THE ROLE OF THE NUCLEAR MEDIUM IN HIGH ENERGY SCATTERING
(Hadrons in nuclei: new theoretical and experimental developments)

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***Nuclear Physics at JPARC*, June 2007**

Università degli Studi di Perugia

OUTLINE

. **Introduction: the standard model of nuclei**

. **Hadrons in nuclei-1. Nucleon-Nucleon correlations: the new wave**

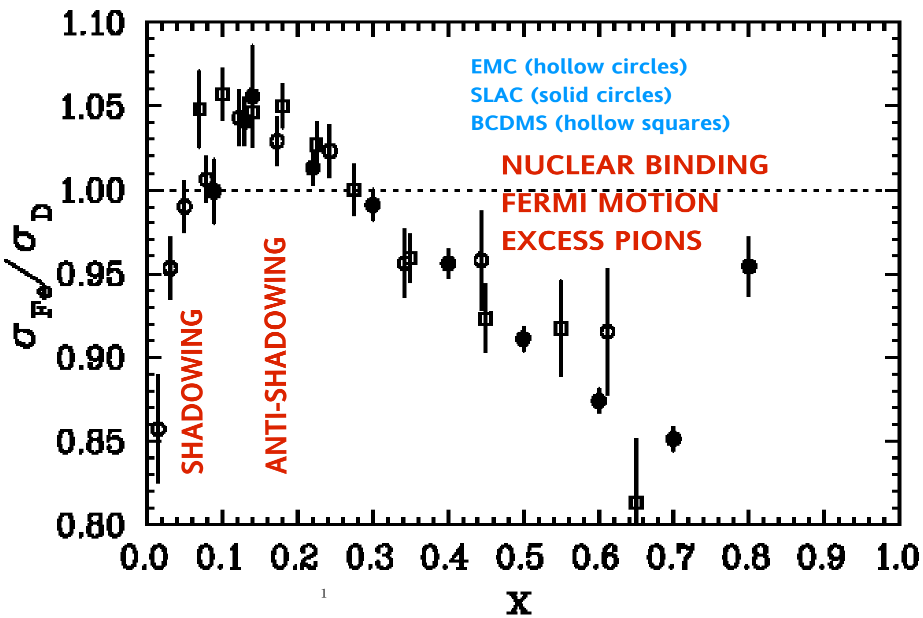
. **Hadrons in nuclei-2. Deep inelastic scattering: tagged structure functions and hadronization**

. **Summary and conclusions**

1. INTRODUCTION

Iigh energy particles are impinging on a nucleus: what do they ee? *Independent particles*, $F_A(x,Q^2) = AF_2^N(x,Q^2)$ **Or** *something else* .g. $F_A(x,Q^2) \neq AF_2^N(x,Q^2)$?

We know the answer $\rightarrow$ *EMC EFFECT*



Particles sees a complex many-body system. How do we de-cribe it?

1.2 The standard model of nuclei

$$\hat{\mathbf{H}}\,\Psi_n = E_n\,\Psi_n\,, \quad with: \quad \hat{\mathbf{H}} = -\frac{\hbar^2}{2\,m}\sum_i \hat{\nabla}_i^2 + \frac{1}{2}\sum_{i<j}\hat{v}_{ij}$$

where

$$\hat{v}_{ij} = \sum_n v^{(n)}(r_{ij})\,\hat{\mathcal{O}}_{ij}^{(n)}$$

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

The same operatorial dependence is cast onto 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.

1.3 The ground state energy - A novel approach

- **The ground state energy E_0 is given by:**

$$E_o = -\frac{\hbar^2}{2\,m}\int d\boldsymbol{r}\left[\hat{\nabla}^2\,\rho^{(1)}(\boldsymbol{r},\boldsymbol{r}')\right]_{\boldsymbol{r}=\boldsymbol{r}'} + \sum_n \int d\boldsymbol{r}_1 d\boldsymbol{r}_2\,\hat{v}^{(n)}\rho^{(2)}_{(n)}(\boldsymbol{r}_1,\boldsymbol{r}_2)$$

$$\longrightarrow\ \rho^{(1)}(\boldsymbol{r},\boldsymbol{r}') = A\int \prod_{j=2}^{A} d\boldsymbol{r}_j\,\Psi_o^\dagger(\boldsymbol{r},\boldsymbol{r}_2\ldots,\boldsymbol{r}_A)\,\Psi_o(\boldsymbol{r}',\boldsymbol{r}_2\ldots,\boldsymbol{r}_A)$$

$$\longrightarrow\ \rho^{(2)}_{(n)}(\boldsymbol{r}_1,\boldsymbol{r}_2) = \frac{A(A-1)}{2}\int \prod_{j=3}^{A} d\boldsymbol{r}_j\,\Psi_o^\dagger(\boldsymbol{r}_1\ldots,\boldsymbol{r}_A)\,\hat{O}^{(n)}_{12}\,\Psi_o(\boldsymbol{r}_1\ldots,\boldsymbol{r}_A)$$

- $\rho^{(1)}(\boldsymbol{r},\boldsymbol{r}')$ **and** $\rho^{(2)}_{(n)}(\boldsymbol{r}_1,\boldsymbol{r}_2)$ **are *cluster expanded*;**
- **the wave function and correlation functions which minimize the ground-state energy are used to calculate the expectation value of any operator at the same order.**

PHYSICAL REVIEW C **72**, 054310 (2005)

und-state energies, densities and momentum distributions in closed-shell nuclei calculated within a cluster expansion approach and realistic interactions

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(Received 4 July 2005; published 16 November 2005)

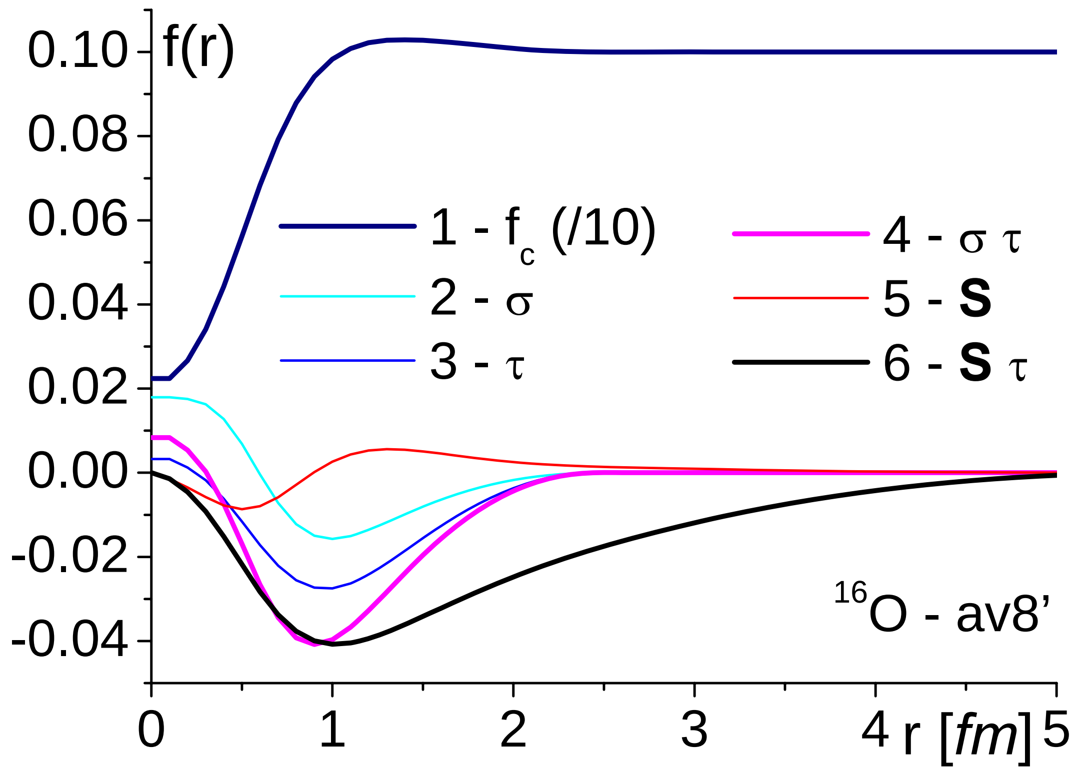
A linked cluster expansion suitable for the treatment of ground-state properties of complex nuclei, as well as of various particle-nucleus scattering processes, has been used to calculate the ground-state energy, density, and momentum distribution of ^{16}O and ^{40}Ca in terms of realistic interactions. First, a benchmark calculation for the ground-state energy is performed with the truncated $V8'$ potential and consisting of the comparison of our results with the ones obtained by the Fermi hypernetted chain approach, adopting in both cases the same mean-field wave functions and the same correlation functions. The results exhibited a nice agreement between the two methods. Therefore the approach has been applied to the calculation of the ground-state energy, density, and momentum distributions of ^{16}O and ^{40}Ca by use of the full $V8'$ potential, and again a satisfactory agreement was found with the results based on more advanced approaches in which higher-order cluster contributions are taken into account. It appears therefore that the cluster expansion approach can provide accurate approximations for various diagonal and nondiagonal density matrices, so that it could be used for a reliable evaluation of nuclear effects in various medium- and high-energy scattering processes off nuclear targets. The developed approach can be readily generalized to the treatment of Glauber-type final-state interaction effects in inclusive, semi-inclusive, and exclusive processes off nuclei at medium and high energies.

DOI: 10.1103/PhysRevC.72.054310 PACS number(s): 21.60.−n, 21.10.Dr, 27.20.+n, 27.40.+z

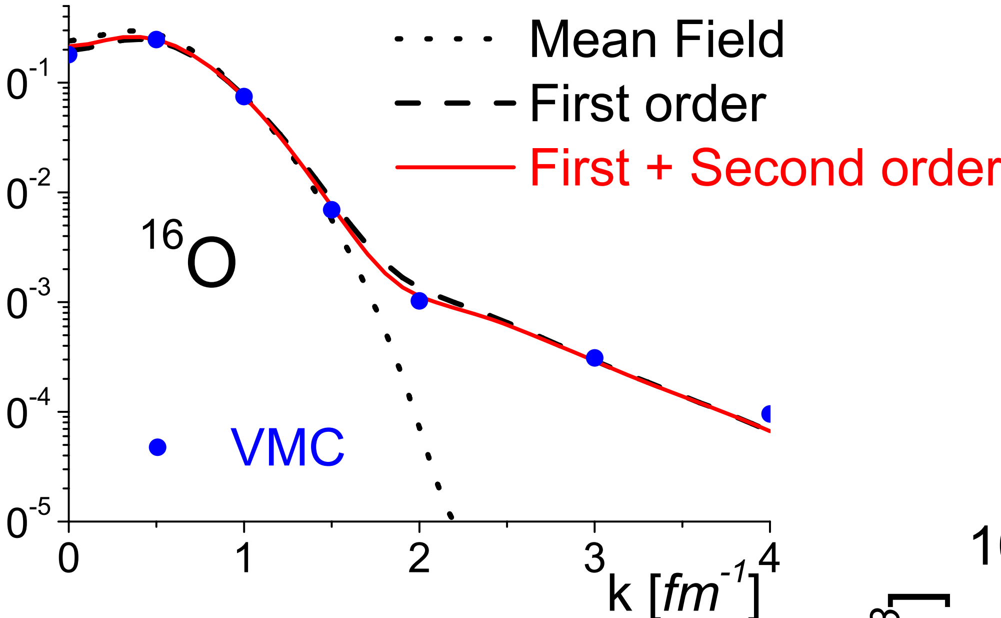
ground state energy: ^{16}O - *Argonne* $V8'$

	$< V_c >$	$< V_\sigma >$	$< V_\tau >$	$< V_{\sigma\tau} >$	$< V_S >$	$< V_{S\tau} >$	$< \mathbf{V} >$	$< \mathbf{T} >$	**E**	**E/A** MeV
η−*exp*	0.19	-35.88	-9.47	-171.32	-0.003	-172.89	-389.40	323.50	**-65.90**	-4.12
FHNC	0.694	-40.13	-10.61	-180.00	-0.07	-160.32	-390.30	325.18	**-65.12**	-4.07

correlation functions: *Central*, *Spin-Isospin*, *Tensor*



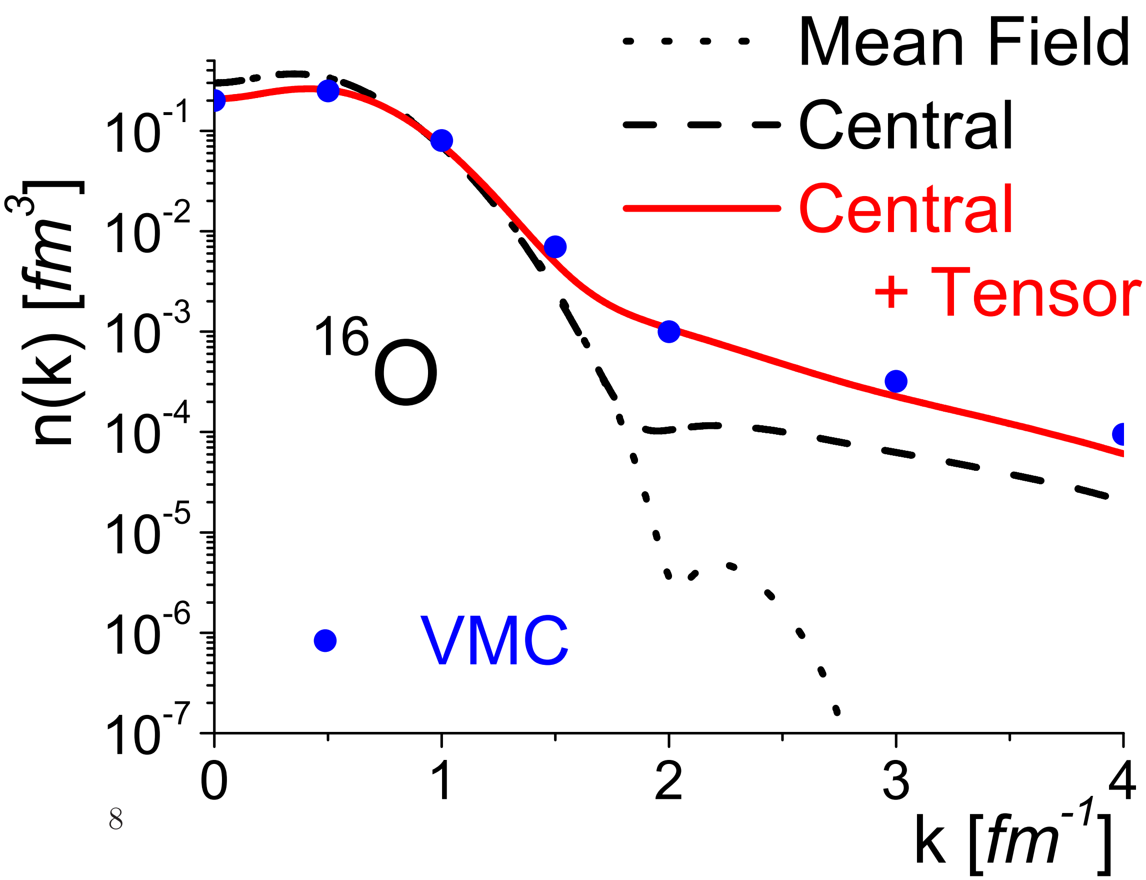
Momentum distributions and *tensor forces*



$\longleftarrow$ **cluster expansion convergence**

$\mathbf{k > 1.5\ fm^{-1}}$: $\longrightarrow$

Tensor correlations!



1.4 The Nucleon Spectral Function and correlations

$$P_A(|\mathbf{k}|, E) = P_0(|\mathbf{k}|, E) + P_1(|\mathbf{k}|, E)$$

$$P_0(|\mathbf{k}|, E) = \sum_{\alpha<\alpha_F} \tilde{n}_\alpha(|\mathbf{k}|)\delta(E - |\epsilon_\alpha|) \qquad \int \tilde{n}_\alpha d\boldsymbol{k} < 1$$

$$P_1(|\mathbf{k}|, E) = \sum_{f\neq\alpha} \left| \int d\mathbf{r}\; e^{i\mathbf{k}\cdot\mathbf{r}}\; G_{f0}(\vec{r}) \right|^2 \delta[E - (E^f_{A-1} - E_A)]$$

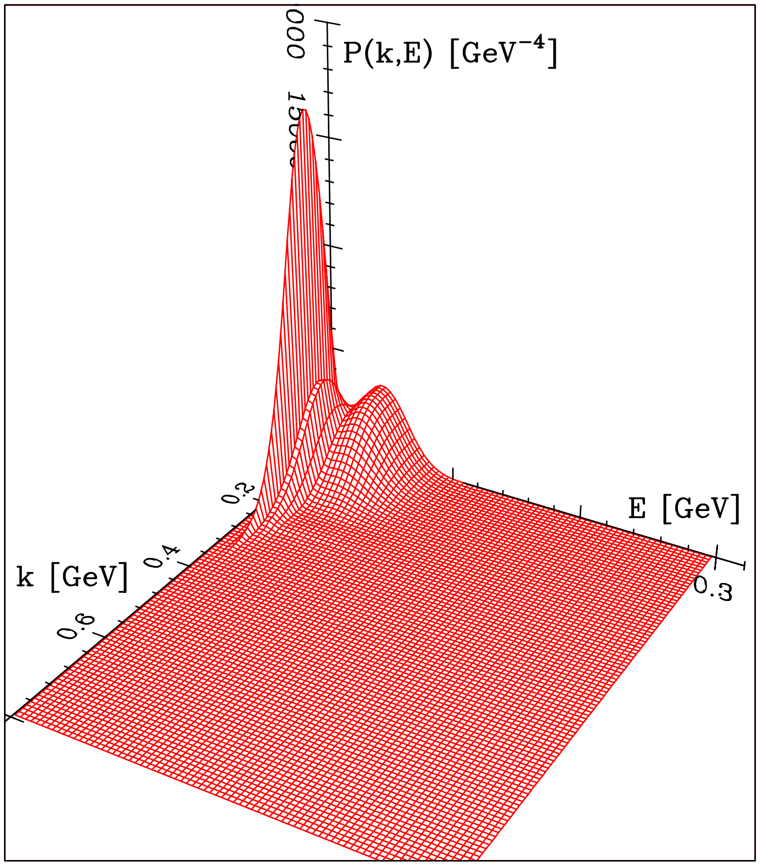
P_0 - **renormalized shell model** $\qquad$ P_1 - **correlations**

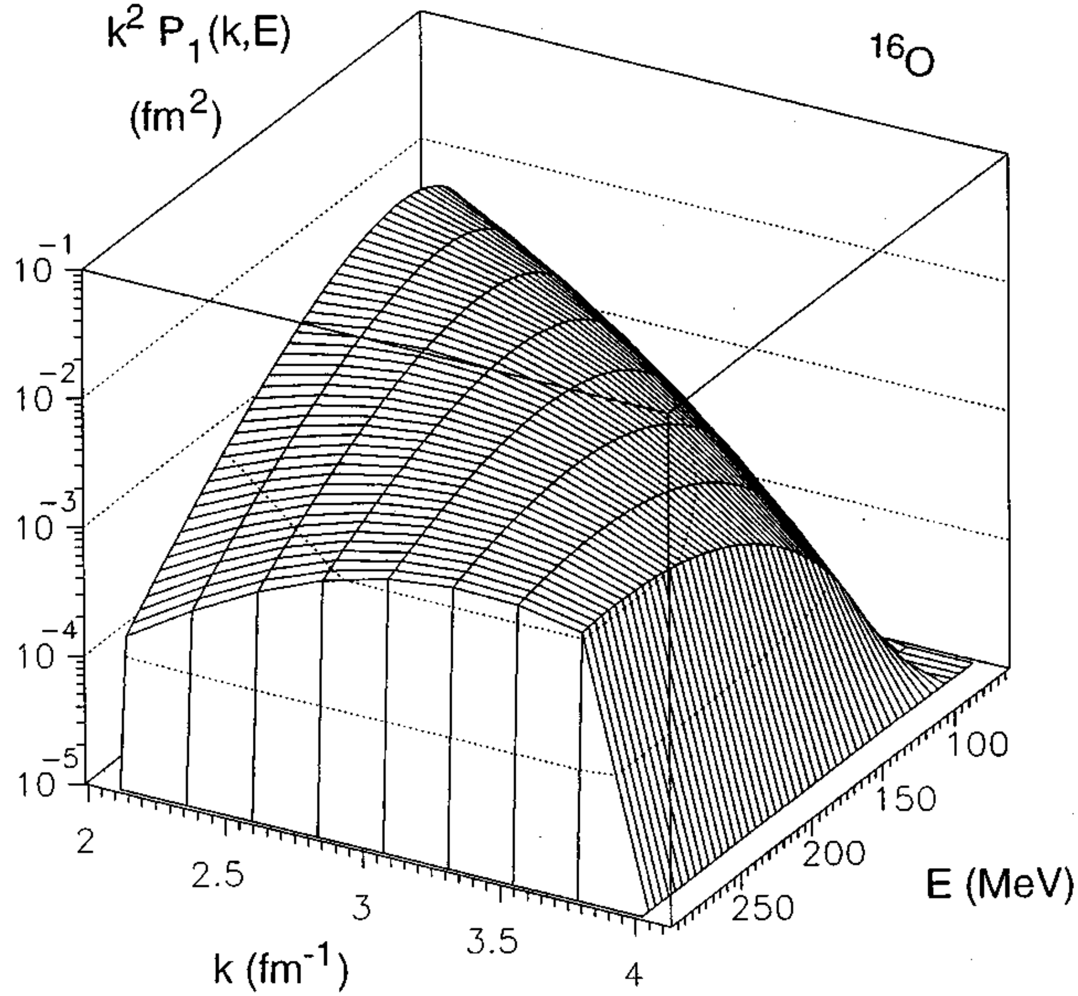
A=3 and ∞ Theory OK $\qquad$ **Complex Nuclei - Models**

The Few-Nucleon Correlation Model (FNC) (*F & S, CdA, Simula*)

$$P_1^A(|\mathbf{k}|, E) = \int d\mathbf{P}_{cm}\; n^A_{rel}(|\mathbf{k} - \mathbf{P}_{cm}/2|)\, n^A_{cm}(|\mathbf{P}_{cm}|) \cdot$$
$$\cdot\,\delta\left[E - E^{(2)}_{thr} - \frac{(A-2)}{2M(A-1)} \cdot \left(\mathbf{k} - \frac{(A-1)\mathbf{P}_{cm}}{(A-2)}\right)^2\right]$$

Spectral Function - ^{16}O





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

$\boldsymbol{M \quad (E = \epsilon_\alpha): \; 80\%}$ $\boldsymbol{Correlations \;\; (E \simeq k^2/2m_N): \; 20\%}$

S. Simula, CdA - PRC 53 (1996)

Realistic model of the nucleon spectral function in few- and many-nucleon systems

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(Received 13 July 1995)

By analyzing the high-momentum features of the nucleon momentum distribution in light and complex nuclei, it is argued that the basic two-nucleon configurations generating the structure of the nucleon spectral function at high values of the nucleon momentum and removal energy can be properly described by a factorized ansatz for the nuclear wave function, which leads to a nucleon spectral function in the form of a convolution integral involving the momentum distributions describing the relative and center-of-mass motion of a correlated nucleon-nucleon pair embedded in the medium. The spectral functions of ^{3}He and infinite nuclear matter resulting from the convolution formula and from many-body calculations are compared, and a very good agreement in a wide range of values of nucleon momentum and removal energy is found. Applications of the model to the analysis of inclusive and exclusive processes are presented, illustrating those features of the cross section which are sensitive to that part of the spectral function which is governed by short-range and tensor nucleon-nucleon correlations.

PACS number(s): 21.10.Jx, 21.65.+f, 24.10.Cn, 27.10.+h

95, 052502 (2005) PHYSICAL REVIEW LETTERS week ending 29 JULY 2005

erpretation of the Processes ^{3}He$(e, e'p)^2$H and ^{3}He$(e, e'p)(pn)$ at High Missing Momenta

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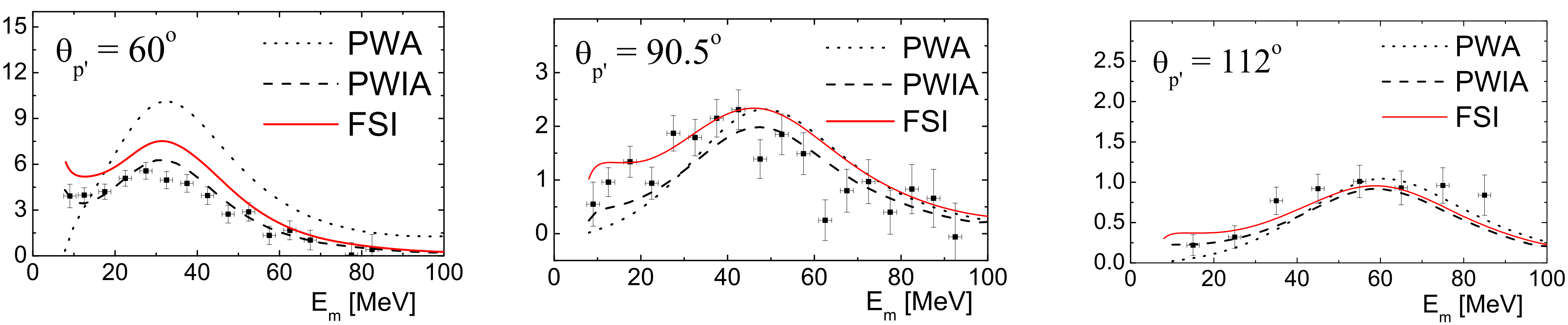
(Received 26 March 2005; published 27 July 2005)

Using realistic three-body wave functions corresponding to the $AV18$ interaction, it is shown that the effects of the final state interaction in the exclusive processes ^{3}He$(e, e'p)^2$H and ^{3}He$(e, e'p)(pn)$, can be successfully treated in terms of a generalized eikonal approximation based upon the direct calculation of the Feynman diagrams describing the rescattering of the struck nucleon. The relevant role played by the double rescattering contribution at high values of the missing momentum is illustrated.

DOI: 10.1103/PhysRevLett.95.052502 PACS numbers: 24.10.−i, 25.10.+s, 25.30.Dh, 25.30.Fj

$$d^6\sigma/dE'_e\, d\Omega'_e\, d\Omega_p\, dE_m \qquad [pb\, MeV^{-1}\, sr^{-1}]$$



$He(e,e'p)(np)$: ***correlation bumps at*** $E_m \simeq p_m^2/2m_n$ ***clearly seen***

2. HADRONS in NUCLEI - 1.

UCLEON-NUCLEON CORRELATIONS: THE NEW WAVE

Obtaining information on SRC is useful in various fields of physics:

. check of the standard model of nuclei;

. the structure of cold nuclear matter at high densities;

. EoS of neutron stars;

. quark-gluon physics.

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*

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

Does it makes sense to speak in this situation about nucleons since

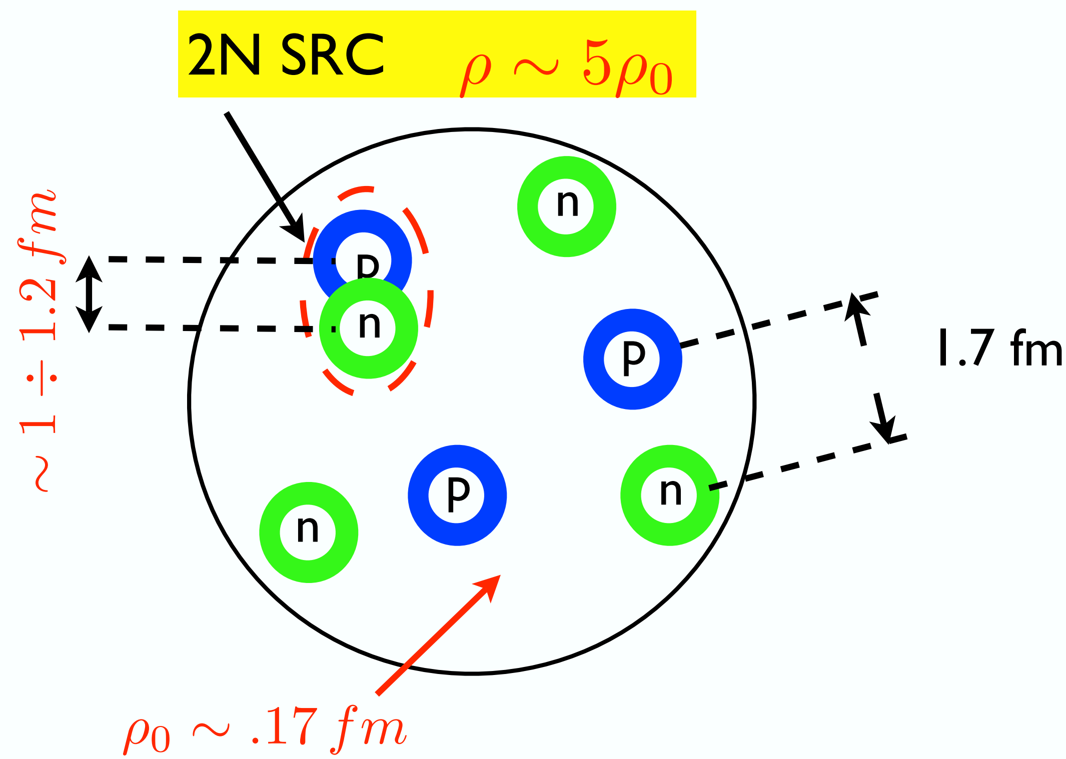
$$r_N = \left\langle r^2_{p_{e.m.}} \right\rangle^{1/2} \approx 0.8\, fm \quad \text{and} \quad r_c \ll 2r_N \ ?$$

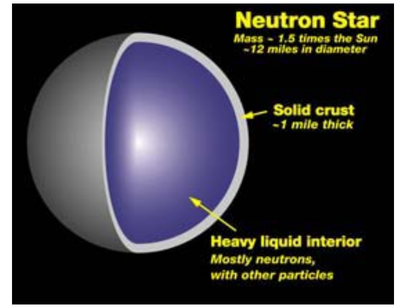
Quark distribution in the nucleon is $\rho_N(r) = \exp(-\mu r)$, $\mu = 0.8$ GeV

$2\rho_N(r_c/2) = \rho_N(0) \quad \Rightarrow \quad r_c = .35$ fm

F&S 75

hort-range NN orrelations (SRC) have lensities comparable to he density in the center of nucleon - *drops of cold lense nuclear matter*



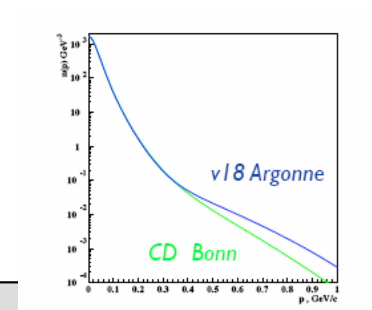


Study of cold dense nuclear matter complementary to study of hot dense nuclear matter

Dynamics of neutron star formation and structure

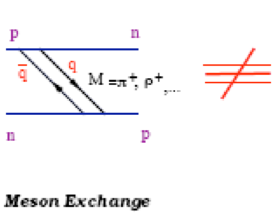
SRC

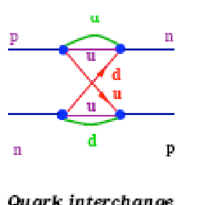
in nuclei

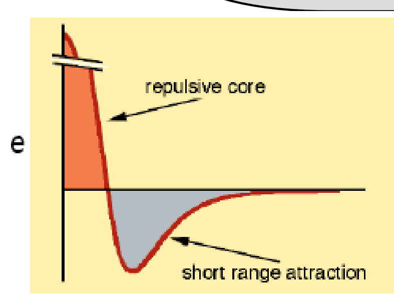


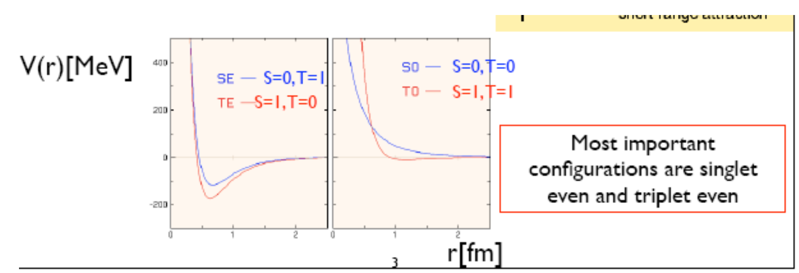
NN interaction:
short range repulsive core and
the role played by the tensor force

Quark vs. hadronic degrees of freedom in nuclei









NEW WAVE

IN THE EXPERIMENTAL STUDY OF CORRELATIONS:

RECENT ORIGINAL AND DEDICATED EXPERIMENTS

WITH

LEPTONIC

&

HADRONIC

PROBES

THE NEW WAVE

(from ***F. Truffaut, Jules et Jim***, the movie (FR, 1961))

INCLUSIVE LEPTON SCATTERING $A(e,e')X$ at JLAB

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

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Chen,[11] P. L. Cole,[3
R. DeVita,[16] P. V. D
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A. Empl,[30] P. Euge
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F. W. Hersman,[24] K
D. G. Ireland,[13] B.
M. Khandaker,[25] K
H. Kramer,[10,34] V. K
D. Lawrence,[22] T.
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M. Qin,[27] B. A. Rau
Rowntree,[21] P. D.
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B. E. Stokes,[11] P. S
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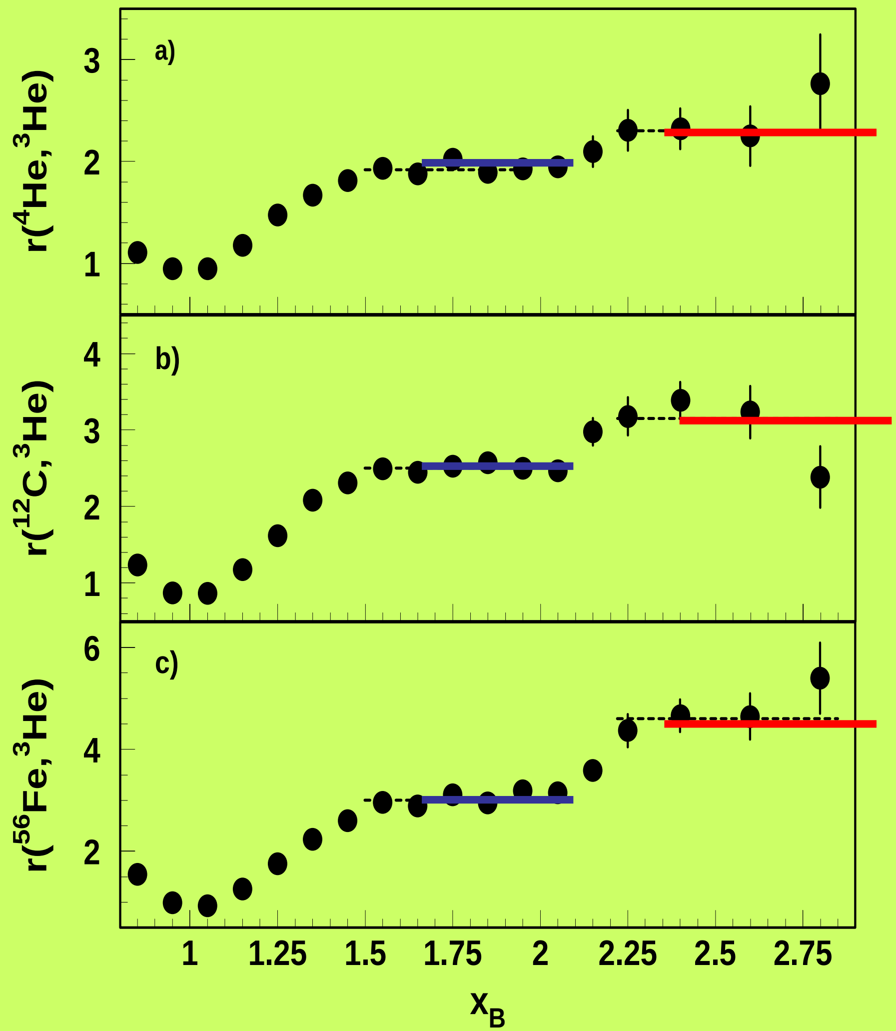
New CLAS A(e,e') Result:

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 ^{3}He.

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

THE NEW WAVE

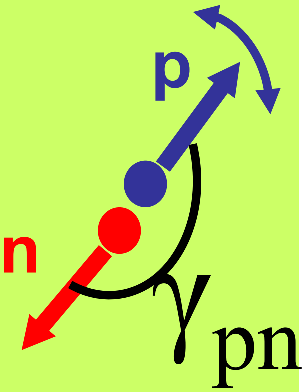
HADRON SCATTERING

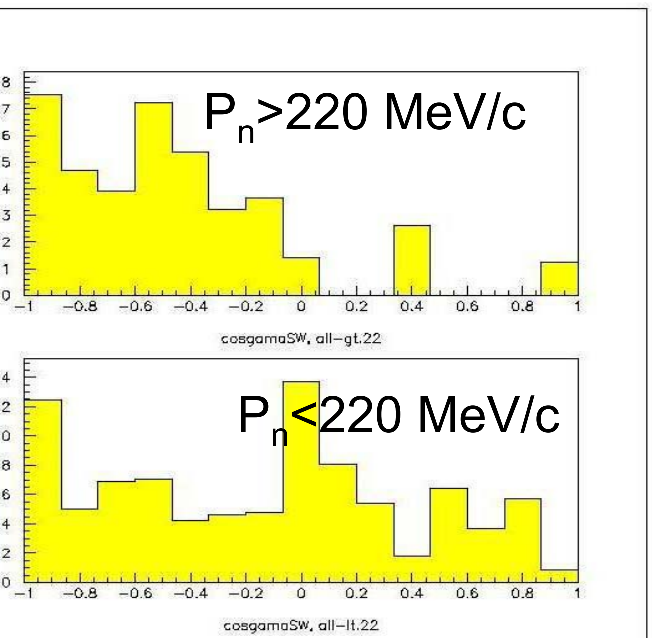
$$A(p, 2p + n)X$$

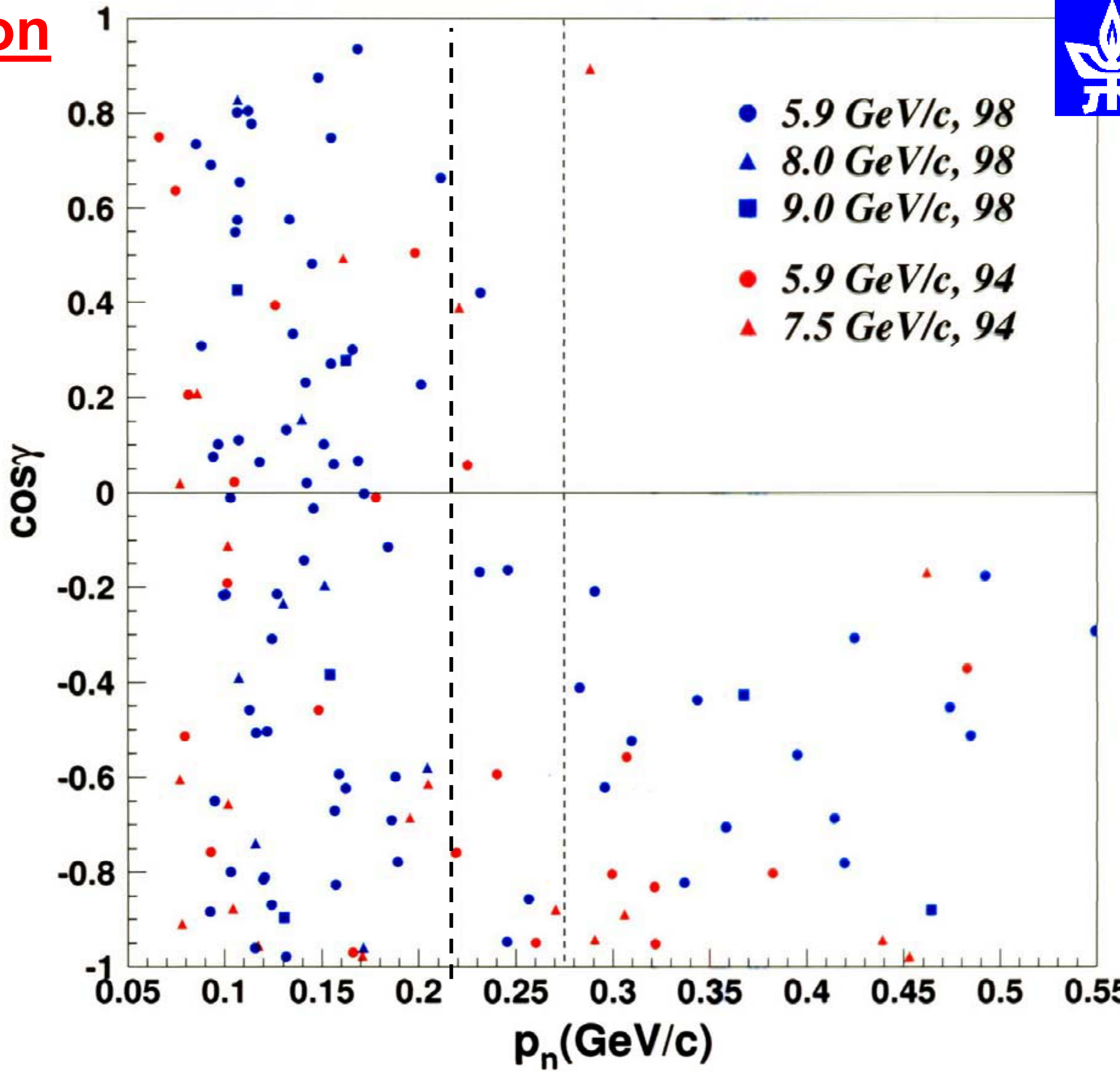
at BNL

Directional correlation

(p,2pn)







The EVA/BNL collaboration

Evidence for Strong Dominance of Proton-Neutron Correlations in Nuclei

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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]:

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

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 [$P_{NN}(^{12}\mathrm{C}) = 0.20 \pm 0.042$] 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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THE NEW WAVE

FUTURE EXPERIMENTS

at

JLAB

Studying Short-Range Correlations in Nuclei at the Repulsive Core Limit via the Triple Coincidence $(e, e'pN)$ Reaction

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Massachusetts Institute of Technology, Cambridge, MA, USA

B.D. Anderson, A.R. Baldwin, G. Petratos, *J.W. Watson (spokesperson)*, R. Subedi, and W-Ming Zhang

Kent State University, Kent, OH, USA

E. Chudakov, J.P. Chen, J.-O. Hansen, *D.W. Higinbotham (spokesperson)*, M. Jones, J.-M. Laget, J.J. LeRose, D. Meekins, A. Saha, and S. Wood

Thomas Jefferson National Accelerator Facility, Newport News, VA, USA

V. Sulkosky

THE NEW WAVE

(new wave: Ryuichi Sakamoto, JP)

FUTURE EXPERIMENTS at JPARC?

$$A(p,2p)X \quad A(p,2pN)$$

- **Higher cross sections**
- **FSI also increase but reliable theoretical approaches based upon Glauber multiple scattering are available**
- **Correlations**
- **Beyond the standard model of nuclei (exotic components in the nuclear wave function)**
- **Color transparency**

Data from EVA experiment

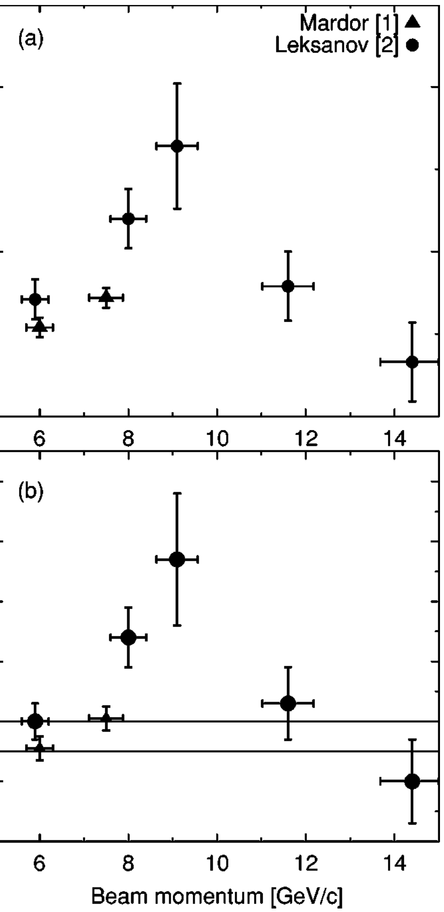
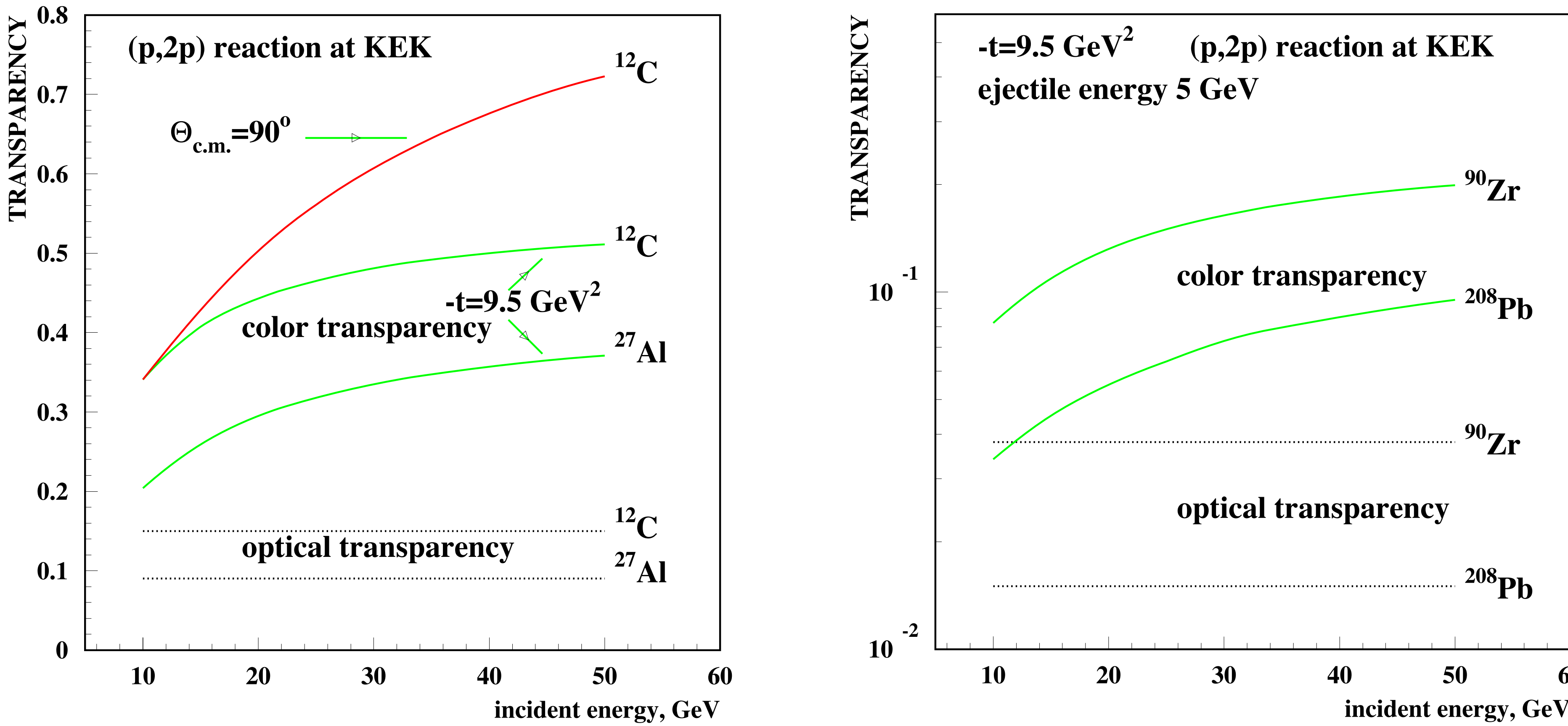


FIG. 11. (a) (top frame) The nuclear transparency ratio T_{CH} as a function of beam momentum. (b) (bottom frame) The nuclear transparency T_{pp} as a function of the incident beam momentum. The events in these plots are selected using the cuts of Eq. (9), and a restriction on the polar angles as described in the text. The errors shown here are statistical errors, which dominate for these measurements.

- Eikonal approximation calculation with proper normalization of the wave function (Frankfurt, Zhalov, MS) agrees well the 5.9 GeV data.

- Significant effect for p= 9 GeV where l_{coh}= 2.7 fm. 10 GeV is sufficient to suppress to some extent expansion effects. Hence one can use energies above 10 GeV to study other aspects of the dynamics

- Glauber level transparency for 11.5 -14.2 GeV a problem for all models as $24\ GeV^2 \leq s' \leq 30\ GeV^2$ since it is too broad for a resonance of for interference of quark exchange and Landshoff mechanisms



Energy dependence of the nuclear transparency calculated in the quantum diffusion model with $\Delta m^2 = 0.7 GeV^2$ ~ as compared to the expectations of the Glauber model.

SRC in scattering at high energies

- **SRC: are they relevant only in dedicated medium energy experiments?**
- **exact many-body wave functions (Foldy & Walecka):**

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

where the *two-body contraction* $\boldsymbol{\Delta}$ is

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

The total *neutron – Nucleus* cross section at high energies:

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

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

The usual approximation in Glauber-type calculations

$$\left|\Psi(\boldsymbol{r}_1,...,\boldsymbol{r}_A)\right|^2 = \prod_{j=1}^{A}\rho(\boldsymbol{r}_j) \quad i.e. \quad \boldsymbol{\Delta}(\boldsymbol{r}_\mathbf{i},\boldsymbol{r}_\mathbf{j}) = 0$$

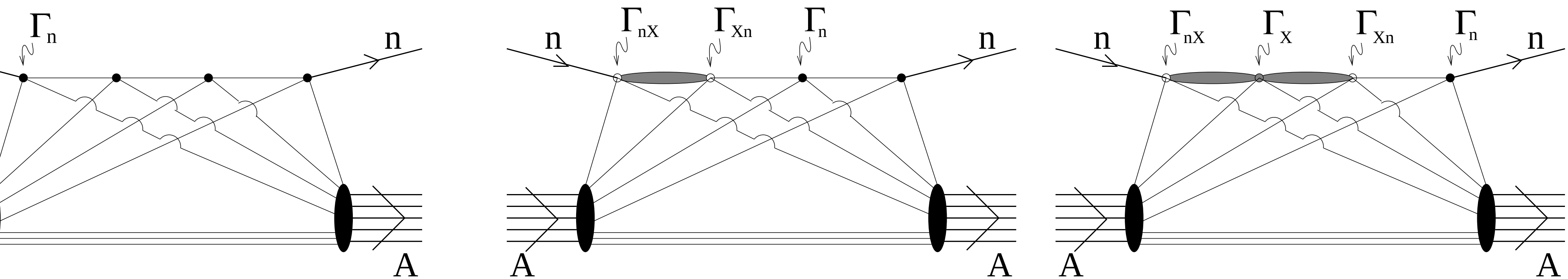
If correlations are taken into account i.e.

$$\boldsymbol{\Delta}(\boldsymbol{r}_\mathbf{i},\boldsymbol{r}_\mathbf{j}) = \rho^{(2)}(\boldsymbol{r}_i,\boldsymbol{r}_j) - \rho^{(1)}(\boldsymbol{r}_i)\,\rho^{(1)}(\boldsymbol{r}_j) \neq 0;$$

$$\sigma_{\mathbf{tot}} = \sigma_{\mathbf{G}}^{(\mathbf{1})} + \sigma_{\mathbf{G}}^{(\mathbf{2})}$$

Glauber + Inelastic shadowing

(*Diffractive excitation of the projectile*)

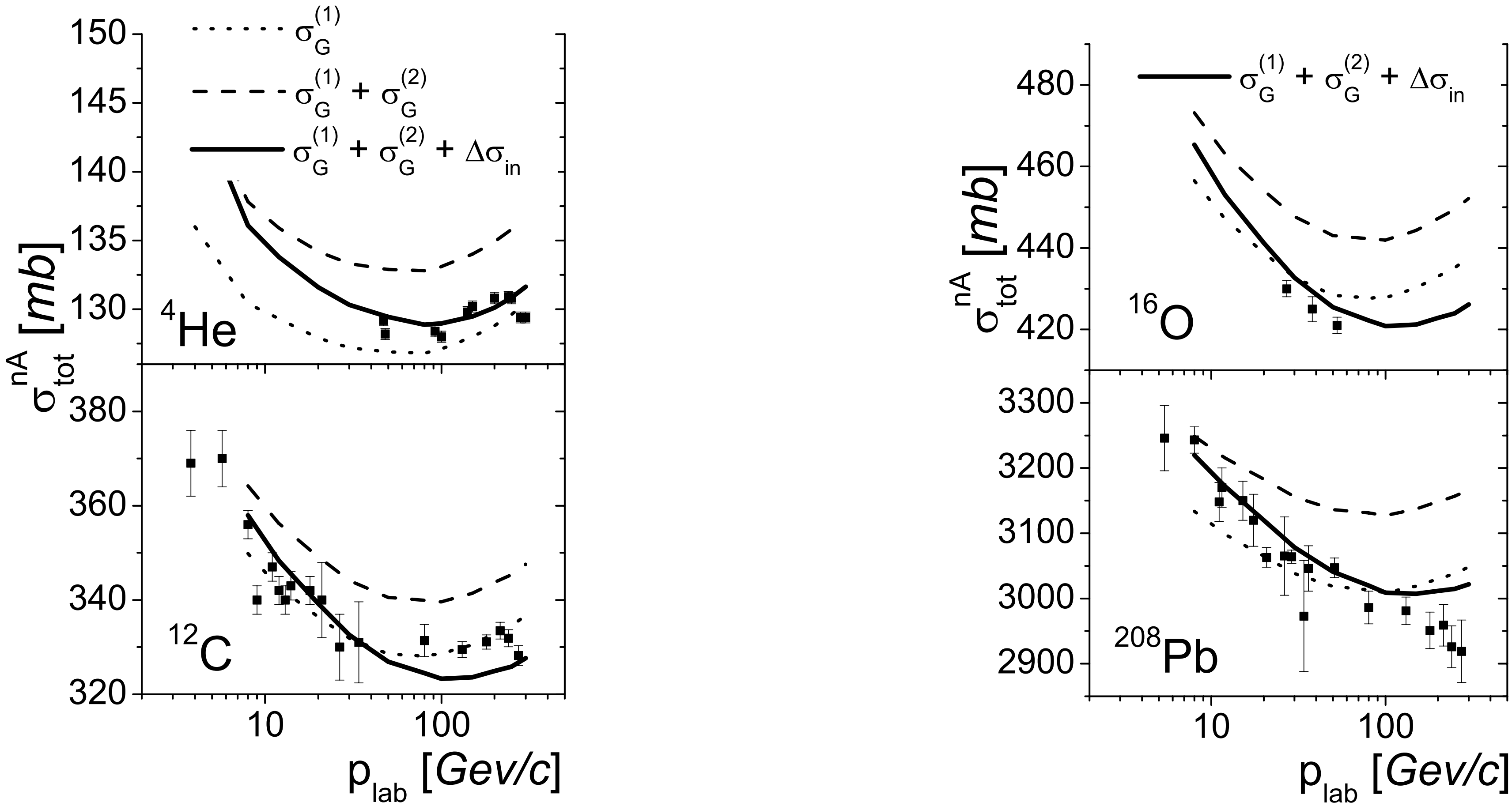


(Glauber) **(Inelastic Shadowing)**

total neutron-Nucleus cross section:

$$\sigma_{\mathbf{tot}} = \sigma_{\mathbf{G}}^{(\mathbf{1})} + \sigma_{\mathbf{G}}^{(\mathbf{2})} + \mathbf{\Delta}\sigma_{\mathbf{in}}$$

RESULTS



No adjustable parameters

M.Alvioli, CdA, I.Marchino, H.Morita and V.Palli,

nucl-th:07053613

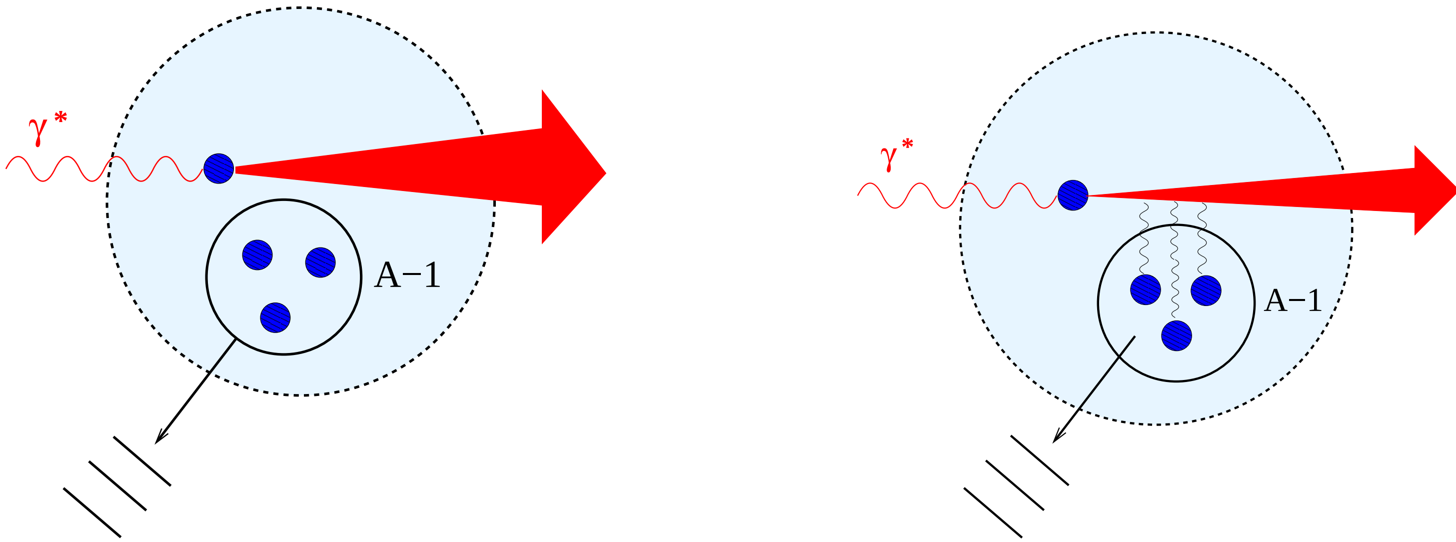
. HADRONS in NUCLEI-2. TAGGED STRUCTURE FUNCTIONS AND HADRONIZATION

The Semi-Inclusive DIS process $\mathbf{A(e, e'B)X}$ process within the Spectator Mechanism

The *quark-gluon debris* propagates through the nucleus

PWIA

FSI



$$\frac{\mathbf{d\sigma^A}}{\mathbf{dx\, dQ^2\, d\vec{P}_{A-1}}} \propto \mathbf{F_2^{N/A}(x_A, Q^2, p_1^2)\, N_A(|\vec{p}_1|)} \qquad \mathbf{\vec{p}_1 \equiv -\vec{P}_{A-1}}$$

$F_2^{N/A}(x_A, Q^2, p_1^2)$ **Bound Nucleon Structure Function**

PWIA:

$\mathbf{N_A}(|\mathbf{p}_1|)$ **Nucleon Momentum Distribution**

Quark-gluon debris rescattering (FSI):

$\mathbf{N_A}(|\mathbf{P}_1|) \longrightarrow$ *Distorted* (D) **Momentum Distributions** $\mathbf{N}_A^D(\mathbf{P}_{A-1})$

$$\mathbf{N}_A^D(\mathbf{P}_{A-1}) = \left| \int_z^\infty e^{i\mathbf{P}_{A-1}\cdot\mathbf{r}} \phi(\mathbf{b}, z) e^{-\frac{1}{2}S(\mathbf{b},z)} \right|^2$$

$$S(\vec{b}, z) = \int_z^\infty dz' \, \rho_A(\vec{b}, z') \, \sigma_{eff}(z' - z)$$

evaluated within Glauber theory *but* $\longrightarrow$ time-dependent profile function

$$\Gamma^{\mathbf{NN}}(\mathbf{b}_1 - \mathbf{b}_i) \longrightarrow \Gamma^{\mathbf{N^*N}}(\mathbf{b_1} - \mathbf{b_i}, \mathbf{z_i} - \mathbf{z_1})$$

The EFFECTIVE Debris-Nucleon CROSS SECTION

(CdA, B. Kopeliovich, EPJA, A17 (2003) 133)

he hadronization model:

. Kopeliovich, J. Nemchik, E. Predazzi, A. Hayashigaki, ucl.Phys. A740(2004)212

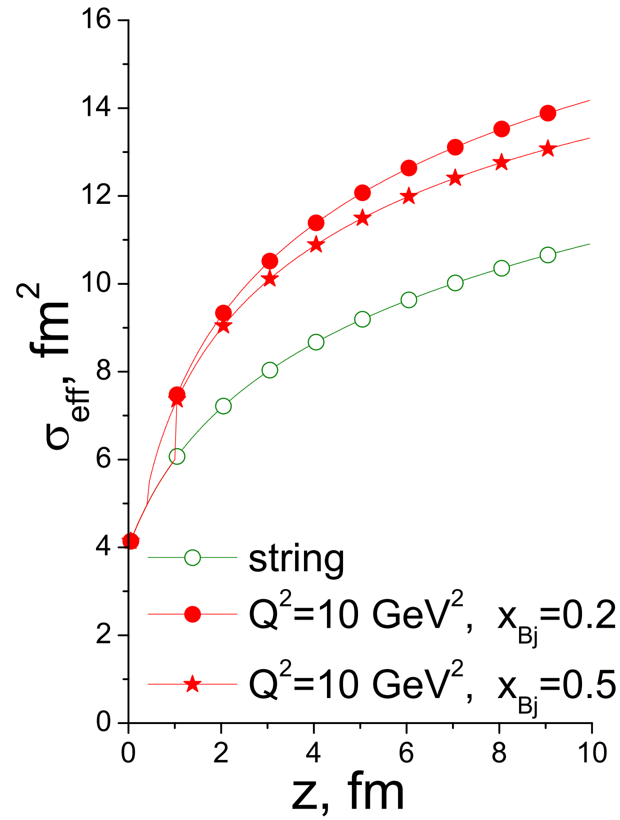
he formation of the final hadrons occurs during and after the ropagation of the created nucleon debris through the nucleus, ith a sequence of soft and hard production processes.

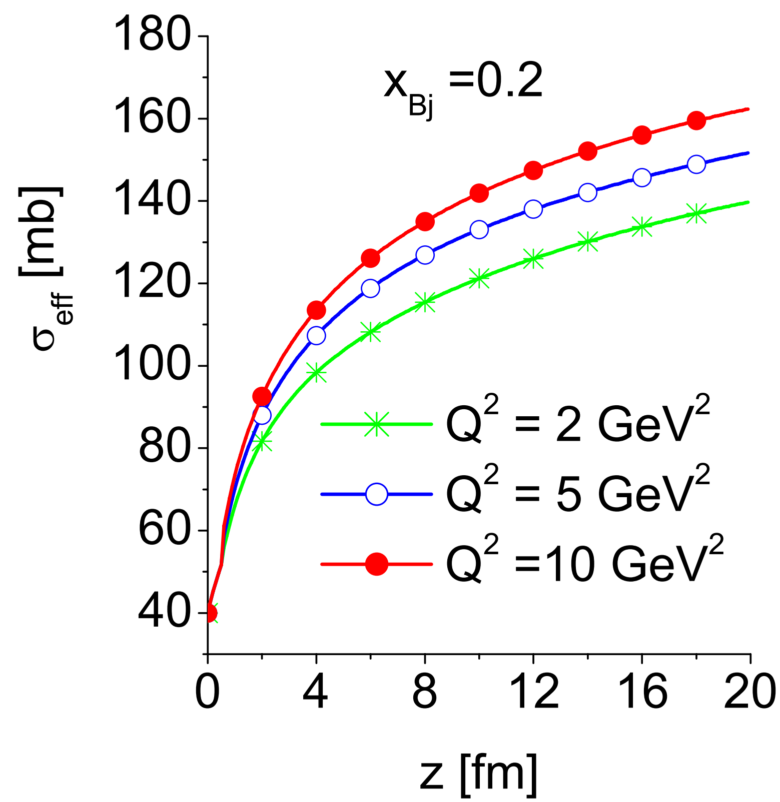
oft production $\rightarrow Q < \lambda = 0.65\, GeV$ **npQCD**, string model

ard production $\rightarrow Q > \lambda = 0.65\, GeV$ **pQCD**, gluon radiation odel .

The EFFECTIVE Debris-Nucleon CROSS SECTION

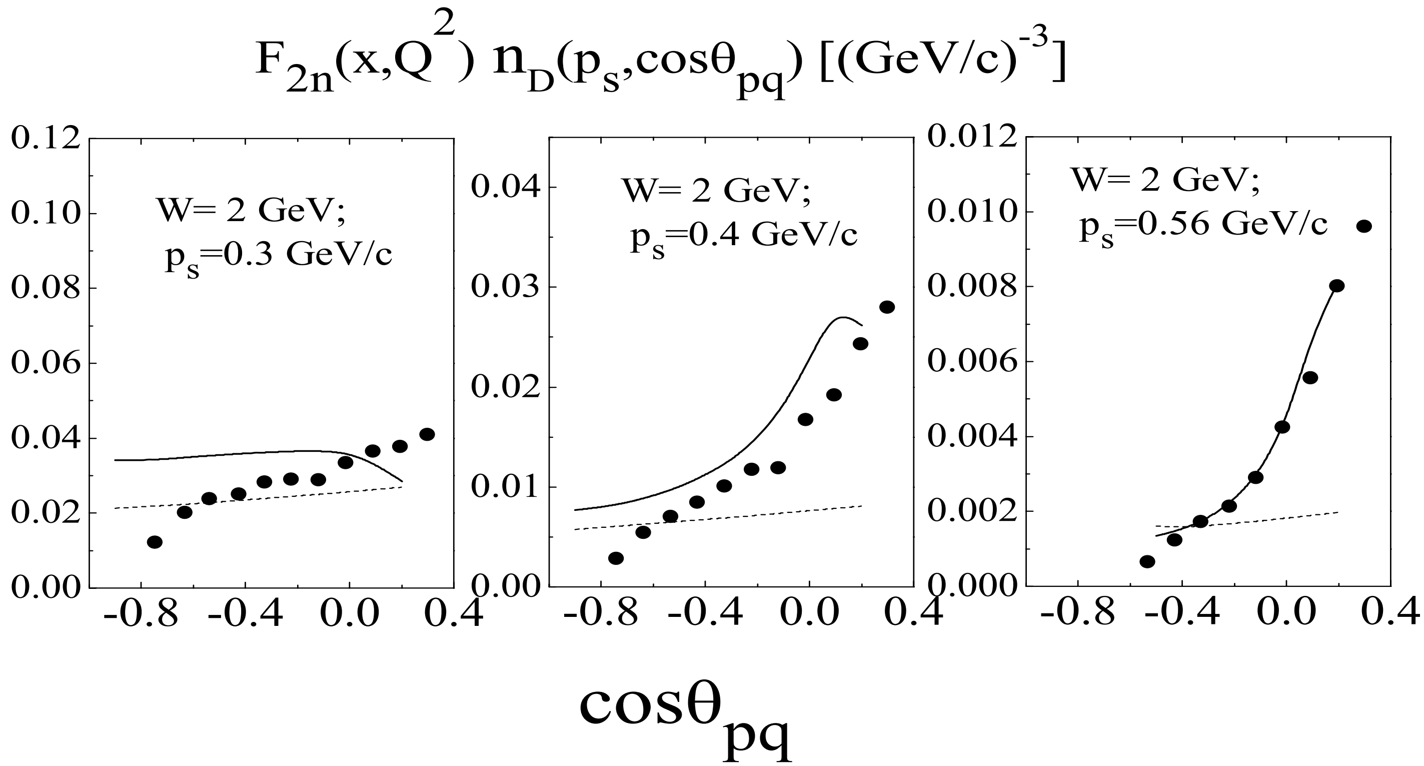
$$\sigma_{\mathbf{eff}}(\mathbf{t}) = \sigma^{\mathbf{NN}}_{\mathbf{tot}} + \sigma^{\mathbf{MN}}_{\mathbf{tot}}[\mathbf{n_M}(\mathbf{t}) + \mathbf{n_G}(\mathbf{t})]$$





- **Steep rise with time (distance).**
- Q^2 **and** x_Bj **dependence due to gluon radiation mechanism.**

^{2}H(e, e′p)X theory vs. experiment



.V. ***Klimenko, S.E. Kuhn et al. Phys. Rev.* C73** (2006) 035212;

M.Alvioli, CdA et al., *nucl-th:07053617*

4. CONCLUSIONS

- **reliable predictions of the full correlated structure of the nucleus are being produced;**
- **a new wave of experimental studies at medium energies aimed at mapping the intermediate and short range structure of nuclei is going on; first results confirm the basic validity of the two-nucleon correlation picture of SRC;**
- **much remains to be done (e.g. the core region and the isospin structure of NN correlations, the medium effects on the nucleon properties (tagged structure functions, etc); to this end the extension of the experiments to higher energies using both leptonic and hadronic probes would be extremely useful.**