After the beam dropped Monday morning, April 9, 2007, the Faraday cup was installed as shown in Fig. 1 left.

On the following Friday, April 13, 2007, beams returned from about 10 am to 4 pm. The signal from the Faraday cup looked very odd. It did not have one single peak, but wiggled around for a long time (Fig. 1 right). Eric Colby (E163) set up a measurement: The signal was split up: One part (green line in Fig. 1 right) was fed directly into the oscilloscope, the other part delayed and split again. One part was fed directly into the oscilloscope (blue line), the other into the box car analyzer (Stanford Research Systems SR250). The output of the box car analyzer was the magenta line in Fig. 1 right. The yellow line on the oscilloscope indicated the gate of 150 ns, applied to all three signals, also applied in the box car analyzer. The oscilloscope was able to then measure the average voltages (of 32 pulses) within the (yellow) gate for the signal itself, the time before the signal, and the signal coming out of the box car analyzer. We took several such measurements for several currents.

The following week, after Dieter Walz talked to Bob Simmons’ supervisor, we received help from Bob. He looked at our measurements, especially at the photograph of the signal (Fig. 1 right), went to ESA to take some measurements of the signal, and concluded that there was so much noise on the cable and too many reflections so that the measurements we took on that Friday could not be interpreted. He said that instead of measuring the voltage of the signal, we better measure the current coming out. The cable, he said, is sufficiently good for such a DC measurement. Since according to Dieter the Faraday
cup captures practically all of the current, the following two main challenges remained: Reducing noise pickup on the cable (which he said can come from any number of sources, and may even be caused by just people moving around in the area), and setting up a circuit to measure a current that doesn’t flow continuously, but only in one pulse once a second.

Bob said that the cable itself has no losses, i.e., is insulated. However, he measured initially a current of about 9 pA (of course and even, without any beams). Since he didn’t trust the G10 sheet, on which the Faraday cup was sitting, he insulated with the help of Carl, an ESA technician, the Faraday cup with four Teflon blocks (visible in Fig. 2 left), and the current dropped to 5 pA. Carl then built a shielding around the Faraday cup (Fig. 2 right), and the current went down to ~1 pA, which is low enough even for Bob. This shielding is connected to ground at ESA, just as the outer part of the cable that carries the signal up.

Figure 2: Left: Faraday cup inside cover sitting on Teflon blocks and G10 plate; right: cover over Faraday Cup

To measure the current, Bob set up a little system and tested it in his lab. He uses an Agilent 34401 (formerly called HP 34401) multimeter to measure the voltage drop over a 10 MΩ resistor of the current buffered with a 35 µF capacitor. The capacitance of the Faraday cup was measured to be 125 pF and is therefore negligible. The time constant of this circuit is then 350 s. After about 1800 s (half an hour) of charging up, the voltage will be stable, meaning the charge lost through the resistor within one second is equal to the charge added by the beam. To do the measurement we will not need perfect beams all the time during the charging. Just once the circuit is stable, we measure the average beam current with the toroid and the average voltage. This average voltage can be measured with the multimeter accurately to about 0.1%.
Bob tried out such a measurement in the lab and is satisfied with the setup. To easily correlate the beam measurements and the multimeter readings, Bob suggests to read out the multimeter via GP-IB at the same time as the toroid readings and write both values together into one file or database. This is something he suggests us to help him set up.

Soon the Faraday cup will need to be moved aside to allow installation of the beam pipe for the July ILC experiments. Once those experiments are over, the Faraday cup will be moved back into the beam line, Bob will check the cable again and if all is still good, the system is ready for the measurement. Since Bob has no vacation planned for this summer, he said he would be around to assist us.

Calculations on the measurement

If a certain voltage $V_0$ is on a capacitor with capacitance $C$ at time $t = 0$, which over time loses its charge through a resistor with resistance $R$, the current can be described versus time by

$$I(t) = \frac{V_0}{R} e^{-\frac{t}{RC}}.$$

Within time $t'$, the capacitor loses the charge

$$Q = \int_0^{t'} I(t)dt = \frac{V_0}{R} \int_0^{t'} e^{-\frac{t}{RC}} dt = \frac{V_0}{R} RC \left(1 - e^{-\frac{t'}{RC}}\right) = V_0 C \left(1 - e^{-\frac{t'}{RC}}\right).$$

When the circuit is stable, this charge $Q$ is the same as the charge delivered by the beam. For our case, $C = 35 \mu F$, $R = 10 M \Omega$, $t' = 1 s$. For our nominal beam of $Q_{nominal} = 4 \times 10^9 e^-/s = 4 \times 10^9 \times 1.6 \times 10^{-19} = 0.64 nC$, we expect to measure a voltage $V_{nom}$ of

$$V_{nom} = \frac{Q_{nom}}{C \left(1 - e^{-\frac{t'}{RC}}\right)} = \frac{0.64 nC}{35 \mu F \left(1 - e^{-\frac{1}{35 \mu F 10 M \Omega}}\right)} = 6.41 mV.$$

Within each second, the voltage drops (varies) by $1 - e^{-\frac{1}{350}} = 0.3\%$, which is much lower than our goal of 5\%.