Working Group 1: ggF Update

Conveners:
(EXP) Jonathon Langford, Haider Abidi
(TH) Stephen Jones, Alexander Huss

Current Tasks

Update ggF Cross Section **(Current focus of TH conv.)**

N^{3}LO QCD (without threshold expansion)

NNLO QCD Corrections w/ m_T

QCD-EW gg Light-quark Contributions

Update Boosted Higgs Recommendations **(Next focus of TH conv.)**

Publish Existing Boosted Higgs Note

Provide Updated Recommendations

Extend p_T Range ($p_T < 1.25$ TeV)

Update PS: HJ and HJJ

Mass Scheme Uncertainties (addressed by 2206.10490)

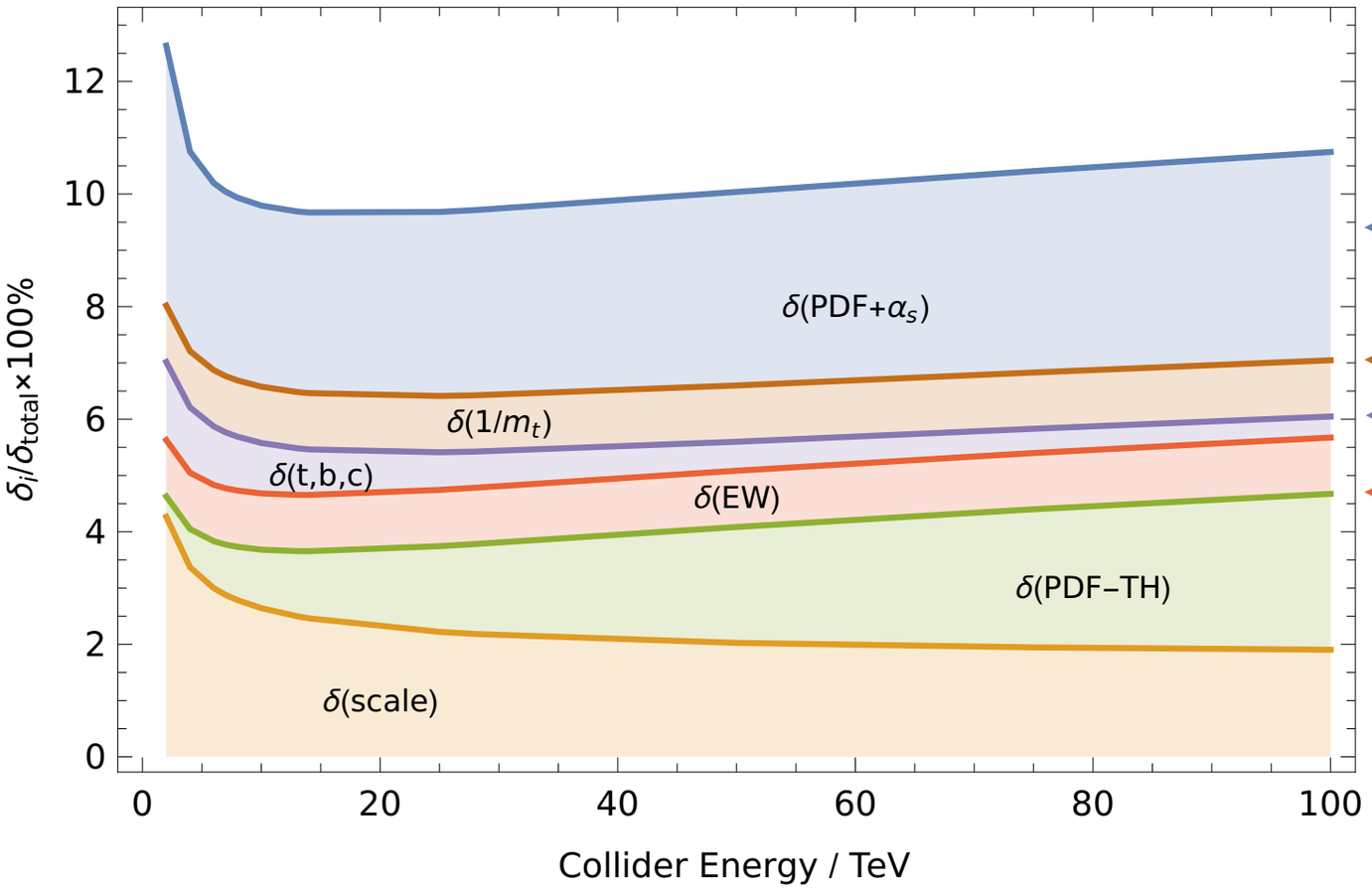
Provide Study/Guidelines for Parton Shower Uncertainties **(Stalled)**

Needs TH input to proceed

ggF cross section

Overview

Goal: accurately reflect changes in TH uncertainty since YR4



iHixs2: Dulat, Lazopoulos, Mistlberger 18

PDF4LHC WG 22

Czakon, Harlander, Klappert, Niggetiedt 21

Can be removed (?)

Reduced to 0.6% (gg light-quark)

Becchetti, Bonciani, Del Duca, Hirschi, Moriello, Schweitzer 20

Missing $\mathrm{N^3LO}$ PDFs

McGowan, Cridge, Harland-Lang, Thorne 22

$\mathrm{N^3LO_{HTL}}$ - use iHixs2 Dulat, Lazopoulos, Mistlberger 18 (+ n3loxs Baglio, Duhr, Mistlberger, Szafron 22 ?)

$\delta(1/m_t)$ - NNLO QCD w/ m_T use Czakon et al. 21 (mass-scheme uncert. estimate?)

$\delta(t,b,c)$ - Not yet in literature ($m_q \sim 0$, m_b & m_t) (asked Czakon et al. if timeline available)

$\delta(\mathrm{EW})$ - gg-channel light-quark contributions use Becchetti et al 20. (asked for timeline for other channels)

$\delta(\mathrm{PDF-TH})$ - estimate with individual sets (PDF4LHC21 has no NLO set), separate comparison to $\mathrm{aN^3LO}$

Parameter Choices

Most parameters: (thanks to Karlberg, Mistlberger, Malcles, Di Nardo)

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHWG136TeVxsec

Each group asked if they can produce full or reduced scan

Each group asked if $m_H! = 125$ BSM scan is possible

Additional parameters/choices:

Central Scale set to $\mu_0 = \frac{m_H}{2}$

Requested 7-point scale variation

Not yet identified any omissions/ambiguities in above settings, groups asked to communicate to us if they need further input

Timeline

Sep 22 Identify results of interest to WG

Nov 22 Authors summarise work at general assembly

+ Assess $\delta(t, b, c)$ and $\delta(\mathrm{EW})$ outlook
+ Community feedback

Dec 22 Initial exploratory runs of iHixs ($\mathrm{N^3LO_{HTL}}$)

Dec 22 Initial meeting with $\mathrm{aN^3LO}$ authors (Cridge)

Mar 23 Request Czakon et al. 21 results for updating $\delta(1/m_t)$

Request Becchetti et al 20. results for updating $\delta(\mathrm{EW})$

Apr 23 Begin full runs of iHixs ($\mathrm{N^3LO_{HTL}}$)

Ask $\mathrm{aN^3LO}$ and other PDF authors for input/study of $\delta(\mathrm{PDF-TH})$

Jun 23 WG1: ggF meeting

+ Presentation of results from each group
+ Initial combination
+ Community feedback

Jul 23 Update twiki & fully document all input/choices

Sep 23 WG note with studies (e.g. PDFs, EW TH uncert, …)

Community Input/ Requests

1) BSM scan with non-SM Higgs Mass

Assuming step size and range ($m_H = [10{,}3000]$ GeV) of Report 4 (still ok?)

Higgs Mass range	step size	# of points	addendum
[10,150] GeV	5 GeV	29 points	
[150,500] GeV	10 GeV	35 points	+ M_H=125.09 GeV
[500,3000] GeV	50 GeV	50 points	

- Total 115 points for M_H=[10,3000] GeV.

2) $\sigma(gg \to H) = \sigma_{tt} + \sigma_{tb} + \sigma_{bb}$ breakdown

Corrections have significantly different K-factors

Useful for BSM studies with different t/b weighting

$$\begin{aligned} \sigma(gg \to H) &= \sigma_{tt} + \sigma_{tb} + \sigma_{bb} \\ K_{tt} &\sim 1.68 \\ K_{tb} &\sim 0.97 \\ K_{bb} &\sim 1.20 \end{aligned}$$

$\Rightarrow$ up to $20-30\%$ differences in NLO cxn [m_b: scheme/scale dep.?]
$\Rightarrow$ not possible to use SM-like cxns in many BSM cases
for different weighting of top and bottom loops

Talk: M. Spira (19th General Assembly)

Other Topics

Boosted Higgs: Overview

Previous note

Publication within few months

Update

Parameters/energies (13.6 TeV, PDF4LHC21)

Extend to $p_T < 1.25$ TeV

Mixed QCD-EW Corrections

Parton Shower updates for HJ, HJJ

HJ mass scheme uncertainties known @ NLO

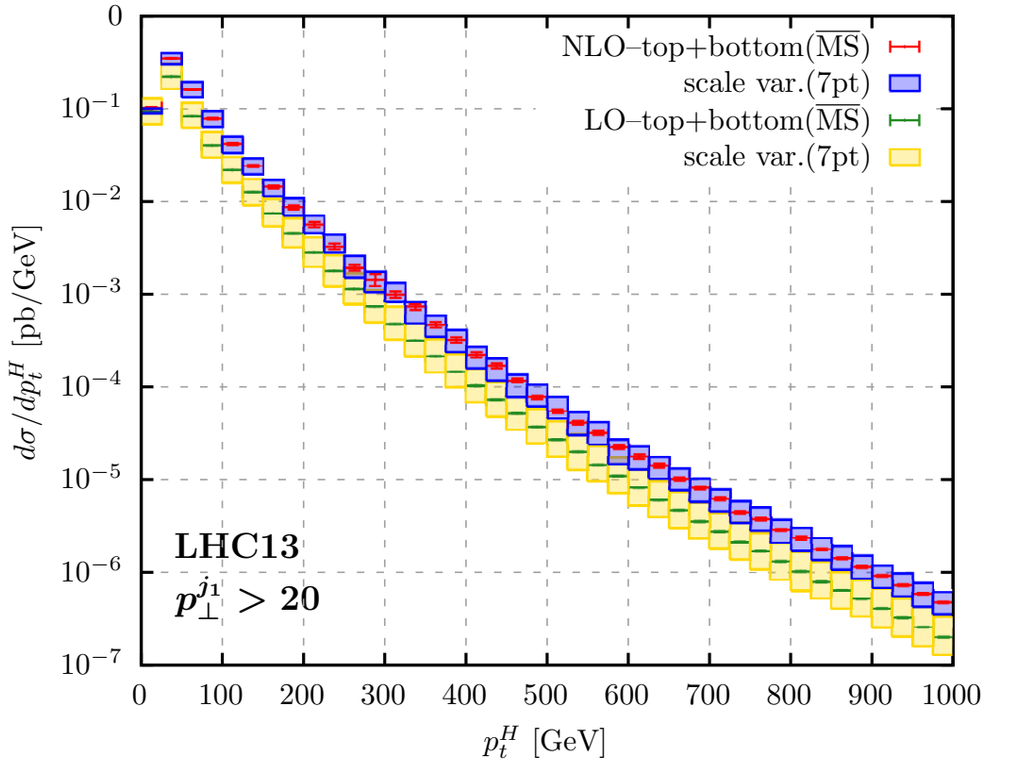
All channels contributing (cross WG meeting)

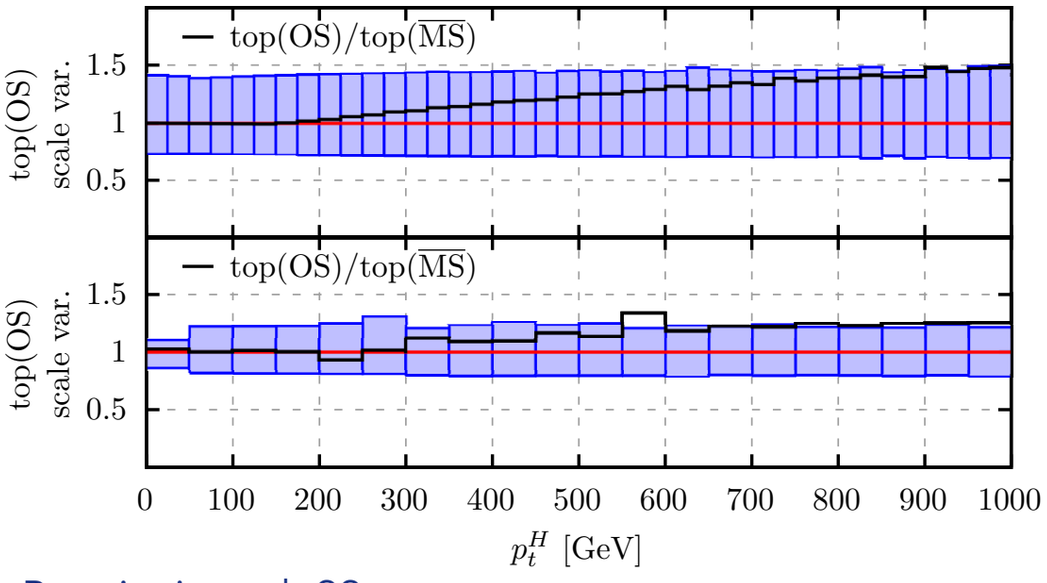
Timeline

(Apr) Identify relevant work

(Jul) Presentations in boosted meeting

(Aug?) Update tWiki





Bonciani, et al. 22

Parton Shower Uncertainties: Overview

	ggF + $b\bar{b}$H	VBF	WH	ZH	$t\bar{t}H$	tH
Uncertainty source	$\Delta\sigma$[%]	$\Delta\sigma$[%]	$\Delta\sigma$[%]	$\Delta\sigma$[%]	$\Delta\sigma$[%]	$\Delta\sigma$[%]
Theory uncertainties						
Higher-order QCD terms	±1.4	±4.1	±4.1	±12	±2.8	±16
Underlying event and parton shower	±2.5	±16	±2.5	±4.0	±3.6	±48
PDF and α_s	< ±1	±2.0	±1.4	±2.3	< ±1	±5.8
Matrix element	< ±1	±3.2	< ±1	±1.2	±2.5	±8.2
Heavy-flavour jet modelling in non-$t\bar{t}H$ processes	< ±1	< ±1	< ±1	< ±1	< ±1	±13
Experimental uncertainties						
Photon energy resolution	±3.0	±3.0	±3.8	±4.8	±3.0	±12
Photon efficiency	±2.7	±2.7	±3.3	±3.6	±2.9	±9.3
Luminosity	±1.8	±2.0	±2.4	±2.7	±2.2	±6.6
Pile-up	±1.4	±2.2	±2.0	±2.3	±1.4	±7.3
Background modelling	±2.0	±4.6	±3.6	±7.2	±2.5	±63

Theory input would significantly help experiments

Dominant TH for ggF cross sections & most other channels

Potentially limiting impact of improved fixed-order recommendations

Goals

Define consistent scheme for PS uncertainties (across WG1 subgroups?)

Explore ways to reduce their impact (now/ near future)

Timeline: Stalled in need of TH input

Working Group 1: ggF Summary

In Progress

Full Update of Inclusive ggF Cross Section Recommendation

- N^{3}LO QCD Corrections (without threshold expansion)
- Top Quark Mass Effects @ NNLO (Missing: b & c quark mass effects)
- Mixed QCD-EW Corrections (Missing: $qg, q\bar{q}$ channels)
- PDF4LHC21 & PDF-TH uncertainty (Use PDF4LHC21, compare w/ aN3LO PDFs)

Upcoming

Publish Boosted Higgs Note

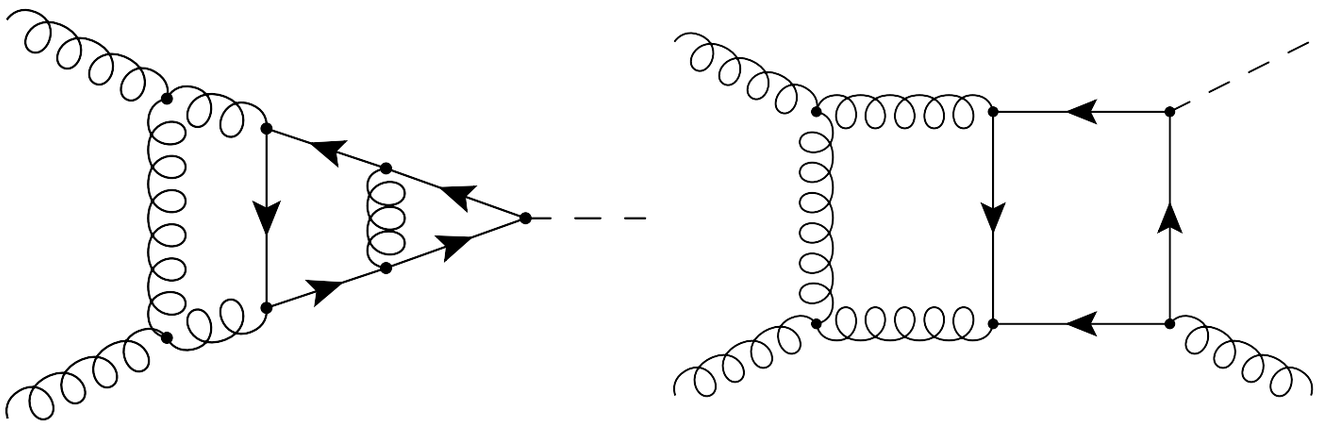
Update of Boosted Higgs Recommendation

Request for Input

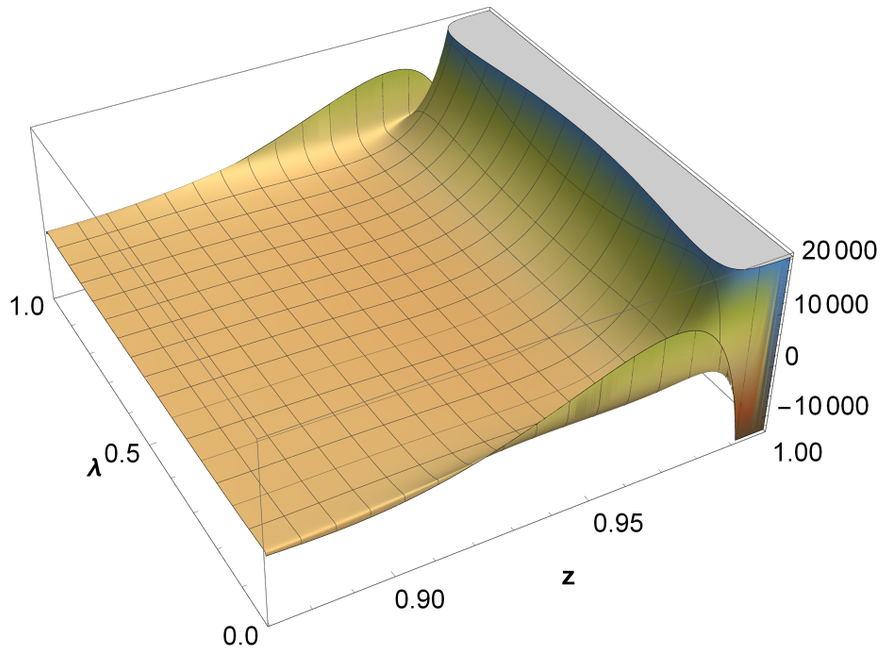
Parton shower uncertainties and associated systematics

Backup

NNLO with full top-quark mass



$gg \to Hg$



$2\mathrm{Re}\langle M^{(1)}_{\mathrm{exact}} | M^{(2)}_{\mathrm{exact}} \rangle |_{\mathrm{regulated}}$

H+1jet @ 2-loop & H @ 3-loop with m_T using numerical solution of differential equations

Czakon, Niggetiedt 20;
Czakon, Harlander, Klappert, Niggetiedt 21

Decreases σ_{tot} by $-0.26\,\%$ @ 13 TeV compared to heavy top limit (HTL)

Intricate interplay between mass effects $gg\ (+0.62\%), qg\ (-16\%), qq\ (-15\%)$
Complete NNLO results obtained using STRIPPER framework

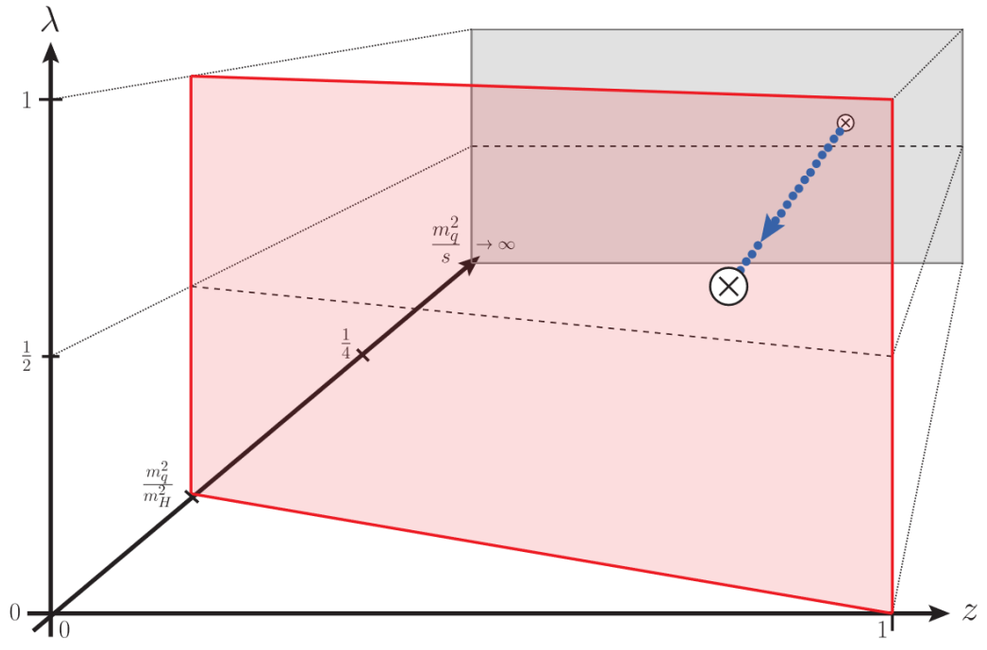
What to do with bottom/charm quarks?

Would be very useful to know bottom/charm effects @ NNLO (reduce $\delta(t, b, c)$)

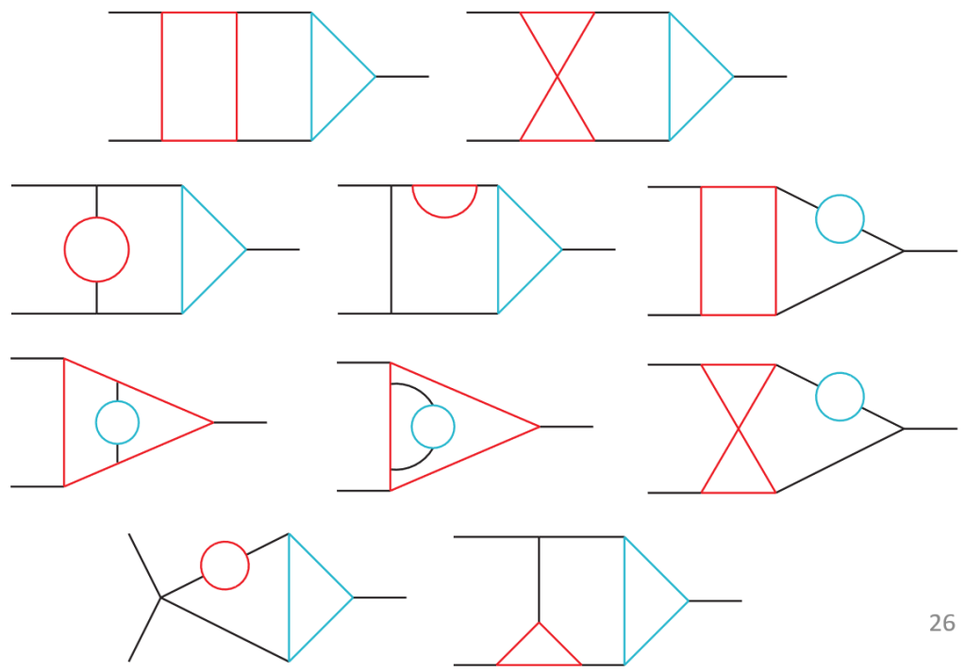
However, technically very challenging to get NNLO results

Summary

- Same techniques can be applied to compute bottom quark mass effects…
- Large hierarchy between m_b^2 and m_H^2 can lead to numerical instabilities when solving the differential equations
- Boundaries at $m_q^2 \to \infty$ not optimal



Corrections to $gg \to H$ at three loops for two different massive quark flavors unknown



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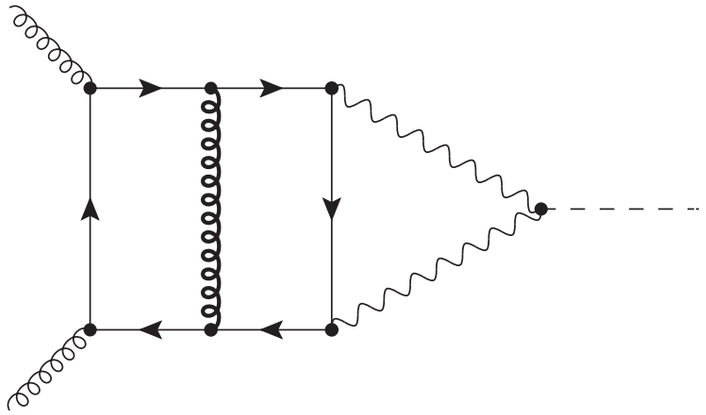
Slide: Marco (Monday)

Mixed QCD-EW Corrections @ $\mathrm{NLO}_{\mathrm{QCD}}$

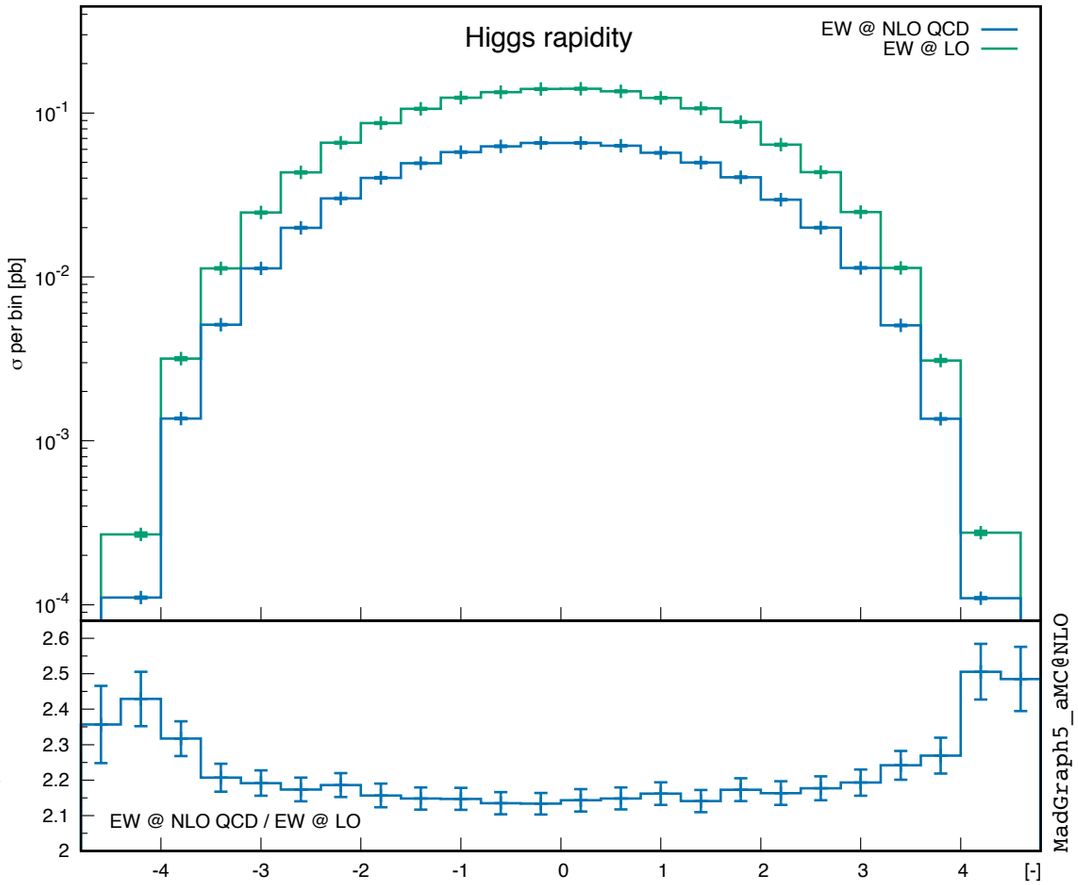


Challenging calculations

Bonetti, Melnikov, Tancredi 17

Bonetti, Panzer, Smirnov, Tancredi 20

Dominant light-quark mediated contributions computed, rather flat K-factor (for rapidity distribution)



Becchetti, Bonciani, Del Duca, Hirschi, Moriello, Schweitzer 20

Increases σ_{tot} by $+5.1\,\%$ @ 13 TeV, reduces residual uncertainty $\delta(\mathrm{EW}) \sim 0.6\,\%$

Favouring factorisation of EW corrections: $\sigma = \sigma_{\mathrm{LO}}\,(1+\delta_{\mathrm{QCD}}) \times (1+\delta_{\mathrm{EWK}})$

Compatible with previous estimates:

Soft approx: $+5.4\,\%$,
Bonetti, Melnikov, Tancredi 18;

$M_H \ll M_V : +5.2\,\%$,
Anastasiou, Boughezal, Petriello 09;

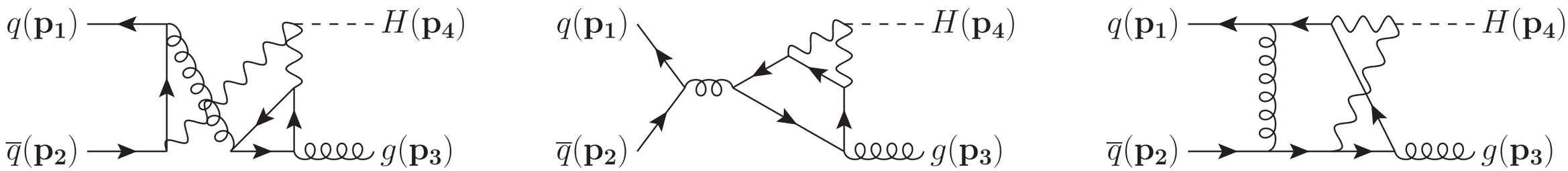
$M_H \gg M_V : +5.4\,\%$
Anastasiou, Del Duca, Furlan, Mistlberger, Moriello, Schweitzer, Specchia 19

What to do with the $qg, \bar{q}g, q\bar{q}$ channels?

Previous calculation of QCD-EW corrections only considers dominant gg channel

Impact of the quark channels expected to be relatively suppressed (due to large gg lumi), primary impact likely to be $\mathcal{O}(-2\%)$ shift at large/moderate p_T

But: 2-loop $q\bar{q}Hg$ amplitudes known



Bonetti, Panzer, Tancredi 22

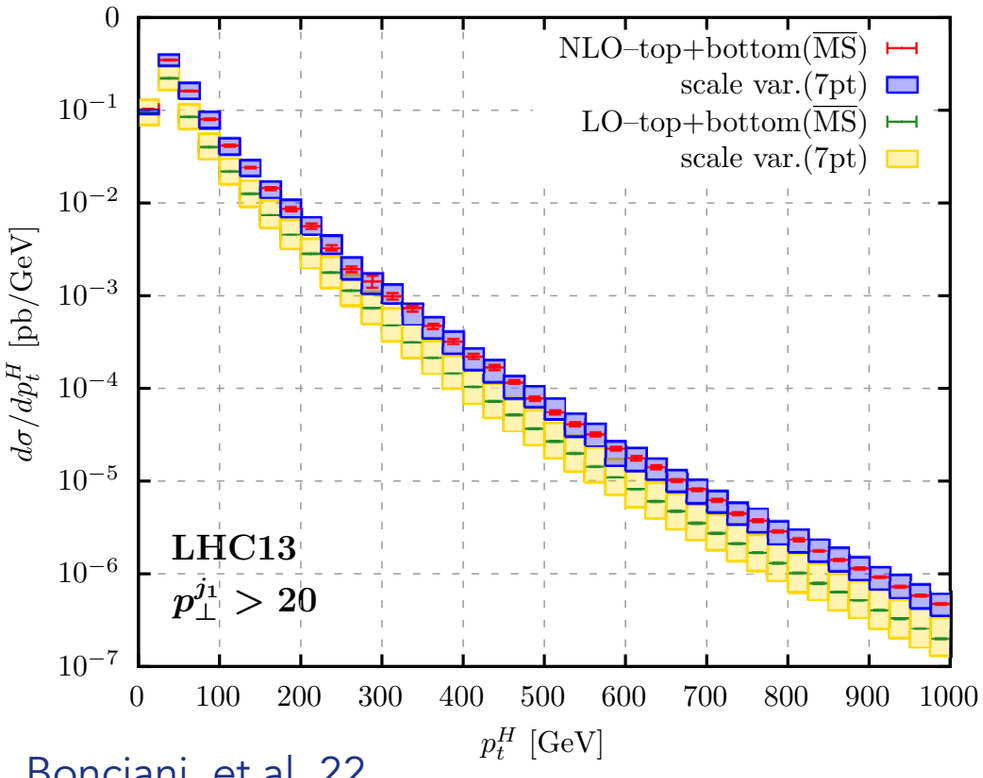
Presumably, all-channel QCD-EW estimate is within reach

Proposal:
The sub-group should continue assembling the ingredients required for an update (including the existing QCD-EW corrections), iron out any issues, keep in touch with authors who may produce an improved QCD-EW estimate.

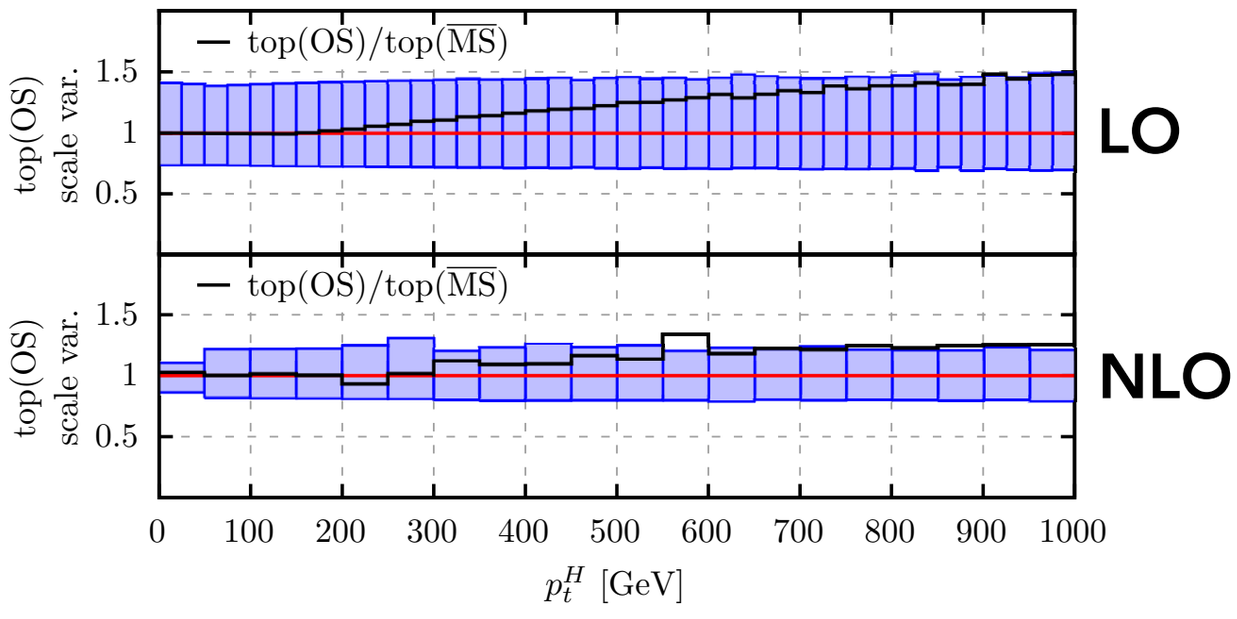
Boosted Higgs: NLO H+j

HTL not valid for $p_T \gtrsim m_t$: (b,t)-quark mass effects now known for H+j at NLO

Bonciani, Del Duca, Frellesvig, Hidding, Hirschi, Moriello, Salvatori, Somogyi, Tramontano 22;
Kudashkin, Melnikov, Wever, Lindert/ Neumann/ Chen, Huss, SPJ, Kerner, Lang, Luisoni, Zhang 18-21



Bonciani, et al. 22



Bottom and top/bottom interference effects relevant only for low-p_T

Mass scheme uncertainty now known:

Reduced @ NLO but still comparable to scale uncertainty