ERL Optics Considerations for ELIC

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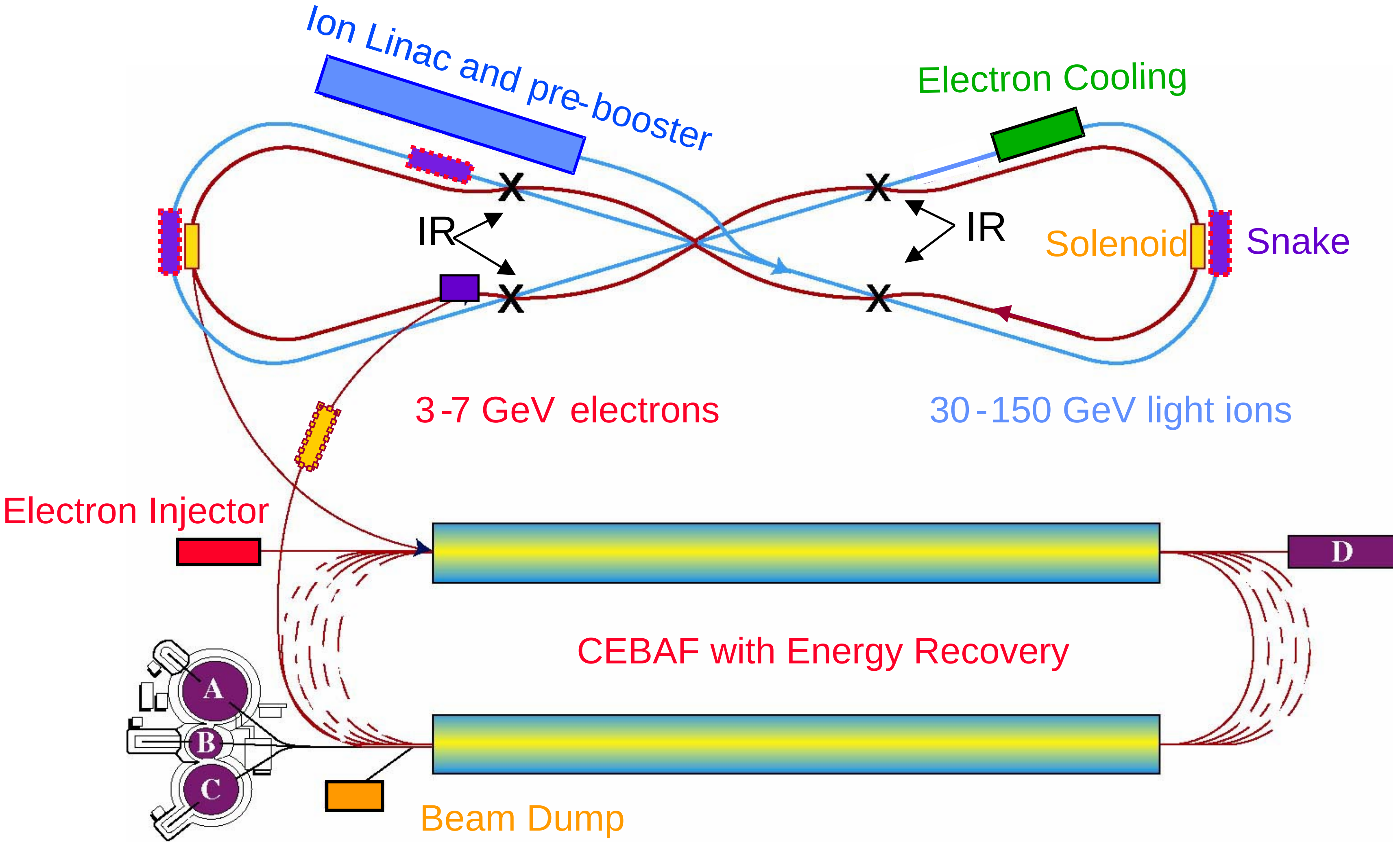
Nuclear Physics Requirements

- The features of the facility necessary to address these issues:
  - Center-of-mass energy between 20 GeV and 65 GeV

    with energy asymmetry of ~10, which yields

    $E_e \sim 3$ GeV on $E_i \sim 30$ GeV up to $E_e \sim 7$ GeV on $E_i \sim 150$ GeV
  - CW Luminosity from 10^{33} to 10^{35} cm^{-2} sec^{-1}
  - 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 extremely desirable
  - Spin-flip of both beams extremely desirable

ELIC Layout


Ion Linac and pre-booster
Electron Cooling
IR
IR
Solenoid
Snake
3-7 GeV electrons
30-150 GeV light ions
Electron Injector
D
CEBAF with Energy Recovery
A
B
C
Beam Dump

Accelerator Transport

6-D emittance preservation and phase space management during acceleration and energy recovery

I. Special feature of ELIC: ERL combined with Circulator Ring (CR)

Various schemes of loading bunches into CR -> affect ERL physics

II. Transverse matching

III. Longitudinal matching

IV. High current stability in ERL -> adequate damping of longitudinal and transverse HOMs **(CR!)**

V. Emittance growth at collision points (up to 4) -> effect on deceleration and energy recovery

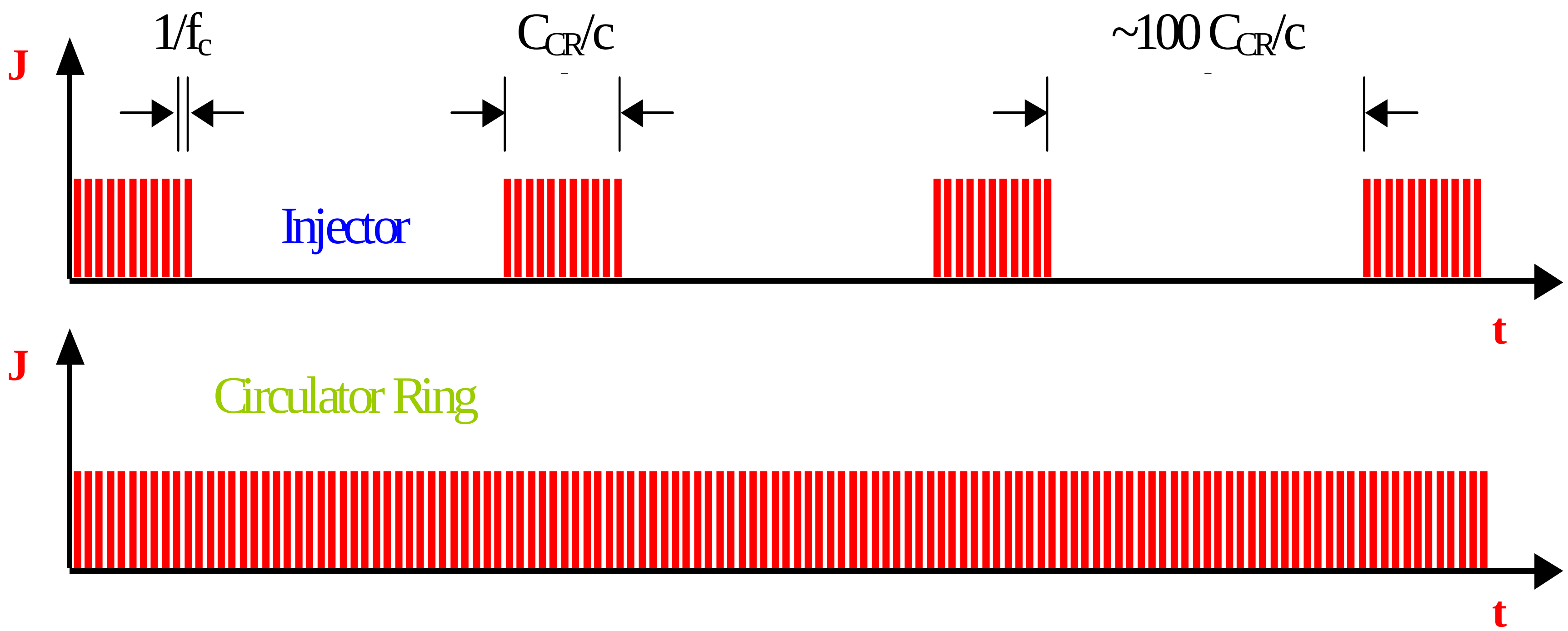
VI. Match spin after transport in linac

- Wien filter + solenoid before linac
- Two solenoid Siberian snakes in arcs for long. spin in 4 IP

VII. Synchrotron radiation power in CR -> energy difference between accelerating and decelerating passes

VIII. Coherent Synchrotron Radiation

Circulator Ring



Different filling patterns are being explored (Derbenev, Hutton, Litvinenko)

Transverse Matching

Requirement:

- Electron-Ion Colliders: High energy (GeV scale) demonstration of energy recovery. A significant extrapolation from FEL ERL paradigm (~ 100 MeV).

The challenge:

- Demonstrate sufficient operational control of <u>two coupled beams</u> of <u>substantially different energies</u> in a <u>common transport channel</u>, in the presence of steering, focusing errors.

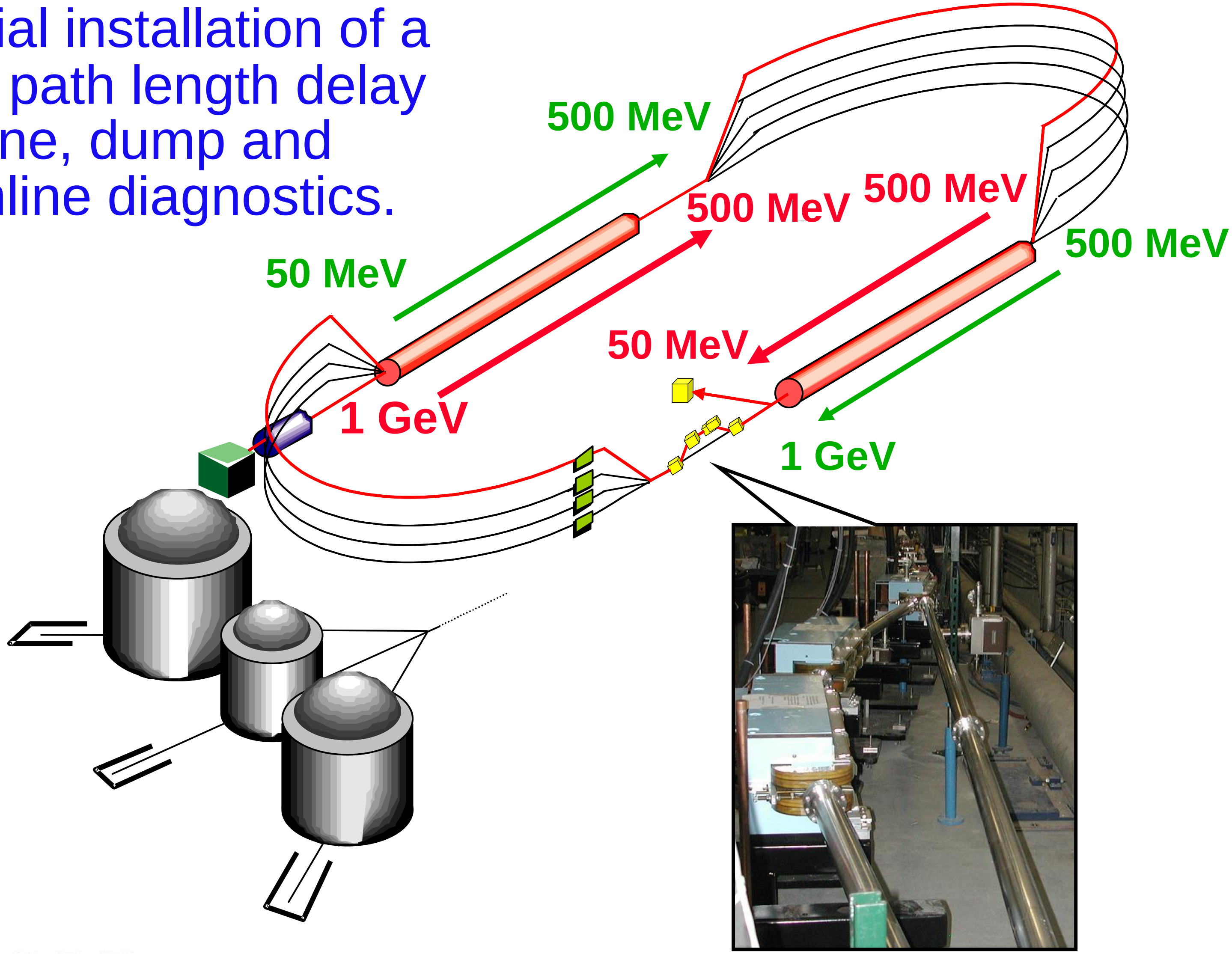
CEBAF-Energy Recovery Experiment

- **CEBAF-ER** is a 1 GeV demonstration of energy recovery in CEBAF – 40 cryomodules.
  - Quantify evolution of transverse phase space during acceleration and energy recovery.
  - Test the dynamic range of system: large ratio of final-to-injected (E_{fin}/E_{inj}) beam energies

Larger E_{fin}/E_{inj} ratio ⟶ higher ERL efficiency!

CEBAF-ER Experiment

Special installation of a $\lambda_{RF}/2$ path length delay chicane, dump and beamline diagnostics.



CEBAF-ER Preliminary Results

- Demonstrated a significant operational extension of energy recovery to high energy (1 GeV), through a large (~1 km circumference), superconducting RF system (40 cryomodules).
- Demonstrated feasibility of energy recovery with ratio of final-to-injected energy up to 50:1 (1GeV ⇄ 20 MeV).
- No significant emittance dilution was measured as a result of the energy recovery process. No surprises were uncovered.

Longitudinal Matching ?

- Energy spread ~10^{-3} at ~ 10 GeV

  -> $\delta E/E$ ~ 100% at 10 MeV

Nonlinear distortions in phase space must be corrected for proper energy recovery?

Measurements Performed

- In an effort to gain a quantitative understanding of the 6D phase space, the following measurements were taken:
  - Measuring the transverse emittance of the beam in the injector, in each Arc and immediately before being sent to the dump
  - To characterize the longitudinal phase space, the momentum spread was measured in each Arc
- Measure energy recovered beam profiles with a large dynamic range as a way to characterize halo
- Measured the RF's response to energy recovery

These measurements were performed with E_{inj} = 55 MeV and 20 MeV

(i.e. exercise final-to-injector energy ratios (E_{final} / E_{inj}) of 20:1 and 50:1)

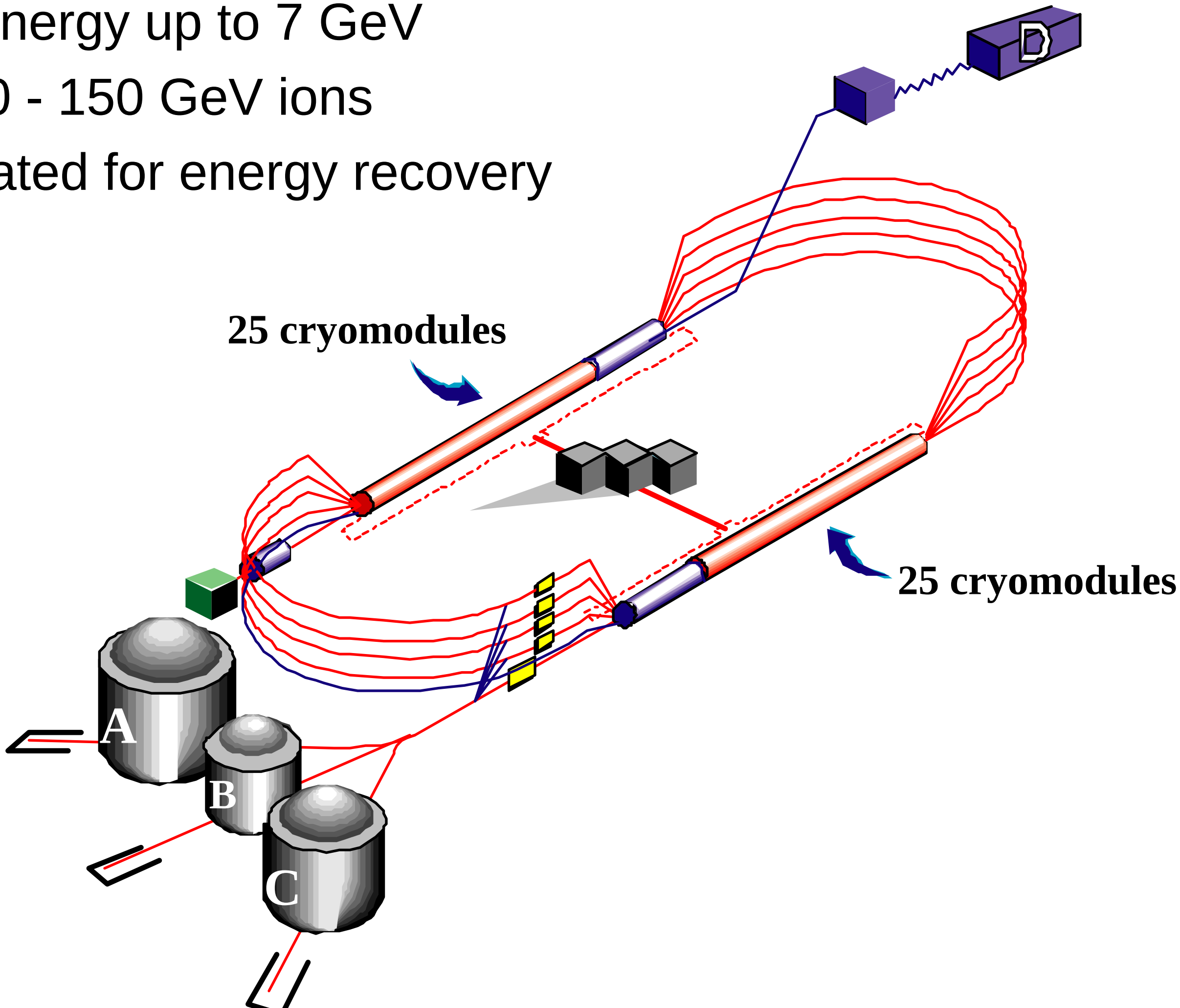
A. Bogacz, et al., "CEBAF Energy Recovery Experiment," Proc. PAC 2003

CEBAF-ER Preliminary Results

- Demonstrated the feasibility of energy recovering a high energy (1 GeV) beam through a large (~1 km circumference), superconducting (39 cryomodules) machine.
- 80 μA of CW beam accelerated to 1055 MeV and energy recovered at 55 MeV.
- 1 μA of CW beam, accelerated to 1020 MeV and energy recovered at 20 MeV, was steered to the ER dump -> Performance limit at low injection energy.
- Tested the dynamic range on system performance by demonstrating high final-to-injector energy ratios (E_{final}/E_{inj}) of 20:1 and 50:1.

CEBAF with Energy Recovery

- Install 50 CEBAF Upgrade (7-cell) cryomodules at gradient up to 23 MV/m
- Single-pass CEBAF energy up to 7 GeV
- After collisions with 30 - 150 GeV ions
- Electrons are decelerated for energy recovery



ELIC Parameters at different CM energies

Parameter	Unit	Value	Value	Value
Beam energy	**GeV**	**150/7**	**100/5**	**30/3**
Cooling beam energy	**MeV**	**75**	**50**	**15**
Bunch collision rate	**GHz**	**1.5**		
Number of particles/bunch	10^{10}	**.4/1.0**	**.4/1.1**	**.12/1.7**
Beam current	**A**	**1/2.4**	**1/2.7**	**.3/4.1**
Cooling beam current	**A**	**2**	**2**	**.6**
Energy spread, rms	10^{-4}	**3**		
Bunch length, rms	**mm**	**5**		
Beta-star	**mm**	**5**		
Horizontal emittance, norm	**μm**	**1/100**	**.7/70**	**.2/43**
Vertical emittance, norm	**μm**	**.04/4**	**.06/6**	**.2/43**
Number of interaction points		**4**		
Beam-beam tune shift (vertical) per IP		**.01/.086**	**.01/.073**	**.01/.007**
Space charge tune shift in p-beam		**.015**	**.03**	**.06**
Luminosity per IP*, 10^{34}	$cm^{-2} s^{-1}$	**7.7**	**5.6**	**.8**
Core & luminosity IBS lifetime	**h**	**24**	**24**	**> 24**
Lifetime due to background scattering	**h**	**200**	**> 200**	**> 200**