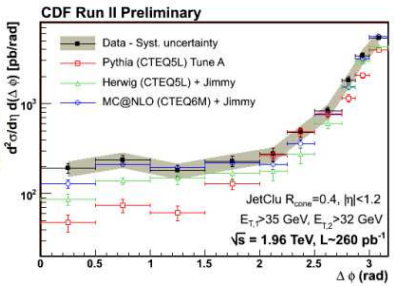
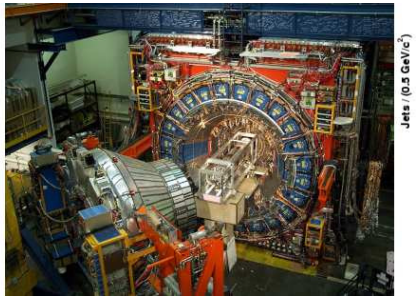
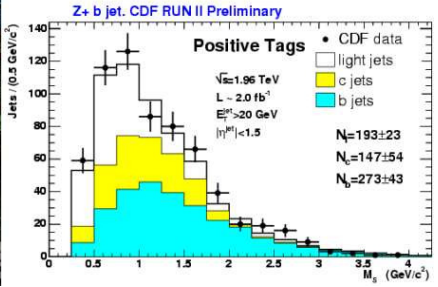
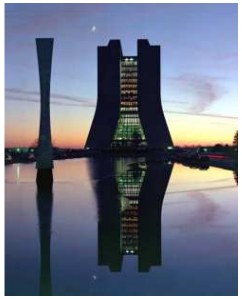


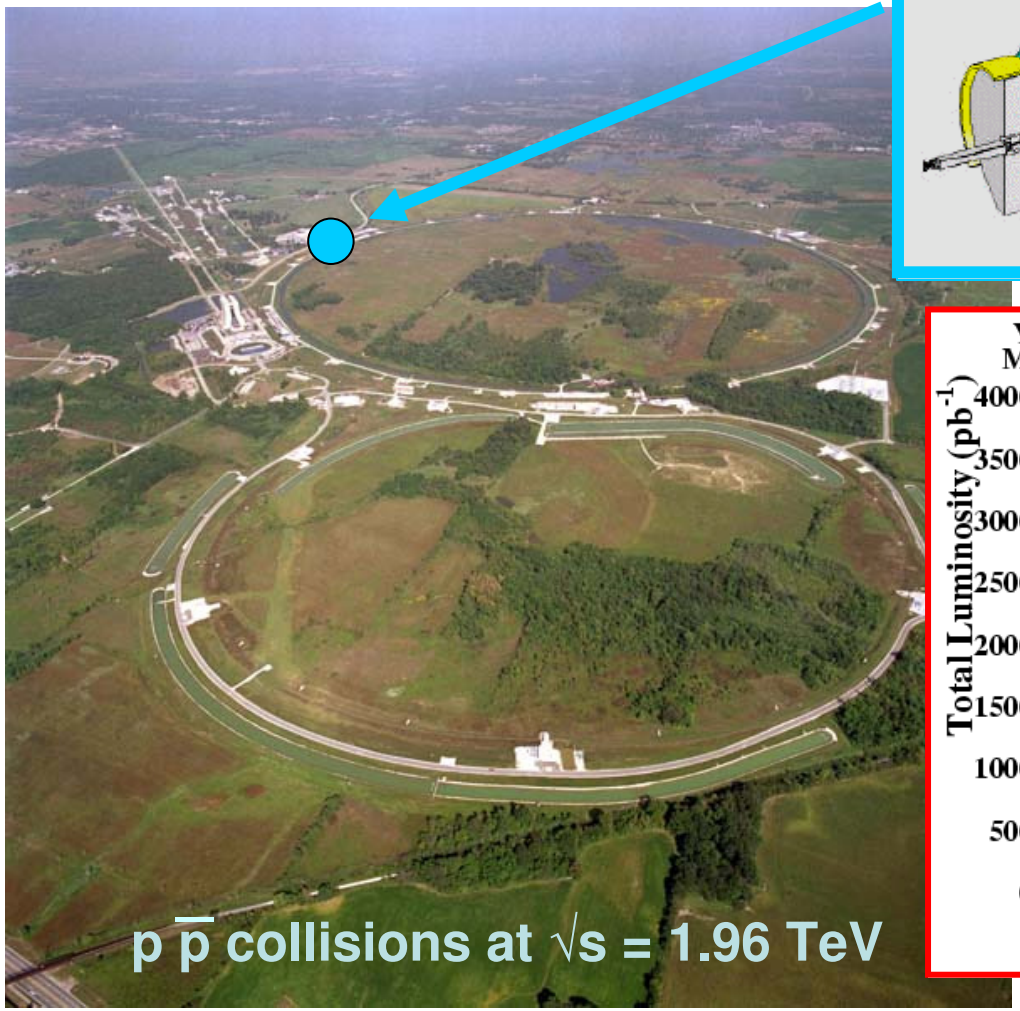


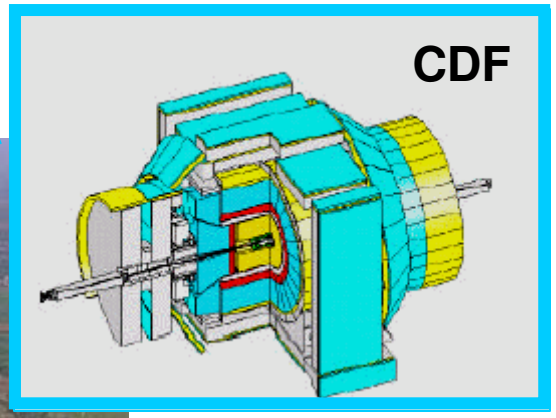



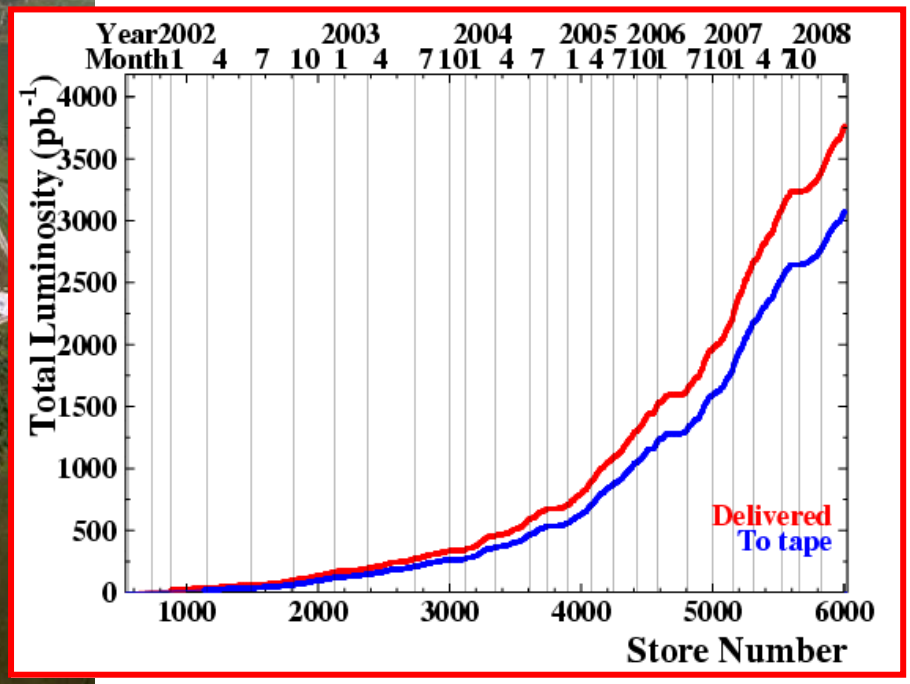
# Beauty production at CDF



Tara Shears
UNIVERSITY OF LIVERPOOL


p p̄ collisions at √s = 1.96 TeV


CDF

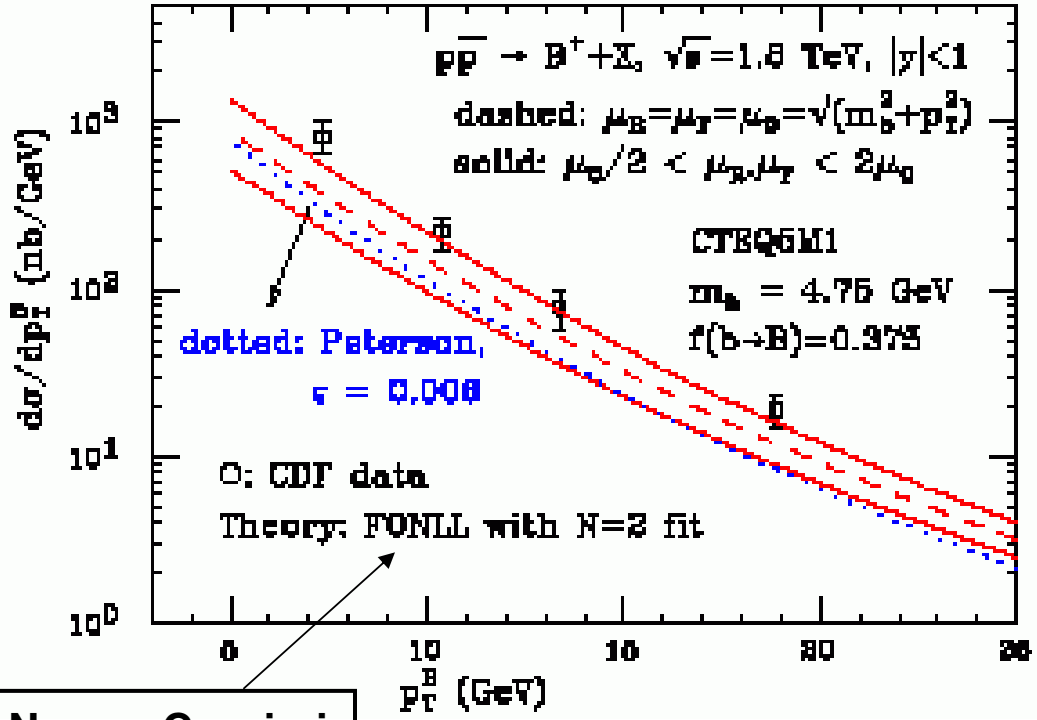

Year 2002 2003 2004 2005 2006 2007 2008
Month 1 4 7 10 1 4 7 10 1 4 7 10 1 4 7 10 1 4 7 10
Total Luminosity (pb⁻¹)
0 500 1000 1500 2000 2500 3000 3500 4000
1000 2000 3000 4000 5000 6000
Store Number
Delivered
To tape

**σ(B+): Phys Rev D65 052005**

**Discrepancy** from Run 1:

**B:** σ(data)/σ(**improved** theory) ~ **1.7**

**Aim:** test predictions at Run 2




**Nason, Cacciari**

**UPRF-2002-4**

# Improvements…….

**Theory:**

- Improved calculations (FONLL)
- Better treatment of fragmentation
- More recent PDF sets used

→ **higher** predicted cross-sections

**Data:**

Now **avoid** deconvolution to quark level, use:

- **Jets** (no fragmentation uncertainty)
- **Hadrons** (no jet energy scale uncertainty)

Run 2: greater integrated luminosity

- Large b cross-section (~50 μb)
- SVT trigger (lifetime based)

## Inclusive b production:

- B hadron — Phys. Rev. D71 032001 (2005)
- **b jet**
- **B hadron** (semi-reconstructed)
- **$B^+$ hadron** (fully reconstructed)

## b + X:

- **b + $\bar{b}$ jets**
- **B + $\bar{B}$ hadrons** (semi-reconstructed)
- **b jet + Z**
- b jet + $\gamma$ — See Mario Campanelli's talk (Had. final states, Tues.)
- b + $\bar{b}$ + W — CDF public note CDF8410

300 pb$^{-1}$

**Trigger** on jet final states

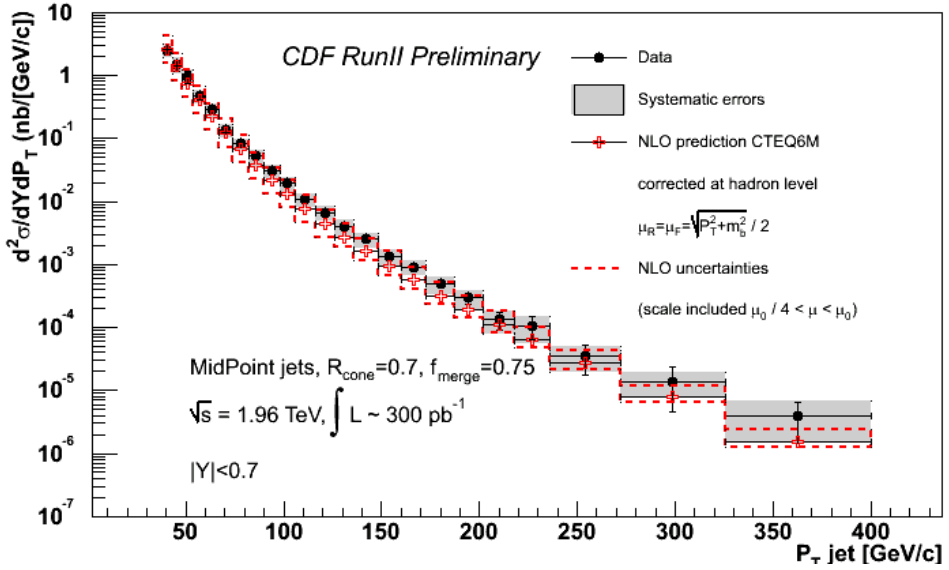
**Identify b jet**:

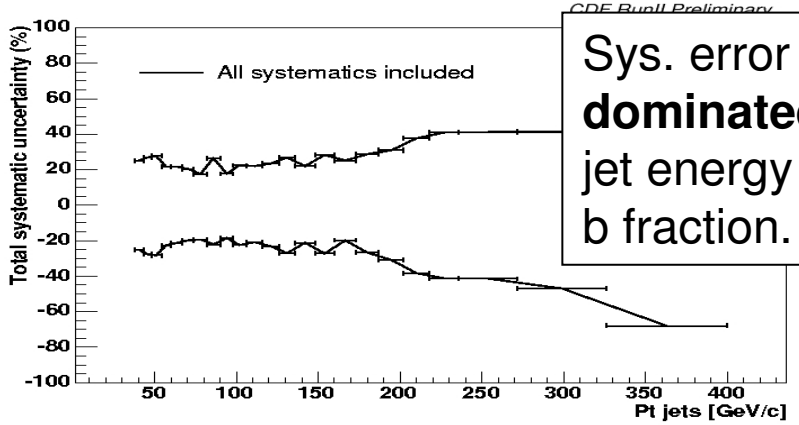
require 1 jet, |η|<0.7, Et 38 – 400 GeV, with separated secondary vertex

**Determine b fraction** by fit to **secondary vertex mass**

Results **consistent with NLO**

Frixone, Mangano, Nucl. Phys. B483, 321 (1997) + CTEQ 6M




Sys. error **dominated** by jet energy scale, b fraction.

**Semi-reconstruct B hadron** instead of using jet.

$B \rightarrow \mu^- D^0 X$, $D^0 \rightarrow K^-\pi^+$

$B \rightarrow \mu^- D^* X$, $D^* \rightarrow D^0\pi^+$ $D^0 \rightarrow K^-\pi^+$

**Trigger** with SVT: lepton + displaced track

**Identify B hadrons** within:

$pT(\mu D^0 X) > 9$ GeV,

$|\eta(\mu D^0 X)| < 0.6$

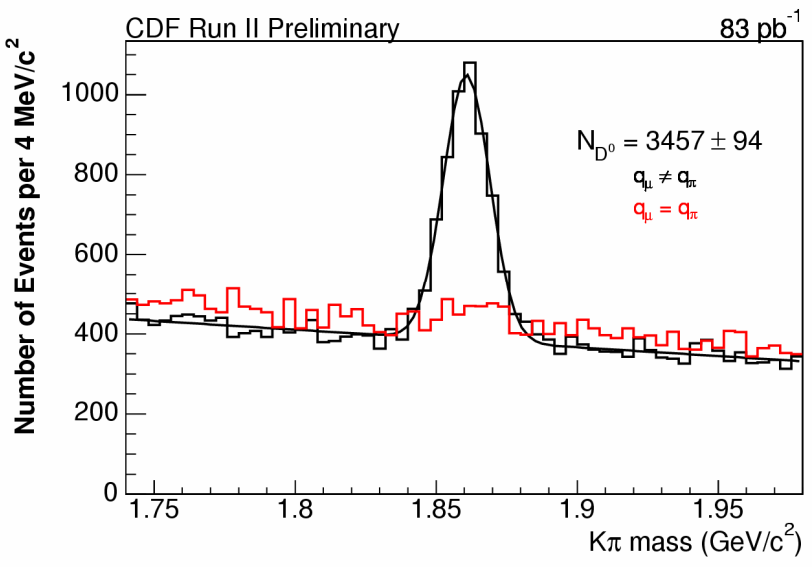
**Determine B fraction** by fit to

(i) invariant mass of $D^0$,

(ii) impact parameter + MC to estimate residual charm,

(iii) like-sign $\mu-\pi$ to estimate $B \rightarrow DX + B \rightarrow \mu X$ combinatorics

83 $pb^{-1}$



**Inclusive cross-section:**

$\sigma(b) = 1.34 \pm 0.08$ (stat) $+0.13-0.14$ (sys) $\pm 0.07$ (BR)

Sys. dominated by lumi (6%), COT track efficiency (3%)

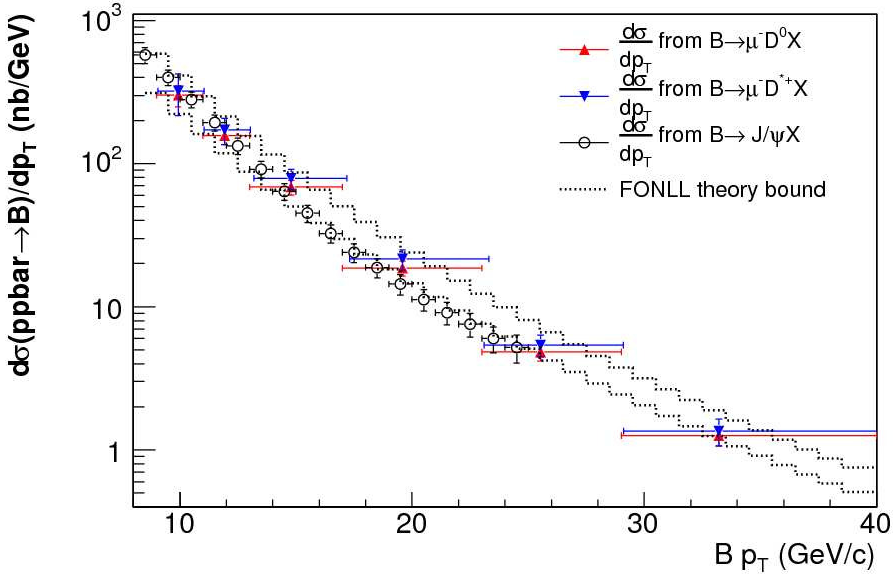
cf. $\sigma(b) = 1.39\ +0.49-0.34\ \mu b$

M. Cacciari, S. Frixione, M.L. Mangano, P. Nason, G. Ridolfi, JHEP 0407:033 (2004)

Also **differential cross-section:**

**Determine pT (B hadron)** from $pT(\mu D^0)$ (with MC input)

Both **consistent with NLO**



# B hadron cross-section (2)

739 $pb^{-1}$

**Fully reconstruct** B hadron **$B^+ \rightarrow J/\psi K^+$**

**Trigger** on J/ψ final states

**Reconstruct B hadron** within:

pT(B) ≥ 6GeV, |η(B)|≤1

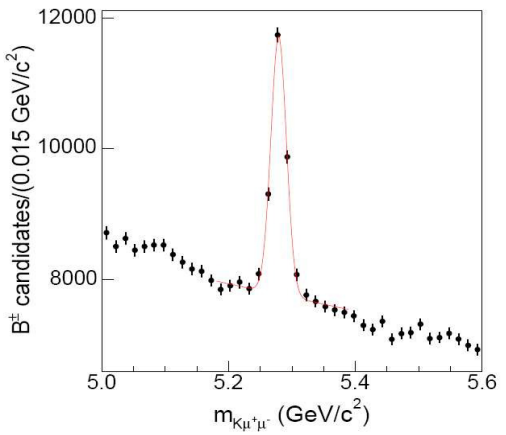
**Estimate B fraction** by fit to m(B)

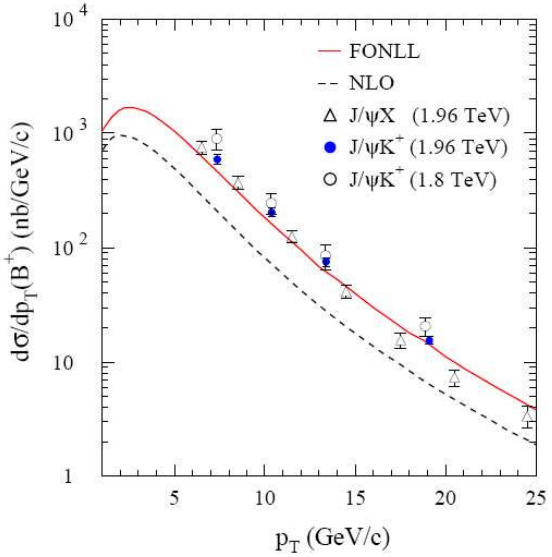
**Results:** σ(B+)=2.78 +- 0.24 μb

4.4% stat. error.

7.6% sys (6% lumi, 3.6% branching fractions)

**Differential cross-section consistent with FONLL** predictions




**PRD75, 012010 (2007)**

260 $pb^{-1}$

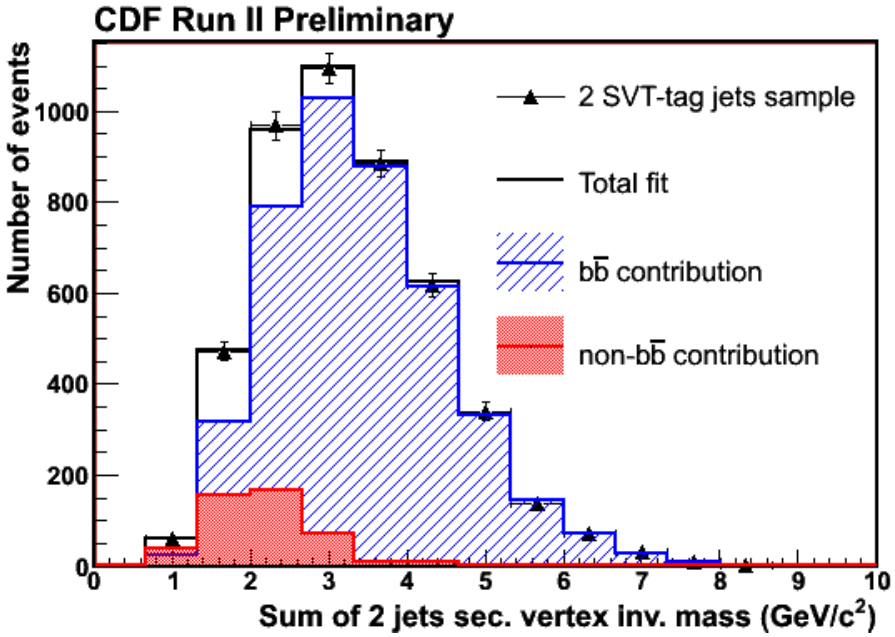
**Trigger** using SVT; two displaced tracks

**Identify b jets**:

cone 0.4 jets, 1st jet Et>35 GeV, 2nd jet Et>32 GeV, $|\eta|<1.2$ for both

**Estimate b fraction** using sec. vertex tag, fit sec. vertex mass to extract bb contribution.

Correct jets to hadron level.



**Inclusive cross-section:**

Systematic error 20-30%

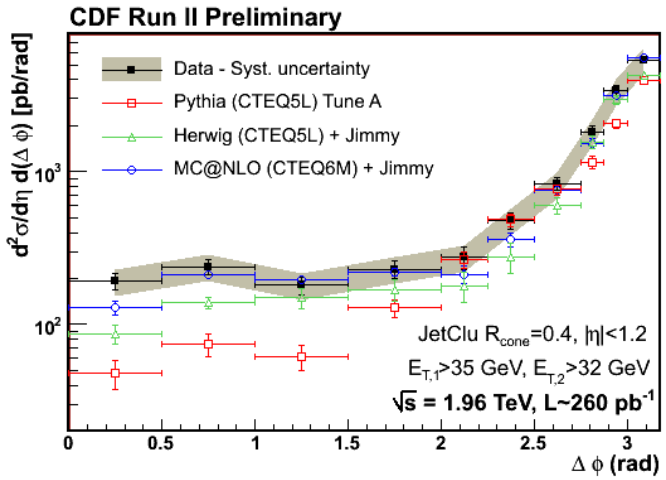
- dominated by jet energy scale (13-20%), b purity (7-8%), luminosity (6%)

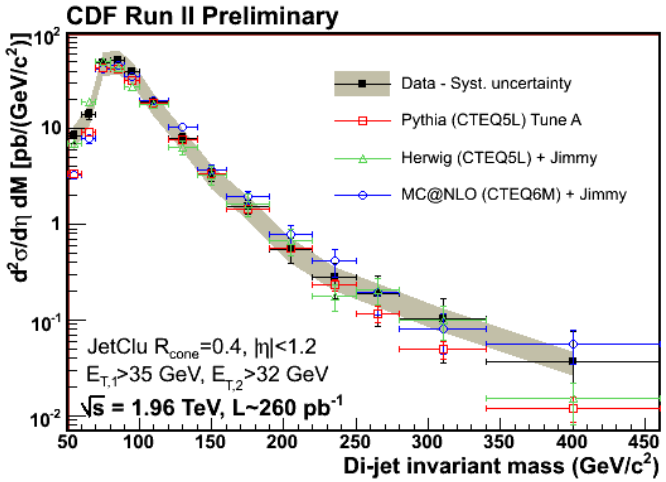
**Consistent with NLO + JIMMY**

| CDF Run II Preliminary | $\sigma$ [pb] $\lvert\eta_{1,2}\rvert < 1.2$, $E_{T,1} > 35$ GeV, $E_{T,2} > 32$ GeV |
|---|---|
| Data | $\sigma = 5664 \pm 168$ (stat.) $\pm 1270$ (syst.) |
| Pythia (CTEQ5L) Tune A | $\sigma = 5136 \pm 52$ (stat.) |
| Herwig (CTEQ5L) + Jimmy | $\sigma = 5296 \pm 98$ (stat.) |
| MC@NLO (CTEQ6M) + Jimmy | $\sigma = 5421 \pm 105$ (stat.) |

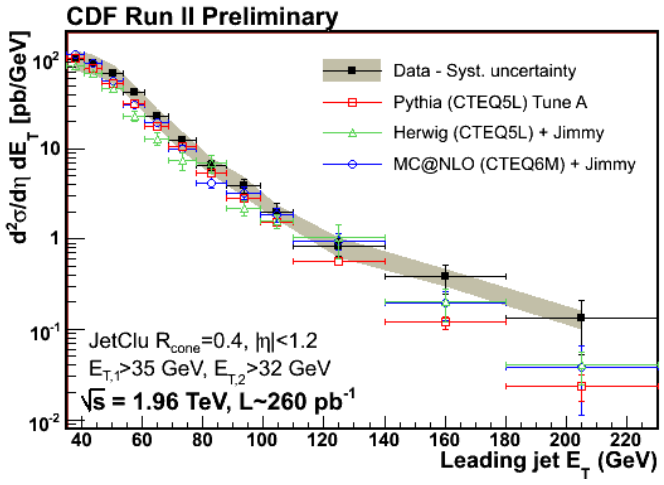
# b dijet cross-section

B dihadron cross-section
b jet + Z cross-section




Differential cross-section shows
**best agreement with NLO**



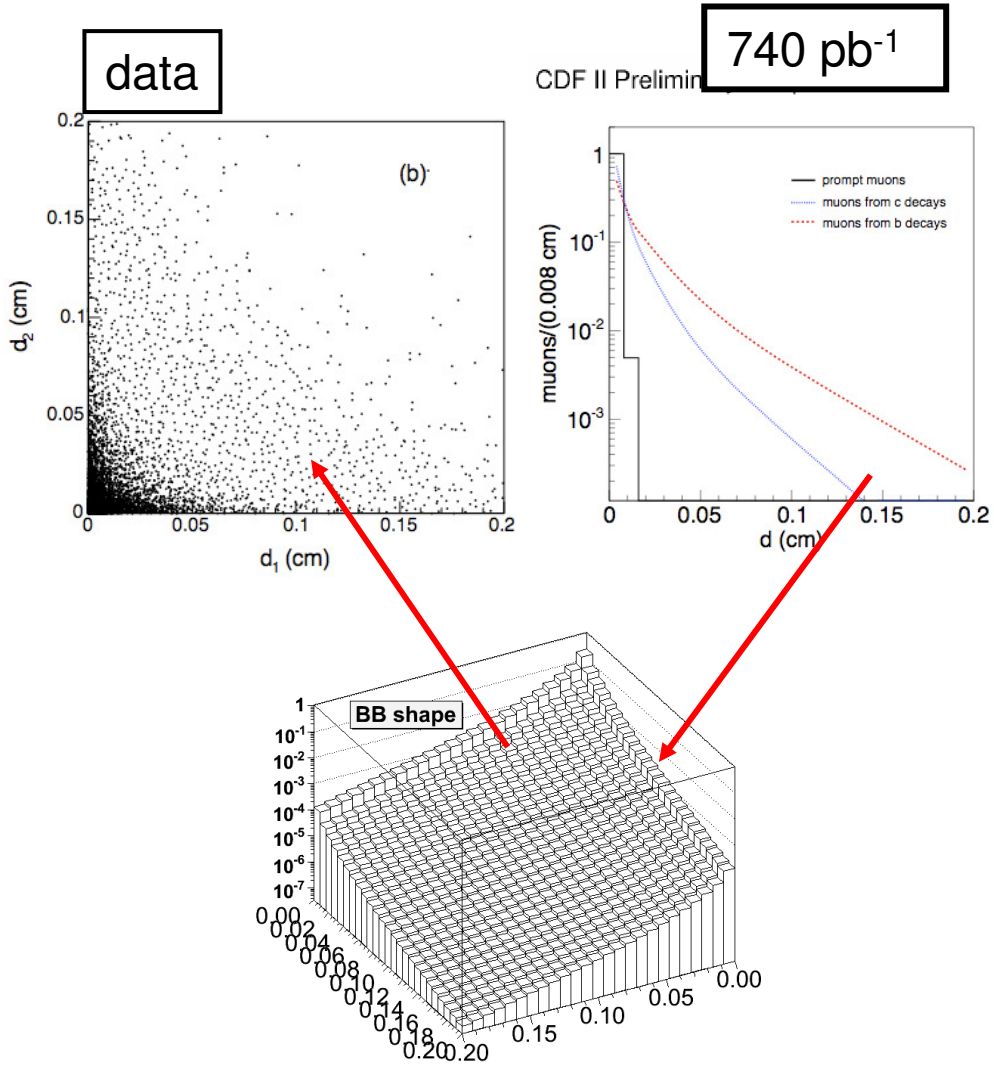
Identify hadrons by semi-exclusive reconstruction **B→μX, B→μX**

**Trigger** on dimuon final states

**Identify B hadrons**:

- pT( μ ) ≥ 3 GeV, |η(μ)| ≤ 0.7
- pT(μμ) > 2 GeV, |y(μμ)|<1.3
- 5 < mμμ < 80 GeV

**Identify BB hadron fraction** by fitting muon impact parameters to MC templates (Herwig)



Determine inclusive cross-section cf. NLO: MNR + EVTGEN + MRST98

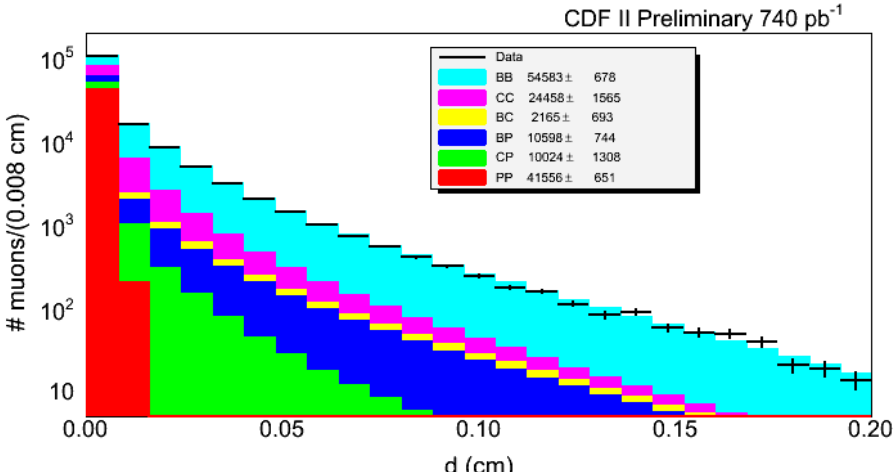
Data: $\sigma(b\rightarrow\mu, b\rightarrow\mu) = 1549 \pm 133$pb

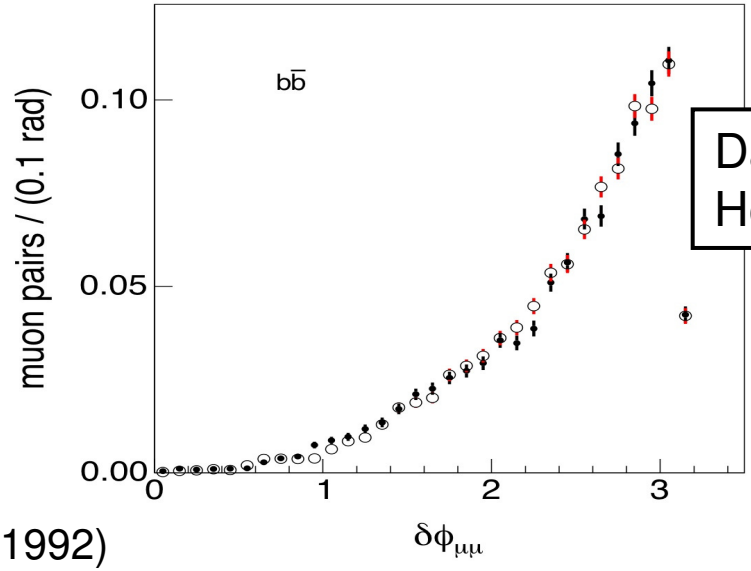
1.2% stat error

Systematic error dominated by luminosity (6%), mis-id muon (2.9%)

NLO: $\sigma(b\rightarrow\mu, b\rightarrow\mu) = 1293 \pm 201$ pb

**Consistent with NLO.**




Data vs. Herwig

MNR: Mangano et. al. Nucl. Phys. B373, 295 (1992)

**Trigger** on $Z \rightarrow e^+e^-$ ($|\eta|<2.5$), $\mu^+\mu^-$ ($|\eta|<1.5$)

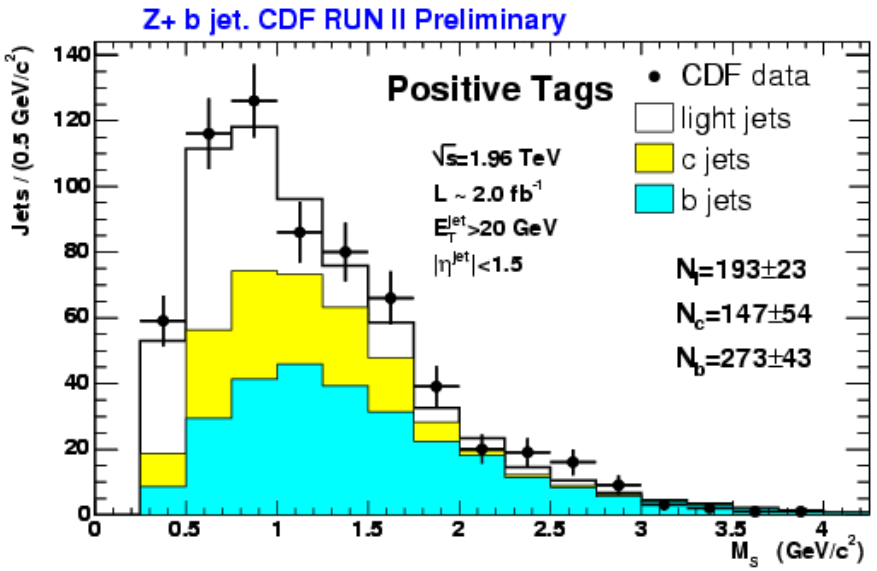
**Identify b jet**; cone 0.7 jet with Et>20 GeV, | eta |<1.5, secondary vertex tag.

**Estimate b fraction** by secondary vertex tag, fit sec. vertex mass to MC templates to obtain b fraction.

Compare to NLO

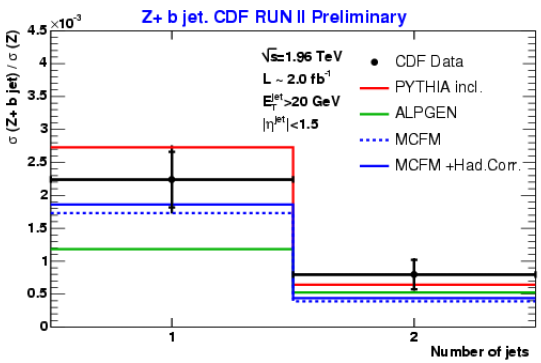
MCFM + CTEQ6M, $M_Z+p_T^2$ for the factorisation and renormalisation scales (~15% error)

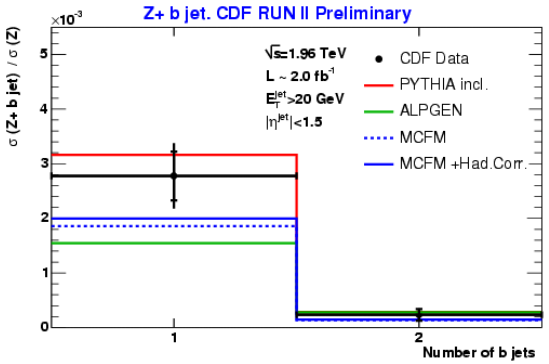
2 $fb^{-1}$

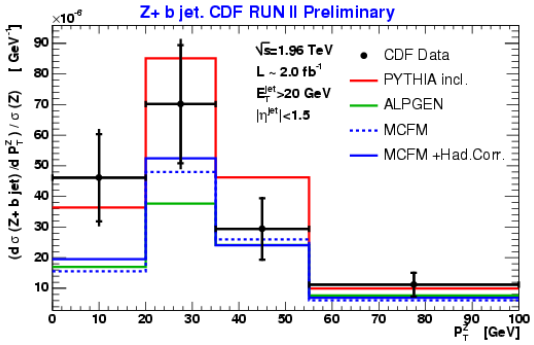


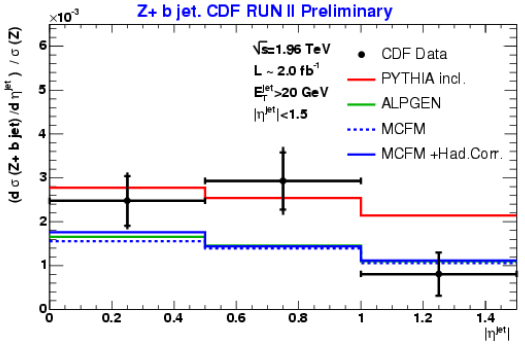

Main sys: ET modelling (8%), lumi (6%)

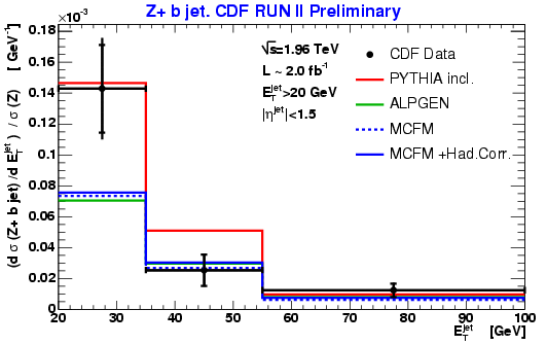
| | CDF Data | PYTHIA | ALPGEN | HERWIG | NLO | NLO +U.E+hadr. |
|---|---|---|---|---|---|---|
| $\sigma(Z+b\,\text{jet})$ | $0.86 \pm 0.14 \pm 0.12$ pb | – | – | – | 0.51 pb | 0.53 pb |
| $\sigma(Z+b\,\text{jet})/\sigma(Z)$ | $0.336 \pm 0.053 \pm 0.041\%$ | 0.35% | 0.21% | 0.21% | 0.21% | 0.23% |
| $\sigma(Z+b\,\text{jet})/\sigma(Z+\text{jet})$ | $2.11 \pm 0.33 \pm 0.34\%$ | 2.18% | 1.45% | 1.24% | 1.88% | 1.77% |




Differential distributions for **σ(Z+b jet)/σ(Z)** **most consistent with Pythia**.

NLO predictions for σ(Z) ~ factor 2 (~1.7σ) lower than data.

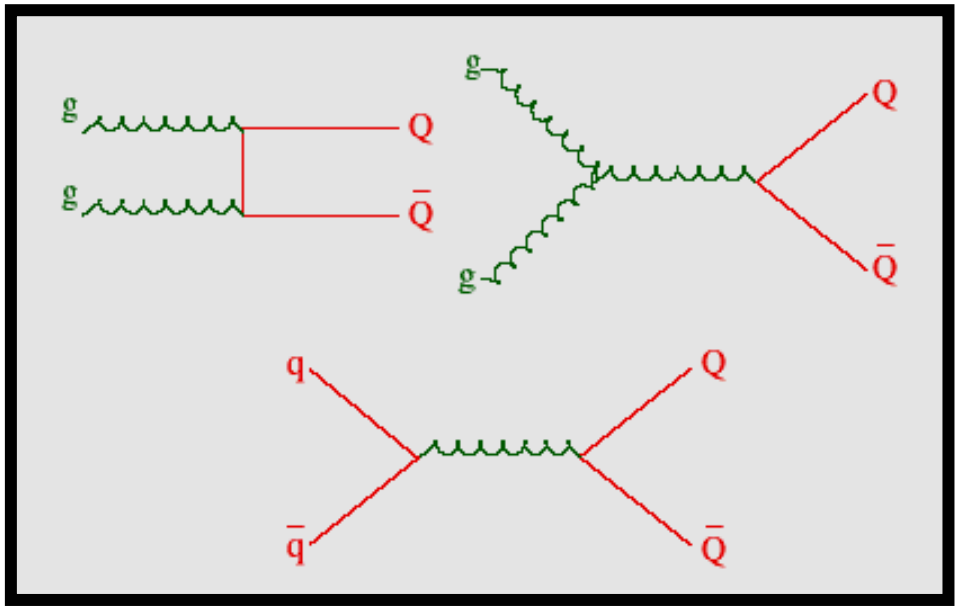
**B production has been tested in many ways at CDF:**

- Inclusive production to jets and hadrons (precision→9%)
- Dijet, dihadron production (precision→9%)
- b jet + Z production (precision ~ 20%)

**NLO (and FONLL) predictions describe CDF data well**

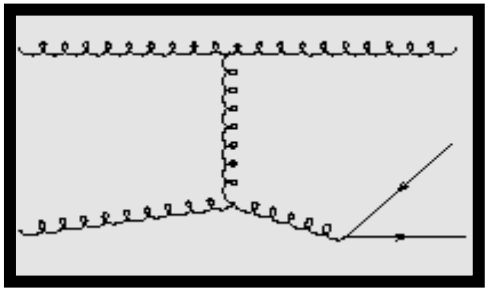
# backup

# b production @ Tevatron



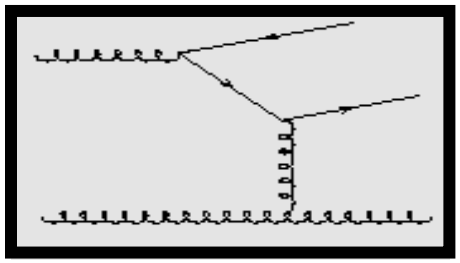

Flavour creation

LO



NLO

Gluon splitting



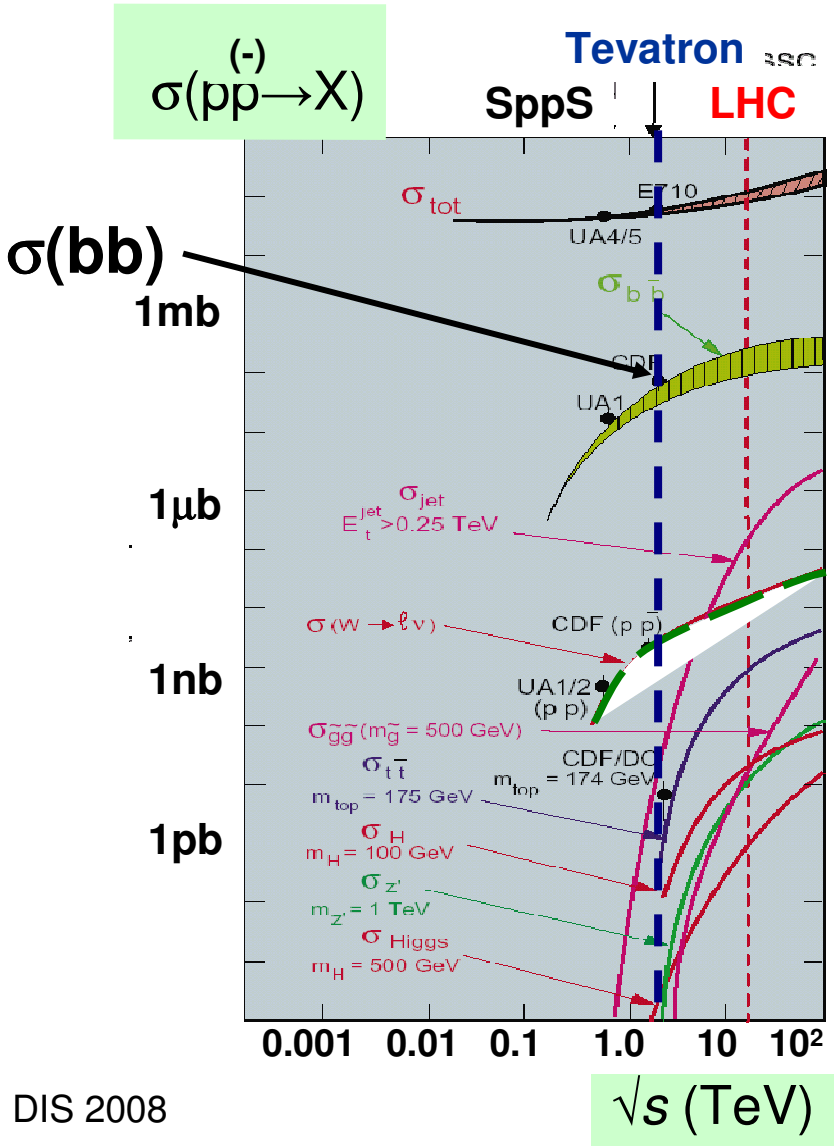
NLO

Flavour excitation

# How to isolate b experimentally

**Large cross-section (~50μb)**

- **Isolate** by triggering on:
  - Jets
  - Semileptonic decays
  - Displaced tracks (SVT)
- **Identify b** by:
  - Lifetime (secondary vertex / impact parameter)
  - (semi) exclusive reconstruction



# Z + b jet production

Background processes to Higgs


Probe b content of proton