

# Tortuous way to the extraction of neutron observables from inclusive lepton scattering data

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- I) Introduction: New data (ND) on inclusive scattering of electron on A.
- II) Total cross sections in DIS region; EMC ratios
- III) Analysis of total cross section in QE region. Problems..
- IV) CLAS collaboration data in QE region→ Extraction of  $G_M^n$
- V) DIS region of same →  $F_2^n$
- VI) Outlook

## I. Introduction.

E03-102; E02-109 : data for  $E_b=5.76$  GeV;  $\theta = 18^\circ, 22^\circ, 26^\circ, 32^\circ, 40^\circ, 50^\circ$ , for D,  $^3,^4\text{He}$ ,  $^9\text{Be}$ , C, Al, Cu, Au.  $2.0 \gtrsim x \gtrsim 0.35 - 0.50$

To be published:  $A \leq 12; x \lesssim 0.93$

A second set for  $E_b= 5.02$  GeV, only for largest angles and lightest targets. Not yet 'final'.

Reduced  $\sigma$  for unpolarized  $e$

$$K^A(x, Q^2, \theta) = \frac{d^2\sigma^A(E; \theta, \nu)}{d\Omega d\nu} \Big/ \sigma_M(E; \theta, \nu) = \frac{2xM}{Q^2} F_2^A(x, Q^2) + \frac{2}{M} F_1^A(x, Q^2) \text{tg}^2(\theta/2)$$

Entire content in 2 nuclear SFs. Theory used which yields convolution

$$F_k^A(x, Q^2) = \int_x^A \frac{dz}{z^2-k} f^{PN,A}(z, Q^2) \left[ Z F_k^p\left(\frac{x}{z}, Q^2\right) + N F_k^n\left(\frac{x}{z}, Q^2\right) \right] / A.$$

$F^{p,n}$  SFs of  $p, n$  (actually off-shell),  $f^{PN,A}$  SF of fictitious nucleus composed of point- $N$ .

Alternatively: distribution function of  $N$  in  $A$ . For light  $A$  calculable; otherwise modeled.

Overwhelmingly initiating process NI :  $K^{NI}$

$$N + \gamma^* \rightarrow N^*$$

In QE region competing NE

$$N + \gamma^* \rightarrow N$$

Those lead to contributions

$$F^{A,NE}(x, Q^2) \propto f^{PN;A}(x, Q^2) [\mathcal{G}^N(Q^2)]$$

$\mathcal{G}^N$  is a combination of squared Nucleon FFs, functions of  $Q^2$   
i.e. separation of  $x, A$  and  $Q^2$  dependence.

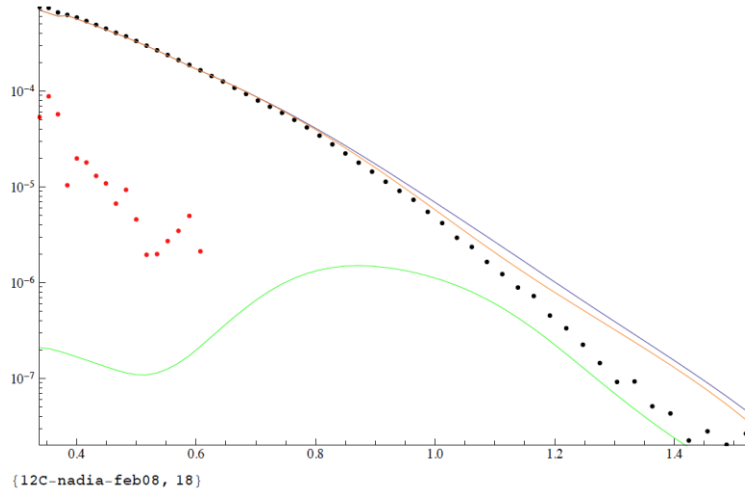
NI components have to be calculated.

NE?

- 1)  $NE^{FF}$  above expressed in terms of FF (smooth!)
- 2)  $NE^{extr} = \text{data} - NI^{comp}$  (has vagaries of data)

For perfect data and theory the two expressions should coincide.

## II. Total reduced cross sections and EMC ratios



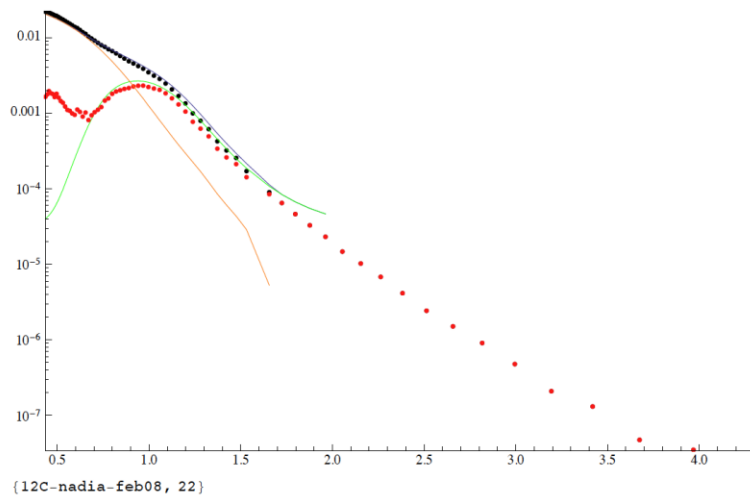
$$K^A(\theta, x) = NI + NE$$

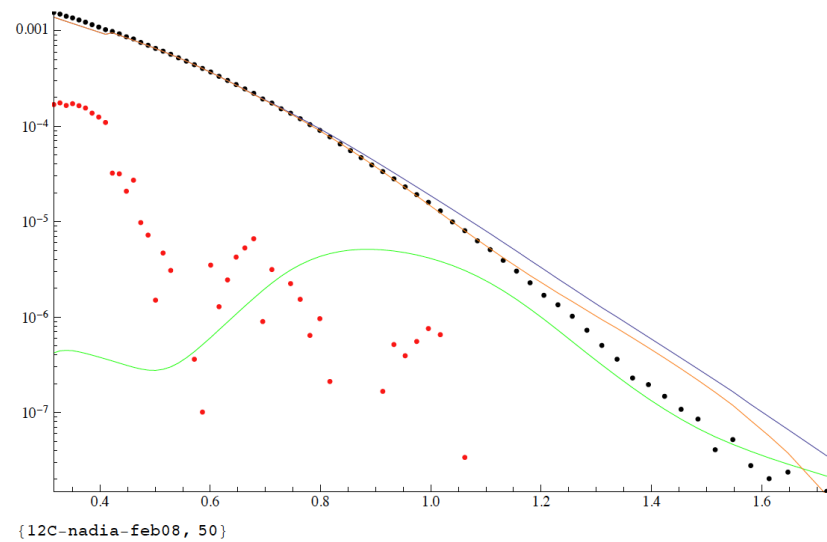
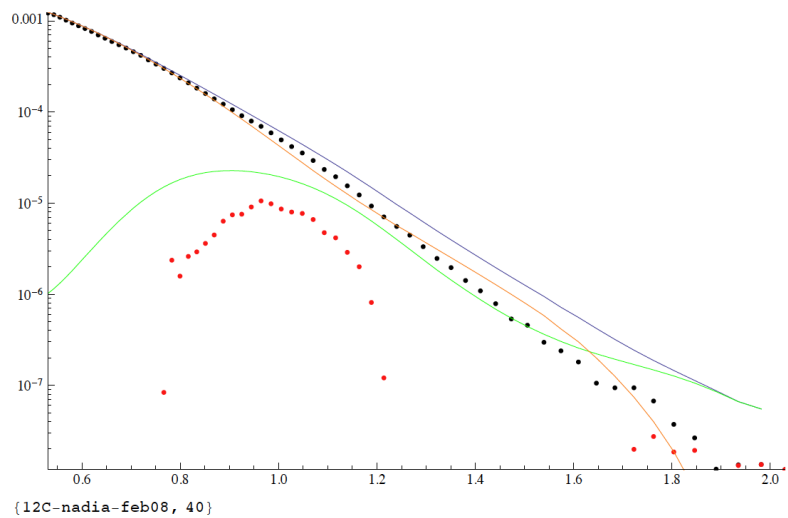
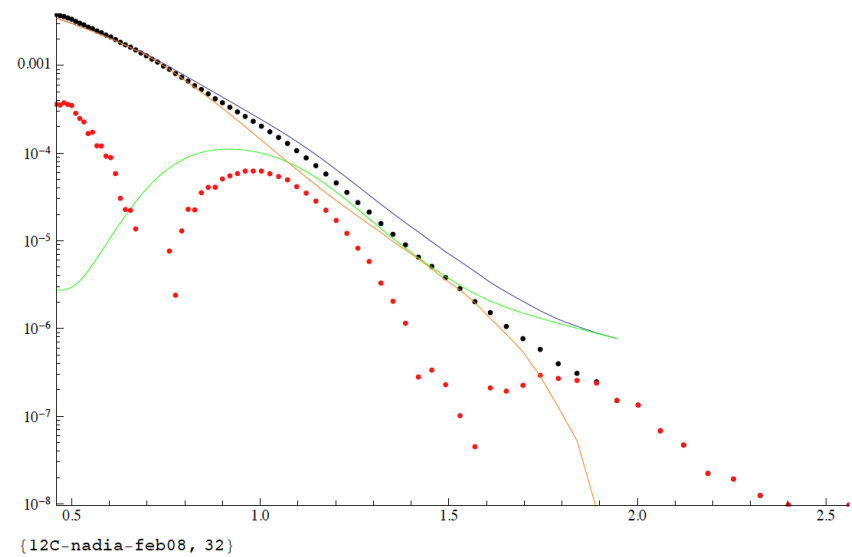
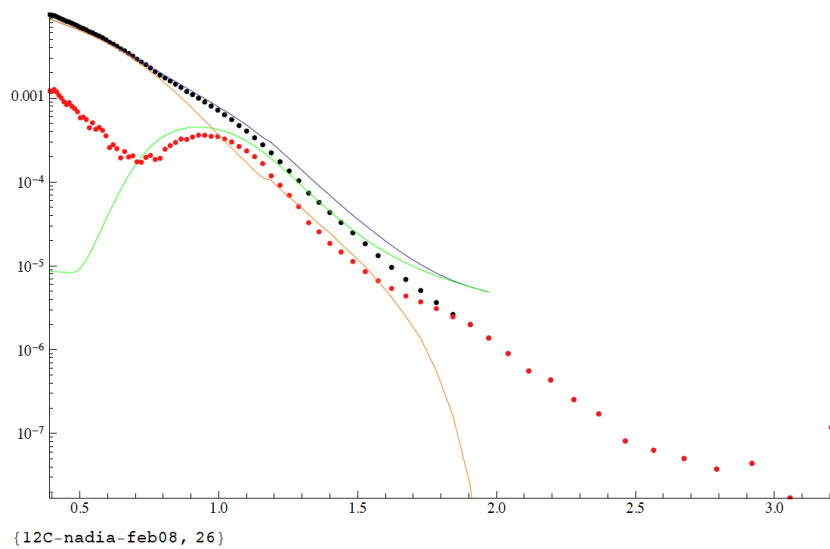
- i) data: black dots without (small) error bars
- ii) smooth green line:  $NE^{PP}$
- iii) smooth orange line:  $NI^{comp}$
- iv) smooth blue line:

$$K = NI + NE^{PP}$$

- vi) red dots are  $[data - NI]$ . NB: scatter or absence, if

$$NI^{comp} \geq data$$

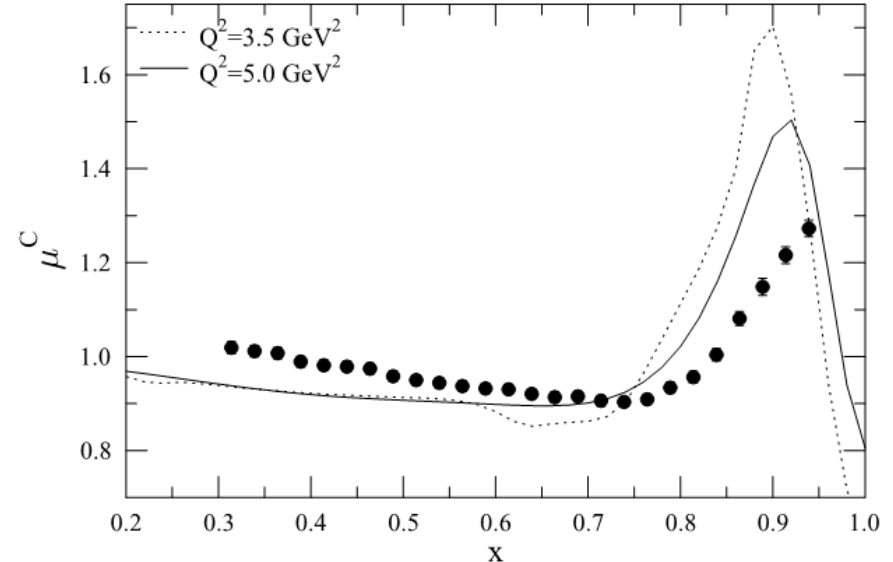
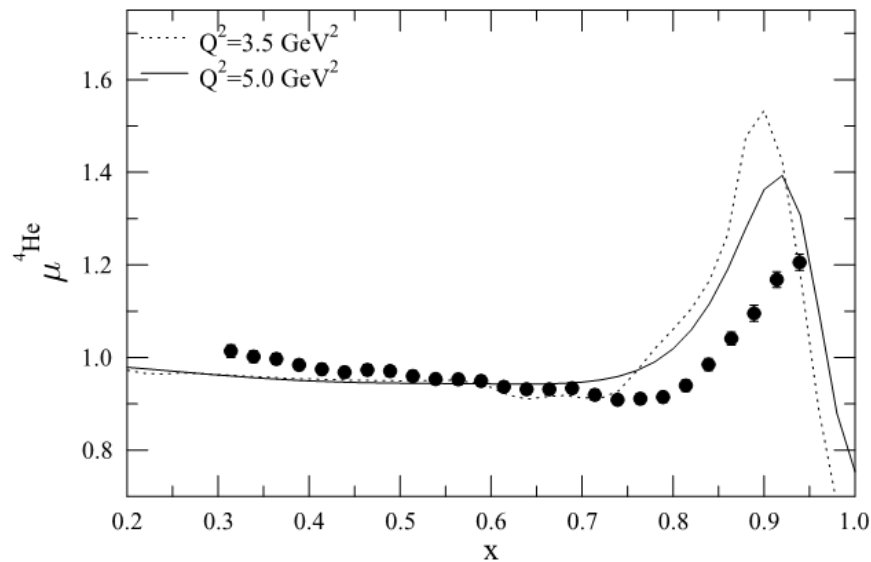




a) Up to QE region  $\sigma$  dominated by NI, shows on log scale tolerable agreement. Conclusion:  $\text{NI}^{comp}$  there must be reliable.

b) For QE where  $\text{NI} \ll \text{data}$ :  $\text{NE}^{extr}$  and  $\text{NE}^{FF}$  differ considerably.

c) New exp. (ND) gives EMC ratios for lightest nuclei  $A \leq 12$  and only up to  $x = 0.93$ . Do errors/uncertainties partly cancel in EMC ratios?



Drawn lines predictions from hadron representation

Dotted lines from parton representation

Data disagree from predictions.

For one: All  $F_2^A(x, Q^2)$  about equal for  $x \approx 0.18 - 0.20$ . Using convolution leading to

$$\mu^A(x, Q^2) = 1 \text{ for } x \approx 0.2$$

Borne out by data. For ND,  $\mu^A = 1$  intercept at  $x \gtrsim 0.3$



Table I. Values of  $F_2^D(x, Q^2)$ , extracted and computed from ND, and the same from CL for a chosen  $x$ -range (columns 1). Columns 2 give  $Q^2(x, \theta)$  for that  $x$  range and  $\theta = 18^\circ, 22^\circ$ , respectively  $\theta = 32^\circ, 40^\circ$ . Columns 3,4,5, are  $F_2^{D,extr}$ ,  $F_2^{D,comp}$ ,  $F_2^{D,CL}$  for given  $x$  and a pair of angles .

$x$	$Q^2(18^\circ)$	$F_2^{D;R}(18^\circ)$	$F_2^{D;comp}(18^\circ)$	$F_2^{D;CL}(18^\circ)$	$Q^2(26^\circ)$	$F_2^{D;R}(26^\circ)$	$F_2^{D;comp}(26^\circ)$	$F_2^{D;CL}(26^\circ)$
0.5	2.03	0.149	0.152	0.156	—	—	—	—
0.6	2.17	0.0985	0.102	0.105	3.31	0.0871	0.0832	0.0094
0.7	2.28	0.0571	0.057	0.0559	3.56	0.0512	0.0542	0.0556
0.8	2.36	0.0397	0.0343	0.0464	3.79	0.0232	0.0236	0.0272
0.9	2.43	0.0213	0.0181	0.0171	3.98	0.0111	0.0106	0.0126
1.0	2.51	0.0369	0.0402	0.0406	4.15	0.0107	0.0116	0.0129
1.1	2.56	0.0095	0.0120	0.0097	4.29	0.0023	0.0026	0.0022

$x$	$Q^2(32^\circ)$	$F_2^{D;R}(32^\circ)$	$F_2^{D;comp}(32^\circ)$	$F_2^{D;CL}(32^\circ)$	$Q^2(40^\circ)$	$F_2^{D;R}(40^\circ)$	$F_2^{D;comp}(40^\circ)$	$F_2^{D;CL}(40^\circ)$
0.4	—	—	0.173	—	3.37	0.172	0.176	0.187
0.5	—	—	0.122	—	4.02	0.122	0.123	0.128
0.6	3.95	0.0808	0.0817	0.0775	4.59	0.0745	0.0769	0.0785
0.7	4.33	0.0460	0.0471	0.0450	5.09	0.0412	0.0436	0.0442
0.8	4.66	0.0211	0.0217	0.0225	5.58	0.0189	0.0185	0.0212
0.9	4.95	0.0082	0.0077	0.0096	5.99	0.0062	0.0059	0.0088
1.0	5.23	0.0055	0.0061	0.0053	6.39	0.0034	0.0036	0.0035
1.1	5.49	0.0010	0.0012	0.0059	6.72	0.0005	0.0006	—

Sizeable differences.

### III. Magnetic FF of $n$

FFs reside in NE. Would like to see that for all  $x$

$$NE = data - NI$$

Not observed (see Figs. 1).

Have used before a criterion:

Find around QEP  $x \approx 1$  continuous  $x$ -range for which

$$K^A(x, Q^2; \theta, E_b) / f^{PN,A}(x, Q^2)$$

within, say, 10% : independent of  $x, A, \theta, E_b$ .

Each data point  $x_i, Q^2$  leads to reduced FF

$$\alpha_n = \mu_n G_M^n / G_d$$

Unavoidable:  $\alpha_n$  will be  $x_i$ -dependent  $\rightarrow$  Average.

For E03-102:

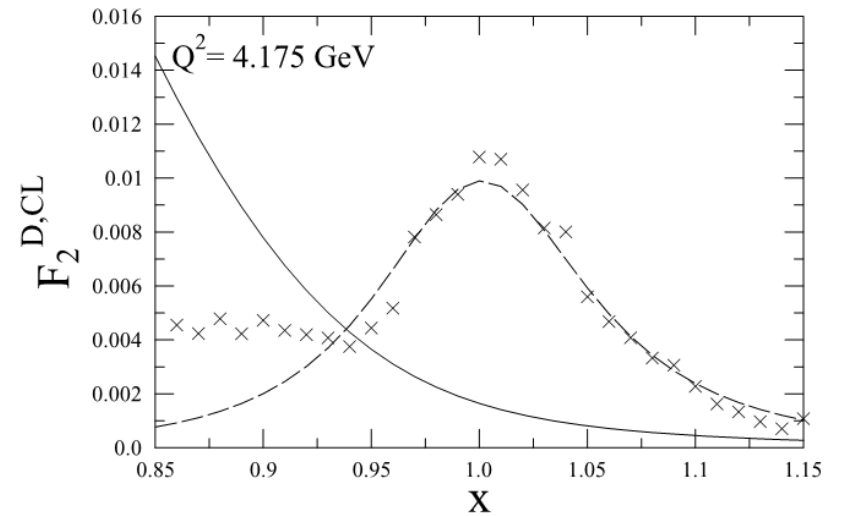
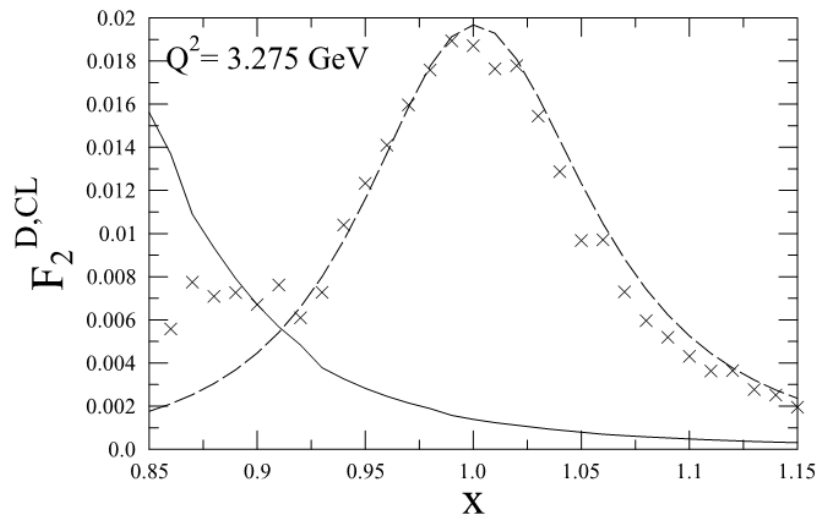
- i) Essentially impossible to obtain  $x$ -range
- ii) Nevertheless trying to obtain  $\alpha_n$  from  $x \approx 1$ , produces bad  $\alpha_n$

For previous old data (OD), each set produced  $\langle \alpha_n(Q^2) \rangle$ . Different data sets have occasionally overlapping  $Q^2$ : show same  $\langle \alpha_n(Q^2) \rangle$

Conclusion: Since same code used for OD and ND, the two are incompatible. Which one to be blamed? With internal consistency of OD...

Analysis of CLAS data on  $F_2^{p,D}$ : dense  $Q^2$ -net. For each  $Q^2$ : dense  $x$ -net.

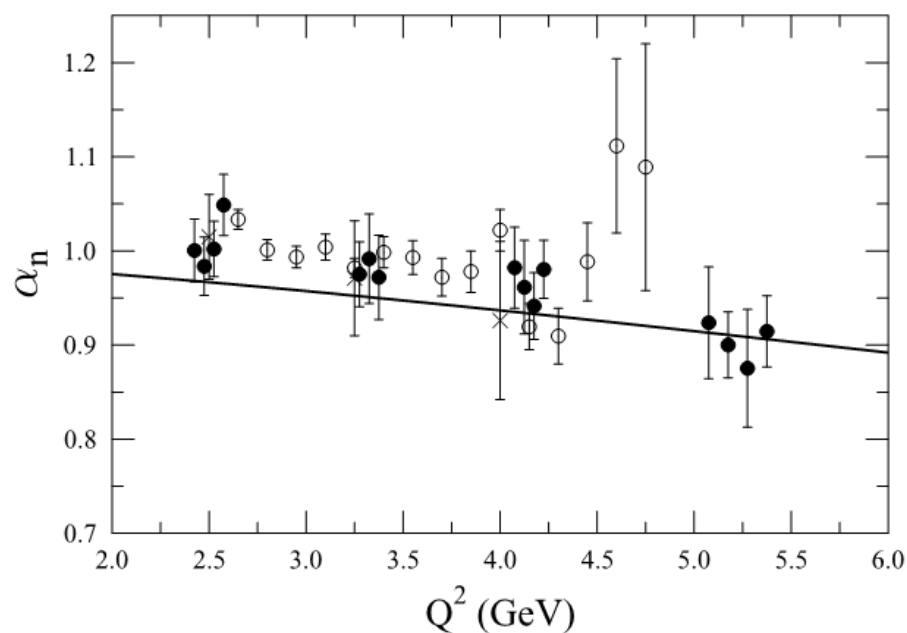
Application of criterion possible if points *within* each chosen  $x$ -range outside 10% margin removed  $\rightarrow \alpha_n$  extraction possible for  $Q^2 \lesssim 5.2 \text{ GeV}^2$ ,



No CLAS data beyond

Table II.  $\alpha_n$  extracted from ND. Columns give  $Q^2$  around  $Q^2 = 2.50, 3.34, 4.15, 5.24 \text{ GeV}^2$  (correspond to values ND for  $\theta = 18^\circ, 22^\circ, 26^\circ, 32^\circ$ ). Columns 2-3, are  $x$ -range around QEP and no. of selected points  $n$ . Last column: reduced FF  $\langle \alpha_n(Q^2) \rangle$  and error of the mean.

$Q^2 \text{ [GeV]}^2$	$x$ -interval	$n$	$\langle \alpha_n \rangle \pm \delta \alpha_n$
2.425	0.9235-1.0405	12	$1.0005 \pm 0.0334$
2.475	0.9235-1.0405	12	$0.9837 \pm 0.0310$
2.525	0.9235-1.0315	12	$1.0020 \pm 0.0294$
2.575	0.9235-1.0315	10	$1.0488 \pm 0.0324$
3.275	0.9415-1.0225	9	$0.9752 \pm 0.0344$
3.325	0.9595-1.0225	6	$0.9917 \pm 0.0475$
3.375	0.9325-1.0225	7	$0.9720 \pm 0.0448$
4.075	0.9685-1.0675	9	$0.9822 \pm 0.0430$
4.125	0.9775-1.0855	9	$0.9614 \pm 0.0497$
4.175	0.9685-1.0855	11	$0.9415 \pm 0.0354$
4.225	0.9775-1.0765	8	$0.9804 \pm 0.0309$
5.075	0.9865-1.0675	6	$0.9237 \pm 0.0593$
5.175	0.9685-1.0585	6	$0.9001 \pm 0.0350$
5.275	0.9865-1.0765	5	$0.8753 \pm 0.0625$
5.375	0.9685-1.1035	7	$0.9145 \pm 0.0378$



Old and new results for neighboring  $Q^2$ :  $\langle\alpha_n\rangle$  decreases somewhat slower than OD.

Black dots calc's for neighboring  $Q^2$ : No  $Q^2$  dependence: Instrumental spread! Crosses from Lung; empty circles: Lachniet-Brooks. Each point measured with 2-3% accuracy: Relative spread of neighboring points far larger.

## V. Extraction of $F_2^n$ from CLAS data.

Needed for

a)  $u_v, d_v$  quark distribution ftns. Frequently used 'primitive' approximation

$$F^n = 2F^d - F^p$$

Then, for instance using  $[F^n(x=1)/F^p(x=1)]_{SU6} = 3/5$

$$u_v = 2d_v$$

Primitive Ansatz deteriorates for growing  $x \gtrsim 0.35$

b) Calculation of any  $F^A$  requires  $F^n$

Corollary:

i) Assume  $C = F_k^n/F_k^p$  to be  $k$ -independent.

ii) Finite Gottfried sum  $\int_0^1 [F_2^p(x) - F_2^n(x)]/x < \infty$

implies  $C(x=0, Q^2) = 1$

iii) Use primitive choice for  $x = 0.15, 0.25$

$$\text{iv) } C(x, Q^2) = \sum_{k \geq 0} d_k(Q^2)(1-x)^k$$

For  $k=3$ , one parameter left: Choose

$$C(1, Q^2) = d_0(Q^2) = -\sum_{k \geq 1} d_k(Q^2)$$

Remarks:

$$F^{p,n}(x, Q^2) \rightarrow 0; x \rightarrow x_{cr} \approx 0.9$$

Between  $x_{cr}$  and elastic point  $x = 1$ , above parametrization does not account for vanishing  $F^N(x, Q^2)$ . Its continuation is sensitive to smallest values of  $F^N$

At  $x = 1$

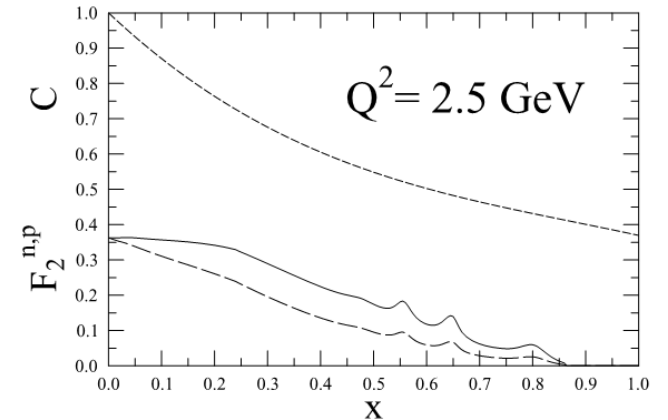
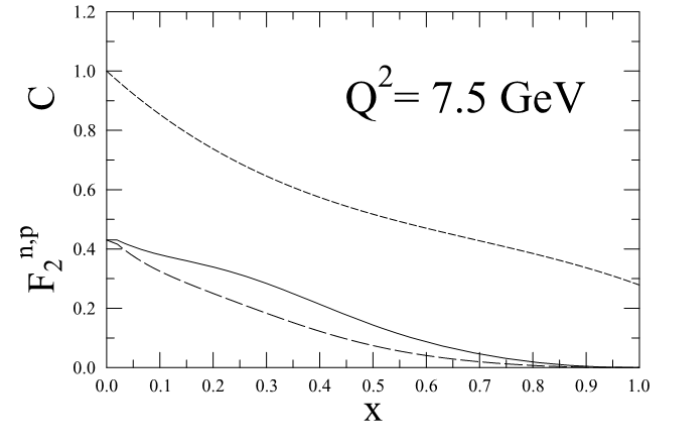
$$\lim_{x \rightarrow 1} C^{FF}(x, Q^2) = \left[ \frac{\mu_n \alpha_n(Q^2)}{\mu_p \alpha_p(Q^2)} \right]^2 \left[ 1 + \frac{4M^2}{Q^2} \left( \frac{\gamma(Q^2)}{\mu_p} \right)^2 \right]^{-1}$$

with

$$\gamma(Q^2) = \frac{\mu_p G_E^p(Q^2)}{G_M^p(Q^2)}$$

$$\frac{\alpha_n(Q^2)}{\alpha_p(Q^2)} = \frac{G_M^n(Q^2)/\mu_n}{G_M^p(Q^2)/\mu_p}$$

Rewrite convolution using  $C(x, Q^2)$ . Perform Least Squares fits for  $C(x = 1)$





Most attempts to obtain  $F_2^n$  consider  $f^{PN,D}$  as a smearing function, which amounts to some average. Here it is immaterial whether a simple momentum distribution or a more complicated distribution is used:

$$[F_2^n]^{\text{smearred}} \equiv F_2^D - [F_2^p]^{\text{smearred}}$$

is a similarly averaged  $n$  part one has to invert.

CL data have been used before to extract leading twist moments of  $F_2^{p,D}$ . By means of a convolution those are subsequently used to construct parallel twist moments for the  $n$ . The involved averaging may explain feasibility. Authors did not attempt inversion.

## VI. Outlook

Many attempts to extract  $G_M^n$  and approaches for, as accurate as possible a description.

All were refined over the years, but reached limit. Results rather disappointing. No improvement when data are renormalized, shifted or squeezed.

Cause? Sustained accuracy. Each individual data point apparently measured with great accuracy. Scatter of adjacent data points frequently much larger.

Outlook for precision measurements rather bleak. Will not much improve for L,T separated data, tagged n, seemingly simple reactions as are  $[e(D,p)e'X]/[e(D,n)e'X]$