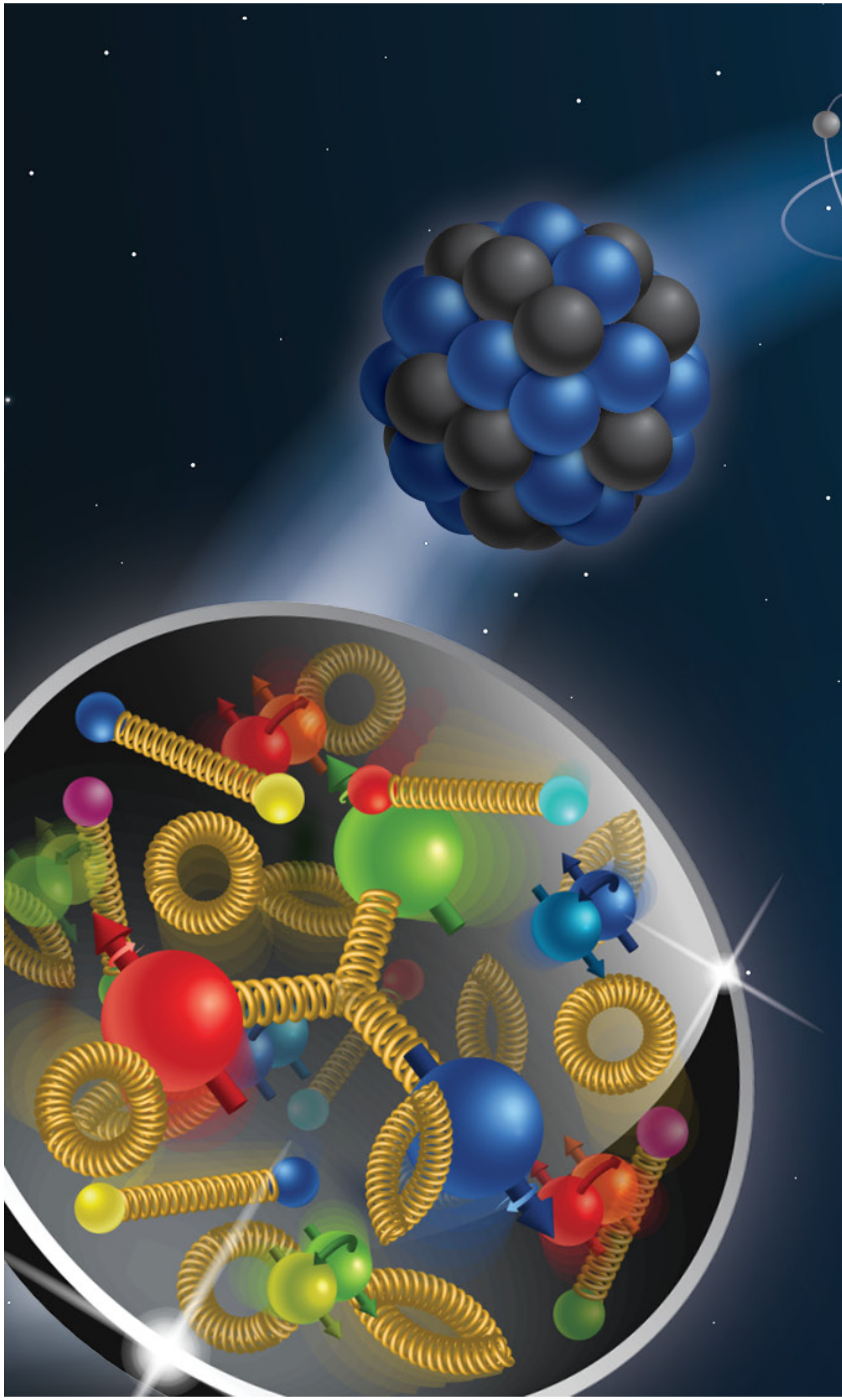

Design of eRHIC Storage Ring

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EIC Accelerator Collaboration Meeting

Newport News

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Electron Ion Collider – eRHIC

BROOKHAVEN NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY | Office of Science

Electron Storage Ring Requirements

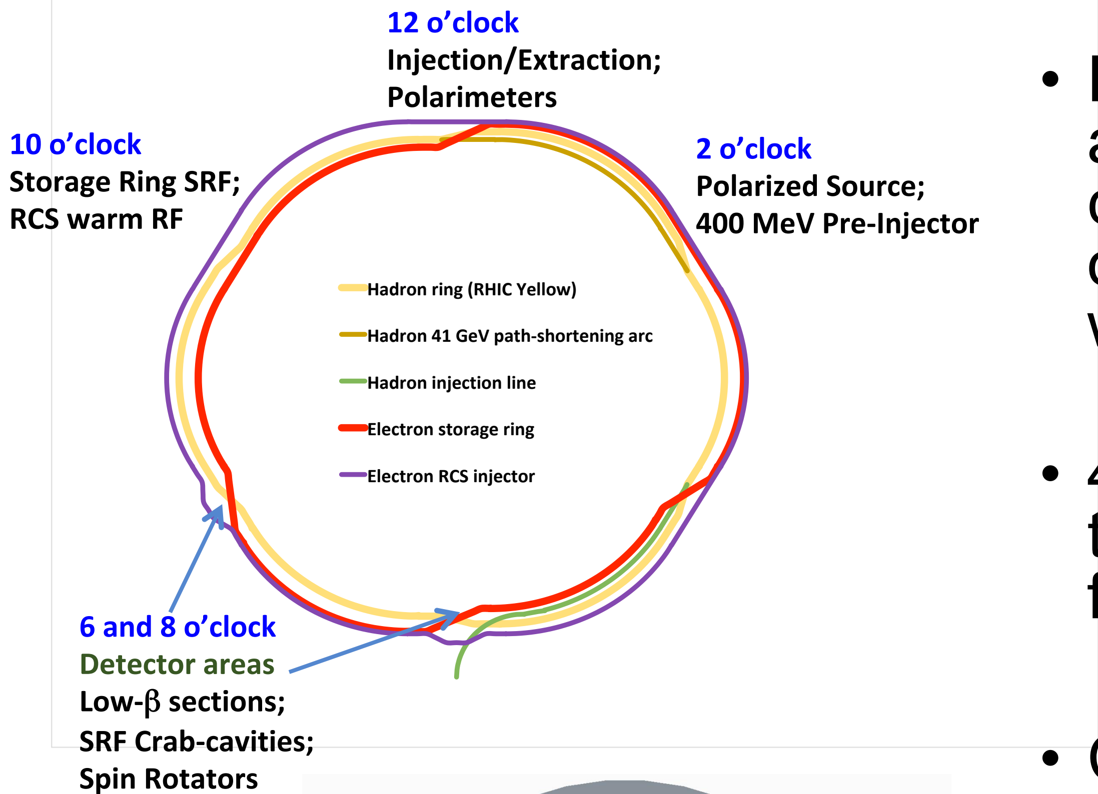
- Store electron beam in energy range 5-18 GeV
- Up to 2.5A beam current, up to 10 MW synchrotron radiationpower
- Provide at least 70% average polarization level and longitudinal polarization in experimental points
- The ring has to fit in available space along circumference of present RHIC tunnel

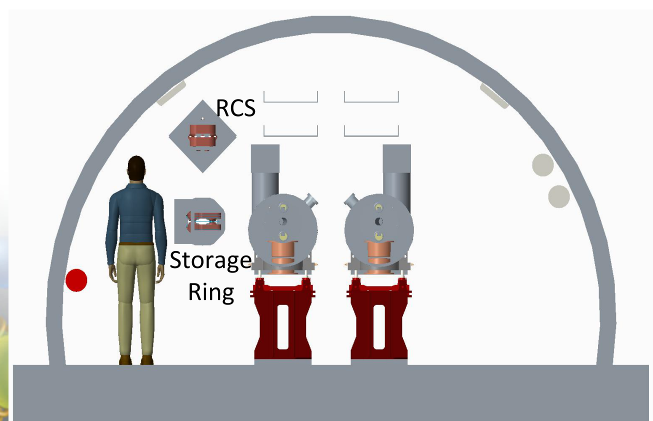
Based on accelerator technologies of B-factories and HERA

Storage Ring Beam Parameters

Beam energy	**GeV**	**5**	**10**	**18**
Beam current	A	2.5	2.5	0.26
Number of bunches		1320	1320	330
Total SR power	MW	3.3	9.2	10
Energy loss per turn	MeV	1.3	3.7	39
Horizontal RMS emittance	nm	20	20	22
Vertical RMS emittance	nm	2.0	1.0	3.3
RMS energy spread	10^{-4}	5.8	5.5	10
Transverse damping time	ms	99	70	12

Electron Storage Ring in RHIC Tunnel



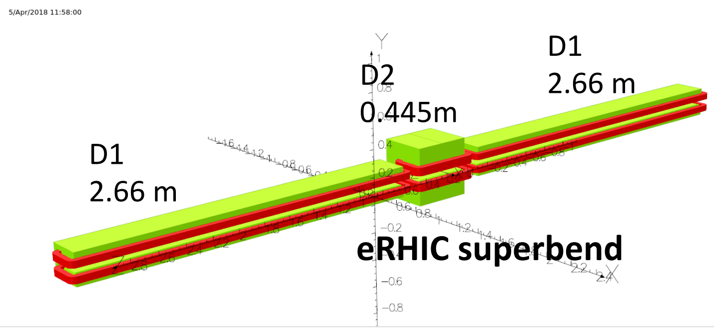


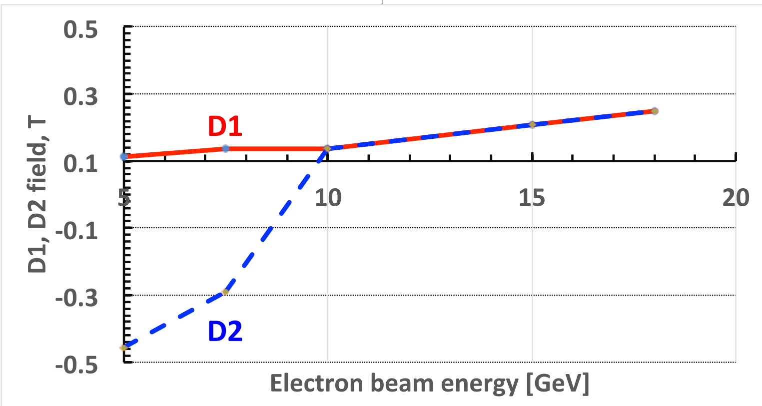
- Electron storage ring runs around the tunnel circumference at the plane of the hadron ring; with ~1m offset

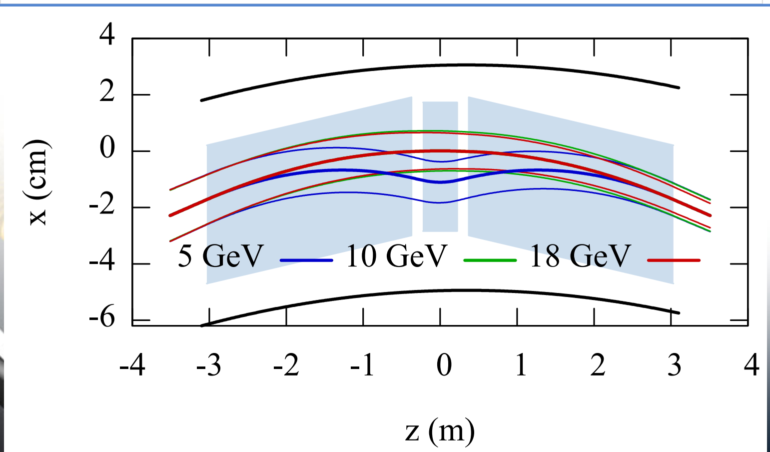
- 4 crossings of hadron ring; two of them can be used for experimental detectors

- C_{ESR} = 3833.94 m
  C_{RCS} = 3842.14 m
  (C_{RHIC} = 3833.85 m)

Arc Lattice and Superbends







- Arc sextant is based on FODO cells
  - Cell length: 16.1 m
  - Cell phase advances:
    - 60º /cell for 5 and 10 GeV
    - 90º /cell for 18 GeV
  - R_{ave} = 381 m
  - Dipole filling factor = 72%

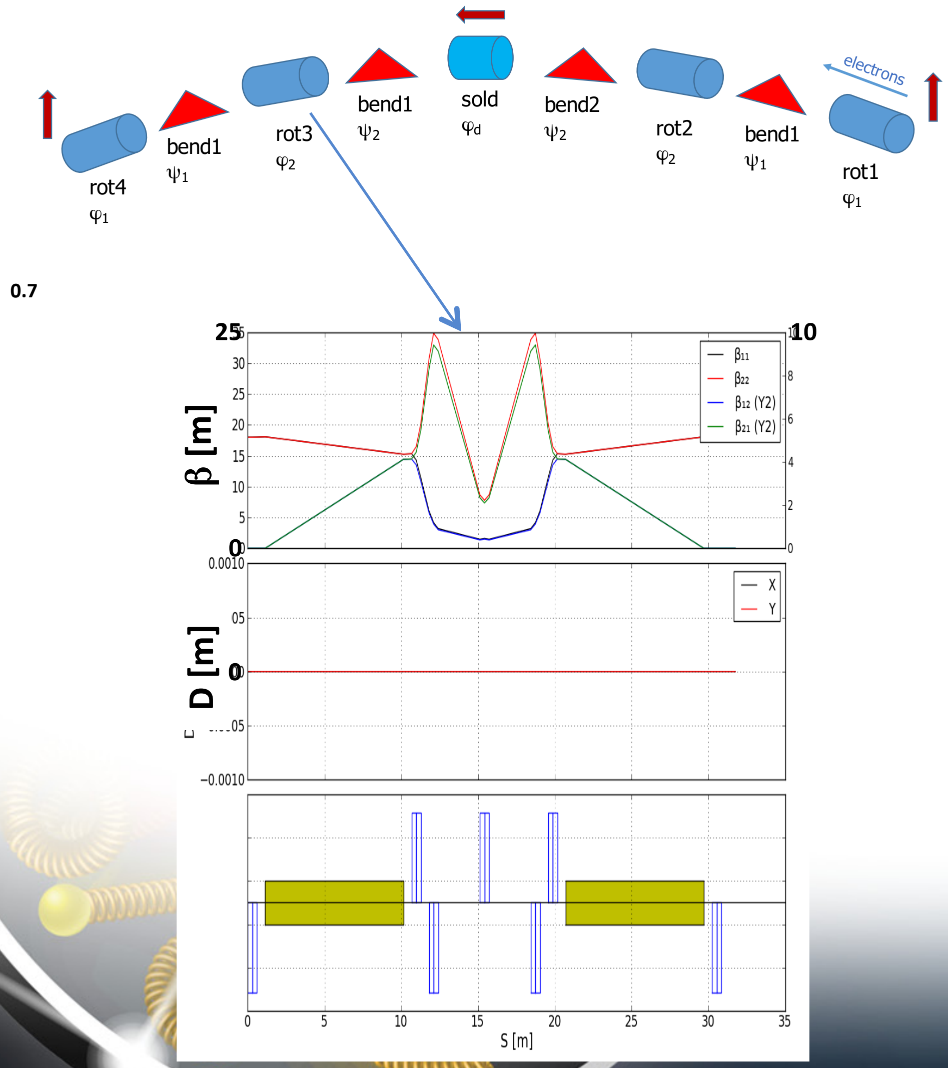
- The main bending element is a superbend consisting of three rectangular dipole magnets.

Superbends are used for emittance and damping decrement control .

Storage Ring Lattice Parameters

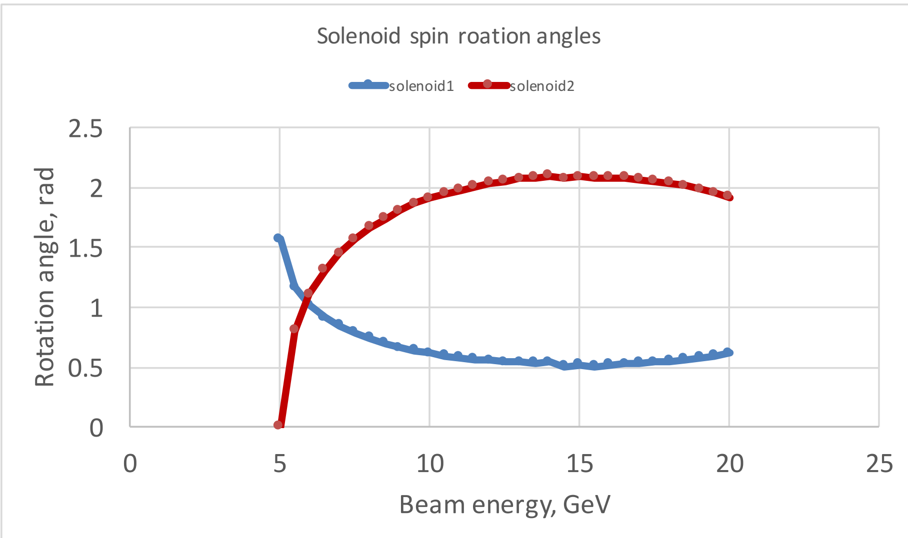
Parameter	5 GeV	10 GeV	18 GeV
Phase advance per cell [degrees]	60	60	90
Horizontal emittance [nm]	20	20	22
Relative energy spread [10^{-4}]	5.8	5.5	10.0
Transverse damping time [turns]	7750	5450	940
Natural chromaticity x/y	-96.2/-89.5	-96.2/-89.5	-101.2/-99.6
Momentum compaction factor [10^{-3}]	1.03	1.04	0.53
Quadrupole strength k_{QF} [m^{-2}]	0.215	0.215	0.283
Quadrupole strength k_{QD} [m^{-2}]	0.216	0.216	0.279
Hor./Vert. sextupole families/sextant	3	3	2
Arc $\beta_x^{\max}$ [m]	27.7	27.7	26.5
Arc $\beta_y^{\max}$ [m]	27.4	27.4	26.8
Arc maximum dispersion [m]	0.95	0.95	0.57
Quadrupole aperture requirement x/y [mm]	30/30	30/30	30/30

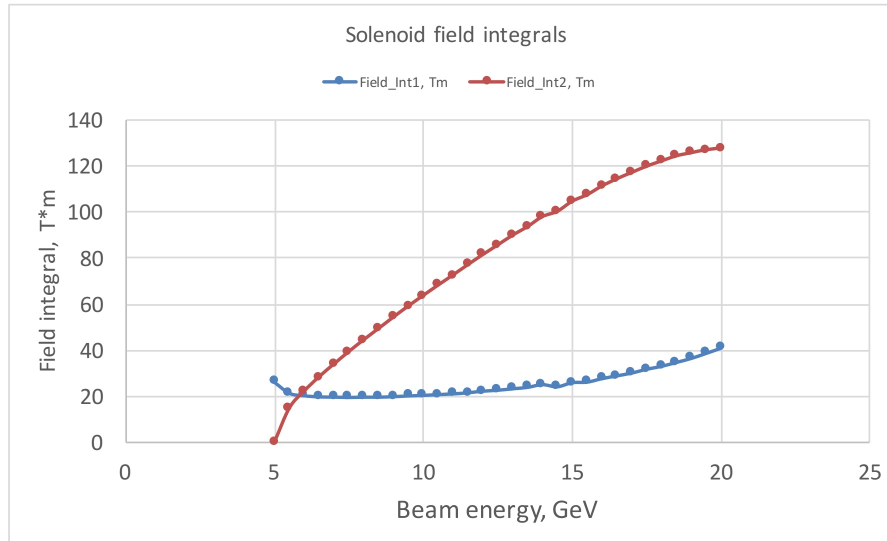
Spin Rotators



- Spin rotators provide the longitudinal polarization over entire energy range (5-18 GeV)
- A HERA-type rotator (based on sequence of vertical and horizontal bend) creates meter scale orbit excursion at lower energies
- The scheme based on interleaved solenoidal and dipole magnets was chosen
- Each solenoidal insertion has betatron coupling locally compensated

Spin Rotator Fields

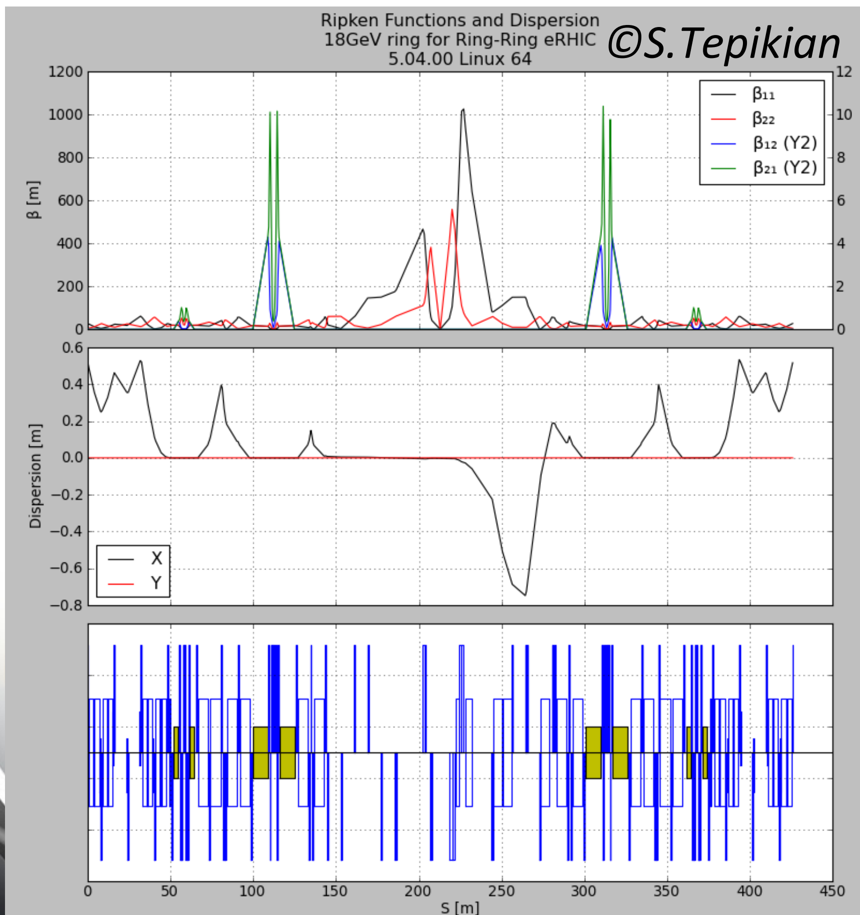




Parameter	Short solenoid module	Long solenoid module
Field integral range [T · m]	20-34	4-122
Solenoid length [m]	5.4	18.
Solenoid spin rotation angle at 18 GeV	32°	116°
Location in the RHIC tunnel	RHIC dipole 9-10	RHIC dipole 6-8

IR Straight Section

The pCDR electron lattice.
Note that newer IR design with considerably reduced values of beta-max will be presented in the IR design session.

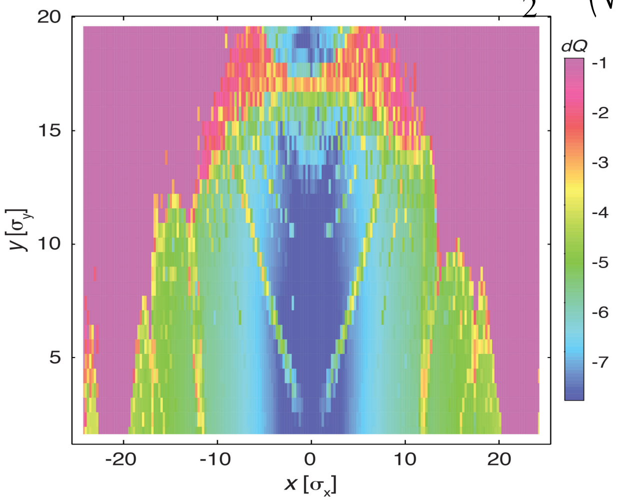


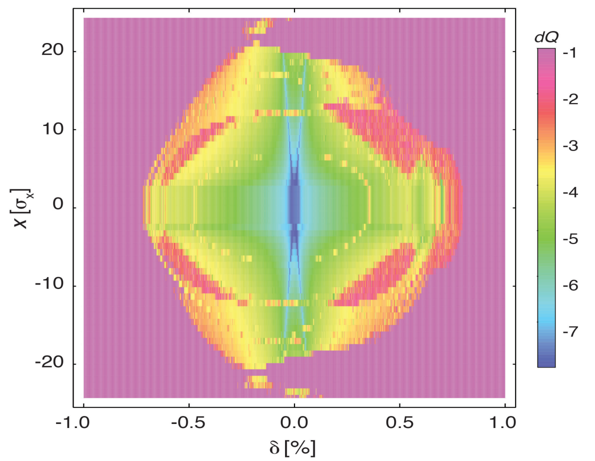
- Electron IR magnets, including low-beta IR quads and rear side chicane
- Dispersion suppressor ensures no dispersion in the solenoidal insertion areas
- Spin rotator solenoidal insertions with locally compensated betatron coupling and special optics conditions for spin matching

Chromaticity Correction and DA

The stability areas for 60 degree lattice, as characterized by betatron tune diffusion index of Frequency Map Analysis

$$dQ = \frac{1}{2}\log\left(\sqrt{\Delta Q_x^2 + \Delta Q_y^2}\right)$$





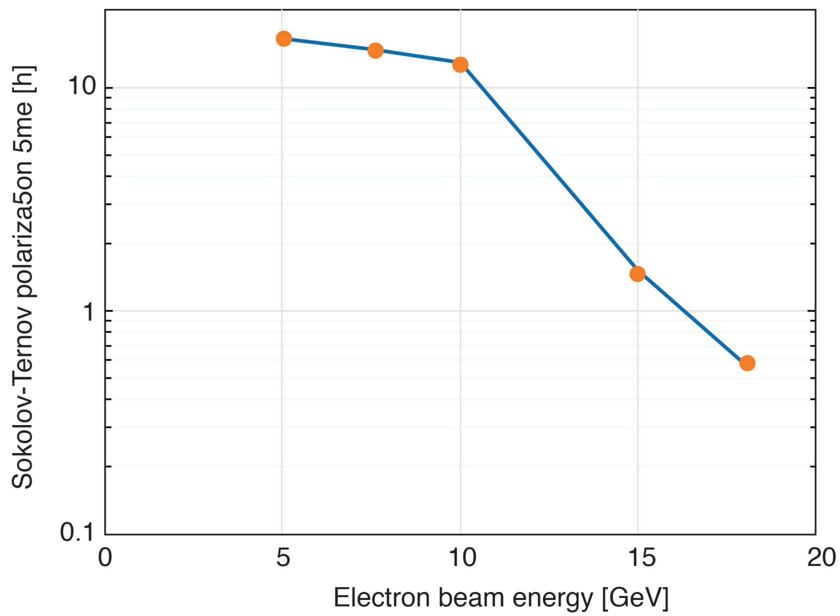
$Q_x = 51.08$
$Q_y = 48.06$

- Arc sextupoles are used to correct chromatic beta-beat and non-linear chromaticity produced at the IR, at the same minimizing resonance driving terms
  Each arc cell has one horizontal and one vertical sextupole.
- Chromaticity correction scheme depends on cell phase advance
  - For 60 degree lattice a scheme with 36 sextupole families (3 h and 3 v families per sextant) is used:
    - 20 sigma dynamic aperture
    - 0.8% momentum aperture
  - For 90 degree lattice a scheme with 2h/2v sextupole families per sextant is being explored. Studies on-going.

Beam and Polarization Lifetime

Beam-gas lifetime (at 10^{-8} Torr): ~20-30h
Touschek lifetime (0.8% momentum aperture): from 14.5h (5 GeV) to 200h (18 GeV)

Depolarization time
(due to Sokolov-Ternov effect only)



- 80-85% polarized electron bunches are delivered by the RCS injector
- Fill pattern, required by experiments, uses bunches with opposite polarization
- The bunch polarization, initially oriented along the magnetic field, will deteriorate with time due to the Sokolov-Ternov effect.
- Beam lifetime defined by Touschek and Beam-gas scatterings is considerably longer at all energies than the polarization lifetime
- Calls for swap-out injection scheme to maintain high polarization

Injection Parameters vs Energy

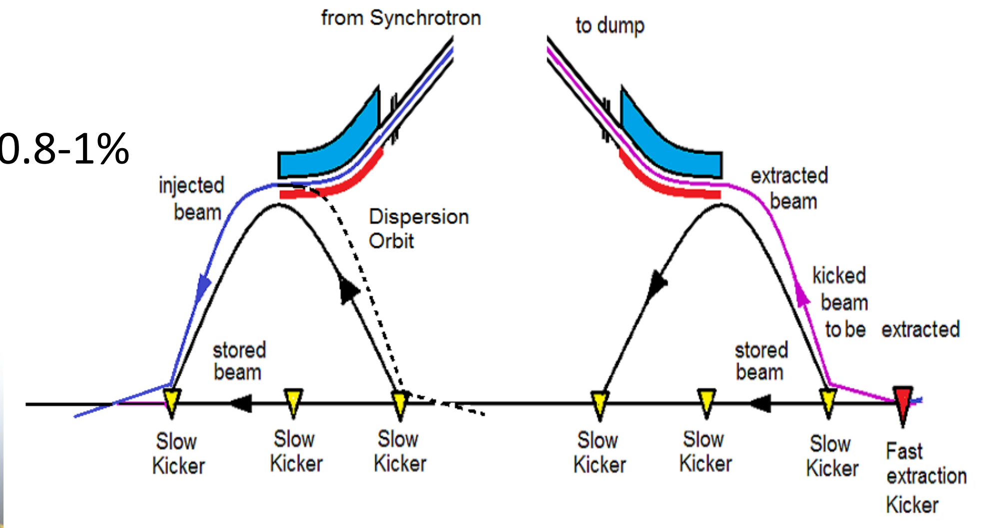
Parameter	Operation without cooling			Operation with cooling		
Energy [GeV]	5	10	18	5	10	18
Bunch Charge from RCS [nC]	10	10	10	5	5	10
Bunch Charge in Storage Ring [nC]	50	50	10	25	25	10
Number of Accumulations per bunch	5	5	5	5	5	1
Number of Bunches in Storage Ring	660	660	330	1320	1320	330
Injection Rate [sec^{-1}]	1	1	1	1	1	1
Bunch Replacement Time [min]	55	55	5.5	110	110	5.5

Swap-out Injection Scheme

- Swap-Out Injection scheme is realized at IR12 straight section.
- Slow injection/extraction bumps have half-sine time of 26 μs.
- Extraction is done using fast transverse kicker with less than 7 ns rise/fall times.
- Injection is done in the longitudinal plane, in order to avoid the detrimental effect on hadrons due to beam-beam interactions. The synchrotron phase space injection was used in LEP.

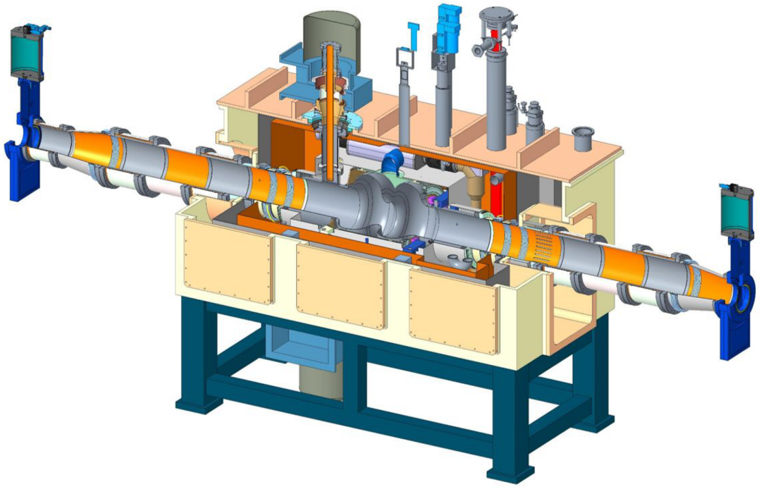
$dE_{inj}/E_0 = 0.8\text{-}1\%$

$D_{inj}=1.7m$



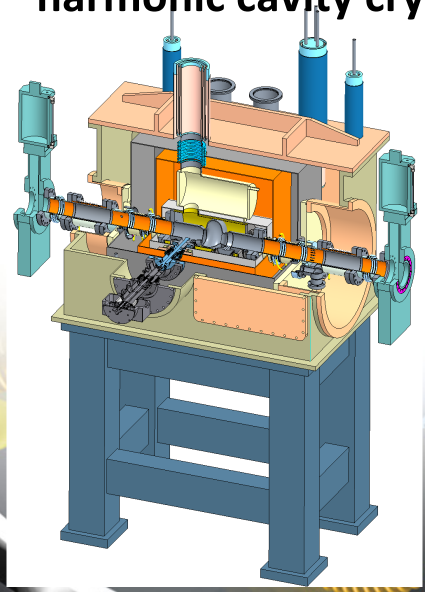
Superconducting RF System

563 MHz cavity cryomodule



- Single 2-cell 563 MHz SRF cavity per cryomodule
- V = 8 MV/cavity
- 2x 500 kW adjustable fundamental power coupler.
- 4x SiC Beamline HOM Absorbers (BLAs)
- 12 cryomodules in total
- The power source: IOT

3rd harmonic cavity cryomodule

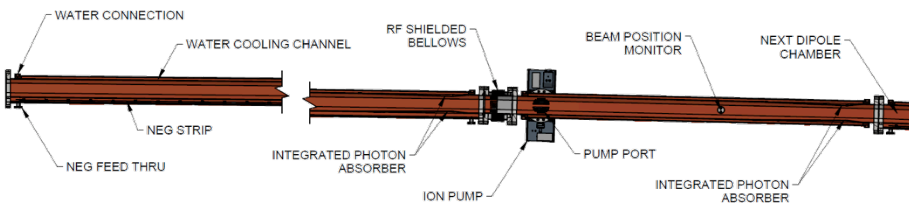


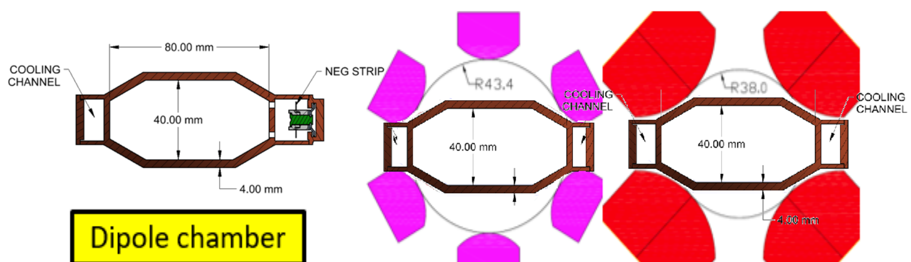
Both cavity systems operate at 2 K

- Provides bunch lengthening for beam stability and reduced HOMs
- Single 1-cell 1689 MHz SRF cavity per cryomodule
- V = 1.9 MV/cavity
- Tunable FPC
- 2x SiC Beamline HOM Absorbers (BLAs).
- 4 cryomodules in total

Design of Vacuum system and Magnets

- Vacuum chamber from CuCrZr Alloy
  Good thermal and mechanical properties,
  Easily available at reasonable price
- Pumping based on integrated NEG Pumps
- Thermal SR Power Load – OK
  Maximum temperature 173°C well below yield strength limit



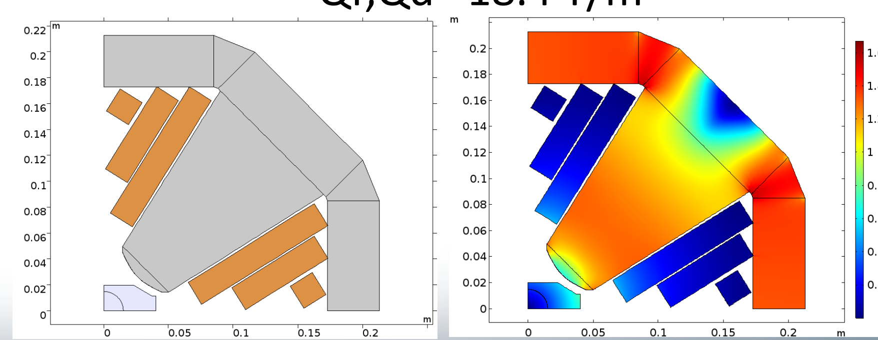


- Design of all storage ring magnets has been developed satisfying field strength and field tolerance requirements.

D2, 0.7 T

(a) 3D Geometry D2 dipole magnet
(b) Pole end geometry of the D2 magnet

Qf,Qd 18.4 T/m



(a) Geometry of the arc quadrupole magnet
(b) Magnetization

Summary

- eRHIC Electron Storage Ring design has been developed, which provides electron beam parameters required for high luminosity of the collider over all energy range (5-18 GeV).
- The superbend dipole magnets are employed to enhance the damping decrements at lower electron energies (5-10 GeV).
- Different cell phase advance (60 and 90 degree) together with superbends allow to achieve required emittance values.
- Spin rotator design is based on combination of solenoidal and dipole magnets. The rotator optics ensure the spin matching conditions and betatron coupling compensation.
- Chromaticity correction employs different sextupole powering scheme for 60 and 90 lattice. Acceptable DA has been demonstrated for 60 degree lattice. The work in progress on 90 degree lattice.
- Swap-out injection scheme is used to maintain high electron polarizaton. The injection is done in synchrotron phase space to prevent the injection impact on the beam collision and detector backgrounds.
- Initial design of all storage ring accelerator systems has been developed, allowing for reliable cost estimate.