Critical Accelerator R&D for Jefferson Lab Electron Ion Collider (JLEIC Collaboration)

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DOE-NP Accelerator R&D PI Meeting

DOE Headquarters, Germantown, MD

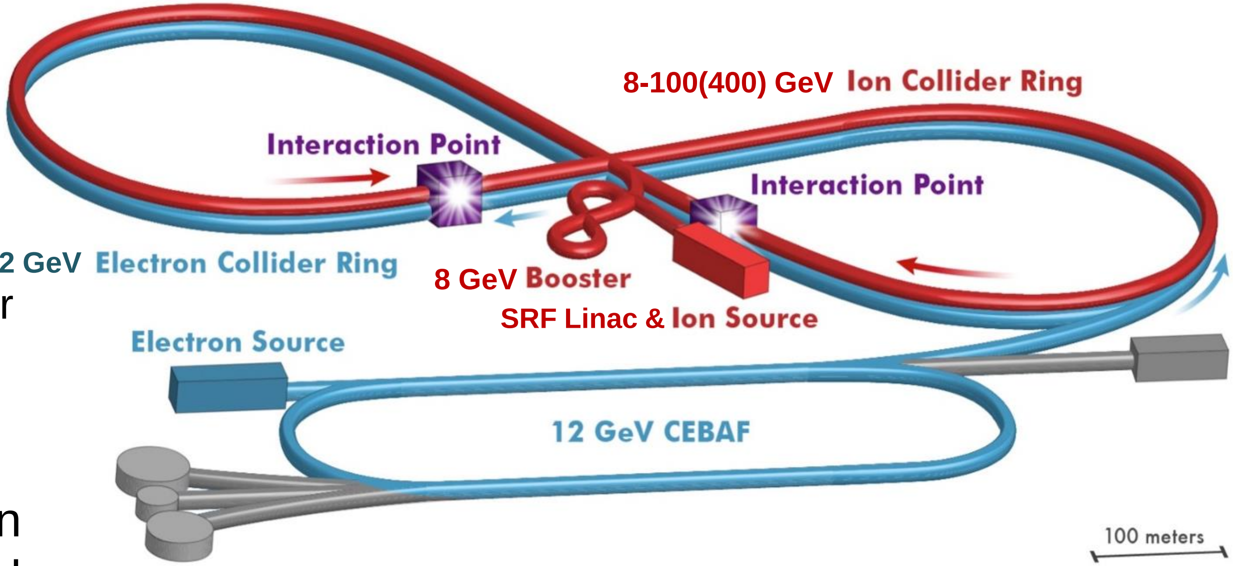
10/20/2017

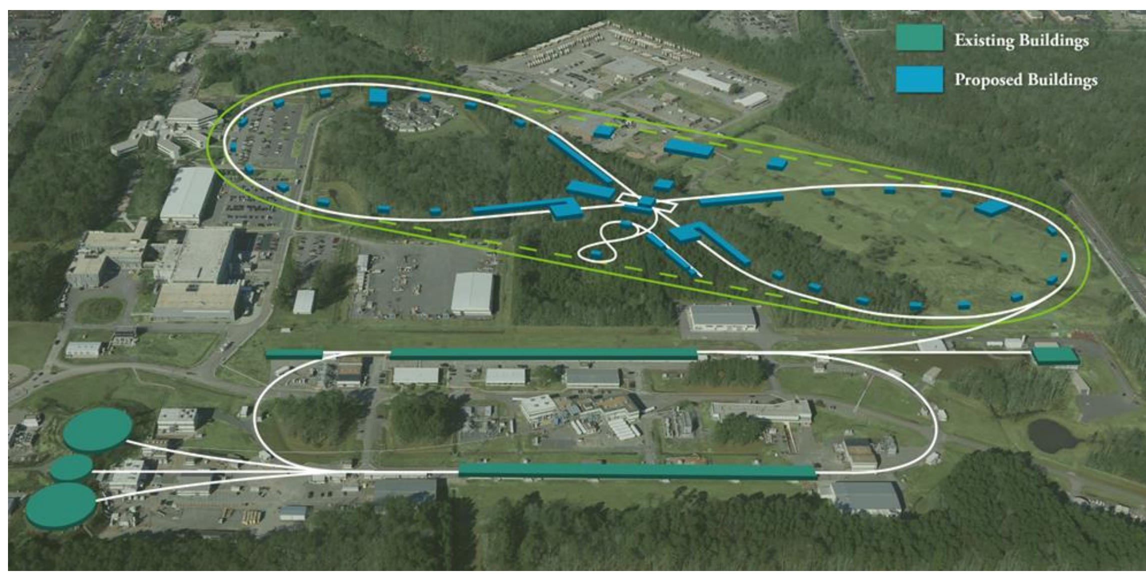
Outline

- Overview of JLEIC design
- DoE-NP support R&D and budget
- Project descriptions and plans

JLEIC Layout

- Electron complex
  - CEBAF
  - Electron collider ring
- Ion complex
  - Ion source
  - SRF linac (285 MeV/u for protons)
  - Booster
  - Ion collider ring
- Optimum detector location for minimizing background






MEIC Design Summary

January 20, 2015

Author List

Author Institutions

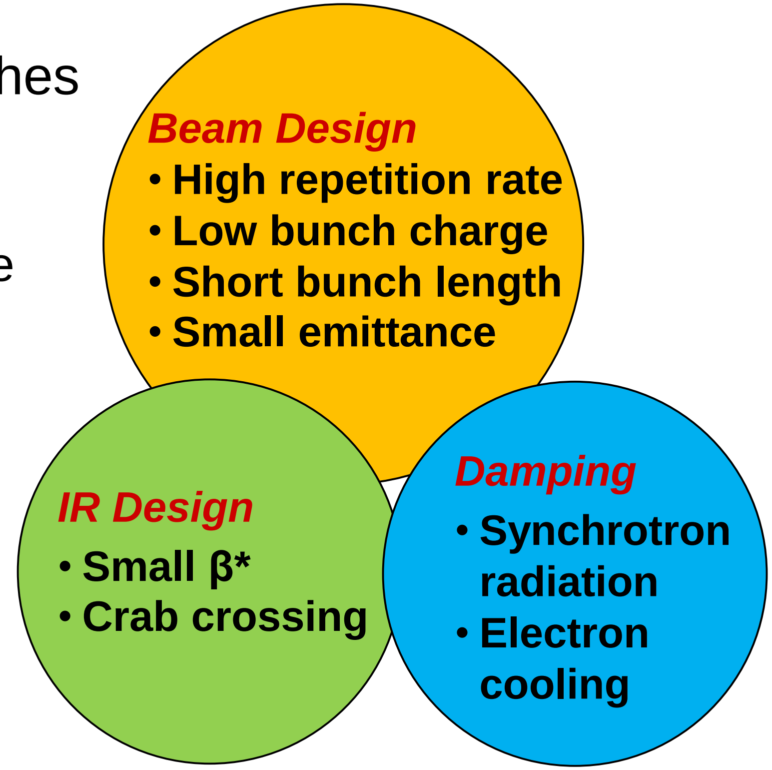
arXiv:1504.07961

May 17 update:
https://eic.jlab.org/wiki/index.php/Main_Page

Key Design Concepts

- **High luminosity**: **high collision rate** of short modest-charge low-emittance bunches
  - **Small beam size**
    - Small β* ⇒ Short bunch length ⇒ Low bunch charge, high repetition rate
    - Small emittance ⇒ Cooling
  - Similar to lepton colliders such as KEK-B with L > 2×10^{34} $cm^{-2}s^{-1}$

$$L = f\frac{n_1 n_2}{4\pi\sigma_x^*\sigma_y^*} \sim f\frac{n_1 n_2}{\varepsilon\beta_y^*}$$

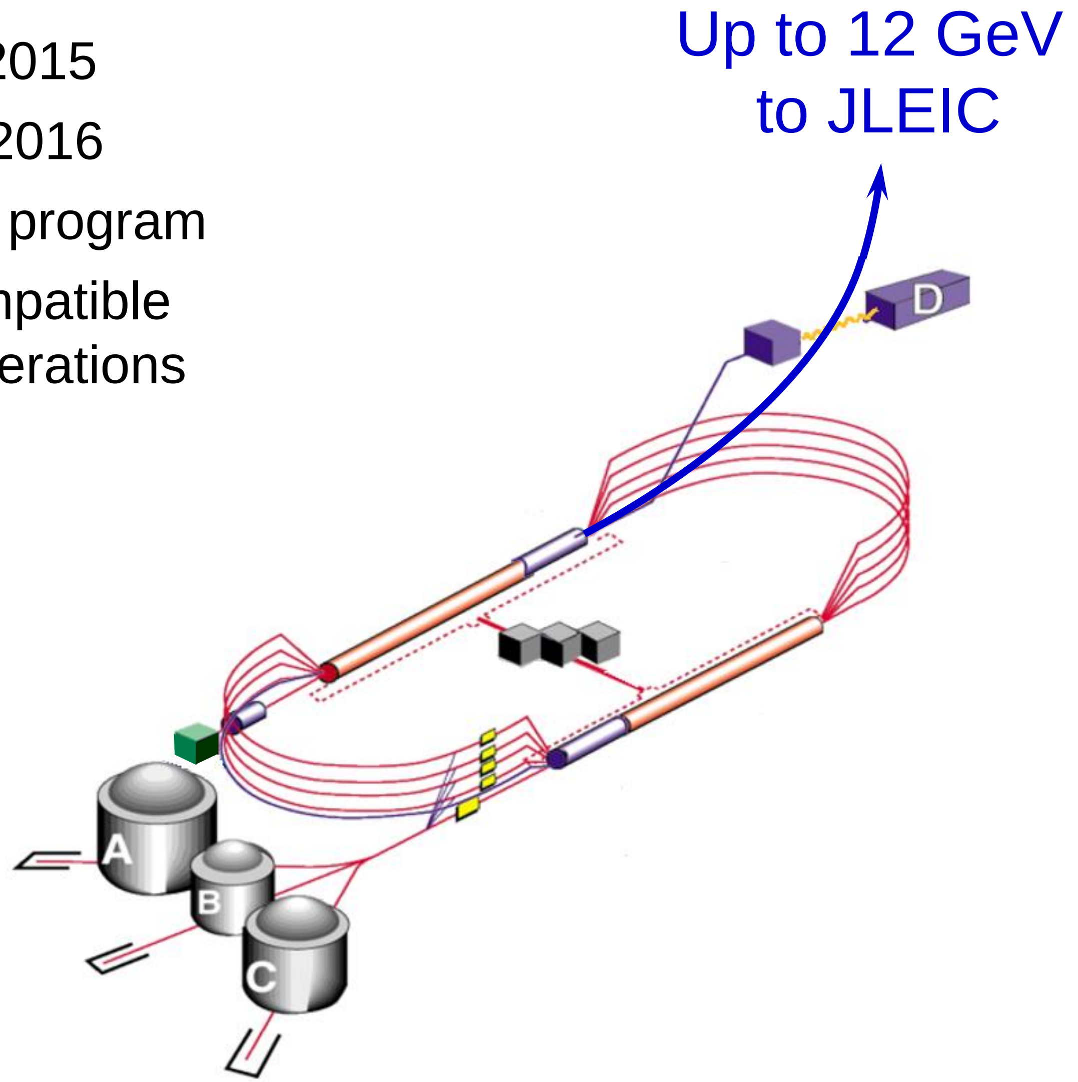


- **High polarization**: **figure-8** ring design
  - Net spin precession zero
  - Spin easily controlled by small magnetic fields for any particle species

- **Full acceptance primary detector** including **far-forward acceptance**

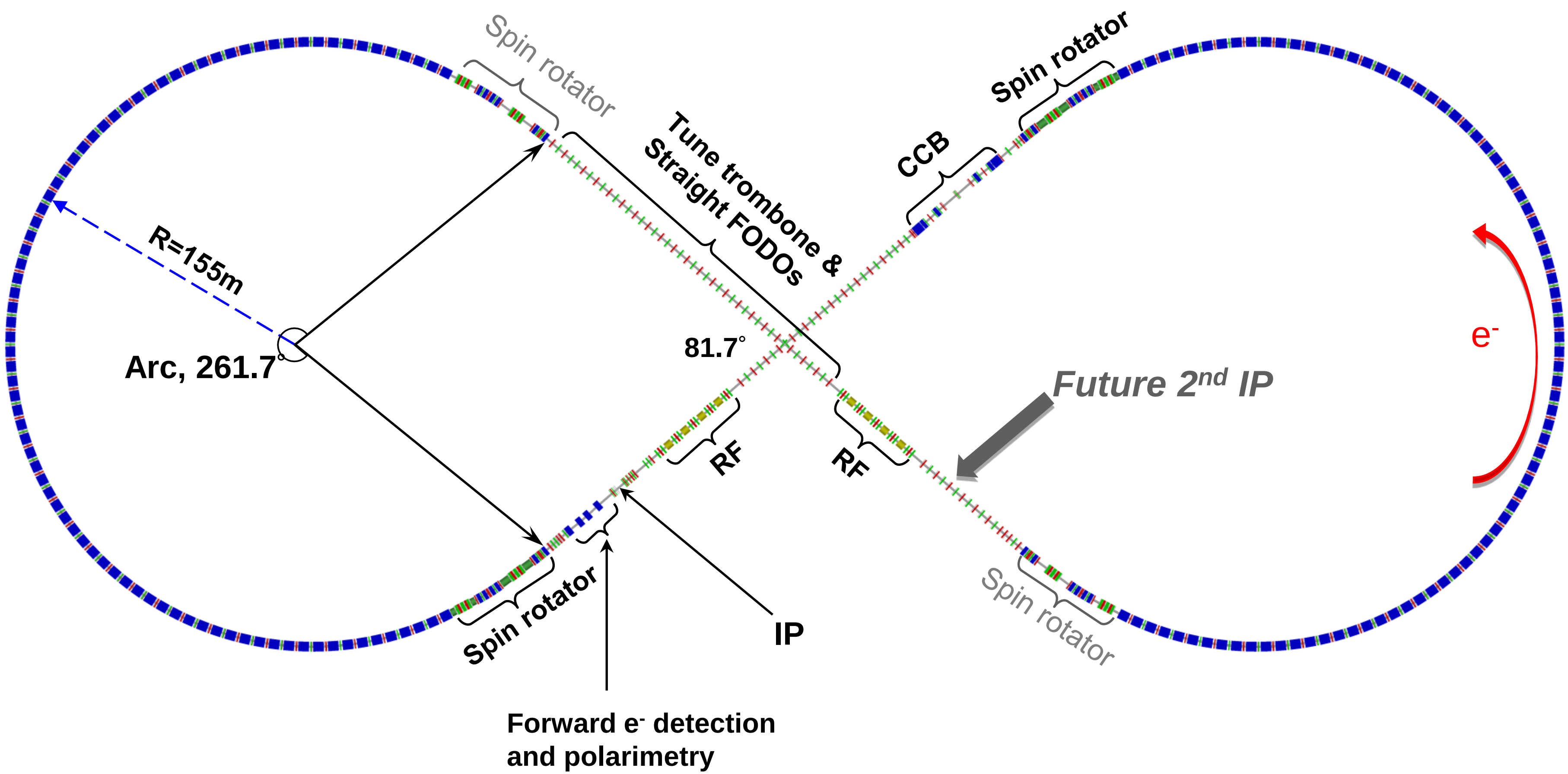
12 GeV CEBAF as Injector

- Commissioned in Spring 2014
- Operated at 12 GeV in Fall 2015
- First Physics Run in Spring 2016
- Exciting fixed-target science program
  - Fixed-target program compatible with concurrent JLEIC operations
- JLEIC injector
  - Fast fill of collider ring
  - Full energy
  - ~85% polarization
  - Enables top-off



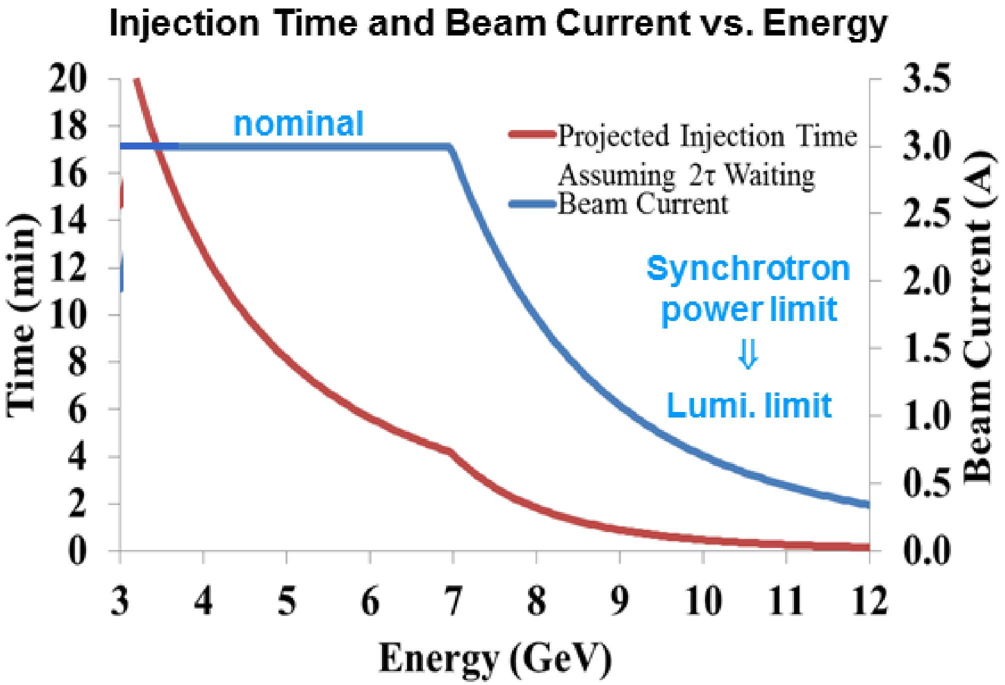
Electron Collider Ring Layout

- Possible cost reduction by reusing PEP-II RF and vacuum pipe

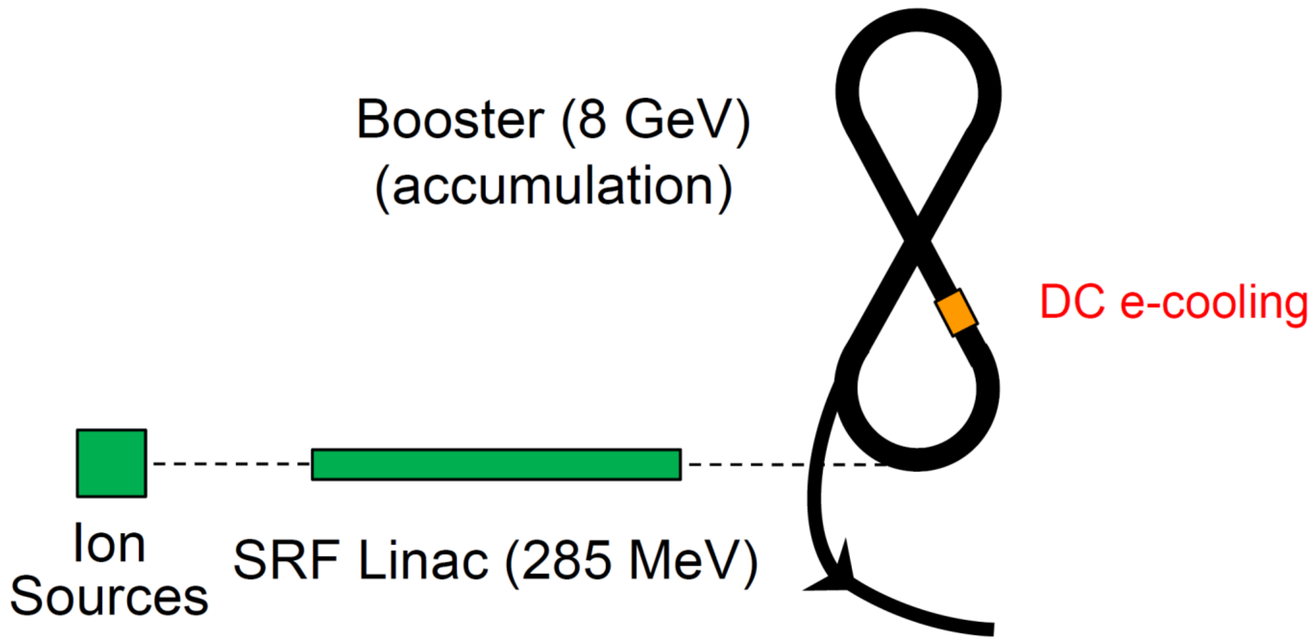


Electron Beam

- Electron injection from CEBAF
  - Existing CEBAF electron gun
  - **Two polarization state** injection
  - f_{ring} / f_{CEBAF} = 476.3 MHz / 1497 MHz = 7 / 22
- Electron beam
  - **3 A** at up to 7 GeV
  - Normalized emittance **54 µm** @ 5 GeV
  - Synchrotron power density < **10kW/m**
  - Total power up to **10 MW**



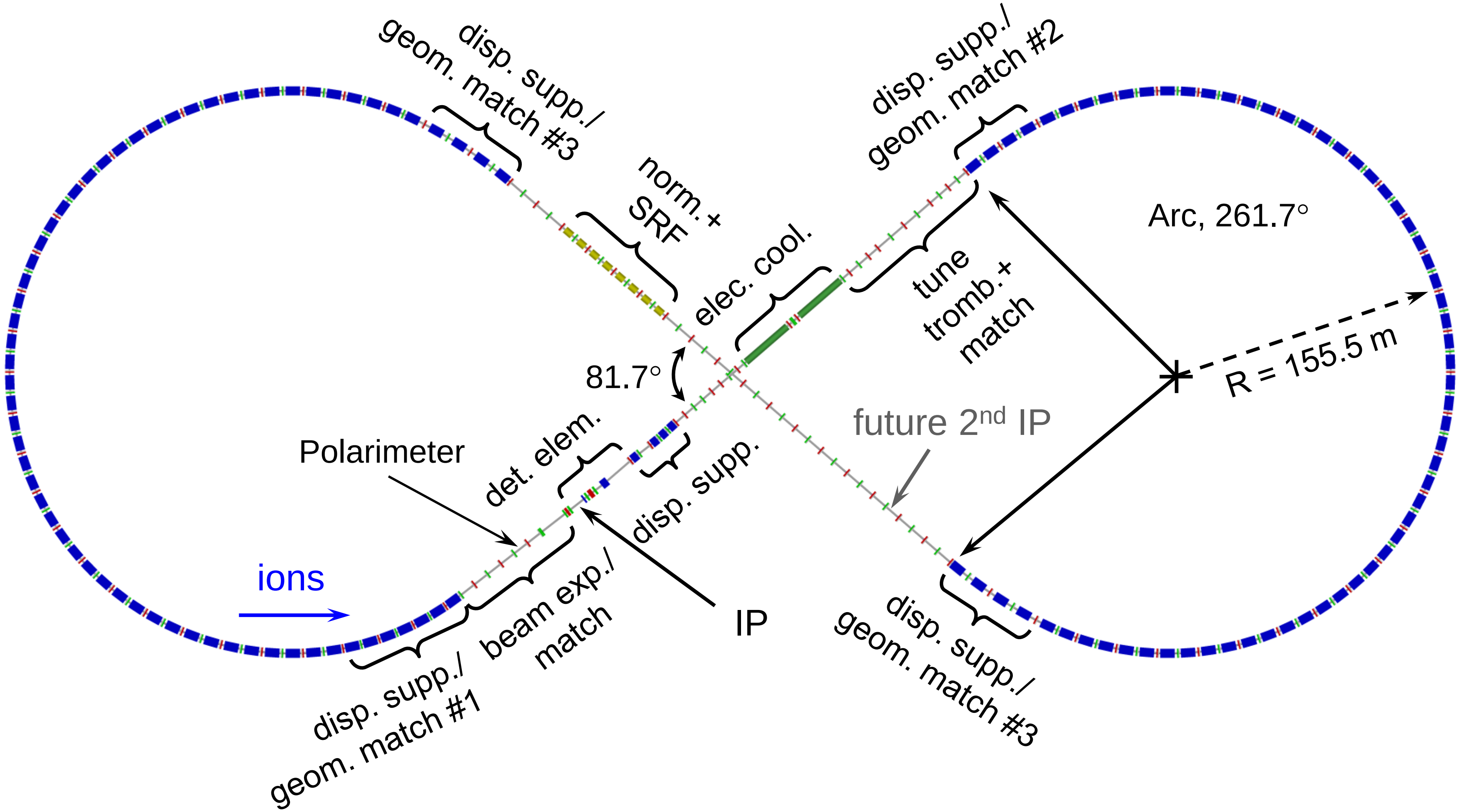
Ion Injector Complex Overview



- Ion injector complex relies on demonstrated technologies for sources and injectors
  - Atomic Beam Polarized Ion Source (ABPIS) for polarized or unpolarized light ions, Electron Beam Ion Source (EBIS) and/or Electron Cyclotron Resonance (ECR) ion source for unpolarized heavy ions
  - Design for an SRF linac based on ANL design
  - 8 GeV Booster with imaginary transition energy
  - Injection/extraction lines to/from Booster are designed

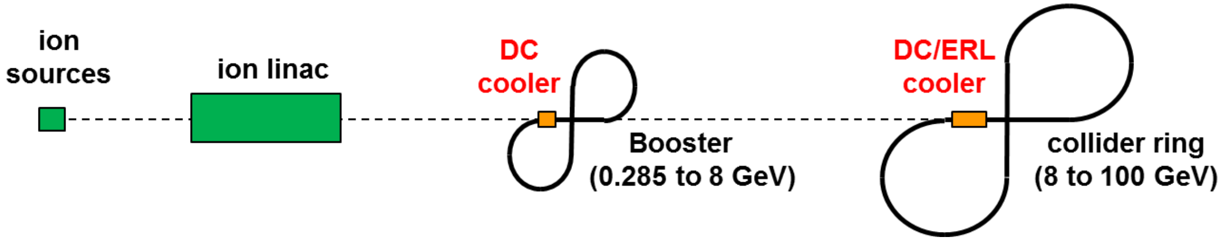
Ion Collider Ring Layout

- Protons: 100 GeV/u (63 GeV/u in COM with 10 GeV e)
  Lead: 40 GeV/u (40 GeV/u in COM with 10 GeV e)
- Super-ferric magnets (cosθ under consideration as risk mitigation)



Multi-Step Cooling Scheme

- Cooling of JLEIC proton/ion beams for
  - Achieving very small emittance (~10x reduction)
  - Reaching very short bunch length ~1 cm (with SRF)
  - Suppressing IBS induced emittance degradation



Pre-cool when energy is low

$$\tau_{cool} \sim \gamma^2 \frac{\Delta\gamma}{\gamma} \sigma_z \varepsilon_{4d}$$

Cool when emittance is small (after pre-cool at low energy)

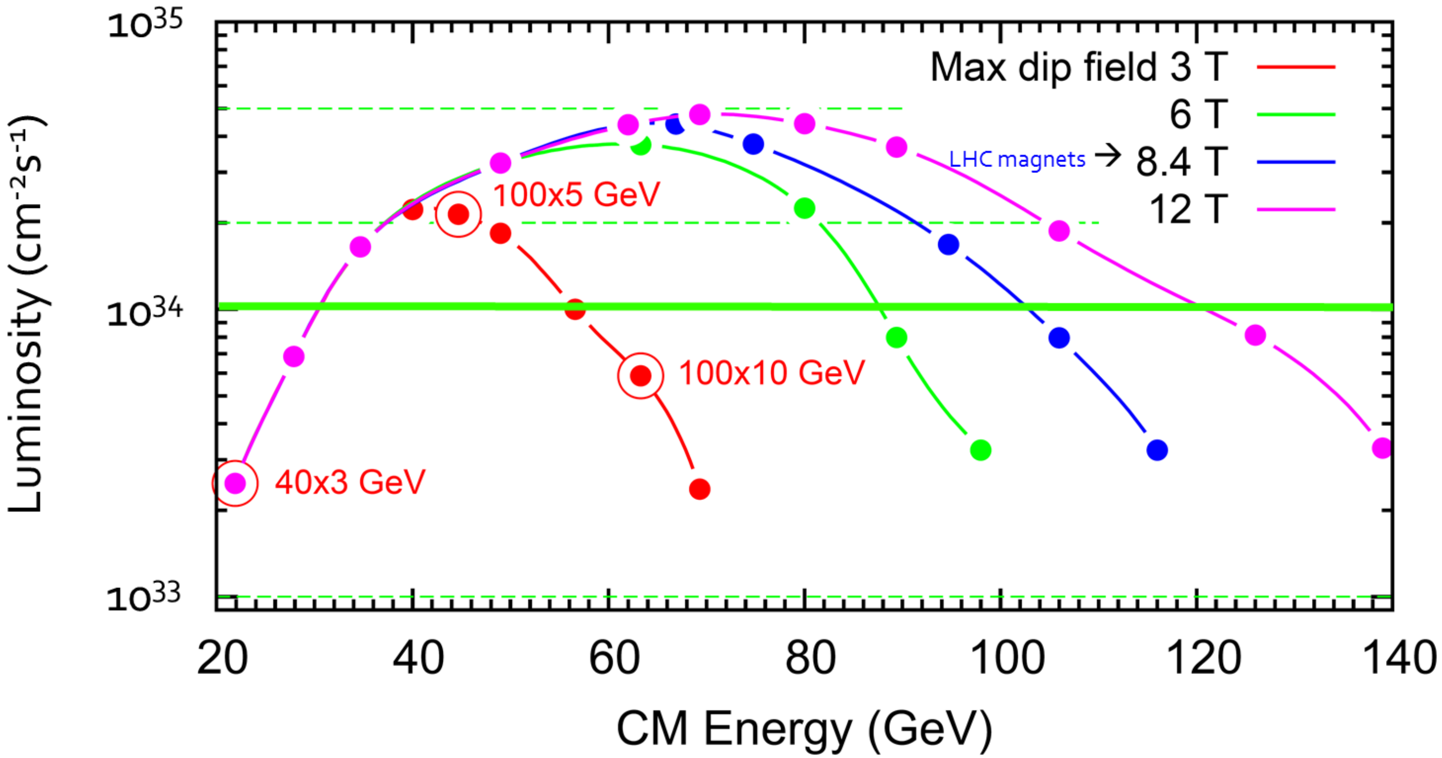
Ring	Functions	Kinetic energy (GeV / MeV)			Cooler type
		Proton	Lead ion	Electron	
booster ring	Accumulation of positive ions		0.1 (injection)	0.054	DC
collider ring	Maintain emitt. during stacking	7.9 (injection)	2 (injection)	4.3 (proton) 1.1 (lead)	DC
	Pre-cooling for emitt. reduction	7.9 (injection)	7.9 (ramp to)	4.3	DC
	Maintain emitt. during collision	Up to 100	Up to 40	Up to 54.5	ERL

Can't reduce emittance due to space charge limit

Pre-cooling both protons and lead ions

ERL cooler can't reach energy below 20 MeV

JLEIC Energy Reach and Luminosity



CM Energy (in each scenario)	Main luminosity limitation
low	space charge
medium	beam-beam
high	synchrotron radiation

JLEIC Parameters (3T option)

CM energy	GeV	21.9 (low)		44.7 (medium)		63.3 (high)	
		p	e	p	e	p	e
Beam energy	GeV	40	3	100	5	100	10
Collision frequency	MHz	476		476		476/4=119	
Particles per bunch	10^{10}	0.98	3.7	**0.98**	3.7	3.9	3.7
Beam current	A	0.75	2.8	0.75	2.8	0.75	0.71
Polarization	%	**80%**	**80%**	**80%**	**80%**	**80%**	**75%**
Bunch length, RMS	cm	3	1	**1**	1	2.2	1
Norm. emittance, hor / ver	μm	0.3/0.3	24/24	**0.5/0.1**	54/10.8	0.9/0.18	432/86.4
Horizontal & vertical β*	cm	8/8	13.5/13.5	**6/1.2**	5.1/1.0	10.5/2.1	4/0.8
Ver. beam-beam parameter		0.015	0.092	0.015	0.068	0.008	0.034
Laslett tune-shift		0.06	7×10^{-4}	0.055	6×10^{-4}	0.056	7×10^{-5}
Detector space, up/down	m	3.6/7	3.2/3	3.6/7	3.2/3	3.6/7	3.2/3
Hourglass(HG) reduction		1		0.87		0.75	
Luminosity/IP, w/HG, 10^{33}	$cm^{-2}s^{-1}$	**2.5**		**21.4**		**5.9**	

DoE-ONP Support for JLEIC R&D

- FY10-12: *Advanced Electron Ion Collider Design*
  Lead PI: Geoffrey Krafft

- FY12-13: *Developments Towards a High Luminosity Polarized Electron Ion Collider*
  Lead PI: Yuhong Zhang
  In collaboration with ANL, SLAC, and Northern Illinois University

- FY14-15: *Critical Accelerator R&D for Achieving High Performance of a Polarized Medium Energy Electron-Ion Collider*
  Lead PI: Yuhong Zhang
  In collaboration with ANL, SLAC, and Texas A&M University

- FY16-17: *Critical Accelerator R&D for Jefferson Lab Electron-Ion Collider*
  Lead PI: Fulvia Pilat

FY14-15: Critical Accelerator R&D for MEIC

Project 1: Interaction Region

Task 3.1: Optimization of Momentum Acceptance and Dynamic Aperture (Jones report: #53, Medium)

Project 2: Polarized Beams in Figure-8 Ring

Task 4.1: Electron Polarization Tracking (#37, High)

Task 4.2: Ion Beam Polarization (#37, High)

Project 3: Technology Development

Task 5.1: RF System R&D for MEIC (#47, High)

Task 5.2: Design Studies and Prototyping of Superferric Magnets (#17, High-B)

FY16: Critical Accelerator R&D for JLEIC

Jefferson Lab

Task 1: Studies of Cooling and Beam Transport in the ERL Cooler (#40, High-C)

Argonne National Lab

Task 1: Design and Cost Optimization of the Linac (#68, Low)

SLAC

Task 1: Interaction Region Design Optimization (#44, High)

Task 2: Lattice Design and Single-Particle Dynamics (#53, Medium)

Texas A&M University

Task 1: Superferric Dipole 1.2 m Prototype (#17, High-B)

FY17: Critical Accelerator R&D for JLEIC

Project 1: Electron Cooling R&D

Task 1.a: Electron Cooling Simulation Development (#3, 4 High-A)

Project 2: Magnet R&D

Task 2.a: IR FFQ Prototype Definition (#5, High-A)

Task 2.b: Complete and Test a Full Scale Suitable Superferric Magnet (partially subcontracted to Texas A&M Univ.) (#17, High-B)

Project 3: SRF Technology R&D

Task 3.a: Fast Feedback System and Kicker Design for e-Ring Coupled-Bunch Instability Control with 2 ns Spacing (#19, High-B)

Task 3.b: Test of CEBAF Electron Injection Mode (#22, High-B)

Project 4: Interaction Region and Beam Dynamics R&D

Task 1.a: Crab crossing design and simulations (#1, High-A)

Summary of Expenditures by Fiscal Year

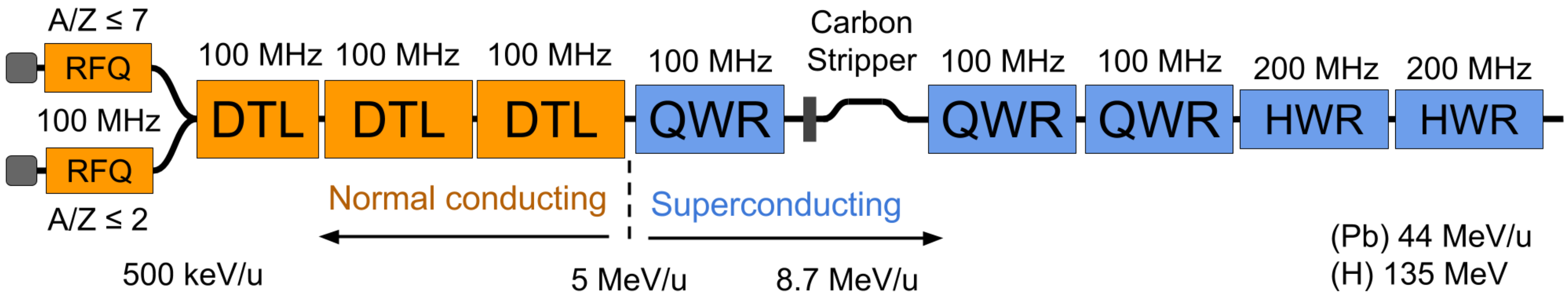
	FY10+FY11	FY12+FY13	FY14+FY15	FY16+FY17	Totals
a) Funds allocated	$0	$47,852	$692,000	$1,043,000	$1,782,852
b) Actual costs to date	$0	$47,727	$649,452	$450,453	$1,147,632

Description of Projects

- Ion linac (talk by B. Mustapha) [FY16 funding]
- Lattice design, detector integration, and nonlinear dynamics (talk by Y. Nosochkov) [FY16 funding]
- Superferric magnet development (talk by P. McIntyre) [FY16 funding]
- RF System R&D [FY15 funding, completed]
- Crab crossing design and simulations [FY17 funding, in progress]
- Electron and ion polarizations [FY14 funding, in progress]
- Electron cooler development [FY16 funding, completed]
- Electron cooling simulation [FY17 funding, in progress]

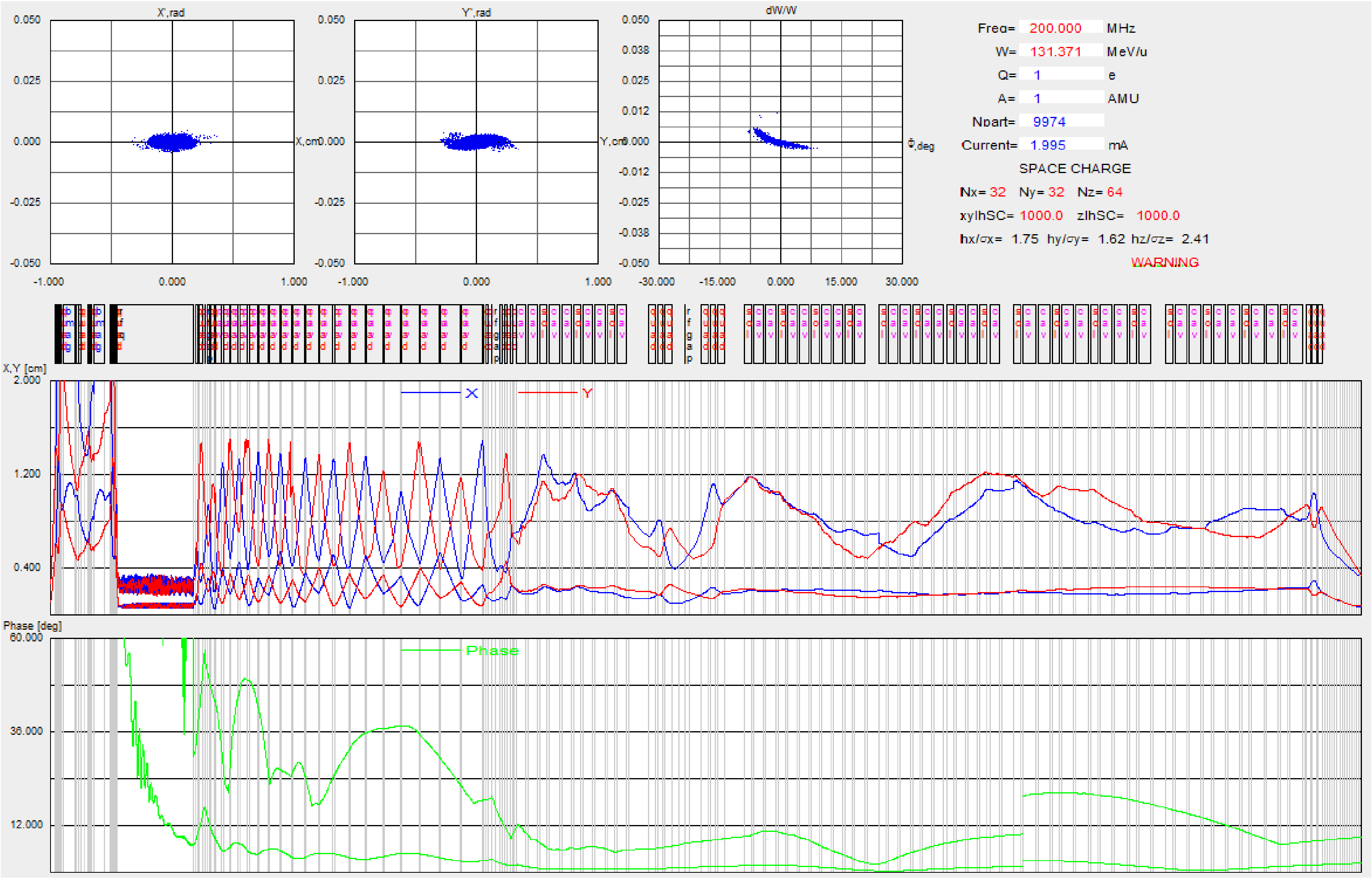
JLEIC Injector Linac Design

- Two RFQs: One for light ions (A/q ~ 2) and one for heavy ions (A/q ~ 7)
  - Different emittances and voltage requirements for polarized light ions and heavy ions
- RT Structure: IH-DTL with FODO Focusing Lattice
  - FODO focusing → Significantly better beam dynamics
- Separate LEBTs and MEBTs for light and heavy ions
- Stripper section for heavy-ions followed by an SRF section
- Pulsed Linac: up to 10 Hz repetition rate and ~ 0.5 ms pulse length



talk by B. Mustapha, FY16

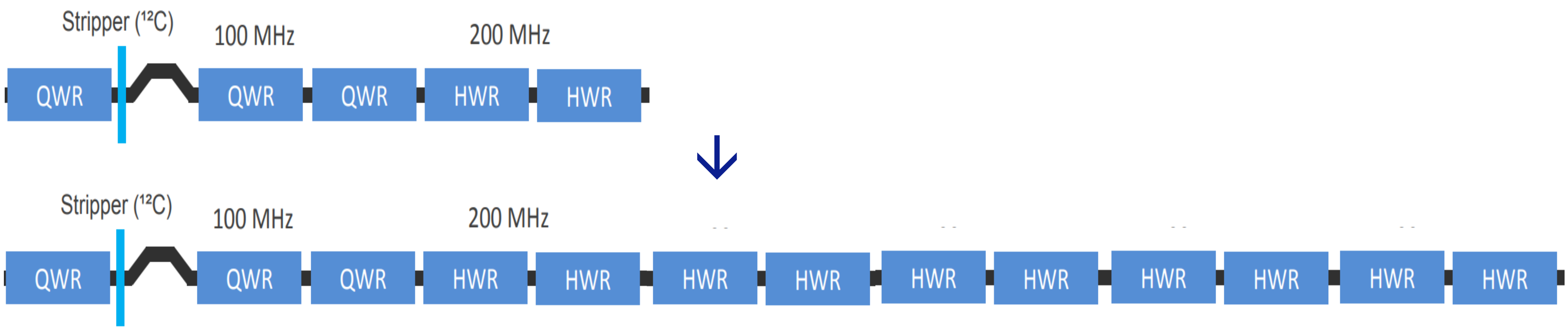
Start-to-End Simulation of 2 mA Proton Beam

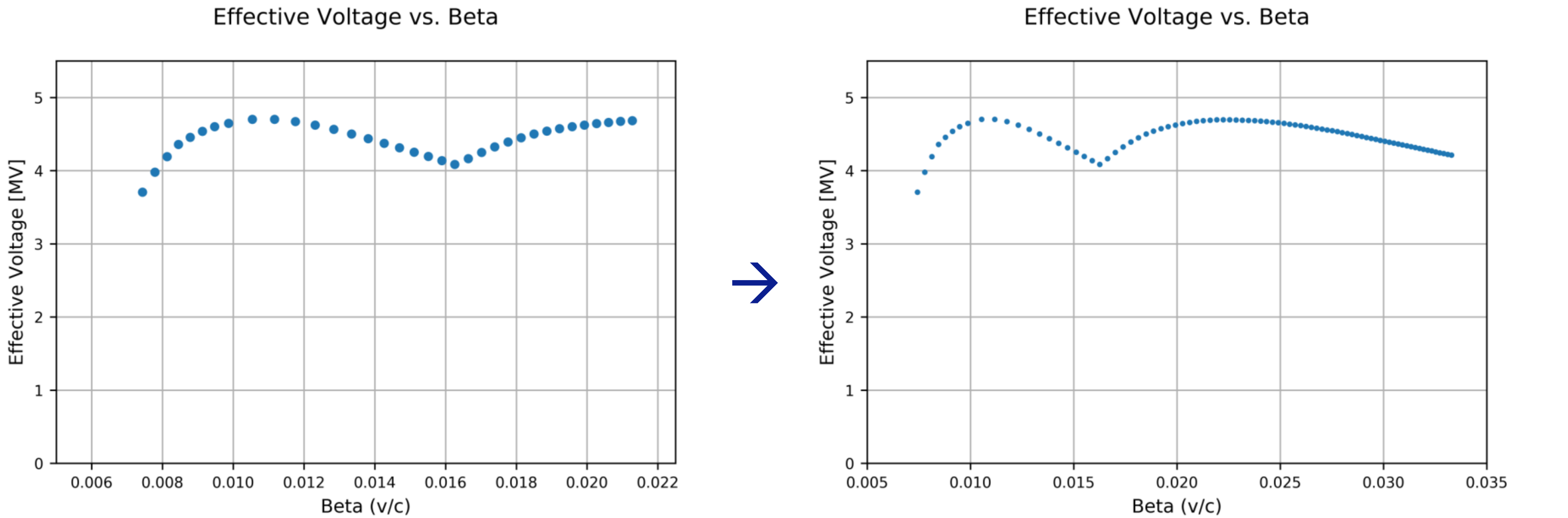


talk by B. Mustapha, FY16

Adding HWR Modules for: p - 280 MeV / Pb - 100 MeV/u

- Same type of HWR still efficient → No need for a new cavity type



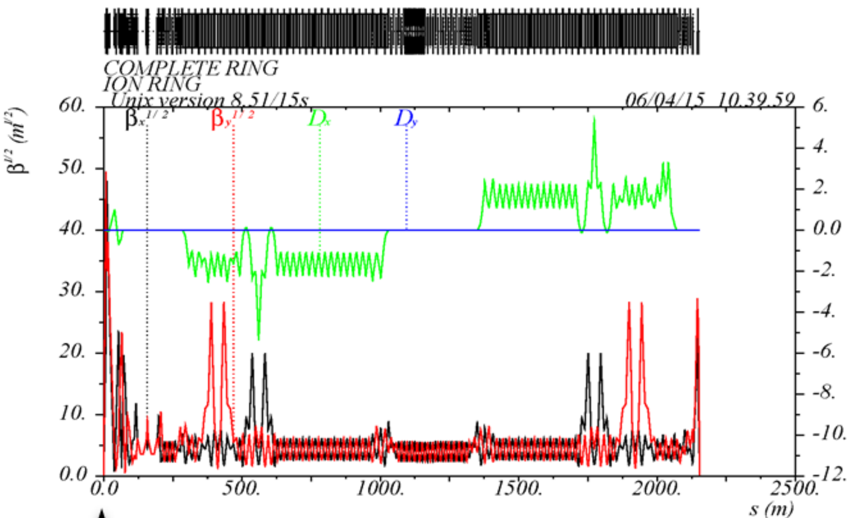


talk by B. Mustapha, FY16

Ion Beam Dynamics

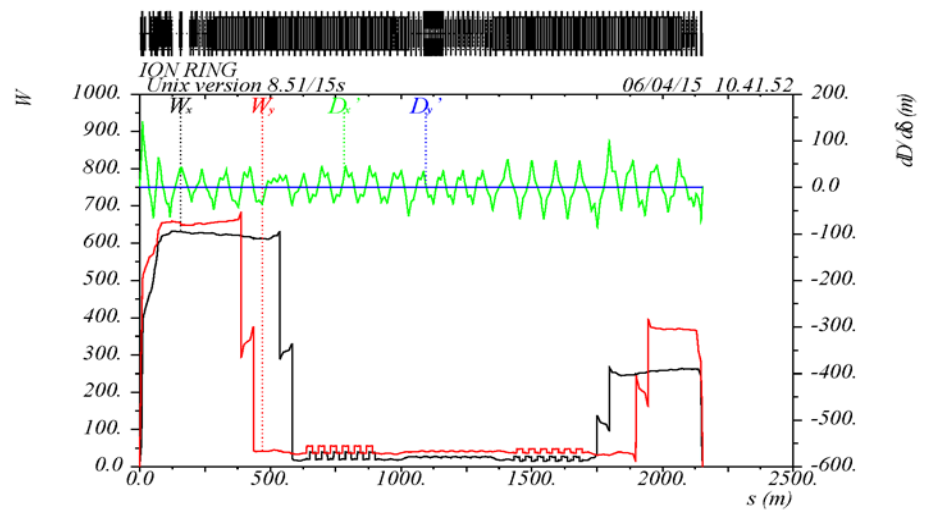
talk by Y. Nosochkov, FY16

- Linear optics

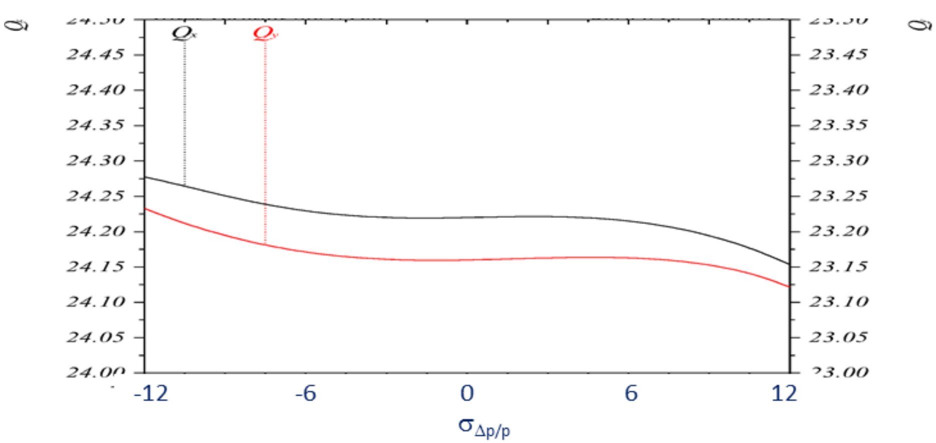


IP

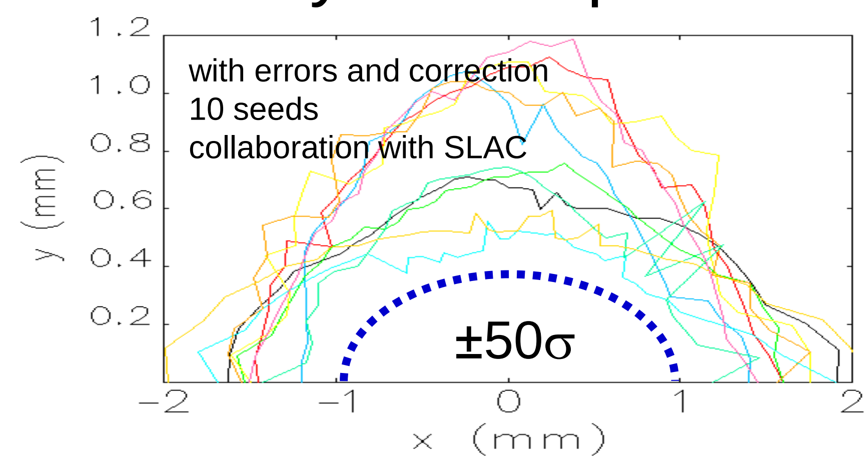
- Chromaticity compensation



- Momentum acceptance



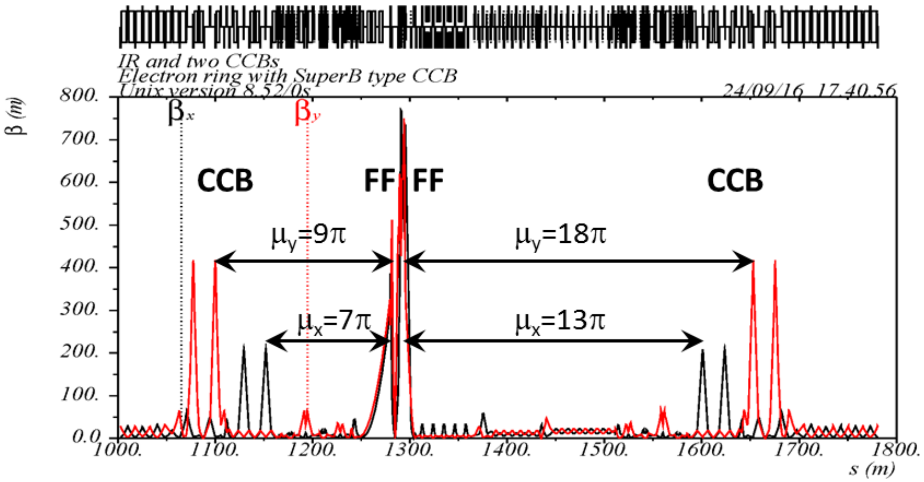
- Dynamic aperture



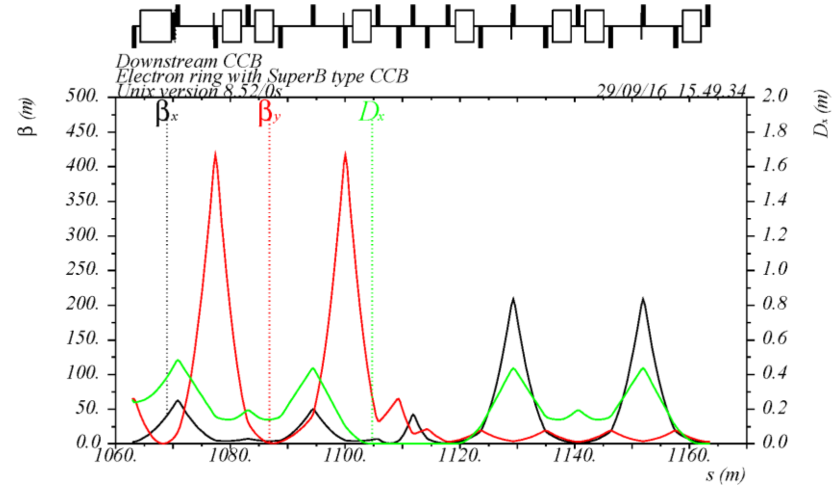
Electron Beam Dynamics

talk by Y. Nosochkov, FY16

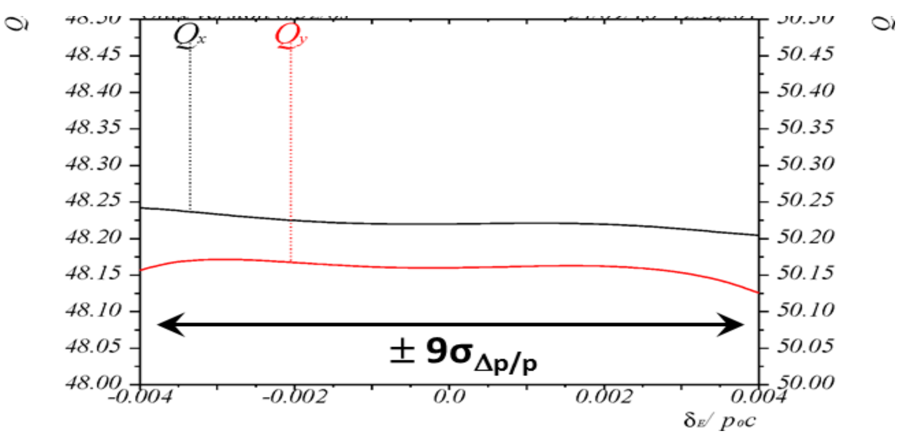
- Linear optics



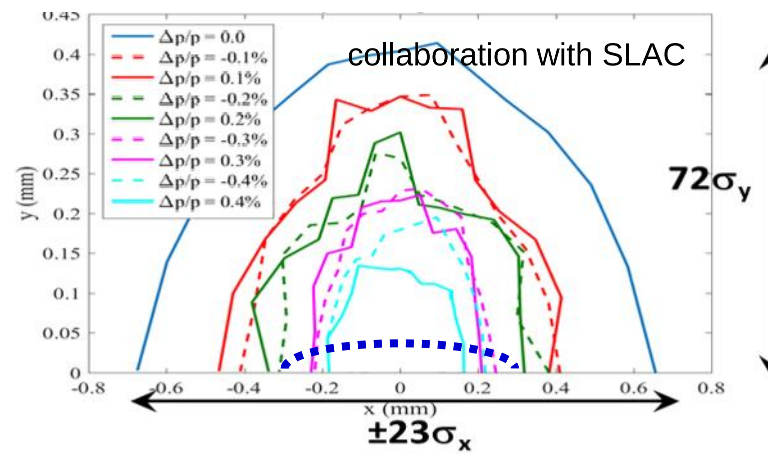
- Chromaticity compensation



- Momentum acceptance



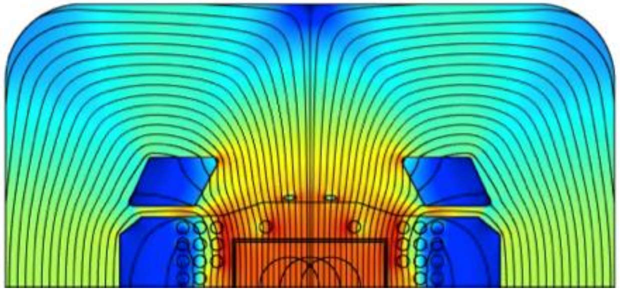
- Dynamic aperture

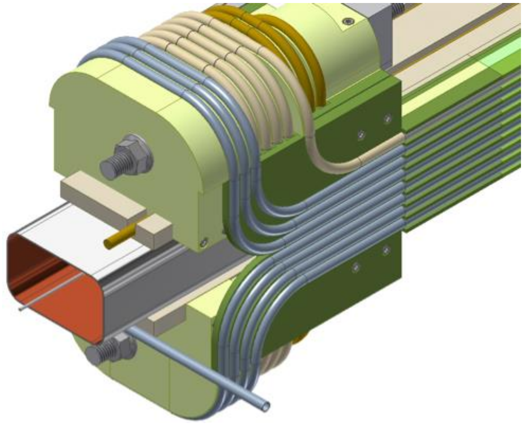


Super-Ferric Magnets

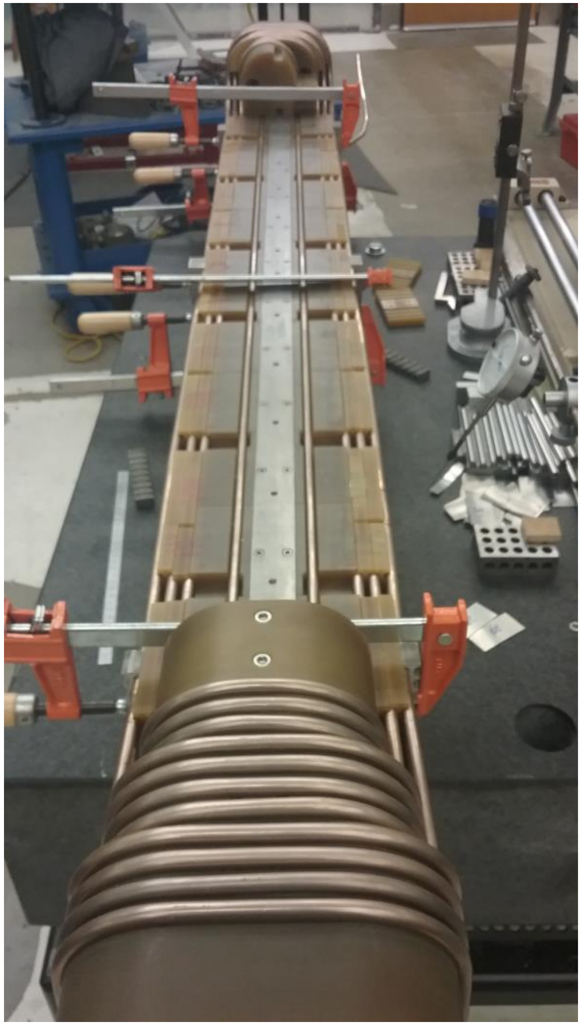
talk by P. McIntyre, FY16

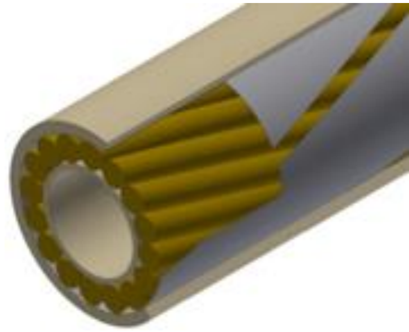
- 3 T
- Cost effective
- Fast ramp rate [1 T/s]
- Cable-in-conduit conductor

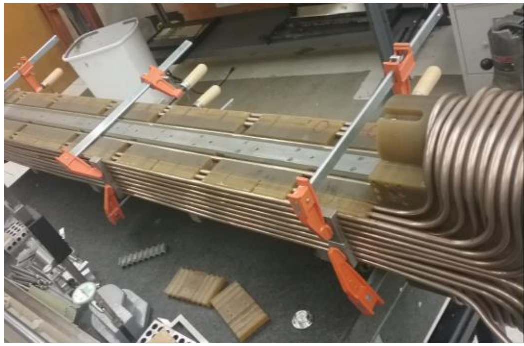


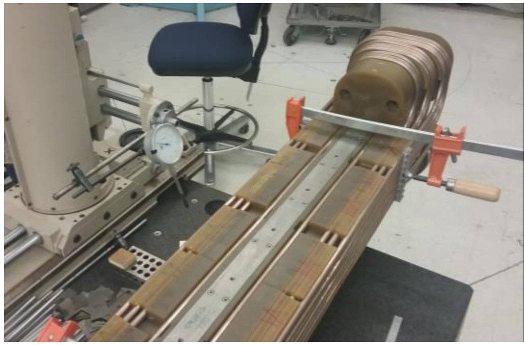


- Prototype winding







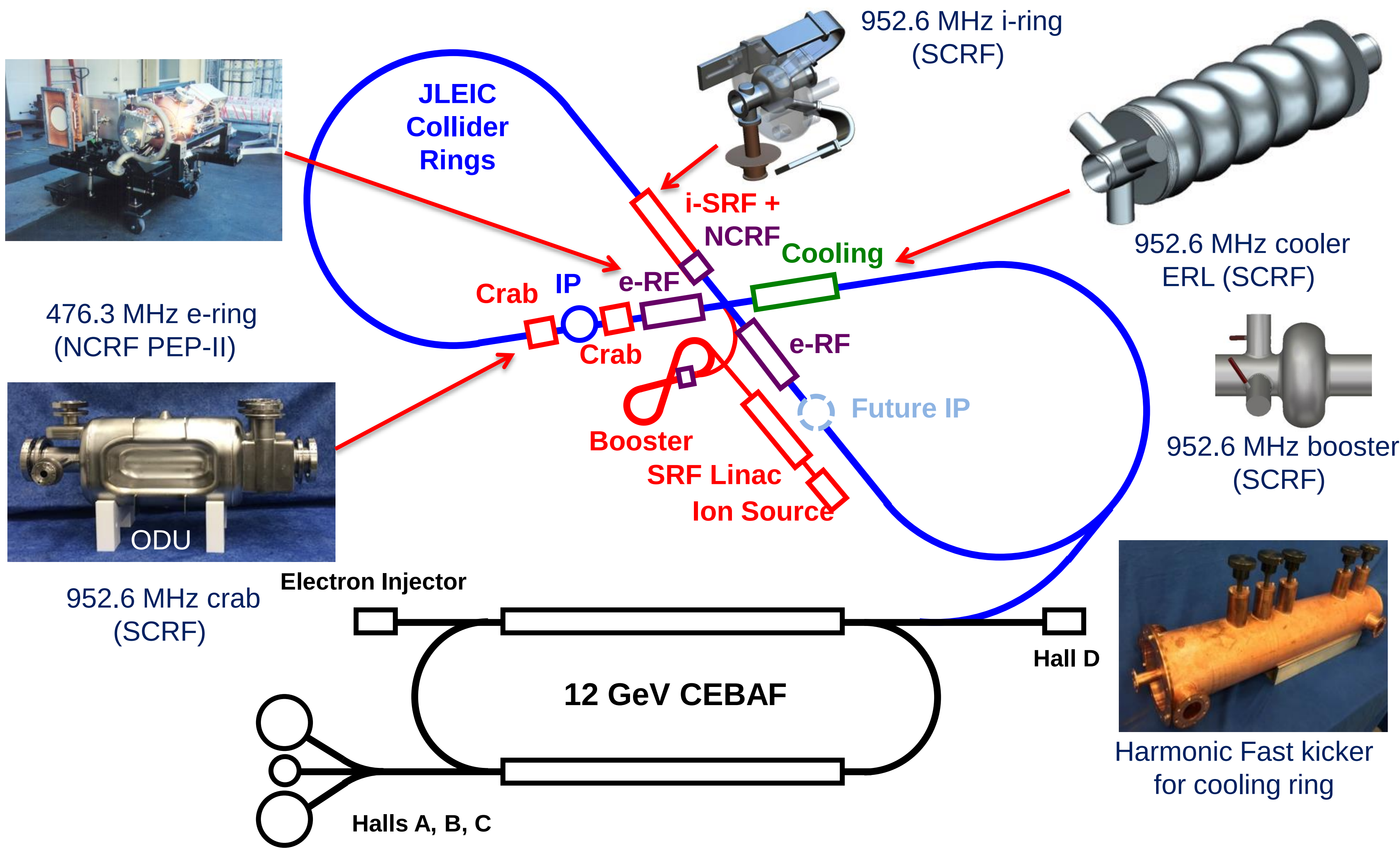


Mockup Winding Complete

talk by P. McIntyre, FY16

FY15

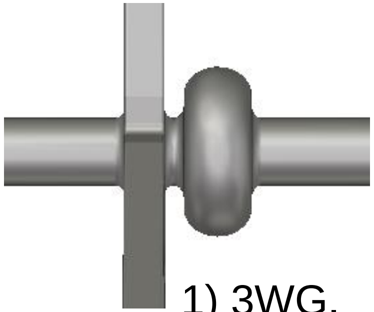
RF Cavities for JLEIC



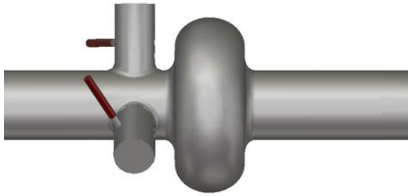
952.6 MHz SRF: HOM Damping

FY15

- New 952.6 MHz high-current cavity shape
- 1-cell prototype in progress
- HOM damping schemes under evaluation
  - Progress designing on-cell waveguide dampers
- RF system parameter tables being defined

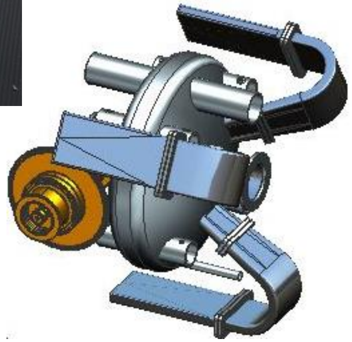


1) 3WG.



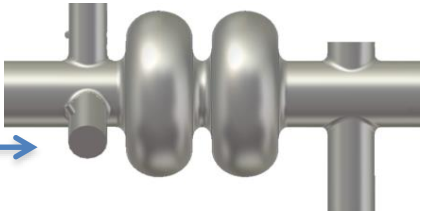
2) 3 x coax dampers.

3) enlarged beam pipes (ref)



4) on-cell dampers

Cooler needs **5-cells** in the ERL, 1-cells in the injector. Ion ring might use **2-cells**



First 952.6 MHz Cavity Fabrication Status

FY15

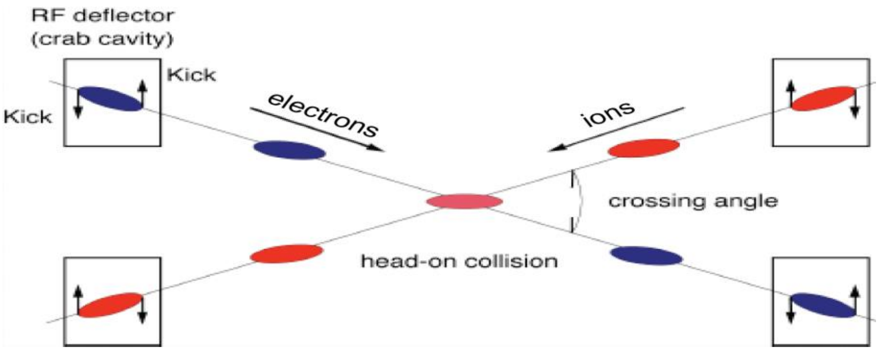
Cavity	Qty.	Material	Nb blanks for half cells	Nb blanks for beam tubes	Half cells deep-drawn	Beam Tubes	Flanges	Endgroups	Cavity
1-cell	1	Nb	2/2 – wire EDM completed	wire EDM completed	2/2 - completed	Completed/ machined	Completed/ machined (Nb flanges)	2/2 Welding completed	Waiting for RF trim fixture
1-cell	2	Cu	4/4 – wire EDM completed	wire EDM completed	4/4 - completed	Rolled/ not machined yet	SS CF flanges - to be ordered	Not yet Started	-
5-cell	1	Nb	10/10 – wire EDM completed	wire EDM completed	2/10 (new fixture in place to ease release of cells)	Completed/ machined	In stock – not yet used	Not yet started	-

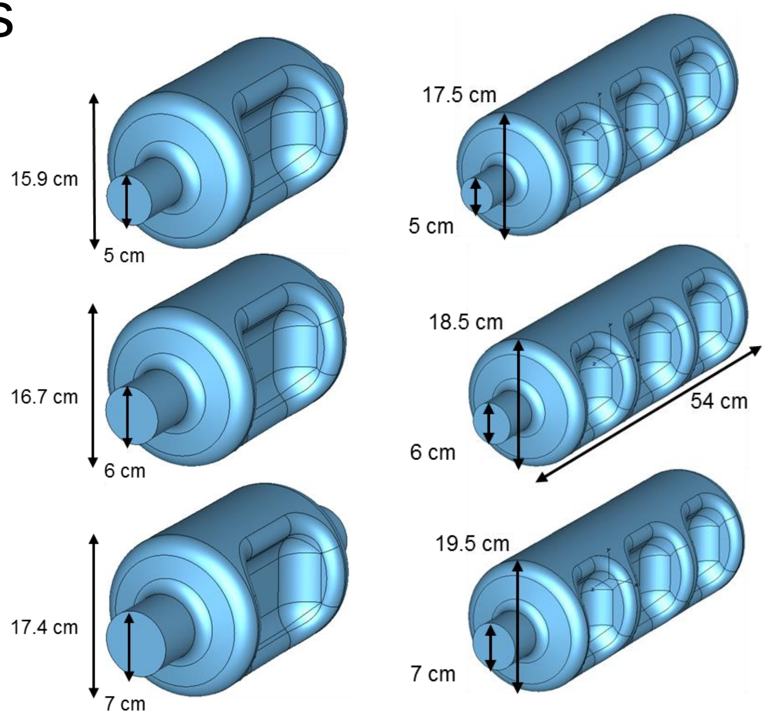
- Single-cell Nb cavity endgroups ready, getting close to complete cavity




Crab Crossing

- Restore effective head-on collisions
- Local compensation scheme
  - Set of crab cavities upstream and downstream of IP

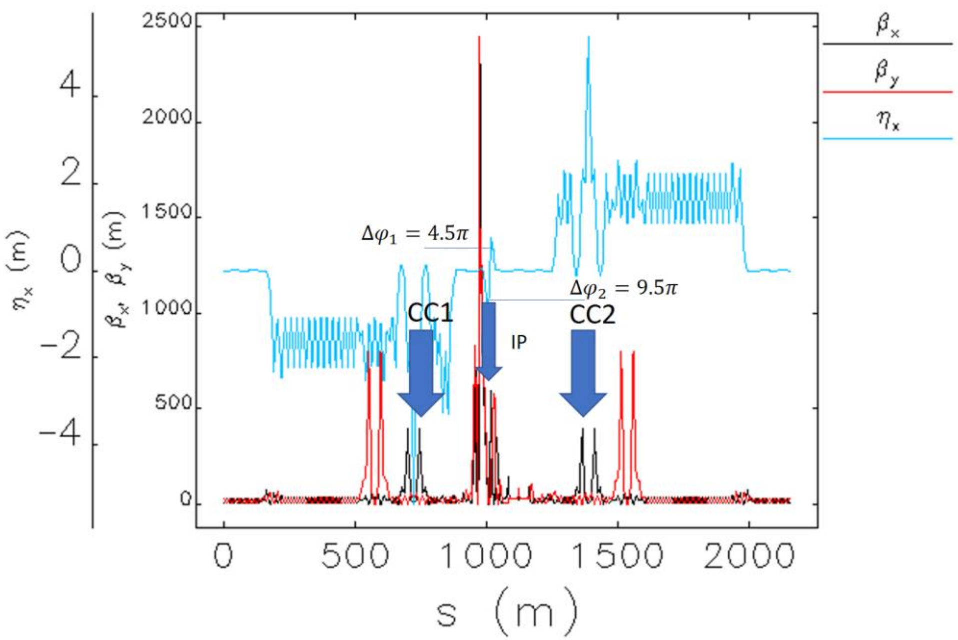




- Deflective crabbing
  - Demonstrated at KEK-B
  - Essential for high-luminosity LHC (collaboration opportunity)
- Prototype developed at ODU

Crab Crossing Scheme of JLEIC

- Without crabbing, geometric luminosity loss is about a factor of 12 and there is potential for dynamic instabilities.
- Locations of horizontal chromatic sextupoles are also adequate for crab cavities:
  - Right phase advance
  - High β_x values
- Found that sextupoles between crab cavities may lead to emittance increase, avoid them.
- Dispersion at the crab cavities satisfies the beam stability criterion.

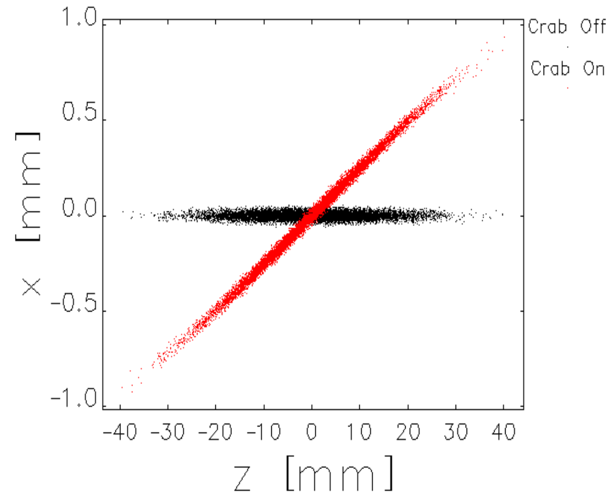


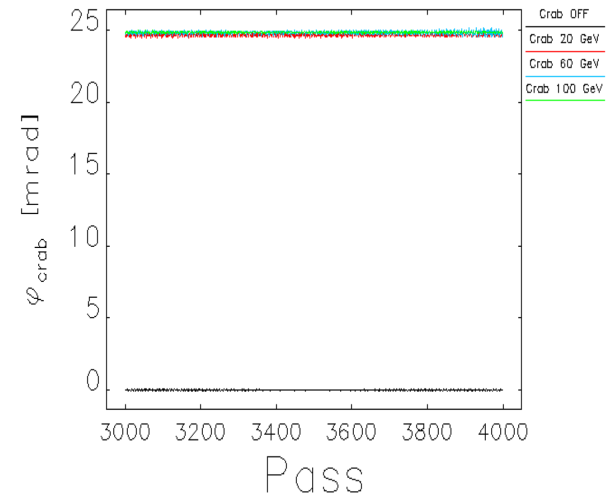
Parameter	Unit	Proton
Energy	GeV	100
Frequency	MHz	952.6
Crossing angle	mrad	50
β^*	cm	10
β_x @ crab cavity location	m	363
Crab voltage	MV	20.8

Crab Dynamics Simulations

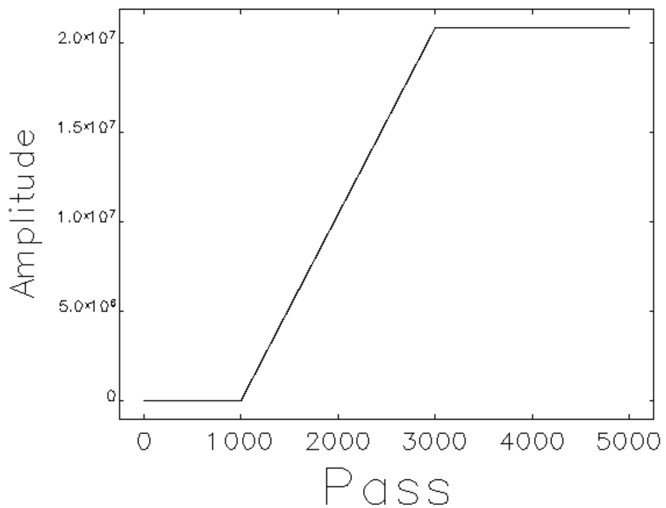
- Bunch with and without crabbing at IP

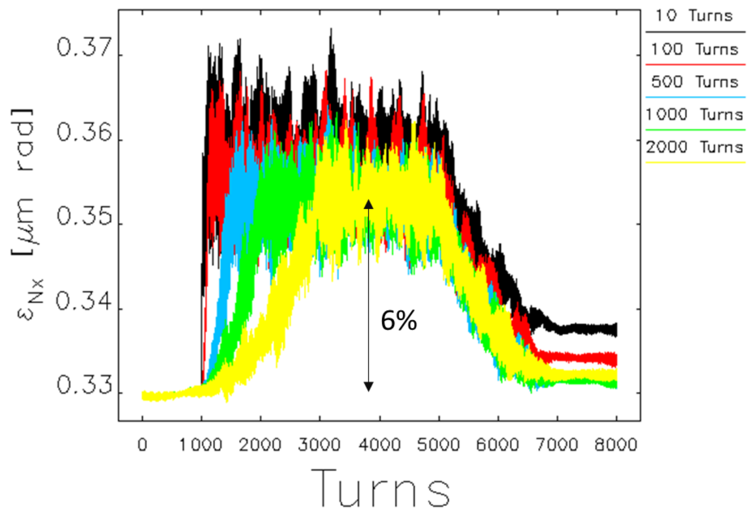
Beam parameters	
# of particles	500
ε_{nx}	0.35 μm
$\Delta p/p$	$3 \cdot 10^{-4}$
σ_s	1 cm
Gaussian distribution 3σ	





- Turn on effect: sufficiently slow turn on causes no emittance degradation





FY17

Crab Crossing Studies

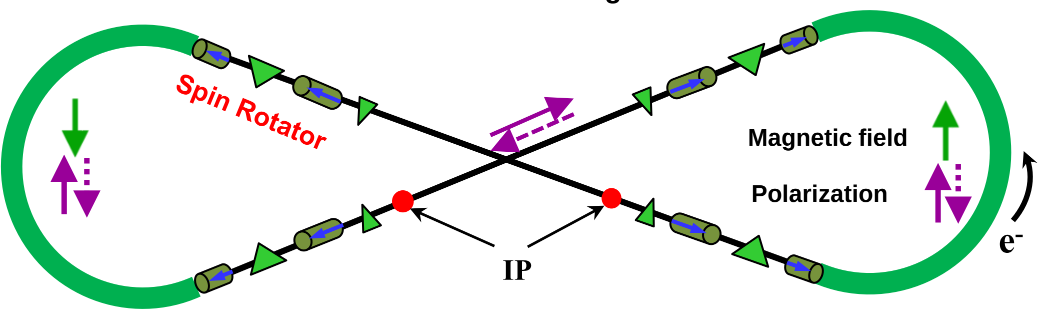
- Main goals from now through July, 2018
  - Implement a realistic model of a crab system in the ion collider ring
  - Implement weak-strong beam-beam interaction of the ion beam with the electron beam
  - Study the impact of non-linear effects on the crab dynamics
  - Study the impact of errors and parameter stability on the crab dynamics
  - Specify higher-order mode and impedance requirements for the ion crab cavities

Electron Polarization Strategies

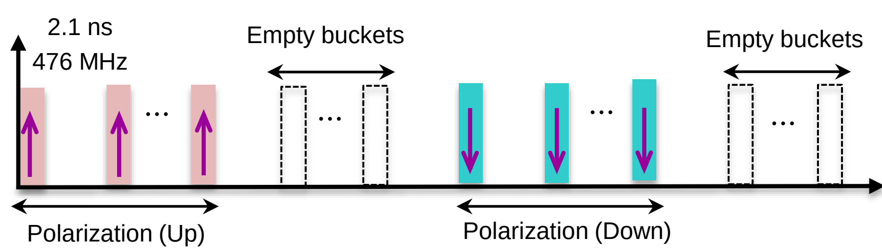
FY14

- Highly vertically polarized electron beams are injected from CEBAF
- Polarization is designed to be vertical in the JLEIC arc to avoid spin diffusion and longitudinal at collision points using spin rotators
- Universal spin rotator (fixed orbit) rotates electron polarization from 3 to 12 GeV
- Desired spin flipping is implemented by changing the source polarization
- Polarization configuration with figure-8 geometry removes electron spin tune energy dependence, significantly suppress the synchrotron sideband resonance
- Continuous injection of electron bunch trains from the CEBAF is considered to maintain a high equilibrium polarization
- Spin matching in some key regions is considered to improve polarization lifetime
- Compton polarimeter provides non-invasive measurements of electron polarization

Polarization configuration



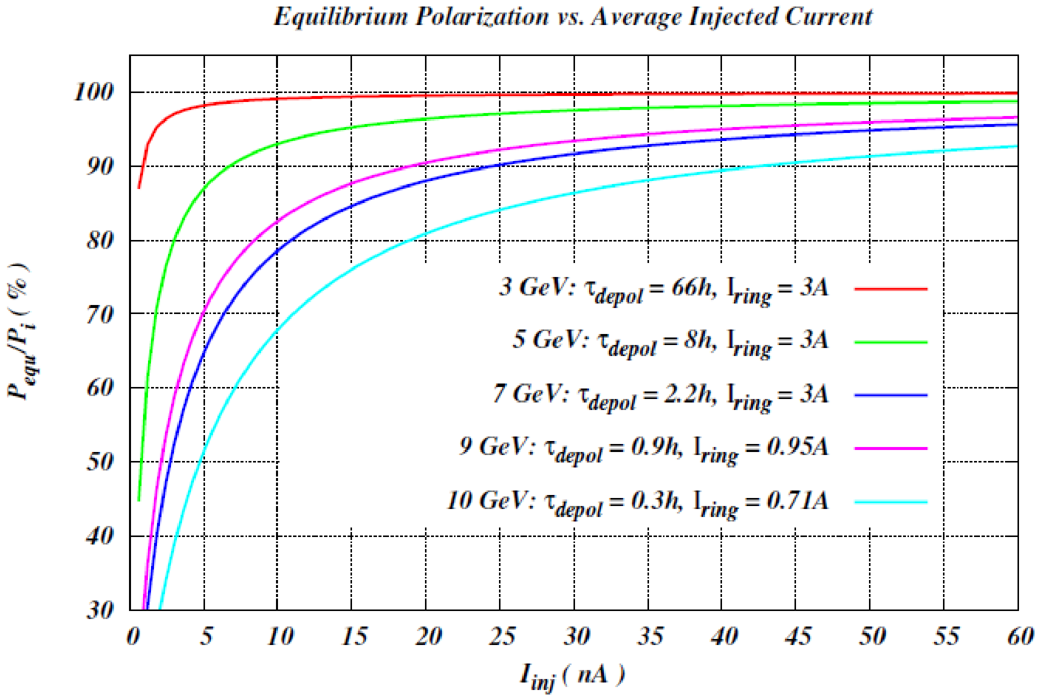
bunch train & polarization pattern (in arcs)



Polarization w/ Continuous Injection

FY14

- Polarization w/ continuous injection
- Equilibrium polarization $P_{equ} = P_0 \left(1 + \frac{T_{rev} I_{ring}}{\tau_{DK} I_{inj}}\right)^{-1}$

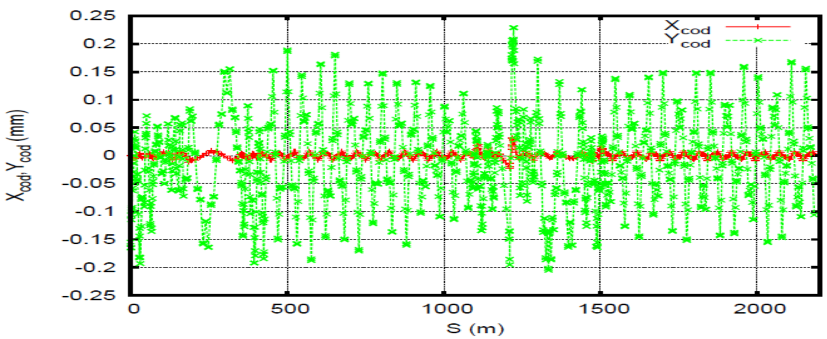


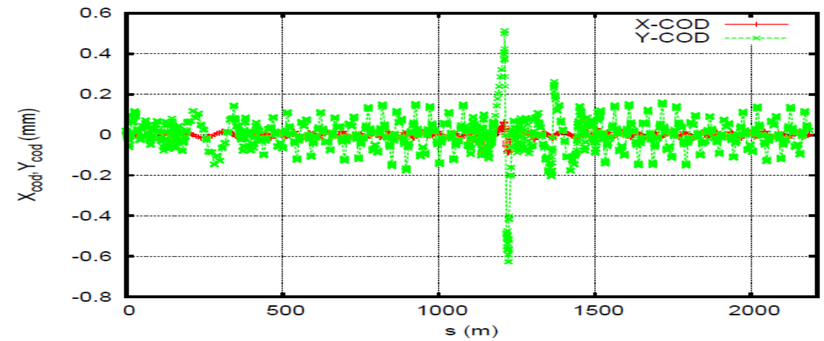
- A relatively low average injected beam current of tens-of-nA level can maintain a high equilibrium polarization in the whole energy range.
- Beam lifetime must be balanced with the beam injection rate and $\tau_{beam} \ll \tau_{pol}$

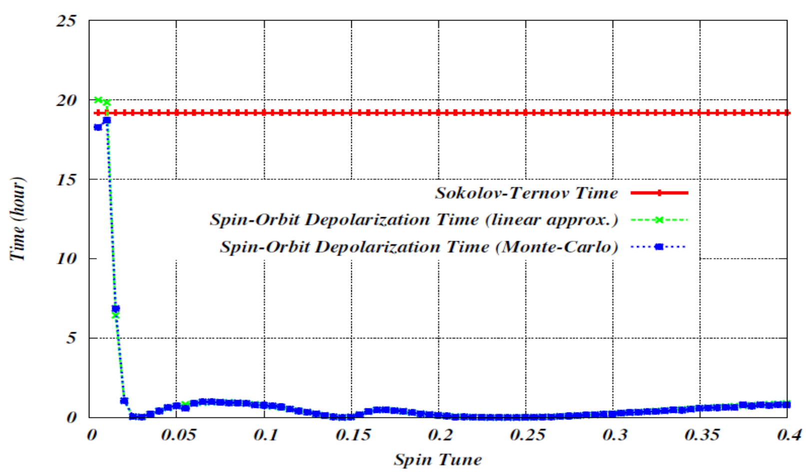
SLICKTRACK vs ZGOUBI

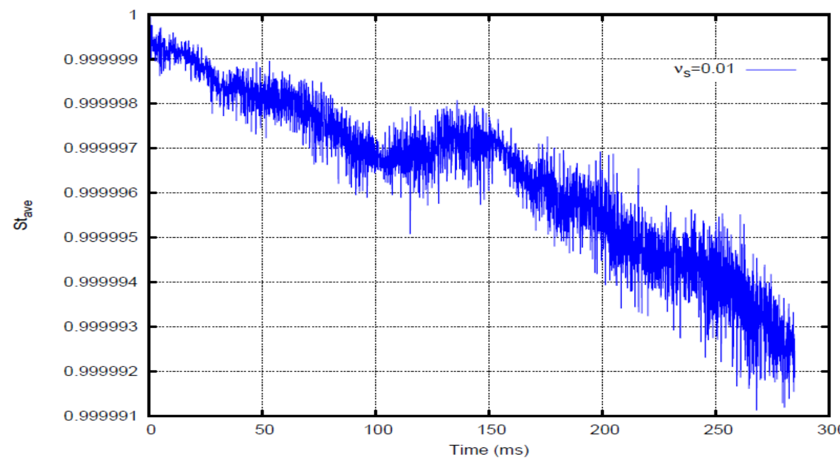
FY14

- From SLICKTRACK
  - Only vertical quad misalignments
  - $\sigma_x^{co} = 0.006$ mm, $\sigma_y^{co} = \mathbf{0.086}$ mm
  - $\boldsymbol{\tau_{dep}}$ **~19 hours** at $\nu_{spin} = 0.01$
- From ZGOUBI
  - Only vertical quad misalignments
  - $\sigma_x^{co} = 0.021$ mm, $\sigma_y^{co} = \mathbf{0.087}$ mm
  - $\boldsymbol{\tau_{dep}} =$ **10.5 hours** at $\nu_{spin} = 0.01$
- The difference could be due statistics or more simplified model in SLICKTRACK





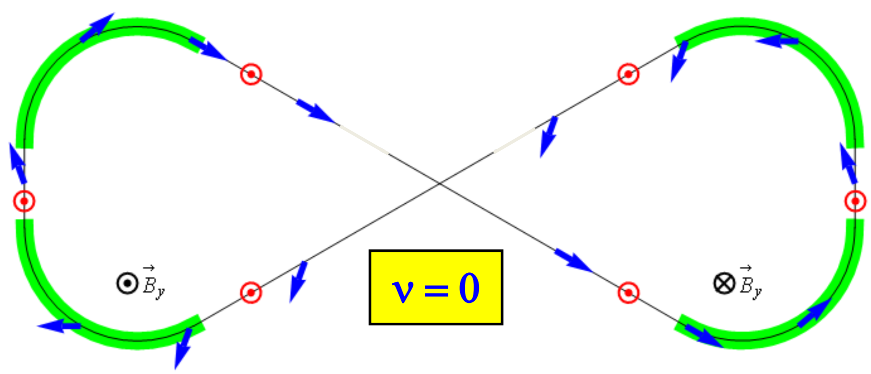




Ion Polarization

FY14

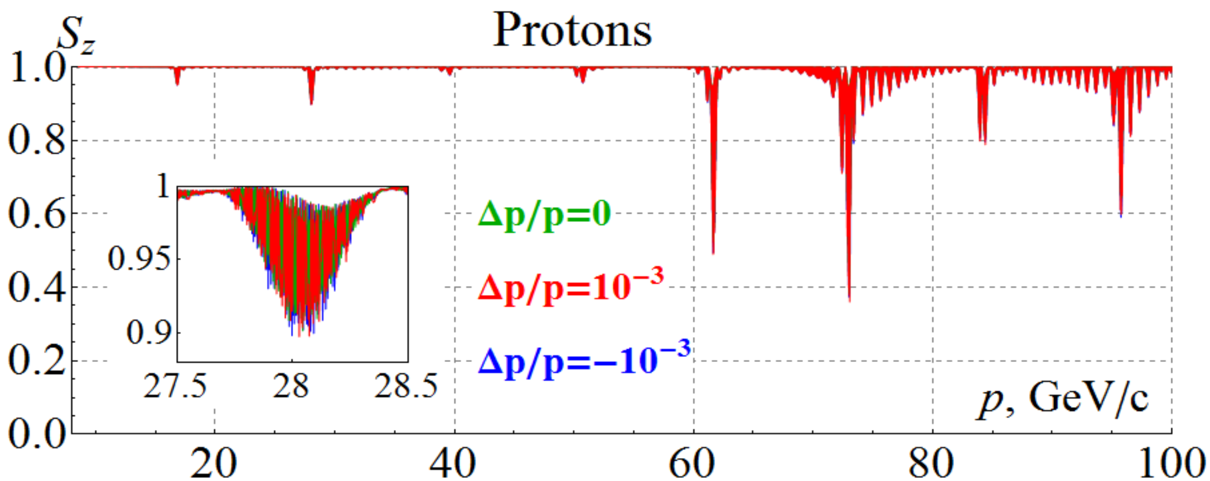
- Figure-8 concept: Spin precession in one arc is exactly cancelled in the other
- Spin stabilization by small fields: ~3 Tm vs. < 400 Tm for deuterons at 100 GeV
  - Criterion: induced spin rotation >> spin rotation due to orbit errors
- **3D spin rotator**: combination of small rotations about different axes provides any polarization orientation at any point in the collider ring
- No effect on the orbit
- Polarized deuterons
- Frequent adiabatic spin flips



FY14

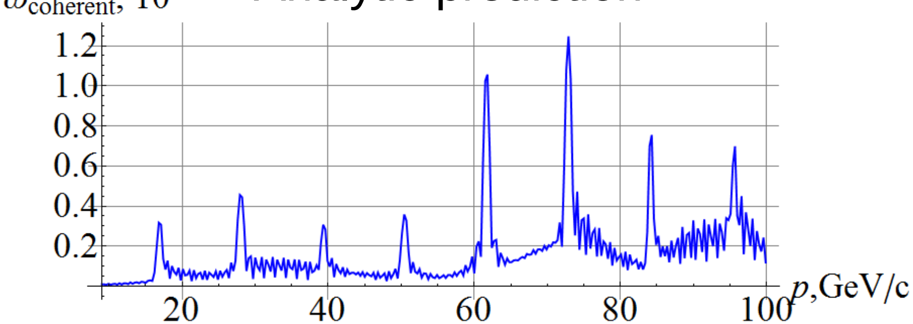
Start-to-End Proton Acceleration

- Three protons with $\varepsilon_{x,y}^{N} = 1\ \mu m$ and $\Delta p/p = 0, \pm 1 \cdot 10^{-3}$ accelerated at ~3 T/min in lattice with 100 μm rms closed orbit excursion, $\nu_{sp} = 0.01$

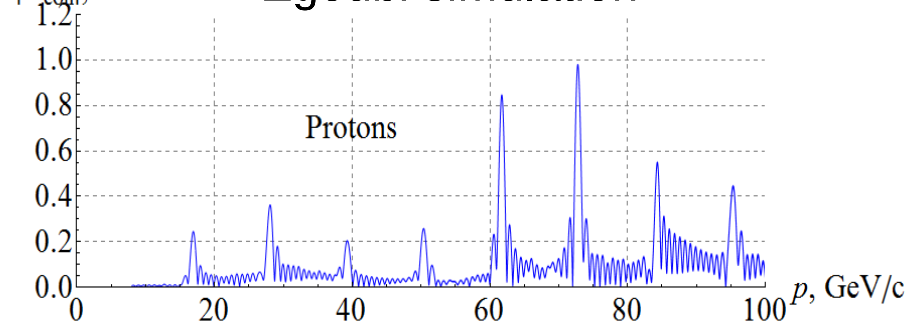


- Coherent resonance strength component

Analytic prediction



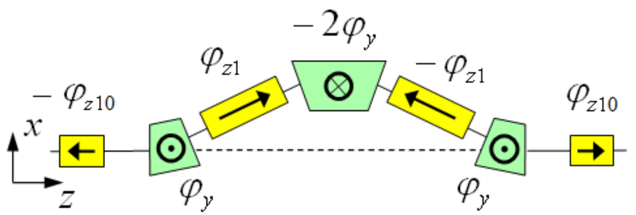
Zgoubi simulation



Polarization Control in Ion Collider Ring

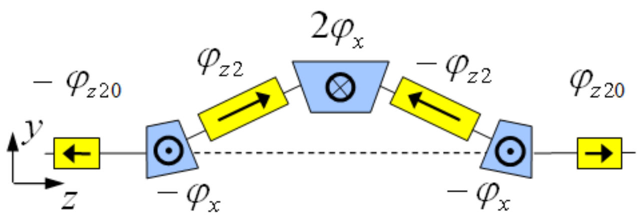
FY14

- 3D spin rotator: control of the radial, vertical, and longitudinal spin components
- Module for control of the radial component (fixed radial orbit bump)

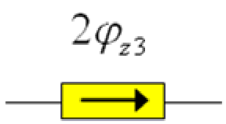


$L_{tot} = 7$ m, $\Delta x = 15$ mm, $B_{dip}^{max} = 3$ T, $B_{sol}^{max} = 3.6$ T

- Module for control of the vertical component (fixed vertical orbit bump)

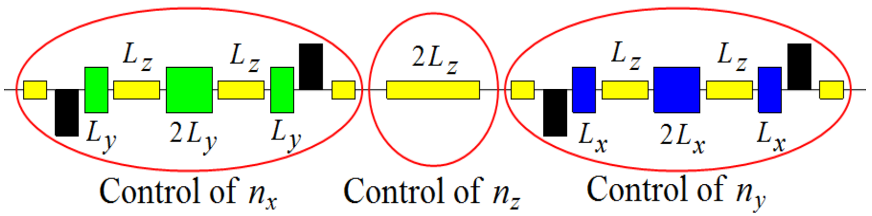


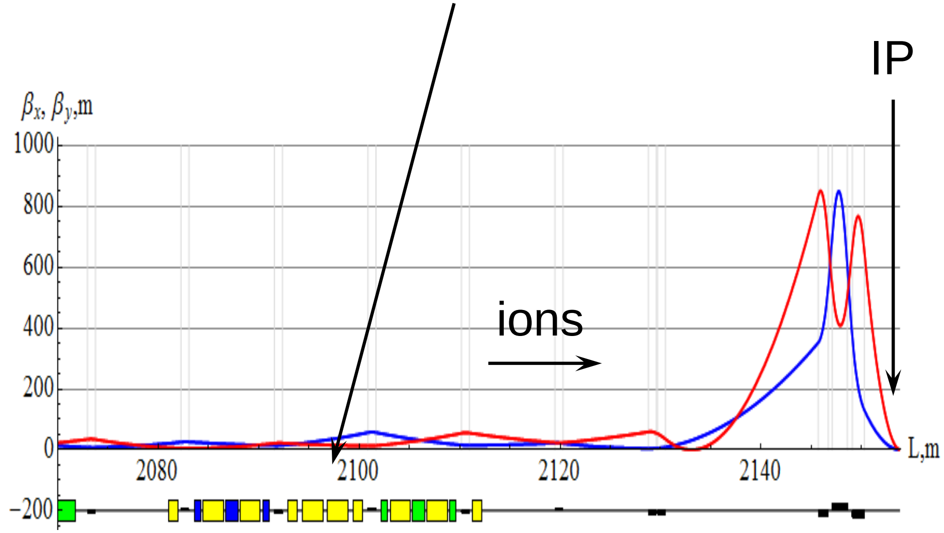
- Module for control of the longitudinal component



$L_x = L_y = 0.6$ m, $L_{zi} = 2$ m, $L_{zi0} = 1$ m, $\alpha_{orb} = 0.31^{\circ}$

3D spin rotator

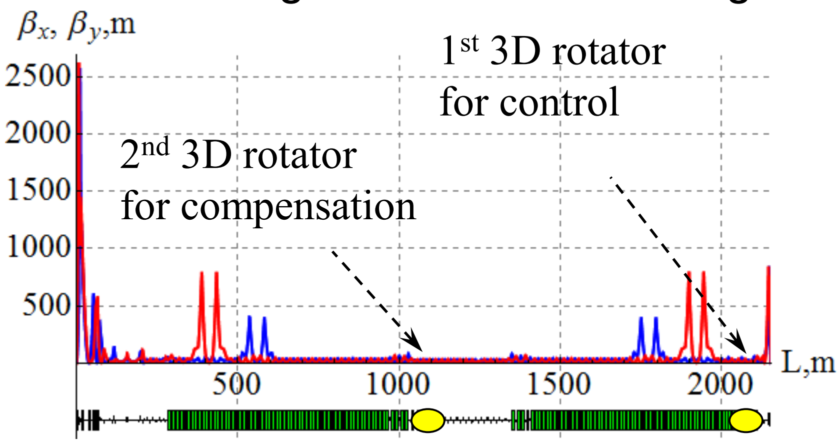


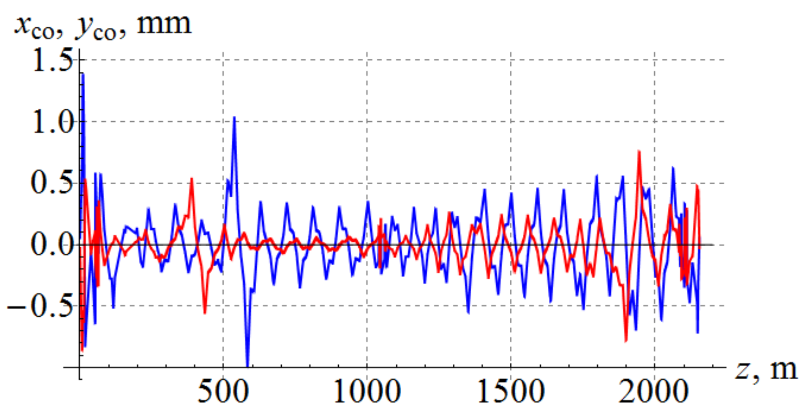


Spin Dynamics in Ion Collider Ring

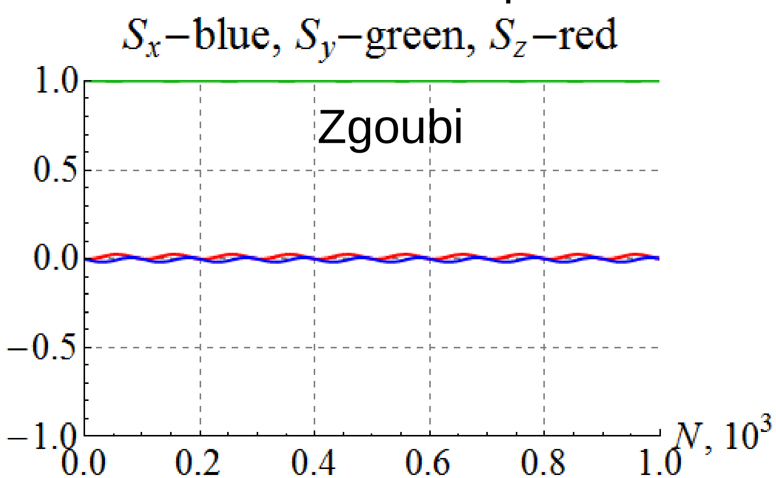
FY14

- 100 GeV/c figure-8 ion collider ring with transverse quadrupole misalignments

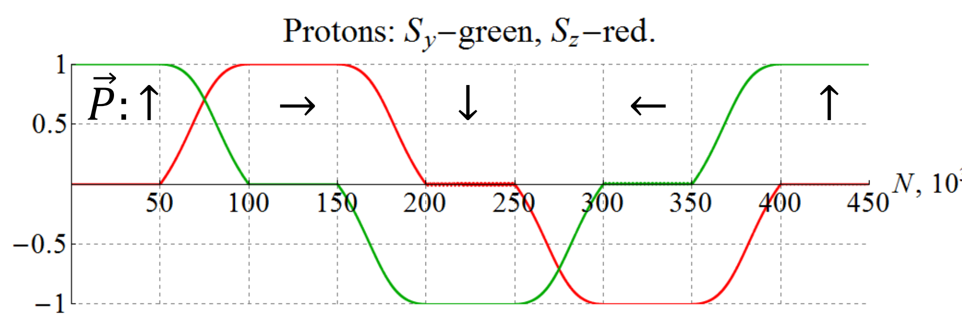




- Example of vertical proton polarization at IP.
  The 1st 3D rotator: $\nu = 10^{-2}$, n_y=1.
  The 2nd 3D rotator compensates error effect.



- Zgoubi simulation of proton spin flip



Plan for Polarization Studies

FY14

- Deliverables for the period of 6/16/2017 – 6/15/2018

  1st and 2nd quarters

  - Evaluation of crab crossing effect on *ion and electron* polarizations
  - Investigate implementation of the *Spin Response Function* method for suppression of depolarization in the interaction region including the beam-beam influence on the *ion and electron* spins
  - Development of Spin Matching design for increasing *electron polarization* lifetime

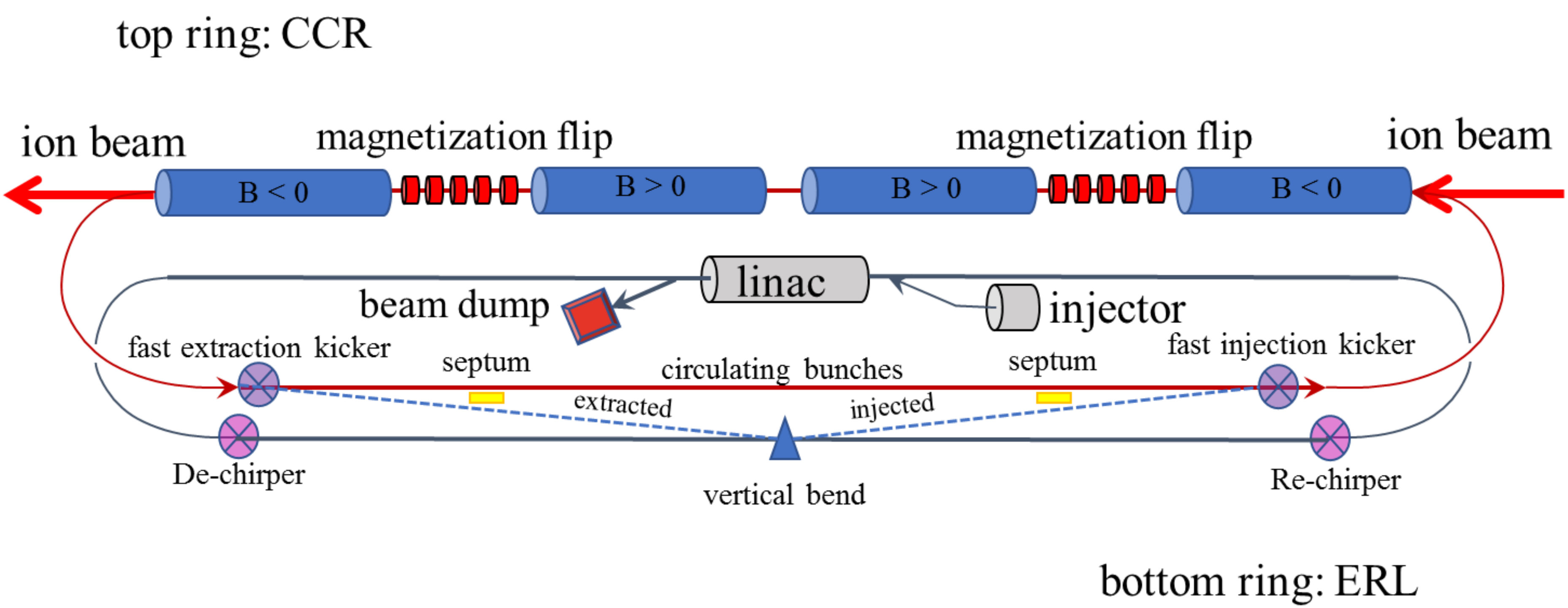
  3rd and 4th quarters

  - Design and optimization of an electron spin rotator with vertical bends to improve ion polarization performance and reduce ion collider ring circumference by keeping the ion ring flat
  - Continue Spin Matching design for increasing *electron polarization* lifetime
  - Proof-of-principle simulations

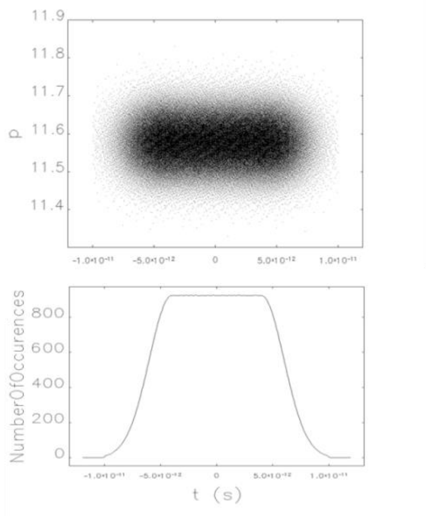
Baseline Design: Cooling Ring Fed by ERL

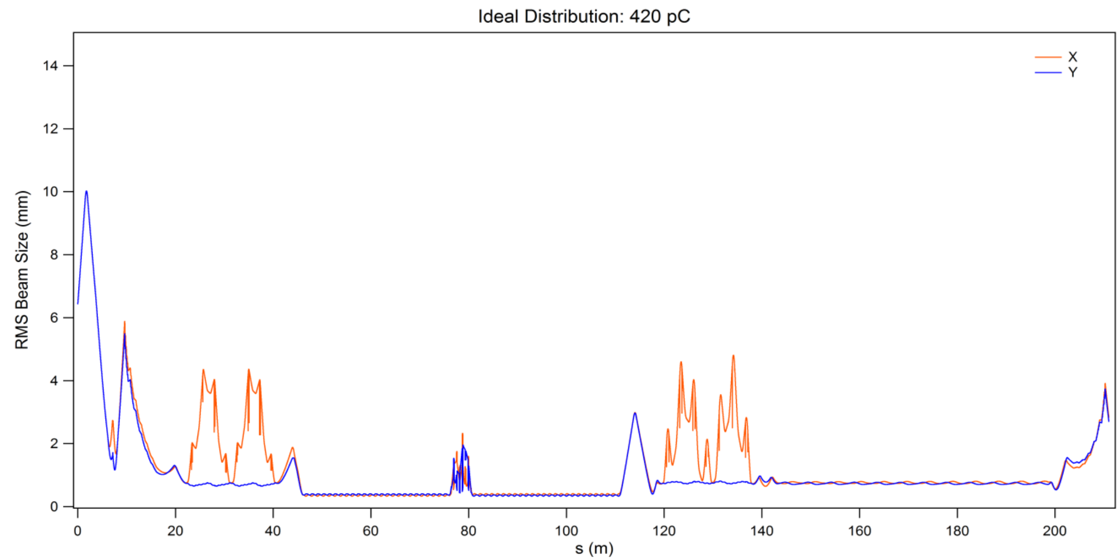
FY16

- Same-cell energy recovery in 952.6 MHz SRF cavities
- Uses harmonic kicker to inject and extract from CCR (divide by 11)
- Assumes high charge, low rep-rate injector (w/ subharmonic acceleration and bunching)
- Use magnetization flips to compensate ion spin effects

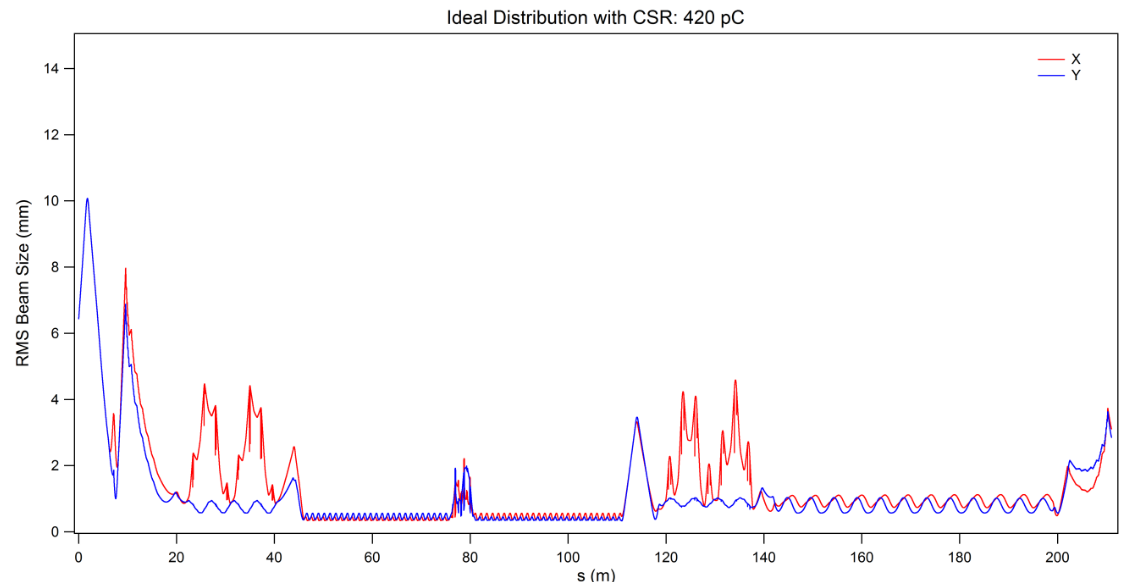


Transverse Behavior in ERL



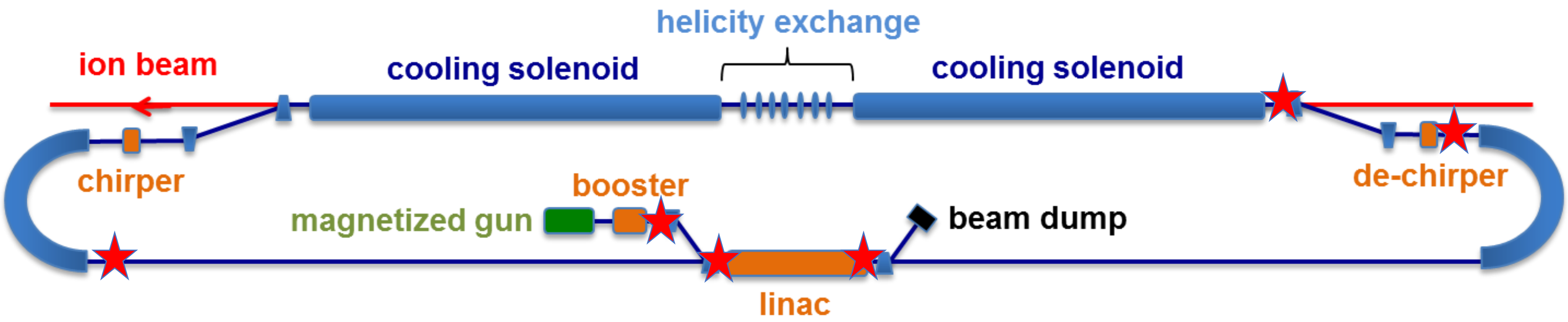


- Start with ideal distribution at booster exit (above)
- Find *rms* beam size vs. distance without (top) and with (bottom) CSR
- No re-optimization performed with CSR



Larmor Emittance vs. Distance

FY16

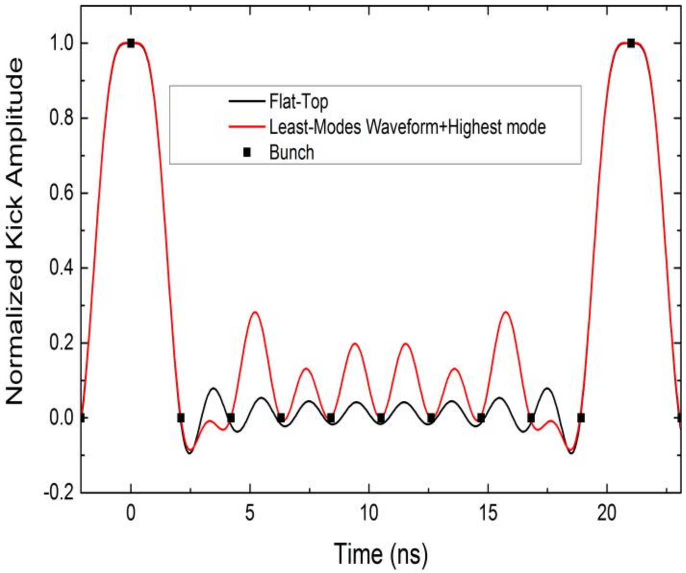


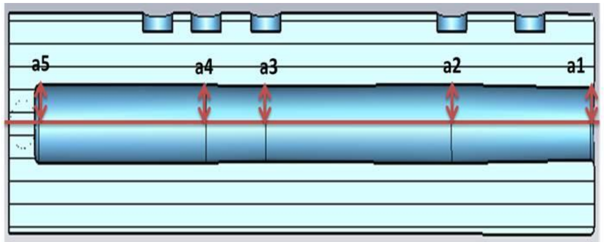
Location	I2E 420 pC	I2E 420 pC + CSR	S2E 420 pC	Ideal 2 nC
Initial Distribution	2.0	2.0	2.0	2.0
Merger Exit	3.01	7.24	2.72	15.96
Linac Exit	2.87	7.09	2.79	23.59
Arc 1 Exit	3.03	7.32	2.80	22.42
Solenoid Entrance	3.02	7.26	2.76	22.45
Arc 2 Exit	3.46	6.60	3.98	22.19
Linac Exit	4.44	7.79	4.06	22.92

Big challenge: preserving the emittance in the injector merger.

Harmonic Kicker

- A first 952.6 MHz copper cavity has been prototyped, bench measured, and satisfies beam dynamic requirements for a Circulator Cooler Ring.

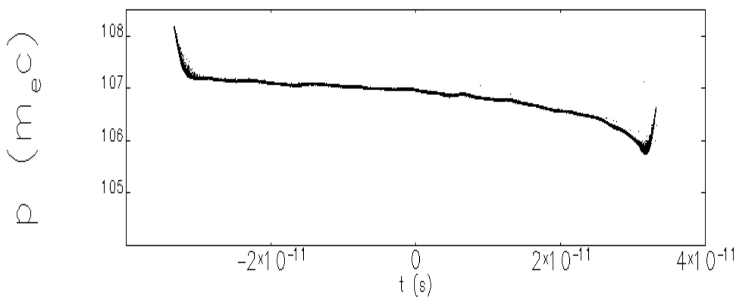




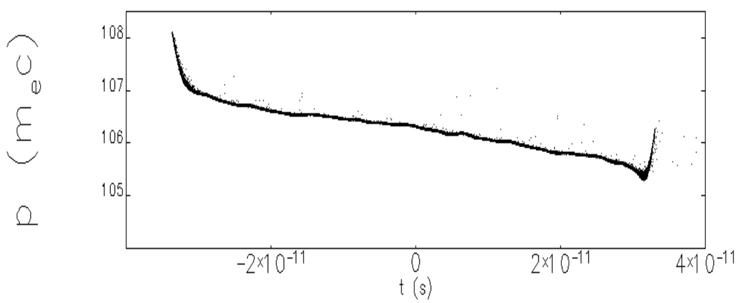
CSR Effect in Circulator Ring

FY16

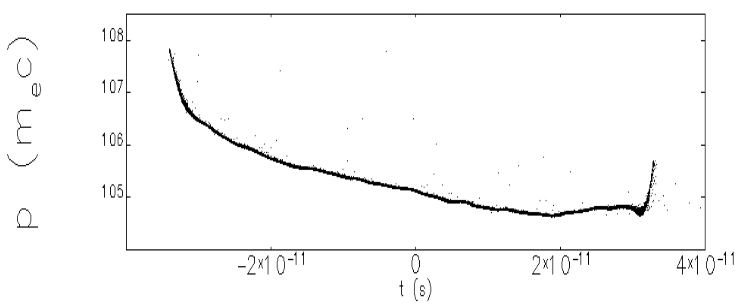
- CSR induces slew in energy
- Use RF cavity to remove chirp and reaccelerate the beam



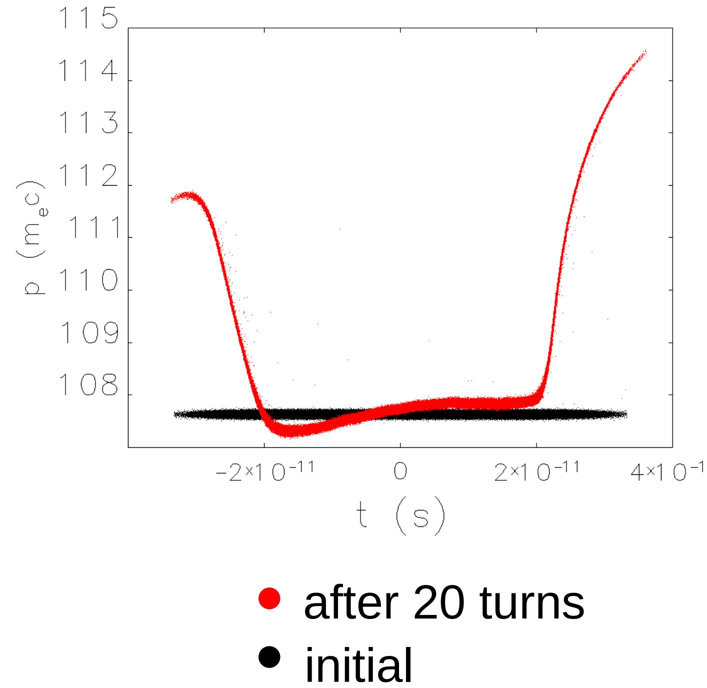
5-turns



10-turns



20-turns



Status of Cooler Design

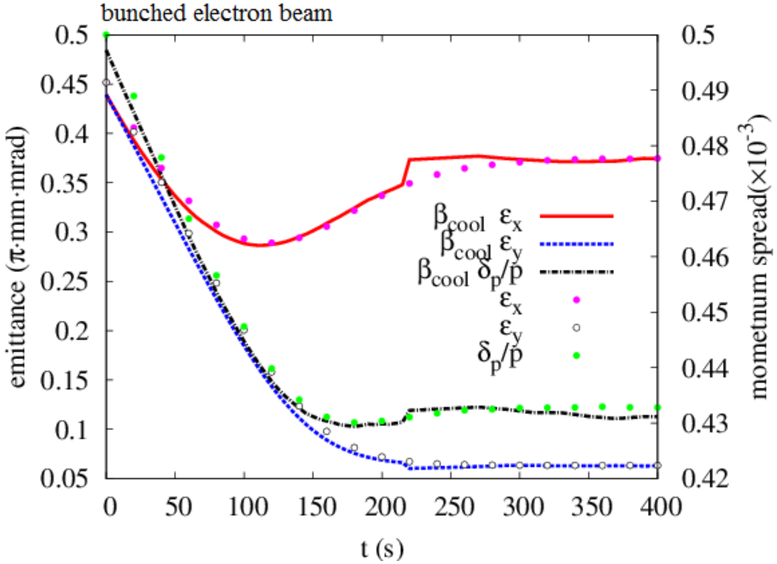
FY16

- ✓ ERL Design
  - ➢ Add doglegs and update injector design.
  - ➢ Calculate collective effects (BBU, ion trapping, halo formation)
- ✓ Beam exchange design
- ✓ Linac design
  - ➢ Optimize HOM damping.
  - ➢ Consider 3rd harmonic cavity for CCR operation.
- ✓ Cooling Insertion
  - ➢ Balance cooling partition
  - ➢ Specify solenoid tolerances
- ✓ CCR Design
  - ➢ Microbunching gain is low.
  - ➢ Explore shielding
  - ➢ Calculate collective effects (ion trapping, wakes, resonances)
- ○ Injector design
  - ➢ Magnetization is preserved up to end of booster
  - ➢ Need to try lower frequency
- ○ Merger Design
  - ➢ Many options to explore
  - ➢ Might be able to just go straight in (straight merger).

Electron Cooling Simulations

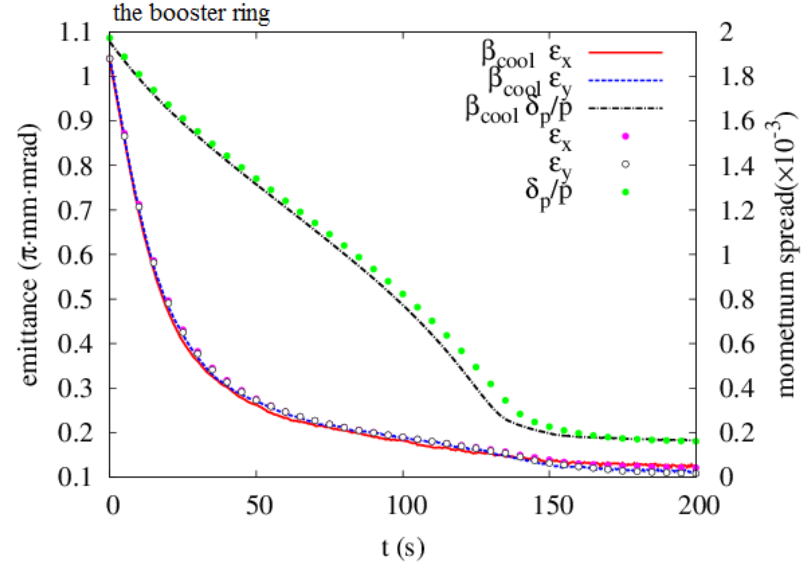
- BETACOOL and JSPEC used for electron cooling simulations for JLEIC
- JSPEC (JLab Simulation Package for Electron Cooling)
  - Developed at JLab for JLEIC (supported by JLab LDRD FY15-16)
  - Provides more flexibility and higher efficiency
  - Benchmarked with BETACOOL
  - Open source, code, executable, tutorial available online
- In the following simulation:
  - Friction force is calculated by the Parkhomchuk formula
  - IBS expansion rate is calculated by the Martini model (no vertical dispersion)

30 GeV bunched proton beam with IBS and cooling by bunched electron beam



Benchmark with BETACOOL

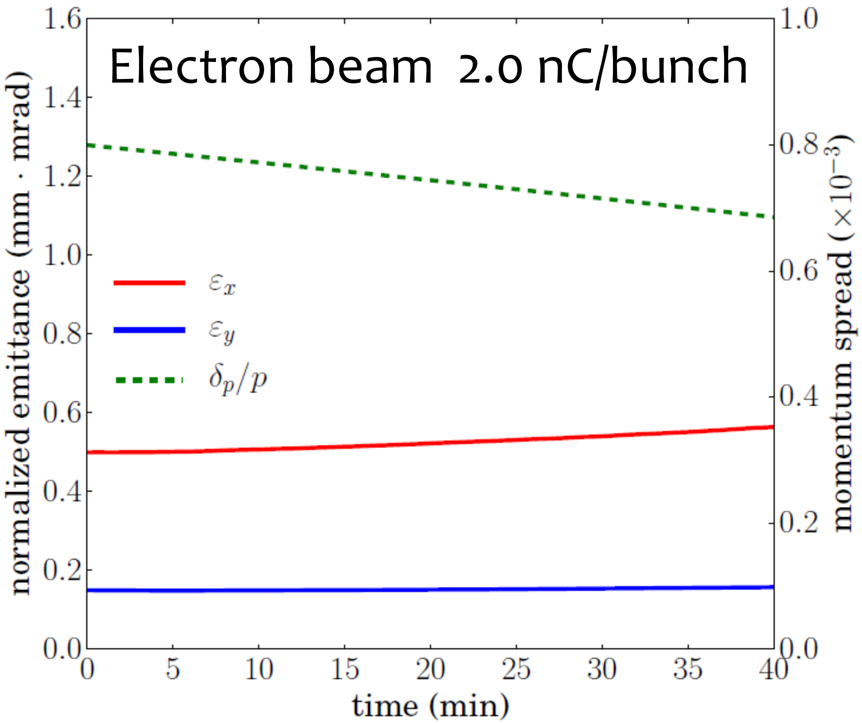
2 GeV coasting proton beam with IBS and DC cooling at the booster ring

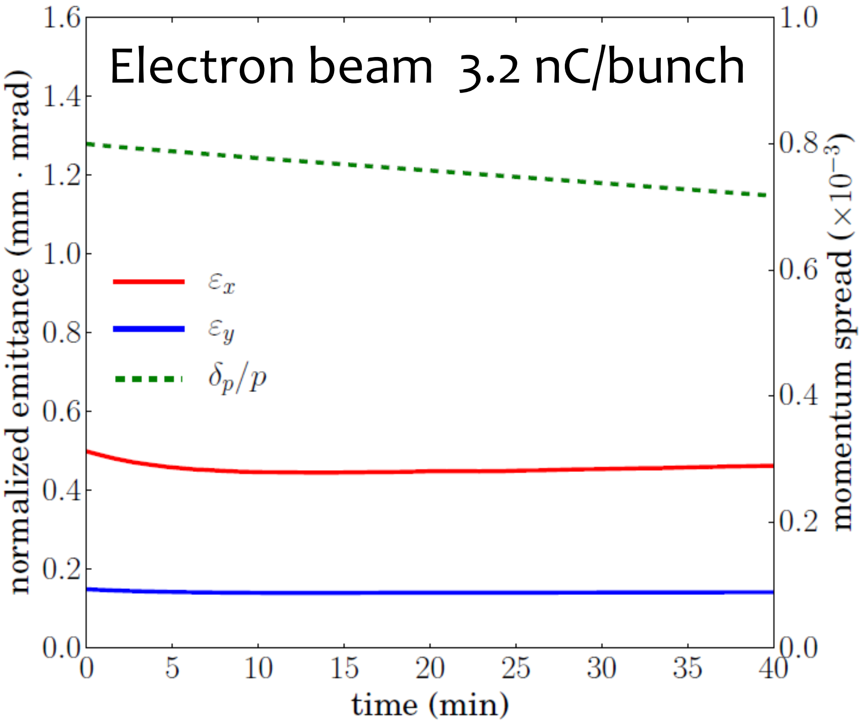


Cooling Proton Beam During Collision

- Proton beam (CM energy 44.7 GeV):
  - Energy: 100 GeV
  - Proton number: 0.539×10^{10} (55%)
  - Normalized emit. (rms): 0.50/0.15 μm
  - Bunch length (rms): 1.5 cm
  - Transverse coupling: 40%

- Proton beam (CM energy 44.7 GeV):
  - Energy: 100 GeV
  - Proton number: 0.804×10^{10} (82%)
  - Normalized emit. (rms): 0.50/0.15 μm
  - Bunch length (rms): 1.5 cm
  - Transverse coupling: 40%





Electron Cooling Simulation Development

FY17

- Main goals from now through July, 2018
  – Create a new model to simulate the cooling process using an electron bunch smaller than the ion bunch for JLEIC design.
  – Simulate low energy bunched beam cooling using the IMP experiment parameters and benchmark the result with the experimental data.
  – Investigate the techniques to redistribute the cooling effect and to enhance the cooling rate, such as sweeping and introducing velocity gradient of the electron bunch, model and simulate these techniques.

Conclusion

- JLEIC design is driven by and meets physics requirements
- The overall risk is kept low
- Key features:
  - High luminosity
  - High polarization
  - Full-acceptance detection
- Current work
  - Key R&D
  - Completion of consistent design
  - Performance and cost optimization