ggF: Theory Update

Conveners:
(TH) Stephen Jones, Bernhard Mistlberger

Outline

Overview of Recent Progress

- Fully differential + fiducial cross-section @ N^{3}LO QCD
- Mixed EW-QCD corrections
- Top-quark mass effects @ NNLO QCD
- High-p_T H+j and H+2j production @ NLO QCD

Future Directions for the Working Group

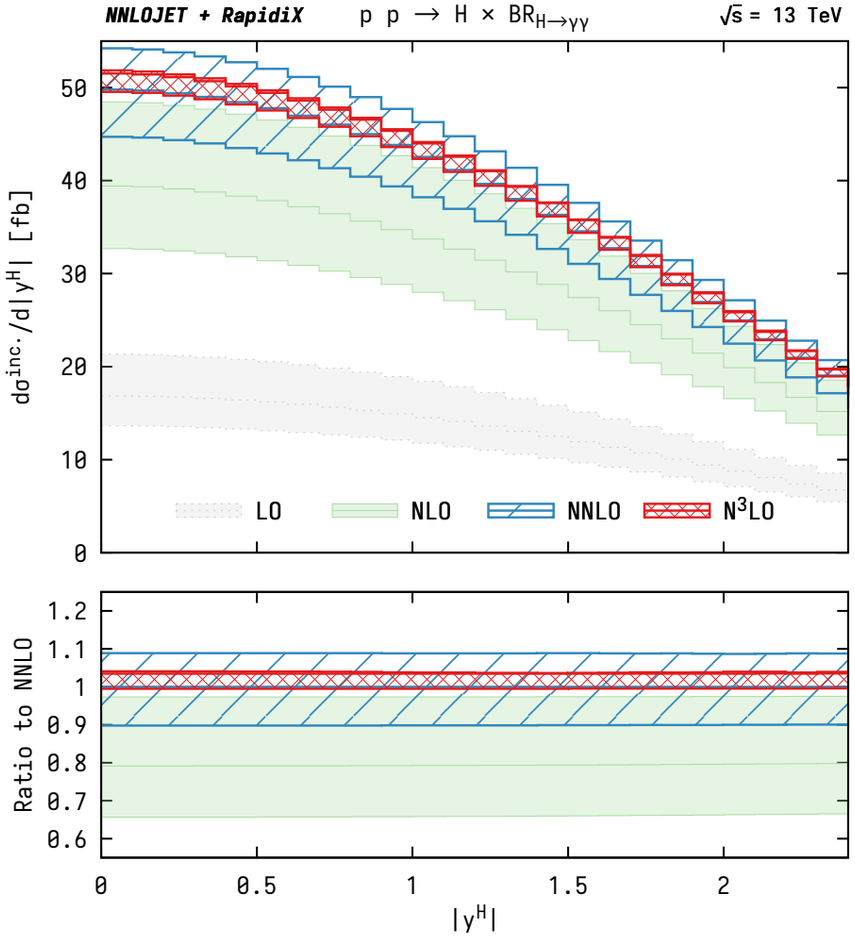
- Boosted Higgs note
- Update ggF cross section
- Parton shower uncertainties / systematics (needs interested TH)

Recent Highlights*

***Apologies: I had to make a very unfair selection**
Please feel free to bring up other important results during questions/discussion!

N³LO Differential

Inclusive



ATLAS cuts

$$p_T^{\gamma_1} > 0.35\ m_{\gamma\gamma}$$

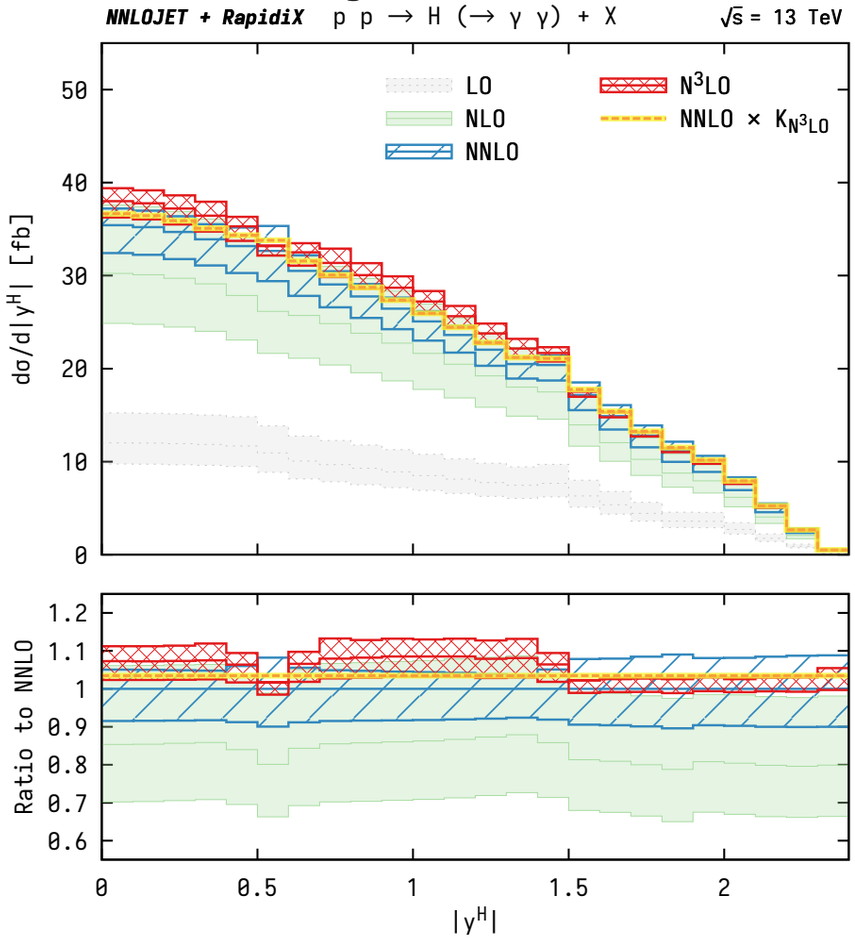
$$p_T^{\gamma_2} > 0.25\ m_{\gamma\gamma}$$

$$|y^{\gamma}| < 2.37$$

$$1.37 < |y^{\gamma}| < 1.52 \text{ (reject)}$$

$$\Delta R < 0.2$$

Fully Differential



Chen, Gehrmann, Glover, Huss, Mistlberger, Pelloni 21

Used projection-to-born method, presented: $y^H, y^{\gamma_1}, \Delta y^{\gamma_1\gamma_2}$

Perturbative expansion looks reasonable (reduced uncertainties, stable)

Inclusive: remarkably flat K-factor (as expected)

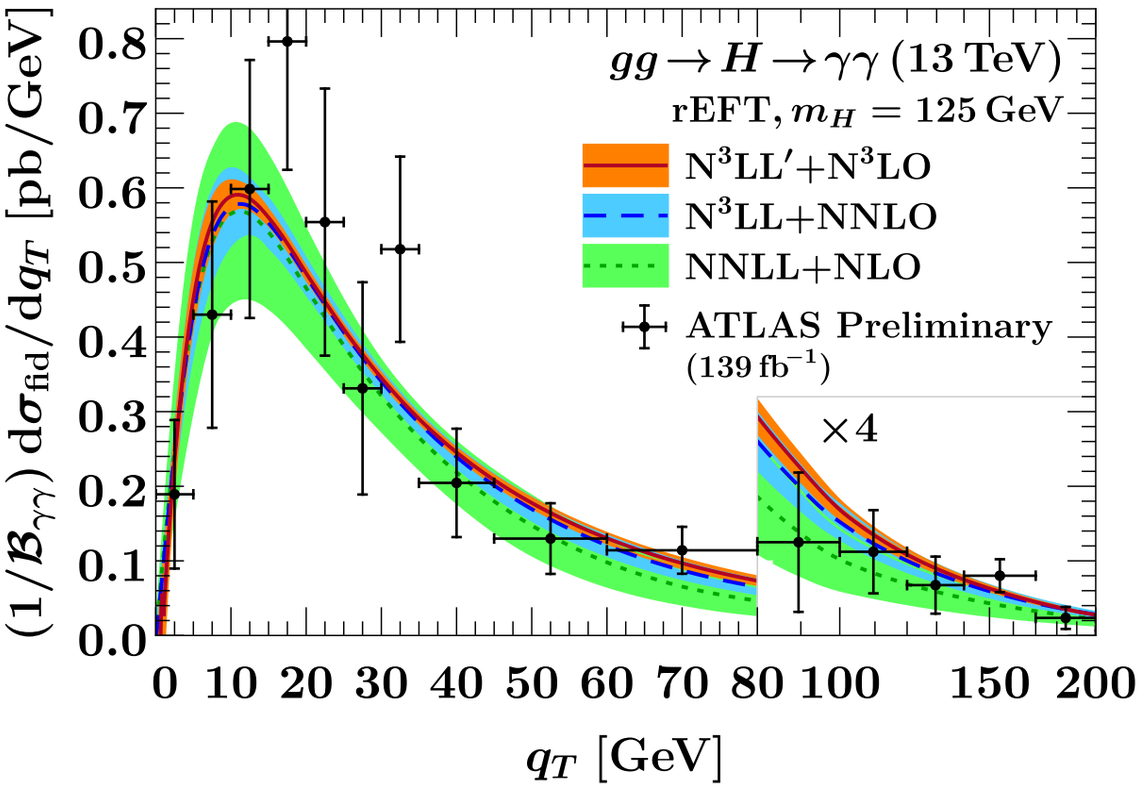
For these cuts: naïve rescaling fails for $|y^H| < 1.5$, IR sensitivity @ $|y^H| \sim 0.5$

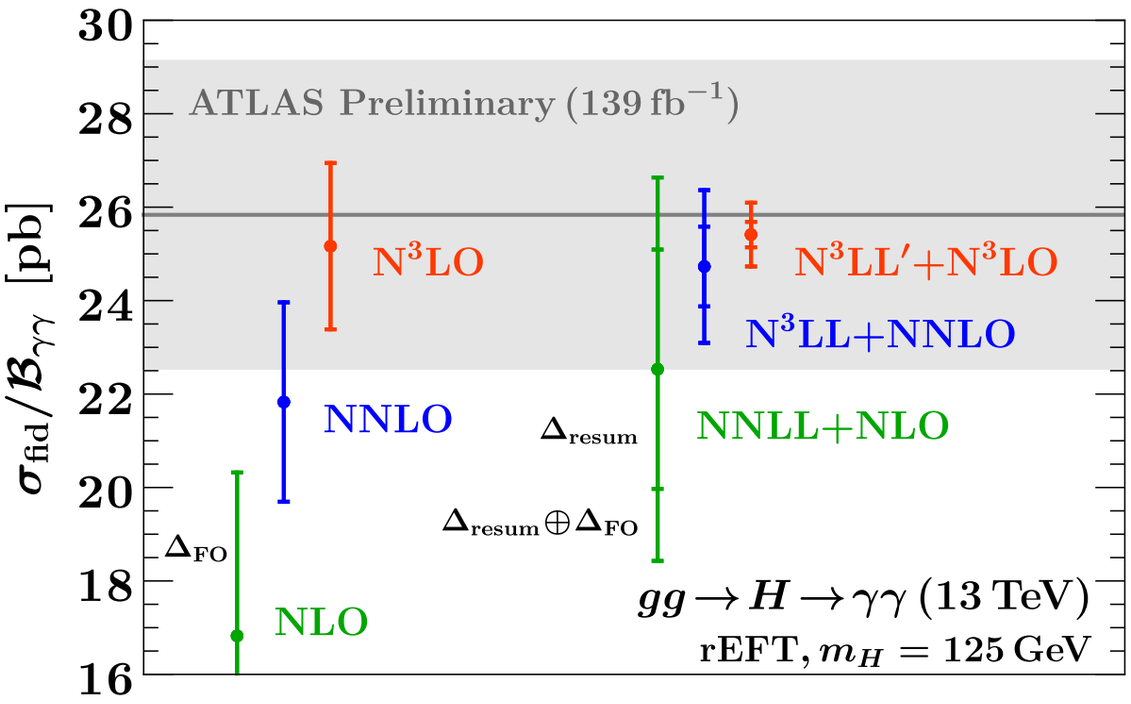
Different cuts allow this behaviour to be cured/avoided **G. Salam (Friday)**

$N^3LL' + N^3LO$ Differential

Also known at $N^3LL' + N^3LO$ with fiducial cuts **J. Michel/M. Ebert (Friday)**

IR sensitivity can be avoided by resumming fiducial power corrections





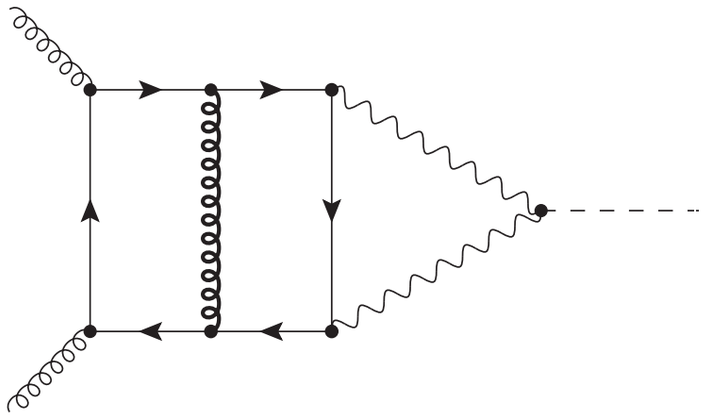
Billis, Dehnadi, Ebert, Michel, Tackmann 21

Integrating over the resummed result gives prediction for $\sigma_{\rm fid}$

$$\sigma_{\rm fid} = 57.69\,(1 \pm 2.7\%_{\rm pert} \pm 2.1\%_{\rm BR} \pm 3.2\%_{\rm PDF+\alpha_s} \pm 2\%_{\rm EW} \pm 2\%_{t,b,c})\,{\rm fb}$$

Fiducial results for Higgs p_T also available at $N^3LL' + NNLO$ within the RadISH framework Re, Rottoli, Torrielli 21

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

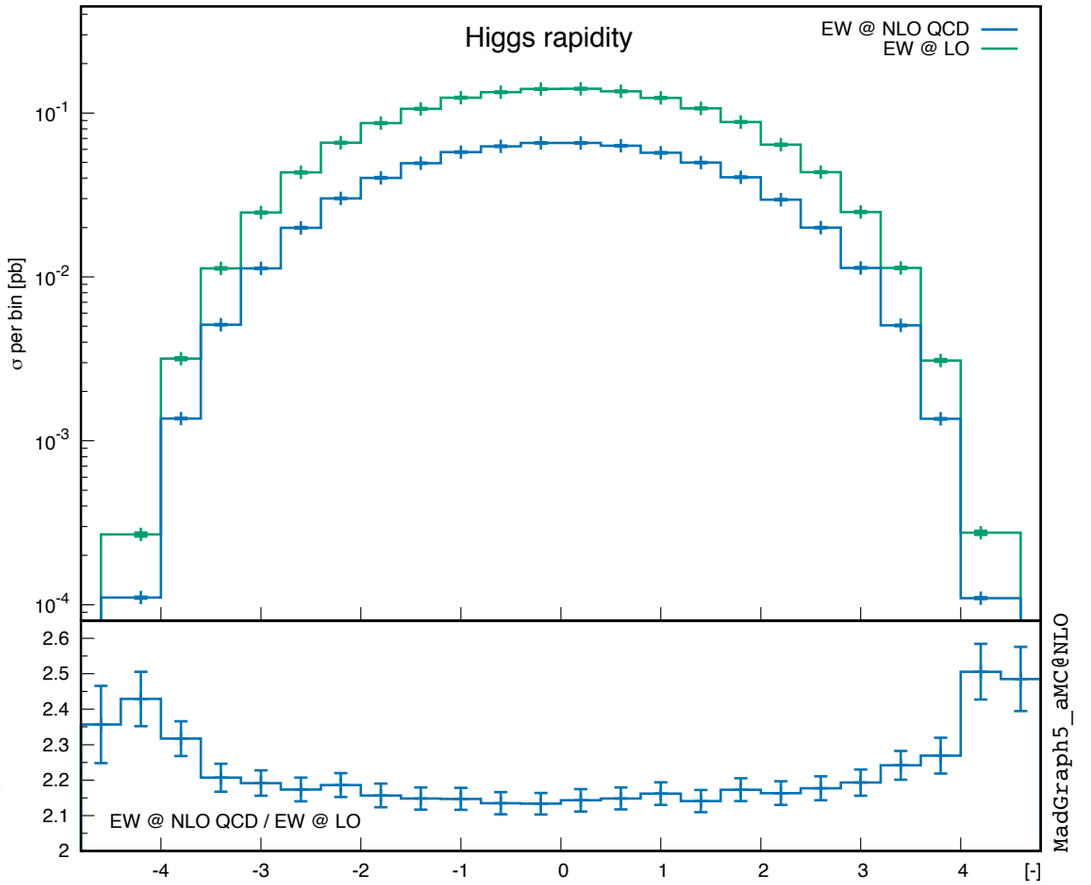


Challenging calculations

Bonetti, Melnikov, Tancredi 17

Bonetti, Panzer, Smirnov, Tancredi 20

Dominant light-quark contributions computed, rather flat K-factor (at least 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: $\sigma = \sigma_{\mathrm{LO}}\,(1+\delta_{\mathrm{QCD}}) \times (1+\delta_{\mathrm{EWK}})$

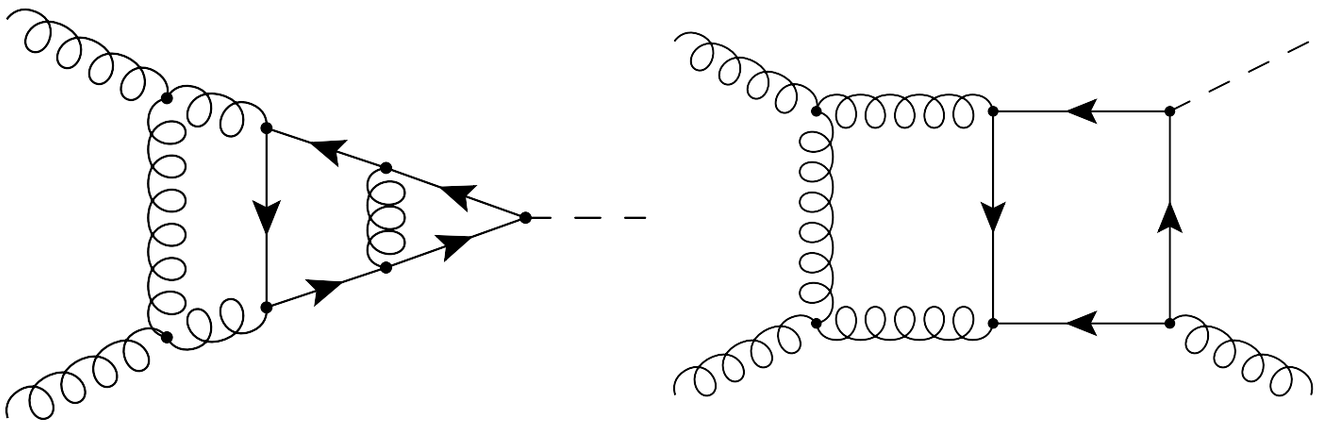
Compatible with previous estimates:

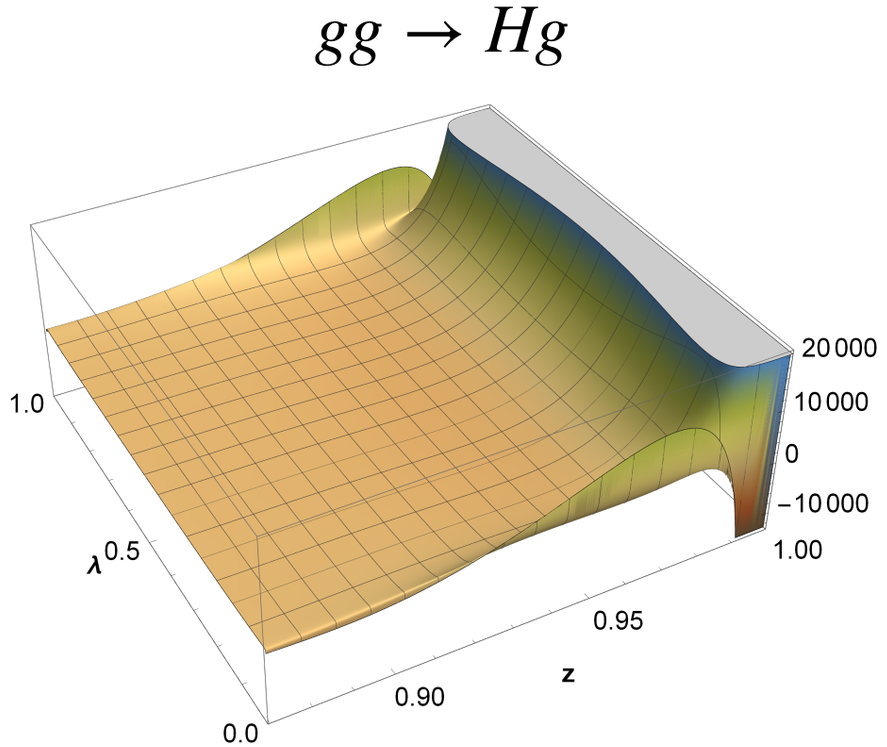
Soft approx: $+5.4\,\%$,
Bonetti, Melnikov, Tancredi 18;

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

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

NNLO with full top-quark mass





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

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

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

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

Future:
Technology could be used to include light quark mass effects (large logs/need to resum?)

NLO H+j and H+2j at High p_T

HTL not valid for $p_T \gtrsim m_T$

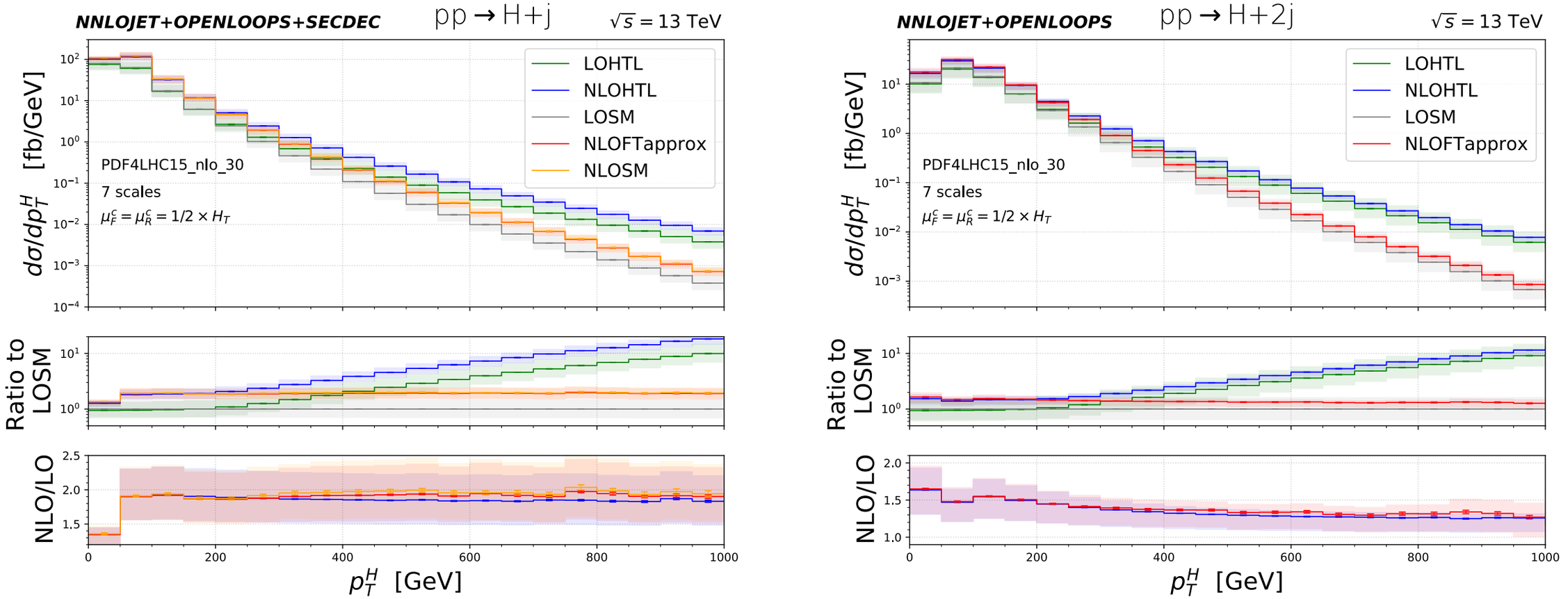
Top quark mass effects in H+j known for $p_T \gg m_T$ and exactly

Kudashkin, Melnikov, Wever 17 + Lindert 18; Neumann 18; SPJ, Kerner, Luisoni 18

Approximation $\mathrm{FT}_{\mathrm{approx}}$ Maltoni, Vryonidou, Zaro 14 **works surprisingly well**

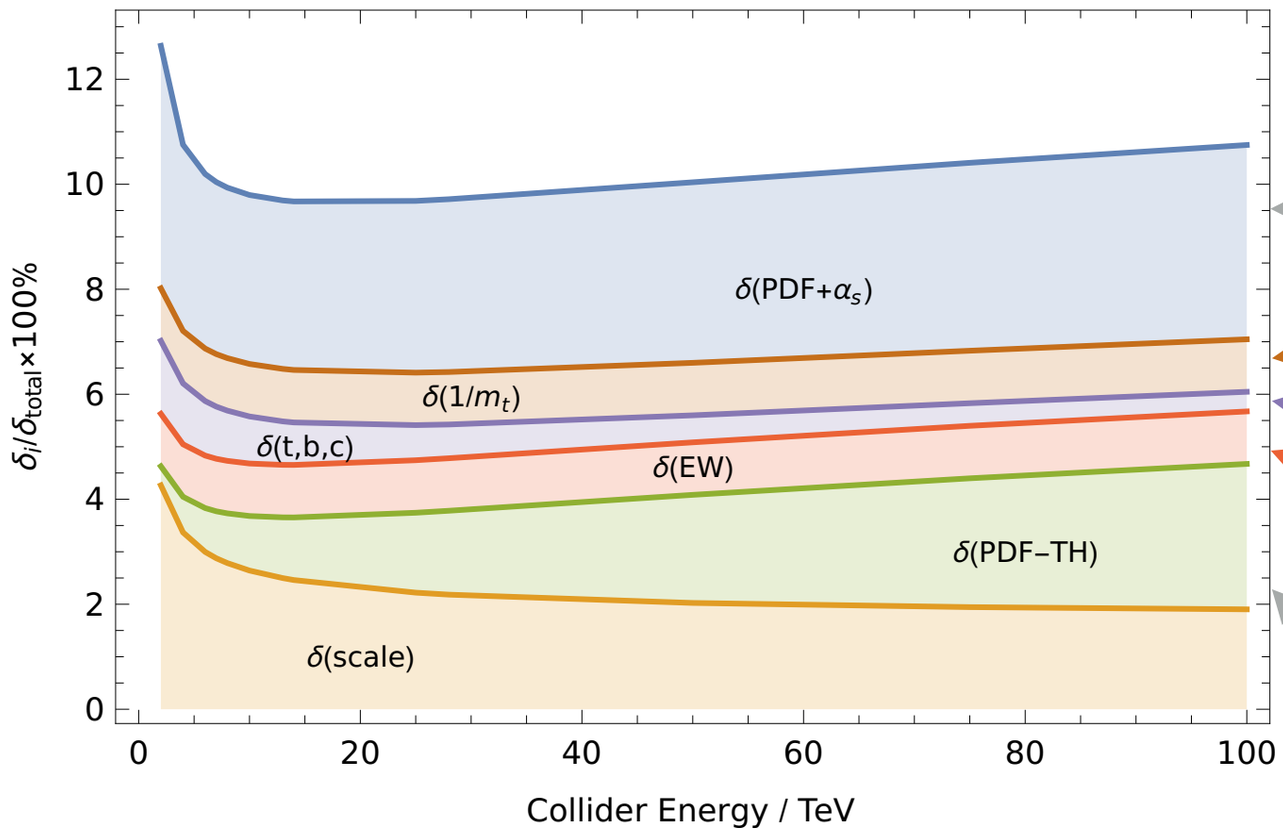
Use Exact Born + Reals

Approximate 2-loop Virtuals with $|\mathscr{M}_4^2(m_t, \mu_R^2; \{p\})|^2 \to |\mathscr{M}_4^1(\infty, \mu_R^2; \{p\})|^2 \dfrac{|\mathscr{M}_4^1(m_t; \{p\})|^2}{|\mathscr{M}_4^0(\infty; \{p\})|^2}$



Chen, Huss, SPJ, Kerner, Lang, Lindert, Zhang 21

Obligatory Error Budget Plot



iHixs2: Dulat, Lazopoulos, Mistlberger 18

Progress is steadily beating down sources of TH uncertainty

Needs data/more accurate determination

Removed

Czakon, Harlander, Klappert, Niggetiedt 21

Can be removed (?) similar techniques

Reduced from ~1% to 0.6%

Becchetti, Bonciani, Del Duca, Hirschi, Moriello, Schweitzer 20; + Bonetti, Panzer, Smirnov, Tancredi, Melnikov, …

Missing N^3LO PDFs

Also exposing new sources of uncertainty/ areas where we can do better

Fiducial power corrections (covered previously)

Next-to-leading power corrections @ threshold

Beneke, Garny, Jaskiewicz, Szafron, Vernazza, Wang 19; van Beekveld, Laenen, Sinninghe Damsté, Vernazza 21;

The precision era mantra:

TH: Do we miss sources of uncertainty? (PDF MHOU, Schemes, NLP, …)

EXP: Do we use the most accurate results? (PS validation, Match/ Merge)

WG1 ggF Plans/Projects

Short term

Update & Publish Boosted Higgs Note (CERN-TH-2020-074)

Medium term

Update Inclusive ggF Cross Section Recommendation (also @ 13.6 TeV)

Exact Mixed QCD-EW Corrections

Top Quark Mass Effects @ NNLO

N^3LO QCD Corrections (without threshold expansion)

(Missing: b/c quark mass effects, PDF4LHC21)

Longer term / needing input

Parton Shower Uncertainties and Associated Systematics (see next talk)

Happy to hear more topics/directions to explore from EXP/TH colleagues

Thank you for listening!