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AGS Main Magnet Field Measurement using Polarized Protons

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AGS Complex Machine Studies **(AGS Studies Report No.368)** **AGS Main Magnet Field Measurement using Polarized Protons**
Study Period: 1 - 14 November 1997
Participants: E880 Group
Reported by: L. Ahrens
Machine: AGS
Beam: Polarized Proton
Tools: Polarimeter, Polarized beam, frequency meter, Gauss Clock Courts, Main Magnet Program
Aim: To calibrate the Gauss Clock using Imperfection Spin Flips

Data Analysis of the (AGS Magnetic Field – Gauss Clock Counts – Polarization Implied Gamma) Data from the Oct-Nov 1997 Polarized Proton Run

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The successful acceleration of polarized protons in the AGS requires beam gymnastics (e.g. the pulsing of the A.C. dipole and the setting of measurement and extraction Main Magnet magnetic porches) be performed as the protons pass through the forest of resonances linked with the beam momentum. The final product – the polarization of the beam at extraction – provides the sensitive meter to measure that these gymnastics are indeed performed at the right momenta. The meter is not so convenient as for example the intensity to read, but it is accurate in a unique way as a measurer of momentum. From the point of view of polarized proton acceleration, we would like to be able to set the AGS up to produce polarized beam without having to tune each sensitive dance using the tedious measurement of the surviving polarization. Having reproducible calibrated "secondary" meters would allow this. If we understand these meters, they can be applied to all the uses made of the AGS. The secondary meters we are talking about, and which are the subject of this note, are the AGS Gauss Clock system and the AGS Main Magnet program – the hardware and the software. We don't get the answers here, but do present some curious data.

From the recent (November 1997) polarized proton run, we have a wealth of associated measurements of (Bprog, Frf, and Gauss clock counts (Up-Down)) taken while scanning the magnetic porch where polarization measurements were made. Bprog is the magnetic field requested in the AGS main magnet program – in this case the request for the extraction porch. Frf is the rf frequency measured from one of the available rf signals in MCR. The measurement is made over the last 20 ms before the rf is turned off, on the extraction porch. The Gauss clock counts (GCC) are the net number of "up" and "down" counts occurring over an interval starting at AGS T0 and ending 200 ms into the extraction magnetic porch where the polarization was measured. The final unique information associated with this set is the beam polarization measurement. During the acceleration cycle the partial snake causes the beam polarization to reverse each time the beam passes through a point where $G\gamma$ = an integer ,where $\gamma = (1-\beta^2)^{-1/2}$, and G is about 1.79. The first exercise for the present analysis is to extract the best values for the three parameters (Bprog, Frf, and GCC) for the available known "γ" points. For these points the knowledge of γ fixes the beam momentum. If the beam were on the AGS "central orbit" (defined as having circumference $2\pi r_0$), this would also uniquely specify the AGS magnetic field. Now the beam isn't constrained to be on the central orbit. However knowledge of Frf specifies what the beam equilibrium orbit circumference actually is. Then the difference of this orbit from the central orbit allows the just determined momentum to be adjusted to account for the radial shift and hence allows the magnetic field actually present to be determined. The last two steps require "outside" input: first of the central orbit of the machine (r_0 =12845.28cm) , then of the bend radius ρ - to connect P with B - (ρ=3361.352"=8537.834cm) , and in addition of γ_{tr} - to set the sensitivity of beam momentum to the radial shift from r_0. (γ_{tr} = 8.5) The numbers given here are those used in this analysis. The distances come from Bleser's Acc Division Tech Note # 215. Now we has the true magnetic fields for these points (which we refer to as $B(P(r_0))$) and can use them to calibrate both the Gauss clock and the main magnet field (Bprog).

First we look for the cleanest places where the polarization is seen to reverse – which correspond to places were $G\gamma$ passes through integers. We find 6 rather well defined (in the other three parameters) crossings. What does it mean cleanest? What the magnetic field scan qives is a pattern of polarization vs magnetic field setting which from a distance simply toggles -, +, -, + as the field is monotonically shifted, with a sign reversal about every 204 Gauss – the interval which corresponds (from apriori calibrations) to 1 unit of $G\gamma$. As one zeros in on any particular crossing a more complicated (polarization vs field) structure usually becomes visible which in particular undermines a fit of the polarization to a simple universal rounded square wave against field. This structure is understood as resulting from relatively weak intrinsic depolarization resonances coaxed out of obscurity and into influencing the beam by the very slow crossing speed implied by the porch location. The approach taken here is to choose the integer regions showing least structure and having actual polarization measurements near the apparent crossing points, (which set in fact satisfactorily covers the explored region) and select the two closest points bracketing the crossing. Now we define the "first pass" values for Bprog, Frf, and net GCC as the average at these two points weighted by the polarizations at the two points. This yields the six sets of [Bprog and GCC vs (B(P(ro))] which are derived from Gγ and Frf. A refined interpolation is eventually carried out from the results of the first pass fit. Table 1 gives the raw data; table 2 the extracted six points.

Ggamma	Frf(MHz)	GCC	Bprog(KG)	analy pwr
31	2.9664100	104476	6.275	-2.4
	2.9664930	105448	6.325	1.4
32	2.9667280	108550	6.475	2.5
	2.9668000	109323	6.525	-2.7
40	2.9684430	140557	8.145	3.9
	2.9684620	141040	8.170	-0.6
41	2.9685908	144603	8.354	-3.9
	2.9686074	145091	8.379	2.4
46	2.9691761	164724	9.390	-2.1
	2.9691848	165075	9.408	1.8
47	2.9692718	168704	9.594	2.2
	2.9692831	169200	9.620	-3.3

Table 1 The raw Data used for the Determination of $B(P(r_0))$

Bprog Kgauss	Ggam	gamma	p GeV/c	frf MHz	rad cm	dR cm	dP to r0	p(ro) at ro	B(p(r0)) Kgauss	GCC
6.303	31	17.291388	16.19218	2.966456	12845.93	0.646112	-0.05884	16.13333	6.303119	105020.3
6.505	32	17.849174	16.71623	2.966771	12845.89	0.609271	-0.05729	16.65894	6.508471	109013.8
8.165	40	22.311468	20.90713	2.968458	12845.86	0.581987	-0.06844	20.83869	8.141451	140950.6
8.372	41	22.869255	21.43084	2.968602	12845.86	0.581949	-0.07015	21.36069	8.345394	144944.6
9.399	46	25.658188	24.04909	2.969181	12845.89	0.609283	-0.08242	23.96668	9.363524	164906.5
9.604	47	26.215975	24.57269	2.969276	12845.89	0.607113	-0.08391	24.48878	9.567502	168897.4

Table 2 The Derived Set of Variables at Points of Known Gamma

The equilibrium orbit circumference derived from each set gives both encouragement and raises a question. The calculation takes only the postulated value for γ and the measured rf frequency and yields the circumference (displayed by convention as an effective radius). The result, for all six points, agree to within .05 cm. Further the reported value is .6 cm greater than the central value ($= r_0$). So the value agrees very well; what is the problem? Only this, the radial loop has the ability to shift this radius. Now the same reference was set to the loop for most of the data, but we believe the request to the loop was for a lower reference (0 V vs +.225 V) for the two points near Gγ=30. Further we believe the calibration for the loop corresponded to a shift of (-3cm/Volt); which would imply the radius should be larger for the first two points by .7cm. We can find wiggle room of about .2 cm in the uncertainty in the rf frequency; not enough to explain anything. Perhaps the radial command was not zero.

The six extracted B values (labeled $B(P(r_0))$ - meaning B derived from P (the momentum from γ) but evaluated at r_0 (that is on the design central orbit rather than the orbit implied by the rf frequency measurement) - can then by compared with the associated GCC and Bprog values. Consideration of the errors in the rf frequencies at the point pairs imply that uncertainties in the following analysis are dominated by the uncertainty in where between the pairs of measured points the crossing actually occurs. The data cover a healthy field range, nearly 4 KGauss, with the highest porch at about 9.5 KGauss. Attempting to extract linear relationships among the various parameters is interesting.

First we compare the Gauss Clock (up-down) counts with the $B(P(r_0))$ values. There is no systematic deviation from linearity over the region covered by the polarization measurements as shown in figure 1. The "error bars" in the figure correspond to the assumption that we can actually localize the Gauss Clock value only to the closest points in the field scan. That the data does not show excursions consistent with the error bars is expected. Our interpolation should be an improvement over just taking the nearest point. The least squares fit (ignoring these error bars) gives **GCC = 18355** (167)+**19570** (20)***B(P(r_0)).** The numbers inside the parentheses are the "standard errors" reported by the spreadsheet fit. The coefficient 19570 means 19.57 GCC are worth 1 Gauss – close to the system design number of 20, and not far from the value used for setting the A.C. dipole pulsing times during this run (19.39 GCC/Gauss). However the difference is important for the polarized setup. The question can be asked, is there a uyniversal calibration. Is the field change between Gauss clock counts rate purely dependent on the field change and independent of other factors – e.g. the rate of field change. We can investigate this a bit from this data. There is one other point where the field is known, namely is at AGS injection. Here we do not know γ. We do know the rf frequency and at least roughly the circumference. From these two numbers (Frf = 2.7478+/-.0002 MHz, R= r_0 +/- 2 cm) we can conclude that the field at injection was 886 +/- 9 Gauss where the error from the radius dominates. Since by definition the number of GCC at the start of the cycle is zero, if the clock were linear all the way down our fit to the polarization points would predict a field at injection – namely 938 Gauss. This field is then about 50 Gauss or 1000 GCC above the actual field. We have too few net counts. The "sense" of this problem is consistent with the smaller calibration value used during the run, which was derived from the average value from injection up to the $G\gamma = 31$ flip measurement. Figure 1 includes this point. The error bar is due to the uncertainty in the beam radius at injection – and assumes the 2 cm value mentioned above.

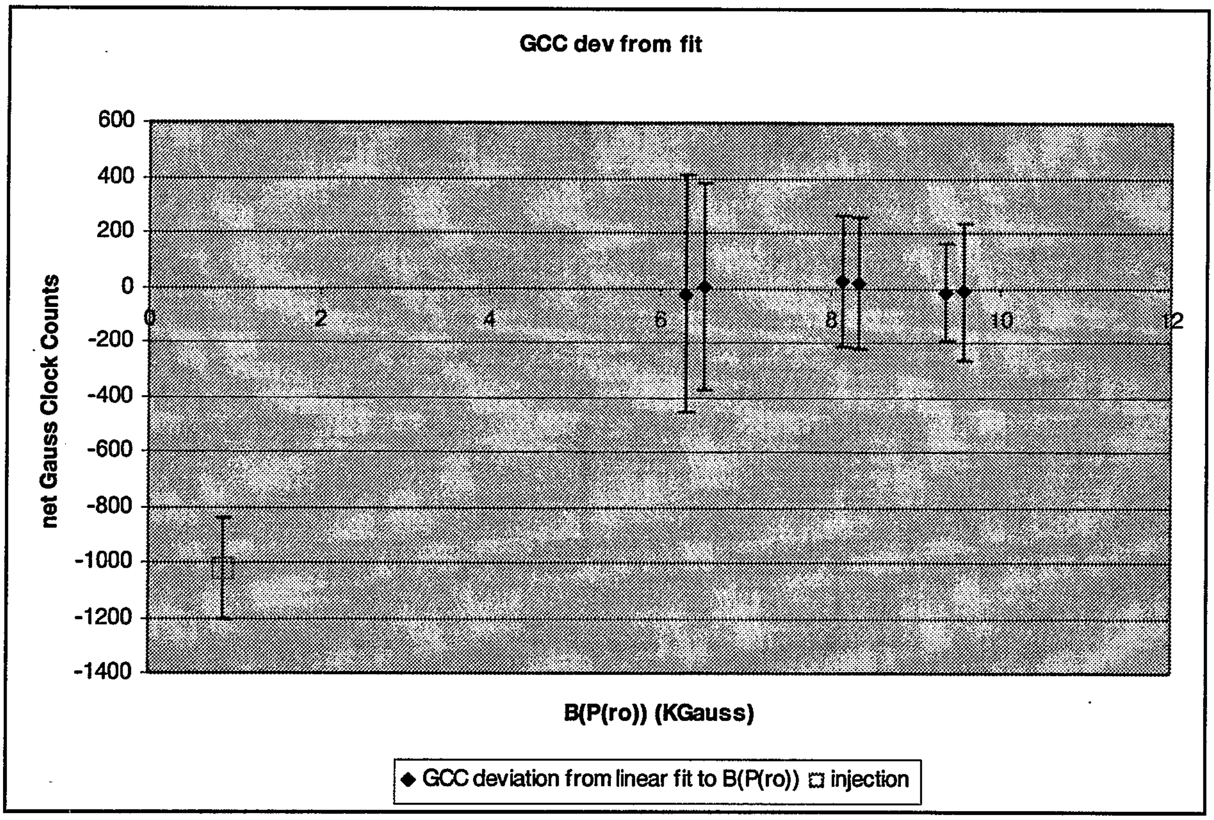

Figure 1 The GCC Deviation from a Linear Fit for the B(P(ro)) Data Set . GCC = -18355+19570*B if only the polarization data is used in the fit.

Next we compare the Bprog with B(P(r_0)). The data is shown in figure 2. Again the "error bars" are the extreme program values associated with the closest pair of input points for each evaluation and again these are too big if a linear result is in fact truth. A least squares fit gives **Bprog = -.0806** (.008)+(**1.0125** (.001)***B(P(r_0))**). Again there is no systematic deviation from linearity within the six points derived from the polarization measurements. There is a systematic disagreement between the field expected from the program and the field derived from the (gamma,Frf) pair, which curiously goes through zero for the points near 6.5 KGauss. And again we can ask what this relation (between Bprog and the B(P(r_0))) would claim for injection were it to hold to there. Bprog at injection is set to 878 Gauss. Inserting this gives a predicted field at injection of 947 Gauss, again about 50 Gauss above the expected field. The injection point is added to figure 2.

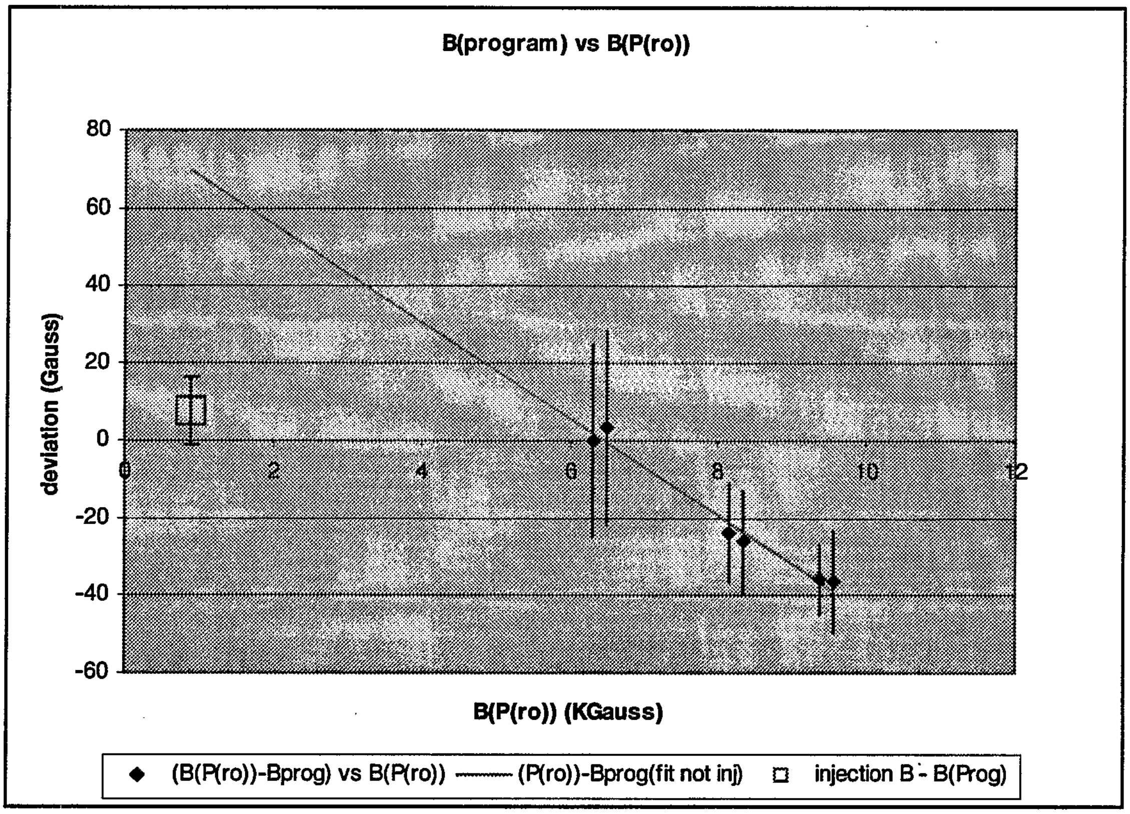

Figure 2 The Deviation of Bprog from a Least- Squares fit of Bprog to B(P(r_0)), with the Injection Point Added. The fit to the six polarization points is shown. The equation of the fit is : Bprog = -.0806+1.0125*B(P(r_0)).

We note, somewhat grimly, that both the Gauss Clock counts and the B program when fit linearly just to the polarization data predict an injection field high by about 50 Gauss. Could there be a systematic problem with the analysis. Can the main magnet program and the Gauss clock counts conspire to both equally misrepresent the true average field seen by the beam – in a linear fashion – from 6 toe 10 KGauss? To continue in this line, we fit the Gauss Clock counts against the Bprog settings (using the six points, though this correlation has no need of the polarization intermediary). The fit yields the equation GCC= -16797 (192) + 19329(23)*Bprog. Plugging in 0 GCC (injection) gives a predicted Bprog at injection of 869+/-10 Gauss compared to the set value of 878 Gauss, agreement acceptable with the fit. Figure 3 shows the usual plot of data against fit, only now the "nearest measurement" error bars are not included. The location of the injection point is consistent with the scatter in the six polarization points.

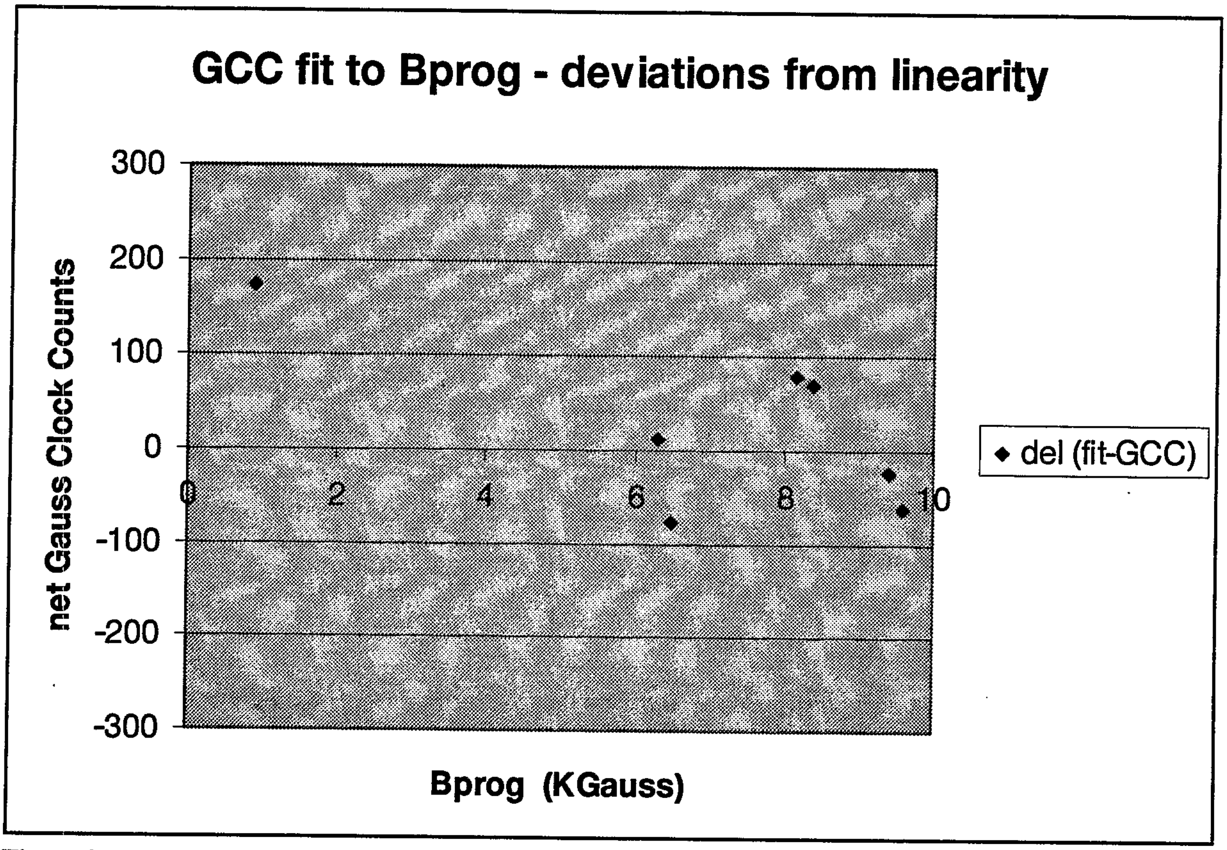

Figure 3 Gauss Clock Counts Fit to the Bprog Settings for the Six Polarization Points The deviations of the points from the fit, as well as the deviation at injection (which point was not included in the fit) are shown. The fit: GCC = 16797+19329*Bprog.

From this set of data one might suspect that the two parameters (GCC and Bprog) stay linearly locked over the entire acceleration cycle. So a consistent picture would have the change in field in the reference magnet (which is what is measured by the Gauss Clock), agreeing with the change in Bprog throughout the cycle. The field the beam sees nearly agrees with Bprog at injection and again at 6.5 KGauss but moves quite linearly down from Bprog (and from the reference magnet field if the above conjecture were true) beyond 6.5 KGauss. A model having the $B(P(r_0)$ (or equivalently "the average magnetic field seen by the beam") rising above Bprog for a while between injection and 6.5 KGauss is not ruled out, and at least avoids a discontinuous slope at about 6.5 KGauss. Having polarization points (crossing the imperfections, with Frf measured) between injection and 6.5 Kgauss would add some light. Even more interesting is the high field end. Is the apparent linear character of the data just a result of the street light we happen to be standing under?

At the moment this is all somewhat confusing. We do one other thing. For the November 1997 polarized proton run we would like a connection between the setting put into the Gauss line and $G\gamma$. Since we stay at a fixed radius for the measurement magnetic porches during the run, we may as well just work there. We simply fit GCC against the six $G\gamma$'s. We find: GCC = -18745 + 3992*$G\gamma$. Now an event on the Gauss line will occur when the GCC takes the value set in the Gauss Line Event less the offset put in for the dwell field, which offset (an SLD known as "calibrate") was set to 17150 counts for the November '97 run. Adding this gives: **$G\gamma$ = .4 + (2.5×10^{-4})*(Gauss Line Event setting).**