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Thoughts on p_T distributions

WG3 MSSM neutral subgroup

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HELMHOLTZ
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p_T distributions in gluon fusion diverge for $p_T \to 0$ at fixed order!
Thus: Need for resummation of Sudakov logarithms $\sim \log(p_T/m_\phi)$

✓ NNLL+NNLO (N^{3}LL+N^{3}LO since 2016) in the heavy top-limit
[Catani et al. '88, Yuan '92, Kauffman '92, Bozzi et al. '03 '05, Cao et al. '09, de Florian et al. '11, Catani Grazzini '11, Wang et al. '12]; in the context of SCET [Idilbi et al. '05, Gao et al. '05, Mantry et al. '10, Becher et al. '10 '12, Stewart et al. '11 '13] + Huge progress in 2015/2016

✓ Light-quark contributions and top-quark mass effects at NLL+NLO in SM
[Bagnaschi Degrassi Slavich Vicini '11, Mantler Wiesemann '12, Grazzini Sargsyan '13, Banfi Monni Zanderighi '13]
+ Corrections beyond NLO since 2016: [Melnikov et al., Caola et al.; Frederix et al.]

Current procedure: Resummation scales (μ) for individual contributions:

$$\frac{d\sigma}{dp_T^\phi} = \left.\frac{d\sigma_t}{dp_T^\phi}\right|_{\mu_t} + \left.\frac{d\sigma_b}{dp_T^\phi}\right|_{\mu_b} + \left.\frac{d\sigma_{\rm int}}{dp_T^\phi}\right|_{\mu_{\rm int}}$$

Resummation frameworks in extended Higgs sectors:

▷ (m) POWHEG (gg_H_MSSM, gg_H_2HDM) - Resummation through parton shower ($\mu = h$)
[Bagnaschi Degrassi Slavich Vicini '11, Bagnaschi Vicini '15]

(POWHEG-SusHi [Mantler unpublished])

▷aMCSusHi - SusHi amplitudes to MG5_aMC@NLO [Alwall et al. '14] ($\mu = Q^{\rm shower}$)
[Mantler Wiesemann '15]

▷MoRe-SusHi - Analytic resummation ($\mu = Q^{\rm res}$)
[Harlander Mantler Wiesemann '14]

Determination of scales (see also arXiv:1510.08850 by authors listed below):

▷ Bagnaschi-Vicini (BV): [Bagnaschi Vicini '15]

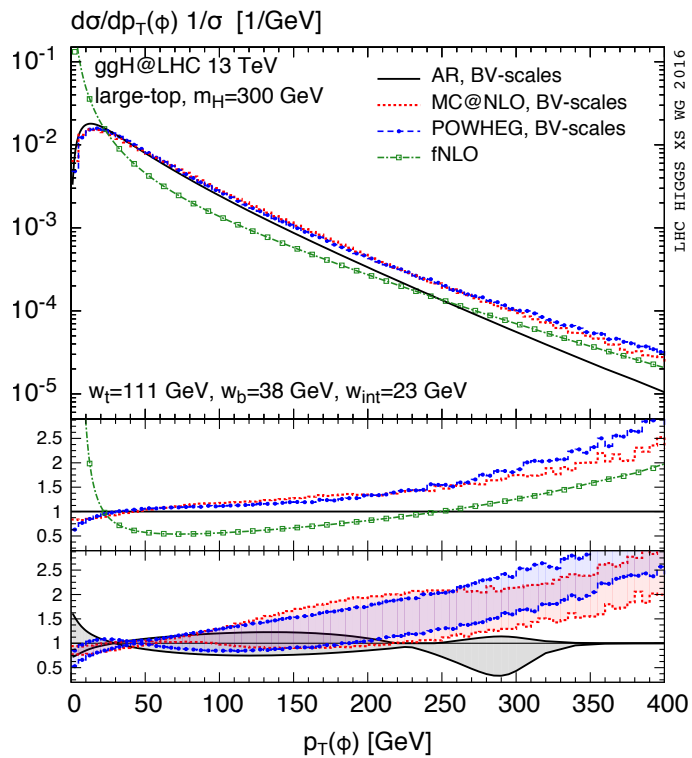
partonic level, low p_T,

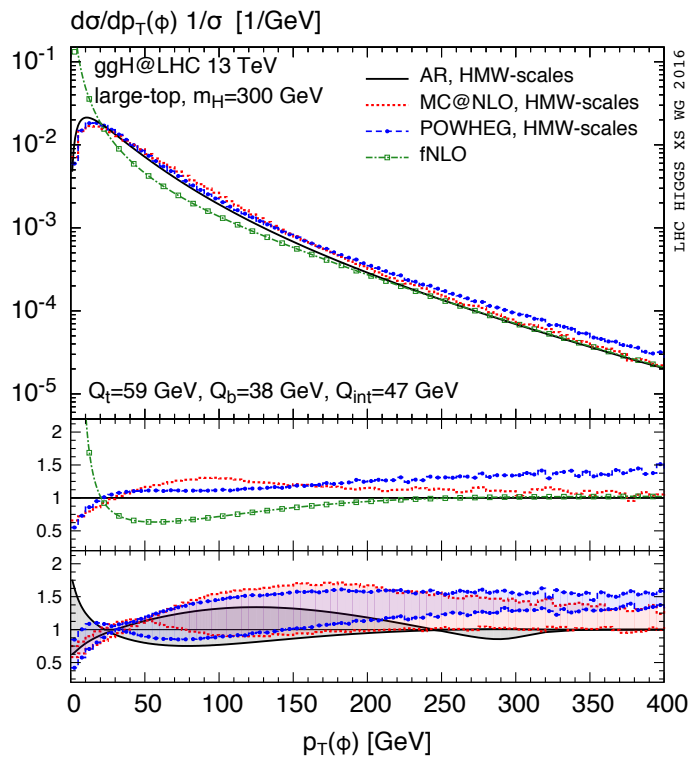
apply resummation when the collinear limit is a good approximation

▷ Harlander-Mantler-Wiesemann (HMW): [Harlander Mantler Wiesemann '14]

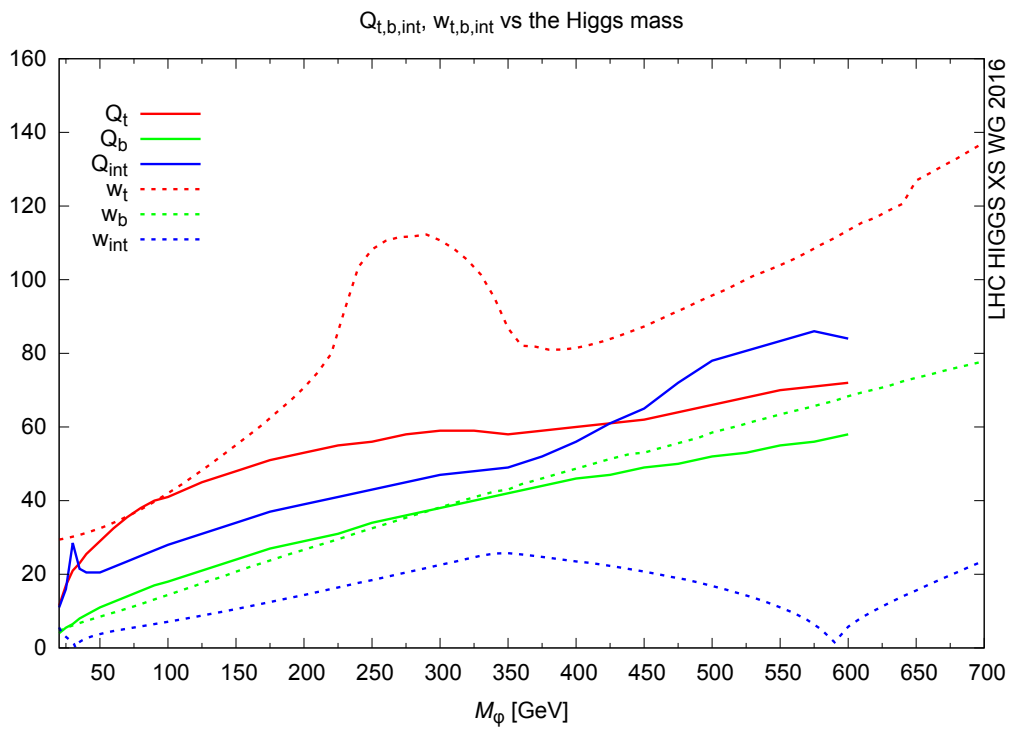
hadronic level, high p_T, recover the NLO behavior sufficiently fast for $p_T \geq m_\phi$

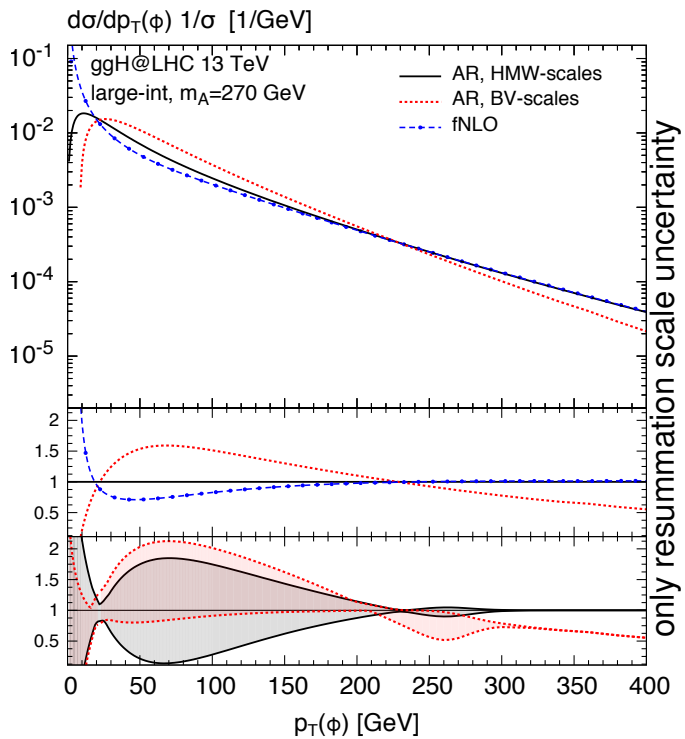
YR4 contains a description of the approaches and main results of comparison:





Main result of arXiv:1510.08850:
Variation of resummation scales within $(\mu/2, 2\mu)$ and addititional variation of renormalization and factorization scales gives comparable results between the different codes. Uncertainties capture differences of order $\mathcal{O}(50)$%! Both scale choices (w =BV and Q =HMW) are then acceptable.





Let me outline a **possible**, conservative procedure to obtain uncertainties:

0. Pick one tool and one scale setting approach.
1. Calculate the three contributions for t, b and int for three choices of μ^{res} (9 curves: $d\sigma_{t,b,\mathrm{int}}/dp_T(\mu^{\mathrm{res}})$) keeping $(\mu_{\mathrm{R}}, \mu_{\mathrm{F}})$ fixed.
2. Calculate the three contributions for t, b and int for seven (three?) choices of $(\mu_{\mathrm{R}}, \mu_{\mathrm{F}})$ (21 curves: $d\sigma_{t,b,\mathrm{int}}/dp_T(\mu_{\mathrm{R}}, \mu_{\mathrm{F}})$) keeping μ^{res} fixed.
3. Reweight curves to the MSSM (see Yuta's talk, by $Y_{t,b}^{\mathrm{MSSM,2HDM}}$).
4. Obtain the maximal and minimal curves from all combinations of curves in 1. and 2. individually and calculate the absolute errors for both:

$$\Delta\sigma(p_T) = \frac{\sigma^{\max}(p_T) - \sigma^{\min}(p_T)}{2} \qquad \text{with} \qquad \sigma(p_T) = \left.\frac{d\sigma}{dp_T}\right|_{p_T}$$

Add the errors in quadrature (Assumption: Uncorrelated!):

$$\Delta\sigma(p_T) = \sqrt{(\Delta\sigma^{\mu^{\mathrm{res}}}(p_T))^2 + (\Delta\sigma^{(\mu_{\mathrm{R}},\mu_{\mathrm{F}})}(p_T))^2}$$

Note: Steps 3.+4. can be performed on the fly within the ROOT files given we store the curves from 1.+2. as a function of the Higgs mass m_H/m_A.

Saving this information in the ROOT files?
If we store all contributions including uncertainties as a function of m_H/m_A in the ROOT files, then we should do the same for bottom-quark associated production relevant in large parts of the parameters space. Results for bbh can be reweighted from (not yet generated) SM results (provided e.g. by the bbh subgroup) including uncertainties.

Questions:
Can such a procedure be included in the tool `NLOReweightingTool`?
Before we start including this into the ROOT files, we have other priorities, namely to update the ROOT files with new SM input, charged Higgs information, etc..

Opinions?
Thanks to you and to Emanuele for input.