A New Tool for Correlation Studies in Hall A at JLab

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INTRODUCTION

The study of short-range nucleon-nucleon correlations has a long history. The idea was first invoked in order to explain the large photo-induced proton yield on nuclei [1]. Such studies have become more feasible in recent years due to the availability of CW photon and electron beams at LEGS, NIKHEF, Mainz and JLab. [2]. Several dedicated two nucleon, 2N, knock-out experiments in photo- and electro-production have been completed recently, for a review, see reference [3]. In order to emphasize various aspects of the physics, kinematics must be chosen to permit measurements in the Q^2 range up to several $(\mathrm{GeV}/c)^2$. Such difficult measurements are only possible with beam energies and intensities available at JLab. In Hall A at JLab luminosities up to $5 \cdot 10^{38}\ \mathrm{cm}^{-2}/\mathrm{s}$ are available, required for the measurement of low cross sections at high Q^2. However, the usable luminosity depends on the target thickness, background, detector parameters, and other details of the proposed experiment. In Hall B at JLab, where the CLAS detector subtends a large phase space, the available luminosity is $1 \cdot 10^{34}\ \mathrm{cm}^{-2}/\mathrm{s}$. The data with CLAS have already been taken, but must be summed over several kinematics parameters including Q^2 [4] in order to provide sufficient statistics.

In preparation for 2N knock-out experiments in Hall A, a Monte Carlo simulation code describing particle yields for protons, neutrons, pions, electron, gammas, etc. was used [5] and several experimental tests were performed to test the calculations [6]. The first study of particle flow was actually motivated by a Compton scattering experiment [7]. More experimental tests were performed to study and optimize conditions for the 2N knock-out experiments. Recently, an experiment was performed to test the detection of the (e,e'pn) process in Hall A at high luminosity [8]. A critical parameter in determining effective rates in an experiment is the detector acceptance. A large momentum and angular acceptance magnetic dipole spectrometer with moderate momentum resolution was developed and used at NIKHEF [9]. Modification of the detector system and electronics will allow to use BigBite at luminosities up to $1 \cdot 10^{38}\ \mathrm{cm}^{-2}/\mathrm{s}$ [10]. We discuss the plans to upgrade BigBite as a new tool for correlation studies. The high luminosity and simultaneous multi-particle detection capability of BigBite provide an opportunity to detect two correlated protons at small relative momentum. This physics was addressed in proposal [11], but for a limited range of kinematics. Here we present the results of the above studies.

THE INSTRUMENTATION IN HALL A

The parameters of Hall A equipment are quite impressive (see [12]):

Beam

- electron energy $0.5 - 6.0\,GeV$.
- current $0.5 - 150\,\mu A$.
- energy stability and spread $\sim 10^{-5}$.
- spot stability $\sim 10\,\mu m$.
- electron polarization of 75 – 80%.
- polarization measurement accuracy of 2%.
- energy measurement accuracy of 0.02%.

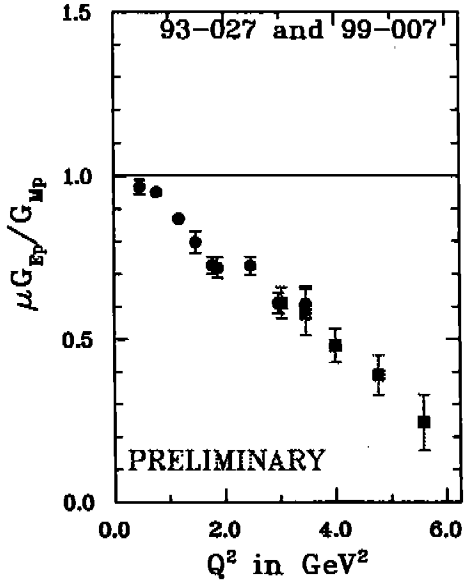
Targets

- nuclear targets - C, Li, Pb and water.
- liquid cryogenic targets of hydrogen and deuterium.
- cryogenic target of ^4He and ^3He.
- polarized ^3He target.

Detectors

- Two High Resolution Spectrometers, HRS, for momentum up to 4 GeV/c with 6 msr solid angle and momentum resolution of $2 \cdot 10^{-4}$.
- focal plane polarimeter in one of the HRS for momentum range $0.5 - 4\,\mathrm{GeV}/c$.
- photon calorimeter with 700 lead glass modules.

Among well-known experiments, already completed in Hall A, are the studies of the high-momentum structure of ^{16}O, the strangeness content of the proton (HAPPEX), the proton electric form factor (G_E^p), the high-momentum structure of the deuteron. The G_E^p result, shown in Fig. 1, leads to the conclusion that non-pQCD components play a dominant role in the proton elastic form factor at momentum transfers as large as 6 (GeV/c)^2.



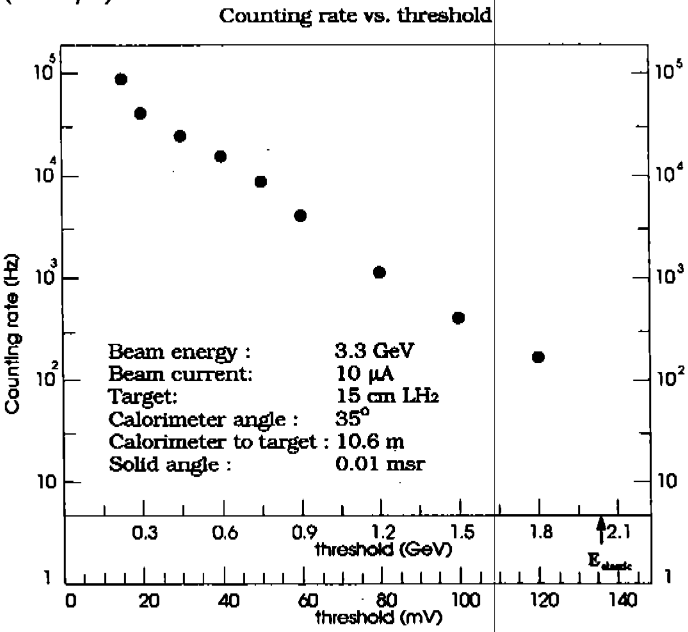


Figure 1. Proton electric and magnetic form factors ratio vs. Q^2.

Figure 2. The rate in the photon calorimeter vs. threshold.

In order to perform 2N knock-out (e,e'2N) experiments one needs to add a Third Arm detector in Hall A. Such a detector should operate at a maximum momentum of 1 GeV/c. Also, a large solid angle and large momentum acceptance are important requirements.

THE STUDIES OF THE PARTICLE YIELDS

The first approved experiment which has an additional detector on the floor of Hall A was Real Compton scattering [13], RCS. The initial test [7] quickly demonstrated that a very high rate detector is needed for photon detection. The choice of a lead glass calorimeter was justified during a test run in 1998 [14]. Figure 2 shows the rate in the calorimeter at different levels of the threshold or deposited energy. One can see that rate vs. energy can be described by $exp(-E/0.21(GeV))$. In the RCS experiment, the photon energy is close to the maximum energy of an electron scattered at the same angle. Because at large energy the rate is low, it is possible to measure RCS at high luminosity. A luminosity up to $2 \cdot 10^{38}$ cm^{-2}/s with a 6% Cu radiator can be used in large t kinematics.

We would like to emphasize that the design of the experiment requires an optimal choice of the detector system. For example, in the RCS experiment a high luminosity becomes possible because the lead glass calorimeter provides a good angular resolution and a high rate capability. In the Deeply Virtual Compton scattering experiment [15], where exclusivity of the reaction and a low value of t demand the detection of a proton with momentum of several hundred MeV/c, the moderate angular resolution in the proton arm is sufficient, but one should make best use of the relatively large proton kinetic energy. It was suggested to accomplish this by using a thick plastic scintillator.

The Monte Carlo code [5] was used to describe particle production by the high energy electron beam. Figure 3 shows the layout of the experimental hall and particles entering into the volume of the RCS detector. The vector lengths represent the particle's energy. We found that most of the particles with an energy above 1 MeV come from the target, and only a very small number from the beam pipe and dump. The experimental study of radiation damage of the lead glass also supports an idea that even the soft part of the background predominantly originates from the target.

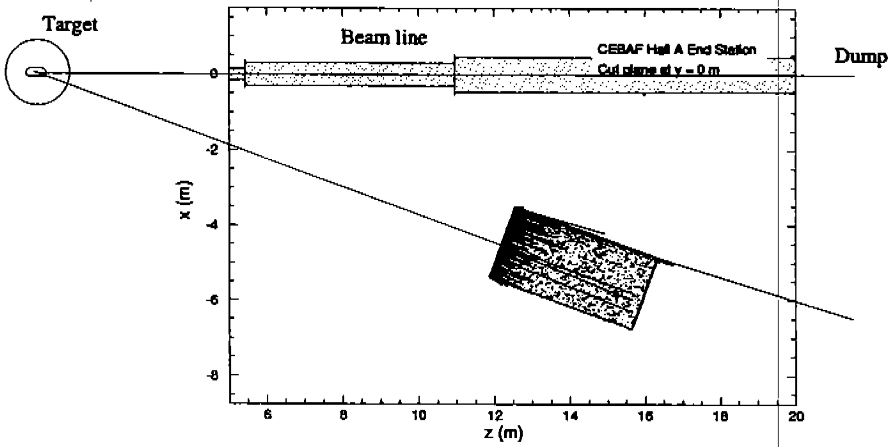


Figure 3. The layout of the Hall A and particles entering RCS detector. The length of the vector represents particle energy.

The same Monte Carlo code was used to describe proton production. Figure 4 shows the calculations and experimental data on the proton yield for 3.6 GeV electron beam energy at 60°. The data fall below the prediction by a factor of 2. Such agreement is sufficient for the background estimate.

Figure 5 presents another experimental study done in Hall A [16]. In this case the average anode currents from 154 PMTs (with balanced gains) were measured. The setup was made of 77 plastic scintillator counters 10x10x160 cm dimensions (UVa neutron bars) with a PMT at each end. The detectors were arranged as 11 vertical walls and 7 horizontal rows. It was unshielded and placed at an angle of 63° relative to the beam direction at a distance 6 m from the target. The data were taken at a luminosity of $2 \cdot 10^{36}$ cm^{-2}/s at 2.3 GeV beam energy. The dropping anode currents with detector position clearly demonstrate that the total energy deposited in the detector material is dominated by particles coming directly from the target. The reduction of the currents for inner counters shows that shielding by 10 cm of plastic reduces the light output by a factor of 3-4.

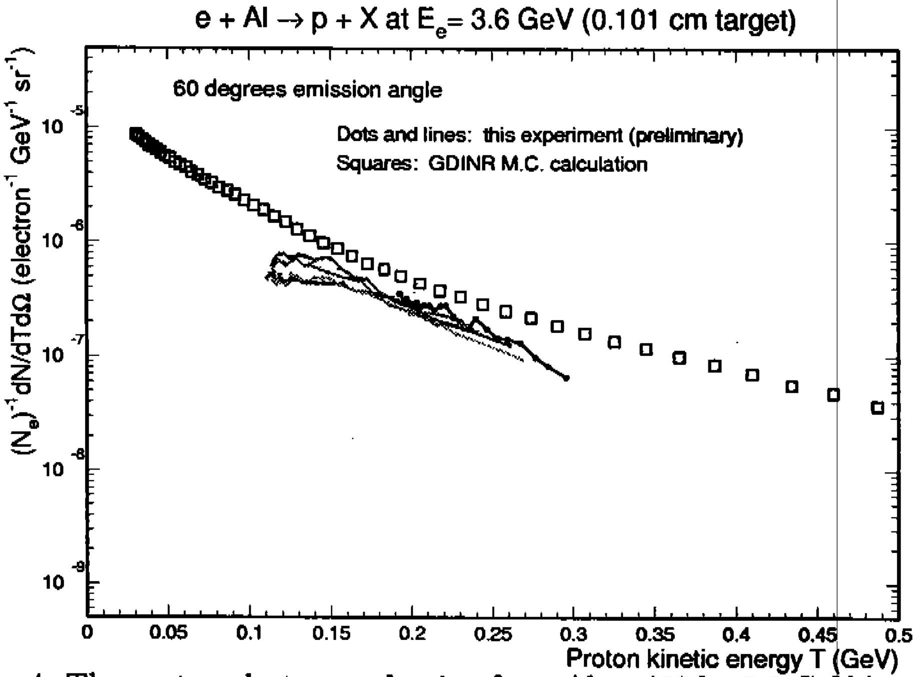
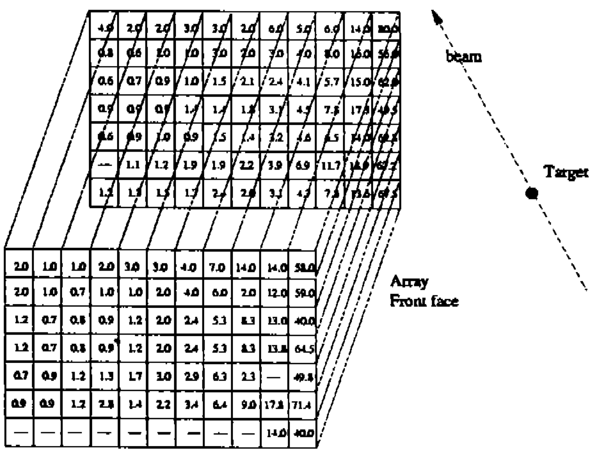


Figure 4. The proton electro-production from Al at 60° by 3.6 GeV beam.



4.0	2.0	2.0	3.0	3.0	2.0	6.0	5.0	6.0	14.0	300
0.8	0.6	2.0	1.0	3.0	2.0	3.0	4.0	8.0	16.0	56.0
0.6	0.7	0.9	1.0	1.5	2.1	2.4	4.1	5.7	15.0	[illegible]
0.9	0.9	0.9	1.4	1.4	1.8	3.1	4.5	7.8	17.8	[illegible]
0.6	0.9	1.0	0.9	1.5	1.4	3.2	4.6	6.5	14.0	[illegible]
—	1.1	1.2	1.9	1.9	2.2	3.9	6.9	11.7	[illegible]	[illegible]
1.2	1.3	1.5	1.7	2.4	2.8	3.1	4.7	7.8	13.6	[illegible]

2.0	1.0	1.0	2.0	3.0	3.0	4.0	7.0	14.0	14.0	58.0
2.0	1.0	0.7	1.0	1.0	2.0	4.0	6.0	2.0	12.0	59.0
1.2	0.7	0.8	0.9	1.2	2.0	2.4	5.3	8.3	13.0	40.0
1.2	0.7	0.8	0.9	1.2	2.0	2.4	5.3	8.3	13.8	64.5
0.7	0.9	1.2	1.3	1.7	3.0	2.9	6.3	2.3	—	49.8
0.9	0.9	1.2	2.8	1.4	2.2	3.4	6.4	9.0	17.8	71.4
—	—	—	—	—	—	—	—	—	14.0	40.0

Figure 5. The anode current survey (in μA) of 7x11 detector array.

One can also observe that variation of the current in the vertical group is small, even for detectors deeply inside the stack, which means that shielding of detectors at top and bottom is not necessary.

THE LUMINOSITY AND DETECTORS FOR 2N EXPERIMENT

We will concentrate here on the (e,e'pp) reaction. The yield of low energy particles is a slow function of beam energy. The MC results for 3 GeV electron energy (Figures 6-9) represent the typical situation. Photons and electrons are the most abundant particles in the forward direction. As also observed in the presented calculation, protons form the dominant positively charged background in the forward hemi-sphere. The yield rises dramatically at low energies. So, the first step in designing an experiment is to choose the minimum momentum of the proton which will be detected. For a given Q^2, the larger beam energy yields a better ratio of signal to noise, because the flux of high Q^2 virtual photons increases faster with beam energy than the flux of low Q^2 virtual photons. In an L/T separation experiment, where the beam energy is low for the backward electron scattering angle, the ratio of signal to noise suggests the use of much lower luminosity than for the forward scattering angle. The approved triple coincidence experiment [17], designed for $P_{proton}^{min} \sim 250\,\mathrm{MeV}/c$, will take data at $Q^2 = 2\ (\mathrm{GeV}/c)^2$, which is much higher than all previous measurements.

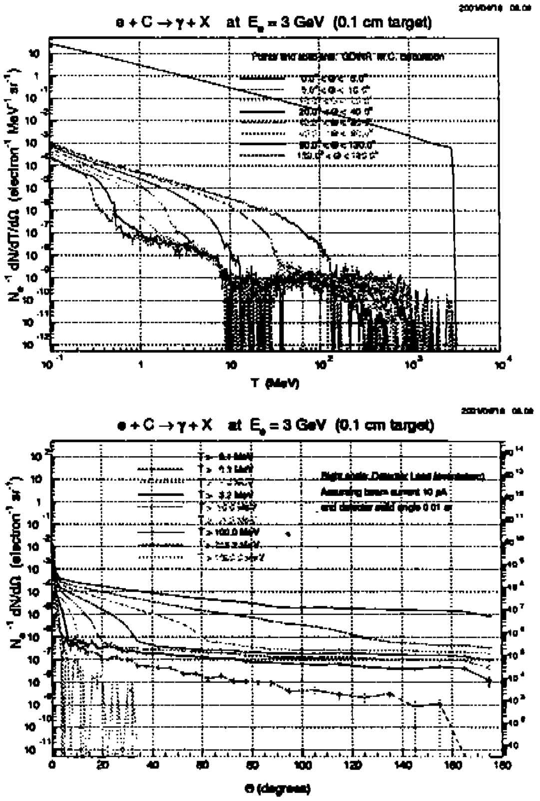


Figure 6. The calculated gamma yield vs. angle and energy from carbon.

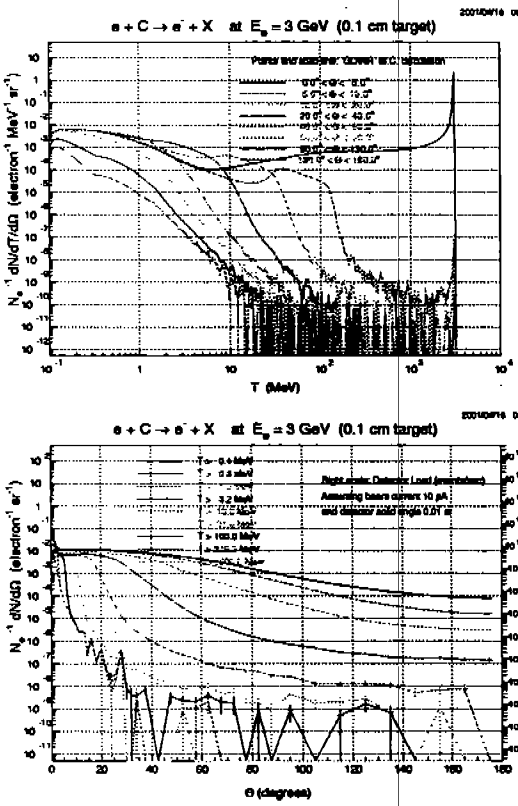


Figure 7. The calculated electron yield vs. angle and energy from carbon.

The luminosity choice of $0.8 \cdot 10^{38}\,\mathrm{cm}^{-2}/\mathrm{s}$ was supported by experimental tests [6] and upgraded BigBite parameters. Since the magnet allows only momentum of protons above 200 MeV/c, the expected proton rate is approximately 10 MHz.

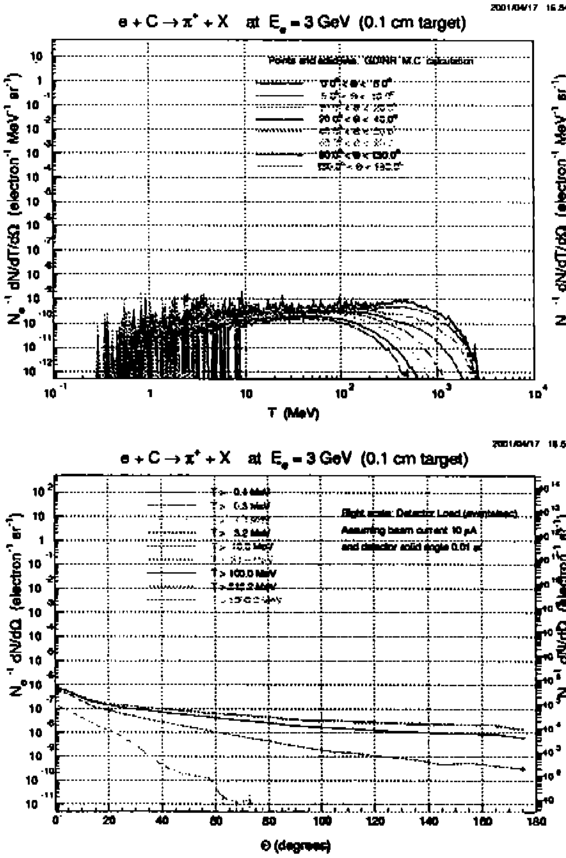


Figure 8. The calculated π^- yield vs. angle and energy from carbon.

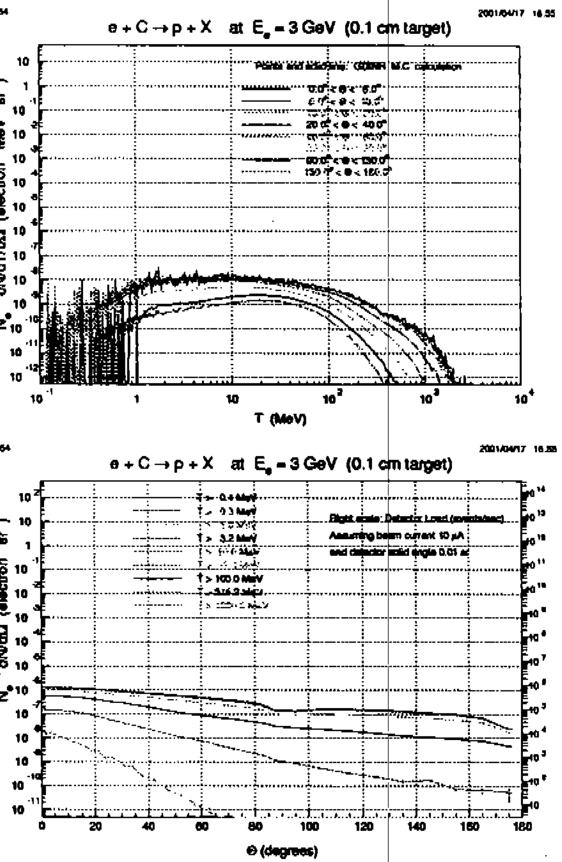


Figure 9. The calculated proton yield vs. angle and energy from carbon.

The basic parameters of the BigBite spectrometer are close to the original values [9]:

- solid angle is $\sim 70\,\mathrm{msr}$.
- momentum range is of 200-900 MeV/c.
- momentum resolution is $\sim 1\%$.
- angular resolution is $\sim 1-2$ mrad.

The main features of the new detector system are a high segmentation and a high rate capability. Tracking is performed by two MWPC, each of which has four planes of signal wires. The trigger plane has two layers of plastic scintillators. Both layers are segmented into 16 counters. Each counter is equipped with two fast PMTs. For experiments which require 10% momentum resolution or less, an additional plane of very thin plastic scintillators can be used instead of the MWPC. A coincidence gate of 30 ns will be used between the HRS and the BigBite triggers. In the off-line analysis, the correction on trajectory path length and particle momentum will allow us to reduce the width of TOF window to 2-3 ns, which defines the signal to noise ratio. For particle identification the time-of-flight resolution (FWHM) of 1 ns will allows us to distinguish pions from protons and select the right track among those detected by the tracking system. The GEANT simulation [18] of the upgraded BigBite acceptance and resolution for proton detection are presented in Fig. 10.

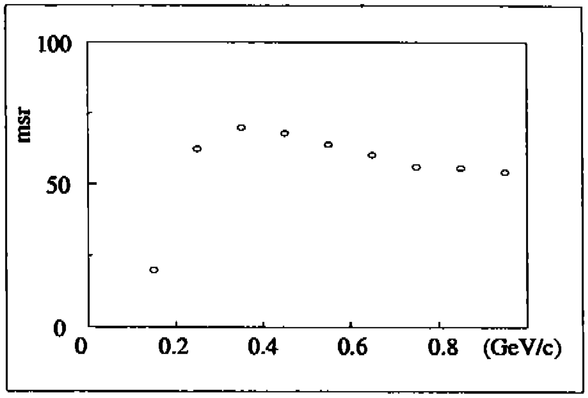


Figure 10a.
The solid angle
of BigBite.

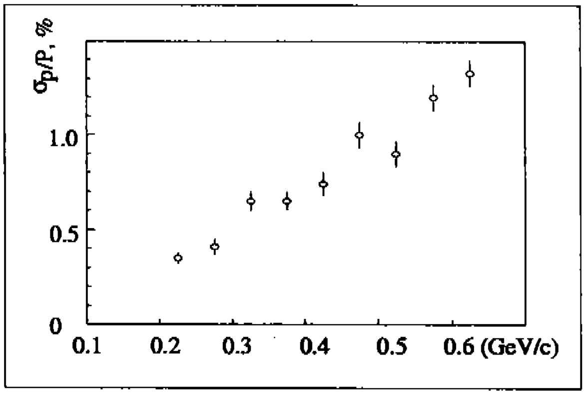


Figure 10b.
The momentum resolution
of BigBite (protons).

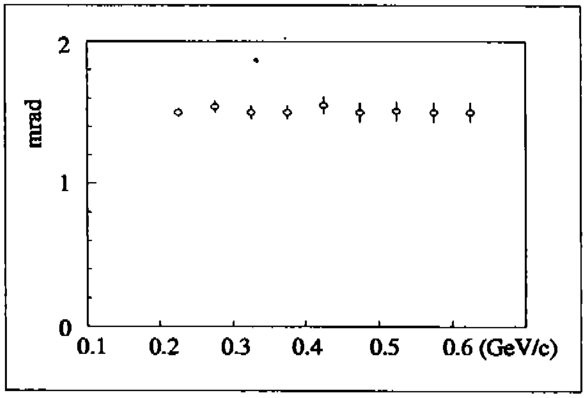


Figure 10c.
The angular resolution
of BigBite (protons).

CONCLUSION

The BigBite spectrometer under construction in Hall A will serve as a new tool for correlation studies. Nucleon correlation experiments with luminosities up to $1 \cdot 10^{38}$ cm^{-2}/s will be possible when the proton threshold momentum is about 200 MeV/c. Detailed MC calculations and experimental tests have demonstrated that at such a luminosity the positive particle rate will be about 10 MHz in BigBite's solid angle of 70 msr at 90° relative to the beam direction.

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