

## SIMULTANEOUS INTERNAL AND EXTERNAL TARGETING AT THE AGS\*

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### Introduction

The development of the AGS Slow External Beam (SEB)<sup>1</sup> has posed problems of operational compatibility with the existing "flat top" internal targeting facility. During the past operating period, we have used two methods of sharing these facilities: (1) a running period where only internal targeting is performed followed by a period of only external targeting, and (2) alternate sharing of AGS pulses with internal targeting for T pulses followed by external beam for S pulses. These methods are most efficient in utilization of the available protons but are wasteful in terms of utilization of experimental equipment and personnel. Moreover, they are inefficient in proton utilization for cases where the intensity of the AGS beam is greater than required on the internal or external target alone. The AGS intensity has increased during the past year to a peak value of  $3 \cdot 10^{12}$  protons/pulse with  $\sim 2, 3 \cdot 10^{12}$  attainable regularly in operations. However, radiation damage to the machine is extensive at these higher intensities and it has been necessary to limit the internal target to  $\sim 1,5 \cdot 10^{12}$  protons/pulse. In the external beam it has been necessary in some experiments to reduce the intensity to  $\sim 7 \cdot 10^{11}$  to avoid excessive counting rates and deterioration of targets. These problems will become more severe when the AGS Conversion program<sup>2</sup> is completed with a design intensity of  $\sim 10^{13}$  protons/pulse. Obviously, we require a method of sharing protons among several targets during the same AGS pulse. For the immediate future a method of sharing between internal and ex-

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ternal targets is required; ultimately, we plan to discontinue internal targeting and share the external beam among several targets by beam-splitting techniques. Two methods of internal-external sharing on the same flat top were considered: (1) sequential, i. e., SEB followed by internal targeting, and (2) simultaneous targeting. The sequential method has disadvantages of (a) reducing the spill duration without a commensurate reduction in spill rate, and (b) requiring a dwell time on the flat top during which SEB components are turned off and internal targeting components are energized. This dwell time could be comparable to the 100 ms fall time of the SEB sextupole magnet current and thus a significant fraction of the present 500 ms flat top.

For the simultaneous method, we were concerned with dilution of the SEB emittance and reduction in extraction and targeting efficiency. We report here the results of vertical SEB emittance measurements for various fractions of beam internally targeted and data on SEB and total efficiency.

### Emittance of External Beam

Emittance measurements were performed by obtaining beam profiles in a special test channel of the external beam which contained an array of 12 insulated aluminum plate detectors<sup>3,4</sup> located 710 inches downstream of a quadrupole lens. The plates were 0.012 in. thick, 1 in. long, and inclined at 3° to the incident beam. A 0.012 in. steel foil biased at +60V was positioned between each insulated plate to prevent cross-talk. Current resulting from electrons emitted from a plate (typically ~10 nA for 10<sup>11</sup> protons/sec passing through the plate) produced a voltage across an RC network (1 ms time constant) shunting an operational amplifier. The signal was transmitted to a PDP-8 computer interface, amplified again, and read by the computer ADC in ~50 μs. A complete profile was obtained in ~0.6 ms and stored on magnetic tape.

The profiles were fitted on a CDC-6600 computer to an empirical, modified Lorentz function from which the half-width  $W$  at  $1/e^2$  of the profile peak was obtained. If we assume an elliptical emittance contour of the form<sup>5</sup>

$$(1) \quad \varepsilon = \beta x'^2 + 2\alpha x x' + \frac{(1+\alpha^2)}{\beta} x^2$$

with emittance  $E = \pi\varepsilon$ , then the half-width of the beam at the detector position can be related to the ellipse parameters  $\alpha$ ,  $\beta$ ,  $\varepsilon$  at the entrance of the quadrupole lens by Steffen's transformation<sup>6</sup>

$$(2) \quad W^2 = \left[ M_{1,2}^2 \beta - 2\alpha M_{11} M_{12} + \frac{(1+\alpha^2)}{\beta} M_{12}^2 \right] \varepsilon$$

where  $M_{11}$  and  $M_{12}$  are matrix elements of the transport matrix through the quadrupole and drift space. In previous<sup>7</sup> emittance determinations, we

obtained profiles for only three quadrupole strengths and solved Eq. (2) algebraically to obtain  $\varepsilon$ . The algebraic method, however, proved unreliable unless the three points are prudently chosen and accurately measured. More over, the algebraic method gives no information on the validity of the elliptical contour assumption. For the present data we obtained widths for many quadrupole strengths and fitted the data to Eq. (2) by a least squares method. The data and best fits are given in Fig. 1 for cases of internal target removed and with 51% of the beam interacting internally. Uncertainties in the data are rms deviations calculated from many profiles at each quadrupole setting. Corrections were applied for finite detector size<sup>7</sup>. The vertical emittances are

$$(3) \quad \begin{aligned} E_v &= (0,037 \pm 0,001)\pi \text{ inch-mrad} \quad \text{internal target removed} \\ F_v &= (0,068 \pm 0,003)\pi \text{ inch-mrad} \quad 51\% \text{ on internal target.} \end{aligned}$$

The quoted uncertainties in emittance do not include systematic errors. We have evidence from comparison of computer and hand fits that the computer widths may be too large by 5-10%. The data are well represented by Eq. (2) and thus the assumption of elliptical contours appears valid. Data analysis for horizontal emittance has not been completed.

In Fig. 2 we show profile width as a function of fraction of beam interacting internally for two quadrupole strengths. The nearly linear variation implies a quadratic dependence of emittance on internal target fraction.

#### Efficiency of SEB Extraction and Internal Targeting

For efficiency tests we measured the external beam intensity in a calibrated secondary emission chamber (SEC)<sup>8</sup> and monitored the interactions in the internal target with a counter telescope. The AGS circulating beam monitor (CBM)<sup>9</sup> measured the internal beam. The SEB efficiency was calculated from

$$(4) \quad \varepsilon_{\text{SEB}} = \text{SEC/CBM}(1 - f_{\text{int}})$$

for various fractions  $f_{\text{int}}$  of the beam targeted internally and is plotted in Fig. 3. The fraction  $f_{\text{int}}$  was calculated from the ratio of counter telescope counts with SEB sextupoles on and off and was varied by changing the position of the internal target. Corrections were applied to  $f_{\text{int}}$  for counter telescope efficiency variation with target position. Uncertainties in  $\varepsilon_{\text{SEB}}$  reflect only the scatter in SEC readings and do not include uncertainty in  $f_{\text{int}}$ . from Fig. 3, the SEB efficiency is seen to **increase** with fraction internally targeted. Although the fraction  $f_{\text{int}}$  used in Eq. (4) is only an estimate of the protons removed from the machine by the internal target, we feel that it is an underestimate and tath the increase in  $\varepsilon_{\text{SEB}}$  cannot be ascribed to uncertainty in  $f_{\text{int}}$ .

Additional tests were performed during AGS High Energy Physics operations to measure the overall efficiency of simultaneous targeting. For these tests it was necessary to install a  $\lambda/2$  orbit deformation centered at the internal target since the target position is determined by the directions of secondary beams. The internal target monitor was calibrated in terms of the targeting efficiency  $\epsilon_t^0$  with SEB components off. The SEB extraction efficiency with internal targeting off is denoted by  $\epsilon_s^0$ . The efficiencies measured for several different conditions are given in Table I.

Table I

Condition	Targeting Efficiency
A. Only SEB quadrupoles on	1,11 $\epsilon_t^0$
B. Only SEB $3\lambda/2$ orbit deformation on	0,89 $\epsilon_t^0$
C. Only SEB sextupoles off	0,91 $\epsilon_t^0$
D. Simultaneous SEB+internal targeting	0,52 $\epsilon_s^0$ + 0,39 $\epsilon_t^0$

Result A implies that  $\epsilon_t^0$  cannot be larger than 0,90. Using this value and the measured extraction efficiency  $\epsilon_s^0=0,70$  for this run, the overall targeting efficiency  $\epsilon_s+\epsilon_t=0,68$ . The measured extraction efficiency during the simultaneous run was  $\epsilon_s\approx 0,20$  and thus the maximum possible overall efficiency is  $(\epsilon_s+\epsilon_t)_{\max}=0,84$ . We therefore lost 16% of the circulating beam in simultaneous operation. These losses were detected by AGS radiation monitor counters to occur at the maximum inside excursions of the SEB  $3\lambda/2$  orbit deformation. We subsequently installed a  $\lambda/2$  deformation for the SEB to eliminate the loss.

Fig. 4 shows typical beam spills for simultaneous and non-simultaneous operations. During simultaneous operation the internal target orbit deformation is programmed by a spill counter signal in a servo loop.

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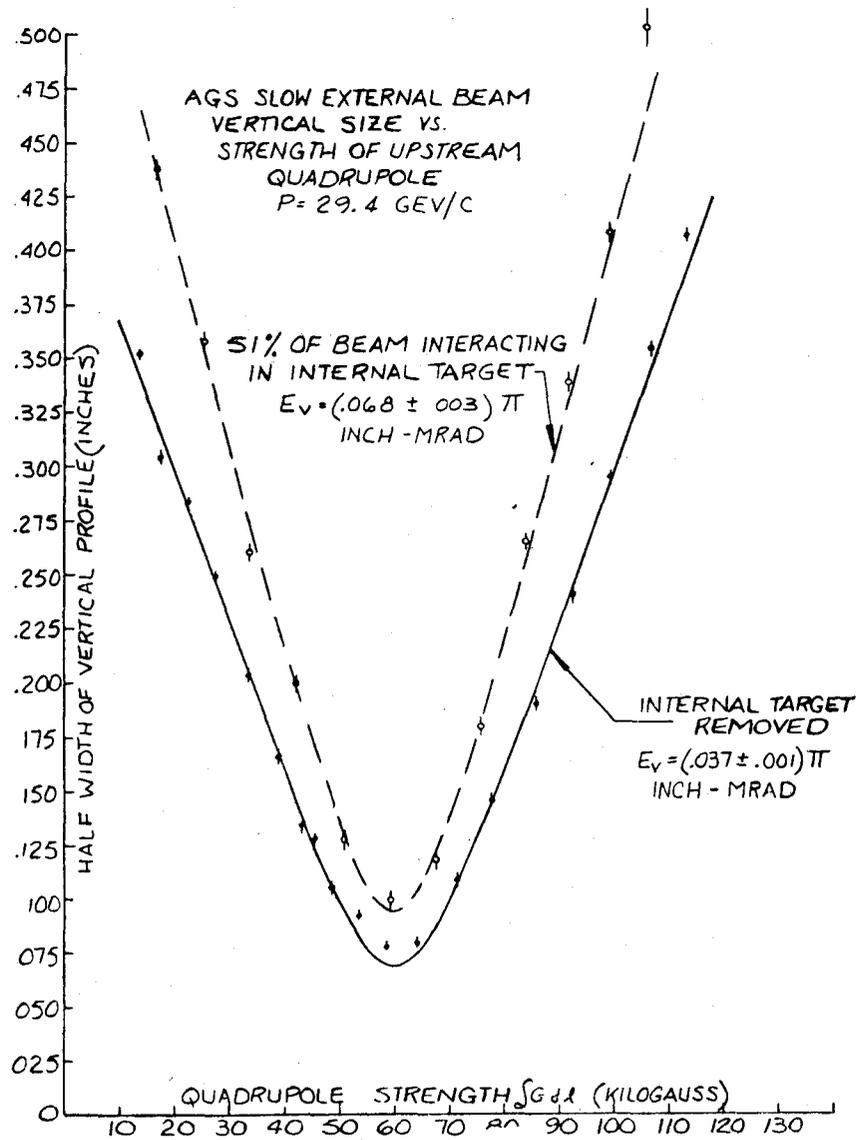


Fig. 1. Vertical half-width of AGS slow external beam as a function of strength of upstream quadrupole for (1) internal target removed and (2) 51% of circulating beam interacting in target. Curves are least squares fits to data using Eq. (2)

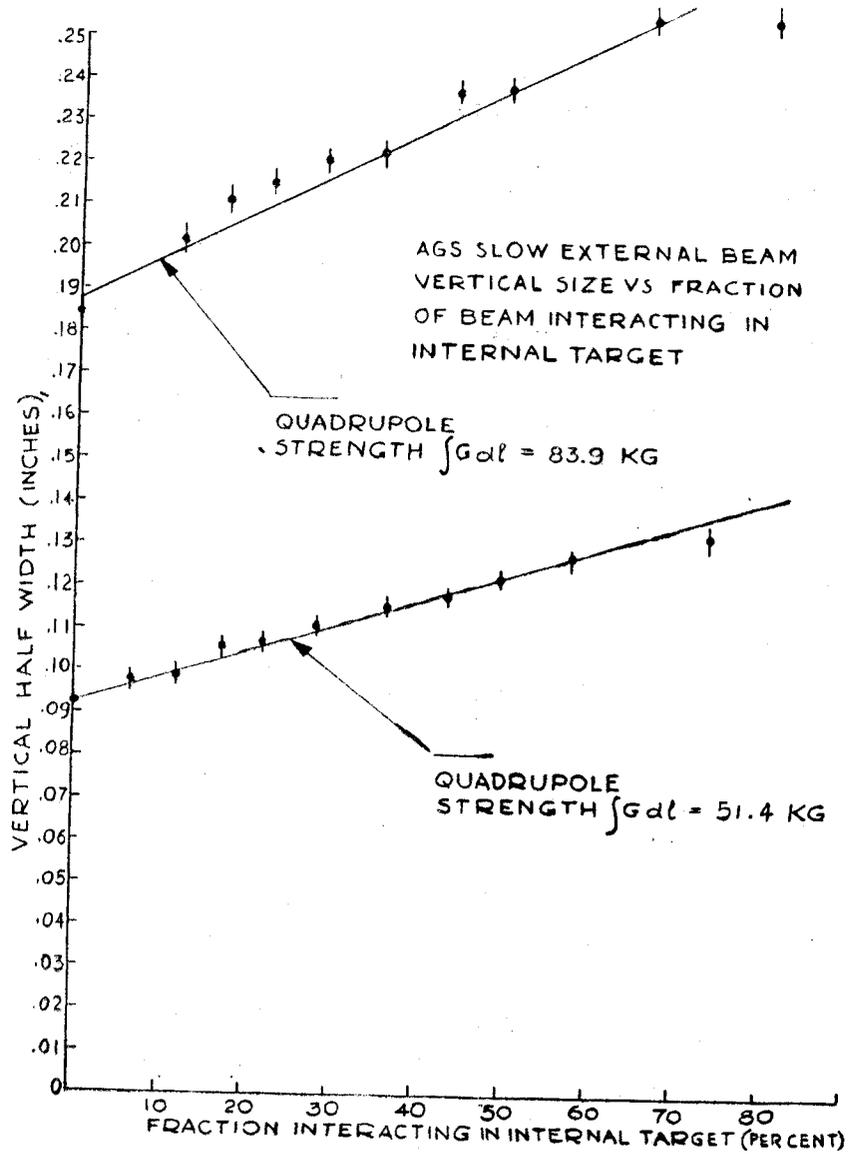


Fig. 2. Vertical half-width of AGS slow external beam as a function of fraction of circulating beam interacting in internal target for two values of upstream quadrupole strength.

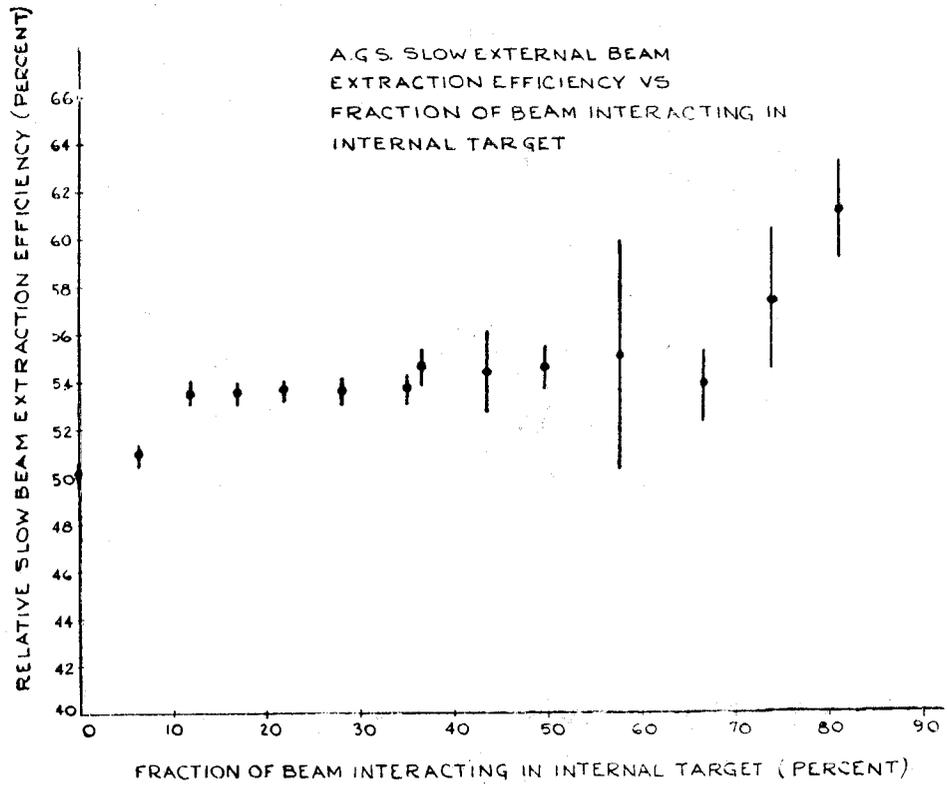


Fig. 3. Extraction efficiency of AGS slow external beam as a function of fraction of circulating beam interacting in internal target. Efficiencies were calculated from Eq. (4).

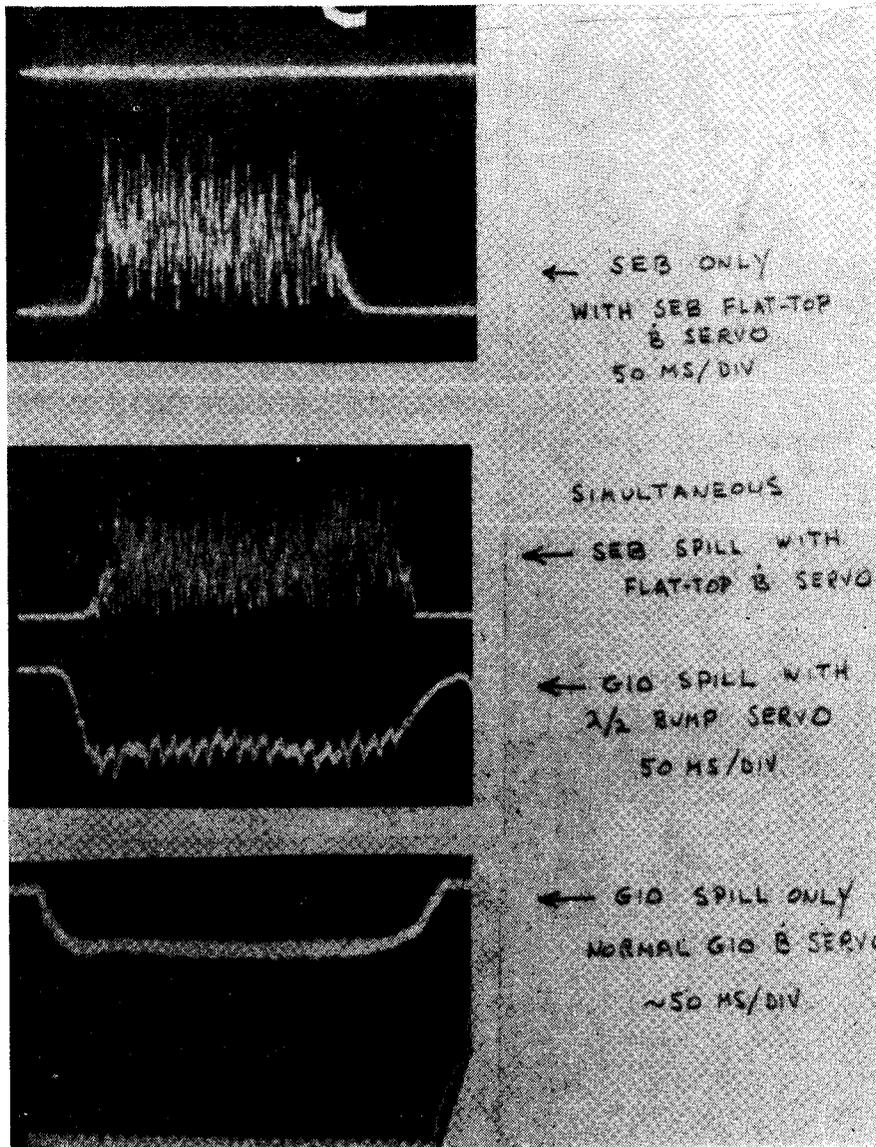


Fig. 4. Spill signals from AGS external and internal beam at horizontal speed of 50 ms/div. Top: External beam spill in ono-simultaneous mode. Center: External and internal simultaneous targeting with SEB spill servo controlling flat top current in AGS magnets and internal spill controlling  $\lambda/2$  orbit deformation in G-superperiod. Bottom: Internal targeting in non-simultaneous mode.

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## ДИСКУССИЯ

**Bovet:** Does your analytical method for computing the emittance imply a Lorentz distribution?

In a 1968 internal Report Guignard and myself described a method valid for any profile distribution.

**Blumberg:** The method implies that the phase space contour is elliptical but does not put any requirement on the shape of the profile. In our data analysis the Lorentzian appeared to fit the data better than a Gaussian: the choice of function was only empirical however.

**Bovet:** Your emittance measurement is made by tuning a quadrupole. In a normalized phase plane where the ellipse is a circle the best information is obtained when the profile measurements are made at a relative phase shift of  $60^\circ$ . The emittance circle is then circumscribed by a hexagone.

**Parain:** I have one remark and one question about the beam emittance measurement.

1. It is possible to use the same method with 3 detectors in a straight section near the crossover of the beam. In this case the same pulse is used for emittance measurement.

2. Did you try to determine the beam emittance as a function of the time tuning the spill?

**Blumberg:** No. In our data the emittance was measured about 200 msec after the spill started. We are, however, quite interested in the possibility of emittance variation with time and intend to make the measurements soon.

**Martin:** The measurement of beam shape at one position for 3 different quadrupole settings is equivalent to measurements at 3 different positions with the same quadrupole current. In the latter case it is easy to see that one must measure the curvature of the envelope to obtain an emittance. For this it is necessary that one of the measurements be near a waist in order to obtain any accuracy.