*ANS MC2015 - Joint International Conference on Mathematics and Computation (M&C), Supercomputing in Nuclear Applications (SNA) and the Monte Carlo (MC) Method* · Nashville, Tennessee · April 19–23, 2015, on CD-ROM, American Nuclear Society, LaGrange Park, IL (2015)

# PROTON INDUCED GAIN IN A PORTABLE FARADAY CUP

**Shaun Marshall and Blake Currier**
Department of Physics
Worcester Polytechnic Institute
100 Institute Rd, Worcester, MA 01609

**Andrew D Hodgdon, CHP**
Radsim, LLC
584 Grove St, Newton, MA 02462
adhodgdon@radsim.org

## 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 I

## 2.2 GO14

## 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 occuring physical process (collisions, absorbtions, 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 thickenesses: 59 $\mu$m, 100 $\mu$m and 200 $\mu$m. 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

$$s_{q \rightleftharpoons KA} = \pm q \times \max\left[r_{\%}, z_{\%}\right], \tag{1}$$

  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 ($\mu$m) |
| Kapton1 | S59 | 59 |
| | S100 | 100 |
| | S200 | 200 |
| Silver | +Ag/KA | 12 |
| Kapton2 | +Ag/KA | 62 |

### 3.2.2 Experimental parameters

Table II 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. 1. Table III shows a sample output of each model in both air and vaccuum, the latter to remove oversaturation of beta emissions from the air due to delta-ray production (LATER: citation needed).

## 5 DISCUSSION

## 6 CONCLUSIONS

## 7 ACKNOWLEDGMENTS

We would like to express our sincerest gratitude to Paul Romano and Tom Sutton, who provided the template for this paper.

## APPENDIX A

Code bits?

**??**

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

| Model | Energy (MeV) | (-Ag/KA) | (-Ag/KA) *in vacuo* | (+Ag/KA) | (+Ag/KA) *in vacuo* |
|---|---|---|---|---|---|
| S59 | 70.03 | 0.953 588 | 1.000 36 | 0.983 320 | *in progress...* |
| | 100.46 | 0.967 417 | 1.000 68 | 0.982 263 | |
| | 130.52 | 0.975 593 | 1.001 18 | 0.982 531 | |
| | 160.09 | 0.981 094 | 1.001 77 | 0.983 127 | |
| | 190.48 | 0.985 111 | 1.002 38 | 0.984 641 | |
| | 221.06 | 0.988 151 | 1.003 14 | 0.986 131 | |
| | 250.00 | 0.990 298 | 1.003 58 | 0.987 536 | |
| S100 | 70.03 | 0.953 827 | 1.000 36 | 0.983 731 | |
| | 100.46 | 0.966 795 | 1.000 72 | 0.982 408 | |
| | 130.52 | 0.975 725 | 1.001 21 | 0.982 508 | |
| | 160.09 | 0.981 055 | 1.001 80 | 0.983 059 | |
| | 190.48 | 0.985 189 | 1.002 45 | 0.984 910 | |
| | 221.06 | 0.988 149 | 1.003 26 | 0.986 215 | |
| | 250.00 | 0.990 324 | 1.003 49 | 0.987 278 | |
| S200 | 70.03 | 0.954 372 | 1.000 37 | 0.983 544 | |
| | 100.46 | 0.966 915 | 1.000 68 | 0.982 554 | |
| | 130.52 | 0.975 377 | 1.001 26 | 0.982 246 | |
| | 160.09 | 0.980 998 | 1.001 78 | 0.983 405 | |
| | 190.48 | 0.985 217 | 1.002 44 | 0.984 706 | |
| | 221.06 | 0.988 312 | 1.003 20 | 0.986 402 | |
| | 250.00 | 0.990 213 | 1.003 43 | 0.987 178 | |