top and bottom-mass effects in HNNLOPS

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in collaboration with Keith Hamilton and Paolo Nason

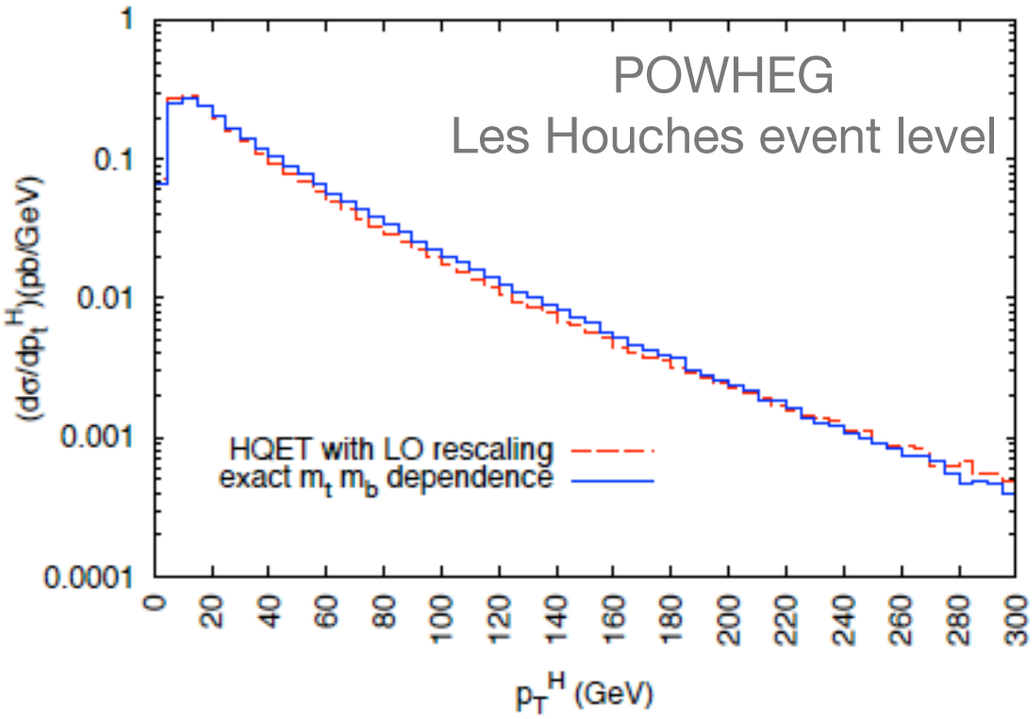
Outline

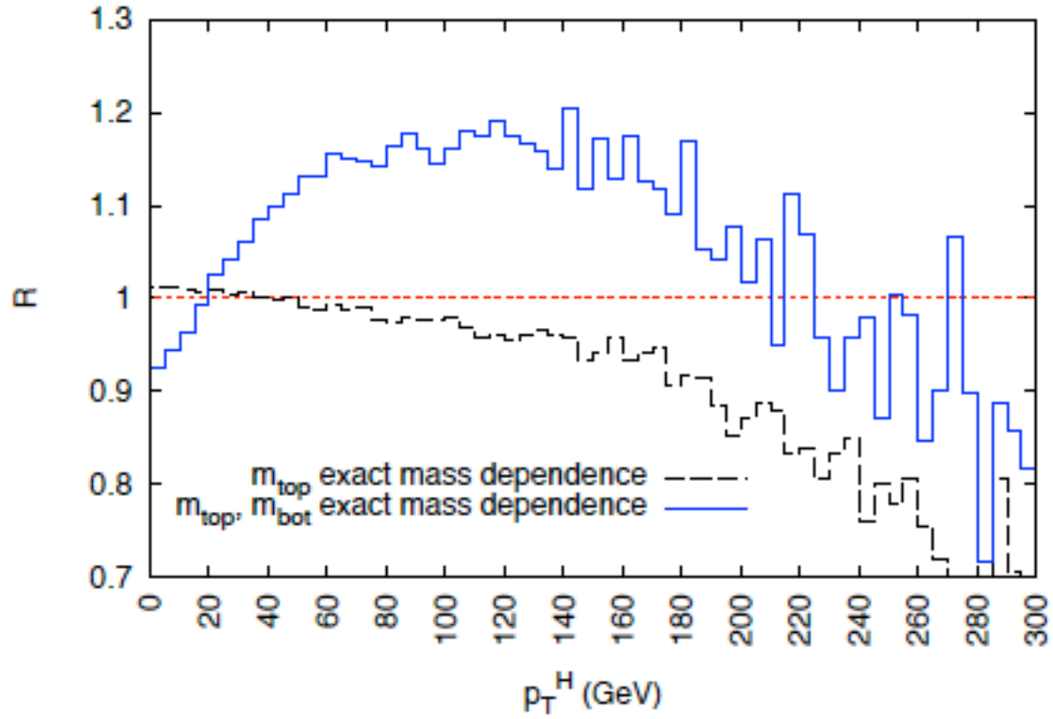
- Higgs production most studied in the heavy-top effective theory, since this approximation was shown to work in practice remarkably well (even if $m_H \lesssim m_t$) as long as $p_{t,H} < m_t$
- recently more attention paid to finite-quark mass effects
- discussions triggered by paper of Bagnaschi et al 1111.2854, which shows very large effects in the $p_{t,H}$ distribution even at high $p_{t,H}$ in POWHEG when finite-mass effects are included. In the following:
  - start from Bagnaschi et al results
  - discussion of the problem
  - sketch of Grazzini & Sargsyan 1306.4581 and of Banfi, Monni and GZ 1308.4634 approaches
  - *new:* b-mass effects in HNNLOPS and associated uncertainty

see talks by Hayk Sargsyan and Pier Monni

Higgs production with t,b

Bagnaschi et al 1111.2854





- large effects, even at high $p_{t,H}$
- sizable difference wrt to MC@NLO or resummed calculations
- reason..?

Higgs production with t,b

POWHEG Sudakov form factor is computed using b-mass effects

$$\exp\left[-\int_{p'_T>p_T}\frac{R(\Phi_{\rm B},\Phi'_{\rm rad})}{B(\Phi_{\rm B})}\,{\rm d}\Phi'_{\rm rad}\right]$$

Standard resummed calculations assume that when gluons are soft ($p_t \ll m_H$) the real emission is Altarelli-Parisi × Born

But soft gluons ($m_b \approx p_t \ll m_H$) resolve bottom loops and violate this structure

Two approaches:

- use a resummation scale of the order of m_b (i.e. use only fixed order above m_b)

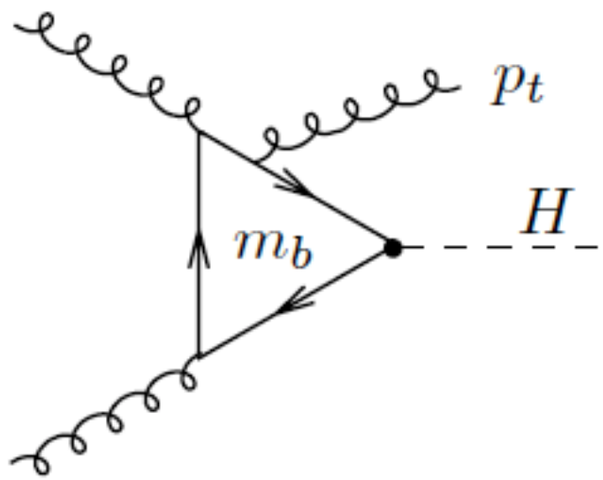
  Grazzini and Sargsyan 1306.4581
- show that soft m_b double logs cancel and that the impact of m_b can be treated as any finite remainder

  Banfi, Monni, Zanderighi 1308.4634

Mass effects in JetVHeto

Banfi, Monni, Zanderighi 1308.4634

- bottom-mass effects suppressed by Yukawa and m_b from loop, i.e. start at $O(m_b^2)$ in the amplitude
- but enhanced by large logs $\log^2(p_t/m_b)$ (exp. region of interest if pt ~ 25-30 GeV)
- dominant contribution from interference $O((m_b m_t/m_H^2)^2 \log^2(p_t/m_b) \log^2(p_t/m_t))$ in the region $m_b << p_t << m_H$
- soft terms shown to cancel at this order



For $p_t << m_b$ standard factorization holds, hence these terms are finite for $p_t \to 0$ and it is legitimate to treat them as a finite remainder, i.e. they are computed at fixed-order and matched to the resummed result

Mass effects in JetVHeto

Banfi, Monni, Zanderighi 1308.4634

Top/bottom mass effects included in JetVHeto in the following way:

Large logs $\log(m_H/p_t)$ (singular) treated in the large m_t limit

$$\Sigma(p_t) \sim C(\alpha_s, m_H, m_t, m_b, \ldots) e^{-R(p_t)} \mathcal{F}(R') + \text{remainder}$$

Coefficient functions in heavy top limit and one-loop virtual with top/bottom in the loop, contains $\log(m_H/m_b)$ (non-singular)

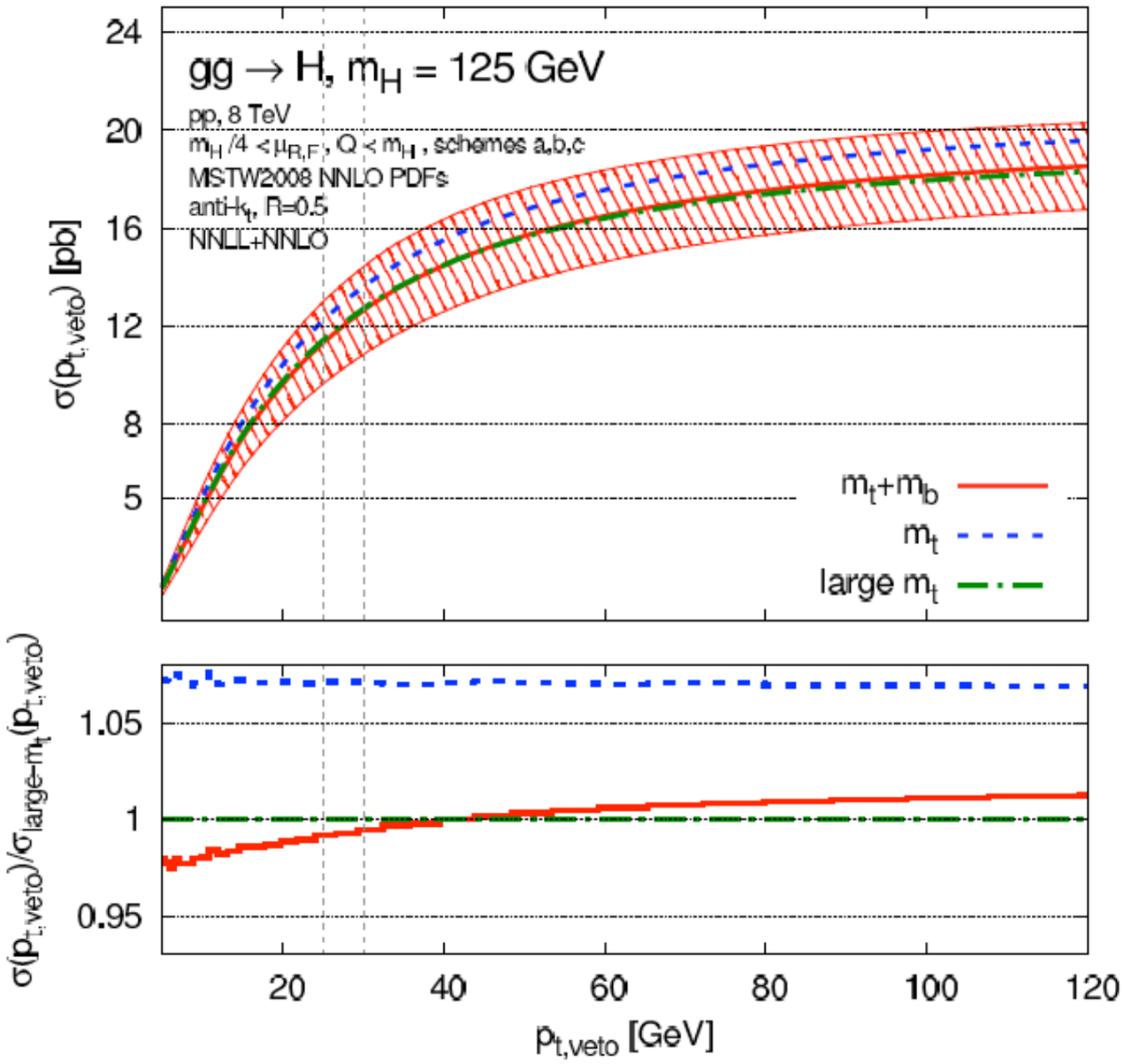
Power-suppressed terms and non-factorizing logs $\log(m_b/p_t)$ (non-singular)

Mass effects in JetVHeto

Banfi, Monni, Zanderighi 1308.4634

Impact of bottom-mass effects in the jet-veto cross-section:

- m_b cancels positive mt effect, but gives also a shape distortion
- overall smaller effect (about 3%)

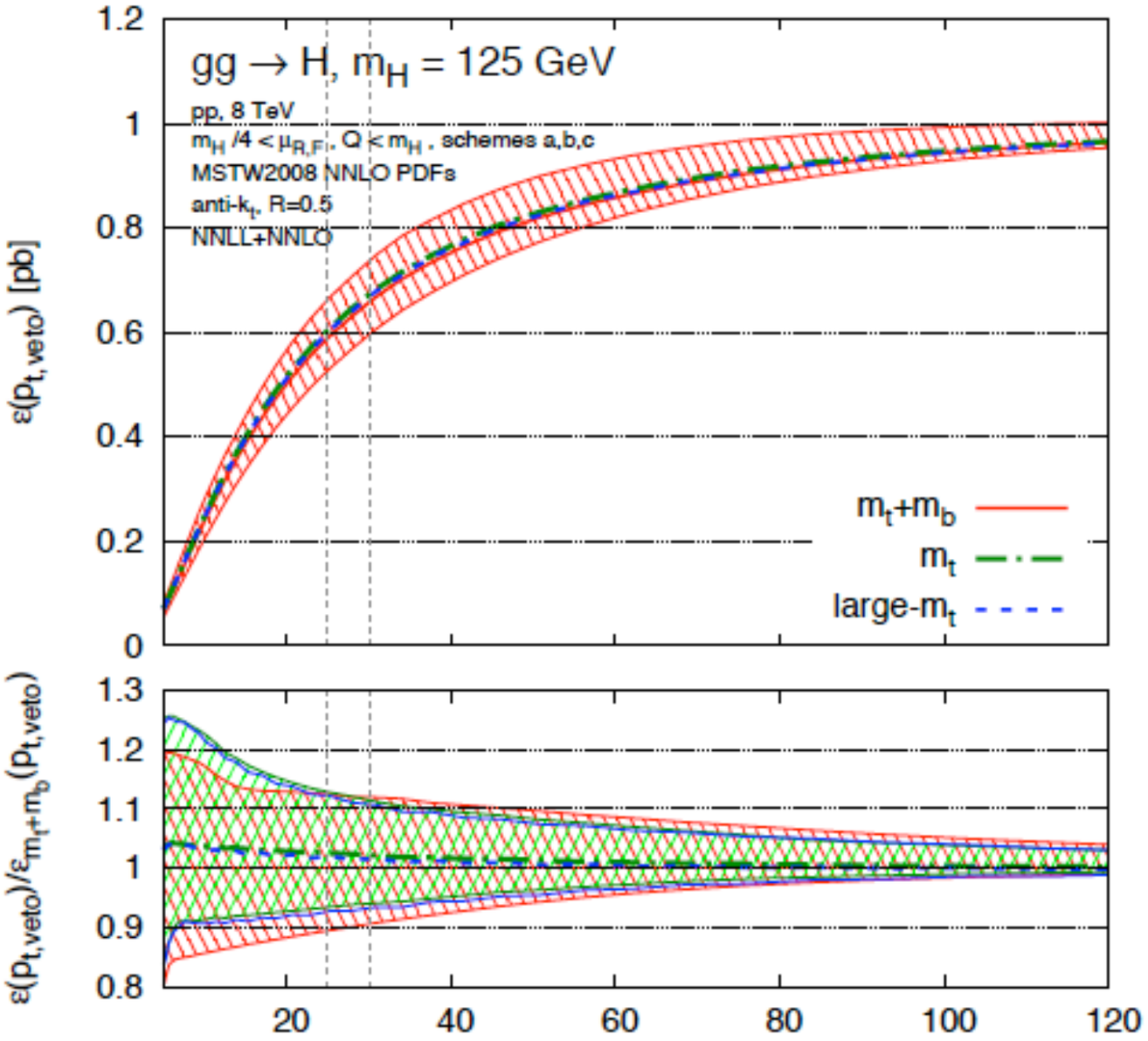


Mass effects in JetVHeto

Banfi, Monni, Zanderighi 1308.4634

Impact of bottom-mass effects in the jet-veto efficiency:

- within the uncertainty of the large m_t approximation (estimated with JVE method)
- uncertainty slightly larger at 25 GeV when mass effects are included



Mass effects in JetVHeto

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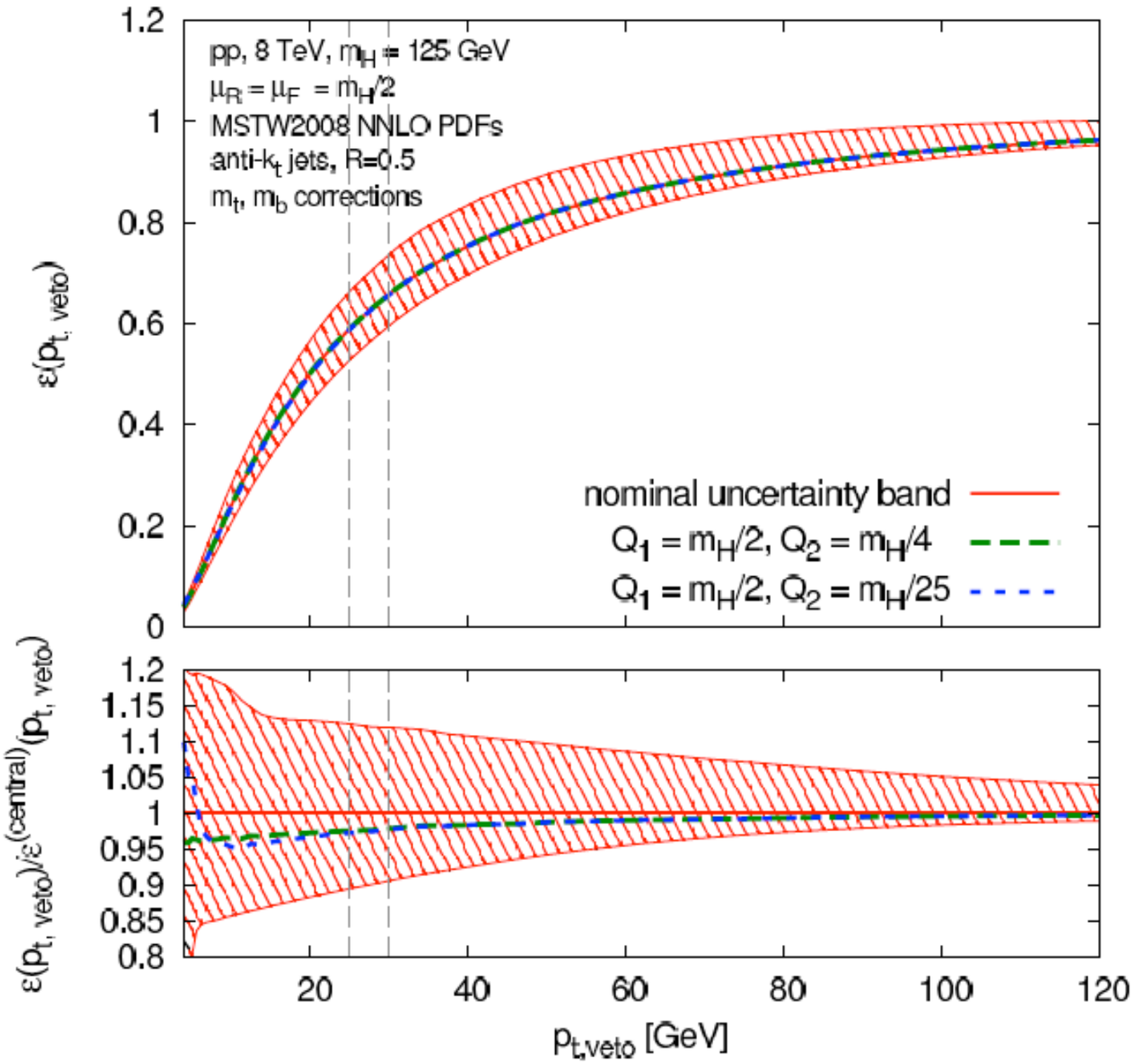
Impact of resummation scale:

- theory arguments suggest that resummation scale for bottom induced (Q_2) should be smaller
- variation of Q_2 very modest impact
- similar effect of $p_{t,H}$



MiNLO-NNLOPS method

Reminder: within the MiNLO approach, a NNLOPS generator is constructed using the following ingredients

see talk by Paolo Nason

1. plain HJ NLO generator
2. MiNLO procedure on HJ ⇒ HJ-MiNLO (finite and NLO accurate even for inclusive Higgs production)
3. NNLO results (e.g. from HNNLO or HPro) differential in the Higgs rapidity distribution (in general in the Born phase phase)
4. re-weighting of Les Houches events from HJ-MiNLO with ratio of HNNLO/HJ-MiNLO Higgs rapidity distribution

In the following, I will discuss how quark-mass effects can be implemented in 1. - 4., and how the uncertainty associated to missing higher orders related to b-mass effects can be estimated

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1. t,b-mass in HJ

Mass-effects known exactly for HJ at LO only, i.e. no O(α_s^4) for Higgs + jet with mass effects available at the moment

At NLO re-weight Born, real, virtual and subtraction terms computed in the effective theory, *point-by-point in phase space* with

$$\frac{|M_{\text{Born}}^{\text{HJ},t+b}|^2(p_{\text{B}},\dots)}{|M_{\text{Born}}^{\text{HJ},\infty}|^2(p_{\text{B}},\dots)}$$

- Born matrix elements include mass effects exactly
- collinear and soft singular real and virtual terms proportional to the Born are also correct
- no effect on POWHEG Sudakov, as R/B unchanged

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2. t,b-mass in MiNLO

Two options:

1. assume that there are no large (m_b) logs to all orders, so keep the original MiNLO Sudakov (correct only matrix elements)

2. assume that bottom-mass effects exponentiate to all orders, so multiply the MiNLO Sudakov by

$$\Delta_{m_b}(p_{t,H}, y_H) = \exp\left[-\int_{p'_{t,H}>p_{t,H}} \left(\frac{R_{tb}}{B_{tb}} - \frac{R_{m_t=\infty}}{B_{m_t=\infty}}\right)\right]$$

<u>Notice:</u> this is the factor that turns the inclusive `H POWHEG` Sudakov in the effective theory into the one that includes mass effects ⇒ expect results similar to those of Bagnaschi et al.

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3. t,b-mass in NNLO

Use HNNLO2.0 with t,b-mass effects, i.e.

- t, b mass implemented exactly at NLO $O(\alpha_s^3)$
- currently NNLO $O(\alpha_s^4)$ mass effects not included
- could be implemented approximatively as a rescaling of NNLO results by Born top-mass correction factor $|F_0(\tau_t)|^2$, ...

$$|\mathcal{M}_B|^2 = |\mathcal{M}_B^\infty|^2 |\sum_q F_0(\tau_q)|^2$$

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4. t,b mass in re-weighting

The re-weighting procedure obviously unchanged, only the ingredients are modified, as discussed before

Validation and results

Settings and input parameters

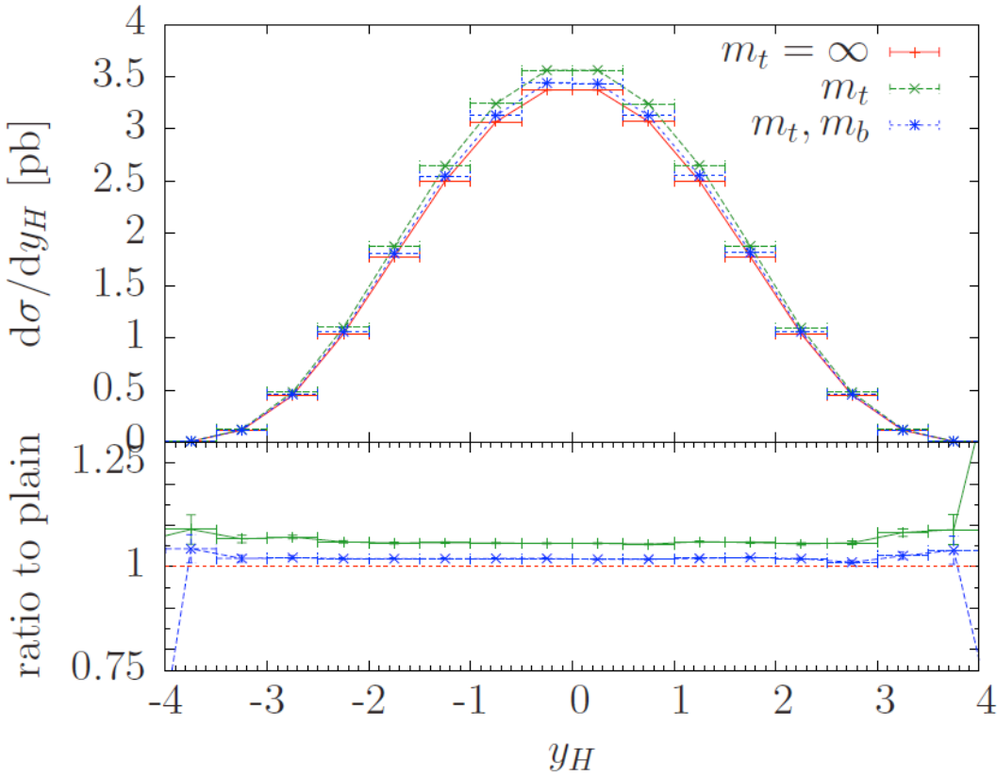
- 8 TeV LHC collisions, MSTW2008NNLO pdfs
- m_H = 125.5 GeV, m_t =172.5 GeV, m_b = 4.75 GeV (pole mass)

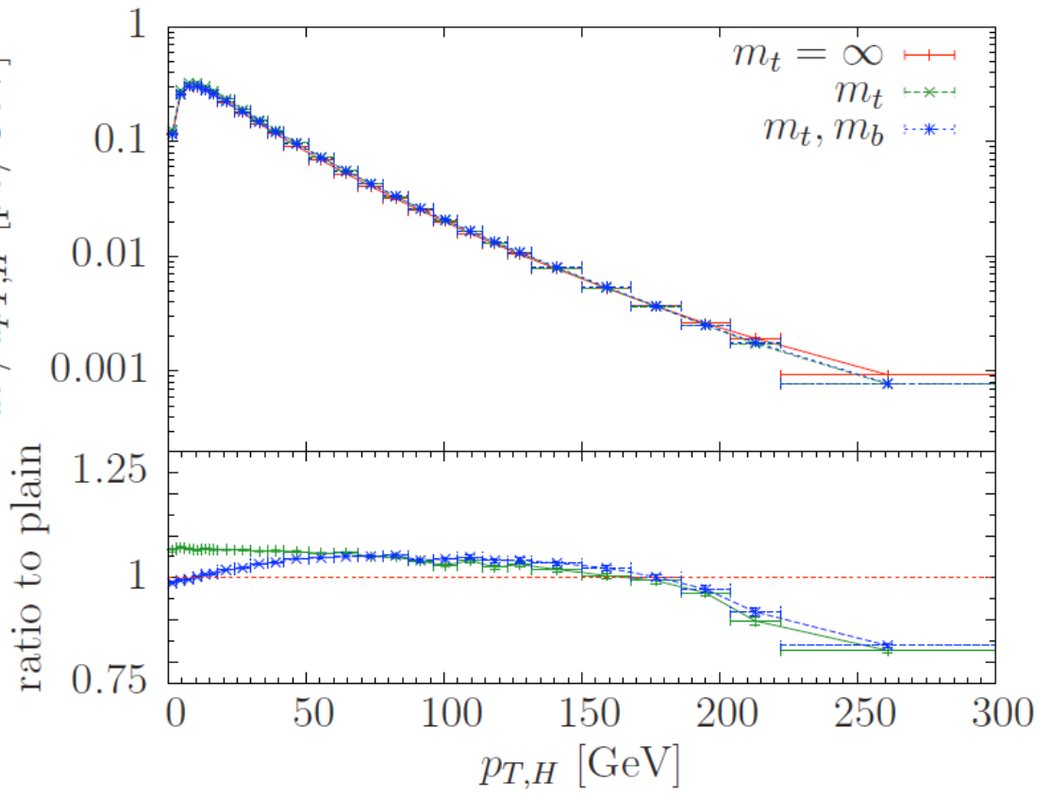
Scheme for b-mass: no NLO scheme compensation. Use as default MSbar-scheme (i.e. corresponds to setting m_b = 3.38 GeV) since

- sensible to use a running mass at the Higgs hardness scale (bottom in loop, not on-shell production)
- impact of mass effects more similar at LO and NLO

	on-shell scheme	$\overline{\text{MS}}$ scheme
$\sigma_{tb}^{\text{LO}}/\sigma_t^{\text{LO}}$	0.89	0.93
$\sigma_{tb}^{\text{NLO}}/\sigma_t^{\text{NLO}}$	0.93	0.94

t,b in matrix elements only





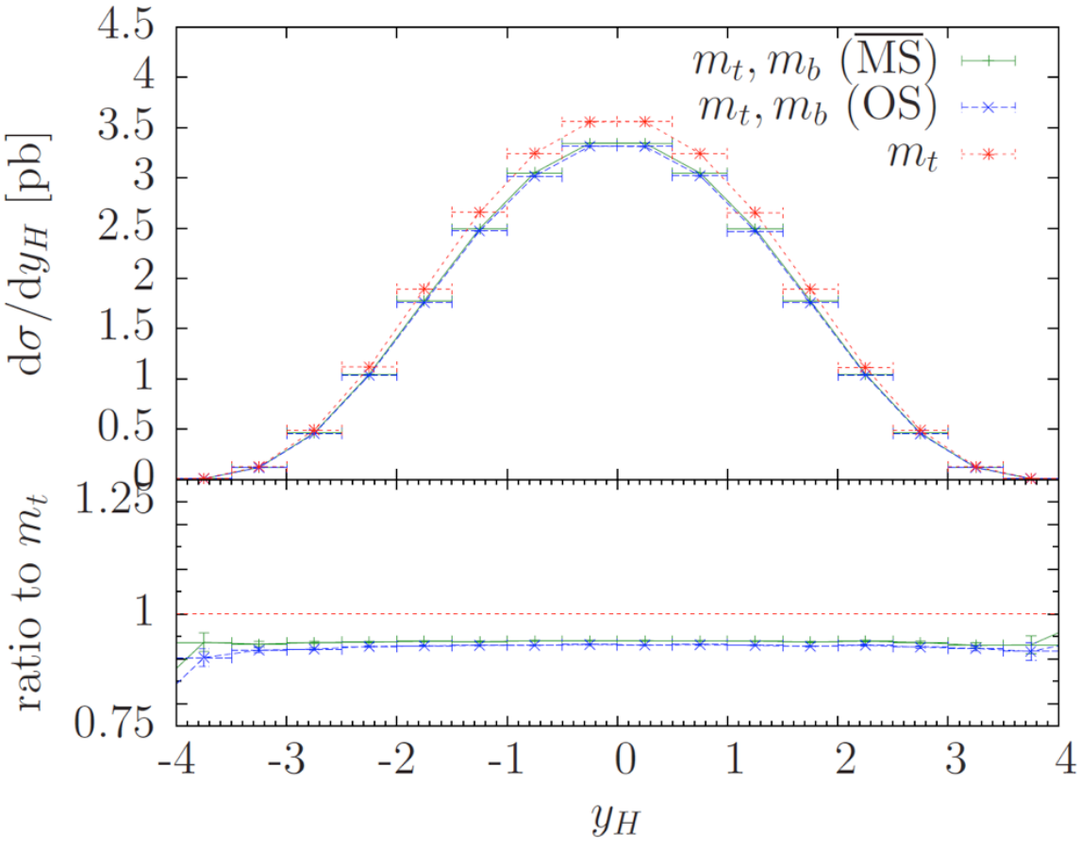
Pattern very similar to what observed for inclusive Higgs production at NLO, i.e.

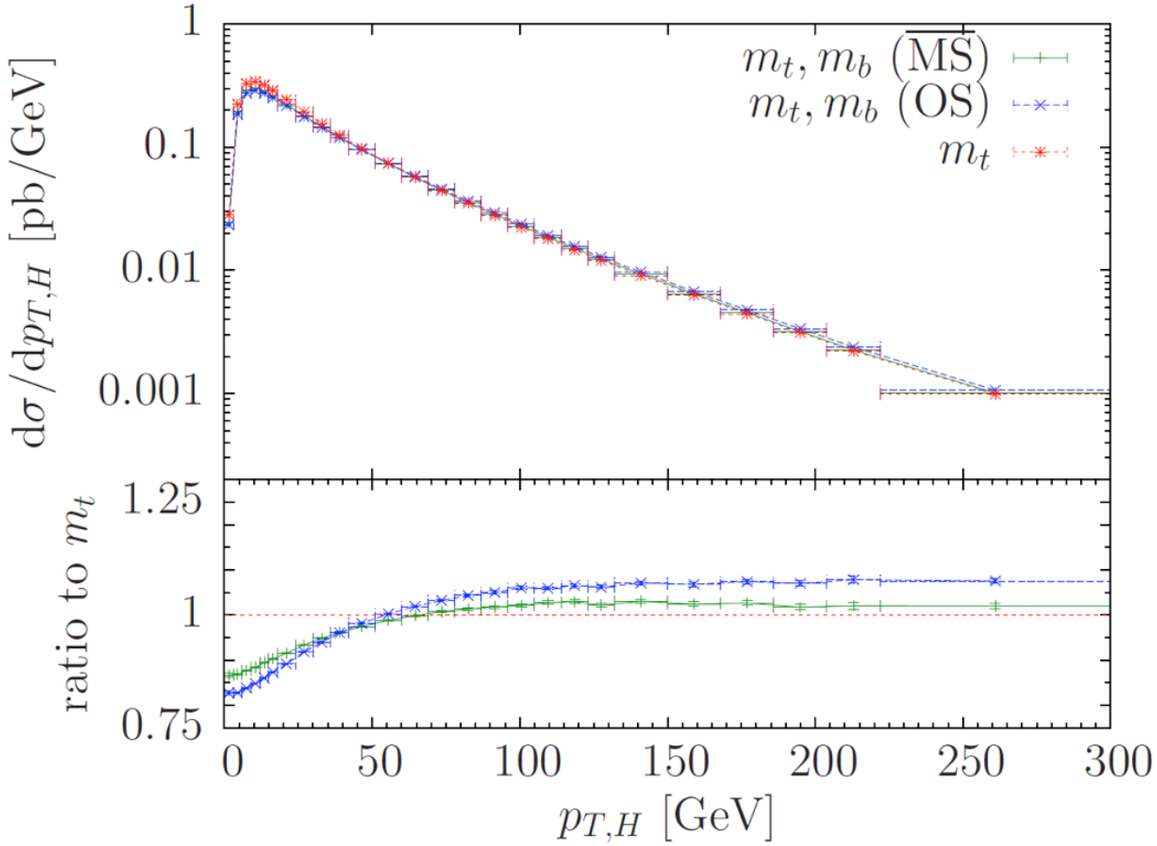
- ✓ $m_t \Rightarrow +(6\text{-}7)\%$
- ✓ $m_t+m_b \Rightarrow \pm 1\%$

This is non-trivial and due to MiNLO

Resummed t,b-effects

Expected size of effect from Bagnaschi et al (ggH_quark-mass-effects):

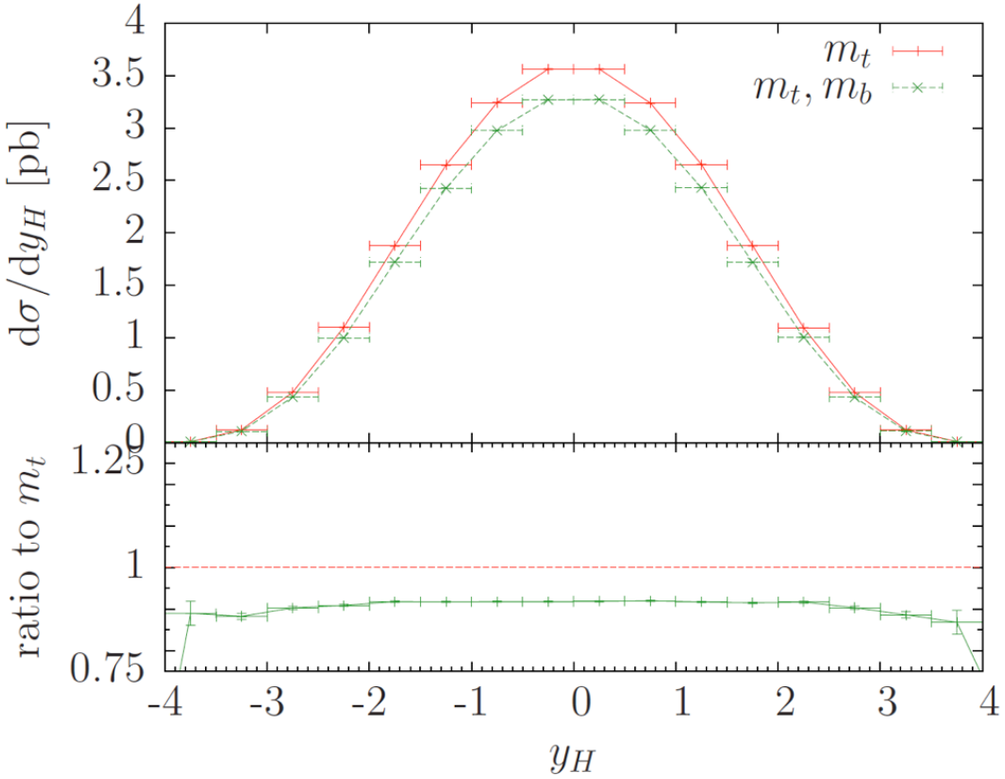


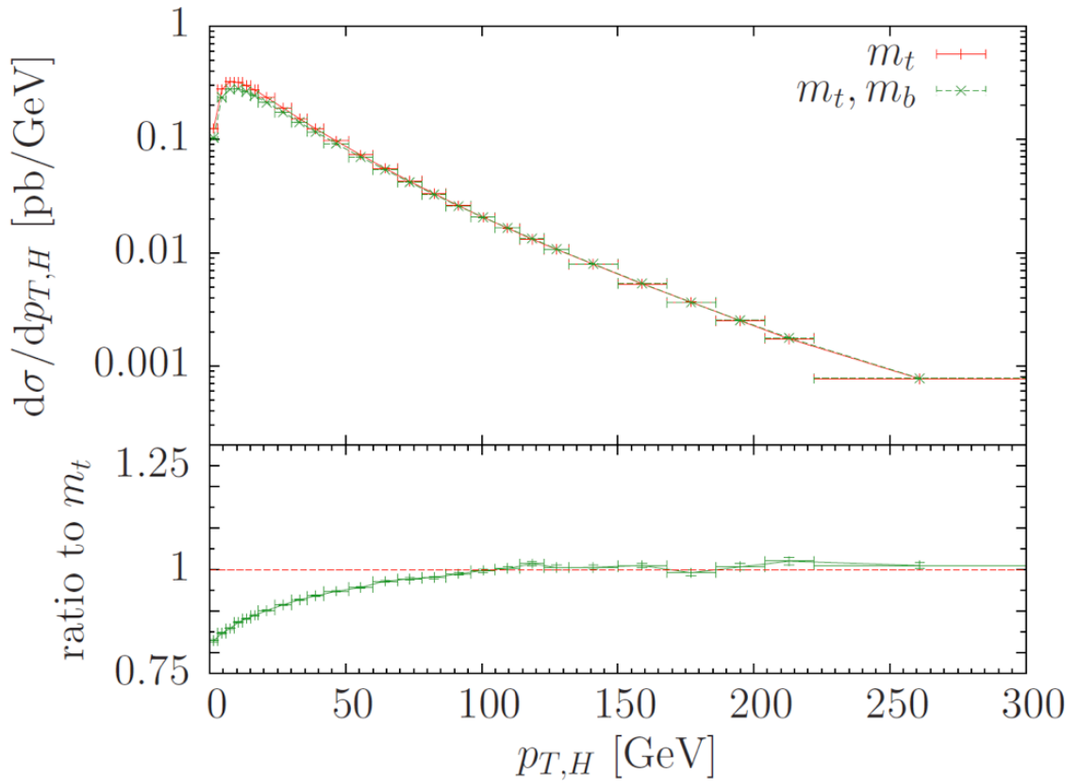


- in MSbar scheme: about 15-20% at low $p_{t,H}$, 5-10% intermediate $p_{t,H}$, vanishes asymptotically (larger effects in OS)
- mass effects more modest in MS scheme (expected)

Resummed t,b-effects

HJ-MiNLO with masses (no HNNLOPS yet...)





- sizable m_b effect at low $p_{t,H}$, affects normalization of rapidity dist.
- must estimate the uncertainty associated with unknown higher order structure of b-mass corrections
- two options in HJ-MiNLO: fully exponentiate the effect in MiNLO Sudakov, or not. Difference between two approaches provides a robust assessment of theory uncertainty

Conclusion

- presented work in progress on implementation of t,b-mass effects in HJ-MiNLO
- effects can be resummed in MiNLO Sudakov, or not ⇒ robust uncertainty estimate
- phenomenology for full HNNLOPS with mass effects in progress
- code will be released soon (January?)