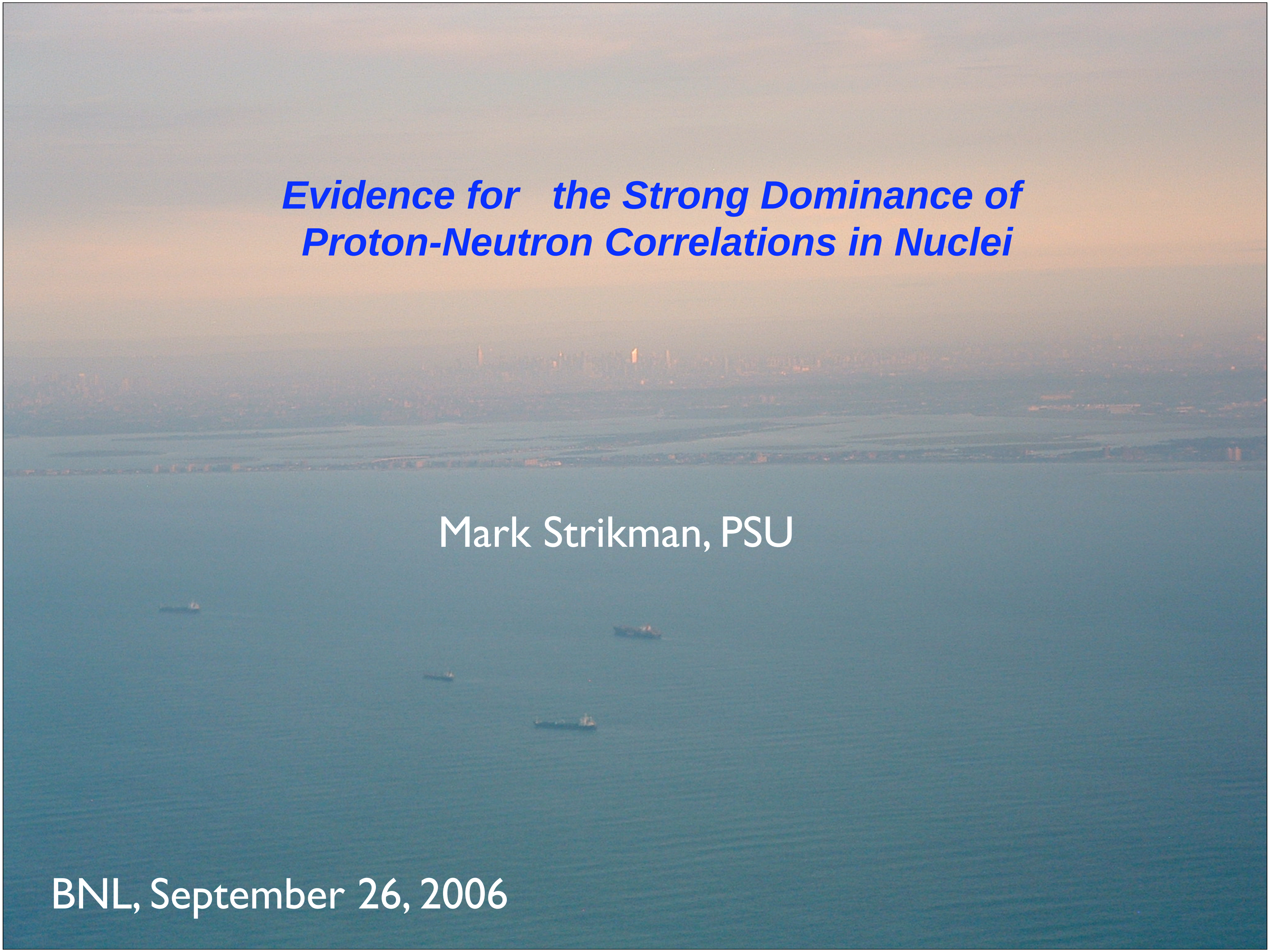


Evidence for the Strong Dominance of Proton-Neutron Correlations in Nuclei

Mark Strikman, PSU

BNL, September 26, 2006

Outline

Introduction - Short range correlations in nuclei - questions and summary of E850 result

Theoretical expectations for SRC related properties of nuclear wave function/spectral function, decay function

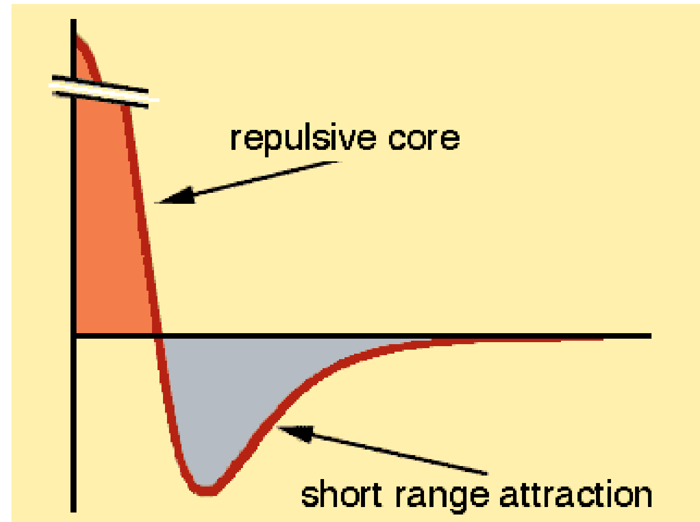
Theoretical analysis of E850 (p,2p), (p,2pn) data

Other SRC related hard phenomena: (e,e') at x> 1, fast backward particle production

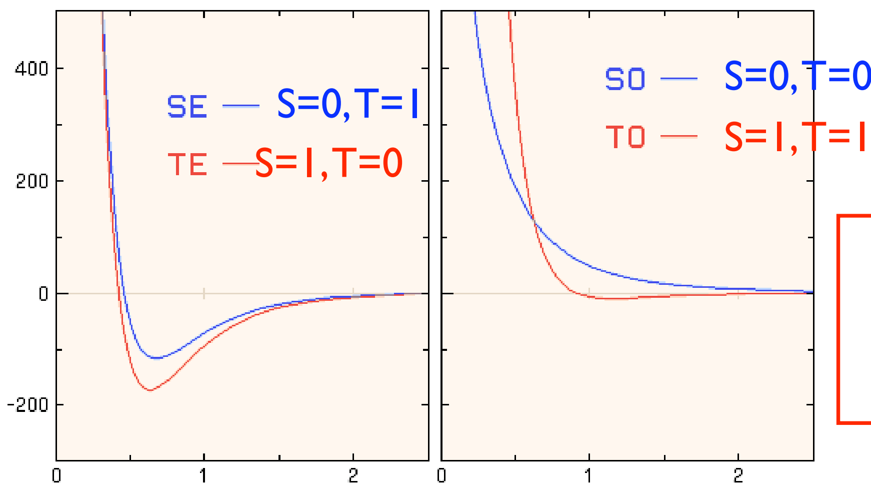
Summary and outlook

Old and persistent question: *Why nuclei do not collapse into a system of size of a nucleon/ quark soup?*

Traditional answer: *Short-range repulsion between nucleons - repulsive core*



V(r)[MeV]



r[fm]

Most important configurations are singlet even and triplet even

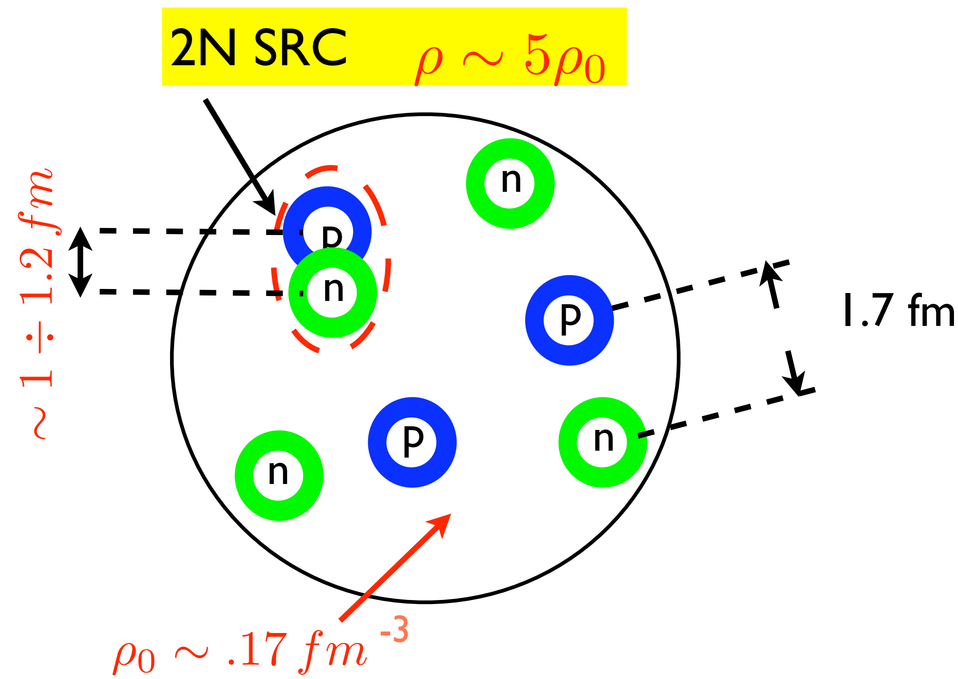
Strong repulsion at $r < r_c \sim 0.4$ fm !!!

Does it makes sense to speak in this situation about nucleons since $r_N = \left\langle r^2_{p\,e.m.} \right\rangle^{1/2} \approx 0.8\, fm$ and $r_c \ll 2r_N$?

Quark distribution in the nucleon is $\rho_N(r) = \exp(-\mu r)$, $\mu = 0.8$ GeV

$2\rho_N(r_c/2) = \rho_N(0) \Rightarrow \quad r_c = .35$ fm F&S 75

Short-range NN correlations (SRC) have densities comparable to the density in the center of a nucleon - *drops of cold dense nuclear matter*



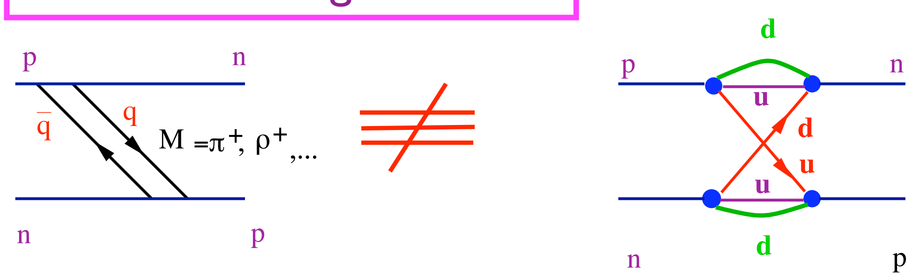
Microscopic
nuclear structure
& study of cold dense nuclear matter - complementary to studies of hot dense matter

Dynamics of neutron star formation and structure

SRC

Quark vs hadronic degrees of freedom in nuclei
Origin of intermediate and short range nucleon-nucleon
forces- quark vs meson exchanges

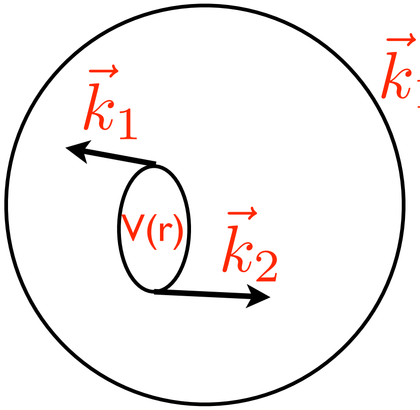
Events generators for heavy ion collisions - fluctuations in central collisions
Baym, Blattel and F &S 93
still not implemented



Meson Exchange

Quark interchange

Short-range correlations in nuclei - for years referred as an elusive though important feature of the nuclear wave structure.



$$\vec{k}_1 + \vec{k}_2 \approx 0$$

Two nucleon short-range correlation.

For our purposes medium range D-wave correlations are included in this definition - *which is a physical/practical one - removal of one nucleon of the correlation leads to a release of the second one.*

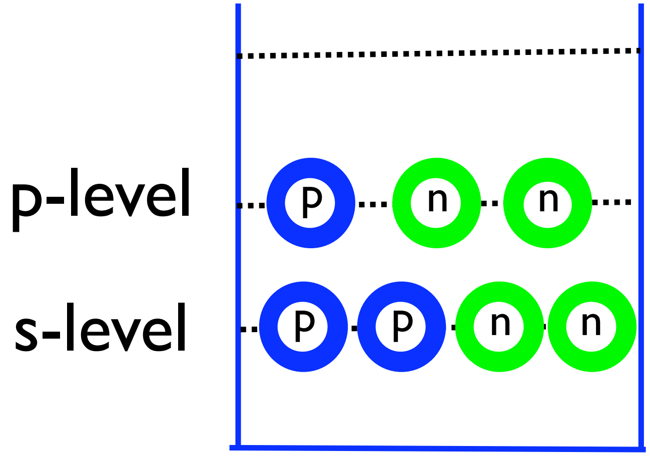
To resolve short-range structure of nuclei *on the level of nucleon/hadronic constituents* one needs processes which transfer to the nucleon constituents both energy and momentum larger than the scale of the NN short range correlations $q_0 \geq 1GeV, \vec{q} \geq 1\,GeV$

$\Rightarrow$ Need to treat the scattering processes in the relativistic domain. There is a price to pay: relativistic (light-cone) treatment of the nucleus - however in broad kinematic range a smooth connection with nonrelativistic description of nuclei.

Will discuss this later in the talk.

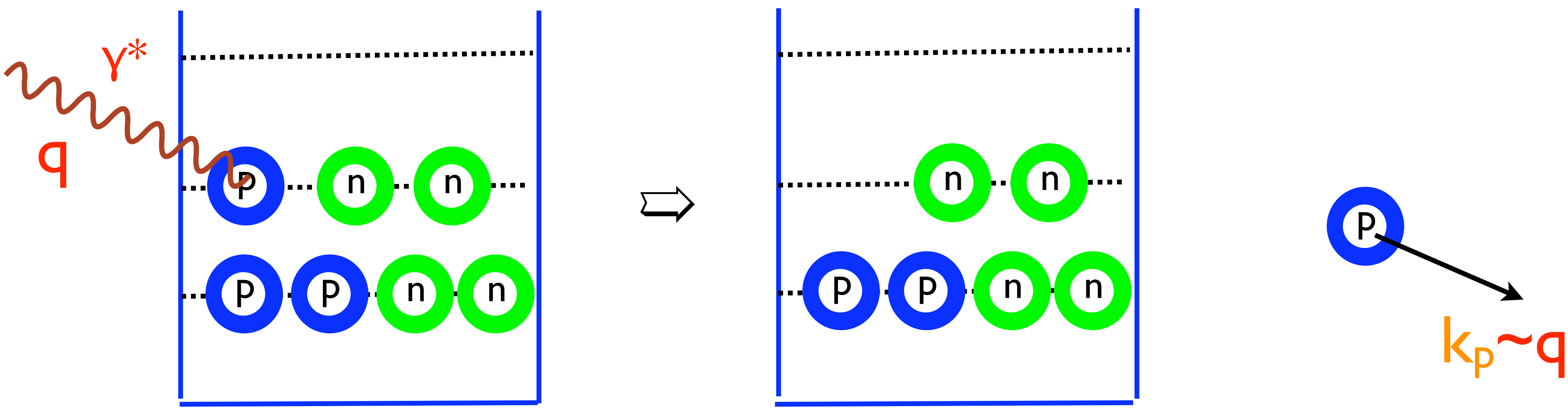
Corollary: Properties of nuclei seen by low energy probes described well using notion of quasiparticles - SRC effects are hidden in parameters of these quasiparticle.

Textbook picture of nuclei:



Nucleons occupy the lowest levels given by the shell model

What happens if a nucleon is removed from the nucleus?



removal of a nucleon

residual nucleus in ground or excited state of the shell model Hamiltonian

Analysis of

BNL E850 data

PRL in press

Evidence for the Strong Dominance of Proton-Neutron Correlations in Nuclei

E. Piasetzky,[1] M. Sargsian,[2] L. Frankfurt,[1] M. Strikman,[3] and J. W. Watson[4]

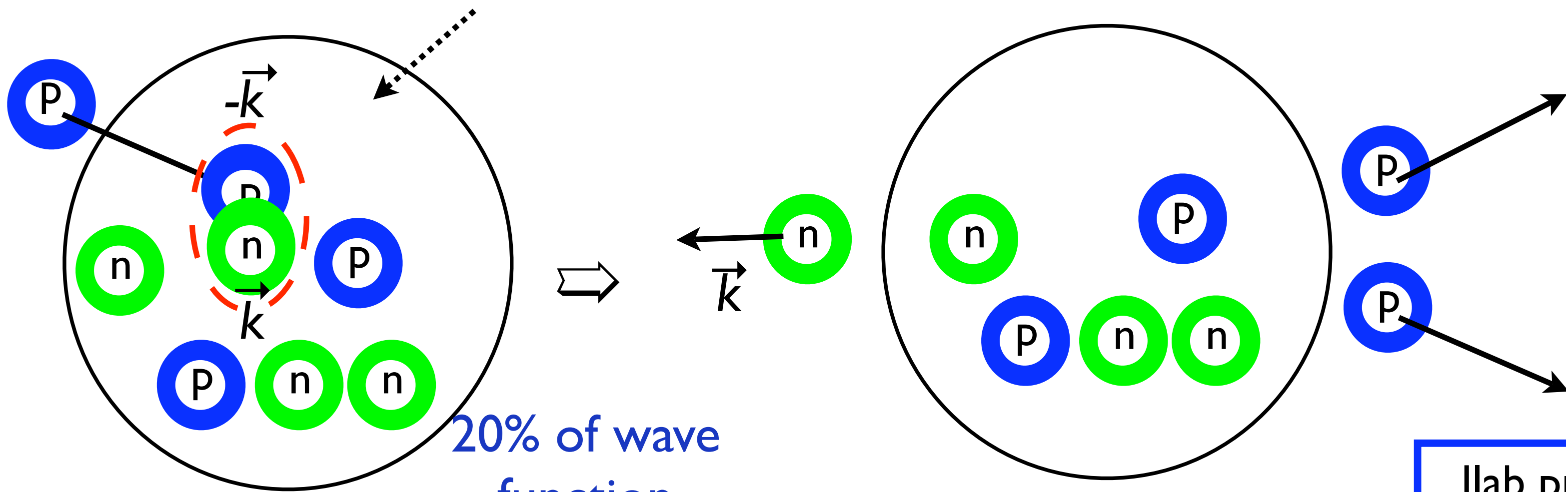
n-p Short-Range Correlations from (p,2p + n) Measurements

A. Tang[a], J. W. Watson[a], J. Aclander[b], J. Alster[b], G. Asryan[d,c], Y. Averichev[h], D. Barton[d], V. Baturin[f,e], N. Bukhtoyarova[d,e], A. Carroll[d], S. Heppelmann[f], A. Leksanov[f], Y. Makdisi[d], A. Malki[b], E. Minina[f], I. Navon[b], H. Nicholson[g], A. Ogawa[f], Yu. Panebratsev[h], E. Piasetzky[b], A. Schetkovsky[f,e], S. Shimanskiy[h], D. Zhalov[f]

at energy and momentum transfer ≥ 3 GeV

PRL 04

spectator mechanism of backward nucleon production *FS77*



20% of wave function

removal of a proton with momentum > 250 MeV/c

~90% probability of emission of neutron with similar but opposite momentum

\+

Jlab preliminary: ~10% probability of proton emission

~100 % correlation! & much stronger dominance of pn correlations than according to naive SU(4) symmetry estimate:n/p ~2

Effect was predicted in

VOLUME 62, NUMBER 10 PHYSICAL REVIEW LETTERS 6 MARCH 1989

Study of Bound Nucleons by Quasiexclusive Scattering with Large Momentum Transfer

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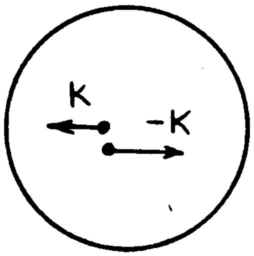
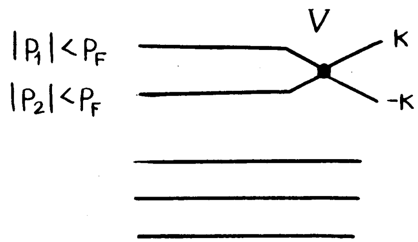
(Received 26 April 1988)

based on our previous studies of the short-range correlations effects hard high energy phenomena

Nonrelativistic approximation (A=many nucleon system described by the Schrodinger equation) expectations for SRC

General considerations - asymptotic of the wave function is determined by the singularity of the potential



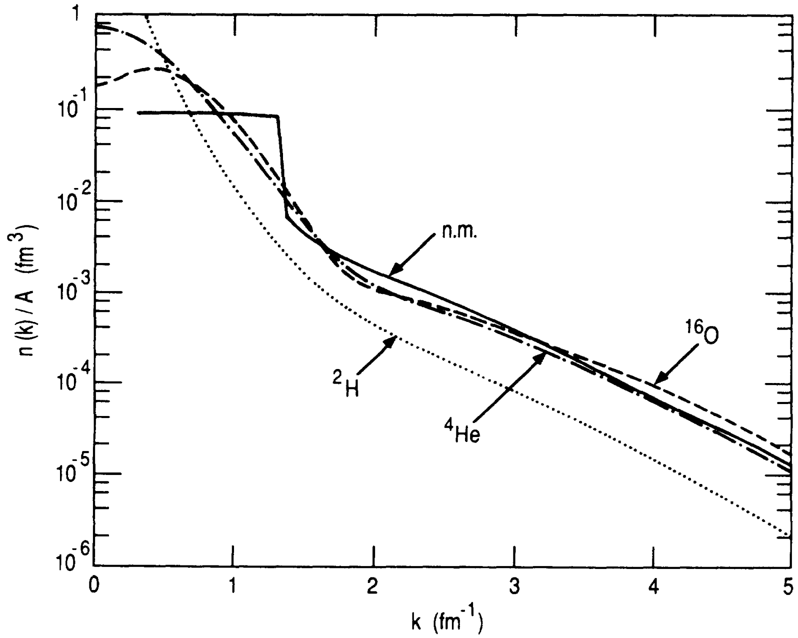


For the single nucleon density matrix $n_A(k) = \int d^3k_i \psi_A^2(k_i)\delta(k-k_1)\delta(\sum_1^A k_i)$

$$V(k)\big|_{k\to\infty} \sim k^{-n}, \qquad n_A(k)\big|_{k\to\infty} \sim \frac{V^2(k)}{k^4}.$$

$$\Rightarrow \qquad n_A(k)_{|k\to\infty} = a_2(A)\psi_D^2(k)$$

$k>k_F$?



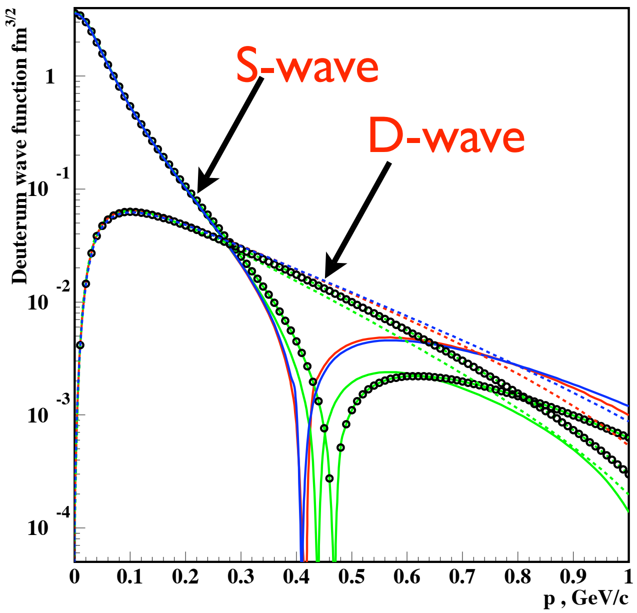
Pieper et al 92

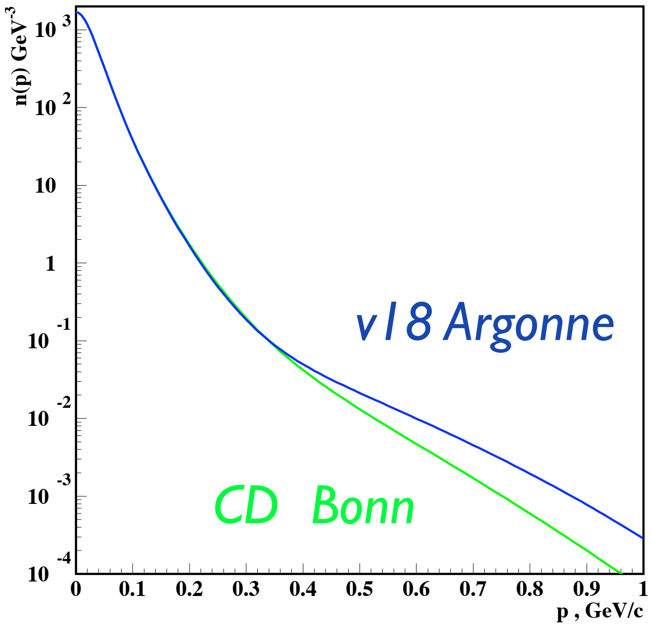
n(k) for ^{2}H, ^{4}He ^{16}O, nuclear matter

Consistent with a fast onset of the asymptotic behavior above the Fermi momentum

a_2(n.m.) ~ 5÷6

Deuteron wave function

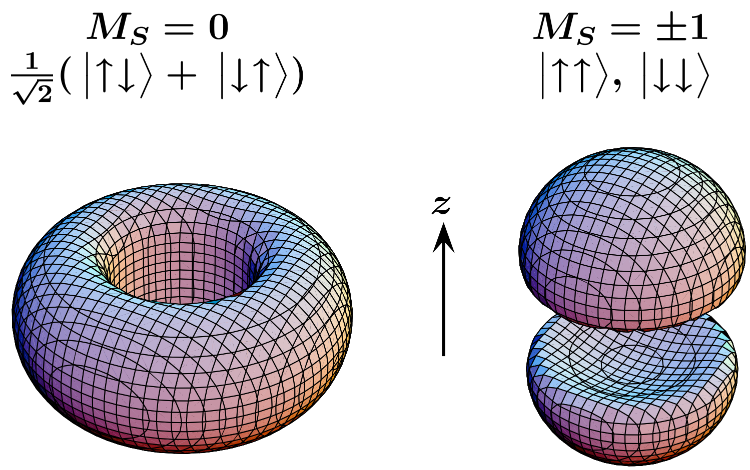




D-wave dominates in a large momentum range above 300 MeV/c.

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

Strong dependence of deuteron space density on spin state of nucleons for small distances/large momenta



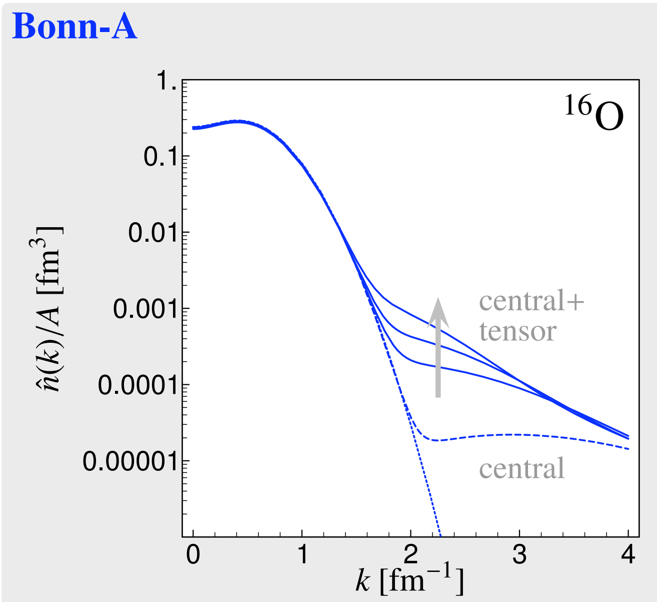
- spin-projected two-body density $\rho^{(2)}_{1,M_S}(\vec{r})$
- **exact deuteron solution** for Argonne V18 potential

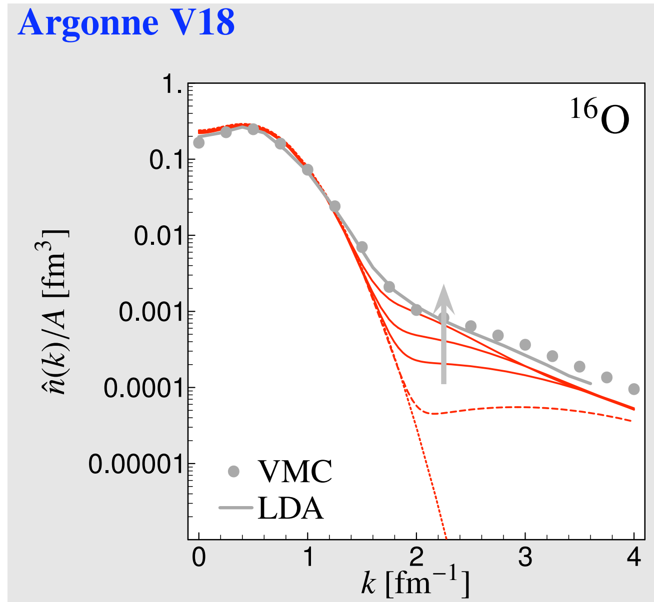
Tensor correlations - couple the relative spacial / momentum orientation of to nucleons with their spin orientation. Predominantly I=0,S=1 - pn pairs

Cannot be described by a single or superposition of few Slater determinants. Only recently implemented in many body calculations.

$\Downarrow$

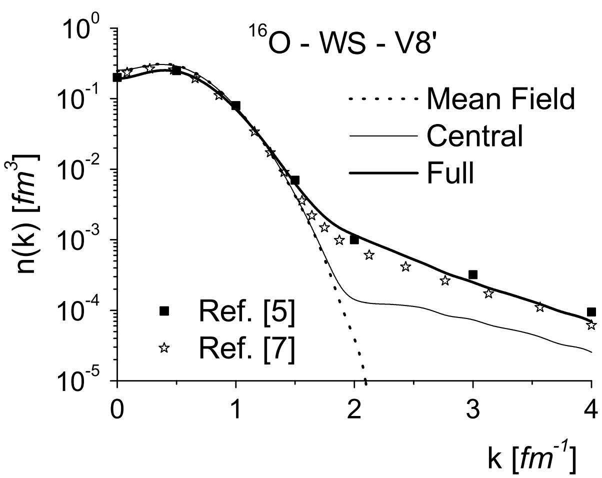
Tensor (D-wave) SRC should be very important in $n_A(k)$

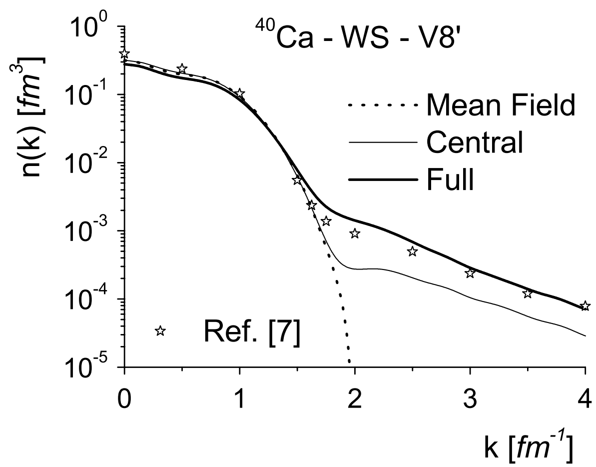




Neff et al 03

$n_A(k)$ for large k are quite different for different potentials, but a_2 values are rather close





Alvioli et al 05

Calculations confirm dominance of tensor forces, but relative contribution of central forces varies from 10 to 20 %

important number for interpretation of E850 pn rates, will use later

Can one check whether indeed the tail is due to SRCs?

Consider distribution over the residual energies, E_R, for A-1 nucleon system after a nucleon with momentum k was instantaneously removed -

nuclear spectral function

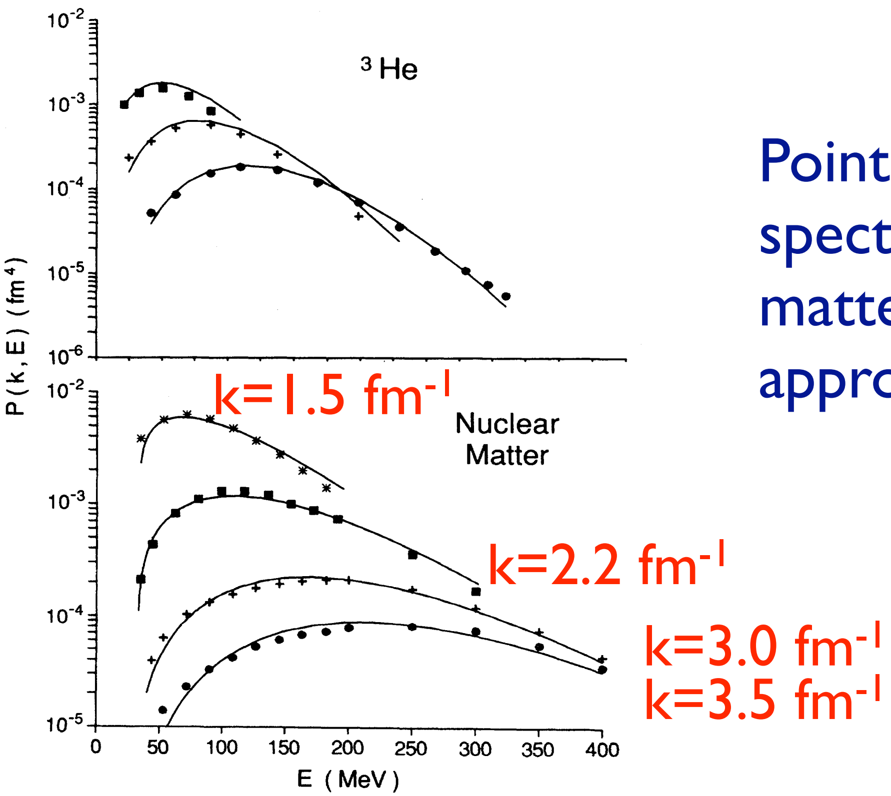
$$P_A(k, E_r), n_A(k) = \int dE_R P_A(k, E_r)$$

for 2N SRC: $\langle E_R(k) \rangle = k^2/2m_N$

FS81-88

Confirmed by numerical calculations

Numerical calculations in NR quantum mechanics confirm dominance of two nucleon correlations in the spectral functions of nuclei at k> 300 MeV/c - could be fitted by a motion of a pair in a mean field   (Ciofi, Simula,Frankfurt, MS - 91). However numerical calculations ignored three nucleon correlations - 3p3h excitations. Relativistic effects maybe important rather early as the recoil modeling does involve k^2/m_N^2 effects.



Points are numerical calculation of the spectral functions of ^{3}He and nuclear matter - curves two nucleon approximation from CSFS 91

In addition to 2N correlations higher order correlations

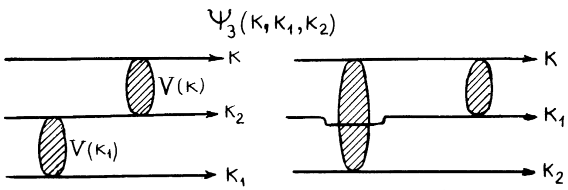
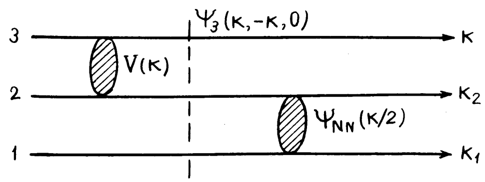


FIG. 8.8:

$$P_A(k,E)\big|_{E<\text{const.},\ k\to\infty} \sim \left(\frac{V(k/2)}{(k/2)^2}\right)^4 \sim n_A^2(k/2).$$



$$P_A(k, E_R(k))_{|k>k_F} = \sum_{j=2}^{A} P_j(k, E_R(k))$$

A new quantity to provide even cleaner test of the structure of SRCs- nuclear decay function (FS 77-88) - probability to emit a nucleon after removal of a fast nucleon. For 2N SRC can model decay function as decay of a NN pair moving in mean field (like for P_A) Piasetzky et al 06

Studies of the spectral and decay function of 3He reveal both two nucleon and three nucleon correlations - Sargsian et al 2004

The EVA Collaboration

Alvioli et al 05

A. Malki[a], J. Alster[a], G. Asryan[c,b], D. Barton[c], V. Baturin[e,d], N. Buchkojarova[c,d], A. Carroll[c], A. Chtchetkovski[c,d], S. Heppelmann[e], T. Kawabata[f], A. Leksanov[e], Y. Makdisi[c], E. Minina[e], I. Navon[a], H. Nicholson[g], Yu. Panebratsev[h], E. Piasetzky[a], S. Shimanskiy[h], A. Tang[i], J.W. Watson[i], H. Yoshida[f], D. Zhalov[e] Acland

[a]Tel Aviv University. [b]Yerevan Physics Institute [c]Brookhaven National Laboratory. [d]St. Petersburg University. [e]Pennsylvania State University. [f]Kyoto University. [g]Mount Holyoke College. [h]J.I.N.R. [i]Kent State University.

Relevant publications :

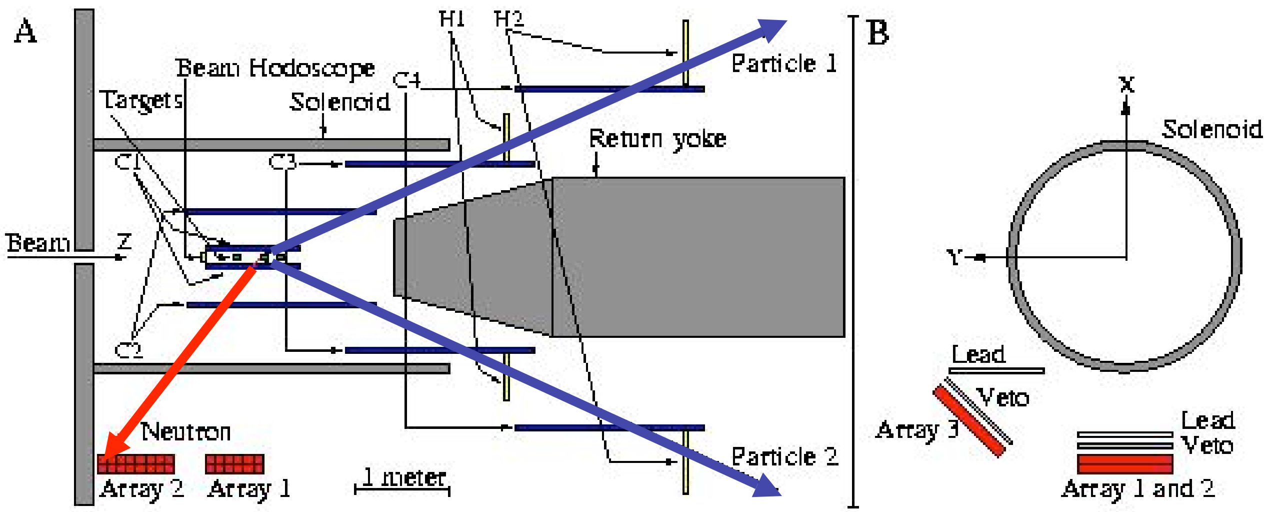
J. Aclander et al. Phys. Lett. B453 (1999) 211.

A. Malki et al. Phys. Rev. C65 (2001) 015207.

A. Tang Phys. Rev. Lett. 90 ,042301 (2003) .

I. Yaron et al., PRC C66, 024601 (2002).

The EVA spectrometer and the neutron counters:

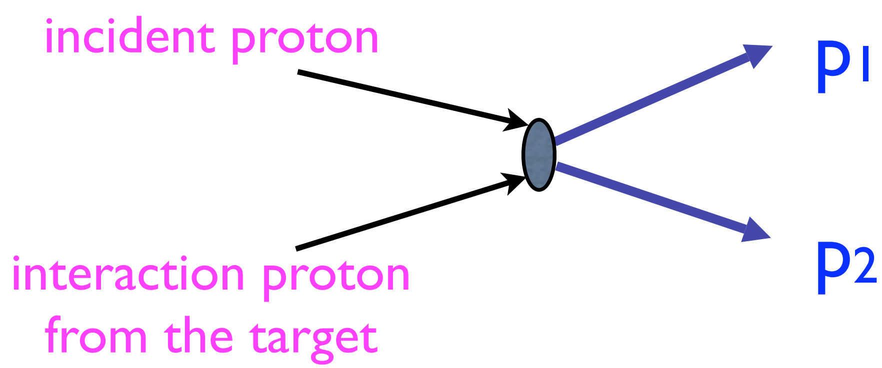


Very good resolution in $E - p_z = (m_N^2 + p_t^2)/(E + p_z)$

LC variables: $q_{\pm} = q_0 \pm q_3$,

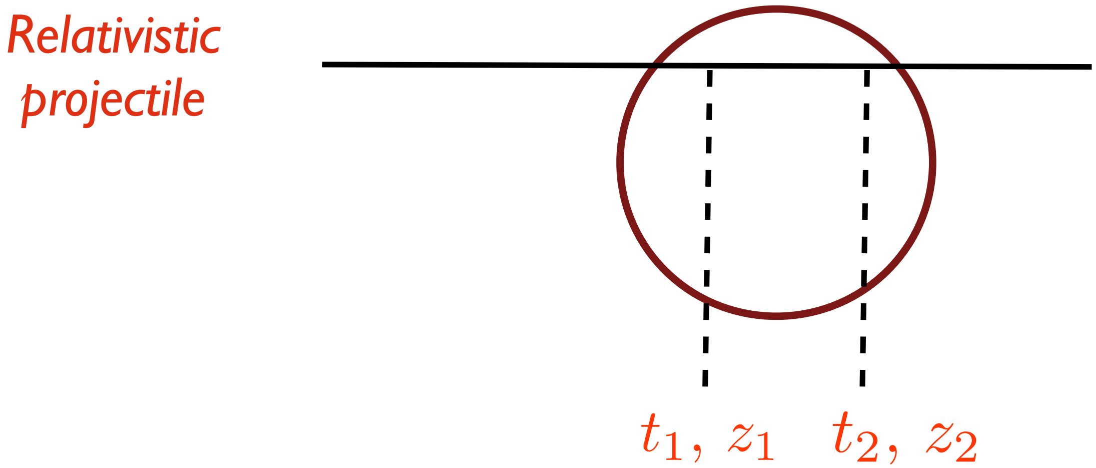
for any vector $a_\mu = (a_+, a_-, a_t)$,

$$\alpha \equiv \frac{A p_-^{\mathrm{int}}}{P_-^A}, \; p_t \equiv p_t^{\mathrm{int}} = -p_t^{\mathrm{rec}}$$



➠ excellent resolution in $\alpha = \alpha_1 + \alpha_2 - \alpha_{inc.nucl.}$

$\Rightarrow$ High energy process develops along the light cone.



$$t_1 - z_1 = t_2 - z_2$$

Similar to the perturbative QCD the amplitudes of the processes are expressed through the wave functions on the light cone. *Note: in general no benefit for using LC for low energy processes.*

However for low momentum component in nuclei and for 2N SRC correspondence with nonrelativistic wave functions is unambiguous and rather simple FS76

High energy processes are dominated by interactions near light cone- hence their cross sections are simply expressed through light cone wave functions.

$$\rho_{\mathrm{A}}^{\mathrm{p}}(\alpha,k_\perp) = \int \psi^2(\alpha_1\ldots\alpha_A,k_{1\perp}\ldots k_{A\perp})\prod_{i=1}^{A}\frac{\mathrm{d}\alpha_i}{\alpha_i}\mathrm{d}^2k_{i\perp}\delta\left(1-\frac{\sum\alpha_i}{A}\right)$$
$$\times\ \delta\left(\sum_{i=1}^{A}k_{i\perp}\right)\sum_{i=1}^{Z}\alpha_i\delta(\alpha-\alpha_i)\delta(k_{i\perp}-k_\perp).$$

Single nucleon light cone density matrix

$$\int_0^A \rho_{\mathrm{A}}^{\mathrm{N}}(\alpha,k_\perp)\frac{\mathrm{d}\alpha}{\alpha}\mathrm{d}^2k_\perp = A$$

$$\int_0^A \alpha\rho_{\mathrm{A}}^{\mathrm{N}}(\alpha,k_\perp)\frac{\mathrm{d}\alpha}{\alpha}\mathrm{d}^2k_\perp = \int_0^A \rho_{\mathrm{A}}^{\mathrm{N}}(\alpha,k_\perp)\frac{\mathrm{d}\alpha}{\alpha}\mathrm{d}^2k_\perp\frac{\sum\alpha_i}{A} = A.$$

Example
$$F_{2A}(x,Q^2) = \sum_{\mathrm{N=p,n}}\int F_{2\mathrm{N}}(x/\alpha,Q^2)\rho_A^{\mathrm{N}}(\alpha,k_{\mathrm{t}})\frac{\mathrm{d}\alpha}{\alpha}\mathrm{d}^2k_{\mathrm{t}}.$$

$$\frac{d\sigma^{h+A\to h'+N'+(A-1)}}{dt}=\int\frac{d\alpha}{\alpha}\,dp_t^2\,\rho_A^N(\alpha,p_t)\,\frac{d\sigma^{h+N\to h'+N'}}{dt}(s',t)\,\theta(s'+t-2m_N^2-2m_h^2)\,.$$

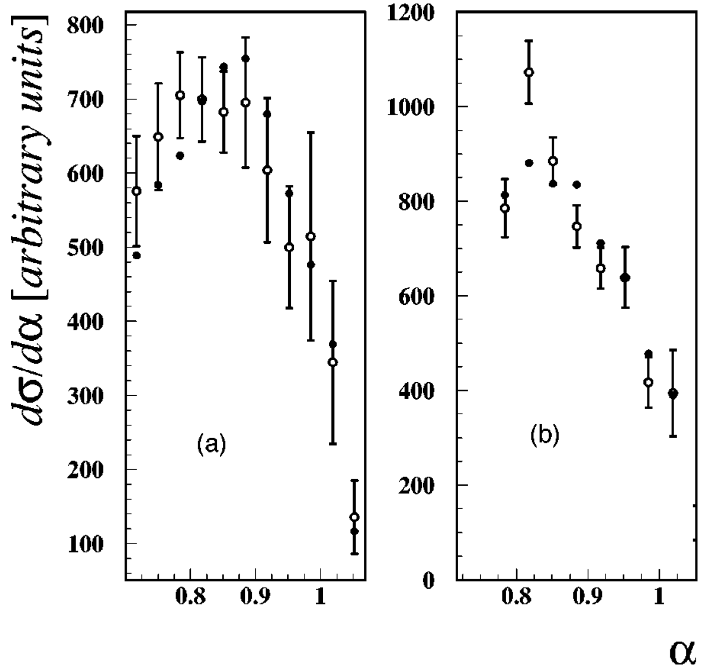
where s' is invariant energy of the h'N system

$$s'=2E_h m_A\frac{\alpha}{A}+m_h^2+\frac{\alpha}{A}\left(m_A^2-\frac{M_{\mathrm{res}}^2+p_t^2}{1-\alpha/A}\right).$$

Cross section of large angle pp scattering is $\propto s^{-10}$

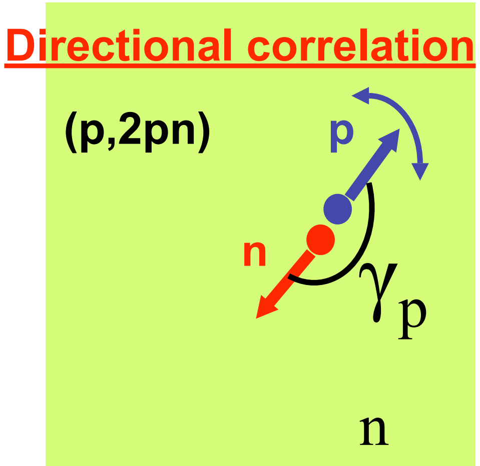
$\Rightarrow$ Strong enhancement of the scattering off forward moving (α <0.8) nucleons which are likely to belong to SRC

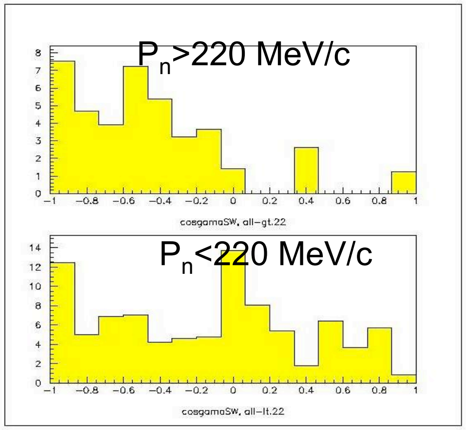
This prediction agrees well with a detailed analysis of the EVA data by I.Yaron, E.Piasetzky, M.Sargsian and F&S 2002 within 2N SRC model including fsi effects, etc

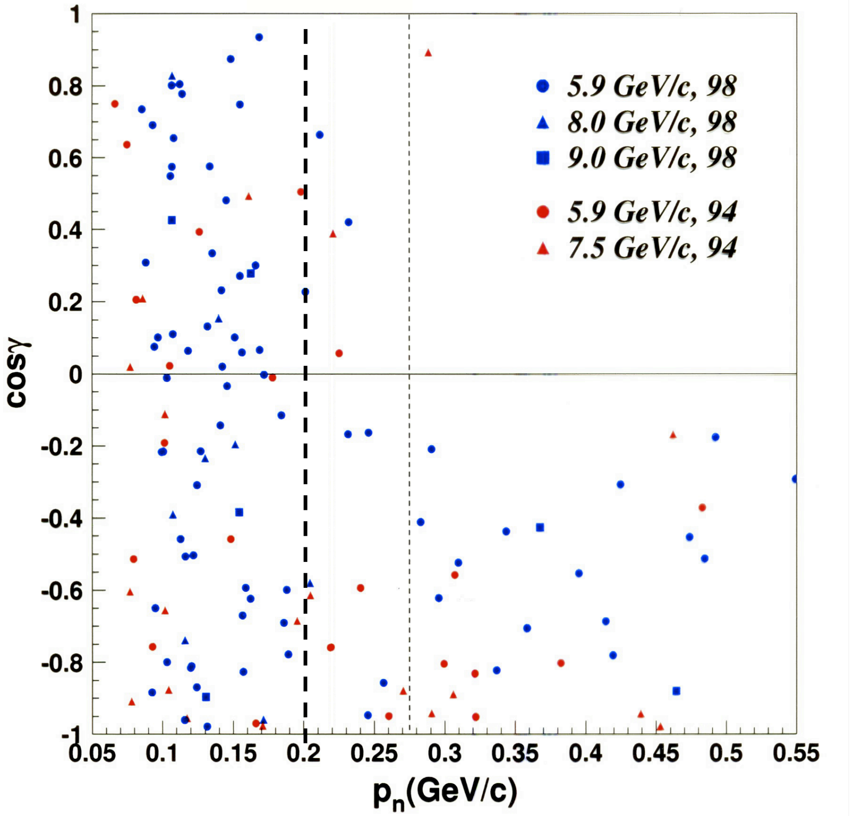


A comparison between calculated α distributions (●) and the experimental data (○) at 5.9 GeV/c (a) and 7.5 GeV/c (b).

(p,2p) data do find high momentum component - is it mostly due to 2N SRC?







The EVA/BNL collaboration

Probability to emit a neutron in (p,2p):

$$\left.\frac{\text{Triple rate- (p,ppn)}}{\text{Double rate (p,2p)}}\right|_{\text{corrected for detector efficiency}} = \begin{cases} \text{For } P_p > P_F,\ P_n > P_F \\ (49 \pm 13)\ \% \\ \text{For } P_p < P_F,\ P_n > P_F \\ 0 \end{cases}$$

This is a lower limit on the coincidence rate since no estimate was made of the correction due to the angular acceptance of the neutron detector (requires a theoretical model for neutron production).

A. Tang et al Phys. Rev. Lett. 90 ,042301 (2003) :

“ Therefore we conclude that 2N-SRC must be a major source of high-momentum nucleons in nuclei.”

New analysis (Piasetzky et al 06):

- Develop a model for the decay function based on 2N SRC - similar to the model for the spectral function: convolution of (deuteron wave function)^2 and c.m. of NN pair

$$D_{np} = \rho_{src}(\mathrm{P}_{\mathrm{rel}})\rho_{CM}(P_{CM}) = a(A)\psi_D^2(\mathrm{P}_{\mathrm{rel}})\, e^{-\frac{P_{CM}^2}{2\sigma^2}}$$

The measured longitudinal CM momentum of the correlated pair is:

$\sigma = 143 \pm 17$ MeV/c. **(PRL 90(2003)042301)**

σ is very similar to one calculated by **Ciofi PRC 44(1991)7 in 2N SRC model** and used to model spectral function

- Introduced a small correction for absorption been larger for (p, 2pn) than (p,2p) (correction is small since scattering off the edge by virtue of large absorption in (p,2p))

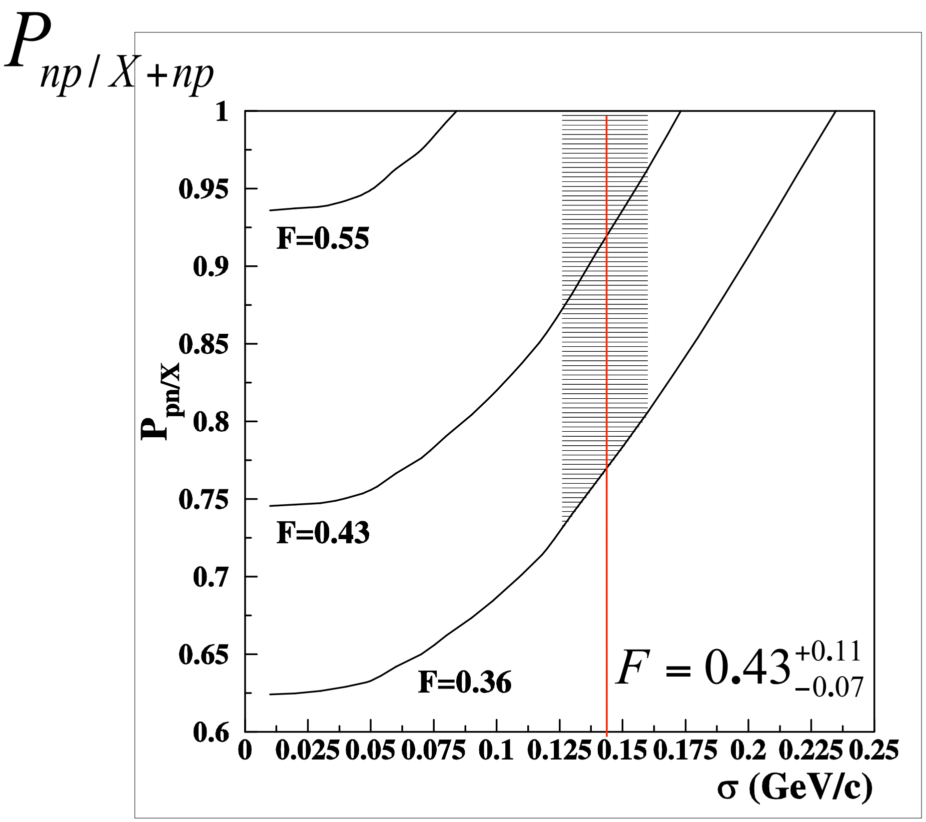
- A stricter cut on the nucleon momenta: p_{min}=275 MeV

$$F = 43^{+11}_{-7}\%$$

The errors are dominated by the statistics of the triple coincidence measurement.

Define the probability of finding a np-SRC pair: $P_{np/X+np}$

X includes pp pairs, 3N SRC, scattering off mean field



$$P_{np/X+np} = 0.92^{+0.08}_{-0.18}$$

np-SRC dominance:

$P_{np/X+np} > 74\%$

First experimental information on $P_{np/X+np}$

Increase of $P_{np/X+np}$ due to Fermi motion of the pair - typical trigger bias effect - selecting a fast nucleon triggers on the pairs moving in the same direction and hence having recoil nucleon with smaller momentum which has a larger chance to be missed.

What is a naive expectation for $P_{np/X+np}$?

Wigner SU(4) symmetry - probabilities of pp, pn, nn pairs are related as

$$P_{pp}:P_{pn}:P_{nn}=1:4:1$$

In coincidence rate pp pairs enter with a factor of 2

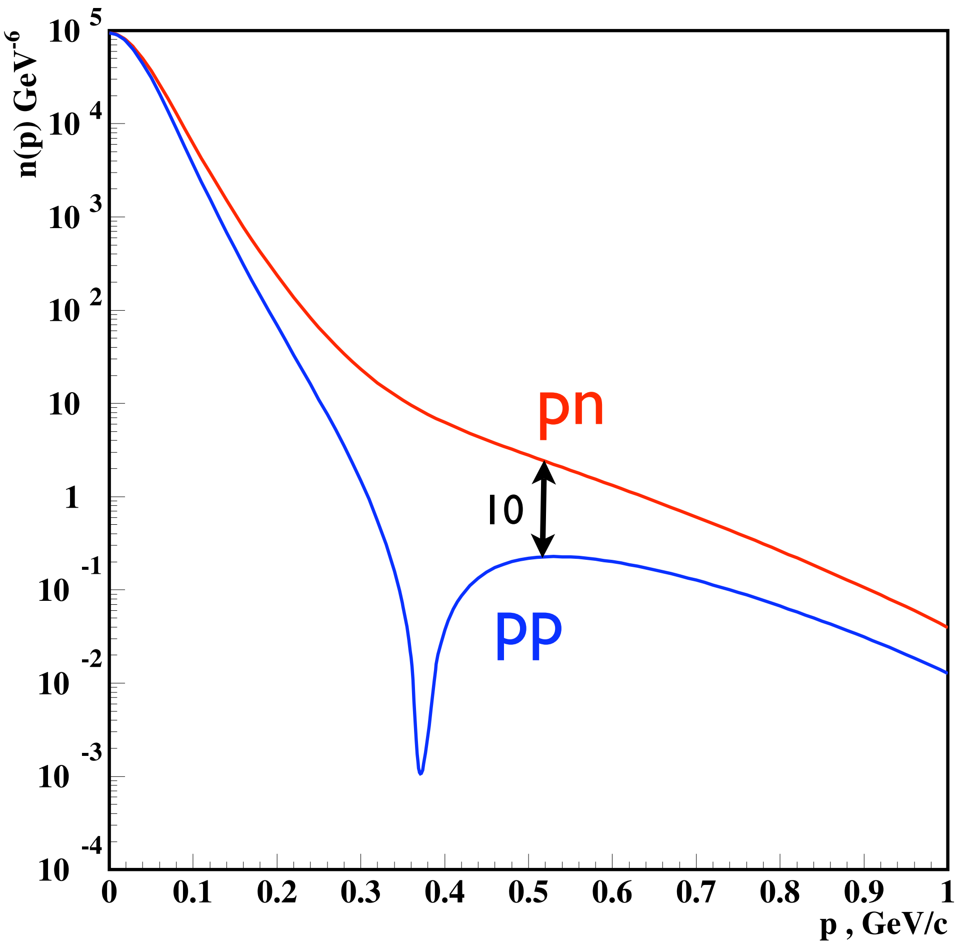
➠ $P_{np/X+np}=2/3$ → **Data indicate Enhancement of pn SRC**

However tensor correlations are strongly enhanced according to nonrel. calculations of n(k). Scalar ones contribute fraction λ~ 10-20% to n(k) for discussed momentum range. Assuming that tensor correlations are predominantly pn correlations (likely but not proven), and scalar SRC are isotriplet

$$P_{pp/pp+np}= \frac{2}{3}\frac{\lambda}{1+\lambda} = .06 \div .11$$

Studies of pp/pn yields will allow to discriminate between different models of nuclei/ NN interaction at high nucleon densities.

The pp/pn ratio is likely to depend on the momentum of the struck nucleon. For example for ^{3}He for a pn/pp pair with the third nucleon at rest. Fermi motion of the pair smears the momentum dependence of the ratio (M.Sargsian)



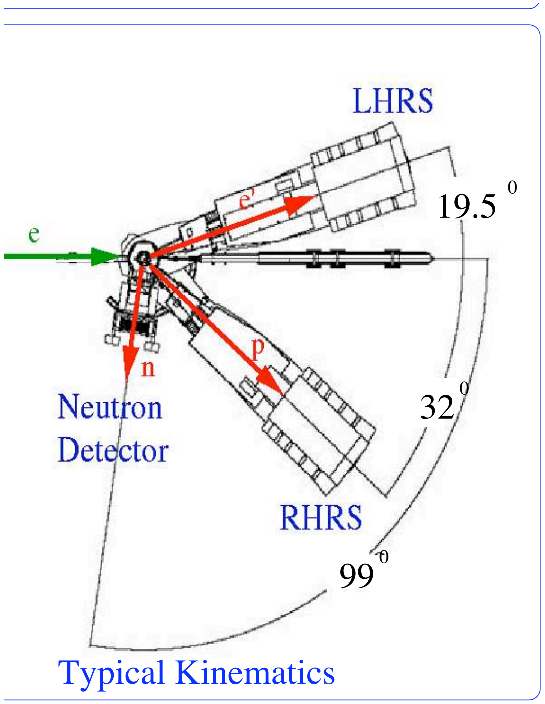
ΣΣ  E850 provided the first direct observation of 2N SRC in nucle

 Established strong dominance of pn SRC correlations

 Large pn/pp qualitatively consistent with dominance of tensor forces in the high momentum component

A triple coincidence measurement of the (e, e’pn) and (e, e’pp) reactions

Jlab / Hall A EXP 01-015



Large energy/momentum transfer ~ 1GeV is provided by electron instead of proton

Preliminary result for $P_{pp/pp+Xp}$= 8±2%
Confirms dominance of pn correlations

Direct measurement of R=σ(e,e'pp)/σ(e,e' pn) finds R << 1

Proton with momentum 600> p> 300 MeV/c

belongs to a pn correlation with probability $94\% \geq P_{pn} \geq 74\%$
belongs to a pp correlation with probability $8\% \geq P_{pp} \geq 6\%$

31>"# of pn pairs"/"# of pp pairs" >18.5

Compare to SU(4) expectation of 4

Future detailed comparisons of (p,2pn) and (e,e'pn) data - important test of universality of the decay function, understanding of interaction mechanism

Previous less direct evidences for SRC in nuclei

The simplest reaction to check dominance of 2N, 3N SRC
and to measure absolute probability of SRC is A(e,e') at x>1

Define $x=Q^2/2q_0m_N$

x=1 is **exact** kinematic limit **for all Q^2** for the scattering off a free nucleon

x=2 (x=3) is **exact** kinematic limit **for all Q^2** for the scattering off a A=2(A=3) system (up to <1% correction due to nuclear binding

$$W^2 = Q^2 + 2q_0M_A + M_A^2 \geq M_A^2$$

$$\implies Q^2 + 2q_0M_A \geq 0$$

$$\implies x \leq M_A/m_N$$

Scaling of the ratios of (e,e') cross sections

Qualitative idea - to absorb a large Q at x>j at least j nucleons should come close together. For each configuration wave function is determined by local properties and hence universal. In the region where scattering of j nucleons is allowed, scattering off j+1 is a small correction.

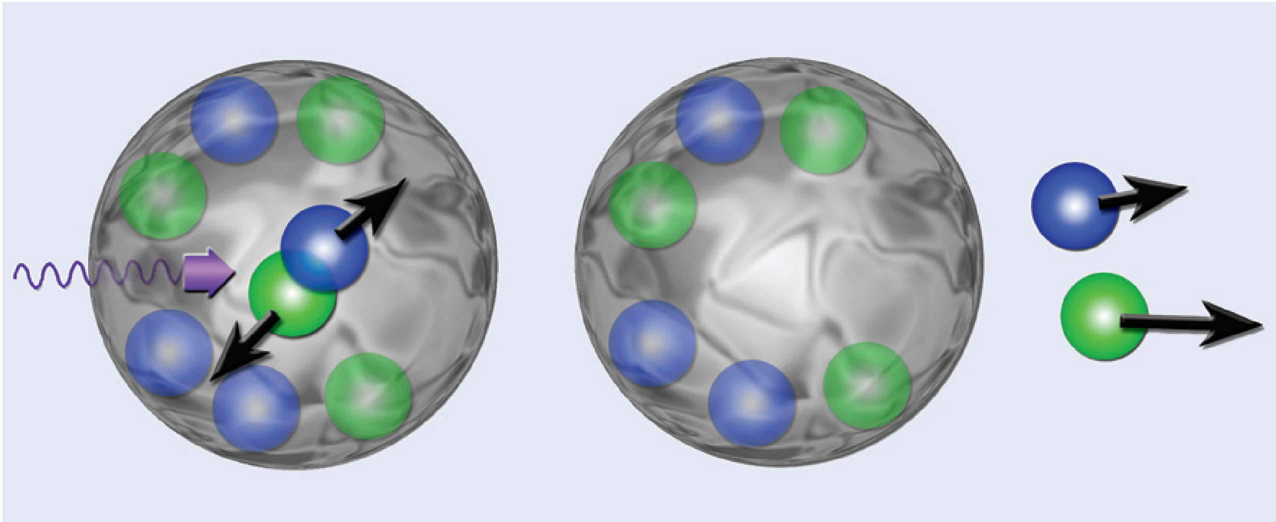
$$\sigma(A) = \sum_{j=2} A\frac{a_j(A)}{j}\sigma(j) \qquad a_j(A) \propto \frac{1}{A}\int d^3r \rho_A^j(r)$$

$$a_2 \sim A^{0.15}; \qquad a_3 \sim A^{0.22}; \qquad a_4 \sim A^{0.27}$$ ***for A> 12***

$$\sigma_{eA}(x,Q^2)/\sigma_{eC}(x,Q^2)\big|_{j-1<x<j} = (A/C)a_j(A)/a_j(C).$$

FSI is present in the interaction with j -nucleons, but not with the rest of the system as they are far away, while j nucleons have a small invariant mass in the final state. However it is also practically universal (NN interaction is practically the same for I=0,1 except very close to the threshold).

Scattering off a two-nucleon correlation, x>1.5

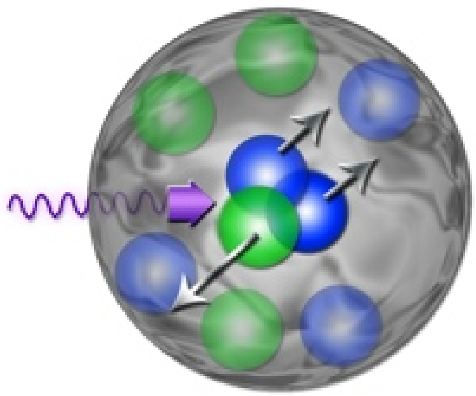


Before absorption of the photon

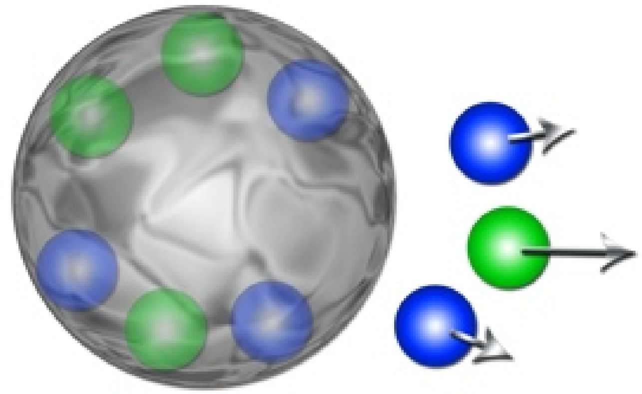
After absorption

W for γ^* scattering off two nucleon system is well below the threshold for production of Δ-isobar. Hence inelastic processes $eN \to eX$ are strongly suppressed. For same reason scattering off 6q configurations (even if they are present in nuclei) does not contribute in this kinematics

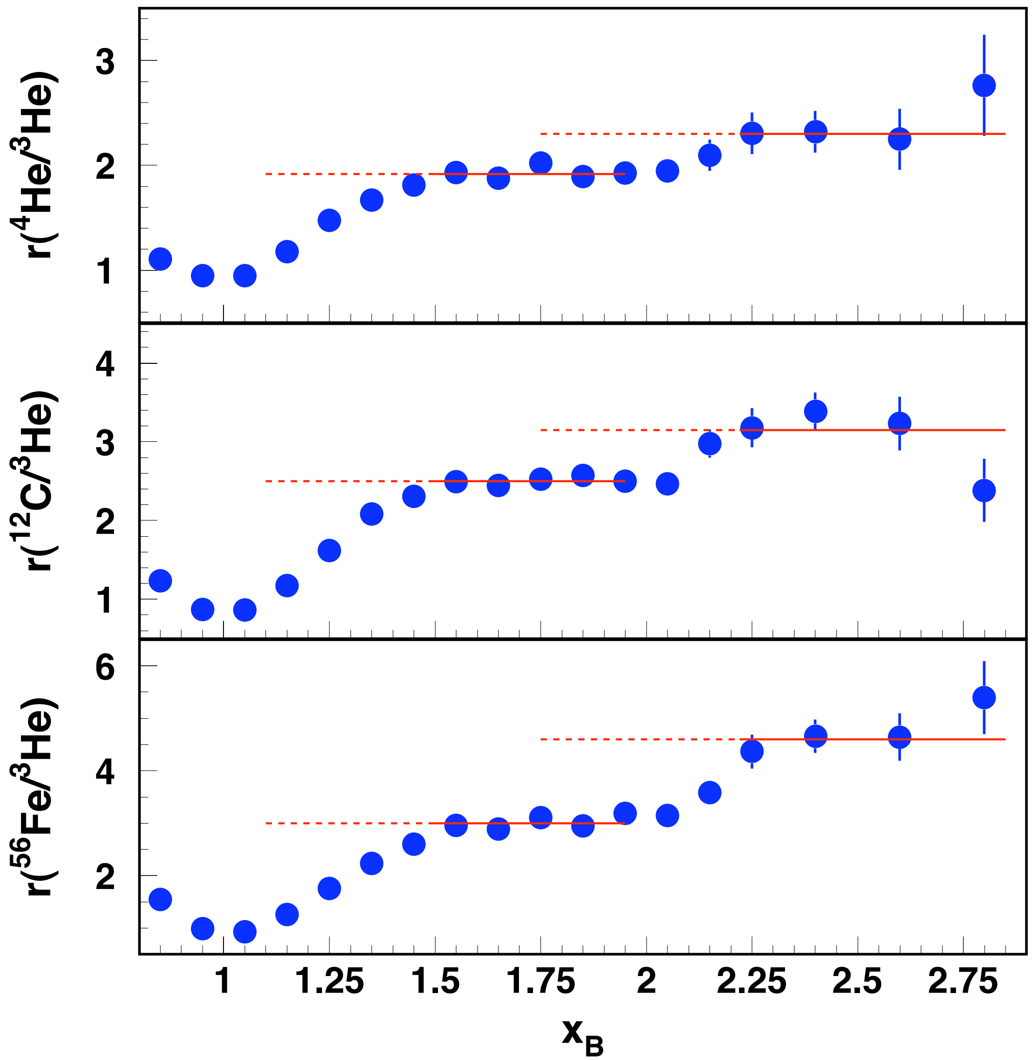
Scattering off a three-nucleon correlation, x>2.25



Before absorption of the photon



After absorption



New Jlab data from Hall B.

$Q^2 > 1.5$ GeV^2

Fe/C ratios for x~1.75, x~2.5 agree within experimental errors with our prediction - density based estimate:

$$a_2 = (A_1/A_2)^{0.15}$$
$$a_3 = (A_1/A_2)^{0.22}$$

The best evidence for presence of 3N SRC. One probes here interaction at internucleon distances <1.2 fm corresponding to local matter densities $\geq 5\rho_0$ which is comparable to those in the cores of neutron stars!!!

FSI of struck nucleon with slow nucleons at x> 1.3

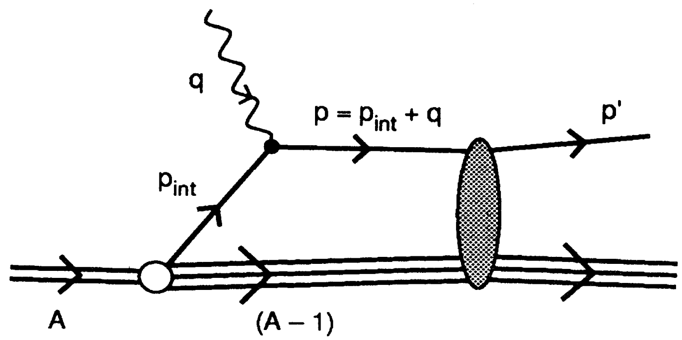


FIG. 8. Reaction diagram for nucleon knockout including final state interactions.

The struck nucleon has virtuality $\Delta M^2 = m_N^2 - p^2$

where $p=p^{int}+q$

If $|p^{int}|$ is small, $\Delta M^2 \approx m_N^2 - Q^2\left(-1+\frac{1}{x}\right) - (p^{\rm int})^2$

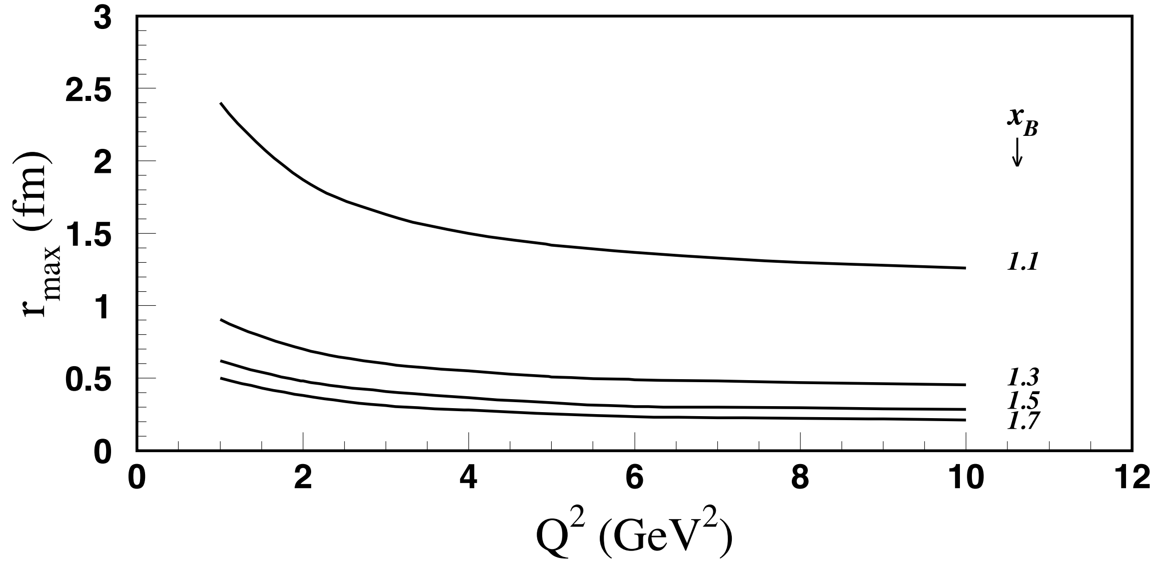
is large. Hence it is not legitimate to apply semiclassical approximation for the calculation of the Green function.

Statements in the literature that FSI with low momentum nucleon is large and strongly enhances the cross section in the discussed limit (O.Benhar et al) are due to neglect of these effects.

Switch to old fashioned non-covariant formalism where energy is not conserved and momentum is conserved to determine what at what distances, r, fsi can contribute

$r \approx \frac{1}{\Delta E v}$ where v is the struck nucleon velocity v=p/E,

$$\Delta E = -q_o - M_A + \sqrt{(m^2 + (q + p^{\rm int})^2} + \sqrt{M^{*2}_{A-1} + (p^{\rm int})^2}.$$



Distances for which FSI of a struck nucleon with momentum less than the Fermi momentum can contribute to the inclusive cross section

Only fsi close to mass shell when momentum of the struck nucleon is close to one for the scattering off a correlation. At very large Q - light-cone fraction of the struck nucleon should be close to x (similar to the parton model situation) - only for these nucleons fsi can contribute to the total cross section, though even this fsi is suppressed.

History of study of the scaling ratios.

- ☺ Prediction FS 80
- First evidence from 3He/D - FS81
- Al/D - provided by S.Rock , curves by Misak , 88
- Evidence for x> 2 scaling for 4He /3He, 88
- Finally extracted data from SLAC NA3 experiment together with Donal Day and Misak Sargsian 93
- A/^{3}He, 2>x>1, - Jlab 2004
- A/^{3}He, 3>x>2, - Jlab 2005

$W - M_D \leq 50\, MeV$

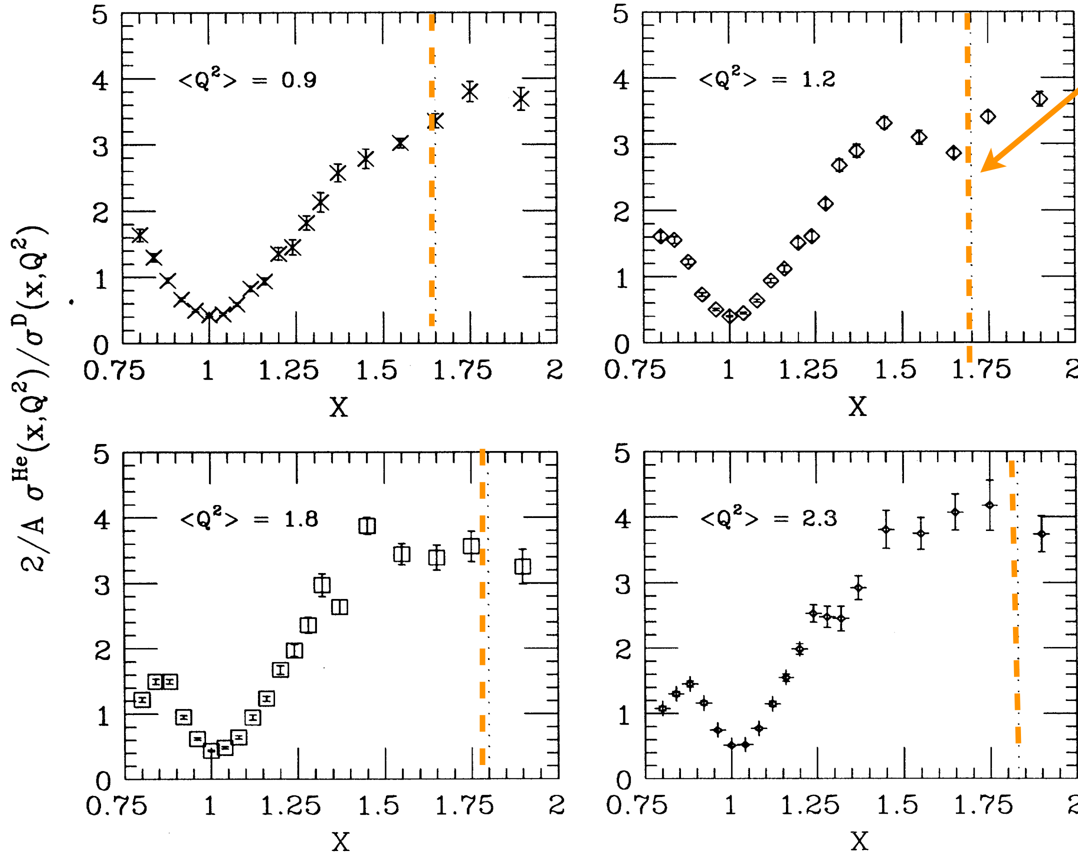


FIG. 1. Ratio $\frac{2}{A}\frac{\sigma_A(x,Q^2)}{\sigma_D(x,Q^2)}$ for ^{4}He at four different Q^2's. The average Q^2 is given for each frame. To the right of the vertical dashed line are those data which correspond to a final state less 50 MeV greater than the deuteron rest mass.

Masses of NN system produced in the process are small - strong suppression of isobar, 6q degrees of freedom.

Assuming in the spirit of the dominance of the two nucleon correlations in the spectral function that the mean value of excitation energy corresponds to the scattering off the 2N SRC pair at rest we can determine mean value of the light cone fraction at which scattering happens

$$\boxed{\alpha_{tn} = 2 - \frac{q_- + 2m}{2m}\left(1 + \frac{\sqrt{W^2 - 4m^2}}{W}\right)}$$

FS88

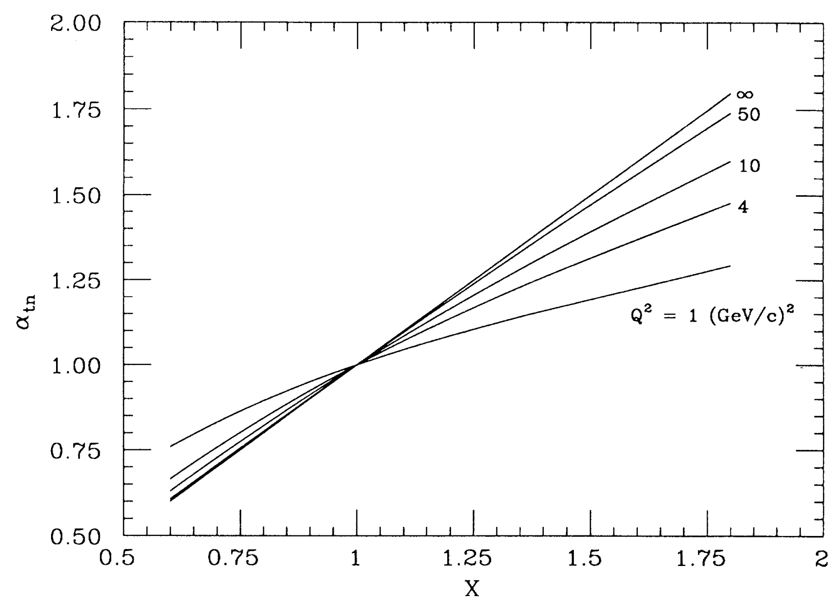


FIG. 5. α_{tn} against x for $Q^2 = 1, 4, 10, 50, \infty$. At $Q^2 = \infty$, $\alpha_{tn} = x$.

$$\frac{\sigma_{A_1}(x,Q^2)}{\sigma_{A_2}(x,Q^2)} = \frac{\int \rho_{A_1}(\alpha_{tn},p_t)d^2p_t}{\int \rho_{A_2}(\alpha_{tn},p_t)d^2p_t}.$$

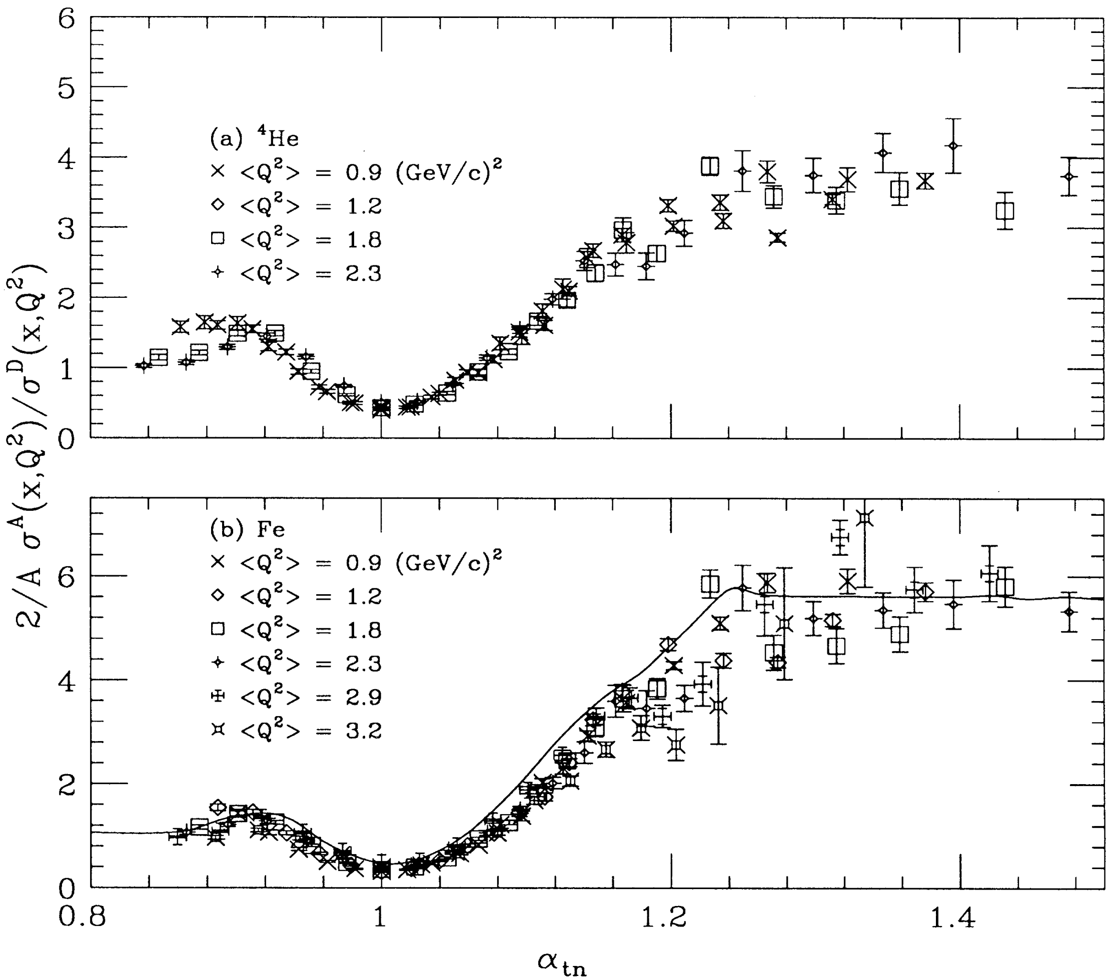


FIG. 6. Ratio $\frac{2}{A}\frac{\sigma_{Fe}(x,Q^2)}{\sigma_D(x,Q^2)}$ for ^{56}Fe for six different Q^2's plotted together against the scaling variable α_{tn}. The solid line is a calculation based on the nuclear spectral function of Ref. [22] (see Sec. VI).

Day, L.Frankfurt, Sargsian, MS, 93

$$a_2(^3\mathrm{He}) = 1.7(0.3)\ ,$$
$$a_2(^4\mathrm{He}) = 3.3(0.5)\ ,$$
$$a_2(^{12}\mathrm{C}) = 5.0(0.5)\ ,$$
$$a_2(^{27}\mathrm{Al}) = 5.3(0.6)\ ,$$
$$a_2(^{56}\mathrm{Fe}) = 5.2(0.9)\ ,$$
$$a_2(^{197}\mathrm{Au}) = 4.8(0.7)\ ,$$

Significant uncertainties in absolute scale

	$a_2(A/^3\mathrm{He})$	$a_{2N}(A)(\%)$	$a_3(A/^3\mathrm{He})$	$a_{3N}(A)(\%)$
$^3\mathrm{He}$	1	$8.0\pm0.0\pm1.6$	1	$0.18\pm0.00\pm0.06$
$^4\mathrm{He}$	$1.96\pm0.01\pm0.03$	$15.6\pm0.1\pm3.2$	$2.33\pm0.12\pm0.04$	$0.42\pm0.02\pm0.14$
$^{12}\mathrm{C}$	$2.51\pm0.01\pm0.15$	$20.0\pm0.1\pm4.4$	$3.18\pm0.14\pm0.19$	$0.56\pm0.03\pm0.21$
$^{56}\mathrm{Fe}$	$3.00\pm0.01\pm0.18$	$24.0\pm0.1\pm5.3$	$4.63\pm0.19\pm0.27$	$0.83\pm0.03\pm0.27$

K.Egiyan, et al 2005

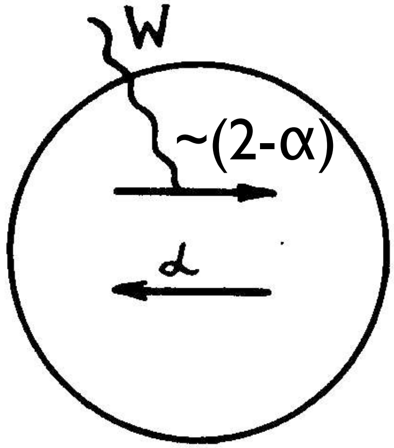
Amazingly good agreement between two analyses for a_2 (A)

Compare also to the analysis of EVA data on (p,2p) - $a_2(C) \sim 5$

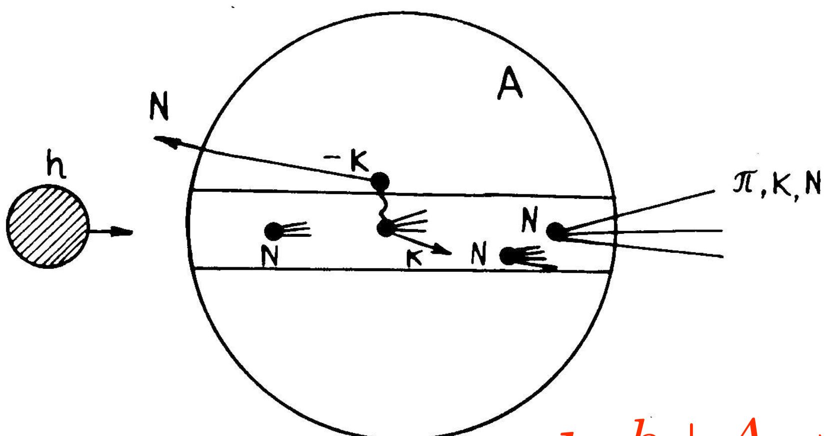
Yaron et al 02

We started studies of structure and ways to probe short range correlations - SRC in A>2 nuclei back in 77 when no electron data were available. We suggested that phenomenon of production of fast backward (FB) nucleons and mesons*) is due to the interaction with SRC

*) We wanted to name them backfires but were afraid because of censorship problems.



Production of a fast backward nucleon in the W* scattering from the two-nucleon correlation spectator mechanism.

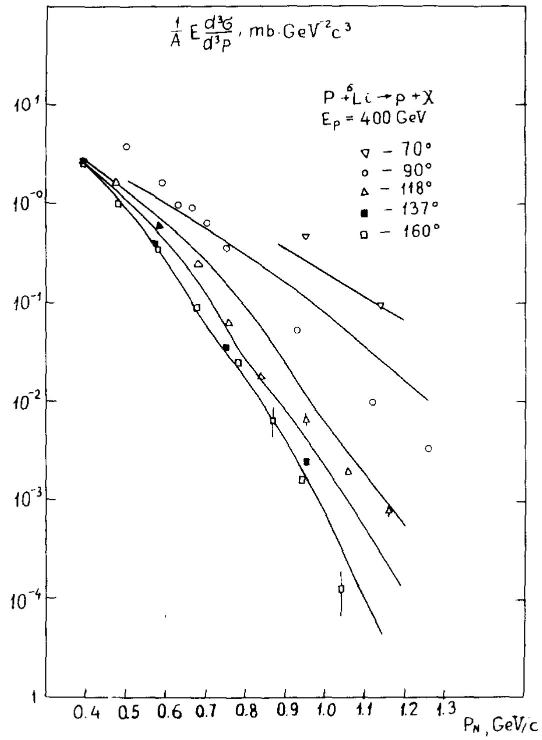


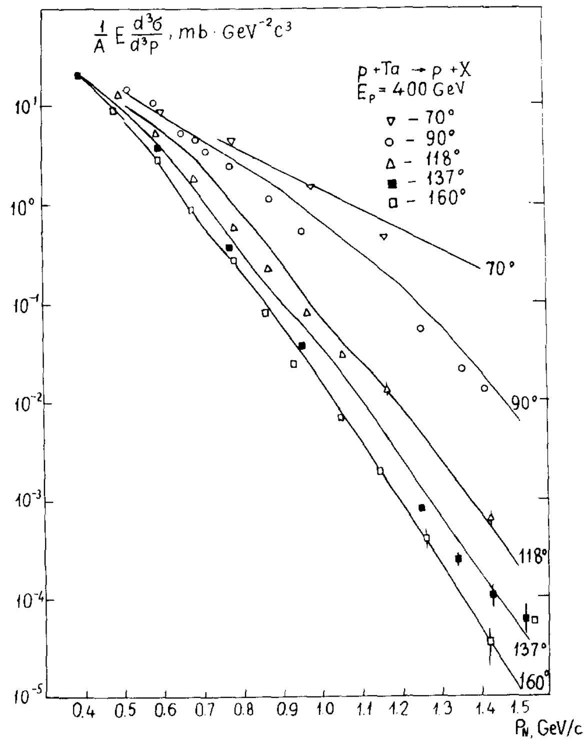
Production of a fast backward nucleon in the hadron - nucleus scattering

$$G_h^{A/N}(\alpha, p_t) \equiv \frac{d\sigma^{h+A\to N+X}}{\frac{d\alpha d^2 p_t}{\alpha}} = \kappa_h A \sigma_{in}^{hN} \rho_A^N(\alpha, p_t)$$

where factor κ_h accounts for local screening effects

Plenty of data were described using few nucleon SRC approximation with 3N, 4N correlations dominating in certain kinematic ranges. Strength of 2N correlations is similar to the one found in (e,e'),(p,2p)





Comparison of few nucleon SRC approximation with pA data at E_p^{inc}=400 GeV

Observations of (p,2pn) &(e,e') at x>1 confirm the origin of SRC as the dominant source of the fast backward nucleons

Summary

Recent experiments confirmed expectations of large practically universal SRC in nuclei - 25% probability for two nucleon SRC in heavy enough nuclei with dominant contribution due to pn correlations.

First extensive evidence for presence of 3N short range correlations in nuclei

Dominance of nucleonic degrees of freedom in SRC

The recent experiments confirmed merits of high momentum transfer probes for study of SRC. Further studies are necessary, preferably both leptonic and hadronic:

Studies of forward - backward correlations for a range of light nuclei $^3He/^4He(e,e')$ pp/pn at Jlab at $Q^2=2 \div 4$ GeV^2. A-dependence of the pp/pn ratio, its dependence on momentum of hit nucleon. Looking for effects of 3N correlations in A(e,e' p +2 backward nucleons). Reminder: for the neutron star dynamics mostly isotriplet nn, nnn,.. SRC are relevant.

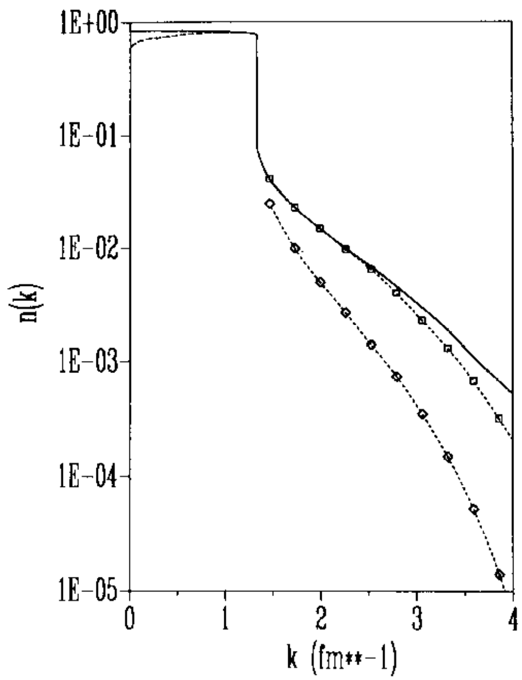
Tagged structure functions: $e + {}^2H \rightarrow e$ + "backward nucleon + X

$e+A \rightarrow e$ +forward p + Backward isobars, N*'s +X,...

Use of the hadronic facilities - J-PARC, GSI, FNAL (?)

Calculation of the nuclear LC wave functions, spectral functions and decay functions for A>2

Two supplementary slides.

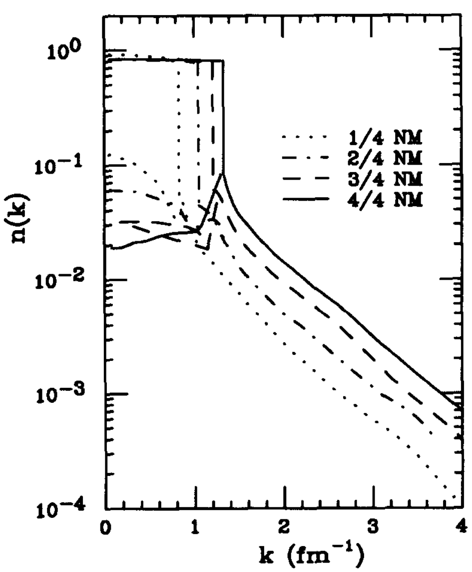


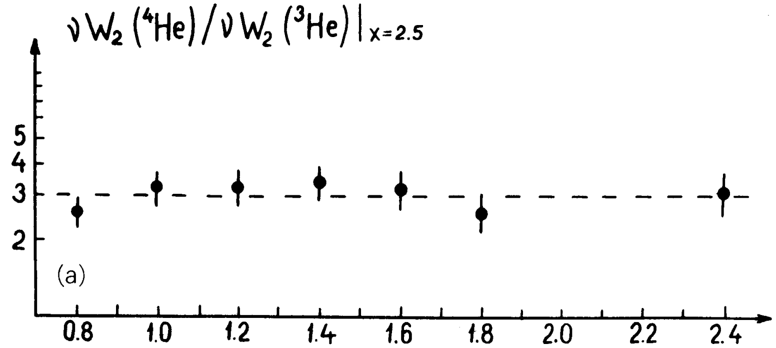
n(k) for nuclear matter with a cut on the excitation energy, E

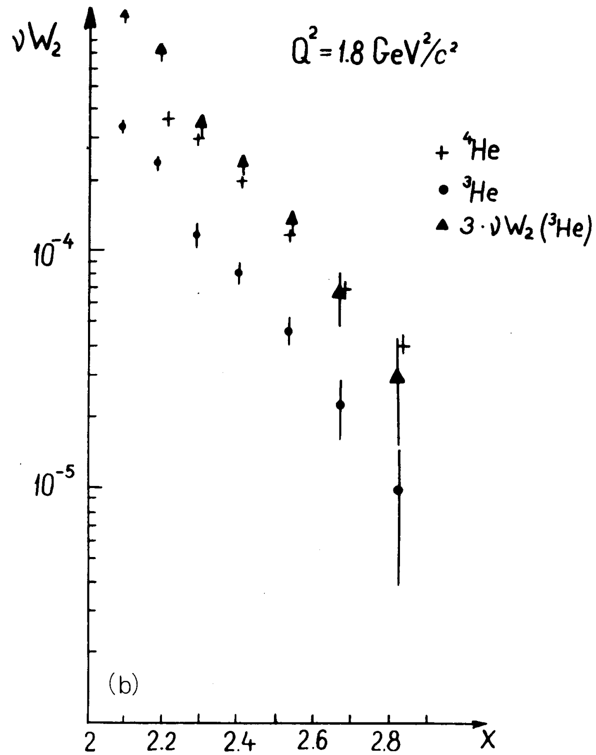
E< 300 MeV

E< 100 MeV

Benhar et al 1989 - 1994







Evidence for scaling of 4He/3He ratios at x> 2 from FS88 analysis of the SLAC data

$$\left.\frac{\sigma_{e\ ^4\mathrm{He}}(x,Q^2)}{\sigma_{e\ ^3\mathrm{He}}(x,Q^2)}\right|_{2<x<3} \simeq 2\frac{\sigma(\mathrm{e}\text{“ppn”})+\sigma(\mathrm{e}\text{“pnn”})}{\sigma(\mathrm{e}\text{“ppn”})} = 2+2\frac{\sigma(\mathrm{e}\text{“pnn”})}{\sigma(\mathrm{e}\text{“ppn”})} \simeq 3$$