SHORT-RANGE CORRELATIO

from

$^{12}C(p,2p + n)$ and $^{12}C(e,e'p + N)$

John W. Watson
Kent State University

and the
EVA Collaboration

Trento Workshop March 2004

Experiment E850

The EVA Collaboration

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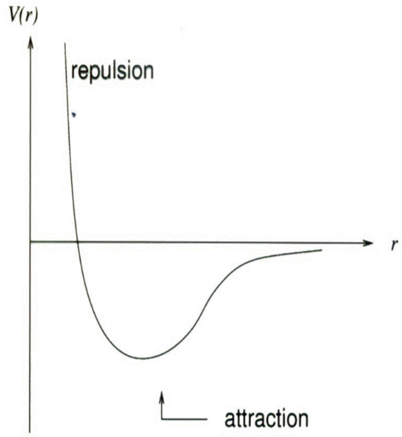
J.I.N.R., Dubna

The N-N Interaction, the Shell Model and

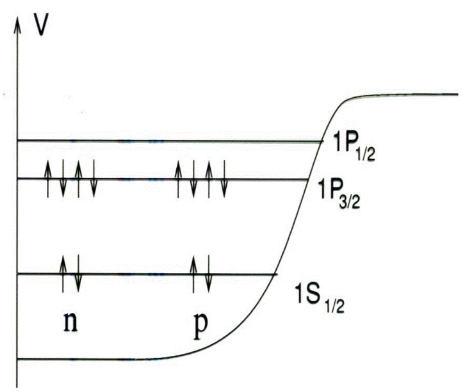


N–N interaction

Nuclear Shell Model (~ 1950) { Maria Mayer
J.H.D. Jensen
Nobel Prize in 19

The attractive part of the N-N interaction in combination
Pauli principle produces an average attractive potential wi
defined quantum states.

^{12}C
(shell model picture)



Short-range repulsion → saturation of nuclear densities,
However, the short-range repulsive part must also manifest
the wavefunctions of nucleons in the nucleus. Because it is
range, high-momentum components will be affected. Typic

Nuclear Fermi Momenta from Quasielastic Electron Scattering

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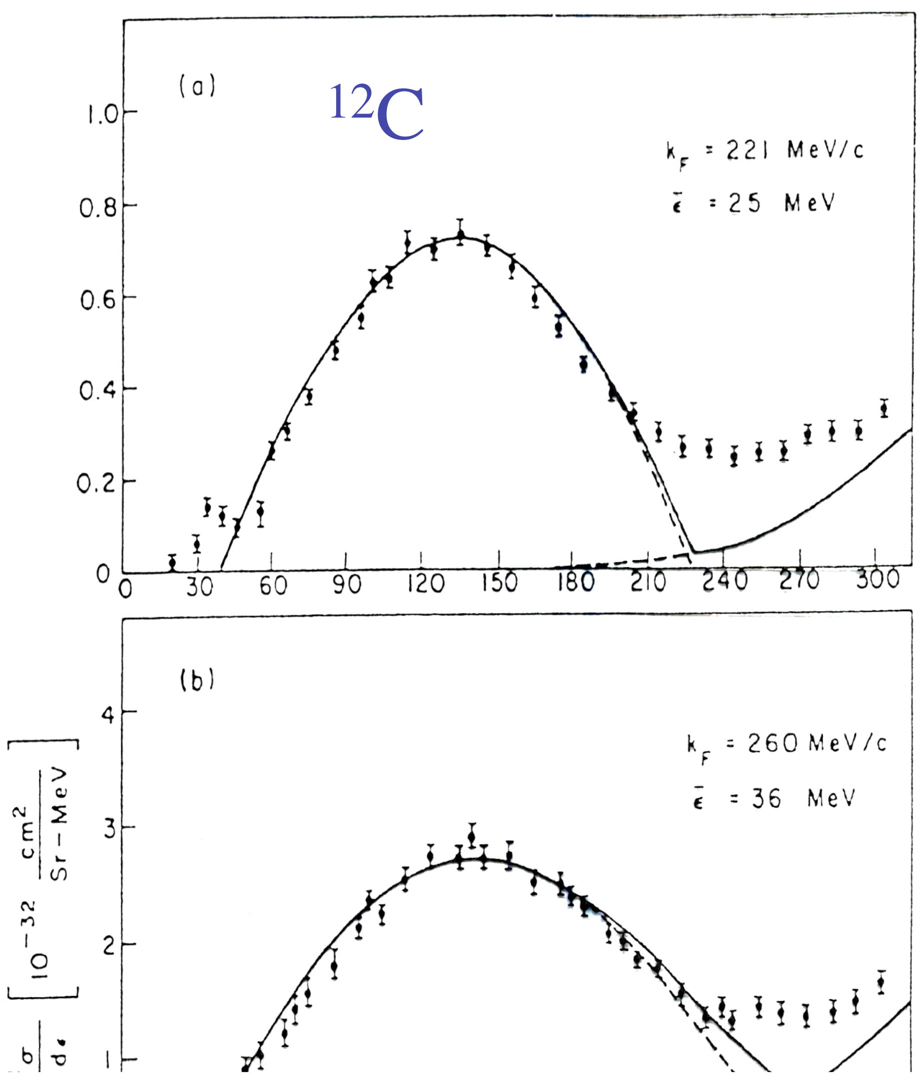
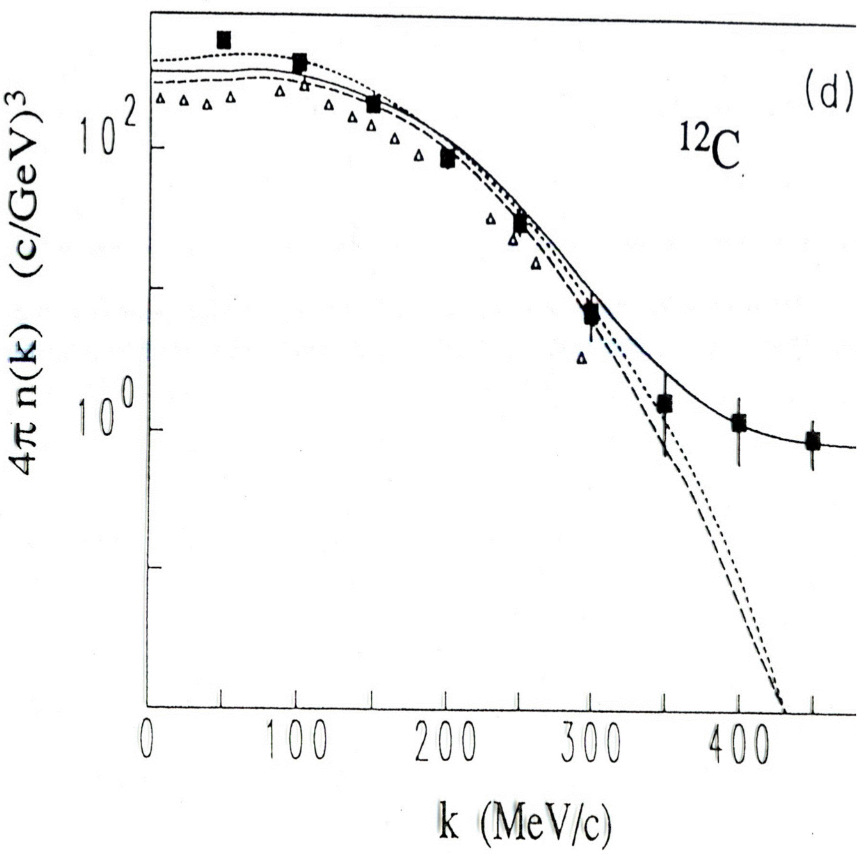


Trento Workshop March 2004

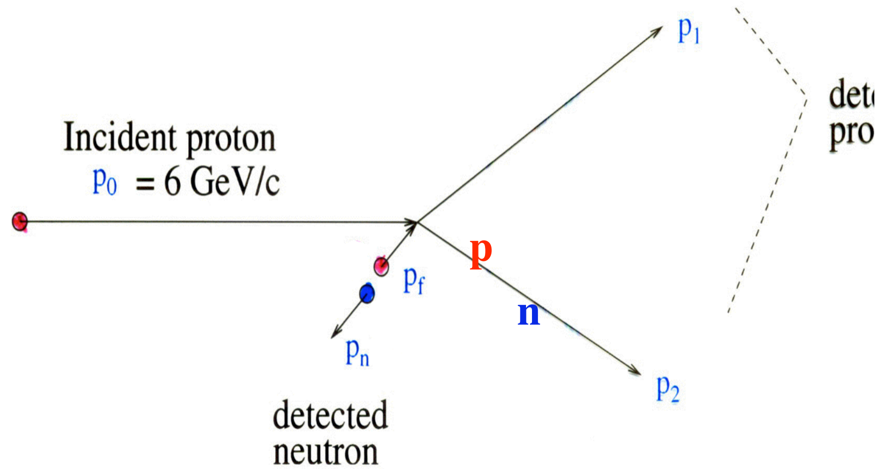
EVIEW C VOLUME 43, NUMBER 3

ing analysis of quasielastic electron scattering and nucleon momen
in few-body systems, complex nuclei, and nuclear matte

C. Ciofi degli Atti,[1,2] E. Pace,[1,3] and G. Salmè[1]



For quasi-elastic reaction, we can apply impu
approximation (IA) to the interaction of the pro
and the one active target nucleon:



We reconstruct the momentum $\vec{p}_f$ of the stru
proton:

$$\vec{p}_f = \vec{p}_1 + \vec{p}_2 - \vec{p}_0$$

We then ask is there a neutron in coincidence, a
$\vec{p}_n$ and $\vec{p}_f$ "Correlated"

i.e. roughly *equal* and *opposite*?

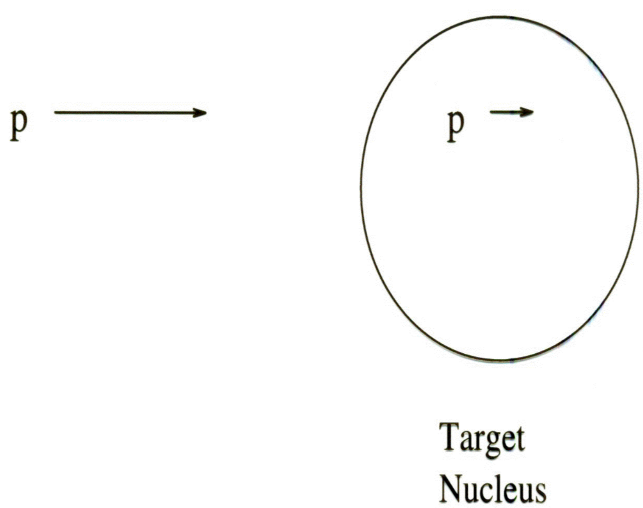
For energies of several GeV and up,
For p-p elastic scattering near 90° c.m.,

$$\frac{d\sigma}{dt} \sim s^{-(n_1+n_2+n_3+n_4-2)}$$

$$\sim s^{-10}$$

where the Mandelstam variable $s = (P_0 + P_F)^2$
square of the total c.m. energy.

So for quasi-elastic p-p scattering near 90° c.m
have a very strong preference for reacting with r
protons with their Fermi motion in the beam dir



This minim

Preferentia
selects high momentum components

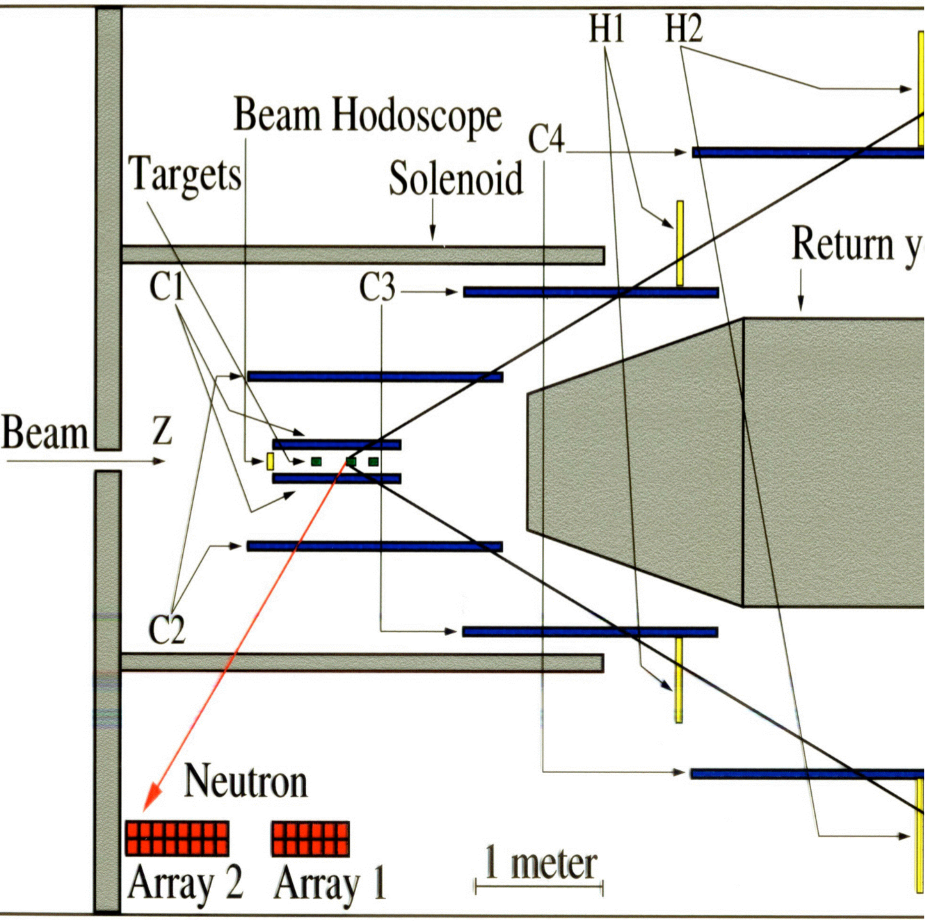
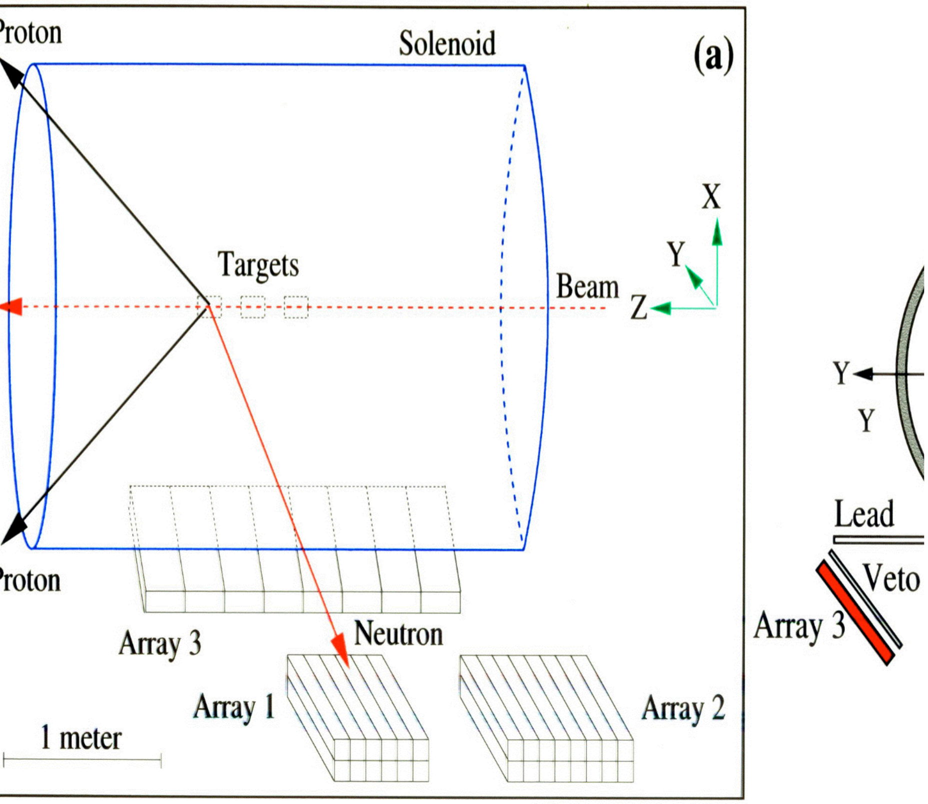


Figure 1: A schematic side view of the EVA spectron



Array 1: total area 0.6×1.0 m^2, 12 counters, 2 layers 0.12

Array 2: total area 0.8×1.0 m^2, 16 counters, 2 layers 0.12

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

igure 5: A schematic side view (a) and a head-on view (b) of the l
d the neutron counter arrays.

Bunch Formation:

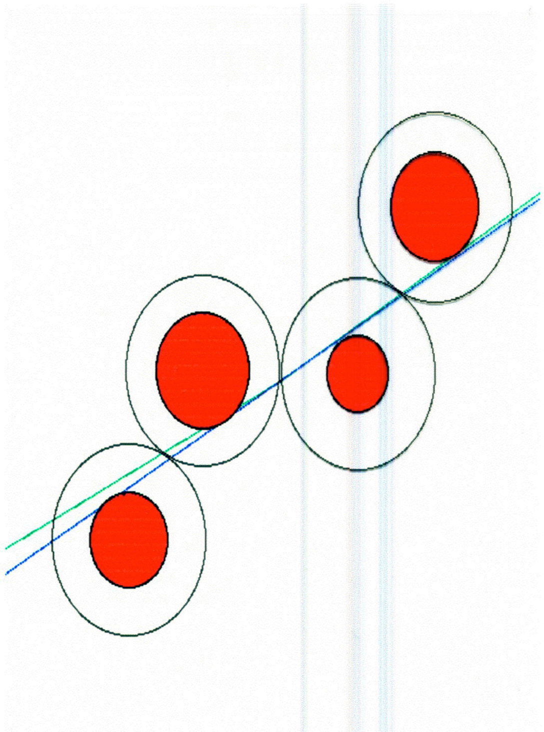


Figure 11: An example of a straw-tube bunch. The outer cles represent the walls of the tube. The radius of the inne circles is the drift distance. The blue line is the local deriv to a trajectory and the green line is the global particle tra

Track Fit:

$$y(x) = bx + cx^2$$

Quasi-elastic analysis:

➥ Track Reconstruction:

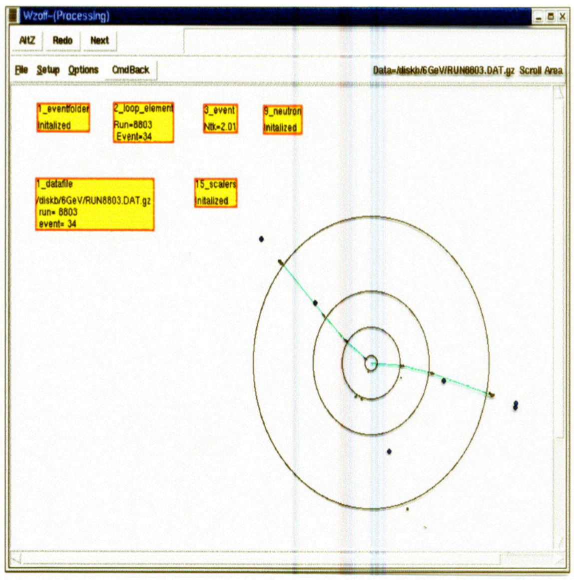
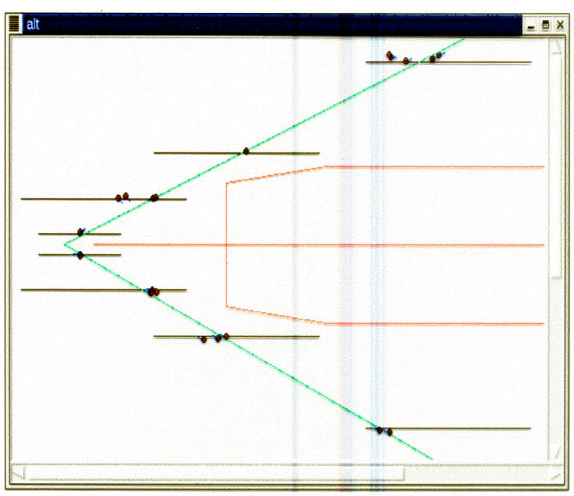


Figure 9: *wzoff* event display in transverse plane.



➥ Calculation of Kinematic Variables:

z-coordinate of The Vertex:

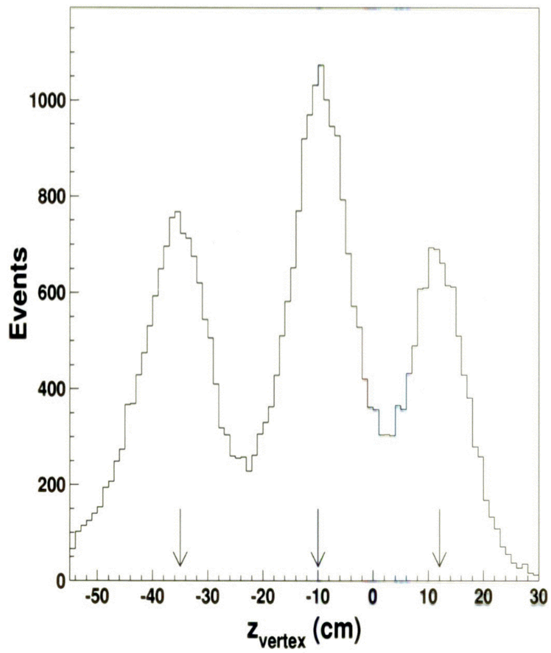


Figure 12: Distribution of z_{vertex} for reconstructed ev
at 5.9 GeV/c beam momentum. The length of each target
cm and the arrows show the three target central positions.

Cuts to identifying the targets:

$$dz < 15 \text{ cm}$$

$$\text{-45} < z_{vertex} < \text{-25} \longrightarrow \text{target at -35 cm}$$

$$\text{-20} < z_{vertex} < 0 \longrightarrow \text{target at -10 cm}$$

Polar Angle and Azimuthal Angle:

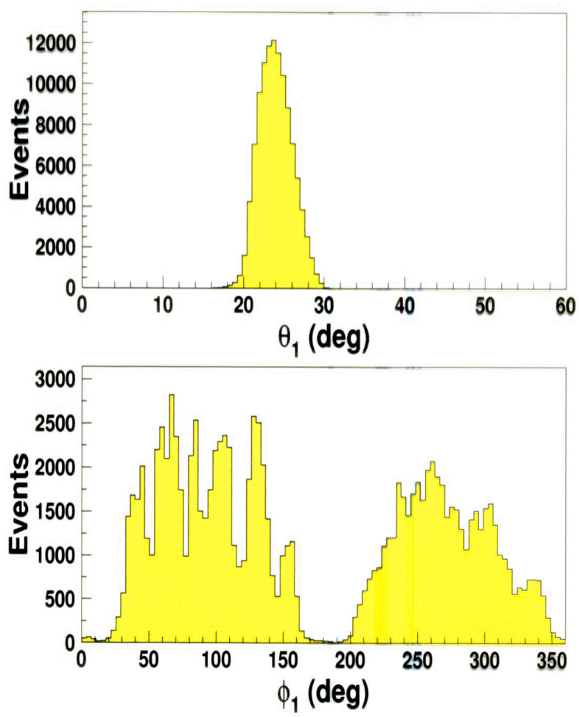


Figure 13: Distributions of the polar angle θ_1 and th imuthal angle ϕ_1 (for the smaller-angle proton) for $^{12}C($ events at 5.9 GeV/c beam momentum.

Transverse Momentum:

The transverse momentum of an outgoing pro was calculated from the radius of the curvatu its track:

➥ Calculation of Physical Quantities:

Missing Energy:

$$E_{miss} = E_0 + m - E_1 - E_2$$

where E_0 is the beam energy, m is the mass proton, E_1 and E_2 are the energies of the tw outgoing protons.

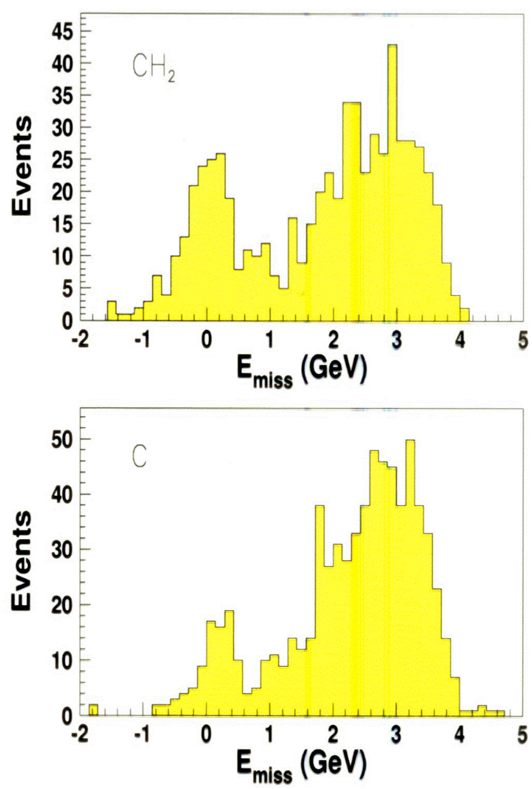


Figure 14: Missing energy spectra for (p,2p) events a

8 October 1998

PHYSICS

ELSEVIER

Physics Letters B 437 (1998) 257–263

Measurement of quasi-elastic $^{12}C(p,2p)$ scattering at high momentum transfer

Y. Mardor [a], J. Aclander [a], J. Alster [a], D. Barton [b], G. Bunce [b], A. Carr
N. Christensen [c,1], H. Courant [c], S. Durrant [a,b], S. Gushue [b], S. Heppelma
E. Kosonovsky [a], I. Mardor [a], M. Marshak [c], Y. Makdisi [b], E.D. Minor
I. Navon [a], H. Nicholson [e], E. Piasetzky [a], T. Roser [b], J. Russell [f], C.S. Su
M. Tanaka [b,3], C. White [c], J-Y Wu [d,4]

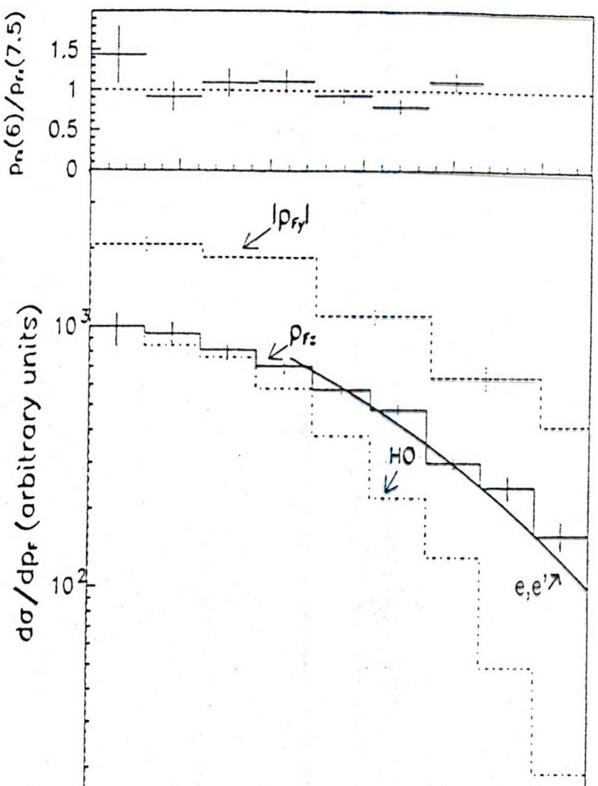


Fig. 3. The upper part of the figure shows the ratio of the two distributions measured at 6 and 7.5 GeV/c (the last two highest momentum points were measured at 6 GeV/c only). p_{Fz} is the

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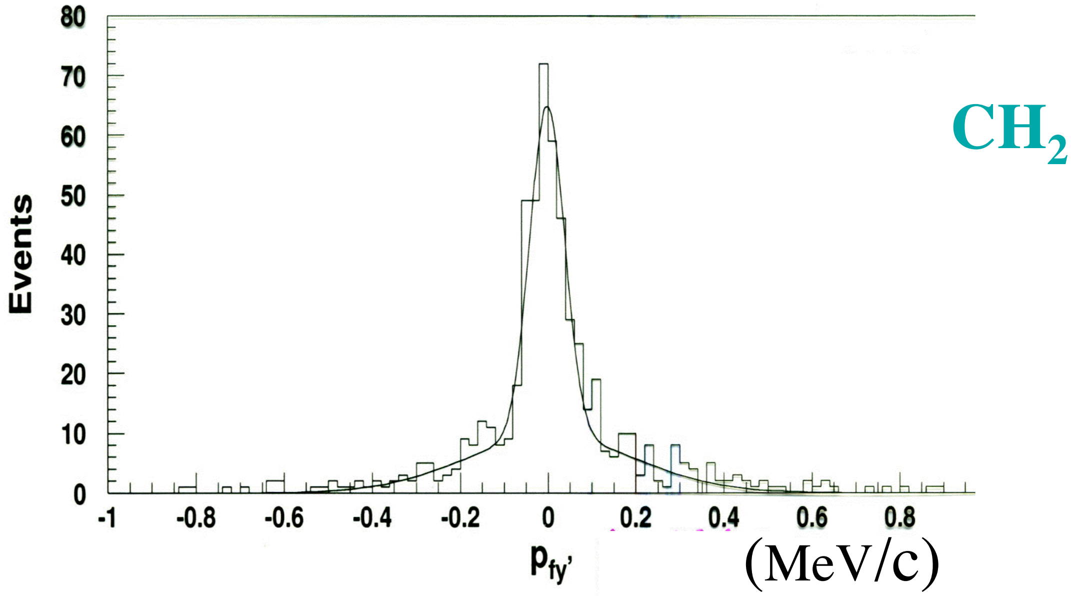
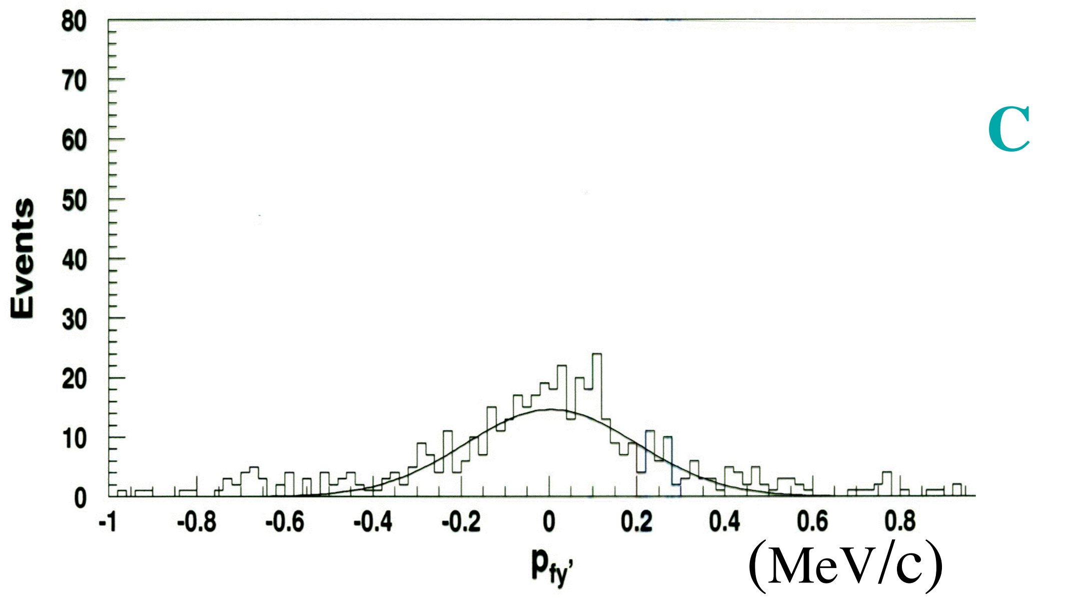

CH2
Events
pfy'
(MeV/c)


C
Events
pfy'
(MeV/c)

Light Cone Description of the (p,2p+n) Reactio

The momentum of a nucleon is described in ligh space by (p_t, α), where p_t is the transverse mome and α defined as:

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

represents the fraction of the nuclear momentur ried by the target nucleon in the light-cone refe frame.

- Mandelstam variable s:

$$\begin{aligned} s &= (P_0 + P_F)^2 \\ &= m^2 + m1^2 + 2P_0P_F \\ &= m^2 + m1^2 + (E_0 - P_0)(E_F + p_F^z) + \alpha m(\\ &\sim m^2 + m1^2 + 2\alpha m p_0 \end{aligned}$$

where $\alpha = \frac{E_F - p_F^z}{m}$ is the light cone variable f target nucleon and for large incident momenta,

Longitudinal Fermi Momentum and α:

From the momentum conservation:

$$p_{fz} = \frac{p_{t1}}{tan\theta_1} + \frac{p_{t2}}{tan\theta_2} - p_0$$

From light cone variable α:

$$\alpha = \frac{E_f - p_{fz}}{m} \sim 1 - \frac{p_{fz}}{m}$$

$$p_{fz} = m \cdot (1 - \alpha).$$

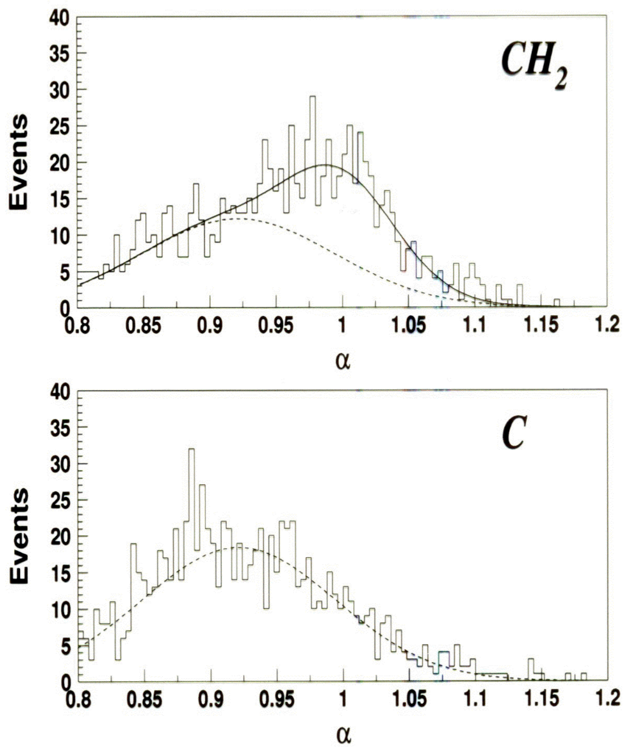


Figure 16: Light cone variable α distribution for CH

Neutron Analysis:

➡ Inverse Velocity:

$$v^{-1} = \frac{TOF}{l} = \frac{TOF}{\sqrt{x_{hit}^2 + y_{hit}^2 + (z_{hit} - z_{target})^2}}$$

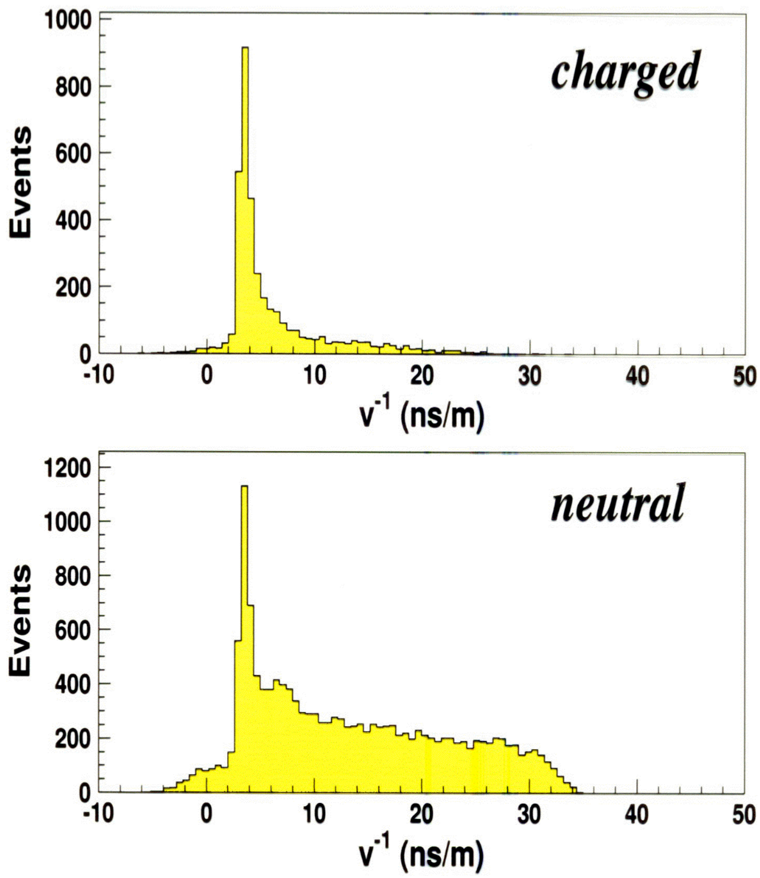


Figure 17: Inverse velocity spectra for charged and ne

Results and Conclusions

List of Cuts Applied For Triple Coincident Ev

Cuts on protons:

Čerenkov cut: select protons

Number of tracks: 2 tracks

Target Positions: $|z_{target} + 10| < 10$

$|z_{target} + 35| < 10$

$|z_1 - z_2| < 12$

Missing Energy: $|E_{miss} - 0.32| < 0.5$

ϕ (for arrays 1 and 2): $45^\circ < \phi_1 < 135^\circ$, or

$225^\circ < \phi_1 < 315^\circ$

ϕ (for array 3): $0^\circ < \phi_1 < 90^\circ$, or

$180^\circ < \phi_1 < 270^\circ$

Cuts on neutrons:

Identification of Correlated Events

One-Dimensional Correlations:

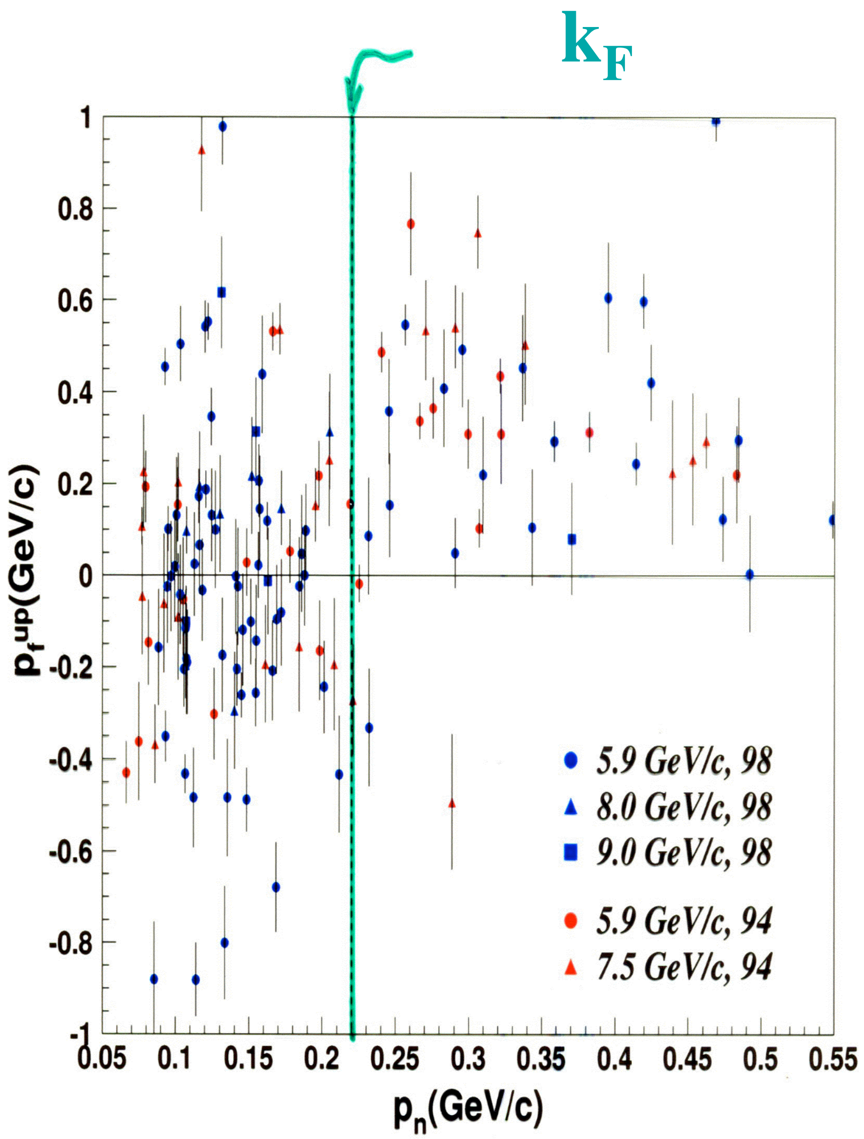
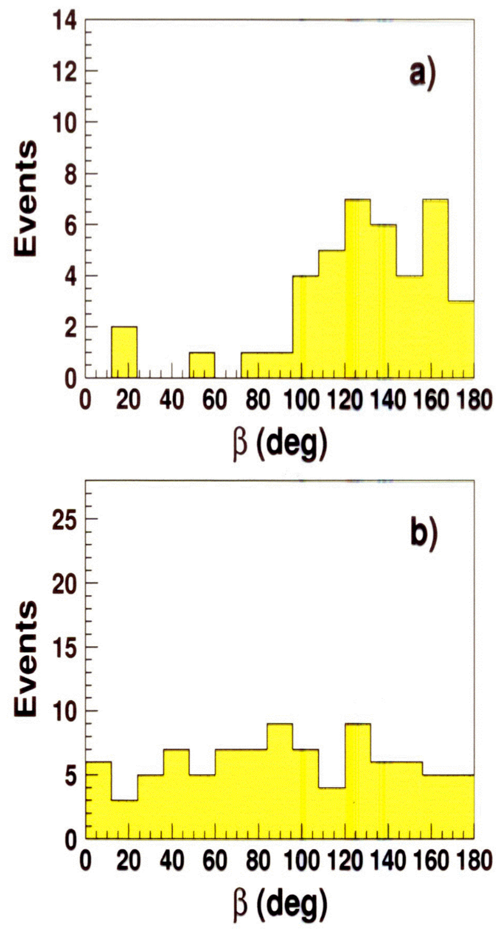


Figure 19: p_f^{up} vs. p_n for ^{12}C(p,2p+n) events. Data lab
"98" (solid symbols) are for 98 runs (this experiment).
labelled "94" are from Aclander, et al. The vertical line at

Transverse Correlations:

The angle between the transverse momenta c
proton and neutron is defined as:

$$\beta = \cos^{-1}\left(\frac{\vec{p}_{nt} \cdot \vec{p}_{ft}}{|\vec{p}_{nt}||\vec{p}_{ft}|}\right).$$



$p_n > k_F$

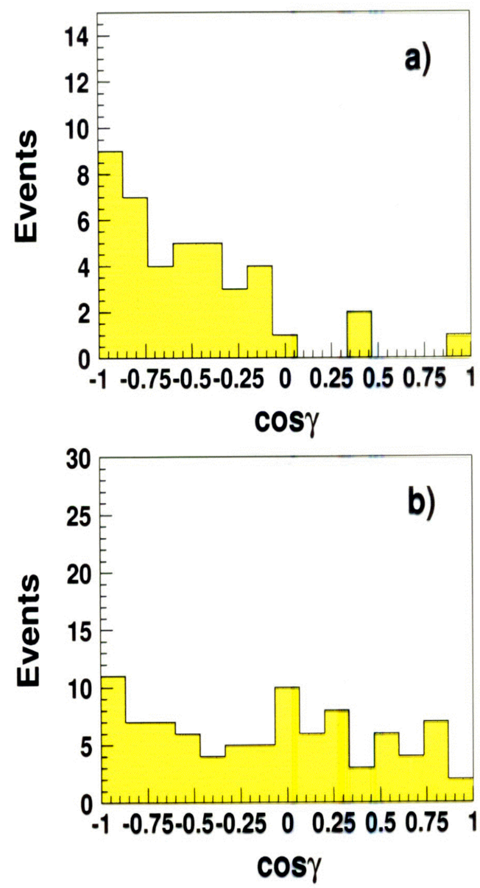
$p_n < k_F$

Figure 20: Plots of β, the angle in the transverse plan
tween $\vec{p}_f$ and $\vec{p}_n$. Panel (a) is for events with $p_n > 0.22$ Ge

Full Correlations:

We then construct the directional correlation between $\vec{p}_f$ and $\vec{p}_n$ as

$$cos\gamma = \frac{\vec{p}_f \cdot \vec{p}_n}{|\ \vec{p}_f\ ||\ \vec{p}_n\ |}$$



$p_n > k_F$

$p_n < k_F$

Figure 21: Plots of cosγ, where γ is the angle betwee
and $\vec{p}_n$. Panel (a) is for events with $p_n > 0.22$ GeV/c

k_F

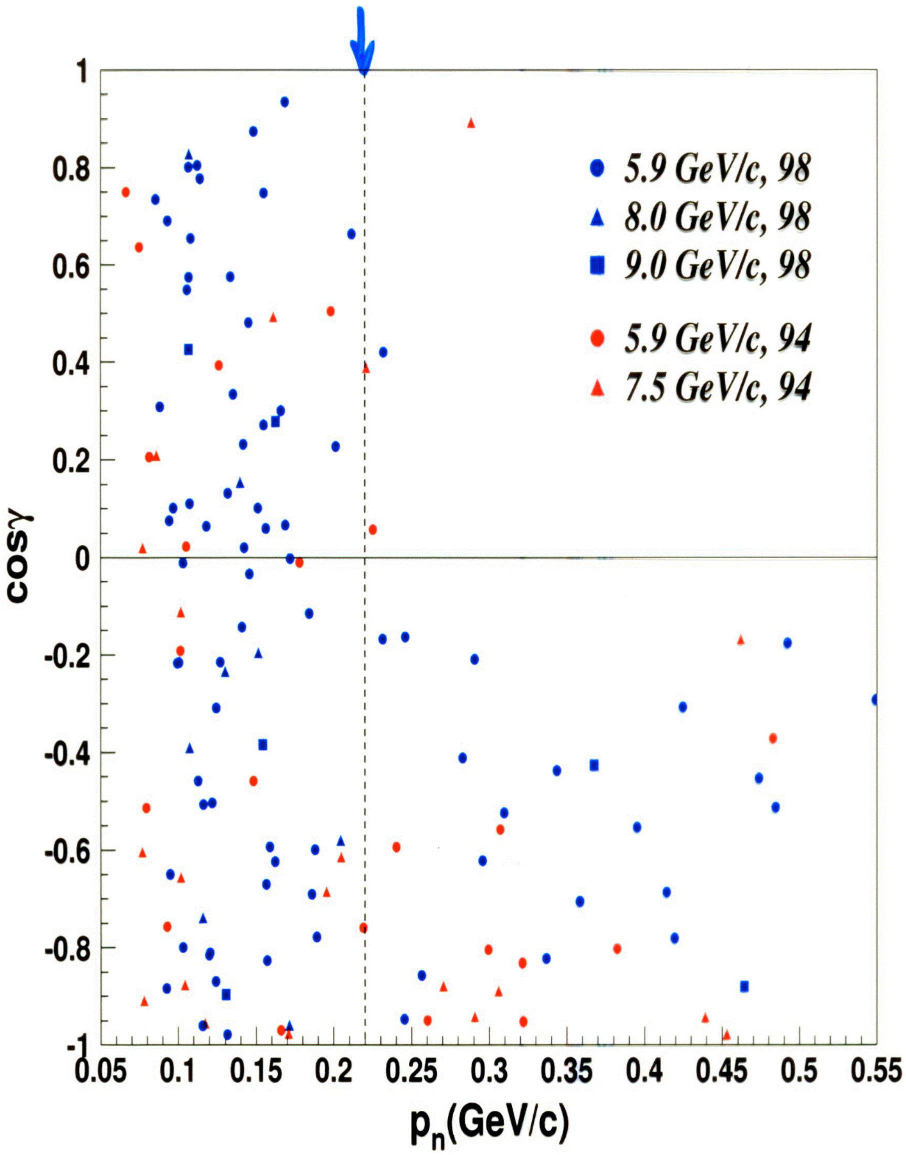


Figure 22: $\cos\gamma$ vs. p_n for ^{12}C(p,2p+n) events. The ver line at 0.22 GeV/c corresponds to k_F, the Fermi momentu ^{12}C.

The Correlated Fraction of (p,2p) Events:

For the 6 GeV 1998 data set we estimated t
fraction of (p,2p) events with $p_f > 0.22$ GeV
which have a correlated backwards neutrons v
$p_n > 0.22$ GeV/c.

$$F = \frac{corrected\ \#\ of\ (p,2p+n)\ events}{\#\ of\ (p,2p)\ events} = \frac{A}{B}$$

The quantity A was obtained from the samp
of all 18 (p,2p+n) events with $p_n \geq k_F = 0.$
GeV/c, where a correction for flux attenuation
detection efficiency was applied event-by-ever
and then corrected for the solid-angle coverag

$$A = \frac{2\pi}{\Delta\Omega} \sum_{i=1}^{18} \frac{1}{\epsilon_i} \cdot \frac{1}{t_i} = 1090.$$

The average value of $(1/e_i t_i)$ was 8.2 ± 0.82 a
$2\pi/\Delta\Omega = 7.42$. We can then calculate

$$F = \frac{A}{-} = \frac{1090}{} = 0.49 \pm 0.13.$$

➥ The Center of Mass Motion of the $n - p$ Pa

$$p_z^{cm} = p_{nz} + p_{fz}$$

We can express this in terms of α as

$$\alpha_p + \alpha_n = \frac{E_f - p_p^z}{m} + \frac{E_f - p_n^z}{m}$$

$$= (1 - \frac{p_{fz}}{m}) + (1 - \frac{p_{nz}}{m})$$

⇨

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

➥ The Relative Motion of the Correlated Nucl

$$\alpha_p - \alpha_n = (1 - \frac{p_{fz}}{m}) - (1 - \frac{p_{nz}}{m})$$

$$= (\frac{p_{nz} - p_{fz}}{m})$$

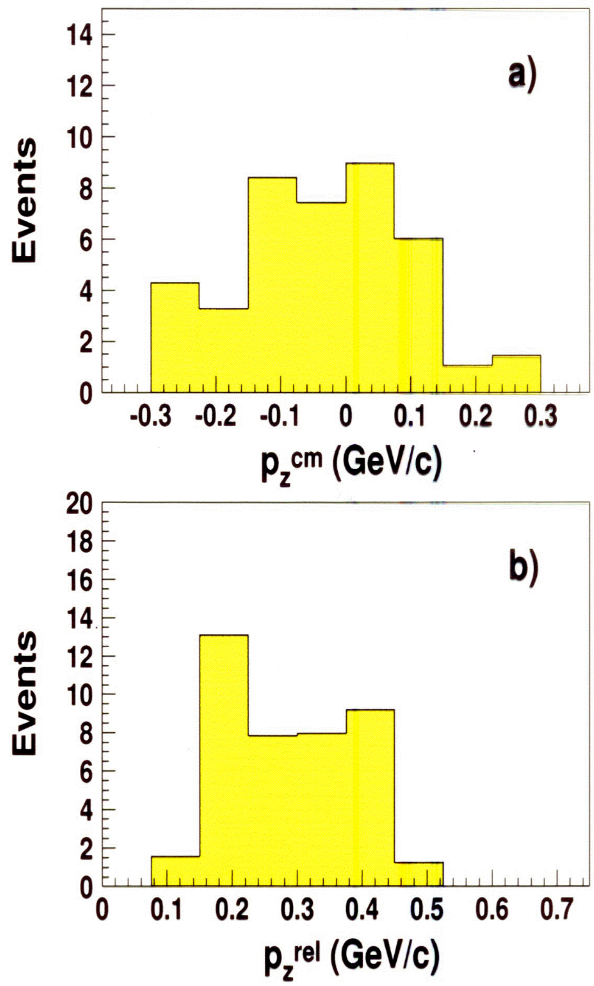
⇨

$$p_z^{rel} = |p_{fz} - p_{nz}|$$

The Relative and c.m. Motion of Correlated
Pairs:

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

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



Centroid = -0.013 ± 0.02
σ = 0.143 ± 0.01

Centroid = 0.289 ± 0.01
σ = 0.097 ± 0.00

Figure 23: Plots of (a) p_z^{cm} and (b) p_z^{rel} for correlat

Summary

1. For quasielastic (p,2p) events we reconstru $\vec{p}_f$ the momentum of the knocked-out proton be the reaction; $\vec{p}_f$ was then compared with $\vec{p}_n$, measured, coincident neutron momentum. F $|\vec{p}_n| > k_F = 0.220$ GeV/c (the Fermi moment a strong back-to-back directional correlation between $\vec{p}_f$ and $\vec{p}_n$ was observed, indicative short-range n-p correlations.

2. We determined that 49 ± 13 % of events w $|\vec{p}_f| > k_F$ had directionally correlated neutro with $|\vec{p}_n| > k_F$. Thus 2N SRCs are a major so of high-momentum nucleons in nuclei.

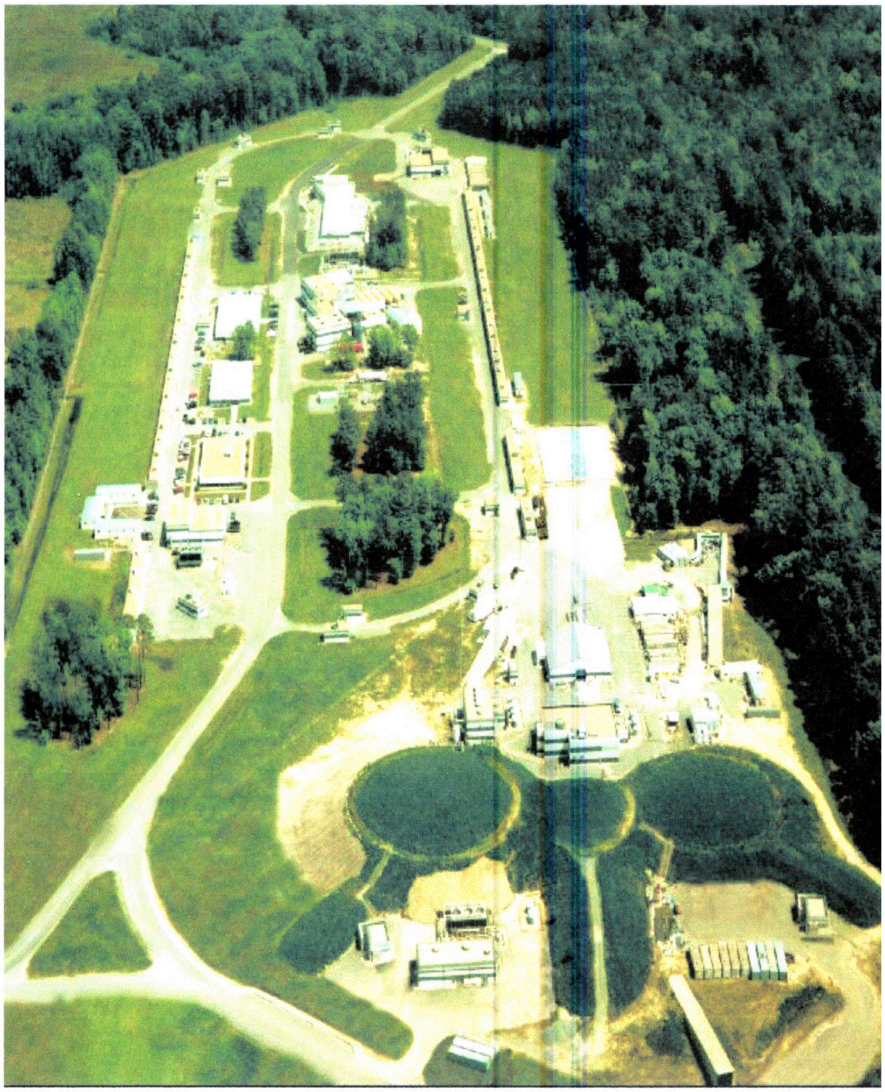
3. We also measured the c.m. and relative momenta of correlated n-p pairs in the longituc direction.

4. And . . .

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

. JLab Experiment E01-015
Scheduled for Fall 2004

Spokesmen: Bill Bertozzi, MIT
Eli Piazetski, Tel Aviv
John Watson, Kent Sta
Steve Wood, JLab



The CEBAF accelerator complex
at Thomas Jefferson Laboratory

Trento Workshop   March 2004

We optimized the kinematics to minimize competing proceses

HIGH ENERGY, LARGE Q^2 (2 GeV^2/c^2)

MEC are reduced as $1/Q^2$

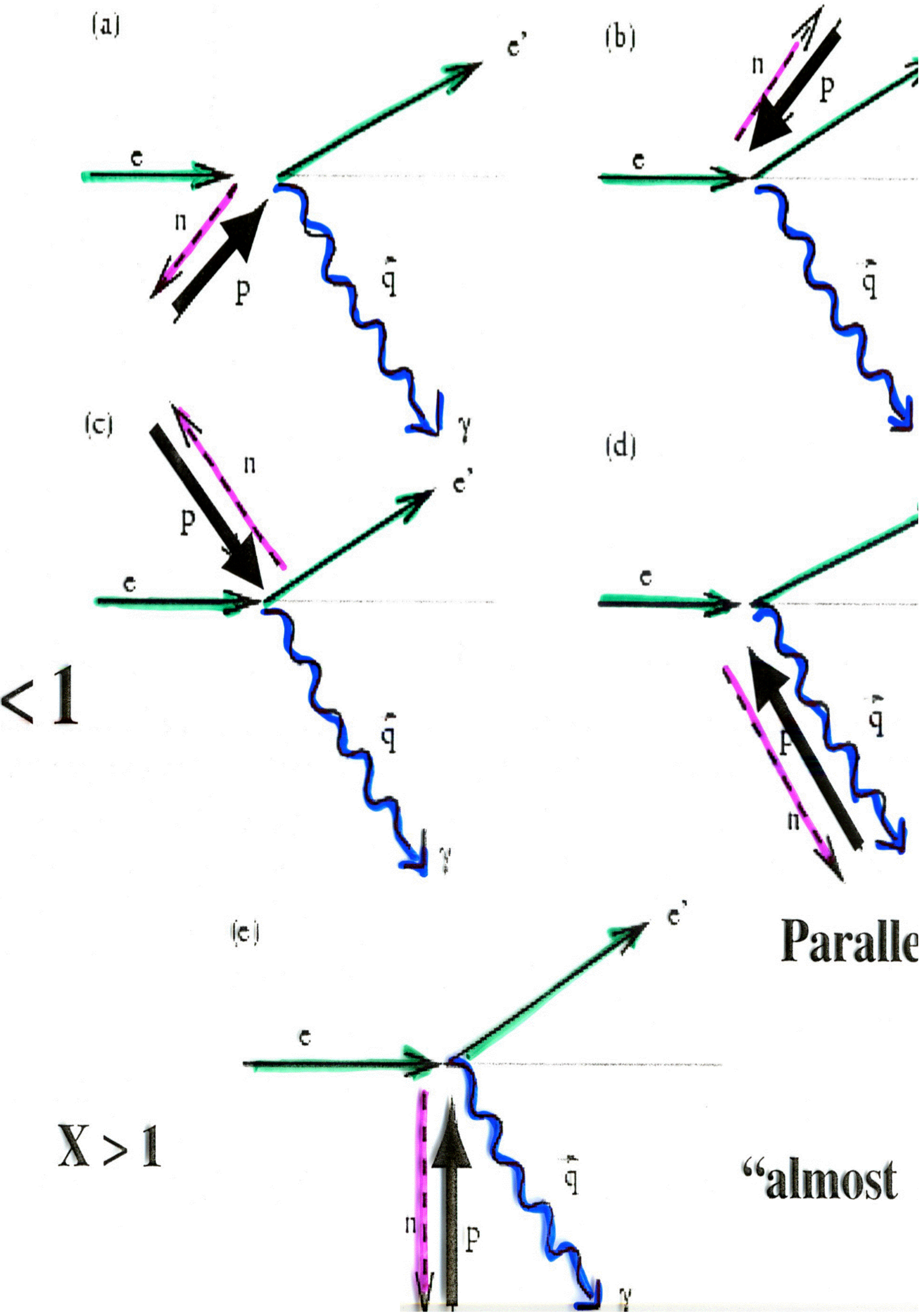
LARGE X $= Q^2/2m\nu$

IC are reduced by performing the experiment in "anti-parallel" kinematics ($x_B > 1$), which is possible only for large Q^2.

LARGE E_m, P_m, P_{mz}

FSI can be treated in Glauber approximation. Also, the relevant parameter in the light-cone formalism (α) is not sensitive to FSI.

Significant reduction, compared to low-Q^2 measurements, in the ambiguity of the identification of the struck and recoil nucleons.


(a)
e'
e
n
p
q
γ
(b)
n
p
e
q
(c)
n
p
e'
e
q
γ
(d)
e
q
p
n
< 1
(e)
e'
e
q
n
p
γ
X > 1
Paralle
"almost

XXXL

We optimized kinematics to minim
the competing processes

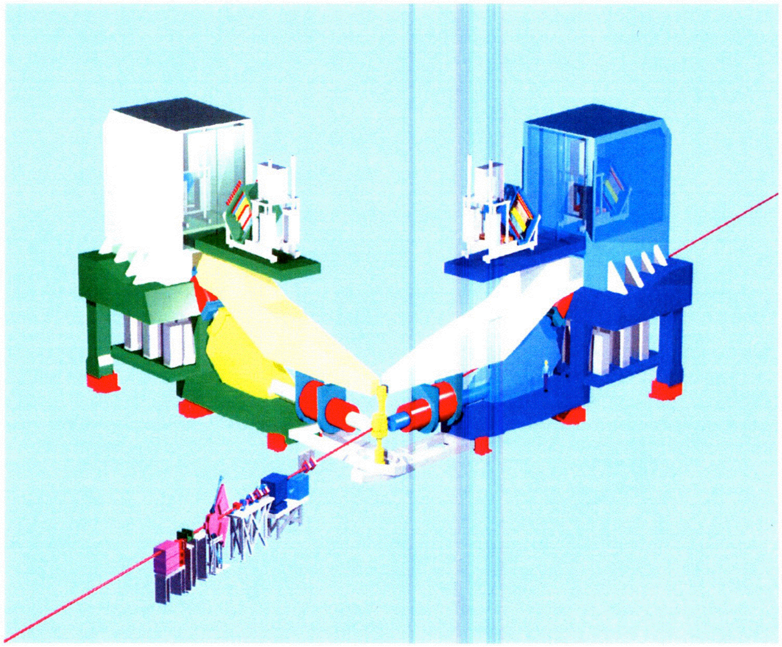
HIGH ENERGY

LARGE Q^2

LARGE X

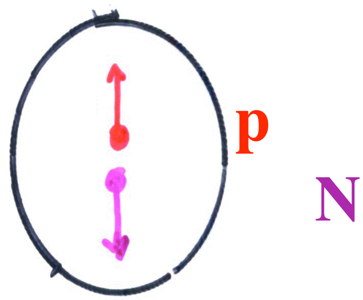
LARGE E_m, p_m, p_{mz}

Hall A at Jefferson Lab

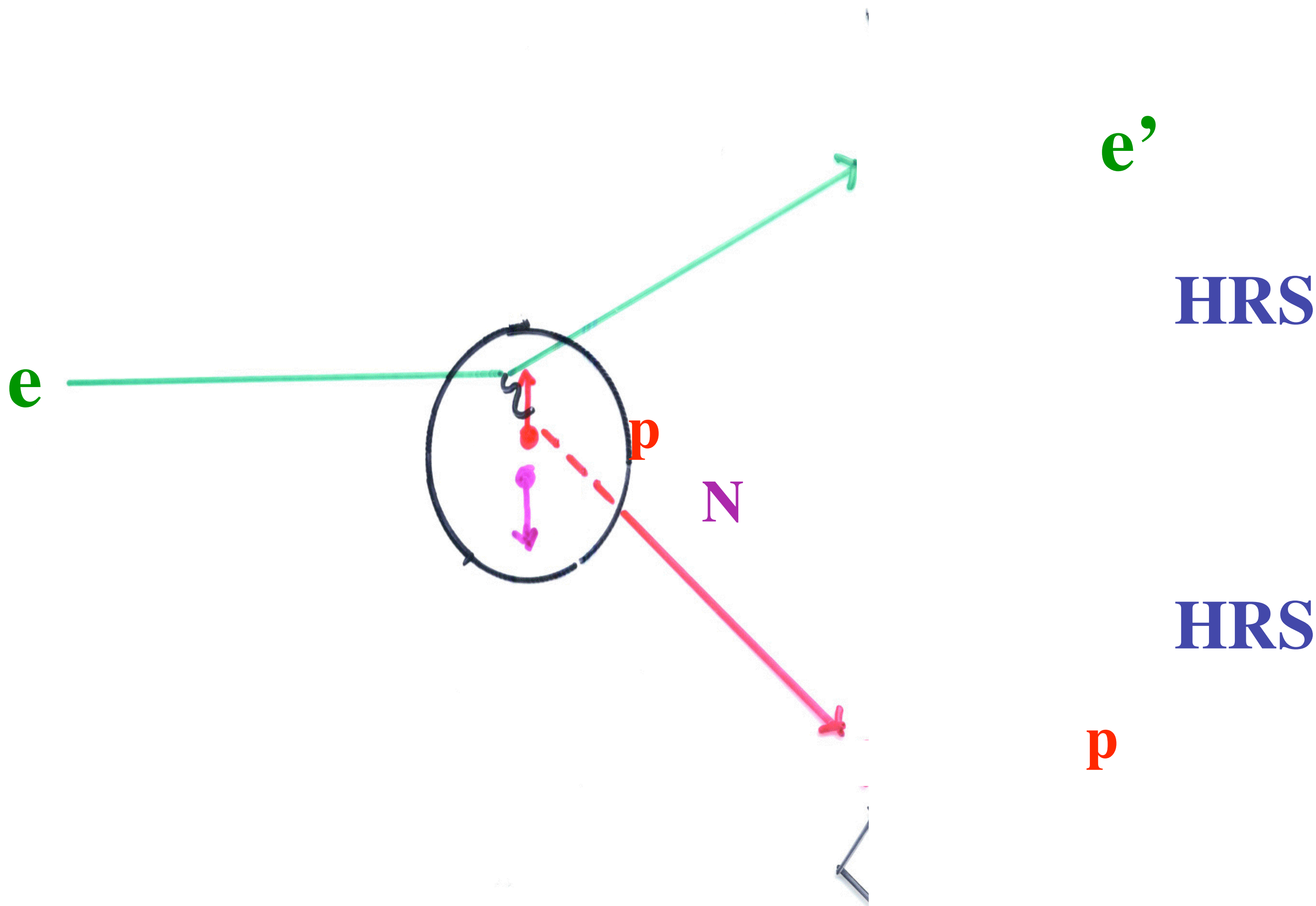


- Two large high resolution spectrometers (HRS
  in hall A.
- Hall A has much expertise in performing (e,e′p
  experiments.
- BigBite spectrometer will be used as a third arn
  in conjunction with the two HRS.

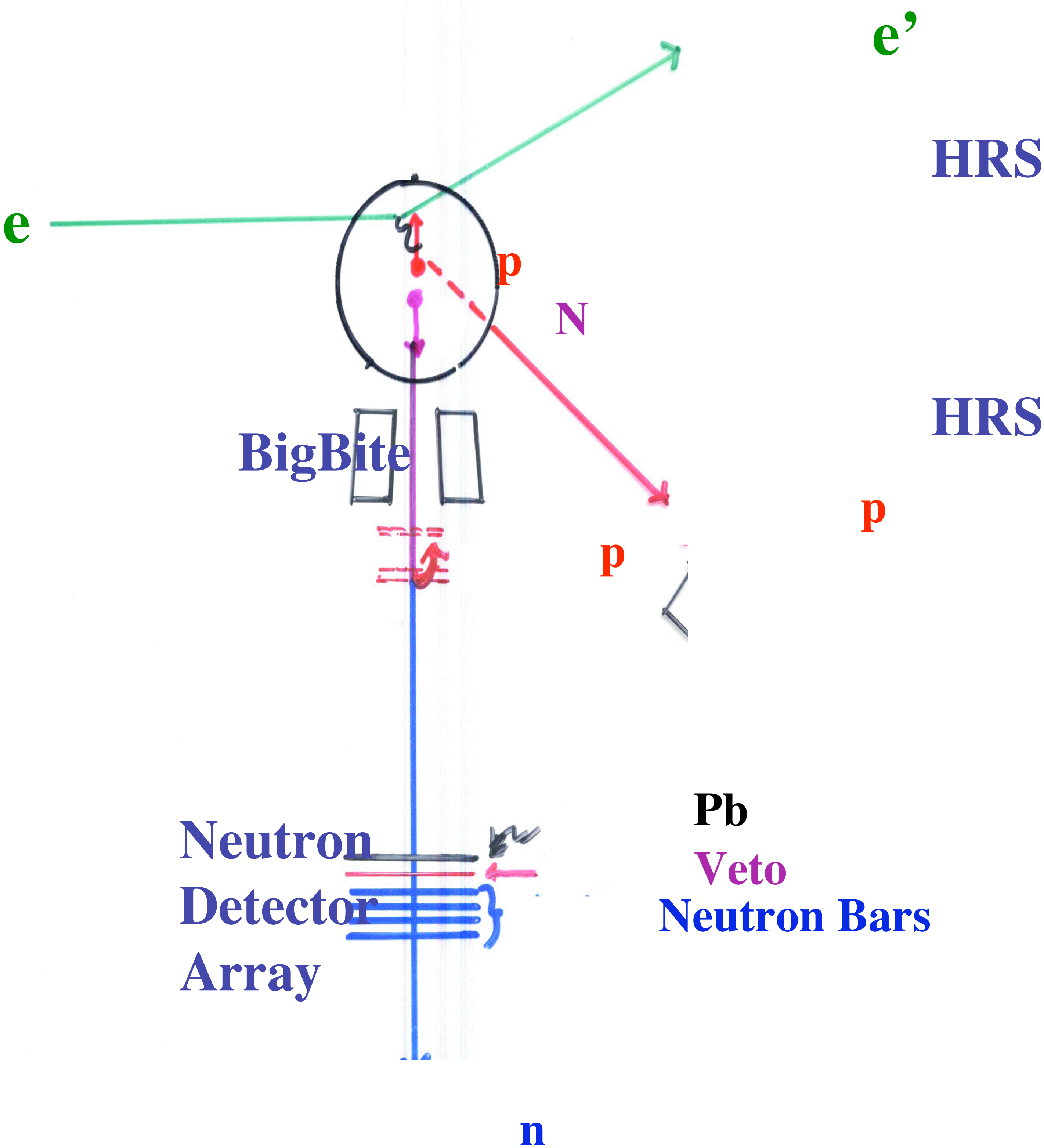
^{12}C



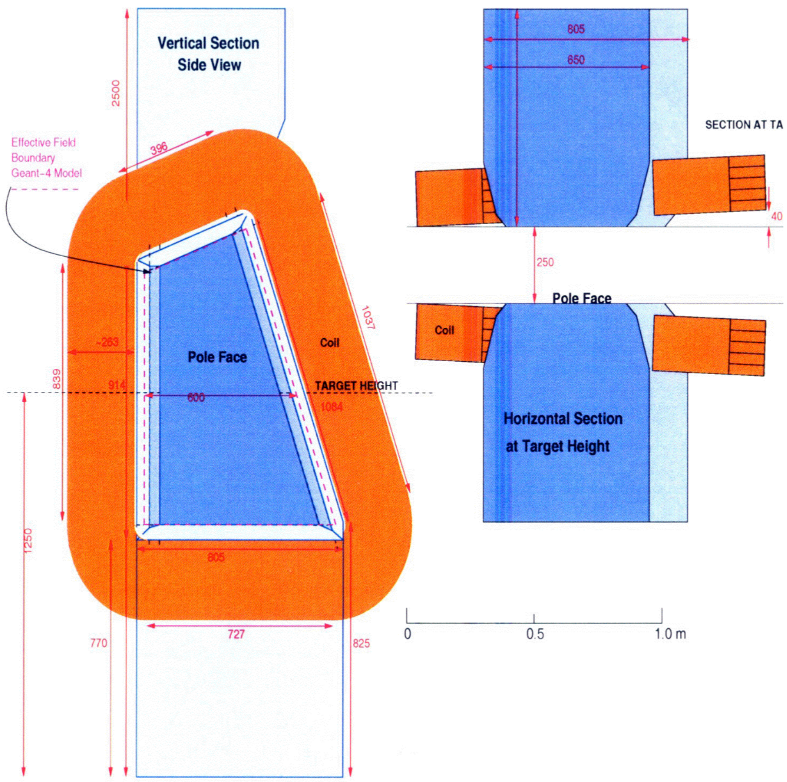
^{12}C(e,e'p



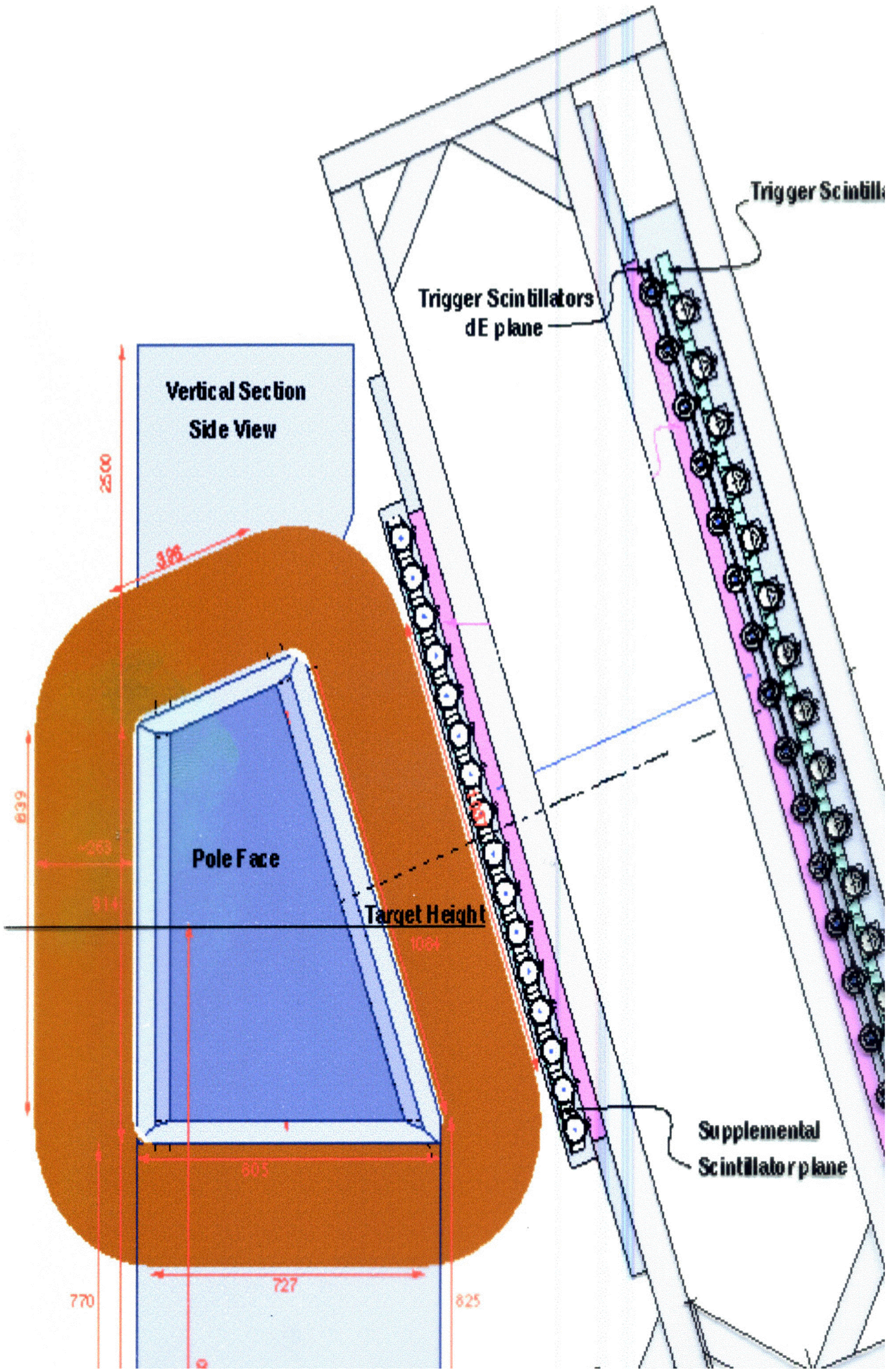
$^{12}C(e,e'p + N)$


e'
HRS
e
p
N
HRS
BigBite
p
p
Pb
Neutron
Detector
Array
Veto
Neutron Bars
n

The BigBite Magnet

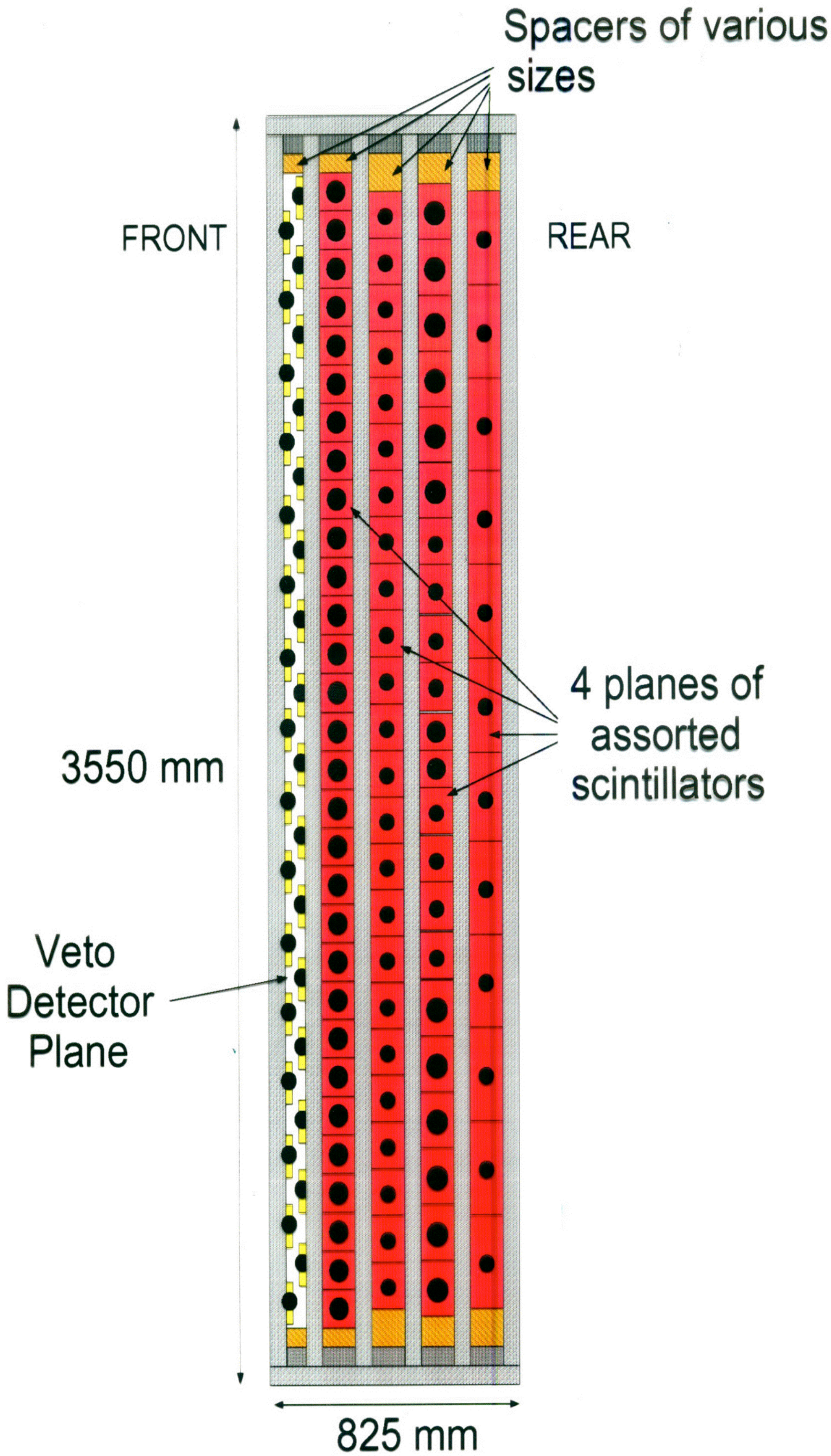


- Angular acceptance of 96 msr.
- Magnetic field strength of up to 1.2 T; expe ment will use a field strength of 0.92 T.
- Nominal momentum acceptance of 250 - 900

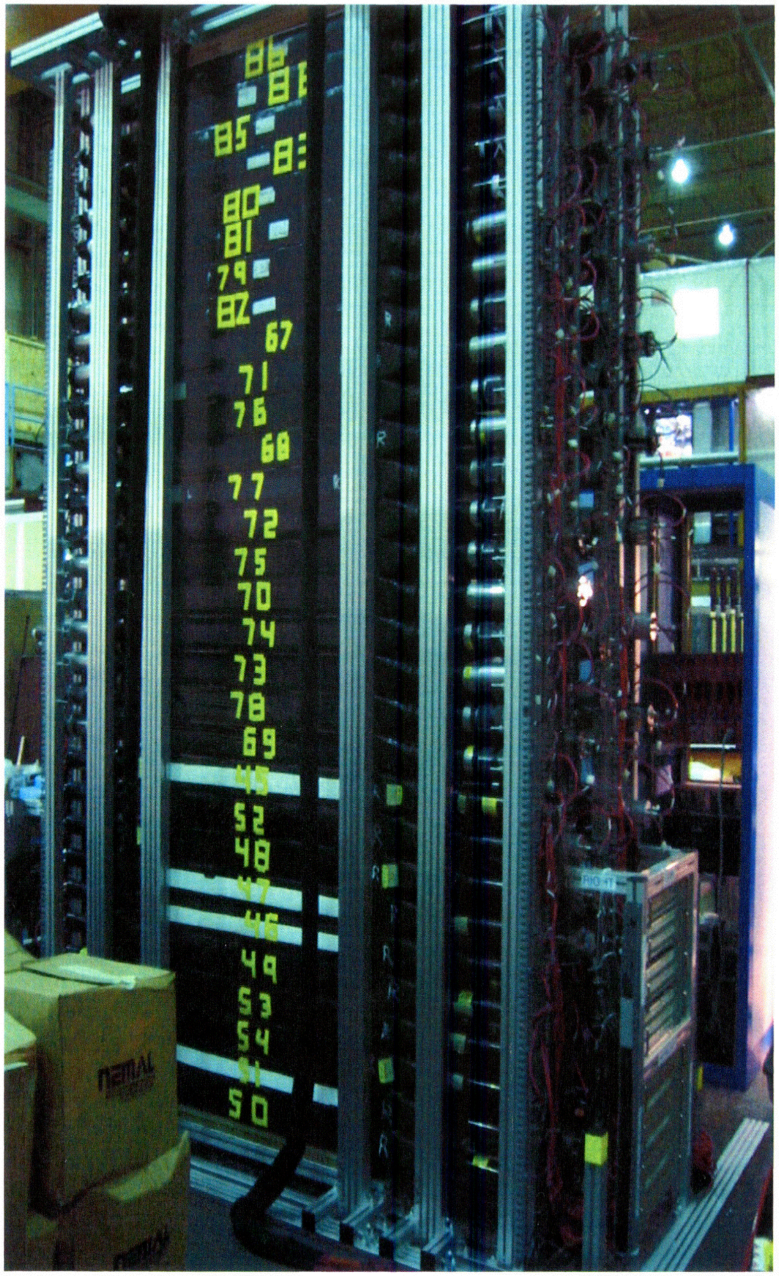

Trigger Scintilla
Trigger Scintillators
dE plane
Vertical Section
Side View
2500
Pole Face
Target Height
Supplemental
Scintillator plane
727
770
825

The Proton Detector

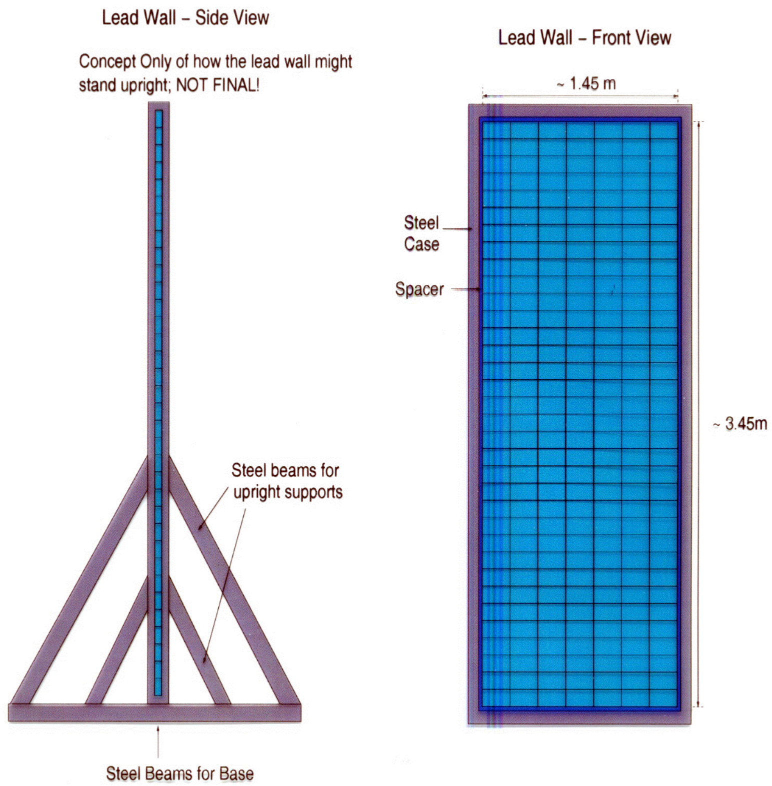
Neutron Detector – Side View



The Neutron Detector - 2



Lead Wall



- Require a 2 inch thick lead wall in front of neu-tron detector to provide radiation shielding.
- Propose to build a wall 3.45m high and 1.45m wide using 238 2 x 4 x 8 inch lead bricks as il-lustrated.