Heavy Quark Production at the LHC

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Outline and Introduction

- Top production at the LHC: study top-quarks in abundance !
  Check QCD predictions for the total rate.

- Top decay and top mass measurement:
  Measure the top mass down to 1 GeV

- LHC: can we better understand b-production?
  b-jets, b-mesons and b-fragmentation: check total rate v.s. QCD
  Is there New Physics in this observable?

- Interested in open B-production,
- Will not go into the LHCb B-physics program

Top Production

- Top is fundamental. Not much known from direct measurements:

M_top = 171 ± 2.1 GeV latest combined result from Tevatron

- A handful of single-top events seen at the Tevatron (DZero); enough to confirm V_tb in the SM interval (0.68 – 1.0) with 95% C.L.

- Testing the top is important not only for SM; It might be exclusively correlated with new physics.

Top Production

- LHC: a new era in top physics
  - Huge statistics – a top pair each second,

  - σ_top measured within 10%. Can we do better? And how?
  - Recall the talk by Dissertori: b-tagging brings 7% out of 10% total!

  - Theory: currently firmly at NLO
  - Theory uncertainty around 15% (10% with resummations, 3-4% pdf).
  - Check? NNLO needed.

- What theory can/should provide for precision top physics?

  - First – the total cross-section (pp → tt+X) at NNLO
  - Then – more differentially
  - Work underway; results not very soon …

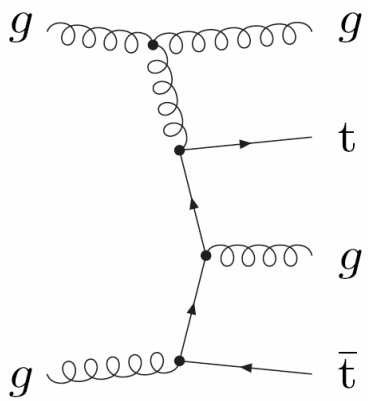
Top Production (cont.)

- Recent result on pp → tt+Jet+X at NLO

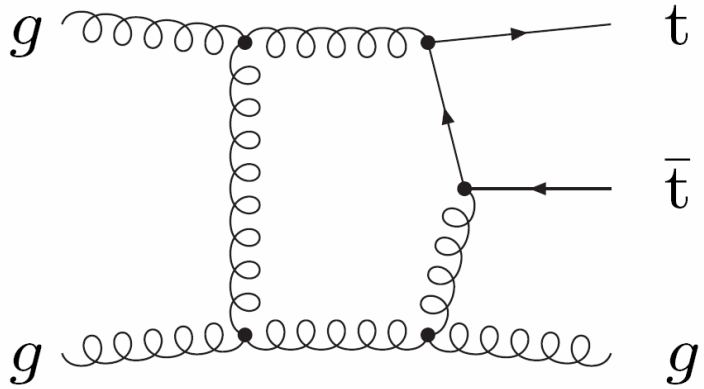
S. Dittmaier, P. Uwer and S. Weinzierl ('07)

Real Emission:

$gg \to t\bar{t}gg$:
(123 diagrams)



Virtual corrections:



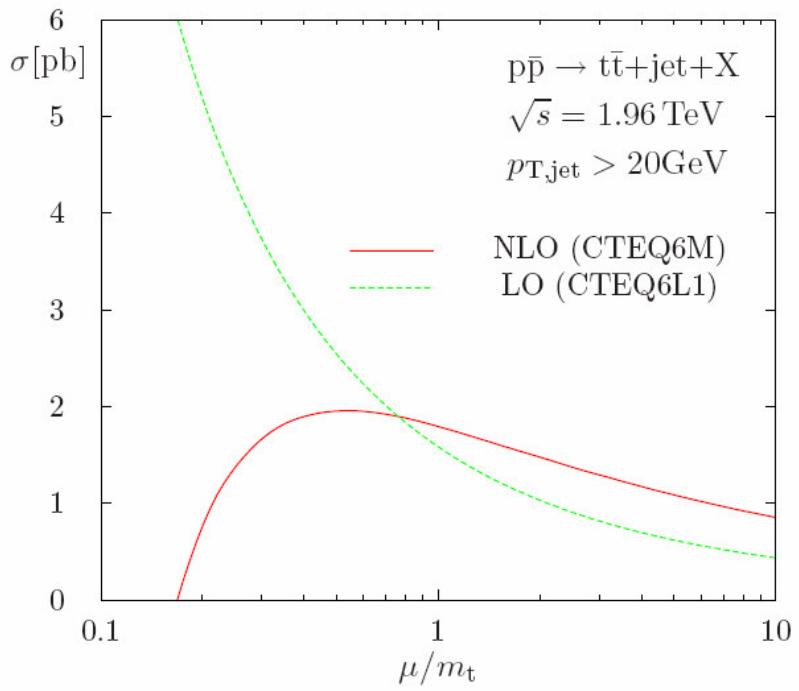
- Result important for:
  - Forward/Backward charge asymmetry of heavy quarks at NLO
  - background for Higgs at the LHC pp → ttH+X

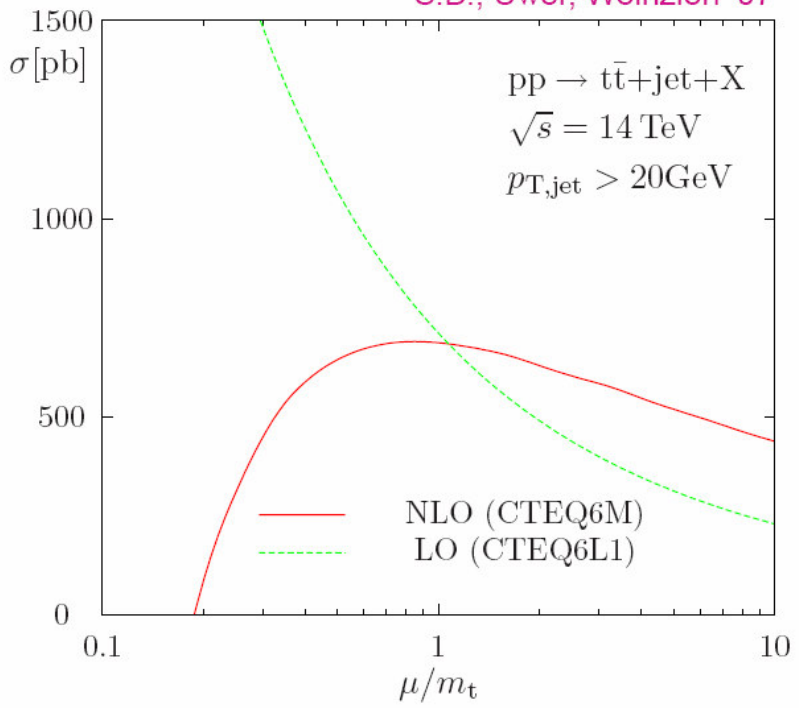
Top Production (cont.)

- Numerical results on pp → tt+Jet+X at NLO

LO versus NLO cross section at the Tevatron and the LHC:

S.D., Uwer, Weinzierl '07



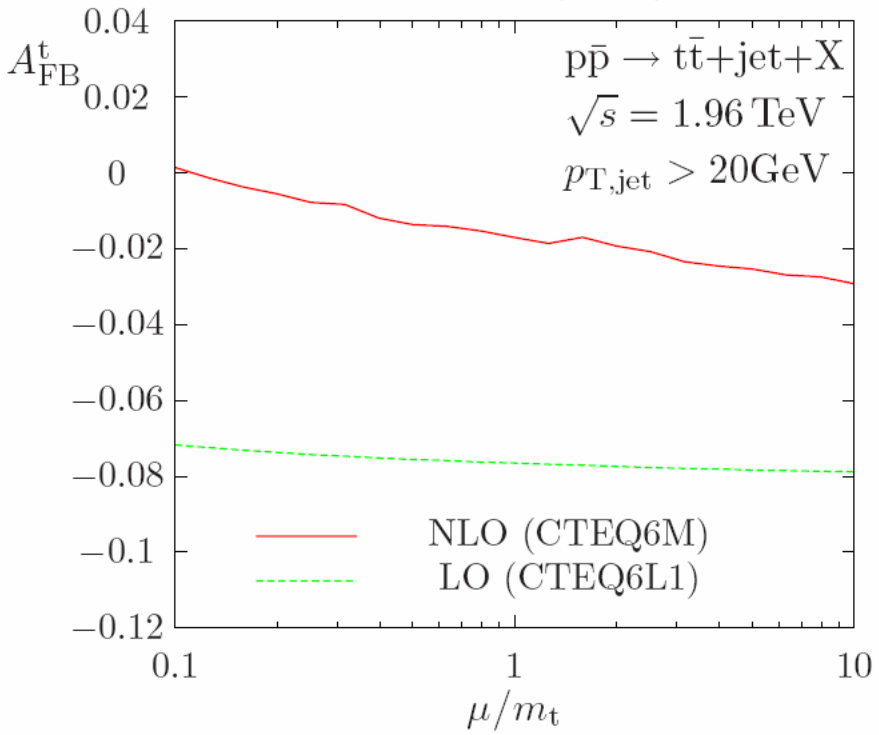


- Clear stabilization of the scale dependence at NLO!

Top Production (cont.)

- F/B assymetry in pp → tt+Jet+X at NLO

S.D., Uwer, Weinzierl '07



$$\sigma_{\rm LO}^{\pm} = \sigma_{\rm LO}(y_{\rm t}{>}0) \pm \sigma_{\rm LO}(y_{\rm t}{<}0)$$

$$A_{\rm FB,NLO}^{\rm t} = \frac{\sigma_{\rm LO}^{-}}{\sigma_{\rm LO}^{+}}\left(1 + \frac{\delta\sigma_{\rm NLO}^{-}}{\sigma_{\rm LO}^{-}} - \frac{\delta\sigma_{\rm NLO}^{+}}{\sigma_{\rm LO}^{+}}\right)$$

$$A_{\rm FB,LO}^{\rm t} = \frac{\sigma_{\rm LO}^{-}}{\sigma_{\rm LO}^{+}}$$

$$(\mu = \mu_{\rm ren} = \mu_{\rm fact})$$

- Large NLO corrections?

Top decay and top mass

- Top decay so far studied at NLO
  - The real simplification comes from ignoring interference production/decay
- The decay is important for top mass reconstruction

R. Chierici, CMS + ATLAS, ICHEP 2006

Method	δm_t (stat.)	δm_t (syst. instr.)	δm_t (syst. theory)	δm_t
bbqq$\ell\nu$	0.2	1.0	0.6	1.1
bbqq$\ell\nu$ (high p_T)	0.2	0.9	1.4	1.7
bb$\ell\nu\ell\nu$	0.5	1.0	0.3	1.2
bbqbbq	0.2	2.3	3.5	4.2
J/Ψ decays	0.5	0.5	1.4	1.5
Via σ_{tt}	0.1	0.7	4.0	4.1

Top mass

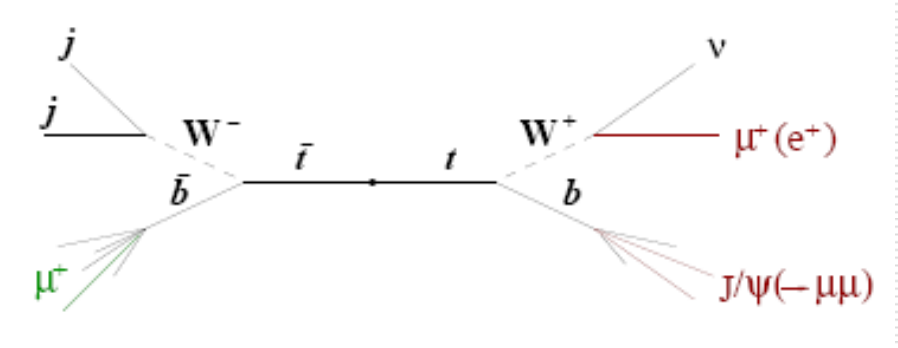
- "Traditional" methods – jet measurements
- However, the huge statistics at LHC allows a different approach:

A. Kharchilava (1999) R. Chierici, A. Dierlamm CMS NOTE 2006/058

- Uncertainty below 1 GeV possible!

- Main uncertainty: b-fragmentation:

Source	δm_t (GeV/c^2)
Proton PDF	0.28
Scale definition	0.71
Λ_{QCD}	0.31
Q^2	0.56
Light jet fragmentation	0.46
b-quark fragmentation	0.51
Minimum bias/Underlying event	0.64
Total theoretical	1.37
Electron E scale	0.21
Muon p scale	0.38
Electron E resolution	0.19
Muon p resolution	0.12
Jet E scale	0.05
Jet E resolution	0.05
Background knowledge	0.21
Total experimental	0.54
Total systematic	1.47



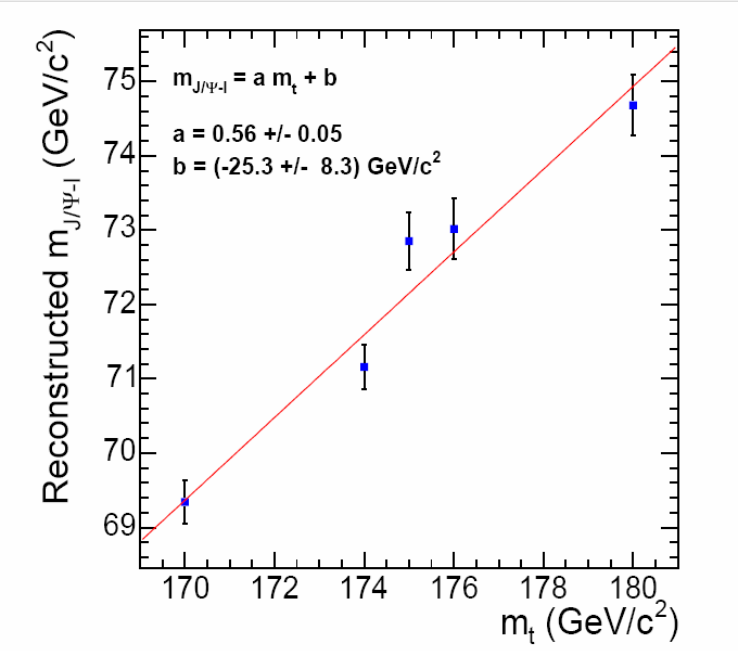
- The experimental uncertainty is low;
- The theory must be carefully analyzed.

- Ongoing work here in Zeuthen:
  (with Cacciari, Moch and Vogt)
- On b-fragmentation at NNLO

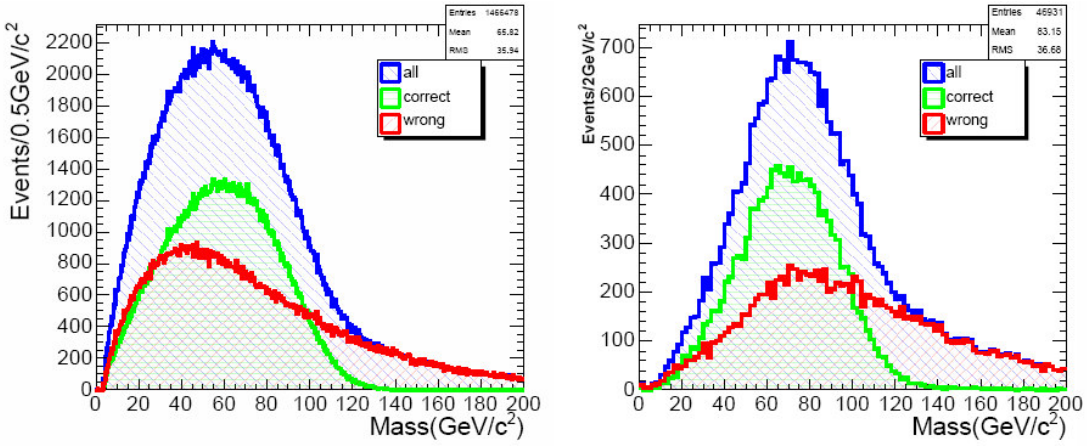
Top mass

- Correlation between the the invariant mass and M_top
- Contribution from "correct" and "wrong" lepton identification

R. Chierici, CMS + ATLAS, ICHEP 2006



R. Chierici, A. Dierlamm CMS NOTE 2006/058



B-production at the LHC

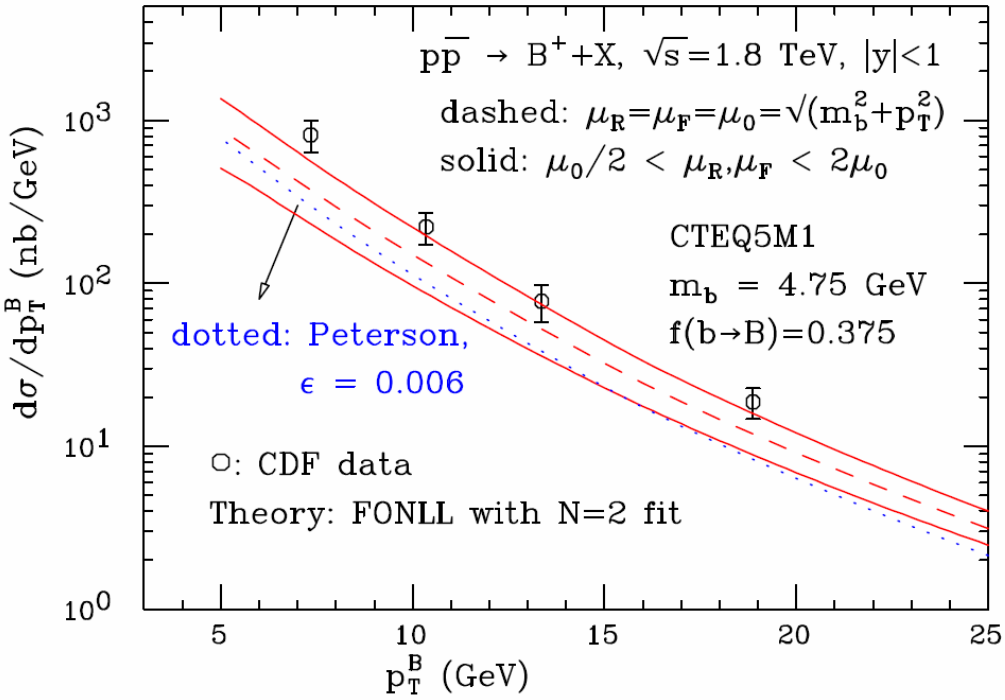
- Important for:
  - Controlling QCD
  - Higgs and New Physics searches (b is often a decay mode)

- It is worthwhile recalling the b-saga at the Tevatron:

  Cacciari, Nason ('02); Cacciari, Frixione, Mangano, Nason, Ridolfi ('03)

Recall: the total b-rate is reconstructed exclusively!

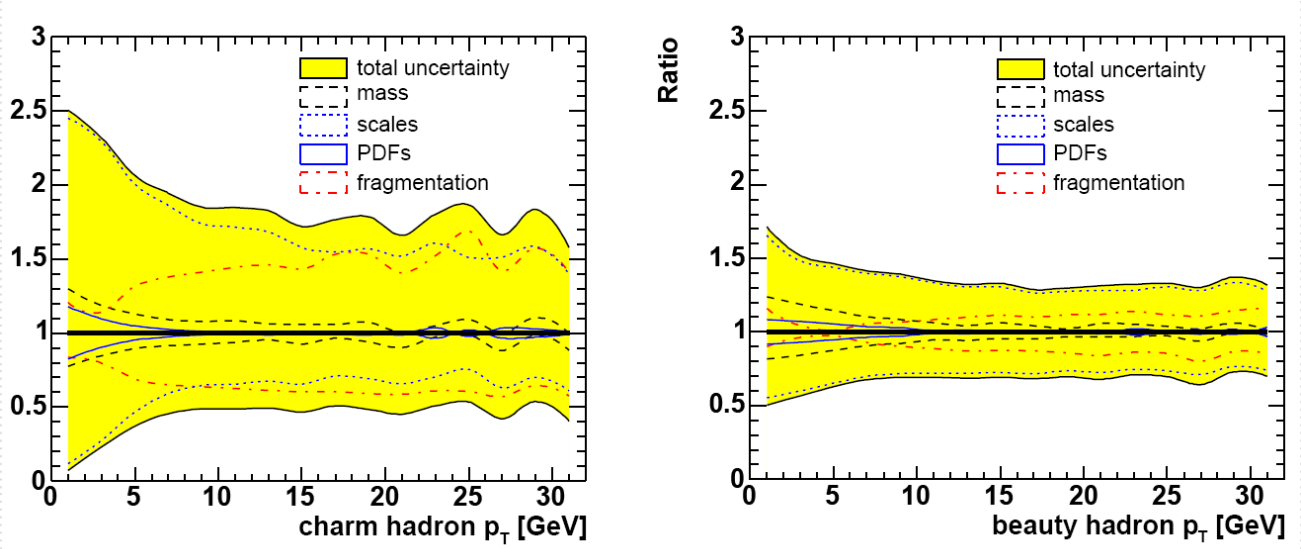
- Sensitivity to fragmentation !



B-production at the LHC

- Spectacular B-studies at LHC:
  - P_T spectra up to 1000 GeV
  - 16M/year at CMS alone

HERA-LHC workshop ('06)

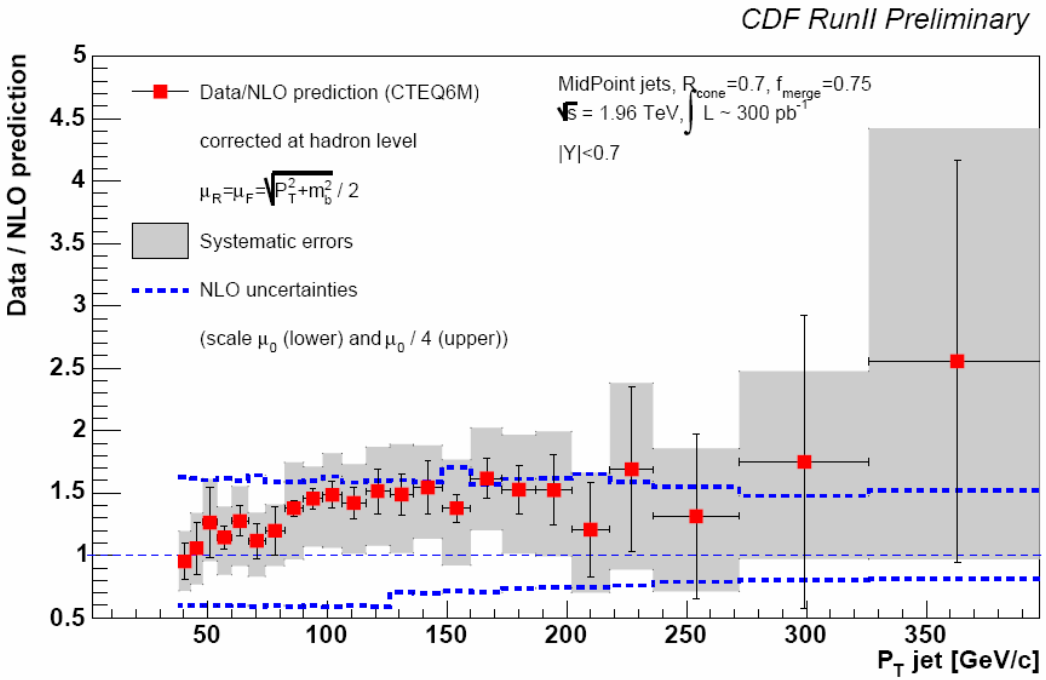


- Dominant uncertainty – NNLO corrections and b-fragmentation

B-jets at the LHC

- Surprisingly large NLO uncertainties at the Tevatron:

CDF Collaboration, Note 8418



What is this large uncertainty due to?

A. Banfi, G. P. Salam and G. Zanderighi: incorrect b-jet definition!

- In short: IR definition of the flavor is needed, or is bb-bar=b?
- They propose to define the jet of the flavor according to its net flavor.

B-jets at the LHC

- The effect of this new definition seems to be rather important:
  - Small perturbative corrections,
  - One can use purely massless calculations at large P_T (< 5% effect)

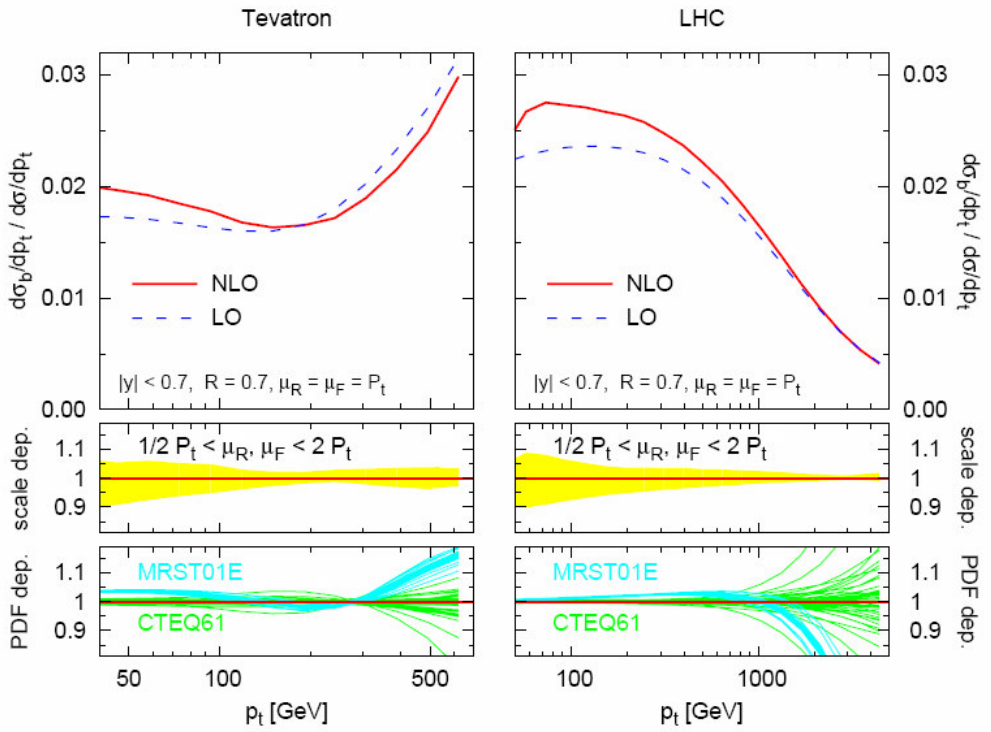
With the new jet definition
NLO uncertainty just 5%-10%!

? Can this improve b-jet measurements at the LHC (important for top production)?

Potential problem:

g → bb has zero flavor

unless one of the b's is not tagged. Unknown effect!



Summary

- I reviewed top and bottom production at LHC (from a narrow prospective)
- Emphasis on more inclusive observables
- Message: we work for some precise observables (NNLO)

- Questions: what is the experimental situation?
- Are improvements with b-measurements anticipated?