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NEW MEASUREMENT TECHNIQUES FOR GEAR-CHANGING RESEARCH USING DESIREE*

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Abstract

In this work we cover some of the newer techniques developed to measure the effects of a gear changing system maintained in DESIREE at Stockholm University. Gear-changing is a collider synchronization method where two rings with different harmonic numbers in them maintain collisions through different velocities, pathlengths or a combination of the two. This system has been demonstrated using the low energy ion collider DESIREE at Stockholm university. We have not only continued our previous methods of studying the beam using a repeating pattern technique where one bucket in each ring is intentionally left empty, but we now also use recently installed pickups outside of the merger region to study the beams separately while they collide.

INTRODUCTION

This work is a continuation of the Direct Observations in DESIREE of Gear-changing Events (DODGE) program [1-3]. Gear-changing is a collider synchronization method that collides beams with different harmonic numbers, and thus different numbers of bunches, through a combination of different pathlengths and/or different particle velocities [4]. For example, in a 4 on 3 gear-changing system the beam with three bunches would move at 4/3 the velocity of the beam with 4 bunches. Gear-changing allows for more flexibility in colliding slower moving heavy ions in a collider without having to modify the pathlength of the machine. It can also allow the reuse of existing infrastructure for new types of experiments. Since each bunch in a machine interacts with each other bunch there is a reduction in systematic errors for an experiment. However, this can also lead to harmful resonances [5].

DESIREE is a small ion collider at Stockholm University in Sweden [6]. It can collide a variety of singly, oppositely charged, ions of up to 100 keV on up to 25 keV. It has a unique geometry where instead of colliding head-on the beams move with each other in the same direction. DESIREE was designed to study mutual neutralization reactions between ions to approximate reactions found in the interstellar medium. DESIREE's energy range allows us to "dial-in" relative velocities, making it an excellent test bed for gear-changing research. It was designed to have the beams move together at the same velocity for its mutual neutralization experiments, but since gear-changing requires different velocities there are still collisions in a moving reference frame.

Since 2020 we have performed multiple experiments to study gear-changing collisions using DESIREE. In this work we examine several of the techniques we have developed to set up and study gear-changing interactions. A diagram of DESIREE with its diagnostics highlighted is shown in Fig. 1. We developed a "missing bunch" method that allows us to set up our interactions, as well as measure the effects of the interactions over time. We had to adjust our measurement system so that we could extract the necessary data without worrying about spurious readings. In an attempt to measure the beam without using the missing bunch method we attempted to kick away one beam while measuring the other. Finally, we made use of expanded capabilities that came from an additional pair of beam position monitors that had been added to DESIREE to allow us to study the beams without early extraction or the missing bunch method.

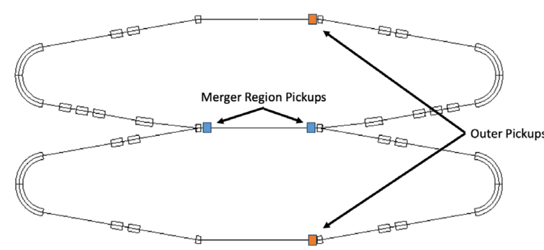

Figure 1: Outline of the DESIREE collider with instrumentation highlighted.

MISSING BUNCH METHOD

Since the beginning of the DODGE program, we understood the need to develop a way to quickly visualize and determine that gear-changing was happening. Early on we developed a "missing bunch method" which would leave one bucket empty in each ring. Thus, in a 4 on 3 gear-changing system, there would be three bunches colliding with two, with empty slots in each. While this method was initially created as a quick visual check, it quickly showed itself to be a very powerful method of setting up and measuring the beam-beam interactions. This type of method creates a repeating pattern with collisions, an empty section where the empty buckets both enter the merger region at the same time, and instances where one of the bunches collides with an empty bucket. An example of this is shown in Fig. 2.

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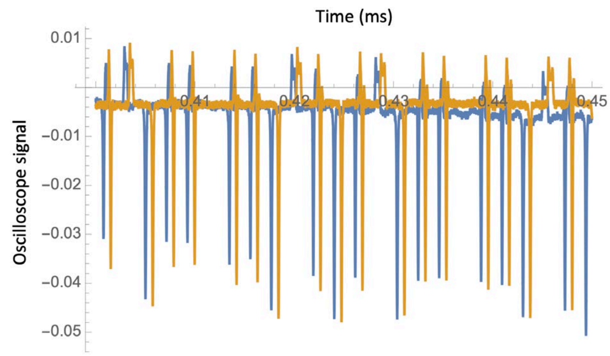

Figure 2: Oscilloscope traces of the repeating missing bunch pattern, with 3 buckets of hydrogen on four buckets of helium.

This pattern is useful in two ways, both to help set up the collisions, and to help measure the collisions as they happen. As has been reported earlier, we use the periodic uncollided bunches to measure the longitudinal bunch distribution of the beam as it evolves over time. While this does lose out on some of the interactions that would occur during collisions, until recently this was the only way to extract data from the beam as it was colliding.

The missing bunch method also helps us to set up the collisions when we begin an experimental run. In order to keep the beam bunched long term we use a pair of Schottkey cavities as RF cavities. Due to the asymmetric nature of the cavities' placement in the two rings we have to get the phase between them correct, in addition to getting the correct timing of the two beams coming out of the ion sources. To do this we set up a missing bunch method and manually change the timing coming out of the sources such that early bunches overlap each other symmetrically between the pickups on either side of the merger region. We then match the phase of the RF to one of the beams. Once that is done, we move to a later time in the collisions to see if the bunches show the same symmetric behavior. If they do, we can proceed, otherwise we alter the phase until they match. We can then cycle the RF voltage; this will change the synchrotron frequency so we can see that the phase is such that the beam is centered in the bucket.

Finally, we can check that we have the timing down by tracking the time difference between unkicked bunches of each ion species. If we subtract out the orbit period then the difference will oscillate around a fixed number. So long as those oscillations never cross zero, we are colliding every pass. An example is shown in Fig. 3.

ANALYSIS ALGORITHM

When we first began these experiments, we extracted info from the missing bunch plots using a curve fitting algorithm. We assumed that the bunches would mostly be gaussians so this would give us good info. While that did give us some good data, as we pushed to higher and higher values we ended up creating systems where much of the bucket was filled while a more dense centroid was also undergoing synchrotron motion. This would sometimes create spurious side bands in the spectrum of the longitudinal motion since sometimes the algorithm was detecting the center bunch and sometimes it was detecting the outer area. We dealt with this by changing the method used to extract info from the bunches. We essentially removed the noise floor of the signal, and treated the pickup signal like a histogram. Using this histogram, we could calculate things like the center of the bunch and its standard deviation. A diagram of what we are using is shown in Fig. 4.

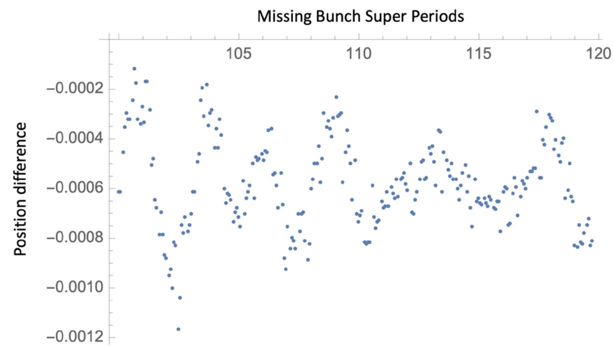

Figure 3: An example from the 2022 experimental run of the difference between carbon and nitrogen beams. Since the number never crossed zero, the bunches were colliding every turn without missing.

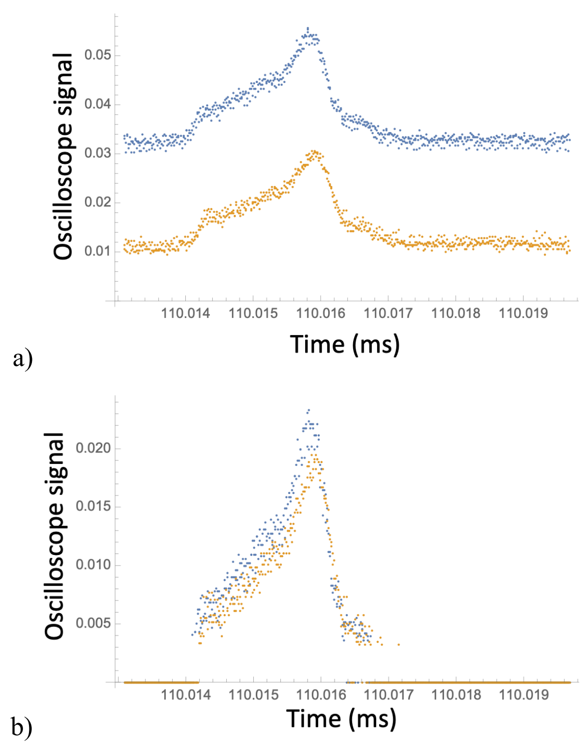

Figure 4: In a) we see a raw carbon signal, in b) we see the signal with the background removed, it can now be treated like a histogram.

KICK AWAY METHOD

We attempted to use a technique where we would fill all the buckets, let them collide for an extended period, then kick one of the beams out. This would allow us to hopefully measure the unkicked beam to see if anything had changed during its time being collided. We unfortunately had a

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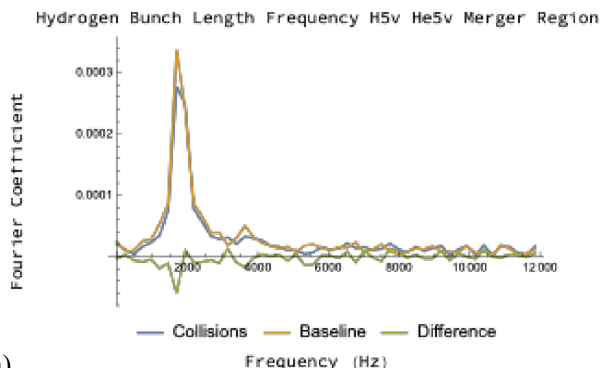
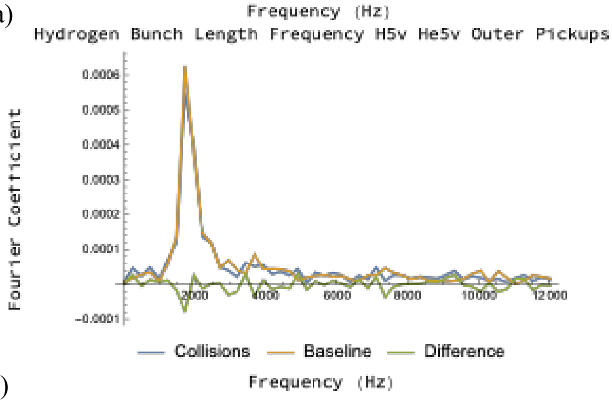
number of problems with the sources during the run in which we tried that technique. Several of our baseline scans didn't include stable beams so it is difficult to measure any changes. This method was later rendered obsolete by using the outer pickups in DESIREE to track the beams instead.

OUTER PICKUPS

In our most recent set of measurements, we were able to make use of the outer pickups which allowed us to collide full bunches in the ring while still extracting useful longitudinal information about the beams. We also took data with the same parameters using the missing bunch method in the merger region as a comparison. When comparing the effects of the bunches using the same empty bucket pattern, we see plots like Fig. 5.



a)



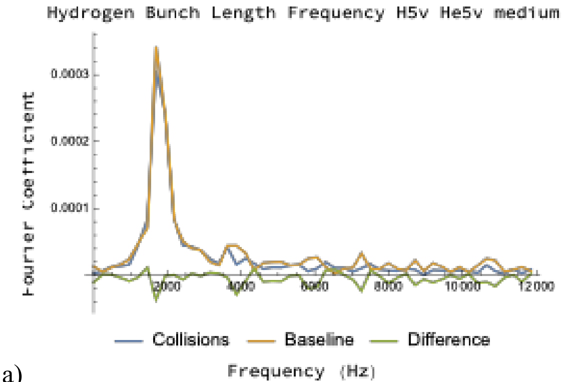
b)

Figure 5: In these plots we see the Fourier spectrum of the longitudinal bunch size in the merger region a) and the outer pickups b). Both are using missing bunch patterns.

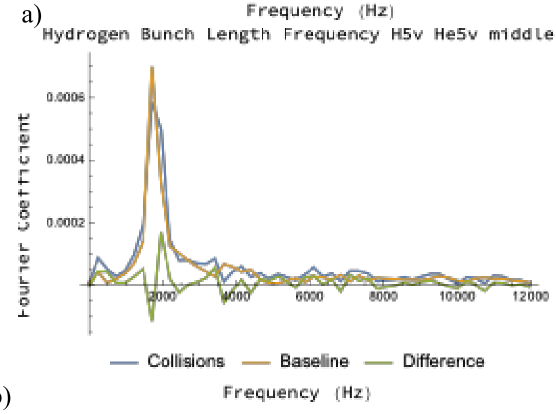
If, instead, we use the ability of the outer buckets to fill every bunch we can see that the Fourier spectrum will show a difference between the merger region pickups and the outer pickups. This is shown in Fig. 6.

CONCLUSIONS

Over the past 5 years we have created sophisticated methods of measuring the properties of ion beams in DESIREE as they undergo gear-changing interactions. We have developed a missing bunch method to allow us to measure the beam using only BPMs/pickups. We have altered our method of calculating moments, and we have developed new techniques to gather data from the bunches as they collide without using any empty buckets.



a)



b)

Figure 6: In these plots we see bunch length oscillation frequency using the merger region missing bunch method a) and the outer pickups with every bucket filled b).

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