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Mini-bunched and Micro-bunched Slow Extracted Beams from the AGS *

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Abstract

Brookhaven National Laboratory's (BNL's) Alternating Gradient Synchrotron (AGS) has a long history of providing slow extracted proton beams to fixed target experiments. [1] This program of providing high quality high intensity beams continues with two new experiments currently being designed for operation at the AGS. Both experiments require slow extracted beam, but with an added requirement that those beams be bunched. Bunched beam slow extraction techniques have been developed for both experiments and initial tests have been performed. In this report we describe the beam requirements for the two experiments, and present results of detailed simulations and initial beam tests.

INTRODUCTION

Two new experiments to be constructed at the AGS will require a continuous stream of particles but with time structure. Each experiment has different requirements, and to achieve these two different extraction schemes have been developed [2, 3, 4, 5]. One method of putting time structure on the spill is to force debunched coasting beam between empty longitudinal buckets. In this case, particles are pushed into the resonance by lowering of their betatron tune through lowering the main magnet field and exploiting the large horizontal chromaticity. This method we call micro-bunched slow extraction. By choosing a high frequency RF system for the empty buckets one can achieve very short extracted bunches with whatever spacing is desired. Another method is to keep the beam bunched inside RF buckets and use the radial beam control to move the bunches into resonance. In this case particles are pushed into resonance by changing the average momentum of the bunches, again exploiting the large horizontal chromaticity. This method we call mini-bunched slow extraction. The bunch frequency is defined by the frequency of the main RF system and the pattern of filled RF buckets. Bunch lengths are longer than for micro-bunched slow extraction, since they depend on the momentum width of the resonance, as opposed to the time width of a gap between two empty RF buckets (which depends on the dB/dt needed to get the full beam extracted). In micro-bunched slow extraction the momentum of the beam exiting the accelerator is time dependent (higher at the beginning of the spill) whereas in mini-bunched slow extraction this is not the case. Two important parameters for bunched beam slow extraction are the bunch lengths and the number of particles that exist in between the bunches (referred to as extinction). Bunch lengths in micro-bunched slow extraction depend on the momentum spread of the beam (smaller dB/dt means empty buckets are closer together), the RF frequency, and the RF voltage. Addition of a higher harmonic cavity can reduce the bunch lengths even further. Bunch lengths in mini-bunched slow extraction depend on the momentum width of the resonance and the longitudinal distribution of the beam. In each case, power supply ripple can cause variations in the bunch lengths. Extinction in micro-bunched slow extraction depends on the relative location of the empty RF buckets to the resonance, the extraction efficiency (since scattering on septa contributes to the intra-bunch population). Extinction in mini-bunched slow extraction depends on scattering on septa (particles pushed outside RF buckets will form a DC ribbon of beam). In addition, if the parameters for the experiment are such that not all the RF buckets are filled (i.e., experiment wishes a particular energy and bunched beam frequency that require only some RF buckets to be filled), then any beam trapped in the empty buckets will contribute to the intra-bunch extinction.

RSVP OVERVIEW

The Rare Symmetry Violating Processes (RSVP) program consists of two proposed experiments that use extremely sensitive measurements of low energy processes to test the Standard Model of particle physics and to search for new physics processes. The two experiments comprise a search for coherent, neutrino-less conversion of muons to electrons in the field of a nucleus and a determination of the rate for the CP violating decay of long-lived neutral kaons into a neutral pion, a neutrino and an anti-neutrino. The experiments are to be performed in new, intense muon and kaon beams at the AGS. The KOPIO experiment will use a 25.5 GeV/c bunched proton beam to produce a low energy neutral kaon beam with a clear time structure, which will allow determination of the incident kaon momentum. The experiment will then look for the decay $K^0_L \rightarrow \pi^0 \nu \bar{\nu}$, which has a predicted branching ratio of 3×10^{-11} [6]. This decay mode is unique in that it is dominated by mixing-induced CP symmetry violation which is one of the most important outstanding issues in the study of elementary particle physics and it is one of the main areas of worldwide

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activity in particle physics. The MECO experiment will use an 8 GeV proton beam that strikes a heavy metal target within a high field solenoid magnet to create a shower of secondary particles, including pions that decay into muons. The experiment seeks to observe the conversion of these muons to electrons by a very sensitive measurement that first requires particle filtering, through sign and momentum selection, to preclude unwanted background particles from entering the region in which the detection apparatus is located. An essential element of the muon beam is that it is pulsed, with the time between pulses equal to approximately 1 μsec. To meet the goals of the MECO experiment, the extinction must be below 10^{-9}.

MICRO-BUNCHED EXTRACTION FOR KOPIO

Two beam tests of the micro-bunched slow extraction have been performed recently. In the first of these a 93 MHz RF cavity was used to generate the micro-bunches from a low intensity coasting beam. Much of this beam test was focused on techniques for measuring the extinction level, although the goal was to collect data for comparison to simulations. The 93 MHz beam tests were limited by the amount of voltage on the RF cavity, and so the effect of the voltage could only be studied over a small range. The detector used in this test was a set of counters looking directly at particles scattering from a thin target. For the second beam test a completely different approach was taken, both in the measurement and in the method of generating the bunches. In this test the main AGS RF system was used (operating at 4.4 MHz), which allowed us to study the effect of the RF voltage on bunch width, extinction level, and on beam losses. For the measurement we used a separated beam of anti-protons. This allowed us to get a very clean beam in which secondaries from other sources could not as easily corrupt the extinction measurement. Figure 2 shows the micro-bunch time structure from the 93 MHz beam test in 2002, accumulating 1/4 of the micro-bunches in the spill, with the horizontal axis in nanoseconds. The reason for the 1/4 has to do with details in the data acquisition system. The RMS width is 262 picosecond. There is an instrumental contribution which can be removed in quadrature, giving an intrinsic width of 240 ps. Careful examination shows there is 1.5 % intra-bunch events between the micro-bunches. Figure 2 shows the 93 MHz simulation with a width of 218 ps. This particular simulation does not account for power supply ripple. In general, simulations indicate that ripple can contribute to increased width as well as poorer extinction, so it is not surprising the simulated width is narrower. The simulation used is a first order 2 + 2 dimensional tracking system. Longitudinal motion is treated separately from the transverse horizontal motion, and the vertical phase plane is not treated. However longitudinal motion does feed into the horizontal motion via the chromaticity. The equations of motion are integrated numerically (symplectic) and particles are tracked through the integrator in normalized betatron phase space. The normal transformations are made to express results in real space coordinates. For more information please consult reference [7]. In the most recent beam test, with a 4.5 MHz cavity, extraction can be accomplished with much improved extinction, exceeding the KOPIO specifications but also better than predicted by the simulation. Results from this run are still being analyzed.

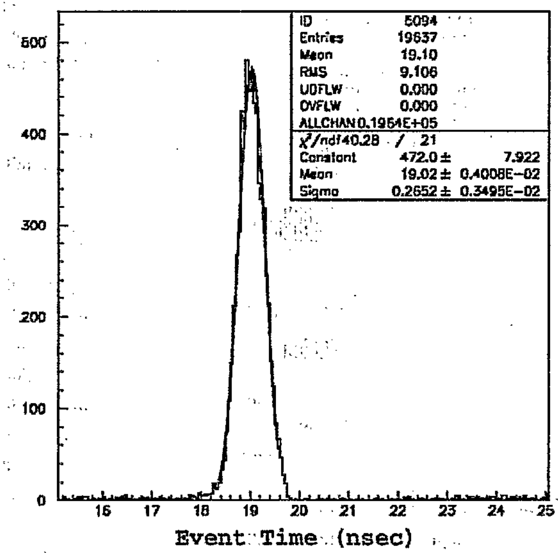

Figure 1: Measured 93 MHz micro-bunch time structure, with the horizontal axis in nanoseconds.

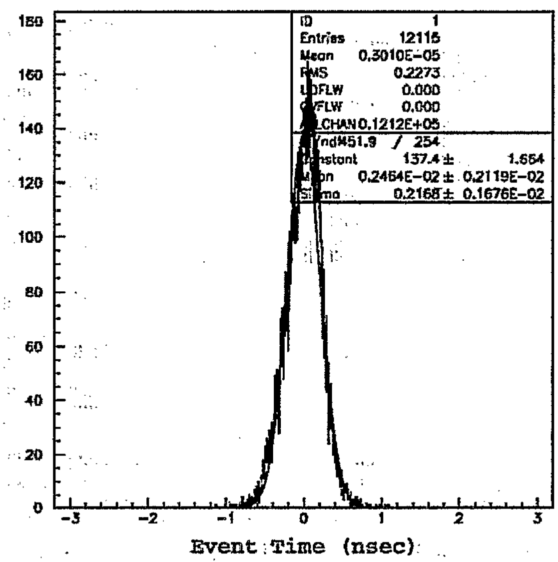

Figure 2: Simulation of 93 MHz micro-bunch time structure, with the horizontal axis in nanoseconds.

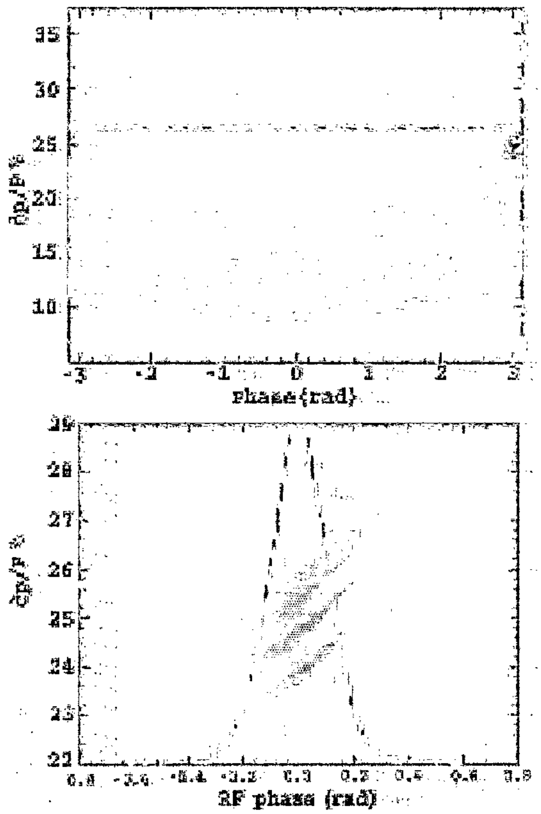

Figure 3: Simulation of 93 MHz extraction and corresponding bunch.

MINI-BUNCHED EXTRACTION FOR MECO

No beam studies have been performed for MECO since 1996 [3]. There are four main challenges in the beam dynamics: First, the experiment will operate at 8.1 GeV/c (below γ_{tr} in the AGS), with the AGS RF on harmonic 6 and with just 2 buckets out the 6 filled with beam, and with an intensity of 4×10^{13} protons/pulse (40 TP). The repetition period will be 1 to 2 seconds, which depends mostly on beam loss levels, but also on power supply duty factor. The peak intensity achieved in a single bunch at the AGS is approximately 17.5 TP in the AGS Booster. Given expected efficiencies in the accelerator chain, we would require over 22 TP/bunch in the Booster to get 20 TP/bunch at extraction. Two advantages of the MECO configuration, over previous high intensity operation are that we are operating below γ_{tr} in the AGS, and so have none of the constraints of the transition jump, and we require only two fills at AGS injection, keeping the injection porch relatively short so that bunches do not spend significant time at injection energy. The second challenge is in achieving the $< 10^{-9}$ extinction during the extraction process. To meet this specification we plan on upgrading the AGS AC-dipole power supply to operate in a CW mode and we plan to upgrade the AGS stripline kickers (part of the AGS Damper system) to be capable of providing significant kick at 8.1 GeV/c. The AC-dipole will operate at approximately 80 kHz and will resonate all particles in the accelerator out of the aperture. The stripline kickers will damp the betatron oscillations of the two bunches, to keep those particles inside the accelerator. With this operating during the entire beam spill we will sweep out any intra-bunch particles. The addition of collimators in the beam transfer line to the experiment will catch any particles which did not get swept out, since these particles will necessarily have larger transverse amplitudes than the main bunches. The third problem is in the time structure of the beam spill during slow extraction. In the beam tests in 1996 there was well over 100 % modulation of the spill. There is some evidence that this may in part be due to synchrotron motion and structure in the longitudinal distribution. The study in 1996 was very short and there was not sufficient time to work on minimizing power supply ripple which was a significant but solvable contributor to the over-all spill structure. Finally, the extraction system for the AGS was designed for > 24 GeV/c beams in the pre-Booster era of the AGS. For 8.1 GeV/c high intensity beams the acceptances of the extraction devices are not sufficient to contain the beam. As a result we need to design new septa devices which can accept both the 8.1 GeV/c MECO beams and the 25 GeV/c KOPIO beams.

SUMMARY

The two RSVP experiments make new demands on the accelerator that are technically challenging, but achievable. We have made significant progress in the past year in understanding these challenges and in developing solutions to them.

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