ELIC: An Electron - Light Ion Collider based at CEBAF

L. Merminga, K. Beard, L. Cardman, Y. Chao, S. Chattopadhyay, K. de Jager, J. Delayen, Ya. Derbenev, J. Grames, A. Hutton, G. Krafft, R. Li, M. Poelker, B. Yunn, Y. Zhang

Center for Advanced Studies of Accelerators
Jefferson Lab

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Outline

- Nuclear Physics Motivation & Requirements
- Early Design Studies
- ELIC Layout
- Luminosity Potential
- Accelerator Physics & Technology Issues
  - Ion Ring
  - Electron Linac
  - Electron-Ion Collisions
- Integration with 25 GeV Fixed Target Program
- R&D Topics/Strategy
- Conclusions

Nuclear Physics Motivation

- A high luminosity polarized electron – light ion collider has been proposed as a powerful new microscope to probe the partonic (quarks and gluons) structure of matter
- Over the past two decades we have learned a great amount about the hadronic structure
- Some crucial questions remain open:
  - What is the structure of hadrons in terms of their quark and gluon constituents?
  - How do quarks and gluons evolve into hadrons?

Nuclear Physics Requirements

- The features of the facility necessary to address these issues:
  - Center-of-mass energy between 20 GeV and 45 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 $E_i \sim 100$ GeV
  - CW Luminosity from 10^{33} to 10^{35} cm^{-2} sec^{-1}
  - Ion species of interest: protons, deuterons, ^3He
  - Longitudinal polarization of both beams in the interaction region $\geq$ 50% –80% required for the study of generalized parton distributions and transversity
  - Transverse polarization of ions extemely desirable
  - Spin-flip of both beams extremely desirable

Two Design Scenarios

- Two accelerator design scenarios have been proposed:
  - ring – ring*
  - linac – ring

- Linac – ring option presents advantages with respect to
  - spin manipulations
  - reduction of synchrotron radiation load on the detectors
  - wide range of continuous energy variability

- Feasibility studies were conducted at BNL† (based on RHIC) and Jefferson Lab‡ to determine whether the linac-ring option is viable

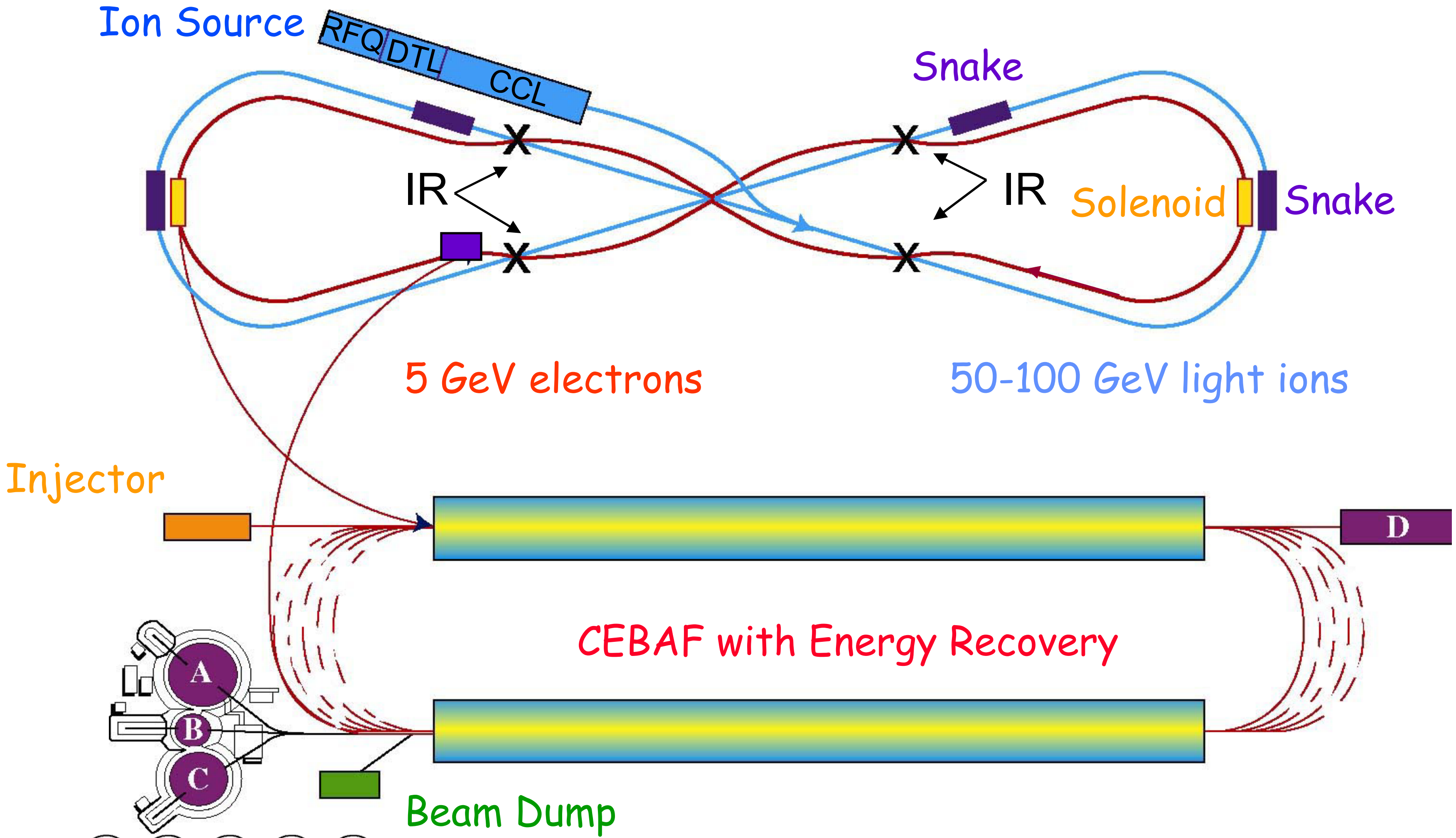
* Y. Shatunov et al., 2nd EPIC Workshop, 2000
† I. Ben-Zvi, J. Kewisch, J. Murphy, S. Peggs, NIM A Vol. 463 (2001)
‡ L. Merminga, G. Krafft, V. Lebedev, Proc. of HEACC 2001

Conclusions of Generic Linac-Ring Studies

- Luminosities at the 10^{33} cm^{-2} sec^{-1} level appear attainable with an electron linac-on-proton ring design
- Rf power and beam dump considerations require that the electron linac is an Energy Recovering Linac (ERL)
- Electron cooling of the protons is required for luminosity at or above 10^{33} cm^{-2} sec^{-1}

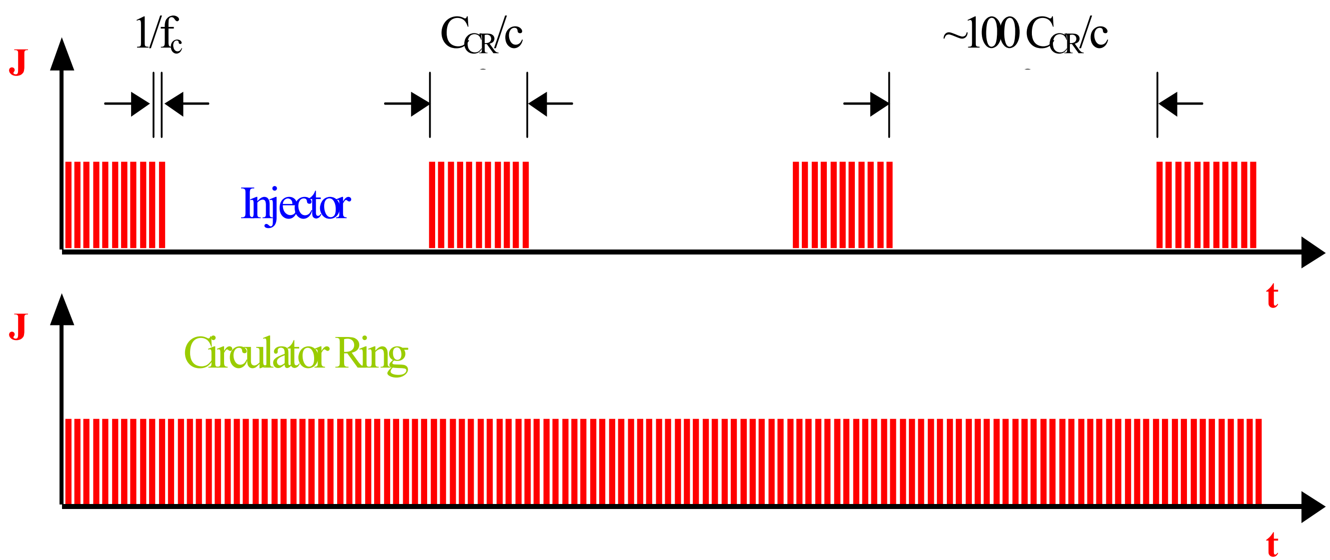
ELIC Layout

One accelerating & one decelerating pass through CEBAF



Circulator Ring

Y. Derbenev



Different filling patterns are being explored (Hutton, Litvinenko)

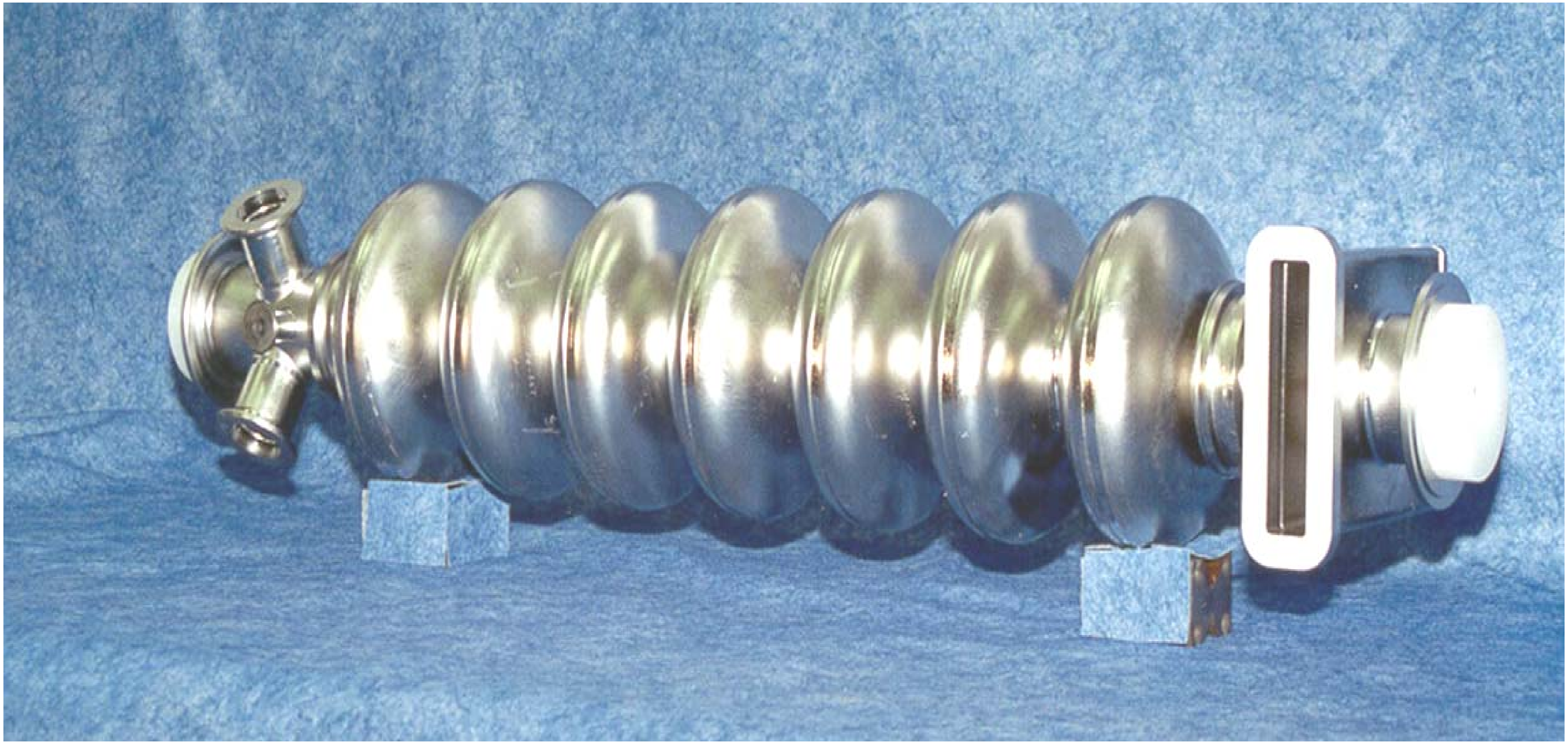
Parameter Table

Parameter	Units	Point Design 0		Point Design 1		Point Design 2		Point Design 3	
		e^-	Protons	e^-	Protons	e^-	Protons	e^-	Protons
Energy	GeV	5	50	5	50	5	50	5	50/100
Cooling	-	-	No	-	Yes	-	Yes	-	Yes
CR			No		No		Yes		Yes
Lumi	cm^{-2} sec^{-1}	1×10^{32}		1×10^{33}		1×10^{34}		6×10^{34} / 1×10^{35}	
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	4.5/3.2	4.5/3.2
ε_n	μm	10	2	10	0.2	10	0.2	10	0.1
β^*	cm	200	5	20	5	4	1	2/1	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

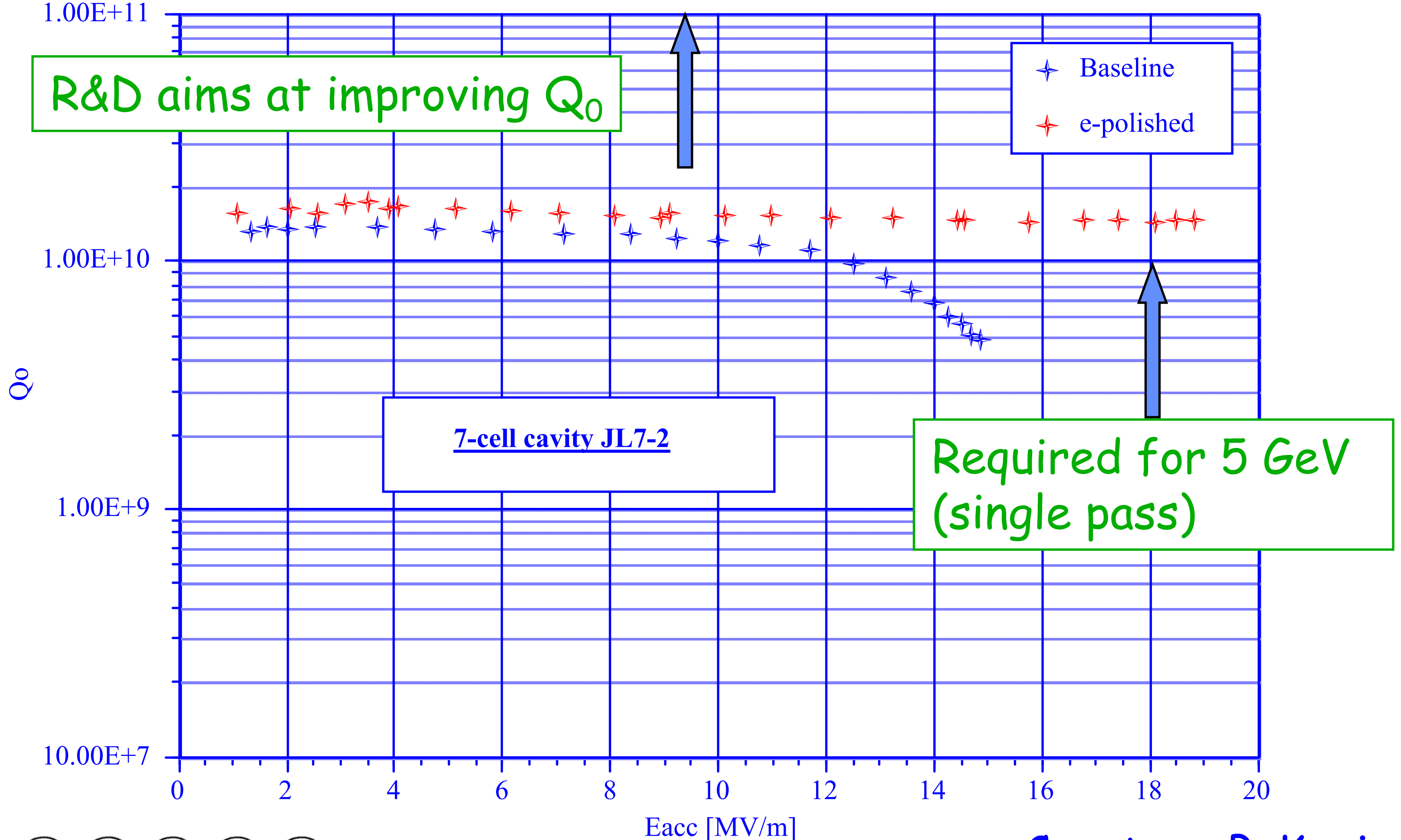
Accelerator Technology Issues

- Electron Source
  - State of the art in high average current, polarized sources: ~1 mA at 80% polarization [C. Sinclair, Cornell University]
    Circulator ring appears promising
- RF Issues
  - ERLs favor high Q_{ext} for rf power savings, increased system efficiency
  - Optimum Q_{ext}~$3x10^7$ (25 Hz amplitude of microphonic noise)
  - RF Control becomes more difficult with high Q_{ext} at high gradient
- 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



Courtesy P. Kneisel

Accelerator Physics Issues of the Ion Ring

- Intrabeam scattering: Transverse and longitudinal
  ⇒ For luminosity >10^{32} $cm^{-2}sec^{-1}$ electron cooling is required
  - Electron cooling of 100 GeV protons requires 50 MeV electrons. Practical only if based on SRF-ERL technology, which is routinely used at the JLab IR FEL
  - BNL/BINP, with help from JLab, seriously pursuing an ERL-based electron cooling device for heavy ions at RHIC*
- Collective Effects
  - Longitudinal mode coupling
  - Transverse mode coupling instability

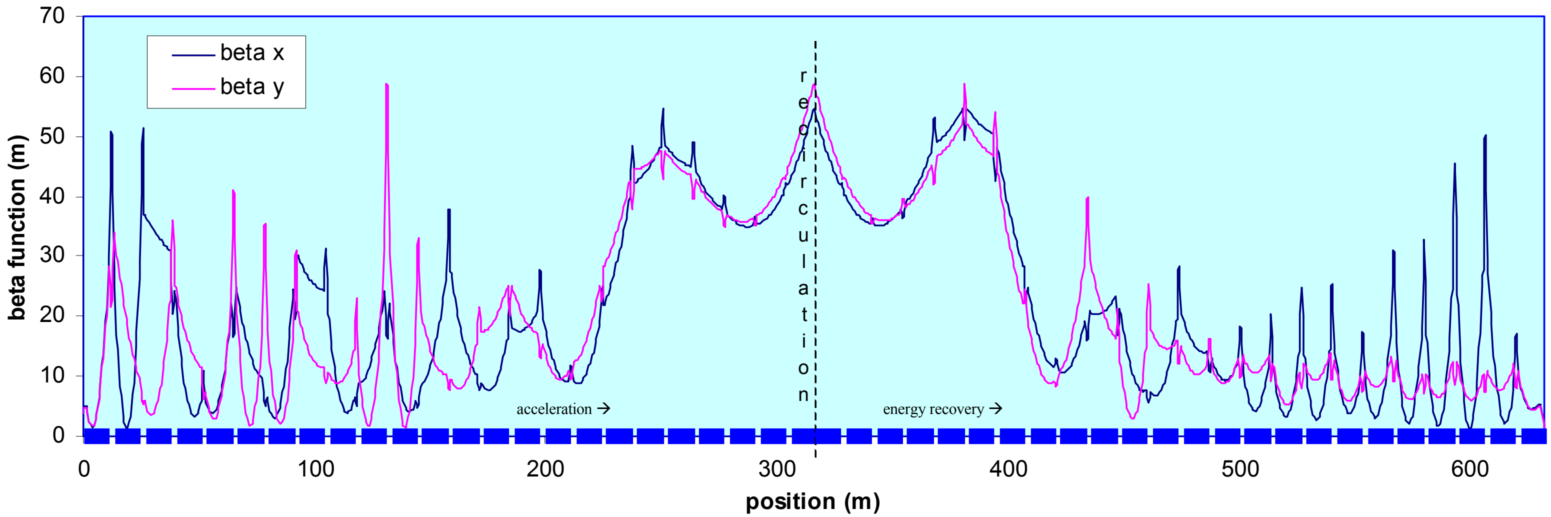
* V. Parkhomchuk and I. Ben-Zvi, *C-A/AP/47*, 2001

Accelerator Physics Issues of the ERL

- Accelerator Transport
  - Demonstrate energy recovery with large energy ratio
- Beam Loss
- Collective Effects
  - Single-bunch effects
  - Multipass, Multibunch Beam Breakup (BBU) Instability
- HOM Power Dissipation
  - ~kW per cavity (Circulator ring greatly ameliorates this problem)

Linac Optics

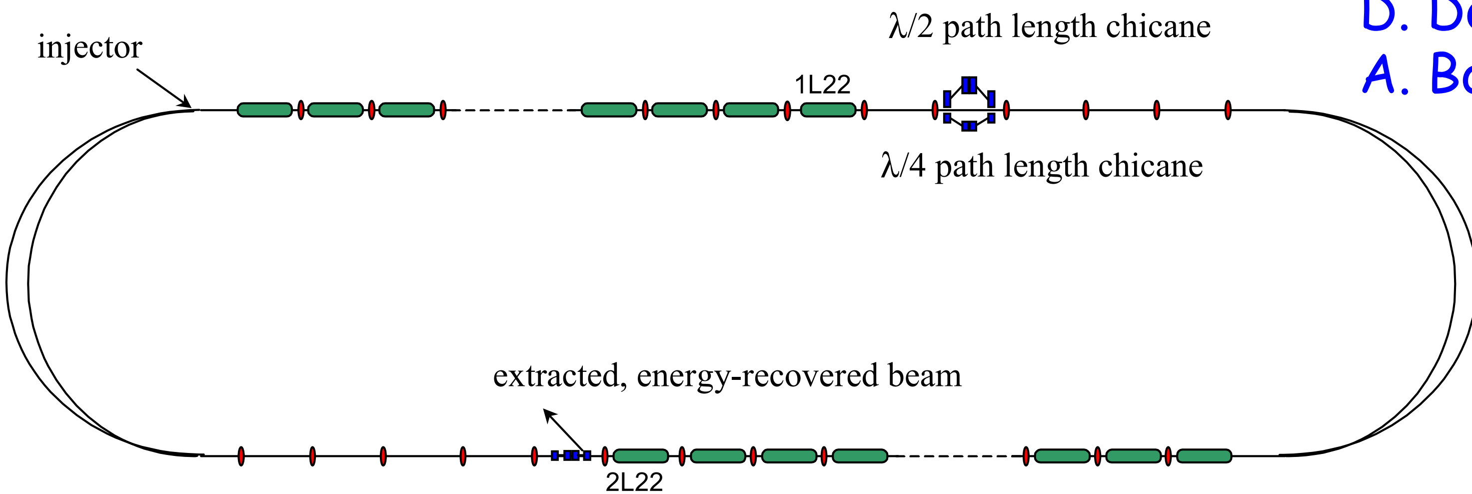
- Two beams of different energies must remain confined in the same focusing channel. A possible solution (I. Bazarov, Cornell University) for a 5 GeV ERL

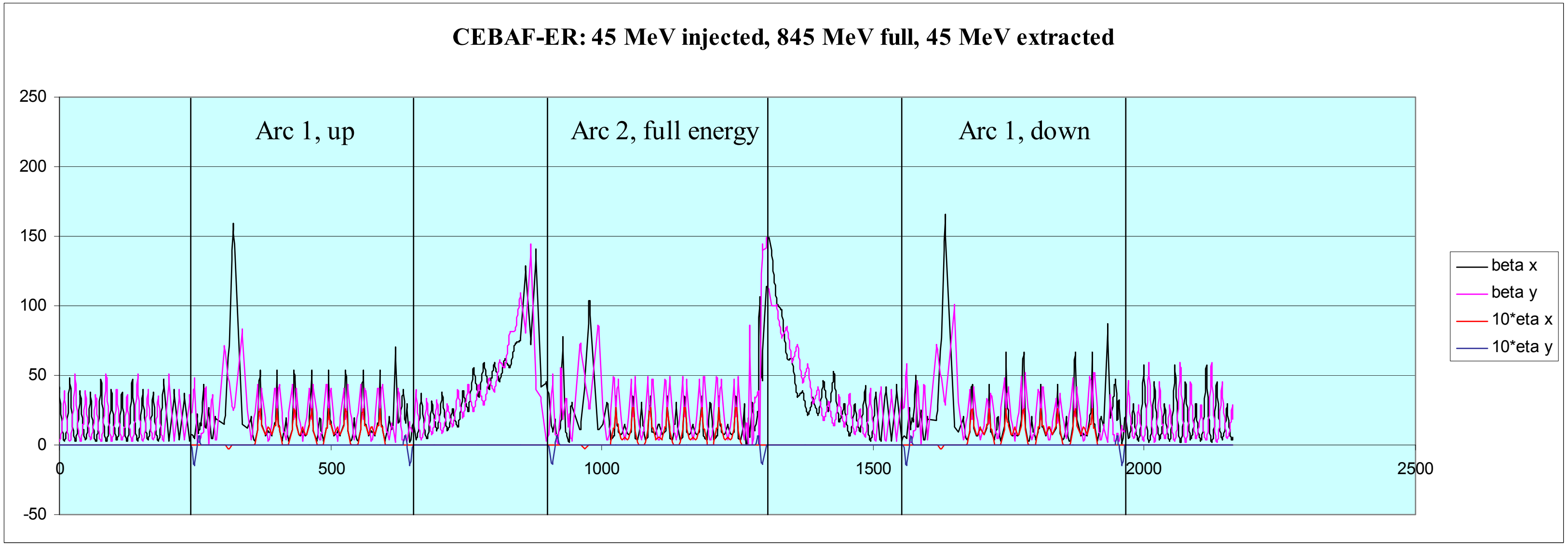


- CEBAF-ER: An energy recovery experiment at CEBAF, has been proposed and planned for March 2003 to address energy recovery issues in large scale systems

CEBAF-ER Experiment

D. Douglas &
A. Bogacz





Accelerator Physics Issues of the Electron-Ion Collisions

- IR design integrated with real detector geometry
- Crab crossing
- Emittance growth of the electrons (which have to be recirculated and energy recovered) due to collisions with the ions
- Beam-beam head-tail instability

Beam-Beam Head-Tail Instability

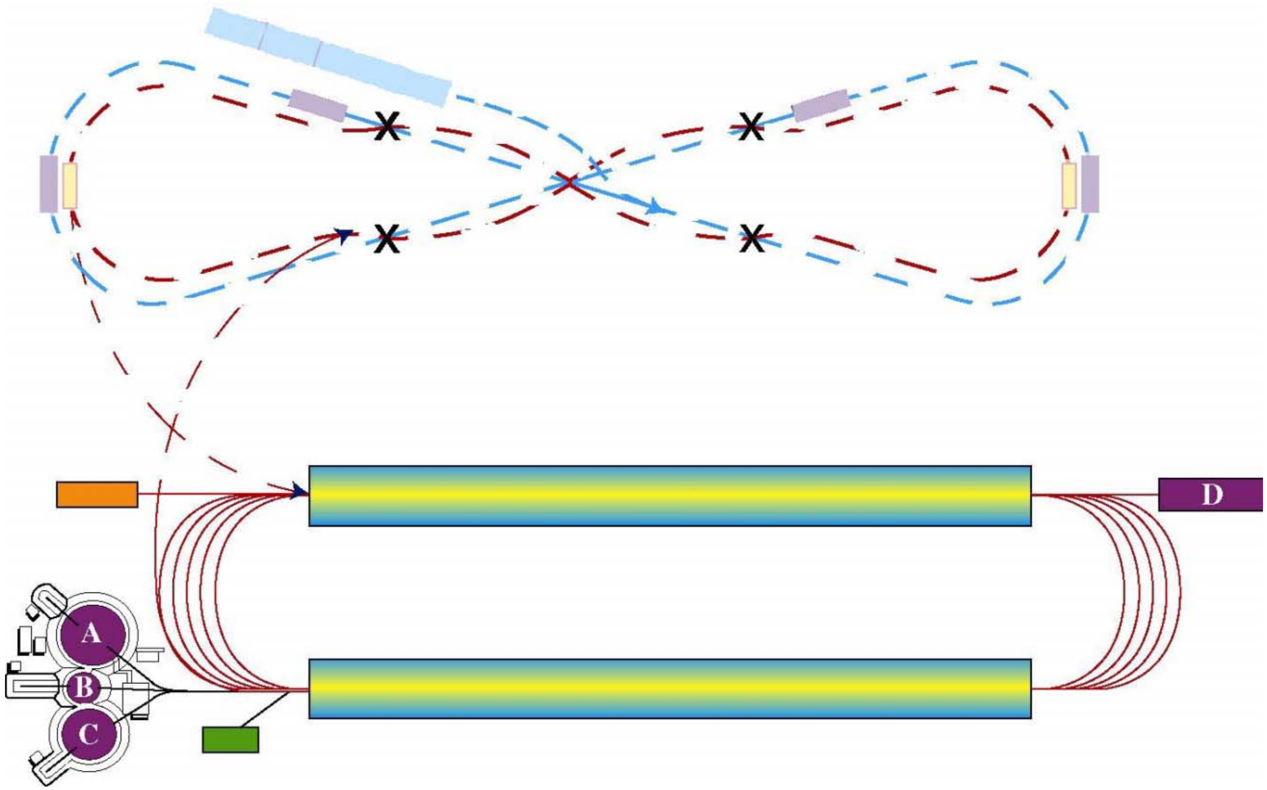
- The beam-beam force due to the relative offset between the head of the proton bunch and the electron beam will deflect the electrons. The deflected electrons subsequently interact with the tail of the proton bunch through beam-beam kick
- The electron beam acts as a transverse impedance to the proton bunch, and can lead to an instability
- 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
- Landau damping introduced by tunespread caused by electron beam and perhaps chromaticity expected to increase the threshold current of the instability

The same electron accelerator can also provide 25 GeV electrons for fixed target experiments for physics

- Implement 5-pass recirculator, at 5 GeV/pass, as in present CEBAF

(One accelerating & one decelerating pass through CEBAF ⇒ 20-45 GeV CM Collider Program)

- Exploring whether collider and fixed target modes can run simultaneously



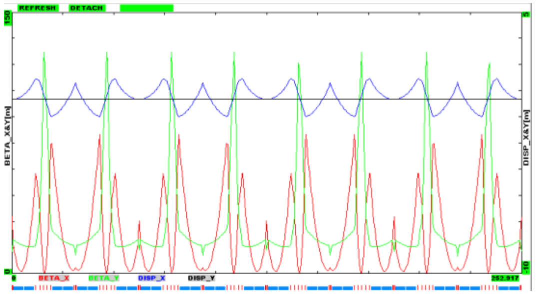
R&D Strategy

- Several important R&D topics have been identified
- Our R&D strategy is multi-pronged:
  - Conceptual development
    - "Circulator Ring" concept promises to ease high current polarized photoinjector and ERL requirements significantly
    - Additional concepts for luminosity improvements are being explored
  - Analysis/Simulations
    - Electron cooling and short bunches
    - Beam-beam physics
    - Circulator ring dynamics
    - ERL physics
  - Experiments
    - JLab FEL (10mA), Cornell/JLab ERL Prototype (100mA), BNL Cooling Prototype (50-100mA) to address high current ERL issues
    - CEBAF-ER: The Energy Recovery experiment at CEBAF to address ERL issues in large scale systems

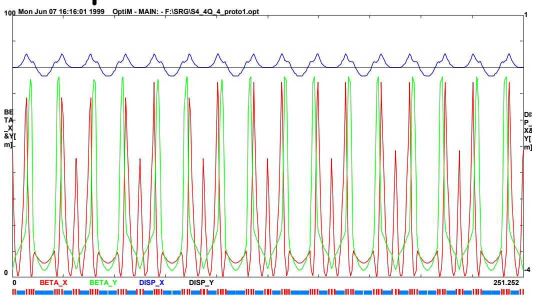
Conclusions

- The hadron physics community is asking for a high luminosity, polarized electron-light ion collider
- Our design studies have led to an approach that promises luminosities up to 10^{35} cm^{-2} sec^{-1}
- This design can be realized cost-effectively using energy recovery on the JLab site and can be integrated with a 25 GeV fixed target program for physics
- Planned R&D will address open issues

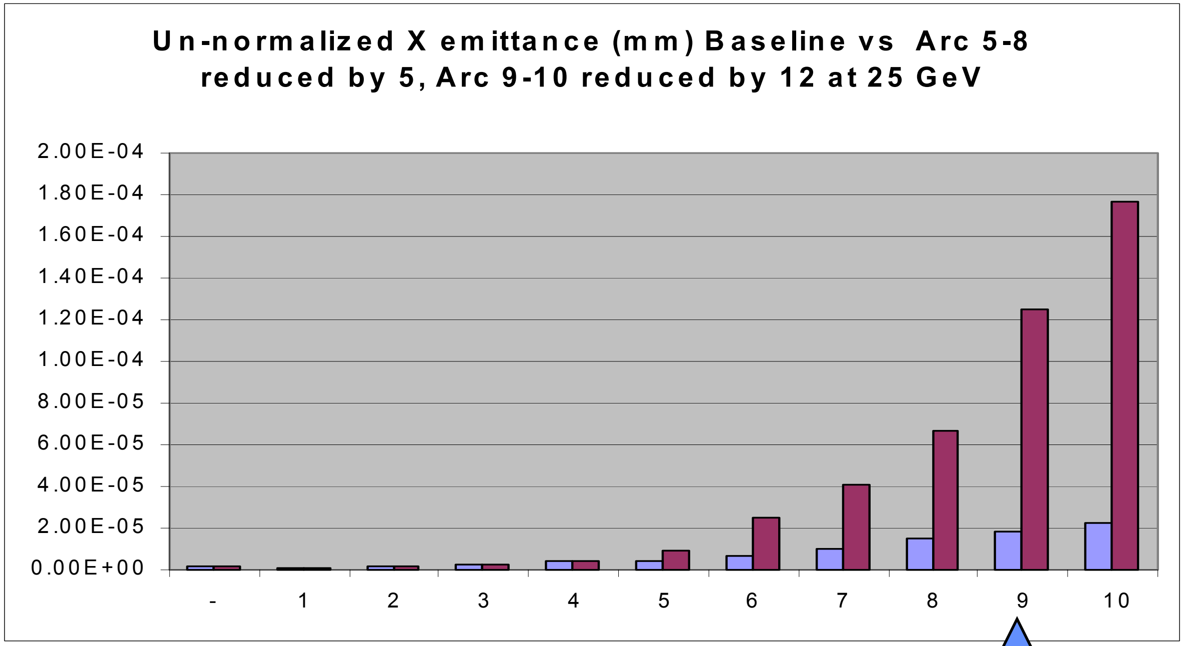
Feasibility of 25 GeV FT Program at CEBAF



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