Electroweak corrections to $gg \to Hg$ at the LHC

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Based on: arxiv.2508.02588
In cooperation with:
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Nov 25th, 2025 Pohang 포항시
2nd APCTP Workshop on
Precision Calculation and Collider Phenomenology

apctp 아시아태평양이론물리센터
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Introduction

- Introduction
- Calculation strategy
- Results
- Summary

Higgs boson discovery

High-precision era for LHC

Process	State of the Art	Desired
H	$d\sigma$ @ NNLO QCD (expansion in $1/m_t$) full m_t/m_b dependence @ NLO QCD and @ NLO EW NNLO+PS, in the $m_t \to \infty$ limit	$d\sigma$ @ NNNLO QCD (infinite-m_t limit) full m_t/m_b dependence @ NNLO QCD and @ NNLO QCD+EW NNLO+PS with finite top quark mass effects
H + j	$d\sigma$ @ NNLO QCD (g only) and finite-quark-mass effects @ LO QCD and LO EW	$d\sigma$ @ NNLO QCD (infinite-m_t limit) and finite-quark-mass effects @ NLO QCD and NLO EW

[Les Houches 2013]

process	known	desired
$pp \to H$	$\mathrm{N^3LO_{HTL}}$ $\mathrm{NNLO_{QCD}^{(t,t\times b)}}$ $\mathrm{N^{(1,1)}LO_{QCD\otimes EW}^{(HTL)}}$ $\mathrm{NLO_{QCD}}$	$\mathrm{N^4LO_{HTL}}$ (incl.)
$pp \to H + j$	$\mathrm{NNLO_{HTL}}$ $\mathrm{NLO_{QCD}}$ $\mathrm{N^{(1,1)}LO_{QCD\otimes EW}}$	$\mathrm{NNLO_{HTL}} \otimes \mathrm{NLO_{QCD}} + \mathrm{NLO_{EW}}$ $\mathrm{N^3LO_{HTL}}$ $\mathrm{NNLO_{QCD}}$

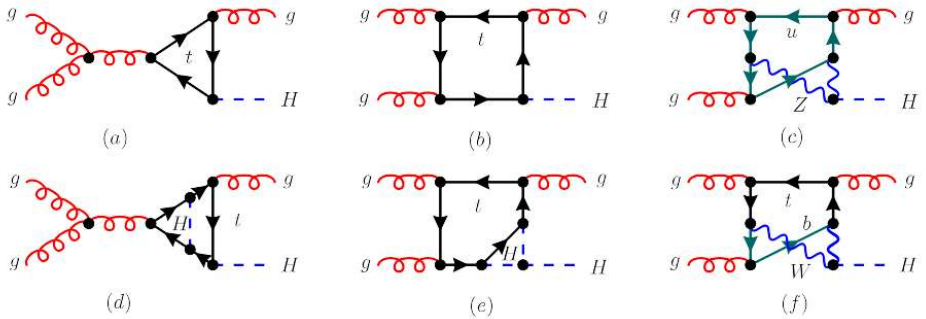
[Les Houches 2023]

High-order corrections for Higgs-related processes:

a long-standing problem on the theoretical physicists' Wishlist

Why Higgs+jet is important ?

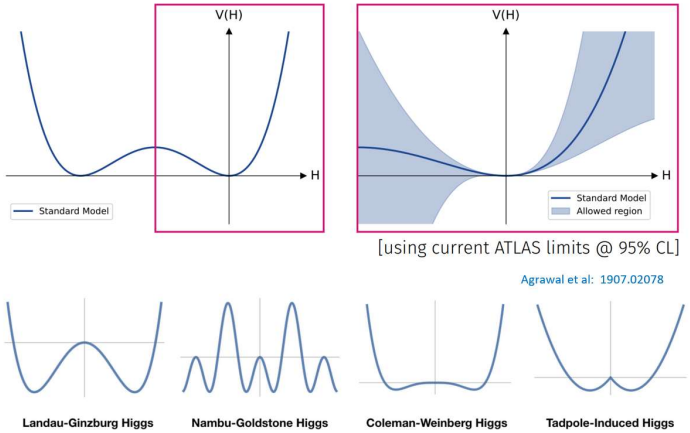
Motivation for Higgs + jet production @ the LHC



For SM:

$$\mathcal{L}_{\text{Higgs}} = (D_\mu \Phi)^\dagger D_\mu \Phi + \mu^2 \Phi^\dagger \Phi - \lambda \left(\Phi^\dagger \Phi\right)^2$$

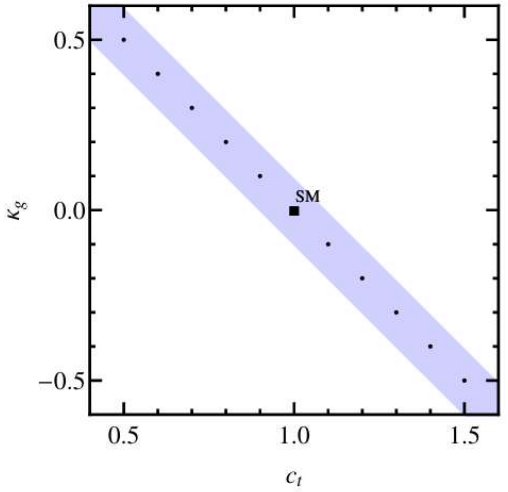
Plot taken from B. Moser: Higgs 2023

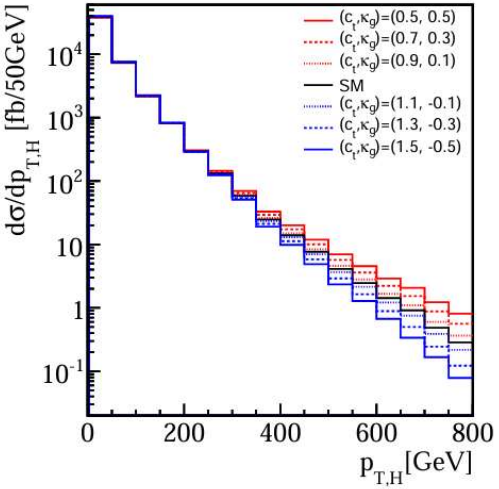


For Beyond SM:

$$\mathcal{L}_{\text{eff}} = -c_t \frac{m_t}{v} \bar{t}tH + \kappa_g \frac{\alpha_S}{12\pi} \frac{h}{v} G^a_{\mu\nu} G^{a\,\mu\nu} + \mathcal{L}_{\text{QCD}},$$

Schlaffer, Spannowsky, Takeuchi, Weiler, Wymant 1405.4295





Status of QCD corrections

- NLO QCD
  - NLO QCD in heavy-top limit (HTL) approximation : 1410.5806; 1501.04637; 1604.03017; 1609.00367; 1801.08226; 1802.02981
  - NLO QCD with full top-quark mass dependence: 1802.00349; 2110.06953; 2206.10490
- NNLO QCD
  - NNLO QCD in HTL, 1302.6216; 1408.5325; 1504.07922; 1505.03893; 1508.02684; 1906.01020; 1607.08817; 1905.13738
- Attempts for NNNLO QCD
  - Relevant Feynman integrals and scattering amplitude in various approximation: 2302.12776; 2301.10849; 2410.19088; 2504.06490

Status of NLO EW corrections

- NLO EW
  - light-fermion loop contributions: 2007.09813; 2010.09451
  - Higgs boson trilinear self-coupling: 2302.04160; 2408.13186
  - HTL approximation with partial Feynman diagram: 2308.01355

We present the first complete results of EW corrections for gg -> Hg

Electroweak loop corrections to $gg \to gH$ at the LHC

Huan-Yu Bi (Hainan U.), Yan-Qing Ma (Peking U. and Peking U., CHEP), Dao-Ming Mu (Peking U.) (Aug 4, 2025)

e-Print: 2508.02588 [hep-ph]

Electroweak corrections to Higgs+jet production in gluon fusion

Long-Bin Chen (Guangzhou U.), Hai Tao Li (Shandong U.), Wen-Long Sang (SWU, Chongqing) (Jul 28, 2025)

e-Print: 2507.20882 [hep-ph]

Calculation strategy

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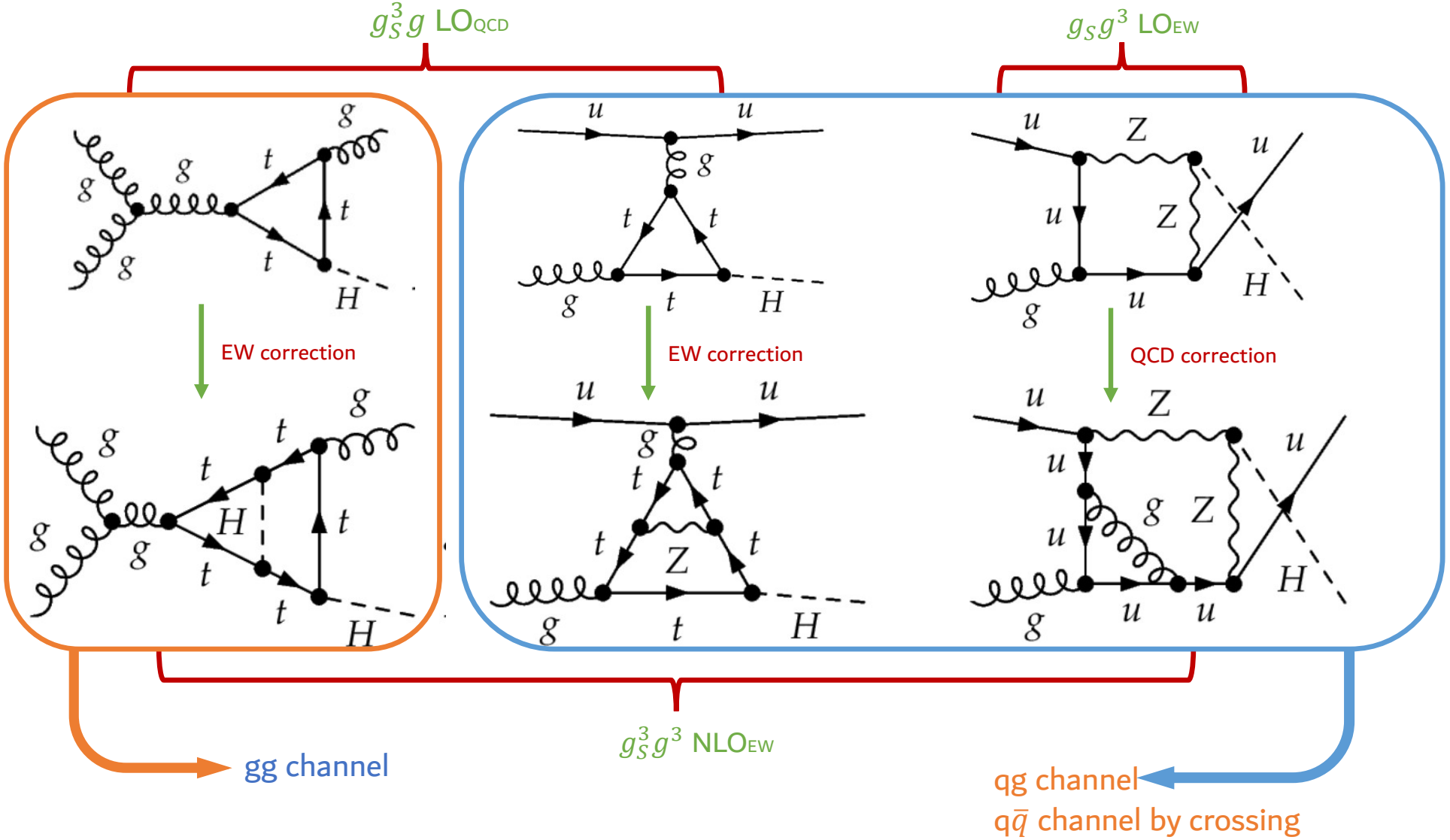
pp->Hj: expansion in coupling constants



dominated

Workflow for Fixed Order Perturbation Calculation

- Generate Feynman diagrams and amplitudes using Feynarts hep-ph/0012260
- Express squared amplitudes or form factors in Feynman Integrals (FIs) using Calcloop

$$|M|^2=\sum_{i,j} d_{ij} FI_i FI_j \qquad F = \sum_i d_i FI_i$$

- Reduce FIs to Master Integrals (MIs) using Blade 2405.14621

$$FI_i = \sum d_j I_j$$

- Calculate MIs I_i

Calculation MIs

- Phase space MC integration

Most difficult part of NLO_{EW} corrections for Higgs+jet
Most time consuming part

Calculations of two loop integrals

Analytically calculation:

☺ Advantage:

- Results can be formulated analytically.

☹ Disadvantage:

- Results are only valid in some particular limit.
  - Results are expressed as an expansion respect to some parameters.
- Only partial sub-diagrams can be calculated analytically.

Numerically calculation:

☺ Advantage:

- MIs are easier to compute.
- Public packages are available: **AMFlow** Liu et al:2201.11669; **pySecDec** Borowka et al: 1703.09692

☹ Disadvantage:

- MIs need to be calculated at a lot of points to obtain cross sections

Different equations for I_k

Construct differential equations (DEs): $\vec{I}(x) = \{I_1(x), I_2(x) \dots I_N(x)\}$

$$\frac{dI_m(x)}{dx} = \sum_n A_{m,n}(x)\, \mathrm{I}'_{\mathrm{n}}(x) \quad \xrightarrow{\text{IBP}} \quad \frac{d\vec{I}(x)}{dx} = A(x)\vec{I}(x)$$

- $\vec{I}(x)$ can be expanded as a power expansion near x_0,
  - regular:$S = \{0\}, k_0 = 0,$
  - singular:$S = \{-2\epsilon, 1 + \epsilon \dots\}, k_\mu \geq 0,$

$$I_i(x) = \sum_{\mu \in S} (x - x_0)^\mu \sum_{k=0}^{k_\mu} \log(x - x_0)^k \sum_{n=0}^{m} c_{i,\mu,k,n} (x - x_0)^n$$

- $c_{i,\mu,k,n}$ can be determined once any boundary $\vec{I}(x_1)$ are provided.
- $\vec{I}(x_1)$ can be determined by AMFlow Liu et al:2201.11669
- Taking adequate expansion order m, we can eventually achieve predictions with high precision.
- $\vec{I}(x)$ can be evaluated at any points of x efficiently.

Electroweak loop corrections to Higgs+jet production at the LHC: interpolation

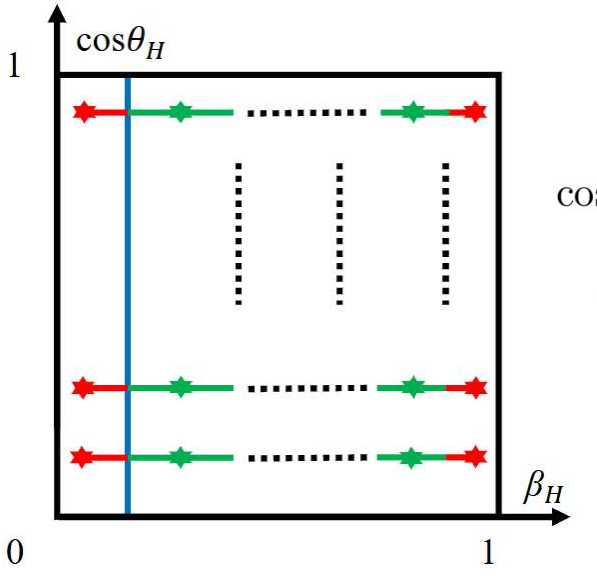
How we handle the computation of complex two-loop Feynman integrals

- Manually setup several 1D asymptotic expansions on the 2D phase-space plane
  - On MIs level
  - On matrix element squared level
- Use 1D asymptotic expansions for 1D interpolation of squared amplitudes at any point in the phase-space plane

$$I_i(\cos\Theta_H, \beta) = \sum_{\mu\in S}(\beta-\beta_0)^\mu \sum_{k=0}^{k_\mu} \log(\beta-\beta_0)^k \sum_{n=0}^{m} c_{i,\mu,k,n}(\beta-\beta_0)^n$$

$$|M|^2 = \sum_{i,j} d_{ij}(x) I_i(x) I_j(x)$$

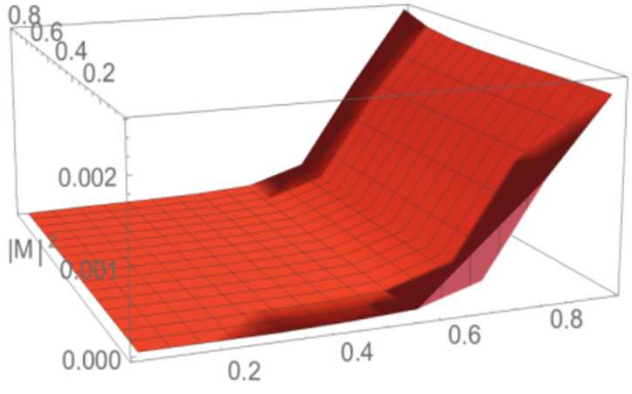
$$|M|^2(\cos\Theta_H, \beta) = \sum_{\mu\in S}(\beta-\beta_0)^\mu \sum_{k=0}^{k_\mu} \log(\beta-\beta_0)^k \sum_{n=0}^{m} c_{i,\mu,k,n}(\beta-\beta_0)^n$$



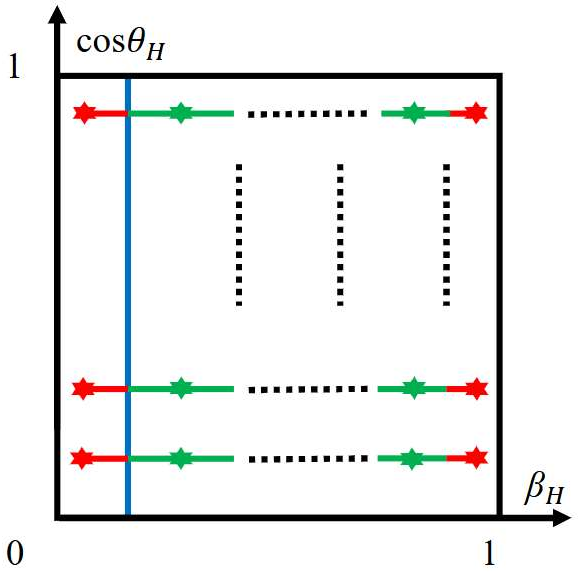
$$\cos\theta_H = (\hat{u}-\hat{t})/(\hat{s}-m_H^2)$$

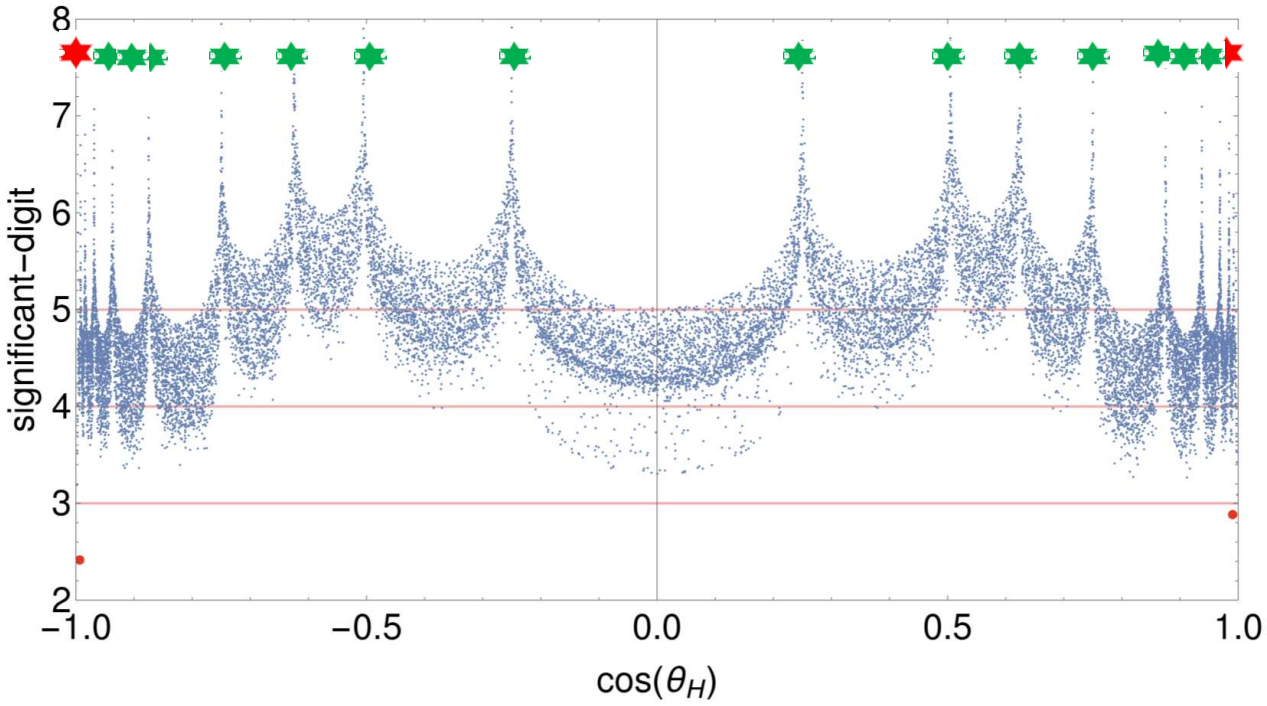
$$\beta_H = (\hat{s}-m_H^2)/(\hat{s}+m_H^2)$$

Traditional 2D interpolation based on grads



Validating the interpolation





We test 20000 different phase space points

- We first compute k-fac for these phase space points in high precision with DE methods
- We then compute k-fac for these phase space points with 1D interpolation

  - 3-digit agreement for 99.99% of the phase space points
  - 4-digit agreement for 94% of the phase space points
  - 5-digit agreement for 37% of the phase space points

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Input Paramaters

$$m_t = 172.69 \text{ GeV}$$

PDG2022

$$\frac{m_H^2}{m_t^2} = \frac{12}{23}, \quad \frac{m_Z^2}{m_t^2} = \frac{23}{83}, \quad \frac{m_W^2}{m_t^2} = \frac{14}{65},$$

$$G_\mu = 1.166378 \times 10^{-5} \text{ GeV}^{-2}$$

$$\alpha = \frac{\sqrt{2}}{\pi} G_\mu m_W^2 \left(1 - \frac{m_W^2}{m_Z^2}\right)$$

CKM=1

PDFs: NNPDF31_nlo_as_0118

on-shell renormalization: masses and fields; G_μ-scheme: Electromagnetic coupling

Denner et al:1912.06823

D=4-2ε ， ε =±1/1000

$$\sigma(\varepsilon)=a_0+ a_1\varepsilon + a_3\varepsilon^2 + \cdots$$

$$\sigma(0)\sim \frac{\sigma(+1/1000)+\sigma(-1/1000)}{2} = a_0+a_3\varepsilon^2+\ldots$$

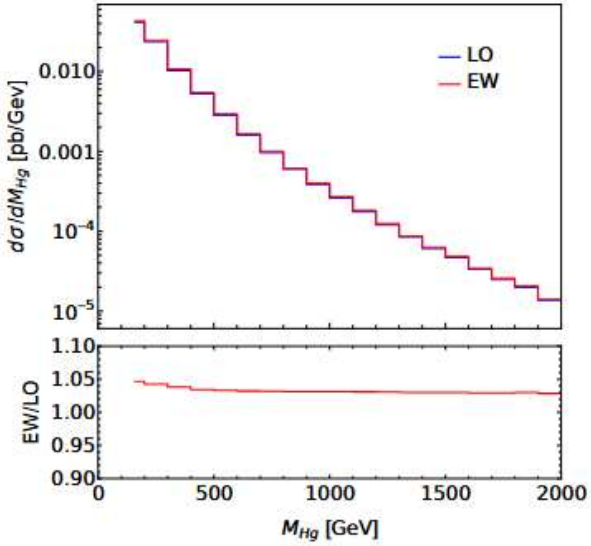
Results

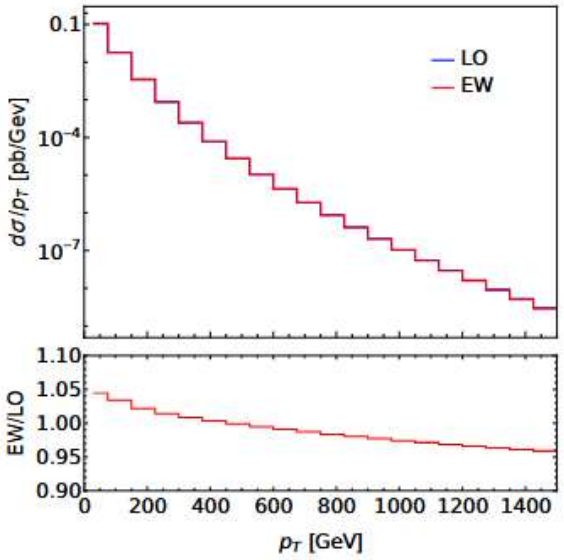
Once squared amplitudes are computed efficiently, total and differential cross sections can be obtained via Monte Carlo

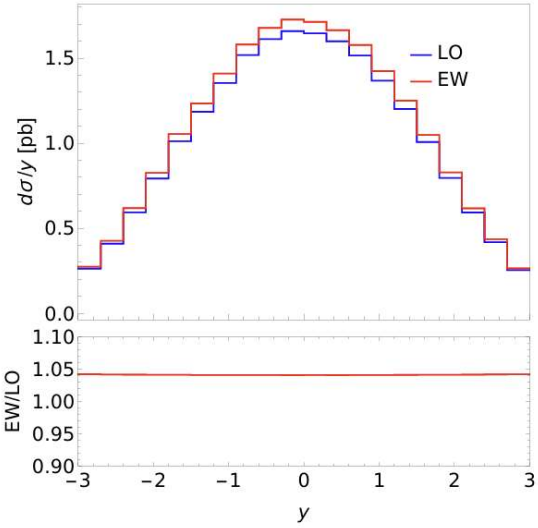
(μ_r, μ_f)	(μ_0, μ_0)	$(\mu_0, 0.5\mu_0)$	$(\mu_0, 2\mu_0)$	$(0.5\mu_0, \mu_0)$	$(2\mu_0, \mu_0)$	$(0.5\mu_0, 0.5\mu_0)$	$(2\mu_0, 2\mu_0)$
$\sigma_{\rm LO}$	6.37(2)	6.43(2)	6.25(2)	8.83(2)	4.75(1)	8.91(2)	4.66(1)
$\sigma_{\rm EW}$	6.63(2)	6.69(2)	6.51(2)	9.20(2)	4.95(1)	9.27(2)	4.85(1)
$\mathcal{K}$-factor	1.041	1.041	1.041	1.041	1.041	1.041	1.041

$$\mu_0 = \frac{1}{2}\sqrt{p_T^2 + m_H^2} + \frac{1}{2}p_T$$

+4% for total cross section



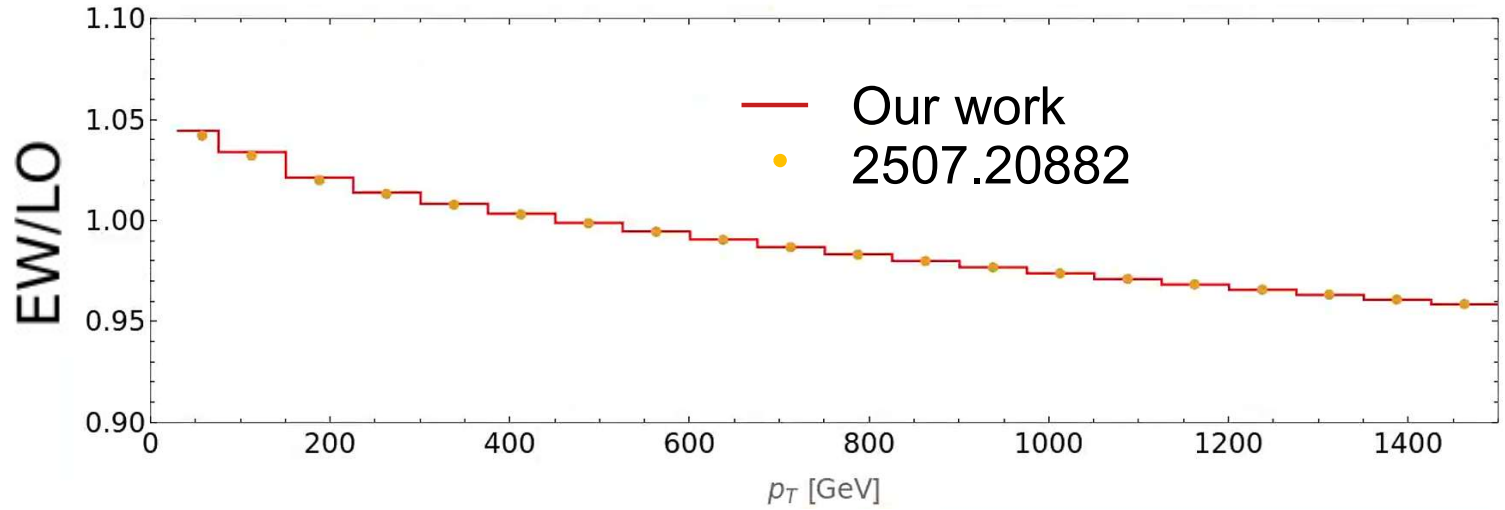


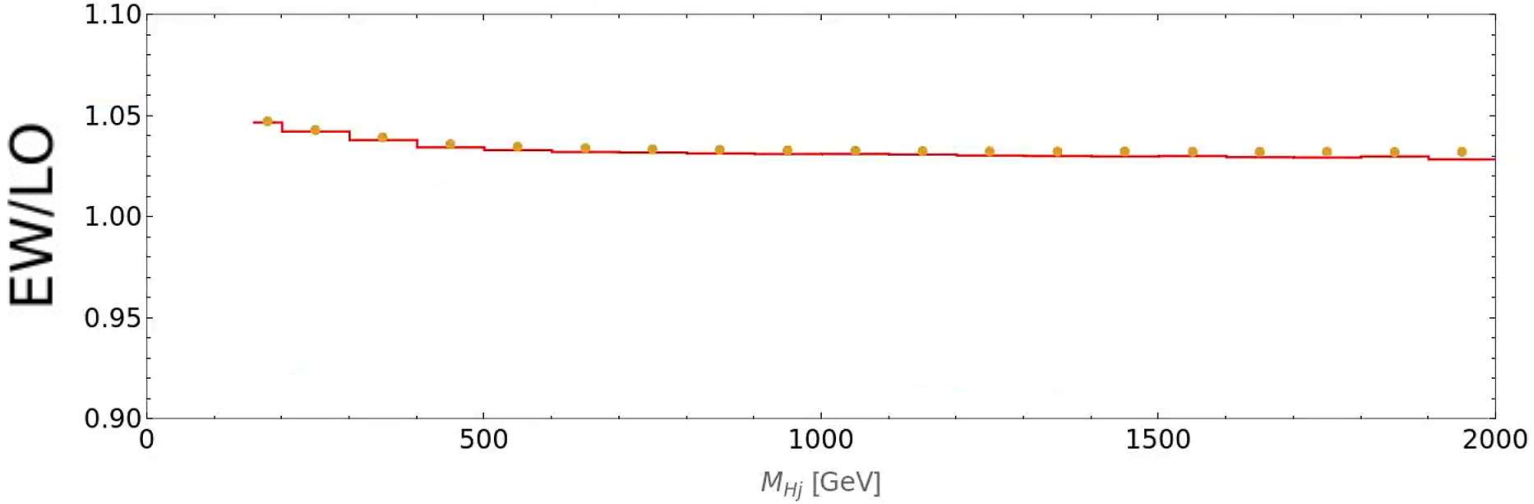


A noticeable shape distortion for this distribution

- the corrections exceed +4% in the low Higgs transverse momentum region
- fall below −4% in the high transverse momentum region

Results compared to 2507.20882





2507.20882

scheme	σ^{LO}[pb]	$\sigma^{\mathrm{NLO-EW}}$[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

Summary

- New physics is sensitive to High pt Higgs.
- The study of $\sigma(Hj)$ can be used to identify new physics models.
- Our full calculation includes all the diagrams and all the mass effects.
- 4% EW corrections at total cross section level.
- For dimensionful observables, EW corrections reach up to +4% at the beginning of the spectrum and −4% in the tail.
- Our results represent a necessary step towards to complete next-to-leading order electroweak correction of the Higgs + jet process.

Thanks for your attention!