Quasi elastic cross sections for the $^{209}Bi(e,e'p)^{208}Pb$ reaction: Jefferson Lab experiment E06007

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Abstract. Quasi elastic cross sections were measured for the first time for both negative and positive missing momenta for the $^{209}Bi(e,e'p)^{208}Pb$ reaction leading to the ground state and hole states of ^{208}Pb. Experimental cross sections obtained between -0.3 GeV/c to 0.3 GeV/c agree with theoretical calculations using RDWIA techniques both in shape and magnitude for the ground state. The data for the ground state production of ^{208}Pb are consistent with a theoretical model assuming a single proton(1.06 ± 0.10) in the 1h9/2 orbit in ^{209}Bi.

1. Introduction

Experiments show that the occupation probabilities of shell model states at the Fermi level are significantly smaller than the simplest models predict [1]. Attempts to explain this depletion of up to 35% of the shell model occupation probabilities invoke nucleon-nucleon short range and long range correlations. States at the Fermi level are particularly susceptible to nucleon depopulation, presumably because Fermi blocking is much less effective here than for deeply bound states. ^{209}Bi provides an interesting test system of the validity of the nuclear shell model, being practically a text book case of the model. In the simplest picture of its ground state there should be a single proton in the 1h9/2 orbit about the double shell closed core of ^{208}Pb. Proton occupation probability for the 1h9/2 orbit can be determined by the probability of removing protons from the ^{209}Bi ground state and producing the ^{208}Pb ground state. Such measurements have included proton pick up reactions such as (d,^{3}He) [2] or (e,e'p) knockout reactions [3], [4]. In the case of (d,^{3}He) high resolution allows the identification of the precise distribution of relevant proton orbital momenta. However, the strong absorption in the entrance and exit channels limit the proton pick up to a region about 10F from the center of the nucleus. Hence, the spatial distribution of the proton's wave function inside the nucleus is not directly probed. In the case of the two previous (e,e'p) measurements the electron probes the entire nuclear volume and provides a much more sensitive test of the proton's spatial distribution. The previous (e,e'p) measurements were restricted to proton angles larger than the direction of the three momentum transfer $\vec{q}$ from the electron ($\vec{q} = \vec{e} - \vec{e'}$). With the JLab CEBAF facility the (e,e'p) measurement reported here allowed a much wider range of proton ejection angles about $\vec{q}$ and in quasi elastic kinematics, $x_{Bjorken} \approx 1$. Our measurements were performed for incident electron energy of 2.652 GeV, for four momentum transfer (ω, q), q = 1 GeV/c, ω = 0.436 GeV. From the point of view of the electron's kinematics quasi elastic scattering views the interaction of the virtual photon with the struck proton as if the proton were moving in a smooth potential and not engaged in close encounters with neighboring nucleons.

2. Results

A comparison of the measured missing energy spectrum and a GEANT3.2 simulation which includes kinematic broadening, radiative corrections and additional experimental broadening is shown in figure 1. Only the ^{208}Pb ground state (gs) and a single state at 5.4 MeV is included in the simulation. The simulation attempts to match the low missing energy shoulder of the ground state and hole states structures. The 3^- collective state at 2.6 MeV excitation is assumed to be only weakly excited due to its absence in the previous (e,e'p) measurement and small excitation probability from (d,^{3}He) reactions. This state is not expected to be excited with appreciable strength due to the single proton knockout character of the (e,e'p) reaction. The additional strength seen above the ground state may be due to states in ^{208}Pb above 3.2 MeV or to additional experimental broadening. One needs more theory to attempt to fit the complex seen at 5.4 MeV as a sum of states. Branford et al. found a complex of states at 4.1 MeV excitation which corresponds to the (d,^{3}He) pickup strength of L=0 plus L=2.

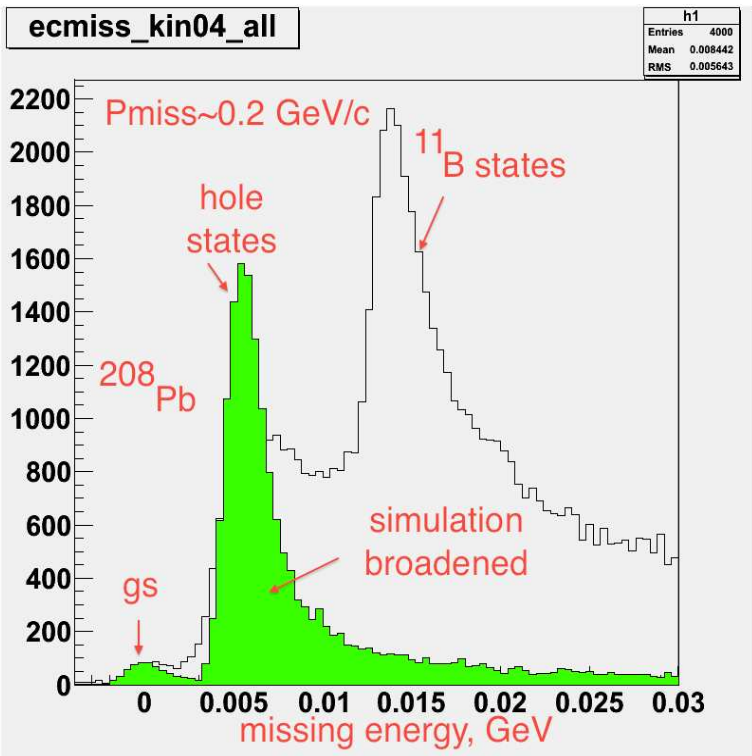

Figure 1. Kin04, centered at $p_{miss} = 0.2$ GeV/c for the $^{209}Bi(e, e'p)^{208}Pb$ reaction. The ^{11}B states are broadened because Bi kinematics are used to reconstruct the missing energy spectrum.

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Table 1. $^{209}Bi(e,e'p)^{208}Pb$, March 2007. Cross sections in nbarn/sr^2/MeV. Radiative corrections have been applied. A 13% uncertainty due to radiative corrections is included in the ground state cross sections and an additional 5% uncertainty from radiative corrections is included in the hole states cross sections. Theoretical cross sections are from the Madrid group. Theory assumes one proton in the 1h9/2 shell and includes out of plane cos(ϕ) terms. Theory is integrated over the simulation. Hole states include counts between 2.4 MeV to 7 MeV excitation.

kin	θ_p	$p_{miss}(GeV/c)$	data, gs	Theory gs	hole states
kin02	59.83	0.1	0.112 ± 0.022	0.120	2.35 ± 0.13
kin03	48.37	-0.1	0.099 ± 0.023	0.0651	2.09 ± 0.13
kin04	65.36	0.2	0.132 ± 0.019	0.166	1.93 ± 0.11
kin05	42.58	-0.2	0.117 ± 0.022	0.0894	0.99 ± 0.06
kin06	71.44	0.3	0.0095 ± 0.005	0.0094	0.08 ± 0.01
kin07	36.76	-0.3	0.033 ± 0.026	0.00477	0.10 ± 0.03

Cross sections measured in this experiment for the ^{208}Pb ground state and for hole states are shown in Table 1. Uncertainties in the cross sections are determined from the statistical errors and the radiative cross section uncertainties added in quadrature. The statistical uncertainties for kin02, kin04, kin06 in the table are 13%, 7.4% and 50% respectively. Uncertainties due to radiative corrections are shown in the table. These radiative correction uncertainties arise because of difficulty in establishing the high missing energy cut off point for each peak. For the ground state with smaller yield than the hole states the uncertainty is larger. By trying a variety of different high missing energy cuts we established the spread in the deduced cross sections.

Theoretical values using the prescription of the RDWIA([5]-[7]) are also tabulated. The theory has been integrated over the simulation of the experiment. The table lists the missing momenta ($\vec{p}_{miss} = \vec{q} - \vec{p}_p$) using the typical nomenclature where negative missing momenta are associated with proton angles smaller than $\vec{q}$.

The proton occupation probability of the 1h9/2 state in ^{209}Bi is consistent with 1 if all the data are included. If only the positive missing momenta cross sections are used then the ratio of data to theory for one proton in the 1h9/2 shell is 0.86 ± 0.10. Using the values from Table 1 we find:

$$(\sum_{\theta_p}(sin(\theta_p)d\sigma^5/d\Omega_e d\Omega_p dE_e)_{data})/(\sum_{\theta_p}(sin(\theta_p)d\sigma^5/d\Omega_e d\Omega_p dE_e)_{theory}) = 1.06 \pm 0.10 \qquad (1)$$

A comparison of the theory and data for the ground state is seen in figure 2.

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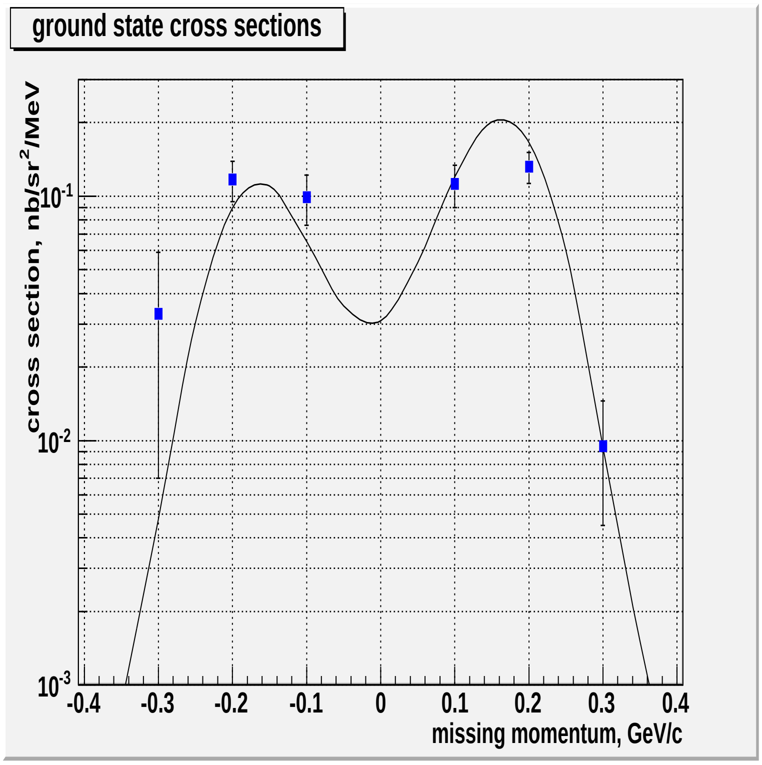

Figure 2. Absolute comparison of RDWIA theoretical prediction(solid line) vs data(squares) for the ground state cross section of the $^{209}Bi(e,e'p)^{208}Pb$ reaction. Theory assumes there is one proton in the 1h9/2 state in ^{209}Bi.

Proton hole states of the structure [1h9/2,$(3s1/2)^{-1}$], [1h9/2,$(2d3/2)^{-1}$], [1h9/2,$(1h11/2)^{-1}$], [1h9/2,$(2d5/2)^{-1}$] have been reported in the earlier (e,e'p) and (d,^{3}He) experiments. The theory, assuming full occupancy, for the hole states produced from the 2d3/2, 2d5/2 and 1h11/2 orbits integrated over the simulation is shown in figure 3.

The theory is fitted to the data at p_{miss} = -0.1 and -0.2 GeV/c with the weighting shown in figure 4.

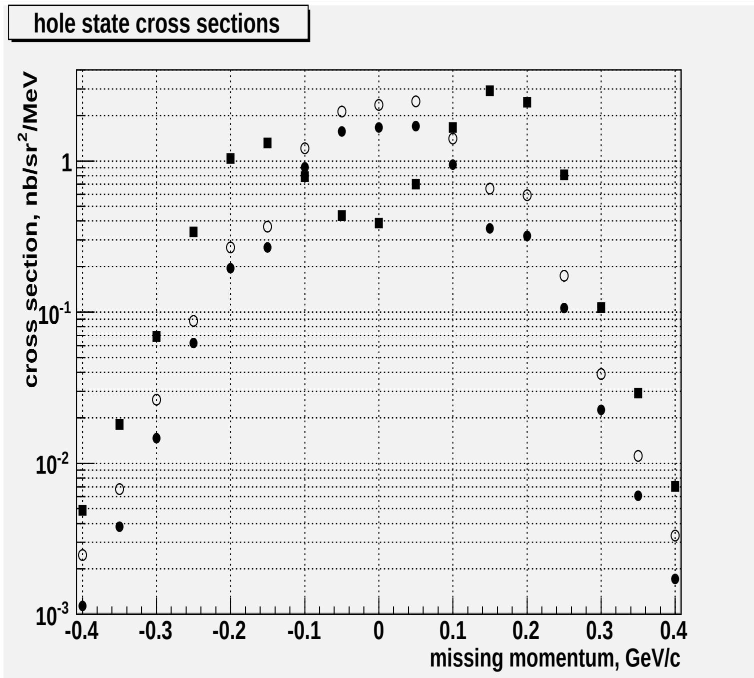

Figure 3. Theoretical cross sections in nb/MeV/sr^2 for knocking protons out of the 2d5/2(open circles), 2d3/2(solid circles) and 1h11/2(squares) orbits assuming full occupancy.

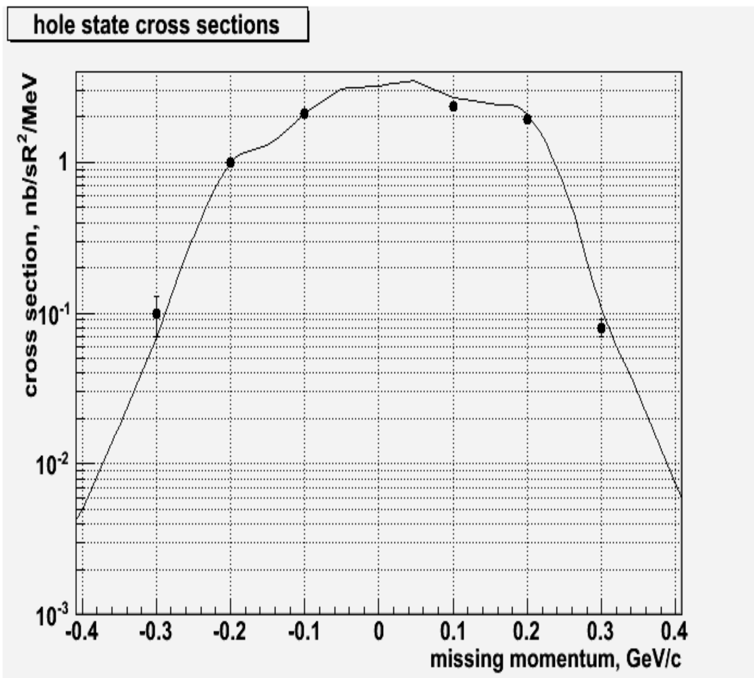

Figure 4. Holes state cross sections compared to theory. Theory is fitted to data at p_{miss} = -0.1 and -0.2 GeV/c. Theory = 0.759*(2d3/2 + 2d5/2) + 0.615*(1h11/2).

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3. High power bismuth target

The low melting temperature of the bismuth target presents an experimental challenge. Since the electromagnetic interaction is much weaker than hadronic interactions beam currents are substantially larger with electron beams than hadronic beams. The measurements were run in two separate periods. In the first period, from which these data were obtained, we damaged the bismuth target but were able to extract reliable cross sections, nevertheless. With a redesigned target we ran successfully using a 60 μA electron beam over several hours. The basic features of the target include supporting the bismuth foil between two diamond foils(carbon vapor deposition) mounted in a cryogenic holder, and rastering the beam over a pattern of 4mm x 6mm size. The raster system [8] at Hall A in Jefferson Lab uses a triangular wave current supply for the raster magnets which produces a very uniform illumination of the target within the raster pattern. Count rates from 36 plaquettes into which we could divide the target using the optics of the High Resolution Spectrometers by software were uniform to about 1.4%. No damage was seen on the targets by visual inspection after the run. Reports of the target performance and details of the target thickness analysis are available as Jefferson Lab technical reports [9].

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