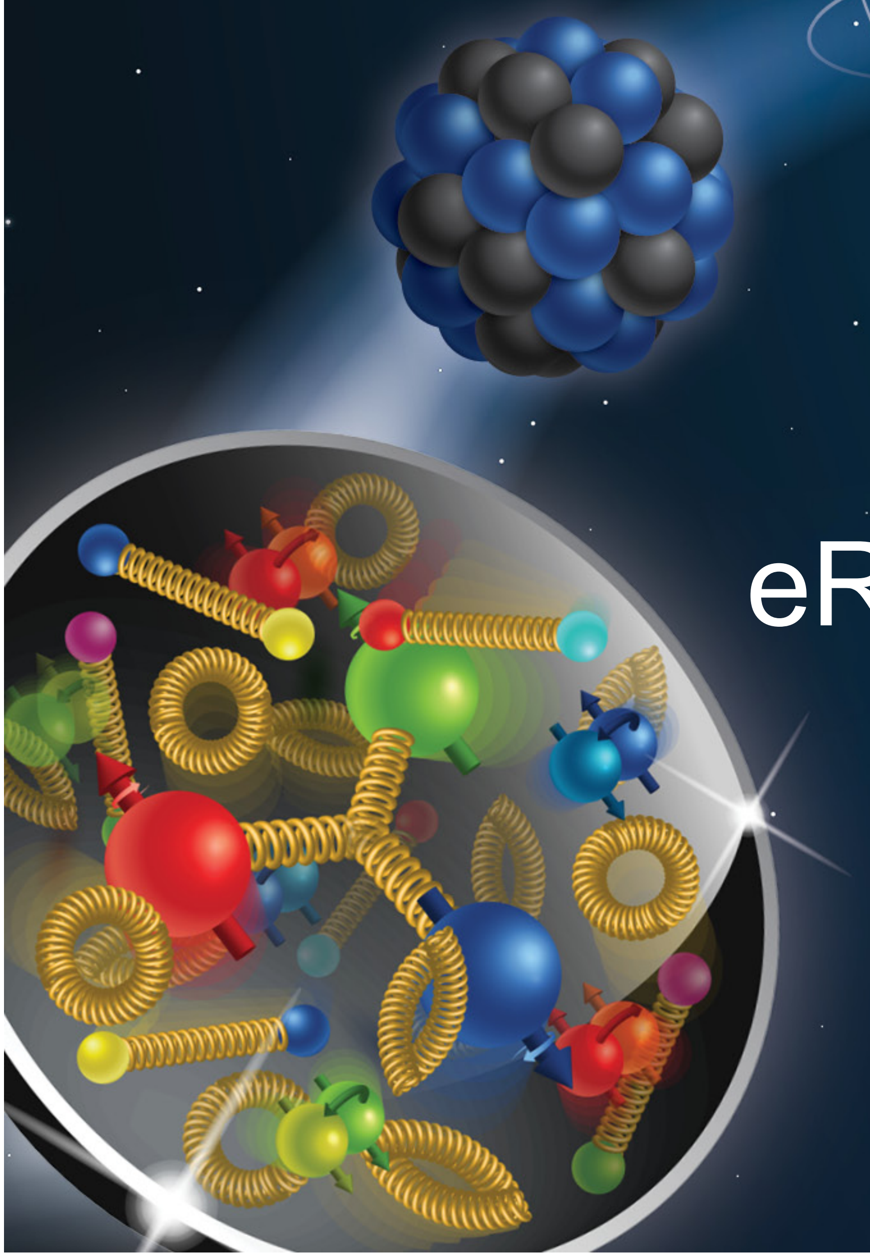

eRHIC Design Status

Vadim Ptitsyn

IPAC 2018

Vancouver, Canada

Electron Ion Collider – eRHIC

BROOKHAVEN NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY | Office of Science

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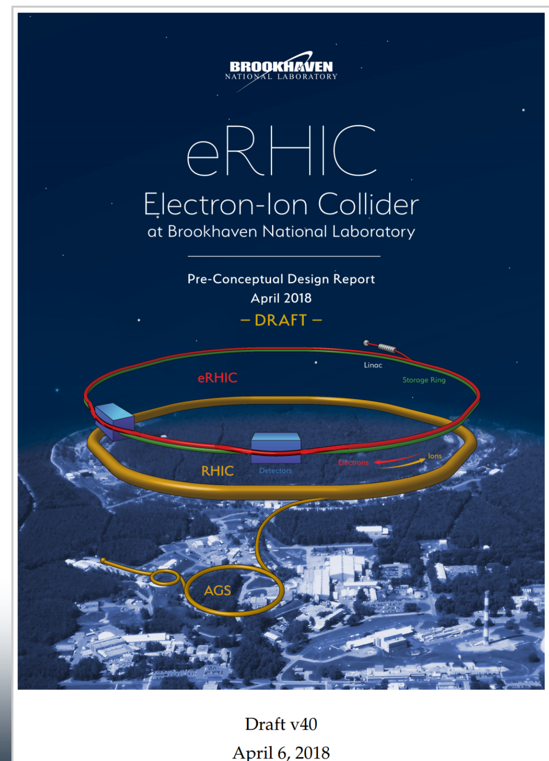
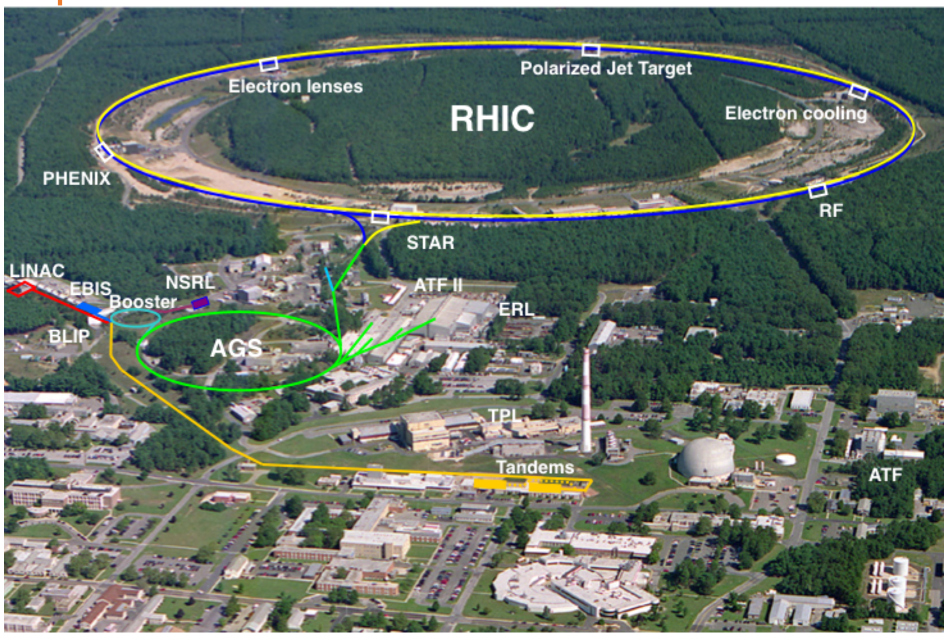
Also, we are in a final stage of preparing extensive (~800 pages) document:
eRHIC Pre-Conceptual Design Report.
Goal release date: the end of June.



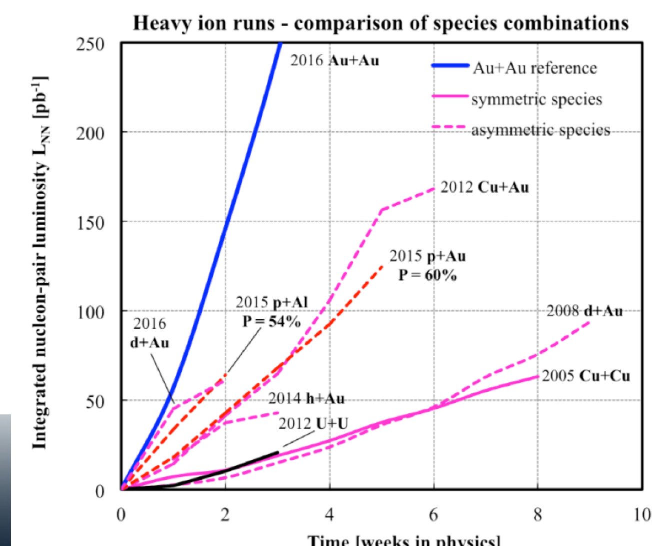
Relativistic Heavy Ion Collider at BNL

From 1999 operating with heavy ions and polarized proton collisions in several experiments

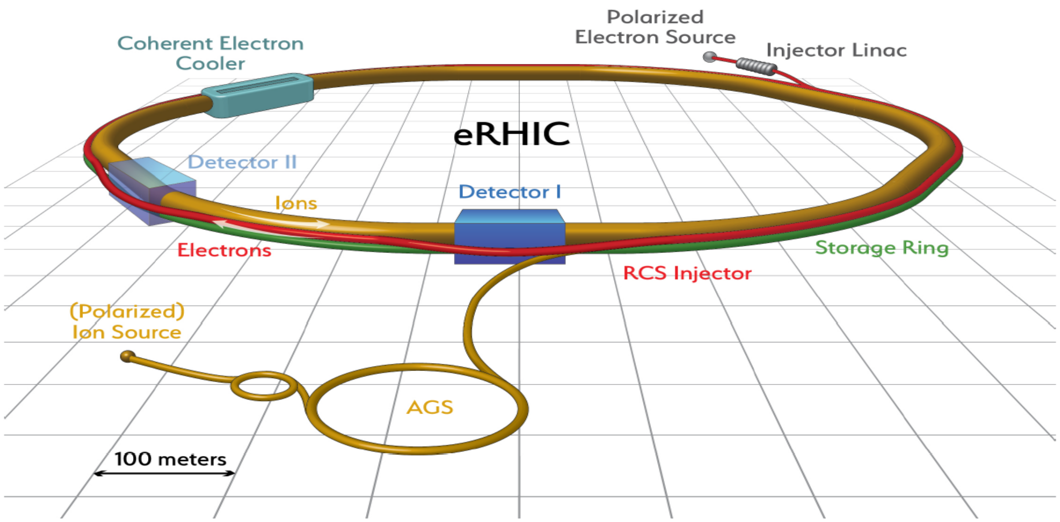


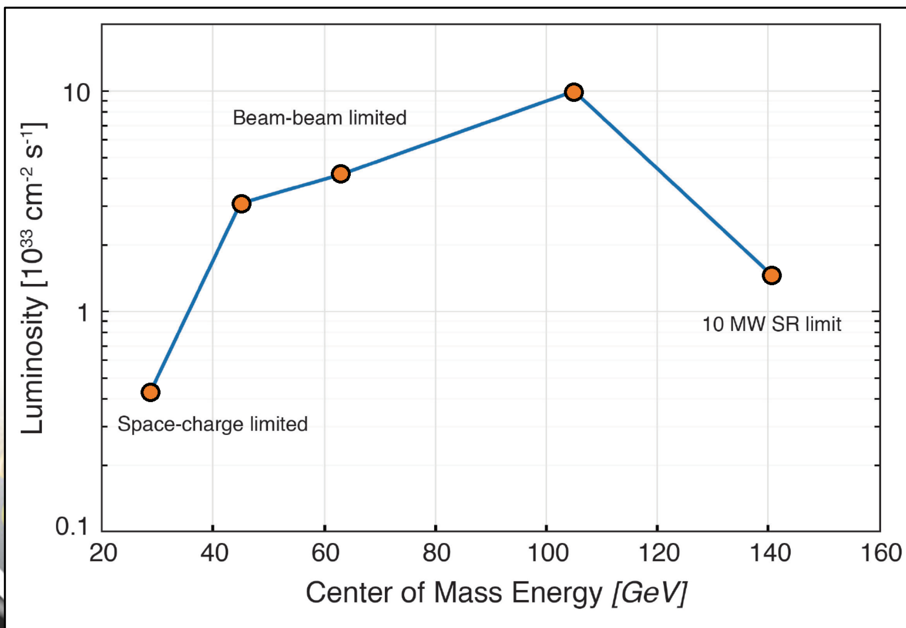
Circumference	: 3.8 km
Max dipole field	: 3.5 T
Energy	: 255 GeV p
	: 100 GeV/nucleon Au
Species	: p↑ to U (incl. asymmetric)
Experiments	: STAR, PHENIX (→ sPHENIX)

- Discovery and detailed study of properties of quark-gluon perfect fluid matter, existing at very origin of the Big Bang
- Study of proton spin composition, especially its gluon component
- Improving machine luminosity in every run
- Only place in the world with high energy polarized proton beams;
  employing numerous techniques and devices to achieve high proton polarization (up to 60%) of colliding beams
- Present plan: to continue A-A and polarized p-p experiments till 2024



eRHIC Design Concept

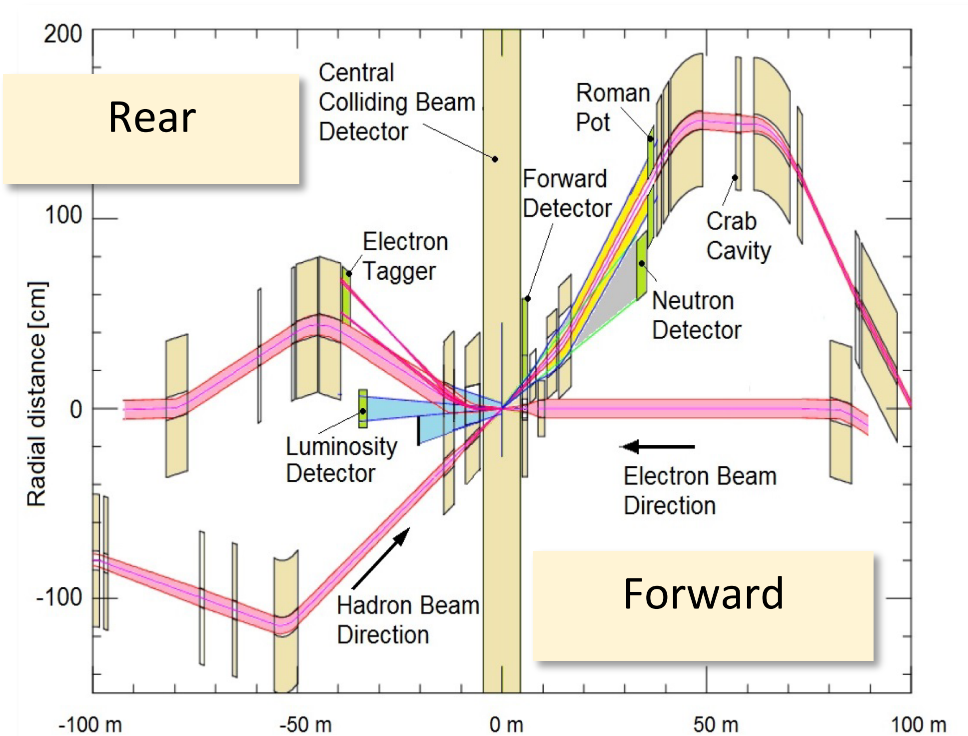


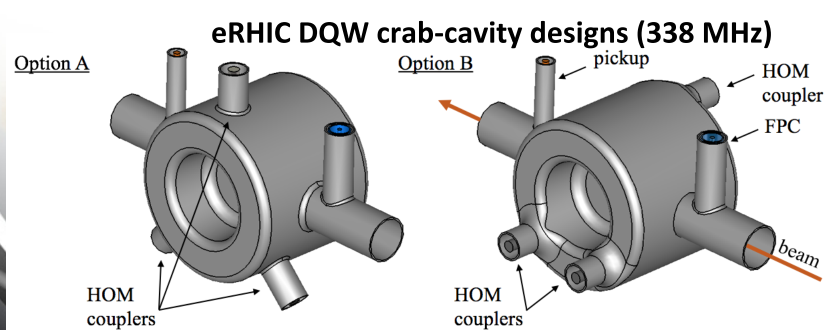


- Design goal: **$L = 10^{34} cm^{-2}s^{-1}$**
- eRHIC takes full advantage of existing RHIC complex, entirely re-using injection chain and one of RHIC rings.
- Electron storage ring and the electron injector (400 MeV linac and RCS) are added inside the existing RHIC tunnel.
- Wide coverage in Center-of-Mass energy: 29-140 GeV

  E_p: 41-275 GeV, E_e : 5-18 GeV
- Polarized beams (e, p, ^{3}He, d) with variable spin patterns
- Luminosity limitation factors on based of experience from previous colliders
- Hadron cooling is required to reach $L = 10^{34} cm^{-2}s^{-1}$;
  Without cooling the peak luminosity reaches 4.4 $10^{33} cm^{-2}s^{-1}$

eRHIC Interaction Region





- **Large detector acceptance**
  - ✧ No accelerator magnets +/-4.5 m
  - ✧ Forward detector components (neutron detector, "roman pots")
  - ✧ Large aperture of forward hadron
  - ✧ Limited beam divergence
  - ✧ Hadron dipole spectrometer magnet
- **Flat beams, small β^* for high luminosity**;

  β_x^*/β_y^*: 90cm/4cm for p, 42cm/5cm for e
- **Fast beam separation using 22 mrad crossing angle**

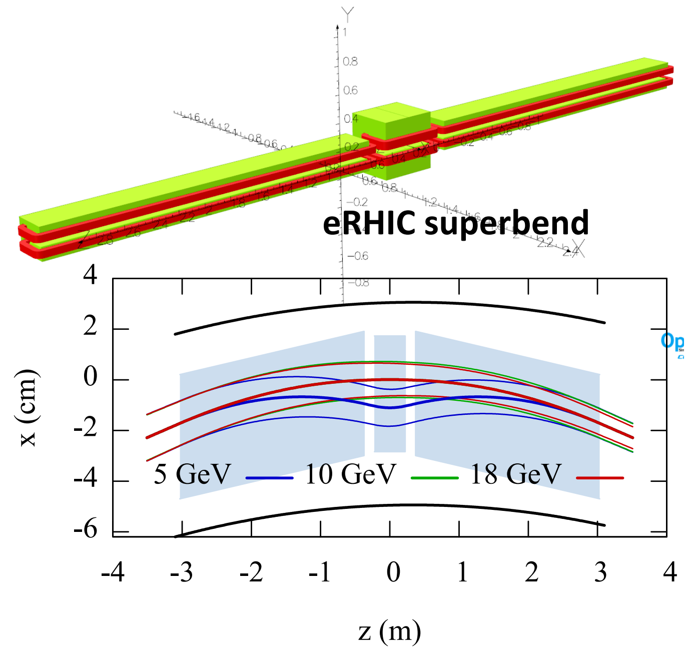
  Crab crossing using hadron and electron crab cavities 90° from IP
- **Managing synchrotron radiation**,
  - ✧ no electron bends on the forward side
  - ✧ large aperture electron magnets on rear side *absorbing SR far from IP*
  - ✧ masks against backscattered SR photons
- **Electron chicane on rear side**

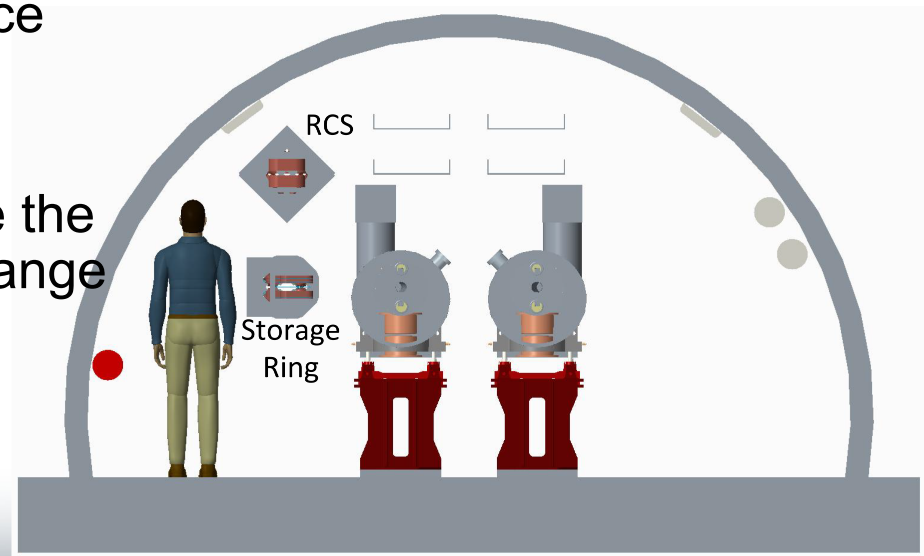
  supporting luminosity measurements and electron tagging

Novel types of magnets in the IR are required

Electron Storage Ring

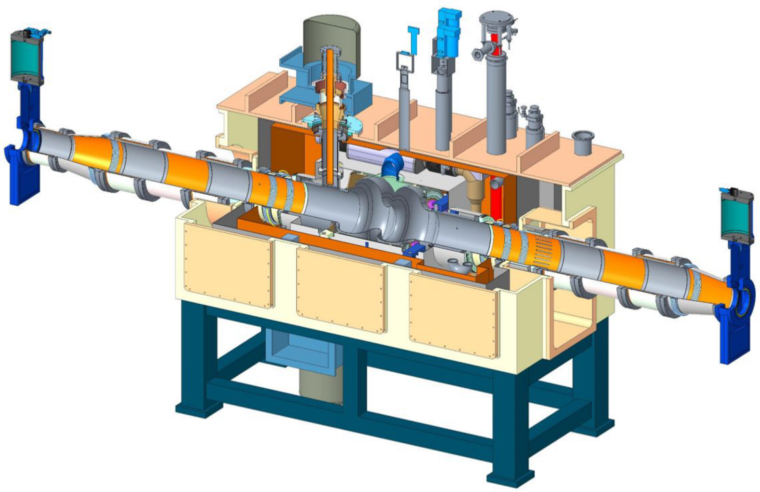
- High intensity storage ring (I_e up to 2.5 A) based on accelerator technologies of B-factories and HERA
- 10 MW of synchrotron radiation (self-imposed limit) at 10-18 GeV
- Composed of six FODO arcs with 60º /cell for 5-10 GeV and 90º /cell for 18 GeV
- Super-bends for 5-10 GeV for emittance and damping decrement control
- Spin rotators based on interleaved solenoidal and dipole magnets provide the longitudinal polarization in all energy range (5-18 GeV)





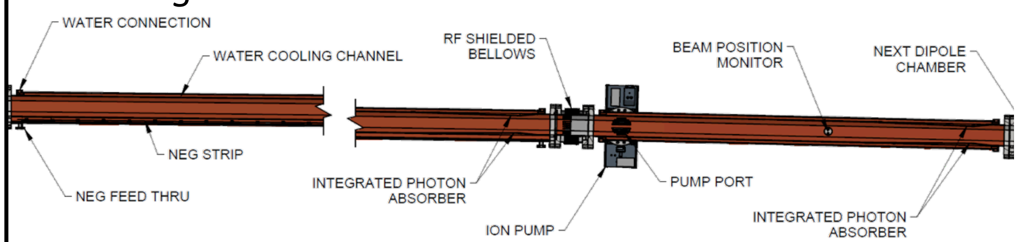
Storage Ring Components

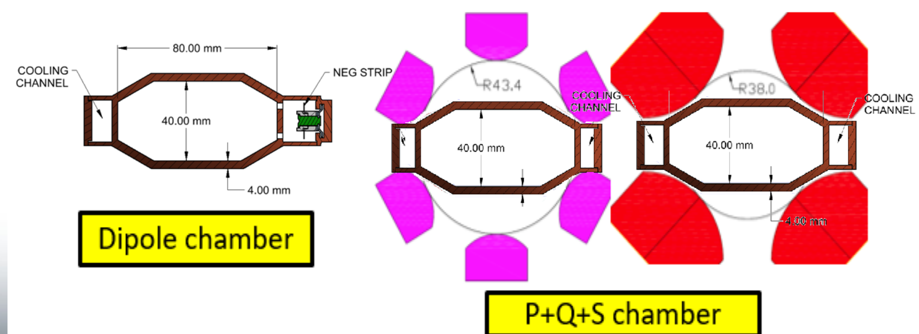
Preliminary design of various SR components has been done.



- Single 2-cell 563 MHz SRF cavity per cryomodule
- Operating at 2 K.
- 2x 500 kW adjustable fundamental power couplers.
- 4x SiC Beamline HOM Absorbers (BLAs).
- 12 cryomodules in total.
- Multibeam IOT is the likely option for the power source.

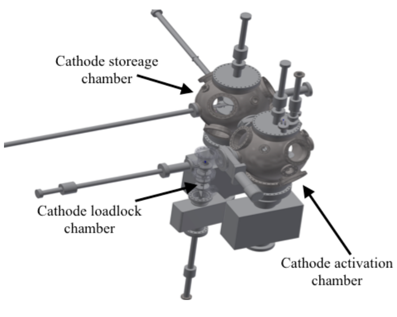
- Vacuum chamber from CuCrZr Alloy
  Good thermal and mechanical properties, Easily available at reasonable price
- Pumping based on integrated NEG Pumps
- Thermal SR Power Load – OK
  Maximum temperature 173°C well below yield strength limit



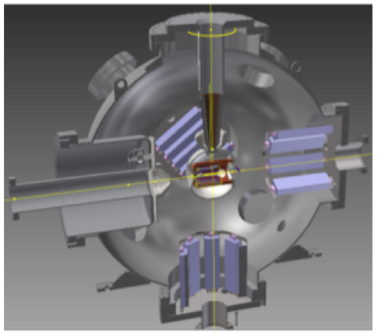


Electron Injector

- Full energy injector provides 5-10 nC bunches at 1 Hz rate with alternating (up and down) spin.
- The eRHIC polarized electron gun has been designed based on experience from both SLC PES high charge gun and JLab inverted guns. *Construction of a polarized electron source as one of the eRHIC R&D projects is in progress.*
- 2.856 GHz 400 MeV pre-injector has been simulated. Meets the requirements.
- Spin transparent Rapid Cycling Synchrotron is used for acceleration from 0.4 GeV up to 18 GeV .
  - High lattice quasi-symmetry with spin-transparent straight sections suppress intrinsic depolarizing resonance during the ramp
  - 100-200 ms acceleration ramp is sufficiently fast to cross resonances without loss of polarization
- Swap-out injection into the storage ring is used to maximize the beam polarization. *Injection/accumulation is done in longitudinal plane to avoid transient beam-beam effects.*



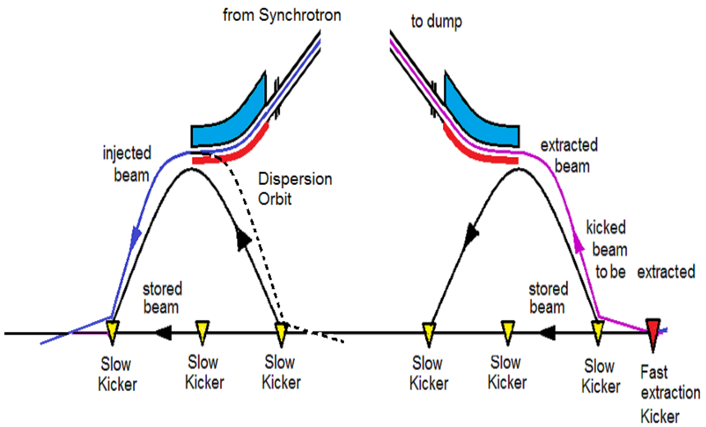
Cathode preparation system



HV DC Gun

eRHIC polarized gun

eRHIC swap-out injection scheme



eRHIC R&D Program is underway

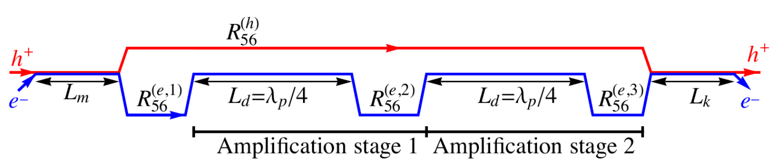
- Strong Hadron Cooling
  - Theoretical and simulation studies of advanced techniques
  - Coherent electron Cooling experimental Proof-of-Principle test at RHIC
  - High-current multi-pass ERL using FFAG recirculation passes (CBETA facility at Cornell)
- Active shielding technology for IR magnets
- In-situ coating of RHIC beam pipe
- High charge polarized electron gun prototype
- Crab-cavities: prototypes and study of related beam dynamics
- Beam-beam simulation studies
- Polarized ^{3}He production and acceleration

Strong Hadron Cooling

Different methods of strong hadron cooling are being explored.
Goal to achieve cooling time <2h for 275 GeV protons

Coherent electron cooling with FEL amplifier or micro-bunching amplifier

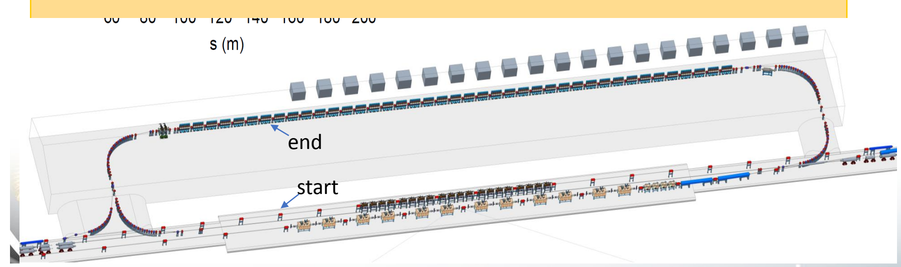
- Most promising approach at this point is micro-bunched electron beam cooling with 2 plasma amplification stages.



- Required cooling rates are achieved with ~100 mA electron current in 150 MeV 3-turn ERL-based accelerator
- CeC with FEL amplifier: PoP experiment being carried on at RHIC

Bunched Beam Electron Cooling with an electron storage ring

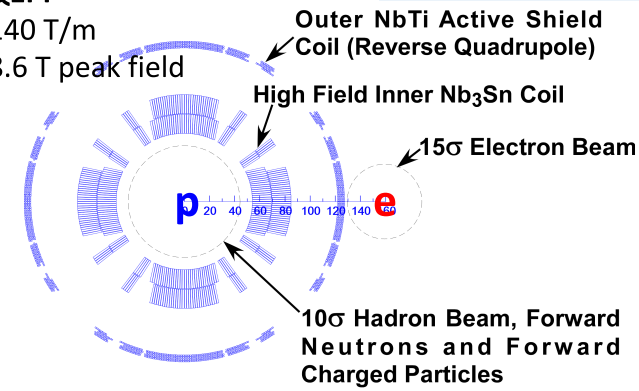
- Ampere scale beam current
- The electron dynamics are dominated by IBS and radiation damping.
- 200m, 4T H wiggler with 5 cm period
- Arcs with 15 m radius and good focusing



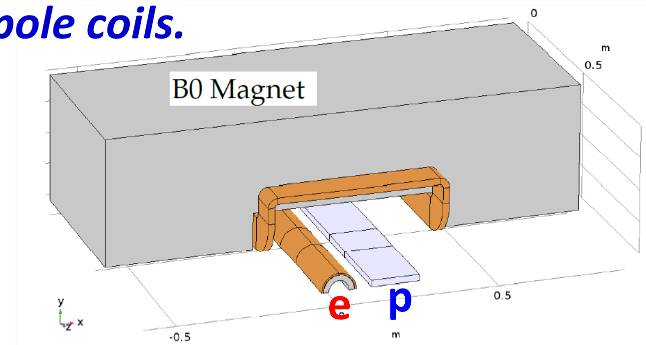
IR magnets

Variety of novel approaches is used for IR magnets

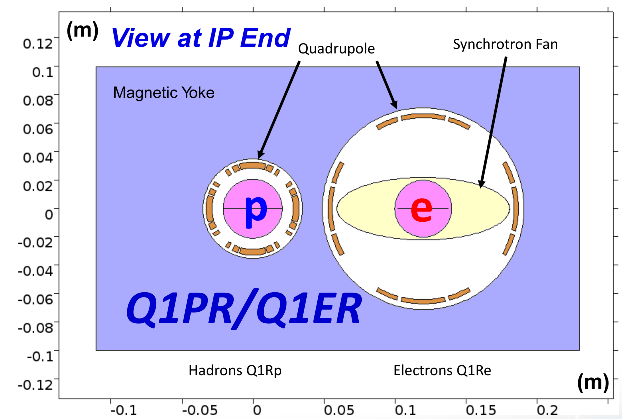
Q1PF
140 T/m
8.6 T peak field

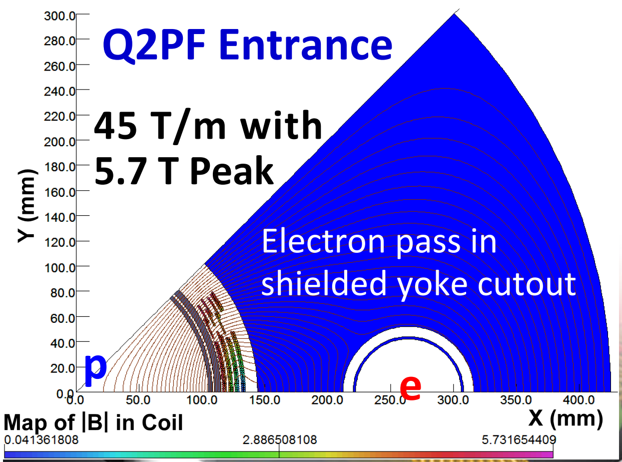


Hadron spectrometer magnet with detector elements inside. Superconducting coils. For electrons: dipole cancelling coil and quadrupole coils.



Funded **BNL/Jlab R&D effort**: designing, building and testing a short prototype based on existing Nb_3Sn coils (from LARP work) actively shielded by new NbTi coil.





Concept for a Direct Wind tapered coil design for Q1PR that has a nearly constant gradient along its entire length

Beam-Beam Physics

- ξ_p =0.013, ξ_e = 0.1
- Operate electrons near integer Resonance
  $Q_{x,y} \gtrsim$ integer to benefit from pinch effect

Concerns:

- Slow emittance growth, examined using long term weak-strong simulation

➔ No evidence

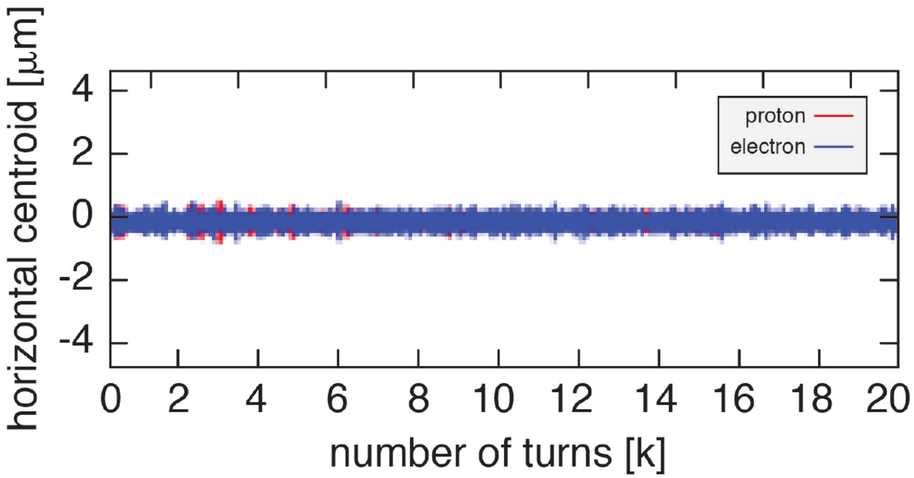
- Coherent beam-beam instability as observed in HERA occasionally
  Examined by strong-strong simulations using several codes

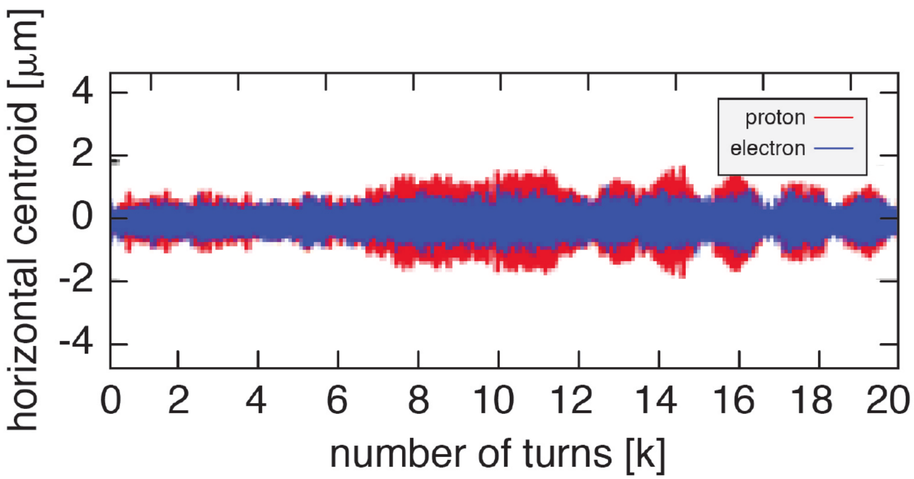
➔ Threshold found for N_p = 2 x N_p-design

- Radiation found not to have a strong impact

- Crab-crossing studies are underway.

➔ May affect the choice of the working point and/or crab-cavity frequency

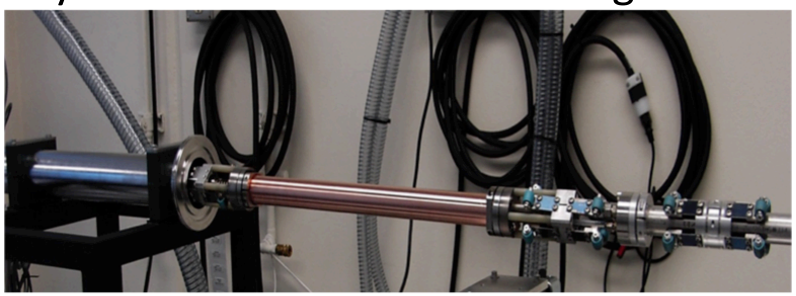




Increasing proton intensity and repetition rate

Proton parameters	Achieved at RHIC	eRHIC nominal
Beam current, mA	330	1000
Bunch frequency, MHz	9.4	112.6
Peak current, A	12	24

In-situ copper coating of existing stainless steel beam pipe to reduce cryo-load from resistive heating.



Magnetron mole for coating long narrow tubes has been designed and built. Presently: equipment testing and preparing for coated surface measurements

Electron cloud

- Beam scrubbing is an efficient tool based on LHC experience
- But additional remedies may be needed to reduce SEY. Under evaluation:
  - aC coating (using the tooling developed for Cu-coating)
  - Laser-engineered grooving
- e-cloud simulation studies are on-going (PyEcloud, CSEC)

Required hardware upgrades:

- New injection kickers (<12 ns rise time)
- RF system upgrade to incorporate bunch splitting and bunch compression

Summary

- eRHIC takes full advantage of existing RHIC complex, entirely re-using injection chain, one of RHIC rings and existing infrastructure.
- Electron accelerator based on 18 GeV storage ring and the full energy polarized injector is added into the RHIC tunnel.
- Goal luminosity **$L = 10^{34} cm^{-2}s^{-1}$** achieved with strong hadron cooling, which is a topic of ongoing R&D.
- A fall back position without cooling has a respectable peak luminosity of **$L = 0.44 \cdot 10^{34} cm^{-2}s^{-1}$** .
- eRHIC design for storage ring based electron accelerator has progressed very well and will result in the pCDR document in June 2018.
- Wide R&D program is underway which addresses the hadron cooling, IR magnets, beam-beam effects, polarized sources, and others important aspects of eRHIC design.