6/12 GeV CEBAF and HPS beam requirements

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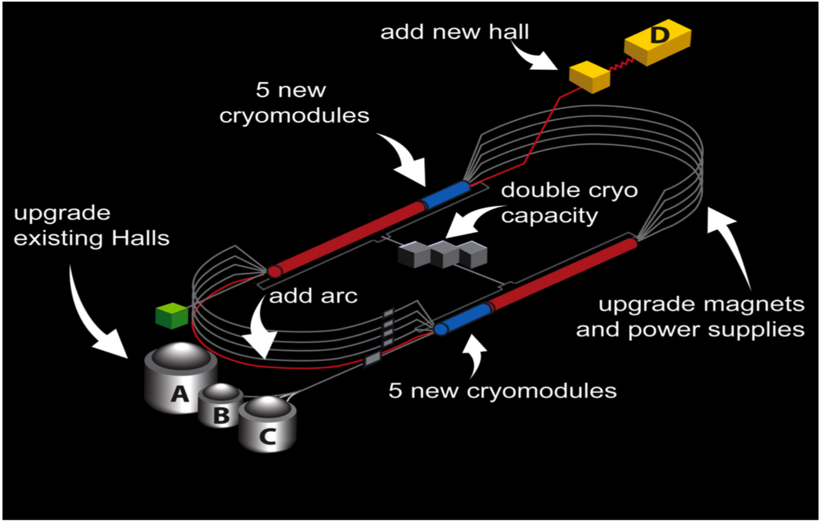
May 26, 2011

12 GeV Overview



Accelerator CD-4 Requirements: DOE Deliverables

CD-4 Deliverables

Endstations		ABC	D
Energy	(GeV)	>6	>10
Current	(nA)	>2	>2
ε_x	(nm-rad)	NA	<20
ε_y	(nm-rad)	NA	<20

Clearly these are necessary but not sufficient for Nuclear Physics (NP) research with 12 GeV CEBAF.

CD-4 goals for the End Stations (not shown here) are staged in time, End Station A & D first (FY14) and B & C in FY15.

12GeV Beam Requirements for Initial 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	$\sigma_x < 400$ $\sigma_y < 400$	$< 2 \times 10^{-4\dagger}$
C	$\varepsilon_x < 10$ $\varepsilon_y < 10$	<0.05	$\sigma_x < 500$ $\sigma_y < 500$	$< 2 \times 10^{-4\dagger}$
D	$\varepsilon_x < 50$ $\varepsilon_y < 10$	<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.

(GlueX-doc-775-v4, GlueX-doc-646-v5)

12GeV 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.
(GlueX-doc-775-v4, GlueX-doc-646-v5)

Comparison of emittance and energy spread for 6 GeV and 12 GeV CEBAF

$\sigma_x = \sqrt{\varepsilon_x \beta_x}$

Expected 12 GeV CEBAF beam emittance and energy spread
12GeV beam transport calculations include synchrotron radiation and magnetic multipole contributions.

Where	E (GeV)	$\frac{dp}{p}$ (%)	ε_x (nm)	ε_y (nm)
Pass-1(ABC)	2.3	0.003	0.22	0.22
Pass-2(ABC)	4.4	0.003	0.17	0.16
Pass-3(ABC)	6.6	0.005	0.28	0.21
Pass-4(ABC)	8.8	0.009	0.69	0.38
Pass-5(ABC)	11	0.015	1.88	0.86
Pass-5.5(D)	12	0.018	2.70	1.03

Expected 6 GeV CEBAF beam emittance and energy spread
Linear model with no synchrotron radiation effects. Emittance and energy spread for 6-pass beam probably underestimated.

Where	E (GeV)	$\frac{dp}{p}$ (%)	ε_x (nm)	ε_y (nm)
Pass-1(ABC)	1.3	0.005	0.39	0.39
Pass-2(ABC)	2.5	0.002	0.20	0.20
Pass-3(ABC)	3.7	0.002	0.14	0.14
Pass-4(ABC)	4.9	0.001	0.10	0.10
Pass-5(ABC)	6.0	0.001	0.09	0.09

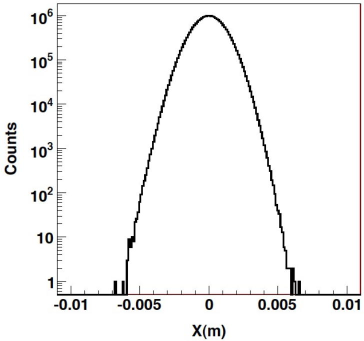
12 GeV CEBAF on 1^{st}, 2^{nd} and 3^{rd} pass comparable to 6 GeV CEBAF performance.

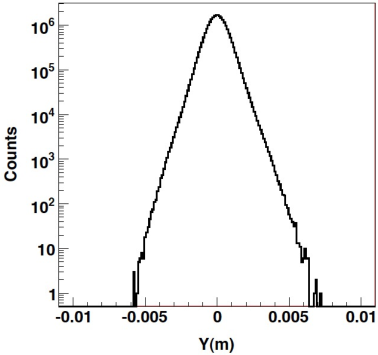
Synchrotron radiation on passes 4, 5 and 5.5 result in emittance and energy spread values that are larger than operational experience.

Halo

Sources of beam halo include: non-linear magnetic fields, beam-gas scattering.

Non-linear magnetic fields modeled at the 12 GeV specification level. 40×10^6 electrons pushed from the Injector to Hall-D ($\sim$3 μs of beam time, days of CPU time).





Horizontal profile non-Gaussian due to the presence of non-linear fields that the are sampled by the large horizontal beam size.

Although the shape is distorted, the beam is well contained and there are no outliers (aka halo).

Y. Roblin `JLAB-TN-08-042`

HPS and Ribbon Beams

- Most CEBAF experiments request round beams: $\frac{\sigma_x}{\sigma_y} \sim 1$
- Typical beam size request in the range of $100\mu m \leq \sigma_y \leq 250\mu m$
- Very small beam sizes typically undesired due to the very high power density of the beams (damage to target windows).
- HPS request for a ribbon beam is new to CEBAF operations for two reasons, the very small vertical beam size and the request for a non-round beam.

$$\sigma_y = \sqrt{\varepsilon_y \beta_y + (\eta_y \frac{dp}{p})^2}$$

β_y is the beam transport function β (not v/c) and is determined by the beam parameters at the entrance to the beamline and the quadrupole settings of the beamline. (aka beam transport)

β_y can be made very small to achieve a small beam size, so call low beta optics that are common in colliding beam experiments. Low β is achieved at the expense of large divergence y', complicating post target transport.

Having a small ε_y value helps, but ε_y is not easily changed or controlled.

Beamline design to achieve a Ribbon Beam for HPS

This is a linear optics problem, use linear optics codes to determine a quadrupole magnet locations and fields to achieve HPS requirements.

All codes assume that the entrance beam properties are *matched* to the line and that incoming ε is the design value.

Optics code will vary selected elements for optimization to achieve the design goal. In

order to test this process and answer some questions from the TAC/PAC a test was perform Feb. 18th. The existing Hall-B beamline was optimized to produce a ribbon beam at the *tagger* harp.

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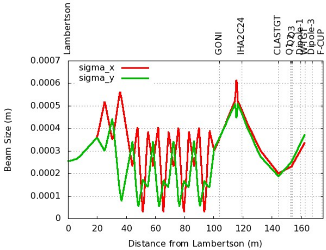
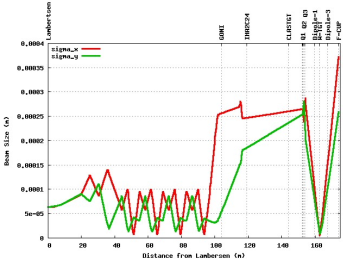
&end
```

Default Hall-B → HPS Optics

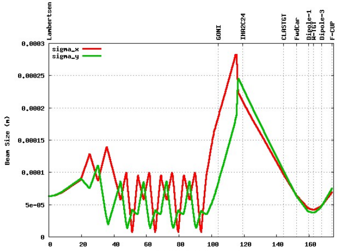
Default electron optics: Focus at CLAS Target



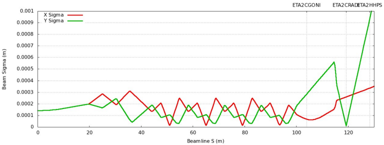
Three quads added at the FC.



Attempt to achieve small beam size at HPS target with standard Hall-B elements



Optics for HPS test to demonstrate sub 20μm beam size at the tagger wire scanner.

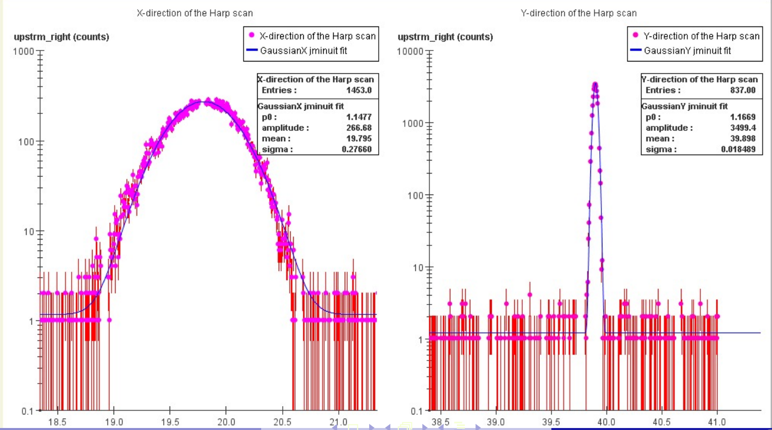


HPS Beam Size Test
Feb 18th 2011

Speed of the harp was lowered to 100mum/second
File name: harp_tagger_02-18-11_17:03:09.txt
PMT channel: upstrm_right

Fit Results

Name(X)	Parameter(X)	Error(X)	Name(Y)	Parameter(Y)	Error(Y)
p0	1.1477	0.0316	p0	1.1669	0.0316
amplitude	266.6800	1.9595	amplitude	3499.4156	1.9595
mean	19.7953	0.0016	mean	39.8982	0.0016
sigma	0.2766	0.0012	sigma	0.0185	0.0012



12 GeV Beam Schedule Scenarios

Uncertainty in future funding makes it very difficult to predict the Weeks of Operation in the 12 GeV commissioning period and out-years.

12 GeV operations will cost more per week than 6 GeV operations:

1. Power required increases from 18 MW (6 GeV CEBAF) to about 28 MW (12 GeV CEBAF), considerably less than a factor of two. But still a large increase.
2. 1 CHL (6 GeV) vs. 2 CHL (12 GeV), cost of no beam operations increases as well. This includes taking one CHL to 4K during downtimes.
3. 3 Halls (6 GeV) vs 4 Halls (12 GeV), increase in consumables and support staff to maintain an extra hall.

6 GeV CEBAF has operating $\sim$41 wks in a year when appropriately funded. 41wks/yr is *Full Utilization* of CEBAF, scheduling more than 41 weeks/yr would lead to a decrease in CEBAF Reliability.

12 GeV Beam Schedule Pessimistic Scenario

Pessimistic Funding through FY17 at *Constant Effort*. JLAB budget grows at about 3.5% per year

This scenario does not represent the funding necessary for full utilization of 12 GeV CEBAF.

Annual weeks of operations likely to be in the range of 21→27weeks/yr.

Hall multiplicity will remain at the 6 GeV level.

FY13 First 12GeV operations. 11 weeks to establish one-pass beam at 10GeV or higher five pass energy.

FY14 Machine commissioning including commissioning the Hall-A and Hall-D transport lines and detectors.

FY15 Commissioning the Hall B & C transport lines and detectors. Goal is to resume two-hall operation. 9-weeks of Research Operations (Physics!).

FY16 Finish Engineering Runs in B&C, 8 weeks. 18 weeks of Research Operations at same hall multiplicity as 6 GeV CEBAF.

12 GeV Beam Schedule Optimistic Scenario

Optimistic Funding to support 35 wks/year of Research operations in a typical year.

Hall multiplicity will increase to about 2.9 from the average 6 GeV value of 2.4 halls.

- **FY13** First 12GeV operations. 11 weeks to establish one-pass beam at 10GeV or higher five pass energy.
- **FY14** Machine commissioning including commissioning the Hall-A and Hall-D transport lines.
- **FY15** Commissioning the Hall B & C transport lines. Goal is to resume two-hall operation. 9-weeks of Research Operations (Physics!).
- **FY16** Finish Engineering Runs in B&C 8 weeks. 27 weeks of Research Operations with increase (compared to 6 GeV CEBAF) in Hall multiplicity.

Summary

- Hall-B line can be configured to delivered asymmetric beam spots
- Quadrupole triplet on the FC needed to achieve small beams in the alcove
- Test of ribbon beam uncharacteristically straight forward.
- Synchrotron radiation effects on the upper 4^{th} & 5^{th} passes of the 12GeV machine produces beams with larger ε and $\frac{dp}{p}$. But lower passes have beam parameters very similar to present 6GeV CEBAF.
- 12GeV commissioning and beam plans still being formed, but expect to see some effort into this over the next several months.