ELIC: An Electron – Light Ion Collider based at CEBAF

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Jefferson Lab

EIC Accelerator Workshop
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Outline

- Nuclear Physics Requirements
- Basis of Proposal / Concept
- ELIC Layout
- Parameter Choices / Table
- Accelerator Technology issues
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- Accelerator Physics Issues
  - Proton Ring
  - Energy Recovering Linacs
  - Electron-Ion Collisions
- Integration with 25 GeV Fixed Target Program
- R&D Topics and Conclusions

Nuclear Physics Requirements

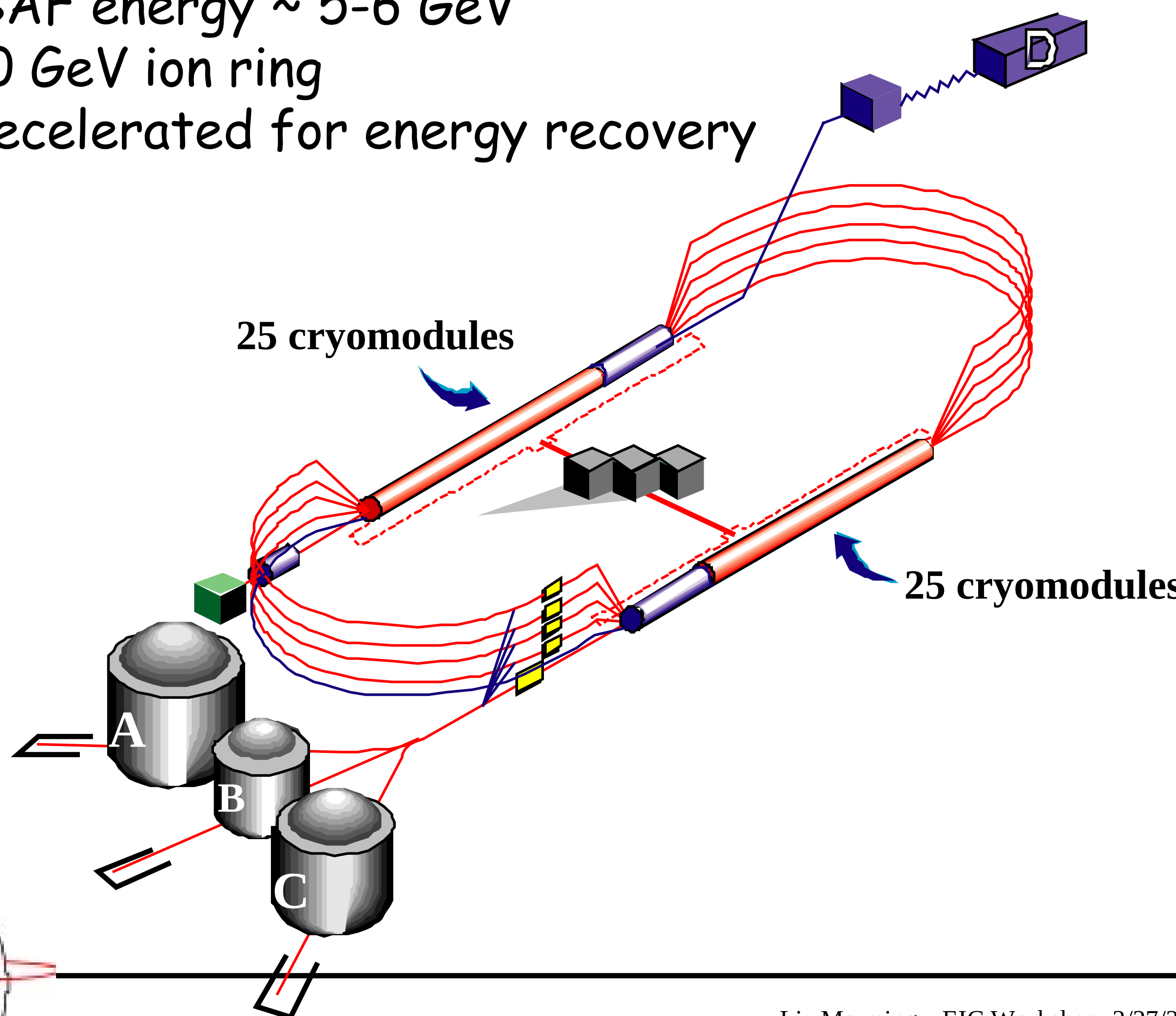
- An electron – light ion collider with the following requirements has been proposed as a means for studying hadronic structure:
  - Center-of-mass energy between 20 GeV and 30 GeV with energy asymmetry of ~10, which yields $E_e \sim 3$ GeV on $E_i \sim 30$ GeV up to $E_e \sim 5$ GeV on $E_i \sim 50$ GeV
  - CW Luminosity from 10^{33} to 10^{35} cm^{-2} sec^{-1}
  - Ion species of interest: protons, deuterons, He^3
  - Longitudinal polarization of both beams in the interaction region $\geq 50\%$ –80%
  - Spin-flip of both beams extremely desirable for exclusive measurements

Basis of Proposal

- CEBAF is used for the acceleration of electrons
- Energy recovery is used for rf power savings and beam dump requirements
- "Figure-8" storage ring is used for the ions for flexible spin manipulations of all light-ion species of interest
- Circulator ring for the electrons may be used to ease high current polarized photoinjector requirements

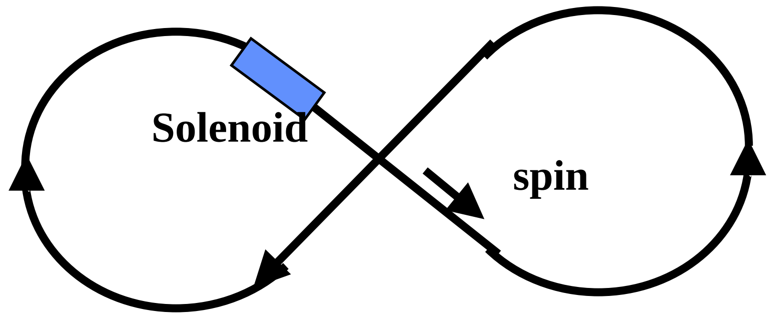
CEBAF with Energy Recovery

- Install 50 Upgrade CEBAF cryomodules at ~20 MV/m in both linacs
- Single-pass CEBAF energy ~ 5-6 GeV
- Collision with 50 GeV ion ring
- Electrons are decelerated for energy recovery

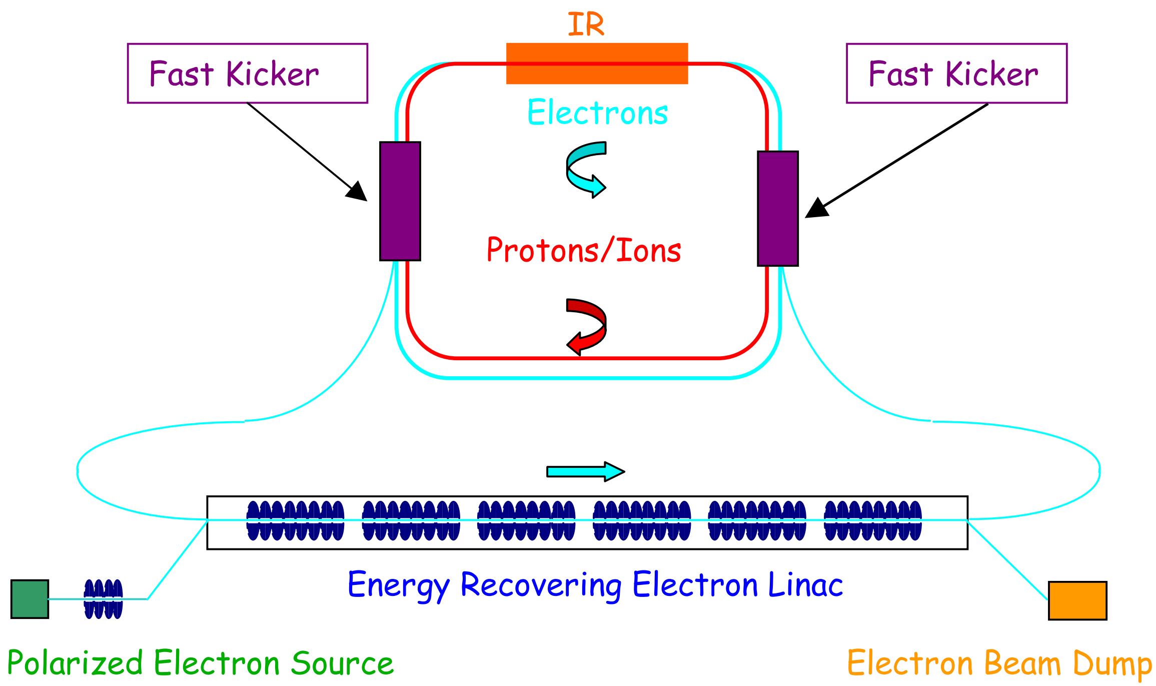


"Figure-8" Ion Ring

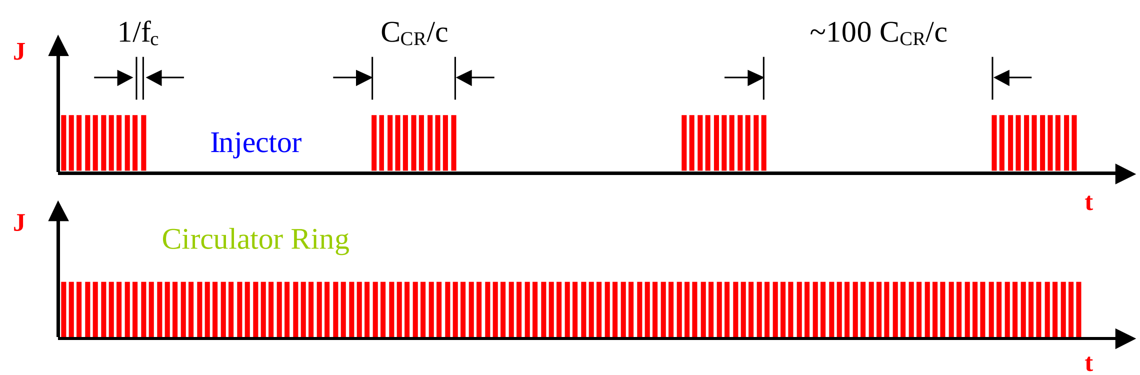
- Zero spin tune avoids intrinsic spin resonances
- No spin rotators are needed
- Can get longitudinal polarization for all ion species at all energies continuously



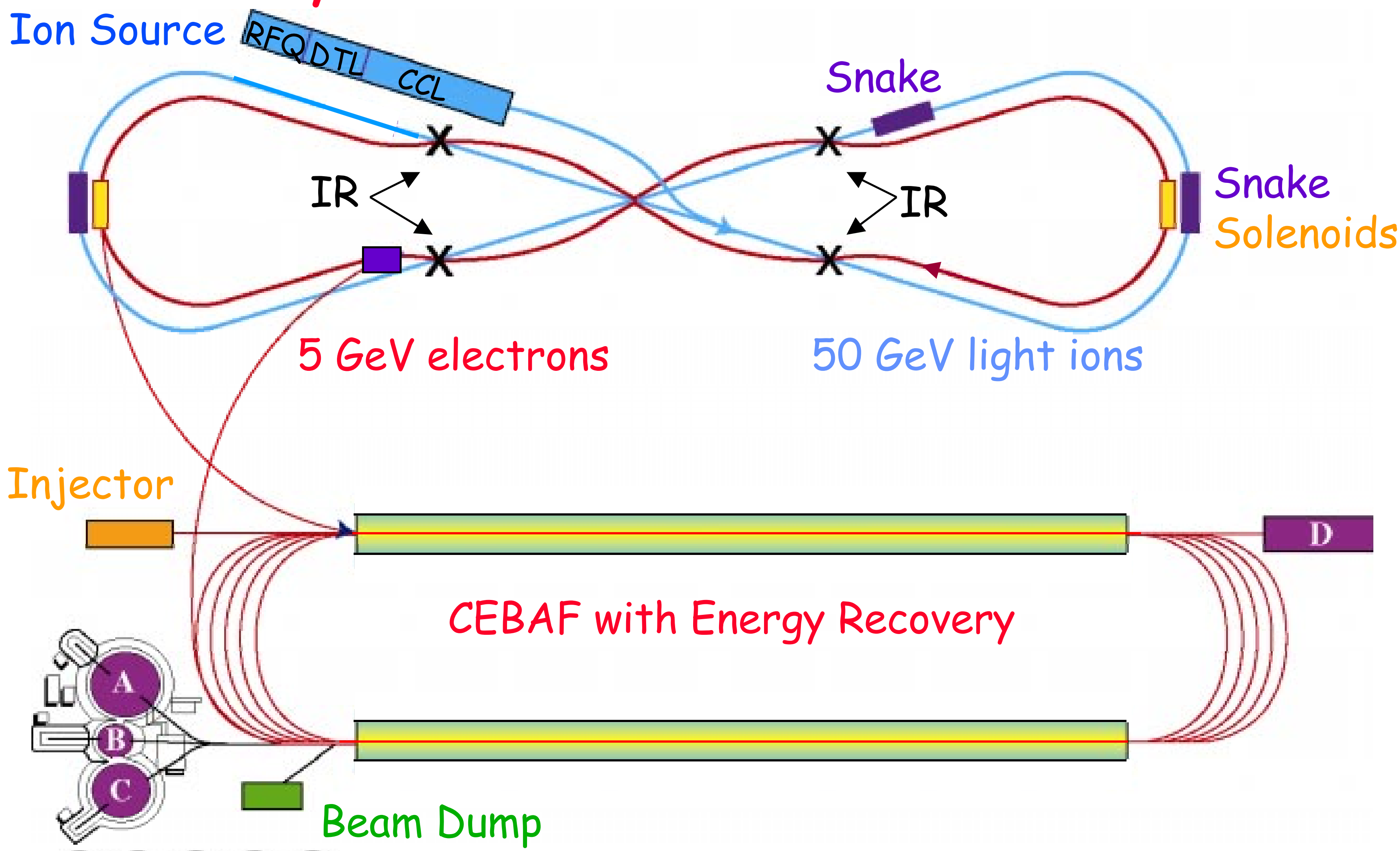
Circulator Ring



Different filling patterns are being explored (Hutton, Litvinenko)



ELIC Layout



Ion Source
RFQ
DTL
CCL
Snake
IR
IR
Snake
Solenoids
5 GeV electrons
50 GeV light ions
Injector
D
CEBAF with Energy Recovery
A
B
C
Beam Dump

Parameter Choices

- We have developed self-consistent parameters for 4 point designs (PDs):
  - PD0: Max peak luminosity without cooling and
    parameters based on demonstrated performance to date
  - PD1: Max luminosity of 1×10^{33} cm^{-2} sec^{-1}
    Electron cooling required
  - PD2: Max luminosity of 1×10^{34} cm^{-2} sec^{-1}
    Electron cooling required -> short ion bunches
    Circulator ring
    Crab crossing
  - PD3: Max achievable luminosity
    Electron cooling required -> short ion bunches
    Circulator ring
    Crab crossing
    Traveling focus ?
- Assumptions
  E_e=5 GeV, E_i = 50 GeV, ε_n^e = 10 μm, ε_n^i = 2 μm (w/out cooling)
  Equal beam sizes for electrons and ions are assumed at the IP

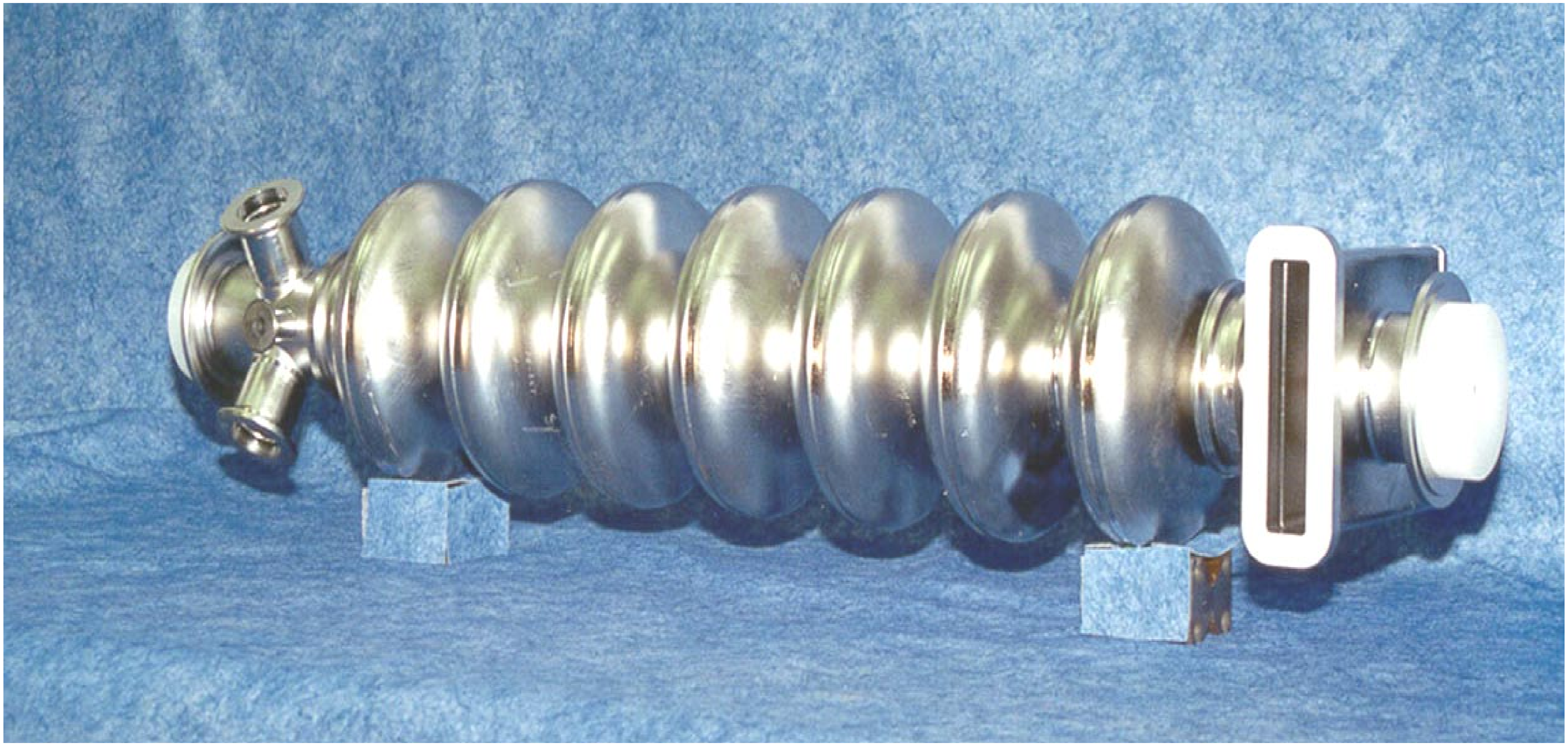
Parameter Table

Parameter	Units	Point Design 0		Point Design 1		Point Design 2		Point Design 3	
		e^-	Ions	e^-	Ions	e^-	Ions	e^-	Ions
Energy	GeV	5	50	5	50	5	50	5	50
Cooling	-	-	No	-	Yes	-	Yes	-	Yes
Lumi	cm^{-2} sec^{-1}	1×10^{32}		1×10^{33}		1×10^{34}		6×10^{34}	
N_{bunch}	ppb	1×10^{10}	2.5×10^{10}	1×10^{10}	2.5×10^{10}	2×10^{10}	5×10^{9}	1×10^{10}	1×10^{10}
f_c	MHz	150		150		500		1500	
I_{ave}	A	0.24	0.6	0.24	0.6	1.6	0.4	2.5	2.5
σ^*	μm	45	45	14	14	6	6	4.5	4.5
ε_n	μm	10	2	10	0.2	10	0.2	10	0.1
β^*	cm	200	5	20	5	4	1	2	1
σ_z	cm	0.1	5	0.1	5	0.1	1	0.1	1
ξ_e / ξ_i	-	0.5	.0006	0.5	0.006	0.1	0.01	0.2	0.01
$\Delta\nu_L$	-	-	0.005	-	0.05	-	0.05	-	0.09

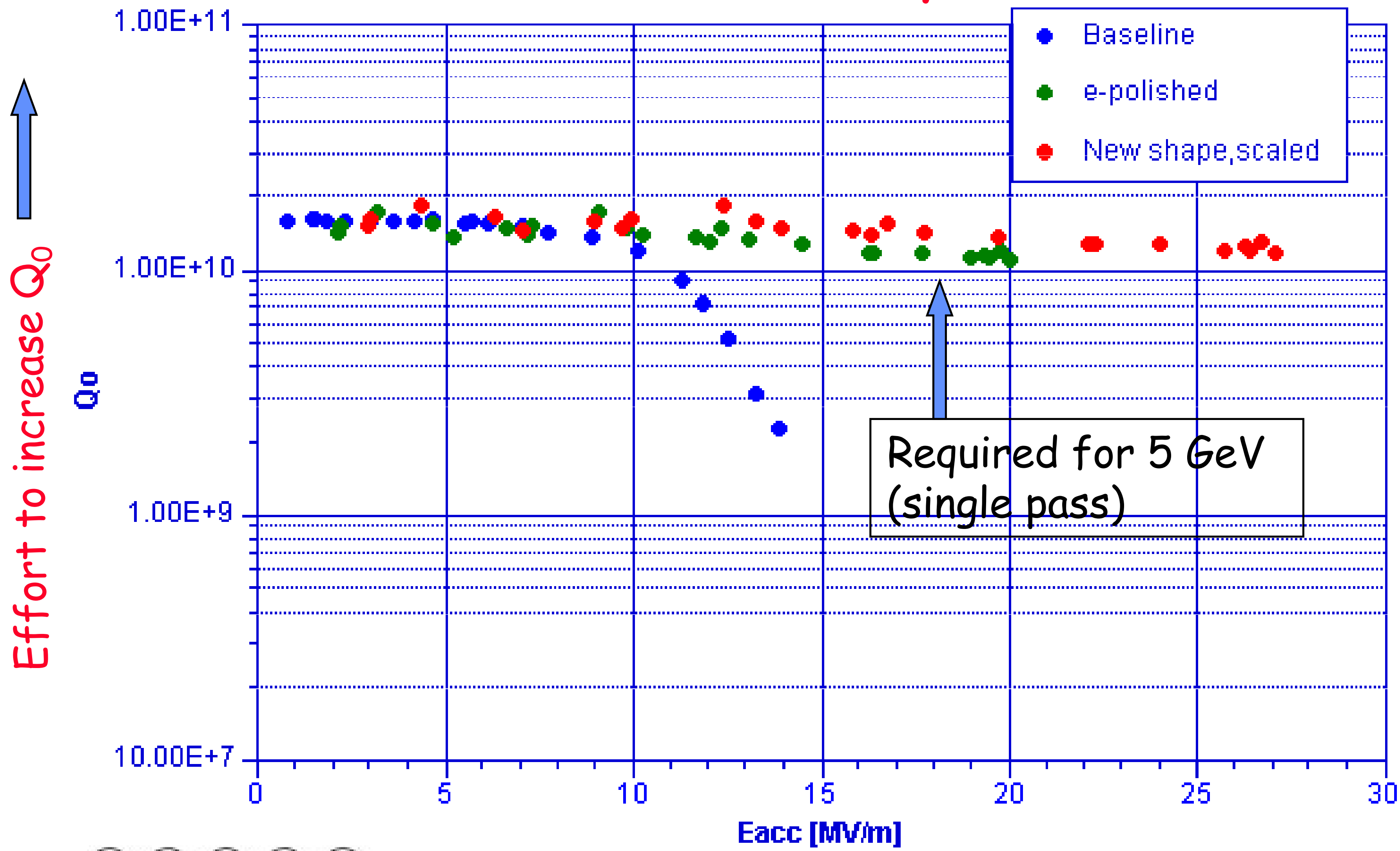
Accelerator Technology Issues

- Electron Source
  → State of the art in high average current, polarized sources:
  ~1 mA at 80% polarization [C. Sinclair, JLab]
  Circulator ring appears promising
- RF Issues
  ERLs favor high Q_{ext} for rf power savings, increased system efficiency
  For 25 Hz amplitude of microphonic noise, optimum Q_{ext}~$3x10^7$
  → RF Control becomes more difficult with high Q_{ext} at high gradient
  (See J. Delayen, "RF Issues in Energy Recovering Linacs" L/R WG)
- Superconducting RF Issues
  → Demonstrate high CW gradient (18 MV/m) at high Q_0 ($1x10^{10}$)
- Cryogenics
  → At Q_0=$1x10^{10}$ dynamic load ~10 kW, installed ~20 kW (x2 Upgrade CEBAF)

Jefferson Lab 7-cell Cavity



Jefferson Lab 7-cell Cavity Performance



Accelerator Physics Issues of the Proton Ring

- Intrabeam scattering: Transverse and longitudinal
  ⇒ For luminosity >10^{33} $cm^{-2}sec^{-1}$ electron cooling is required

- Collective Effects
  - Longitudinal mode coupling
  - Transverse mode coupling instability

Accelerator Physics Issues of the ERL

- Accelerator Transport
  → Demonstrate energy recovery with large energy ratio
  An energy recovery experiment at CEBAF has been proposed and is being planned (D. Douglas)
- Beam Loss
  → Is 4×10^{-6} relative loss achievable?
- Collective Effects
  - Single-bunch effects
    → Emittance growth and energy spread due to wakes
  - Multipass, Multibunch Beam Breakup (BBU) Instability
    → I_{th} ~ 200 mA, growth rate ~2 msecs ⇒ feedback ?
- HOM Power Dissipation
  → ~kW per cavity
  JLab FEL and the ERL Prototype (Cornell/JLab) to address several of these issues

Accelerator Physics Issues of the Electron-Ion Collisions

- IR design integrated with real detector geometry
- Crab crossing tolerances and resonance excitation effects
- Emittance growth of the electrons (which have to be recirculated and energy recovered) due to a single collision with the protons $\Rightarrow N_p < 1.5 \times 10^{12}$
- Beam-beam kink instability

Beam-Beam Kink Instability

- The beam-beam force due to the relative offset between the head of the proton bunch and the electron beam will deflect the electrons. The deflected electrons subsequently interact with the tail of the proton bunch through beam-beam kick.
- The electron beam acts as a transverse impedance to the proton bunch, and can lead to an instability.
- In the linear approximation, and disregarding the evolution of the wake within the proton bunch, a stability criterion has been derived [Li, Lebedev, Bisognano, Yunn, PAC 2001]

$$D_e \xi_p \leq 4\nu_s$$

- For the case of equal bunches and linear beam-beam force, chromaticity appears to increase the threshold of the instability [Perevedentsev, Valishev, PRST '01].
- The instability has been observed in numerical simulations [R. Li, J.Bisognano, Phys. Rev. E (1993)] during the beam-beam studies of linac-ring B-Factory. The code is presently being used to simulate unequal bunches and a nonlinear force. We also expect chromaticity to be beneficial in this case

* See Rui Li, "Beam-beam stability in Linac-Ring colliders" L/R WG

Beam-Beam in Linac-Ring Colliders

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Strong-strong simulation on the beam-beam effect in a linac-ring *B* factory

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Since the inherently low emittance required by the linac-ring *B* factory implies high disruption for the linac bunch, previous investigations of the beam-beam tune-shift limit may not apply. A strong-strong simulation scheme was developed based on a macroparticle model to simulate beam-beam interaction in this situation self-consistently. Included in the ring dynamics are linear betatron oscillations and synchrotron motion, as well as transverse and longitudinal damping and quantum excitation. As a benchmarking test, the coherent quadrupole effect in a ring-ring collider was observed by the simulation. The code was then used to study the stability of the storage-ring bunch in a linac-ring collider and yielded strong synchrobetatron coupling due to the deep envelope modulation of the linac bunch. It was, however, observed that when initial conditions for the linac beam were properly chosen to match the focusing provided by the ring beam at IP, the beam-beam tune-shift limit of the ring beam could be comparable to that of a ring-ring collider.

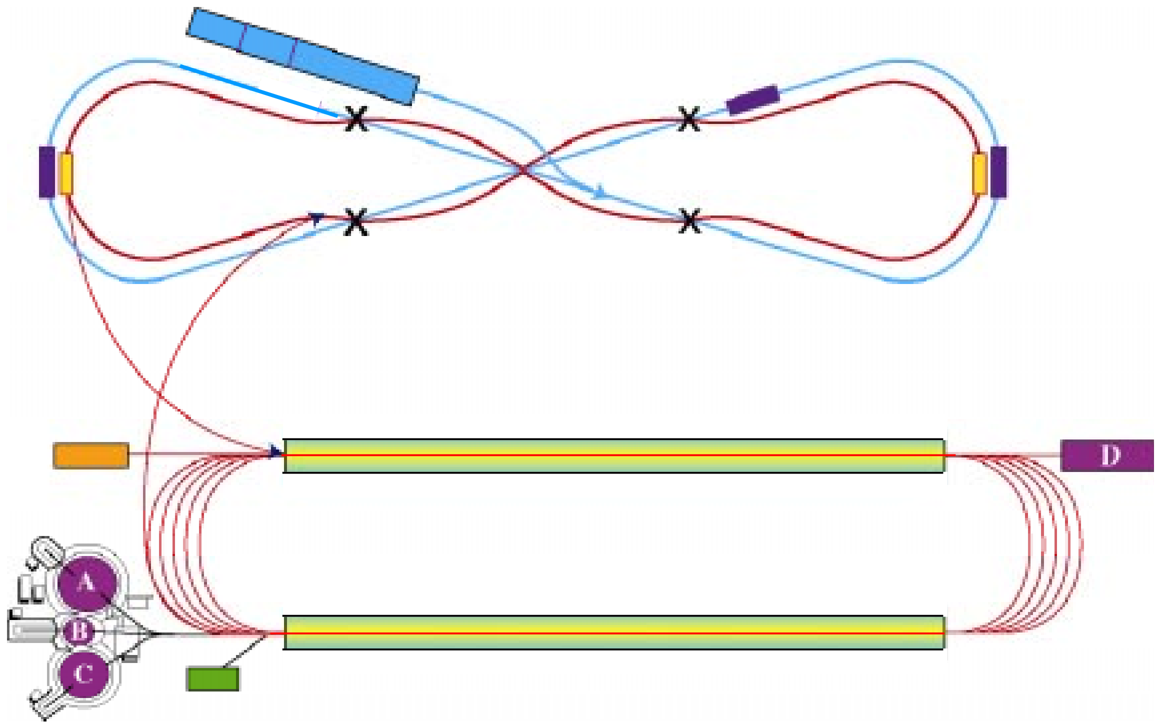
PACS number(s): 41.85.−p, 41.75.−i

Integration with 25 GeV Fixed Target Program

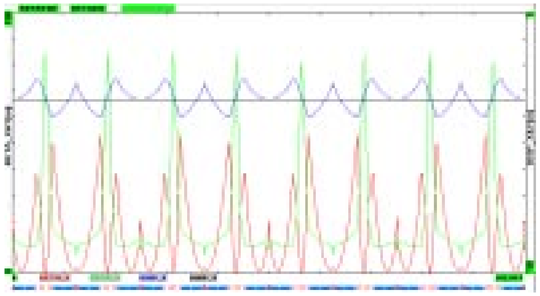
- Five accelerating passes through CEBAF
  ⇒ 25 GeV Fixed Target (FT) Program

- One accelerating/one decelerating pass through CEBAF
  ⇒ 30 GeV CM Collider Program

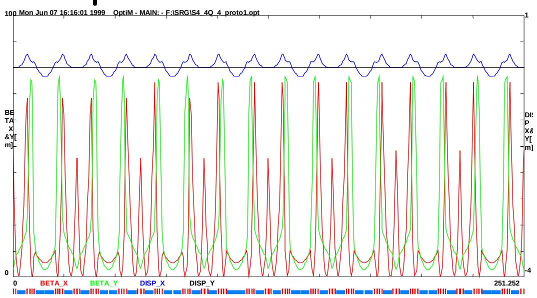
Exploring whether collider and fixed target modes can run simultaneously or in alternating mode



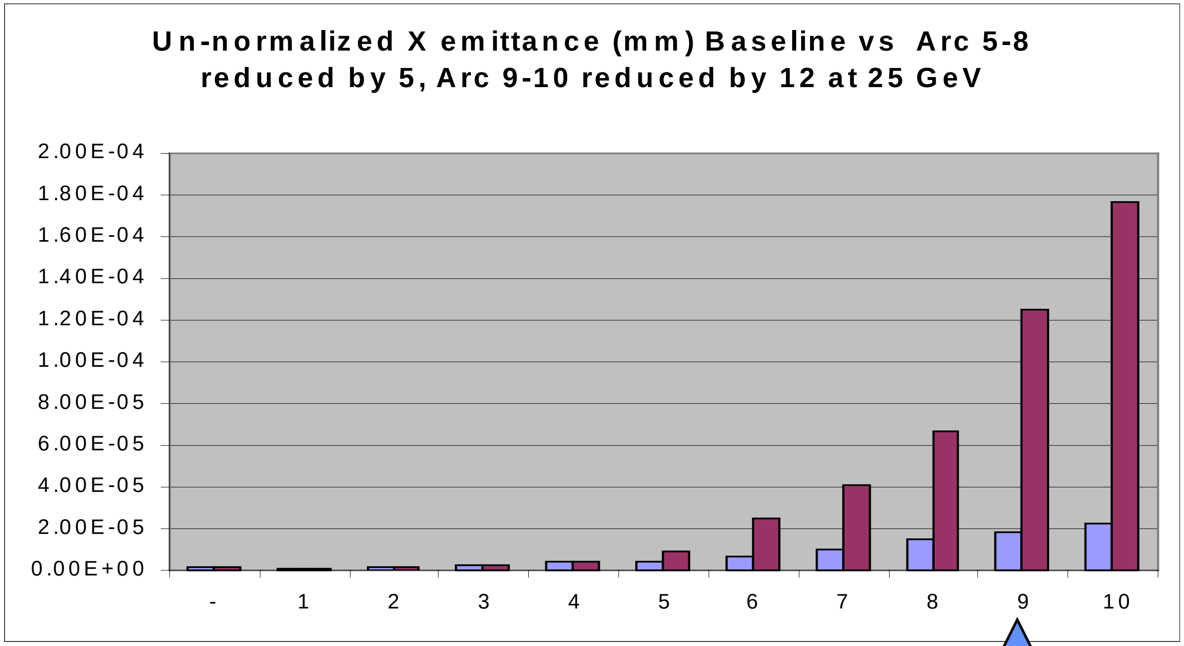
Feasibility of 25 GeV FT Program at CEBAF



Optics for arcs 5-8



Optics for arcs 9, 10

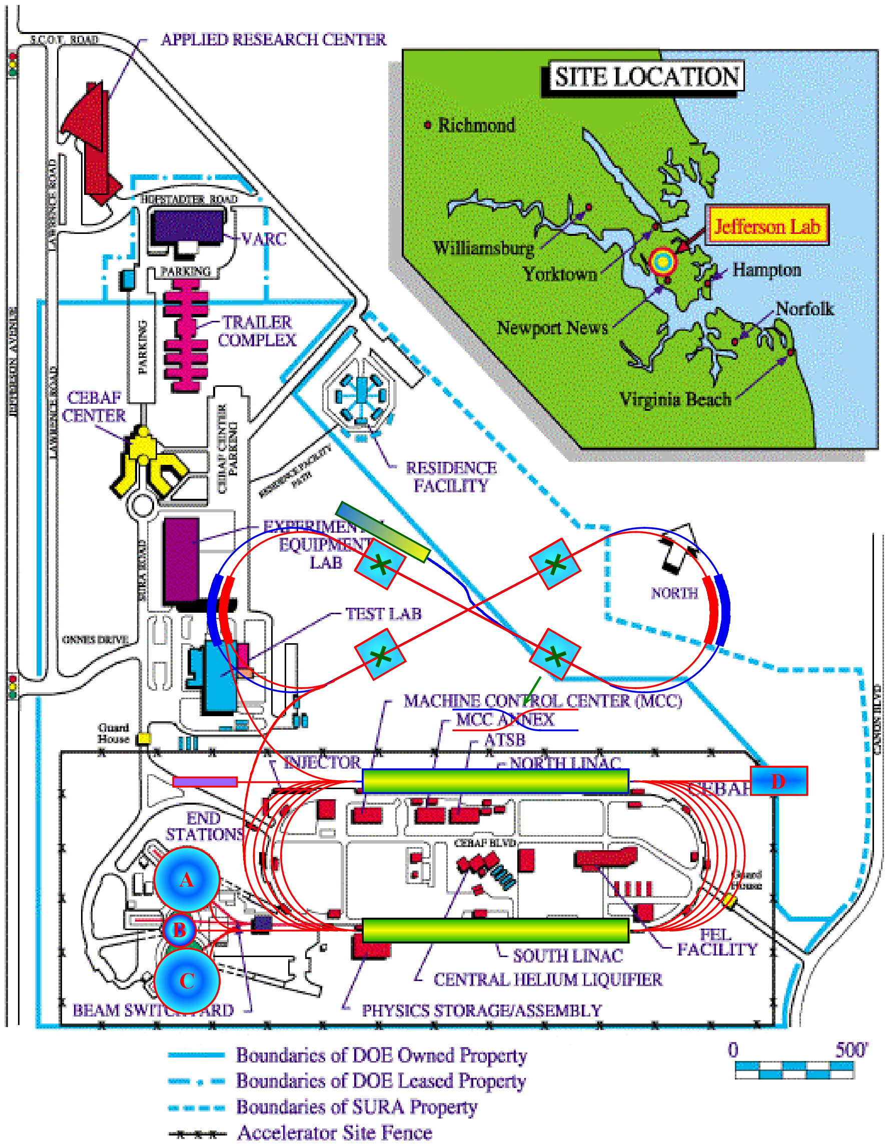


Arc 9 β-functions ~70 m	Emittance incl. SR at arc 9: 2×10^{-8} m rad

SR leads to spot sizes at the IP of 0.3-0.5 mm at 25 GeV

See Y. Chao, Jlab TN 99-037

Site Map



APPLIED RESEARCH CENTER
SITE LOCATION
Richmond
Williamsburg
Yorktown
Jefferson Lab
Hampton
Norfolk
Newport News
Virginia Beach
S.C.O.T. ROAD
HOFSTADTER ROAD
VARC
PARKING
TRAILER COMPLEX
CEBAF CENTER
CEBAF CENTER PARKING
JEFFERSON AVENUE
LAWRENCE ROAD
SURA ROAD
ONNES DRIVE
RESIDENCE FACILITY
EXPERIMENT EQUIPMENT LAB
TEST LAB
NORTH
MACHINE CONTROL CENTER (MCC)
MCC ANNEX
ATSB
INJECTOR
NORTH LINAC
CEBAF
D
END STATIONS
CEBAF BLVD
A
B
C
Guard House
FEL FACILITY
SOUTH LINAC
CENTRAL HELIUM LIQUIFIER
PHYSICS STORAGE/ASSEMBLY
BEAM SWITCHYARD
CANON BLVD
Boundaries of DOE Owned Property
Boundaries of DOE Leased Property
Boundaries of SURA Property
Accelerator Site Fence
0
500'

Conclusions / R&D Strategy

- The feasibility of an electron-light ion collider based at CEBAF has been examined
- Self-consistent sets of parameters have been developed
- Luminosities of 10^{33} to several 10^{34} appear feasible. Electron cooling is required
- "Circulator ring" concept promises to ease polarized electron source requirements significantly
- Additional conceptual luminosity improvements are being explored
- ERL Prototype to address high average current issues of EIC colliders
- Energy Recovery experiment at CEBAF to address high input/output energy issues of EIC colliders
- An integrated electron-ion collider program (CM energy 20-30 GeV) and fixed target program (at 25 GeV) based at CEBAF appears feasible