HIGHER ORDER CORRECTIONS TO HIGGS PROCESSES

Nicolas Deutschmann

Higgs Hunting – July 24th, 2017

Université catholique de Louvain
Université de Lyon

MAJOR ANALYTIC RESULTS

THREE MILESTONES IN 2015

A prolific year for analytic calculations

- Higgs production through gluon fusion at N^3LO

[Anastasiou, Duhr, Dulat, Furlan, Gehrmann, Herzog, Lazopoulos, Mistlberger] – 2015

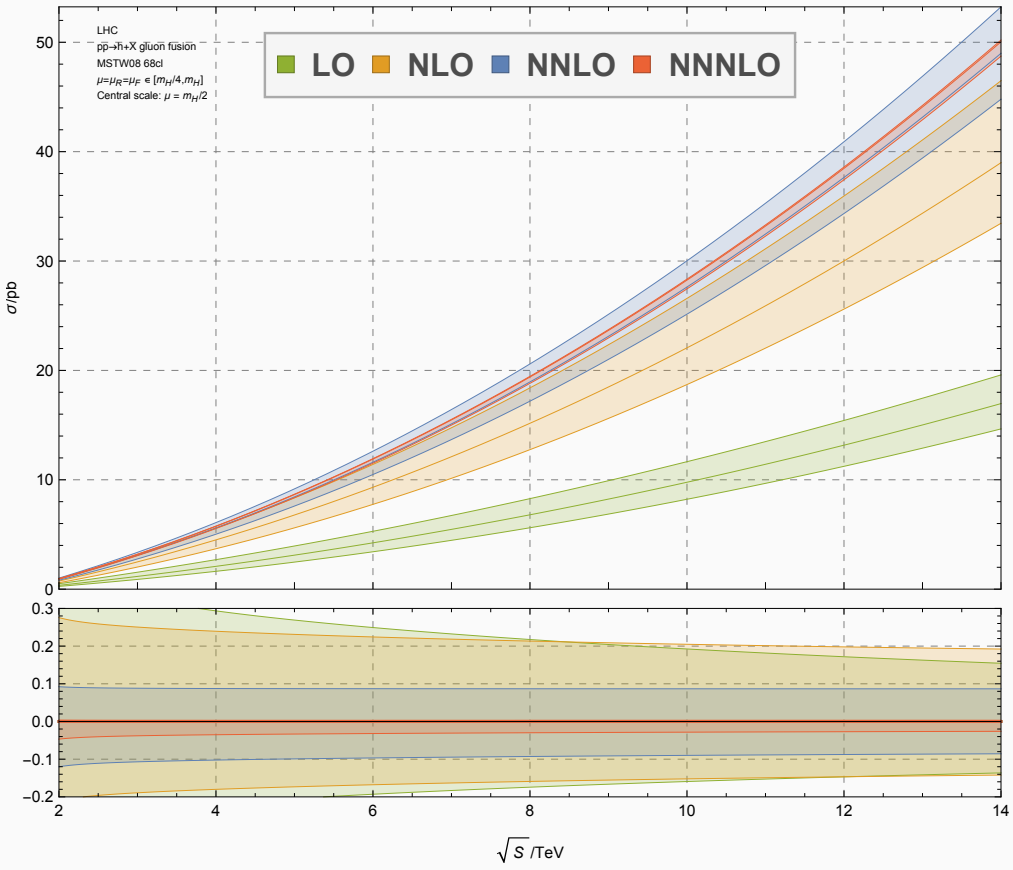
- Higgs+jet production at NNLO

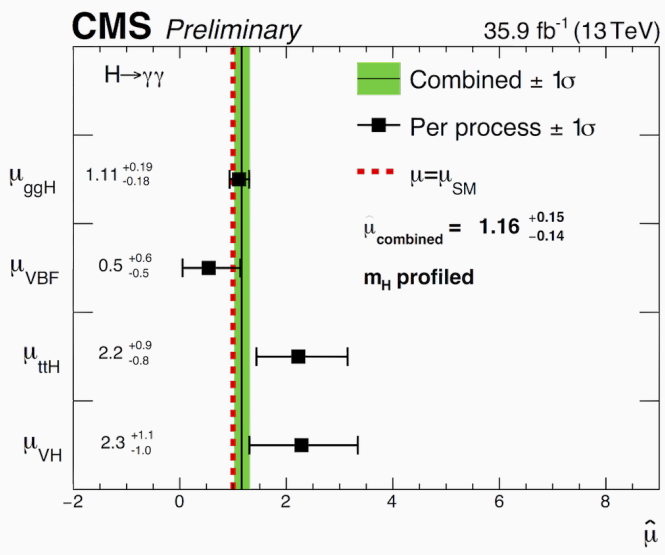
[Boughezal, Caola, Melnikov, Petriello, Schulze] – 2015
[Boughezal, Focke, Giele, Liu, Petriello] – 2015
[Chen, Gehrmann, Glover, Jaquier] – 2016

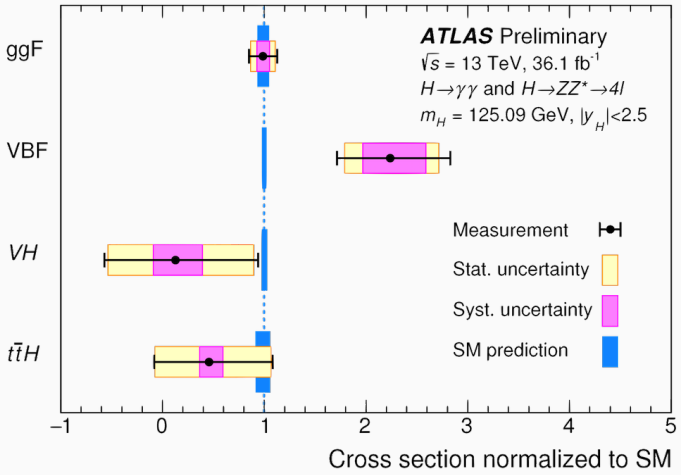
- Fully differential vector boson fusion at NNLO

[Cacciari, Dreyer, Karlberg, Salam, Zanderighi] – 2015

GLUON FUSION AT N3LO







Theory uncertainty pushed to $\sim$ 6%

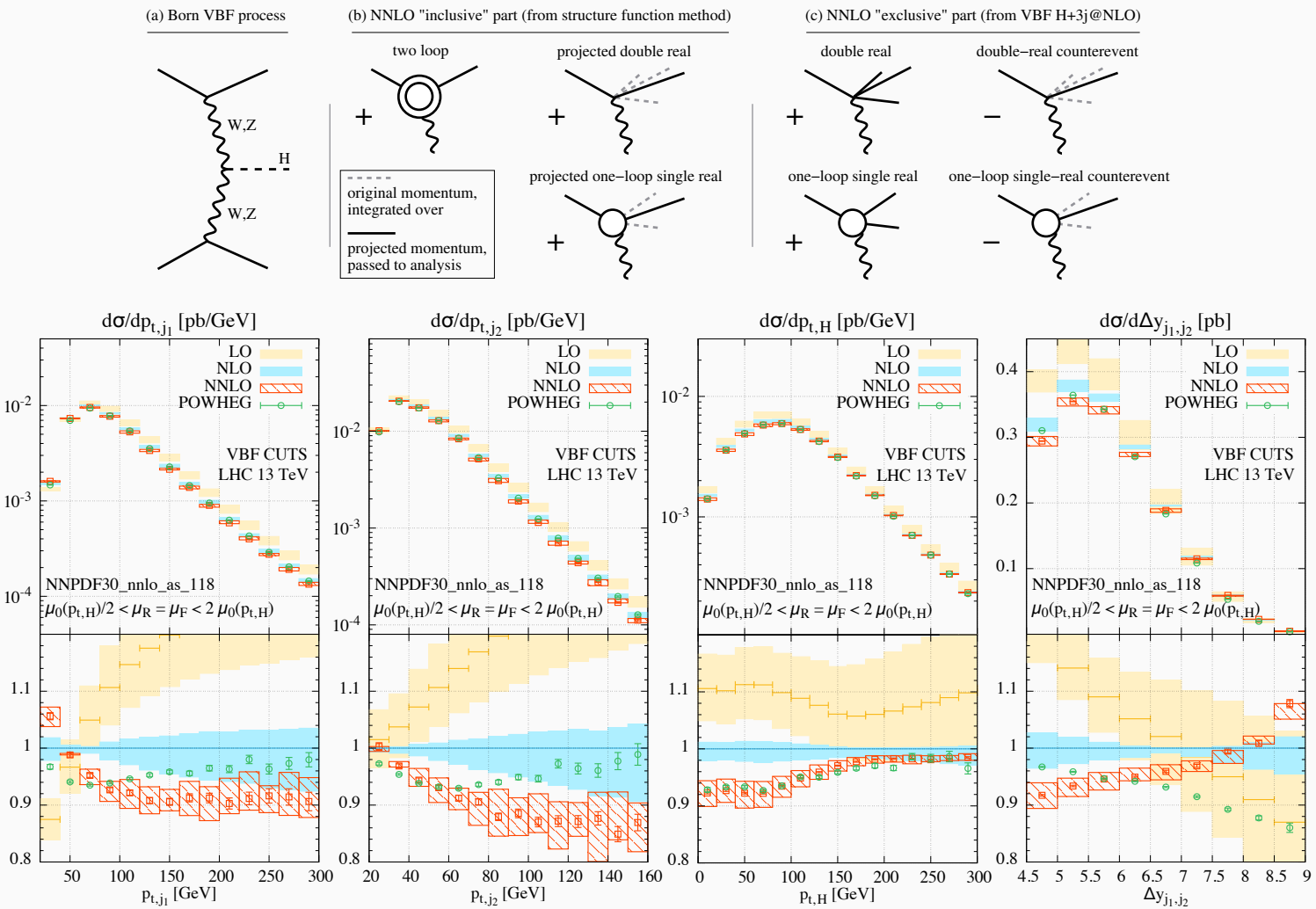
[Anastasiou, Duhr, Dulat, Furlan, Gehrmann, Herzog, Lazopoulos, Mistlberger] – 2015

CMS-PAS-HIG-16-040

ATLAS-CONF-2017-047

FULLY DIFFERENTIAL VBF AT NNLO

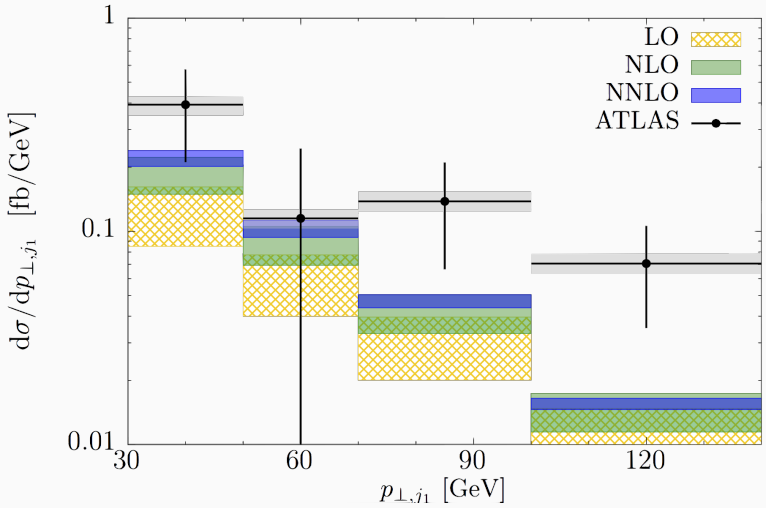
Approximation as a double DIS process (< 1% at NLO)



[Cacciari, Dreyer, Karlberg, Salam, Zanderighi] – 2015

HIGGS+JET: PHENOMENOLOGICAL RESULTS

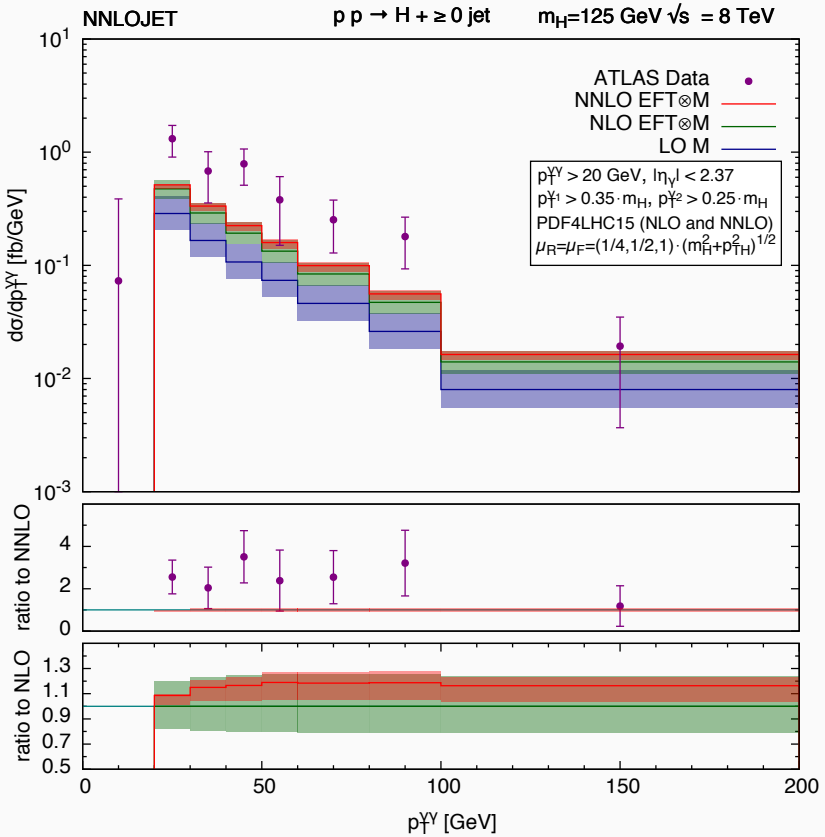
Fiducial cross section in the HEFT ($m_t \to \infty$)



[Caola, Melnikov, Schulze] – 2015

Tension with ATLAS normalization

+ LO-improved HEFT



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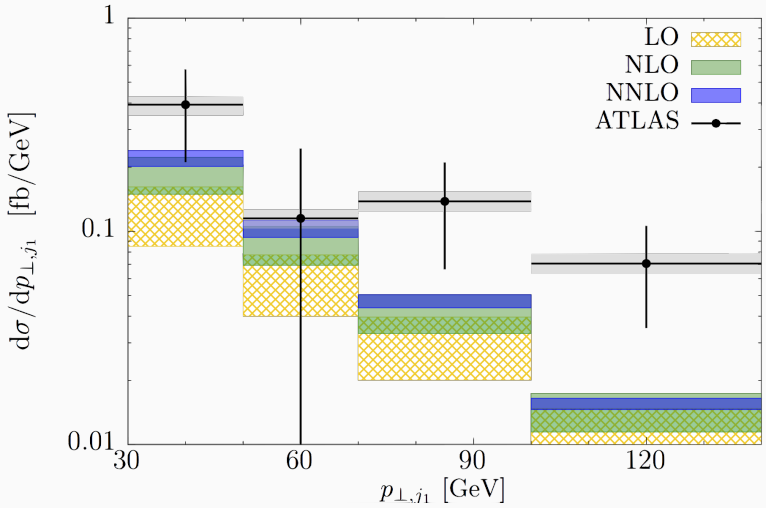

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Better agreement in shape

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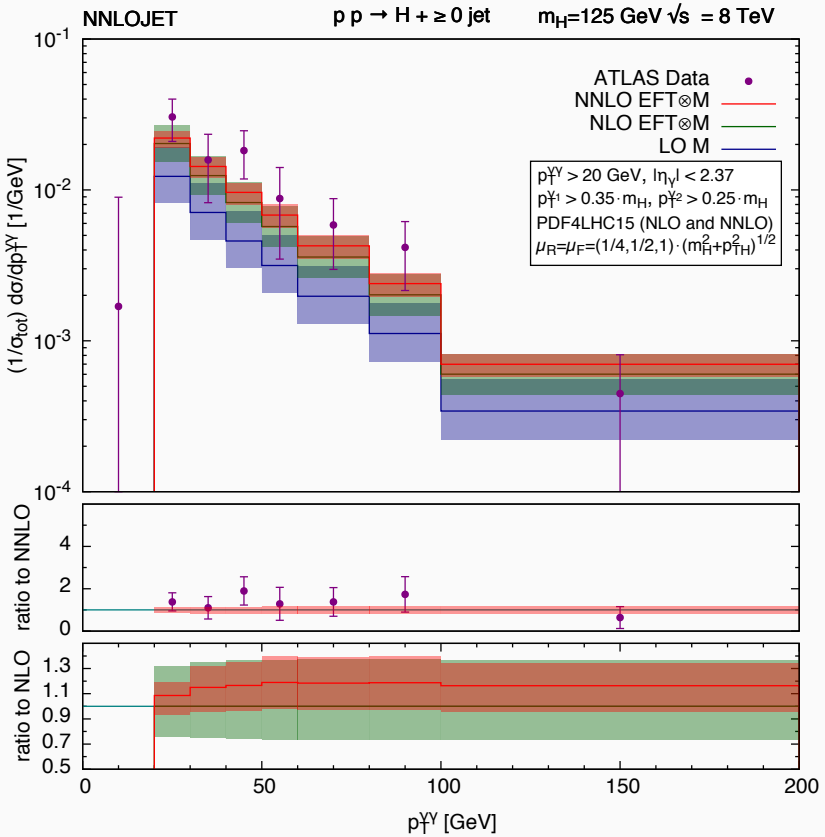

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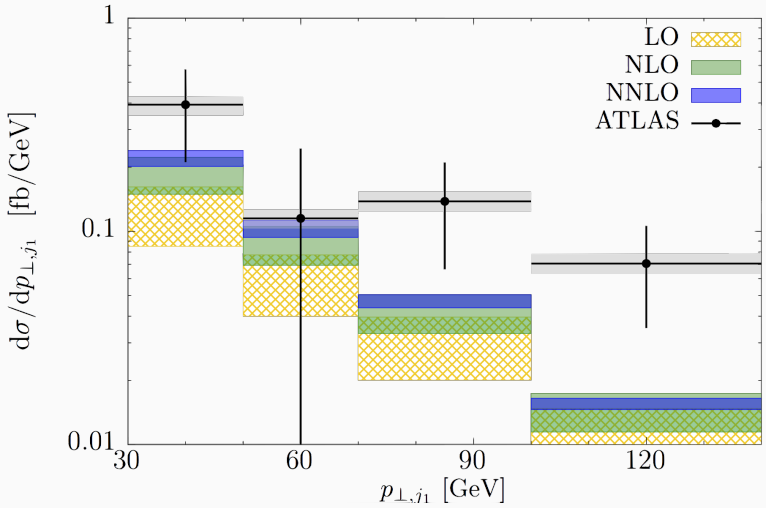

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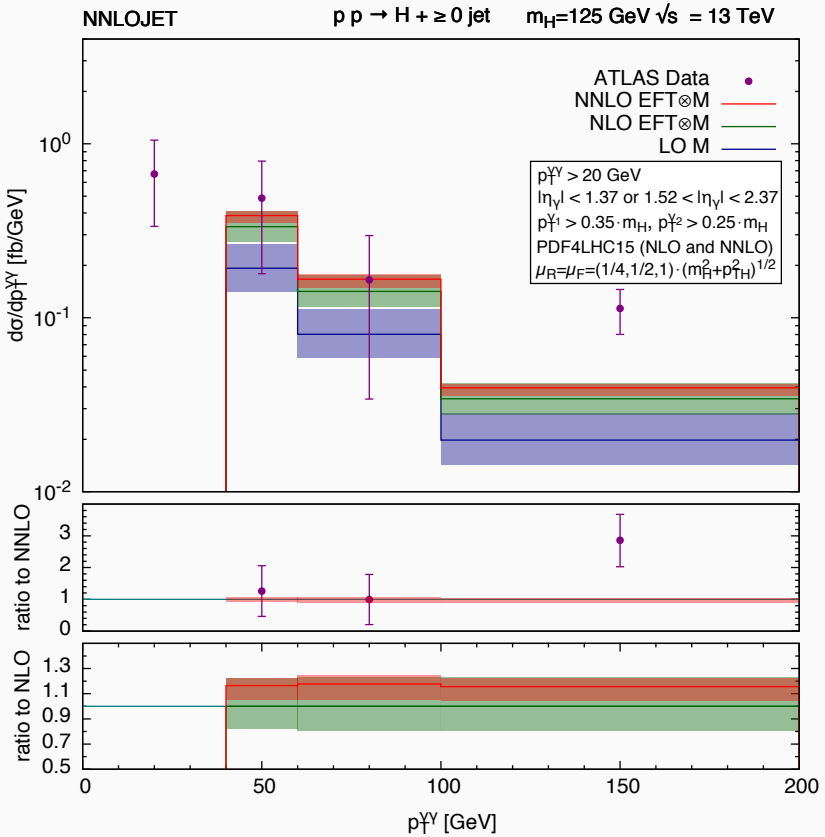

[Chen, Gehrmann, Glover, Jaquier] – 2016

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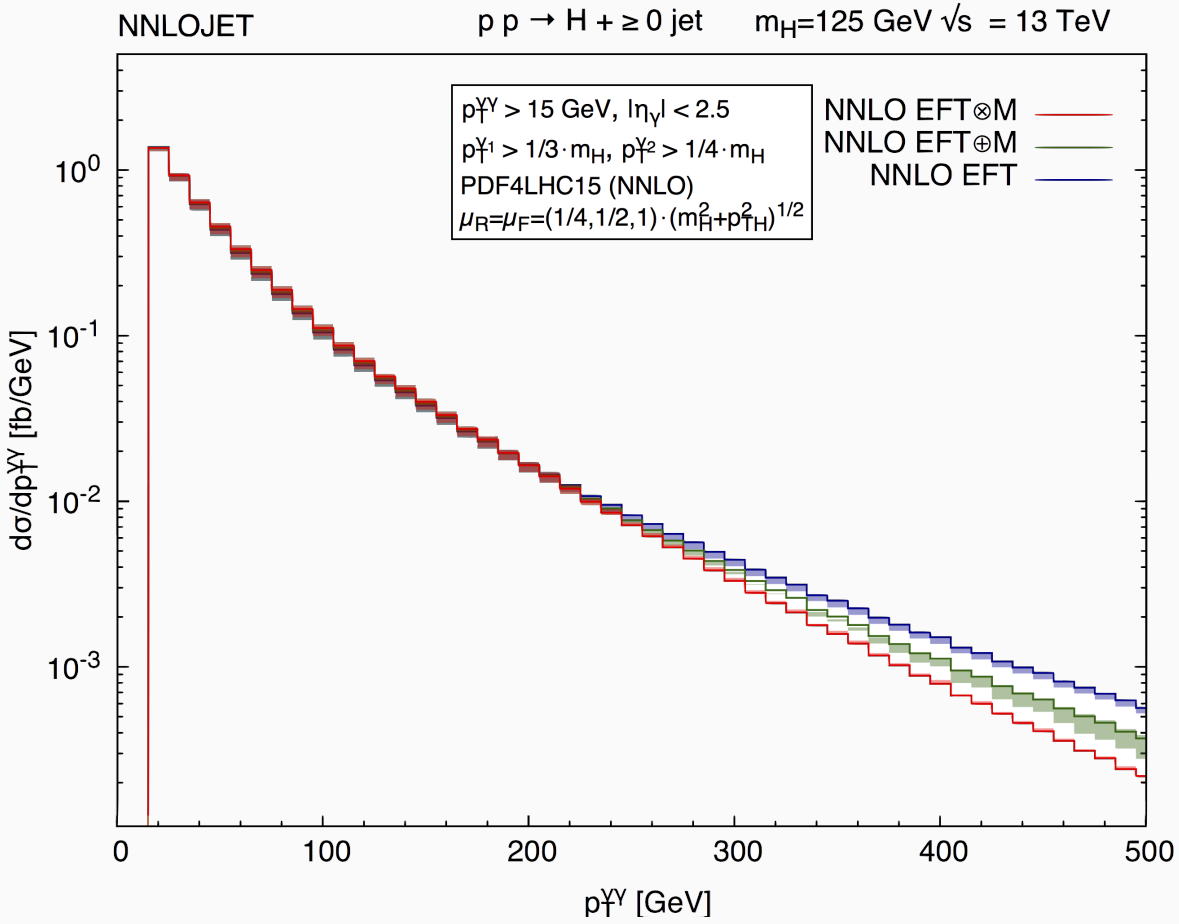
Better agreement in shape

Better normalization at 13 TeV

BEYOND CONTACT INTERACTIONS IN H+J

LO-improved HEFT results are unreliable when $p_T \gtrsim m_t$



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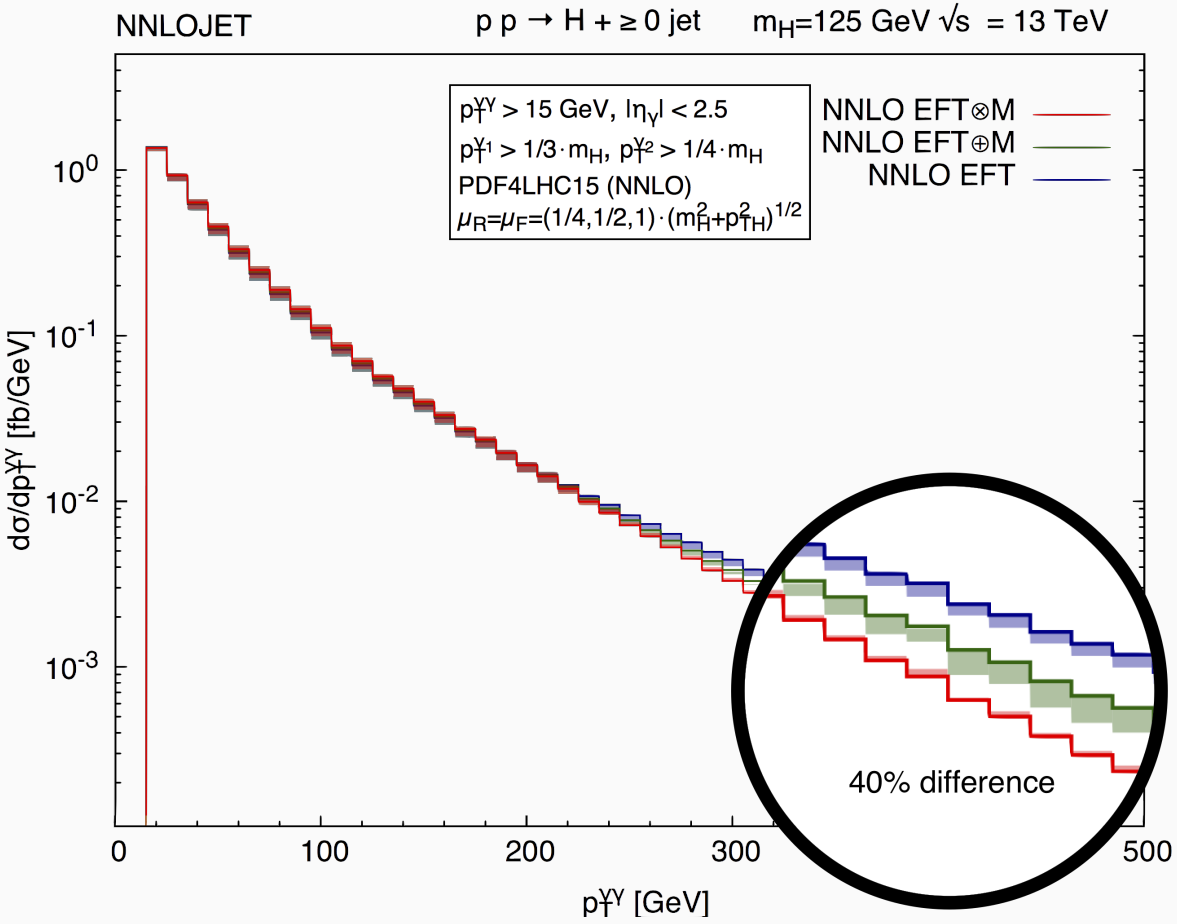

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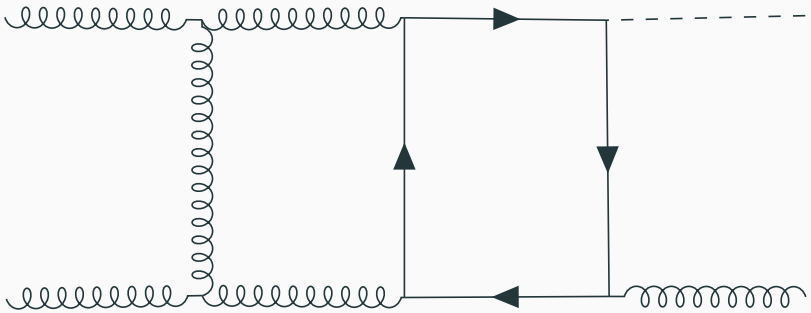
Toward an exact NLO result

Analytic results for planar integrals



[Bonciani, Del Duca, Frellesvig, Henn, Moriello, Smirnov] – 2017

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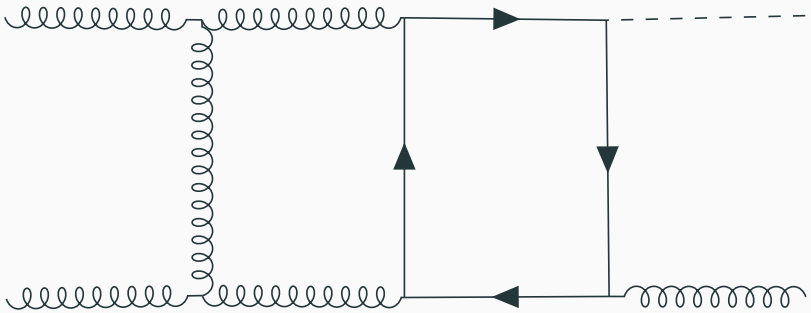


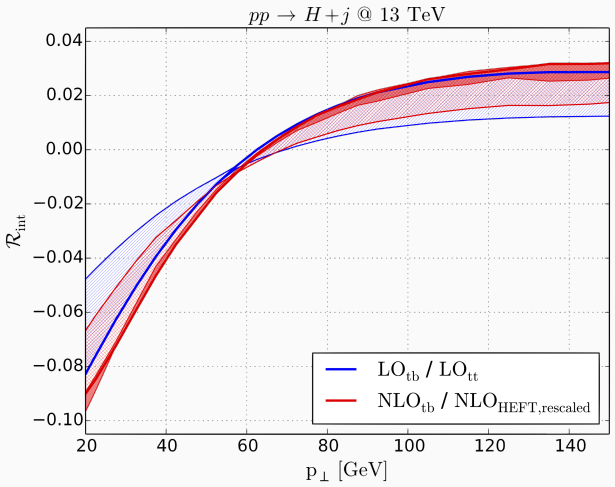
[Bonciani, Del Duca, Frellesvig, Henn, Moriello, Smirnov] – 2017

Bottom mass effects at NLO

Clear hierarchy:

$$m_b \ll p_T^j, m_H, m_t$$

NLO corrections to top-bottom interference as series in m_b

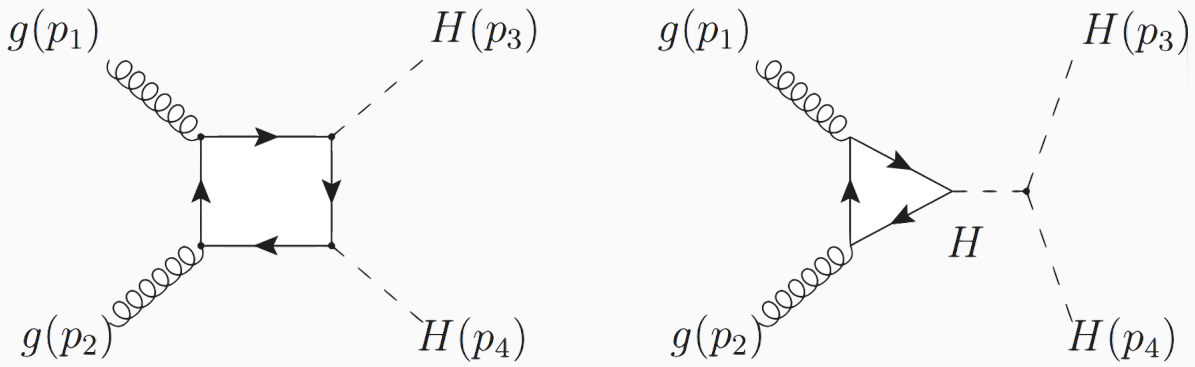


[Lindert, Melnikov, Tancredi, Wever] – 2017

HIGGS PAIR PRODUCTION AT NLO

A HANDLE ON THE HIGGS SELF COUPLING

One of the last SM parameters with no direct constraints



Exp challenge: cross section and large negative interference

TH challenge: Only known analytically at LO

[Eboli, Marques, Novaes, Natale] – 1987

[Glover, van der Bij] – 1988

Several proposals using HEFT improved with top mass effects

[S. Dawson, S. Dittmaier, and M. Spira] – 1998, [F. Maltoni, E. Vryonidou, and M. Zaro] – 2014

[J. Grigo, J. Hoff, K. Melnikov, and M. Steinhauser] – 2013-2015, [Degrassi, Giardino, Gröber] – 2016

NUMERICAL INTEGRAL EVALUATION

Exact NLO results obtained numerically using the sector decomposition method

[Borowka, Greiner, Heinrich, Jones, Kerner, Schlenk, Schubert, Zirke] – 2016

$$\sigma_{\text{NLO}} = 27.80^{+13.8\%}_{-12.8\%}\ \text{fb} \pm 0.3\%(\text{stat.}) \pm 0.1\%(\text{int.}).$$

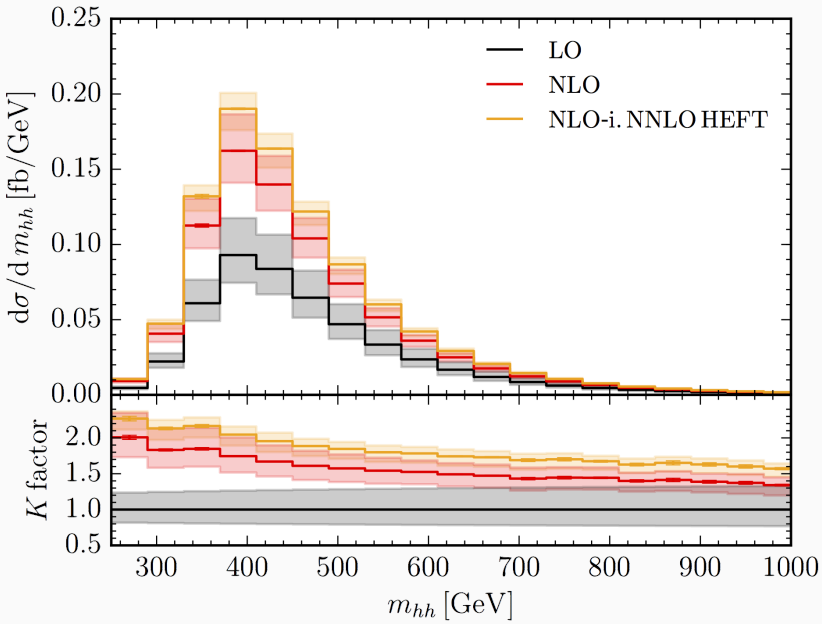
Daunting task: very long analytic & numeric processing

"The median GPU time per phase-space point was 2 hours"

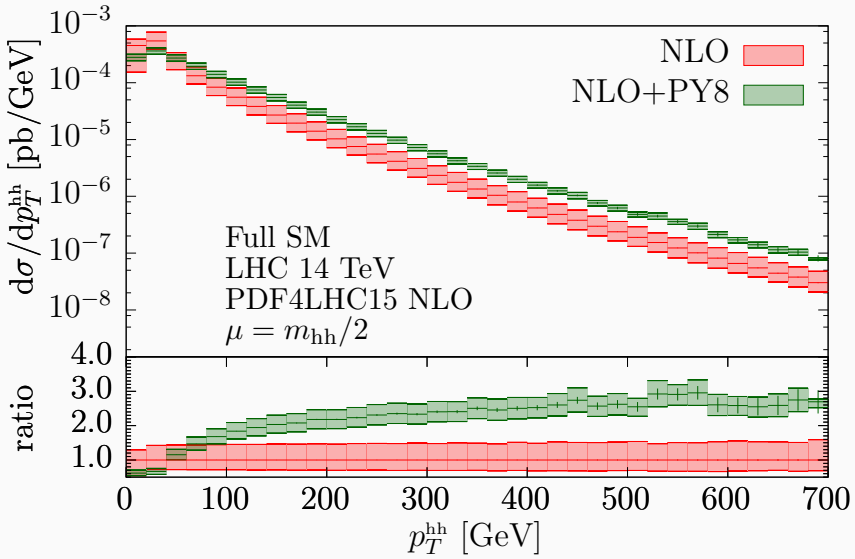
[Jones] – 2016

PHENOMENOLOGICAL RESULTS

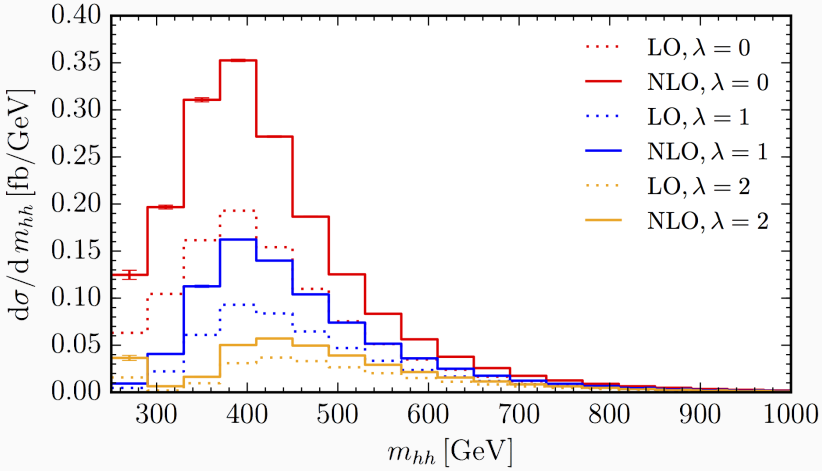
NLO corrections



Parton shower effects



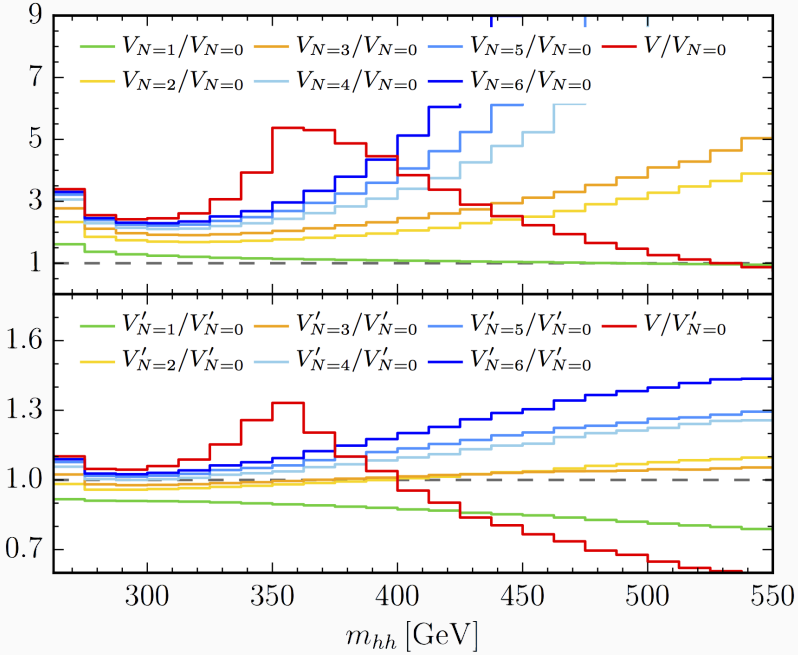
Self-coupling dependence

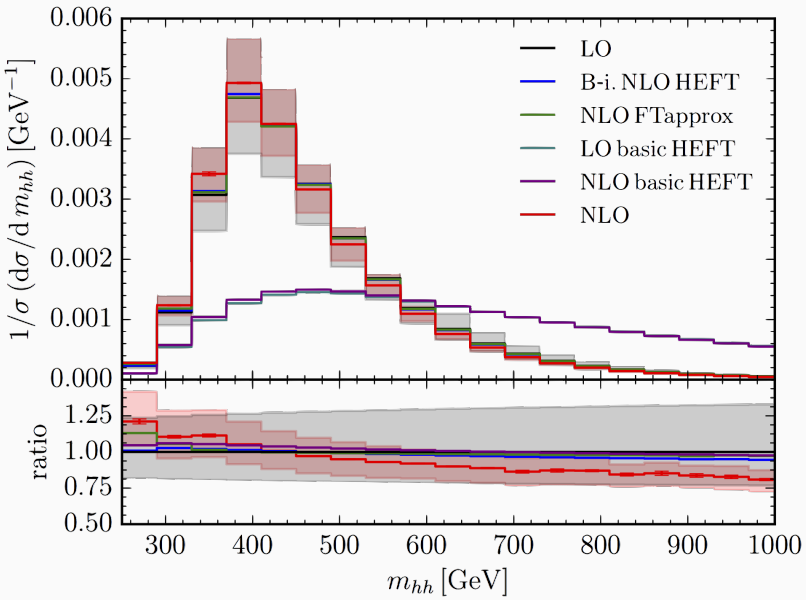


[Borowka, Greiner, Heinrich, Jones, Kerner, Schlenk, Schubert, Zirke] – 2016
[Heinrich, Jones, Kerner, Luisoni, Vryonidou] – 2017

ASSESSMENT OF APPROXIMATE PREDICTIONS

Both high order HEFT expansion and rescaled HEFT fail





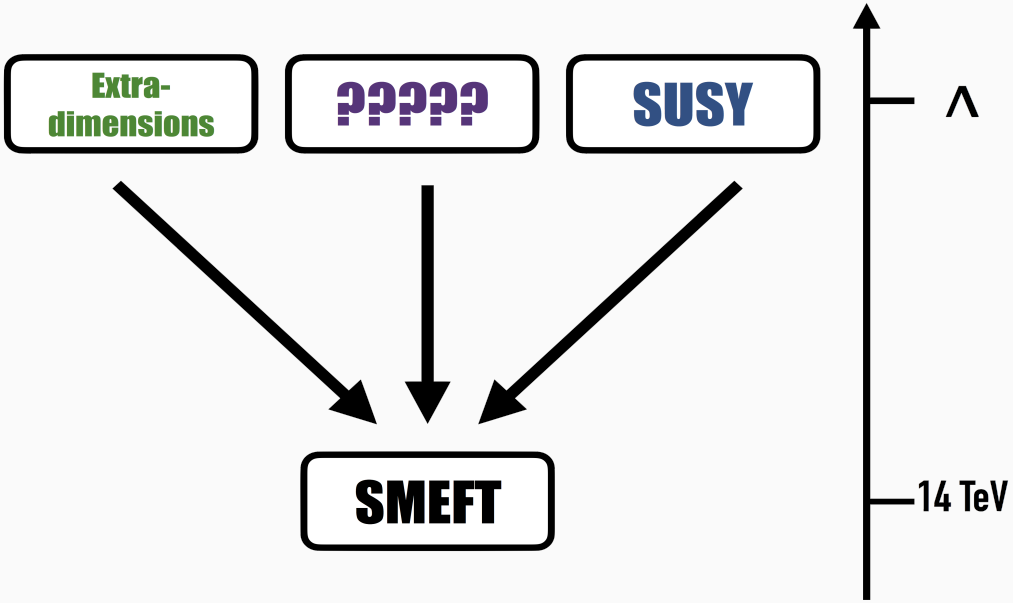
Born-improved HEFT improves distributions but still 25% off

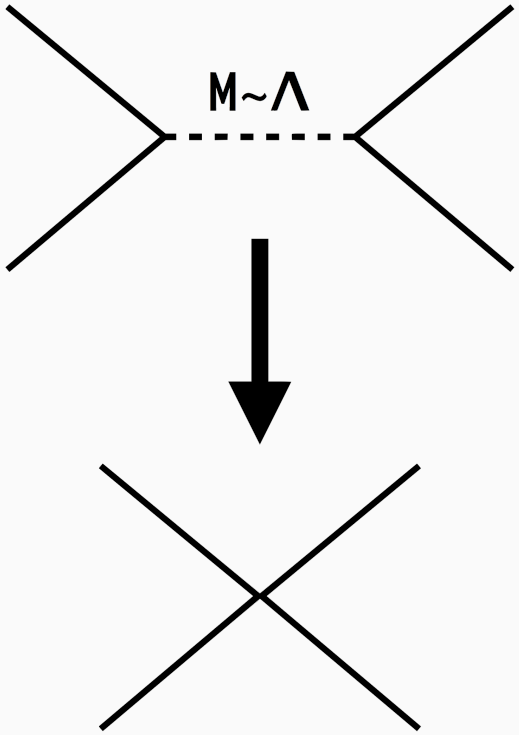
GLUON FUSION AT NLO IN THE SMEFT

MODEL INDEPENDENT CONSTRAINTS ON NEW PHYSICS

Universal EFT describing heavy new physics

$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_{k=1}^{N} \frac{1}{\Lambda^k} \sum_i C_i \mathcal{O}_i^{[k+4]} \tag{1}$$

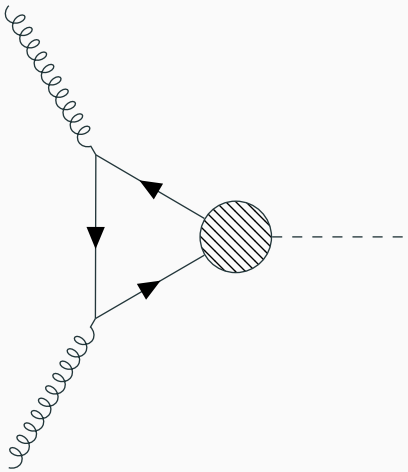




MODIFYING THE TOP LOOP

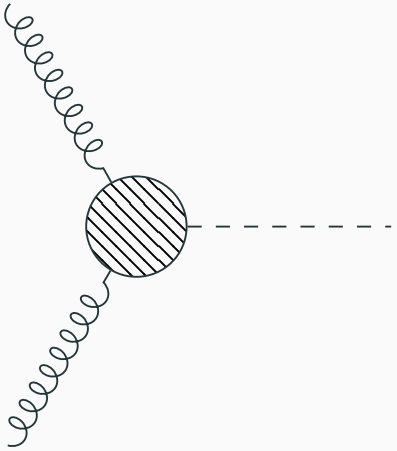
Yukawa correction

$C_1 \bar{Q} \sigma^{\mu\nu} t_R \phi (\phi^\dagger \phi)$



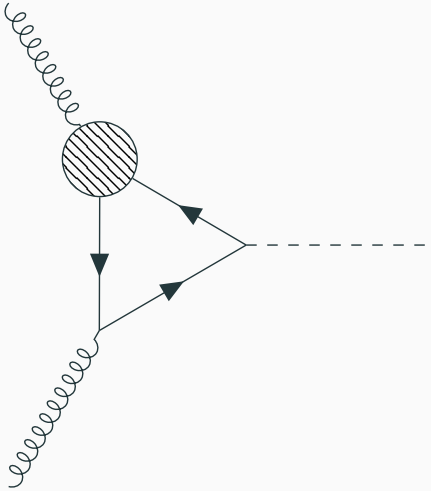
Gluon fusion

$g_s^2 C_2 \phi^\dagger \phi G_{\mu\nu} G^{\mu\nu}$



Chromomagnetic

$g_s C_3 \bar{Q} \sigma^{\mu\nu} t_R \phi G_{\mu\nu}$



LO: [Degrande,Gérard,Grojean,Maltoni,Servant] – 2013

NLO+NLL (O_1 & O_2) [Grazzini,Ilnicka,Spira,Wiesemann] – 2016

NLO CROSS SECTIONS AND CRUDE LIMITS

$$\sigma = \sigma_{\mathsf{SM}} + \frac{(1\ \mathrm{TeV})^2}{\Lambda^2}\left(\mathsf{C}_1\sigma_1 + \mathsf{C}_2\sigma_2 + \mathsf{C}_3\sigma_3\right)$$

[ND, Duhr, Maltoni, Vryonidou]

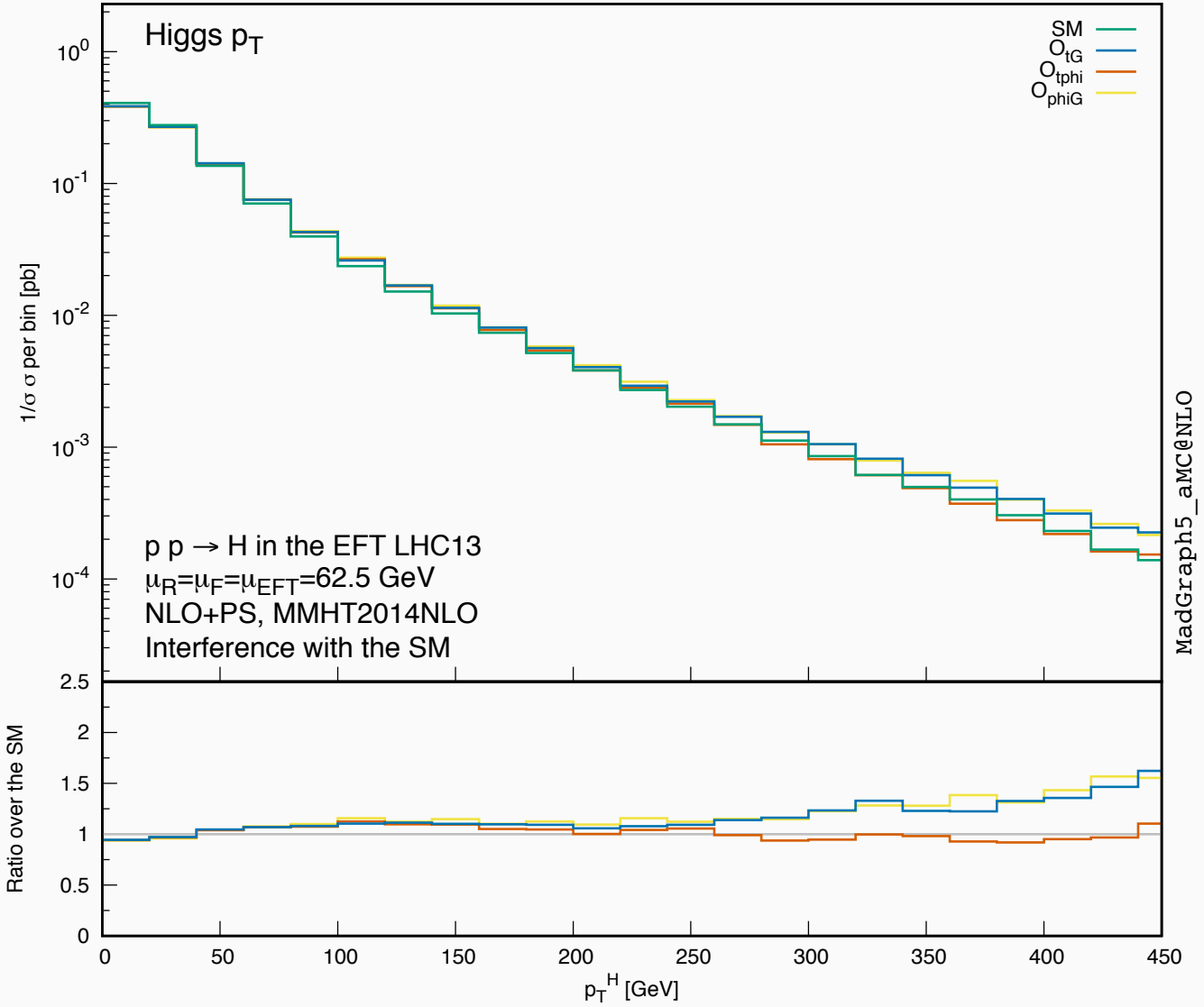
NLO CROSS SECTIONS AND CRUDE LIMITS

$$\sigma = \sigma_{\mathrm{SM}} + \frac{(1\ \mathrm{TeV})^2}{\Lambda^2}\left(C_1\sigma_1 + C_2\sigma_2 + C_3\sigma_3\right)$$

13 TeV	σ_1	σ_2	σ_3
LO (pb)	$-2.93^{+34\%}_{-25\%}$	$2660^{+34\%}_{-25\%}$	$50.5^{+34\%}_{-25\%}$
NLO (pb)	$-4.70^{+25\%}_{-20\%}$	$4130^{+24\%}_{-20\%}$	$83.5^{+26\%}_{-21\%}$
K-factor	1.61	1.55	1.65
Bound	$-0.3 < -0.13C_1 + 111C_2 + 2.3C_3 < 0.48$		

[ND, Duhr, Maltoni, Vryonidou]

DIFFERENTIAL CROSS SECTIONS



[ND, Duhr, Maltoni, Vryonidou]

CONCLUSION

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Many impressive results in SM Higgs predictions

- Analytic calculations for gluon fusion, $H + j$ and VBF
- Numerical calculation for HH

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New challenges to tackle

- Internal masses beyond the reach of our standard toolbox
- Analytic complexity is becoming a problem

Thank you for your attention