C. CIOFI degli ATTI

Short Range Correlations and their impact on nuclear and particle physics and astrophysics: recent advances and possible studies at J-PARC

KEK Theory Center workshop
on
Short-range correlations and tensor structure at J-PARC

700 Years 1308 -2008
Università degli Studi di Perugia
PHYSICS DEPARTMENT

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1 Introduction: two recent "popular" papers on short range correlations (SRC)

CERN COURIER

Jan 27, 2009

Protons and neutrons cosy up in nuclei and neutron stars

Douglas Higinbotham, Eli Piasetzky and Mark Strikman investigate recent measurements that have probed the cold, dense nuclear systems of nucleons comparable to those of neutron stars.

Résumé

Rapprochement entre protons et neutrons dans les noyaux et les étoiles à neutrons

future exclusive experiments will focus on ^{4}He (a nucleus where both full and mean-field calculations can come together) and push the limits of the recoil momentum to extend our understanding of the repulsive part of the nucleon-nucleon potential.

Douglas Higinbotham, Jefferson Laboratory, Eli Piasetzky, Tel Aviv University and Mark Strikman, Penn State University.

Further reading

M Alvioli *et al*. 2008 **Phys. Rev. Lett. 100** 162503.

K S Egiyan *et al*. 2006 **Phys. Rev. Lett. 96** 082501.

E Piasetzky *et al*. 2006 **Phys. Rev. Lett. 97** 162504.

M Sargsian *et al*. 2005 **Phys. Rev. C 71** 044615.

R Schiavilla *et al*. 2007 **Phys. Rev. Lett. 98** 132501.

R Subedi *et al*. 2008 **Science 320** 1475.

SCIENCE 320, 1476 (2008)

R. SUBEDI et al Probing Cold Dense Nuclear Matter

The protons and neutrons in a nucleus can form strongly correlated nucleon pairs. Scattering experiments, in which a proton is knocked out of the nucleus with high-momentum transfer and high missing momentum, show that in carbon-12 the neutron-proton pairs are nearly 20 times as prevalent as proton-proton pairs and, by inference, neutron-neutron pairs. This difference between the types of pairs is due to the nature of the strong force and has implications for understanding cold dense nuclear systems such as neutron stars.

2. THE STANDARD MODEL OF NUCLEI

$$\left[-\frac{\hbar^2}{2m}\sum_i \hat{\nabla}_i^2 + \sum_{i<j}\hat{v}(i,j) + \sum_{i<j<k}\hat{v}(i,j,k) + \ldots\right]\Psi_o = E_o\Psi_0$$

$$\hat{v}_{ij}(x_i,x_j) = \sum_n v^{(n)}(r_{ij})\hat{\mathcal{O}}_{ij}^{(n)} \qquad r_{ij} \equiv |\mathbf{r}_i - \mathbf{r}_j|$$

$$\hat{\mathcal{O}}_{ij}^{(n)} = \left[1,\, \boldsymbol{\sigma}_i\cdot\boldsymbol{\sigma}_j\,,\, \hat{S}_{ij}\,,\, (\boldsymbol{L}\cdot\boldsymbol{S})_{ij}\,,\, \ldots\right] \otimes \left[1,\, \boldsymbol{\tau}_i\cdot\boldsymbol{\tau}_j\right].$$

short-range repulsion (common to many systems)

- intermediate- to long-range tensor character (unique to nuclei)

THE MEAN FIELD APPROXIMATION

$$\left[-\frac{\hbar^2}{2\,m}\sum_i \hat{\nabla}_i^2 + \sum_{i<j} \hat{v}_{ij}\right] \Psi_o \,=\, E_o\,\Psi_o$$

$$\Downarrow$$

$$\left[-\frac{\hbar^2}{2\,m}\sum_i \hat{\nabla}_i^2 + \sum_i \,V_i\right] \Phi_o \,=\, \epsilon_o\,\Phi_o$$

Independent particle motion → Shell Model

Mean field or Shell Model: nucleons occupy all available states below the Fermi level; all states above the Fermi level are empty. Great success (magic numbers, magnetic moments, low excitation levels, etc). Recent developments: establish the limits of validity by advanced solution of the nuclear many-body problem.

THE "EXACT" MANY-BODY SOLUTION

Recent developments towards the exact solution of

$$\hat{\mathbf{H}}\,\Psi_o = E_n\,\Psi_o \;, \quad \text{with} \quad \hat{v}_{ij} = \sum_n v^{(n)}(r_{ij})\,\hat{\mathcal{O}}_{ij}^{(n)}$$

The same operatorial dependence appearing in $\hat{v}_{ij}$ is cast onto the trial function Ψ_o:

$$\Psi_o = \hat{\mathbf{F}}\,\Phi_o$$

where Φ_o is the ***mean-field*** wave function and

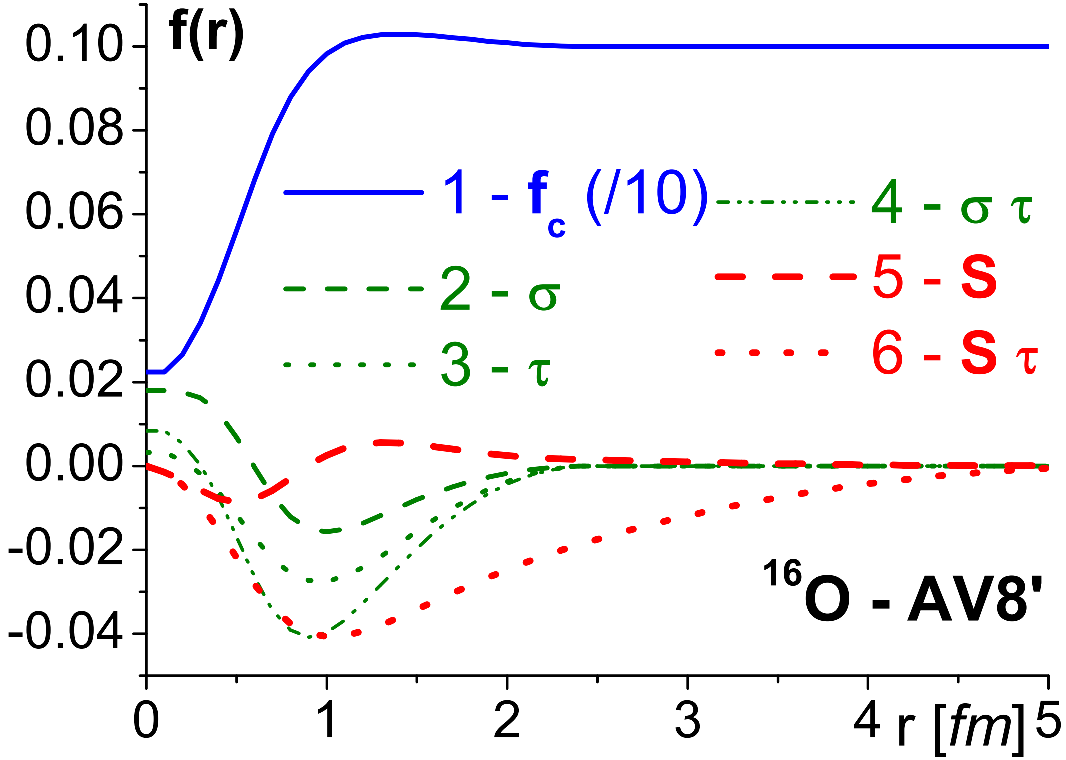
$$\hat{\mathbf{F}} = \hat{S}\prod_{i<j}\hat{f}_{ij} = \hat{S}\prod_{i<j}\sum_n f^{(n)}(r_{ij})\,\hat{\mathcal{O}}_{ij}^{(n)}$$

is a ***correlation*** operator.

Variational monte carlo (Urbana Group)

Cluster expansion techniques (Here:Alvioli, Cda, Morita)

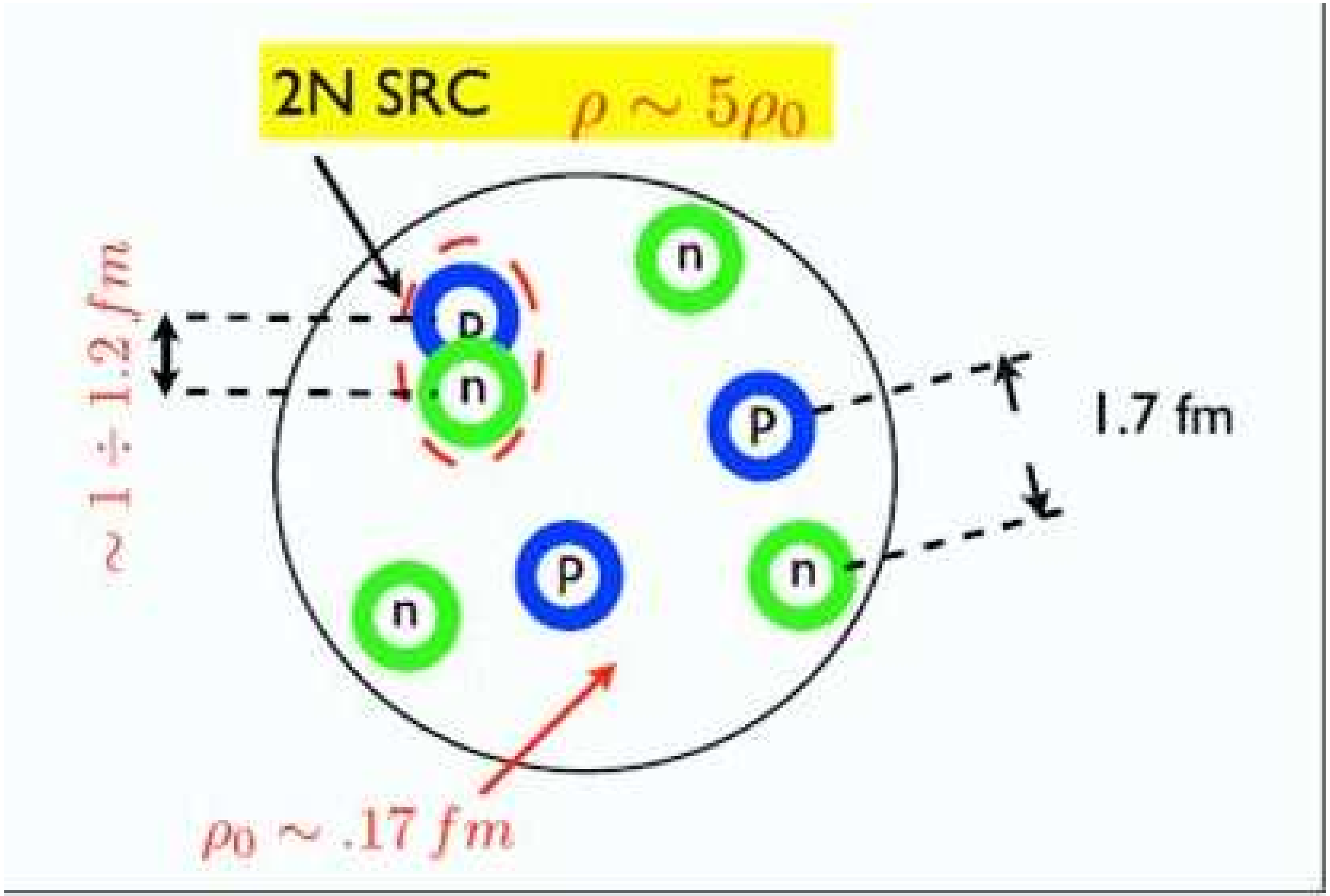
The correlation functions f_{ij}: *Central*, *Spin-Isospin*, *Tensor* ...



SRC $\rightarrow$ two nucleons at separation shorter than average separation

$(\simeq 1.7\, fm)$

THE NOVEL VIEW OF THE ATOMIC NUCLEUS



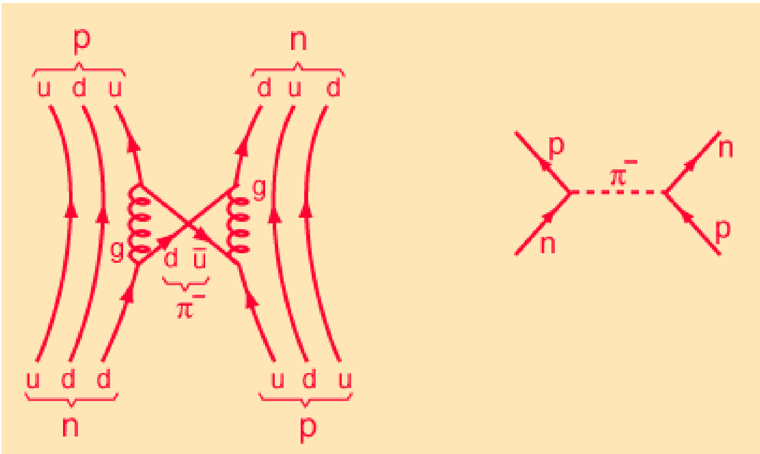
Nuclei consist also of drops of cold high density matter

Crucial question: what is the percentage of SRC? Can we measure it? Why it is important to know it

3. RELEVANCE OF SRC IN DIFFERENT PROCESSES

3.1. Study of core and tensor correlations

Quark, gluon or pion descriptions of NN interaction?



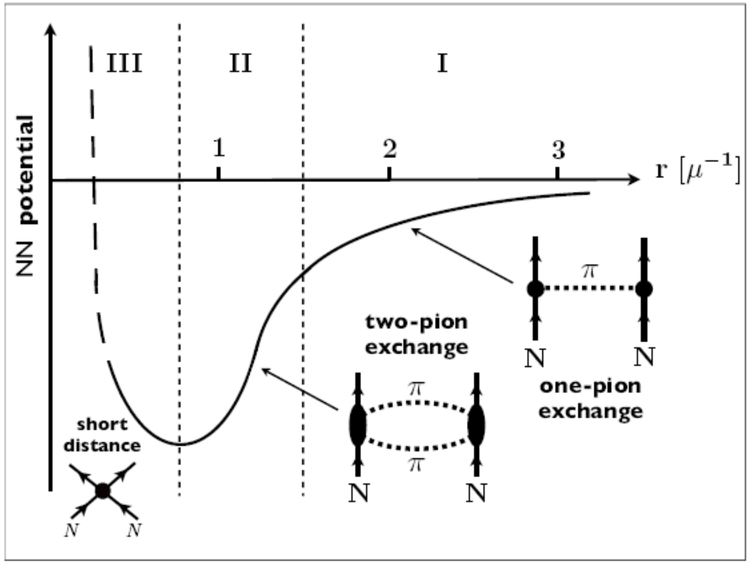
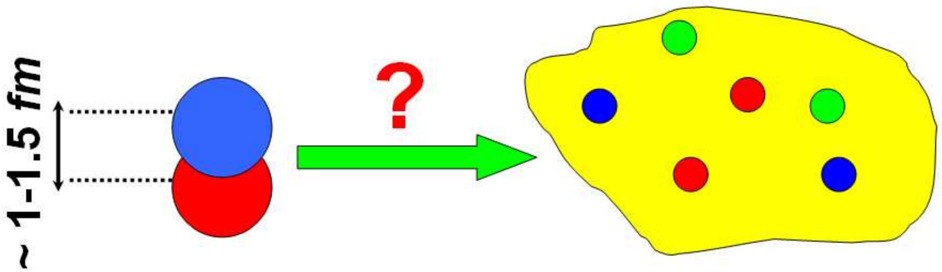


Fig. 2. Hierarchy of scales governing the nucleon-nucleon interaction (adapted from Taketani [5]). The distance r is given in units of the pion Compton wavelength, $\mu^{-1} \simeq 1.4$ fm.

Adapted from: W. Weise, Nucl. Phys. A 805(2008)145c

3.2 Transition from hadron to quark gluon descriptions of nuclei



Nucleon radius $< r^2 >^{1/2} \simeq 0.8 fm^{-1} \Rightarrow$ Nucleon overlap.

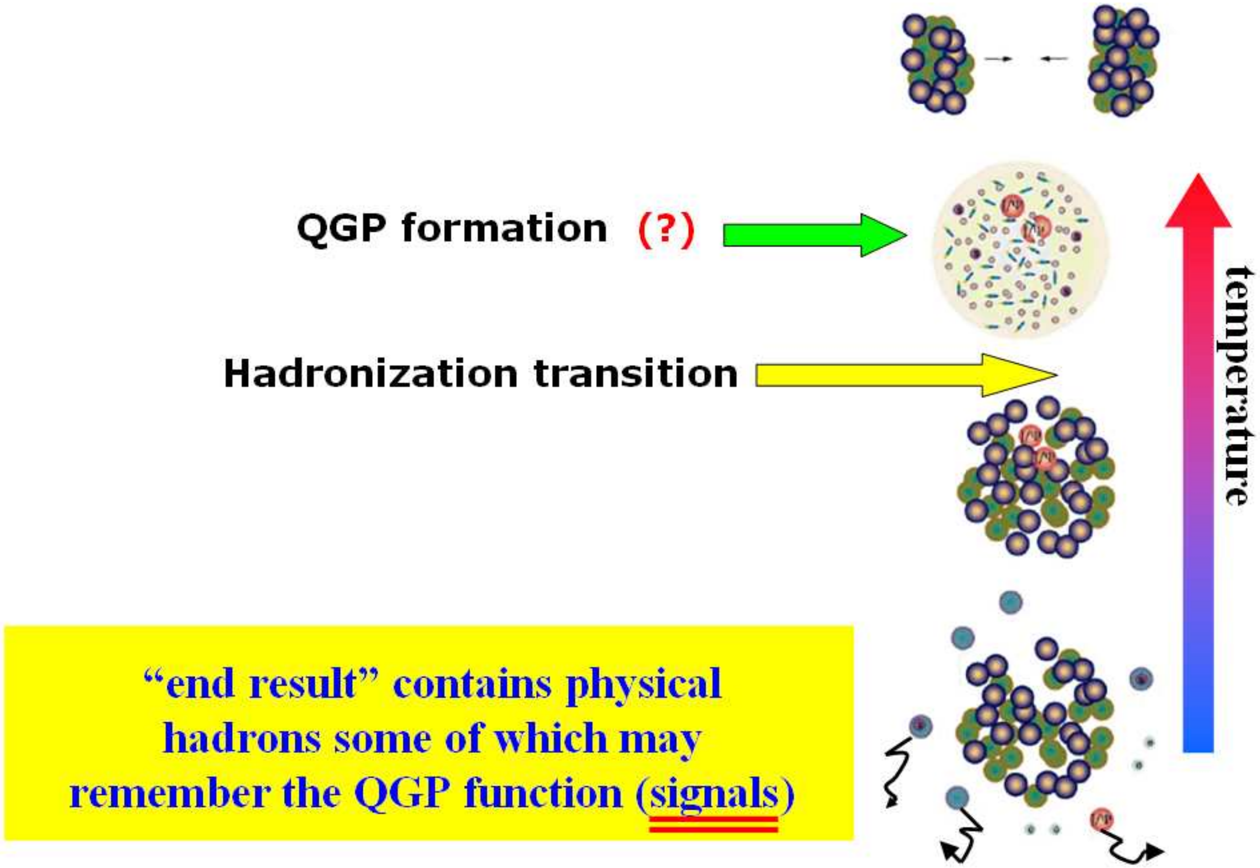
3.3 Medium induced modifications of hadron properties ??

EMC effect and SRC

CdA, L. Kaptari, L. Frankfurt, M. Strikman, Phys. Rev. C 76 (2007) 055206

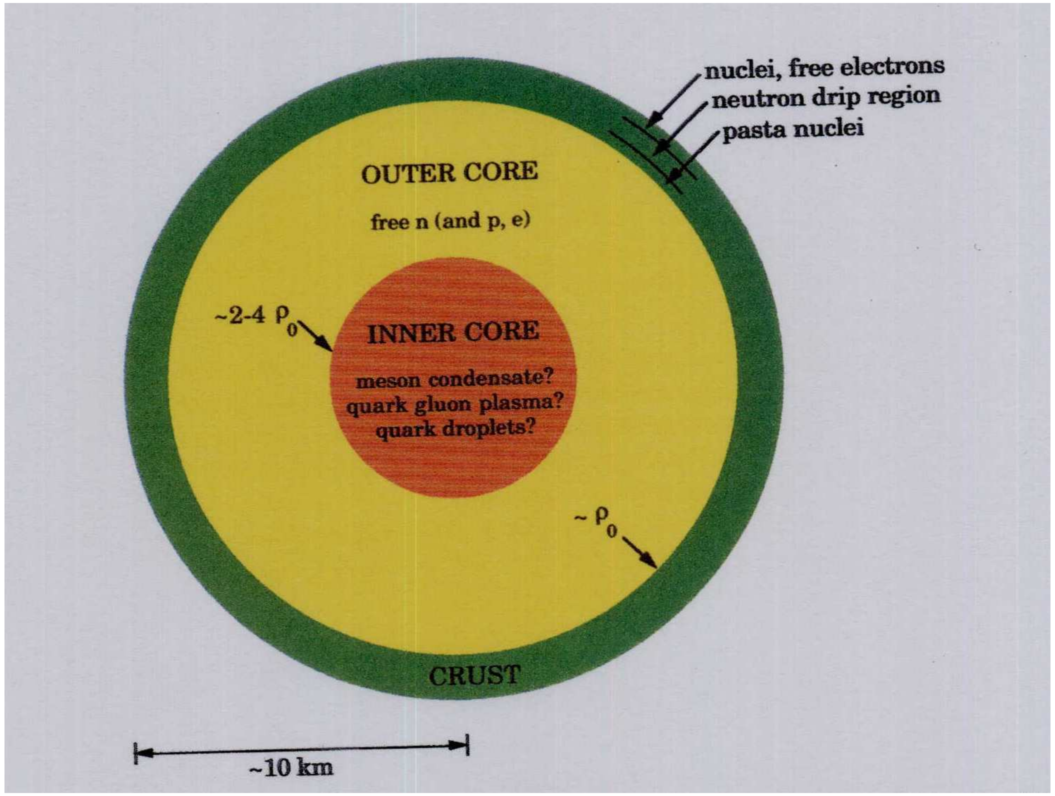
3.4 High energy scattering processes

The little bang in the laboratory



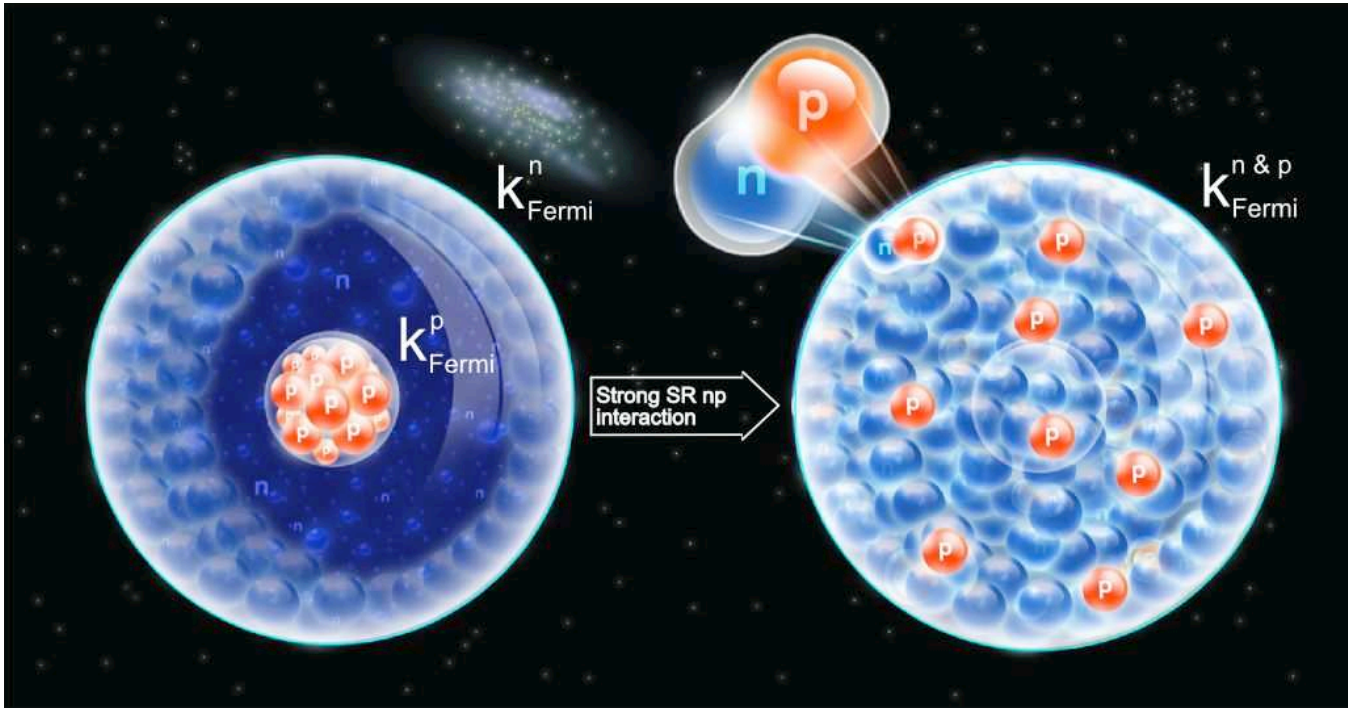
Signals depends upon the way hadrons propagated in the medium.
SRC do affect hadron propagation.

3.5 Formation of cold dense nuclear matter in the laboratory



How are neutron star properties affected by SRC?

Implications for Neutron Stars



- At the core of neutron stars, most accepted models assume :~95% neutrons, ~5% protons
- Neglecting the np-SRC interactions, one can assume two separate Fermi gases
- Since np interaction is large compared to nn, n gas heats the p gas
- This could effect the upper limit on mass of neutron and allow the neutrons in the star decay

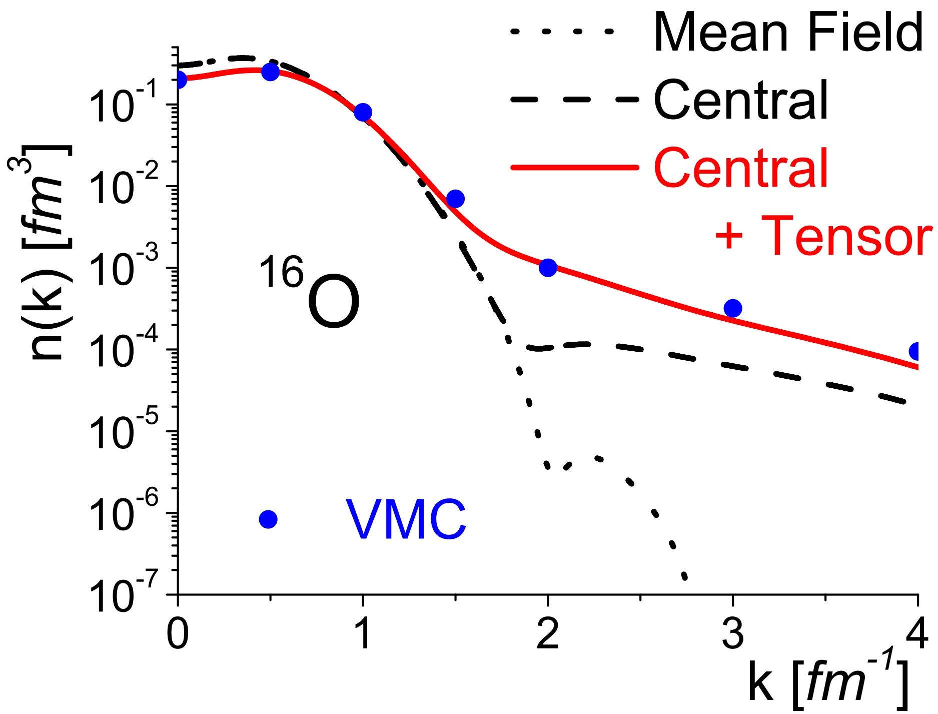
4. INDEPENDENT NUCLEONS AND CORRELATED NUCLEONS: WHICH ARE THE SMOKING GUNS?

- Repulsive core and tensor force generate high momentum components ($k >> k_F \simeq 1.4\ fm^{-1}$)

- Properties of nuclear matter at short distances resemble the properties of the deuteron (T=0, S=1 proton-neutron pairs)("deuteron scaling")

- Wide spectrum of excitation energy of the nucleus (Spectral Function)

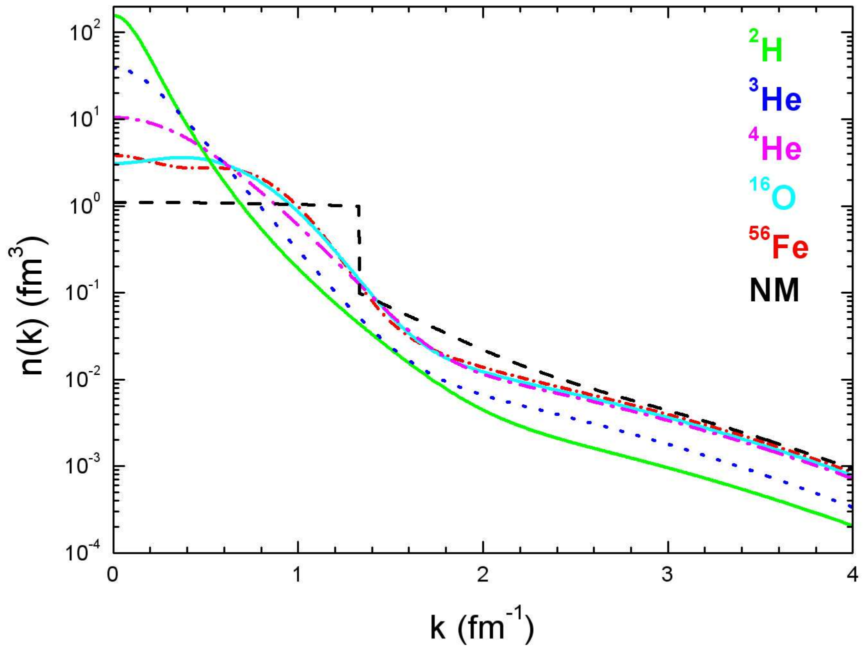
4.1 High momentum components. The role of the core and the tensor force



Tensor forces acting in T=0 S=1 states produce the largest amount of high momentum components. Mean field distributions drop to zero at $k \geq 1.5 - 2\, fm^{-1}$ (Adapted from Alvioli, CdA, Morita,Phys. Rev. C72(2005)054310)

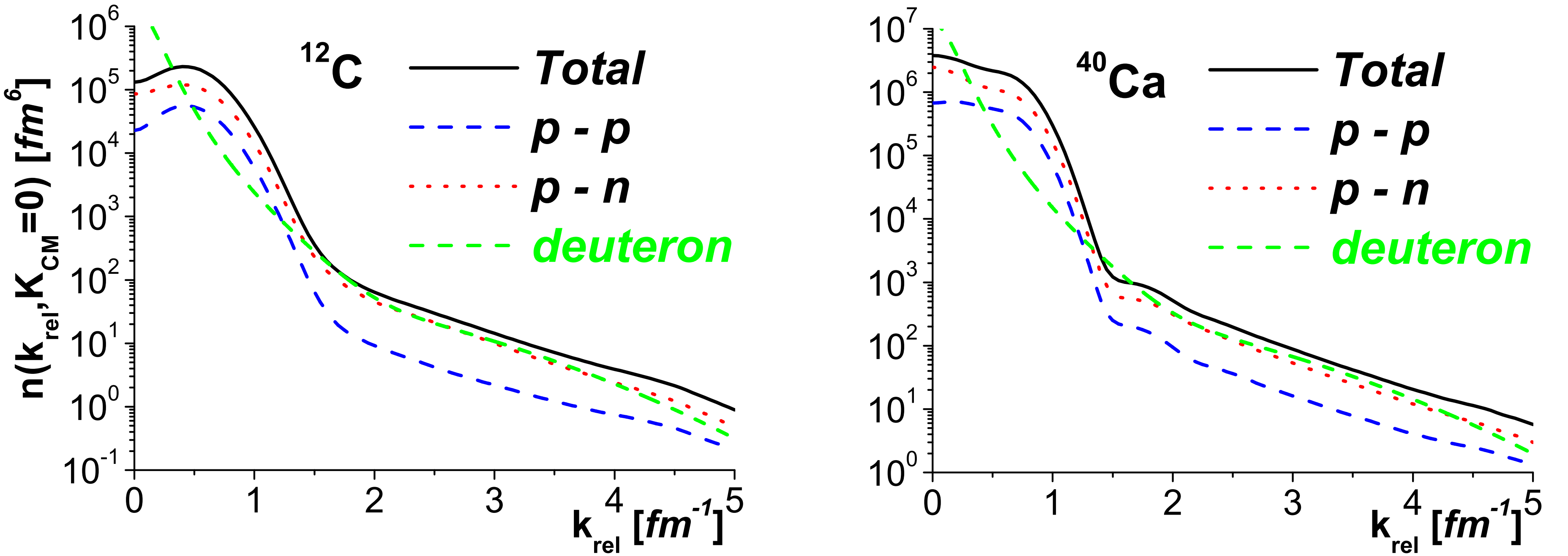
4.2 High momentum components and deuteron scaling

due to NN correlations the 1-body momentum distributions acquire peculiar high momentum components



The high momentum ($k > k_F$) part of $n_A(k)$ can be viewed as the rescaled deuteron momentum distribution: $n_A(k) \simeq C_A\, n_D(k)$.
(Adapted from Cda, Simula, Phys. Rev. 53(1996)1689)

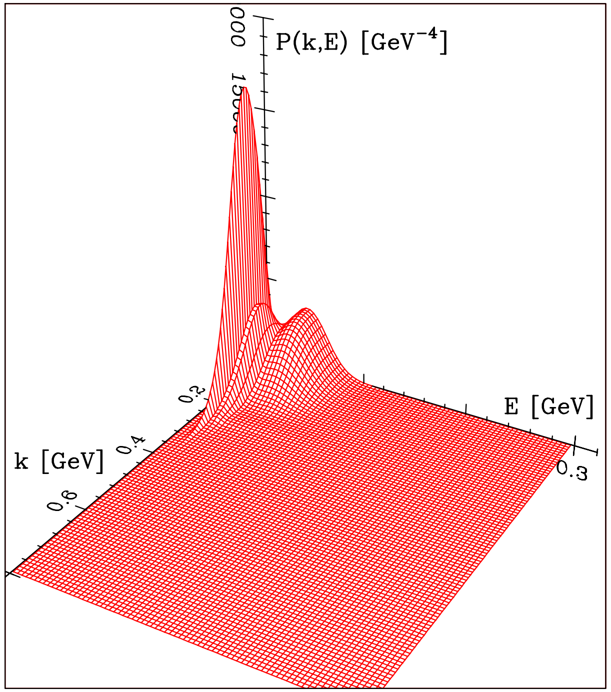
Role of correlations better seen in the 2-body momentum distributions

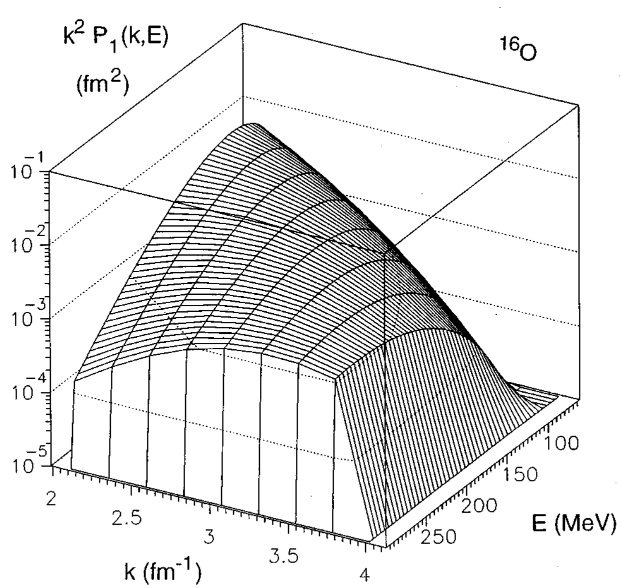


M. Alvioli, CdA, H.Morita, Phys. Rev. Lett, 100, 162503, (2008)

The tensor deuteron-like (T=0, S=1)dominance at $k_{rel} \geq 1.5 - 2\, fm^{-1}$occurs both in few-nucleon systems and complex nuclei.

4.3 High excitation energy components





$\mathbf{P_0(k,E)}$ $\qquad\qquad$ $\mathbf{P_1(k,E)}$

S M $(E = \epsilon_\alpha)$ **: 80%** $\qquad$ ***Correlations*** $(E \simeq k^2/2m_N)$ **: 20%**

S. Simula, CdA - Phys. Rev. C53 (1996) 1689

5. EXPERIMENTAL STUDY OF CORRELATIONS

CAN THESE RELEVANT DEVIATIONS FROM THE WELL HONORED MEAN FIELD DESCRIPTION OF NUCLEI EXPERIMENTALLY BE DETECTED?

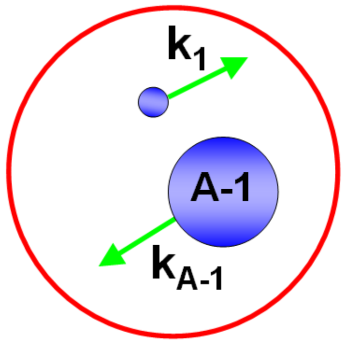
YES THEY CAN BY REMOVING THE NUCLEUS CONSTITUENTS AT HIGH ENERGY AND MOMENTUM TRANSFERS

THE $A(e, e'N)X$ and $A(e, e'NN)X$ PROCESSES

THE $A(p, p'N)X$ and $A(p, p'NN)X$ PROCESSES

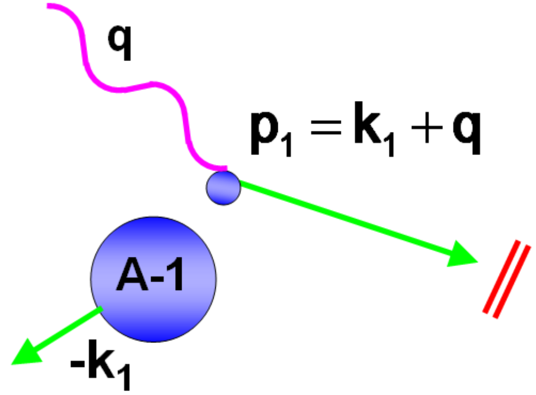
In double and triple coincidence experiments the kinematics is fully determined

Example: the (e,e'p) process on mean field and correlated nucleons.



Mean Field:

$$\boldsymbol{k}_1 + \boldsymbol{k}_{A-1} = 0$$



The double coincidence cross section:

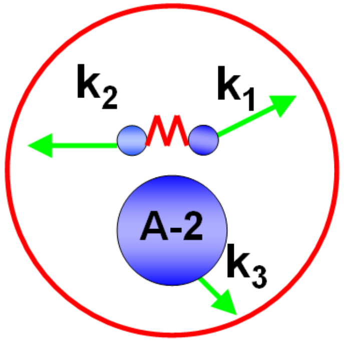
$$\frac{d\sigma}{d\vec{e}' d\vec{p}} \propto \sigma_{ep}(\vec{q}, \vec{k}_1\, \nu) \times P_0(k_1, E)$$

$$P_0(k_1, E) = \sum_\alpha n_\alpha(k_1)\delta(E - \epsilon_\alpha)$$

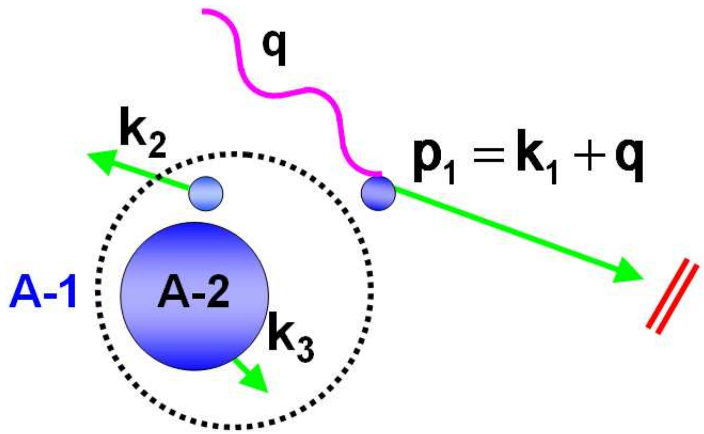
Correlations:

$$\boldsymbol{k}_1+\boldsymbol{k}_2+\boldsymbol{k}_3=0 \quad \boldsymbol{k}_3 \equiv \boldsymbol{K}_{A-2}$$

Simple model:



$$\begin{cases} \boldsymbol{k}_2 \simeq -\boldsymbol{k}_1 \quad \boldsymbol{k}_3 \simeq 0 \quad E^*_{A-2}=0 \\ E^*_{A-1} \simeq \frac{A-2}{A-1}\frac{\mathrm{k}_1^2}{2\,m_N} \end{cases}$$



Realistic model:

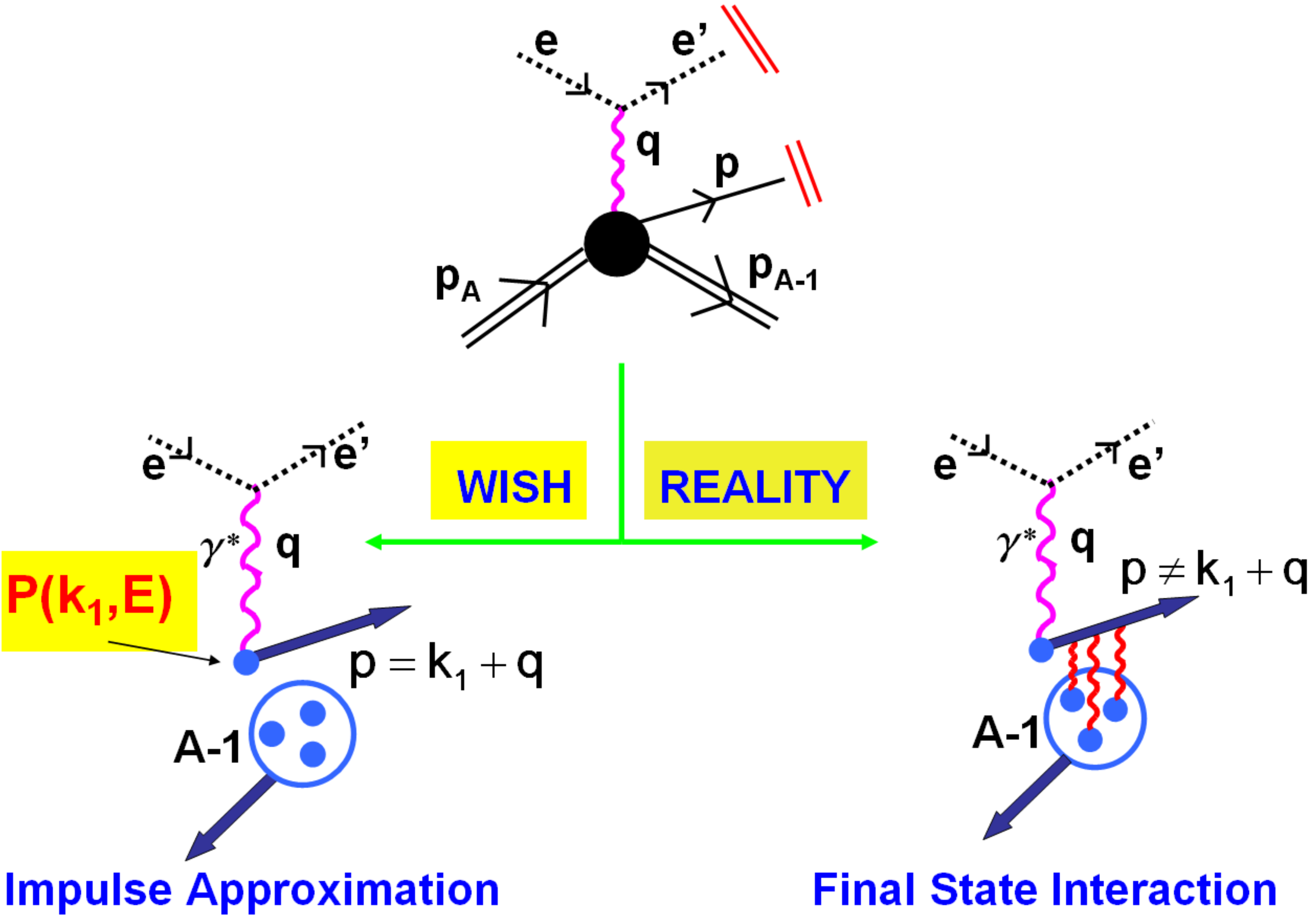
$$\begin{cases} \boldsymbol{k}_3 \neq 0 \qquad E^*_{A-2} \neq 0 \\ E^*_{A-1} = \frac{A-2}{2m_N(A-1)}\left[\boldsymbol{k}_1+\frac{A-1}{A-2}\boldsymbol{k}_3\right]^2+\bar{E}_{A-2} \end{cases}$$

The double coincidence cross section:

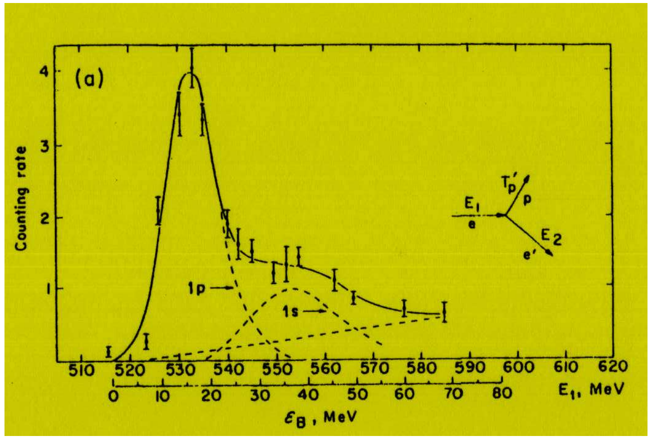
$$\frac{d\sigma}{d\vec{e}'d\vec{p}} \propto \sigma_{ep}(\vec{q},\vec{k}_1\,\nu) \times P_1(k_1,E)$$

$P_1(k_1,E)=\{$**models which includes correlations**$\}$ $\rightarrow$ Morita's talk

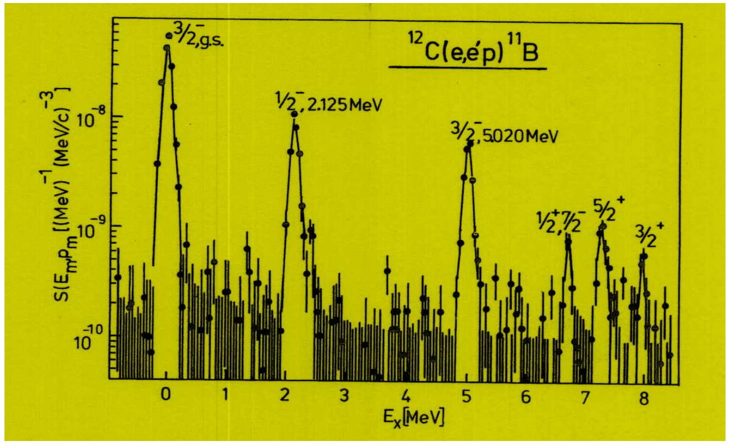
One important caveat



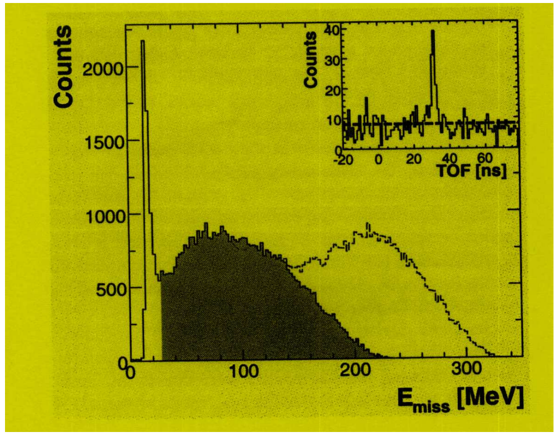
The $^{12}C(e,e'p)X$ process from its birth to present day



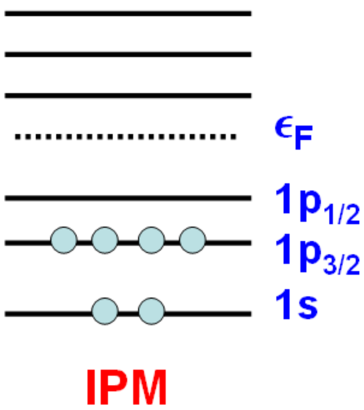
1966 LNF (Italy)

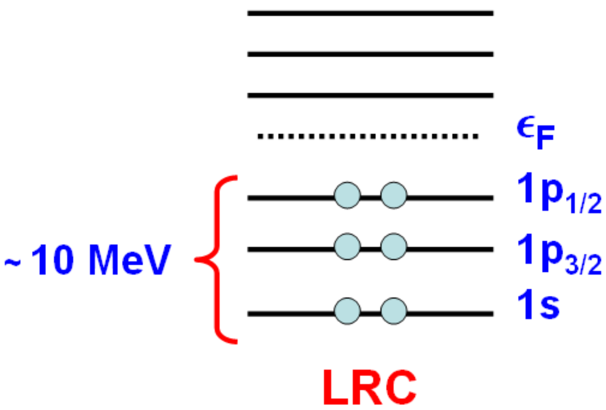


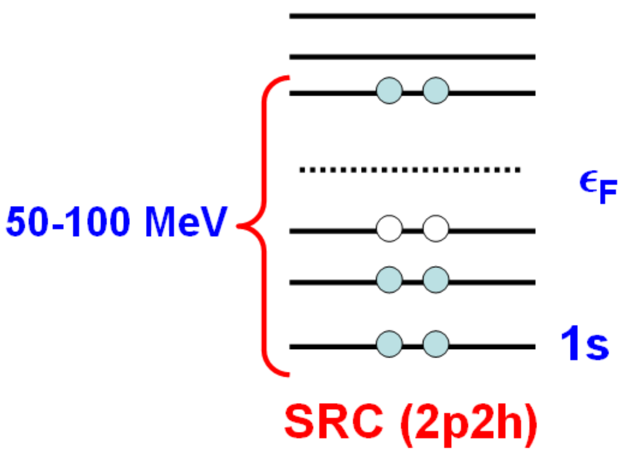
1988 NIKHEF (Holland)



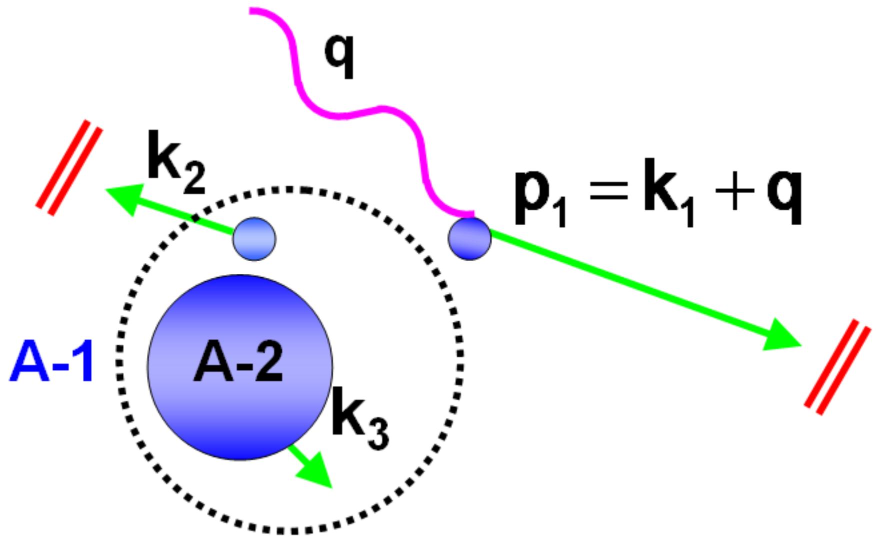
2006 JLab (USA)







Recent Developments (triple coincidence experiments)



By detecting 2 Nucleons in the final state the initial pair correlation can be studied

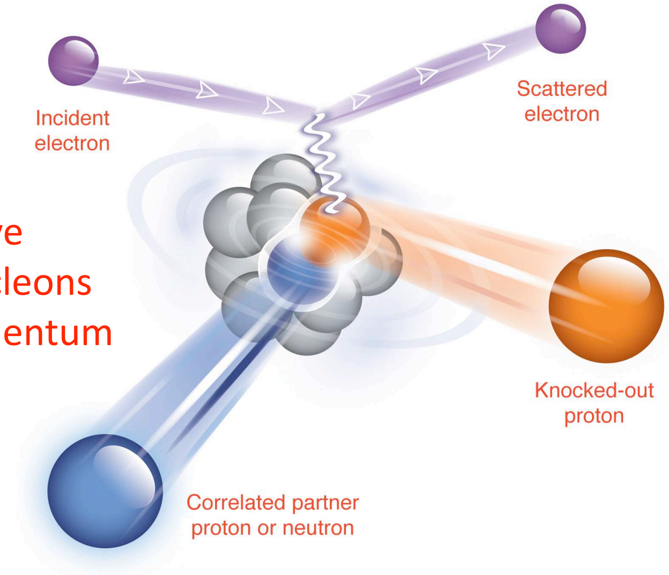
Triple coincidence experiment $A(a, a'NN)X \quad a = \{p,\ e\}$

BNL and JLAB EXPERIMENTS

Customized (e,e'pN) Measurement

To study nucleon pairs at close proximity and their contributions to the large momentum tail of nucleons in nuclei.

A pair with "large" relative momentum between the nucleons and small center of mass momentum



- high Q2 to minimize MEC
- x>1 to suppress isobar contributions
- anti-parallel kinematics to suppress FSI

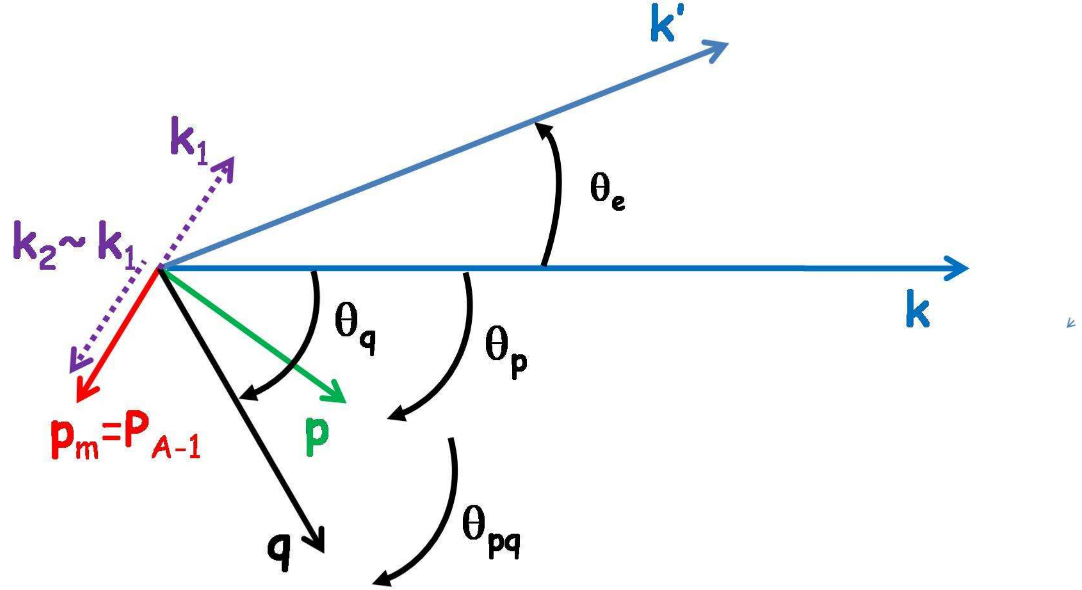
Sixth International Conference on Perspectives in Hadronic Physics Jefferson Lab

Momentum conservation

$$\mathrm{q} = \mathrm{p} + \mathrm{P}_{A-1}$$

Missing momentum

$$\mathrm{p}_m = \mathrm{q} - \mathrm{p} = \{IA\} = \mathrm{q} - (\mathrm{k}_1 + \mathrm{q} - \mathrm{q}) = -\mathrm{k}_1 = \mathrm{P}_{A-1}$$

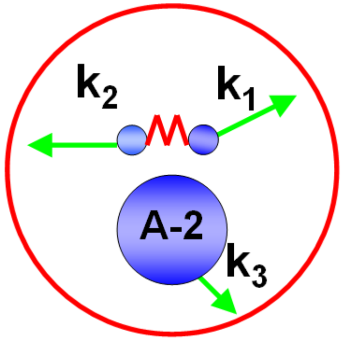


Detect k' , p and place a detector at the direction of P_{A-1}. Since if 2NC model is correct we have $\mathrm{P}_{A-1} = \mathrm{k}_2 + \mathrm{P}_{A-2} \simeq -\mathrm{k}_1$, we should detect the correlated partner of nucleon "1" with momentum p_m.

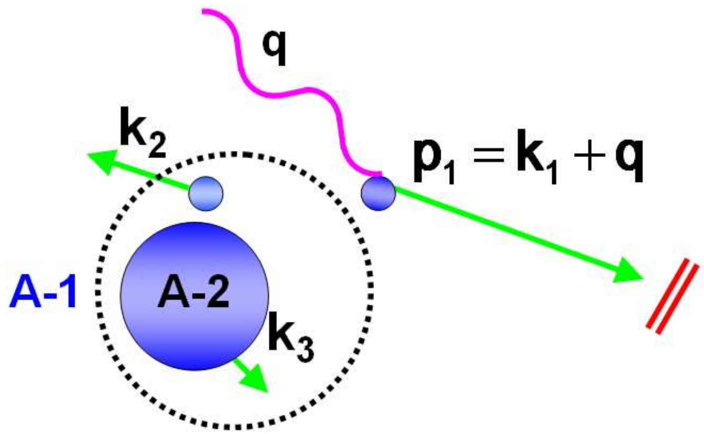
Correlations:

$$\boldsymbol{k}_1+\boldsymbol{k}_2+\boldsymbol{k}_3 = 0 \quad \boldsymbol{k}_3 \equiv \boldsymbol{K}_{A-2}$$

Simple model:



$$\begin{cases} \boldsymbol{k}_2 \simeq -\boldsymbol{k}_1 \quad \boldsymbol{k}_3 \simeq 0 \quad E^*_{A-2} = 0 \\ E^*_{A-1} \simeq \frac{A-2}{A-1}\frac{\mathrm{k}_1^2}{2\,m_N} \end{cases}$$



Realistic model:

$$\begin{cases} \boldsymbol{k}_3 \neq 0 \qquad E^*_{A-2} \neq 0 \\ E^*_{A-1} = \frac{A-2}{2m_N(A-1)} \left[\boldsymbol{k}_1 + \frac{A-1}{A-2}\,\boldsymbol{k}_3\right]^2 + \bar{E}_{A-2} \end{cases}$$

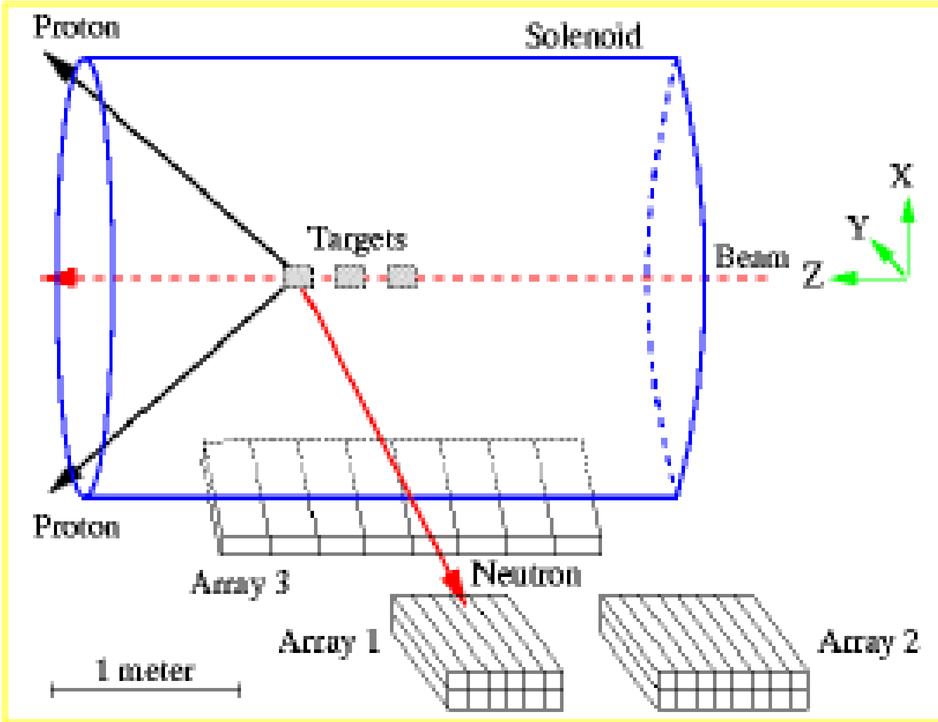


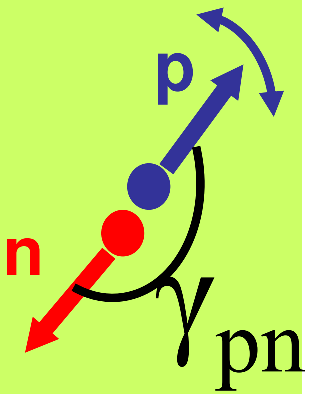
FIGURE 1. Layout of the experiment

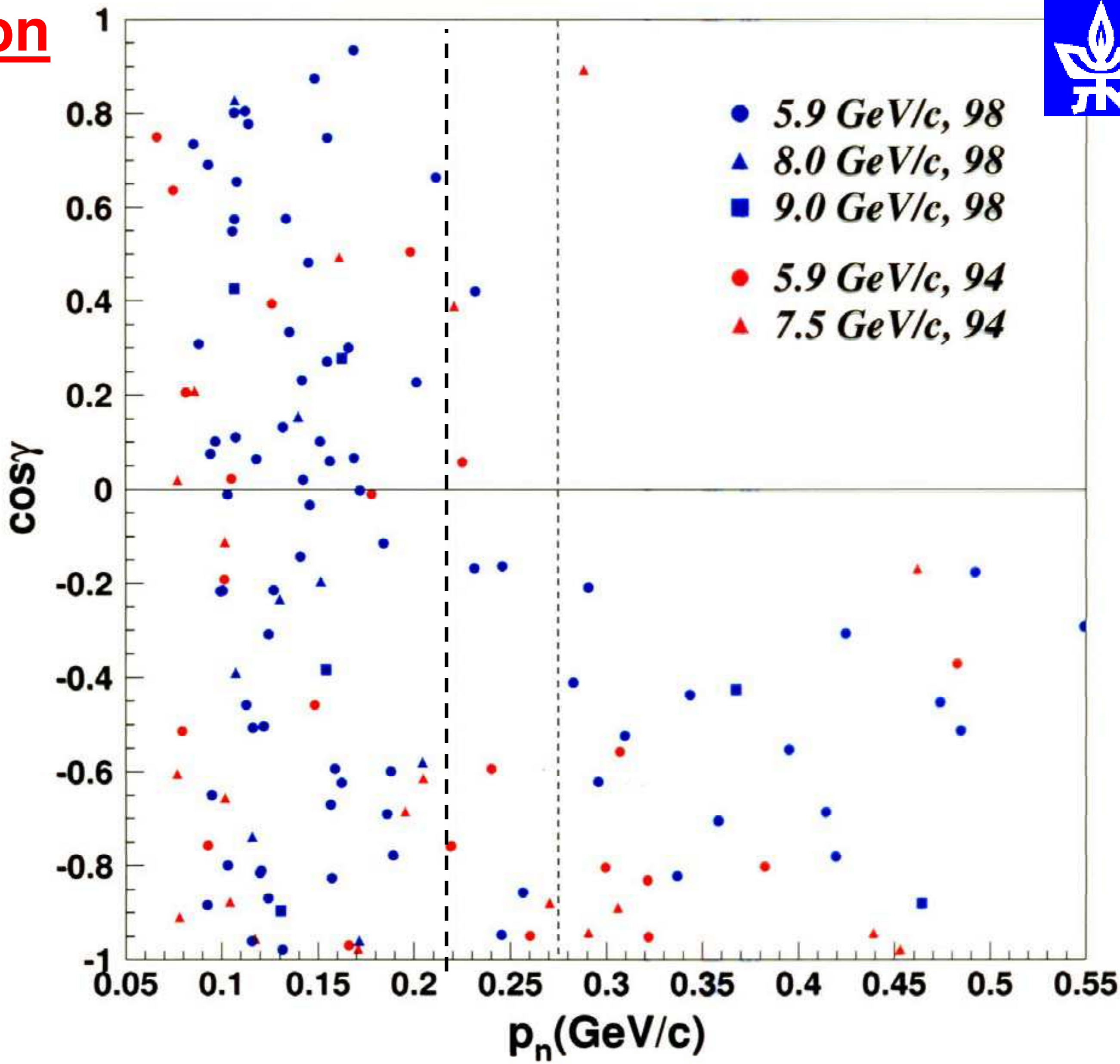
BNL p beam $5.9 - 7.5\, GeV/c$, ^{12}C target

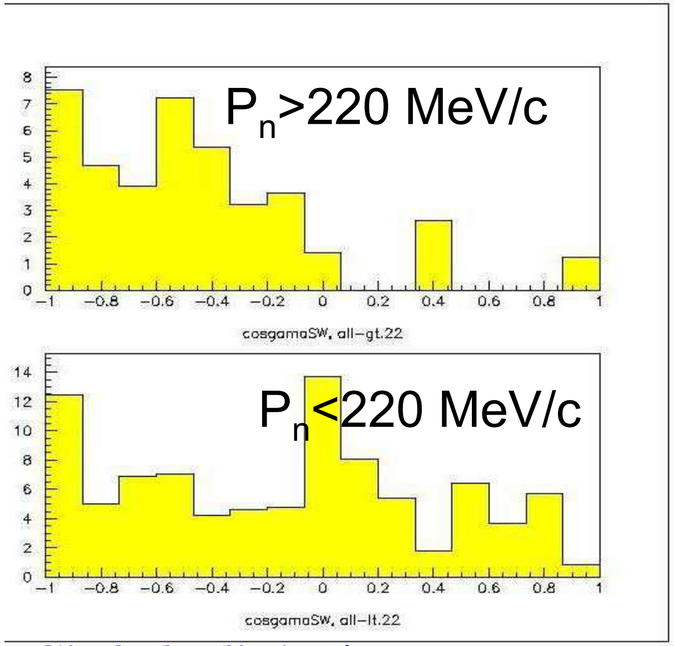
Phys. Lett. B453 (99) 202; Phys. Rev. C65 (01) 015207; Phys. Rev. Lett. 90 (03) 042301

Directional correlation

(p,2pn)







The EVA/BNL collaboration

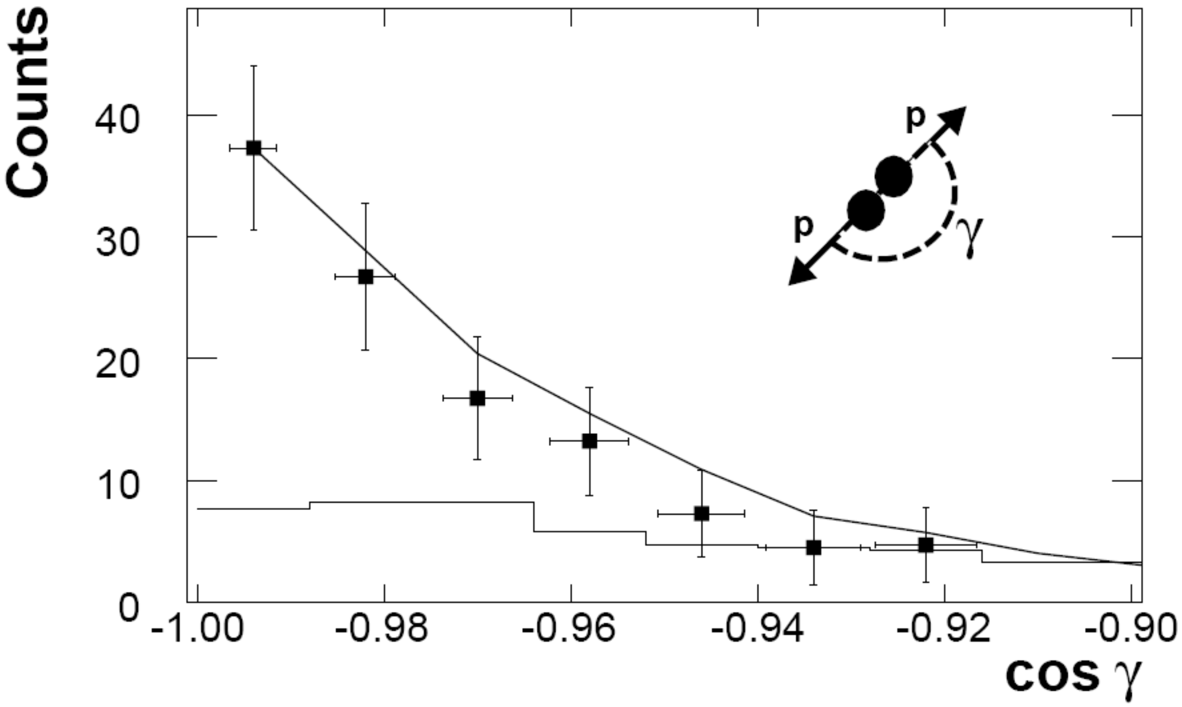


Figure 5. For the ^{12}C$(e, e'pp)$ reaction at $Q^2 > [1\text{GeV/c}]^2$, the distribution of the cosine of the opening angle between the $\vec{p}_{miss}$ and $\vec{p}_{rec}$ for a p_{miss} = 0.55 GeV/c. The histogram shows the distribution of random events. The curve is a simulation of the scattering off a moving pair with a width of 0.136 GeV/c for the pair center of mass momentum. Reprinted with permission from Shneor R *et al.* (Hall A) 2007 *Phys. Rev. Lett.* **99** 072501. Copyright 2007 by the American Physical Society.

PRL 97, 162504 (2006) PHYSICAL REVIEW LETTERS week ending 20 OCTOBER 2006

Evidence for Strong Dominance of Proton-Neutron Correlations in Nuclei

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[3]*Department of Physics, The Pennsylvania State University, University Park, Pennsylvania, USA*
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(Received 11 April 2006; published 18 October 2006)

We analyze recent data from high-momentum-transfer (p, pp) and (p, ppn) reactions on carbon. For this analysis, the two-nucleon short-range correlation (NN-SRC) model for backward nucleon emission is extended to include the motion of the NN pair in the mean field. The model is found to describe major characteristics of the data. Our analysis demonstrates that the removal of a proton from the nucleus with initial momentum 275–550 MeV$/c$ is $92^{+8}_{-18}\%$ of the time accompanied by the emission of a correlated neutron that carries momentum roughly equal and opposite to the initial proton momentum. This indicates that the probabilities of pp or nn SRCs in the nucleus are at least a factor of 6 smaller than that of pn SRCs. Our result is the first estimate of the isospin structure of NN-SRCs in nuclei, and may have important implication for modeling the equation of state of asymmetric nuclear matter.

DOI: 10.1103/PhysRevLett.97.162504 PACS numbers: 21.60.−n, 21.65.+f, 24.10.−i, 25.40.Ep

Using the above values of R, T_n, and F, we estimate $P_{pn/pX}$ from Eq. (6). Figure 3 shows the σ dependence of $P_{pn/pX}$ for $F = 0.36$, 0.43, and 0.55, respectively. Since $P_{pn/pX} \leq 1$, there is an interesting correlation between σ and $P_{pn/pX}$, which allows us to put a constraint on σ. For

evaluate $P_{pn/pX}$ we use the magnitude of $\sigma^{\exp} = 143 \pm 17$ MeV/c extracted from the same data set [7]. This value is in excellent agreement with the theoretical expectation of 139 MeV/c of Ref. [16]. Note that $\sigma^{\exp}$ dictates the

removal of a fast proton is accompanied by the emission of a fast recoil neutron. It allows us also to estimate an upper limit of the ratio of absolute probabilities of pp- to pn-SRCs [21]:

$$\frac{P_{pp}}{P_{pn}} \leq \frac{1}{2}(1 - P_{pn/pX}) = 0.04^{+0.09}_{-0.04}. \quad (13)$$

This result can be used to estimate separately the absolute probabilities of pn, pp, and nn SRCs in the nuclear wave function. For this we use the total probability of NN-SRCs [$P_{NN}(^{12}C) = 0.20 \pm 0.042$] obtained by combining the

with J. Alster, K. Egiyan, and A. Gal. This research is supported by the Israel Science Foundation, the US-Israeli Binational Scientific Foundation, the US Department of Energy, and the National Science Foundation.

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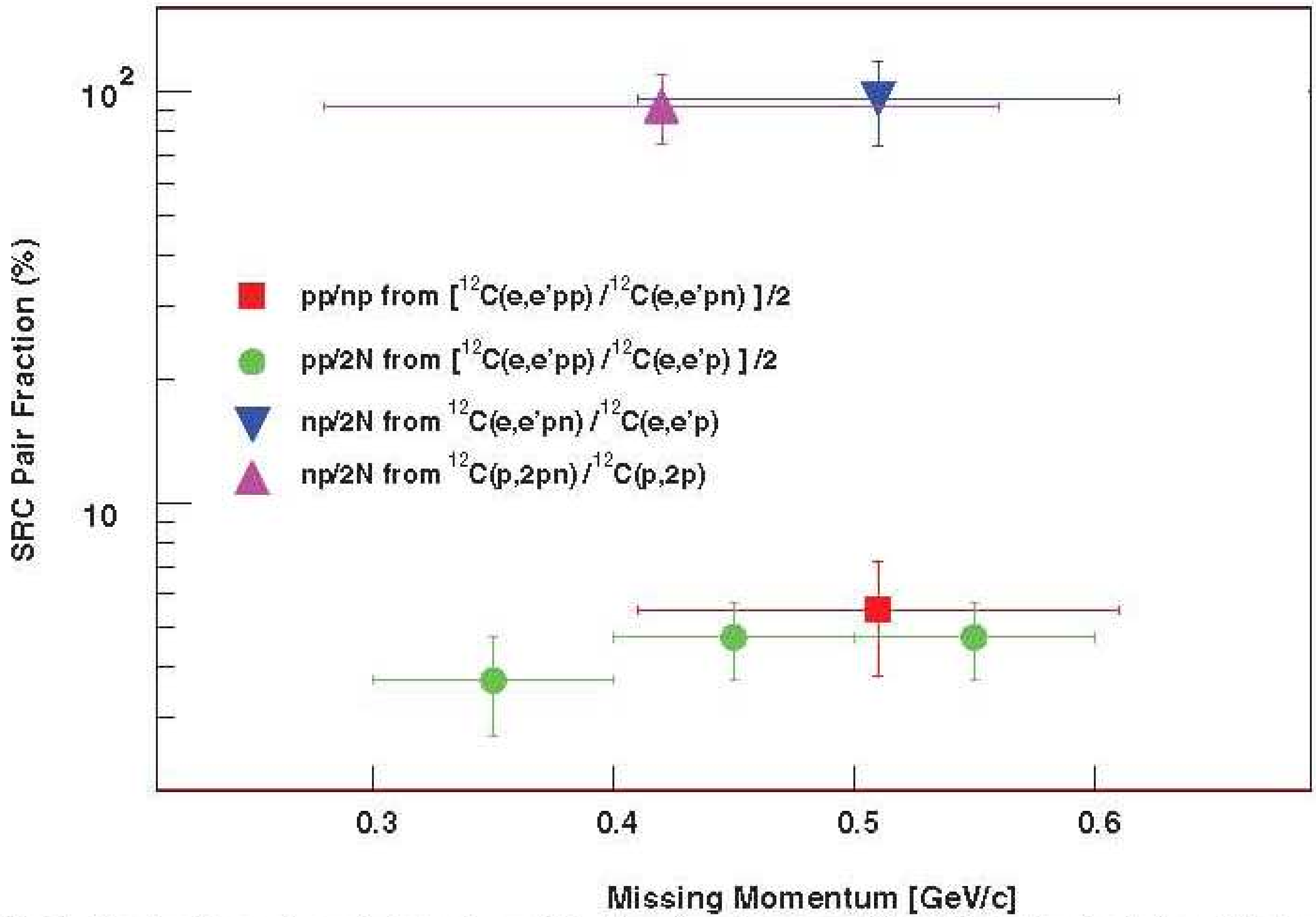
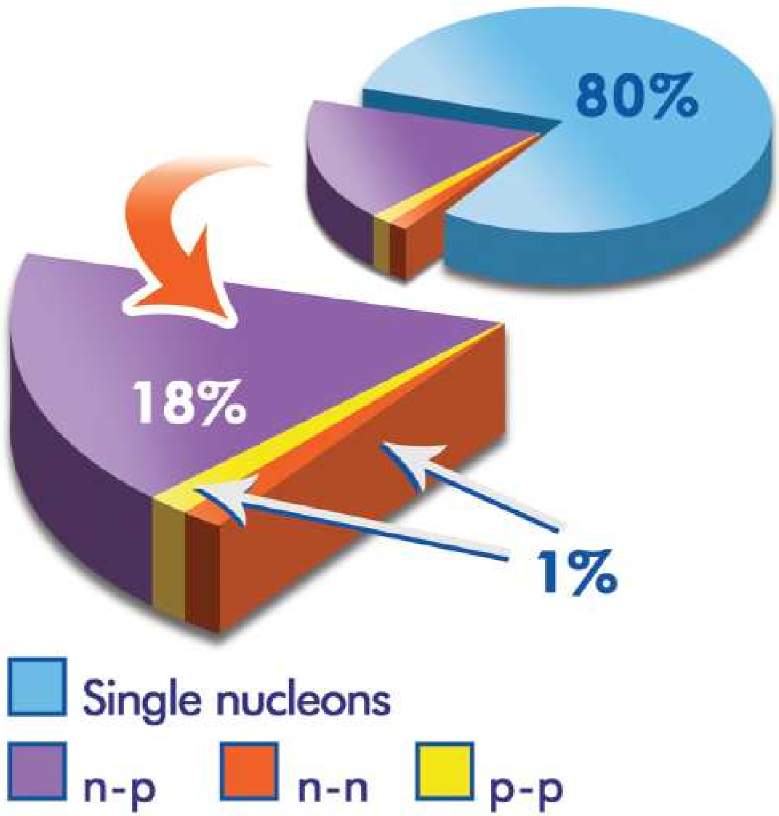


Fig. 2. The fractions of correlated pair combinations in carbon as obtained from the (e,e'pp) and (e,e'pn) reactions, as well as from previous (p,2pn) data. The results and references are listed in table S1.

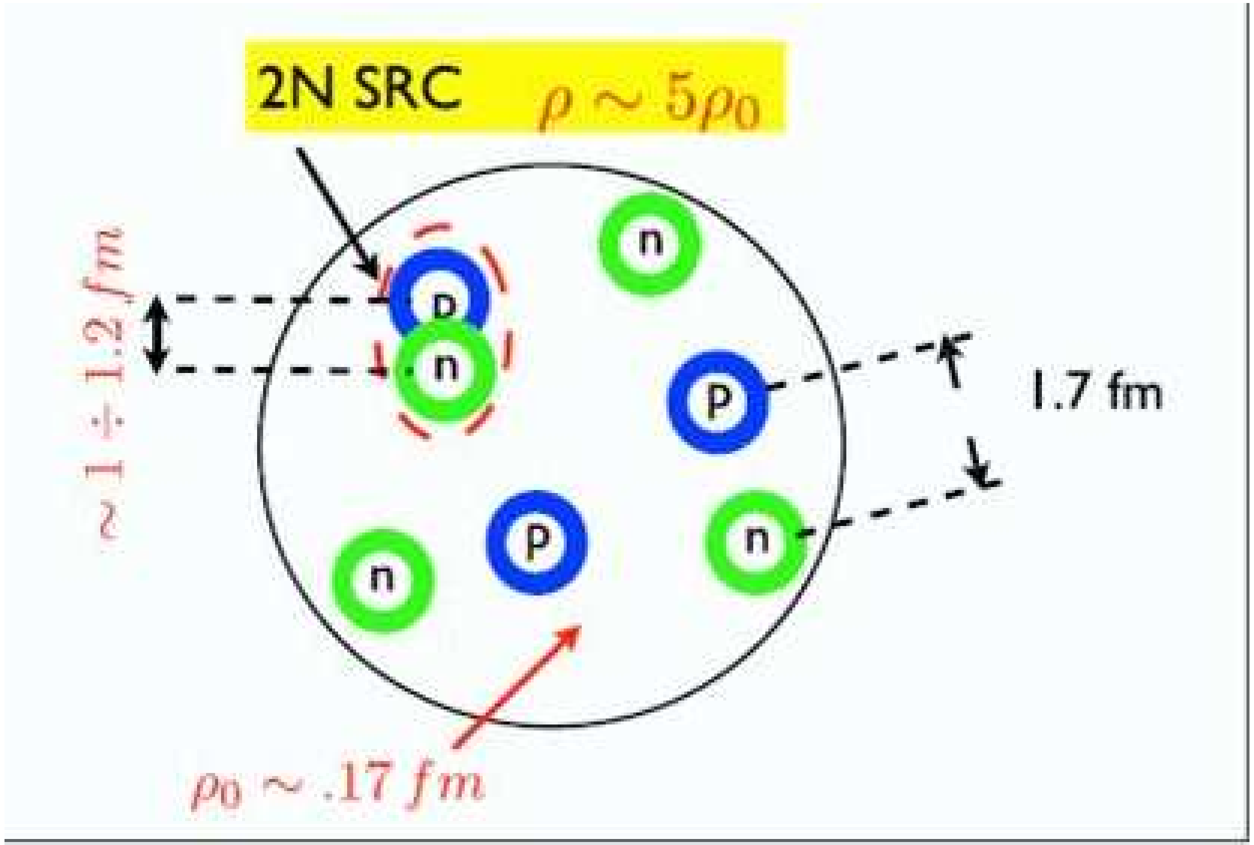
R. Subedi et al, *Science* 320, 1476 (2008)

The correlation pizza in ^{12}C



R. Subedi et al, *Science* 320, 1476 (2008)

The novel view of the atomic nucleus



6 TWO AND THREE NUCLEON CORRELATIONS: INCLUSIVE $A(e,e')X$ PROCESSES

TWO-NUCLEON CORRELATIONS::

$$\boldsymbol{k}_1 \simeq -\boldsymbol{k}_2 \ \text{large and} \ \boldsymbol{k}_3 \simeq 0$$

THREE-NUCLEON CORRELATIONS:

$$\boldsymbol{k}_1 + \boldsymbol{k}_2 + \boldsymbol{k}_3 = 0 \ \text{all three momenta are large}$$

Correlations can be linked to the value of the Bjorken scaling variable $x_B = \frac{Q^2}{2\, m_N\, \nu}$ ⇒ 2N CORRELATIONS: a kind of "two-body system"; 3N CORRELATIONS: a kind of "three-body systems"

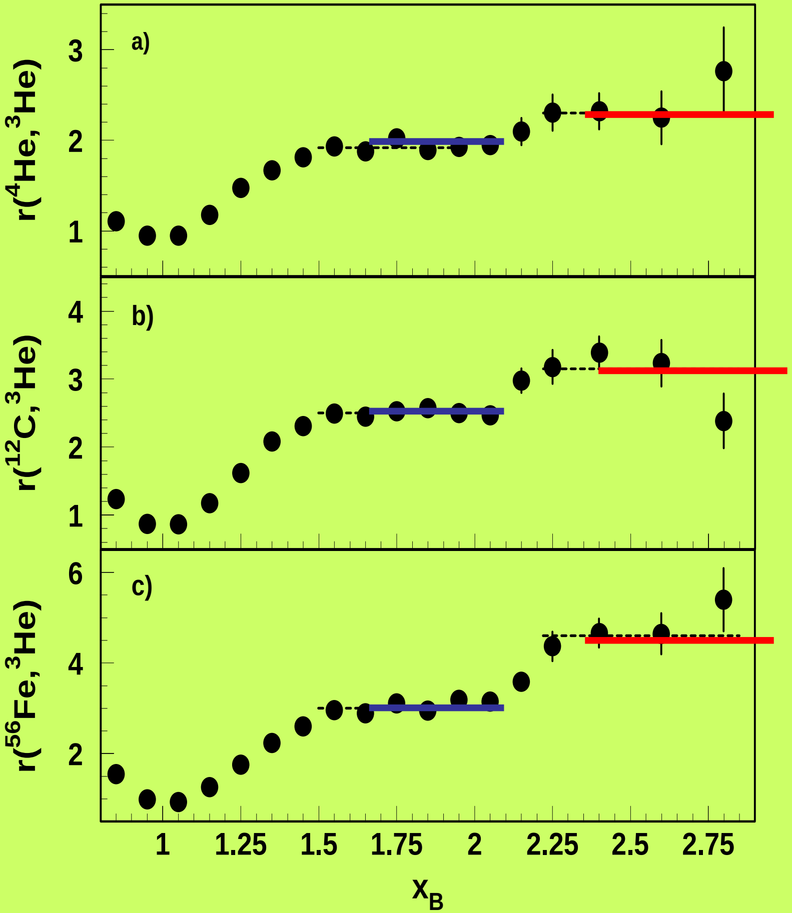
scattering on a single nucleon: $0 < x_B < 1$
scattering on 2 correlated nucleons: $1 < x_B < 2$
scattering on 3 correlated nucleons: $2 < x_B < 3$

Measurement of Two- and Three-Nucleon Short-Range Correlation Probabilities in Nuclei

K. S. Egyian,[1,34] N. B. Das
M. Anghinolfi,[16] B.
N. A. Baltzell,[33] V. Bat
A. S. Biselli,[30,4] B. E.
S. Bültmann,[27] V. D. B
S. Chen,[11] P. L. Cole,[34,14]
R. DeVita,[16] P. V. Degt
J. Donnelly,[13] D. Doughty,
A. Empl,[30] P. Eugenio,
N. G. Gevorgyan,[1] G. I
K. A. Griffioen,[38] M. C
F. W. Hersman,[24] K. Hi
D. G. Ireland,[13] B. S. Is
M. Khandaker,[25] K. Y.
L. H. Kramer,[10,34] V. Kuba
D. Lawrence,[22] T. Le
B. A. Mecking,[34] M.
R. Miskimen,[22] V. Mokee
R. Nasseripour,[10] S.
G. V. O'Rielly,[22] M. Osip
D. Pocanic,[37] O. Pogorelk
L. M. Qin,[27] B. A. Raue,[10,
D. Rowntree,[21] P. D. Ru
V. S. Serov,[18] Y. G. Shar
B. E. Stokes,[11] P. Stole
A. Tkabladze,[27,26] S.
D. P. Weygand,[34] M. W
(CLAS Collaboration)

New CLAS A(e,e') Result:

K. Sh. Egiyan et al. PRC 68, 014313.
K. Sh. Egiyan et al. PRL. 96, 082501 (2006)



$$x_B = \frac{Q^2}{2M\nu} > 1.5, \quad P_{in} \geq 275 MeV/c$$

$$2 < x_B = \frac{Q^2}{2M\nu} < 3,$$

$$Q^2 > 1.4 GeV^2$$

The observed "scaling" means that the electrons probe the high-momentum nucleons in the 2/3-nucleon phase, and the scaling factors determine the per-nucleon probability of the 2/3N-SRC phase in nuclei with A>3 relative to ^3He.

The probabilities for 3-nucleon SRC are smaller by one order of magnitude relative to the 2N SRC.

For ^{12}C:

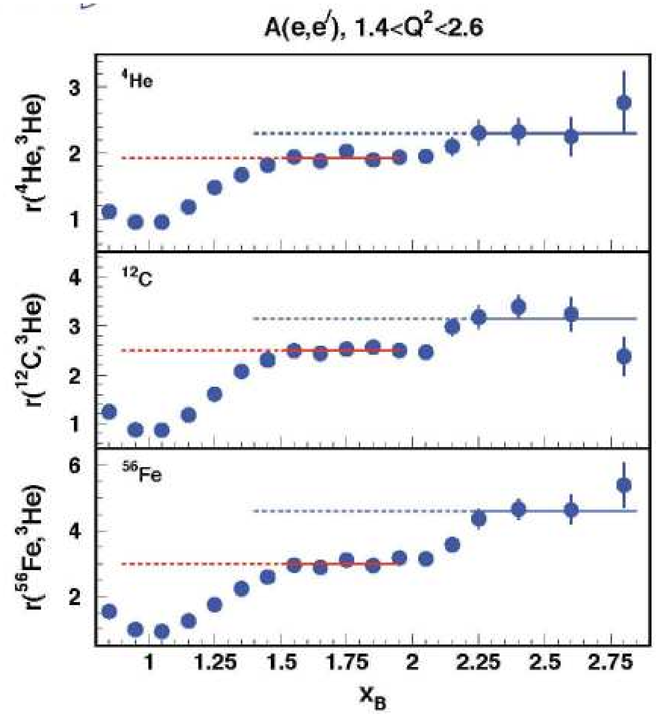
2N-SRC(np,pp,nn) = 0.20 ± 0.045%

3N-SRC Less than 1% of total

[1]Yerevan Physics Institute, Yerevan 375036, Armenia

Mezzetti's talk

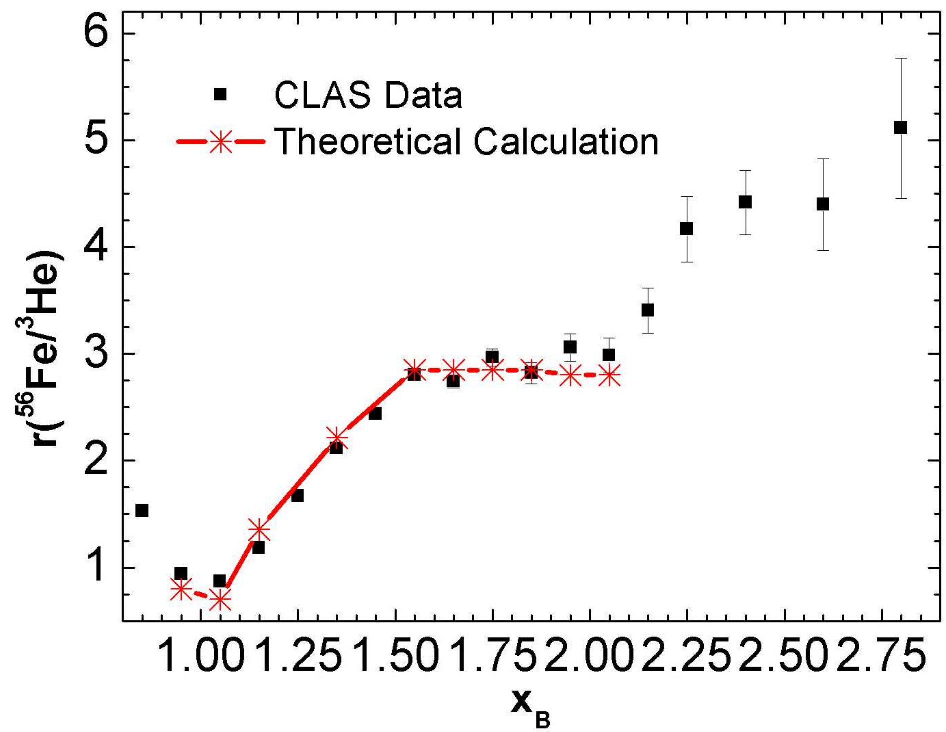
C. Ciofi degli Atti, C.B. Mezzetti, Phys. Rev. C 79 (2009) 051302(R); C.B. Mezzetti, C. Ciofi degli Atti, arXiv:0906.5564 (2009)



$\alpha_{2N} \approx 20\%$
$\alpha_{3N} \approx 1\%$

CLAS data
Egiyan et al., PRL 96, 082501, 2006

$a_j(A)$ is probability of finding a j-nucleon correlation



7 HADRON SCATTERING OFF NUCLEI AT HIGH ENERGIES (HERA, RHIC, LHC)

The total neutron – Nucleus cross section at high energies:

$$\sigma_{\mathbf{tot}} = \frac{4\pi}{k} Im\left[F_{00}(0)\right] \qquad F_{00}(\boldsymbol{q}) = \frac{ik}{2\pi}\int d^2 b_n e^{i\mathbf{q}\cdot\mathbf{b_n}}\left[1 - \mathbf{e}^{\mathbf{i}\,\chi_{\mathbf{opt}}(\mathbf{b_n})}\right]$$

$$\mathbf{e}^{\mathbf{i}\,\chi_{\mathbf{opt}}(\boldsymbol{b}_\mathbf{n})} = \int \prod_{j=1}^{A} d\boldsymbol{r}_j \prod_{j=1}^{A}\left[1-\Gamma(\boldsymbol{b}_n-\boldsymbol{s}_j)\right] \left|\Psi_0(\boldsymbol{r}_1,...,\boldsymbol{r}_A)\right|^2 \delta\left(\frac{1}{A}\sum \mathbf{r}_j\right).$$

The exact expansion of $|\Psi|^2$ (Glauber, Foldy & Walecka):

$$|\Psi(\boldsymbol{r}_1,...,\boldsymbol{r}_A)|^2 = \prod_{j=1}^{A}\rho(\boldsymbol{r}_j) + \sum_{i<j=1}^{A} \boldsymbol{\Delta}(\boldsymbol{r}_\mathbf{i},\boldsymbol{r}_\mathbf{j}) \prod_{k\neq(il)}^{A}\rho(\boldsymbol{r}_k) + $$

$$+ \sum_{(i<j)\neq(k<l)} \boldsymbol{\Delta}(\boldsymbol{r}_\mathbf{i},\boldsymbol{r}_\mathbf{j})\,\boldsymbol{\Delta}(\boldsymbol{r}_\mathbf{k},\boldsymbol{r}_\mathbf{l}) \prod_{m\neq i,j,k,l} \rho_1(\boldsymbol{r}_m) + \ldots$$

$$\boldsymbol{\Delta}(\boldsymbol{r}_\mathbf{i},\boldsymbol{r}_\mathbf{j}) = \rho^{(2)}(\boldsymbol{r}_i,\boldsymbol{r}_j) - \rho^{(1)}(\boldsymbol{r}_i)\,\rho^{(1)}(\boldsymbol{r}_j);$$

$$|\Psi(\boldsymbol{r}_1, ..., \boldsymbol{r}_A)|^2 = \prod_{j=1}^{A} \rho(\boldsymbol{r}_j) + \sum_{i<j=1}^{A} \boldsymbol{\Delta}(\boldsymbol{r}_\mathbf{i}, \boldsymbol{r}_\mathbf{j}) \prod_{k\neq(il)}^{A} \rho(\boldsymbol{r}_k) +$$

$$+ \sum_{(i<j)\neq(k<l)} \boldsymbol{\Delta}(\boldsymbol{r}_\mathbf{i}, \boldsymbol{r}_\mathbf{j})\, \boldsymbol{\Delta}(\boldsymbol{r}_\mathbf{k}, \boldsymbol{r}_\mathbf{l}) \prod_{m\neq i,j,k,l} \rho_1(\boldsymbol{r}_m) + \ldots$$

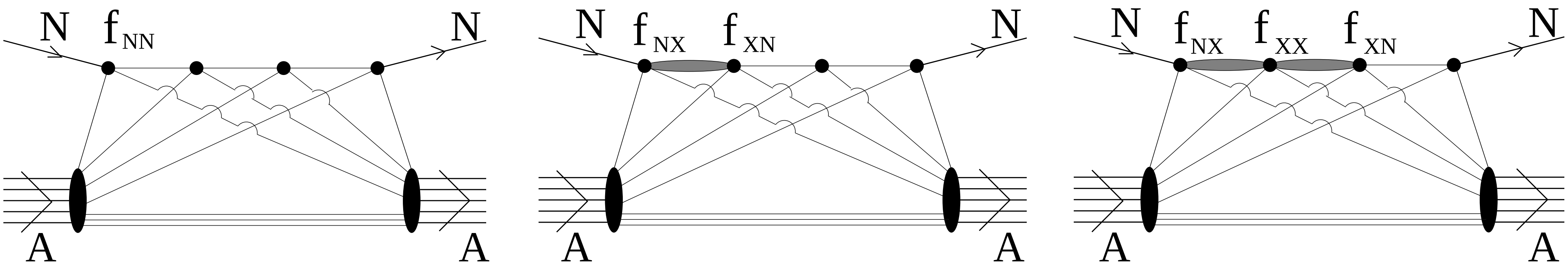
$$\simeq \prod_{j=1}^{A} \rho(\boldsymbol{r}_j)$$

Usual approximation in Glauber-type calculation: what is its validity?

Glauber + Inelastic shadowing

(Diffractive excitation of the projectile)

V. N. Gribov, *Sov. JETP 29 (1969) 483;*
V.A.Karmanov,L.A.Kondratyuk, *JETP Lett. 18 (1973) 451;*
B. Z. Kopeliovich, I. K. Potashnikova, I. Schmidt, *Phys. Rev. C73 (2006)034901*



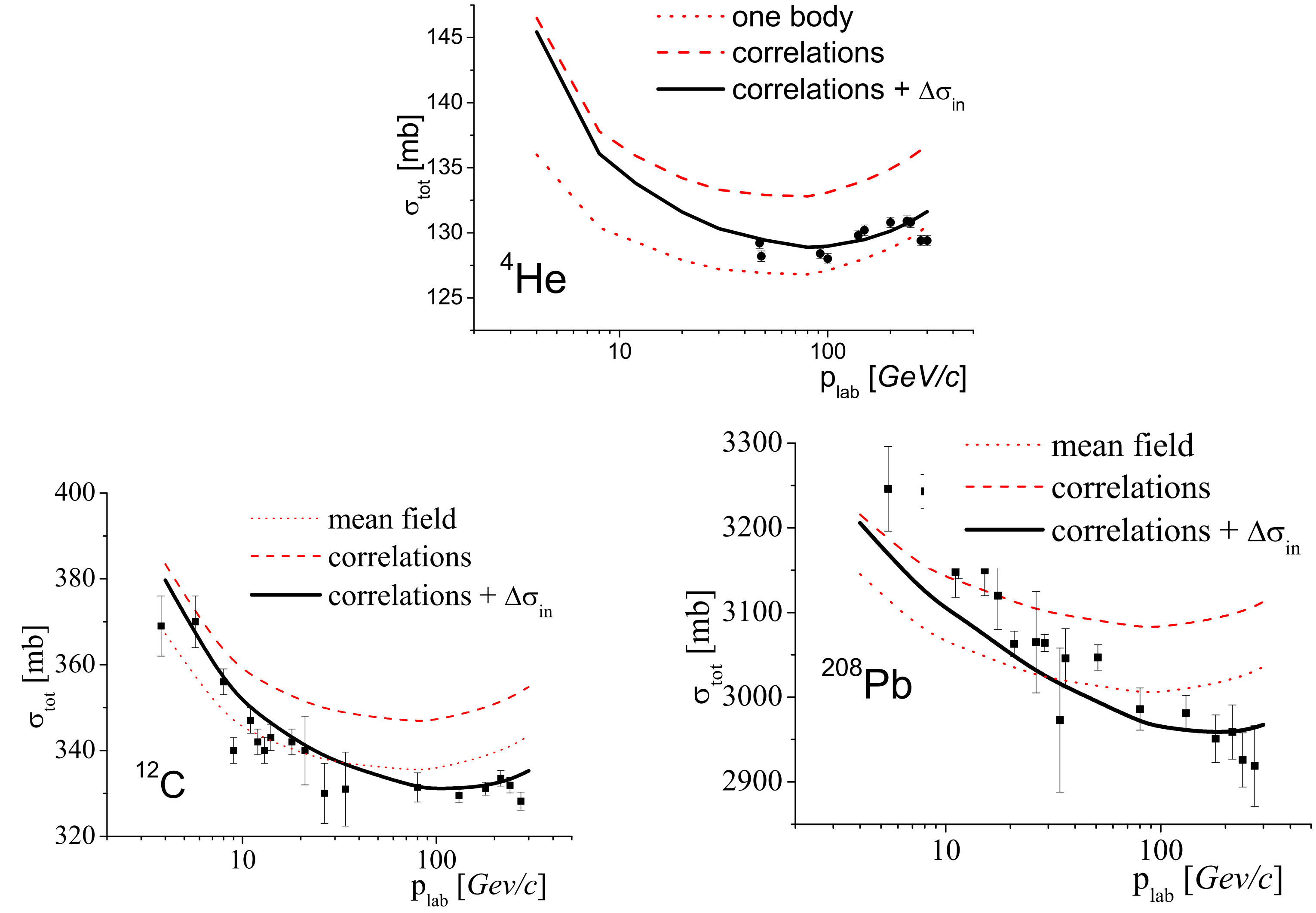
(Glauber) (Inelastic Shadowing)

total neutron-Nucleus cross section

$$\sigma_{tot} = \frac{4\pi}{k} Im \left[F_{00}^{G}(0) \right] + \Delta\sigma_{in} = \sigma_G + \Delta\sigma_{in}$$

M. Alvioli, C.d.A, I. Marchino, H. Morita, V. Palli

Phys. Rev. C78(R),031601(2008) No free parameters!!



Calculations of total, elastic, quasi-elastic and diffraction hadron-Nucleus cross sections at HERA, RHIC and LHC energy, taking inelastic Gribov corrections and SRC into account, are in progress. (Alvioli, CdA, Kopeliovich, Schmidt, Potashnikova)

Experimental data and theoretical calculations of this type would be of great relevance in the fields of, e.g., high energy heavy ion collisions, hadronization mechanism, and other phenomena which could be investigated by using the atomic nucleus as a micro detector of QCD effects.

8. CONCLUSIONS

- Advanced solutions of the nuclear many-body problem lead to nuclear wave functions exhibiting a rich SRC structure.
- The tensor force plays a dominant role in creating high momentum components.
- Reliable experimental information on 2NC and, partly, on 3NC became available confirming the basic structure of SRC, e.g. high relative momenta of the correlated pair and small pair CM momentum.
- Correlation pizza cooked out only for ^{12}C. Experiments on other nuclei both with lepton and hadronic probes are called for.
- SRC have relevant impact on the structure of cold dense matter and intermediate and high energy scattering processes.