Project Proposal
Boosted Higgs: Mass Scheme Uncertainty

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OS vs $\overline{\rm MS}$

Can relate the OS and $\overline{\rm MS}$ masses straightforwardly:

$$m_0 = Z_m^{\rm OS}\ m^{\rm OS}$$
$$m_0 = Z_m^{\overline{\rm MS}}\ m^{\overline{\rm MS}}$$

$$\rightarrow \quad m^{\overline{\rm MS}} = m^{\rm OS}\,\frac{Z_m^{\rm OS}}{Z_m^{\overline{\rm MS}}}$$

known to 4-loop (not a big source of uncertainty here)

Marquard , Smirnov, Smirnov, Steinhauser 15

The $\overline{\rm MS}$ mass depends on a scale μ (i.e. it is a ``running mass'')

Scale dependence fixed by RGE:

$$m^{\overline{\rm MS}}(\mu) = m^{\overline{\rm MS}}(\mu_0)\,\frac{c(\alpha_s(\mu)/\pi)}{c(\alpha_s(\mu_0)/\pi)}$$

also known to 4-loop (not a big source of uncertainty here)

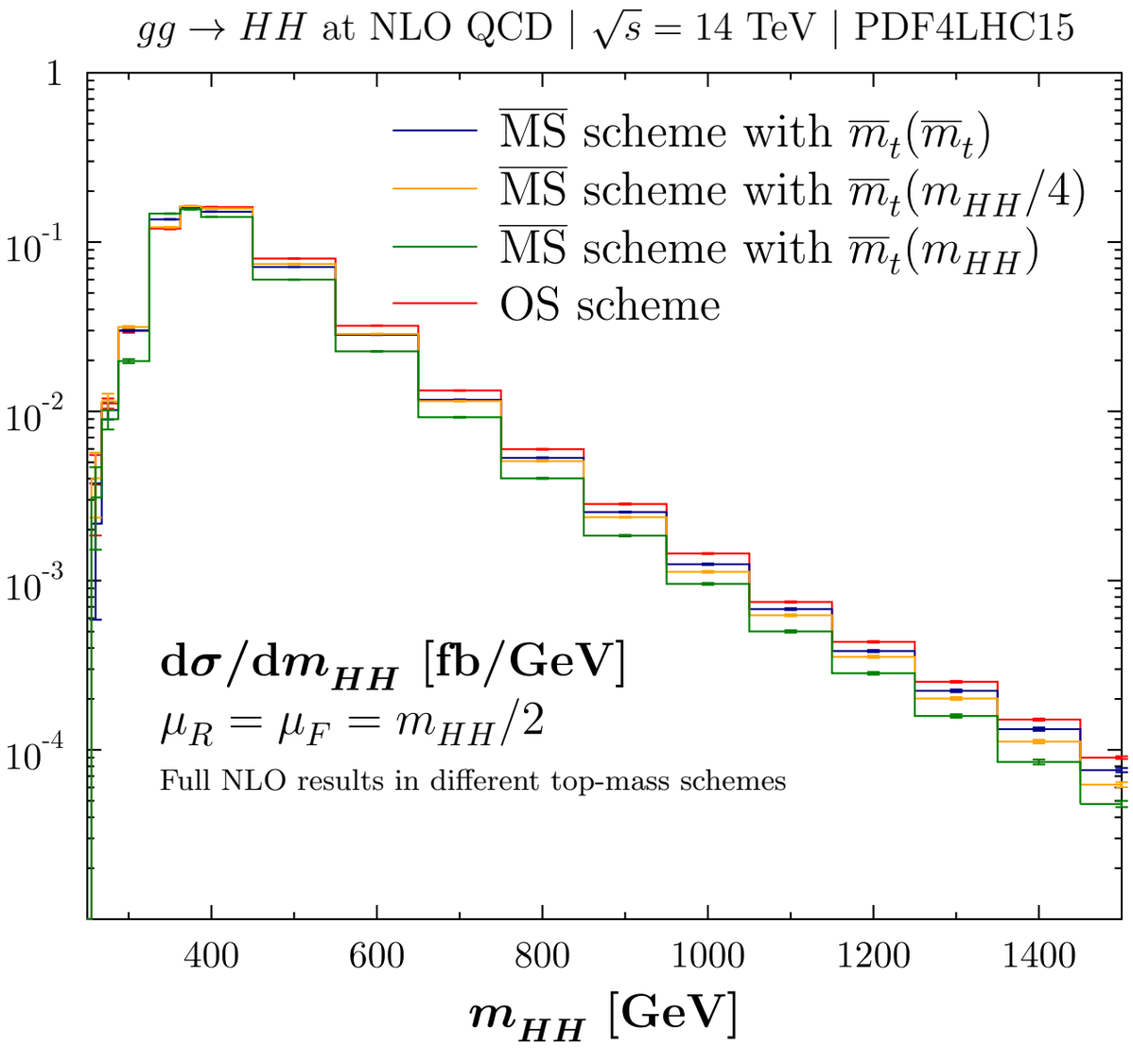
Chetyrkin 97; Vermaseren, Larin, van Ritbergen 97

HH Mass Scheme Uncertainties @ NLO

HH @ NLO: m_t in the OS and $\overline{\text{MS}}$ scheme

$$\sigma_{\text{tot}} = 32.81(7)^{+13.5\%\ +4\%}_{-12.5\%\ -18\%}\ \text{fb}$$

Baglio, Campanario, Glaus, Mühlleitner, (Ronca), Spira, Streicher 18, 20, 20



Studied top quark mass scheme/scale uncertainties:

$$\left.\frac{d\sigma(gg \to HH)}{dQ}\right|_{Q=300\ \text{GeV}} = 0.0312(5)^{+9\%}_{-23\%}\ \text{fb/GeV},$$

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

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

$$\left.\frac{d\sigma(gg \to HH)}{dQ}\right|_{Q=1200\ \text{GeV}} = 0.000435(4)^{+0\%}_{-30\%}\ \text{fb/GeV},$$

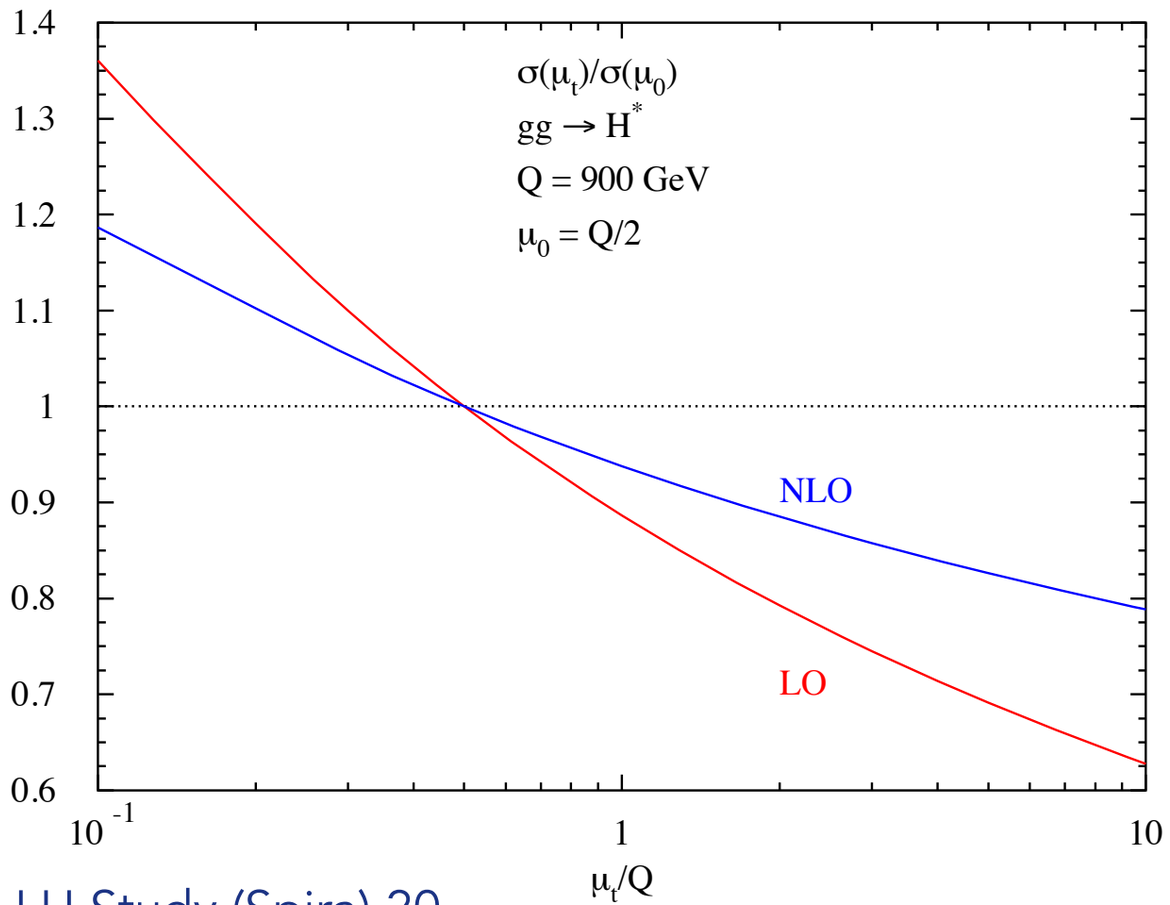
Large uncertainty obtained comparing OS scheme with $\overline{\text{MS}}$ scheme at scale m_{HH}

H* Mass Scheme Uncertainties @ LO & NLO

Les Houches study examined H*, HH, HJ, ZZ

LH Study 20

Consider $gg \to H^*$ @ $Q = 900$ GeV:



LH Study (Spira) 20

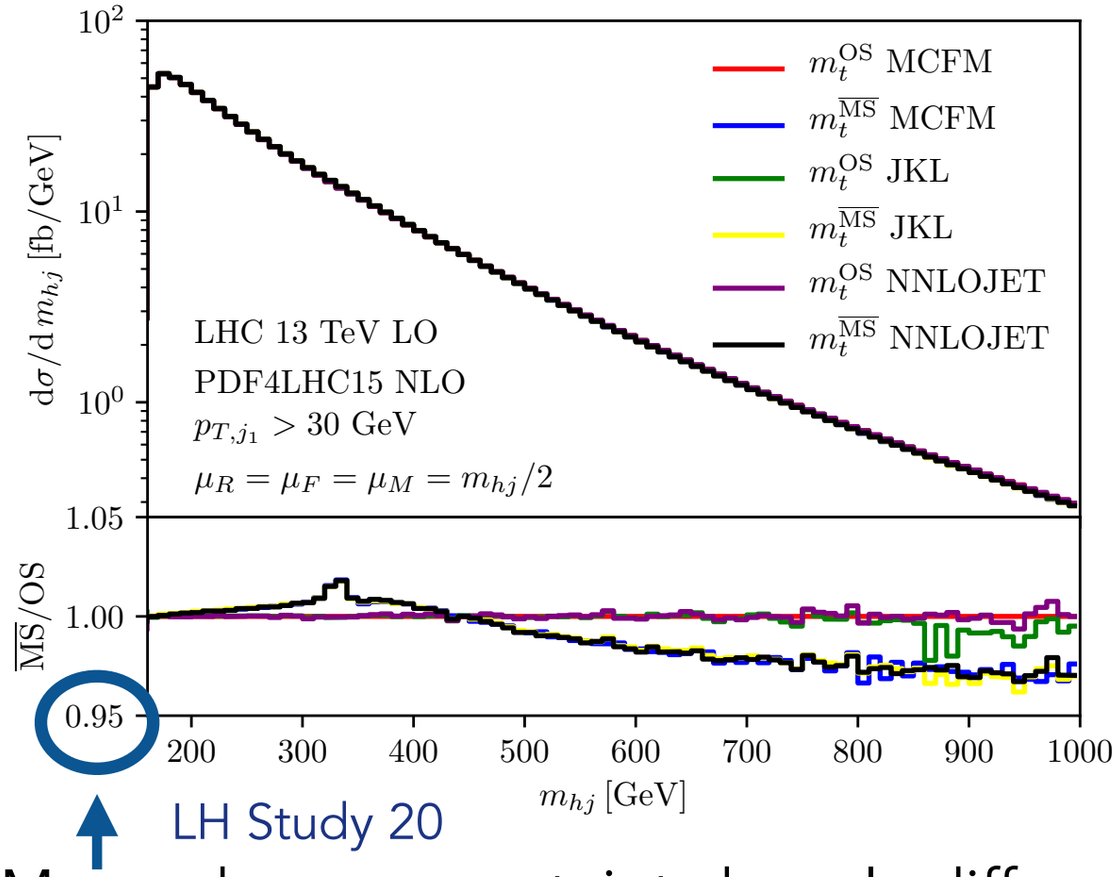
$\sigma(gg \to H^*)$ [pb]	$Q = 125$ GeV	$Q = 900$ GeV
LO	$18.43^{+0.8\%}_{-1.1\%}$	$0.139^{+0.0\%}_{-36.0\%}$
NLO	$42.17^{+0.4\%}_{-0.5\%}$	$0.230^{+0.0\%}_{-22.3\%}$

Similar to HH production, m_T scheme dependence reduced by only factor ~2

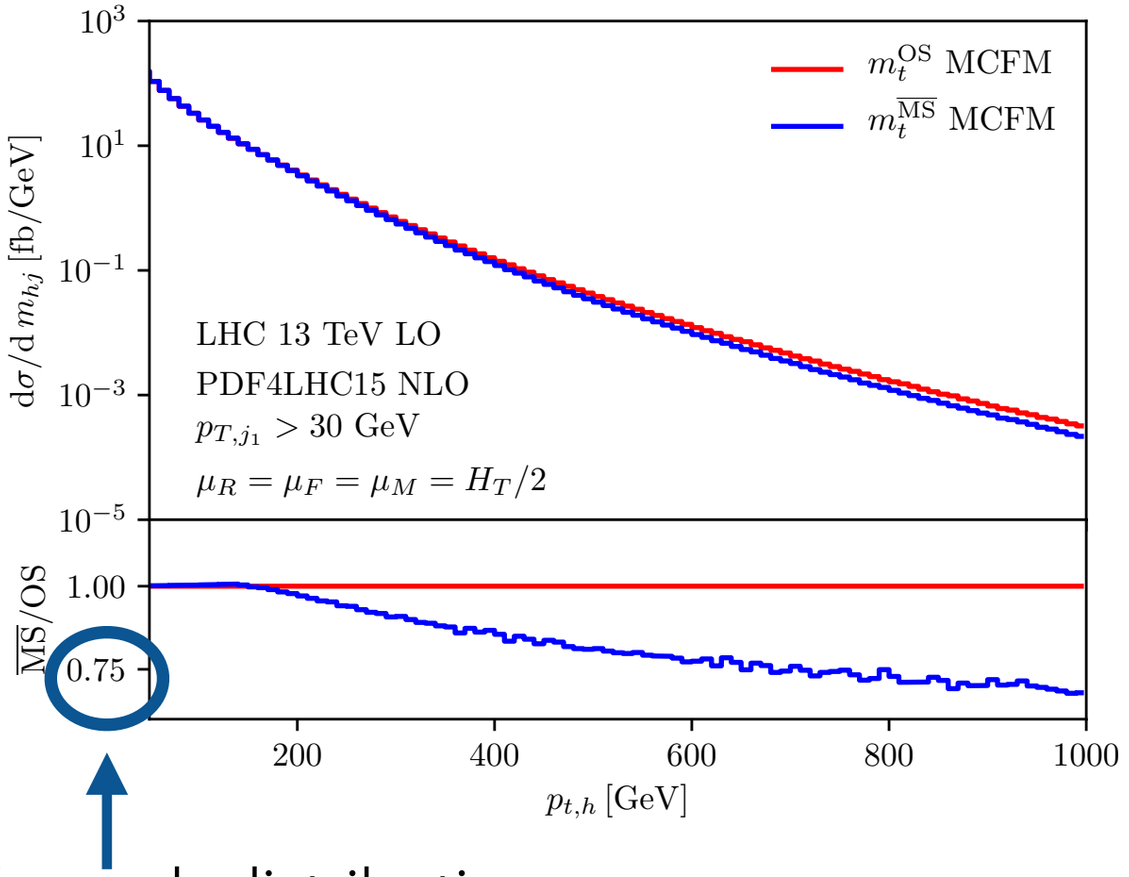
Note: For on-shell $H(125)$ production uncertainty is tiny

Suggests that mass scheme uncertainties could be quite sizeable for many (loop-induced) Higgs processes with scales $\gtrsim m_T$ (?)

HJ Mass Scheme Uncertainties @ LO



LH Study 20

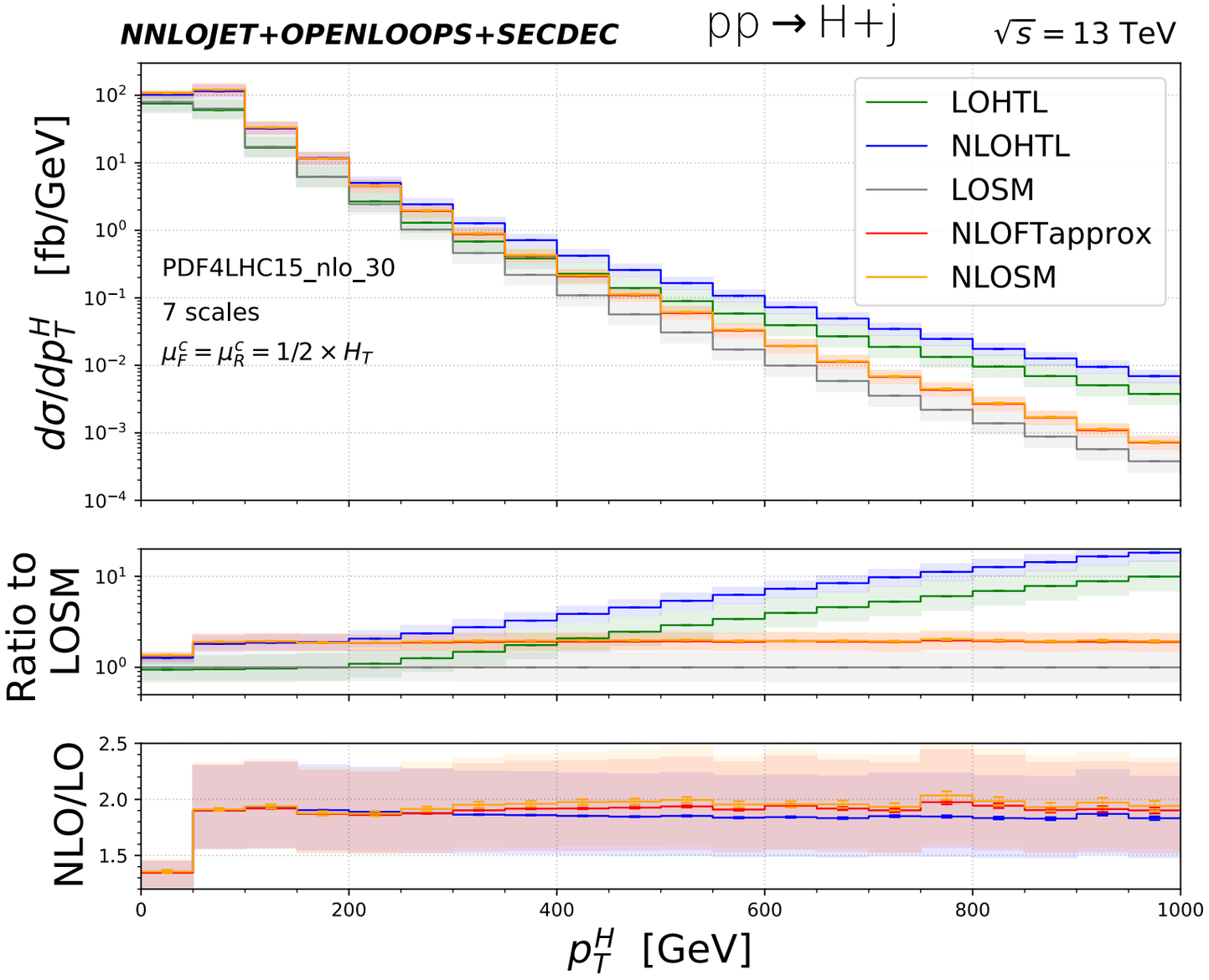


Mass scheme uncertainty hugely different for each distribution

Invariant mass plot dominated by contributions with a small p_T which do not probe the top-quark threshold (verified by applying $p_{T,j_1} > 300\ \mathrm{GeV}$ cut)

For boosted Higgs at LO we can see quite large effects ~ 25% at high-p_T
LO scale uncertainty ~±30% and NLO scale uncertainty ~±16%

HJ @ NLO



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

Full result known (numerically or via expansion in small-m_T) for OS scheme

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

Very stable and fast reals are available

Apparently only few % effect from including the top-quark mass in the virtuals (vs born reweighted HTL virtuals)

e.g. Chen, Huss, SPJ, Kerner, Lang, Lindert, Zhang 21

HJ Expanded Virtuals

Can consider Higgs boson & top quark masses as small

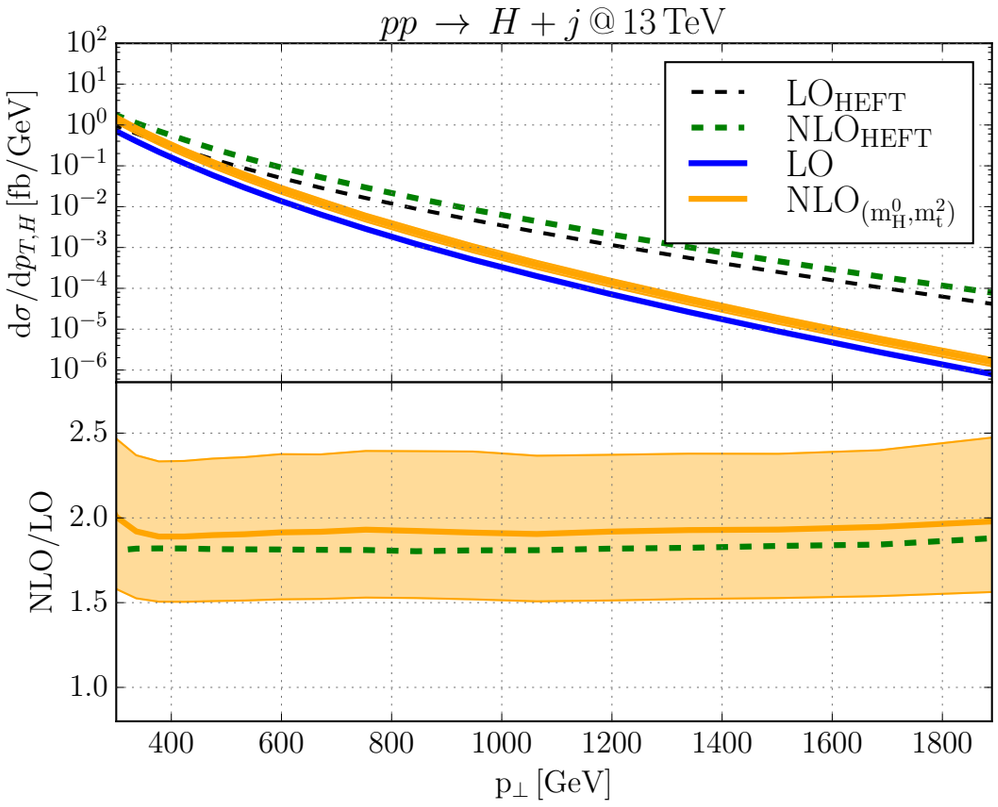
Introduce variables:

$$\eta = -\frac{m_H^2}{4m_T^2}, \quad \kappa = -\frac{m_T^2}{s}, \quad z = \frac{u}{s}$$

Expand integrals to $\mathcal{O}(\eta^0\kappa^1)$ justified for $m_H^2, m_T^2 \ll |s| \sim |t| \sim |u|$,

For example at large $p_T^2 = ut/s$

Kudashkin, Melnikov, Wever 17



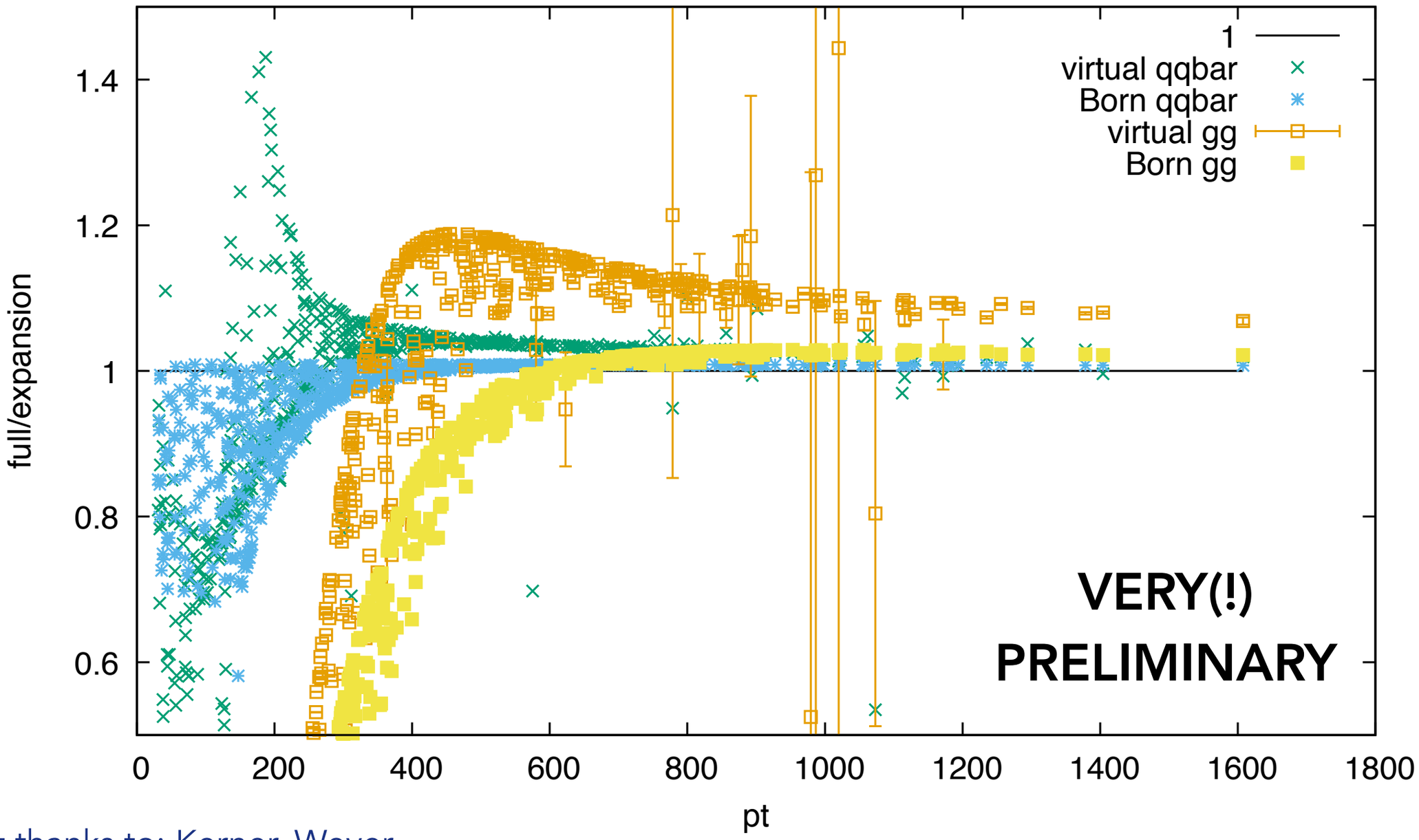
Expanded 2-loop virtuals can be combined with full reals to predict Higgs boson p_T distribution above top threshold

Lindert, Kudashkin, Melnikov, Wever 18

Easy(?) to change top-quark mass scheme in these results

Expanded Virtuals vs Full

Can compare just the virtuals (V_{fin}) in the full and expanded results, differences at the level of 10-20% (but virtuals apparently only account for small part of total)



Plot thanks to: Kerner, Wever

Summary

Proposal

Perform a study of HJ mass scheme uncertainty at NLO

Ingredients

Use reals from study of Chen et al.
Use virtuals from Melnikov et al.
(cross-check with numerical result of SPJ, Kerner, Luisoni)

Happy to hear comments on/interest in this proposal

Thank you for listening!