Higgs pair production and Perturbative Corrections

Haitao Li (李海涛)

山东大学物理学院
SCHOOL OF PHYSICS, SHANDONG UNIVERSITY

HTL, Si, Wang, Zhang, Zhao, *arXiv:2402.00401*

HTL, Si, Wang, Zhang, Zhao, arXiv:2407.14716

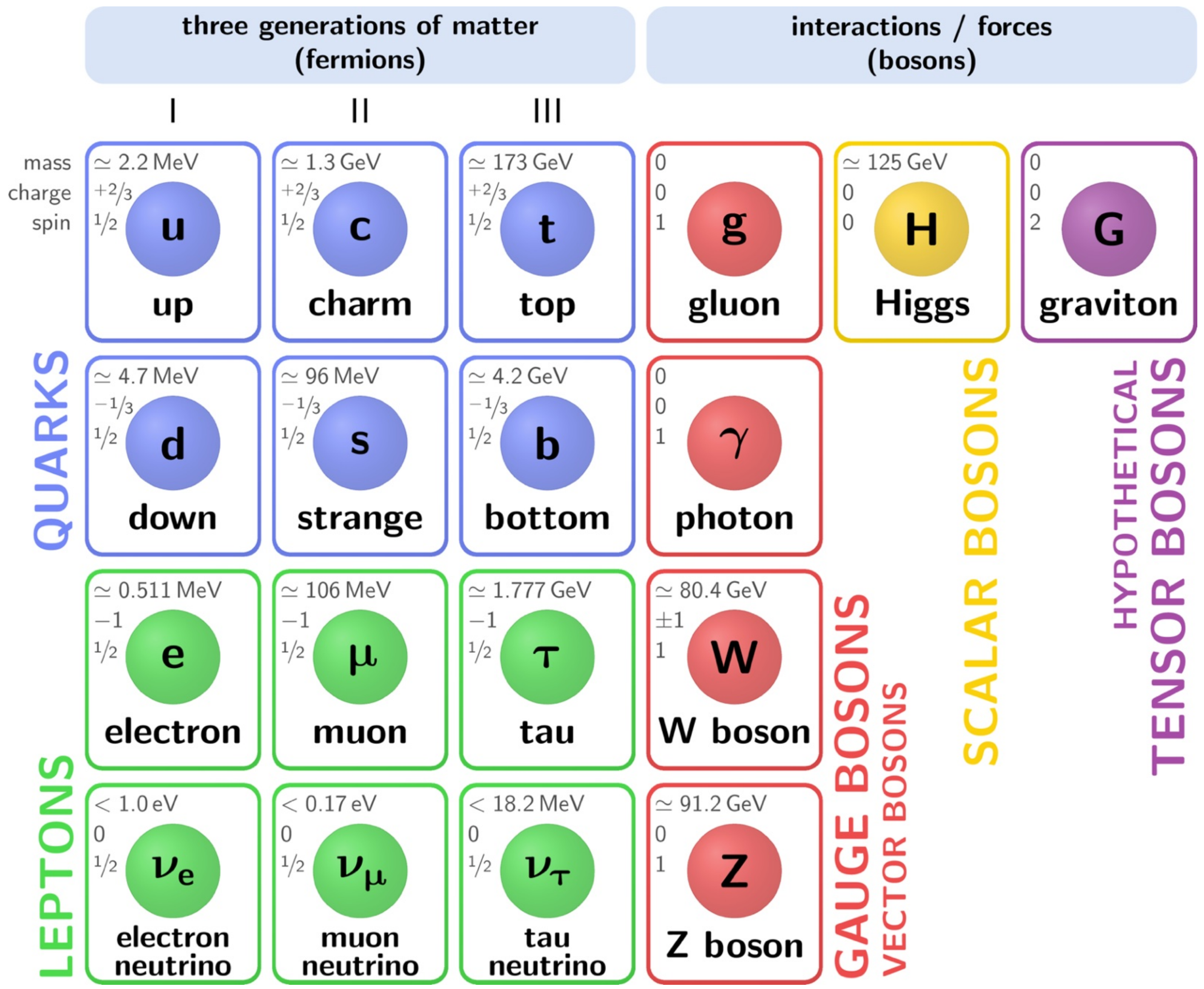
HTL, Si, Wang, Zhang, Zhao, arXiv:2503.22001

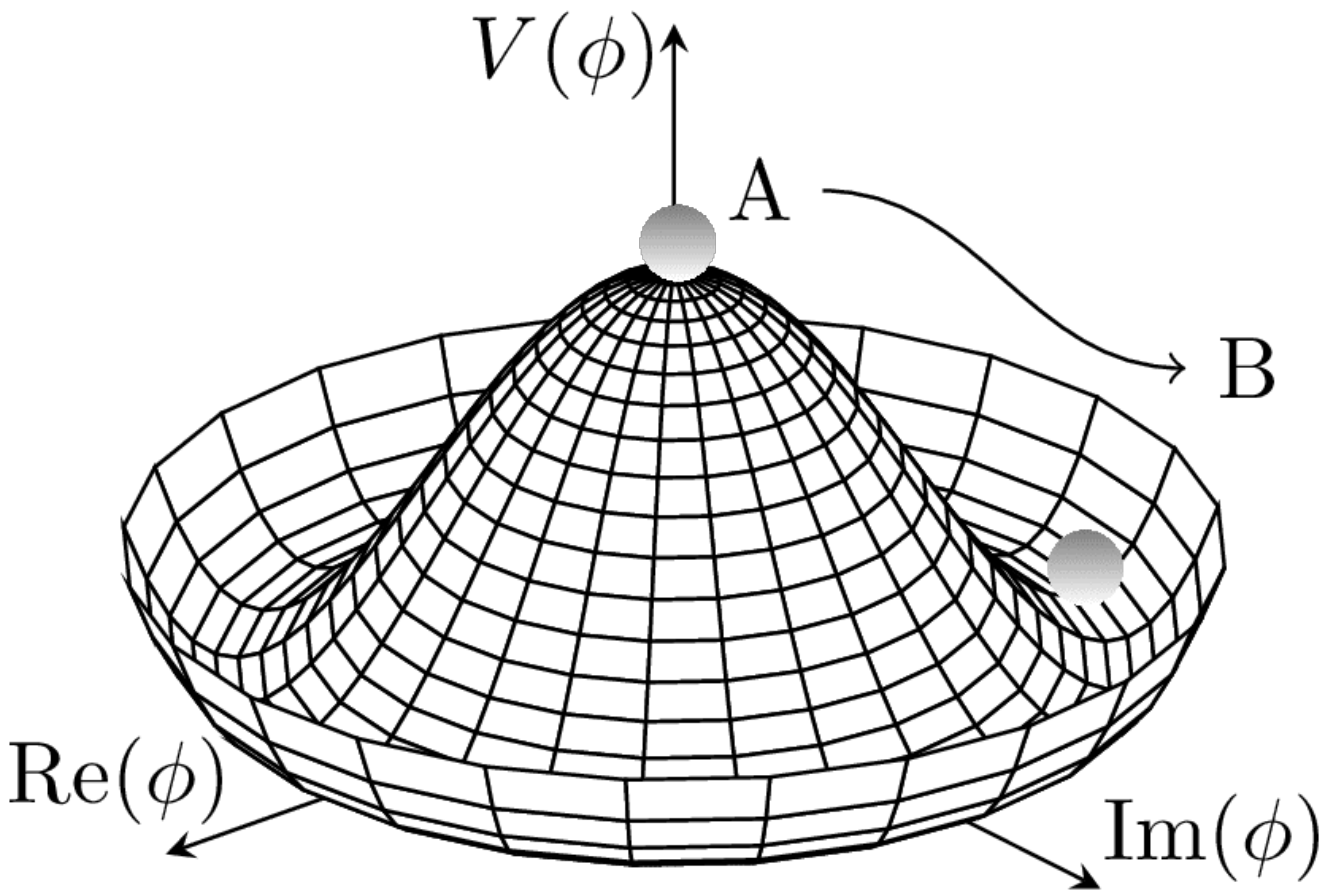
and works in progress

第七届全国重味物理与量子色动力学研讨会

南京 2025.04.21

Introduction





from tikz.net

Introduction

Higgs self-coupling is a crucial parameter for Higgs potential and electroweak symmetry

$$V(H) = -\mu^2 H^\dagger H + \lambda^{\rm SM} \left(H^\dagger H\right)^2 \qquad \lambda_{\rm SM} = \frac{m_h^2}{2v^2}$$

Shape of the potential connected to the phase transition of the early universe from the unbroken to the broken electroweak symmetry

A deviation of the potential from the SM would directly point to new physics

- **with additional scalar particles (SUSY, additional singlets, etc)**
- **whether the Higgs is composite**
- **with first-order electroweak phase transition**

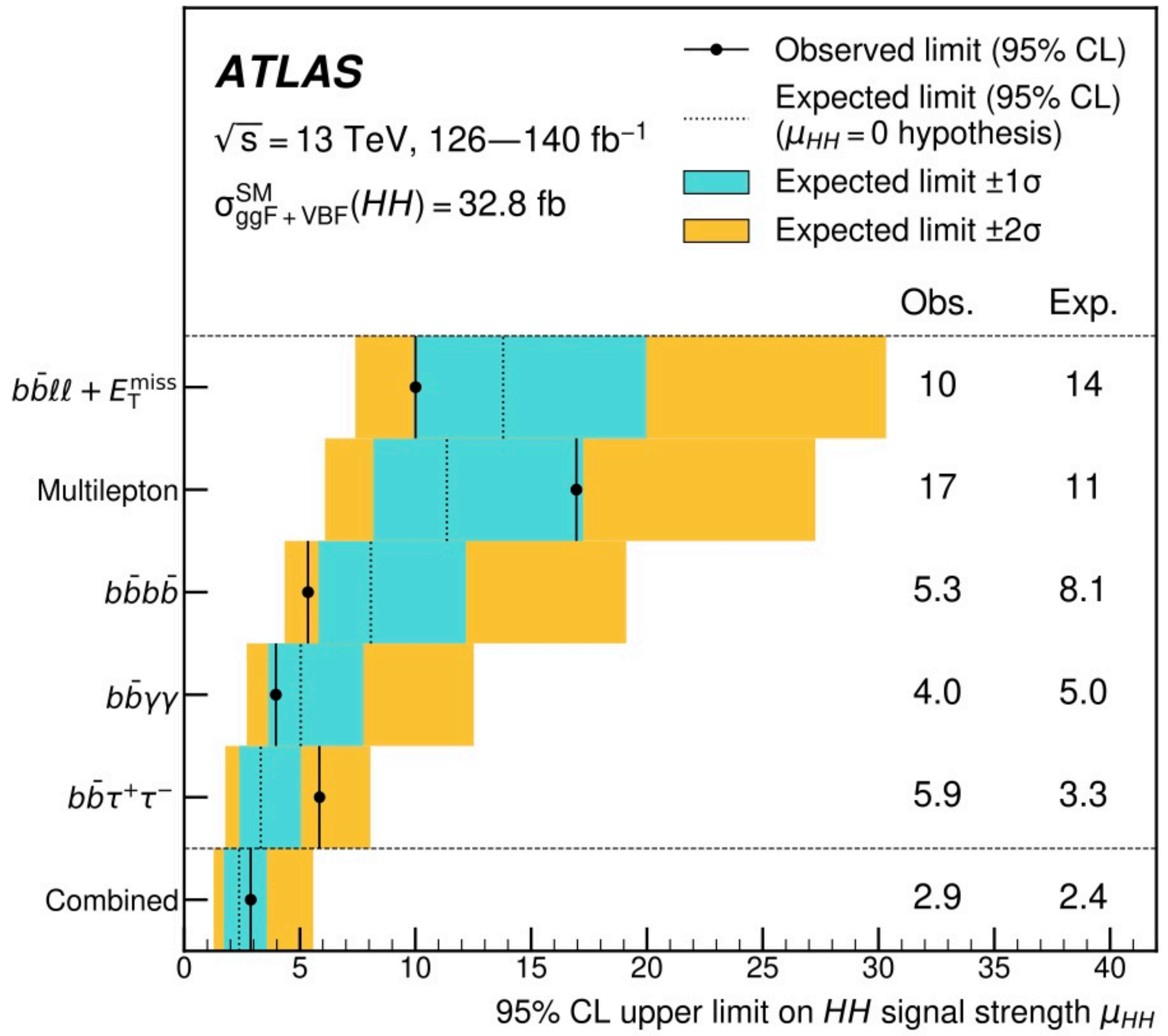
The precise measurement of the Higgs self-coupling is one of top priorities of the current and future high-energy collider experiments

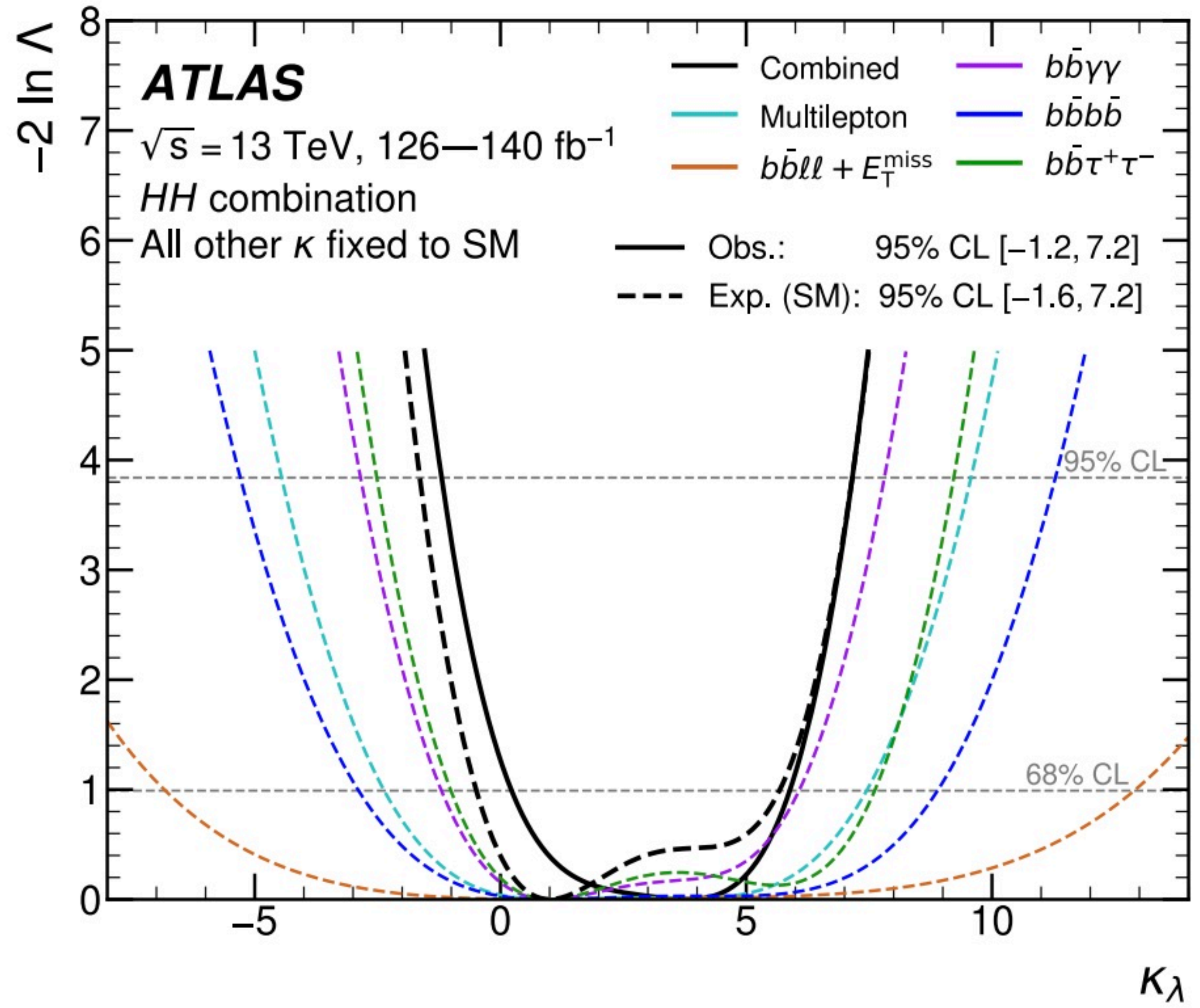
Introduction

At the LHC

explored in the ggF and VBF H
production processes.

ATLAS, arXiv: 2406.09971



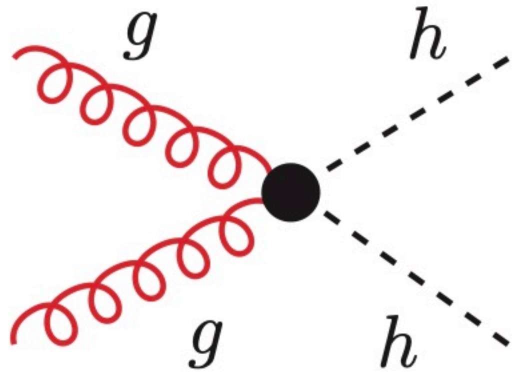


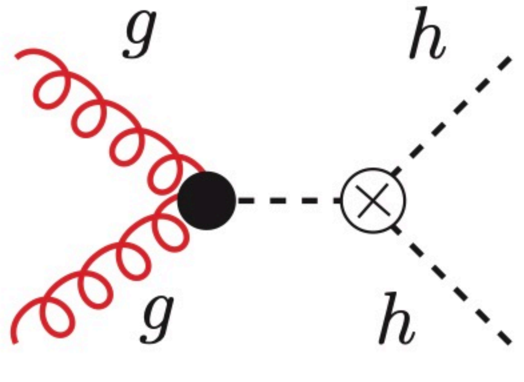
combination of single and double
Higgs boson production

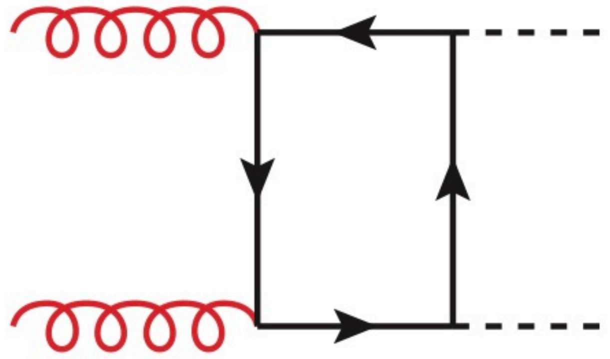
CMS, arXiv: 2407.13554

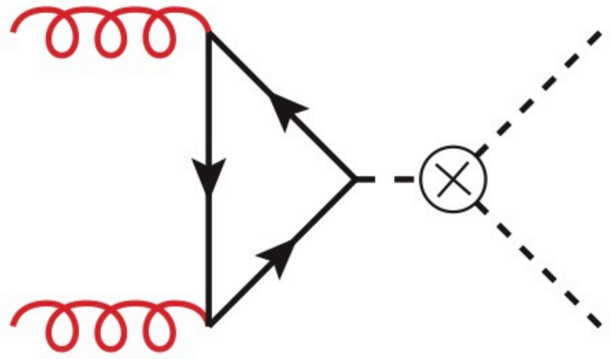
	Best fit κ_λ value $\pm1\sigma$		2σ interval	
Hypothesis	Expected	Observed	Expected	Observed
Other couplings fixed to the SM prediction	$1.0^{+4.6}_{-1.7}$	$3.1^{+3.0}_{-3.0}$	$[-2.0, 7.7]$	$[-1.2, 7.5]$
Floating $(\kappa_V, \kappa_{2V}, \kappa_f)$	$1.0^{+4.7}_{-1.8}$	$4.5^{+1.8}_{-4.7}$	$[-2.2, 7.8]$	$[-1.7, 7.7]$
Floating $(\kappa_V, \kappa_t, \kappa_b, \kappa_\tau)$	$1.0^{+4.8}_{-1.8}$	$4.7^{+1.7}_{-4.1}$	$[-2.3, 7.7]$	$[-1.4, 7.8]$
Floating $(\kappa_V, \kappa_{2V}, \kappa_t, \kappa_b, \kappa_\tau, \kappa_\mu)$	$1.0^{+4.8}_{-1.8}$	$4.7^{+1.7}_{-4.2}$	$[-2.3, 7.8]$	$[-1.4, 7.8]$

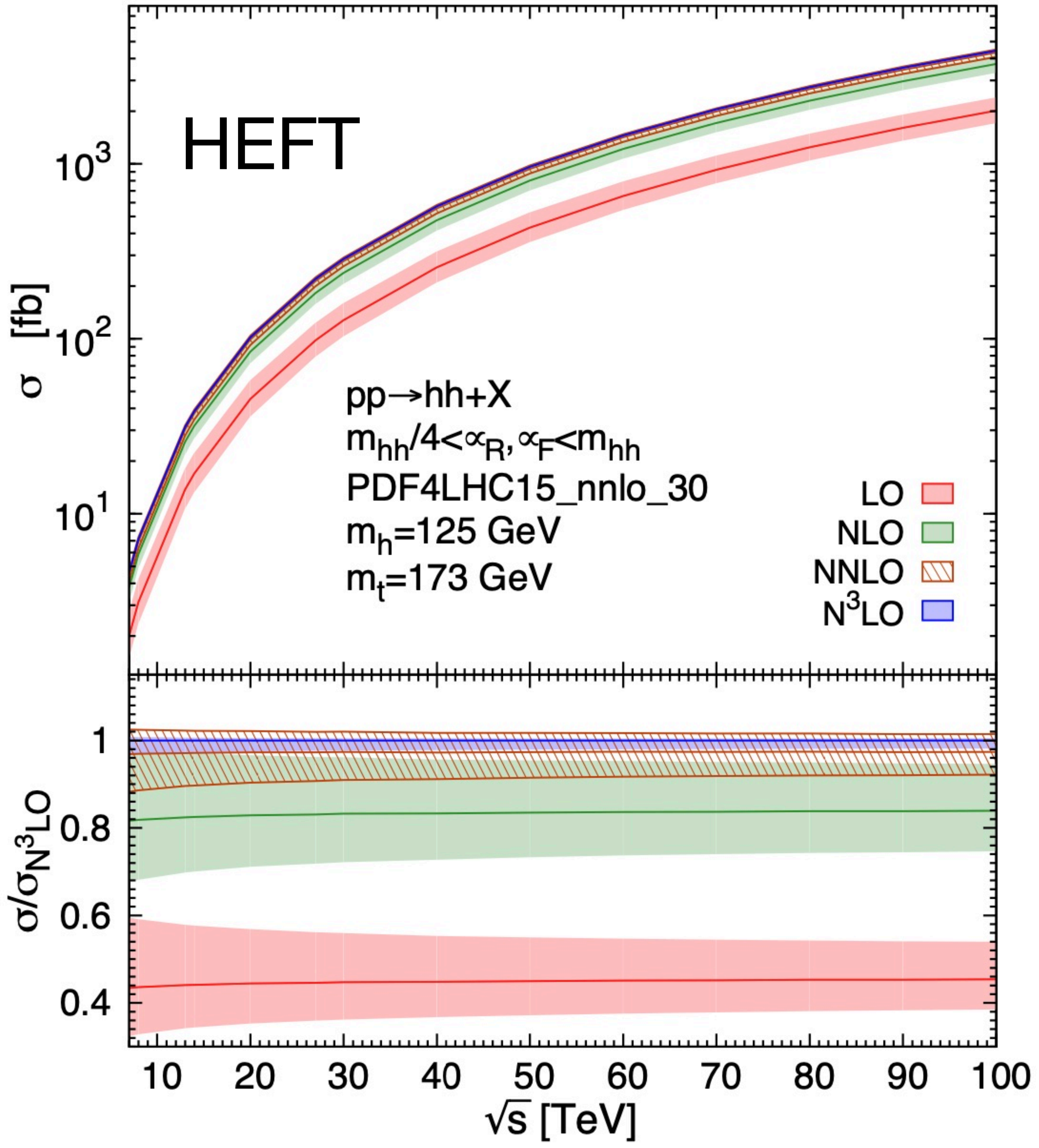
Perturbative corrections





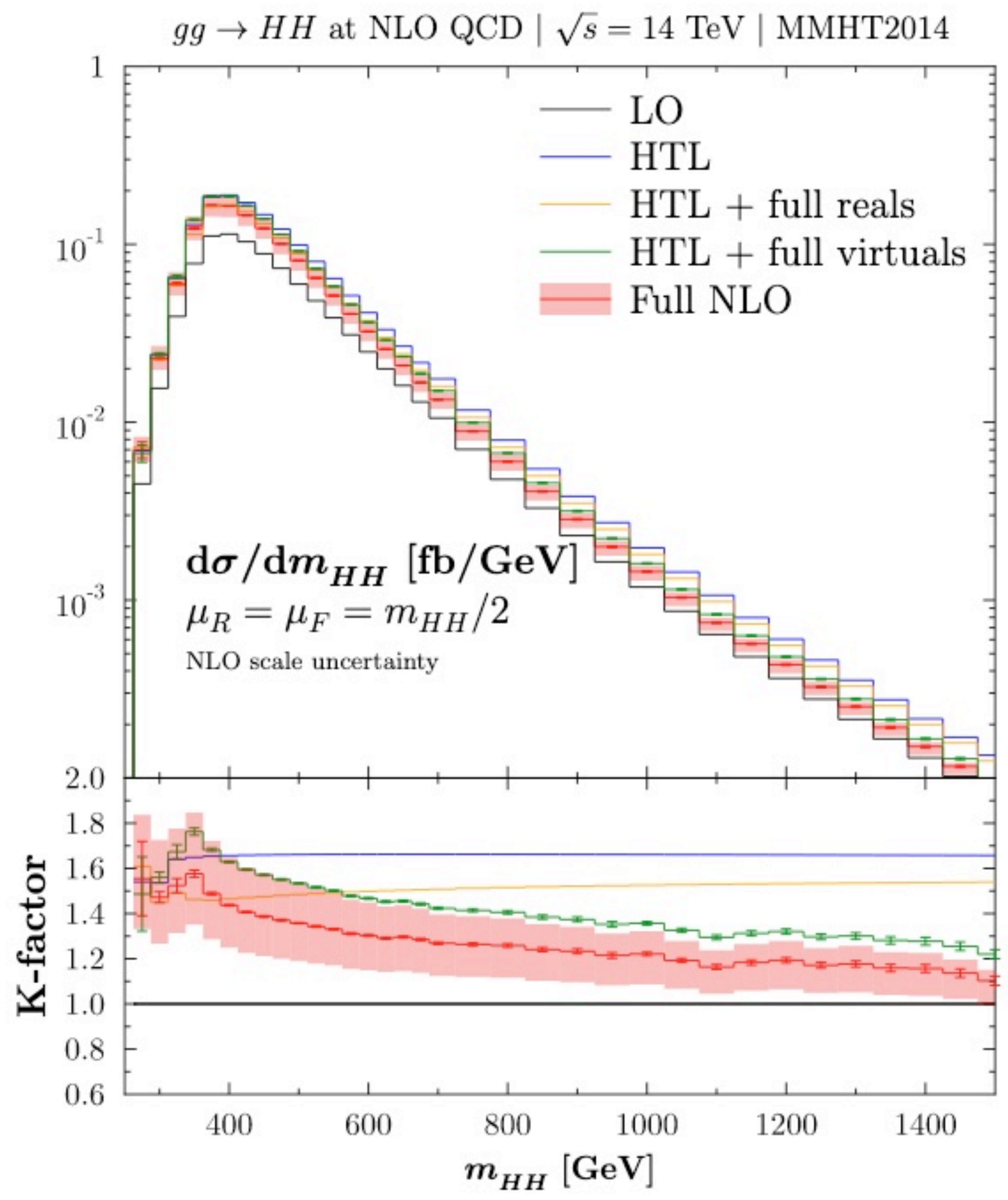






Improving results by matching

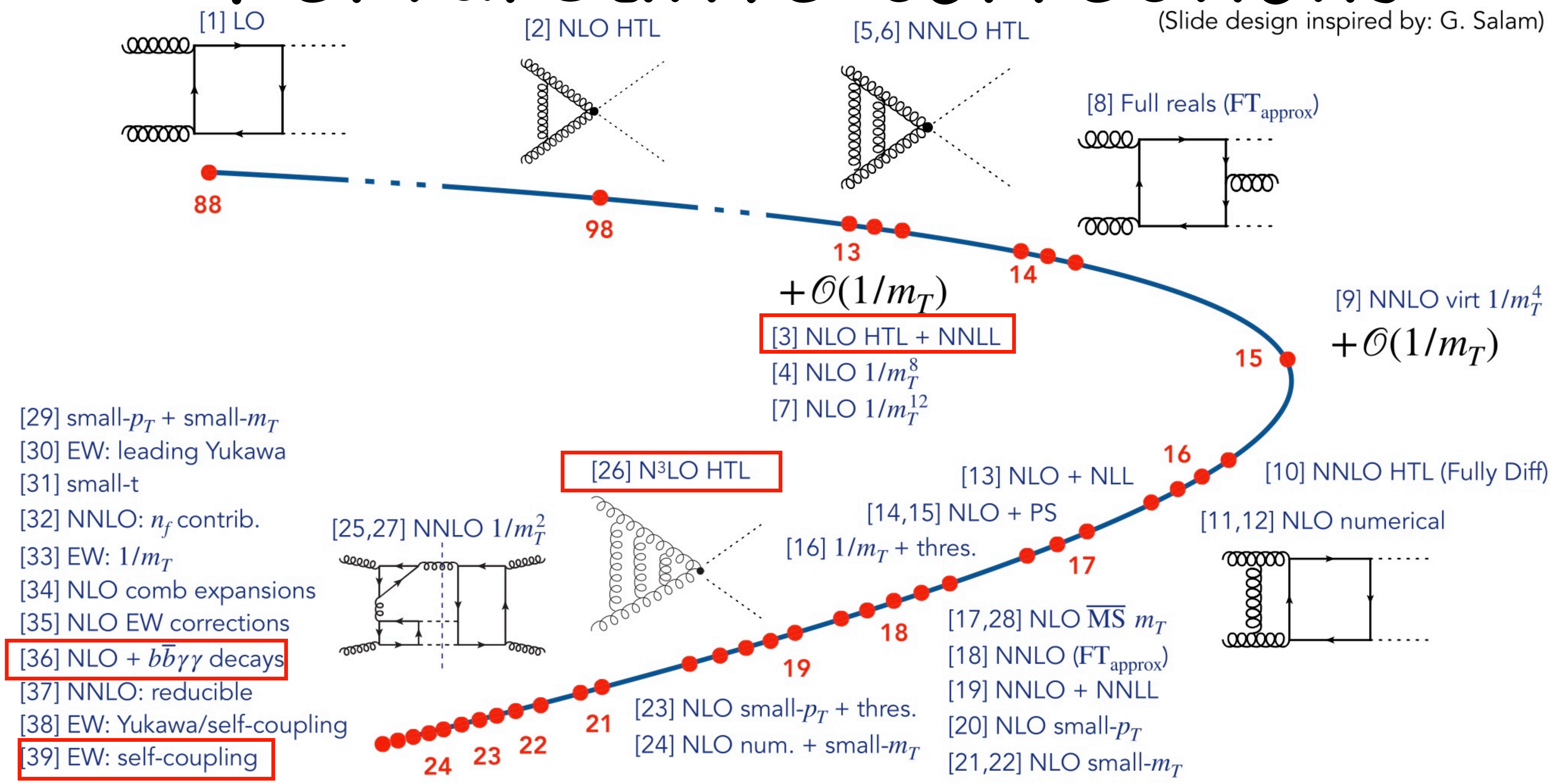
- replace the EFT tree amplitude to one-loop ones in full theory
- reweight loop amplitudes with the ratio of tree ones



large top quark mass effects

Perturbative corrections

gg2HH



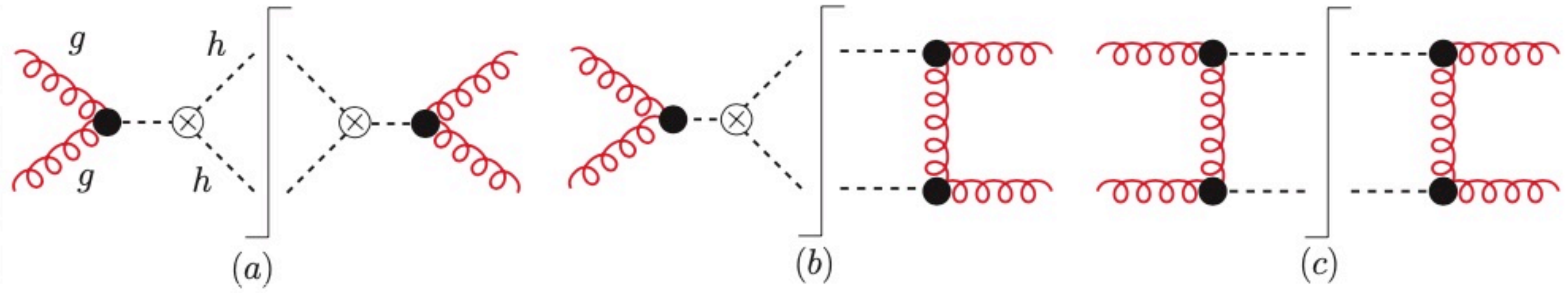
[1] Glover, van der Bij 88; [2] Dawson, Dittmaier, Spira 98; [3] Shao, Li, Li, Wang 13; [4] Grigo, Hoff, Melnikov, Steinhauser 13; [5] de Florian, Mazzitelli 13; [6] Grigo, Melnikov, Steinhauser 14; [7] Grigo, Hoff 14; [8] Maltoni, Vryonidou, Zaro 14; [9] Grigo, Hoff, Steinhauser 15; [10] de Florian, Grazzini, Hanga, Kallweit, Lindert, Maierhöfer, Mazzitelli, Rathlev 16; [11] Borowka, Greiner, Heinrich, SPJ, Kerner, Schlenk, Schubert, Zirke 16; [12] Borowka, Greiner, Heinrich, SPJ, Kerner, Schlenk, Zirke 16; [13] Ferrera, Pires 16; [14] Heinrich, SPJ, Kerner, Luisoni, Vryonidou 17; [15] SPJ, Kuttimalai 17; [16] Gröber, Maier, Rauh 17; [17] Baglio, Campanario, Glaus, Mühlleitner, Spira, Streicher 18; [18] Grazzini, Heinrich, SPJ, Kallweit, Kerner, Lindert, Mazzitelli 18; [19] de Florian, Mazzitelli 18; [20] Bonciani, Degrassi, Giardino, Gröber 18; [21] Davies, Mishima, Steinhauser, Wellmann 18, 18; [22] Mishima 18; [23] Gröber, Maier, Rauh 19; [24] Davies, Heinrich, SPJ, Kerner, Mishima, Steinhauser, David Wellmann 19; [25] Davies, Steinhauser 19; [26] Chen, Li, Shao, Wang 19, 19; [27] Davies, Herren, Mishima, Steinhauser 19, 21; [28] Baglio, Campanario, Glaus, Mühlleitner, Ronca, Spira 21; [29] Bellafronte, Degrassi, Giardino, Gröber, Vitti 22; [30] Davies, Mishima, Schönwald, Steinhauser, Zhang 22; [31] Davies, Mishima, Schönwald, Steinhauser 23; [32] Davies, Schönwald, Steinhauser 23; [33] Davies, Schönwald, Steinhauser, Zhang 23; [34] Bagnaschi, Degrassi, Gröber 23; [35] Bi, Huang, Huang, Ma Yu 23; [36] Li, Si, Wang, Zhang, Zhao 24; [37] Davies, Schönwald, Steinhauser, Vitti 24; [38] Heinrich, SPJ, Kerner, Stone, Vestner; [39] Li, Si, Wang, Zhang, Zhao 24

taken from Spira's talk at Higgs 2024

Perturbative corrections

According to the number of effective vertices at the squared amplitude level, there are there channels.

There are two (class-a), three (class-b) and four (class-c) effective vertices insertions respectively.

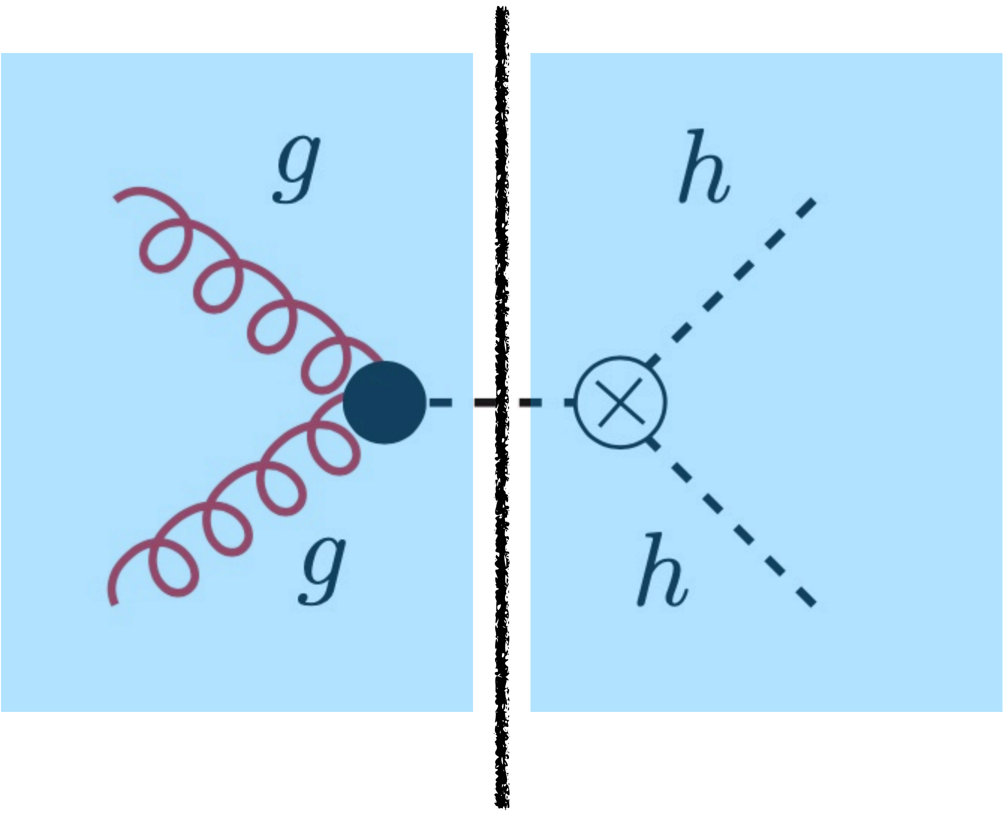


$$d\sigma_{hh} = d\sigma^a_{hh} + d\sigma^b_{hh} + d\sigma^c_{hh}.$$

	LO	NLO	NNLO	N^{3}LO
total	$\mathcal{O}(\alpha_s^2)$	$\mathcal{O}(\alpha_s^3)$	$\mathcal{O}(\alpha_s^4)$	$\mathcal{O}(\alpha_s^5)$
class-a	$\mathcal{O}(\alpha_s^2)$	$\mathcal{O}(\alpha_s^3)$	$\mathcal{O}(\alpha_s^4)$	$\mathcal{O}(\alpha_s^5)$
class-b	0	$\mathcal{O}(\alpha_s^3)$	$\mathcal{O}(\alpha_s^4)$	$\mathcal{O}(\alpha_s^5)$
class-c	0	0	$\mathcal{O}(\alpha_s^4)$	$\mathcal{O}(\alpha_s^5)$

Chen, HTL, Shao, Wang, arXiv:1909.06808, arXiv:1912.13001

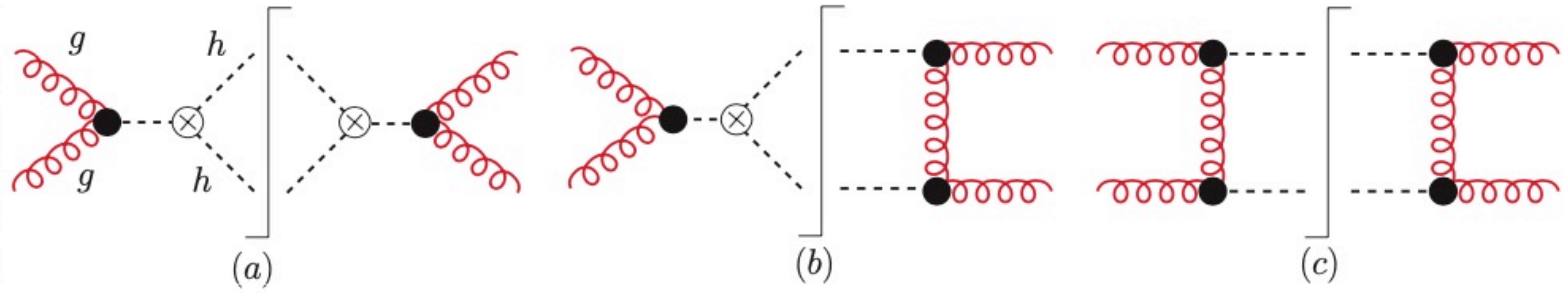
For class-a NNNLO cross section we have



Perturbative corrections

According to the number of effective vertices at the squared amplitude level, there are there channels.

There are two (class-a), three (class-b) and four (class-c) effective vertices insertions respectively.

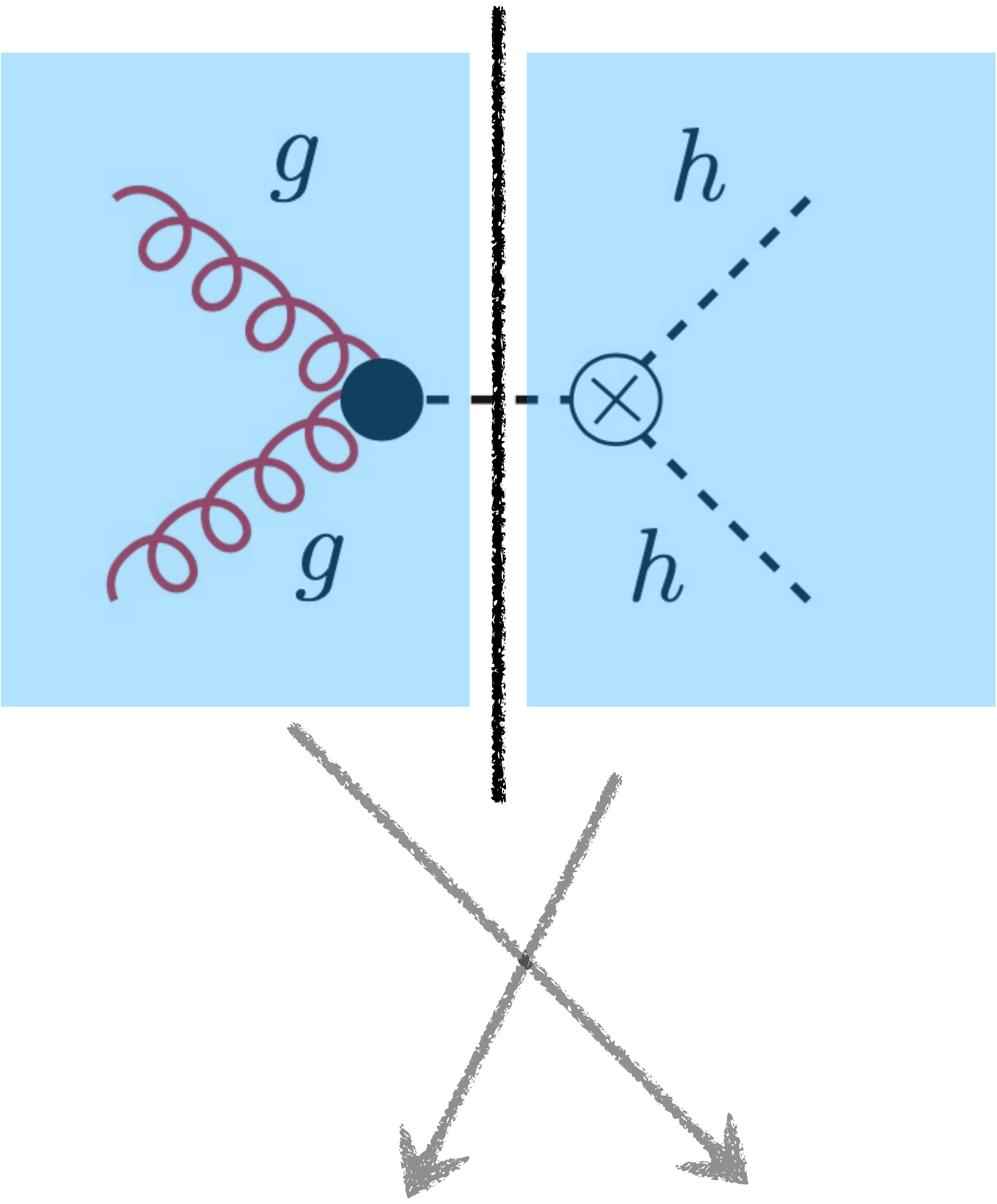


$$d\sigma_{hh} = d\sigma^a_{hh} + d\sigma^b_{hh} + d\sigma^c_{hh}.$$

	LO	NLO	NNLO	N^{3}LO
total	$\mathcal{O}(\alpha_s^2)$	$\mathcal{O}(\alpha_s^3)$	$\mathcal{O}(\alpha_s^4)$	$\mathcal{O}(\alpha_s^5)$
class-a	$\mathcal{O}(\alpha_s^2)$	$\mathcal{O}(\alpha_s^3)$	$\mathcal{O}(\alpha_s^4)$	$\mathcal{O}(\alpha_s^5)$
class-b	0	$\mathcal{O}(\alpha_s^3)$	$\mathcal{O}(\alpha_s^4)$	$\mathcal{O}(\alpha_s^5)$
class-c	0	0	$\mathcal{O}(\alpha_s^4)$	$\mathcal{O}(\alpha_s^5)$

Chen, HTL, Shao, Wang, arXiv:1909.06808, arXiv:1912.13001

For class-a NNNLO cross section we have



$$\frac{d\sigma^a_{hh}}{dm_{hh}} = f_{h\to hh} \left(\frac{C_{hh}}{C_h} - \frac{6\lambda_{hhh} v^2}{m_{hh}^2 - m_h^2} \right)^2 \times \left(\sigma_h|_{m_h \to m_{hh}}\right)$$

Phase Space Factor

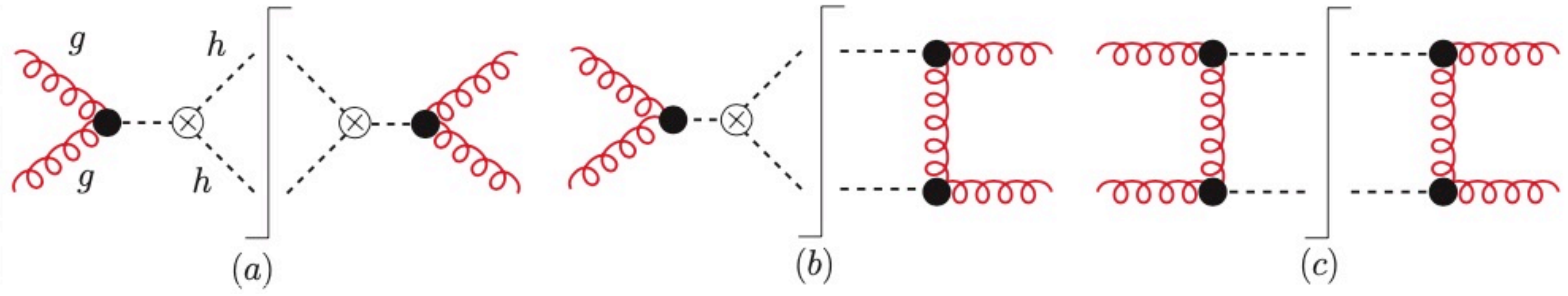
ratio of matrix element square

cross section for single Higgs production

Perturbative corrections

According to the number of effective vertices at the squared amplitude level, there are there channels.

There are two (class-a), three (class-b) and four (class-c) effective vertices insertions respectively.

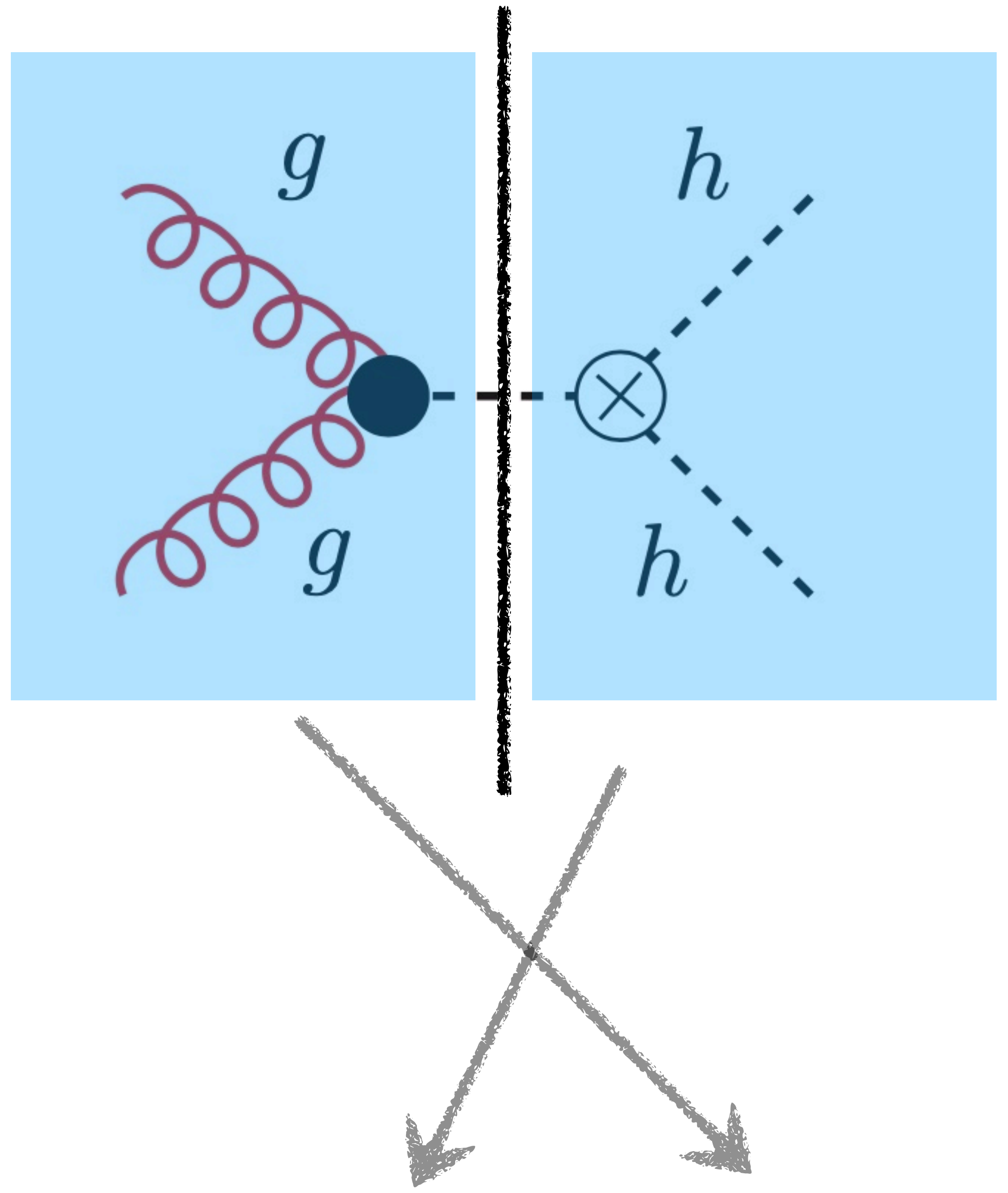


$$d\sigma_{hh} = d\sigma^{a}_{hh} + d\sigma^{b}_{hh} + d\sigma^{c}_{hh}.$$

	LO	NLO	NNLO	N^{3}LO
total	$\mathcal{O}(\alpha_s^2)$	$\mathcal{O}(\alpha_s^3)$	$\mathcal{O}(\alpha_s^4)$	$\mathcal{O}(\alpha_s^5)$
class-a	$\mathcal{O}(\alpha_s^2)$	$\mathcal{O}(\alpha_s^3)$	$\mathcal{O}(\alpha_s^4)$	$\mathcal{O}(\alpha_s^5)$
class-b	0	$\mathcal{O}(\alpha_s^3)$	$\mathcal{O}(\alpha_s^4)$	$\mathcal{O}(\alpha_s^5)$
class-c	0	0	$\mathcal{O}(\alpha_s^4)$	$\mathcal{O}(\alpha_s^5)$

Chen, HTL, Shao, Wang, arXiv:1909.06808, arXiv:1912.13001

For class-a NNNLO cross section we have



$$\frac{d\sigma^{a}_{hh}}{dm_{hh}} = f_{h\to hh} \left(\frac{C_{hh}}{C_h} - \frac{6\lambda_{hhh} v^2}{m^2_{hh} - m^2_h} \right)^2 \times \left(\sigma_h |_{m_h \to m_{hh}} \right)$$

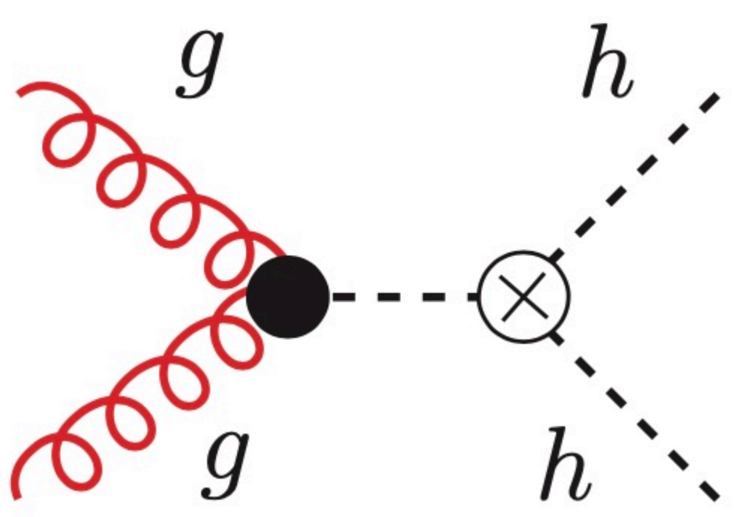
Phase Space Factor

ratio of matrix element square

cross section for single Higgs production

iHix2: arXiv:1802.00827

Perturbative corrections



For each class, $d\sigma_{hh} = d\sigma_{hh}|_{p_T^{hh} < p_T^{\text{veto}}} + d\sigma_{hh}|_{p_T^{hh} > p_T^{\text{veto}}}$

Standard NLO/NNLO calculations

$$\frac{d\sigma_{hh}}{dp_T^{hh}} = H \otimes B_g \otimes B_g \otimes S \times \left(1 + \mathcal{O}\left(\frac{(p_T^{hh})^2}{Q^2}\right)\right)$$

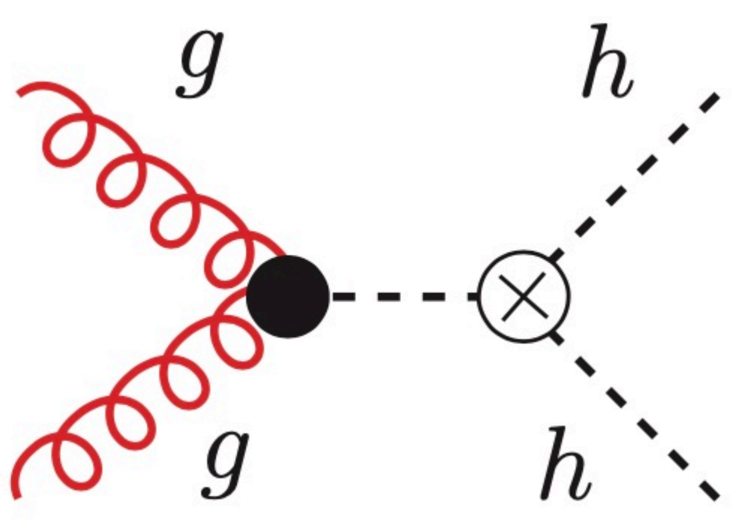
Hard function | **beam functions or TMD PDFs** | **soft function**

which is perfect for the calculations of $\mathcal{O}(\alpha_s^3)$ corrections

see Z.L.Liu's talk

Chen, HTL, Shao, Wang, arXiv:1909.06808, arXiv:1912.13001

Perturbative corrections



For each class, $d\sigma_{hh} = d\sigma_{hh}\big|_{p_T^{hh} < p_T^{\rm veto}} + d\sigma_{hh}\big|_{p_T^{hh} > p_T^{\rm veto}}$

Standard NLO/NNLO calculations

$$\frac{d\sigma_{hh}}{dp_T^{hh}} = H \otimes B_g \otimes B_g \otimes S \times \left(1 + \mathcal{O}\left(\frac{(p_T^{hh})^2}{Q^2}\right)\right)$$

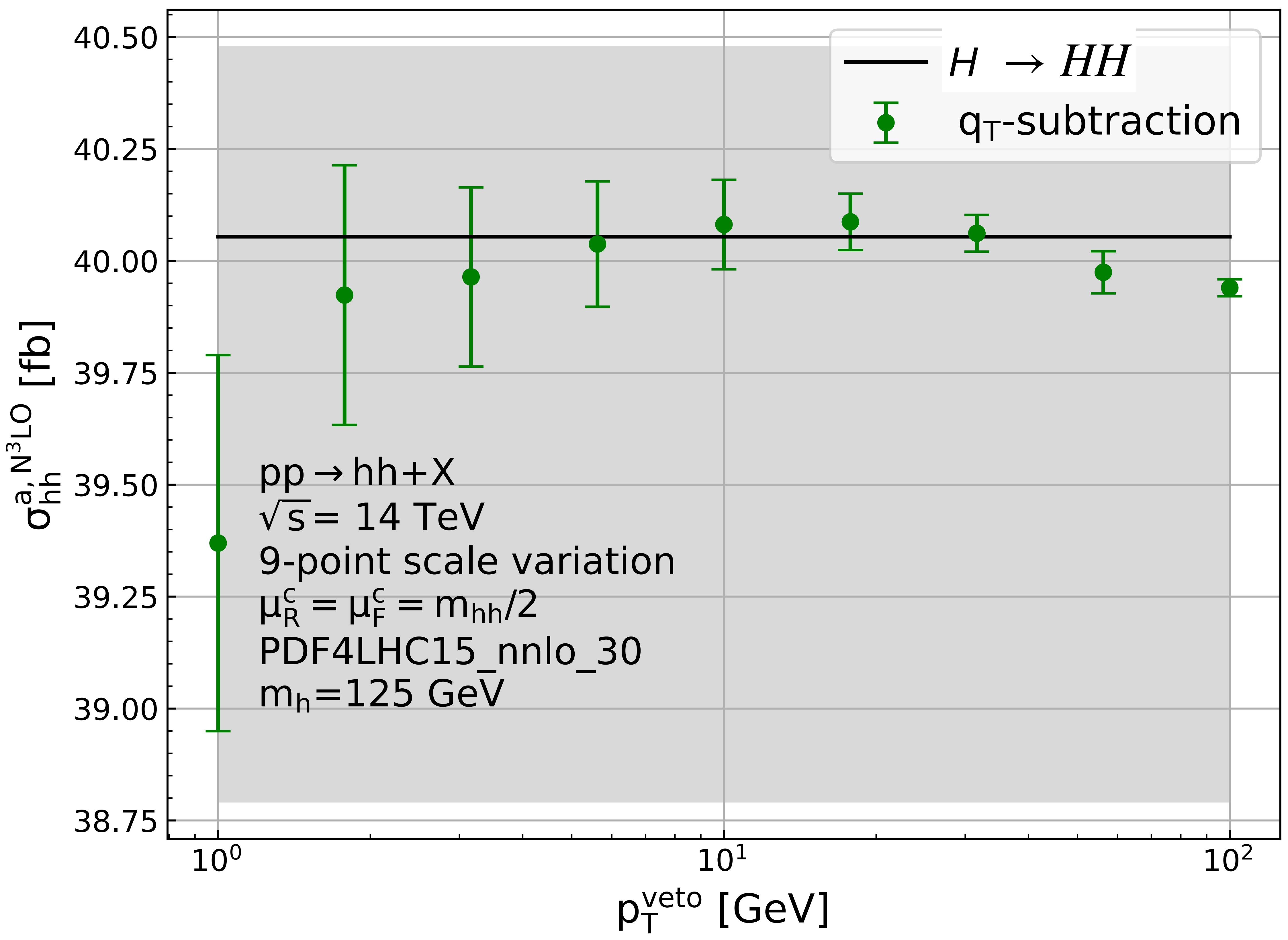
Hard function **beam functions or TMD PDFs** **soft function**

which is perfect for the calculations of $\mathcal{O}(\alpha_s^3)$ corrections

see Z.L.Liu's talk

Chen, HTL, Shao, Wang, arXiv:1909.06808, arXiv:1912.13001

Chen, Dai, HTL, Li, Wang, work in preparation



Fully differential HH production

Perturbative corrections

Di-Higgs decay with a measurement function F_J

$$\Gamma_{\rm dec} \equiv \int d\Gamma_{H_1} \int d\Gamma_{H_2}\; F_J$$

Cross section for Di-Higgs production and decay

$$\sigma^{(n)}_{\rm pro+dec(X_1,X_2)} = \left(\sigma_{\rm pro} \frac{1}{\Gamma_{H_1\to X_1}} \frac{1}{\Gamma_{H_2\to X_2}} \Gamma_{\rm dec(X_1,X_2)} \Big|_{\text{expanded to } \alpha_s^n} \right) \times R(H_1 \to X_1) R(H_2 \to X_2)\,.$$

expanded in series of α_s

NLO corrections as sum of corrections to production and decay individually

$$\sigma^{(1)}_{\rm pro+dec(b\bar{b},\gamma\gamma)} = \sigma^{\rm pro(1)}_{\rm pro+dec(b\bar{b},\gamma\gamma)} + \sigma^{\rm dec(1)}_{\rm pro+dec(b\bar{b},\gamma\gamma)}$$

production part

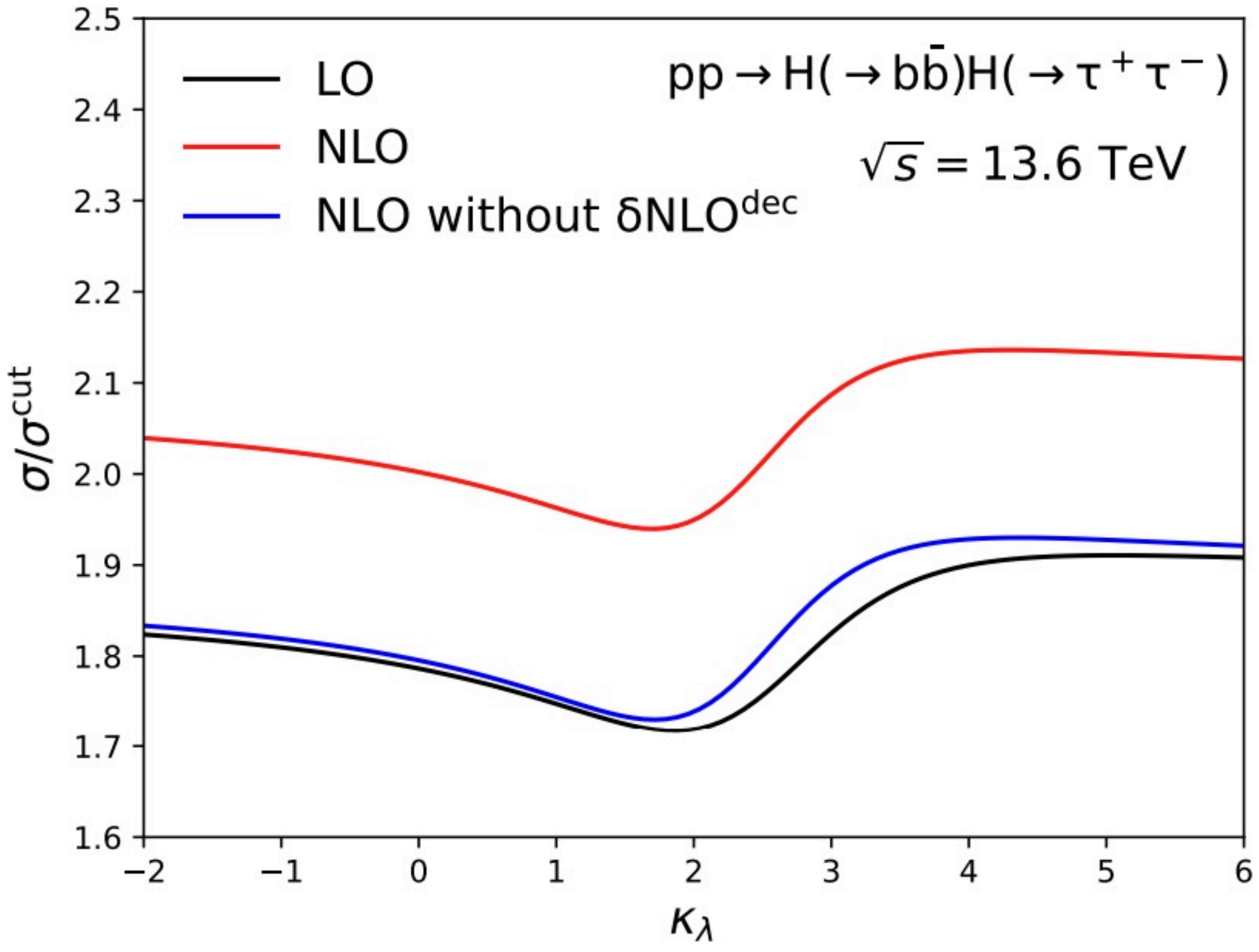
$$\sigma^{\rm pro(1)}_{\rm pro+dec(b\bar{b},\gamma\gamma)} = \sigma^{(1)}_{\rm pro} \frac{1}{\Gamma^{(0)}_{H_1\to b\bar{b}}} \frac{1}{\Gamma^{(0)}_{H_2\to\gamma\gamma}} \Gamma^{(0)}_{\rm dec(b\bar{b},\gamma\gamma)} \times R(H_1 \to b\bar{b}) R(H_2 \to \gamma\gamma)$$

HTL, Si, Wang, Zhang, Zhao, 2407.14716, 2503.22001

Perturbative corrections

$$\sigma^{\rm dec(1)}_{\rm pro+dec(b\bar{b},\gamma\gamma)} = \sigma^{(0)}_{\rm pro} \frac{1}{\Gamma^{(0)}_{H_1\to b\bar{b}}} \frac{1}{\Gamma^{(0)}_{H_2\to\gamma\gamma}} \Gamma^{(0)}_{\rm dec(b\bar{b},\gamma\gamma)} \left(\frac{\int d\Gamma^{(1)}_{H_1\to b\bar{b}} F_J}{\int d\Gamma^{(0)}_{H_1\to b\bar{b}} F_J} - \frac{\Gamma^{(1)}_{H_1\to b\bar{b}}}{\Gamma^{(0)}_{H_1\to b\bar{b}}} \right) \times R(H_1 \to b\bar{b}) R(H_2 \to \gamma\gamma)$$

	without decays	with decays but no cuts		with decays and cuts	
		$\rm LO^{dec}$	$\rm \delta NLO^{dec}$	$\rm LO^{dec}$	$\rm \delta NLO^{dec}$
$\rm LO^{pro}_{\infty}$	$17.07^{+31\%}_{-22\%}$	$0.02257^{+31\%}_{-22\%}$	0	$0.01257^{+30\%}_{-22\%}$	$-0.00175^{+42\%}_{-28\%}$
$\rm LO^{pro}_{m_t}$	$19.85^{+28\%}_{-20\%}$	$0.02624^{+28\%}_{-20\%}$	0	$0.01395^{+27\%}_{-20\%}$	$-0.00261^{+39\%}_{-27\%}$
$\rm \delta NLO^{pro}_{\infty}$	$14.86^{+6\%}_{-7\%}$	$0.01964^{+6\%}_{-7\%}$	–	$0.01064^{+6\%}_{-7\%}$	–
$\rm \delta NLO^{pro}_{m_t}$	$13.08^{+4\%}_{-8\%}$	$0.01729^{+4\%}_{-8\%}$	–	$0.00914^{+4\%}_{-8\%}$	–
Full NLO result					
$\rm NLO_{\infty}$	$31.93^{+18\%}_{-15\%}$	$0.04221^{+18\%}_{-15\%}$		$0.02146^{+15\%}_{-14\%}$	
$\rm NLO_{m_t}$	$32.93^{+14\%}_{-13\%}$	$0.04354^{+14\%}_{-13\%}$		$0.02047^{+10\%}_{-11\%}$	

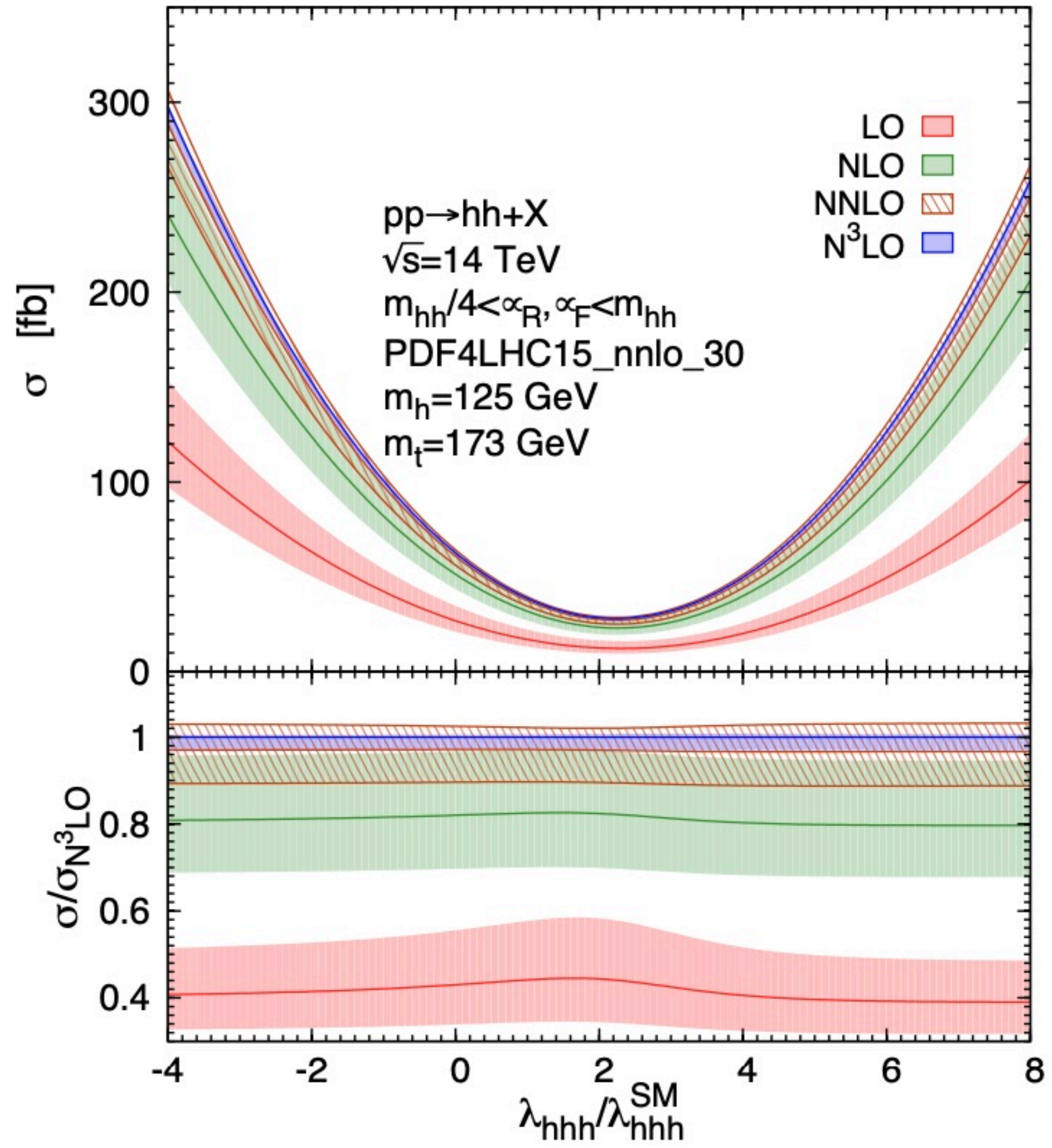


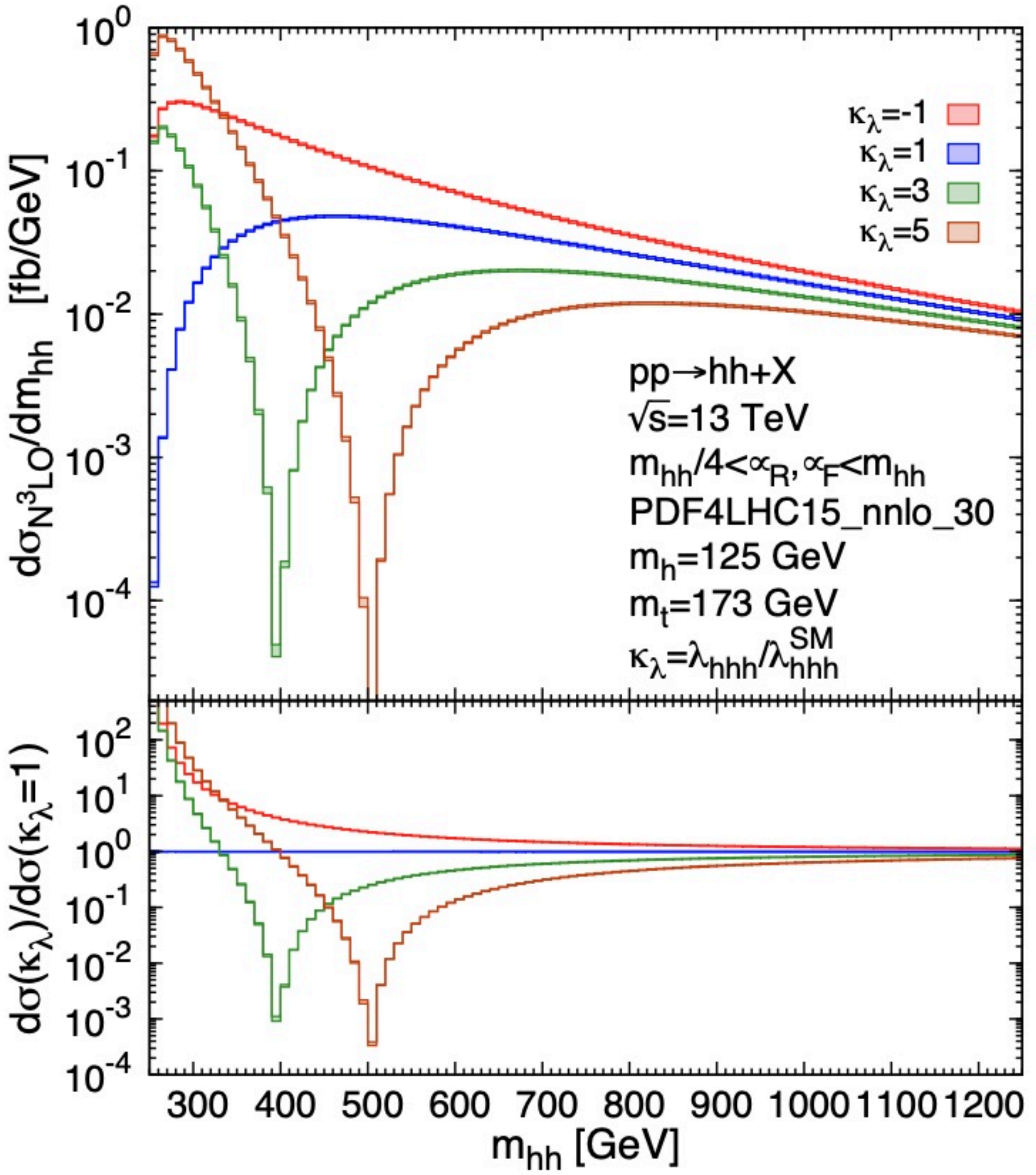
HTL, Si, Wang, Zhang, Zhao, 2407.14716, 2503.22001

EW corrections

(a) (b)

$$\sigma^{\kappa_\lambda}_{\mathrm{ggF,NNLO-FT}} = (\ 10.8\ \kappa^2_{\lambda_{3H}} - 49.6\ \kappa_{\lambda_{3H}} + 70.0\ )\ \ \mathrm{fb},$$

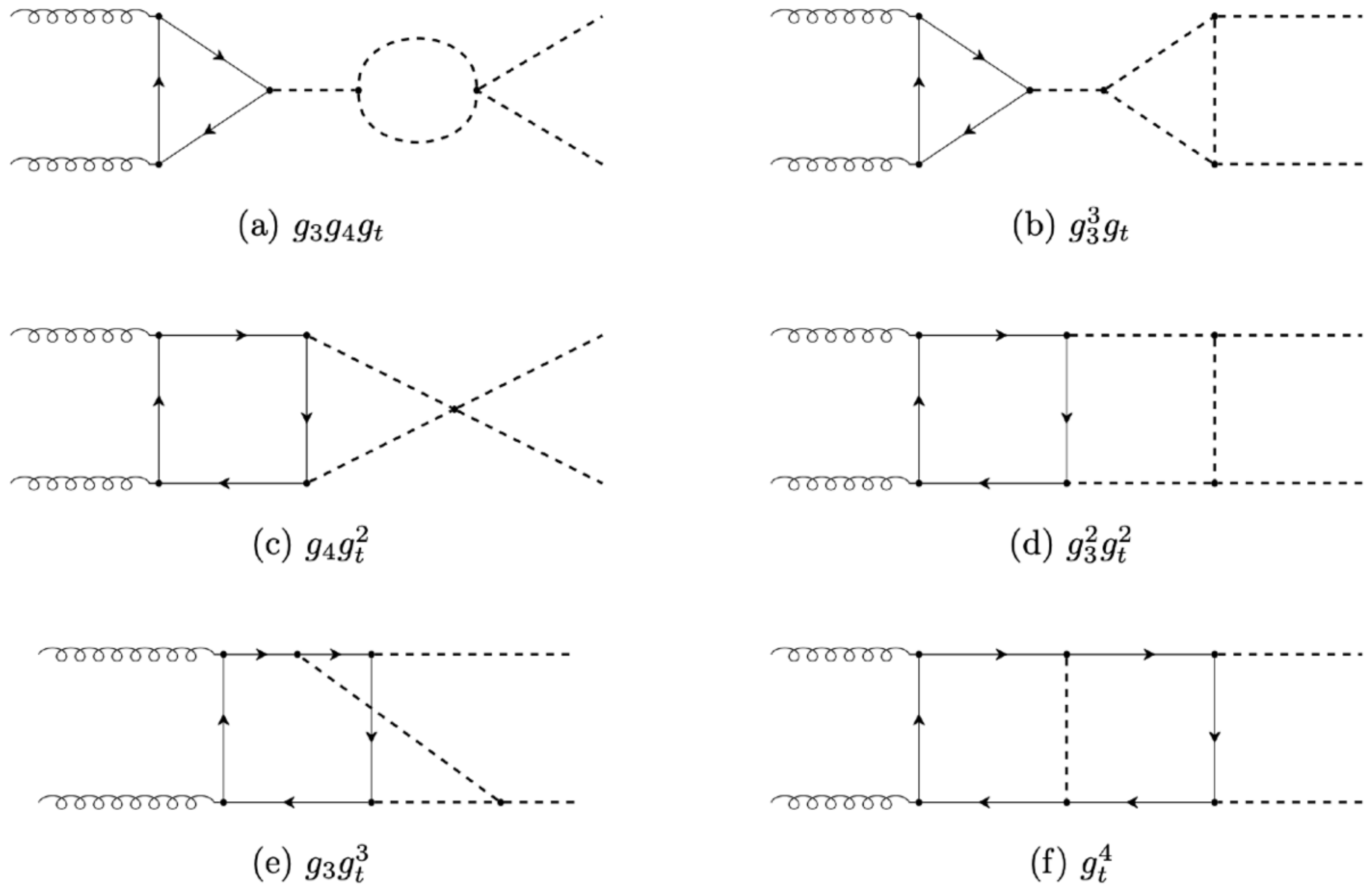




Higgs self coupling can be extracted from

EW corrections

Top-Yukawa-induced and Higgs self coupling-induced corrections



Muhlleitner, Schlenk, Spira arXiv:2207.02524
Davies, Mishima, Schonwald, Steinhauser, Zhang arXiv:2207.02587
Heinrich, Jones, Kerner, Stone, Vestner, arXiv:2407.04653

EW correction with $1/m_t$ expansion

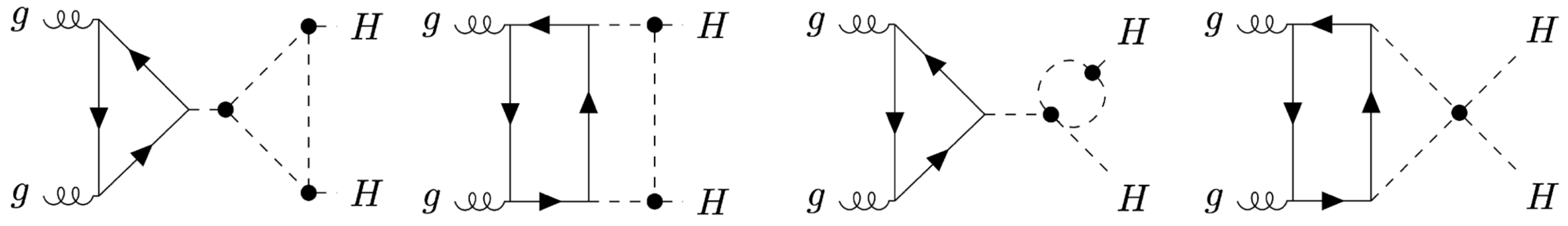
Davies, Schönwald, Steinhauser, Zhang, 2308.01355

complete EW corrections obtained numerically

μ	$M_{HH}/2$	$\sqrt{p_T^2 + m_H^2}$	m_H
LO	19.96(6)	21.11(7)	25.09(8)
NLO	19.12(6)	20.21(6)	23.94(8)
$\mathcal{K}$ factor	0.958(1)	0.957(1)	0.954(1)

Bi, Huang, Huang, Ma, Yu, PRL, 2024

EW corrections



$$\delta\sigma_{\mathrm{EW}} = \delta_A + \delta_B\lambda + \delta_C\lambda^2 + \delta_D\lambda^3 + \delta_E\lambda^4$$

- Higher-order EW corrections include Feynman diagrams with one or more triple Higgs or quadruple Higgs vertices.

- These corrections exhibit a distinct functional dependence on the Higgs self-coupling.

EFT approach

$$V^{\mathrm{SM}}(\Phi) = -\mu^2(\Phi^\dagger\Phi) + \lambda(\Phi^\dagger\Phi)^2$$

$$V^{\mathrm{NP}}(\Phi) \equiv \sum_{n=3}^{\infty} \frac{c_{2n}}{\Lambda^{2n-4}} \left(\Phi^\dagger\Phi - \frac{1}{2}v^2\right)^n$$

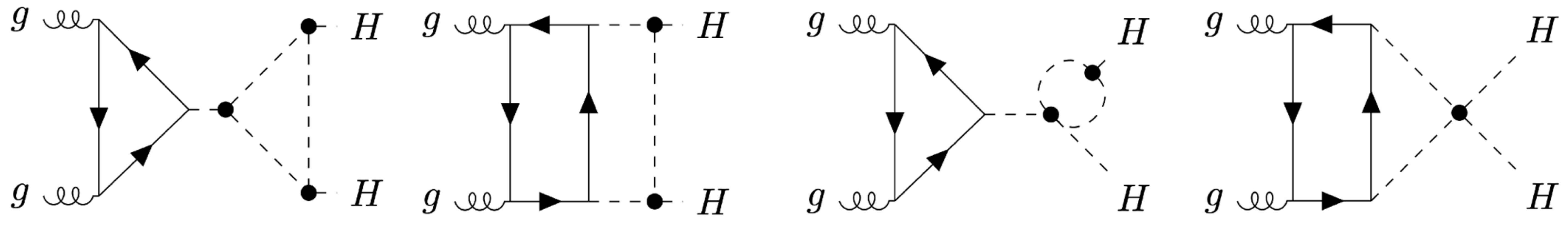
If one count the power exactly, cross section only depends on κ_3 and κ_4 linearly

$$\kappa_3 \equiv \frac{\lambda_3}{\lambda_3^{\mathrm{SM}}} = 1 + \frac{c_6 v^2}{\lambda\Lambda^2} \equiv 1 + \bar{c}_6,$$

$$\kappa_4 \equiv \frac{\lambda_4}{\lambda_4^{\mathrm{SM}}} = 1 + \frac{6c_6 v^2}{\lambda\Lambda^2} + \frac{4c_8 v^4}{\lambda\Lambda^4} \equiv 1 + 6\bar{c}_6 + \bar{c}_8\,.$$

Davies, Mishima, Schonwald, Steinhauser and Zhang arXiv:2207.02587

EW corrections



$$\delta\sigma_{\mathrm{EW}} = \delta_A + \delta_B\lambda + \delta_C\lambda^2 + \delta_D\lambda^3 + \delta_E\lambda^4$$

- Higher-order EW corrections include Feynman diagrams with one or more triple Higgs or quadruple Higgs vertices.

- These corrections exhibit a distinct functional dependence on the Higgs self-coupling.

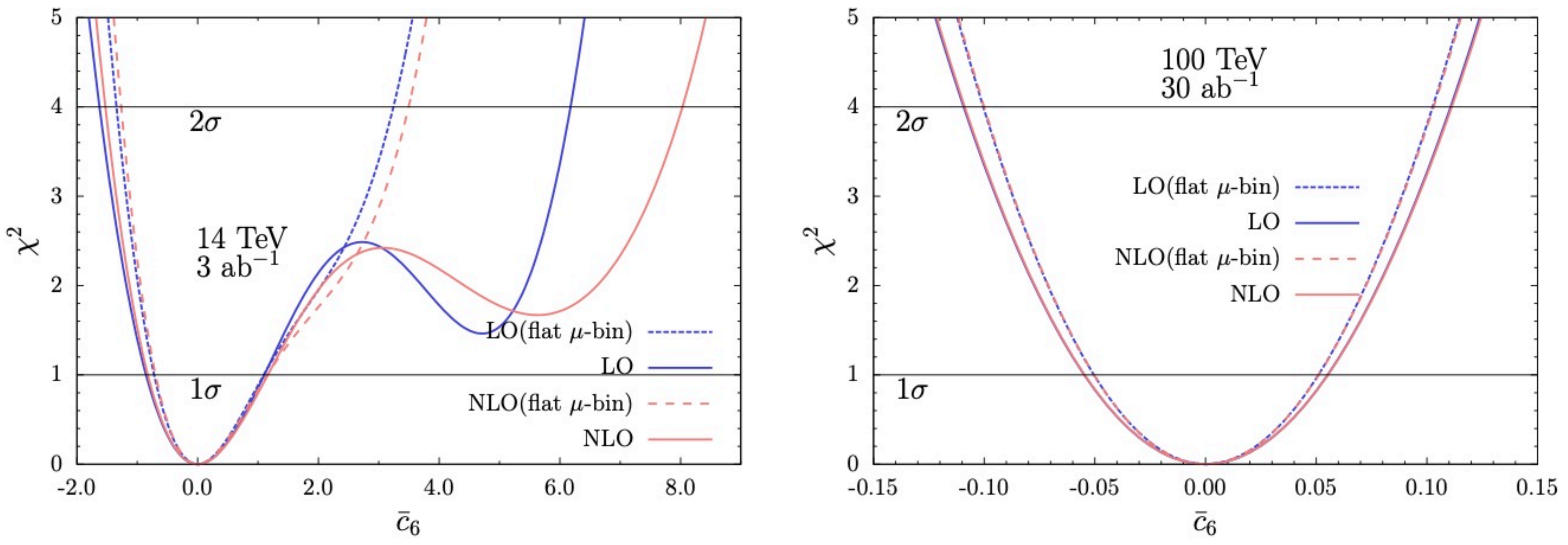
EFT approach

$$V^{\mathrm{SM}}(\Phi) = -\mu^2(\Phi^\dagger\Phi) + \lambda$$

$$V^{\mathrm{NP}}(\Phi) \equiv \sum_{n=3}^{\infty} \frac{c_{2n}}{\Lambda^{2n-4}} \left(\Phi^\dagger\Phi\right.$$

$$\kappa_3 \equiv \frac{\lambda_3}{\lambda_3^{\mathrm{SM}}} = 1 + \frac{c_6 v^2}{\lambda\Lambda^2} \equiv 1 + \bar{c}_6,$$

$$\kappa_4 \equiv \frac{\lambda_4}{\lambda_4^{\mathrm{SM}}} = 1 + \frac{6c_6 v^2}{\lambda\Lambda^2} + \frac{4c_8 v^4}{\lambda\Lambda^4} \equiv 1 + 6\bar{c}_6 + \bar{c}_8\,.$$

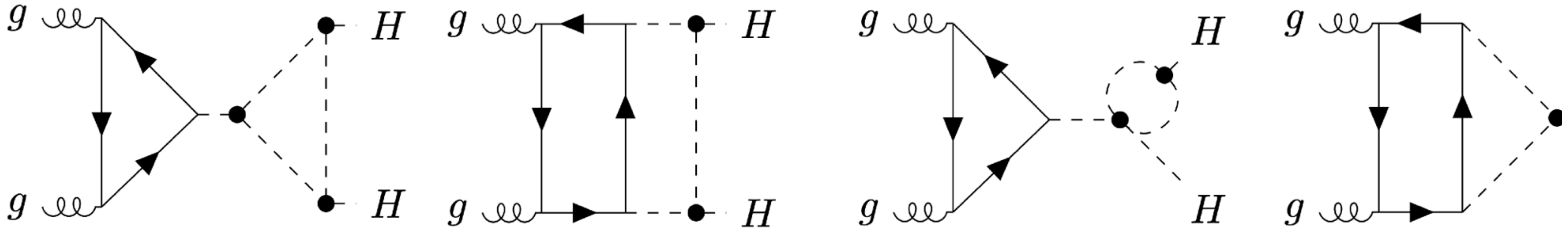


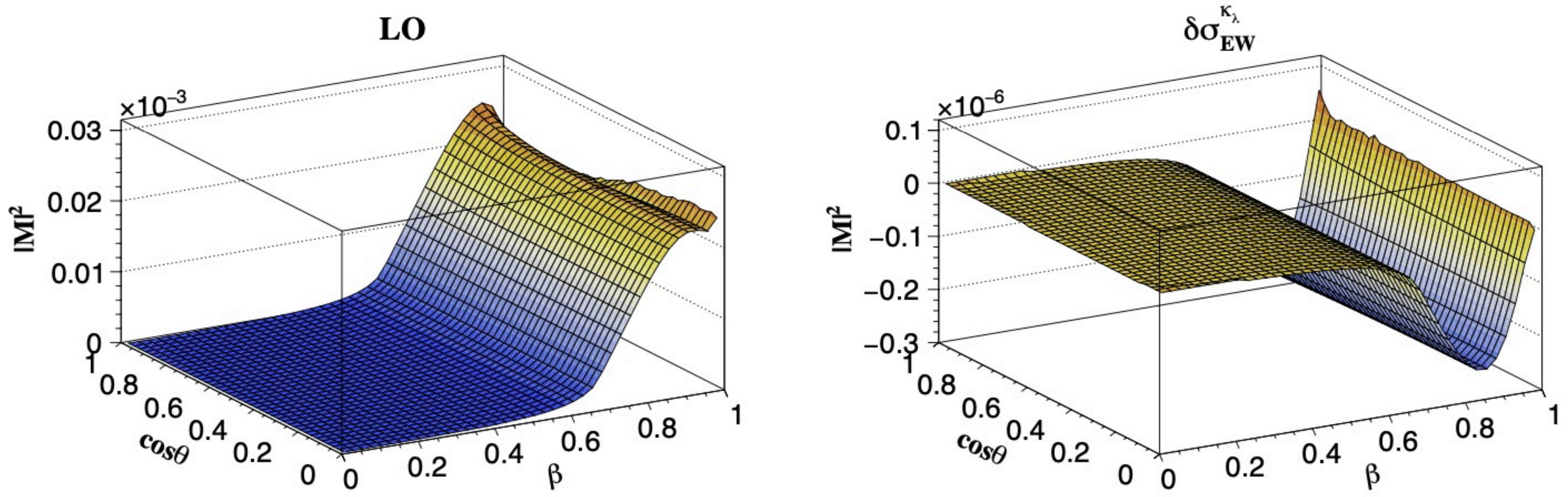
Davies, Mishima, Schonwald, Steinhauser and Zhang arXiv:2207.02587

EW corrections

$$\mathcal{L}_{\rm H} = (D_\mu\phi_0)^\dagger(D^\mu\phi_0) + \mu_0^2(\phi_0^\dagger\phi_0) - \lambda_0(\phi_0^\dagger\phi_0)^2,$$

$$\mathcal{L}_{\rm H} = \frac{1}{2}Z_\phi(\partial_\mu H)^2 - \left(-\frac{1}{2}Z_{\mu^2}Z_\phi Z_v^2\mu^2v^2 + \frac{1}{4}Z_\lambda Z_\phi^2 Z_v^4\lambda v^4\right) - (Z_\lambda Z_\phi^2 Z_v^3\lambda v^3 - Z_{\mu^2}Z_\phi Z_v\mu^2 v)H$$
$$- \left(\frac{3}{2}Z_\lambda Z_\phi^2 Z_v^2\lambda v^2 - \frac{1}{2}Z_{\mu^2}Z_\phi\mu^2\right)H^2 - \boxed{Z_{\kappa_{3\rm H}}Z_\lambda Z_\phi^2 Z_v\lambda_{3\rm H}vH^3} - \boxed{\frac{1}{4}Z_{\kappa_{4\rm H}}Z_\lambda Z_\phi^2\lambda_{4\rm H}H^4} + \cdots,$$

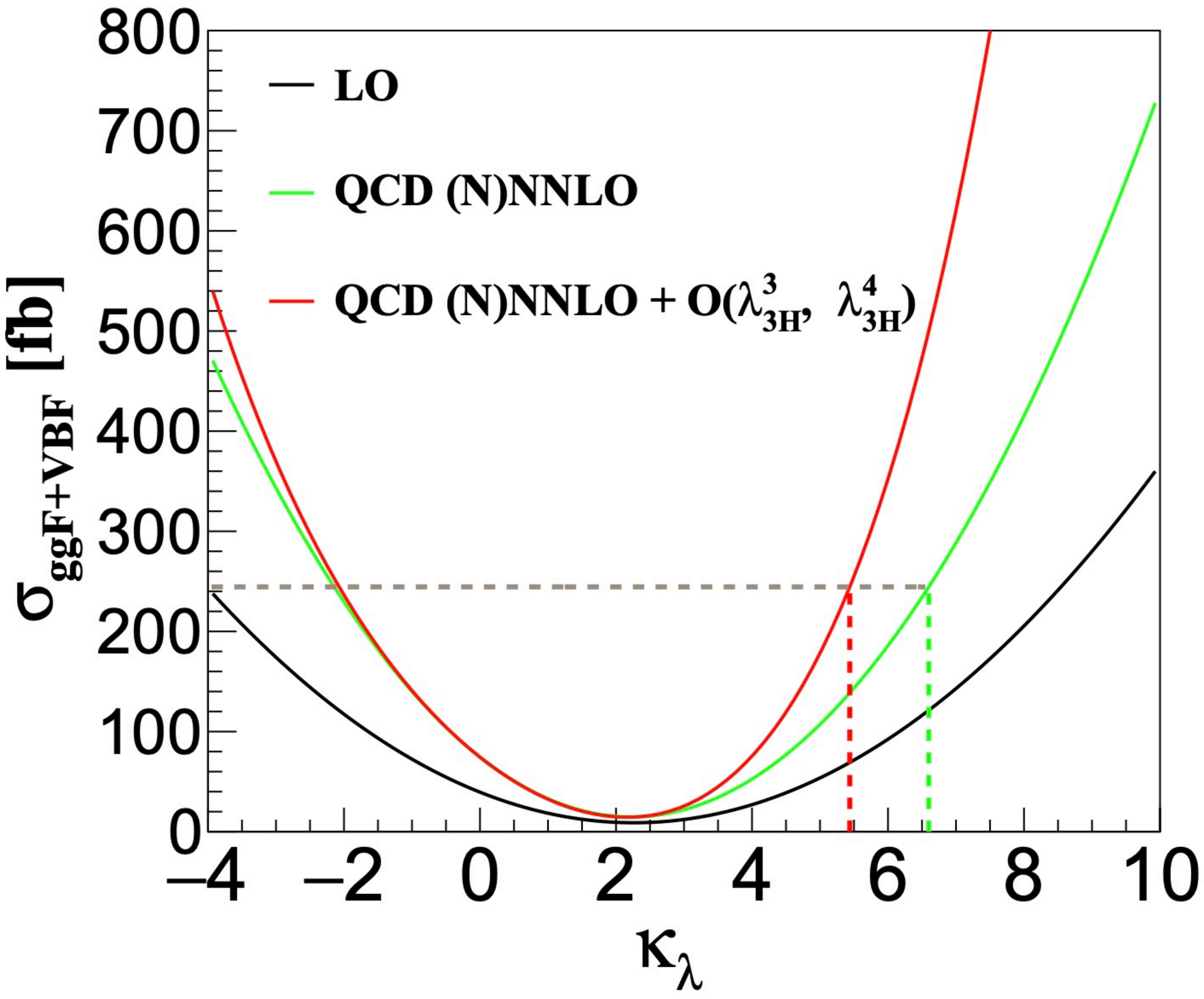




$$\delta\sigma^{\kappa\lambda}_{\rm ggF,EW} = (0.075\kappa_{\lambda_3}^4 - 0.158\kappa_{\lambda_3}^3 - 0.006\kappa_{\lambda_3}^2\kappa_{\lambda_4} - 0.058\kappa_{\lambda_3}^2 + 0.070\kappa_{\lambda_3}\kappa_{\lambda_4} - 0.149\kappa_{\lambda_4})\ \ {\rm fb}$$

$$\delta\sigma^{\kappa\lambda}_{\rm VBF,EW} = (0.0215\kappa_{\lambda_3}^4 - 0.0324\kappa_{\lambda_3}^3 - 0.0019\kappa_{\lambda_3}^2\kappa_{\lambda_4} - 0.0043\kappa_{\lambda_3}^2 + 0.0151\kappa_{\lambda_3}\kappa_{\lambda_4} - 0.0211\kappa_{\lambda_4})\,{\rm fb}$$

EW corrections



- EW corrections include higher order terms in κ_λ
- Large effects observed for large κ_λ
- The upper limit by the ATLAS and CMS collaboration on κ_λ is 6.6 and 6.49
- With EW correction, the , the upper limit is narrowed down to 5.4 and 5.37

Conclusion

- Measurement about Higgs self-coupling is a cornerstone for understanding electroweak symmetry breaking and probing new physics.
- A precision study for HH production and decay is required
- A method proposed to extract the κ_λ dependence in the cross section
- A better constraint obtained after considering EW corrections

微扰量子场论及其应用前沿讲习班

Jul 6 – 20, 2025
Asia/Shanghai timezone

Enter your search term

- Overview
- Registration
- Participant List

Contact
haitao.li@email.sdu.edu...
jian.wang@email.sdu.ed...

为帮助研究生系统了解粒子物理科研现状、前沿方向、未来发展等专业知识，"微扰量子场论及其应用"前沿讲习活动将于2025年7月6日至20日在山东大学中心校区举办。7月6日报到，7月20日离会。

讲习活动以"微扰量子场论和对撞机物理"为主要内容，由电弱规范理论、量子色动力学理论、对撞机唯象学、微扰量子场论方法、有效场论思想及应用、新物理研究方法等内容组成，同时暑期学校计划安排粒子物理宇宙学、引力波探测、高能宇宙射线等方向的专题讲座。

本次讲习活动主要面向研究生，不收取注册费。**请申请学员认真填写注册表格，并安排导师写一封推荐信，发给会务组，注册截止时间为4月30日。**申请截止后，暑期学校将根据申请人的学术背景和研究兴趣来确定最终名单。**为了保证教学效果，暑期学校限定学员总数为50人，要求全程参加，不接受请假。**

会务组为学员提供餐食，住宿和交通费用自理。如学员需要资助，可联系会务组，择优资助部分费用。

本次讲习活动由国家自然科学基金委理论物理专项、国家自然科学基金委创新群体项目资助。本次学术活动由山东大学主办。

会务组：陈龙，陈暄，蒋军，李海涛，李世渊，刘言锐，路鹏程，司宗国，王健，王耀光，吴群。

讲习班主页：https://indico.ihep.ac.cn/event/25318/

泉城-济南

https://indico.ihep.ac.cn/event/25318/

Thank You !!