Brookhaven National Laboratory

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Gold Beams at NSRL

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Introduction

In preparation for the running of Gold beams at NSRL in the spring of 2010, we prepared two small ion chambers and a collection of scintillators to allow for calibration of the beam flux. Normal dosimetry will be difficult with the Gold beam because the maximum energy Gold that can be delivered by the Booster is 200 MeV/n, and the energy loss is so rapid with fully stripped Gold that ions can barely make it through the air in the NSRL Target Room, let alone the ion chambers and Binary Filter.

The small ion chambers and scintillators are designed to me mounted as close to the vacuum window as possible. And the components for construction were chosen to minimize the material that the Gold ions had to pass through before impacting the experiment. The Binary Filter had to be re-made, smaller and finer to allow for more accurate depth-dose scanning.

This note describes the details of the construction of the small ion chambers, scintillators, and Bragg filter. An estimate of the Gold beam energy on target is made, based on the capabilities of the Booster and the known material in the beam line.

Scintillators

The existing NSRL Fragmentation counter consists of 4 photomultiplier tubes mounted in aluminum tubes on a rigid frame that rides on the NSRL rails. A more complete description of the system can be found at NSRL-TN-05-001. A variety of scintillator configurations are glued to black phenolic standoffs attached to aluminum caps that fit onto the aluminum tubes. Aluminized Mylar film lines the inside of the aluminum tubes making for an air light guide to the PMT. The aluminum tubes are machined to allow for a 2"x2" hole allowing the beam to pass through unimpeded, except for a thin layer of Tedlar (25 microns) to ensure the tubes are light-tight.

The selection of radiators includes a frosted UVT plastic block used as a Cherenkov radiator, and plastic scintillators (BC-400) that are typically 14x14mm^2 with thicknesses of 1mm, 2mm, 5mm and 6mm. There is a “centering” counter that is 10x10mm^2 and 2mm thick, and a veto counter that has a 10mm diameter circular hole in the middle of a 20x20mm^2 2mm thick counter. For Gold ions, we made new 1mm thick counters to count ions with minimal energy losses. We have a small scintillator cube, 2x2x2mm^3 to measure the total flux delivered during experiments. The small size was chosen based on the expectation of 10^7 Gold ions per square cm during experiments, and the rate capabilities of the PMT. The small cube is mounted on a 10mm diameter 8-stage PMT (Hamamatsu H3164-10) via an 8" straw with an adjustable iris to close down the light output. The LET of Gold ions should be more than 9 times that of Iron. However the scintillator is far into saturation at those values of LET, so we expect less than 3 times the total light output.

In addition to the dE/dx counters, we have a thick (BC-408) scintillator block 4"x6" in size and 8.25" long mounted on a 5" PMT. This is used for total energy measurement; calorimetry of stopping particles. It is thick enough to completely contain a ~180 MeV proton shower.

With this combination of thin counters for beam development, small counters for dosimetry based on ion counting, and thick counters for calorimetry, we will be able to give a complete characterization of the Gold beam in the NSRL Target Room.

Construction of small ion chambers:

There are two small ion chambers. The first was constructed as part of the Stack, for doing single shot Bragg peak measurements, and is known as "Chamber Zero". It has a 6"x6" Lucite frame with inner cut-out that is 4"x4", with 0.5" thick sides. The windows are Kapton, 5 mils (127 microns) thick. The Kapton has been sprayed with conductive spray paint. The paint is predominantly nickel in an acrylic binder. The thickness of the paint layer is ~2 mils (50 microns). The total thickness of the paint was measured to be 7.8±1.0 mg/cm^2. Chamber Zero was constructed with conductive paint on both sides of the Kapton foils.

Both of the chambers operate in air at ambient pressure and temperature.

Table 1: Material description of the "Chamber Zero" Ion Chamber

Material Name	**Thickness (microns)**	**Mass in beam (mg/cm^2)**	**Composition, by weight (%)**
Lucite (frame)	12700	0	0
Conductive paint	50	7.8	Ni(<100%)
Kapton (upstream window)	127	18.0	H(2.6), C(69.1), N(7.3), O(20.9)
Conductive paint	50	7.8	Ni(<100%)
Air gap	25400	3.05	N(80), O(20)
Conductive paint	50	7.8	Ni(<100%)
Kapton (downstream window)	127	18.0	H(2.6), C(69.1), N(7.3), O(20.9)
Conductive paint	50	7.8	Ni(<100%)
Lucite (frame)	12700	0	0
Total		**70.2**	

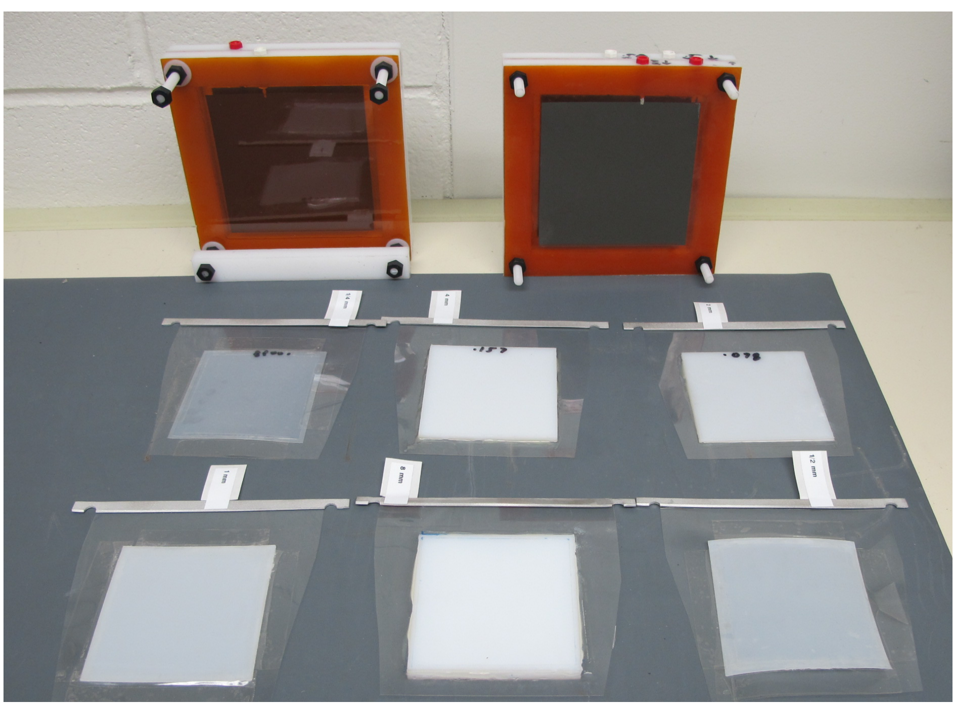


Figure 1: Chamber One (left) and Chamber Zero (right) with the selection of degrader slabs in front.

Chamber One differs from Chamber Zero in that the Kapton foils are thinner, only 3 mils (76 microns) and are painted on the inside surface only. For this reason Chamber One has only a single HV connector (red) and Signal connector (white) on top, whereas Chamber Zero has two of each. Chamber One also has extra long nylon threaded rods used to keep the Lucite frame together. The rods are used to hang the degrader slabs when performing Bragg peak scans. The lower rods extend with a foot to give support when the slabs are being hung.

As can be seen in Figure 1, Chamber Zero shows the darkened and roughened conductive paint surface on the outside of the Kapton foil. The same paint covers the inside of the foil as well. Front and back foils are identical, so that chamber can operate with either side facing the beam.

Table 2: Material description of the "Chamber One" Ion Chamber

Material Name	**Thickness (microns)**	**Mass in beam (mg/cm^2)**	**Composition, by weight (%)**
Lucite (frame)	12700	0	0
Kapton (upstream window)	76	10.8	H(2.6), C(69.1), N(7.3), O(20.9)
Conductive paint	50	7.8	Ni(<100%)
Air gap	25400	3.05	N(80), O(20)
Conductive paint	50	7.8	Ni(<100%)
Kapton (downstream window)	76	10.8	H(2.6), C(69.1), N(7.3), O(20.9)
Lucite (frame)	12700	0	0
Total		**40.2**	

Degrader

Also shown in Figure 1 are the selection of degrader slabs. The degraders come in thicknesses in binary steps from 8mm down to $^1/_8$ mm. The slabs were mounted in a thin plastic sheet that is attached to an aluminum bar that can be hung from the nylon threaded rods that protrude from the Lucite frame of the chamber. The aluminum rods are notched to give good alignment with the beam. The plastic sheets are tapered to allow the degraders to be slid easily into place from above. Each degrader sheet is labeled with its thickness, in mm.

The degrader is fabricated out of sheets of High Density Polyethylene (HDPE) with a density of $\rho = 0.92$ g/cm^2. They are ~$3^1/_8$" square, sized to be slightly larger than the $7x7cm^2$ beam we expect to use. The 8mm slab was machined down from thicker stock, and still bears some machining marks giving a slightly irregular surface. This will be sanded down to make for a more uniform thickness. The 4mm, 2mm, and 1mm are from stock with smooth surfaces and good uniformity of thickness. The ½ mm and ¼ mm were also machined down from thicker stock. We are purchasing some thin polyethylene sheeting, 1 mil (25 microns) and 4 mils (100 micron) thick. We plan to use this material to build up degraders of 125, 250, and 500 microns in thickness. This sheeting is Low Density Polyethylene, $\rho = 0.92$ g/cm^2.

Table 3: Measured thicknesses of degrader slabs

Nominal thickness (microns)	Measured thickness	Variation	Thickness (mg/cm^2)
125			
250	219	9	20.0
500	485	11	44.2
1000	1015	18	92.6
2000	2014	14	183.7
4000	4044	11	369
8000	8045	21	734

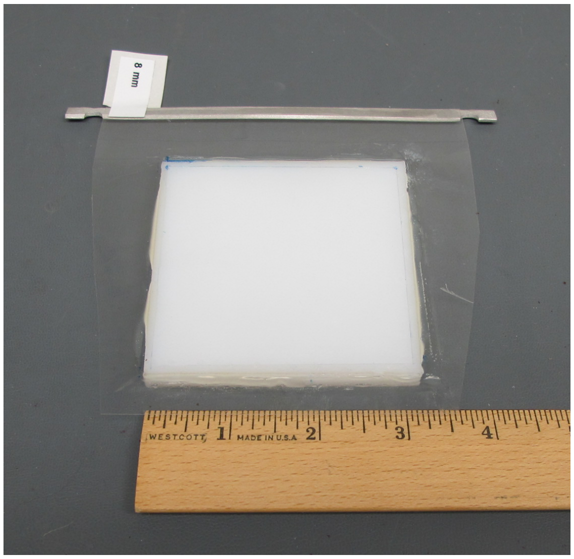


Figure 2: Degrader for the Chamber One Bragg Peak measurements

Beam Energy

The maximum beam energy that can be obtained for a gold beam is determined by the Booster RF. Using Au^{31+} in the Booster (the same charge state that RHIC uses) allows for 204.17 MeV/n when using the sixth harmonic of the RF cavities operating at 5.1 MHz. This requires the Booster main magnet current to be 5000 A, corresponding to a magnetic rigidity of 15.8 Tm. At this rigidity it may be possible to achieve a higher Gold beam energy by using the third harmonic of the RF operating at 2.7852401 MHz. This would give a maximum Gold beam kinetic energy of 261.56 MeV/n extracted from the Booster. Currently it is not anticipated that we will have the manpower to switch from the sixth harmonic (normal Booster operations) to the third harmonic. The last time this was attempted, in order to run deuterons into RHIC in 2008, tuning up took several weeks of dedicated RF work.

With that in mind, we can expect to be extracting 204 MeV/n Gold ions this year. The Gold beam loses energy as it passes through the stripping foil used to extract the beam form the Booster. It also loses energy in the vacuum window at the end of the r-line before entering the NSRL Target Room. I have used the code LET to estimate these energy losses, as well as the losses in the ion chamber which may be used upstream of any Device Under Test (DUT).

The thinnest stripping foil is 2 mil (50 micron) Copper. The spreadsheet GoldBeam.xlsx contains these calculations. Using a density for Copper of 8.96 g/cm^3, and a thickness of 50.8 microns, the average LET(Cu) is 18.39 GeV cm^2/g at 202 MeV/n for a total energy loss of 837 MeV/ion or 4.24 MeV/n giving the Gold beam energy of 199.9 MeV/n exiting the stripping foil. Applying the same treatment for the 0.020 (508 micron) thick Aluminum vacuum window, and an LET(Al) of 22.08 GeV cm^2/g at 190 MeV/n

Table 4: Energy loss calculation for material in the beam upstream of the DUT.

Material	**Density (g/cm^3)**	**Thickness (microns)**	**<LET> (GeV cm^2/g)**	**Energy In (MeV/n)**	**Energy Out (MeV/n)**
Copper foil	8.96	50.8	18.39	204.17	199.92
Aluminum	2.70	508.0	22.08	199.92	180.35
Kapton (2 layers)	1.43	152.4	28.68	180.35	177.18
Nickel (2 layers)	8.91	17.4*	20.83	177.18	175.54
Air	$1.2x10^{-3}$	~1 meter	25.86	175.54	~160

*Note: The thickness of the nickel is measured at 7.75 mg/cm2, so this is the "effective thickness". The measured thickness of the Nickel paint layer is ~50 microns, but this includes acrylic binder.

Table 4 shows the calculations performed for determining the sum of the energy losses in the Gold beam prior to reaching the DUT. In the calculations I have added the effect of approximately 1 meter of air. The losses in air are comparable to the aluminum vacuum window, illustrating the need to mount the experiment as close to the vacuum window as possible.

Summary and Future Plans

This is a living document. As we measure the properties of the Gold beam, the results will be added to this note. Feedback is always welcome.

Here are some extra images of the new ion chambers.

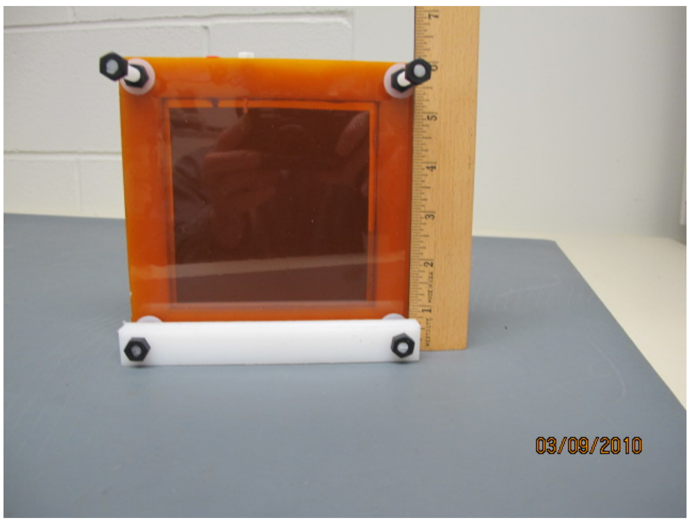


Figure 3: View of Chamber One from the Upstream side.

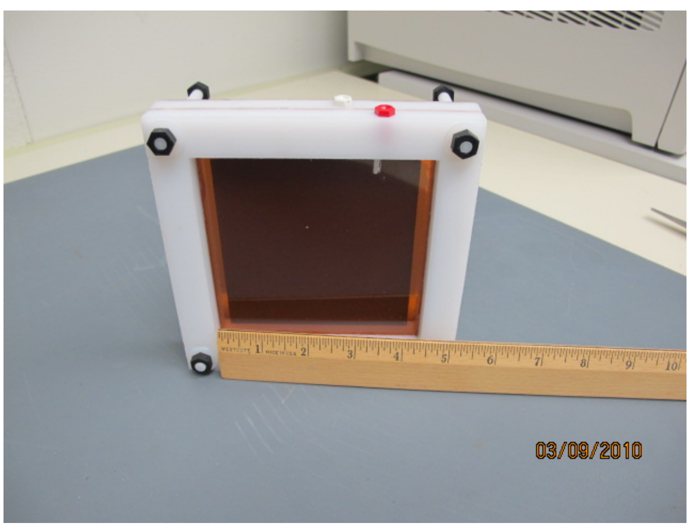
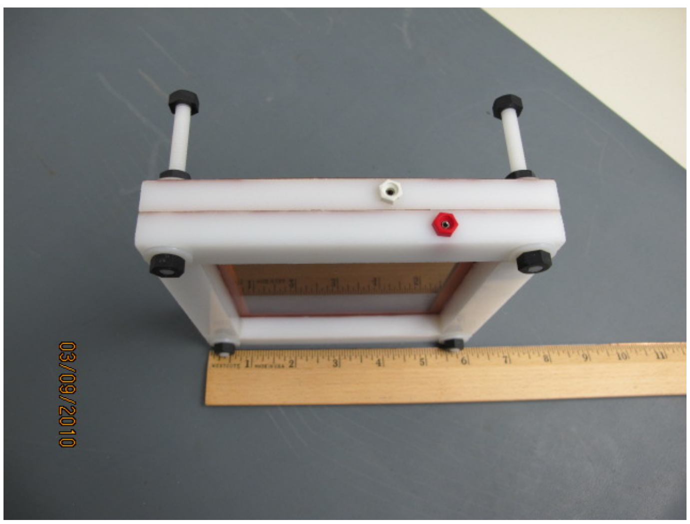


Figure 4: View of Chamber One from the Downstream side.

Figure 5: Side View of Chamber One, Beam side to the right.



Figre 6: Top View of Chamber One showing the HV (red) and Signal connectors.

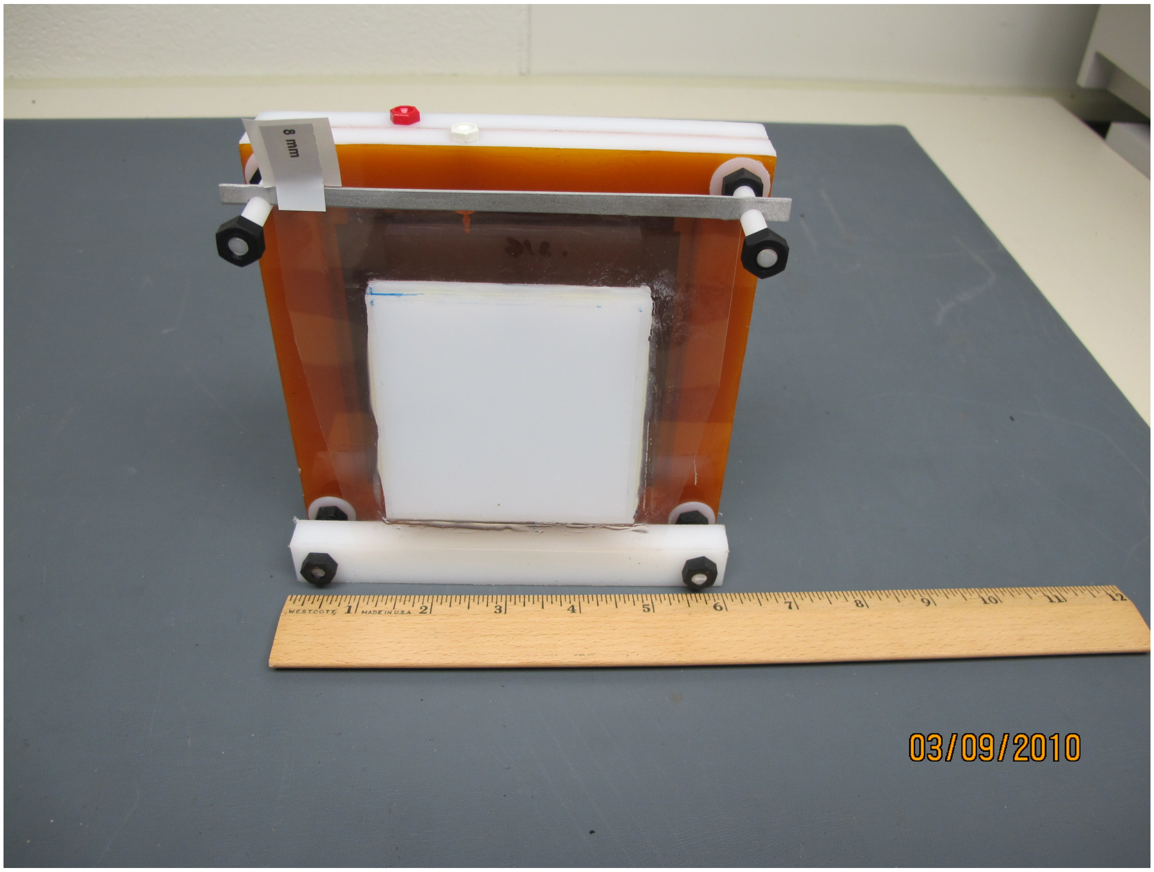


Figure 7: Chamber One with the 8mm degrader in place.