Making NLO predictions for Method 2

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Introduction

- We must understand QCD production of:

$W+$ jets $W+b\bar{b}$ $W+b\bar{b}+$ jets	as large backgrounds to:	$t\bar{t}$ single top Higgs production other new physics

- There are many LO tools (ALPGEN, COMPHEP, Madevent, etc.) but:
  - LO lacks a predictive normalization;
  - often does not include all partonic processes (for example, $gg \to W+1$ jet enters at NLO only).
- We would like to use NLO predictions throughout, but the current state of the art in this area is limited to $W+2$ jets and $W+b\bar{b}$ (MCFM, http://mcfm.fnal.gov/).

CDF's 'Method 2'

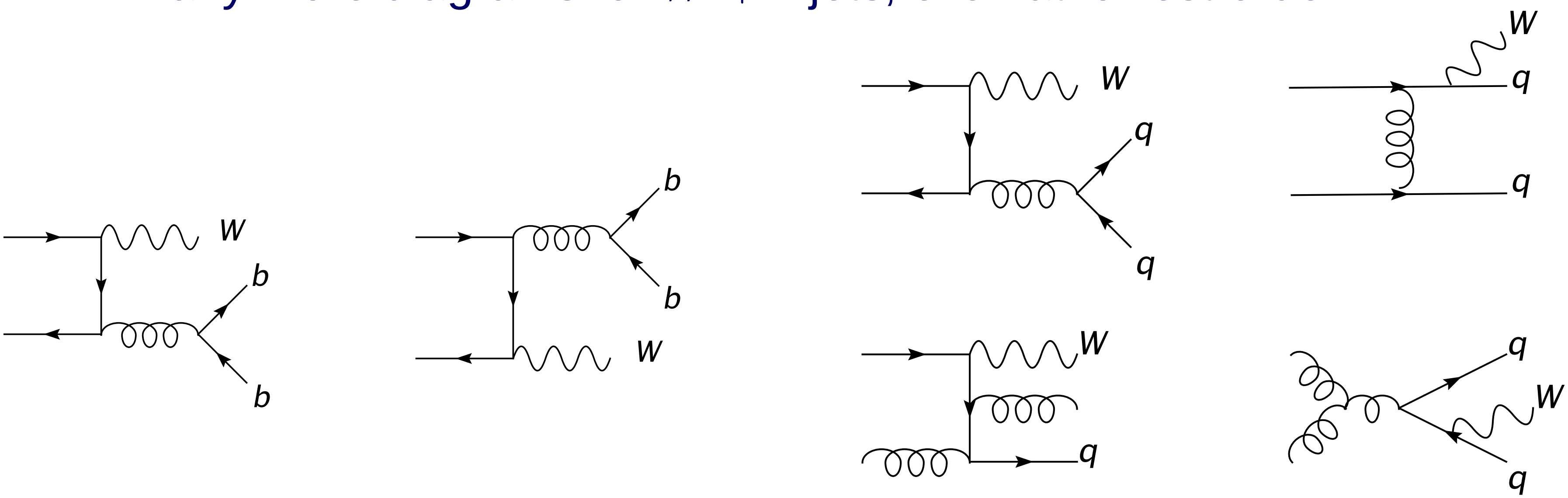
- To predict the number of $W + b\bar{b}+$ jet events, CDF uses a mix of theory and data.
- They use ALPGEN (leading order) + Herwig to estimate the fraction of $W + n$ jet events that contain two b's.
- The prediction for the $W + b\bar{b}+$ jets cross-section is then obtained from:

$$\sigma(Wb\bar{b} + (n-2)\ \mathrm{jets}) = \left[\frac{\sigma(Wb\bar{b} + (n-2)\ \mathrm{jets})}{\sigma(W + n\ \mathrm{jets})}\right]_{MC} \times \left[\sigma(W + n\ \mathrm{jets})\right]_{\mathrm{data}}$$

- One would like to know how this ratio depends on:
  - the order in perturbation theory;
  - the choice of renormalization and factorization scales;
  - the number of jets, n.
- Can investigate some of these issues for $n = 2$ using MCFM.

$Wb\bar{b}$ vs. $W+2$ *jets*

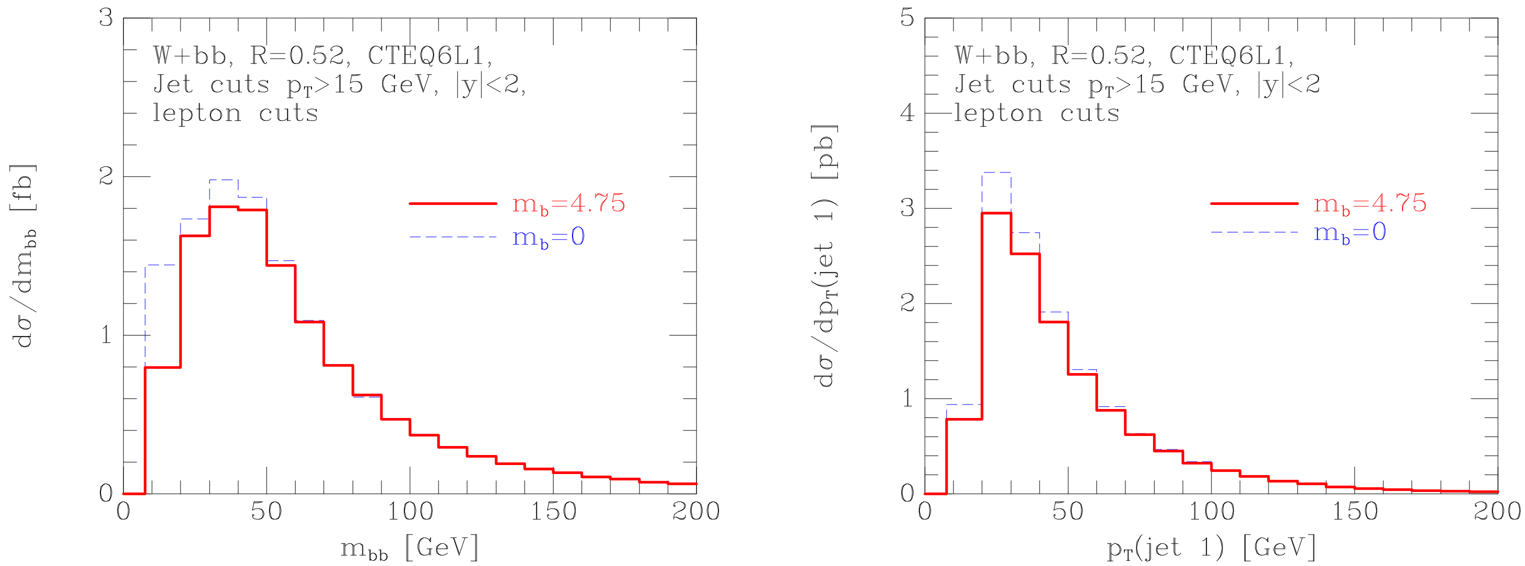
- Many more diagrams for $W+2$ jets, even at lowest order.



- Notably, $Wb\bar{b}$ has no gluonic contribution in the initial state at LO and b's are produced by gluon splitting only.
- b is treated as a massless particle in MCFM and the singularity protected by an invariant-mass cutoff.

Mass effects

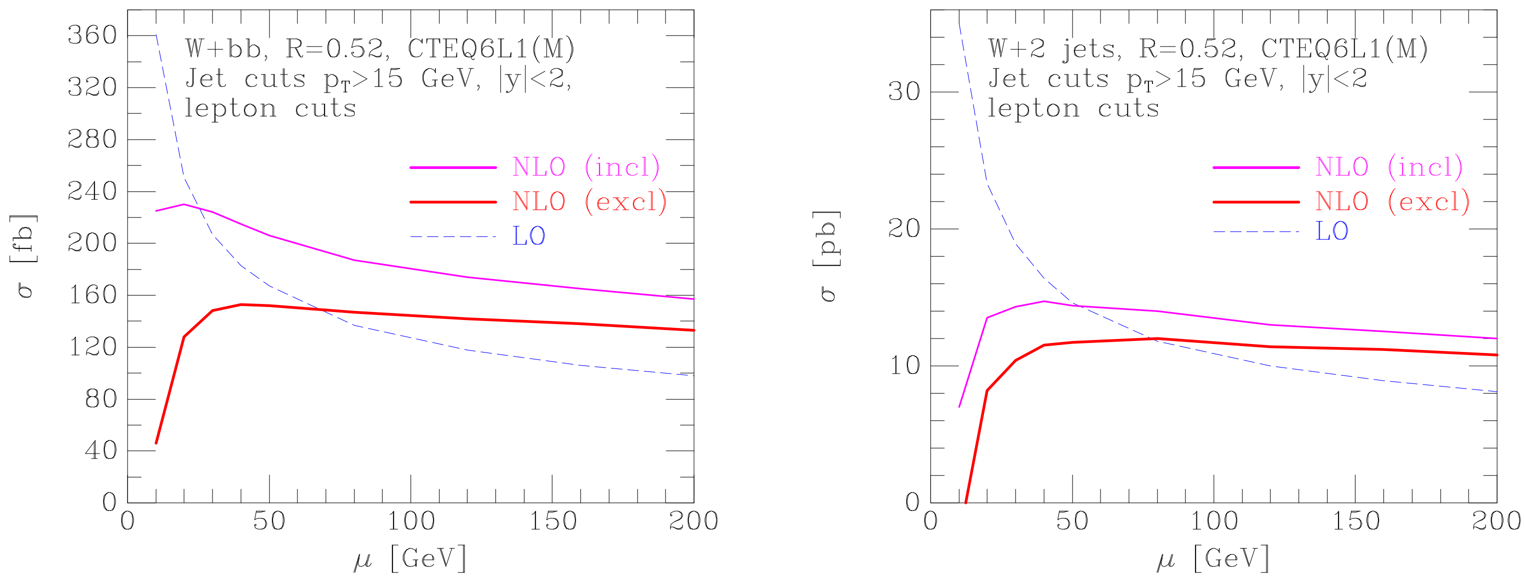
- Examine the effects of introducing the b-mass at lowest order, which is easily calculable.



- Overall the cross section decreases by approximately 10%. Kinematic distributions are not much affected away from regions of low $p_T(b)$.

Scale dependence

- Usual scale dependence, much reduced at NLO. Corrections are modest at typical scales, $\mu \sim M_W$.

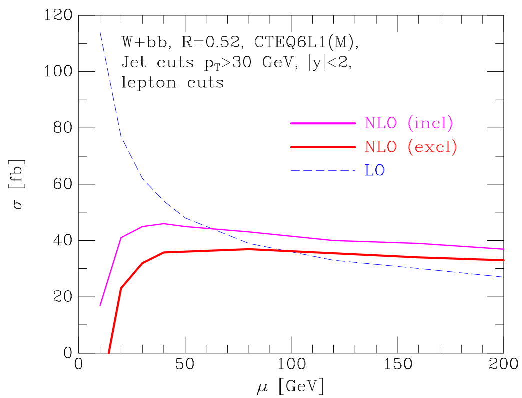


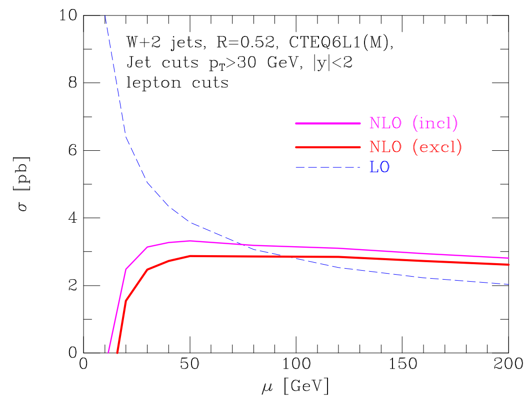
- Exclusive cross-sections stable over a large range of scales.
- Inclusive result (allows $Wb\bar{b}j$, $W+3$ jet configurations) shows more scale dependence, as expected (but still better than LO).

Jet p_T dependence

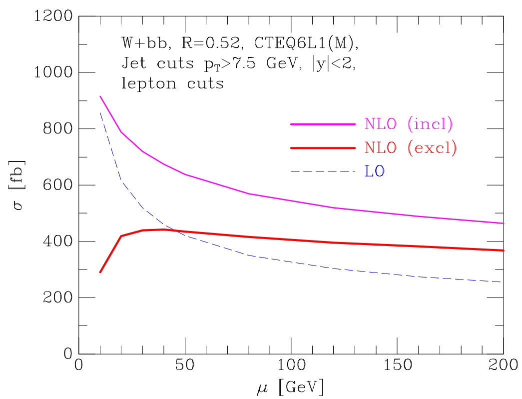
- Increasing the minimum jet p_T reduces the 3 jet contribution compared to the 2 jet one, so the behaviour of the inclusive cross-section improves.

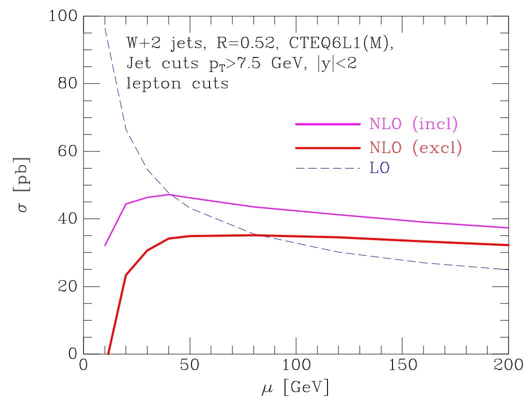
p_T(jet) > 30 GeV





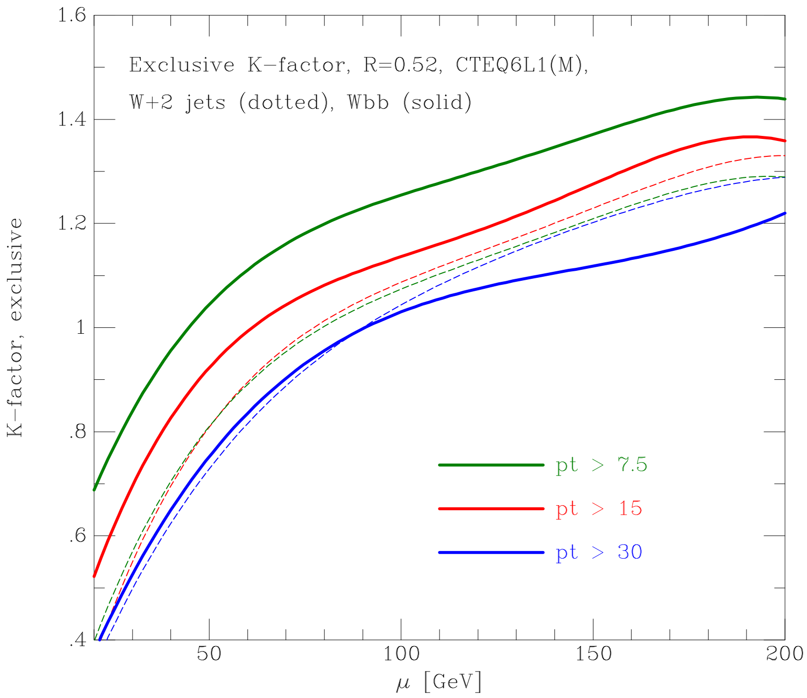
p_T(jet) > 7.5 GeV





Scale dependence of K-factors

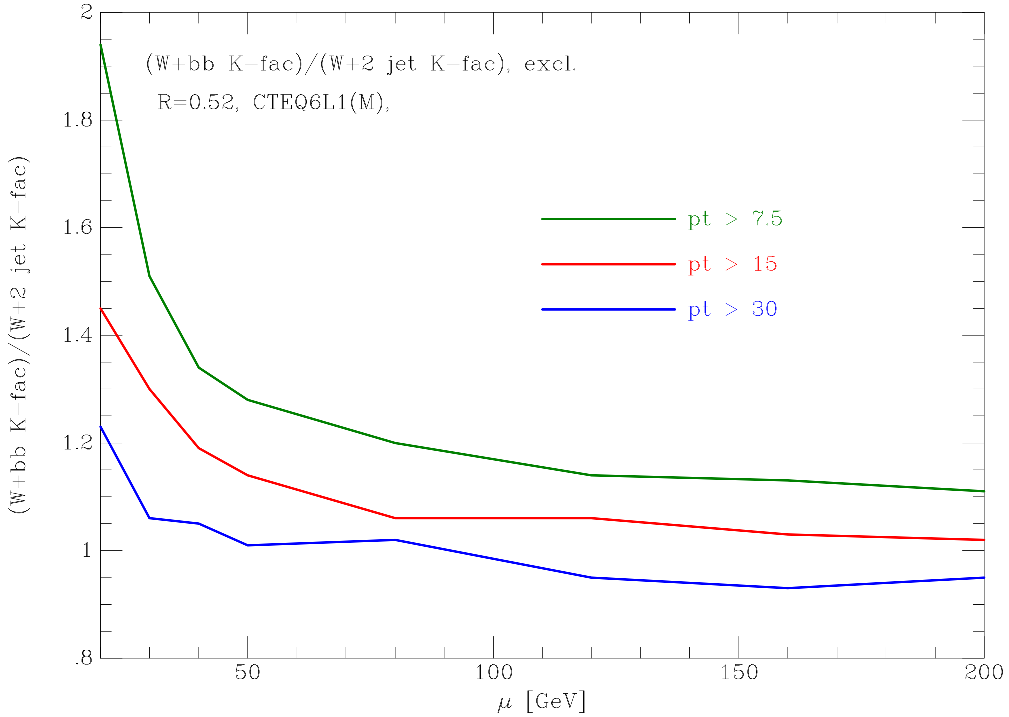
- Strong scale dependence.
- The $Wb\bar{b}$ K-factor varies greatly with the minimum jet p_T, whereas the $W+2$ jets one does not.



- Scale dependence has a similar shape for both processes.

Reliability of Method 2 at NLO

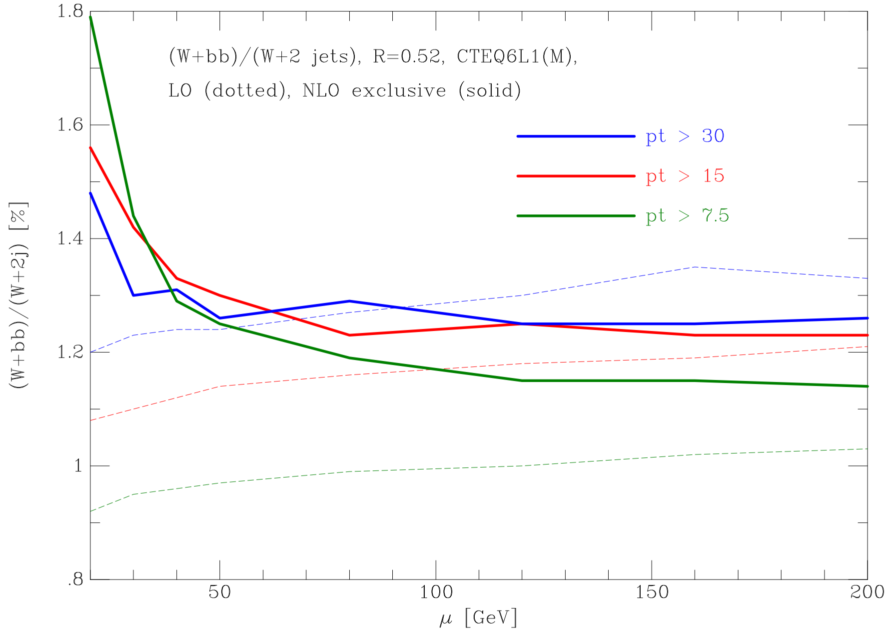
- If we are to trust Method 2, the ratio of K-factors should be ~ 1.



- This seems to be true for scale choices around 50 GeV or greater and p_T cuts of about 15 GeV or greater.
- As the jet p_T cut is lowered, the ratio gets worse (increases).

b-jet fraction

- At NLO, ratio is stable across a wide range of scales.

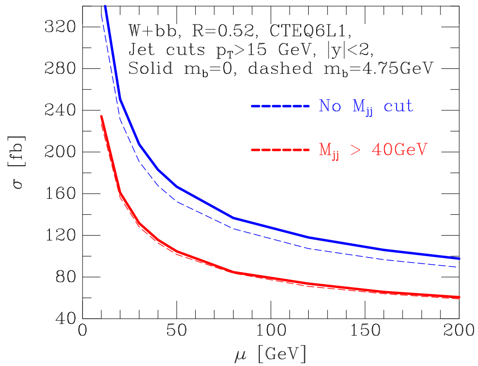


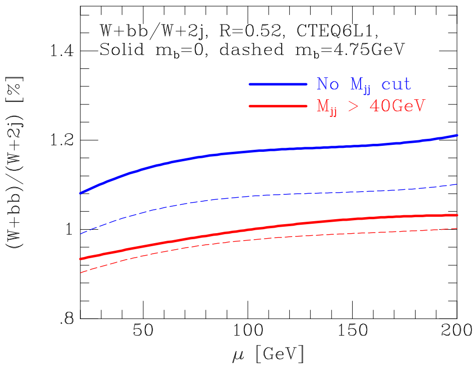
- For a p_T cut of 15 GeV and $\mu \sim M_W$, we have:

$$\left[\frac{\sigma(Wb\bar{b})}{\sigma(W+2\text{ jets})}\right]_{LO} = 1.16\%, \qquad \left[\frac{\sigma(Wb\bar{b})}{\sigma(W+2\text{ jets})}\right]_{NLO} = 1.23\%$$

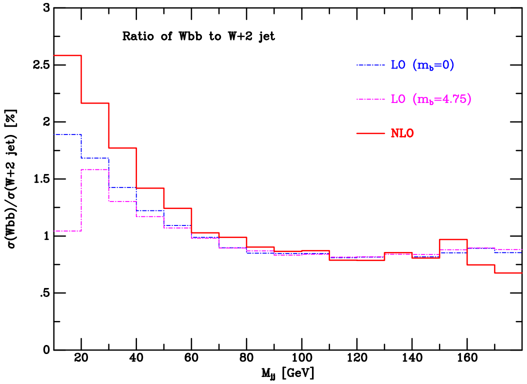
$b\bar{b}$ mass cut

- Such a cut would be helpful, if it could be experimentally enforced:
  - It improves the massless approximation



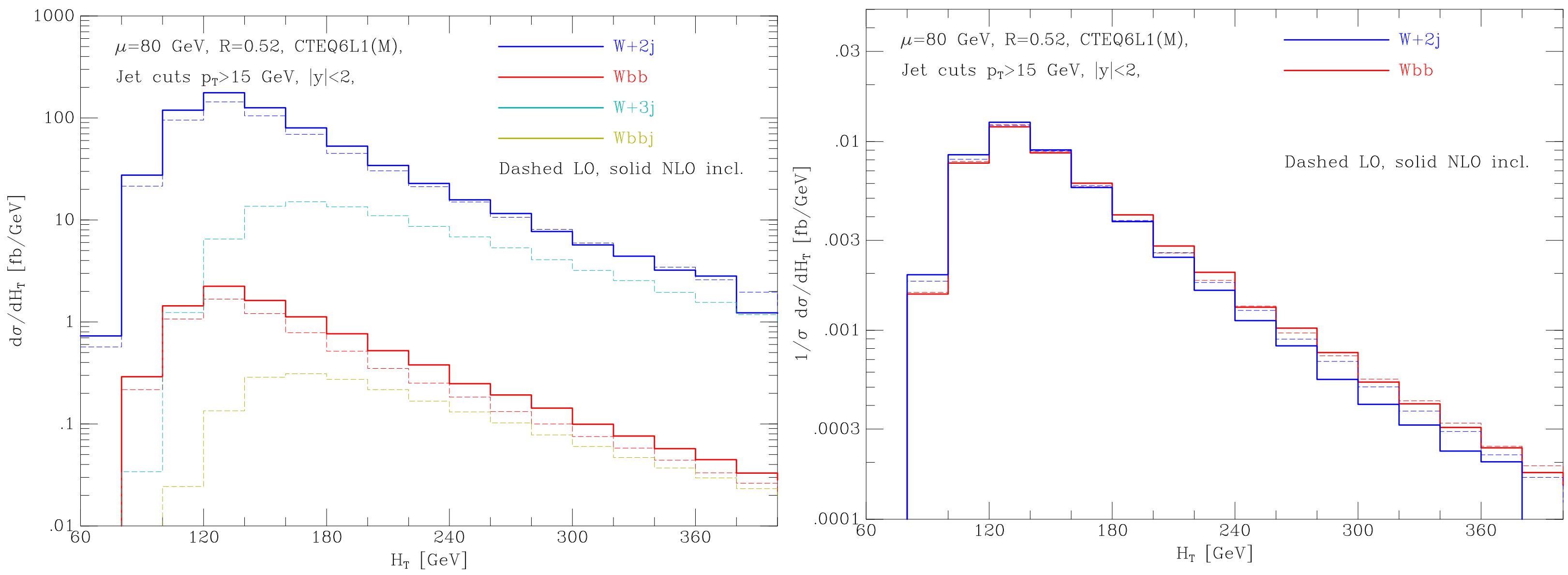


  - It reduces this background compared to, for example, $t\bar{t}$ production, since here the b's like to lie at low invariant mass.



Kinematic distributions

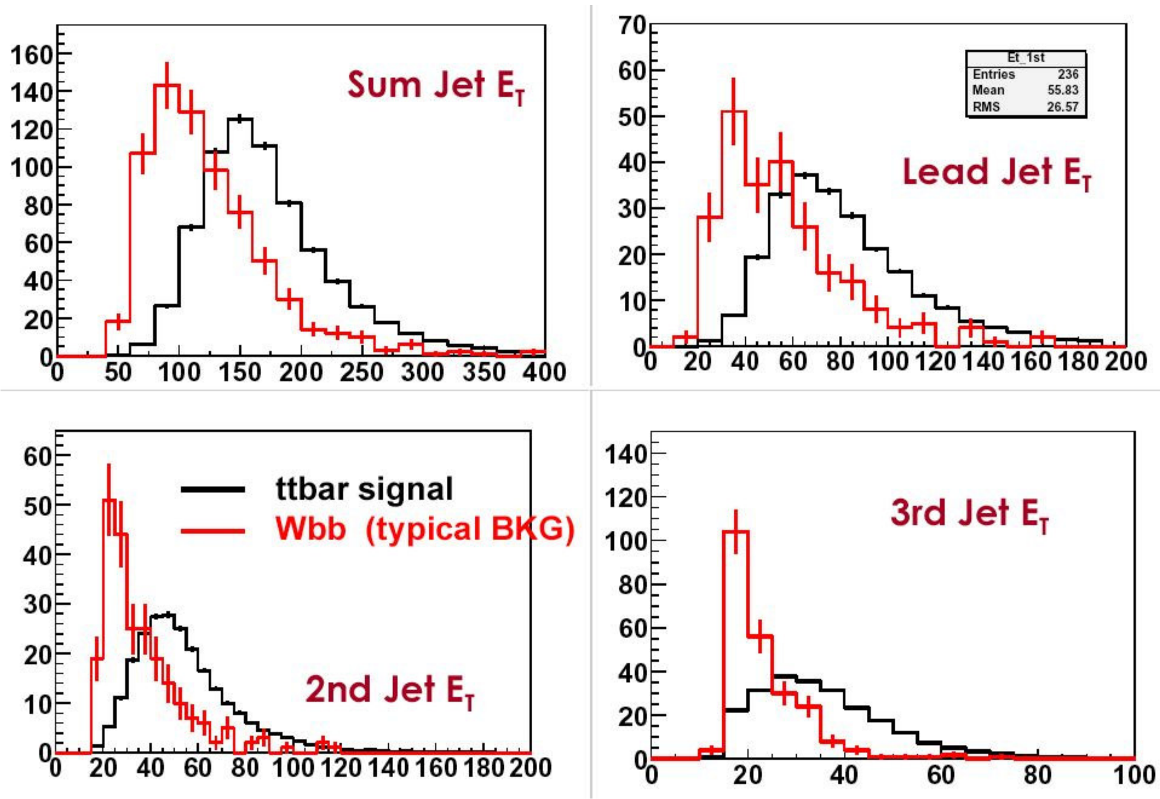
- NLO behaviour may provide clues to processes with more jets, especially for more inclusive variables such as $\sum E_T(\text{jet})$ and $H_T = \sum_{\text{event}} E_T$.



- $Wb\bar{b}$ shape is relatively unchanged at NLO, compared to $W + 2$ jets.

Shape comparisons

- Top analysis, which would like to make kinematic cuts to reduce the $W+$ jet backgrounds, relies on the shapes of the distributions being similar in the b-tagged and untagged samples.

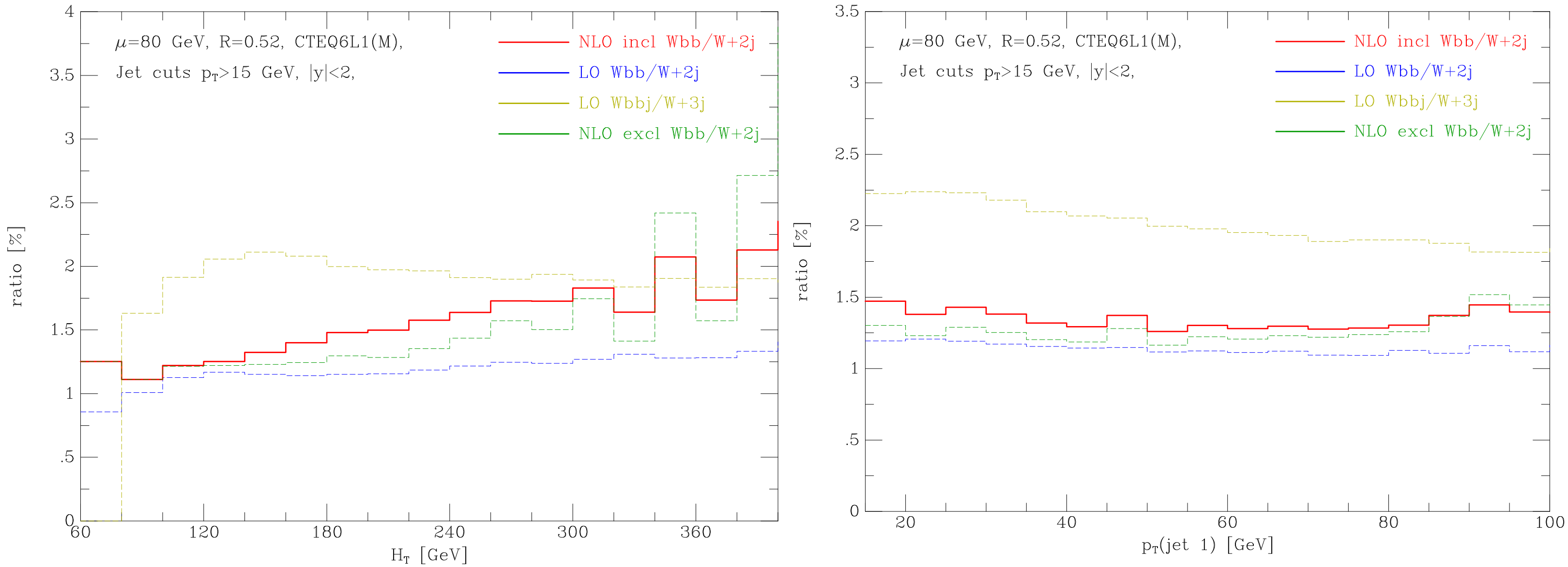


NLO predictions

- At NLO, there is a change of shape in the H_T distribution.

Lowest order
Lowest order+jet

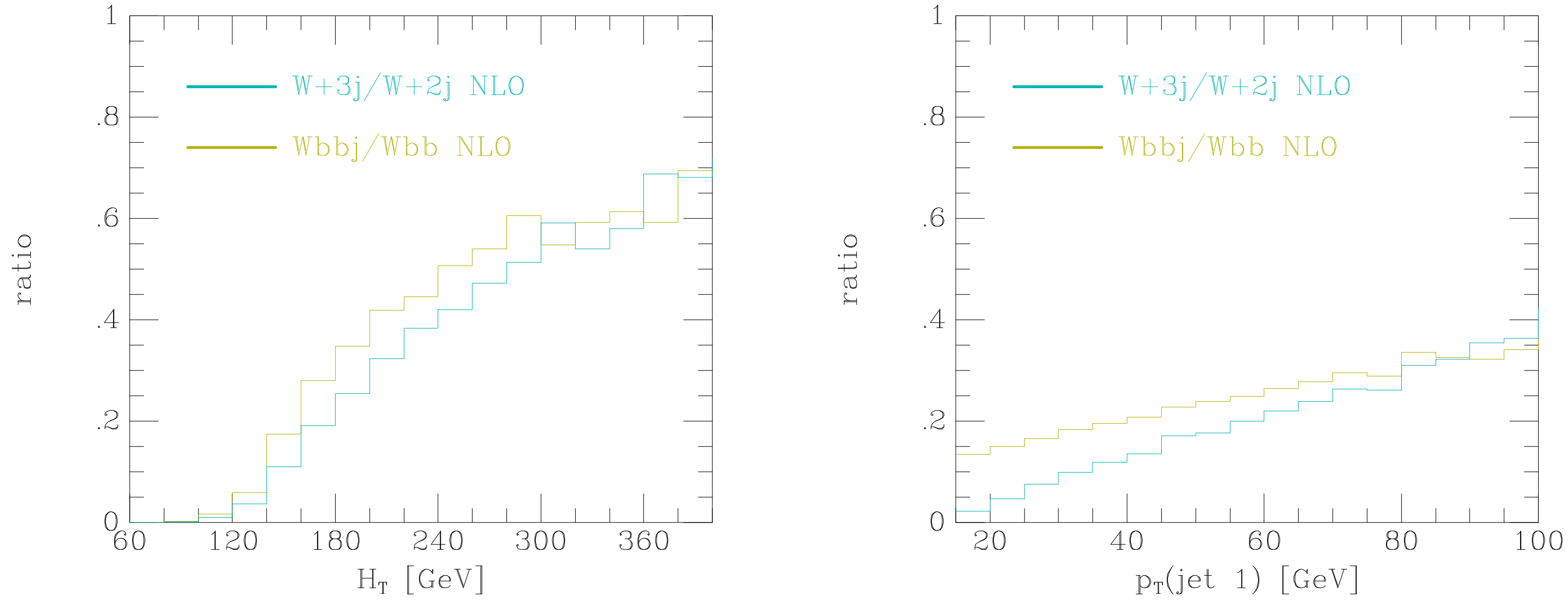
NLO inclusive
NLO exclusive



- This change is not entirely due to the extra $W + 3$ jet events allowed in the inclusive sample.
- The p_T distribution of the hardest jet shows no change in shape.

Extra jet contribution

- In the NLO inclusive result, the contribution to the H_T distribution from $W+3$ jet events is negligible at small H_T and dominant at large H_T.
- Similar ratio for $Wb\bar{b}j$ to $Wb\bar{b}$.



- Extra jet contribution to the jet p_T distribution is never dominant over this range.

LHAPDF and MCFM

- MCFM can use the PDF library LHAPDF (see http://pdf.fnal.gov/).
- A preliminary beta version of the LHAPDF code (Mike Whalley) is implemented in MCFM, which uses grid versions of the PDF's.
  - Grid versions (PDFLIB-style) are very fast.
- At each Monte Carlo integration point, the parton luminosities for each PDF member (e.g. 40 for CTEQ6M) can be calculated very quickly.
  - No overhead due to initializing each PDF member:

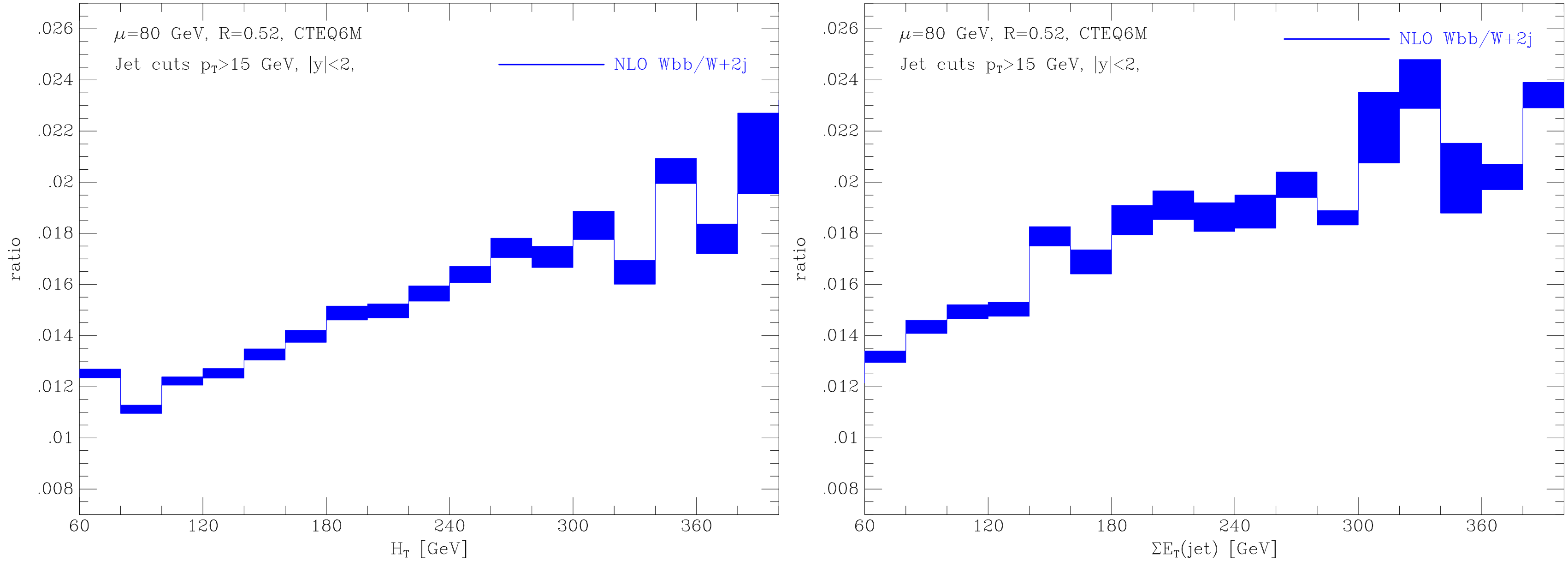
    ```
    call InitPDF(PDFmember)
    ```
- Cross-sections using all members of a given PDF set can be calculated in one Monte Carlo run.
- Integration is weighted by the central PDF luminosity and the result for each error set recorded separately.
- PDF sets currently implemented in this manner: MRST2001, CTEQ6M, Alekhin '02.

PDF uncertainties

- Total cross-section uncertainty:

$$Wb\bar{b} \rightarrow 2.5\% \,, \qquad W + 2j \rightarrow 1.5\%.$$

- Uncertainty in the ($Wb\bar{b}/W + 2$ jet) ratio:



Outlook

- The $W+$ jets channel is very important for many physics searches in Run II and should be understood to the best of our ability.
- Unfortunately, for events with many jets, we are limited to LO.
- However, there may be lots to learn from the NLO corrections that we know about, i.e. $Wb\bar{b}$ and $W+2$ jets.
- We're trying to understand the implications for Run II analyses.
  - Preliminary results suggest that some relevant observables do not suffer from large NLO effects and we can proceed with more confidence in analyses based on LO tools.
  - However, beware of variables that change shape at NLO (H_T).
- Inclusion of PDF errors in the Monte Carlo (and LHAPDF) is a good step forward.
- Comparisons with parton shower approaches and data should be coming soon.