Double-Higgs boson production at NLO

Combine numerical evaluation and analytic high energy approximation

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JHEP 1803 (2018) 048
JHEP 1901 (2019) 176
[arXiv:1907.06408]

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λ_{HHH} in the Standard Model

Higgs potential $$V(H) = \frac{1}{2} m_H^2 H^2 + \lambda_{HHH} v H^3 + \frac{1}{4} \lambda_{HHHH} H^4$$

in SM: $$\lambda_{HHH} = \frac{m_H^2}{2v^2} = 0.13\ldots$$ (not directly measured)

[CMS: arXiv:1811.09689]: $$-11.8 < \lambda/\lambda_{\mathrm{SM}} < 18.8$$

[ATL-PHYS-PUB-2019-009]: $$-3.2 < \lambda/\lambda_{\mathrm{SM}} < 11.9$$

λ_{HHH} in the Standard Model

talk slide by Nicola De Filippis on 1st Oct.

Summary/Conclusions

HL-LHC: potential for new physics discoveries and precision measurements in the Higgs sector:

- Few per-cent level precision on most Higgs cross sections and couplings
- significance of about 2.6σ for HH production → triple self coupling
- Higgs width measurable to within 1 MeV
- sensitivity to BSM effects in Higgs physics derived

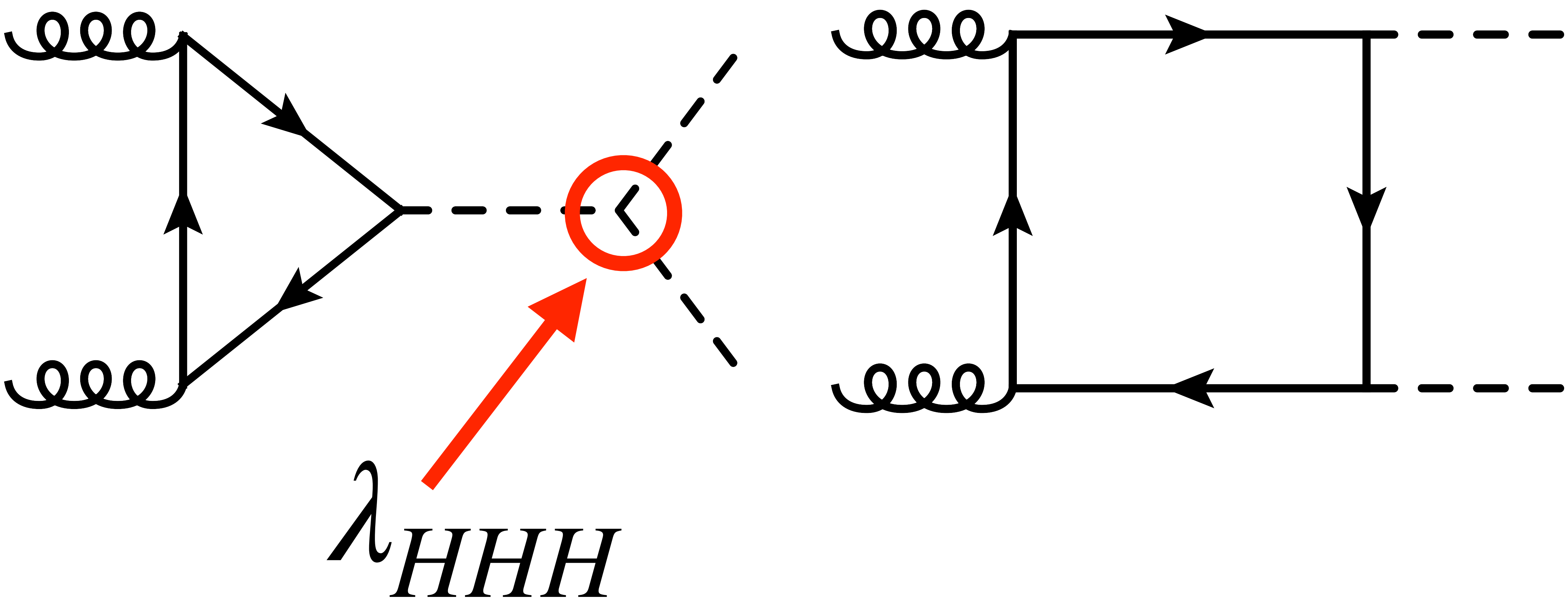
Many inclusive measurements limited by systematic uncertainties → work needed from theoretical and experimental side

An exciting journey ahead!

N. De Filippis Sept 30 - Oct 4, Higgs couplings 2019 22

λ_{HHH} in the Standard Model

The simplest process is Higgs pair production.



Previous works

exact analytic@LO
[Eboli, Marques, Novaes, Natale, ’87, Glover, van der Bij ’88, Plehn, Spira, Zerwas, ‘96]

Born-improved HEFT@NLO
[Dawson, Dittmaier Spira, ’98]

$\mathrm{FT}_{\mathrm{approx}}$, $\mathrm{FT}'_{\mathrm{approx}}$
[Maltoni, Vryonidou, Zaro, ’14]

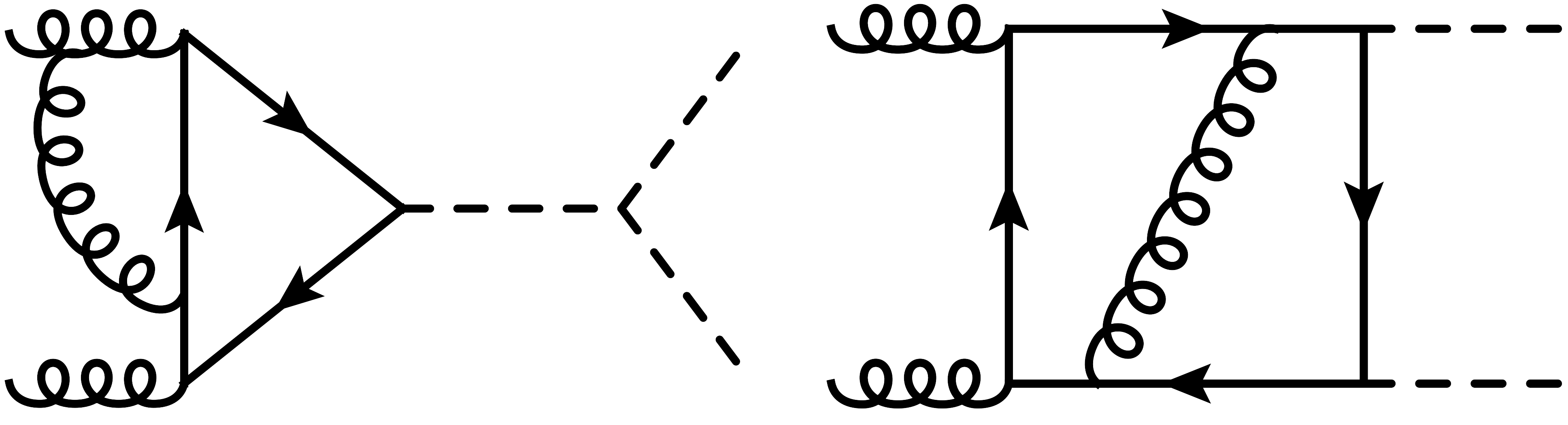
HEFT@NNLO with 1/mt corr.
**[Grigo, Hoff, Melnikov, Steinhauser, ’13,
Grigo, Melnikov, Steinhauser, ’14,
Grigo, Hoff, Steinhauser, ’15, Degrassi, Giardino, Gröber, ‘16]**

exact numerical@NLO
**[Borowka, Greiner, Heinrich, Jones, Kerner, Schlenk, Zicke, ’16,
Baglio, Campanario, Glaus, Mühlleitner, Spria, Streicher, ’18]**

Padé approximation using the large top-mass and the threshold expansion@NLO
[Gröber, Maier Rauh, ’17]

small p_T expansion@NLO
[Bonciani, Degrassi, Giardino, Gröber, ’18]

Our work



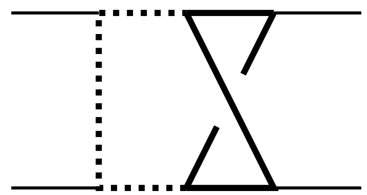
two-loop integrals: high-energy approximation
and
numerical evaluation

high-energy approximation

based on JHEP 1803 (2018) 048, JHEP 1901 (2019) 176, JHEP 1902 (2019) 080

Expand each Feynman diagrams by means of **the method of region.**

[Beneke, Smirnov '97, Smirnov `02, Jantzen `11]



$$= \sum_{n_h=0,1} \left(\frac{m_h^2}{s}\right)^{n_h} \sum_{n_t} \left(\frac{m_t^2}{s}\right)^{n_t} c_{n_h,n_t}$$

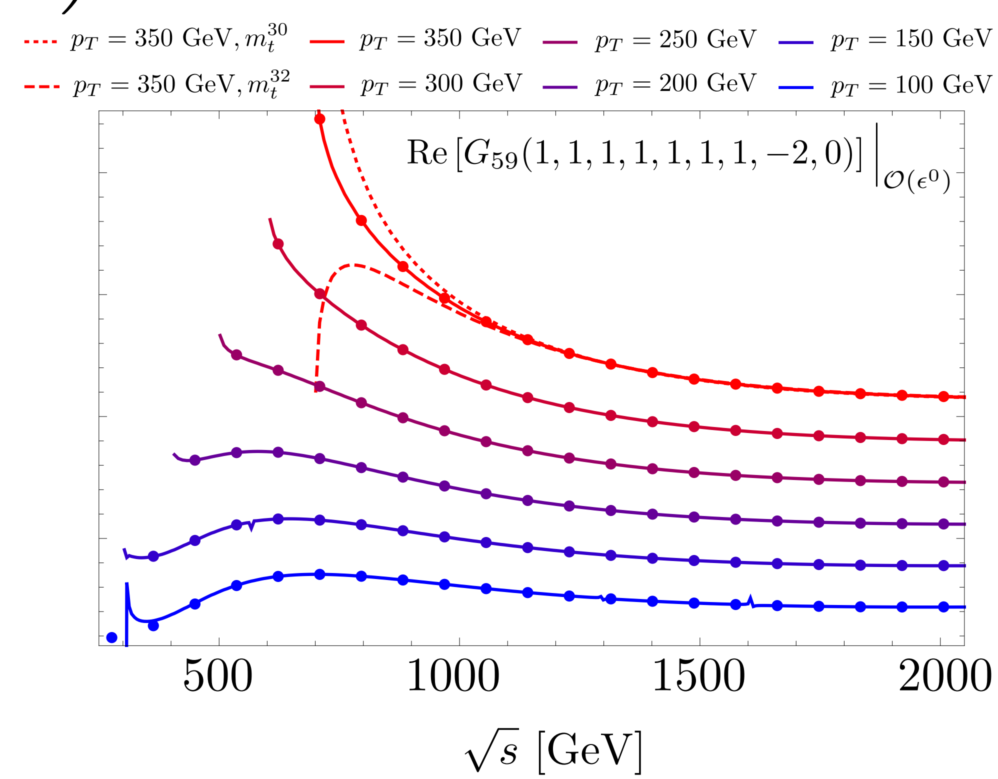
Cross section is expressed as a series in m_t (we have obtained up to m_t^{32}).

$$\delta\sigma^{\rm NLO}_{\rm virtual} = \sum_{n_h=0,1} \left(\frac{m_h^2}{s}\right)^{n_h} \sum_{n_t} \left(\frac{m_t^2}{s}\right)^{n_t} d_{n_h,n_t}$$

Apply the Padé approximation with respect to m_t .
-> The region of convergence is significantly improved.

$$f_0 + f_1 x + \cdots + f_{n+m} x^{n+m}$$

$$\rightarrow \frac{a_0 + a_1 x + \cdots + a_n x^n}{1 + b_1 x + \cdots + b_m x^m}$$



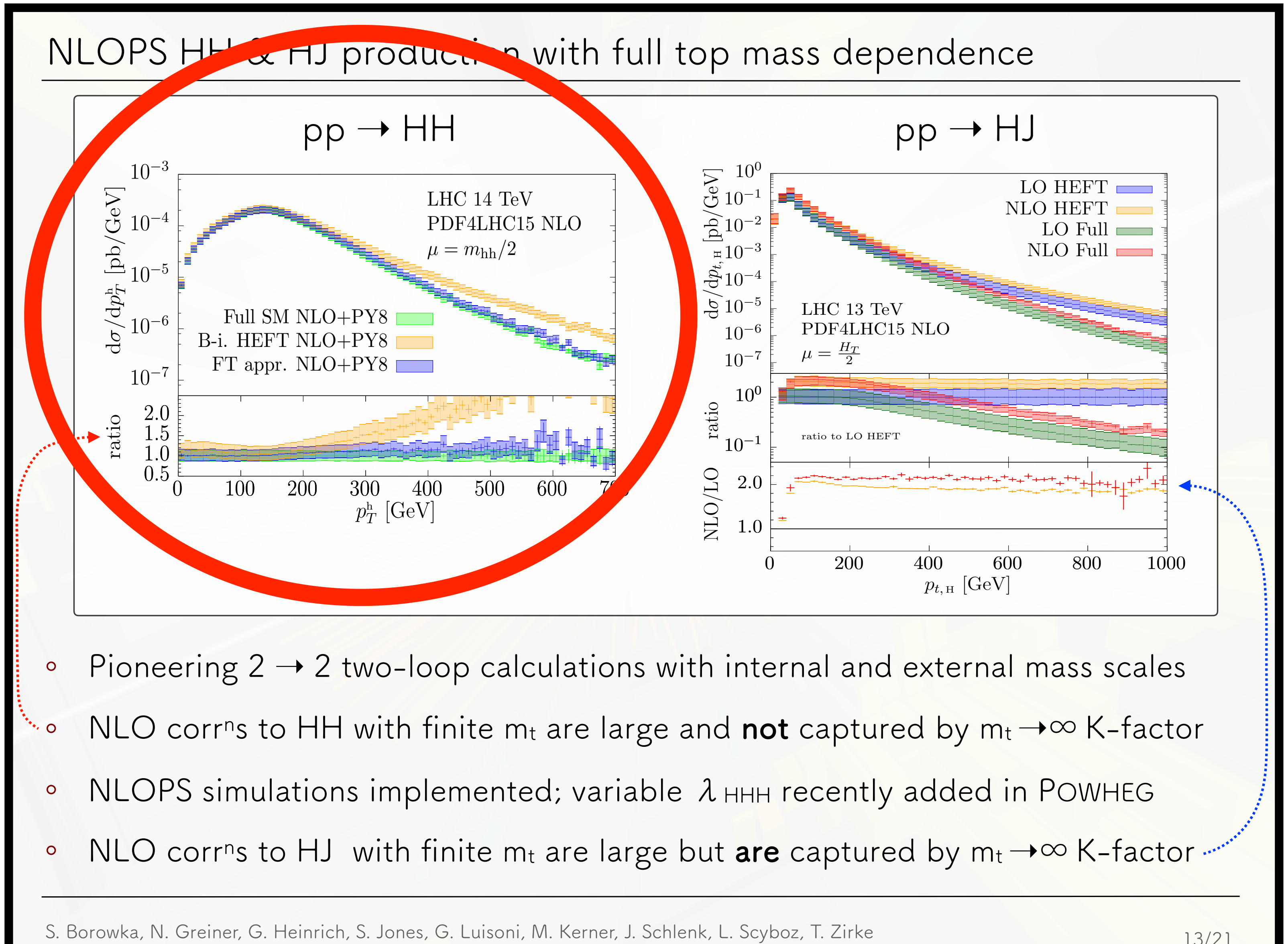
numerical evaluation

based on PRL 117 (2016) 012001, JHEP 1610 (2016) 107, JHEP 1708 (2017) 088

Numerically evaluated two-loop integrals (virtual correction) combined with parton showers within the POWHEG-BOX-V2 and MG5_aMC@NLO frameworks.

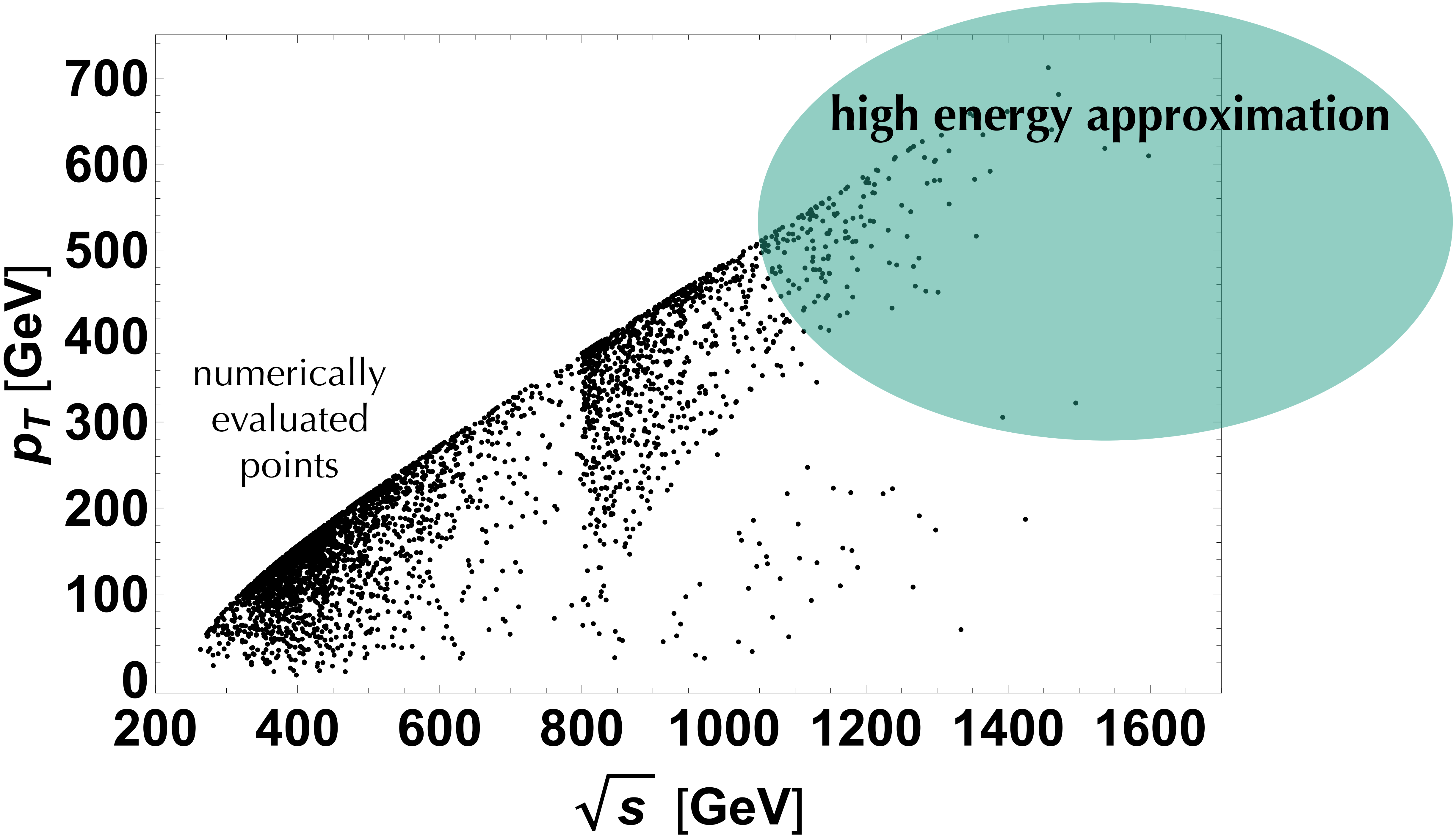
talk slide by
Keith Hamilton
on 1st Oct.

We are trying to improve this!

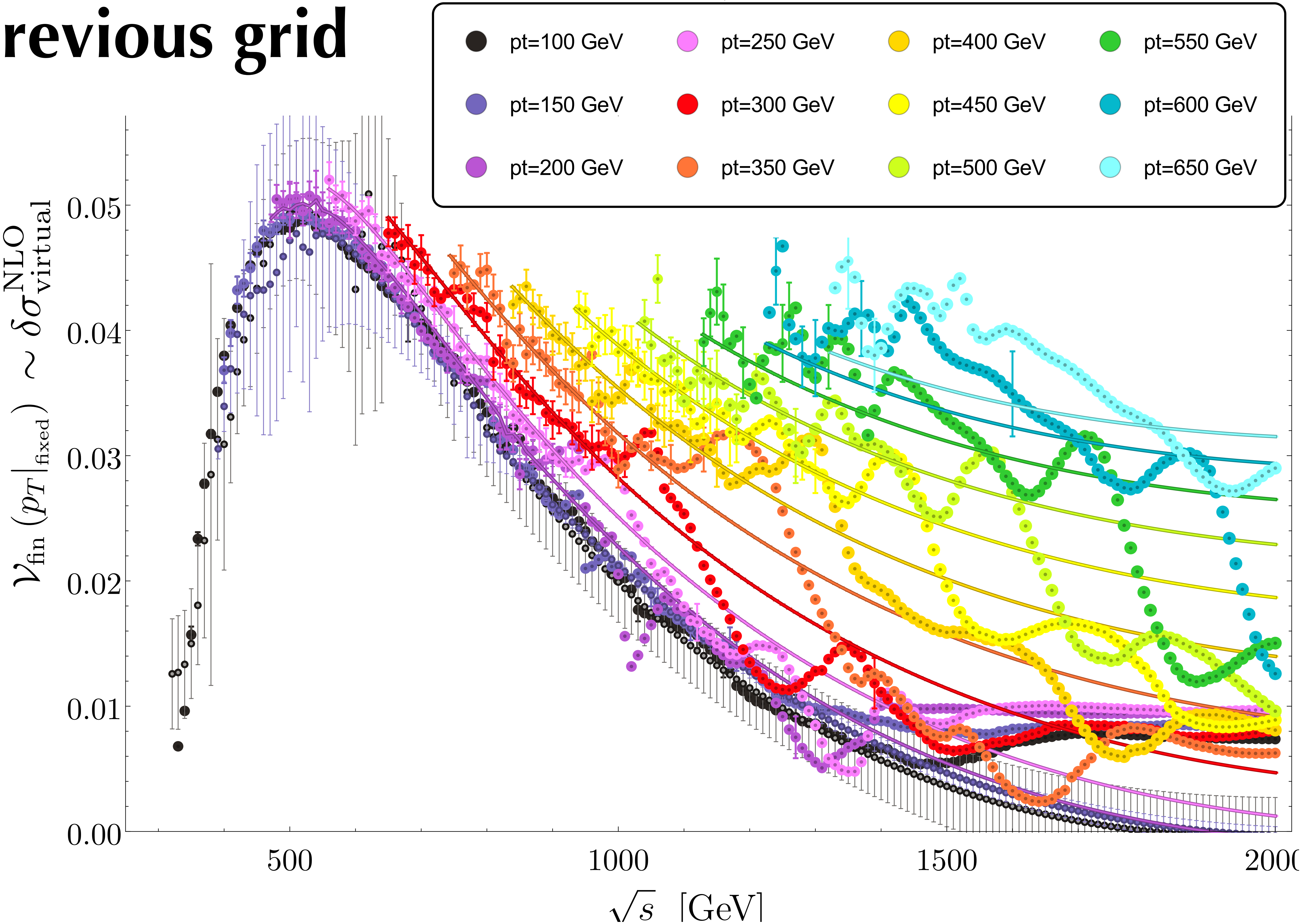


Two-loop integrals: evaluated points are increased: 3398 → 6320

Complementarity of HE approximation and numerics

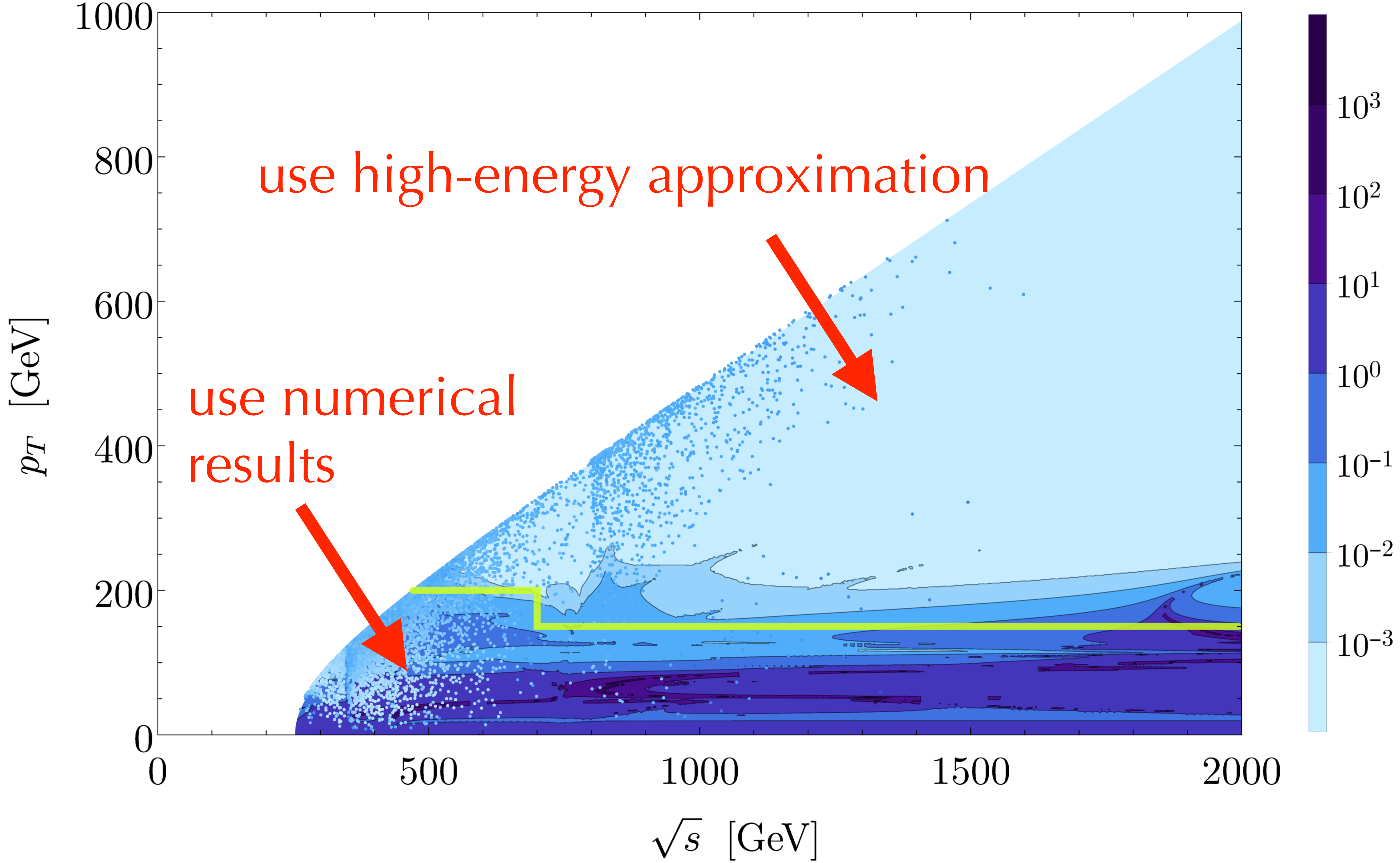


Previous grid



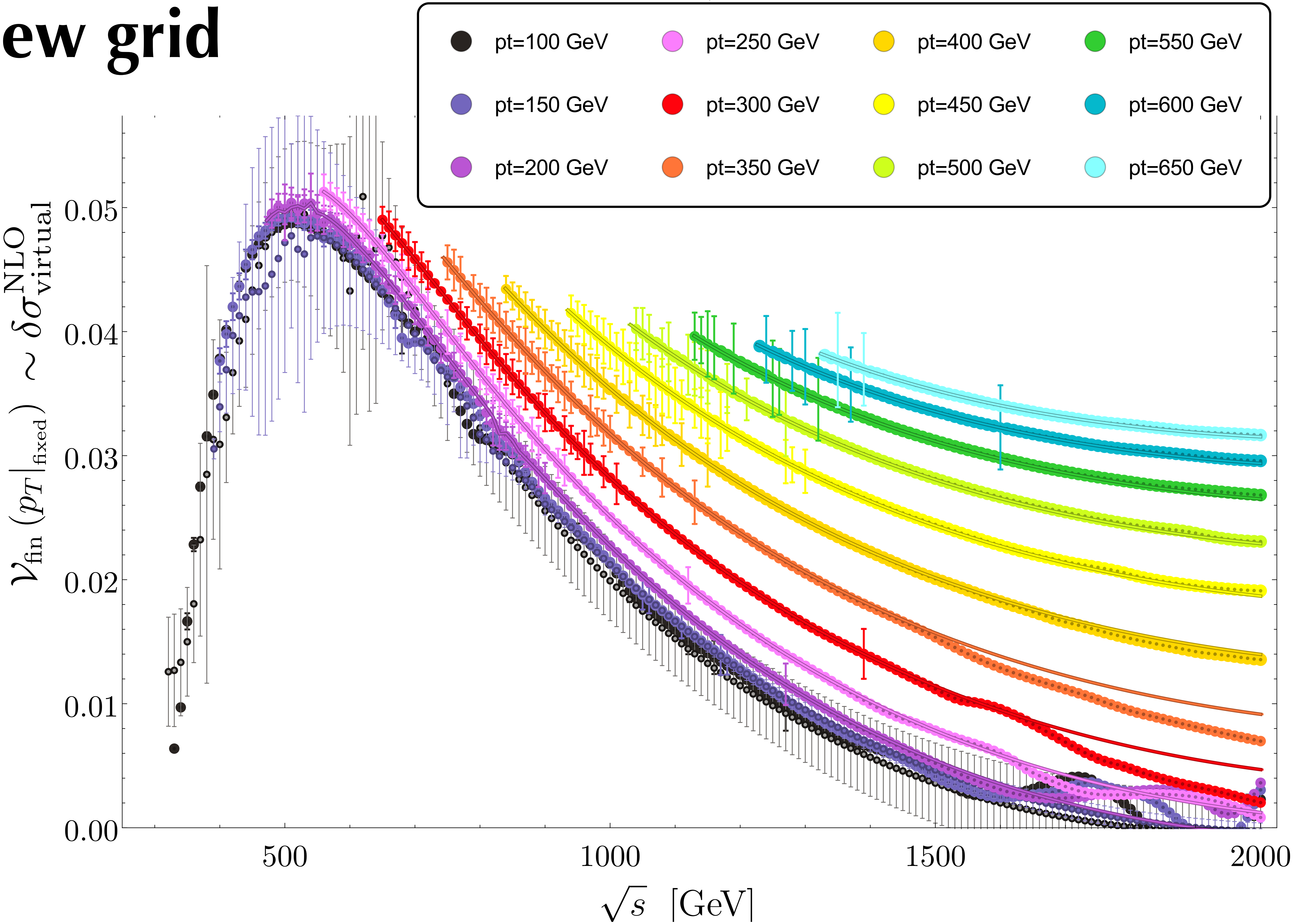
Double-Higgs boson production at NLO

Combine HE approximation and numerics



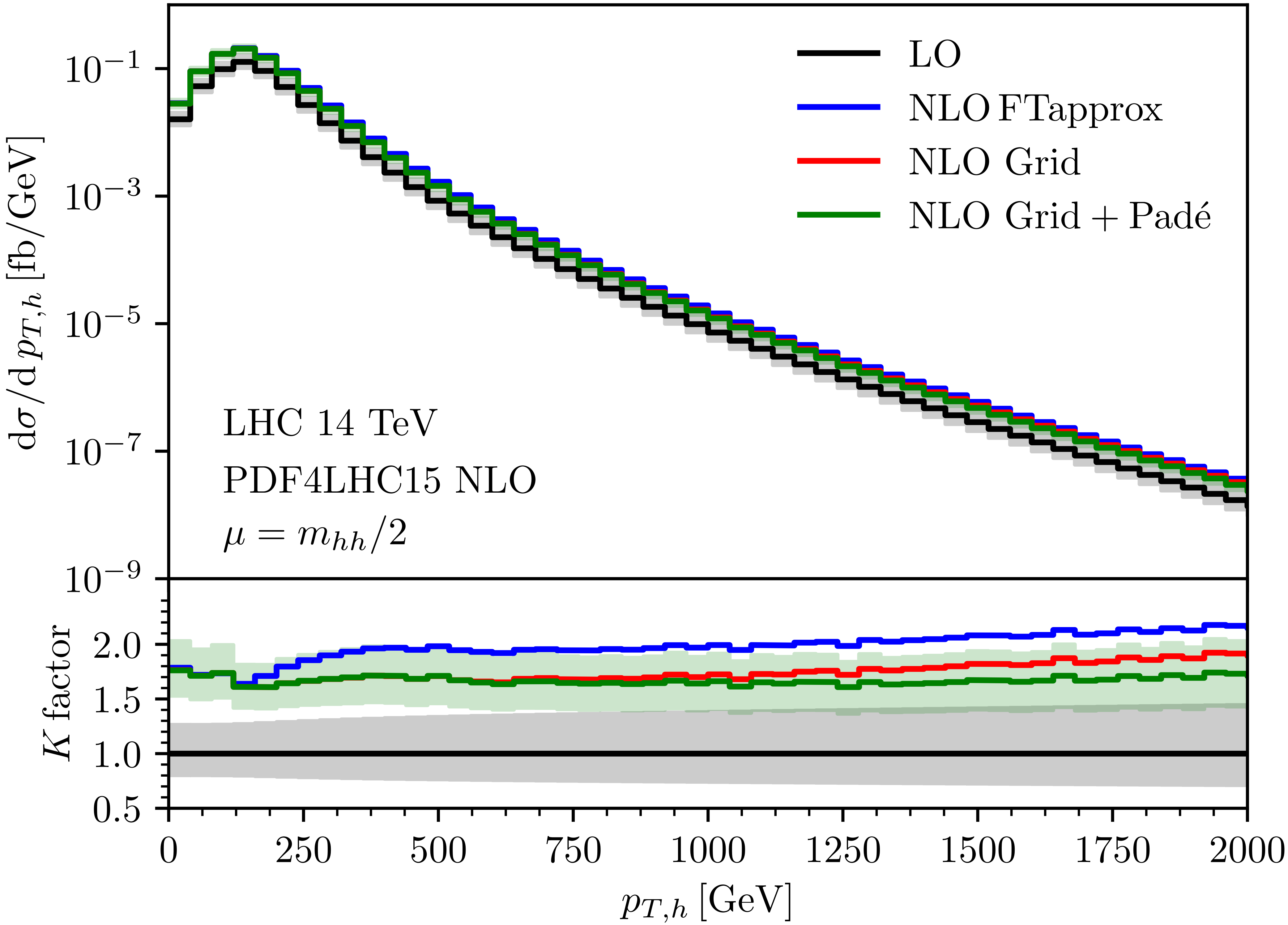
Double-Higgs boson production at NLO

New grid

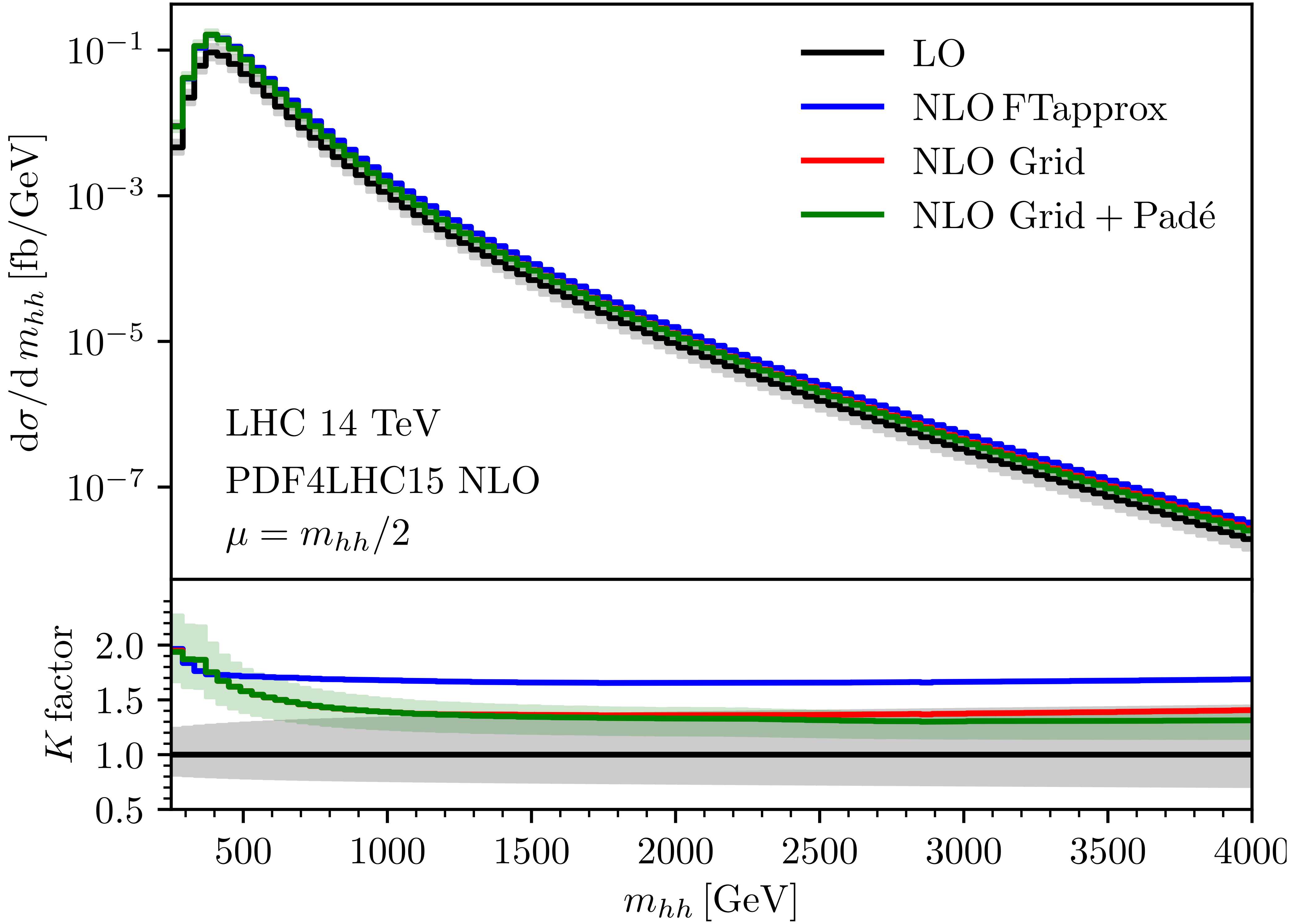


pt=100 GeV
pt=250 GeV
pt=400 GeV
pt=550 GeV
pt=150 GeV
pt=300 GeV
pt=450 GeV
pt=600 GeV
pt=200 GeV
pt=350 GeV
pt=500 GeV
pt=650 GeV
$\mathcal{V}_{\mathrm{fin}}\left(p_T|_{\mathrm{fixed}}\right) \sim \delta\sigma^{\mathrm{NLO}}_{\mathrm{virtual}}$
0.05
0.04
0.03
0.02
0.01
0.00
500
1000
1500
2000
$\sqrt{s}$ [GeV]

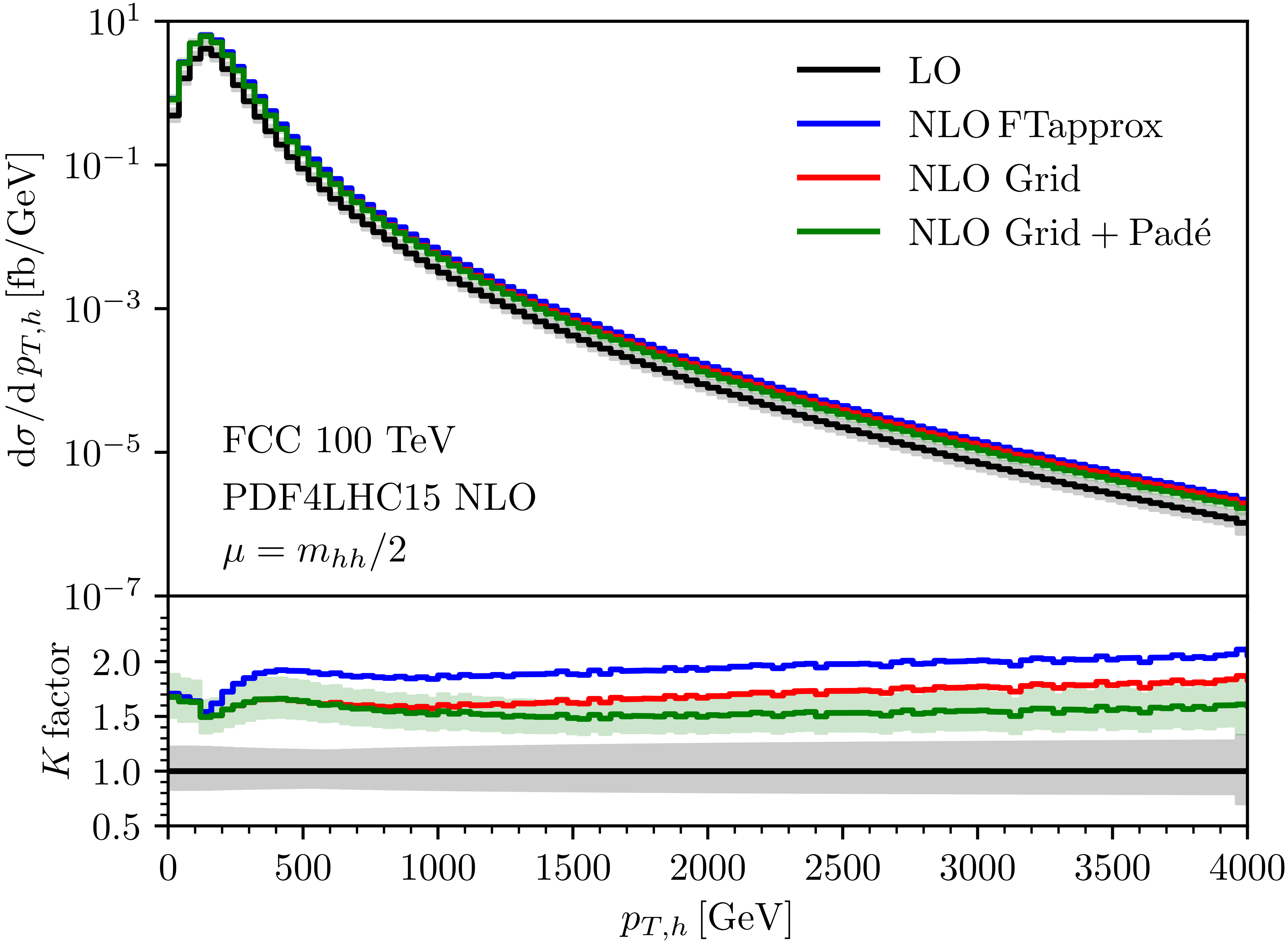
Result: p_T distribution at 14 TeV



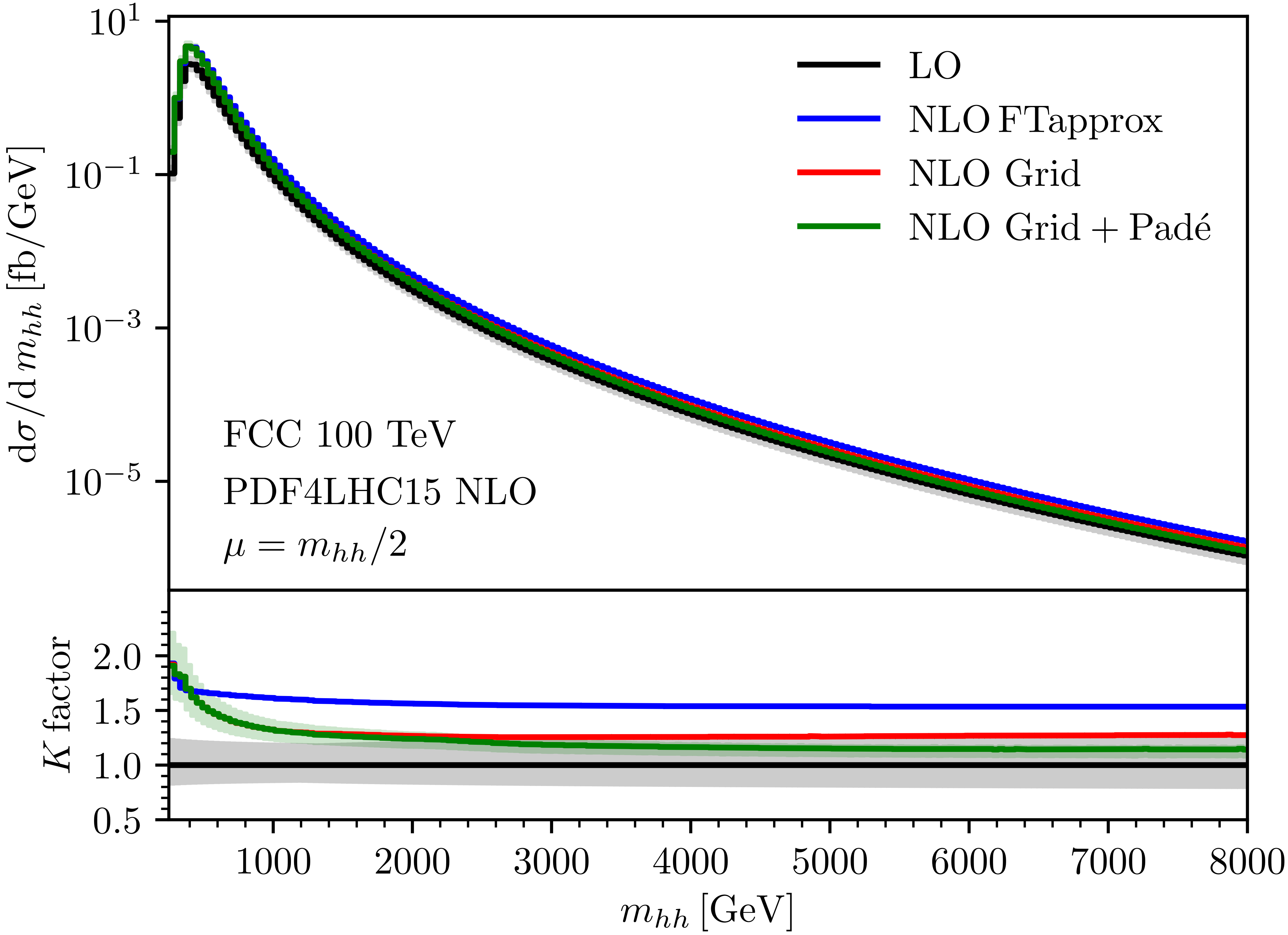
Result: m_{hh} distribution at 14 TeV



Result: p_T distribution at 100 TeV



Result: m_{hh} distribution at 100 TeV



Summary

- We have improved the NLO virtual corrections to the Higgs pair production cross section via gluon fusion by combining **numerical evaluation** and the **high-energy approximation**.
- The two method agree when $200\ \mathrm{GeV} < p_T < 400\ \mathrm{GeV}$, $\sqrt{s} < 800\ \mathrm{GeV}$
- **Padé improved high-energy approximation** provides reasonable results even down to $p_T \simeq 150\ \mathrm{GeV}$
- The updated gird is available at https://github.com/mppmu/hhgrid