Beam Parameter Specifications for the G^0 Experiment (Back Angle running)

From: R. Carlini, S. Page, M. Pitt for the G^0 collaboration
To: Hari Areti, Matt Poelker, Michael Tiefenback
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This is our response to the request for a beam parameter specification sheet for the G^0 experiment in its backward angle mode of running. The parameters and discussion in this document are for the most part identical to that in the document we provided the lab for the forward angle run. Here is a summary of the major changes:

1. The beam time structure will be the normal 499 MHz time structure (rather than the 31 MHz time structure from the forward angle run. The maximum desired current will be 100 μA, while the nominal current will be 80 μA.
2. The requirements on maximum allowed run-averaged helicity-correlation for energy, angle, current, and position have been relaxed by a factor of 2 relative to the forward angle run. This is primarily because the measured asymmetries in the back angle mode are larger than those for the forward angle mode.
3. The discussion of “betatron match” or “adiabatic damping” in point 11 has been updated to reflect the numbers observed during the forward angle running. We continue to support any development time that can be given to Y. Chao for further understanding and control of this issue.
4. A new point (point 12) has been added for further clarification of our requirements regarding beam halo.

Our beam property requirements are summarized in Table 1. For each beam property, we list requirements in the categories defined below. Some of the beam requirements are taken directly from a table prepared (10/31/01) by J-C. Denard that summarized the work of the committee that recently determined standard parameters for beam delivery.

Categories:

1. **Nominal value:** This is the usual desired central value of the beam property.
2. **Maximum deviation from nominal (DC):** This is how far the DC (averaged over several seconds; ie. EPICS update timescale) central value of the beam property can drift from the nominal value before corrective action is required.
3. **Maximum noise at the helicity reversal frequency:** Operationally, we integrate the signal from any given beam property over a 33 msec time period. Then we form differences between two successive 33 msec integration periods. The standard deviation of the distribution of those differences is what we refer to as the “noise at the helicity reversal frequency”. It needs to be kept small enough so that we can measure helicity-correlated position differences and current asymmetries accurately enough to do feedback. The values quoted in the table are already typically

achieved, with the exception of the current stability with the G^0 laser which is not known yet.

4. **Maximum noise at all other frequencies:** This is the upper limit on the random noise in a given beam property at frequencies other than the helicity reversal frequency. (for example, 60 Hz noise and higher harmonics)
5. **Maximum allowed run-averaged helicity-correlation:** This refers to the maximum value of the helicity-correlated difference (or asymmetry) that can be tolerated in that beam property after averaging over the entire 700 hour run. This assumes that injector-based helicity-correlated feedback systems will be in place to achieve these values. We are participating with the injector group to develop and test systems to do this prior to our run. It should be noted that the run-averaged values listed in the table were achieved during the 1999 HAPPEX run with a strained GaAs crystal.

   To clarify this category a little better, we consider the specific example of helicity-correlated differences in the beam position. Assuming that the fluctuations in the beam position at the reversal frequency are 20 μ, we can determine the helicity-correlated beam position difference in a 1 hour run with a precision of ±86 nm. The feedback system for this (piezoelectric mirror) would likely be updated on this timescale. If we then look at the distribution of all 700 one hour long helicity-correlated position differences measurements at the end of the run, it would roughly be a Gaussian with a centroid that is less than the number in Table 1 (<20 nm) and a standard deviation around 86 nm. So it is difficult to specify a "maximum tolerable" position difference in 1 hour, since statistics dictates that there will occasionally be a large one by chance. One needs to average the data over a reasonable timescale (say 8 hours) to determine if we have a problem that needs corrective action.

Table 1: Beam property specification table for G^0. Definition of the various categories can be found in the text.

Beam Property	Nominal value	Maximum deviation from nominal (DC)	Maximum noise at the helicity reversal frequency	Maximum noise at all other frequencies	Maximum allowed run-averaged helicity-corrrelation
Energy(average)	3.0 GeV	± 0.01 %	0.001% (35μ at 35mm/%)	0.01% (350 μ at 35 mm/%)	$<5 \times 10^{-8}$ 180 nm at 35 mm/%
Energy spread (1σ)	$\sigma_E/E < 5 \times 10^{-5}$	$\sigma_E/E < 5 \times 10^{-5}$			
CW average current	80 μA	± 5.0 %	0.2%	1.0%	< 2 ppm
Position at G^0 target	"0"	± 0.2 mm	20 μ	0.2 mm	< 40 nm
Angle at G^0 target	"0"	± 0.050 mr	2 μr	0.02 mr	< 4 nr
Angular divergence at G^0 target	$\sigma_{x'}, \sigma_y < 100$ μr	± 50%			
rms size (unrastered) at G^0 target	< 200 μ	± 25%	20 μ	0.2 mm	< 4 μ
Polarization	> 70%				
Beam halo at G^0 target	$< 1 \times 10^{-6}$ outside of a 3 mm radius				< 0.2% of nominal halo tolerance

Other considerations and clarifications:

1. **Basic beam tune:** The tune should be achromatic at the target (< 1 mm/% dispersion) with large enough dispersion (35 mm/%) at the center of the Hall C arc to make an accurate relative energy measurement.
2. **Raster pattern:** The raster for G^0 is being developed by Chen Yan. The current specifications call for a square pattern with raster frequencies of f_x=25 kHz and f_y=25.02 kHz. The maximum length per side of the square is 3 mm.
3. **Helicity-defining Pockels cell:** The laser arrangement should be set up so that the Hall C beam is on the center of the Pockels cell, and the Pockels cell should be adjusted to provide the maximum possible circular polarization for the Hall C beam.
4. **Rotateable half-wave plate:** The rotateable half-wave plate should be set to the value that minimizes the Hall C current asymmetry when no other helicity-correlated feedback systems are turned on.
5. **Stability of electron beam polarization:** As is well known, there have been issues associated with measuring the electron beam polarization at different beam currents. These arise from the way the laser beams are combined and leakage currents from one hall to another. Whether any such issues will exist for the G^0 time structure is unclear at this point. It will be important to assess the situation when we have beam to determine if there is any situation like this that will compromise our experiment's ability to determine the beam polarization with a relative precision of ±2%.
6. **Cross-talk with other halls:** There are two possible categories of cross-talk of other hall's beams into the Hall C beam:
   - **a.** Current leakage: We want the contribution of the summed beam currents from other hall's beams to be less than 1% of the Hall C beam current.
   - b. "Helicity-correlated" leakage: It has been observed during HAPPEX running in 1999 that a helicity-correlated intensity in another hall's beam can induce helicity-correlated energy and position differences in their beam. The exact origin of this was not determined, but the solution is to have helicity-correlated feedback controls on the other hall's lasers. This will need to be done to the extent that it is necessary to satisfy the helicity-correlation specifications in Table 1.
7. **Helicity-correlated feedback systems:** For helicity-correlated feedback systems at the polarized injector, we prefer that each laser beam have separate helicity-correlated feedback controls. We prefer that devices that are common to all laser beams (the helicity-defining Pockels cell and the rotateable half-wave plate) not have active feedback on them, and they should only occasionally be adjusted while keeping to the guidelines in points 2 and 3.
8. **Fast energy and position locks:** Our experience during the forward angle run was that it was best for us to run with these systems off.
9. **Beam position and angle modulation:** We will be using air core steering coils in the Hall C beamline upstream of the arc to modulate the beam position and angle at the G^0 target over ranges of ± 1 mm and ± 1 mr , with the timescale for changes being ~200-300 msec. This type of modulation was done during both HAPPEX runs, so the protocols for safety have been thought out before, and we will follow them. The

frequency for runs of this type has not yet been determined, but it could be as often as once per hour.

10. **Beam energy modulation:** This system was in use during HAPPEX to modulate the beam energy by varying a cavity in the South Linac. This affects the other halls beams, as well, but it was done routinely during HAPPEX running. The frequency for runs of this type has not yet been determined, but it could be as often as once per hour.
11. **Betatron match:** While this is still an area of active development, we request that the accelerator tune be "betatron-matched" as well as the current accelerator instrumentation allows. We are interested in this because of the adiabatic damping effect that can suppress helicity-correlated position differences in the experimental hall. Our main diagnostic for this is the comparison between the size of helicity-correlated position differences in the experimental hall versus the 5 MeV region of the injector. We will be able to monitor this ratio continuously when we are running. It will be useful to see if there is a correlation between this diagnostic and the accelerator measurements of the Courant-Snyder parameters. Suppression factors of ~10 were observed for the forward angle run. In principle, the adiabatic damping should be much better than this. Most of the loss of adiabatic damping appears to be in the injector region. We support the continued efforts of Y. Chao to understand and improve this situation.
12. **Beam halo specification:** There are two ways that significant beam halo could potentially be problematic for the experiment. They are:

- **Interaction of beam halo with the thick parts of the G^0 target flange:** The specification in the table (< 1 x 10^{-6} outside of a 3 mm radius) primarily comes from the fact that we want to minimize the interaction of any part of the beam with the thick parts of the G^0 target flange (which start at a radius of 5.5 mm). During the forward angle run, we monitored this specification by continuously running with an aluminum target (2 mm thick) with a 6 mm diameter hole in it located about 8 meters upstream of the G^0 target. Downstream of this hole target there were PMTs with scintillators at large (15 degrees) and small (3 degrees) angles. We calibrated the system by putting 5 nA of beam directly into the 2 mm thick part of the aluminum halo target. From this, we could directly show that the above specification was being achieved, and we monitored it continuously during running. The specification was routinely achieved (for the potentially more problematic 31 MHz beam) except in some cases where the tune suddenly went drastically bad, and usually there was a clear cause why things had gone bad.
- **Interaction of the beam halo with some small upstream aperture:** The potential problem here is that beam halo interacting with a small upstream aperture could generate background that gets detected in our scintillators. This could either cause higher PMT anode currents than we can live with or contribute a background to our coincidence count rate. To measure this, we remove the main G^0 target and the halo target entirely. During the forward angle run, this rate was completely negligible. But during the forward angle running the scintillation detectors were downstream of the magnet, which provided some protection against backgrounds of this type. In the backangle mode of running, the detectors are upstream of the magnet, so they do not have this protection. To attempt to set a (crude) specification here, we would need to

know where the smallest upstream aperture in the beamline is, what material it is made of, and how thick it is. Then we could make some estimates of what fraction of the beam could hit that aperture before it created problems for our scintillation detectors downstream in the experimental hall.