# HEAVY QUARK PRODUCTION: RECENT DEVELOPMENTS

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Results obtained in collaboration with Stefano Frixione, Michelangelo Mangano and Paolo Nason.
(hep-ph/9702287 CERN-TH/97-16 and refs. therein).

- CHARM PRODUCTION:

  DO WE UNDERSTAND HIGHER ORDERS + NON PERT. EFFECTS ?

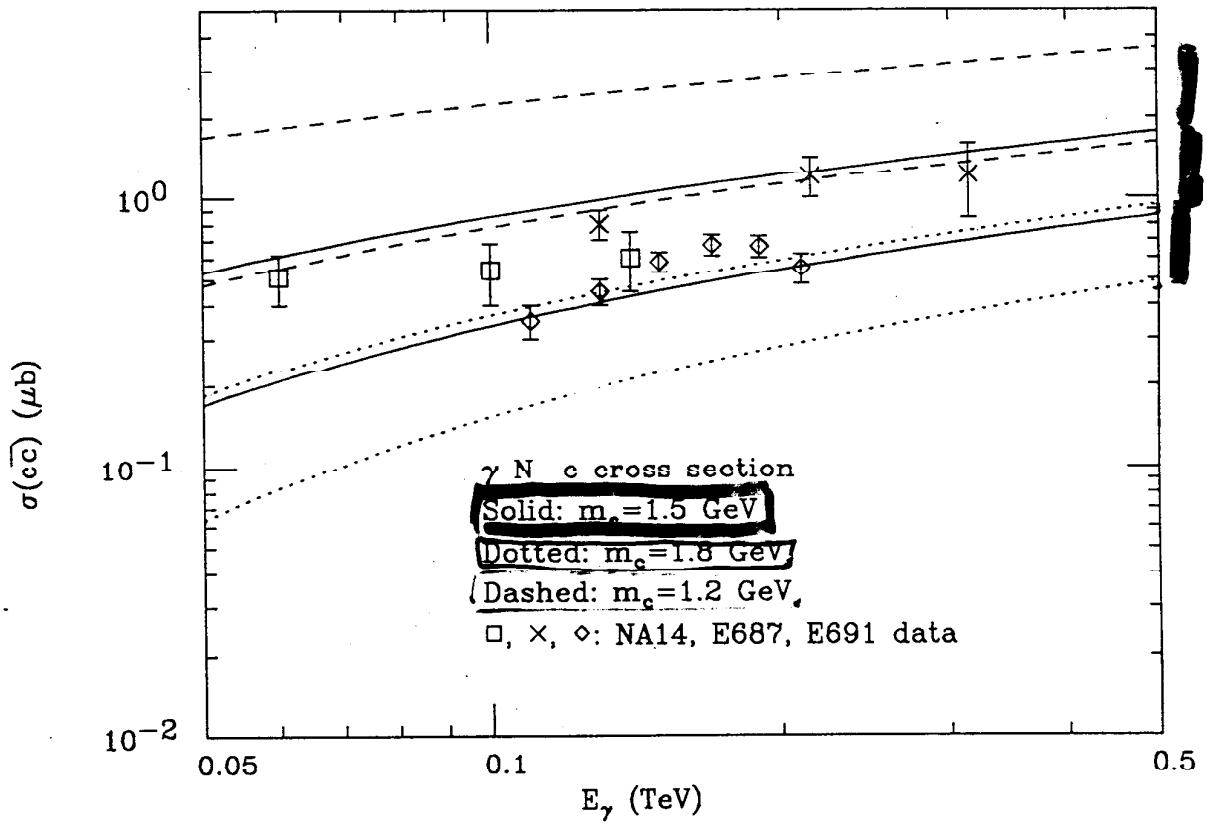
- BOTTOM PRODUCTION:

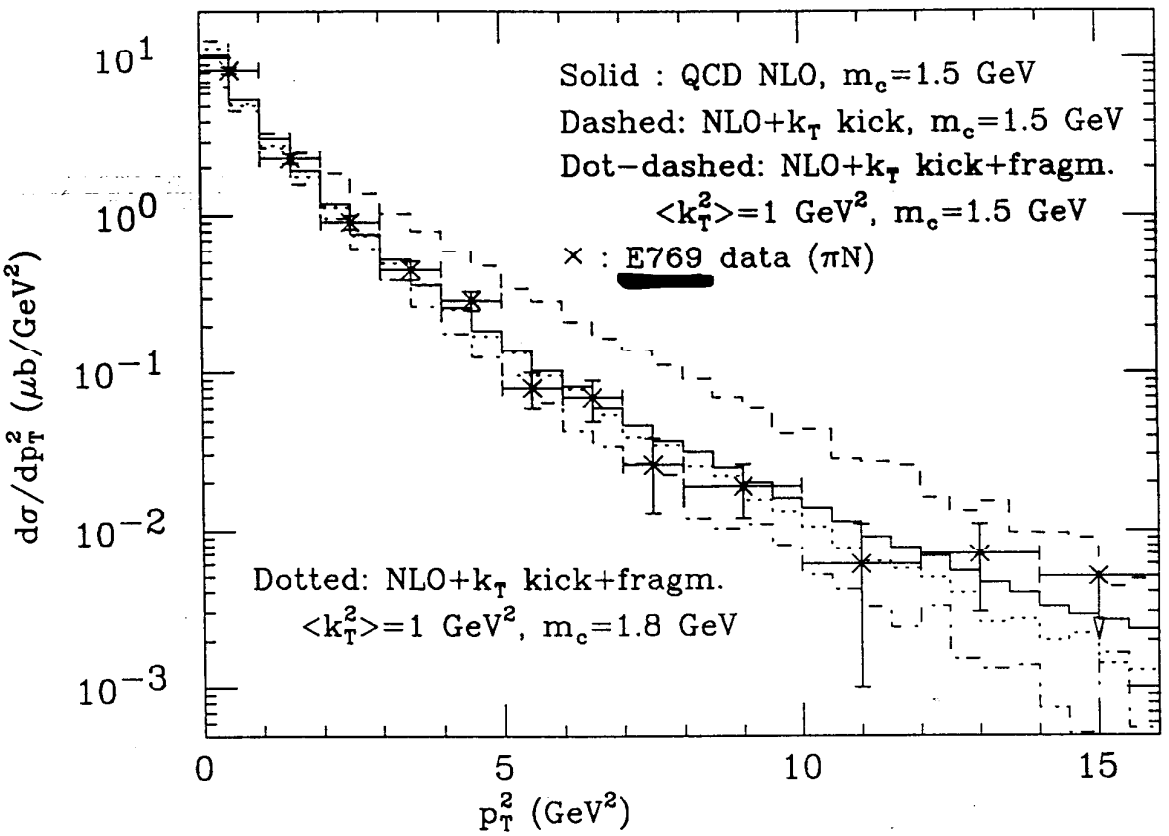
  STATUS OF THE DATA - THEORY COMPARISON

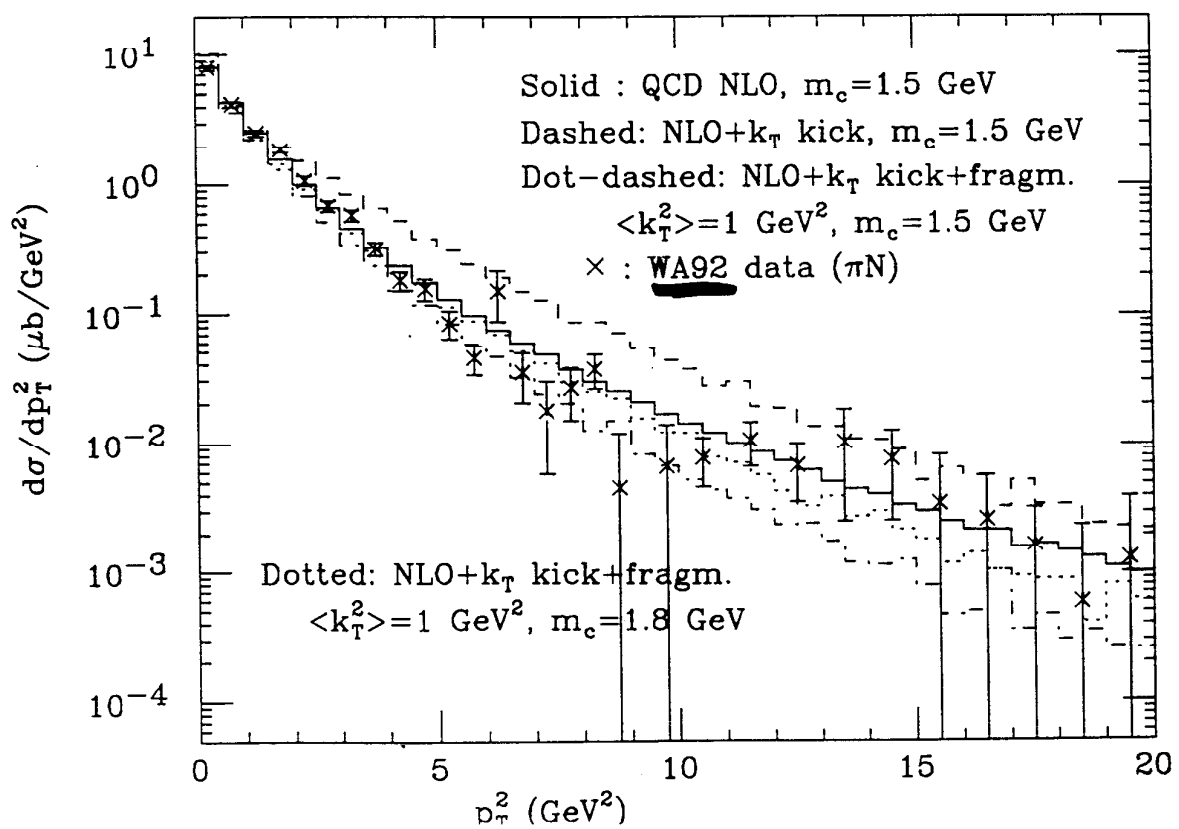
- TOP PRODUCTION:

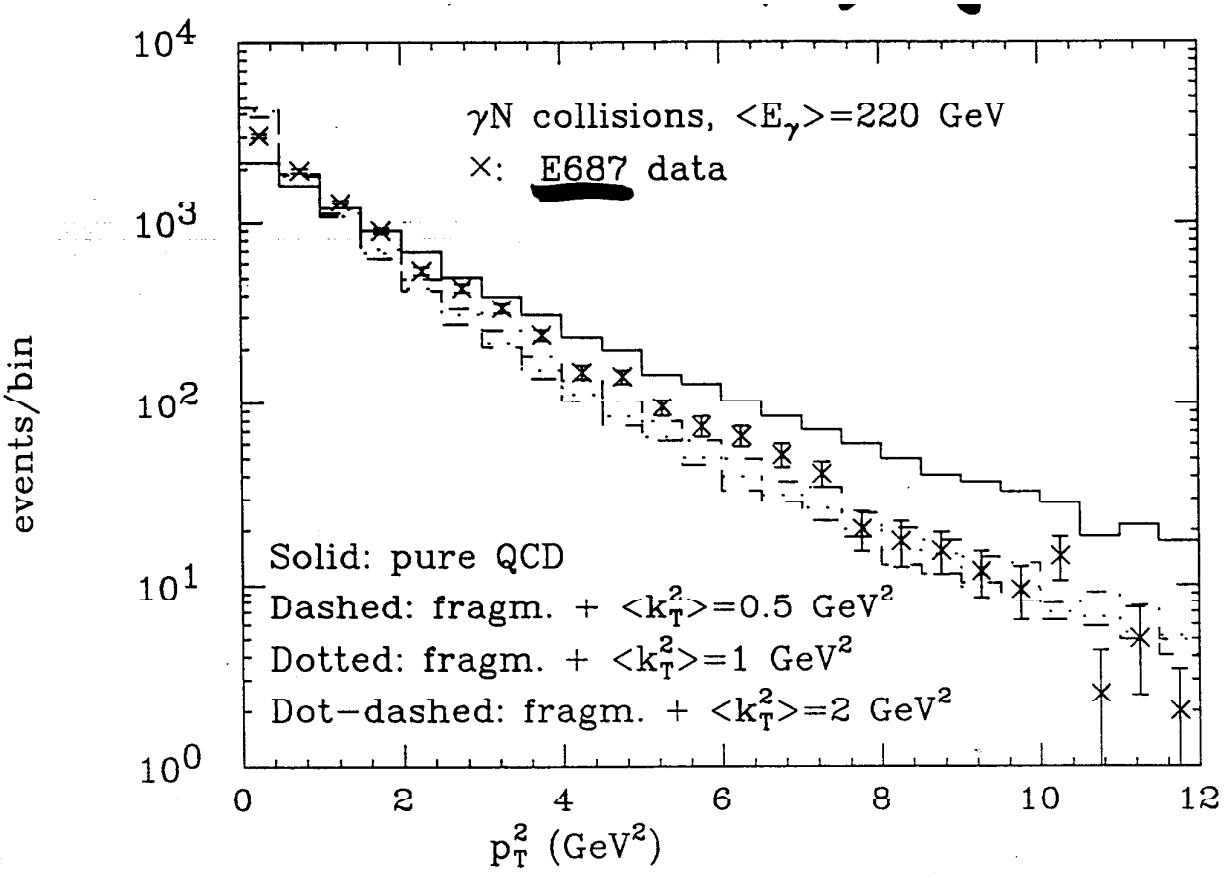
  SEE ED BERGER'S TALK

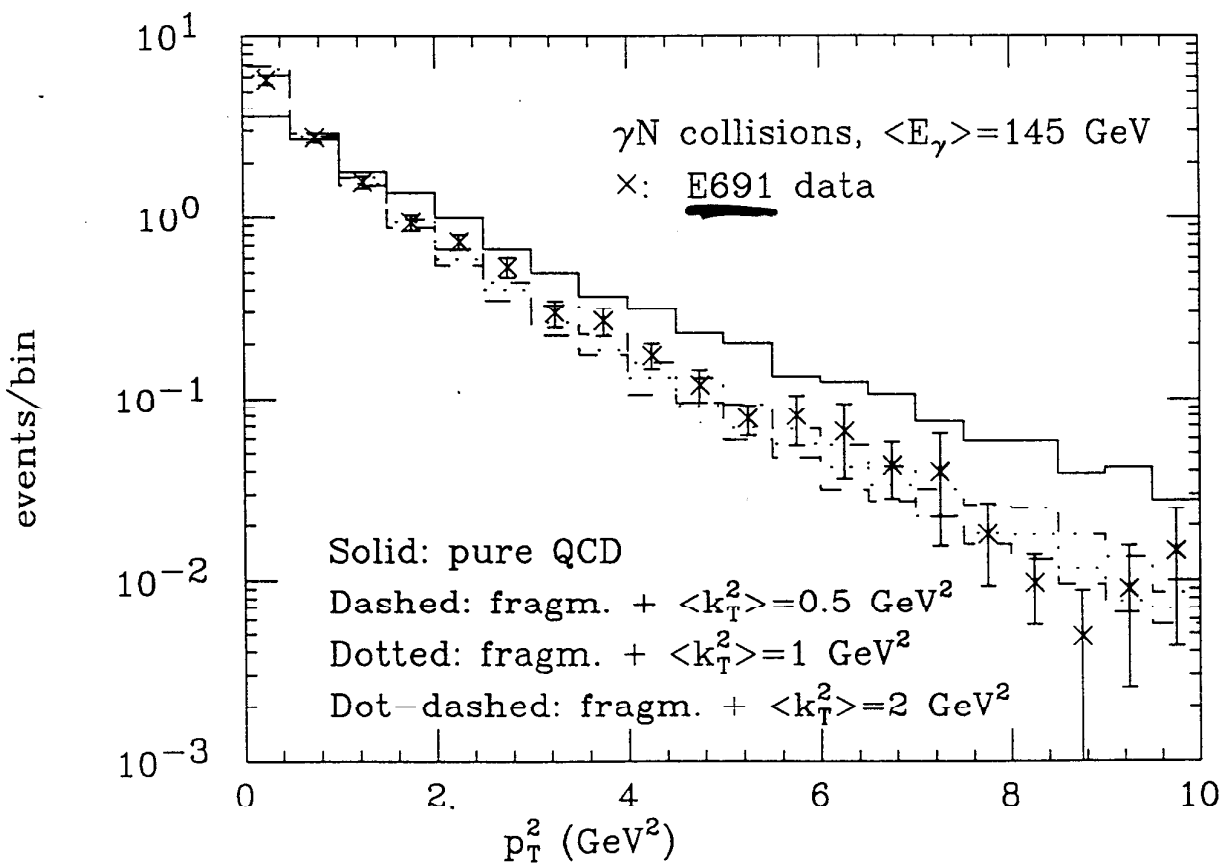
# TOTAL $c\bar{c}$ CROSS-SECTION in $\gamma N$ COLLISIONS

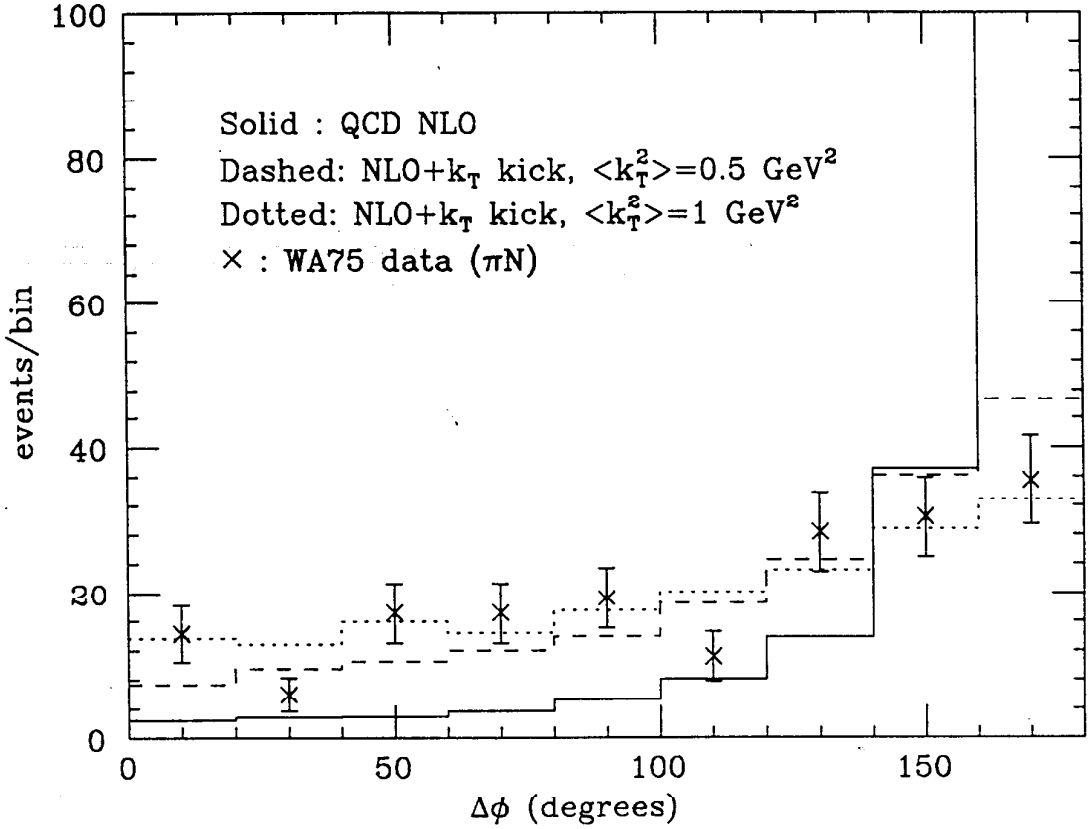



Solid : QCD NLO, $m_c$=1.5 GeV
Dashed: NLO+$k_T$ kick, $m_c$=1.5 GeV
Dot−dashed: NLO+$k_T$ kick+fragm.
$\langle k_T^2 \rangle$=1 GeV$^2$, $m_c$=1.5 GeV
× : E769 data ($\pi$N)
Dotted: NLO+$k_T$ kick+fragm.
$\langle k_T^2 \rangle$=1 GeV$^2$, $m_c$=1.8 GeV
$d\sigma/dp_T^2$ ($\mu$b/GeV$^2$)
$p_T^2$ (GeV$^2$)


Solid : QCD NLO, $m_c$=1.5 GeV
Dashed: NLO+$k_T$ kick, $m_c$=1.5 GeV
Dot−dashed: NLO+$k_T$ kick+fragm.
$\langle k_T^2 \rangle$=1 GeV$^2$, $m_c$=1.5 GeV
× : WA92 data ($\pi$N)
Dotted: NLO+$k_T$ kick+fragm.
$\langle k_T^2 \rangle$=1 GeV$^2$, $m_c$=1.8 GeV
$d\sigma/dp_T^2$ ($\mu$b/GeV$^2$)
$p_T^2$ (GeV$^2$)

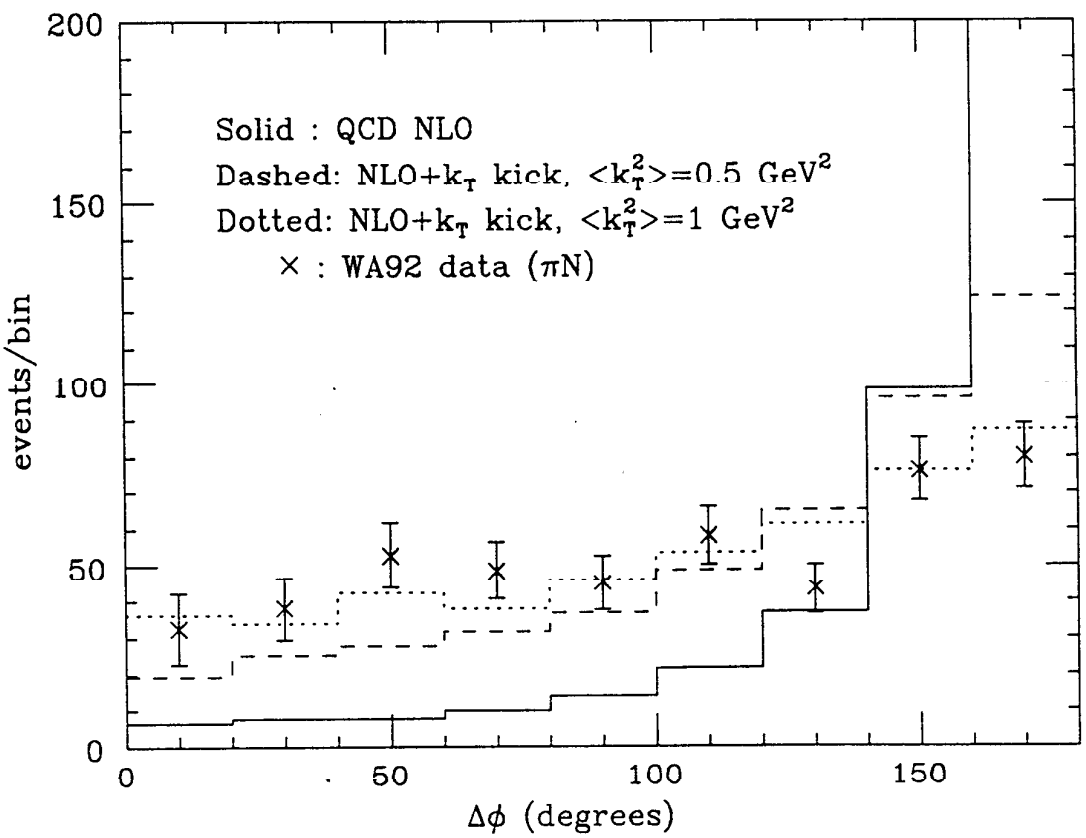

γN collisions, <E_γ>=220 GeV
×: E687 data
Solid: pure QCD
Dashed: fragm. + <k_T^2>=0.5 GeV^2
Dotted: fragm. + <k_T^2>=1 GeV^2
Dot−dashed: fragm. + <k_T^2>=2 GeV^2
events/bin
p_T^2 (GeV^2)

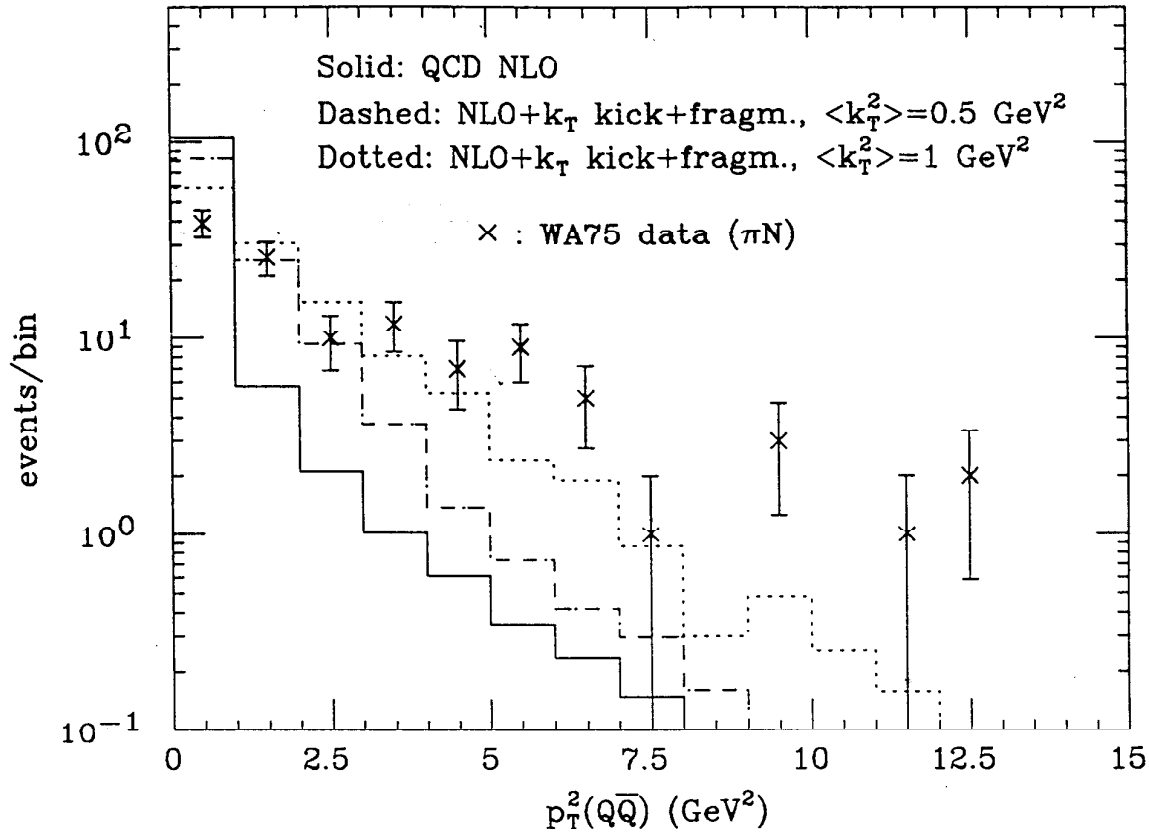

γN collisions, <E_γ>=145 GeV
×: E691 data
Solid: pure QCD
Dashed: fragm. + <k_T^2>=0.5 GeV^2
Dotted: fragm. + <k_T^2>=1 GeV^2
Dot−dashed: fragm. + <k_T^2>=2 GeV^2
events/bin
p_T^2 (GeV^2)



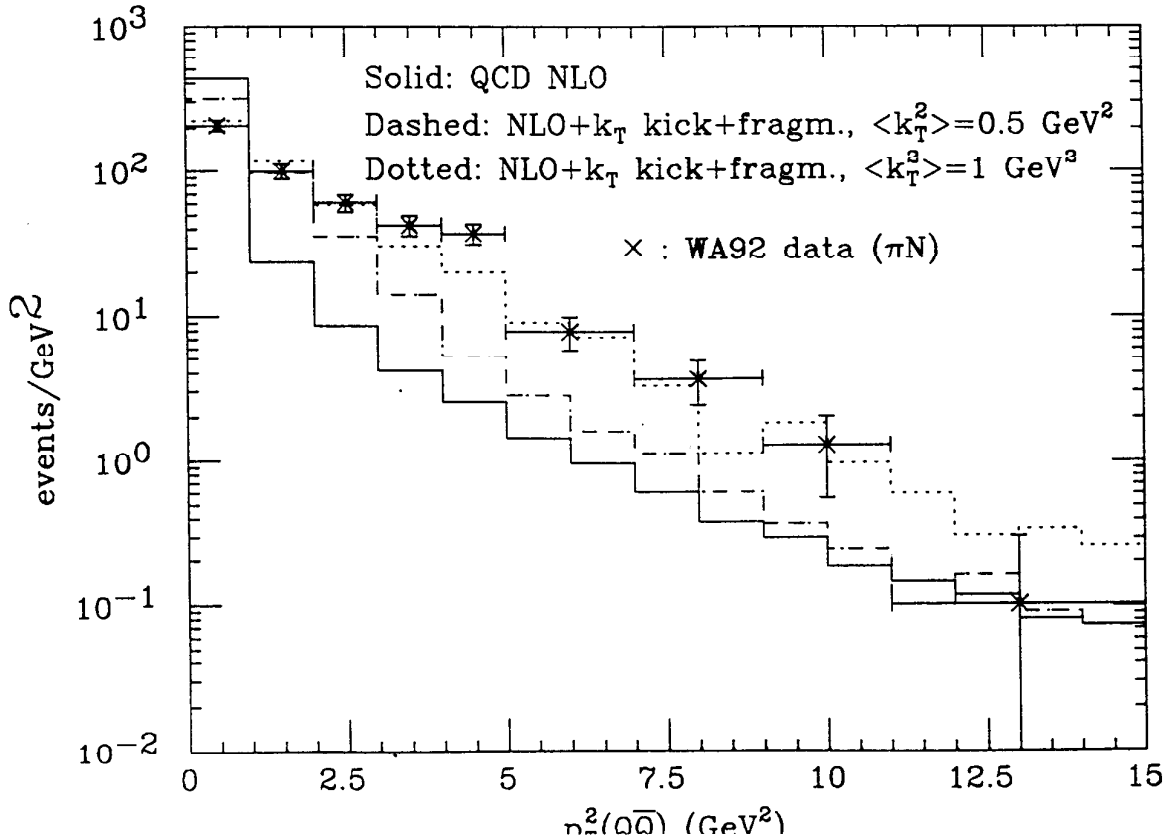

AZIMUTH $c\bar{c}$ CORRELATION

$\pi N$ FIXED TARGET






$p_T(Q\bar{Q})$ $\pi N$ fixed Target



CHARM PRODUCTION AT FIXED TARGET:

- Total cross sections "OK", but large th. uncertainties

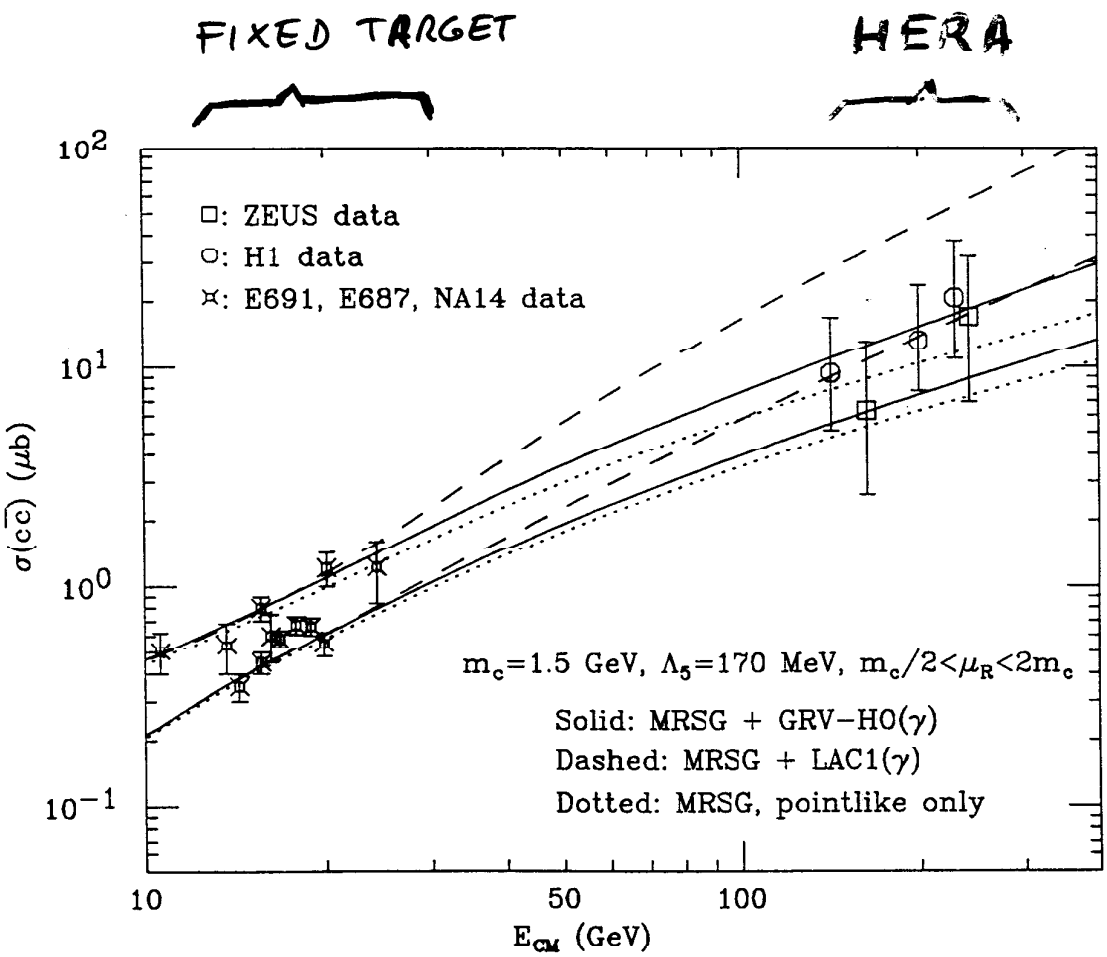
- Some modelling of non-perturbative effects needed to account for observed distributions

  Ratio. agreement in phase mechanism than in hadroproduction

- Correlations: generally broader than in pure QCD.

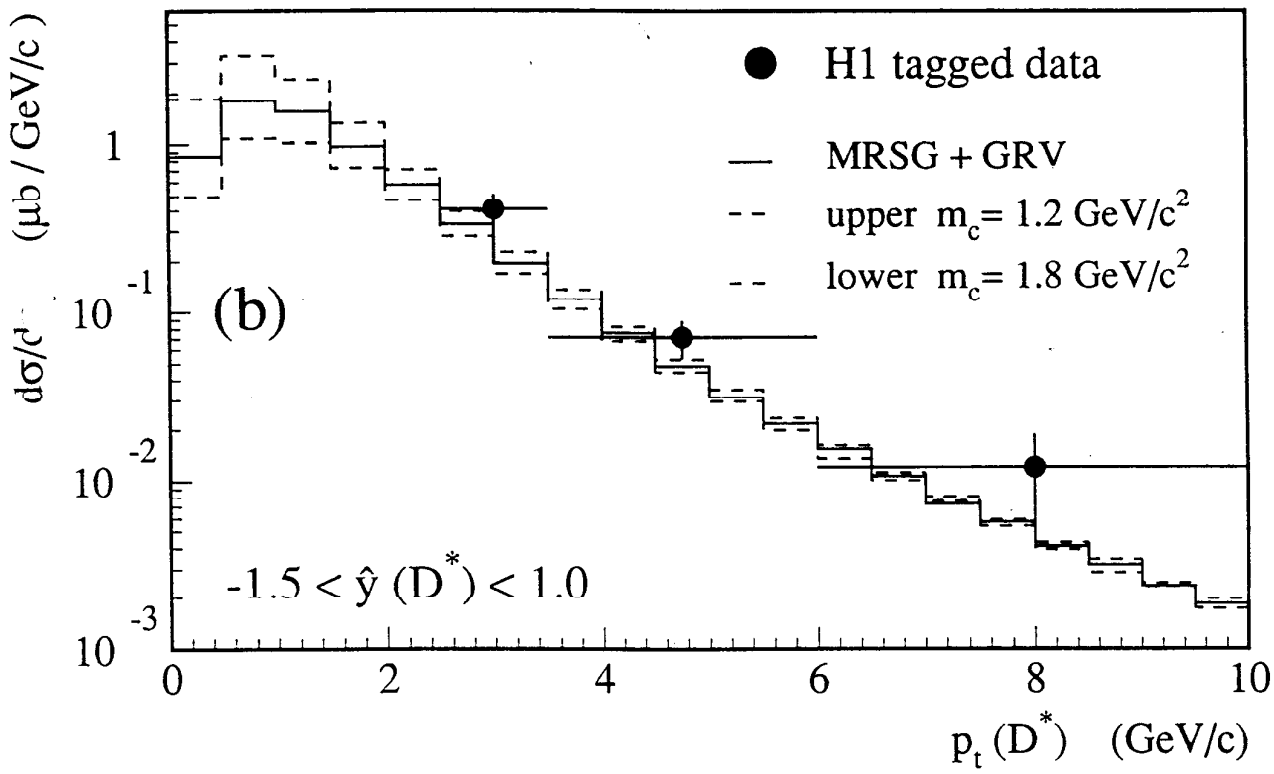
  A problem with $p_T(Q\bar{Q})$

# TOTAL CROSS-SECTIONS FOR CHARM PHOTO-PRODUCTION




DOTTED: POINT LIKE PHOTON

SOLID, DASHED: TWO DIFFERENT PARAMETRIZATIONS OF THE HADRONIC COMPONENT




$P_T$ DISTRIBUTION OF $D^*$

AT HERA VS THEORY

# HEAVY QUARK PHOTOPRODUCTION

$$d\sigma = \sum_j \int dx_\gamma \, dx \; f(x_\gamma) \, f_j^H(x) \, d\hat{\sigma}_{\gamma j}(x_\gamma P_1, x P_2)$$

$$+ \sum_{i,j} \int dx_1 \, dx_2 \; f_i^\gamma(x_1) \, f_j^H(x_2) \, d\hat{\sigma}_{ij}(x_1 P_1, x_2 P_2)$$

$f(x_\gamma) \longrightarrow$ • photon beam spectrum for fixed-target experiments

• Weizsäcker-Williams distribution for electro production

$f_i^\gamma(x) \longrightarrow$ Parton densities in the photon.

The second line ("hadronic" or "resolved" component of the photon) is negligible at fixed-target experiments, but can become important at HERA.

COMPUTATION OF $d\hat{\sigma}_{\gamma j}$, $d\hat{\sigma}_{ij}$ SIMILAR AS IN THE HADROPRODUCTION CASE.

A SIMPLE APPLICATION: THE DETERMINATION OF THE GLUON DENSITY OF THE PROTON AT HERA

AT LEADING ORDER:

$$\frac{d\sigma^{(0)}}{dy_{Q\bar{Q}}\, dM^2_{Q\bar{Q}}} = \frac{1}{E^2} f_\gamma^{(e)}(x_\gamma)\, f_q^{(P)}(x_q)\, \hat{\sigma}^{(0)}_{\gamma q}(M^2_{Q\bar{Q}})$$

$$x_\gamma = \frac{M_{Q\bar{Q}}}{E} e^{y_{Q\bar{Q}}}$$

$$x_q = \frac{M_{Q\bar{Q}}}{E} e^{-y_{Q\bar{Q}}}$$

IDENTIFY L.H.S. WITH DATA → GET A FIRST DETERMINATION OF $f_q^{(P)}(x_q)$:

$$f_q^{(P)} \simeq f_q^{(0)}(x_q) = \left[\frac{d\sigma}{dy_{Q\bar{Q}}\, dM^2_{Q\bar{Q}}}\right]_{exp.} \frac{E^2}{f_\gamma^{(e)}(x_\gamma)\, \hat{\sigma}^{(0)}_{\gamma q}(M^2_{Q\bar{Q}})}$$

NOW INTRODUCE RADIATIVE CORRECTIONS:

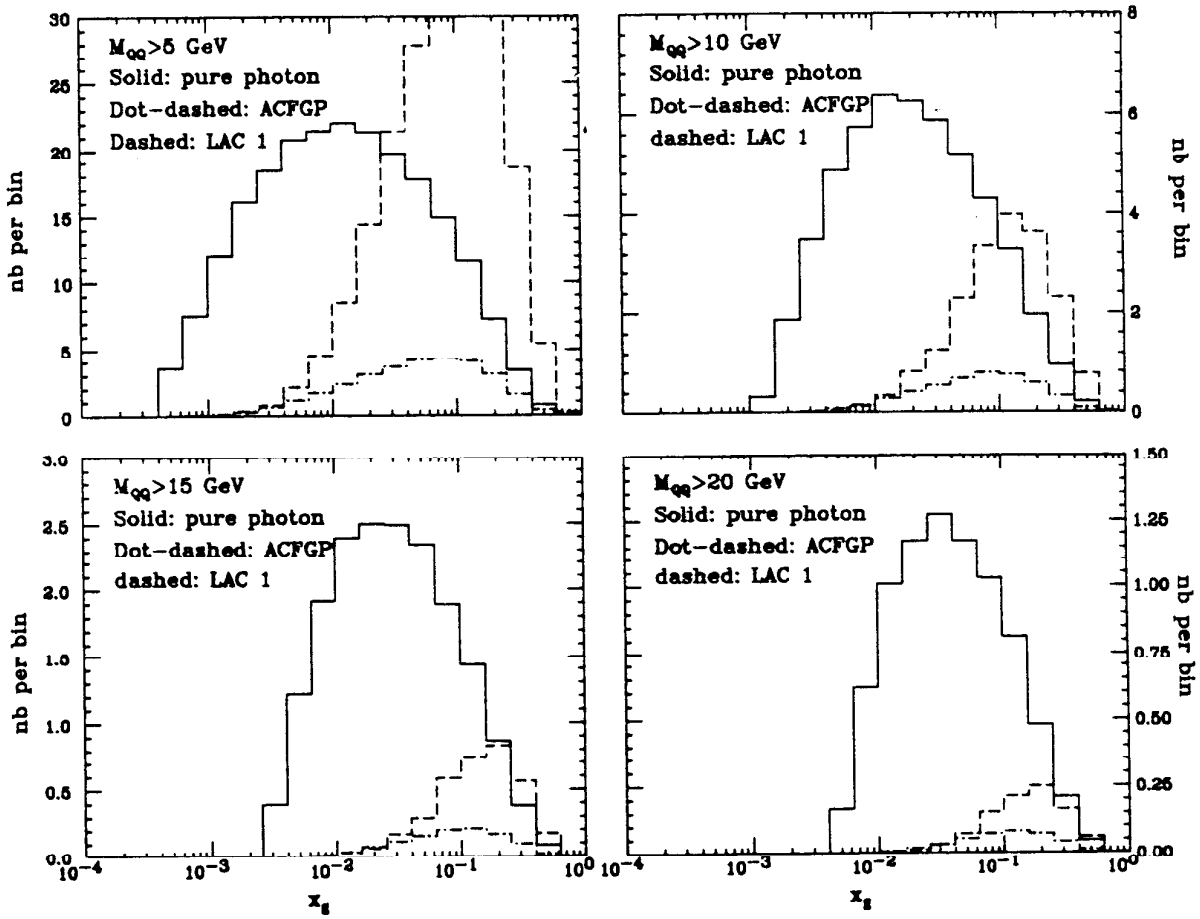
$$\frac{d\sigma}{dy_{Q\bar{Q}}\, dM^2_{Q\bar{Q}}} = \frac{1}{E^2} f_e^{(\gamma)}(x_\gamma)\, f_q^{(P)}(x_q)\, \hat{\sigma}^{(0)}_{\gamma q}(M^2_{Q\bar{Q}}) + \Delta[f_q^{(P)}, x_q, M^2_{Q\bar{Q}}]$$

AND USE $f_q^{(P)} = f_q^{(0)} + f_q^{(1)}$ TO GET

$$f_q^{(1)}(x_q) = -\frac{E^2 \Delta[f_q^{(0)}, x_q, M^2_{Q\bar{Q}}]}{f_\gamma^{(e)}(x_\gamma)\, \hat{\sigma}^{(0)}(M^2_{Q\bar{Q}})}$$

[illegible]

S. FRIXIONE, M. MANGANO, P. NASON, G. R.
CERN-TH.6864/93
PHYS. LETT. B308 (93) 137

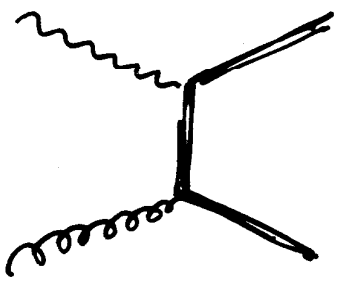


POSSIBLE WAY TO MEASURE $\Delta g$ DIRECTLY:

STUDY THE PRODUCTION OF HEAVY QUARK PAIRS IN PHOTON-PROTON COLLISIONS:

AT LEADING ORDER, THE ONLY PARTONIC SUBPROCESS INVOLVED IS

$$q + \gamma \rightarrow Q + \bar{Q}$$



(REAL $\gamma$, NOT DIS!)

(ALSO THE UNPOLARIZED DISTRIBUTION $g(x)$ CAN BE MEASURED IN THE SAME WAY).

CONSIDER THE QUANTITY

$$d\Delta\sigma_{\gamma p} = \frac{1}{2}\left[d\sigma_{\gamma p}^{\uparrow\uparrow} - d\sigma_{\gamma p}^{\uparrow\downarrow}\right]$$

IT IS PROPORTIONAL TO $\Delta g$:

$$\boxed{d\Delta\sigma_{\gamma p} = \Delta g(x, Q^2)\, d\Delta\hat{\sigma}_{\gamma g}\, dx_g}$$

$Q^2$ FACTORIZATION SCALE

$d\Delta\hat{\sigma}_{\gamma g}$ CROSS SECTION FOR THE PARTONIC PROCESS $\gamma g \rightarrow Q\bar{Q}$

WHAT CAN HERA DO ?

TWO POSSIBLE WAYS OF ANALYZING DATA:

1) REAL PHOTONS IN THE ELECTRON BEAM DISTRIBUTED ACCORDING TO THE POLARIZED WEIZSÄCKER-WILLIAMS FUNCTION:

$$\Delta d\sigma_{ep} = \Delta f_{WW}(x_\gamma) \cdot d\Delta\sigma_{\gamma p}(x_\gamma, x_q)\, dx_\gamma$$

$$\Delta f_{WW}(x_\gamma) = \frac{\alpha_{em}}{2\pi} \frac{1-(1-x_\gamma)^2}{x_\gamma} \log \frac{Q^2_{max}(1-x_\gamma)}{m_e^2 x_\gamma}$$

2) TAG THE OUTGOING ELECTRON → DETERMINE THE PHOTON ENERGY.

— | —

"REASONABLE" KINEMATICAL CUTS :

$$p_T^Q > 2 \text{ GeV}$$

$$|\eta^Q| < 1.5$$

( $Q \equiv$ CHARM FROM NOW ON )

- TOTAL CROSS SECTION ASYMMETRY

COMPARE THEORETICAL PREDICTIONS WITH THE MINIMUM OBSERVABLE ASYMMETRY AT HERA.

$$\Delta\sigma \equiv \frac{\Delta\sigma}{\sigma} \cdot \sigma$$

COMPUTED AT NLO

ONLY LO CALCULATION AVAILABLE - RAD CORR. MAY APPROXIMATELY CANCEL

OBSERVABLE IF

$$N^{\uparrow\uparrow} - N^{\uparrow\downarrow} > \delta N_{TOT}$$

OR

$$\frac{\Delta\sigma}{\sigma} > \frac{1}{\sqrt{2\mathcal{L}\sigma\varepsilon}}$$

$\mathcal{L}$ = INTEGRATED LUMINOSITY

$\sigma$ = TOTAL CROSS SECTION

$\varepsilon$ = EXPERIMENTAL EFFICIENCY (CHARM IDENTIFICATION, BEAM POLARIZATION, ...)

RESULTS:

ELECTROPRODUCTION AT $\sqrt{s} = 314$ GeV

$$\left[\frac{\Delta\sigma}{\sigma}\right]_{ep} \cong 0.005 \div 0.013 \; ; \quad \frac{1}{\sqrt{2\mathcal{L}\sigma}} \cong 0.0003$$

PHOTOPRODUCTION AT $\sqrt{s} = 200$ GeV

$$\left[\frac{\Delta\sigma}{\sigma}\right]_{\gamma p} \cong 0.0[illegible] \div 0.09[illegible] \; ; \quad \frac{1}{\sqrt{2\mathcal{L}\sigma}} \cong 0.0008$$

- $\mathcal{L} = 100 \; pb^{-1}$
- $p_T > 2$ GeV , $|\eta| < 1.5$
- PETERSON FRAGMENTATION APPLIED.

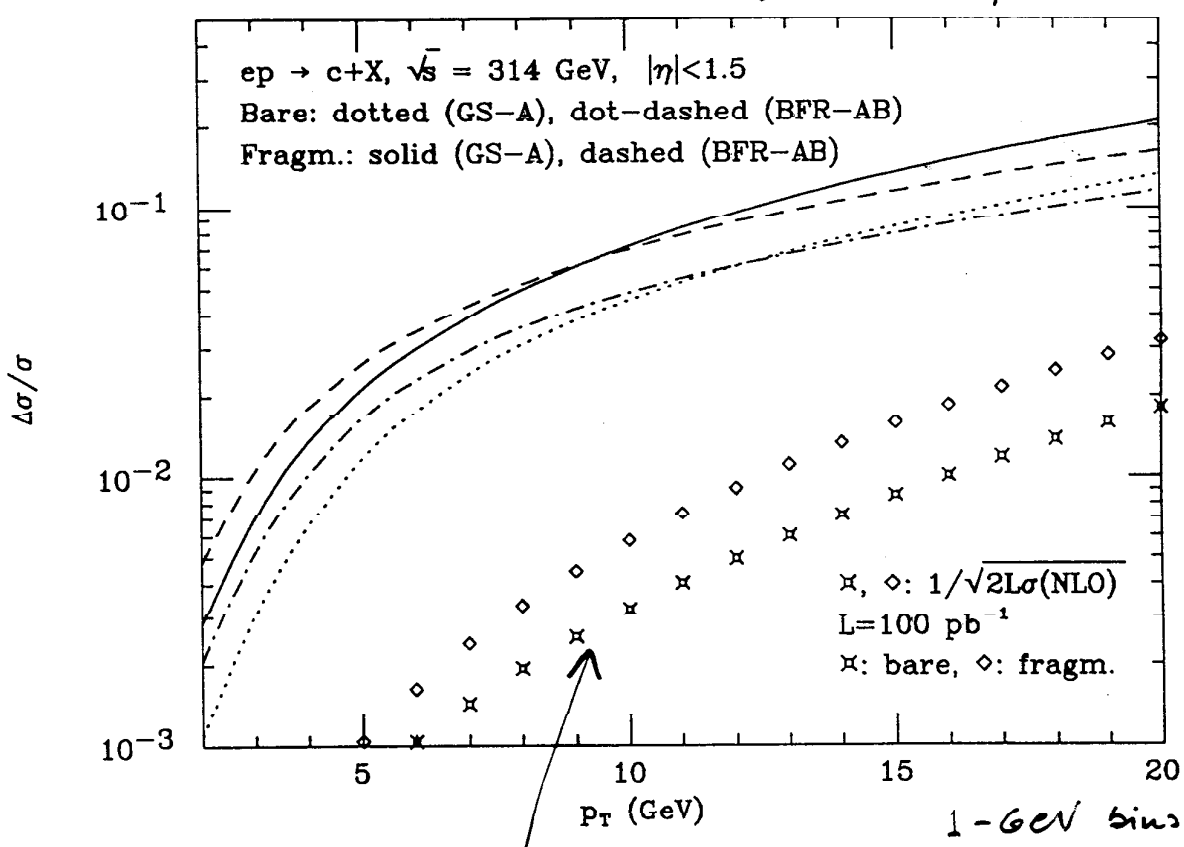
- SINGLE - INCLUSIVE $P_T$ DISTRIBUTION

  - ASYMMETRY GROWS WITH $P_T$
  - ALWAYS LARGER THAN THE MINIMUM
  - DIFFICULT TO DISTINGUISH BETWEEN DIFFERENT PARAMETRIZATIONS

# CHARM ELECTROPRODUCTION AT HERA

## $P_T$ DISTRIBUTION

S. FRIKICNE, E.R.

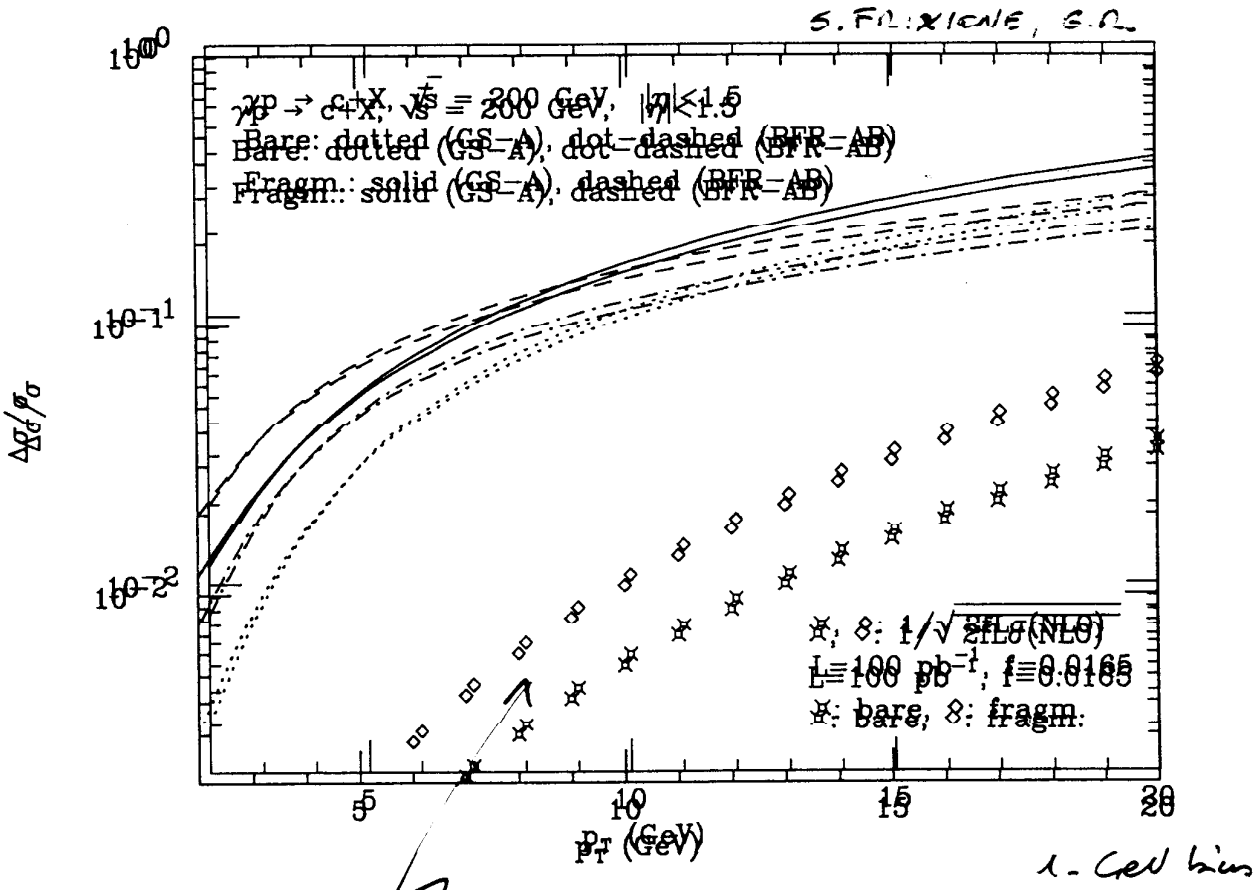



MINIMUM ASYMMETRY OBSERVABLE WITH 100 $pb^{-1}$ AND $\varepsilon = 1$

CHARM PHOTOPRODUCTION AT HERA

$\sqrt{s} \sim 200$ GeV

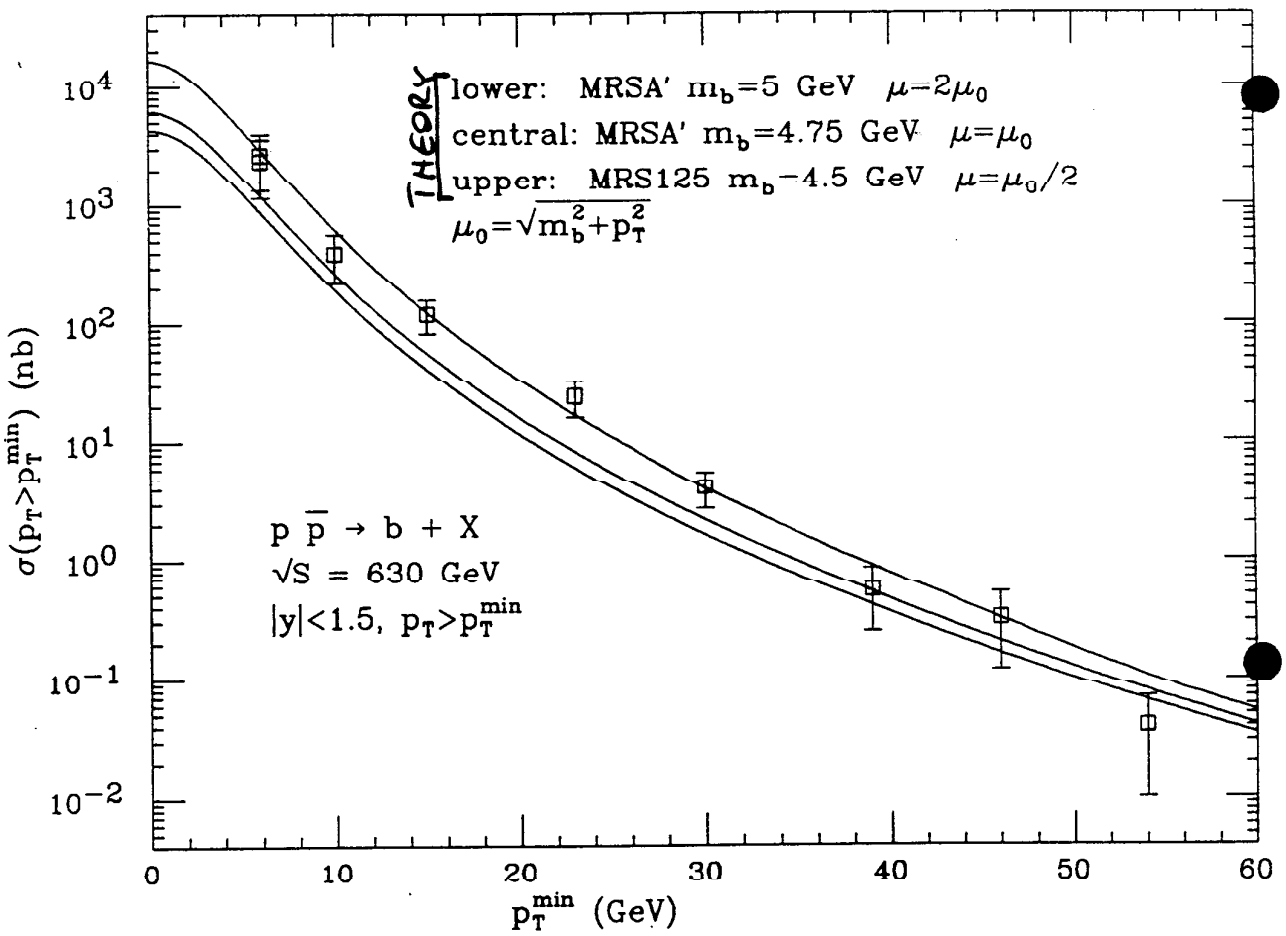
$p_T$ DISTRIBUTION



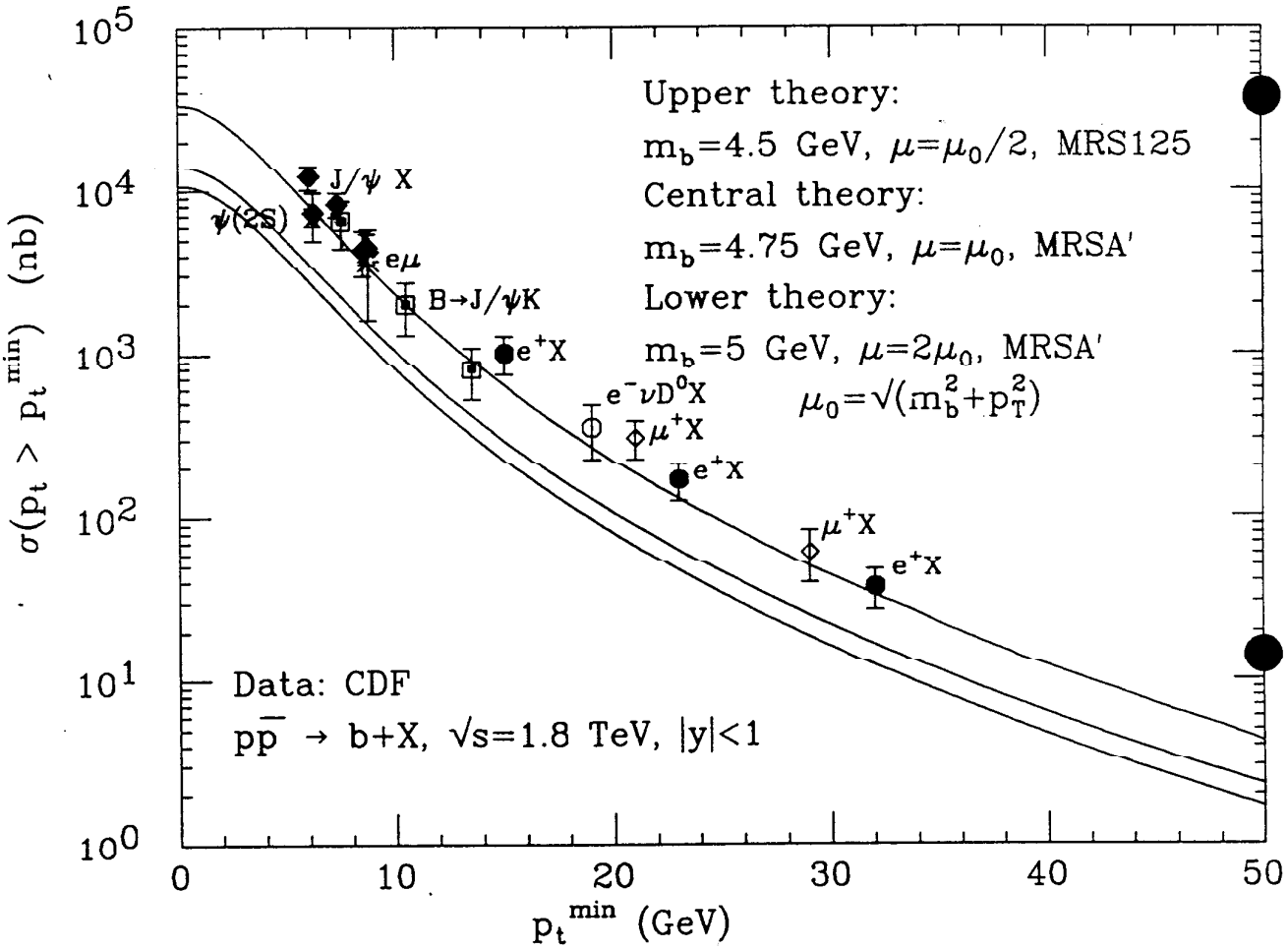

MINIMUM $\frac{\Delta\sigma}{\sigma}$ OBSERVABLE.

# UA 1 DATA

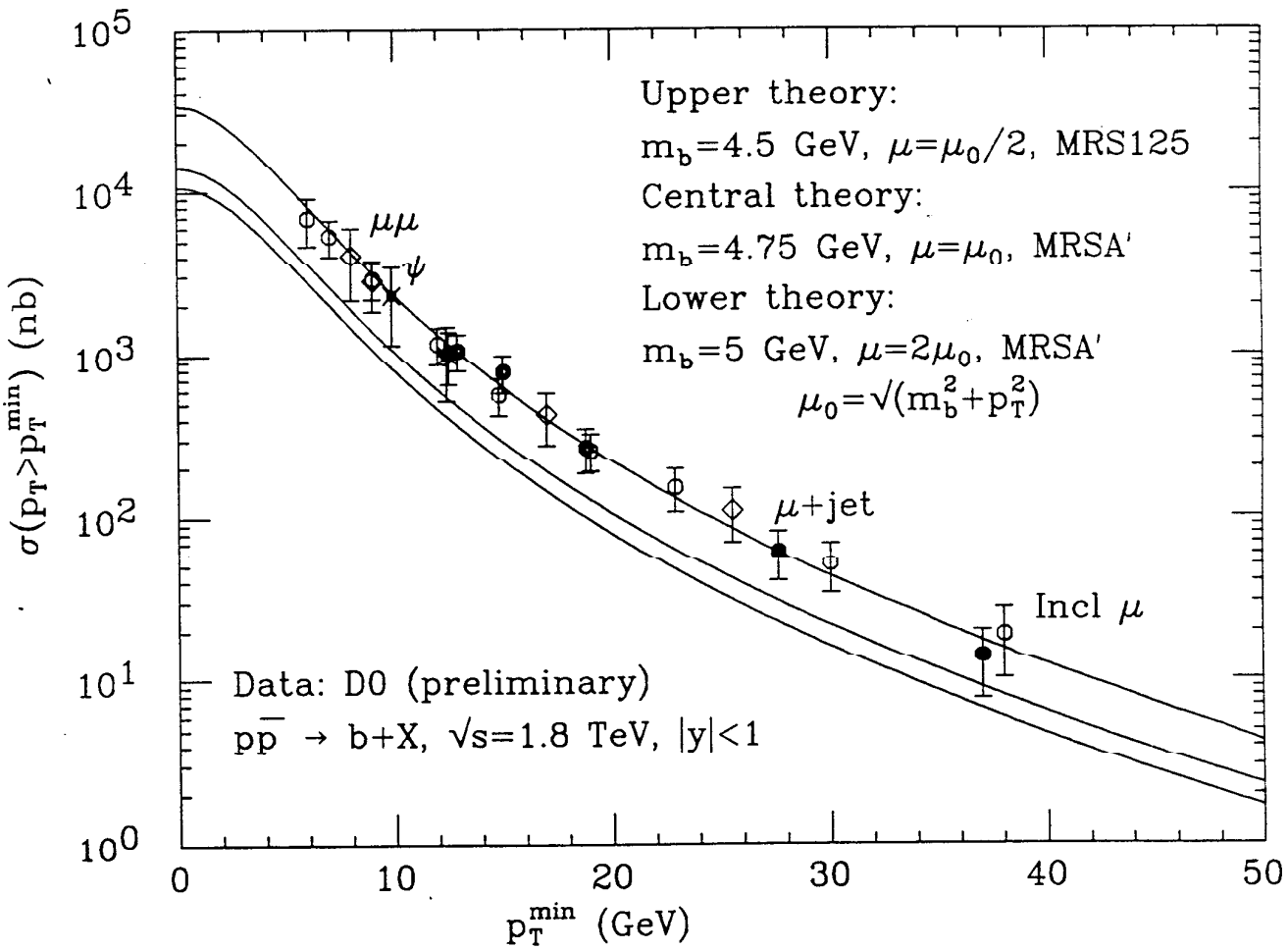
FOR $\int_{p_{T\,MIN}}^{\infty} \frac{d\sigma}{dp_T}\, dp_T$



# CDF DATA vs. THEORY



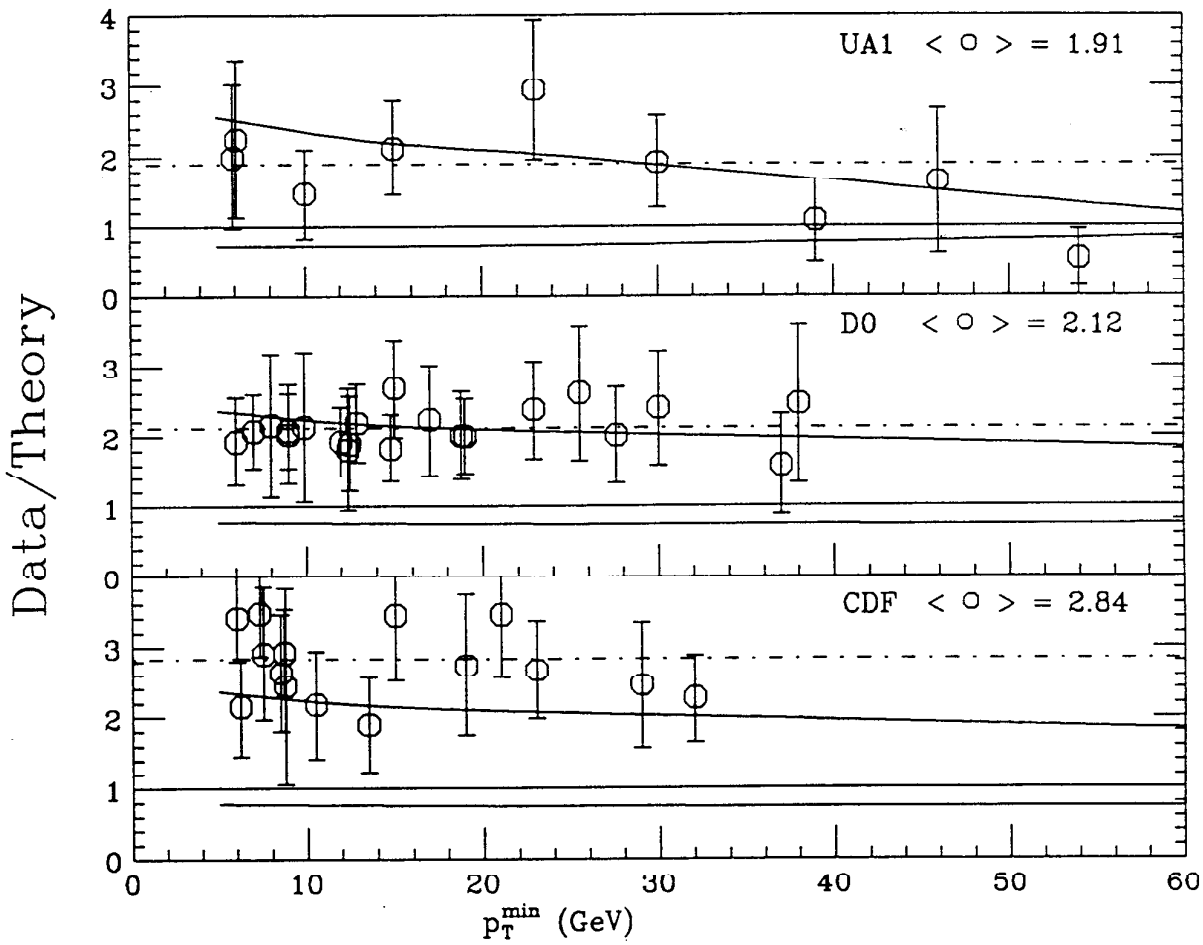
# DØ DATA vs. THEORY



# SUMMARY FOR $d\sigma(b)/dp_T$ AT COLLIDERS

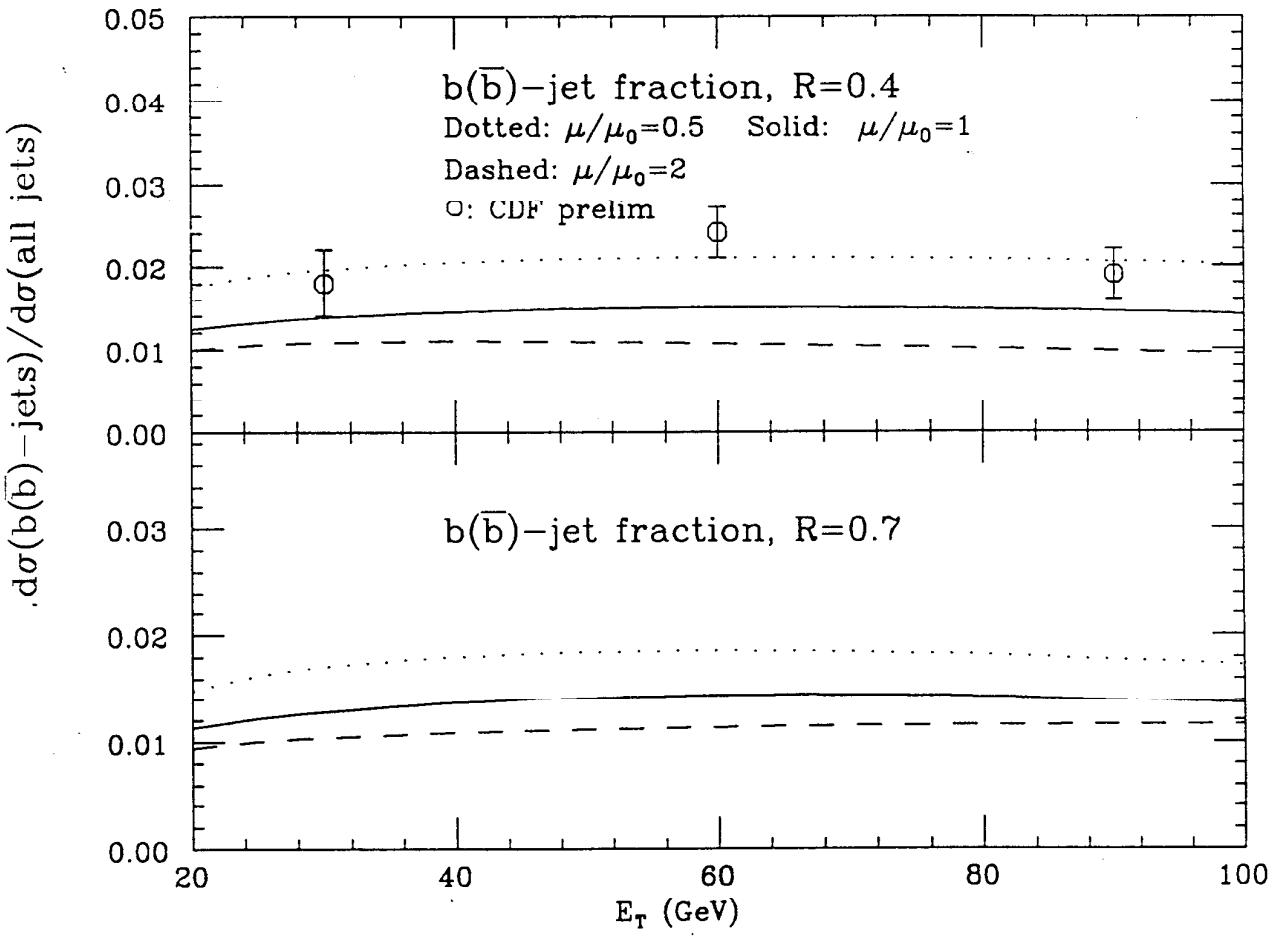
—·—·— FIT TO DATA

——— THEORY: CENTRAL, UPPER, LOWER

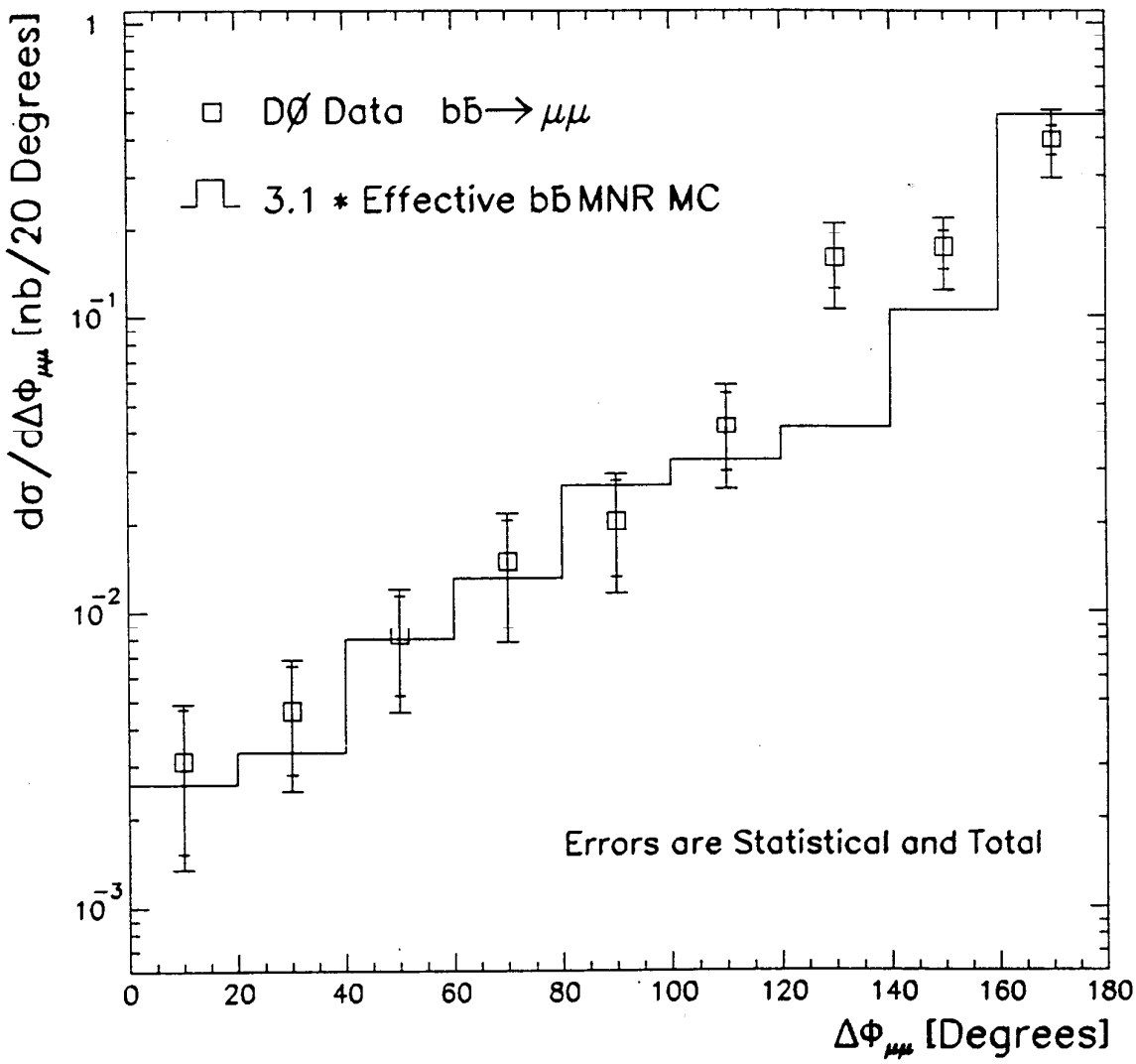


$b(\bar{b})$ JET FRACTION

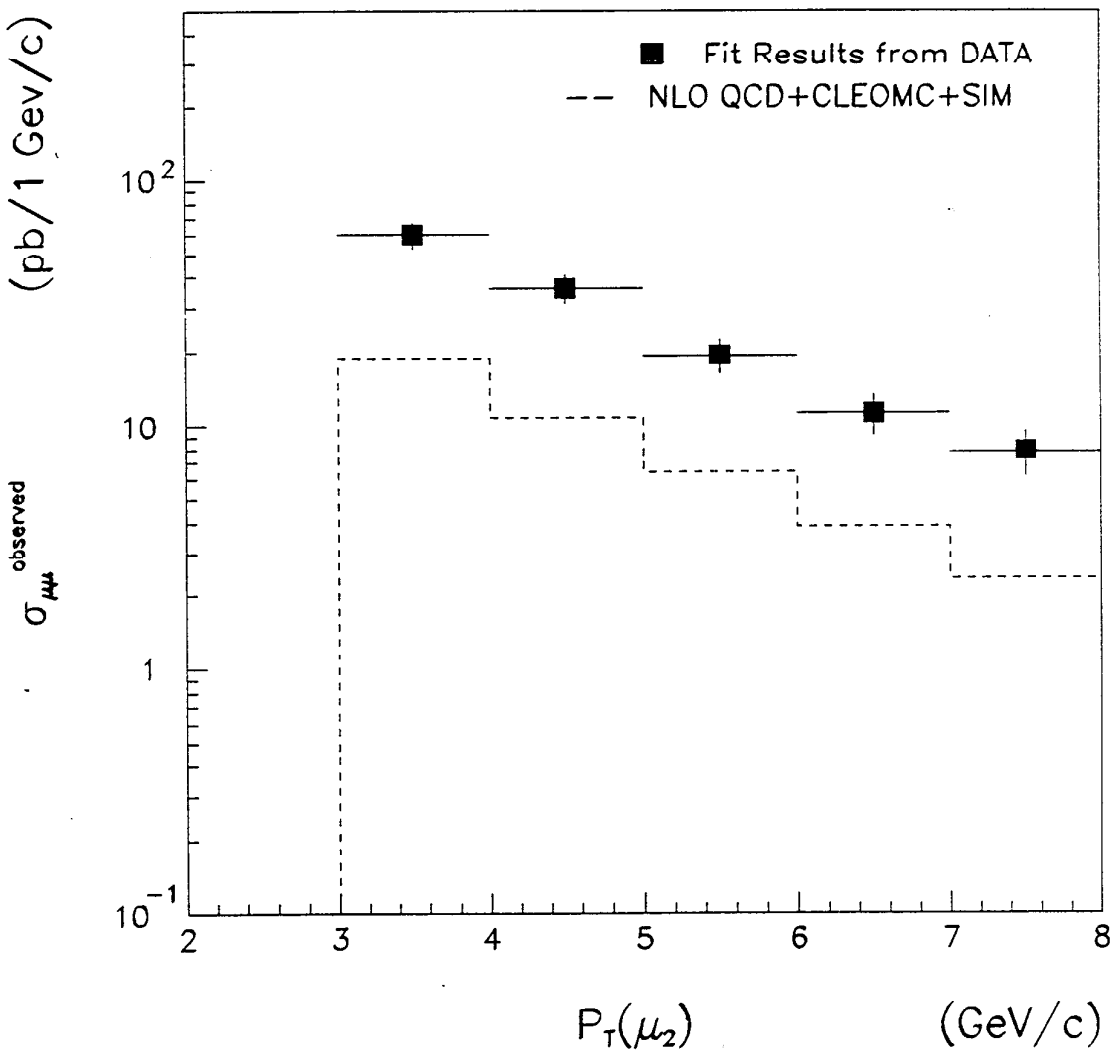
$\sqrt{s} = 1.8$ TeV



# DØ: $b\bar{b}$ AZIMUTHAL CORRELATION



CDF Preliminary



CDF

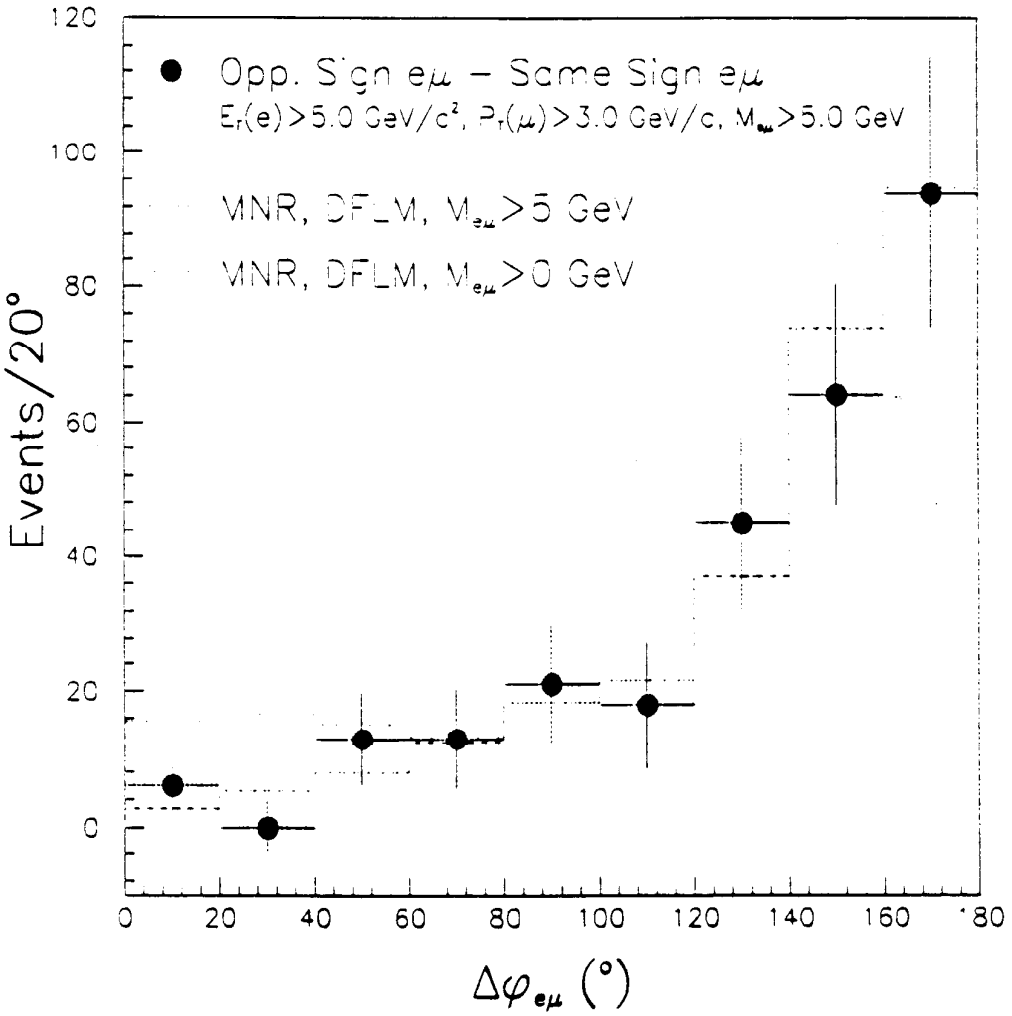

Opp. Sign eμ − Same Sign eμ
E_T(e)>5.0 GeV/c², P_T(μ)>3.0 GeV/c, M_eμ>5.0 GeV
MNR, DF_M, M_eμ>5 GeV
MNR, DFLM, M_eμ>0 GeV
Events/20°
Δφ_eμ (°)
0
20
40
60
80
100
120
140
160
180

**Figure 4:**

A1 COLL.
CERN PPE/93-153

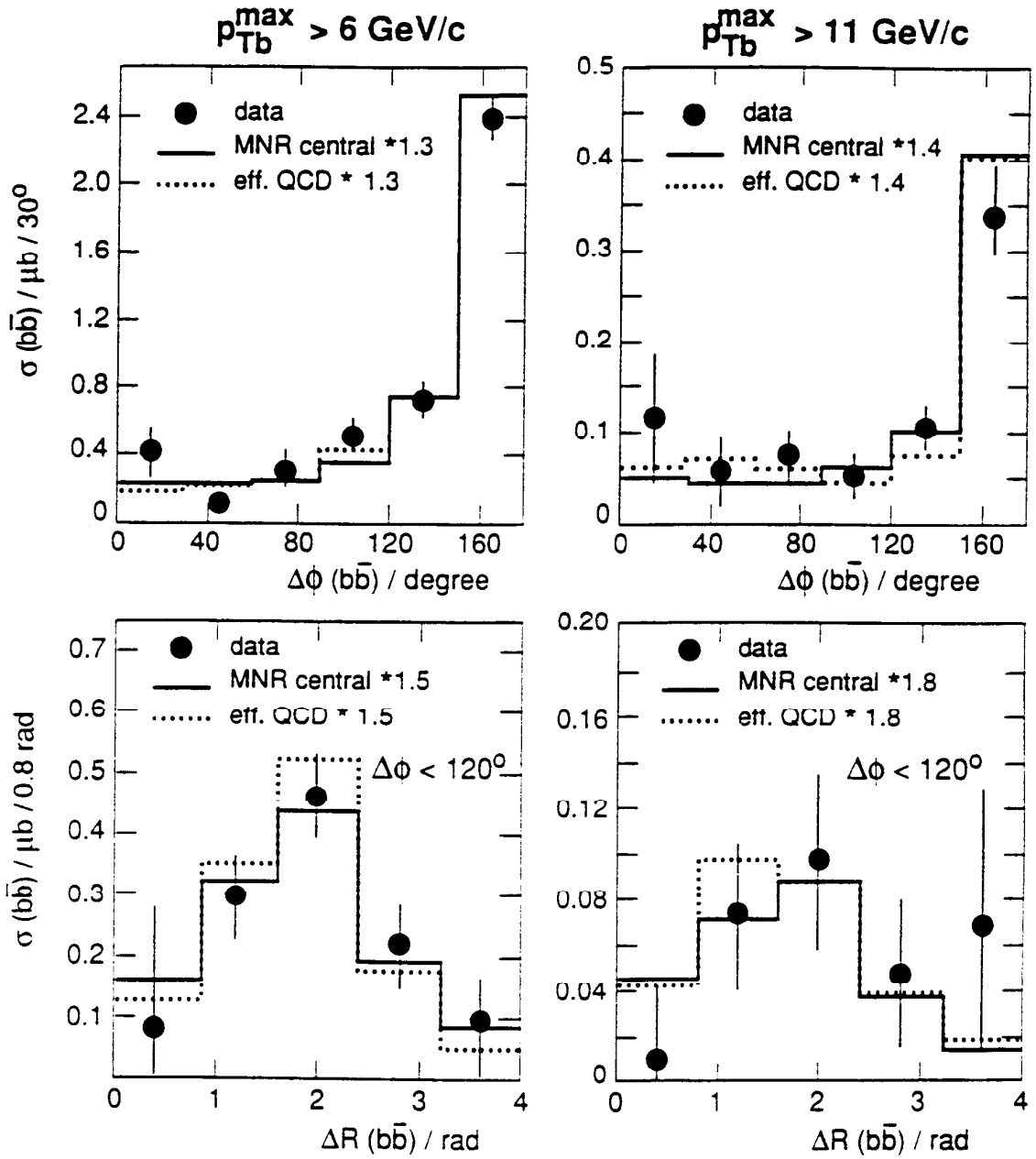



Figure 6: *Measured $b\bar{b}$ angular distributions for b quark pairs with a $p_T$ of the higher $p_T$ quark > 6 GeV/c (left) and > 11 GeV/c (right). Errors are statistical only. Shown are the distributions for $\Delta\phi$ (azimuth angle) and $\Delta R$ ('space angle'). A cut of $\Delta\phi < 120°$ has been applied for the $\Delta R$ distribution. Also shown are the central $O(\alpha_s^3)$ QCD predictions from the calculation of Mangano, Nason, and Ridolfi (MNR) [9] and the prediction of the effective QCD Monte Carlo [12] used for the acceptance calculation.*

# BOTTOM PRODUCTION : SUMMARY

- Good agreement with NLO QCD shape for $p_T$ distributions at central rapidities

- The discrepancy in the overall normalization ($\sim$ a factor of 2) can be reduced with extreme choices of input parameters (e.g. $\Lambda_{QCD}$)

- 30% discrepancy CDF $\leftrightarrow$ DØ @ 1.8 TeV
  30% discrepancy UA1 $\leftrightarrow$ CDF @ 0.63 TeV

- Large discrepancies in the forward region

- $b\bar{b}$ correlations well described in shape by QCD