Tevatron Results on *b*-quark Cross Sections and Correlations

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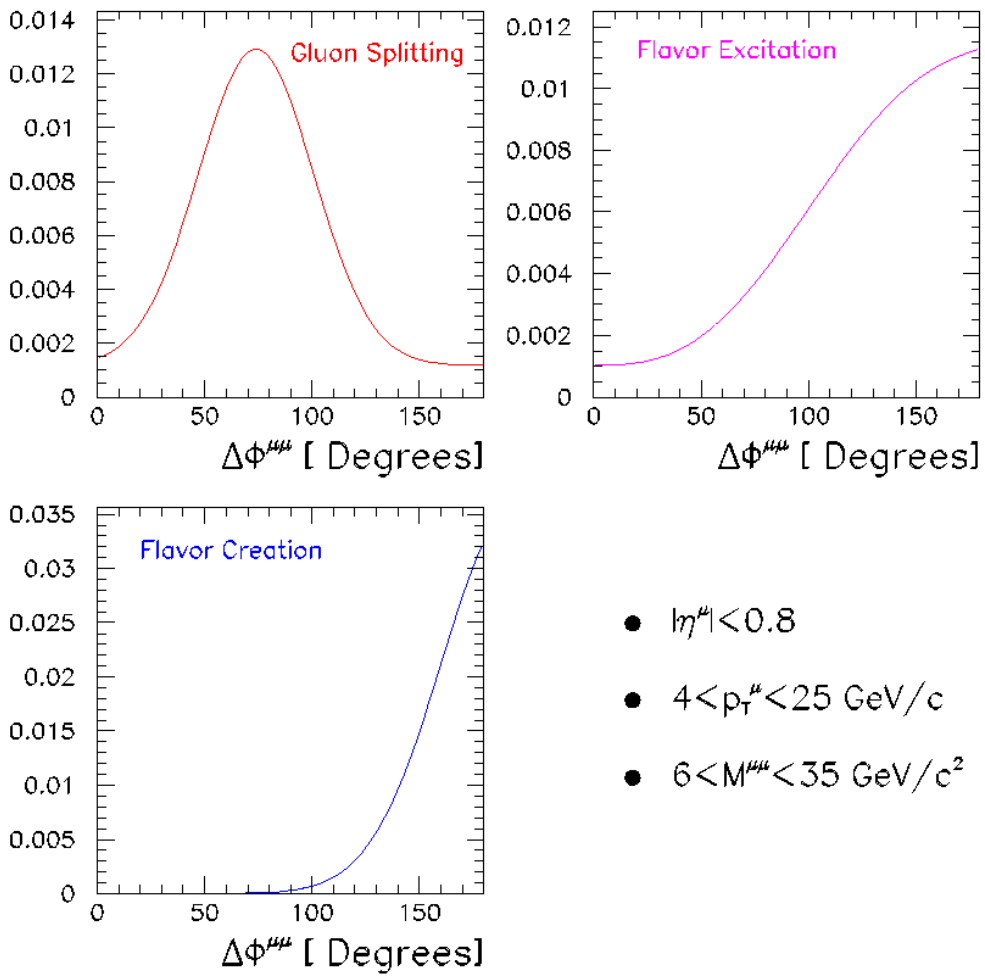
Outline

* $b\bar{b}$ Angular Correlations and Inclusive b-quark Production
* $b\bar{b}$ Rapidity Correlations
* Forward μ and b-quark Production
* Conclusions

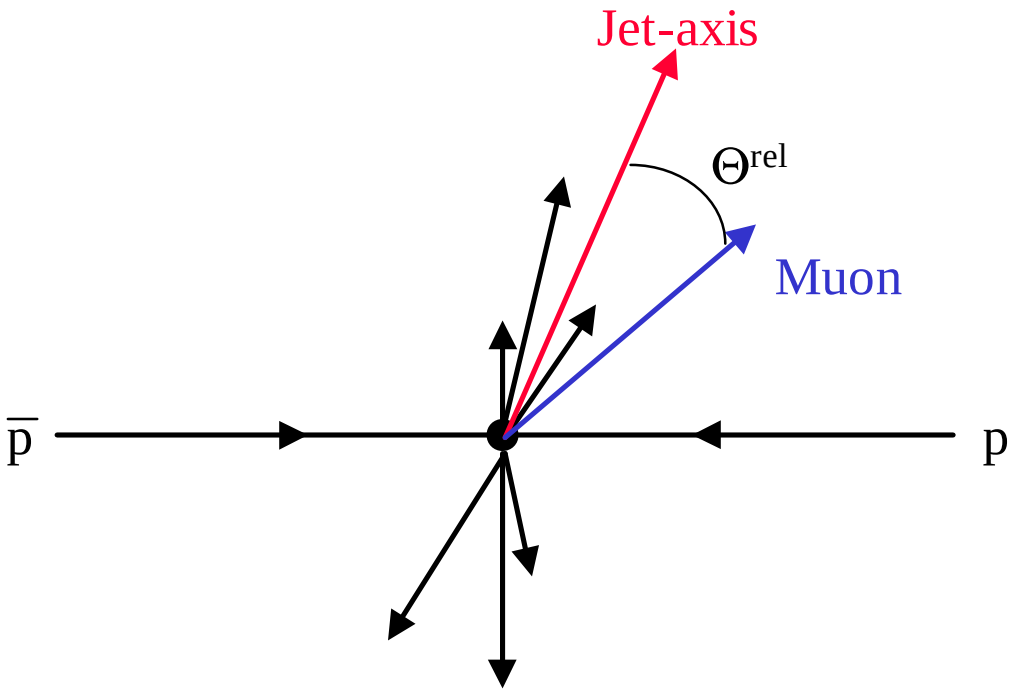
$b\bar{b}$ Angular Correlations and Inclusive b-quark Production (DØ)

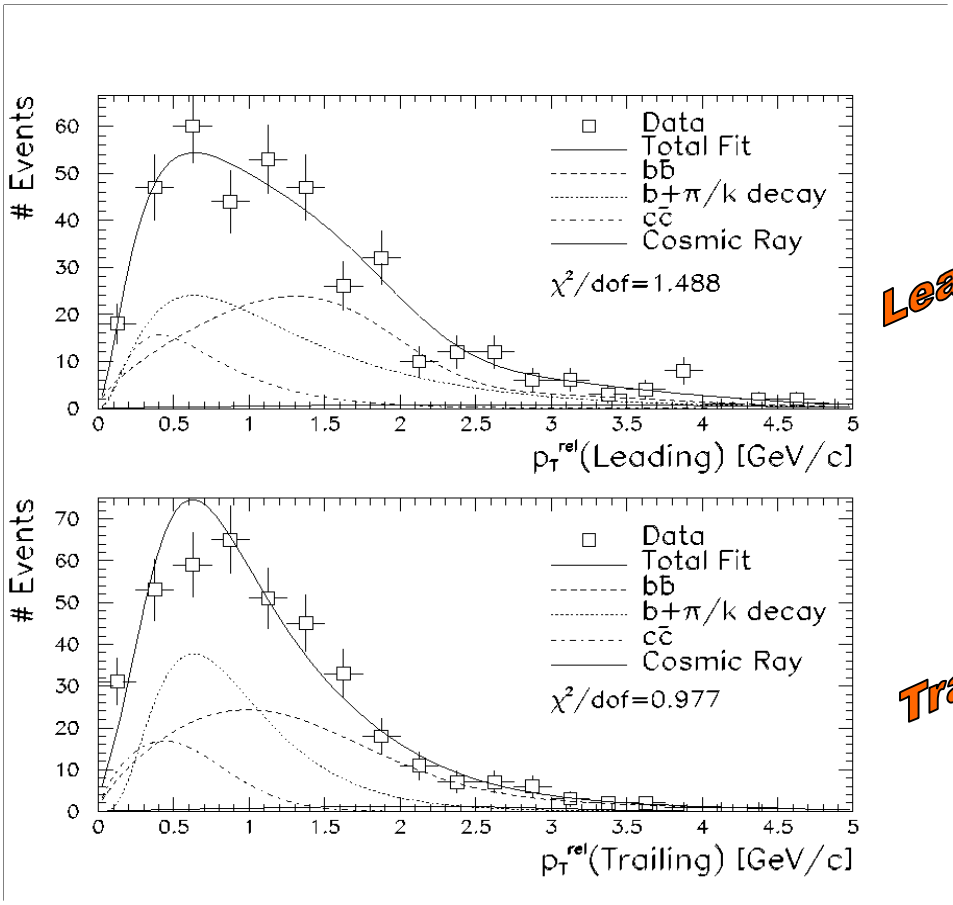
- Analysis Procedure
- $b\bar{b}$ Angular Correlations
- Inclusive b-quark Production Cross Section

- Important test of NLO QCD prediction
- Azimuthal correlations are sensitive to higher order contributions



- Use muon pairs to determine azimuthal correlation between the b and the $\bar{b}$
- Invariant mass : $6 < M^{\mu\mu} < 35$ GeV/c^2
- $4 < p_T^{\mu} < 25$ GeV/c
- $|\eta^{\mu}| < 0.8$
- Require associated jet with each muon
- Use p_T^{rel} to determine fraction of events from $b\bar{b}$ production





Pt(rel) Leading muon

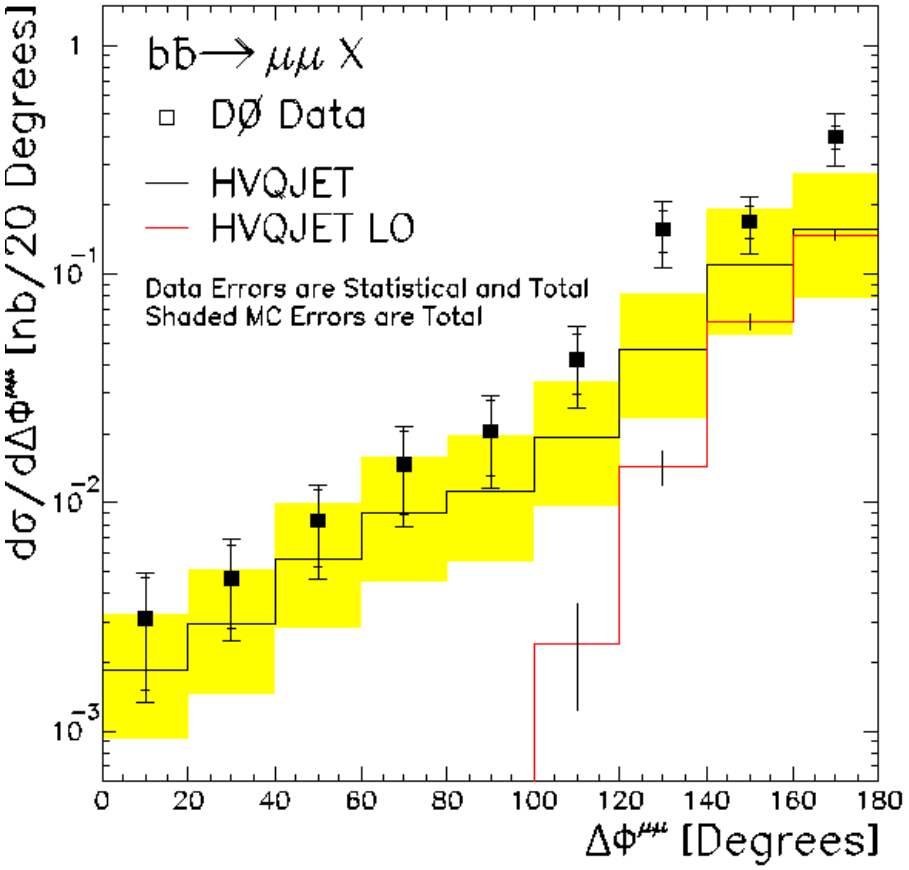
Pt(rel) Trailing muon

Source	Fit
$b\bar{b}$	43.5 ± 5.8 %
$b + \pi/K$ decay	37.9 ± 5.6 %
cc	14.0 ± 3.8 %
Cosmic Muon	2.8 ± 1.6 %

$\Rightarrow$ yields $b\bar{b}$ fraction as a function of $\Delta\phi$

$b\bar{b}$ Angular Correlations

- Azimuthal angle between muons from $b\bar{b}$ production compared to NLO QCD prediction (HVQJET)



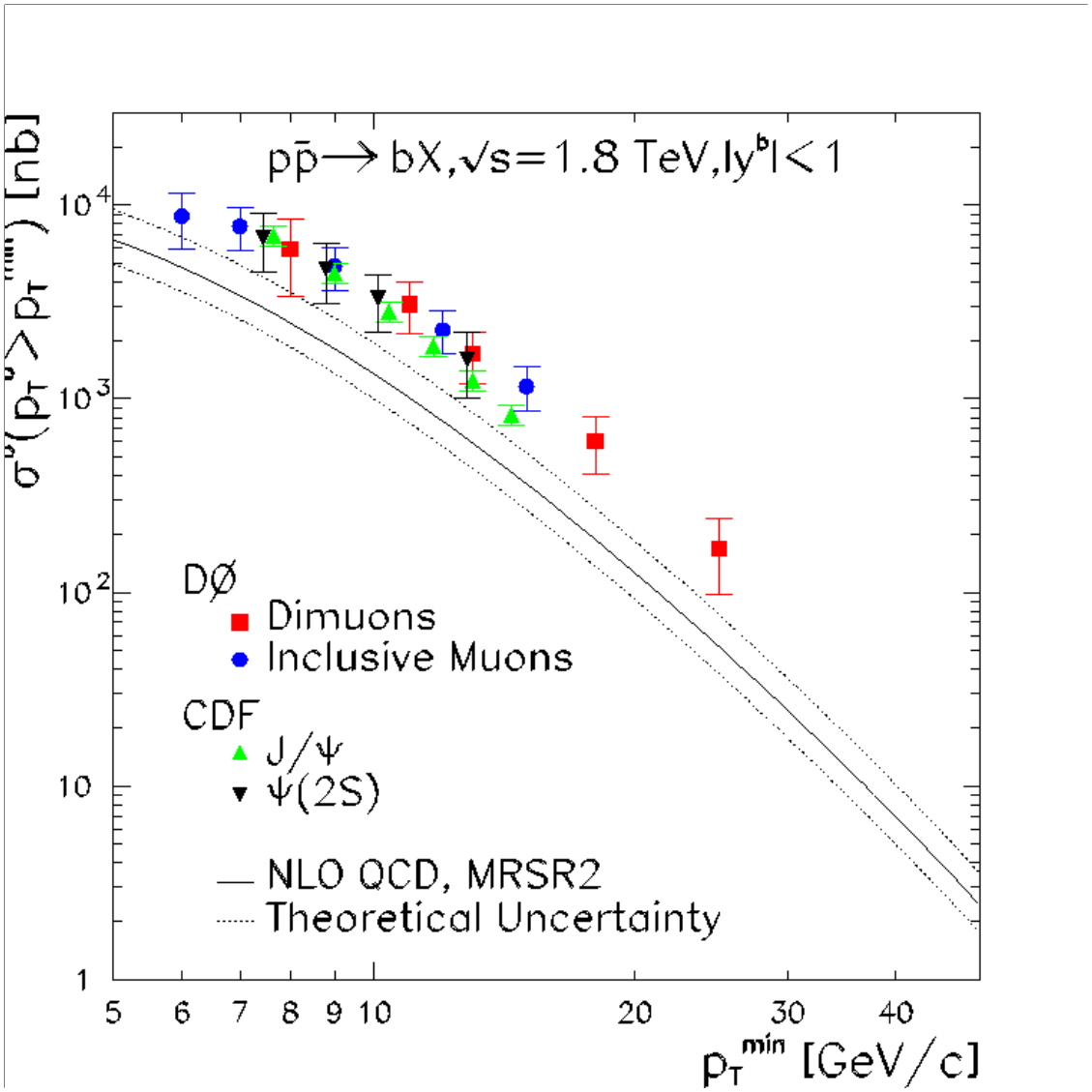
- Good agreement in shape but not in overall normalization

Inclusive *b*-quark Production Cross Section

- Use $b\bar{b} \rightarrow \mu\mu$ cross section to extract inclusive *b*-quark production cross section for $|y_b|<1.0$

- Updated results of inclusive single muon analysis from PRL (1995)
  - New hadronization and decay model (HVQJET)
  - High p_T^{μ} data points not shown due to uncertainties in background subtraction

- Cross section for for $|y^b|<1.0$



- Good agreement between different measurements
- Data still a factor of ~2.5 above the central value of NLO QCD

$b\bar{b}$ Rapidity Correlations (CDF)

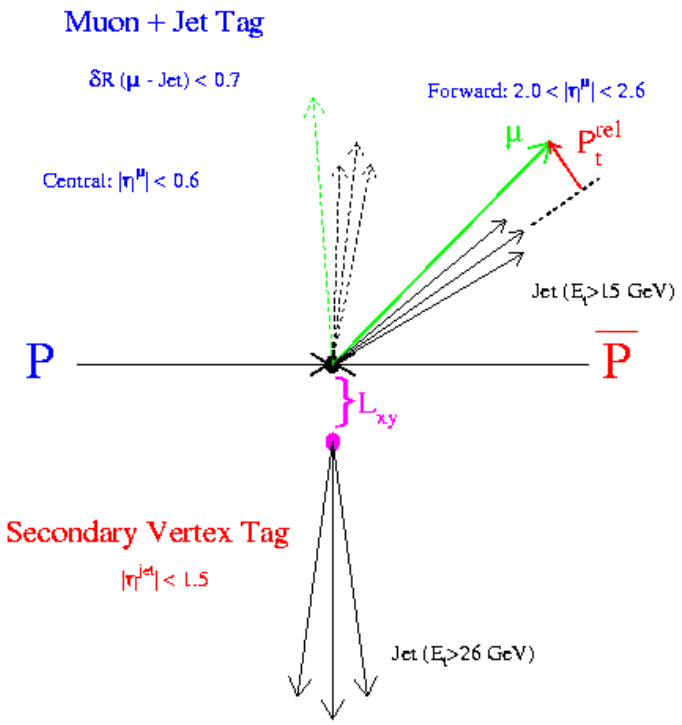
- Analysis Procedure
- Ratio of Forward-Central/Central-Central Cross Sections
- Comparison to Theory

- Previous studies based on $\Delta\phi$
- This analysis measures rapidity correlations for $b\bar{b}$ production

$$\frac{s_{b\bar{b}}(\text{central} - \text{forward})}{s_{b\bar{b}}(\text{central} - \text{central})}$$

- Ratio of cross sections reduces experimental systematic uncertainties

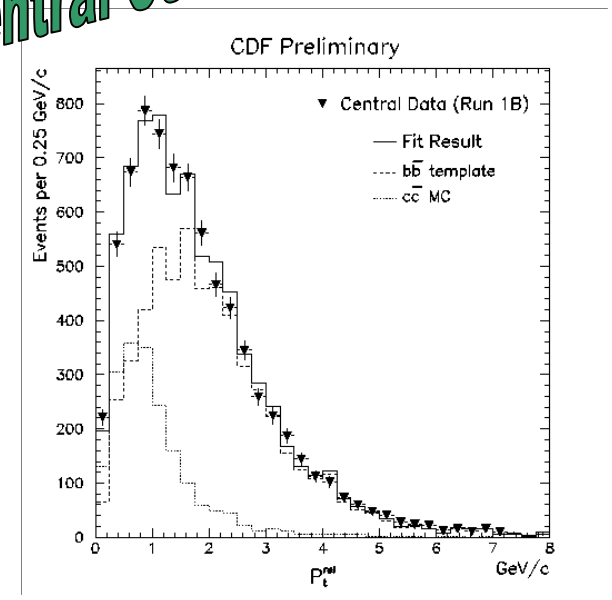
- Event selection
  - central *b*-quark jet ($|\eta^{jet}|<1.5$) with displaced secondary vertex
  - second *b*-quark decaying to muon+jet either in central ($|\eta^{\mu}|<0.6$) or forward ($2.0< |\eta^{\mu}|<2.6$) rapidity region

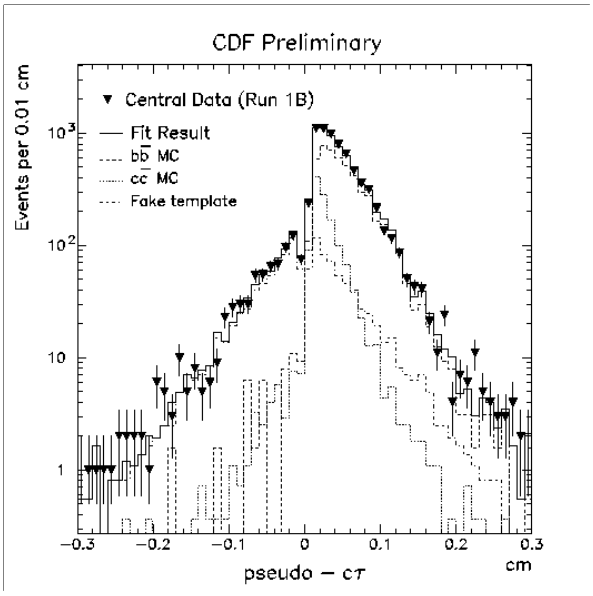


- 1994-1995 Tevatron run $\Rightarrow$ 77 pb^{-1}
  - 382 central-forward events
  - 7544 central-central events

- Signal extracted by fits to p_T^{rel} of the muon and to pseudo-cτ of the *b*-jet

Central-Central





Source (*b*-tag/μ-tag)	Forward-central	Central-central
b / *b*	0.815±0.060	0.617±0.017
c / *c*	0.083±0.051	0.148±0.014
Real *b* / Fake	$0.000^{+0.059}_{-0.000}$	0.066±0.021
Fake / Real *b*	$0.017^{+0.047}_{-0.017}$	0.070±.010
Fake / Real *c*	$0.086^{+0.035}_{-0.046}$	0.099±0.010

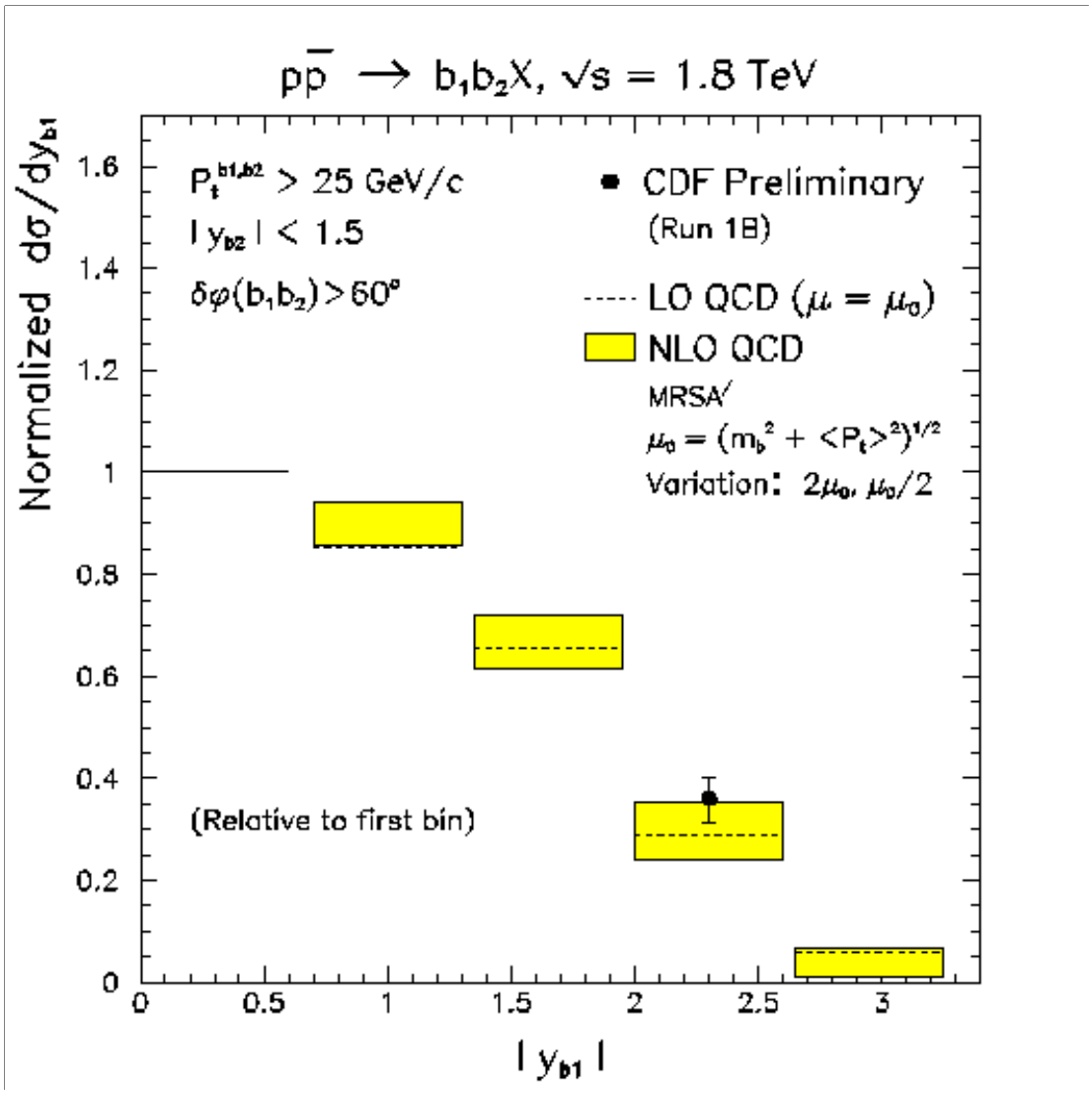
Cross Section Ratio

$$R_{Data} = \frac{s\left(p\bar{p} \to b_1 b_2 ; 2.0 < | y_{b_1} | < 2.6\right)}{s\left(p\bar{p} \to b_1 b_2 ; | y_{b_1} | < 0.6\right)}$$

where : $p_T(b_1 b_2) > 25$ GeV/c
$|y_{b2}| < 1.5$
$\delta\Phi > 60^o$

$$R_{Data} = 0.361 \pm 0.033(stat)\,^{+0.011}_{-0.031}(syst)$$

$$R_{Theory} = 0.338\,^{+0.014}_{-0.097}$$


$p\bar{p} \rightarrow b_1 b_2 X$, $\sqrt{s}$ = 1.8 TeV
$P_t^{b1,b2}$ > 25 GeV/c
$|y_{b2}| < 1.5$
$\delta\varphi(b_1 b_2) > 60°$
CDF Preliminary
(Run 1B)
LO QCD ($\mu = \mu_0$)
NLO QCD
MRSA'
$\mu_0 = (m_b^2 + \langle P_t \rangle^2)^{1/2}$
Variation: $2\mu_0$, $\mu_0/2$
(Relative to first bin)
Normalized $d\sigma/dy_{b1}$
$|y_{b1}|$
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
0.5
1.5
2
2.5
3

Forward μ and *b*-quark Production (DØ)

- Analysis Procedure
- Inclusive Muon Cross Section
- *b*-Produced Muon Cross Section

- Results for central ($|y|<1.0$) *b*-quark production lie above NLO QCD
- Forward production more sensitive to smaller x_F
- Combine with central results to obtain rapidity dependence of *b*-produced muon cross section
- Analysis based on Small Angle Muon System (SAMUS)
  - Magnetized Iron Toroid
  - 3 Layers of Drift Tubes
  - Pseudorapidity coverage of $2.2<|\eta|<3.3$

- Dedicated 1994-1995 Runs corresponding to $111 \pm 6\ nb^{-1}$
  - $2.4 < |y^{\mu}| < 3.2$
  - $p^{\mu} < 150$ GeV/c
  - $p_T^{\mu} > 2$ GeV/c
  - Quality cuts
  - Calorimeter confirmation
  - Single interaction

$\Rightarrow$ 6709 Events in final sample

Inclusive Muon Cross Section

- Muon detection efficiencies calculated using Monte Carlo
- Reconstructed Monte Carlo distributions match data

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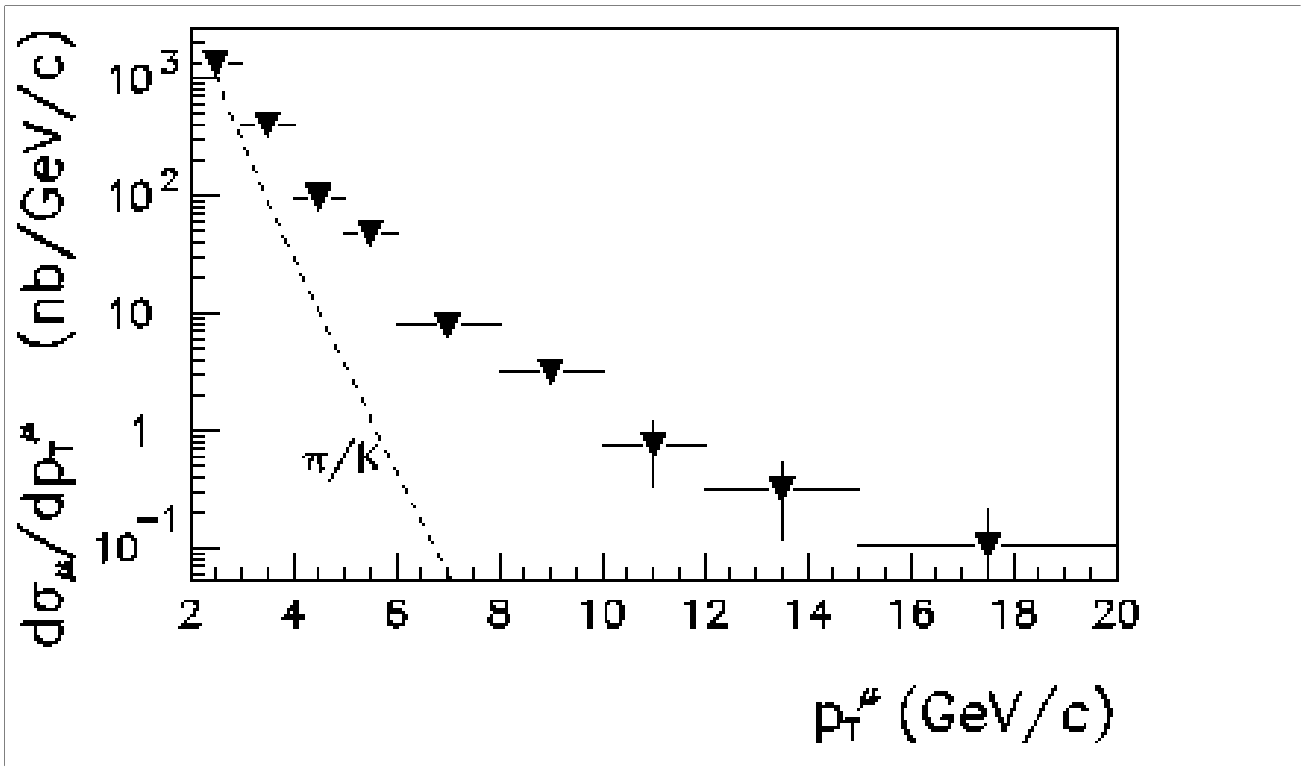
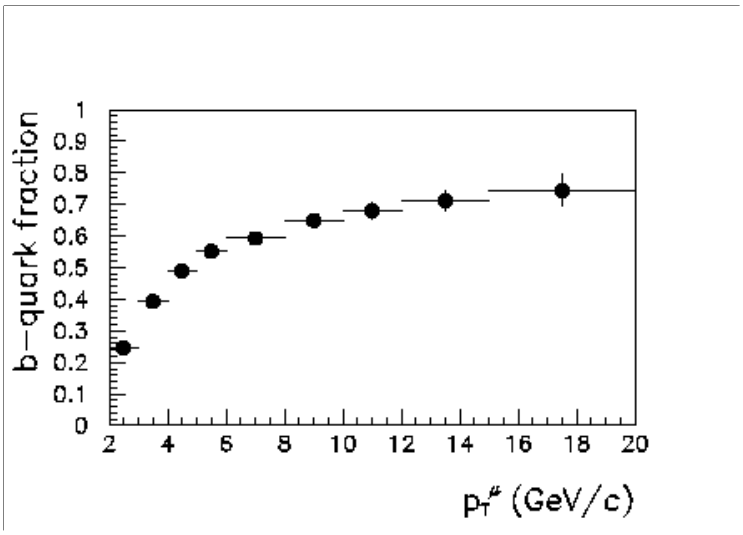
- Determine unfolded p_T^{μ} spectrum of forward muons
  - Statistical errors only
  - Systematic errors range from 14-18%
  - π/K spectrum obtained using ISAJET
    - Charged particle spectrum agrees with CDF measurement for $|y|<1.0$
    - Data and π/K match in first bin



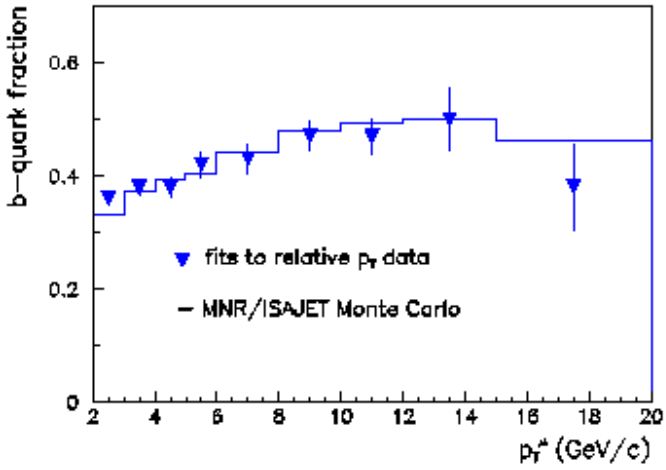
- Determination of *b*-quark contribution
  - Use fraction of muons due to *b*-quark decay

$$f_b \equiv \frac{s\,(b \to m)}{s\,(b \to m) + s\,(c \to m)}$$

as predicted by NLO QCD (Mangano, Nason, Ridolfi)



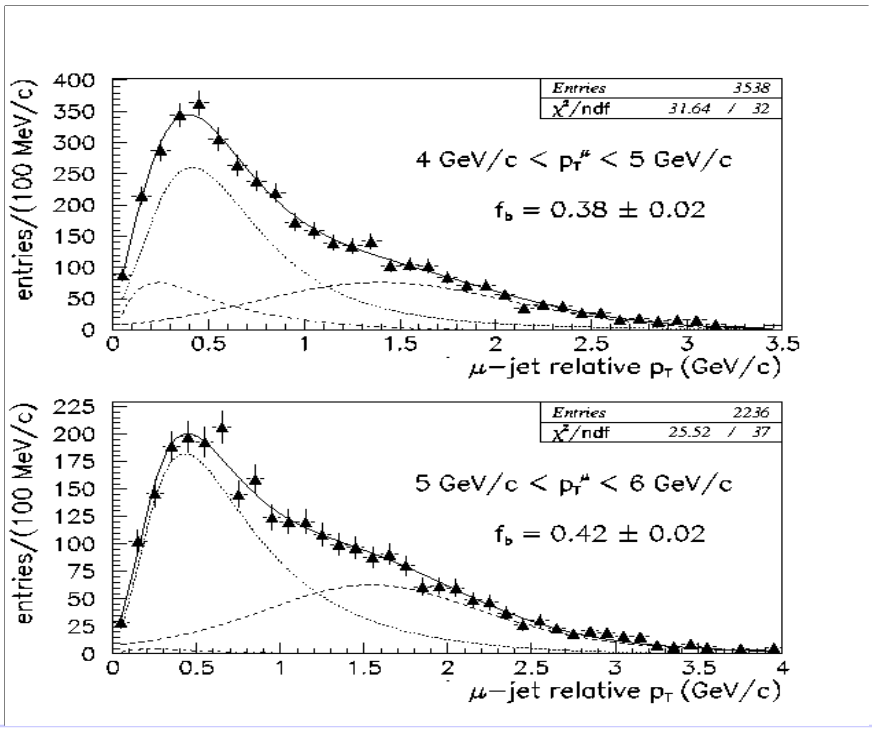
  - Cross check f_b with muon + jet events



Good agreement between data & QCD

b-Fraction Cross Check

- Determine f_b for events with reconstructed associated jet (7% of sample)
  - Use all Run IB data ⇒ 90 pb^{-1}
  - no trigger requirement ⇒ 20K events
  - Shape of p_T^{rel} distributions obtained from real data (π/K) or ISAJET (*b*- and *c*-quarks)
  - Muons from *b*® *c*® μ included with *c*-quark sample
  - p_T^{rel} fits done for each p_T^{μ} bin

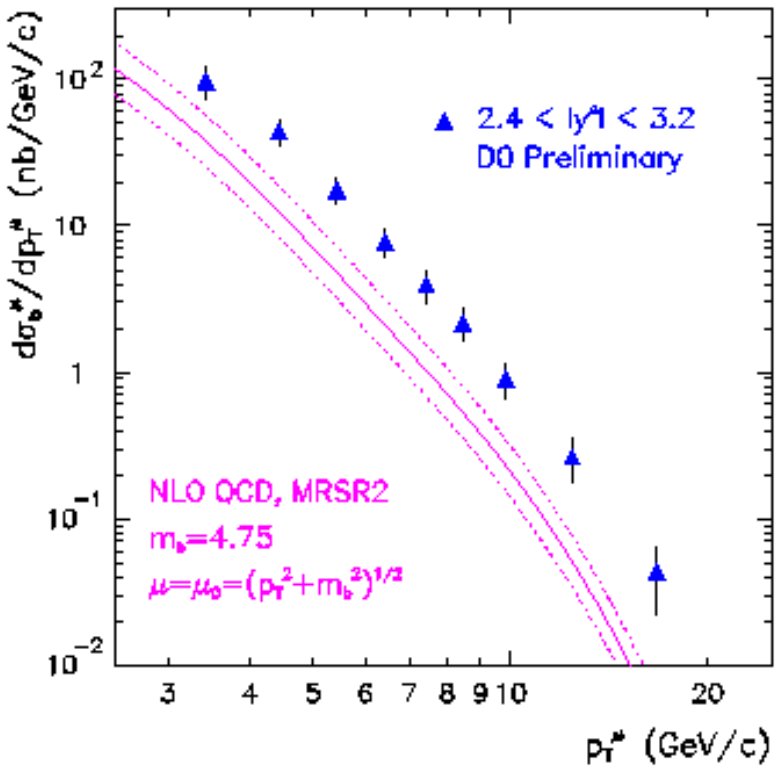


4<pt<5 GeV/c

5<pt<6 GeV/c

b-produced Muon Cross Section

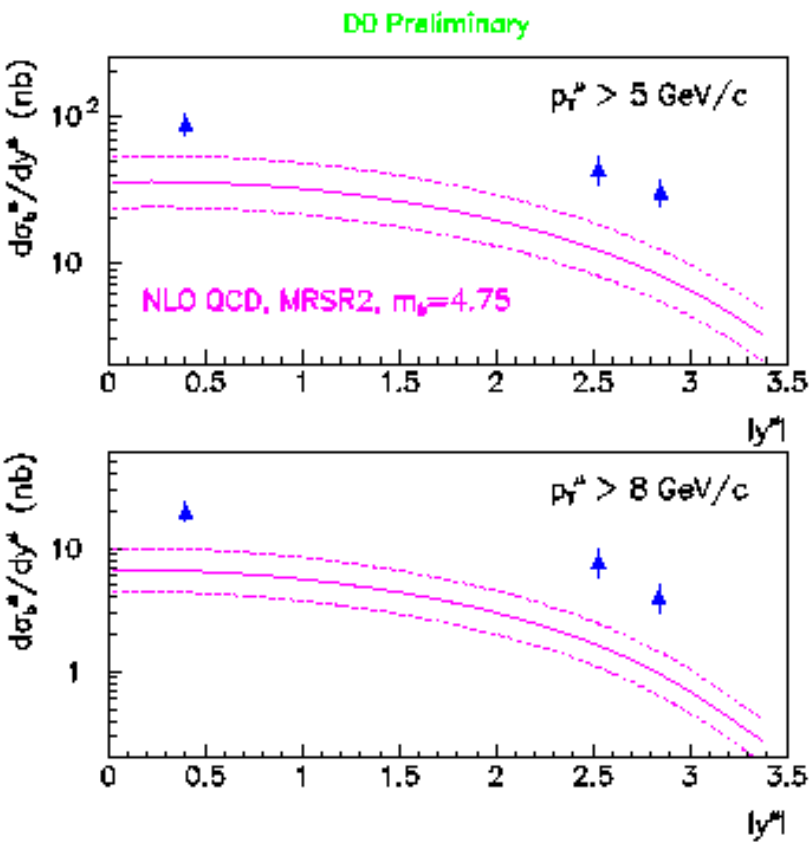
- p_T spectrum of forward muons from *b*-decays compared to NLO QCD



- Systematic uncertainty : 29 - 46%
- Measured cross section is ~4 times above the central NLO QCD prediction

Rapidity Dependence

- *b*-produced muon cross section vs. rapidity compared to NLO QCD



- Ratio of Data/Theory for p_T^μ >5 GeV/c

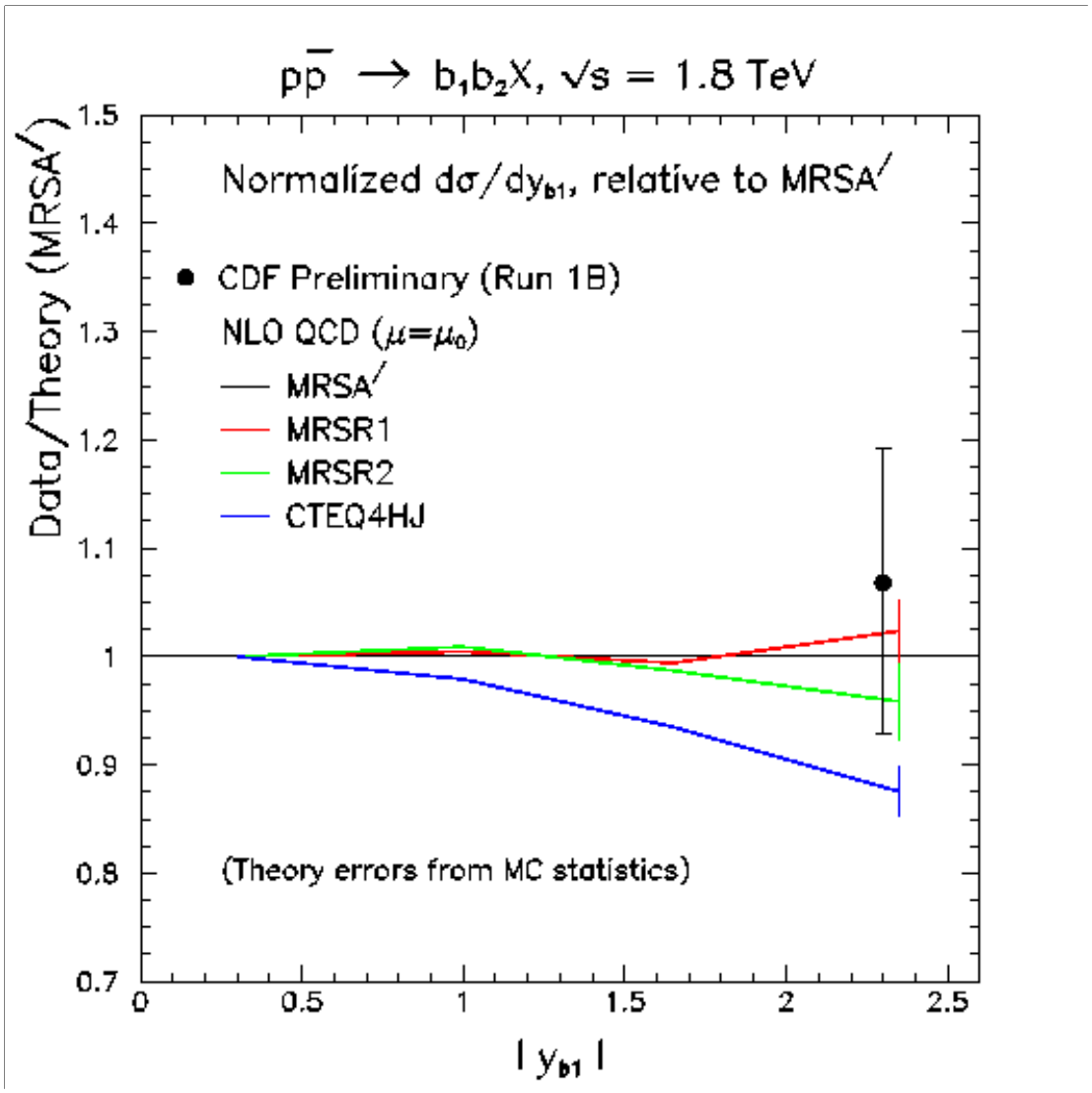
$$|y^m| < 0.8 = 2.5 \pm 0.4$$

$$2.4 < |y^m| < 3.2 = 3.6 \pm 0.8$$

Conclusions

- Forward *b*-quark Production
  - DØ has measured rapidity dependence of the *b*-quark production cross section
  - $d^2 s_b^{\mu} / dp_T^{\mu} dy^{\mu}$ agrees in shape with NLO QCD but rapidity dependence does not
- $b\bar{b}$ Angular Correlation
  - $d s / dD f$ agrees in shape with NLO QCD
  - NLO contributions clearly present
  - Inclusive *b*-quark production cross section for $|y_b| < 1.0$ still above NLO QCD prediction

- $b\bar{b}$ Rapidity Correlation
  - CDF measurement of central-forward to central-central cross section is in agreement with NLO QCD prediction
  - Results are sensitive to gluon distribution in the proton for $x > 0.15$ but larger statistics needed to distinguish between various parton distribution sets


$p\bar{p} \rightarrow b_1 b_2 X$, $\sqrt{s}$ = 1.8 TeV
Normalized $d\sigma/dy_{b1}$, relative to MRSA′
CDF Preliminary (Run 1B)
NLO QCD ($\mu=\mu_0$)
MRSA′
MRSR1
MRSR2
CTEQ4HJ
(Theory errors from MC statistics)
Data/Theory (MRSA′)
$|y_{b1}|$
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0
0.5
1
1.5
2
2.5