KUHLMANN

PARTON DISTRIBUTIONS

Fast Review of All Partons

What Are The Uncertainties?

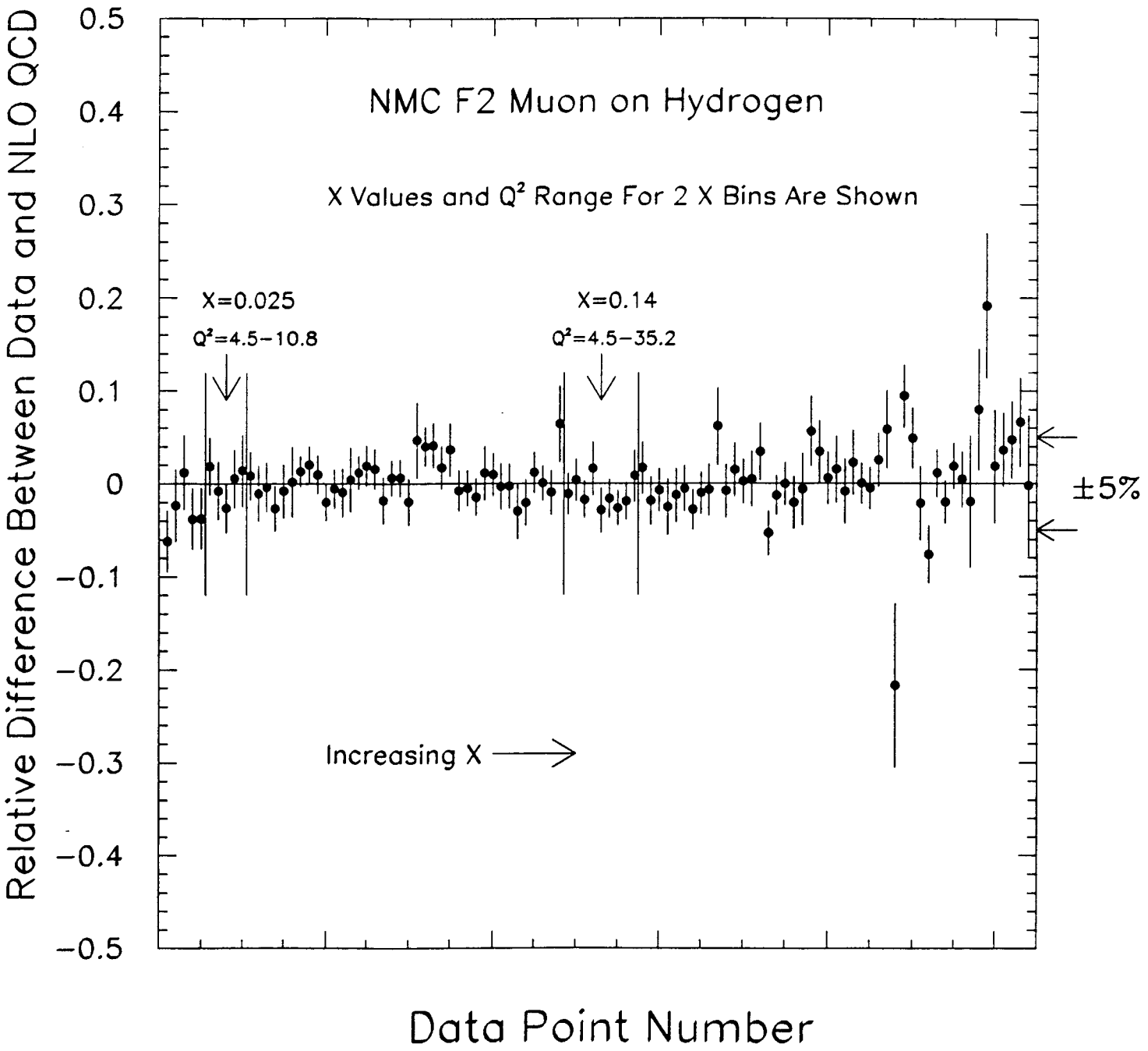
Special Studies Involving Jets

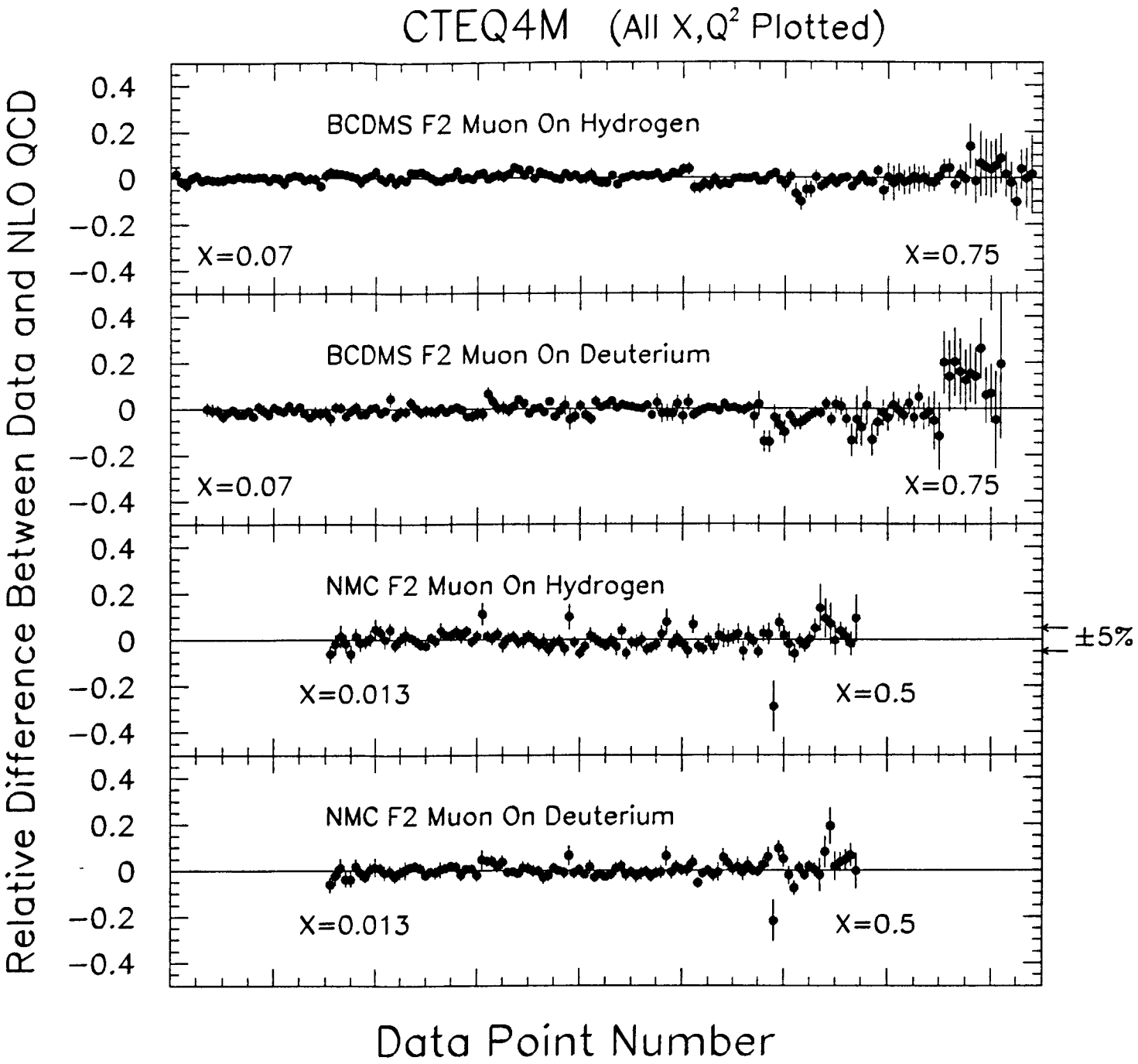
$(u+\bar{u})$ AND $(d+\bar{d})$

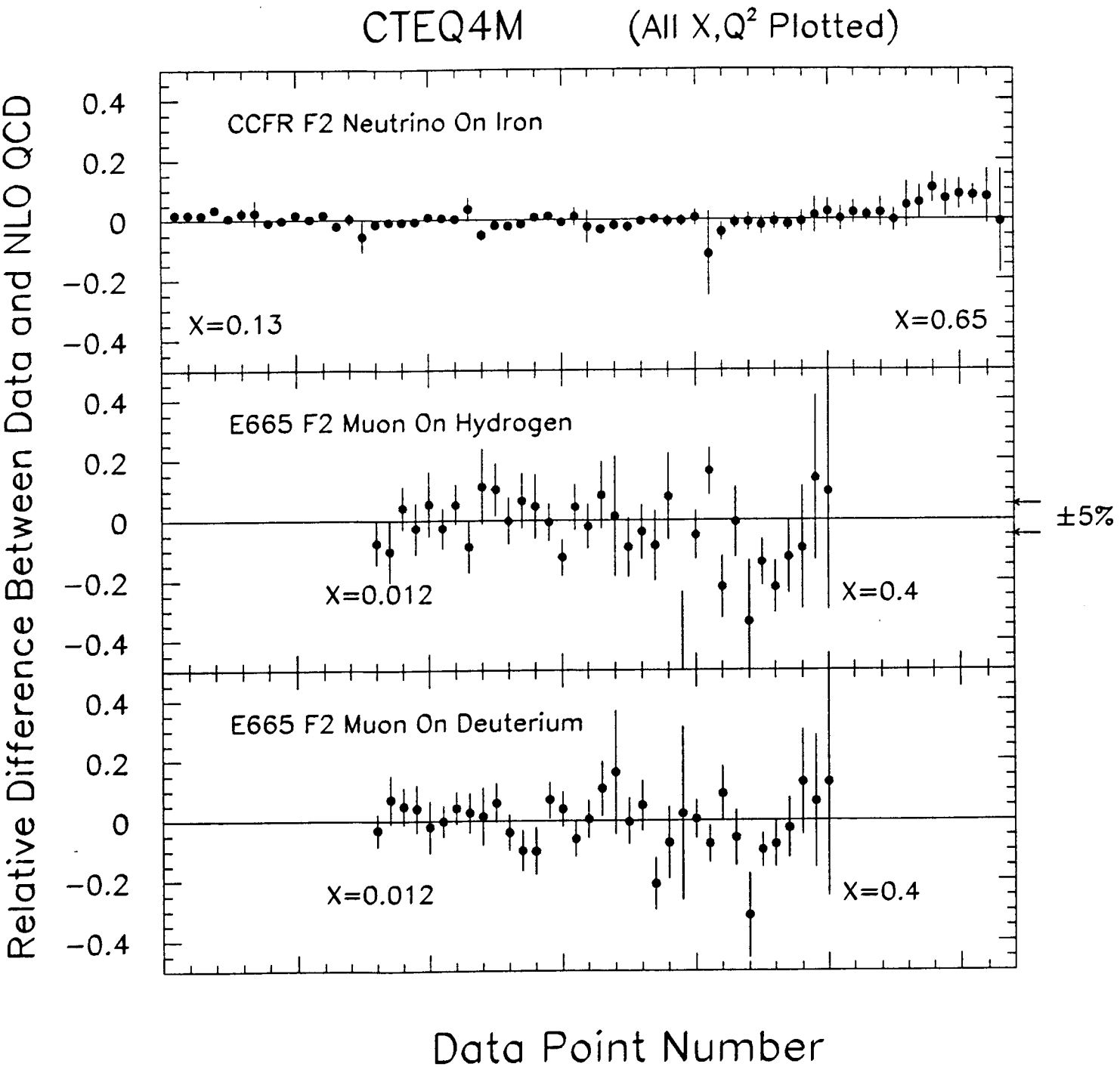
Both Derived From Combinations
of Fixed Target $F_2^{\mu p}, F_2^{\mu n}, F_2^{\nu}$
(x=0.01-0.7)

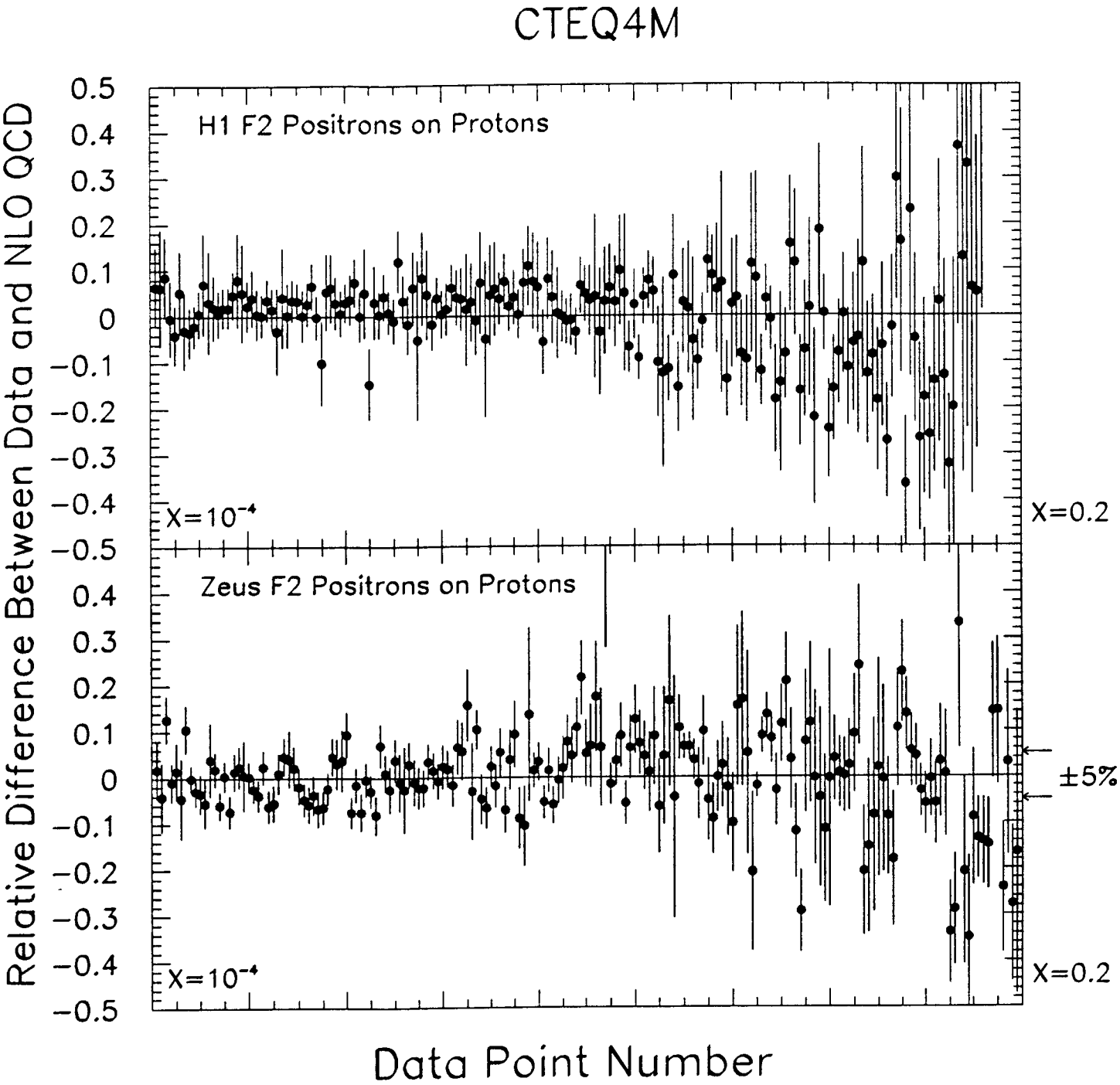
At $x = 10^{-4}$ $u = d = \bar{u} = \bar{d}$ From HERA

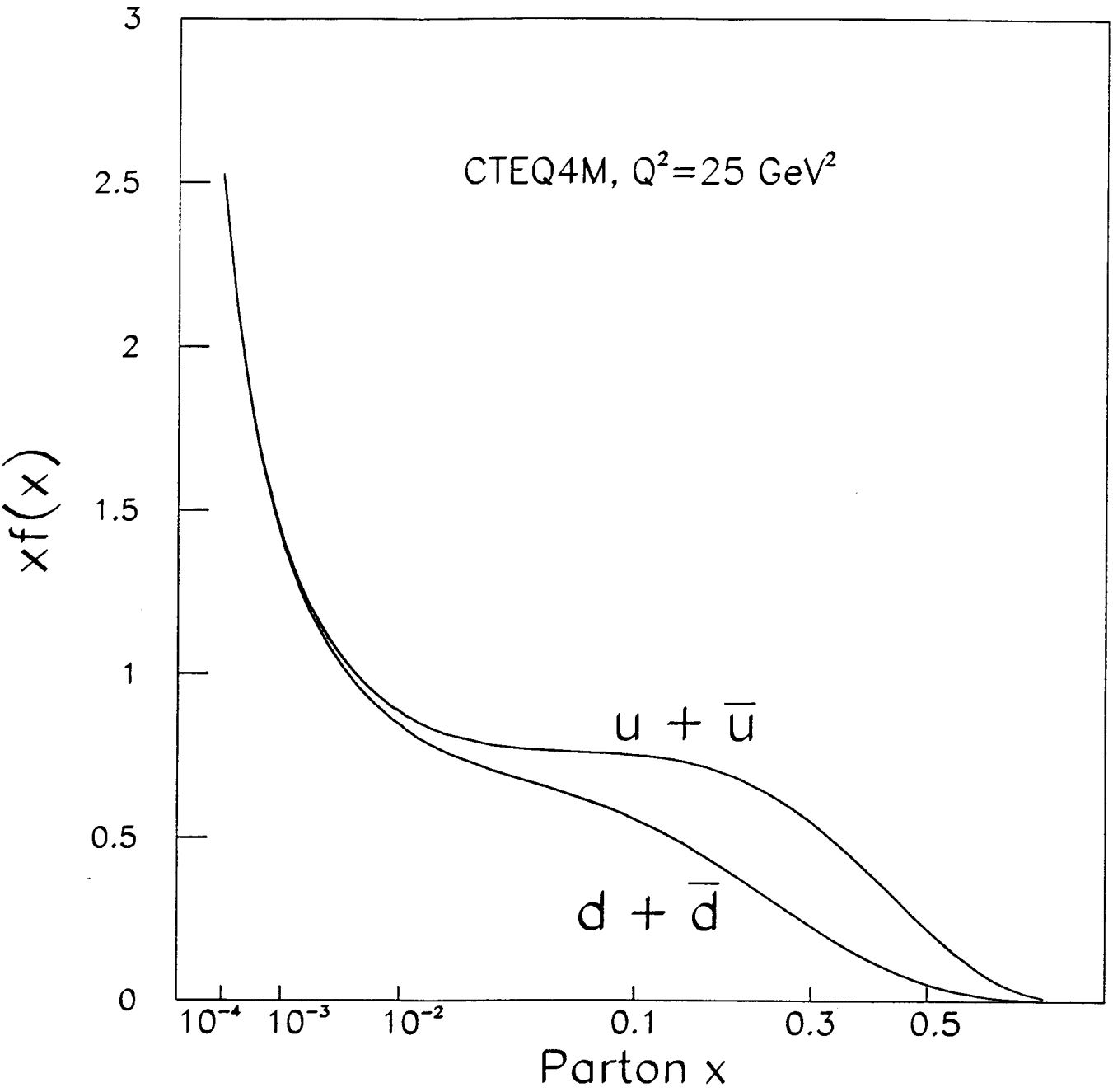
9 Measurements With Precision $\approx 2\%$


NMC F2 Muon on Hydrogen
X Values and Q² Range For 2 X Bins Are Shown
X=0.025
Q²=4.5–10.8
X=0.14
Q²=4.5–35.2
Increasing X
±5%
Relative Difference Between Data and NLO QCD
Data Point Number
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
−0.5


CTEQ4M (All X,Q² Plotted)
Relative Difference Between Data and NLO QCD
0.4
0.2
0
−0.2
−0.4
BCDMS F2 Muon On Hydrogen
X=0.07
X=0.75
BCDMS F2 Muon On Deuterium
X=0.07
X=0.75
NMC F2 Muon On Hydrogen
X=0.013
X=0.5
±5%
NMC F2 Muon On Deuterium
X=0.013
X=0.5
Data Point Number


CTEQ4M
(All X,Q² Plotted)
Relative Difference Between Data and NLO QCD
CCFR F2 Neutrino On Iron
X=0.13
X=0.65
E665 F2 Muon On Hydrogen
X=0.012
X=0.4
±5%
E665 F2 Muon On Deuterium
X=0.012
X=0.4
0.4
0.2
0
−0.2
−0.4
Data Point Number


CTEQ4M
H1 F2 Positrons on Protons
Zeus F2 Positrons on Protons
X=10⁻⁴
X=0.2
±5%
Relative Difference Between Data and NLO QCD
Data Point Number
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
−0.5


CTEQ4M, Q^2=25 GeV^2
$u + \bar{u}$
$d + \bar{d}$
xf(x)
Parton x
3
2.5
2
1.5
1
0.5
0
10^{-4}
10^{-3}
10^{-2}
0.1
0.3
0.5

Isolating $\bar{u}, \bar{d}$

Gottfried Sum Rule $\int (F_2^{\mu p} - F_2^{\mu n}) dx/x$

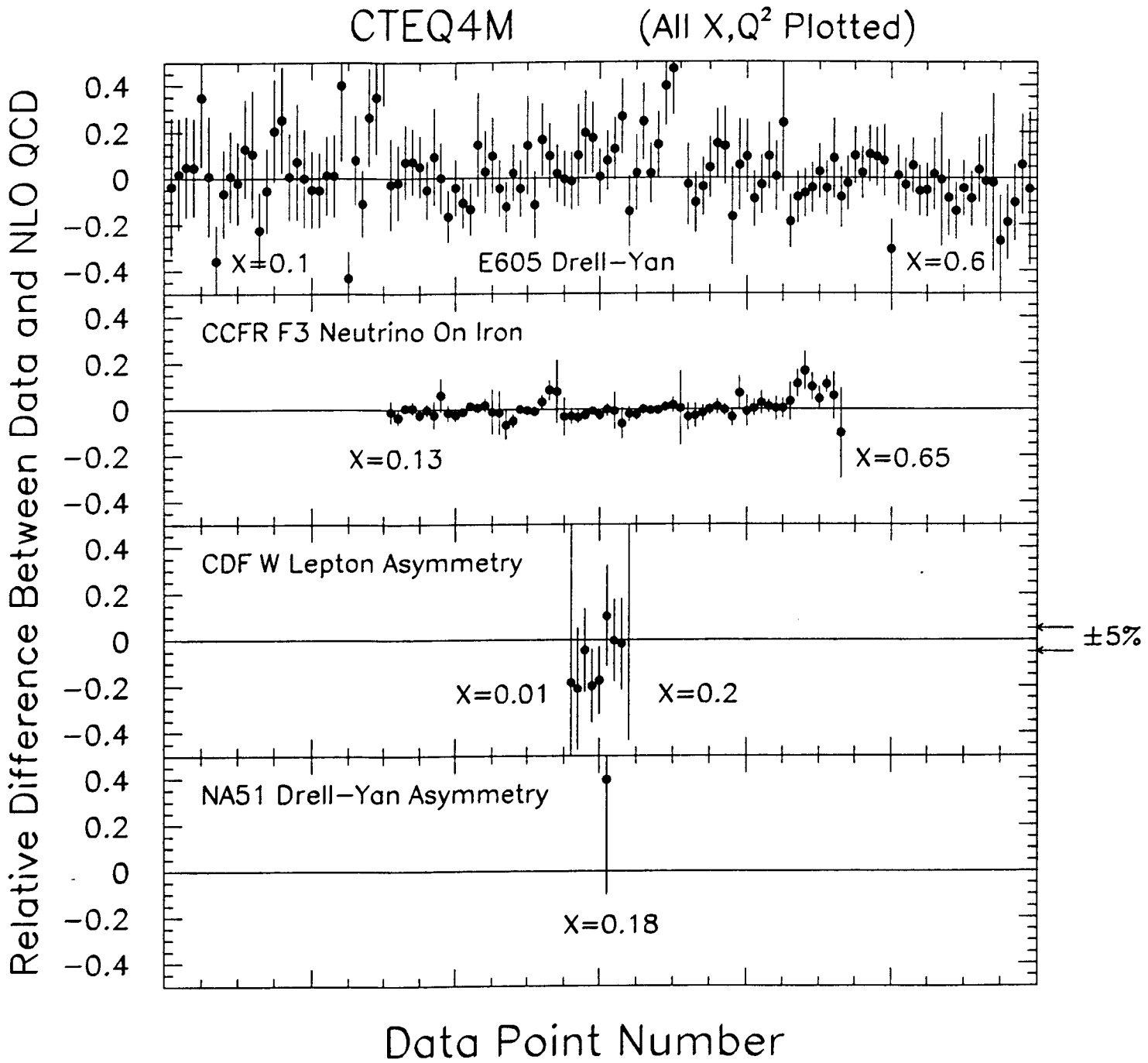
$$F_3^{\nu} \approx (u + d) - (\bar{u} + \bar{d})$$
$$x = 0.13 - 0.65$$

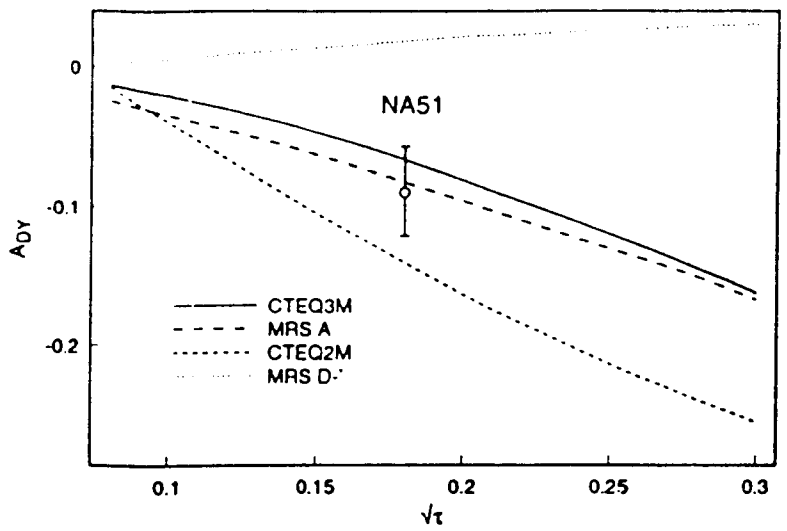
Drell-Yan$\approx (4\bar{u} + \bar{d})(u + d)$
$$x = 0.1 - 0.6$$

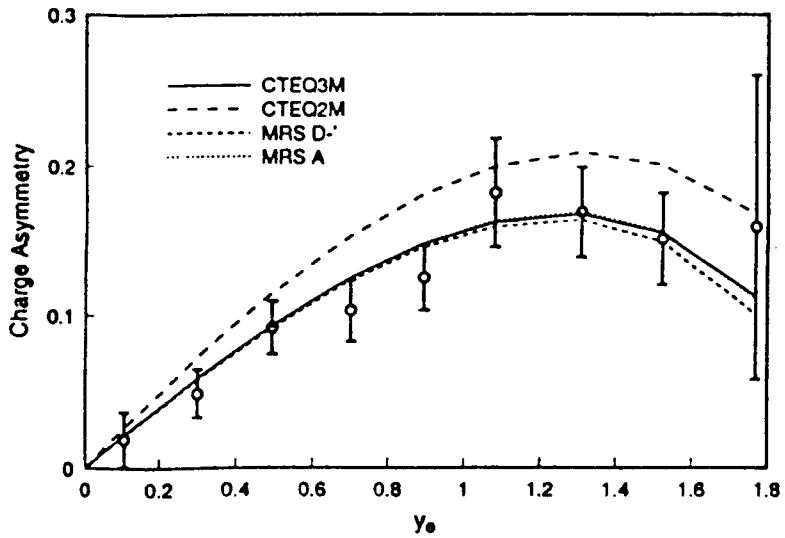
W Lepton Asymmetry $\approx d/u$ Slope
$$x = .01 - 0.2$$

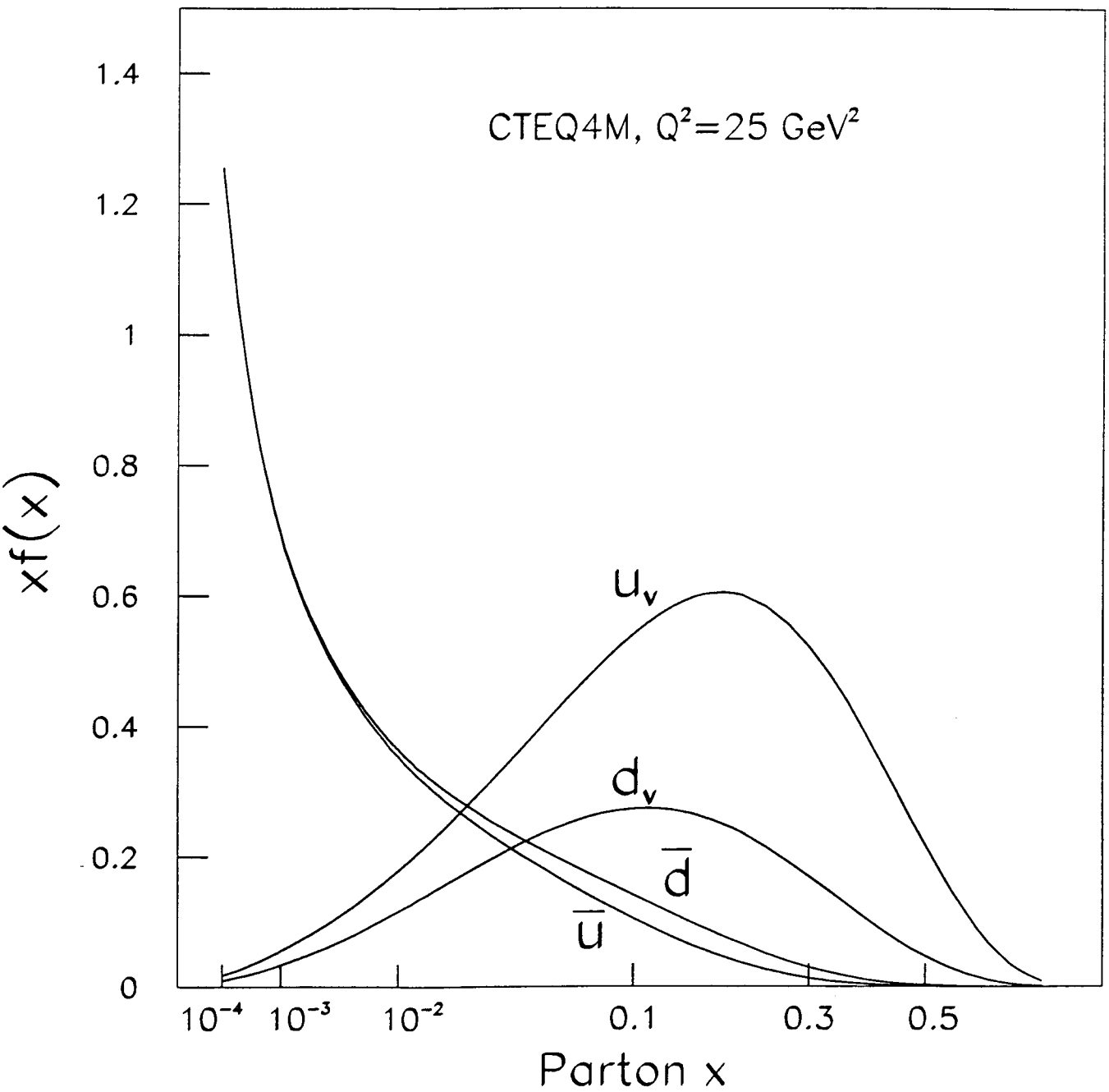
Drell-Yan Asymmetry $\approx (\bar{u} - \bar{d})$
x=0.18

Crucial For Future Tevatron W Mass


CTEQ4M
(All X,Q² Plotted)
Relative Difference Between Data and NLO QCD
0.4
0.2
0
−0.2
−0.4
X=0.1
E605 Drell−Yan
X=0.6
CCFR F3 Neutrino On Iron
X=0.13
X=0.65
CDF W Lepton Asymmetry
X=0.01
X=0.2
±5%
NA51 Drell−Yan Asymmetry
X=0.18
Data Point Number


NA51
CTEQ3M
MRS A
CTEQ2M
MRS D-'
A_{DY}
$\sqrt{\tau}$
0
-0.1
-0.2
0.1
0.15
0.2
0.25
0.3


CTEQ3M
CTEQ2M
MRS D-'
MRS A
Charge Asymmetry
y_e
0.3
0.2
0.1
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8


CTEQ4M, Q^2=25 GeV^2
1.4
1.2
1
0.8
0.6
0.4
0.2
0
xf(x)
u_v
d_v
$\bar{d}$
$\bar{u}$
10^{-4}
10^{-3}
10^{-2}
0.1
0.3
0.5
Parton x

The Strange Quark Distribution

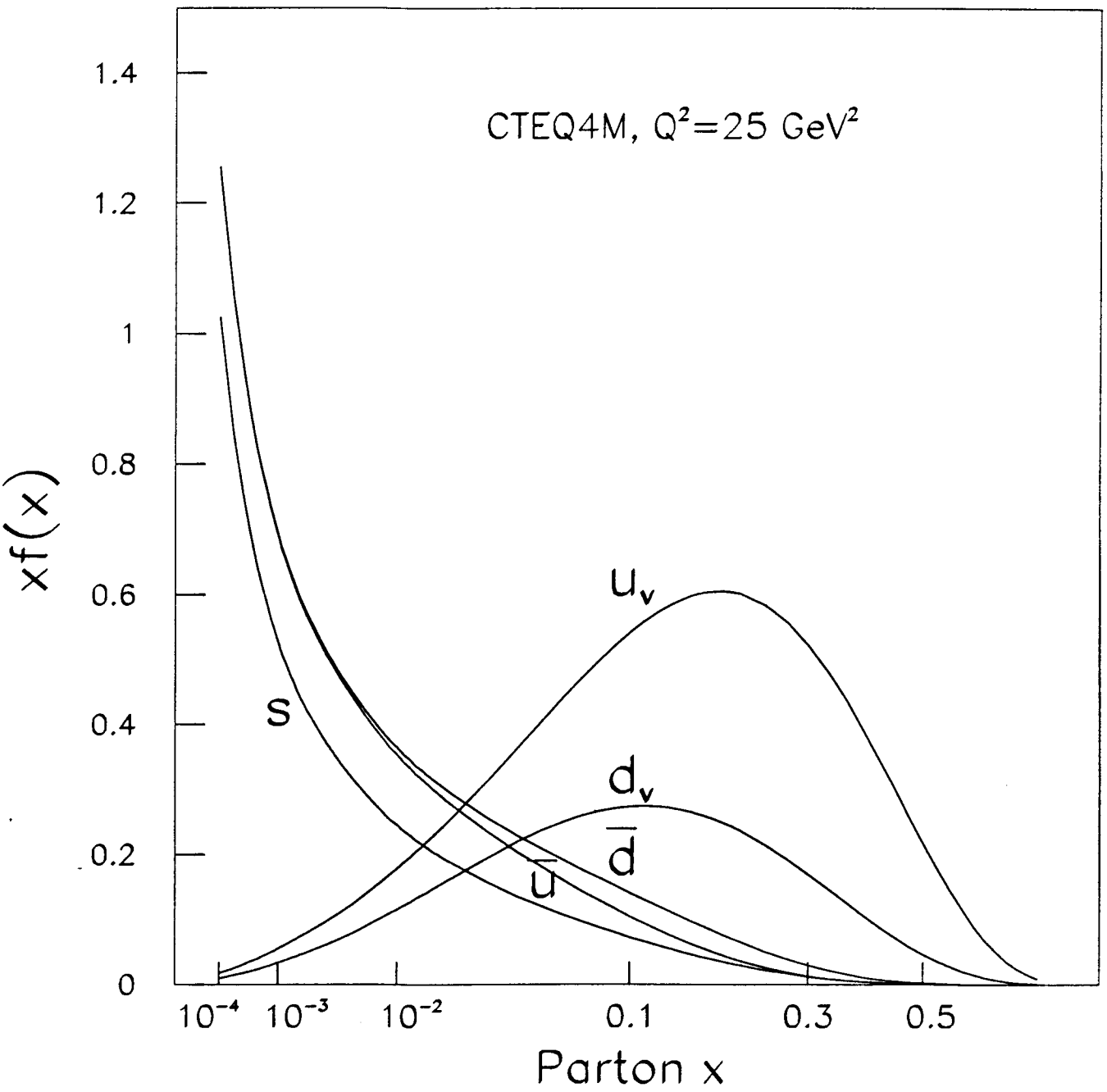
Assume $s = \bar{s}$ and Shape$= \bar{u} + \bar{d}$

Some Models Predict
These Assumptions Are Wrong

With These Assumptions,
$xs = \kappa x(\bar{d} + \bar{u})/2$

CCFR Dimuons Measure $\kappa = 0.477 \pm 0.06$

$\kappa = 0.5$ Typically Used


CTEQ4M, Q^2=25 GeV^2
xf(x)
Parton x
u_v
d_v
s
$\bar{d}$
$\bar{u}$
1.4
1.2
1
0.8
0.6
0.4
0.2
0
10^{-4}
10^{-3}
10^{-2}
0.1
0.3
0.5

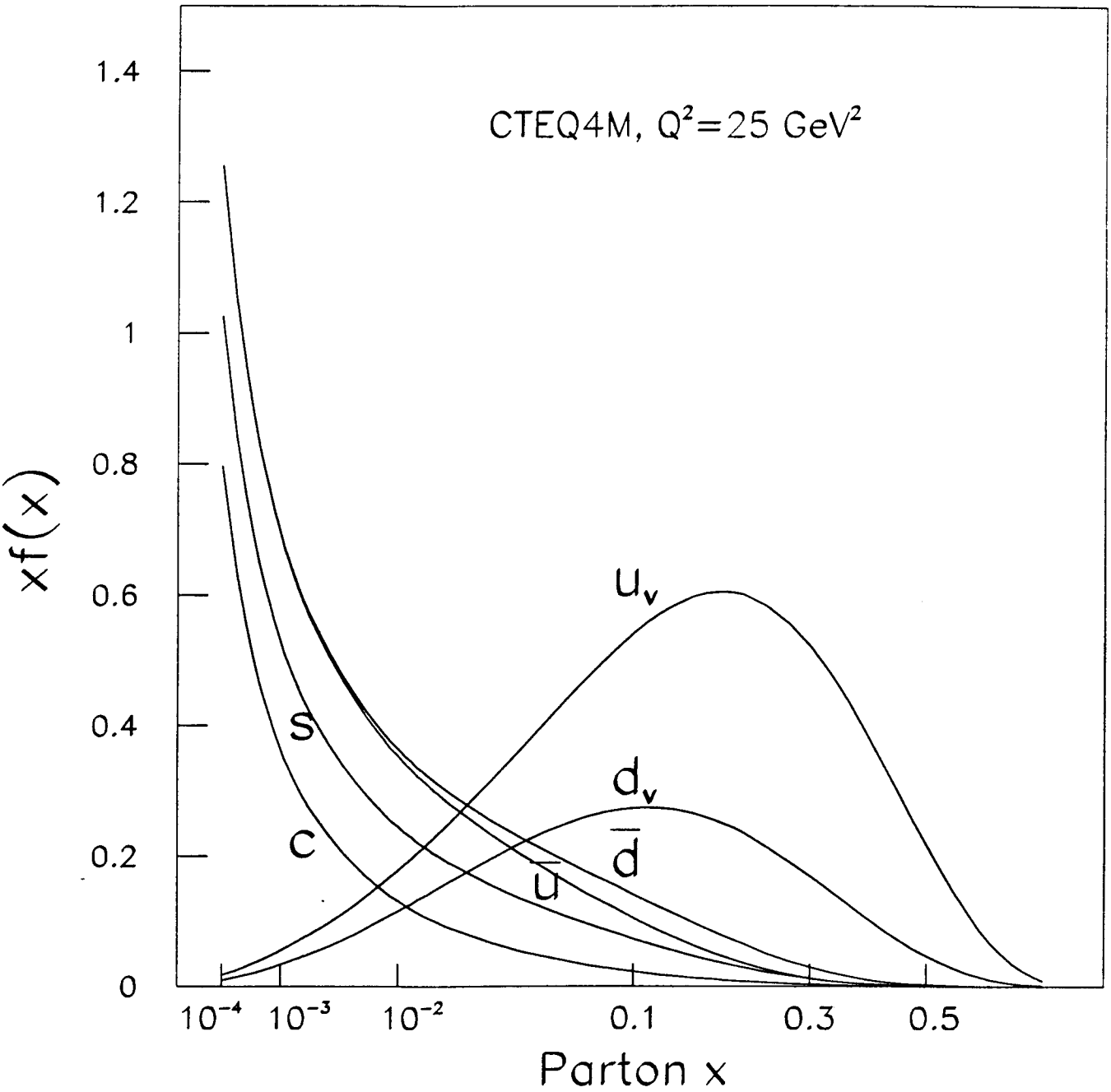
The Charm Quark Distribution

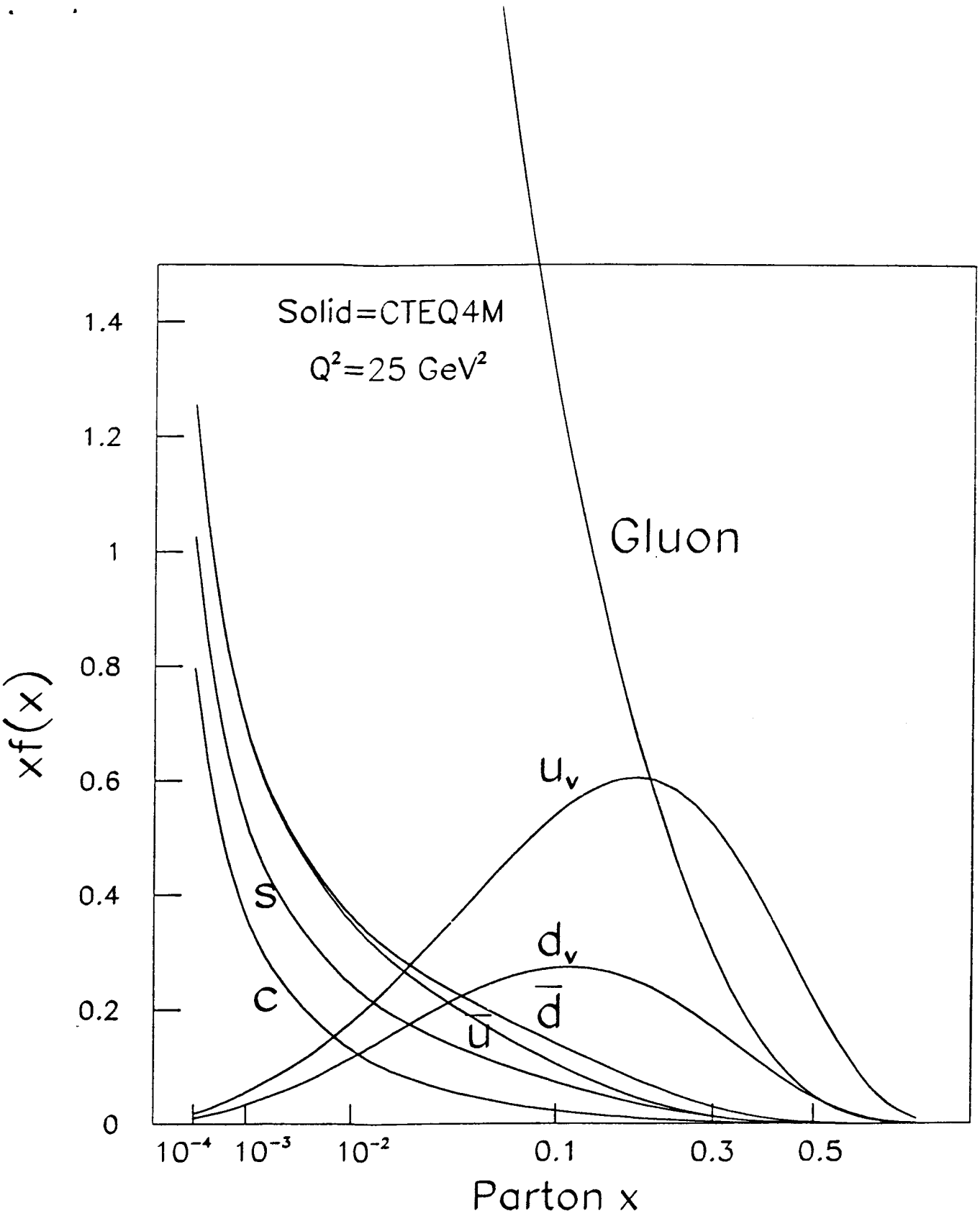
Assume No Intrinsic Charm ($xc = 0$ At Q_0)
Then Generate From Normal Evolution

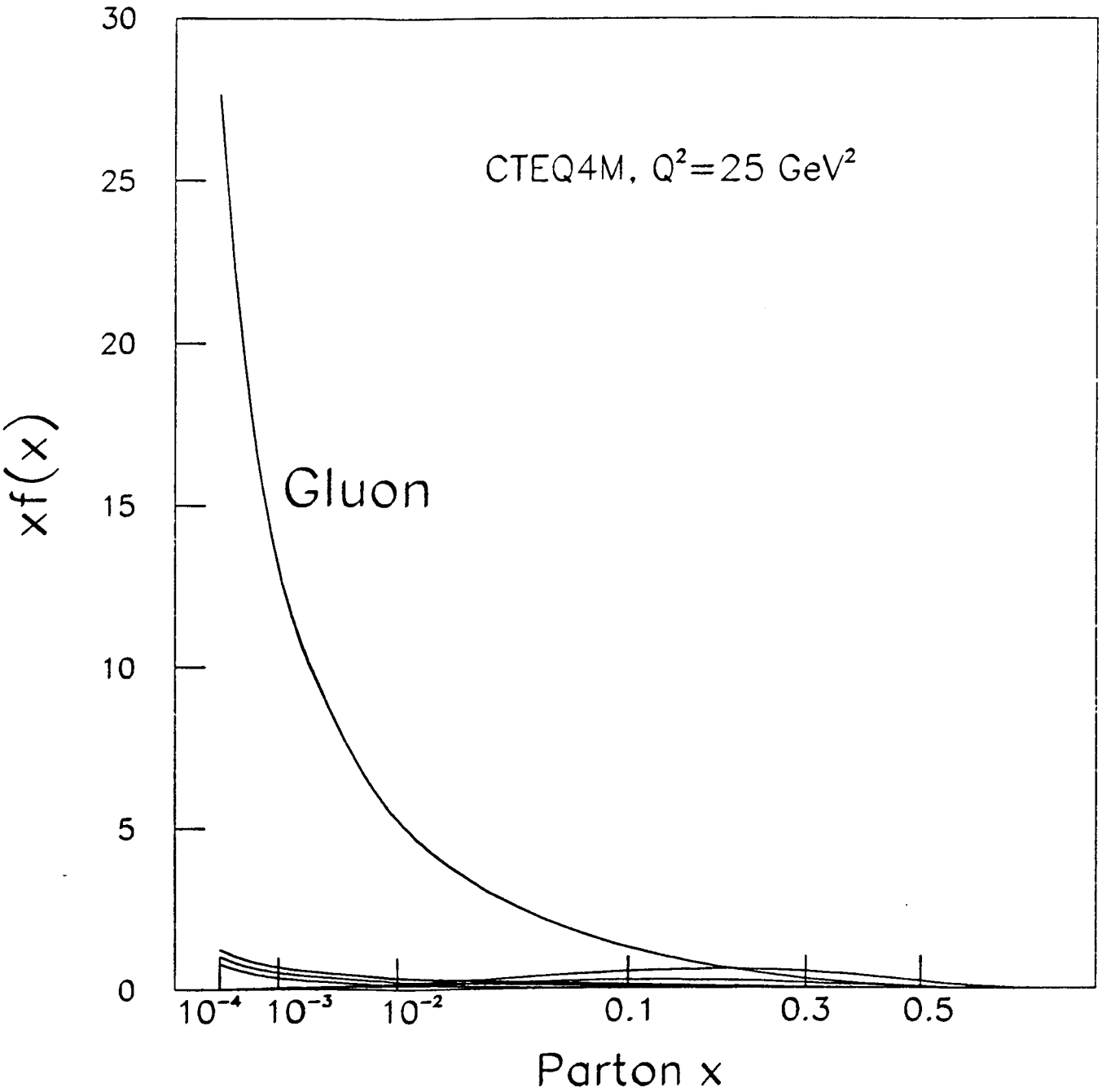
Checked With HERA/EMC F_2^c and
Tevatron Photon+Charm

OK For Most Applications,
But Potential Consistency Problem in
Heavy Flavor Production

For This Reason, GRV94 Eliminated
Charm and Bottom Distributions


CTEQ4M, $Q^2=25$ GeV^2
xf(x)
Parton x
1.4
1.2
1
0.8
0.6
0.4
0.2
0
10^{-4}
10^{-3}
10^{-2}
0.1
0.3
0.5
u_v
d_v
$\bar{d}$
$\bar{u}$
s
c


Solid=CTEQ4M
Q^2=25 GeV^2
Gluon
u_v
d_v
$\bar{u}$
$\bar{d}$
s
c
xf(x)
Parton x
1.4
1.2
1
0.8
0.6
0.4
0.2
0
10^{-4}
10^{-3}
10^{-2}
0.1
0.3
0.5


CTEQ4M, $Q^2=25$ GeV^2
Gluon
xf(x)
Parton x
30
25
20
15
10
5
0
10^{-4}
10^{-3}
10^{-2}
0.1
0.3
0.5

The Gluon Distribution $x < 0.3$

Momentum Sum Rule

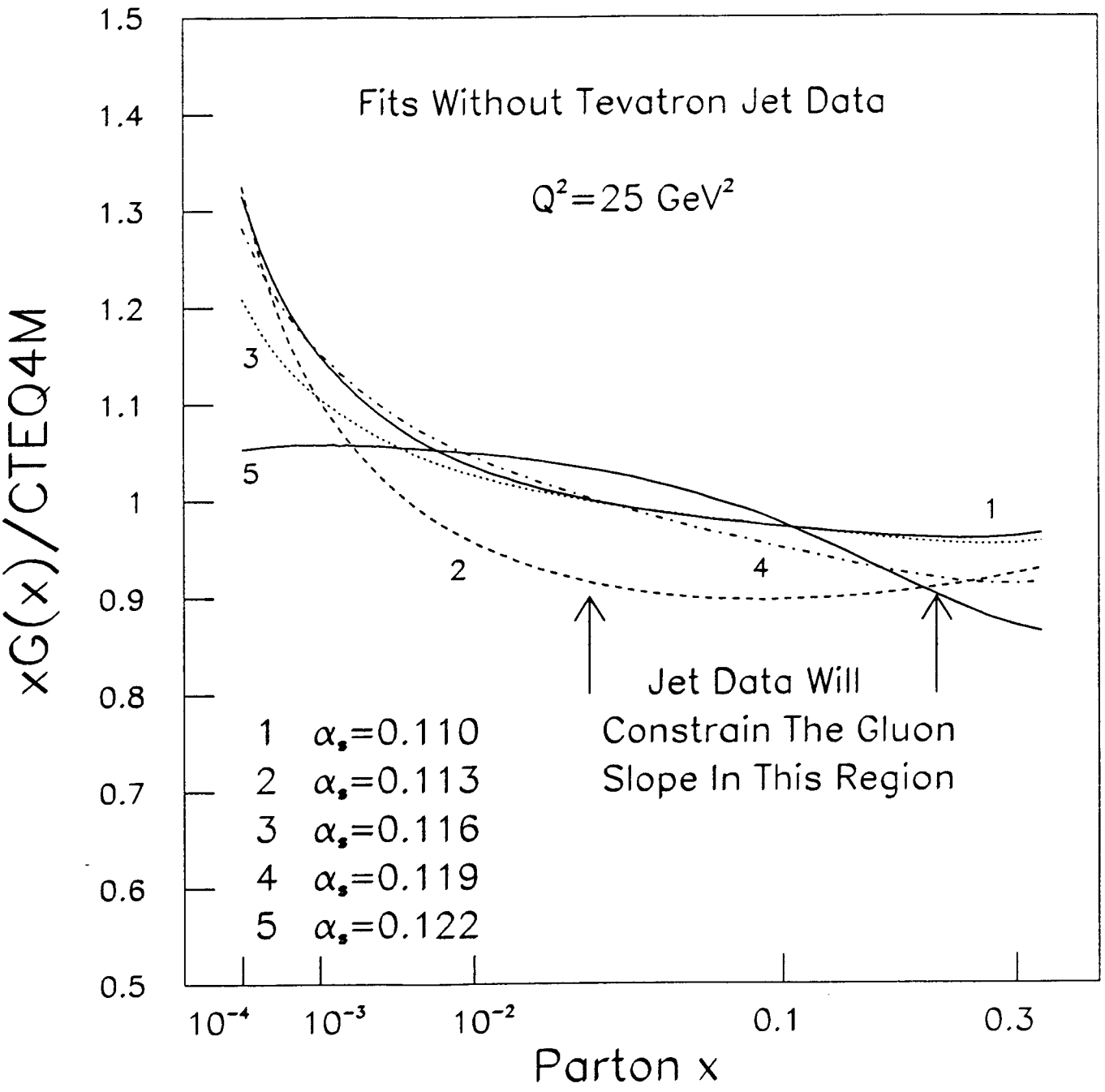
$$1.0 - \int xQ(x)dx = \int xG(x)dx$$

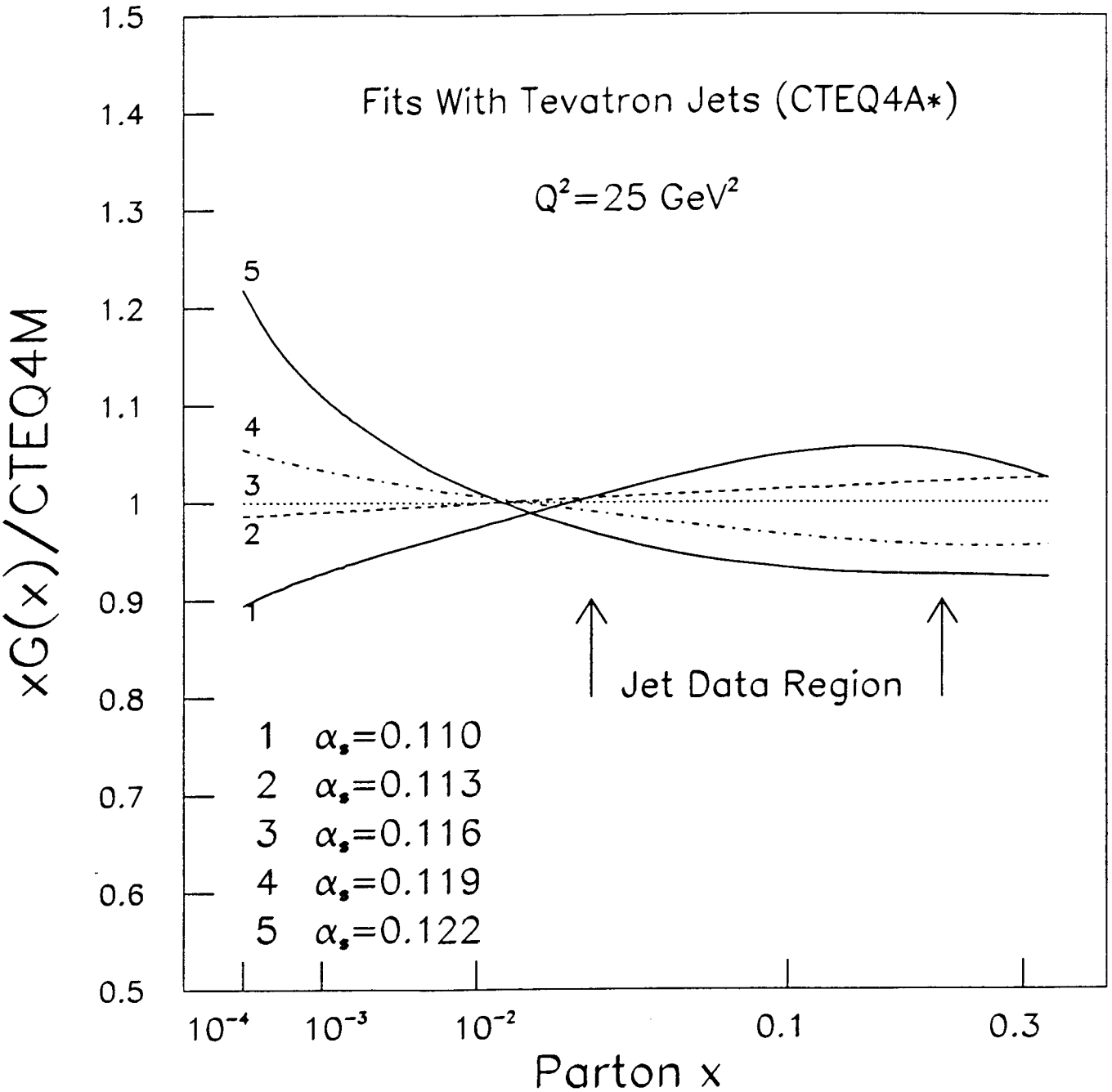
Main Information is $dF_2/dQ^2 \approx \alpha_S G(x)$

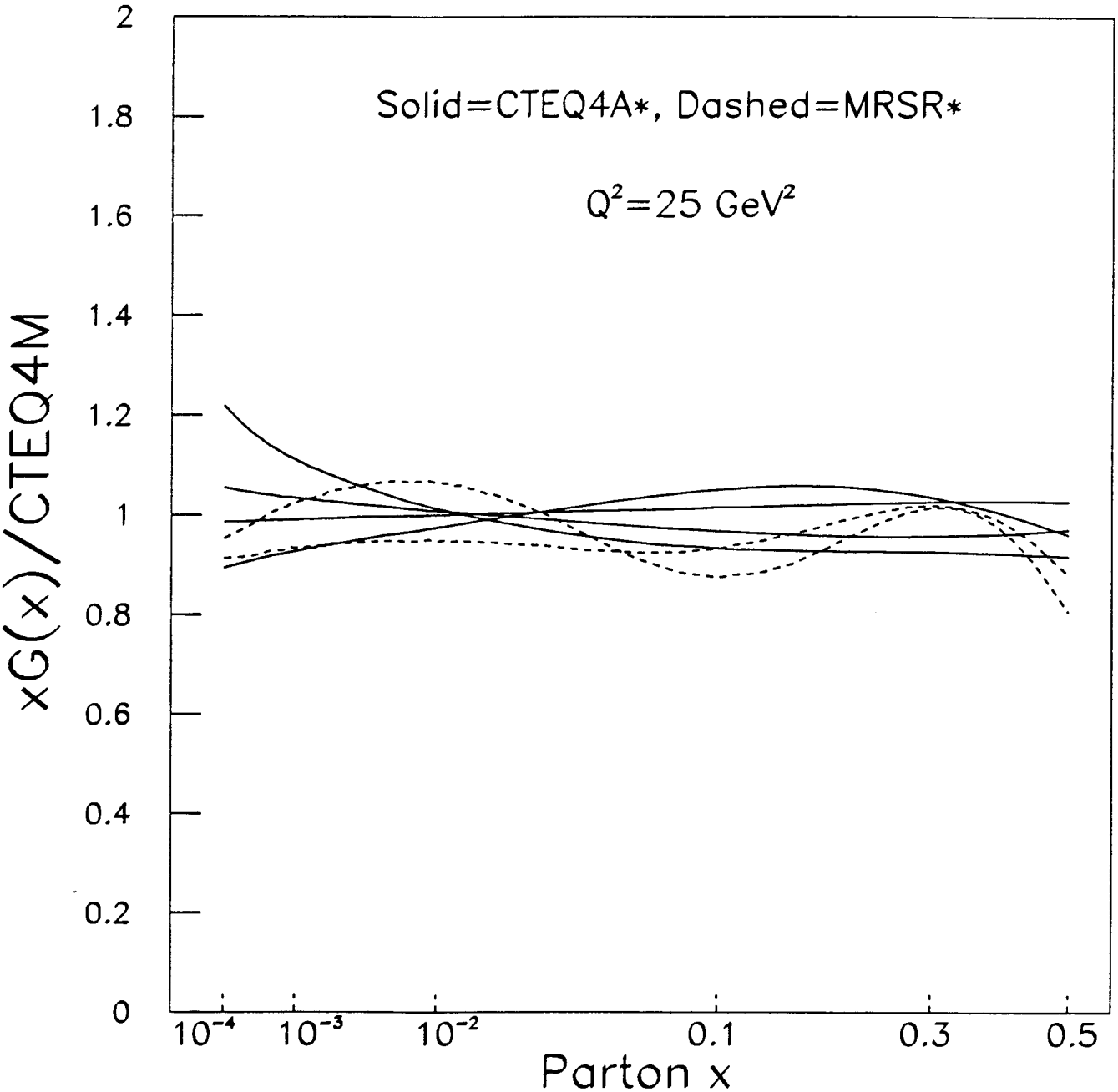
Direct Photons? See Saturday's Session

New $\rightarrow$ Tevatron Jet Production

Many Other Cross-Checks
With $20 - 30\%$ Precision


Fits Without Tevatron Jet Data
Q^2=25 GeV^2
xG(x)/CTEQ4M
Parton x
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
10^{-4}
10^{-3}
10^{-2}
0.1
0.3
1
2
3
4
5
Jet Data Will
Constrain The Gluon
Slope In This Region
1 α_s=0.110
2 α_s=0.113
3 α_s=0.116
4 α_s=0.119
5 α_s=0.122


Fits With Tevatron Jets (CTEQ4A*)
$Q^2=25\ GeV^2$
xG(x)/CTEQ4M
Parton x
Jet Data Region
1 α_s=0.110
2 α_s=0.113
3 α_s=0.116
4 α_s=0.119
5 α_s=0.122
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
10^{-4}
10^{-3}
10^{-2}
0.1
0.3


Solid=CTEQ4A*, Dashed=MRSR*
Q^2=25 GeV^2
xG(x)/CTEQ4M
Parton x
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
10^{-4}
10^{-3}
10^{-2}
0.1
0.3
0.5

THE UNCERTAINTIES?

$\sum Q(x)$ Used In Most Applications
(Uncertainty $\leq 5\%$ From $x = 10^{-4}$ To 0.7)

Individual Parton Uncertainties
Are $\approx 10 - 20\%$ If $xf(x) > 0.1$

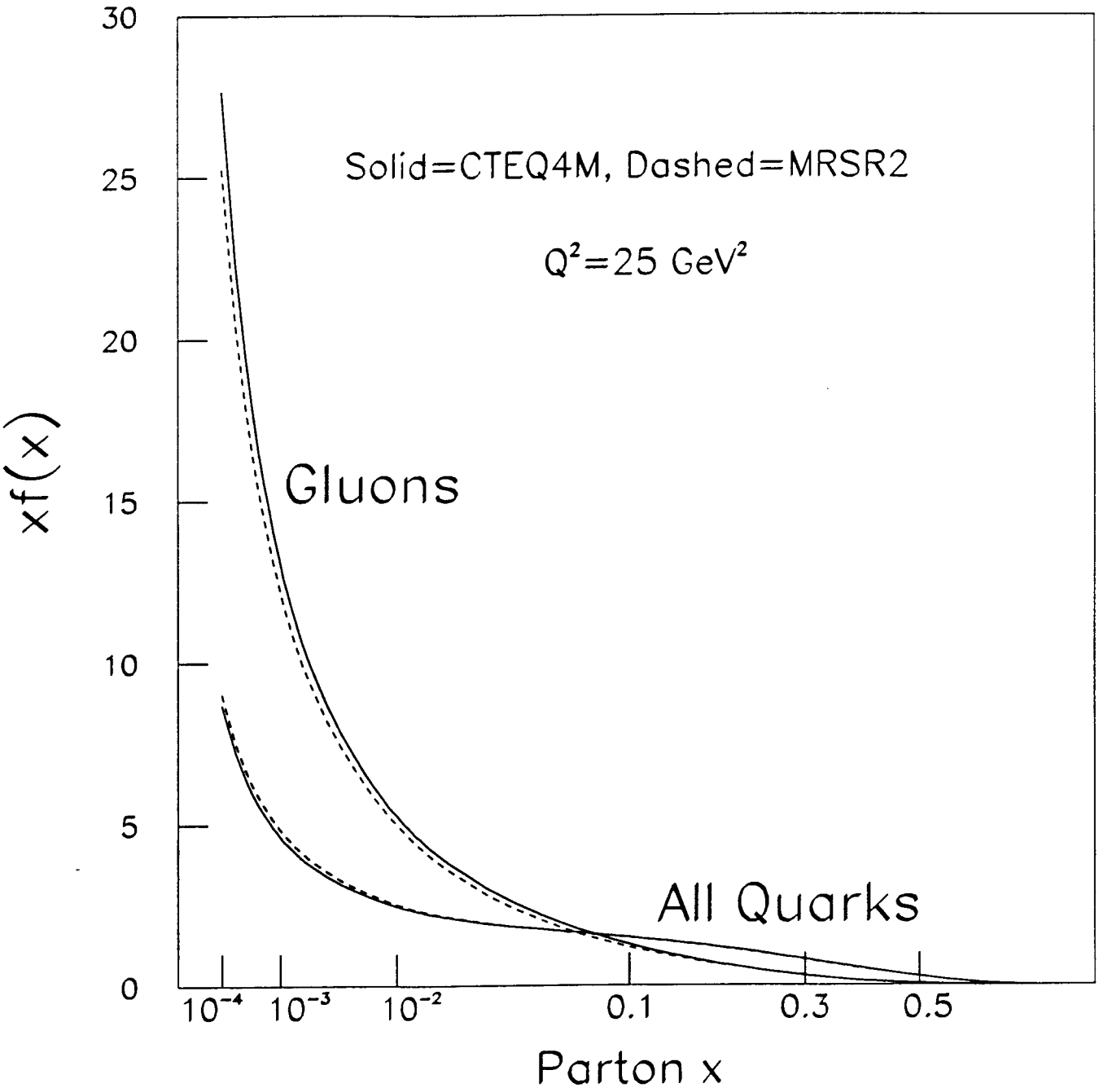
Some of The Uncertainty Lies in "Choices"
And The Lack of Data To Test Them

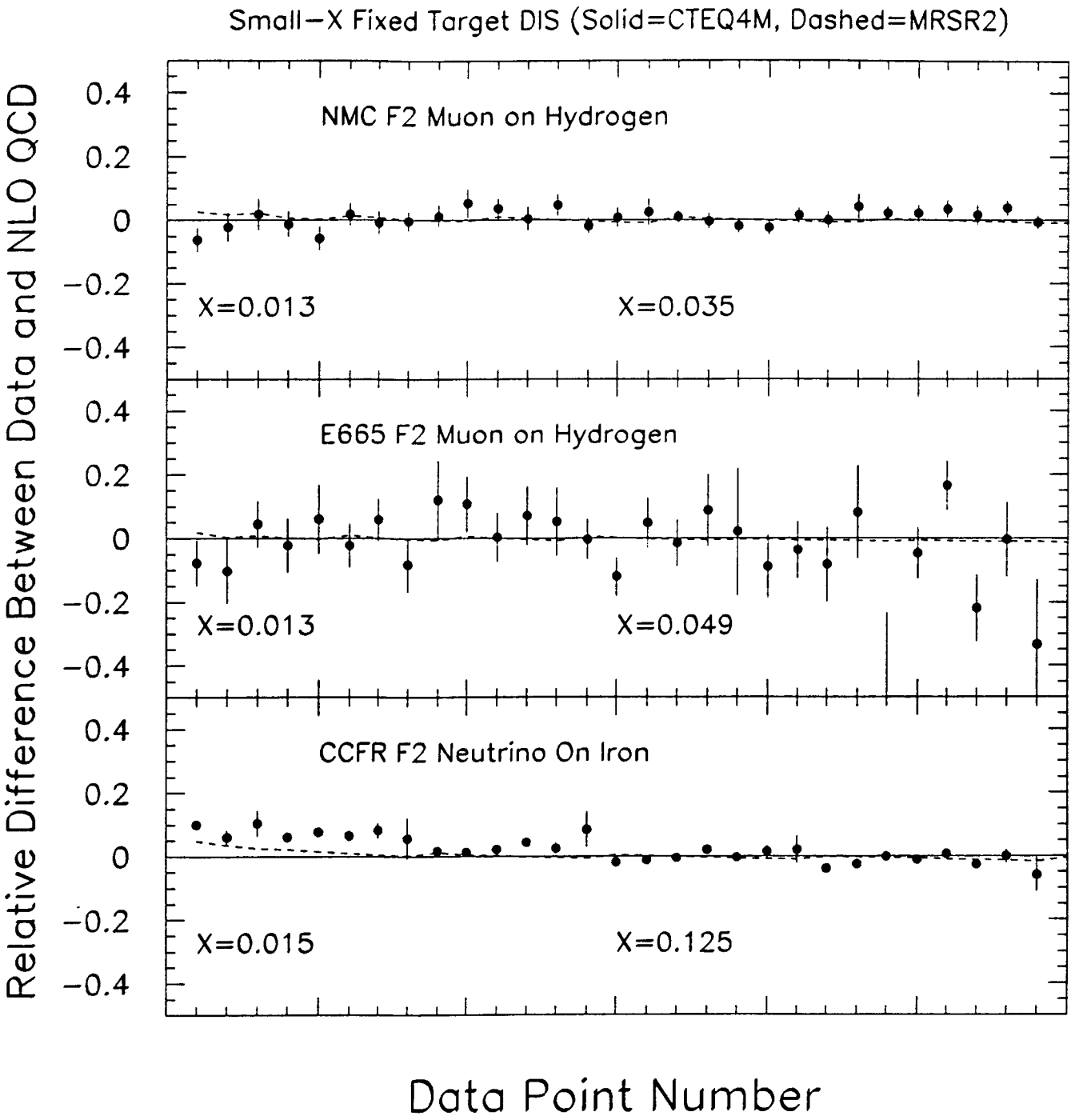
A Few Examples: ($\Delta\chi^2 = 50 - 100$ Typical)

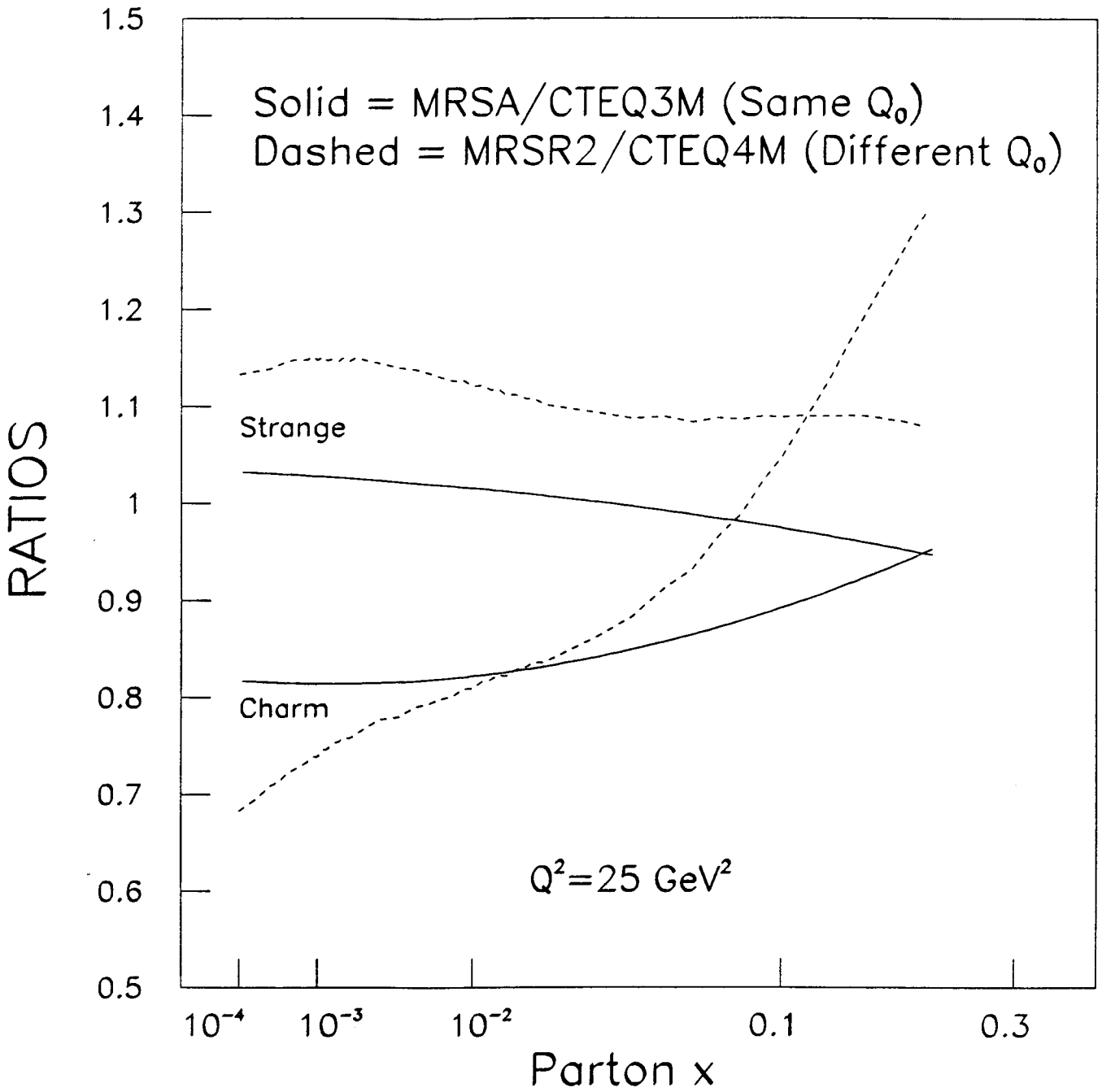
Choice of Datasets (See DIS Plot)

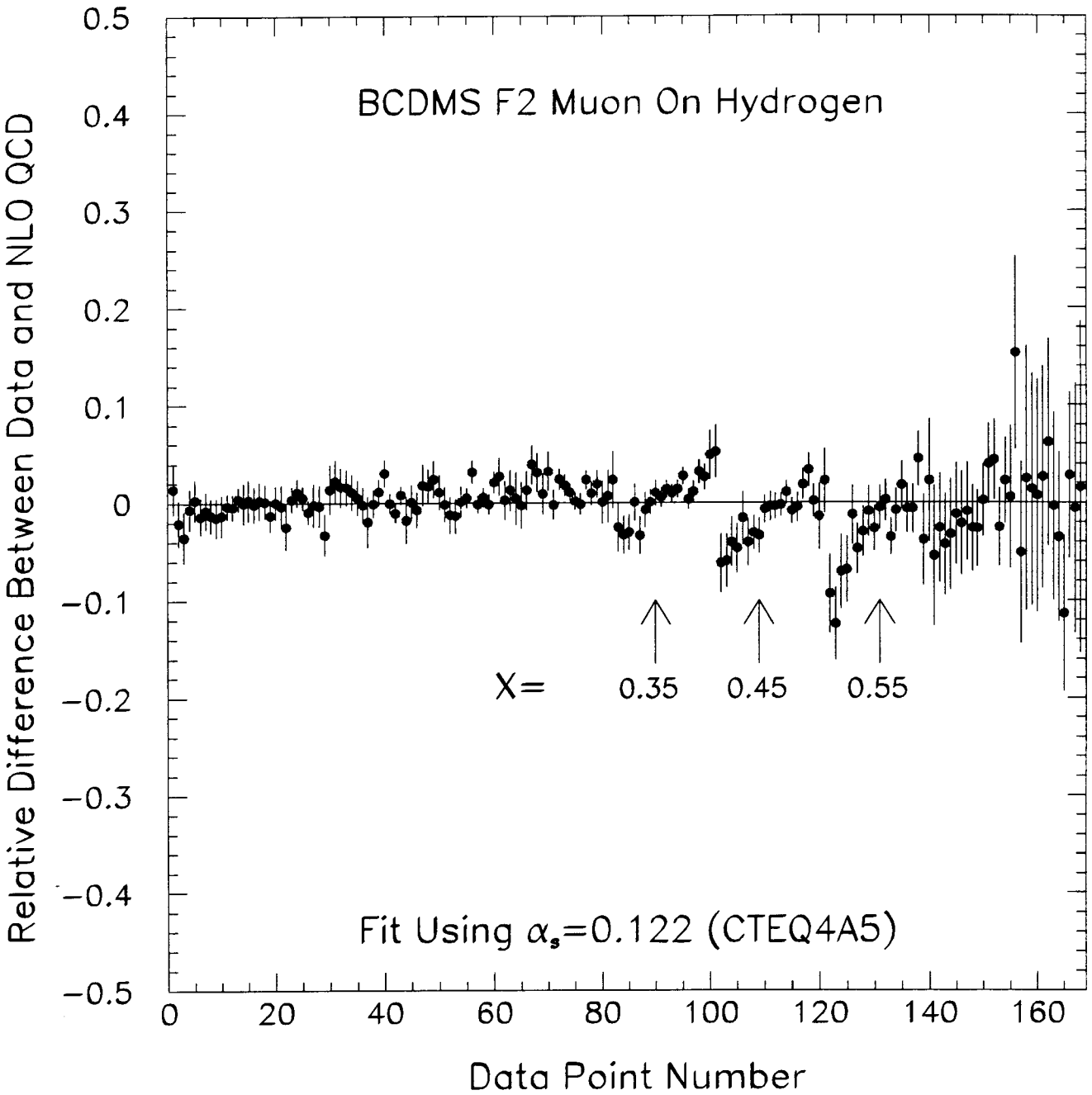
Choice of Q_0 (See MRS/CTEQ Plot)

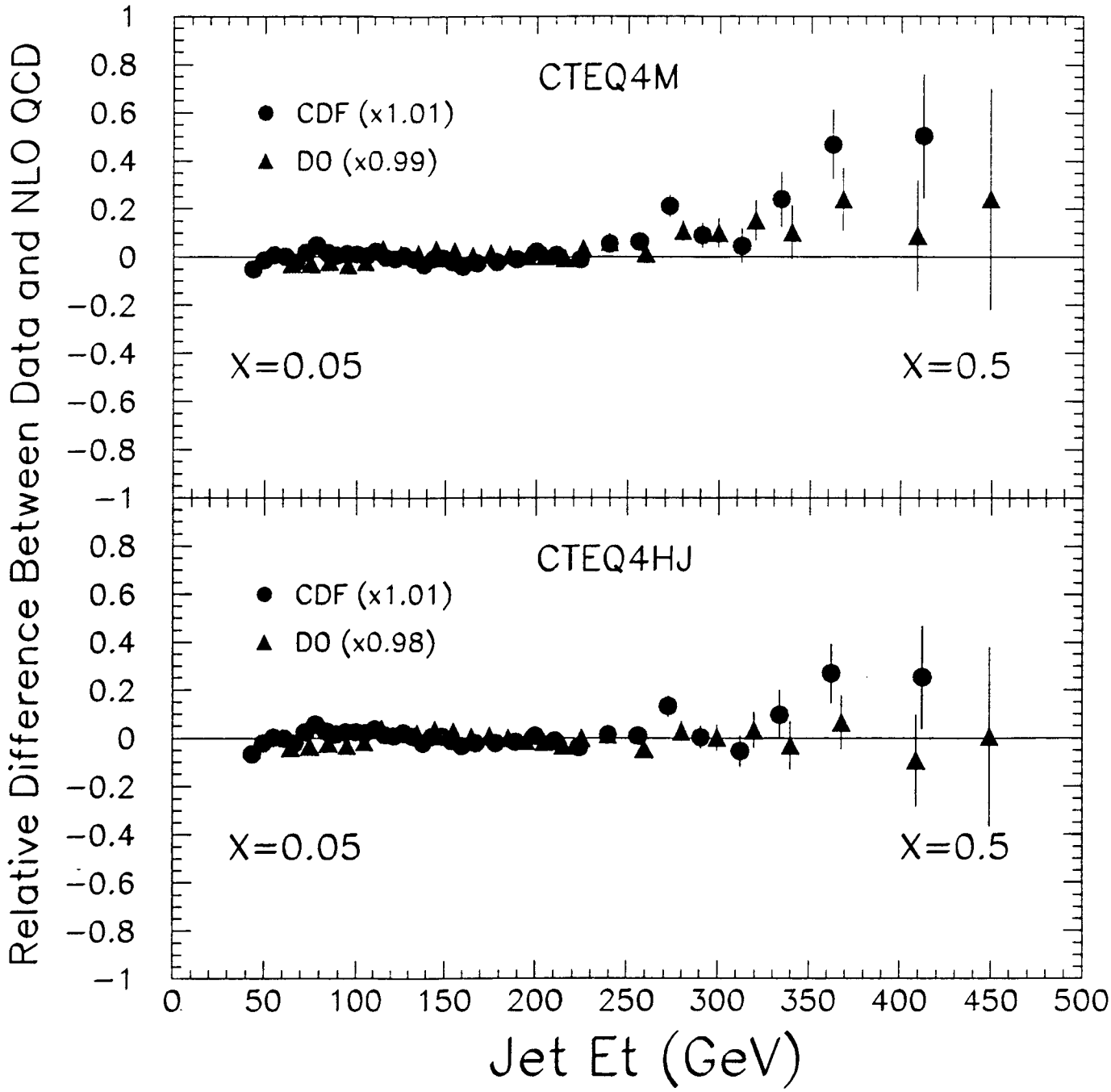
Choice of α_s (See Gluon Plot)


30
25
20
15
10
5
0
xf(x)
Solid=CTEQ4M, Dashed=MRSR2
Q^2=25 GeV^2
Gluons
All Quarks
10^{-4}
10^{-3}
10^{-2}
0.1
0.3
0.5
Parton x


Small−X Fixed Target DIS (Solid=CTEQ4M, Dashed=MRSR2)
Relative Difference Between Data and NLO QCD
0.4
0.2
0
−0.2
−0.4
NMC F2 Muon on Hydrogen
X=0.013
X=0.035
E665 F2 Muon on Hydrogen
X=0.013
X=0.049
CCFR F2 Neutrino On Iron
X=0.015
X=0.125
Data Point Number


Solid = MRSA/CTEQ3M (Same Q_0)
Dashed = MRSR2/CTEQ4M (Different Q_0)
Strange
Charm
Q^2=25 GeV^2
RATIOS
Parton x
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
10^{-4}
10^{-3}
10^{-2}
0.1
0.3


BCDMS F2 Muon On Hydrogen
Relative Difference Between Data and NLO QCD
Data Point Number
X=
0.35
0.45
0.55
Fit Using α_s=0.122 (CTEQ4A5)
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
−0.5
0
20
40
60
80
100
120
140
160

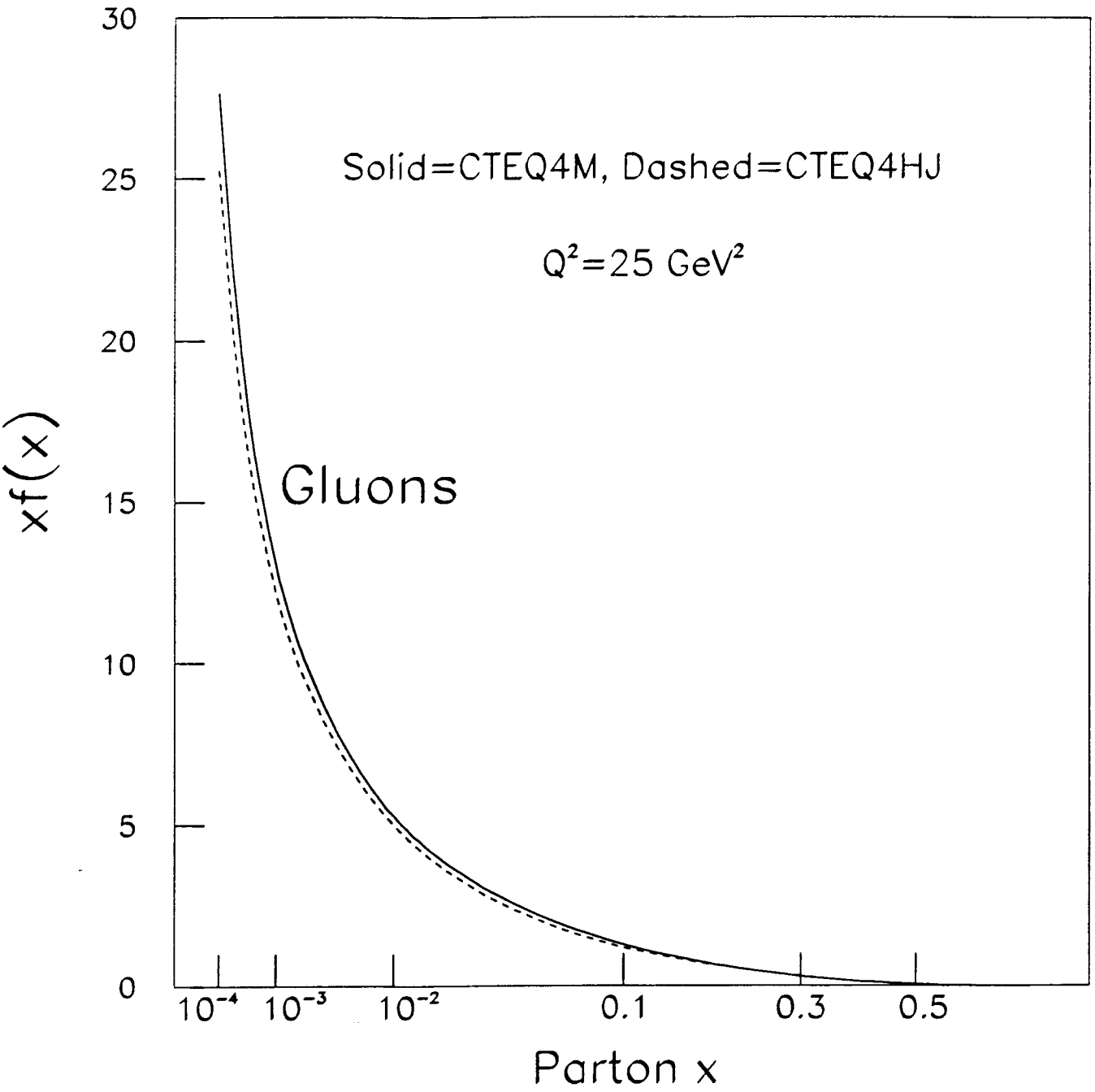

CTEQ4M
CDF (x1.01)
D0 (x0.99)
X=0.05
X=0.5
CTEQ4HJ
CDF (x1.01)
D0 (x0.98)
X=0.05
X=0.5
Relative Difference Between Data and NLO QCD
Jet Et (GeV)
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
0
50
100
150
200
250
300
350
400
450
500

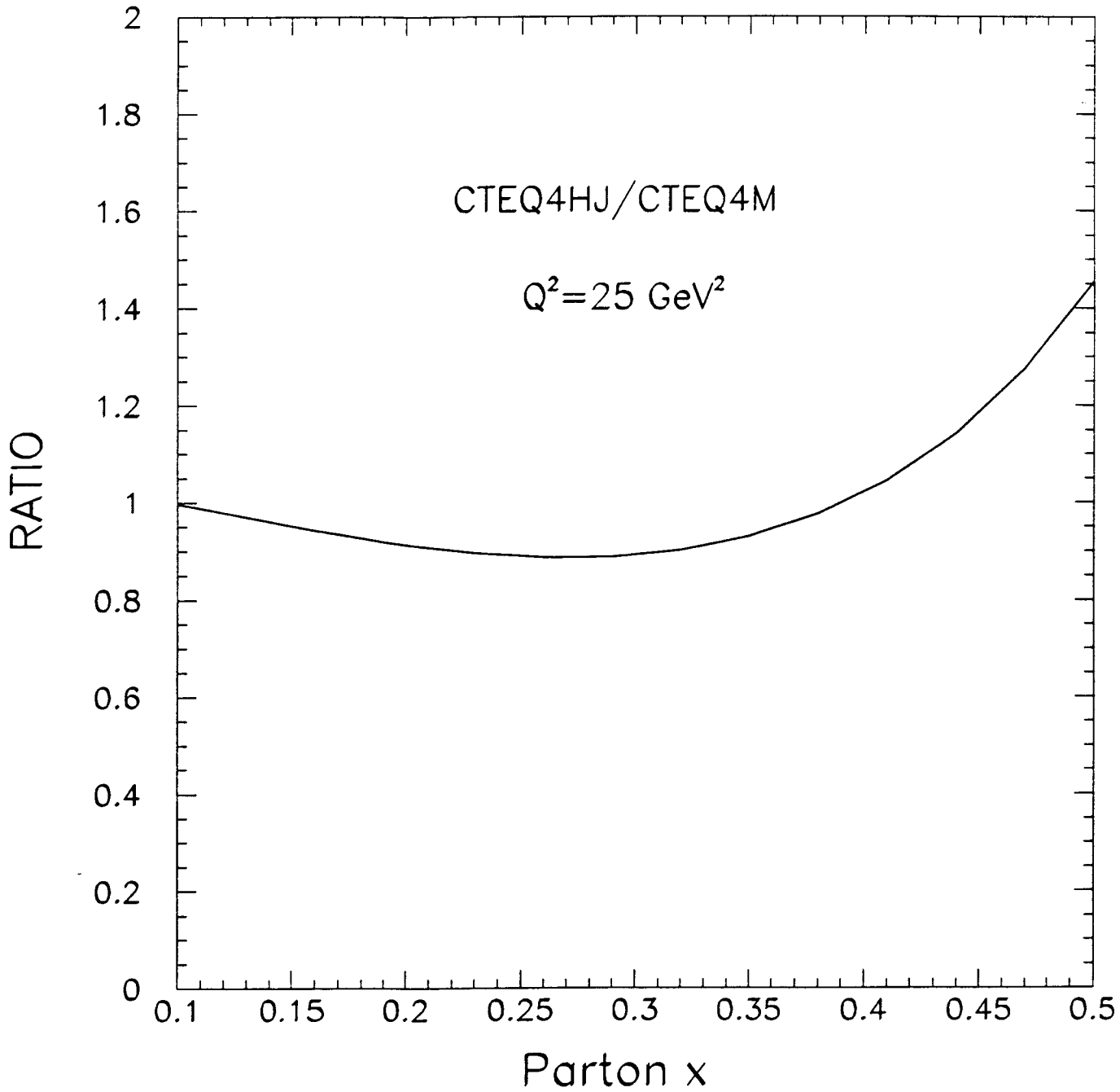
GLUON PARAMETERIZATIONS

MRS: $x^a(1-x)^b(1+c\sqrt{x}+dx)$

CTEQ: $x^a(1-x)^b(1+cx^d)$

The Functional Form x^d
Is Necessary To Fit High-Pt Jets


30
25
20
15
10
5
0
xf(x)
Solid=CTEQ4M, Dashed=CTEQ4HJ
Q^2=25 GeV^2
Gluons
10^{-4}
10^{-3}
10^{-2}
0.1
0.3
0.5
Parton x


CTEQ4HJ/CTEQ4M
Q^2=25 GeV^2
RATIO
Parton x
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5

2 SPECIAL STUDIES INVOLVING JETS

A Good Fit: High-Pt Jets (CTEQ4HJ)

When The Gluon Is Increased At $x > 0.3$,
8 Other χ^2 Improve, 6 Get Worse

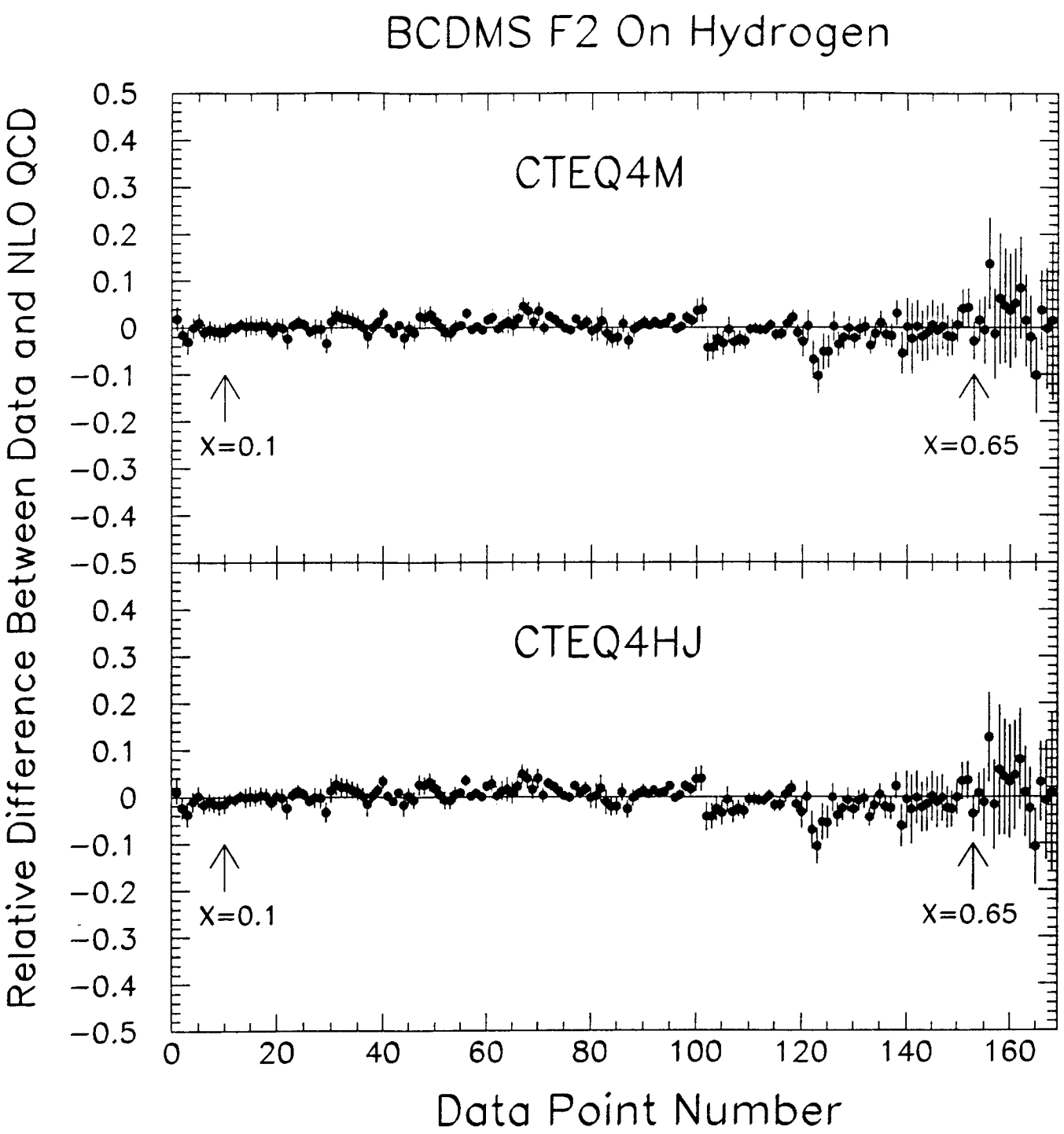
Main Complaint Is From BCDMS Due to
Insignificant Changes in Quarks (See Plot)

A Bad Fit: Low-Pt Jets at $\sqrt{s} = 630$ GeV

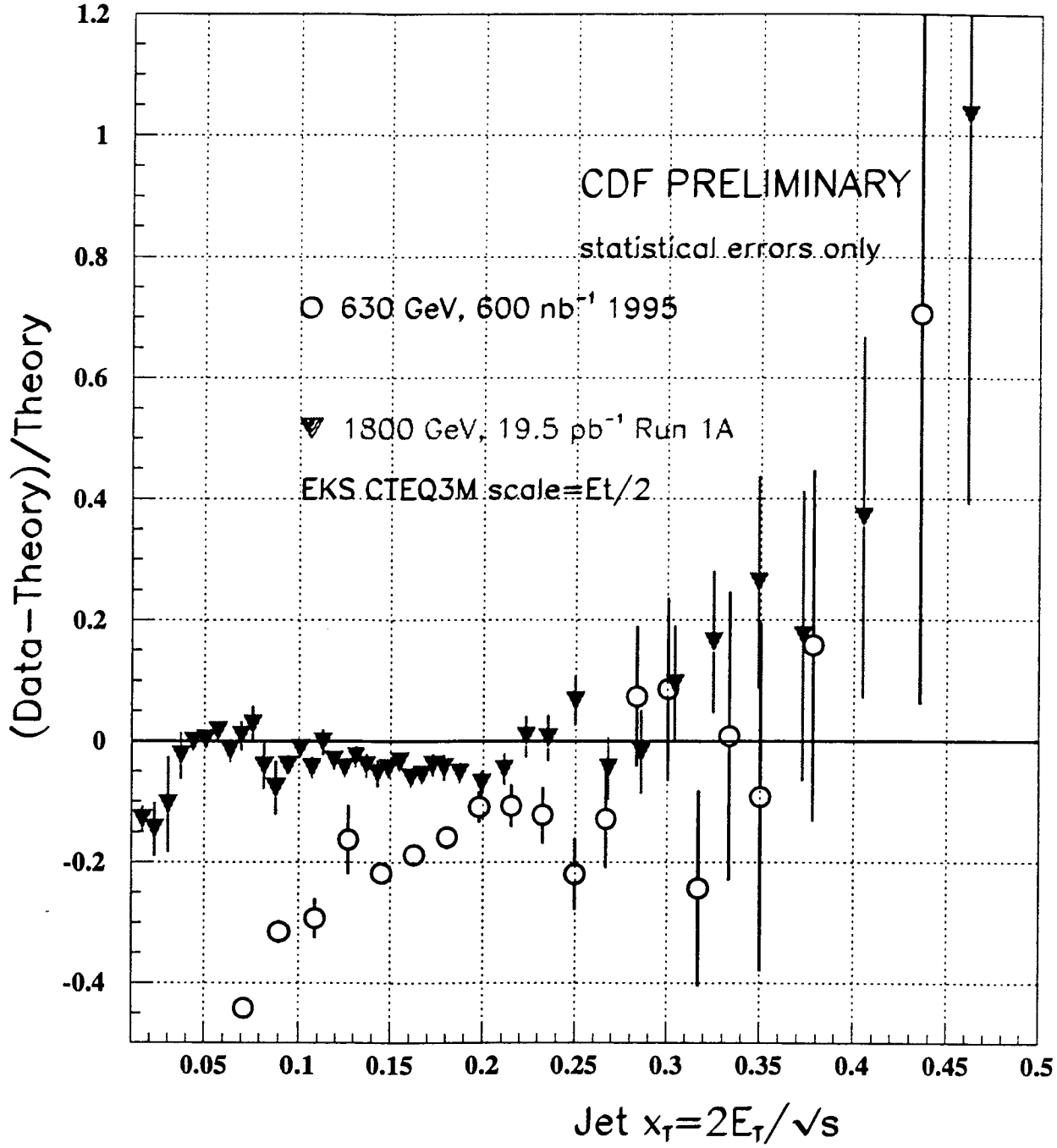
11 χ^2 Get Worse, 3 Improve

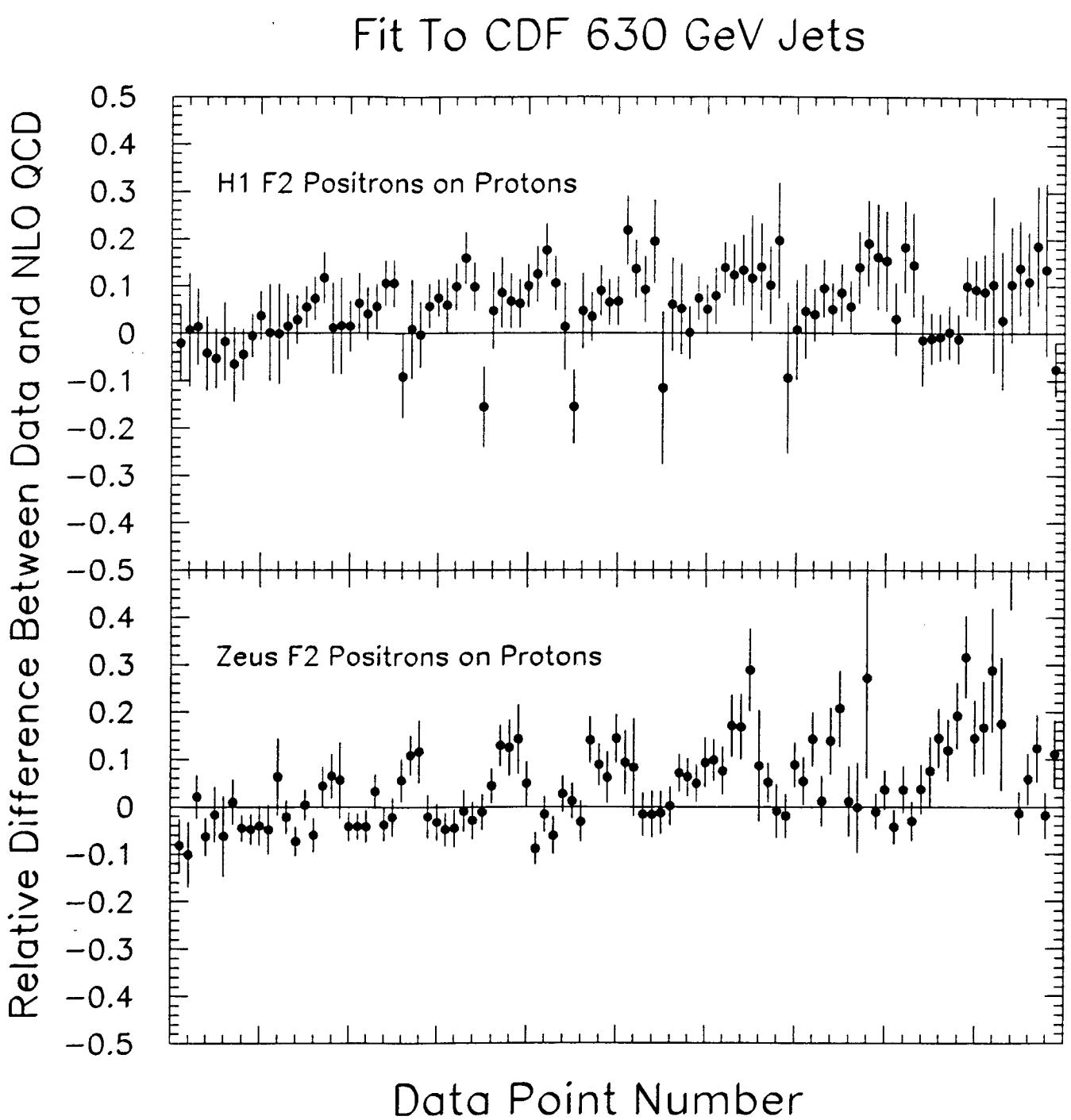
α_s Drops To 0.103 (5σ Off)

Noticeable Discrepancies With Other Data


BCDMS F2 On Hydrogen
CTEQ4M
CTEQ4HJ
X=0.1
X=0.65
X=0.1
X=0.65
Relative Difference Between Data and NLO QCD
Data Point Number
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
−0.5
0
20
40
60
80
100
120
140
160

CDF: 630 GeV vs 1800 GeV




Fit To CDF 630 GeV Jets
Relative Difference Between Data and NLO QCD
H1 F2 Positrons on Protons
Zeus F2 Positrons on Protons
Data Point Number
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
−0.5

FUTURE PROSPECTS

Final NMC, CCFR Data

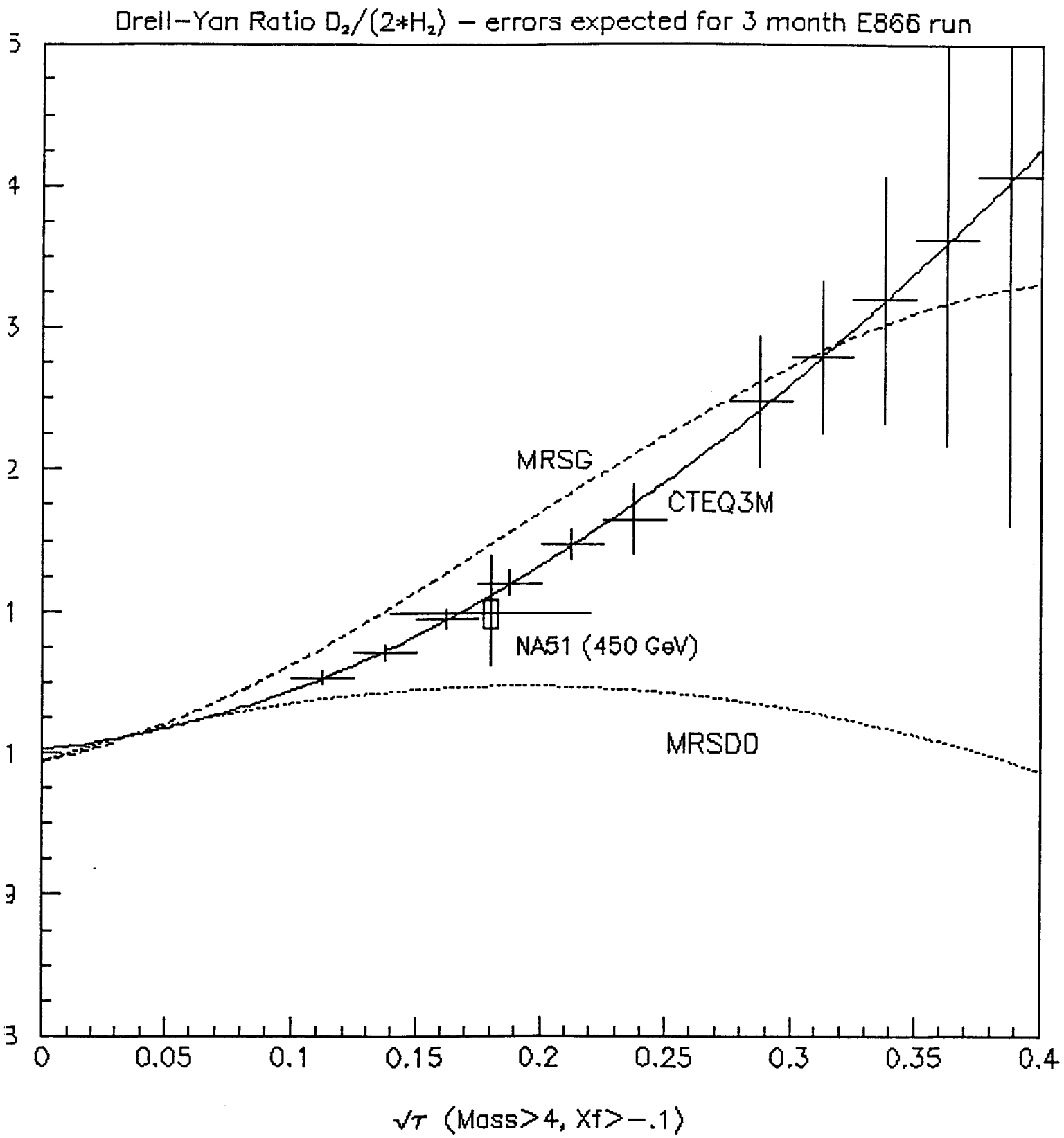
More Data From Hera and W Asymmetry

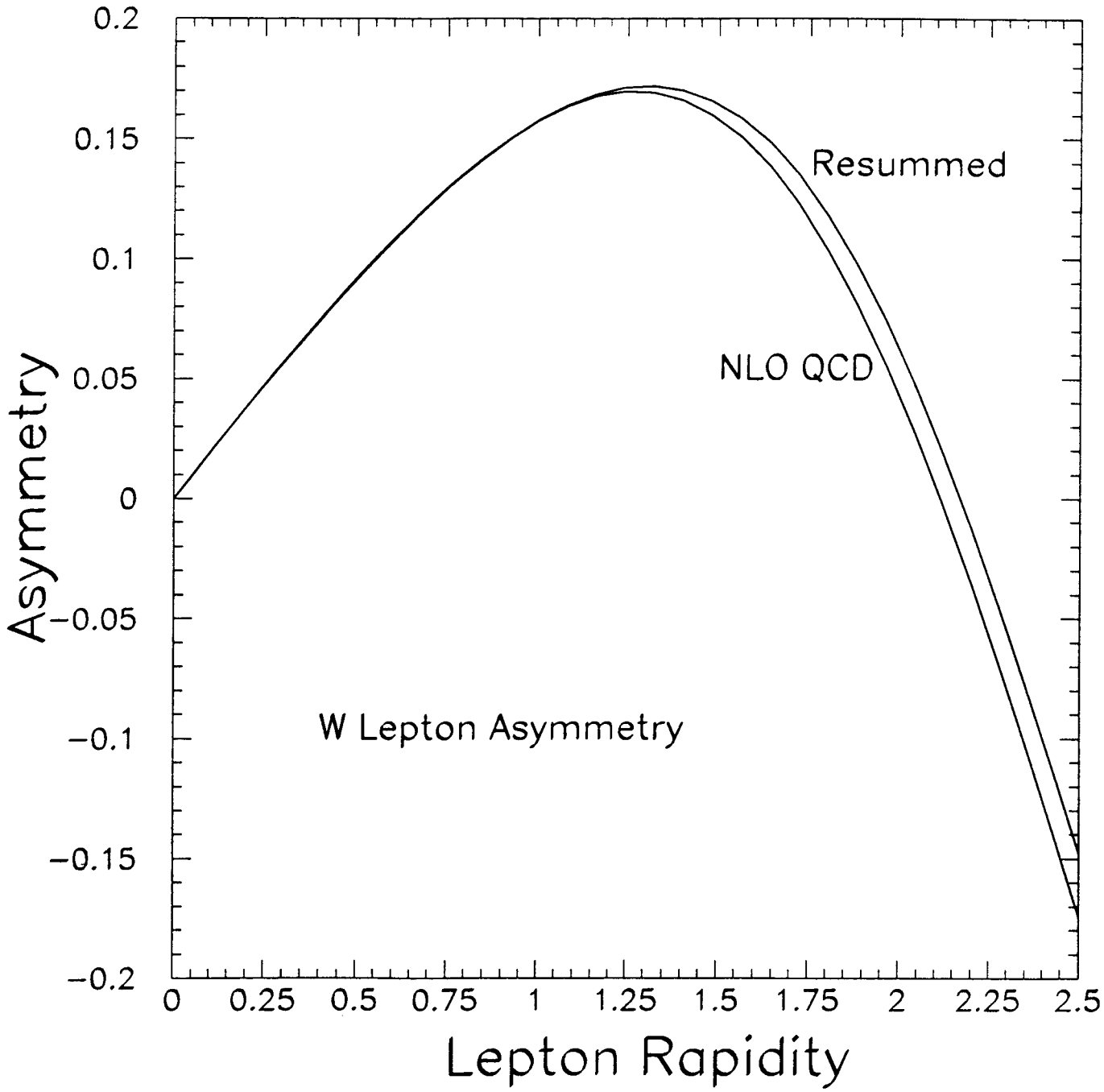
Much Better Information On
Drell-Yan Asymmetry From NUSEA

Tevatron Low-Mass Drell-Yan

Much More Gluon Information

What About Resummation???


Drell–Yan Ratio $D_2/(2*H_2)$ – errors expected for 3 month E866 run
MRSG
CTEQ3M
NA51 (450 GeV)
MRSD0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
$\sqrt{\tau}$ (Mass>4, Xf>−.1)


0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
Asymmetry
Resummed
NLO QCD
W Lepton Asymmetry
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
2.25
2.5
Lepton Rapidity