Update on the Monte Carlo MCFM

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ANL

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MCFM Summary - v. 3.4

$p\bar{p} \to W^{\pm}/Z$	$p\bar{p} \to W^{+} + W^{-}$
$p\bar{p} \to W^{\pm} + Z$	$p\bar{p} \to Z + Z$
$p\bar{p} \to W^{\pm} + \gamma$	$p\bar{p} \to W^{\pm}/Z + H$
$p\bar{p} \to W^{\pm} + g^{\star}\ (\to b\bar{b})$	$p\bar{p} \to Zb\bar{b}$
$p\bar{p} \to W^{\pm}/Z +$ 1 jet	$p\bar{p} \to W^{\pm}/Z +$ 2 jets
$p\bar{p}(gg) \to H$	$p\bar{p}(gg) \to H +$ 1 jet
$p\bar{p}(VV) \to H +$ 2 jets	

- MCFM aims to provide a unified description of a number of hadron-hadron processes at NLO accuracy. More processes are available at LO only.
- Various leptonic and/or hadronic decays of vector bosons are included as further sub-processes.
- MCFM version 2.0 is part of the CDF code repository.

MCFM Information

- Version 3.4 available at:
  `http://mcfm.fnal.gov`
- Improvements over previous releases:
  - more processes
  - better user interface
  - support for PDFLIB, Les Houches PDF accord
  - ntuples as well as histograms
  - unweighted events
  - Pythia/Les Houches generator interface (LO)
  - ‘Behind-the-scenes’ efficiency
- Coming attractions:
  - even more processes
  - photon fragmentation

Web pitfalls

- `www.mcfm.org`
  - not quite the same!

- `mcfm.fnal.gov`
  - only 2nd on Google

MASSACHUSETTS COUNCIL ON FAMILY MEDIATION

The Massachusetts Council On Family Mediation is a private, nonprofit organization established in 1982 by family mediators interested in sharing knowledge and setting guidelines for mediation practice in Massachusetts. It is the oldest professional organization in Massachusetts devoted **exclusively to family mediation.**

The Massachusetts Council On Family Mediation serves its membership and the public by:

- Providing information about divorce and family mediation.
- Publicizing divorce mediation and family mediation as a non-adversarial approach to resolving divorce and family conflict.
- Providing continuing education to divorce mediators and other professionals.

The Massachusetts Council On Family Mediation further advances family mediation through the following:

Mediator Locator A method of finding qualified family mediators anywhere in Massachusetts.

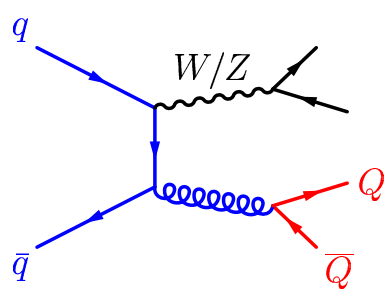
Referral Directory A list of Massachusetts divorce and family mediators who abide by the practice standards.

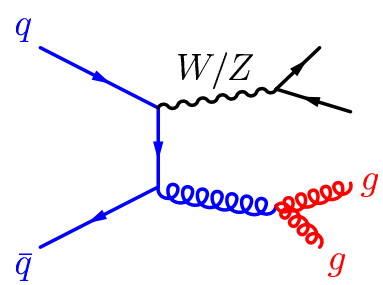
Certification The highest level of MCFM qualification reserved for family mediators with extensive, postgraduate educational training and mediation experience.

Practice Standards A guide of ethical considerations and professional standards for family mediators and their clients.

Vector boson + jets

- W,$Z + n$ jets jets calculable at NLO in MCFM for $n = 0, 1, 2$.
  - $n = 1$: previously calculated in DYRAD.
  - $n = 2$: new (and only) calculation.

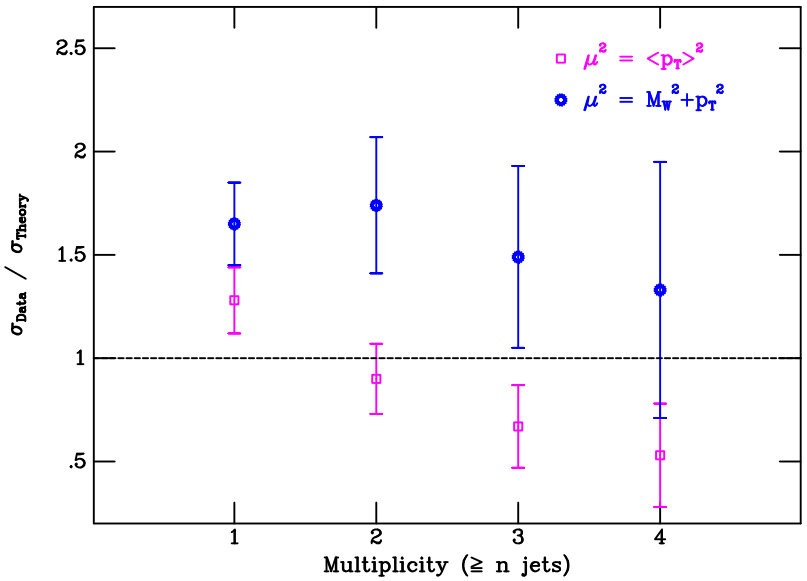




- W,$Z + b\bar{b}$ calculable at NLO in MCFM, with caveats.
  - b's treated as massless, with basic cuts to make them b-like
  - This assumption is fine for p_T^b 'large', but results must be interpreted with care.
- Implementation of massive b's planned later this year.

$W + n$-jet cross-sections

- $W+ \geq n$ jets cross-sections from CDF Run I, compared with (enhanced) leading order theory, for two choices of scale.

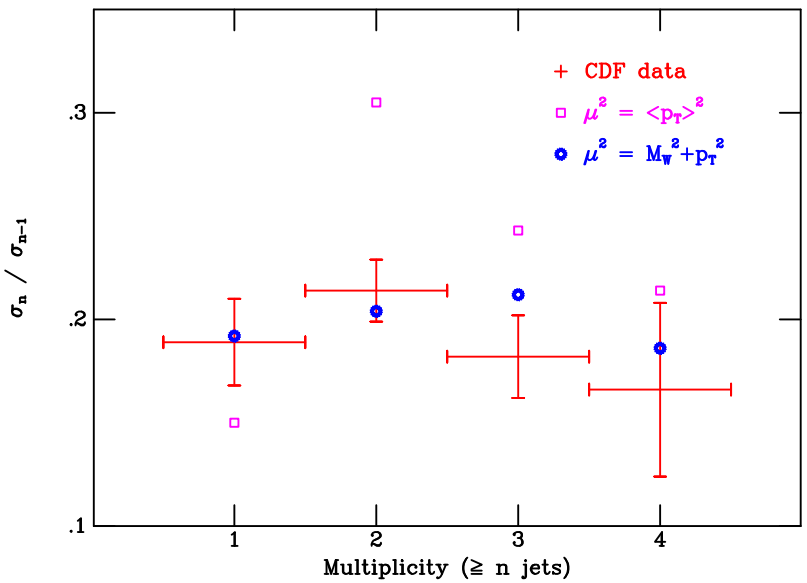


$$\mu_R = \mu_F \equiv \mu$$

- To reproduce the raw cross-sections, especially for the $W + 1, 2$ jet data, the low scale $\mu^2 = \langle p_T \rangle^2$ is preferred.

$(W + n$-jet$)/(W + n - 1$-jet$)$ ratio

- In the ratio of $W + n$-jet cross sections, σ_n/σ_{n-1} one expects some systematic errors to cancel.

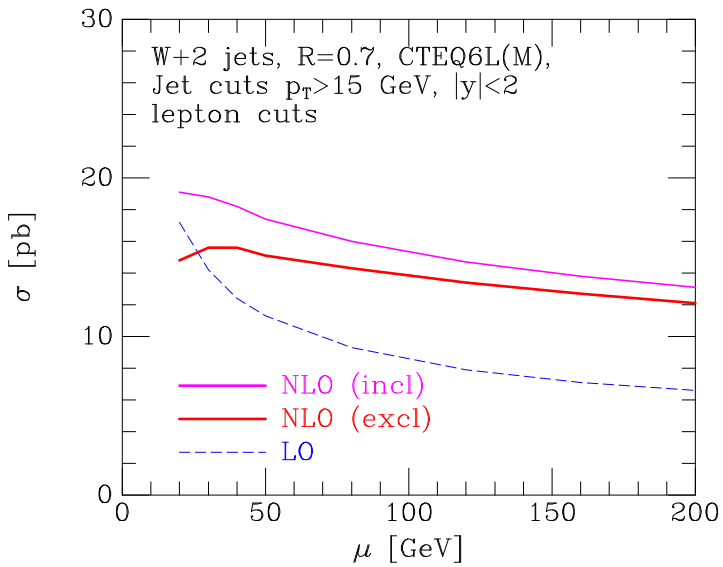


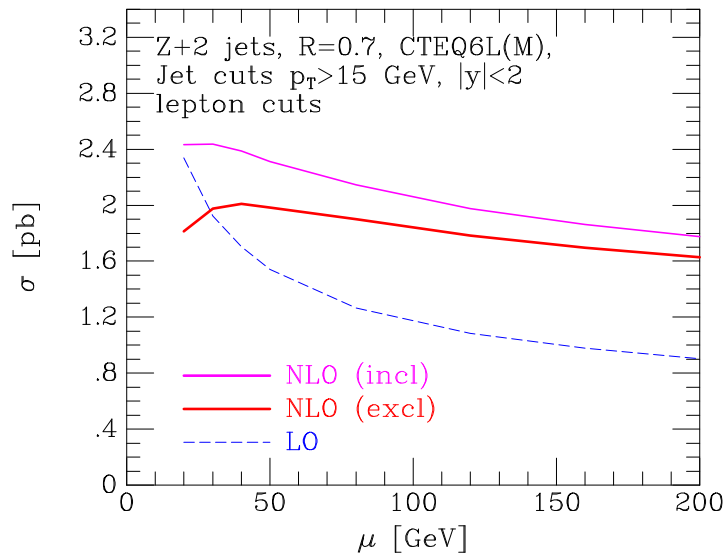
$$\mu_R = \mu_F \equiv \mu$$

- Choosing $\mu^2 = \langle p_T \rangle^2$ gives this ratio a large dependence on n.
- High scale $\mu^2 = M_W^2 + p_T^2$ now much closer to data.

Scale dependence

- Choose equal factorization and renormalization scales and examine the scale dependence of the $W, Z + 2$ jets cross-section at the Tevatron, in LO and NLO.

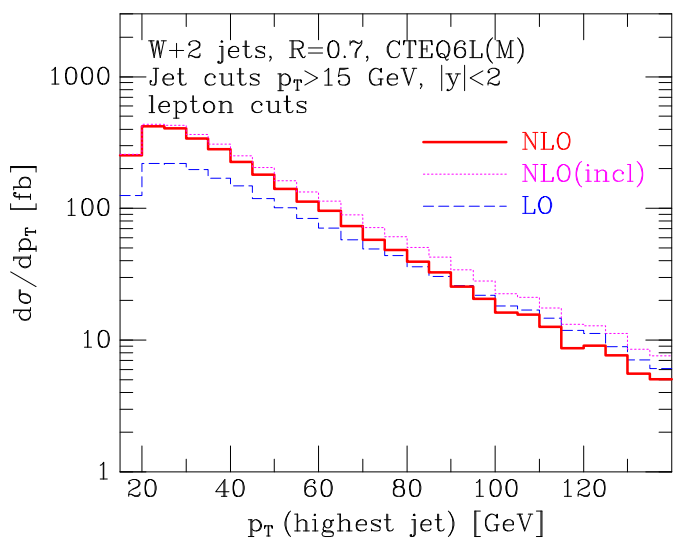


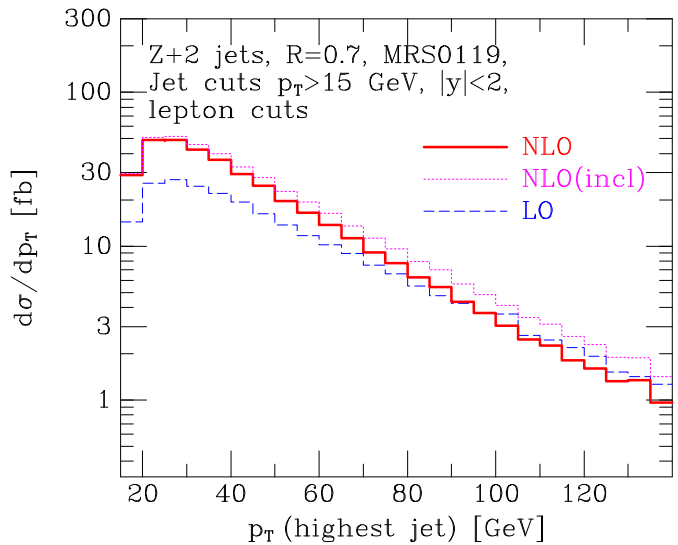


- Exclusive cross-section requires exactly 2 jets at NLO. Inclusive also includes the (lowest order) 3 jet contribution.
- Scale dependence is much reduced in both cases.

Leading p_T distribution

- p_T distribution of the hardest jet in W, Z+2 jet events, using the scale $\mu = 80$ GeV.

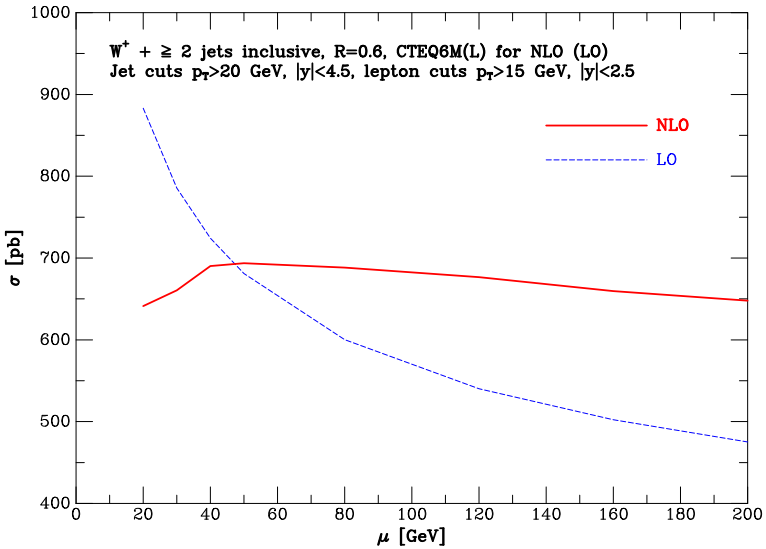


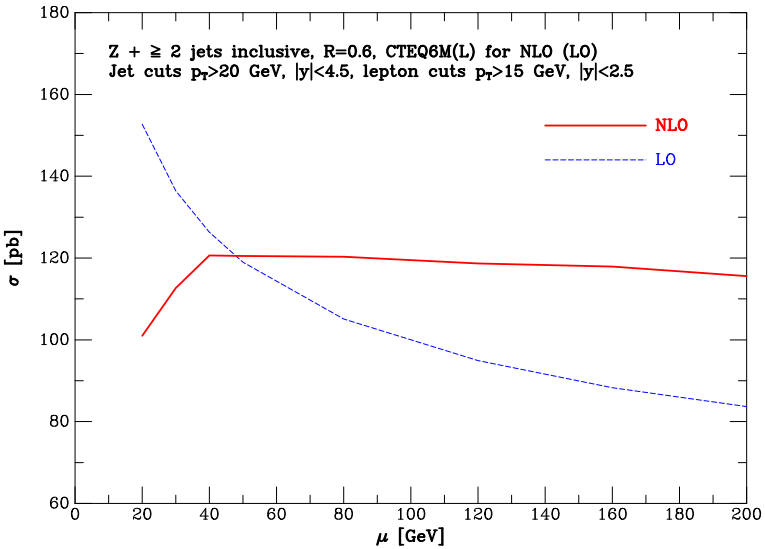


- Turn-over at low p_T since 15 GeV $< p_T^2 < p_T^1$.
- The high-E_T tail is 'filled in' for the inclusive case. High p_T jets very likely to radiate an extra one.

$V+ \geq 2$ *jets at the LHC*

- Different set of cuts at $\sqrt{s} = 14$ TeV and here we consider the inclusive cross section.

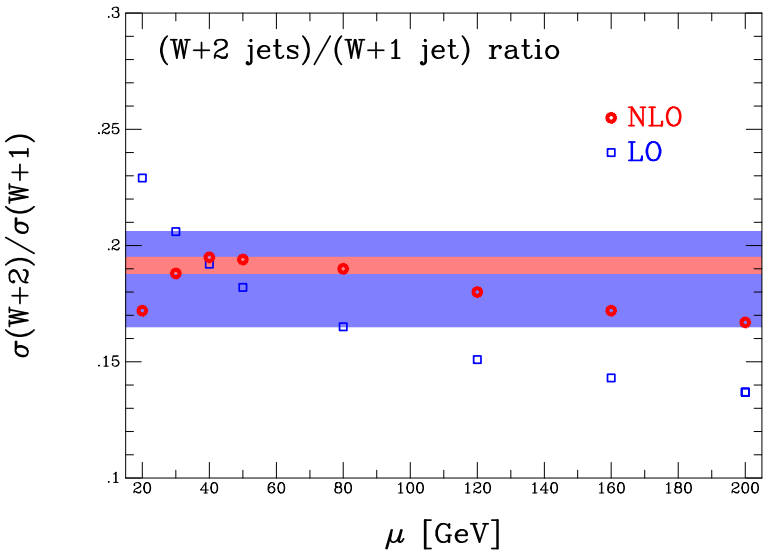


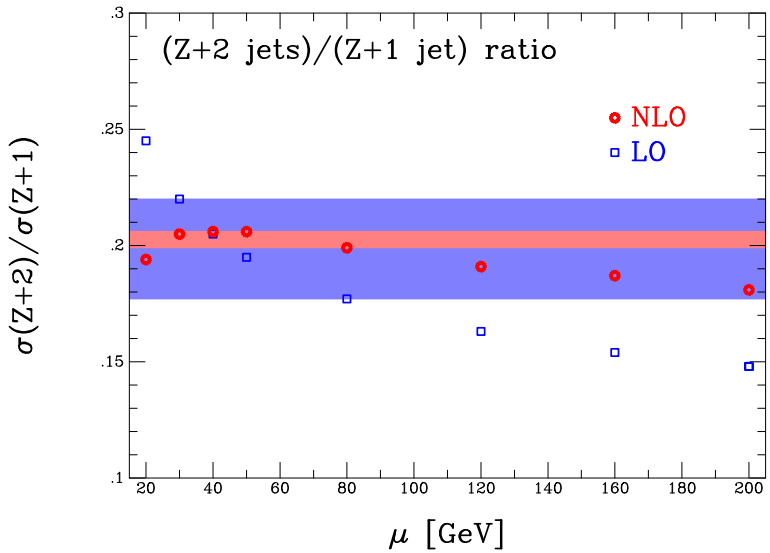


- The NLO corrections are somewhat smaller than at the Tevatron, approximately $10 - 20\%$ around $\mu = M_W$. Much less sensitivity to the scale μ.
- Detailed study is a work in progress.

Cross-section ratios at NLO

- Ratios calculated for Run II, so not directly comparable to previous slides.





- As expected, much more stable at NLO than LO, particularly in the region of conventional scales $\sim 30 - 80$ GeV.
- More studies underway.

Heavy flavour content

- Many signals of new physics involve the production of a W or Z boson in association with a heavy particle that predominantly decays into a $b\bar{b}$ pair.
- Most well-known example is a light Higgs:

$$p\bar{p} \longrightarrow W(\to e\nu)H(\to b\bar{b})$$
$$p\bar{p} \longrightarrow Z(\to \nu\bar{\nu}, \ell\bar{\ell})H(\to b\bar{b})$$

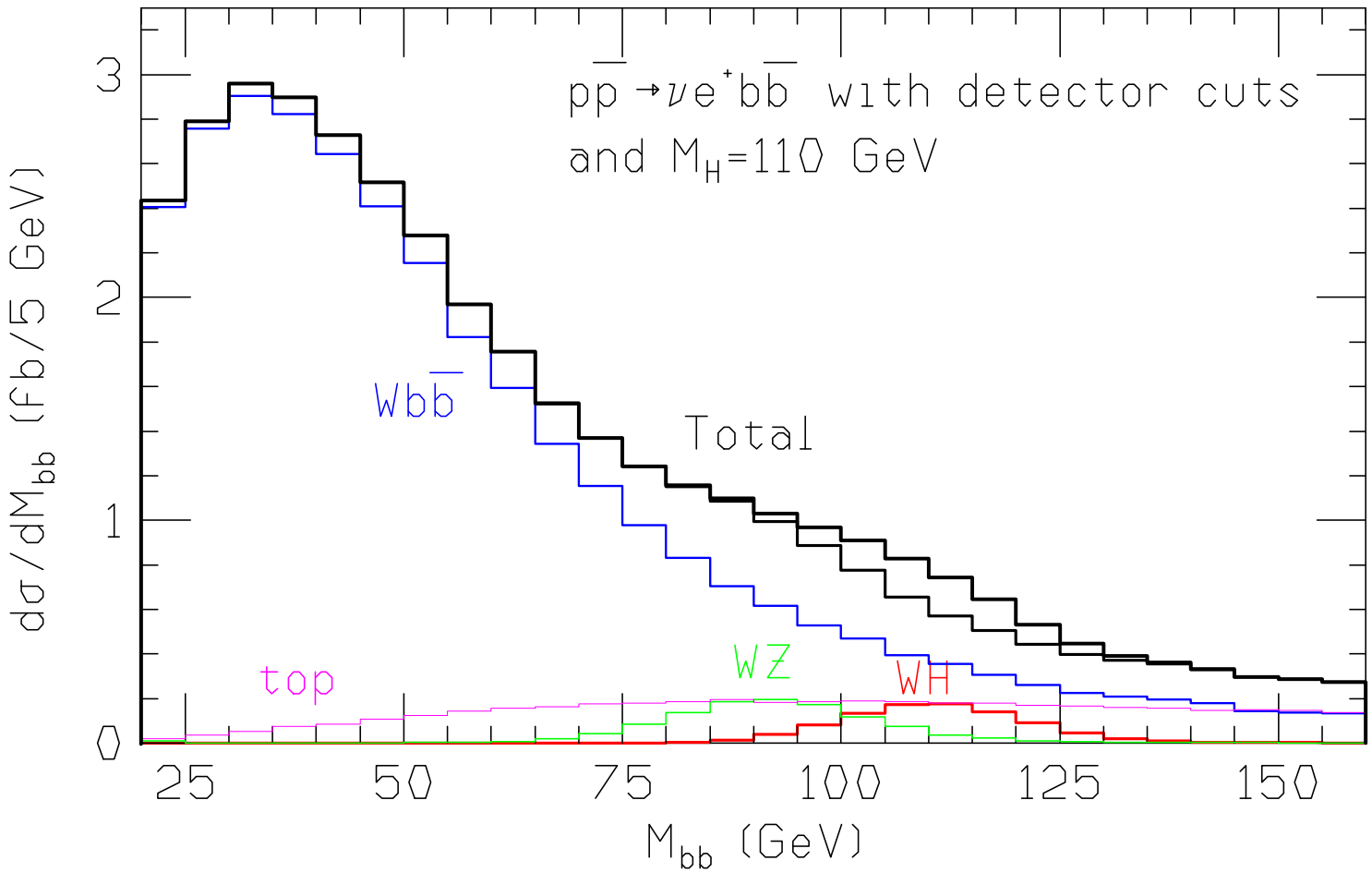
- However, we will need to understand our SM backgrounds very well to perform this – or any similar – search.
- The largest background is ‘direct’ production:

$$p\bar{p} \longrightarrow W\, g^{\star}(\to b\bar{b})$$
$$p\bar{p} \longrightarrow Z\, b\bar{b}$$

- Also important to understand these as backgrounds to signals that we expect, such as top.

Background importance

- NLO study of WH search using MCFM.



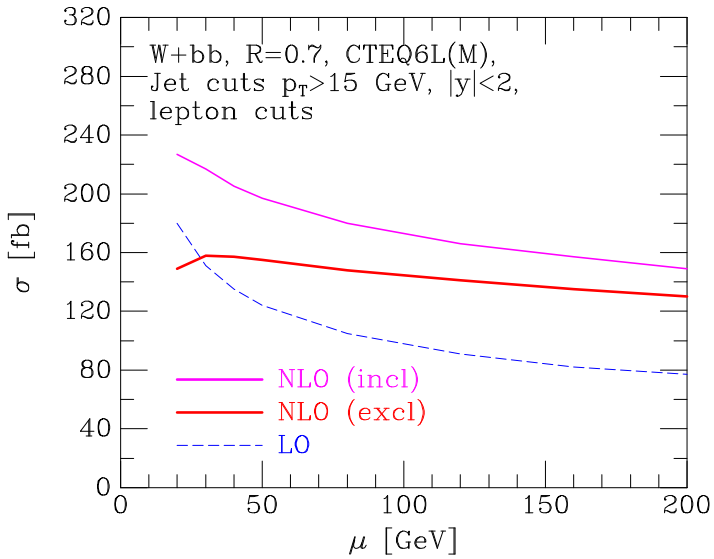
Measuring the $Wb\bar{b}$ background

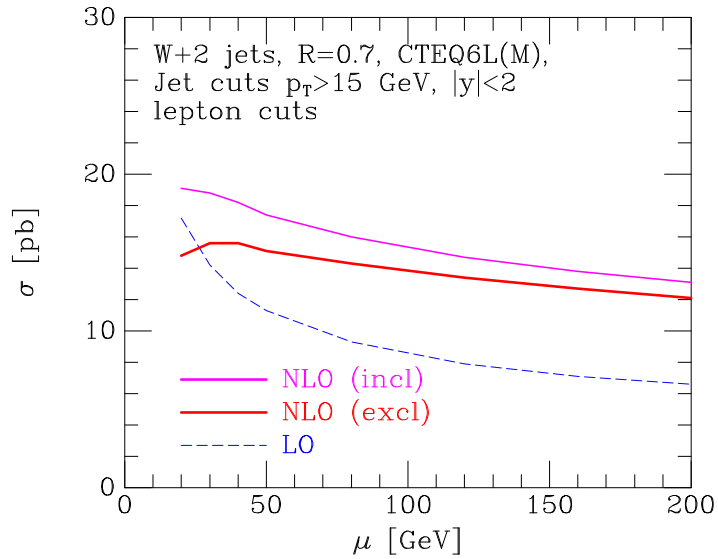
- $Wb\bar{b}$ background can be measured using CDF's 'Method 2':

$$\sigma(Wb\bar{b}) = \left[\frac{\sigma(Wb\bar{b})}{\sigma(W+2\text{ jet})}\right]_{MC} \times [\sigma(W+2\text{ jet})]_{\text{data}}$$

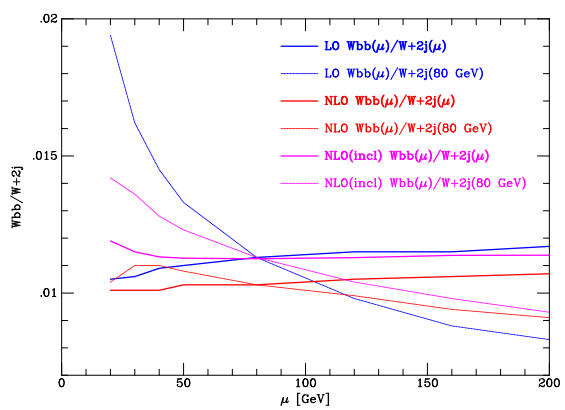
- We can calculate the ratio at NLO in MCFM.
- One sees a much reduced scale dependence in each of the cross-sections at NLO, but . . .
  - If we choose the same scales in the numerator and denominator, is the ratio also stable?
  - If the same scale is not appropriate, is this ratio useful? $Wb\bar{b}$ is simply gluon-splitting at LO, suggesting a different renormalization scale may be appropriate.
- At the moment, MCFM works only with $\mu_R = \mu_F$ – working on untangling these scales at the moment.

Scale dependence - $Wb\bar{b}$ vs. $W+2$ jets



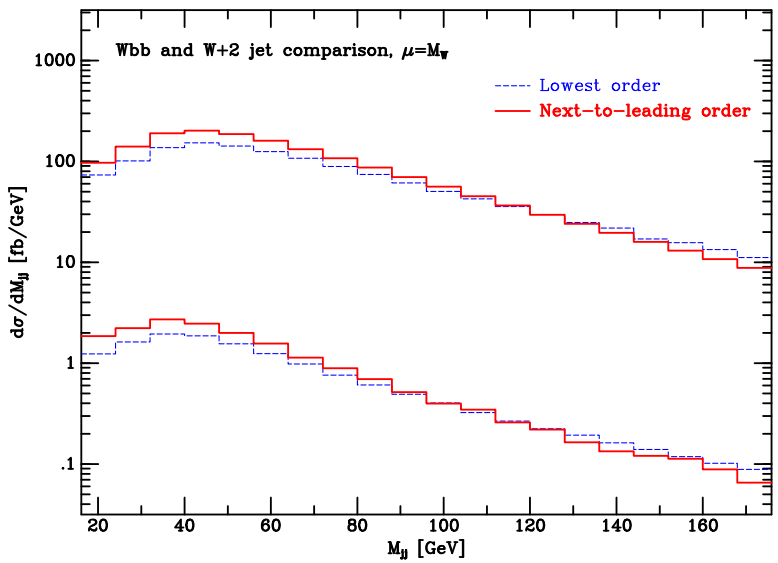


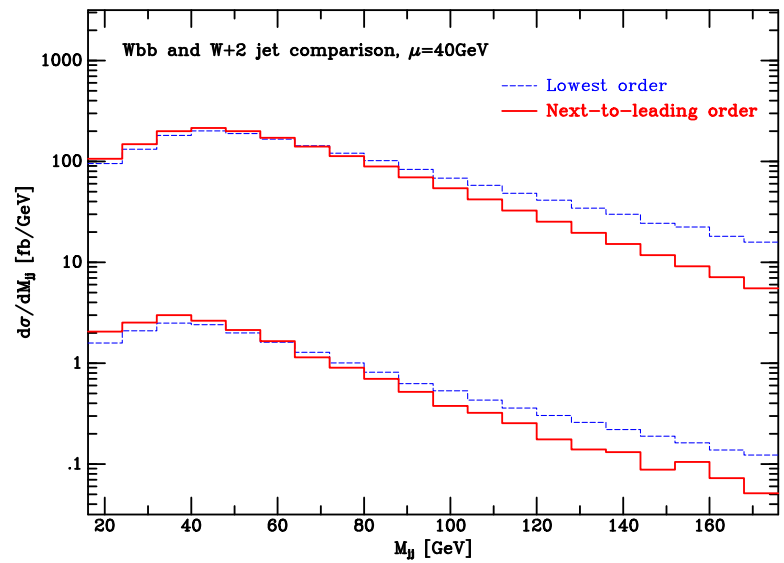
Ratio is much more stable at NLO, whether or not the same scale is used for $Wb\bar{b}$ as for $W+2$ jets.



m_{JJ} distributions

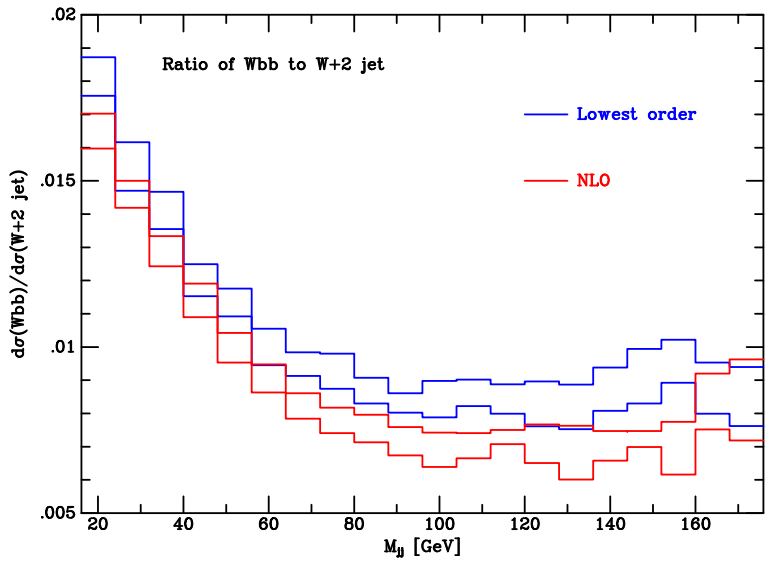
- $Wb\bar{b}$ and $W+2$ jet distributions appear very similar in shape at both LO and NLO. The shapes change when moving to a lower scale, with a depletion in the cross-section at high M_{jj}.





Heavy flavour fraction vs. m_{JJ}

- Look at the variation of the ratio as the scale is changed (in both numerator and denominator) from ~ 30 GeV up to ~ 160 GeV.



- The ratio of b-tagged to untagged jets changes little at NLO and appears to be predicted very well by perturbation theory.
- The fraction peaks at low M_{jj}, but in the reliable domain $M_{jj} > 60$ GeV, the value is fairly constant $\sim 0.8\%$.

Conclusions

- The currect version of our program is MCFM v3.4, which can be found at `mcfm.fnal.gov`.
- This includes NLO corrections for $W/Z + 2$ jets, which show a great reduction in scale dependence. Some distributions are considerably changed upon inclusion of the QCD corrections.
- The fraction of a $W + 2$ jet sample that contains two b-jets can be predicted at NLO and appears fairly robust. More studies are currently underway.
- Extensions - such as separating renormalization and factorization scale dependence and including b mass effects - are planned.