BNL-104179-2014-TECH

AGS.SN306;BNL-104179-2014-IR

Gold 77+ Extraction Momentum Measurement

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September 1993

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U.S. Department of Energy

USDOE Office of Science (SC)

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Date: 11/29/93 AGS Studies Report No. 306

AGS Complex Machine Studies **(AGS Studies Report No. 306)** **Title: Gold^{77+} Extraction Momentum Measurement**
Study Period: 28,29 September 1993
Participants: L. Ahrens, W. vanAsselt
Reported by: L. Ahrens
Machine: AGS
Beam: Au^{77+}
Tools: Tune meter, Frequency generator, Mt. range scope
Aim: Extraction momentum determination

I. Introduction

The exact value of the energy of the gold ions extracted from AGS for the 1993 heavy ion run was a point of discussion and debate during September. One method to determine this quantity is to simultaneously measure the beam revolution frequency and the orbit circumference at any time after the accelerating rf has been turned off. This note reports such a measurement made near the end of the run.

II. Method

We need to determine two quantities, the beam revolution frequency (or equivalently the bunch or rf frequency) and the orbit circumference (or equivalently the "radius" R, defined as the circumference divided by 2π). Given these, the beam velocity $\{=\beta*c\} = f_{rev}*(2\pi*R)$, and total momentum $P=(\beta)*(\gamma)*M$. M is the mass of Au^{77+}, namely 183.4339 GeV/c^2 (Gardner note 24Sep92). The two quantities are much easier to measure while the beam still retains the bunch structure imposed by the rf acceleration system. However as long as the rf is still active, the beam momentum may still be changing. The measurements of frequency and radius given below are made while the beam is debunching just after the accelerating rf is switched off.

What sort of accuracy is required? We are calculating the velocity and want to know the momentum. $dP/P = (\gamma)^2*d(\beta)/\beta$. γ at extraction is about 12. If we want a momentum error (dP/P) of less than 1%, we need to keep the error in β ($d\beta/\beta$) below 7×10^{-5}. This much fractional error in either the frequency or the radius will do the job. Putting in rough numbers for the rf frequency (4.5MHz) and AGS radius (128460 mm) we see that a 1% momentum error will result from a 300 Hz error in rf frequency or from a 9mm error in radius.

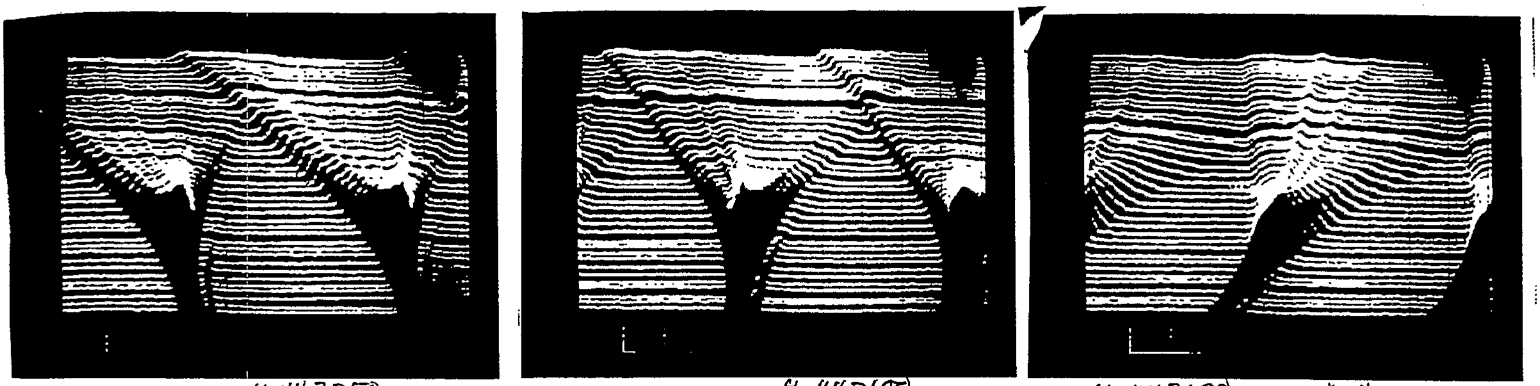


Figure 1. Mountain Range Displays of Debunching before AGS Extraction for several Mountain Range Trigger Frequencies

Frequency:

The bunch revolution frequency is obtained by adjusting the triggering frequency of the sweeps on a mountain range display of the debunching beam until the mountain range marches vertically up the display. Figure 1 shows such displays (taken on 29Sept93) for three settings of triggering frequency varying by -50 amd 80 Hz. Clearly the central frequency is determined to be 4.44210 MHz to better than 30 Hz. A 30 Hz error would result in a fractional momentum error of .1%. The speed with which the beam spreads out is a measure of the momentum spread intentionally put into the beam as part of the slow extraction process. A slip of the slowest particle relative to the fastest of 400 ns in 8 ms corresponds to a momentum difference between these two particles of .7%. (We take the transition gamma as 8.5 so the frequency slip factor $(1/(\gamma)^2-1/(\gamma_{tr})^2)$ is about .007). This sets a scale for the required accuracy of the momentum measurement. Pushing beyond .1% is gilding the lily; the frequency measurement is good enough.

Radius:

The second part of the problem is the determination of the orbit circumference or the associated "radius" at the time of the frequency measurement. An approximate value for this follows simply from the fact that the beam is surviving in the machine. The radius of the ideal central orbit in the AGS (which is usually referred to as R_0) is 128452.6 mm (Bleser note 11/26/90 "The Radius of the AGS" or AGS tech note #258). However, the AGS aperture allows the radius to be moved by about 2 cm either way from this, so the momentum is constrained only to about +/- 2%.

To do better, we make use of a measurement of the beam position. We cannot use the orbit acquisition system (an average of the 72 pue's for example; whose absolute position has been determined in the past) because the intensity of the gold beam is too low for this system to handle. We can use the average of the position at two pue's which provides a beam position input to the radial loop of the rf system. This analog signal is available via the mux in MCR. The pues are about half a betatron oscillation apart, making the average relatively insensitive to orbit distortions. This radial signal is flat with time in the vicinity of debunching, (figure 2) and persists well beyond the point where the rf itself is off. Now all we need is the offset and gain for this signal.

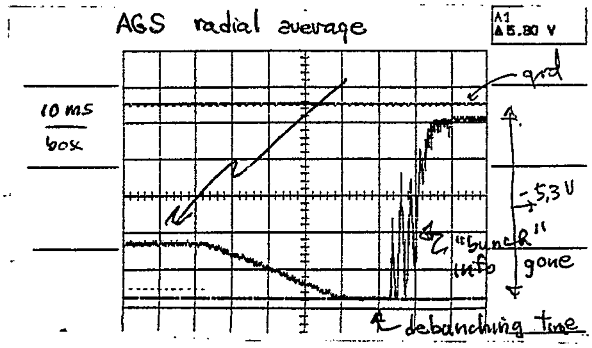


Figure 2. AGS Radial Average Signal Late in the Accel Cycle

A single auxiliary study gives us these numbers. The study is to measure the vertical betatron tune, the rf frequency, and the radial analog signal vs radial command just before extraction for two settings of the vertical sextupole string (table 1). From the change in frequency the gain of the radial signal (mm/Volt) can be extracted. Figure 3 shows that the data yields a straight line with a calibration of .2 Volts per mm. (for that signal, that day, that scope, that mux connection...).

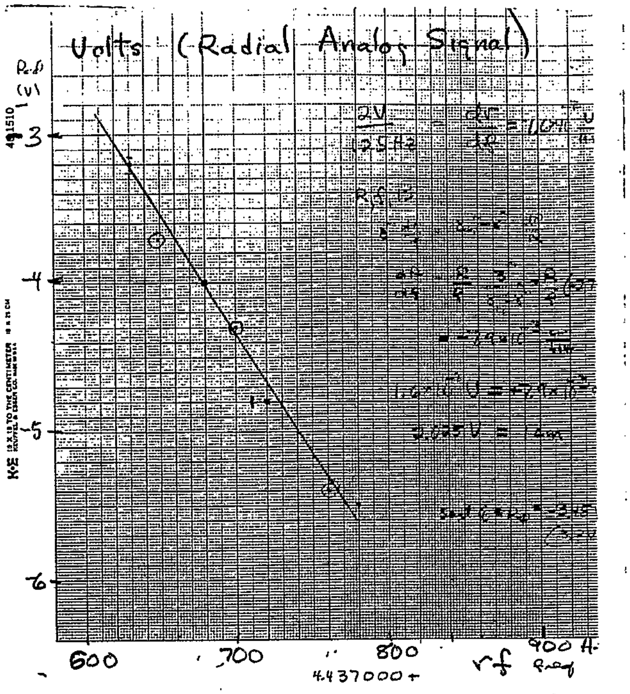
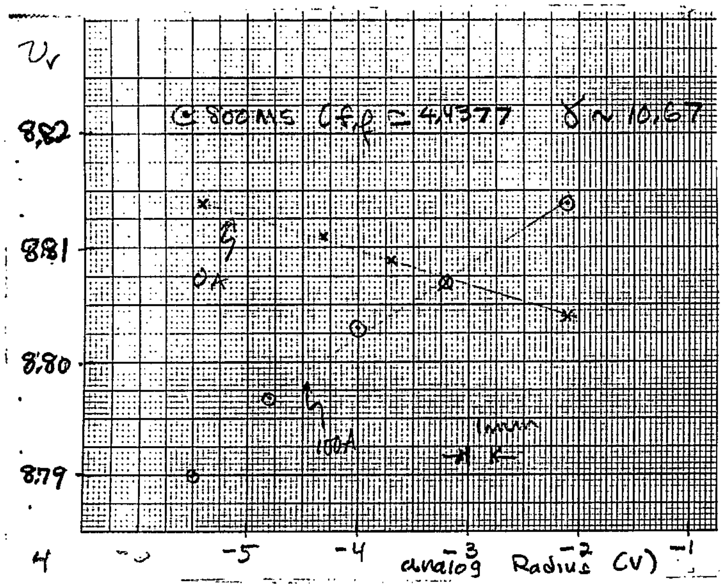


Figure 3. Analog Radial Signal vs RF Frequency Near Extraction

The curves of tune vs radius for two settings of the sextupoles allow a way to get to an absolute reference. The sextupoles in the string being powered are surveyed in on the R_0 orbit mentioned above. If the beam passed through the centers of all the sextupoles, the tune of the beam would be unaffected by current in the string. The radial position which gives no change in tune with sextupole current is R_0. That data is shown in Figure 4. If you are skeptical, we include figure 5, which comes from an old AGS study by Ratner (#258, April 1989). This figure is similar to figure 3, tune vs radius, but now with a whole series of settings of the current in same sextupole string as in figure 4, and the horizontal scale is the average of entire set of orbit pue's rather than just two. This data was taken under a high intensity situation so the orbit system was available. True the "center" seems to move around, but for the polarity of currents of the new study, the intersection is about -5.2mm from the pue zero. The pue average center lies 4.5 mm farther out in radius than R_0 (again see the Bleser note) which implies that the intersection point is .7 mm inside R_0. So there is consistency here at the 1 mm level.



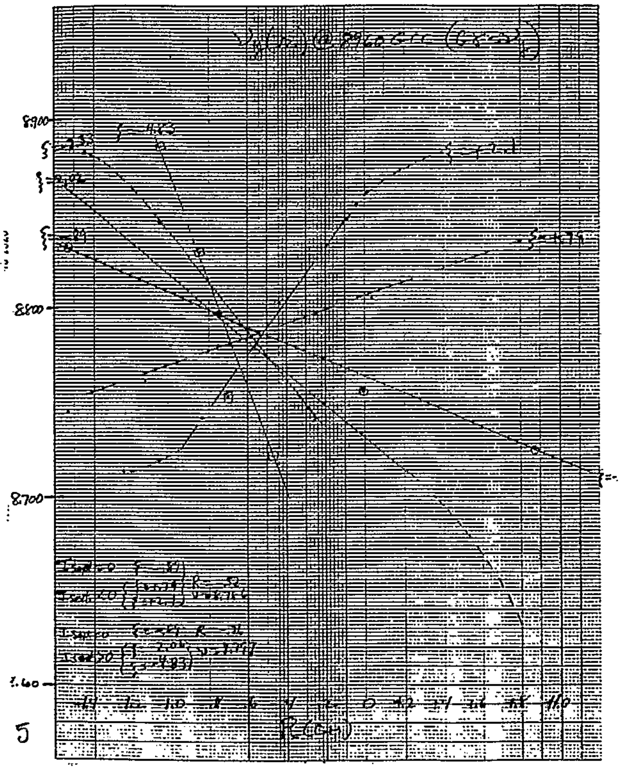


Figure 4. Tune vs Radius (this study)

Figure 5. Tune vs Radius (1989)

From figure 4 then, we conclude that R_0 corresponds to -3.2 Volts on the radial analog signal. The voltage actually present on this signal at extraction when we measured the frequency on 29Sept93 was -5.3+/-.1 Volts. Using the .2 Volt/mm slope; we conclude that the beam was 10.5(+/-1) mm inside of R_0 or at an absolute radius of 128442.1(+/-1) mm. The estimate of error in this extraction is not as clear as for the frequency; doubling it to 2mm seems reasonable, which makes radius determination the larger source of error.

Result:

Plugging in the above frequency, radius, and an error estimate of .25% gives a beta of .99649 and a total momentum for the Gold of 2184 GeV/c, or a momentum per nucleon of 11.086(+/-.03)GeV/c/nuc, (or a proton equivalent momentum of 28.36(+/-.07)GeV/c).

A set of measurements of frequency and radius were taken one day earlier than the results given above. The extracted frequency was 20 Hz higher, the radial analog signal was lower by .2 Volts. The resulting momentum per nucleon is 11.081 GeV/c/nuc which is encouraging in the sense that the variation at least over one day is small but of course the result doesn't reflect systematic errors.

One other number associated with the radial system can be extracted which may have relevance in the future, namely the value of the radial command which corresponds to R_0. From the data in the table, a fit between radial command and analog signal (Bleser) gives (Readback)= (-10.75)+(2.1)*(Command); from which the command slope comes out nearly .1 Volt/mm and R_0 corresponds to a command of +3.6.

Current Vert Sext (Amps)	Radial Cmd (Volts)	Radial Analog (Volts)	RF Frequency (MHz)	Vert Tune
100	2.4	-5.5	4.43778	8.790
	2.7	-4.8	4.43772	8.797
	3.1	-4.0	4.43768	8.803
	3.5	-3.2	4.43763	8.807
	4.0	-2.1	4.43759	8.814
0	2.5	-5.4	4.43776	8.814
	3.0	-4.3	4.43770	8.811
	3.25	-3.7	4.43765	8.809
	3.5	-3.2	4.43763	8.807
	4.0	-2.1	4.43759	8.804

Table 1. Vert Tune, RF Freq, and Radial Signal vs Radial Command