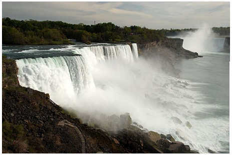
Associated production of a weak gauge boson and bottom quarks at hadron colliders

Doreen Wackeroth
University at Buffalo, SUNY



University at Buffalo
The State University of New York

in collaboration with
Fernando Febres Cordero (UCLA) and Laura Reina (FSU)

J. Campbell, R.K. Ellis, F. Maltoni, S. Willenbrock

Theory Seminar
Southern Methodist University
March 2, 2009

Introduction

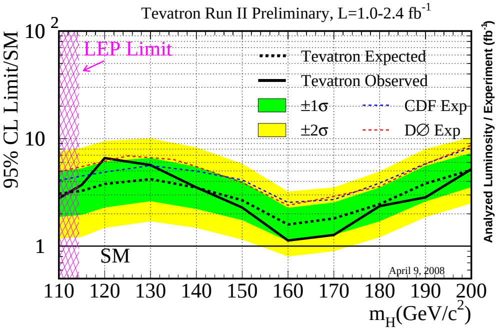
$p\bar{p} \rightarrow Zb\bar{b}$ and $p\bar{p} \rightarrow Wb\bar{b}$

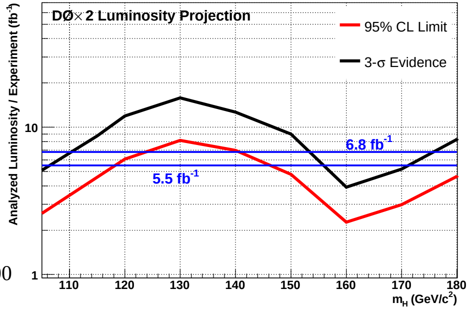
- are important background processes to
  - Standard Model (SM) Higgs boson searches for a light Higgs boson ($M_H < 135$ GeV):
    $p\bar{p} \rightarrow WH$ and $p\bar{p} \rightarrow ZH$ with $H \rightarrow b\bar{b}$,
  - single-top production, $t\bar{b}, \bar{t}b$ with $t \rightarrow W^+b, \bar{t} \rightarrow W^-\bar{b}$, and
  - searches for signals of physics beyond the SM
- are interesting in their own right as testing grounds for perturbative QCD. $W + 1b$-quark jet is sensitive to the b-quark content of the proton.

SM Higgs searches at the Tevatron

LEPII & electroweak precision data: LEPEWWG Summer 2008

$$114\,\mathrm{GeV} < M_H < 185\,\mathrm{GeV}(95\%\mathrm{C.L.})$$





Tevatron New Phenomena & Higgs WG, arXiv:0804.3423

G.Bernardi, arXiv:0809.5265

At the Tevatron, with $\mathcal{L} \approx 7\mathrm{fb}^{-1}$ the entire M_H range preferred by EWPOs can be excluded at 95 % C.L. (now: $5.8\mathrm{fb}^{-1}$, by 2010: $8 - 8.5\mathrm{fb}^{-1}$).

SM Higgs searches at the Tevatron

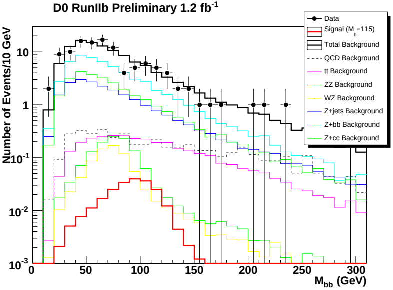
Example: SM Higgs search in $ZH \to l^+l^- b\bar{b}$ at D0: D0note 5570-CONF

no. of events	1 b tagged	2 bs tagged
$Z(\mu^+\mu^-)b\bar{b}$	$39.8 \pm 0.3 \pm 14$	$17.5 \pm 0.1 \pm 6.2$
Total bckg	$75.6 \pm 0.3 \pm 15.8$	$34.1 \pm 0.1 \pm 6.9$

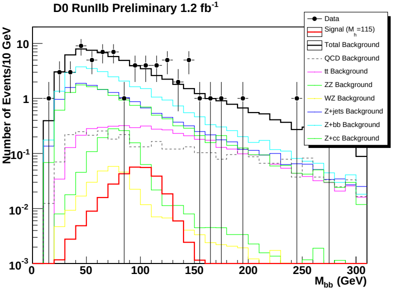
Systematic error due to theory uncertainty: $\delta\sigma(Zb\bar{b})/\sigma \approx 30\%$.

$M_{b\bar{b}}$ distributions for signal ($M_H = 115$ GeV) and backgrounds:

2 bs tagged



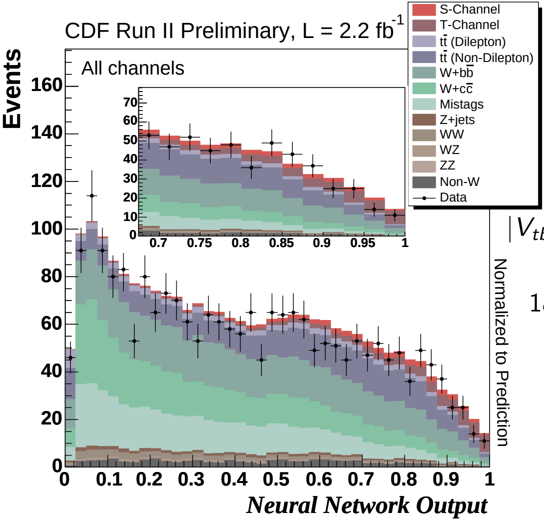
1 b tagged



The D0 Collaboration, D0note 5570-CONF

Evidence for single top production at the Tevatron

Background and signal prediction and CDF data for
$W + 2$ or 3 jets with at least 1 $b-$quark jet:



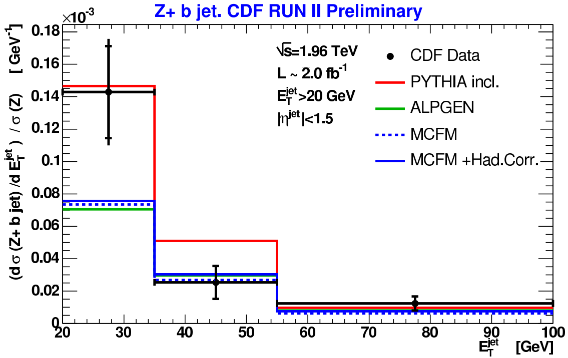
$$\sigma_{s+t} = 2.2 \pm 0.7 \text{ pb}$$

$$|V_{tb}| = 0.88 \pm 0.14(\text{exp}) \pm 0.07(\text{theory})$$

1σ deviation from SM expectation

R.C.Group *et al.* (for the CDF Collaboration at ICHEP08), arXiv:0809.4670

$Wb\bar{b}$ and $Zb\bar{b}$ production at the Tevatron and the LHC



C.Neu (for the DO and CDF collaborations at HCP2008), arXiv:0809.1407

LHC: $\delta\sigma(Zb\bar{b}, Z \to l^+l^-)/\sigma = 30\%$ with $\mathcal{L} = 100\,\mathrm{pb}^{-1}$.

The CMS collaboration, CMS PAS EWK-08-001

Status of SM predictions

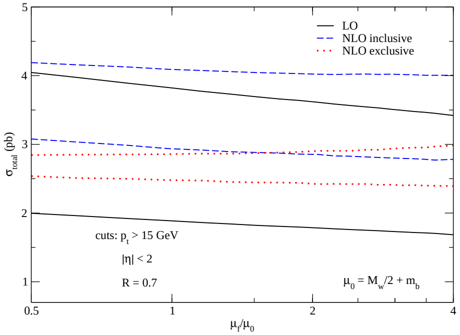
	NLO QCD	NLO EW
WH/ZH	HW 1991/MY 1997/BDH 2003 (NNLO)	CDK 2003
single top	SSW 1997+1998/HLPSW 2002/CSBBY 2005	BMRV 2006
	CSY 2004/CY 2004/S 2004+2005	
$Wb\bar{b}$	EV 1998/FRW 2006	
$Zb\bar{b}$	CE 2000/FRW 2008	
ZQ	CEMW 2003	
Wc/Wb	GKL 1995/CEMW+FRW 2008	
ZQj	CEMW 2005	
WQj	CEMW 2006	

Han, Willenbrock (HW); Mrenna, Yuan (MY); Brein, Djouadi, Harlander (BDH); Ciccolini, Dittmaier, Krämer (CDK); Stelzer, Sullivan, Willenbrock (SSW); Harris, Laenen, Phaf, Sullivan, Weinzierl (HLPSW); Cao, Schwienhorst, Benitez, Brock, Yuan (CSBBY); Cao, Schwienhorst, Yuan (CSY); Cao, Yuan (CY); Sullivan (S); Beccaria, Macorini, Renard, Verzegnassi (BMRV); Ellis, Veseli (EV); Cambell, Ellis (CE); Campbell, Ellis, Maltoni, Willenbrock (CEMW); Giele, Keller, Laenen (GKL); Febres Cordero, Reina, W. (FRW)

CE/CEMW/EV assume massless bottom-quarks with
$M_{b\bar{b}} > 2m_b, p_b > m_b$
FRW take into account full bottom-quark mass dependence

$Wb\bar{b}$ and $Zb\bar{b}$ production at NLO QCD

LO QCD predictions exhibit a strong renormalization/factorization scale dependence, e.g., scale dependence of $\sigma(Wb\bar{b})$ at the Tevatron:



F.Febres Cordero, L.Reina, DW, PRD74 (2006)

$\delta\sigma_{LO}(Wb\bar{b})/\sigma_{LO} \approx 40\%$
$\delta\sigma_{LO}(Zb\bar{b})/\sigma_{LO} \approx 45\%$

$Wb\bar{b}$ and $Zb\bar{b}$ production at NLO QCD

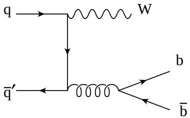
NLO QCD predictions are needed

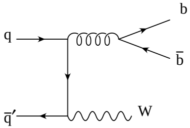
- for theoretical stable predictions by decreasing the scale dependence,
- because $O(\alpha_s)$ corrections can strongly increase/decrease the total production rate, and
- because $O(\alpha_s)$ corrections can significantly affect the shape of kinematic distributions.

$O(\alpha_s)$ corrections to $p\bar{p}, pp \to W/Zb\bar{b}$: technical details

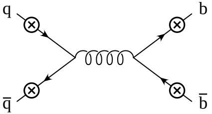
Feynman-diagrams at LO QCD:

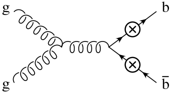
$Wb\bar{b}$:

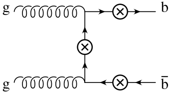


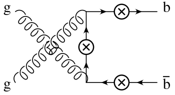


$Zb\bar{b}$:

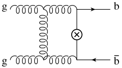




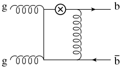




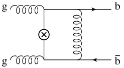
Examples of real and virtual $\mathcal{O}(\alpha_s)$ corrections to $p\bar{p} \to b\bar{b}Z$:



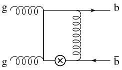
$P_{1,t}$



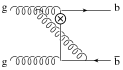
$P_{2,t}$



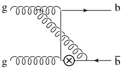
$P_{3,t}$



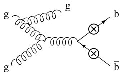
$P_{4,t}$

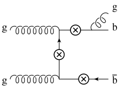


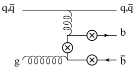
$P_{5,t}$



$P_{6,t}$







NLO QCD total inclusive cross section to $p\bar{p}, pp \rightarrow Vb\bar{b}(V = W, Z)$:

$$\sigma_{NLO} = \sum_{ij=q\bar{q},gg,qg} \frac{1}{1+\delta_{ij}} \int dx_1 dx_2 [\mathcal{F}_i^p(x_1,\mu)\mathcal{F}_j^{\bar{p}}(x_2,\mu)\hat{\sigma}_{\rm NLO}^{ij}(x_1,x_2,\mu) + (1 \leftrightarrow 2)]$$

with the parton level cross sections

$$\hat{\sigma}_{\rm NLO}^{ij} = \hat{\sigma}_{\rm LO}^{ij} + \frac{\alpha_s}{\pi}\delta\hat{\sigma}_{\rm NLO}^{ij} \text{ with } \delta\hat{\sigma}_{\rm NLO}^{ij} = \hat{\sigma}_{\rm virt}^{ij} + \hat{\sigma}_{\rm real}^{ij}$$

$\hat{\sigma}_{\rm virt}^{ij}$:

- UV divergences: renormalized in $d = 4 - 2\epsilon$ dimensions by a suitable set of counterterms and finite parts are fixed in the $\overline{MS}$ scheme.
- IR divergences: regularized in $d = 4 - 2\epsilon$ dimensions $\Rightarrow$ soft and collinear singularities appear as poles in $\frac{1}{\epsilon^2}, \frac{1}{\epsilon}$. IR singularities are completely canceled by corresponding IR poles in

$\hat{\sigma}_{\rm real}^{ij}$:

- IR divergences: extracted by suitable cuts on the gluon phase space using phase space slicing and the remaining initial-state IR singularities are absorbed in PDFs (mass factorization).

Phase Space Slicing with two cut-off parameters: δ_s, δ_c

Phase Space Slicing: isolate the region of the $Vb\bar{b}+g$ phase space where

$$s_{ig} = 2p_i \cdot p_g = 2E_i E_g(1-\beta_i \cos\theta_{ig}) \to 0$$

by introducing suitable cut-off parameters: Bergman, Baer, Ohnemus, Owens, Reno, ..., for a review see, e.g., B.Harris, J.Owens, PRD 65 (2002)

$$\hat{\sigma}^{ij}_{real} = \int d(PS_4)|\mathcal{A}_{real}(ij \to Vb\bar{b}+g)|^2 = \hat{\sigma}_{soft}(E_g < \frac{\sqrt{s}}{2}\delta_s)+\hat{\sigma}_{hard}(E_g > \frac{\sqrt{s}}{2}\delta_s)$$

In the soft limit ($E_g \to 0$):

$$d(PS_4) \xrightarrow{soft} d(PS_3)d(PS_g) = d(PS_3)\frac{d^{d-1}k}{(2\pi)^{d-1}2E_g}$$

$$|\mathcal{A}_{real}|^2 \xrightarrow{soft} (4\pi\alpha_s)|\mathcal{A}_{LO}|^2\Phi_{eik} \text{ with } \Phi_{eik} \propto \sum_{ij}\left(\frac{s_{ij}}{s_{ig}s_{jg}} - \frac{m_i^2}{s_{ig}^2} - \frac{m_j^2}{s_{jg}^2}\right)$$

$$\hat{\sigma}_{soft} = \int d(PS_3)|A_{LO}|^2 \int d(PS_g)\Phi_{eik}$$

Analytical integration in $d = 4-2\epsilon$: $\hat{\sigma}_{soft} \propto \frac{1}{\epsilon}, \frac{1}{\epsilon^2}$

. . . moreover

$$\hat{\sigma}_{hard} = \hat{\sigma}_{coll}((1-\cos\theta_{ig}) < \delta_c) + \hat{\sigma}_{non-coll}((1-\cos\theta_{ig}) > \delta_c)$$

In the collinear limit $(i \to i'g,\ p_i' = zp_i,\ p_g = (1-z)p_i)$

$$d(PS_4)(ij \to Vb\bar{b} + g) \stackrel{collinear}{\longrightarrow} d(PS_3)(i'j \to Vb\bar{b})zd(PS_g)$$

$$|\mathcal{A}_{real}(ij \to t\bar{t}h + g)|^2 \stackrel{collinear}{\longrightarrow} |A_{LO}|^2(4\pi\alpha_s)\frac{2P_{ii'}(z)}{z\, s_{ig}}$$

with $P_{ii'}$ denoting the Altarelli-Parisi splitting functions.

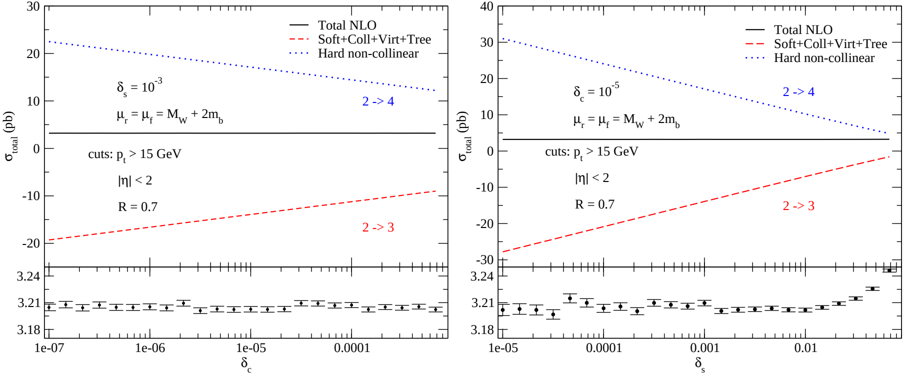
$$\hat{\sigma}_{coll} \propto \int d(PS_3)|A_{LO}|^2 \int d(PS_g) \sum_i \frac{P_{ii'}}{s_{ig}}$$

Analytical integration in $d = 4 - 2\epsilon$: $\hat{\sigma}_{coll} \propto \frac{1}{\epsilon}$.
The remaining real hard part

$$\hat{\sigma}_{non-coll} = \int d(PS_4)_{non-coll}|\mathcal{A}_{real}(q\bar{q} \to t\bar{t}h + g)|^2$$

is computed numerically.

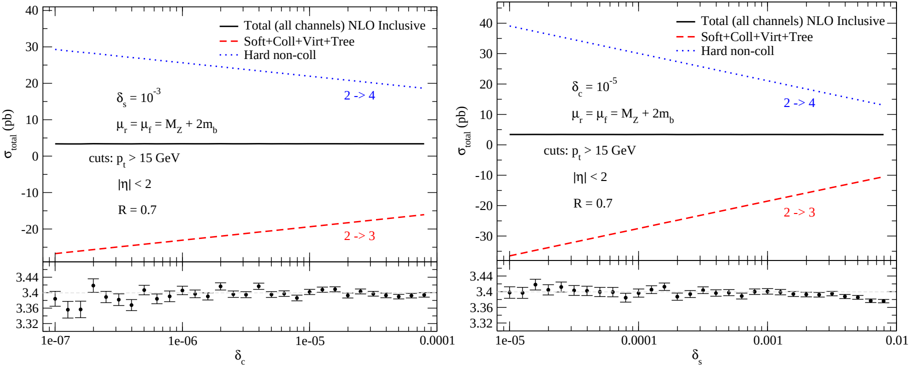
Cancellation of cut-off dependences in $\sigma_{\mathrm{NLO}}(Wb\bar{b})$



from F.Febres Cordero, L.Reina, DW, PRD74 (2006)

see also F.Febres Cordero, arXiv:0809.3829

Cancellation of cut-off dependences in $\sigma_{\rm NLO}(Zb\bar{b})$



from F.Febres Cordero, L.Reina, DW, PRD78 (2008)

see also F.Febres Cordero, arXiv:0809.3829

Numerical instabilities due to spurious divergences

After Veltman-Passarino reduction of high-ranked tensor integrals to scalar integrals, the solution of the resulting system of linear equation involves inverse powers of so-called Gram Determinantes (GD), e. g., pentagon diagrams yield

$$\frac{[s-(2m_b+M_V)^2]}{64}[M_V^4+(s-s_{b\bar{b}})^2-2M_V^2(s+s_{b\bar{b}})]s\, s_{b\bar{b}}\sin^2\theta_{b\bar{b}}\sin^2\phi_{b\bar{b}}\sin^2\theta$$

which vanishes at phase space boundaries.

- New, more efficient tensor reduction algorithms see, e.g., A.Denner, S.Dittmaier, hep-ph/0509141; T.Binoth, arXiv:0801.1616
- Direct, numerical integration without reduction to scalar integrals
- Unitarity-cut based methods to extract coefficients to a certain set of scalar integrals
- Reduce powers of GD by combining gauge invariant subsets and cancel propagators against numerators wherever possible $\Rightarrow$ numerically stable results for NLO QCD calculations of $2 \to 3$ processes such as $Ht\bar{t}$, $Hb\bar{b}$ and $Vb\bar{b}$.

Numerical results

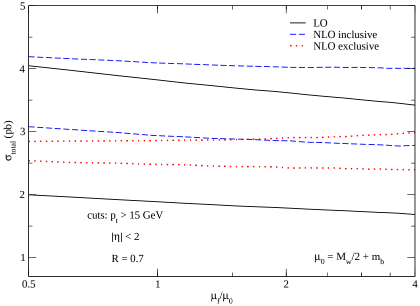
- Jet identification as implemented in MCFM: k_t jet algorithm with cone size $R = 0.7$
- We require all events to have a $b\bar{b}$ jet pair in the final state with

$$p_T^{b,\bar{b}} > 15\ \mathrm{GeV} \ \text{ and } \ |\eta^{b,\bar{b}}| < 2$$

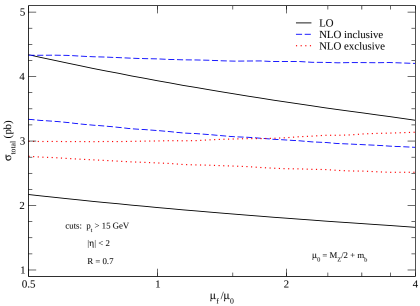
- The hard non-collinear extra parton is treated either *inclusively*, i.e. two- and three-jet events are included, or *exclusively*, i.e. exactly two b-quark jets are required in the event
- LO/NLO CTEQ6 set of PDFs with LO/NLO running of α_s for LO/NLO predictions

Main result: reduced scale dependence

$p\bar{p} \rightarrow b\bar{b}W$ at the Tevatron



$p\bar{p} \rightarrow b\bar{b}Z$ at the Tevatron

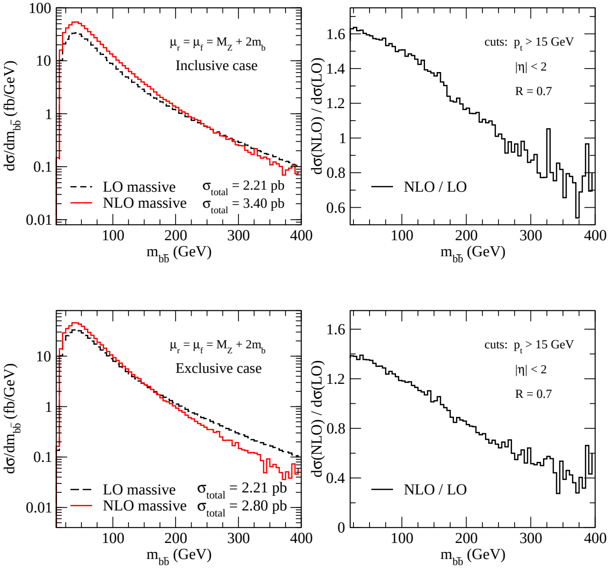


$$\delta\sigma_{NLO}/\sigma_{NLO} \approx 20\%(\text{inclusive}), 10\%(\text{exclusive})$$

$$K = \sigma_{NLO}/\sigma_{LO}(Zb\bar{b}) = 1.54(\text{inclusive}), 1.27(\text{exclusive})$$
$$K = \sigma_{NLO}/\sigma_{LO}(Wb\bar{b}) = 1.45(\text{inclusive}), 1.20(\text{exclusive})$$

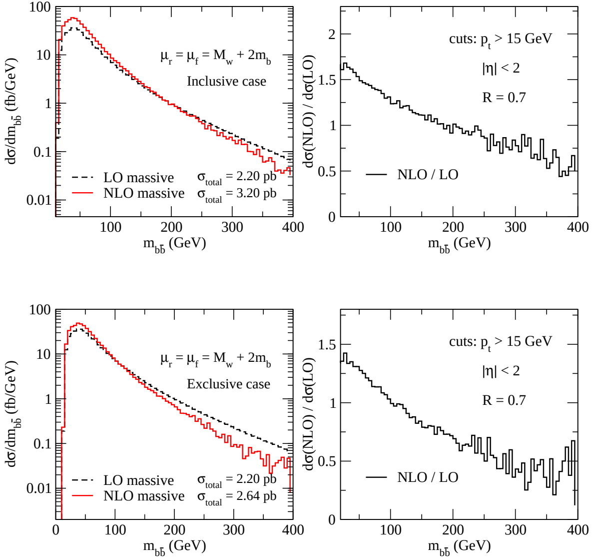
from F.Febres Cordero, L.Reina, DW, PRD74 (2006); PRD78 (2008)

Impact on $M_{b\bar{b}}$ distributions in $p\bar{p} \to Zb\bar{b}$



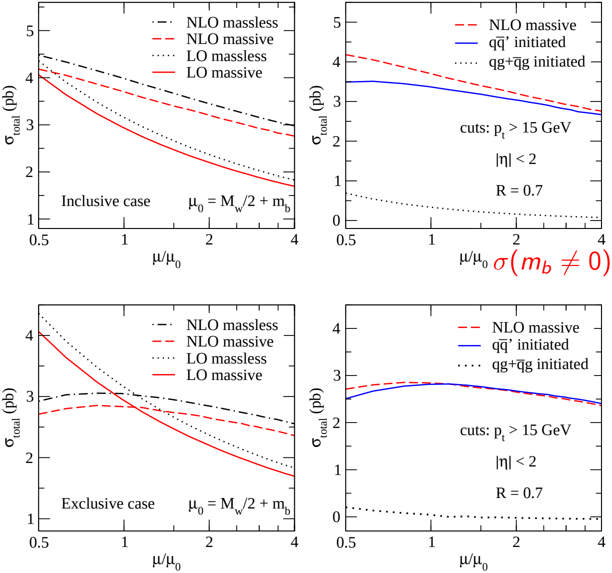
from F.Febres Cordero, L.Reina, DW, PRD78 (2008)

Impact on $M_{b\bar{b}}$ distributions in $p\bar{p} \to Wb\bar{b}$



from F.Febres Cordero, L.Reina, DW, PRD74 (2006)

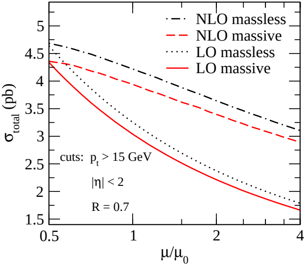
b-quark mass effects in $\sigma_{\mathrm{LO,NLO}}(Wb\bar{b})$

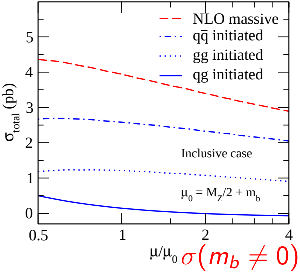


$\sigma(m_b \neq 0)/\sigma(m_b = 0) = 0.92$

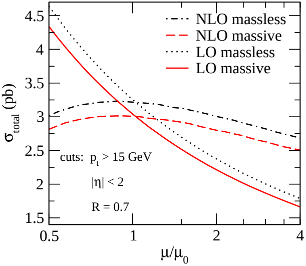
from F.Febres Cordero, L.Reina, DW, PRD74 (2006)

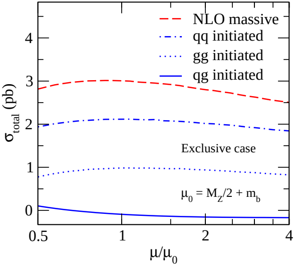
b-quark mass effects in $\sigma_{\mathrm{LO,NLO}}(Zb\bar{b})$





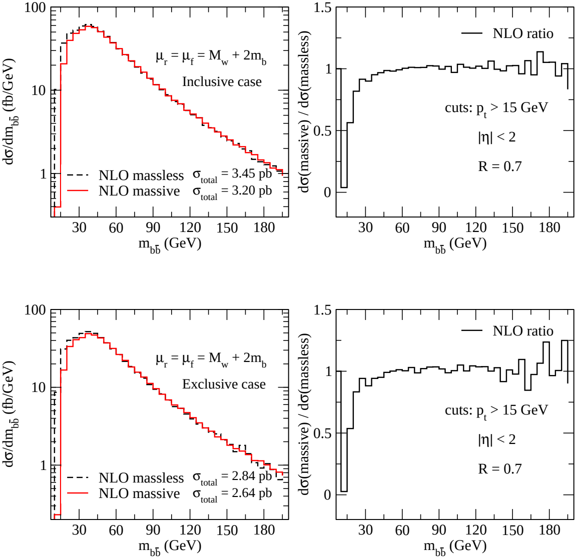
$\sigma(m_b \neq 0)/\sigma(m_b = 0) = 0.93$





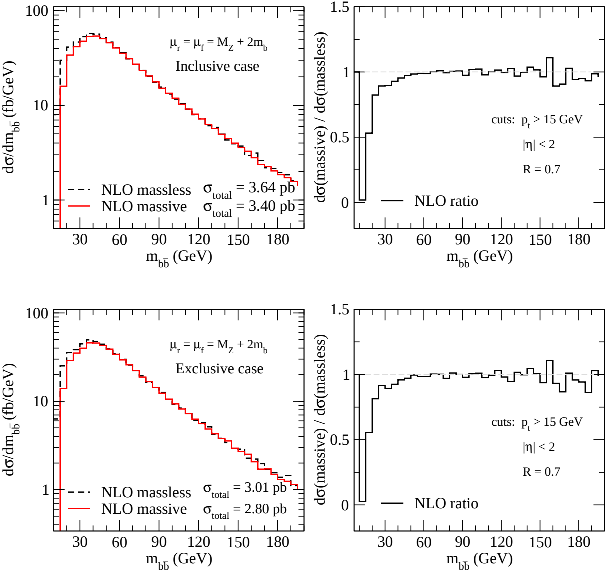
from F.Febres Cordero, L.Reina, DW, PRD78 (2008)

b-quark mass effects in $d\sigma_{\mathrm{NLO}}(Wb\bar{b})/dM_{b\bar{b}}$



from F.Febres Cordero, L.Reina, DW, PRD74 (2006)

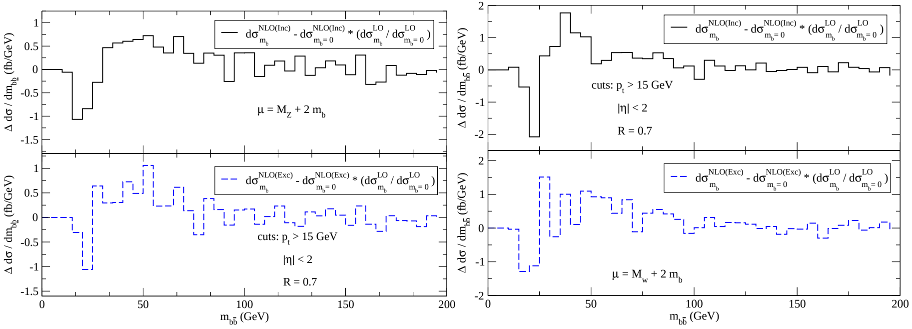
b-quark mass effects in $d\sigma_{\mathrm{NLO}}(Zb\bar{b})/dM_{b\bar{b}}$



from F.Febres Cordero, L.Reina, DW, PRD78 (2008)

Rescaling of NLO ($m_b = 0$) with LO ratios

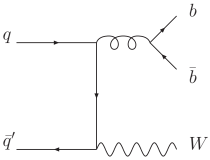
$$\Delta \frac{d\sigma}{dm_{b\bar{b}}} = \frac{d\sigma^{NLO}}{dm_{b\bar{b}}}(m_b \neq 0) - \frac{d\sigma^{NLO}}{dm_{b\bar{b}}}(m_b = 0)\,\frac{d\sigma^{LO}(m_b \neq 0)}{d\sigma^{LO}(m_b = 0)}\,.$$

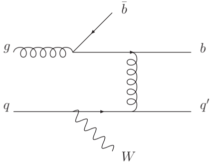


from F.Febres Cordero, L.Reina, DW, PRD74 (2006); PRD78 (2008)

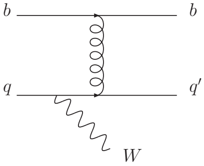
Improving predictions for Wb production

Assuming that there is only one high-p_t b-quark in the event increases the production rate and introduces a sensitivity to b quark PDFs:





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



convoluted with a b-quark PDF

Improving predictions for *Wb* production

Large logarithms proportional to $\log(Q^2/m_b^2)$ may arise due to initial and final-state collinear $g \to b\bar{b}$ splitting.

- Initial-state collinear logarithms $[\alpha_s \log(M_W^2/m_b^2)]^n$ can be resummed by using a b-quark PDF at $\mu_F = Q = M_W$ which is determined perturbatively from DGLAP evolution equations. Approximate solution of DGLAP equation with initial condition $b(x, \mu^2) = 0$ at $\mu = m_b$:

$$\tilde{b}(x, \mu^2) = \frac{\alpha_s(\mu^2)}{2\pi} \log(\frac{\mu^2}{m_b^2}) \int_x^1 \frac{dz}{z} P_{qg}(z) g(\frac{x}{z}, \mu^2)$$

  Aivazis *et al*, hep-ph/9312319; Collins, hep-ph/9806259; Olness, Scalise, PRD57 (1998); see also Stelzer *et al*, hep-ph/9705398

- Final-state collinear logarithms may be avoided by using an appropriate jet identification algorithm. see, e.g., Banfi, Salam, Zanderighi, arXiv:0704.2999

Improving predictions for *Wb* production

There are a variety of processes that must be calculated at NLO QCD:

1. $q\bar{q}' \to Wb\bar{b}$ at tree level and one loop ($m_b \neq 0$)
2. $q\bar{q}' \to Wb\bar{b}g$ at tree level ($m_b \neq 0$)
3. $bq \to Wbq'$ at tree level and one loop ($m_b = 0$)
4. $bq \to Wbq'g$ at tree level ($m_b = 0$)
5. $bg \to Wbq'\bar{q}$ at tree level ($m_b = 0$)
6. $gq \to Wb\bar{b}q'$ at tree level ($m_b \neq 0$) $[-\tilde{b}q \to Wbq']$

Separation and jet identification cuts:

Tevatron:	$p_{Tj} > 15$ GeV	$\lvert\eta_j\rvert < 2$
LHC:	$p_{Tj} > 25$ GeV	$\lvert\eta_j\rvert < 2.5$
$\lvert\Delta R_{b\bar{b}}\rvert > 0.7$		$\lvert\Delta R_{bj}\rvert > 0.7$

If $|\Delta R_{b\bar{b}}| < 0.7$, the two b-quarks are considered to be one b-jet.

J.Campbell *et al.*, PRD79 (2009), arXiv:0809.3003

Results for Wb production: $\sigma_{LO,NLO}$

	Exclusive cross sections (pb)	
Collider	Wb	
	$[\mathrm{LO}(q\bar{q}')+\mathrm{LO}(bq)]$ $\mathrm{NLO}(q\bar{q}')+\mathrm{NLO}(bq/bg/gq)(qg)$	$\frac{\sigma_{NLO}}{\sigma_{LO}}$
TeV $W^{\pm}$	[5.28+0.75=6.03] 8.64(-0.05)	1.43
LHC W^{+}	[30.2+54.3=84.5] 40.0+48.4=88.4(22.6)	1.05
LHC W^{-}	[21.6+31.4=53.0] 29.8+29.4=59.2(12.6)	1.12
	Inclusive cross sections (pb)	
Collider	$Wb+X$	
	$[\mathrm{LO}(q\bar{q}')+\mathrm{LO}(bq)]$ $\mathrm{NLO}(q\bar{q}')+\mathrm{NLO}(bq/bg/gq)(qg)$	$\frac{\sigma_{NLO}}{\sigma_{LO}}$
TeV $W^{\pm}$	[7.56+1.81=9.37] 11.77+2.40=14.17(0.77)	1.51
LHC W^{+}	[39.3+106.0=145.3] 53.6+136.1=189.7(68.9)	1.31
LHC W^{-}	[27.9+67.0=94.9] 39.3+88.2=127.5(44.6)	1.34

from J.Campbell *et al.*, PRD79 (2009), arXiv:0809.3003

Results for $W(b\bar{b})$ production: $\sigma_{LO,NLO}$

	Exclusive cross sections (pb)	
Collider	$W(b\bar{b})$	
	[LO($q\bar{q}'$)] NLO($q\bar{q}'$)+NLO(gq)	$\frac{\sigma_{NLO}}{\sigma_{LO}}$
TeV $W^{\pm}$	[2.66] 3.73-0.02=3.71	1.39
LHC W^{+}	[17.6] 22.7+11.7=34.4	1.95
LHC W^{-}	[12.9] 17.2+6.5=23.7	1.84
	Inclusive cross sections (pb)	
Collider	$W(b\bar{b})+X$	
	[LO($q\bar{q}'$)] NLO($q\bar{q}'$)+NLO(gq)	$\frac{\sigma_{NLO}}{\sigma_{LO}}$
TeV $W^{\pm}$	[2.66] 4.17+0.39=4.56	1.71
LHC W^{+}	[17.6] 25.1+35.9=61.0	3.47
LHC W^{-}	[12.9] 18.9+23.6=42.5	3.29

from J.Campbell *et al.*, PRD79 (2009), arXiv:0809.3003

Scale dependence of $\sigma_{LO,NLO}$ in Wb production

	Exclusive cross sections (pb)
Collider	Wb $[\mathrm{LO}(\mu_r+\mu_f)]$ $\mathrm{NLO}(\mu_r+\mu_f)$
TeV $W^\pm$	$\left[6.03\times(1^{+0.27+0.02}_{-0.19-0.03})\right]$ $8.64\times(1^{+0.13+0.004}_{-0.12-0.003})$
LHC W^+	$\left[84.5\times(1^{+0.27+0.11}_{-0.19-0.14})\right]$ $88.4\times(1^{+0.11+0.08}_{-0.11-0.10})$
LHC W^-	$\left[53.0\times(1^{+0.27+0.12}_{-0.19-0.14})\right]$ $59.2\times(1^{+0.12+0.08}_{-0.11-0.10})$
	Inclusive cross sections (pb)
Collider	Wb $[\mathrm{LO}(\mu_r+\mu_f)]$ $\mathrm{NLO}(\mu_r+\mu_f)$
TeV $W^\pm$	$\left[9.37\times(1^{+0.27+0.02}_{-0.19-0.03})\right]$ $14.17\times(1^{+0.15+0.0002}_{-0.13-0.001})$
LHC W^+	$\left[145.3\times(1^{+0.27+0.12}_{-0.19-0.14})\right]$ $189.7\times(1^{+0.16+0.07}_{-0.13-0.10})$
LHC W^-	$\left[94.9\times(1^{+0.27+0.12}_{-0.19-0.15})\right]$ $127.5\times(1^{+0.16+0.08}_{-0.13-0.10})$

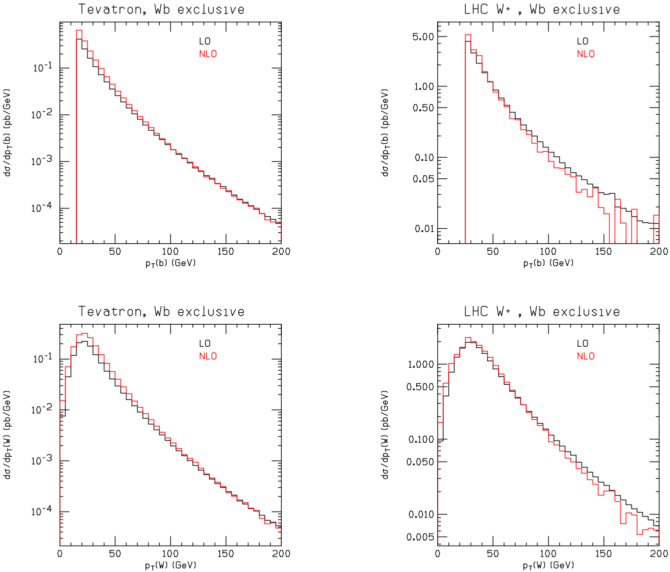
from J.Campbell *et al.*, PRD79 (2009), arXiv:0809.3003

Scale dependence of $\sigma_{LO,NLO}$ in $W(b\bar{b})$ production

	Exclusive cross sections (pb)
Collider	$W(b\bar{b})$
	$[\mathrm{LO}(\mu_r+\mu_f)]$ $\mathrm{NLO}(\mu_r+\mu_f)$
TeV $W^\pm$	$\left[2.66\times(1^{+0.27+0.04}_{-0.19-0.04})\right]$ $3.71\times(1^{0.12+0.01}_{-0.11-0.01})$
LHC W^+	$\left[17.6\times(1^{+0.27+0.09}_{-0.19-0.10})\right]$ $34.4\times(1^{+0.23+0.03}_{-0.16-0.04})$
LHC W^-	$\left[12.9\times(1^{+0.27+0.09}_{-0.19-0.11})\right]$ $23.7\times(1^{+0.21+0.03}_{-0.15-0.04})$
	Inclusive cross sections (pb)
Collider	$W(b\bar{b})$
	$[\mathrm{LO}(\mu_r+\mu_f)]$ $\mathrm{NLO}(\mu_r+\mu_f)$
TeV $W^\pm$	$\left[2.66\times(1^{+0.27+0.04}_{-0.19-0.04})\right]$ $4.56\times(1^{+0.17+0.03}_{-0.14-0.02})$
LHC W^+	$\left[17.6\times(1^{+0.27+0.09}_{-0.19-0.10})\right]$ $61.0\times(1^{+0.33+0.02}_{-0.21-0.02})$
LHC W^-	$\left[12.9\times(1^{+0.27+0.09}_{-0.19-0.11})\right]$ $42.5\times(1^{+0.32+0.02}_{-0.21-0.03})$

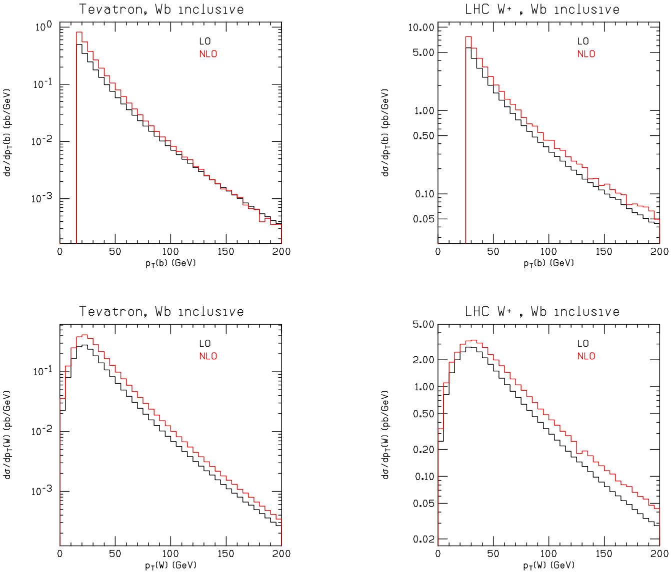
from J.Campbell *et al.*, PRD79 (2009), arXiv:0809.3003

Results for Wb production: $d\sigma_{LO,NLO}/dp_T$



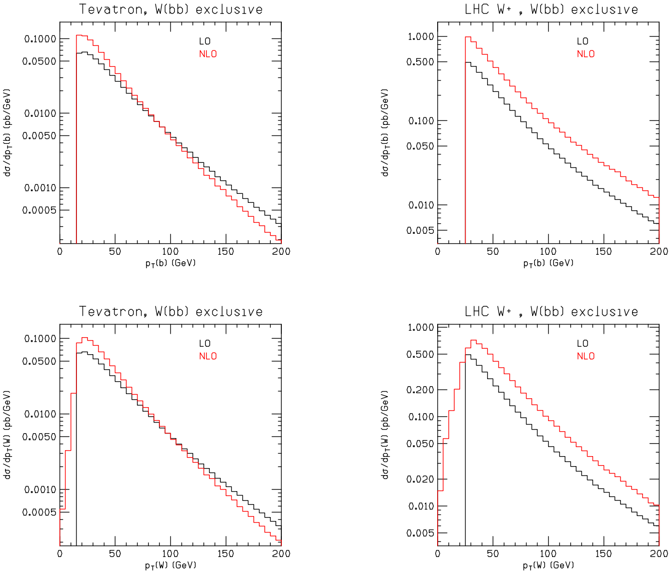
from J.Campbell *et al.*, PRD79 (2009), arXiv:0809.3003

Results for Wb production: $d\sigma_{LO,NLO}/dp_T$



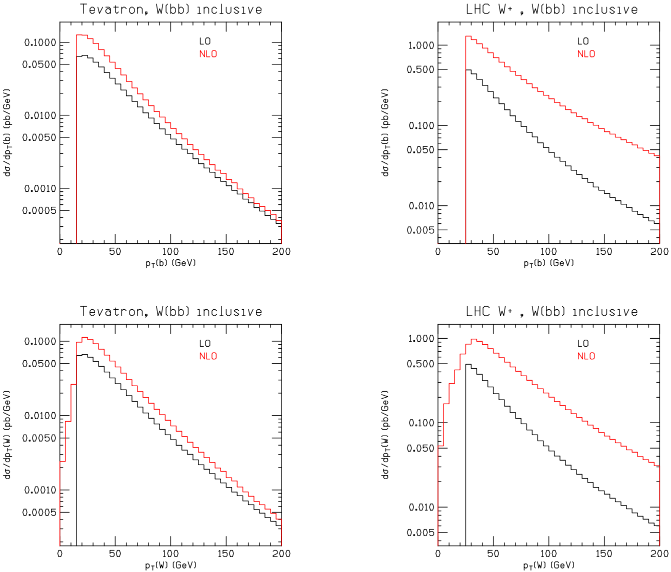
from J.Campbell *et al.*, PRD79 (2009), arXiv:0809.3003

Results for $W(b\bar{b})$ production: $d\sigma_{LO,NLO}/dp_T$



from J.Campbell *et al.*, PRD79 (2009), arXiv:0809.3003

Results for $W(b\bar{b})$ production: $d\sigma_{LO,NLO}/dp_T$



from J.Campbell *et al.*, PRD79 (2009), arXiv:0809.3003

Conclusion and Outlook

$Wb\bar{b}$ and $Zb\bar{b}$ production:

- The associated production of a weak gauge boson and one or two b-quark jets constitutes an important background to SM Higgs boson searches at the Tevatron, single top production and to searches for signals of physics beyond the SM at both the Tevatron and the LHC.
- We calculated and studied the impact of NLO QCD corrections to $Wb\bar{b}$ and $Zb\bar{b}$ production on the total production rate and the $M_{b\bar{b}}$ distribution and compared our results with a calculation based on the massless b-quark approximation (MCFM).

Conclusion and Outlook

- Findings:
  - factorization and renormalization dependence is considerably reduced: $\delta\sigma_{NLO}/\sigma_{NLO} \approx 20\%(\text{inclusive}), 10\%(\text{exclusive})$,
  - bottom-quark mass effects can amount to about 8% of σ_{NLO} and considerably impact the shape of the $M_{b\bar{b}}$ distribution,
  - bottom-quark mass effects can be sufficiently well described by rescaling $\sigma_{NLO}(m_b = 0)$ with $\sigma_{LO}(m_b \neq 0)$.
- We improved the NLO QCD calculation of Wb production by combining the NLO QCD calculations of $Wb\bar{b}(m_b \neq 0)$ with $Wbj(m_b = 0)$ (MCFM). The latter resums initial-state collinear singularities $(\alpha_s \log(M_W^2/m_b^2))$ to all orders by using a b-quark PDF. We studied observables to Wb and $W(b\bar{b})$ production and found modest NLO corrections in the Wb case but large corrections to $W(b\bar{b})$.
- Possible further improvements:
  - resummation of final-state collinear singularities
  - applications of alternative jet algorithms (Wb)
  - qg initiated process at NLO QCD ($W/Zb\bar{b}$)

Resources

- ATLAS and CMS TDRs and Notes,
- CDF Physics results at www-cdf.fnal.gov/physics/physics.html,
- D0 Physics results at www-d0.fnal.gov/Run2Physics/WWW/results.htm,
- Recent overview of Tevatron results see, e.g., talk by A.Juste at LCWS08 www.linearcollider.org/lcws08.
- and references on slides.

Many Thanks !