CONTINUOUS EXTRACTED BEAM IN THE AGS FAST EXTERNAL BEAM LINE.*

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Abstract

A method to split off a few percent of the 6x10^13 AGS beam delivered to the Slow External Beam (SEB) lines and send it down the Fast External Beam line (FEB) has been developed. The mission is to feed a counter experiment off the FEB that directly measures the neutrino mass using the muon storage ring. The use of normal thin septum splitters would have an excessive loss overhead and been optically difficult. The AGS Slow Extraction uses a third integer resonance with sextupole strength so the resonance width is a few percent of the beam width. This results in a low density tail which will be clipped by a bent crystal and deflected into the FEB channel. This clipping off of the tail should reduce losses in the SEB transport line. Details of modelled orbits, particle distribution and extraction trajectories into and out off the crystal will be given..

1 INTRODUCTION

An experiment to directly measure the mass of the neutrino (NuMass) has been approved to run at the AGS. It would use for its spectrometer the muon storage ring used to measure the anomalous magnetic moment of the muon (g-2). The experiment needs a steady stream of a few million pions per second delivered to the ring which requires about 10^{12} protons/sec on the production target. The current proton supply for this production target is single bunches of AGS beam, extracted one at a time down our Fast External Beam (FEB) line. The spill required for this experiment is the same as we deliver to our Slow External Beam (SEB) lines. Various options were examined:

Transporting pions from the SEB D target – The long beam was expensive and would have few pions left compared to electrons and muons.

Transporting protons from the D line to the V target. – This would be an expensive beam line with much shielding and many Tesla Meters of bending.

Install an SEB system to bring beam out through the H10 magnet. – This would have required dedicated operation of the AGS for the experiment and significant modifications to the accelerator.

Utilize a 'bent crystal' to split off a few percent of the SEB resonating beam and deflect it into the FEB line in order to run compatibly with other SEB users. – This is the preferred mode of operation as modifications are minimal and facility use is maximised.

2 THE CRYSTAL OPTION

The goal is to run the experiment in conjunction with the rare K-decay experiments running in the normal SEB beam lines. We also noted the SEB transport suffers from a few percent tail [1] of higher energy particles that develop too large an oscillation amplitude during extraction. This tail aggravates beam loss in the SEB transport line. H10 appears to be dynamically at an ideal position to clip this tail off, and we have a user here to use this beam. Approved SEB users require 25 GeV protons; the ejector for FEB (H10) is designed for pulsed operation and can not be powered continuously due to heat limitations. Crystal bending of beams is fast becoming 'state of the art' [2] and was chosen for simplicity. Two options present themselves: (1) The use of a crystal deflector to replace the H10 bend. Or (2) It may be necessary to replace H10 with a new DC magnet to improve beam steering stability into RHIC, where erratic steering dilutes the stored gold beam in RHIC and thus reduce luminosity and as well onto the production target for the pion beam. Then a smaller crystal upstream of H10 could be used to skip its septum, requiring a smaller bend in the crystal and enhancing efficiency.

Beam is removed from the AGS for the SEB users by a sextuple driven third integer resonance at Q = 26/3, this creates three 'seperatricies' of unstable protons in phase space, populated on subsequent turns by the beam, growing in oscillation amplitude to skip septa for extraction. There are three septa placed around the AGS ring at appropriate phases to these seperatricies. The first [H20] is only 75 microns thick but being electrostatic only bends a fraction of a milli-radian; less than the angular divergence of the beam. The particles are moved into a faster streaming region of phase space and after nearly three turns, the bend creates a low particle density 'shadow' to reduces losses on the next septum [F5]. This magnet then bends a mill-radian to channel the beam into a 1 ¼ degree magnet [F10] that directs the beam out of the AGS into beam lines that feed SEB production targets. The AGS equilibrium orbit is distorted using 'three half lambda' bumps to place the circulating beam near these septa.

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2.1 Replacing the Ejector with a Crystal

The extraction oscillation, which grows all around the AGS, has one of the anti-nodes near H10, the entrance to the FEB line that feeds the pion production target for NuMass. Splitting the few percent off the edge of the beam using conventional magnets was not considered as there is little room for septum deflectors and the size of the beam to FEB is only a milli-meter or so. It turns out that a bent crystal deflector is ideal for this application. First the effective field within a crystal is phenomenal, about 10^11 Volts/Meter or ~3 Mega-gauss equivalent; to be sure over sub-micron distances, but many parallel channels are part of the crystal lattice structure. A crystal splitting deflector is small and thus will easily fit in our crowded accelerator. The other feature that makes a bent crystal ideal is that the distance between no field and full field is also sub-micron, thus septum losses will be minimal. The required bend is large, 25 milli-radians but this allows the beam to be extracted without using the pulsed extraction septa. These advantages far outweigh the problem that 70% or so of the beam is not bent by the crystal. As we need about 3% of the total beam this lost beam is only a couple of percent of the total beam produced by the AGS.

These features of high gradient and thin 'septum' have allowed bent crystals to be used [or abused] at many accelerators for extraction by scattering. What will be unique in our use of a crystal is that the face of the crystal, or the channel entrances, will be directly illuminated by the resonate blow up of the beam at a location in the AGS where the angular dispersion is about 40 micro-radians. This is less than the 'critical angle' acceptance of a crystal. It will not be necessary to use the crystal to scatter the beam to make it grow until protons enter the channels and are transported out of the accelerator, as is typically done. With the clean illumination of the channel entrances by the resonance which provides a beam with divergence well within the acceptance of the channels, we expect efficiencies of nearly 40% even with the large bend of 25 milli-radians.

Simple modelling shows an ideal match between normal SEB trajectories and what is need to bring beam out the FEB. Particles were started in a simplified dynamic model of the AGS [3] with a gausian distribution amplitudes in phase space and allowed to grow as they passed through the resonance. Those that grew to the location of the septa were captured in a file to be mapped into the H10 straight section in the AGS. Fig 1 shows phase space detail of the turn that will be extracted. Units are in mm & m radians with offset origins. A cut of 3% of the beam is shown.

This ensemble was then fed to Biryukov's model of a bent crystal, Fig 3 shows the distribution of what exits the crystal with a 25 milli-radian bend.

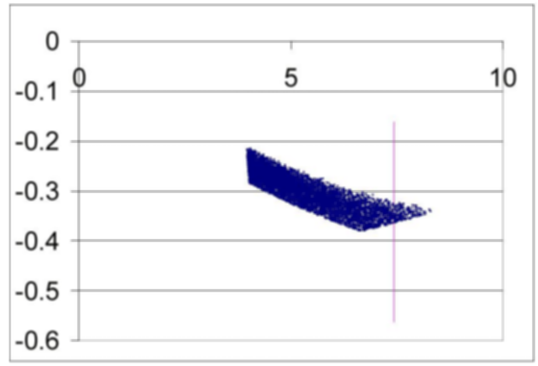

Fig 1. Phase Space Plot of Last Turn SEB Particles at the H10 Straight Section.

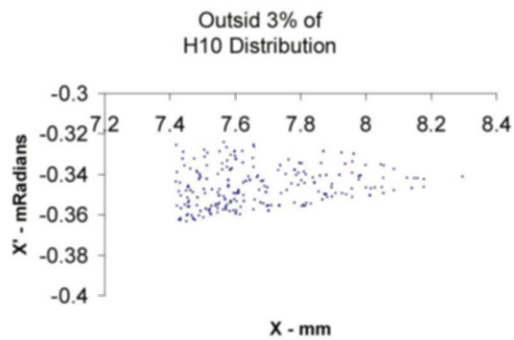

Fig 2, 3% of Particles that Enter the Crystal

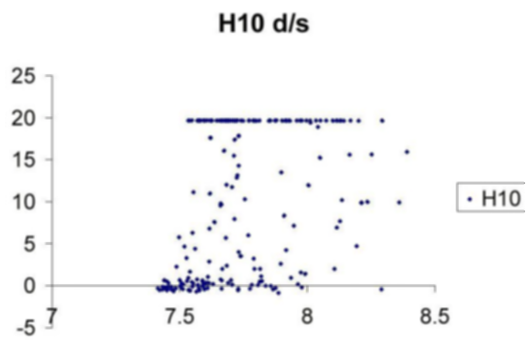

Fig 3. Particle Distribution After Crystal..

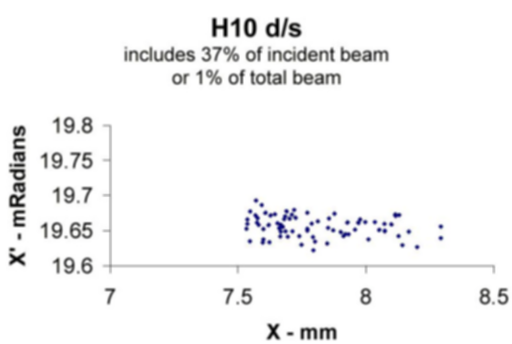

Fig 4 Blowup of Channelled Particles.

Note that the 'eminence' of this beam in Fig 4. is about 10 pi nano-meter radians, geometric.

2.2 With a DC Ejector

The current ejector has a capacitor discharge supply that is regulated to about a part in a thousand. With this jitter and some timing difficulties, it appears that it is one of the main contributors to variation in matching into the RHIC ring. It is planed, but not scheduled, to replace it with a DC magnet. When this occurs, one could move the crystal upstream to the H9 straight section. Here it would be used to split the beam off and send across the 0.4” septum of the ejector. This would only require less than half the bend, thus crystal transport efficiency would be improved. Fig 5 shows 5% of the resonant beam here. The problem here is that the divergence is a bit greater than the acceptance of a crystal. The required bend is only about 9 milli-radians so enhanced efficiency from less bend may offset the slight inadequacy in acceptance. Shaving the entrance of the crystal may improve capture as the acceptance angle would be a function of position. This technique has not been perfected for accelerators yet. This ensemble of particles have not yet been carried through a model of a crystal at 10 m rad.

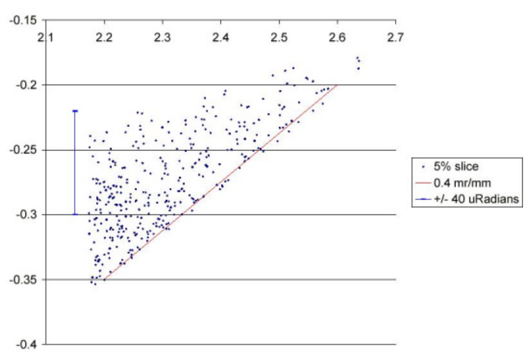

Fig 5 Phase Space Dist. of Particles at H9.

3 REQUIRED MODIFICATIONS TO THE AGS

Only two modifications are required to the AGS.

A crystal scrapper is being installed into our RHIC, 200 GeV collider. It will 'extract' the halo of the coasting proton beam into a copper block to shield experimental detector from stray hits. The precision of the crystal support platform position control exceeds what is needed for the AGS extraction crystal by a factor of 3 to10. This part of the system will be standard for us

Orbit bumps would have to be modified to move the beam near the H10 crystal as well as holding it near the H20 ESS used for SEB extraction. These locations presently are approached by independent bumps centred at H11 and H19, slightly more that a quarter wavelength away.

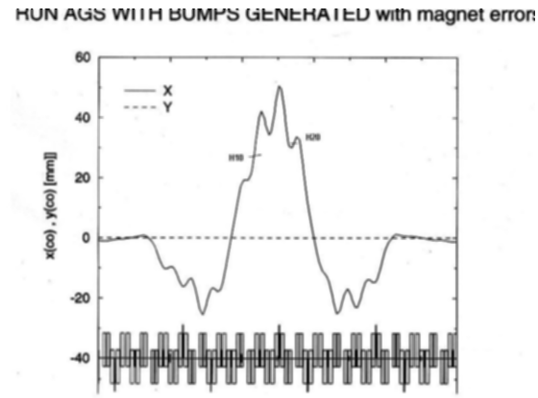

Fig 6 A Long Bump in the AGS Orbit.

4 MAD MODELLING

Work has started on modelling this set-up with MAD to confirm the simple modelling. The Phase space for an ensemble of particle was plotted at the H9 straight section. This is still ‘work in progress’ but sows the same characteristics in distribution as the simple model.

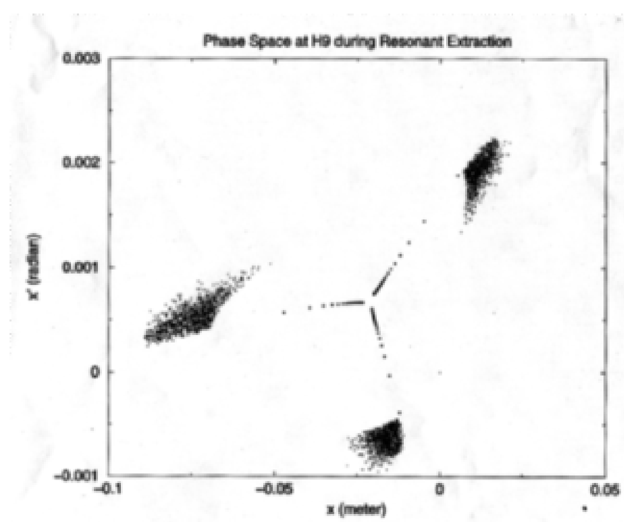

Fig 7 MAD Simulation of Beam Being Extracted at H9

5 CONCLUSION

The use of a bent crystal to rededicate the FEB line to counter experiments appears to be ‘a natural’. Crystal extraction is a new technology for beam extraction and its potential is developing

6 REFERENCES

[1L Ahrens, et. Al. “AGS Resonant Extraction with High Intensity Beams,” PAC’99, New York, pp3291.

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[3] JW Glenn, et. Al., “Micro-bunching the AGS Slow External Beam” PAC’97, Vancouver, pp 2806