Design Status of ELIC

Ya. Derbenev for Design Team

EIC Collaboration meeting

Stone Brook, Dec.6-7, 2007

ELIC Study Group & Collaborators

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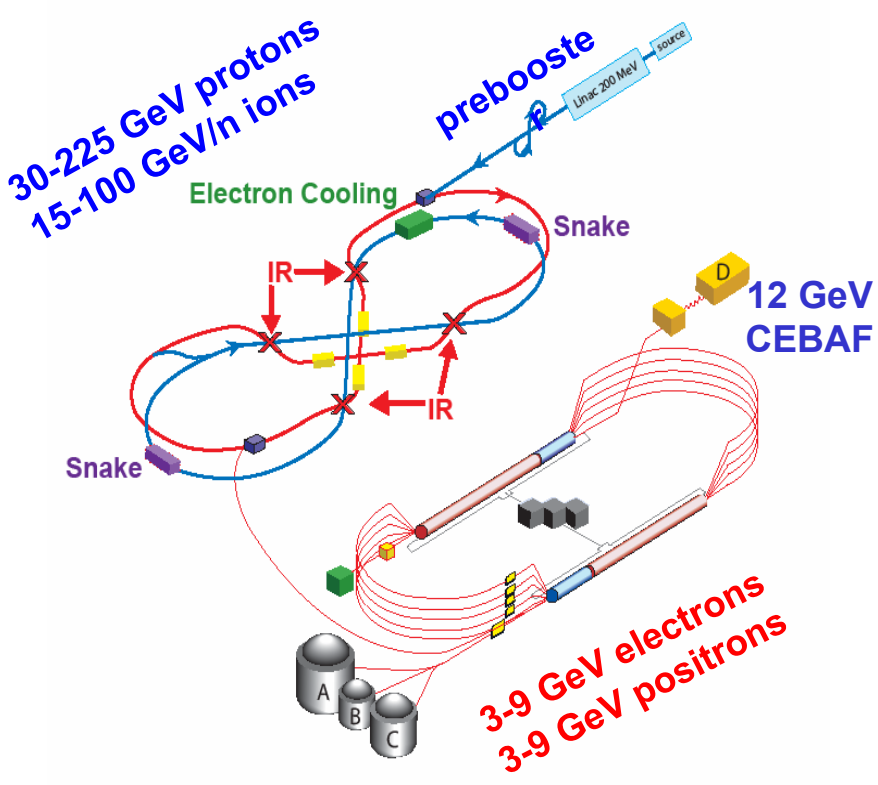
Outline

- ELIC: An Electron-Ion Collider at CEBAF
- Features of the green field design
- Basic parameters
- List of recent developments/specs
- Forming Ion Beams
- Electron Cooling
- Summary

Evolution of the Principal Scheme

- Energy Recovery Linac-Storage-Ring (ERL-R)
- ERL with Circulator Ring – Storage Ring (CR-R)
- **Back to Ring-Ring (R-R) – by taking CEBAF advantage as full energy polarized injector**
- Challenge: high current polarized electron source
  - ERL-Ring: 2.5 A
  - Circulator ring: 20 mA
  - State-of-art: 0.1 mA
- **12 GeV CEBAF Upgrade polarized source/injector already meets beam requirement of ring-ring design**
- **CEBAF-based R-R design still preserves high luminosity, high polarization (+polarized positrons…)**

ELIC Conceptual Layout and Features



Green-field design of ion complex directly aimed at full exploitation of science program.

- Unprecedented high luminosity
  - Enabled by short ion bunches, low β*, high repetition rate
  - Large synchrotron tune
  - Requires crab crossing
- Electron cooling is an essential part of ELIC
- Four IPs for high science productivity
- "*Figure-8*" ion & lepton storage rings
  - Ensure spin preservation & ease manipulation.
  - No spin sensitivity to energy for all species.
- Present CEBAF gun/injector meets storage-ring requirements
- The 12 GeV CEBAF can serve as a full energy injector to electron storage ring
- *Simultaneous* operation of collider and CEBAF fixed target program.
- Experiments with polarized positron beam are possible.

ELIC (e/p) Design Parameters

Parameter	Unit	Ring-Ring			
Beam energy	GeV	225/9	150/7	100/5	30/3
e/A ring circumference	km	1.5			
Bunch collision frequency	GHz	1.5			
Number of particles/bunch	10^{10}	0.42/.77	0.4/1	0.4/1.1	0.12/1.7
Beam current	A	1/1.85	1/2.4	1/2.7	0.3/4.1
Energy spread, rms	10^{-4}	3/3			
Bunch length, rms	mm	5/5			
Beta*	mm	5/5			
Horizontal emittance, norm	μm	1.25/90	1/90	.7/70	.2/43
Vertical emittance, norm	μm	.05/3.6	.04/3.6	.06/6	.2/43
Beam-beam tune shift (vertical) per IP		.006/.086	.01/.086	.01/.078	.009/.008
Peak luminosity per IP, 10^{34} (*including hourglass effect*)	$cm^{-2}\ s^{-1}$	5.7	6.0	5.0	.7
Number of IPs		4			
Core & lumi. IBS lifetime	hrs	24			

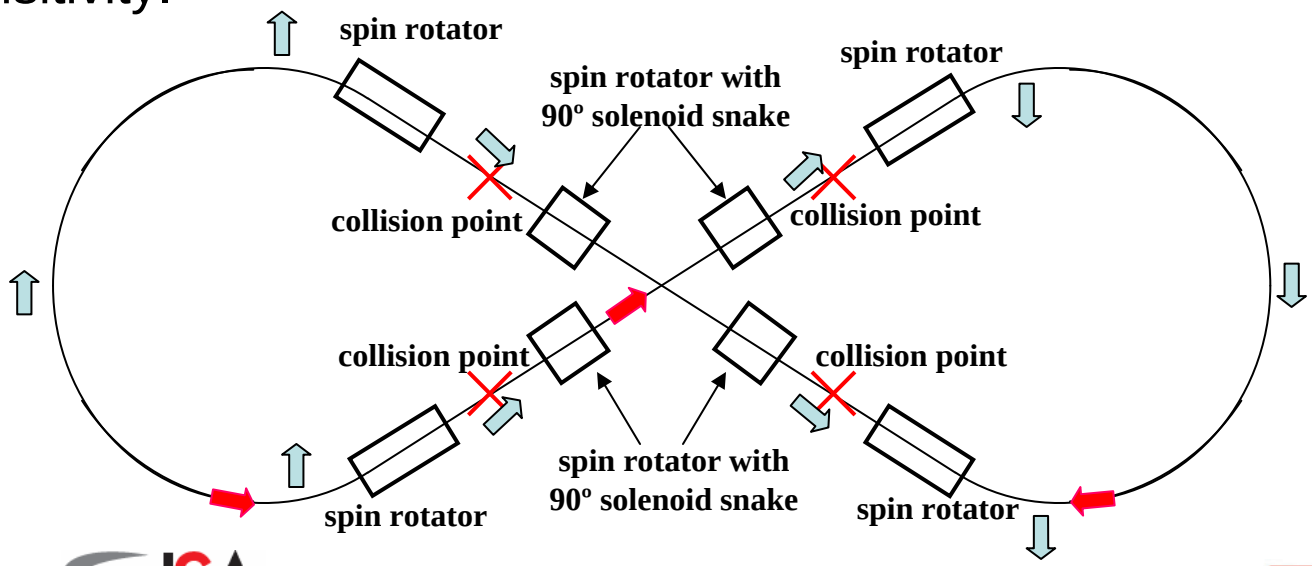
ELIC (e/A) Design Parameters

Ion	Max Energy ($E_{i,max}$)	Luminosity / n (7 GeV x $E_{i,max}$)	Luminosity / n (3 GeV x $E_{i,max}/5$)
	(GeV/nucleon)	10^{34} cm^{-2} s^{-1}	10^{33} cm^{-2} s^{-1}
Proton	150	7.8	6.7
Deuteron	75	7.8	6.7
$^{3}H^{+1}$	50	7.8	6.7
$^{3}He^{+2}$	100	3.9	3.3
$^{4}He^{+2}$	75	3.9	3.3
$^{12}C^{+6}$	75	1.3	1.1
$^{40}Ca^{+20}$	75	0.4	0.4
$^{208}Pb^{+82}$	59	0.1	0.1

*Luminosity is given per unclean per IP

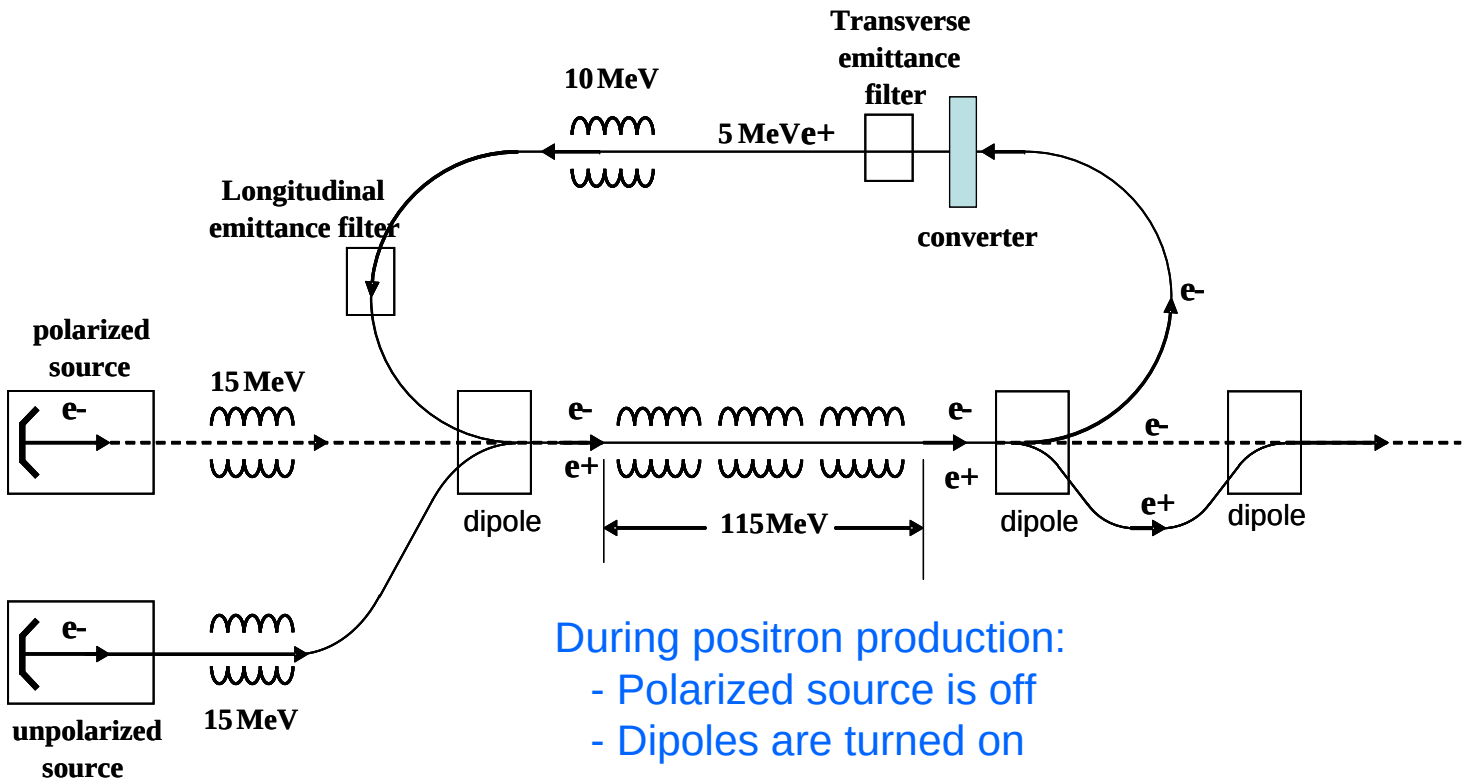
Electron Polarization in ELIC

- Producing at source
  - Polarized electron source of CEBAF
  - Preserved in acceleration at recirculated CEBAF Linac
  - Injected into Figure-8 ring with vertical polarization
- Maintaining in the ring
  - High polarization in the ring by electron self-polarization
  - SC solenoids at IPs removes spin resonances and energy sensitivity.



Positrons in ELIC

- Non-polarized positron bunches generated from modified electron injector through a converter
- Polarization realized through self-polarization at ring arcs



During positron production:
- Polarized source is off
- Dipoles are turned on

Recent Developments/specs

- **Rings Lattice design update for higher energies**
- **Interaction Region update (reduced crab…)**

(to be reported by Alex Bogacz)

- **Beam-beam study/simulation**

(to be reported by Yuhong Zhang)

- **Stochastic Cooling/Stacking all species ion beams**
- **Electron Cooling specs/advances (cool protons…)**

ELIC R&D: forming intense Ion Beam

Use stochastic cooling for stacking and pre-cooling

- Stacking/accumulation process
  - Multi-turn (10 – 20) injection from SRF linac to pre-booster
  - Damping of injected beam
  - Accumulation of 1 A coasted beam at space charge limited emittence
  - RF bunching/acceleration
  - Accelerating beam to 3 GeV, then inject into large booster
- Ion space charge effect dominates at low energy region
- Transverse pre-cooling of coasted beam in collider ring (30 GeV)

Stacking proton beam in pre-booster with stochastic cooling

Parameter	Unit	Value
Beam Energy	MeV	200
Momentum Spread	%	1
Pulse current from linac	mA	2
Cooling time	s	4
Accumulated current	A	0.7
Stacking cycle duration	Min	2
Beam emittance, norm.	μm	12
Laslett tune shift		0.03

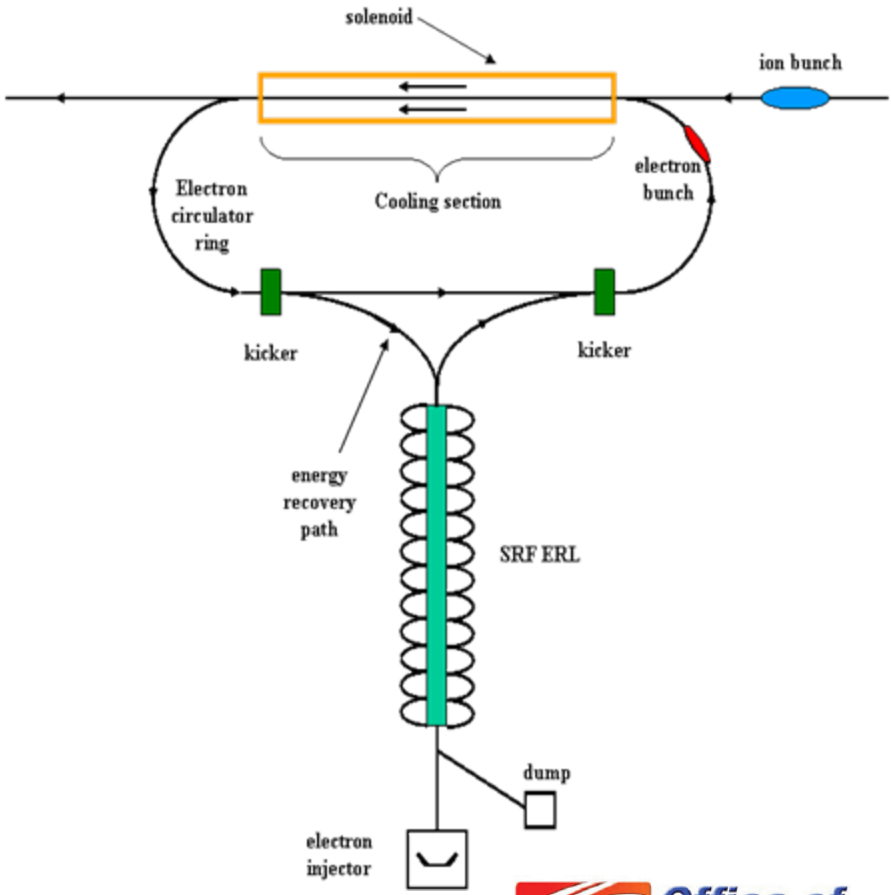
Transverse stochastic cooling of coasted proton beam after injection in collider ring

Parameter	Unit	Value
Beam Energy	GeV	30
Momentum Spread	%	0.5
Current	A	1
Freq. bandwidth of amplifiers	GHz	5
Minimal cooling time	Min	8
Initial transverse emittance	μm	16
IBS equilibrium transverse emitt.	μm	0.1
Laslett tune shift at equilibrium		0.04

ELIC R&D: Electron Cooling

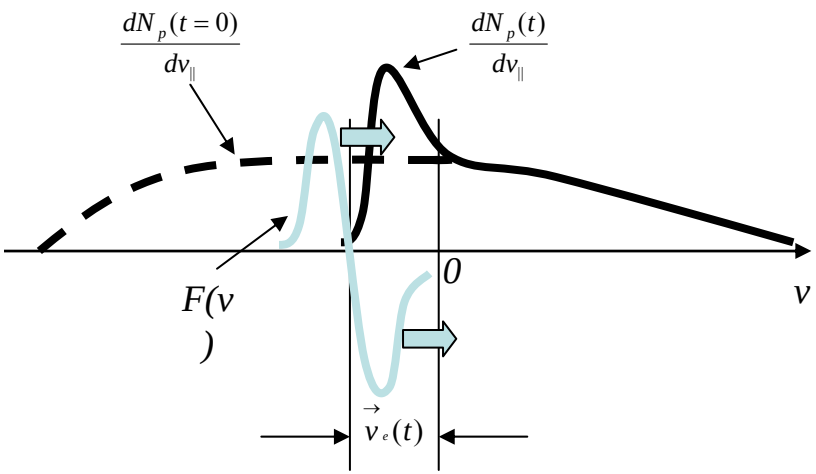
.Effective for heavy ions (higher cooling rate), difficult for protons.

- State-of-Art
  - Fermilab electron cooling demonstration (4.34 MeV, 0.5 A DC)
  - Feasibility of EC with bunched beams remains to be demonstrated
- ELIC Circulator Cooler
  - 3 A CW electron beam, up to 125 MeV
  - SRF ERL provides 30 mA CW beam
  - Circulator cooler for reducing average current from source/ERL
  - Electron bunches circulate 100 times in a ring while cooling ion beam
  - Fast (300 ps) kicker operating at 15 MHz rep. rate to inject/eject bunches into/out circulator-cooler ring



Advancing the EC

- *Staged cooling*
  - Start electron cooling (longitudinal) in collider ring at injection energy,
  - Continue electron cooling (in all dimension) after acceleration to high energy
- *Sweep cooling*
  - After transverse stochastic cooling, ion beam has a small transverse temperature but large longitudinal one.
  - Use *sweep cooling to* gain a factor of longitudinal cooling time



- *Dispersive cooling*
  - compensates for lack of transverse cooling rate at high energies due to large transverse velocity spread compared to the longitudinal (in rest frame) caused by IBS
- *Flat beam cooling*

  -based on flattening ion beam by reduction of coupling around the ring

  -IBS rate at equilibrium reduced compared to cooling rate

Cooling Time and Ion Equilibrium

Multi-stage cooling scenario:

- 1st stage: longitudinal cooling at injection energy (after transverses stochastic cooling)
- 2nd stage: initial cooling after acceleration to high energy
- 3rd stage: continuous cooling in collider mode

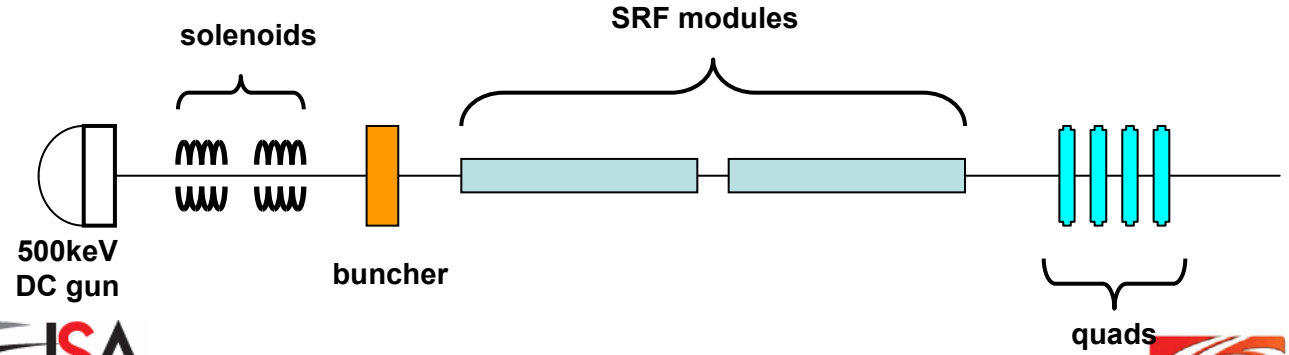
Cooling rates and equilibrium of proton beam

Parameter	Unit	Value	Value
Energy	GeV/MeV	30/15	225/123
Particles/bunch	10^{10}	0.2/1	
Initial energy spread*	10^{-4}	30/3	1/2
Bunch length*	cm	20/3	1
Proton emittance, norm*	μm	1	1
Cooling time	min	1	1
Equilibrium emittance $\varepsilon_x/\varepsilon_y$, **	μm	1/1	1/0.04
Equilibrium bunch length**	cm	2	0.5
Cooling time at equilibrium	min	0.1	0.3
Laslett's tune shift (equil.)		0.04	0.02

*** max.amplitude**
**** norm.,rms**

Injector and ERL for Electron Cooling

- ELIC CCR driving injector
  - 30 mA@15 MHz, up to 125 MeV energy, 1 nC bunch charge, magnetized
- Challenges
  - Source life time: 2.6 kC/day (state-of-art is 0.2 kC/day)
    → source R&D, & exploiting possibility of increasing evolutions in CCR
  - High beam power: 3.75 MW → Energy Recovery
- Conceptual design
  - High current/brightness source/injector is a key issue of ERL based light source applications, much R&D has been done
  - We adopt light source injector as initial baseline design of ELIC CCR driving injector
- Beam qualities should satisfy electron cooling requirements (based on previous computer simulations/optimization)

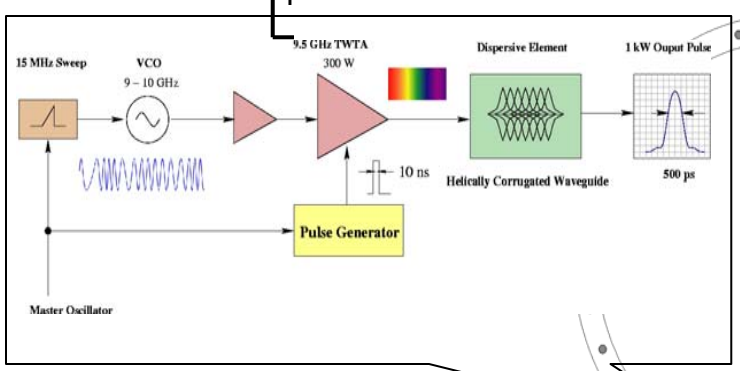


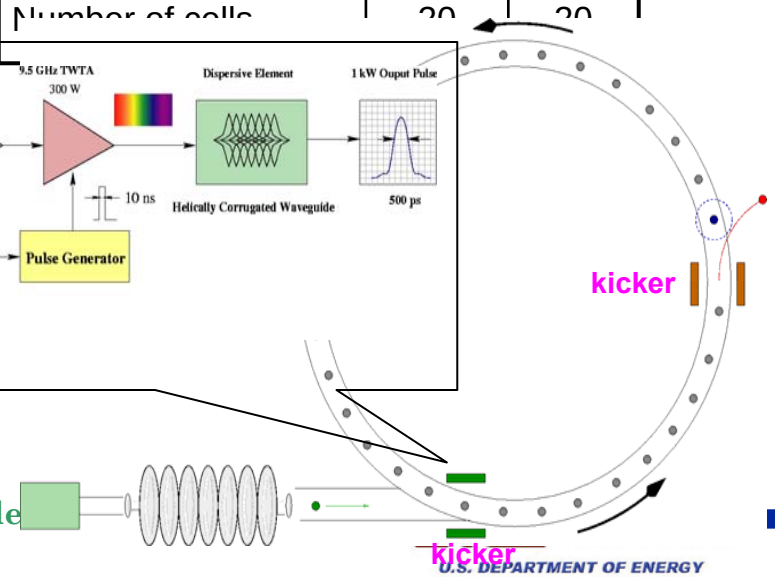
Fast Kicker for Circulator Cooling Ring

- Sub-ns pulses of 20 kW and 15 MHz are needed to insert/extract individual bunches.
- RF chirp techniques hold the best promise of generating ultra-short pulses. State-of-Art pulse systems are able to produce ~2 ns, 11 kW RF pulses at a 12 MHz repetition rate. This is very close to our requirement, and appears to be technically achievable.
- Helically-corrugated waveguide (HCW) exhibits dispersive qualities, and serves to further compress the output pulse without excessive loss. Powers ranging from up10 kW have been created with such a device.
- Collaborative development plans include studies of HCW, optimization of chirp techniques, and generation of 1-2 kW peak output powers as proof of concept.
- Kicker cavity design will be considered

Estimated parameters for the kicker

Beam energy	MeV	125
Kick angle	10^{-4}	3
Integrated BdL	GM	1.25
Frequency BW	GHz	2
Kicker Aperture	Cm	2
Peak kicker field	G	3
Kicker Repetition Rate	MHz	15
Peak power/cell	KW	10
Average power/cell	W	15
Number of cells	20	20





Summary

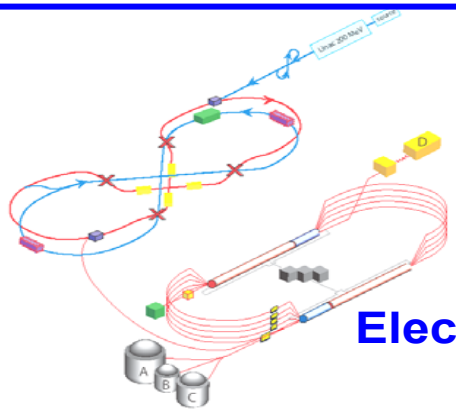
Recent Advances/specs in ELIC design

- CW Electron cooling with circulator ring
- Crab crossing and crab cavity reduction
- Forming all species intense ion beam
- Beam-beam effects

Continue design advances/optimization

- Resolve (design) high rep.rate issue (high lumi vs detector)
- Minimize quantum depolarization of electrons (spin matching)
- Study ion stability
- Flipping spin specs
- Coherent Electron Cooling (V.Litvinenko)
- More…

Thank you!



Zeroth–Order Design Report for the Electron-Ion Collider at CEBAF

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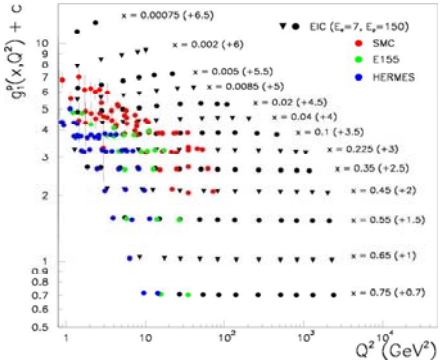

http://casa.jlab.org/research/elic/elic_zdr.doc