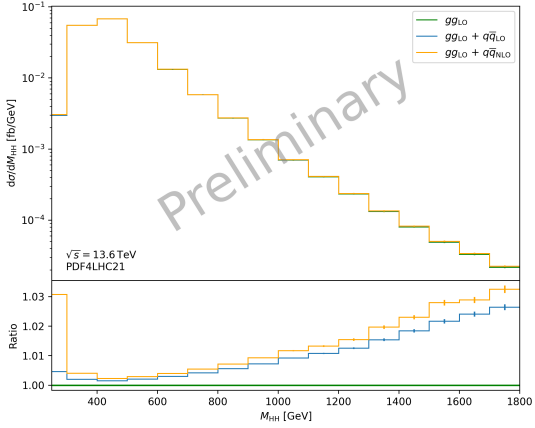
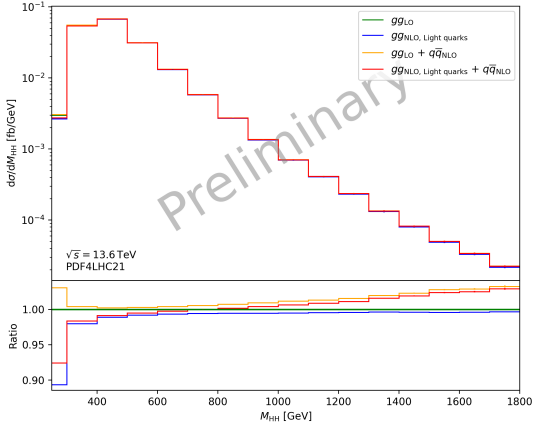
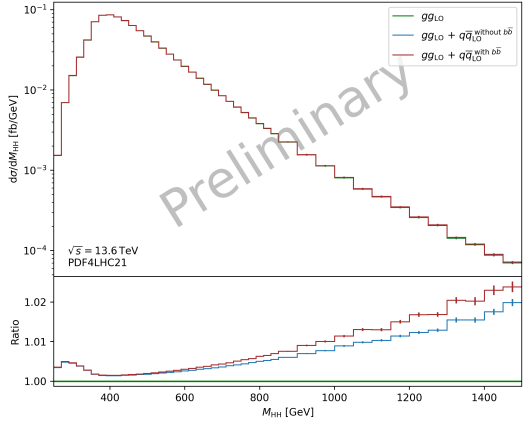
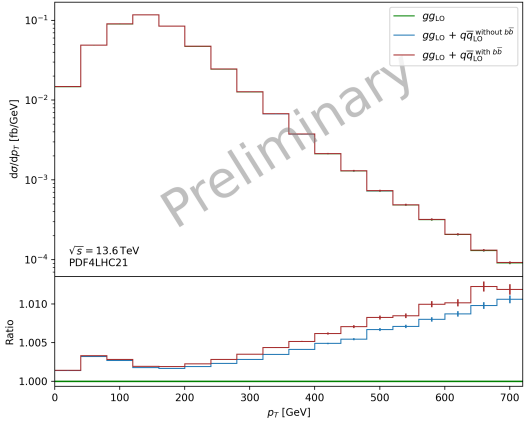
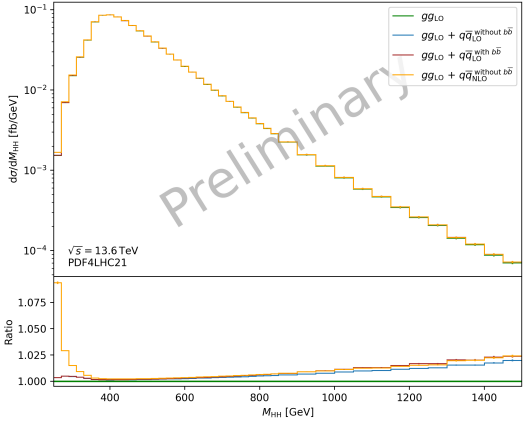
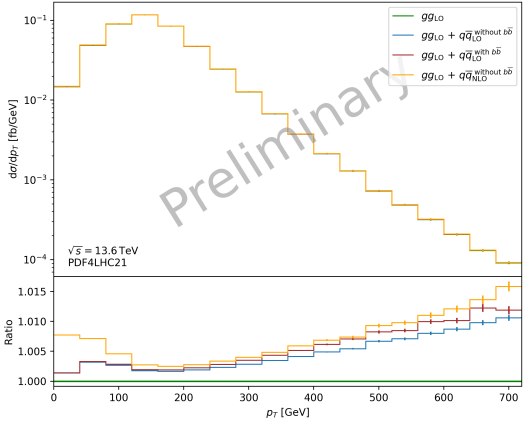


Results: Combined: 100 GeV bins



Effect of $b\bar{b}$

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