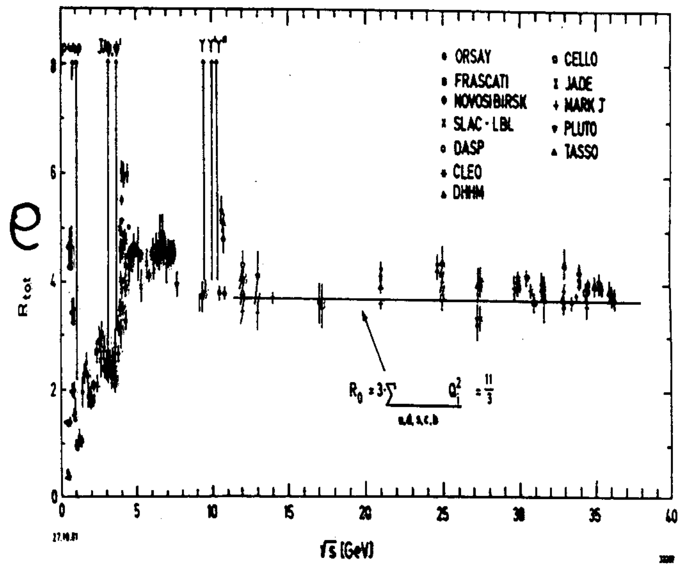
R. ENT

On the Onset of ~~Duality~~ Scaling ($\neq$ Leading Twist)

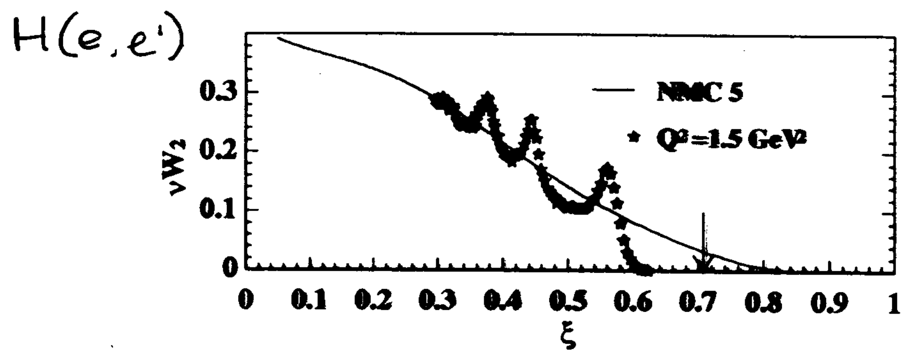
* Duality in F_2
* Duality in g_1
* Duality in Nuclei
* Duality in Meson Electroproduction

Our Understanding of Duality

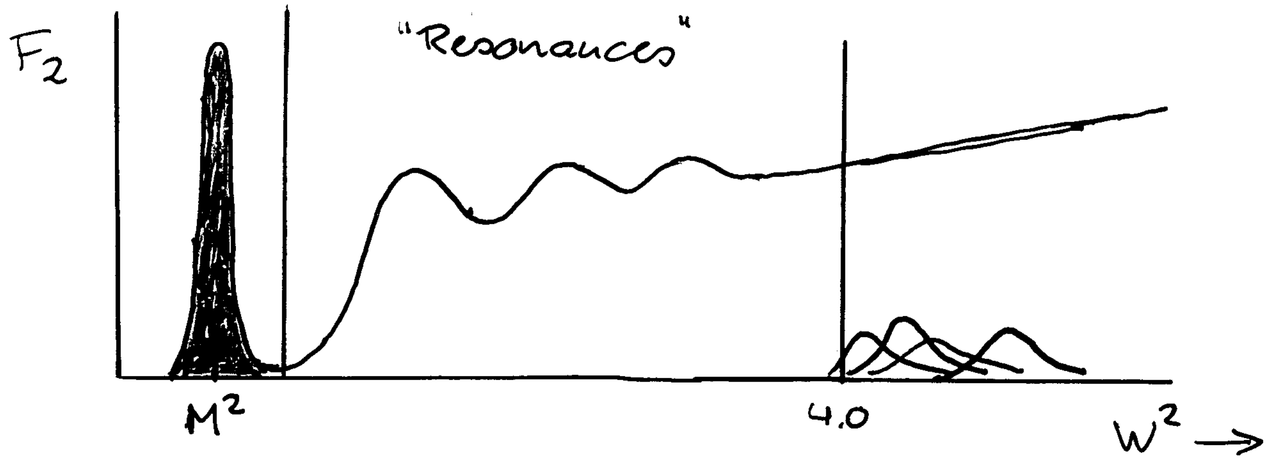
Unitarity $\Rightarrow R = \dfrac{\sigma(e^- e^+ \to \text{hadrons})}{\sigma(e^- e^+ \to \mu^- \mu^+)}$ averages to QPM prediction:

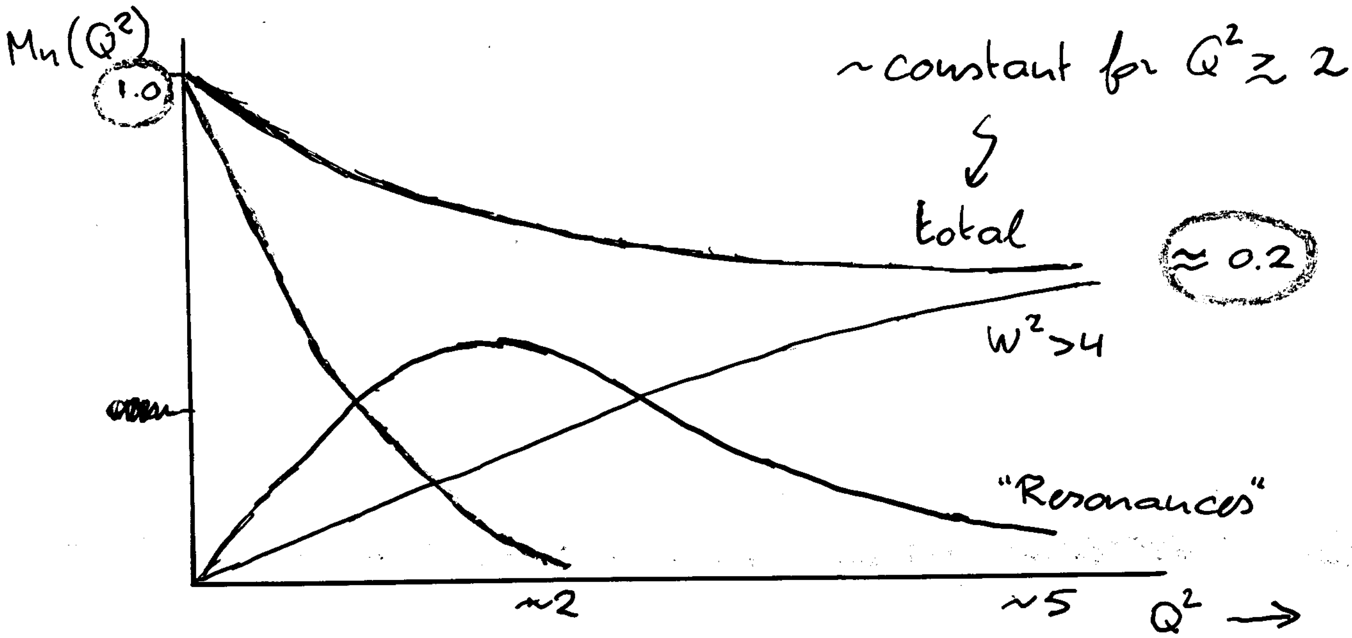


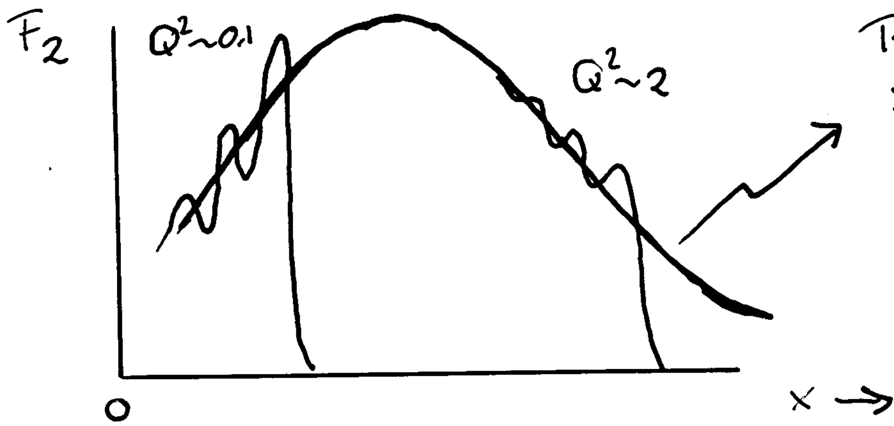
Inclusive duality in terms of moment analysis:



But we have no fundamental understanding of local duality at low Q^2, and certainly no understanding of special cases: semi-exclusive reactions, longitudinal vs. transverse, spin-dependence.





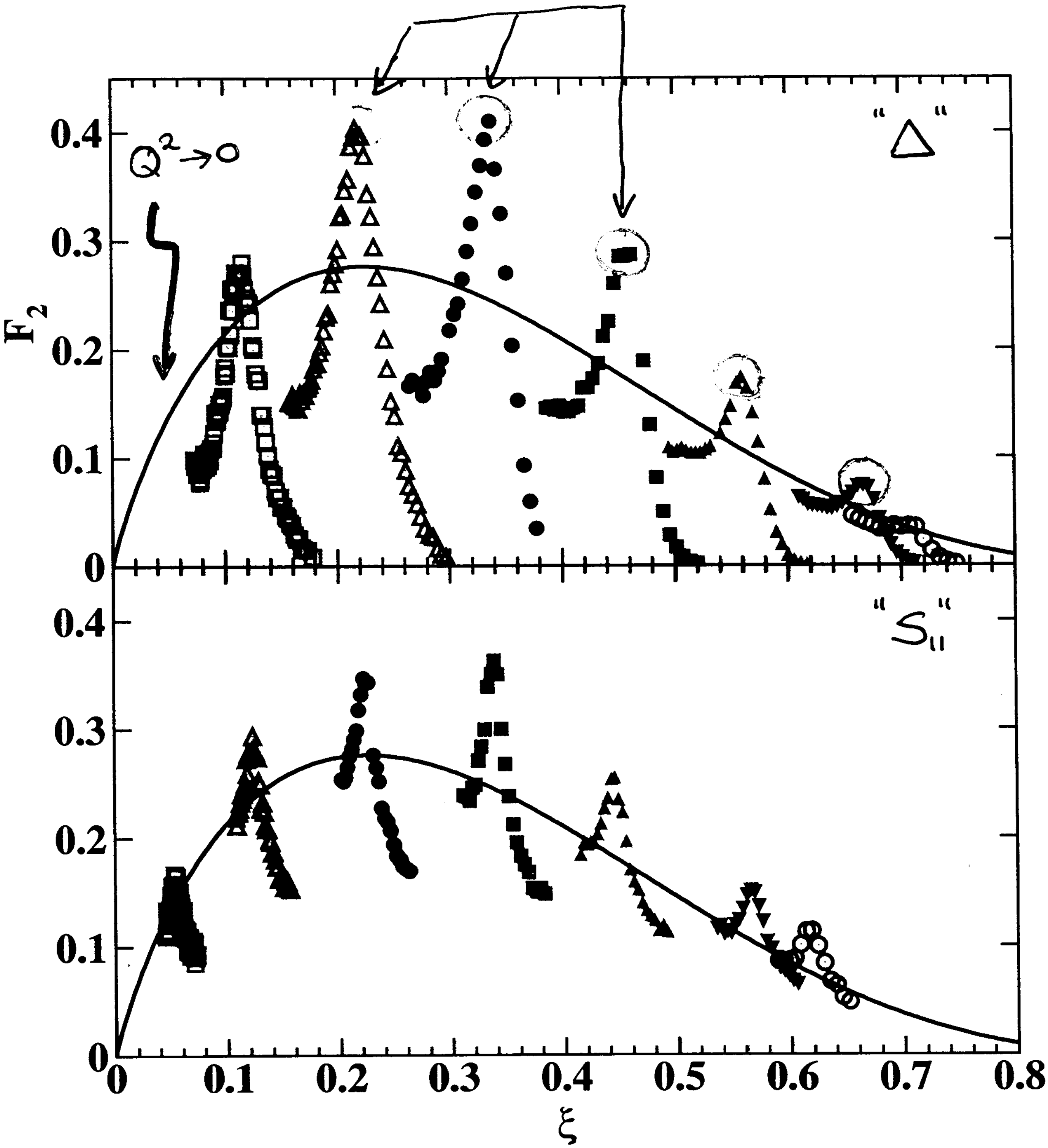


Resonances
Seem to oscillate
around one curve!

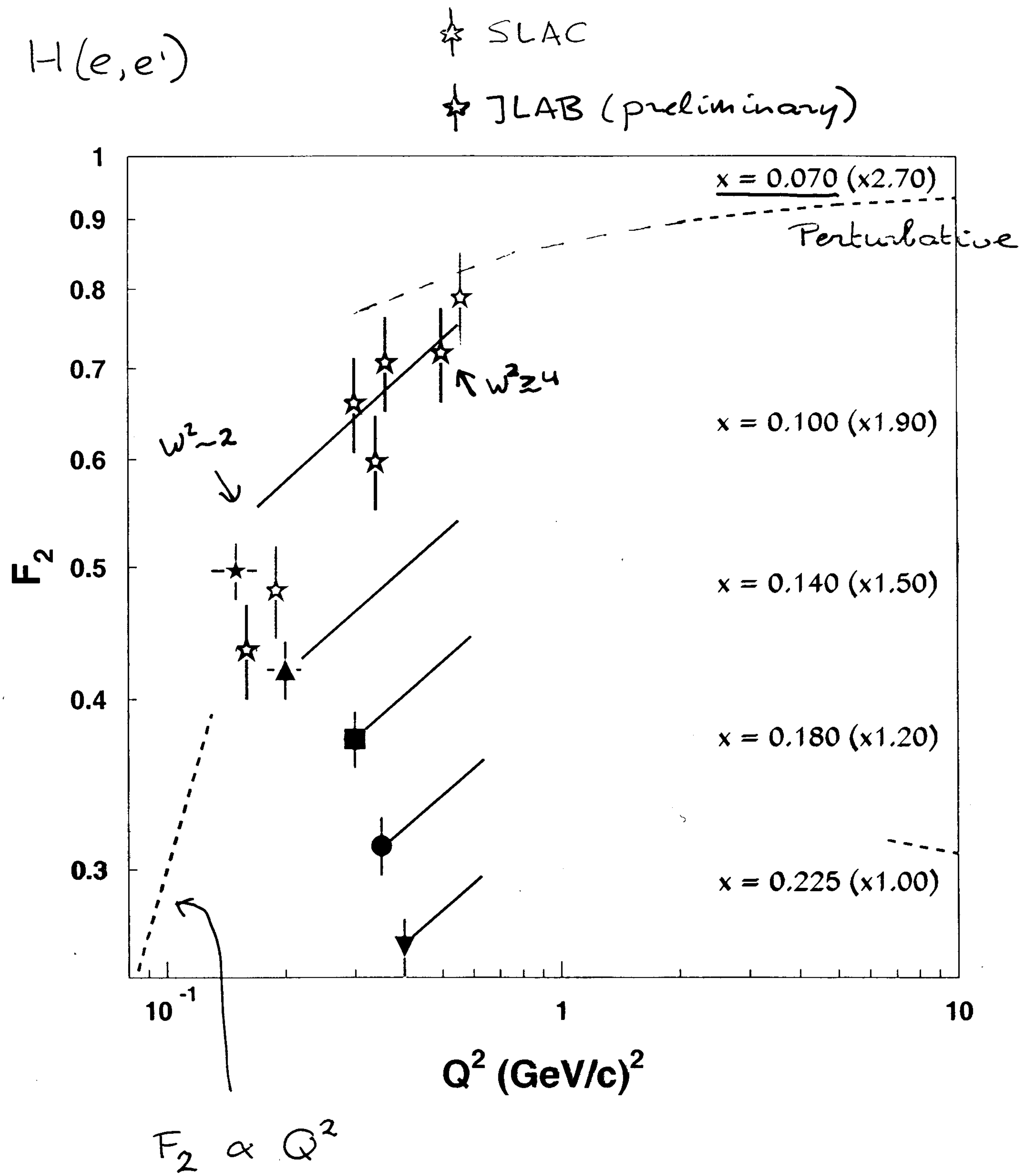
Q^2 dependence of
FF's @ $Q^2 \gtrsim 0.2$!!!

Select # of states : Longitudinal
Spin
Semi-inclusive

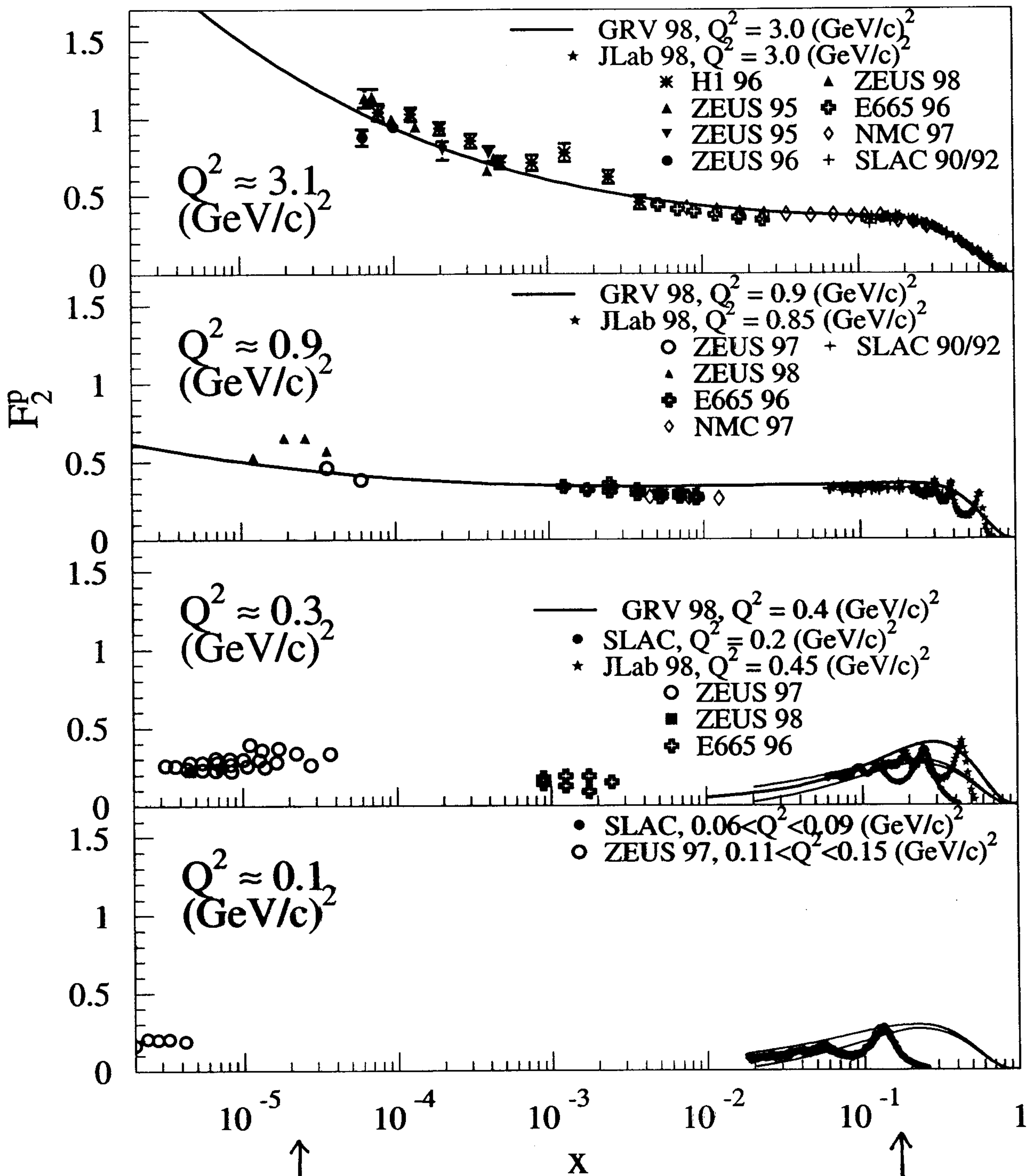
No "Duality" on top of peak !



Needs averaging !!



H(e,e')
SLAC
JLAB (preliminary)
x = 0.070 (x2.70)
Perturbative
$W^2 \gtrsim 4$
$W^2 \sim 2$
x = 0.100 (x1.90)
x = 0.140 (x1.50)
x = 0.180 (x1.20)
x = 0.225 (x1.00)
F_2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
10^{-1}
1
10
Q^2 (GeV/c)^2
$F_2 \propto Q^2$



$F_2 \propto Q^2$

Q^2 dependence

?

E143 data

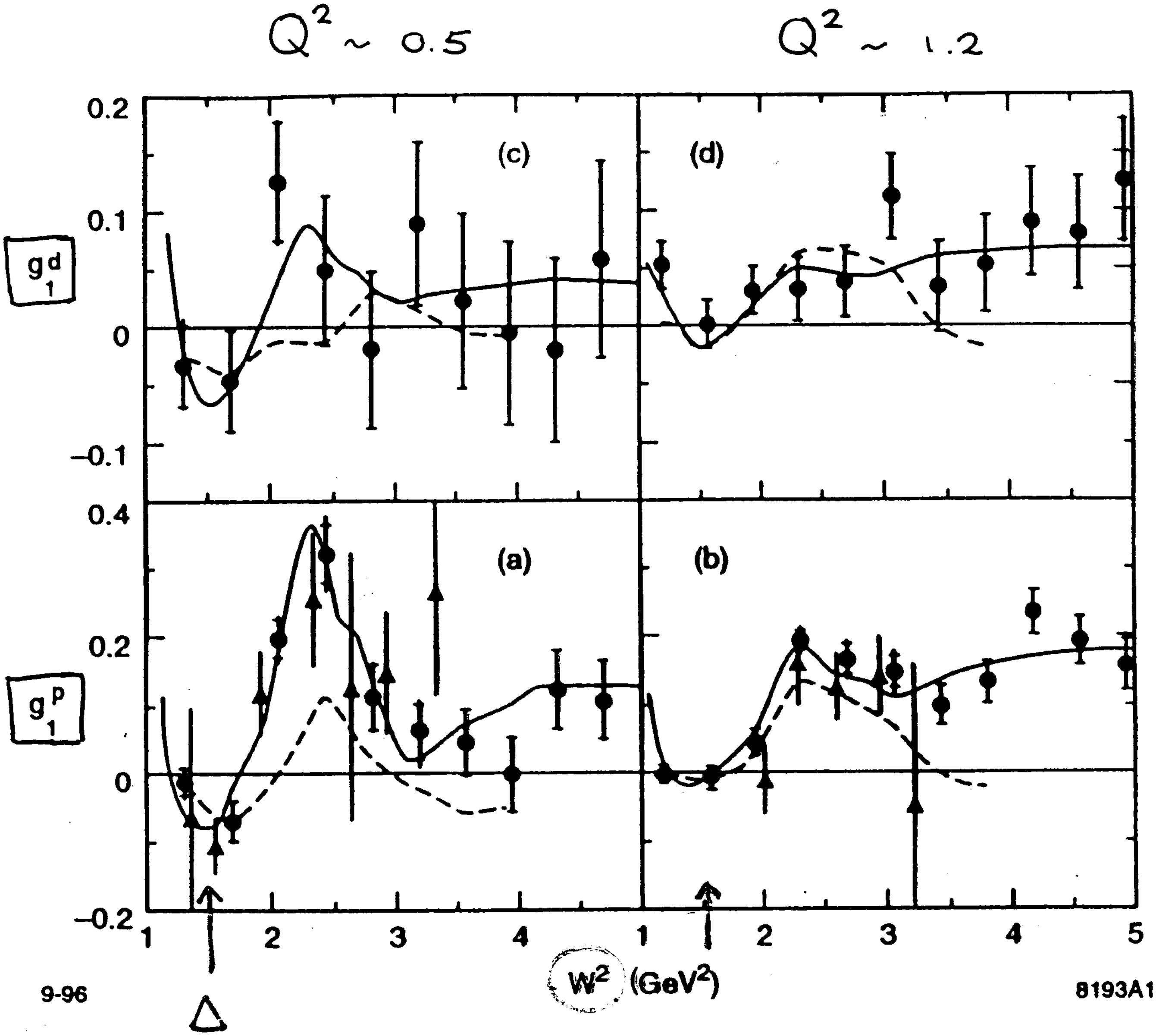


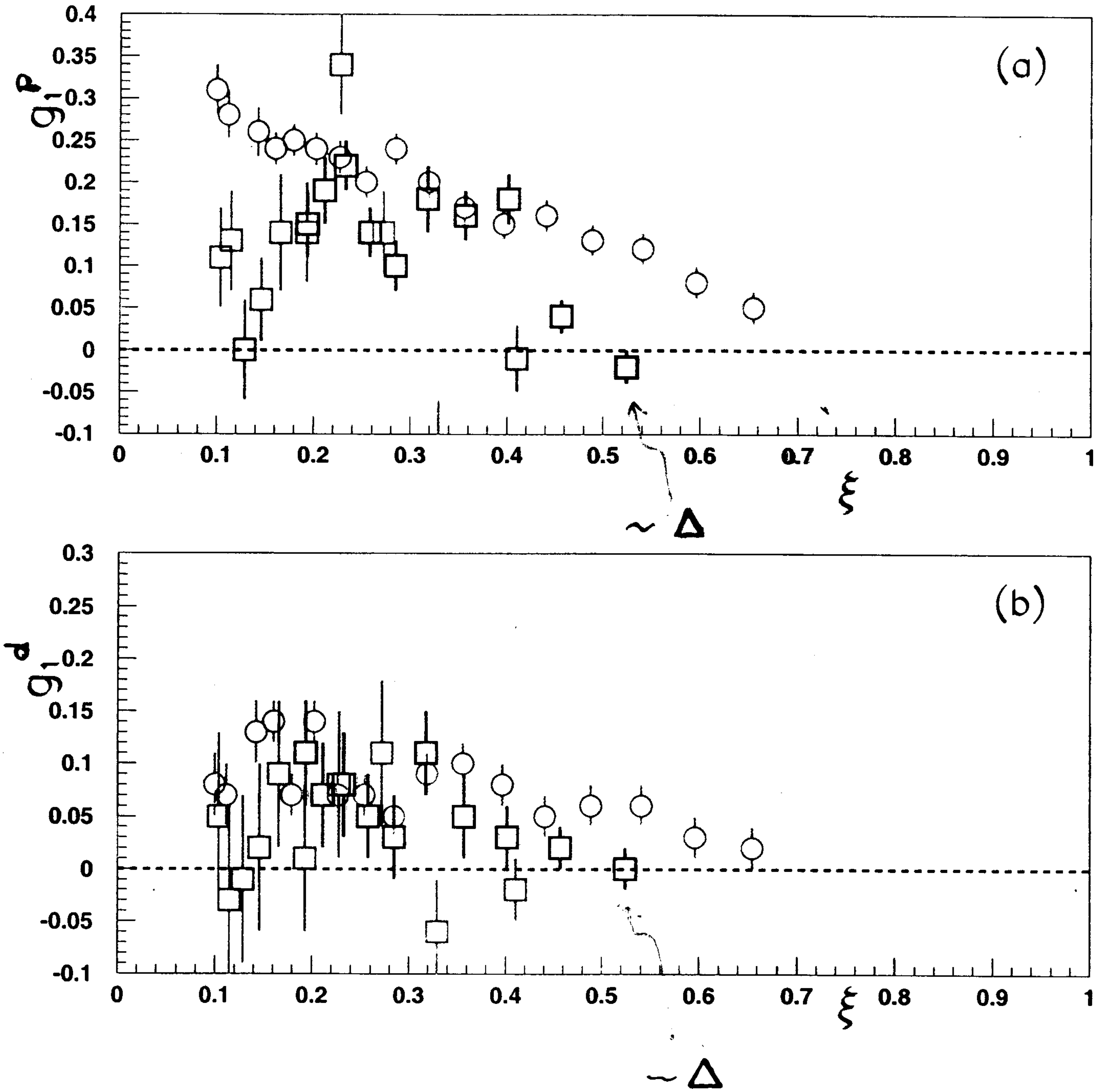
Fig. 1. Measurements of g_1 as a function of W^2 for the proton at (a) 4.5° and (b) 7°; and for the deuteron at (c) 4.5° and (d) 7°. The present data (circles) are plotted together with the data of Baum *et al.* (triangles), our Monte Carlo simulation (solid line), and the model AO of Burkert and Li[15] (dashed line). The full error bars correspond to statistical and systematic errors added in quadrature, whereas the cross bars indicate statistical errors only.

E143

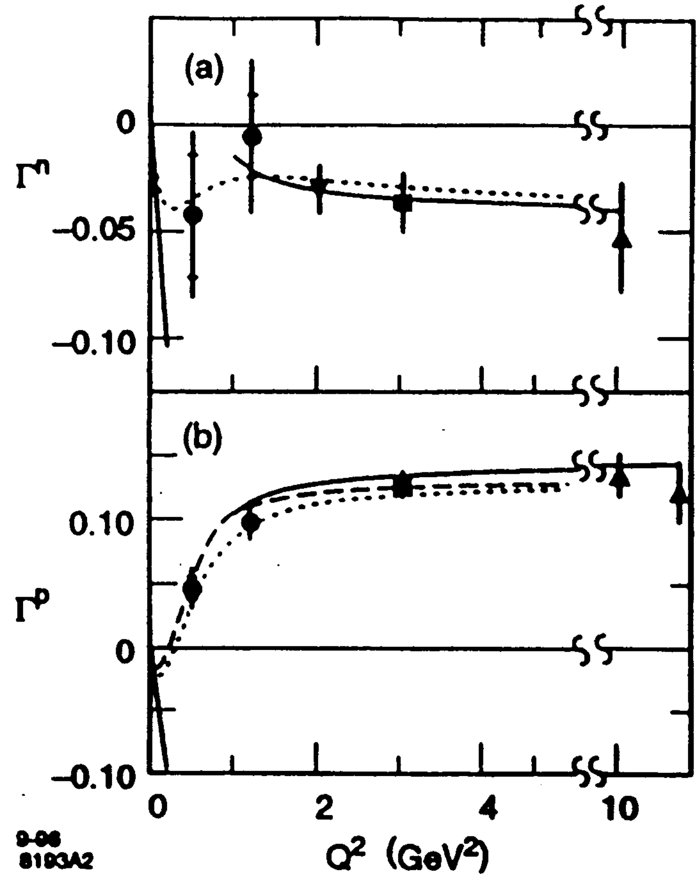
○ DIS data

□ Resonance Region $Q^2 \sim 0.5$

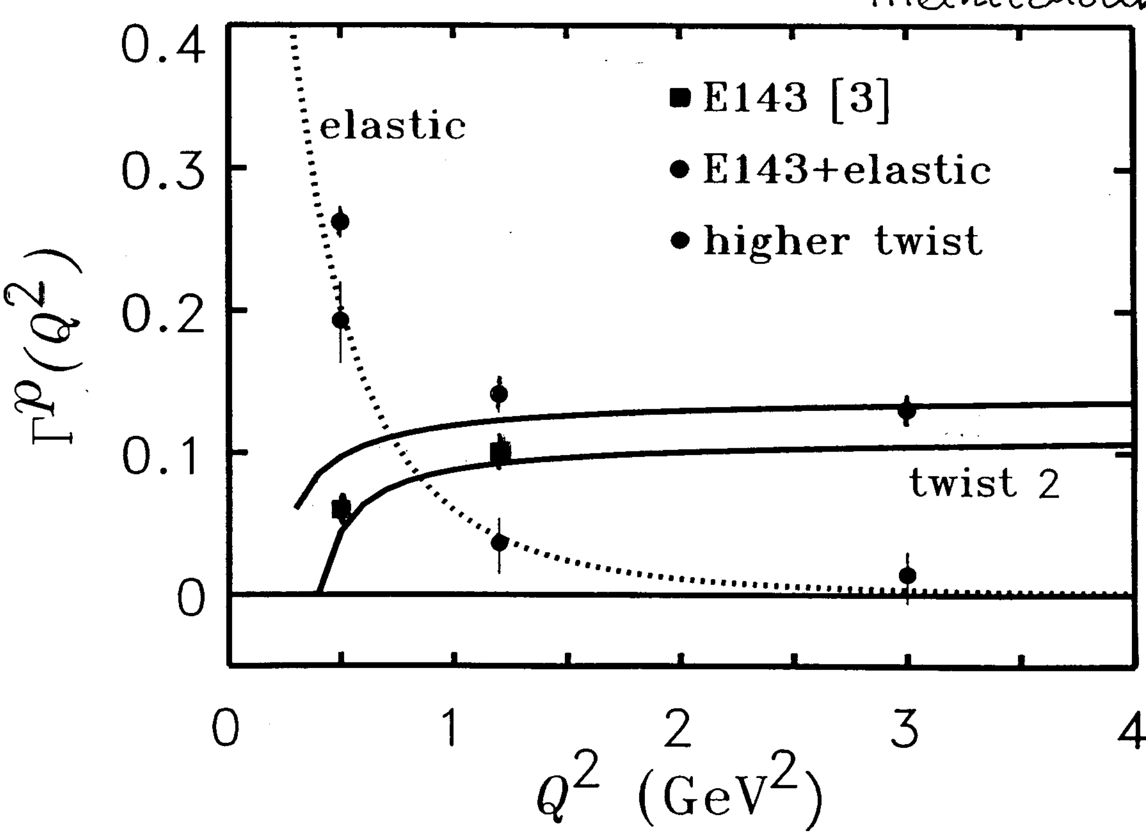
□ " " $Q^2 \sim 1.2$



E143

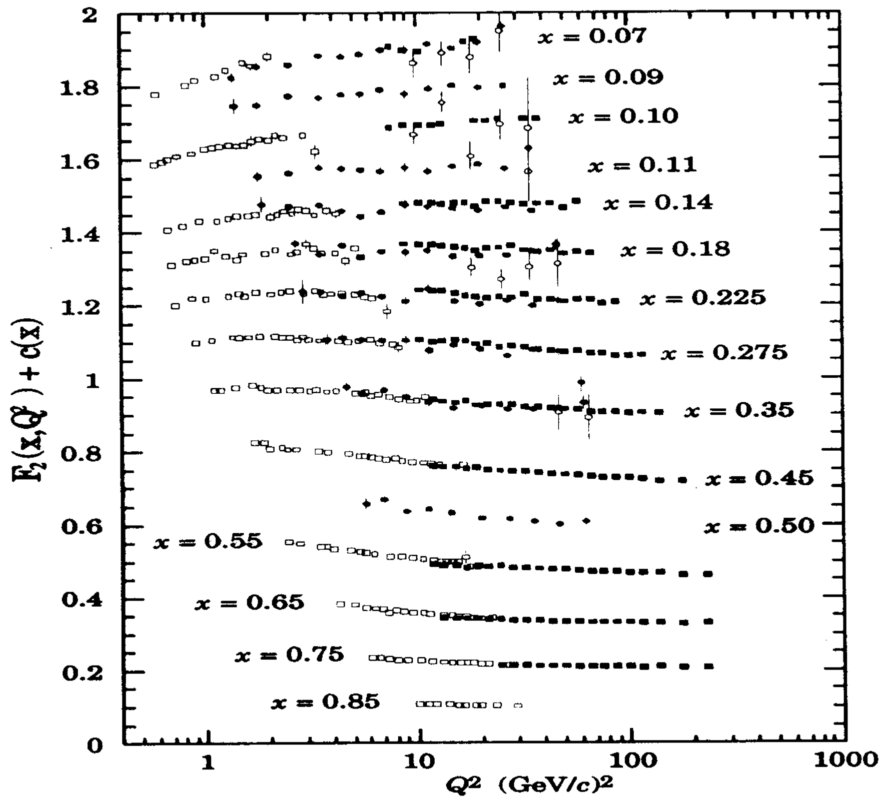


Melnitchouk



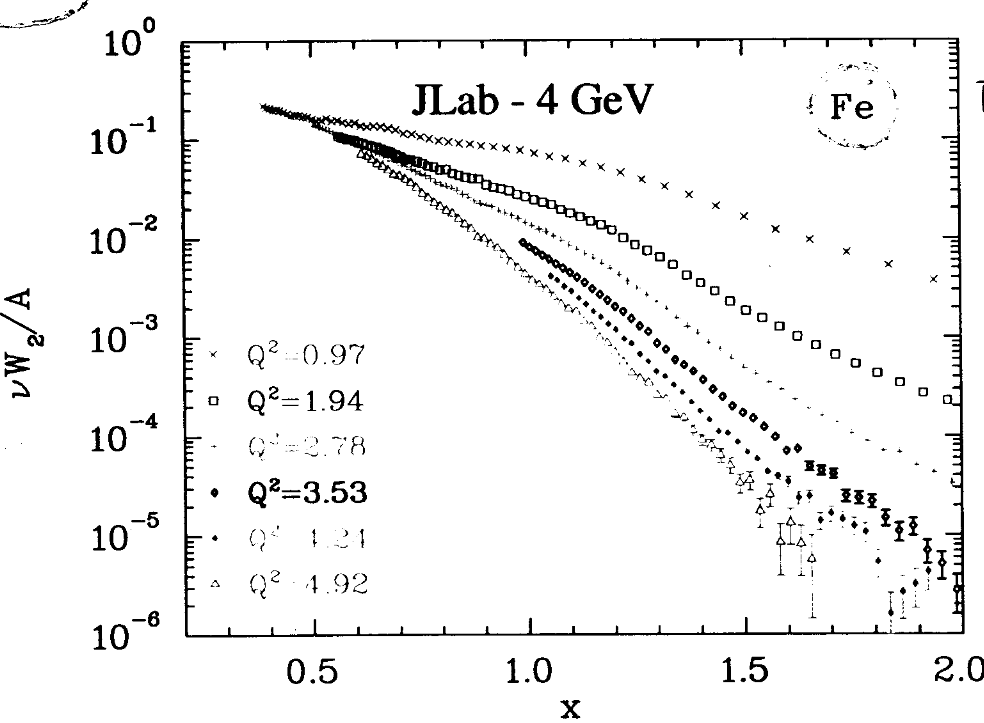
x-scaling.

Scaling seen in proton over large x region.



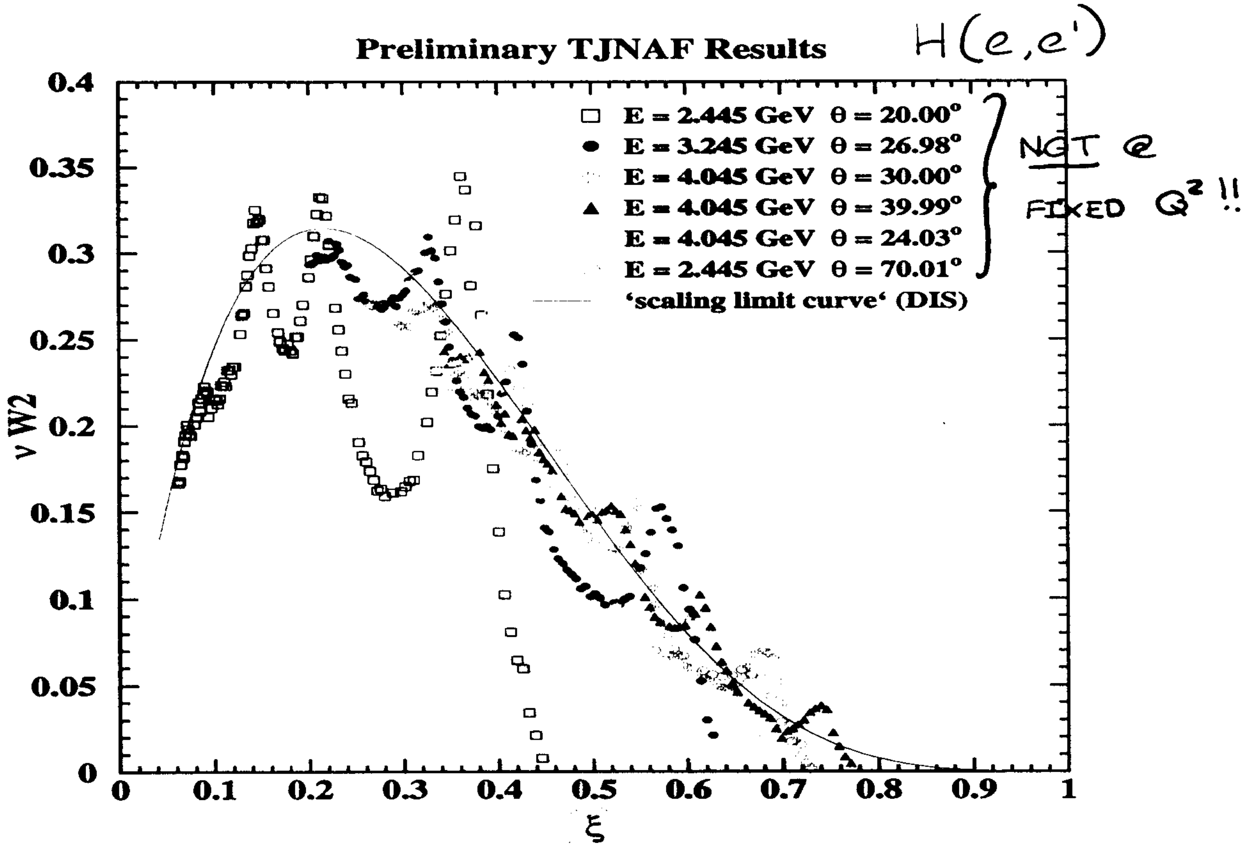
H(e,e')

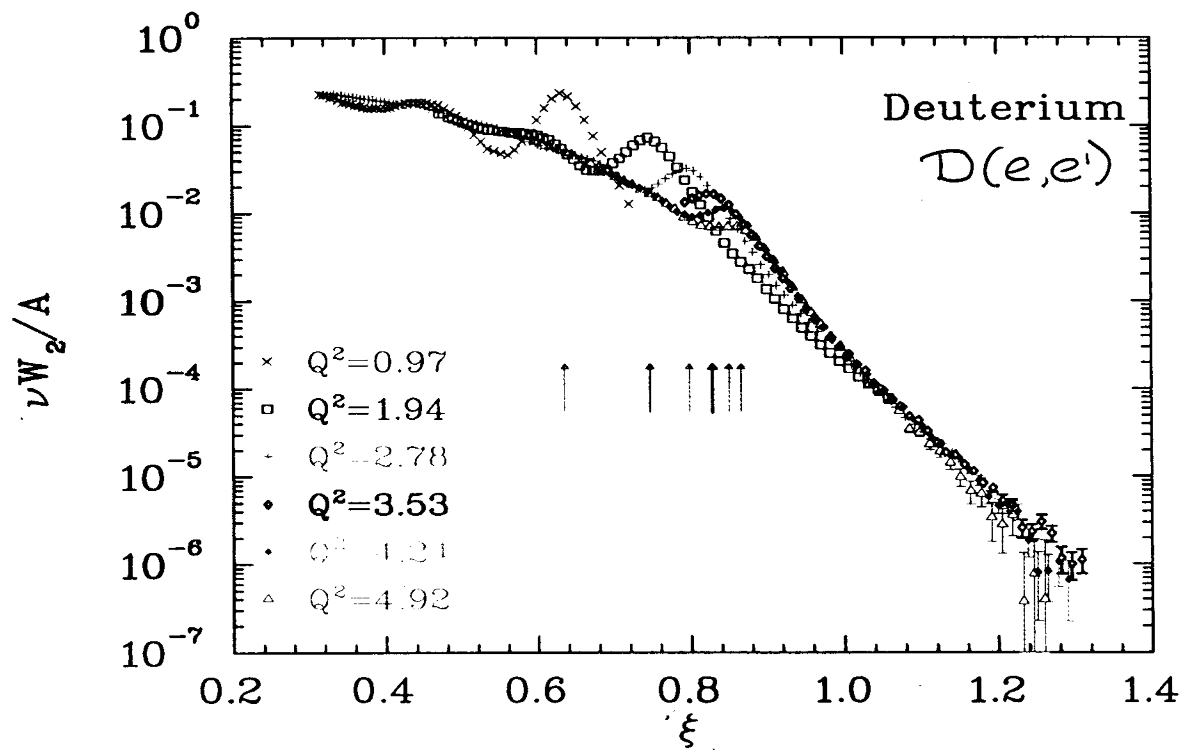
For nuclei, current data scales only at low x (x<0.5-0.6).



Fe(e,e')

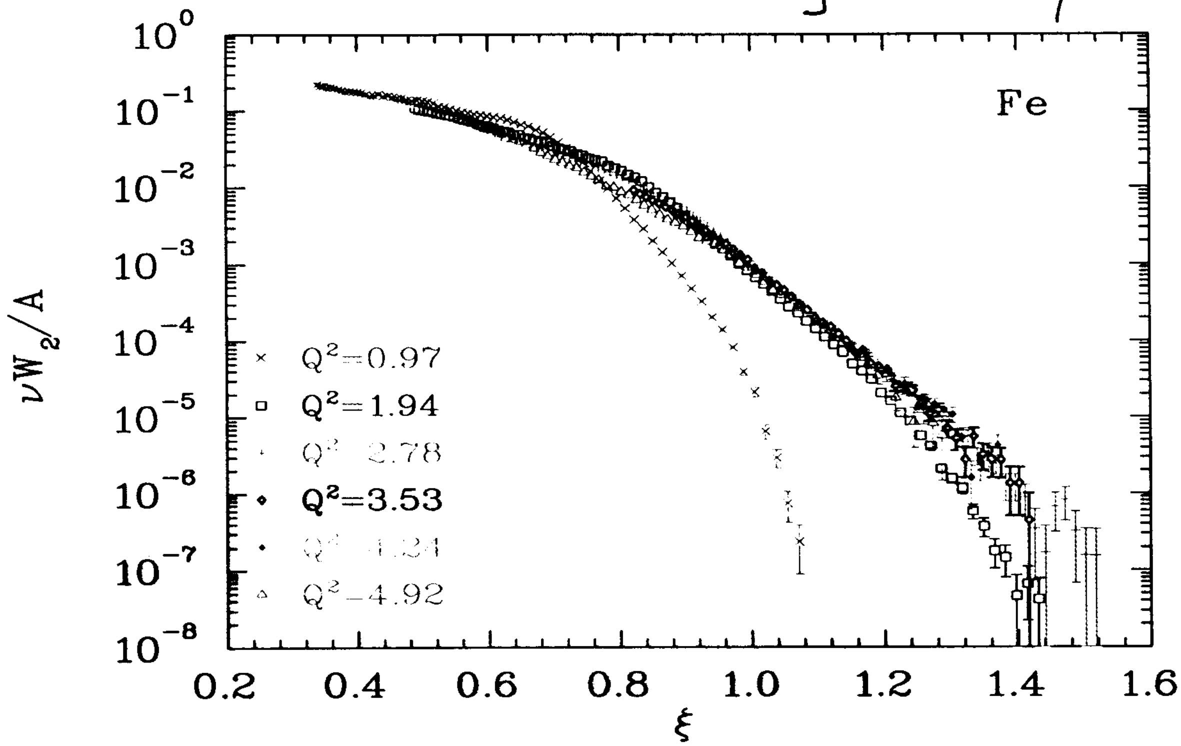
Duality in A(e,e'): ξ-Scaling.

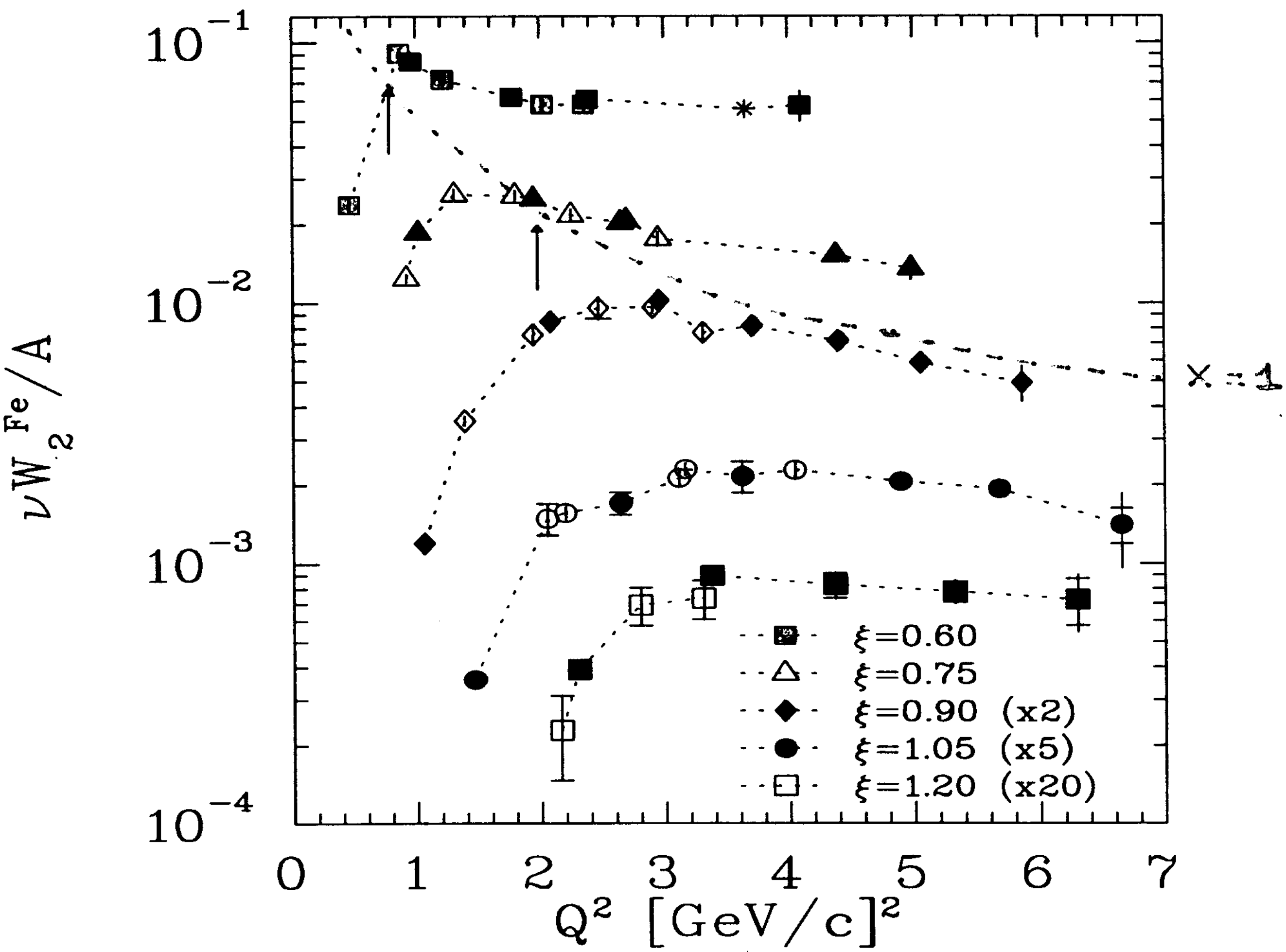




Duality in A(e,e'): ξ-Scaling.

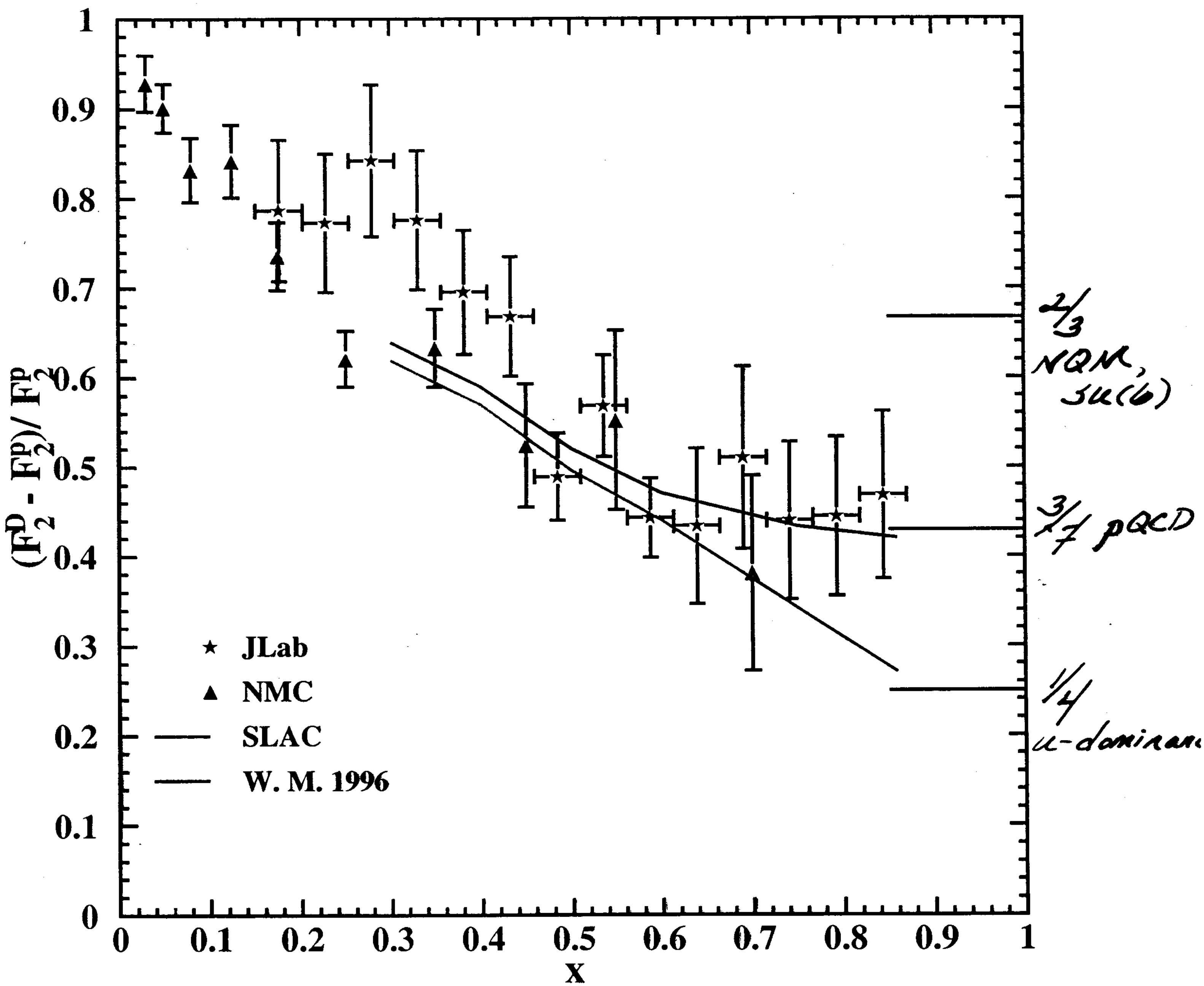
JLAB E89-008



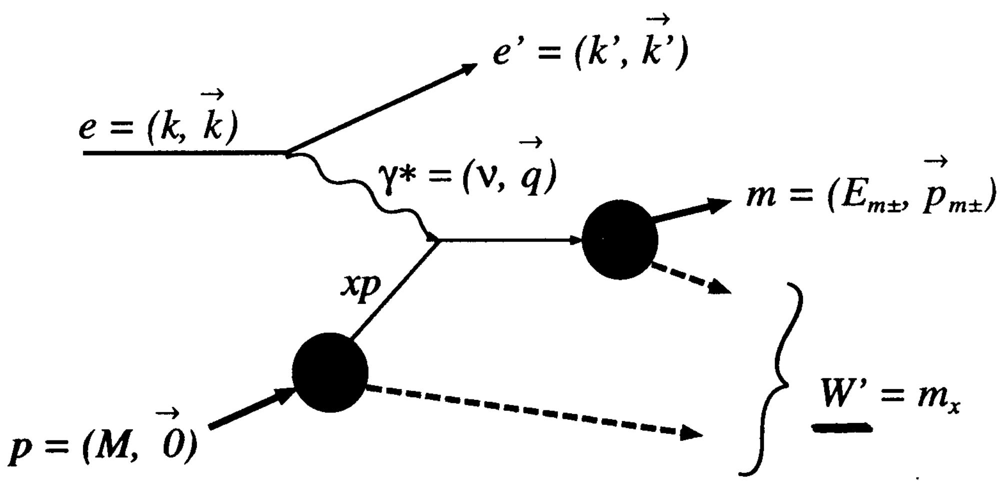


D(e,e') Inelastic data only!
Resonance Region Scans + "x>1" data

Assume Duality $\longrightarrow F_2^n / F_2^p$



Duality in Meson Electroproduction



$$z = \frac{E_m}{\nu}$$

(e,e') $$W^2 = m_p^2 + Q^2\left(\frac{1}{x} - 1\right)$$

m_m small, m colinear w. $\vec{\gamma}$, $\frac{Q^2}{\nu^2} << 1$

(e,e'm) $$W'^2 \approx m_p^2 + Q^2\left(\frac{1}{x} - 1\right)(1 - z)$$

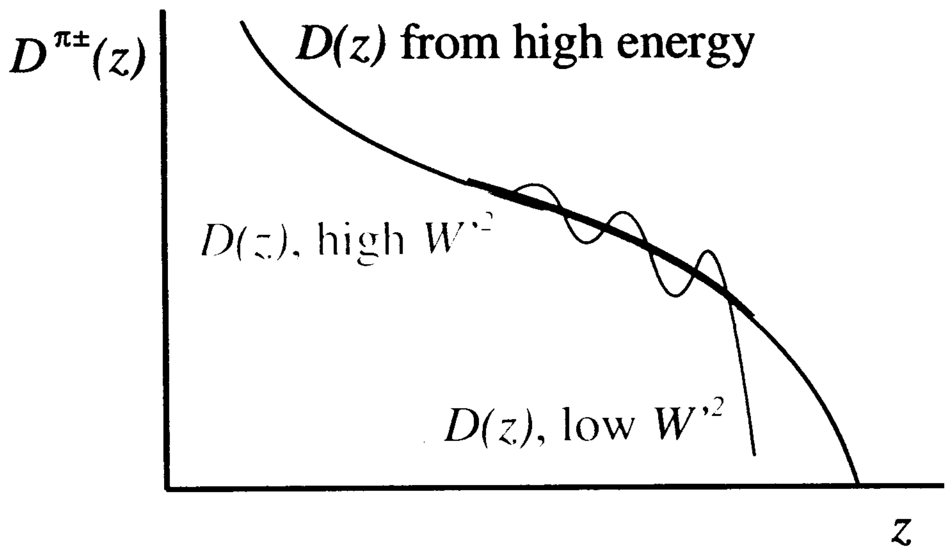
Tag w. meson

(e, e'm)

What might 'tagged' duality look like?

$$N^{\pi^\pm}(\underline{x}, \underline{z}) \propto \sum_i e_i^2 \left[q_i(x)\, D_{q_i}^{\pi^\pm}(z) + \overline{q}_i(x)\, D_{\overline{q}_i}^{\pi^\pm}(z) \right]$$

$D_f^{\pi^\pm}(z)$ are fragmentation functions



Three Questions:[1]

- Do the low W'^2 spectra average to a single curve?
- Is the resonance-to-background ratio constant?
- What is the Q^2 behavior of the resonant bumps?

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[1] C. E. Carlson, Jefferson Lab with 6–12 GeV Beams (1998)

Factorization

At high energies, the cross section factorizes:

$r > r_0$? $\quad z > z_0$?

(e,e'm) $\quad \sigma \propto f(z, Q^2)\, g(x, Q^2)$

cf. (e,e') !! $\quad \sigma \propto g(x, Q^2)$

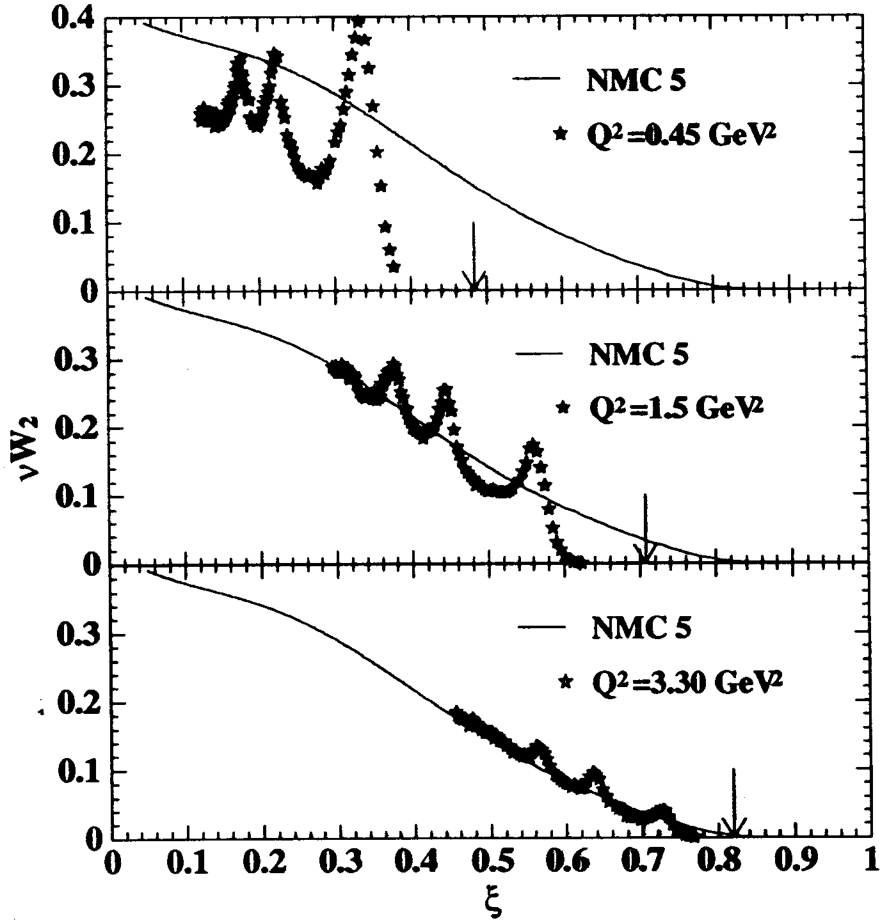
➠ $g(x, Q^2)$ describes the photon-quark interaction

➠ $f(z, Q^2)$ describes the quark hadronization

Factorization holds at high energies; how low does it work?

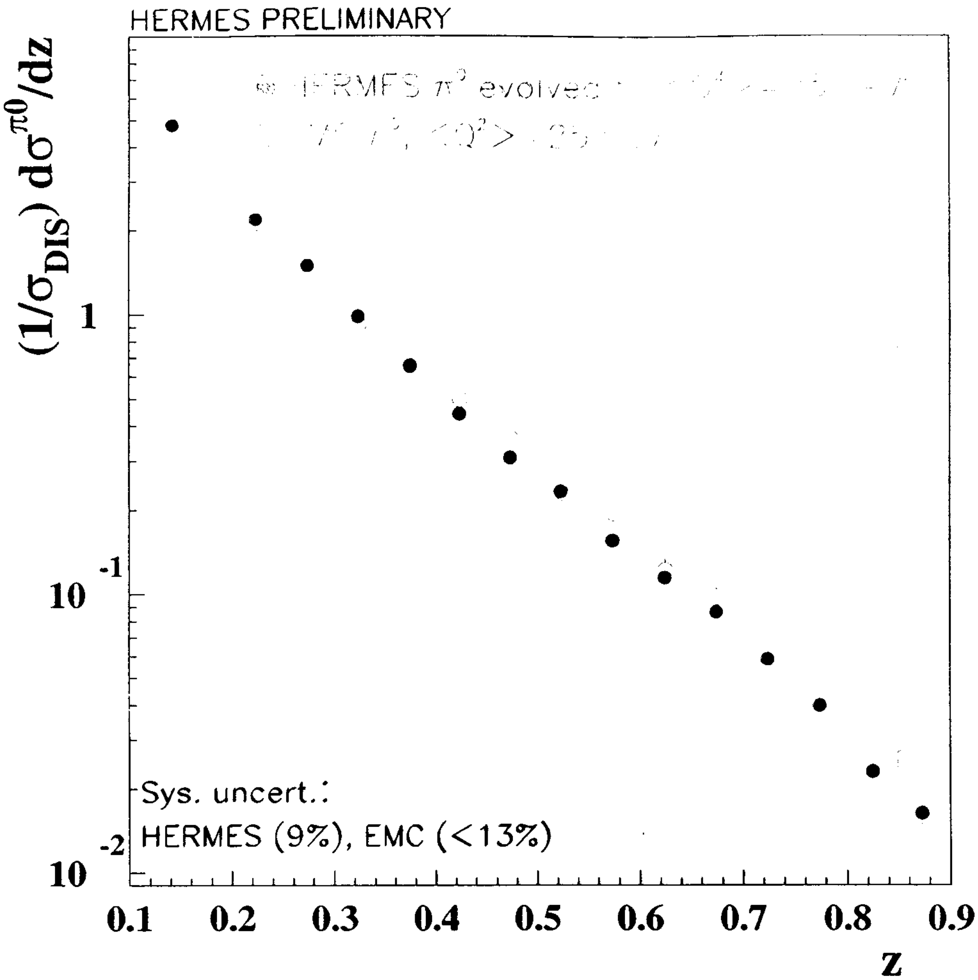
To the extent that factorization holds at low energies, we can use high-energy fragmentation functions $f(z, Q^2)$ to learn about duality in $g(x, Q^2)$

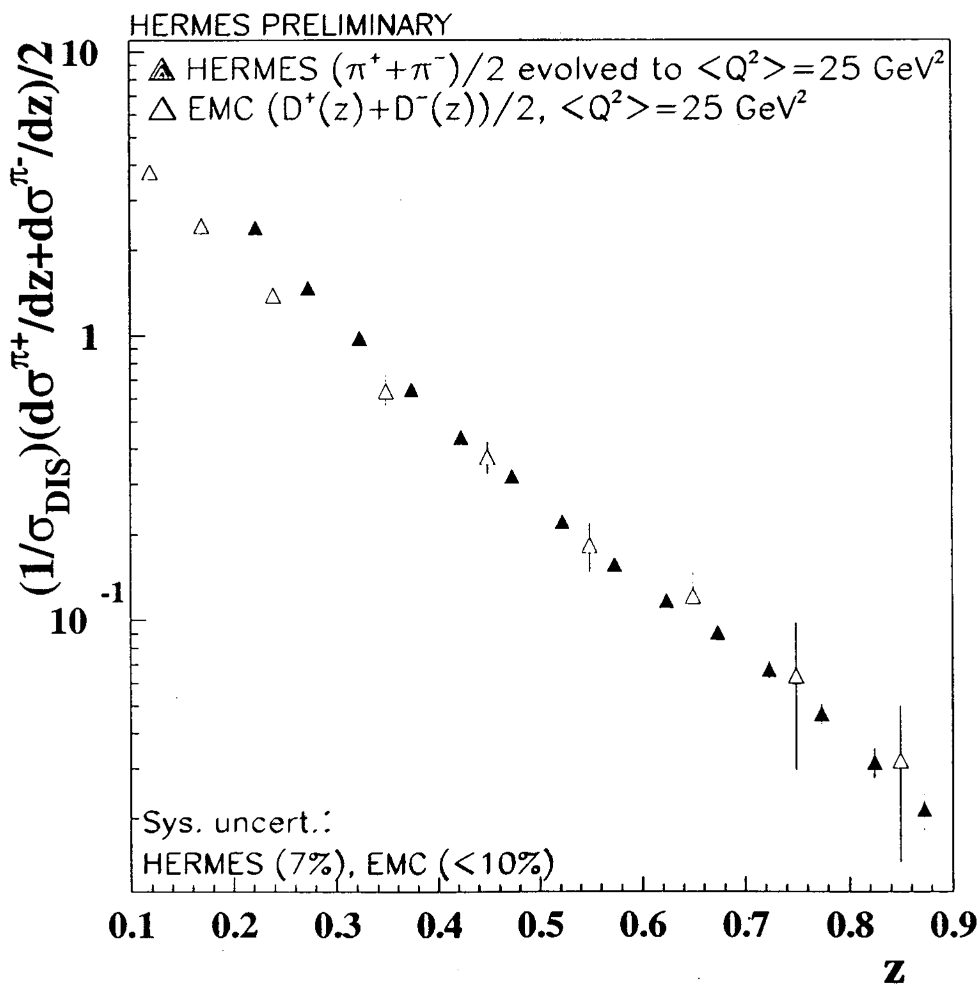
Bloom-Gilman Duality



- Resonance-region spectra oscillate about a single curve
- Resonance-to-background ratio is fairly constant

Looks like single-quark scattering
- parton model ?





(FROM $\langle Q^2 \rangle \sim 2.5$)

$\nu \sim 10 - 20$ GeV/c

$Z > 0.1$

H(e,e'π^+)   D(e,e'π^+)

H(e,e'π^-)   [D(e,e'π^-) = $\frac{\mathrm{A\ell}(e,e'\pi^-)}{\mathrm{A\ell}(e,e'\pi^+)}$ * D(e,e'π^+)]

JLab Test Run Analysis

~ 8 hours !!

E GeV	$\theta_{e'}$ deg.	E' GeV	Q^2 $(\mathrm{GeV}/c)^2$	x	θ_π deg.	p_π GeV/c	z	$\boxed{W'^2}$ GeV^2
5.51	30.0	1.6	2.36	0.32	13.0	2.0	0.51	3.3
ν ~ 4 GeV						2.5	0.64	2.6
						3.0	0.77	2.0

$W^2 \sim 5$

$$q \leftrightarrow \bar{q} \quad \Rightarrow \quad D_q^{\pi^+} = D_{\bar{q}}^{\pi^-} \quad \text{Charge Inv.}$$

$$u \leftrightarrow d \quad \Rightarrow \quad D_u^{\pi^+} = D_d^{\pi^-} \quad \text{Isospin Inv.}$$

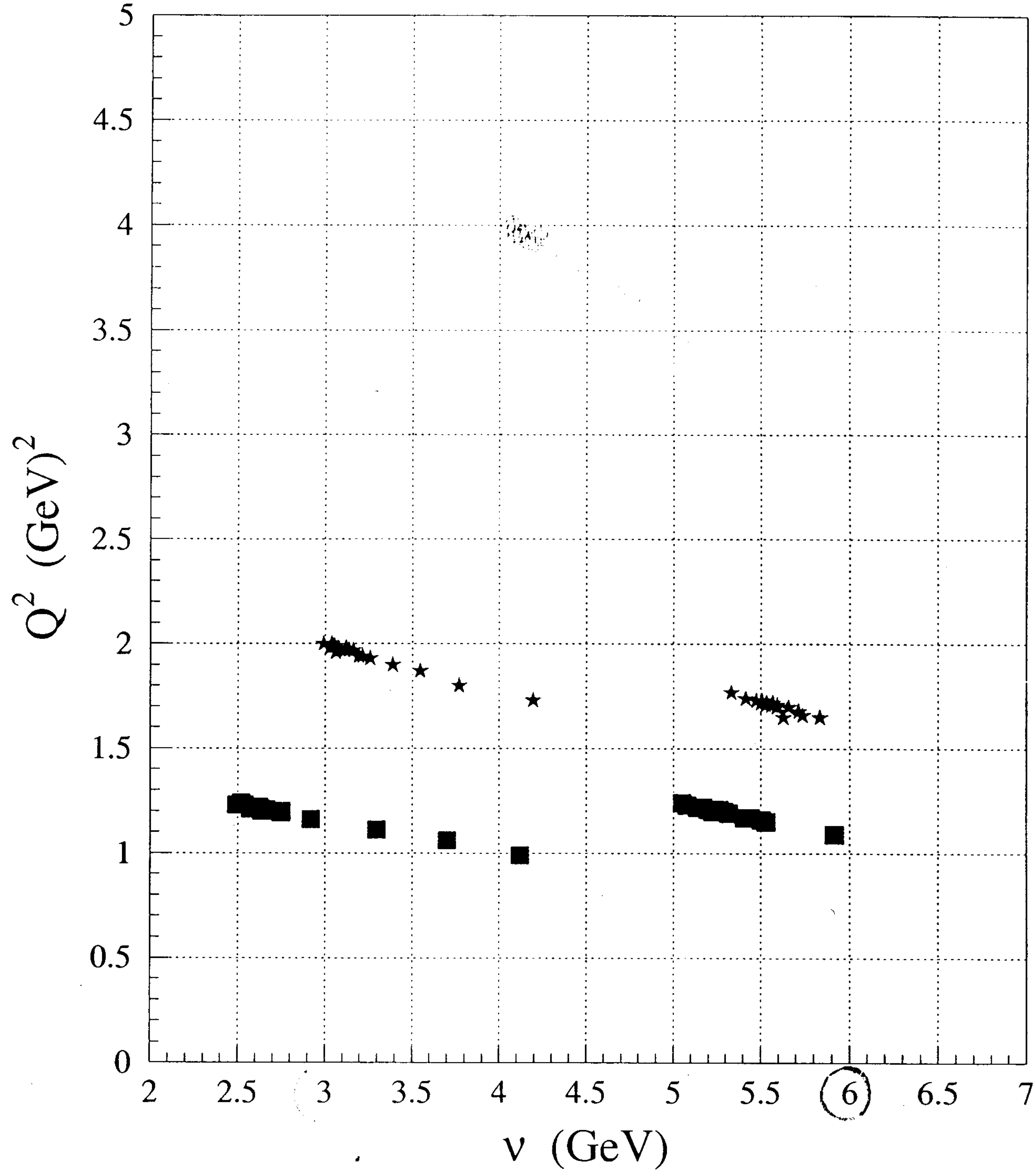
$$n \leftrightarrow p \quad \Rightarrow \quad u_p = d_n$$

Favored: $D^+ \equiv D_u^{\pi^+} = D_d^{\pi^-} = D_{\bar{u}}^{\pi^-} = D_{\bar{d}}^{\pi^+}$

Unfavored: $D^- \equiv D_u^{\pi^-} = D_d^{\pi^+} = D_{\bar{u}}^{\pi^+} = D_{\bar{d}}^{\pi^-}$

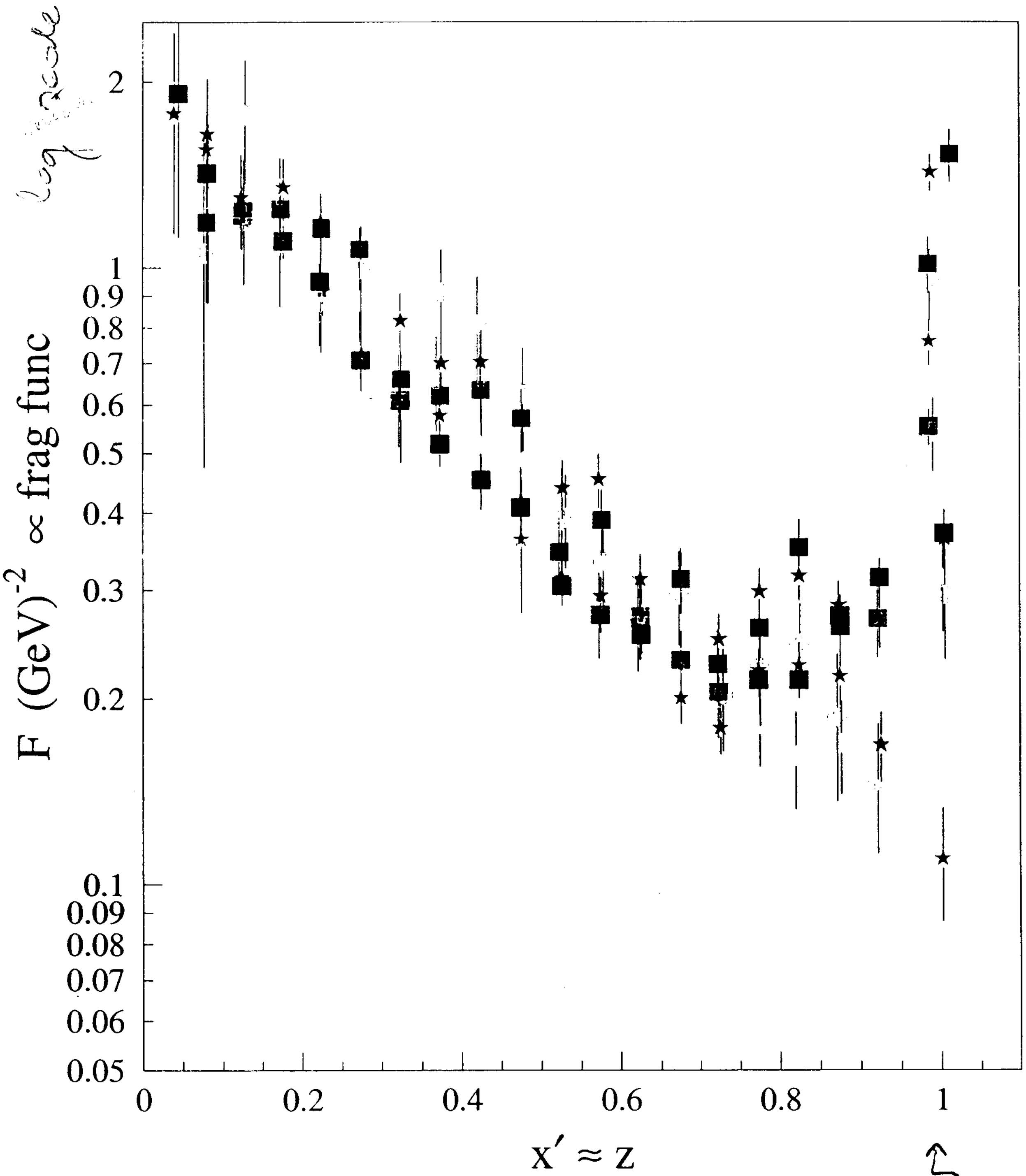
$$\frac{1}{N_e}\frac{dN^h}{dz} = \frac{\sum_f e_f^2\, q_f(x)\, D_f^h(z)}{\sum_f e_f^2\, q_f(x)}$$

CORNELL , '70's



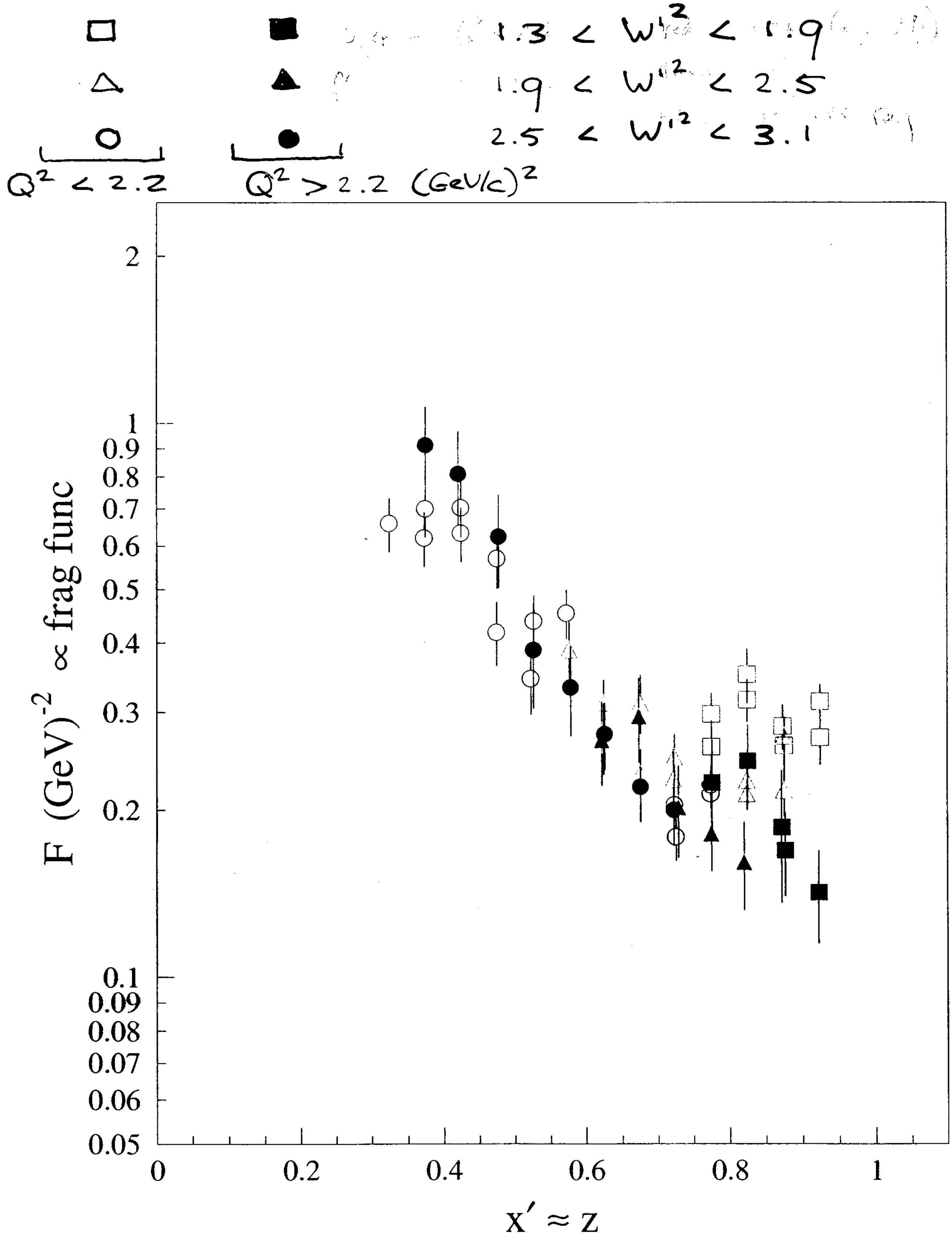
Cornell data '70's

No Q^2 evolution applied



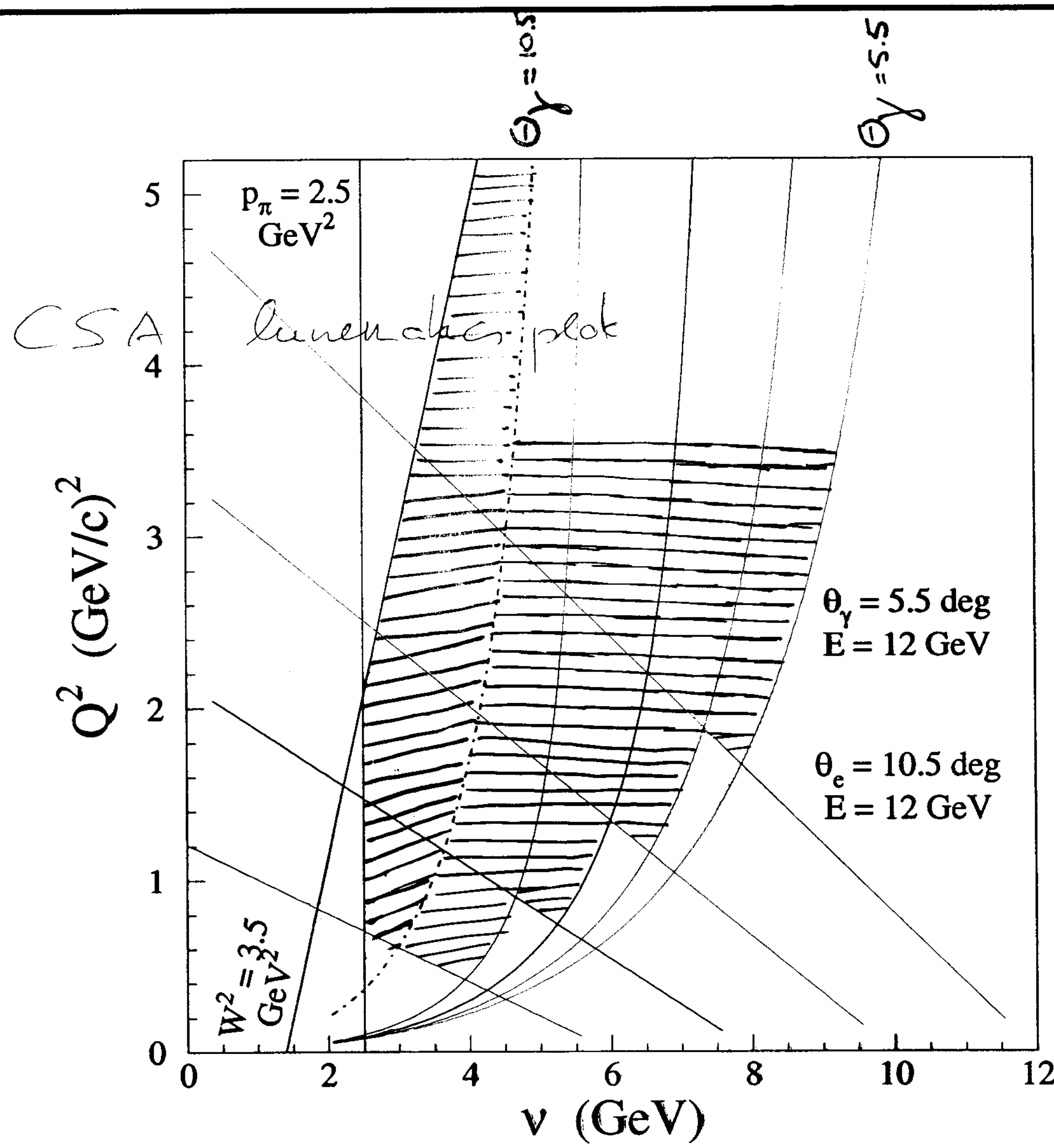
$W'^2 \sim 1$

"elastic"



1.3 < W'² < 1.9
1.9 < W'² < 2.5
2.5 < W'² < 3.1
Q² < 2.2
Q² > 2.2 (GeV/c)²
F (GeV)⁻² ∝ frag func
x' ≈ z

Expanded Kinematics at High Energies



Since $z = \frac{E_m}{\nu}$, and factorization is expected to improve with ν, we really want access to large energy losses!

Goals of Factorization/Duality Measurements

- How well does factorization work at low energies? Study onset of scaling in (x, z, Q^2) grid
- Use JLab to measure d_v/u_v, etc?
- Duality studies
  - Do resonances oscillate about a single curve?
  - Is that curve the fragmentation function?
  - Is the resonance-to-dip ratio constant?

Duality seems to govern the onset of Scaling

* F_2 : Scaling @ $Q^2 \gtrsim 1$

  $W^2 \geq 4$ + $W^2 \leq 4$

* g_1 : Scaling @ $Q^2 \gtrsim 2.0$??

  $W^2 \leq 4$

* Nuclei : Scaling @ $Q^2 \gtrsim 1 \ldots 3$

  $\xi \lesssim 1$ $\quad$ $\xi > 1$

* Mesons : Scaling @ $Q^2 \gtrsim 1$

  $\left.\begin{matrix} z > 0.2 \\ W'^2 > 4 \end{matrix}\right\}$? $+ W'^2 \leq 4$??

  $x > 0.3$?