MEIC

Machine Design Status

Geoffrey Krafft and Yuhong Zhang

CASA

For the JLab EIC Study Group

EIC Collaboration Meeting, Catholic University of America, July 29-31, 2010

Outline

- **Introduction & Highlights**
- **Machine Design Status**
- **Design Details**
- **Path forward**
- **Summary**

ELIC: JLAB's Future Nuclear Science Program

- JLab has been developing a preliminary design of an EIC based on the CEBAF recirculating SRF linac for nearly a decade.

- Requirements of the future nuclear science program drives ELIC design efforts to focus on achieving
  - ultra high luminosity per detector (up to 10^{35}) in multiple detectors
  - very high polarization (>80%) for both electrons & light ions

- Over the last 12 months, we have made significant progress on design optimization
  - The primary focus is on a **M**edium-energy **E**lectron **I**on **C**ollider (*MEIC*) as the best compromise between science, technology and project cost
    - Energy range is up to 60 GeV ions and 11 GeV electrons
  - A well-defined upgrade capability to higher energies is maintained
  - High luminosity & high polarization continue to be the design drivers

Highlights of Last Six Months of MEIC Design Activities

- Continuing design optimization
  - Tuning main machine parameters to better serve the science program
  - Now aim for high luminosity ***AND*** large detector acceptance
  - Simplified design and reduced R&D requirements

- Focused on detailed design of major components
  - Completed baseline design of two collider rings
  - Completed 1st design of Figure-8 pre-booster (*B Erdelyi, July 30*)
  - Completed beam polarization scheme with universal electron spin rotators (*P. Chevtsov, July 30, Morozov*)
  - Updated IR optics design (*A. Bogacz, July 31*)

- Continued work on critical R&D
  - Beam-beam simulations (*B.Terzic, July 29*)
  - Nonlinear beam dynamics and instabilities (*B. Yunn, July 31, Zhang*)
  - Chromatic corrections (*V. Morozov, July 31*)

Short Term (6 Months) Design "Contract"

MEIC accelerator team is committed to completing a MEIC design within by International Advisory Committee Meeting with the following features

- CM energy up to 51 GeV, ➔ up to 11 GeV electron, 60 (30) GeV proton (ion)
- Upgrade option to high energy
- Three IPs, at least two of them are available for medium energy collisions
- Luminosity up to of order 10^{34} cm^{-2} s^{-1} *per* collision point
- ***Large acceptance for at least one medium-energy detector***
- High polarization for both electron and light ion beams

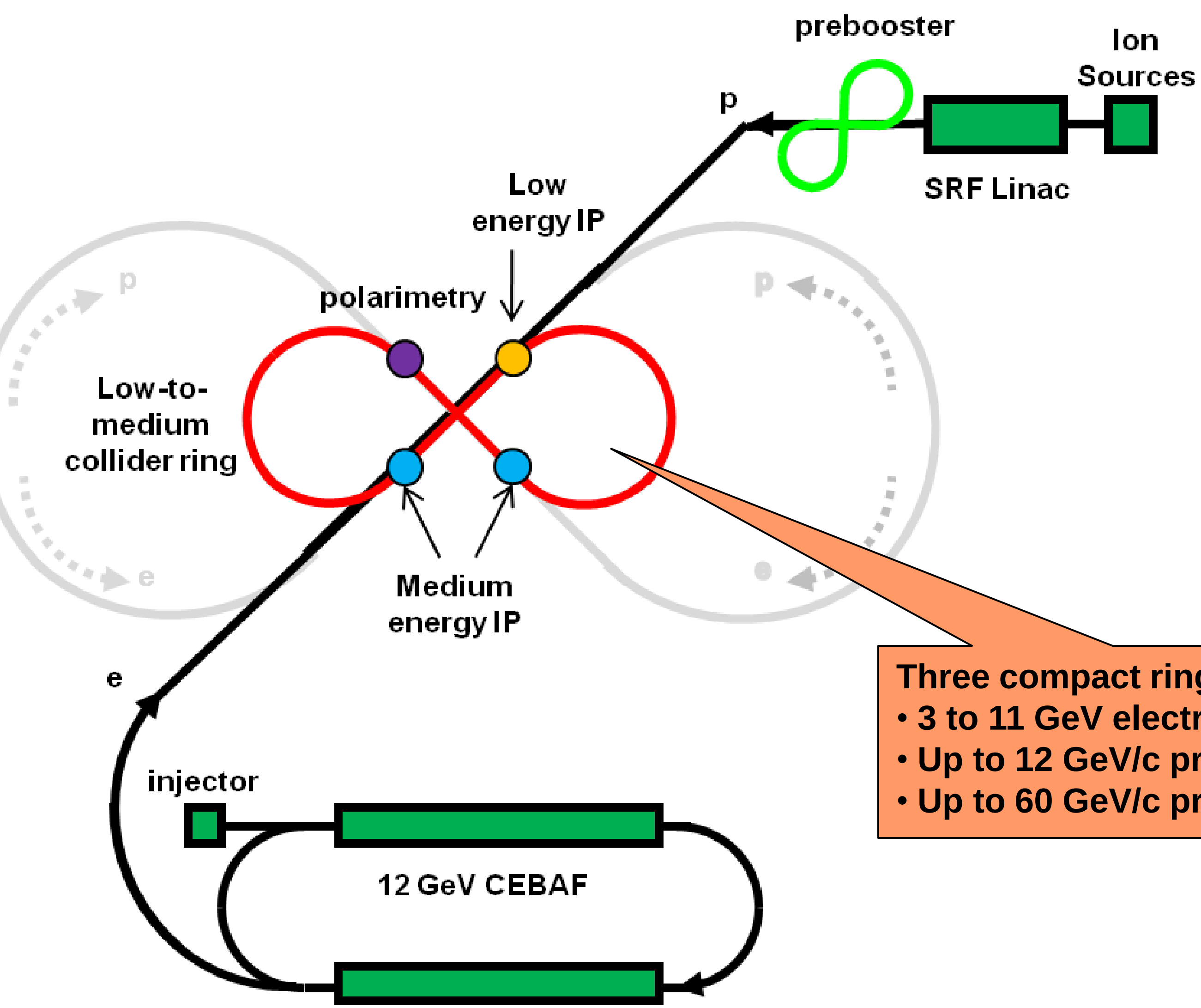
This "contract" will be renewable every 6 months with major revision of design specifications due to development of

- Nuclear science program
- Accelerator R&D

Short Term Technical Strategy

- Focus of MEIC accelerator team during this period is to work out a complete machine design with sufficient technical detail.
- We are taking a ***conservative*** technical position by limiting many MEIC design parameters *within or close to* the present state-of-art in order to minimize technical uncertainty.
  - Maximum peak field of ion superconducting dipole is 6 T
  - Maximum synchrotron radiation power density is 20 kW/m
  - Maximum betatron value at FF quad is 2.5 km
- This conservative technical design will form a baseline for future design optimization guided by
  - Evolution of the science program
  - Technology innovation and R&D advances.

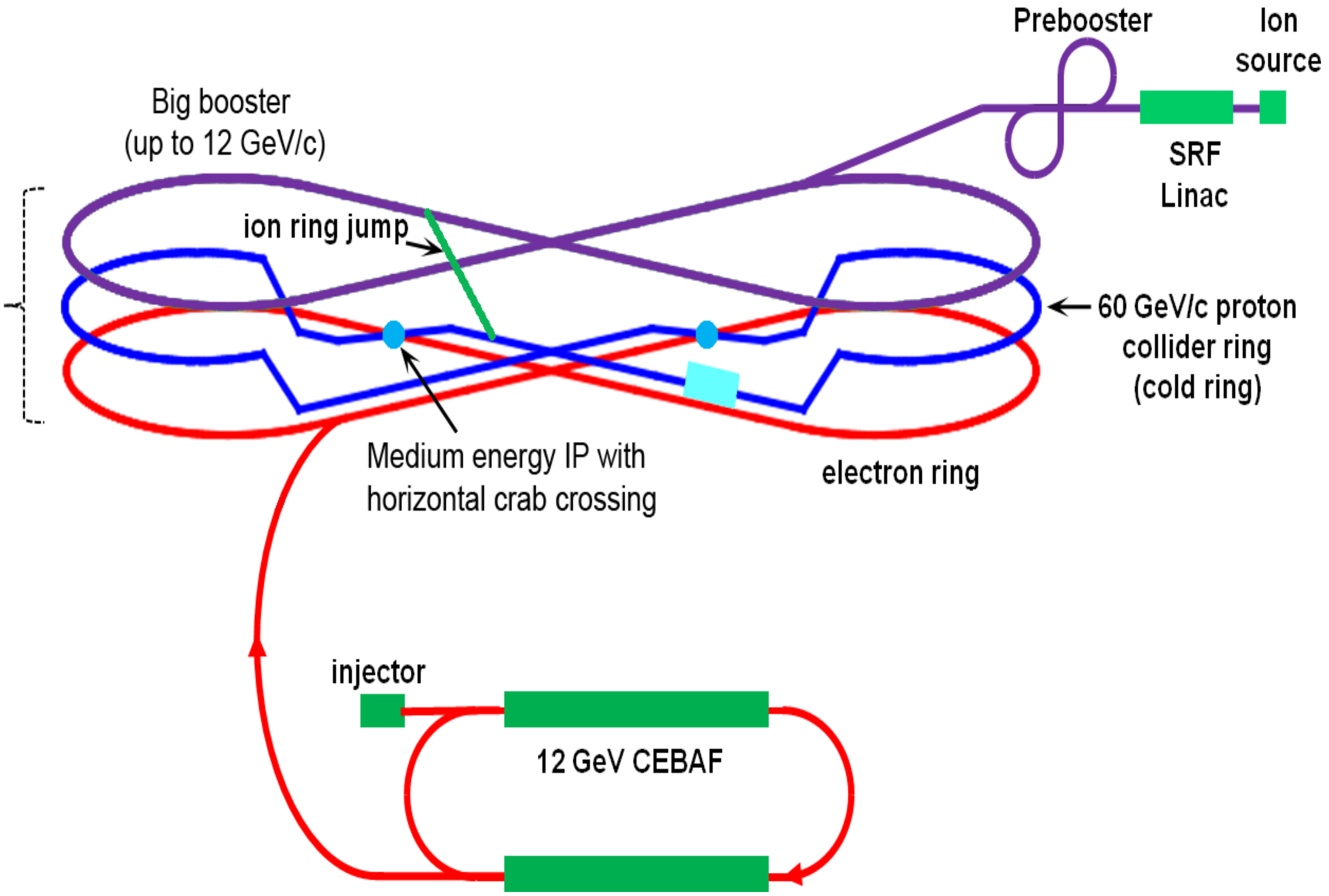
MEIC : Medium Energy EIC



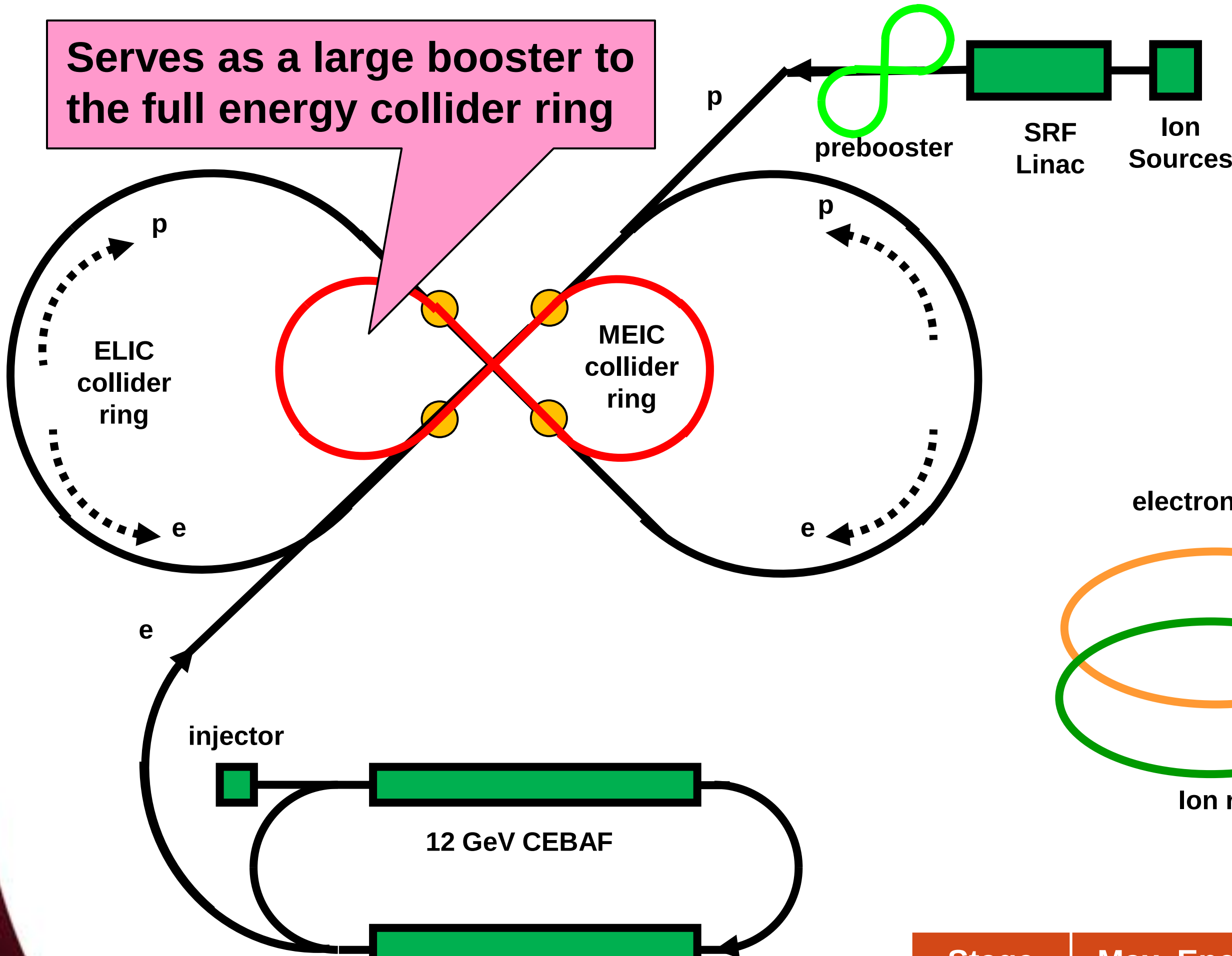
Three compact rings:

- **3 to 11 GeV electron**
- **Up to 12 GeV/c proton (warm)**
- **Up to 60 GeV/c proton (cold)**

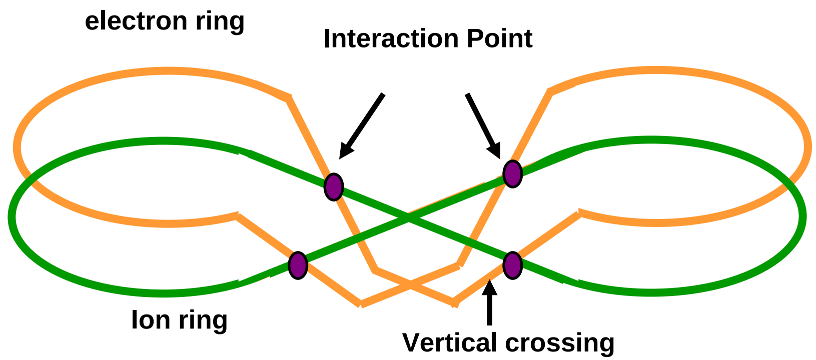
MEIC Detailed Layout



ELIC: High Energy & Staging



Circumference	m	1800
Radius	m	140
Width	m	280
Length	m	695
Straight	m	306



Stage	Max. Energy (GeV/c)		Ring Size (m)		Ring Type		IP #
	p	e	p	e	p	e	
Medium	60	5 (11)	1000		Cold	Warm	3
High	250	10	1800		Cold	Warm	4

Collider Luminosity

- **Probability an event is generated by a Beam 1 bunch with Gaussian density crossing a Beam 2 bunch with Gaussian density**

$$P = \frac{N_1 N_2}{2\pi\sqrt{\sigma_{1x}^2+\sigma_{2x}^2}\sqrt{\sigma_{1y}^2+\sigma_{2y}^2}}\sigma$$

- **Event rate with equal transverse beam sizes**

$$\frac{dN}{dt} = \frac{fN_1 N_2}{4\pi\sigma_x\sigma_y}\sigma = \mathcal{L}\sigma$$

- **Linear beam-beam tune shift**

$$\xi_x^i = \frac{N_{\bar{i}} r_i}{2\pi\gamma_i}\frac{1}{\varepsilon_x^i\left(1+\sigma_y/\sigma_x\right)} \qquad \xi_y^i = \frac{N_{\bar{i}} r_i}{2\pi\gamma_i}\frac{1}{\varepsilon_y^i\left(1+\sigma_y/\sigma_x\right)\left(\sigma_x/\sigma_y\right)}$$

Luminosity beam-beam tune-shift relationship

- Express Luminosity in terms of the (larger!) vertical tune shift (*i* either 1 or 2)

$$\mathcal{L} = \frac{fN_i \xi_y^i \gamma_i}{2r_i \beta^*}\left(1+\sigma_y/\sigma_x\right) = \frac{I_i}{e}\frac{\xi_y^i \gamma_i}{2r_i \beta^*}\left(1+\sigma_y/\sigma_x\right)$$

- Necessary, **but not sufficient**, for self-consistent design

- Expressed in this way, and given a "known" limit to the beam-beam tune shift, the only variables to manipulate to increase luminosity are the stored current, the aspect ratio, and the β^* (beta function value at the interaction point)

- Applies to ERL-ring colliders, stored beam (ions) only

MEIC Design Parameters for a Large Acceptance Detector

		Proton	Electron
Beam energy	GeV	60	5
Collision frequency	GHz	1.5	1.5
Particles per bunch	10^{10}	0.416	1.25
Beam Current	A	1	3
Polarization	%	> 70	~ 80
Energy spread	10^{-4}	~ 3	7.1
RMS bunch length	cm	10	7.5
Horizontal emittance, normalized	µm rad	0.35	54
Vertical emittance, normalized	µm rad	0.07	11
Horizontal β*	cm	10	10
Vertical β*	cm	2	2
Vertical beam-beam tune shift		0.007	0.03
Laslett tune shift		0.07	Very small
Distance from IP to 1st FF quad	m	7	3.5
Luminosity per IP, 10^{33}	$cm^{-2}s^{-1}$	5.6	

MEIC Design Parameters for a High Luminosity Detector

		Proton	Electron
Beam energy	GeV	60	5
Collision frequency	GHz	1.5	1.5
Particles per bunch	10^{10}	0.416 (0.3)	1.25
Beam Current	A	1 (0.7)	3
Polarization	%	>70	~ 80
Energy spread	10^{-4}	~ 3	7.1
RMS bunch length	cm	10 (5)	7.5
Horizontal emittance, normalized	µm rad	0.35	54
Vertical emittance, normalized	µm rad	0.07	11
Horizontal β*	cm	5 (2)	5 (2)
Vertical β*	cm	1 (0.4)	1 (0.4)
Vertical beam-beam tune shift		0.007	0.03
Laslett tune shift		0.07 (0.1)	Very small
Distance from IP to 1st FF quad	m	5 (3)	3.5
Luminosity per IP, 10^{33}	$cm^{-2}s^{-1}$	11.2 (20)	

MEIC : CM Energy Range

Figure-8 Ring Circumference	Maximum Peak Dipole Field	Luminosity Design Point	Maximum energy	CM Energy Range (S)
m	T	GeV x GeV	GeV	GeV^2
1000	6	~ 60 x 5 (s=1200)	60/11	2640
1000	8	~ 80 x 5 (s=1600)	80/11	3520

After LHC demonstrates its SC magnets can provide 8 T peak field

Figure-8 Ring Circumference	Maximum Peak Dipole Field	Luminosity Design Point	Maximum Energy	CM Energy Range (S)
m	T	GeV x GeV	GeV	GeV^2
1250	6	~ 100 x 7 (s=2800)	108/11	4752
1250	8	~ 125 x 7 (s=3500)	154/11	6776

- Increase of arc part only by 50%, cost increase is about 10%.
- More space for arc dipoles for bending higher energy ions.
- Increase electron current by reducing synchrotron radiation by 50%.
- There is no need to increase length of the straight sections.
- Where is the richest physics program?

MEIC Ring-Ring Design Features

- Ultra high luminosity
- Polarized electrons and polarized light ions
- Up to three IPs (detectors) for high science productivity
- "*Figure-8*" ion and lepton storage rings
  - Ensures spin preservation and ease of spin manipulation
  - Avoids energy-dependent spin sensitivity for all species
- Present CEBAF injector meets MEIC requirements
  - 12 GeV CEBAF can serve as a full energy injector
    - Simultaneous operation of collider & CEBAF fixed target program possible
- Experiments with polarized positron beam would be possible

Figure-8 Ion Rings

- Figure-8 optimum for polarized ion beams
  - Simple solution to preserve full ion polarization by avoiding spin resonances during acceleration
  - Energy independence of spin tune
  - *g-2* is small for deuterons; a figure-8 ring is the only practical way to arrange for longitudinal spin polarization at interaction point
  - Long straights can be useful
    - Allows multiple interactions in the same straight – can help with chromatic correction
  - Main disadvantage is small cost increase
  - There are no technical disadvantages

MEIC Adopts Proven Luminosity Approaches

High luminosity at B factories comes from

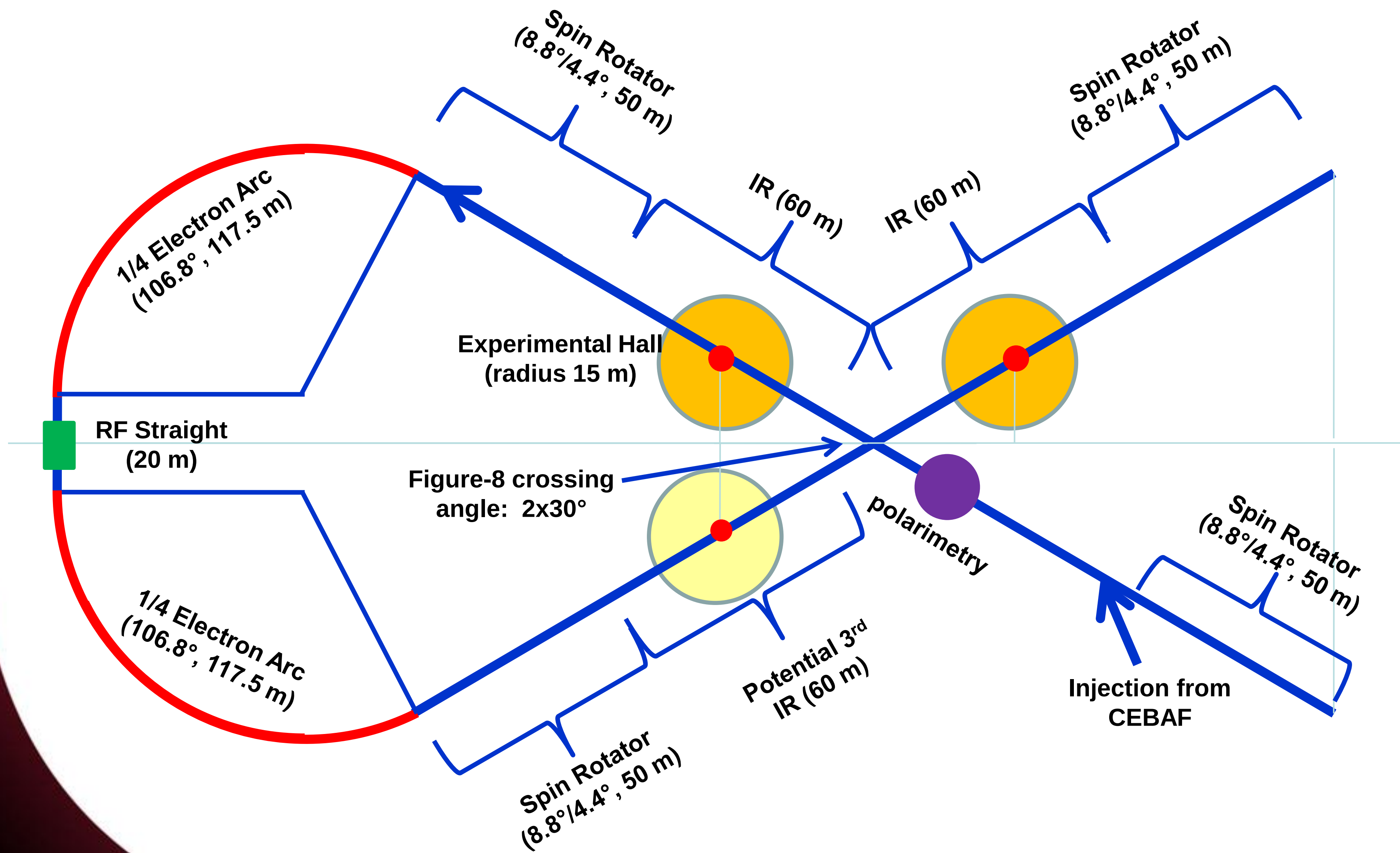
- Very small β* (~6 mm) to reach very small spot sizes at collision points
- Very short bunch length (σ_z~ β*) to avoid hour-glass effect
- Very small bunch charge which makes very short bunch possible
- High bunch repetition rate restores high average current and luminosity
- Synchrotron radiation damping

➔ **KEK-B and PEPII already over 2×10^{34} /cm²/s**

		KEK B	MEIC
Repetition Rate	MHz	509	1500
Particles per Bunch	10^{10}	3.3/1.4	0.42/1.25
Beam current	A	1.2/1.8	1/3
Bunch length	cm	0.6	1/0.75
Horizontal & Vertical β*	cm	56/0.56	10/2
Luminosity per IP, 10^{33}	$cm^{-2}s^{-1}$	20	5.6 ~ 11

JLab believes these ideas should be replicated in the next electron-ion collider

Electron Figure-8 Collider Ring

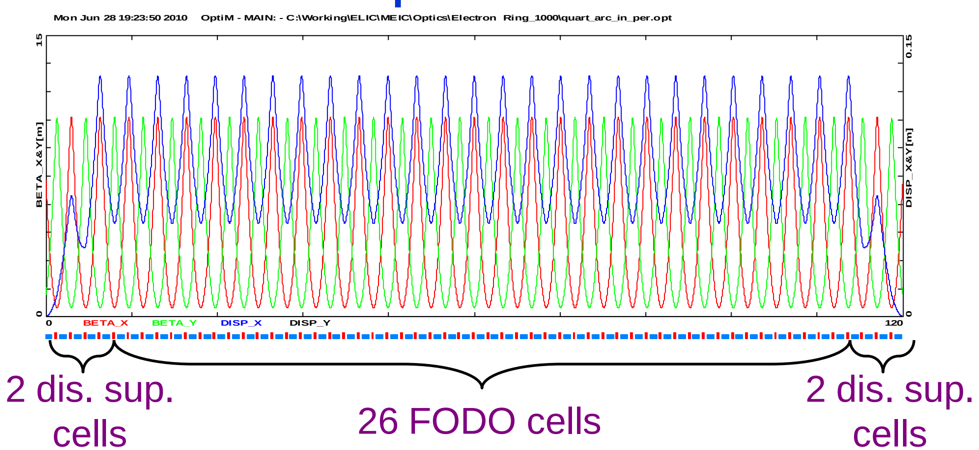


Electron Collider Ring

Electron ring is designed in a modular way

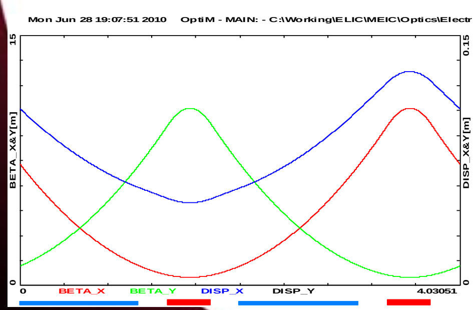
- two long (140 m) straights (for two IPs)
- two short (20 m) straights (for RF module), dispersion free
- four identical (106.8º) quarter arcs, made of 135º phase advance FODO cell with dispersion suppressing
- four 50 m long electron spin rotator blocks

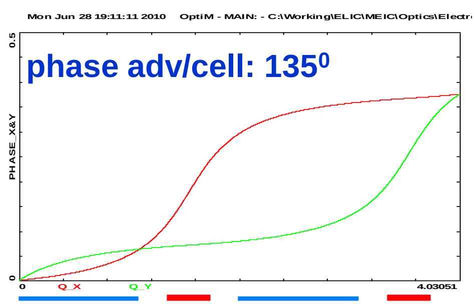
One quarter arc

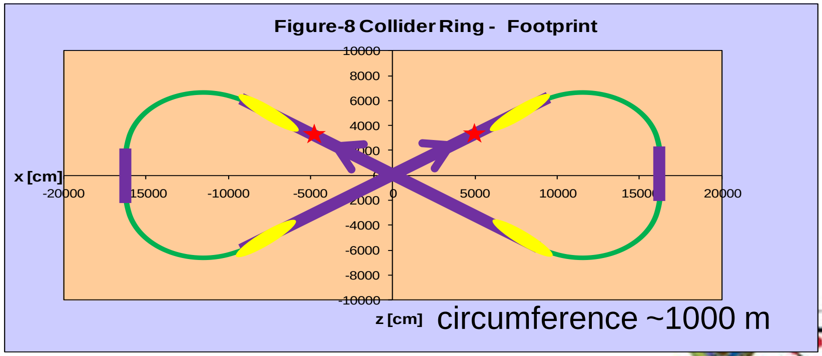


135º FODO Cell for arc

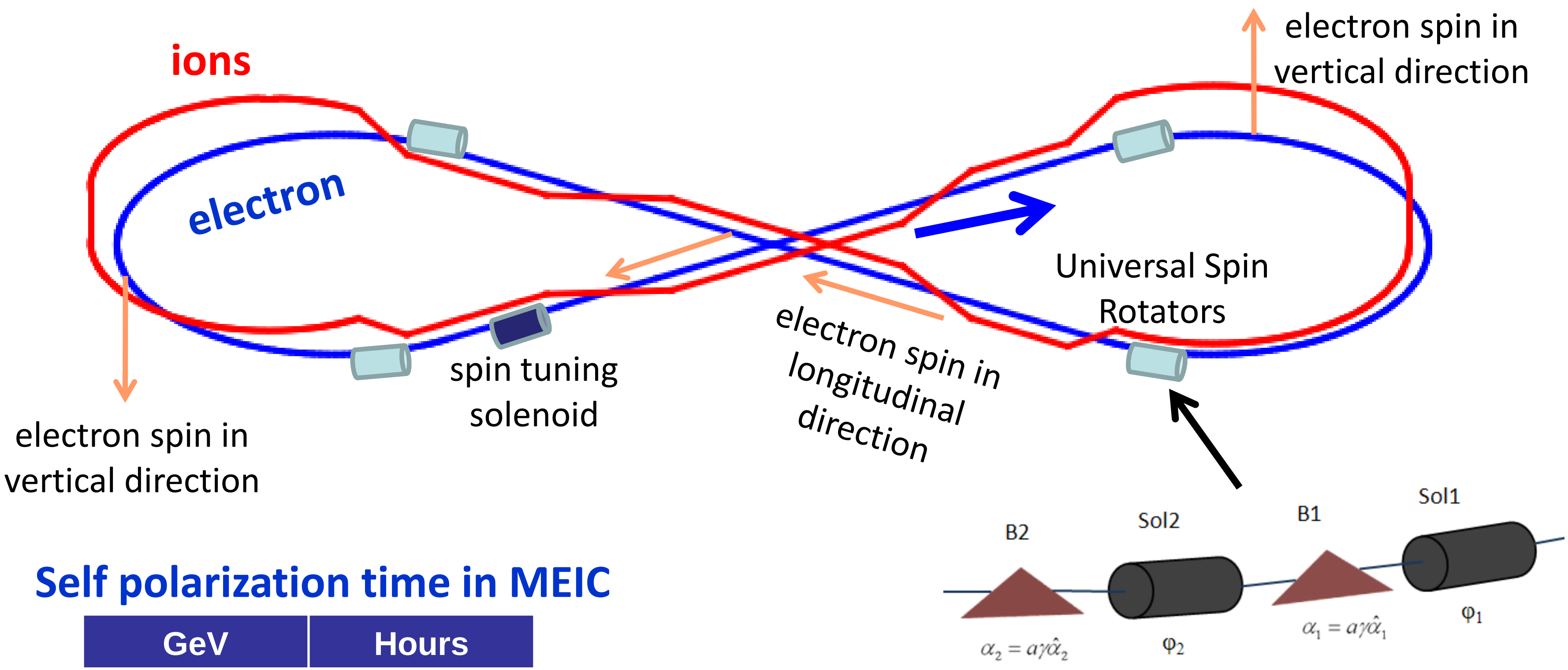
	Length	Field
Dipole	1.1 m	1.25 T (2.14 deg)
Quad	0.4 m	9 kG/cm
Cell	4 m	







Electron Polarization in Figure-8 Ring

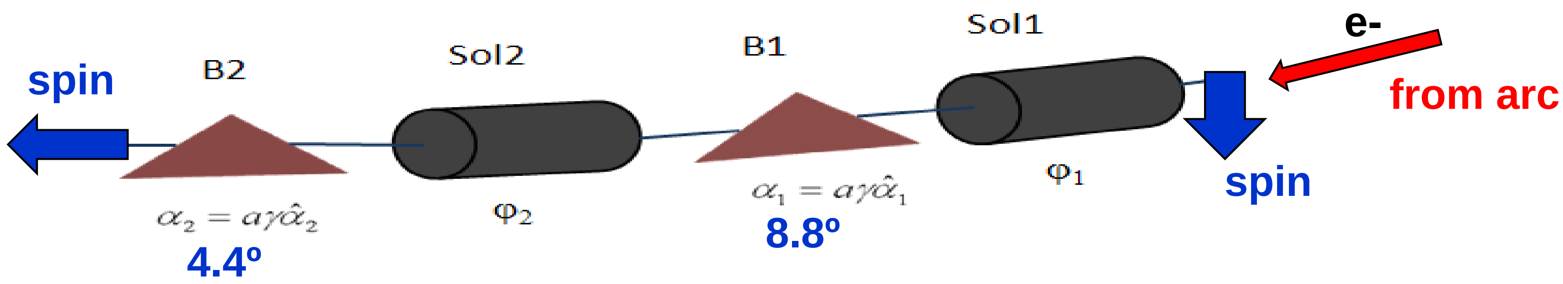


Self polarization time in MEIC

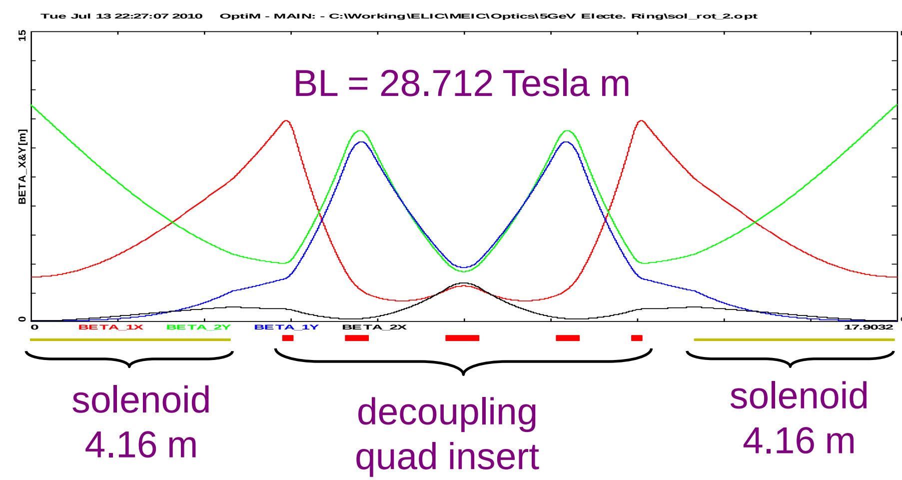
GeV	Hours
3	14.6
4	3.5
5	1.1
6	0.46
9	0.06
11	0.02

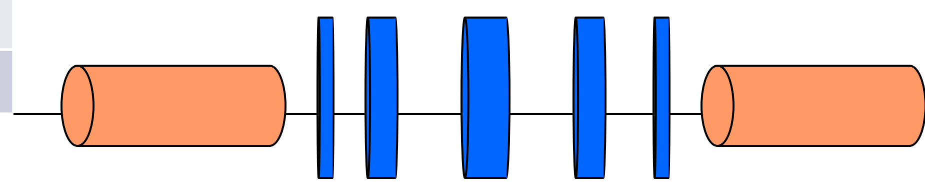
- Polarized electron beam is injected at full energy from 12 GeV CEBAF
- Electron spin is in vertical direction in the figure-8 ring, taking advantage of self-polarization effect
- Spin rotators will rotate spin to longitudinal direction for collision at IP, than back to vertical direction in the other half of the ring

Universal Spin Rotator



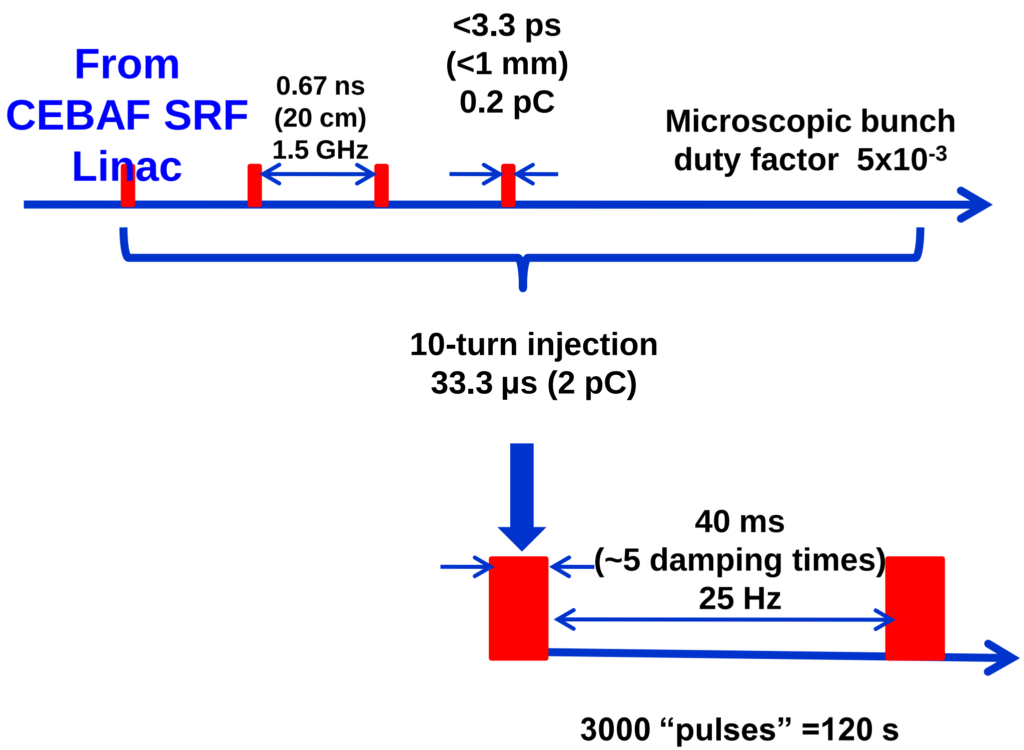
E	Solenoid 1		Solenoid 2		Spin rotation	
	spin rot.	BDL	spin rot.	BDL	arc bend 1	src bend 2
GeV	rad	T m	rad	T m	rad	rad
3	π/2	15.7	0	0	π/3	π/6
4.5	π/4	11.8	π/2	23.6	π/2	π/4
6	0.63	12.3	π-1.23	38.2	2π/3	π/3
9	π/6	15.7	2π/3	62.8	π	π/2
12	0.62	24.6	π-1.23	76.4	4π/3	2π/3





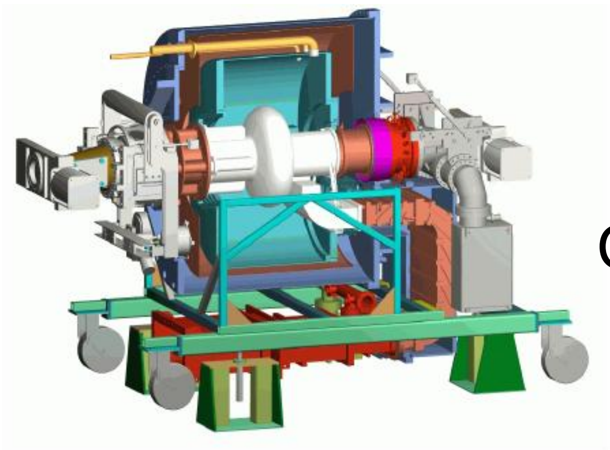
$$M = \begin{pmatrix} C & 0 \\ 0 & -C \end{pmatrix}$$

Electron Beam Time Structure & RF System

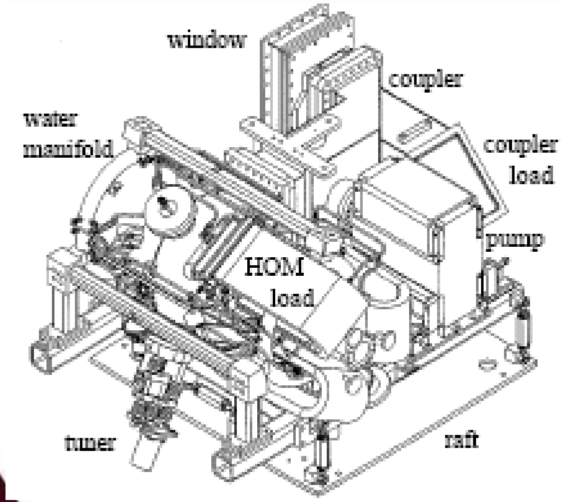


		MEIC
RF operation frequency	MHz	1.497
Total Power	MW	6.1
Harmonic number		4969
RF Voltage	MV	4.8
Beam current	A	3
Energy loss per turn	MeV	2
R/Q		90
HOM Power	kW	2
Accelerating voltage gradient	MV/m	1
Unloaded Q		1.2×10^{9}
Number of cavities		16

Possible Electron Ring RF Systems



CESR



BESSY

PEP II

RF may prefer 748.5 MHz (coupler limits)

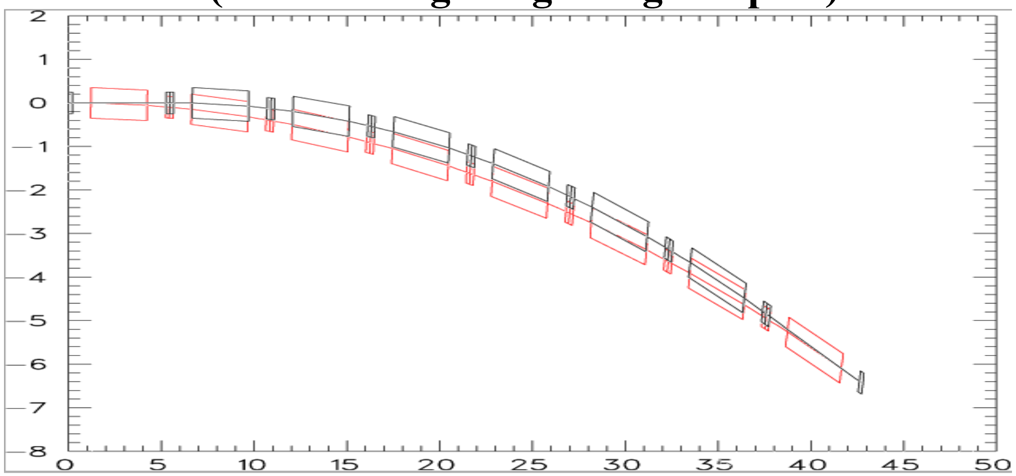
Beam Synchronization

- Electron speed is already speed of light at 3 to 11 GeV, ion speed is not, there is 0.3% variation of ion speed from 20 to 60 GeV
- Needs over 67 cm path length change for a 1000 m ring
- Solution for case of two IPs on two separate straights
  - At the higher energies (close to 60 GeV), change ion path length
    - ➔ ion arc on movers
  - At the lower energies (close to 20 GeV), change bunch harmonic number
    - ➔ Varying number of ion bunches in the ring
- With two IPs in a same straights ➔ Cross-phasing
- More studies/implementation scheme needed

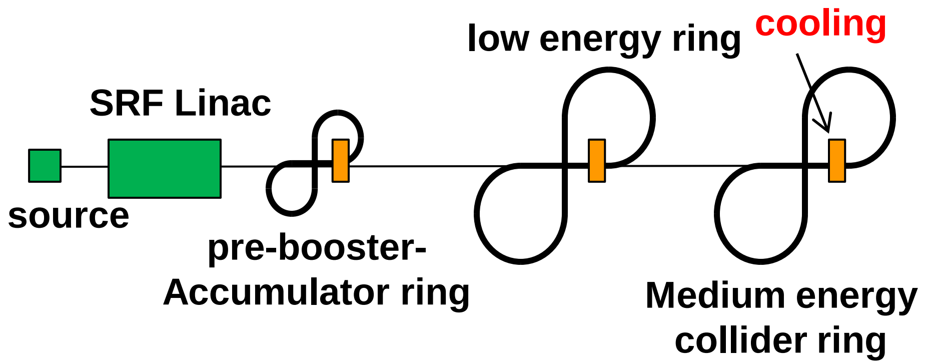
Harmonic Number vs. Proton Energy

n	β=(h-n)/h	γ	Energy (GeV)
0	1	inf	Inf
1	0.9998	47.44	43.57
2	0.9996	33.54	30.54
3	0.9993	27.39	24.76
4	0.9991	23.72	21.32
5	0.9989	21.22	18.97
6	0.9987	19.37	17.24

eRHIC e-Ring Path Length Adjustment
(eRHIC Ring-Ring Design Report)



Forming the High-Intensity Ion Beam



Stacking proton beam in ACR

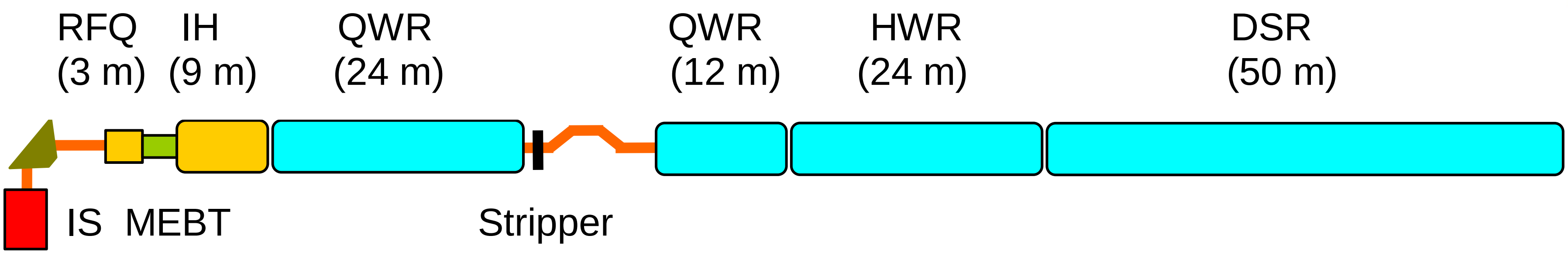
Circumference	m	100
Energy/u	GeV	0.2 -0.4
Cooling electron current	A	1
Cooling time for protons	ms	10
Stacked ion current	A	1
Norm. emit. After stacking	µm	16

	Energy (GeV/c)	Cooling	Process
Source/SRF linac	0.2		Full stripping
Prebooster/Accumulator-Ring	3	DC electron	Stacking/accumulating
Low energy ring (booster)	12	Electron	RF bunching (for collision)
Medium energy ring	60	Electron	RF bunching (for collision)

Stacking/accumulation process

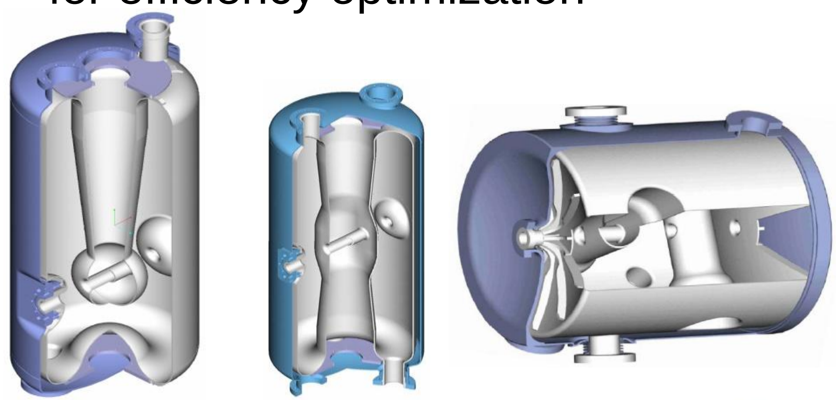
- Multi-turn (~20) pulse injection from SRF linac into the prebooster
- Damping/cooling of injected beam
- Accumulation of 1 A coasted beam at space charge limited emittance
- Fill prebooster/large booster, then accelerate
- Switch to collider ring for booster, RF bunching & staged cooling

Ion SRF Linac (First Cut)



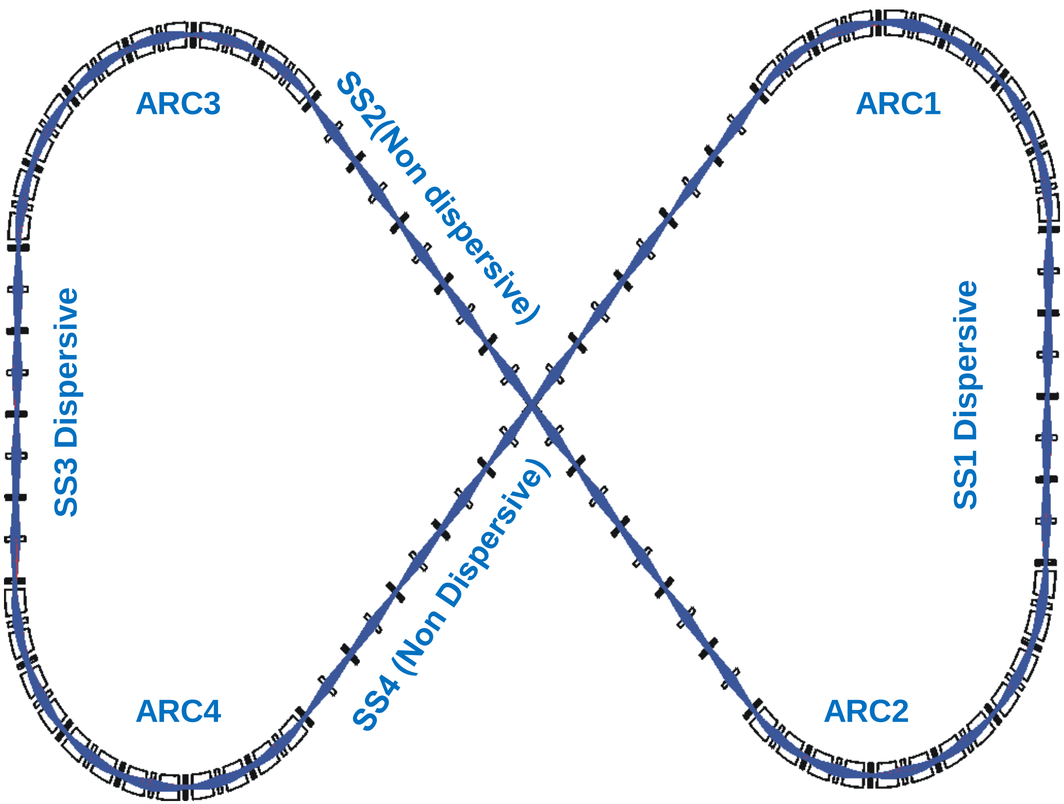
Ion species		Up to Lead
Ion species for reference design		^{208}Pb
Kinetic energy of lead ions	MeV/u	100
Maximum beam current averaged over the pulse	mA	2
Pulse repetition rate	Hz	10
Pulse length	ms	0.25
Maximum beam pulsed power	kW	680
Fundamental frequency	MHz	115
Total length	m	150

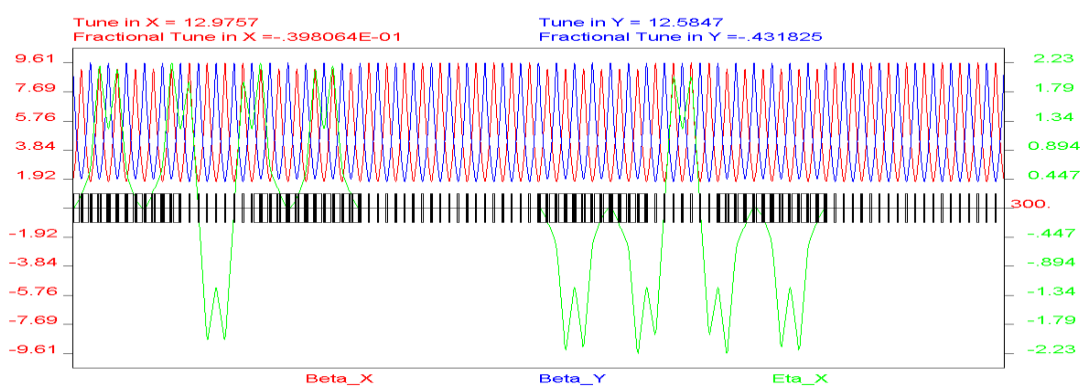
- Accelerating a wide variety of polarized light ions and unpolarized heavy ion
- Up to 285 MeV for H^- or 100 MeV/u for $^{208}Pb^{+67}$
- Requires stripper for heavy ions (Lead) for efficiency optimization



QWR HWR DSR

MEIC Ion Pre-booster

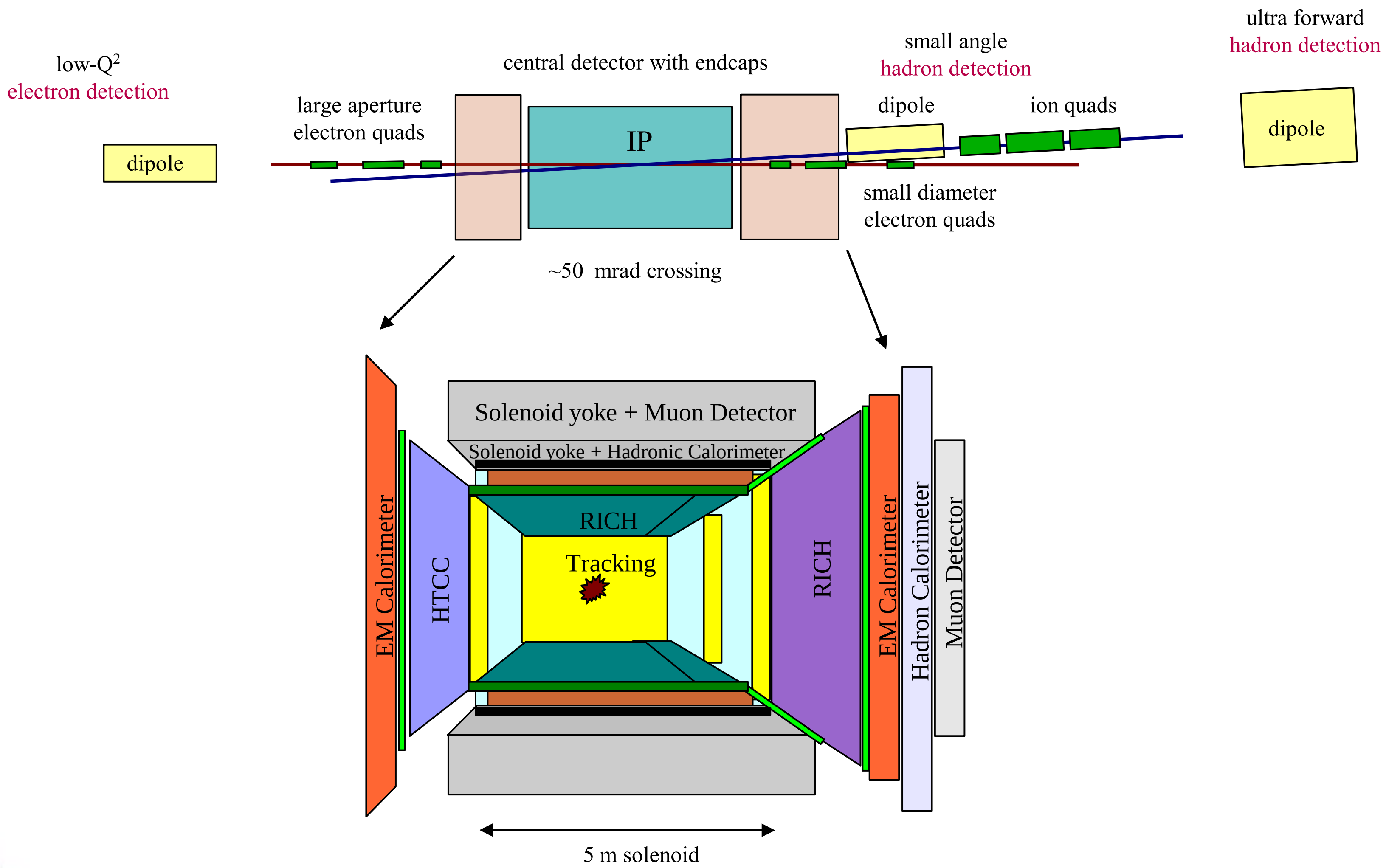




Drift (arc)	m	0.35
Drift (SS)	m	3
Quad	m	0.4
Max Quad Field (arc)	T	0.81
Dipole	m	2
Bending angle	deg	11.47

Total length	m	300
Straight (long)	m	2x57
Straight (short, in arc)	m	2x23
Figure-8 angle	deg	95.35
Max particle γ		4.22
Transition γ		5.4
Momentum compaction		0.0341

Detector Concept and IR layout

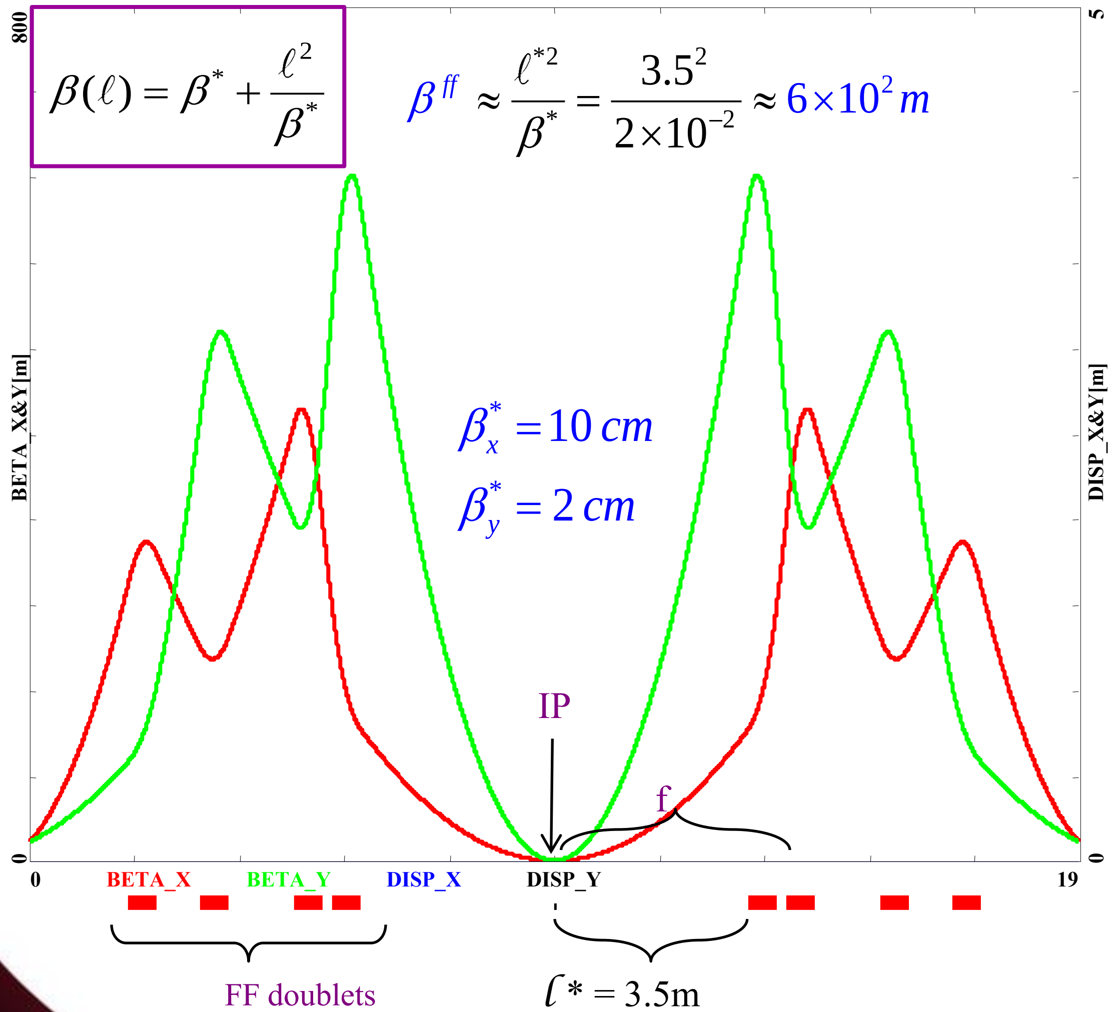


Pawel Nadel-Turonski

IR Optics (electrons)

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

$$\beta^{ff} \approx \frac{\ell^{*2}}{\beta^*} = \frac{3.5^2}{2\times10^{-2}} \approx 6\times10^2\, m$$



$$\beta_x^* = 10\, cm$$

$$\beta_y^* = 2\, cm$$

$$\zeta_{IR} \sim \frac{f^2}{\beta^*}\frac{1}{f} = \frac{f}{\beta^*}$$

$$\zeta_1 := \frac{1}{4\pi}\int_0^l \beta_x\,(-g_0 + \eta_0\, g_1)\, ds;$$

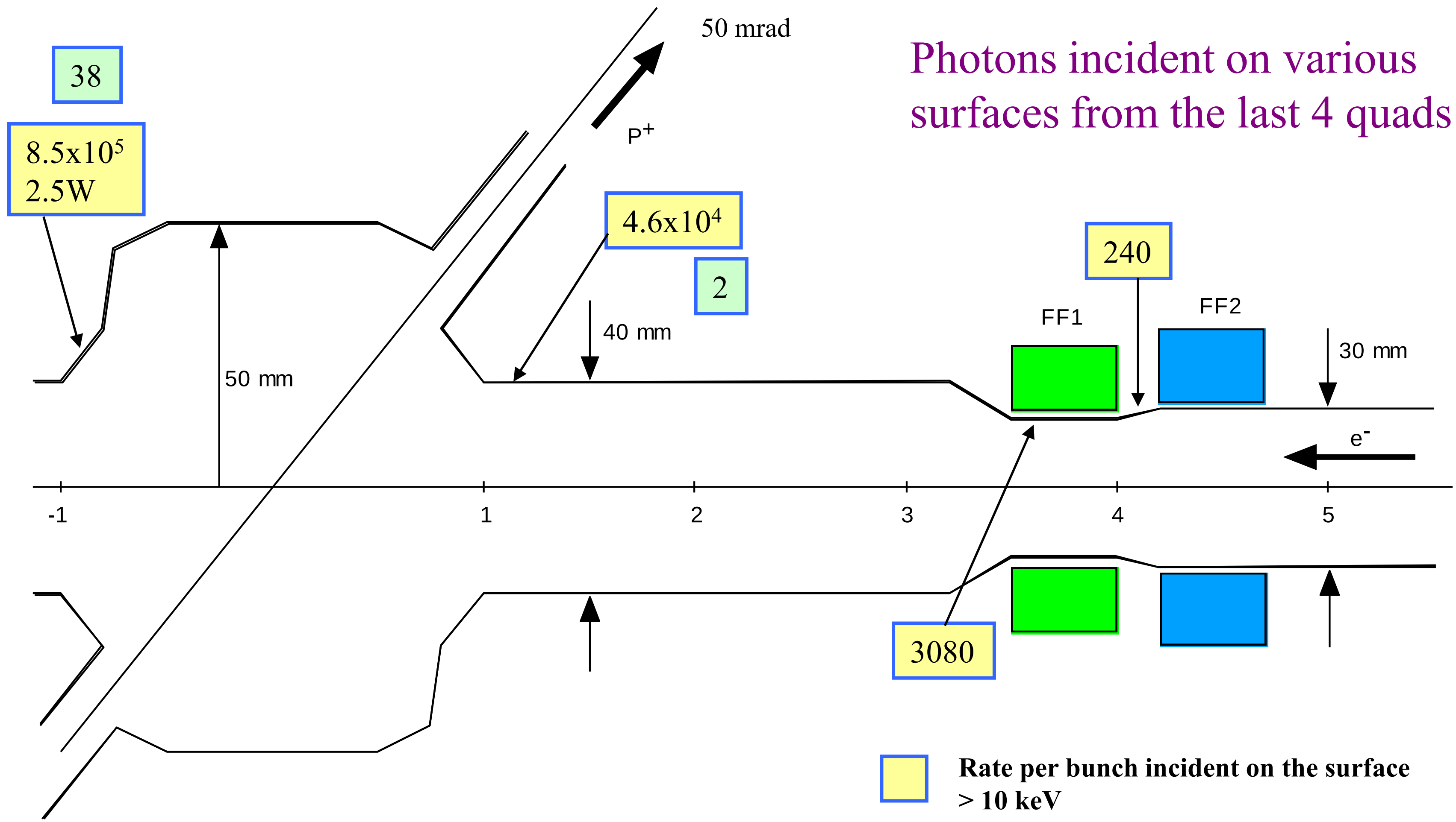
$$\beta^{\max} g_0^{FF}$$

Natural Chromaticity:

$\zeta_x = -47$ $\zeta_y = -66$

Synchrotron Radiation Background

Photons incident on various surfaces from the last 4 quads



Beam current = 2.32 A
2.9×10^{10} particles/bunch

Rate per bunch incident on the surface > 10 keV

Rate per bunch incident on the detector beam pipe assuming 1% reflection coefficient and solid angle acceptance of 4.4 %

MEIC Beam-beam Studies

- Simulating the beam-beam effects becomes critically important as part of the feasibility study of this conceptual design
- Staged approach to simulations (Terzić talk on 7/29):
  - Current: isolate beam-beam effects at IP (idealized linear beam transport)
  - Next: incorporate non-linearity in the beam transport around the ring
- Main points of this stage of beam-beam simulations:
  - Developed a new, automated search for working point based on an evolutionary algorithm (near half-integer resonance: exceeds design luminosity by ~33%)
  - Short-term stability verified to within capabilities of strong-strong code
  - As beam current is increased, beam-beam effects do not limit stability
  - *Beam-beam effects are not expected limit the capabilities of the MEIC*

Electron Beam Stability

The following issues have been studied

- Impedances
  - Inductive impedance budget
  - Resistive wall impedance
  - CEBAF cavity
  - HOM loss
- Single bunch instabilities
- Multibunch instabilities
- Intrabeam scattering
- Touschek scattering
- Beam-gas scattering
- Ion trapping & fast beam-ion instability
- Electron clouds

- As long as design of vacuum chamber follows the examples of ring colliders, especially B-factories, we will be safe from the single bunch instabilities.
- No bunch lengthening and widening due to the longitudinal microwave instability is expected
- No current limitation from transverse mode coupling instability.
- The performance of MEIC e-ring is likely to be limited by multi-bunch instabilities. Feedback system able to deal with the growth has to be designed.
- All ion species will be trapped. Total beam current limitation and beam lifetime will depend upon the ability of the vacuum system to maintain an acceptable pressure, about 5 *nTorr* in the presence of 3 A of circulating beam.

MEIC Critical Accelerator R&D

We have identified the following critical R&D for MEIC

- Interaction region design and limits with chromatic compensation
- Electron cooling
- Crab crossing and crab cavity

- Forming high intensity low energy ion beam
- Beam-beam effect
- Beam polarization and tracking

- Traveling focusing for very low energy ion beam

Level of R&D	Low-to-Medium Energy (12x3 GeV/c) & (60x5 GeV/c)	High Energy (up to 250x10 GeV)
Challenging		
Semi Challenging	IR design/chromaticity Electron cooling Traveling focusing (for very low ion energy)	IR design/chromaticity Electron cooling
Likely	Crab crossing/crab cavity High intensity low energy ion beam	Crab crossing/crab cavity High intensity low energy ion beam
Know-how	Spin tracking Beam-Beam	Spin tracking Beam-beam

Future Accelerator R&D

We will concentrate R&D efforts on the most critical tasks

Focal Point 1: Complete Electron and Ion Ring designs

sub tasks:
- Finalize chromaticity correction of electron ring and complete particle tracking
- Insert interaction region optics in ion ring
- Start chromaticity correction of ion ring, followed by particle tracking

Focal Point 2: IR design and feasibility studies of advanced IR schemes

sub tasks:
- Develop a complete IR design
- Beam dynamics with crab crossing
- Traveling final focusing and/or crab waist?

Future Accelerator R&D

Focal Point 3: Forming high-intensity short-bunch ion beams & cooling

sub tasks: Ion bunch dynamics and space charge effects (simulations)

Electron cooling dynamics (simulations)

Dynamics of cooling electron bunch in ERL circulator ring

Led by Peter Ostroumov (ANL)

Focal Point 4: Beam-beam interaction

sub tasks: Include crab crossing and/or space charge

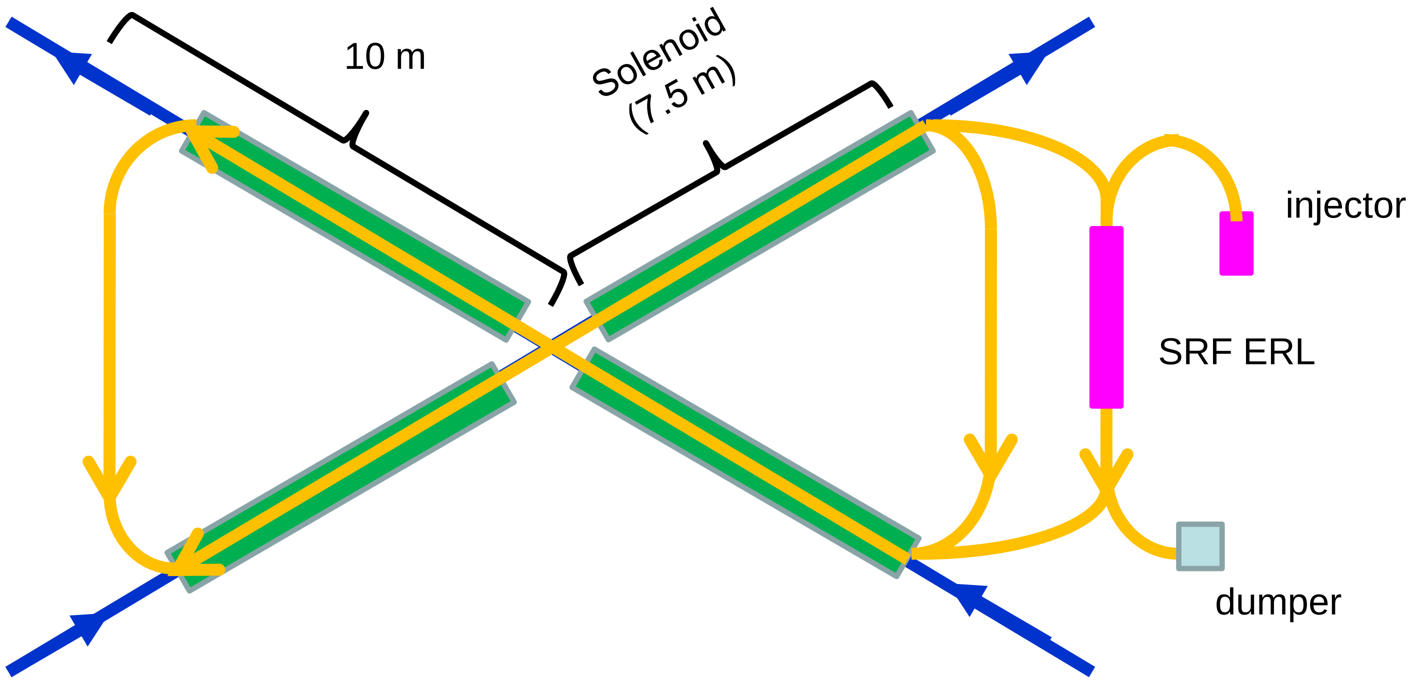
Include multiple bunches and interaction points

Additional design and R&D studies

Electron spin tracking, ion source development

Transfer line design

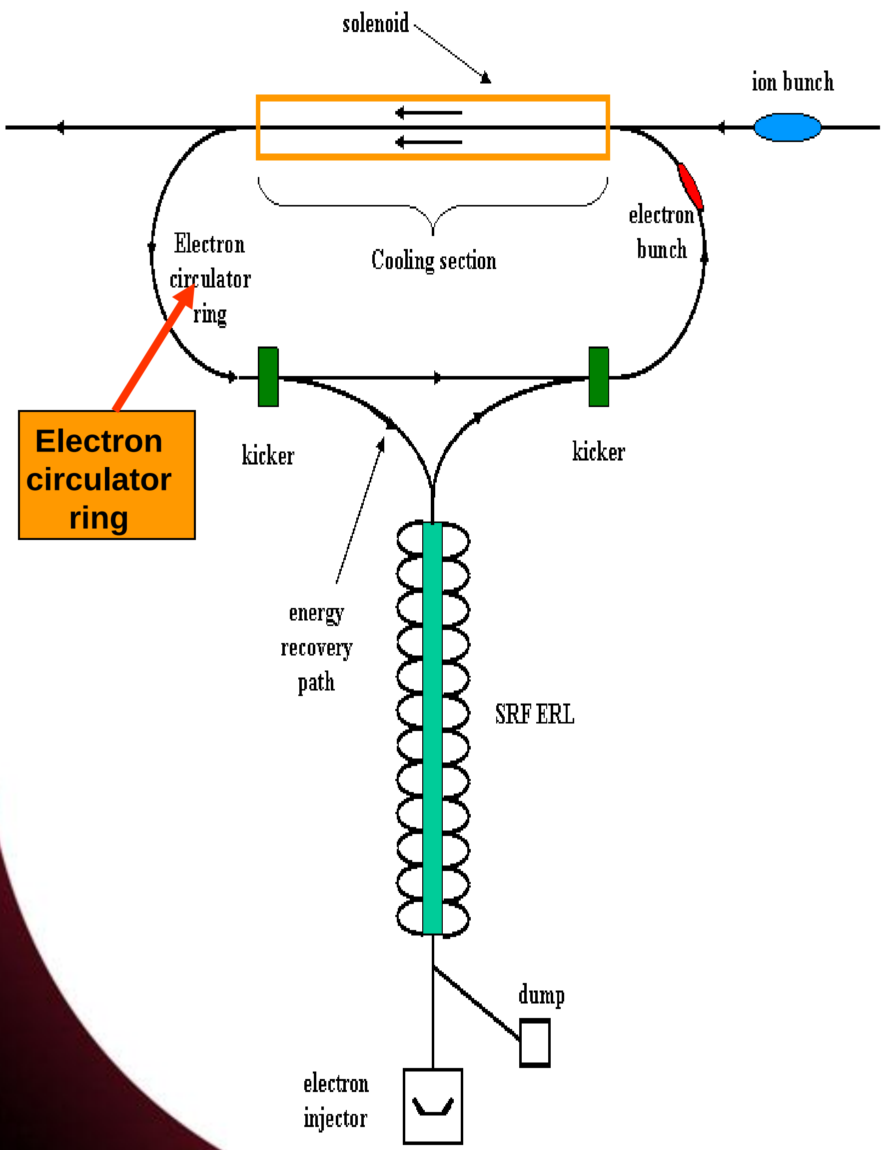
Electron Cooling of Colliding Ion Beams



- Electron cooler is located at center for figure-8 ring
- Compact cooler design
- Doubled length of cooling section, therefore the cooling rate
- Reduces number of circulation

<table>
<tr><th></th><th>Cooling (Derbenev)</th><th>IBS (Piwinski)</th><th>IBS (Derbenev)</th></tr>
<tr><td></td><td>s</td><td>s</td><td>S</td></tr>
<tr><td>Horizontal</td><td rowspan="2">7.8</td><td>86</td><td></td></tr>
<tr><td>longitudinal</td><td>66</td><td>51</td></tr>
</table>

ERL Circulator Cooler



Design goal

- Up to 33 MeV electron energy
- Up to 3 A CW unpolarized beam
  (~nC bunch charge @ 499 MHz)
- Up to 100 MW beam power!

Solution: ERL Circulator Cooler

- ERL provides high average current CW beam with minimum RF power
- Circulator ring for reducing average current from source and in ERL
  (# of circulating turns reduces ERL current by same factor)

Technologies

- High intensity electron source/injector
- Energy Recovery Linac (ERL)
- Fast kicker

Collaborations Established

- Interaction region design — M. Sullivan (SLAC)
- ELIC ion complex front end — P. Ostroumov (ANL)

  (From source up to injection into collider ring)
  - Ion source — V. Dudnikov, R. Johnson (Muons, Inc)

    V. Danilov (ORNL)
  - SRF Linac — P. Ostroumov (ANL), B. Erdelyi (NIU)
- Chromatic compensation — A. Netepenko (Fermilab)
- Beam-beam simulation — J. Qiang (LBNL)
- Electron cooling simulation — D. Bruhwiler (Tech X)
- Electron spin tracking — D. Barber (DESY)

ELIC Study Group

A. Afanasev, A. Bogacz, J. Benesch, P. Brindza, A. Bruell, L. Cardman, Y. Chao, S. Chattopadhyay, E. Chudakov, P. Degtiarenko, J. Delayen, Ya. Derbenev, R. Ent, P. Evtushenko, A. Freyberger, D. Gaskell, J. Grames, L. Harwood, T. Horn, A. Hutton, C. Hyde, R. Kazimi, F. Klein, G. A. Krafft, R. Li, L. Merminga, J. Musson, A. Nadel-Turonski, M. Poelker, R. Rimmer, A. Thomas, M. Tiefenback, H. Wang, C. Weiss, B. Wojtsekhowski, B. Yunn, Y. Zhang - Jefferson Laboratory staffs and users

W. Fischer, C. Montag - Brookhaven National Laboratory

D. Barber - DESY

V. Danilov - Oak Ridge National Laboratory

V. Dudnikov - Brookhaven Technology Group

P. Ostroumov - Argonne National Laboratory

V. Derenchuk - Indiana University Cyclotron Facility

A. Belov - Institute of Nuclear Research, Moscow, Russia

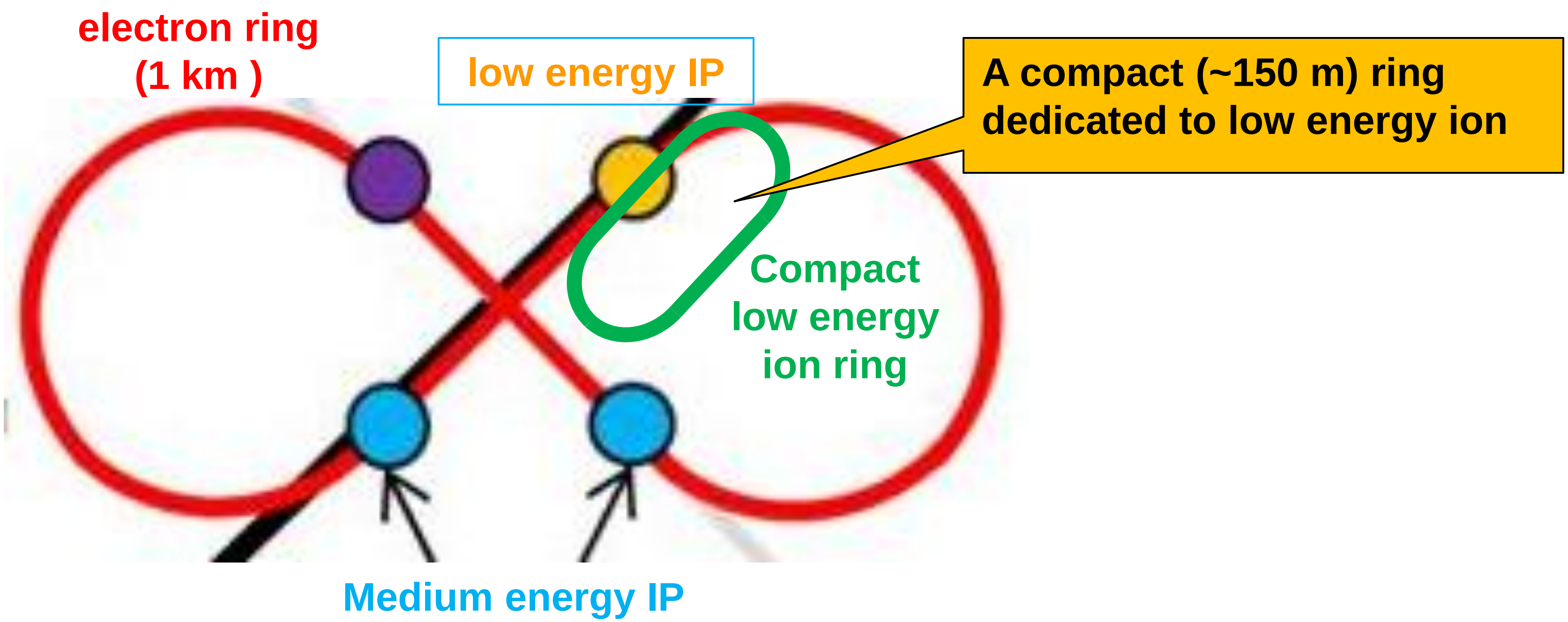
V. Shemelin - Cornell University

Summary

- MEIC is optimized to collide a wide variety of polarized light ions and unpolarized heavy ions with polarized electrons (or positrons)
- MEIC covers an energy range matched to the science program proposed by the JLab nuclear physics community (~2500 GeV^2) with luminosity up to $6x10^{33}$ $cm^{-2}s^{-1}$
- An upgrade path to higher energies (250x10 GeV^2), has been developed which should provide luminosity of $1x10^{35}$ $cm^{-2}s^{-1}$
- The design is based on a Figure-8 ring for optimum polarization, and an ion beam with high repetition rate, small emittance and short bunch length
- Electron cooling is absolutely essential for cooling and bunching the ion beams
- We have identified the critical accelerator R&D topics for MEIC, and hope to start working on them soon

MEIC is the future of Nuclear Physics at Jefferson Lab

MEIC : Reaching Down Low Energy



- Space charge effect is the leading factor for limiting ion beam current and luminosity
- A small ring with one IP, two snake, injection/ejection and RF
- Ion energy range from 12 GeV to 20 GeV
- Increasing ion current by a factor of 6, thus luminosity by 600%

ELIC Design Goals

- **Energy**

  Wide CM energy range between 10 GeV and 100 GeV
  - Low energy: 3 to 10 GeV e on 3 to 12 GeV/c p (and ion)
  - Medium energy: up to 11 GeV e on 60 GeV p or 30 GeV/n ion

  and *for future upgrade*
  - High energy: up to 10 GeV *e* on 250 GeV *p* or 100 GeV/n *ion*

- **Luminosity**
  - 10^{33} up to 10^{35} cm^{-2} s^{-1} *per* collision point
  - Multiple interaction points

- **Ion Species**
  - Polarized H, D, ^{3}He, possibly Li
  - Up to heavy ion A = 208, all stripped

- **Polarization**
  - Longitudinal at the IP for both beams, transverse of ions
  - Spin-flip of both beams
  - All polarizations >70% desirable

- **Positron Beam** *desirable*

MEIC Science Drivers

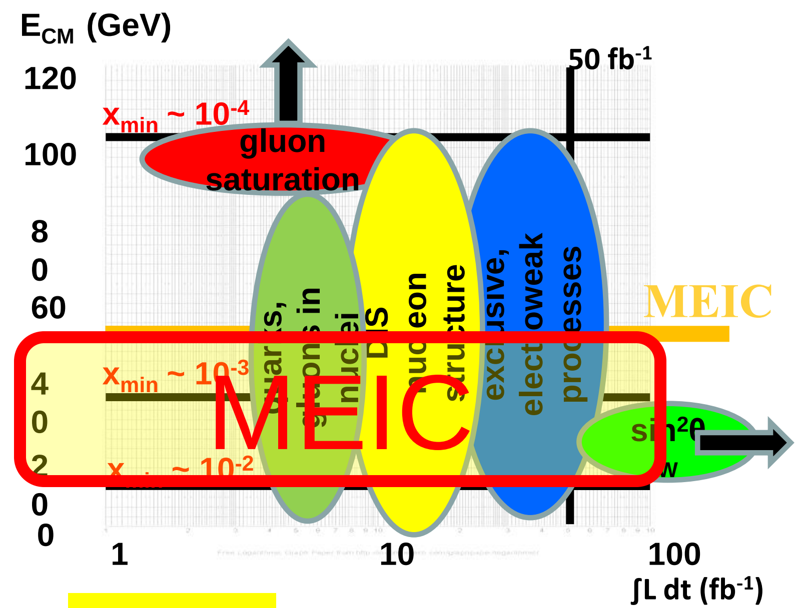
Key issues in nucleon structure & nuclear physics

- Sea quark and gluon imaging of nucleon with GPDs (x >~ 0.01)
- Orbital angular momentum, transverse spin, and TMDs
- QCD vacuum in hadron structure and fragmentation
- Nuclei in QCD: Binding from EMC effect, quark/gluon radii from coherent processes, transparency

Machine/detector requirements

- High luminosity > 10^{34}: Low rates, differential measurements
- CM energy s~1000 GeV^2: Reach in Q^2, x
- Detectability: Angular coverage, particle ID, energy resolution

➔ **favors lower & more symmetric energies**



R. Ent

MEIC Enabling Technologies

- Pushing the limits of present accelerator theory
  - Issues associated with short ion bunches (e.g.. cooling)
  - Issues associated with small β* at collision points
    - Focus on chromatic compensation
  - Beam-beam effects
- Development of new advanced concepts
  - Dispersive crabbing
  - Beam-based fast kicker for circulator electron cooler

Achieving High Luminosity

MEIC design luminosity

$L \sim 6\times10^{33}$ cm^{-2} s^{-1} for medium energy (60 GeV x 3 GeV)

Luminosity Concepts

- High bunch collision frequency (0.5 GHz, can be up to 1.5 GHz)
- Very small bunch charge ($<3\times10^{10}$ particles per bunch)
- Very small beam spot size at collision points ($\beta^*_y \sim 5$ mm)
- Short ion bunches ($\sigma_z \sim 5$ mm)

Keys to implementing these concepts

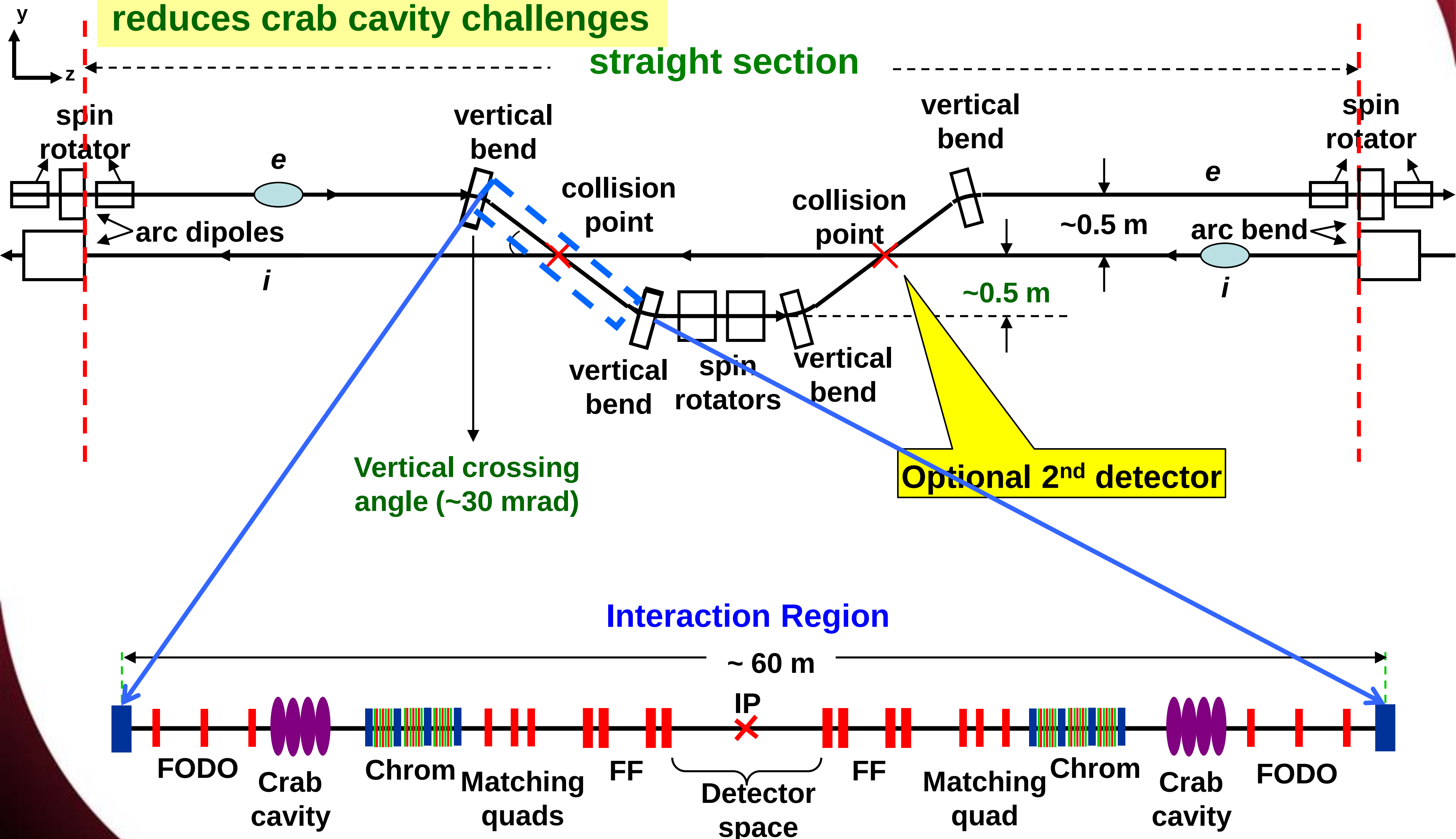
- Making very short ion bunches with small emittance
- SRF ion linac and (staged) electron cooling
- Need crab crossing for colliding beams

Additional ideas/concepts

- Relative long bunch (comparing to beta*) for very low ion energy
- Large synchrotron tunes to suppress synchrotron-betatron resonances
- Equal (fractional) phase advance between IPs

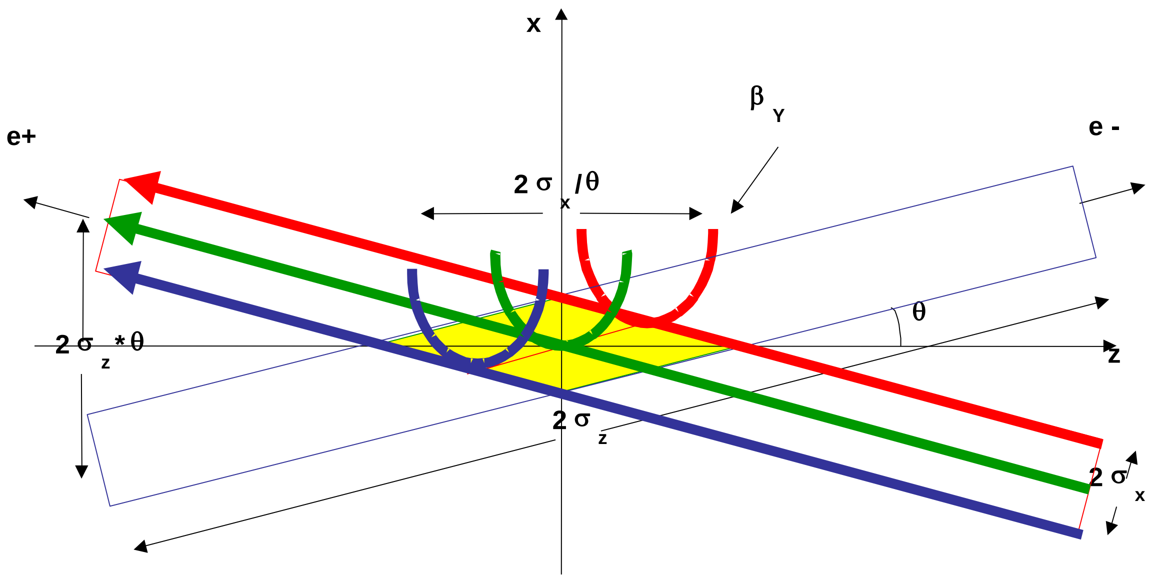
Straight Section Layout

Minimizing crossing angle reduces crab cavity challenges



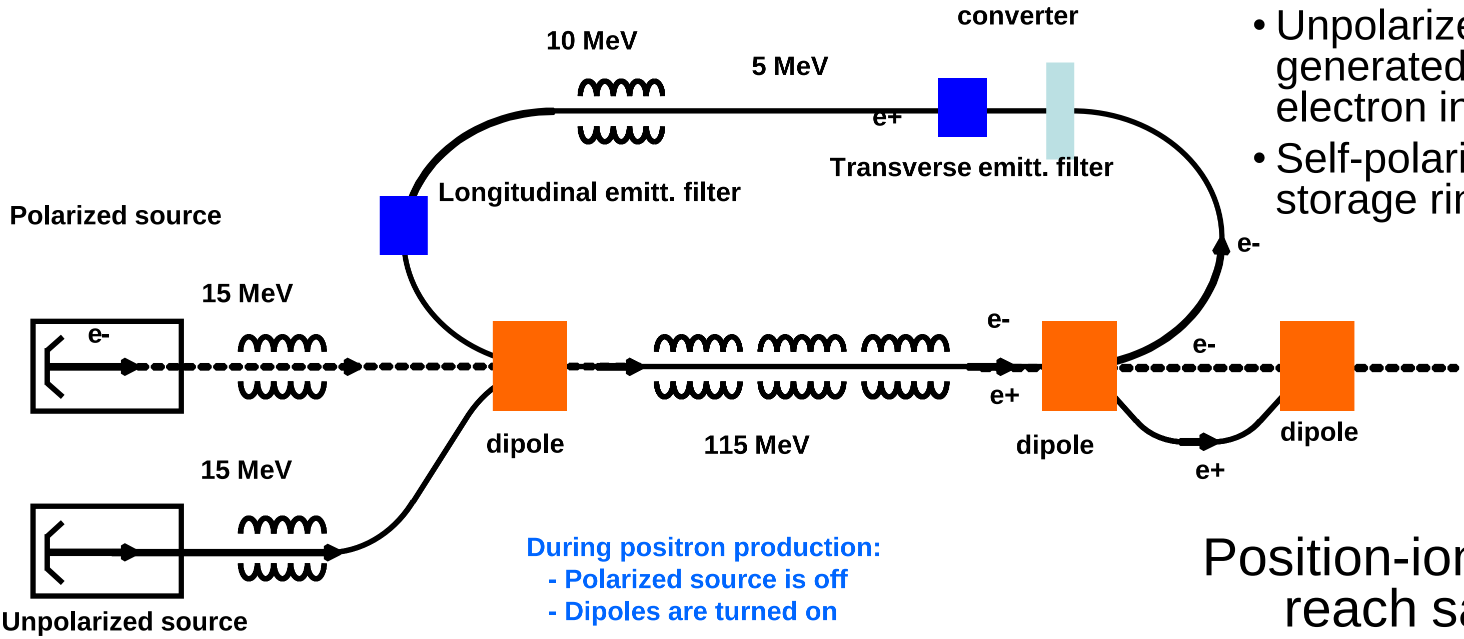
Technology Under Consideration: Crab Waist

- Proposed for Super-B factory for luminosity enhancement (Raimondi)
- Deals with large Piwinski angle and low vertical beta-star
- Super-B design calls for 0.2 mm β* while bunch length is 6 mm
- Recent proof-of-principle experiment at DAΦNE very positive



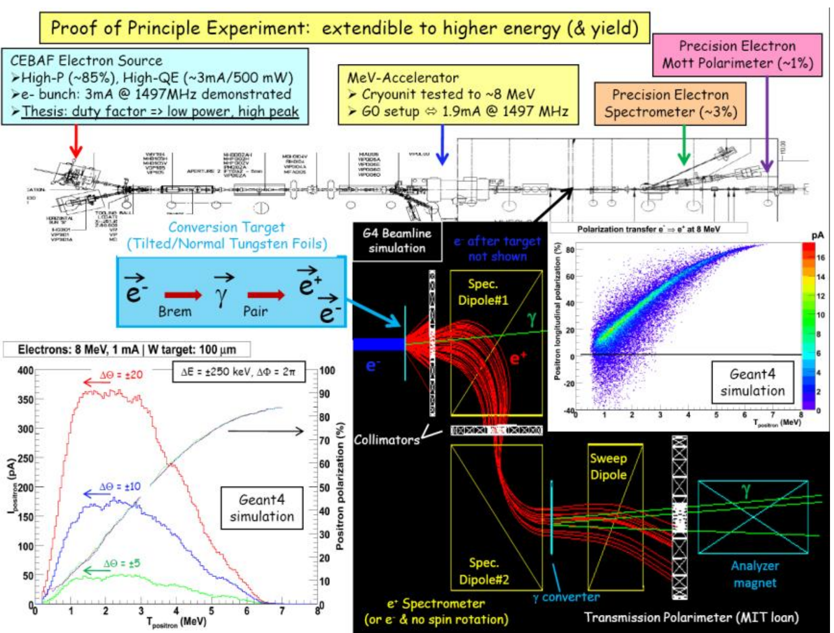
Crabbed waist can be realized with a sextupole in with IP in x and at π/2 in y

Positrons in CEBAF/MEIC



- Unpolarized positrons generated from the modified electron injector by a converter
- Self-polarization in the lepton storage ring

Position-ion collisions should reach same luminosity as electron-ion collisions



Positron source development at JLab

- **"CEPBAF", S. Golge (Ph. D thesis)**
- **Polarized e+ Source, J. Dumas (PhD thesis)**
- **Joint JLab/Idaho Univ. Positron Program**

(M. Poelker)

International Workshop on Positrons at Jefferson Lab

March 25-27, 2009

Technology Under Consideration: Traveling Final Focusing

- Space charge effect dominates in a very low energy ion beam
- Laslett tune-shift limits total charge that can be loaded into a bunch
- Long ion bunch can hold more charge with same charge density, therefore increasing luminosity
- Hour glass effect can kill luminosity if the bunch length is much large than β*
- "Traveling final focusing" has been proposed to mitigate hour glass effect (Brinkmann/Dohlus), originally using RF cavity
- New realization scheme: crab crossing with sextupoles