Producing the ^{2}H(d,n)^{3}He Reaction with the Houghton College Cyclotron

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I. Abstract

The Houghton College Cyclotron accelerates ions inside of a 17 cm inner diameter evacuated aluminum chamber placed between the poles of a 1.2 T electromagnet. Very low-pressure gas allowed into the evacuated chamber is ionized by electrons coming from a filament. Inside the chamber, a high voltage RF signal applied to a "dee" shaped electrode accelerates the ions each time they are between the dee and a grounded "dummy dee", resulting in a spiral path because of the magnetic field. The cyclotron has successfully accelerated hydrogen, helium and most recently, deuterium. The deuterons were allowed to implant into a copper target, where they reacted via ^{2}H(d,n)^{3}He to produce neutrons which were detected using a plastic scintillator outside the vacuum chamber.

II. Theory

A cyclotron accelerates ion in a roughly spiral path. As shown in Fig. 1, an ion of charge q and mass m traveling with velocity $\vec{v}$ perpendicular to a constant magnetic field $\vec{B}$ will travel in a circular orbit of radius r due to the centrally directed Lorentz force

$$\vec{F} = q\vec{v} \times \vec{B} = -\frac{mv^2}{r}\hat{r}. \qquad (1)$$

Each time the ion passes between two hollow electrodes (called "dees") it gains energy due to the electric field between them, resulting in a larger orbit. The polarity of the dees is switched at an RF frequency such that the ion arrives at the gap at just the right time to get a boost, regardless of the ion orbit radius. The frequency is simply the velocity from Eq. 1 divided by the circumference of the orbit,

$$f = \frac{v}{2\pi r} = \frac{qB}{2\pi r}. \qquad (2)$$

The ion non-relativistic kinetic energy after reaching radius r is therefore

$$T = \frac{1}{2}mv^2 = \frac{q^2B^2r^2}{2m} = 2N\Delta\phi \qquad (3)$$

where N is the number of orbits and $\Delta\phi$ is the potential difference between the dees.

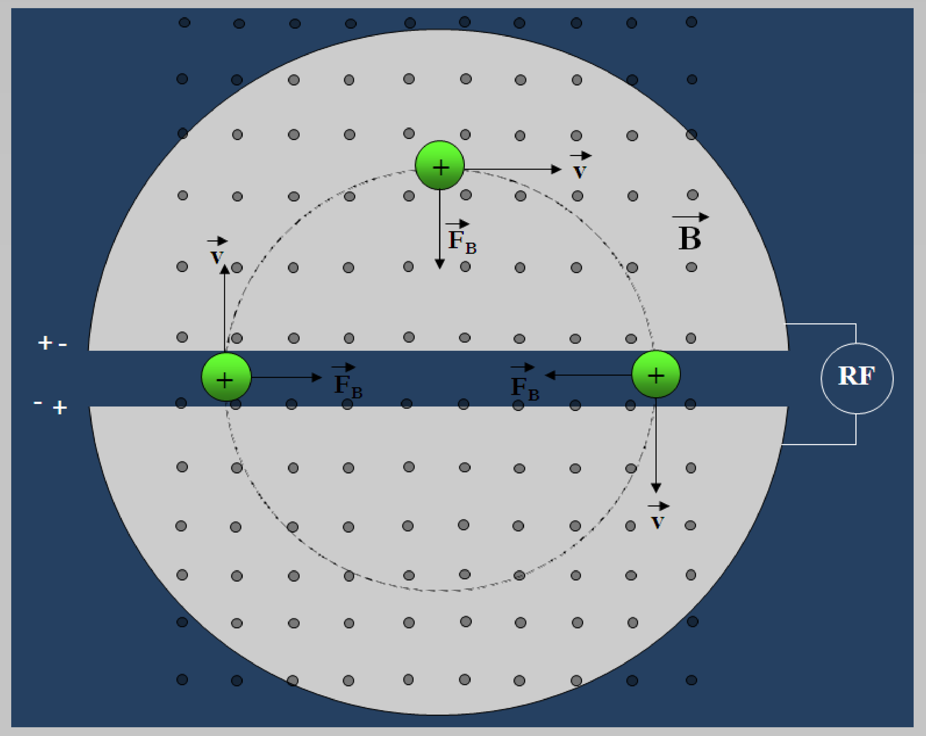
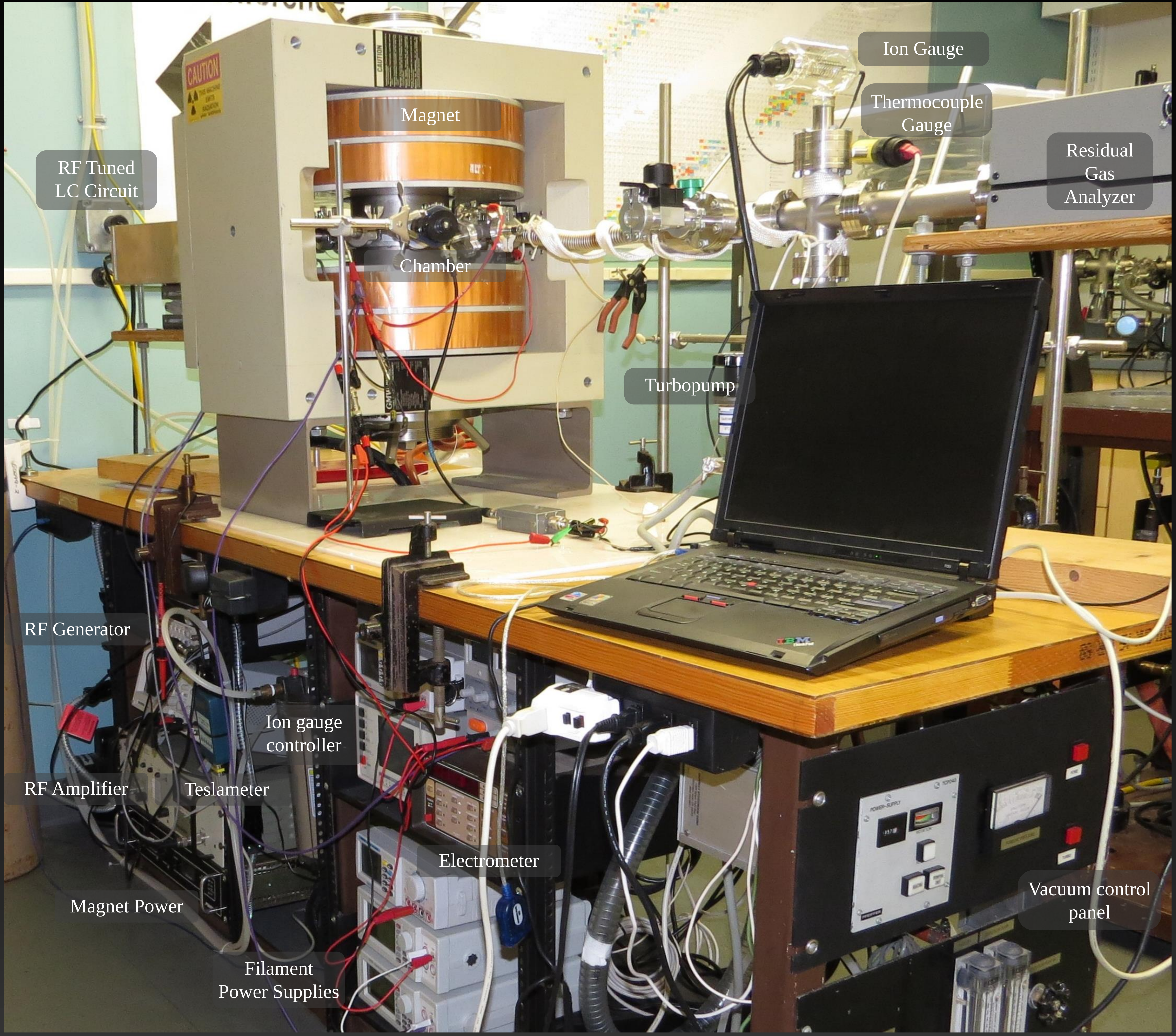


Figure 1. (Above) An ion of charge q and mass m travelling with velocity $\vec{v}$ in uniform magnetic field $\vec{B}$ pointed out of the figure.



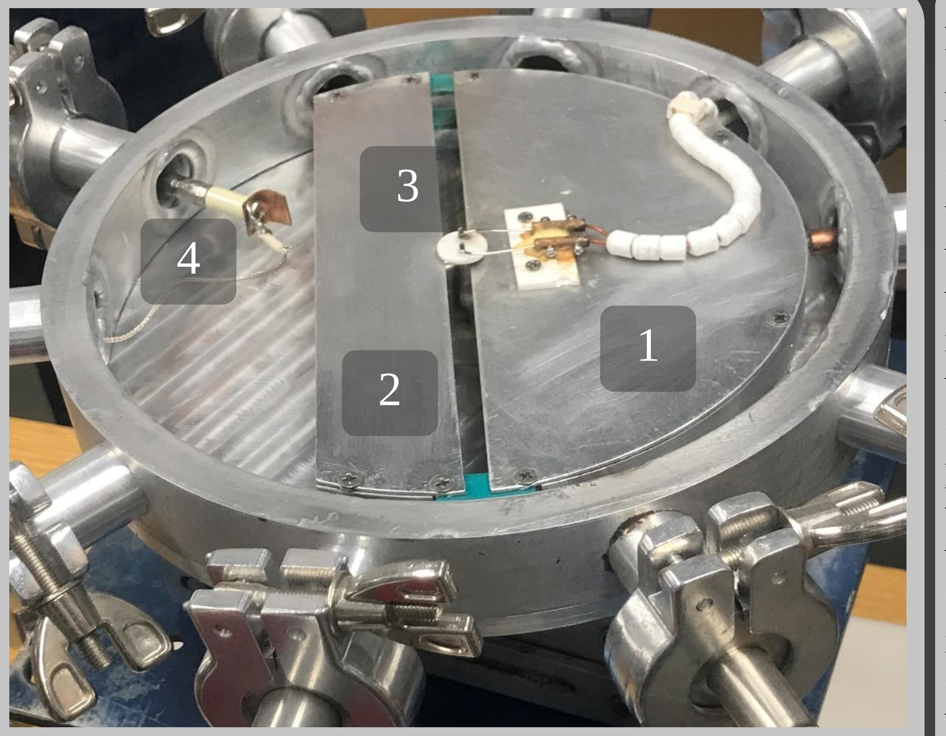
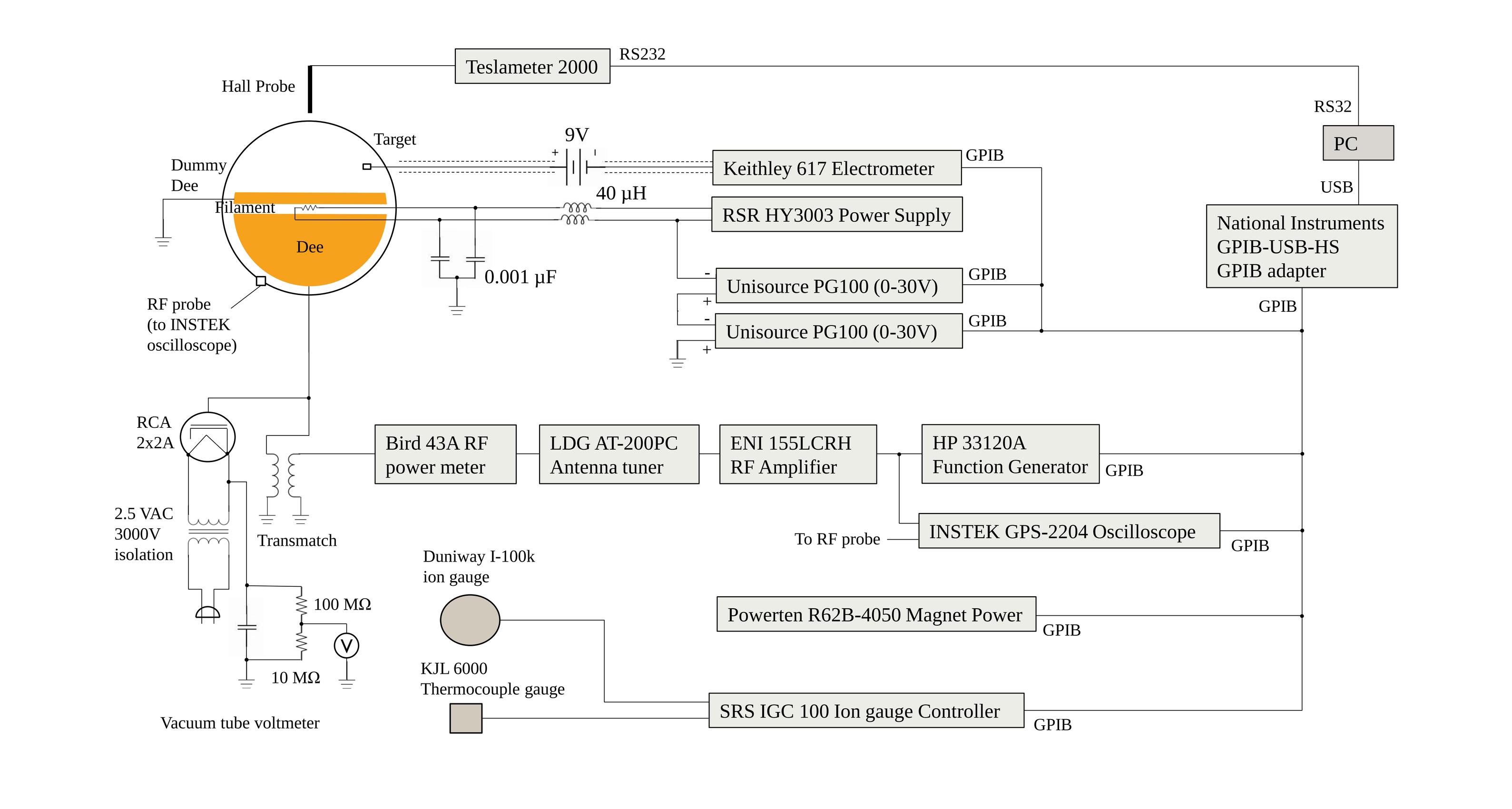


Figure 2. (Above) Photograph of the chamber showing the dee (1), dummy dee (2), filament (3), and target (4).

Figure 3. (Right) A block diagram of the cyclotron electronics, showing the RF system, the vacuum tube voltmeter for measuring the dee voltage, the filament controls, the magnet power supply and teslameter, and the vacuum measurement system. Most instruments are controlled remotely by a PC via GPIB and RS232 interfaces.



III. The Experiment

Deuterium ions were accelerated for the first time at a frequency of 5.831 MHz with the target at a radius of 55.4 mm. The magnetic field strength was scanned and the resulting beam current was measured and plotted in Fig. 4. Peaks corresponding to dividing the primary cyclotron resonance frequency from Eq. 2 by odd integers can be seen. These peaks result from the dee voltage switching multiple times while the ion is inside the electric field-free region inside the conducting dee.

The magnet was then set to 255 mT, giving a beam current of 20 nA at 4.8 keV. At this energy, beam deuterons implanted in the copper target could interact with incident deuterons via ^{2}H(d,n)^{3}He. After implanting for 50 min, a plastic scintillator detector just outside the chamber wall was turned on, and counted 7913 $\pm$ 587 events for the next 50 min of beam after background subtraction.

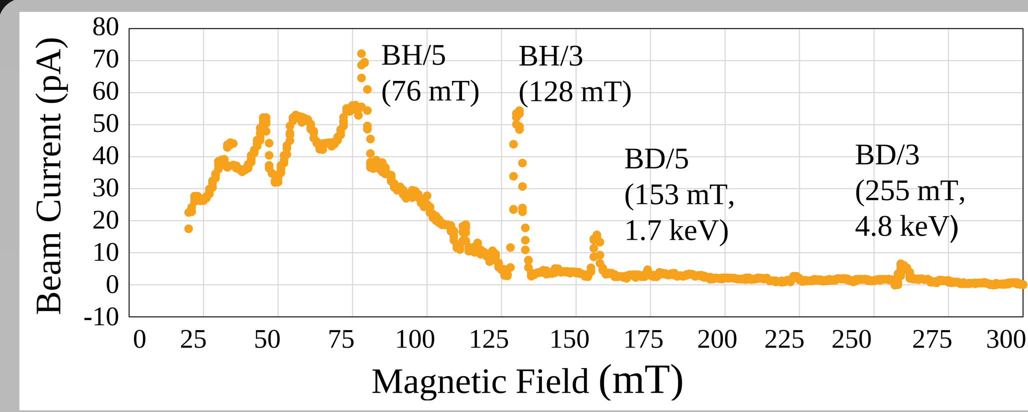


Figure 4. The beam current as a function of magnetic field for the for deuterium ions. The peaks are at the frequencies predicted by Eq. 2 divided by odd-integers.

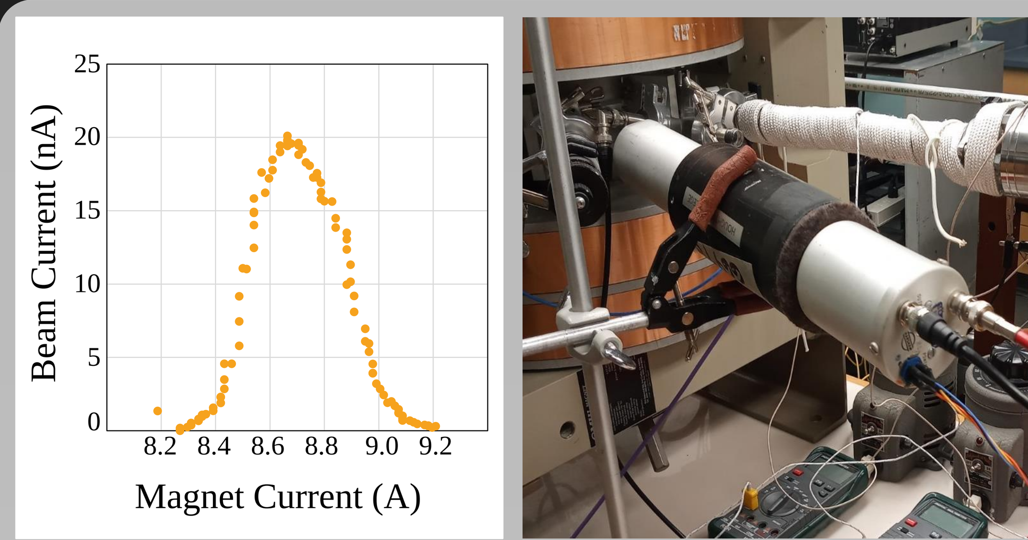


Figure 5 (Above Left) Beam current as a function of magnet current at the 255 mT resonance. **(Above Right)** A 2 inch diameter by 6 inch plastic scintillator detected radiation, presumably either neutrons or x-rays, that penetrated the chamber wall.

IV. Future Plans

In the future, in order to confirm that neutrons were detected, a ^{3}He proportional detector will replace the plastic scintillator. This detector should allow neutron events to be separated from x-ray events.

Furthermore, a new internal target holder has been constructed that will allow either the copper target, useful for measuring the beam current, or a deuterated polyethylene target, to be rotated into the beam. The deuterated polyethylene target will provide many more target deuterium nuclei which should greatly increase the ^{2}H(d,n)^{3}He reaction rate.