Les Houches Session 1, 2019 19 June 2019

Higgs Summary (TH)

Conveners:
(TH) Daniel de Florian, Stephen Jones

Higgs Summary (TH)

- Higgs + Jet

  fiducial region with decay in two photons

- Top Mass Scheme Uncertainties

- EFT interpretation of Higgs measurements

- EFT for HH @ NNLO

- Photon Isolation

H+Jet Improved Fiducial Predictions

H+Jet known:

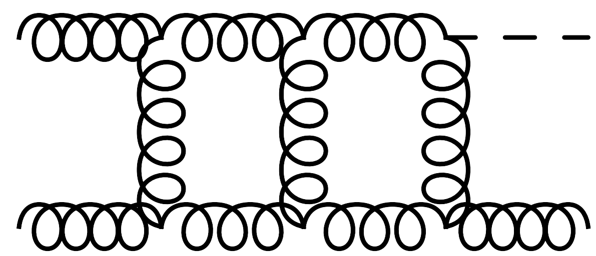
1) NNLO QCD (HTL)

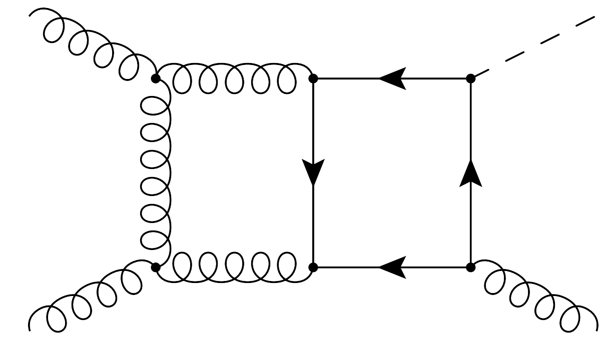
Chen, Gehrmann, Glover, Jaquier 14; Boughezal, Caola, Melnikov, Petriello, Schulze 15; Boughezal, Focke, Giele, Liu, Petriello 15; Campbell, Ellis, Seth 19

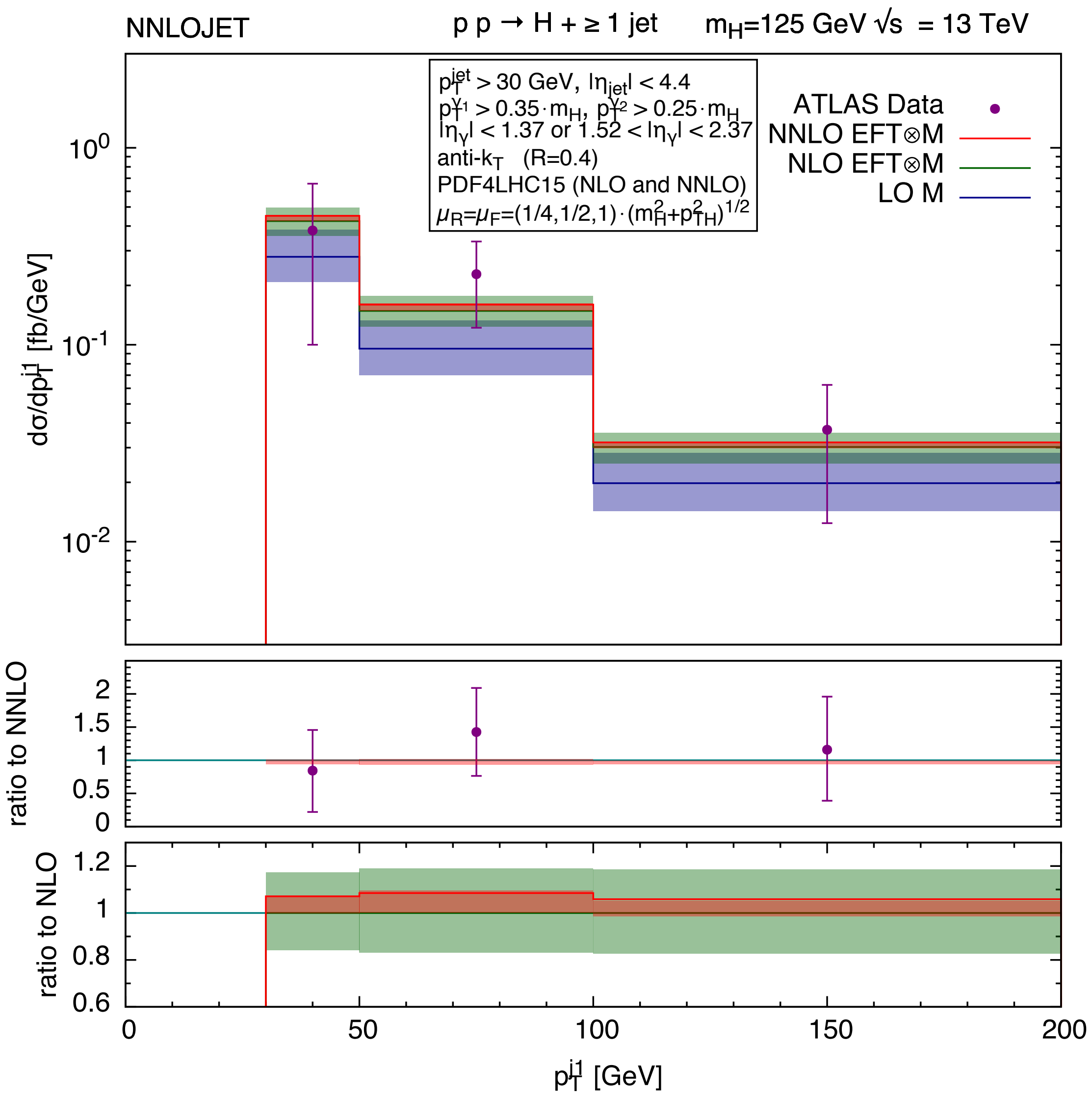
2) NLO QCD (full m_T dependence)

Jones, Kerner, Luisoni 18

S.Jones, X.Chen and J.Huston @ Les Houches







Chen, Cruz-Martinez, Gehrmann, Glover, Jaquier 16

At large p_T the $m_T \to \infty$ approx fails:

Rescale NLO by $K_{NNLO} = NNLO_{HTL}/NLO_{HTL}$

$$\frac{d\sigma^{\text{EFT-improved (1), NNLO}}}{dp_\perp} = \frac{\frac{d\sigma^{\text{QCD, NLO}}}{dp_\perp}}{\frac{d\sigma^{\text{EFT, NLO}}}{dp_\perp}} \frac{d\sigma^{\text{EFT, NNLO}}}{dp_\perp}$$

Project:

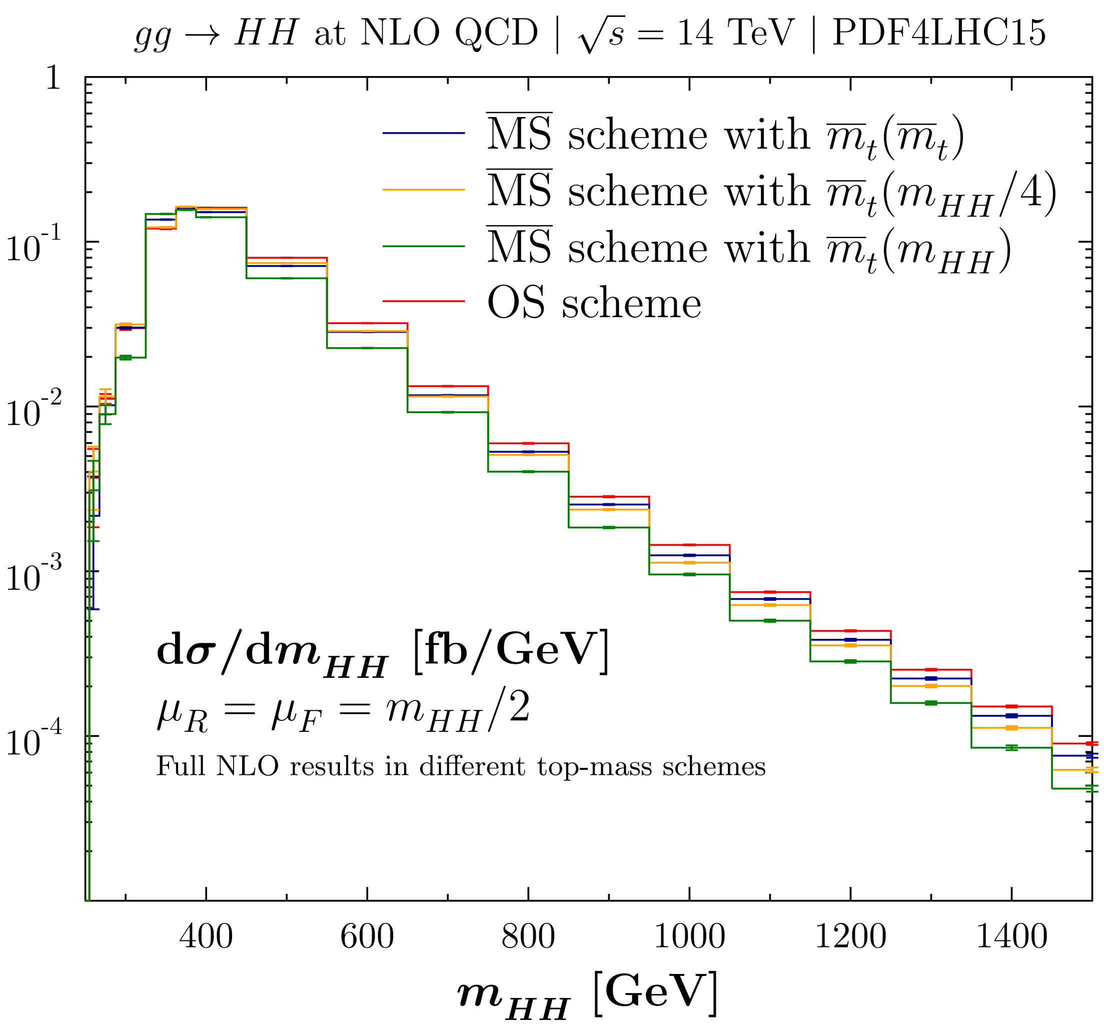
Produce NLO improved NNLO predictions for $H \to \gamma\gamma$ with fiducial cuts, study impact at high p_T

Interested Participants:

Stephen Jones, Xuan Chen, Joey Huston

Top Mass Scheme Uncertainties

HH production



Baglio, Campanario, Glaus, Mühlleitner, Spira, Streicher 18

M.Spira @ Les Houches

- transform $m_t \to \overline{m}_t(\mu)$ ($\overline{\mathrm{MS}}$)

  $\to$ modification of mass CT

- use m_t, $\overline{m}_t(\overline{m}_t)$ and scan $Q/4 < \mu < Q$

  uncertainty = envelope

$$\frac{d\sigma(gg \to HH)}{dQ}\Big|_{Q=300~\mathrm{GeV}} = 0.031(1)^{+10\%}_{-22\%}~\mathrm{fb/GeV},$$

$$\frac{d\sigma(gg \to HH)}{dQ}\Big|_{Q=400~\mathrm{GeV}} = 0.1609(4)^{+7\%}_{-7\%}~\mathrm{fb/GeV},$$

$$\frac{d\sigma(gg \to HH)}{dQ}\Big|_{Q=600~\mathrm{GeV}} = 0.03204(9)^{+0\%}_{-26\%}~\mathrm{fb/GeV},$$

$$\frac{d\sigma(gg \to HH)}{dQ}\Big|_{Q=1200~\mathrm{GeV}} = 0.000435(4)^{+0\%}_{-30\%}~\mathrm{fb/GeV}$$

preliminary interpolation:

$$\sigma_{NLO} = 32.78(7)^{+13.5\%}_{-12.5\%}~fb$$

"usual" uncertainty

need to combine them

$$\sigma(gg \to HH) = 32.78^{+4\%}_{-17\%}~\mathrm{fb}$$

extra top mass uncertainty

CONCLUSIONS

M.Spira @ Les Houches

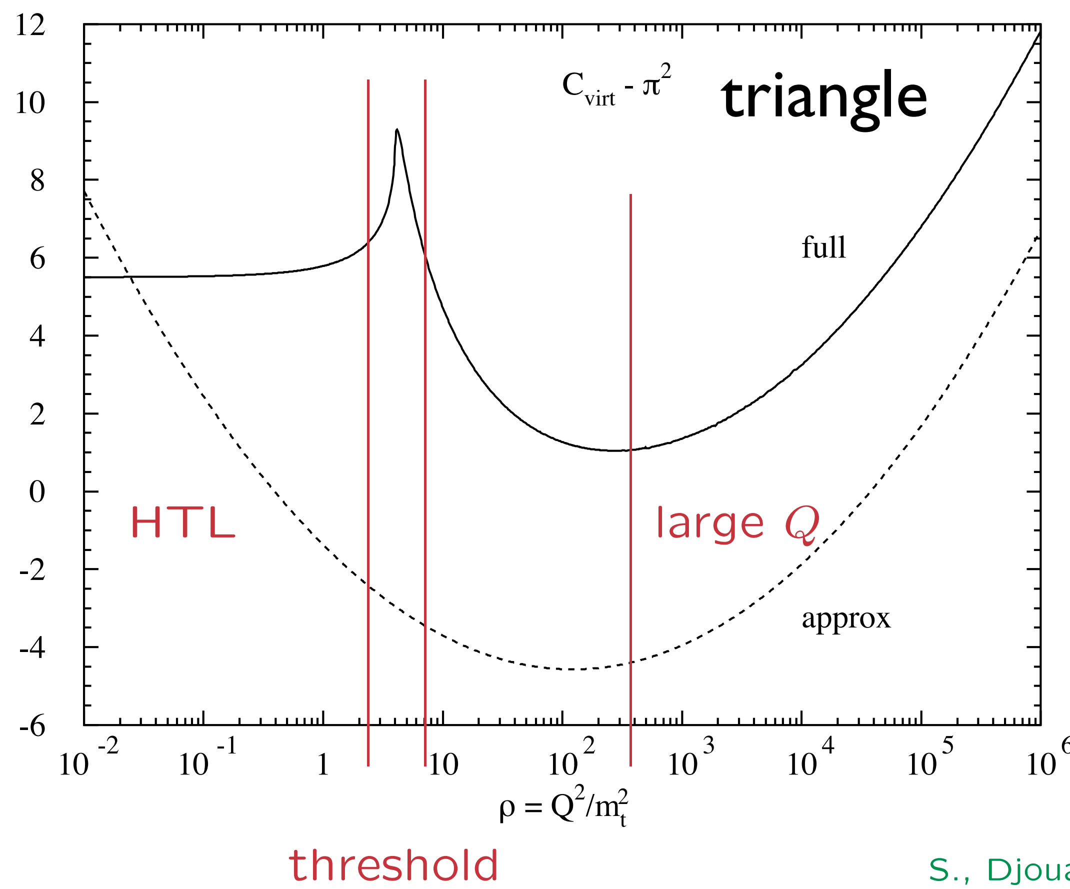
- Higgs pair production at full NLO for variable top/Higgs masses [top loops]
- top mass effects on top of LO up to 20–30%
- factorization/renormalization scale uncertainties $\sim$ 15%
- uncertainties due to scale/scheme choice of m_t sizeable $\lesssim$ 30% $\to$ reduction unclear

▸ Higher order would reduce uncertainty: very complicated…

3 loop amplitude with m_T

▸ Resummation of these effects far from trivial different regions need different treatments

Investigate small Q with $1/m_T$ expansion



Top Mass Scheme Uncertainties : what about single Higgs?

$$\sigma(gg \to H)|_{M_H=125\ \text{GeV}} = 42.17^{+0.4\%}_{-0.5\%}\ \text{pb}$$

very small for on-shell H

$$\sigma(gg \to H)|_{M_H=300\ \text{GeV}} = 9.85^{+7.5\%}_{-0.3\%}\ \text{pb}$$

$$\sigma(gg \to H)|_{M_H=400\ \text{GeV}} = 9.43^{+0.1\%}_{-0.9\%}\ \text{pb}$$

$$\sigma(gg \to H)|_{M_H=600\ \text{GeV}} = 1.97^{+0.0\%}_{-15.9\%}\ \text{pb}$$

$$\sigma(gg \to H)|_{M_H=900\ \text{GeV}} = 0.230^{+0.0\%}_{-22.3\%}\ \text{pb}$$

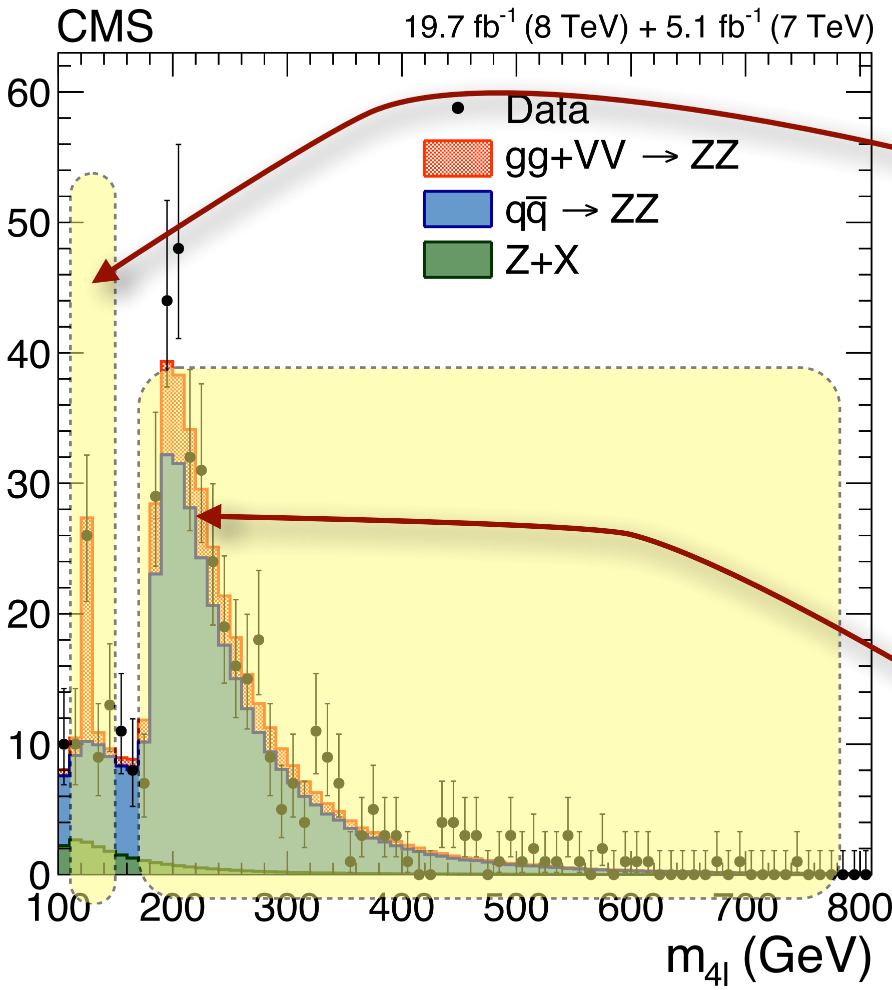
$$\sigma(gg \to H)|_{M_H=1200\ \text{GeV}} = 0.0402^{+0.0\%}_{-26.0\%}\ \text{pb}$$

(almost) nobody cared

- In principle not much a problem since 125 GeV Higgs is light
- But off-shell production becomes relevant for extraction of Higgs width

Width measurement from off-shell

$gg \to H \to VV$



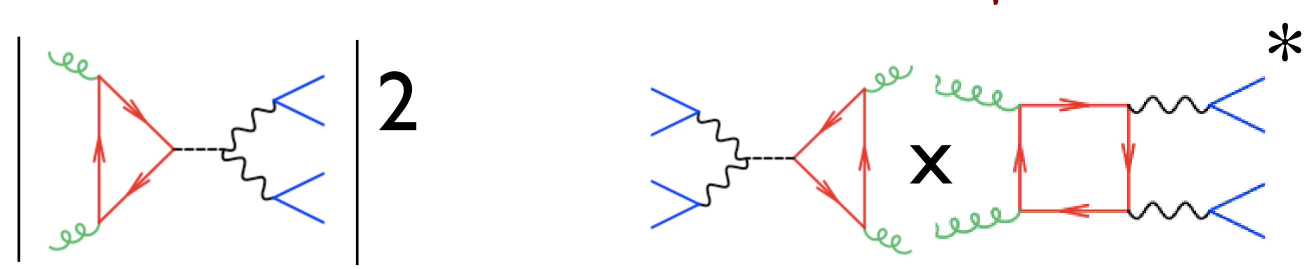
$$\sigma^{\rm on} \quad \int_{M_H^2-\Delta^2}^{M_H^2+\Delta^2} dq^2 \frac{|A_{gg\to H\to VV}|^2}{(q^2-M_H^2)+\Gamma_H^2 M_H^2} \sim \frac{g_{ggH}^2(M_H^2)\, g_{HVV}^2(M_H^2)}{\Gamma_H}$$

SM assumptions on couplings (running)

$$g = \xi\, g^{SM}$$
$$\Gamma_H = \xi^4\, \Gamma_H^{SM}$$

$$\sigma^{\rm off} \int_{q^2 \gg M_H^2} dq^2 \frac{|A_{gg\to H\to VV}|^2}{(q^2-M_H^2)+\Gamma_H^2 M_H^2} \sim \int dq^2 g_{ggH}^2(q^2)\, g_{HVV}^2(q^2)$$

$$\sigma^{\rm exp} = \sigma^{\rm back} + \sigma^{\rm on} + \sigma^{\rm off} \times \frac{\Gamma_H}{\Gamma_H^{SM}} + \sigma^{\rm int} \times \sqrt{\frac{\Gamma_H}{\Gamma_H^{SM}}}$$

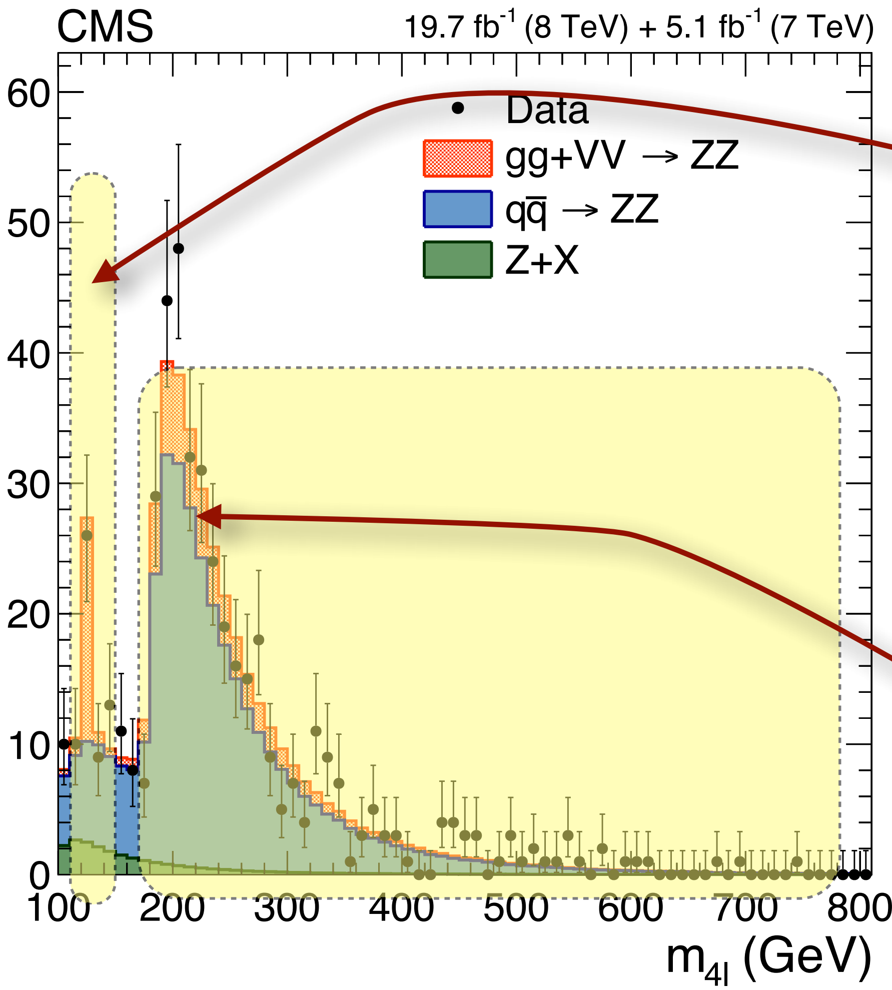


CMS

$3.2^{+2.8}_{-2.2}$ MeV

dF @ LH

Width measurement from off-shell $gg \to H \to VV$



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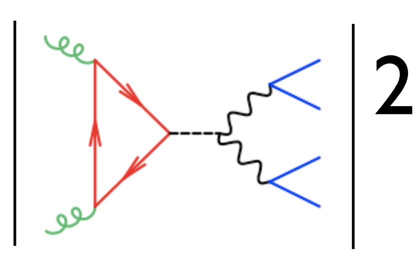
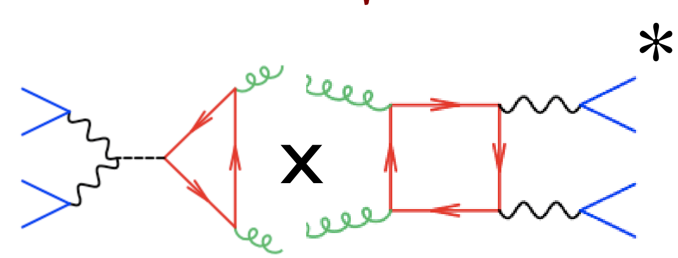


Δ_{m_T}



$\sim \sqrt{\Delta_{m_T}}$?

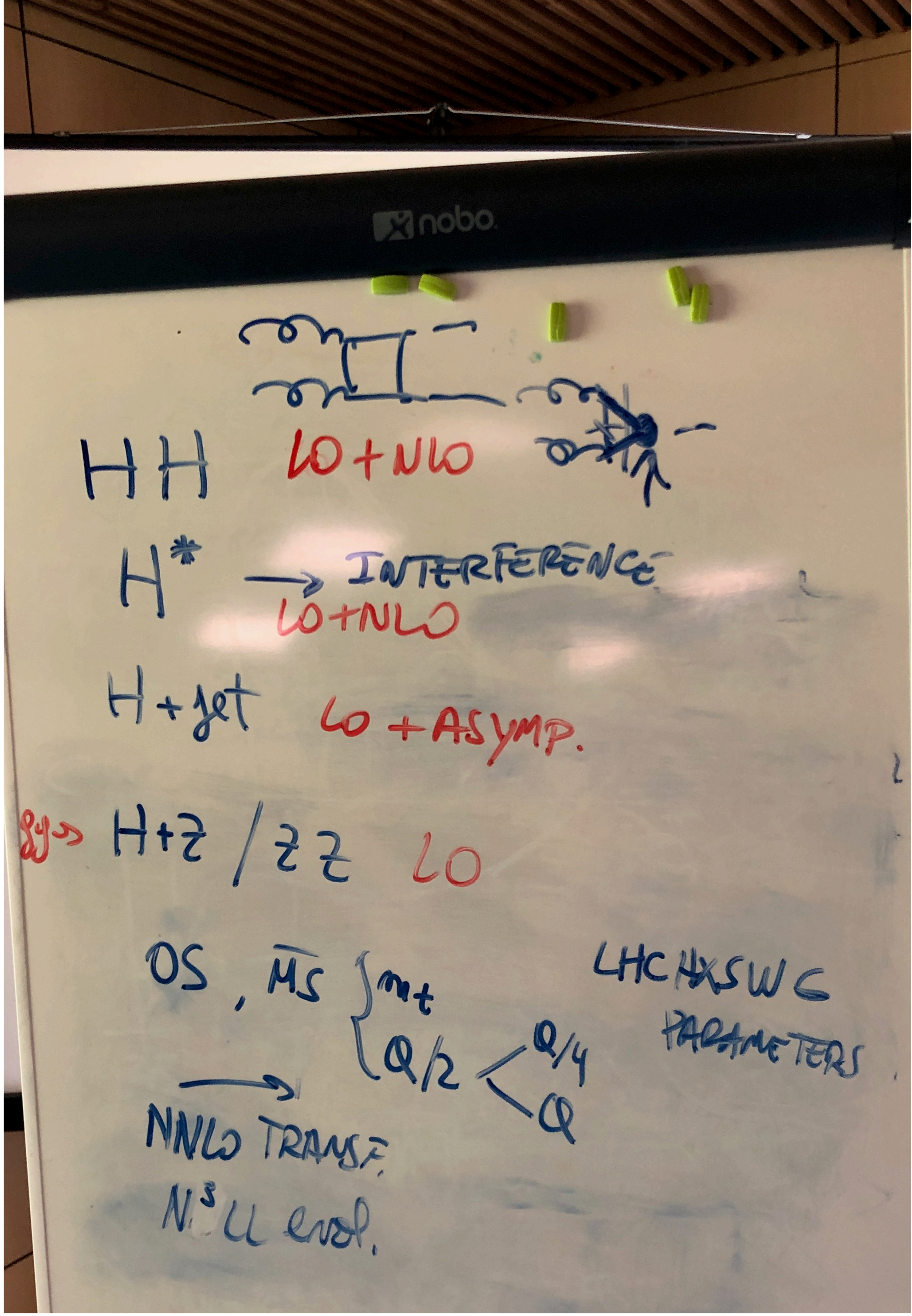
dF @ LH

- Look at other processes and Characterise the problem

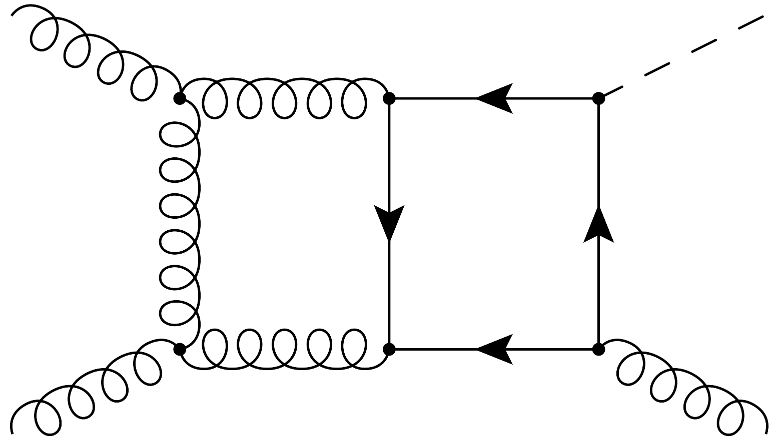
- How large is the uncertainty induced by m_T definition?

- Call the attention!

- Many open issues



Higgs + Jet



S.Jones and R.Röntsch
@ Les Houches

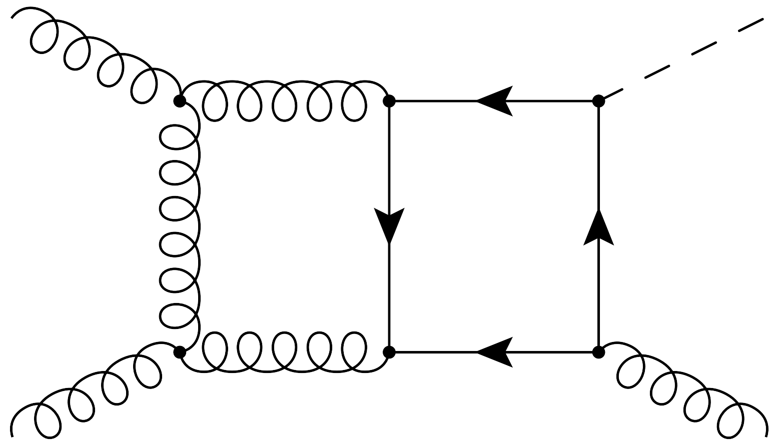
LO — SPJ, Kerner, Luisoni 18

NLO (full available but no m_T variation possible yet)

NLO asymptotic result $m_H^2, m_T^2 \ll |s| \sim |t| \sim |u|$

(Lindert), Kudashkin, Melnikov, Wever 17,18; Neumann 18

Higgs + Jet



S.Jones and R.Röntsch @ Les Houches

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NLO asymptotic result $m_H^2, m_T^2 \ll |s| \sim |t| \sim |u|$

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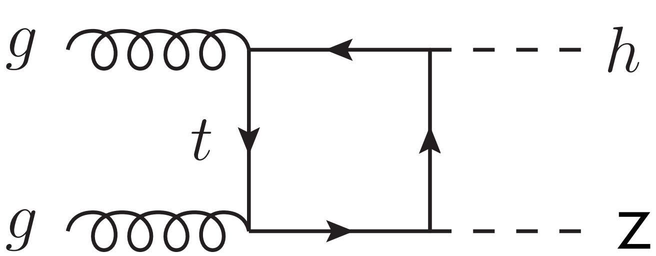
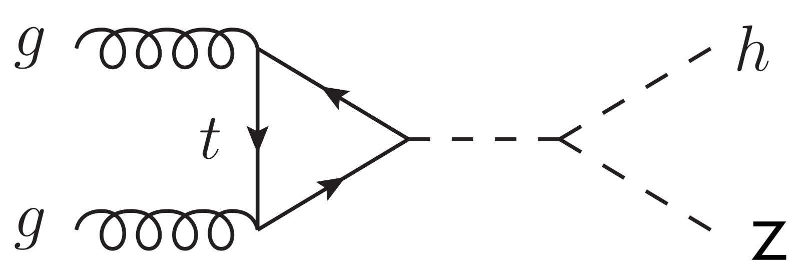
Higgs + Z





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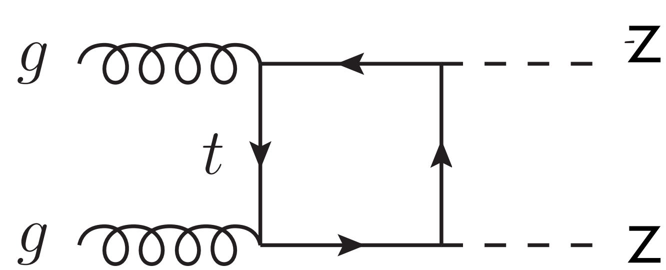
LO

and compare to gg -> ZZ



~ characterise impact of Yukawa and propagator

EFT interpretation of Higgs measurements

- Experiments moving from Anomalous Couplings to more general EFT approach to constrain new interactions at the LHC

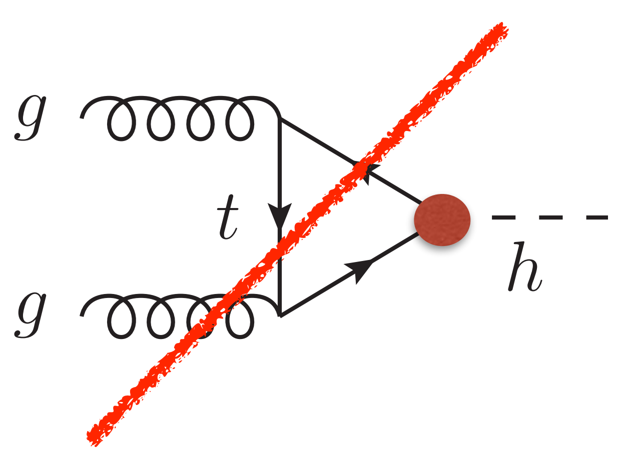
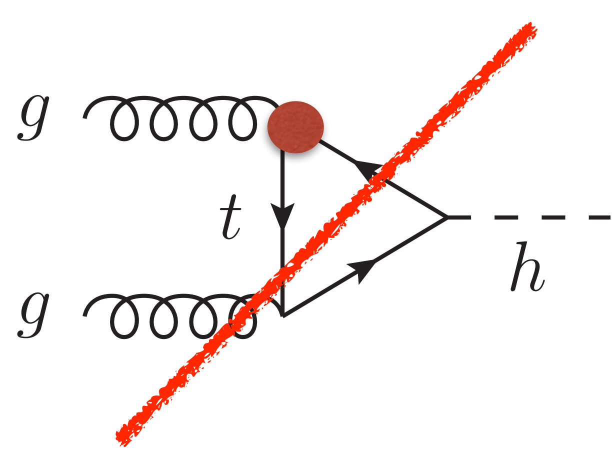
A. Cueto Gomez @ Les Houches

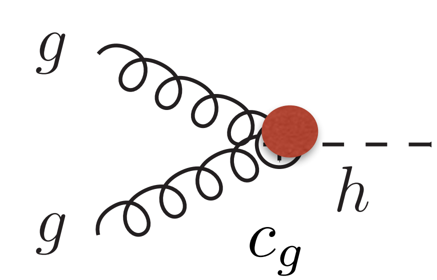
  - Warsaw basis agreed

$$\mathcal{L}_{\text{Eff}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{C_i^{(6)} O_i^{(6)}}{\Lambda^2} + \mathcal{O}(\Lambda^{-4})$$

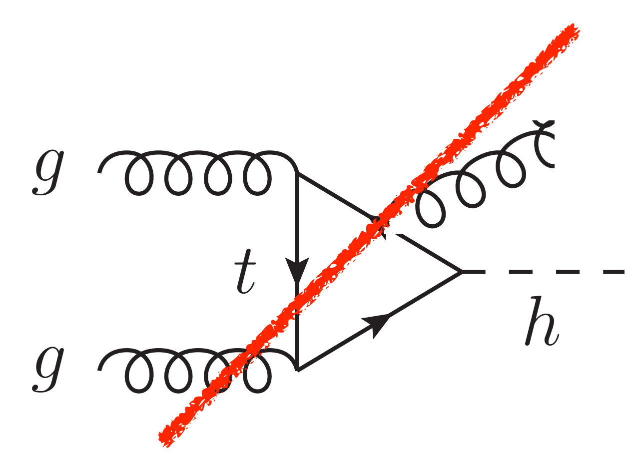
  - Number of tools to automatise calculations within SMEFT
    - none of them is yet "fully complete"

SMEFTsim LO tool : consistent at LO accuracy (all operators but ~no loops)

ggH	cHG
	



H+J



Important physics can be missed if the LO is used for loop-induced processes

SMEFT@NLO   HH: talk by E.Vryonidou

- Automated calculation at NLO (madGraph) : including loops
- Recently released, 4 fermions operators at LO but work in progress

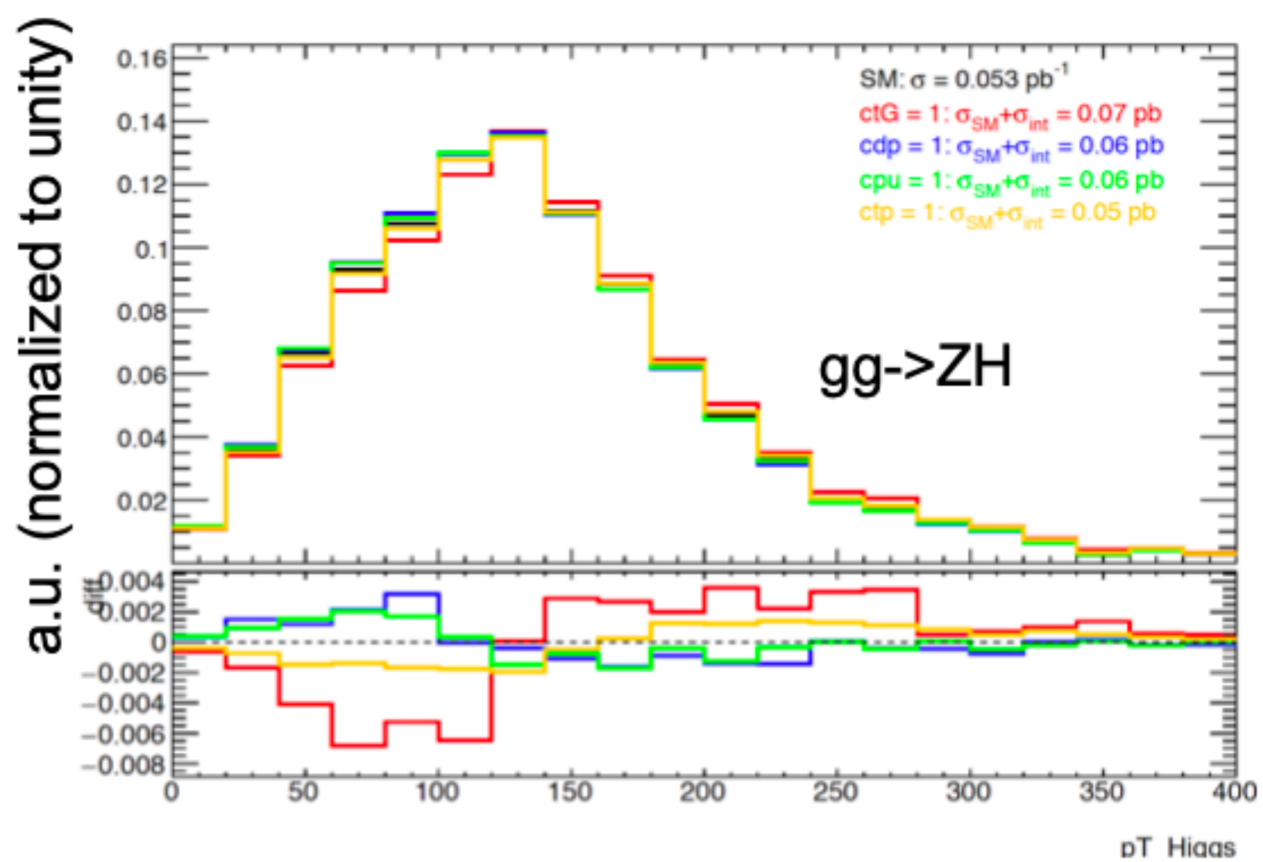
73 degrees of freedom (top, Higgs, gauge)

M.Moreno, M.Delmastro, A.Cueto, N.Berger, P.Francavilla, S.Falke, D.deF, M.Donega, J.McFayden @ LesHouches

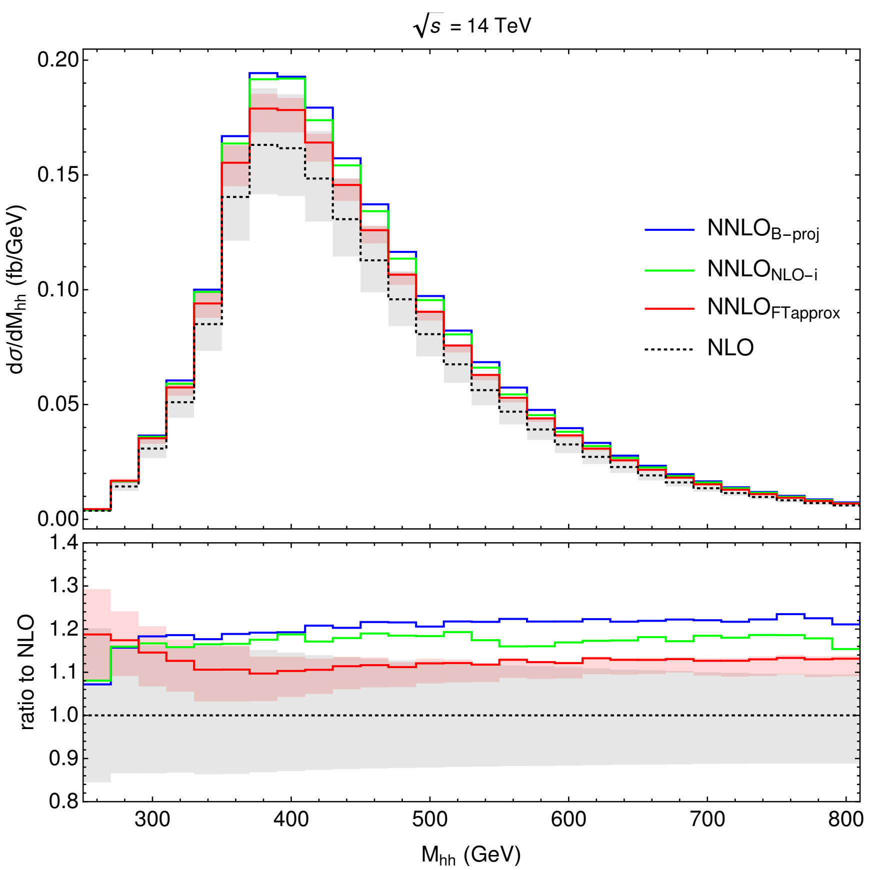
- Study of ggH and ggZH at NLO EFT
  In different variables
  With all Wilson coefficients
  Provide parametrization of STXS bins

- Check consistency of SMEFTsim and SMEFT@NLO running at LO

Process: p p > l+ l- h (5FS)		
	SMEFTsim	SMEFTatNLO
SM	0.02426 pb	0.02541 pb
cHW (=1, int)	0.01753 pb	0.01848 pb
cHB (=1, int)	0.002437 pb	0.002322 pb



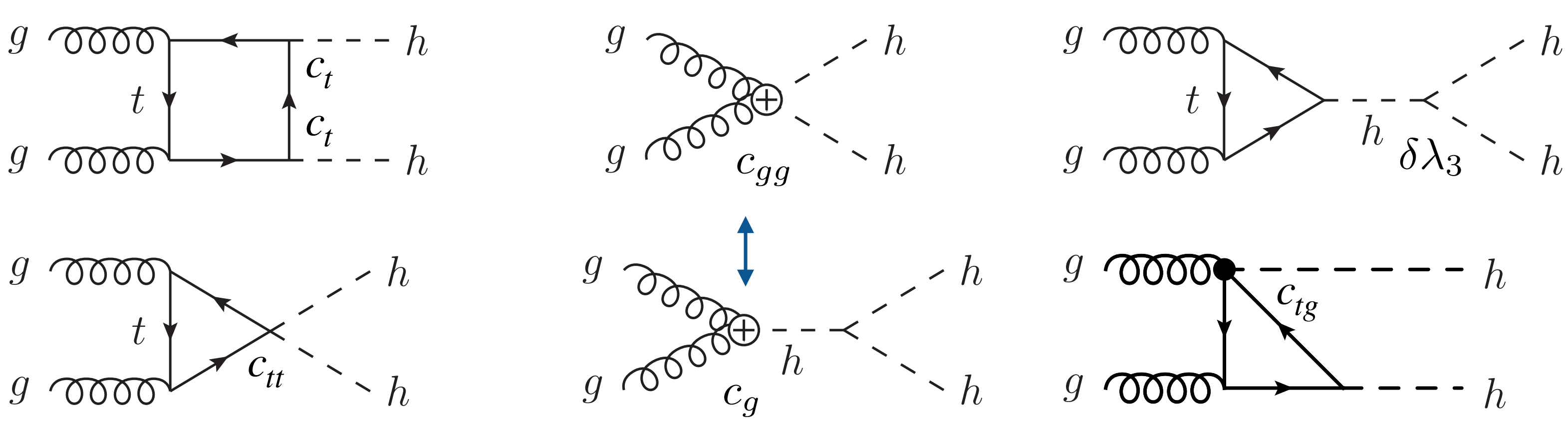
EFT for HH @ NNLO



- SM HH production
  - full m_T at NLO
  - HTL at NNLO

results combined using difference approximations NNLO HH cross section

- EFT HH production
  - full m_T at NLO
  - HTL at NNLO



J.Mazzitelli, S. Jones, DdeF @ Les Houches

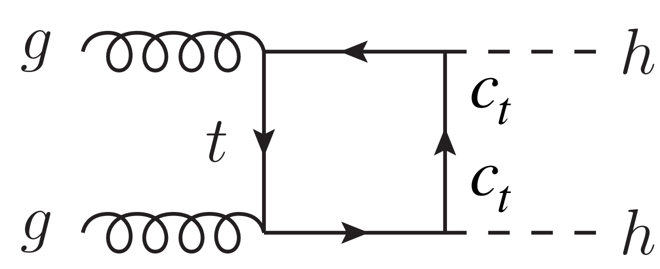
Combination applying $K_{NNLO} = NNLO_{HTL}/NLO_{HTL}$ to full m_T at NLO

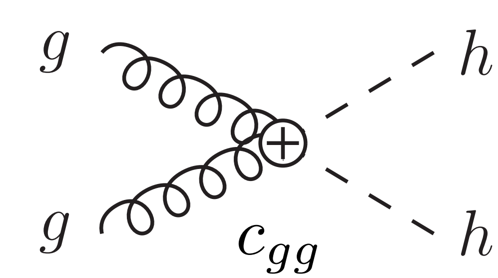
Benchmarks @ HXSWG

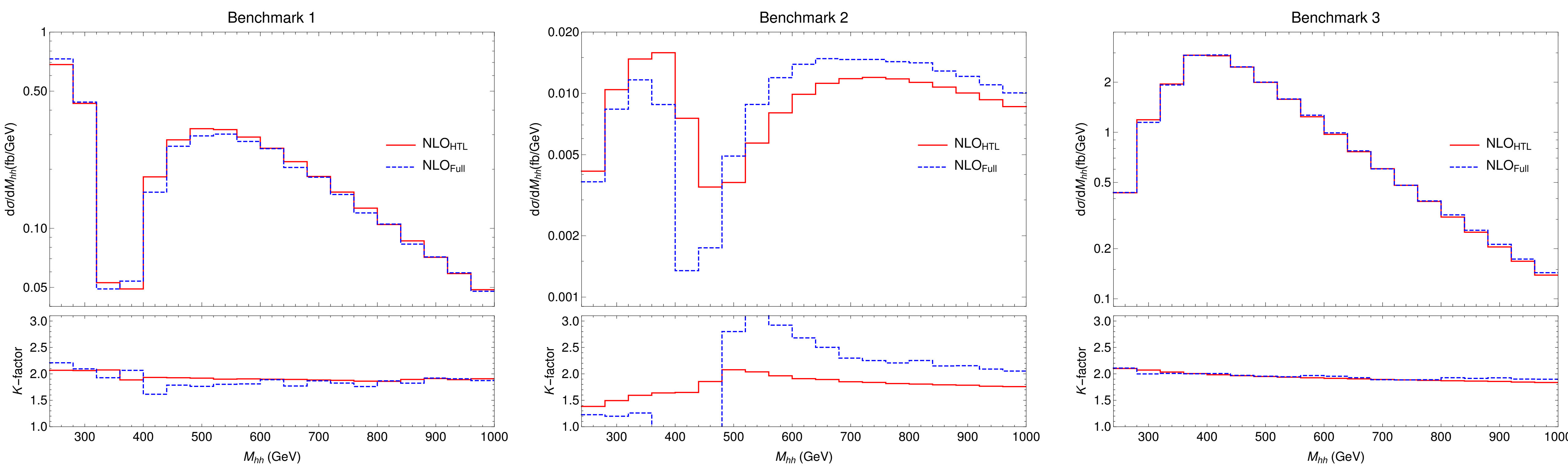
Benchmark	c_{hhh}	c_t	c_{tt}	c_{ggh}	c_{gghh}
1	7.5	1.0	-1.0	0.0	0.0
2	1.0	1.0	0.5	$-\frac{1.6}{3}$	-0.2
3	1.0	1.0	-1.5	0.0	$\frac{0.8}{3}$
4	-3.5	1.5	-3.0	0.0	0.0
5	1.0	1.0	0.0	$\frac{1.6}{3}$	$\frac{1.0}{3}$
6	2.4	1.0	0.0	$\frac{0.4}{3}$	$\frac{0.2}{3}$
7	5.0	1.0	0.0	$\frac{0.4}{3}$	$\frac{0.2}{3}$
8a	1.0	1.0	0.5	$\frac{0.8}{3}$	0.0
9	1.0	1.0	1.0	-0.4	-0.2
10	10.0	1.5	-1.0	0.0	0.0
11	2.4	1.0	0.0	$\frac{2.0}{3}$	$\frac{1.0}{3}$
12	15.0	1.0	1.0	0.0	0.0
SM	1.0	1.0	0.0	0.0	0.0

$$\mathcal{L} \supset -m_t \left(c_t \frac{h}{v} + c_{tt} \frac{h^2}{v^2} \right) \bar{t}\, t - c_{hhh} \frac{m_h^2}{2v} h^3 + \frac{\alpha_s}{8\pi} \left(c_{ggh} \frac{h}{v} + c_{gghh} \frac{h^2}{v^2} \right) G^a_{\mu\nu} G^{a,\mu\nu}$$

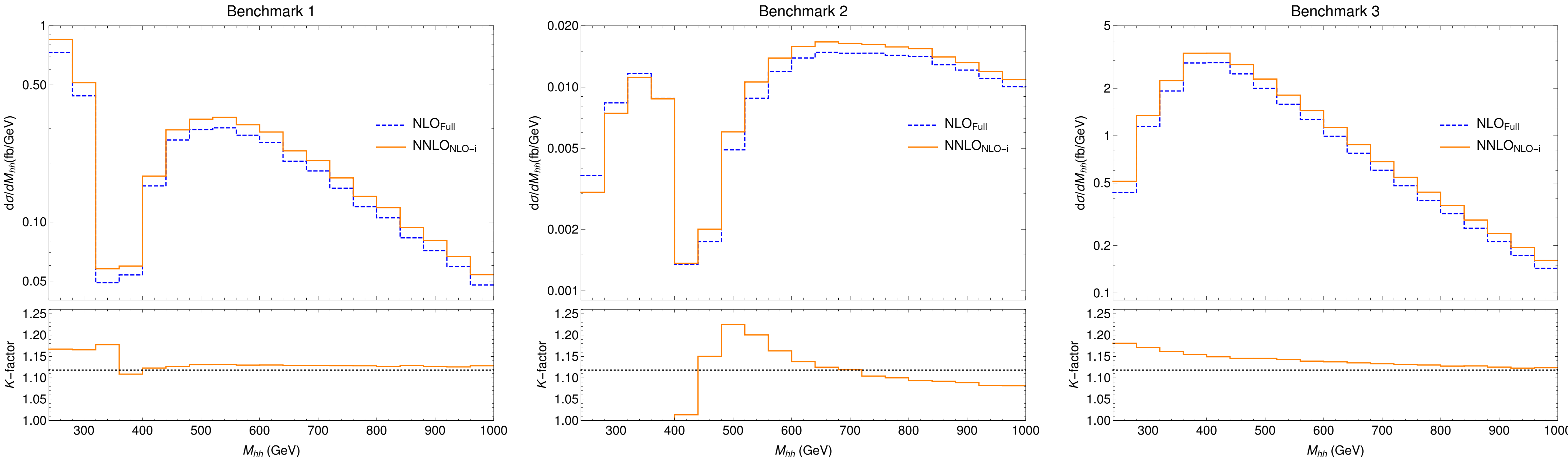
K factors @NLO : HTL vs full m_T





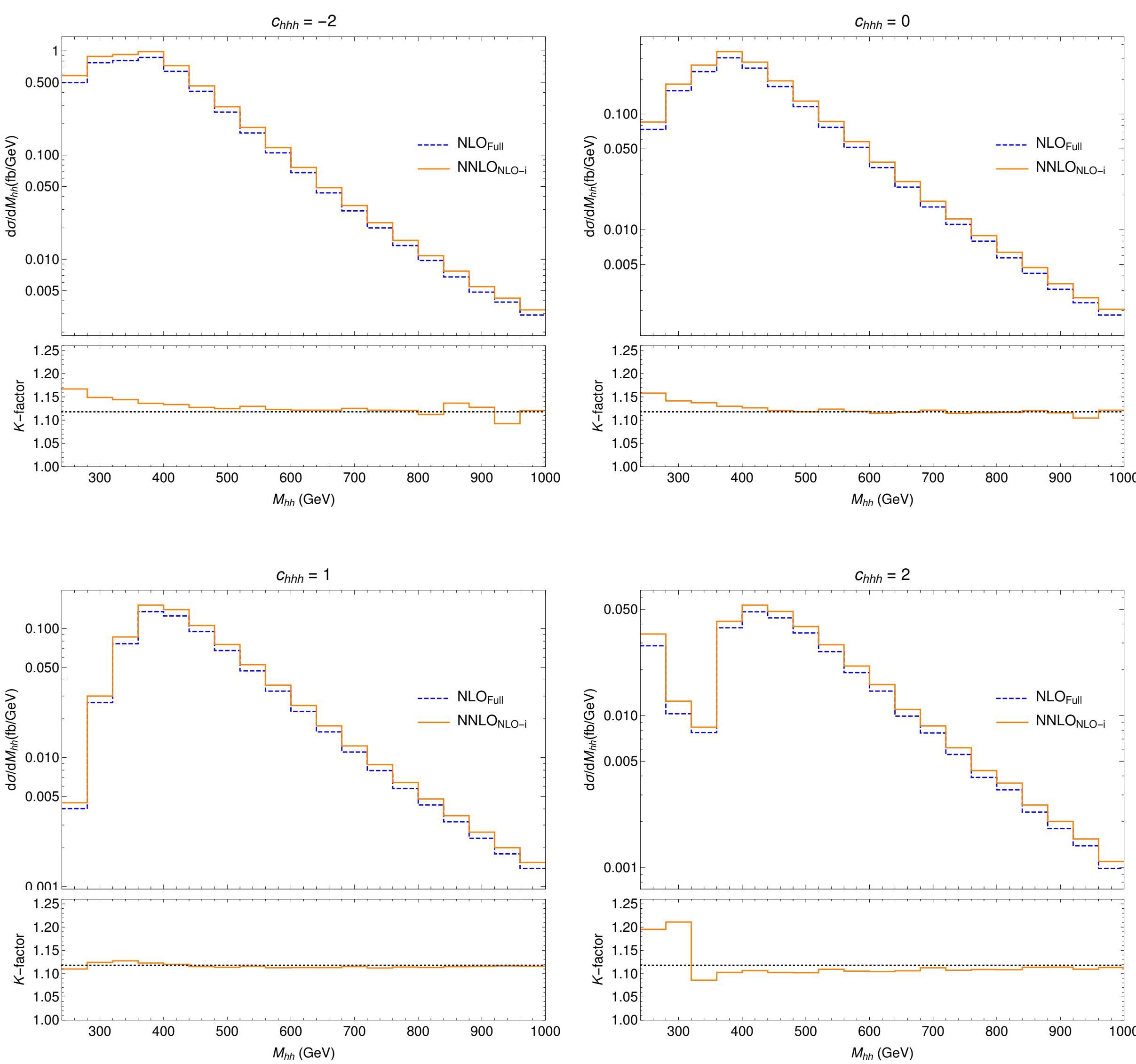


Sometimes very similar (depending on EFT parameters)



only variations on HHH coupling

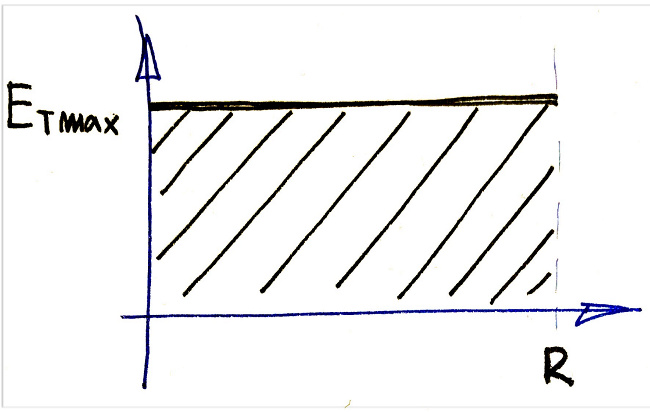
NNLO approx



- typically 10-15% NNLO corrections
- More exclusive distributions and NNLO$_{FT}$ approximation: match state of the art for SM

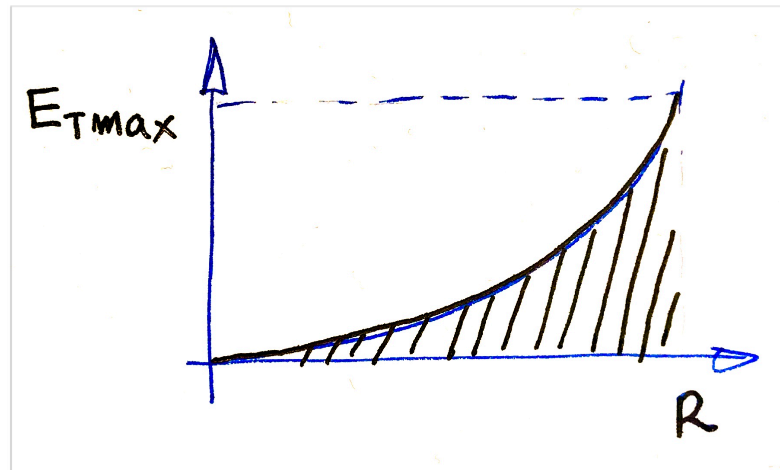
Photon Isolation

Standard



$$E_T^{had}(R) \leq E_{T\,\max}$$

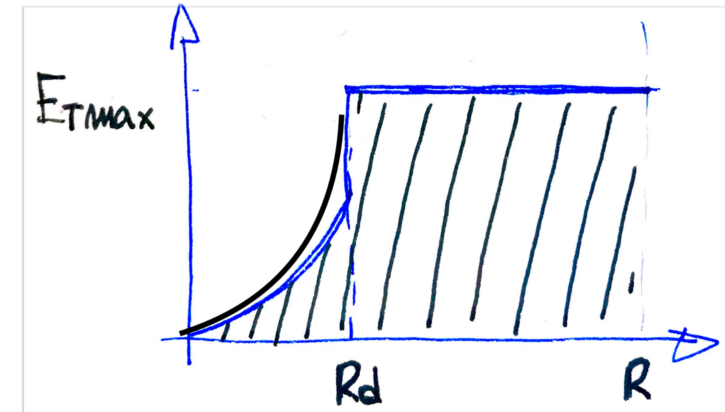
Smooth



$$E_T^{had}(r) \leq E_{T\,\max}\, \chi(r;R)\ ,$$

in *all* cones with $r \leq R$

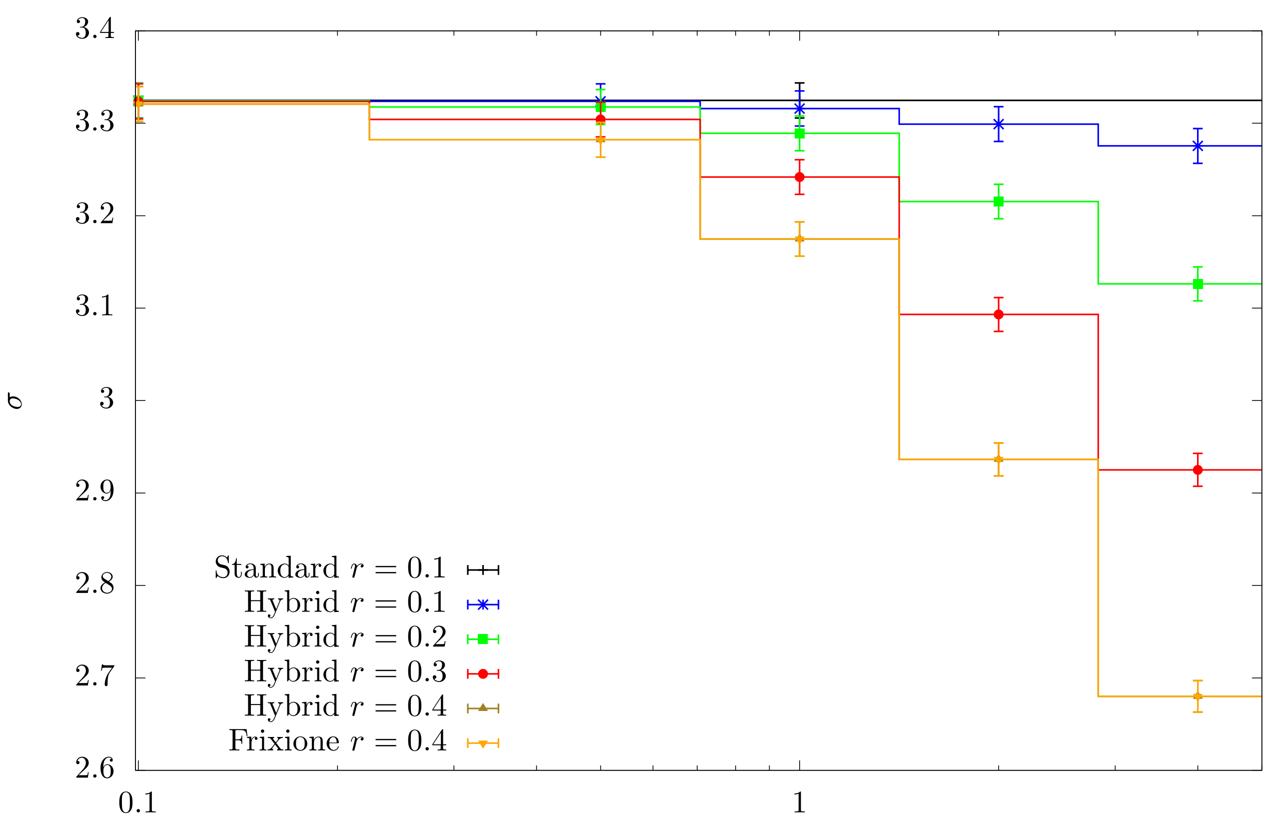
Hybrid



$$\chi(r;R) = \left(\frac{r}{R}\right)^{2n}$$

$$R_d \ll R$$

Implies: $d\sigma_{\text{smooth}}(R; E_{T\,\max}) < d\sigma_{\text{Hybrid}}(R; r_d, E_{T\,\max}) < d\sigma_{\text{standard}}(R; E_{T\,\max})$



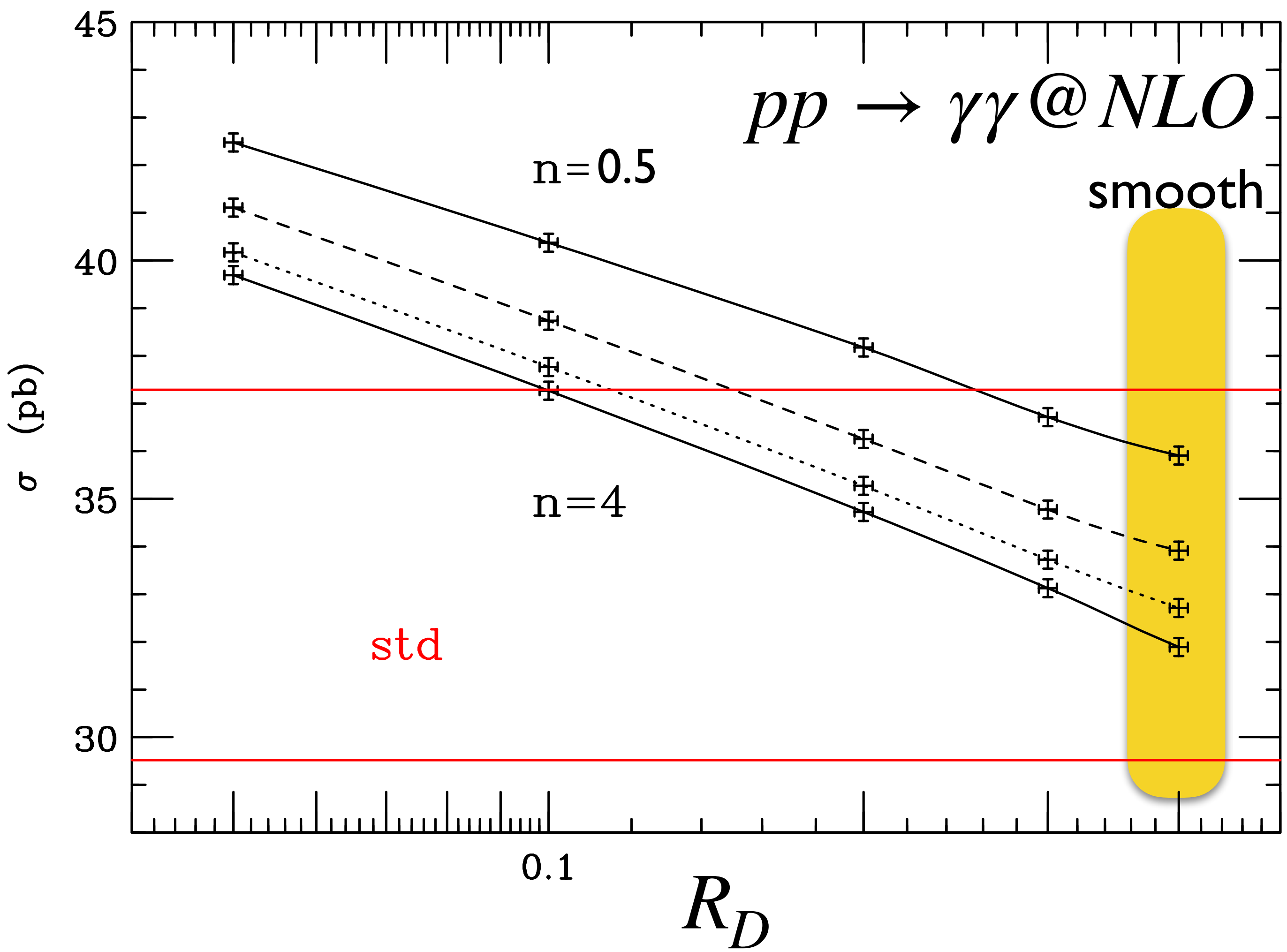
OK in MonteCarlo simulation

$W\gamma(+jet)$ POWHEG+MinLO

L.Cieri, A.Cueto Gomez, M.Chiesa @ Les Houches

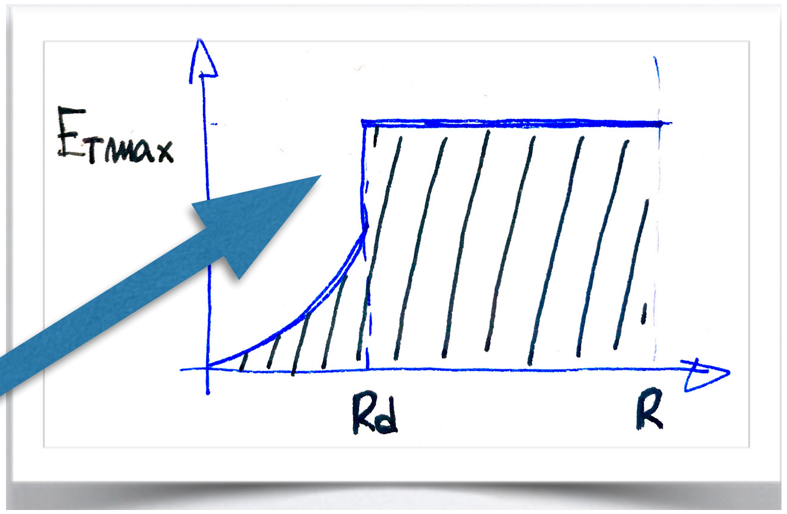
$$d\sigma_{\rm smooth}(R; E_{T\,\rm max}) < d\sigma_{\rm Hybrid}(R; r_d, E_{T\,\rm max}) < d\sigma_{\rm standard}(R; E_{T\,\rm max})$$

Fails in perturbative calculation : infrared sensitive $\log \frac{R_D}{R}$



ongoing work

L.Cieri, A.Cueto Gomez, M.Chiesa @ Les Houches



- Observe logarithmic behaviour
- Breaking of "perturbative Unitarity"
- Can be worse with "mismatched" hybrid

- Attempt for new set of fragmentation functions (NNLO?)

JP.Guillet, DdeF @ Les Houches

Thanks to all the participants!