ELECTRON CLOUD MEASUREMENTS USING A SHIELDED PICKUP IN A QUADRUPOLE AT CESRTA*

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Abstract

We have recently constructed a shielded pickup in a quadrupole magnet for time-resolved detection of electron cloud. Cloud electrons pass into the detector through an array of small holes in the wall of the beam-pipe that shield the collecting electrode from the direct beam signal. There are two collectors, each aligned on a pole face: one near the longitudinal center of the quadrupole, the other in the fringe field. The signals from the collectors are recorded with a digital oscilloscope. We present a summary of the design, construction and commissioning of this device, as well as initial beam measurements. This work was performed at the Cornell Electron Storage Ring which has been reconfigured as a test accelerator (CESRTA) with positron or electron beam energies ranging from 2 GeV to 5 GeV.

INTRODUCTION

Investigation of electron cloud (EC) growth and decay is an important part of the CESRTA program. Shielded pickups (SPU) in two field free regions have been in use since 2009 and significant progress has been made in connecting simulations with data from these detectors [1]. Parameters used in simulation of the electron cloud are tuned to match the data, including modeling of the detectors . The introduction of dipole or quadrupole fields makes this connection more difficult, mostly in accurate modeling of the detectors rather than modeling of the electron cloud. There was an interest in constructing a simple device that would give time-resolved information about the EC density in a quadrupole field since there is some evidence and modeling that electron cloud could be trapped there [2, 3, 4].

The quadrupole shielded pickup (QSPU) is based on the successful design of the SPU. An important part of that design is the array of holes that connect the vacuum space to the detector. The 1:3 diameter to depth ratio of the holes provides significant attenuation of the direct beam signal [5]. This is important, since a typical direct beam signal will be tens of volts, while the largest (unamplified) electron cloud signals that we have seen are tens of millivolts. Even with this attenuation, some direct beam signal is visible in the detector output.

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QSPU DETECTOR

The QSPU has two collectors, both aligned with a pole face as shown in Fig. 1: one in the longitudinal center of the quadrupole , the other is located in the fringe field. This paper contains data only from the centered detector.

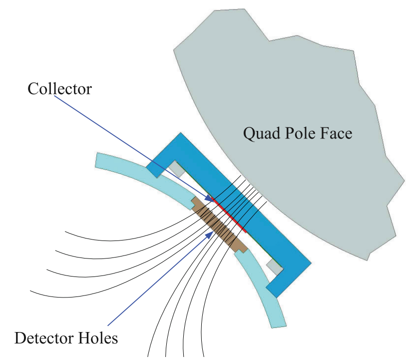

Figure 1: The QSPU detector is centered on one of the quadrupole pole faces. The rectangular collector is 10 x 100 mm copper on kapton centered longitudinally along the pole face behind an array of holes in the beam-pipe wall.

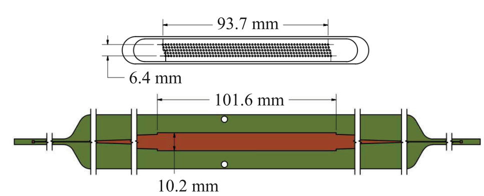

Figure 2: The 5 x 60 array of 0.79 mm diameter holes allow cloud electrons in the beam-pipe to enter the detector. The wall thickness is 2.4 mm. Electrons are collected on the copper flex circuit and the signal routed to feed-throughs at either end of the quadrupole chamber (not shown).

In the QSPU, the collector is an approximately 10 x 100 mm copper rectangle on a 0.13 mm thick kapton flex circuit with a ground plane shown in Fig. 2. Tapered striplines on the flex circuit couple the signal to SMA vacuum feed-throughs approximately 1 m apart at either end of the quadrupole chamber. For comparison, the collector in the field free SPU, is a 1.7 cm diameter button of the type used for beam position monitors.

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The collectors for both the QSPU and SPU and biased at +50 V to ensure the capture of incident electron current. The collector signals are AC coupled to a cable that is routed to two cascaded 20 dB amplifiers (ZFL-500 from Mini-Circuits) that give a total voltage gain of 100. The signals are digitized with an oscilloscope that uses a timing system trigger and provides signal averaging.

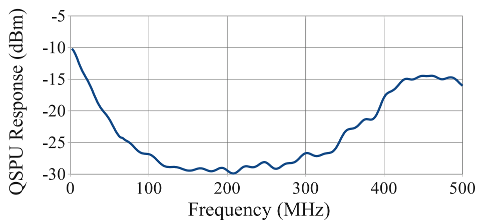

Figure 3: The response of the collector flex circuit was measured with a spectrum analyzer. There is a low-pass feature due to the collector capacitance with a -3 dB point at about 13 MHz and a high-pass feature above 300 MHz.

The QSPU collector has fairly high capacitance due to its construction on the thin kapton flex circuit. As shown in Fig. 3, it acts as a low-pass filter with a -3 dB rolloff at about 13 MHz. At frequencies above 300 MHz, the circuit has a high-pass characteristic that results in significant direct beam signal from the detector.

BEAM SIGNALS

Witness bunch measurements with the field free SPU have provided useful comparisons to simulations of EC density build-up using ECLOUD [1]. Most of these measurements have been carried out with pairs of bunches, where (roughly speaking) the first bunch generates a cloud and the second bunch accelerates this cloud into the detector. The revolution period at CESRTA is 2562 ns which is long compare to the expected EC decay time of about 100 ns. So with short trains of bunches, the EC density is taken to be zero with the arrival of the first bunch. The signal from the first bunch is dominated by photo-electrons and is much smaller than that of the second bunch, where electrons near the beam are accelerated to hundreds of electron volts into the detector.

Although the array of holes in the QSPU provides significant attenuation of the direct beam signal, it is still visible in the detector output. Figure 4 shows the output from a 20-bunch train of positrons with 14 ns spacing and a bunch population of 1.36×10^{11} (8.5 mA). The raw data is digitally filtered by convolving it with a 12 ns impulse response.

Figure 5 shows an overlay of witness bunch measurements with a field free SPU where a 10-bunch train of 5.3 GeV positrons is followed by a witness bunch with delays from 28 to 140 ns. All of the bunches have the same population of 1.36×10^{11} positrons/bunch. As witness bunches are placed at various distances after the bunch train, they map the decay of the cloud that the train produced. Also, the signal from the first bunch of the train is quite small, about 0.2 V or less, while the signal from the second bunch is roughly 1.7 V. This is consistent with EC density decaying to zero in the 2.5 μs beam revolution time.

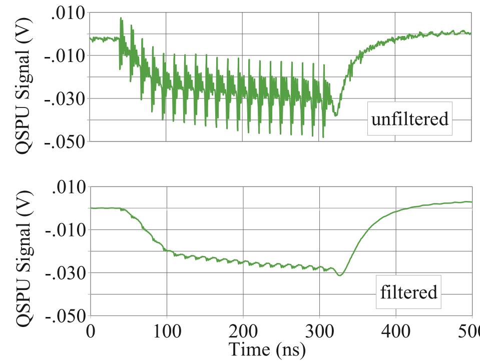

Figure 4: The signal from the QSPU with a 20-bunch train of 5.3 GeV positrons at 1.36×10^{11} positrons/bunch shows significant direct beam signal (upper). The data is filtered by convolving with a 12 ns impulse response (lower).

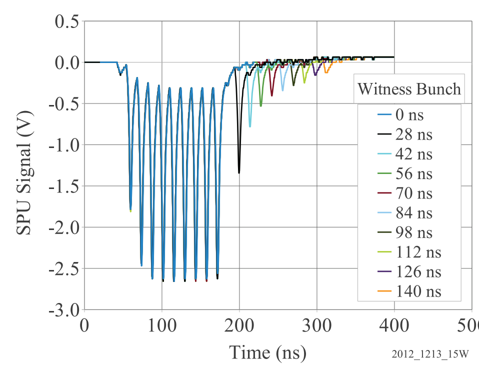

Figure 5: Signals from a field free SPU are overlaid, for a 10-bunch train that is followed by witness bunches at various spacings. The decreasing signals from the witness bunches show the decay of the cloud.

A similar measurement was made with the QSPU, where a 10-bunch train of 5.3 GeV positrons was followed by witness bunches from 28 to 84 ns. All bunches are at 8 mA (1.28×10^{11} positrons/bunch) and a 6 ns filter was applied to the data before plotting. The plots overlaid in Fig. 6 show a decrease in signal amplitude that is on a time scale similar to that of the field free SPU. An expanded detail in Fig. 7 shows the time delay between the direct beam signal and the peak in collection of electrons. This delay of about 18 ns is considerably longer than that observed in the field free region. The beam-pipe geometries are somewhat different – the field free SPU is in oval pipe with a height of 5 cm, whereas the quadrupole SPU is in round pipe that is 9 cm diameter. But it is likely that the presence of the

7.4 T/m field is responsible for most of the time delay since the cloud electrons have more complicated trajectories.

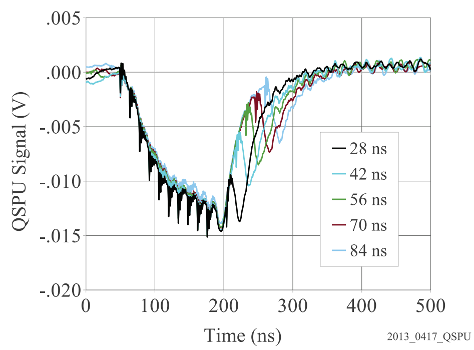

Figure 6: With the QSPU in a 7.4 T/m field, a 10-bunch train of positrons spaced by 14 ns is followed by a single bunch spaced at intervals from 28 to 84 ns. An overlay of these measurements shows a decrease in the witness bunch signal.

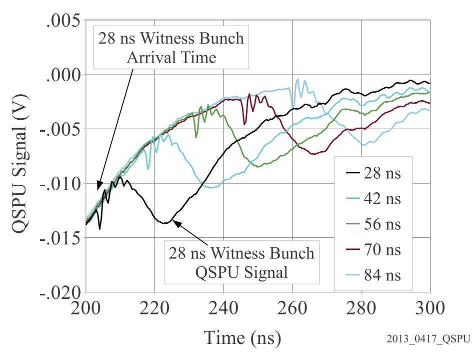

Figure 7: In this detail of the QSPU witness bunch signals, the direct beam signal is seen about 18 ns before the arrival of electrons in the detector.

Data was also taken with both the SPU and QSPU with a 20-bunch train of 14 ns spaced 5.3 GeV positrons. The bunch currents ranged from 4.3 to 10.4 mA/bunch which corresponds to 0.69×10^{11} to 1.67×10^{11} positrons/bunch. The overall shape of the signal from the field free SPU is an amplitude that increases quickly, then reaches an equilibrium value as can be seen in Fig. 8. The shape is similar over a range of bunch charges.

The overall shape of the QSPU signal with the same 20-bunch train (Fig. 9) changes with bunch charge. At higher bunch charge the signal never reaches an equilibrium value. There are also two slopes to the data: a rapid rise at the beginning followed by a more gradual increase out to the end of the bunch train.

CONCLUSIONS

We have constructed a device to make time-resolved measurements of electron cloud in a quadrupole. Witness bunch measurements after a train of ten bunches in the 7.4 T/m quadrupole field gives an electron cloud decay time that is similar to that obtained in a field free region. A 20-bunch train has a signal with a somewhat different character in the two types of detectors. The signal in the quadrupole does not reach equilibrium at the highest bunch currents. Further experiments and simulations are needed to better understand these initial measurements.

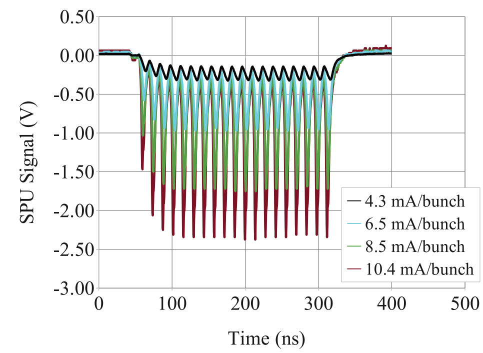

Figure 8: The SPU signal with a 20-bunch train of positrons at 5.3 GeV reaches an equilibrium value early in the train independent of bunch current.

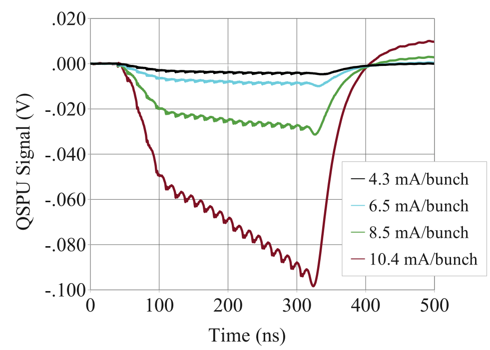

Figure 9: The QSPU signal with a 20-bunch train never reaches an equilibrium value and appears to have two slopes at the highest bunch charge of 10.4 mA/bunch (1.67×10^{11} positrons/bunch).

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