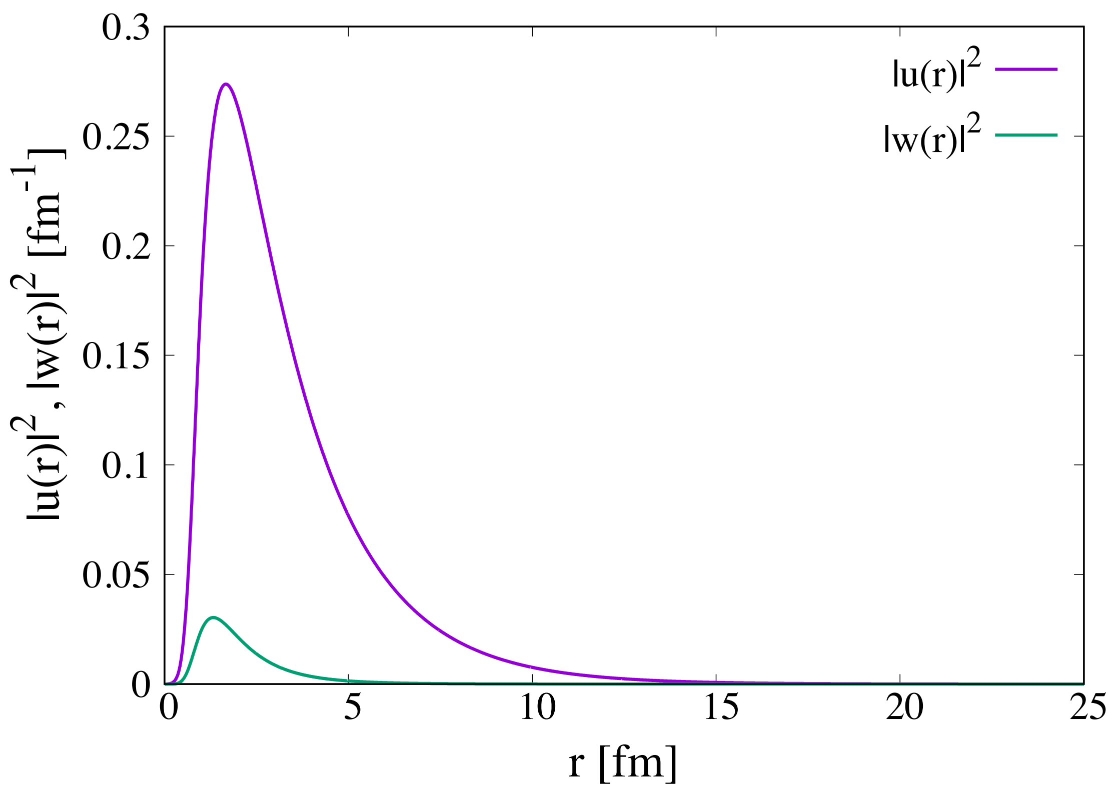
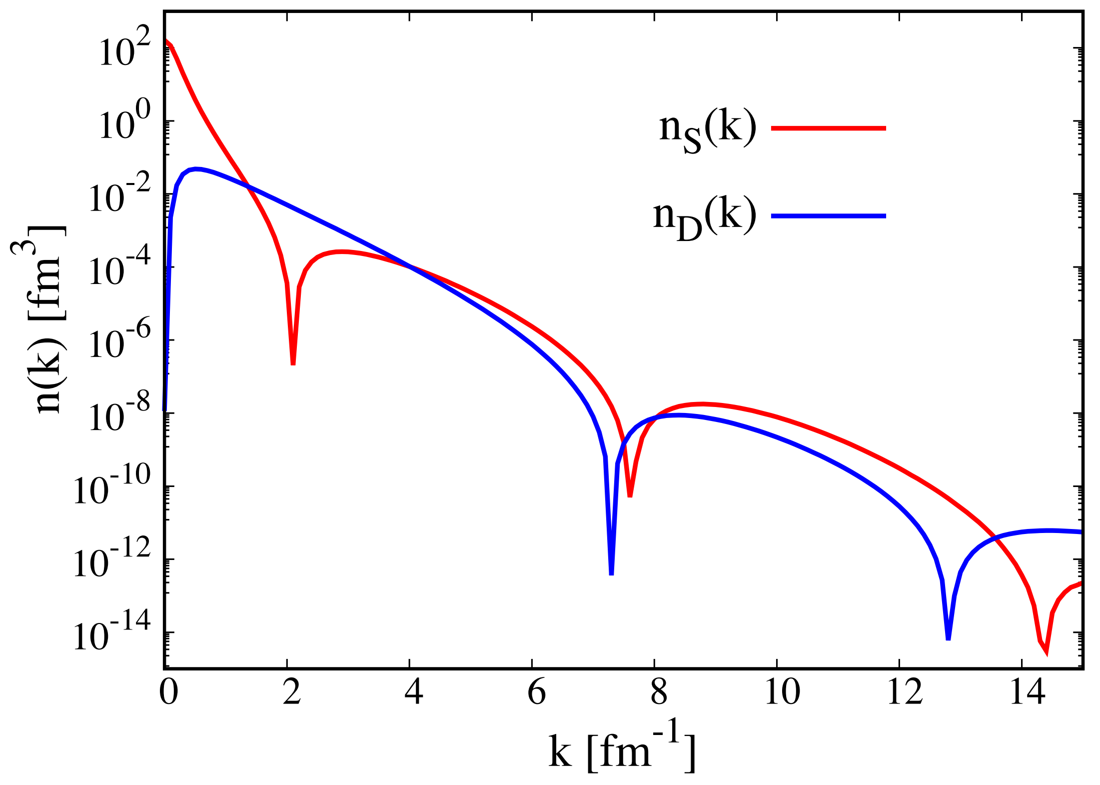
~~Short -range~~

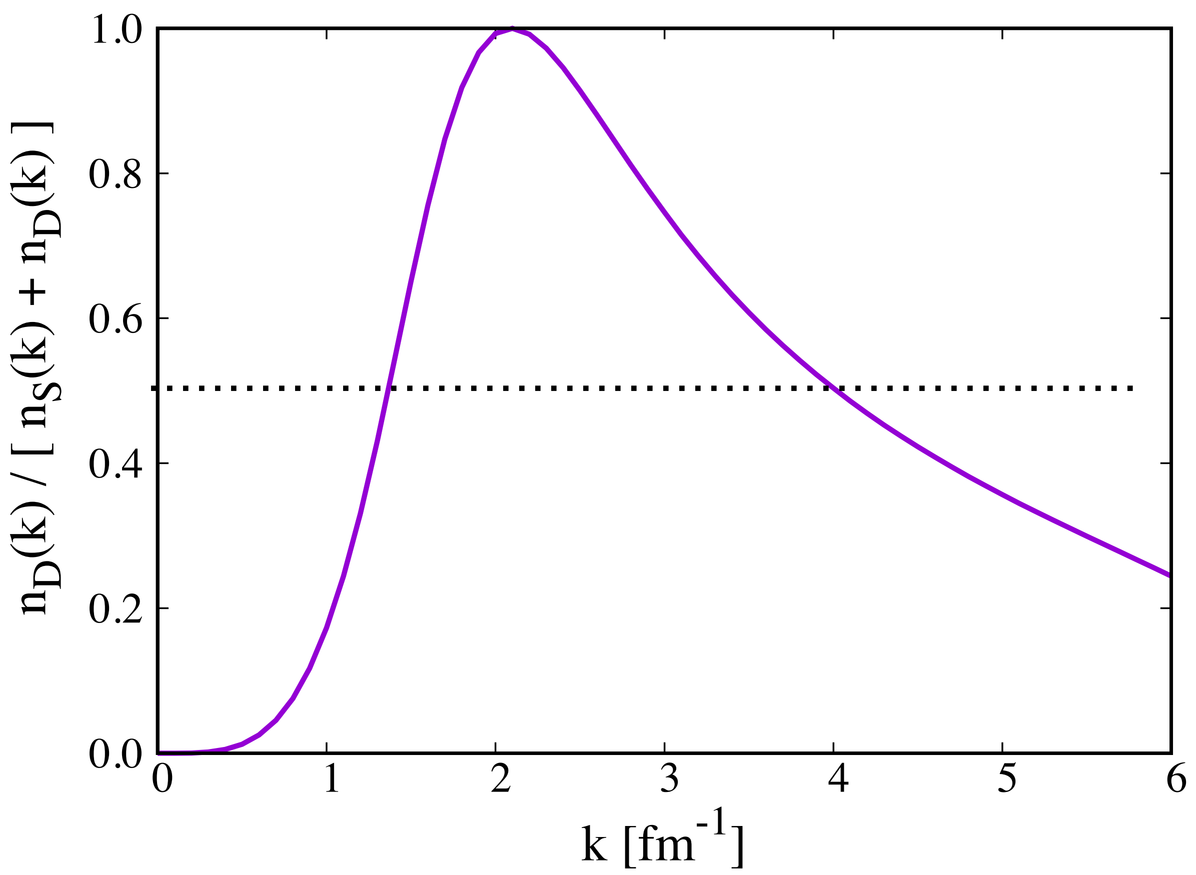
High momentum correlations in nuclei

Mark Strikman , 25 Jan 2023

A quick look at coordinate and momentum deuteron wave functions







D-wave dominates in momentum space between 300 and 800 MeV/c in spite of being much smaller than S wave at all distances. High momentum tail in this region is due to Fourier transform of rapidly changing integrand.

No simple relation "high momentum — small distance"

Is w(k) /u(k) universal for k> 300 MeV/c?

No direct calculations so far.

Critical to perform measurements with polarized deuteron. To separate S and D wave and also probe light cone dynamics

Experience of quantum field theory - interactions at different resolutions (momentum transfer) resolve different degrees of freedom - renormalization,.... Describe the effects of the Dirac sea… No simple relation between relevant degrees of freedom at different resolution (virtuality)scales.

$\boxed{\text{➟ Complexity of the problem}}$

Three important scales

1 To resolve nucleons with $k < k_F$, one needs $Q^2 \geq 0.8$ GeV^2.

related effect: Q^2 dependence of quenching, Q

related to the rate of eA—> e'p(A-1) process

② Hard nuclear reactions I: energy transfer > 1 GeV and momentum transfer q > 1 GeV.

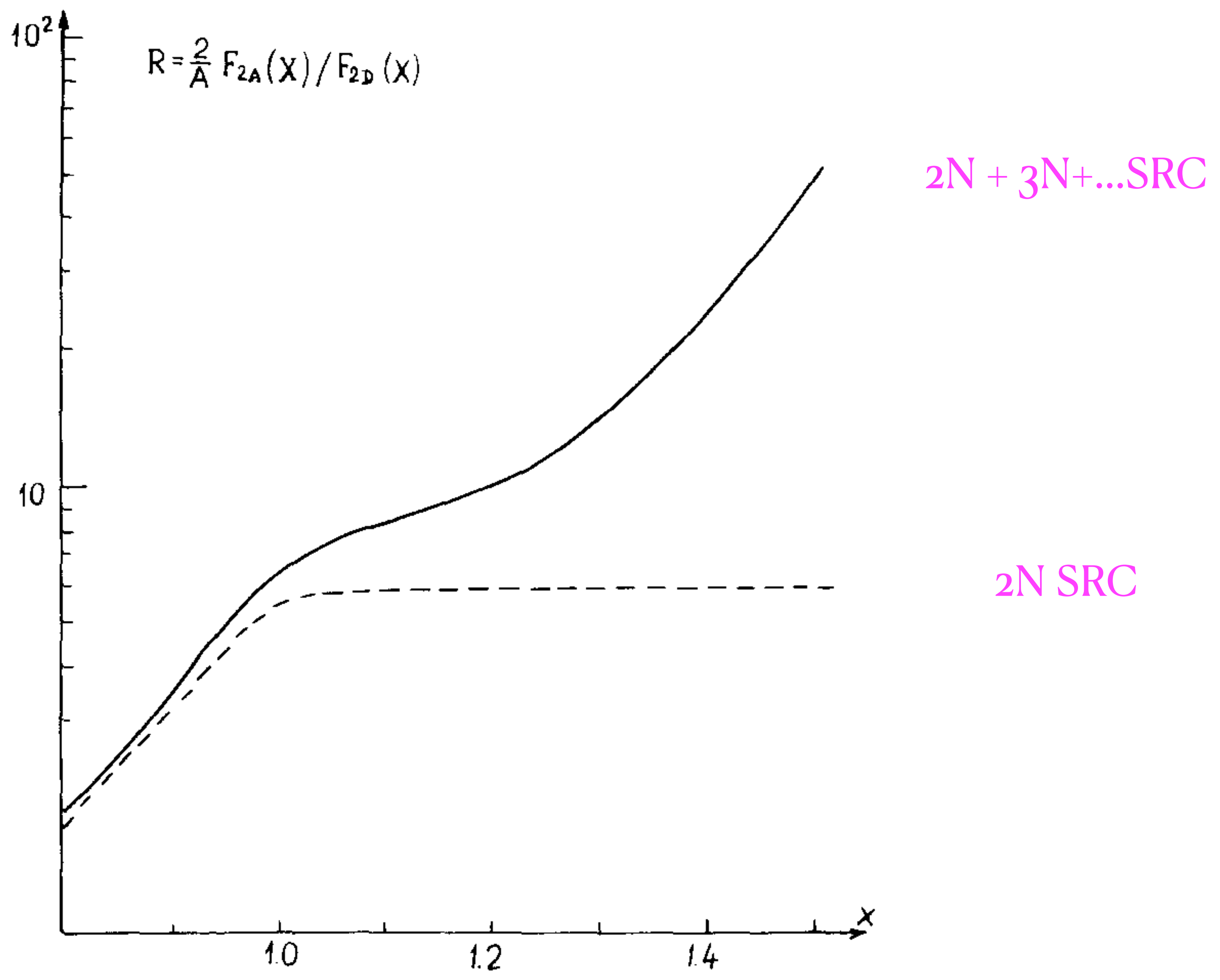
$$q_0 \geq 1GeV \gg |V_{NN}^{SR}|, \vec{q} \geq 1GeV/c \gg 2\ k_F$$

Sufficient to resolve short-range correlations (SRCs) = direct observation of SRCs but not sensitive to quark-gluon structure of the constituents

③ Hard nuclear reactions II: energy transfer ≫ 1 GeV and momentum transfer q ≫ 1 GeV. May involve nucleons in special (for example small size configurations). Allow to resolve quark-gluon structure of SRC: difference between bound and free nucleon wave function, exotic configurations

③ Is simplest /easiest to interpret when final mass is large (for example x=const Q large)

PARTON DENSITIES

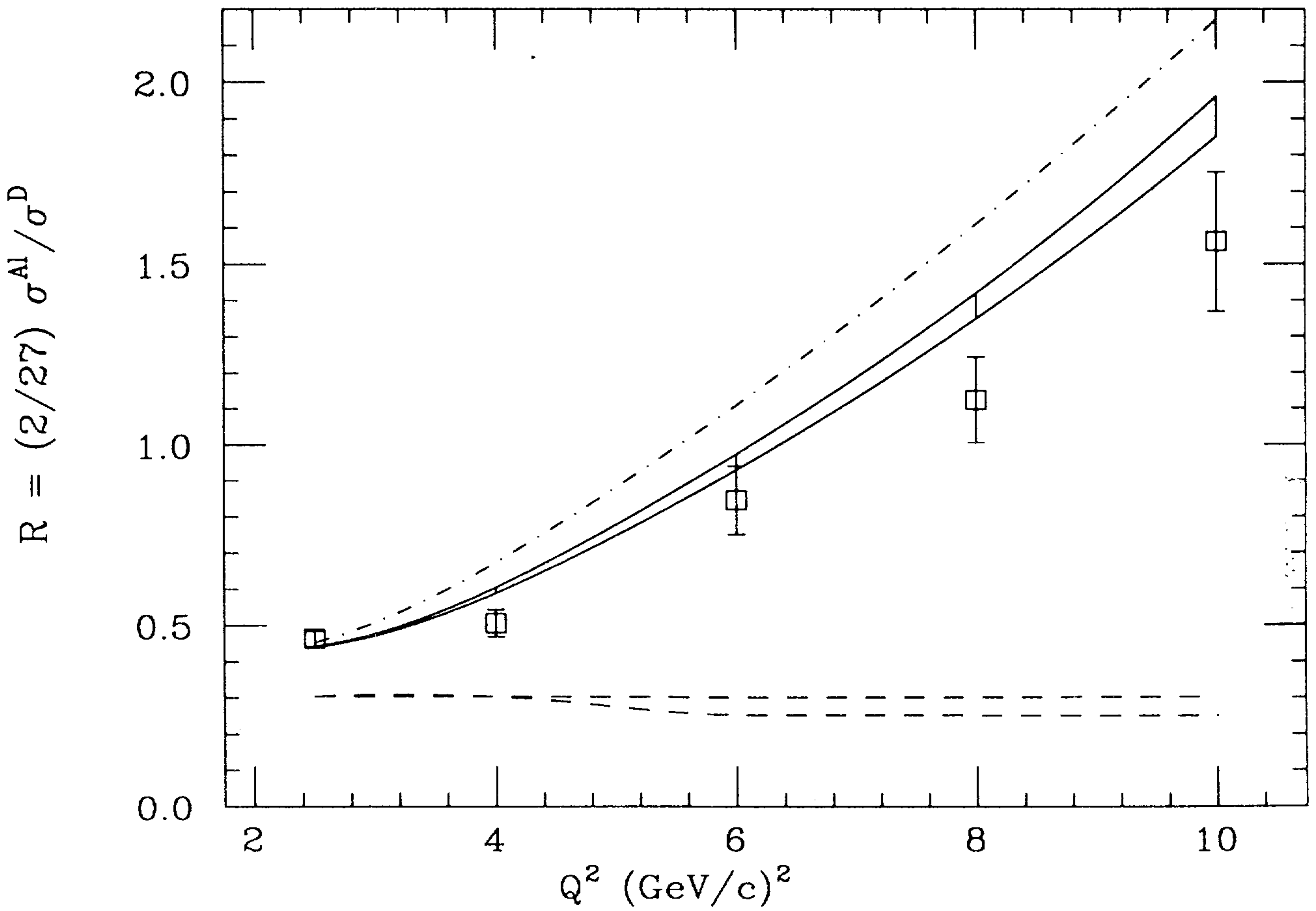


$<\alpha> \sim x+0.5$ F&S 80

Early sensitivity to 3 N high momentum correlations

The estimate of the (F2A (x)/F2D(x) in ratio using realistic nuclear WF with few-nucleon correlations (solid curve) and using the two-nucleon correlation approximation.

PROBLEM IS HIGHER TWIST / QUASIELASTIC CONTRIBUTIONS



$\frac{2\sigma^{Al}}{27\sigma^{D}}$ as a function of Q^2 for $x = 1$. Data is from [5,3]. The dash-dotted curve is a calculation including inelastic channels but without consideration of the EMC effect. The solid curve encloses a range of values that are possible (due to uncertainties in the model) in the color minidelocalization model of the EMC effect [7]. The two dashed curves are the results of a calculation without inelastic contributions with the lower of these including the effect of nucleon swelling.

DAY, SARGSIAN, FANKFURT, MS 1993

SCALING TERM DOMINATES STARTING AT Q2 ~ 15 —20 GEV2

FEASIBLE AT 22 GEV J.Arrington talk

Possible to perform e time check - measure the ratio for wide range of x, Q with different role of 2N and 3 N correlation

New directions for study of nuclear pdfs & EMC effect

Convolution model for parton densities (α -light cone fraction) = nucleons are not deformed + no other constituents

Since spread in α due to Fermi motion is modest $\Rightarrow$ do Taylor series expansion in (1- α): $\alpha = 1 + (\alpha - 1)$

Fermi motion

$$R_A(x,Q^2) = 1 - \frac{\lambda_A x F_N'(x,Q^2)}{F_N(x,Q^2)} + \frac{xF_{2N}'(x,Q^2) + (x^2/2)F_{2N}''(x,Q^2)}{F_{2N}(x,Q^2)} \cdot \frac{2(T_A - T_{{}^2H})}{3m_N}$$

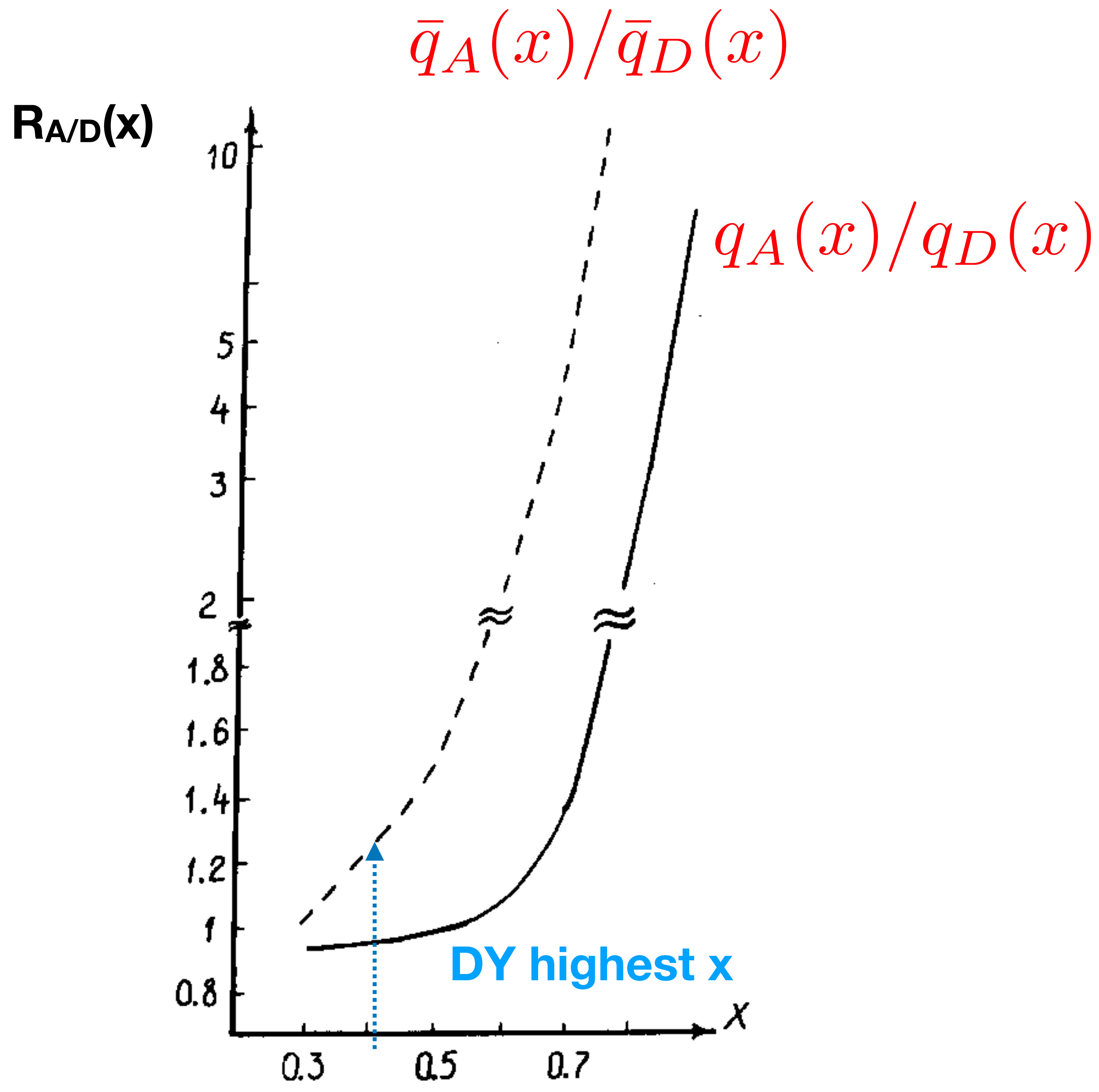
$$F_{2N} \propto (1-x)^n, n \approx 3 \qquad R_A(x,Q^2) = 1 - \frac{\lambda_A n x}{1-x} + \frac{xn\left[x(n+1)-2\right]}{(1-x)^2} \cdot \frac{(T_A - T_{{}^2H})}{3m_N}$$

small negative for x <0.5
> 0 and rapidly growing for x >0.5

Jlab - due to HT effects n~ 2. Crossover x=0.66

EMC effect is unambiguous evidence for presence of non nucleonic degrees of freedom in nuclei. The question - what are they?

Fermi motion expectations - no nonnucleonic degrees of freedom



crossover (R=1) point

$$R_{cr} = 2/(n+1)$$

$$x\bar{q}(x) \propto (1-x)^n, n = 7.$$

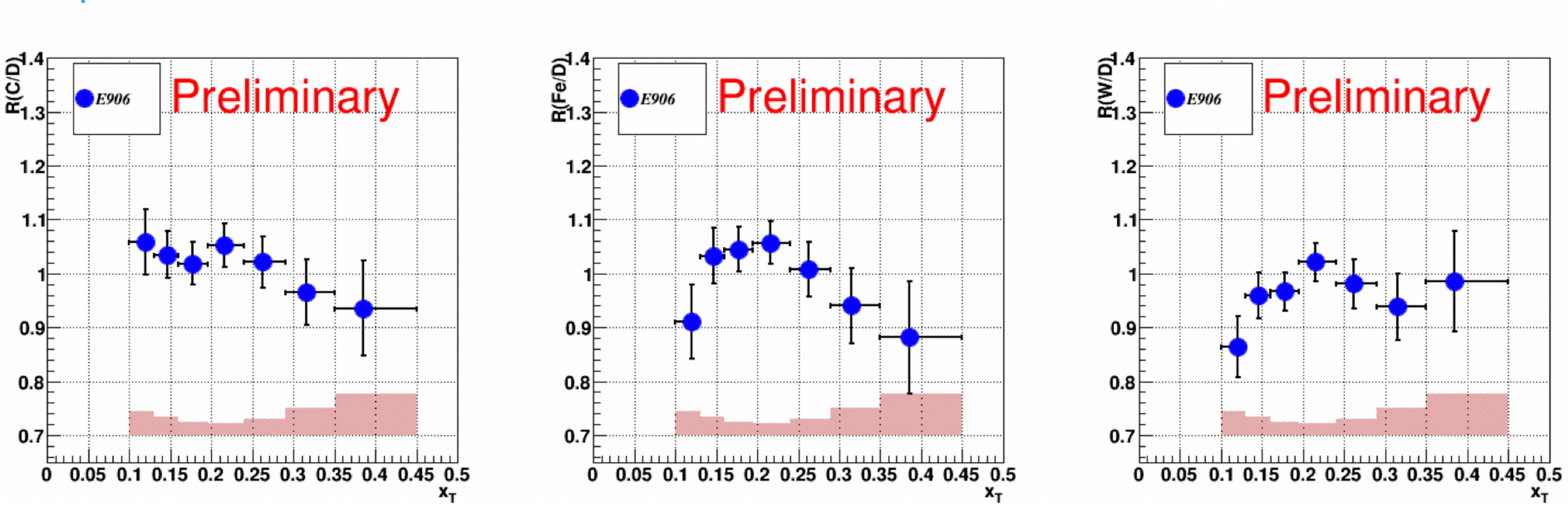
from MS & Leonid Frankfurt, Nucl.Phys. B,1980

EMC effect for antiquarks ?

MS + Alvioli analysis of preliminary Drell Yan data

SEAQUEST RESULTS

Present by Arun Tadepalli



EMC effect like pattern?

R(Fermi motion) ~1.2

EMC effect for antiquarks ?

MS + Alvioli analysis of preliminary Drell Yan data.

Can energy losses explain the observed pattern? Does not work.

More DY data is needed. Can DIS help - study K- production/

Does similar pattern holds for gluons? Open charm at 22 GeV probes a right kinematics.

Study total cross section for charm reduction off D, 4He, C to reduce effects of f.s.i.

If confirmed with a better precision DY measurement would be a second critical contribution of DY studies into understanding of quark- gluon nuclear structure (the first one was ruling out enhancement of antiquarks due to scattering off pions).

General pattern : Softening of x distribution of quarks and antiquarks (and gluons?) in bound nucleons

Evidence from data analysis that EMC SUPRESSION IS PROPORTIONAL TO PROBABILITY OF HIGH MOMENTUM CORRELATIONS

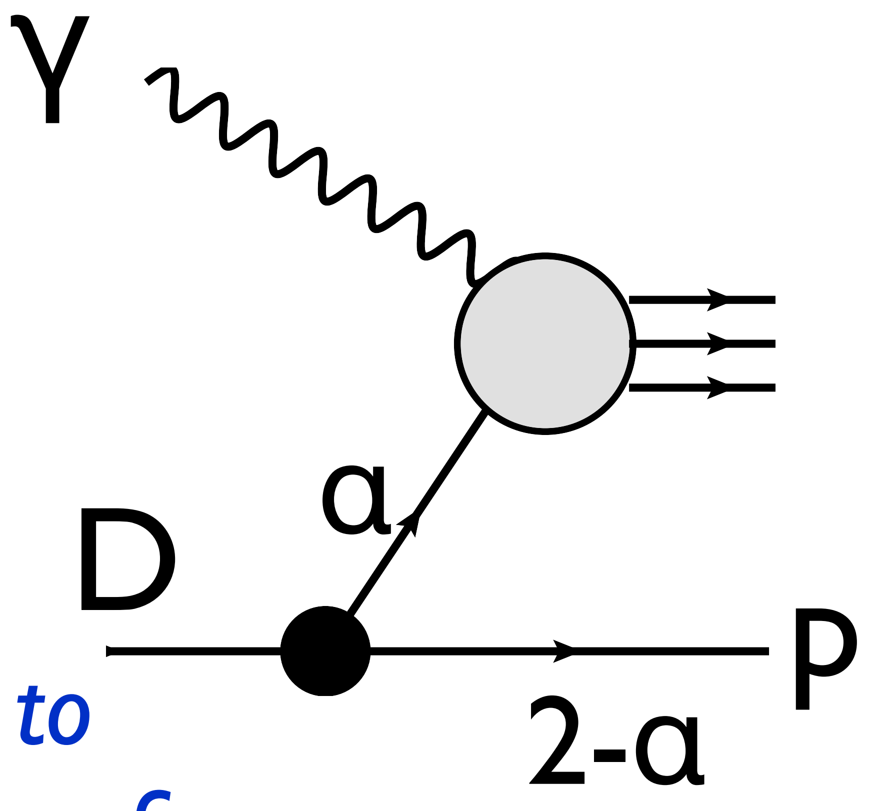
Could the EMC effect be solely due to SRCs? Difficult - indeed

Suppression for say carbon / nucleon is 12 %.

Probability of SRC in C ~15 — 20%

Nucleons with momenta > K_Fermi practically do not have quarks with x> 0.5.

Tagging of proton and neutron in e+D→e+ backward N +X as a probe of the origin of the EMC effect (FS 85)



interesting to measure tagged structure functions where modification is expected to increase quadratically with tagged nucleon momentum. It is applicable for searches of the form factor modification in (e,e'N).

$$1 - F_{2N}^{bound}(x/\alpha, Q^2)/F_{2N}(x/\alpha, Q^2) = f(x/\alpha, Q^2)(m^2 - p_{int}^2)$$

Here α is the light cone fraction of interacting nucleon

$$\alpha_{spect} = (2 - \alpha) = (E_N - p_{3N})/(m_D/2)$$

In practice, small background for 2- α >1, and in this kinematics one expects an EMC like effect already for smaller spectators momenta, since x/α > x.

Importance caveat: for large nucleon momenta nucleons closer to each other and chances of f.s.i maybe larger. Not the case in semi exclusive case eD—>e +p + "resonance". But maybe relevant for larger W. Need dedicate studies of f.s.i. in DIS in the nucleus fragmentation region.

Optimistic possibility - EMC effect maybe missing some significant deformations which average out when integrated over the angles

A priori, deformation of a bound nucleon can also depend on the angle ϕ between the momentum of the struck nucleon and the reaction axis as

$$d\sigma/d\Omega/ < d\sigma/d\Omega >= 1 + c(p, q).$$

Here $<\sigma>$ is cross section averaged over ϕ and $d\Omega$ is the phase volume and the factor c characterizes non-spherical deformation.

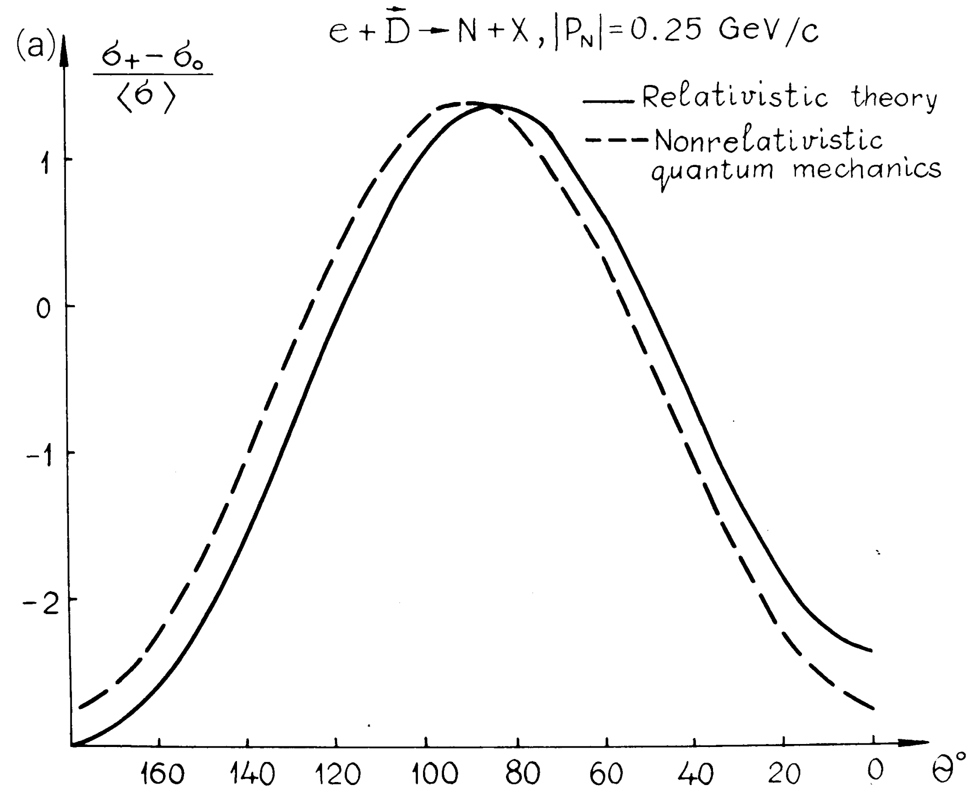
Such non-spherical polarization is well known in atomic physics *(discussion with H.Bethe)*. Contrary to QED detailed calculations of this effect are not possible in QCD. However, a qualitatively similar deformation of the bound nucleons should arise in QCD. One may expect that the deformation of bound nucleon should be maximal in the direction of radius vector between two nucleons of SRC.

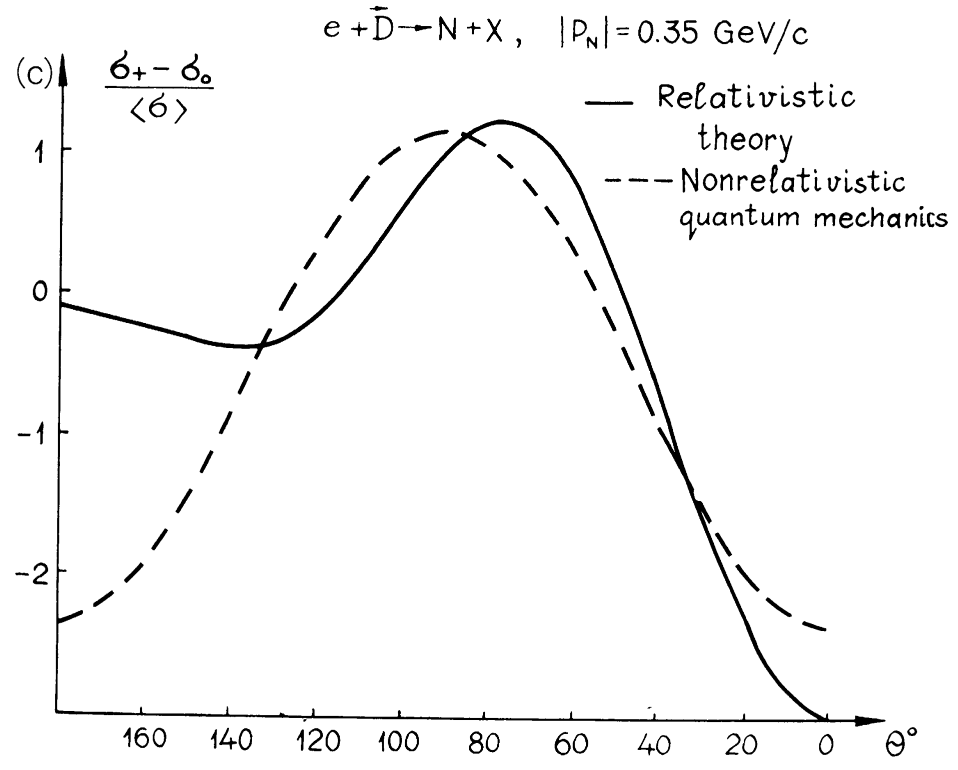
further open questions:

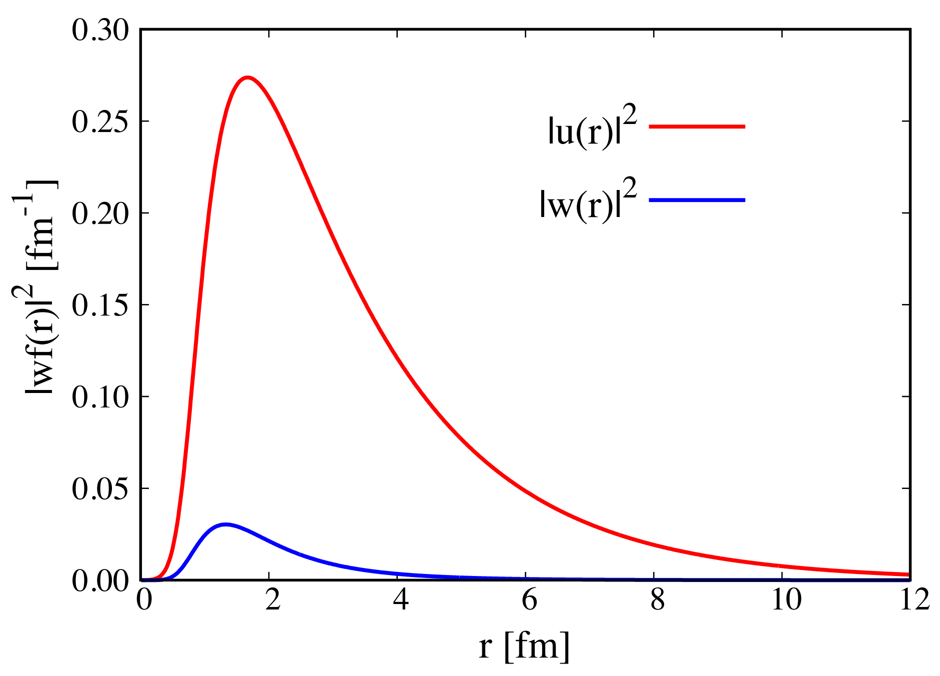
- **with what is accuracy WF of pn pair $\propto$ $\psi^2_D(\kappa)$?; FSIs** Boeglin talk

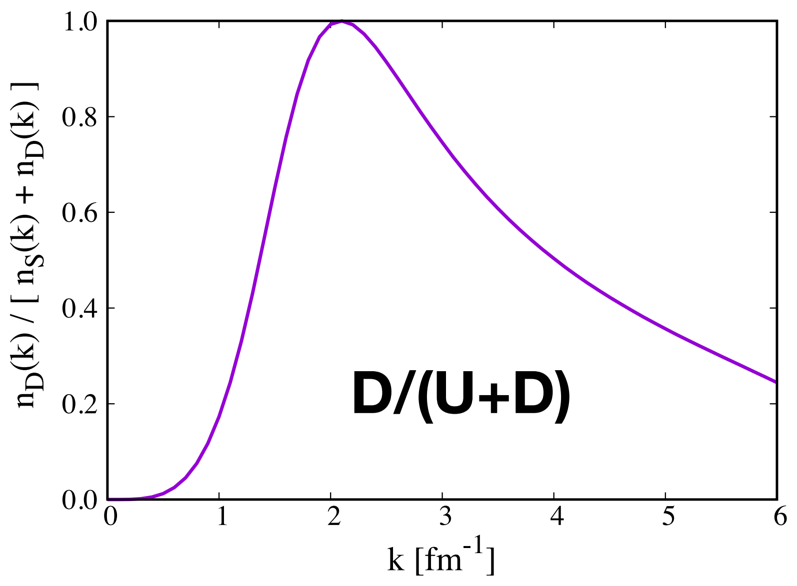
- **Need observables sensitive to LC dynamics**

study scattering off polarized deuteron (S/D ratio) or studying variation of scalar/tensor ratio for different angles and same momentum









small component in coordinate space generates dominant contribution in momentum space

- **off shell eN cross section**

Three nucleon SRCs = three nearby nucleons with large relative momenta

Since NN interaction is sufficiently singular for large momenta

$\rho_A^N(\alpha, p_t)$ can be expanded over contributions of j-nucleon correlations $\rho_j(\alpha, p_t)$

$$\rho_A^N(\alpha > 1.3, p_t) = \sum_{j=2}^{A} a_j(A)\rho_j(\alpha, p_t)$$

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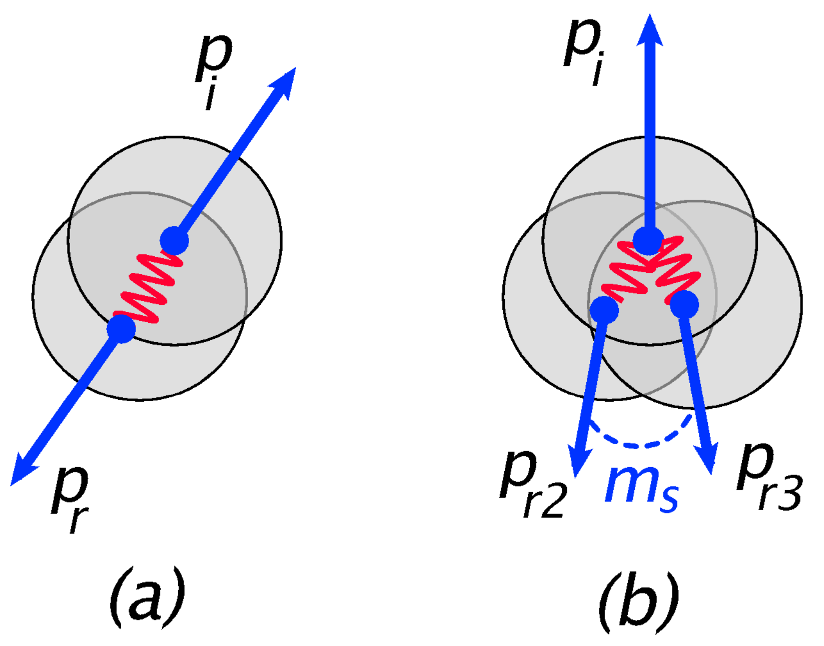
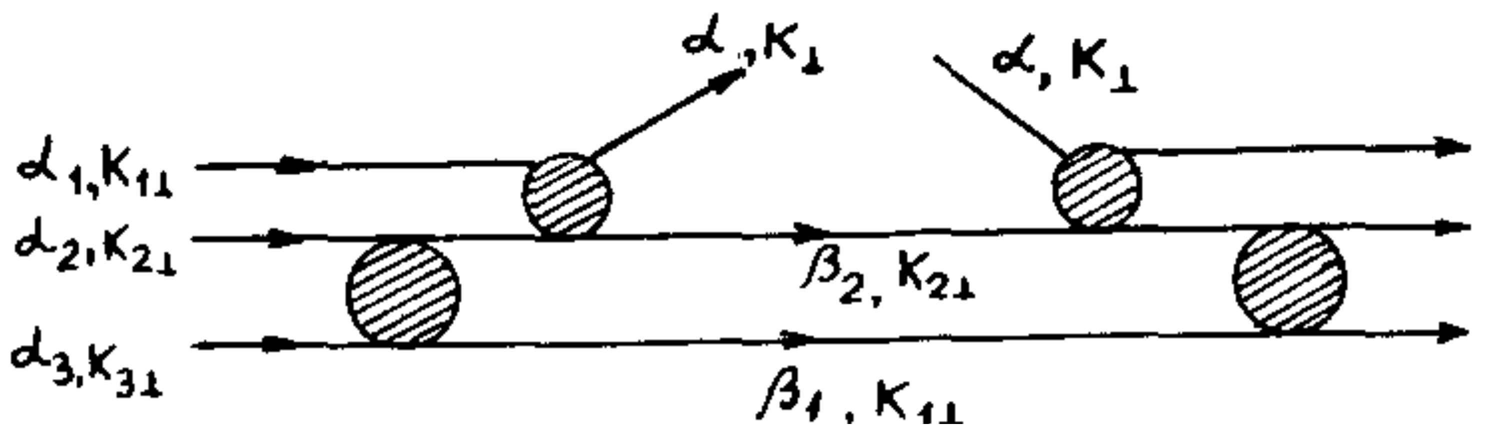


iterations of NN interactions (Plus 3N from 3N forces possible)



$$\rho_j(\alpha, p_t)(j-\alpha)^{n(j-1)+j-2},\ where\, \rho_j(\alpha, 0) \propto (2-\alpha)^n$$

α up to 2 (3) are allowed for 2N (3N) SRC (plus small mean field corrections)

NR case large k = 2N SRC, qualitative difference relativistic and nonrelativistic dynamics

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Evidence from NR calculations? *3N SRC can be seen in the structure of decay of ³He* (Sarsgian et al).

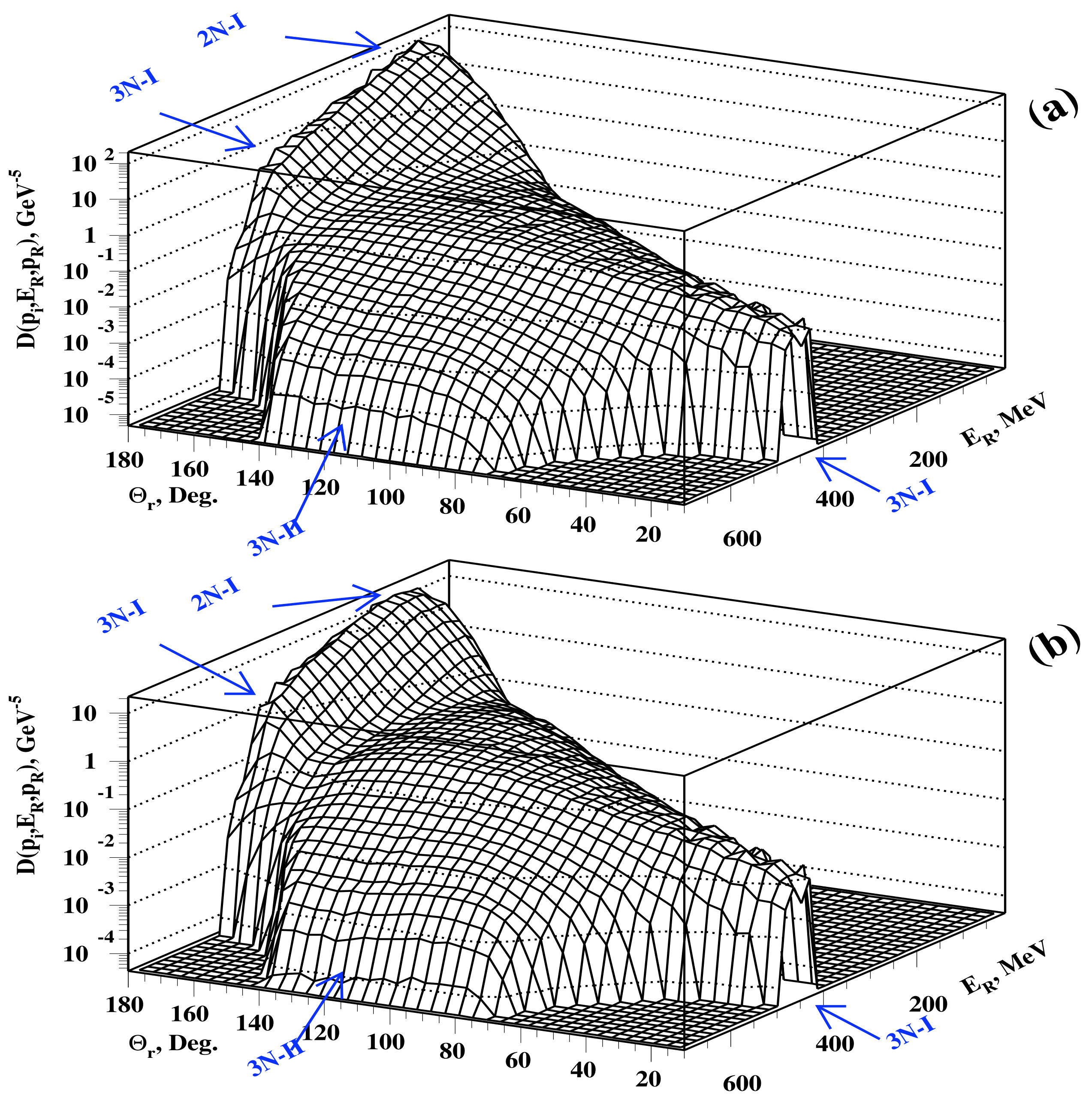

Figure 8: Dependence of the decay function on the residual nuclei energy and relative angle of struck proton and recoil nucleon. Figure (a) neutron is recoiling against proton, (b) proton is recoiling against proton. Inital momentum of the struck nucleon as well as recoil nucleom momenta is restricted to $p_{in}, p_r \geq 400$ MeV/c.

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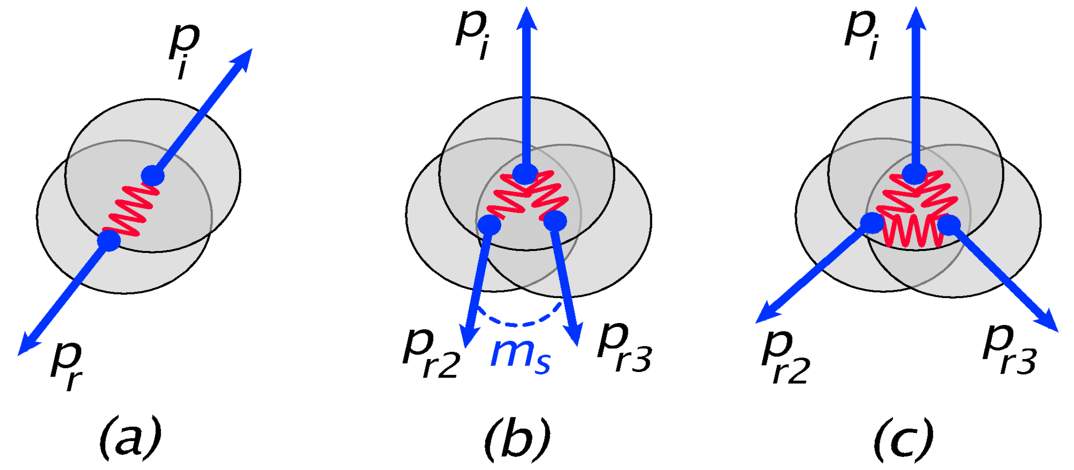
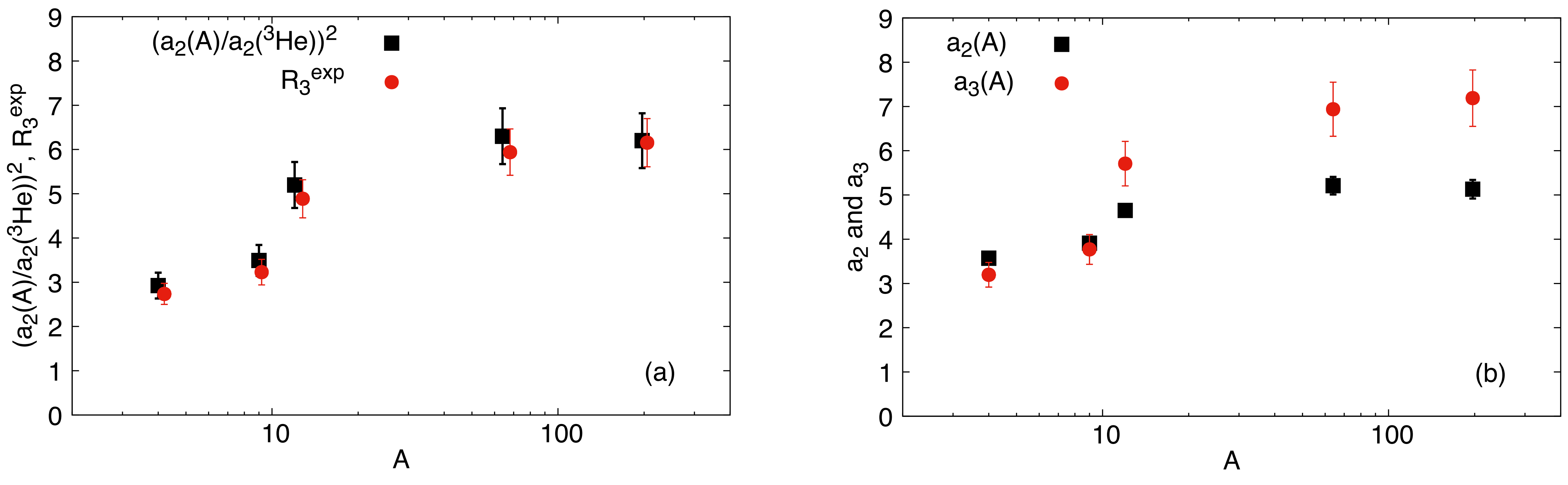


Triple correlations in (e,e') - expect flat region in x where 3N dominate & faster A dependence of 3N SRC



G. 17: (a) The A dependence of the experimental evaluation of R_3 compared with the predicti
Eq.27. (b) The A dependence of $a_3(A, Z)$ parameter compared to $a_2(A, Z)$ of Ref.[6].

However statistic is low, data have significant systematics issues.

Need data at larger Q and much higher statistics

Reminder: 3N forces, correlations are important for dynamics of neutron stars

Suplement slides

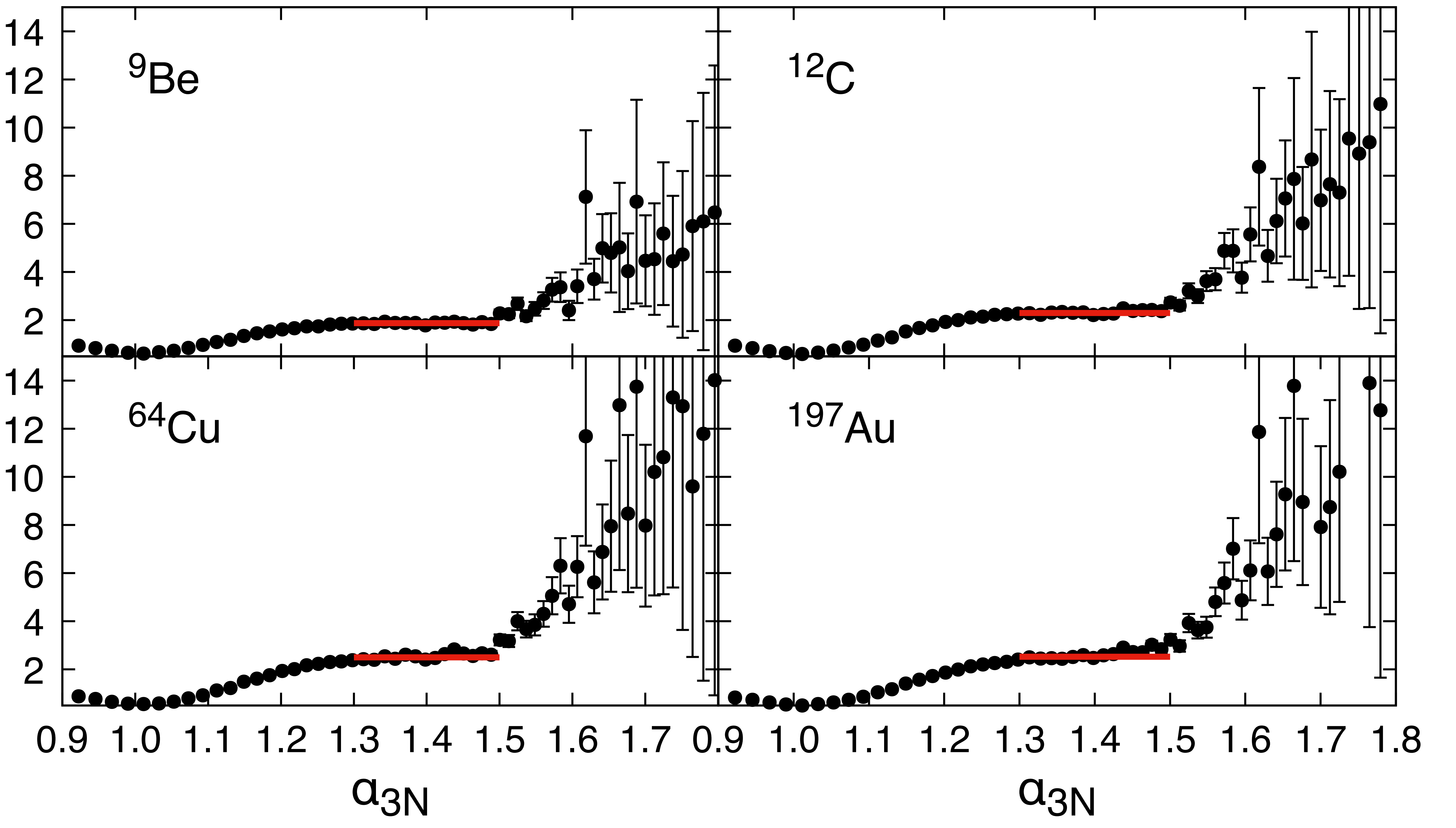


FIG. 16: Per-nucleon cross section ratios for ^{9}Be, ^{12}C, ^{64}Cu, ^{197}Au to ^{3}He. Horizontal lines indicating $\frac{a_2(A)}{a_2(^3He)}$ in the 2N-SRC region.