A CLOSE LOOK AT THE THEORETICAL UNCERTAINTY ON THE B CROSS SECTION

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- Introduction
- Initial state logs
- Final state logs
- Approaches to resummation
- Non-perturbative fragmentation

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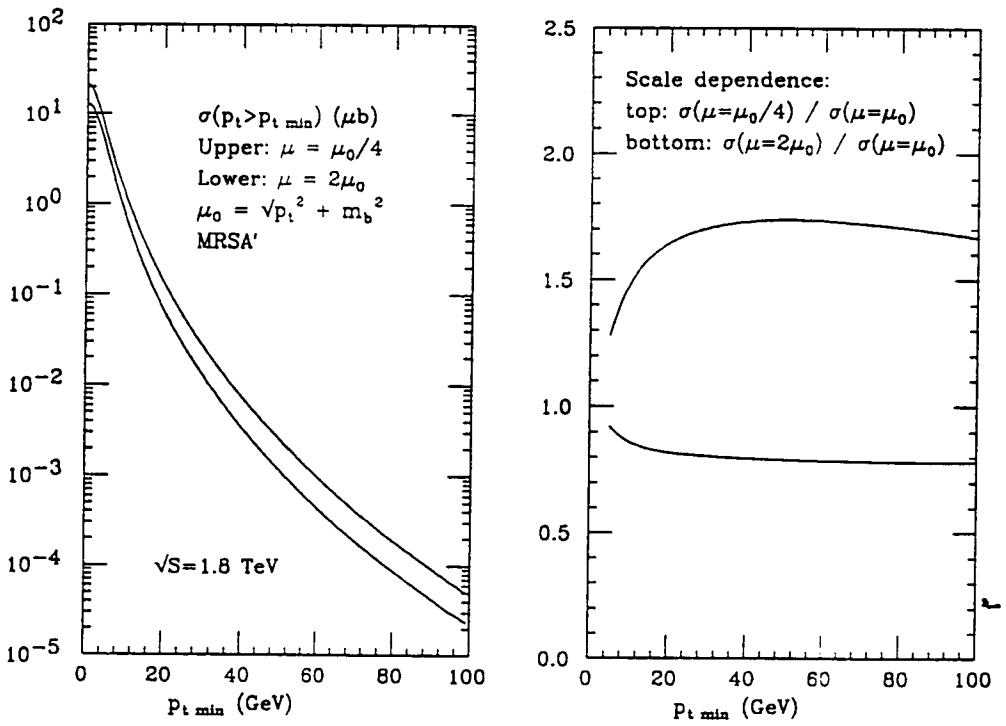
INTRODUCTION

Nason Dawson RK Ellis, Beenakker et al

The heavy quark cross section is known to NLO. There is evidence that this is not an accurate estimate, because of the large scale dependence:



AIM OF THE TALK:

Identify the possible sources of large higher-order corrections, try to estimate their impact, and present recent attempts to reduce it.

Large scale dependence is a symptom of large NNLO corrections

Sources of large higher order corrections:

- "Accidentals" (e.g. large coefficients, π^2's, etc., not controlled by scale dependence)

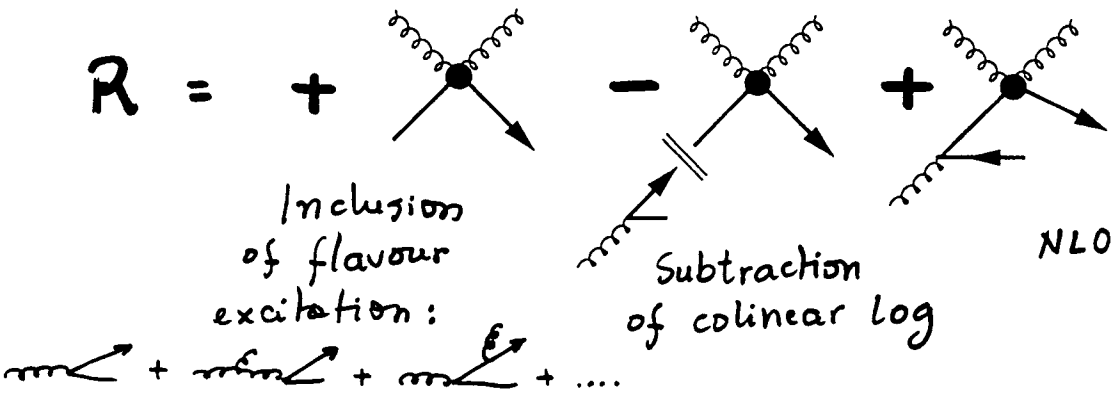
- Large Log's due to the coexistence of different scales. E.g.:

$$\log \frac{S}{m^2} \quad , \quad \log \frac{{p_T}^2}{m^2} \qquad (1)$$

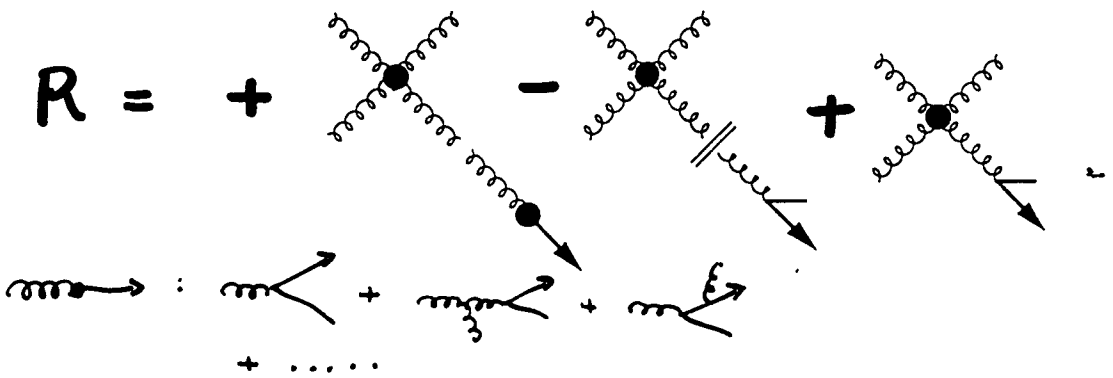
The origin of these logs is known, and in principle they can be resummed.

In this talk I will concentrate on the $\log \frac{{p_T}^2}{m^2}$ terms, as they are more relevant to the regions of experimental interest

- Logs from ISR can be resummed by considering the b-quark parton density (Flavour Excitation)

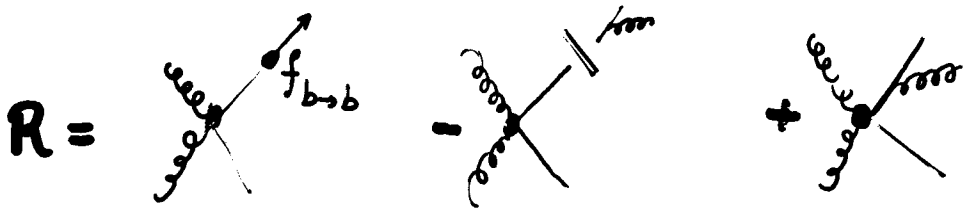


- Logs from FS gluon splitting can be resummed by considering the $g \rightarrow b$ fragmentation function:



- Logs from FSR can be resummed by considering the b-quark fragmentation function:

$$\left(\frac{d\sigma}{dp_T}\right) \rightarrow \left(\frac{d\sigma}{dp_T}\right) \otimes f_{b\rightarrow b} \qquad (2)$$



Two studies in the literature have addressed these resummation problems:

1. Cacciari and Greco (1994):
   NLO, $m_b = 0$ (only valid at large p_T)

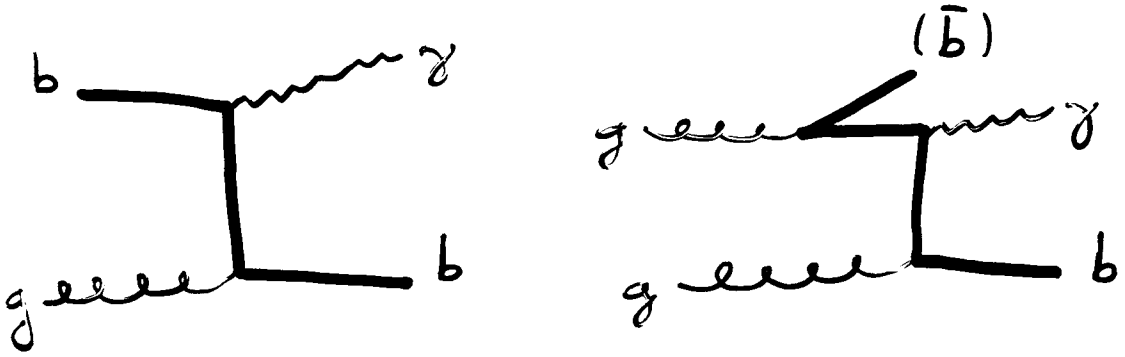
2. Olness, Scalise and Tung (1996):
   $m_b \neq 0$, matching to full NLO at low p_T, but LO at high p_T.

I will discuss these results later on.

Meanwhile I will address the question of how big we expect these effects to be, and which are the dominant sources of uncertainties.

INITIAL STATE LOGS

I will argue that these logs are not large in the current p_T experimental range. To do this I will consider a simpler problem, namely associated production of γb. This process admits two descriptions:

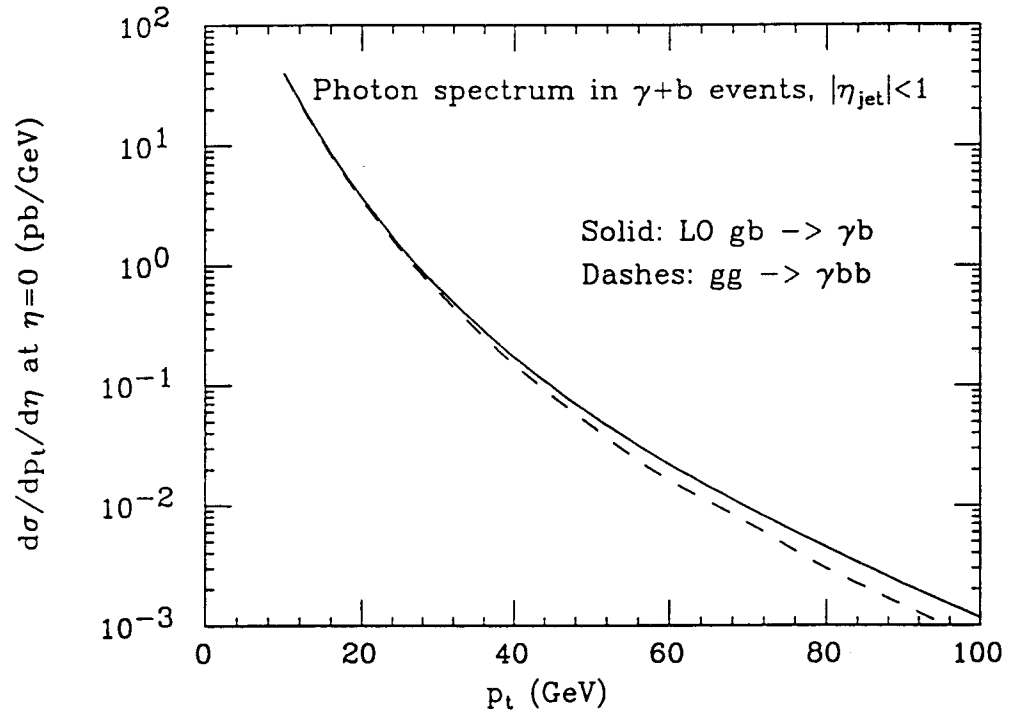


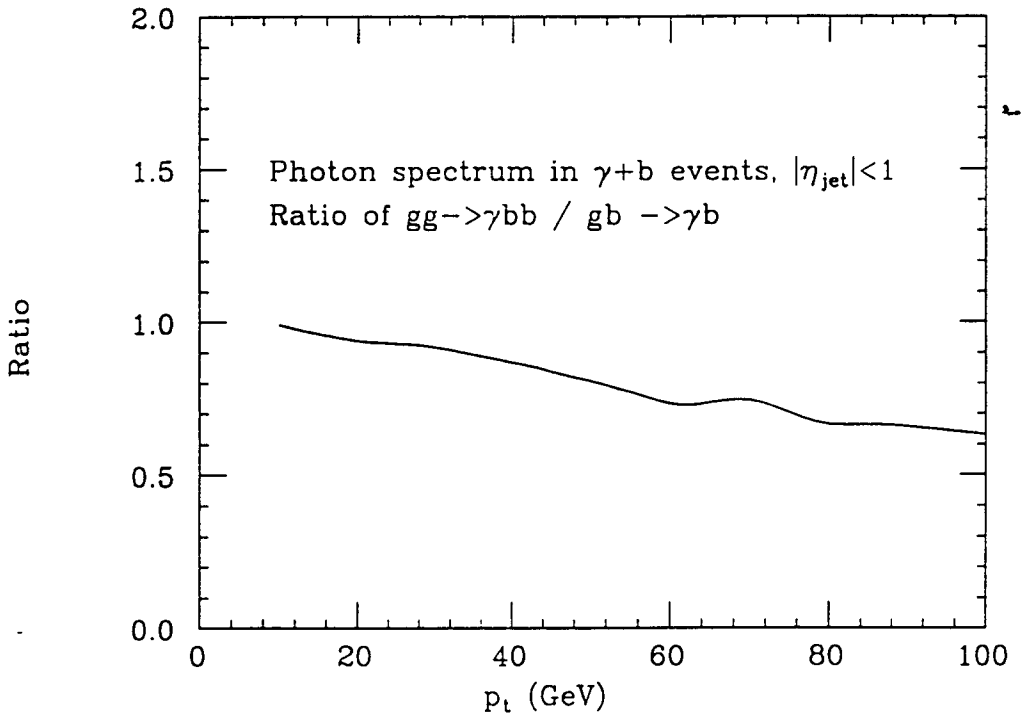
(FE) (NLO)

1. In the first case one uses the b-quark density from some PDF set (FE description). This evaluation is more accurate at high p_T, as it resums possibly large logs.

2. The second description includes $g \to b\bar{b}$ logs at the 1^{st} order only. However the threshold effects are correctly evaluated.

The difference between the two calculations indicates how large the higher order logs are:



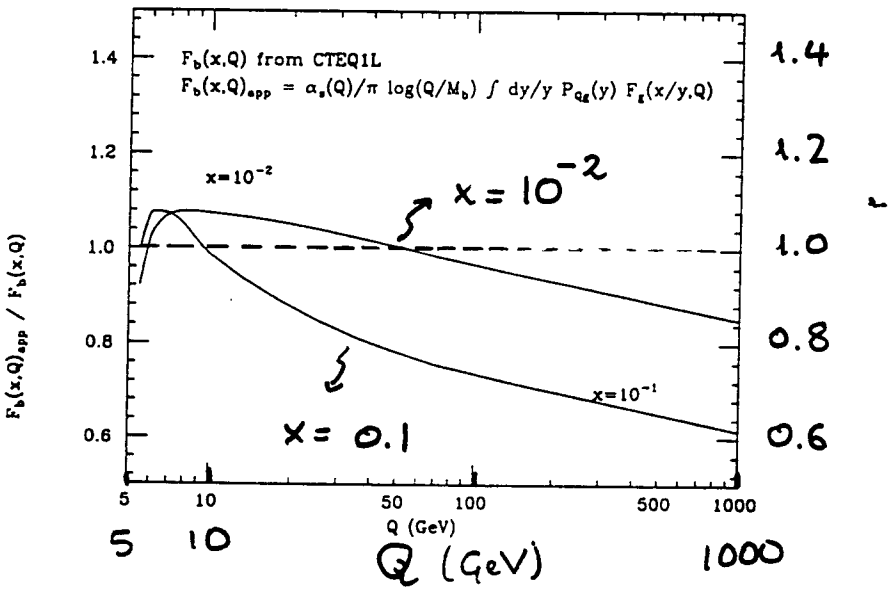


CONCLUSIONS of this exercise:

1. The FE approach gives a very good description EVEN near threshold, provided one uses the Collins and Tung prescription ($\mu_0 = m_Q$ instead of the naive $\mu_0 = 2m_Q$. We used CTEQ4L in the previous figs)

2. The "NLO" approach works well (to within 20%) up to $p_T \sim 50$ GeV.

This is SUPPORTED by the following comparison:



BOTTOM LINE:
Initial State logs are not very large in this p_T range. They cannot, by themselves, explain the large scale dependence of the b cross section.

FINAL STATE MASS SINGULARITIES

(i.e. b fragmentation)

The logs come from the emission of gluons collinear to the b. These logs are cancelled by virtual corrections to the b-propagator:

= finite

and therefore do not appear in observables for which all 3 diagrams contribute. E.g. the energy flowing through the cut.

These logs vanish in the evaluation of a collinear-safe quantity

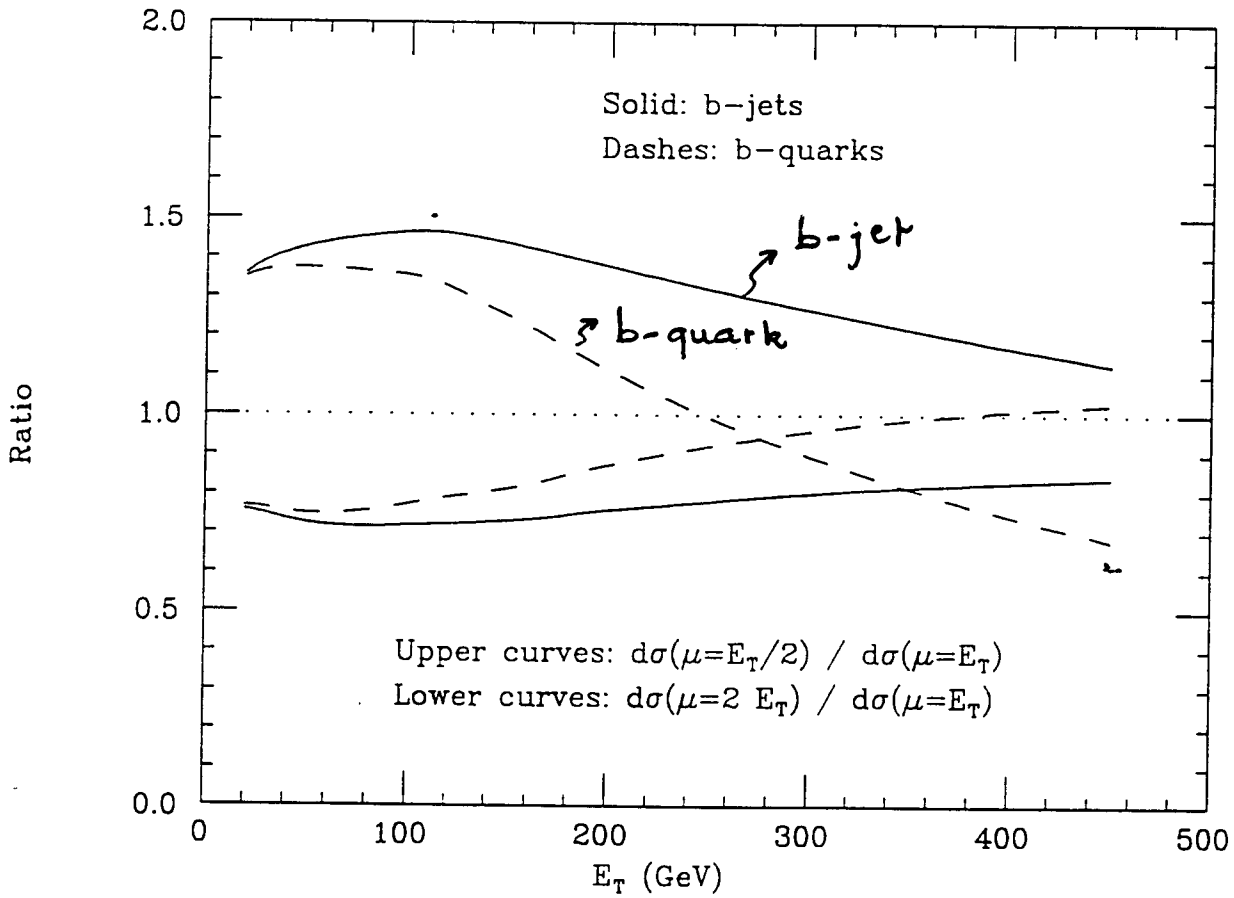
EXAMPLE: The b-jet E_T rate

Consider as an observable the E_T of a jet containing a b quark.

Calculate therefore (MLM and S.Frixione, 1996):

$$\frac{d\sigma}{dE_T^{\text{b-jet}}} \qquad (3)$$

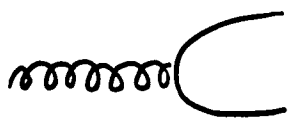
Remember that the analogous quantity for jets of light partons is very stable under scale variations ($\pm 10\%$). In our case:



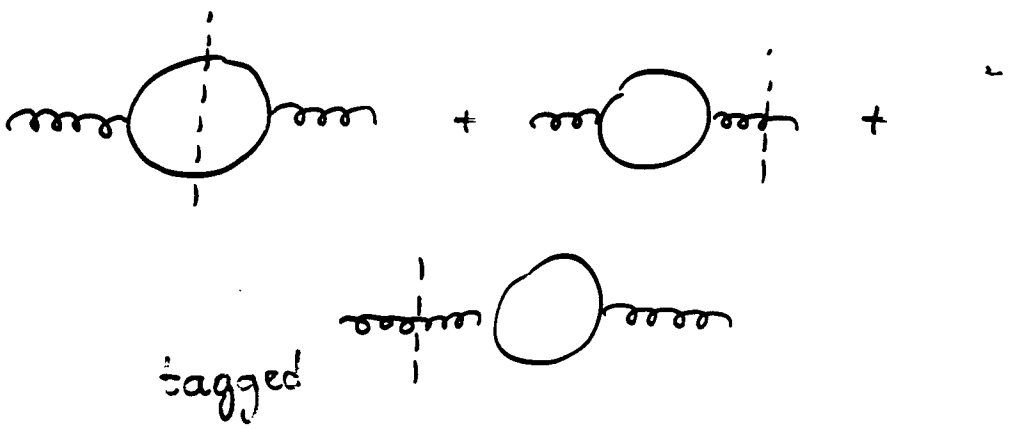
LARGE SCALE DEPENDENCE $\Rightarrow$ other sources of large logs which have nothing to do with the b-fragmentation process !

GLUON SPLITTING LOGARITHMS

In the case of light jets these logs are cancelled because in light jets we don't tag light partons, so the diagrams:



are cancelled by the gluon self-energy corrections:

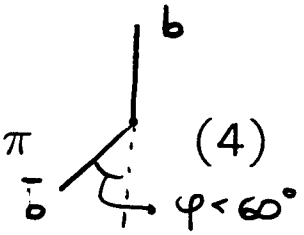


In the case of b quarks the virtual diagrams cannot contribute, so we have left-over logs.

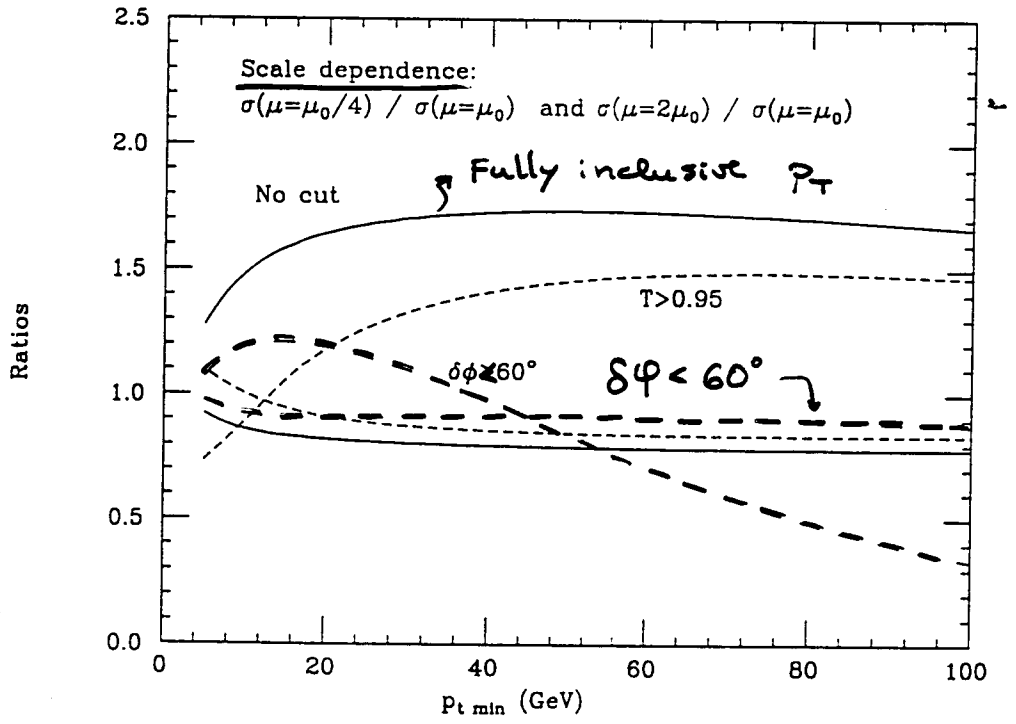
The comparison of the scale dependence of the b-jet X-section with that of the open-b suggests that indeed most of the scale dependence is caused by the $g \rightarrow b\bar{b}$ process.

As additional evidence, consider the following quantity:

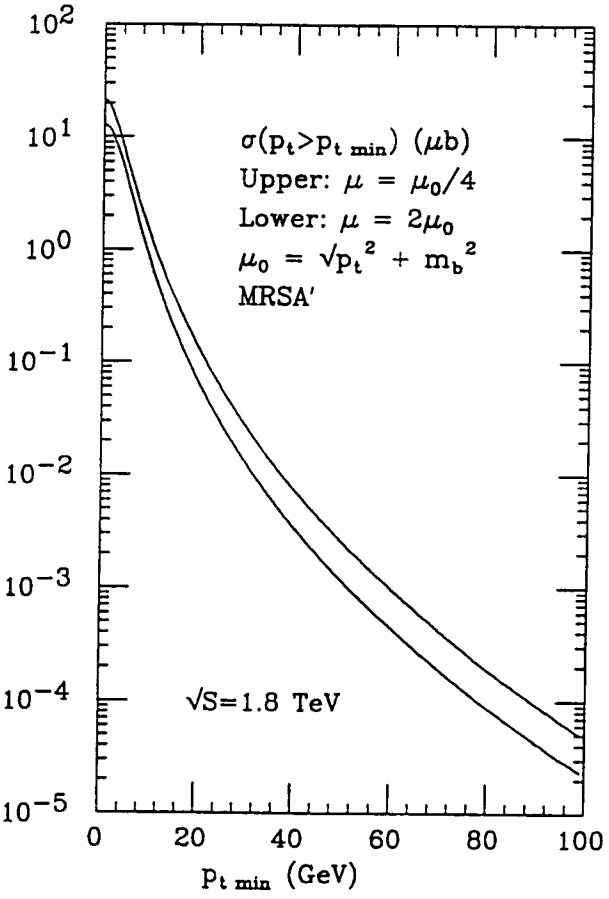
$$\frac{d\sigma}{dp_T^b}, \quad \text{with} \quad \frac{2}{3}\pi < \Delta\phi_{b\bar{b}} < \pi \qquad (4)$$

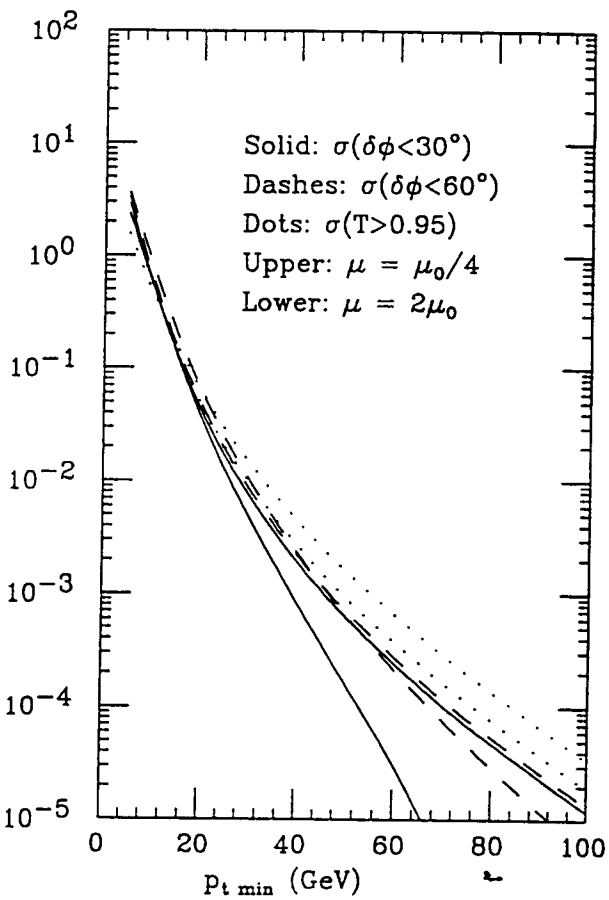


we call this the "2-body" x-section (introduced by UA1, 1994). This observable implicitly reduces the impact of the gluon-splitting process. It is calculable at full NLO (MNR).



On absolute scale:





The scale dependence is reduced to $\pm 10\%$, which is consistent with the scale dep of the inclusive-jet NLO X-section.

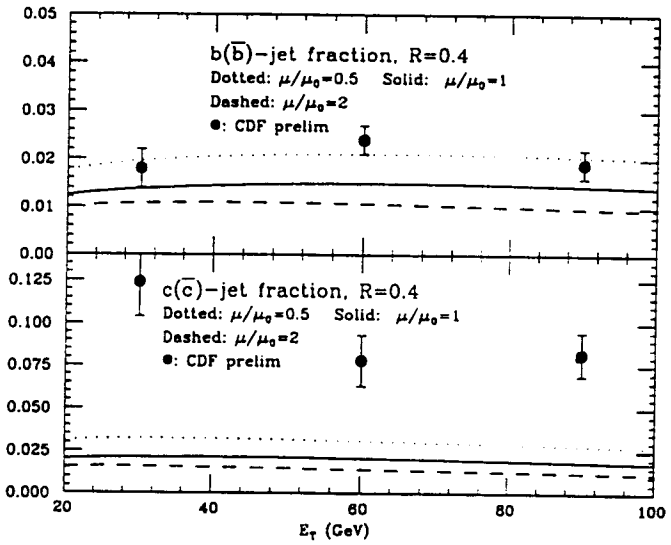
HERE IS A QUANTITY that it would be worth measuring at the Tevatron !! (see UA1–1996 for their analysis).

BOTTOM LINE

- All evidence points in the direction of putting most of the blame for the large scale dependence of the inclusive p_T spectrum of b quarks on the $g \rightarrow b\bar{b}$ process

- In the case of charm production, for which the $g \rightarrow c\bar{c}$ contribution is even larger, the consequences can be dramatic:

data from CDF (P. Koehn's thesis)



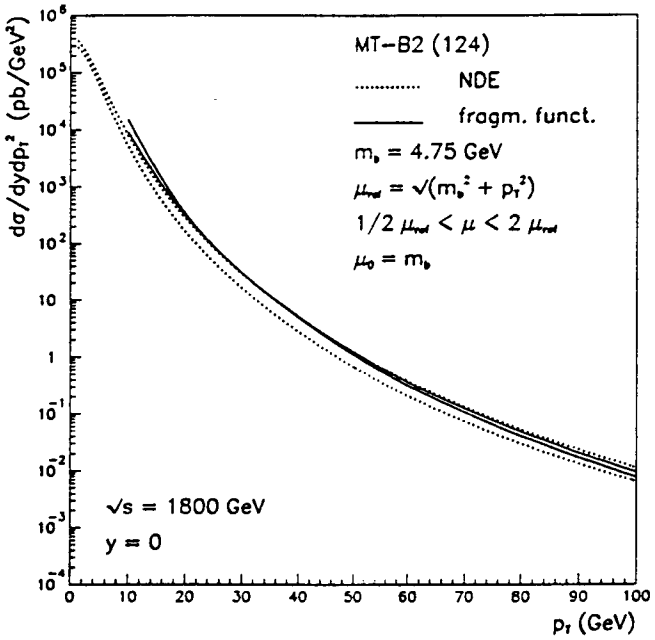
b-jet fraction

c-jet fraction

- There exist observables for which the NLO calculation is very stable under scale variations

SOME RESULTS ON RESUMMATIONS

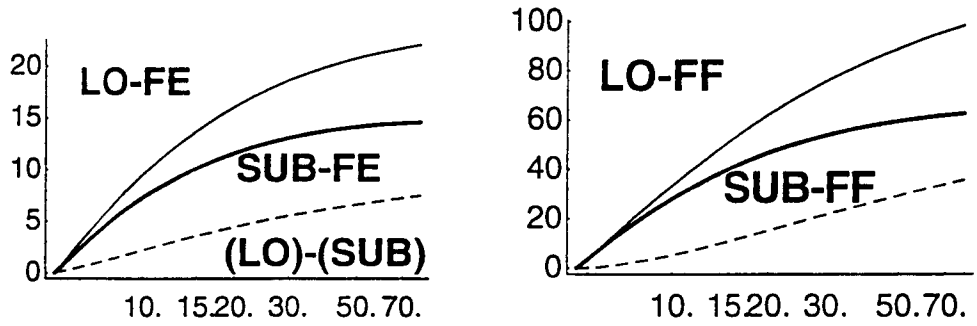
CACCIARI and GRECO:

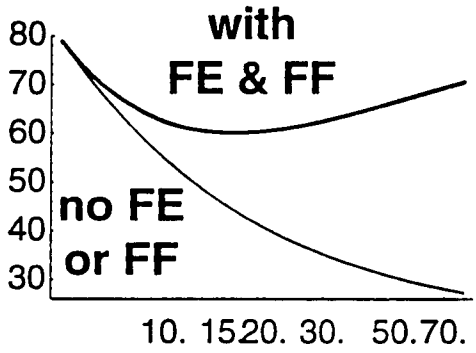


COMMENTS:

- Indeed signficant reduction in scale dependence
- Steepening of the p_T distribution
- Resummed result lies WITHIN the NLO error band: the cross-section does NOT increase at high p_T.

OLNESS, SCALISE and TUNG:





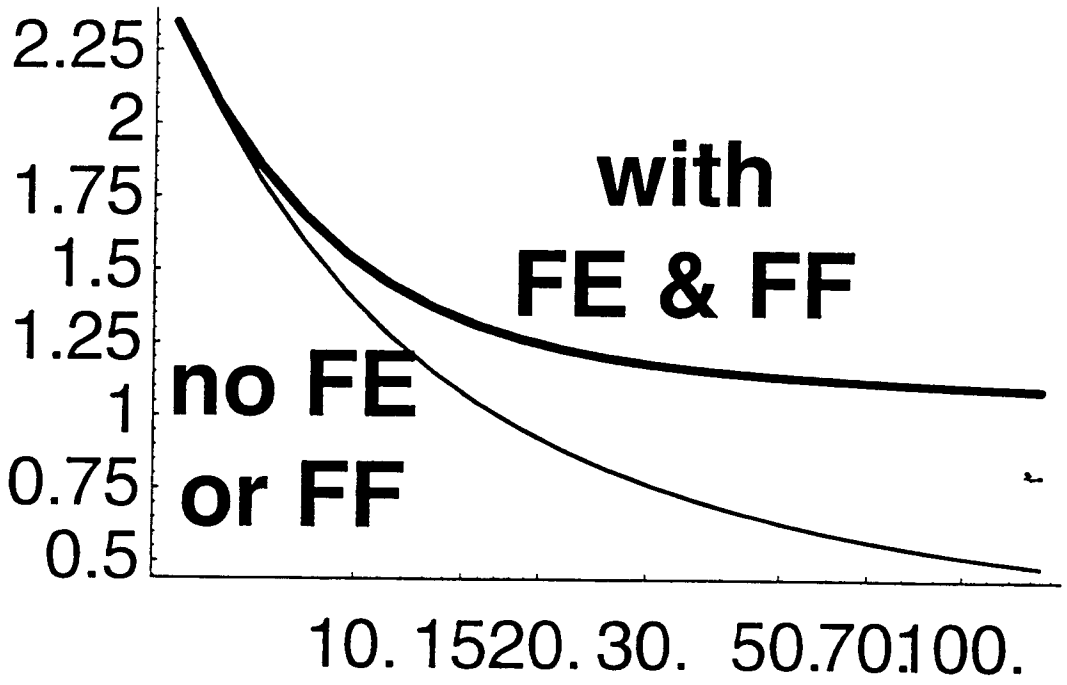
COMMENTS:

- As expected the effect of FS logs is much bigger than that of IS logs.

- At the scale of $\mu = \mu_0/2$ the overall effect is however not much different than the NLO result ($\sim 15\%$ increase).

- Indication that choices of μ in the range $\mu_0/4 < \mu < \mu_0/2$ are better.

Results for p_T=40 GeV:



ADDITIONAL REMARKS on the RESUMMED RESULTS

- Silght more effort necessary to obtain a complete calculation with both the

  1. extrapolation to $p_T \sim m_b$ *and*

  2. full NLO control over the scale dependence

- A complete study of the scale dependence should keep separate the 5 (!) independent scales involved in the problem:

  1. Renormalization scale

  2. Initial scales at which the boundary conditions for the perturbative evolution of the b partonic density and b fragmentation functions are assigned

  3. Initial and final factorization scales

- We should keep in mind that the experimental evidence that PQCD can describe the fragmentation properties of b quarks is still poor. Things are even worse in the case of charm:

	$\bar{n}_{g\to c\bar{c}}$ (%)
[OPAL95]	$2.27 \pm 0.28 \pm 0.41$
[ALEPH96]	$2.65 \pm 0.74 \pm 0.51$
[Seymour95]	
$\Lambda_5^{\overline{MS}} = 150\,\text{MeV}$	$1.35^{+0.48}_{-0.30}$
$\Lambda_5^{\overline{MS}} = 300\,\text{MeV}$	$1.85^{+0.69}_{-0.44}$

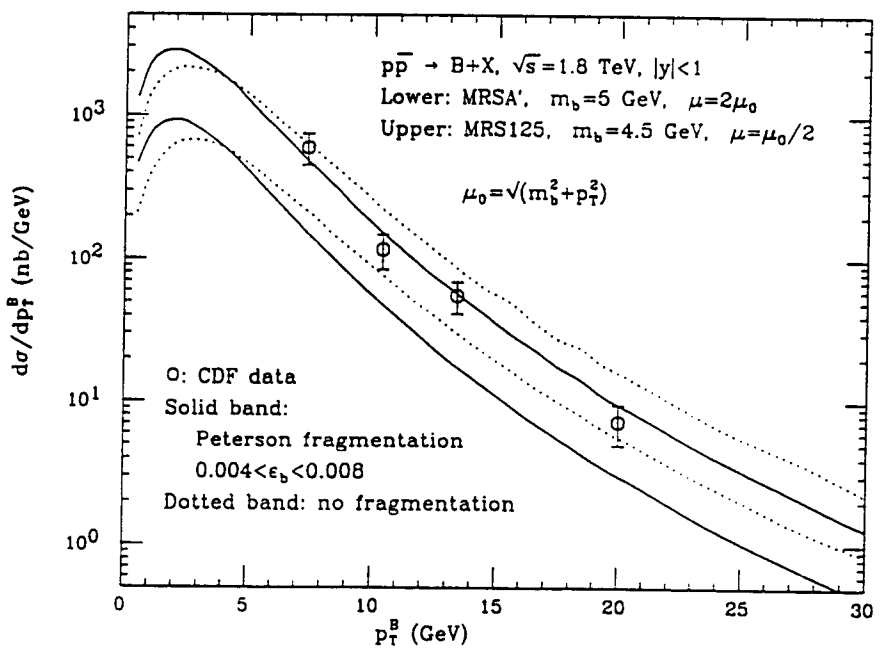
(For the b:

	$\bar{n}_{g\to b\bar{b}}$ (%)
[DELPHI96]	$0.22 \pm 0.10 \pm 0.08$
[Seymour95]	
$\Lambda_5^{\overline{MS}} = 150\,\text{MeV}$	0.20 ± 0.02
$\Lambda_5^{\overline{MS}} = 300\,\text{MeV}$	0.26 ± 0.03

NON-PERTURBATIVE FRAGMENTATION FUNCTIONS (FFs)

At the end of the perturbative evolution, one still expects hadronization effects to alter the spectrum of the b quark while it transforms into a hadron. These effects are usually described in terms of a non-perturbative fragmentation function. Typical example is the Peterson *et al.* FF.

To connect the observed experimental data to the theory of b-quark production one needs to understand this element as well.



There is evidence that this step is subject to bigger syst uncertainties than previously thought:

- No solid basis for assuming that $F_{NP}^{e^+e^-}$ extracted from e^+e^- data is an accurate estimate of $F_{NP}^{p\bar{p}}$. In $p\bar{p}$ production of b-quarks has a large $g \to b\bar{b}$ contribution. Not obvious that higher-twist effects are the same as in $e^+e^- \to b\bar{b}$.

- e^+e^- observables are mostly sensitive to the 1st moment of the FF:

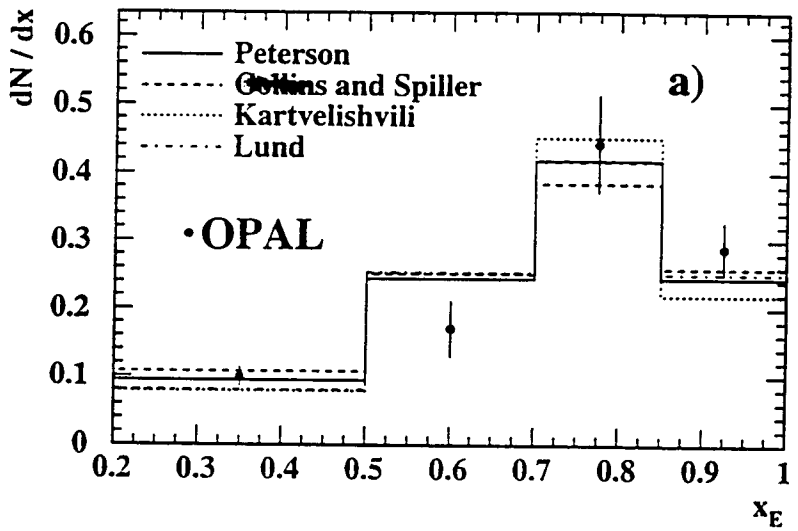
$$\langle z \rangle = \int_0^1 dz\, z\, F(z) \qquad (5)$$

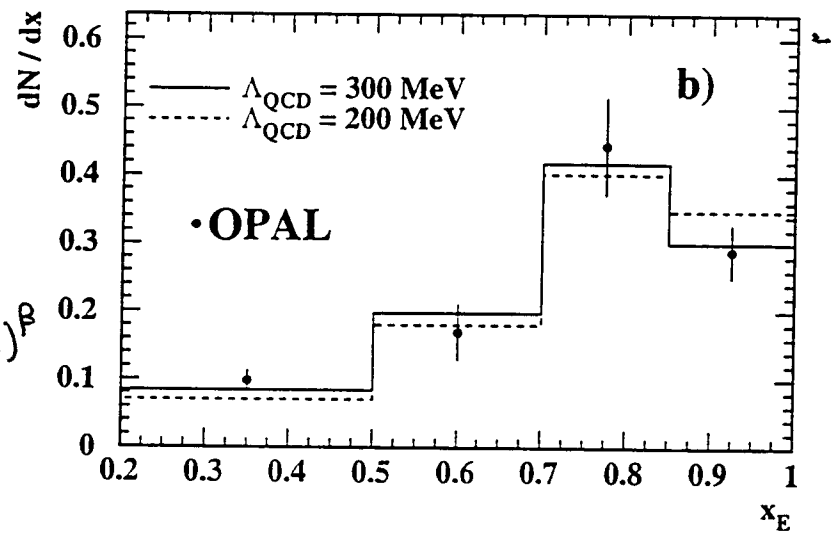
The $p\bar{p}$ observables probe large moments of the NP fragmentation function:

$$\left(\frac{d\sigma}{dp_T}\right)_b = \frac{A}{{p_T}^n} \Rightarrow$$

$$\left(\frac{d\sigma}{dp_T}\right)_B = \frac{A}{{p_T}^n} \times \int dz\, z^{n-1} F(z)\,. \quad (6)$$

- New accurate LEP data indicate that the Peterson form does not provide the best possible fit to the shape of the FF. Other shapes should be explored, in view of the previous remark.





Theory:

NLO QCD (Nason & Mele)

⊕ FF $\propto x^{\alpha}(1-x)^{\beta}$

- Strong correlation between α_S and ϵ_b. Latest results on α_S point to smaller ϵ_b than previously thought (large $\alpha_S \Rightarrow$ more PT evolution $\Rightarrow$ less NP p_T degrading required $\Rightarrow$ smaller ϵ_b.

- In $p\bar{p} \rightarrow b\bar{b}$ a larger α_S implies a larger quark rate. Therefore the two effects (larger α_S and smaller ϵ_b) sum up coherently, instead of cancelling each other, as in e^+e^-.