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12 GeV CEBAF Beam Parameter Tables

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Abstract

A team including four APELs (Accelerator Physicist Experimental Liaisons): Y. Roblin (Hall A), M. Tiefenback (Hall B), J. Benesch (Hall C) and T. Satogata (Hall D), has been charged with generating a 12 GeV Beam Parameter Tables document similar to the table describing 6 GeV CEBAF beam properties produced by L. Cardman and J-C. Denard in 2001 (see Appendix A).

This resulting document consists of four tables describing beam parameters, a potential user may expect, for beam delivery to Halls A, B, C and D. The fifth table – Parity Beam Parameters - summarizes standard beam properties for parity violation experiments along with a list of special considerations.

These are typical numbers that are readily achievable at the various halls with standard 12 GeV era setup procedures. Other parameters may be achievable with extra setup time, hardware changes or additions, or both. Experiment planners considering parameters outside of this scope should consult the relevant hall APEL and accelerator experts when writing experimental proposals to assess feasibility of those parameters. Presented tables provide the 'next level' refinement on 'Beam Requirements for Out-Year Operations' (see Appendix B).

This note will hopefully serve as a useful guide to proponents of new experiments at CEBAF.

Hall A

<table>
<tr><th>Beam Property</th><th colspan="5">Nominal Value/Range</th><th>Temporal Stability over 8 hours</th></tr>
<tr><td>Spot size at target (rms) [μm]</td><td colspan="5">Horizontal < 250
Vertical < 200</td><td>Horizontal ~ 20
Vertical ~ 20</td></tr>
<tr><td>Angular divergence at target [μrad]</td><td colspan="5">< 20</td><td>< 2</td></tr>
<tr><td>Current [μAmp]</td><td colspan="5">1 - 120♦</td><td>10%</td></tr>
<tr><td>Charge per bunch [fCoul]</td><td colspan="5">4 - 480</td><td>10%</td></tr>
<tr><td>Bunch repetition rate [MHz]</td><td colspan="5">249.5*</td><td>NA</td></tr>
<tr><td>Beam position</td><td colspan="5">offsets parallel to diagnostic girder axis within 2.5 mm radius</td><td>< 40 μm (slow lock)
< 20 μm FFB (at 60Hz)</td></tr>
<tr><td rowspan="2">Energy spread♠ (rms)</td><td>Pass-1</td><td>Pass-2</td><td>Pass-3</td><td>Pass-4</td><td>Pass-5</td><td></td></tr>
<tr><td>< 10^{-4}</td><td>< 10^{-4}</td><td>< 10^{-4}</td><td>3×10^{-4}</td><td>5×10^{-4}</td><td>~ 10% of nominal (linac crested)</td></tr>
<tr><td>Beam direction</td><td colspan="5">± 300 μrad (rasterized at 3 mm x 3 mm)</td><td>< 2 μrad (position lock)</td></tr>
<tr><td>Energy range [GeV]</td><td colspan="5">1 - 11</td><td>NA</td></tr>
<tr><td>Energy accuracy♥ (rms)</td><td colspan="5">3×10^{-3}</td><td>stable</td></tr>
<tr><td>Beam polarization∇</td><td colspan="5">up to 85%</td><td>stable</td></tr>
<tr><td>Charge asymmmetry▲</td><td colspan="5">< 0.1%</td><td>stable</td></tr>
<tr><td>Background beam halo</td><td colspan="5">< 0.1%</td><td>stable</td></tr>
<tr><td>Beam availability (including RF trips)</td><td colspan="5">60%</td><td>stable</td></tr>
</table>

'<' – 'not to exceed'

♦ Limited by 900 kW dump at higher passes.

* Other frequencies such as 499 MHz available at lower passes and pass 5 when Hall D is not running.

♠ These are ideal numbers, no RF phase errors, just synchrotron radiation. This assumes phasing software running in background to minimize effects of RF curvature.

♥ Set by errors in dipole field measurements only.

▲ Smaller value can be achieved if a feedback used.

∇ Polarization on target shared between concurrent experiments as decided by Physics Division.

Hall B

<table>
<tr><th>Beam Property</th><th colspan="5">Nominal Value/Range</th><th>Temporal Stability over 8 hours</th></tr>
<tr><td>Spot size measured by 2H01A harp (rms) [μm]</td><td colspan="5">< 100 for 1 GeV - 6 GeV
< 200 for 7 GeV - 11 GeV</td><td>periodic measurement and adjustment can enforce lower bound</td></tr>
<tr><td>Angular divergence at target [μrad]</td><td colspan="5">< 100</td><td>goverened by the formula: emittance/(spot size)</td></tr>
<tr><td>Current [nAmp]</td><td colspan="5">1• - 160♦</td><td>< 5% for currents > 5 nAmp</td></tr>
<tr><td>Charge per bunch [fCoul]</td><td colspan="5">4×10^{-3} - 0.64</td><td>< 5% for currents > 5 nAmp</td></tr>
<tr><td>Bunch repetition rate [MHz]</td><td colspan="5">249.5*</td><td>NA</td></tr>
<tr><td>Beam position♣</td><td colspan="5">as required within ± 2 mm of beam axis as measured on IPM2H00/IPM2H01</td><td>< 0.1mm for currents above 30 nA</td></tr>
<tr><td rowspan="2">Energy spread♠ (rms)</td><td>Pass-1</td><td>Pass-2</td><td>Pass-3</td><td>Pass-4</td><td>Pass-5</td><td></td></tr>
<tr><td>$< 10^{-4}$</td><td>$< 10^{-4}$</td><td>$< 10^{-4}$</td><td>3×10^{-4}</td><td>5×10^{-4}</td><td>~ 10% of nominal (linac crested)</td></tr>
<tr><td>Beam direction</td><td colspan="5">Parallel to beam line axis, consistent with ambient field and positions of beam on target and dump</td><td>stable to < 20 μrad</td></tr>
<tr><td>Energy range [GeV]</td><td colspan="5">1 - 11</td><td>NA</td></tr>
<tr><td>Energy accuracy♥ (rms)</td><td colspan="5">3×10^{-3}</td><td>$< 2\times10^{-4}$ (slow locks)
$< 3\times10^{-5}$ (fast feedback)</td></tr>
<tr><td>Charge asymmmetry▲</td><td colspan="5">< 0.1%</td><td>stable</td></tr>
<tr><td>Background beam halo</td><td colspan="5">$< 10^{-5}$outside radius of the greater of (5×sigma or 1 mm)</td><td>NA</td></tr>
<tr><td>Beam polarization▽</td><td colspan="5">up to 85%</td><td>stable</td></tr>
<tr><td>Beam availability (including RF trips)</td><td colspan="5">60%</td><td>stable</td></tr>
</table>

'<' – 'not to exceed'

• Sub-nAmp current can be provided.

♦ Consistent with 900 kW beam power and limits on Faraday cup and beam stopper.

* Other frequencies such as 499 MHz available at lower passes and pass 5 when Hall D is not running.

♣ Limited by relocatable beam line components.

♠ These are ideal numbers, no RF phase errors, just synchrotron radiation. This assumes phasing software running in background to minimize effects of RF curvature.

♥ Set by errors in dipole field measurements only.

▲ Smaller value can be achieved if a feedback is used.

▽ Polarization on target shared between concurrent experiments as decided by Physics Division.

Hall C

Beam Property	Nominal Value/Range					Temporal Stability over 8 hours
Spot size (X/Y)♦ at pivot (rms) [μm]	Pass-1	Pass-2	Pass-3	Pass-4	Pass-5	
	100-190	150-260	175-300	200-275	230-500	20
Angular divergence at target [μrad]	±25					NA
Current [μAmp]	2.5 - 150#					10%
Charge per bunch [fCoul]	10 - 600					10%
Bunch repetition rate [MHz]	249.5*					NA
Beam position	offsets parallel to diagnostic girder axis within 2.5 mm radius					< 40 μm (slow lock) < 20 μm FFB (at 60Hz)
Energy spread♠ (rms)	Pass-1	Pass-2	Pass-3	Pass-4	Pass-5	
	$< 10^{-4}$	$< 10^{-4}$	$< 10^{-4}$	3×10^{-4}	5×10^{-4}	~ 10% of nominal (linac crested)
Beam direction	beam divergence, dump aperture and raster combine to limit imposed angles under 800 μrad					< 20 μrad (position lock)
Energy range [GeV]	1 - 11					NA
Energy accuracy♥ (rms)	3×10^{-3}					stable
Beam polarization▽	up to 85%					stable
Charge asymmmetry▲	< 0.1%					stable
Background beam halo	less than 10^{-4} of integral of Gaussian core					stable
Beam availability (including RF trips)	60%					stable

'<' – 'not to exceed'

♦ Beam will not be round at the pivot, when matched only with data taken at dumplet. Manual adjustment of the last quad needed to get it round, hence maxima listed above.

Limited by 900 kW dump at higher passes.

* Other frequencies such as 499 MHz available at lower passes and pass 5 when Hall D is not running.

♠ These are ideal numbers, no RF phase errors, just synchrotron radiation. This assumes phasing software running in background to minimize effects of RF curvature.

♥ Set by errors in dipole field measurements only.

▲ Smaller value can be achieved if a feedback used.

∇ Polarization on target shared between concurrent experiments as decided by Physics Division.

Hall D

Beam Property	Nominal Value/Range	Temporal Stability over 8 hours
Spot size at target♦ (rms) [μm]	Horizontal < 1000 Vertical < 500	Horizontal ~ 100 Vertical ~ 100
Angular divergence at target [μrad]	< 15	< 1
Current [nAmp]	1 - 2000#	10%
Charge per bunch [fCoul]	4×10^{-3} - 8	10%
Bunch repetition rate [MHz]	249.5*	NA
Beam position	± 1 mm	< 40 μm (with 5C11B lock)
Energy spread♠ (rms)	2×10^{-3} - 3×10^{-3}	~ 10% of nominal (linac crested)
Beam direction	± 30 μrad	< 2 μrad (active collimator lock)
Energy range [GeV]	8.8 - 12.1	NA
Energy accuracy♥ (rms)	3×10^{-3}	stable
Background beam halo	< 0.1%	stable
Beam availability (including RF trips)	60%	stable

'<' – 'not to exceed'

♦ Based on emittance measurement at 5C00 logged since late 2015. Straightforward tuning provides geometric emittances of: $\varepsilon_x \sim 7\times10^{-9}$ m-rad, $\varepsilon_y \sim 5\times10^{-9}$ m-rad.

Consistent with 900 kW beam power and limits on Faraday cup and beam stopper.

* Other frequencies, such as 499 MHz are also available.

♠ These are ideal numbers, no RF phase errors, just synchrotron radiation. This assumes phasing software running in background to minimize effects of RF curvature

♥ Set by errors in dipole field measurements only.

Parity Beam Parameters

Beam Property	Nominal Value/Range	Helicity Correlated 8-hour Average	Maximum Jitter at 30 Hz
Current [μAmp]	5 – 100[#]	< 5 ppm	2000 ppm
Energy [GeV]	1 – 11	$\left(\frac{\Delta E}{E}\right) < 15$ppb (50 nm@ 35 mm/%)	35 μm (x-position in center of hall ARC)
Energy spread (rms)	$<10^{-3}$	NA	NA
Position x at target	0	<25 nm	15 μm
Angle x' at target	0	<10 nrad	5 μrad
Position y at target	0	<25 nm	15 μm
Angle y' at target	0	<10 nrad	5 μrad
Spot size at target	100 – 500 μm ($\sigma_{x,y}$ unrastered) 5 mm x 5 mm (rastered)	$\left(\frac{\delta\sigma}{\sigma}\right) < 10^{-3}$	NA
Beam polarization[∇]	$P_L > 85\%$ (P_V, $P_H < 1\%$)	NA	NA
Beam halo	$<10^{-4}$ integrated (> 2 mm from edge of rastered beam)	NA	NA

'<' – 'not to exceed'

[#] Limited by 900 kW dump at higher passes.

[∇] Polarization on target shared between concurrent experiments as decided by Physics Division.

Notes for Table Headers

1. **Nominal Value and Range:** This is the desired central value of the beam property.
2. **Helicity Correlated 8-hour Average:** This refers to the maximum value of the helicity-correlated difference (or asymmetry) that can be achieved after averaging over 8-hour run. These 8-hour averages are specified with the assumption that the averages are statistically distributed, with an active charge feedback, and with no measurable offset. If the 8-hour averages are not distributed around a negligible systematic offset, corrective action will be necessary.
3. **Maximum Jitter at 30 Hz:** Parity Violation (PV) measurements are operated by integrating the signal for a given beam property over a 33 msec time period, and forming differences between two successive 33 msec periods. The standard deviation of the distribution for those differences is what we refer to as “30 Hz jitter.” Many PV experiments run at a higher helicity reversal frequency. The expectation is that the

increase in "jitter" will not be as extreme as the "root-N" scaling limit, as observed in the 6 GeV era. This scaling behavior should ideally be checked with short dedicated studies early in the 12 GeV era.

4. **Spot Size at Target:** The helicity-correlated spot size variations can only be measured on the laser table by experimentalists. An upper bound can be established from an understanding of the source configuration and cancellations.

Special Considerations for Parity Violation Experiments

5. **Helicity Reversal Frequency:** The helicity board is programmed to provide 1 - 2000 Hz helicity reversal with wide range of T_Settle and T_Stable selections. The electro-optical properties of the KD×P Pockels Cell limit higher frequencies.
6. **Polarization Orientation:** PV experiments are highly sensitive to components of transverse polarization and require maximum longitudinal polarization. Beam with both vertical and horizontal transverse polarization components below 1% can be delivered. This will require small tweaks to the injector launch angle during the course of the experiment based on measurements of transverse-polarization asymmetries in the experimental hall. In addition, the Mott polarimeter will be used to zero the vertical polarization component to within 1%.
7. **Priority in source configuration:** PV experiments have priority in the source configuration (centering on the Pockels Cell). In order to tune the source to minimize helicity correlated beam systematics, it will also be necessary to control setpoints for common devices such as the Insertable Halfwave Plate, Rotating Waveplate, and Pockels Cell voltages. Changes to these setpoints can be made without significant impact on most experiments, for example, with negligible effect on beam polarization. Other requirements for the source configuration may be negotiated with the Electron Gun Group.
8. **Time for source configuration:** Dedicated time for configuration of the laser optics of the source will be allocated before the start of PV experiments.
9. **Control of other source lasers:** Previous experience has suggested that significant helicity-correlated beam asymmetries can be generated in an otherwise well-configured “parity-quality” beam, when operated simultaneously with another hall with large helicity-correlated asymmetries. PV experiments have access to existing feedback mechanisms to control the helicity-correlated charge asymmetry of the other three halls.
10. **Electron Beam Transmission:** Significant clipping of the electron beam between the photocathode and the target can create excessive charge jitter or helicity correlated systematics on the beam. In particular, such clipping can create a helicity-correlated intensity asymmetry from helicity-correlated position differences or even a varying intensity asymmetry across the beam with very large asymmetries in the halo part of it. This can confuse diagnostics of the source and cause misguided corrections, using source optics, of problems created in beam transport. It is thought that clipping can also create higher moments of helicity-correlated asymmetries, such as spot-size asymmetries, and conditions with poor injector transmission have been seen to lead to high background

rates in the Compton. To avoid such problems, PV experiments should have clean electron transmission from source to target.

11. **Helicity Correlated Beam Halo:** Of concern is halo with helicity correlated asymmetries that are vastly different than those of the main beam. When interacting with beamline pipe and components, helicity correlated backgrounds are generated that are very hard to measure and correct for. Clean electron transmission from source to target may minimize this problem. Since the root cause is unknown, it may not.

12. **Helicity-Correlated Beam Spot Size:** No direct method exists to measure helicity correlated differences in the beam spot size. While our understanding of the polarized source suggests that effects will be 10^{-4} or less, the sensitivity to this is high, and a credible result will require a convincing demonstration of a null effect. Spin rotation in the injector provides a method for a convincing "helicity flip" which does not interfere with the beam profile or mechanisms which might lead to a spot size asymmetry. Using the double-Wien spin rotator with a frequency between two days and one week is foreseen for the PV experiments.

13. **Beam tune and halo acceptable for Compton polarimeter:** it may be required to have reliable data from the Compton polarimeter continuously during PV experiments. It is therefore necessary that the beam be suitable for the use of the Compton polarimeter. A commonly-used criteria for operation of the Compton is the counting rate in the Compton photon and electron detectors, with the Compton laser off. The accelerator will work with the experimentalists to have an operational Compton polarimeter. At least four hours will be required to match the beam optics exiting the arc to that at the center of the Compton chicane.

14. **Fast Feedback:** The fast feedback system for position and energy lock will be operational (if it is needed to remove 60/120/180 Hz components in position or energy).

15. **Beam Modulation:** Air core steering coils in the experimental hall beamline and the energy Vernier in SL20 are used to modulate beam position, angle, and energy in order to measure sensitivity to those parameters. PV experiments shall have the option to "pause" fast position lock and energy lock during these modulation periods. The successful use of the beam modulation system requires a significant phase advance between the modulation magnets and between the monitors used to characterize the beam motion, so that independent motions spanning the beam phase space can be observed.

16. **Match to Design Beam Optics:** The accelerator optics should be well matched to design during PV experiments. Beam size as defined by Sqrt(emittance×beta) shall be within a factor of four of design throughout the machine and preferably less than three at fifth pass extraction.

17. **Tracking Run Beam Intensity:** 100 pA to 10 nA is available for special low current runs. This beam will meet the standard beam requirements but not the parity-quality requirements.

Acknowledgments

We thank Joe Grames, Joe Gubeli, Theo Larrieu, Mike McCaughan, Daniel Moser and Mike Spata for their useful comments.

Appendix A – 6 GeV Beam Parameters

BEAM REQUIREMENTS (10/31/01)

Parameter	**Nominal Value and Range**	**stability (during 8 hours) (note 1)**	**helicity correlated unbalance averaged over 1 hour**
rms spot size at the target	A: $\sigma_{x\ and\ y}$ = 50 to 200μm; B: 50 < $\sigma_{x\ and\ y}$ < 250 μm; C: $\sigma_{x\ and\ y}$= 100 to 500μm A & C may request specific sizes (note 2)	A & C: 25% of requested value; B: any value within nominal range	A & C: 100% of nominal size; B: 60 μm
angular divergence at the target	$\sigma_{x'}$, $\sigma_{y'}$ < 100 μr	50% of value	100% of beam divergence tolerance
Beam position	any value requested by experiment within 3 mm of optics axis	drifts A: < 50% of spot size; B: < 120 μm; C: < 250 μm; transients A, B, C: < 1 mm	A & C < 10 μm; B < 60 μm
Beam direction	any value requested by experiment within 1 mr of optics axis to dump center	< 50 μr (1/2 beam divergence tolerance)	100% of beam divergence tolerance
Energy (average)	multipass operation: 0.63 to 5.75 GeV; 1 pass 1 hall dedicated operation: 0.33 GeV to 0.63 GeV	A or C: ΔE/E < 1E-4 B: ΔE/E < 5E-4 and ΔE/E < 1E-3 over days for all	100% of energy spread tolerance
Energy Spread (1σ)	A & C: σ_E/E < 5E-5 for E>1GeV B: σ_E/E < 4E-4	A & C: σ_E/E < 5E-5 for E>1GeV B: σ_E/E < 4E-4	X
Parameter	**Nominal Value and Range**	**stability (during 8 hours) (note 1)**	**helicity correlated unbalance averaged over 1 hour**
Background (Beam halo) close to the target	A, B, C: < 1 E-4 outside of a 5 mm radius **(notes 3 & 4)**	any value within the nominal range	100% of nominal halo tolerance
CW average current (Note: 5 & 6)	1 μA < A < 120 μA 1 nA < B < 1 μA 1 μA < C < 120 μA A+C < 180 μA ; A + C < 800 KW A or C < 180 μA (single hall)	within +/- 5% of nominal value (includes high frequency fluctuations)	A < 200 ppm; B & C< 1000 ppm 3 Halls: excursions of 5 second samples up to 5 times the nominal value are acceptable.
Polarization (current range to be determined between physics and Accelerator Divisions)	> 70% all halls with currents up to 100 μA in A or C	polarization > 70%	X
Effective duty factor DF	loss (1-DF) including trips: < 5% @ 0.33 to 5 GeV (5 + (E-5)*20) % @ 5 to 6 GeV	X	X

note 1: With continuous monitoring the beam is good when within tolerances. With invasive diagnostics, one does not know the beam quality between measurements. The user accepts the uncertainty except if he can provide a continuous non-invasive diagnostic.
note 2: Some beam size requests in the range will preclude the Moller optics to be the same as the beam-delivery-on-target optics
note 3: After the halo monitors for halls A and C are operational
note 4: Hall A requests for FY2002 that the total halo outside a 5 mm radius be < 10-(
note 5: Lower currents can be delivered with relaxed tolerances
note 6: Proper impingement on beam dump has to be checked with accelerator operation (centering on dump face, current density on dump face, visibility on dump viewer, amount of radiation in the hall, on the site, etc…

J-C. Denard; beam_parameters

Appendix B – Beam Requirements for Out-Year Operations

Hall	Emittance (nm-rad)	Energy Spread σ (%)	Spot Size σ (μm)	Halo
A	$\varepsilon_x < 10$ $\varepsilon_y < 5$	< 0.05 (12 GeV) < 0.003 (2-4 GeV)	$\sigma_x < 400$ $\sigma_y < 200$ ($\sigma_y < 100$) (2-4 GeV)	$< 1 \times 10^{-4\dagger}$
B	$\varepsilon_x < 10$ $\varepsilon_y < 10$	< 0.1	$\sigma_x < 400$ $\sigma_y < 400$	$< 1 \times 10^{-4\dagger}$
C	$\varepsilon_x < 10$ $\varepsilon_y < 5$	< 0.05 < 0.03 (6 GeV)	$\sigma_x < 400$ $\sigma_y < 200$	$< 1 \times 10^{-4\dagger}$
D	$\varepsilon_x < 10$ $\varepsilon_y < 5$	< 0.5	At Radiator: $\sigma_x < 1550$, $\sigma_y < 550$ At Collimator $\sigma_x < 540$, $\sigma_y < 520$	$< 1\%^{\ddagger}$

† Ratio of the integrated non-Gaussian tail to Gaussian core.
‡ Ratio of Halo background event rate to physics event rate.