Update on $b\bar{b} \to Z$

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work in collaboration with
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Higgs Working Group @ TEV4LHC, BNL, Febraury 2005

Outline

- Motivations
- Status of the calculation and applications to the TeV and LHC
- Open question: the experimental side

Motivations

#1 : Higgs production in association with b-quarks

#2 : Understanding QCD backgrounds Z+b's

#3 : "Measure" the b-pdf

Motivations

#1 : Higgs production in association with b-quarks

- important theoretical progress in the last years

- different ways of performing calculations give compatible results => confidence in our predictions

- Z+b's is similar to Higgs+b's : same inputs and uncertaintes. We can use the Z to test our theoretical and experimental tools.

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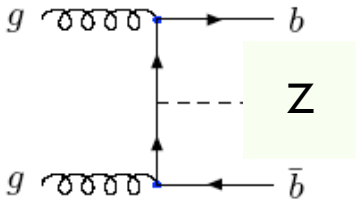
Z boson production with bottom quarks

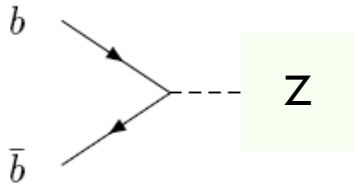
One way:



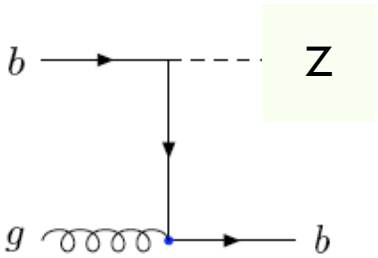
Keep the b massive and use the gg process for all three studies. The b mass acts as an infrared cutoff and there are no divergences. This is the 4 Flavour Scheme (4FS)

or the other:

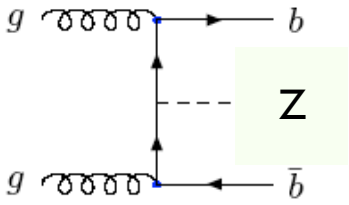
The "leading-order process" depends on how INCLUSIVE is the measurement to be performed:



"FULLY INCLUSIVE b"



1 b at high p_T



2 b's at high p_T

In so doing the large logs $\alpha_S \ln\left(\frac{m_h^2}{m_b^2}\right)$ are resummed into the b distribution function $b(x, m_h^2)$

This is the 5 flavour scheme.

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Z+b: available calculations

- pp>Zbb~ @ NLO, in the 4f scheme, but with massless b's (Campbell & Ellis) $\Rightarrow$ Suitable to describe Z+2jets events with 2 b-tags.
- pp>Z+1 b-jet @ NLO in the 5FS (Campbell, Ellis, FM, Willenbrock) $\Rightarrow$ Suitable to describe Z+1jet events with 1 b-tag.

We do not have NLO calculations for Z+2jets with one b-tag and Z+inclusive b in the 4f scheme.

Purpose of our study is the calculation of Z+b's in the 5f scheme up to order NNLO.

Motivations

#1 : Higgs production in association with b-quarks

#2 : Understanding QCD backgrounds Z+b's

#3 : "Measure" the b-pdf

Some examples of b-initiated processes

Process	Interest	Accuracy
single-top t-channel	SM, top EW couplings and polarization, V_{tb}. Anomalous couplings.	NLO
single-top + W		NLO
Wbj	SM, bkg to single top	(NLO)
gamma+b	SM, SUSY bkg, b-pdf	NLO
Z+b		NLO
inclusive h,A	SUSY discovery/ measurements at large tan(beta)	NNLO
(h,A)+b		NLO
H + t	SUSY discovery, couplings	NLO

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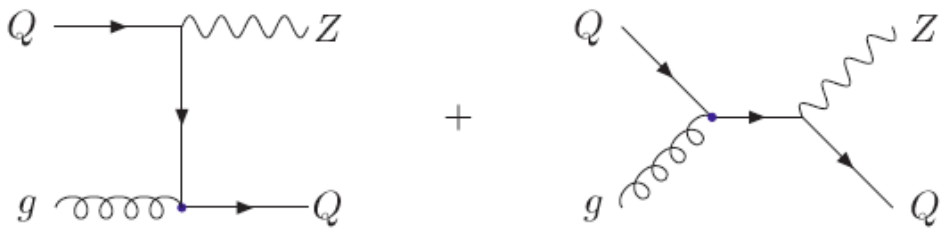
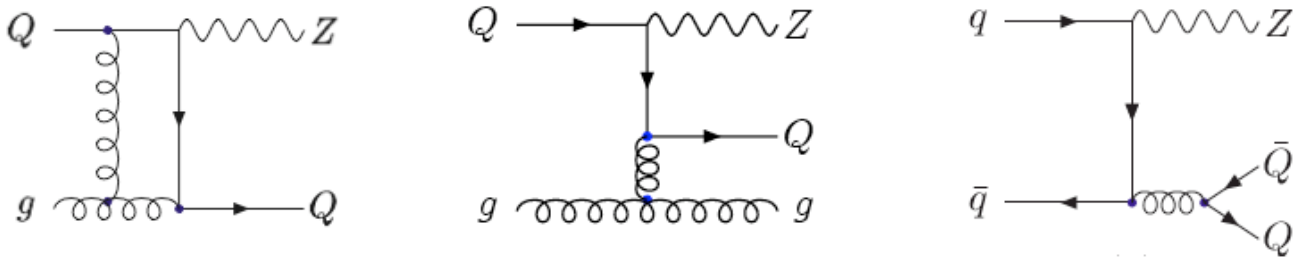
Z + heavy quark at high-pt

Leading order:



Next-to-leading order :



The $q\bar{q}$ contributions are large (50% of gb) at the Tevatron due to the parton lumonisity, but very small the LHC⇒ smaller uncertainty at the LHC.

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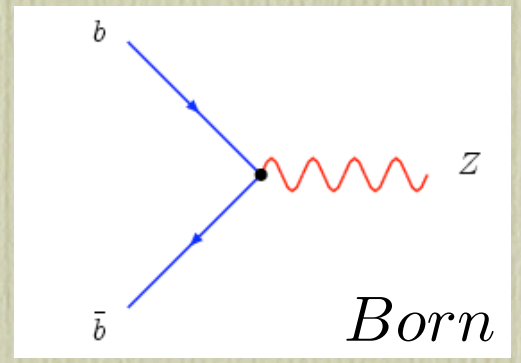
Zb at NLO: LHC

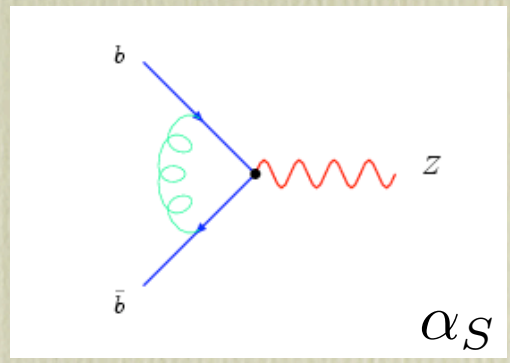
Cross sections (pb)	LHC
	ZQ inclusive
$gb \to Zb$	$1040\ ^{+70\ +70\ \ +30}_{-60\ -100\ -50}$
$q\bar{q} \to Zb\bar{b}$	49.2
$gc \to Zc$	$1390 \pm 100^{+60\ +40}_{-70\ -80}$
$q\bar{q} \to Zc\bar{c}$	89.7
	Zj inclusive
$q\bar{q} \to Zg, gq \to Zq$	$15870\ ^{+900\ +60\ \ +300}_{-600\ -300\ -500}$

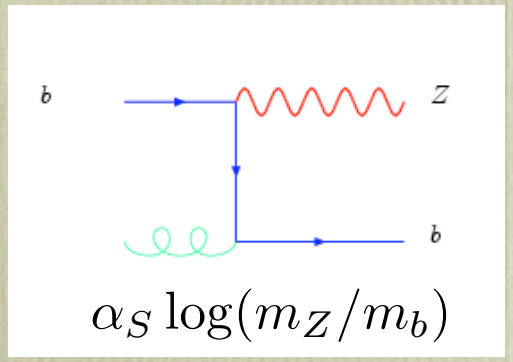
- ☞ Large cross section ⇒ differential measurements (ie rapidity)
- ☞ Small qq contamination
- ☞ Background "only" factor of 15 larger

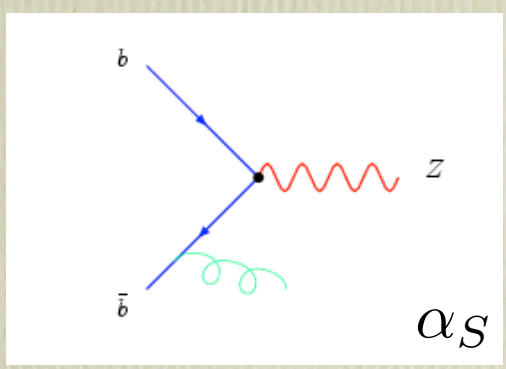
"Measure" the b-pdf:
feasibility study in progress at the HERA-LHC workshop

$b\bar{b} \to Z$ at NLO

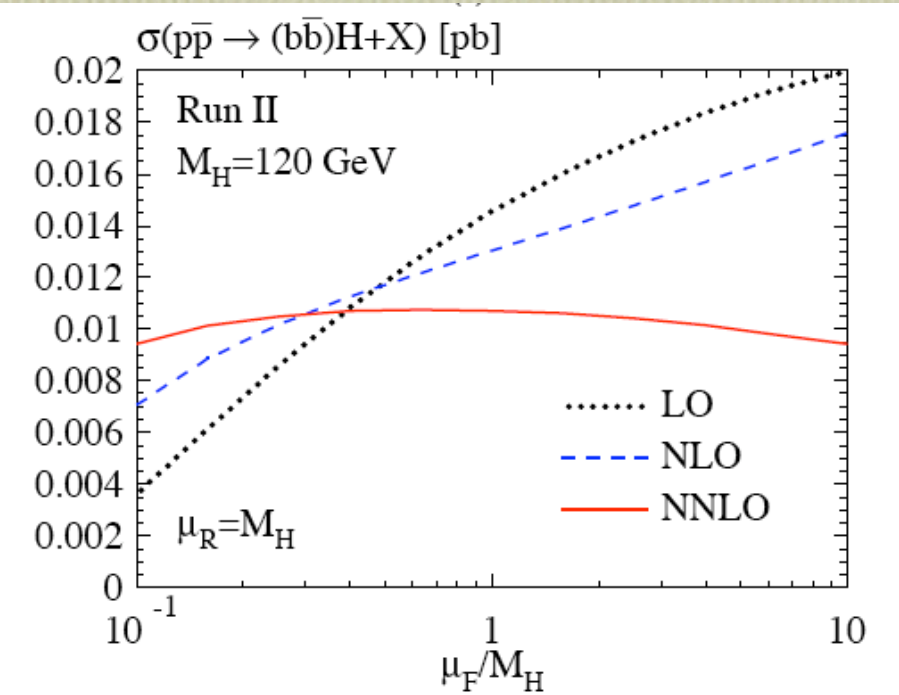








The lesson from $b\bar{b} \rightarrow h$

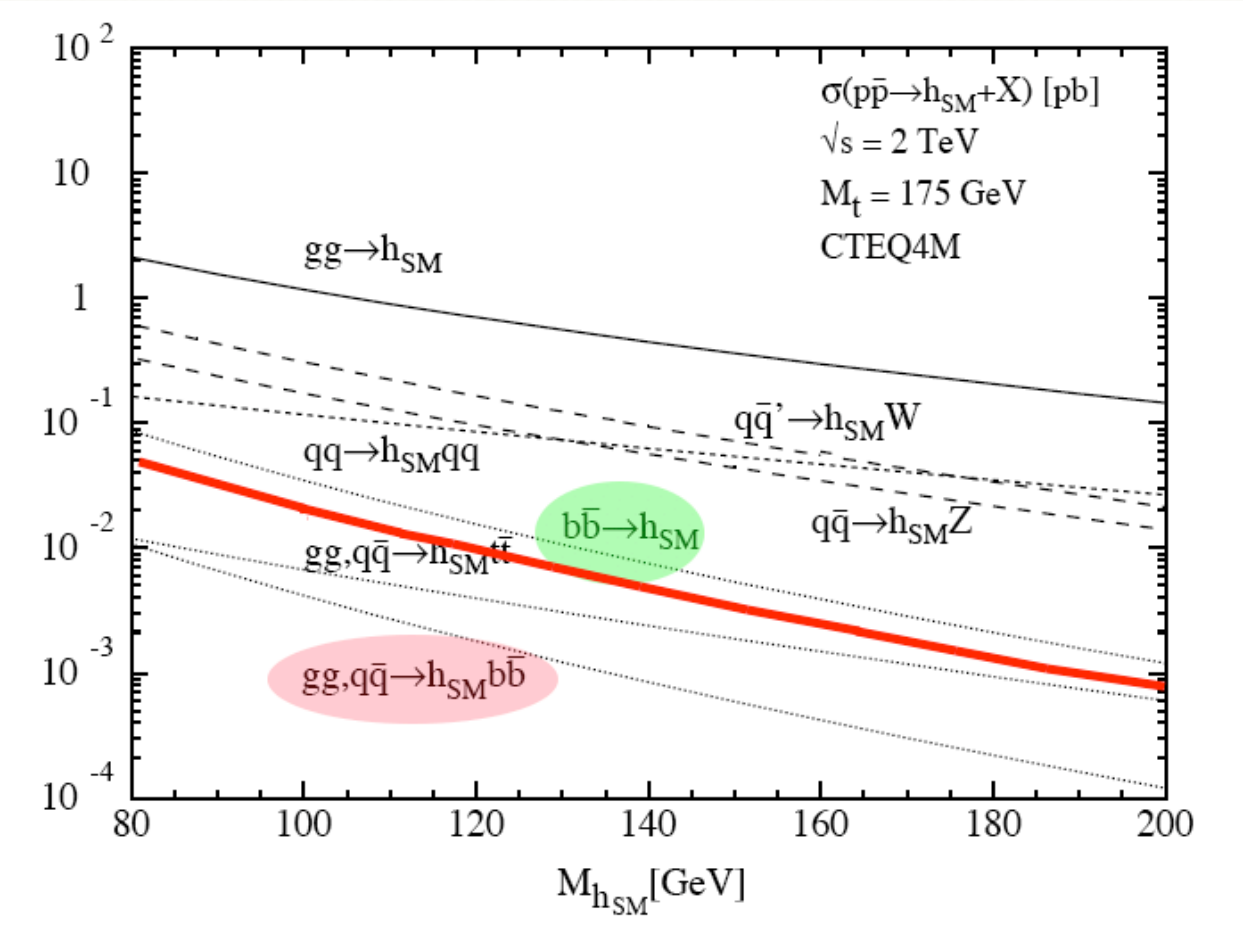


Kilgore & Harlander, 2003

By studying the extension of the collinear plateaux, a preferred scale choice ≈ mh/4 for NLO calculation was determined. (F.M., Sullivan, Willenbrock, 2003)

NNLO calculation confirmed that result.

Theoretical status: 1998 to 2004



Higgs Tevatron Workshop 1998

Inclusion of NLO corrections in the 4f calculation and use of an appropriate scale in both calculations lead to a substantial agreement.

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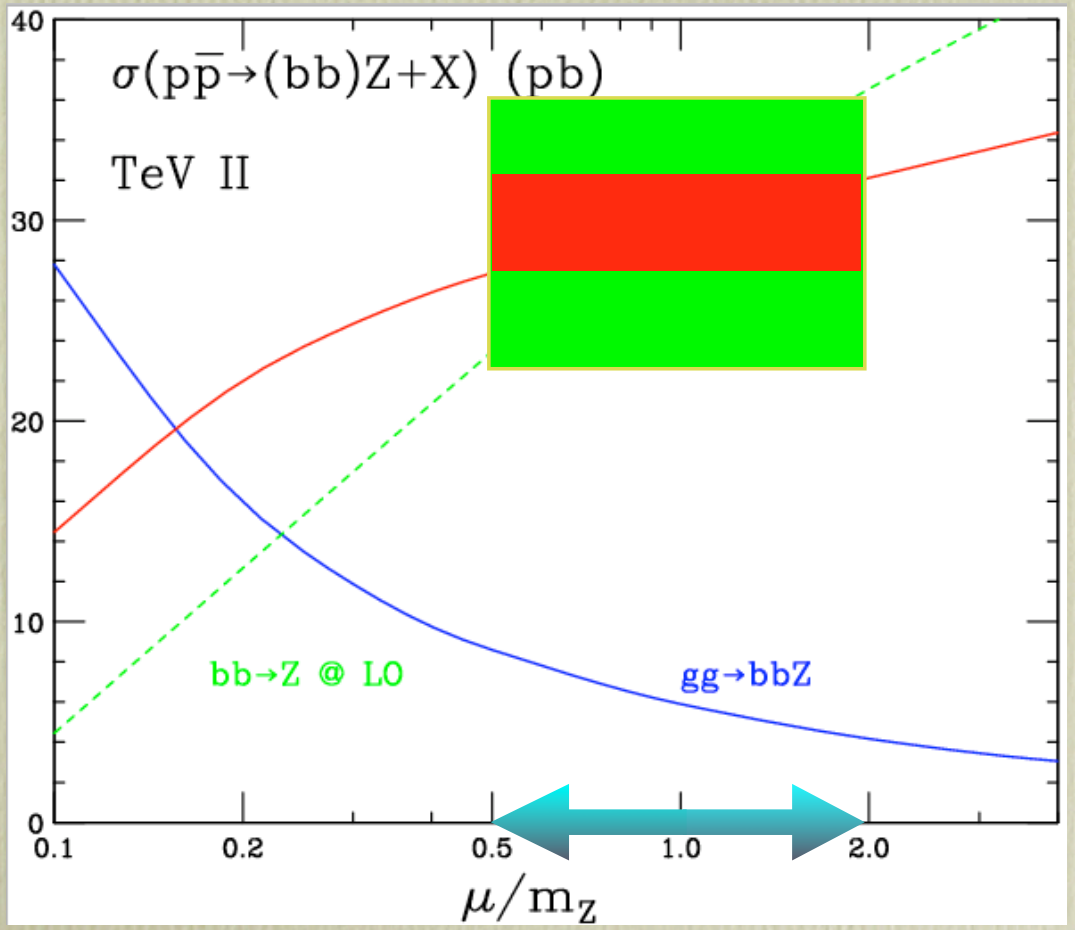
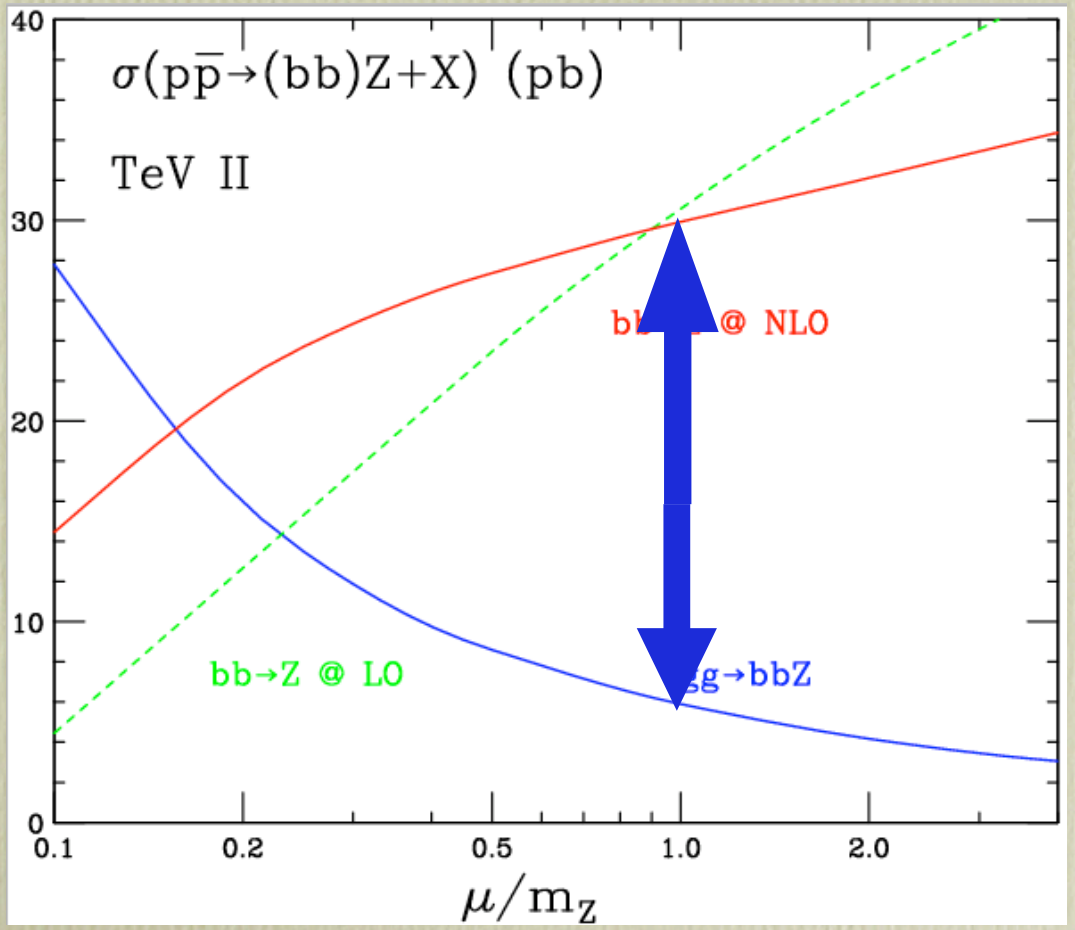
Z + b's at the Tevatron



Strong scale dependence of the LO calculation.
Substantial improvement at NLO.

Finding the best scale at NLO: work in progress

Z + b's at the Tevatron



Strong scale dependence of the LO calculation.
Substantial improvement at NLO.

Factor of 6 difference wrt the 4f calculation for mu=mz.

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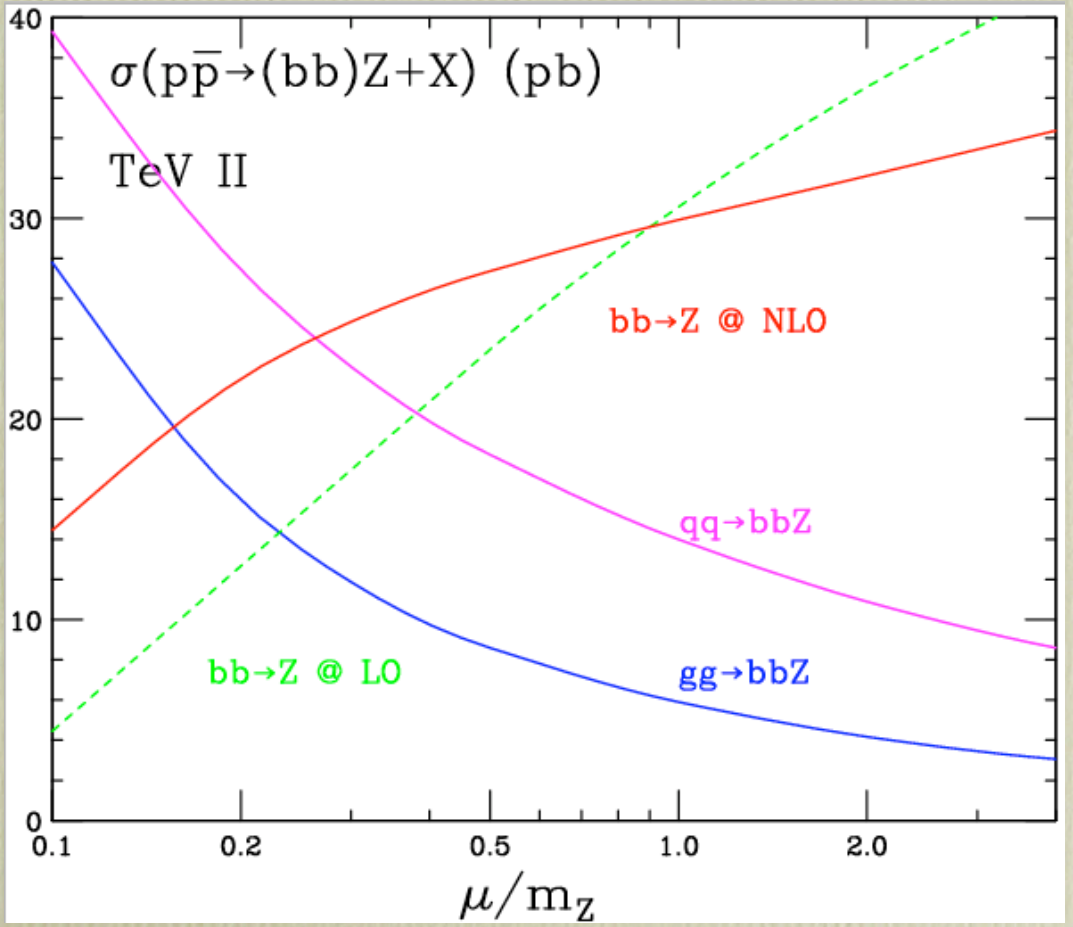
Z + b's at the Tevatron



Strong scale dependence of the LO calculation.
Substantial improvement at NLO.

Factor of 6 difference wrt the 4f calculation for mu=mz.

The qq channel is large due to valence quark pdfs. It is also very scale dependent leading to an intrinsic uncertainty even at NNLO in the 5f calculation. This term is the same as in the 4f scheme. To gain control of the normalization we'd need to know it at NLO (in the 4f scheme).

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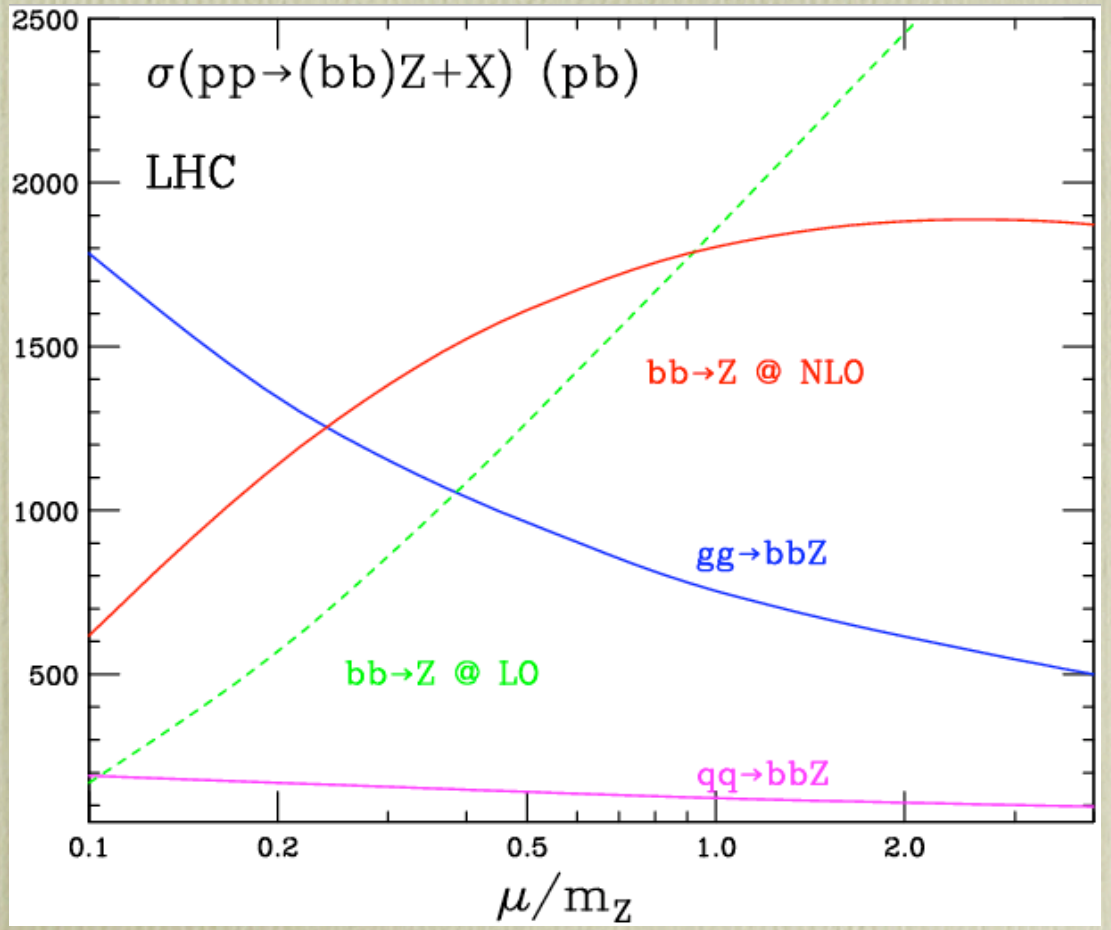
Z + b's at the LHC



Strong scale dependence of the LO calculation.
Substantial improvement at NLO.

Factor of 3 difference wrt the 4f calculation for mu=mz.

The qq channel is small. Cross section is dominated by gg. NNLO calculation in the 5FS will provide a very accurate normalization for this process.

Finding the best scale at NLO: work in progress

Cross sections (pb) for Z + "inclusive b" Summary

Process	TeV	LHC
gg > Zbb	5.9	754
bb>Z	(30.6) 30.0	(1860) 1800
qq > Zbb	14.0	122

$$\mu_F = \mu_R = m_Z$$

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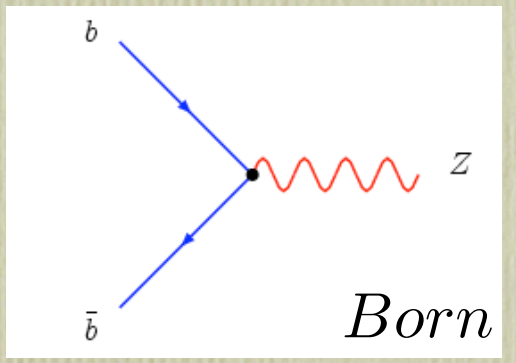
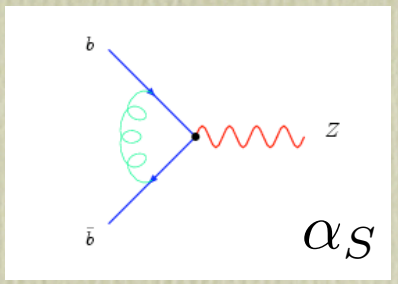
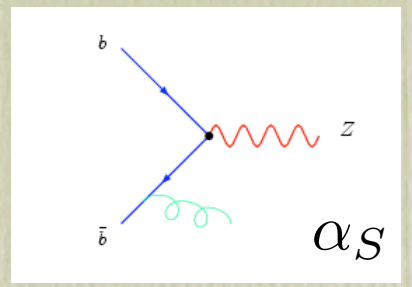
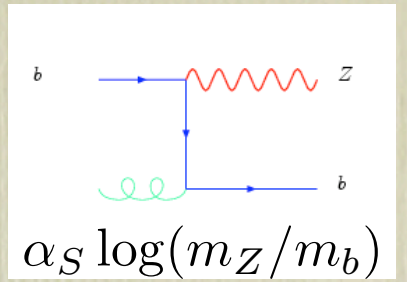
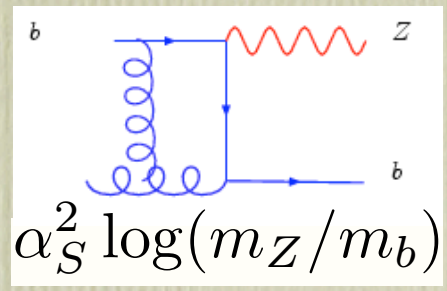
$b\bar{b} \to Z$ at NNLO

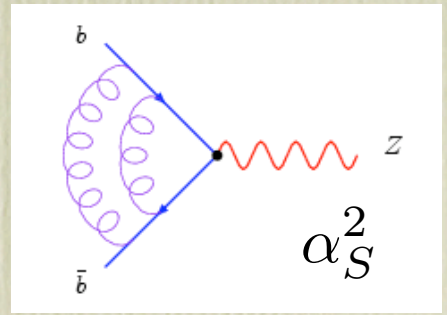


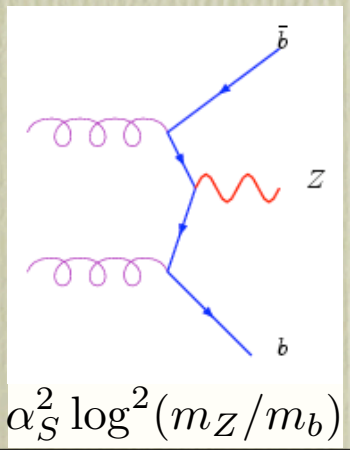


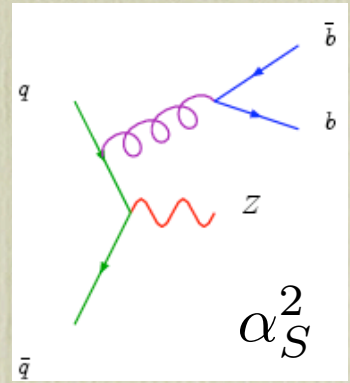


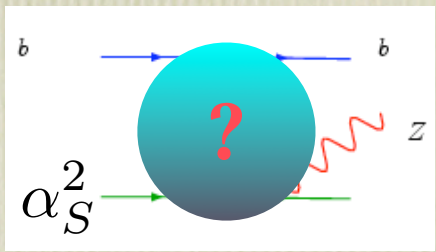












$b\bar{b} \rightarrow Z$ at NNLO

- Extraction from Drell-Yan at NNLO (Hamberg, van Neerven, & Matsuura) in progress.
- A few interesting theoretical issues, not present in bb>h production, are currently under study.
- Once ready, it would be nice to compare with the 4 flavor calculation!

Very useful theoretical exercise but...

can we turn this prediction into a measurement?

“Inclusive” b tagging

- b’s are produced mainly at low pt in bb>h
- asking for a b-tagged jet has a dramatic effect on the cross section
- experimental efficiencies on jet reconstruction give a further suppression

Inclusive approach: look only at the track displacements in the vertex detector and give to the event a probability of containing a b quark.

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Status: Experiment

- Tevatron: are there attempts to measure "inclusive b" cross sections? In DO and CDF?
- LHC: CMS has on-going studies on this. What about ATLAS?
- What is a reasonable number to expect for the efficiency/purity ratio? How important is the charm?

Proposal for the TEV4LHC

Study "inclusive" bottom measurements in W/Z production

theory: we can predict cross sections extremely well
experiment: new approach, maybe better sensitivity

theory : perform the new NLO (and NNLO) calculations for Z and W that are needed

experiment: look at what CMS has done, use CDF and DO data for Wbb and Zbb to test feasibility, find efficiencies, etc...