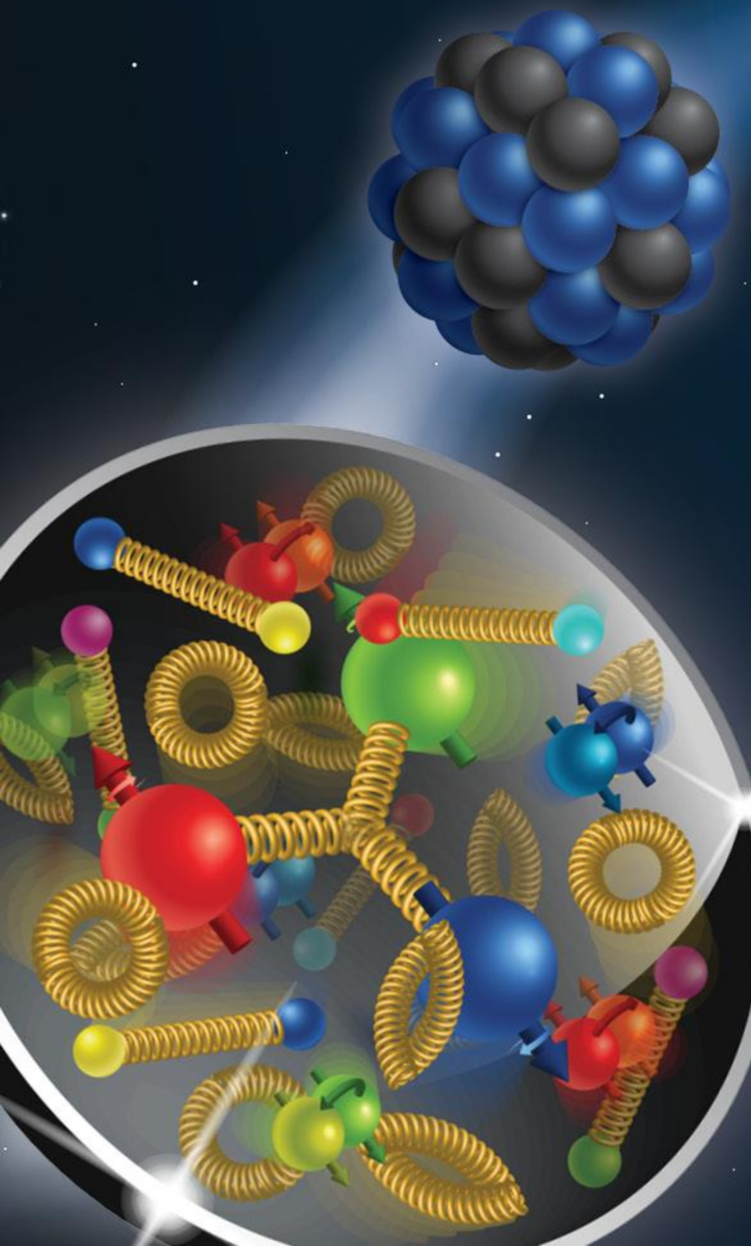


eRHIC
Electron Storage Ring

Nuclear Physics Accelerator R&D

PI Meeting

Christoph Montag, BNL

November 13-14, 2018

Electron Ion Collider – eRHIC

BROOKHAVEN NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY | Office of Science

eRHIC Electron Storage Ring

Funding Source	PI	R&D Report Priority #	R&D Panel Priority Rating	Total $
FY17 Base	Christoph Montag	12, 31	High-B	$838k

- “Complete design of an electron lattice with a good dynamic aperture and a synchronization scheme and complete a comprehensive instability threshold study for this design”
- “Study of Electron Spin Polarization in the Storage Ring”

Outline

- Requirements
- Assumptions
- Lattice Choice and Special Features
- Chromatic Correction and Dynamic Aperture
- Polarization Requirements
- Synchronization Scheme
- Collective Effects
- Vacuum System
- Magnets
- Summary

Design Requirements

- Energy range 5 to 18 GeV
- 20 to 22 nm emittance at all energies
- Fast radiation damping to allow high beam-beam parameter
- 70% average polarization
- Arbitrary spin patterns
- Longitudinal polarization at the IP
- Luminosity $10^{34} cm^{-2} sec^{-1}$

Comparison with B-Factories

	CESR-B	PEP-II LER/HER	KEKB LER/HER	eRHIC
Circumference C [m]	768	2200	3000	3834
No. of bunches N_b	36	1588	1584	1320 (660)
Beam current I [A]	0.365	2.45/1.55	1.3/1.6	2.5
Bunch intensity N_e $[10^{10}]$	16.2	7.0/4.4	5.0/6.2	15 (30)
Beam-beam parameter ξ_e	0.062	0.064/0.055	0.12/0.1	0.1
Transv. damp. decr. $\delta[10^{-4}]$	1.1	1.8/2	2.5	1.25

- Parameters are very challenging, comparable to B-Factories

Assumptions

- Electron storage ring will be installed in the existing RHIC tunnel
- Maximum RF power 10 MW (superconducting)
- Detectors in IRs 6 and 8
- There will be a full-energy polarized injector with ~1Hz rep. rate (Rapid-Cycling Synchrotron, RCS)

Lattice Choice

- FODO cell provides higher dipole packing factor than low-emittance light source lattices like DBA, TBA, etc.
- Arc cell length ~16m
- Required emittances achieved by proper phase advance (90 degrees at 18 GeV, 60 degrees at 10 and 5 GeV), plus radial shift and/or super-bends

Synchrotron Radiation

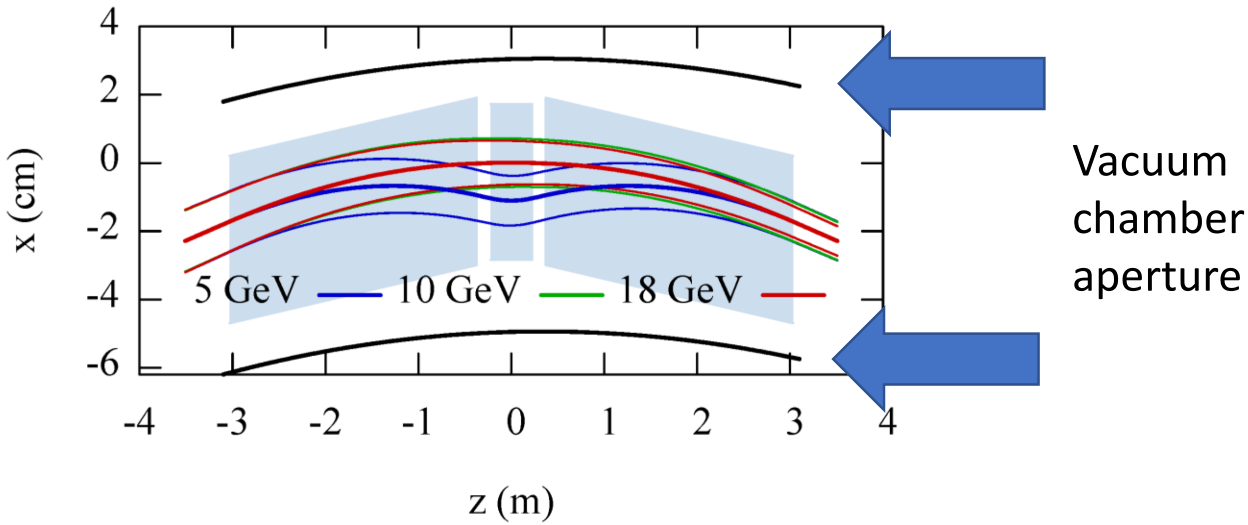
Conflicting Requirements:

- At high energy, radiation power needs to be minimized by a large dipole packing factor to allow high beam currents
- At low energy, radiation damping needs to be artificially increased to allow large beam-beam parameters ξ=0.1

Solution: Super-bends

Super-Bends

- Arc dipoles to be split into 3 segments:



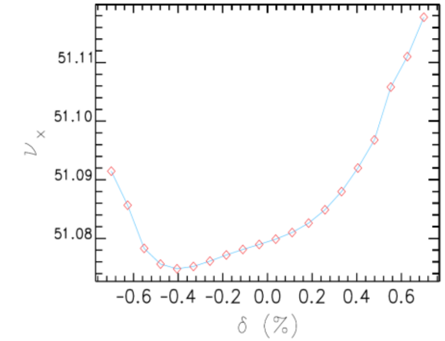
- Above 10 GeV, all segments powered uniformly to reduce SR power
- At 5 GeV, short center dipole provides a reverse bend to increase damping decrement

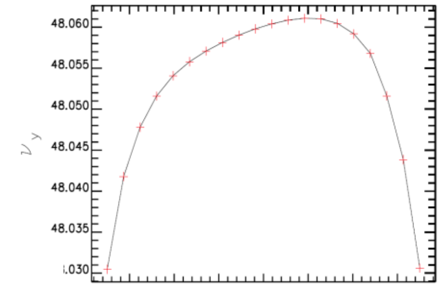
How to Achieve Required Emittances

- 90 degree FODO cell phase advance to achieve 20nm at 18GeV
- At 10 GeV, 60 degree phase advance yields 16nm – need radial offset or some degree of super-bend
- For 20nm at 5 GeV, tight bending radii in super-bends, and probably radial offset
- Vertical emittances controlled by long vertical dispersion bumps

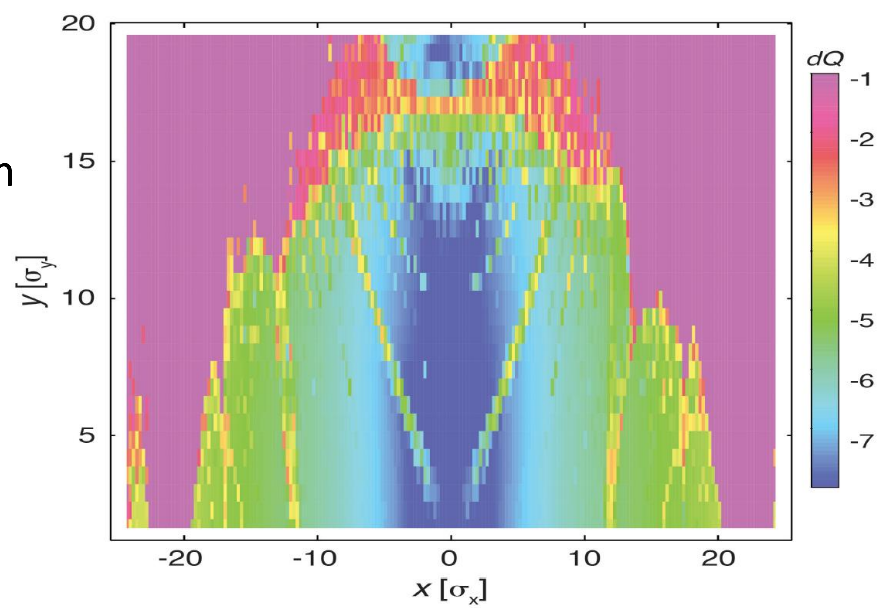
Electron Ring Dynamic Aperture

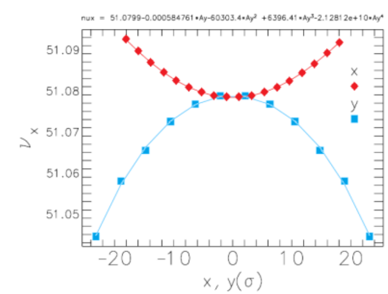
- Requirement: DA > 10 σ in all three planes (lifetime)
- Main issue: 2nd order chromaticity (local IR $\xi_{x,y}$ = -30)
- Sextupole scheme: A-B-E-A-B-A-B-C-A-B-C-A-B-E-A-B
- Off-momentum DA still limited at 0.8% (12σ) by 2nd order vertical chromaticity
- On-momentum DA ~ 20 σ, limited by tune shift with amplitude $\frac{\partial Q_{x,y}}{\partial J_{y,x}}$

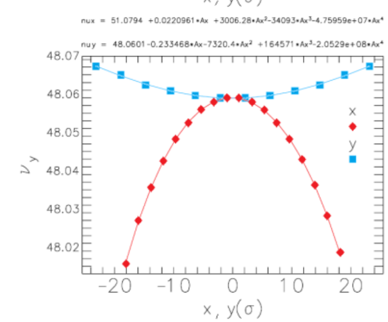




- No results with beam-beam and imperfections yet
- No optimization of non-chromatic sextupoles yet







Dynamic Aperture with 2 IRs

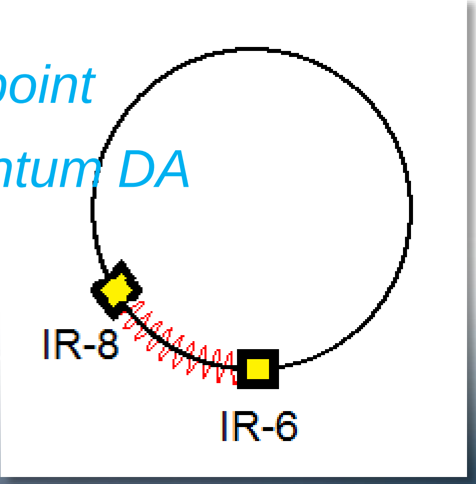
- On-momentum dynamic aperture with 2 IR and **2 family** sextupole correction exceeds 20 σ in tracking studies
- Off-momentum: Arrange phase advances between IRs such that IR-induced β-beats compensate each other

➔ need only 2 sextupole families (one per plane)

HERA-II experience with this concept:

- Without IR-IR compensation, no DA at desired working point

- With IR-IR compensation ➔ sufficient on-and off-momentum DA



- Need to confirm with systematic tracking

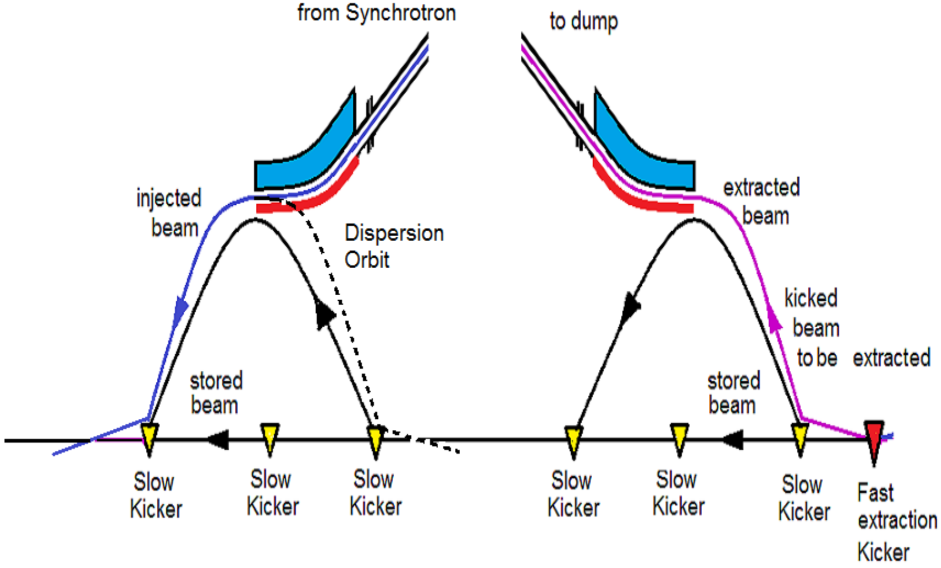
Fully Flexible Electron Spin Patterns

- Electron spin patterns with alternating polarization (as in RHIC proton fills) are required for single-spin physics
- Such fill patterns can be generated by a full-energy polarized injector
- Bunches with the "wrong" (parallel to guide field) polarization direction will slowly flip into the "right" (anti-parallel to guide field) orientation. Time scale given by Sokolov-Ternov self-polarization time
- Bunch-by-bunch replacement at 1Hz (330 bunches in 5.5 minutes, replacing "parallel" spins ~twice as fast as "anti-parallel" ones) yields sufficient polarization even at 18GeV where τ = 26min

Requires minimization of spin diffusion to maximize polarization lifetime, good intensity lifetime (> 1h) to minimize the beam-beam effect of electron bunch replacement on proton bunches, and fast kickers that only effect one bunch in the fill

Bunch Replacement

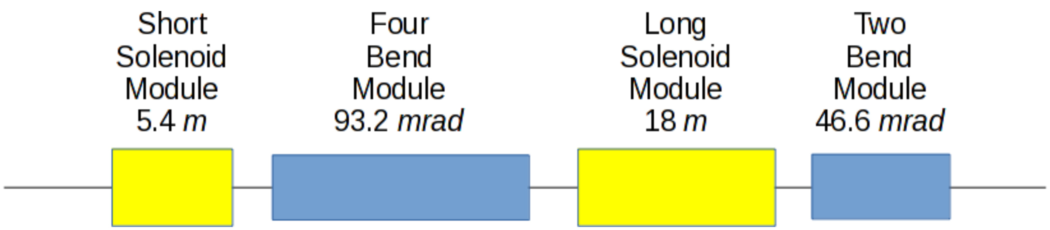
- Single bunches need to be replaced at up to 1Hz
- Replacing a 50nC bunch requires accumulation of 10nC bunches from the RCS
- Fast extraction kicker on top of slow bump to extract a single bunch



- Off-momentum injection/accumulation to avoid detector background and transient beam-beam effects on hadrons

Spin Rotator Concept

- Solenoid-based rotator concept:

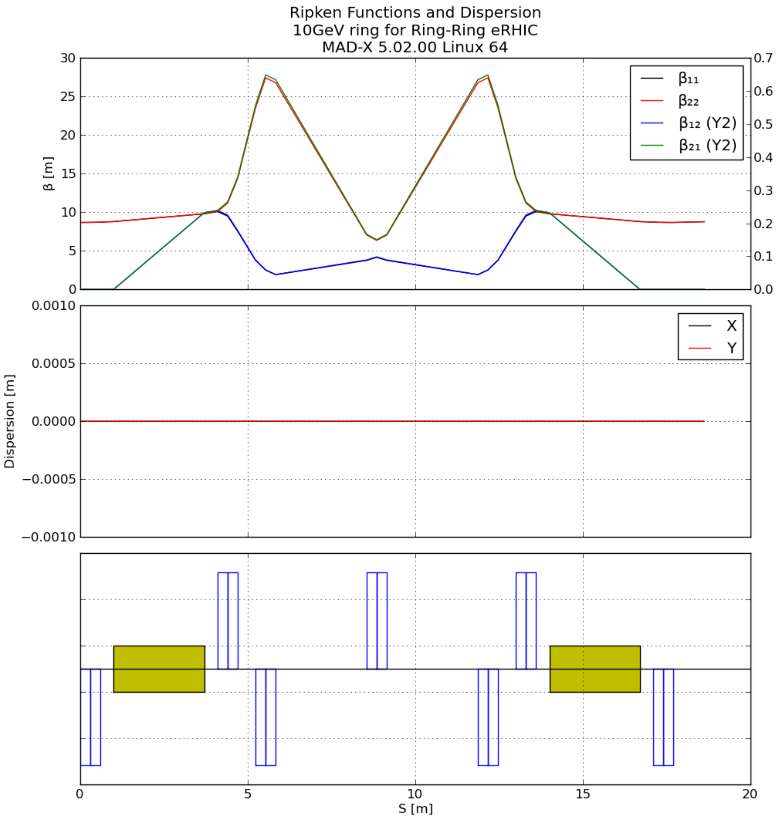


- One solenoid plus 46.6 mrad bend for 18 GeV, one solenoid plus 139.8 mrad bend for 5 GeV
- Use both solenoids at intermediate settings for energies in-between

Local Coupling Compensation of Rotator Solenoids

- Each solenoid is split into two segments, with five quadrupoles in-between

- Pairs of solenoid segments decouple each other locally



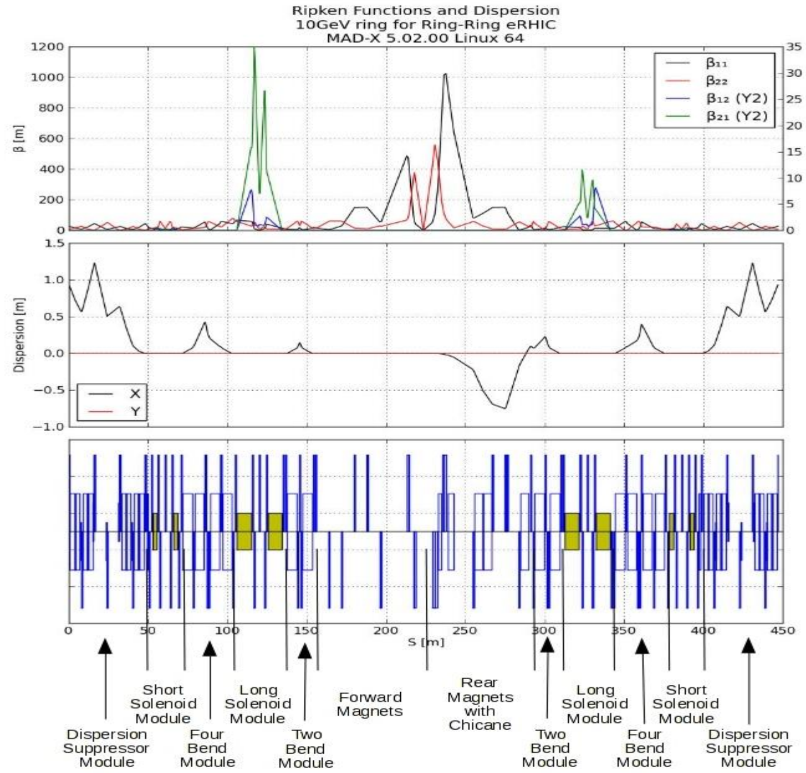
Solenoid module

Spin Matching and Tracking

- Only betatron spin matching conditions are considered so far
- Splitting each rotator solenoid into two segments, with the appropriate transport in-between, automatically results in a spin-matched solution for each pair of solenoid segments
- Longitudinal spin matching would require dispersion in the rotator section. While this is technically feasible it is difficult and may not be necessary for our purposes
- Spin tracking yields an equilibrium polarization of $P(t = \infty) = 50\%$. Sufficient due to fast bunch replacement.

IR Straight Section

- Complete IR straight section with low-β magnets, spin rotators, dispersion suppressors



Synchronization Scheme

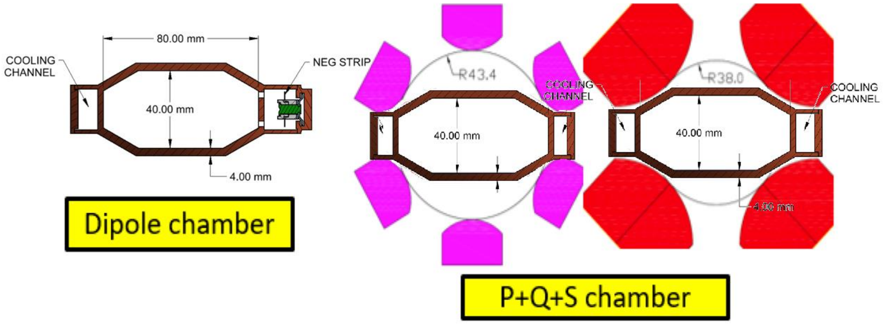
- Synchronization between electron and hadron beams is accomplished by path length changes of the hadron ring
- Between 100 and 275 GeV proton energy, hadron ring aperture is sufficient to allow radius change
- For 41 GeV proton energy, use an existing inner arc of the unused BLUE ring instead of the outer YELLOW arc to shorten circumference by ~90cm

Collective Effects

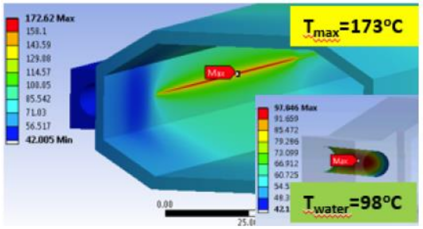
- Single bunch instabilities checked with standard code and appear to be stable.
- Transverse coupled bunch modes appear to be stable.
- Might need a longitudinal damper for coupled bunch instabilities.
- We consider the possibility of omitting the 3rd harmonic RF system ($$).
- **Fast ion instability** is expected to be present but manageable at SuperKEKB vacuum levels. Landau damping due to beam-beam likely sufficient to stabilize beam.

Storage Ring Vacuum System

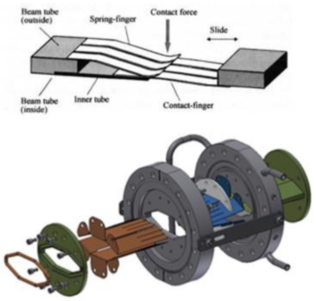
Vacuum chamber from **CuCrZr alloy**
Good thermal properties
Weldable
Easily available
Reasonable price



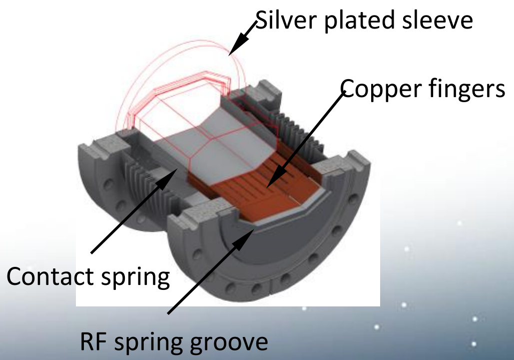
Thermal SR power load
ok
Maximum temperature 173°C
well below yield strength limit



Pumping based on
integrated NEG Pumps

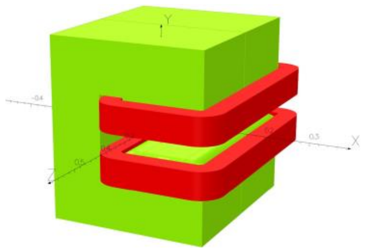


RF Bellows:
Critical element of the vacuum system
Improved NSLS-II bellow with outside
CuCr fingers good candidate

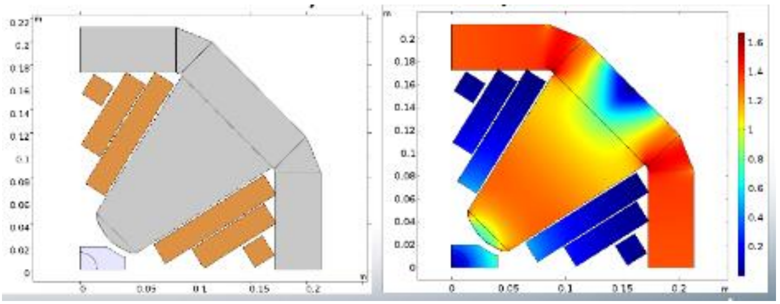


Magnets

- Design examples of all storage magnets have been developed



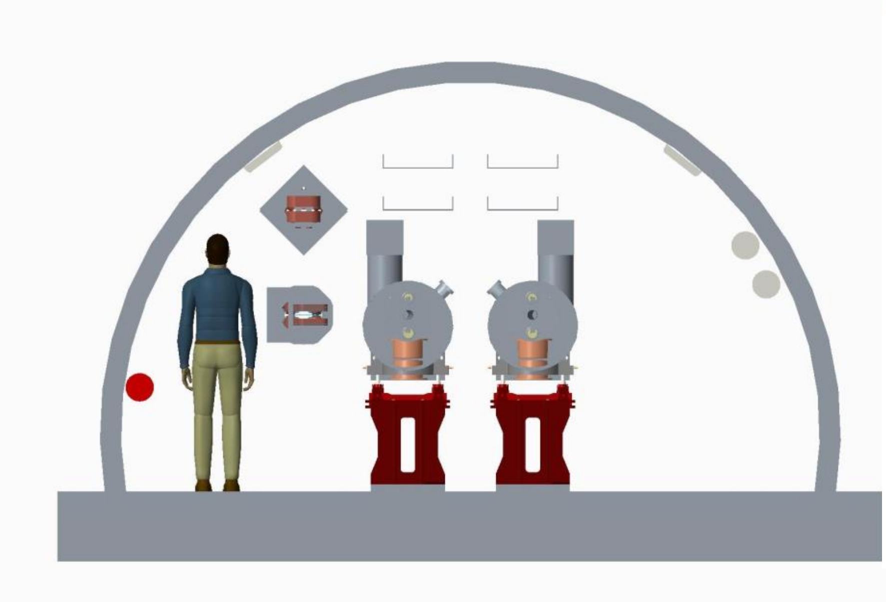
3D Geometry 0.7 tesla D2 dipole magnet

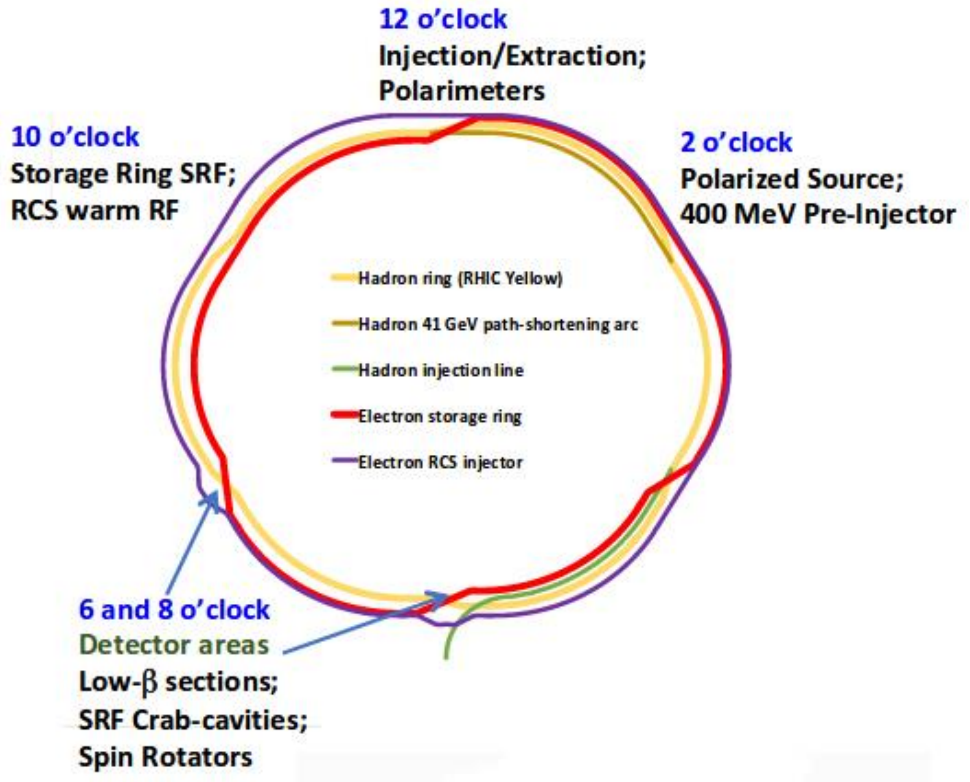


Main quadrupoles QF/QD, 18.4T/m

- All magnets fulfill field strength and quality requirements

Tunnel Layout





- Electron storage ring in same plane as hadron ring (alternative layout above hadron ring under consideration)
- Rings cross in four of the six straight sections to achieve equal circumference while providing additional space for RF in IR10

Costs and Schedule

Lab Base R&D	FY10+FY11	FY12+FY13	FY14+FY15	FY16+FY17	Totals
a) Funds allocated				838,019	838,019
b) Actual costs to date				838,019	838,019

Activity	Start Date	End Date
Storage Ring Design	May 1, 2017	November 3, 2017
Hadron Ring Design	May 1, 2017	November 25, 2017
Interaction Region	May 1, 2017	June 16, 2018
Overall Geometrical Layout	November 25, 2017	December 28, 2017

Summary

- FODO lattice with super-bends provides required emittances and damping decrement, while minimizing radiation power at high energy
- Dynamic aperture studies at 10GeV look promising, but need to include lattice errors
- 18GeV lattice expected to be more difficult for DA
- Spin studies at 18GeV (hardest case) yield sufficient polarization
- Synchronization via path length variation in hadron ring
- Collective effects are manageable
- Selected CuCrZr as vacuum pipe material; vacuum system components (bellows etc.) similar to KEKB, NSLS-II,…
- Design examples of all magnets