The Abdus Salam
International Centre for Theoretical Physics

United Nations
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SMR.1751 - 26

Fifth International Conference on
PERSPECTIVES IN HADRONIC PHYSICS
Particle-Nucleus and Nucleus-Nucleus Scattering at Relativistic Energies

22 - 26 May 2006

Studying close proximity nucleons in nuclei via high-energy/large momentum-transfer exclusive reactions

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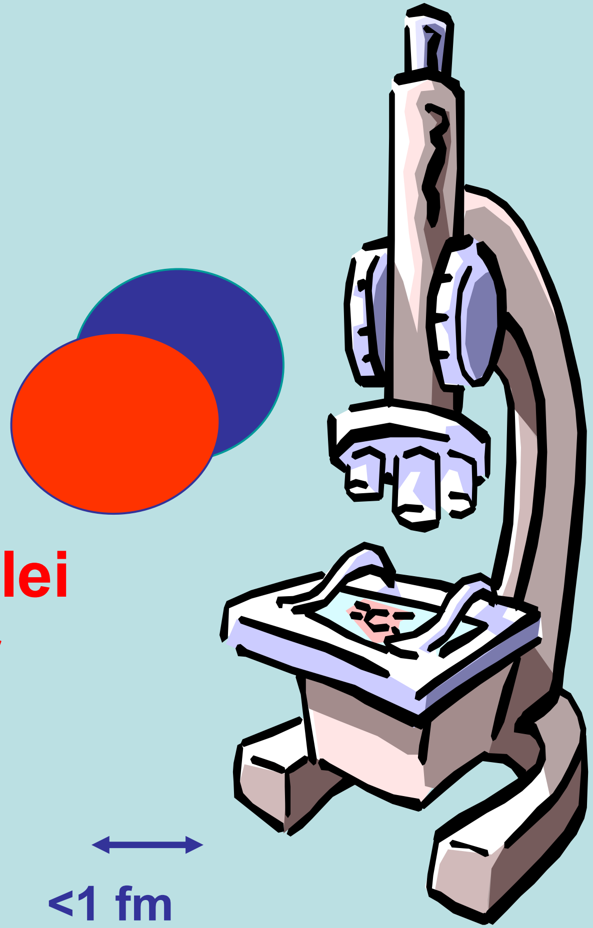
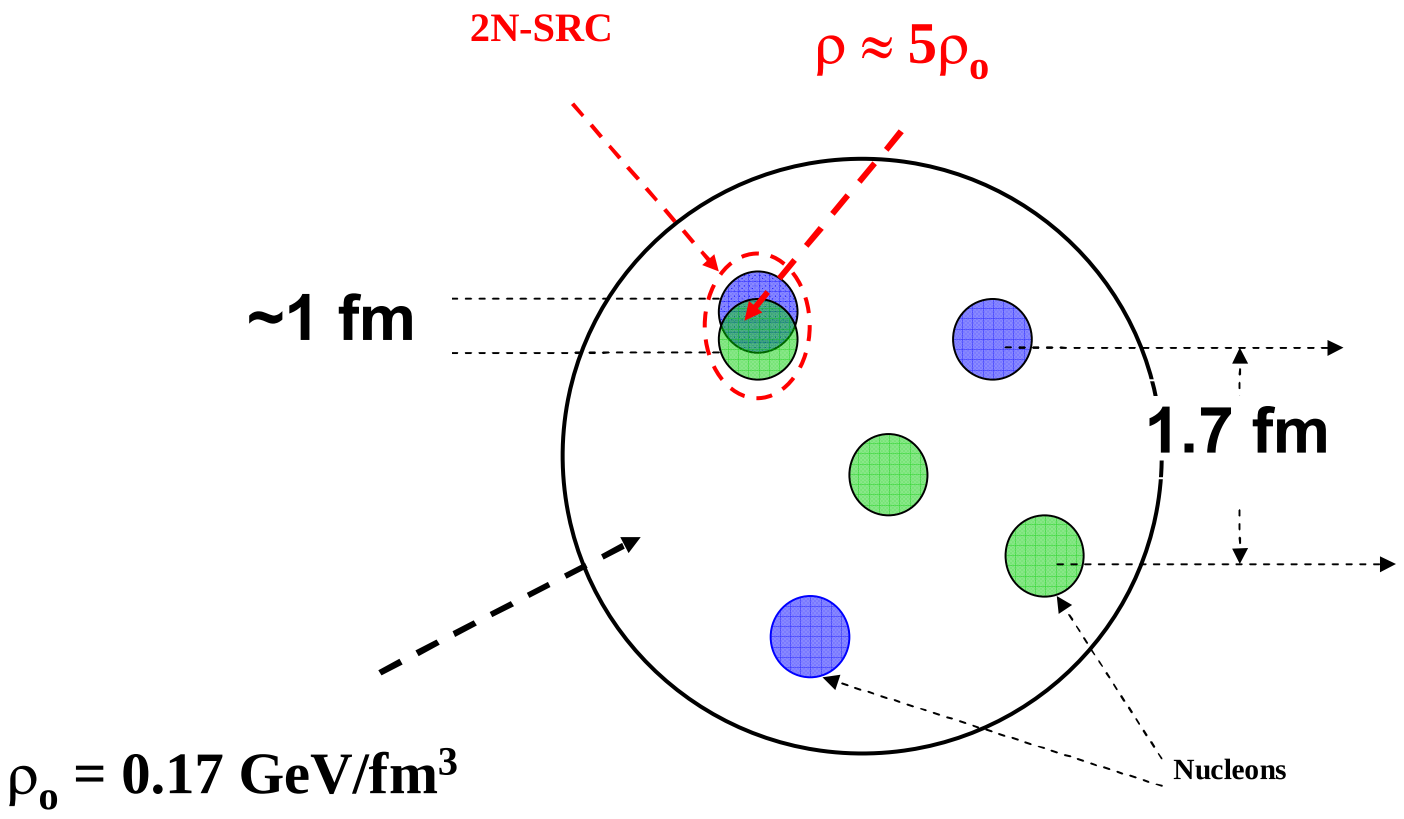


Studying close proximity nucleons in nuclei via high-energy/large momentum-transfer exclusive reactions

Eli Piasetzky

Tel Aviv University, ISRAEL

Picture of 2N-Short Range Correlations (2N-SRC)



The typical distance between nucleons in a nuclei:

$$d = 1 / \sqrt[3]{0.16} \approx 1.8\, fm$$

Density of 2N-SRC for r_{NN}~1fm:

$$\rho_{2N-SRC} / \rho_0 = (1.8/1)^3 \approx 5.8$$

How well do we understand compressed cold nuclear matter?

A neutron star is a HUGE NUCLEUS :

R ~ 10 km

$A \sim M_S/M_p \sim 10^{30}/10^{-27} \sim 10^{57}$

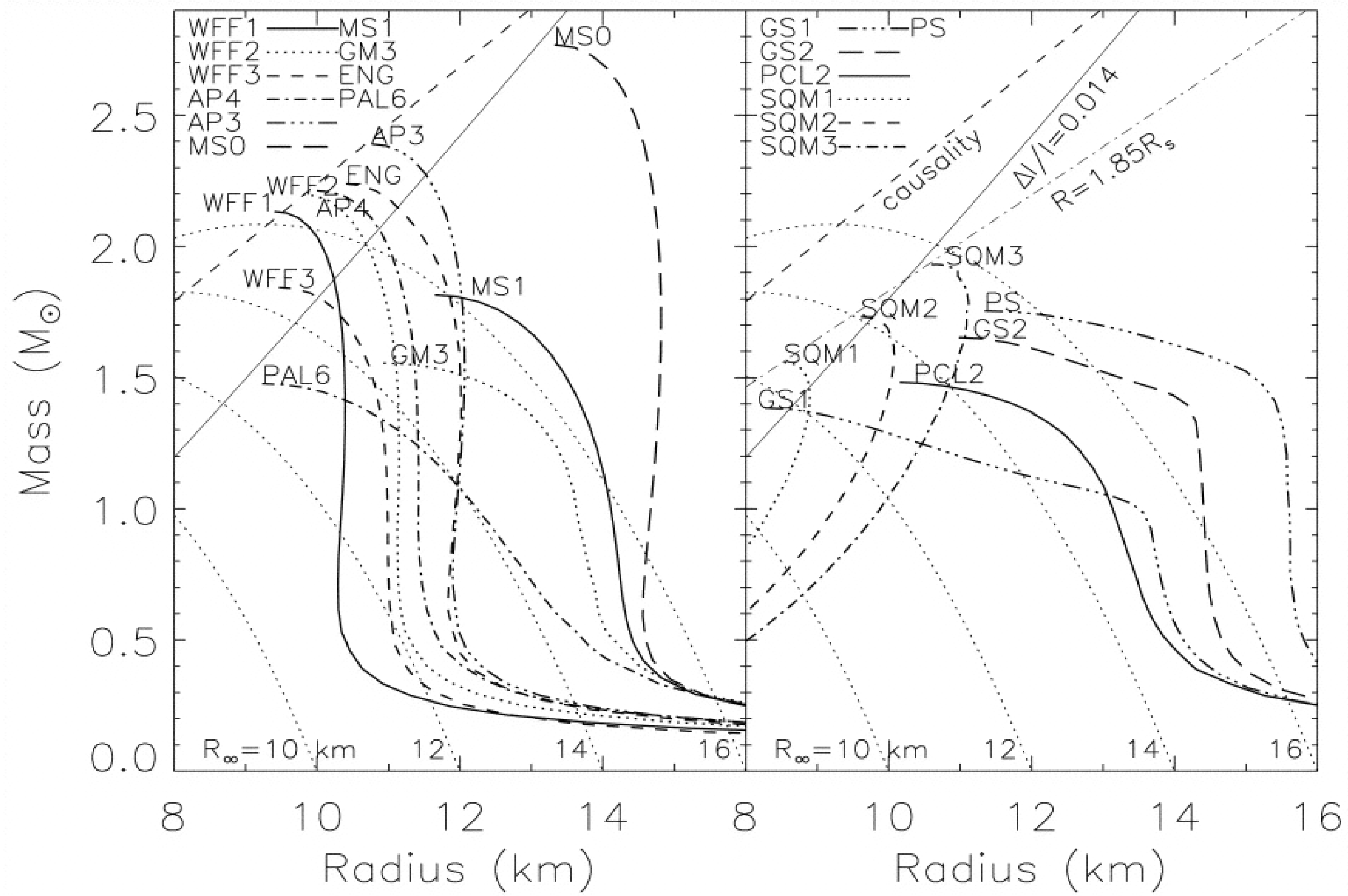
$$\rho = (5-10)\rho_0$$

$$(\rho^* / \rho_0)^{1/3} K_f \approx (400-500) MeV/c$$

Neutron Star Structure and the Equation of State

J. M. Lattimer and M. Prakash

The Astrophysical Journal, 550:426-442, 2001 March 20



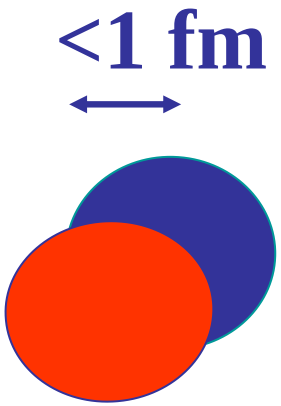
Stars containing nucleons (hyperons)

Stars containing exotic components

What happens to compressed cold nuclear matter?

The answer depends on the behavior
of the strong force at short distances.

We therefore will study the basic system
of a nucleon pair at close proximity



Questions

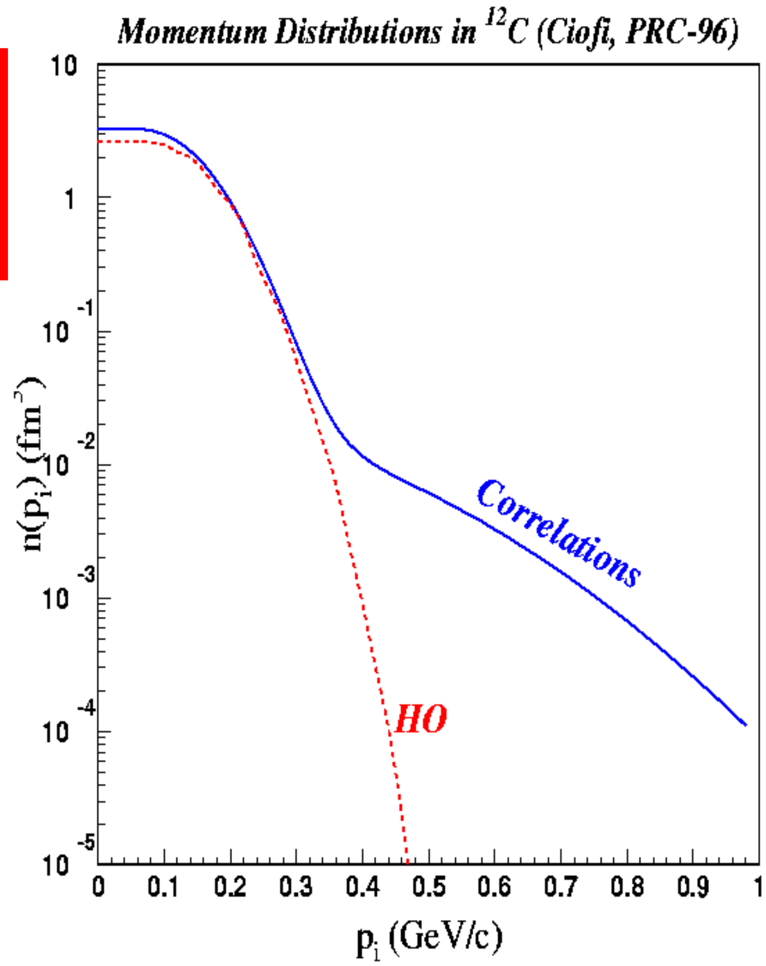
•What fraction of the high missing momentum tail is due to 2N-SRC?

•What is the relative momentum between the nucleons in the pair?

•·What is the pair CM momentum distribution ?

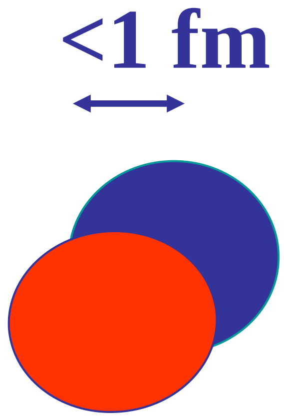
•What is the ratio of pp to pn pairs?

•Are these nucleons different from free nucleons (shape, mass, etc.)?



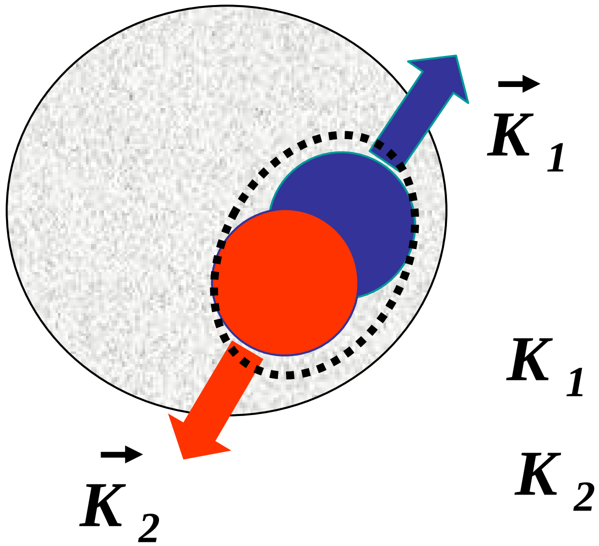
Triple – coincidence measurements
of large momentum transfer high energy reactions:

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



NN SRC

<u>"Redefine" the problem in momentum space</u>



$$\vec{K}_1 \cong \vec{K}_2$$

$$K_1 > K_F ,$$

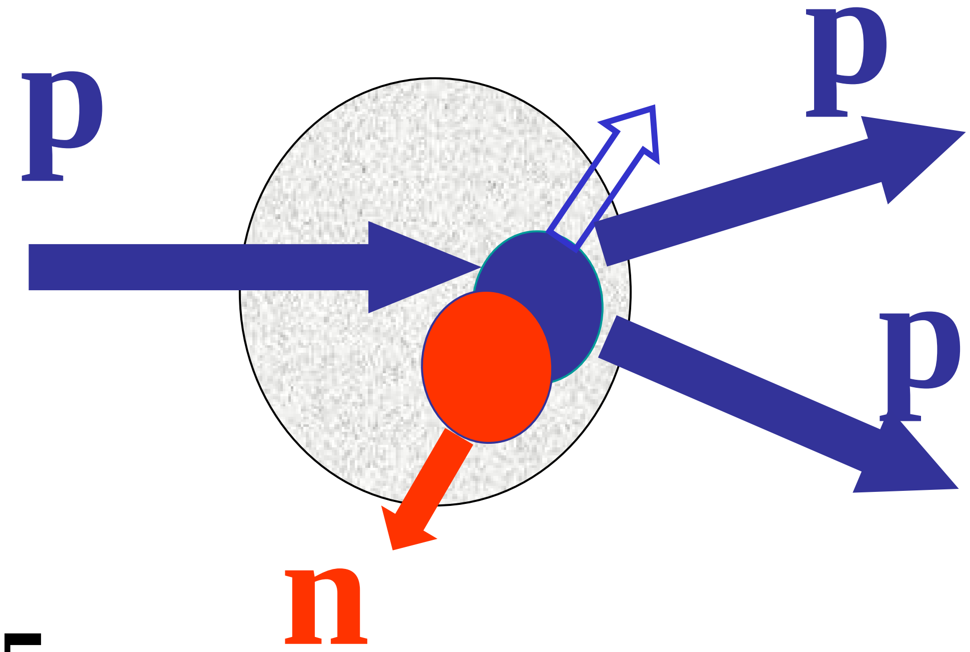
$$K_2 > K_F$$

A pair with "large" relative momentum between the nucleons and small CM momentum.

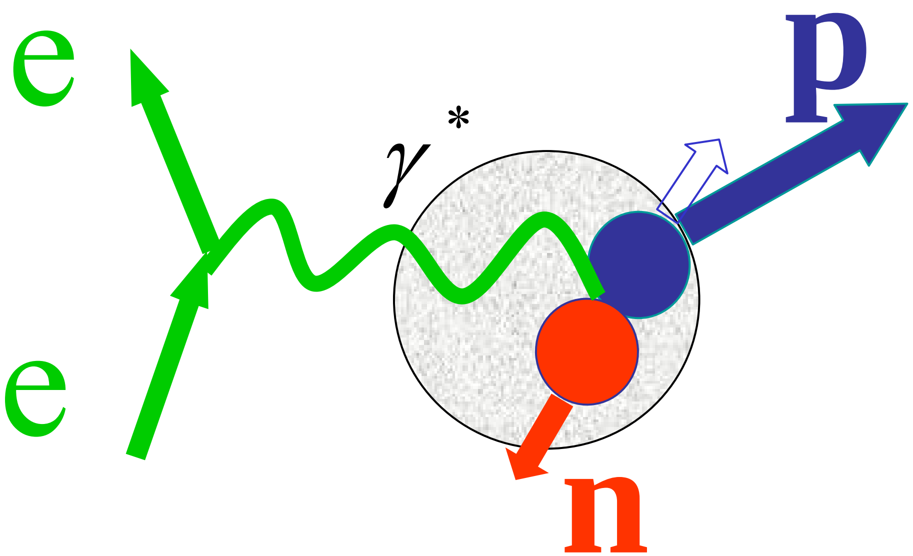
Triple – coincidence measurements:

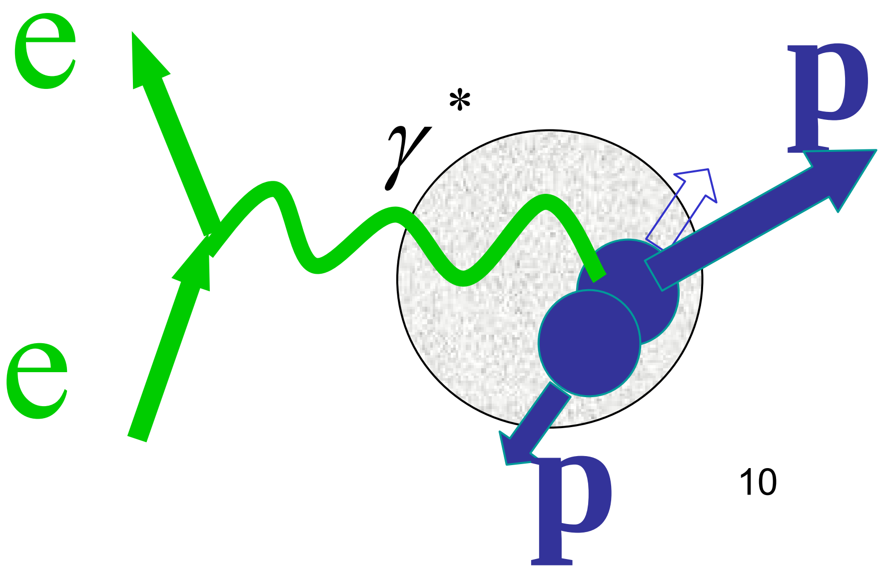
Triple – coincidence measurements:

EVA/BNL



JLAB/E01-015





Color code

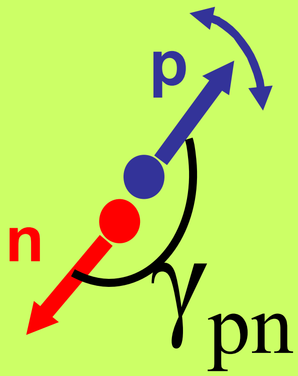
Data

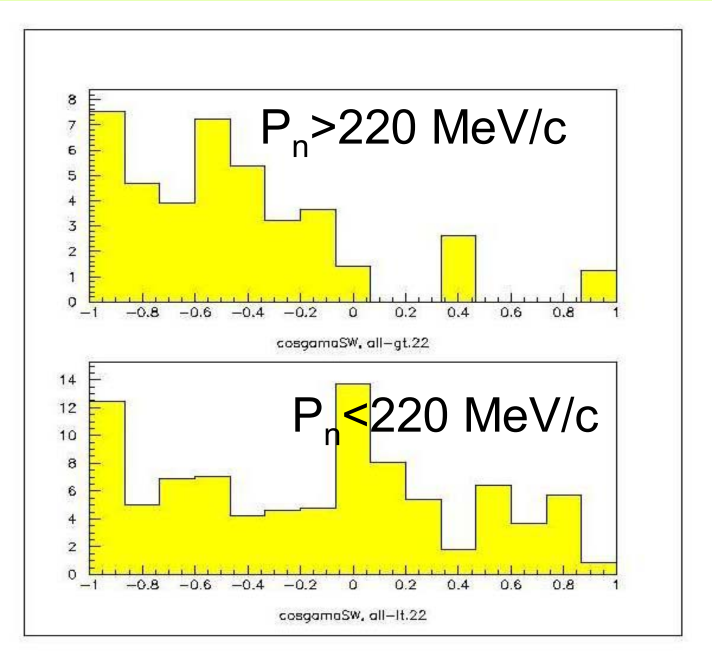
Calculation, speculations, estimates

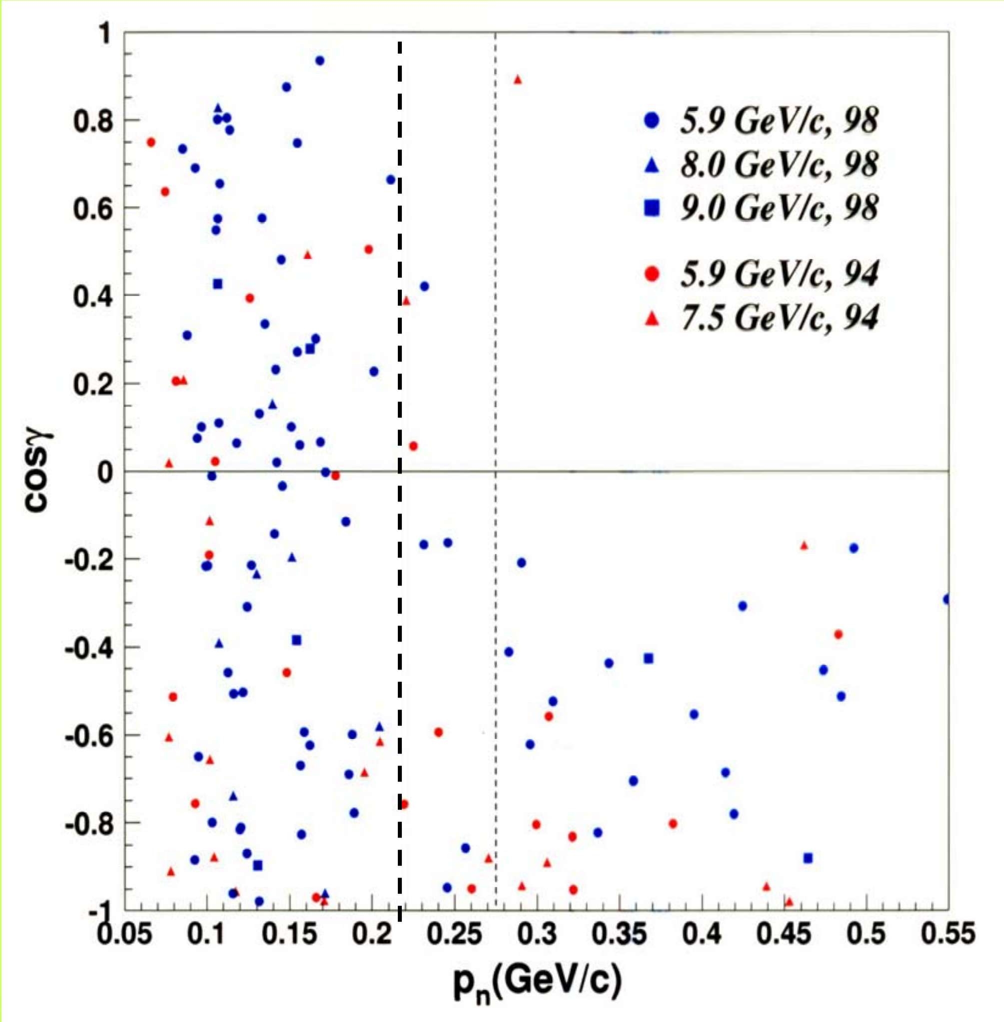
stories

Directional correlation

(p,2pn)



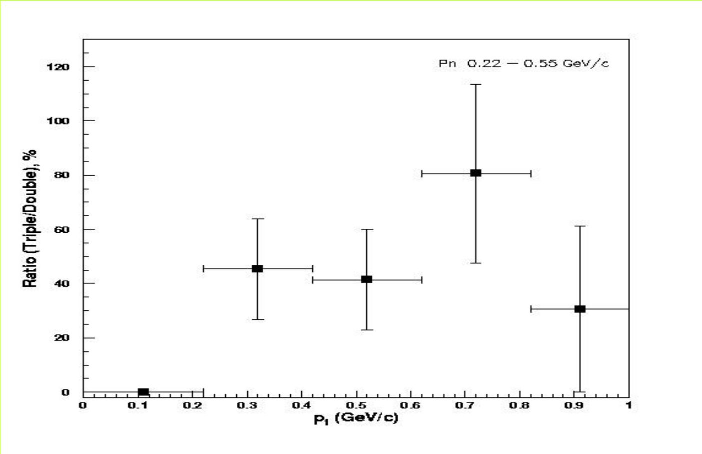




The EVA/BNL collaboration

"Triples" vs. "Doubles"

$$\frac{\#(p,2p+n)}{\#(p,2p)} \bullet \frac{1}{\varepsilon T} \bullet \frac{2\pi}{\Delta\Omega} = \begin{cases} \text{For } P_p > P_F,\ P_n > P_F \\ (49 \pm 13)\ \% \\ \text{For } P_p < P_F,\ P_n > P_F \\ 0 \end{cases}$$



The EVA/BNL collaboration

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

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

$$F = \frac{\#(p, pp+n \quad p_n, p_i > p_{min})}{\#(p, 2p \quad\quad p_i > p_{min})}$$

For ^{12}C :

F= (49 ± 13) % **for p_{min} =K_F=220 MeV/c**

F= (43 ± 11) % → 43^{+11}_{-7} **% for p_{min} =K_F=275 MeV/c**

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

Assuming that for protons with momentum 275-600 MeV/C 2N-SRC dominate and the LC-DWIA approximation one can calculate the ratio F:

$$F = \frac{\int_p \int_n \sigma^{p,2p+n}}{\int_p \sigma^{p,2p}}$$

Where :

$$\sigma^{p,2p} = \sum_{protons} K \frac{d\sigma^{pp}}{dt} S^{P}(\alpha, \vec{p}_t, P_{R^+}) T_{pp}$$

$$\sigma^{p,2p+n} = \sum_{protons} K \frac{d\sigma^{pp}}{dt} D(\alpha, \vec{p}_t, \alpha_n, \vec{p}_{tn}, P_{R^+}) T_{ppn}$$

$$s^{p}(\alpha, \vec{p}_t, P_{R^+}) = \Sigma \int D(\alpha, \vec{p}_t, \alpha_s, \vec{p}_{st}, P_{R^+}) \frac{d\alpha_s}{\alpha_s} d^2 p_{st}$$

If all 2N-SRC were np—SRC:

$$D \Rightarrow \mathrm{D}_{\mathrm{np}} \qquad (s^p = \int_n D_{np})$$

and

$$F = \frac{\int_p \int_n \frac{d\sigma}{dt}^{pp} D_{np} T_{ppn}}{\int_p \frac{d\sigma}{dt}^{pp} S^p T_{pp}} \approx \frac{T_n \int_p \int_n \frac{d\sigma}{dt}^{pp} D_{np}}{\int_p \frac{d\sigma}{dt}^{pp} S^p}$$

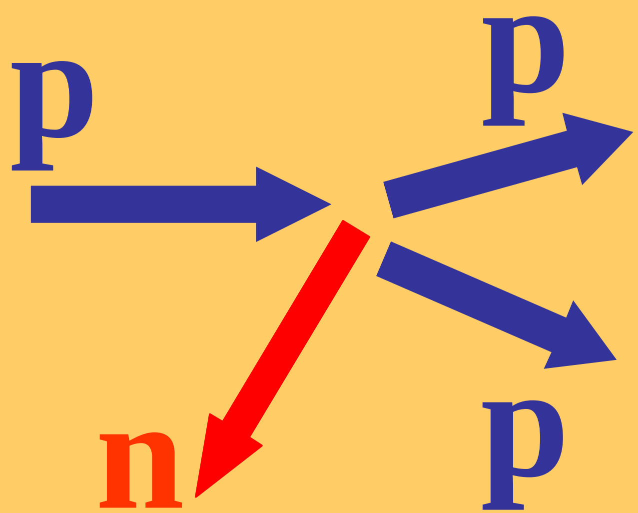
Where:

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

We assumed (following Ciofi PRC 44(1991)7) that the pair CM motion can be described with a Gaussian function. σ is a parameter to be determined from the data.

We also assumed: $T_{ppn} = T_{pp} T_n$

We assumed : $T_{ppn} = T_{pp} T_n$



PHYSICAL REVIEW C 66, 044613 (2002)

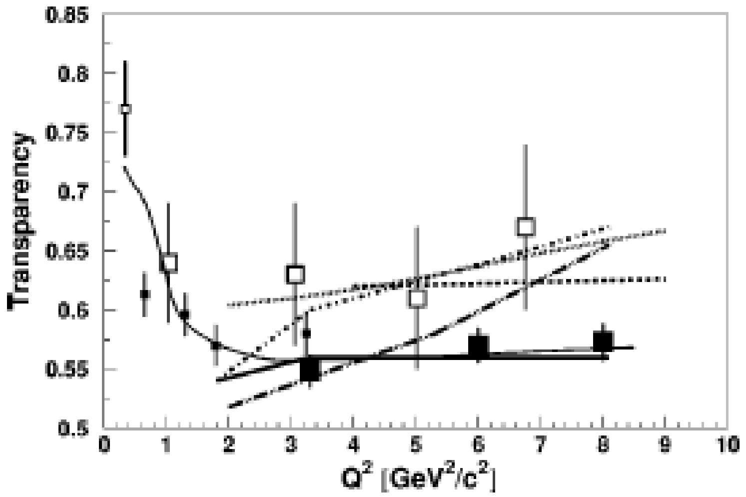
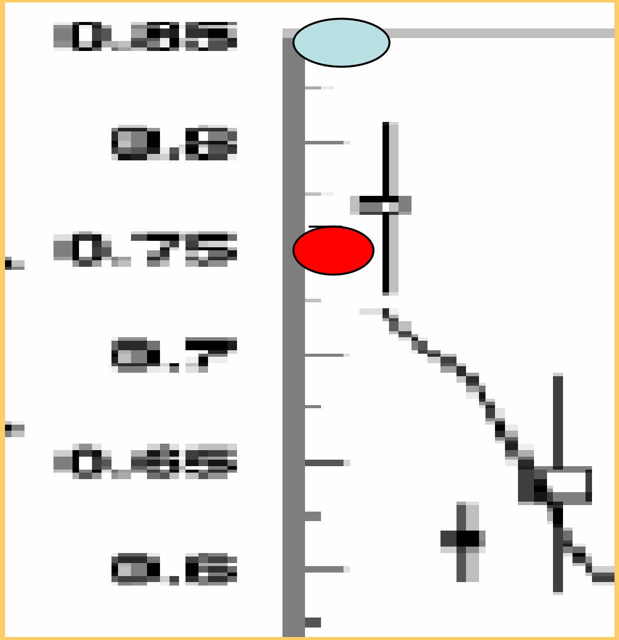


FIG. 7. Nuclear transparency for ^{12}C$(e,e'p)$ quasielastic scattering. Symbols and thin solid curve are identical to Fig. 4. The errors shown include statistical and the point-to-point systematic ($\pm$2.3%) uncertainties, but do not include model-dependent systematic uncertainties on the simulations or normalization-type errors. The net systematic error, consisting of point-to-point, normalization-type, and model-dependent errors, is estimated to be ($\pm$4.6%). The error bars for the previous data sets [8,9,27] include their net systematic and statistical errors. The thick solid curve is a Glauber calculation of Ref. [34]. The dot-dashed, dotted, dashed, and dot-dot-dash curves are color transparency predictions from Refs. [34–36], and [37], respectively.



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

X are nuclear configurations which are not pn-SRC.

Notice: if there were only 2N-SRC, than X is pp-SRC only.

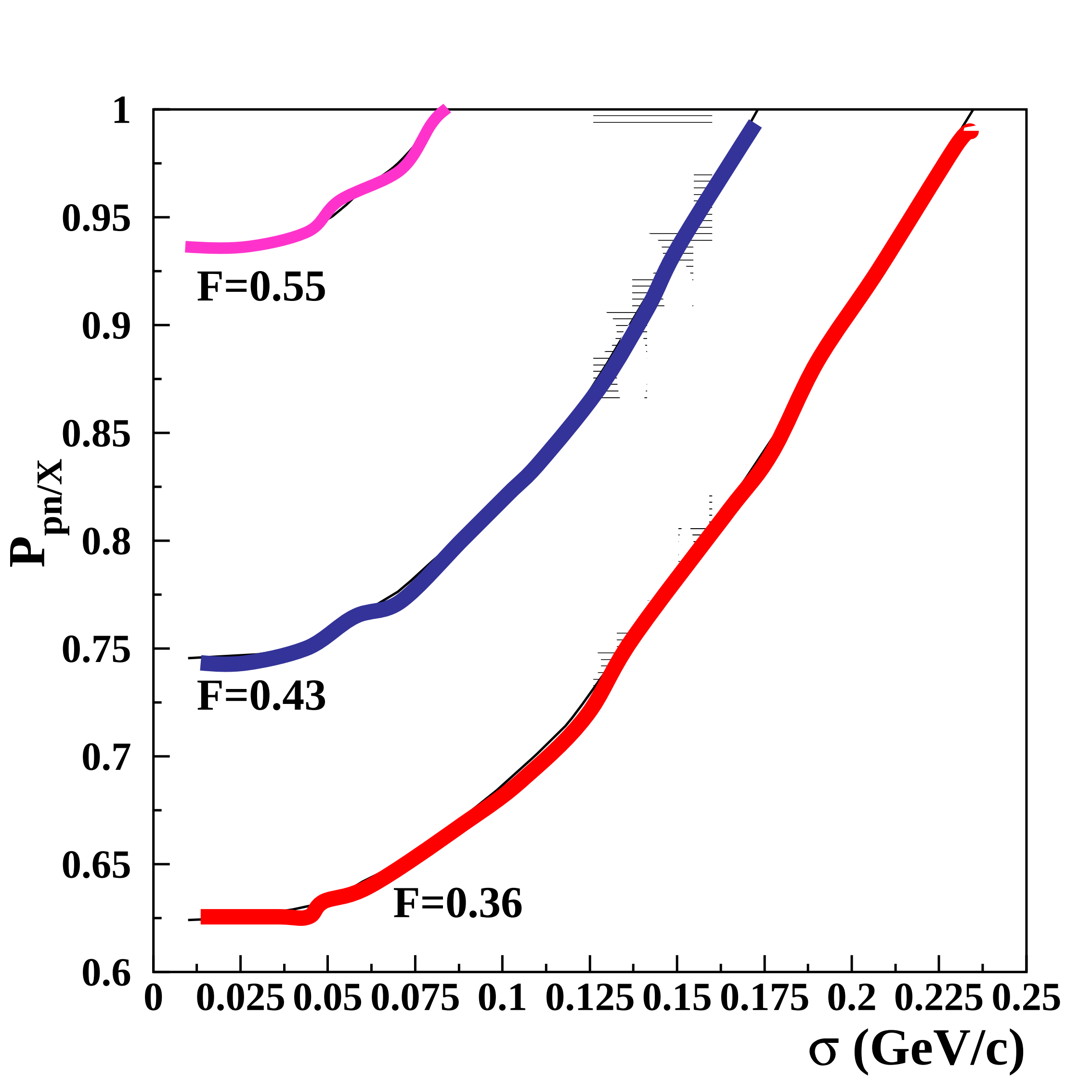
$$F = \frac{T_n \int_p \int_n \frac{d\sigma^{pp}}{dt} D_{np}}{\int_p \frac{d\sigma^{pp}}{dt} S^p} P_{np/X+np} = T_n \; R \; P_{np/X+np}$$

F , Tn are measured quantities.

R can be calculated with the approximations/assumptions listed above.

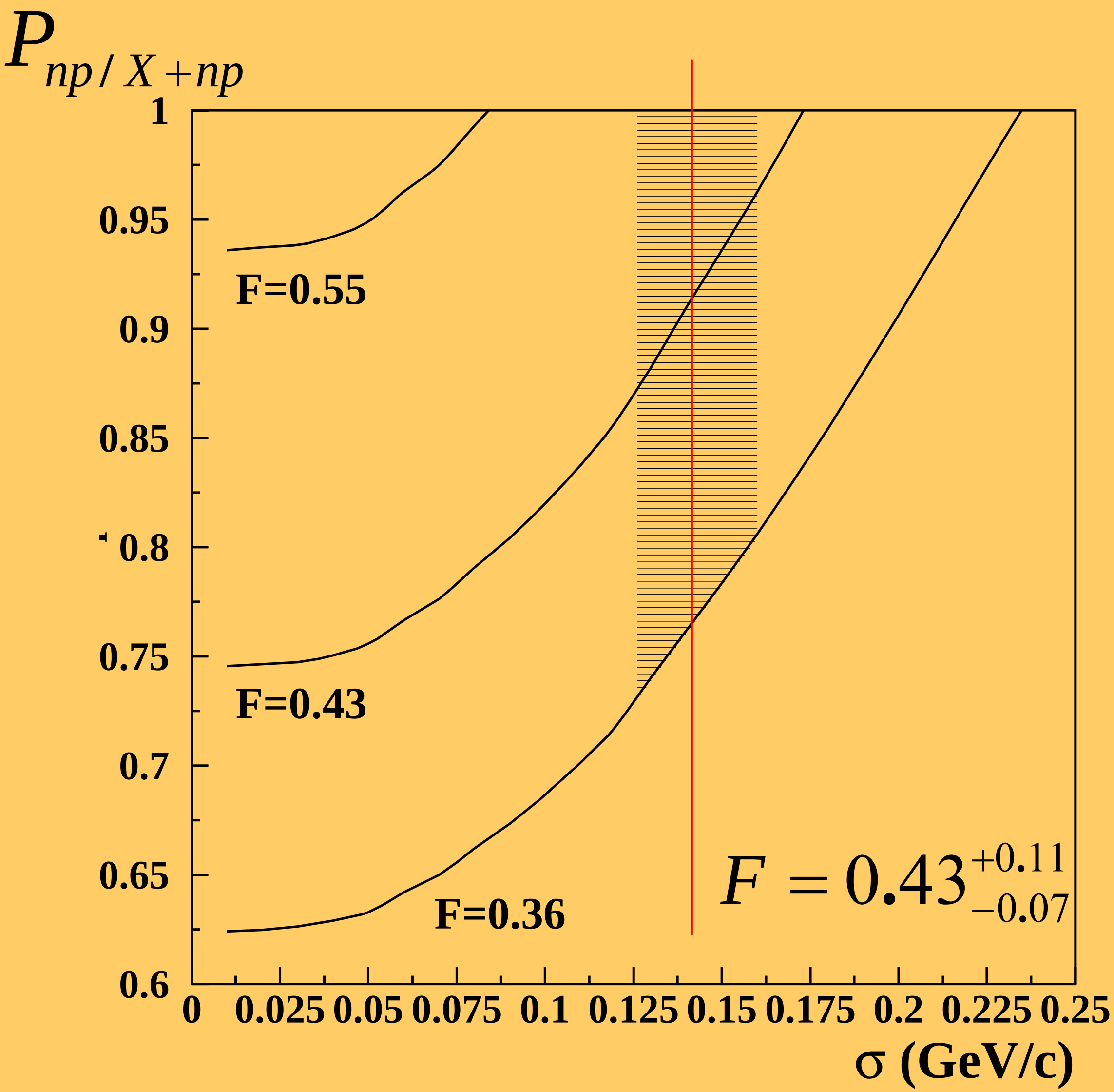
$P_{np/X+np}$ **is the unknown to be determined.**

R was calculated as a function of σ for the experimental acceptance and for $F = 0.43^{+0.11}_{-0.07}$



The measured longitudinal CM momentum of the correlated pair is:

σ = 143 ± 17 MeV/c. **(PRL 90(2003)042301)**



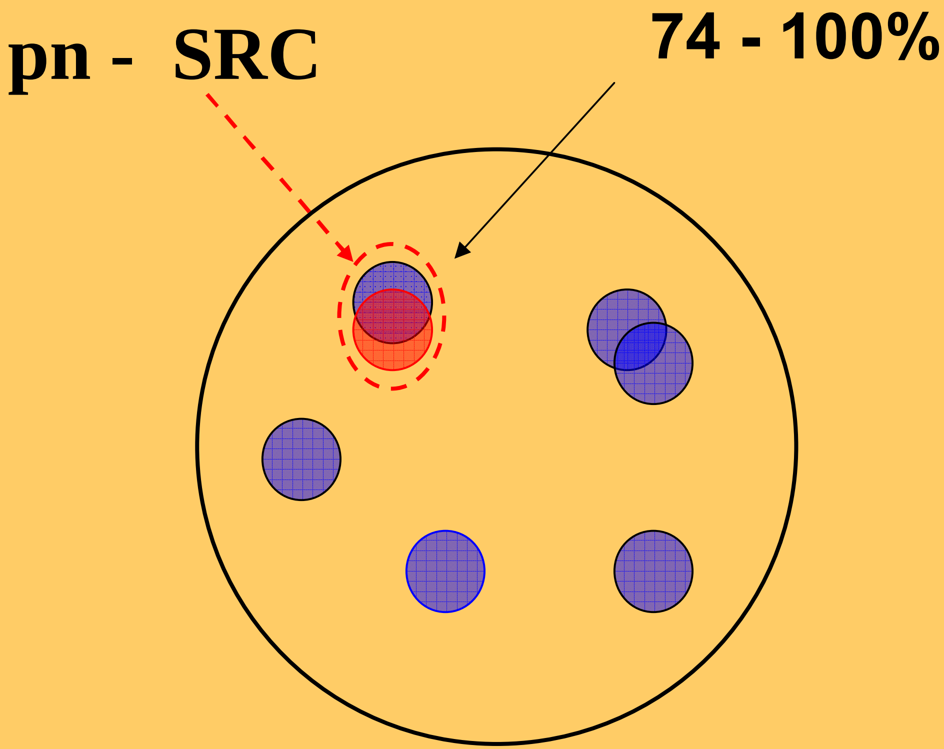
$$P_{np/X+np} = 0.92^{+0.08}_{-0.18}$$

np-SRC dominance:

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

For 275-600 MeV/c protons in ^{12}C:

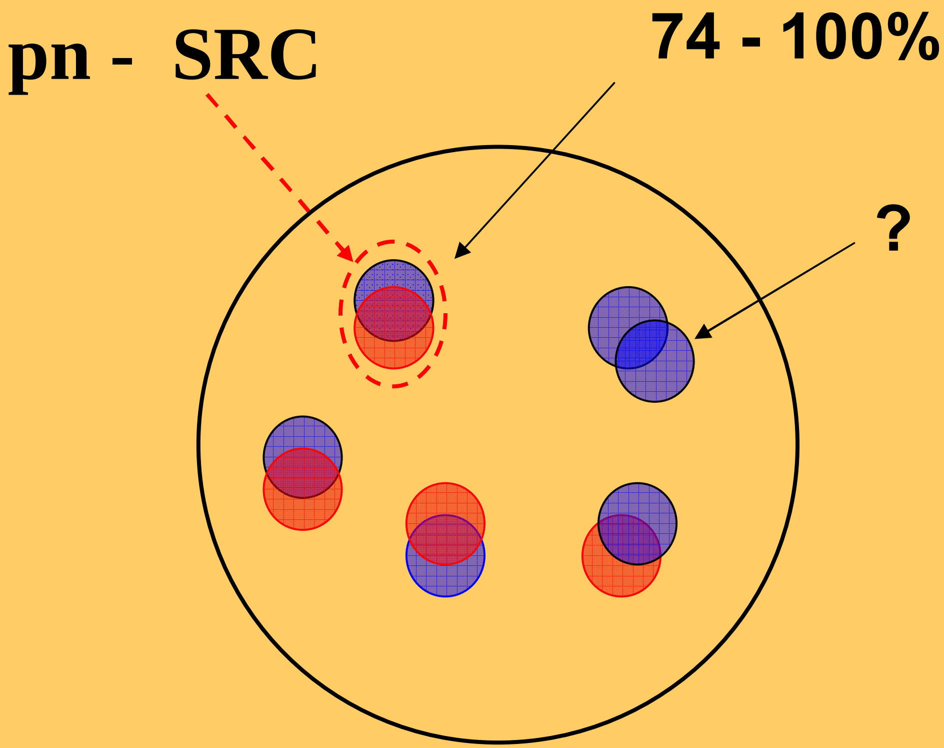
np-SRC dominance:



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

For 275-600 MeV/c protons in ^{12}C:

np-SRC dominance:



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

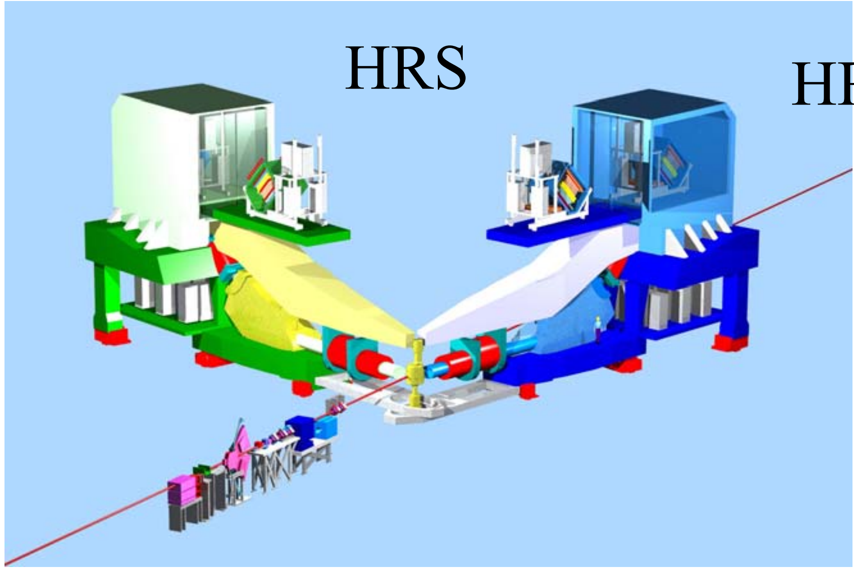
What do we know about pp-SRC ?

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

Jlab / Hall A

The measurement was done Dec. 2004 – Apr. 2005.

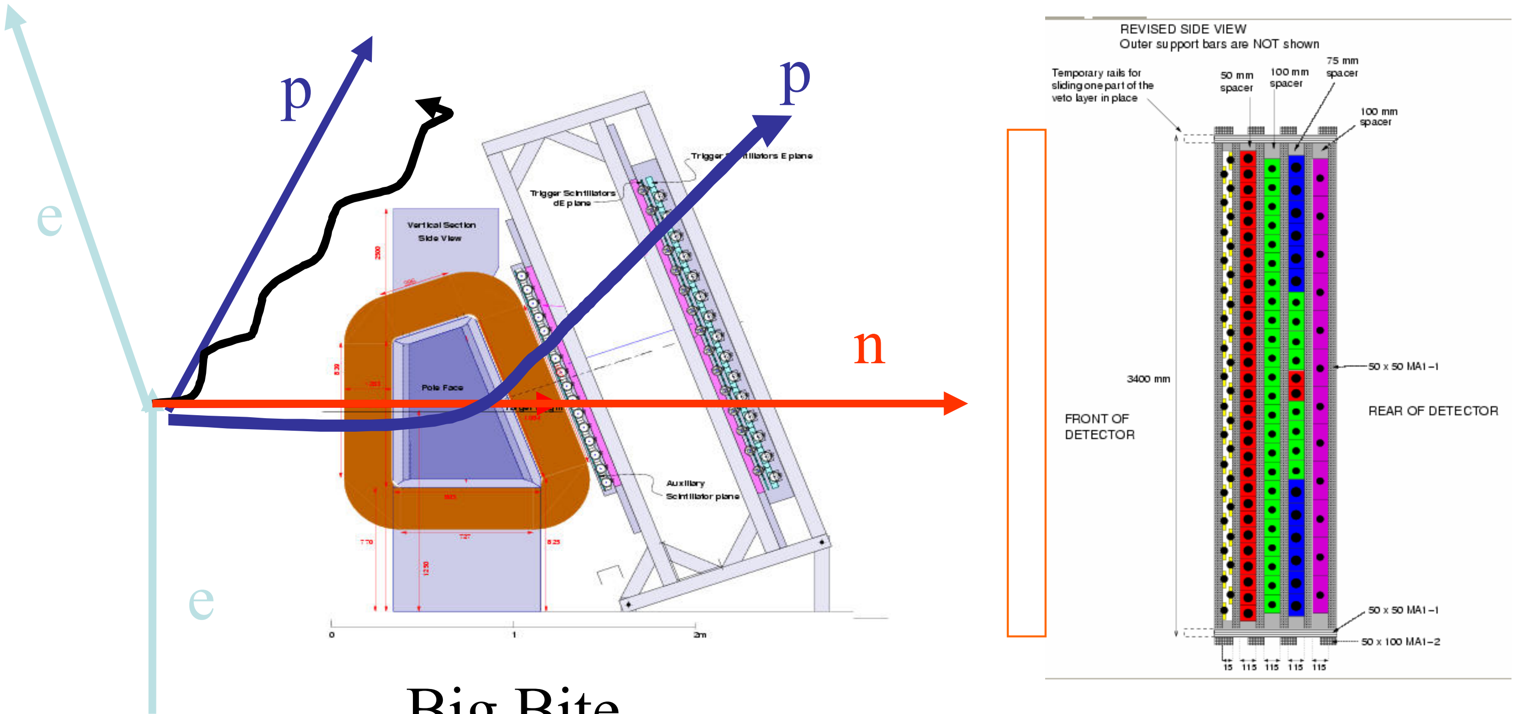
Data are being analyzed by 4 students from TAU, MIT, KSU, and Glasgow.



Experimental setup

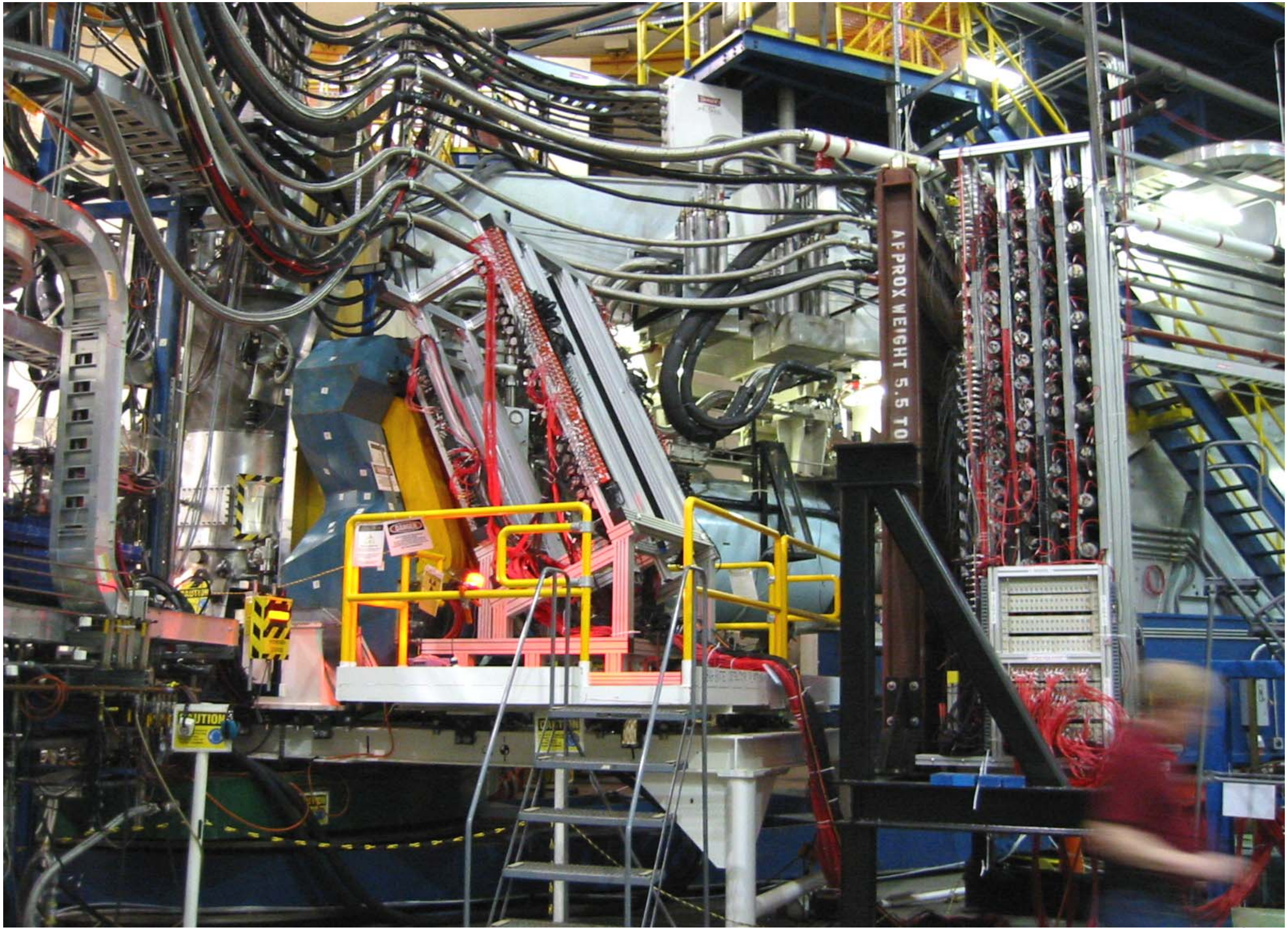
EXP 01-015 / Jlab

n array



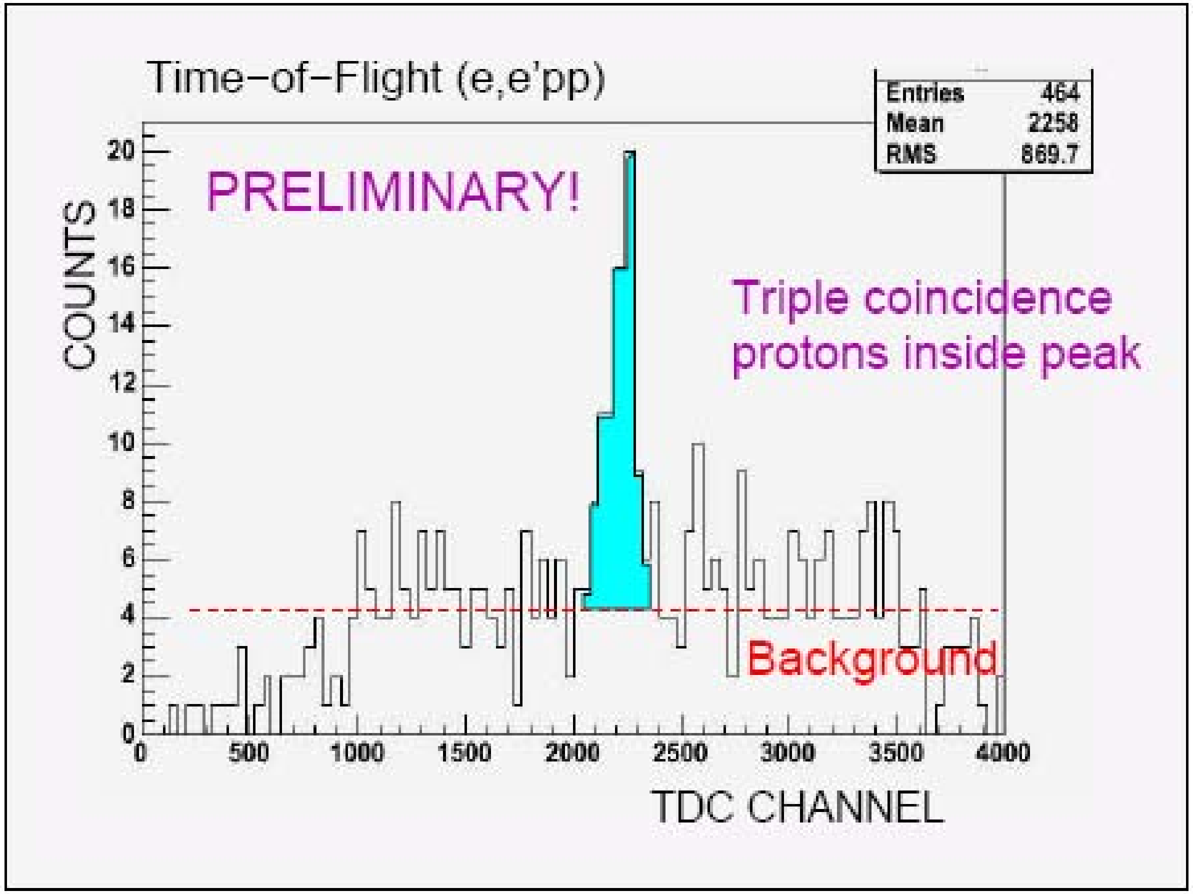
Big Bite

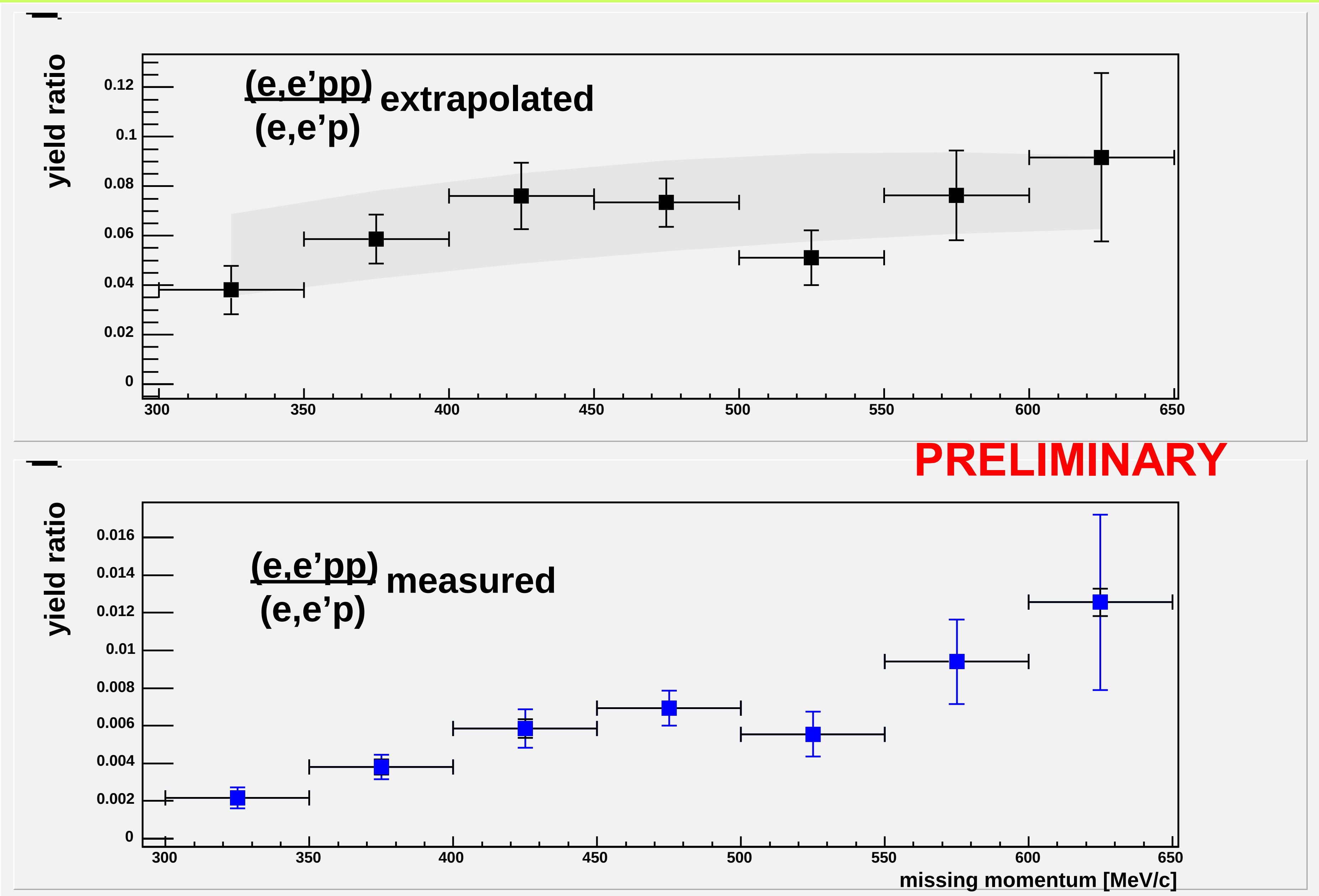
Lead wall



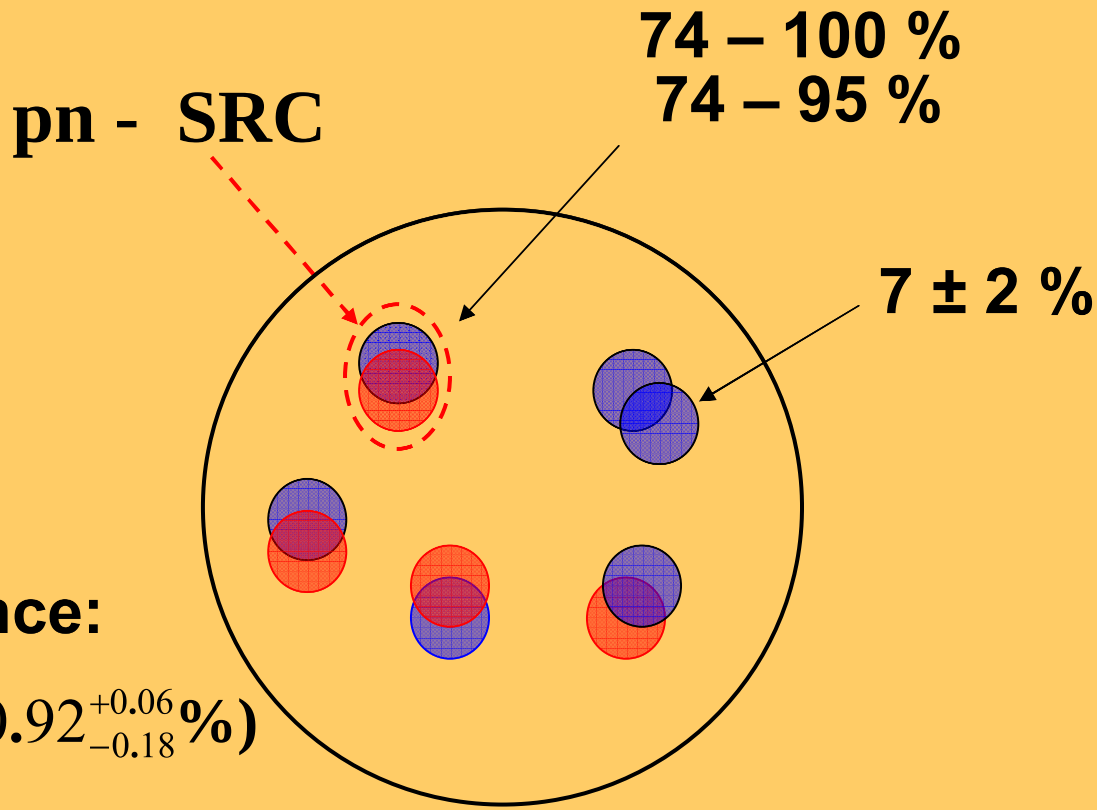
EXP 01-015 **Jlab / Hall A** Dec. 2004 – Apr. 2005

Triple Coincidence Events




yield ratio
(e,e'pp) / (e,e'p) extrapolated
0.12
0.1
0.08
0.06
0.04
0.02
0
300
350
400
450
500
550
600
650
PRELIMINARY
yield ratio
(e,e'pp) / (e,e'p) measured
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
missing momentum [MeV/c]

For 275-600 MeV/c protons in ^{12}C:



np-SRC dominance:

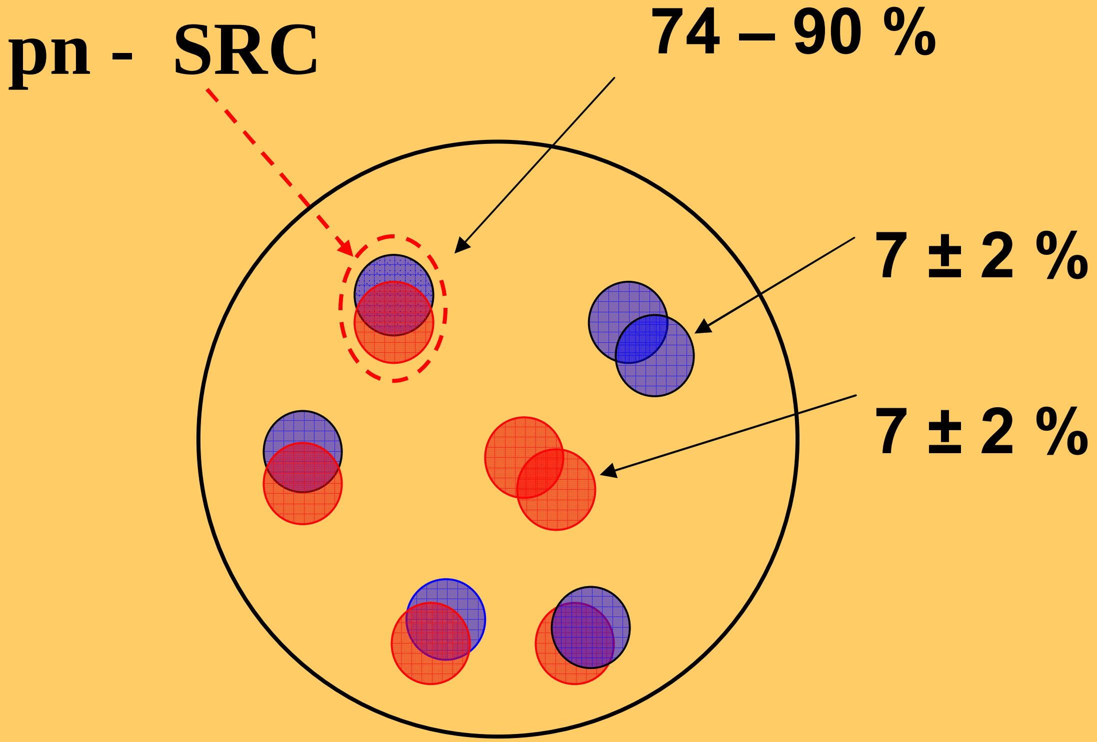
$(0.92^{+0.06}_{-0.18}\%)$

2N-SRC dominance: 82-100%

Notice: 100% is the sum of all the protons in this momentum range

For 275-600 MeV/c protons in ^{12}C:

Assuming for ^{12}C nn-SRC = pp-SRC



2N –SRC dominance

np-SRC dominance

Notice: 100% is the sum of all the nucleons in this momentum range

$$np/pp = 0.92/0.07$$

$$nn + pp + np = 2pp + np = [2 + 0.92/0.07]pp = 100\%$$

$$pp = nn = 7\%$$

$$pn = 86\%$$

$$2N - SRC = 20\% \text{ from } (e, e')$$

$$\Rightarrow \quad pp = nn \cong 1.5\%$$

$$pn \cong 17\%$$

$$P_{pn}(^{12}C)/P_{pp}(^{12}C) = {}^{74-90\%}\!\big/_{7\pm 2\%}$$

$$P_{pn}(^{12}C)/P_{pp}(^{12}C) > {}^{74}\!\big/_{9} \cong 8$$

$$\rightarrow \quad P_{pn}(^{12}C)/P_{pp}(^{12}C) > 8$$

pp-SRC versus pn-SRC pairs

$$\Rightarrow \quad P_{pn}(^{12}C)/P_{pp}(^{12}C) > 8$$

Is this large or small? What to expect?

A statistical distribution obtained by assuming that the SRC are L=0 pairs with equal occupation of each possible quantum state:

np (spin=0,1) : 4 states
pp (spin=0) : 1 state
nn (spin= 0): 1state

$$\Rightarrow \quad P_{pn}(^{12}C)/P_{pp}(^{12}C) = 4$$

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

Does it mean that a nucleus of only protons or only neutrons (like what a n-star might be) behaves more like an ideal Fermi gas or more like nuclei?

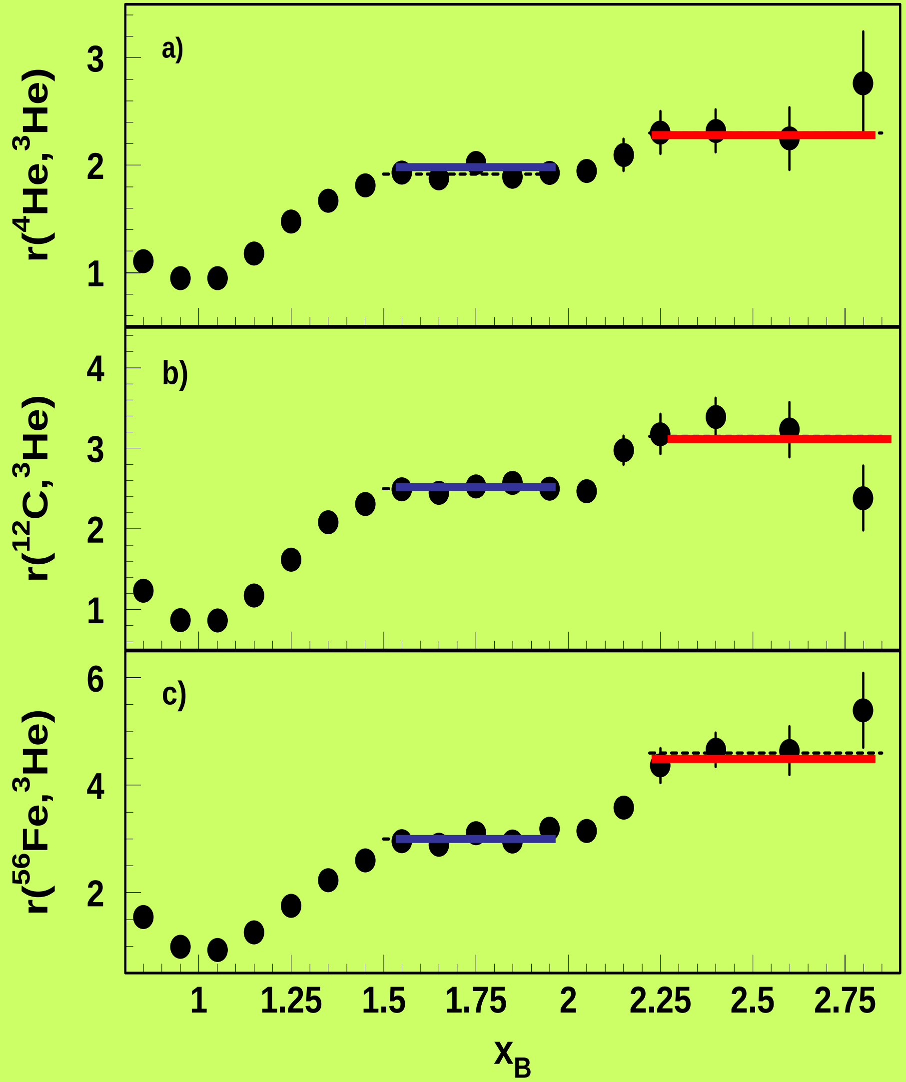
Theory:

Frankfurt, Sargsian, and Strikman

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:

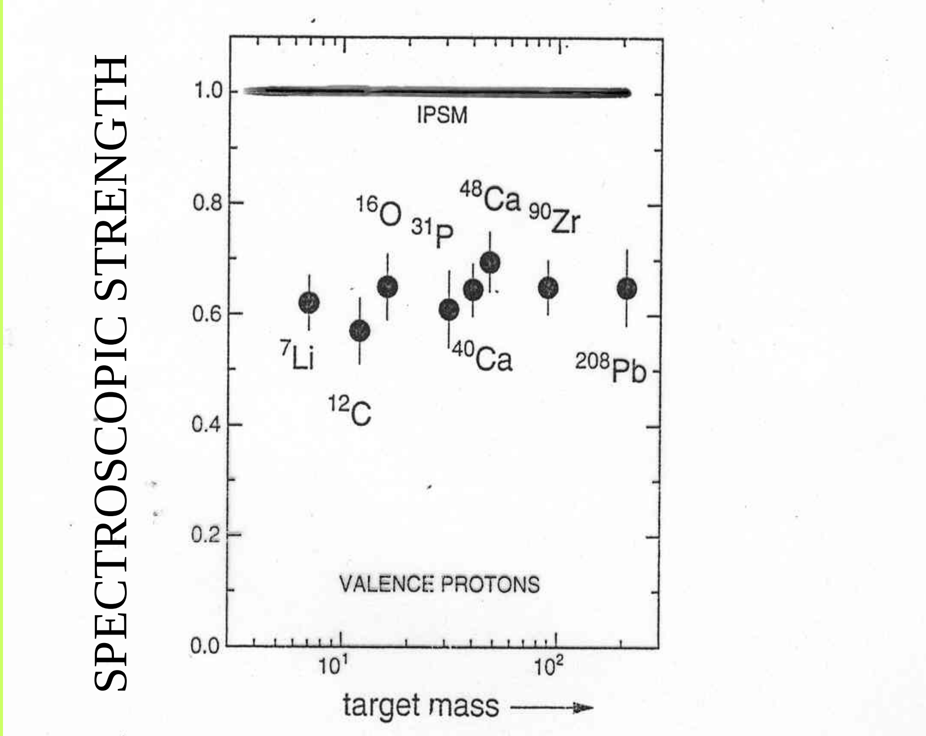
2N-SRC(np,pp,nn) = 0.20 ± 0.045%

3N-SRC Less than 1% of total

Now Include (e,e'p) Data

The Independent Particle Shell Model is based upon the assumption that each nucleon moves independently in an average potential (mean field) induced by the surrounding nucleons.

The (e,e'p) data for knockout of valence and deeply bound orbits in nuclei gives spectroscopic factors that are 60 – 70% of the mean field value.



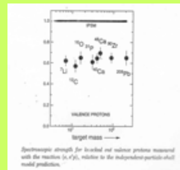
Spectroscopic strength for knocked out valence protons measured with the reaction (e, e'p), relative to the independent-particle-shell model prediction.

Together, the deduced ^{12}C structure is:

80 ± 4.5 % - single particle moving in an average potential.

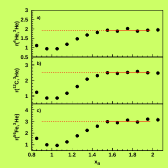
60-70 % - independent particle in a shell model potential.

10-20 % - shell model long range correlations



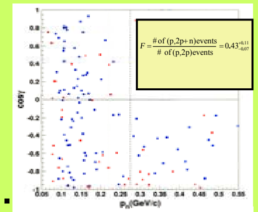
(e,e'p)

(e,e')



20 ± 4.5 % - 2N SRC .

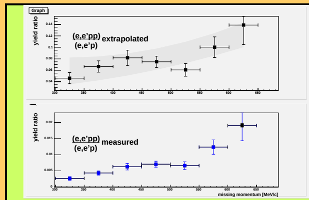
18.4 ± 4.5 % - SRC np pairs .



(p,2pn)

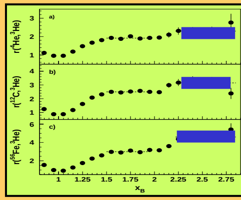
~1.5% - SRC pp pairs.

~1.5 % - SRC nn pairs.



(e,e'pp)

Less than 1% - SRC of "more than 2 nucleons".



(e,e')

Analysis of more data, available from the triple coincidence measurement of the (e, e'pn) and (e, e'pp) reactions at Jlab / Hall A will allow to check, confirm, and reduce the uncertainties

(e,e'pn)/(e,e'p) → pn-SRC to compare with the (p,2pn) result.

(e,e'pp)/(e,e'pn) →A direct comparison between

pn and pp SRC pairs.

Acknowledgment

EVA collaboration / BNL

A. Carroll, S. Heppelman, J. Alster,
J. Aclander, A. Malki, A. Tang

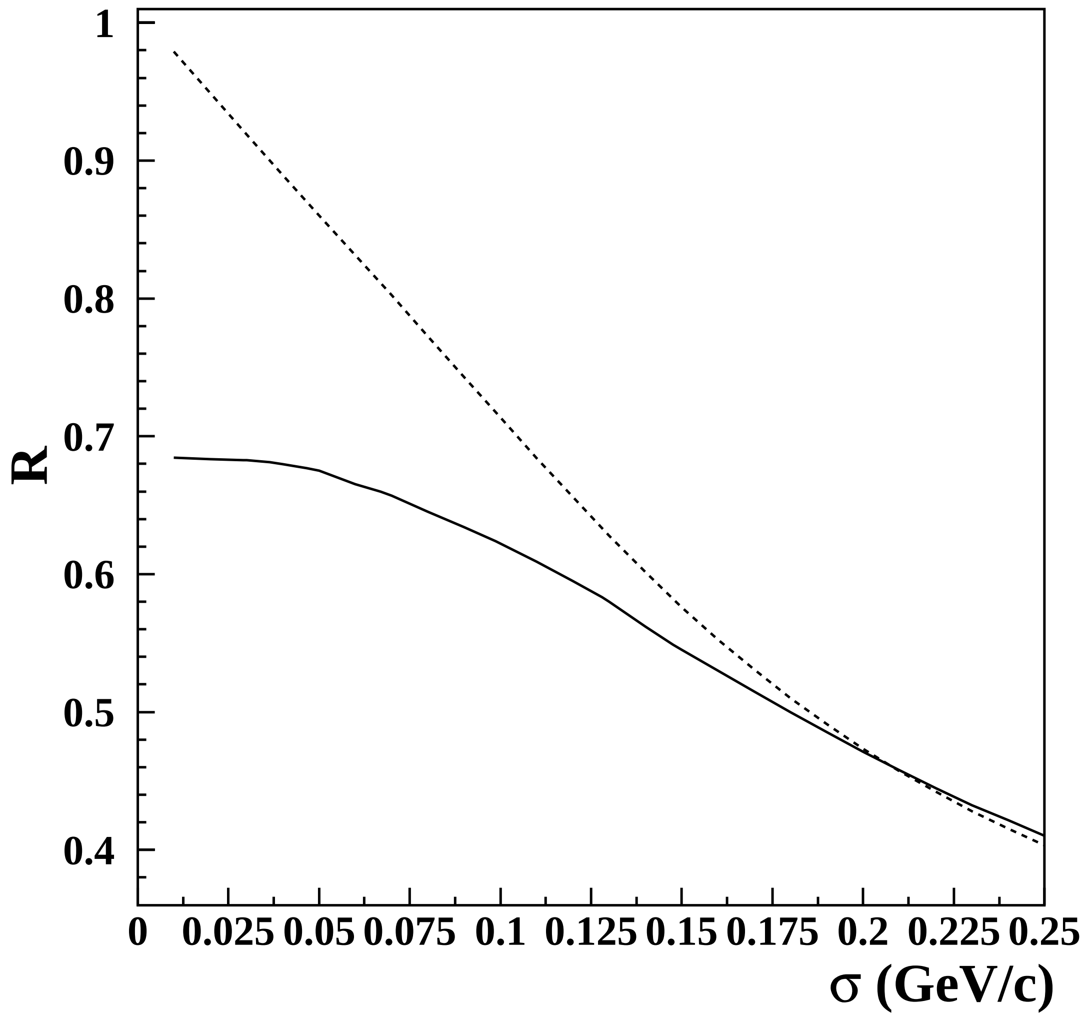
Exp 01 – 015 collaboration Hall A / TJNAF

S. Gilad , S. Wood, J. Watson, W. Bertozzi,
D. Higinbotham, R. Shneor, P. Monaghan, R. Subedi

Hall B collaboration / TJNAF

K. Egiyan

"Evidence for the strong dominanace of pn-correlations in nuclei"
arXiv:nucl-th/0604012 April 06
E. Piasetzky M. Sargsian, L. Frankfurt, M. Strikman, J. W. Watson


1
0.9
0.8
0.7
0.6
0.5
0.4
R
0
0.025
0.05
0.075
0.1
0.125
0.15
0.175
0.2
0.225
0.25
σ (GeV/c)

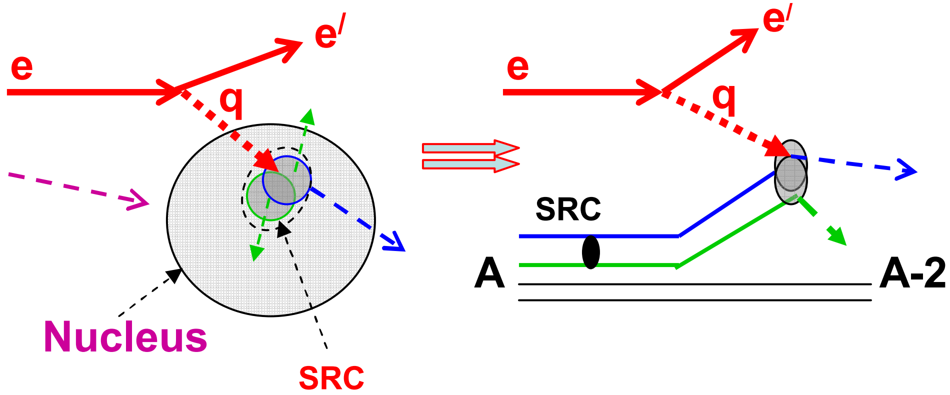
More on inclusive A(e,e')

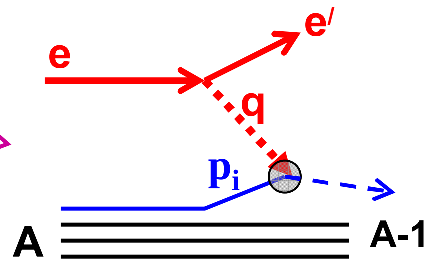
Kinematics for SRC in $A(e,e')$ Reaction

- The reaction we are investigating is.

- In $x_B > 1$ region there is only one background process with larger cross section – the **quasielastic scattering** off low-momentum and uncorrelated nucleons.

- Choose the kinematics where **this process is suppressed**.



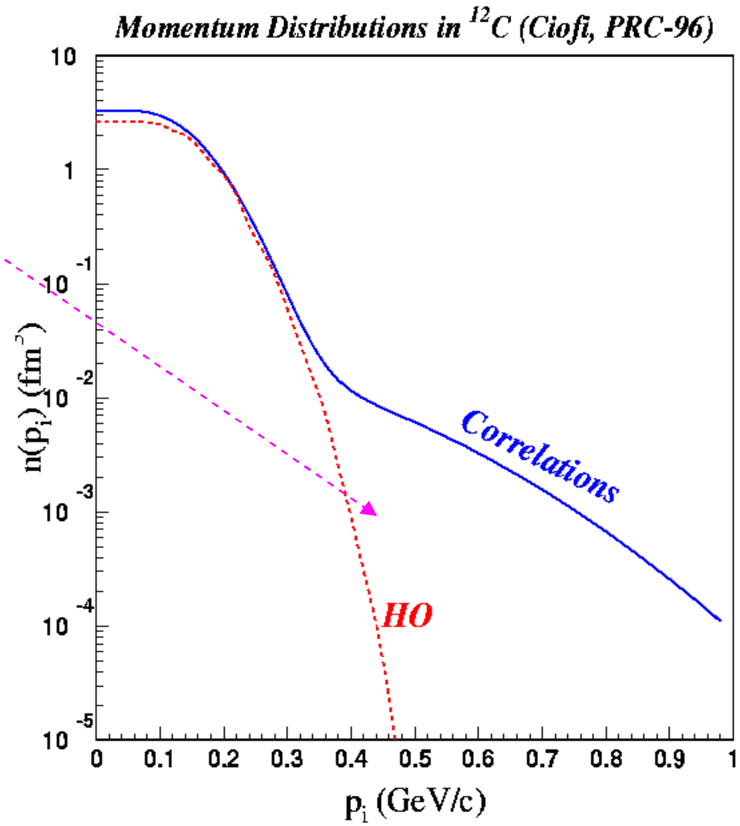


Kinematics for SRC in A(e,e') Reaction (continue)

- For all nuclei the single particle configuration in nuclear wave function vanishes at high nucleon momentum.

- Quasielastic scattering on a single nucleon will not be dominant at high momenta.

- The problem is, how we can identify the high momenum regime in inclusive reaction?

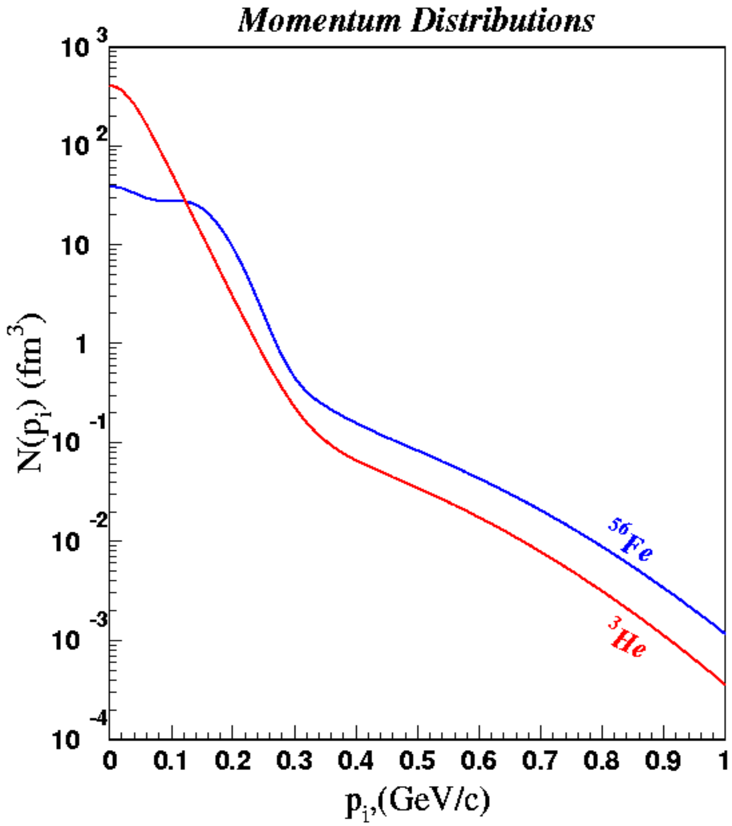


Kinematics for SRC in A(e,e/) Reaction (continue)

- At high momenta nucleon momentum distributions are similar in shape for light and heavy nuclei.

- The cross sections of A(e,e/) at x_B>1 depend primarily on the nuclear wave function, i.e., they should have similar shapes at high momenta for all nuclei.

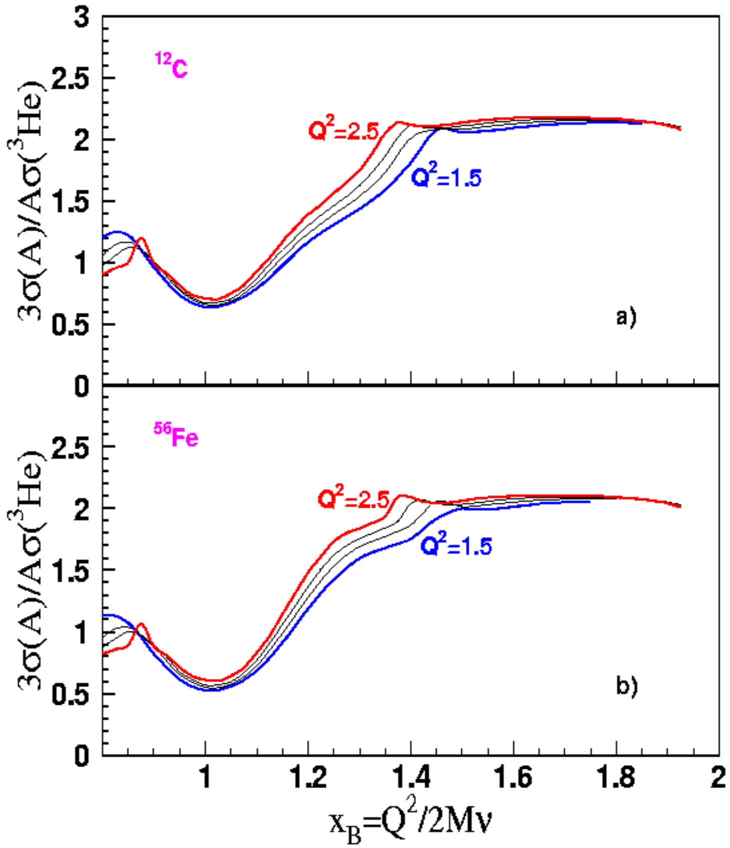
- The cross section ratios for heavy-to-light nuclei should scale at high momenta, where SRC contribution dominate.



Searching of SRC Kinematics in A(e,e/) Reaction (continue)

- Frankfurt and Strikman showed that the same ratios should also **scale** at large x_B for fixed Q^2.

- SRC are expected to be dominant for large x_B where the cross section ratios for heavy and light nuclei are **Scaled.**

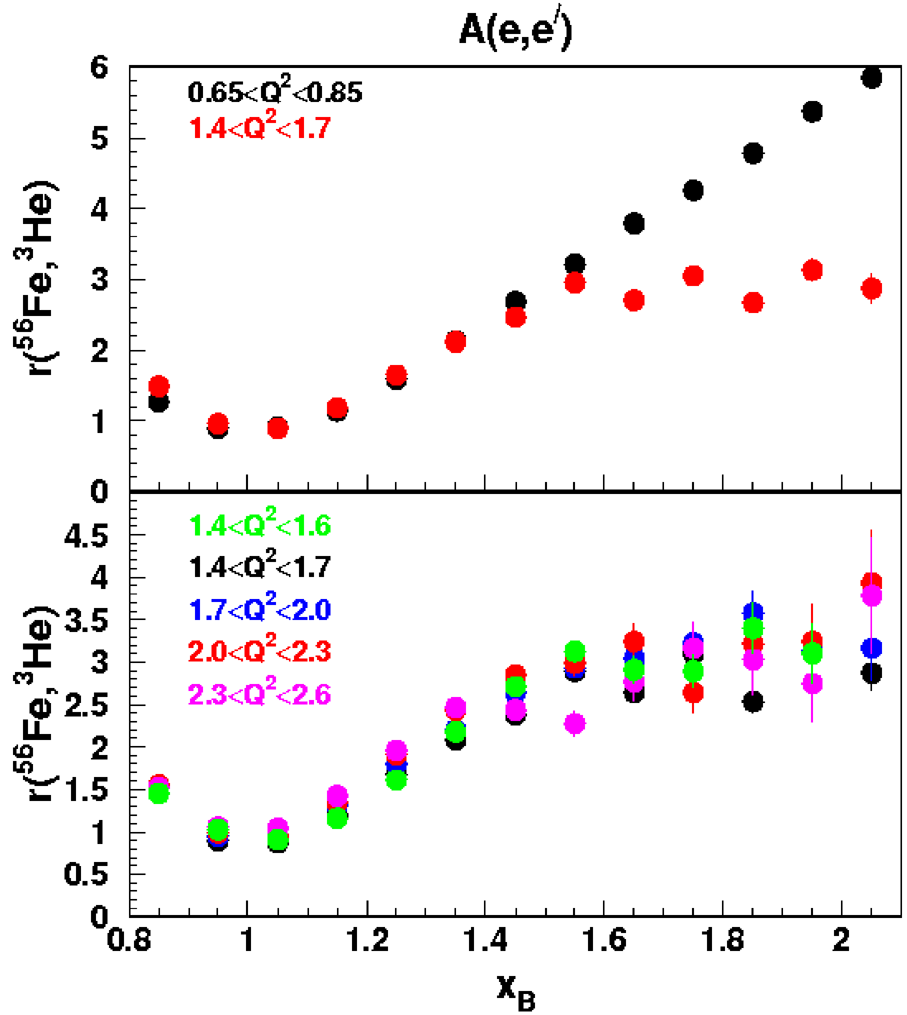


Normalized ratios at $1<x_B<2$

- Analyze the ratio

$$r(A,{}^{3}He) = K(Q^2)\frac{3\sigma(e,A)}{A\sigma(e,{}^{3}He)}$$

K takes into account differences between (e,p) and (e,n) elastic cross sections. In our Q^2 region K=1.14 and 1.18 for ^{12}C and ^{56}Fe respectively.



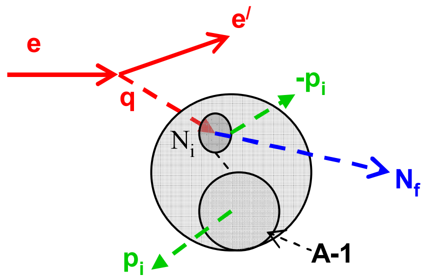
- Results for ^{56}Fe

- Ratios SCALE at $Q^2 > 1.4$ GeV2
  - Scaling vanishes at low Q^2.
  - Onset of scaling observed at $x_B>1.5$

Similar results are obtained for ^{12}C and ^{4}He

Relation between nucleon initial momentum p_i and x_B for (e,N_i) interaction

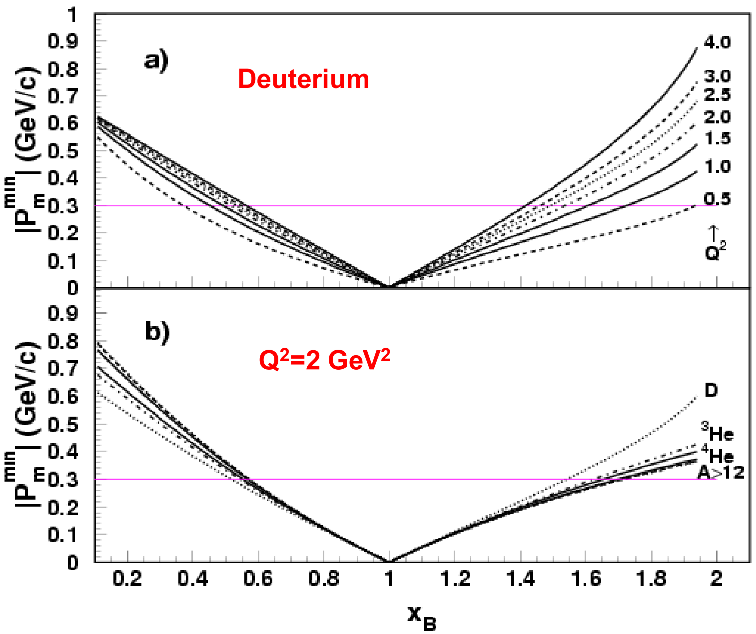
- In $A(e,e')$ at $x_B > 1$ the p_i is unknown. Measuring Q^2 and x_B, the <u>minimum</u> value of p_i can be obtained



$$(q+p_A-p_{A-1})^2=p_f^2=m_N^2$$

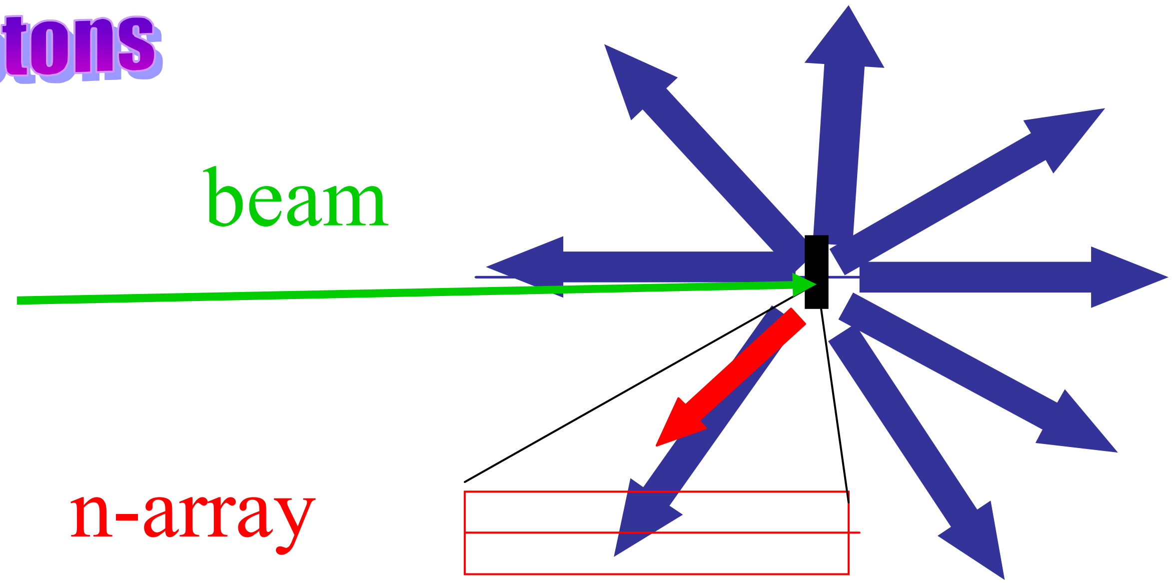
$$Q^2-(Q^2/m_N x_B)(M_A-E_{min})+2q_v p_{min}+2M_A E_{min}-\Delta=0$$

$$\Delta=M_A^2+M_{A-1}^2-m_N^2 \; ; \quad E_{min}=(m_N^2+p_{min}^2)^{1/2}$$

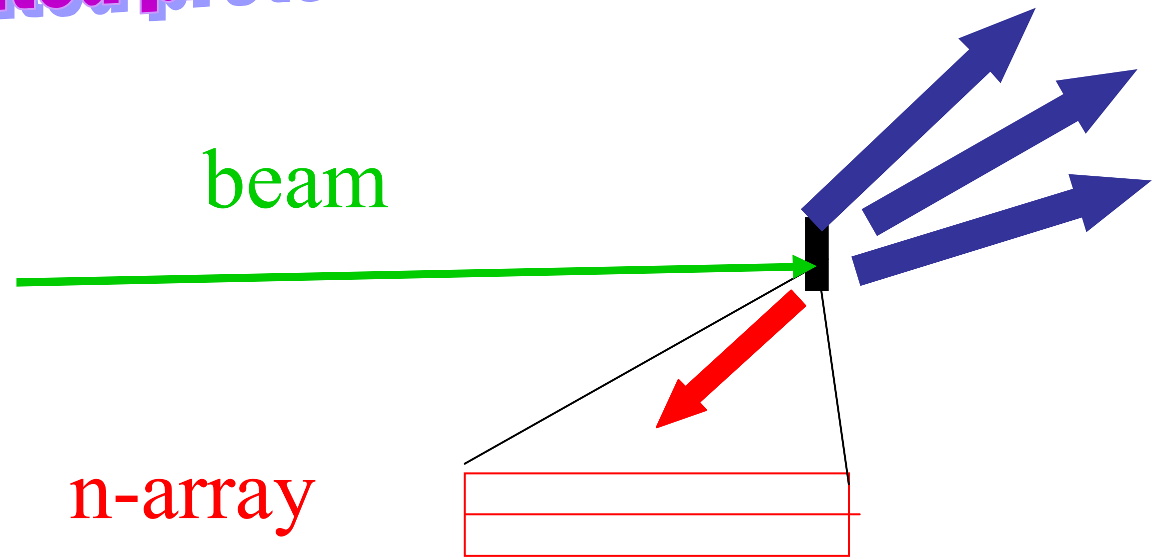


- Events with $p_i > p_{min}$ can be rejected by selecting specific x_B ranges at fixed Q^2.

uncorrelated protons

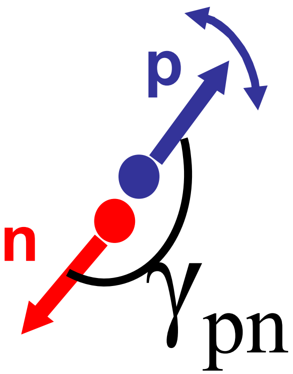


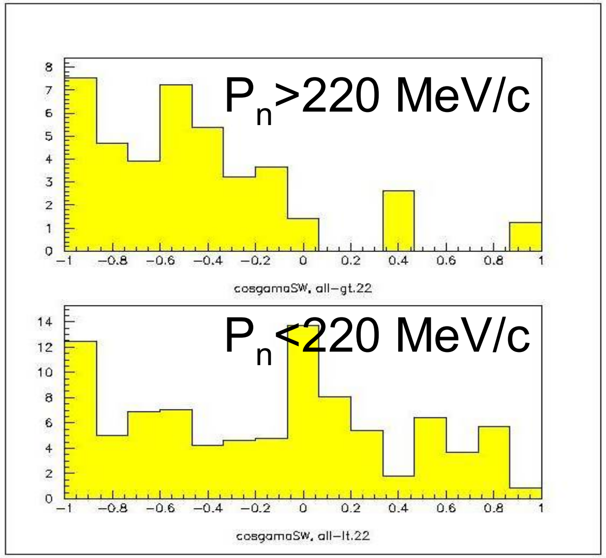
fully correlated protons

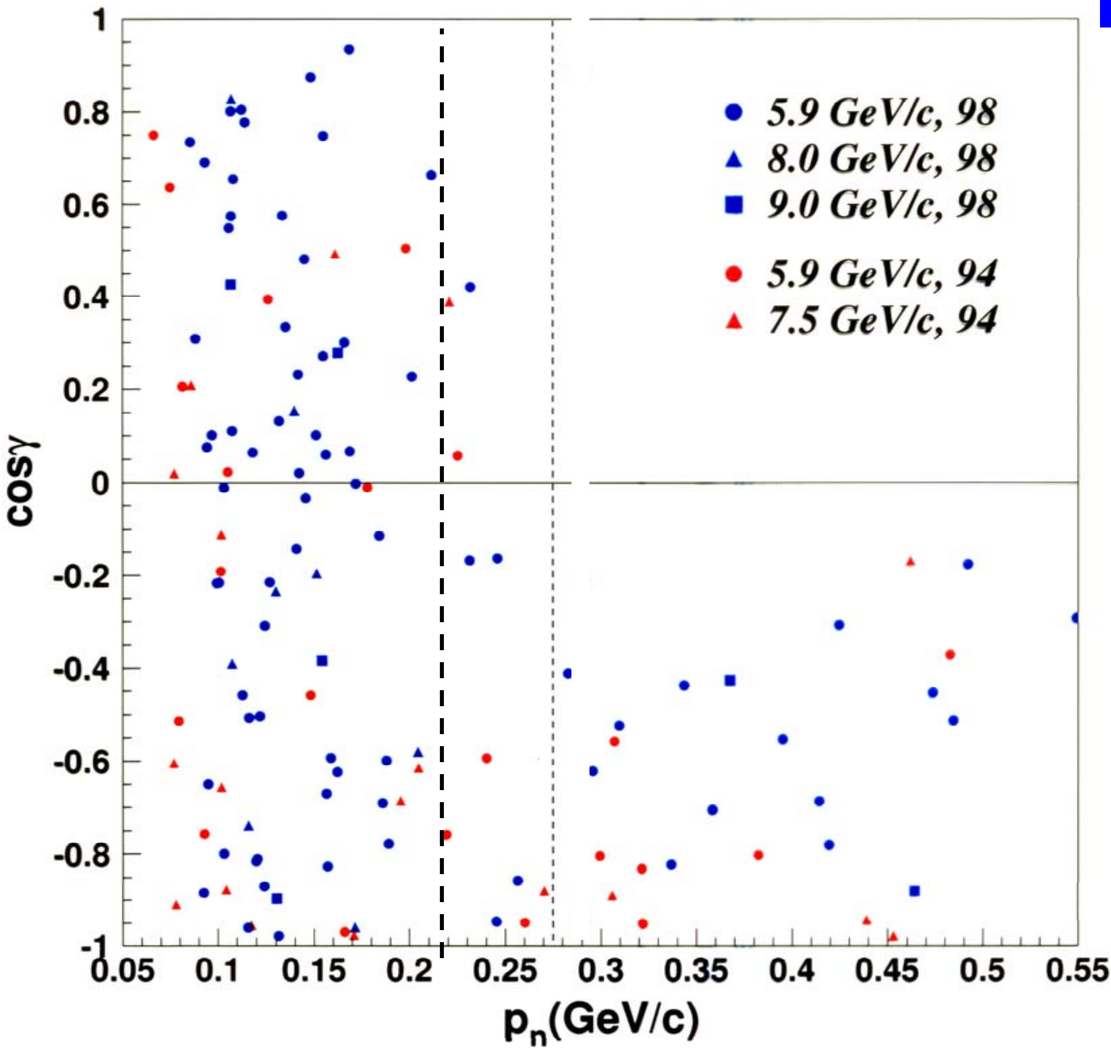


Directional correlation

(p,2pn)

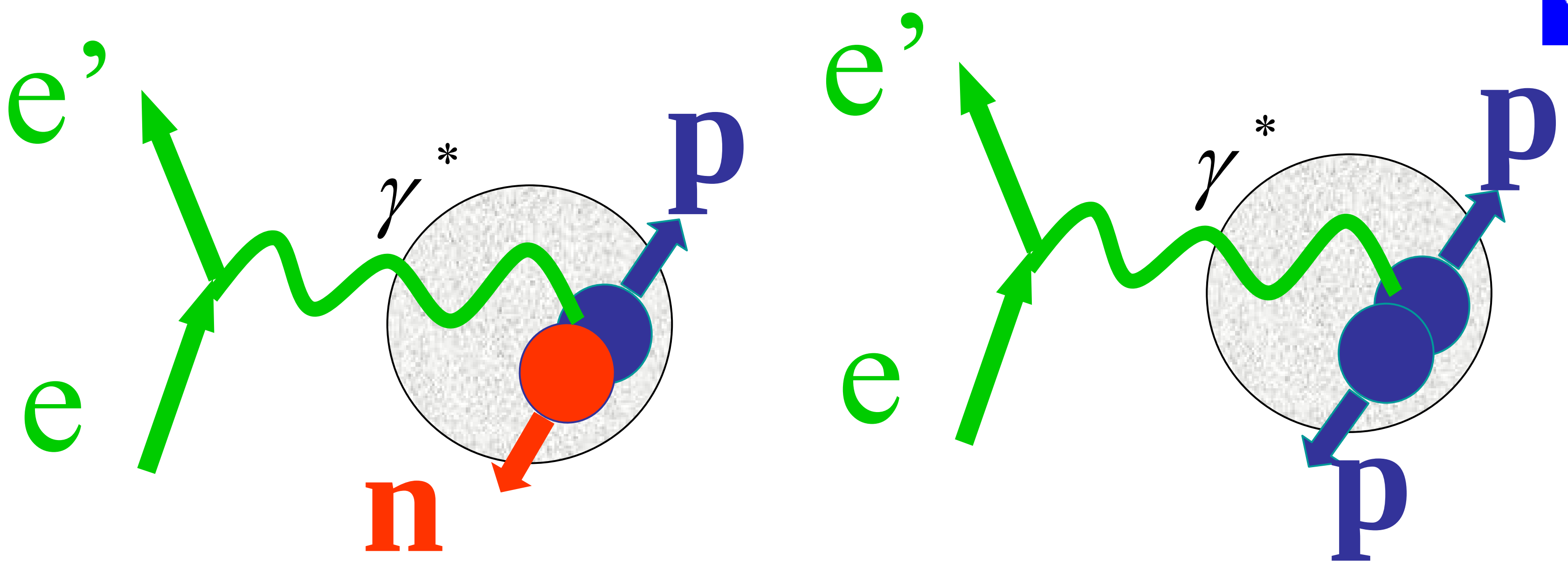






The EVA/BNL collaboration

Triple – coincidence measurements:



We measure the fraction of (e,e'p) events in which NN correlated nucleons are observed, as a function of the missing momentum of the proton in the nucleus.

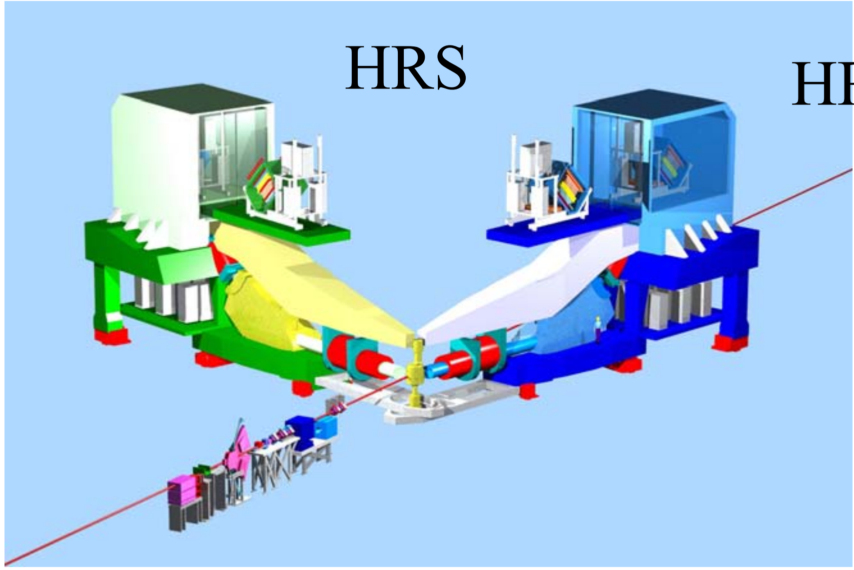
(e,e'p) → **spectral function** $S(E_m, \vec{P}_m)$

(e,e'pN) → **decay function** $D(E_m, \vec{P}_m, \vec{P}_s)$

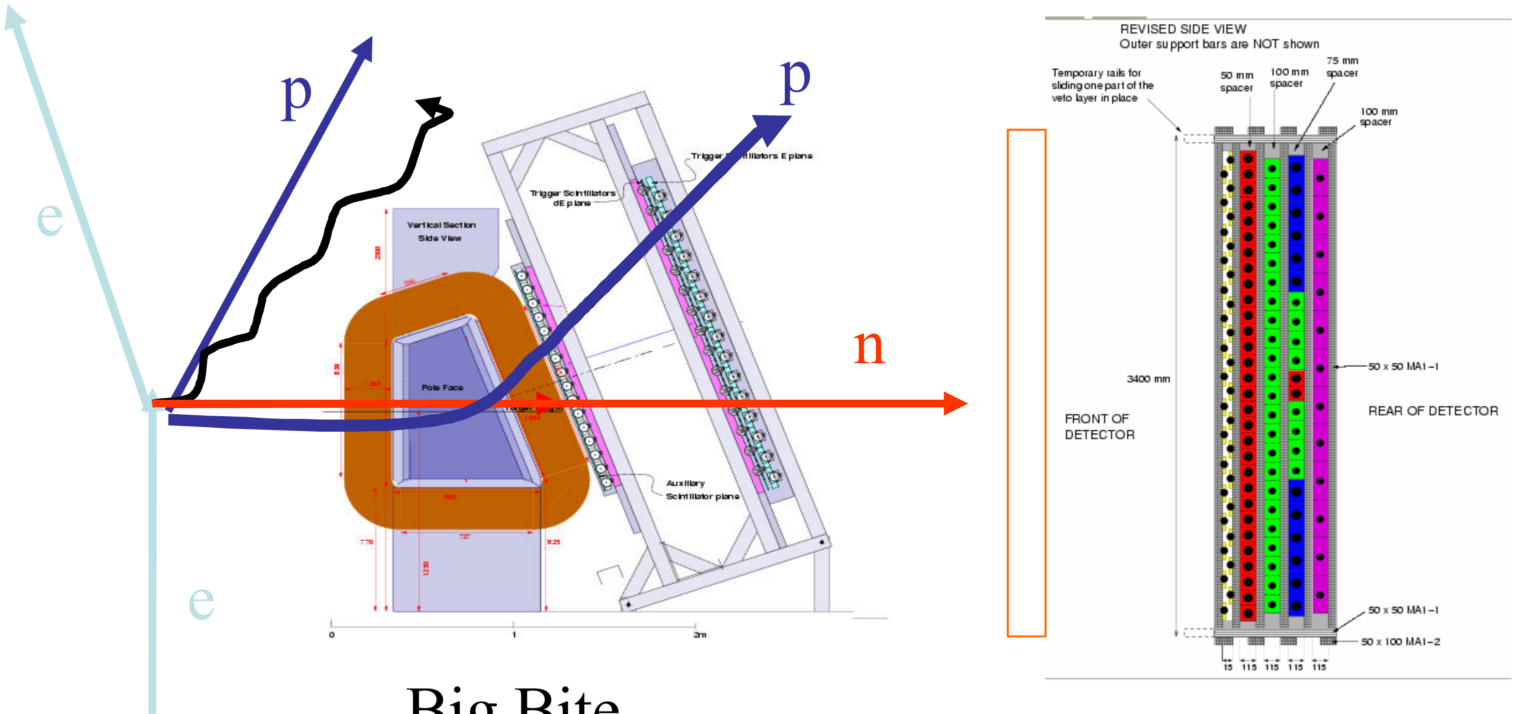
$$\int D(E_m, \vec{P}_m, \vec{P}_s)\, d^3 p_s = S(E_m, \vec{P}_m)$$

Experimental setup

EXP 01-015 / Jlab



n array



Big Bite

Lead wall

Lightcone Variables

The momentum of a nucleon is described in light cone space by (p_t, α), where

$$\alpha = \frac{E - p_z}{m}.$$

From α_p and α_n we can construct the z components of the relative and c.m. motion of the correlated pair:

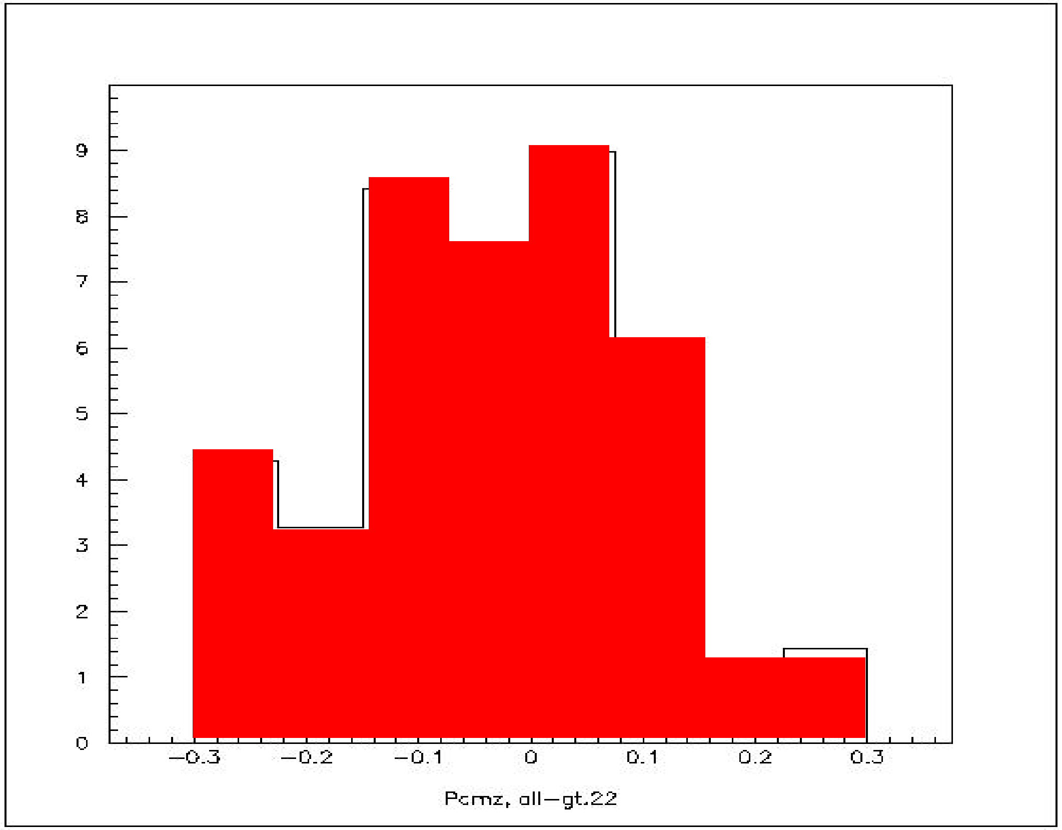
$$p_z^{cm} = 2m(1 - \frac{\alpha_p + \alpha_n}{2}),$$

$$p_z^{rel} = m|\alpha_p - \alpha_n|.$$

The EVA/BNL collaboration

PRL 90(2003)042301

The longitudinal CM momentum of the correlated pair

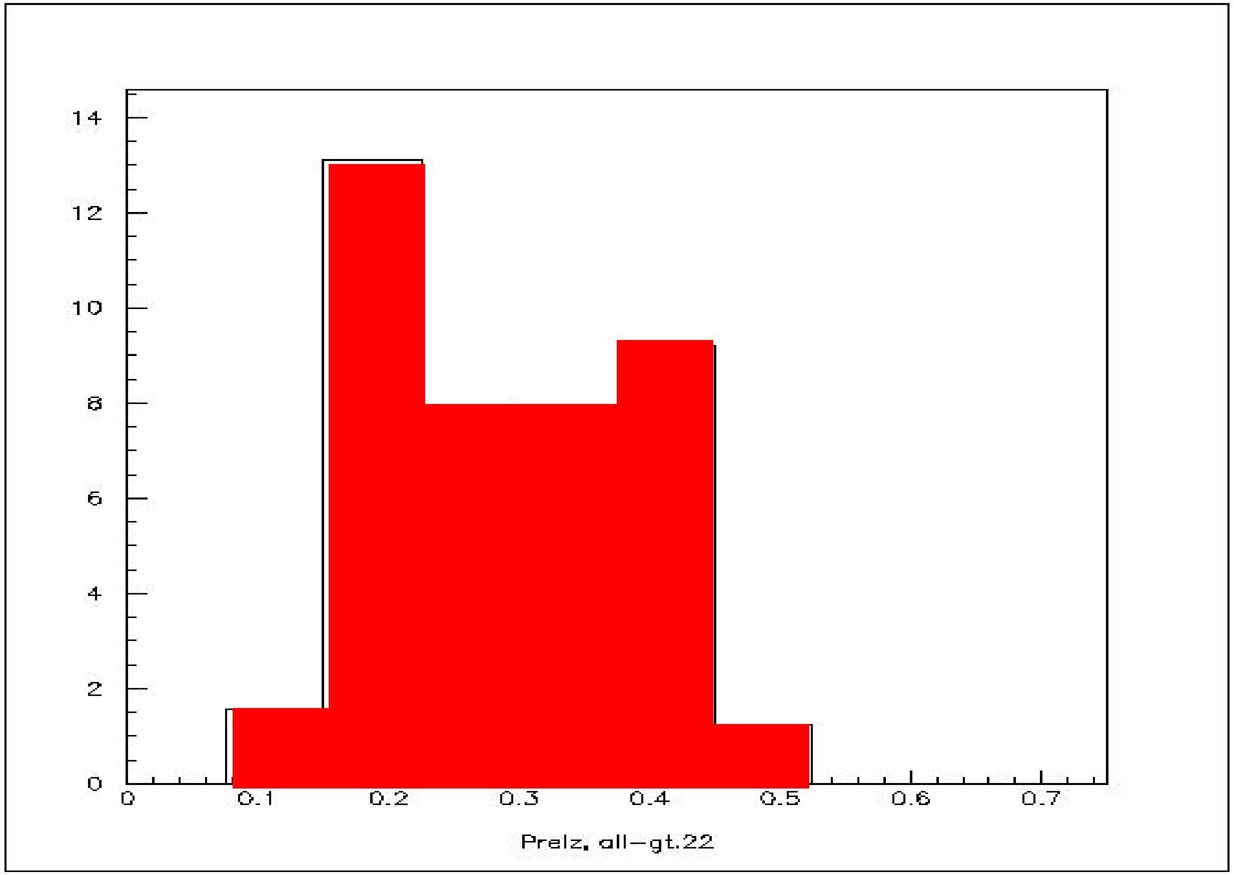


$$P_z^{cm} = 2m\left(1 - \frac{\alpha_p + \alpha_n}{2}\right)$$

$\sigma = 143 \pm 17$ MeV/c

The EVA/BNL collaboration

The partner's longitudinal relative momentum



$$P^{rel}_{z} = 300 \pm 100 \text{ MeV/c} \qquad P_Z^{rel} = m[\alpha_p - \alpha_n]$$

The EVA Collaboration

A. Malki[a], J. Alster[a], G. Asryan[c,b], D. Barton[c], V. Baturin[c,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] Aclander

[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 :

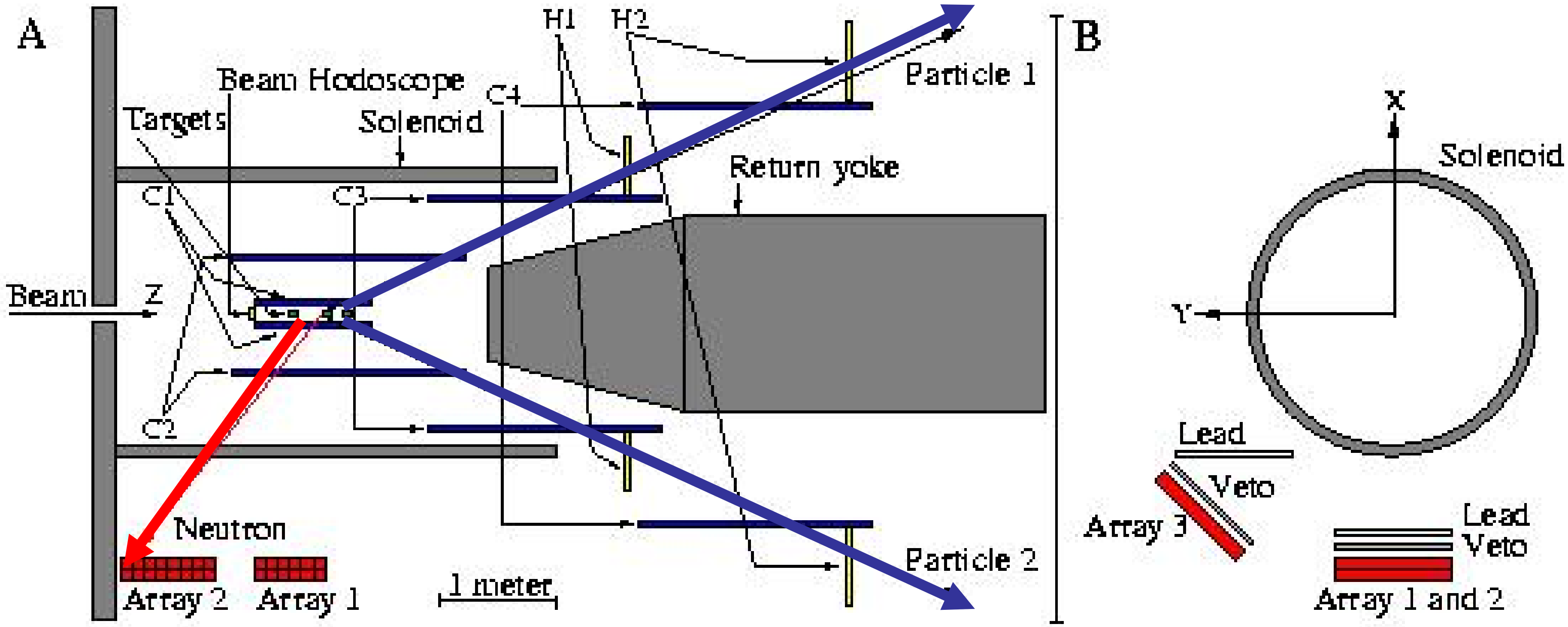
J. Aclander et al. Phys. Lett. B453 (1999) 211.

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

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

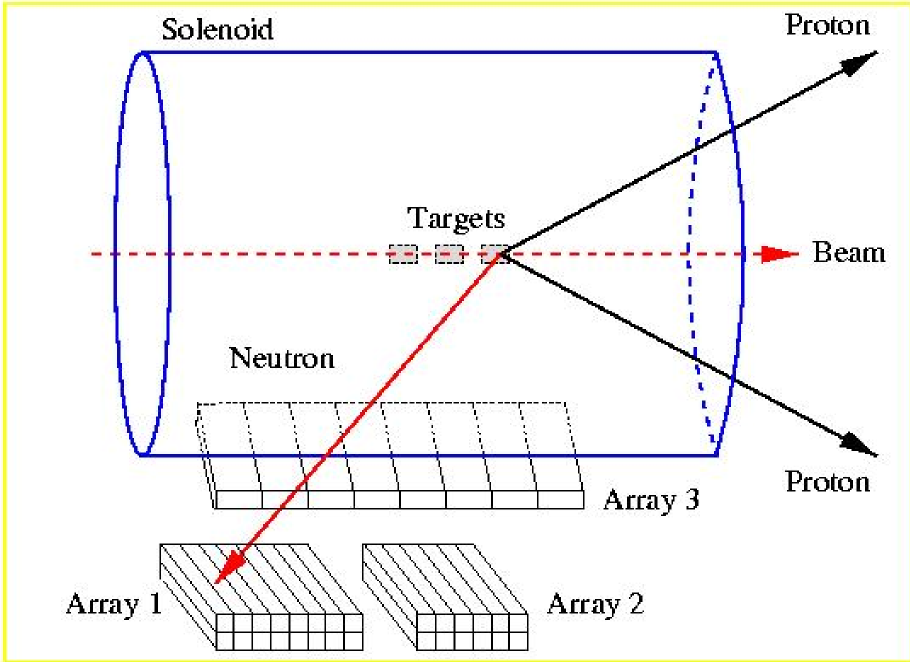
I. Yaron et al., PRC C66, 024601 (2002).

The EVA spectrometer and the n-counters:



The EVA spectrometer and the n-counters:

Acceptance



struck proton:

$$0.6 < \alpha < 1.1 \quad p_2 > p^{\min}$$

recoil neutron:

$$0.9 < \alpha_n < 1.4$$

$$p^{\min} < p_2 > 0.55$$

$$72^0 < \theta_n < 132^0$$

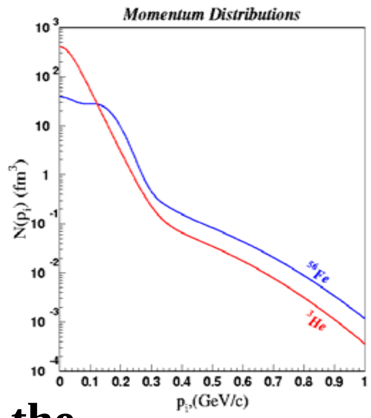
Array 1: total area 0.6×1.0 m^2, 12 counters, 2 layers 0.125 m each.

Array 2: total area 0.8×1.0 m^2, 16 counters, 2 layers 0.125 m each.

Array 3: total area 2×1.0 m^2, 8 counters, 1 layers 0.1 m each.

Extracting the probability of 2N-SRC from the inclusive A(e,e') reaction

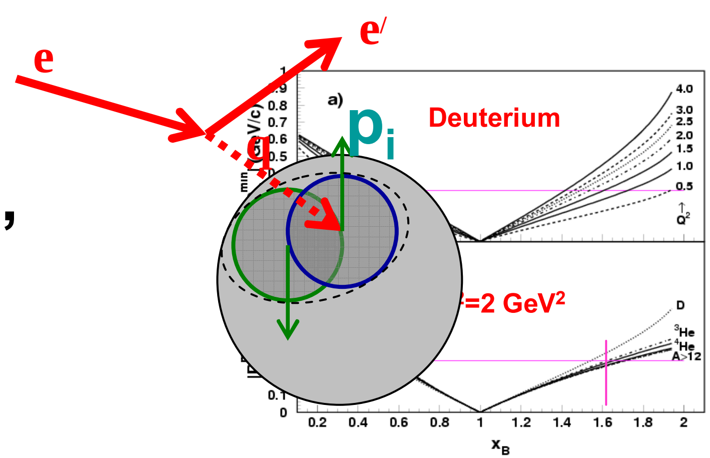
- At high momenta nucleon momentum distributions are similar in shape for light and heavy nuclei: SCALING.



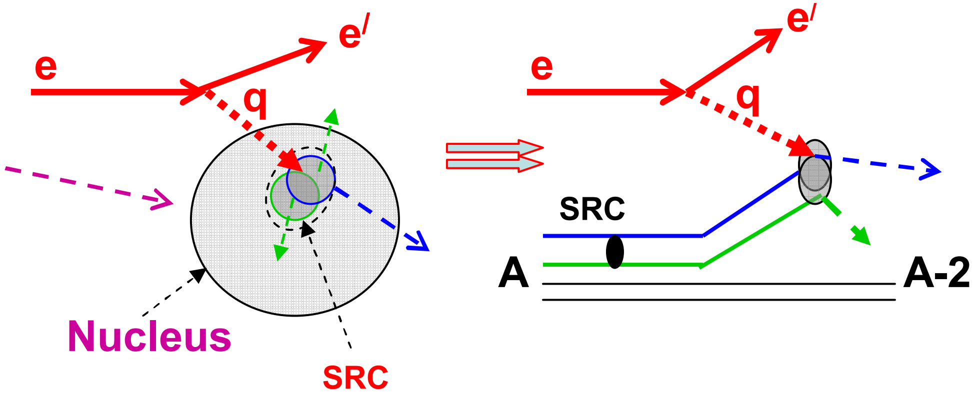
- Frankfurt and Strikman: Can be explained by 2N-SRC dominance.
  - Within the 2N-SRC dominance picture one can get the probability of 2N-SRC in any nucleus, from the scaling factor.

Problem: In A(e,e') the momentum of the struck proton (p_i) is unknown.

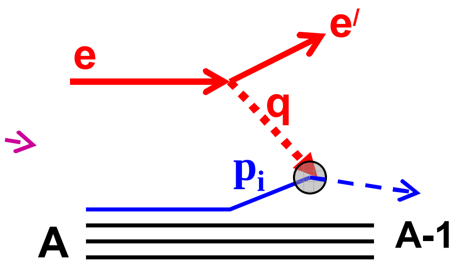
Solution: For fixed Q^2 and $x_B>1$, x_B determines a minimum p_i



The reaction we wish to investigate.

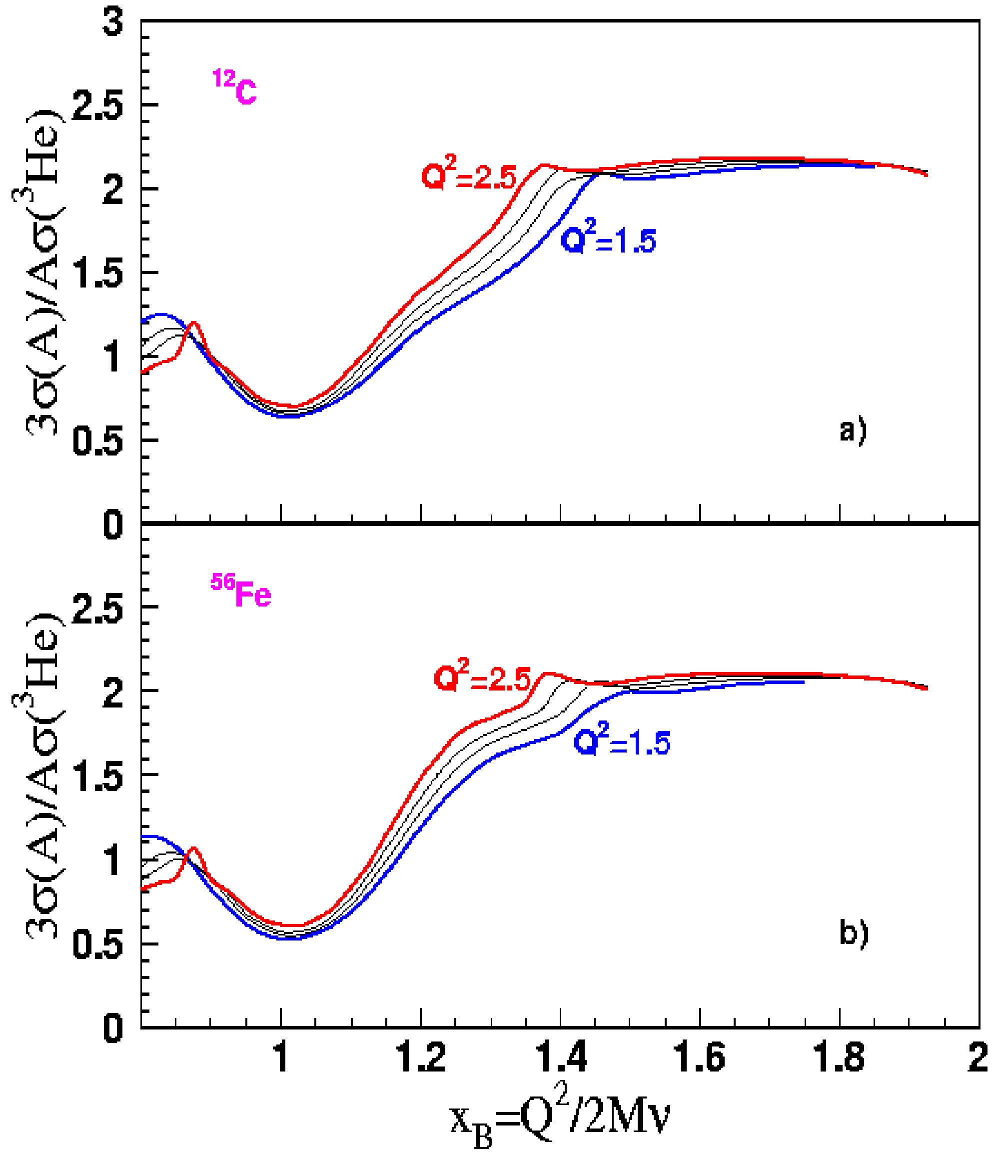


The quasielastic scattering background.



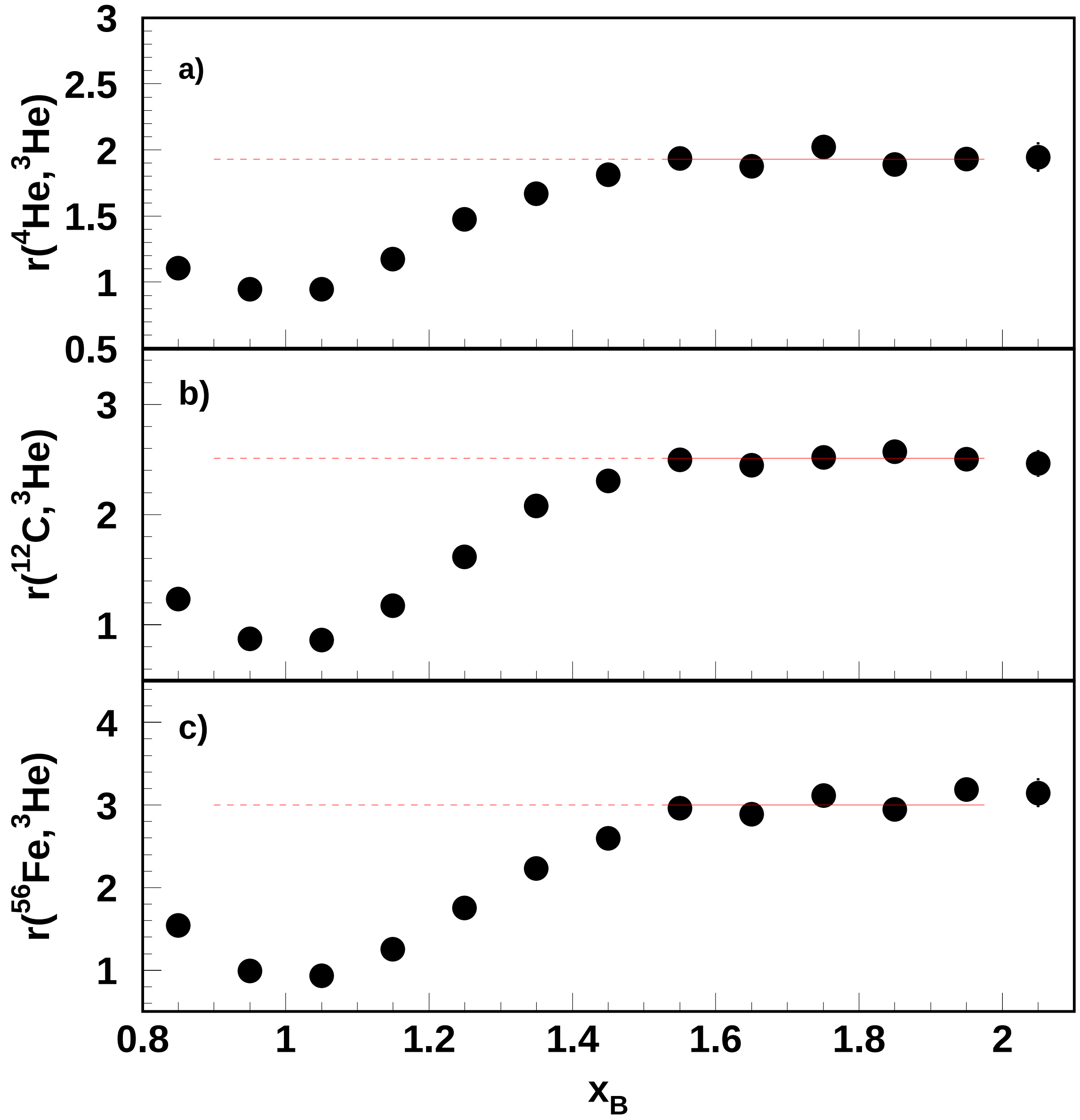
Selecting X_B >1 above some value (P_i above some value) suppresses the single particle background.

Prediction by Frankfurt, Sargsian, and Strikman:



CLAS A(e,e') Data

K. Sh. Egiyan et al. PRC 68, 014313.



$$\mathbf{x_B} = \frac{\mathbf{Q^2}}{2\mathbf{M}\nu} > 1.5,$$

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

suppresses the otherwise dominant contribution from single nucleons with momentum smaller than 275 MeV/c (as can be obtained from the kinematics of electron scattering from single nucleons

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

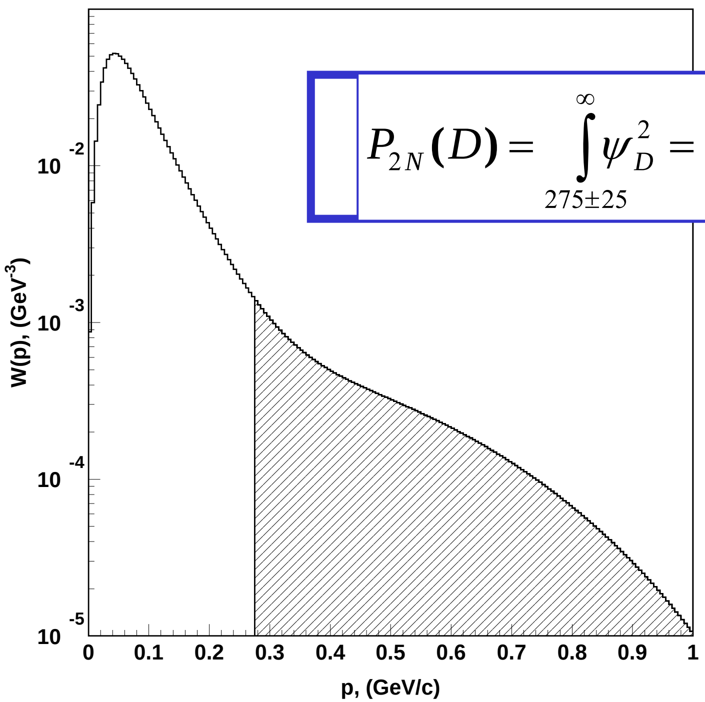
Estimate of 2N-SRC in ^{12}C

$$\frac{P_{2N}(^{12}C)}{P_{2N}(^{3}H_e)} \frac{P_{2N}(^{3}H_e)}{P_{2N}(D)} = 4.93 \pm 0.27 \pm 0.28$$

calculations

measurement

For 275±25 MeV :



$$P_{2N}(D) = \int_{275\pm25}^{\infty} \psi_D^2 = 0.041 \pm 0.008$$

$$P_{2N}(^{12}C) = 0.20 \pm 0.045$$

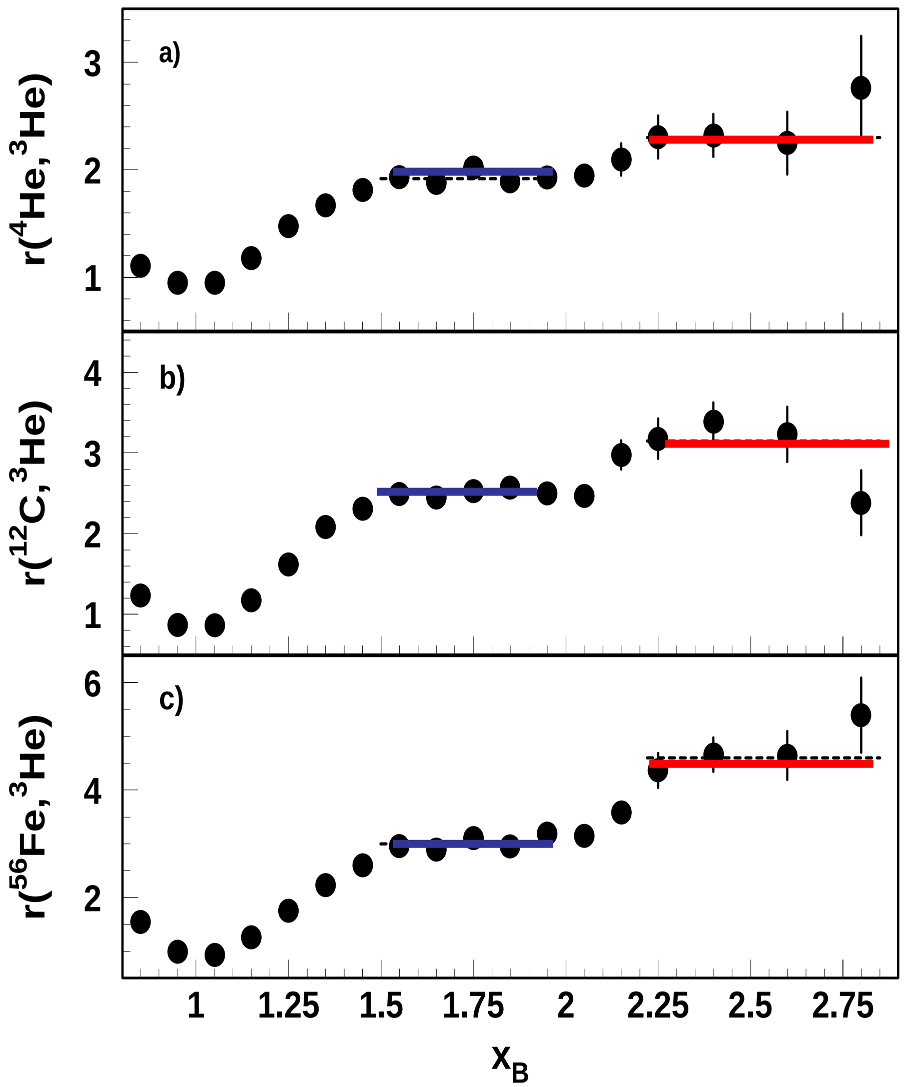
This includes all three isotopic compositions (pn, pp, or nn) for the 2N-SRC phase in ^{12}C.

New CLAS A(e,e') Result

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

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

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



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

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

Less than 1% of total

From the (e, e’) measurements

For ^{12}C :

80 ± 4.5 % - **single particle moving in an average potential.**

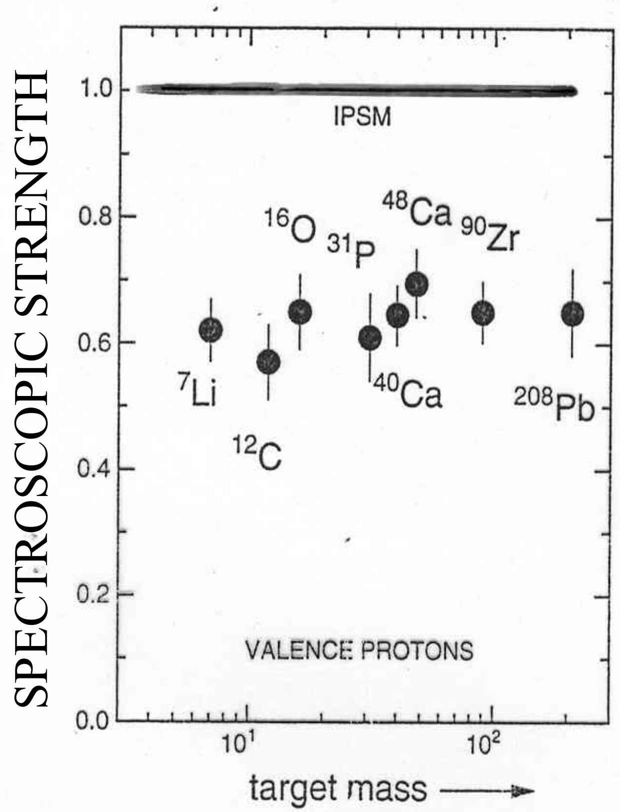
20 ± 4.5 % - **2N SRC** .

Less than 1% **-** “more than 2N correlations”**.**

Now Include (e,e'p) Data

The Independent Particle Shell Model is based upon the assumption that each nucleon moves independently in an average potential (mean field) induced by the surrounding nucleons.

The (e,e'p) data for knockout of valence and deeply bound orbits in nuclei gives spectroscopic factors that are 60 – 70% of the mean field value.

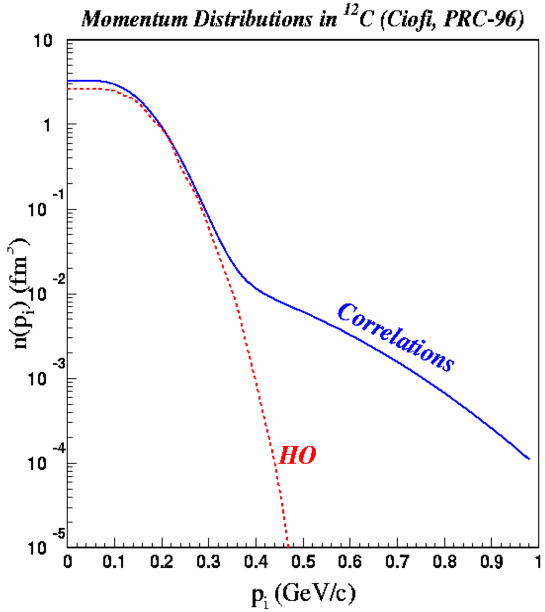


Spectroscopic strength for knocked out valence protons measured with the reaction (e, e'p), relative to the independent-particle-shell model prediction.

Where is the missing strength ?

The IPSM ignores the NN correlations which go beyond the mean field level:

* * The long range NN correlations.
* * The short – range (scalar) correlations that reflect the remnant of the hard - core part of the NN force.
* * The intermediate distance, 1-2 fm, (tensor) correlations.
* * Spin - isospin, spin – orbit correlations.
* * "more than 2 - nucleon" correlations.



The individual roles of the different correlation types was not established experimentally.

From the (e, e') measurements

From the (e, e' p) measurements

For ^{12}C :

80 ± 4.5 % - single particle moving in an average potential.

60 - 70%

independent single particle

10 - 20 %

long range (shell model) correlations,

20 ± 4.5 % - 2N SRC .

Less than 1% - "more than 2N correlations"**.**

This result together with the 2N-SRC probability determined from the inclusive (e,e') data can be used to estimate the absolute probabilities of pn, pp, and nn -SRC pairs in ^{12}C.

$$P_{2N}(^{12}C) = 0.2 \pm 0.042$$

$$\rightarrow \quad P_{pn}(^{12}C) = 0.184 \pm 0.045$$

Assuming X is pp-SRC only, yields an upper limit on the pp-SRC probability which in ^{12}C is assumed to be equal to the nn-SRC probability.

$$\rightarrow \quad P_{pp}(^{12}C) = P_{nn}(^{12}C) \leq 0.03$$

pp-SRC versus pn-SRC pairs

$$\rightarrow \quad P_{pn}({}^{12}C) / P_{pp}({}^{12}C) \geq 6$$

Is this large or small? What to expect?

A statistical distribution obtained by assuming that the SRC are L=0 pairs with equal occupation of each possible quantum state:

np (spin=0,1) : 4 states
pp (spin=0) : 1 state
nn (spin= 0): 1state

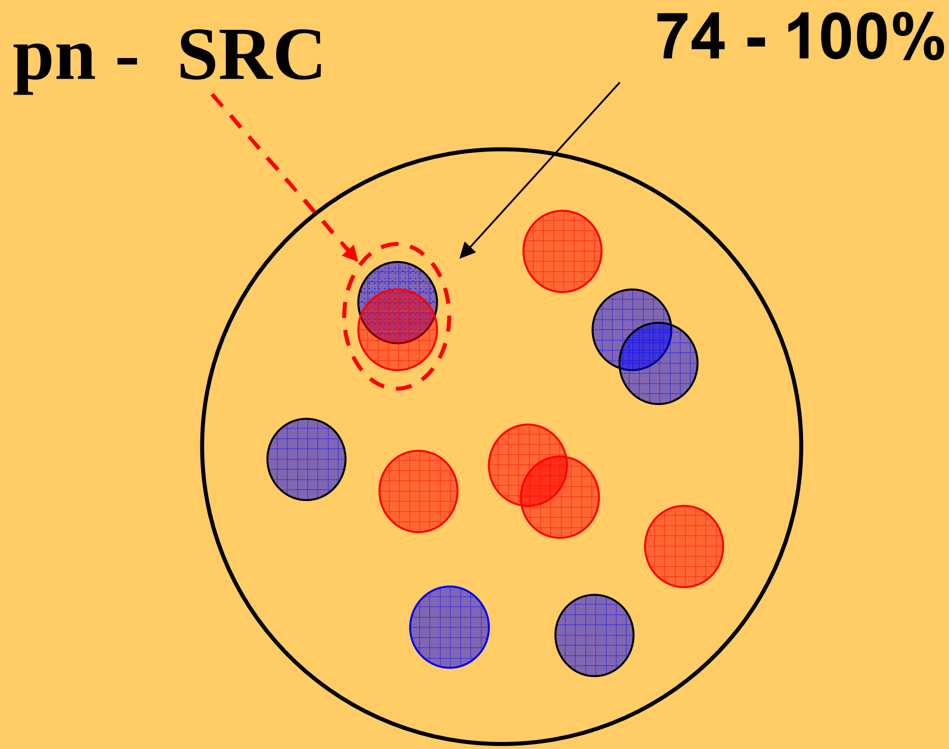
$$\rightarrow \quad P_{pn}({}^{12}C) / P_{pp}({}^{12}C) = 4$$

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

Does it mean that a nucleus of only protons or only neutrons (like what a n-star might be) behaves more like an ideal Fermi gas or more like nuclei?

For 275-600 MeV/c protons in ^{12}C:

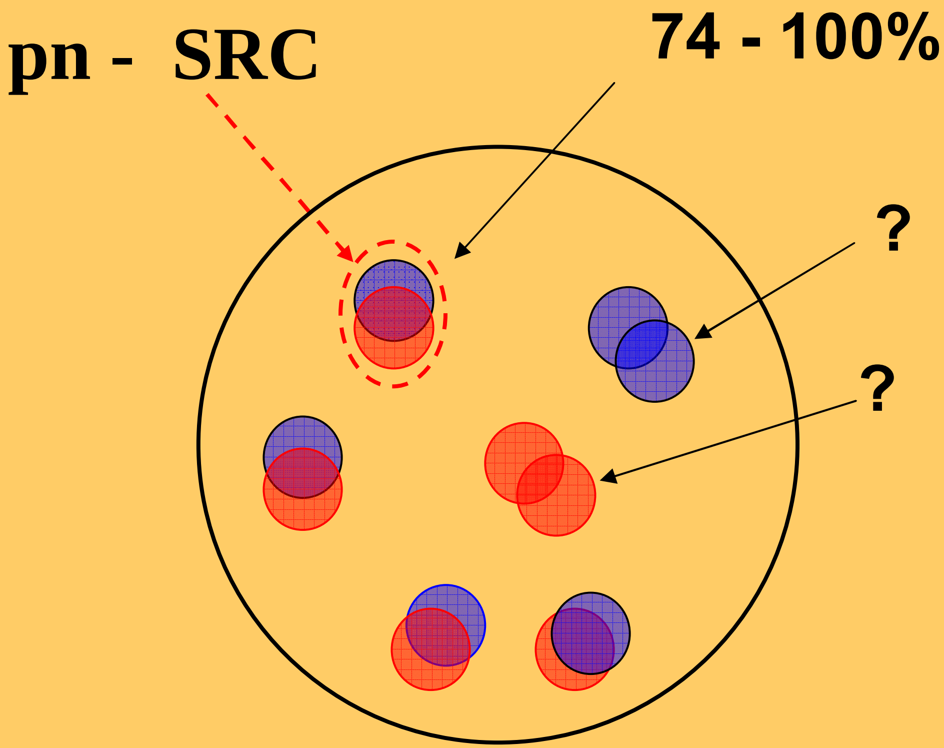
np-SRC dominance:



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

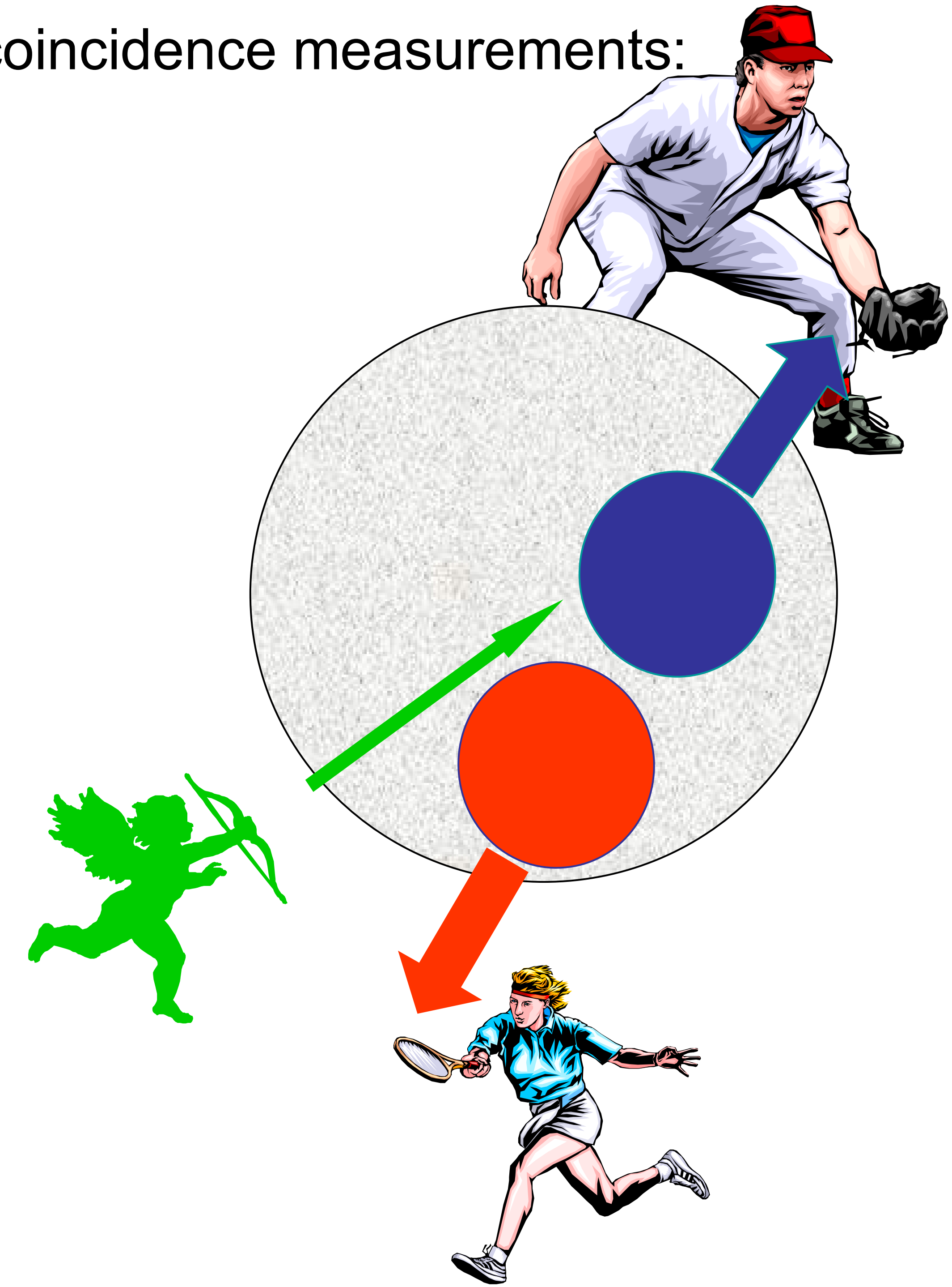
For 275-600 MeV/c protons in ^{12}C:

np-SRC dominance:



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

Triple – coincidence measurements:



Together, the deduced ^{12}C structure is:

80 ± 4.5 % - single particle moving in an average potential.

→ **60-70 %** - independent particle in a shell model potential.

→ **10-20 %** - shell model long range correlations

20 ± 4.5 % - 2N SRC .

→ **18.4 ± 4.5 %** - SRC np pairs .

→ **<3%** - SRC pp pairs.

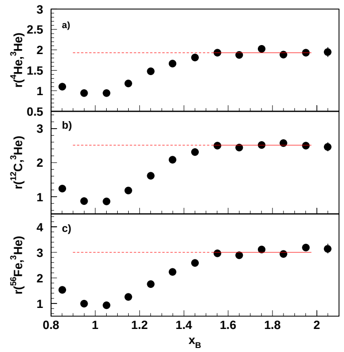
→ **<3 %** - SRC nn pairs.

Less than 1% - SRC of "more than 2 nucleons".

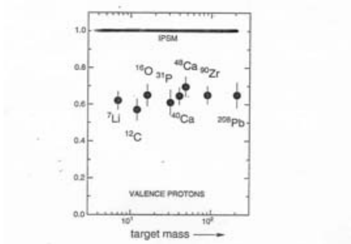
Summary

A comprehensive picture emerges from the new high-energy/large-momentum-transfer measurements:

Inclusive electron scattering yields a (20±4.5)% probability of finding a nucleon of ^{12}C in the 2N-SRC phase, and a more than an order of magnitude smaller probability for SRCs involving more than two nucleons.

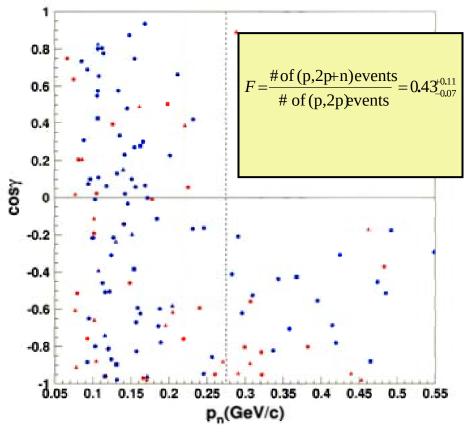


The above is consistent with the (e, e' p) data for knockout of protons from valence and deeply - bound orbits in nuclei which are 60-70% of the value predicted by the IPSM.

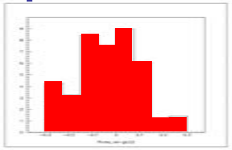


Spectroscopic strength for knocked out valence protons measured with the reaction (e,e'p), relative to the independent-particle-shell model prediction.

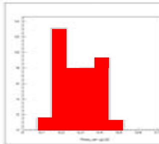
The ^{12}C(p,2p + n) measurement allows to deduce the isospin structure of the 2N-SRC phase: the probability for a nucleon to be part of a SRC np pair is ~18 %, while the probabilities for a nucleon to be a member of a pp or nn SRC pair are each less than 3 %.



The longitudinal CM momentum of the correlated pair is 143 ± 17 MeV/c.

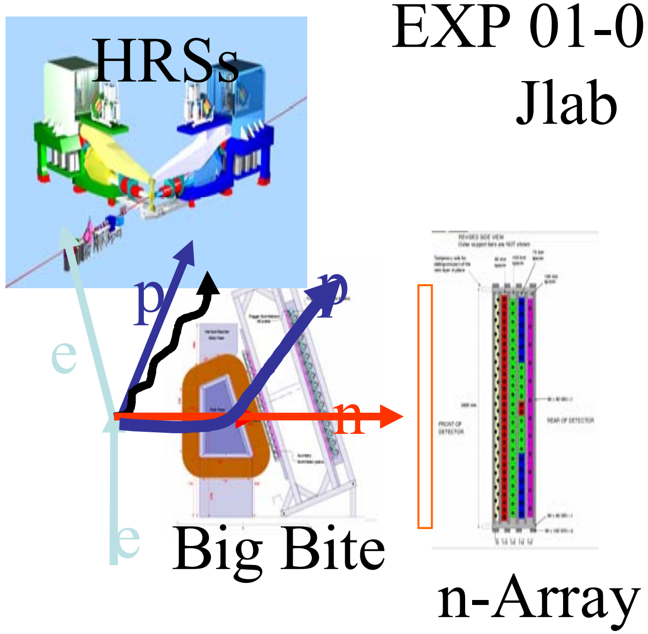


The partner's longitudinal momentum relative to their CM is: 300 ± 100 MeV/c.

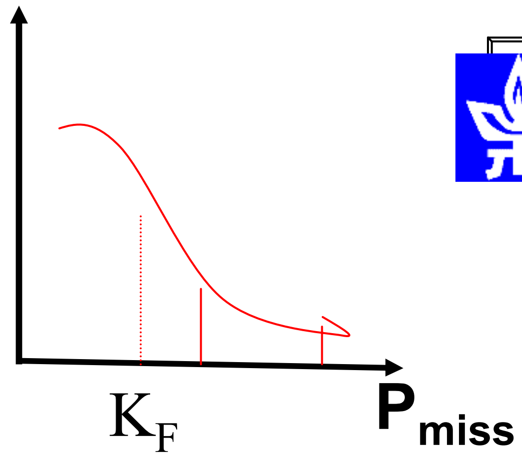


For more precise conclusions, a new experimental study was recently performed at JLab. This will allow us to obtain directly the ratio of pp and pn components in the 2N-SRC phase and to better determine the pair properties .

EXP 01-015 / Jlab



Expected results:



Determination of the fraction of the (e,e'p) events which are associated with NN SRC as a function of the missing momentum. Data are available for missing momentum range of 200-600 MeV/c.

(e,e'pp)/(e,e'p) (e,e'pn)/(e,e'p)

Direct comparison between pn and pp SRC pairs.

(e,e'pp)/(e,e'pn)

Determination of the pair kinematical quantities (CM momentum, relative momentum).

…