Studies of DRAGON acceptance using the Wobbler

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Introduction

As a part of understanding the optics of DRAGON, a study was done examining the transmission of beam when deflected to large angles in the gas target. In a real experiment, the emission of a gamma by a recoil ion can fill a sphere in the center of mass frame of reference. In the lab frame, this translates to a loss or gain of forward momentum, as well as a possible gain of momentum in the plane perpendicular to the forward motion of the ion. This causes an effectual loss or gain in the energy of a recoil, as well as the spreading of the beam into a 'recoil cone'. In order to fully understand the acceptance of DRAGON, therefore, the beam transmission must be studied as a function of energy as well as initial angle.

In order to study this spread in energy, the separator was 'detuned'; set for a different energy than the incoming beam. Thus, by tuning DRAGON for an energy 3% higher than the nominal beam energy, a recoil of 3% lower energy than incoming beam ions was simulated. The beam was deflected to various angles using the 'wobbler', a set of two magnetic dipoles, oriented alternately in the x and y directions. In the epics program the wobbler is SM0X and SM0Y for x- and y-deflections respectively. Transmission was checked using faraday cups, at the charge slits (FCCH), the mass slits (FCM) and the final slits (FCF).

Also studied were some effects of changing the separator quad and sextupole settings, in order to understand what effect various parts of the separator had on the optics of ions deflected by the wobbler. The position of the beam was examined at the three slit positions as a function of deflected angle in order to examine the focus characteristics there, and then measured again with changed separator quad and sextupole settings to measure the effects of each component.

Preliminary analysis had indicated that there was a significant asymmetry in the x-acceptance, and that transmission could be very sensitive to initial beam properties.

Data Analysis

The wobbler contains a three millimeter aperture which can be moved to different X and Y settings. This was used to study the beam properties by moving the aperture and measuring current on FCCH. To study the initial angle spread of the beam, quads 1 and 2 were turned off and the transmission was measured at FC1. The angular spread could be deduced by calculating what percentage of the beam had 'fallen off' the cup, compared to how much deflection the wobbler had contributed. The definition of zero deflection could then be found by finding the position of the charge slit focus with quads still off. Setting the wobbler to a current that centered the focus gave the wobbler setting for zero deflection.

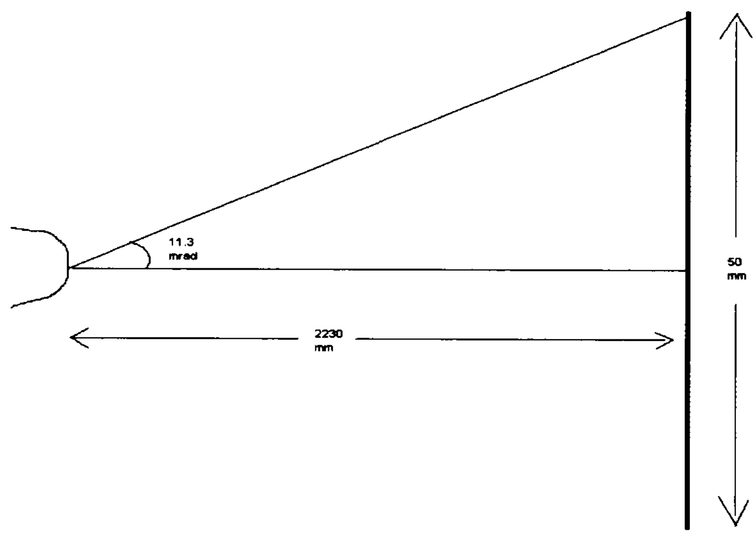

Fig 1: By measuring the deflection where the beam intensity incident on FC1 falls to half, and comparing that to 11.3 mrad, the half intensity point for a perfectly straight, centered beam, outer limits of angular beam spread can be set.

These properties being understood, the transmission could then be plotted as a function of deflection and energy difference.

The wobbler has a deflection to angle relation:

$$\mathbf{a=0.446\ I*q/(A*E)^{1/2}}$$

Where a is in mrad, I in amps, q the charge of the incoming beam, A is the atomic mass in amu, and E is the energy of the beam in MeV. A beam of $^{20}Ne\ 5+$ at .2 MeV/u was used for this study.

At large deflection angles, the aperture had to be moved slightly to eliminate the possibility of losses inside the wobbler. In all cases, the largest source of error came from random fluctuations of beam intensity.

Results

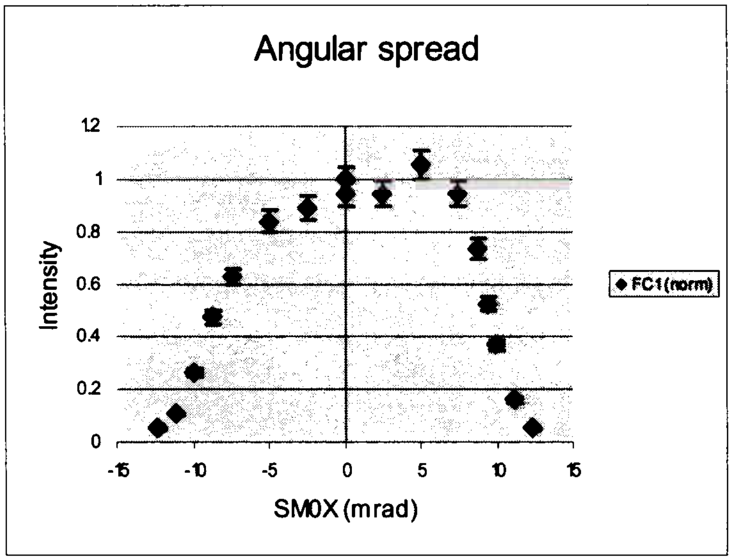

Fig 2a. Angular spread of beam in the X direction.

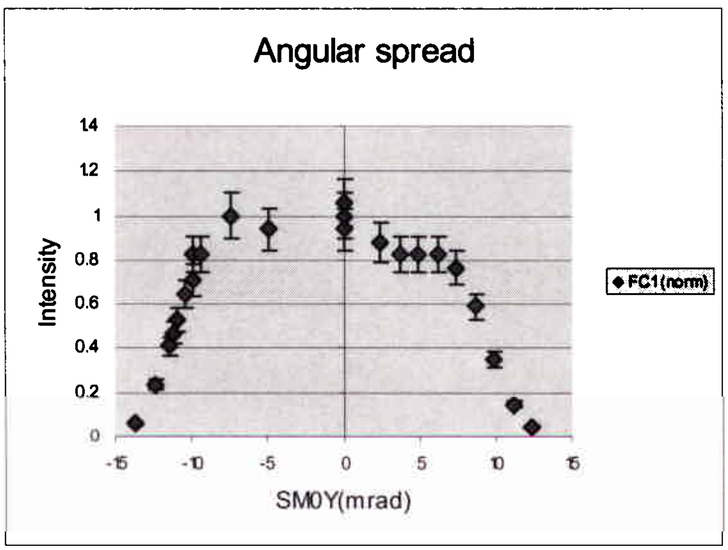

Fig 2b. Beam angular spread in the y direction.

After examining the beam properties, it was found that the beam spot was four millimeters in size, and that the beam spread was not more than four mrad. Plots were made of the transmission as a function of the two parameters, energy and deflection.

Also plotted were combinations of the two, wobbler deflection scans at certain energy tunes. These were done primarily in the x direction, because energy changes are manifested into x displacements in the separator, and because y acceptance seemed to be as specified.

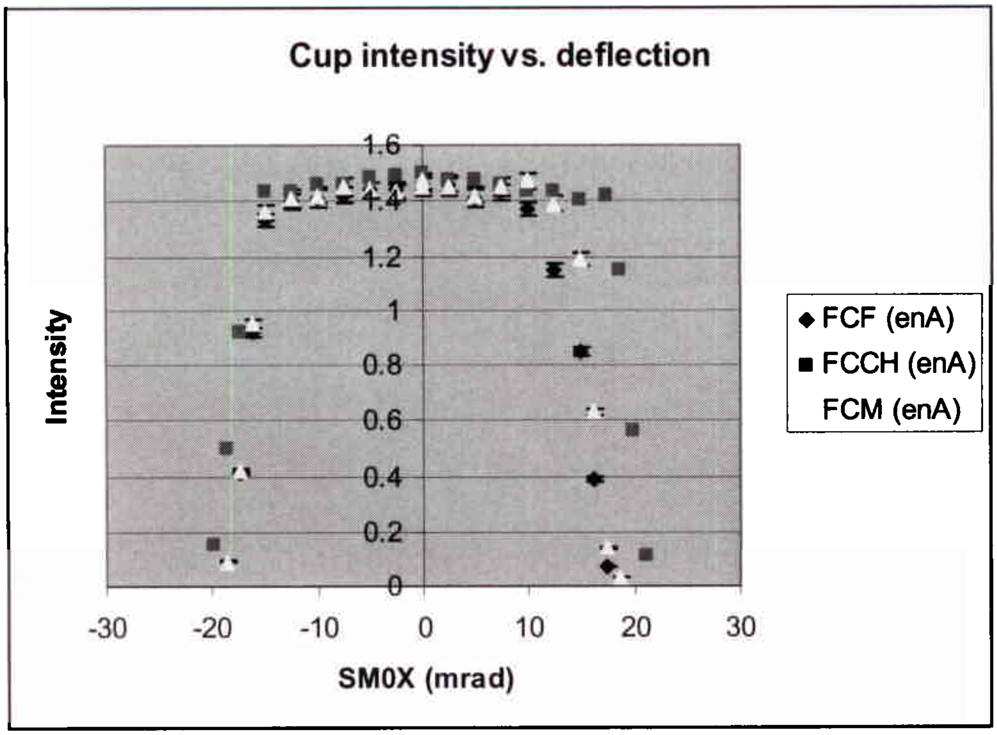

Fig 3a. A wobble in the X direction, at the nominal energy.

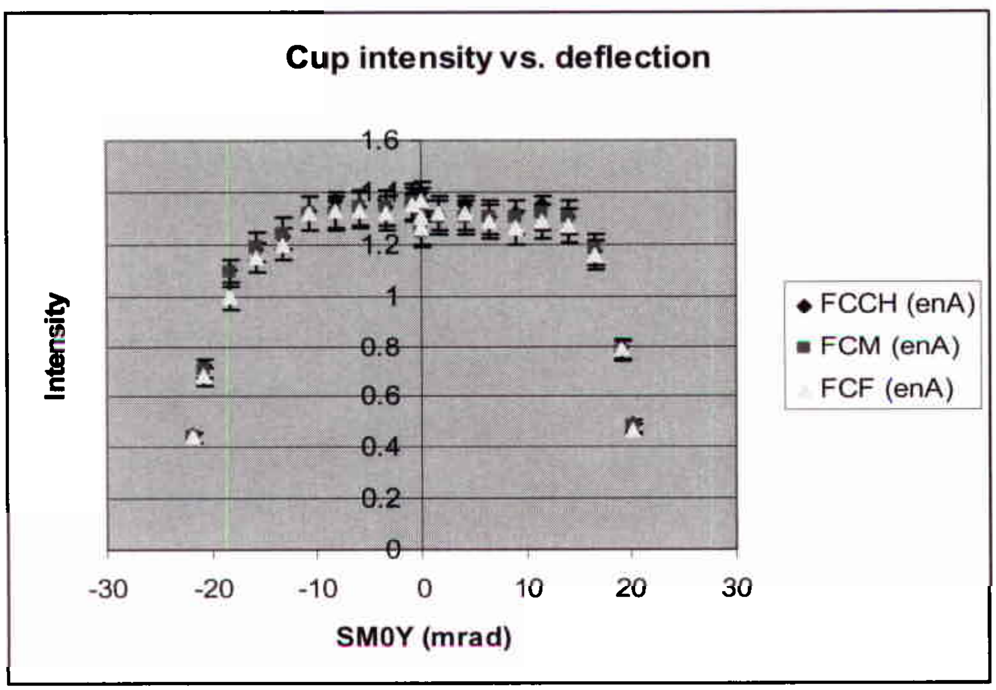

Fig 3b. A wobble in the Y direction, at the nominal energy.

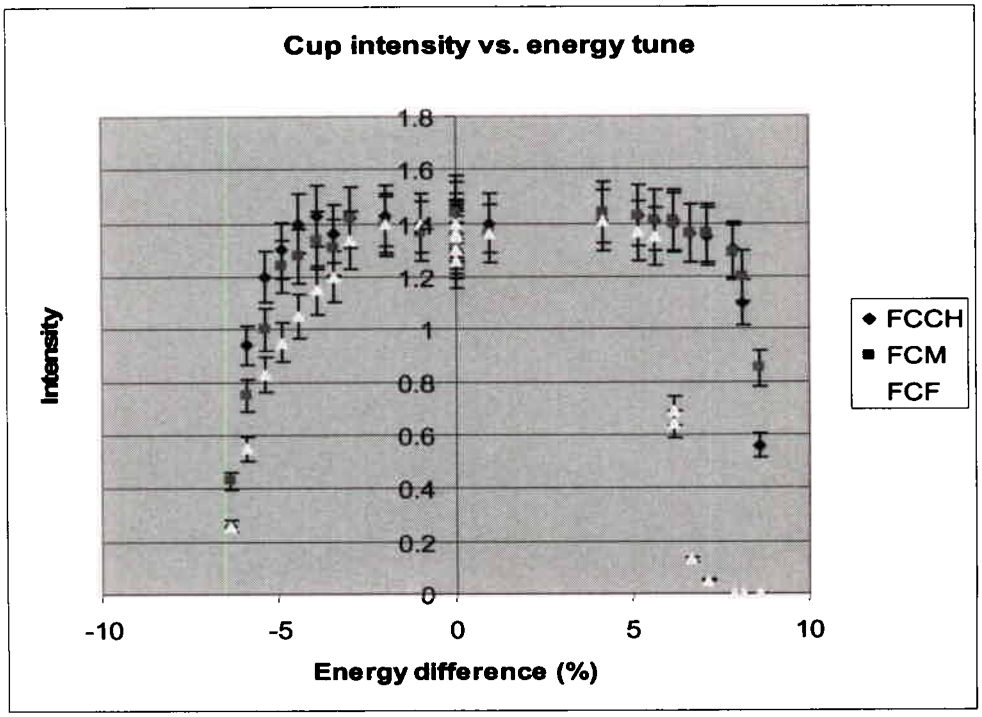

Fig 4. An energy scan with zero deflection. The energy difference is for the ions themselves, so a positive energy difference simulates an ion which gained kinetic energy by emitting a gamma.

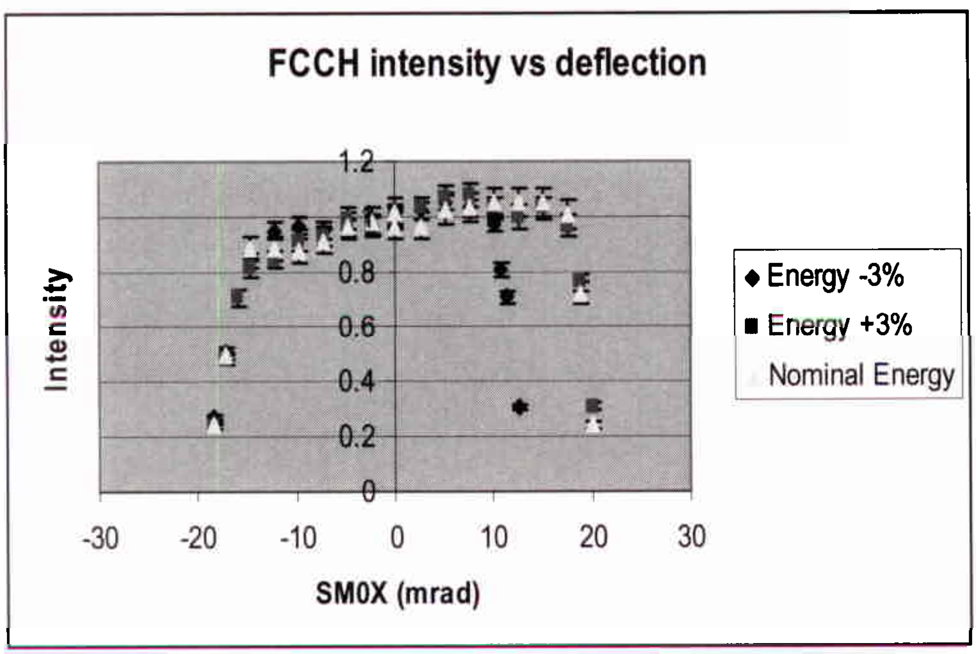

Fig 5a.

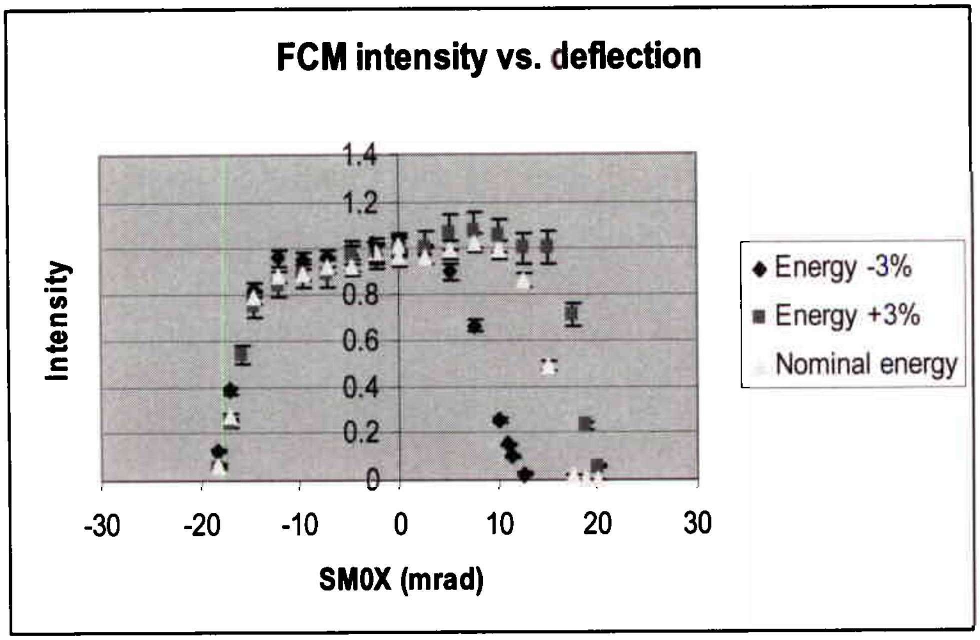

Fig 5b.

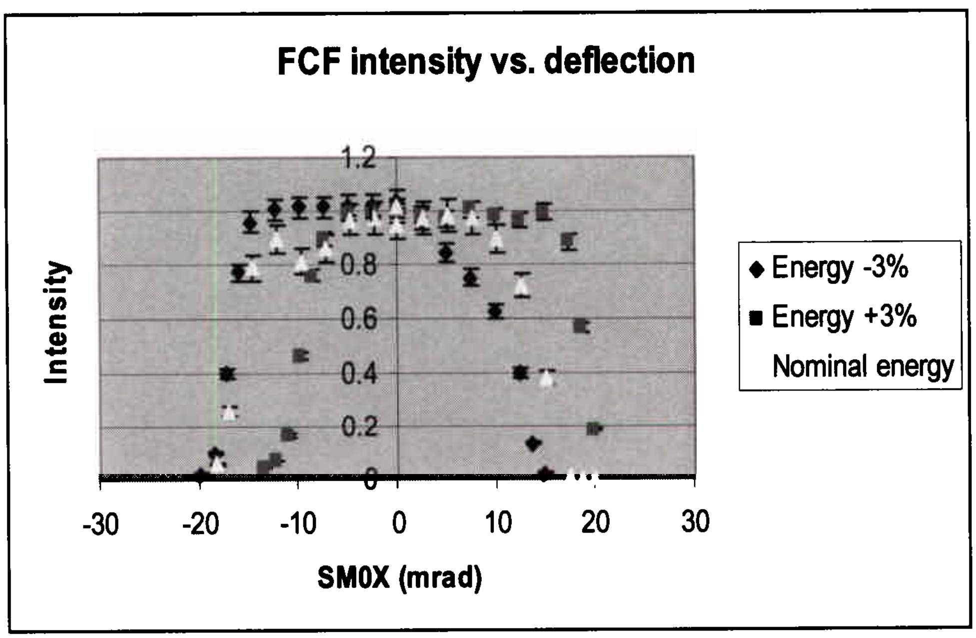

Fig 5c. All three figures are wobbler scans in the x direction, with three different energy settings at each cup.

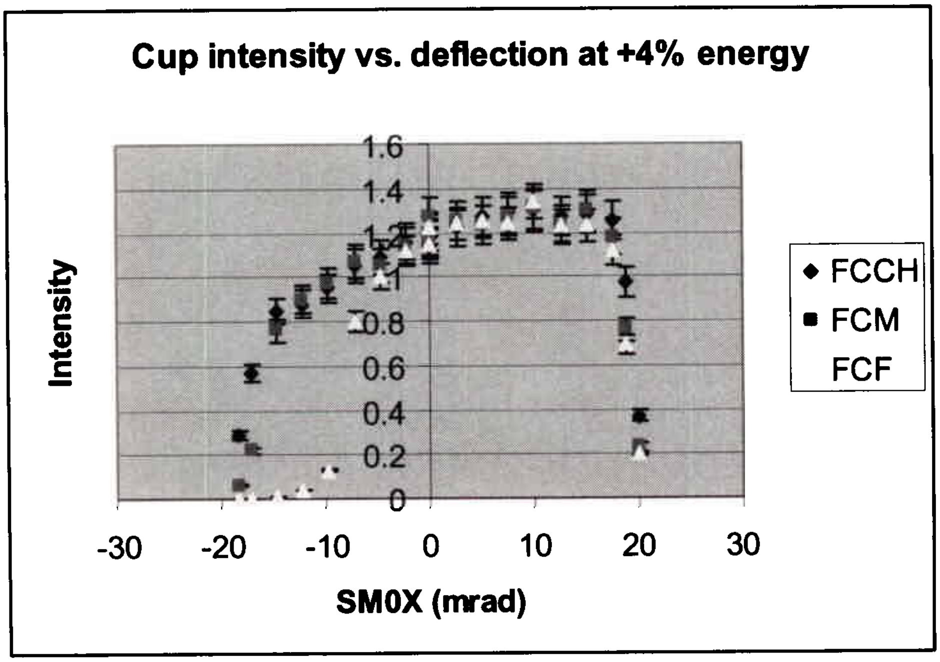

Fig 6a.

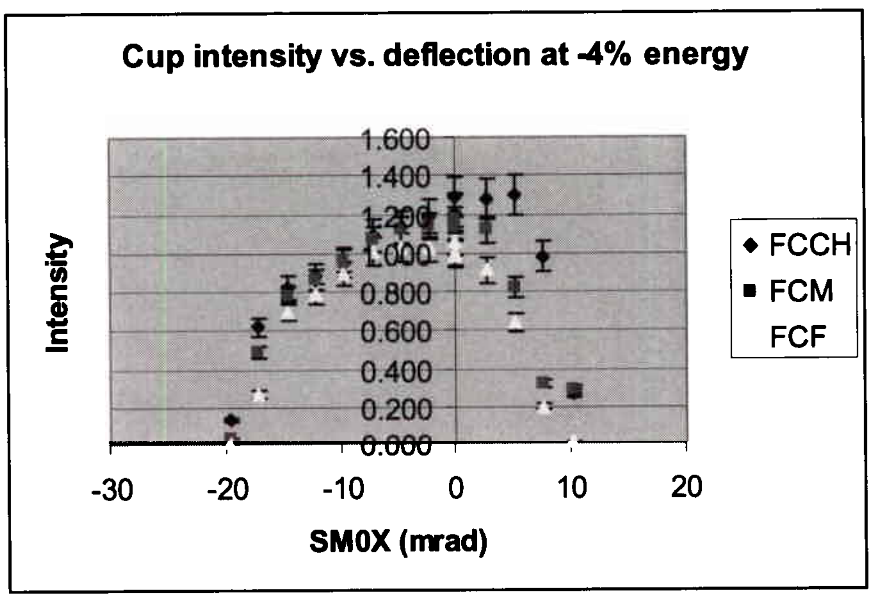

Fig 6b. Both graphs show wobbler scans in the x direction, at all three cups.

Ions deflected in the positive x direction show a loss of acceptance at nominal energy and lower energies than the separator is tuned for. In order to reduce this effect, various elements of the separator were adjusted, to change the path of the ion beam. A new path, it was hoped, would cause the beam to avoid whatever was blocking its path. MD1, SM1X and ED1 were all adjusted to try to increase FWHM at FCM. All of the configurations shifted the plot, but preserved the general shape. The FWHM was unchanged.

In an attempt to understand the acceptance of the separator further, the focus characteristics were examined at the three slit positions, Q1 and Q2 were adjusted to observe the effects of changing the focusing magnets on the acceptance and focus characteristics.

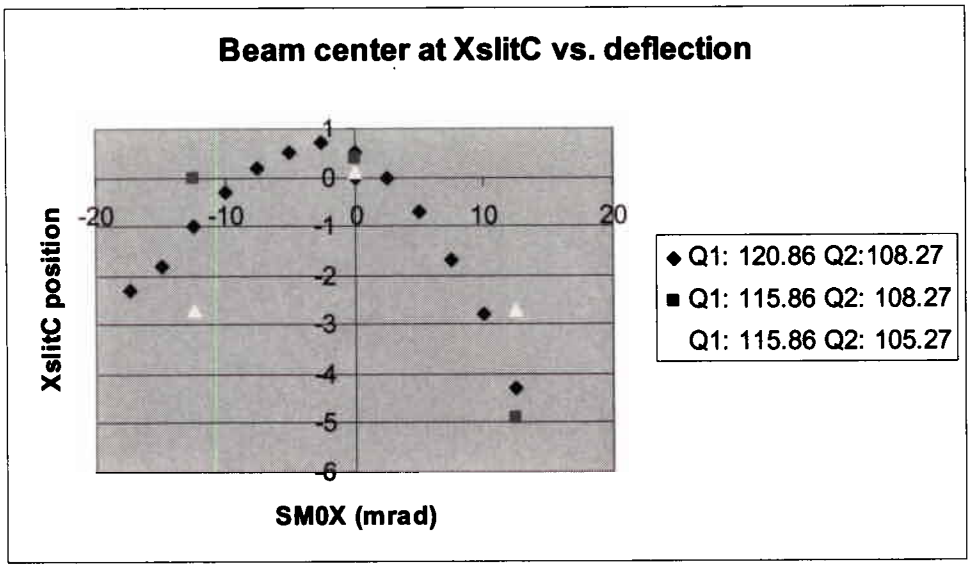

Fig 7a. Beam center position as a function of the x deflection.

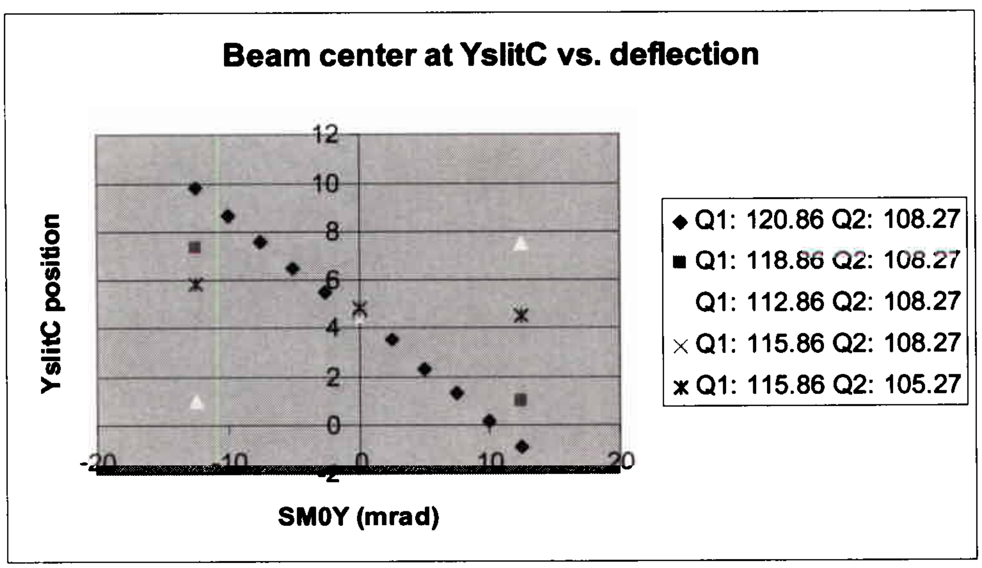

Fig 7b. Beam center position as a function of y deflection.

The focus characteristics were also observed at the mass and final slits. The sextupoles were checked to make sure they had an effect on the beam position at the slits. It was found that when Q1 was set to 115.86 and Q2 105.27, the charge slit focus became better, but it worsened the mass slit focus. These set points corresponded to 1754 G and 1692.7 G respectively, compared with the nominal tune of 1828 G and 1740 G respectively. To see the effect of quad tune on acceptance, the deflection scans were repeated at three different tunes.

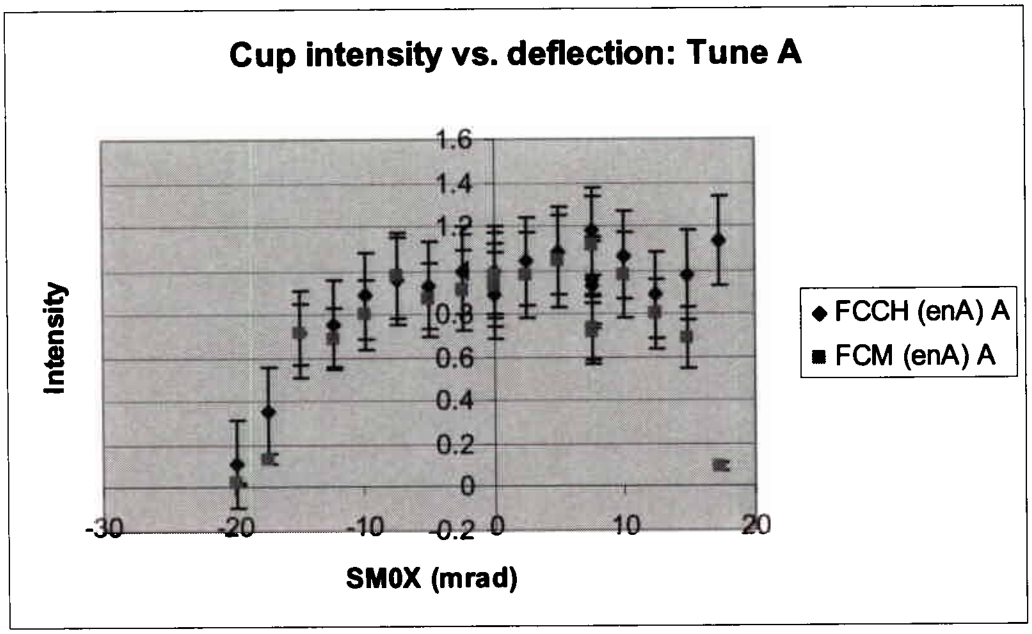

Fig 8a. Tune A is the normal tune, Q1: 1828 G, Q2: 1740 G.

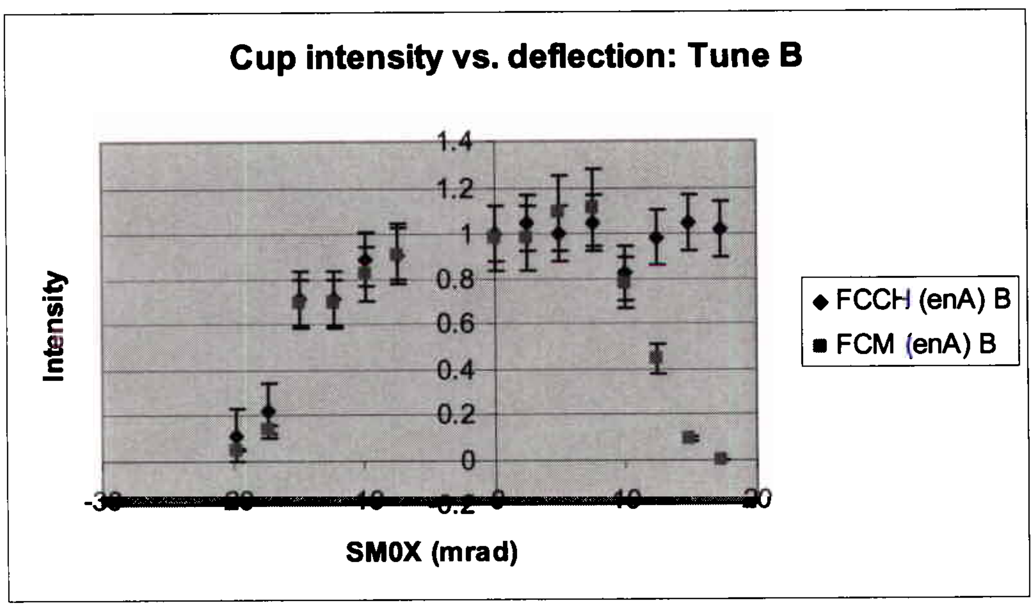

Fig 8b. Tune B is the 'better charge slit' tune, Q1: 1754 G, Q2: 1693 G.

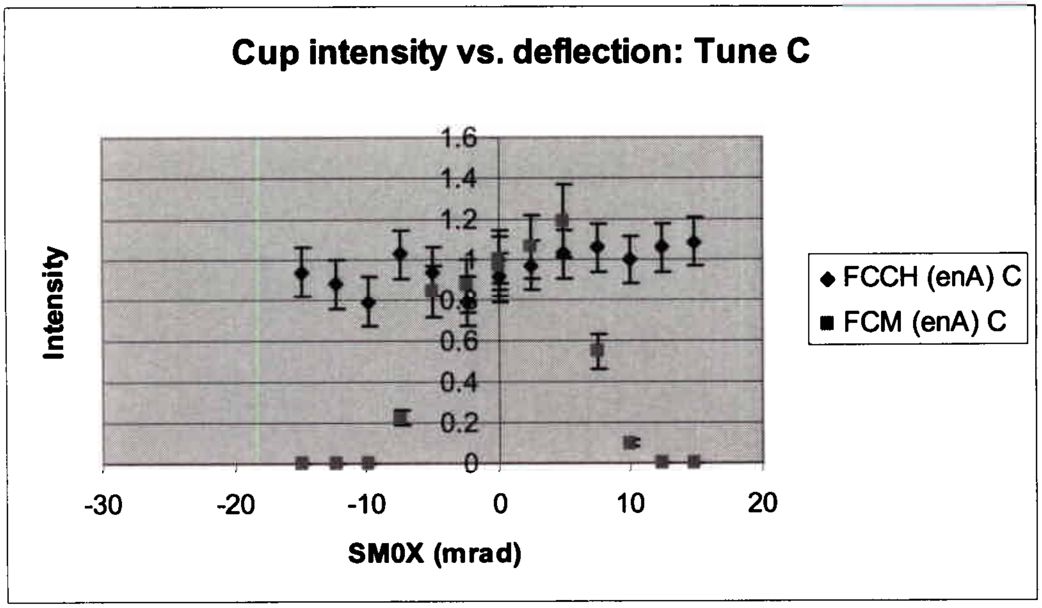

Fig 8c. Tune C is a seriously detuned scan, Q1: 1410 G, Q2: 1394 G.

After doing these studies, old experimental data was checked to look for evidence of asymmetry. It was expected that there would be a loss of left-going ions, corresponding to lower histogram peaks in the right-side gamma array and the right-side DSSSD. It was found that some data showed the ions 'falling off' the top of the DSSSD, or being deflected too far up, such that they were not hitting the end detector. To examine this, a study was done of DSSSD centroid position as a function of deflection. It was found that positive x deflection led to a significant lowering of the y position at the end detector. This coupling of x deflection with y position implied a problem with the setupoles, which affect second order terms in the optics, meaning x characteristics can affect y characteristics. This led to a check of the sextupole polarity, and SX3 and SX4 were found to have reversed polarities. This was changed and the end detector centroid position checked again as a function of deflection.

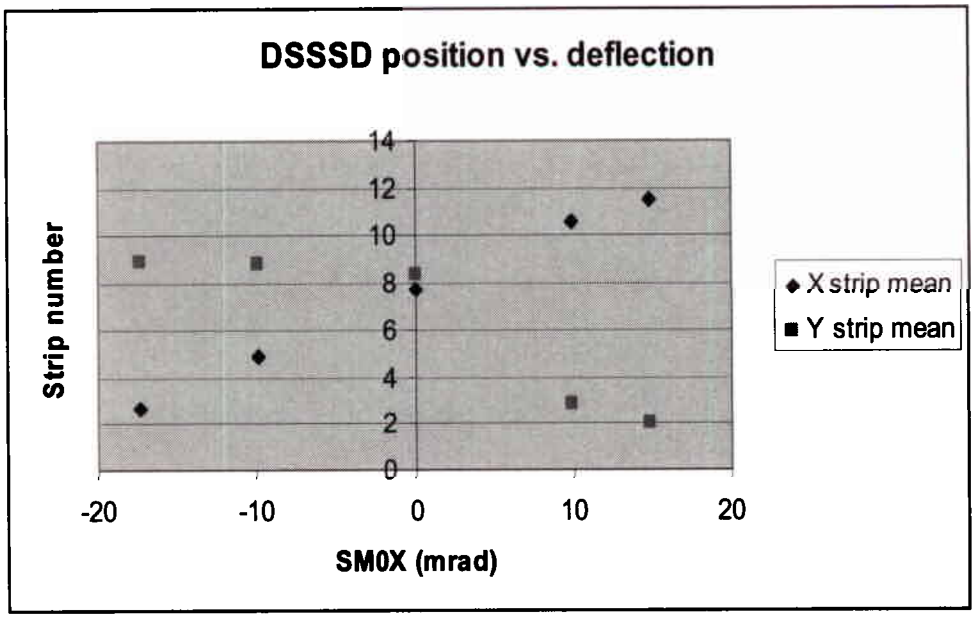

Fig 9a. End detector beam position against X deflection, before SX3 and SX4 fixed. The beam was 'falling off' the bottom of the detector at 10 mrad, strip 2.

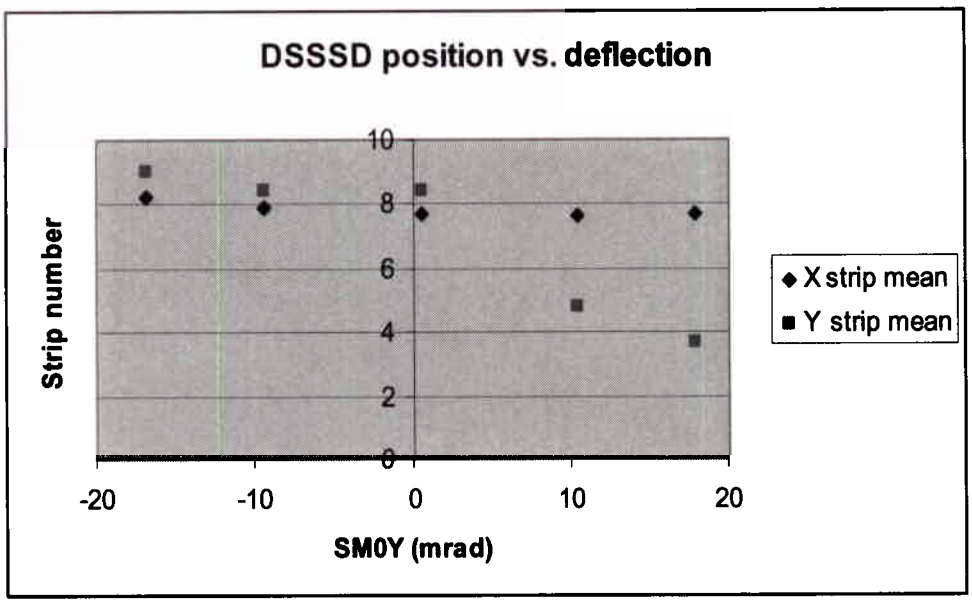

Fig 9b. End detector beam position against Y deflection, before SX3 and SX4 fixed.

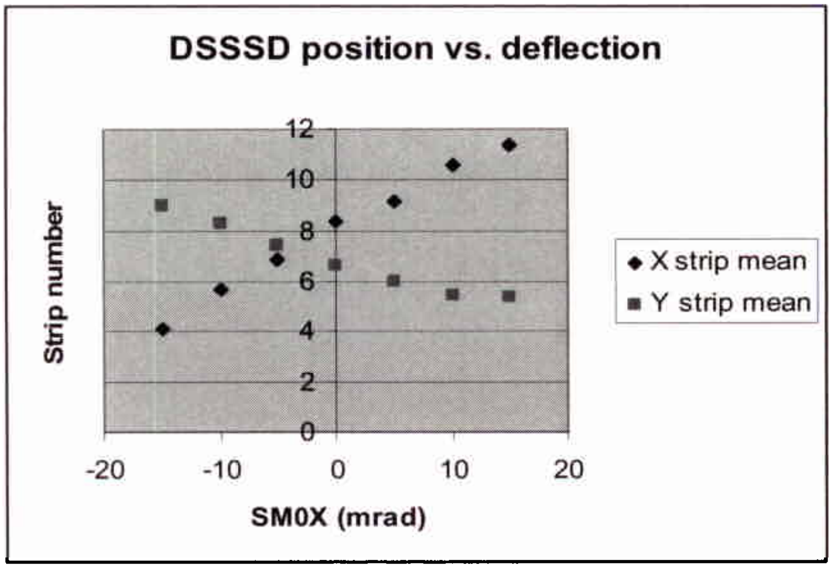

Fig 10a. End detector beam position against x deflection, after SX3 and SX4 fixed.

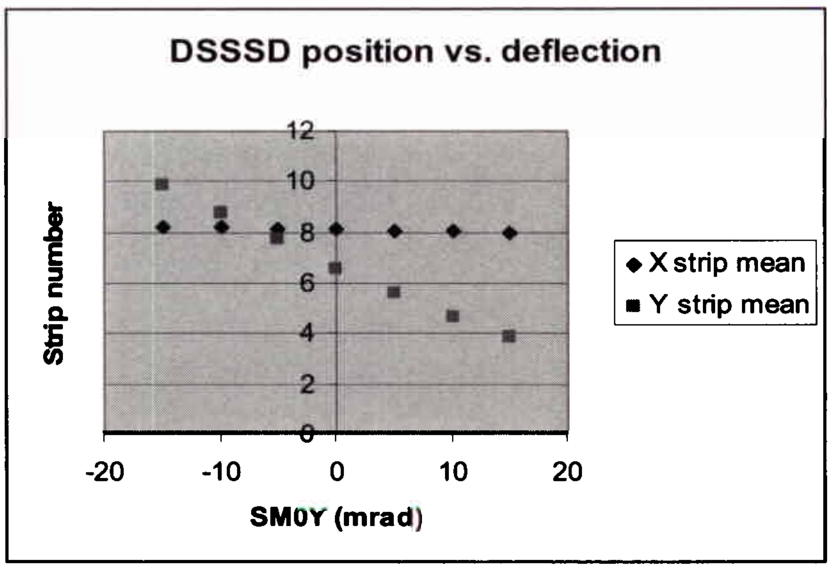

Fig 10b. End detector beam position against y deflection, after SX3 and SX4 fixed.

The DSSSD is located 750 mm behind XslitF, which is a focus. The optics specifications of the separator state that the angular magnification is 1.0 in the horizontal and -.56 in the vertical. From figures 9a, 9b and the strip width, 3 mm, the magnification can be calculated. The horizontal magnification was found to be .96 ± .06, and the vertical magnification -.82 ± .07.

Recommendations

Significant asymmetries were observed in the x acceptance of DRAGON. Losses are observed at around 15 mrad positive x deflection, and there is an energy dependence. This asymmetry has yet to be observed in the experimental data, although the $^{12}C(\alpha,\gamma)^{16}O$ shows an acceptance curve which may resemble the off-energy x deflection acceptance. Lower energy recoils seem to be lost in a comparison between observed and simulated data. Asymmetries have been observed in some ^{12}C-gamma array data which seem to be exactly opposite what is expected; losses seem to be observed for left-going gammas, meaning negatively x-deflected ions. The $^{13}C(p,\gamma)$ has a similar recoil cone, and some of the collected data seems to exhibit these effects. Other experiments have yet to be checked for these effects.

It remains unclear what exactly is causing the acceptance asymmetries; it certainly appears to affect the beam between FCCH and FCM. It is possible that part of the asymmetry is simply a characteristic of the separator optics, but this does not explain the whole effect. Energy acceptance is also clearly a factor. Changing the tune by trial and error does not seem plausible, but it has been suggested that two new quads between the target and Q1 could solve the problem.

Also, the ^{12}C could be run again on the 2+ resonance to look for these effects. It would be interesting to note if recoils are passing above the DSSSD, and if some of the 'missing' low energy recoils observed in current 12C data can be 'found' by tuning the separator to a 3% lower energy. Also, it would be interesting to see if fixing SX3 and SX4 changed the data significantly.

Another interesting question is how long SX3 and SX4 have been reversed. Preliminary attempts to determine this by comparing different data runs have been inconclusive.