QCD Corrections to Weak Vector Boson Production Associated to Heavy Quark Jets at Hadron Colliders

W/Z bb & W b @ NLO

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[hep-ph/0606102] - arXiv:0801.2374 [hep-ph] - arXiv:080X.XXXX [hep-ph]

and John Campbell, Fabio Maltoni and Scott Willenbrock

arXiv:080X.XXXX [hep-ph]

OUTLINE

- Introduction
  - Weak bosons and b-jets
  - W/Z b bbar production with $m_b \neq 0$
  - Wb
- The Calculation & Results
  - Z+2b-jets
  - W+2b-jets (backgrounds to single-top and t tbar production)
  - Wb
- Summary and Outlook

LHC

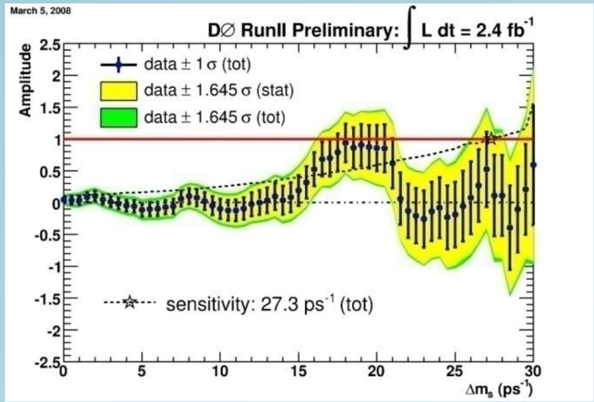
Introduction

TEVATRON

Introduction

TEVATRON

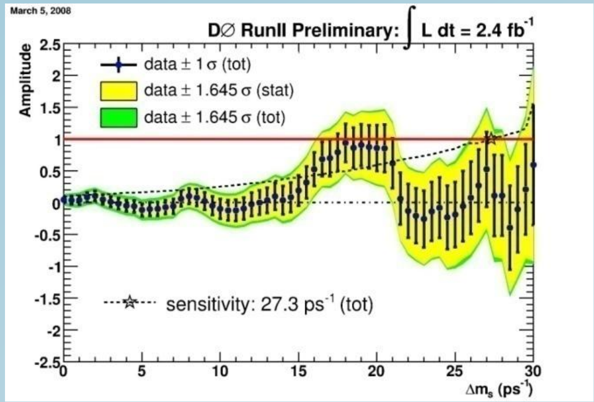
B_s^0–$\bar{B}_s^0$ oscillation frequency



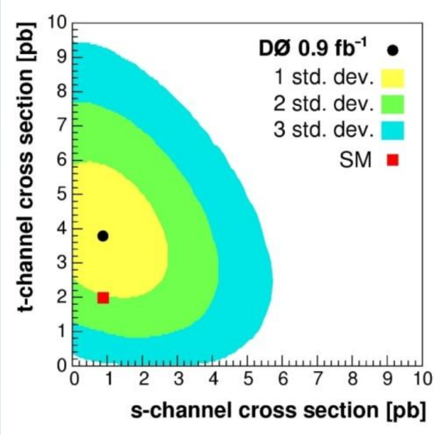
Introduction

TEVATRON

$B_s^0 - \bar{B}_s^0$ oscillation frequency



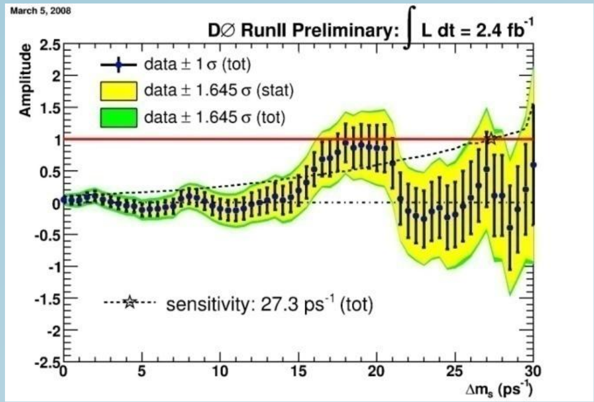
Single top evidence



Introduction

TEVATRON

$B_s^0 - \bar{B}_s^0$ oscillation frequency



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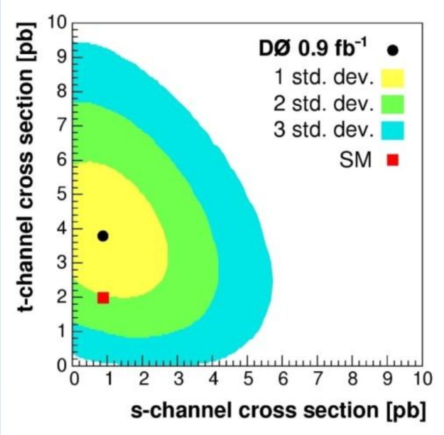
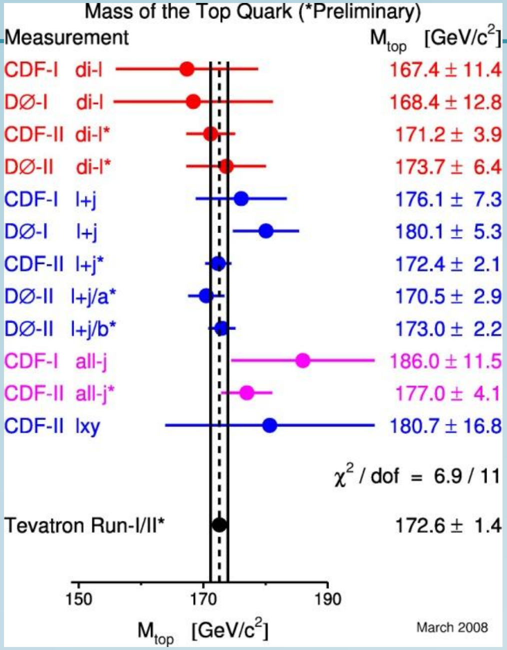


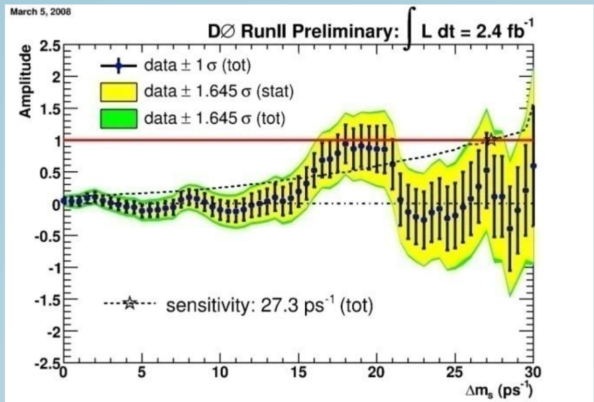
Introduction

Top mass measurement

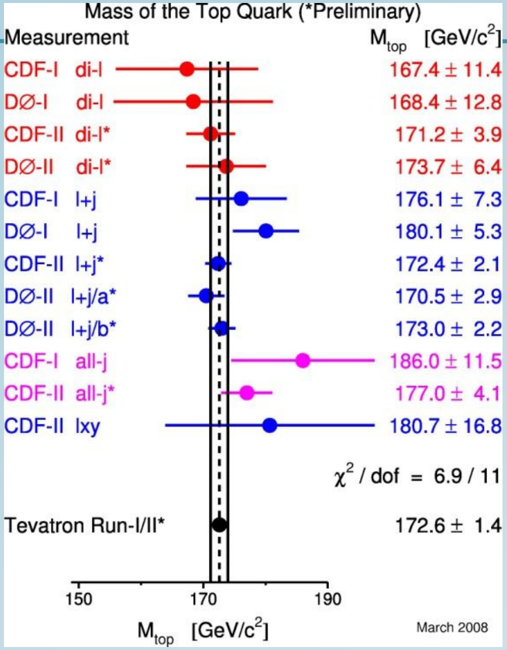


TEVATRON

$B_s^0 - \bar{B}_s^0$ oscillation frequency



Top mass measurement



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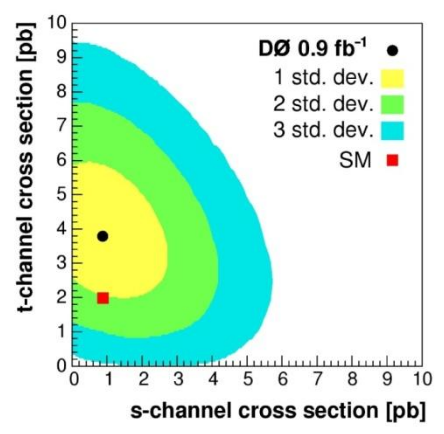
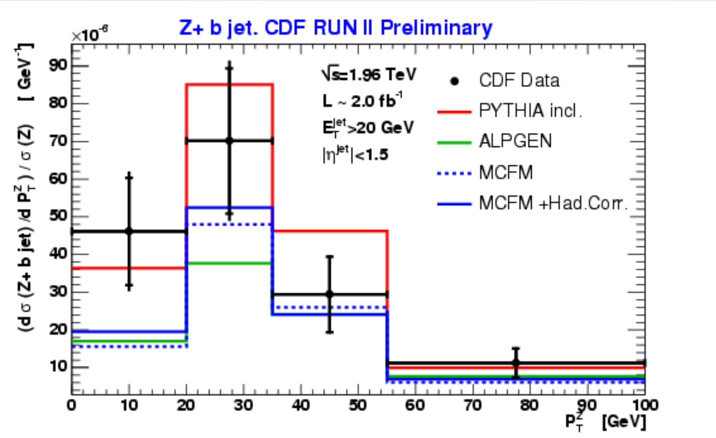


Z+b-jet differential x-sections



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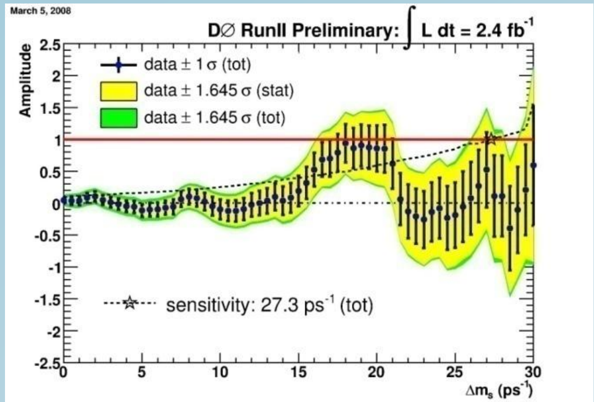
$B_s^0 - \bar{B}_s^0$ oscillation frequency



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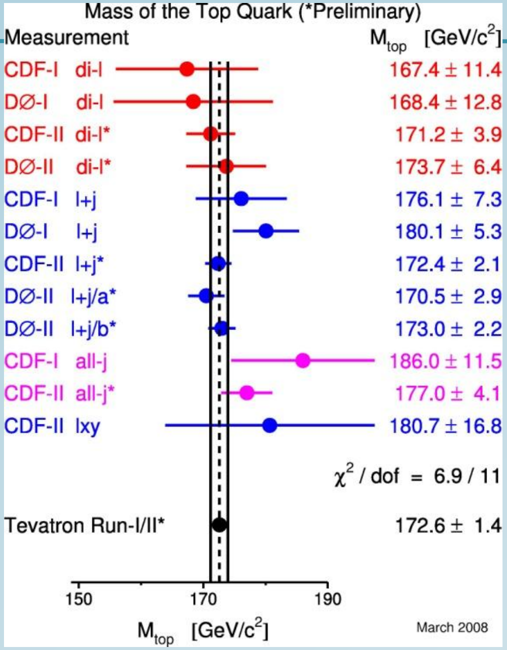

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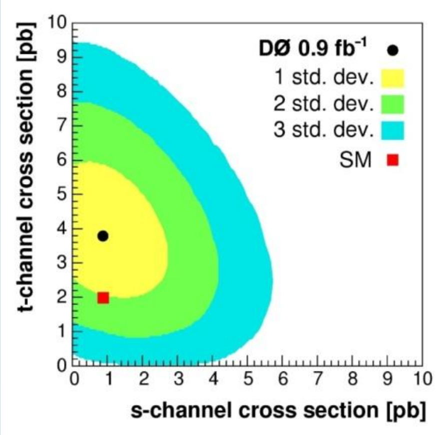
Single top evidence



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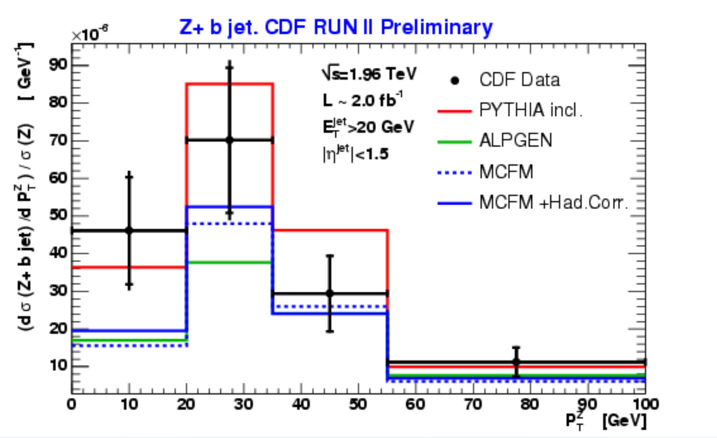
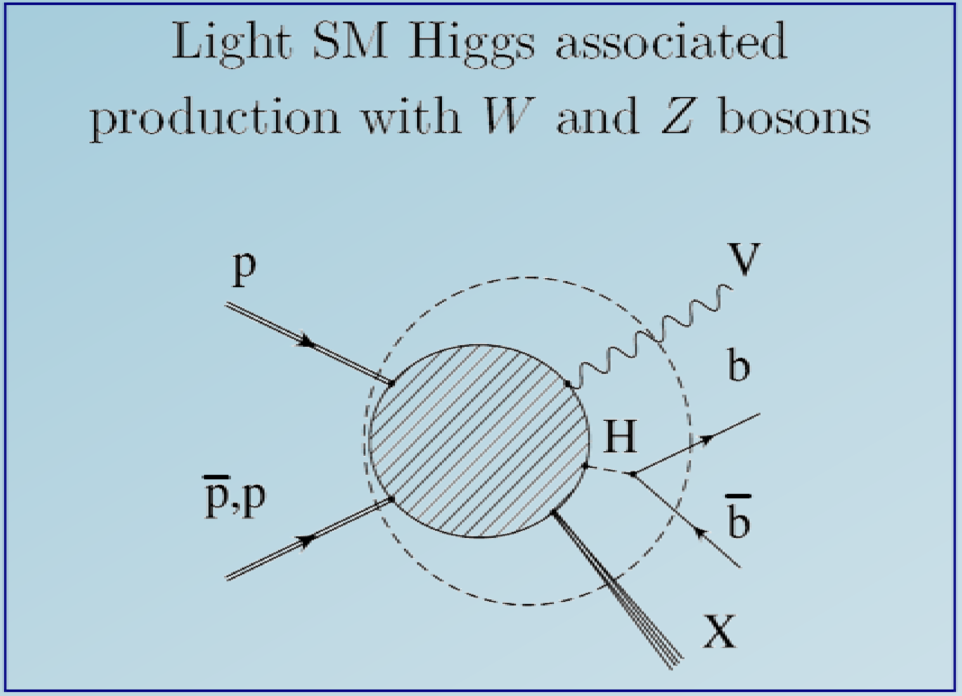
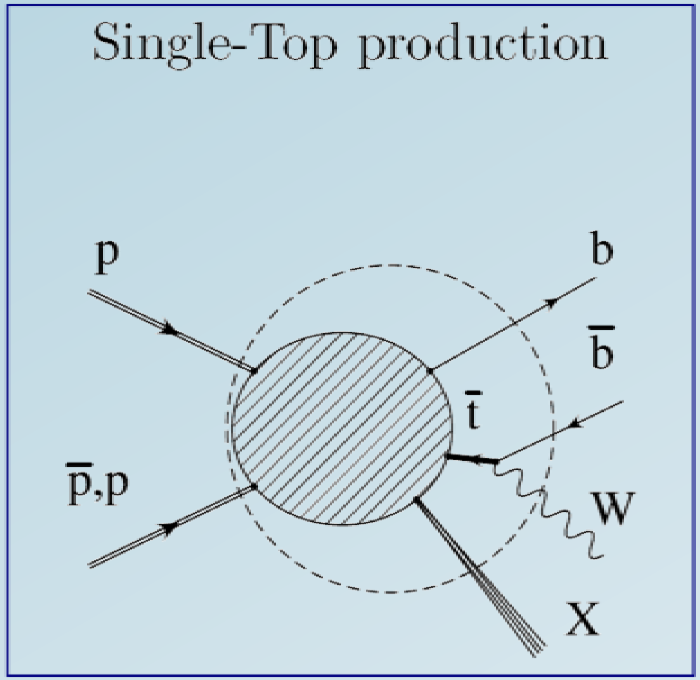


Introduction

QCD CORRECTIONS TO WEAK BOSONS AND B-JETS





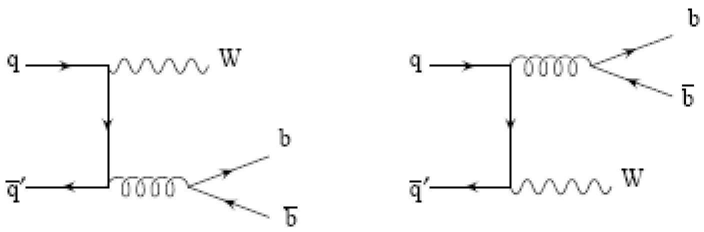
Introduction

QCD corrections to weak bosons and b-jets

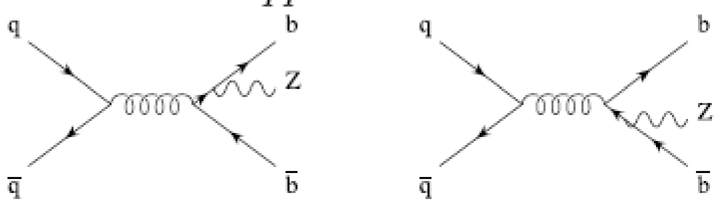
- V → 4 partons: 1-loop massless amplitudes [Bern, Dixon, Kosower,1997]
- pp → Vbb: @NLO, in the 4FS, but with m_b=0 [Campbell, Ellis,1999]
- pp → Vbj: @NLO, in the 5FS [Campbell,Ellis,Maltoni,Willenbrock, 2005,2007]
- pp → Wbb: @NLO, in the 4FS, $m_b \neq 0$ [FFC, Reina, Wackeroth,2006]
- pp → Zbb: @NLO, in the 4FS, $m_b \neq 0$ [FFC, Reina, Wackeroth,2008]
- pp → Wb: @NLO, in the 5FS [Campbell,Ellis,FFC,Maltoni,Reina,Wackeroth, Willenbrock,in progress]

NLO QCD corrections to W/Z bb

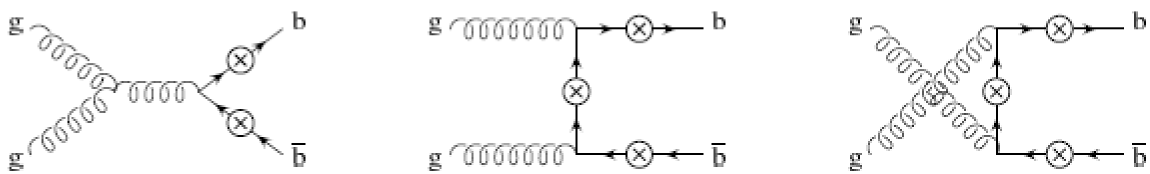
LO Feynman diagrams:



$q\bar{q}' \rightarrow W b\bar{b}$



$q\bar{q} \rightarrow Z b\bar{b}$



$gg \rightarrow Z b\bar{b}$

Subprocesses at LO:

$\longrightarrow$ $W b\bar{b}$: $q\bar{q}' \rightarrow W b\bar{b}$

$\longrightarrow$ $Z b\bar{b}$: $q\bar{q} \rightarrow Z b\bar{b}$ and

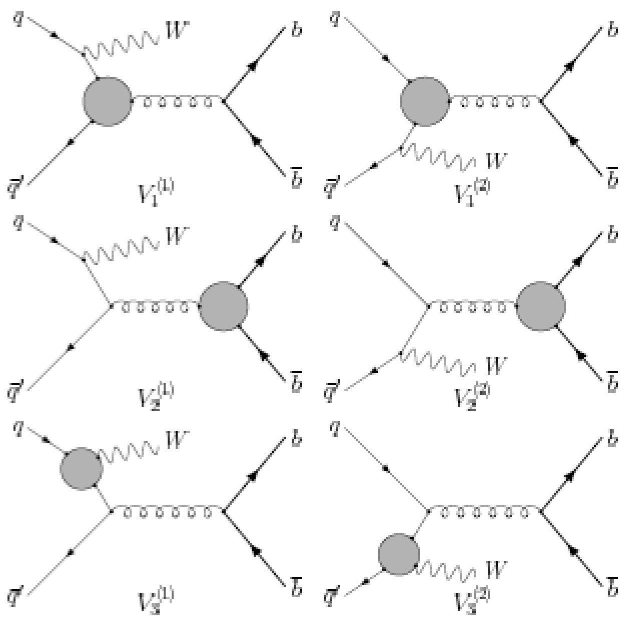
$gg \rightarrow Z b\bar{b}$

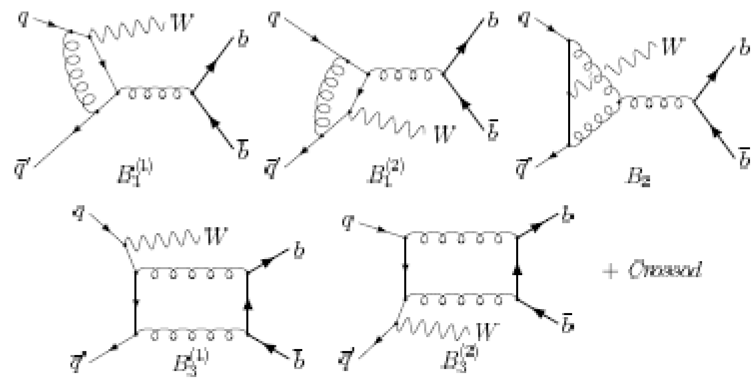
The Calculation

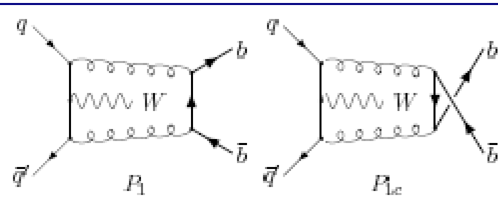
NLO QCD corrections to W/Z bb

Virtual corrections: calculating $\hat{\sigma}_{ij}^{\text{virt}}$

Some of the $Wb\bar{b}$ Diagrams





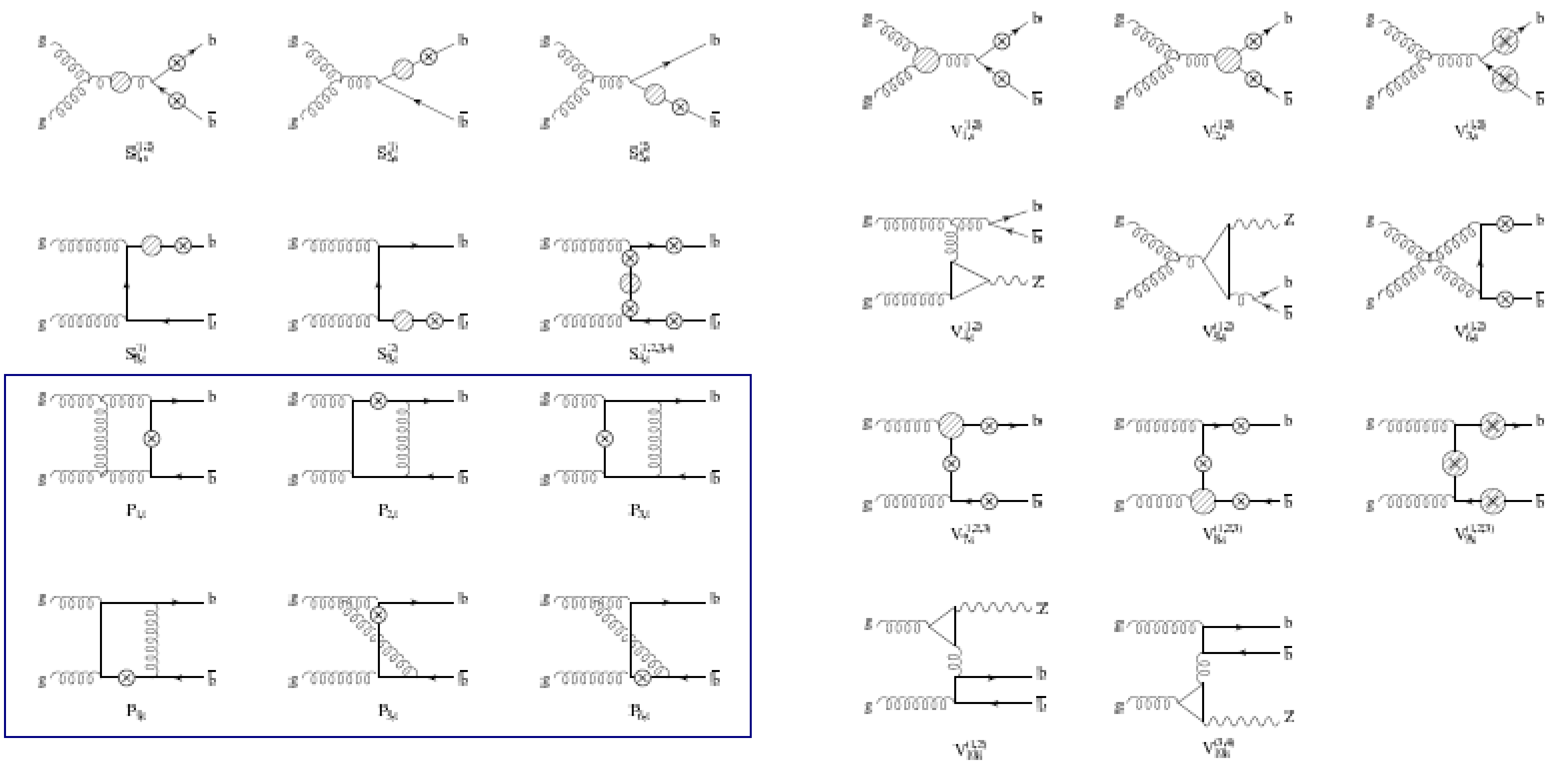


⟶ Counting: 2 diagrams at LO - ∼30 at NLO - 2 pentagons

NLO QCD corrections to W/Z bb

Virtual corrections: calculating $\hat{\sigma}_{ij}^{\text{virt}}$

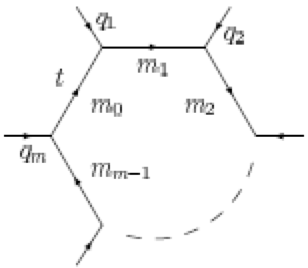
Some of the $gg \to Zb\bar{b}$ Diagrams



$\longrightarrow$ Counting: 8 diagrams at LO - $\sim$100 at NLO - 12 pentagons

NLO QCD corrections to W/Z bb

Virtual corrections: calculating $\hat{\sigma}_{ij}^{\text{virt}}$ - The Integrals



$$In^{\{0,\mu_1\ldots\mu_n\}}(q_1,\ldots,q_{m-1},m_0,\ldots,m_{m-1}) =$$
$$\int \frac{d^dt}{(2\pi)^d}\frac{\{1,t^{\mu_1}\cdots t^{\mu_n}\}}{[t^2-m_0^2][(t+q_1)^2-m_1^2]\cdots[(t+q_1+\cdots+q_{m-1})^2-m_{m-1}^2]}\,.$$

$\longrightarrow$ Tensor integrals reduced using the Passarino-Veltman (PV) method

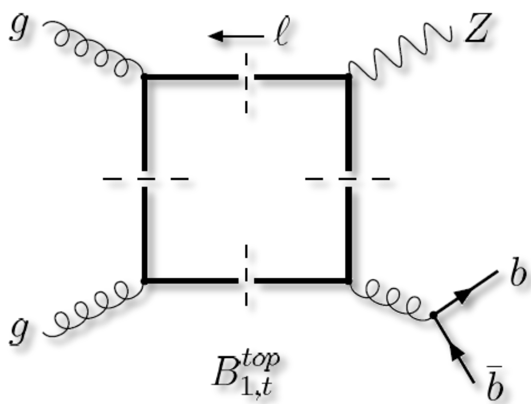
$\longrightarrow$ Intermediate spurious divergencies — appearance of inverse powers of GDs

NLO QCD corrections to W/Z bb

One Check: Comparing to Generalized Unitarity Methods

[Bern,Dixon,Kosower]

[Britto,Cachazo,Feng]



•*Extract box contributions using BCF ansatz and compare to coefficient of corresponding box in our calculation*

$$d_{1234} = \sum_{t=\ell_{\mp}} \left(t^2 - m_t^2\right)\left((t+p_1)^2 - m_t^2\right)\left((t+p_1+p_2)^2 - m_t^2\right)\left((t+p_Z)^2 - m_t^2\right) B^{top}_{1,t}\Big|_t$$

•*Playground for one-loop unitarity techniques including (up to 2) massive fermions lines*

NLO QCD corrections to W/Z bb

Real corrections: calculating $\hat{\sigma}_{ij}^{\text{real}}$ - PSS δ_s and δ_c cuts

[Bergmann,Harris,Owens]

1. Soft cut for extra parton: $E_g \leq \delta_s \sqrt{s}/2$ defines:

$$\hat{\sigma}^{\text{real}} = \hat{\sigma}^{soft} + \hat{\sigma}^{hard}$$

$\hat{\sigma}^{soft}$ calculated in the soft limit $(E_g \to 0)$.

2. Collinear cut for extra parton: $(1-\cos\theta) < \delta_c$ defines:

$$\hat{\sigma}^{hard} = \hat{\sigma}^{hard/coll} + \hat{\sigma}^{hard/non-coll}$$

$\hat{\sigma}^{hard/coll}$ calculated in the collinear limit $(\theta \to 0)$.

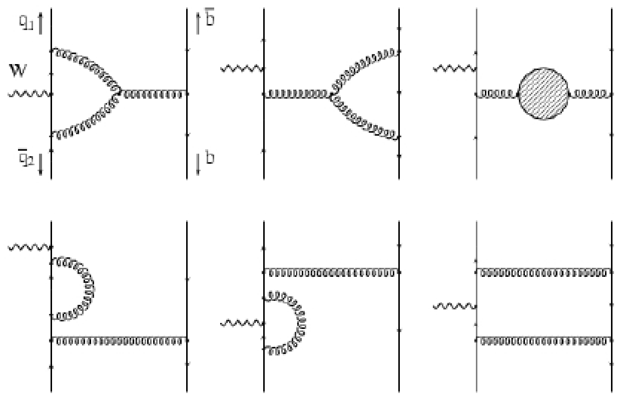
The Calculation

NLO QCD corrections to W/Z bb

$\mathcal{O}(\alpha_s)$ corrections: combining virtual and real pieces

Virtual

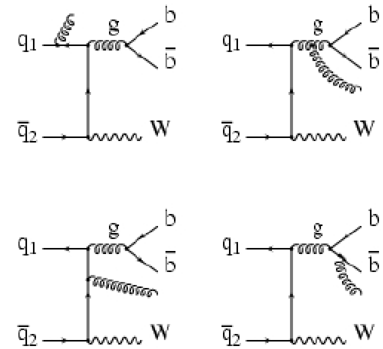
Sample of loop diagrams:



in $\overline{MS}$ renormalization scheme

Real

Sample of diagrams with extra parton:



PSS used to extract IR divergencies

- $\longrightarrow$ After renormalization, $\hat{\sigma}^{\rm virt}$ is UV finite
- $\longrightarrow$ IR-divergencies of $\hat{\sigma}^{\rm virt}$ canceled by IR-divergencies of $\hat{\sigma}^{\rm real}$
- $\longrightarrow$ Remaining IR-divergencies reabsorbed into PDFs
- $\longrightarrow$ Final Hadronic cross section is finite

Z bb @ the Tevatron

Summary of LO and NLO Zbb total cross sections, for both massive and massless

Cross Section	$m_b \neq 0$ (pb) [ratio]	$m_b = 0$ (pb) [ratio]
σ^{LO}	2.21 [-]	2.37 [-]
σ^{NLO} inclusive	3.39 [1.53]	3.64 [1.54]
σ^{NLO} exclusive	2.80 [1.23]	3.01 [1.24]

cuts: $p_t > 15$ GeV

$|\eta| < 2$

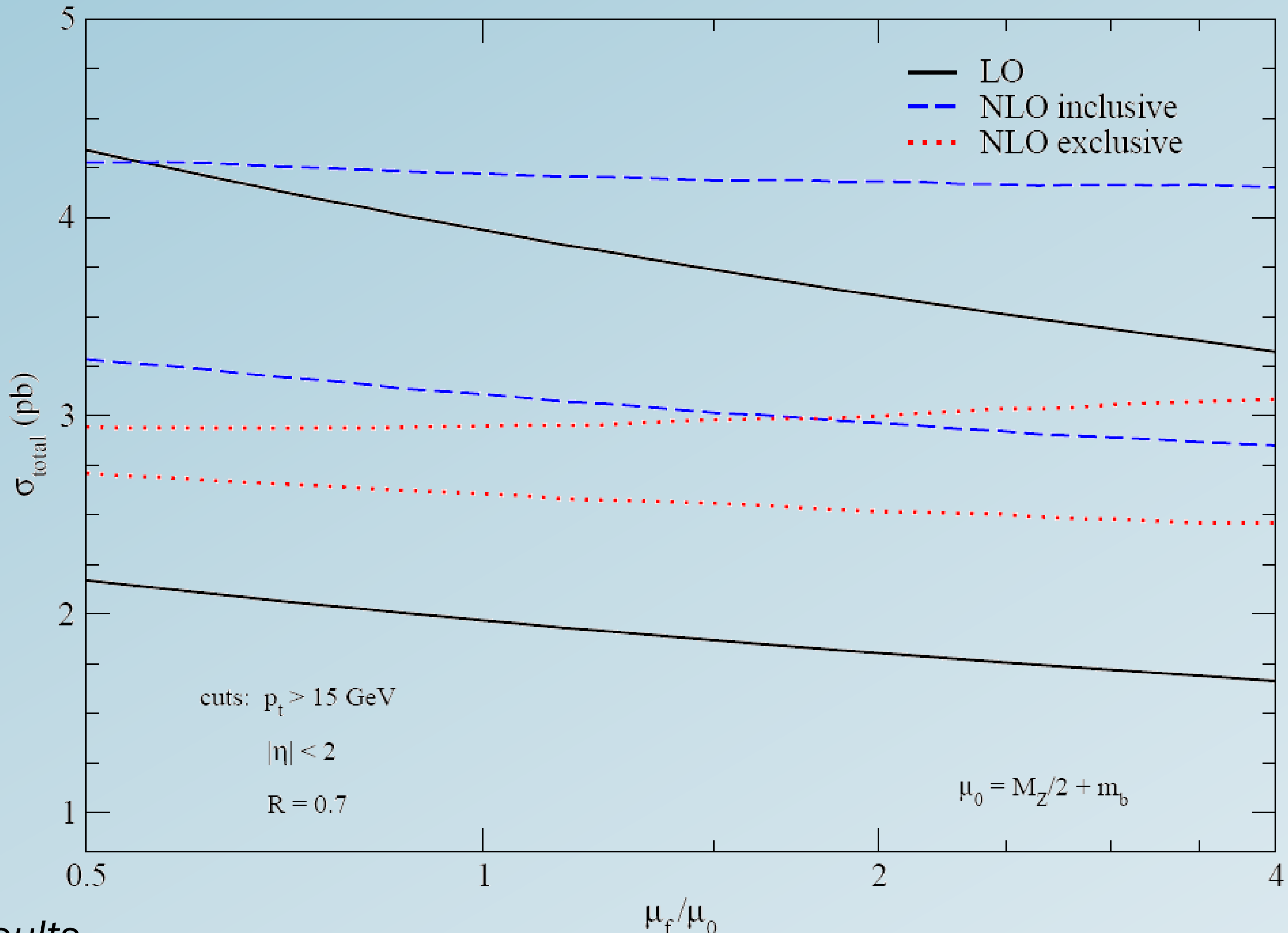
$R = 0.7$

Massless results: [MCFM]

$$\mu_r = \mu_f = M_Z + 2m_b$$

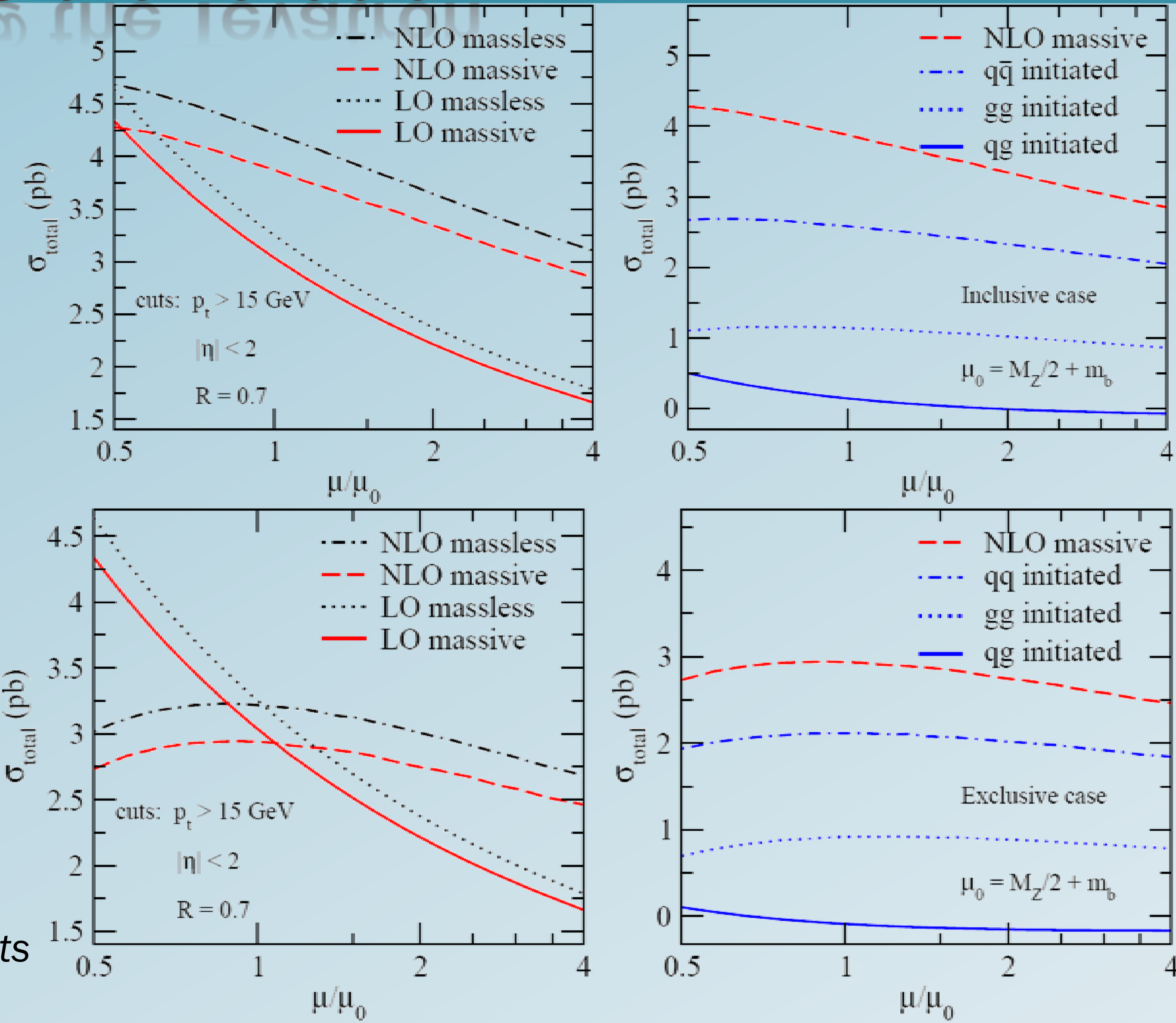
Results

Z bb @ the Tevatron



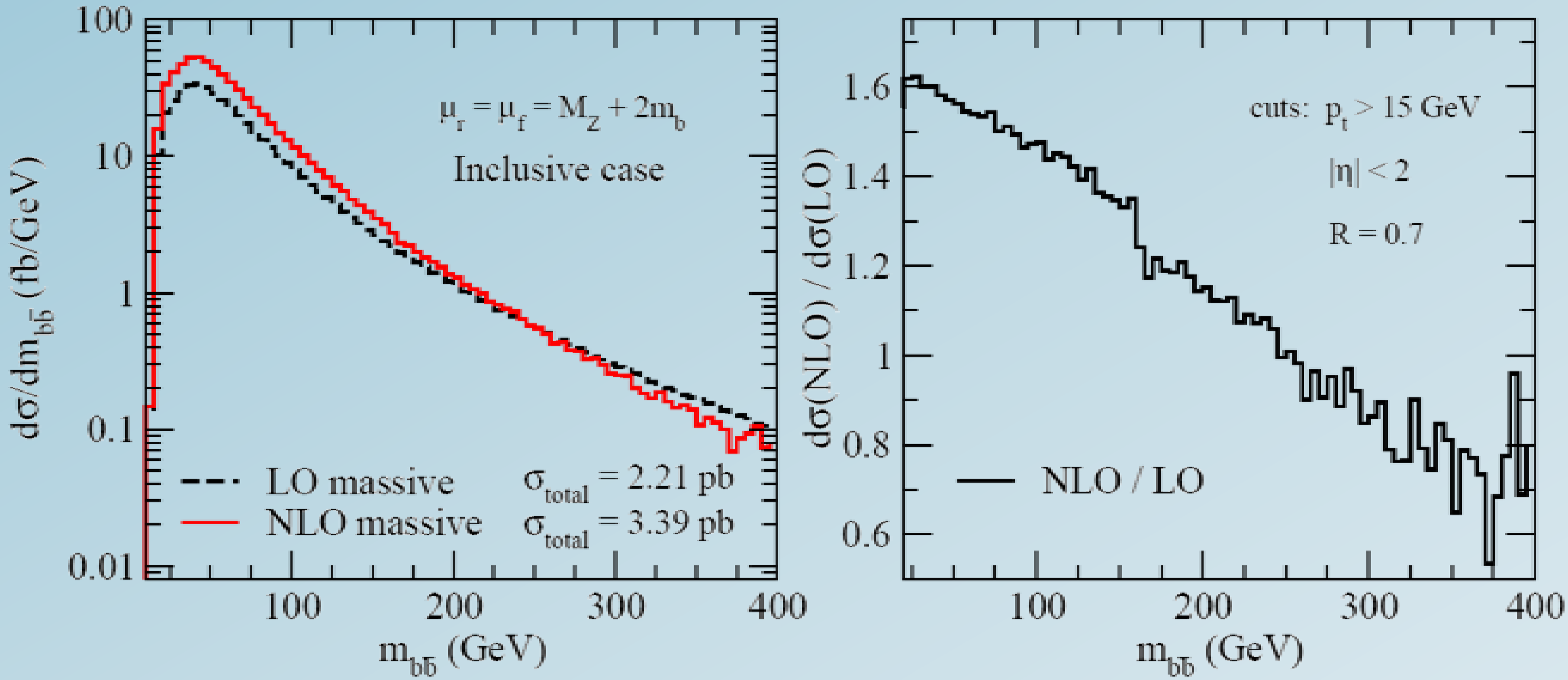
Results

Z bb @ the Tevatron



Results

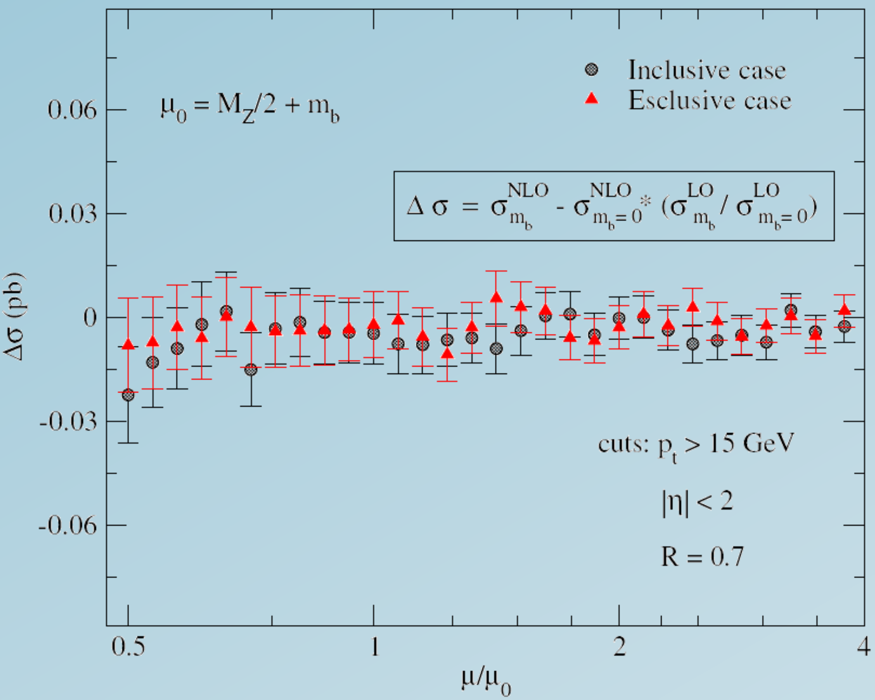
Z bb @ the Tevatron

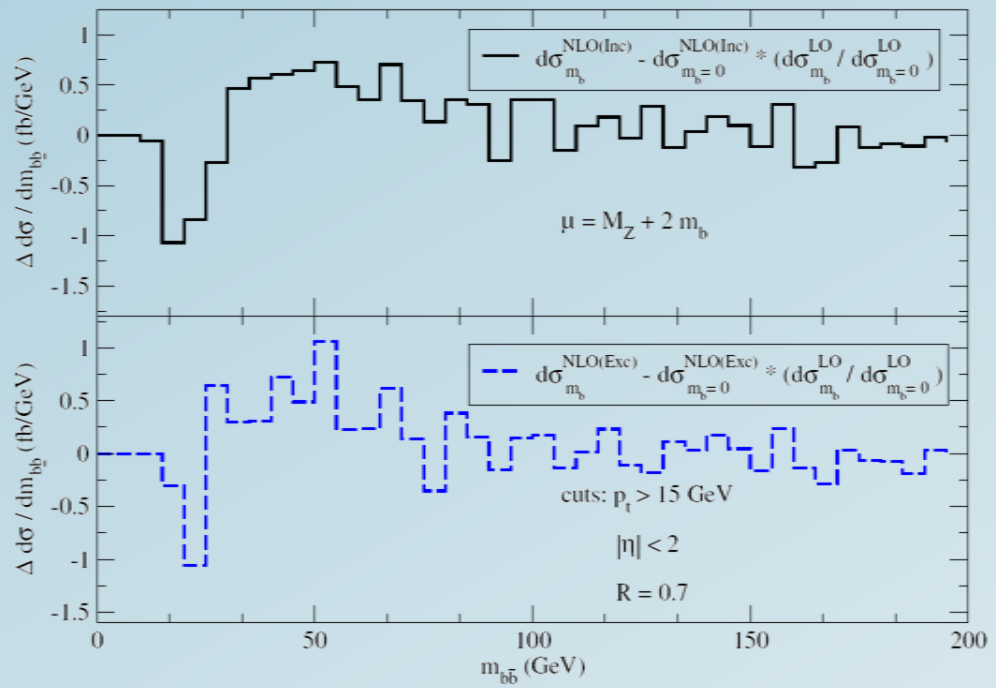


The trouble with K-factors!

Results

Z bb @ the Tevatron





...better a rescaling!

$$\Delta\sigma = \sigma^{\mathrm{NLO}}(m_b \neq 0) - \sigma^{\mathrm{NLO}}(m_b = 0)\,\frac{\sigma^{\mathrm{LO}}(m_b \neq 0)}{\sigma^{\mathrm{LO}}(m_b = 0)}$$

Results

W bb @ the Tevatron

Results

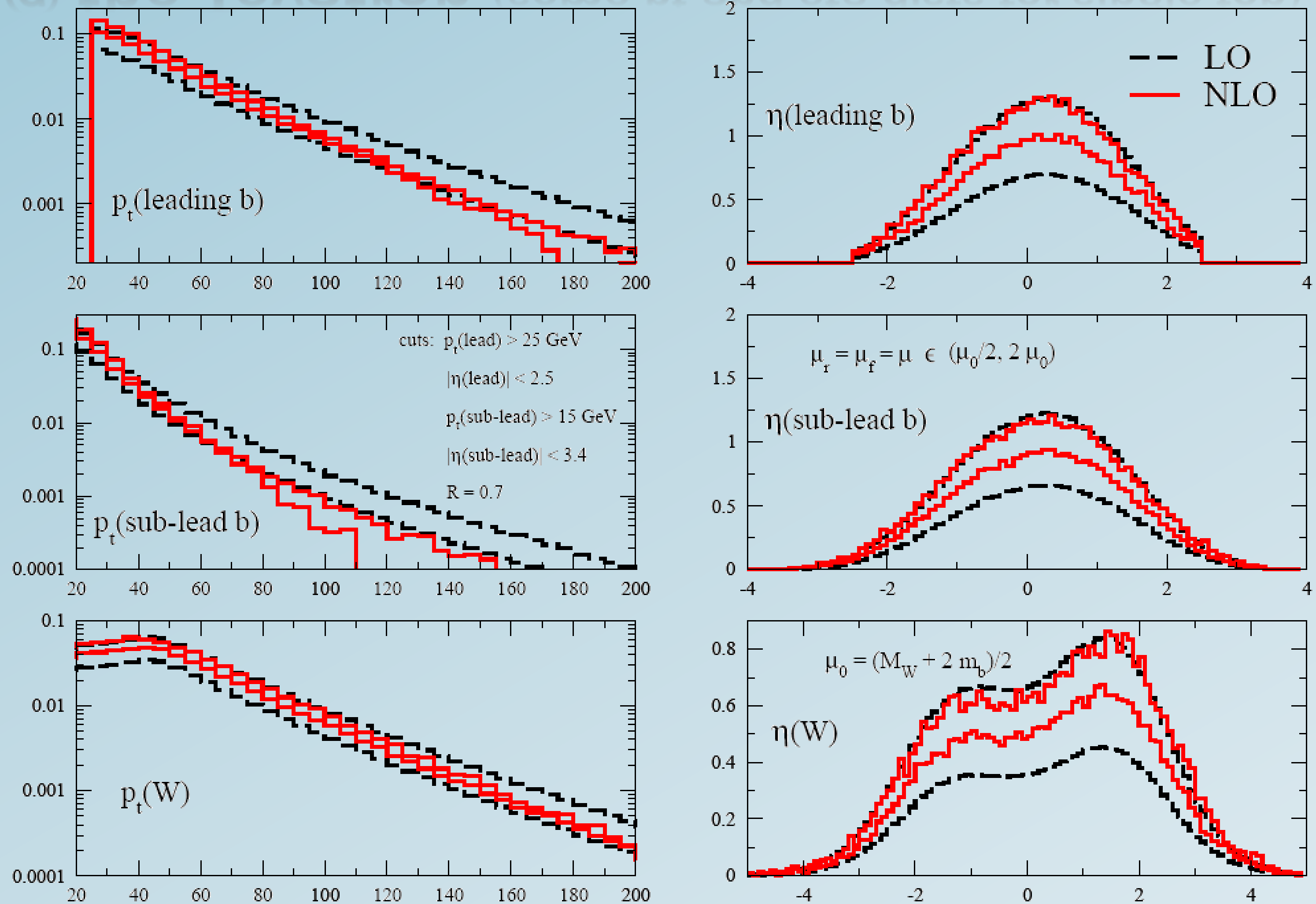
W bb @ the Tevatron

...effects similar to Zbb, so let's look some data relevant to ongoing searches at CDF and DZero:

Single top	t tbar production
cuts: $p_t(\text{lead}) > 25$ GeV	cuts: $p_t(\text{lead}) > 40$ GeV
$\lvert\eta(\text{lead})\rvert < 2.5$	$\lvert\eta(\text{lead})\rvert < 2.5$
$p_t(\text{sub-lead}) > 15$ GeV	$p_t(\text{sub-lead}) > 20$ GeV
$\lvert\eta(\text{sub-lead})\rvert < 3.4$	$\lvert\eta(\text{sub-lead})\rvert < 3.4$
$R = 0.7$	$R = 0.7$
LO: 2.78 pb	LO: 1.30 pb
NLO: 3.34 pb	NLO: 1.37 pb

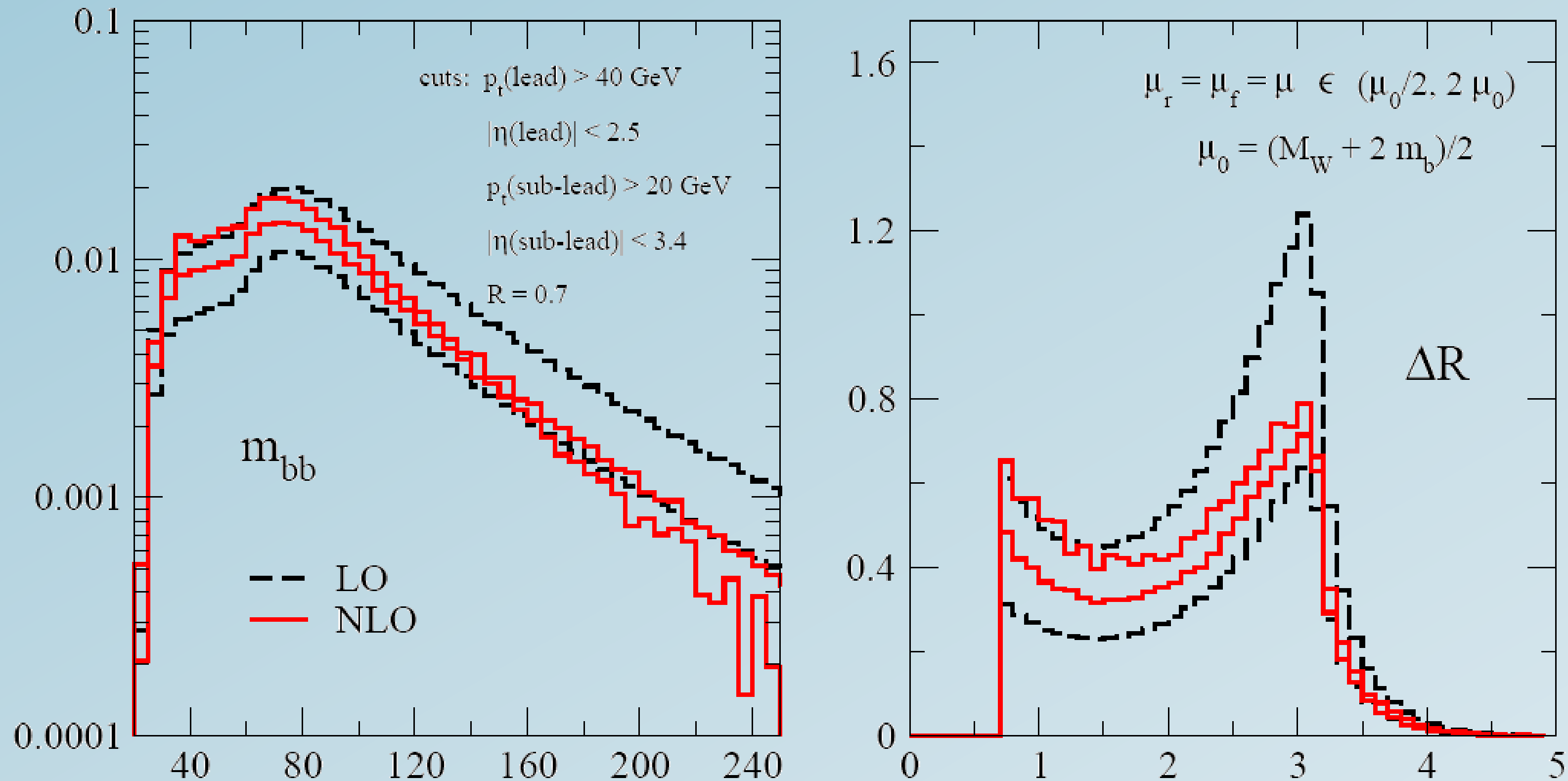
Results

W bb @ the Tevatron (some pt and eta dists for single top)



Results

W bb @ the Tevatron (some mbb and Delta_R dists for t tbar)



Results

W b + X: *divide et impera*

W bb (FF)	W bj (VF)
$q\bar{q}' \to W b\bar{b}$	$bq \to W bq'$
$q\bar{q}' \to W b\bar{b}g$	$bq \to W bq'g$
	$bg \to W bq'\bar{q}$
$gq \to W b\bar{b}q'$	$gq \to W b\bar{b}q'$
[FFC,Reina,Wackeroth]	[Campbell,Ellis,Maltoni,Willenbrock]

W b+X & W(bb) + X @ NLO (VF)

Results

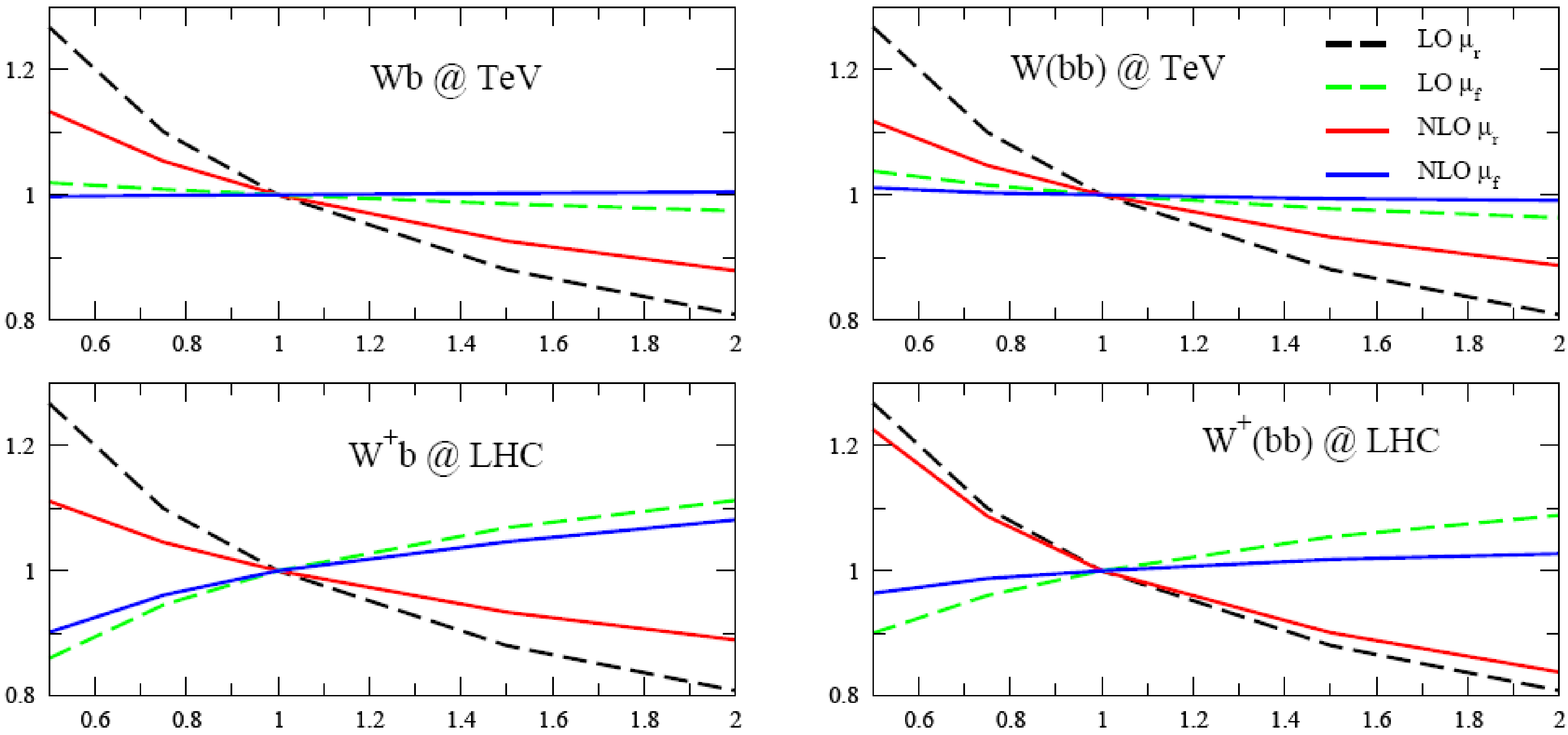
IN PROGRESS

W b @ Tevatron & LHC: *—PRELIMINARY—*

	Exclusive cross sections (pb)	
Collider	Wb	$W(b\bar{b})$
TeV $W^+(=W^-)$	(5.27+0.75=6.02) 8.03+1.27=9.30	(2.66) 3.73-0.02=3.71
LHC W^+	(30.1+54.3=84.4) 40.0+94.7=134.7	(17.6) 22.7+11.7=34.4
LHC W^-	(21.6+31.4=53.0) 29.8+56.9=86.7	(12.9) 17.2+6.5=23.7

Results

W b @ Tevatron & LHC: —*PRELIMINARY*—



Results

SUMMARY and OUTLOOK

W/Z bb @ NLO

- We observe considerably reduction of scale dependence
- Corrections are sizable, and with non-trivial rescaling factor

Wb & W(bb) @ NLO

- Presented preliminary results
- Corrections are quite considerable
- We observe scale dependence improvement
- Tevatron – LHC qualitative difference

Future work

- Zb
- Impact on b-pdf studies
- Gamma b bbar, t<->b
- Playground for Unitarity techniques with a massive fermion line