# Calibration of the Recycler Transverse Schottky Detectors

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1. Introduction

The Recycler Transverse Schottky Detectors are of the split (oval) beam pipe variety which are coupled to a transformer. The primary inductance of the transformer forms a resonant circuit with the detector capacitance, and the signals are matched to 50 $\Omega$ loads via the tunable transformer.

The detector output voltage for incoherent Schottky signals is

$$V = X_{rms} e f_0 \sqrt{N} S,$$

where $X_{rms}$ is the transverse RMS of the beam size, $e =$ unit charge of the electron, $f_0$ is the beam revolution frequency, $N$ is the number of particles, and $S$ is the detector sensitivity. In other words, the integrated output power of a Schottky detector can be used to measure the RMS transverse beam size. In application, this quantity is converted to the 95% normalized emittance with the following equation

$$\varepsilon = \frac{6\pi X_{rms}^2 \beta\gamma}{\beta_{lattice}},$$

where $\beta\gamma$ are associated with the Lorentz boost of the beam, while $\beta_{lattice}$ is the lattice function at the place where the beam size could be measured, if a beam with a Gaussian profile is assumed ($X_{rms} = \sigma$).

One of the most direct methods for calibrating the transverse Schottky detectors is to measure the RMS beam size by scraping away the beam. To make a precise measurement of the beam size in this way we need well calibrated mechanical scrapers for a good knowledge of their positions; sensitive loss monitors for the starting point of beam loss, and a sensitive longitudinal Schottky detector for the extinction point of the beam. To calculate the RMS beam size from this, we recall that

$$X_{rms}^2 = \frac{\int_{x_i}^{x_f} \left(x - x_f\right)^2 f(x)\,dx}{\int_{x_i}^{x_f} f(x)\,dx},$$

where $x_i$ and $x_f$ denote the initial and final positions where beam loss occurs and ends (extinction point), $f(x)$ is the x-projection of the x, x' phase space.. $I(x)$, the beam current as a function of bump displacement, is related to $f(x)$ simply as

$$f(x) \equiv \frac{dI(x)}{dx},$$

since the beam loss through a scraper range is simply the integral of $f(x)$ in $x$ covering the range.

In practice, we scrape the beam away with a calibrated mechanical scraper while recording the beam current and the positions of the scraper as sets of points. The above integral can then be approximated with

$$X_{rms}^2 \approx \frac{\sum_j^f (x_j - x_f)^2 \frac{\Delta I_j}{\Delta x_j} \Delta x_j}{\sum_j^f \Delta I_j} = \frac{\sum_j^f (x_j - x_f)^2 \Delta I_j}{I_{initial}}.$$

This quantity is then easy to compute with, for example, an Excel spreadsheet program.

## 2. Data and Analysis

The following data sets were taken when the Main Injector ramping was halted. The 29 and 2B cycles in the Main Injector have the effect of creating beam loss in both the Recycler and the Main Injector, making the determination of the initial beam loss positions difficult to identify. Here the beam was injected and pre-scraped with a time bump in the Recycler, and then a slow scrape was made with the mechanical scrapers. Figs. 1 and 2 show the beam current, beam loss and zero span longitudinal Schottky spectrum video output versus horizontal and vertical scrapers' positions. It can be seen that the extent of the beam can be determined rather unambiguously with the loss monitor on one side and the longitudinal Schottky detector on the other (extinction point). The data points obtained during the scrapes were sent via an ACNET program (P141) and RMS calculations of the beam sizes outlined above were performed using the Excel program. The preliminary results seem to indicate that the horizontal emittance is well calibrated assuming the Gaussian shapes of the beam. The calculated vertical RMS beam size indicates that the vertical emittance readout is only about 75% of actual assuming a Gaussian distribution of the beam. The change in calibration can be easily made on ACNET R45 (Schottky VSA), however there seems to be uncertainties in the scaling of the mechanical scrapers' movement. Work is being carried out to finalize this scaling issue during a current shutdown, and the new calibration will be made subsequently.

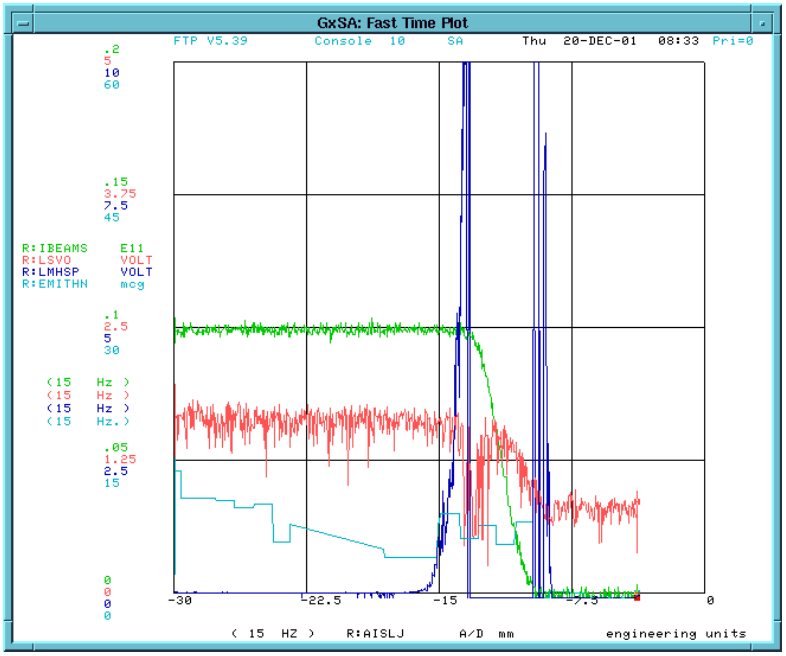


Figure 1: the beam current (green trace), beam loss (purple trace) and longitudinal Schottky video output (red trace) versus the scraper position, horizontal plane.

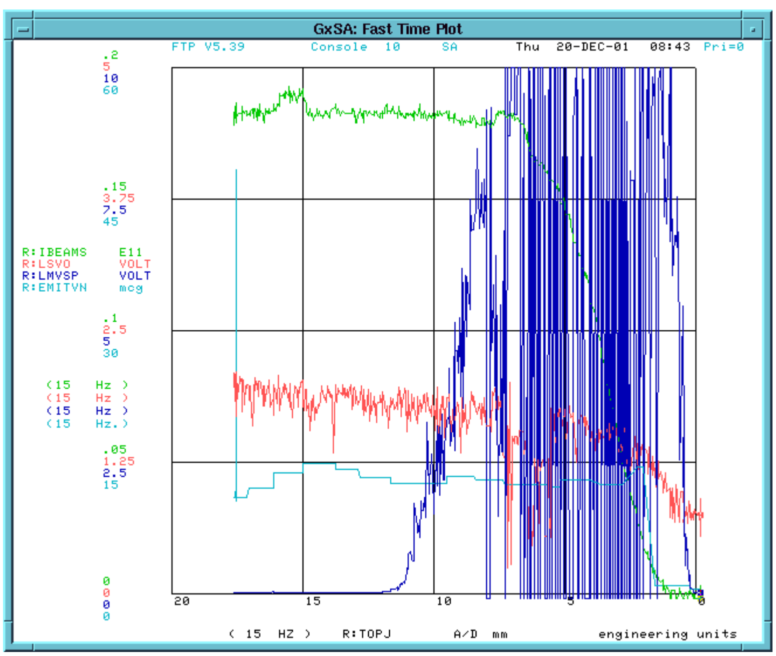


Figure 2: the beam current (green trace), beam loss (purple trace) and longitudinal Schottky video output (red trace) versus the scraper position, vertical plane.