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8/28/94
Wine+cheese

DØ Note
2276

B PHYSICS RESULTS FROM DØ

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for the
DØ Collaboration

Outline

I. Introduction
II. DØ Detector and B Triggers
III. Measurements of the b-Quark Cross Section
IV. J/ψ and Υ Cross Sections
V . Additional B Physics Topics
VI. Conclusions

THE DØ COLLABORATION

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Tata Institute of Fundamental Research, Bombay, India
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Texas A&M University

~ 40 institutions ~ 400 physicists

Introduction

- All results are preliminary.

- The DØ B physics program using 1992-93 collider data focuses on QCD motivated studies of b-quark production and fragmentation.

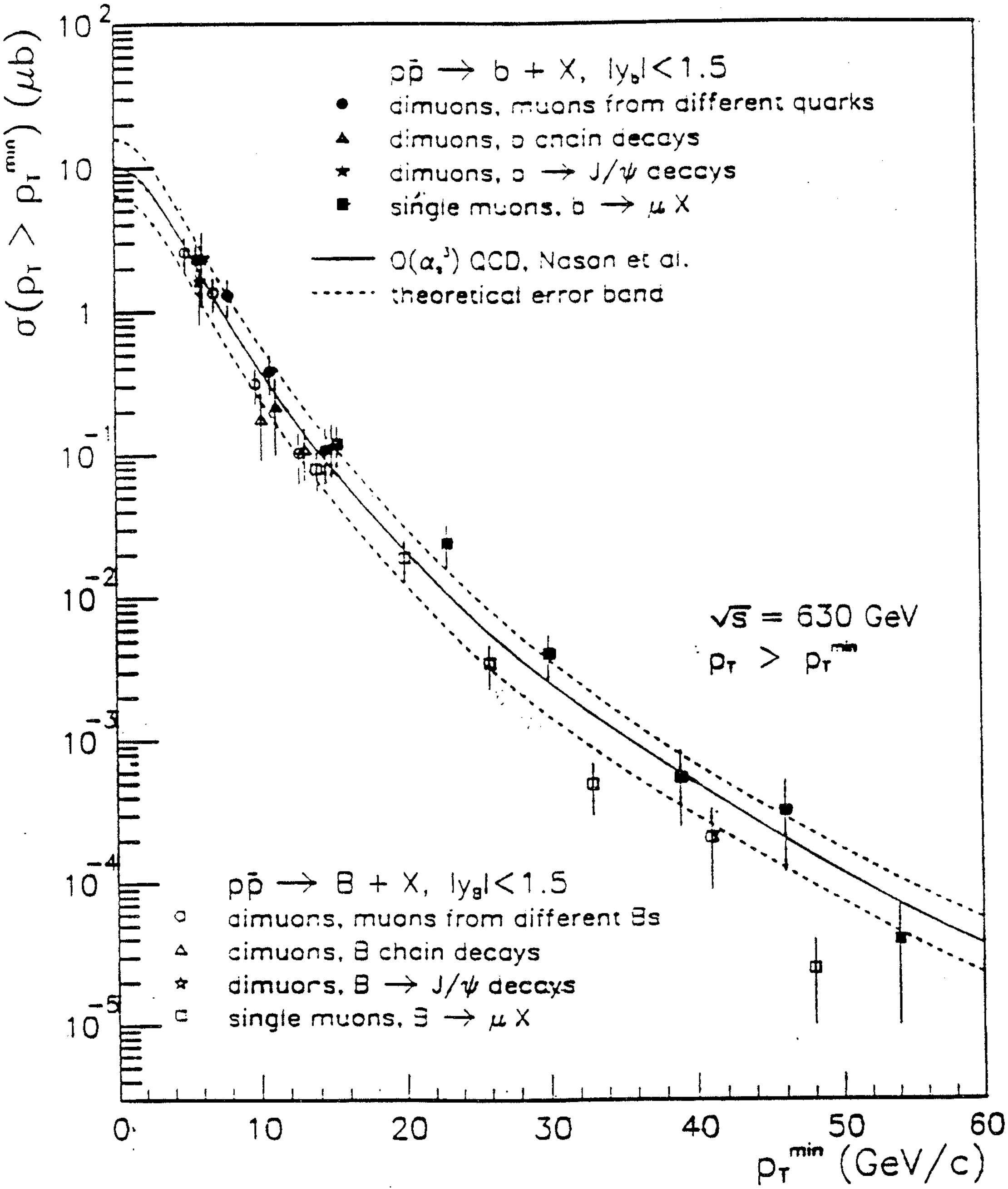
- Because the b-quark can be identified experimentally and has a non-zero mass, theoretical calculations for b-quark production are perhaps more reliable than for other processes.

- Calculations to order α_s^3 (NLO) exist for the b-quark inclusive cross section as well as the fully exclusive $b\bar{b}$ cross section.

- Predictions also exist for the inclusive heavy quark jet cross section as a function of jet E_T.

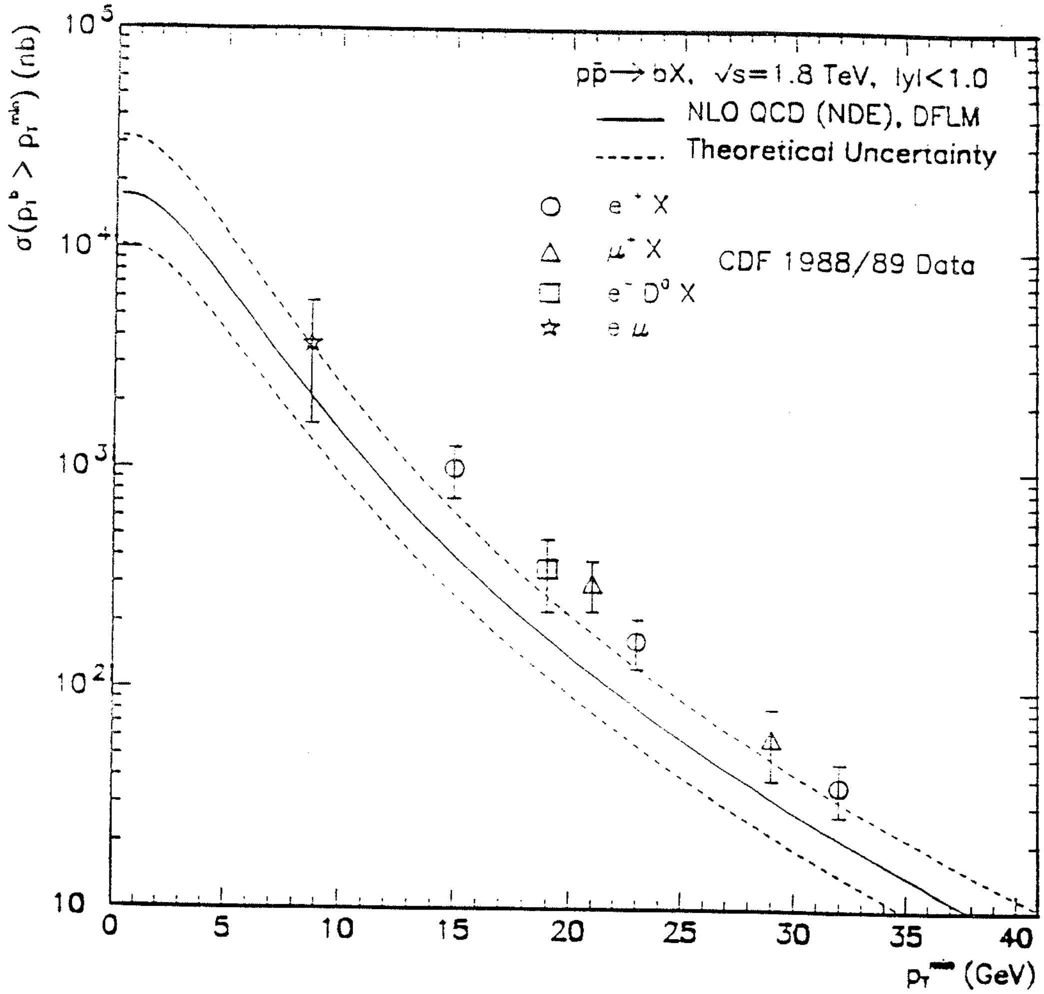
- Measurement of the b-quark cross section in comparison with NLO QCD predictions is a benchmark test which allows the procedures and pieces of perturbative QCD calculations at Tevatron energies to be probed.

UA1

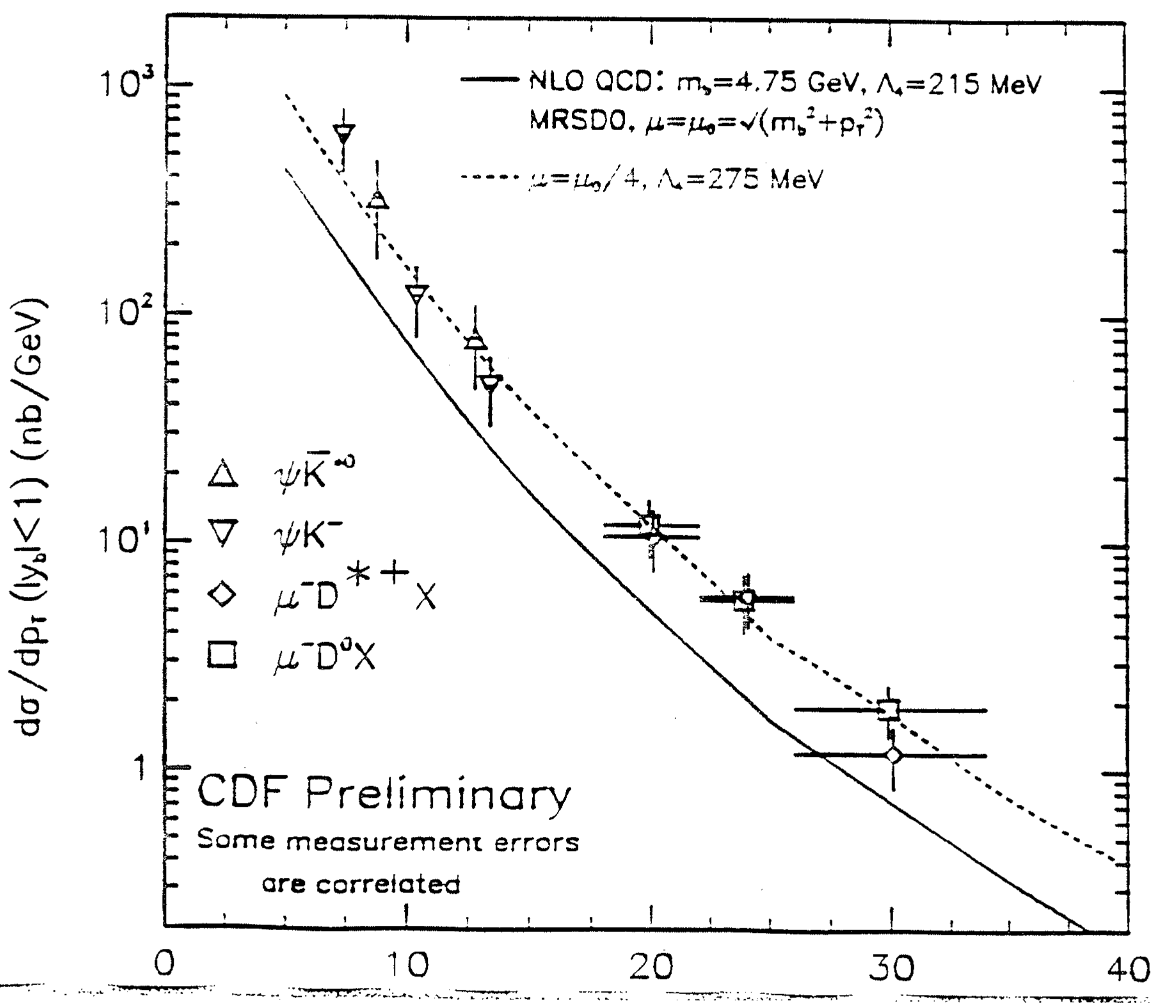


$p\bar{p} \rightarrow b + X, |y_b| < 1.5$
dimuons, muons from different quarks
dimuons, b chain decays
dimuons, b → J/ψ decays
single muons, b → μ X
$O(\alpha_s^3)$ QCD, Nason et al.
theoretical error band
$\sqrt{s}$ = 630 GeV
$p_T > p_T^{min}$
$p\bar{p} \rightarrow B + X, |y_B| < 1.5$
dimuons, muons from different Bs
dimuons, B chain decays
dimuons, B → J/ψ decays
single muons, B → μ X
$\sigma(p_T > p_T^{min})$ (μb)
p_T^{min} (GeV/c)

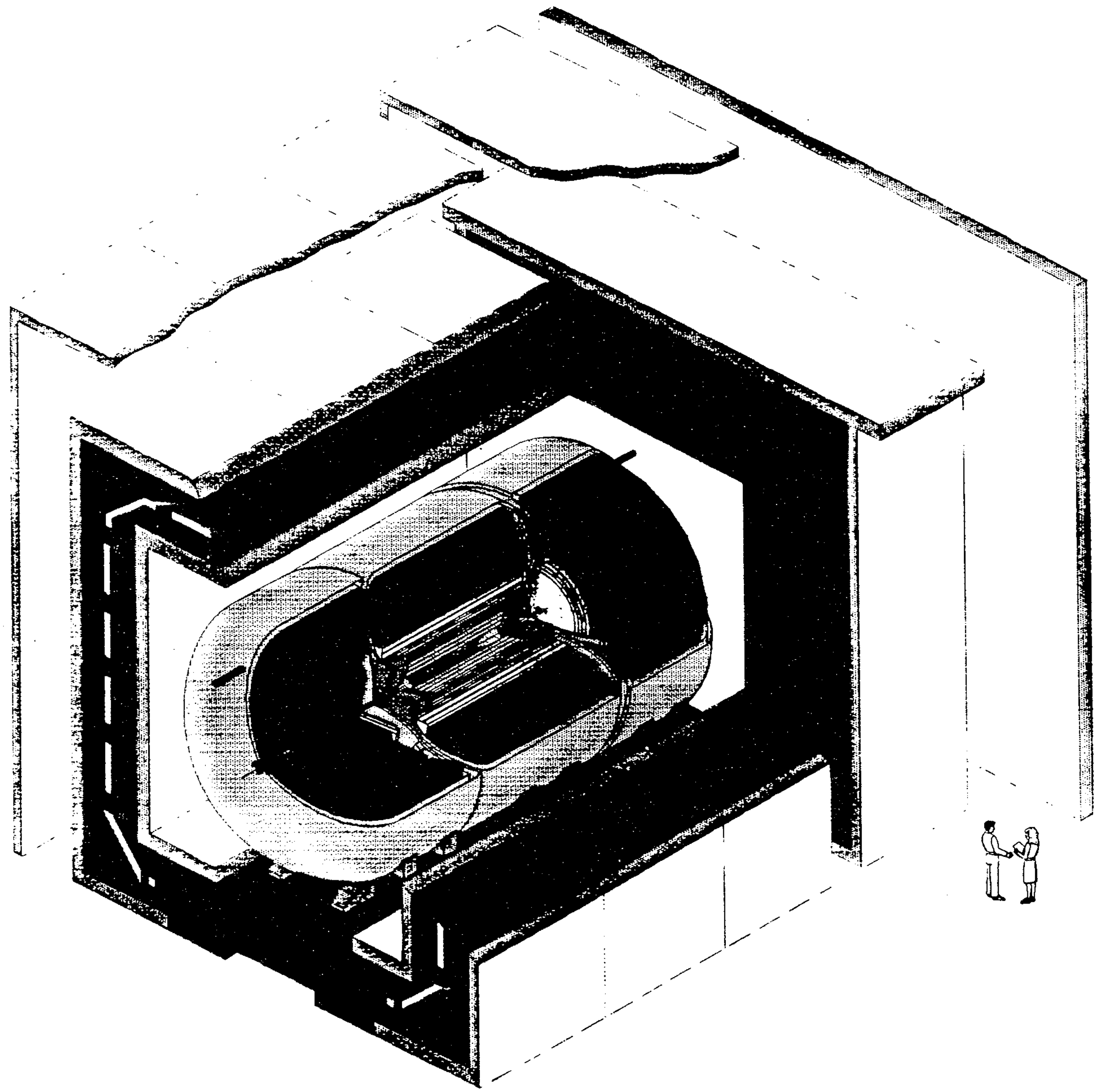
CDF



$p\bar{p} \rightarrow bX$, $\sqrt{s}$=1.8 TeV, |y|<1.0
NLO QCD (NDE), DFLM
Theoretical Uncertainty
e⁻X
μ⁻X
e⁻D⁰X
e μ
CDF 1988/89 Data
σ(p_T^b > p_T^min) (nb)
p_T^min (GeV)



NLO QCD: m_b=4.75 GeV, Λ_4=215 MeV
MRSD0, μ=μ_0=√(m_b²+p_T²)
μ=μ_0/4, Λ_4=275 MeV
ψK̄*0
ψK⁻
μ⁻D*+X
μ⁻D⁰X
CDF Preliminary
Some measurement errors
are correlated
dσ/dp_T (|y_b|<1) (nb/GeV)



DØ Detector

The DØ Detector

- Tracking
  - » Resolution of Vertex in Z ≈ 6 mm
  - » Resolution in $r\phi$
    - ≈ 60 μm for Vertex Detector
    - ≈ 180 μm for Central Drift Chamber
    - ≈ 200 μm for Forward Drift Chamber
- Calorimetry
  - » Coverage $|\eta| < 4$ $(\vartheta > 2^o)$
  - » Granularity $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$
  - » Longitudinal Segmentation 8 - 10 Layers
  - » Electron Energy Resolution

    $15\%/\sqrt{E}$
  - » Hadron Energy Resolution

    $50\%/\sqrt{E}$
- Muon System
  - » Coverage $|\eta| < 3.3$ $(\vartheta > 5^o)$
  - » Good Muon ID, punchthrough $< 10^{-4}$
  - » Modest Momentum Resolution:

$$\delta(1/p)/(1/p) = [(0.18(p-2)/p)^2 + (0.008p)^2]^{1/2}$$

DΦ Muon System

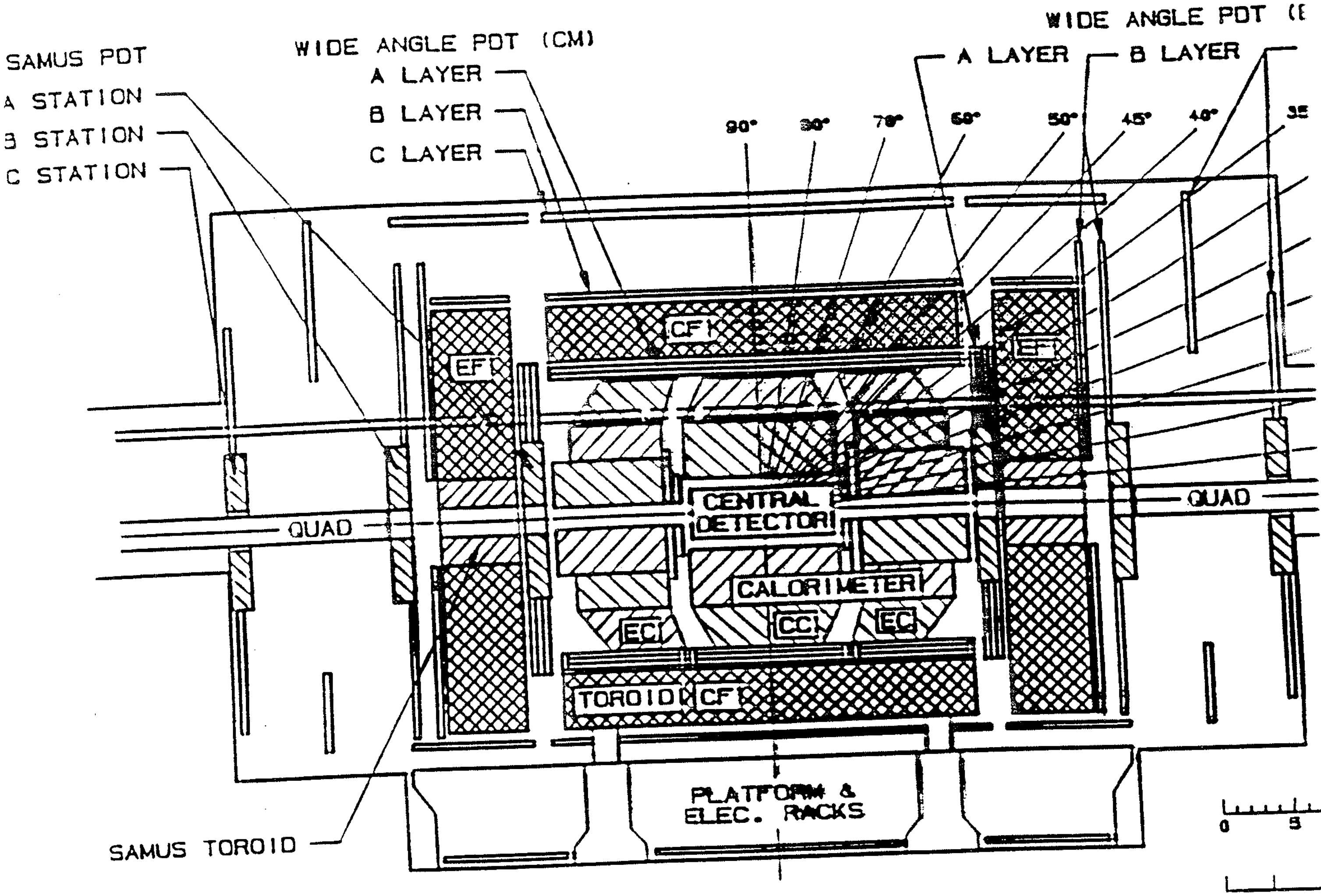
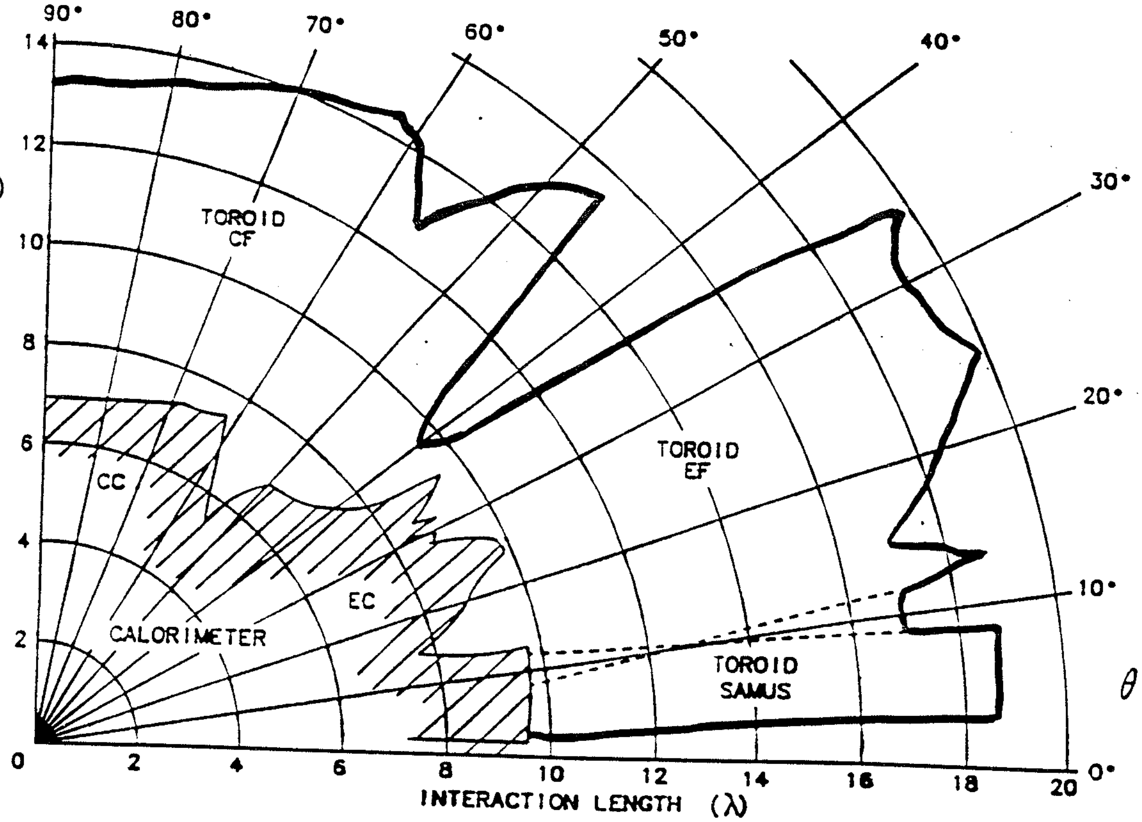


Fig. 1 ELEVATION OF DØ DETECTOR

- 5 iron toroids plus 3 layers of 10 cm proportional drift tubes
- M.C.S. $\Rightarrow \dfrac{\Delta(1/p)}{1/p} = \left\{\left(0.18\,\dfrac{(p-2)}{p}\right)^2 + (0.008p)^2\right\}^{1/2}$
- Thick calorimeter plus toroids $(14-18\lambda) \Rightarrow$ small punchthrough probability (0.005) and good muon
d within a jet

14.

λ.

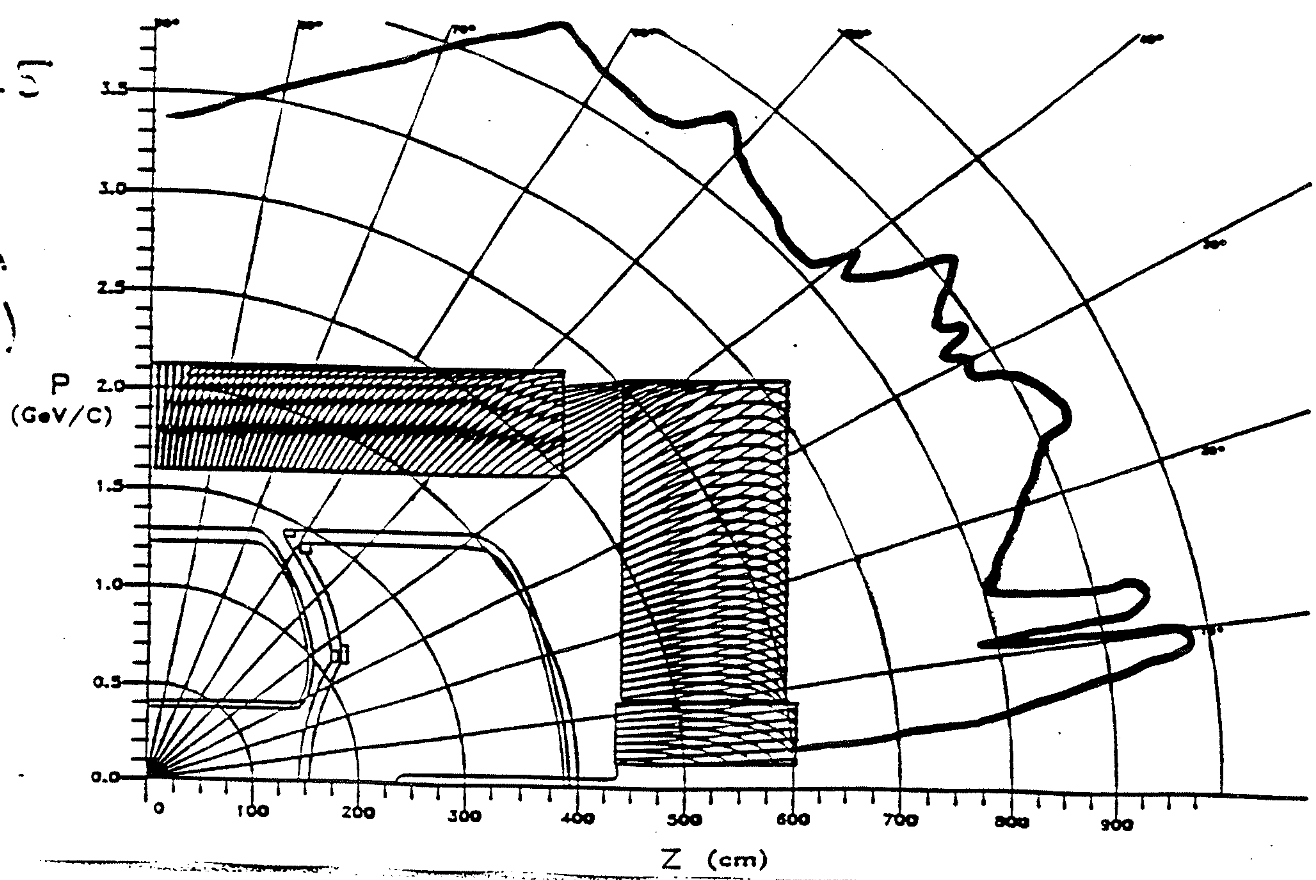


P_{min} of +Muon

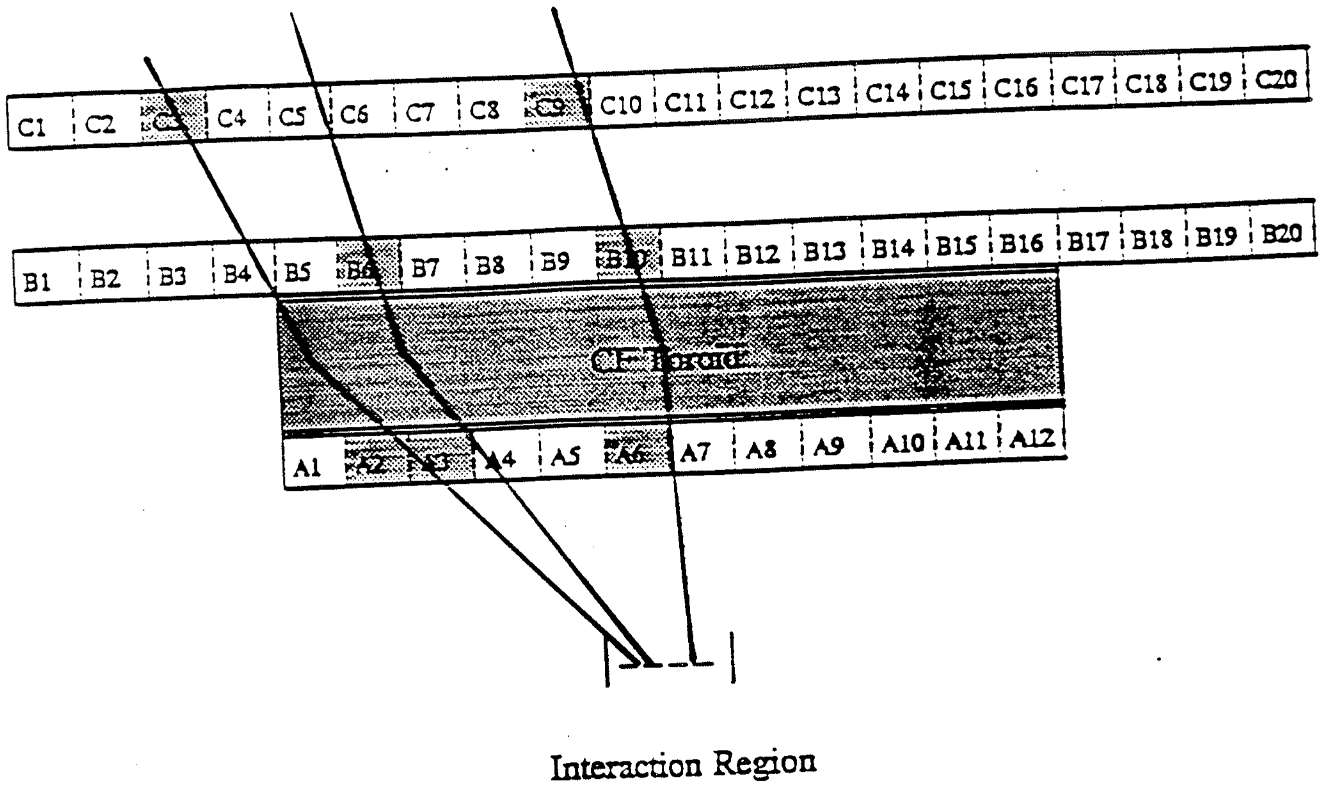
Field is Out of Page

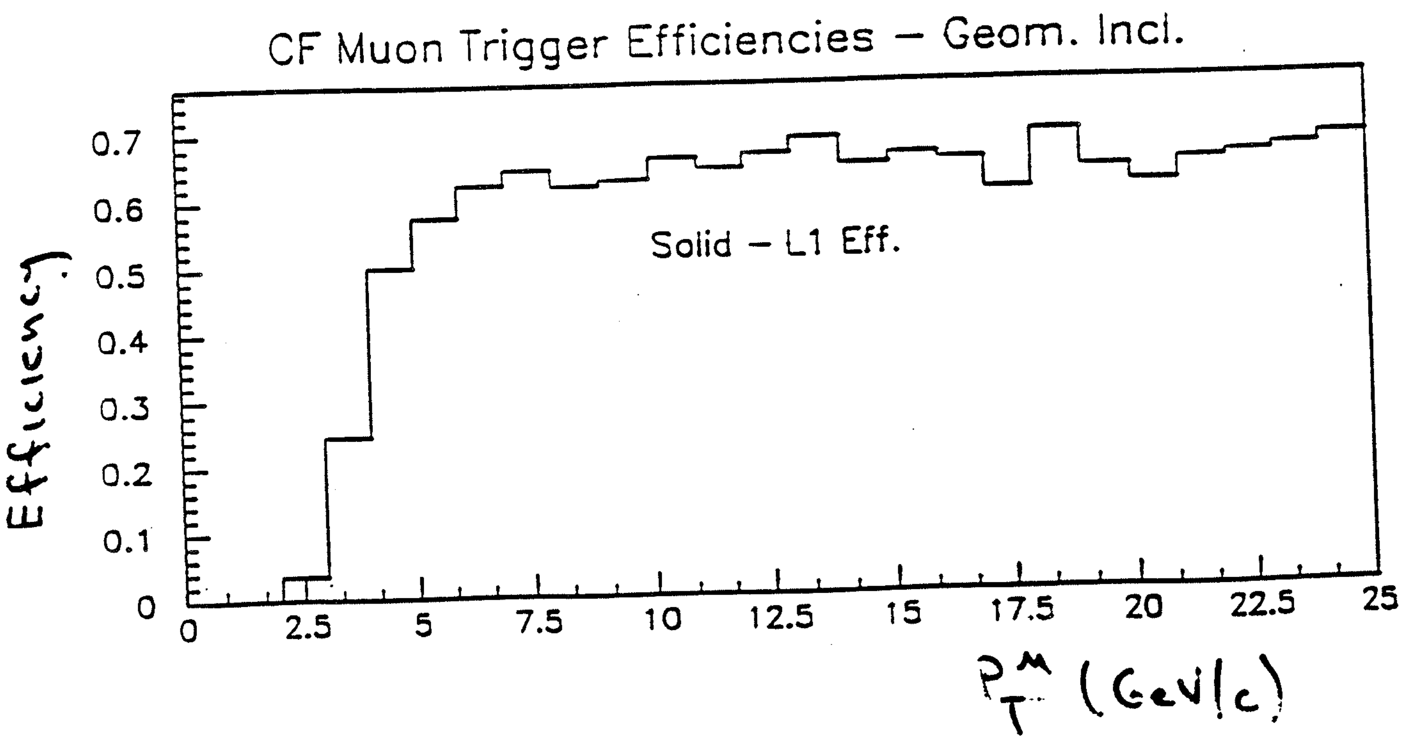
3.5

P_{min} (GeV)



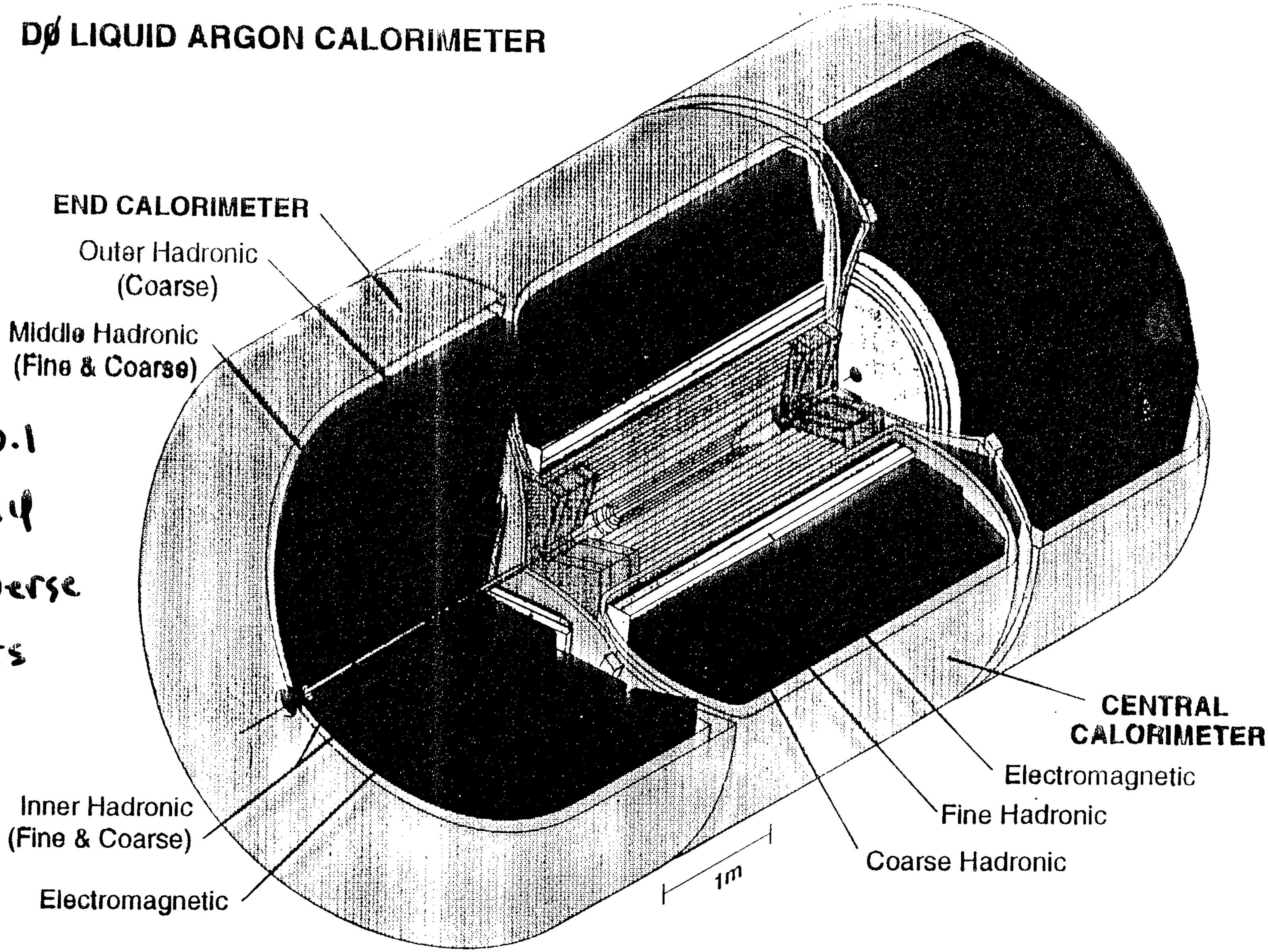
Level 1 Muon Trigger





$|\eta| < 4$ coverage

DØ LIQUID ARGON CALORIMETER



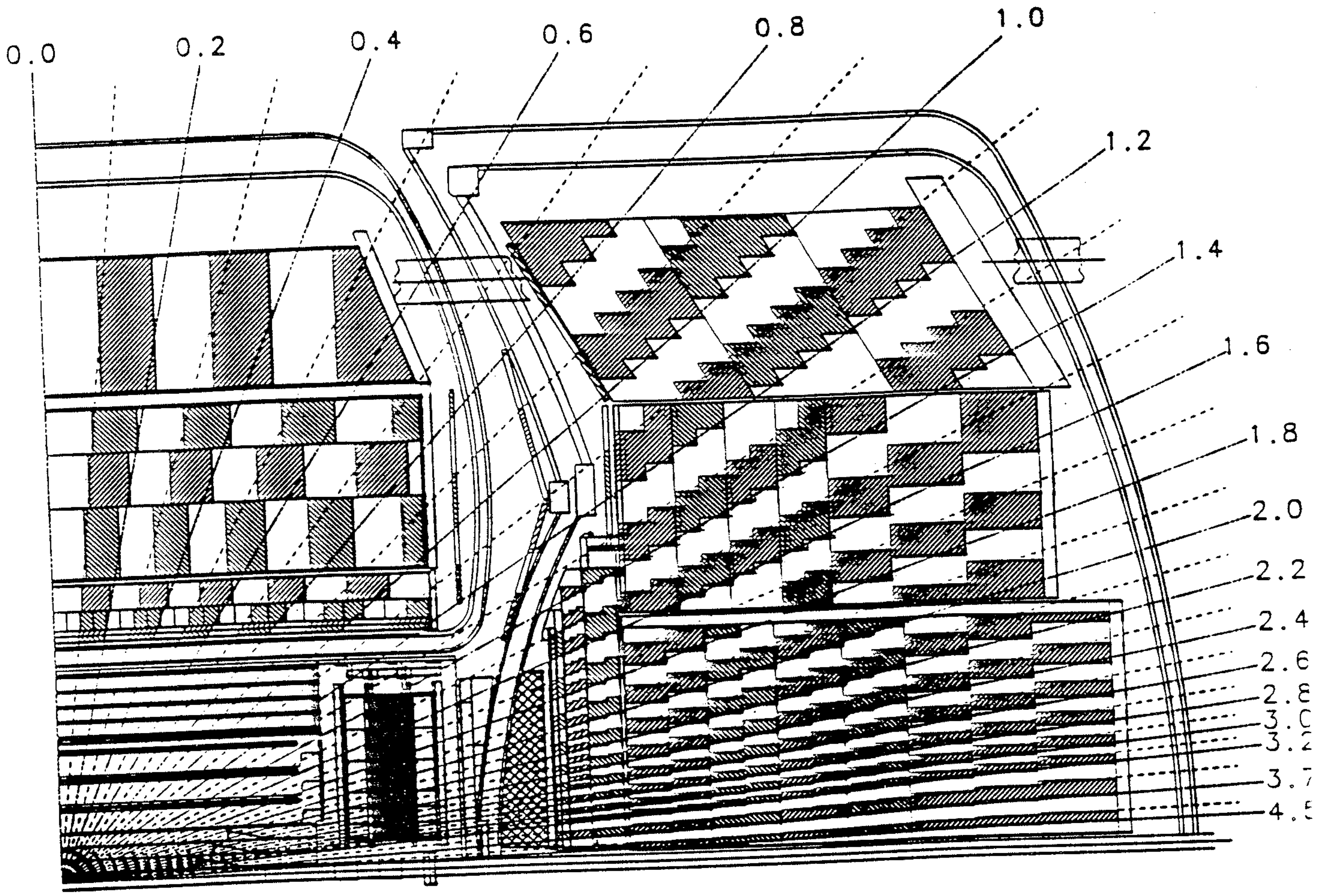
0.1 x 0.1

$\Delta\eta \times \Delta\phi$

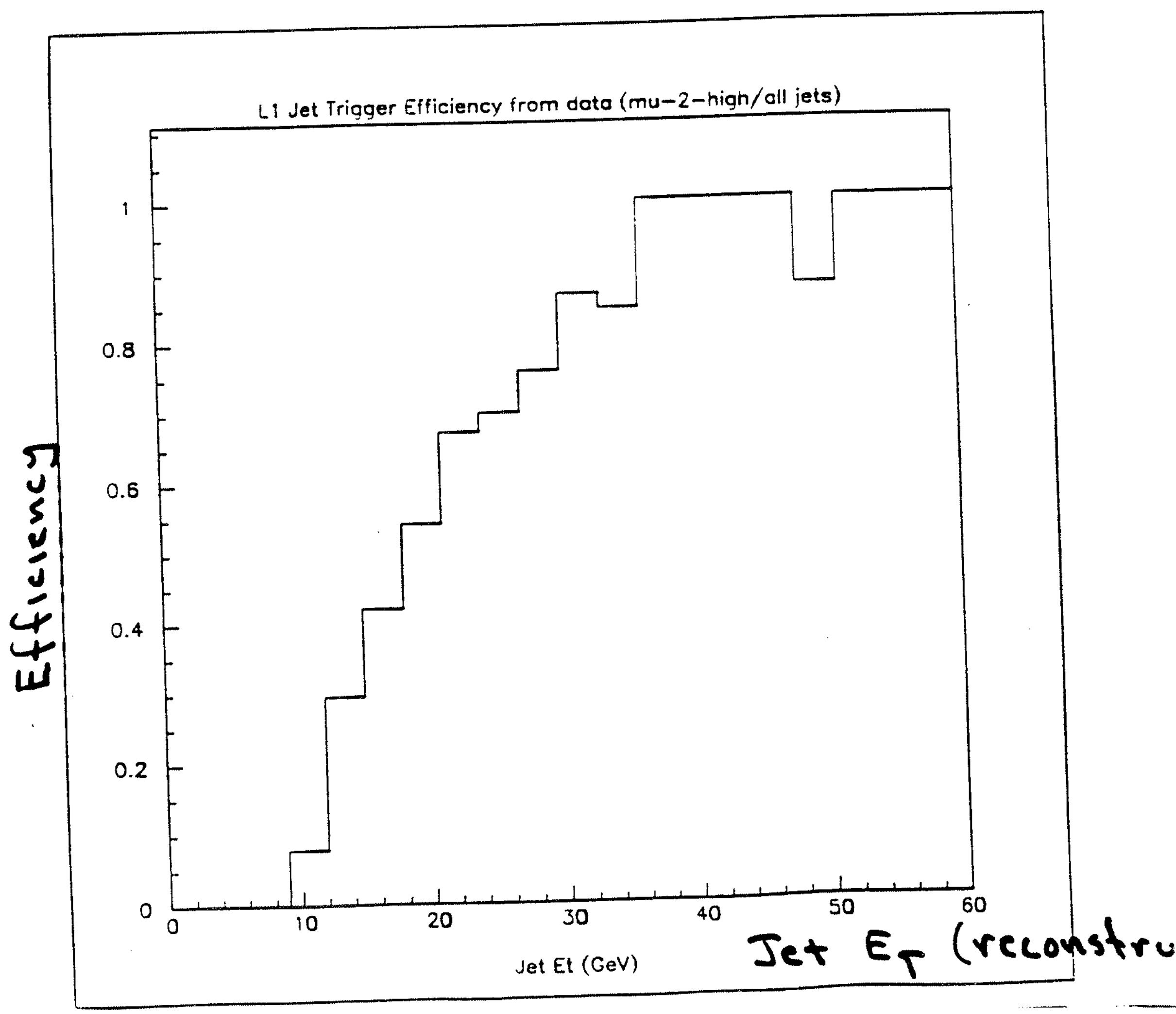
transverse

towers

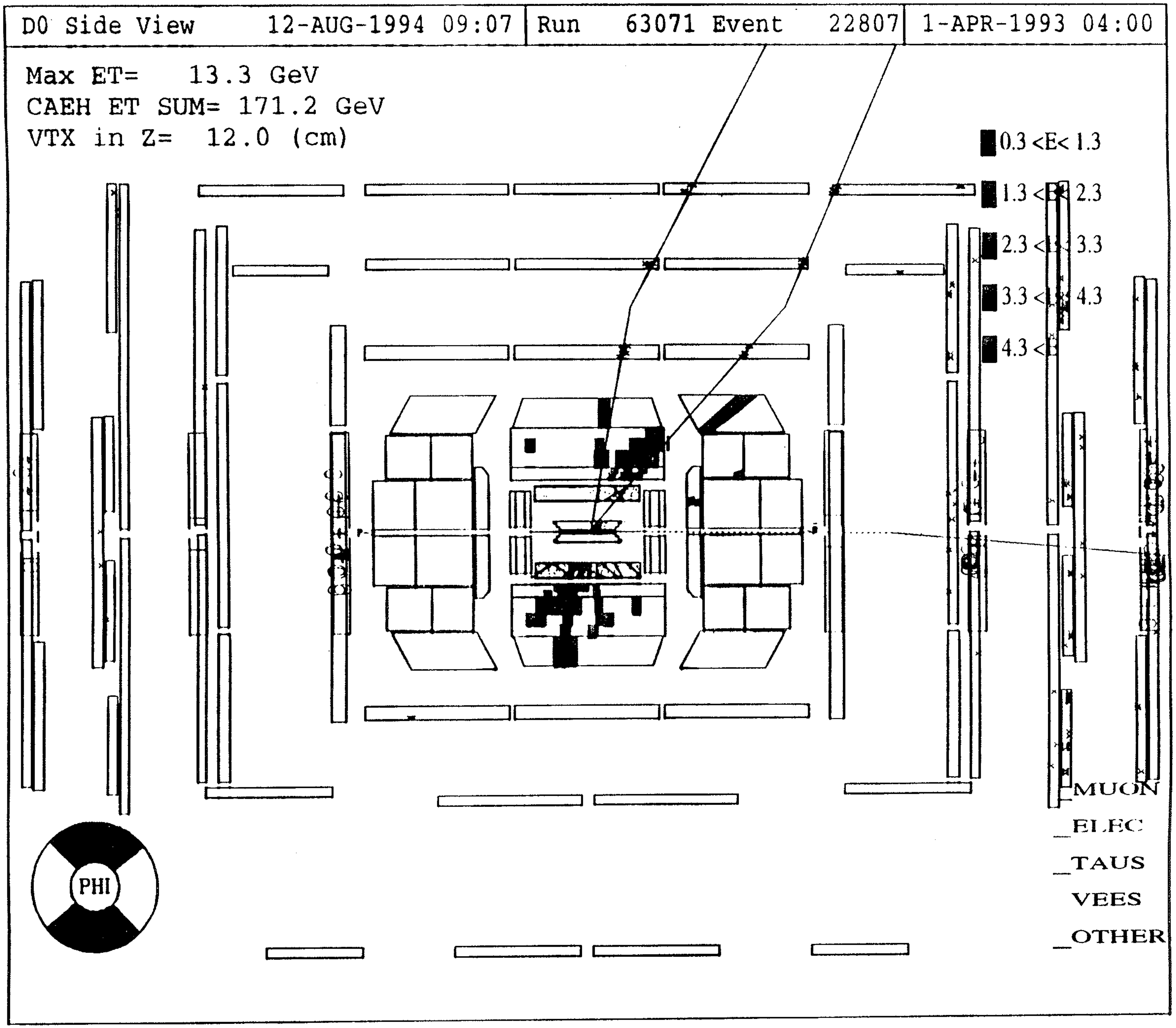
6E 15%

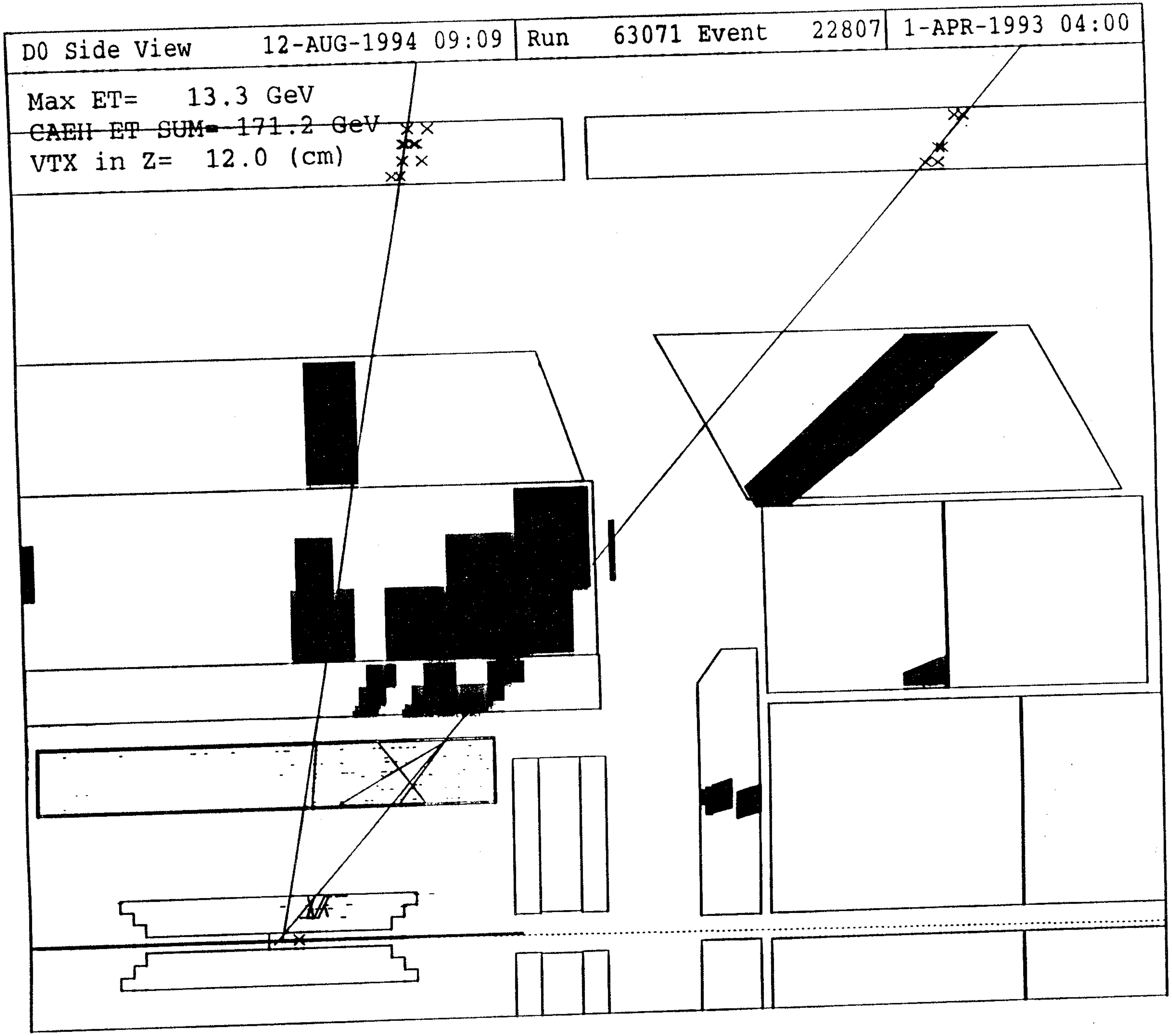


0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6



L1 Jet Trigger Efficiency from data (mu-2-high/all jets)
Efficiency
1
0.8
0.6
0.4
0.2
0
0
10
20
30
40
50
60
Jet Et (GeV)
Jet E_T (reconstru


D0 Side View 12-AUG-1994 09:07
Run 63071 Event 22807
1-APR-1993 04:00
Max ET= 13.3 GeV
CAEH ET SUM= 171.2 GeV
VTX in Z= 12.0 (cm)
0.3 <E< 1.3
1.3 <E< 2.3
2.3 <E< 3.3
3.3 <E< 4.3
4.3 <E
PHI
_MUON
_ELEC
_TAUS
VEES
_OTHER


D0 Side View 12-AUG-1994 09:09
Run 63071 Event 22807
1-APR-1993 04:00
Max ET= 13.3 GeV
CAEH ET SUM= 171.2 GeV
VTX in Z= 12.0 (cm)

Inclusive Single Muon Cross Section

Data Selection

- **Data Collection**

  Dedicated special runs during FNAL 1992-93 collider run

  Total integrated luminosity = 100 nb^{-1}

  Total events after cuts ≈ 17500

- **Trigger Requirements**

  1 muon with $|\eta_\mu| \leq 1.0$ in Level 1 (hardware)

  1 muon with $|\eta_\mu| \leq 1.0$ and $P_T^\mu \geq 3$ GeV in Level 2 (software)

- **Kinematic Cuts**

  $3.5 \text{ GeV} \leq P_T^\mu \leq 60 \text{ GeV}$

  $|\eta_\mu| \leq 0.8$

  $\phi \leq 80°$ or $\phi \geq 110°$ (fiducial cut)

- **Track Quality Cuts**

  3 layer tracks

  Good impact parameter in bend and non-bend views

  $\int B \cdot d\ell \geq 0.6$ GeV (good momentum measurement)

  E_{cal} (in $\Delta R = 0.15$ cone) ≥ 1 GeV

  Matching CD track ($\Delta\phi, \Delta\theta \leq 0.35$ rad)

  Muon X-ing time relative to BC time (T_0) ≤ 100 ns (removes cosmics)

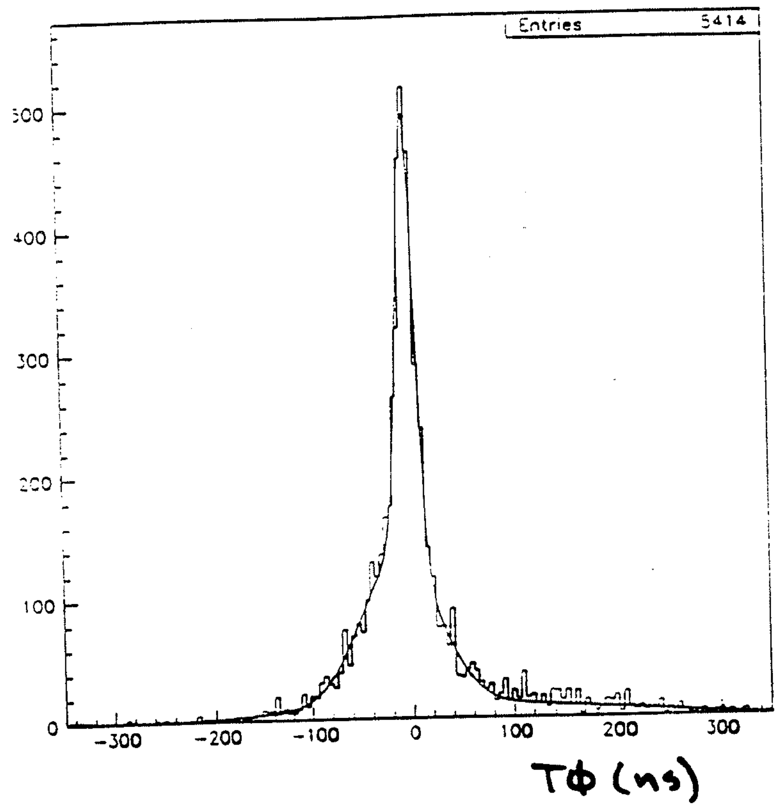
Floating Time T∅

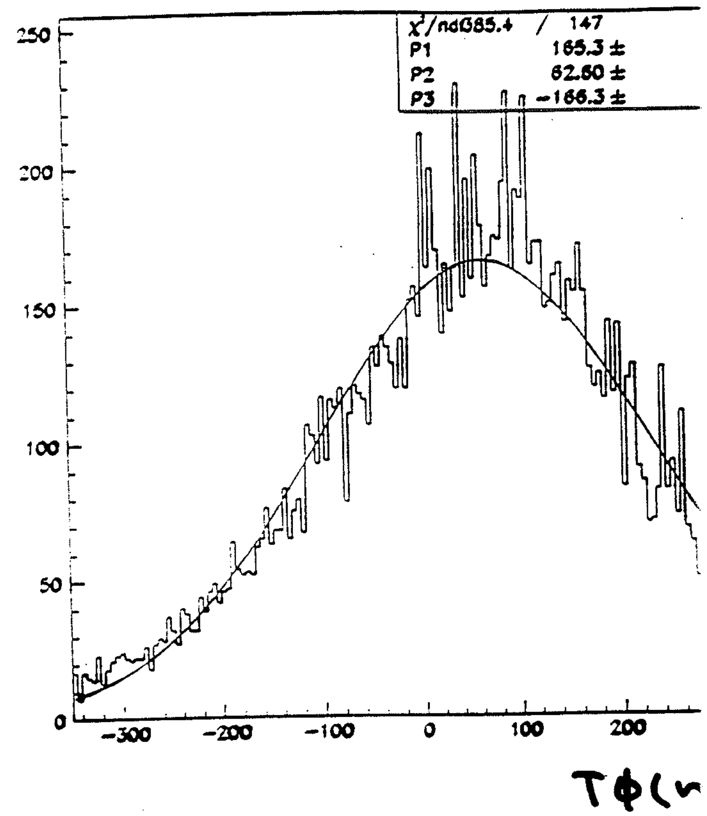
$t_{drift} \approx t_{arrival} - t_{crossing}$

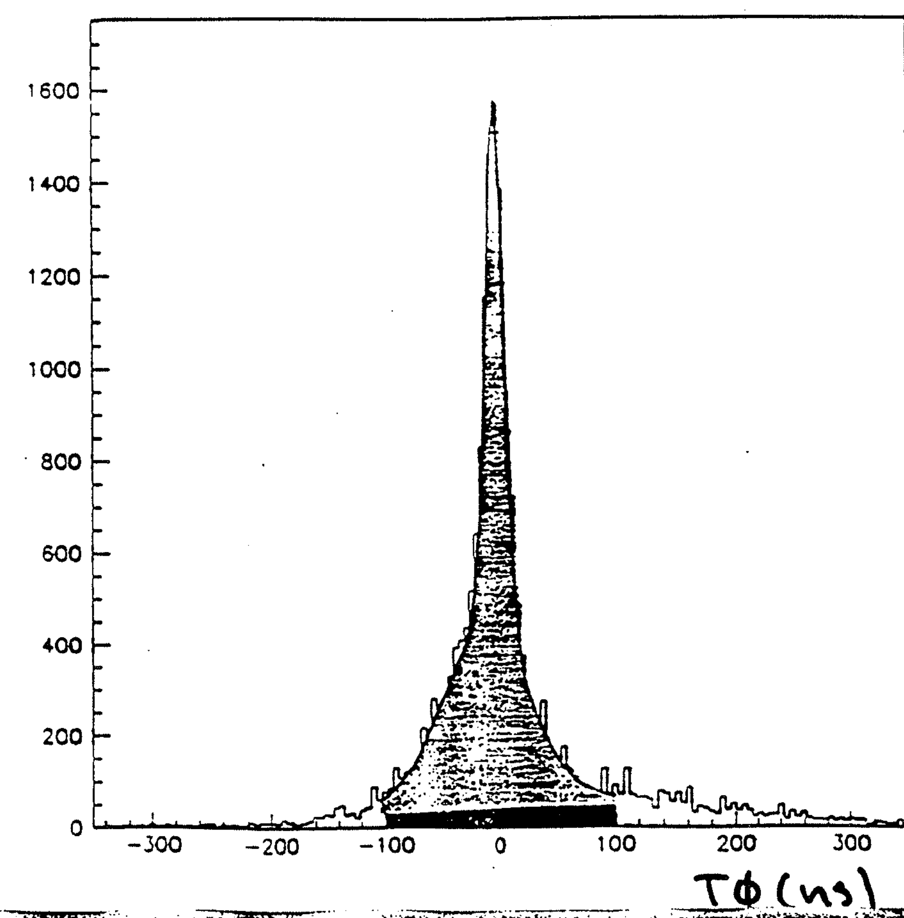
one can allow $t_{crossing}$ to be a free parameter (called $T\emptyset$) and fit for $T\emptyset$ using all the points on a track

expect for beam produced muons that $T\emptyset - t_{crossing} \approx \emptyset$

Floating Time TΦ

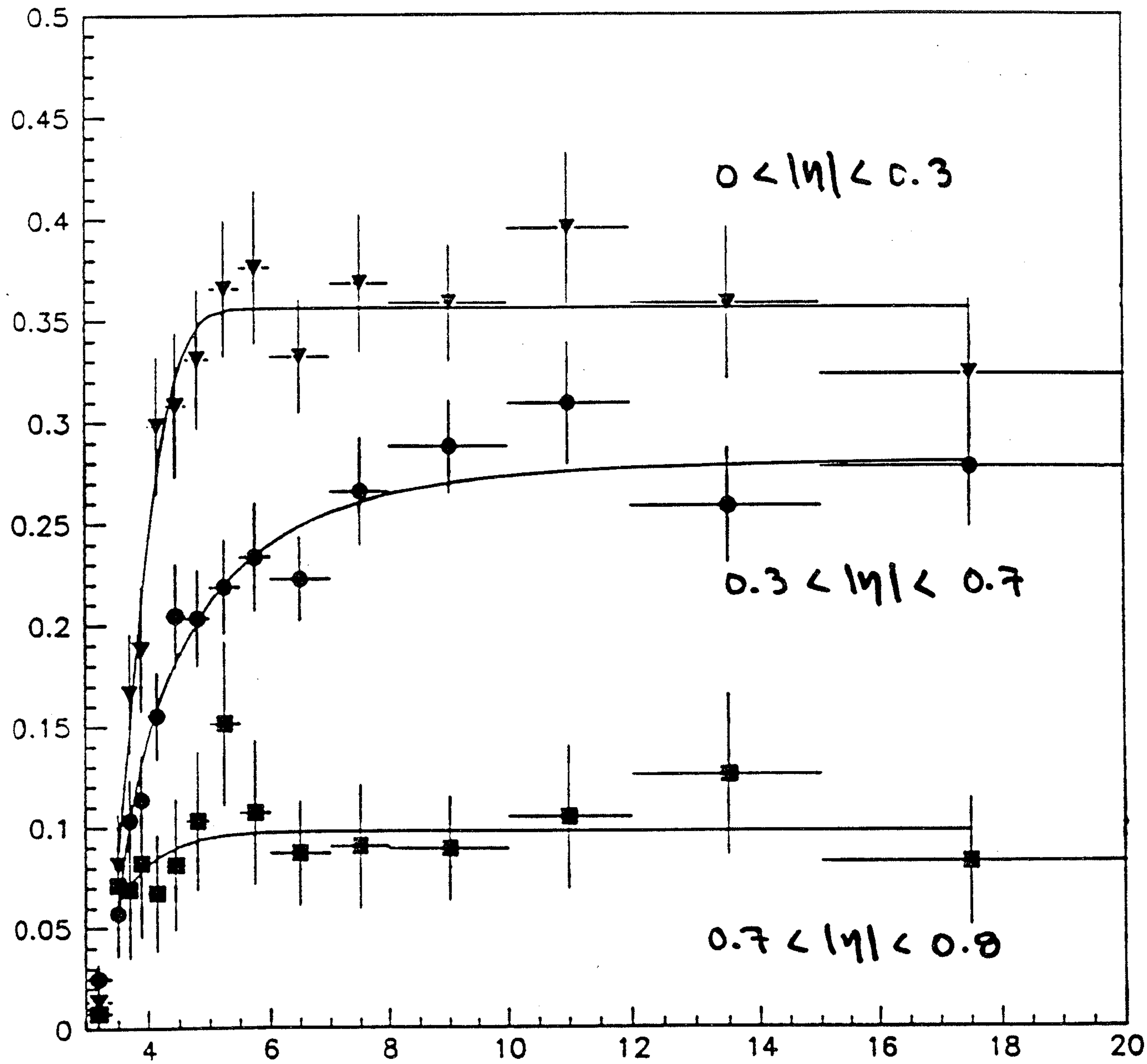


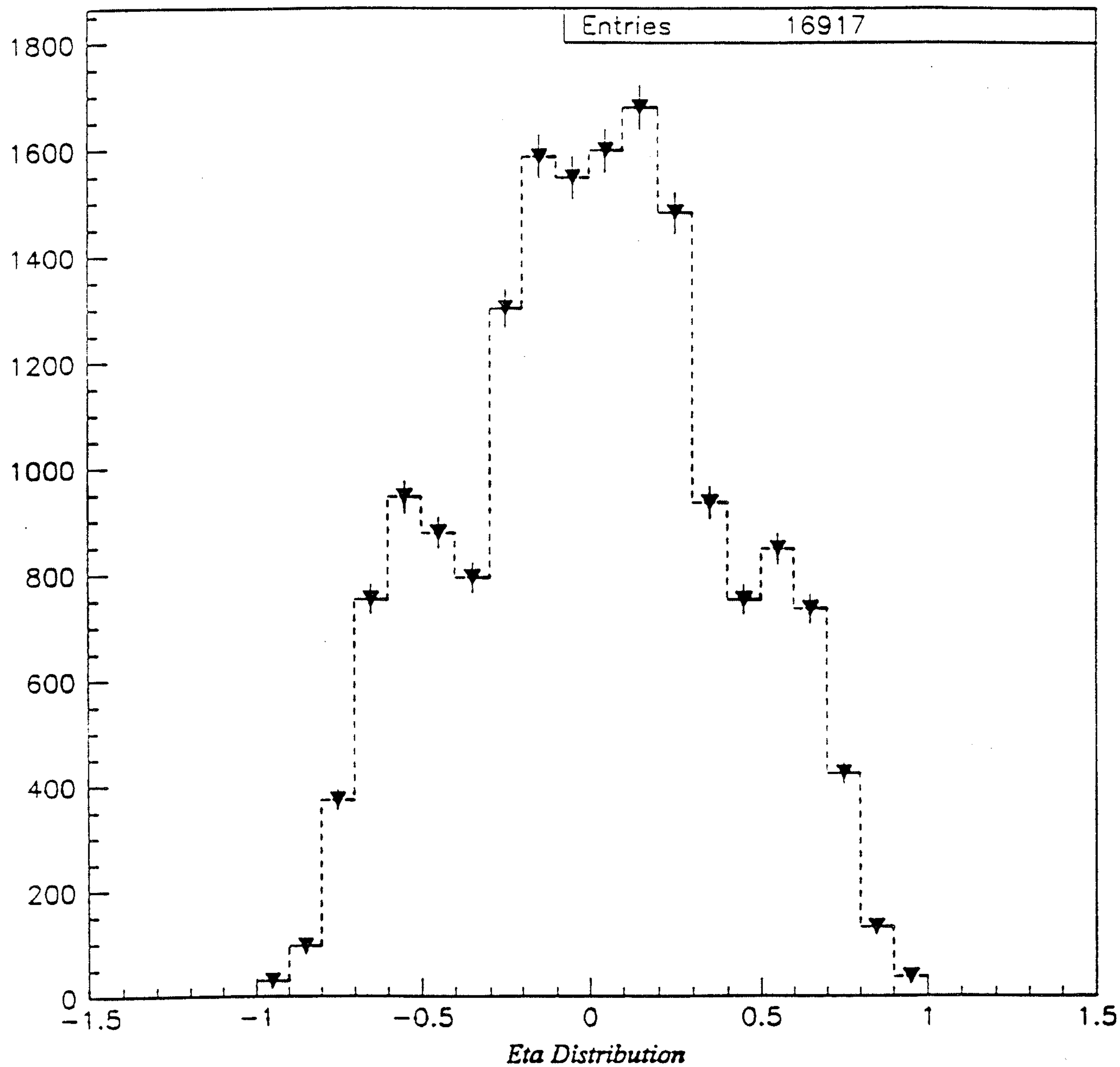


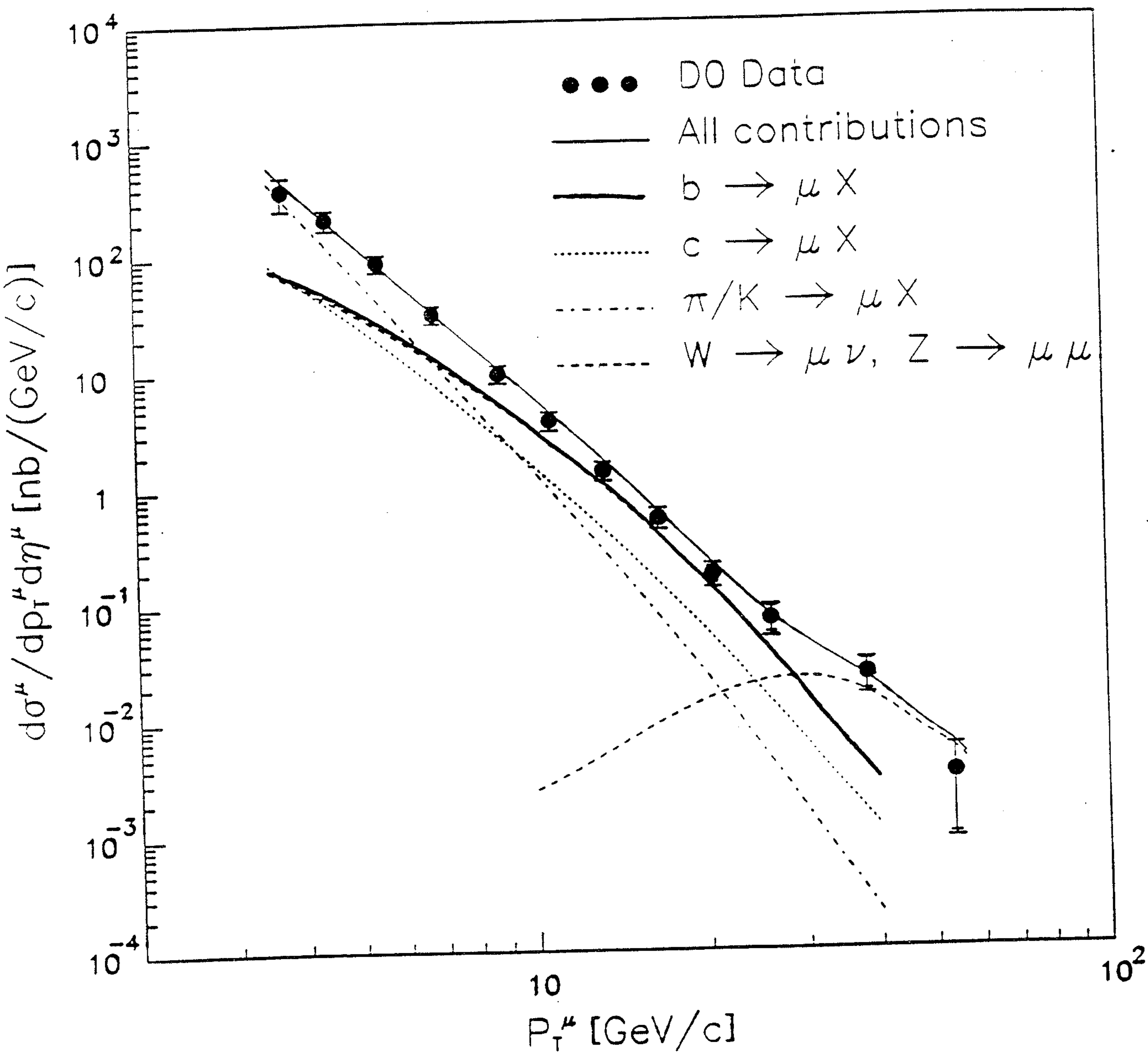


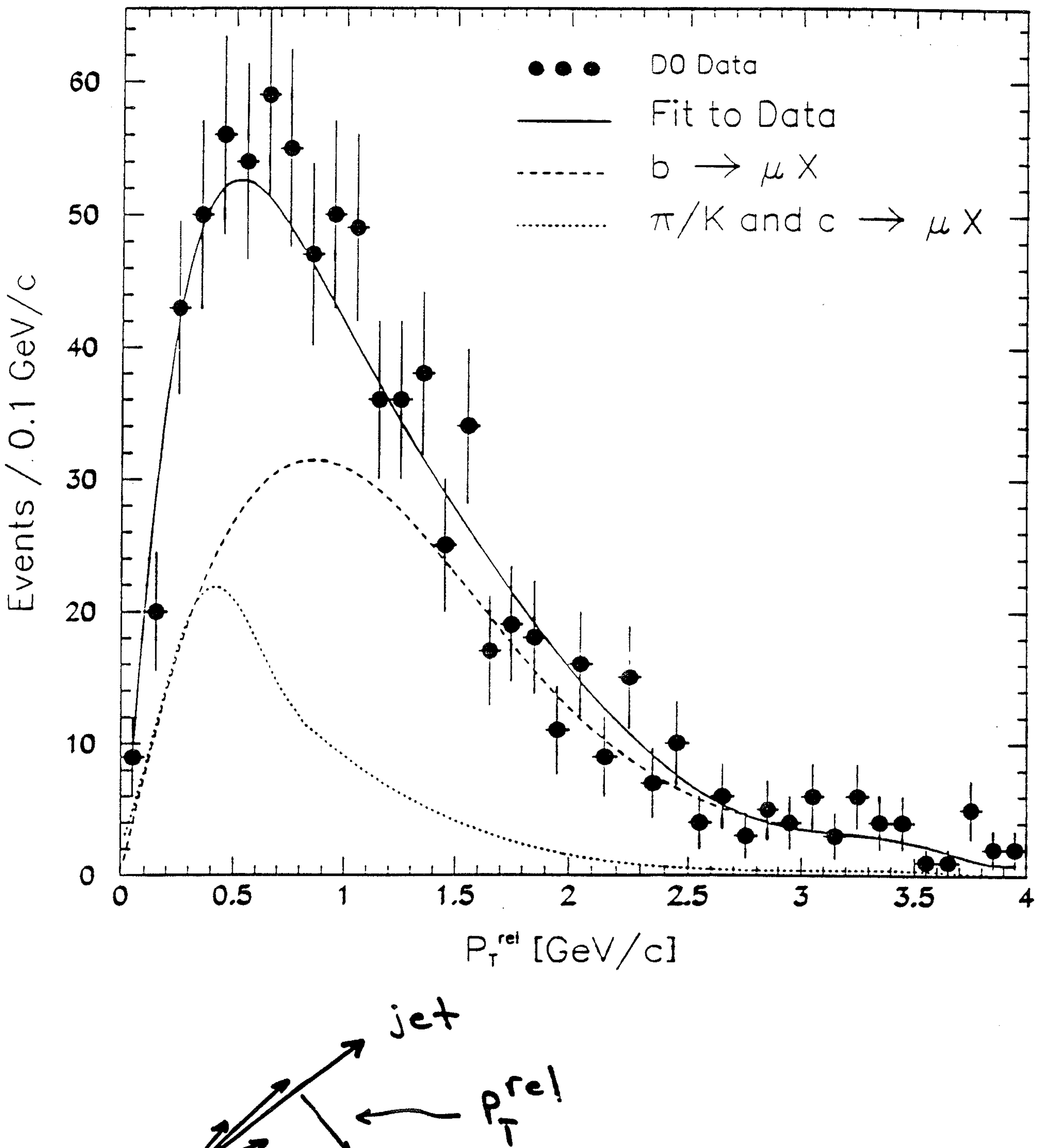
⇒ cosmic fractio[n] = 0.09 ±

Single Muon Detection Efficiency

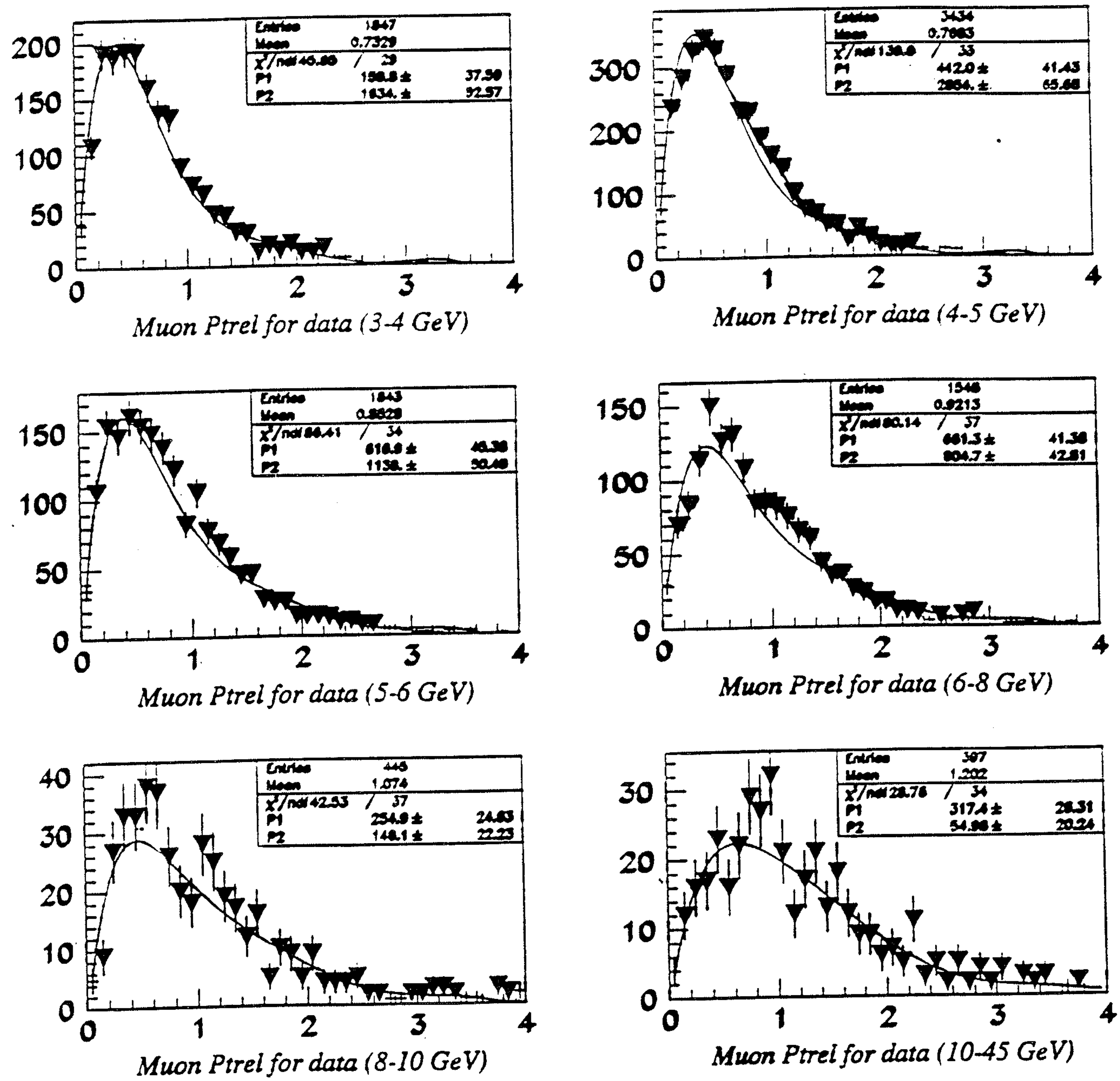


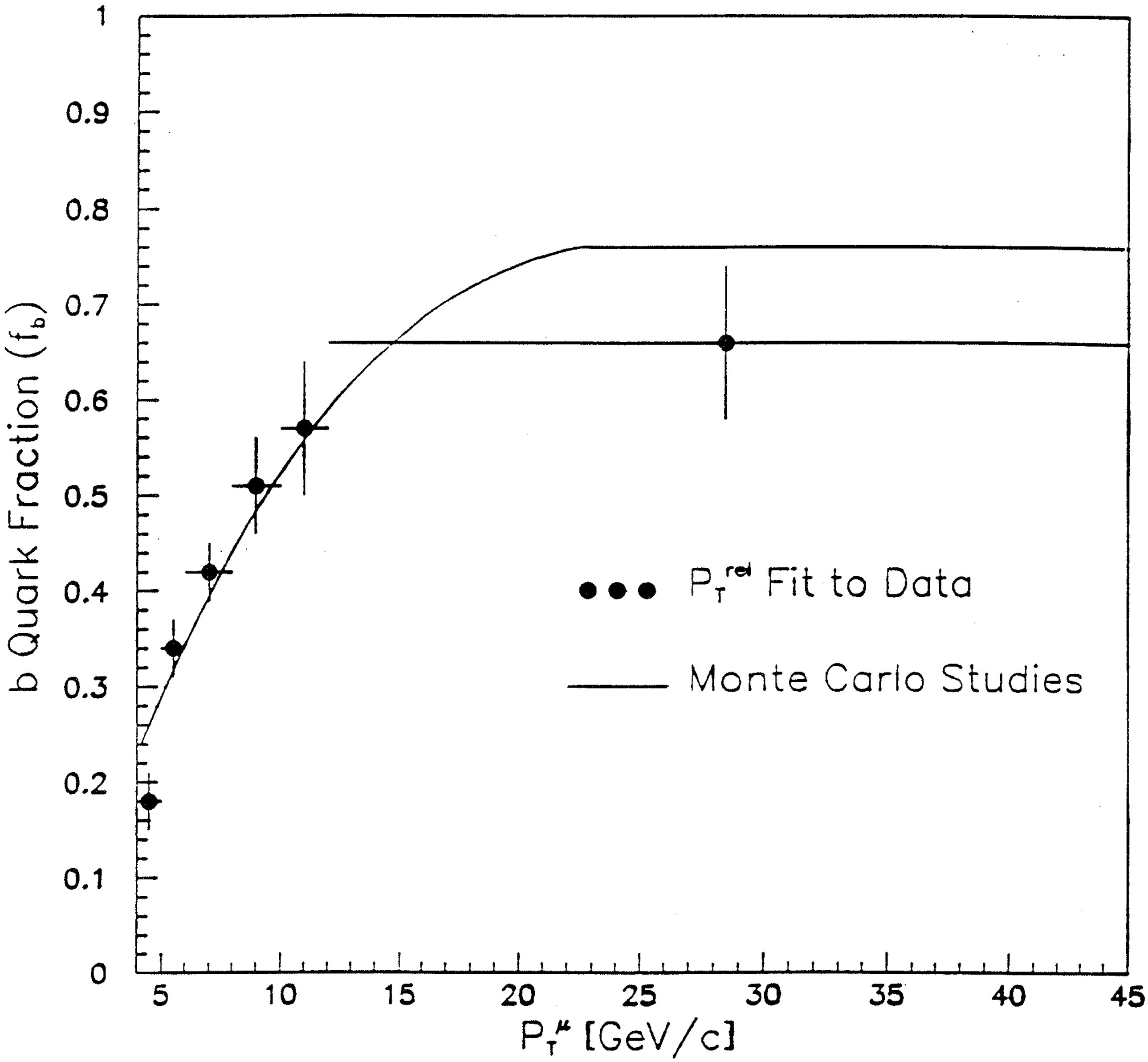

Entries 16917
1800
1600
1400
1200
1000
800
600
400
200
0
−1.5
−1
−0.5
0
0.5
1
1.5
Eta Distribution


D0 Data
All contributions
b → μ X
c → μ X
π/K → μ X
W → μ ν, Z → μ μ
dσ^μ/dp_T^μ dη^μ [nb/(GeV/c)]
P_T^μ [GeV/c]
10^4
10^3
10^2
10
1
10^-1
10^-2
10^-3
10^-4
10
10^2


D0 Data
Fit to Data
b → μ X
π/K and c → μ X
Events / 0.1 GeV/c
P_T^rel [GeV/c]
0
10
20
30
40
50
60
0
0.5
1
1.5
2
2.5
3
3.5
4
jet
p_T^rel
μ

DETERMINATION OF B FRACTION FROM PTREL





b Quark Fraction (f_b)
P_T^{rel} Fit to Data
Monte Carlo Studies
P_T^{μ} [GeV/c]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
5
10
15
20
25
30
35
40
45

Extracting the Inclusive b Quark Cross-Section

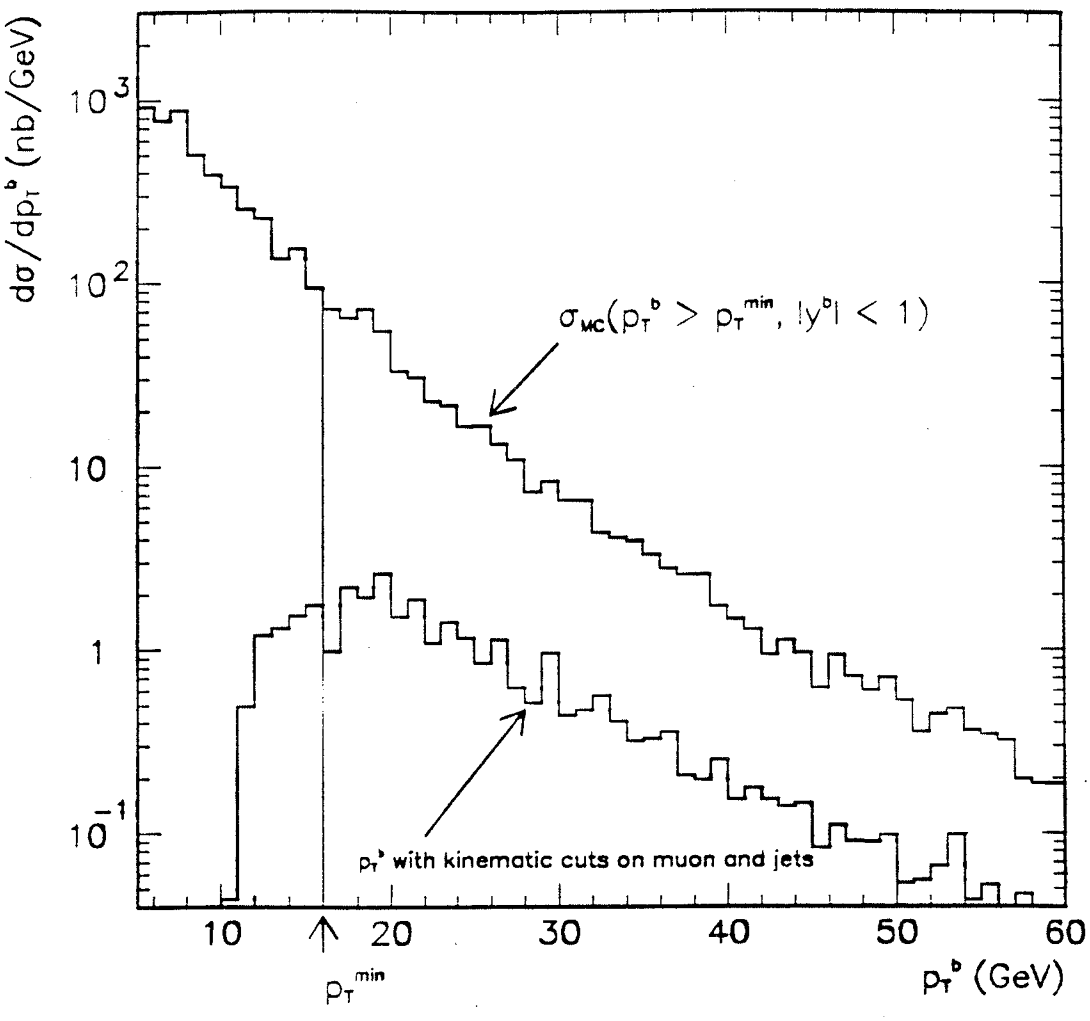
- The $b \rightarrow \mu X$ (or $b \rightarrow \mu + jetX$, $b \rightarrow \mu\mu X$,...) contribution to the measured inclusive muon cross section is obtained by using ISAJET to model the various processes contributing to the inclusive muon cross section.

- ISAJET is also used to obtain that portion of the integrated inclusive b quark cross section which results in muons which pass a given set of kinematic cuts (P_t^μ, η^μ, etc.).

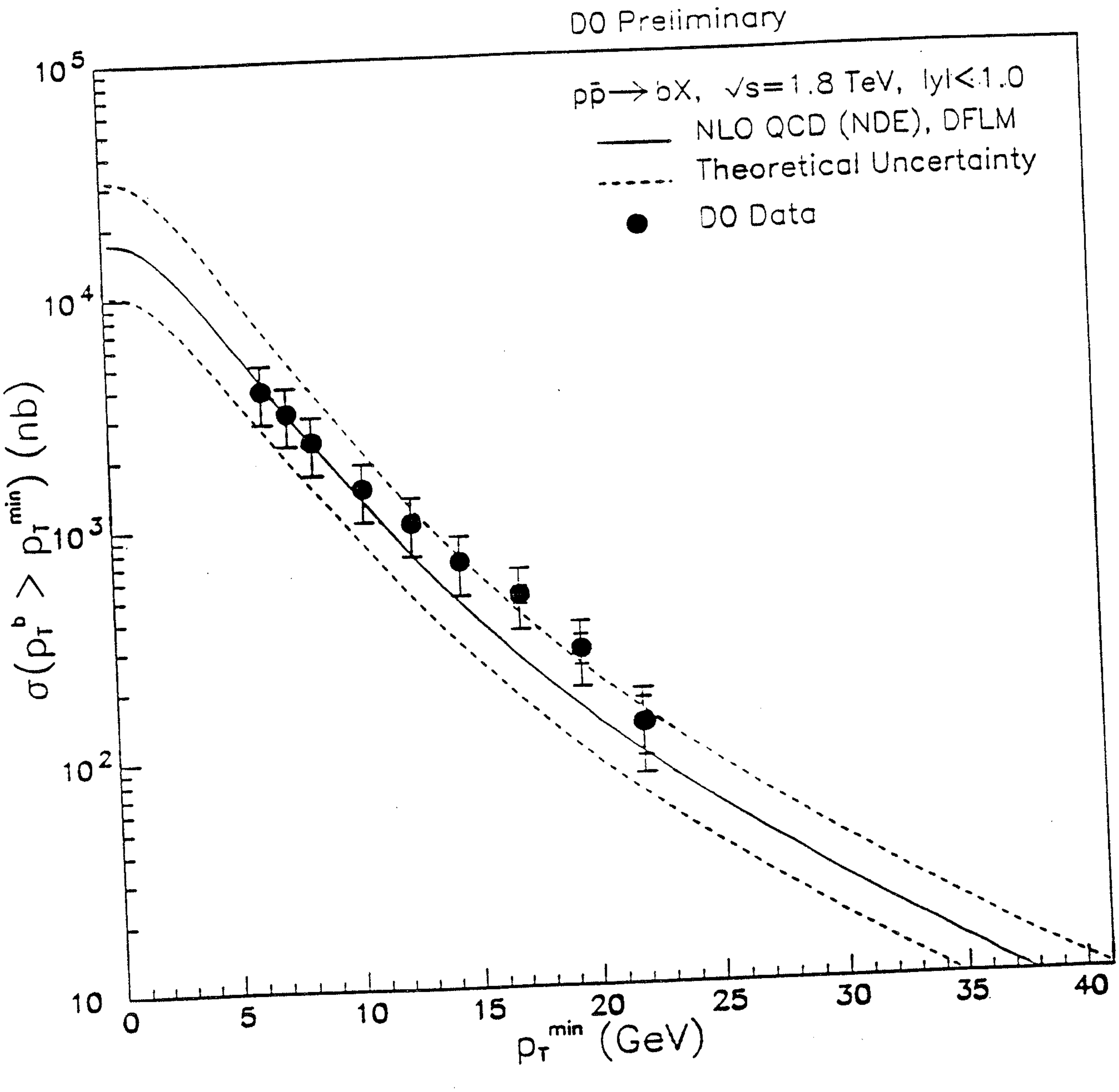
- This part of the integrated inclusive b quark cross section is used to define k_T^{min} of the b quark $\equiv$ 90% of the integrated inclusive b quark cross section giving muons passing some set of kinematic cuts is above k_T^{min} of the b quark.

- ISAJET then used to determine the ratio of the integrated inclusive b quark cross section to the integrated inclusive b quark cross section which results in muons passing kinematic cuts. The integrated inclusive b quark cross section is taken above k_T^{min} of the b quark. The integrated inclusive b quark cross section implied by the data is then given by

$$\sigma^b_{data}(k_T^b > k_T^b(min)) \equiv \sigma^{b\rightarrow\mu X}_{data} \frac{\sigma^b_{MC}(k_T^b > k_T^b(min))}{\sigma^{b\rightarrow\mu X}_{MC}(muon\ kinematic\ cuts)}$$



dσ/dp_T^b (nb/GeV)
10^3
10^2
10
1
10^-1
σ_MC(p_T^b > p_T^min, |y^b| < 1)
p_T^b with kinematic cuts on muon and jets
10
20
30
40
50
60
p_T^min
p_T^b (GeV)



D0 Preliminary
$p\bar{p} \rightarrow bX$, $\sqrt{s}=1.8$ TeV, $|y|<1.0$
NLO QCD (NDE), DFLM
Theoretical Uncertainty
D0 Data
$\sigma(p_T^b > p_T^{min})$ (nb)
p_T^{min} (GeV)

Measurement	Source	Value
Inclusive μ cross section	Cosmic ray subtraction	4 %
	μ detection efficiency	11 %
	Integrated luminosity	12 %
	Total error on μ cross section	17 %
Inclusive b cross section	Momentum resolution	5-20 %
	b-quark fraction	5-10 %
	b-quark p_T shape	10-13 %
	Parametrization of fragmentation	10-15 %
	$B \to \mu X$ branching ratio	5 %
	$B \to \mu X$ decay spectrum	5-10 %
	Total error on b cross section	24-36 %

μ-Jet Data Selection

- **Data Sample**

  Collected during Tevatron 92-93 collider run

  $\int \mathcal{L}dt = 197nb^{-1}$ in dedicated physics runs

- **Trigger Requirements**

  Level 1: 1μ, $|\eta_\mu| \leq 1.7 * 1$ jet trigger tower ≥ 3 GeV

  Level 2: 1μ, $p_t^\mu > 3$ GeV , $|\eta_\mu| \leq 1.7 * 1$ jet, $E_T^{jet} \geq 10$ GeV

  Events to tape $\approx$ 1.5M

- **Kinematic Cuts**

  $p_t^\mu \geq 6$ GeV

  $|\eta_\mu| \leq 0.8$

  $\phi_\mu \leq 80°$ or $\phi_\mu \geq 120°$ (fiducial cut)

  $E_T \geq 12$ GeV, $\Delta R = 0.7$

- **Muon Track Quality Cuts**

  3 layer track

  impact parameter consistent with vertex origin of muon

  $\int$ Bdl > 1.9 Tm (good momentum measurement)

  E_{cal} (in $\Delta\eta \cdot \Delta\phi = 0.3 \cdot 0.3$) ≥ 1 GeV

  Matching CD track

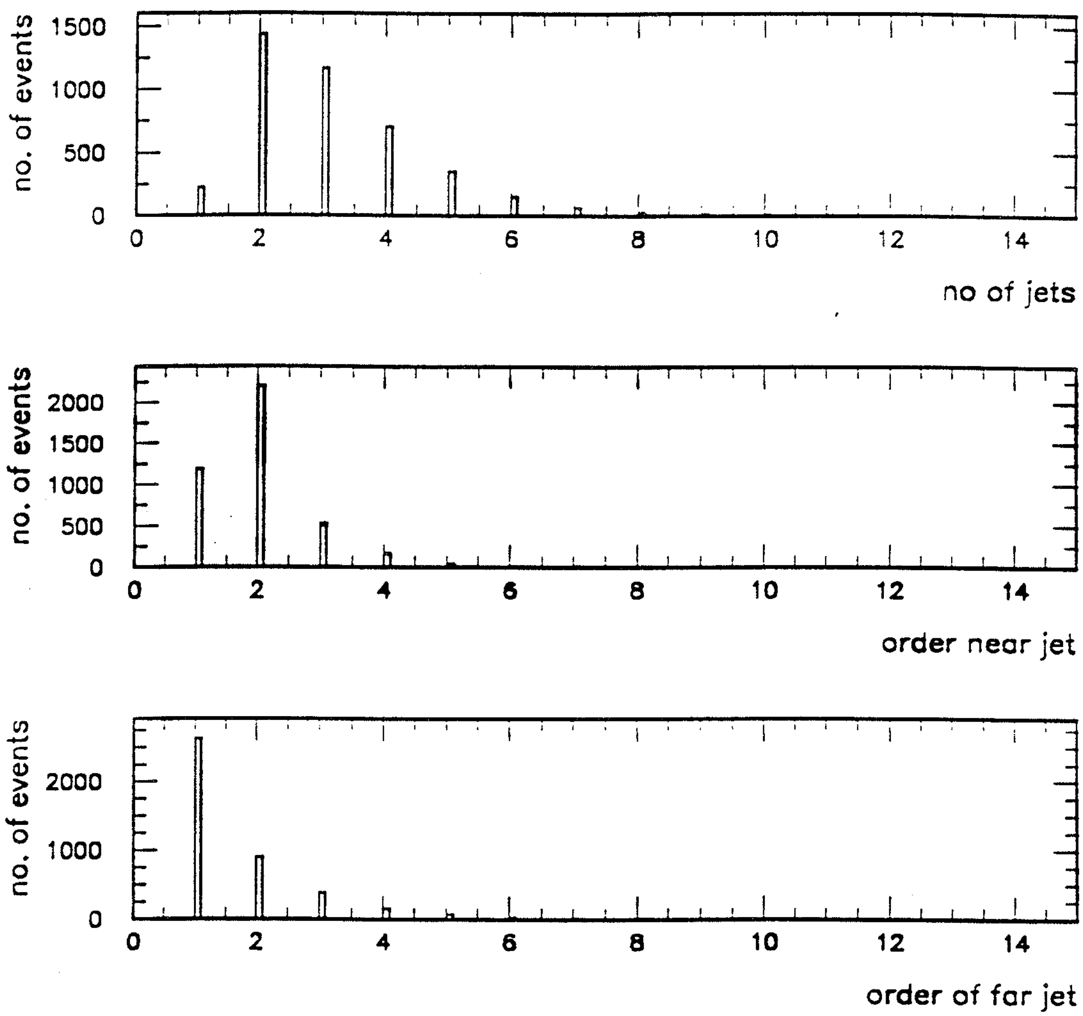
  require muon within 100ns of beam crossing

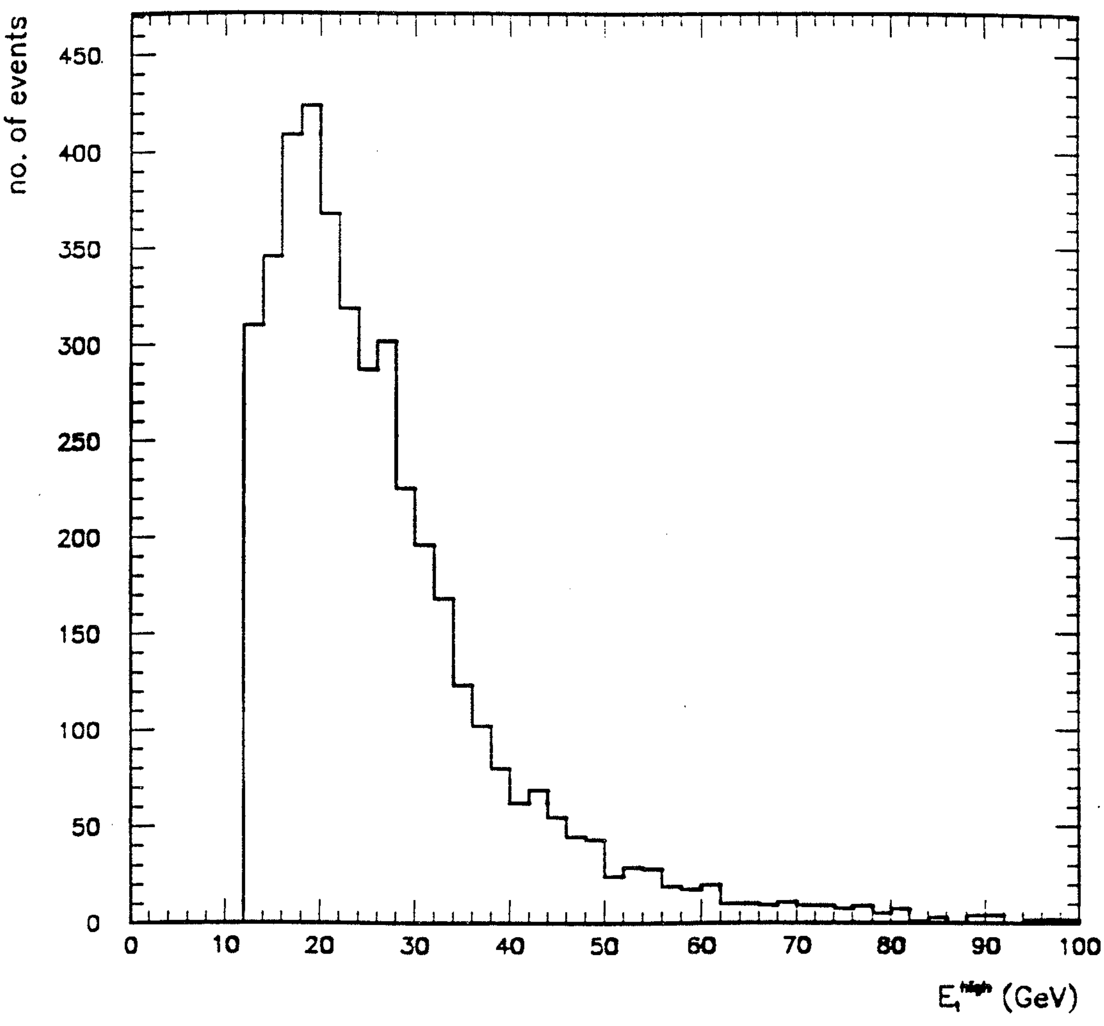
- **Standard Jet Quality Cuts**

- **Events Sample after Cuts: 4300**

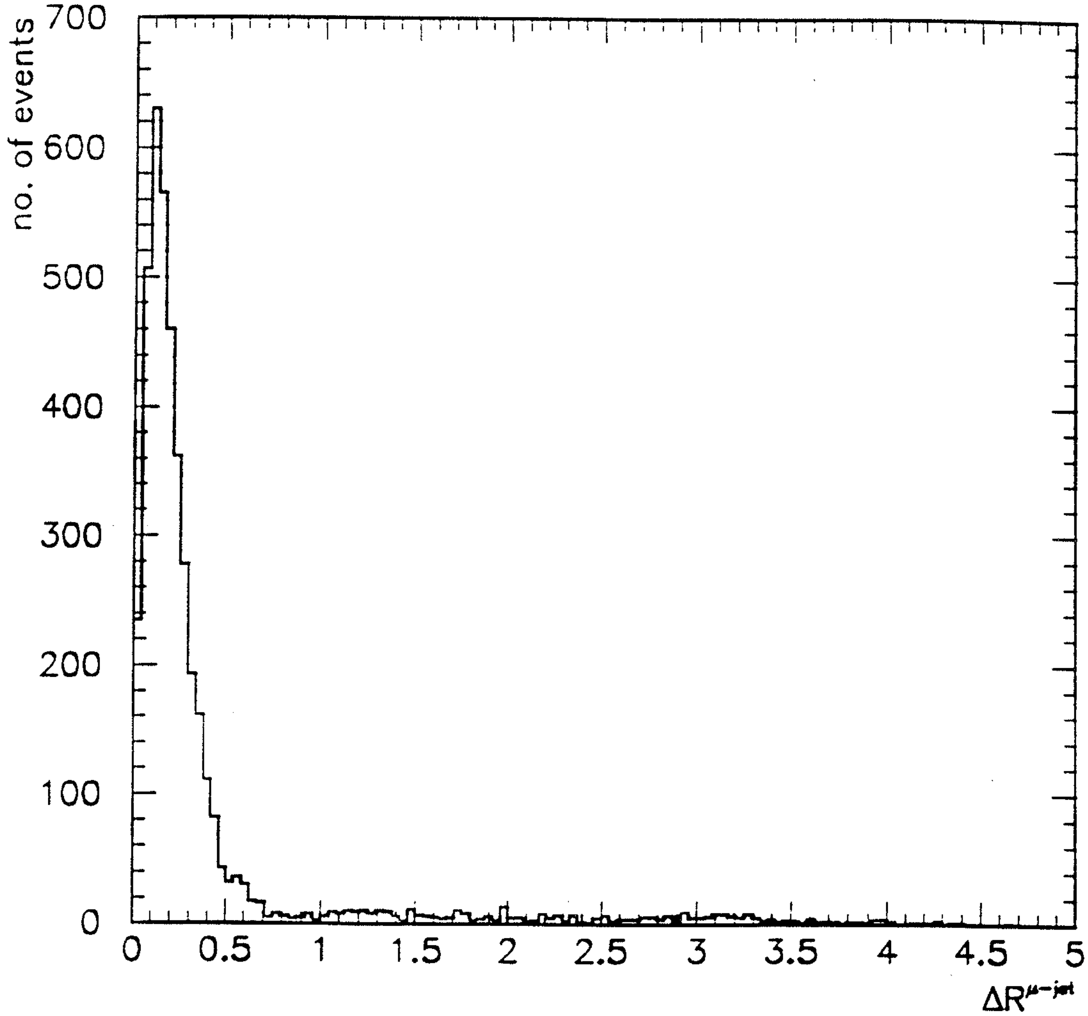
- **Estimate of residual cosmic contamination: (11±4)%**

  $\longrightarrow$ from study of coincidence of μ with beam-crossing

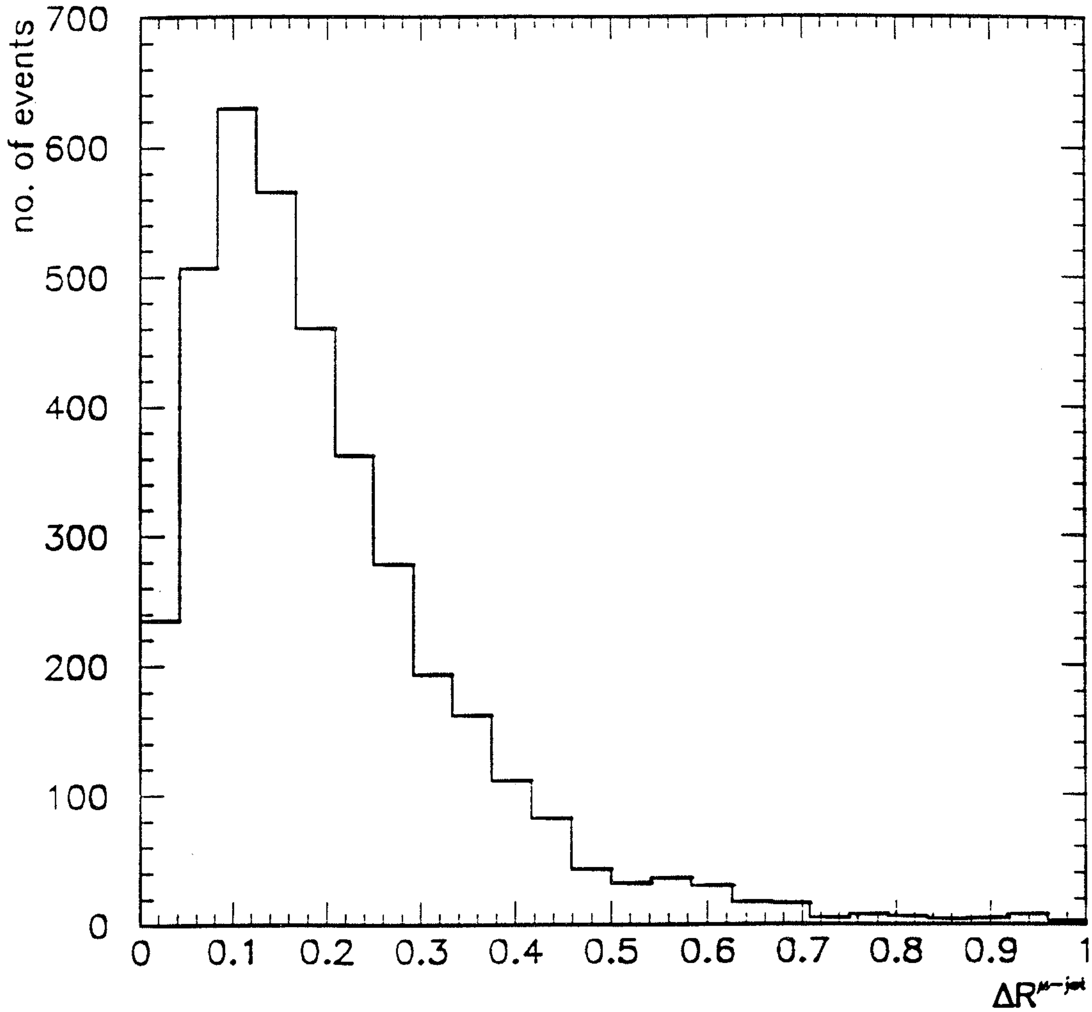

no. of events
1500
1000
500
0
0
2
4
6
8
10
12
14
no of jets
no. of events
2000
1500
1000
500
0
0
2
4
6
8
10
12
14
order near jet
no. of events
2000
1000
0
0
2
4
6
8
10
12
14
order of far jet



no. of events
450
400
350
300
250
200
150
100
50
0
0
10
20
30
40
50
60
70
80
90
100
E_t^{high} (GeV)

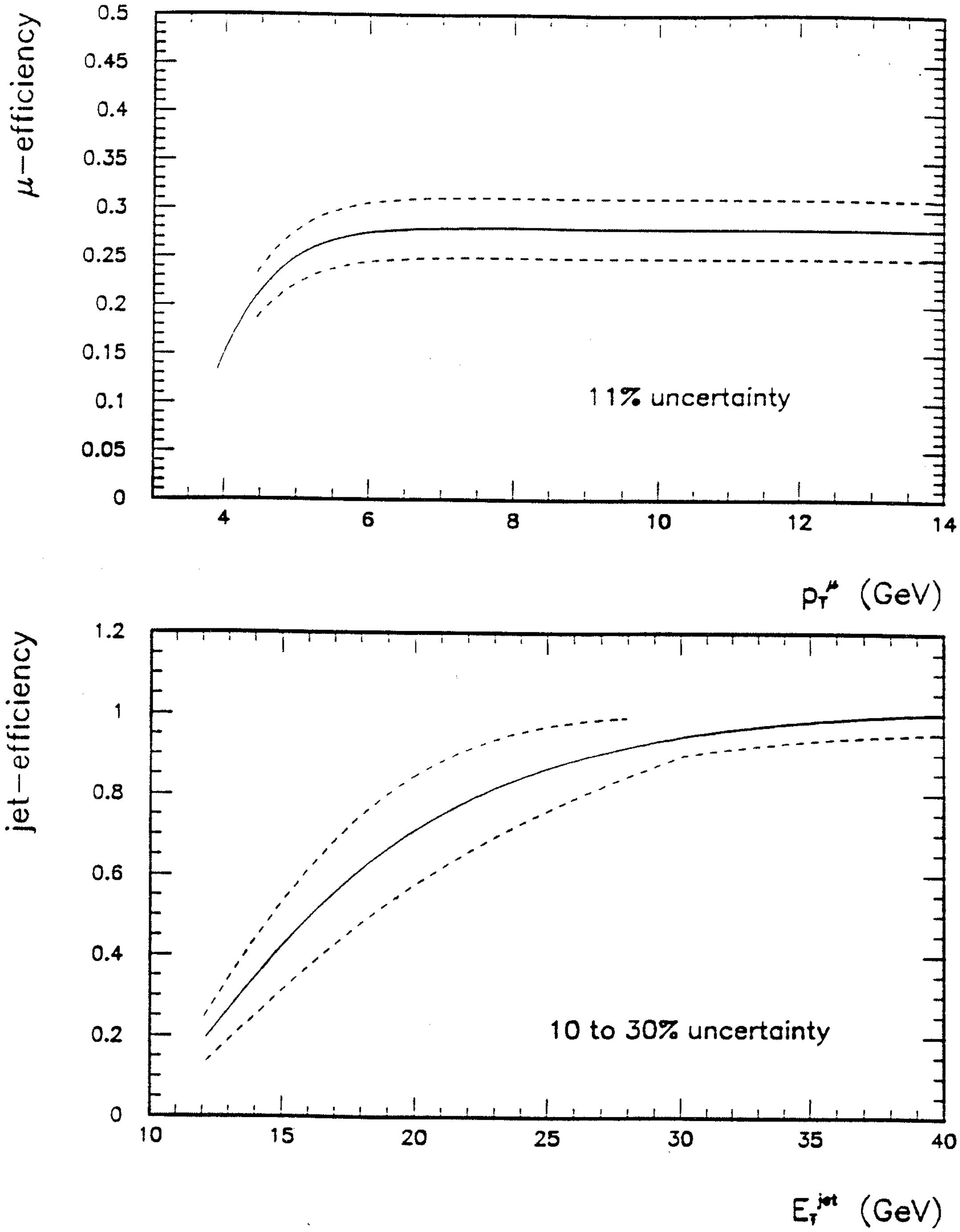


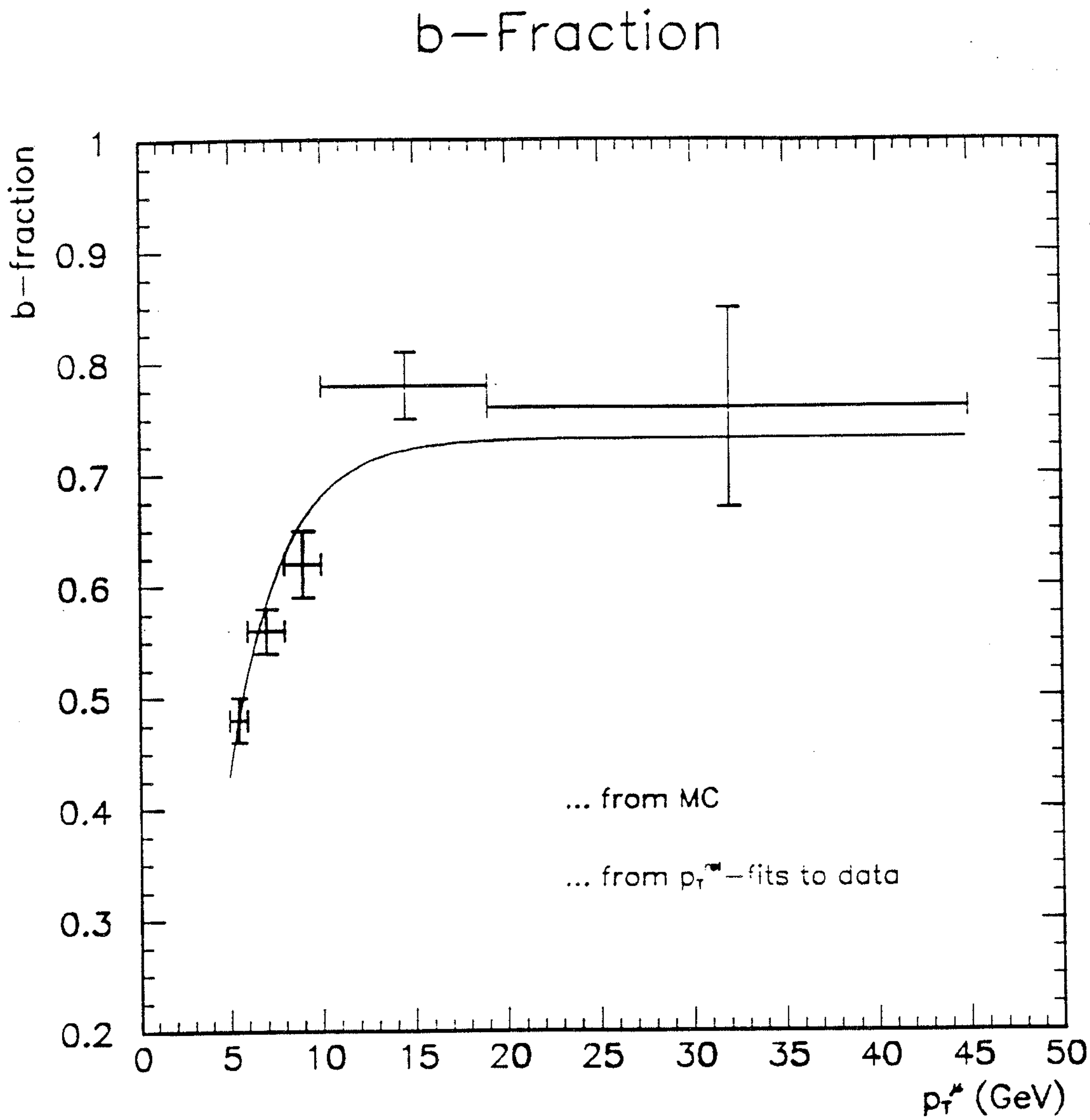
no. of events
700
600
500
400
300
200
100
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
$\Delta R^{\mu-jet}$



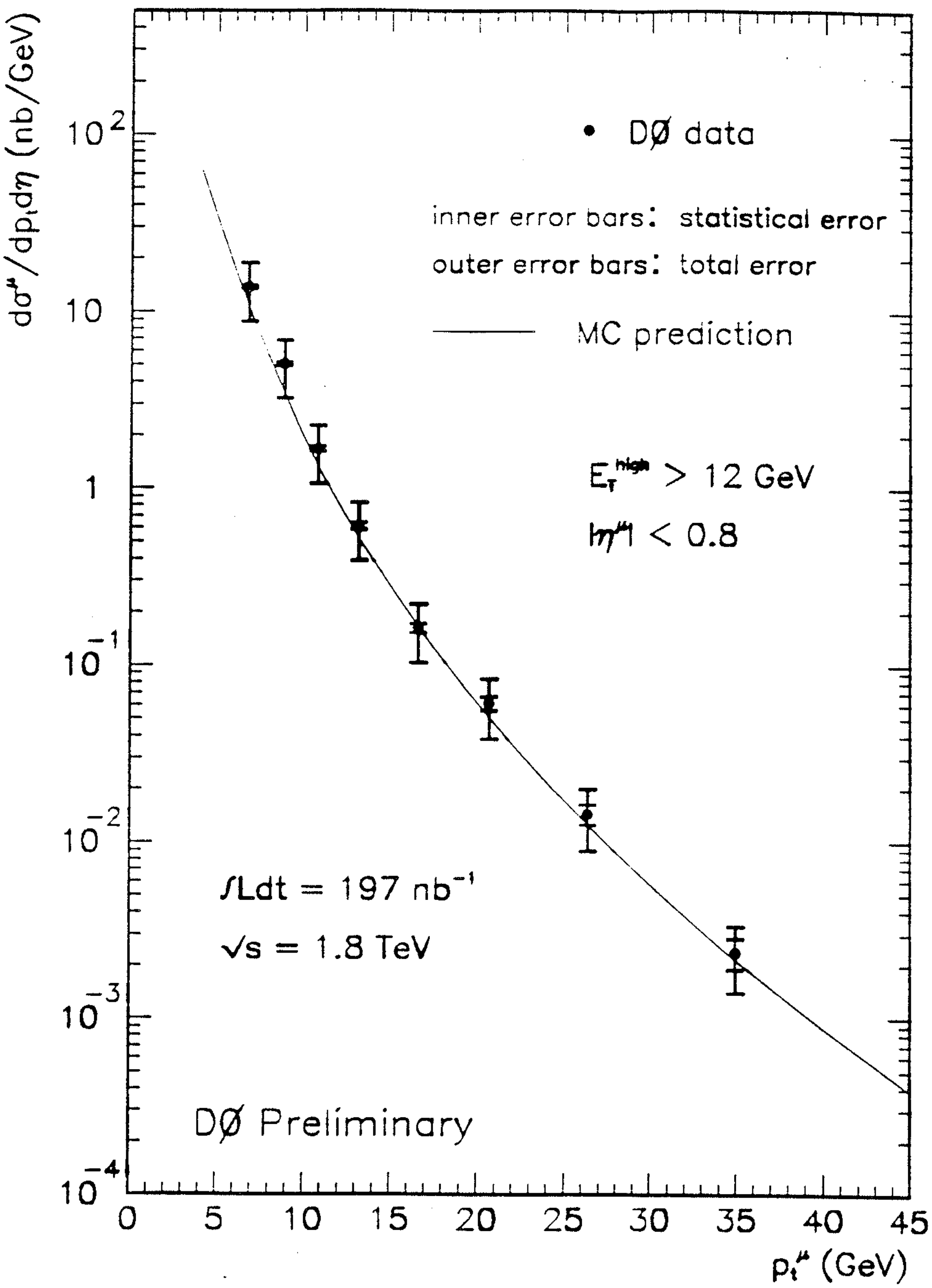
no. of events
700
600
500
400
300
200
100
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
ΔR^μ-jet

Efficiencies

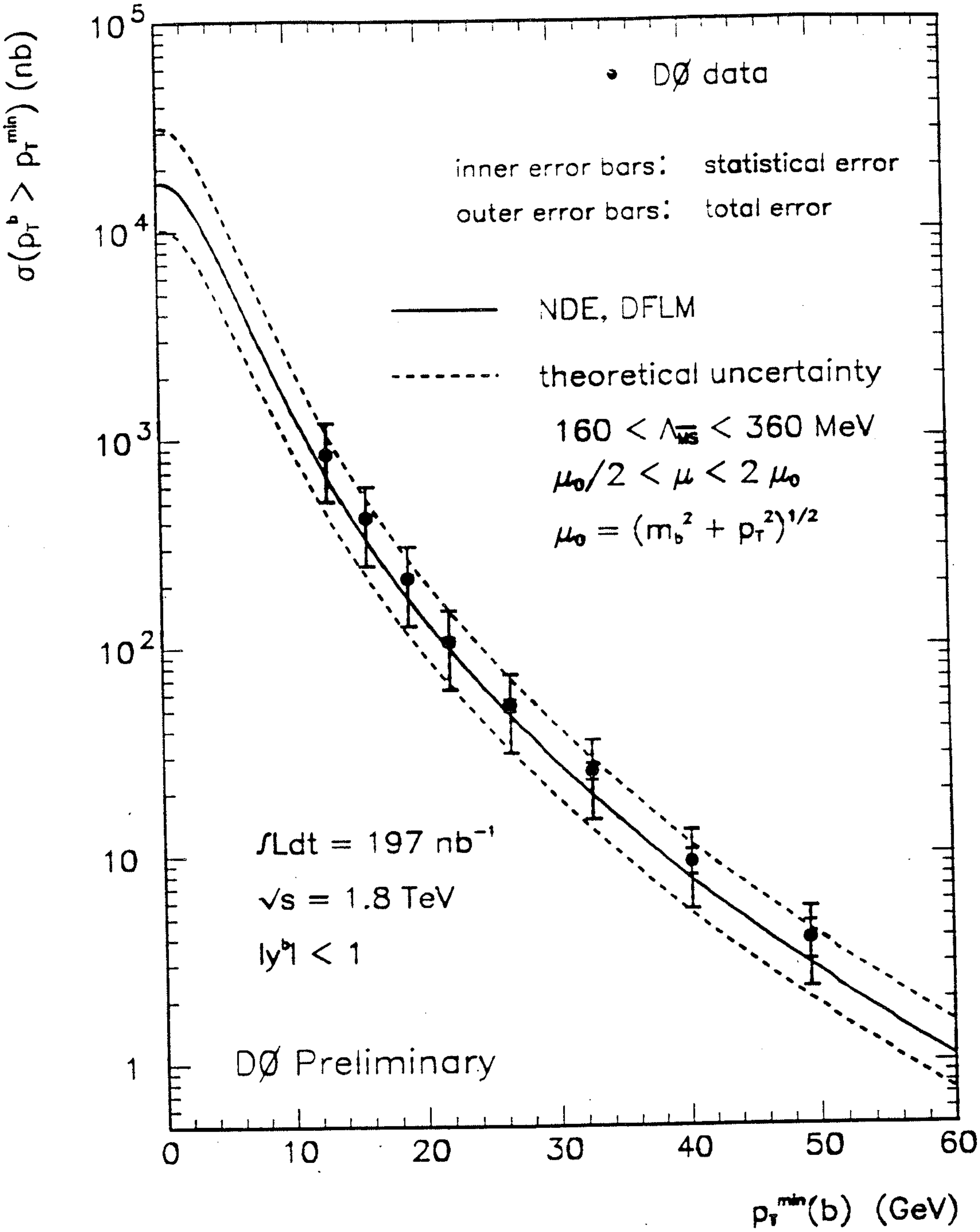



b−Fraction
b−fraction
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
5
10
15
20
25
30
35
40
45
50
p_T^μ (GeV)
... from MC
... from p_T^{rel}−fits to data

b → μX Cross-Section from μ+Jets Data



b−Quark Production (from μ+Jets Events)



Inclusive Dimuon Cross Section

Data Selection

- **Data Collection**

  Collected during FNAL 1992-93 collider run

  Total integrated luminosity = 6.4 pb^{-1}

  Total events after cuts = 552

- **Trigger Requirements**

  2 Muons with $|\eta_\mu| \leq 1.7$ in Level 1 (Hardware)

  2 Muons with $|\eta_\mu| \leq 1.7$ and $p_t^\mu \geq 3$ GeV in Level 2 (Software)

- **Single Muon Kinematic Cuts**

  4 GeV $\leq p_t^\mu \leq$ 25 GeV

  $|\eta_\mu| \leq 0.8$

  $\phi \leq 80°, \phi \geq 110°$ (fiducial cut)

- **Track Quality Cuts**

  2 or 3 layer track

  Good fits in bend and non-bend directions

  $\int$ Bdl > 0.6 GeV (good momentum measurement)

  E_{cal} (in ΔR = .15 cone) $\geq$ 1 GeV

  Matching CD track (removes cosmic rays)

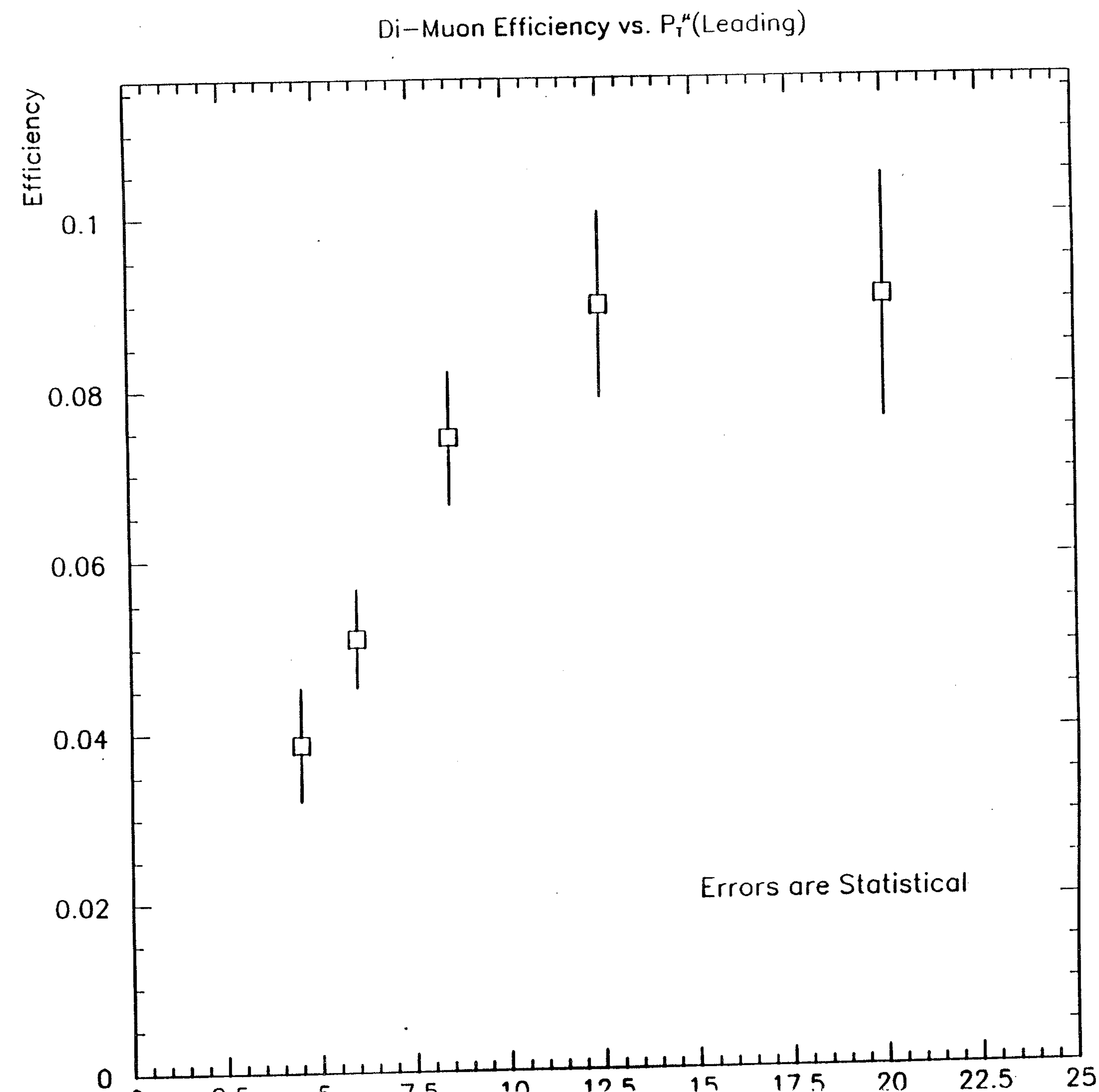
- **Dimuon Kinematic Cuts**

  6 GeV $\leq M_{\mu\mu} \leq$ 35 GeV

  $\Delta\phi_{3D} < 165°$

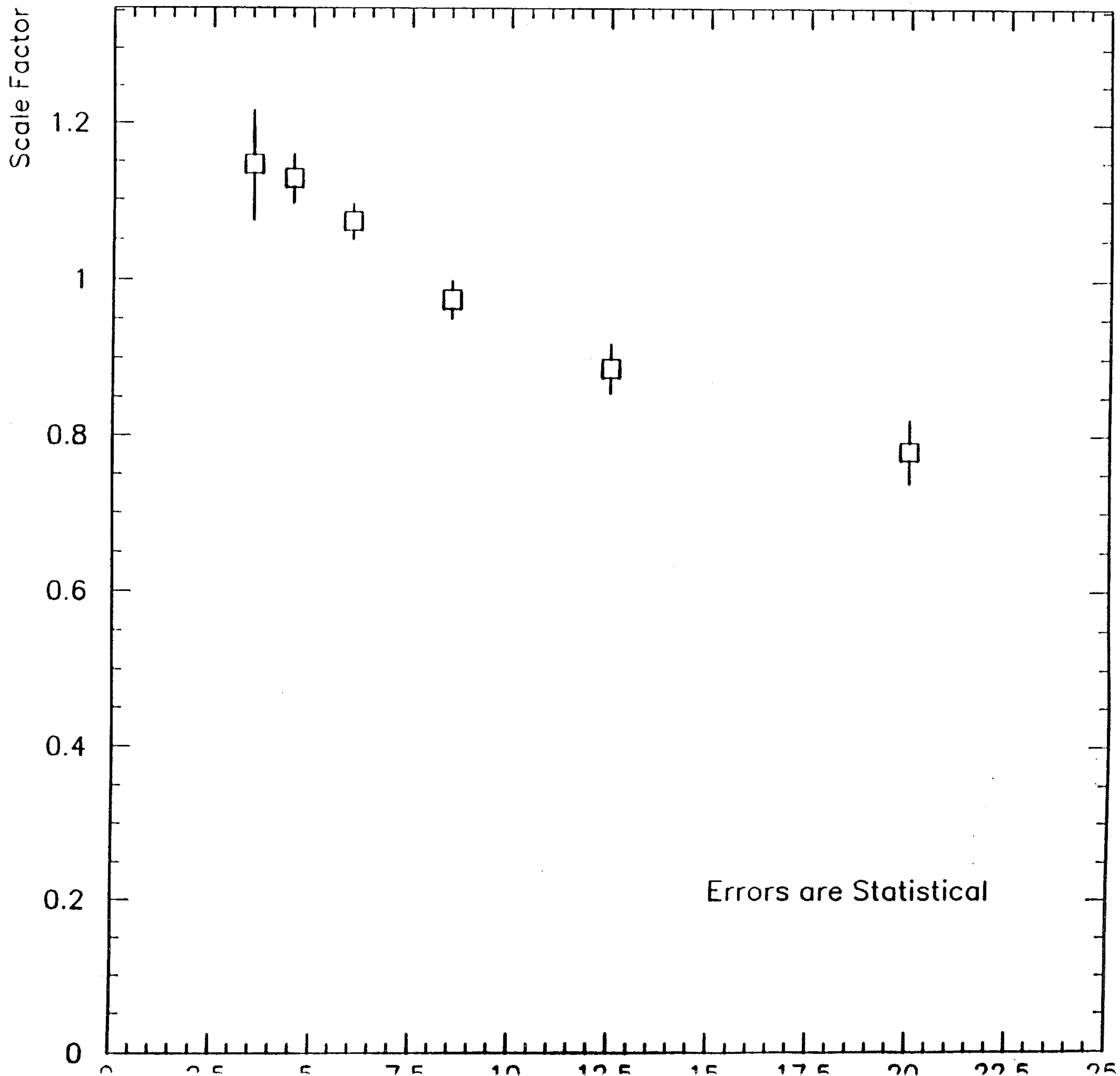
- **Fits to muon crossing time give cosmic ray fraction 0.118 ± 0.014**

- **Event scanning to verify this fraction (0.130 ± 0.031)**



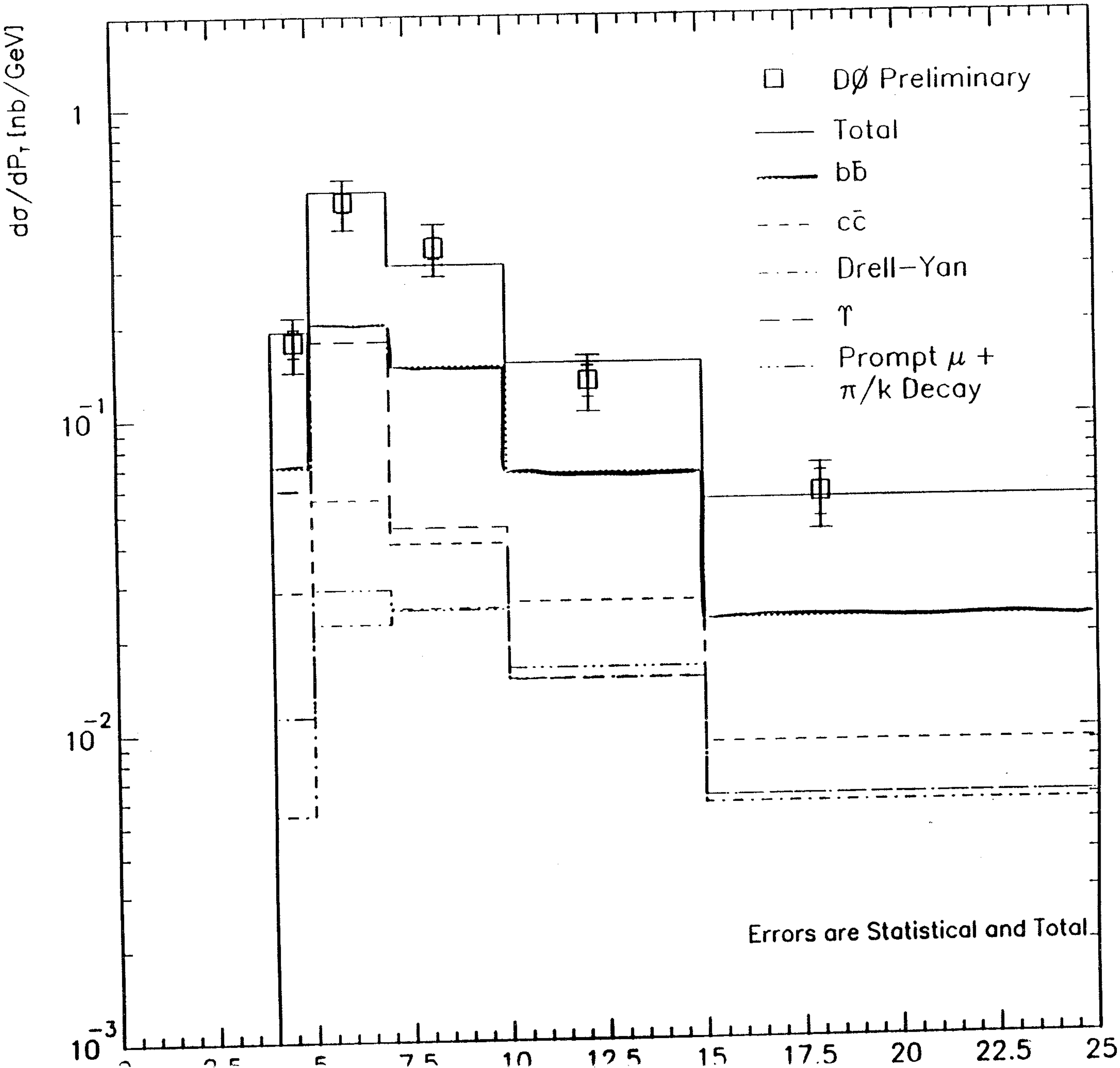
Di–Muon Efficiency vs. P_T^{μ}(Leading)
Efficiency
0.1
0.08
0.06
0.04
0.02
0
Errors are Statistical
22.5
25

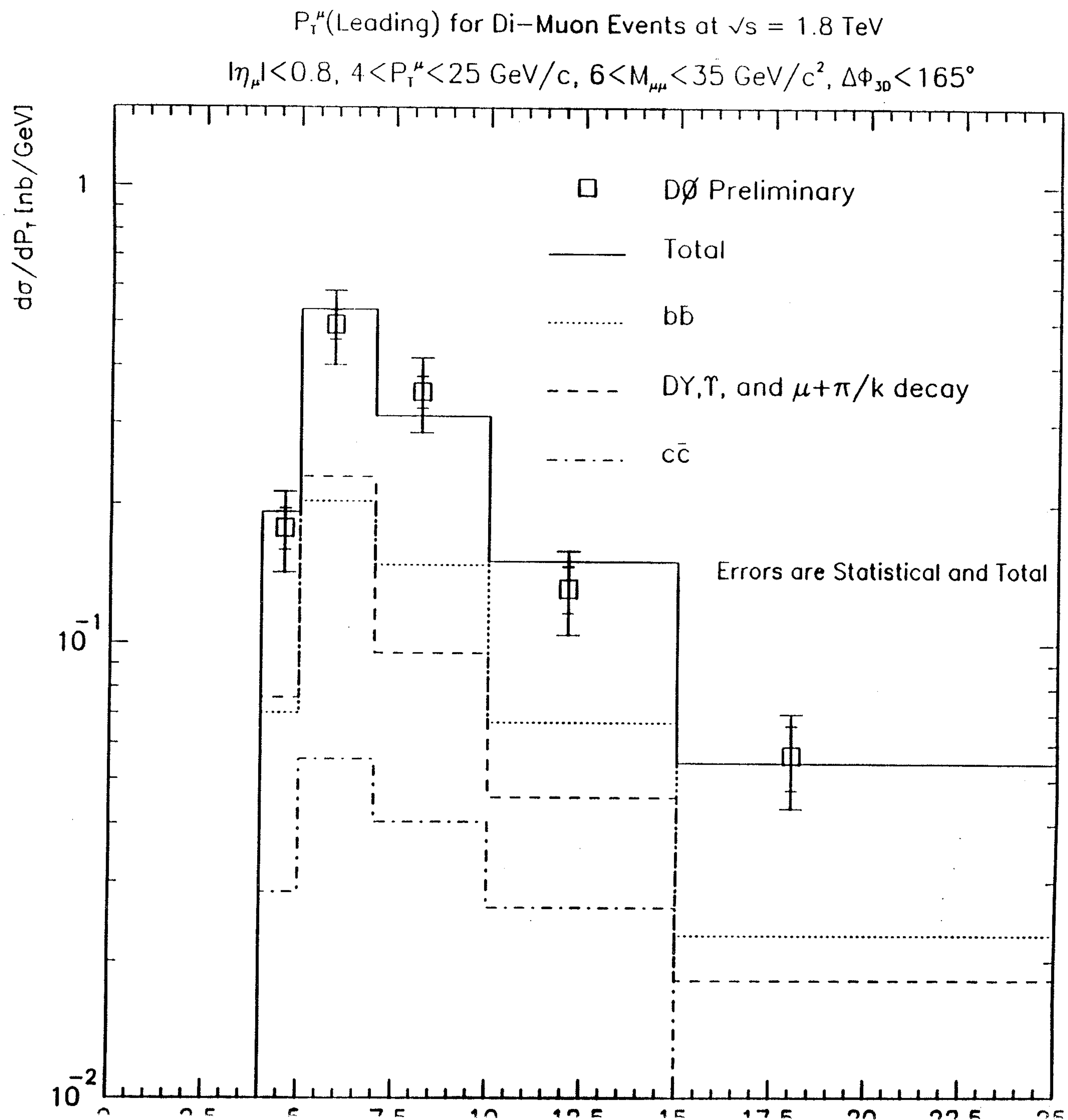
Unfolding Momentum Resolution Spectrum



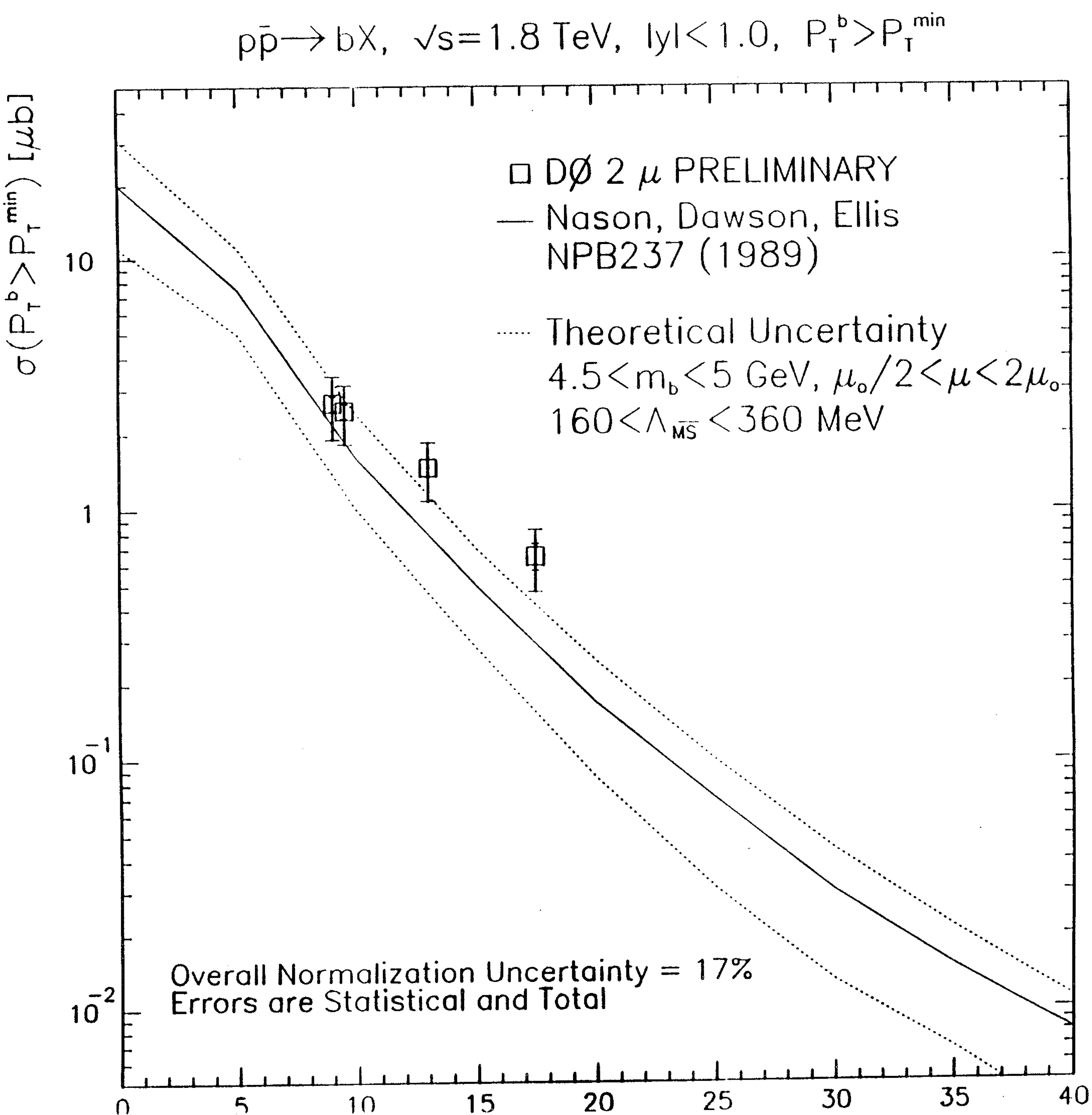
P_T^{μ}(Leading) for Di-Muon Events at $\sqrt{s}$ = 1.8 TeV

$|\eta_{\mu}|<0.8$, $4<P_T^{\mu}<25$ GeV/c, $6<M_{\mu\mu}<35$ GeV/c^2, $\Delta\Phi_{3D}<165°$





P_T^{μ}(Leading) for Di–Muon Events at $\sqrt{s}$ = 1.8 TeV
$|\eta_{\mu}|<0.8$, $4<P_T^{\mu}<25$ GeV/c, $6<M_{\mu\mu}<35$ GeV/c^2, $\Delta\Phi_{3D}<165°$
$d\sigma/dP_T$ [nb/GeV]
1
10^{-1}
10^{-2}
DØ Preliminary
Total
$b\bar{b}$
DY,Υ, and $\mu+\pi/k$ decay
$c\bar{c}$
Errors are Statistical and Total



$p\bar{p} \rightarrow bX$, $\sqrt{s}=1.8$ TeV, $|y|<1.0$, $P_T^b > P_T^{min}$
$\sigma(P_T^b > P_T^{min})$ [μb]
DØ 2 μ PRELIMINARY
Nason, Dawson, Ellis
NPB237 (1989)
Theoretical Uncertainty
$4.5<m_b<5$ GeV, $\mu_0/2<\mu<2\mu_0$
$160<\Lambda_{\overline{MS}}<360$ MeV
Overall Normalization Uncertainty = 17%
Errors are Statistical and Total
10
1
10^{-1}
10^{-2}
0
5
10
15
20
25
30
35
40

Systematic Errors

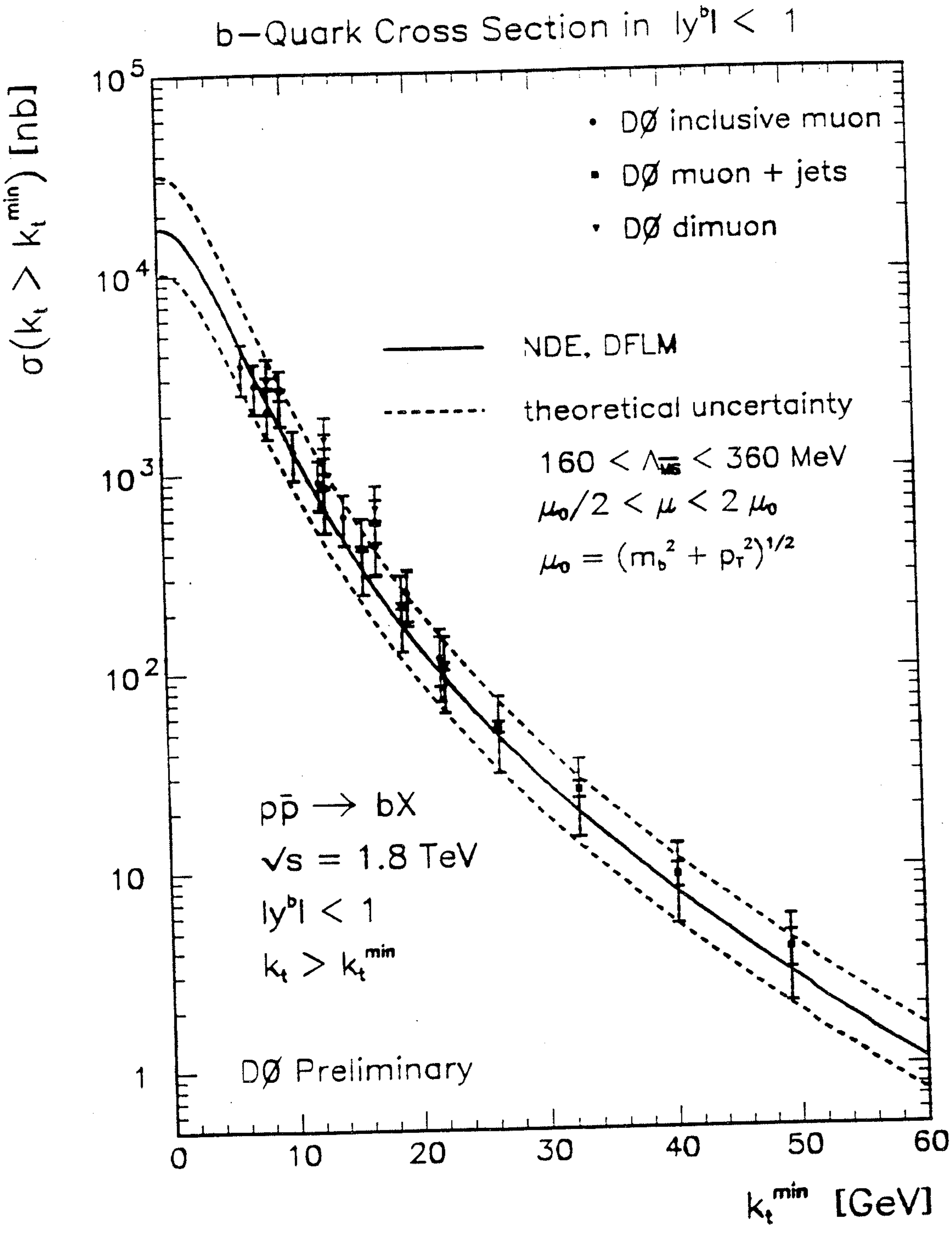
Muon-Level Cross-Section

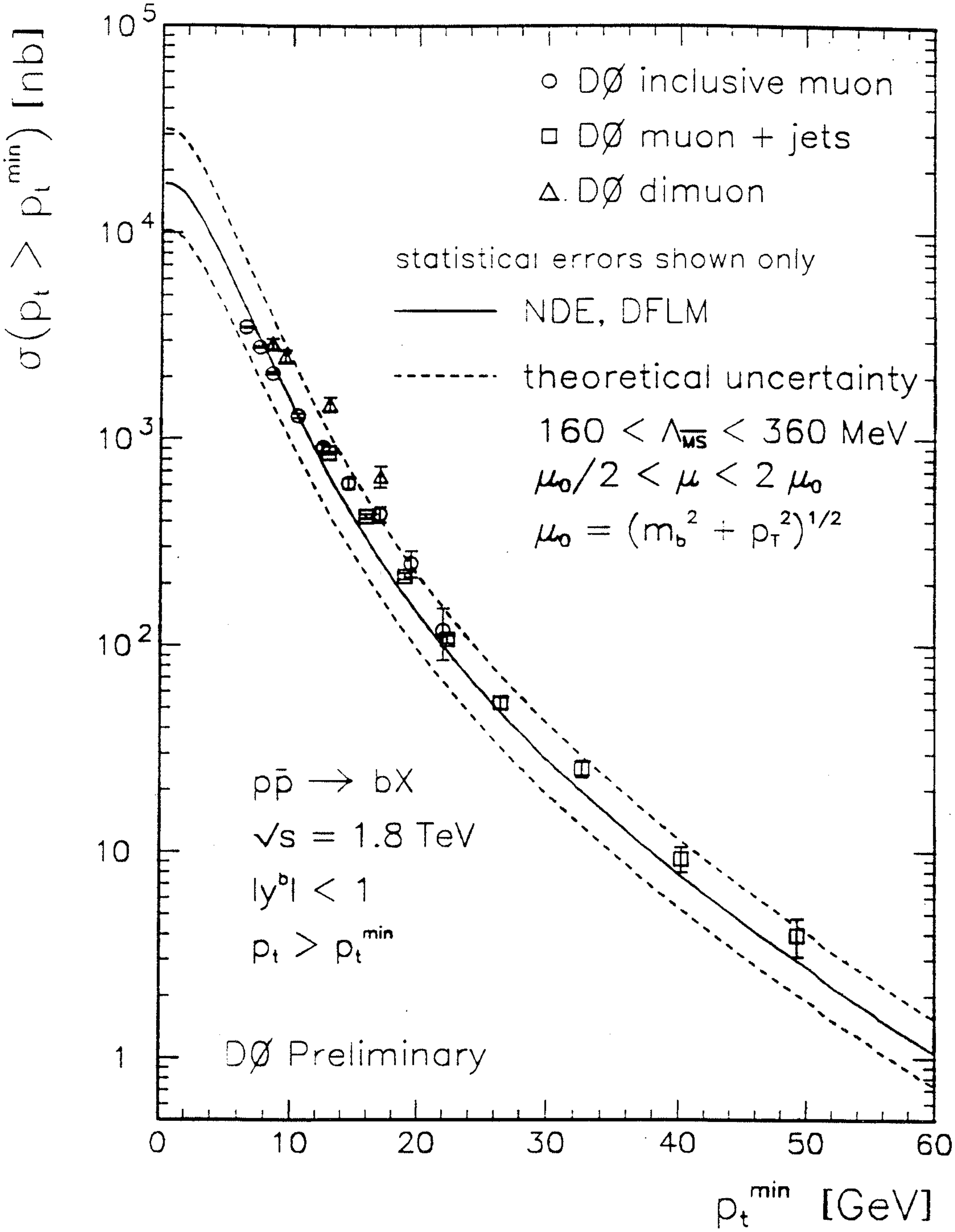
- Luminosity 12%
- Efficiency from MC 10%
- Central Detector Track Match 3%
- Cosmic Subtraction 5%
- **Total(μ)** **17%**

b-Quark Cross-Section

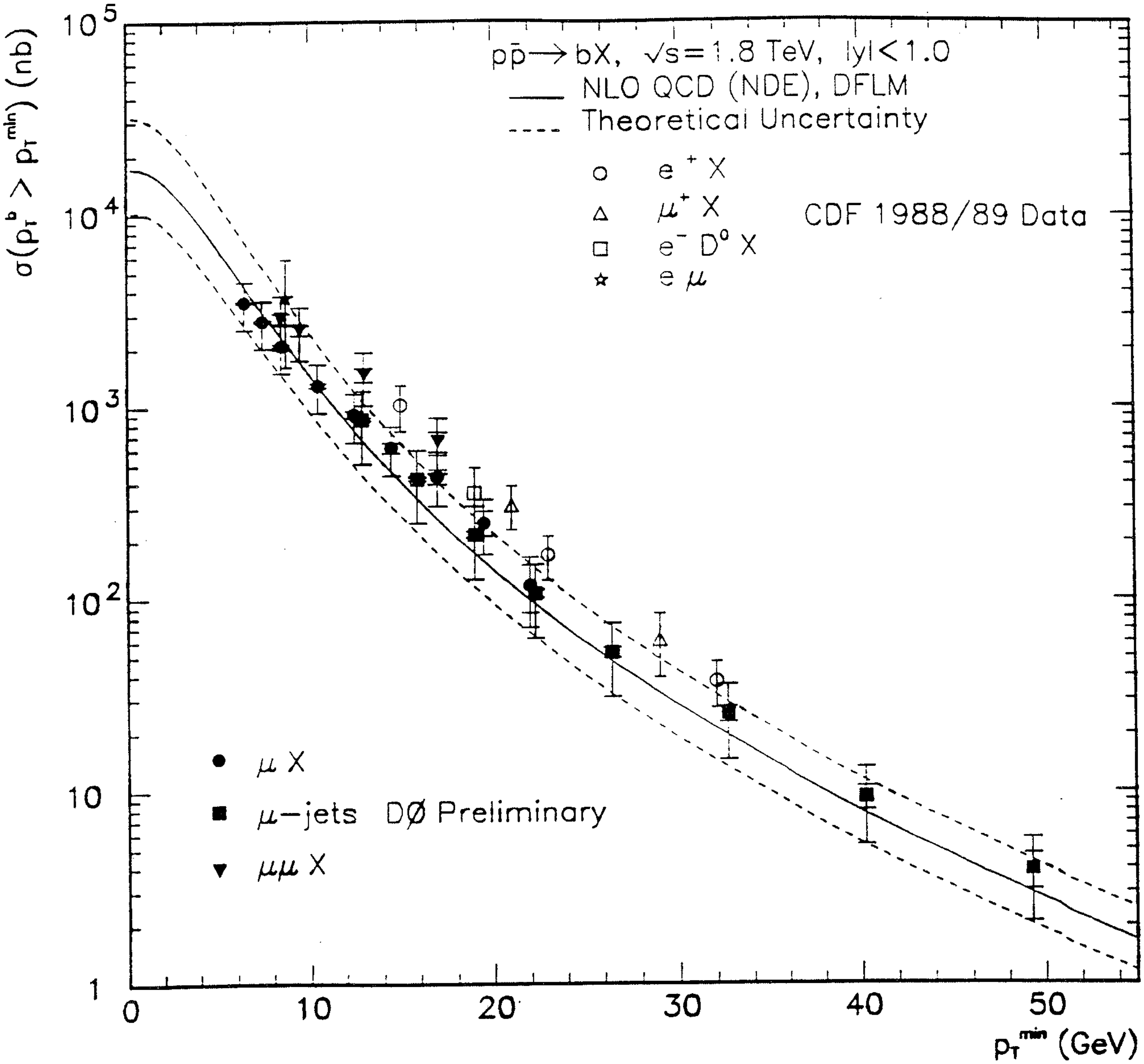
- b-quark Fraction 28%
- b-quark P_T Spectrum 14%
- Parameterization of Fragmentation 21%
- BR for $b \rightarrow \mu + X$ Decay 7%
- Spectrum for $b \rightarrow \mu + X$ Decay 14%
- **Total(b)** **40%**

Summary of DØ Results

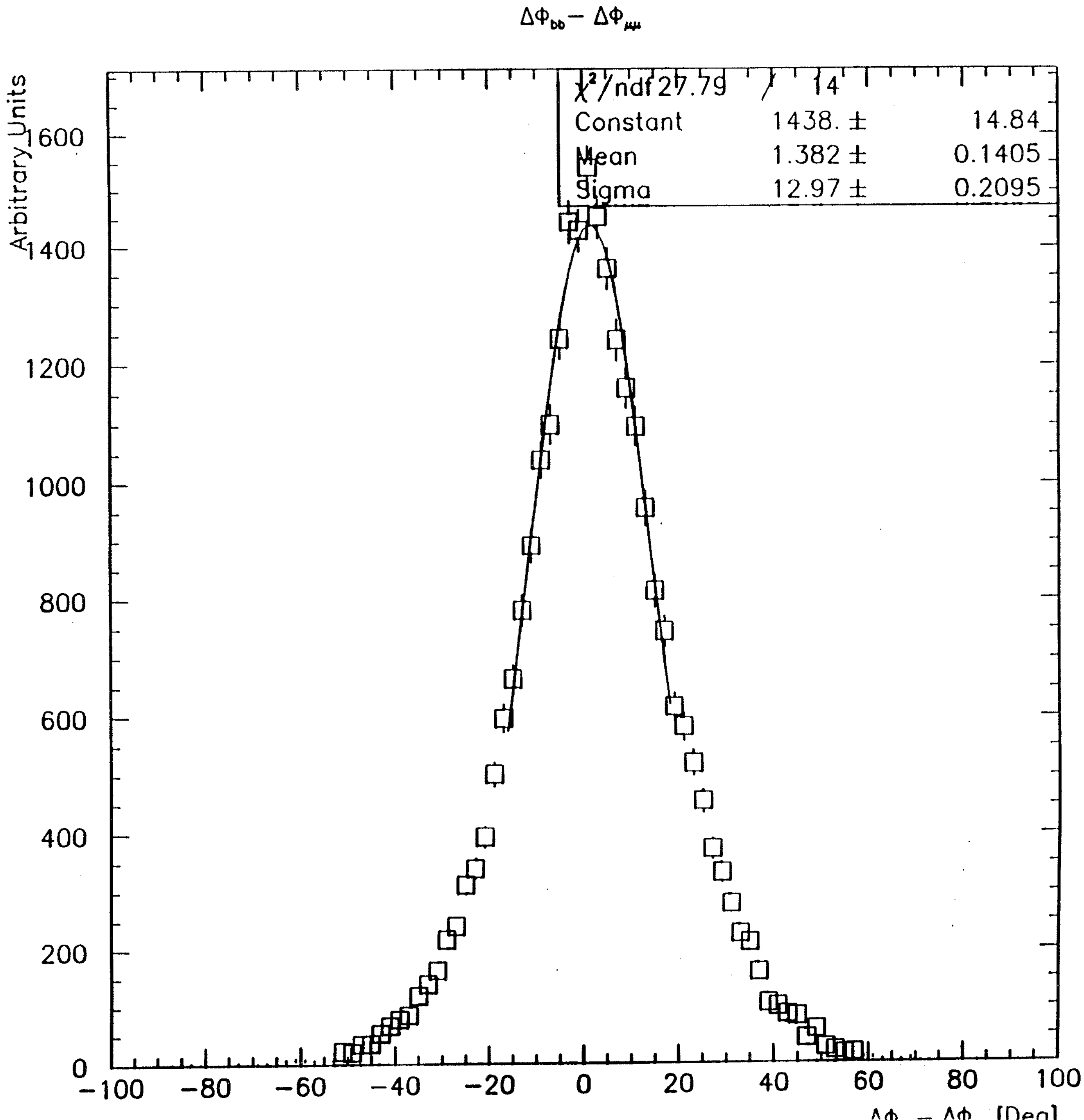




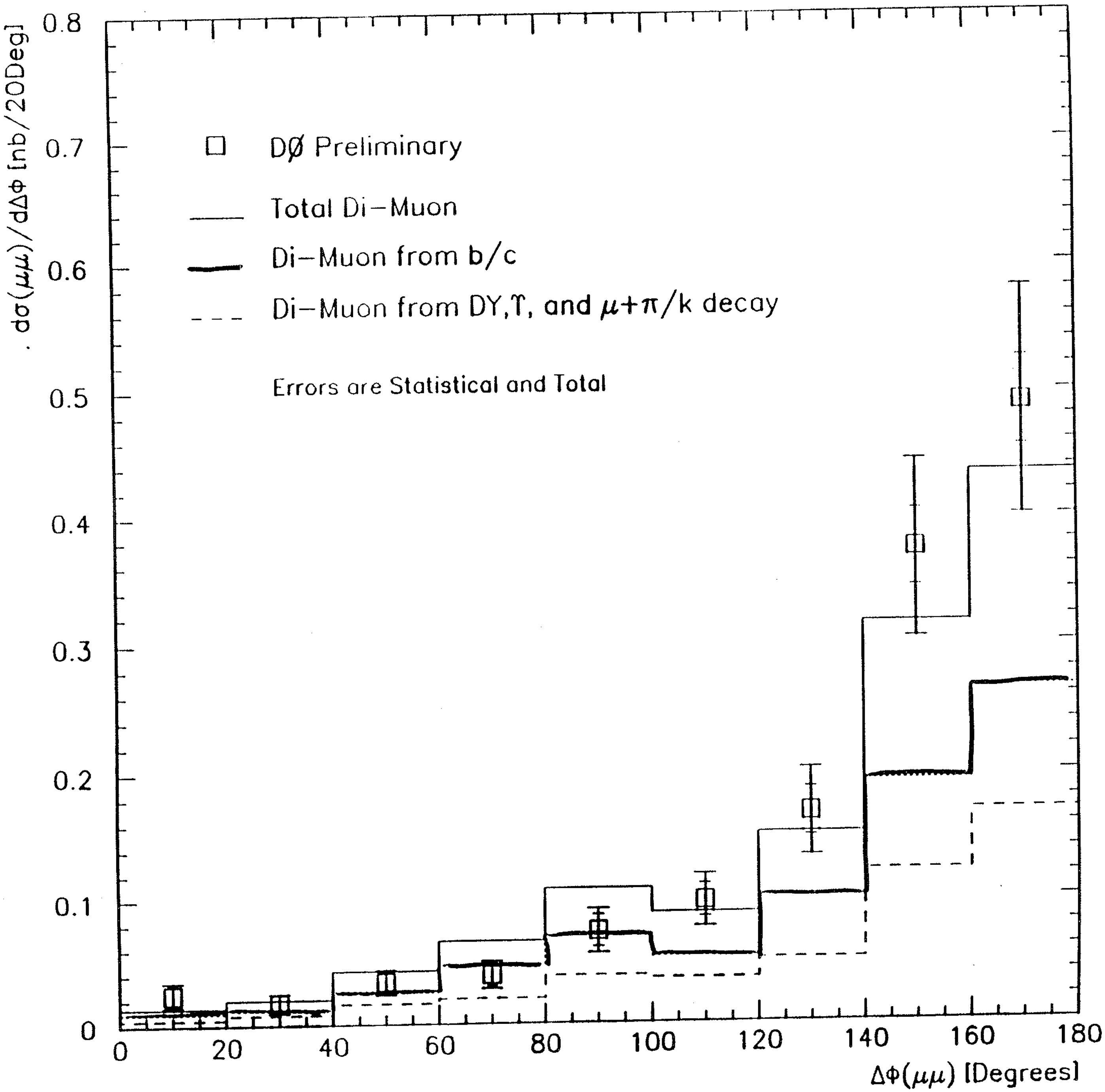
$\sigma(p_t > p_t^{min})$ [nb]
p_t^{min} [GeV]
○ DØ inclusive muon
□ DØ muon + jets
△ DØ dimuon
statistical errors shown only
NDE, DFLM
theoretical uncertainty
$160 < \Lambda_{\overline{MS}} < 360$ MeV
$\mu_0/2 < \mu < 2\,\mu_0$
$\mu_0 = (m_b^2 + p_T^2)^{1/2}$
$p\bar{p} \rightarrow bX$
$\sqrt{s} = 1.8$ TeV
$|y^b| < 1$
$p_t > p_t^{min}$
DØ Preliminary



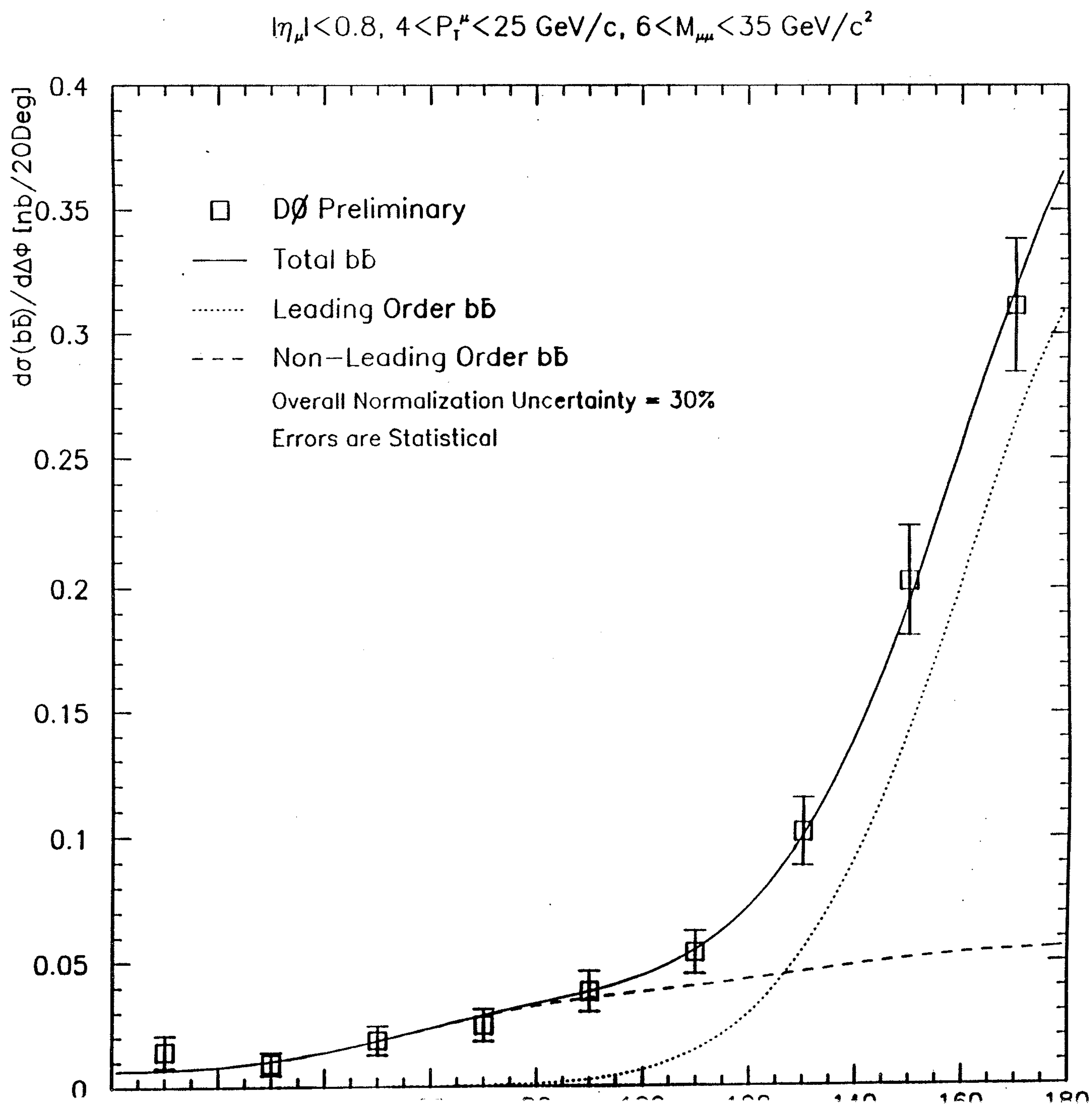
pp̄ → bX, √s=1.8 TeV, |y|<1.0
NLO QCD (NDE), DFLM
Theoretical Uncertainty
e⁺ X
μ⁺ X
e⁻ D⁰ X
e μ
CDF 1988/89 Data
μ X
μ−jets DØ Preliminary
μμ X
σ(p_T^b > p_T^min) (nb)
p_T^min (GeV)
10⁵
10⁴
10³
10²
10
1
0
10
20
30
40
50



ΔΦbb − ΔΦμμ
χ²/ndf 27.79 / 14
Constant 1438. ± 14.84
Mean 1.382 ± 0.1405
Sigma 12.97 ± 0.2095
Arbitrary Units
1600
1400
1200
1000
800
600
400
200
0
−100
−80
−60
−40
−20
0
20
40
60
80
100



DØ Preliminary
Total Di-Muon
Di-Muon from b/c
Di-Muon from DY,ϒ, and μ+π/k decay
Errors are Statistical and Total
dσ(μμ)/dΔΦ [nb/20Deg]
ΔΦ(μμ) [Degrees]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
20
40
60
80
100
120
140
160
180


|η_μ|<0.8, 4<P_T^μ<25 GeV/c, 6<M_μμ<35 GeV/c²
dσ(bb̄)/dΔφ [nb/20Deg]
DØ Preliminary
Total bb̄
Leading Order bb̄
Non−Leading Order bb̄
Overall Normalization Uncertainty = 30%
Errors are Statistical
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
180

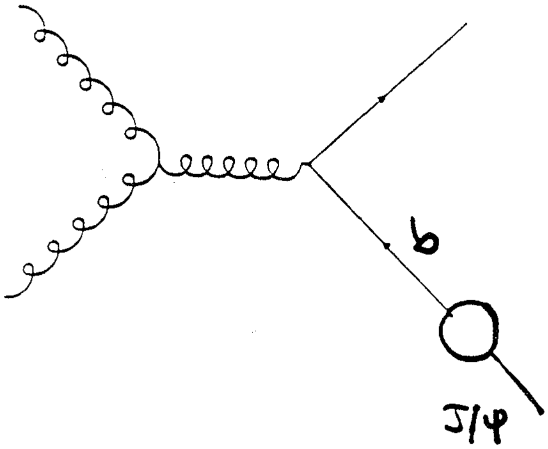
Kinematic Cuts

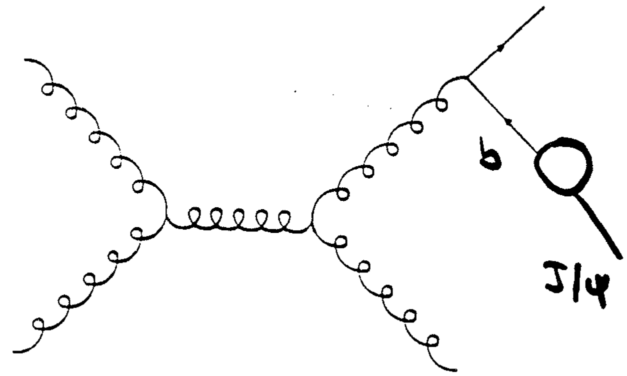
(Di-Muon Data)

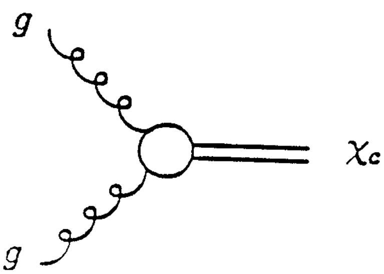
- $4\ GeV/c \leq P_T^{\mu} \leq 25\ GeV/c$
- $|\eta_{\mu}| \leq 0.8$
- $6\ GeV/c^2 \leq Mass_{\mu\mu} \leq 35\ GeV/c^2$

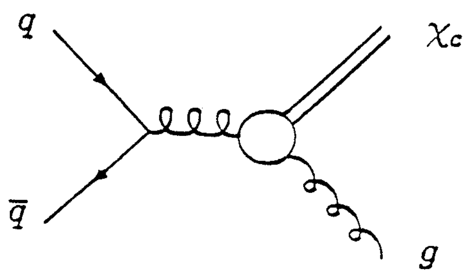
Production Process	*% of σ_b(MC)*	*% of σ_b(Data)*
Gluon Splitting	27±1%	6.3±4.5%
Flavor Excitation	11±1%	31.4±6.7%
Flavor Creation	62±2%	62.3±6.0%
Non-Leading Order	38±2%	37.7±8.1%
Leading Order	62±2%	62.3±6.0%

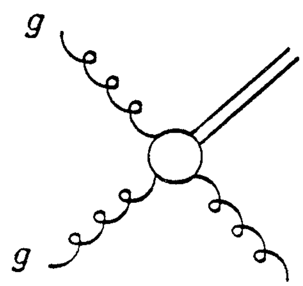
J/Ψ Production

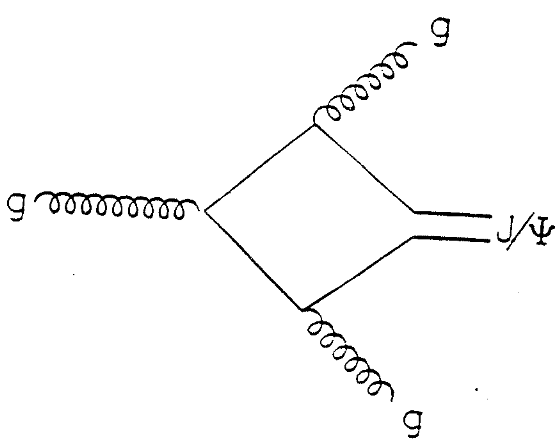


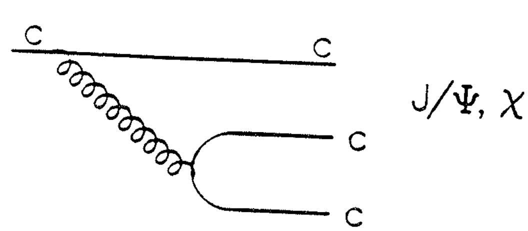


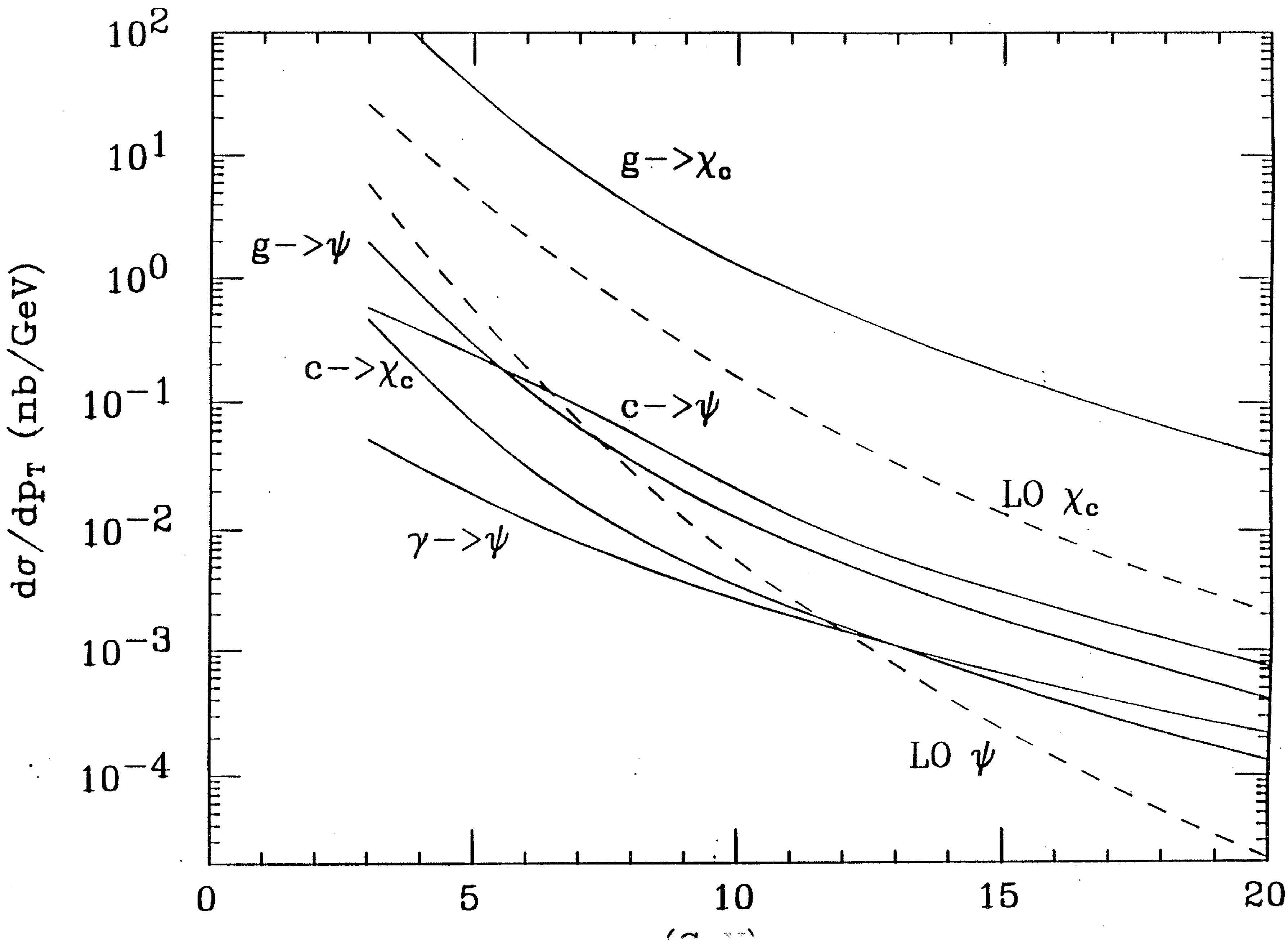












dσ/dp_T (nb/GeV)
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
g->χc
g->ψ
c->χc
c->ψ
γ->ψ
LO χc
LO ψ
0
5
10
15
20

Inclusive $J/\Psi \rightarrow \mu\mu$ Cross Section

<u>Data Selection</u>

- **Data Collection**

  Collected during FNAL 1992-93 collider run

  Total luminosity = 7.3 pb^{-1}

  Total events after cuts and fit $\approx$ 450

- **Trigger Requirements**

  2 Muons with $|\eta_\mu| \leq 1.7$ in Level 1 (Hardware)

  2 Muons with $|\eta_\mu| \leq 1.7$ and $P_T^\mu \geq 3$ GeV in Level 2 (Software)

- **Single Muon Kinematic Cuts**

  $P_T^\mu \geq 3$ GeV

  $|\eta_\mu| \leq 1.0$

- **Track Quality Cuts**

  2 or 3 layer track (A layer required)

  Good fits in bend and non-bend directions

  $\int B \cdot d\ell \geq 0.5$ GeV (good momentum measurement)

  E_{cal} (in $\Delta R = 0.25$ cone) ≥ 1 GeV

  Matching CD track (removes cosmics)

  $\phi \leq 80°$ or $\phi \geq 100°$

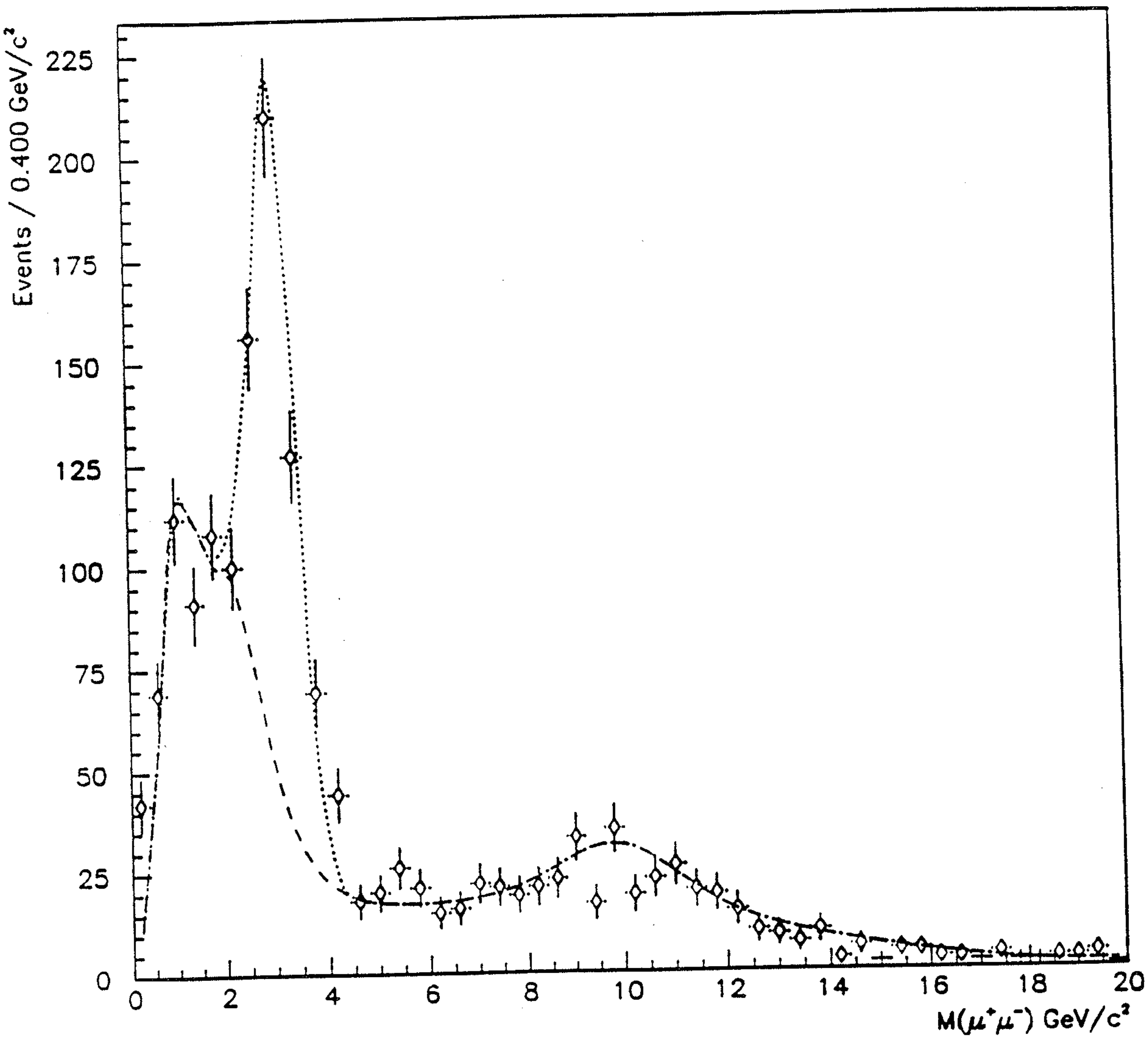
- **Dimuon Kinematic Cuts**

  Opposite sign muons

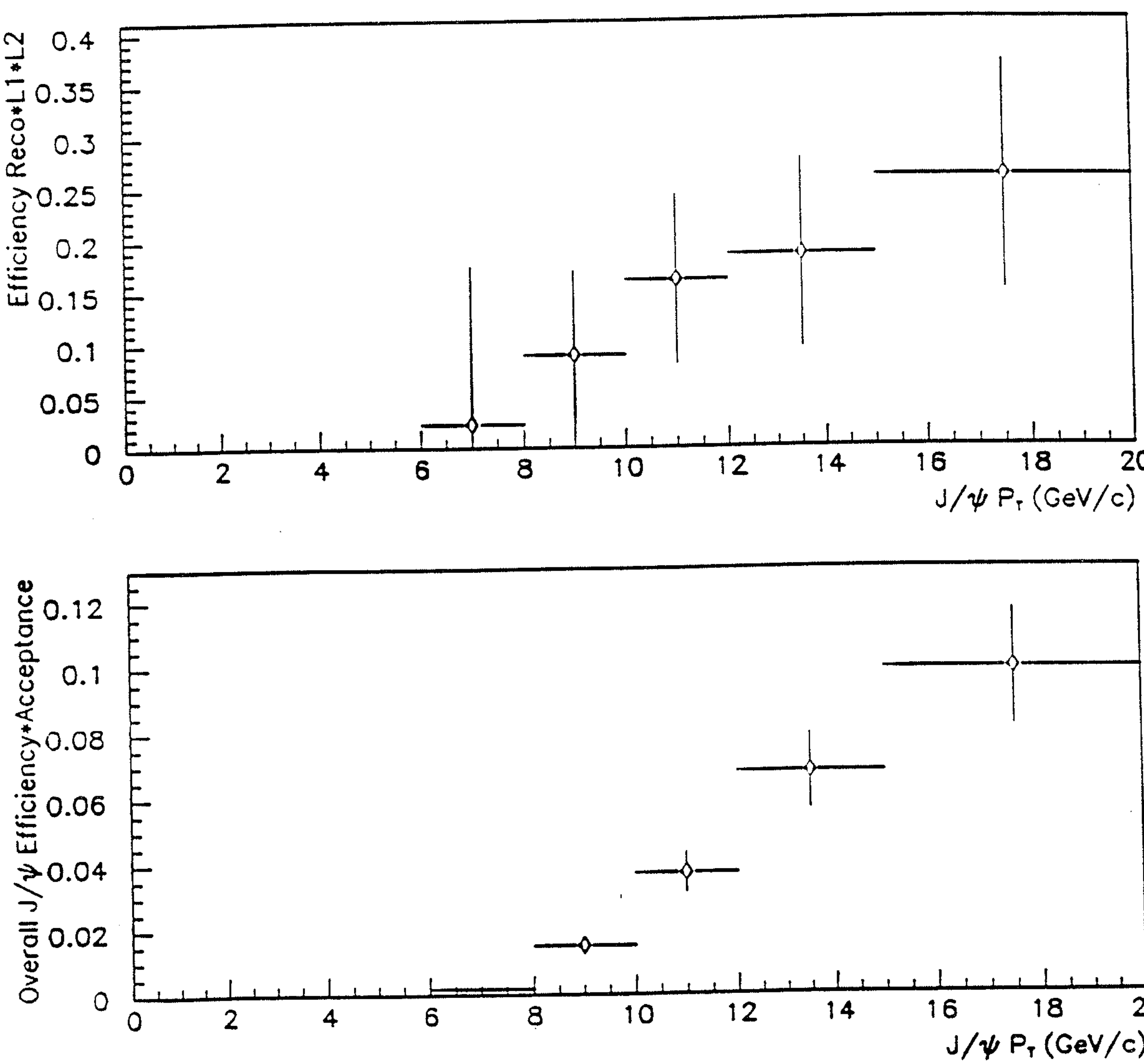
  Dimuon opening angle $\leq 150°$

  2.0 GeV $\leq M_{\mu\mu} \leq$ 4.5 GeV

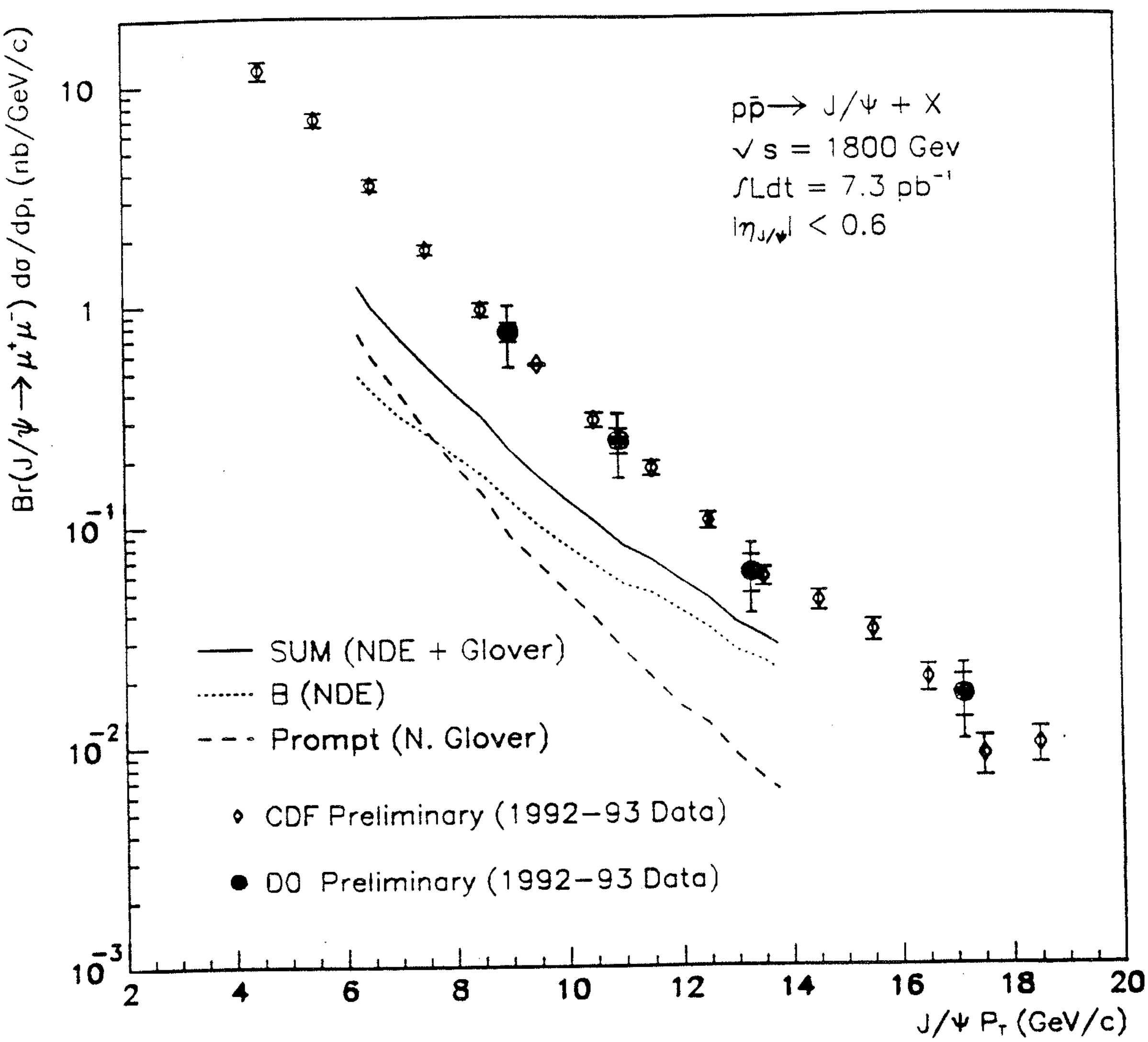
  $|\eta_{J/\Psi}| \leq 0.6$



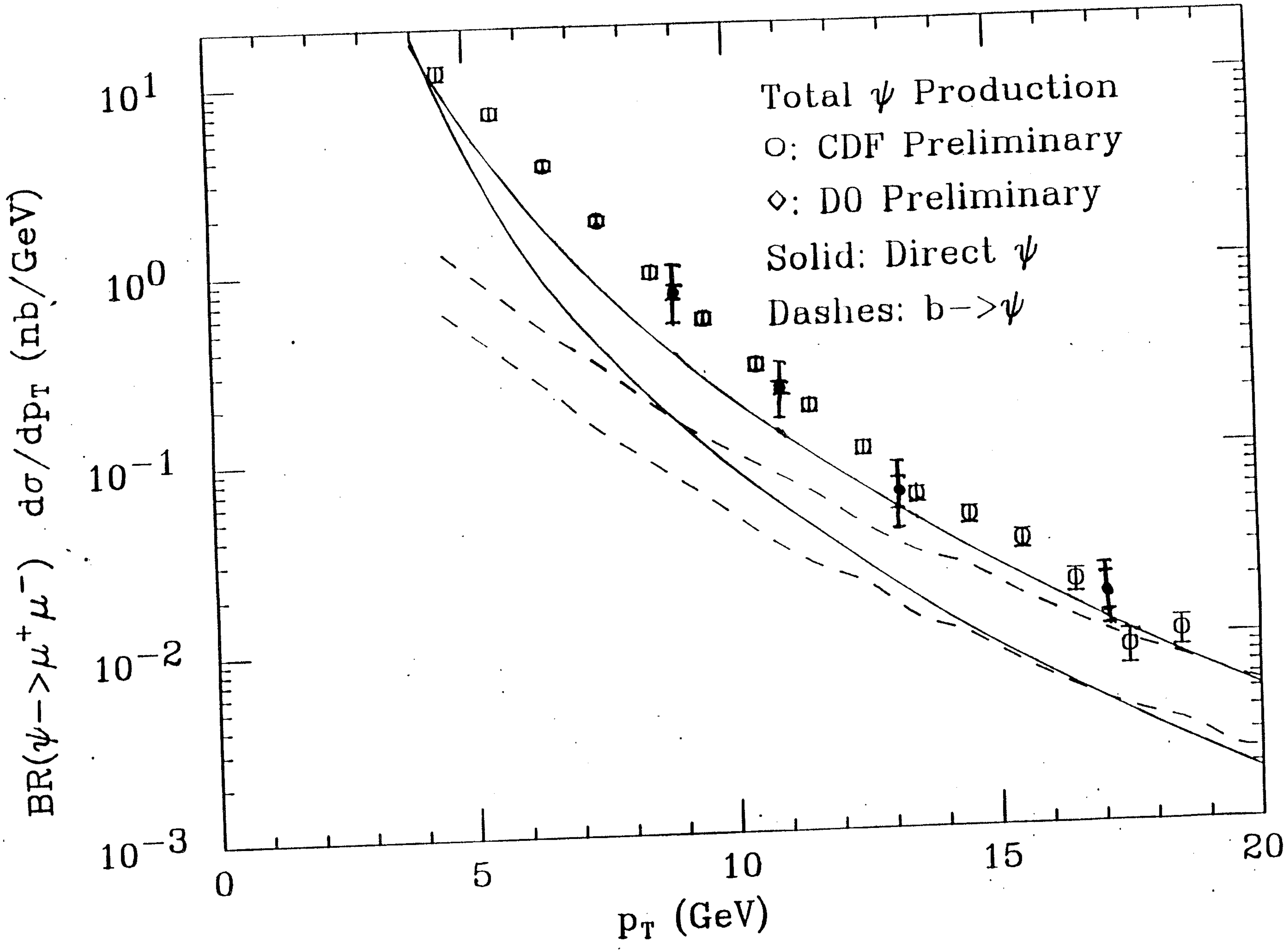
Events / 0.400 GeV/c²
225
200
175
150
125
100
75
50
25
0
0
2
4
6
8
10
12
14
16
18
20
M(μ⁺μ⁻) GeV/c²



Efficiency Reco*L1*L2
0 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4
0 2 4 6 8 10 12 14 16 18 20
J/ψ P_T (GeV/c)
Overall J/ψ Efficiency*Acceptance
0 0.02 0.04 0.06 0.08 0.1 0.12
0 2 4 6 8 10 12 14 16 18 20
J/ψ P_T (GeV/c)



pp̄ → J/ψ + X
√s = 1800 Gev
∫Ldt = 7.3 pb⁻¹
|η_J/ψ| < 0.6
SUM (NDE + Glover)
B (NDE)
Prompt (N. Glover)
CDF Preliminary (1992–93 Data)
D0 Preliminary (1992–93 Data)
Br(J/ψ → μ⁺μ⁻) dσ/dp_t (nb/GeV/c)
J/ψ P_T (GeV/c)
10
1
10⁻¹
10⁻²
10⁻³
2
4
6
8
10
12
14
16
18
20

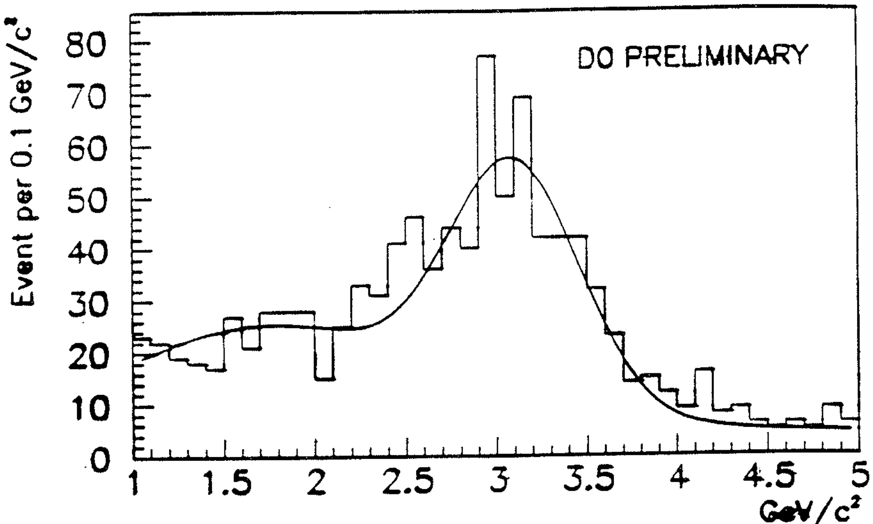


Total ψ Production
O: CDF Preliminary
◇: D0 Preliminary
Solid: Direct ψ
Dashes: b->ψ
BR(ψ->μ⁺μ⁻) dσ/dp_T (nb/GeV)
p_T (GeV)
10^1
10^0
10^-1
10^-2
10^-3
0
5
10
15
20

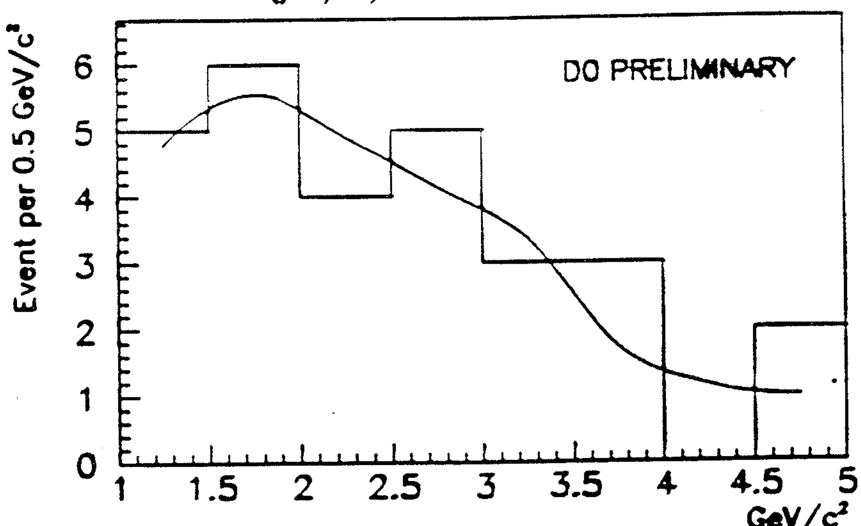
Estimating Fraction of J/ψ from b Deca

① Fit J/ψ plus background in mass range $1 < M_{\mu\mu} < 5$ GeV

$$(N - N_{J/\psi})\, \mathcal{F}(\text{back}) + N_{J/\psi}\, \mathcal{F}(J/\psi$$



M(μ⁺μ⁻): DIMUON EVENTS



M(μ⁺μ⁻): TRIMUON EVENTS

② Using $\mathcal{F}(\text{back})$ and $\mathcal{F}(J/\psi)$ from ① can estimate $N_{J/\psi}$ in $J/\psi + \mu$ events

$N(J/\psi) = 450 \pm 22$

$N(J/\psi + \mu) = 2.5 \, ^{+3.3}_{-2.5}$

$\epsilon(J/\psi + \mu) = 0.042 \pm 0.006$
(ISAJET)

use

$$fr(b \to J/\psi)_{MAX} \approx \frac{N^{3\mu}_{J/\psi} + 2\,\sigma^{3\mu}_{J/\psi}}{N^{Total}_{J/\psi} \cdot \epsilon}$$

to estimate upper limit for J/ψ from $b\bar{b}$ production

$\Rightarrow \; fr(b \to J/\psi) = 0.49$ (95% CL)

(DØ Preliminary)

Inclusive χ_c Cross Section

Data Selection

- **Data Collection**

  Collected during FNAL 1992-93 collider run

  Total luminosity = 15.0 pb^{-1}

  Total J/ψ events after cuts $\approx 670 \pm 80$

  Total isolated J/ψ events after cuts $\approx 81 \pm 23$

  Total χ_c after cuts $\approx 19.2 \pm 5.5$

- **Trigger Requirements**

  2 Muons with $|\eta_\mu| \leq 1.7$ in Level 1 (Hardware)

  2 Muons with $|\eta_\mu| \leq 1.7$ and $P_T^\mu \geq 3$ GeV in Level 2 (Software)

- **Single Muon Cuts**

  $P_T^\mu \geq 3$ GeV and $|\eta_\mu| \leq 0.8$

  Good fits in bend and non-bend directions

  Good vertex projection

  E_{cal} (in $\Delta R < .2$ cone) ≥ 1 GeV

- **Di-Muon Cuts**

  Opposite sign muons

  $P_T^{J/\psi} \geq 8$ GeV and $|\eta_{J/\psi}| \leq 0.8$

- **Isolation Cuts**

  No jet in $\Delta R < 1.0$ cone about either muon

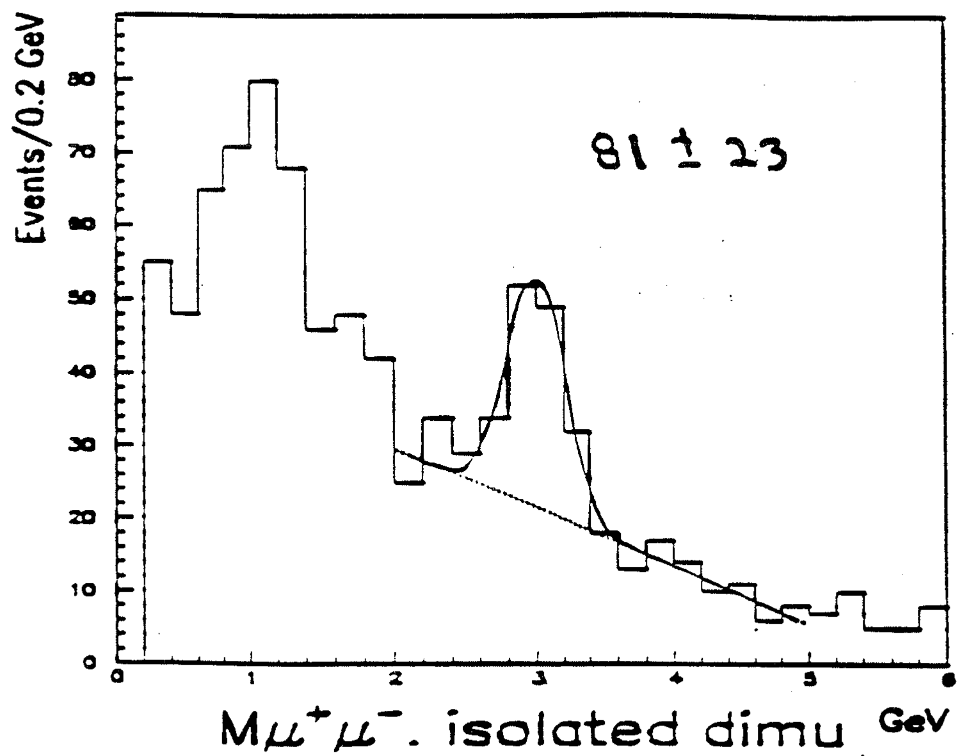
- **Photon Cuts**

  Quality photon cluster

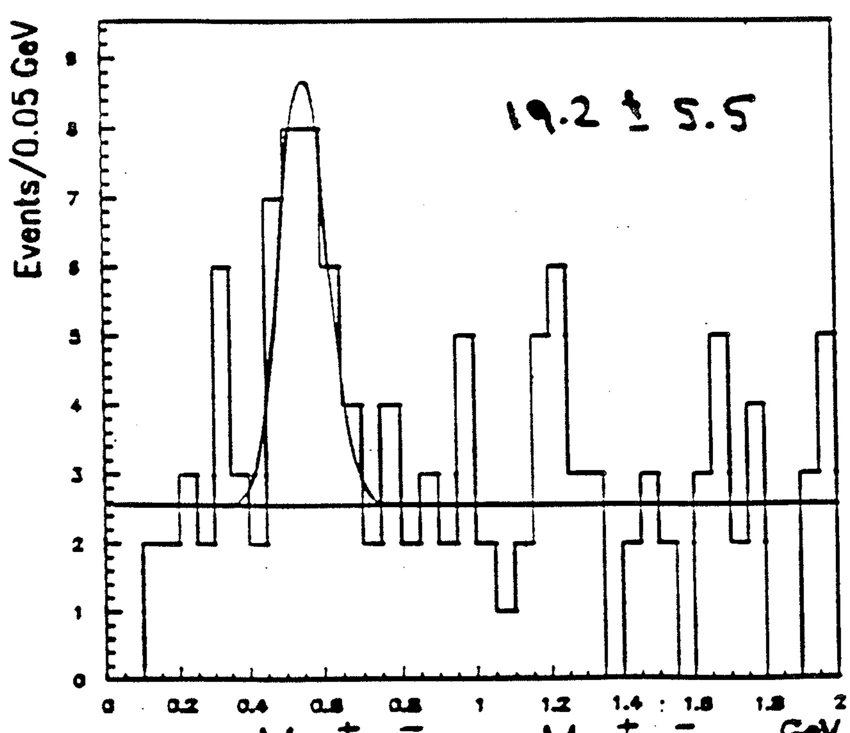
  $E_\gamma > 0.6$ GeV

Inclusive χ_c

Require no jet within $\Delta R = 1$ cone about either muon



Require good photon with $E_\gamma > 0.6$ GeV



Inclusive χ_c

$19.2\ \chi_c / 0.21\ (\epsilon_\gamma) = 91.4\ \chi_c$

$91.4\ \chi_c / 0.33\ (\epsilon_{jet}) = 277\ \chi_c \to J/\psi$

$\Rightarrow fr\ (\chi_c \to J/\psi\ \gamma\ /\ J/\psi)$

$= 0.41 \pm 0.14 \pm 0.20$

for $p_T^{J/\psi} > 8$ GeV/c, $|\eta_{J/\psi}| < 0.8$

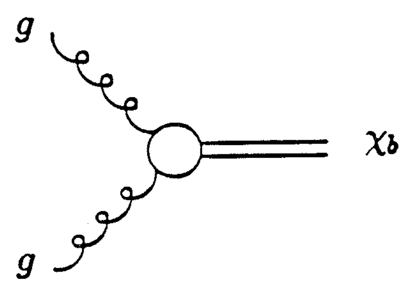
CDF $fr\ (\chi_c \to J/\psi\gamma\ /\ J/\psi)$

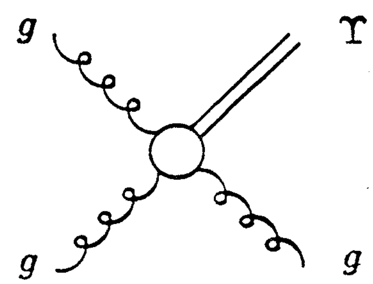
$= 0.45 \pm 0.05 \pm 0.15$

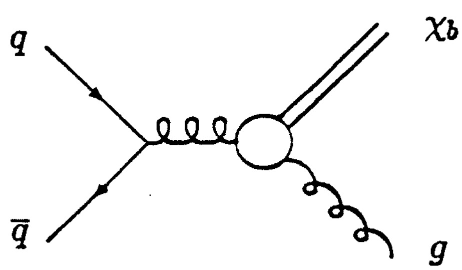
for $p_T^{J/\psi} > 6$ GeV/c, $|\eta_{J/\psi}| < 0.5$

Υ Production in $p\bar{p}$ Collisions

Lowest order QCD diagrams for quarkonium hadroproduction:







Data Selection

- **Data Collection**

  Collected during FNAL 92-93 collider run

  Total luminosity = 6.1pb^{-1}

- **Trigger Requirements**

  2 muons with $|\eta_\mu| \leq 1.7$ in Level 1 (hardware)

  2 muons with $|\eta_\mu| \leq 1.7$ and $p_t^\mu \geq 3$ GeV in Level 2 (software)

- **Single Muon Kinematic and Quality Cuts**

  $p_t^\mu \geq 3$ GeV

  $|\eta_\mu| \leq 0.8$

  2 or 3 layer track

  Good fits in bend and non-bend directions

  $\int Bdl \geq 0.5\ GeV$ (good momentum measurement)

  Minimum ionizing deposition: $E_{cal}^{1NN} \geq 1\ GeV$

  CD track match

  Global Fit $\chi^2 \leq 100$

- **Event Selection Cuts**

  $6 \leq M_{\mu\mu} \leq 40$ GeV

  opposite signed muons

  di-muon opening angle $\leq 165°$ (vertex not used in fit)

  Isolation of *one* muon: $I_\mu^{2NN} \leq 3\sigma$

Trigger, Muon Selection, and Event Selection Efficiencies

$$\varepsilon_{chamber} \otimes \varepsilon_{L1} \otimes \varepsilon_{L2} = 8.8 \pm 1.0\%$$

Good Muon Efficiency(%)	
$\int Bdl$	96 ± 3
CD Match	82 ± 4
Global Fit	83 ± 4
Calorimeter MIP Confirmation	90 ± 3
Muon Reconstruction	95 ± 3
Total	56 ± 5

Υ Acceptance (%)	
η^{μ} and p_{T}^{μ} Cuts	6.5 ± 1.2
opposite track cut (no vertex in fit)	88 ± 4
opposite signed muons	93 ± 4
Muon Selection Cuts (two muons)	31 ± 4
Isolated Muon Cut (one muon)	96 ± 4
Total	1.6 ± 0.4

Determination of Signal and Background Contributions

- **Maximum likelihood fit of data to:**

  Floating time of each muon

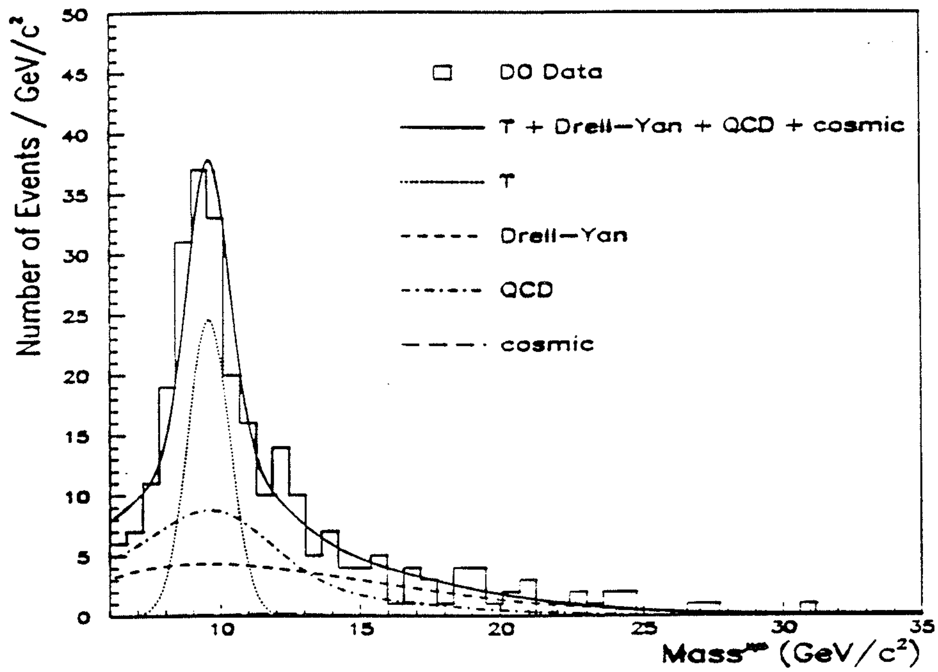
  Halo $(E_{cal}^{\Delta R=0.6} - E_{cal}^{\Delta R=0.2})$ of highest p_T^{μ} isolated muon

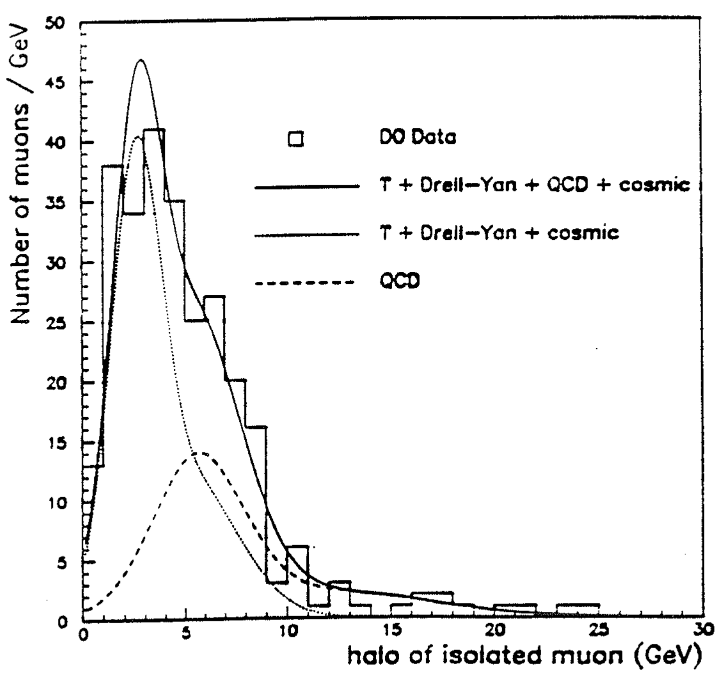
  Di-muon mass

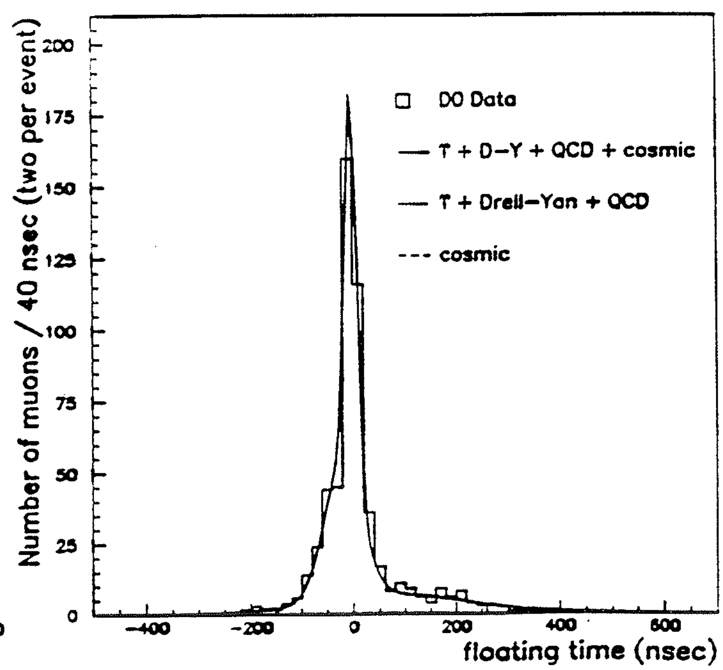
- Results of fit:

Subprocess	Number of events
Υ	81^{+14}_{-13}
Cosmic	2^{+8}_{-2}
QCD	101 ± 14
Drell-Yan	89^{+14}_{-13}

Results of Fits of Distributions to Data







Results and Cross Section Calculation

$$\sigma \cdot Br(\Upsilon \rightarrow \mu\mu) = \frac{N_{\Upsilon}}{(\varepsilon_{trig} \cdot A_{\Upsilon} \cdot lum)}$$

- $N_{\Upsilon} = 81^{+14}_{-13}$ is the number of Υ from fit
- $A_{\Upsilon} = (1.6 \pm 0.4)\%$ is the overall acceptance for Υ
- $\varepsilon_{trig} = (8.8 \pm 1.0)\%$ is the trigger efficiency
- $lum = (6.1 \pm 0.7)\ pb^{-1}$ is the luminosity

- 25% systematic error for Υ Monte Carlo
- 25% systematic error for input distributions to fit

- Results:

$$\sigma_{\Upsilon} \cdot Br(\Upsilon(1S,2S) \rightarrow \mu\mu) = (9.5 \pm 1.1(stat)^{+4.3}_{-4.3}(sys)) \times 1($$

$$\sigma_{\Upsilon} = (4.5 \pm 0.5(stat) \pm 2.1(sys)) \times 10^{5}\ pb$$

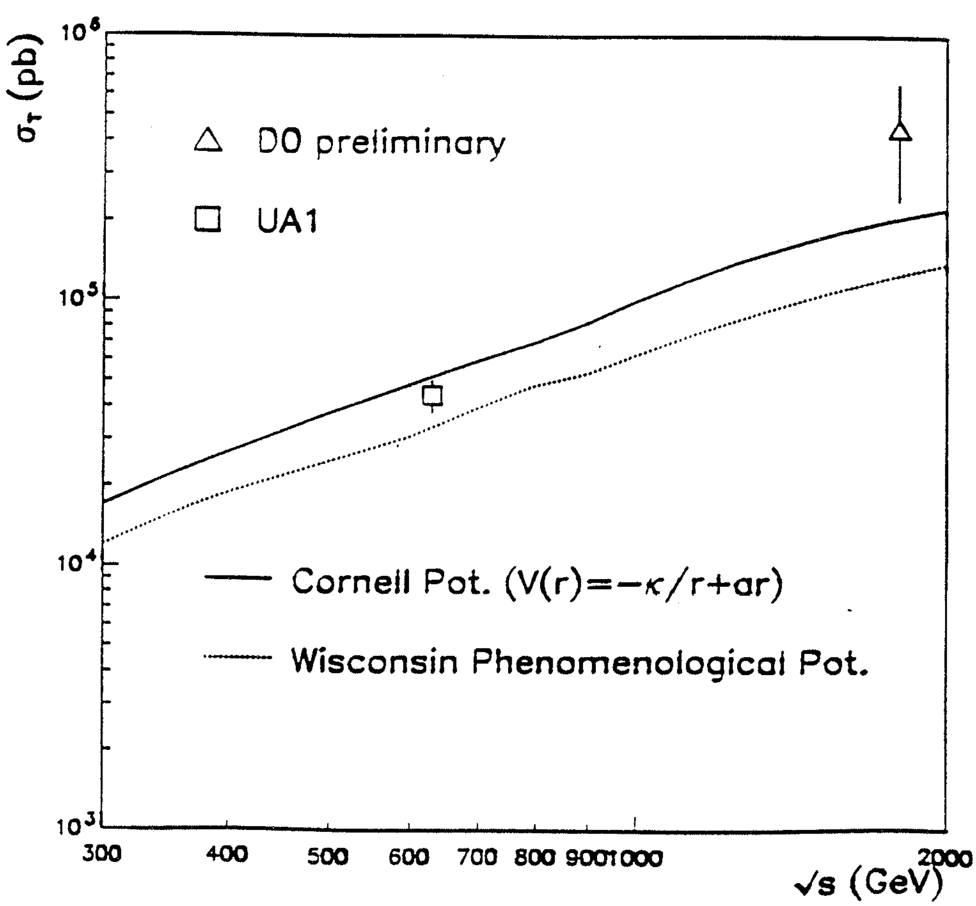
- Consistency check:
  remove E^{1NN}_{cal} cut to let in cosmics
  refit data and recalculate acceptance
  all distributions still properly fit
  resulting cross section agrees with above result

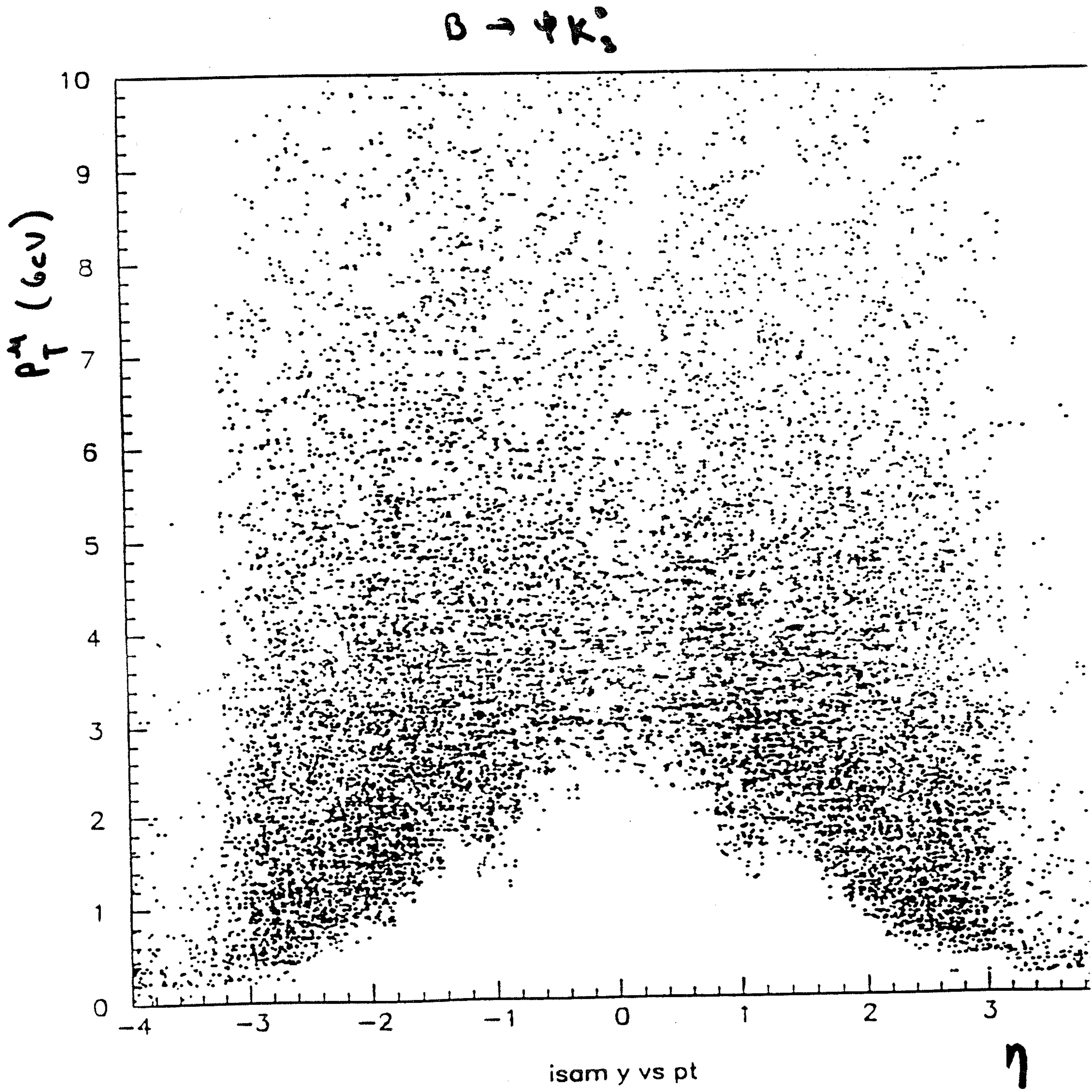
- The Υ signal of 81^{+14}_{-13} events was extracted using a maximum likelihood fit to the data

- The Υ production cross section at $\sqrt{s} = 1.8\ TeV$ was found to be

$$\boxed{\sigma_\Upsilon = (4.5 \pm 0.5(stat) \pm 2.1(sys)) \times 10^5\ pb}$$

- This cross section is above theoretical predictions: (from V.Barger, A.Martin, Phys. Rev. D, **31**,5,(1985).)




B → ψK$_s^0$
p_T^μ (GeV)
10
9
8
7
6
5
4
3
2
1
0
−4
−3
−2
−1
0
1
2
3
isam y vs pt
η

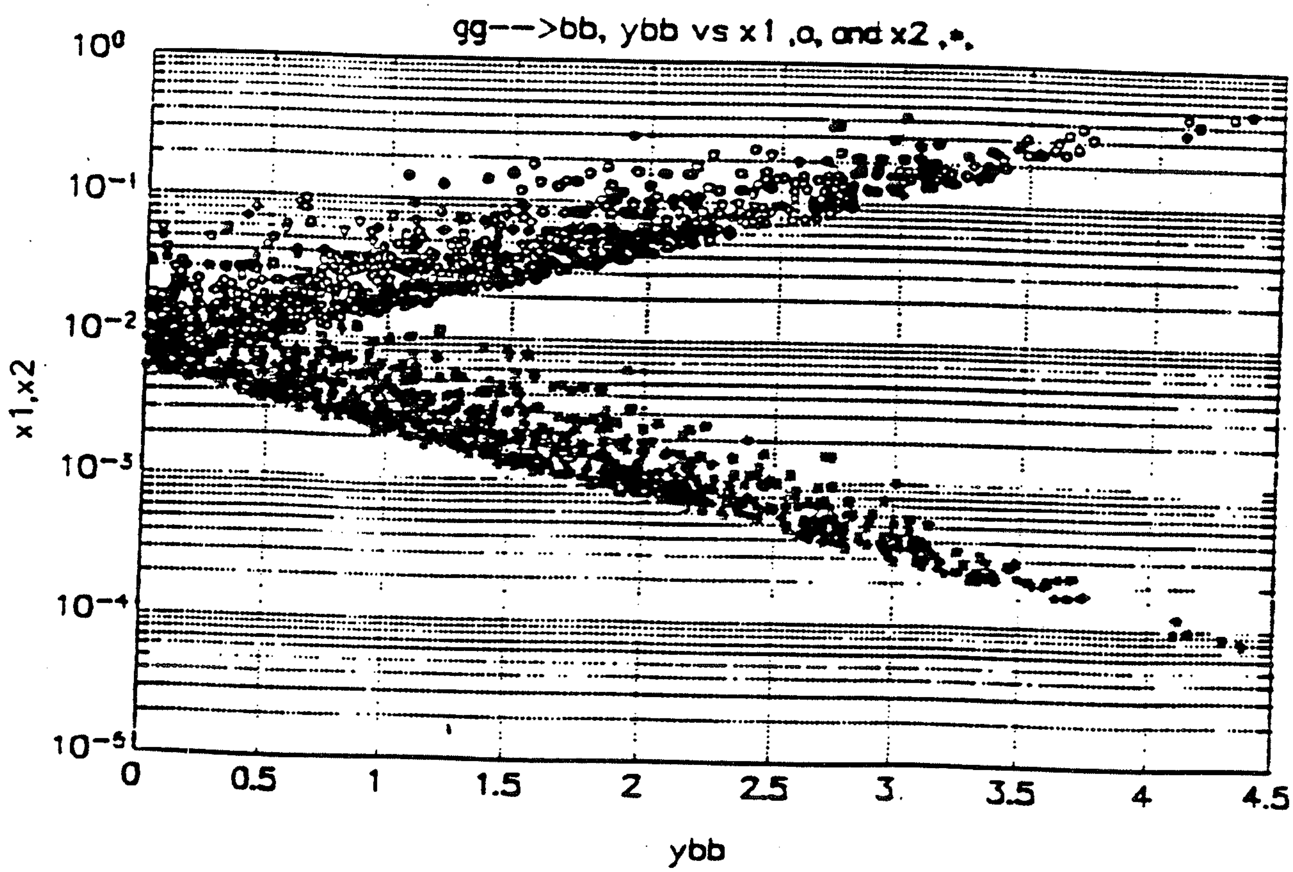
Muons at Small Angles

- Consider $gg \to b\bar{b}$ $\quad (M, Y)$

$$x = x_1 - x_2 \qquad x_1 x_2 s = \hat{s} = M^2$$

$$x = 2P_L/\sqrt{s} = 2M_T \sinh y / \sqrt{s}$$

large $y \Rightarrow$ large x



Inclusive End Angle Single Muon Cross Section

Data Selection

- **Data Collection**

  Dedicated special runs during FNAL 1992-93 collider run

  Total integrated luminosity = 10.0 nb^{-1}

  Total events after cuts ≈ 190

- **Trigger Requirements**

  1 Muon with $1.0 \leq |\eta_\mu| \leq 1.6$ in Level 1 (Hardware)

  1 Muon with $1.0 \leq |\eta_\mu| \leq 1.6$ and $p_t^\mu \geq 3$ GeV in Level 2 (Software)

- **Kinematic Cuts**

  $p_t^\mu \geq 4$ GeV

  $1.0 \leq |\eta_\mu| \leq 1.6$

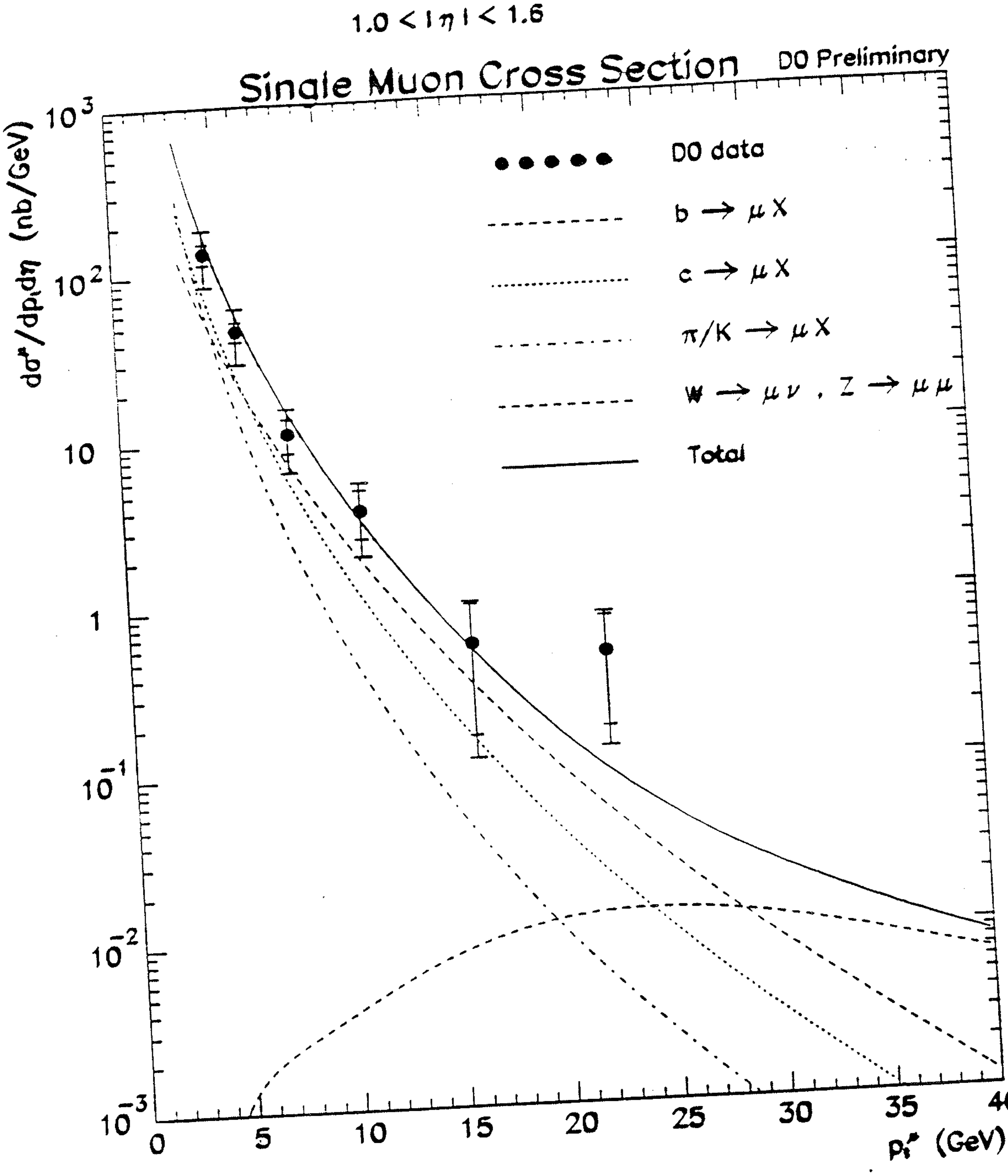
- **Track Quality Cuts**

  3 layer tracks

  Number of hits on track ≥ 7

  Good track fit in bend and non-bend views

  E_{cal} (in $\Delta R = 0.15$ cone) ≥ 2.0 GeV


1.0 < |η| < 1.6
Single Muon Cross Section
D0 Preliminary
dσ^μ/dp_t dη (nb/GeV)
D0 data
b → μ X
c → μ X
π/K → μ X
W → μ ν , Z → μ μ
Total
p_t^μ (GeV)
10^3
10^2
10
1
10^-1
10^-2
10^-3
0
5
10
15
20
25
30
35
40

Inclusive Small Angle Single Muon Cross Section

Data Selection

- **Data Collection**

  Dedicated special runs during FNAL 1992-93 collider run

  Total integrated luminosity = 4.7 nb^{-1}

  Total events after cuts $\approx$ 1080

- **Trigger Requirements**

  1 Muon with $2.2 \leq |\eta_\mu| \leq 3.3$ in Level 1 (Hardware)

  1 Muon with $2.2 \leq |\eta_\mu| \leq 3.3$ and $P_T^\mu \geq 1$ GeV in Level 2 (Software)

- **Kinematic Cuts**

  $P_T^\mu \geq 2$ GeV

  $2.2 \leq |\eta_\mu| \leq 3.3$

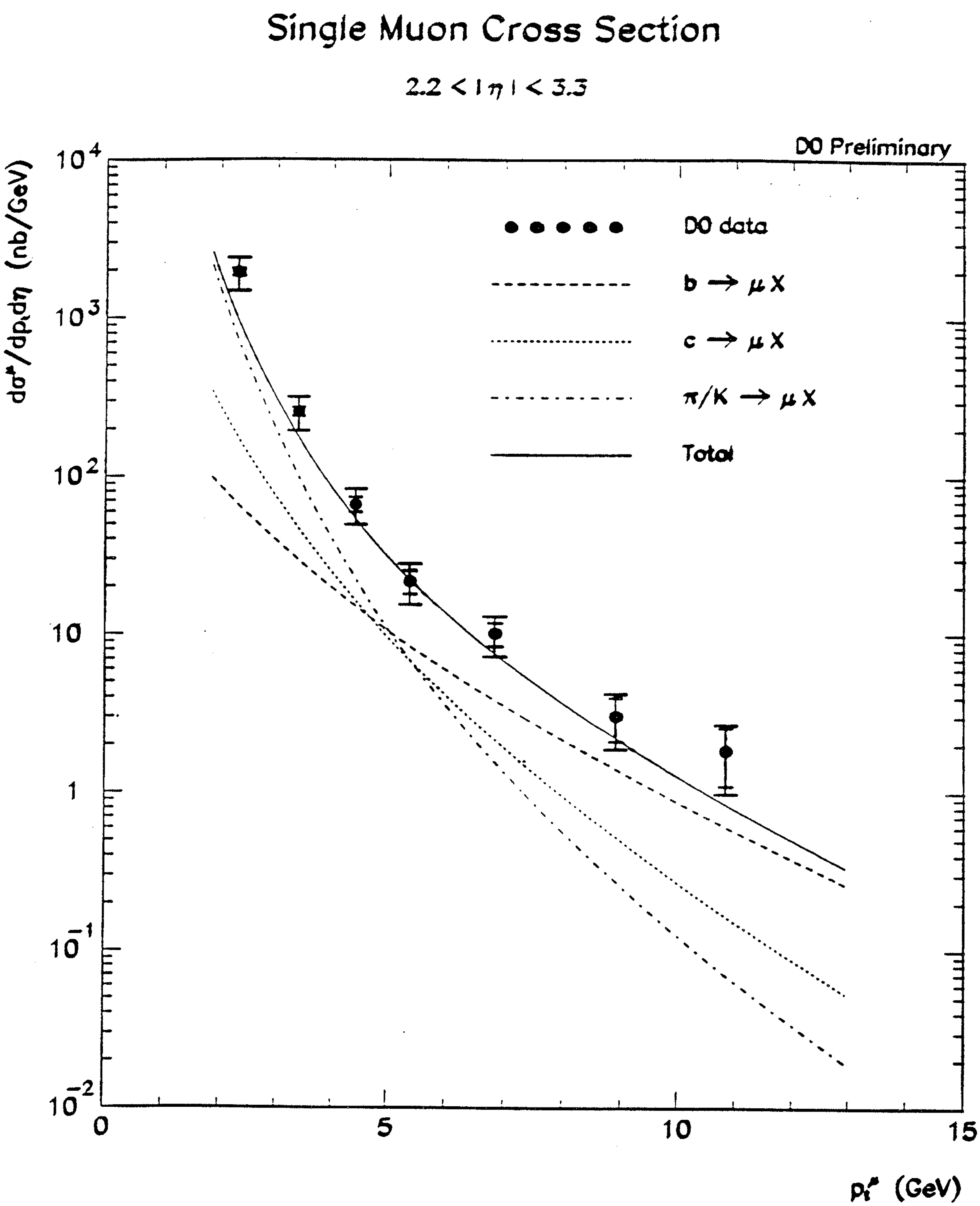
- **Track Quality Cuts**

  3 layer tracks

  Number of hits on track ≥ 18

  Good track fit in bend and non-bend views

  E_{cal} (in $\Delta R < .2$ cone) ≥ 1 GeV



Single Muon Cross Section
2.2 < | η | < 3.3
D0 Preliminary
dσ^μ/dp_t dη (nb/GeV)
10^4
10^3
10^2
10
1
10^-1
10^-2
0
5
10
15
p_t^μ (GeV)
D0 data
b → μ X
c → μ X
π/K → μ X
Total

Muons at Small Angles

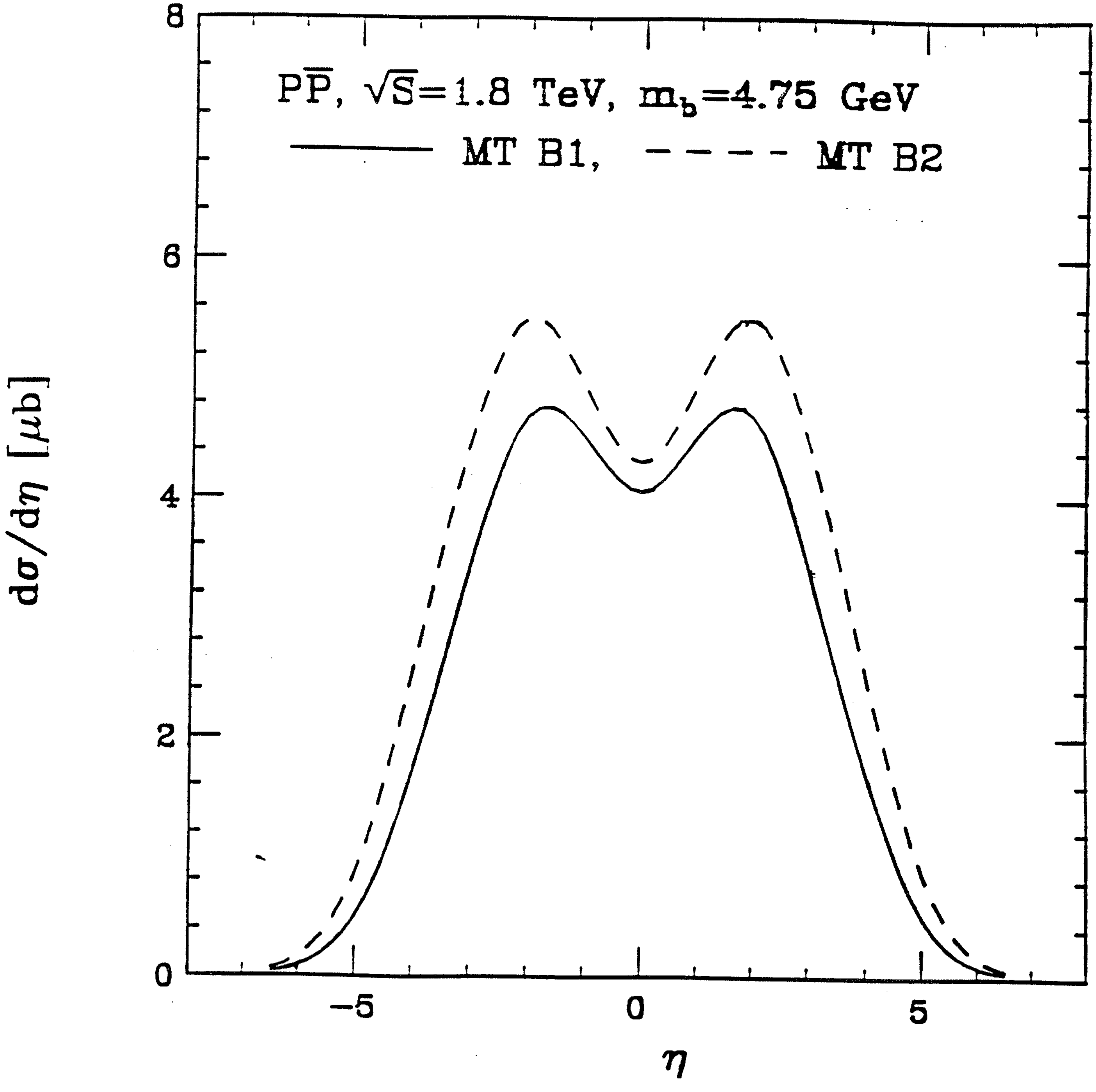
- The goal is to measure $d\sigma/d\eta$.

$$d\sigma \sim (1-x_1)^5 (1-x_2)^5 \frac{1}{M^4} \left\{ \frac{\hat{t}}{\hat{u}} + \frac{\hat{u}}{\hat{t}} \right\} \beta^* dM^2 dy \, d\cos\hat{\theta}$$

gluon distribution — Rutherford — fermion exchange — phase space

- The falloff of the rapidity plateau is sensitive to the gluon distribution functions.

- The sensitivity using η_μ is washed out some. By using the muon-jet or muon-jet-jet system one can reconstruct the b or $b\bar{b}$ system which directly measures the gluon distribution function.



PP̄, √S=1.8 TeV, m_b=4.75 GeV
MT B1,
MT B2
8
6
4
2
0
−5
0
5
dσ/dη [μb]
η

Heavy Flavor Content of Jets

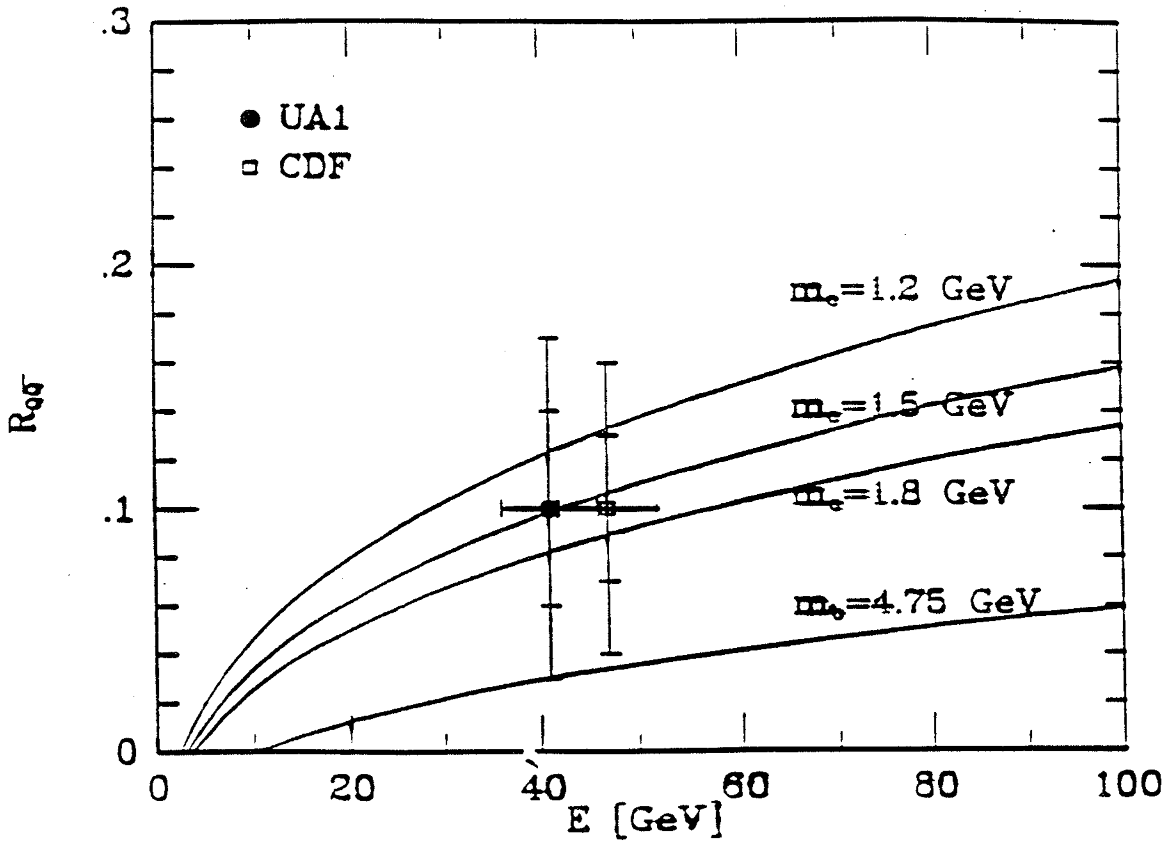
- Try to answer the question "What fraction of jets contain b quarks (or c quarks, J/Ψ's,...) as a function of jet E_T?".

- Again, well defined QCD predictions exist which can be tested.

- The basic process (besides direct $b\bar{b}$ production) is G $\rightarrow b\bar{b}$ or G $\rightarrow$ G G G G $b\bar{b}$ cascade.

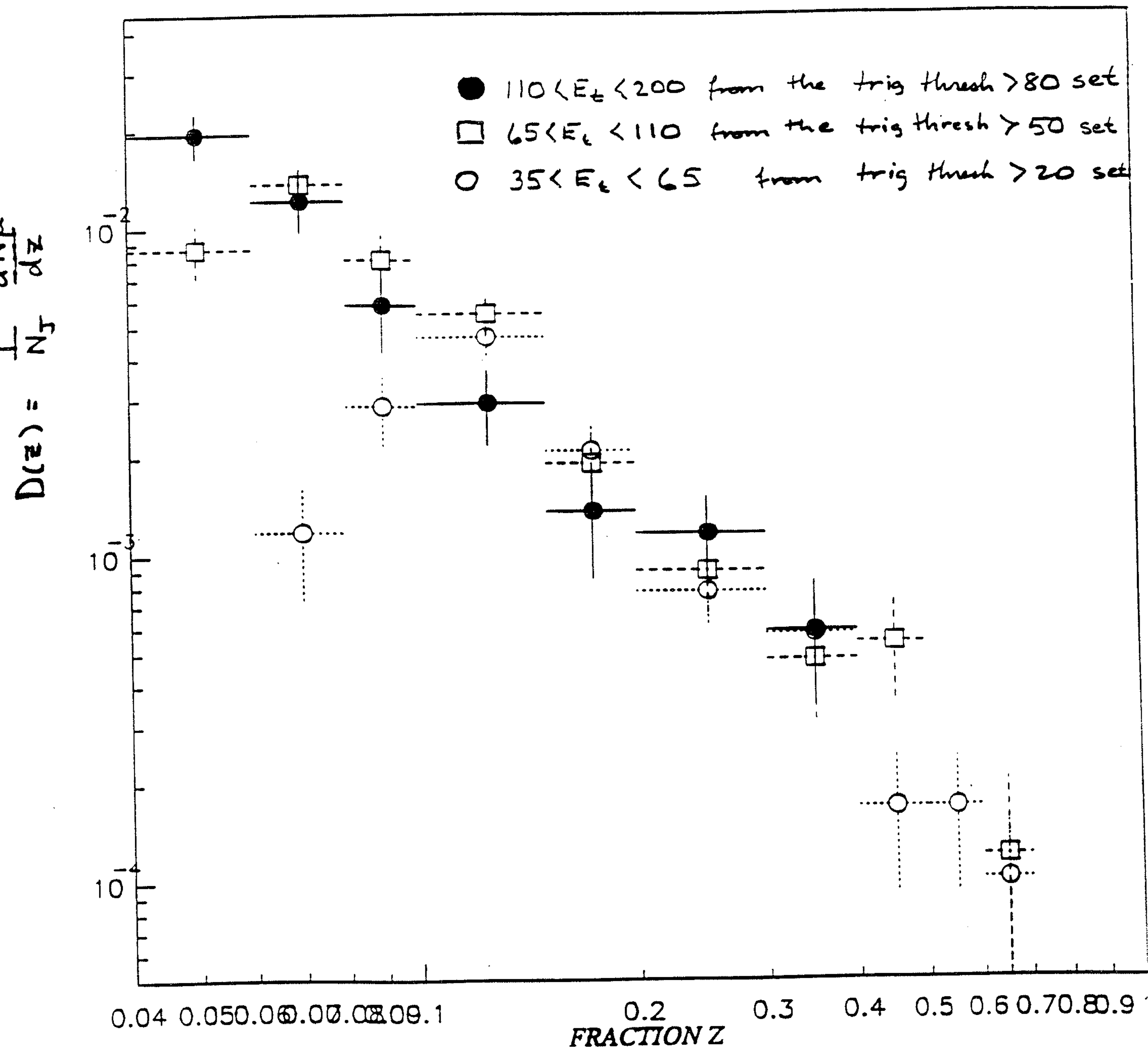
- This can be considered another test of QCD calculation machinery since the region of phase space explored is different than in b quark production cross section measurements.

- The method is to collect muon in jet events. One can measure the ratio of the heavy quark jet cross section to the jet cross section. One can also measure D(z) (jet fragmentation function for the muon) which is sensitive to higher order effects (gluon cascade).



Heavy quarks in jets compared with UA1 and CDF data

D(Z) AS A FUNCTION OF JET ET

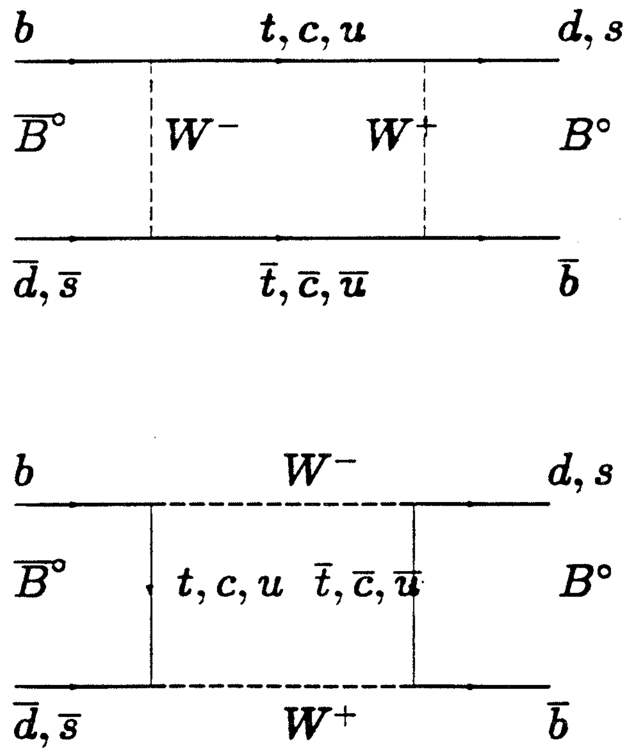


$B^0 - \overline{B}^0$ Mixing

- Mixing between B° and its anti-particle can occur in the Standard Model via second order weak interactions
- The time averaged mixing probability χ is given in terms of the mixing parameter x as

$$\chi = \frac{P(B^\circ \to \bar{B}^\circ)}{P(B^\circ \to B^\circ) + P(B^\circ \to \bar{B}^\circ)} \approx \frac{x^2}{2+2x^2},$$

where x is the mass difference of the mass eigenstates divided by their average decay width.



Box diagrams for B° - $\overline{B}^\circ$ mixing

- The mixing parameters x_d and x_s are of interest because they can be written in terms of parameters of the Standard Model

$$x_q = \frac{G_F^2}{6\pi^2} f_{Bq}^2 B_{Bq} m_{Bq} \tau_{Bq} m_t^2 \frac{A(z)}{z} \eta_q^{QCD} \left| V_{tq} V_{tb}^* \right|^2$$

- For the semileptonic decay of B mesons into muons, the combined mixing probability χ is redefined as

$$\chi \equiv \frac{BR(b \to B^0 \to \bar{B}^0 \to \mu^+)}{BR(b \to \mu^\pm)},$$

which is an average over both B_d° and B_s° mesons which can mix as well as charged B mesons which can not.

- To extract χ one first measures R where

$$R \equiv \frac{N(\mu^+\mu^+) + N(\mu^-\mu^-)}{N(\mu^+\mu^-)}$$

- Next the contributions of all processes contributing to dimuon production are modeled using ISAJET Monte Carlo.

- Once the relative fractions are known a value of χ can be extracted from the measured value R as the solution to a quadratic equation

Experimental Parameter R

$$R \equiv \frac{N(\mu^+\mu^+) + N(\mu^-\mu^-)}{N(\mu^+\mu^-)}, \tag{4}$$

Sources of Dimuon Events

Label	Process	$++/--$	$+-$
P1	$b \to \mu^-, \bar{b} \to \mu^+$	$2\chi(1-\chi)$	$(1-\chi)^2 + \chi^2$
P2	$b \to c \to \mu^+, \bar{b} \to \mu^+$	$(1-\chi)^2 + \chi^2$	$2\chi(1-\chi)$
P3	$b \to c \to \mu^+, \bar{b} \to \bar{c} \to \mu^-$	$2\chi(1-\chi)$	$(1-\chi)^2 + \chi^2$
P4	$b \to c\mu^-, c \to \mu^+$	0%	100%
P5	$c \to \mu^+, \bar{c} \to \mu^-$	0%	100%
P6	D-Y,J/ψ,Υ,Z	0%	100%
P7	π,$K \to \mu$ background	50%	50%

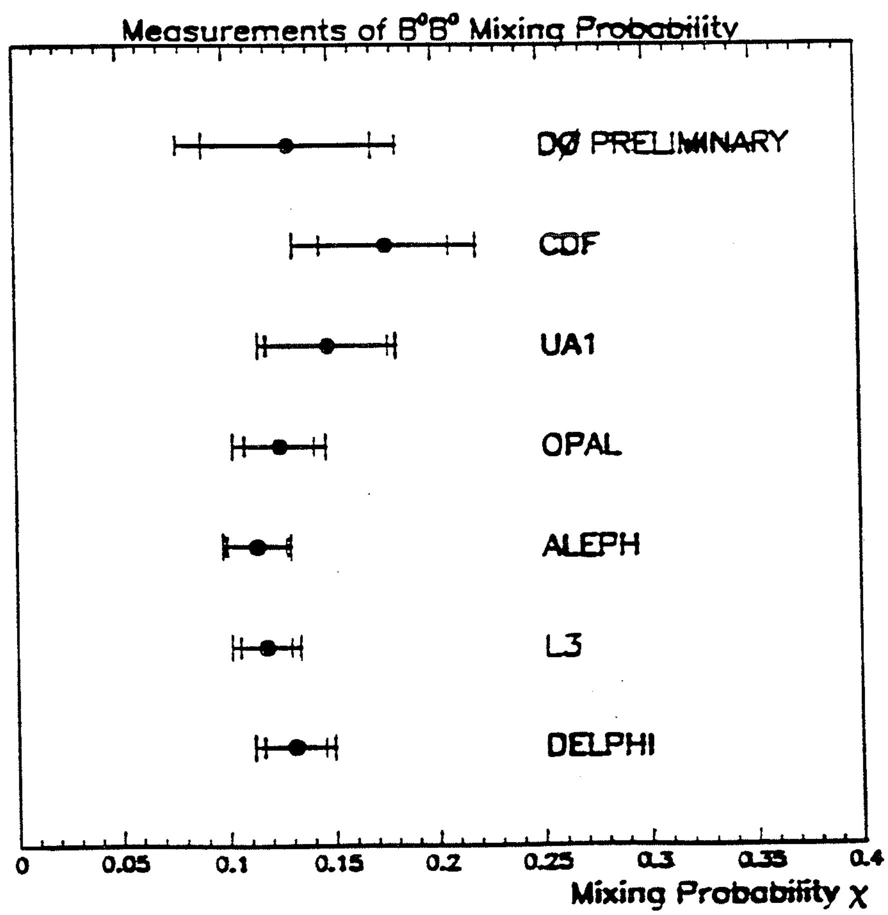
- The relative contributions of the above processes to the dimuon data sample are obtained using Monte Carlo simulations
- Once the relative fractions are known a value of χ can be extracted from the measured value R as the solution to a quadratic equation

- Combining the experimental parameter R with the relative fractions of the dimuon production processes determined from the Monte Carlo one finds

$$\chi = 0.13 \pm 0.05(\text{stat}) \pm 0.04(\text{sys})$$

- The preliminary DØ result is in good agreement with other measurements of the mixing parameter as shown below

- Prospects for reducing both the statistical and systematic error in χ are good as the backgrounds are better understood



DØ Upgrades for B Physics for the 1994-95 Collider Run

- New scintillator installed for better cosmic ray muon rejection

- Level 1.5 muon trigger (hardware) used over the full η range of DØ ($|\eta| \leq 3.3$)

- Additional tools for muon identification in Level 2 trigger (software)

- 50% Improvement in DAQ bandwidth

- Problems with muon chamber efficiency in $1.0 \leq |\eta| \leq 2.2$ region are being addressed

DØ B Physics Goals
for the 1994-95 Collider Run

- Single muon inclusive cross section over full η coverage ($|\eta| \leq 3.3$)

- J/Ψ and dimuon cross sections over full η regions ($|\eta| \leq 3.3$)

- $d\sigma/d\eta$ for above processes and determination of G(x)

- Continued $b\bar{b}$ correlation studies

- More emphasis on heavy quark content of jets (using muons, dimuons and J/Ψ's with associated jets)

Conclusions

- DØ has a vigorous B physics program focused on testing QCD predictions of b-quark production and $b\bar{b}$ correlations.

- We have measured the b-quark cross section using single muons, single muons plus jets, and dimuons. The data are in agreement with NLO QCD predictions.

- We have measured the J/ψ and Υ production cross sections. The J/ψ cross section is larger than the sum of contributions from b-quark decay and direct charmonium production.

- Work is in progress to extract the b-quark cross section and constrain the gluon distribution function using b-quark jets (both the muon and jet are measured).

- Work is also progress to study the heavy flavor content of jets and make comparisons to NLO QCD predictions.