April 16, 2002

# Tagged Neutron Structure Function at Large $x$

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## Valence Quarks at Large $x$

- Probe *spin-flavor* structure of valence quarks without dilution from sea

- $x \sim 1 \Rightarrow$ single quark carries all of hadron's momentum
  $\Rightarrow$ calculate perturbatively

- Structure functions at large $x$ related to $N \to N^*$ transition form factors via *quark–hadron duality*

- Essential input in searches for *new physics* at high energy colliders

# NEUTRON / PROTON STRUCTURE FUNCTION RATIO AT LARGE x

$$\frac{F_2^n}{F_2^p} \approx \frac{1 + 4\,d/u}{4 + d/u}$$

$x \gtrsim 0.4$

## Predictions for $F_2^n/F_2^p$ at $x \to 1$

- SU(6) symmetry:

$$\frac{F_2^n}{F_2^p} = \frac{2}{3}$$

- Broken SU(6) via scalar diquark dominance ($d$ quark suppression):

$$\frac{F_2^n}{F_2^p} \longrightarrow \frac{1}{4}$$

- Broken SU(6) via helicity flip suppression:

$$\frac{F_2^n}{F_2^p} \longrightarrow \frac{3}{7}$$

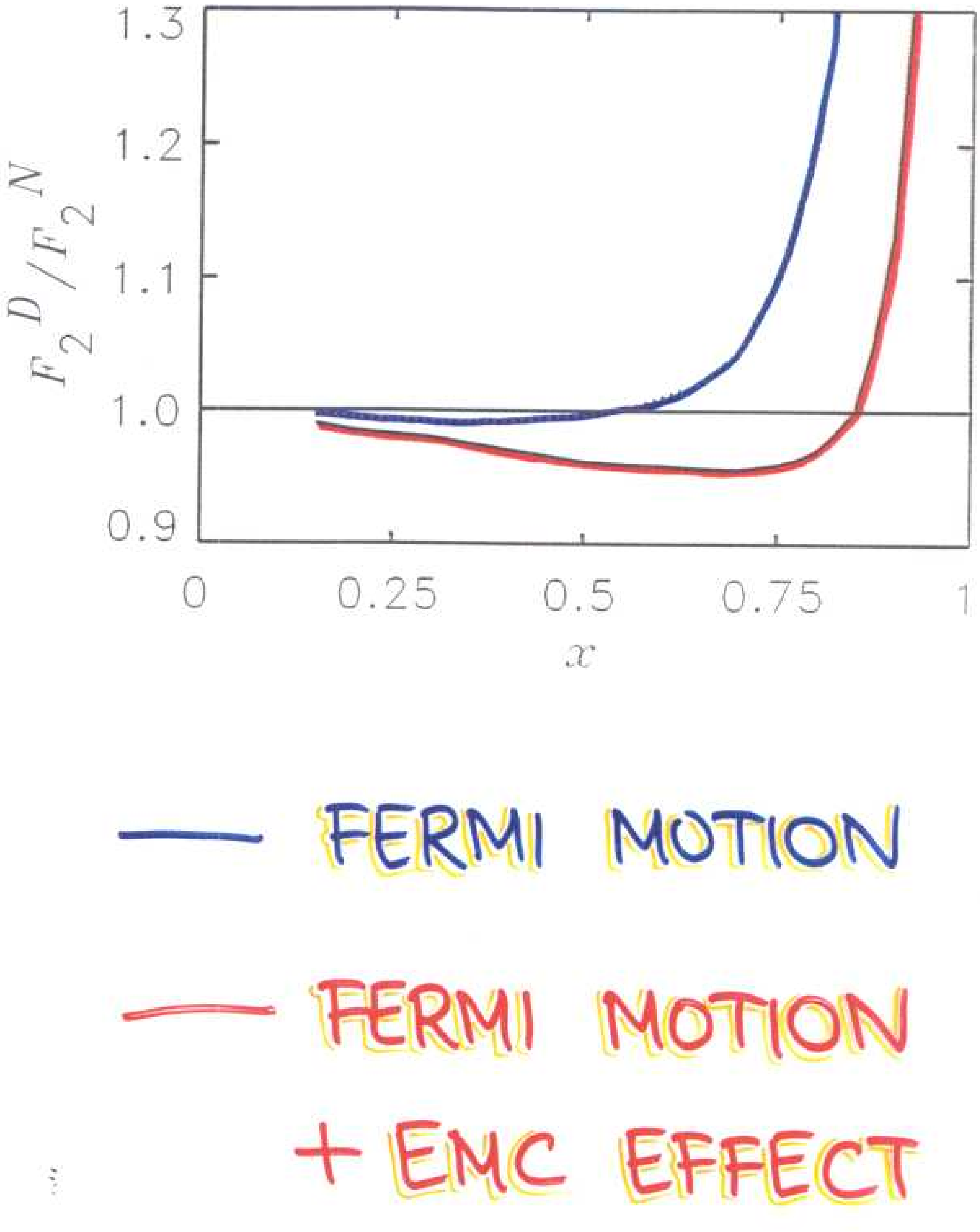
- Quark-hadron duality:

$$\frac{F_2^n}{F_2^p} \longrightarrow \frac{d(G_M^n)^2/dQ^2}{d(G_M^p)^2/dQ^2}$$

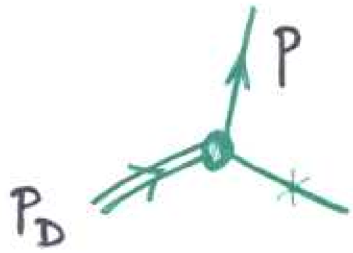
## Extraction of $F_2^n$ from $F_2^D$ & $F_2^p$

- Currently all information on $F_2^n$ comes from inclusive DIS on **deuteron**
- How large is EMC effect in the deuteron?
- Answer still controversial!
- Nuclear Fermi motion and binding (off-shell) effects are large for $x > 0.6$
- Theoretical uncertainty in $F_2^n$ at large $x$ – whether one corrects for Fermi motion, or Fermi motion + binding, $F_2^n$ can differ by $\geq 50\%$

WM, THOMAS 1996

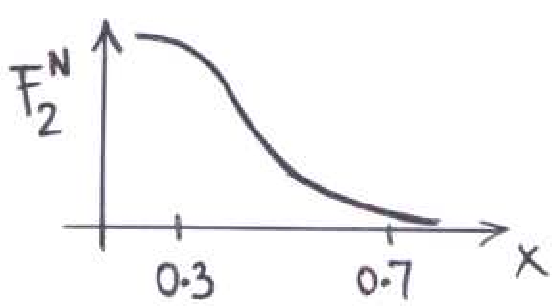


ON-SHELL | OFF-SHELL



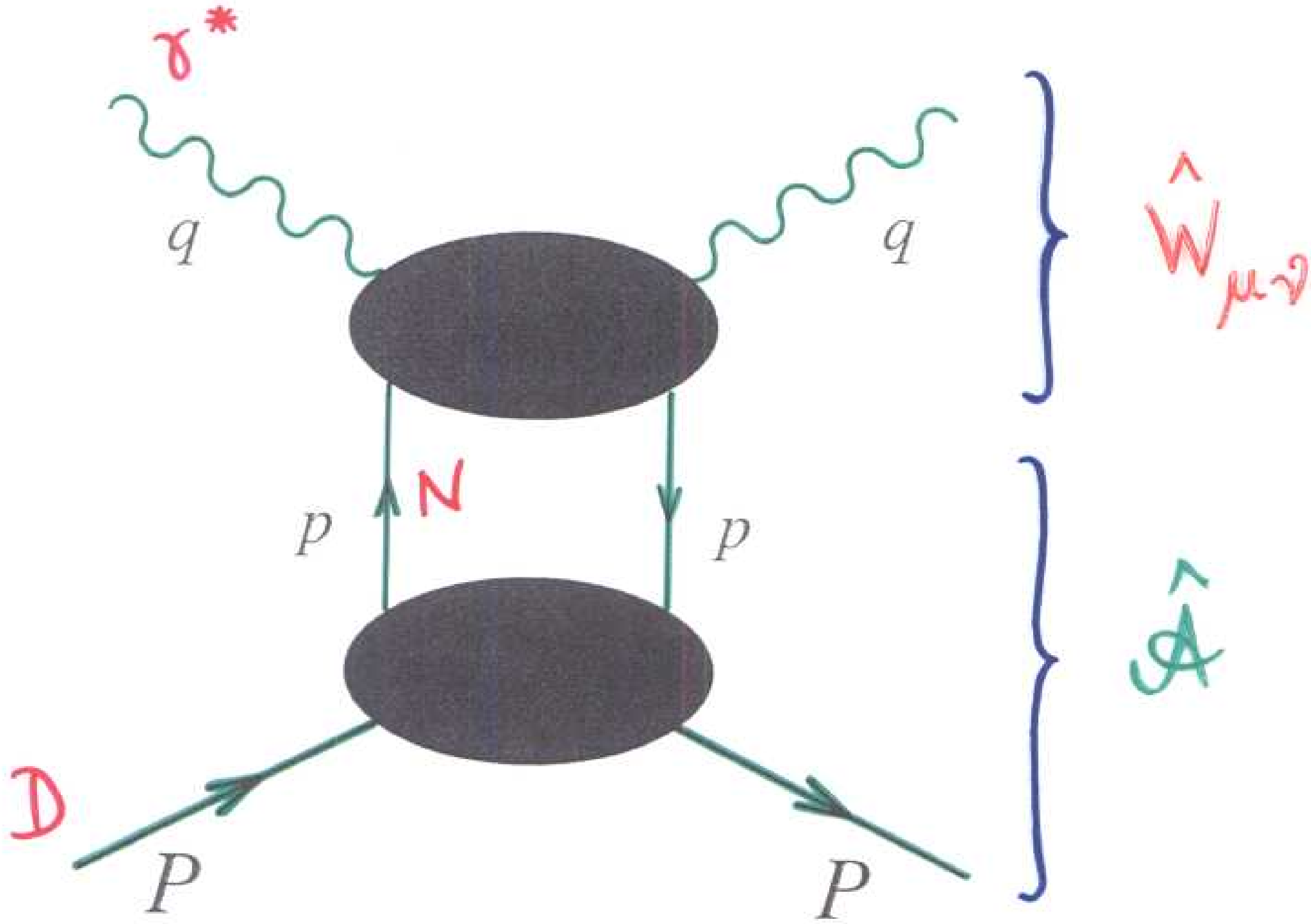

$$y = \frac{p_0 + p_z}{M} \Rightarrow \langle y \rangle = \frac{\langle p_0 \rangle}{M}$$

| ON-SHELL | OFF-SHELL |
|---|---|
| $p_0 = \sqrt{M^2 + \vec{p}^{\,2}}$ | $p_0 = M_D - \sqrt{M^2 + \vec{p}^{\,2}}$ |
| $\langle y \rangle > 1$ | $\langle y \rangle < 1$ |
| $F_2\left(\frac{x}{\langle y \rangle}\right) > F_2(x)$ | $F_2\left(\frac{x}{\langle y \rangle}\right) < F_2(x)$ |




| ON-SHELL | OFF-SHELL |
|---|---|
| $F_2^A / F_2^N > 1$ | $F_2^A / F_2^N < 1$ |

# IMPULSE APPROXIMATION



$$W^{D}_{\mu\nu} = \int d^4p \ \mathrm{Tr}\left[\hat{\mathcal{A}} \cdot \hat{W}_{\mu\nu}\right]$$

$$\hat{\mathcal{A}} = I\,\mathcal{A}_S + \gamma\cdot\mathcal{A}_V$$

$$\hat{W}_{\mu\nu} = g_{\mu\nu}\left(I\,\hat{W}_0 + \not{p}\,\hat{W}_1 + \not{q}\,\hat{W}_2\right) + O(1/Q^2)$$

⬇

$$F^{D}_{2}(x) = \int dy\, dp^2 \left(\mathcal{A}_S\,\hat{W}_0 + p\cdot\mathcal{A}_V\,\hat{W}_1 + q\cdot\mathcal{A}_V\,\hat{W}_2\right)$$

$$\neq \int dy\ f(y)\ F^{N}_{2}\left(\frac{x}{y}\right)$$

# BREAKDOWN OF FACTORISATION

WM, SCHREIBER, THOMAS PHYS. REV. D49 (94) 1183

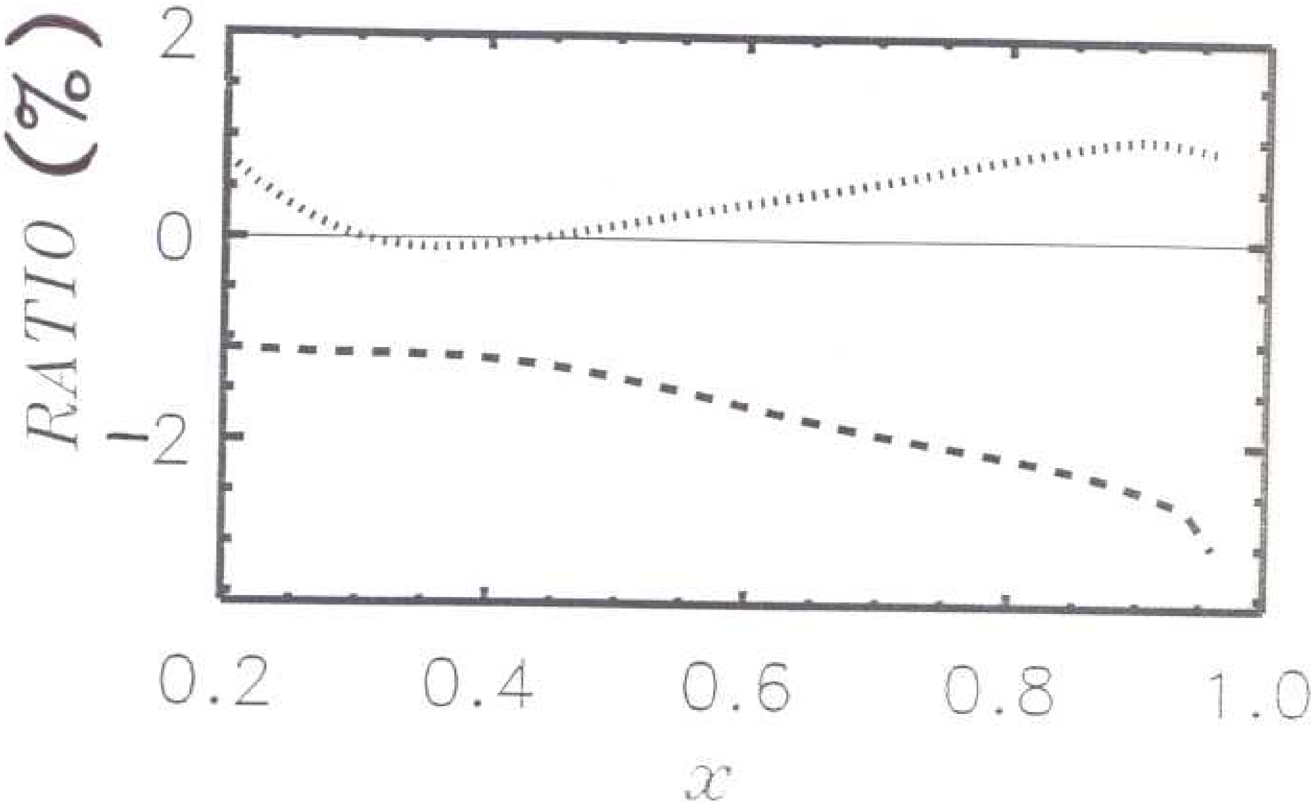
# RELATIVISTIC DEUTERON STRUCTURE FUNCTION

$$F_2^D(x) = \int_x dy\, f(y)\, F_2^N\left(\frac{x}{y}\right)$$

$$+ \underbrace{\delta^{(D)} F_2 + \delta^{(N)} F_2}_{\text{RELATIVISTIC CORRECTIONS} \sim 1\%}$$

$$f(y) = \frac{M_D}{4}\, y \int_{-\infty}^{p^2_{max}(y)} dp^2\, \frac{E_p}{p_0}\, |\psi_D|^2$$

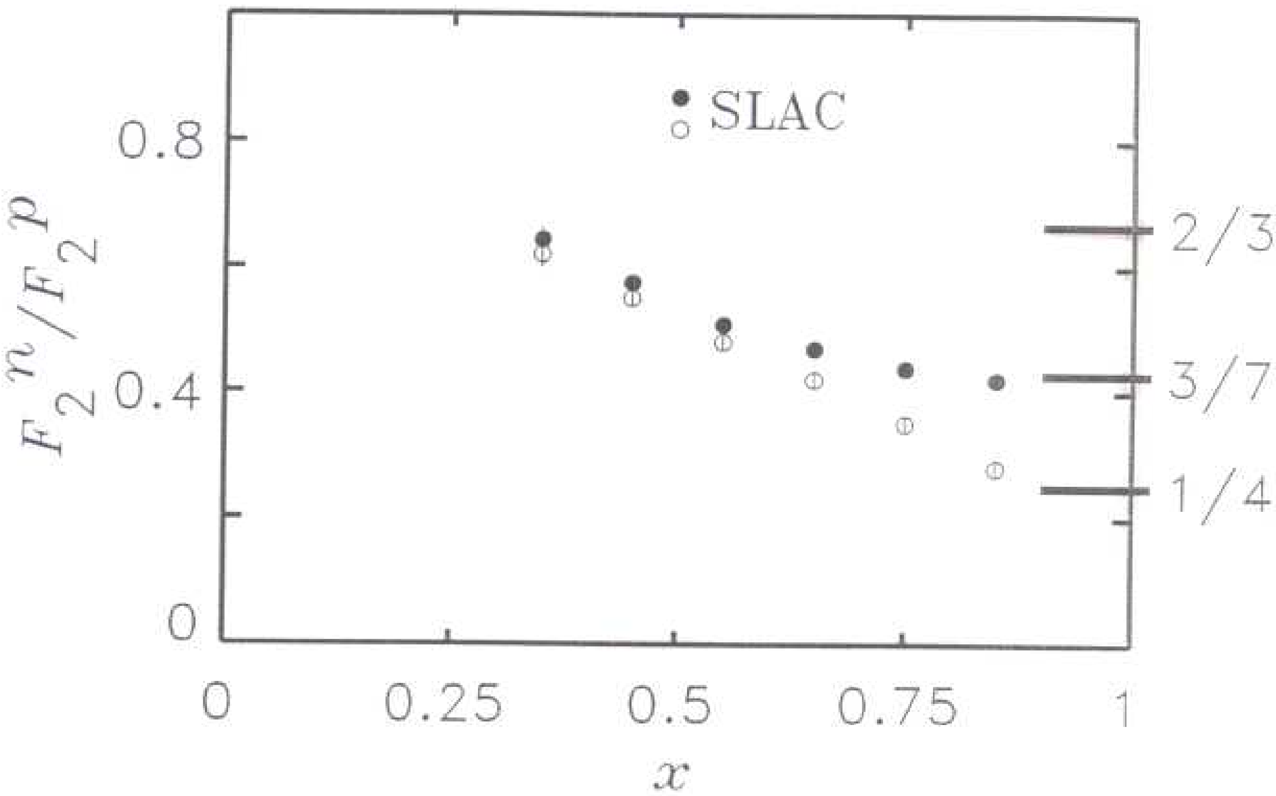
# RELATIVISTIC DEUTERON CORRECTIONS




········ $\delta^{(N)} F_2 / F_2^D$

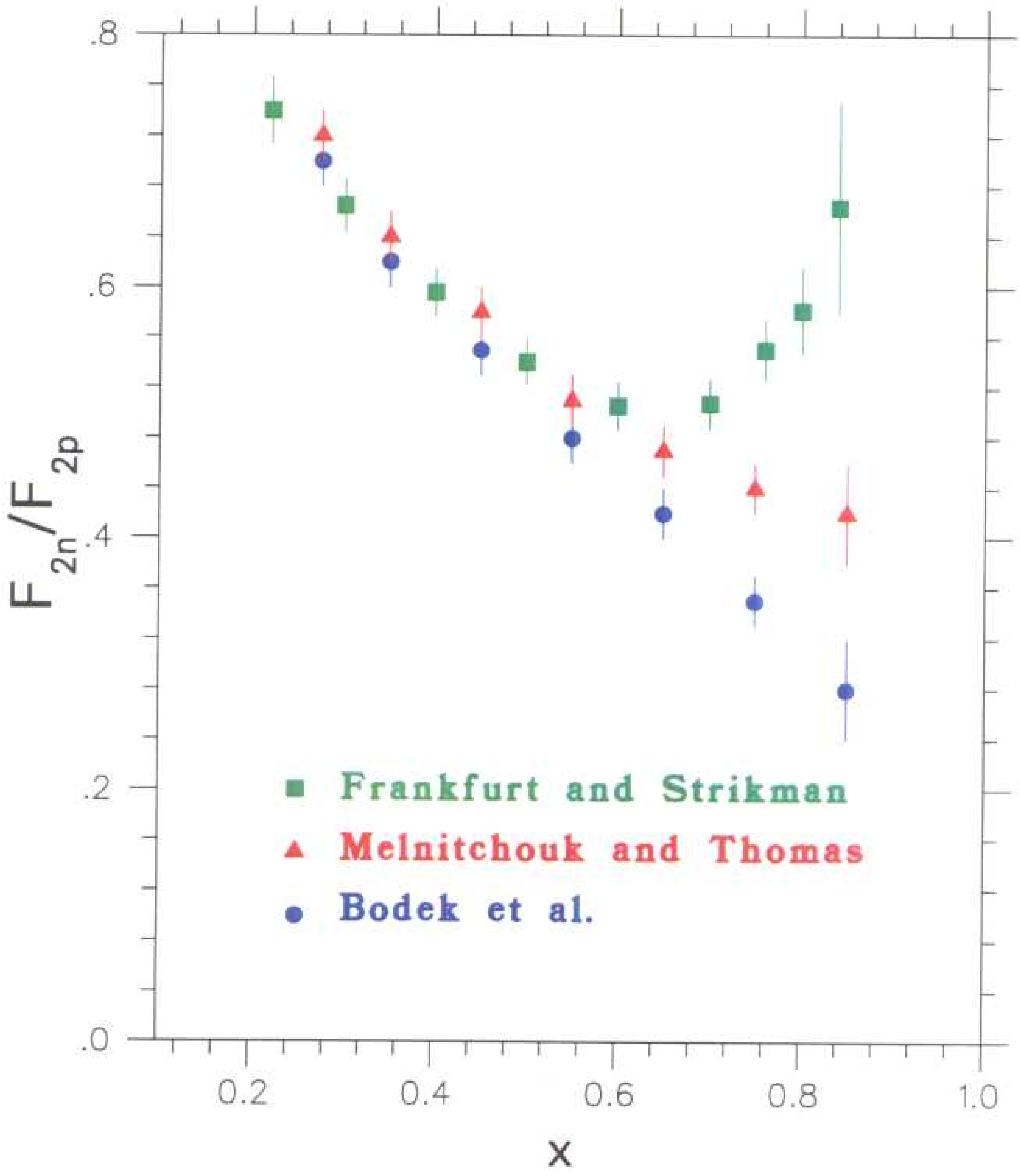
– – – – $\delta^{(D)} F_2 / F_2^D$

WM, THOMAS PLB 377 (96) 11



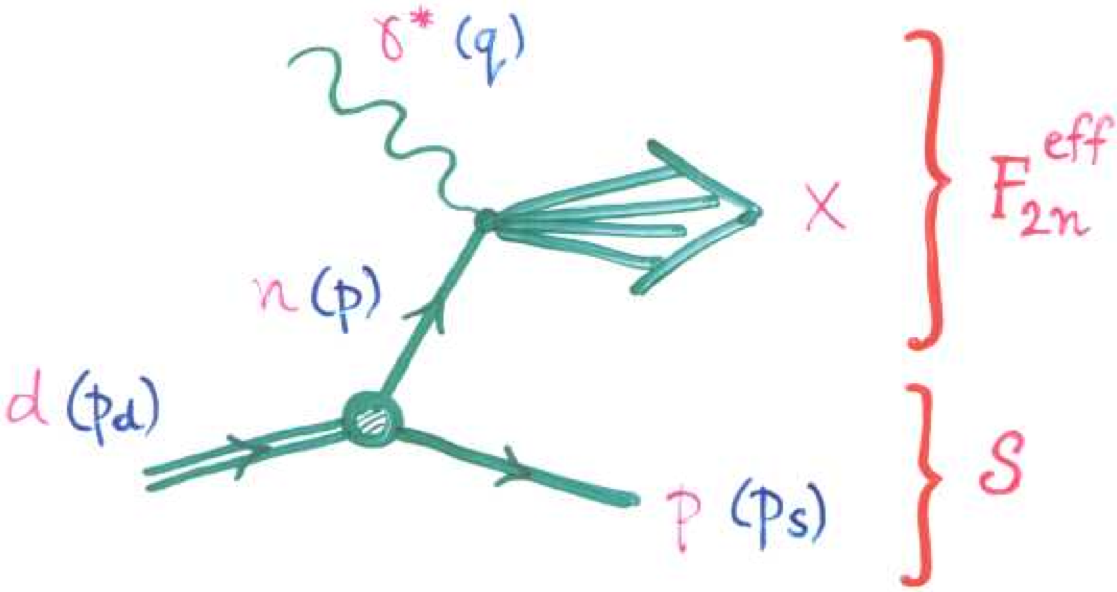

○ FERMI MOTION

● FERMI MOTION
+ EMC EFFECT



.8
.6
.4
.2
.0
0.2
0.4
0.6
0.8
1.0
x
F2n/F2p
Frankfurt and Strikman
Melnitchouk and Thomas
Bodek et al.

## Semi-Inclusive DIS from the Deuteron




$$\frac{d\sigma}{d^3p} \sim S(y, p^2)\ F_{2n}^{eff}(x/y, p^2, Q^2)$$

where

$$y = \frac{p_n \cdot q}{p_d \cdot q} \approx \frac{M_d - E_p + p_s^z}{M_d} \approx \frac{1}{2}(2 - \alpha_s)$$

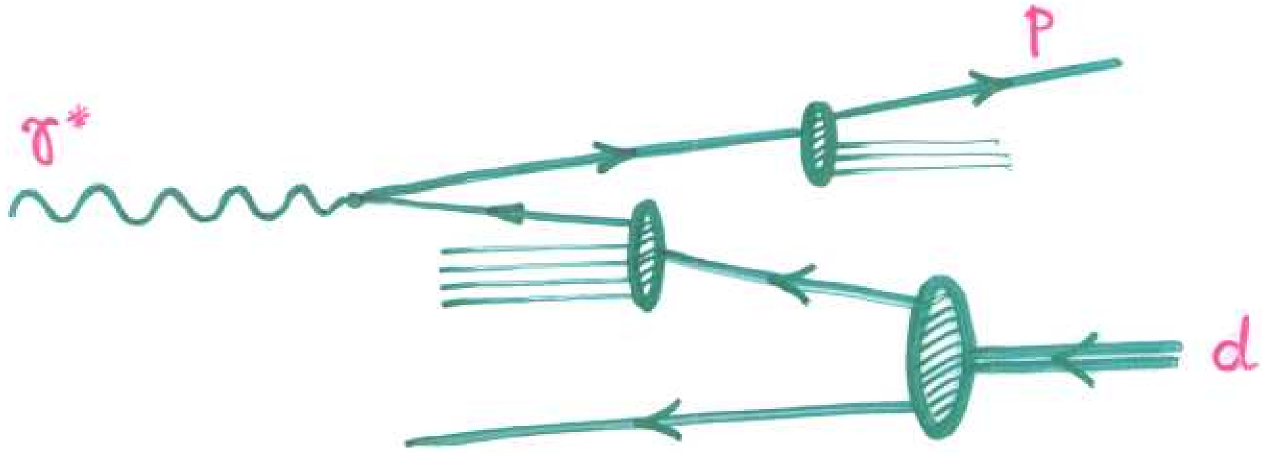
is light-cone momentum fraction carried by neutron with $\alpha_s = (E_s - p_s^z)/M$

Neutron virtuality:

$$p^2 = -\frac{p_T^2}{1-y} - \frac{y}{1-y}\left(M_N^2 - M_d^2(1-y)\right)$$

## Why Backward Kinematics?

- Minimize production of low momentum protons from quark fragmentation




- Minimize final state interactions between spectator proton and neutron remnant

## Final State Interactions

- Use FSI calculation in $d(e, e'p)n$ as a guide
  $\longrightarrow$ replace $p$-$n$ rescattering cross section by effective $p$-$X$ cross section, $\sigma_{eff}$

  Frankfurt, Miller, Greenberg, Sargsian, Strikman 1995

- Because of steep momentum dependnce of deuteron wave function
  $\longrightarrow \psi_d(\alpha_s, p_T) \ll \psi_d(\alpha_s, 0)$
  FSI are strongly suppressed at backward angles

  Frankfurt, Strikman 1988

- Soft neutron production in $\mu$-nucleus DIS
  $\longrightarrow$ effective rescattering cross section $\sigma_{eff} \sim 20$ mb

  Strikman, Tverskoy, Zhalov 1996

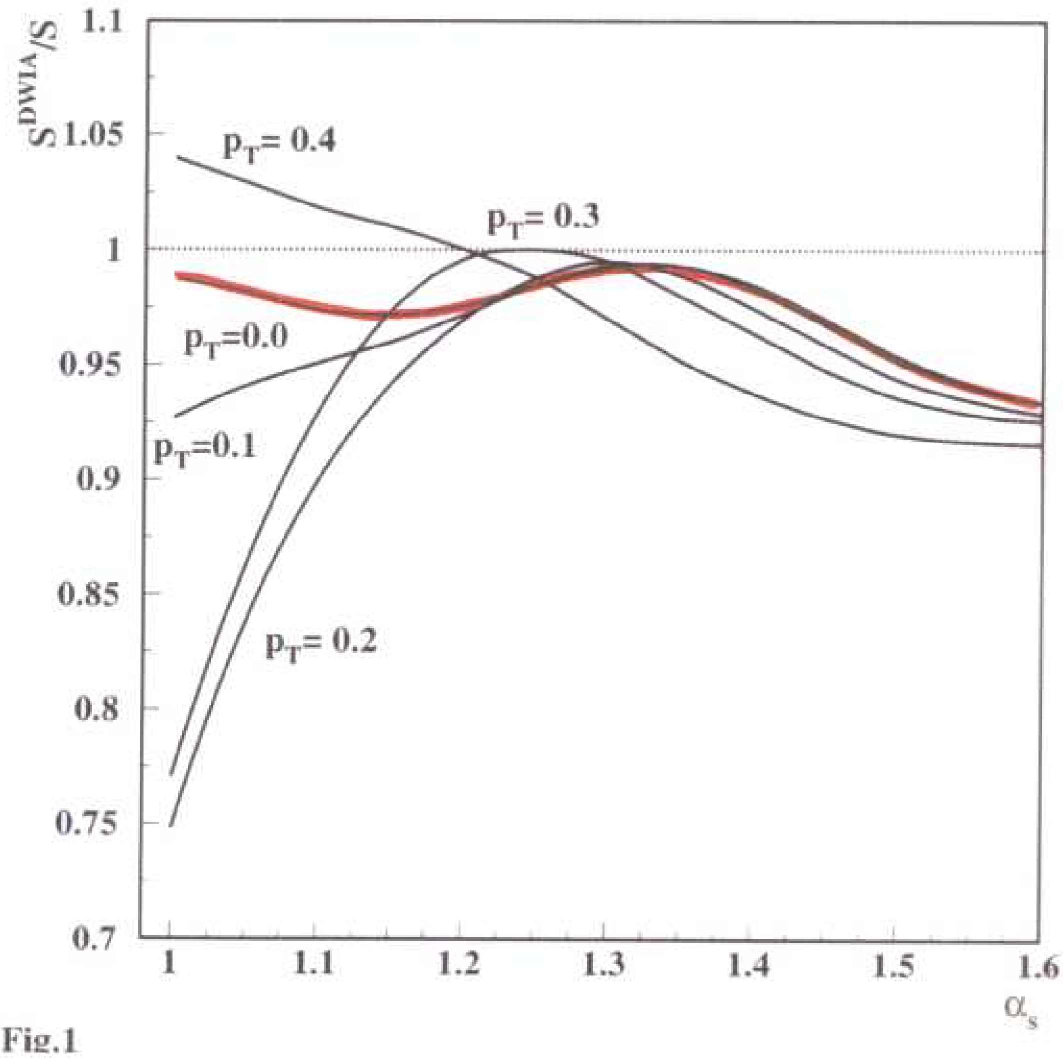
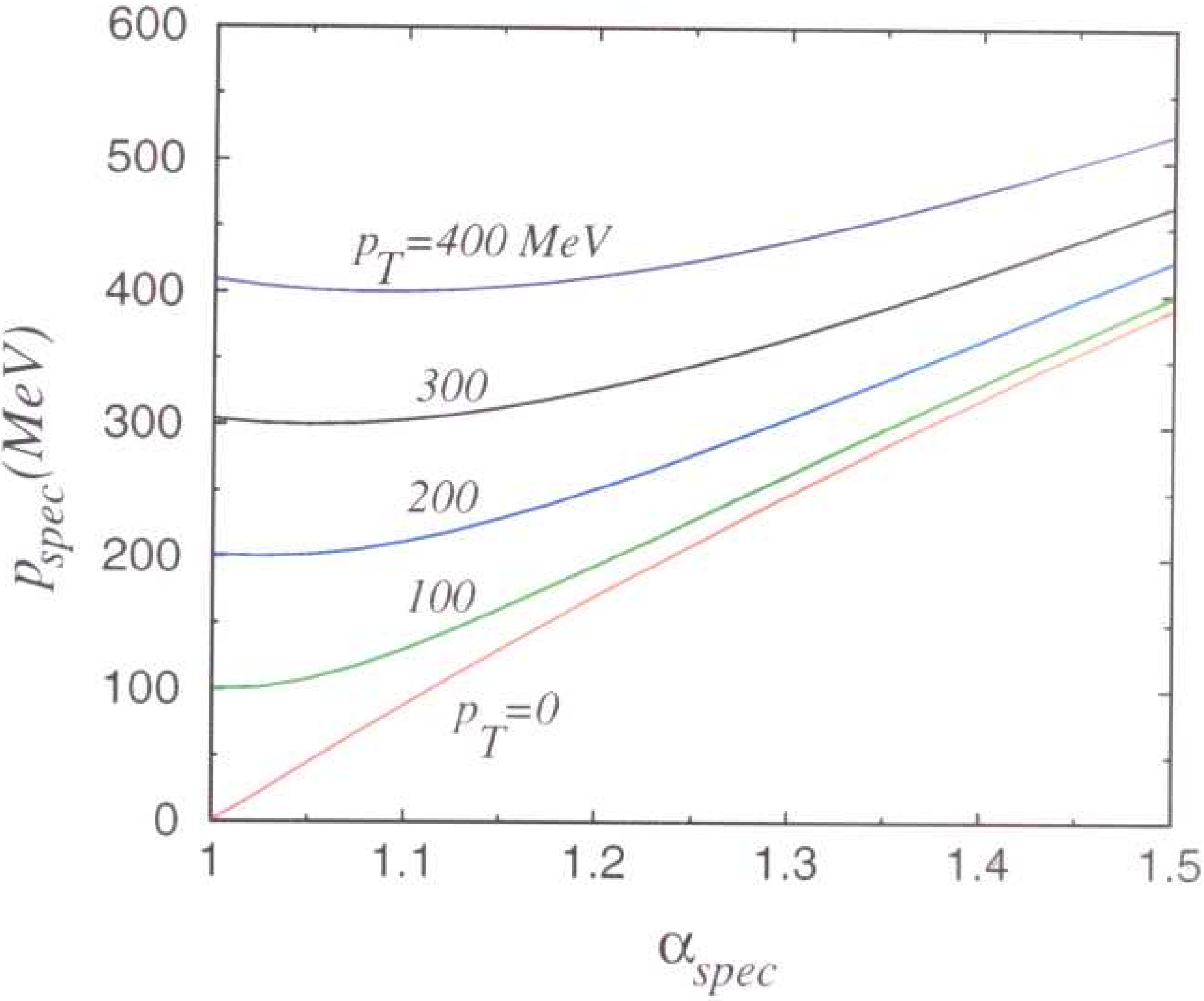



Fig.1

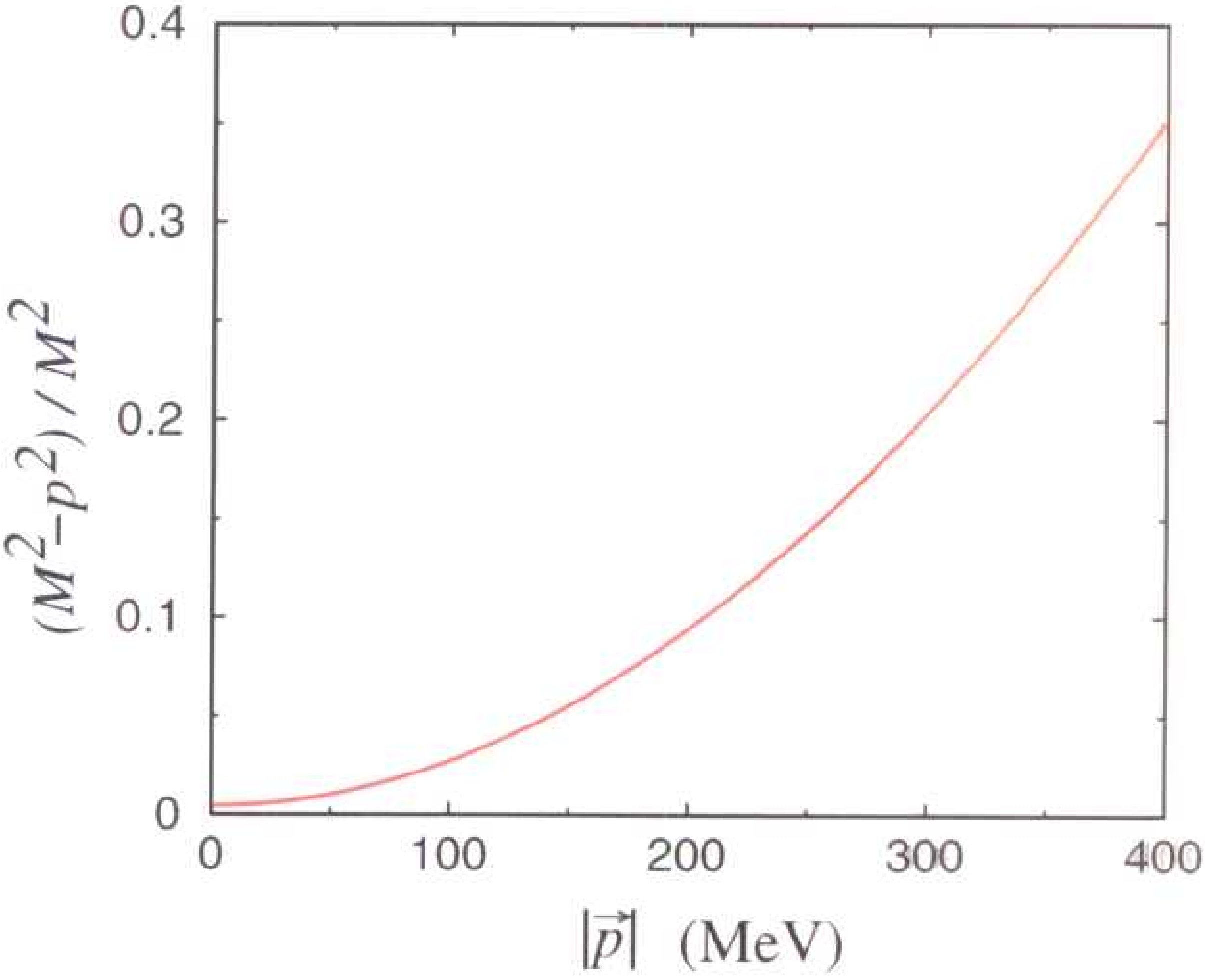
*Effects of FSI on the spectral function*

Melnitchouk, Sargsian, Strikman

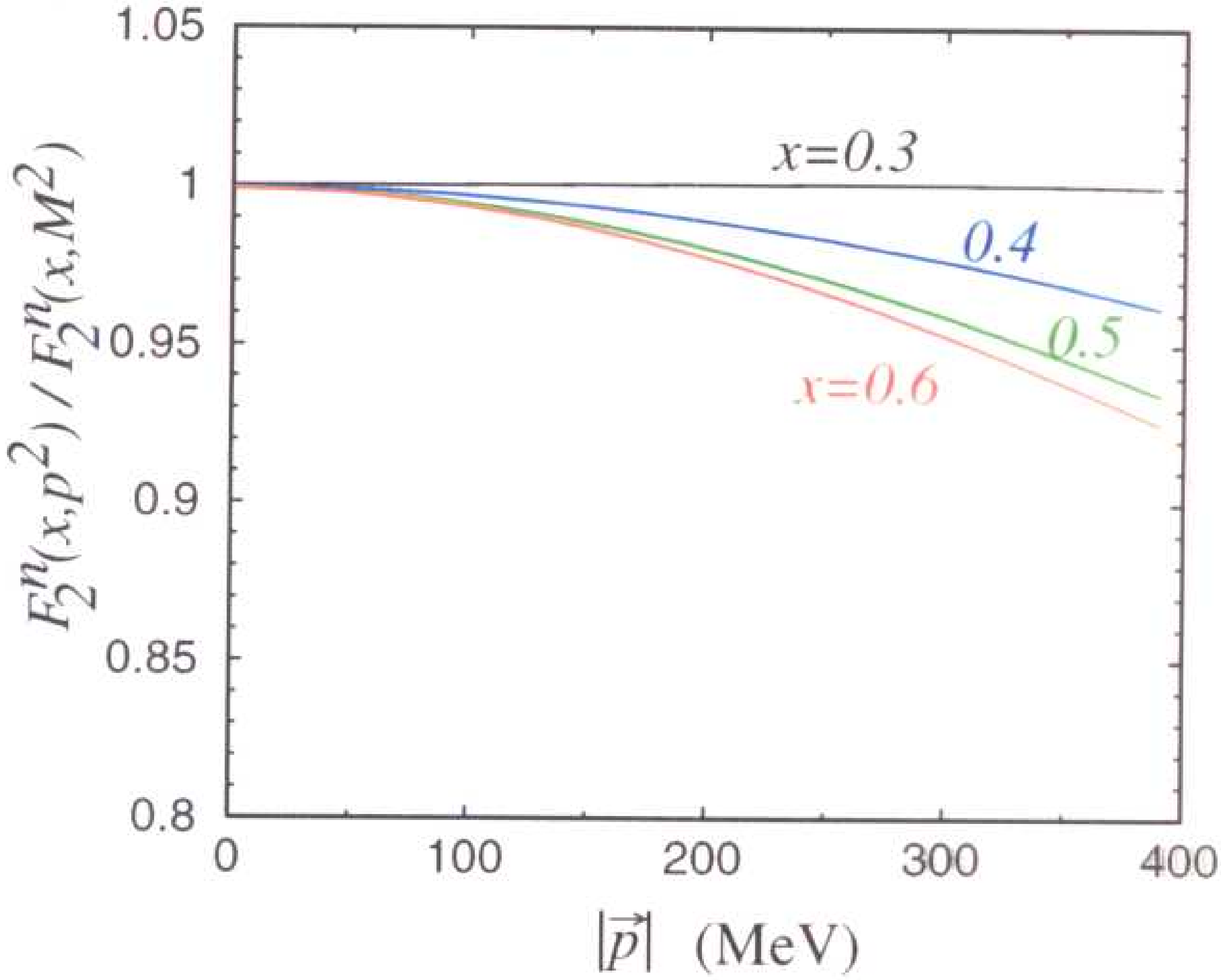
Z. Phys. A 359 (1997) 99




Spectator momentum vs. spectator light-cone variable




Nucleon virtuality vs. spectator momentum




*Bound to free neutron structure function ratio*

*as a function of spectator proton momentum*

*(for $p_T$=0)*

Melnitchouk, Schreiber, Thomas

Phys. Lett. B 335 (1994) 11

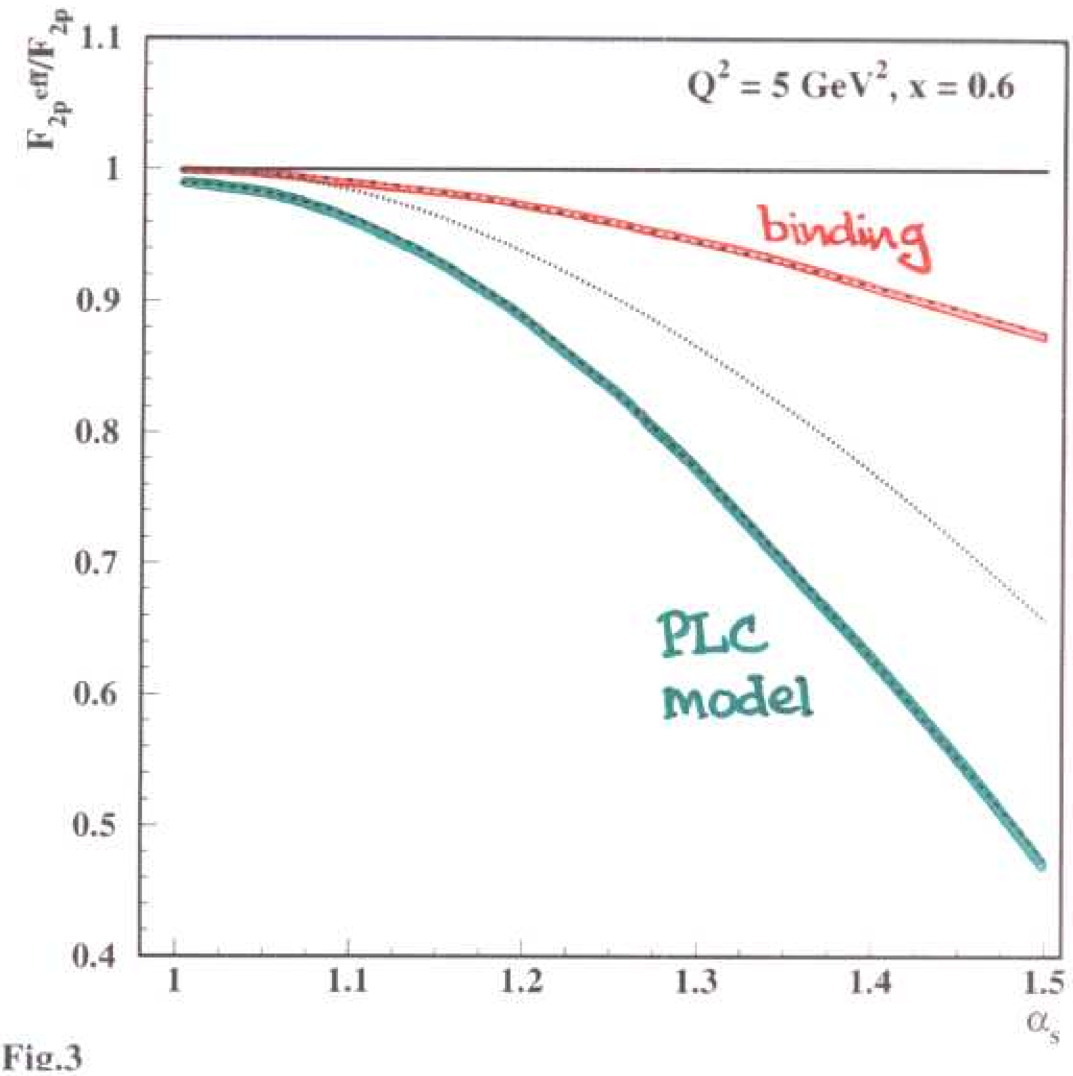



Fig.3

*Model dependence of effective bound nucleon structure function ($p_T = 0$)*

Melnitchouk, Sargsian, Strikman

Z. Phys. A 359 (1997) 99

## *Can size of nucleon off-shell modifications be constrained from other reactions?*

- Nonperturbative dynamics responsible for nucleon structure deformation should also be visible in other observables,

  e.g. electromagnetic form factors

- Polarization transfer experiments $A(\vec{e}, e'\vec{p})$ on $^4$He (at Mainz & JLab) searched for medium modification of proton e.m. form factors

  $\longrightarrow$ data require small amount of off-shell modification

  e.g. in QMC model

- Local quark-hadron duality relates form factors to structure functions at large $x$

  Bloom, Gilman 1970

  De Rujula, Georgi, Politzer 1977

  Ent, Keppel, Niculescu 2000

nucl-ex/0011008

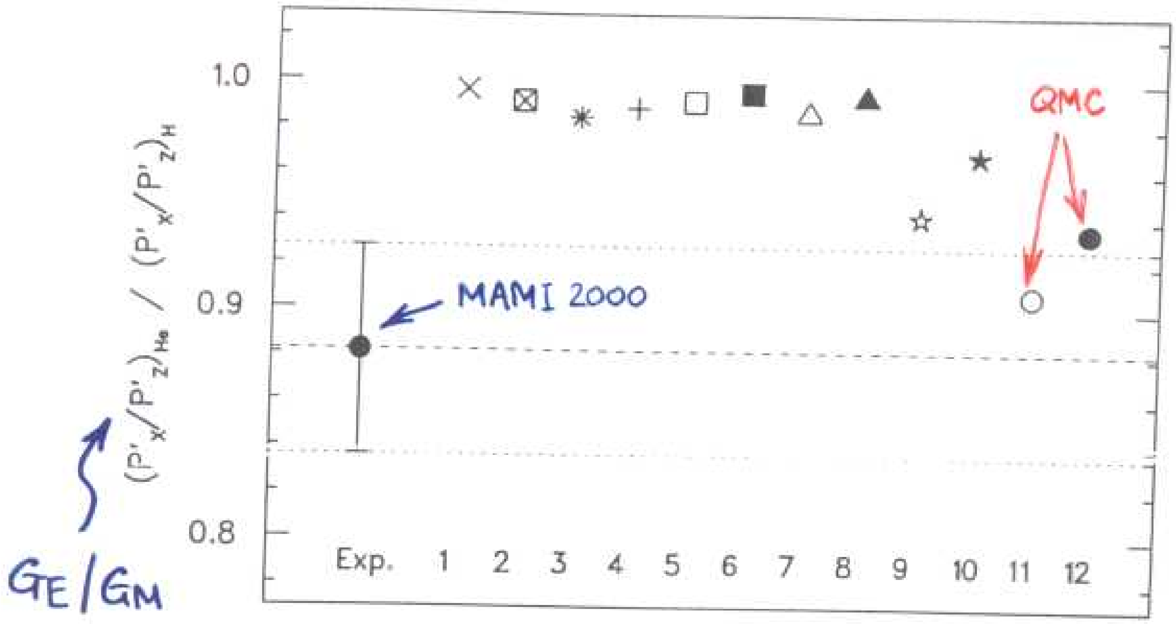
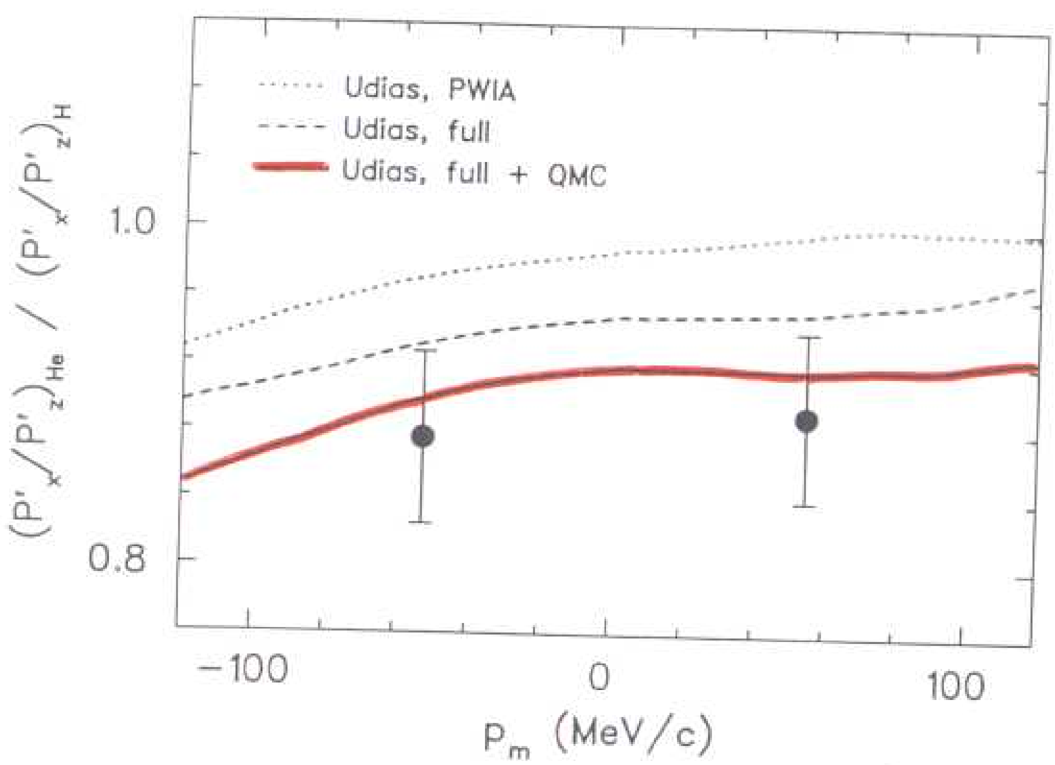
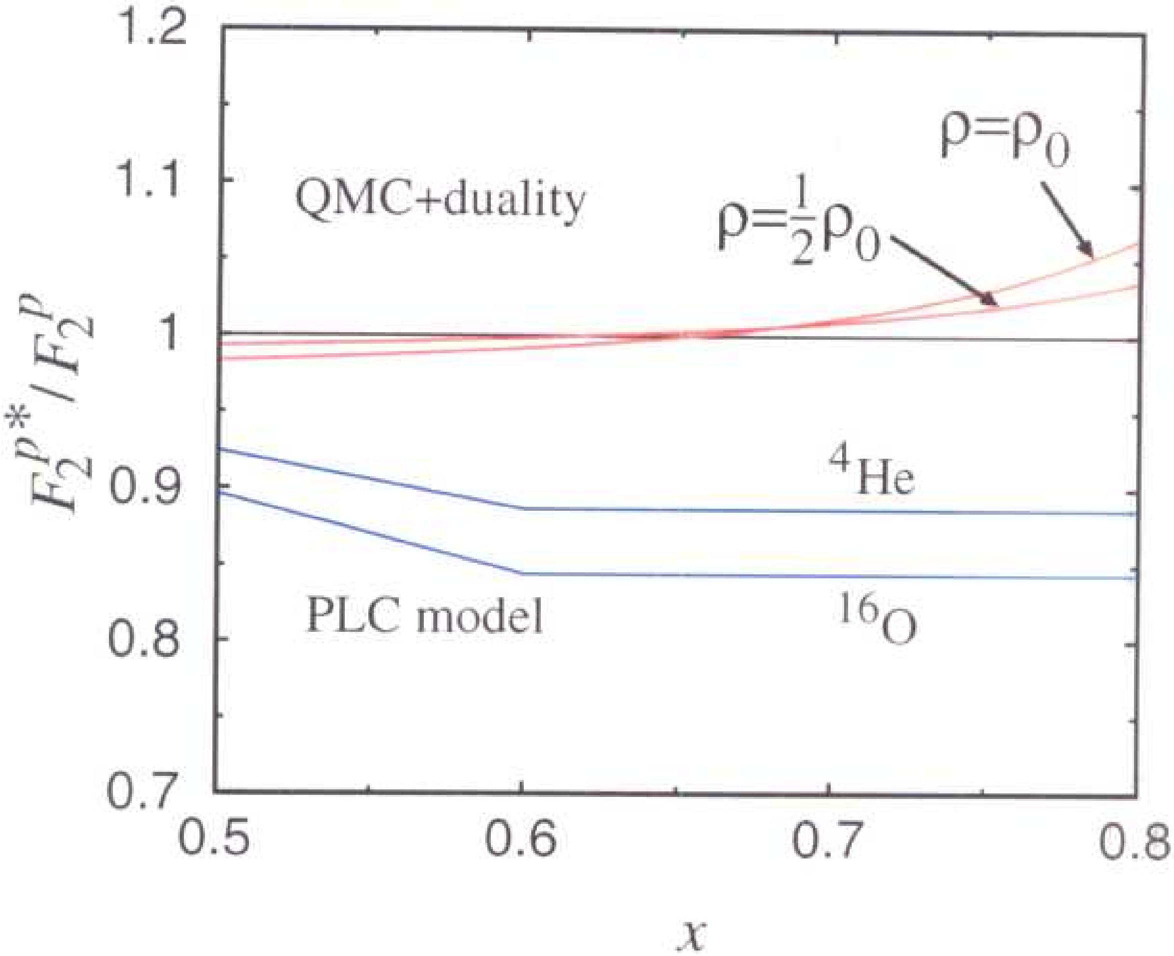


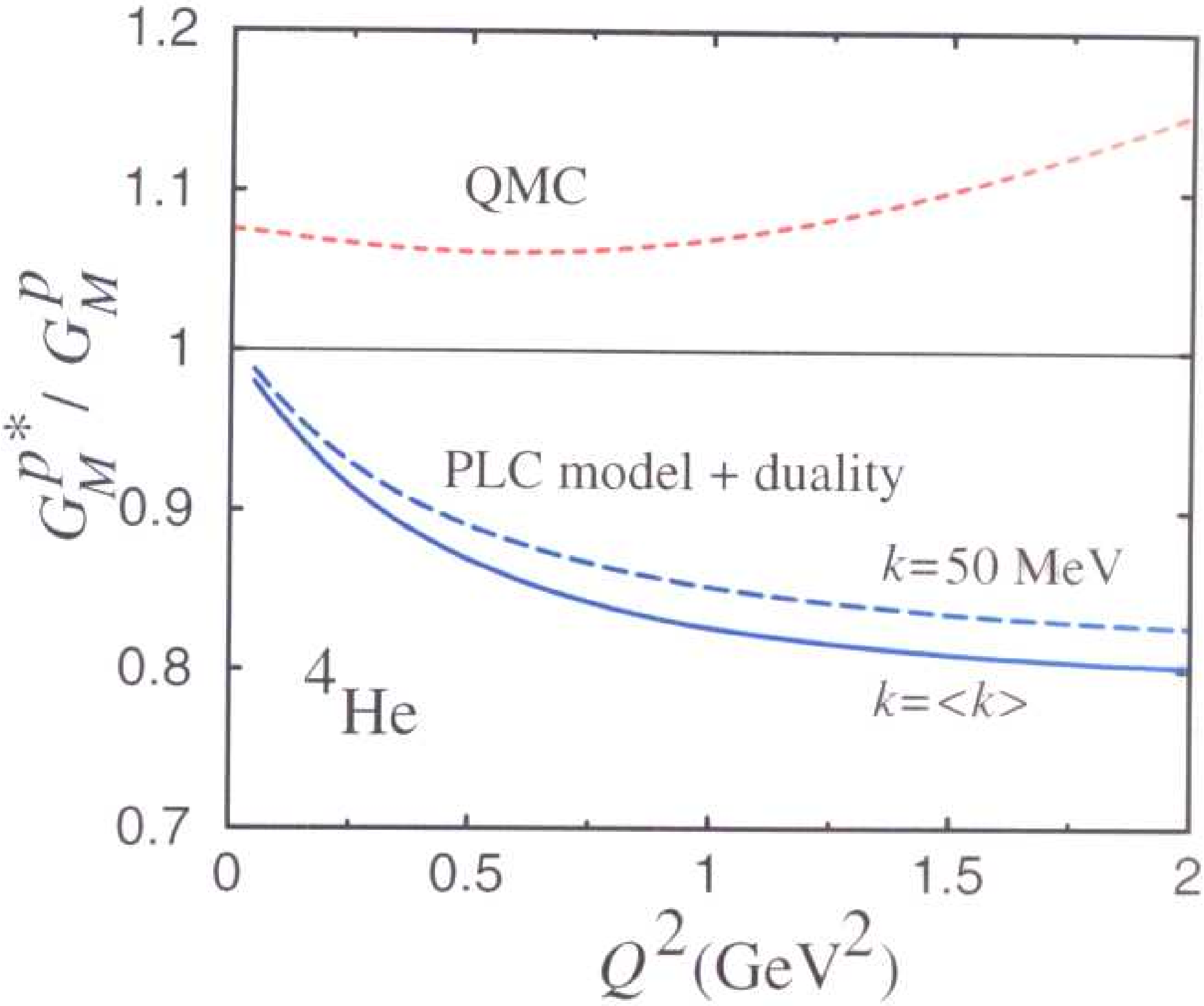

FIG. 1. Comparison of measured $R$ (Exp.) with theoretical calculations. Laget - PWIA (1); full calculation (2). Udias - PWIA, $cc1$ (3), $cc2$ (4); positive energy projection, $cc1$ (5), $cc2$(6); no spinor distortions, $cc1$ (7), $cc2$ (8); fully relativistic, $cc1$ (9), $cc2$ (10); fully relativistic, and QMC, $cc1$ (11), $cc2$ (12).






In-medium to free proton $F_2$ structure function ratio

WM, Tsushima, Thomas
Eur. Phys. J A (2002)
nucl-th/0110071




Ratio of in-medium to free proton magnetic form factors

WM, Tsushima, Thomas
Eur. Phys. J A (2002)
nucl-th/0110071