粒子物理前沿卓越创新中心考核报告

2019-2020年度

张岑

中国科学院高能物理研究所

2020 年 12 月 5 日

教育及科研工作经历

- 2002-2006，北京大学物理系，学士学位。
- 2006-2011，伊利诺伊大学香槟分校(University of Illinois at Urbana-Champaign)物理系，博士学位。
- 2012-2014，法语天主教鲁汶大学(Catholic University of Louvain)，博士后研究员。
- 2014-2016，布鲁克海文国家实验室(Brookhaven National Laboratory)，博士后研究员。
- 2017至今，中国科学院高能物理研究所，人才项目引进项目研究员。

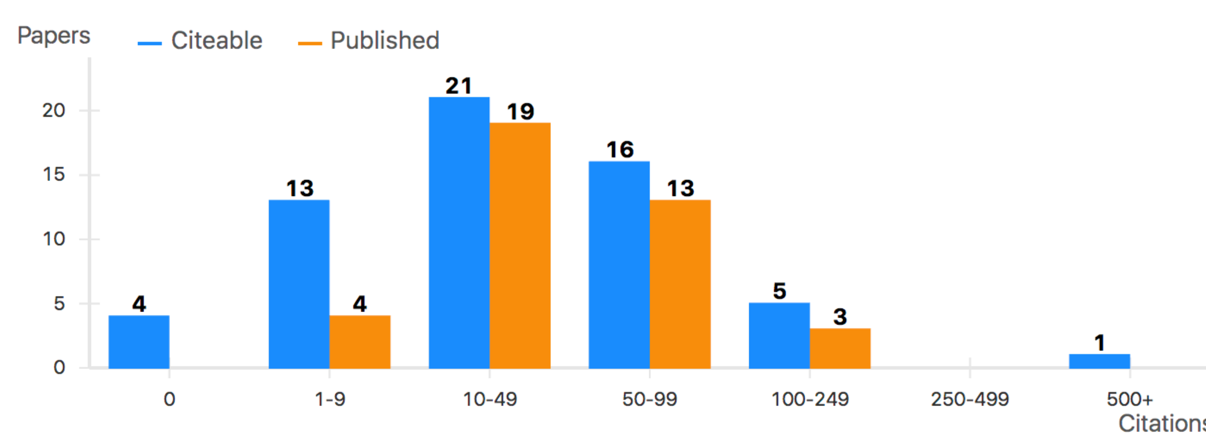
学术论文情况

- （基于inspire数据）可引用工作60篇，总引用超过4000次；发表学术论文39篇，总引用超过2000次。
- 三篇引用100次以上；两篇 Phys.Rev.Lett.（唯一作者 + 一作），一篇 Ann. Rev. Nucl. Part. Sci. 综述。
- h因子 26。

Citation Summary

☐ Exclude self-citations ⓘ

	Citeable ⓘ	Published ⓘ
Papers	60	39
Citations	4,141	2,005
h-index ⓘ	31	26
Citations/paper (avg)	69	51.4



学术论文情况 2020

- Z.-Y. Wang, **C. Zhang**, S.-Y. Zhou, “Generalized elastic positivity bounds on interacting massive spin-2 theories,” arXiv:2011.05190 [hep-th]
- J. Gu, L.-T. Wang, **C. Zhang**, “An unambiguous test of positivity at lepton colliders,” arXiv:2011.03055 [hep-ph]
- C. Degrande, G. Durieux, F. Maltoni, K. Mimasu, E. Vryonidou and **C. Zhang**, “Automated one-loop computations in the SMEFT,” arXiv:2008.11743 [hep-ph], submitted to PRL

已接收↓

- K. Yamashita, **C. Zhang** and S.-Y. Zhou, “Elastic positivity vs extremal positivity bounds in SMEFT: a case study in transversal electroweak gauge-boson scatterings,” arXiv:2009.04490 [hep-ph], **accepted in JHEP**
- B. Fuks, Y. Liu, **C. Zhang** and S.-Y. Zhou, “Positivity in electron-positron scattering: testing the axiomatic quantum field theory principles and probing the existence of UV states,” arXiv:2009.02212 [hep-ph], **accepted by CPC (16-Oct-2020)**

已发表↓

- **C. Zhang** and S.-Y. Zhou, “A convex geometry perspective to the (SM)EFT space,” **PRL 125, 201601 (2020)**
- Y. J. Wang, F. K. Guo, **C. Zhang** and S.-Y. Zhou, “Generalized positivity bounds on chiral perturbation theory,” **JHEP 07, 214 (2020)**
- I. Brivio, S. Bruggisser, F. Maltoni, R. Moutafis, T. Plehn, E. Vryonidou, S. Westhoff and **C. Zhang**, “O new physics, where art thou? A global search in the top sector,” **JHEP 2002, 131 (2020)**

博士后 K. Yamashita 完成论文4篇，1PRD + 2JHEP + 1JBP

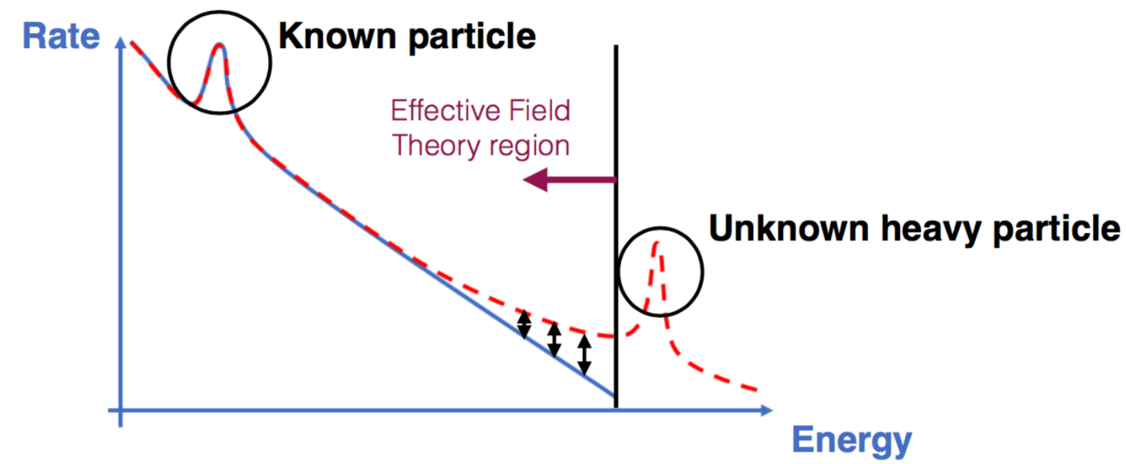
概要

- 研究方向简介
- 本年度研究成果
- 学术交流情况
- 基金情况

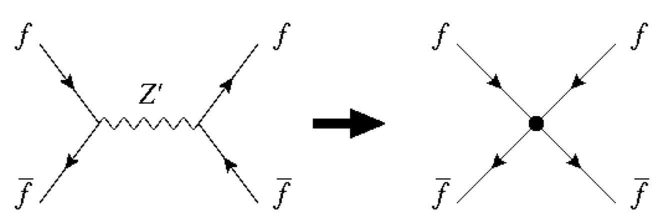
研究方向简介

标准模型有效场论 (SMEFT)

- 寻找新物理的两种方法
  - 直接方法—寻找新的基本粒子
  - 间接方法—寻找新的相互作用



- 通过积出紫外理论的自由度，用有效算符展开低能的相互作用
  - 通过 LHC 的各种测量确定6维算符的系数，寻找非共振的新物理



$$\mathcal{L}_{\rm EFT} = \mathcal{L}_{\rm SM} + \sum_i \frac{f_i^{(6)} O_i^{(6)}}{\Lambda^2}$$

X^3		φ^6 and $\varphi^4 D^2$		$\psi^2\varphi^3$	
Q_G	$f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	Q_φ	$(\varphi^\dagger\varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger\varphi)(\bar l_p e_r \varphi)$
$Q_{\widetilde G}$	$f^{ABC} \widetilde G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_{\varphi\Box}$	$(\varphi^\dagger\varphi)\Box(\varphi^\dagger\varphi)$	$Q_{u\varphi}$	$(\varphi^\dagger\varphi)(\bar q_p u_r \widetilde\varphi)$
Q_W	$\varepsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$Q_{\varphi D}$	$\left(\varphi^\dagger D^\mu\varphi\right)^\star \left(\varphi^\dagger D_\mu\varphi\right)$	$Q_{d\varphi}$	$(\varphi^\dagger\varphi)(\bar q_p d_r \varphi)$
$Q_{\widetilde W}$	$\varepsilon^{IJK} \widetilde W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$				
$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger\varphi\, G^A_{\mu\nu} G^{A\mu\nu}$	Q_{eW}	$(\bar l_p \sigma^{\mu\nu} e_r)\tau^I \varphi W^I_{\mu\nu}$	$Q_{\varphi l}^{(1)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar l_p \gamma^\mu l_r)$
$Q_{\varphi\widetilde G}$	$\varphi^\dagger\varphi\, \widetilde G^A_{\mu\nu} G^{A\mu\nu}$	Q_{eB}	$(\bar l_p \sigma^{\mu\nu} e_r)\varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu \varphi)(\bar l_p \tau^I \gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger\varphi\, W^I_{\mu\nu} W^{I\mu\nu}$	Q_{uG}	$(\bar q_p \sigma^{\mu\nu} T^A u_r)\widetilde\varphi\, G^A_{\mu\nu}$	$Q_{\varphi e}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar e_p \gamma^\mu e_r)$
$Q_{\varphi\widetilde W}$	$\varphi^\dagger\varphi\, \widetilde W^I_{\mu\nu} W^{I\mu\nu}$	Q_{uW}	$(\bar q_p \sigma^{\mu\nu} u_r)\tau^I \widetilde\varphi\, W^I_{\mu\nu}$	$Q_{\varphi q}^{(1)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar q_p \gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger\varphi\, B_{\mu\nu} B^{\mu\nu}$	Q_{uB}	$(\bar q_p \sigma^{\mu\nu} u_r)\widetilde\varphi\, B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu \varphi)(\bar q_p \tau^I \gamma^\mu q_r)$
$Q_{\varphi\widetilde B}$	$\varphi^\dagger\varphi\, \widetilde B_{\mu\nu} B^{\mu\nu}$	Q_{dG}	$(\bar q_p \sigma^{\mu\nu} T^A d_r)\varphi\, G^A_{\mu\nu}$	$Q_{\varphi u}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar u_p \gamma^\mu u_r)$
$Q_{\varphi WB}$	$\varphi^\dagger\tau^I\varphi\, W^I_{\mu\nu} B^{\mu\nu}$	Q_{dW}	$(\bar q_p \sigma^{\mu\nu} d_r)\tau^I \varphi\, W^I_{\mu\nu}$	$Q_{\varphi d}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar d_p \gamma^\mu d_r)$
$Q_{\varphi\widetilde WB}$	$\varphi^\dagger\tau^I\varphi\, \widetilde W^I_{\mu\nu} B^{\mu\nu}$	Q_{dB}	$(\bar q_p \sigma^{\mu\nu} d_r)\varphi\, B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde\varphi^\dagger D_\mu\varphi)(\bar u_p \gamma^\mu d_r)$

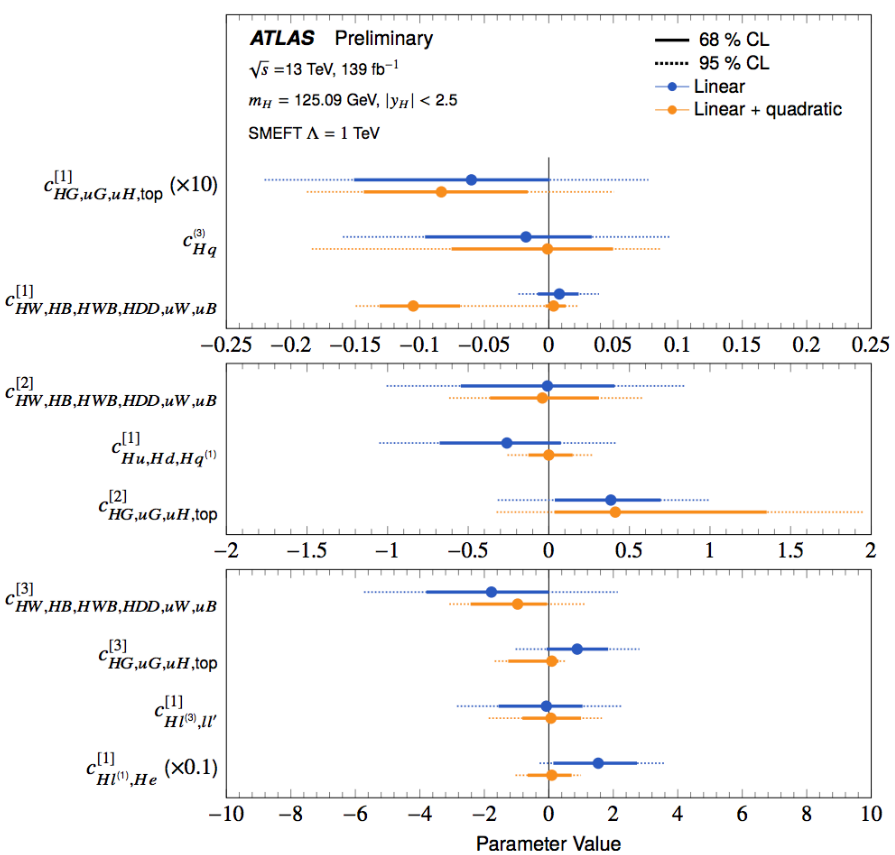
$(\bar LL)(\bar LL)$		$(\bar RR)(\bar RR)$		$(\bar LL)(\bar RR)$	
Q_{ll}	$(\bar l_p\gamma_\mu l_r)(\bar l_s\gamma^\mu l_t)$	Q_{ee}	$(\bar e_p\gamma_\mu e_r)(\bar e_s\gamma^\mu e_t)$	Q_{le}	$(\bar l_p\gamma_\mu l_r)(\bar e_s\gamma^\mu e_t)$
$Q_{qq}^{(1)}$	$(\bar q_p\gamma_\mu q_r)(\bar q_s\gamma^\mu q_t)$	Q_{uu}	$(\bar u_p\gamma_\mu u_r)(\bar u_s\gamma^\mu u_t)$	Q_{lu}	$(\bar l_p\gamma_\mu l_r)(\bar u_s\gamma^\mu u_t)$
$Q_{qq}^{(3)}$	$(\bar q_p\gamma_\mu\tau^I q_r)(\bar q_s\gamma^\mu\tau^I q_t)$	Q_{dd}	$(\bar d_p\gamma_\mu d_r)(\bar d_s\gamma^\mu d_t)$	Q_{ld}	$(\bar l_p\gamma_\mu l_r)(\bar d_s\gamma^\mu d_t)$
$Q_{lq}^{(1)}$	$(\bar l_p\gamma_\mu l_r)(\bar q_s\gamma^\mu q_t)$	Q_{eu}	$(\bar e_p\gamma_\mu e_r)(\bar u_s\gamma^\mu u_t)$	Q_{qe}	$(\bar q_p\gamma_\mu q_r)(\bar e_s\gamma^\mu e_t)$
$Q_{lq}^{(3)}$	$(\bar l_p\gamma_\mu\tau^I l_r)(\bar q_s\gamma^\mu\tau^I q_t)$	Q_{ed}	$(\bar e_p\gamma_\mu e_r)(\bar d_s\gamma^\mu d_t)$	$Q_{qu}^{(1)}$	$(\bar q_p\gamma_\mu q_r)(\bar u_s\gamma^\mu u_t)$
		$Q_{ud}^{(1)}$	$(\bar u_p\gamma_\mu u_r)(\bar d_s\gamma^\mu d_t)$	$Q_{qu}^{(8)}$	$(\bar q_p\gamma_\mu T^A q_r)(\bar u_s\gamma^\mu T^A u_t)$
		$Q_{ud}^{(8)}$	$(\bar u_p\gamma_\mu T^A u_r)(\bar d_s\gamma^\mu T^A d_t)$	$Q_{qd}^{(1)}$	$(\bar q_p\gamma_\mu q_r)(\bar d_s\gamma^\mu d_t)$
				$Q_{qd}^{(8)}$	$(\bar q_p\gamma_\mu T^A q_r)(\bar d_s\gamma^\mu T^A d_t)$
$(\bar LR)(\bar RL)$ and $(\bar LR)(\bar LR)$		B-violating			
Q_{ledq}	$(\bar l_p^j e_r)(\bar d_s q_t^j)$	Q_{duq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(q_s^{\gamma j})^T C l_t^k\right]$		
$Q_{quqd}^{(1)}$	$(\bar q_p^j u_r)\varepsilon_{jk}(\bar q_s^k d_t)$	Q_{qqu}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(u_s^\gamma)^T C e_t\right]$		
$Q_{quqd}^{(8)}$	$(\bar q_p^j T^A u_r)\varepsilon_{jk}(\bar q_s^k T^A d_t)$	Q_{qqq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jn}\varepsilon_{km}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(q_s^{\gamma m})^T C l_t^n\right]$		
$Q_{lequ}^{(1)}$	$(\bar l_p^j e_r)\varepsilon_{jk}(\bar q_s^k u_t)$	Q_{duu}	$\varepsilon^{\alpha\beta\gamma}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(u_s^\gamma)^T C e_t\right]$		
$Q_{lequ}^{(3)}$	$(\bar l_p^j \sigma_{\mu\nu} e_r)\varepsilon_{jk}(\bar q_s^k \sigma^{\mu\nu} u_t)$				

从 2012 Higgs 发现以来
SMEFT 由于其模型无关性逐渐成为 TeV 物理的标准工具之一

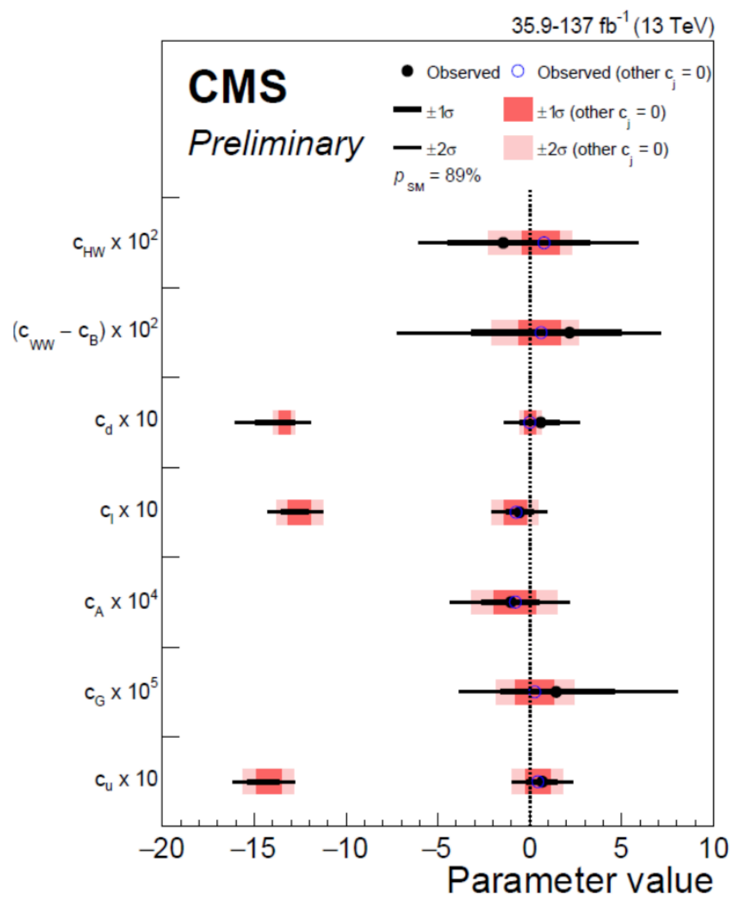
Run-II Higgs combination

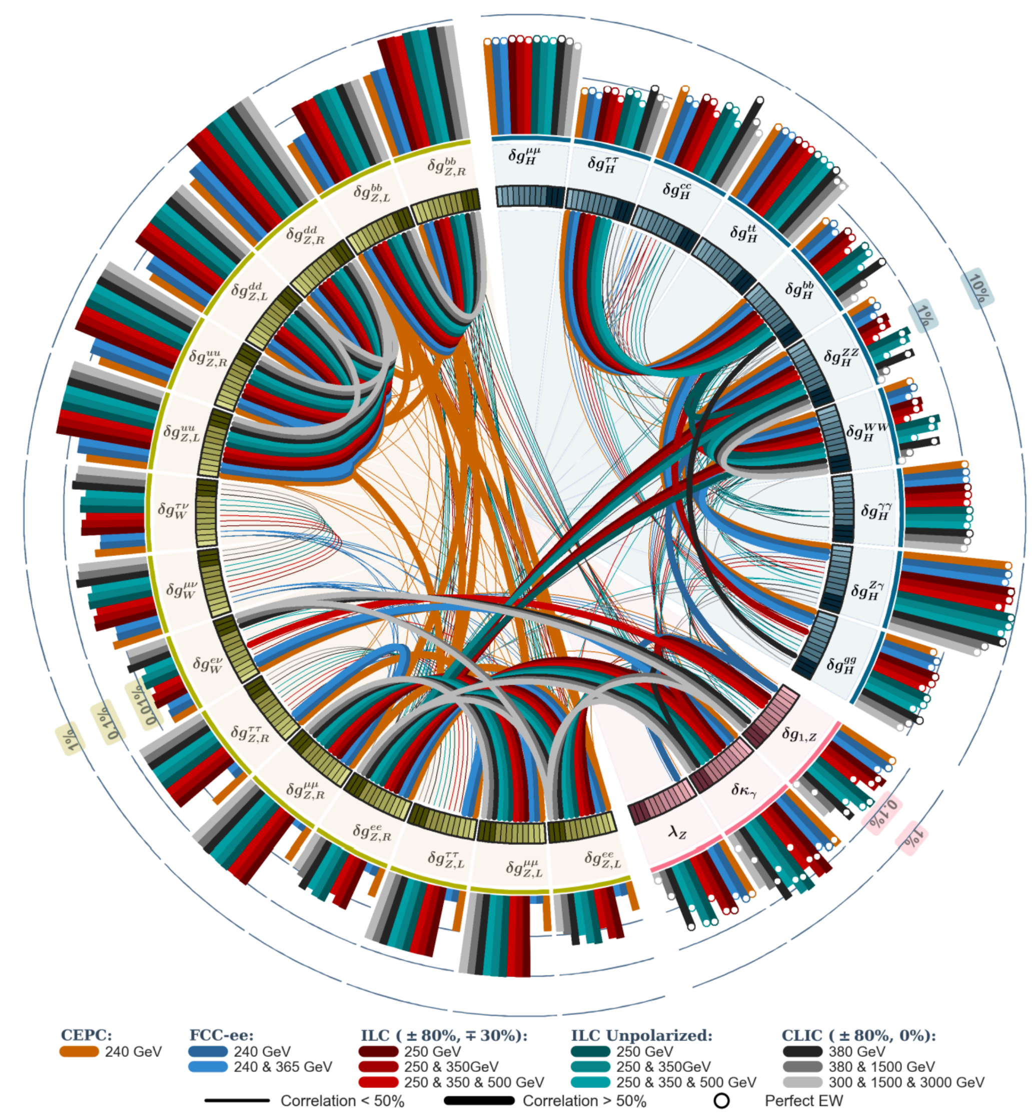
未来正负电子对撞

ATLAS-CONF-2020-053



CMS PAS HIG-19-005





[de Blas et al. 1907.04311]

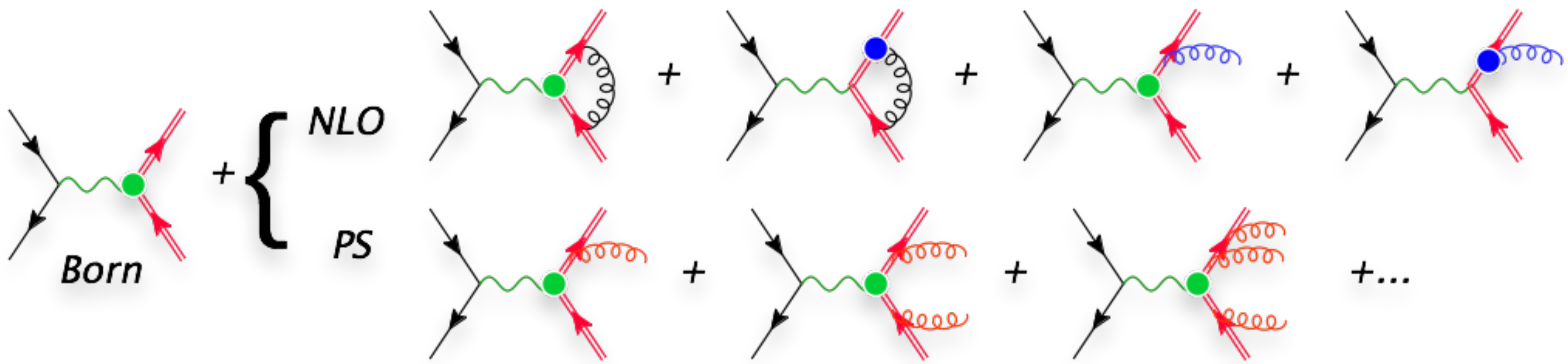
主要研究方向

- 推进 SMEFT 理论预言精度。
  - 全自动、泛用的 NLO 精度蒙卡产生子，推进 LHC 理论研究和实验分析精度。
- 基于 SMEFT 的唯像研究。
  - 通过综合 LHC 测量数据检验标准模型。
- SMEFT 高维算符的几何结构。
  - 场论基本原理（幺正，解析，局域等）在 EFT 中体现为算符空间的凸几何体。
  - 为 “Inverse problem” ——从低能精确测量反推 UV 物理模型——提供新的方法。

本年度研究成果

1. SMEFT @ NLO QCD

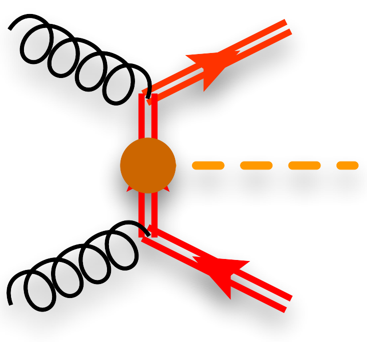
C. Degrande, G. Durieux, F. Maltoni, K. Mimasu, E. Vryonidou and **C. Zhang**,
"Automated one-loop computations in the SMEFT," arXiv:2008.11743 [hep-ph], submitted to PRL



发展基于 MadGraph5_aMC@NLO 的自动化计算方法，完成对任意过程、任意算符的，NLO 精度并且匹配到 parton shower 的蒙卡事例产生器。

Example: ttbar+Higgs

User perspective



MG5_aMC>import model SMEFT

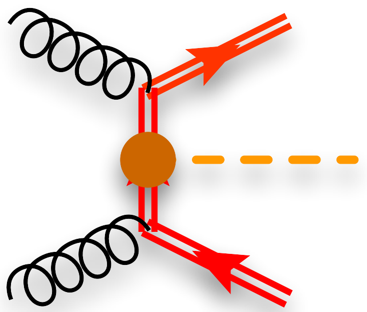
MG5_aMC>generate p p > t t~ H NP=2 [QCD]

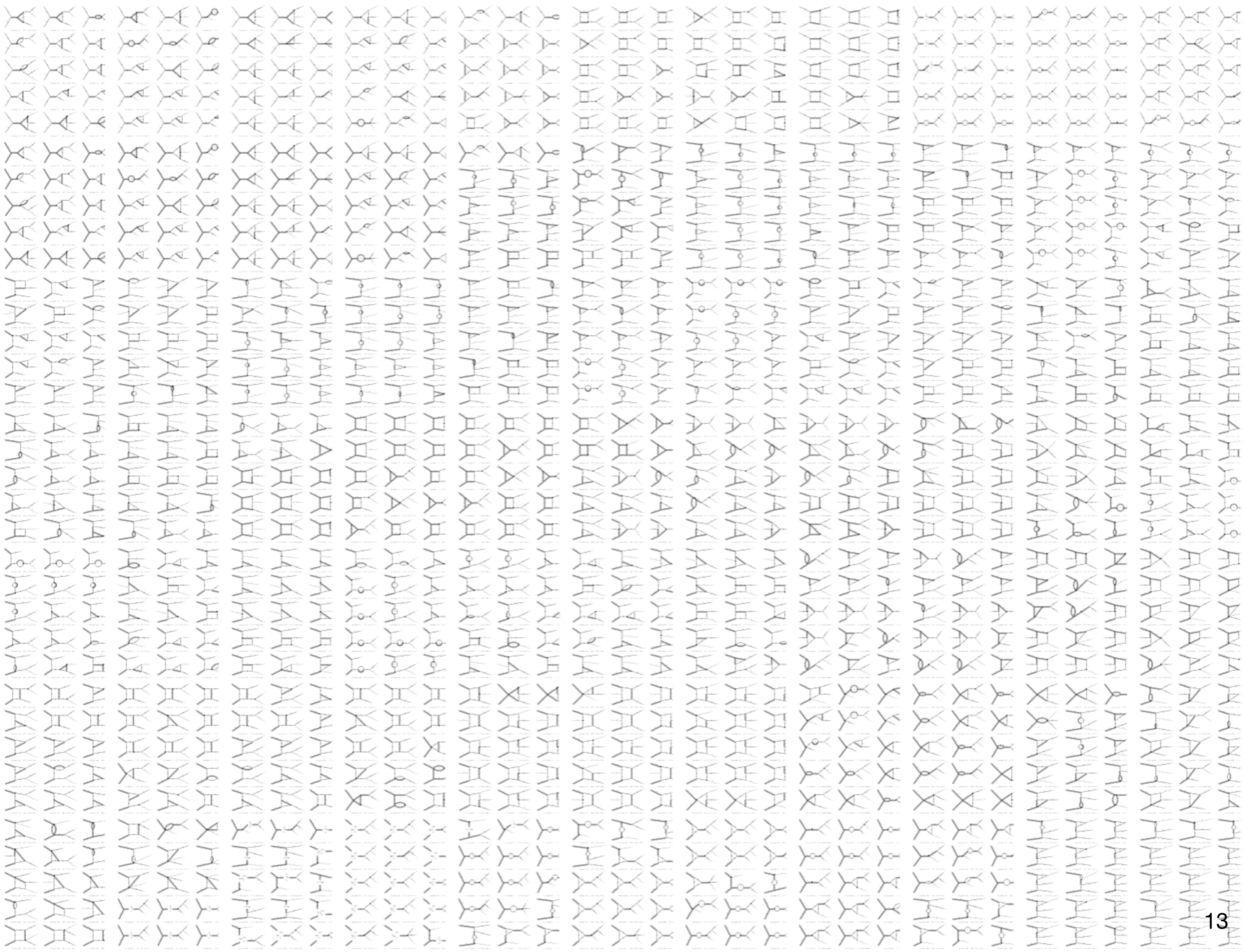
MG5_aMC>output

MG5_aMC>launch

Example: ttbar+Higgs

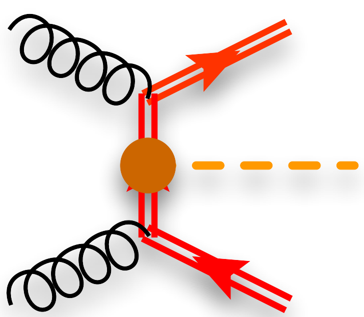
Under the hood

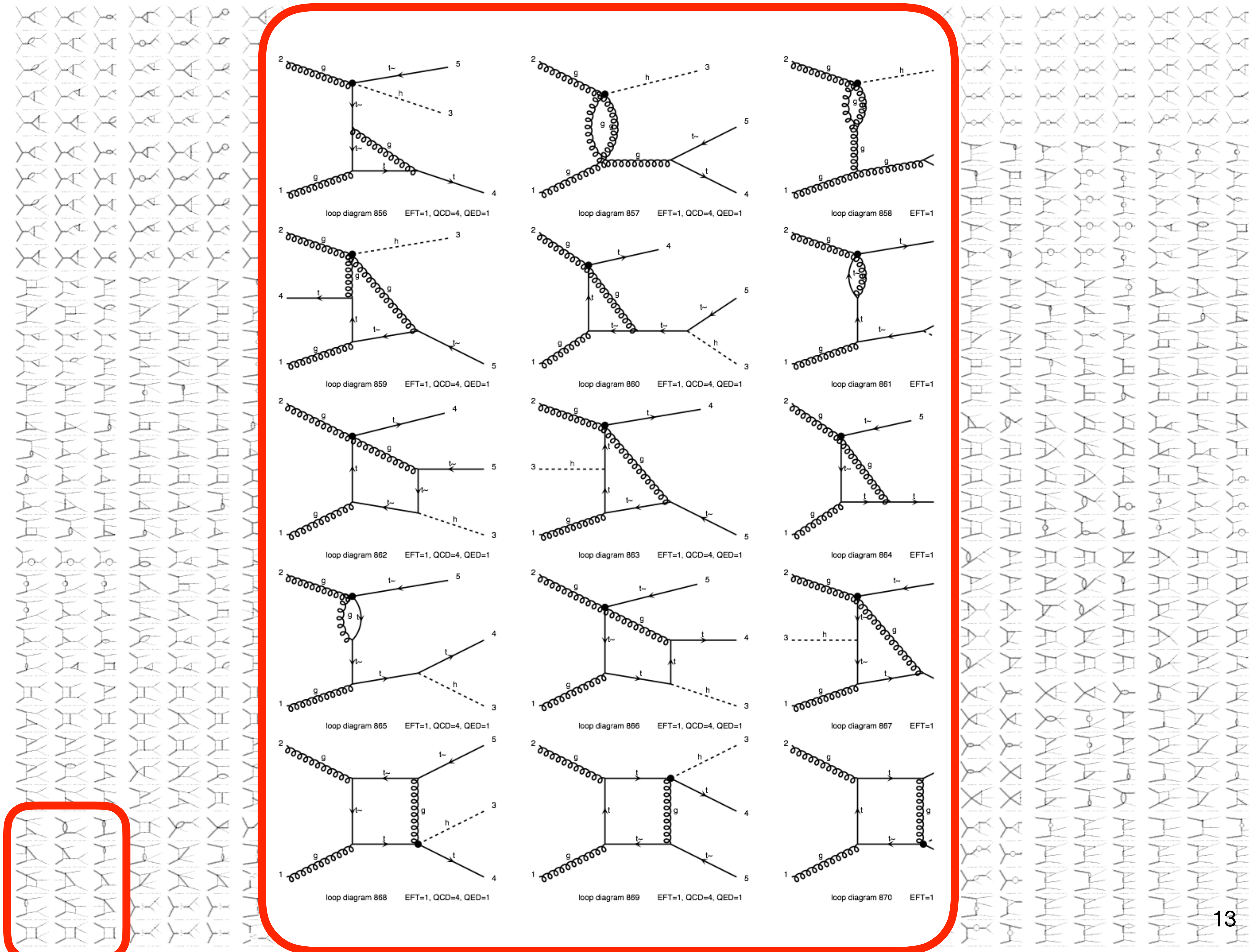




Example: ttbar+Higgs

Under the hood





应用

ATLAS CONF Note

ATLAS-CONF-2020-053

28th October 2020

Interpretations of the combined measurement of Higgs boson production and decay

The ATLAS Collaboration

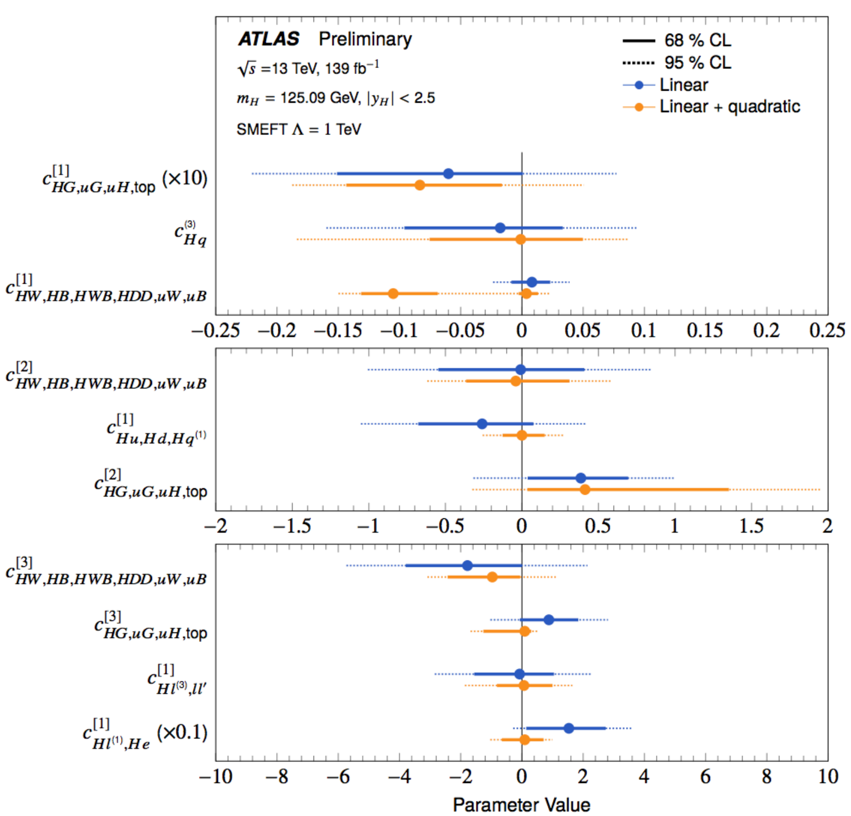


Figure 9: Summary of observed measurements of the parameters c_i' with the SMEFT linearized model (blue) and the SMEFT model with additional quadratic terms (orange). The ranges shown correspond to 68% (solid) and 95% (dashed) confidence level intervals, where all other coefficients and all nuisance parameters were profiled. For the model with quadratic terms, two exactly degenerate solutions are found for $c^{[1]}_{HW,HB,HWB,HDD,uW,uB}$, which are both indicated.

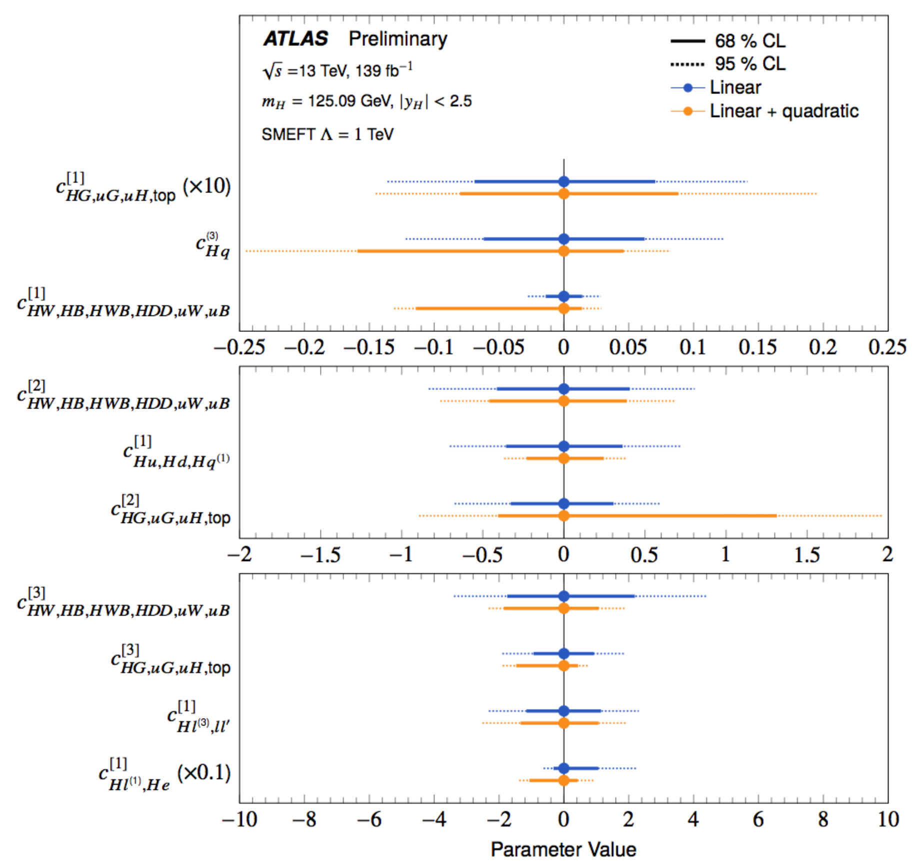
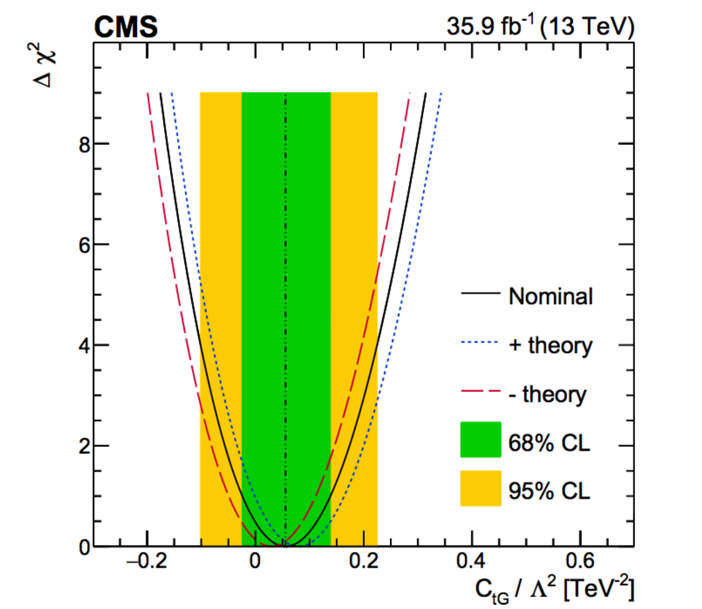
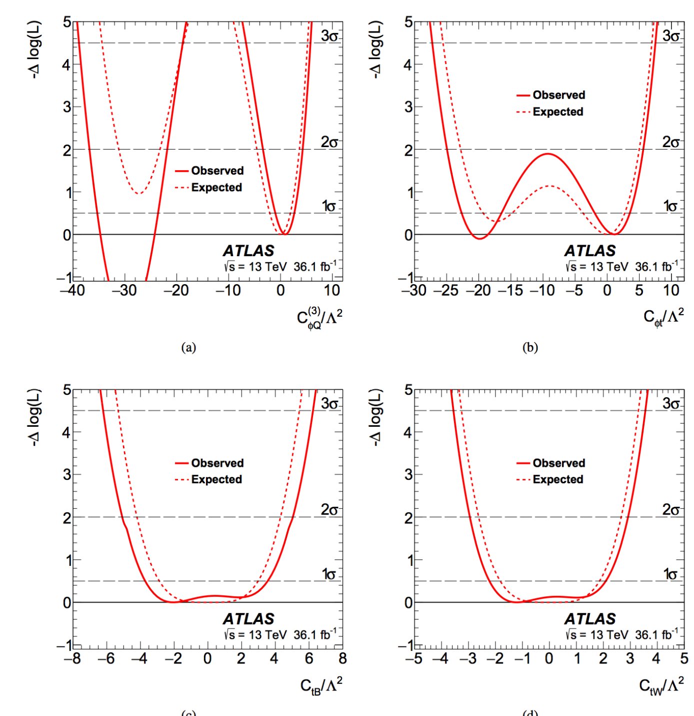


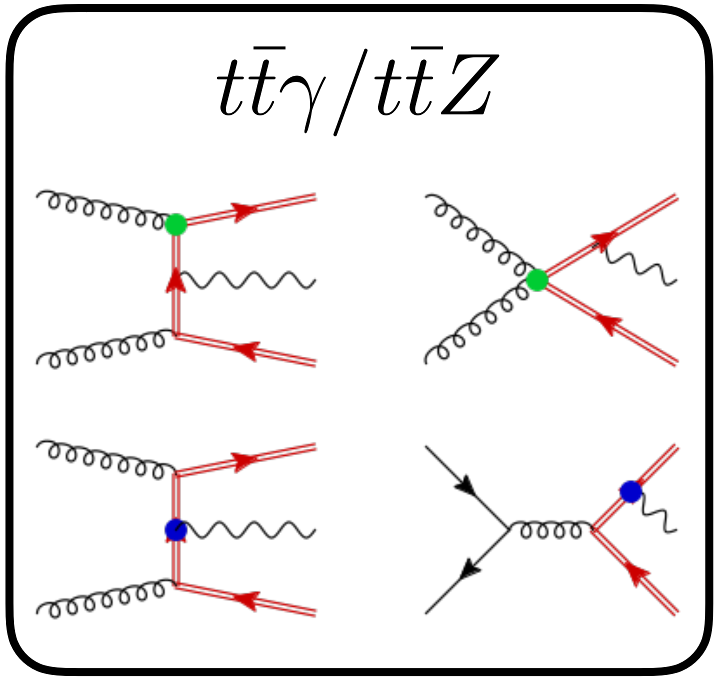
Figure 10: Summary of SM expected measurements of the parameters c_i' with the SMEFT linearized model (blue) and the SMEFT model with additional quadratic terms (orange). The ranges shown correspond to 68% (solid) and 95% (dashed) confidence level intervals, where all other coefficients and all nuisance parameters were profiled.

CMS ttbar spin correlation 1907.03729



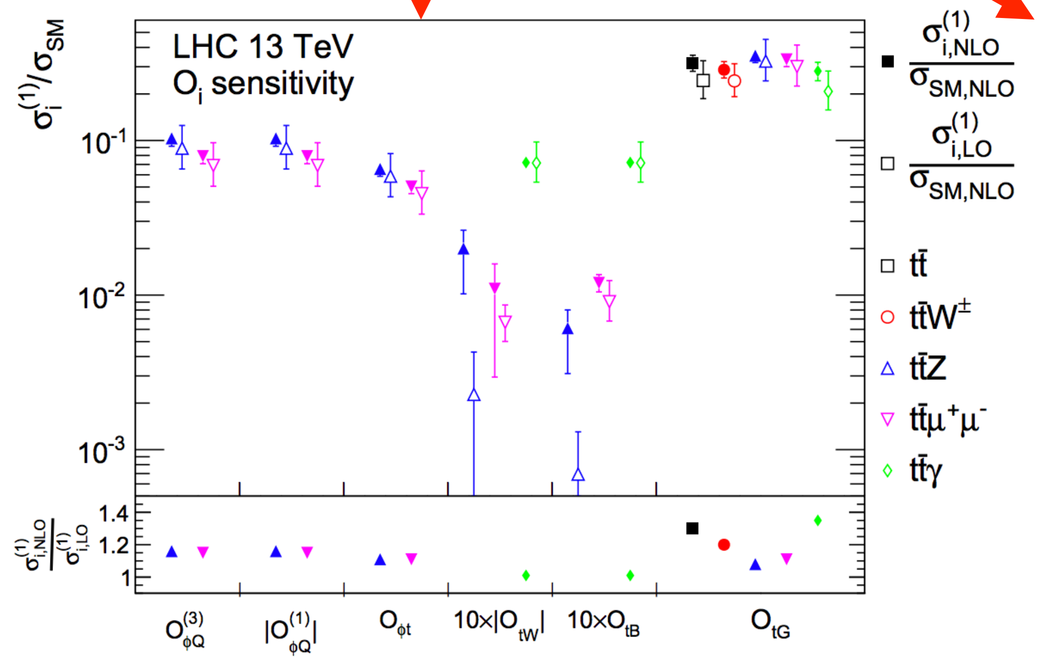
ATLAS ttW/ttZ 1901.03584

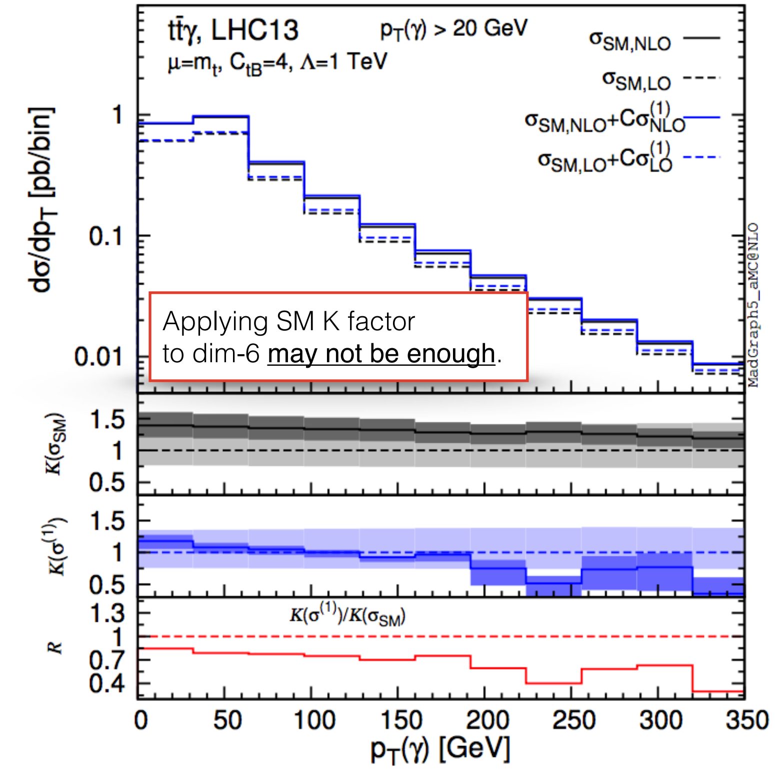


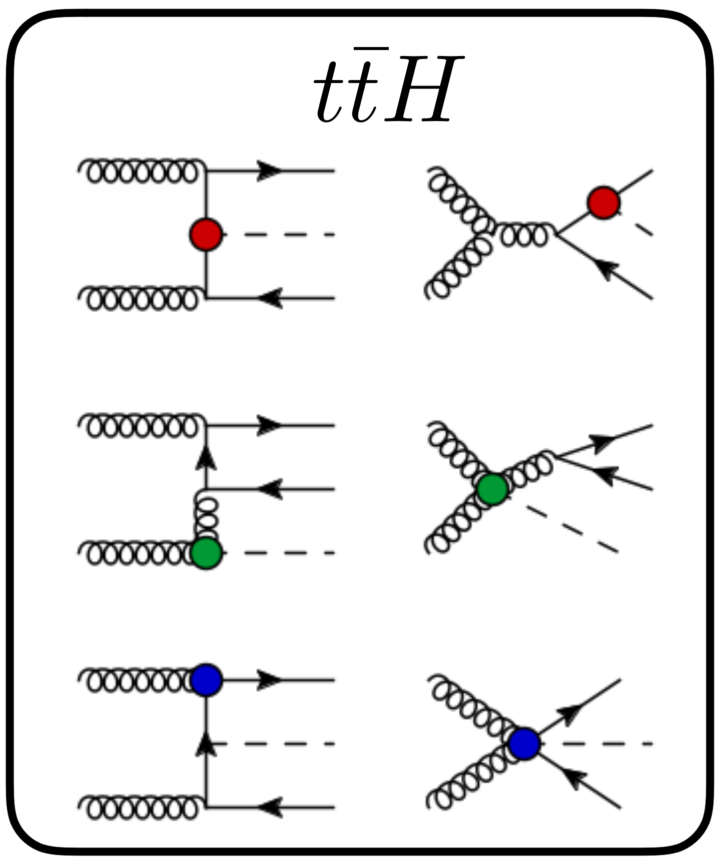


[Bylund et al.; JHEP 1605 (2016) 052]

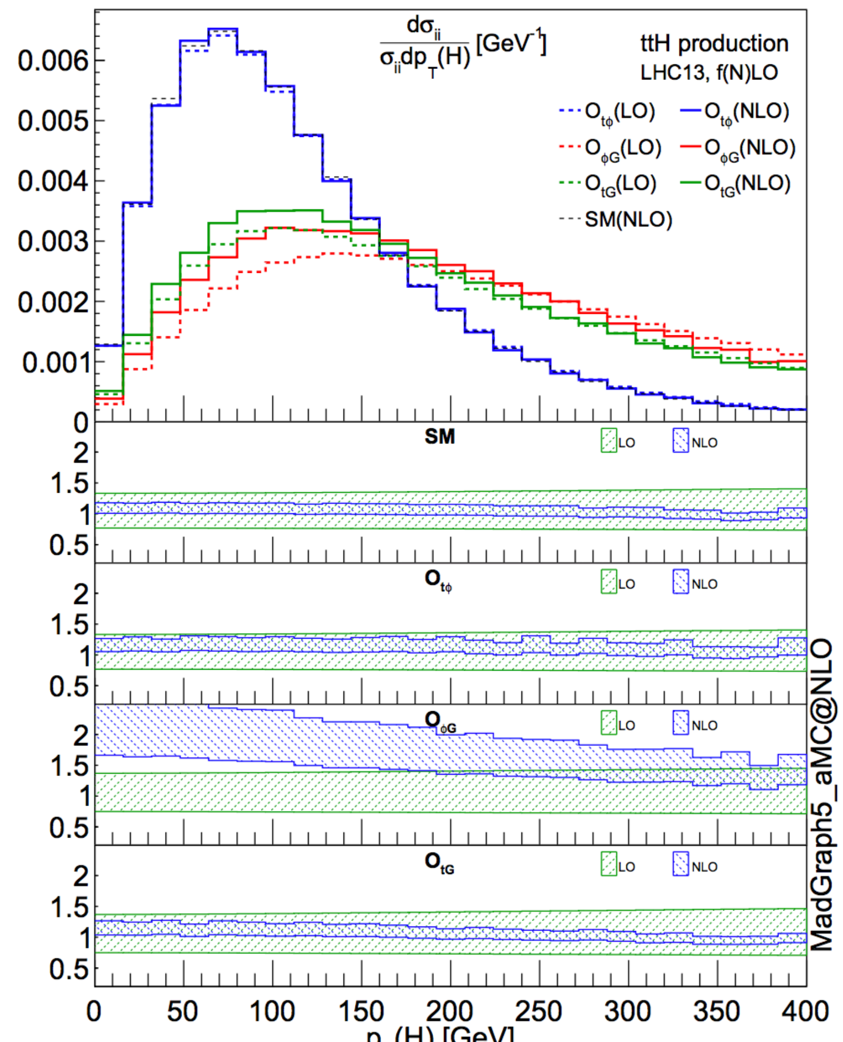
Non-universal K-factors in rates and distributions







[Maltoni, Vryonidou, CZ; JHEP 1610 (2016) 123]



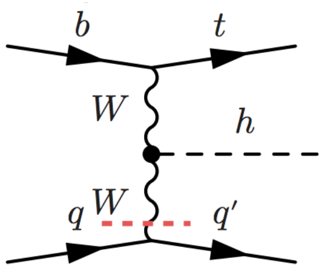
Rates

13 TeV	σ LO	σ NLO	K
σ_{SM}	$0.464^{+0.161}_{-0.11}$	$0.507^{+0.03}_{-0.04}$	1.09
$\sigma_{t\phi}$	$-0.055^{+0.0}_{-0.0}$	$-0.062^{+0.}_{-0.}$	1.13
$\sigma_{\phi G}$	$0.627^{+0.22}_{-0.15}$	$0.872^{+0.13}_{-0.12}$	1.39
σ_{tG}	$0.470^{+0.16}_{-0.11}$	$0.503^{+0.02}_{-0.04}$	1.07
$\sigma_{t\phi,t\phi}$	$0.0016^{+0.0}_{-0.0}$	$0.0019^{+0.0}_{-0.0}$	1.17
$\sigma_{\phi G,\phi G}$	$0.646^{+0.27}_{-0.17}$	$1.021^{+0.20}_{-0.17}$	1.58
$\sigma_{tG,tG}$	$0.645^{+0.27}_{-0.17}$	$0.674^{+0.03}_{-0.06}$	1.04
$\sigma_{t\phi,\phi G}$	$-0.037^{+0.0}_{-0.0}$	$-0.053^{+0.}_{-0.}$	1.42
$\sigma_{t\phi,tG}$	$-0.028^{+0.0}_{-0.0}$	$-0.031^{+0.}_{-0.}$	1.10
$\sigma_{\phi G,tG}$	$0.627^{+0.25}_{-0.16}$	$0.859^{+0.12}_{-0.12}$	1.37

$pp \to tHj,\ tZj$

Sub-amplitudes btWZ/btWH sensitive to deviation in EW sector
(cancellation spoiled among the leading energy dependences of diagrams)

tHj (tZj = h→Z)

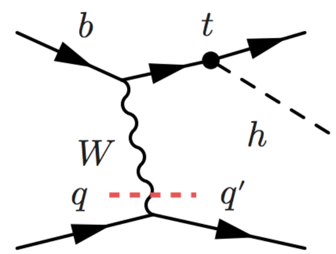


$\mathcal{O}_{\varphi W} : \varphi^\dagger \varphi W_i^{\mu\nu} W^i_{\mu\nu}$

HWW

TGC

$\mathcal{O}_W : \epsilon^{ijk} W_{i,\mu\nu} W_j^{\nu\rho} W^\mu_{k,\rho}$

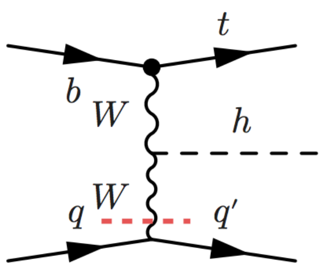


$\mathcal{O}_{t\varphi} : (\varphi^\dagger\varphi)(\bar{Q}t)\tilde{\varphi}$

top Yukawa

ttZ coupling

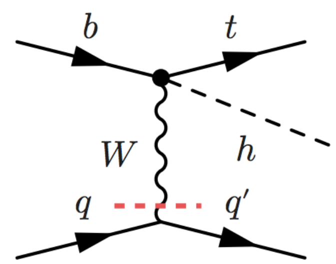
$\mathcal{O}_{\varphi t} : i(\varphi^\dagger \overleftrightarrow{D}_\mu \varphi)(\bar{t}\gamma^\mu t)$



$\mathcal{O}^{(3)}_{\varphi Q} : i(\varphi^\dagger \overleftrightarrow{D}^i_\mu \varphi)(\bar{Q}\gamma^\mu \sigma_i Q)$

Wtb vertex

$\mathcal{O}_{\varphi tb} : i(\tilde{\varphi} D_\mu \varphi)(\bar{b}\gamma^\mu t)$



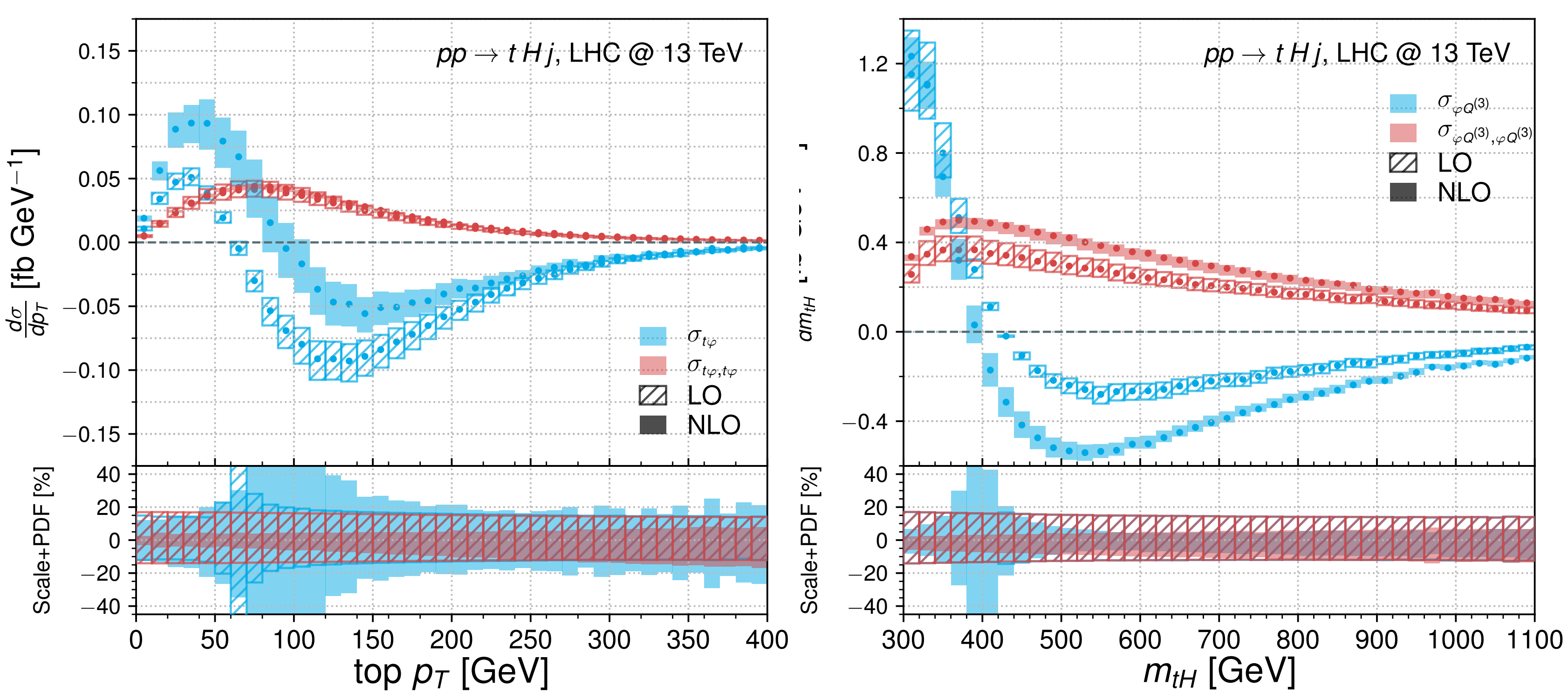
$\mathcal{O}^{(3)}_{\varphi Q} : i(\varphi^\dagger \overleftrightarrow{D}^i_\mu \varphi)(\bar{Q}\gamma^\mu \sigma_i Q)$

Contact terms

$\mathcal{O}_{tB} : (\bar{Q}\sigma_{\mu\nu} t)\tilde{\varphi} B^{\mu\nu}$

[Degrande et al.; JHEP 1810 (2018) 005]

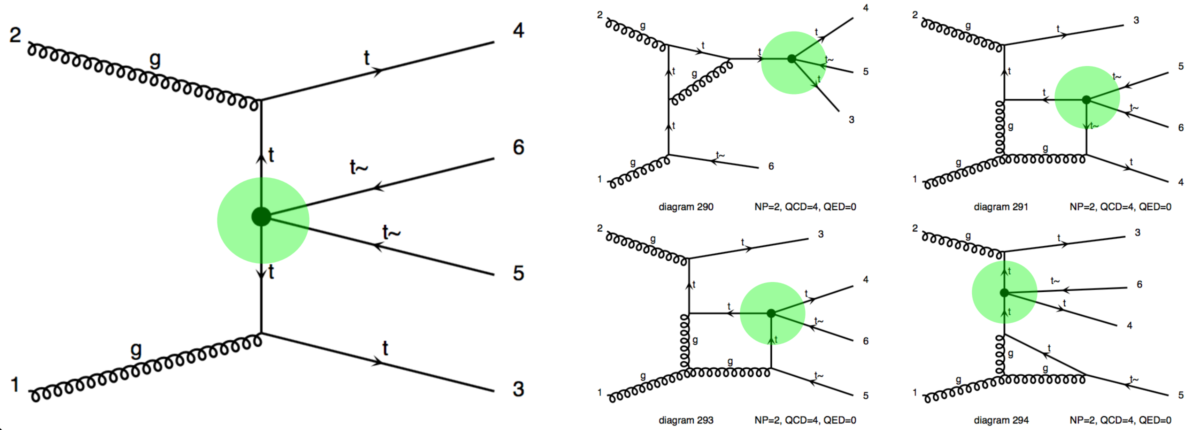
Certain operator show cancellation between different phase-space regions, and are sensitive to QCD corrections.



σ [fb]	K-factor
σ_{SM}	1.32
$\sigma_{\varphi W}$	0.96
$\sigma_{\varphi W,\varphi W}$	1.20
$\sigma_{t\varphi}$	0.20
$\sigma_{t\varphi,t\varphi}$	1.09
σ_{tW}	1.14
$\sigma_{tW,tW}$	1.54
$\sigma_{\varphi Q^{(3)}}$	3.31
$\sigma_{\varphi Q^{(3)},\varphi Q^{(3)}}$	1.36
$\sigma_{\varphi tb}$	–
$\sigma_{\varphi tb,\varphi tb}$	1.54
σ_{HW}	1.50
$\sigma_{HW,HW}$	1.13
σ_{tG}	–
$\sigma_{tG,tG}$	–
$\sigma_{Qq^{(3,1)}}$	0.89
$\sigma_{Qq^{(3,1)},Qq^{(3,1)}}$	0.89
$\sigma_{Qq^{(3,8)}}$	–
$\sigma_{Qq^{(3,8)},Qq^{(3,8)}}$	0.91

[Degrande et al., 2008.11743]

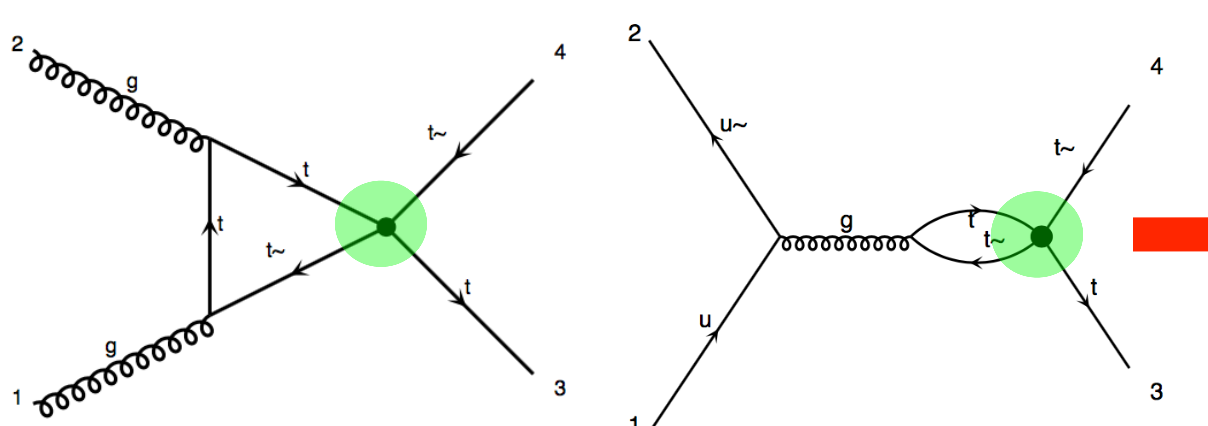
pp -> 4 top 4.3 sigma evidence, ATLAS-CONF-2020-013



c_i	$\mathcal{O}(\Lambda^{-2})$ LO	$\mathcal{O}(\Lambda^{-2})$ NLO	K	$\mathcal{O}(\Lambda^{-4})$ LO	$\mathcal{O}(\Lambda^{-4})$ NLO	K
c^8_{QQ}	$0.126^{+61\%}_{-35\%}$	$0.089^{+8\%}_{-66\%}$	0.71	$0.170^{+53\%}_{-32\%}$	$0.165^{+3\%}_{-26\%}$	0.97
c^8_{Qt}	$0.421^{+63\%}_{-35\%}$	$0.295^{+9\%}_{-69\%}$	0.70	$0.498^{+52\%}_{-32\%}$	$0.333^{+15\%}_{-75\%}$	0.67
c^1_{QQ}	$0.373^{+62\%}_{-35\%}$	$0.20(1)^{+23\%}_{-115\%}$	0.53	$1.513^{+53\%}_{-32\%}$	$1.40^{+3\%}_{-32\%}$	0.93
c^1_{Qt}	$-0.007(1)^{+88\%}_{-84\%}$	$-0.14(3)^{+83\%}_{-40\%}$	21	$2.061^{+53\%}_{-32\%}$	$1.89^{+3\%}_{-33\%}$	0.92
c^1_{tt}	$0.741^{+61\%}_{-35\%}$	$0.42(3)^{+18\%}_{-101\%}$	0.57	$6.08^{+53\%}_{-32\%}$	$5.65^{+3\%}_{-30\%}$	0.93

LHC 13 SM = 13.9 fb

ttbar: loop sensitivity to four-top-quark operators



tttt (4 heavy) operators, loop

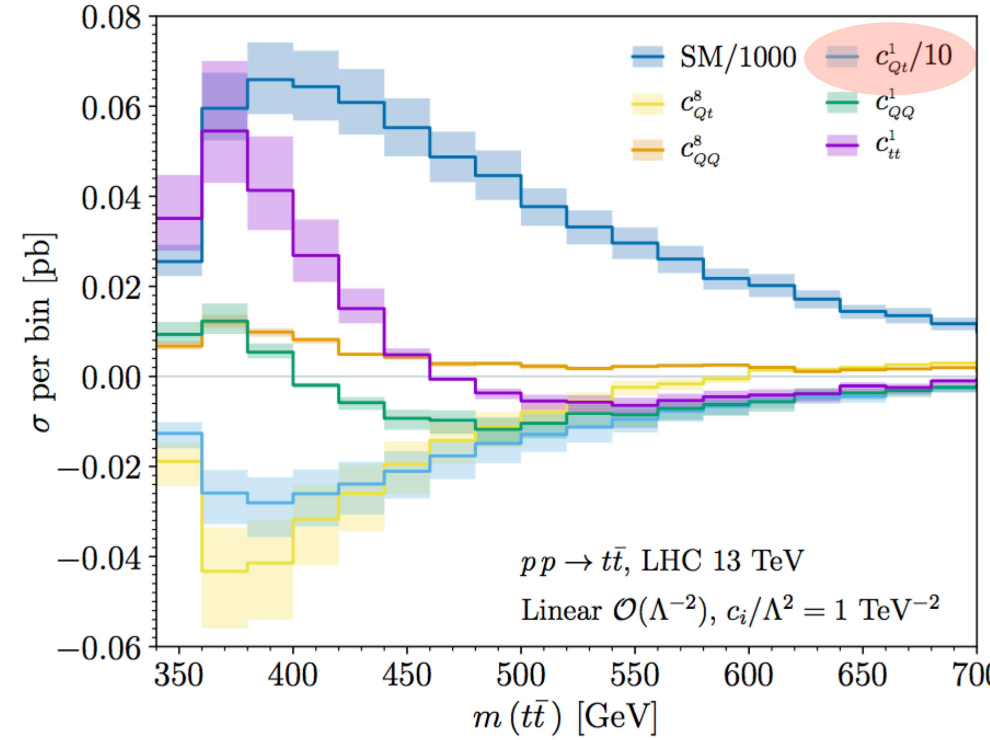


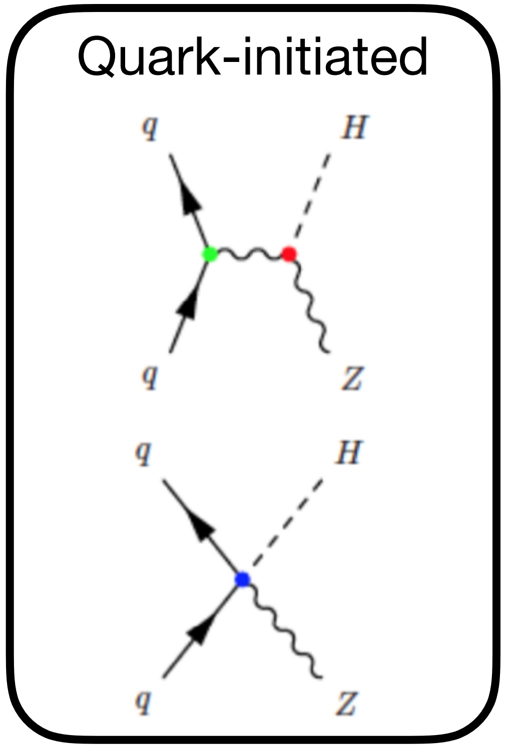
FIG. 1. $t\bar{t}$ invariant-mass distribution of the interference between four-heavy operators and the SM.

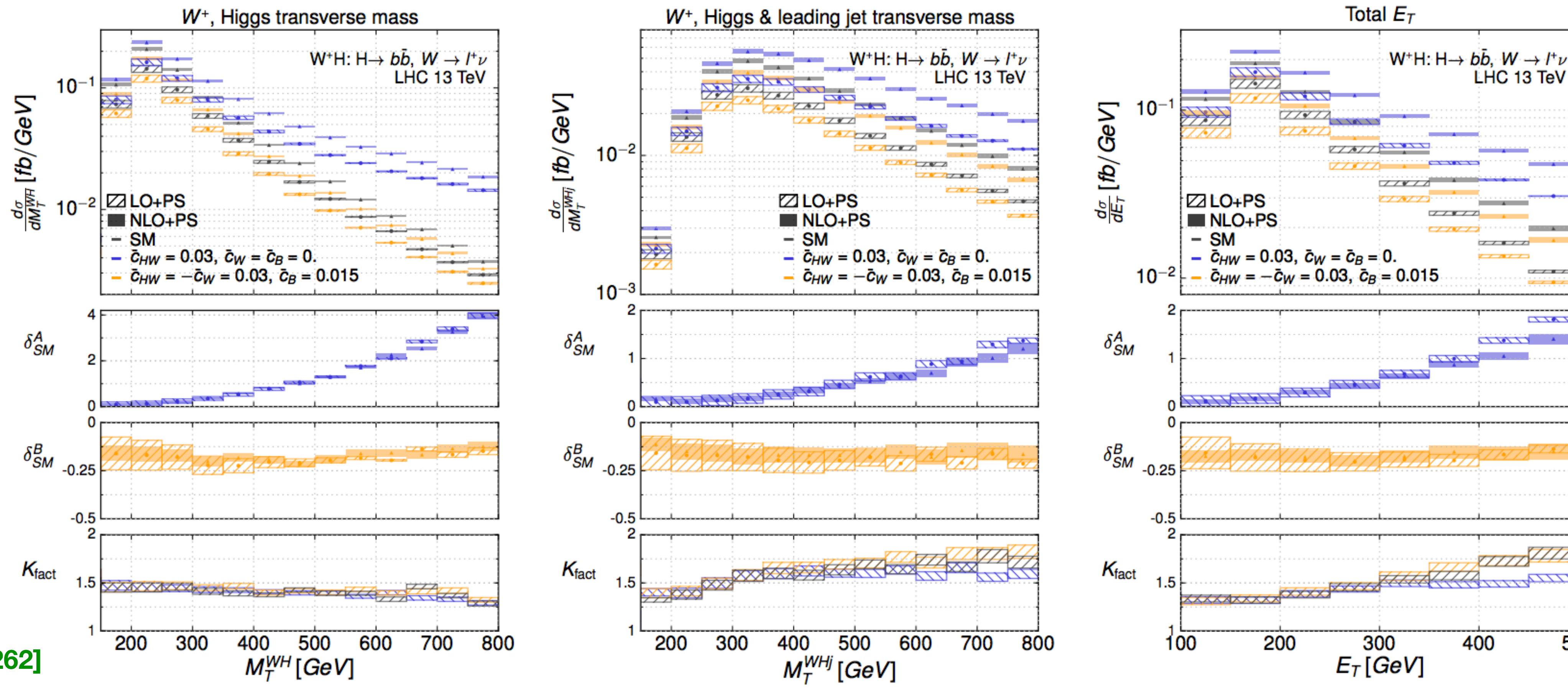
qqtt (2 light 2 heavy) operators, tree

c_i	$\mathcal{O}(\Lambda^{-2})$ LO	$\mathcal{O}(\Lambda^{-2})$ NLO	$\mathcal{O}(\Lambda^{-4})$ LO	$\mathcal{O}(\Lambda^{-4})$ NLO
c^8_{tu}	$4.27^{+11\%}_{-9\%}$	$4.06^{+1\%}_{-3\%}$	$1.04^{+6\%}_{-5\%}$	$1.03^{+2\%}_{-2\%}$
c^8_{td}	$2.79^{+11\%}_{-9\%}$	$2.77^{+1\%}_{-3\%}$	$0.577^{+6\%}_{-5\%}$	$0.611^{+3\%}_{-2\%}$
c^8_{tq}	$6.99^{+11\%}_{-9\%}$	$6.67^{+1\%}_{-3\%}$	$1.61^{+6\%}_{-5\%}$	$1.29^{+3\%}_{-2\%}$
c^8_{Qu}	$4.26^{+11\%}_{-9\%}$	$3.93^{+1\%}_{-4\%}$	$1.04^{+6\%}_{-5\%}$	$0.798^{+3\%}_{-3\%}$
c^8_{Qd}	$2.79^{+11\%}_{-9\%}$	$2.93^{+0\%}_{-1\%}$	$0.58^{+6\%}_{-5\%}$	$0.485^{+2\%}_{-2\%}$
$c^{8,1}_{Qq}$	$6.99^{+11\%}_{-9\%}$	$6.82^{+1\%}_{-3\%}$	$1.61^{+6\%}_{-5\%}$	$1.69^{+3\%}_{-3\%}$
$c^{8,3}_{Qq}$	$1.50^{+10\%}_{-9\%}$	$1.32^{+1\%}_{-3\%}$	$1.61^{+6\%}_{-5\%}$	$1.57^{+2\%}_{-2\%}$
c^8_{QQ}	$0.0586^{+27\%}_{-25\%}$	$0.125^{+10\%}_{-11\%}$	$0.00628^{+13\%}_{-16\%}$	$0.0133^{+7\%}_{-5\%}$
c^8_{Qt}	$0.0583^{+27\%}_{-25\%}$	$-0.107(6)^{+40\%}_{-33\%}$	$0.00619^{+13\%}_{-16\%}$	$0.0118^{+8\%}_{-5\%}$
c^1_{QQ}	$[-0.11^{+15\%}_{-18\%}]$	$-0.039(4)^{+51\%}_{-33\%}$ $[-0.12^{+7\%}_{-5\%}]$	$0.0282^{+13\%}_{-16\%}$	$0.0651^{+5\%}_{-6\%}$
c^1_{Qt}	$[-0.068^{+16\%}_{-18\%}]$	$-2.51^{+29\%}_{-21\%}$ $[-0.12^{+3\%}_{-6\%}]$	$0.0283^{+13\%}_{-16\%}$	$0.066^{+5\%}_{-6\%}$
c^1_{tt}	×	$0.215^{+23\%}_{-18\%}$	×	×

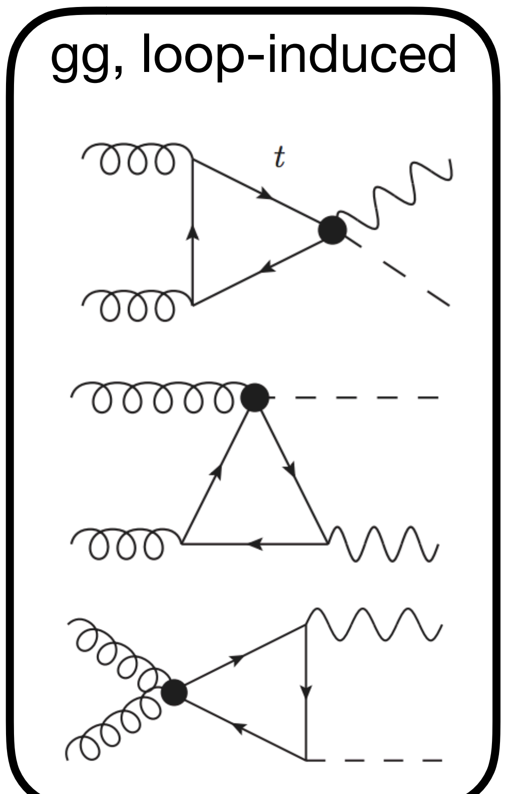
LHC 13, SM(NLO) = 744, [x]: EW interference

$pp \to HZ$



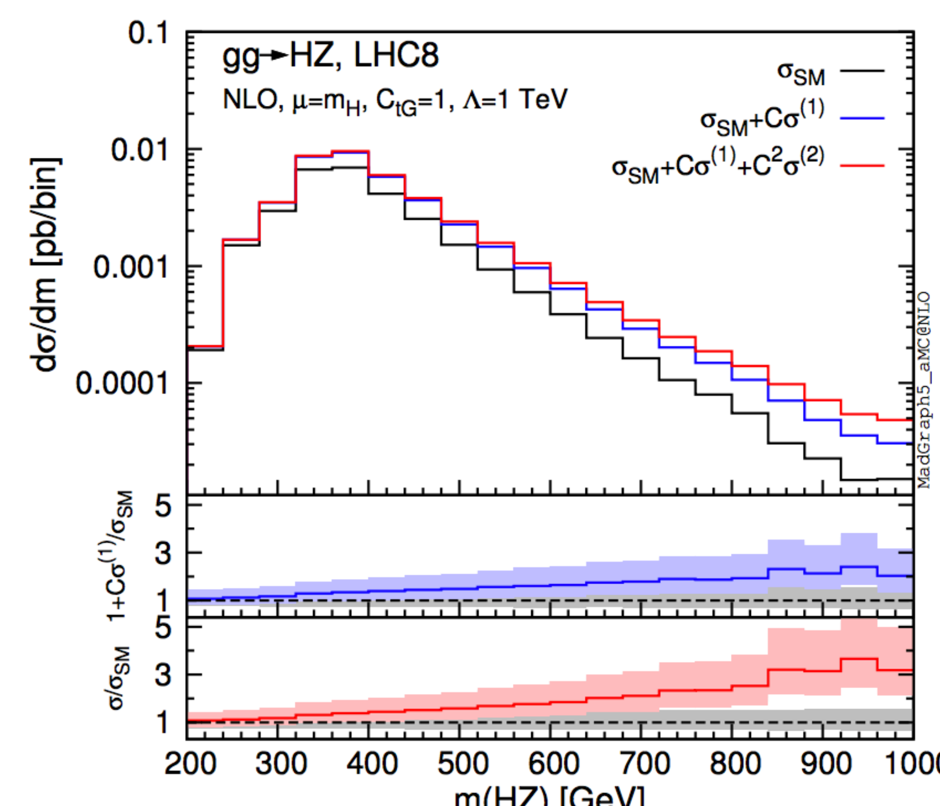


[Degrande, et al.; EPJC 77 (2017) 4, 262]

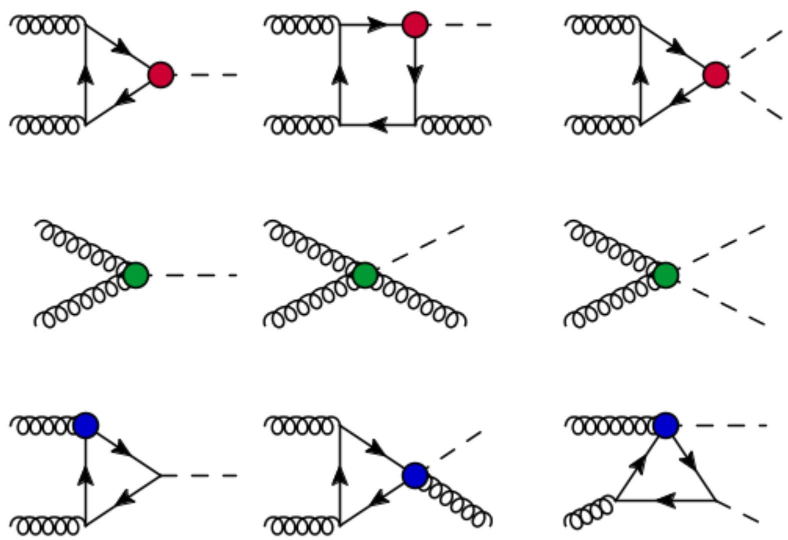


[Bylund et al.; JHEP 1605 (2016) 052]

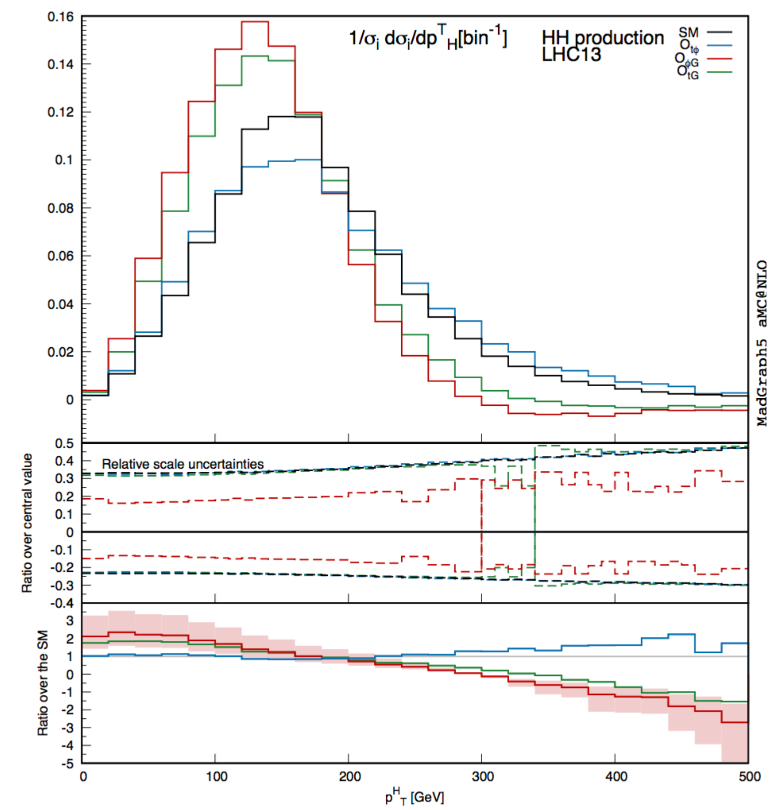
[fb]	SM		$\mathcal{O}_{tG}$	$\mathcal{O}^{(1)}_{\phi Q}$
8TeV	$29.15^{+40.0\%}_{-26.6\%}$	$\sigma_i^{(1)}$	$10.37^{+41.3\%}_{-27.2\%}$	$1.719^{+42.5\%}_{-27.6\%}$
		$\sigma_i^{(2)}$	$1.621^{+45.1\%}_{-28.7\%}$	$0.0469^{+46.5\%}_{-29.2\%}$
		$\sigma_i^{(1)}/\sigma_{SM}$	$0.356^{+0.9\%}_{-0.8\%}$	$0.0590^{+1.8\%}_{-1.4\%}$
		$\sigma_i^{(2)}/\sigma_i^{(1)}$	$0.156^{+2.6\%}_{-2.0\%}$	$0.0273^{+2.8\%}_{-2.3\%}$
13TeV	$93.6^{+34.3\%}_{-23.8\%}$	$\sigma_i^{(1)}$	$34.6^{+35.2\%}_{-24.5\%}$	$5.91^{+36.4\%}_{-24.9\%}$
		$\sigma_i^{(2)}$	$6.09^{+39.2\%}_{-26.1\%}$	$0.182^{+40.2\%}_{-26.6\%}$
		$\sigma_i^{(1)}/\sigma_{SM}$	$0.370^{+0.7\%}_{-0.9\%}$	$0.0631^{+1.6\%}_{-1.5\%}$
		$\sigma_i^{(2)}/\sigma_i^{(1)}$	$0.176^{+2.9\%}_{-2.1\%}$	$0.0309^{+2.8\%}_{-2.2\%}$

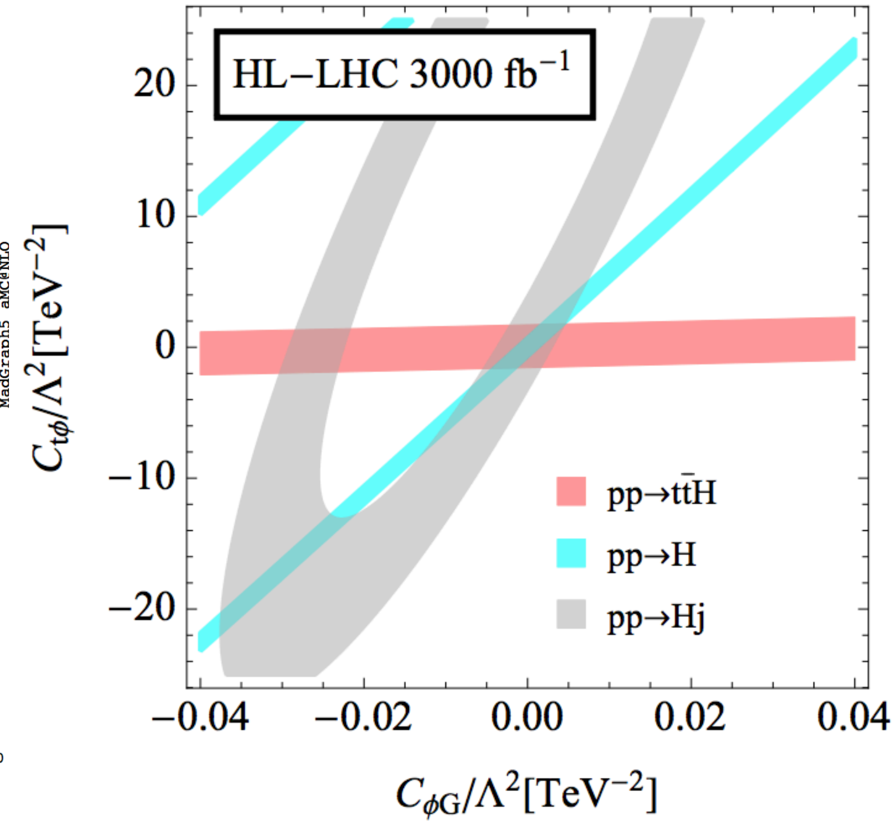


loop-sensitivity, **gg -> H/Hj/HH**

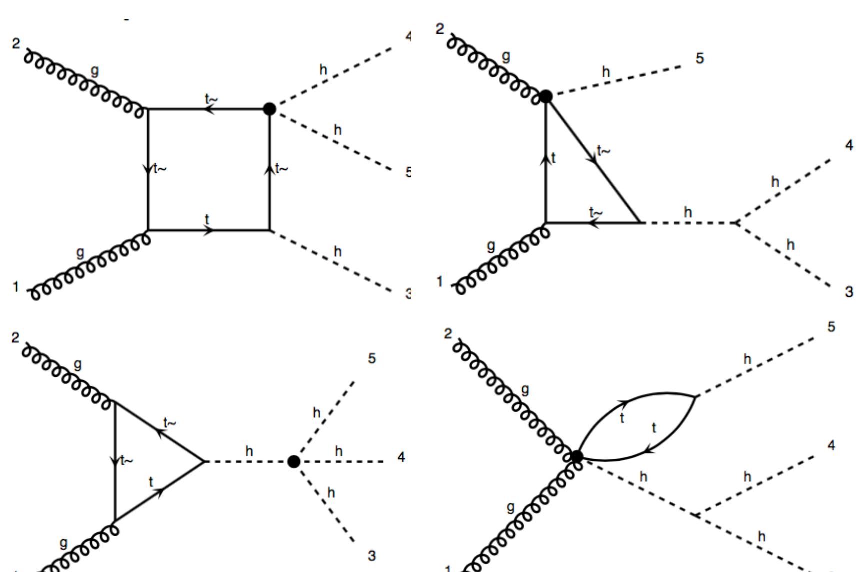


[Maltoni, Vryonidou, CZ; JHEP 1610 (2016) 123]





gg -> H/HH/HHH



[Degrande et al., 2008.11743]

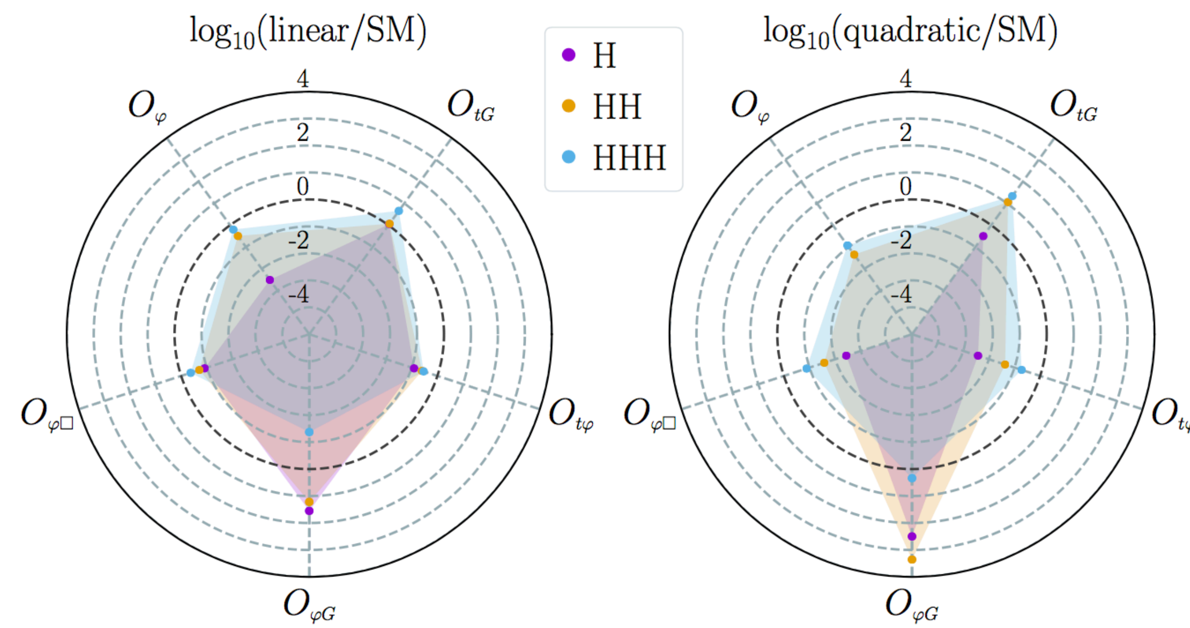
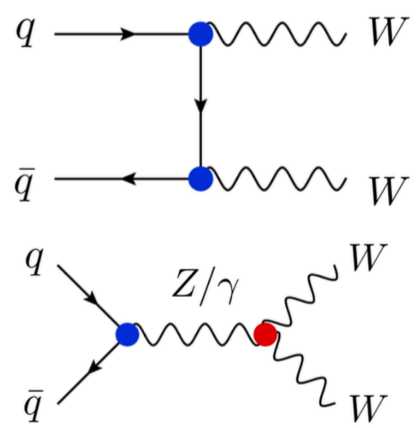


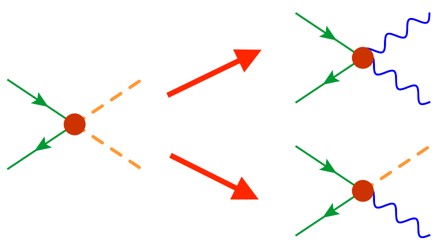
FIG. 3. Linear and quadratic contributions of the five relevant operators to H, HH, and HHH production at a future 100 TeV pp collider, normalised by the corresponding SM predictions.

The projected FCC-hh reach: 1%, 5% and 50% on H, HH and HHH

Diboson, TGC/qqV



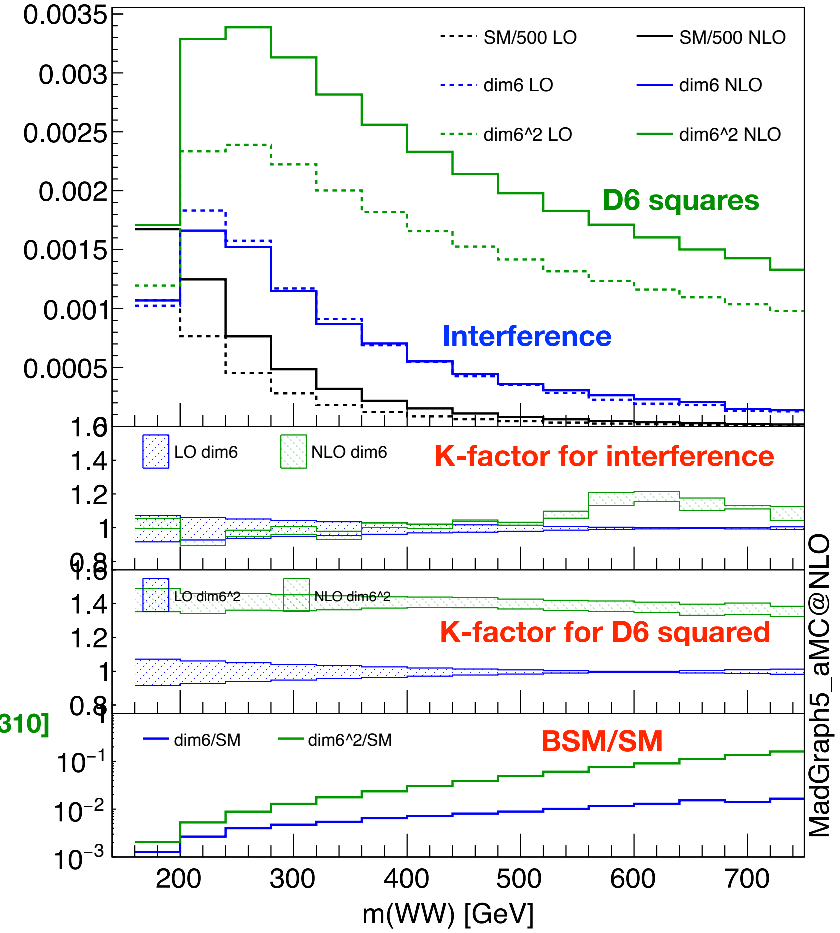
$$\mathcal{O}_L^{(3)} = (\bar{Q}_L \sigma^a \gamma^\mu Q_L)(iH^\dagger \sigma^a \overleftrightarrow{D}_\mu H)$$

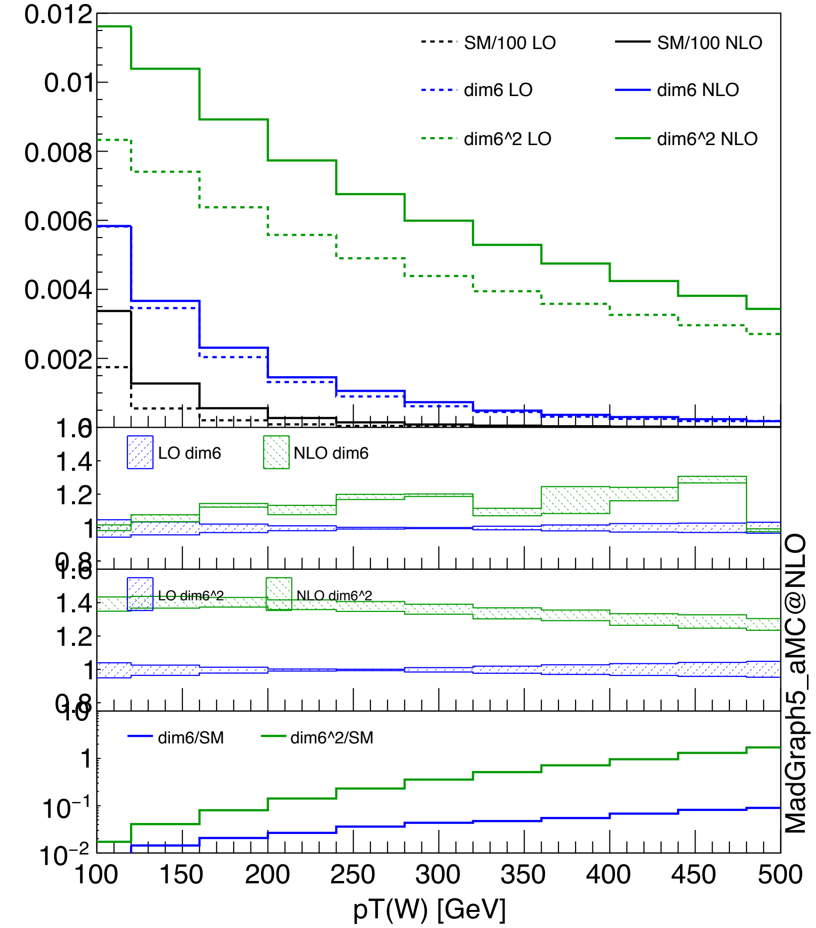


[R. Franceschini et al. 1712.01310]

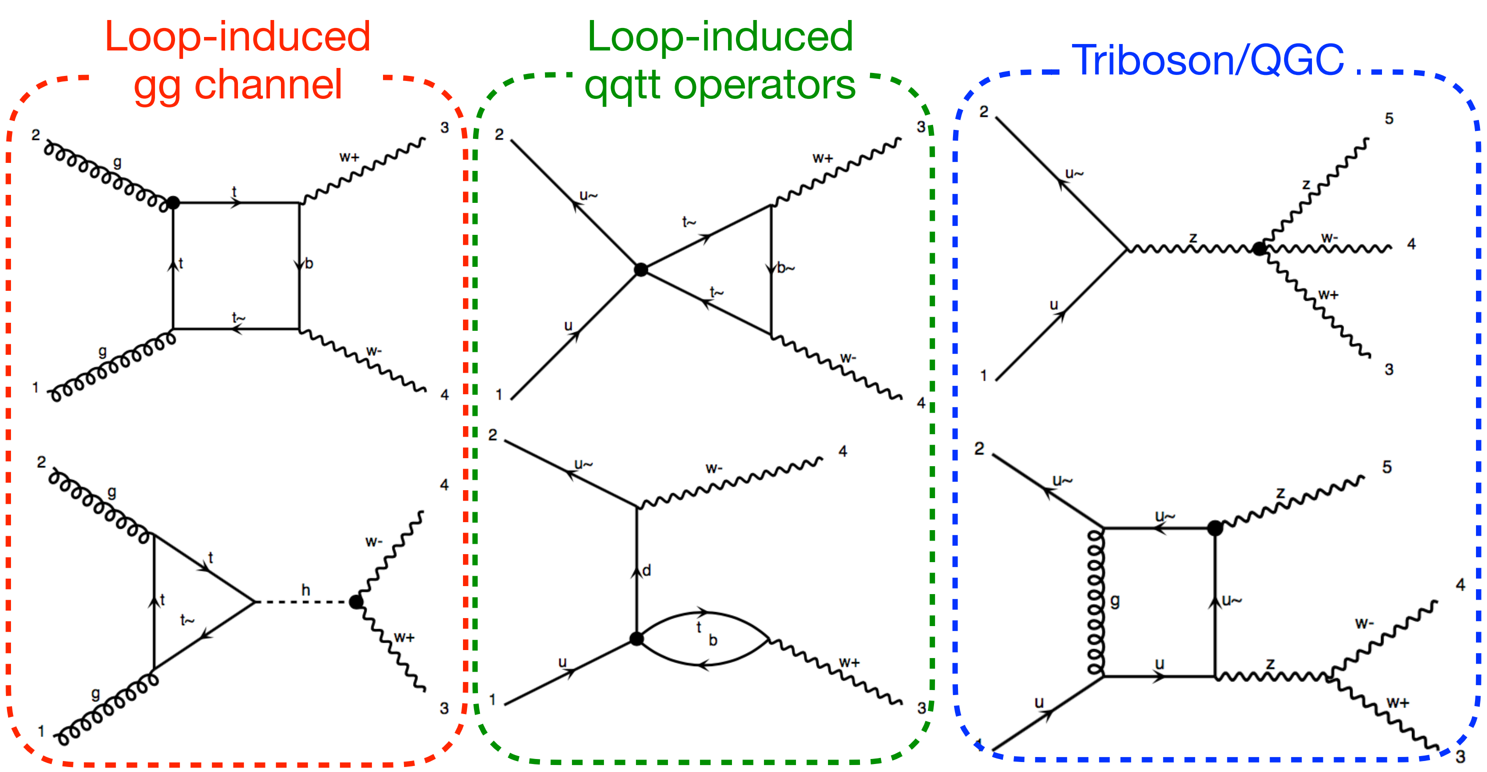
[S. Banerjee et al. 1807.01796]

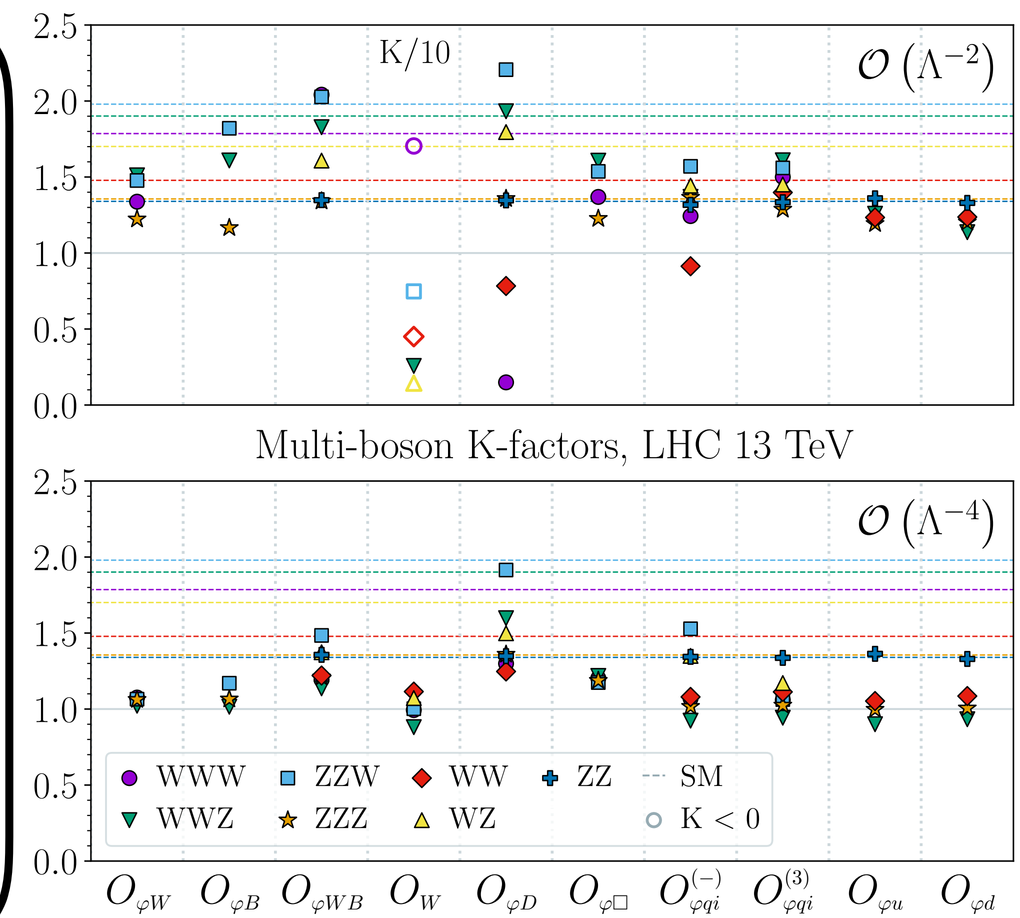
[C. Grojean et al. 1810.05149]





Diboson + multiboson: WW/WZ/ZZ/WWW/WWZ/ZZW/ZZZ





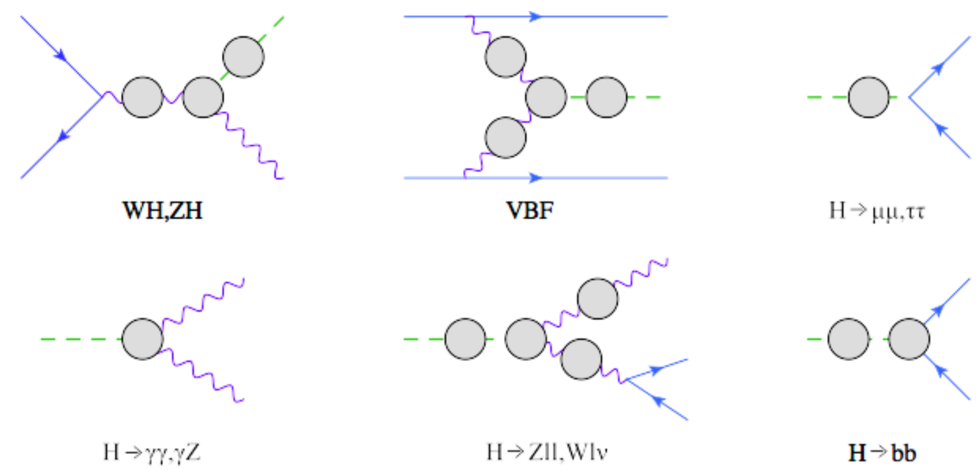
[Degrande et al., 2008.11743]

下一步计划

- 电弱圈图自动化。第一步已完成 dim-6 top loop

[Vryonidou, CZ, JHEP 08 (2018) 036]

  - CEPC：在 ttbar 阈值以下测量 top coupling
  - FCC-ee：top 影响 Higgs fit 精度
  - HL-LHC：通过Higgs过程圈图效应限制top算符



- 适用于 e+e- 对撞的自动事例产生子
  - BSM + NLO QCD (EW) + ISR + beamstrahlung
  - Snowmass LOI submitted (top FCNC)
  - FCPPL project with B. Fuks, H.-S. Shao, and others (LPTHE/Sorbonne)

Precise predictions for top-quark flavor-changing neutral interactions at future lepton colliders

Snowmass letter of intent

Gauthier Durieux, Stefano Frixione, Benjamin Fuks, Hua-Sheng Shao, Liaoshan Shi, Marco Zaro, Cen Zhang, and Xiaoran Zhao

While the analysis of the data recorded during the second run of the LHC is still ongoing, no compelling direct evidence for new physics has been observed so far. These null search results have consequently pushed the limits on the masses of any potential particle extending the Standard Model (SM) of particle physics to rather high scales, well within the TeV regime. For this reason, the Standard Model Effective Field Theory (SMEFT) framework, in which new phenomena are parameterised by higher-dimensional operators in the SM fields, has received more and more attention in the last few years. It is today considered as a proper framework to study deviations from the SM, not only in the sense that it is a useful way to parameterise any new physics effects, but also as it could be tested per se. We propose to focus on the SMEFT operators that impact the phenomenology of the top quark, and in particular those involving new flavor-changing neutral interactions. The reason lies behind the large mass of the top quark, so that one expects it to be intimately linked to new physics. Studying the properties of the top quark is therefore of utmost importance for a potential discovery of any new phenomenon.

On the other hand, the high-energy physics community is currently investigating options for collider experiments to be run in the next decades. We position the work envisaged in this letter of interest within this context, focusing on a future lepton collider. Several future lepton collider proposals are under consideration, including the Circular Electron Positron Collider (CEPC) in China, the Future Circular Collider with e^+e (FCC-ee) at CERN, the International Linear Collider (ILC) in Japan, and the Compact Linear Collider (CLIC) at CERN aiming at running at higher center-of-mass energies. We propose to study and compare the potential sensitivity of these future machines to flavour-changing interactions of the top quark, by achieving test-case studies including precision predictions in the global and model-independent SMEFT framework.

While the collider reaches of these interactions have been studied in the past, comprehensive and model-independent studies based on the SMEFT framework and including realistic collider analyses are still missing. Most results in the literature are either based on the anomalous-coupling approach or have ignored the four-fermion contact flavor-changing interactions. These studies are thus less model-independent, in particular as it has been shown that future lepton colliders have a much better reach on the four-fermion interactions compared to LHC and its future upgrades [1, 2]. Furthermore, a complete SMEFT analysis requires higher-order corrections to be consistently incorporated to any desired order, and should hence rely on precision predictions not only for total rates, but as well as for distributions [3]. Both indeed play crucial roles, given the high accuracy measurements expected at those future machines.

Automatic new physics simulations at the next-to-leading-order (NLO) accuracy in QCD are standard for proton-proton collisions, but they still cannot be obtained straightforwardly for e^+e^- collisions, especially for the full set of processes relevant for top-quark flavor-changing interactions. While a subset of relevant operators have been automated at NLO in QCD already quite a while ago [3], an extension including the full set of operators is only very recent [4]. However, the current implementation enforces flavor conservation and has therefore to be extended. Whilst this is in principle feasible by means of public tools, it is on the other hand well-known that beamstrahlung and initial-state radiation effects can both be crucial at a future lepton collider. We therefore also plan to contribute to the extension of the MadGraph5_aMC@NLO framework [5], so that it could be used for precision SMEFT predictions in the context of electron-positron collisions, including not only NLO QCD corrections (as it is already the case), but also beamstrahlung and initial-state radiation effects. While we expect these effects to be important in the work envisaged in this proposal, embedding them into an automatic framework would also allow for general beyond the SM physics to be studied in any future lepton colliders context, and this by relying on much more reliable theory predictions not only for the SM background but also for any class of new physics signal. Our specific study on top-quark flavor-changing interactions could serve as a test case for this goal.

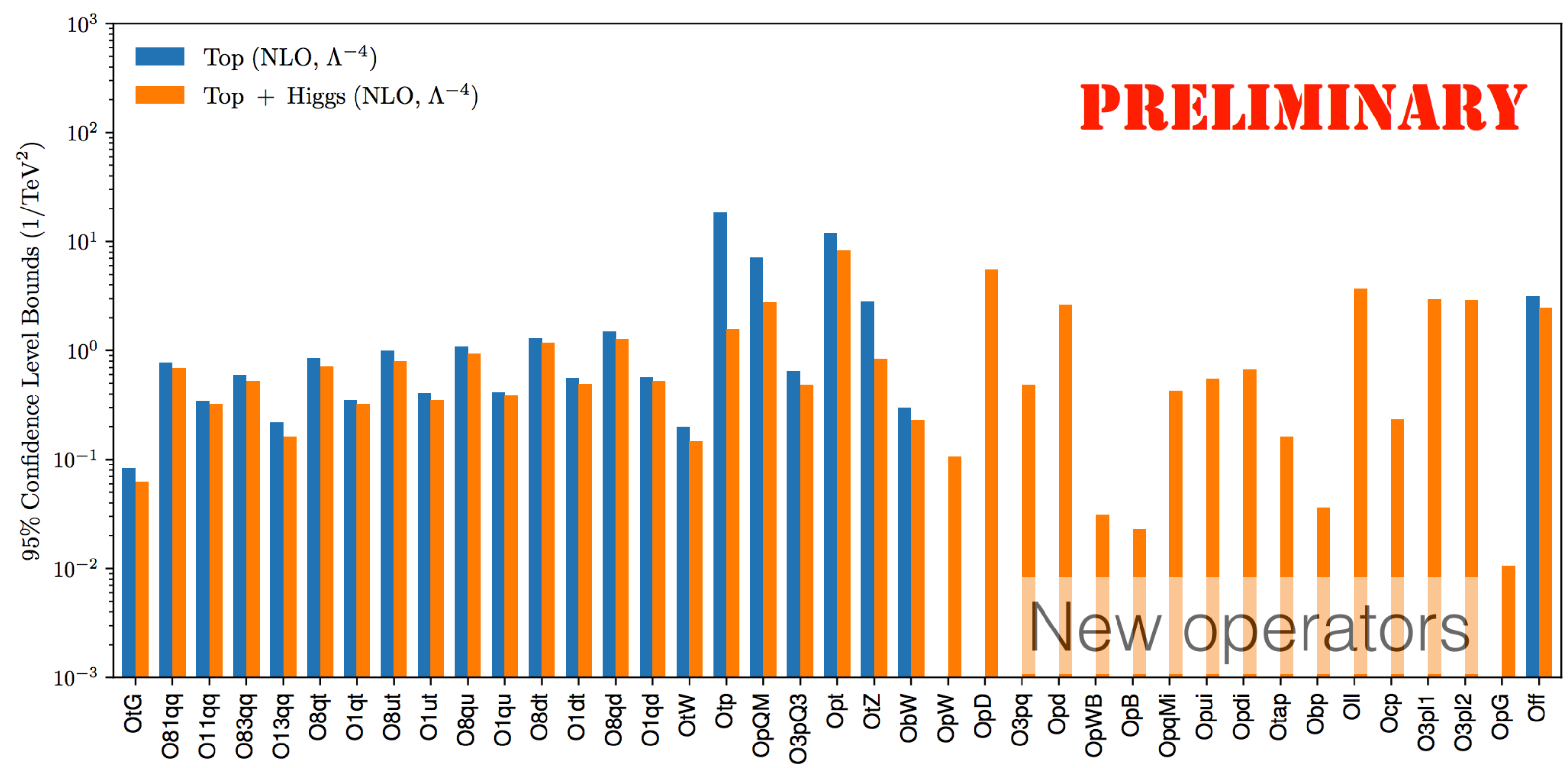
This proposal hence aims to complete a comprehensive study of the neutral flavour-violating effects in the top quark sector, with the global and model-independent SMEFT framework. We hence aim to provide some new inputs to motivate the building of future lepton colliders. Moreover, with this physics goal in mind, we aim at automating NLO QCD computations with MadGraph5_aMC@NLO for lepton collider (including beamstrahlung and initial-state radiation effects) for any class of particle physics models.

[1] G. Durieux, F. Maltoni, and C. Zhang, Phys. Rev. D **91**, 074017 (2015), arXiv:1412.7166 [hep-ph].
[2] L. Shi and C. Zhang, Chin. Phys. C **43**, 113104 (2019), arXiv:1906.04573 [hep-ph].
[3] C. Degrande, F. Maltoni, J. Wang, and C. Zhang, Phys. Rev. D **91**, 034024 (2015), arXiv:1412.5594 [hep-ph].
[4] C. Degrande, G. Durieux, F. Maltoni, K. Mimasu, E. Vryonidou, and C. Zhang, (2020), arXiv:2008.11743 [hep-ph].
[5] J. Alwall, R. Frederix, S. Frixione, V. Hirschi, F. Maltoni, O. Mattelaer, H. S. Shao, T. Stelzer, P. Torrielli, and M. Zaro, JHEP **07**, 079 (2014), arXiv:1405.0301 [hep-ph].

2. SMEFT 全局拟合

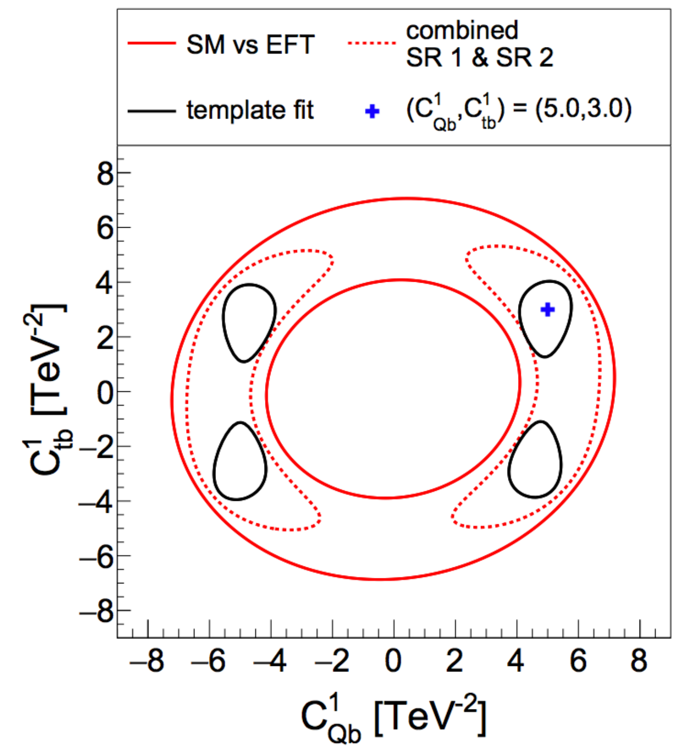
- NLO 精度的 SMEFT Wilson 系数全局拟合：
  - 通过综合 LHC 测量数据检验标准模型。
  - 通过模型无关框架来提供 LHC 实验数据的“legacy”。为当前和未来的理论研究做铺垫。
  - 推动实验物理同行进行 SMEFT框架的实验分析，用top-down分析提高灵敏度，进一步发掘LHC潜力。

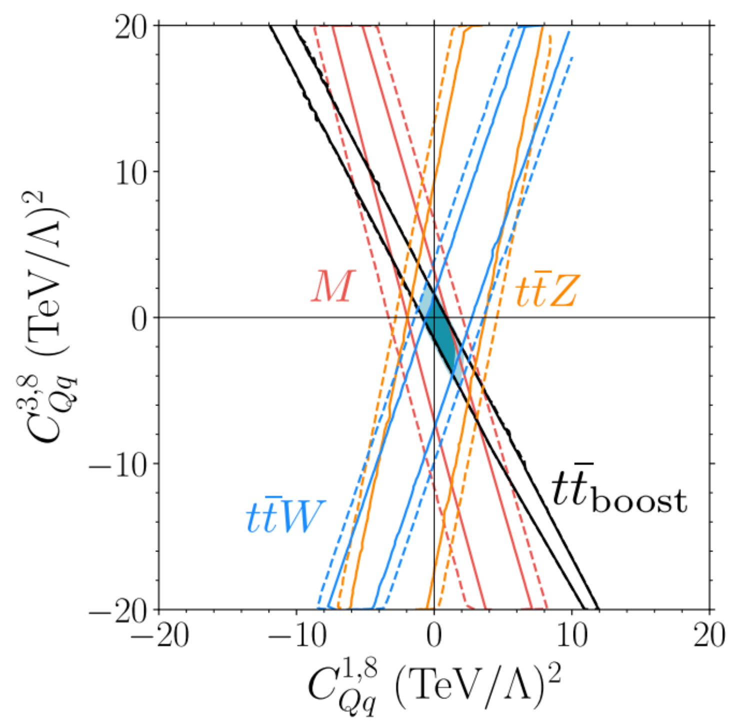
- Top 数据的拟合 **H. P. Hartland et al. JHEP 04 (2019) 100**
  - 与 NNPDF 组合作完成。引用次数~74。
  - 正在加入 Higgs 和 电弱数据，写作进行当中。



其它 SMEFT/Top 相关研究

- Top-EW 和 Top Higgs
  - single top+Z/H: [C. Degrande et al. JHEP 10 (2018) 005]
  - tt+H: [F. Maltoni et al. JHEP 10 (2016) 123]
  - Future e+e-: [G. Durieux et al. JHEP 10 (2018) 168]
    CERN Yellow Rep. Monogr. Vol. 3 (2018)
- tttt: [CZ Chin.Phys.C 42 (2018) 2, 023104]
  CERN Yellow Rep.Monogr. 7 (2019) 1-220
- ttbb: [J. D'Hondt et al. JHEP 11 (2018) 131]
- Top FCNC:
  - HL/HE-LHC: CERN Yellow Rep.Monogr. 7 (2019) 867-1158
  - CEPC: [Shi, CZ, Chin.Phys.C 43 (2019) 11, 113104]
- Global fit (SFitter): [I. Brivio et al. JHEP 02 (2020) 131]
- LHC Top WG 推荐的 top EFT 分析标准
  以及配套的蒙卡模型 [1802.07237 [hep-ph]]

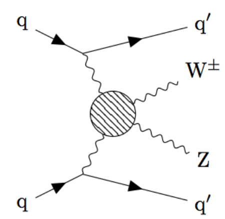




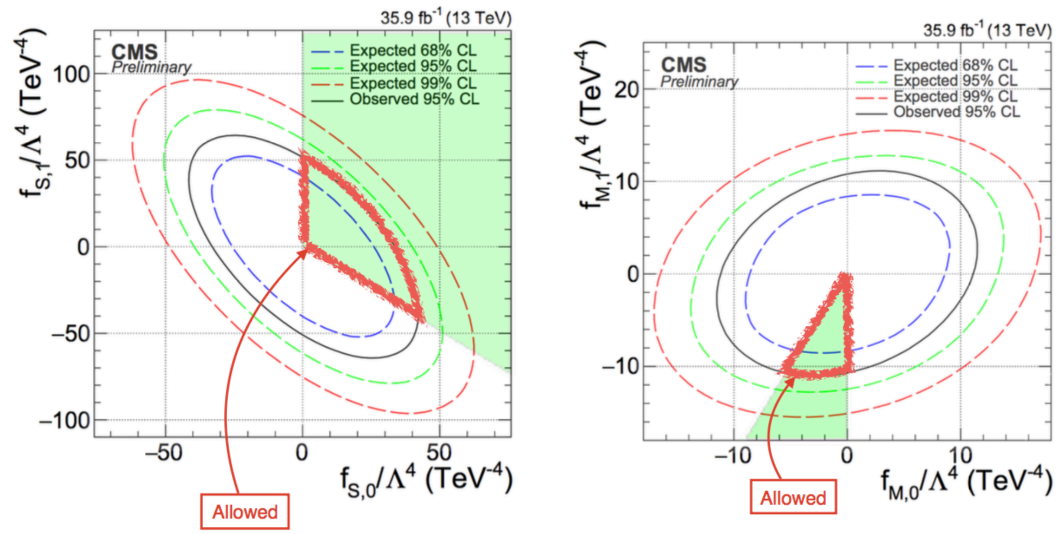
3. SMEFT 高维算符的几何结构

C. Zhang and S.-Y. Zhou, “A convex geometry perspective to the (SM)EFT space,” **PRL 125, 201601 (2020)**

- Positivity bound：量子场论基本原理 -> dim-8 算符系数满足一系列齐次不等式。
  [Q. Bi, CZ, S.-Y. Zhou, JHEP 19]

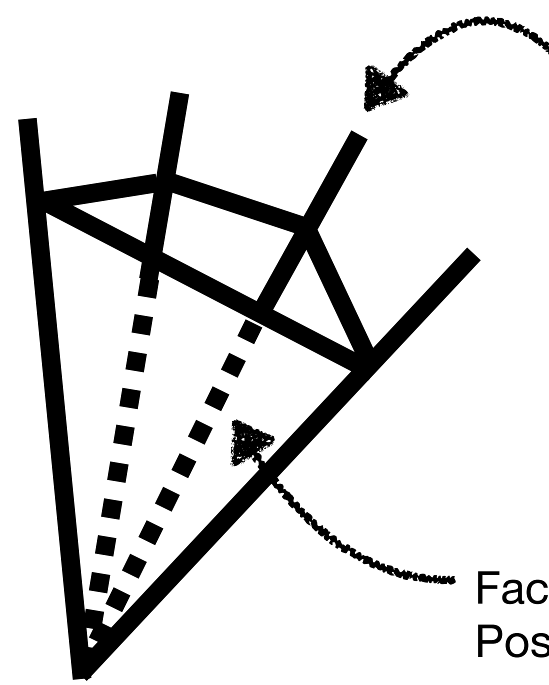


  - 四玻色子 aQGC 参数空间限制到~2%。
    Invited talk at Multi-Boson Interaction 2019。



Positivity restricts the directions in which SM deviation is possible

- **凸体几何为研究 dim-8 参数空间提供新的视角**
  - Krein-Milman 定理：用“极射线”描述允许的参数空间一凸锥。
  - “Vertex enumeration” 推导更紧的限制。
    E.g. 0.681% for transversal QGC.
  - 凸锥的棱，面等结构对应特殊 UV-completion：从测量系数反推 UV 粒子量子数。



Edges:
SM + 1 UV particle
(UV model uniquely determined)

Facets:
Positivity bounds

3. SMEFT 高维算符的几何结构

C. Zhang and S.-Y. Zhou, “A convex geometry perspective to the (SM)EFT space,” **PRL 125, 201601 (2020)**

- Positivity bound：量子场论基本原理 -> dim-8 算符系数满足一系列齐次不等式。
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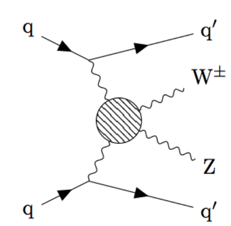

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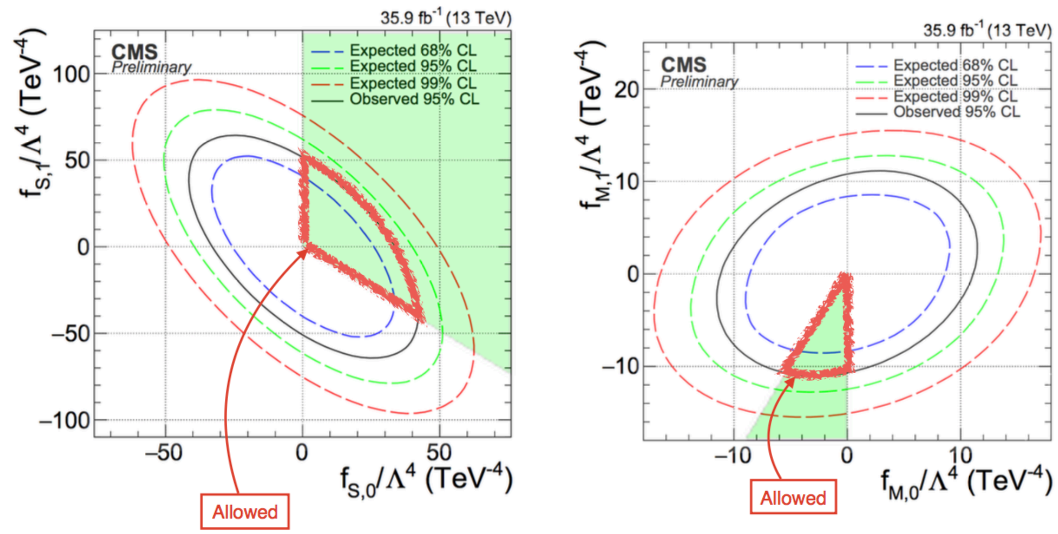
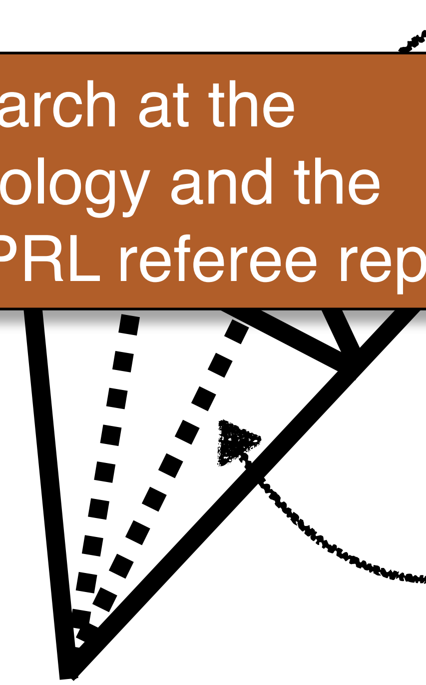


Positivity restricts the directions in which SM deviation is possible

- **凸体几何为研究 dim-8 参数空间提供新的视角**
  - Krein-M… 数空间…
  - “Vertex enumeration”推导更紧的限制。E.g. 0.681% for transversal QGC.
  - 凸锥的棱，面等结构对应特殊 UV-completion：从测量系数反推 UV 粒子量子数。

“opens new directions for interesting research at the intersection of particle physics phenomenology and the mathematical field of convex geometry” (PRL referee report)



3. SMEFT 高维算符的几何结构

- 新的 positivity 方法1："极表示方法" (VBS and aQGC: Snowmass LOI submitted)

  [K. Yamashita, **CZ**, S.-Y. Zhou, 2009.04490]

- 其它对撞机物理应用：

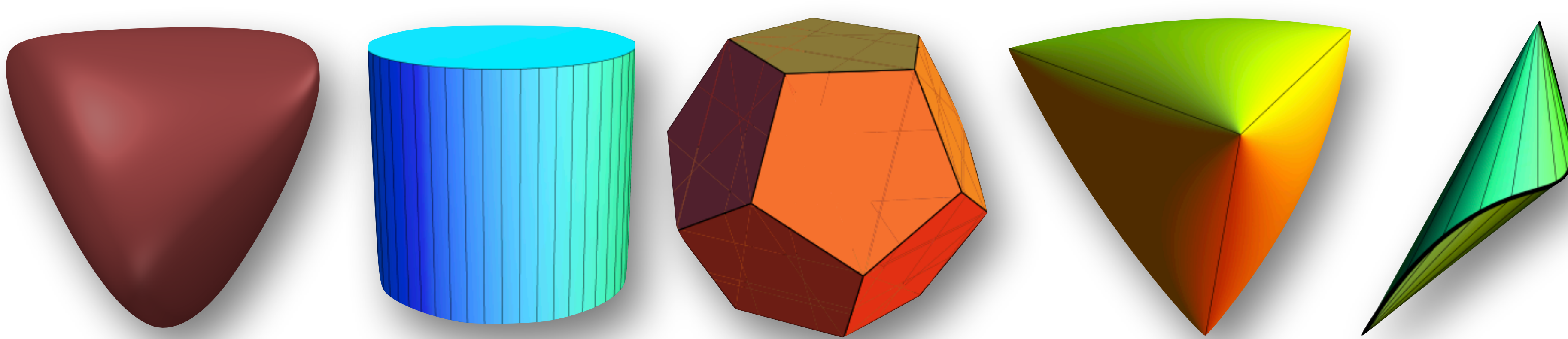
  - 在 CEPC，ILC 等检验 positivity -> 检验量子场论基本原理

    [J. Gu, L.-T. Wang and **CZ,** 2011.03055]

  - Inverse problem: 通过精确测量反推 UV 粒子存在的限制

    [B. Fuks, Y. Liu, **CZ**, S.-Y. Zhou, 2009.02212]

- 新的 positivity 方法2：光谱面 + 半正定规划 (ongoing with 黎栩，杨成杰)



学术交流情况

会议 / 学术报告情况

大会报告

- *“Higgs and top quark physics”*
  11/7/2020 The 6th China LHC Physics Workshop (CLHCP2020), Tsinghua University
- *“Precision quest in interpretation: SMEFT at higher orders”*
  9/2/2020 QCD@LHC-2020, CERN
- *“Single top production via FCNC couplings”*
  1/17/2020 3rd FCC Physics and Experiments Workshop CERN, Geneva
- *“EFT at NLO”*
  “Positivity constraints for SMEFT operator coefficients”
  8/26,27/2019 Multi-Boson Interactions 2019
- *“Electroweak fits and H properties and EFT”*
  7/29/2019 Higgs Hunting 2019

会议 / 学术报告情况

其它会议报告

- “A convex geometry perspective to the SMEFT space”
  5/29/2020 24th Mini-workshop on the frontier of LHC, CHEP, Peking University
- “Positivity bounds on aQGC”
  7/2/2020 Snowmass EF04 Topical Group Community Meeting
  7/8/2020 **Snowmass EF preparatory joint Topical Group sessions** on “Open questions and News Ideas”
- “Elastic positivity vs extremal positivity bounds in SMEFT:
  a case study in transversal electroweak gauge-boson scatterings”
  11/4/2020 VBSCan WG1 periodic meeting
- “Top FCNC at future lepton colliders”
  12/5/2020 Snowmass EF04 Topical Group Community Meeting

会议 / 学术报告情况

学术研讨会

- “The positive structures in SMEFT: polytopes, cones, spectrahedrons, and the physics implication”
  10/12/2020 **KIAS**, “2020 Fall KIAS HEP Seminar Series”

- “Convex Geometry in Standard Model Effective Field Theory”
  10/23/2020 **University of Science and Technology of China**

- “Positivity Bounds in Standard Model Effective Field Theory”
  11/24/2020 **Shanghai Jiaotong University**
  11/27/2020 **Nankai University**
  12/2/2020 **Technion,** “Israeli Joint Particle Physics Meetings, Spring-Summer 2020”

All things EFT

https://sites.google.com/view/all-things-eft
https://indico.ihep.ac.cn/event/12712/

“All Things EFT” international online seminar series.
(with A. Biekoetter, C. Burgess, M. Levi, A. Martin, T. Melia, W. Shepherd, M. Trott, and H. X. Zhu)

ALL *THINGS* EFT...

ABOUT

To allow researchers in the **global Effective Field Theory community** to connect and share their work,

All Things EFT is launched as a weekly **international online lecture series** in **fall 2020,** on September 30th.

Topics include **all aspects of EFTs** such as SMEFT, HEFT, LEFT, Dark Matter EFT, EFTs of gravity, SCET, ...

The lectures will be held via zoom. To receive the link to the zoom room, please subscribe below.

FORMAT

Lectures will be **weekly** on **Wednesdays** at

4pm CET (Geneva) = 10am EST (New York) = 7am PST (Los Angeles) = 11pm CST (Beijing)

Please note the time shift due to daylight saving time!

Lecture Format: 1h plenary-style talk + discussion

One of the opening slides should specify for a **broad audience**:

1) the field content and symmetries and 2) an expansion parameter, i.e. the **EFT(s) of interest**.

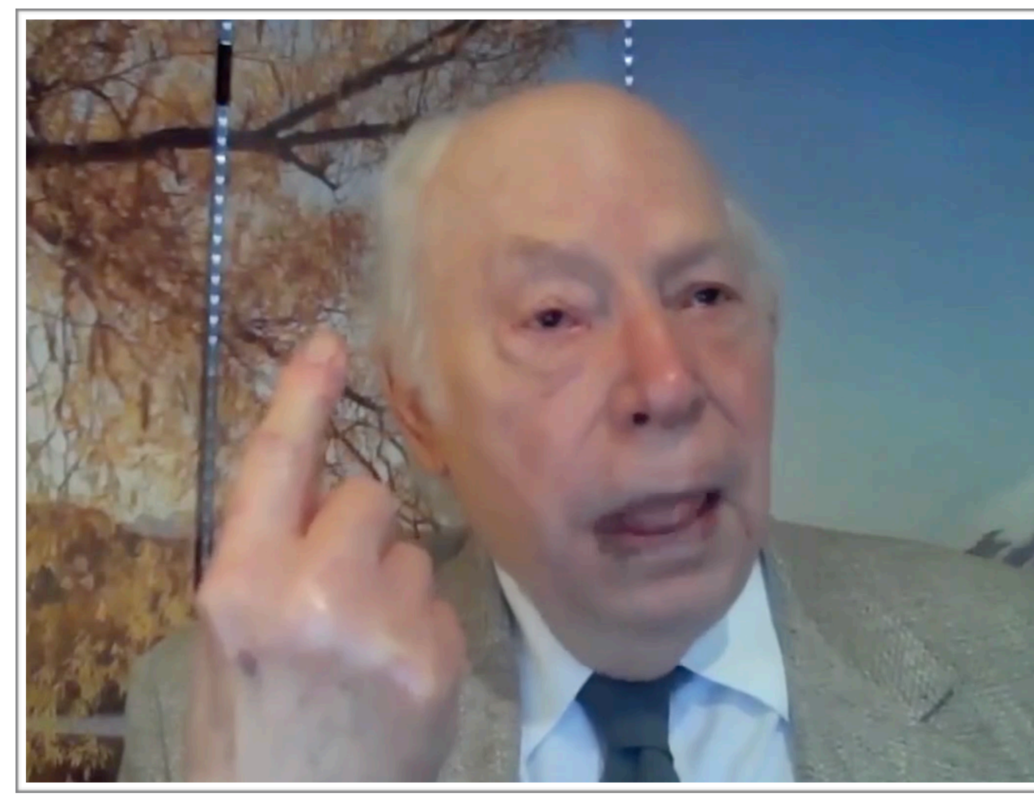
PAST LECTURES

- **Steven Weinberg** (U. Texas Austin)
- **Aneesh Manohar** (UCSD)
- **Matthias Neubert** (Mainz & Cornell)
- **Henriette Elvang** (Michigan)
- **Lian-Tao Wang** (Chicago)
- **Xiaochuan Lu** (Oregon)
- **Claudia de Rham** (Imperial College London)
- **Tim Cohen** (Oregon)

UPCOMING LECTURES

- **Arsenii Titov** (Padua/Valencia)
- **Yael Shadmi** (Technion)
- **Roberto Emparan** (Barcelona)
- **Xiangdong Ji** (Maryland)
- **Walter Goldberger** (Yale)
- **Francesco Riva** (Geneva)
- **Nima Arkani-Hamed** (IAS)

Steven Weinberg, Inaugural Lecture:
On the development of Effective Field Theory



组织会议 / 暑期学校

- MCnet School 2020 （因疫情取消）
- Lecture: “Signal Simulation for BSM and EFT”

  7/18/2020 CHEP Summer School 2020, Peking University
- Electroweak parallel session convener, 2020 CEPC workshop, October 2020.

- **2021年计划**
  - MCnet School 2021 MCnet
  - Higgs and Effective Field Theory 2021

基金情况

- 顶夸克和希格斯玻色子的精准唯象研究，50万，2017-2020。
- 海外人才引进计划青年项目，200万，2018-2020。
- 与法国 LPTHE ／索邦大学的合作课题 TopFCNC@CEPC 获得中法粒子物理实验室 FCPPL 资助。
- Kimiko Yamashita 博士获得国际人才计划 PIFI 资助，2019-2021。

2020 基金申请

- 获得国家自然科学基金面上项目资助，课题“Systematic study for loop-induced processes in SMEFT, their simulation tools and phenomenological aspects”，63万，2021-2024。
- 参与国家自然科学基金重点项目，课题“The EFT study for BSM physics”，316万，申请人廖益，2021-2025。

小结和展望

- 文章情况 1PRL + 1CPC + 3JHEP + 3。
- NLO QCD 精度 SMEFT 全自动事例产生器基本完成。
    - 未来将继续保持优势，考虑电弱修正的自动化。
    - 发展适用于 e+e- 对撞的自动事例产生子。
- LHC Top + Higgs 测量的全局拟合基本完成。
    - 未来考虑成立 SMEFiT 合作组，定期更新 LHC 最新数据 + SM/EFT 理论结果。
- 提出利用凸几何研究 SMEFT 的新方法：极表示 + 光谱面。
    - 将继续探索新的理论方法在对撞机或精确测量实验中的应用。

谢谢！