high momentum

Probing universality of ~~short range~~ nucleon correlations

Momenta are observables, distances are not

Mark Strikman , 29 January, 2023

Outline

Resolution scales

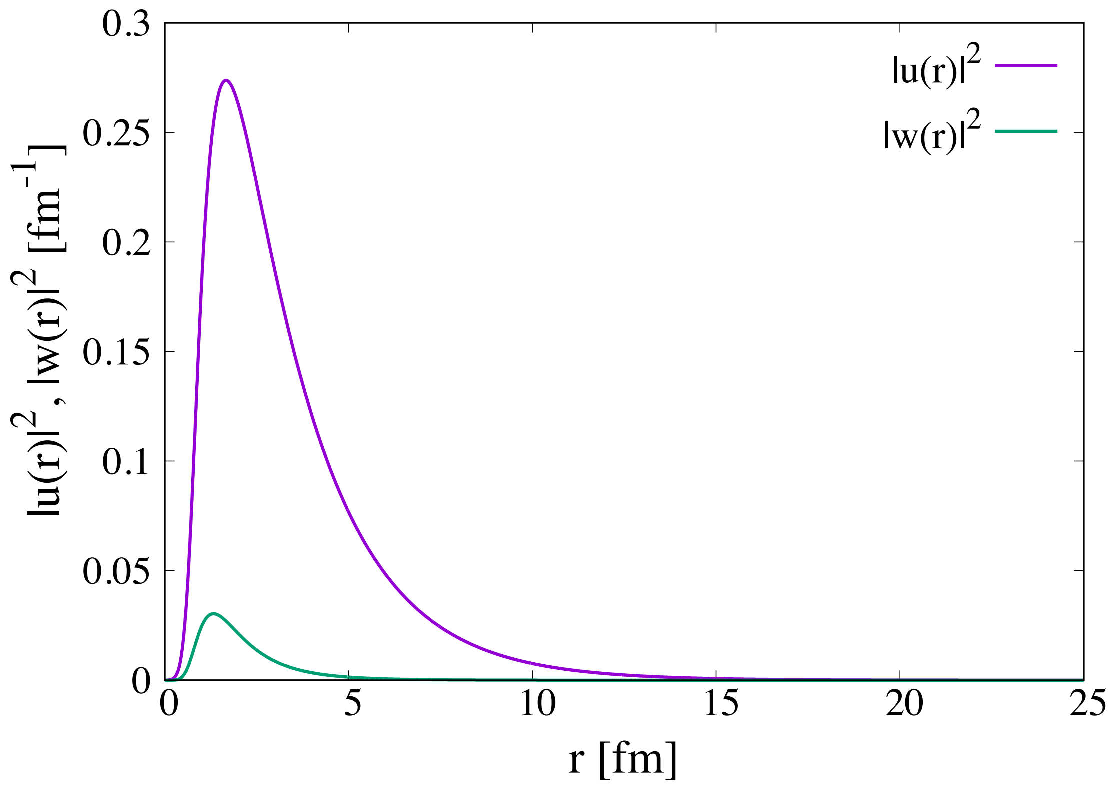
Sources of non-universality

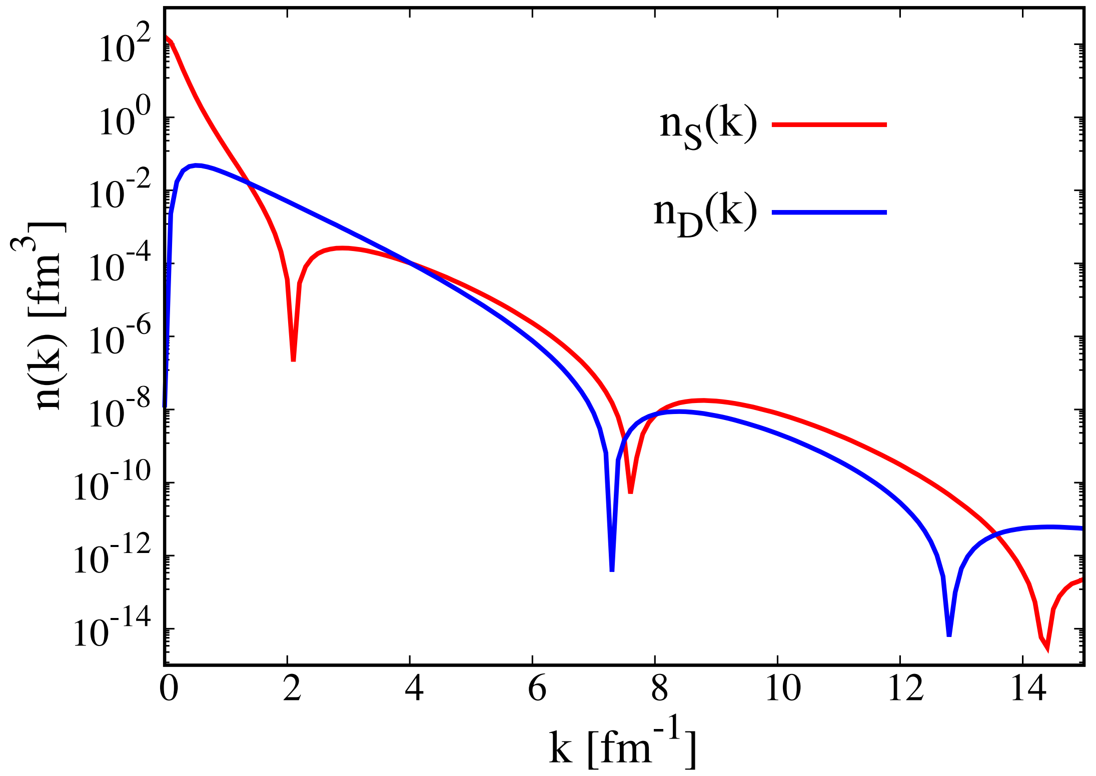
Interactions of projectile with 2N (screening)

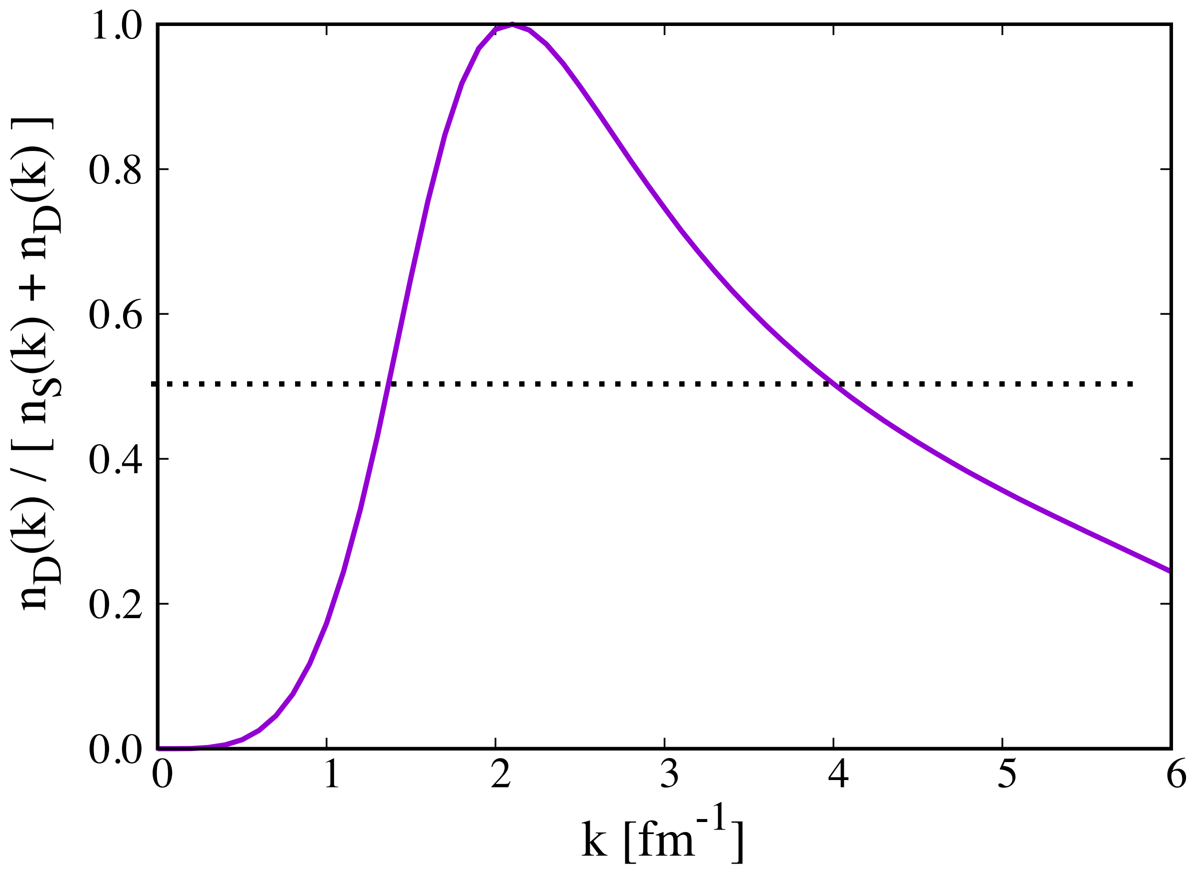
Treatment of absorption of emitted nucleons

3N   (e,e’) & different efficiency for emission of fast nucleons

A quick look at coordinate and momentum space wave functions of deuteron







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"

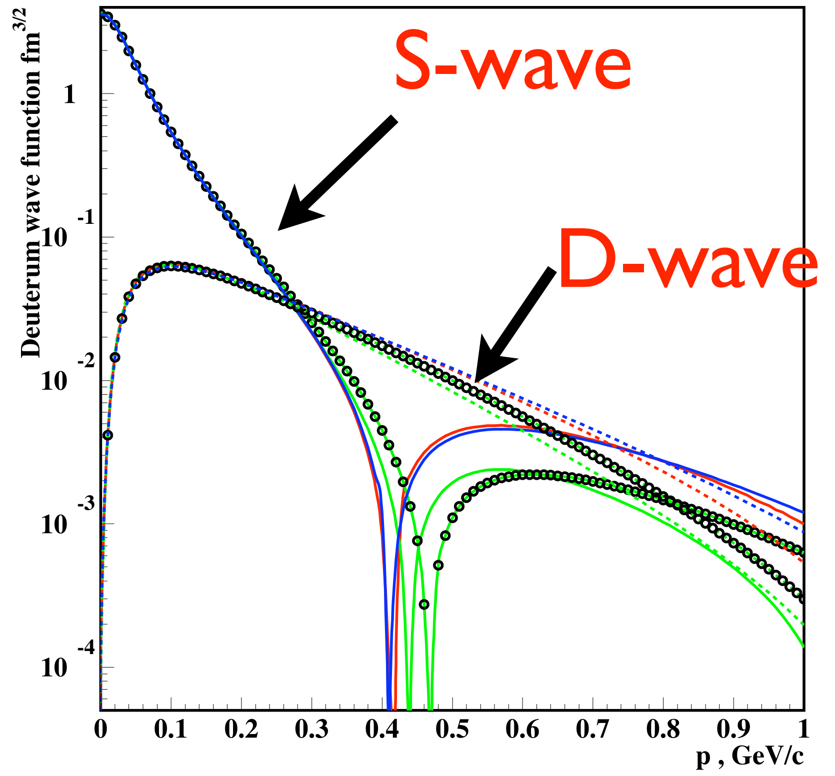
Is w(k) /u(k) universal for k> 300 MeV/c?

No direct calculations so far. Wiringa calculated the sum over all waves

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

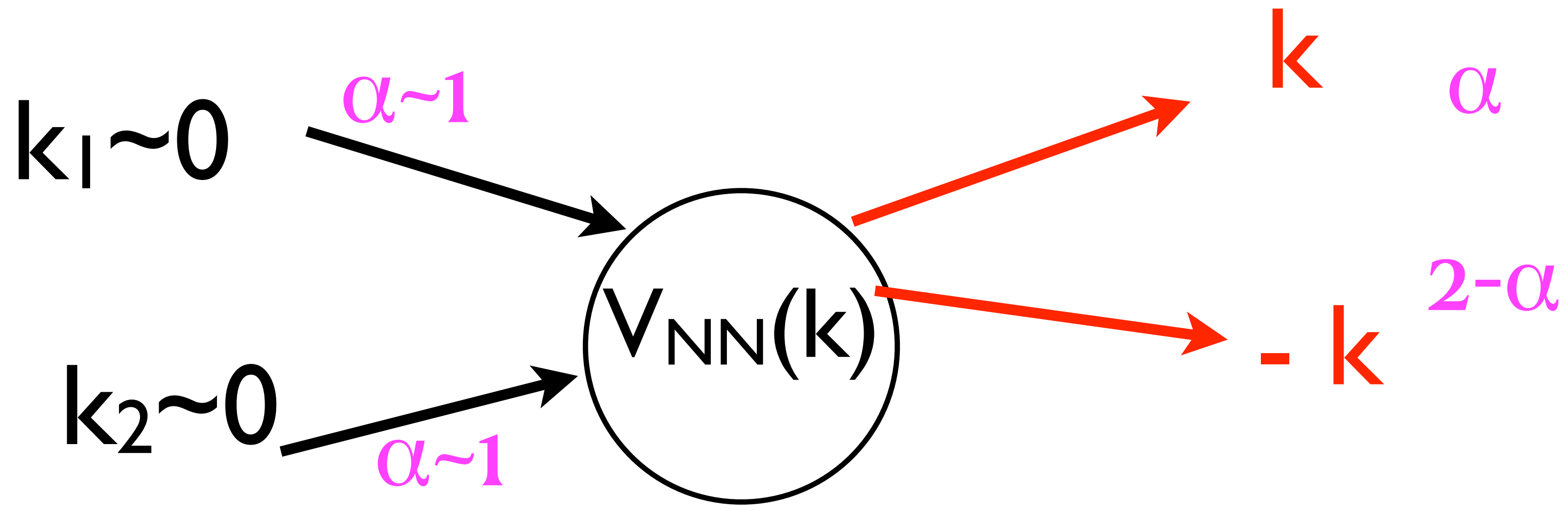
Properties of SRCs (HMCs)

Realistic NN interactions - NN potential slowly (power law) decreases at large momenta
-- nuclear wf high momentum asymptotic determined by singularity of potential:



Deuteron wave function

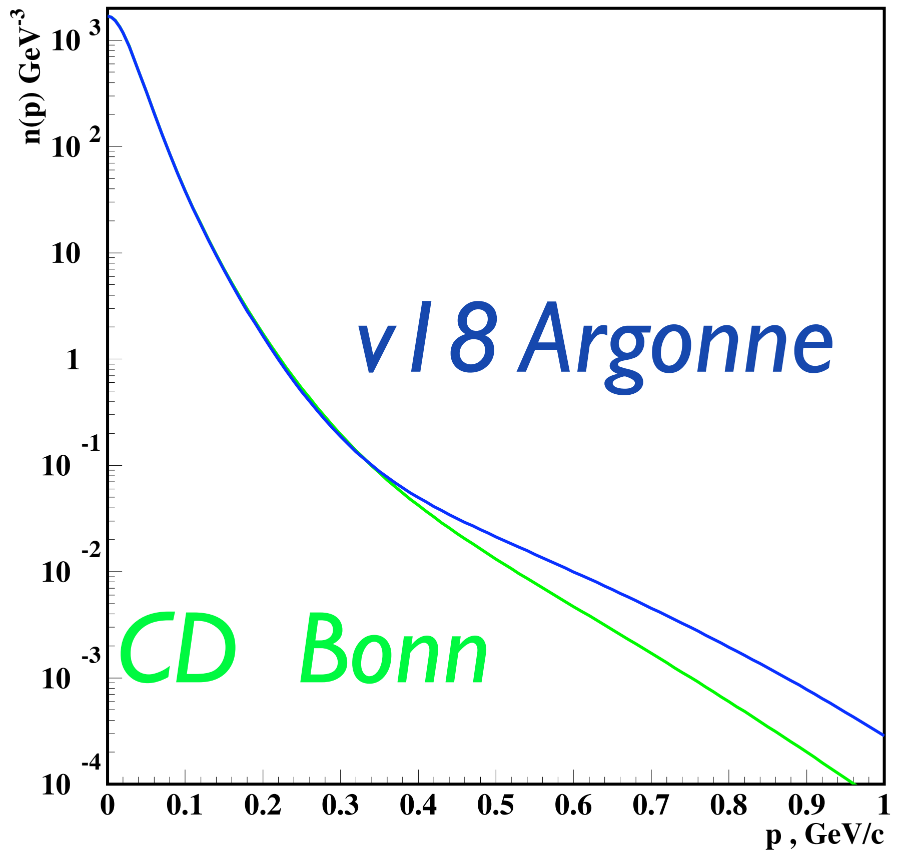
$$\psi_D^2(k)_{|k\to\infty} \propto \frac{V_{NN}^2(k)}{k^4}$$



D-wave dominates in the Deuteron wf
for 300 MeV/c < k < 700 MeV/c

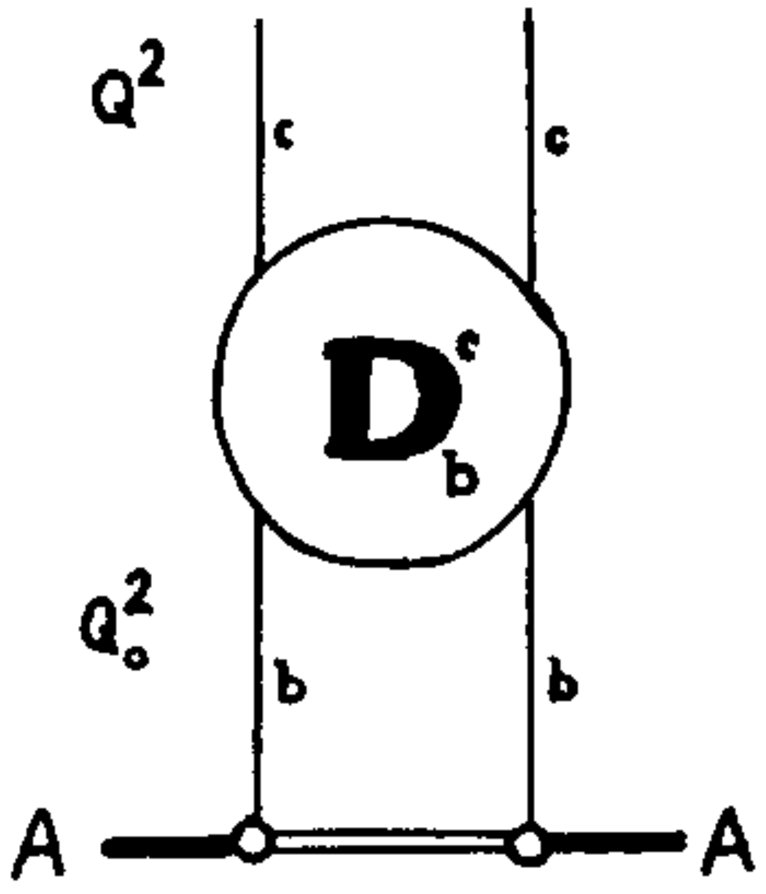
D-wave is due to tensor forces which are much more important for pn than pp

Tensor forces are pretty singular ➟ manifestations very similar to *shorter* range correlations - so we refer to both of them as SRC/HMCs



Large differences between in $n_D(p)=\psi^2_D(p)$ for p>0.4 GeV/c - absolute value and relative importance of S and D waves between currently popular models though they fit equally well pn phase shifts. Traditional nuclear physics probes are not adequate to discriminate between these models.

Change of the number & kind of degrees of freedom with trdolution l is organic property of QFT



$$D^c_A(x, Q^2) = \int_x^1 \frac{dz}{z} \sum_b D^c_b(x/z, Q^2/\Lambda^2, Q_0^2/\Lambda^2) D^b_A(z, Q_0^2) \, .$$

Here the sum goes over all partons b in the target A. Λ is the scale parameter.

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.

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

Three important scales

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

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.

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

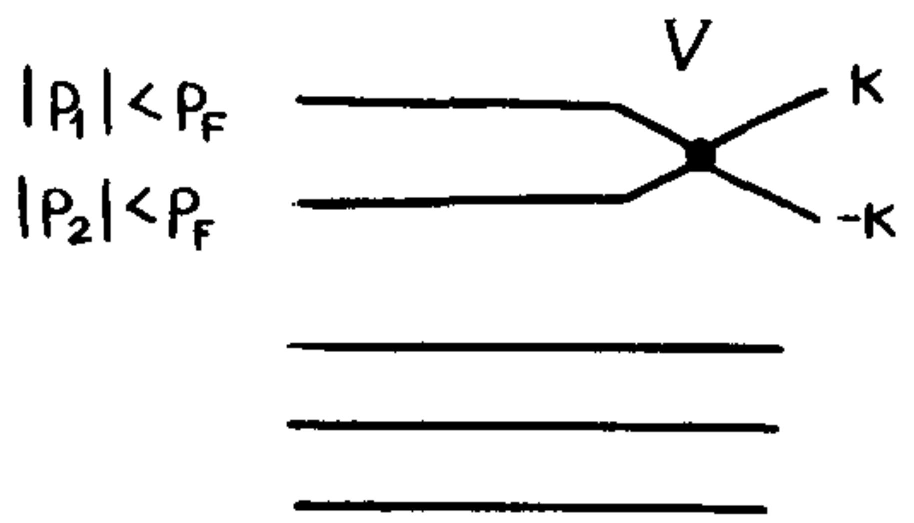
Sufficient to resolve short-range correlations (SRCs) = direct observation of SRCs but not sensitive to quark-gluon structure of the constituents

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

Will consider universality for “2” and “3” limits

The Born term

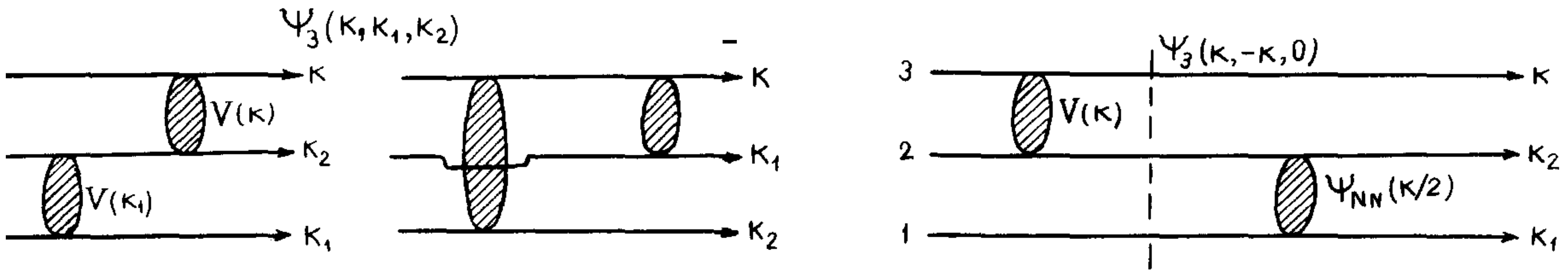


dominates momentum distribution at large momenta

$$n_A(k)\big|_{k\to\infty} \sim \frac{V^2(k)}{k^4}$$

3N contribution is parametrically suppressed as compared to 2N

$$P_A(k,E)\big|_{E<\text{const.},\,k\to\infty} \sim n_A^2(k/2)$$

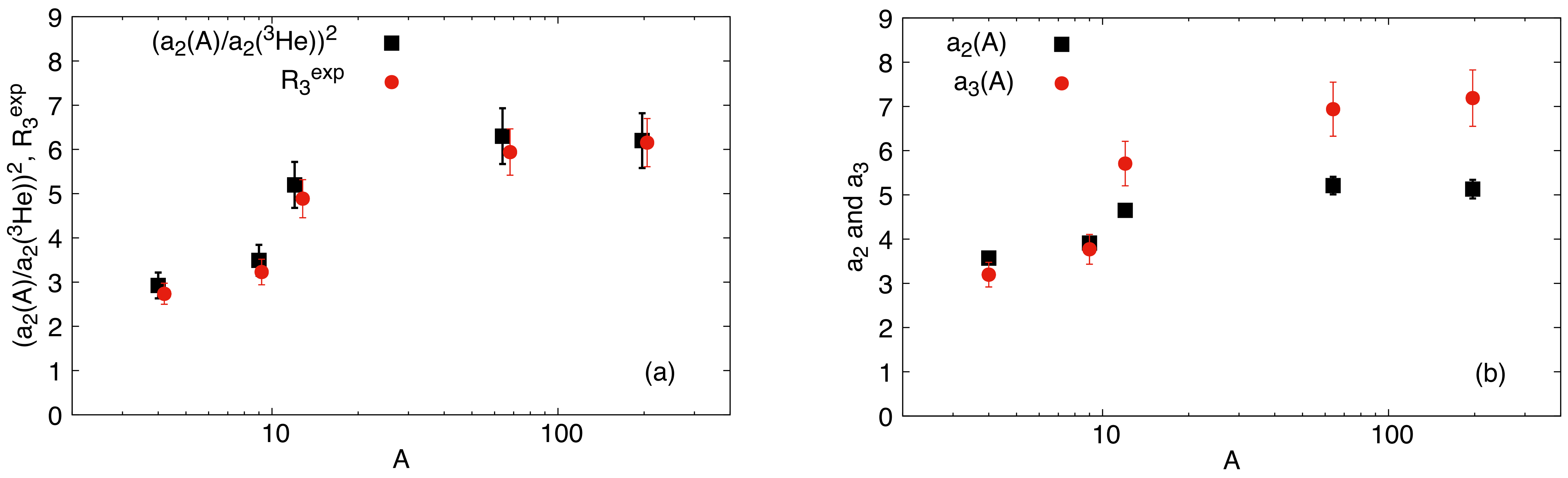


The light cone dynamics - opposite expectation: at α >2 (actually α >1.5) 3N,4N correlations dominate.

A-dependence of 3N and 2N is expected to be different (next slide).

Hence breaking of universality at large α

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



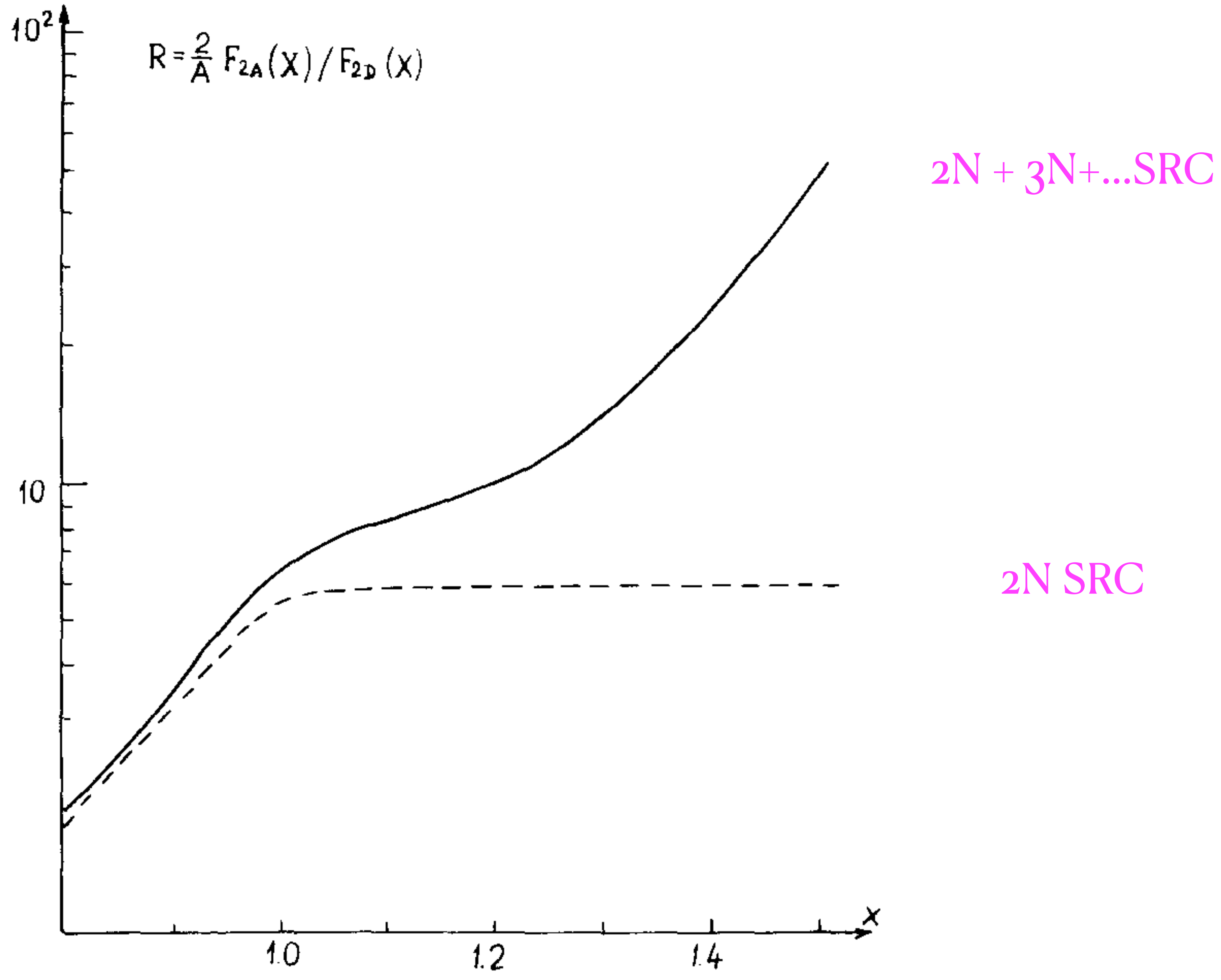
G. 17: (a) The A dependence of the experimental evaluation of R_3 compared with the predicti
Eq.27. (b) The A dependence of $a_3(A, Z)$ parameter compared to $a_2(A, Z)$ of Ref.[6].

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

PARTON DENSITIES



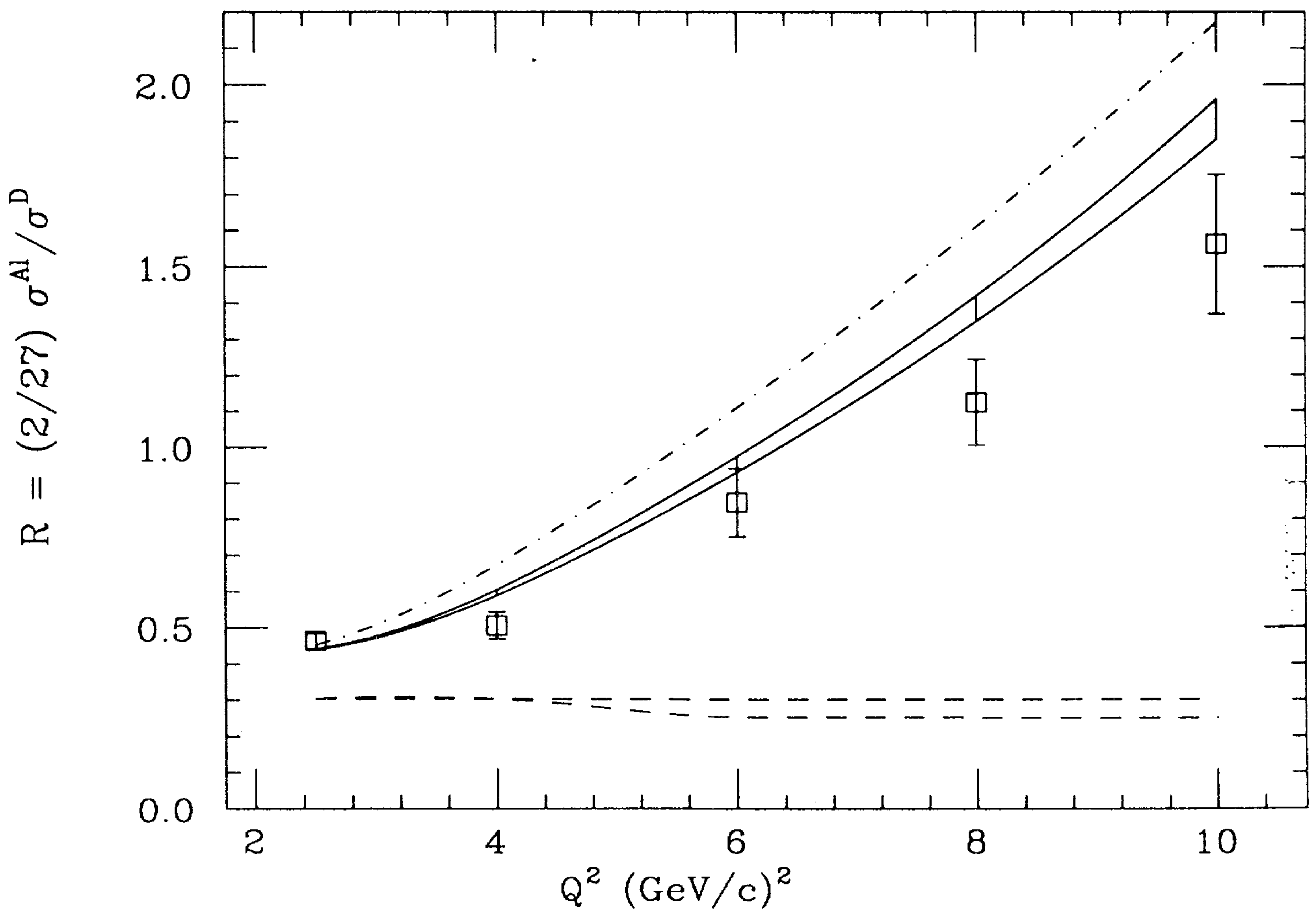
$<\alpha> \sim x + 0.5$

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

Highly desirable to check the picture n by measuring the A/D ratio
for wide range of x, Q with different role of 2N and 3 N correlations

Several classes of non universality of the SRC
for example light cone nucleon density $\rho(\alpha)$
extracted using different processes:

A(p,2p) at large -t , (e,e'p), gamma A —> M +B +(A-2)

Universality of $\rho(\alpha)$, if extraction is corrected for initial and final state absorption T(A) - change from eikonal due to color transparency onset?)

Calculation of absorption including both shell and SRC effects still a challenge.
One needs to treat propagation of fast (eikeonal) and slow (mean field nucleons)

Compare e,e'NN in forward and backward spectator distribution

In C(e,e'p): T(P-shell) T(S-shell) ~ 1.2

Also not only absorption but also distortion: was implemented by Misak in the analysis of the BNL data

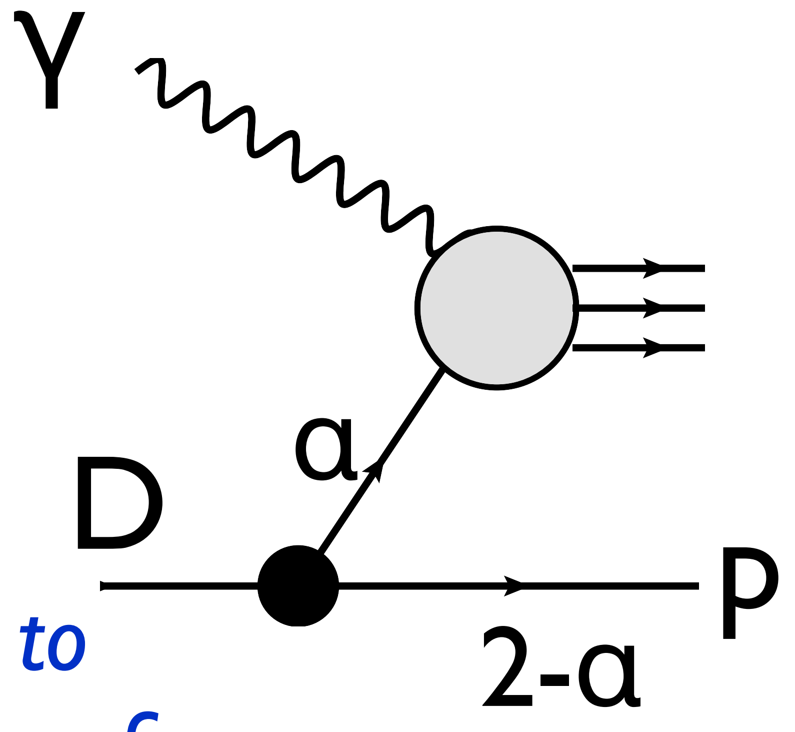
Higher order effect: surface selection stronger for proton projectile than for photon beam - effect on a_2 extracted neglecting this effect.

Amplitude of the projectile - nucleon scattering may depend on nucleon vituality leading to non universality

Potential for 100% Non-unversality

To add A(e,e’) x>1 to analysis, one needs to calculate accurately fsi in (e,e’) for for pn within 100 MeV to the threshold. Arenhovel reported enhancements by up to factor 2

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

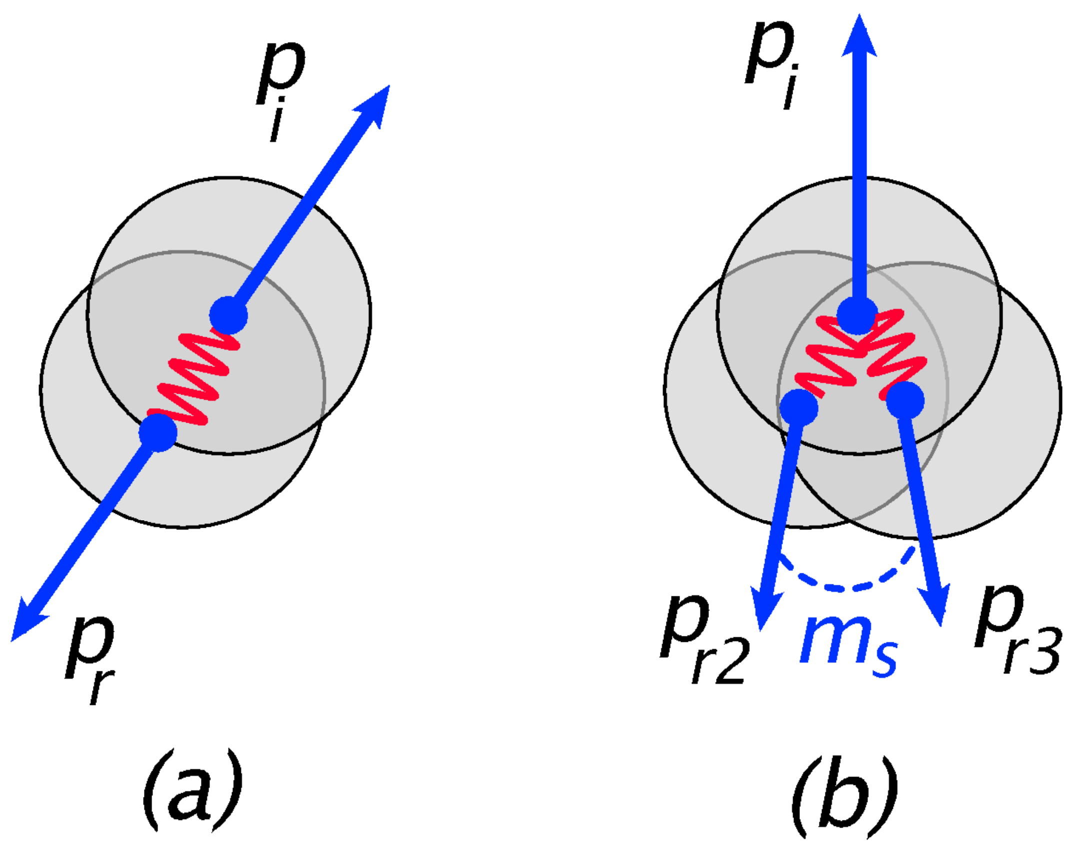
$$\alpha_{spect} = (2-\alpha) = (E_N - p_{3N})/(m_D/2)$$

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.

FSI in different stages:
(a) slow hadron produced ialong the beam aırection,
(b) they destroy would be spectators. Condition for significant FSI : pn are close enough - selects SRCs

3N nonuniversality in nucleon emission vs projectile, and vs (e,e')



TO EMIT NUCLEON 1 BEST IS TO TRANSFER TO NUCLEONS 2 & 3 LARGE MOMENTA. EASY FOR PROTON PROJECTILE NUT NOT VIRTUAL PHOTON

NON-*FACTORISATION*

IMPLICATIONS FOR 2N PRODUCTION OF SPECTAOTRS

Related effect for treating Fermi motion of NN in mean field

INCLUSIVE ELECTRON SCATTERING - NO SUPPRESSION OF 3N, (COMPETITION OF 2N AND 3N)

Related effect for treating Fermi motion of NN in mean field

Conclusions

- For many observables universality should hold after corrections for FSU
- Universality for different projectiles requires correction for interaction with both nucleons of. SRC
- Violation of universality at large x would be a signal for contribution of 3N SRC and break universality of backward spectrum - photons vs proton projectiles
- Effort to study FSI of slow hadrons produced in DIS.