$W/Z + b$ jets: discussion of possible improvements and planned/ongoing activities

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Status of NLO QCD predictions for $Wb\bar{b}/Zb\bar{b}$ production

See talk by Laura Reina at this workshop.

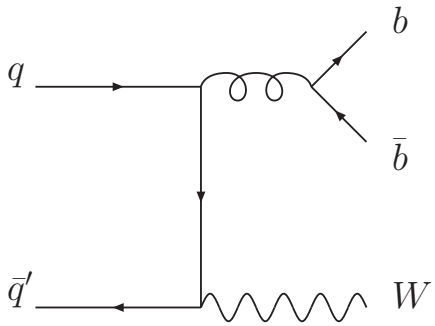
$Wb\bar{b}/Zb\bar{b}$:

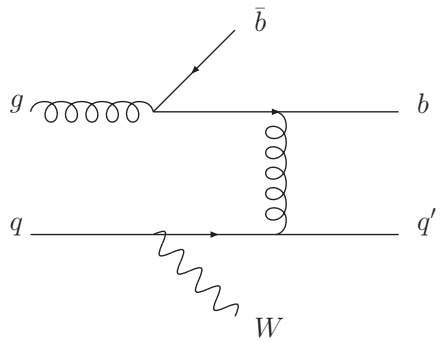
- At the Tevatron, factorization and renormalization scale dependence is reduced at NLO compared to LO predictions: $\delta\sigma_{NLO}/\sigma_{NLO} \approx 20\%(\text{inclusive}), 10\%(\text{exclusive})$.
- At the LHC, there is still a large scale dependence at NLO QCD due to the qg-initiated process which enters for the first time at NLO. This is especially pronounced in the *inclusive* case.
- Bottom-quark mass effects can amount to up to 10% ($p_T^b > 15$ GeV) of σ_{NLO} and can impact the shape of the $M_{b\bar{b}}$ distribution. For $p_T^b > 25$ GeV these effects are considerably reduced.
- Bottom-quark mass effects can be sufficiently well described by rescaling $\sigma_{NLO}(m_b = 0)$ (MCFM) with $\sigma_{LO}(m_b \neq 0)$ apart from phase space regions where relevant kinematic observables become small compared to m_b.

Status of NLO QCD predictions for Wb production

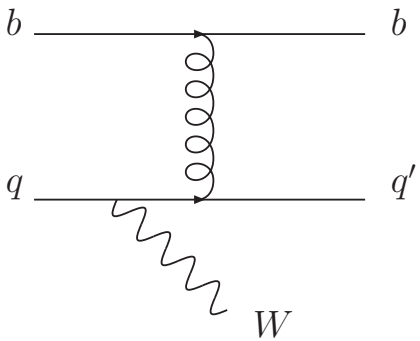
See talk by Fernando Febres Cordero at this workshop.

We combined the NLO QCD calculations of $Wb\bar{b}(m_b \neq 0)$ with $Wbj(m_b = 0)$ (MCFM).
(in collaboration with J. Campbell, R.K. Ellis, F. Maltoni, S. Willenbrock)





where $gq \to Wb\bar{b}q'$ (one low p_T b) is equivalent to



convoluted with a b-quark PDF

Status of NLO QCD predictions for Wb production

Improvements:

- Resummation of initial-state collinear logarithms ($\alpha_s \log(M_W^2/m_b^2)$) by using a b-quark PDF.
- Improved prediction for qg-initiated process by including a set of higher-order corrections.
- $q\bar{q}' \to Wb\bar{b}$ is included with full mass dependence at NLO.

Status of NLO QCD predictions for Wb production

Results:

- At both the Tevatron and the LHC the factorization and renormalization scale dependence is significantly reduced.
- For $W(b\bar{b})$ production we find large corrections and at the LHC only mild (or no) improvement in the scale dependence. The latter is again due to the qg initiated process and is especially pronounced in the *inclusive* case.
- Large logarithms proportional to $\log(Q^2/m_b^2)$ due to final-state collinear $g \longrightarrow b\bar{b}$ splitting may be responsible for the large K-factors for $W(b\bar{b})$.
  Tevatron: Wb: 8.64 pb , $W(b\bar{b})$: 3.71
  from Fernando's talk: Wb: 0.90 pb, $W(b\bar{b})$: 0.16 pb (CDF)
  LHC: W^+b: 88.4 pb, $W(b\bar{b})$: 34.4 pb
  J.Campbell *et al.*, PRD79 (2009), arXiv:0809.3003

Possible improvements for $Wb\bar{b}/Zb\bar{b}$ production

A complete NLO calculation of the qg initiated process ($qg \to Wb\bar{b}q$) may not become available soon. We could check,

- if a suitable choice of cuts can suppress this process (Les Houches study),
- if a study of the scale dependence of kinematical observables could help in identifying these cuts,
- if using a dynamical scale ($\sqrt{p_T^2 + M_W^2}$) instead of a fixed scale can impact the theoretical stability, or
- if replacing the tree-level prediction with a parton shower one can improve the scale dependence (discussion at this workshop).

Possible improvements for Wb production

Improved treatment of final-state $g \to b\bar{b}$ splitting:

- Is it relevant? Study impact of cuts on the fraction of $W(b\bar{b})$ events to Wb events.
- An alternative jet algorithms proposed by Banfi, Salam, Zanderighi, arXiv:0704.2999 treats the $W(b\bar{b})$ events as light-quark jets.

  With CDF selection cuts (1-2 jets where one jet has to be a b-tagged jet) this would remove the $qg \to Wb\bar{b}q$ process from the theory prediction.
- Resummation of final-state collinear logarithms which originate from $g \to b\bar{b}$ splitting.

Possible improvements for Wb production

Discussion at this workshop:
Improved treatment of final-state $g \to b\bar{b}$ splitting:
Can the parton shower approach help ?

- We need the perturbative gluon fragmentation function $f_{g/b}$ so that the resummation-improved cross section reads where $f_{g/b}^{1-loop}$ is subtracted from the 'hard' cross section σ_{NLO} to avoid double counting.
- Start from $q\bar{q} \to Wg$ and shower. Determine the ratio r_b of events where the b-quark originated from the 'first' gluon (equivalent to switching off ISR in shower) to all events (Herwig/Pythia: $r_b \approx .2\%$). Multiply $d\sigma_{NLO,subtracted}$ with r_b (scale dependence of r_b from Altarelli-Parisi and use same scale, m_b in σ_{NLO} and r_b)
- How about contributions from $gu \to bW$ (V_{ub} suppressed) processes ? (Thank you , Michael)

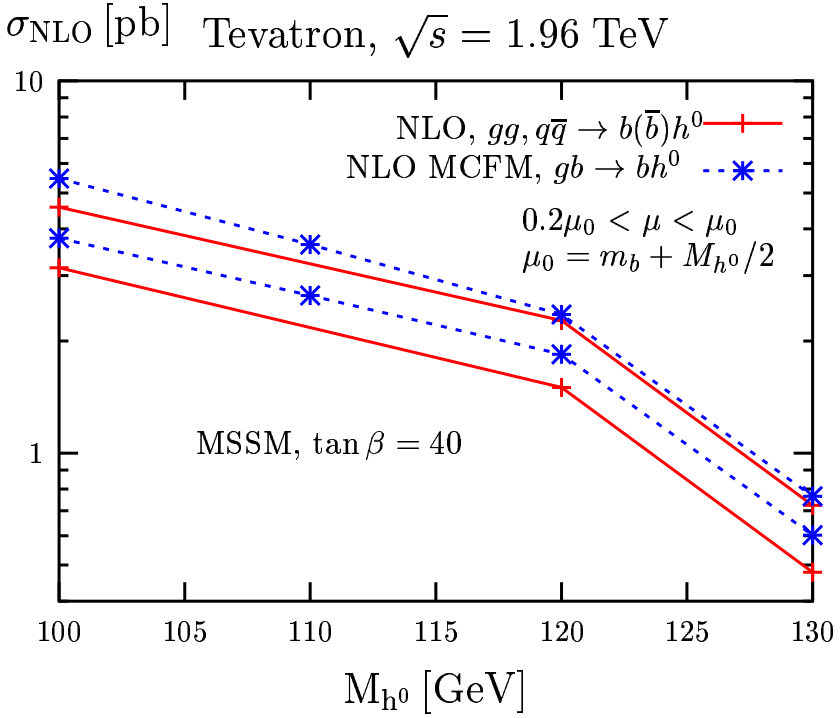
Possible improvements for Zb production

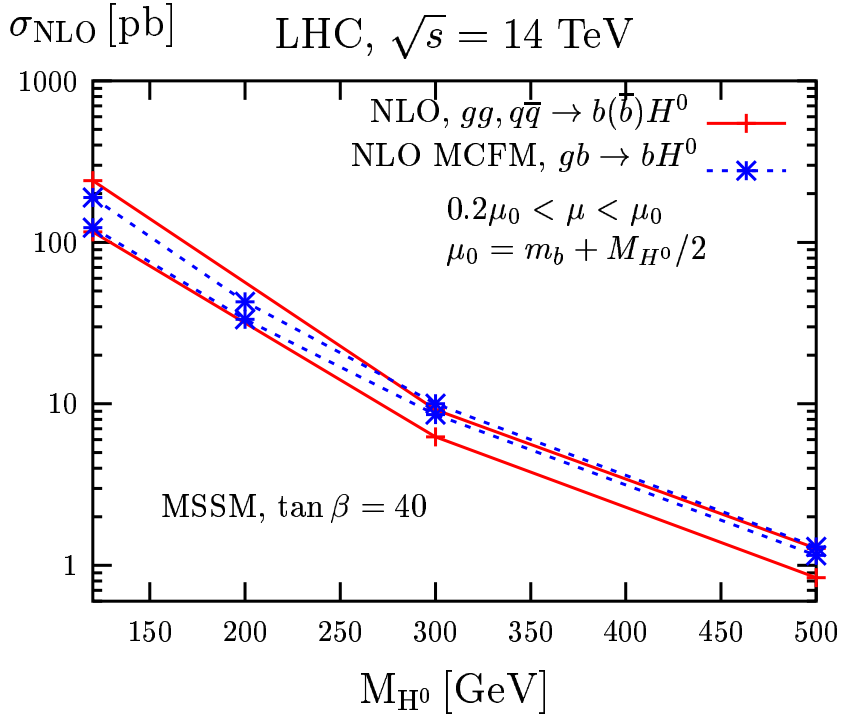
Work in progress (see Laura's talk for details):

- Combination of the NLO calculations of $Zb\bar{b}$ ($m_b \neq 0$) and Zbj ($mb = 0$,MCFM) by carefully subtracting contributions that are included in both calculations.
- Compared to Wb production there is much more overlap between these two calculations.
- There are $Hb\bar{b}$-like contributions such as $gg \longrightarrow Zb\bar{b}$ where we expect 4FNS and 5FNS to be consistent within their theoretical uncertainties.
- For $Wb\bar{b}$-like contributions such as $q\bar{q} \longrightarrow Zb\bar{b}$, where the Z is radiated off initial-state light quarks, we expect to see a similar improvement as in the Wb case.

M_h dependence of σ_{NLO} – 1 b tagged

Comparison with b quark PDF approach by J.Campbell, R.K.Ellis, F.Maltoni, and S.Willenbrock:





from S.Dawson, C.Jackson, L.Reina, D.W., MPLA 21 (2006)
$gb(\bar{b}) \to b(\bar{b})h$: MCFM by J.Campbell *et al.*

More general, possible improvements ($Vb\bar{b}$, $Hb\bar{b}$)

- Matching of NLO predictions with parton shower (POWHEG)
- Including decays of vecor or Higgs boson (more complicated phase-space integration)
- Providing results from NLO MCs in form of ROOT n-tuples.

  Presently we are working closely with experimentalists to provide results for specific setups, cuts etc. (see Laura's talk)

Is there more ? What should have priority ?

A related questions: heavy partons

What if we want to do a complete massive calculation in the 5FNS ?

- NLO matrix element calculation with massive heavy quarks throughout also for initial-state b-quarks.
- Factorization for massive partons (Collins)has been shown and subtraction terms are known (e.g., see Kniehl et al.):
- Which set of PDFs should we use to be consistent ?
- How does it compare to the 5FNS with b-quark densities and massless initial-state b quarks in the matrix element calculation of the hard process ?