b-quark and ϒ production at the Tevatron

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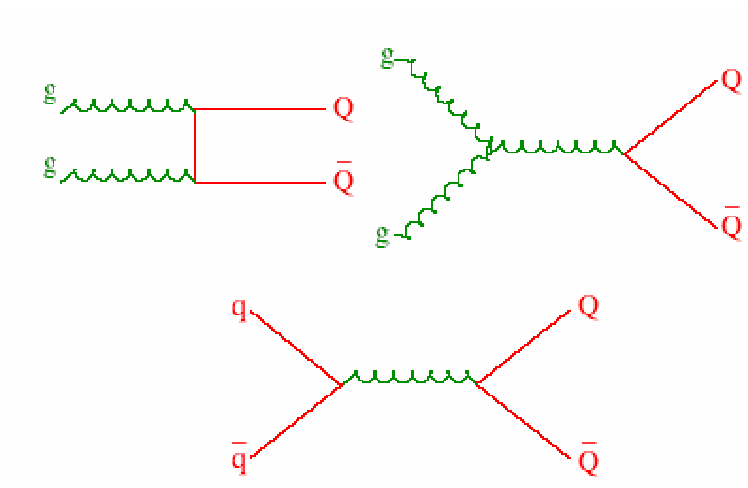
Outline

- J/ψ and *b*-hadron production cross sections (CDF)
- Differential cross sections for ϒ(1S) production (DØ)
- Inclusive *b*-jet cross section (CDF)
- High p_T cross section for μ-tagged jets (DØ)

b-production at the Tevatron

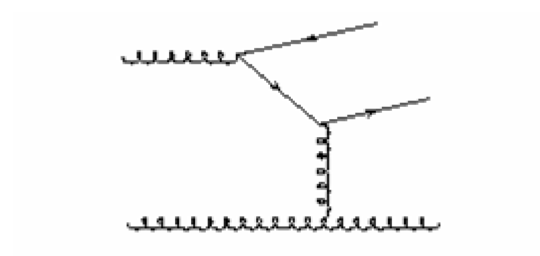
- To probe pertubative QCD: Full calculations are available for NLO and beyond: Fixed order calculation with resummation of next-to-leading logs (FONLL)

leading order

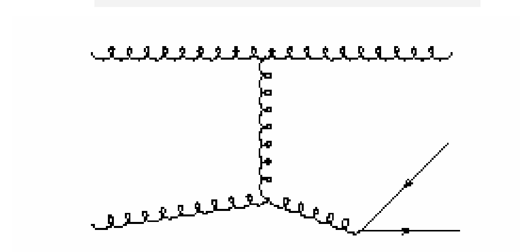


flavor creation

next to leading order



flavor excitation



gluon splitting

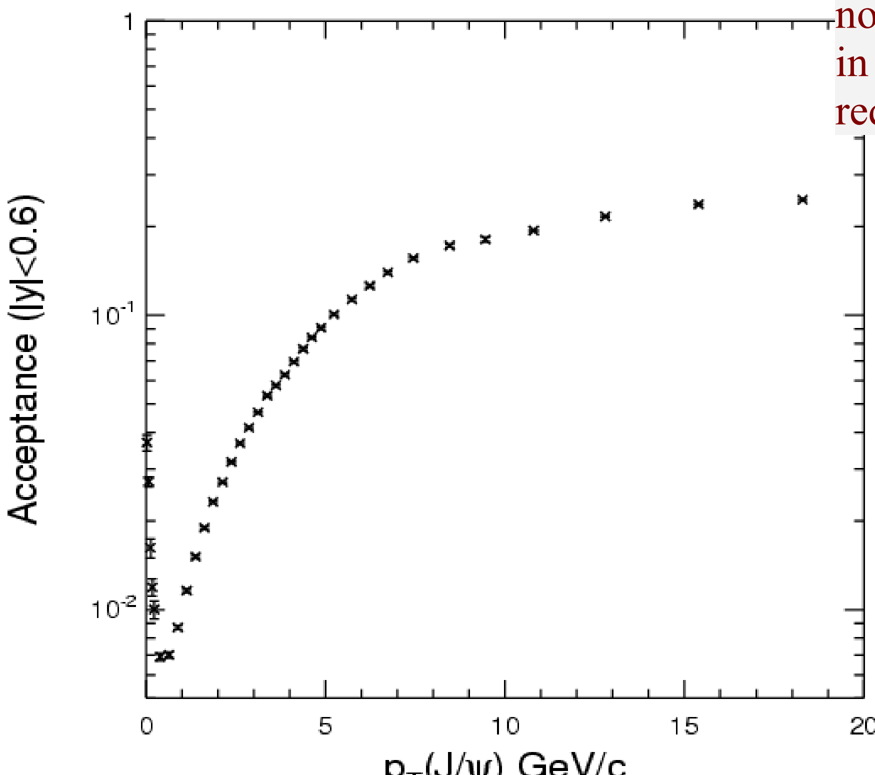
J/ψ and *b*-hadron production (CDF)

Measurement of the J/ψ meson and b-hadron production cross sections in $p\bar{p}$ collisions at $\sqrt{s}$ = 1960 GeV, PRD 71, 032001 (2005)

- First measurement of the J/ψ and *b*-hadron production cross section at $\sqrt{s}$ = 1.96 TeV
- Dataset of ~40 pb^{-1}
- Central rapidity region: $|y| < 0.6$
- Full transverse momentum range: 0-20 GeV/c

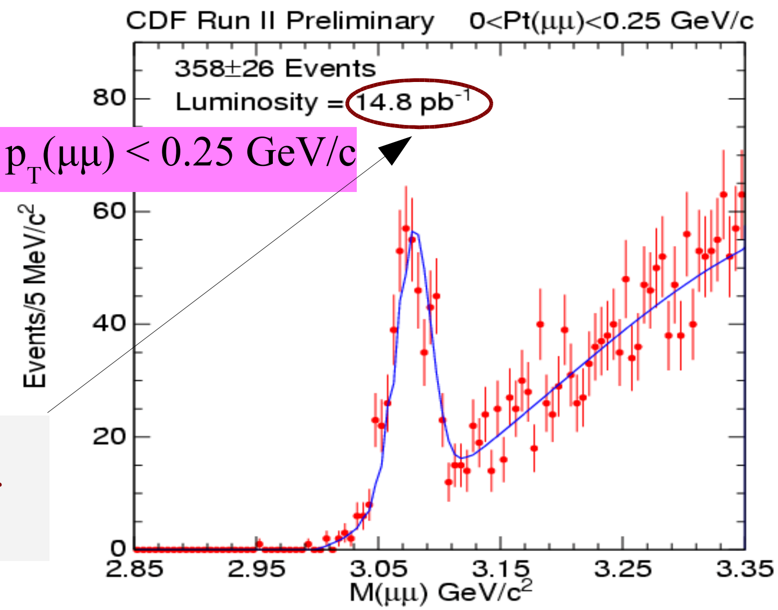
J/ψ production (CDF)

- dimuon trigger
- track matched muon p_T > 1.5 GeV
- 299800 ± 800 J/ψ in sample
  average width 20 ± 0.1 MeV
- mass fit shapes from Monte Carlo

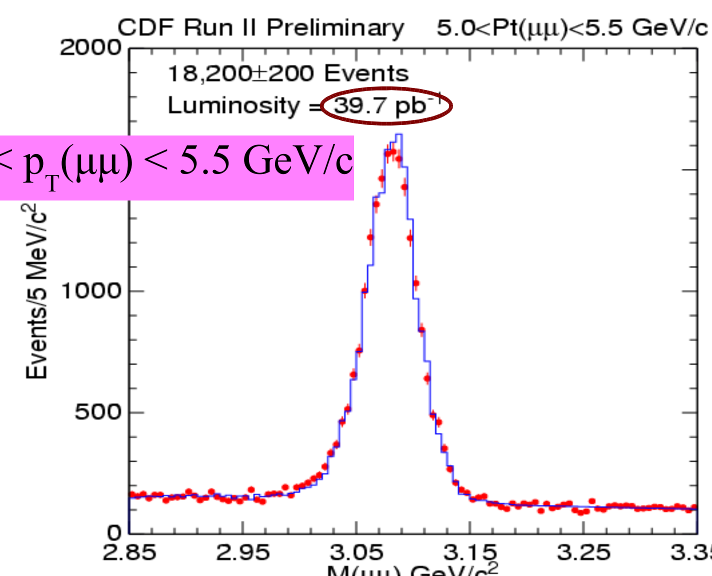


no opening angle in dimuon trigger required

0 < $p_T(\mu\mu)$ < 0.25 GeV/c



5.0 < $p_T(\mu\mu)$ < 5.5 GeV/c



J/ψ cross section (CDF)

$$\sigma_{J/\psi} \times Br \equiv \sigma(pp \rightarrow J/\psi\, X,\ |y(J/\psi)| < 0.6) \times Br(J/\psi \rightarrow \mu\mu)$$

Run II, $\sqrt{s}$ = 1.96 TeV, $p_T(J/\psi) > 0.0$

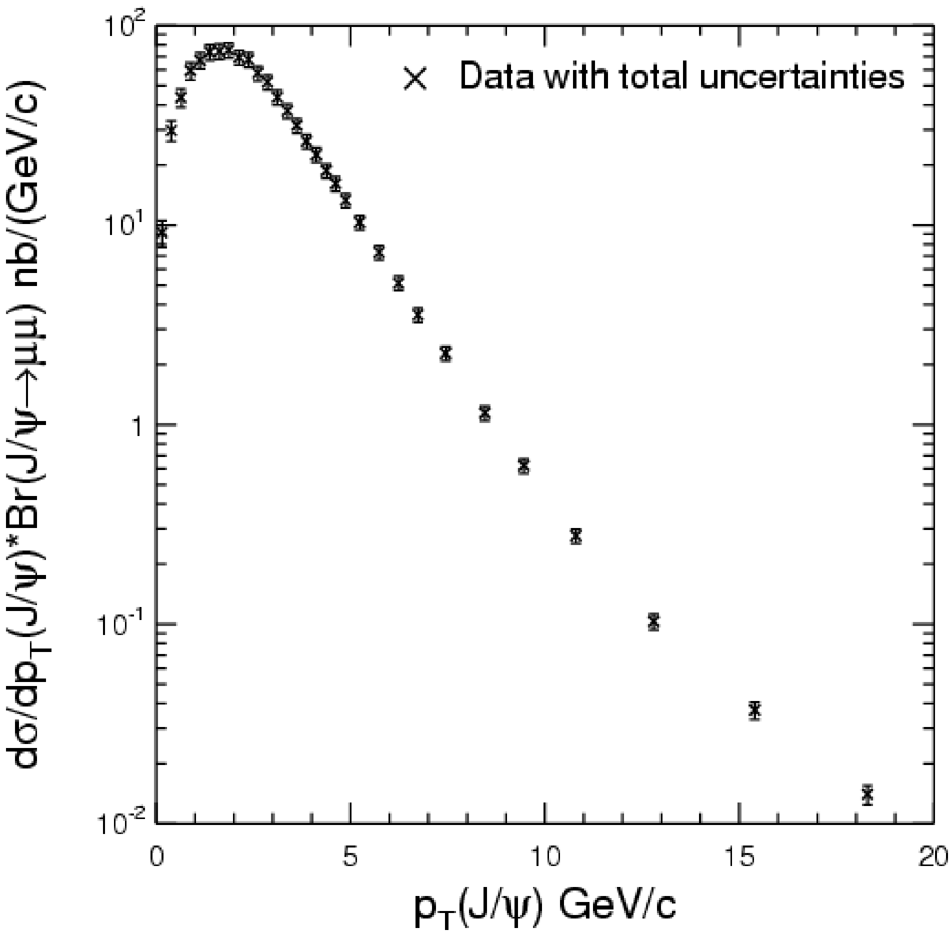
$\sigma_{J/\psi} \times Br = 240 \pm 1\ (\text{stat})\ ^{+21}_{-19}\ (\text{syst})$ nb

Run II, $\sqrt{s}$ = 1.96 TeV, $p_T(J/\psi) > 5.0$

$\sigma_{J/\psi} \times Br = 16.3 \pm 0.1\ (\text{stat})\ ^{+1.4}_{-1.3}\ (\text{syst})$ nb

Run I, $\sqrt{s}$ = 1.8 TeV, $p_T(J/\psi) > 5.0$

$\sigma_{J/\psi} \times Br = 17.4 \pm 0.1\ (\text{stat})\ ^{+2.6}_{-2.8}\ (\text{syst})$ nb



~10% increase in cross section due to increased $\sqrt{s}$ expected.

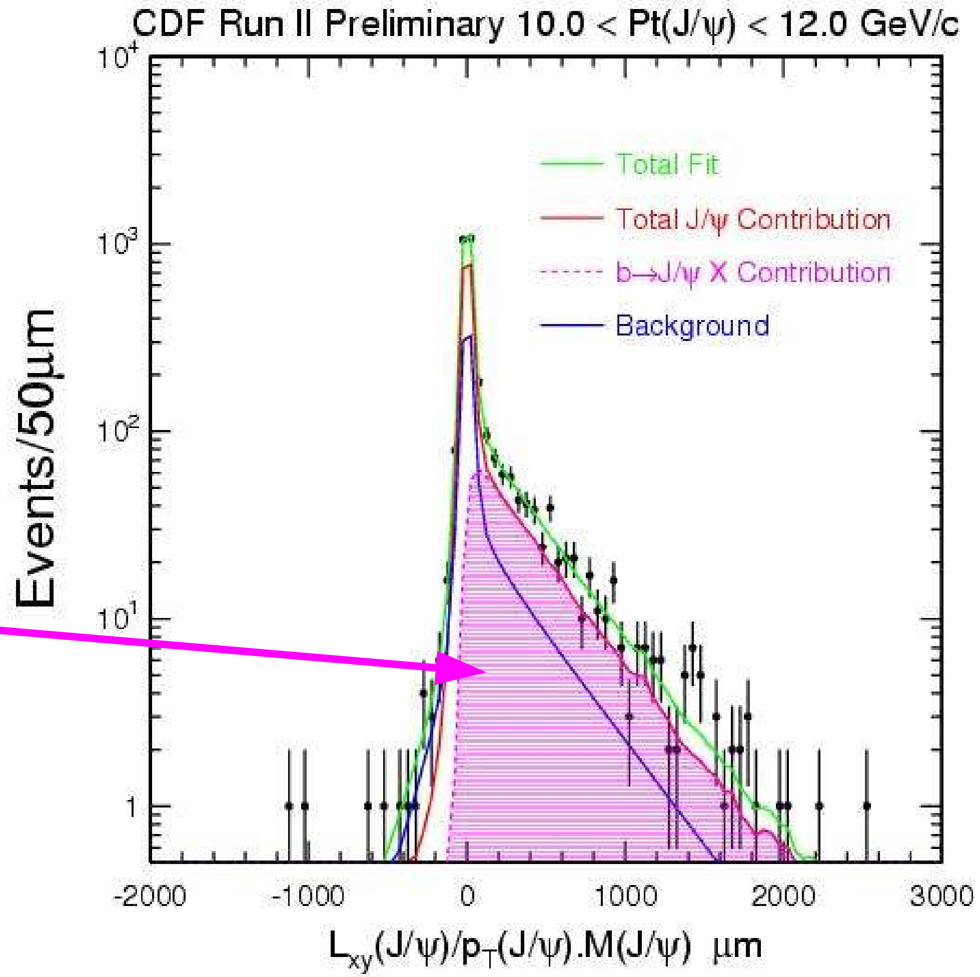
Run I and Run II agree within errors.

b-fraction (CDF)

Projection of the J/ψ flight distance on its transverse momentum L_{xy}

Use pseudo proper decay time
$x = L_{xy}(J/\psi) * m(J/\psi)/pT(J/\psi)$
to separate prompt J/ψ from
b-hadron decays.

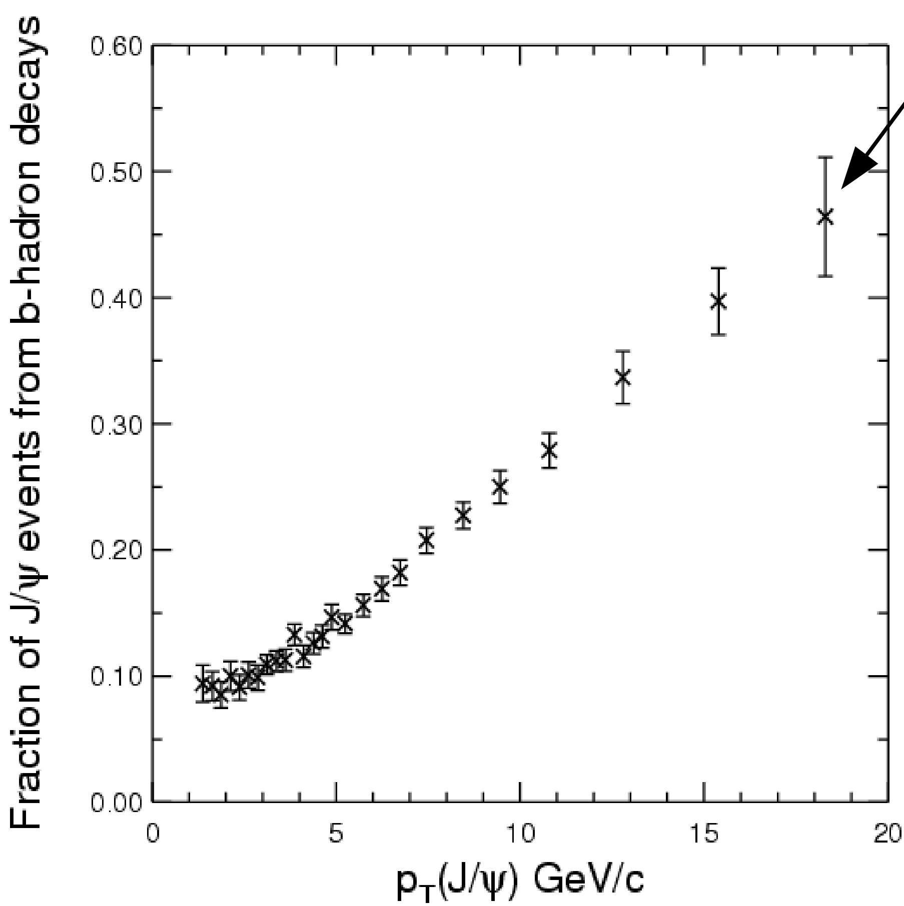
Monte Carlo templates
model $x(J/\psi)_b$

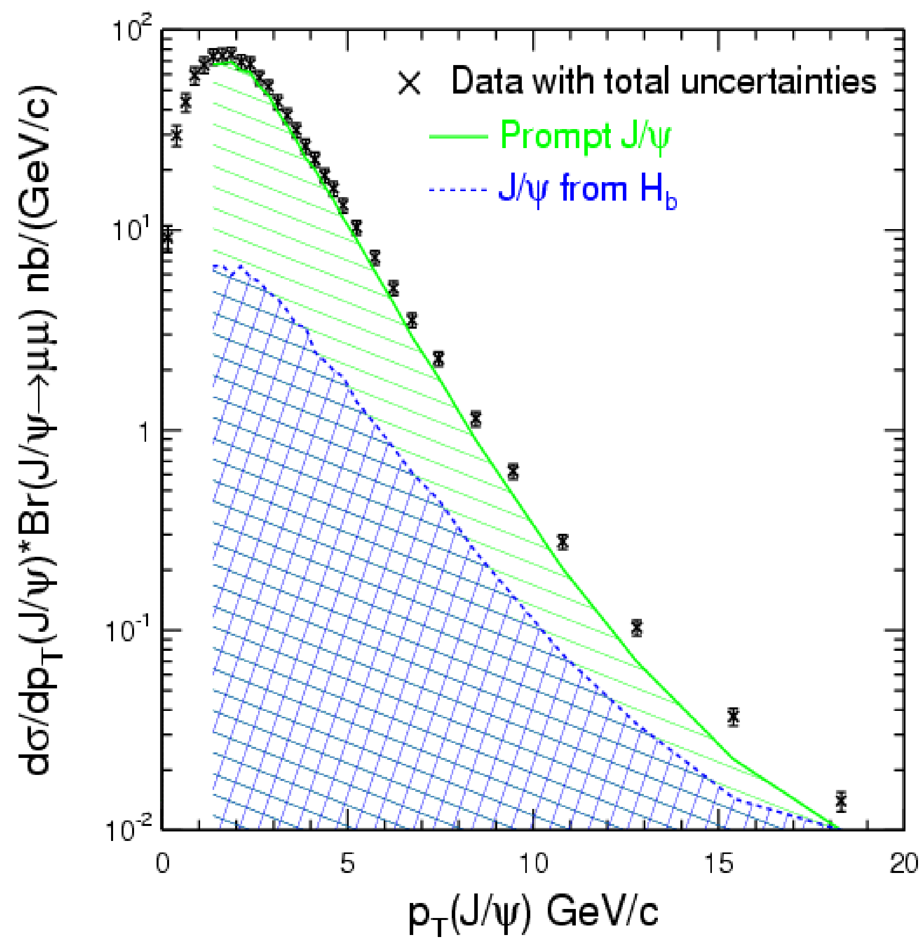


A maximum likelihood fit to x is used to extract the b-fraction.

b-fraction in J/ψ events (CDF)

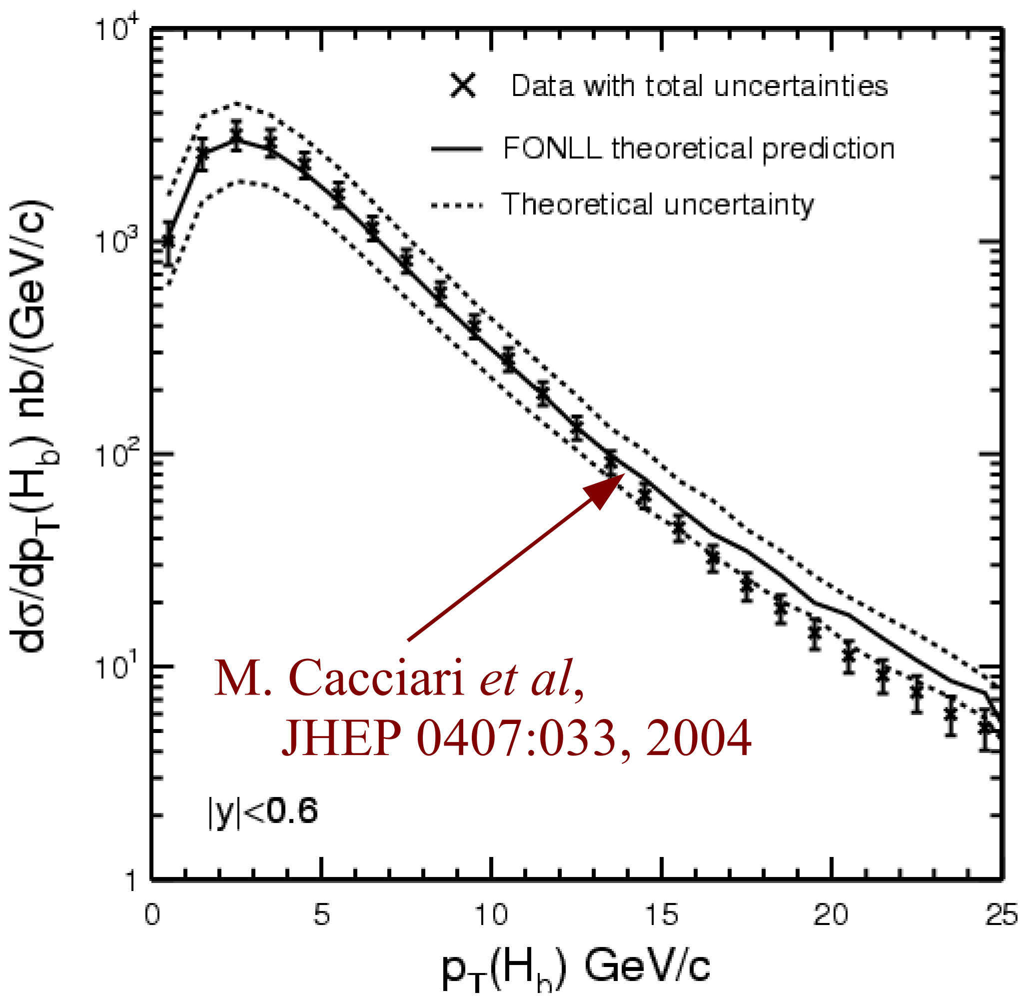
Systematic uncertainties on b-fraction: ± (3-13) %
p_T dependent systematic uncertainties decrease with increasing p_T
errors in high (> 9 GeV) p_T bins statistics dominated



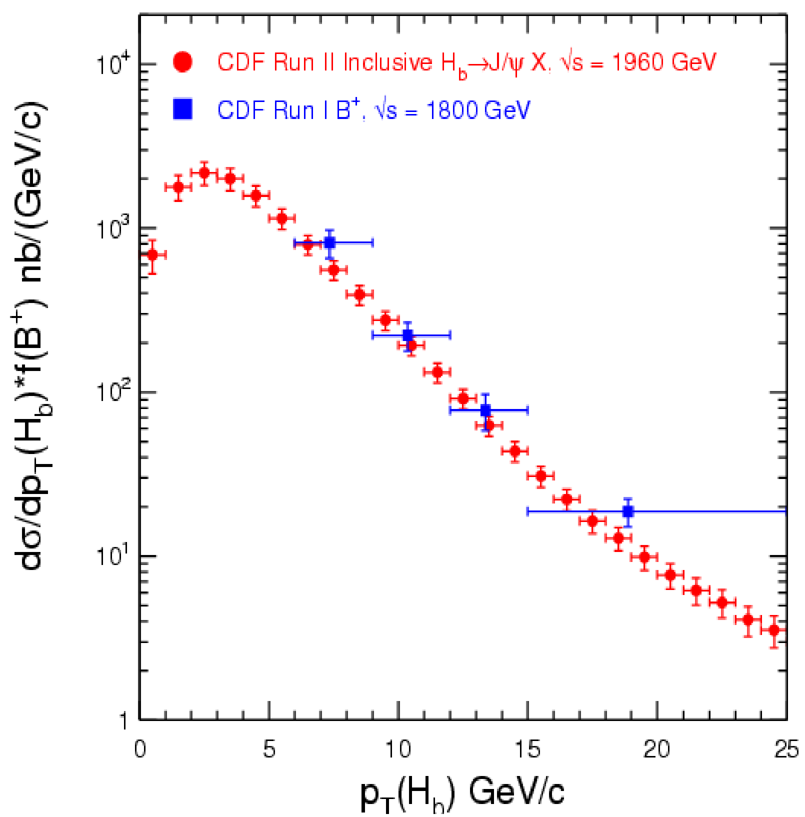


b-hadron production cross section (CDF)

Comparison with theory



Comparison with Run I results



Run I: B^+ cross section, $|y| < 1.0$

Run II: incl. x-sec scaled to $|y| < 1.0$

fragmentation fraction $f(B^+)$ from LEP

b-hadron production cross section (CDF)

$\sigma(p\bar{p} \rightarrow H_b X, |y^{J/\psi}| < 0.6) \times Br(H_b \rightarrow J/\psi X) \times Br(J/\psi \rightarrow \mu\mu)$

Run II, $\sqrt{s}$ = 1.96 TeV, $p_T(J/\psi) > 1.25$

$19.4 \pm 0.3\ (\text{stat})\ ^{+2.1}_{-1.9}\ (\text{syst})$ nb

Run II, $\sqrt{s}$ = 1.96 TeV, $p_T(J/\psi) > 5.0$

$2.75 \pm 0.04\ (\text{stat}) \pm 0.20\ (\text{syst})$ nb

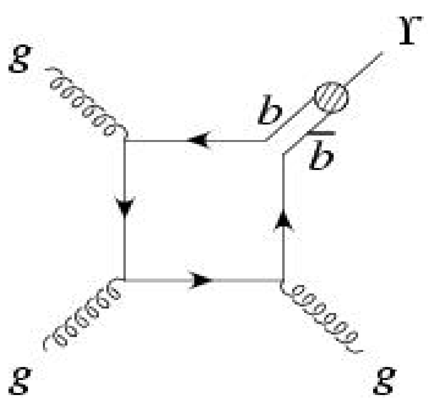
Run I, $\sqrt{s}$ = 1.8 TeV, $p_T(J/\psi) > 5.0$

$3.23 \pm 0.05\ (\text{stat})\ ^{+0.28}_{-0.31}\ (\text{syst})$ nb

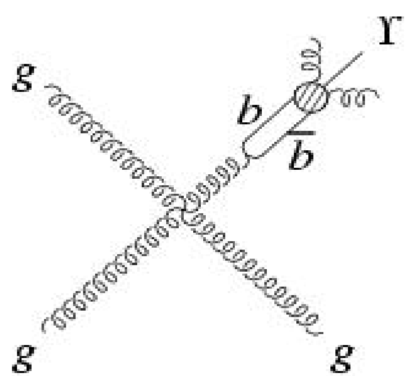
Υ(1S) production

- Quarkonium production is a window on the boundary region between perturbative and non-pertubative QCD

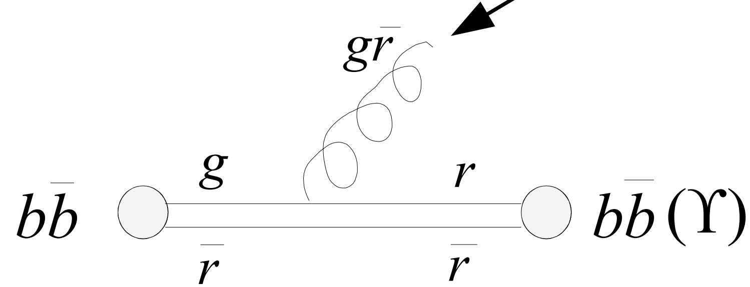
Color singlet mechanism



Color octet mechanism



color evaporation



- V.A. Khoze , A.D. Martin, M.G. Ryskin, W.J. Stirling, hep-ph/0410020
- E.L. Berger, J.Qiu, Y.Wang, Phys Rev D 71 034007 (2005)

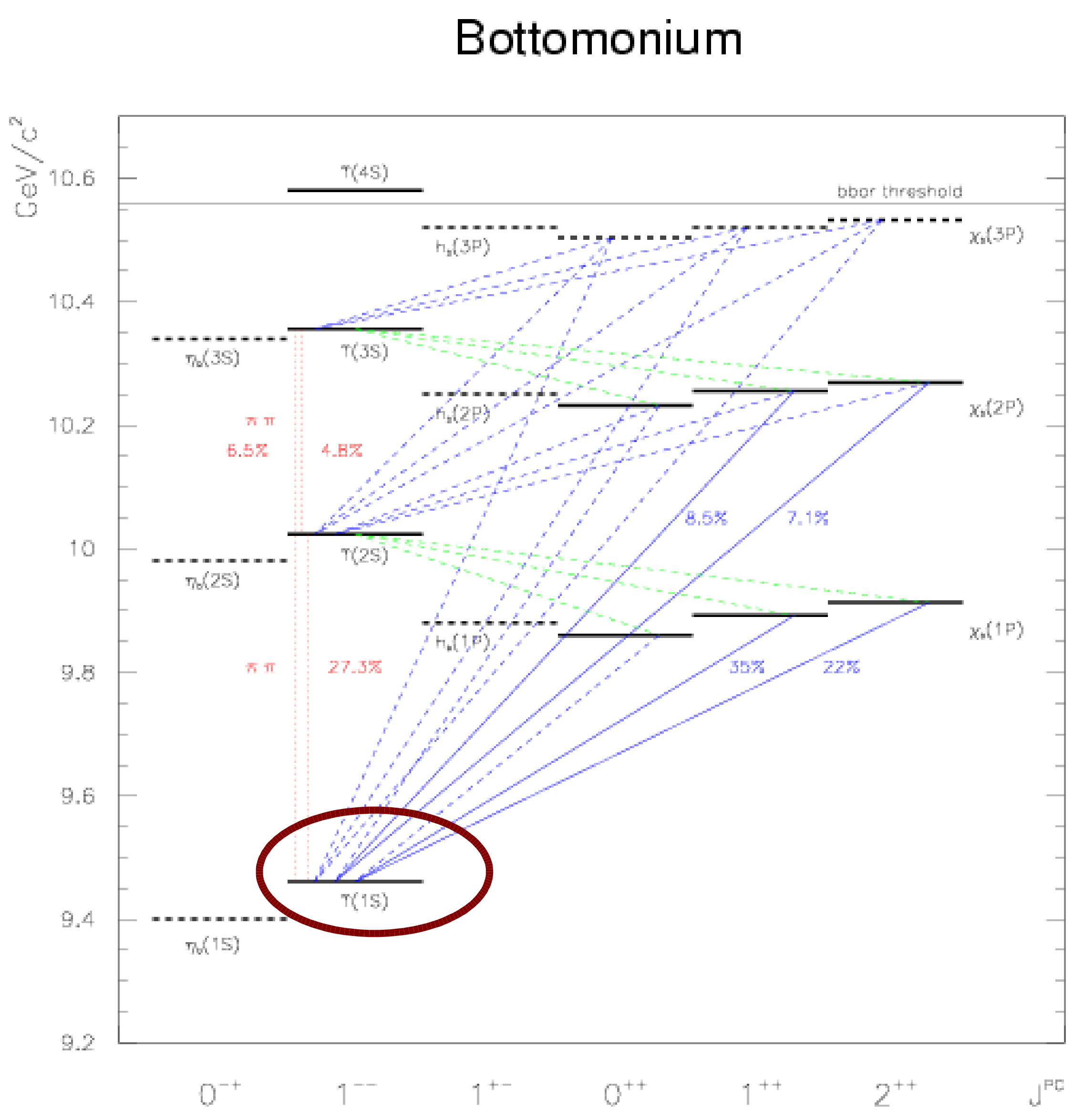
$\Upsilon(1S)$ cross sections (DØ)

Measurement of inclusive differential cross sections for $\Upsilon(1S)$ production in $p\bar{p}$ collisions at $\sqrt{s}$ = 1.96 TeV, Phys. Rev. Lett. 94, 232001 (2005).

- Extends CDF Run I measurement from $|y^{\Upsilon}| < 0.4$ to $|y^{\Upsilon}| < 1.8$
- First measurement of $\Upsilon(1S)$ at $\sqrt{s}$ = 1.96 TeV
- Cross section is determined in three rapidity bins:
  $0 < |y^{\Upsilon}| < 0.6$, $0.6 < |y^{\Upsilon}| < 1.2$ and $1.2 < |y^{\Upsilon}| < 1.8$
  in the channel $\Upsilon \to \mu\mu$ using DØ's large muon coverage
- Larger statistics allow more precise determination of shape of the differential cross section.

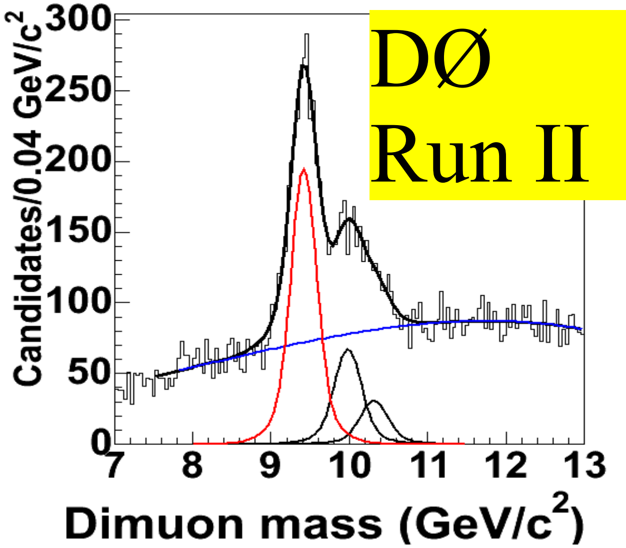
Origins of ϒ(1S)

- All bottomonium states are produced directly (e.g ≠ J/ψ from *B*)
- ~50 % of all ϒ(1S) are produced directly, the rest are the results of higher mass states decaying.



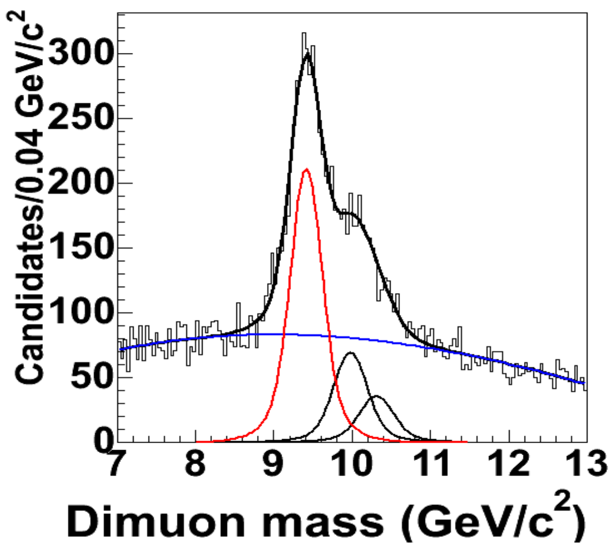
ϒ(1S) signal (DØ)

4 GeV < p_T(ϒ) < 6 GeV



$0 < |y^{\Upsilon}| < 0.6$

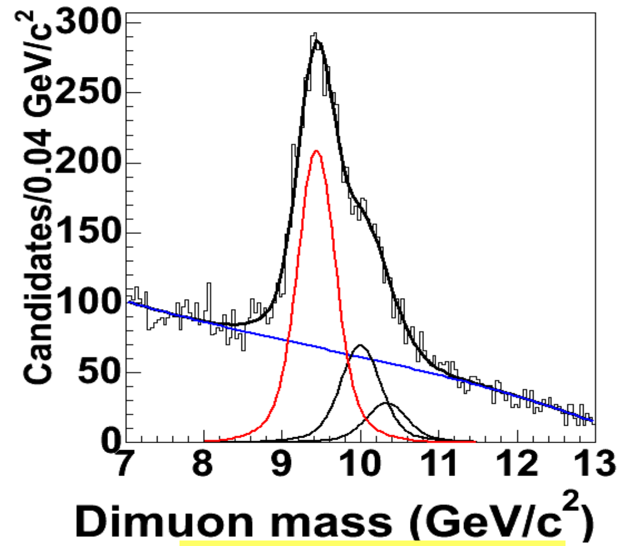
m(ϒ) = 9.419 ± 0.007 GeV



$0.6 < |y^{\Upsilon}| < 1.2$

m(ϒ) = 9.412 ± 0.009 GeV

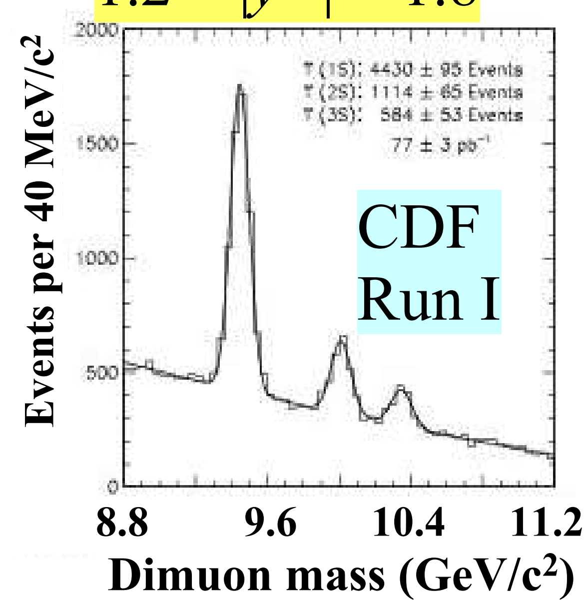
m(ϒ) = 9.437 ± 0.010 GeV



$1.2 < |y^{\Upsilon}| < 1.8$

PDG: m(ϒ(1*S*)) = 9.460 GeV

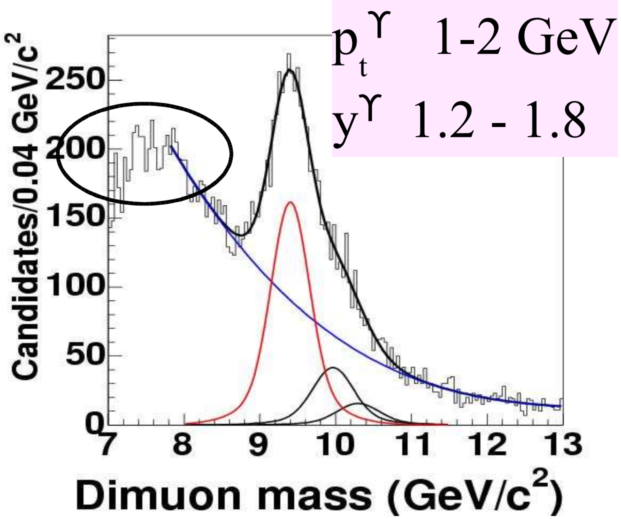
~ 40,000 ϒ(1*S*) in 159 pb^{-1}



Fitting the Υ(1S) signal (DØ)

Signal: 3 double Gaussians: Υ(1*S*), Υ(2*S*), Υ(3*S*)
using ratios for width and normalization from fits to J/ψ

Background: 3rd order polynomial
Fit expects smooth
background → adjust fit limit



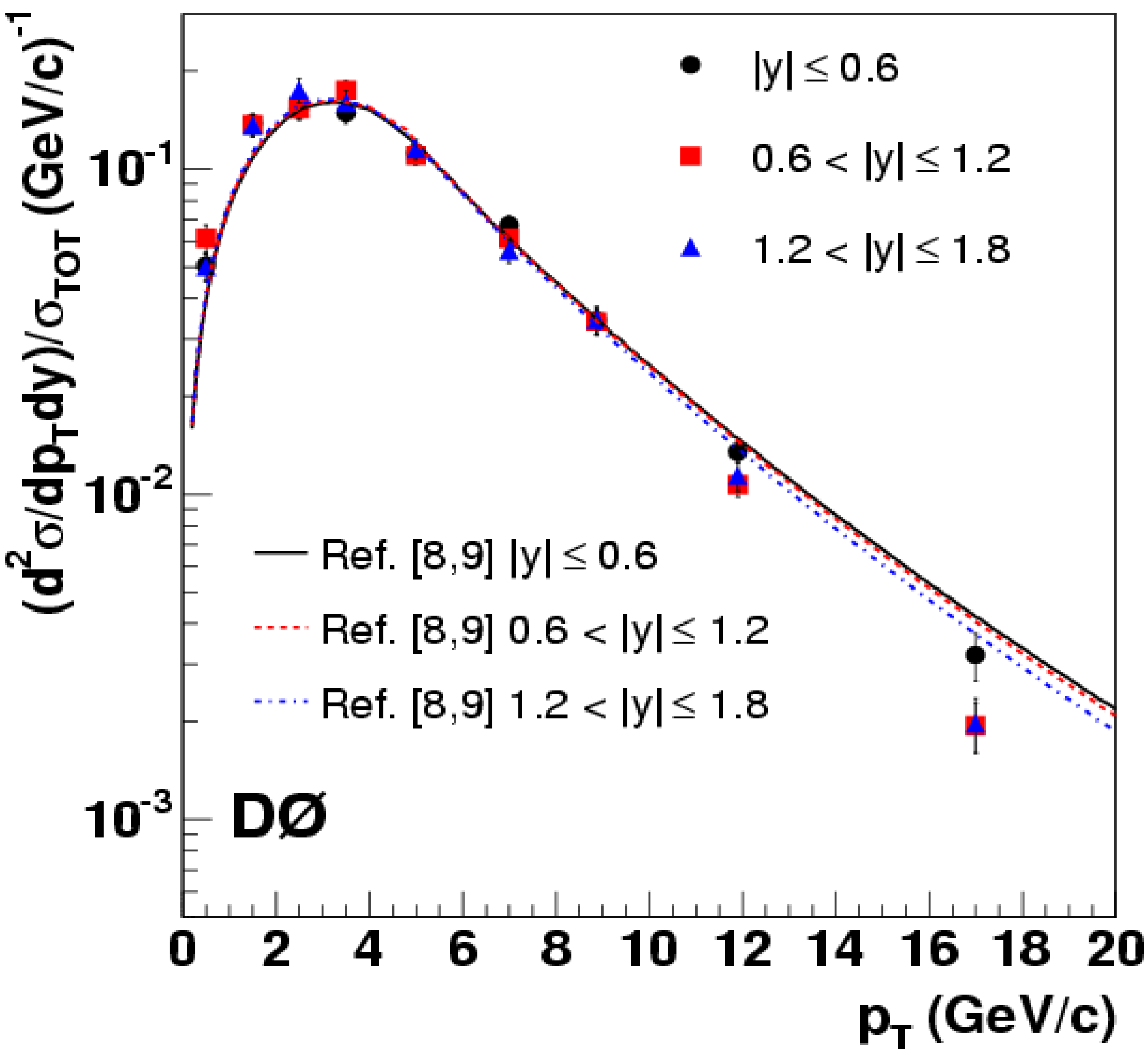
$$m(\Upsilon(2/3S)) = m(\Upsilon(1S)) + \Delta\, m_{PDG}(\Upsilon(2/3S)-\Upsilon(1S))$$

$$\sigma(\Upsilon(2/3S)) = m(\Upsilon(2/3S)/m(\Upsilon(1S)) * \sigma(\Upsilon(1S))$$

→5 free parameters in signal fit:

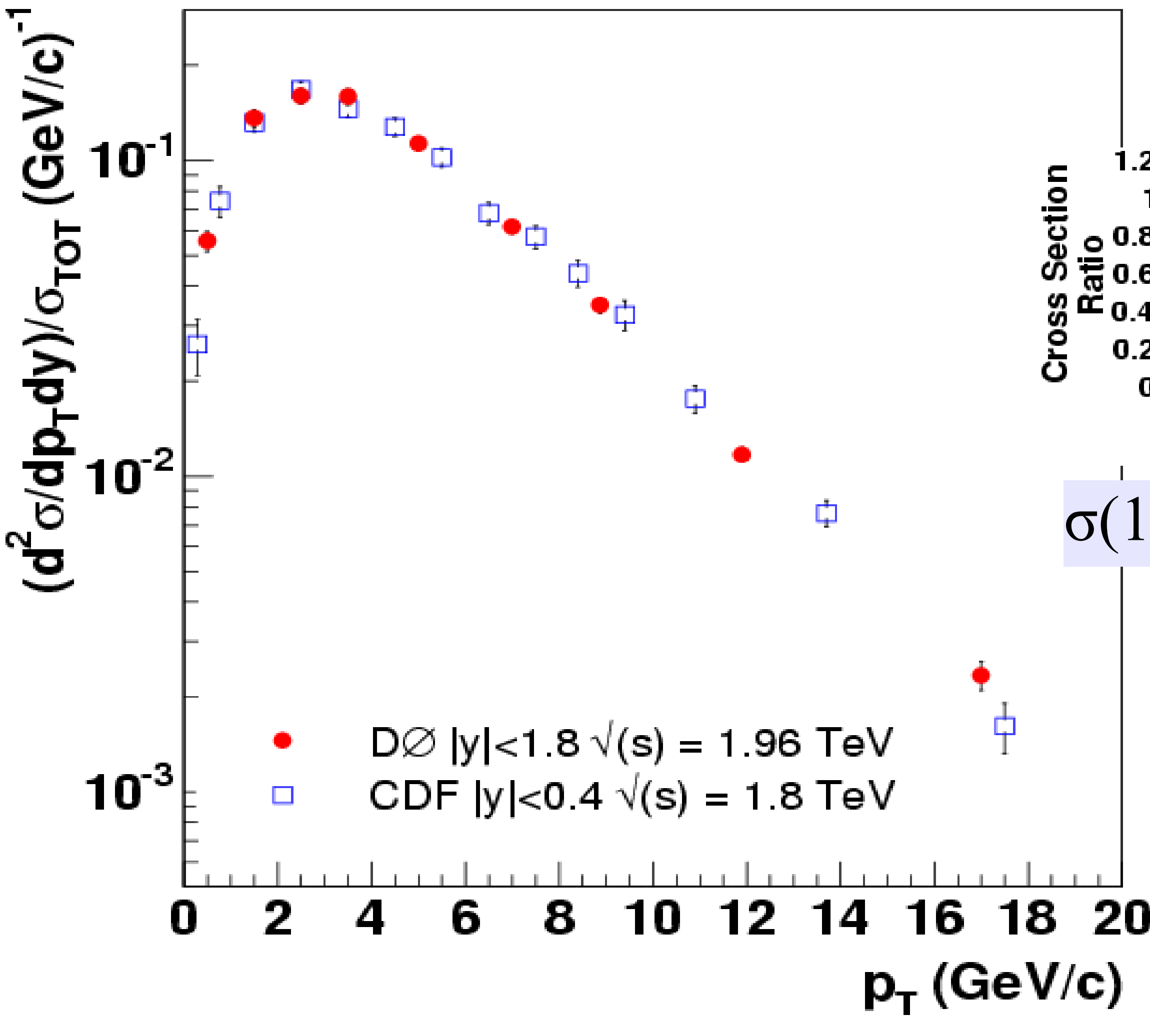
m(Υ(1*S*)), **σ**(Υ(1*S*)), **n**(Υ(1*S*)), **n**(Υ(2*S*)), **n**(Υ(3*S*))

$\Upsilon(1S)$ differential cross section (DØ)

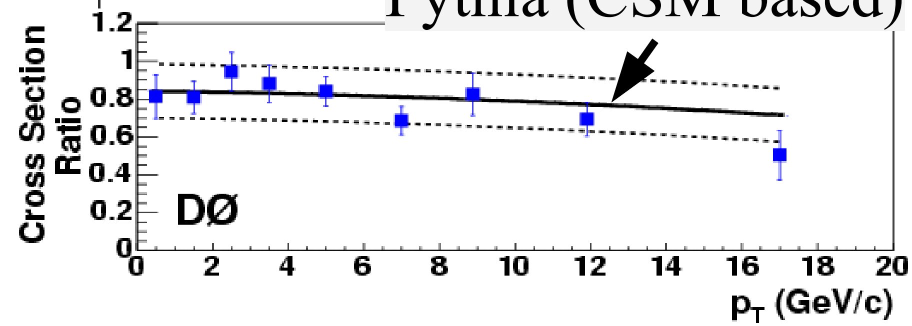


- little variation in the shape of the cross section as a function of rapidity
- reasonable agreement with calculations by Berger *et al,* hep-ph/0411026

Υ(1S) differential cross section (DØ)



Pythia (CSM based)



$\sigma(1.2 < y^{\Upsilon} < 1.8)/\sigma(0.0 < y^{\Upsilon} < 0.6)$

statistical (+'fit') errors only – remaining errors are p_T independent

$\Upsilon(1S)$ cross section (DØ)

Results: $d\sigma(\Upsilon(1S))/dy \times B(\Upsilon(1S)) \rightarrow \mu^+\mu^-$

$0.0 < y^{\Upsilon} < 0.6$	732 ± 19 (stat) ± 73 (syst) ± 48 (lum) pb
$0.6 < y^{\Upsilon} < 1.2$	762 ± 20 (stat) ± 76 (syst) ± 50 (lum) pb
$1.2 < y^{\Upsilon} < 1.8$	600 ± 19 (stat) ± 56 (syst) ± 39 (lum) pb
$0.0 < y^{\Upsilon} < 1.8$	695 ± 14 (stat) ± 68 (syst) ± 45 (lum) pb

CDF Run I: 680 ± 15 (stat) ± 18 (syst) ± 26 (lum) pb

b-jet cross section (CDF)

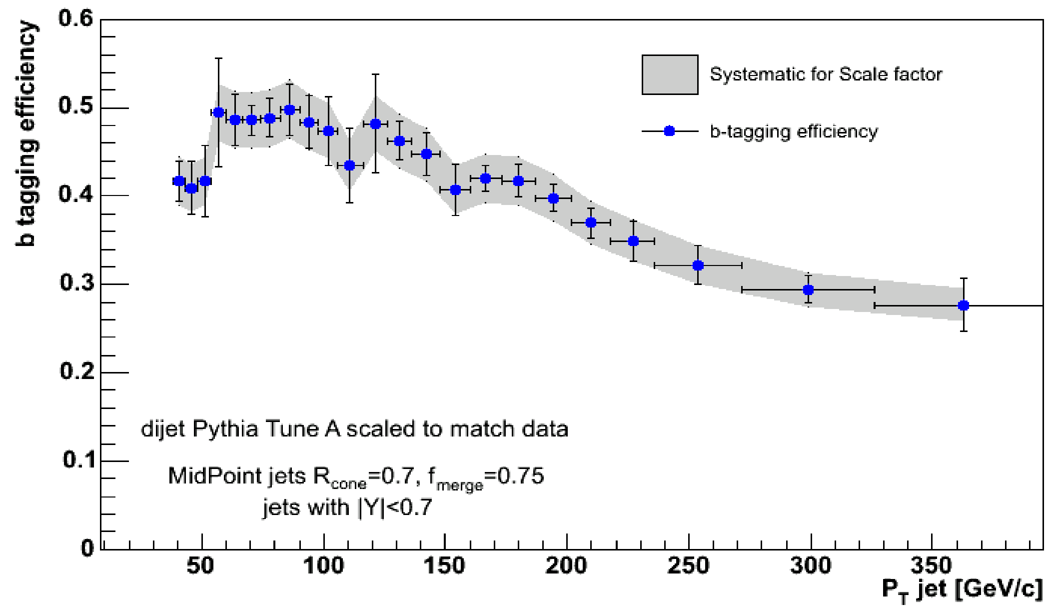
Goal: Measure differential *b*-jet cross section $d\sigma/dp_T$ in range 38-400 GeV/c.

Motivation: The mass of the *b*-quark is considered large enough to justify pertubative expansions to the strong coupling constant → NLO should be sufficient to describe *b*-jet production.

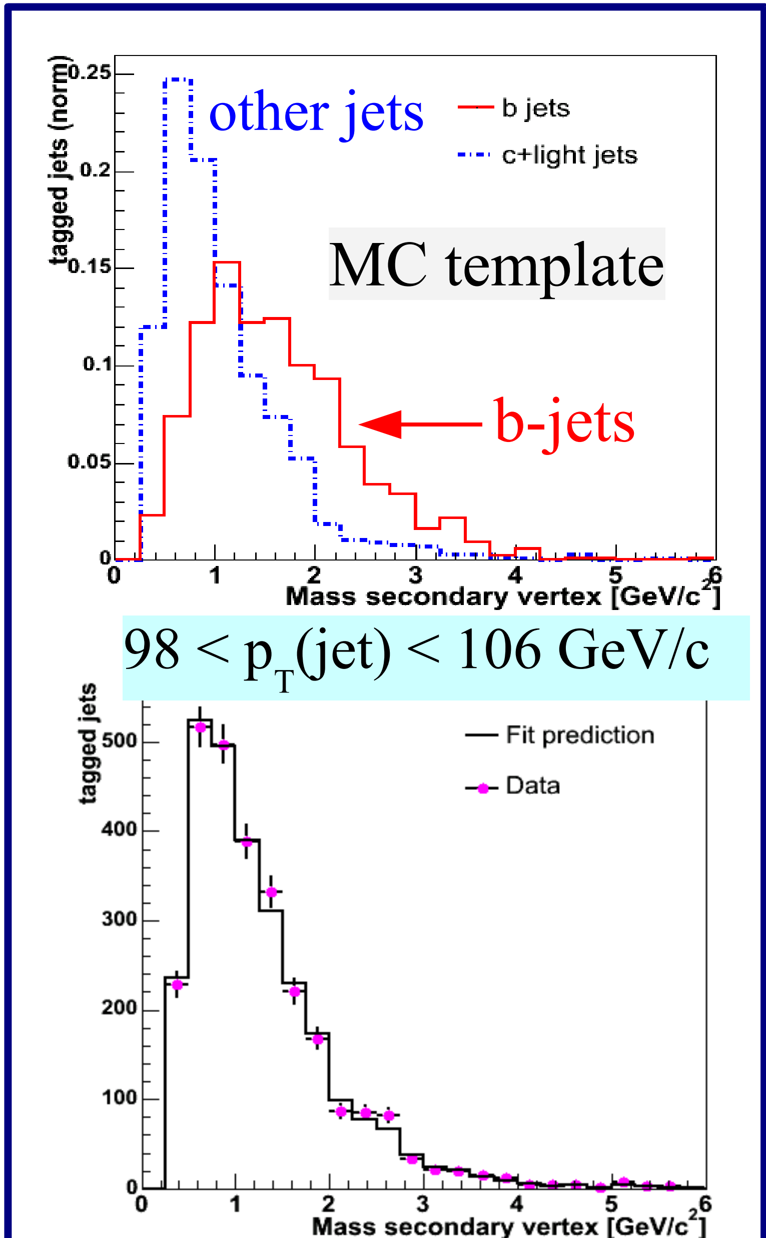
- ~300 pb^{-1}
- R=0.7 cone jets, $|y^{jet}| < 0.7$
- use secondary vertex for *b*-tagging
- use decay length to reject mistagged jets ($L_{xy} > 0$)

b-tagging efficiency

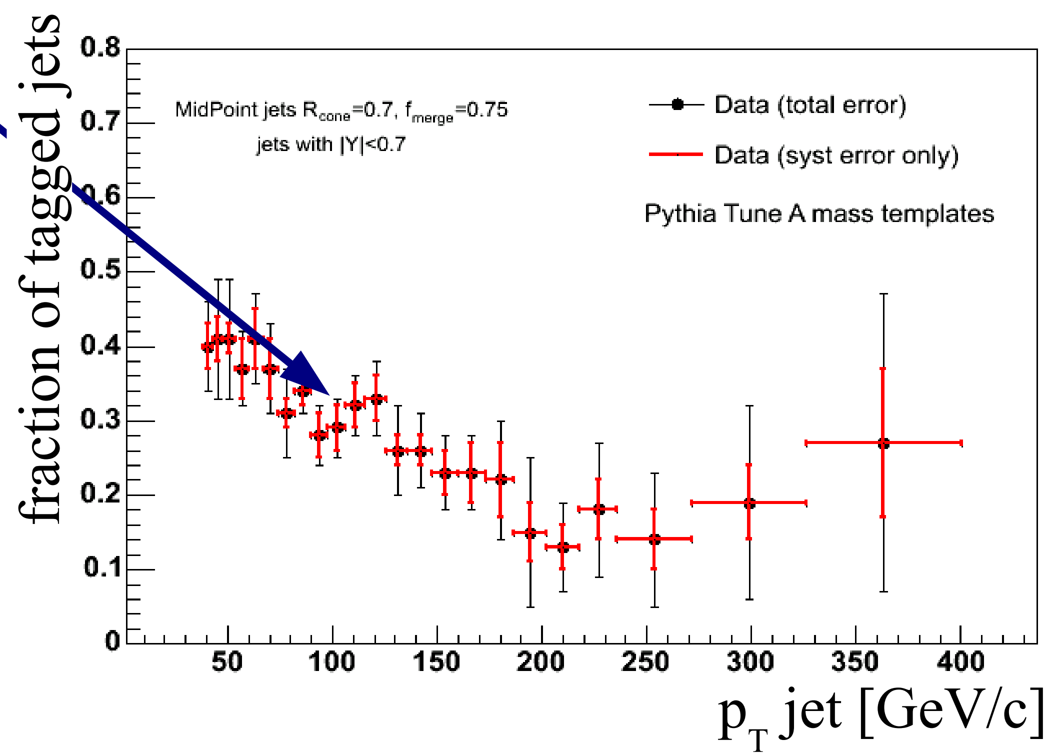
From data (inclusive electron sample – does not depend on secondary vtx) and MC



Fraction of *b*-tagged jets (CDF)

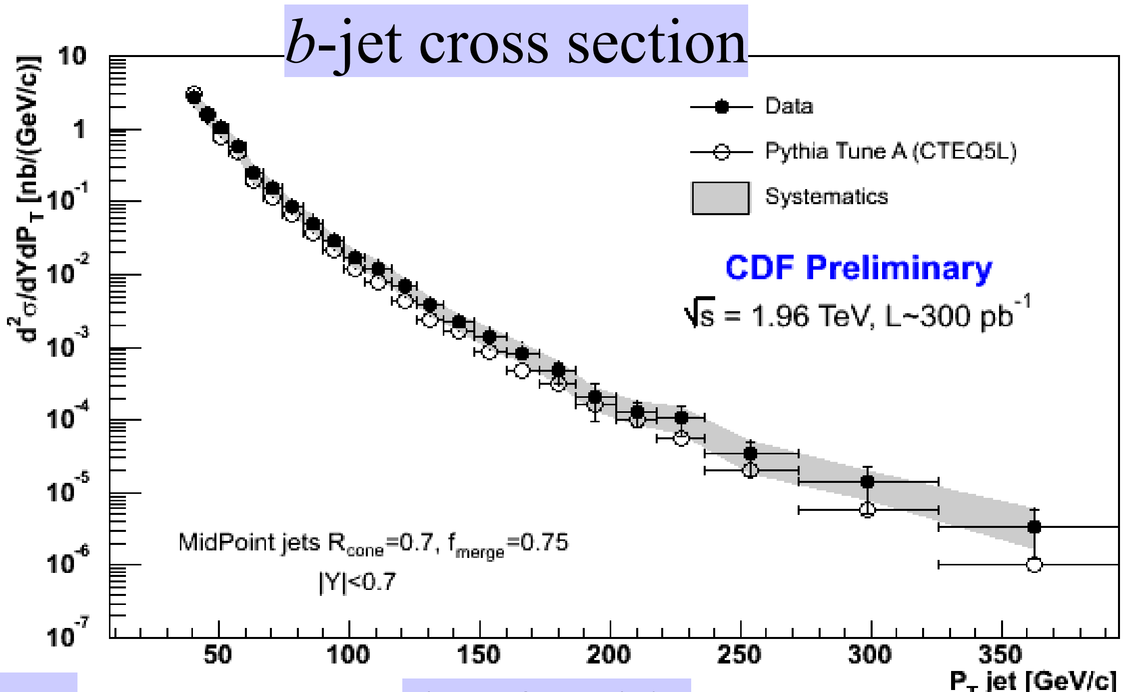


- Extract fraction of b-tagged jets by using the shape of the mass distribution of the secondary vertex as discriminant.
- Bins as a function of p_T(jet)

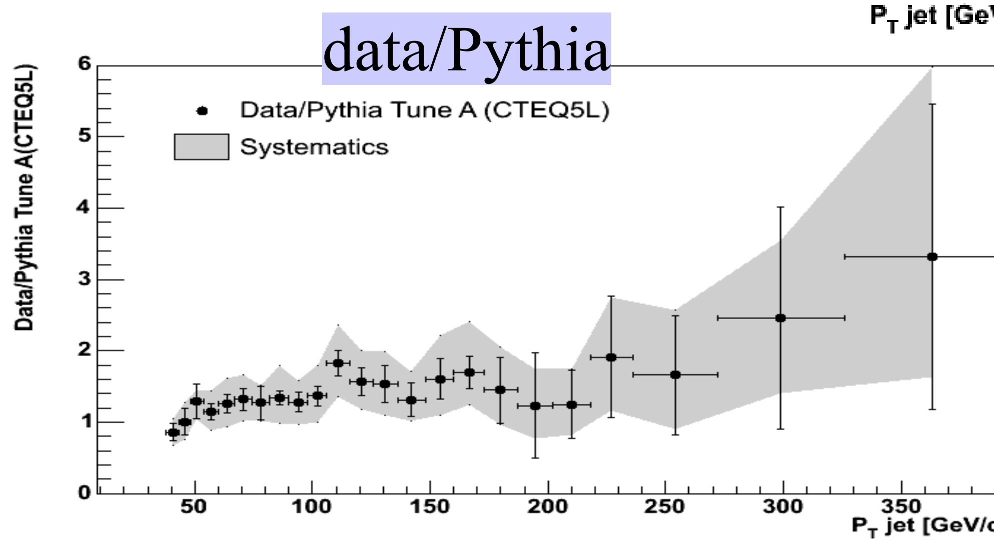


b-jet cross section (CDF)

Systematic Error	low p_T	high p_T
Luminosity	6 %	6 %
Abs. Energy Scale	15-20 %	40 %
Jet Energy Res	6 %	6 %
B-tagging eff	10 %	15 %
B-tagged fraction	10-15 %	40 %
Unfolding	8 %	8 %

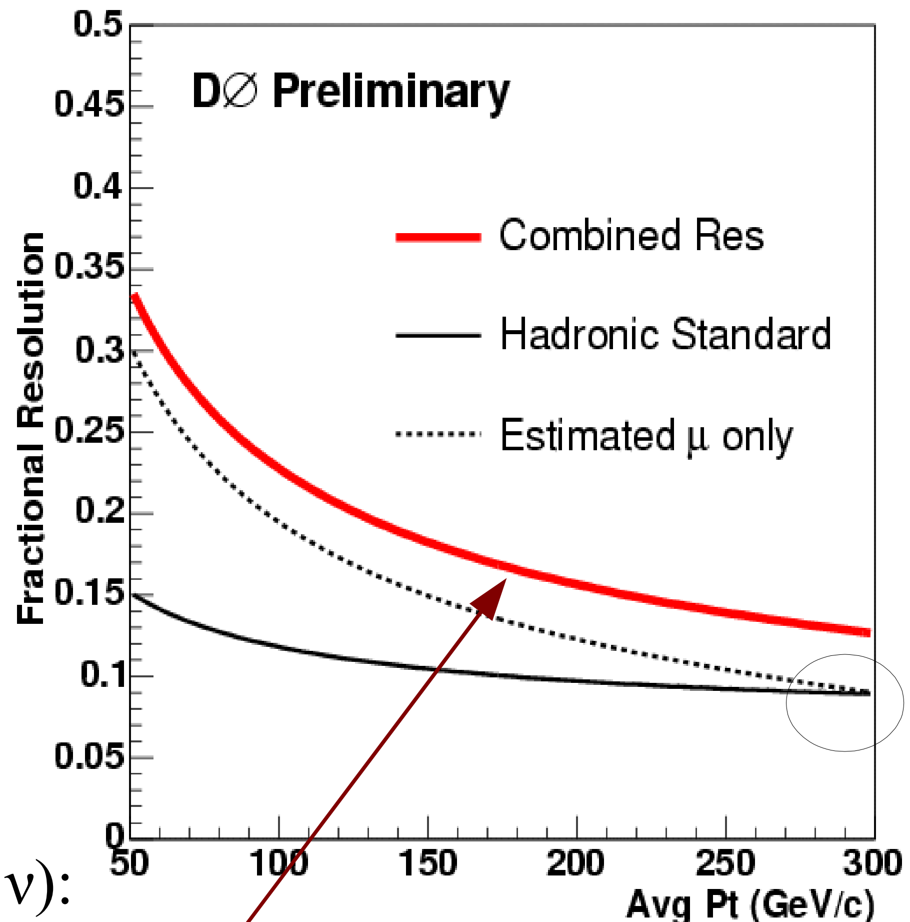


Ratio Data/Pythia(Tune A)
~ 1.4
→ in agreement with expectations



High p_T μ-tagged jet cross section (DØ)

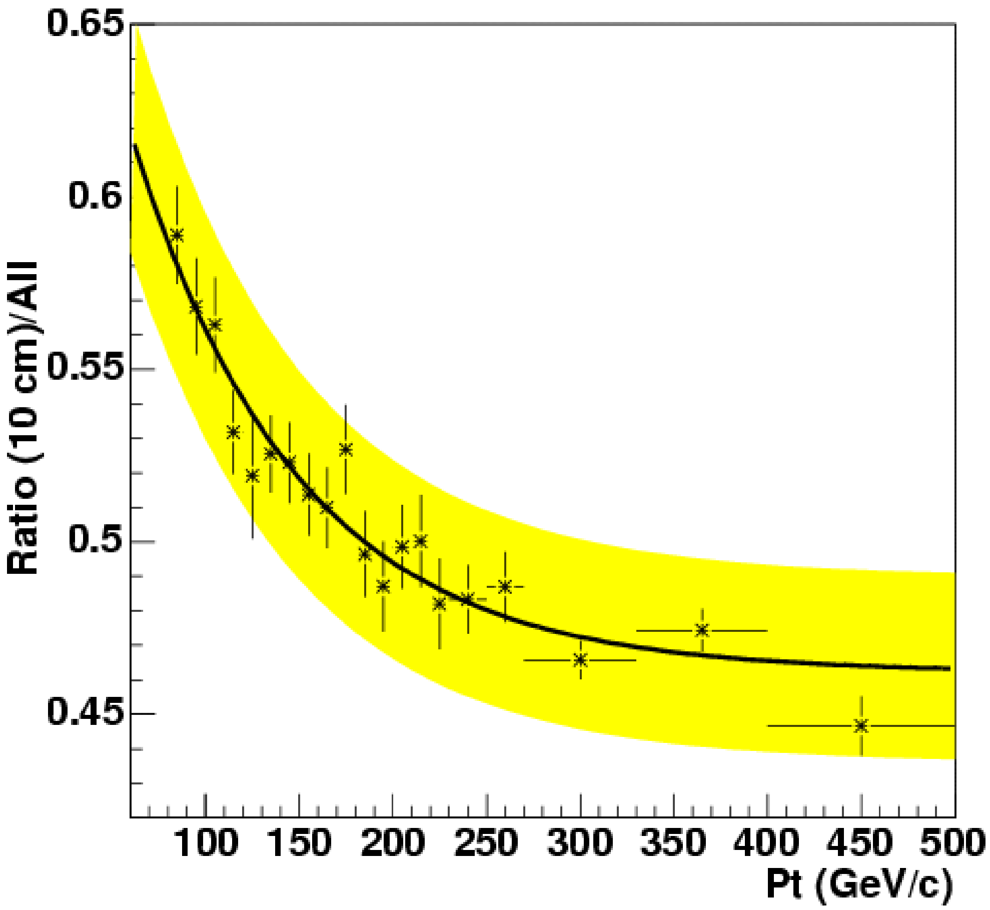
- first step towards $X \to bb$
- search for deviation from SM
- well defined experimental quantity:
  μ-tagged ≡ jet contains a muon at
  r = 10 cm around the beam
- 294 pb^{-1}
- R=0.5 cone jets, $|y^{jet}| < 0.5$ + medium μ
- 4660 μ-tagged jets in sample



- additional jet energy scale correction for μ-tagged jets
- μ-tagged energy resolution (collinear ν):
  use di-jet events with one μ-tagged and one μ-vetoed jet
- efficiencies: μ, trigger, primary vtx, jet quality
- resolution unsmearing

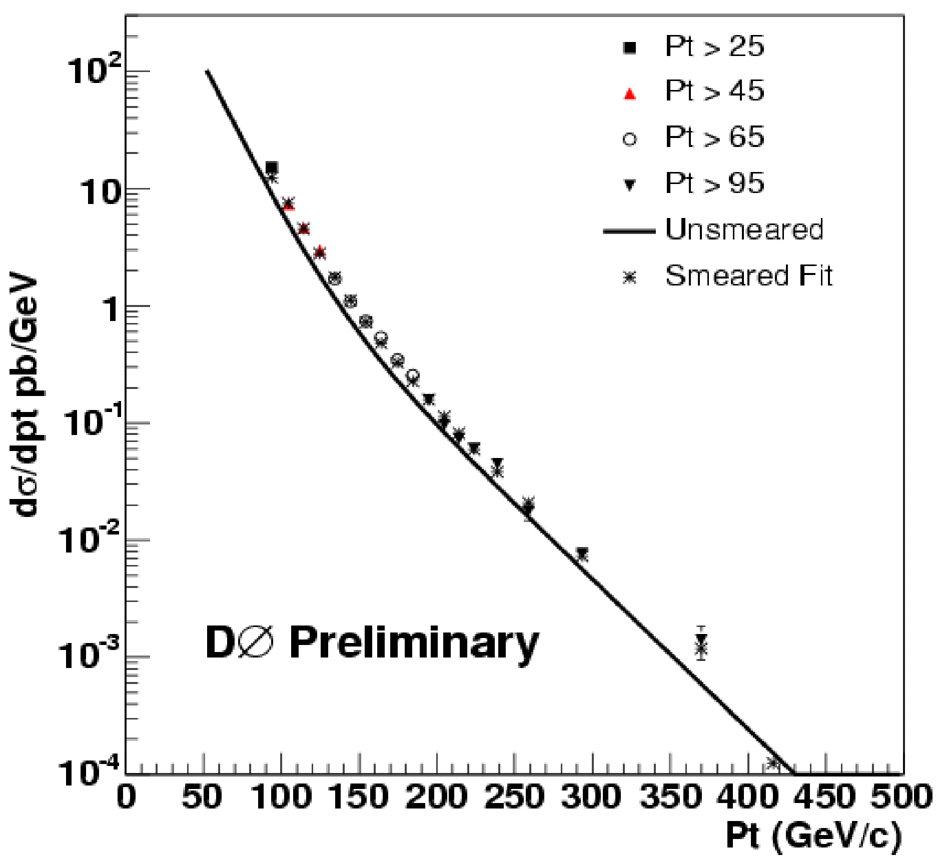
μ-tagged fraction (DØ)

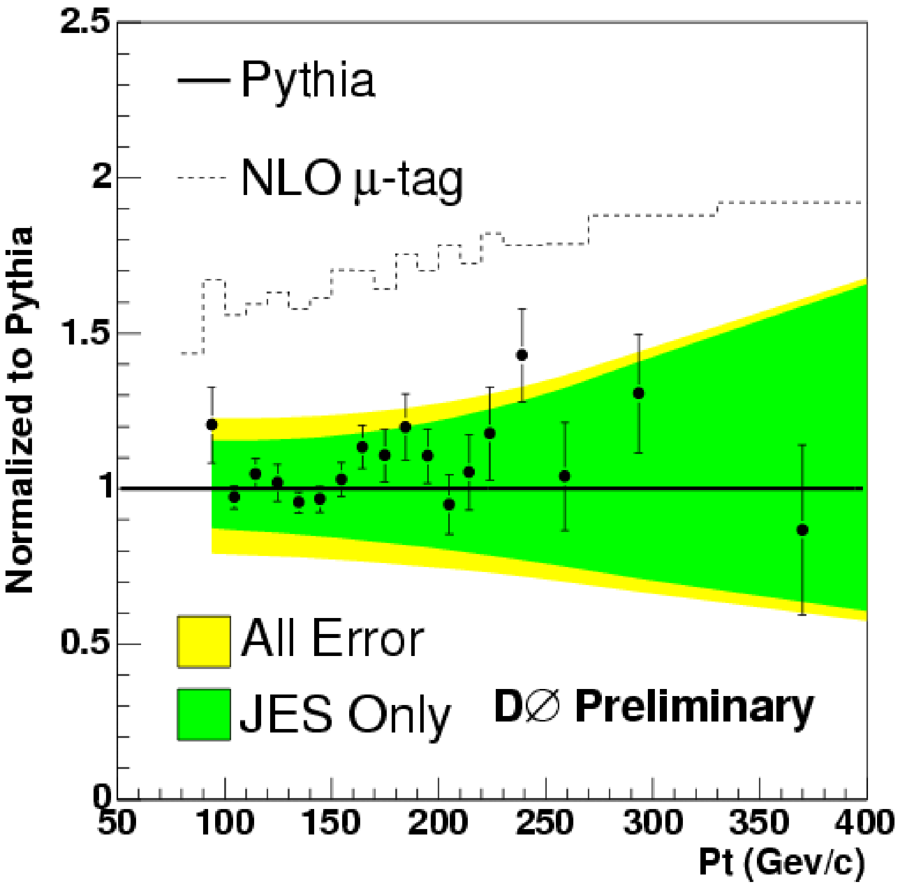
- μ-tagged → b+c quarks
- Contamination from K, π decays estimated from Monte Carlo (Pythia):
  ~ 4.5% at p_T = 100 GeV,
  ~7.5% at p_T > 220 GeV
- Pythia: ~ 55% of all μ-tagged jets from b-decays



μ-tagged jet cross section (DØ)

unsmeared = corrected for finite detector resolution → particle level truth





NLO = NLOJET++, Z. Nagy, Phys. Rev. D 68, 094002

Conclusions

- *b* and quarkonia production measurements probe perturbative and non-pertubative QCD.

- The differences between experimental data and theory that had been observed in Run I at the Tevatron are diminishing.

- J/ψ and *b*-hadron cross section measurements (CDF) are published.
- ϒ(1S) cross section measurement is published (DØ).

- Comparison of *b*-jet cross section (CDF) with NLO predictions (Mangano, Frixione) expected within a couple of weeks.

- DØ is working on *b*-jet cross section and ϒ(1S) polarization measurements.