Using the (n,2p) Reaction to Search for a Preexisting Nuclear Δ++ Component

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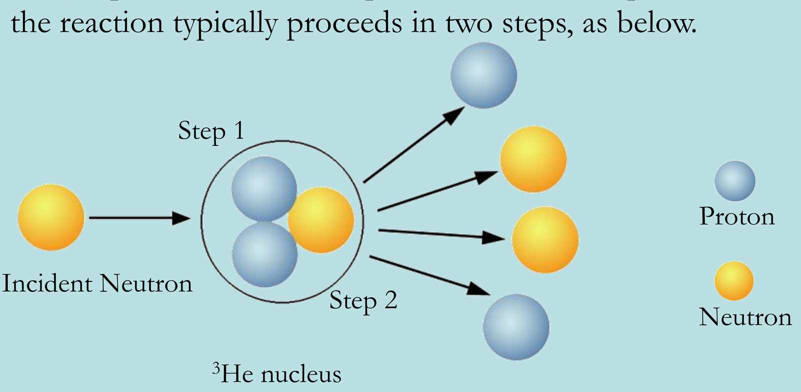
1. Abstract

The ^{3}He(n,2p)2n and the ^{4}He(n,2p)3n cross-sections are being measured as a means to explore the Δ^{++} contribution to the nuclear wave function. The incident neutron beam ranged between 200 and 500 MeV. Scattered protons passed through magnetic spectrometers centered 45° to the right and left of the beam line. Each spectrometer consisted of a thin ΔE scintillator, a drift chamber, a permanent bending magnet, a drift chamber, and a detection barrier of three stacked scintillators.

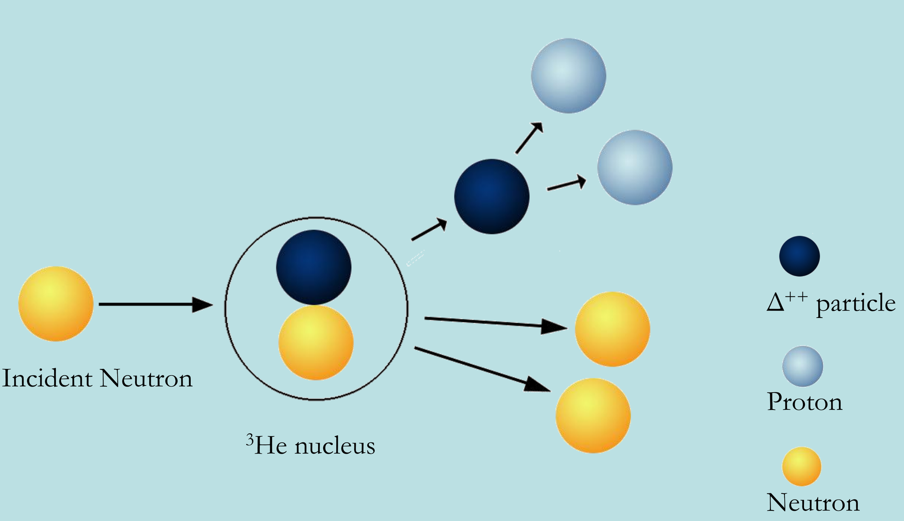
2. Motivation

Traditional models of the nucleus that treat it as a non-relativistic system of nucleons do not completely explain the binding energies and the electromagnetic properties of nuclei. By the 1960s, theorists suggested the presence of a pre-existing Δ(1232) particle in the ground-state nuclear wave function and that this Δ resonance might be important in nuclear structure. The Δ^{++} has a mass of about 1232 MeV, spin and isospin of 3/2, and a +2e charge. To find a Δ^{++} component in the nucleus, the ^{3}He(n,2p)2n and the ^{4}He(n,2p)3n cross-sections are being measured at the Weapons Nuclear Research (WNR) facility at Los Alamos Nuclear Science Center (LANSCE) in Los Alamos, New Mexico.

There are two primary ways that the ^{3}He(n,2p)2n and the ^{4}He(n,2p)3n reactions may proceed. For a two proton nucleus, the reaction typically proceeds in two steps, as below.

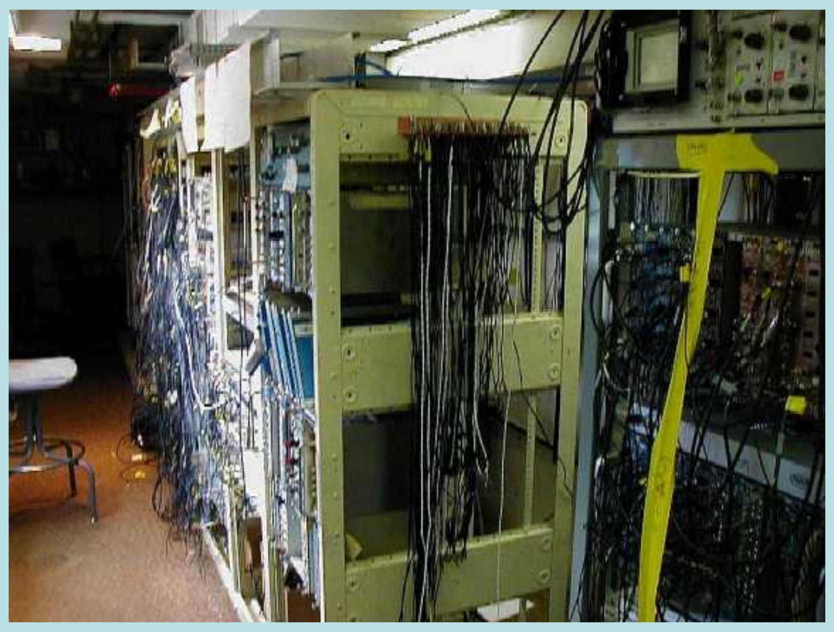


In a Δ^{++} nucleus, the reaction may proceed in one step. Each reaction has a distinguishable kinematic signature allowing the approximate Δ^{++} (n,2p) contribution to be determined. There have been previous investigations of the in the nucleus. Measurements such as those performed by Morris et al. (C.L. Morris et al., Phys. Lett. B419, 25 (1998)) have looked at the Δ^- component in the ^{3}H, ^{3}He, ^{6}Li, ^{7}Li, ^{12}C, ^{13}C, ^{90}Zr, and ^{208}Pb nuclei using the (π^+,π^-p) reaction. Like the (n,2p) reaction, the (π^+,π^-p) reaction will generally proceed in two steps, but with a pre-existing Δ^- particle in the nucleus it may proceed in one step. These measurements indicate a 1-3% Δ^- component of the nuclear wave function. In 1996 and 1997 the ^{3}He(n,2p)2n and the ^{4}He(n,2p)3n reactions were studied by our group of collaborators from MIT and Los Alamos National Laboratory using a different setup at the same facility. Not enough events were detected to determine a statistically meaningful value for a Δ^{++} component. Together, the (π^+,π^-p) data and previous (n,2p) data support the idea of pre-existing Δ components in the nuclear wave function.

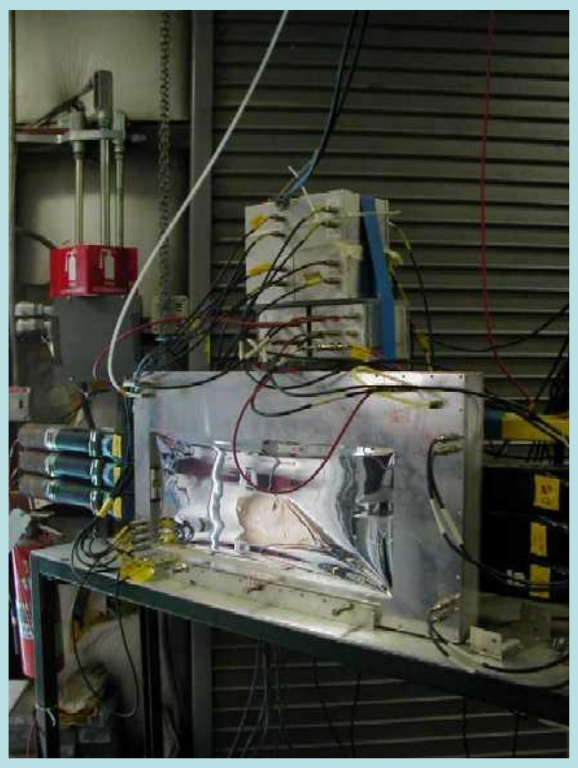


3. Experimental Apparatus

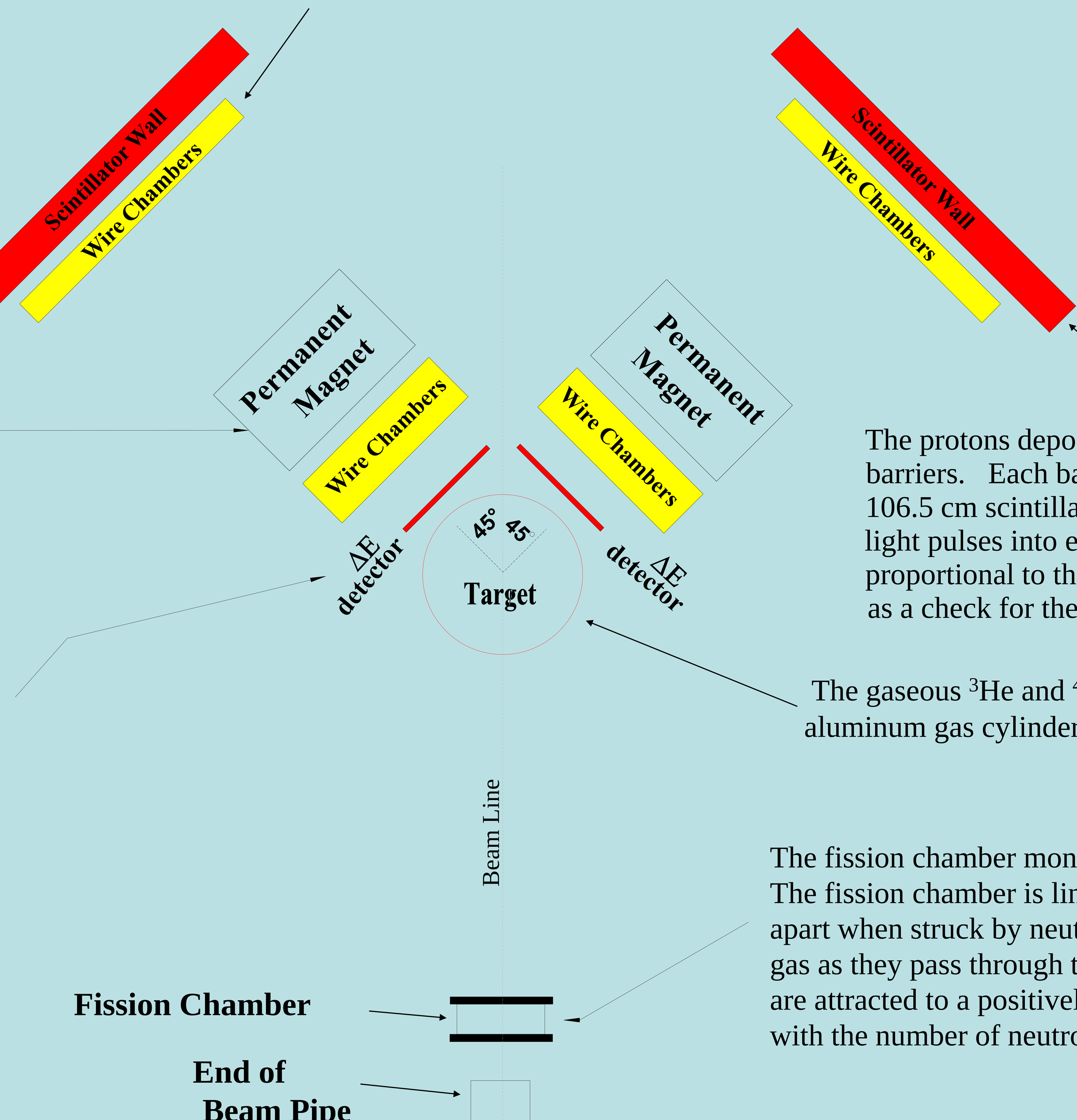
The experimental apparatus was designed to detect two protons that scatter in coincidence as the neutron beam interacts with the target.



The drift chambers are filled with argon gas and contain two perpendicular long wires looped back and forth many times with a spacing of 8 mm so the *x* and *y* position can be found. As protons pass through these chambers, they ionize the gas. The released electrons drift toward the nearest wire loop and cause pulses at each end of the wire. Another drift chamber immediately follows the first to identify another point and thus the particle's trajectory. Drift chambers before and after the permanent magnet are used to find the change in the trajectory due to the magnet.



The permanent magnets bend the trajectories of the protons (which are charged particles) in an amount inversely proportional to their momenta.

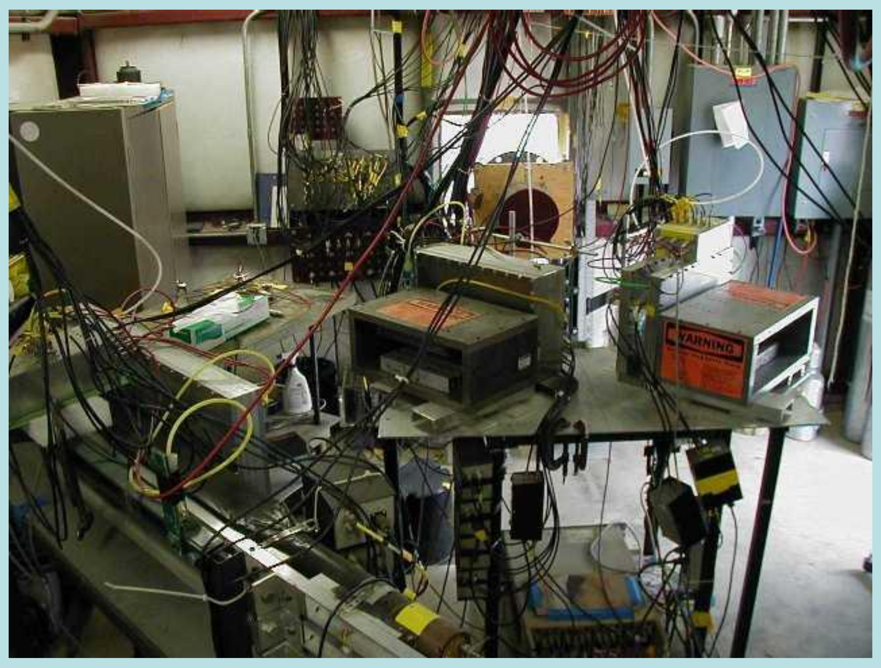


The protons deposit all their energy in the plastic scintillator barriers. Each barrier has a stack of three 10.1 cm x 10.1 cm x 106.5 cm scintillators with photomultiplier tubes to convert the light pulses into electrical pulse signals. The size of the pulse is proportional to the energy deposited in the scintillator, so it acts as a check for the energy calculations using the drift chambers.

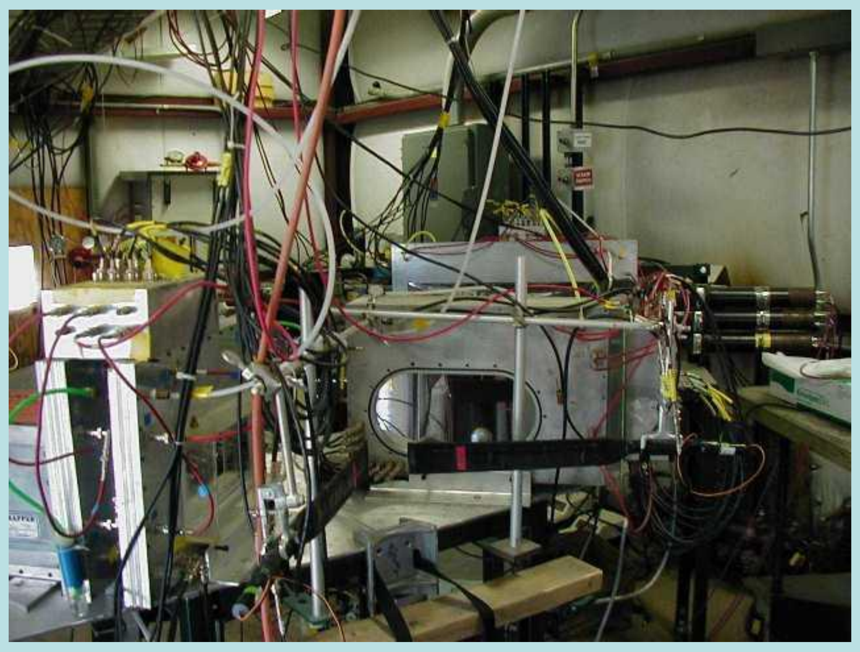
The ΔE detectors are thin plastic scintillators used to reduce background events. The coincidence of a signal in the ΔE and a signal in the scintillator barrier most likely indicates a particle from the target. Neutrons are not likely to trigger the scintillator since neutrons cannot interact via Coulomb interactions and the ΔEs are very thin.

The gaseous ^{3}He and ^{4}He targets are contained in conventional aluminum gas cylinders at 102.7 and 134.6 bar respectively.

The fission chamber monitors the neutron flux on the target. The fission chamber is lined with a fissile isotope which breaks apart when struck by neutrons. The fission fragments ionize a gas as they pass through the chamber. The freed electrons are attracted to a positively charged wire. The current varies with the number of neutrons so neutron flux can be monitored.

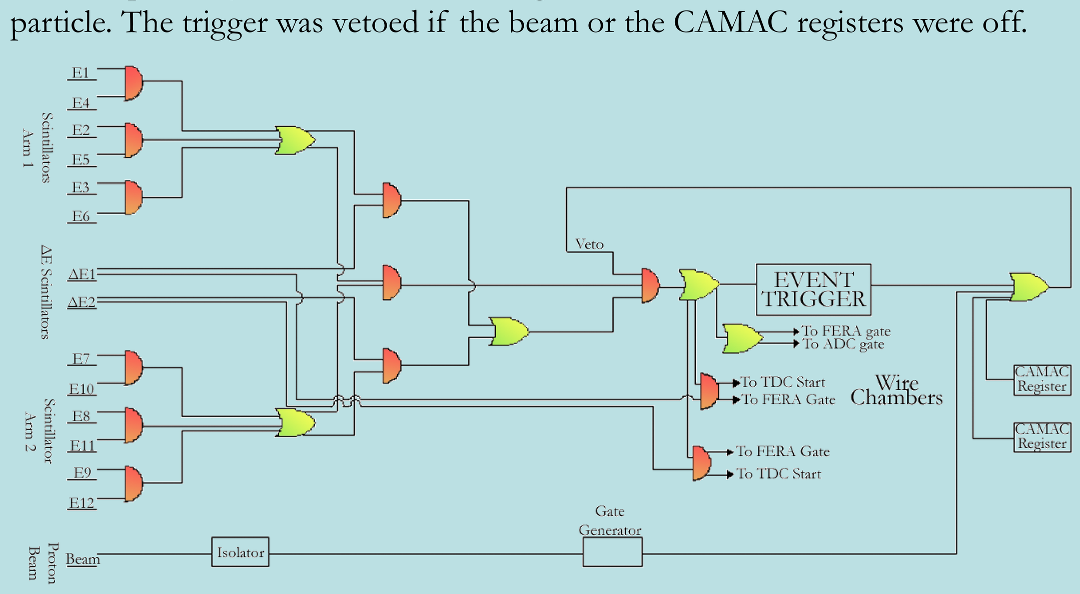


A pulsed 800 MeV, 1 mA proton beam from the LANSCE linear proton accelerator (LINAC) strikes an unmoderated tungsten spallation target to produce a neutron beam with energies ranging from 0.1 MeV to approximately 800 MeV.



4. Electronics

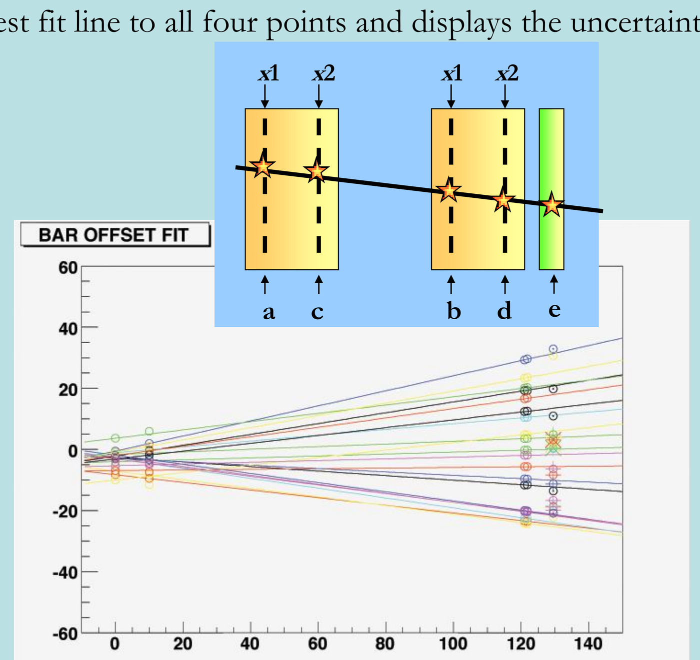
The electronics read in and processed the signals from the various detectors before sending them to the computer. A signal in one ΔE detector and in both scintillator barriers triggered the electronics. This ensures that the particles detected probably scattered from the target and are in coincidence with another particle. The trigger was vetoed if the beam or the CAMAC registers were off.

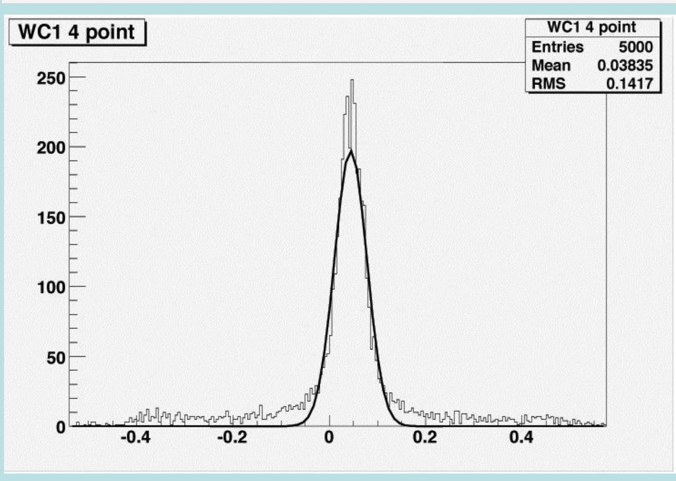


The outputs from the drift chambers were read into the computer using FERA modules. All other signals were read in using CAMAC modules. In the drift chambers, the electrons that drift to the wire cause pulses that go to each end of the wire. The time difference between when the pulses arrive at each end indicates which loop of wire the proton was near. The sum of the pulse times gives the drift time. Using this information from the vertical and the horizontal wires, the position of the proton can be found.

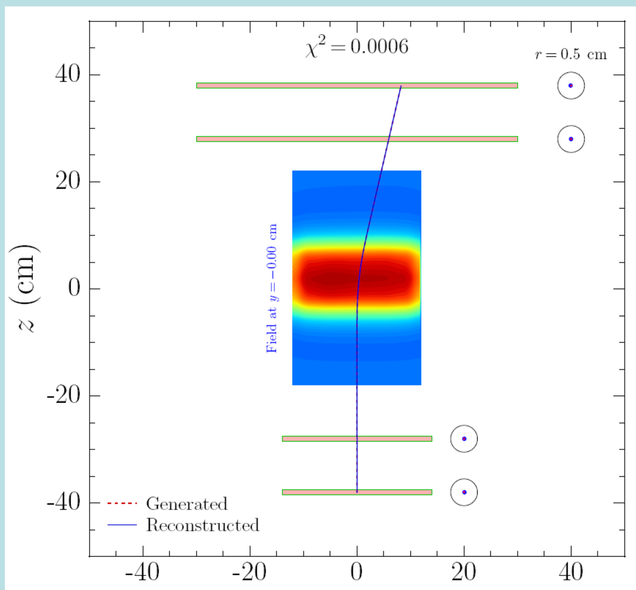
5. Momentum Analysis

In order to determine the positions of the drift chambers and scintillators, a code has been written which fits the offsets and distances to the straight-track trajectories produced when the magnets were removed. The code uses measured offsets for the first planes of the front and rear drift chamber (a and b). It then fits the offsets and the distances for the second planes of each drift chamber (c and d). Finally the code fixes a, b, c, and d at the fit best position and determines the offset for the rear scintillator, e. After all the offsets have been determined it then finds the best fit line to all four points and displays the uncertainty.





To determine the resolution of the drift chambers, histograms were made of the expected position given a straight trajectory versus the actual position where the particle struck. The results suggest a best-case resolution of approximately 200



The momentum analysis code uses the trajectories (determined from the drift chambers) before and after the bending magnet to calculate the particle momentum. The figure above shows a test of the code, in which a track is artificially generated to determine the drift chamber hit positions, then the track is reconstructed from the positions and the particle momentum is calculated.

6. Wire Chamber Analysis

The drift chambers must be calibrated to determine the particle trajectories. First, the time differences between signals from each end of the delay line are analyzed to find the wire nearest the particle path (Figure 1). The drift distance to the wire can be found because it is proportional to the sum of the times from each end of the delay line. Pulses from the cathode wires are used to determine which side of a wire the particle passed. Then, for both *x* or *y* planes in each chamber there are 4 ways to add or subtract the drift distance to the wire position (Figure 2).

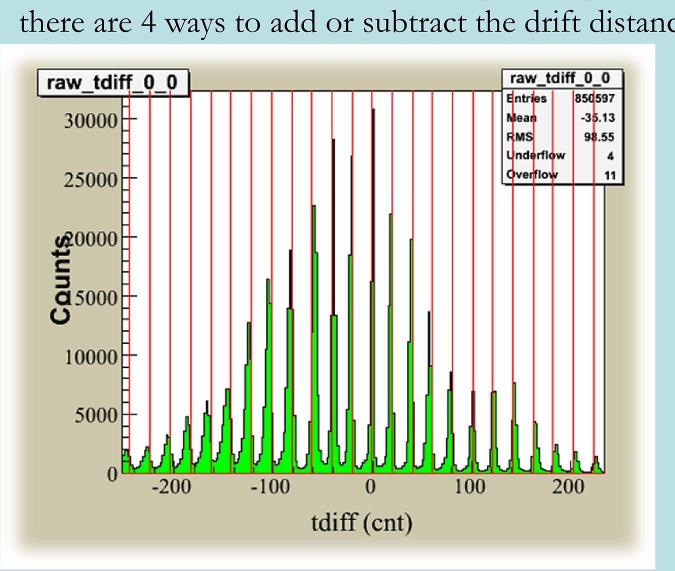


Figure 1

A histogram of time differences showing the positions of the wires.

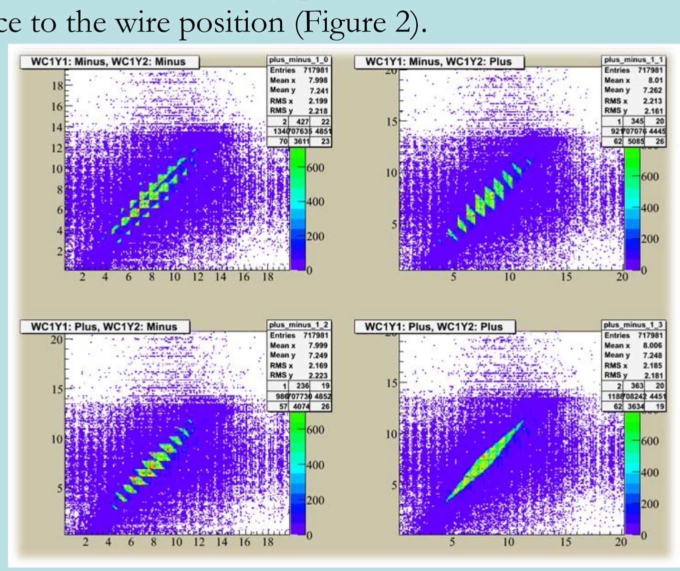


Figure 2

The four possible configurations for adding or subtracting the drift time from the wire positions.

7. Conclusion

^{3}He(n,2p)2n and ^{4}He(n,2p)3n data were taken during 2000 and are being analyzed. Our part of the analysis is focused on interpreting the drift chamber information to calculate the trajectories and momenta of the protons before and after they pass through the permanent magnet. Ultimately, theoretical predictions will be compared to this analysis and a determination of the nuclear Δ^{++} component hopefully made.