

PROTON-INDUCED GAIN IN A PORTABLE FARADAY CUP

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ABSTRACT

A Faraday Cup (FC) is being designed to calibrate therapy-range proton accelerators, i.e., 50 to 250 MeV. The FC must be accurate to 1% as well as portable, hence vacuum-less and low mass. The FC is a copper cylinder coated with kapton insulation and silver ground. The Monte Carlo method (MCNP6 and Geant4) was used to simulate the radiation cascade and predict gain versus height (H), diameter (D) and insulator thickness (K). H and D were mostly functions of proton range. Increasing either increases mass, reducing either increases proton leakage, hence decreases accuracy. Kapton functions to capture backscattered electrons, the function of the fields in a standard FC. Greater K increases capture but increases secondary electron in-leakage. Determining optimal K was made difficult by the lack of low energy proton, electron cross-sections. A secondary electron model was programmed with the SDEF command for the MCNP model based on recently published cross-section approximations. This secondary electron source method was benchmarked against a series of experimental measurements (by others) of protons on copper and on water. Three FCs were built, each with different values of K. They are currently being tested.

Key Words: Monte Carlo, Geant, MCNP, Faraday Cup

1 INTRODUCTION

In modern day radiation therapy, protons have become one increasingly popular method of treating cancer near critical structures, with many dosimetric advantages of charged particle interactions (References). A novel portable vacuumless Faraday Cup measuring device was designed to calibrate proton therapy facilities, in energies ranging from 50 to 250 MeV. The detector is constructed of a copper cylinder, coated with kapton insulation and grounded with silver (Reference). Monte Carlo computational simulations in MCNP6 (Reference) and GEANT4 (Referenced) were performed to evaluate radiation cascade effects and predict signal versus height, diameter and insulator thickness characteristics.

Preliminary results indicated that increasing the mass of the Faraday Cup's conductor reduced proton leakage but increased the system accuracy. While a greater kapton thickness increases

Table I. Measured Gain from HIT Beam Stops

Energy (MeV)	S59	S100	S200
70.03	0.9750	0.9385	0.9350
100.46	0.9850	0.9500	0.9475
130.52	0.9925	0.9580	0.9525
160.09	1.0000	0.9635	0.9590
190.48	1.0075	0.9715	0.9650
221.06	1.0125	0.9800	0.9770

the capture of primary and secondary electrons, it also increases secondary electron leakage. Additionally, determining the optimal kapton thickness has been made difficult by the lack of low energy proton and electron cross-sections in current Monte Carlo based simulation programs (Reference). A comprehensive secondary electron evaluation of the kapton was performed and benchmarked against a series of experimental measurements by Borovsky et al.¹ and J. Gordon et al (Reference).

In conjunction with the computational calculations, three (3) prototype Faraday Cup measuring devices were constructed by Pyramid Technical Consultants, Inc. (Waltham, Ma), each having a different thickness of kapton. The units were tested in Germany to determine accuracy of the new design.

2 EXPERIMENTAL BACKGROUND

2.1 Heidelberg Institute of Technology

Table ??

2.2 G014

2.3 BO88

3 SIMULATION RESULTS

3.1 MCNP6

(LATER: from ADH)

3.2 Geant4

Geant4 is an object-oriented C++ toolkit for developing applications which simulate the passage of particles through matter. Libraries of cross-section tables, elemental/molecular properties, and pre-defined stochastic physics processes allow for rapid, intuitive invocation of necessary system

setup commands. Once initialized, “Manager” modules cooperate to organize and accumulate dynamic information which is organized in the following chronology:

1. The **DetectorConstruction** class is called to verify, store and lock the predefined geometry.
2. The **G4UIManager** initializes upon successful compilation and execution of the *main()* routine. If a visualizer is selected, **G4VisManager** is also invoked.
3. The user issues the command to execute a macro file of *runs*; each run is characterized by the defined beam particle type, the beam energy, and the number of *events*, or number of such isolated simulations. If multithreading is available, **G4RunManager** allocates the events to the available worker threads on a rolling basis.
4. For each event, the simulation of the *primary* (beam) particle proceeds, constructing a new *track*, or well-defined trajectory for every particle not at rest.
5. The behavior of every track is determined dynamically, with each *step*, or stochastically occurring physical process (collisions, absorptions, etc) of the particle in some medium.

3.2.1 UserAction methods

A useful feature of Geant4 is the ability to create user-defined actions (methods) throughout each module, which allows for a very fine-tuned analysis throughout the entire simulation. The following summarizes the custom details and methods for this application

- **DetectorConstruction.cc:** A copper cylinder of radius 3 cm and height 10 cm is covered in Kapton film of varying thicknesses: 59 μm , 100 μm and 200 μm . The film thickness is iterated by a function which is called before the command macro is examined. The top face of the copper lies in the $z = 0$ plane, with the beam approach the system from beneath.
- **SteppingAction.cc:** [For every step,] immediately checks if the step is the finale of a track. If so, the particle’s vertex (original position) and destination volume and coordinates are found, and a charge signal calculation occurs. Entering/Leaving the copper gives a net signal of $\pm q$ where q is the charge of the particle. Entering/Leaving Kapton gives a relative proportionality of

$$s_{q \rightleftharpoons KA} = \pm q \times \max [r\%, z\%], \quad (1)$$

where $r\%$ is the percent distance away from the copper radially and $z\%$ is the percent distance away laterally. The signals are grouped and saved by a unique eventID number.

- **EventAction.cc:** At the end of each event, the signals are tallied, grouped, and saved by a unique runID number.
- **RunAction.cc:** At the end of each run, the average and standard deviation of the signals are acquired.

Table II. Geant4 Simulation Cylindrical Construction

Volume	Radius (mm)	Height (mm)
Copper	30	100
	Model	Thickness (μm)
Kapton1	S59	59
	S100	100
	S200	200
Silver	+Ag/KA	12
Kapton2	+Ag/KA	62

3.2.2 Experimental parameters

Table ?? summarizes the detector geometry of each run. The order of logical volume layers starting from the innermost are 1) the copper cylinder, 2) the Kapton1 film, 3) the silver paint layer, and 4) the Kapton2 film. Constructing cylindrical “layers” is as straightforward as defining a cylinder within another’s logical volume. Data were acquired as a function of impinging proton energy using the 50-250 MeV range as used in the HIT experiment. The Kapton1 thickness optimization was applied to this model both with and without the silver and secondary Kapton (+Ag/KA).

4 RESULTS

The units of signal gain are $\frac{Q_{net}}{Q_P}$, where Q_{net} is the net transfer of charge into the cup, and Q_P is the net charge of the million protons irradiating the cup. Charges entering and leaving the primary Kapton film covering the copper are subject to the linear proportion behavior defined in Eq. ?. Table ?? shows a sample output of each model in both air and vacuum, the latter to remove oversaturation of beta emissions from the air due to delta-ray production (LATER: citation needed).

5 DISCUSSION

In pursuit of the optimization of this portable Faraday Cup, we considered many variants of applicable theoretical models to corroborate with available experimental data. Fig. ?? depicts a very convincing similarity in behavior between the HIT beam stop measurements, and the simulation of the copper Faraday Cup in air without the *no* silver/Kapton layer.

Table III. Predicted Gain from High-Energy Protons using Geant4

Model	Energy (MeV)	(-Ag/KA)	(-Ag/KA) <i>in vacuo</i>	(+Ag/KA)	(+Ag/KA) <i>in vacuo</i>
S59	70.03	0.953 588	1.000 36	0.983 320	0.979 287
	100.46	0.967 417	1.000 68	0.982 263	0.979 775
	130.52	0.975 593	1.001 18	0.982 531	0.981 160
	160.09	0.981 094	1.001 77	0.983 127	0.982 672
	190.48	0.985 111	1.002 38	0.984 641	0.983 603
	221.06	0.988 151	1.003 14	0.986 131	0.985 152
	250.00	0.990 298	1.003 58	0.987 536	0.986 296
S100	70.03	0.953 827	1.000 36	0.983 731	0.979 531
	100.46	0.966 795	1.000 72	0.982 408	0.979 939
	130.52	0.975 725	1.001 21	0.982 508	0.980 993
	160.09	0.981 055	1.001 80	0.983 059	0.982 456
	190.48	0.985 189	1.002 45	0.984 910	0.983 649
	221.06	0.988 149	1.003 26	0.986 215	0.985 251
	250.00	0.990 324	1.003 49	0.987 278	0.986 103
S200	70.03	0.954 372	1.000 37	0.983 544	0.979 594
	100.46	0.966 915	1.000 68	0.982 554	0.979 769
	130.52	0.975 377	1.001 26	0.982 246	0.981 054
	160.09	0.980 998	1.001 78	0.983 405	0.982 137
	190.48	0.985 217	1.002 44	0.984 706	0.983 760
	221.06	0.988 312	1.003 20	0.986 402	0.984 905
	250.00	0.990 213	1.003 43	0.987 178	0.985 874

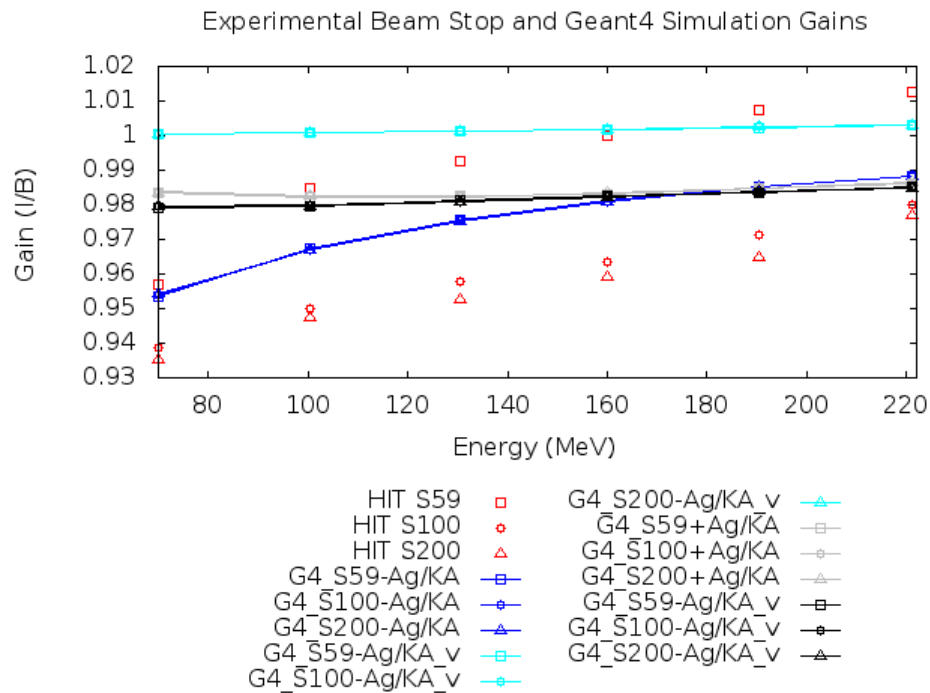


Figure 1. Comparison of Geant4 output and HIT measurement. Generated with Gnuplot.

6 CONCLUSIONS

7 ACKNOWLEDGMENTS

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APPENDIX A

Code bits?

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