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Collider Accelerator Department

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1 Introduction

We were trying to address the question whether or not the Pin Diodes, currently installed approximately 1 meter downstream of the RHIC primary collimators, are suitable to monitor a recombination signal from the future RHIC low energy cooling section. A maximized recombination signal, with the Au^{+78} ions being lost on the collimator, will indicate optimal Au-electron beam overlap as well as velocity matching of the electron beam in the cooling section.

We took data during two APEX sessions: APEX I on May 20^{th} 2015 (fill 19082) from 12:55 to 13:02 and APEX II on June 3^{rd} 2015 (fill 19148). The second study was split into two energies, "II a" at 10 GeV from 8:41 to 8:48 and "II b" at 23.5 GeV from 11:00 to 11:15.

2 APEX I

On May 20^{th} we had 6 Au bunches at the Au injection porch, i.e. 10 GeV, with approximately $1.65 \cdot 10^9$ ions per bunch. In order to force a loss signal on the Pin Diodes (PD) in the collimator area we did bring in the collimators close to the beam prior to taking data, excited one bunch at a time to cause beam growth and measured the response signal on the PDs. Collimators were moved in to approximately 15.7 mm (H) and 8.5 mm (V) from

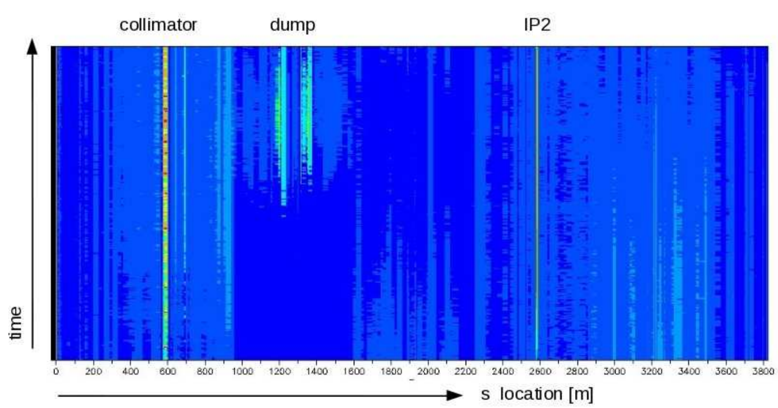

Figure 1: Loss pattern with 6 Au bunches and collimators close to the beam.

the center of the beam pipe prior to the experiment and were not moved during the data taking. Fig. 1 shows the loss pattern in a time window of approximately 7 minutes with the collimators in their IN position. It indicates that the majority of the losses occurs on the collimators with some losses in the dump and IP2 area. Since there are non-negligible losses elsewhere, the amount of beam lost on the collimators can only be considered an upper limit.

Small beam losses were forced in one bunch at a time by using the ARTUS [1] horizontal and vertical kickers. All bunches but the first were excited several times. Each bunch was kicked over 6 turns per trigger and the losses on the primary collimators were monitored with a 1 Hz rate by the Pin Diodes. Fig. 2 shows the beam intensity and PD rate as a

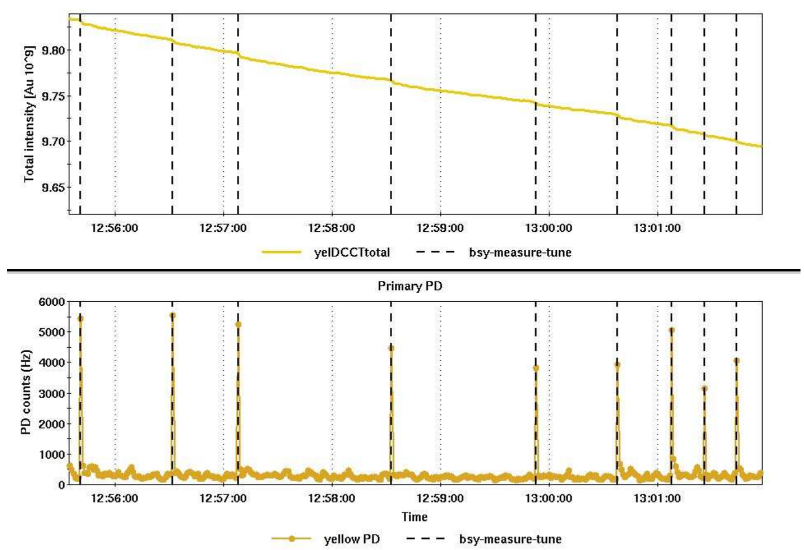

Figure 2: Beam intensity (top) and Pin Diode rate (bottom) as a function of time. Each ARTUS trigger is indicated by a dashed line ("bsy-measure-tune").

function of time during the measurement. A small drop in intensity and a peak in the PD rate are following each trigger of the kickers (indicated by dashed lines). 10 data samples associated with ARTUS triggers were analyzed. In order to determine the actual beam loss at the time of the trigger the 1 Hz intensity data was linearly fitted before and after the time of the trigger. Fig. 3 shows one particular measurement and includes the fit results to illustrate the process. A measurement of a PD rate and associated number of lost beam particles are obtained by the following steps:

- get PD rate baseline during +/- 10 seconds of trigger (grey line in bottom graph), subtract baseline from peak reading.
- fit slope with 10 data points before trigger (red line in top graph).
- fit slope with 10 data points after trigger (green line in top graph).
- extrapolate to actual time of the (asynchronous) trigger (indicated by arrows).
- compute difference before-after at time of trigger to determine the number of lost particles.

Ten datasets were analyzed in that manner drawing a quite consistent picture of PD response following beam loss, i.e. the ratio of PD peak response to lost beam. Fig. 4

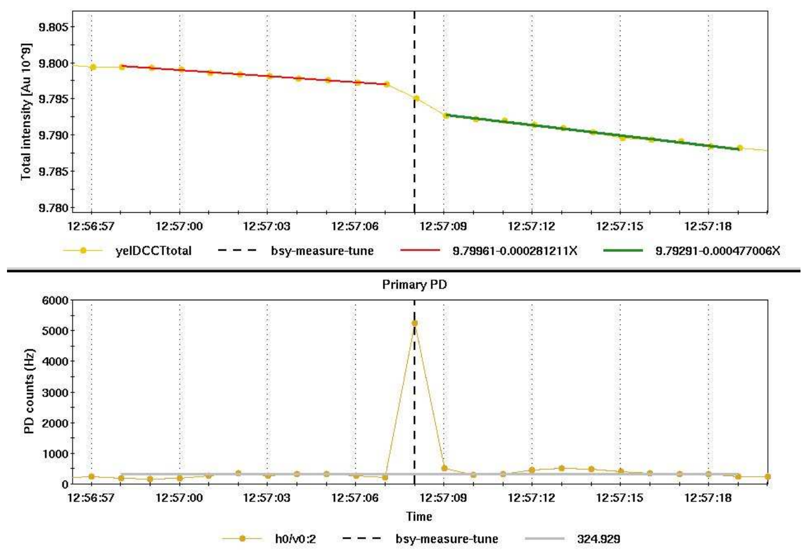

Figure 3: Beam intensity (top) and PD rate (bottom) associated with one ARTUS trigger.

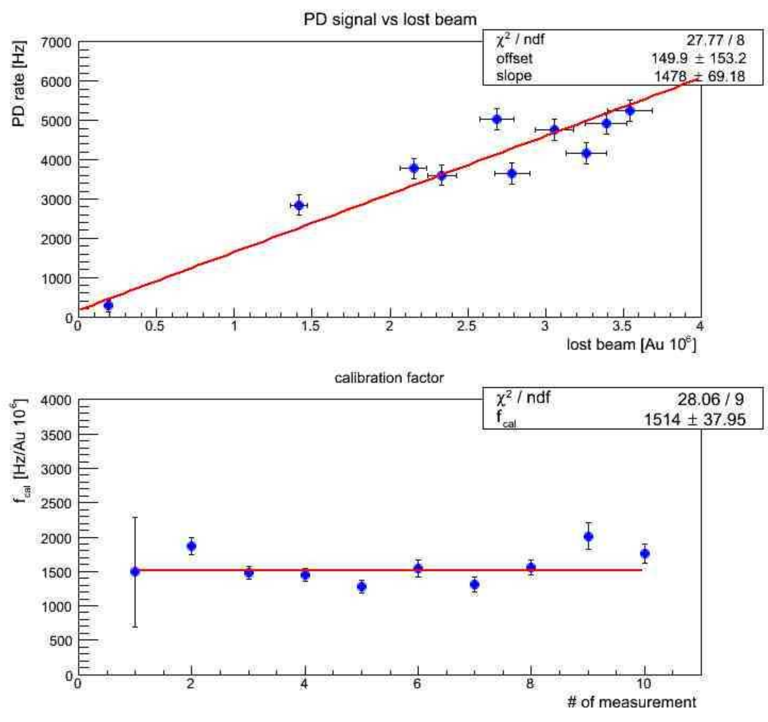

Figure 4: PD peak rate as a function of beam lost on the collimators (top). Peak rate per 1 10^6 lost Au ions as a function of the measurement index (bottom).

summarizes the 10 data samples. The lost beam is given in units of 1 million Au ions. Losses between 0.2 10^6 (continuous loss without ARTUS triggered) and 3.6 $\cdot 10^6$ Au ions were measured. The PD peak response is clearly linearly correlated with a slope of 1478 Hz per 1 million Au ions. Averaging the individual measurements (as shown in the bottom graph) results in 1514 Hz per 1 million Au ions. This result is equivalent to 1 out of 660

Au ions at 10 GeV being detected by the PD in their current configuration and distance from the primary collimators.

Instead of using the peak PD rates triggered by the excitation of one particular bunch we also had a look at the integrated losses during the entire time spent at 10 GeV, covering the “I a” study time plus 5 more minutes, i.e. up to 13:07. The total beam lost during the time window, as measured by the DCCT, was found to be $0.464 \cdot 10^9$. The integrated counts seen in the PDs yielded $0.53 \cdot 10^6$. This corresponds to 1142 counts per 1 million Au ions equivalent to 1 out of 876 Au ion being detected.

3 APEX II

The second APEX study was dedicated to determine how far the PD rate is proportional to the beam decay rate. Due to a PASS system failure beam time was split into two parts. First we had 106 Au bunches in the yellow ring injected and circulating at 10 GeV with intensities between $1.6 \cdot 10^9$ and $1.7 \cdot 10^9$. After a refill and a ramp up to the proton injection porch at about 23.5 GeV we had 111 bunches with intensities between $1.45 \cdot 10^9$ and $1.63 \cdot 10^9$. No additional excitation was applied to any bunch and there was no beam present in the blue ring at both energies. The collimators were at their standard injection position of about 12 mm (H) and 10 mm (V) from the center of the beam pipe respectively. Fig. 5 (left) shows data from the 10 GeV porch as a function of time. The beforementioned failure cut the study period short leaving only the few minutes shown here. Beam decay and PD rate are clearly very well correlated but the beam life time was not optimized and thus beam decay was high and above 35%/hr for the most part. The right plot shows

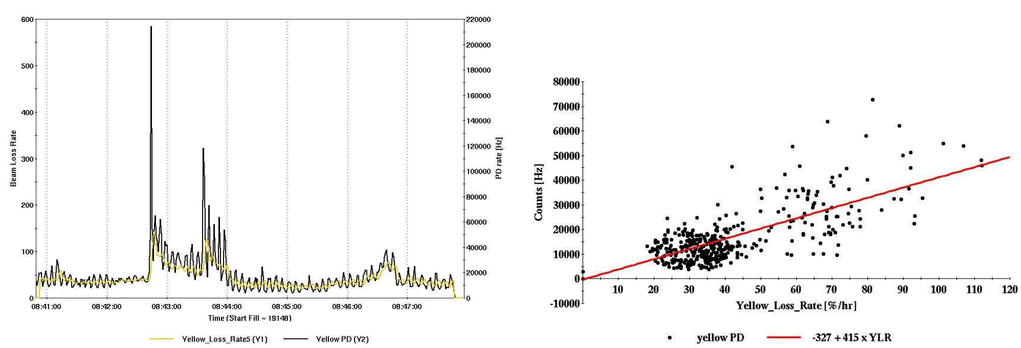

Figure 5: Left: PD rate (black line, right axis) and yellow beam decay measured in %/hr at 10 GeV. Right: correlation plot of the same data.

the PD rate as a function of the yellow beam decay and a fitted correlation factor of 415 $\frac{\text{Hz hr}}{\%}$ at 10 GeV. The scatter is rather large. Unfortunately there was not enough time to change the beam decay for longer periods and to record more data at different levels of beam decay.

After a refill 111 yellow bunches were ramped to 23.5 GeV (proton injection porch). The approximately 15 minutes spent at the proton injection porch cover a larger range of beam lifetimes than before, from about 10%/hr up to over 250%/hr (without interference or external excitation). The Data is shown in Fig. 6. The left plot includes the data as a function of time and demonstrates again that the PD rates are very well correlated with the beam lifetime over the entire range of beam decays. The right graph contains 2 minutes of the same data set. Due to the nature of the beam decay calculation which

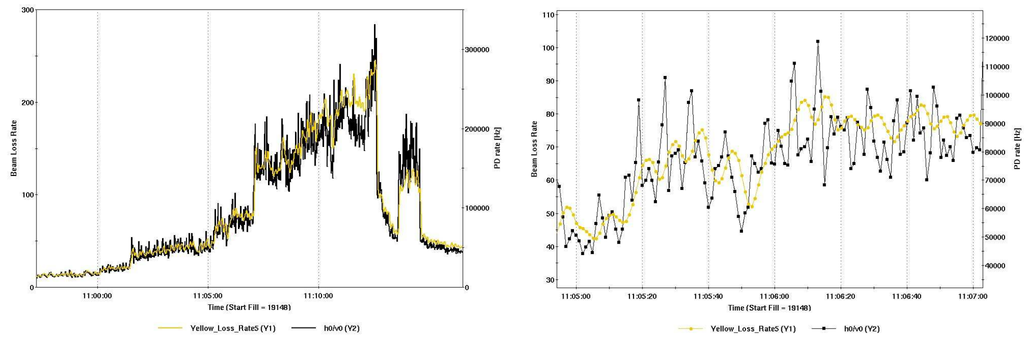

Figure 6: Left: PD rate (black line, right axis) and yellow beam decay measured in %/hr at 23.5 GeV (yellow line, left axis). Right: zoom into the same data.

is always based on the last few seconds of beam current measurements, the two data sets reveal a 4-5 second shift with respect to each other, with the beam decay data being "late". This shift, which is also present in the earlier data set at 10 GeV should explain some of the large visible scatter in Fig. 5 as well as in Fig. 7, which contains a correlation plot of the data set at 23.5 GeV and at 100 GeV. The data at 100 GeV is from a randomly chosen store a few days later, (fill 19158) and from the first 30 minutes of physics. A

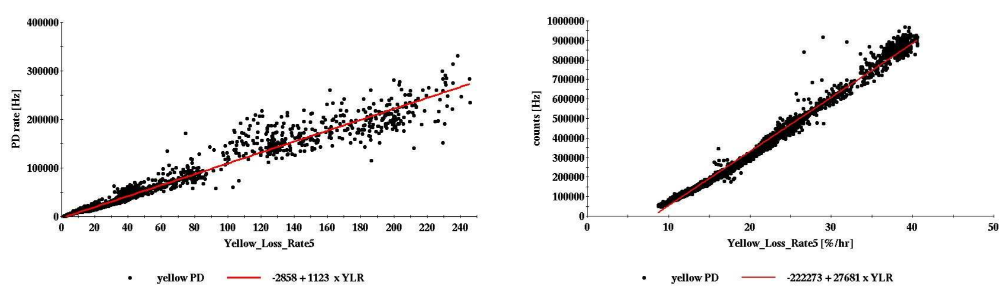

Figure 7: PD rate as a function of yellow beam lifetime at 23.5 GeV (left) and at 100 GeV (right).

linear fit is applied to the data which is shown as a red line. The fit results in a correlation factor of 1123 $\frac{\mathrm{Hz\,hr}}{\%}$ at 23.5 GeV and approximately 28,000 at 100 GeV. The correlation factors were then normalized to a beam intensity of $100 \cdot 10^9$ Au ions. Note that due to the many minutes spanned by the data sets the intensity averaged over the time interval was used. The intensities were 162 $\cdot 10^9$ at 10 GeV, 148 $\cdot 10^9$ at 23.5 GeV and again 162 $\cdot 10^9$ at 100 GeV. The distribution of the fitted and normalized correlation factors at the three energies indicates an exponential dependency of the correlation factor on beam energy. The dependcy is shown in Fig. 8. Keep in mind that this is shown here for illustration purposes only and no error bars are applied due to the lack of repeat measurements and the lack of more careful studirs. In order to compare this study with the earlier measurement and to determine the PD response to a loss of 1 million Au ions we had to integrate the losses during the period of the study at 10 GeV. The total loss (measured by the DCCT) was 7.801 $\cdot 10^9$ ions, compared to an integrated PD signal of 7.23 $\cdot 10^6$ counts during the same time window. This leads to 930 out of 1 million Au ions being detected or 1 out of 1075 Au ions.

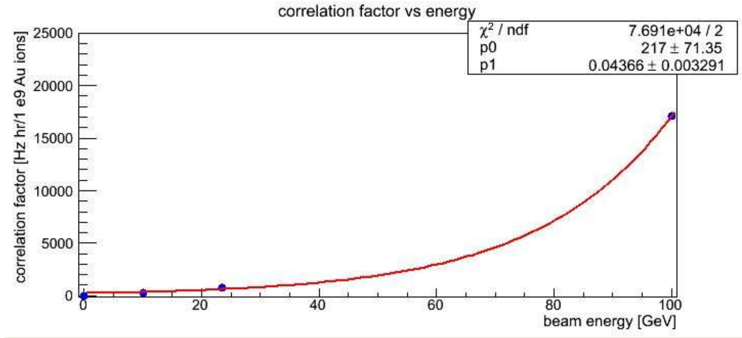

Figure 8: Correlation factor normalized to $100 \cdot 10^9$ total beam intensity as a function of energy.

4 Summary

Using different methods we measured the PD response to Au ions lost on the collimators at 10 GeV. The results (1500, 1140 and 930 per 1 million Au ion) have a rather large scatter that is indicative of the inherent errors in this method, statistical and systematic. A simple averaging yields 1190 counts per 1 million Au ion or 1 Au ion detected out of 840 ions lost. This ratio can likely be improved by adjusting the position of the PDs relative to the collimator jaws. We expect the scatter could be reduced in a future measurement by forcing the collimators in enough to ensure ALL losses on them and by increasing the number of data samples.

In addition and as a consistency check we compared the total loss and integrated counts from the "II b" study period at 23.5 GeV. According to Fig. 8 one would expect an increase of a factor 2.5 to 3, caused by the higher energy of 23.5 GeV. We found 3100 counts per 1 million Au ions, i.e. a factor 2.6 increase. This increase is fully consistent with the increase seen in the correlation factor (compare Fig. 8) when increasing the energy from 10 GeV to 23.5 GeV.

References

[1] K.A. Drees et al, ARTUS: The Tune Measurement System at RHIC, BIW00, Cambridge, MA (2000).