K150 operations and development

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Introduction

We had a very busy year operating the K150 cyclotron. For the reporting period we logged over 6100 hours of beam-on-target or for beam developments. The 15 MeV proton beam was produced regularly throughout the year for the light ion guide (LIG) project. A few 14 and 15 AMeV heavy ion beams were developed and used in experiments, and several 12 AMeV beams, such as $^{6}Li^{3+}$, $^{26}Mg^{10+}$, $^{27}Al^{10+}$, $^{28}Si^{10+}$, and $^{32}S^{11+}$, were extracted and were used by the Tribble and Rogachev groups for experiments in the MDM cave. The Rogachev group also requested a number of 3rd harmonic 1.0 AMeV beams, and fortunately we were able to tune these beams out for them; this is discussed in more detail below. The STAR/LIBERACE group ran four times, using 28 MeV proton and 55 MeV alpha beams; the alpha beam was transported to the neutron ball cave for the first time and the beam optics scheme is discussed below. Also, the K150 beams have been used in two new projects: a feasibility study of the astatine-211 production from irradiation of 29 MeV alpha beam on a bismuth target, and the inauguration of SEE testing using K150 protons beams; the details are discussed below.

Beam Transport to LIG

We accelerated 15 MeV protons over a dozen separate times for the LIG project. However, the beam transport to the LIG target has been somewhat inconsistent, partly because no viewer or a faraday cup at the target position was available to help guide the beam. The beam current was simply optimized on a faraday cup (FC23) 1.5 m downstream of the LIG target. Later it was realized that getting a small beam spot was important, given that the size of the LIG production target is only 16 mm and that the beam must pass through a 16 mm aperture just a few centimeters upstream of the target. We undertook a beam transport study to improve the beam transmission to the LIG gas cell. With a viewer mounted at the target position, without the gas cell or the restrictive aperture in place, we first verified that the all beamline quadrupoles were aligned correctly. Next we had to reposition the gas cell by about 13 mm transverse to the beam, and then we were able to get a beam spot under 13 mm on the center of the viewer. Also, in order to minimize the neutron radiation in the cave, we replaced the window over the upstream 16 mm aperture with a thinner (from 5 μm to 2.5 μm) Havar foil and also we enlarged the downstream beam aperture from 16 mm to 32 mm. The beam transport improved to almost 100% transmission from FC02 to FC22 (FC22 is located 0.5 m upstream of the LIG gas cell) and then to about 75% to FC23. Given its location and its size, FC23 very likely does not catch all of the protons which go through the gas cell. The neutron radiation level in the LIG cave was also reduced after the changes.

Third Harmonic Beams

We described the new beam tuning method using the valley coil 4 (VC04) in the last year's progress report. This VC04 technique was extended to third harmonic beams and we successfully extracted a few 3rd harmonic beams. Unlike our previous 3rd harmonic beams, these were stable enough that they were transported and were used in experiments. 1.0 AMeV $^{16}O^{2+}$, 1.0 AMeV $^{22}Ne^{3+}$, and 1.4 AMeV $^{32}S^{5+}$ beams were developed for G. Rogachev's group and were used in astrophysical measurements in the MDM cave. We, however, have not quite solved the 3rd harmonic tuning problems as we were unable to extract a 4 AMeV deuteron beam. These 1 AMeV beams had less than 1% throughput (ILC02 to FC02 beam current ratio), which is less than 3% throughput observed for a little higher energy, 4-5 AMeV, 3rd harmonic beams, due in large part to very poor 5"-to-35" internal beam transmission of only 15 to 25%; a better vacuum in the cyclotron could have helped to improve the beam transmission. Another problem we have had with these low energy beams was that the beam transport to the MDM target was very poor, about 5 to 10 times worse than any first harmonic beams (6 AMeV and higher) we had transported to MDM. Up to the FC05 faraday cup (located just upstream of the BM04 dipole magnet, or at about halfway from FC02 to the MDM target) all beams showed similar transport efficiency, about 30 to 50% of the FC02 current. With beam losses occurring somewhere downstream of the FC05 for these low energy beams, one obvious reason for the beam losses is the poor vacuum and we will seek to improve the beam transport by improving the vacuum through the beamline in the MDM cave.

Expansion of K150 Usage

We have three new uses for the K150 beams. One is the SEE testing with the installation of a new SEE testing station, the second is the beam irradiation using a small beam box located behind the analyzing magnet, and the third is the initiation of the neutron ball experiments with K150 beams.

With the SEE community's interest in our proton beams, a portable SEE testing station has been installed on a K150 beam line, presently at the end of the Heavy Ion Guide (HIG) line. The testing station is similar to the K500 SEE station, which includes shutters, beam dosimetry counters to monitor the beam flux, and in-air target positioning system. To get ready for the users, we needed to show that the beams could be spread out uniformly as needed by the testers. Spreading the beam uniformly over 3"x3" square was a challenge, especially since the target location is only 3.7 meters from the last quadrupole doublet, whereas for the K500 it is over 10 meters. After demonstrating that we can obtain uniformly spread out beams, four different groups have come to use our 30 to 49 MeV proton beams.

G. Akabani's group was very interested in a high intensity irradiation using a 29 MeV alpha beam on a ^{209}Bi target to produce ^{211}At, and the back of the Analyzing Magnet was identified as a possible site for this irradiation work. One advantage of this plan was that it will keep expected high radiation from the intense alpha beam inside the K150 vault. One concern was that the beam spot might be too large given that the last focusing quadrupole doublet is located about 5 m from the target. A small beam box was mounted behind the Analyzing Magnet along the straight line from the exit of the K150, and an initial beam optics test showed that a 0.6" to 0.75" diameter spot was possible. Then in July 2015 a thin, slanted bismuth target was irradiated for one hour with a 100 nA of 29 MeV alpha beam. Subsequent analysis of the target showed that indeed ^{211}At was produced and that the unwanted ^{210}At was much suppressed compared with ^{211}At. Another irradiation run is being planned to more precisely determine the production rates of ^{211}At and the ^{210}At.

The STAR/LIBERACE group has been working to expand their work with gamma detection with their HYPERION system to neutron detection with our Neutron Ball detector. A 55 MeV alpha beam has

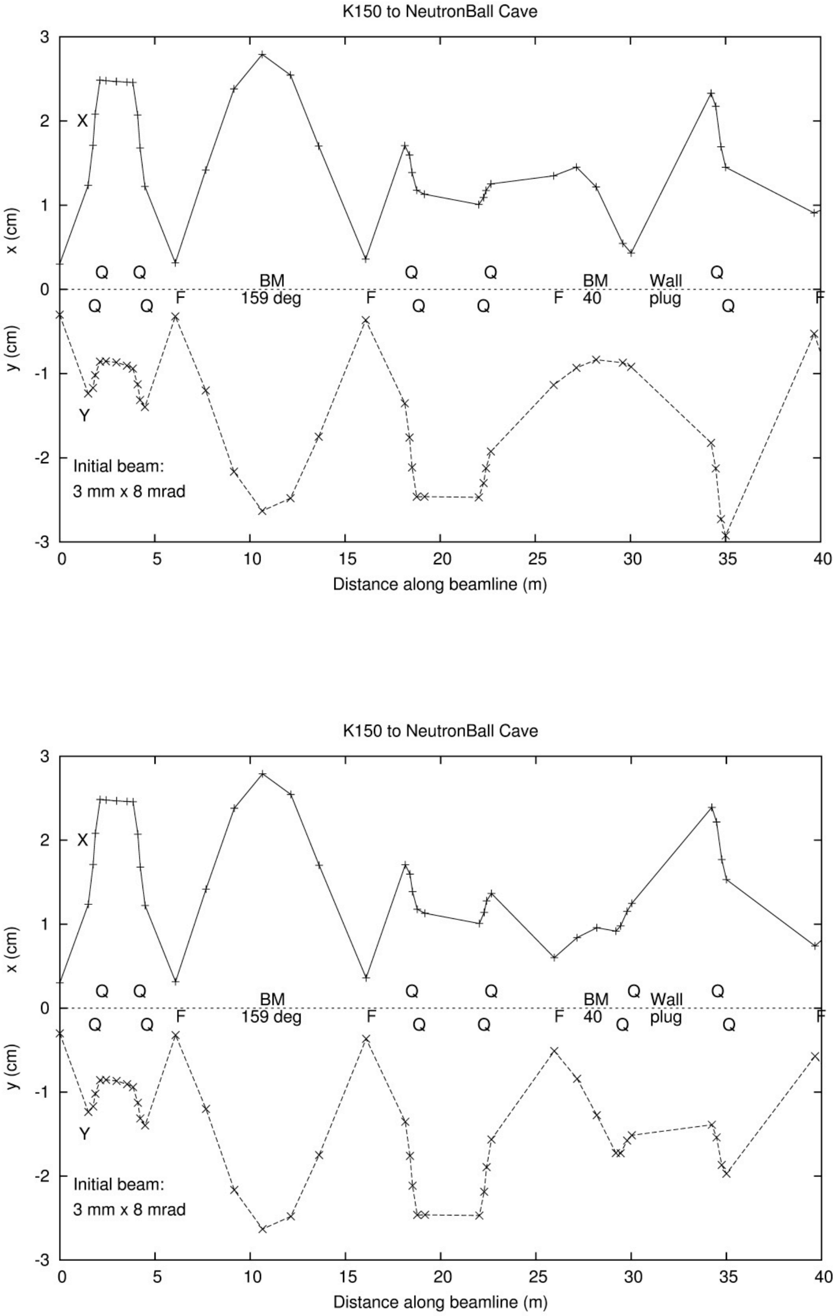

FIG. 1. X and Y beam profiles for the transport to the Neutron Ball Cave, (a) with a new quadrupole doublet installed after the BM04, (b) without the quadrupole doublet.

been transported to the Neutron Ball target; this marked the first time a K150 beam was transported to this cave. The beam optics scheme should be very similar to the MDM beam transport, especially if a quadrupole doublet could be installed just downstream of the BM04 dipole, see Fig. 1. However, currently no doublet has been installed, and due to the limited space between BM04 and the wall, and also because this line is in middle of two other beamlines, it would seem to be very difficult to install a new quadrupole doublet to this line. Between having the doublet (Fig. 1a) and no doublet (Fig. 1b), there is a small difference in the final magnification, especially for the x direction, but the main difference is the size of the beam in the y direction around the last quadrupole before the target. The large size of the beam through the last quadrupoles may lead to a larger growth than what is shown in this first order calculation. We have transported the alpha beam twice to the Neutron Ball and both times a nice small beam spot was achieved. The beamline collimators had to be rather tight to get the beam spot at the expense of the beam intensity, but less than one nanoampere of beam was needed for the experiment.