Electroweak corrections to Higgs+jet production

Haitao Li (Shandong University)

Based on the work arXiv:2507.20882 (*JHEP* 10 (2025) 194)
with Long-Bin Chen, Wen-Long Sang

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33rd INTERNATIONAL WORKSHOP ON **DEEP INELASTIC SCATTERING AND RELATED SUBJECTS**

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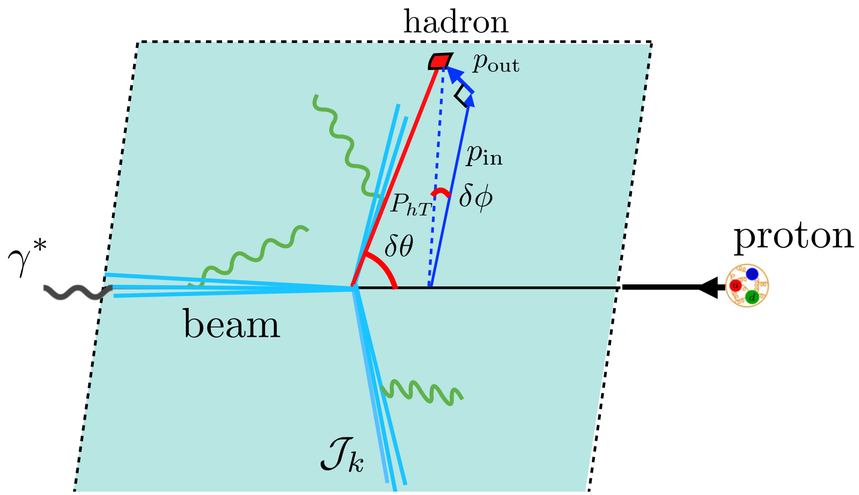
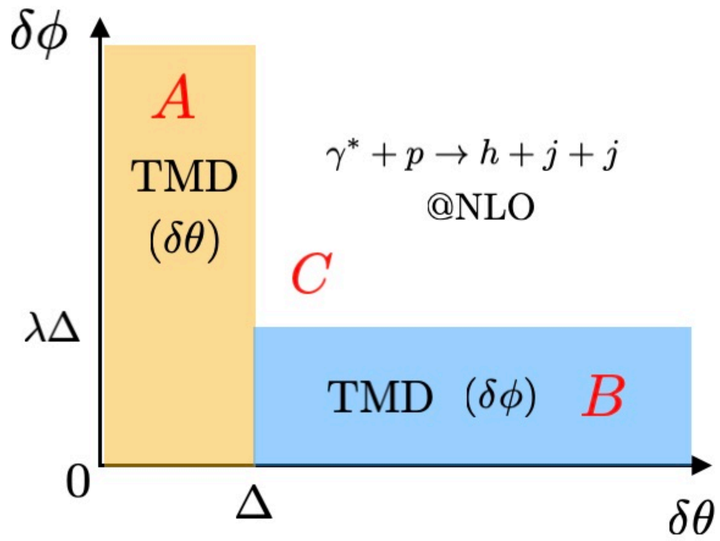
Introduction

Precision era: SIDIS @ N^3LO





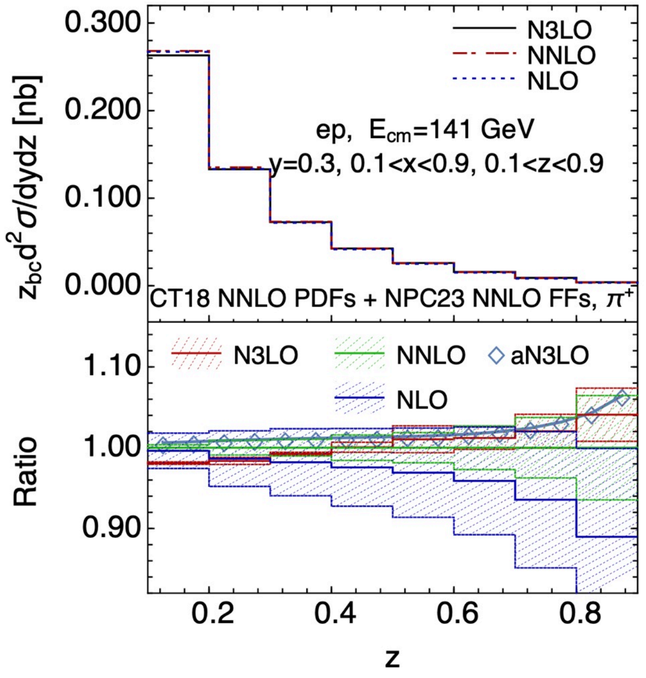
$\gamma^* + p \to h + j + j$
@NLO

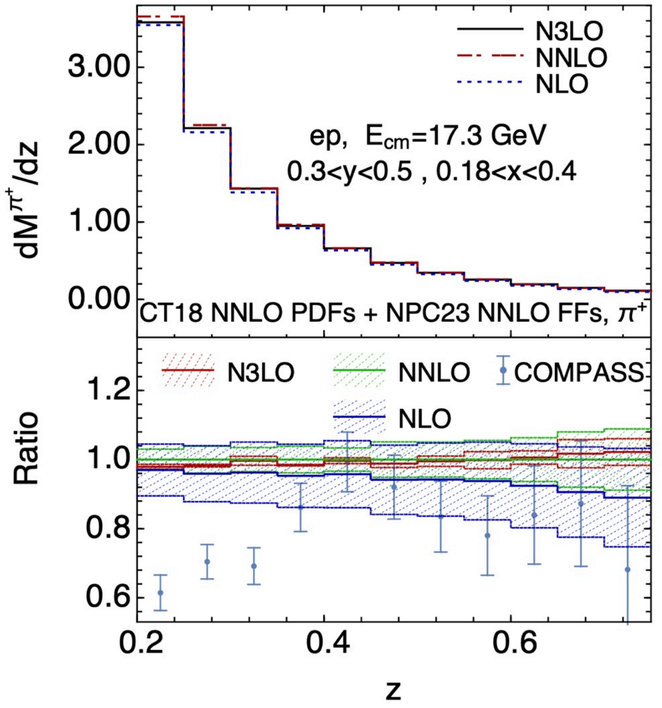
$$\frac{\mathrm{d}\sigma}{\mathrm{d}\mathcal{O}} = \underbrace{\int_0^{\Delta} \mathrm{d}\delta\theta \frac{\mathrm{d}\sigma^A}{\mathrm{d}\delta\theta\ \mathrm{d}\mathcal{O}}}_{\mathrm{A}} + \int_{\Delta}^{\delta\theta^{\max}} \mathrm{d}\delta\theta \times \left(\underbrace{\int_0^{\lambda\Delta} \mathrm{d}\delta\phi \frac{\mathrm{d}\sigma^B}{\mathrm{d}\delta\theta\ \mathrm{d}\delta\phi\ \mathrm{d}\mathcal{O}}}_{B} + \underbrace{\int_{\lambda\Delta}^{\delta\phi^{\max}} \mathrm{d}\delta\phi \frac{\mathrm{d}\sigma^C}{\mathrm{d}\delta\theta\ \mathrm{d}\delta\phi\ \mathrm{d}\mathcal{O}}}_{\mathrm{C}} \right)$$

Gao, H.T.L., Zhu, Zhu, 2602.06364

Dong, Fang, Gao, H.T.L., Shao, Zhu, 2602.22972,

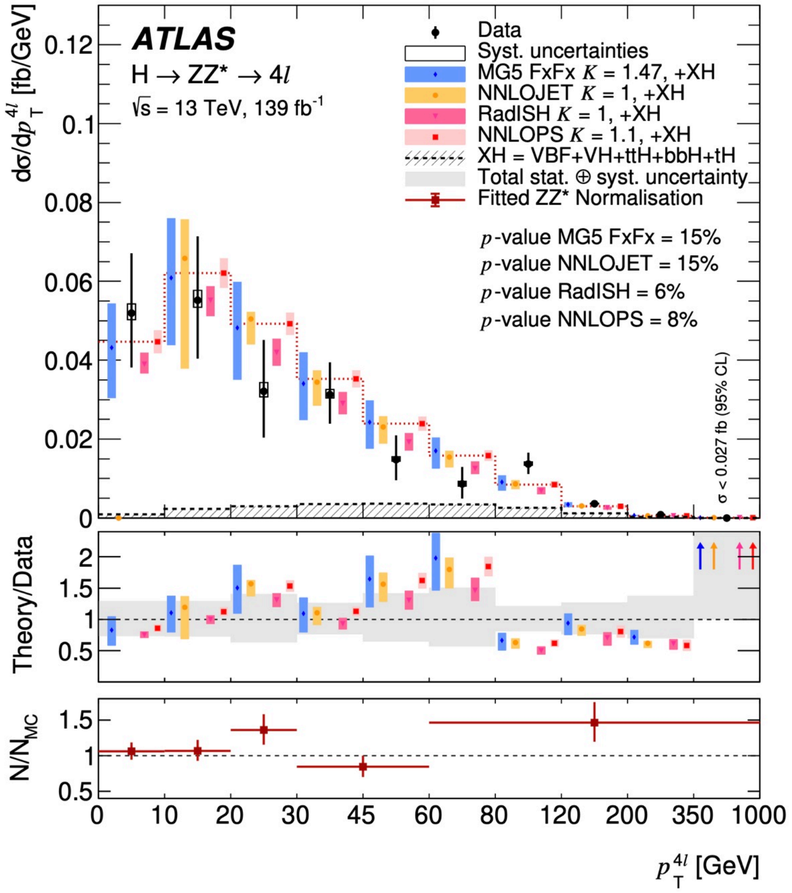
Dong, Fang, Gao, H.T.L., Shao, Zhu, Zhu, 2603.29673





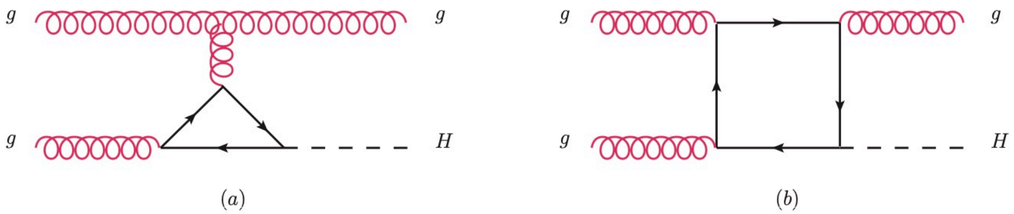
Introduction

- The Higgs mechanism is central to the Standard Model (SM); post-discovery focus has shifted to precision measurements of couplings and kinematics.
- Differential observables such as p_T^h , η are now measured at the 10–15% level by ATLAS and CMS.
- At the High-Luminosity LHC (HL-LHC), statistical uncertainties will drop to~2.5% — theory must match this precision.
- QCD corrections are well under control (NLO with full m_t, NNLO in EFT, resummation); EW orrections become the next bottleneck.



ATLAS, 2004.03969

Introduction



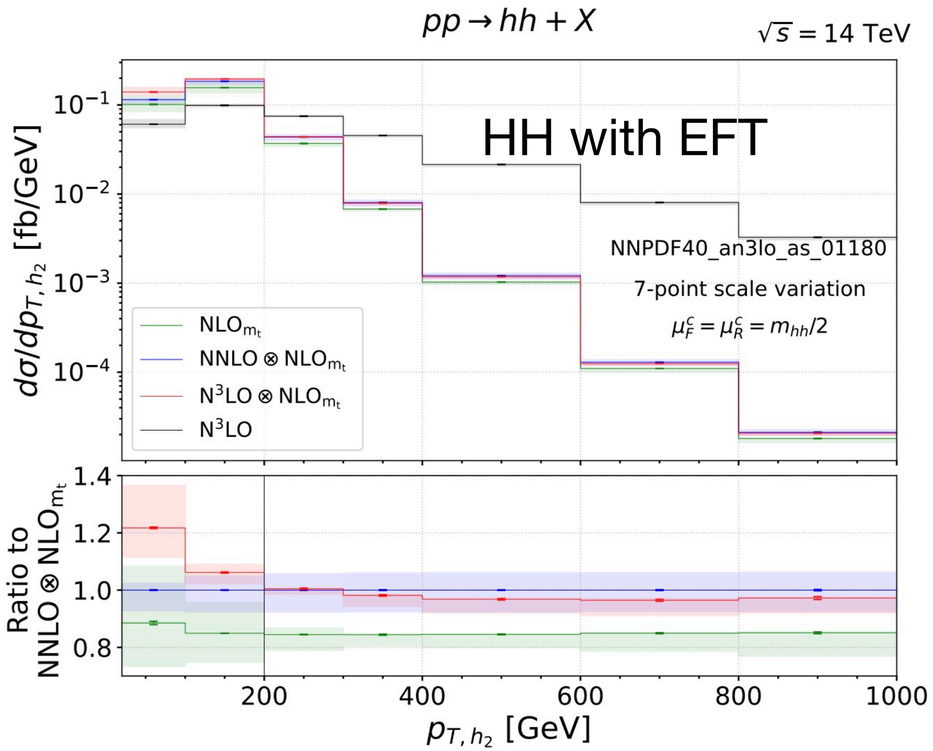
EFT works well for inclusive Higgs cross section

For H+J production, the situation is similar to H pair production

in large top mass limit

the leading power Lagrangian

$$\mathcal{L} = C_t\left(m_t, \mu\right) \frac{\alpha_s(\mu)}{12\pi} \frac{H}{v} \operatorname{Tr}\left(G_{\mu\nu} G^{\mu\nu}\right)$$



Chen, Dai, H.T.L., Li, Shao, Wang, 2601.19990

Introduction

QCD corrections in large top mass limit.

- NNLO to gluon channel with sector-improved residue subtraction method

  Boughezal, Caola, Melnikov, et al, 1302.6216

- NNLO to gluon channel with antenna subtraction

  Chen, Gehrmann, Glover, Jaquier, 1408.5325

- First Complete NNLO with sector-improved residue subtraction method

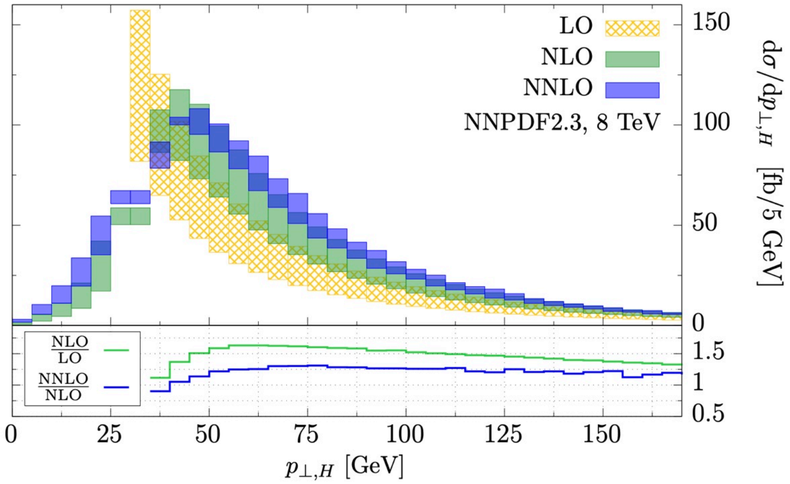
  Boughezal, Caola, Melnikov, et al, 1504.07922

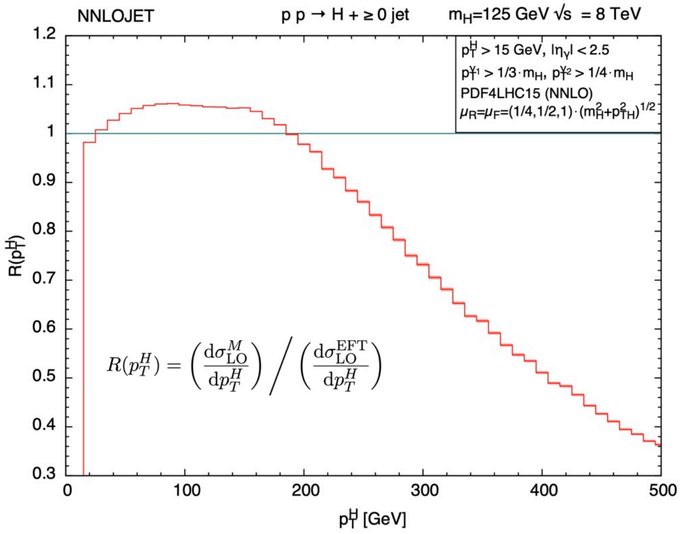
- Complete NNLO with antenna subtraction with Higgs decay

  Chen, Gehrmann, Glover, Jaquier, 1607.08817

- Toward N3LO: three loop amplitude in leading color

  Chen, Guan, Mistlberger, 2504.06490





Introduction

QCD corrections with top quark mass dependence

- two loop amplitude in expansions of large pT

  Kudashikin, Melnikov, Wever, 1712.06549

- NLO with virtual in expansions of large pT

  Lindert, Kudashkin, Melnikov, Wever, 1801.08226

- NLO with Full mt effects with Sector Decomposition,

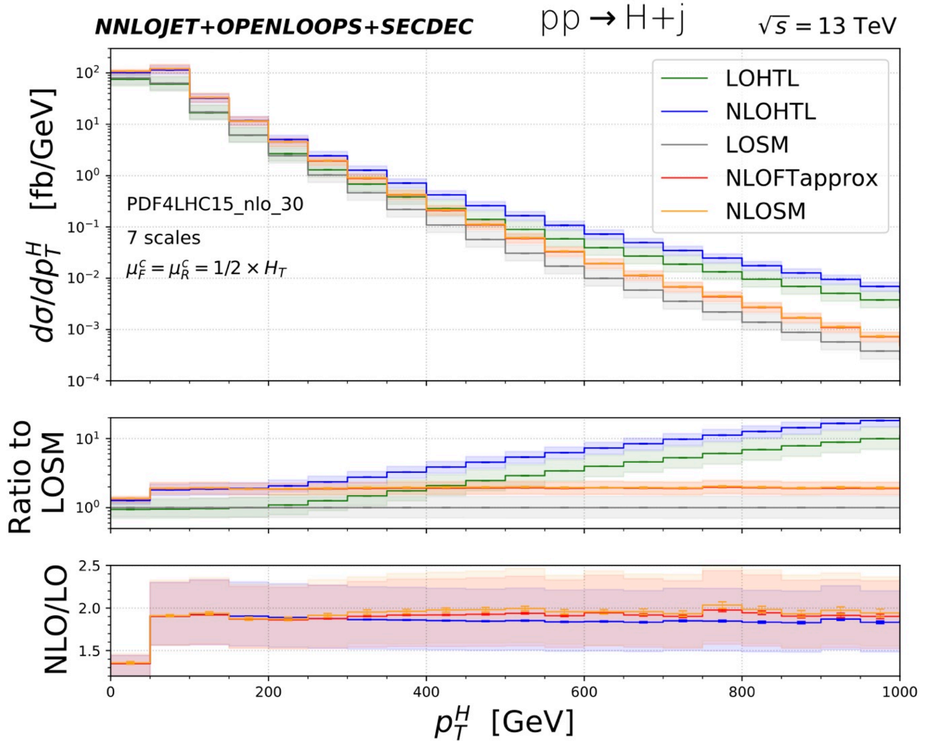
  Jones, Kerner, Luisoni, 1802.00349

- NLO with full mt effects with antenna subtraction

  Chen, Huss, Jones, et al, 2110.06953

- NLO with top and bottom mass

  Bonciani, Duca, Frellesvig, et al, 2206.10490



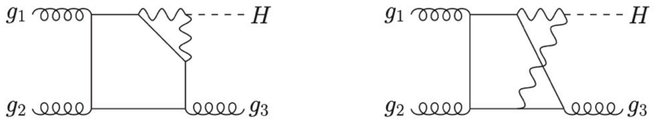
Introduction

EW corrections:

naively $\alpha_s^2 \sim \alpha \sim 1\,\%$, usually a few percent expected

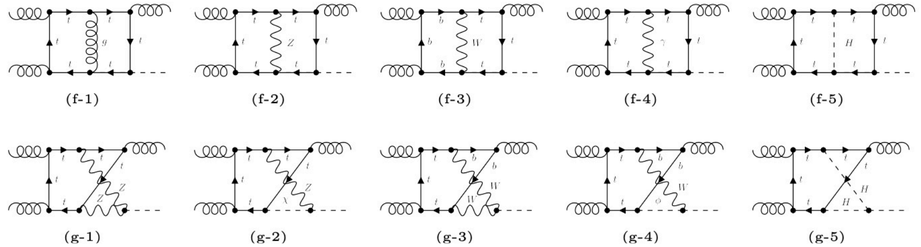
- NLO EW for gluons channel with light quark loops

  Bonetti, Panzer, Smirnov, Tancredi, 2007.09813



- NLO EW for gluons channel expanded up to $1/m_t^8$

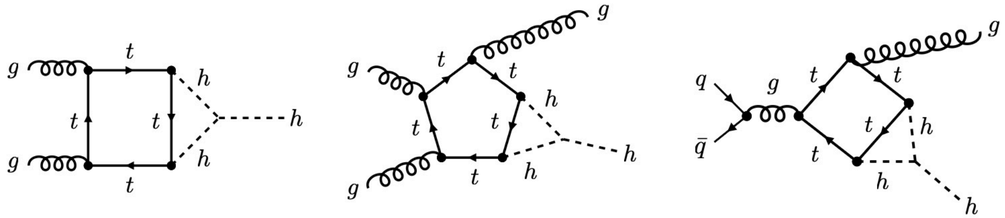
  Davies, Schonwald, Steinhauser, Zhang, 2308.01355



- Exact two-loop amplitudes for a cubic Higgs self-coupling,

  Gao, Shen, Wang, Yang, Zhou, 2302.04160

  Haisch, Niggetiedt, 2408.13186



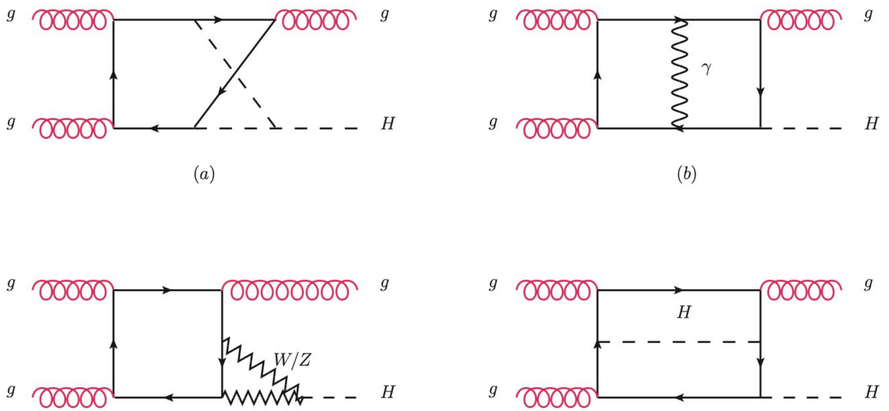
- Complete NLO EW correction to gluon channel

  Chen, H.T.L, Sang, 2507.20882

Method

Amplitudes for $gg \to gH$

$$M^{abc} = f^{abc}\epsilon_{1,\mu}\epsilon_{2,\nu}\epsilon^*_{3,\rho}A^{\mu\nu\rho}(s,t,u)$$



The tensor can be decomposed into

Melnikov, Tancredi, Wever, 1610.03747

$$A^{\mu\nu\rho}(s,t,u) = F_1(s,t,u)g^{\mu\nu}p_2^\rho + F_2(s,t,u)g^{\mu\rho}p_1^\nu + F_3(s,t,u)g^{\nu\rho}p_3^\mu + F_4(s,t,u)p_3^\mu p_1^\nu p_2^\rho$$

The gauge independent form factor F_i

Projectors are

$$P_j^{\mu\nu\rho} = \frac{1}{d-3}\left[c_1^{(j)}\,g^{\mu\nu}\,p_2^\rho + c_2^{(j)}\,g^{\mu\rho}\,p_1^\nu + c_3^{(j)}\,g^{\nu\rho}\,p_3^\mu + c_4^{(j)}\,p_3^\mu p_1^\nu p_2^\rho\right]$$

$$c_1^{(1)} = \frac{t}{s\,u}, \quad c_2^{(1)} = 0, \quad c_3^{(1)} = 0, \quad c_4^{(1)} = \frac{1}{s\,u},$$

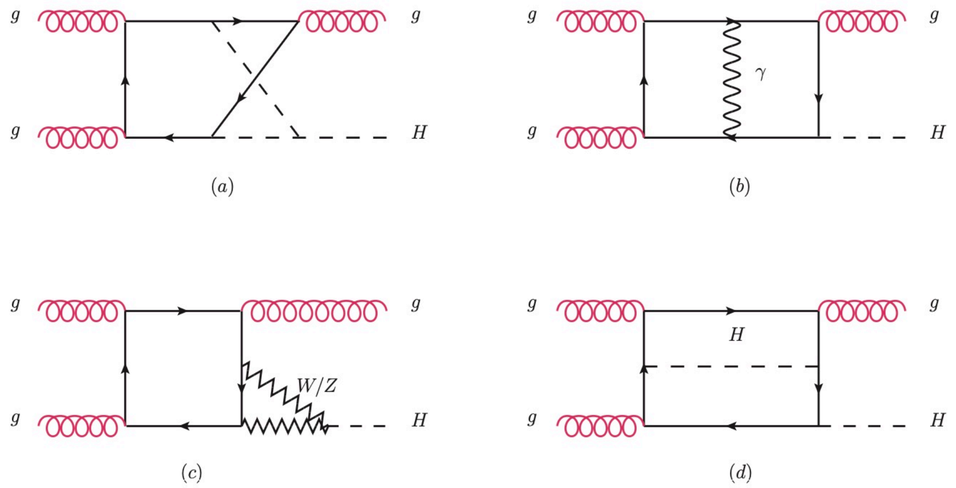
$$c_1^{(2)} = 0, \quad c_2^{(2)} = \frac{u}{s\,t}, \quad c_3^{(2)} = 0, \quad c_4^{(2)} = \frac{1}{s\,t},$$

$$c_1^{(3)} = 0, \quad c_2^{(3)} = 0, \quad c_3^{(3)} = \frac{s}{t\,u}, \quad c_4^{(3)} = -\frac{1}{t\,u},$$

$$c_1^{(4)} = \frac{1}{s\,u}, \quad c_2^{(4)} = \frac{1}{s\,t}, \quad c_3^{(4)} = -\frac{1}{t\,u}, \quad c_4^{(4)} = \frac{d}{s\,t\,u}.$$

Method

- At NLO EW, we encounter 1,416 two-loop diagrams plus 12 one-loop diagrams (generated via FeynArts)
- Algebraic simplification performed with FeynCalc, FormLink, and Form 4.0.
- Integral reduction via IBP identities yields 108 distinct integral families and over 3,600 MIs.
- These are multi-scale, massive, elliptic integrals — analytic evaluation is currently infeasible with existing methods.



Method

- Standard MI bases from reduction packages often contain “bad denominators” — factors nonlinear in d or kinematics, causing numerical instability.
- We developed an optimized basis selection: require denominators to be polynomials of invariants and masses, linear in d (i.e., ad + b).
- We construct differential equations in s and t for the MIs and solve them numerically across phase space.
- Boundary conditions evaluated via AMFlow at high precision (>45 digits) using auxiliary mass flow.
- A numerical grid (~6324 points) was generated for matrix element square at NLO EW corrections

Smirnov, Smirnov, 2002.08042

Usovitsch, 2002.08173

Numerical Results

For the electromagnetic coupling α, we compare three input schemes:

- $\alpha(0)$— Thomson-limit fine-structure constant.
- $\alpha(m_Z)$— running coupling at the Z mass.
- α_{G_μ} — Fermi constant; absorbs universal large-log corrections from muon decay.

Different schemes have different coupling and counter terms

$$\delta Z_e\big|_{\alpha(0)} = \frac{1}{2}\Delta\alpha^{(5)}_{\rm had}(M_Z) + \frac{1}{2}\mathrm{Re}\,\Pi^{AA(5)}(M_Z^2) + \frac{1}{2}\Pi^{AA}_{\rm rem}(0) - \frac{s_W}{c_W}\frac{\Sigma_T^{AZ}(0)}{M_Z^2},$$

$$\delta Z_e\big|_{\alpha(M_Z)} = \delta Z_e\big|_{\alpha(0)} - \frac{1}{2}\Delta\alpha(M_Z), \qquad \delta Z_e|_{G_\mu} = \delta Z_e|_{\alpha(0)} - \frac{1}{2}\Delta r,$$

Differences among schemes quantify a conventional theory uncertainty;

α_{G_μ} scheme is physically motivated since LO amplitudes are proportional to G_μ.

Numerical Results

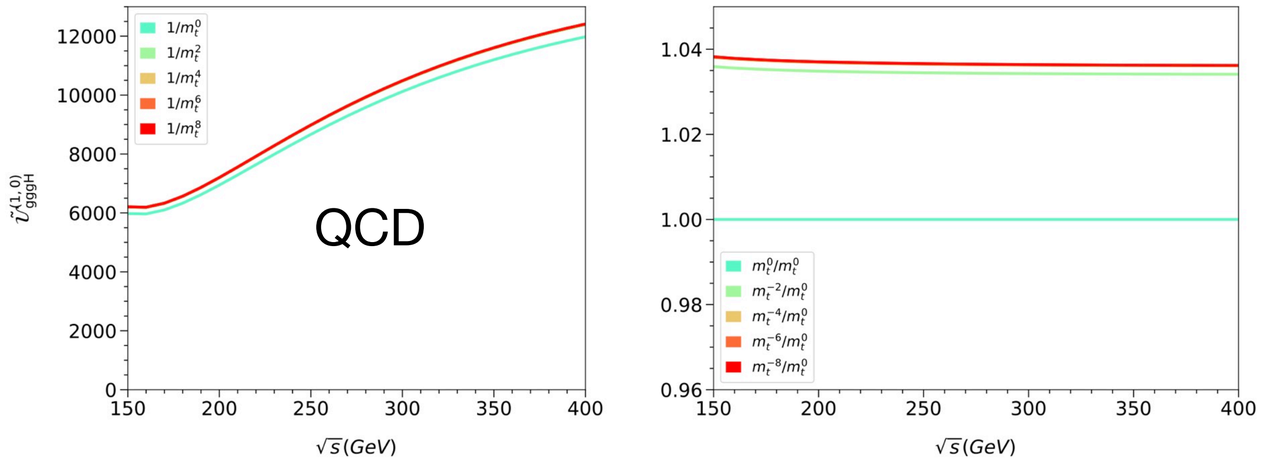
A grid for the ratios between two-loop EW and LO amplitude square is constructed with

$$m_W = 80\ \text{GeV}, \quad m_Z = 91\ \text{GeV}, \quad m_t = 172\ \text{GeV}.$$

The large m_t expended form factors was calculated analytically

Davies, Schonwald, Steinhauser, Zhang, 2308.01355

$$m_t^2 \gg s, t, m_W^2, m_Z^2, m_H^2$$



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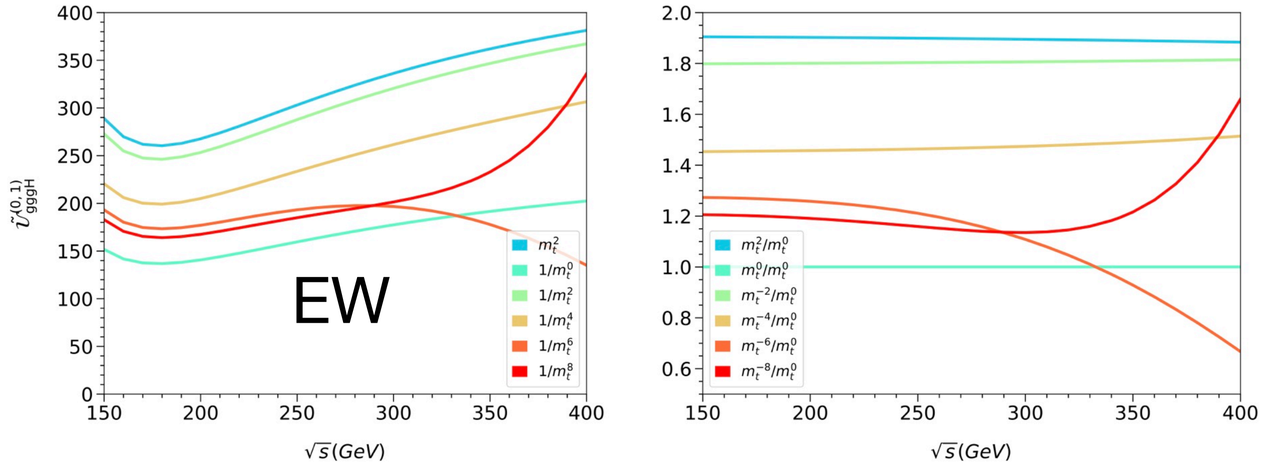

Numerical Results

- We perform a comparison between the full and the large m_t expended form factors

$m_t^2 \gg s, t, m_W^2, m_Z^2, m_H^2$

  - For small energy, the bare and counterterm contributions display good convergence individually.
  - Large numerical cancellations after renormalized occur, leading to a relatively slower convergence of the final result.
  - For instance, the difference between the full and m_t expanded results is around 10% at √s= 150 GeV.

- Amplitude square checked for a few phase points with **Bi, Ma, and Mu, 2508.02588**

Numerical Results

Cross section for $gg \to Hg$ at 13TeV LHC with $p_T^h > 20$ GeV, CT18NLO PDFs with $\mu_{r,f} = \sqrt{{p_T^h}^2 + m_H^2}$

scheme	$\sigma^{\rm LO}$[pb]	$\sigma^{\rm NLO-EW}$[pb]	K-factor
G_μ	7.91	8.25	1.043
$\alpha(0)$	7.56	8.11	1.073
$\alpha(m_Z^2)$	8.04	8.16	1.015

K-factor varies with scheme choices

LO cross section is proportional to α and EW uncertainties 6%

Chen, H.T.L., Sang, 2507.20882

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K-factor varies with scheme choices

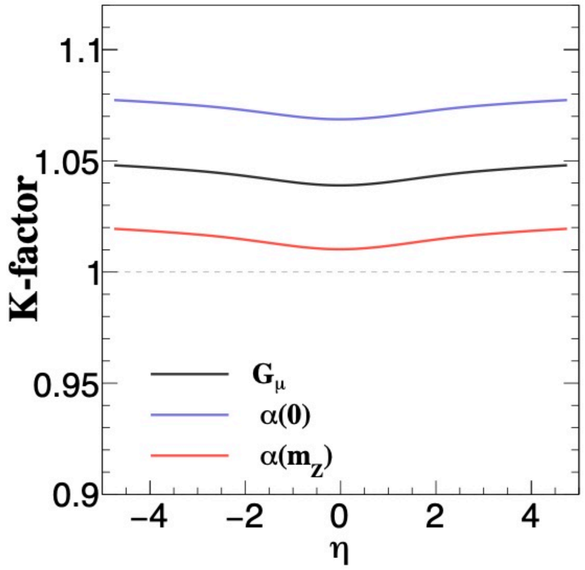
LO cross section is proportional to α and EW uncertainties 6%

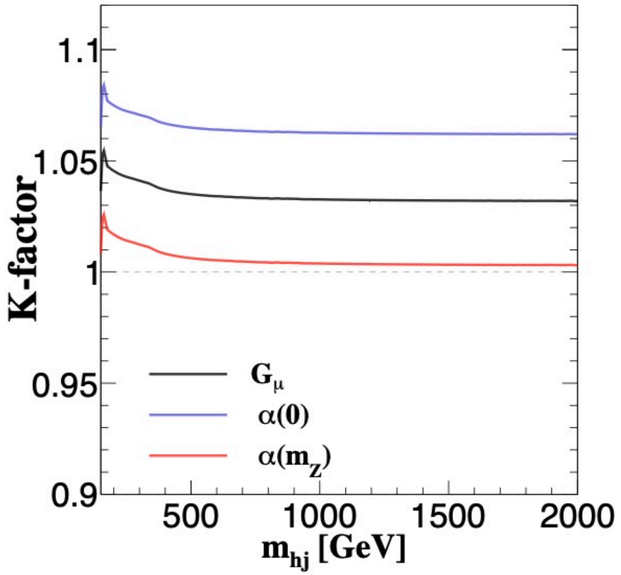
The scheme–dependent EW uncertainty is markedly reduced at NLO, which is ~2%

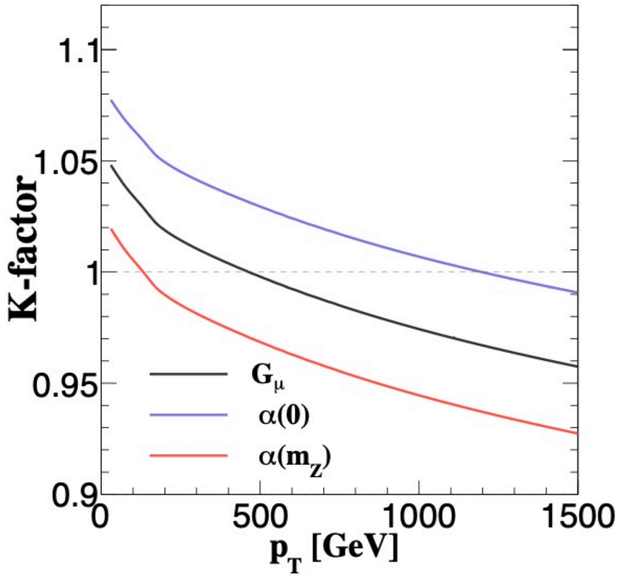
Chen, H.T.L., Sang, 2507.20882

Numerical Results

ratio to LO cross section





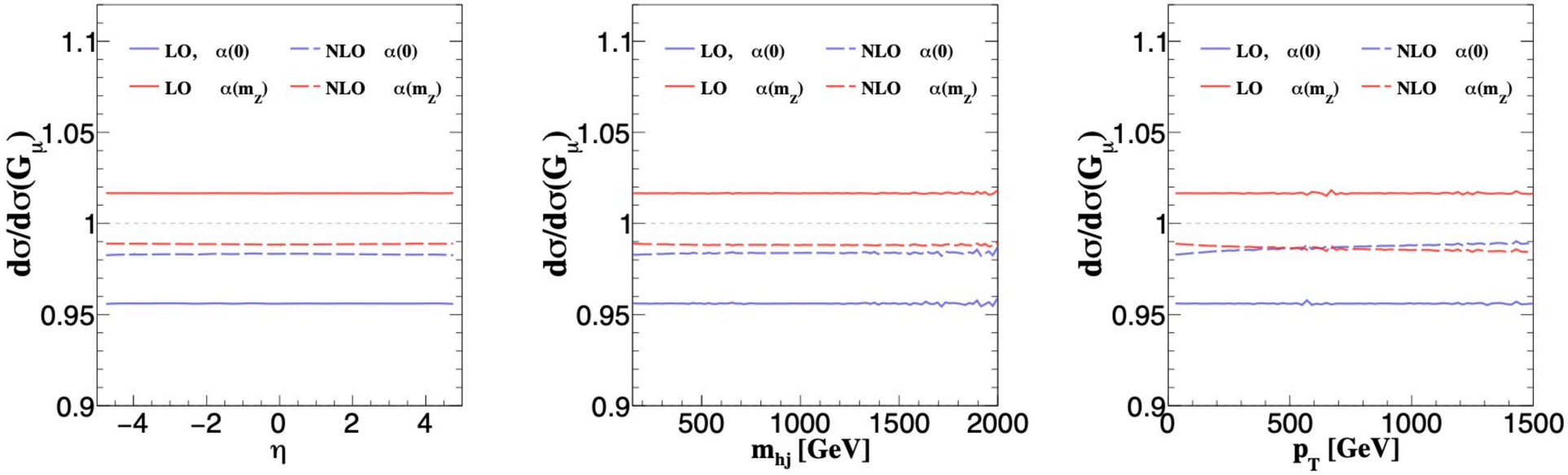


- EW corrections are nearly uniform in Higgs pseudorapidity
- Similarly, m_{hj} distributions show a mild decrease of the K -factor with increasing invariant mass.
- In the α_{G_μ} scheme, the K -factor for p_T decreases from 1.05 at low p_T to 0.95 at high p_T

Chen, H.T.L., Sang, 2507.20882

Numerical Results

raito to α_{G_μ} scheme



- The ratios between different schemes are almost flat
- The LO spread among the schemes is substantial
- The differences shrinks dramatically once the EW corrections are included

Chen, H.T.L., Sang, 2507.20882

Conclusion

- We presented the first NLO EW calculation of $gg \to Hg$ at the LHC, retaining full top-quark mass dependence.
- A novel optimized MI basis combined with differential equations enabled a stable and efficient numerical two-loop evaluation.
- EW corrections amount to 4.3% (α_{G_μ} scheme), with non-trivial kinematic dependence— particularly at high pT.
- NLO EW corrections drastically reduce the scheme dependence that plagues LO predictions, improving theoretical reliability.

Thank you!