# o Summary WG I: Hadron Structure (experiment)

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C. Royon
R. Yoshida

⇒ Structure Functions from fixed target
- CCFR (R. Bernstein)
- NMC (E. Kabuss)

⇒ Sea Asymmetry from Drell-Yan: E866 (R. Tomlin!)

⇒ Direct $\gamma$
- E706 (M. Zielinski)
- Tevatron (R. Blair)

⇒ Structure function from HERA
- ZEUS low x, low $Q^2$ (B. Surrow)
- H1 low x, low $Q^2$ (A. Meyer)
- H1 $\gamma$ structure (T. Ebert)
- ZEUS $F_2^{charm}$ (J. Roldan)
- H1, ZEUS QCD fits (F. Zomer, M. Botje)

⇒ High $Q^2$
- H1 $\sigma^{CC}, \sigma^{NC}$ to 95 (A. Riess)
- High x, High $Q^2$ events (T. Carli, F. Zarnecki)

# Structure Functions from Fixed Target

## CCFR

R. Bernstein

Reanalysis of $\nu$-Fe data

⇒ Improved energy calibration

correcting $xF_3^{\nu Fe}$, $F_2^{\nu Fe}$ to isoscalar target

Several specific choices are made →

Results →

Good agreement with NMC, E665 except at low x.

→ Due to shadowing correction effect?

Extract $\alpha_s$ from QCD fit (more J. Blümlein's summary)

$\alpha_s(M_Z) = 0.119 \pm 0.002\,(\text{exp}) \pm 0.001\,(\text{HT}) \pm 0.004$ (scale)

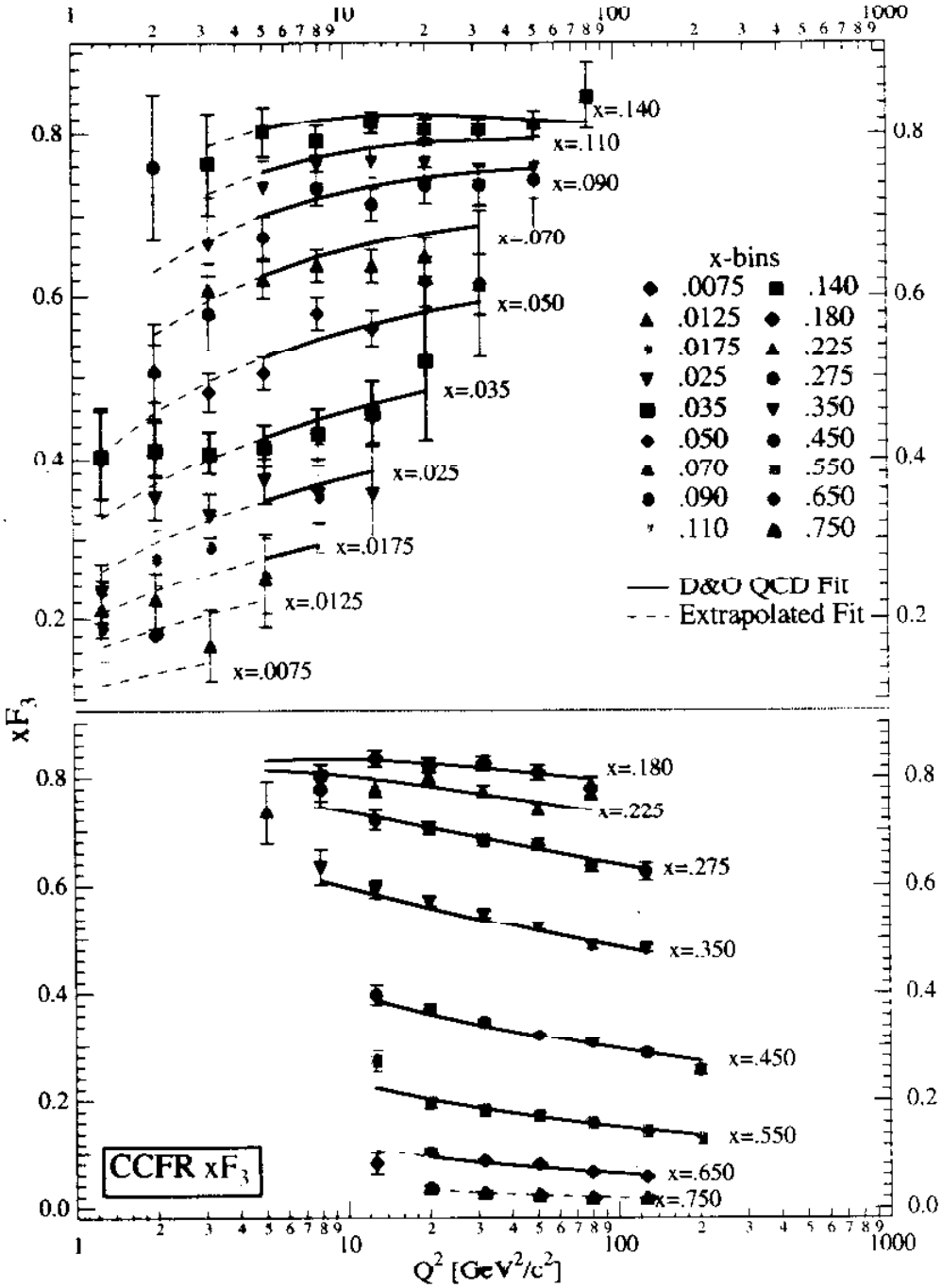
(was $0.111 \pm 0.002 \pm 0.003$)

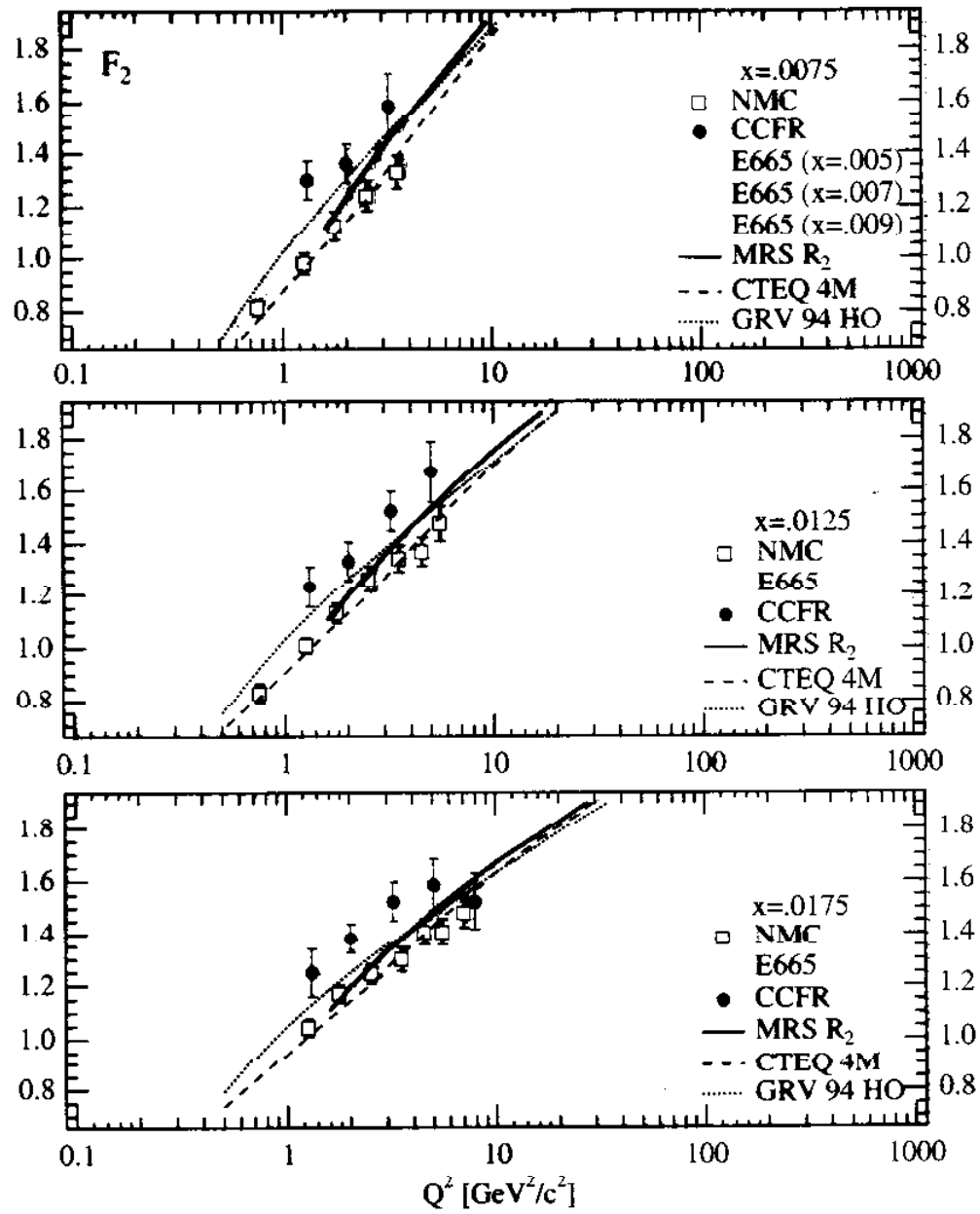
# So What Do We Report?

- $F_2, xF_3$ for
  - Isoscalar Target
  - No Strange Sea
  - Charm Mass = 0
    (no slow-rescaling correction)
  - Remove Physical Radiative Corrections
  - Remove Propagator $Q^2$ Dependence
- Each Correction is Explicitly Given in
  *Seligman, PhD Thesis*
  Down to Code – so you can take it out if you like

*ftp://nevis1.nevis.columbia.edu/pub/* [illegible] *seligm*
or anonymous ftp

# $xF_3$


x=.140
x=.110
x=.090
x=.070
x=.050
x=.035
x=.025
x=.0175
x=.0125
x=.0075
x-bins
.0075 .140
.0125 .180
.0175 .225
.025 .275
.035 .350
.050 .450
.070 .550
.090 .650
.110 .750
D&O QCD Fit
Extrapolated Fit
xF3
x=.180
x=.225
x=.275
x=.350
x=.450
x=.550
x=.650
x=.750
CCFR xF3
Q2 [GeV2/c2]


F2
x=.0075
NMC
CCFR
E665 (x=.005)
E665 (x=.007)
E665 (x=.009)
MRS R2
CTEQ 4M
GRV 94 HO
x=.0125
NMC
E665
CCFR
MRS R2
CTEQ 4M
GRV 94 HO
x=.0175
NMC
E665
CCFR
MRS R2
CTEQ 4M
GRV 94 HO
Q2 [GeV2/c2]

# NMC

E. Kabuß

## Final update on measurements

reported last year:

$$F_2^p,\ F_2^d,\ R^d - R^p,\ F_2^d/F_2^p$$

+

Nuclear effects

$F_2^{Sn}/F_2^C$ $Q^2$ dependence

A dependence of nuclear effects

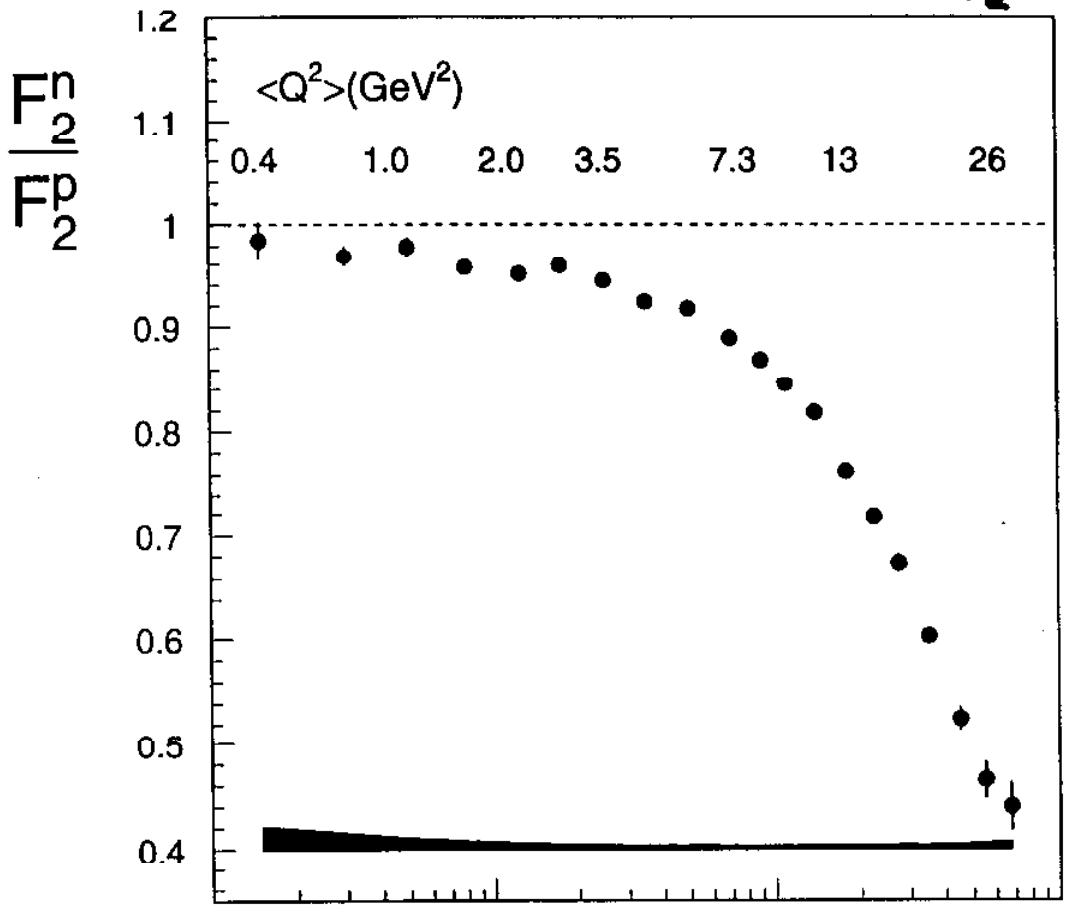
examples

⇒ Very precise "$\frac{F_2^n}{F_2^p}$" (nuclear effects) ⟶

⇒ Measurement of R ⟶

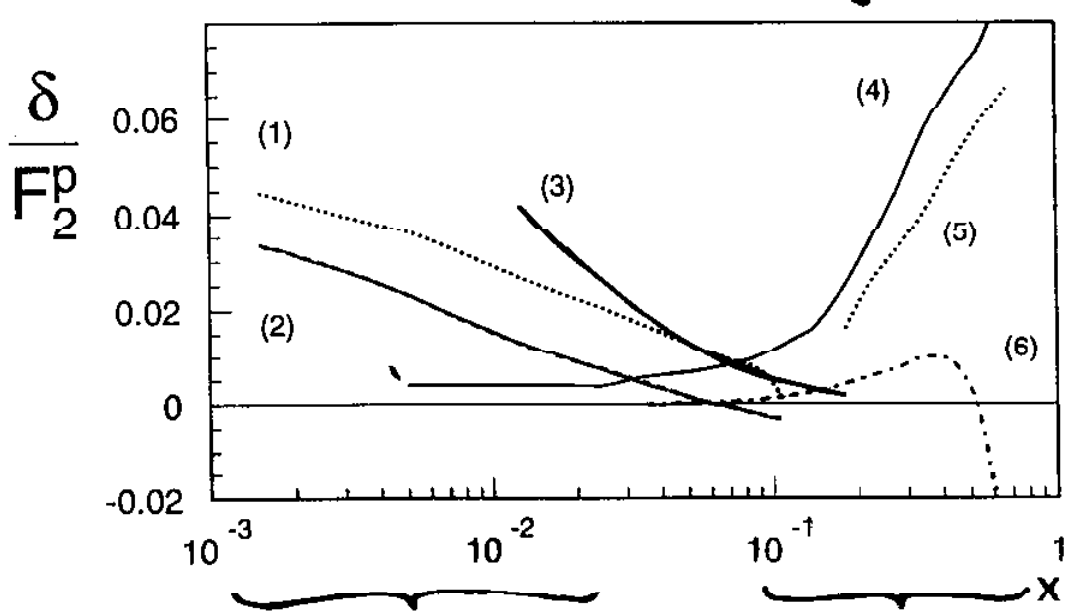
# Results for $F_2^n / F_2^p(x)$

- nuclear effects neglected: $\frac{F_2^n}{F_2^p} = 2\frac{F_2^d}{F_2^p} - 1$




from $F_2^d / F_2$

- nuclear corrections ( $\delta / F_2^p = (F_2^n / F_2^p)_{free} - F_2^n / F_2$



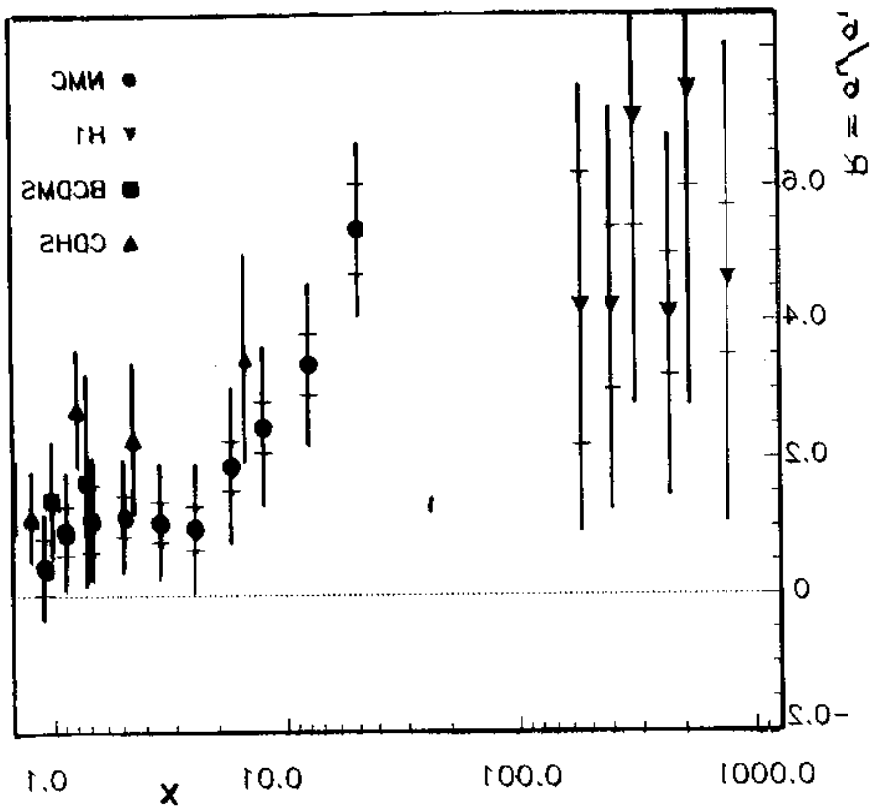

(1) Bad./Kw
(2),(5) Melnitc
(3) Nikolai
(4) Braun/Tokare
(6) Strikma

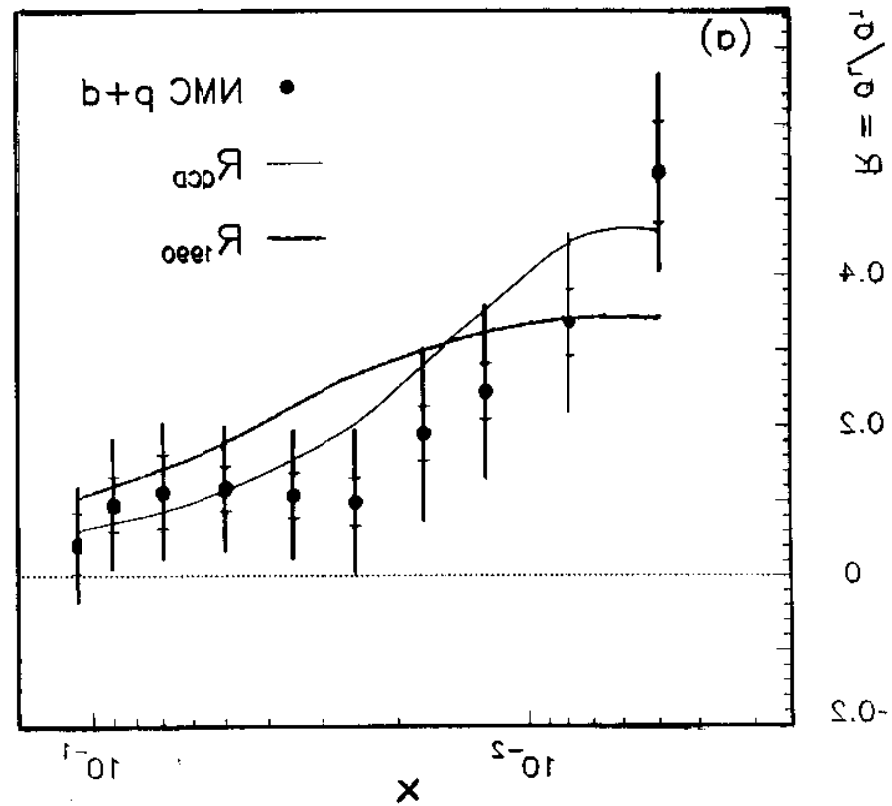
shadowing

EMC effect
Fermi motion

# Results for R(x)

- $R^d = R^p$ assumed
- limited overlap of $Q^2$ ranges => $R(x, \cancel{Q^2})$




- sensitivity to R at small x (due to y range of data)
- x range: $0.005 < x < 0.12$
- systematic errors ~ 0.1 (dominant source: 2% rel. norm.)

# Digression on $R$ measurement at HERA

## H1 $F_L$ determination

Do QCD fit to $\sigma^{NC}$
at $y < 0.35$ ($F_L \sim 0$)
evolve $F_2$ to high $y$ $\Rightarrow$ difference $\longrightarrow$
in $\sigma_{meas}$ (high $y$)
to $F_2$ evolved $\Rightarrow F_L$

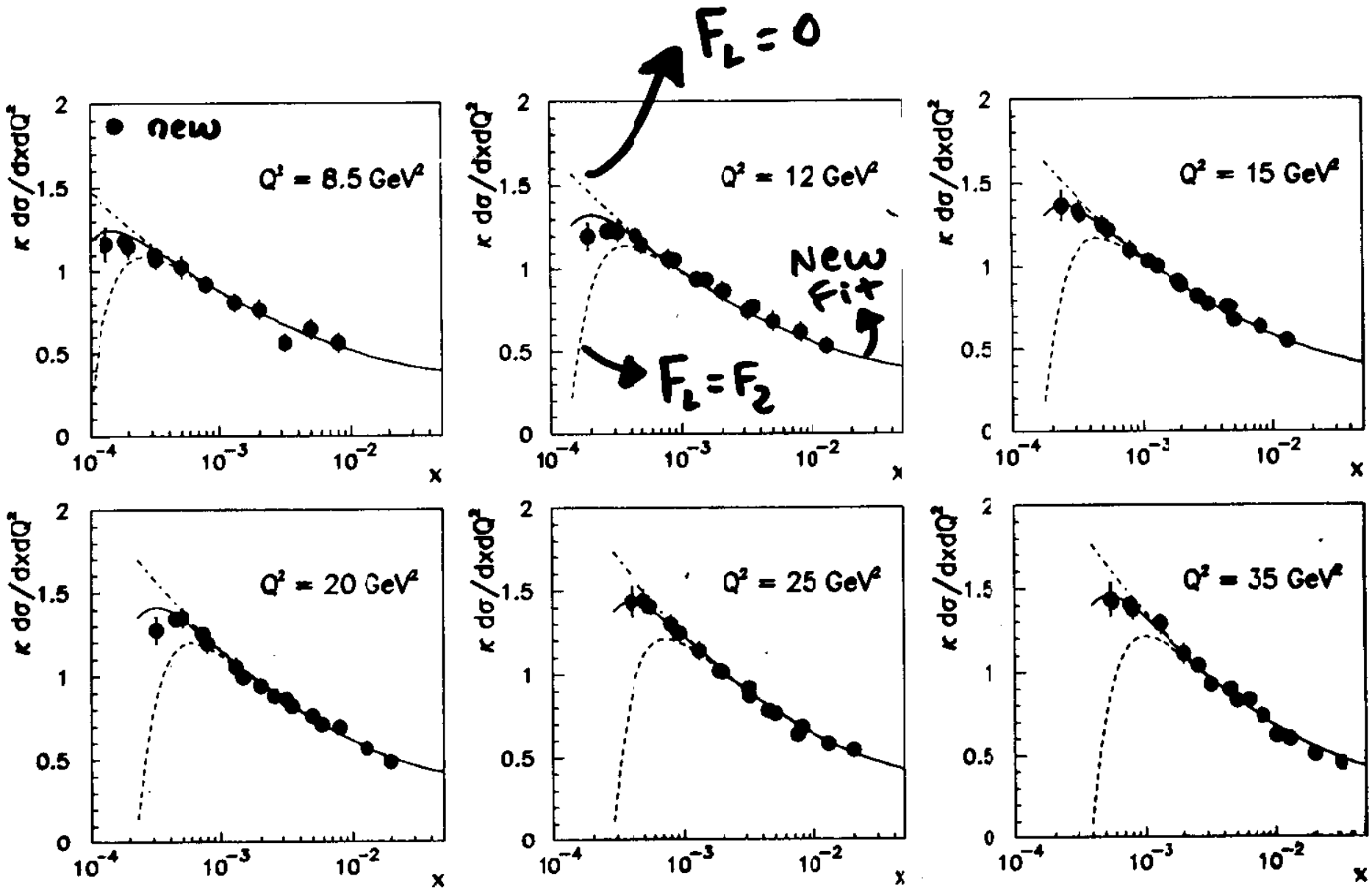
Rely on DGLAP $\Rightarrow$ consistency check?

R. Thorne $\Rightarrow$ summation (more in JB's summary)
of leading terms in $\ln\left(\frac{1}{x}\right)$ or $\ln(Q^2)$

$R \simeq \underline{2 \times R'_{DGLAP}}$ at $x \sim 10^{-4}$, $Q^2 \sim 5$ GeV

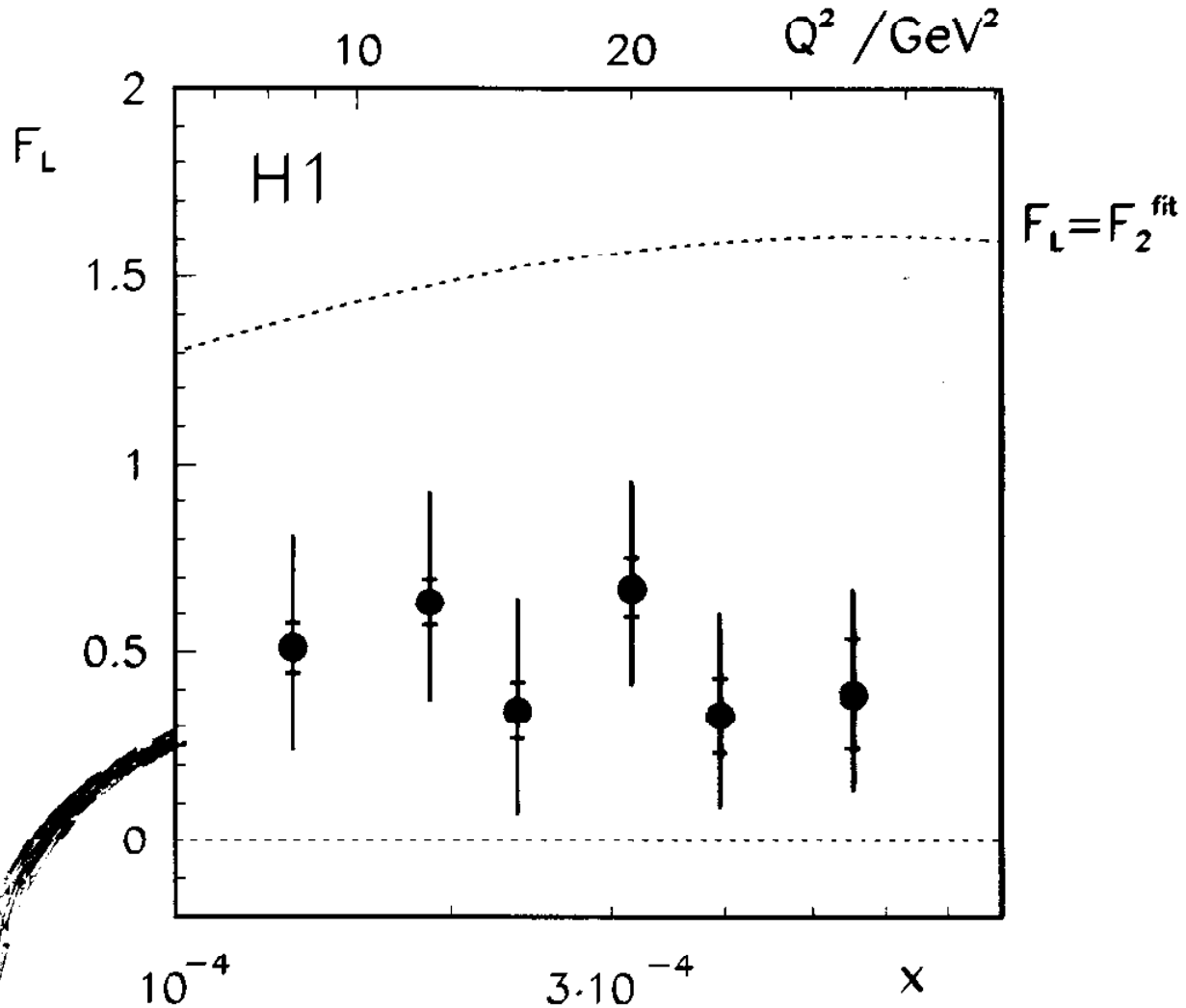
$\therefore$ Still consistent picture: lower $F_L$ $\longrightarrow$
(within H1 systematic errors)

R should be measured!

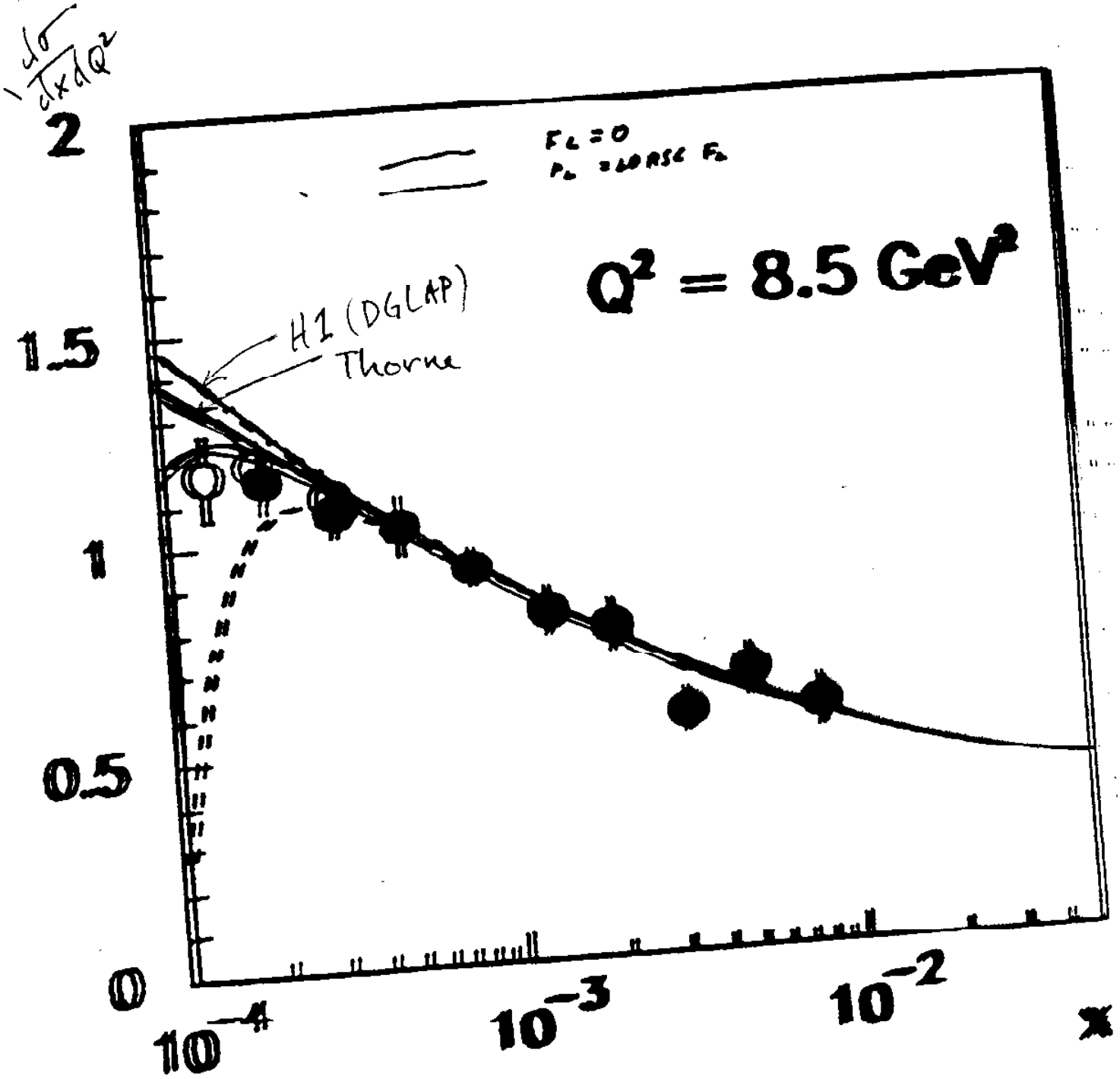

new
$Q^2$ = 8.5 GeV$^2$
$Q^2$ = 12 GeV$^2$
$Q^2$ = 15 GeV$^2$
$Q^2$ = 20 GeV$^2$
$Q^2$ = 25 GeV$^2$
$Q^2$ = 35 GeV$^2$
$\kappa\, d\sigma/dxdQ^2$
x
$F_L = 0$
New fit
$F_L = F_2$

• Extrapolation of new 12 pt at high y

(+ syst. studies on extrapolation)




Cross-section Fit excluding our new high y measurement & using N.L.O $F_L$ calculation


$\frac{d\sigma}{dx\,dQ^2}$
2
1.5
1
0.5
0
$10^{-4}$
$10^{-3}$
$10^{-2}$
x
$Q^2 = 8.5\ GeV^2$
H1 (DGLAP)
Thorne

# $\bar{u}/\bar{d}$ asymmetry from Drell-Yan

NMC Gottfried Sum Rule measurement

$$I_g = 0.235 \pm 0.026$$

$\Rightarrow$ asymmetry in the proton sea

NA51 $\quad \bar{u}/\bar{d} = 0.51 \pm 0.04 \pm 0.05$ at $x \approx 0.18$

$\Downarrow$

Drell-Yan on $D_2$ & $H_2$

Preliminary results from E866 $\quad$ R. Towell

... Note $\quad Q^2(NA51) \sim 25\ GeV^2$ $\rightarrow$

$Q^2(E866) \sim 75\ GeV^2$

$\Rightarrow$ unexpected behavior at high $x$!

# Direct $\gamma$ from E706 Tevatron

Direct $\gamma$ data compared to QCD $\longrightarrow$

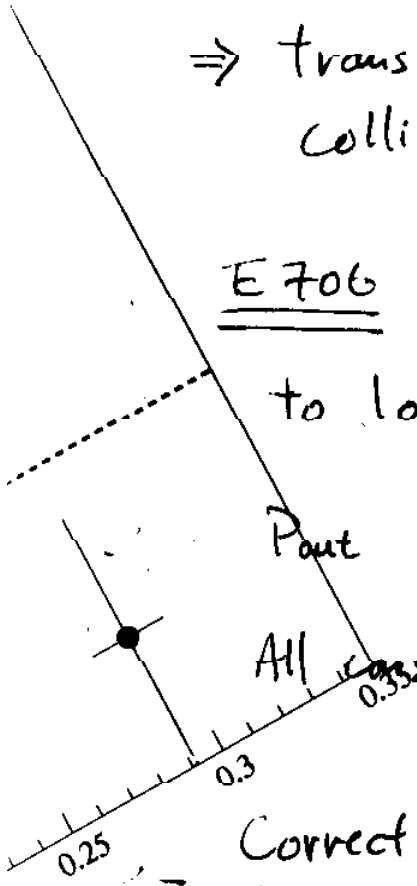
$\Rightarrow$ transverse momenta of colliding partons $\longrightarrow$ $k_T$

M. Zielinski

E706 use $p, \pi\, Be \rightarrow \gamma\gamma X$ (also $\gamma \pi_0 X$, $\pi_0 \pi_0 X$) to look for $k_T$

$P_{out}$ (out of scattering plane momentum) $\rightarrow$

All consistently lead to $\langle k_T \rangle \simeq 1.3$ GeV




Correct theory with $\langle k_T \rangle = 1.3$ GeV for cross section results $\longrightarrow$

(X range 0.2 – 0.7)

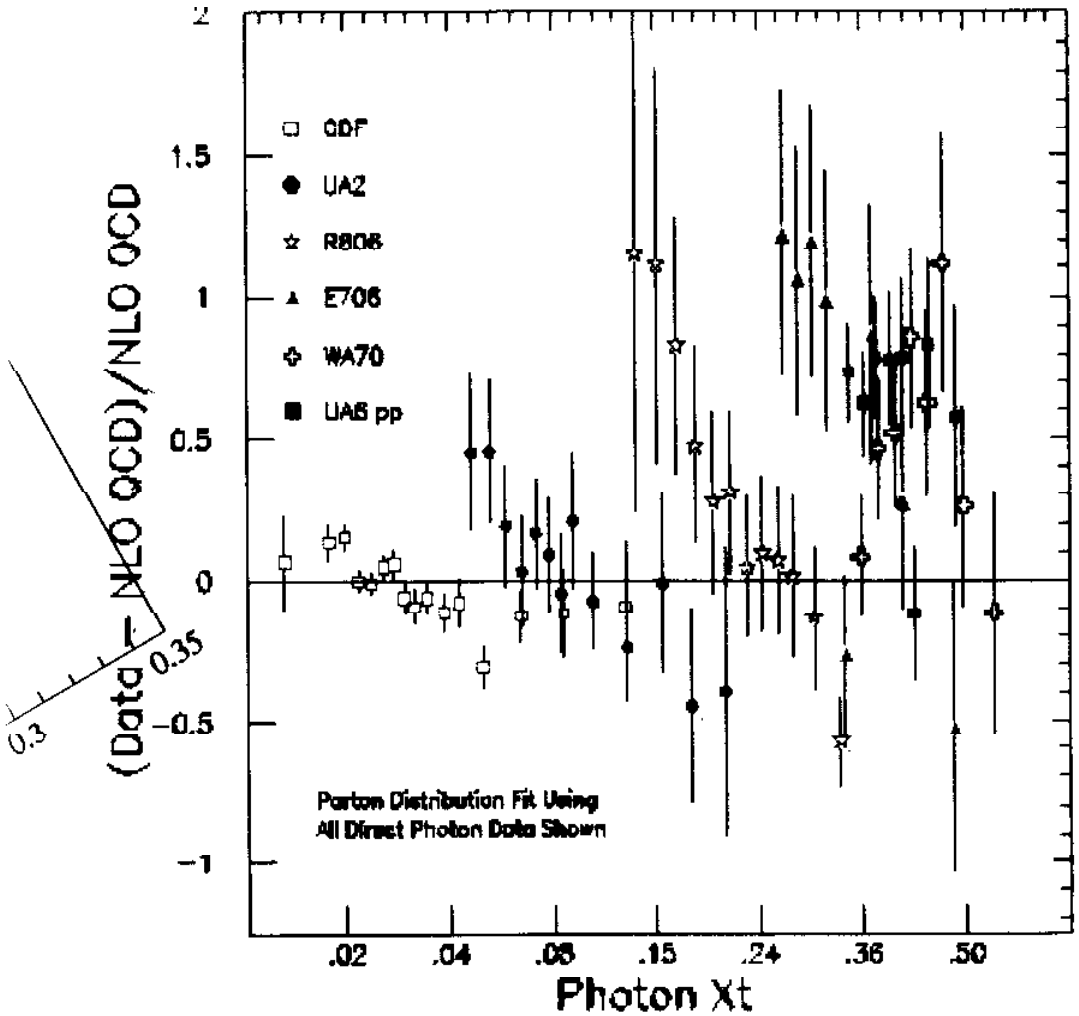
Good agreement with data..

$\rightarrow$ constraint on $g(x)$ at high $x$?

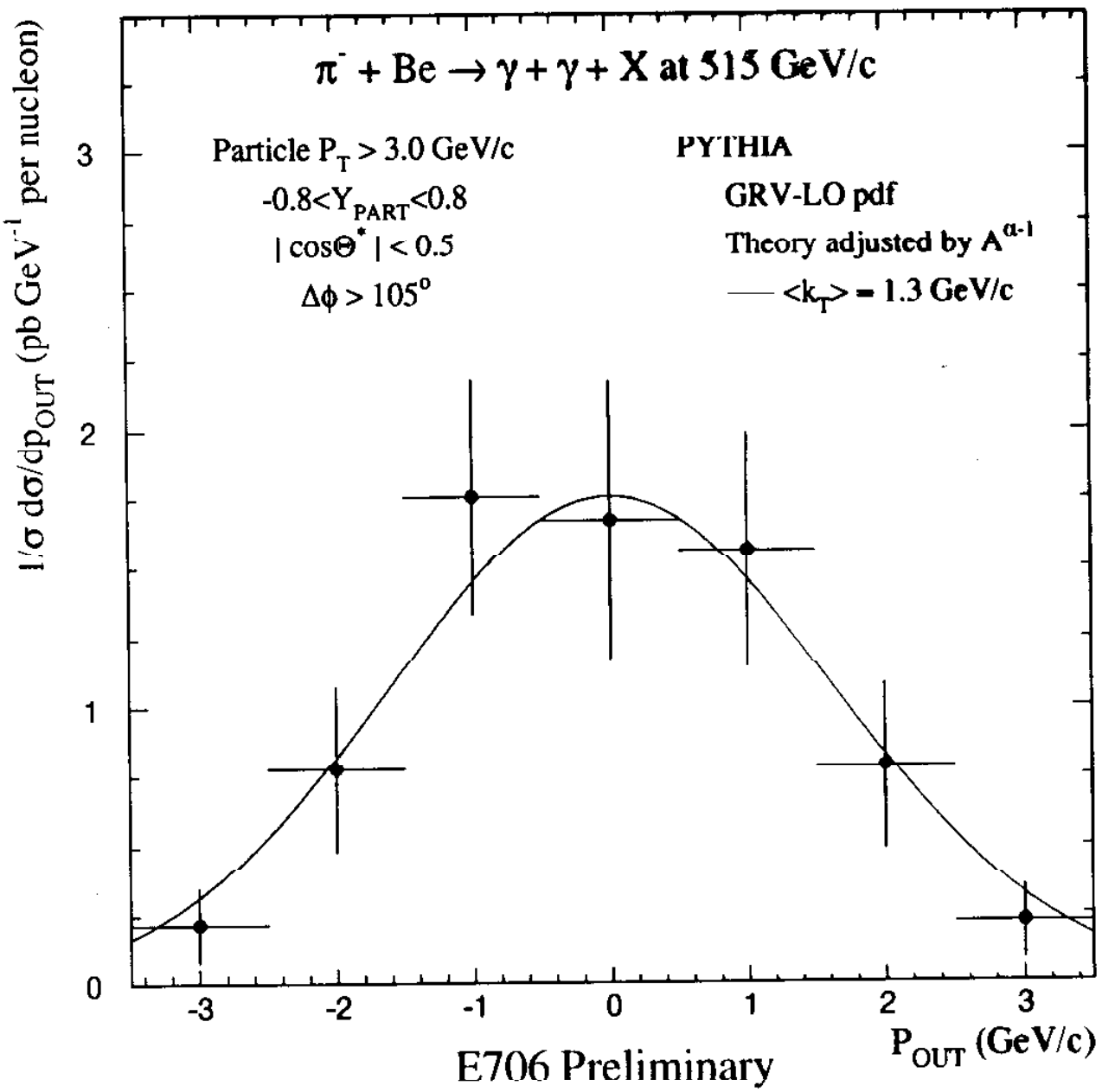
- $\langle k_T \rangle$ result of soft gluon emissions?

$\Rightarrow$ Tevatron direct $\gamma$ data well described by including parton showers $\longrightarrow$

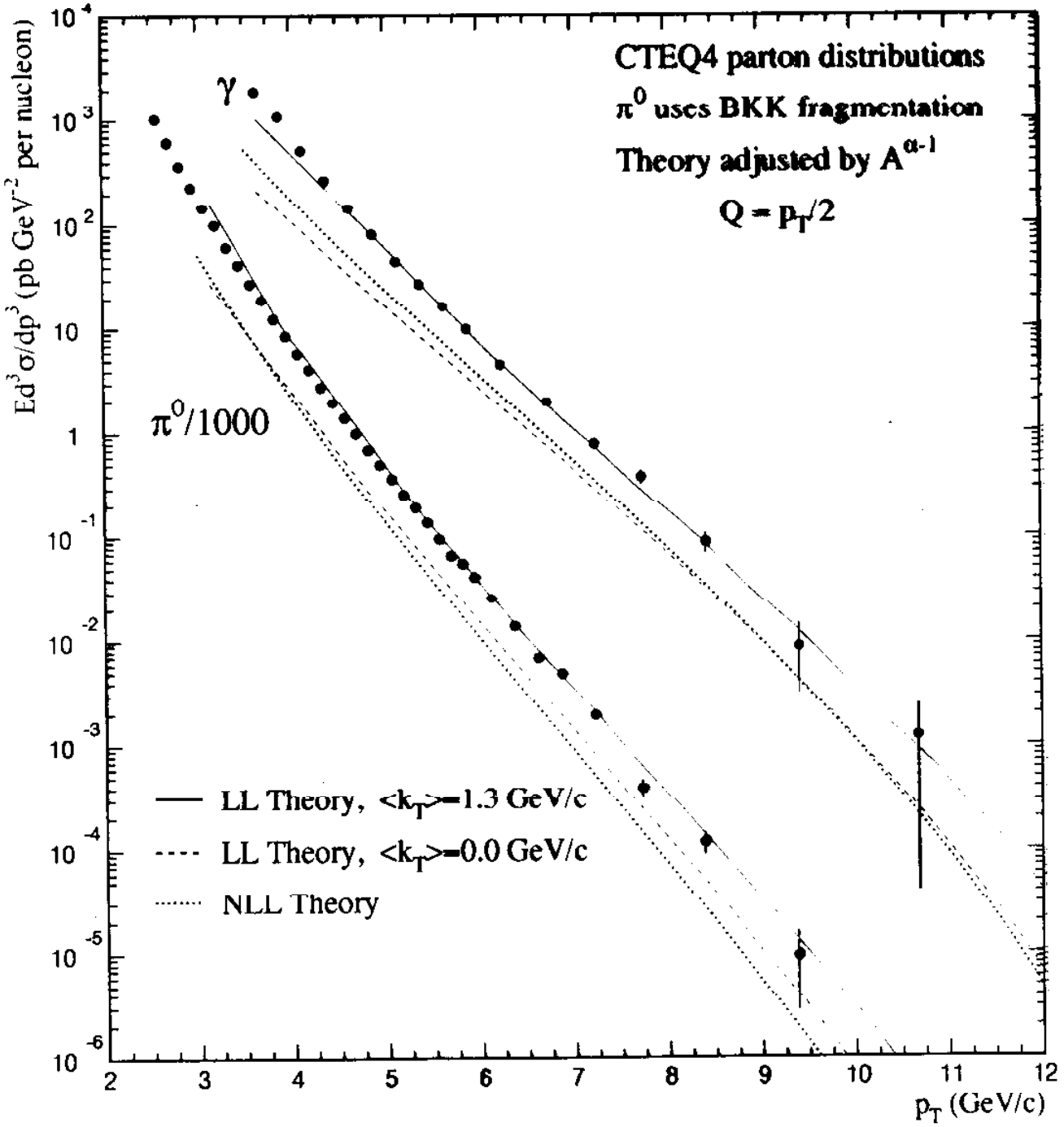
R. Blair

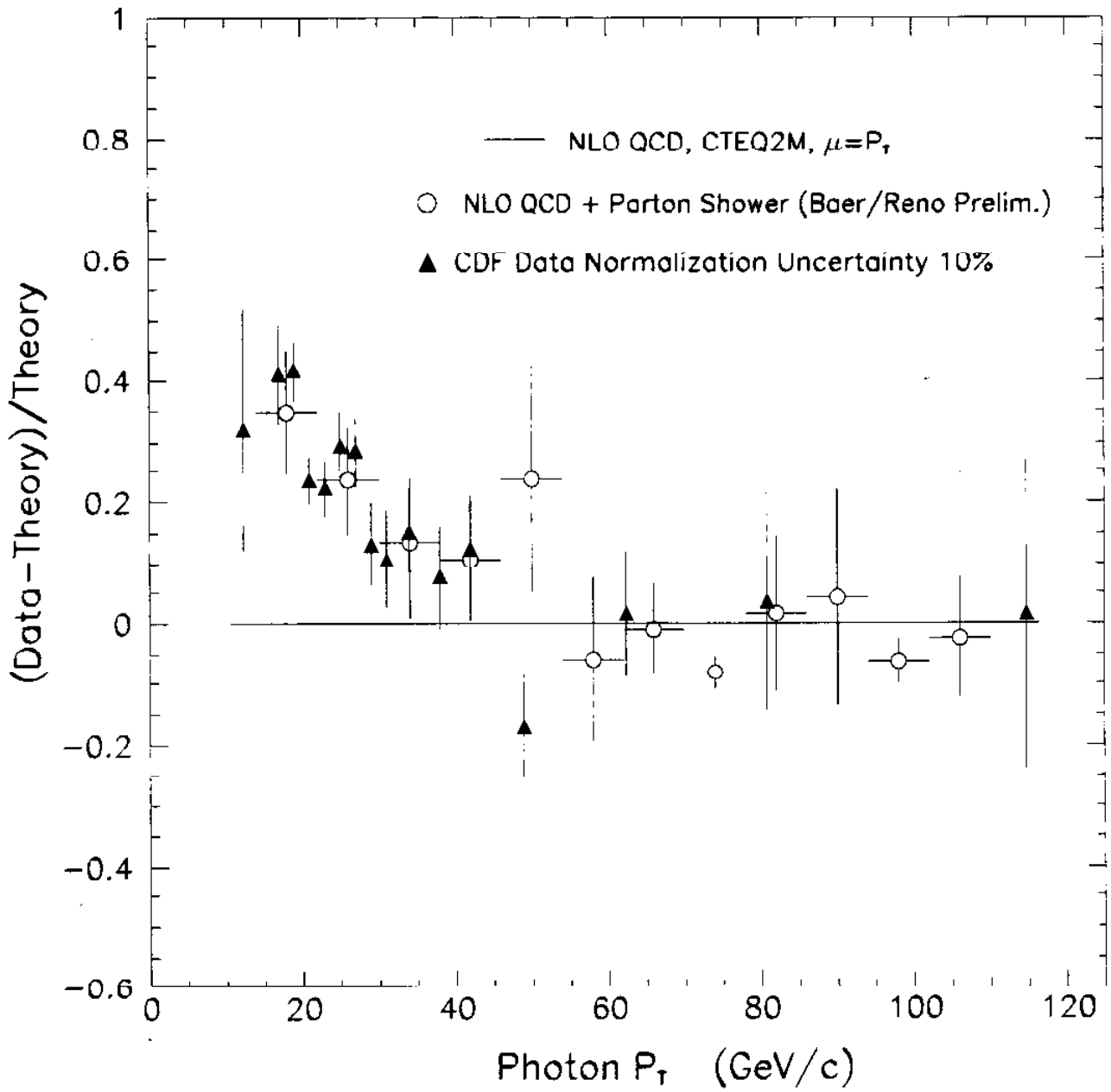



Deviations at low $E_T$ not unusual
seen at low $E_T$ NOT at low x!
The explanation appears to be soft multiple gluon emmission and can be modeled by adding shower MC's to standard NLO QCD.


$\pi^- + Be \rightarrow \gamma + \gamma + X$ at 515 GeV/c
Particle $P_T > 3.0$ GeV/c
$-0.8 < Y_{PART} < 0.8$
$|\cos\Theta^*| < 0.5$
$\Delta\phi > 105^o$
PYTHIA
GRV-LO pdf
Theory adjusted by $A^{\alpha-1}$
$\langle k_T \rangle = 1.3$ GeV/c
$1/\sigma\, d\sigma/dp_{OUT}$ (pb GeV$^{-1}$ per nucleon)
$P_{OUT}$ (GeV/c)
E706 Preliminary

# E706 pBe at 530 GeV




NLO QCD, CTEQ2M, $\mu=P_T$
NLO QCD + Parton Shower (Baer/Reno Prelim.)
CDF Data Normalization Uncertainty 10%
(Data−Theory)/Theory
Photon $P_T$ (GeV/c)
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
0
20
40
60
80
100
120

# Structure functions from HERA

Improved measurements at low $x$ & low $Q^2$ $\longrightarrow$

A. Meyer, B. Surrow

H1, ZEUS modification, upgrade of rear calorimetry

+ Short runs with interaction vertex shifted to improve $Q^2$ acceptance.

- $F_2$ vs $x$ in bins of $Q^2$ $\longrightarrow$
- $\sigma^{tot}_{\gamma^* p} \simeq \frac{4\pi^2\alpha}{Q^2} F_2$ vs. $W$ in bins of $Q^2$ $\longrightarrow$
- $\sigma^{eff}_{\gamma^* p} = \sigma_T + \epsilon\sigma_L$ vs. $Q^2$ in bins of $W$ $\longrightarrow$

Transition from photoproduction to DIS regime is smooth.

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Virtual $\gamma$ structure: H1 T. Ebert.

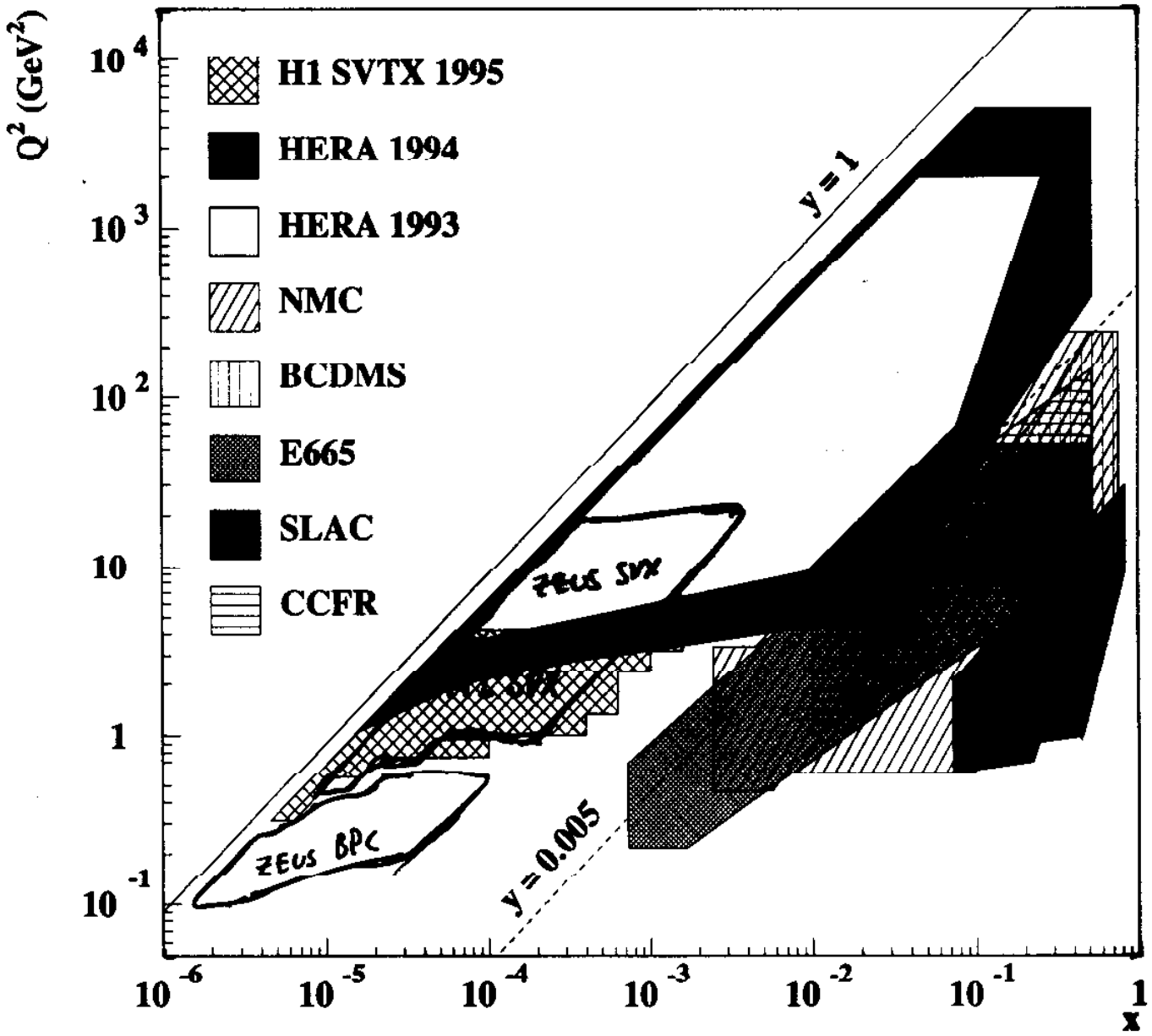
$Q^2 > 0$ but $p_t^2 \gg Q^2$

$\rightarrow$ probe the structure of $\gamma^*$

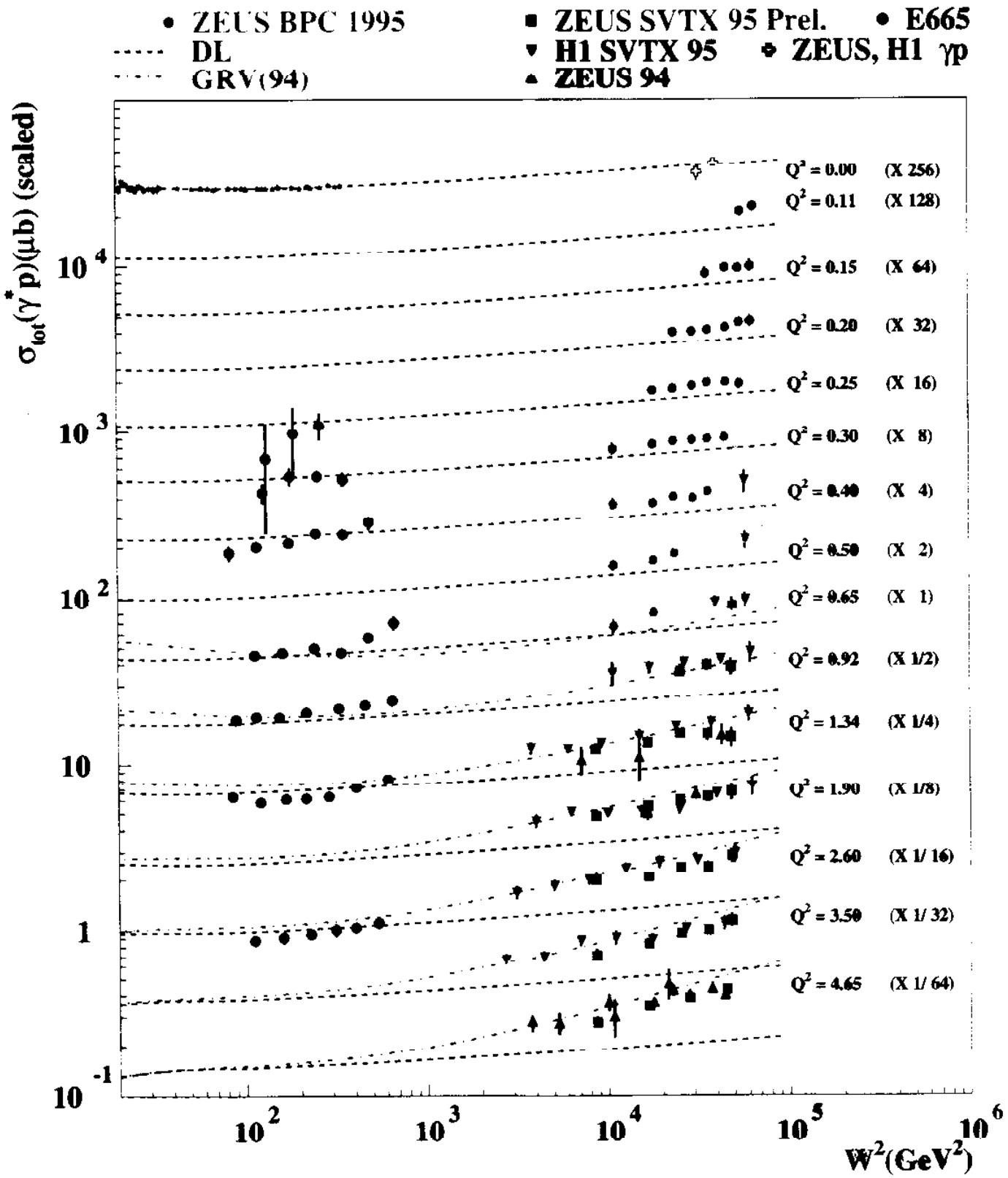
or look for "resolved" component.

use $k_t$ algorithm & look for jets $\longrightarrow$

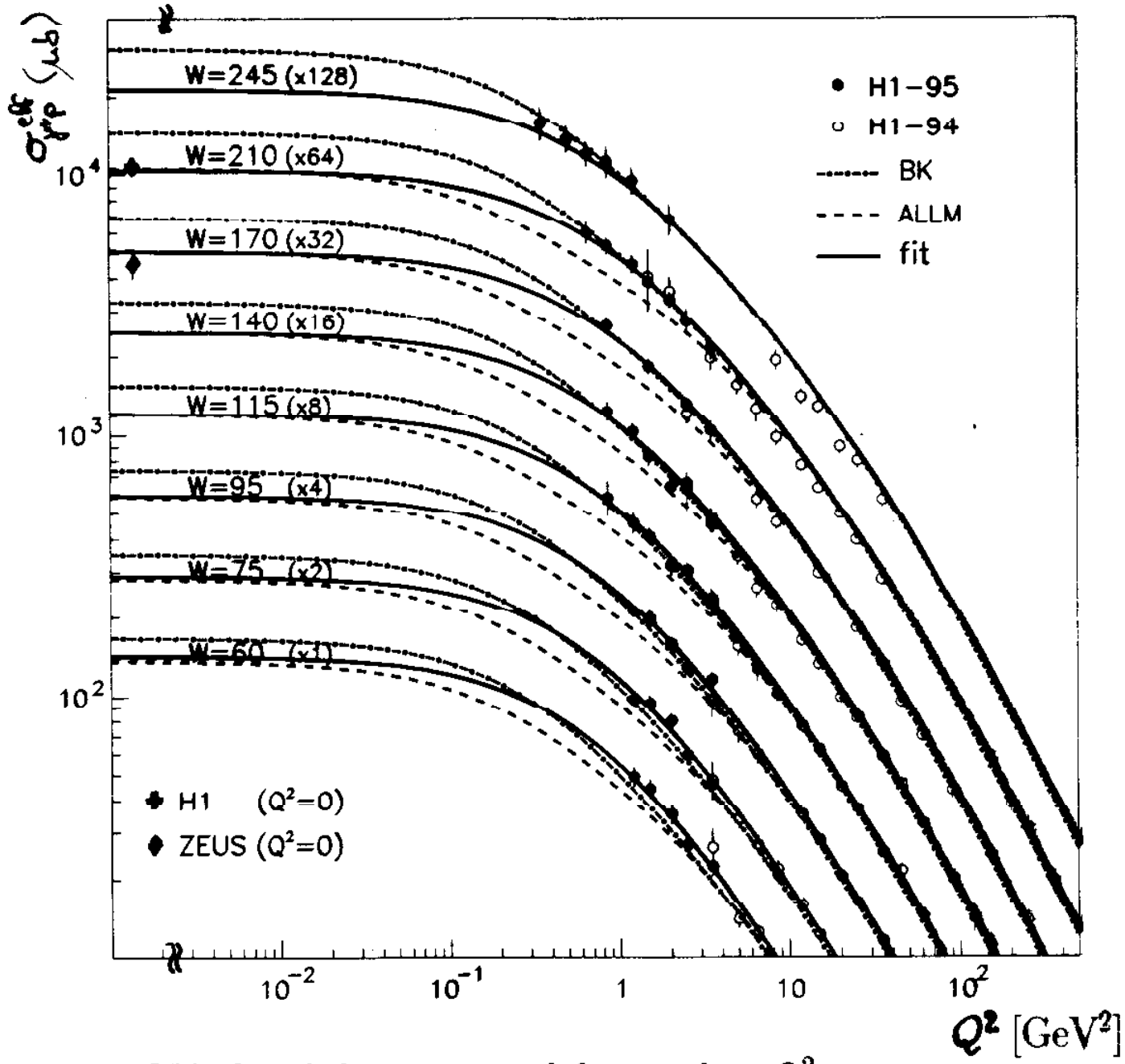
Ask for jets with $E_T^* > 4$ GeV


H1 SVTX 1995
HERA 1994
HERA 1993
NMC
BCDMS
E665
SLAC
CCFR
y = 1
y = 0.005
ZEUS SVX
ZEUS BPC
$Q^2$ (GeV$^2$)
x
$10^4$
$10^3$
$10^2$
10
1
$10^{-1}$
$10^{-6}$
$10^{-5}$
$10^{-4}$
$10^{-3}$
$10^{-2}$
$10^{-1}$
1

- ZEUS $\sigma_{tot}(\gamma^* p)$ results



## $Q^2$ Dependence



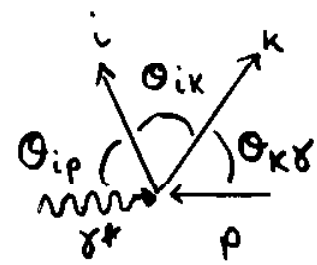

- BK: Good description of data at low $Q^2$.
- Fit to accommodate photoproduction points ($Q^2 = 0$):

$$F_2(x, Q^2) = C_{\rm VMD} \cdot F_2^{\rm VMD}(x, Q^2) + \frac{Q^2}{Q_0^2 + Q^2} F_2^{\rm QCD}(\bar{x}, Q^2 + Q_0^2)$$

$$C_{\rm VMD} = 0.77, \qquad Q_0^2 = 0.45 {\rm GeV}^2$$

## Jet Reconstruction

- Jets reconstructed in $\gamma^*$p centre of mass frame from calorimeter clusters.
- A $k_t$ clustering algorithm was used. (c.f Catani + Webber)
- Use test variables:



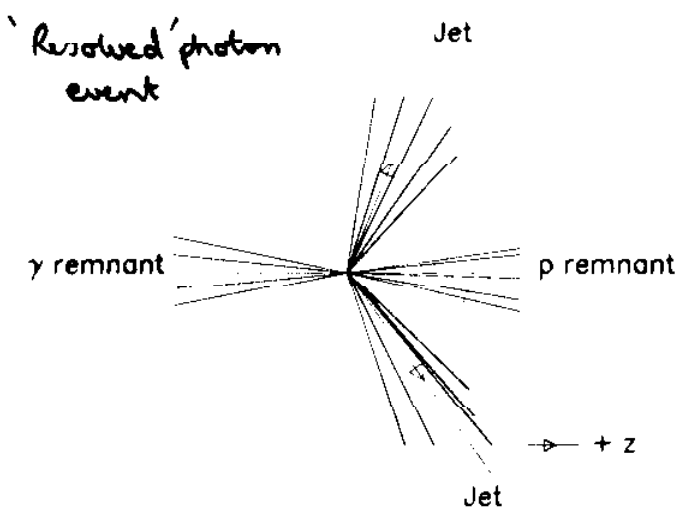

$$y_{k\gamma} = \frac{2(1-\cos\theta_{k\gamma})}{E_{cut}^2} E_k^2$$

$$y_{kp} = \frac{2(1-\cos\theta_{kp})}{E_{cut}^2} E_k^2$$

$$y_{ki} = \frac{2(1-\cos\theta_{ki})}{E_{cut}^2} \min(E_k^2, E_i^2)$$

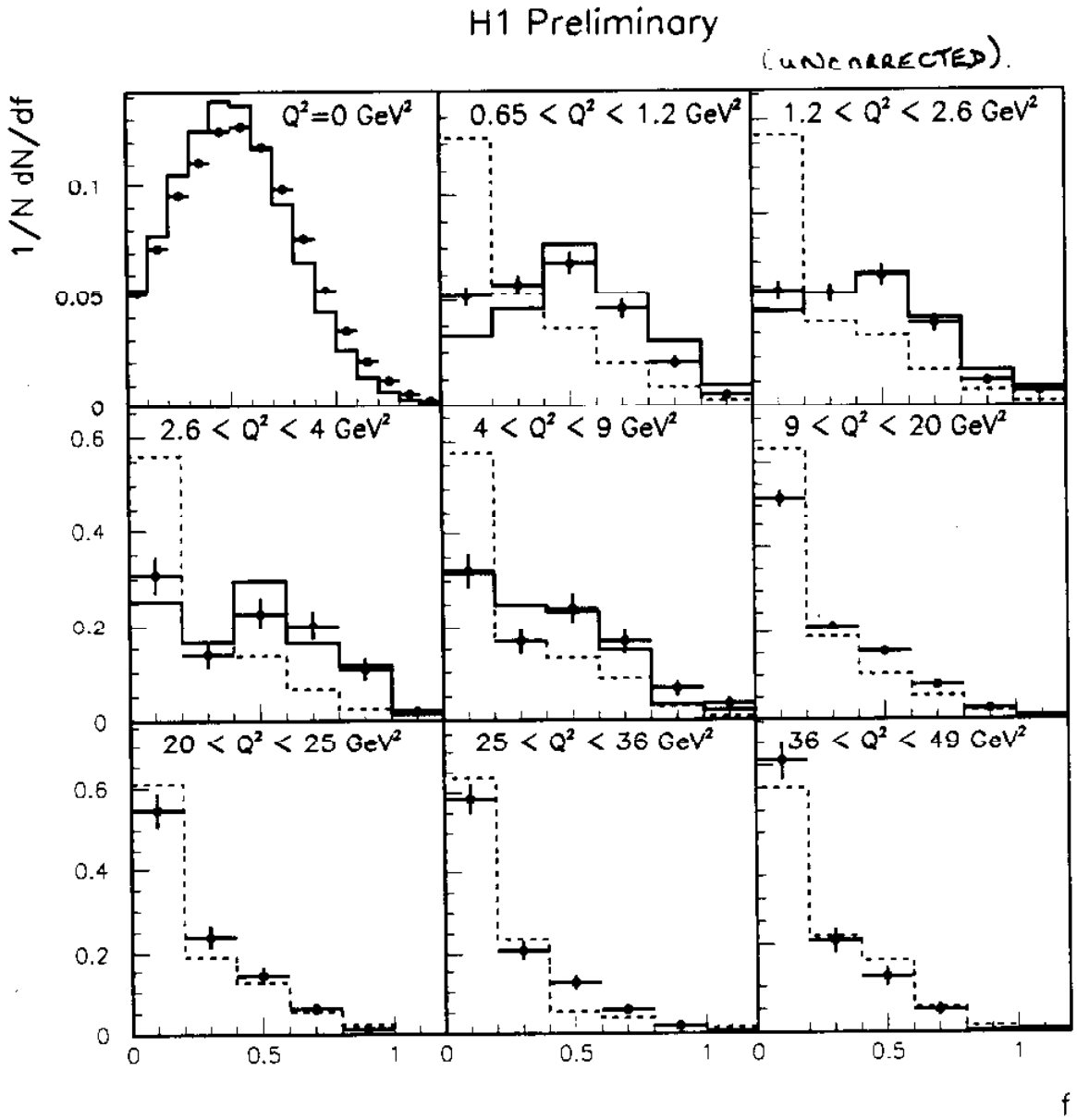
and combine particles by addition of 4-vectors when $y < 1$.

- Particles assigned to photon and proton remnant as well as to high $p_t$ jets.



$f = \frac{\sum_{\gamma\,rem} E_i}{E_\gamma}$

## Photon remnant




- **H1 Data (preliminary)**
- - - - **LEPTO(DIS)**
—— **HERWIG $\gamma^*$p Model (Direct+Resolved)**

# $F_2$ Charm at HERA

From $D^*$ cross section in DIS

ZEUS preliminary 94, 95 results $\longrightarrow$

H1 published 94 results

The real measurement is $D^*$ cross section in a $P_t$ & $\eta$ range..

For ZEUS $P_T(D^*) > 1.3$ GeV

$|\eta(D^*)| < 1.5$ $\longrightarrow$

Use NLO QCD BGF (Smith, Harris) [H1 LOMC] to extrapolate $\sim$ 60%

$\Rightarrow$ Check consistency of gluon extraction

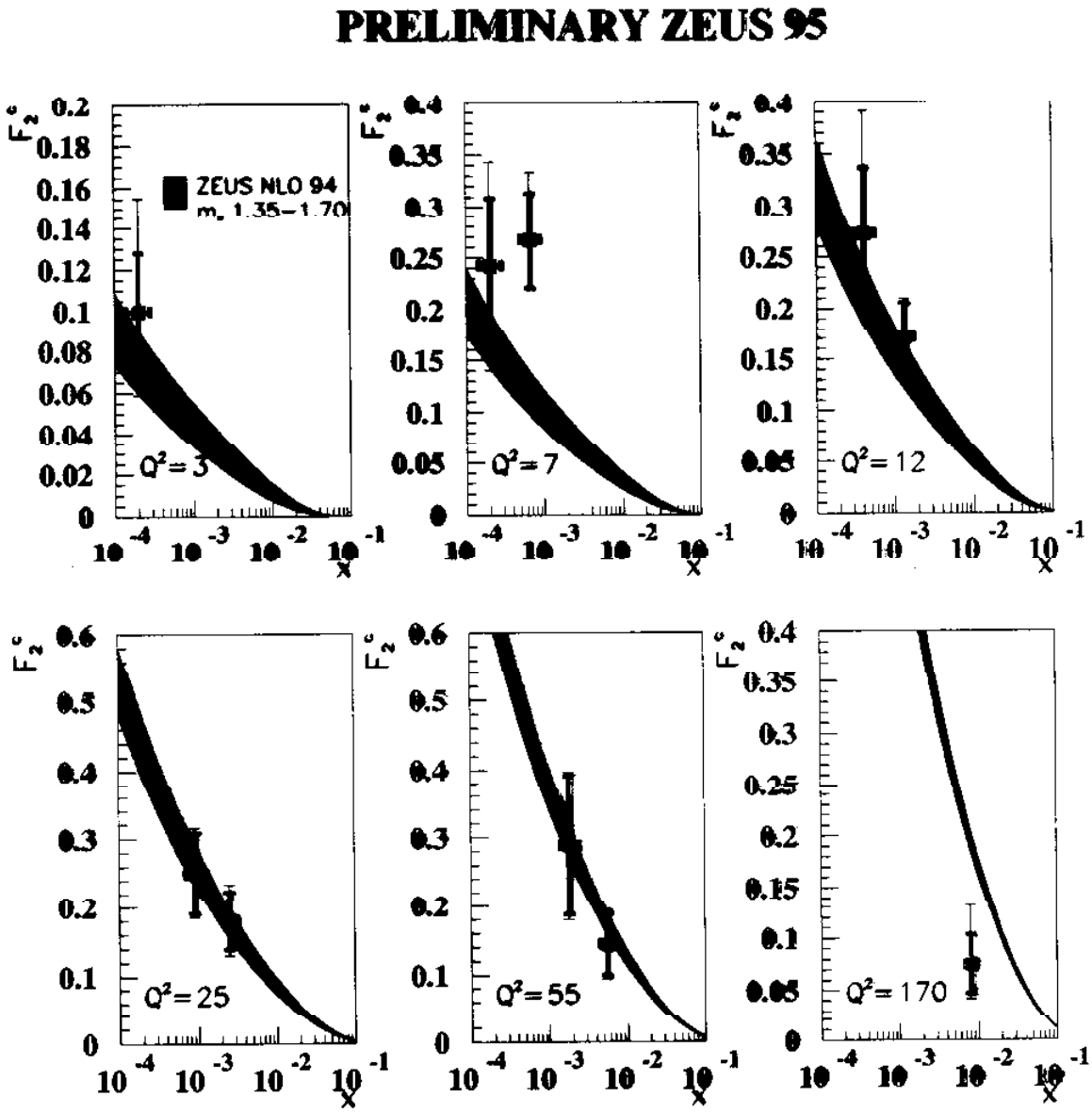
NLO QCD fit in FFN scheme H1 F. Zomer, ZEUS M. Botje

extrapolate $D^*$ cross section with NLO BGF to $F_2^{charm}$

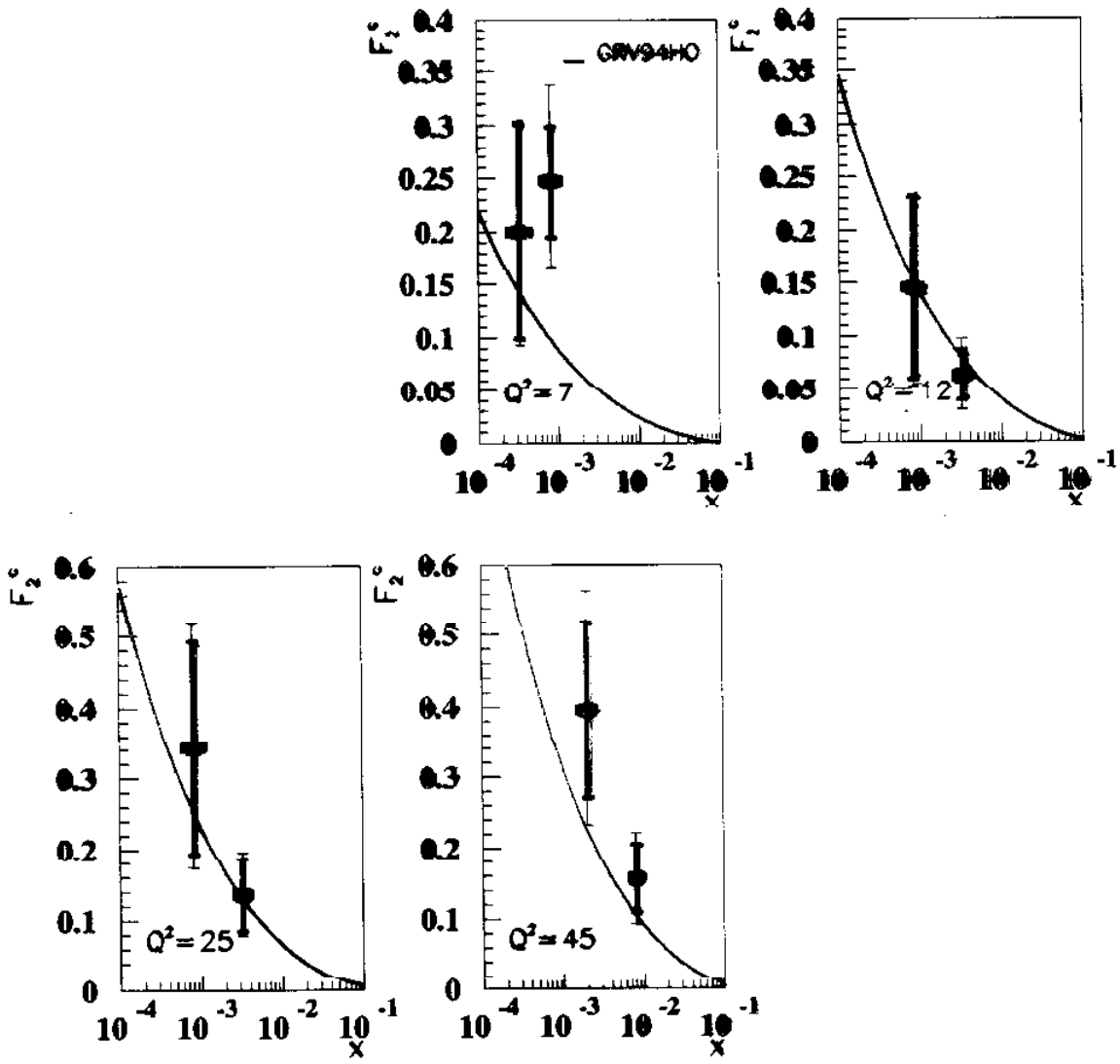
$\longrightarrow$ See if gluon from fit compatible with $F_2^{charm}$.

Tevatron measurement $p\bar{p} \to \gamma c X$ $\longrightarrow$

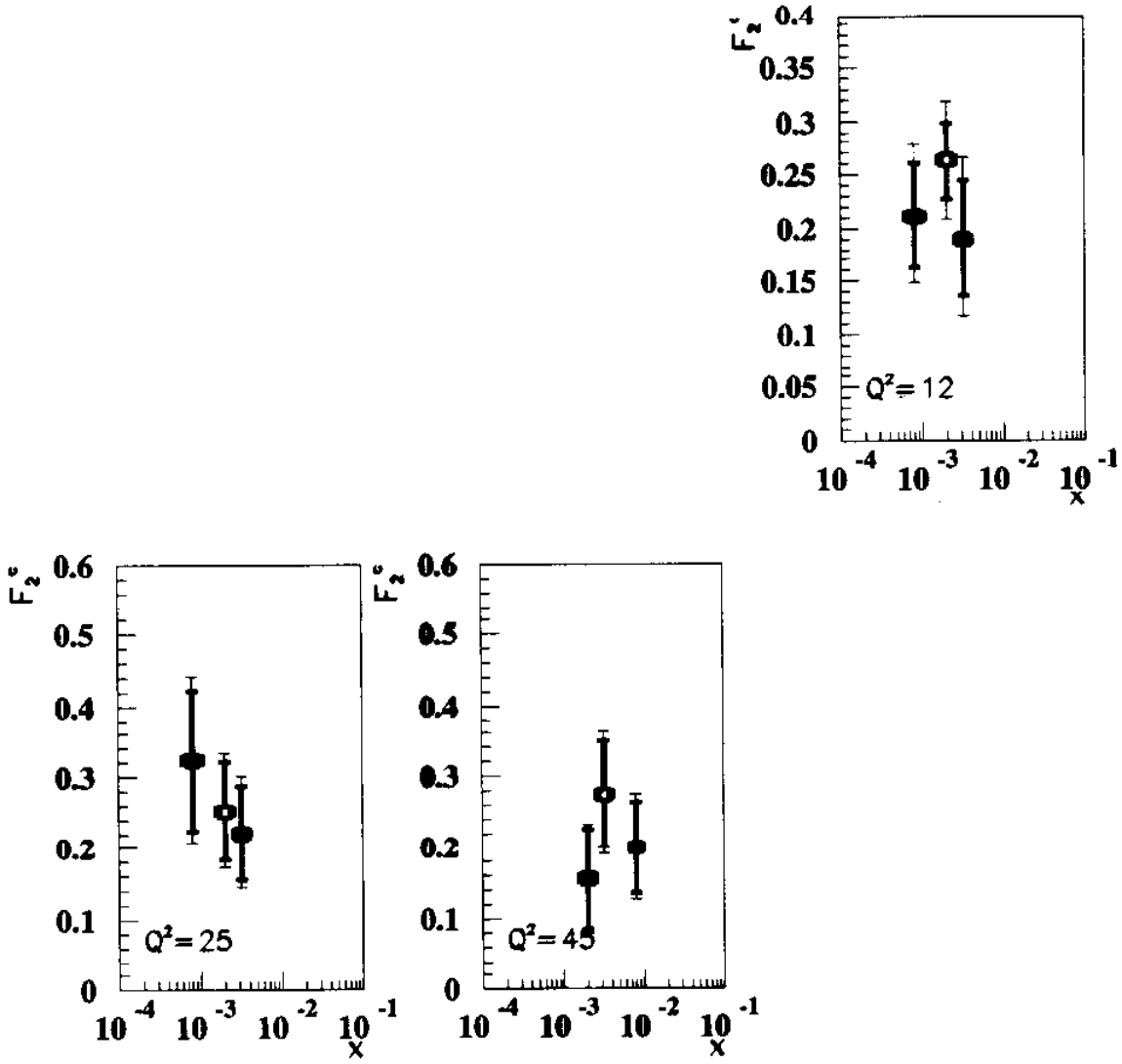
R. Bernstein


PRELIMINARY ZEUS 95
ZEUS NLO 94
$F_2^c$
x
$Q^2 = 3$
$Q^2 = 7$
$Q^2 = 12$
$Q^2 = 25$
$Q^2 = 55$
$Q^2 = 170$

# ZEUS 94

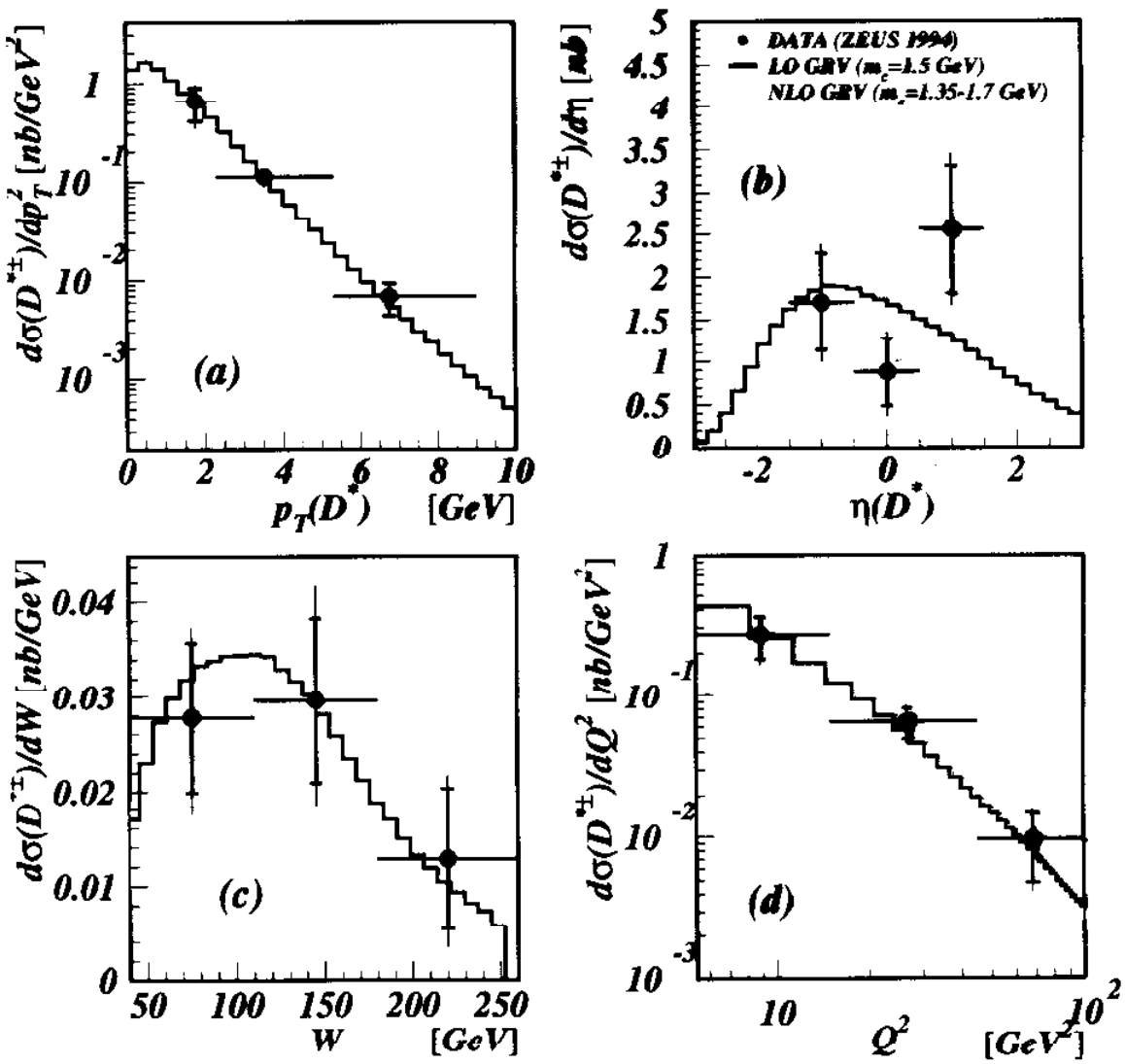


# H1 94


$F_2^c$
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
$Q^2 = 12$
$10^{-4}$ $10^{-3}$ $10^{-2}$ $10^{-1}$
x
$F_2^c$
0.6
0.5
0.4
0.3
0.2
0.1
0
$Q^2 = 25$
$10^{-4}$ $10^{-3}$ $10^{-2}$ $10^{-1}$
x
$F_2^c$
0.6
0.5
0.4
0.3
0.2
0.1
0
$Q^2 = 45$
$10^{-4}$ $10^{-3}$ $10^{-2}$ $10^{-1}$
x

**The same procedure was followed dividing the signal in bins of $W$, $Q^2$, $\eta(D^*)$ and $p_T(D^*)$ to obtain the differential cross sections :**

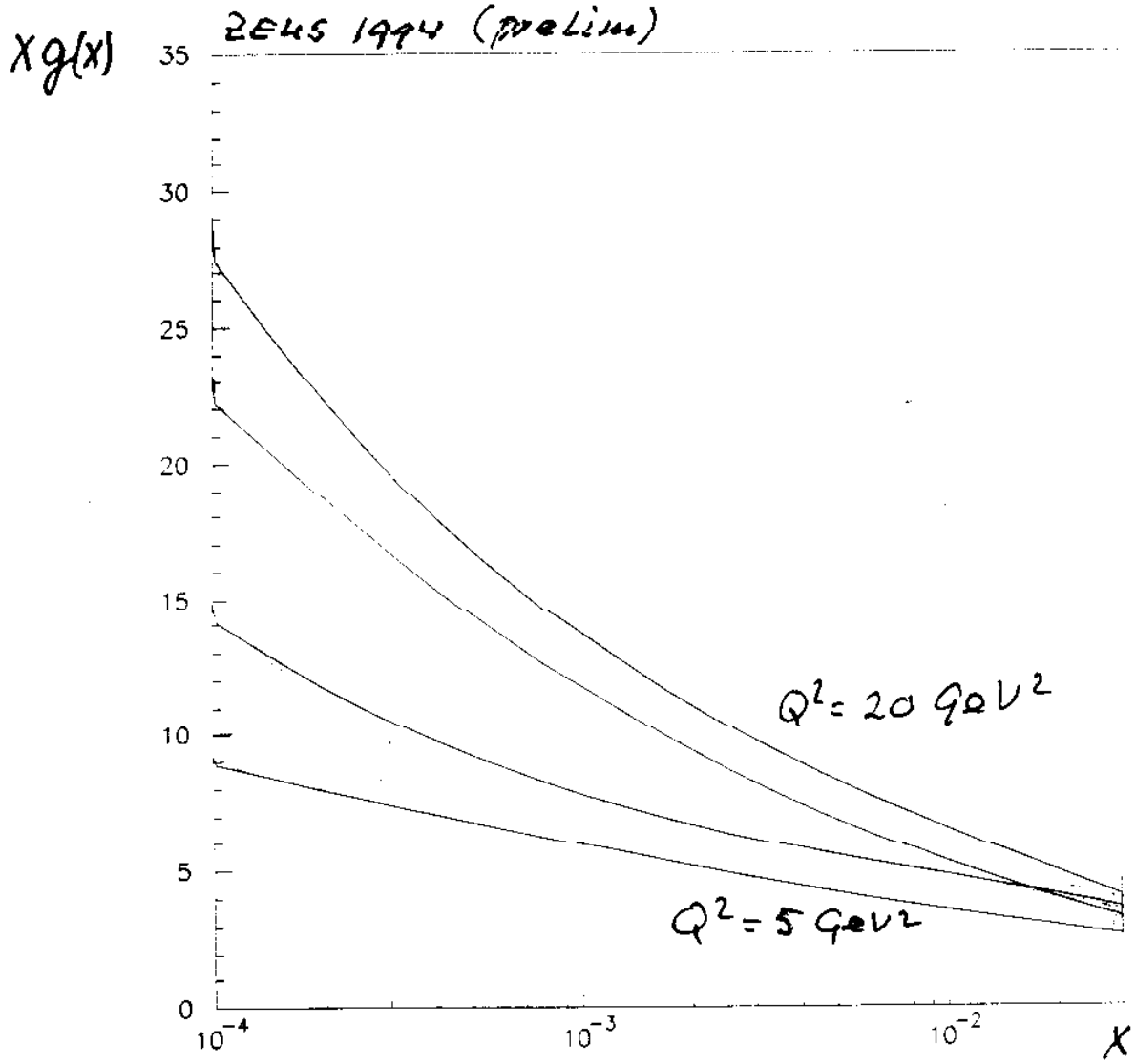
PRELIMINARY

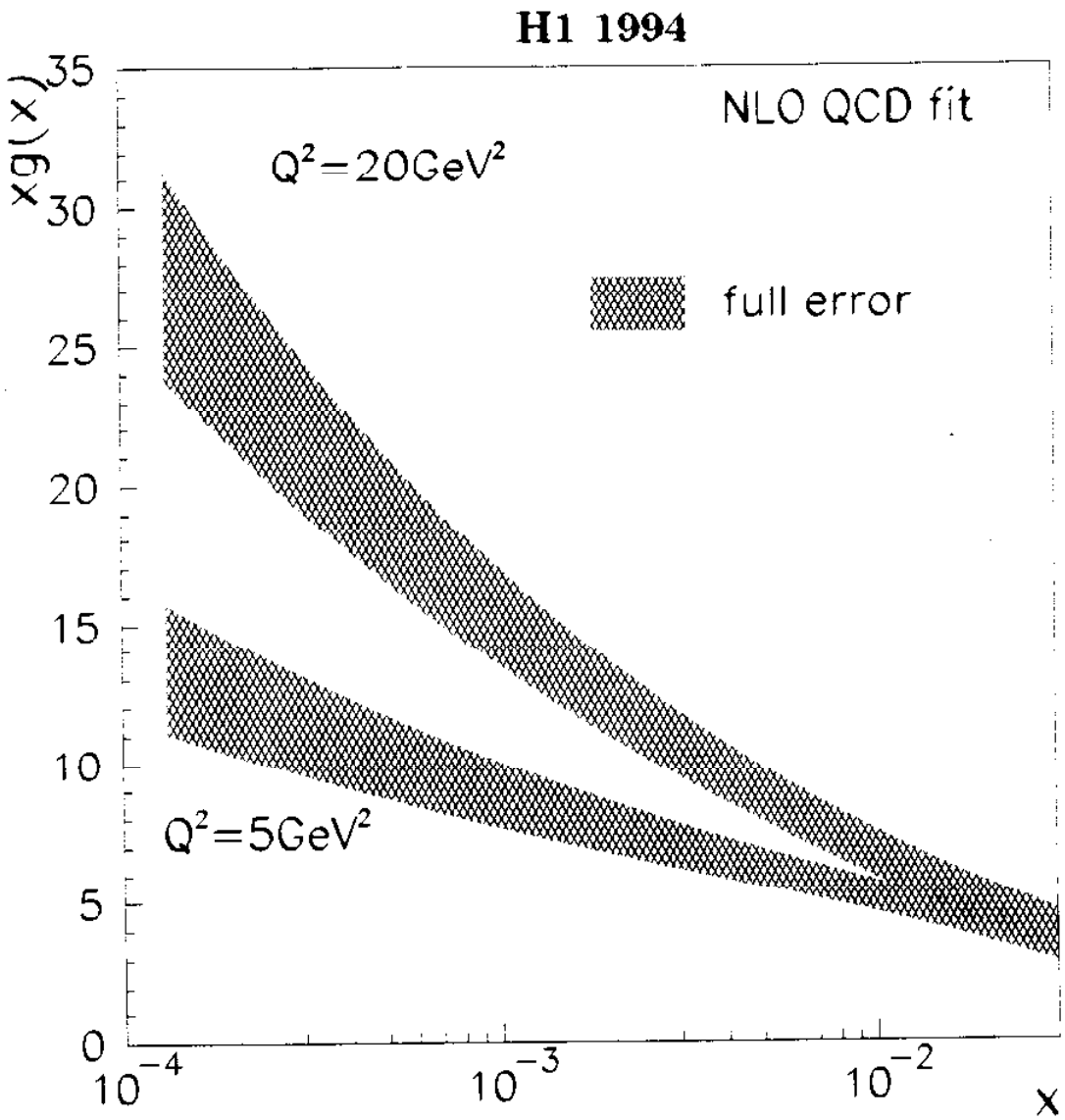



**Differential cross sections for D* production versus $p_T(D^*)$, $\eta(D^*)$, $W$ and $Q^2$. The inner error bars show the statistical errors and the outer ones correspond to the statistic and systematic errors added in quadrature. The NLO PGF prediction of Smith et al. calculated with the NLO gluon densities of GRV94 is shown as a band ( varying $m_c$ from 1.35 to 1.7 ). The LO calculation ( with the LO GRV94 gluon desity ) is shown as histograms.**

$xg(x)$ at $Q^2 = 5$ and 20 GeV

total error band (incl. $\Delta\alpha_s$).



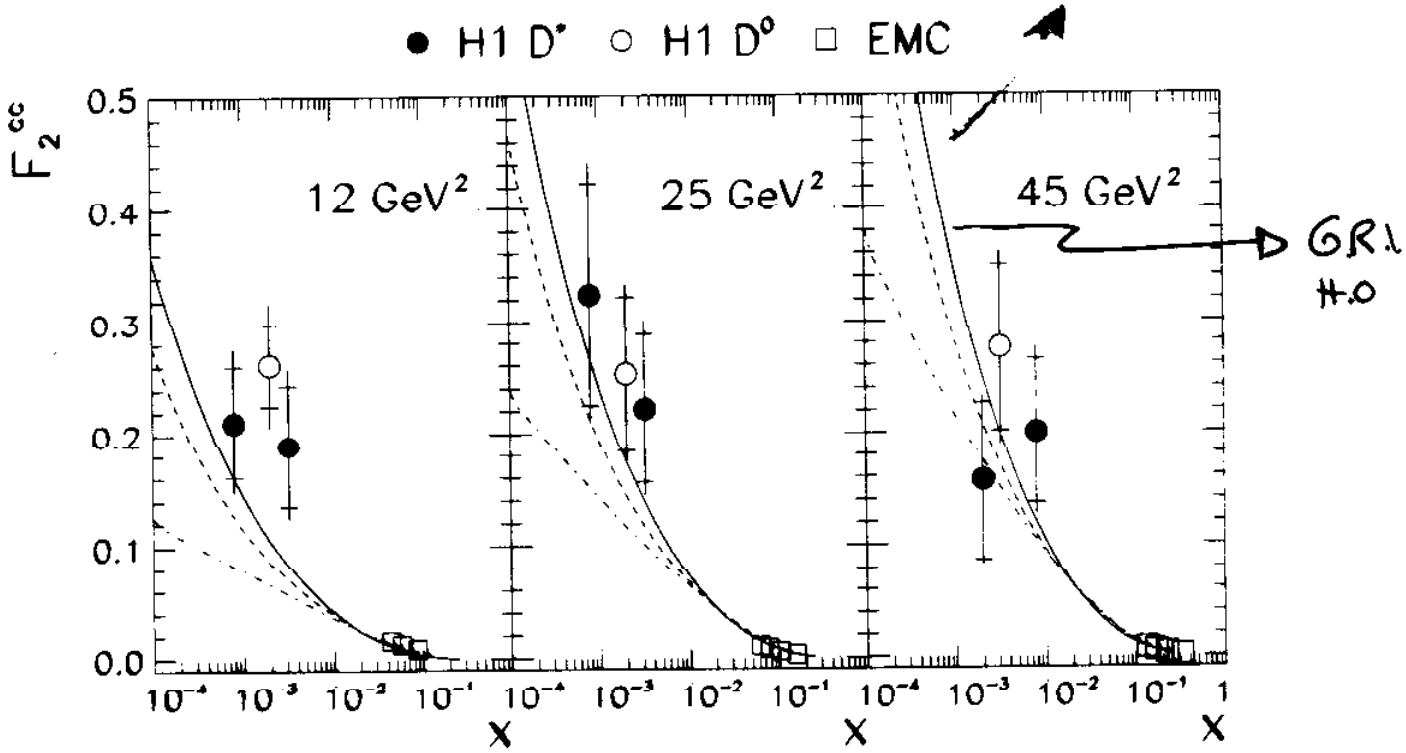

H1 1994
NLO QCD fit
$Q^2=20GeV^2$
full error
$Q^2=5GeV^2$
xg(x)
35
30
25
20
15
10
5
0
$10^{-4}$
$10^{-3}$
$10^{-2}$
x

⇒ comparison with P.G.F using B.G.F (NLO) process :

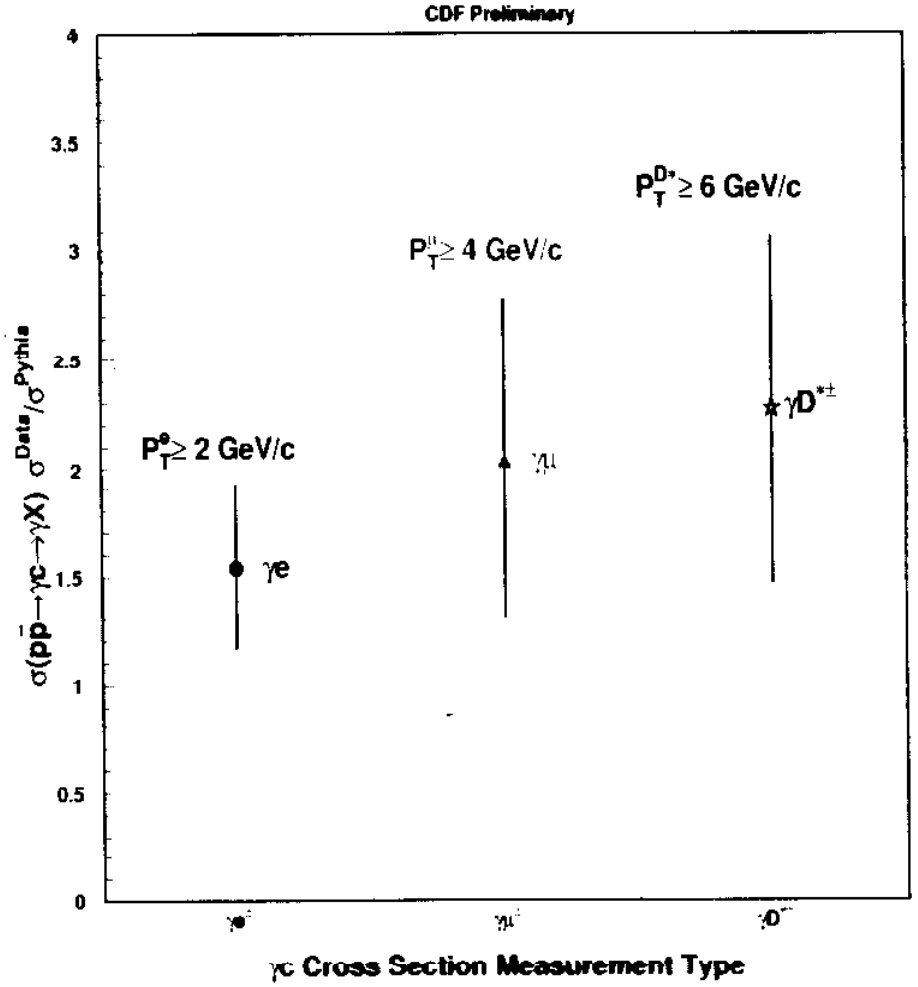
- $m_c = 1.5$ GeV ; $\mu^2_{BGF} = Q^2 + m_c^2$

H1. QCD Fit

lemp. error Propagatio




$$\Rightarrow \left\langle \frac{F_2^{c\bar{c}}}{F} \right\rangle = 23.7\% \pm 2.1\%\Big|_{stat.} \pm 4.1\%\Big|_{syst.}$$




CDF measurements of photon plus charm (sensitive to charm content of the proton). Run 1a only ~20 inverse picobarns of data, but much more photon muon data currently being analysed.

# High $Q^2$, High $x$

1 year ago .... →

Even with 94 + 95 data ($\sim 6\ pb^{-1}$) →
H1 S. Riess

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Significant excess over SM T. Carli, F. Zarnecki
at high $Q^2$, high $x$ by both H1, ZEUS →

Need more statistics
↳ double by end of 97!

SM predictions of $\sigma^{e^+p}$ (Botje / ZEUS)
propagation of experimental
statistical & systematic errors
in QCD fit →
→ conventional parton parametrization

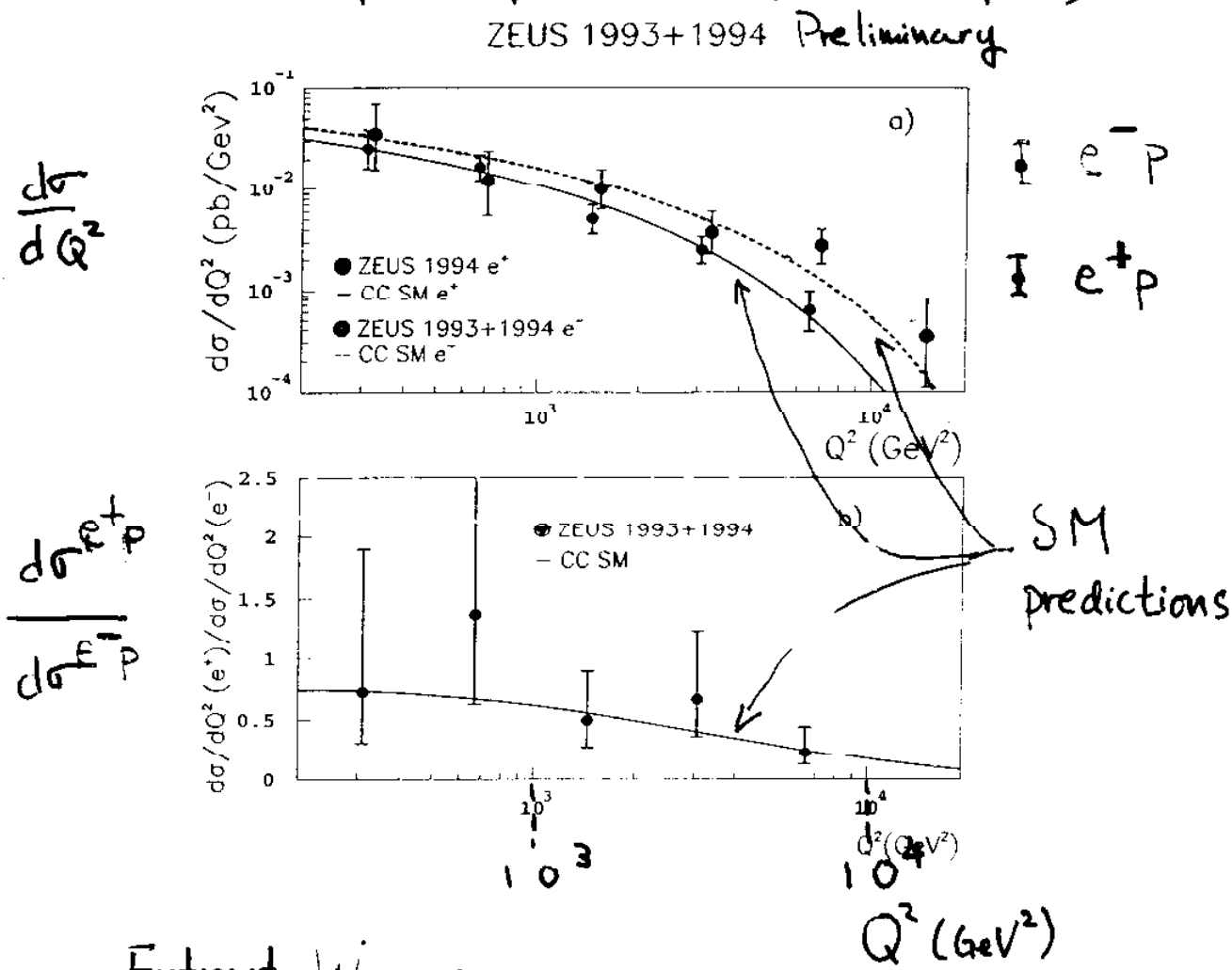
Effect of unconventional ones?
S. Kuhlman (see JB's summary)

Remember neither H1 nor ZEUS
has measured $\sigma^{e^+p}$! →

## 2. Charged Current Cross Section (A. Pieuchot's talk WG1 Tue. Aft.)

W couples to different flavors for $e^{\boxplus}, e^{\boxminus}$ beam

$e^+p$ ($\sim 3\,pb^{-1}$) $e^-p$ ($\sim 0.5\,pb^{-1}$)

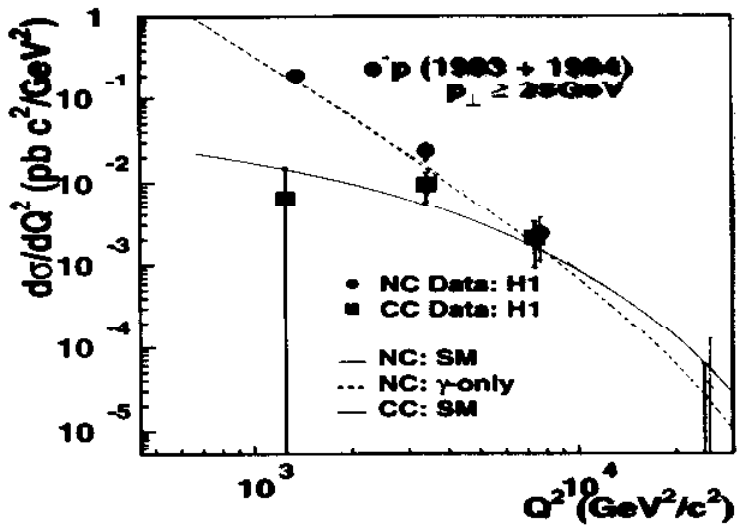



Extract W mass

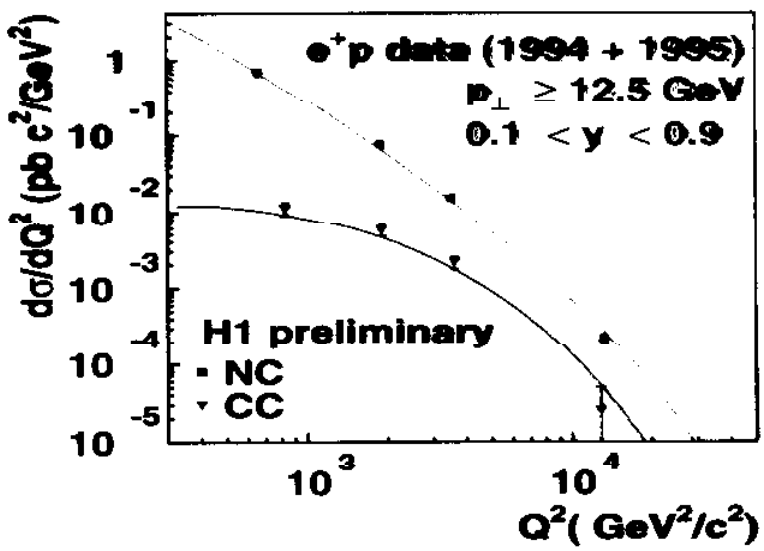
**ZEUS PRELIMINARY** $M_W = 79.0 \begin{smallmatrix} +7.9 \\ -6.9 \end{smallmatrix} \begin{smallmatrix} +5.6 \\ -2.8 \end{smallmatrix}$ GeV (stat. sys)

High $Q^2$ NC 2 CC cross sections are in good agreement with SM, so far.

# $d\sigma/dQ^2$ for NC and CC Reactions

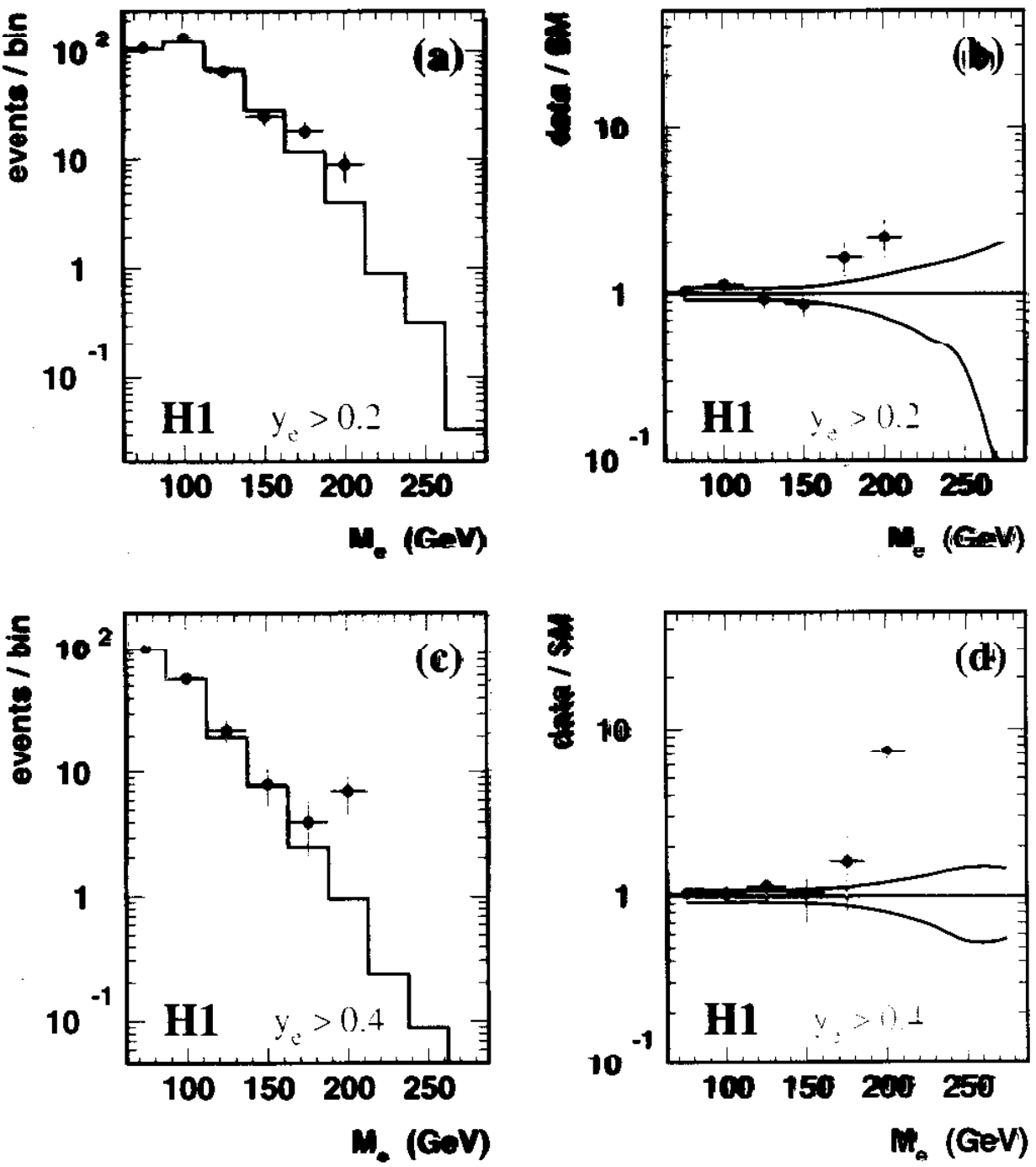



PLB 379(96)319



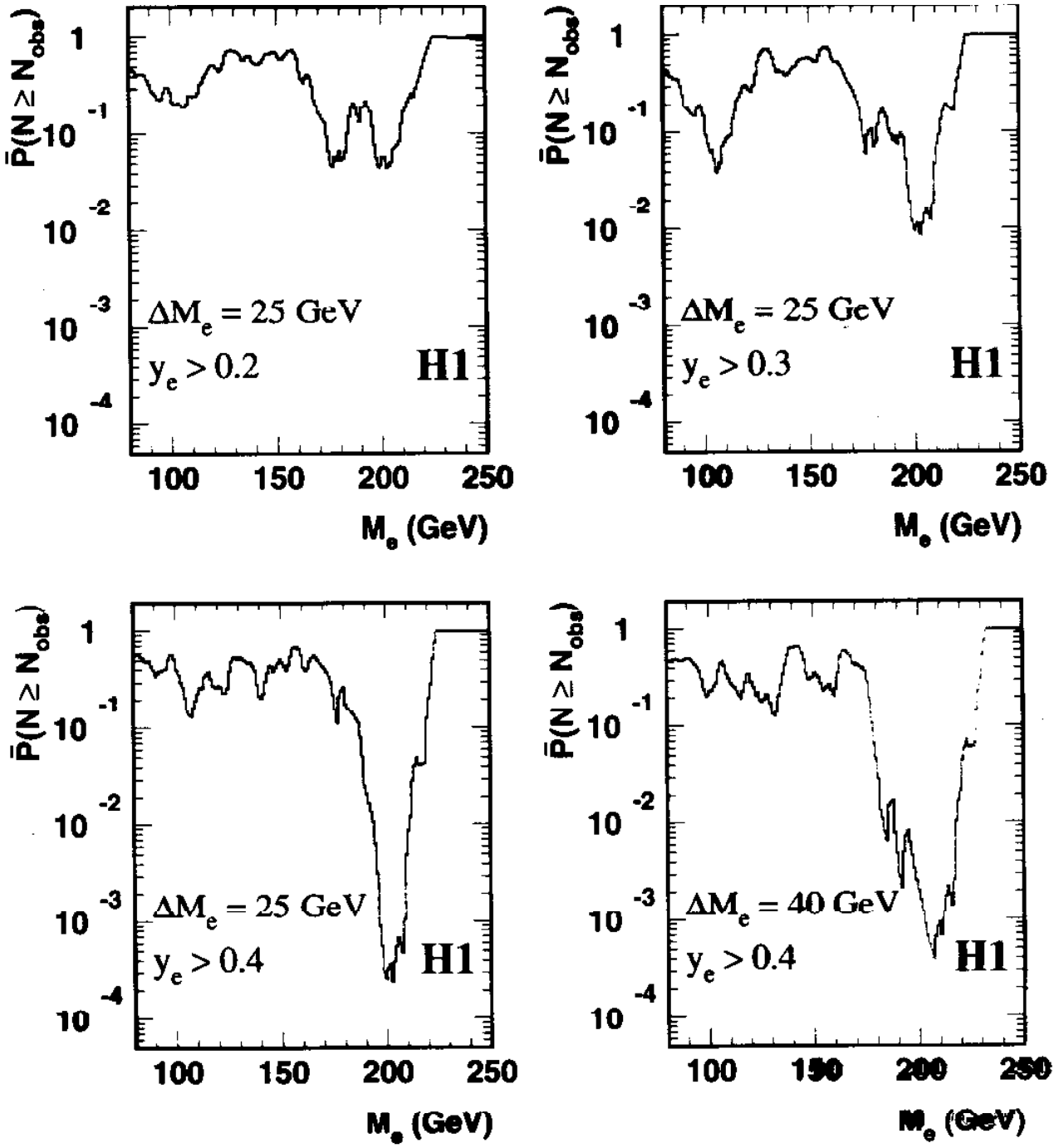

- NC and CC cross section have comparable size for $Q^2 \approx m_Z^2$ GeV$^2$.
- different NC/CC cross sections for $e^{\pm}p$
- in this data $Z^o$ contribution statistically not significant

# Mass dependence




- Excess seen at highest mass
- More visible at large $y_e$

# Probability in sliding Mass Window



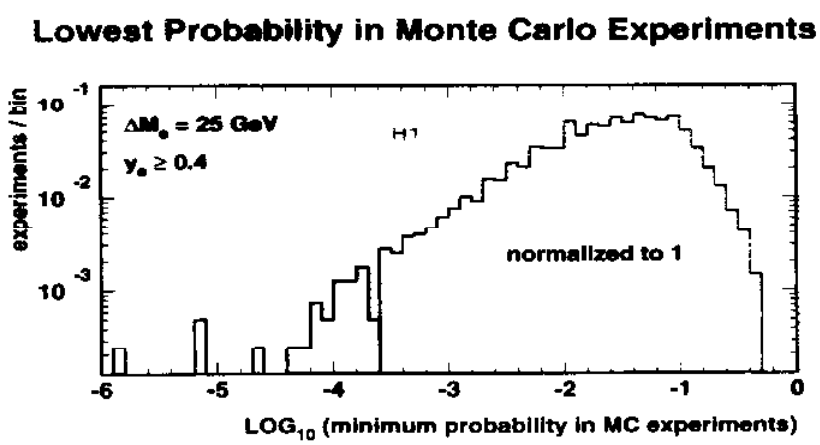

expected $\sim 0.3$ events for $M_e > 220$ GeV

P=1 by construction

# Dependence on the Window Size

| $\Delta M_e$ ( GeV) | 20 | 25 | 30 | 40 |
|---|---|---|---|---|
| $N_{obs}$ | 5 | 7 | 7 | 7 |
| $N_{DIS}$ | 0.63 $\pm 0.13$ | 0.95 $\pm 0.18$ | 1.10 $\pm 0.19$ | 1.57 $\pm 0.28$ |
| $\bar{\mathcal{P}}(N \geq N_{obs})$ | $5.0 \times 10^{-4}$ | $2.6 \times 10^{-4}$ | $2.5 \times 10^{-4}$ | $1.6 \times 10^{-3}$ |

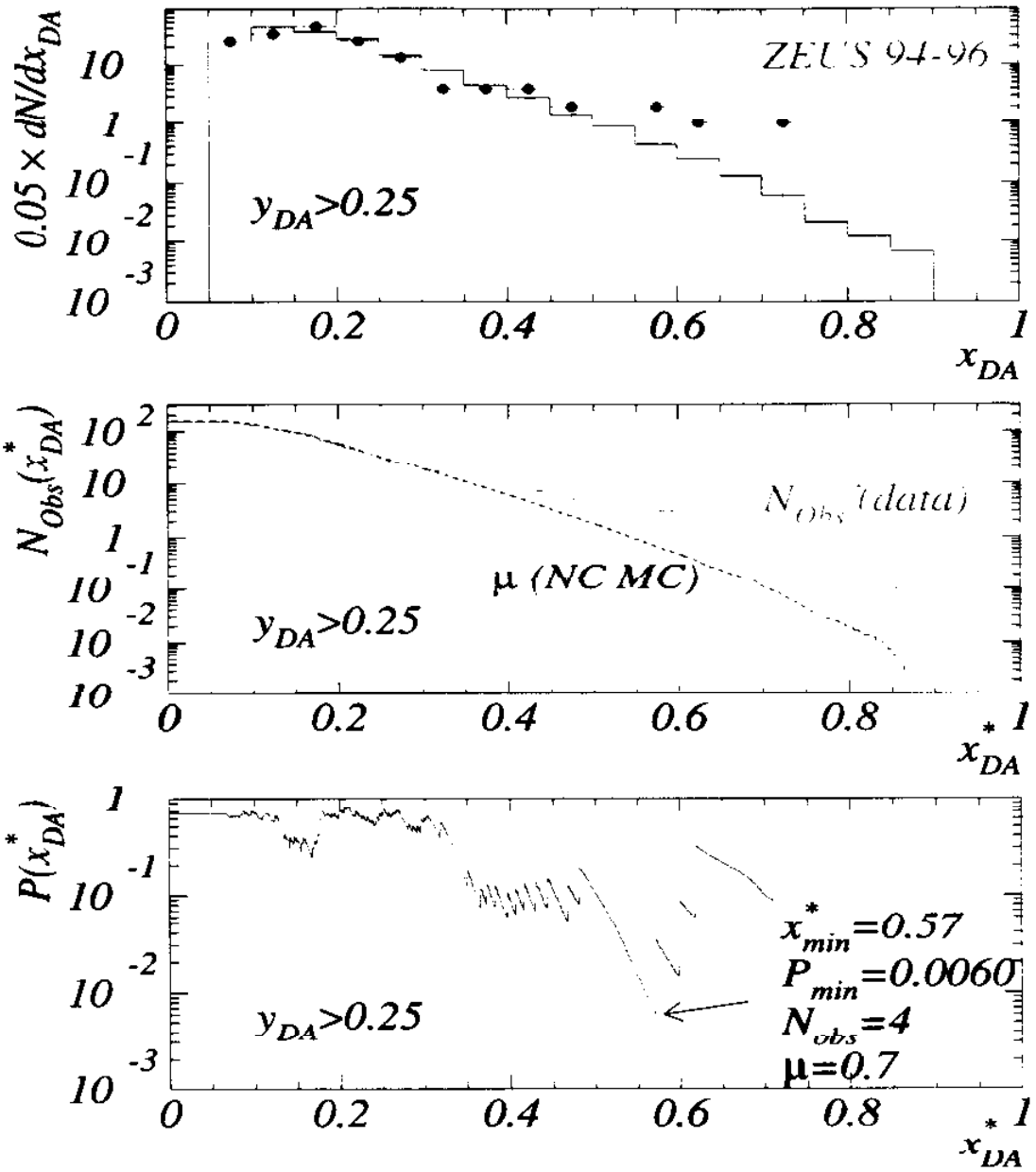
$\mathcal{P}$ to find a fluctuation as large as observed anywhere in the considered mass range:




$\mathcal{P} = 0.9^{+}$

# Significance Analysis

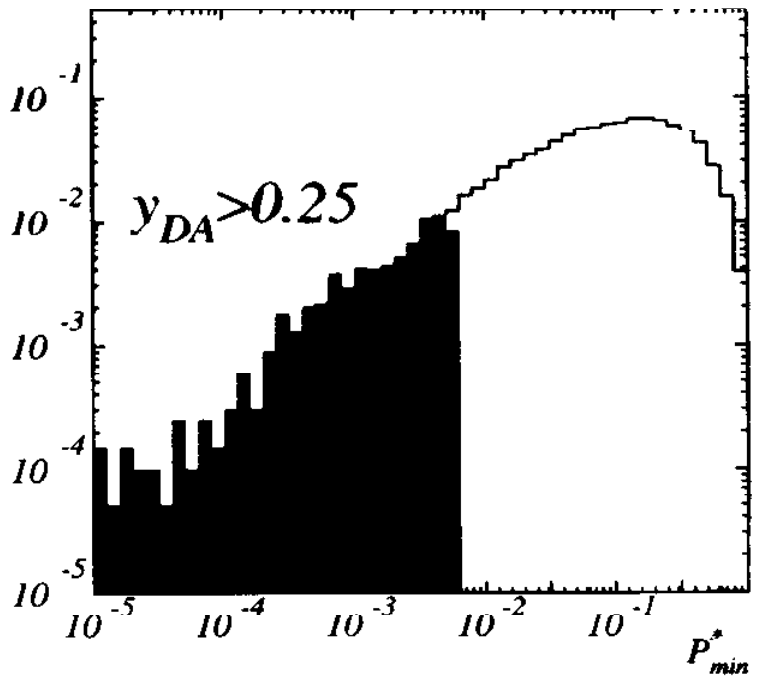
## Excess in $x$




$$N_{\rm obs}(x^*_{\rm DA}) = \int_{x^*_{\rm DA}}^{1} dx_{\rm DA}\, dN/dx_{\rm DA}$$

$$\mathcal{P}(x^*_{\rm DA}) = \sum_{n=N_{obs}}^{\infty} e^{-\mu}\, \frac{\mu^n}{n!}$$

# Excess in $x$ — continued




Minimal Poisson probabilities of the $x_{\rm DA}$ distributions for different $y_{\rm DA}$ cuts

| $y_{\rm DA}$ range | $\mathcal{P}_{min}(x^*_{\rm DA})$ [%] | $x^*_{\rm DA}$ | $N_{\rm obs}$ | $\mu$ | $P_{\rm SM}$ [%] |
|---|---|---|---|---|---|
| $y_{\rm DA} > 0.05$ | 1.61 | 0.708 | 4 | 0.95 | 16.0 |
| $y_{\rm DA} > 0.15$ | 2.57 | 0.708 | 2 | 0.25 | 23.0 |
| $y_{\rm DA} > 0.25$ | 0.60 | 0.569 | 4 | 0.71 | 7.2 |
| $y_{\rm DA} > 0.35$ | 3.38 | 0.708 | 1 | 0.034 | 26.6 |
| $y_{\rm DA} > 0.45$ | 1.32 | 0.569 | 2 | 0.17 | 12.7 |
| $y_{\rm DA} > 0.55$ | 0.96 | 0.708 | 1 | 0.010 | 9.5 |
| $y_{\rm DA} > 0.65$ | 0.50 | 0.708 | 1 | 0.005 | 5.0 |

$\mathcal{P}_{min}(x^*_{\rm DA})$ = the minimal probability

$x^*_{\rm DA}$ = the value of $x_{\rm DA}$ where it occurs

$N_{\rm obs}$ = number of events observed with $x_{\rm DA} > x^*_{\rm DA}$

$\mu$ = expected number of events with $x_{\rm DA} > x^*_{\rm DA}$

$P_{\rm SM}$ = prob. that a simulated experiment yields a lower $\mathcal{P}_{min}(x^*_{\rm DA})$ than observed

$$\tilde{\sigma}^{+} \equiv F_2 - \frac{y^2}{Y_+} F_L - x F_3$$

(24)

$$\Rightarrow x \sim 0.5 \quad Q^2 \sim 3.10^4 \quad \frac{\Delta\sigma^+}{\sigma^+} \sim 9\%$$

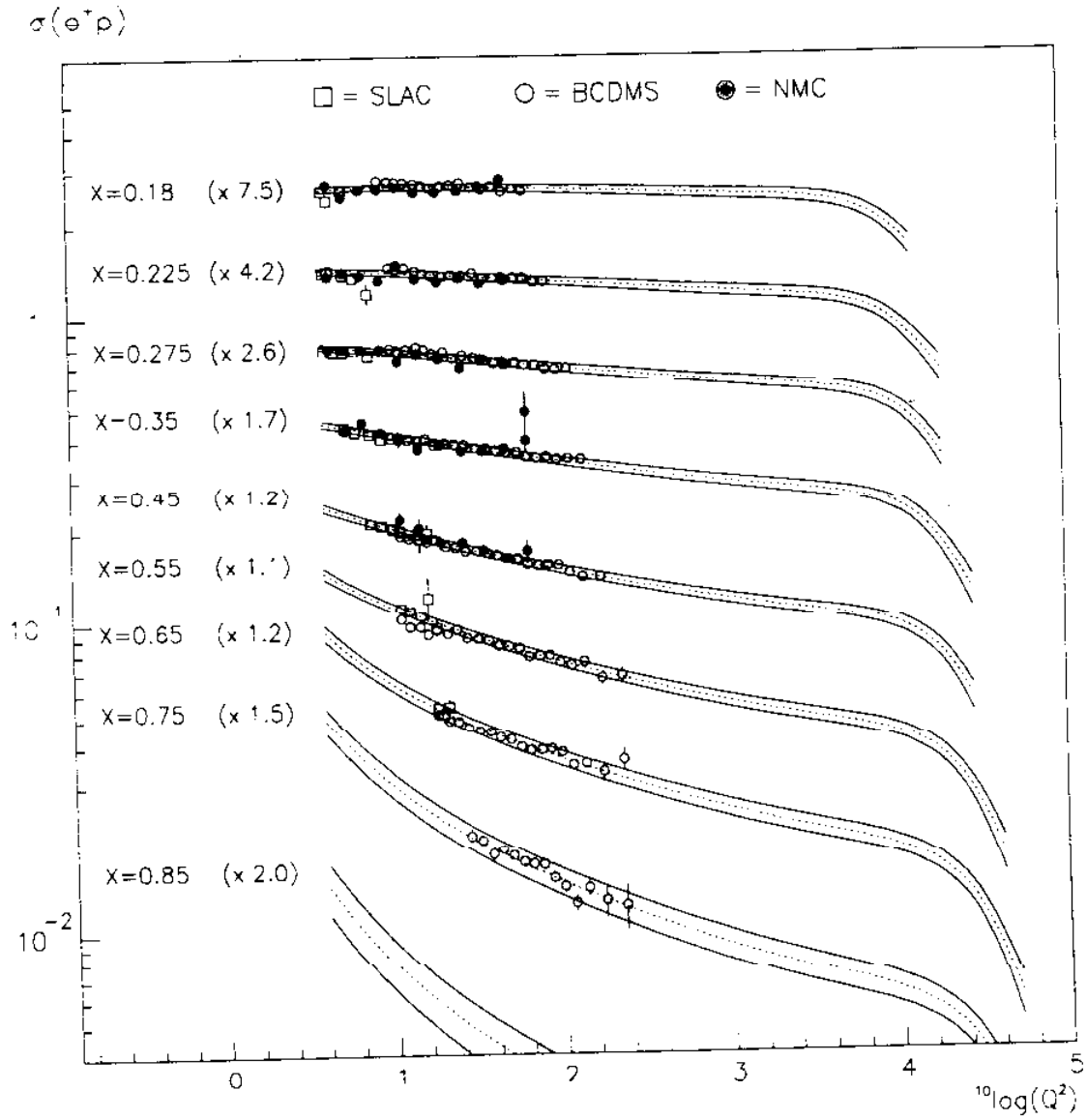
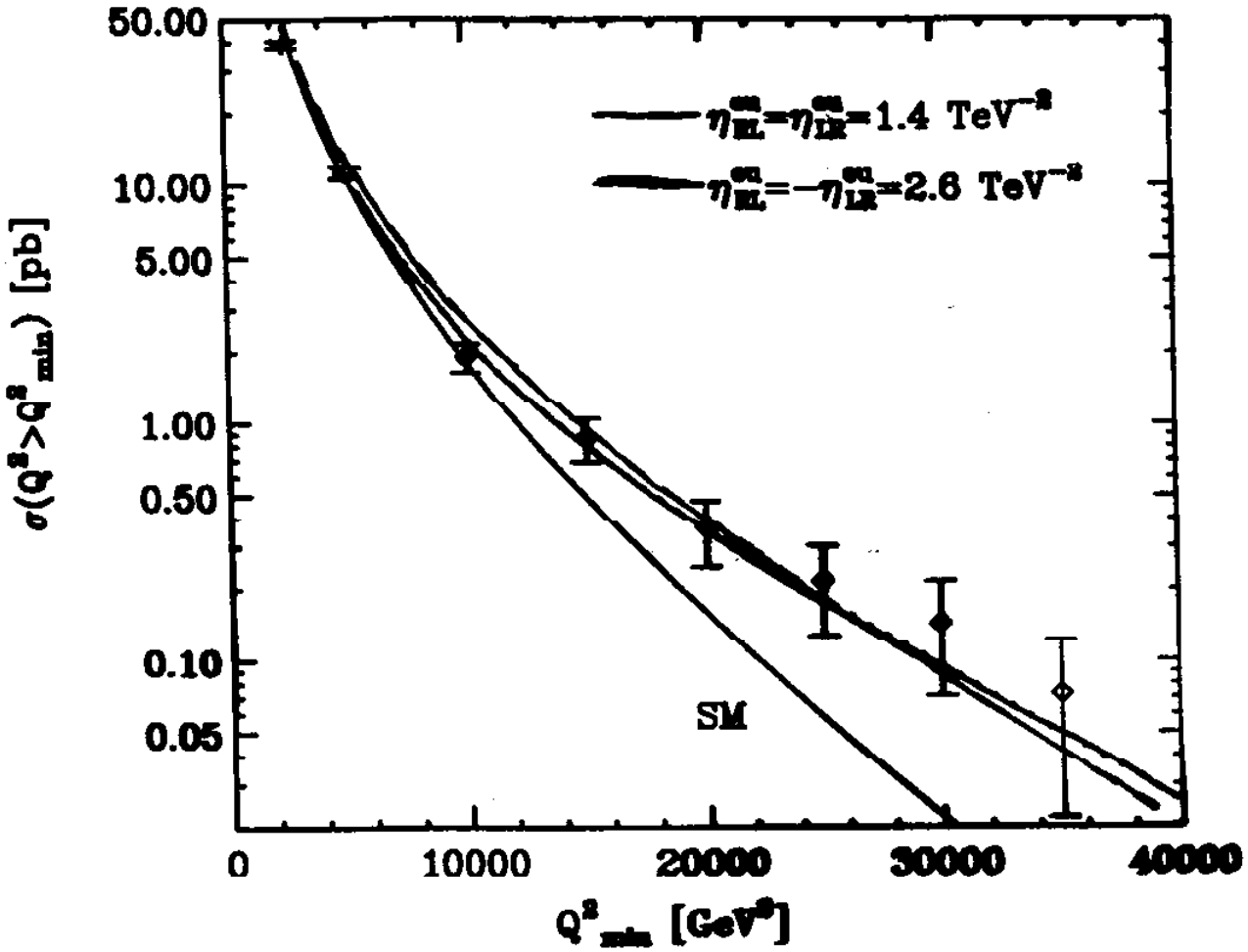



Figure 9: The reduced cross-section $\tilde{\sigma}$ (see text) for $e^+p$ scattering at Hera energies ($E_e = 27.5$, $E_p = 820$ GeV). The bands represent the total error. The fixed target $F_2$ data are converted to $\tilde{\sigma}$ by applying a small correction for $F_L$.

Two examples:

$$\eta^{eu}_{RL} = \eta^{eu}_{LR} = 1.4\ \mathrm{TeV}^{-2} \quad \hat{=} \quad \Lambda \approx 3\,\mathrm{Te}$$

$$\eta^{eu}_{RL} = -\eta^{eu}_{LR} = 2.6\ \mathrm{TeV}^{-2} \quad \hat{=} \quad \Lambda \approx 2.2$$




Shape is "better" for $\eta^{eu}_{RL} = -\eta^{eu}_{LR}$ :

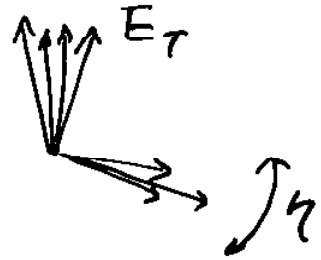
interference with $\gamma$-exchange exactly cancels

# Inclusive Di-jet Diff. Cross Section

F. Chlebana

(CDF)

Fix 1 jet to be central



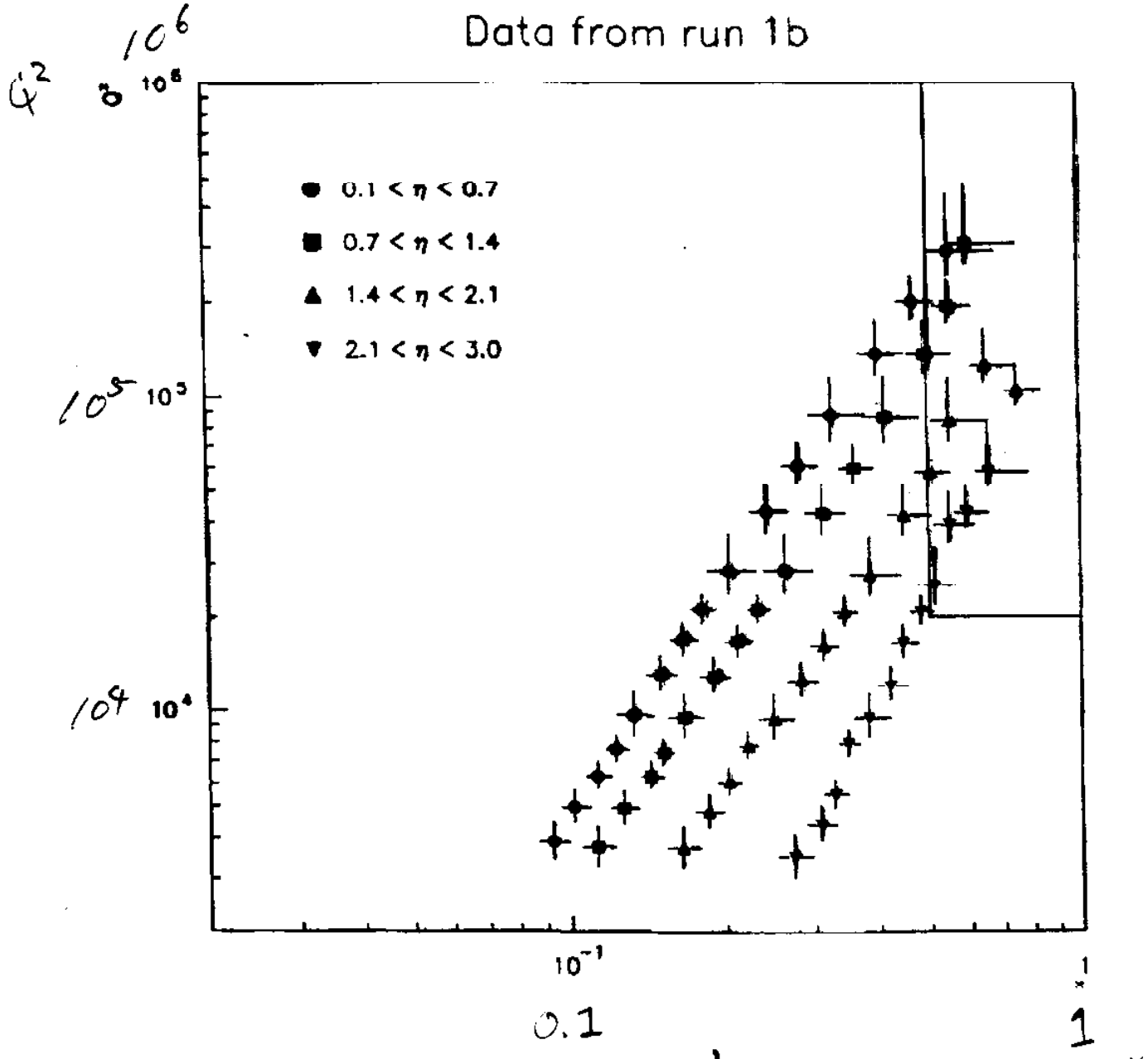

⇒ Access $x$ as high as 0.8 →

$Q^2$ as high $10^5$ GeV$^2$

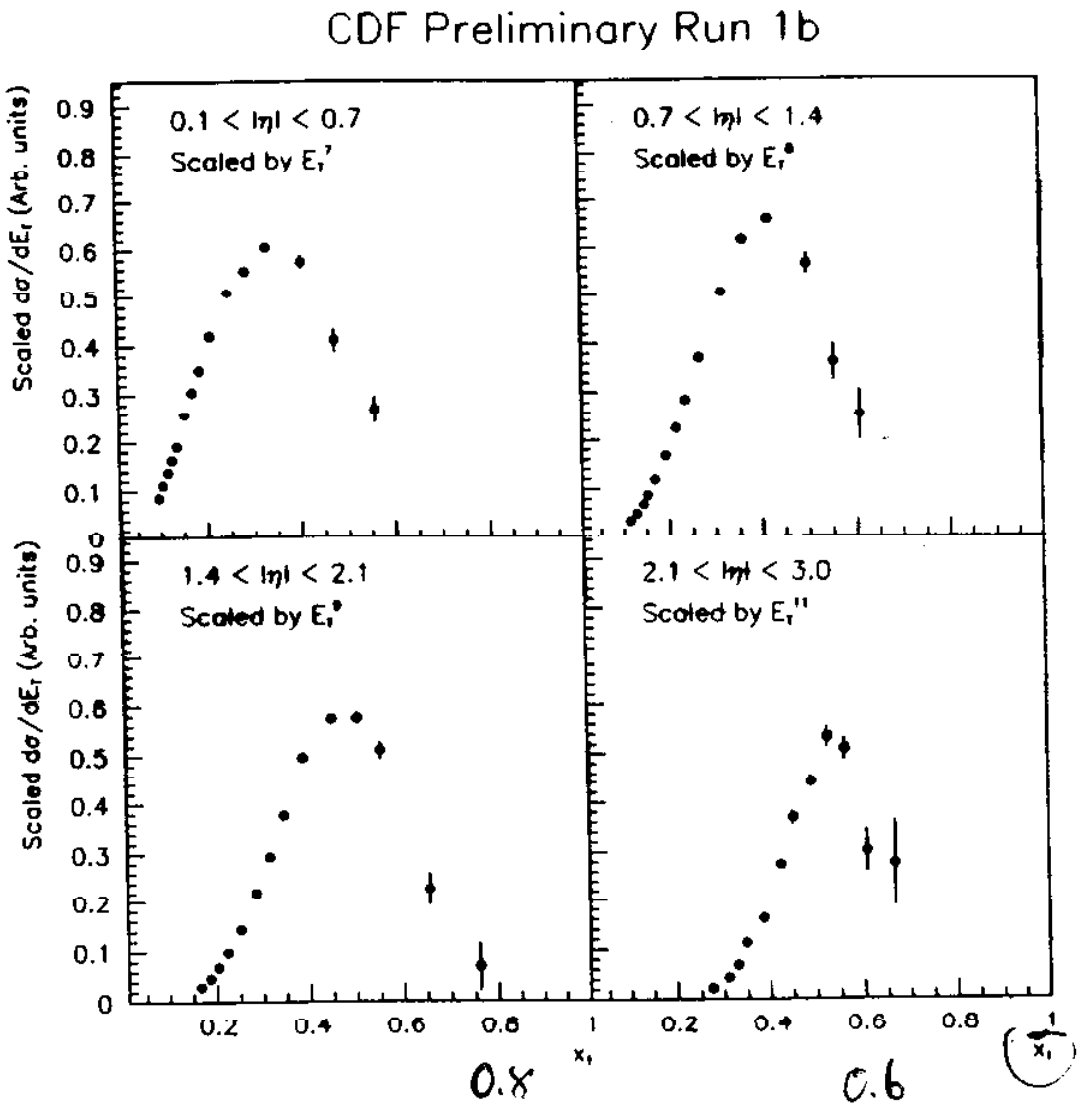
At largest $E_T$ $N_{jets} \gtrsim 4$ jets (calculation not high order enough

Scaled cross sections →

*

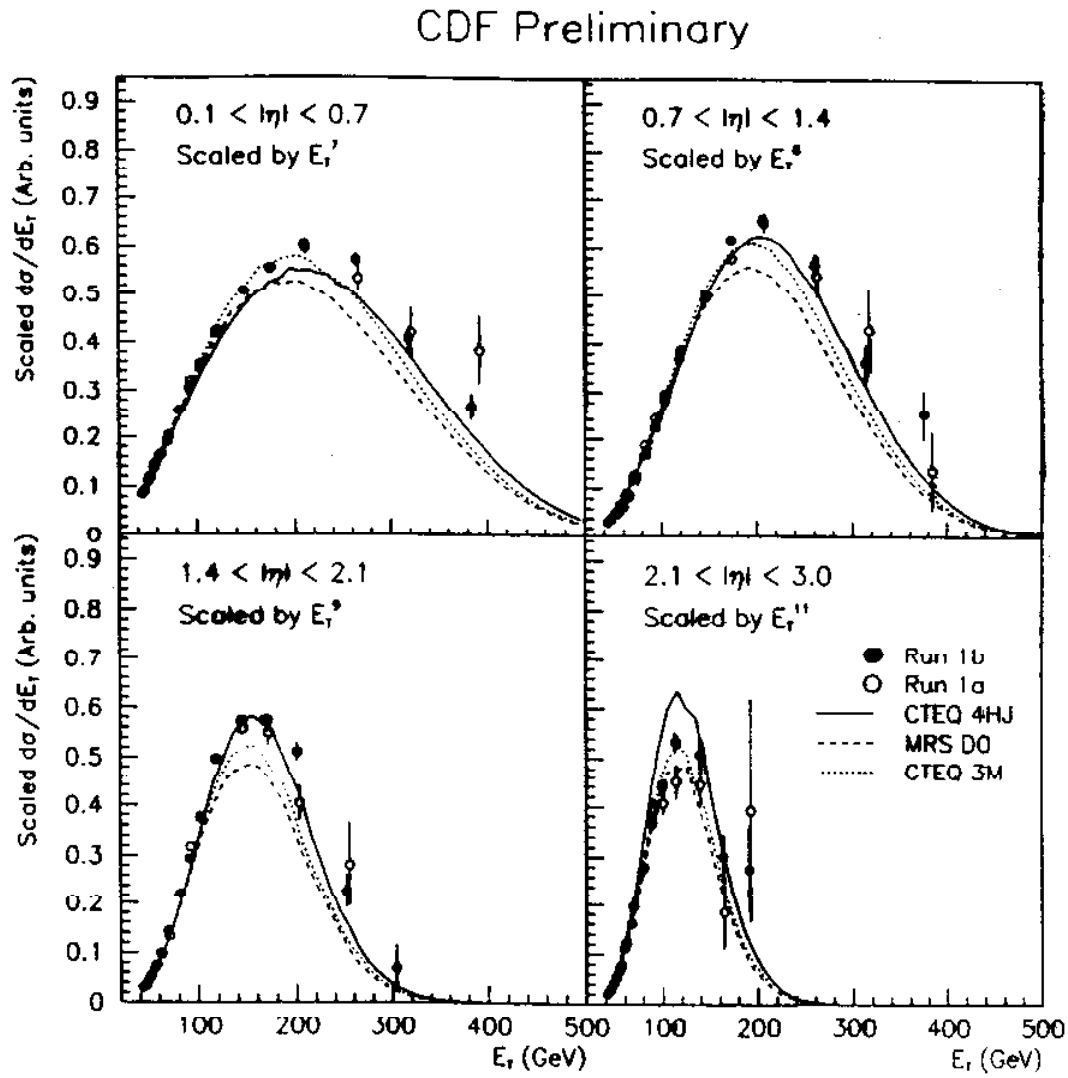

Data from run 1b
$Q^2$
$10^6$
$10^6$
$10^5$
$10^5$
$10^4$
$10^4$
0.1 < η < 0.7
0.7 < η < 1.4
1.4 < η < 2.1
2.1 < η < 3.0
$10^{-1}$
1
0.1
1
x

2 → 3 formula




**Error bars represent the statistical error. The systematic error is under study.**

To see the effect of different pdfs, the cross section was scaled by $E_T^n$ and normalised by different factors for each $\eta$ range.




Open circles show the results from run Ia (19 $pb^{-1}$) and the solid circles are the results from run Ib (87 $pb^{-1}$).

Error bars represent the statistical error. The systematic error is under study.

- Thanks to all WG I participants!

- Looking forward to exciting 97.

- See you at DIS 98!