INCLUSIVE PRODUCTION OF HIGGS OR Z WITH HEAVY QUARKS

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work in collaboration with
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Higgs Working Group @ TEV4LHC, CERN, April 2005

OUTLINE

- Motivations
- QQ → Z at NNLO
- Outlook

Motivations

#1 : Higgs production in association with b-quarks

#2 : Understanding QCD backgrounds: Z+b's

Motivations

#1 : Higgs production in association with b-quarks

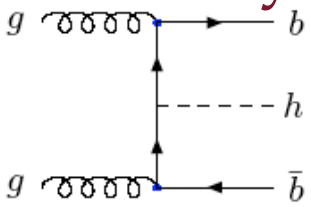
- important theoretical progress in the last years

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

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

Higgs production with bottom quarks

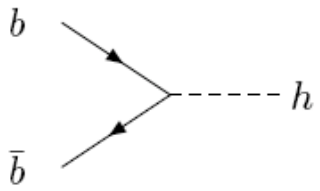
One way:



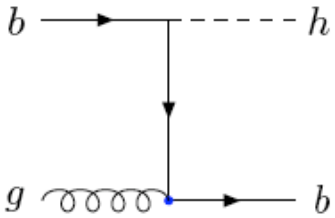
Keep the b massive and use the gg process for all three studies. The b mass acts as an infrared cutoff and there are no divergences. This is the 4 Flavor Scheme (4FS)

or the other:

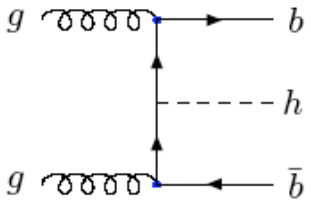
The "leading-order process" depends on how INCLUSIVE is the measurement to be performed:



FULLY INCLUSIVE



1 b at high p_T



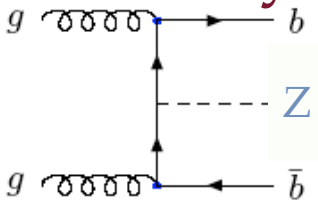
2 b's at high p_T

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 flavor scheme.

Z production with bottom quarks

One way:



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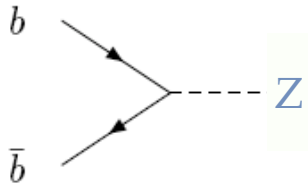
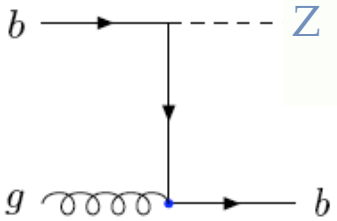


FULLY INCLUSIVE



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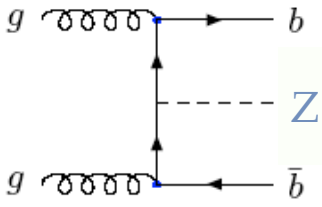
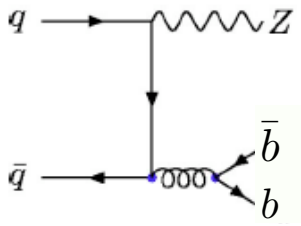




further complication

Motivations

#1 : Higgs production in association with b-quarks

#2 : Understanding QCD backgrounds: Z+b's

Z+b: Available Calculations

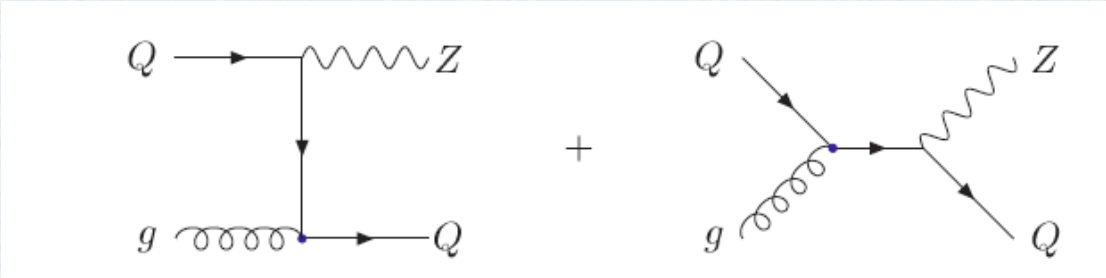
- pp→Zbb @ NLO, in the 4FS, but with mb=0, (Campbell & Ellis)
  ⇒ Suitable to describe Z+2jets events with 2 b-tags.
- pp→Z+1 b-jet @ NLO in the 5FS (Campbell, Ellis, FM, Willenbrock)
  ⇒ Suitable to describe Z+1jet events with 1 b-tag.
- pp→Z(bb) @ NNLO in the 5FS, (FM, McElmurry, Willenbrock)
  ⇒ Suitable to inclusive Z with a soft b-tag.

At present we do not have NLO predictions for:

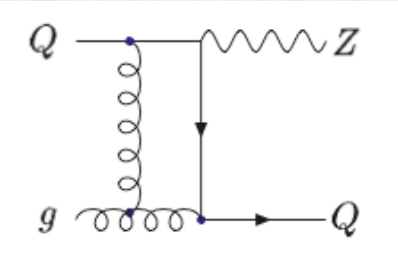
* Z+2 jets with one b-tag (neither in the 4FS nor 5FS)
* Z(bb) in the 4FS

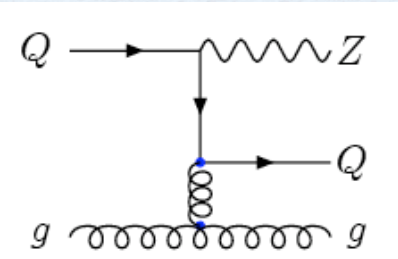
Z+ HEAVY QUARK AT HIGH PT

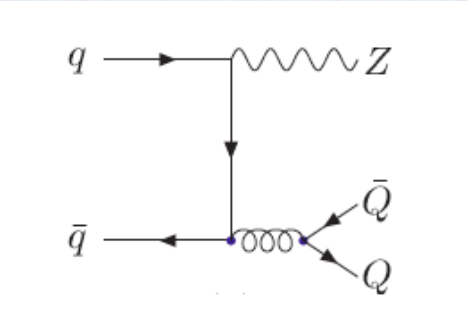
Leading order:



Next-to-leading order :

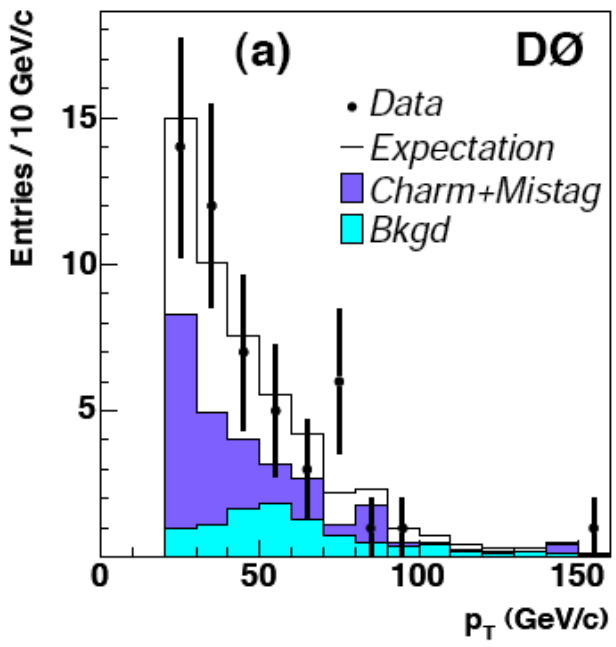


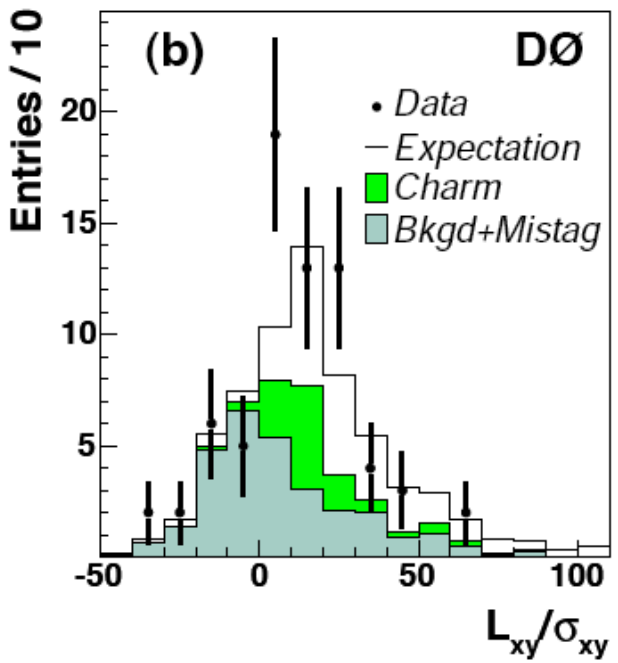




The $q\bar{q}$ contributions are large (50% of gb) at the Tevatron due to the parton luminosity, but negligible at the LHC⇒ smaller uncertainty at the LHC.

Z+1 b-jet: Tevatron





(Dated: February 10, 2005)

Using the data collected with the DØ detector at $\sqrt{s} = 1.96$ TeV, for integrated luminosities of about 180 pb^{-1}, we have measured the ratio of inclusive cross sections for $p\bar{p} \to Z + b$ jet to $p\bar{p} \to Z$+jet production. The inclusive $Z+b$-jet reaction is an important background to searches for the Higgs boson in associated ZH production at the Fermilab Tevatron collider. Our measurement is the first of its kind, and relies on the $Z \to e^+e^-$ and $Z \to \mu^+\mu^-$ modes. The combined measurement of the ratio yields 0.021 ± 0.005 for hadronic jets with transverse momenta $p_T > 20$ GeV/c and pseudorapidities $|\eta| < 2.5$, consistent with next-to-leading order predictions of the standard model.

Z+ 1 jet at NLO : LHC

Process		σ (pb) MCFM
Z+b	gb→Zb	1000
	qq→Zbb	49
Z+c	gc→Zc	1400
	qq→Zcc	90
Z+1 jet		16000

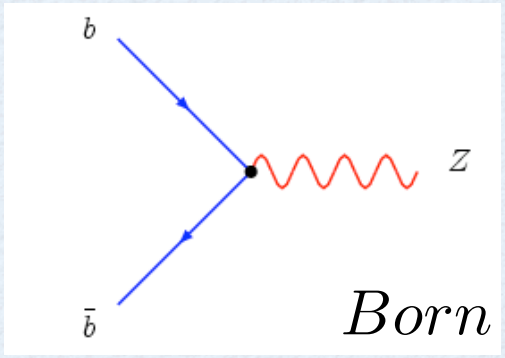
Large cross section
⇒ differential measurements (ie rapidity).

Small qq contamination.

Background "only" factor of 15 larger.

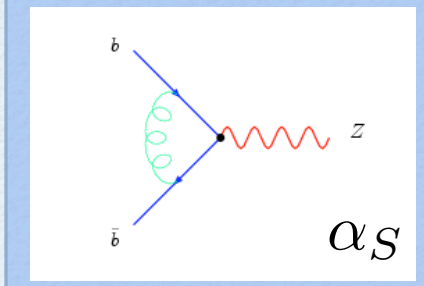
"Measure" the b-pdf:
feasibility study in progress
at the HERA-LHC workshop

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

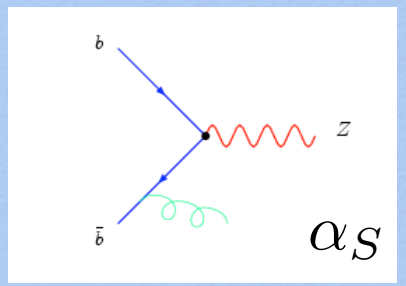


Born

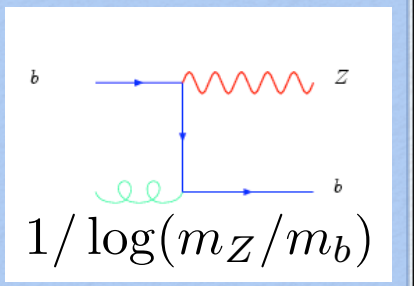
NLO



α_S

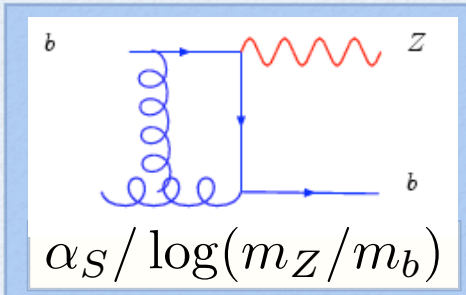


α_S

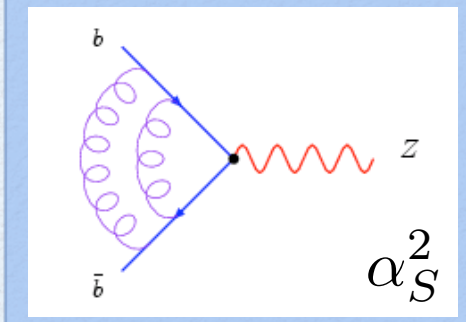


$1/\log(m_Z/m_b)$

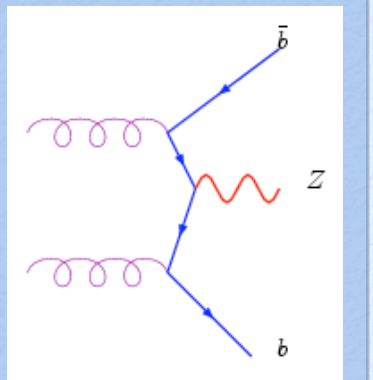
NNLO



$\alpha_S/\log(m_Z/m_b)$



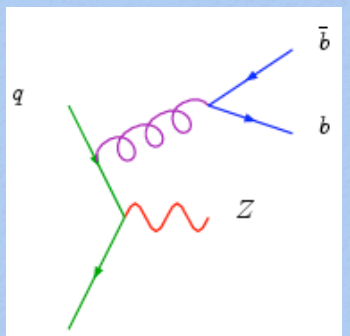
α_S^2



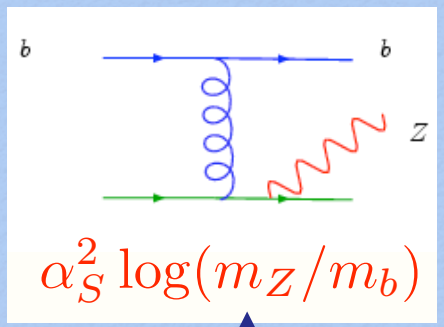
$1/\log^2(m_Z/m_b)$

Higgs-like

Light-quark



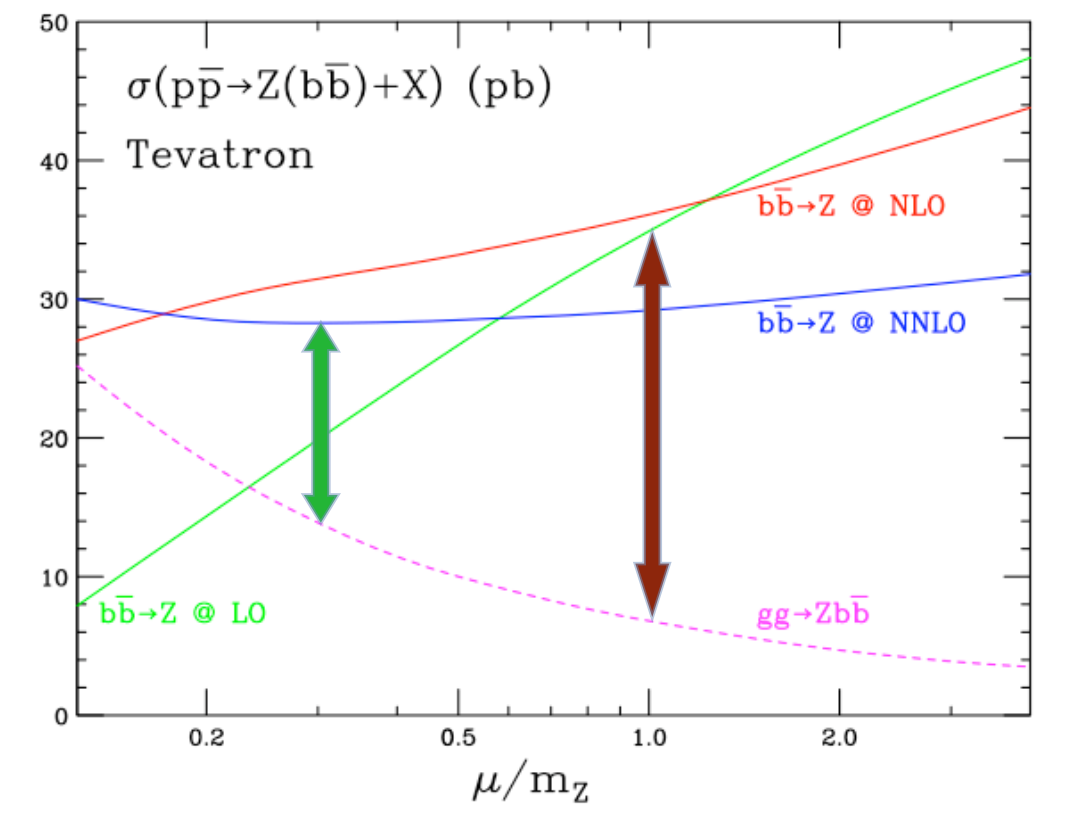
$\alpha_S^2 \log^2(m_Z/m_b)$



$\alpha_S^2 \log(m_Z/m_b)$

not resummed

Z + b's at the Tevatron



Strong scale dependence of the LO calculation. Very flat at NNLO.

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

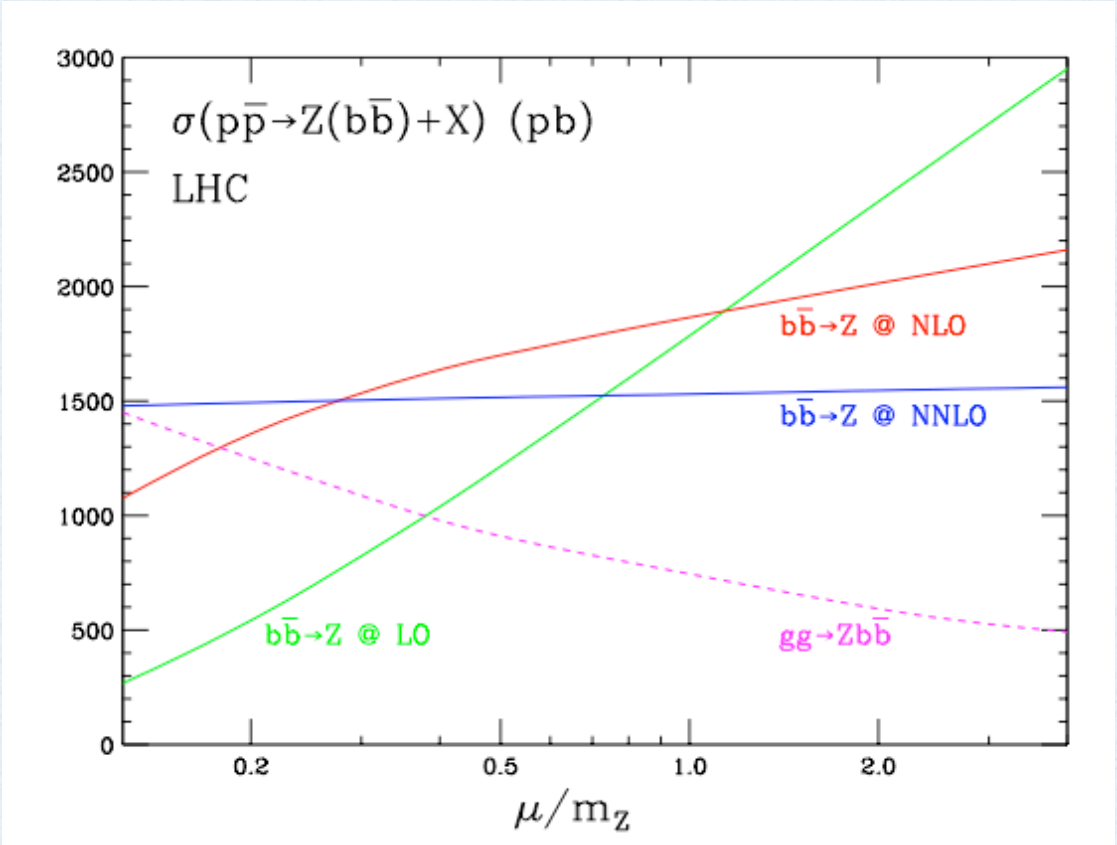
The qq→Zbb channel (not shown) is large due to valence quark pdfs.

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 would need to know it at NLO (in the 4f scheme).

Z + b's at the LHC



Strong scale dependence of the LO calculation.
No dependence at NNLO.

Factor of 2 difference wrt the 4f NNLO calculation for mu=mz.

The qq→Zbb contribution (not shown) is small. qb→Zqb is more important. Anyhow cross section is dominated by bb→Z.

Cross sections (pb) for Z + heavy quarks

Process		TeV	LHC
Z(bb)	bb→Z	28.3	1500
	qq→Zbb	19	120
	qb→Zqb	5.9	430
Z(cc)	cc→Z	77.7	2890
	qq→Zcc	69	430
	qc→Zqc	21	1200
Inclusive Z		7510	56700

qq→ZQQ and qQ→ZqQ are only known at LO ⇒ uncertain

Fraction (%) of heavy quarks in Z + jets

Collider	quark	Inclusive NNLO	1 Q-jet NLO	2 Q-jets NLO
Tevatron	bottom	0.71	2.0	1.9
	charm	2.2	3.4	1.5
LHC	bottom	3.6	6.9	2.4
	charm	8.0	9.3	1.8

It would be a useful to compare with what Pythia and Herwig predict for the above fractions

Fraction (%) of heavy quarks in Z + jets

Collider	quark	Inclusive NNLO	1 Q-jet NLO	2 Q-jets NLO	1 jet + 1 Q-jet NLO
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	charm	2.2	3.4	1.5	
LHC	bottom	3.6	6.9	2.4	
	charm	8.0	9.3	1.8	

work in progress
w/ J. Campbell

1 jet + 1 Q-jet: important for many studies (ex. single top)

"INCLUSIVE" B TAGGING

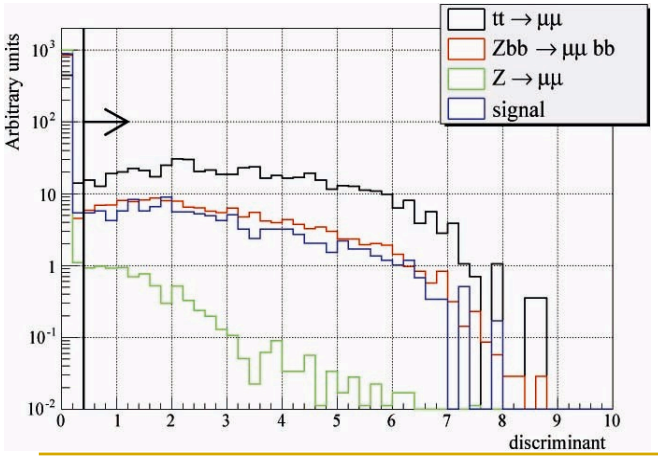
- b's are produced mainly at low pt in bb>h
- asking for a b-tagged jet has an important effect on the cross section
- experimental efficiencies on jet reconstruction give a further suppression

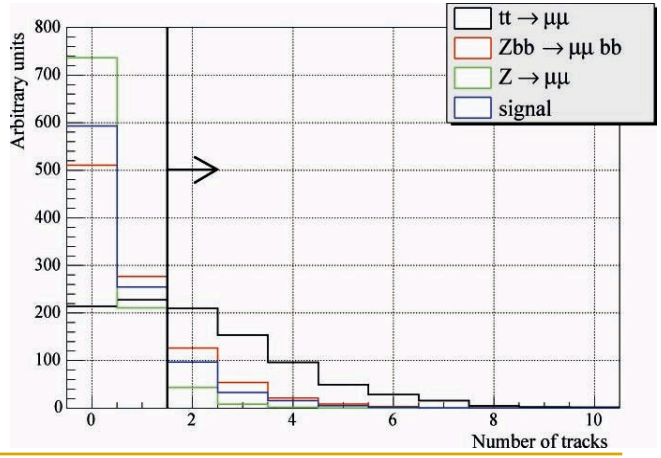
Inclusive approach: look only at the track displacements in the vertex detector and give to the event a probability of containing a b quark.

"INCLUSIVE" B TAGGING

B-Tagging (II)

- Two possibilities:
  1. Based on jets: CombinedBTagging with discriminant > 0.4
  2. Based on tracks: At least two tracks with Transverse Impact Parameter (IP) in the range 0.01 < IP < 0.1 cm (only one track if 0.02 < IP < 0.075 cm)





TeV4LHC PROJECT

Study heavy quark fractions in Z inclusive production

Why ?

theory: we can predict cross sections extremely well.

experiment: alternative approach, better sensitivity?

How ?

theory: NNLO calculation for Z(QQ) is now available.

experiment: look at what CMS has done, compare with MC's (Pythia, Herwig, SHERPA w/ CKKW), study feasibility at CDF and D0.