JLAB Footprint: Adding one more toe^{+}

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JLAB

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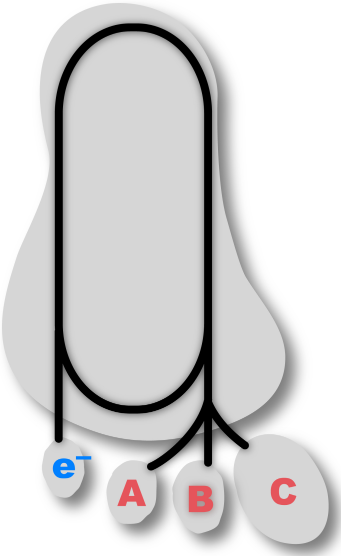
The Footprint Talk

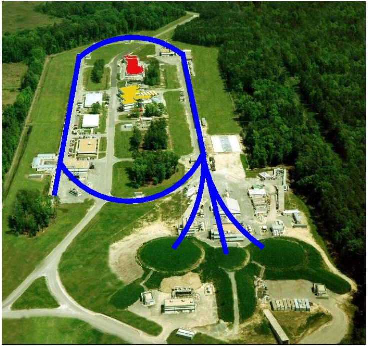
1. JLAB Overview and capabilities
   - CEBAF 6/12 GeV
   - CEBAF 12 GeV Upgrade
   - FEL
   - SRF & Photo-injectors
   - CEBAF Beam Properties
2. Production Options
   - Primary e^- Energy Options
   - 10 MeV Option: CEBAF
   - 100 MeV Option
   - 1000 MeV Option
   - Source Options Summary
3. e^+ in CEBAF: What are the issues
   - Magnets
   - Diagnostics
   - Beam Modes
   - RF
4. Summary



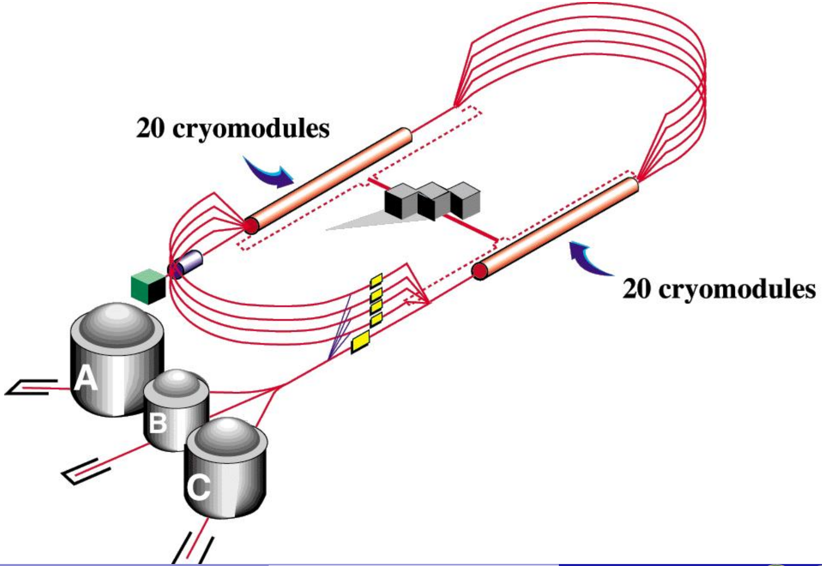
JLAB Overview

CEBAF 6 GeV accelerator for Nuclear Physics Program, to be upgraded to 12 GeV in the next 3 years. It is presumed that a e^+ source for CEBAF will be in the 12 GeV era.

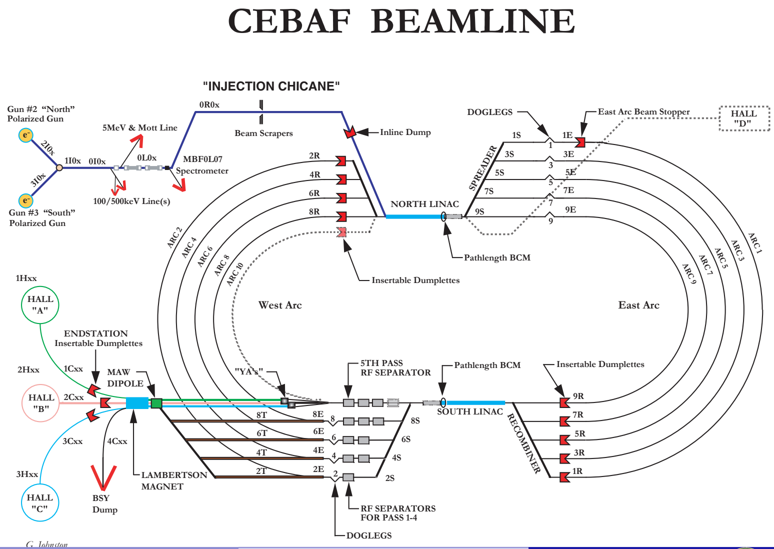
FEL 125 MeV Energy Recovery Linac kilowatt-class, high-average-power, sub-picosecond free-electron laser.



CEBAF 6 GeV



CEBAF 6/12 GeV (another view)

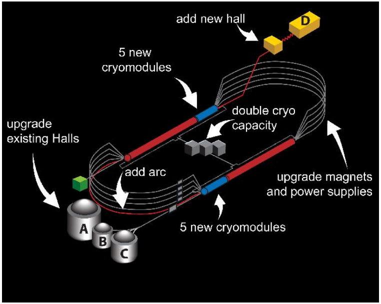


CEBAF 12 GeV

The upgrade of CEBAF to 12 GeV is scheduled to be complete in FY13.

12 GeV Hardware Changes

- Double gradient, add 10 new cryomodules
- Double field in magnets
- Add 10^{th} Arc
- Add Hall-D and transport lines
- **Upgrade injector to 130 MeV** (from 65 MeV)



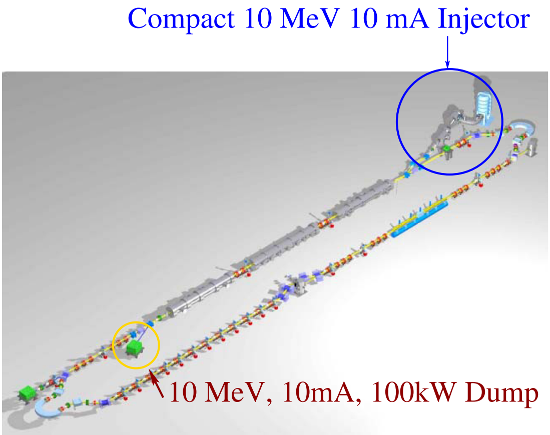
12 GeV Beam Properties

- There will be ε growth due to synchrotron radiation
- There will be $\frac{\delta p}{p}$ growth due to synchrotron radiation

Design team is studying various changes to the Optics to mitigate these effects, for the purpose of this talk the *baseline* 12 GeV optics are used for comparison.

FEL

- Short 10 MeV injector
- Injector capable of producing 9mA beam current
- Acceleration to 100 MeV with 9mA beam current only possible through the use of *energy recovery*.
- FEL could be used as the e^+ source for CEBAF.



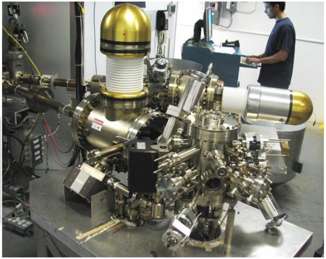
- Production of e^+ at the 10 MeV dump is also possible.

JLAB Overview: SRF and Photo-injectors

Both FEL and CEBAF make use of:

1. Super-conducting (SRF) accelerating cavities operating at 1.5 GHz. Both accelerators produce continuous wave (CW) beam. **CEBAF operates predominately in CW mode**.
2. Photo-cathode sources, CEBAF source uses strained GaAs for polarized (up to 85% polarized) e^-.

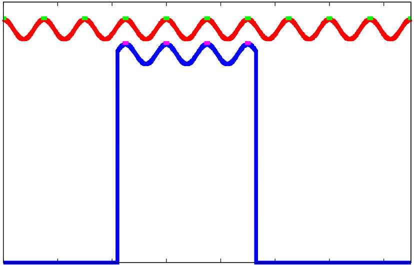
Maximum current for polarized e^- demonstrated is 1 mA. R&D on cathodes needed for higher currents.



JLAB CW Beams

- RF is always on: DC
- Each RF bucket has beam
- Beam as no "pulse" structure
- To JLAB'ers beam current is the average beam current.
  - We do not talk of average in the pulse, peak or other terms.
  - We do not talk of bunch charge, unless you are from the FEL.
  - Duty Factor is 100%
- The beam has quite a bit of stored energy: $10MeV \times 10mA = 100kW$

SRF accelerating gradient at $f = 1.497\text{GHz}$:



- $1\mu A \sim 4000 \frac{e^-}{RFBucket}$
- $1\mu A \sim 0.67 \frac{fC}{RFBucket}$
- $1^\circ = 1.8ps$

CEBAF 6 GeV Beam Properties

Property	Symbol	Value	Unit
Injector Current	I	$0.0001 \rightarrow 1000$	μA
Injector Energy	E	68	MeV
Normalized Emittance	ε_N	5×10^{-7}	m-rad
Geometric ε @ 6 GeV	ε	4×10^{-11}	m-rad
Typical TWISS β at Target	β	20	m
Beam size target	σ_{beam}	30	μm
Energy Spread @ 6 GeV	$\frac{\delta p}{p}$	$3 \rightarrow 10 \times 10^{-5}$	
	ΔE	$180 \rightarrow 600$	keV
Bunch Length	τ_b	< 250	fs

- Emittance growth due synchrotron radiation is negligible in the 6 GeV CEBAF.
- Geometric emittance value at the Hall lines reflects the energy gain through the system and assumes a well matched machine.
- Best $\frac{\delta p}{p}$ achieved to date is 2.5×10^{-5}, the result of careful phase control and monitoring.

CEBAF 6 GeV Accelerator Acceptance

How bad can the beam be and still be transported by CEBAF

The 6 GeV e^- beam is quite exceptional, the e^+ beam will probably not be of the same caliber.

Property	Symbol	Value	Unit
Admittance	$\mathcal{A}$	5×10^{-6}	m-rad
Injection Chicane Momentum Acceptance	$\frac{\delta p}{p}$	1×10^{-2}	
Inj. Chicane Energy Acceptance at 125 MeV	ΔE	1	MeV
Arc1 Momentum Acceptance	$\frac{\delta p}{p}$	1×10^{-3}	
Arc1 Energy Acceptance at 1 GeV	ΔE	1	MeV

- The $\mathcal{A}$ is about $10\times$ the ε_N of the e^- beam. The e^+ beam will be produced with a much greater initial energy ($3 \to 30$MeV) vs 100keV for e^-, the equivalent ε_N for e^+ will be $\mathcal{O}(100)$ to $\mathcal{O}(1000)$ larger.
- Injector Chicane Admittance includes differential pumping aperture.
- Energy Acceptance can be increased by using low dispersion optics.

12 GeV Cumulative rms Emittance and Energy Spread

Baseline Optics

Comparison ε and $\frac{\delta p}{p}$ of the nominal e^- and an hypothetical e^+ produce with $E = 30$ MeV, $\varepsilon = 5 \times 10^3$nm-rad and $\Delta E = 1$MeV.

	e^-		e^+	
	ε_x (nm-rad)	$\frac{\delta p}{p}$ ($\times 10^{-4}$)	ε_x (nm-rad)	$\frac{\delta p}{p}$ ($\times 10^{-4}$)
Arc1	0.43	0.20	126	1.01
Arc2	0.27	0.14	66	0.54
Arc3	0.22	0.26	45	0.44
Arc4	0.21	0.31	34	0.41
Arc5	0.34	0.48	28	0.52
Arc6	0.89	0.76	24	0.78
Arc7	1.32	0.90	21	0.91
Arc8	2.01	1.17	19	1.18
Arc9	3.67	1.56	19	1.56

For TWISS $\beta = 20$m, 19 nm-rad corresponds to a 0.6mm beam spot at the Hall Target.
$\frac{\delta p}{p}$ contribution from bunch length has not been included.

Primary e^- Energy Options

Location	Energy (MeV)	Current (mA)	Power (kW)	Polarized? (yes/no)
FEL Injector or Dump	**10**	**9**	**90**	**no**
CEBAF Inj	**8.5**(10)†	**1**(10)‡	**8.5**(100)	**yes**
CEBAF Inj Chicane(12 GeV)	125	**1**(10)⸸	125(1250)	yes
CEBAF South Linac(12 GeV)⋆	1000	1	1000	yes

† The $\frac{1}{4}$cryomodule as built 10 MeV capable, presently 8.5 MeV capable. Processing of the cavities/waveguide needed to restore 10 MeV capability.

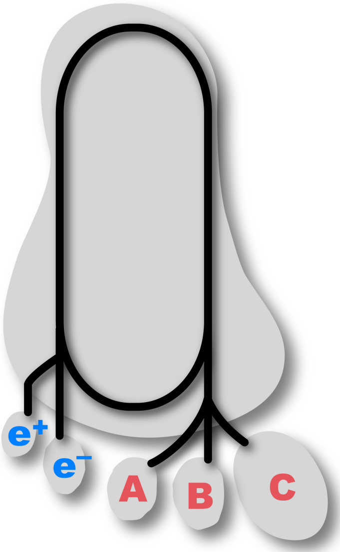
‡ RF power upgrade required on $\frac{1}{4}$cryomodule to achieve higher currents.

⸸ RF power upgrade required on $\frac{1}{4}$ and two cyromodules in injector to achieve higher currents.

⋆ Totally new e^- injector, requires modifications to extraction region as well.

10 MeV: Parameters

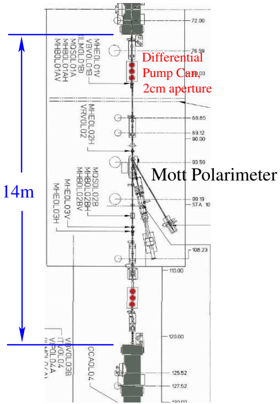
- $E_{e^-} = 10$ MeV, $I_{e^-} = 10$ mA, $P_{e^-} = 100$kW
- Reduced Radiological Issues due to low primary energy
- Significant energy deposition in production target, (20% of 100kW = 20kW).
- $\varepsilon < 5 \times 10^{-6}$ m-rad significant loss, due to large amount of multiple scattering.
- 1 MeV energy bite retains significant portion of produced e^+ due to compact energy spectrum.
- Low e^+ energy $\rightarrow$ time of flight issues, keep the source as compact as possible.



10 MeV: Layout

- Significant amount of real estate
- Proximity of SRF (fore and aft) requires containment of energy and not so good vacuum region.
  - Use thin windows instead of DP cans to keep SRF vacuum isolated.

1/4 Cryomodule, output 5 MeV nominal
(10 MeV capable)



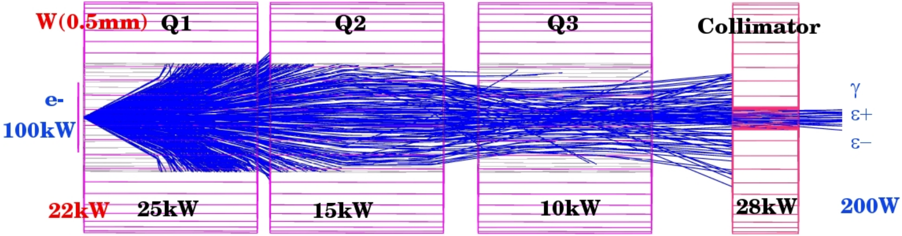
Full Cryomodule Pair
(entrance to first module shown)

10 MeV: Preliminary Study

First attempt to simulate positron production at JLAB.

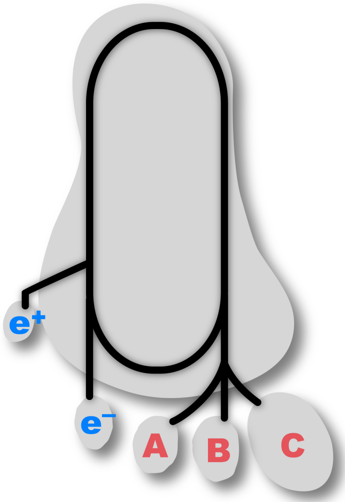
Golge *et.al.* http://cern.ch/AccelConf/p07/PAPERS/THPMS067.PDF

- Developed Figure of Merit based on maximizing the beam brightness. $\mathcal{B} = \frac{N_{e^+}}{\varepsilon_x \varepsilon_y}$
- e^+ capture utilized quadrupole triplet and collimator.
- Very compact design(<1m), to maintain timing within the bunch
- Yield <10nA of e^+ for 10mA e^- beam

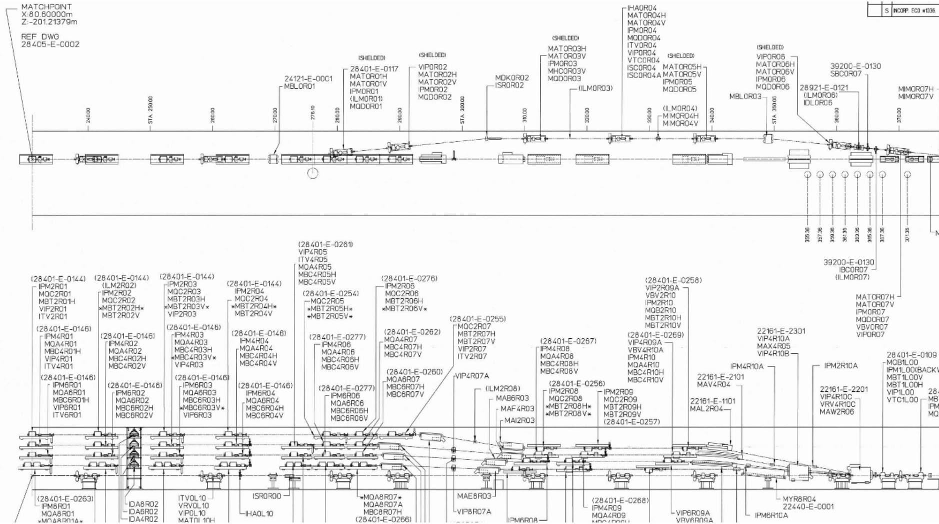


100 MeV: Parameters

- $E_{e^-} = 100$ MeV, $I_{e^-} = 10$ mA, $P_{e^-} = 1000$kW
- Radiation issues
- e^+ angular divergence improved over 10 MeV option.
- e^+ energy spread worse than the 10 MeV option.
- Distance between source and North Linac is large, will this cause the bunch length to grow unacceptably large?



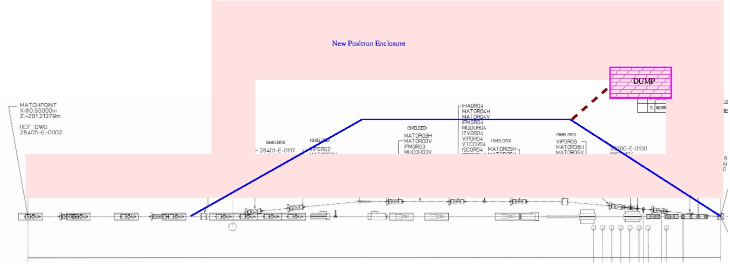
100 MeV: Layout, not much vertical room



100 MeV: Layout with new enclosure

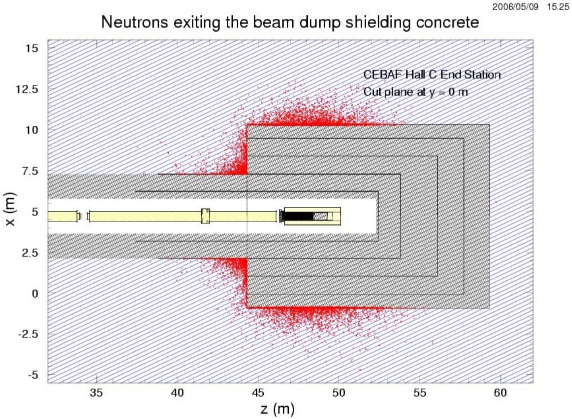
Bring e^- beam through the wall into a new enclosure. This has several advantages:

- Access to e^+ source independent of CEBAF operations
- Radiation from the source and e^- beam dump isolated from main machine.
- Length source section can be tens of meters if needed.



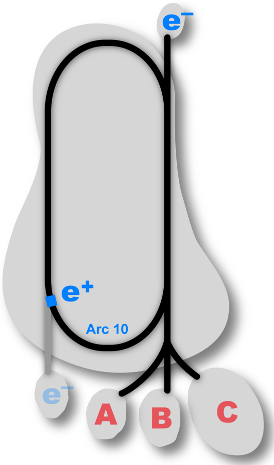
What about that MW dump?

A MW dump is a significant piece of hardware. Require substantial space and maintenance. CEBAF operates and maintains two MW dumps, one in Hall-A and one in Hall-C.

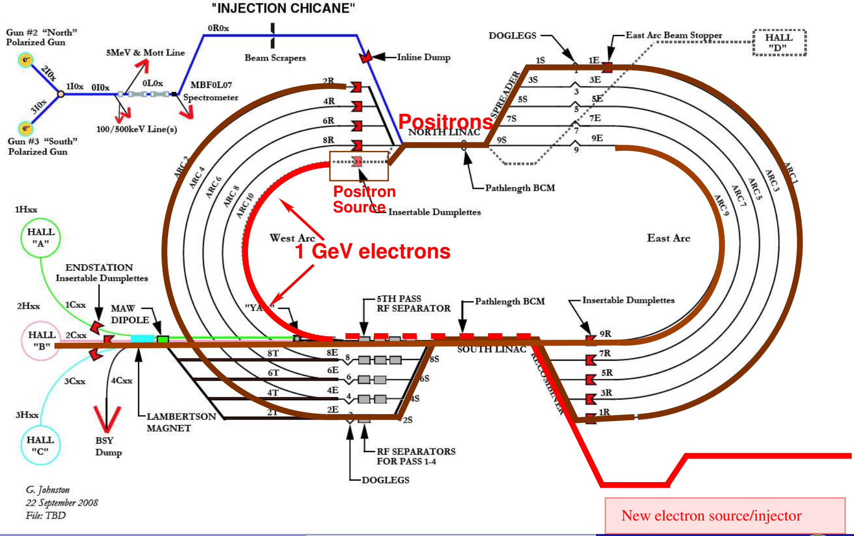


1000 MeV: Parameters

- $E_{e^-} = 1000$ MeV, $I_{e^-} = 1$ mA,
  $P_{e^-} = 1000$kW
- Very conceptual idea of accelerating e^- in the **south** linac up to 1 GeV and using Arc10 (the Hall-D Arc) to bring the e^- to the beginning of the north Linac.
- Obviously Hall-D can not receive beam in this configuration.
- Not only will it require a 1MW dump but also a whole new injector on the south.



1000 MeV: Layout



Production Options: Summary

- **e^- Current** 1mA polarized and 10mA unpolarized e^- beams demonstrated.
- **e^- Energy** Sub-neutron threshold beneficial, but not required. After all CEBAF has two 1MW dumps, radiological staff support already on hand.
- **e^- Power** Would be nice to stick 100kW, but 1MW feasible.
- **Space** 10MeV option might fit in existing tunnel, other options probably require a new enclosure, especially if a MW dump is required.

The ultimate goal is to inject the e^+ into CEBAF and accelerate to 11 GeV. The e^+ must meet the CEBAF admittance requirements. The CEBAF hardware (including diagnostics) should be examined for *charge* sensitivity.

Magnets and e^+

Most magnet power supplies are reversible, except the Arc dipoles. Switching between e^+ and e^- will take perhaps a shift or more.

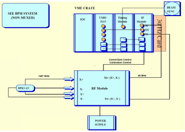
e^- and e^+ reversal

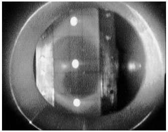
It will not be possible to quickly switch between e^- and e^+. If the physics depends on a precision difference of cross sections, $\sigma_{e^-} - \sigma_{e^+}$, than this is not the right machine.

Diagnostics and e^+

Beam position monitors Have limited sensitivity to low beam currents. CEBAF has several electronic packages for the BPMs: Transport SEE electronics installed Arcs and Hall transport lines requires 50nA of beam current. Linac SEE electronics installed in the Linacs, require μA or more of beam current.

Viewers Will work but controls will have to be changed to allow insertion while delivering low current CW e^+ beam.





CEBAF Beam Modes

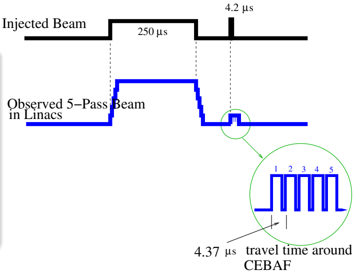
CW Continuous Wave mode, essentially DC beam

Tune Pulsed beam mode on order of tens of μA and 250 μs long with a short after pulse to measure beam positions of the multiple beams in the Linac. Tune mode is used for majority of the beam steering. Beam position monitors work with tune and CW beams.

Viewer Limited Very short beam pulse, order μs, used when viewing beam image on ChromOx viewers.

Will need to redefine CEBAF Beam Modes

The e^+ beam will be of such small currents that the Tune and Viewer Limited Mode beam are not very useful or needed to protect the machine.



RF and e^+

The accelerating sections all have independent phase control (which can be ganged via software). So the RF system does not care if it is working with e^- or e^+.

In addition independent phase control, each linac phase is *ganged* together, so it is straight forward to change the whole linac phase by π.

Establishing the correct pathlength

In order to have each pass through the linac in phase with each other, the pathlength of each *pass* is adjusted via dogleg sections at the entrance to each Arc. The diagnostic that measures the phase difference between passes requires tune mode beam of sufficient current($\sim \mu$A)! Without tune-mode beam and this diagnostic it will be very hard to set the machine up.

Summary

Thanks to Serkan Golge, Jonathan Dumas and Reza Kazimi for information/data and who will also be making presentation this afternoon on e^+ efforts and plans here at JLAB.
Thanks also to Charles Hyde, Jay Benesch and Joe Grames.

- A preliminary survey of CEBAF suggests a polarity change of CEBAF is possible.
- A means setting up the machine with very low currents **without** a robust tune mode beam will need to be established. 50 nA of beam current would allow for beam position measurements. Pathlength diagnostic will need to be upgraded.
- RF power upgrade in the injector region will be needed to support the high currents needed to achieve the desired e^+ beam current.
- Beam power deposition management is likely to be a big issue.

Three possible e^- beam energies, 10,100,and 1000 MeV, have been selected for use in making e^+, which options gives the best beam for the least cost?

Summary: CW e^+ machine based requirements

Regardless of primary e^- energy, the e^+ beam must meet the following requirements at the *injection* point for transport in CEBAF:

Quantity	Symbol	Requirement	Unit
Geometric Emittance	ε	$< 5 \times 10^{-6}$	m-rad
Absolute Energy Spread	ΔE	$< 1^{\dagger}$	MeV
Beam Current	I	$> 50^{\star}$	nA
Bunch Length	τ_b	$< 2^{\ddagger}$	ps
Duty Factor	DF	100	%
Frequency	f	1.497 (or subharmonic)	GHz

Can this be achieved without the use of damping/accumulator ring?

† Could be increased with new low dispersion optics

⋆ Needed for setup, lower beam currents possible once stable transport has been established.

‡ $\tau_b = 2$ps bunch length retains 10^{-4} level energy spread at the Halls, $\tau_b = 4$ps will yield energy spread at the 10^{-3} level.