Conceptual Design of A Medium Energy Electron-Ion Collider Based on CEBAF; A Staged Approach for ELIC

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Outline

- Motivations
- Design Goals
- Layout and Parameters
- Booster and Interaction Points
- Staging to Full Energy ELIC
- R&D Issues
- Summary

(after EIC workshop at Hampton University: not an official EICC recommendation, but rather an informal proposal from Abhay Deshpande, Richard Milner, Rolf Ent)

- **eRHIC:**
  1) Back to drawing board given unrealistic demands of the source.
  2) Request staging of 5+ GeV with 10^{32+} luminosity + cost estimates, with appropriate upgrade paths for luminosity and energy (including changing the RF/optics of the RHIC machine).

- **ELIC:**
  1) 1.5 GHz seems unrealistic, 0.5 GHz may be doable.
  2) Request polarization tracking with full lattice.
  3) Request consideration of staging options, if any.

In addition, request both for estimate of achievable vacuum levels asap.

Motivations

Science (See T. Horn's Talk)

- Expand science program beyond 12 GeV CEBAF fixed target program
  - Gluons via J/ψ production
  - Higher CM energy in valence region
  - Study the asymmetric sea for $x \approx m_\pi / M_N$

Accelerator

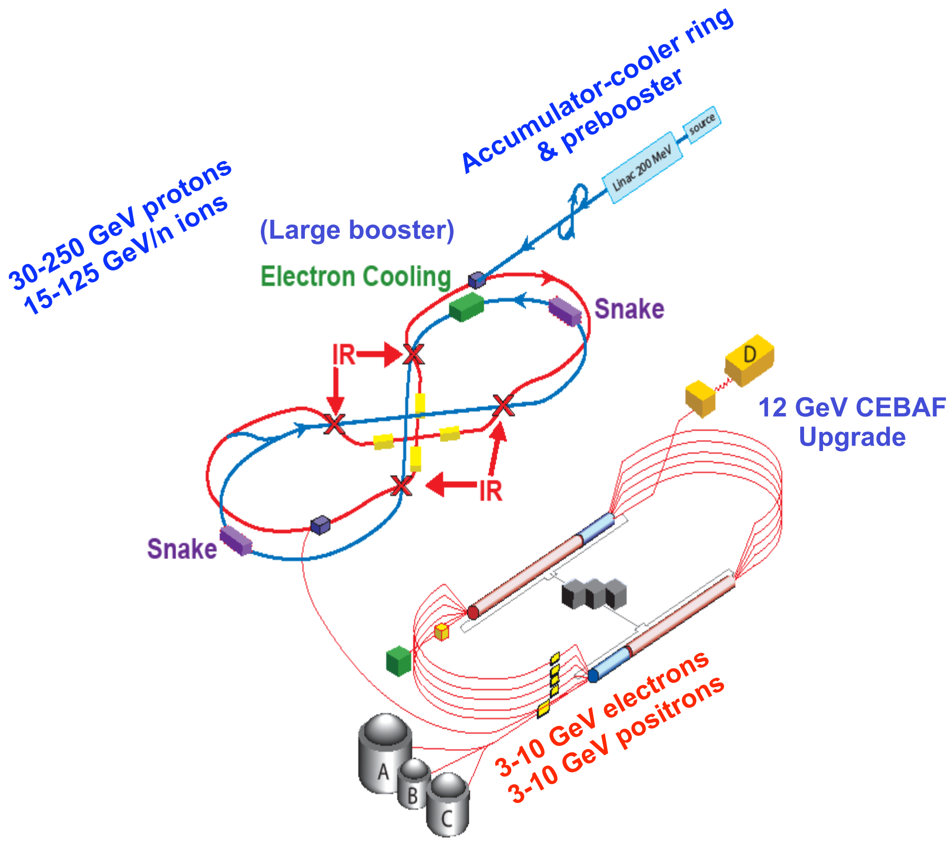
- Bring ion beams and associated technologies to JLab (a lepton lab)
- Have an early ring-ring collider at JLab
- Provides a test bed for new technologies required by ELIC
- Develop expertise and experience, acquire/train technical staff

Staging Possibilities

- A medium energy EIC becomes the low energy ELIC ion complex
- Exploring opportunities for reusing Jülich's Cooler Synchrotron (COSY) complex for cost saving

Design Goals

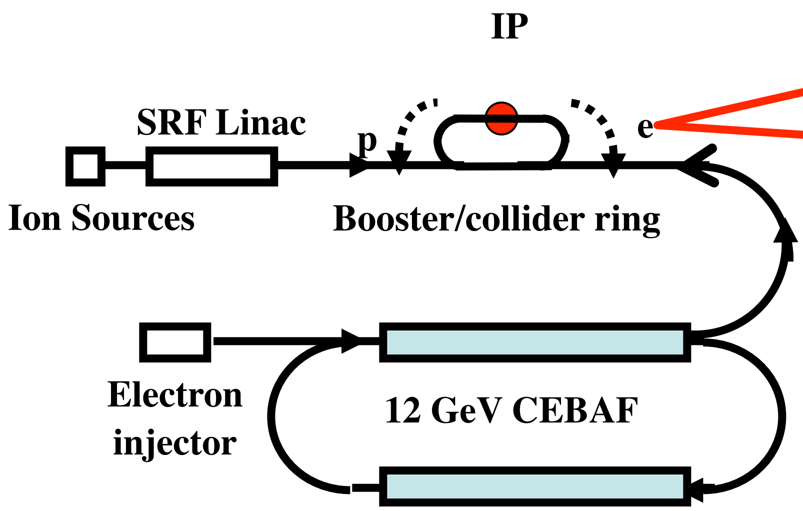
Baseline ELIC



Beam energy	GeV	250/10	150/7	50/5
Figure-8 ring	km	2.5		
Collision freq	MHz	499		
Beam current	A	0.22/0.55	0.15/0.33	0.18/0.38
Particles/bunch	109	2.7/6.9	1.9/4.1	2.3/4.8
Energy spread	10^{-4}	3/3		
Bunch length, rms	mm	5/5		
Hori. emit., norm.	µm	0.70/51	0.42/35.6	.28/25.5
Vertical emit., norm.	µm	0.03/2.0	0.017/1.4	.028/2.6
β^*	mm	5/5		
Vert. b-b tune-shift		0.01/0.1		
Peak lum. per IP	10^{34} cm^{-2}s^{-1}	2.9	1.2	1.1
Luminosity lifetime	hours	24		

Electron parameters are red

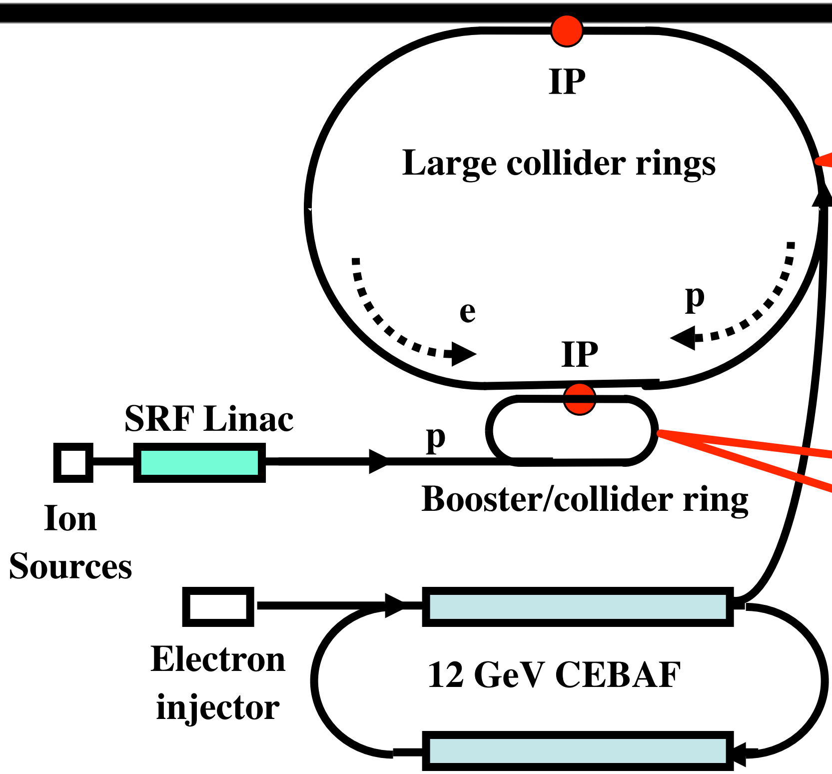
Stage 1: Low Energy Collider



- Two compact rings of 300 m length
- Collision momenta up to 5 GeV/c for electrons & (Z/A)×5 GeV/cu for ions
- Electron & stochastic cooling
- One IP

- A compact booster/storage ring of 300 m length will be used for accumulating, boosting and cooling up to 2.5 GeV/cu (Z/A=1/2) ion beams or 5 GeV/c protons from an ion source and SRF injection linac.
- Full injection energy electron storage ring and the ion ring act as collider rings for electron-ion collisions
- More compact size enables storing higher ion beam current for the same Laslett space charge tune-shift

Stage 2: Medium Energy Collider



- Two large storage rings of 1.4 km length
- Stores 5 to 30 GeV proton beams
- Stores up to 11 GeV electron beam
- Cooling of ion beams
- Up to 11 on 11 GeV symmetric collisions

- Serves as a pre-booster for ion beams
- Continues as a collider ring for ion beam of 2.5 GeV/cu or lower

- Two large rings, the ion ring serving as a booster & collider ring, are required for storing 11 GeV/c electron (from synchrotron radiation) & 15 GeV/cu ion beams (using warm magnets)
- Store & collide low energy (below 2.5 GeV/cu) ion beams in the small ring for optimization of space charge tune-shift limit (a factor of 4 increase of luminosity)
- Possibility of two IPs for *simultaneous* operation of low and medium energy ion beam collisions, two detectors can be optimized for different beam energies

Medium Energy EIC Features

- High luminosity collider
- CM energy region from 10 GeV (5x5 GeV) to 22 GeV (11x11 GeV), and possibly reaching 35 GeV (30x10 GeV)
- High polarization for both electron and light ion beams
- Natural staging path to high energy ELIC
- Possibility of positron-ion collider in the low to medium energy region
- Possibility of electron-electron collider (7x7 GeV) using just small 300 m booster/collider ring

Luminosity

Design luminosity

$L \sim 2.4 \times 10^{33}\ cm^{-2}s^{-1}$ (9 GeV protons x 9 GeV electrons)

Limiting Factors

- Space charge effect for low ion energy
- Electron beam current due to synchrotron radiation
- Beam-beam effect

Luminosity Concepts

- High bunch collision frequency (up to 0.5 GHz)
- Long ion bunches with respect to β^* for high bunch charge ($\sigma_z \sim 5$ cm)
- Super strong final focusing ($\beta^* \sim 2.5$ mm to 5 mm)
- Large beam-beam parameters (0.015/0.1 per IP for *p* and *e*)

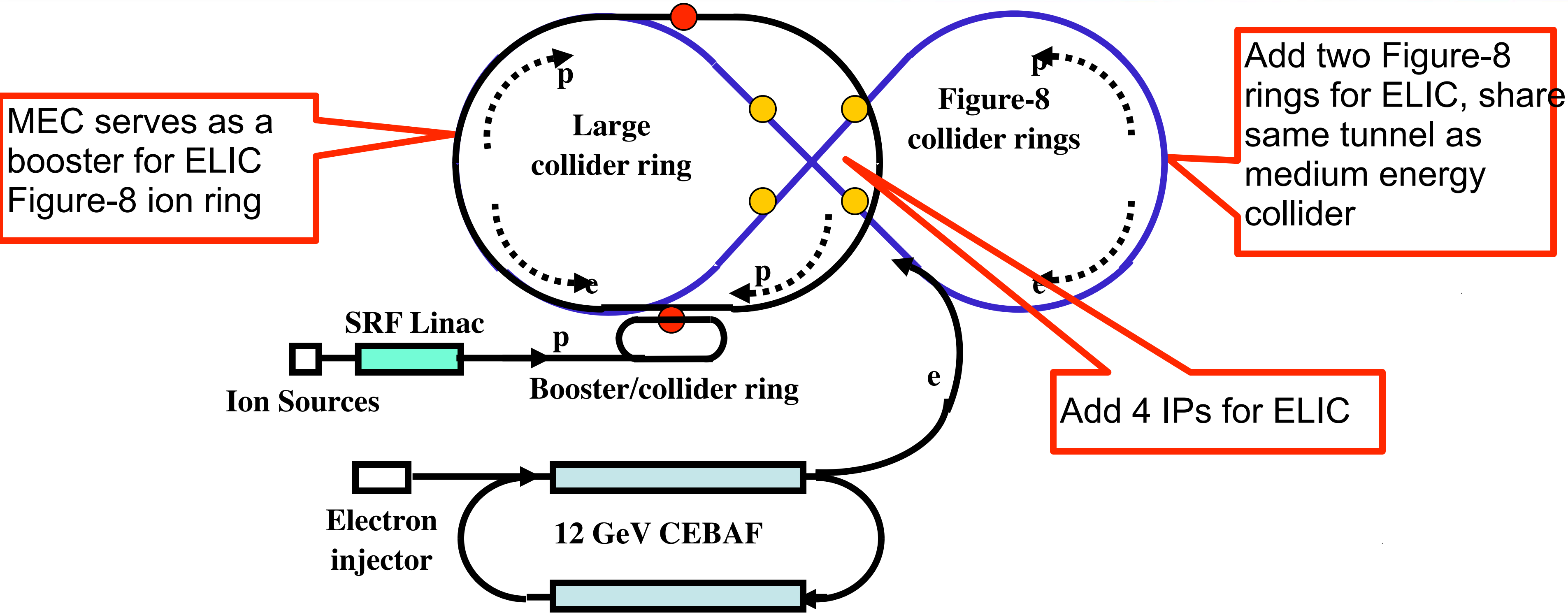
- Need staged cooling for ion beams
- Need crab crossing colliding beams
- Need “traveling focusing” to suppress the hour-glass effect

Parameter Table

Beam Energy	GeV	5/5	9/9	11/11	30/10
Circumference	m	320	1370	1370	1370
Beam Current	A	0.2/0.65	0.17/2.85	0.14/1.25	0.24/1.82
Repetition Rate	GHz	0.5	0.5	0.5	0.5
Particles per Bunch	1010	0.25/0.8	0.21/3.6	0.17/1.56	0.3/2.3
Bunch Length	cm	5/0.25	5/0.25	5/0.25	1/0.25
Normalized Hori. Emittance	mm mrad	0.27/48	0.34/62	0.17/62	0.22/135
Normalized Vert. Emittance	mm mrad	0.27/4.8	0.34/3.9	0.17/2.5	0.22/5.4
Horizontal β^*	cm	0.5/5	0.5/5	1/5	0.5/0.5
Vertical β^*	cm	0.25/25	0.25/40	0.25/31	0.25/6.25
Beam Size at IP (x/y)	μm	14.3/14.3	13.3/9.4	12/6	5.9/4.2
Horizontal B-B Tune Shift		0.004/.014	.015/.01	0.015/0.01	.015/.006
Vertical B-B Tune Shift		0.003/0.1	.011/0.1	0.008/0.1	.01/0.1
Laslett Tune Shift		0.1/small	09/small	096/small	089/small
Luminosity	$10^{33} s^{-1} cm^{-2}$	0.6	2.4	1.5	10.8

Electron parameters are red

Stage 3: ELIC



- Add two Figure-8 rings and 4 new IPs for ELIC
- Medium energy collider (MEC) ring also serves as a booster (15 GeV/cu) for ELIC
- Possibility of *simultaneous* operation of three colliders
  - High energy (30 to 250 GeV on 5 to 10 GeV) at ELIC Figure-8 rings with 4 IPs
  - Medium energy (7 on 7 GeV to 11 on 11 GeV) in the large booster/collider ring
  - Low energy (5 on 5 GeV or lower) in the small booster/collider ring

Producing the Ion Beam

- One Idea
  - SRF to 50 to 300 MeV/c
  - Accumulate current in Low Energy Ring
  - Accelerate to final energy
  - Store in Low Energy Ring or send on to next ring
- Another Idea
  - Accelerate to ~ 2 GeV/c in an SRF linac
  - Accumulate current in Low Energy Ring
  - Accelerate to final energy
  - Store in Low Energy Ring or send on to next ring

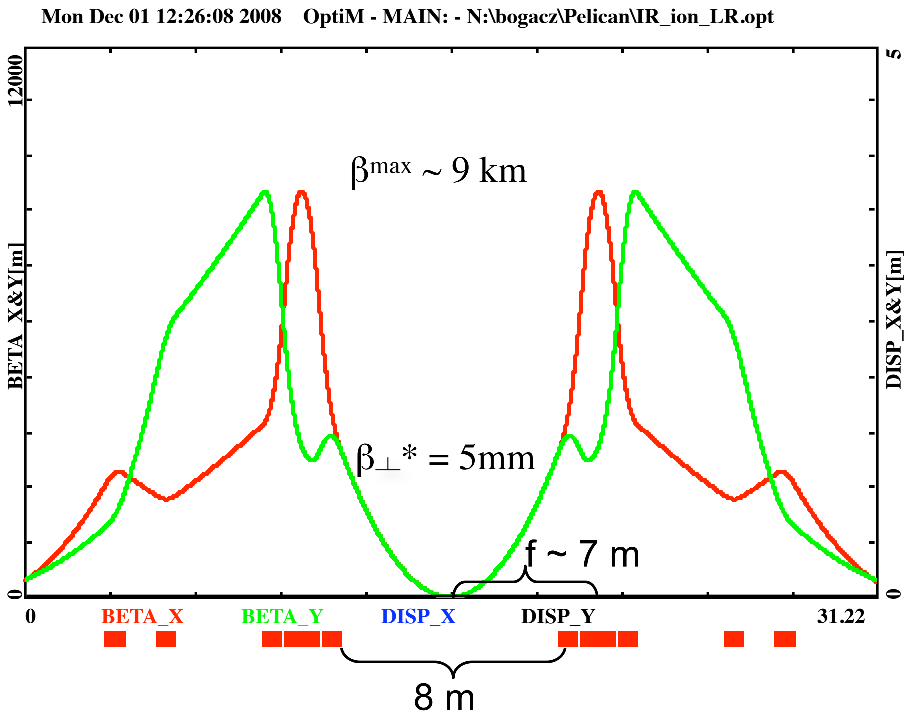
Cooling of Ion Beams

	Length	Momentum(	Cooling Scheme	Processes
Source/SRF Linac		0.05 to 0.3		Full stripping
Prebooster (low energy collider ring)	320	3 to 5	Electron cooling Stochastic cooling Initial/final/continuous	Accumulation Energy boost RF bunching
Big Booster (medium energy collider ring)	1370	11 to 30	Electron cooling Stochastic cooling Initial/final/continuous	Filling large ring Energy booster RF bunching

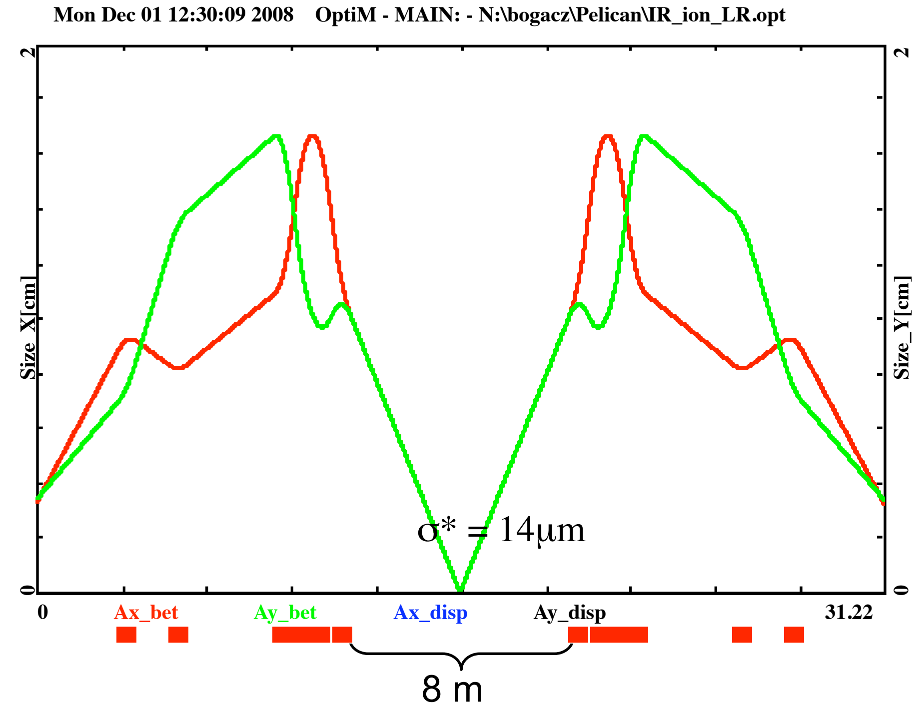
- Electron cooling after ion beam boosted to final energy is essential
- Continuous electron cooling is also planed when ion beam is in colliding mode to continuously suppress emittance growth caused by intra-beam scattering
- Cooling electron energy is between 2.7 to 6 MeV for 5 to 11 GeV proton beam, in a similar energy regime to the Fermilab Electron Cooling Demo

Interaction Region: Simple Optics

Beta functions



Beam envelopes (σ_{RMS}) for ε_N = 0.2 mm mrad



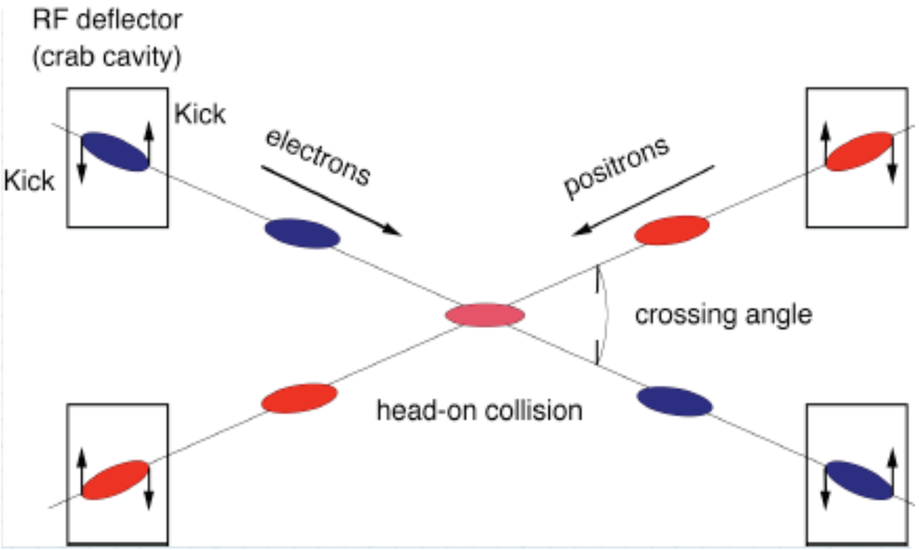
$$\beta(s) = \beta^* + \frac{s^2}{\beta^*}$$

$$\beta^{max} = \beta^* + \frac{f_{tripl}^2}{\beta^*}, \qquad f_{tripl}^2 \approx \beta^{max}\beta^*$$

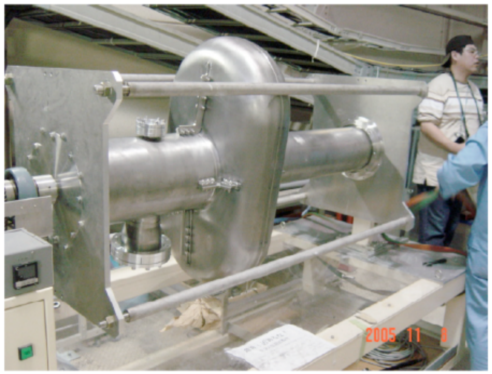
Triplet based IR Optics

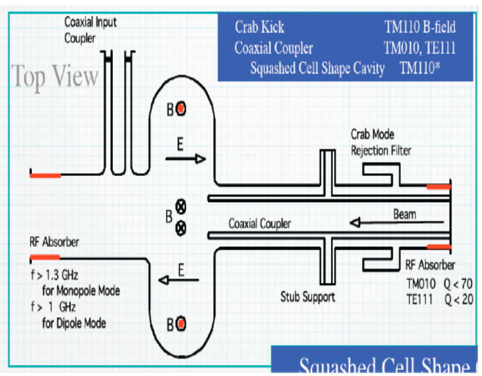
- first FF quad 4 m from the IP
- typical quad gradients ~ 12 Tesla/m for 5 GeV/c protons
- beam size at FF quads, σ_{RMS} ~ 1.6 cm

Interaction Region: Crab Crossing



- High bunch repetition rate requires crab crossing colliding beam to avoid parasitic beam-beam interactions
- Crab cavities needed to restore head-on collision & avoid luminosity reduction
- Since ion beam energy now is a factor of 15 lower than that of ELIC, integrated kicking voltage is at order of 1 to 2 MV, within the state-of-art (KEK)
- No challenging cavity R&D required





State-of-art:

KEKB Squashed cell@TM110 Mode

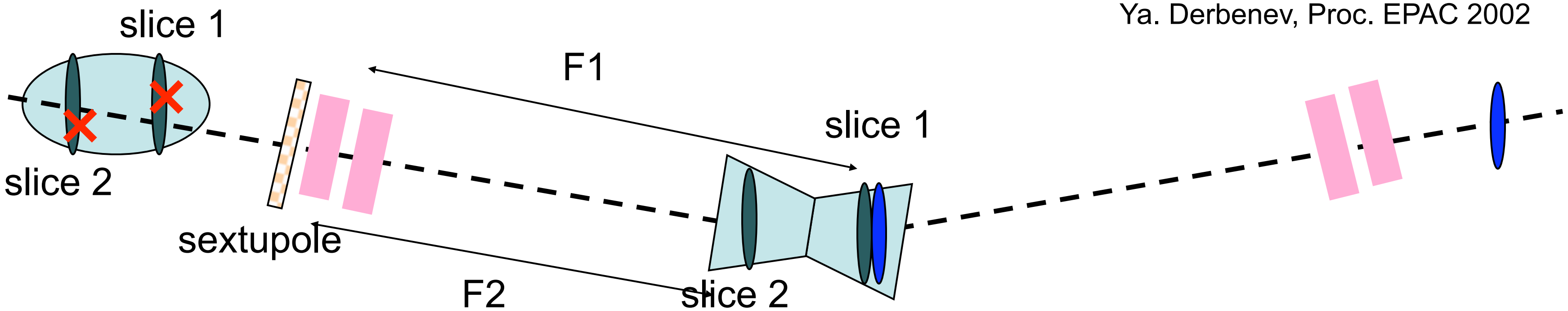
Crossing angle = 2 x 11 mrad

V_{kick}=1.4 MV, E_{sp}= 21 MV/m

Interaction Region: Traveling Focusing

- Under same space charge tune-shift limit, we need to increase ion bunch length in order to increase bunch charge, and hence increase luminosity
- Hour glass effect would normally kill collider luminosity if ion bunch length is much large than β^*
- "Traveling Focusing" scheme can mitigate hour-glass effect by moving the final focusing point along the long ion bunch. This setup enables the short electron bunch to collide with different slices of the long ion bunch at their relative focusing points
- Nonlinear elements (sextupoles) working with linear final focusing block produce non-uniform focus length for different slices of a long bunch

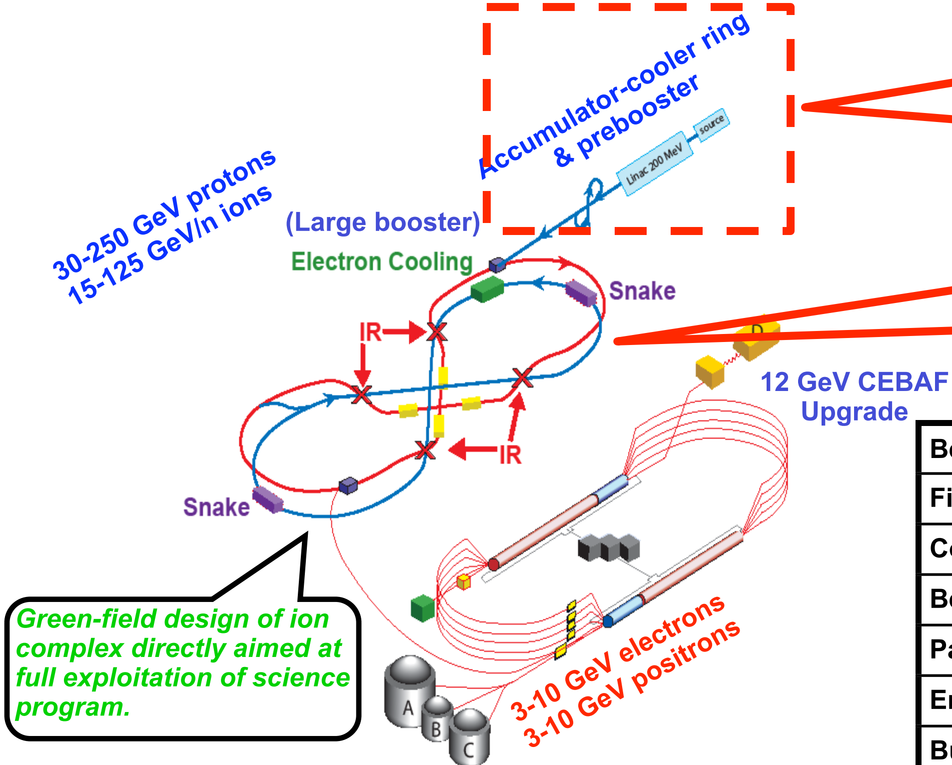
Brinkmann and Dohlus,
Ya. Derbenev, Proc. EPAC 2002



Staging for ELIC

The low-energy collider ring is the pre-booster for ELIC

The medium-energy collider ring is the large-booster for ELIC



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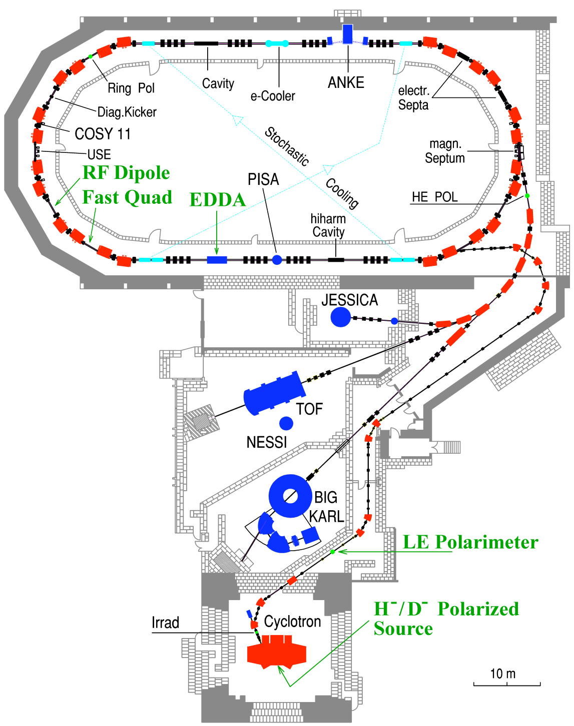
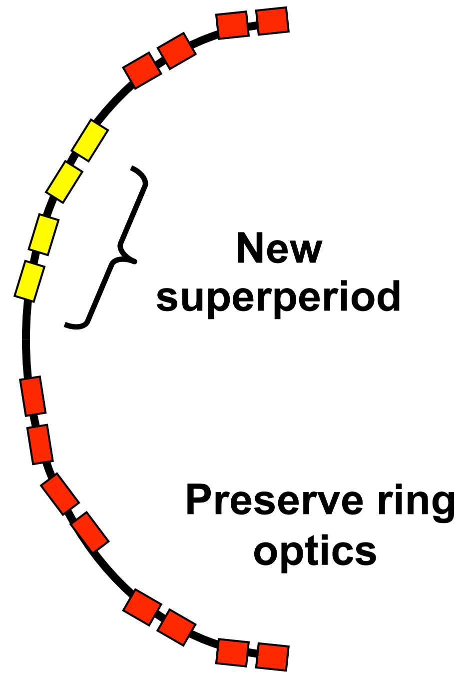
Two COSY upgrade options can be adopted in low to medium EIC

- 50 MeV SRF proton Linac
- 2 MeV electron cooling facility

COSY as Pre-Booster/Collider Ring

- COSY complex provides a good solution for the EIC pre-booster/low energy collider ring
- Adding 4 dipoles on each arc can bring maximum momentum of COSY synchrotron from 3.7 GeV/c to 5 GeV/c, while still preserving its optics
- COSY existing cooling facilities can be reused





Key R&D Issues

- Forming low energy ion beam and space charge effect
- Cooling of ion beams
- Traveling focusing scheme
- Beam-beam effect
- Beam dynamics of crab crossing beams

Summary

- We have investigated various staging ideas for ELIC
- These ideas start with building a high luminosity, low energy ($p < 5$ GeV/c) symmetric collider
- This complex could be followed by a high luminosity medium energy symmetric collider (5 GeV/c $< p <$ 11 GeV/c)
- This equipment would provide beams for injection into the final ELIC complex
- The initial design studies indicate that luminosity of this collider can reach up to 2.4×10^{33} cm^{-2}s^{-1}. This luminosity relays on staged ion beam cooling, crab crossing beam and traveling focusing interaction region design.

Summary

- All three colliders could run simultaneously, if physics interest stays strong in the early ones
- To reduce cost, it may be possible to reuse a substantial portion of the present COSY facility; especially in Stage I. Collaboration between Jefferson Lab and Jülich has been initiated.
- Additional major R&D will be needed on the ion beam space charge effect and travel focusing scheme. Crab cavities and electron cooling should not be challenging.

Making of Ion Beams

- Polarized & un-polarized ion sources (IUCF type, 2 RFQ, to 2.5 MeV/c)
- SRF Linac Injector
  - Baseline design calls for a 50 to 300 MeV/c SRF Linac
  - Options of large SRF linac are also under consideration (with high costs)
    - 2 GeV Project-X type SRF linac
    - Low β SRF cavities to 1.2 GeV/c, then CEBAF recirculated SRF linac to 3 to 5 GeV/c (1 to 2 pass)
- Pre-booster/low energy collider ring (320 m length)
  - Accumulating
  - Accelerating momentum to 3 to 5 GeV/c
  - RF bunching if beam will collide in this small ring
  - Staged beam cooling
- Large booster/medium energy collider ring (1370 m length)
  - Boosting momentum up to 11 GeV/c (highest ring capacity is 30 GeV/c)
  - RF bunching
  - Staged beam cooling