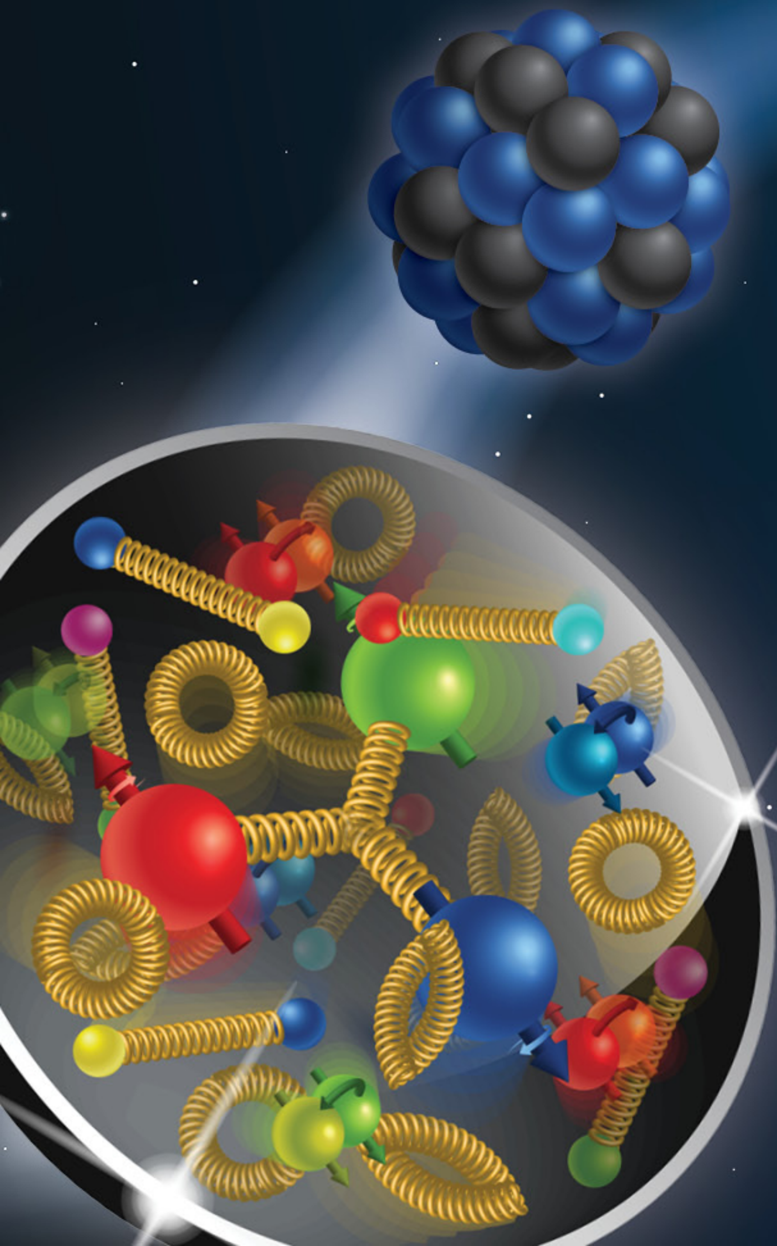

eRHIC Design Update

Christoph Montag, BNL

NAPAC'19

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Electron Ion Collider – eRHIC

BROOKHAVEN NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY | Office of Science

eRHIC Team

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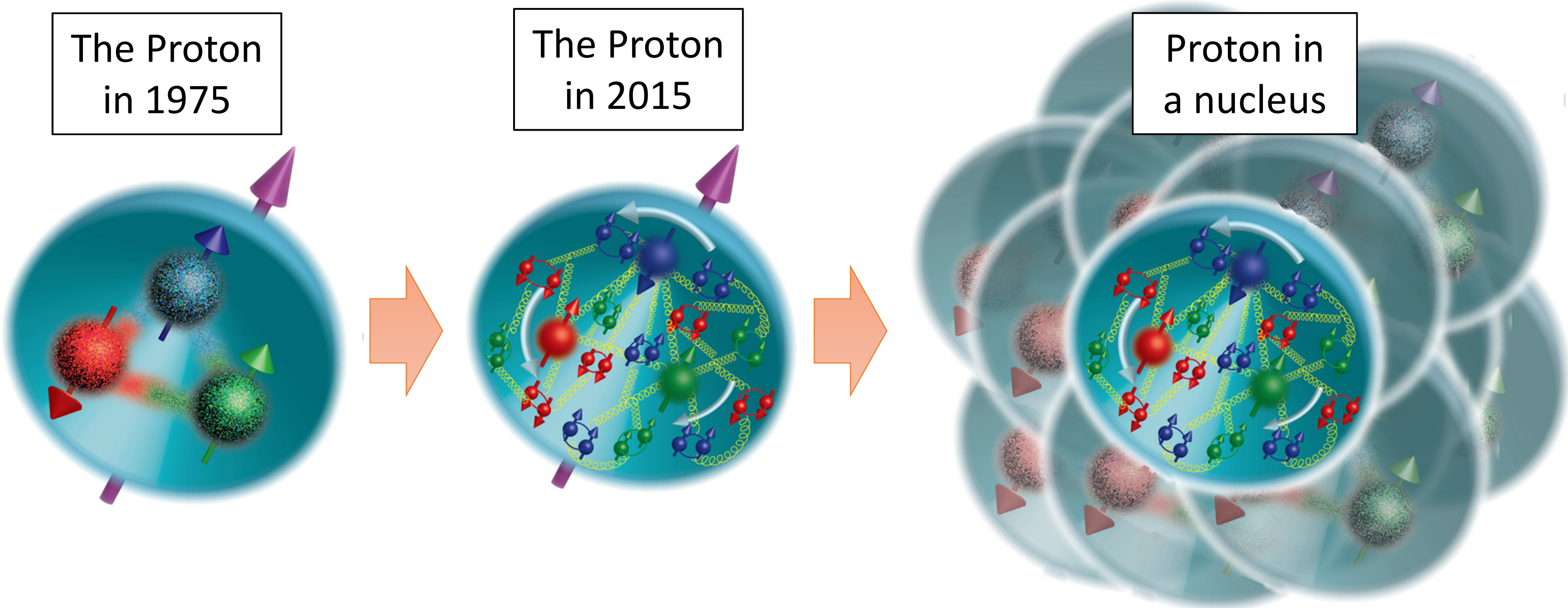
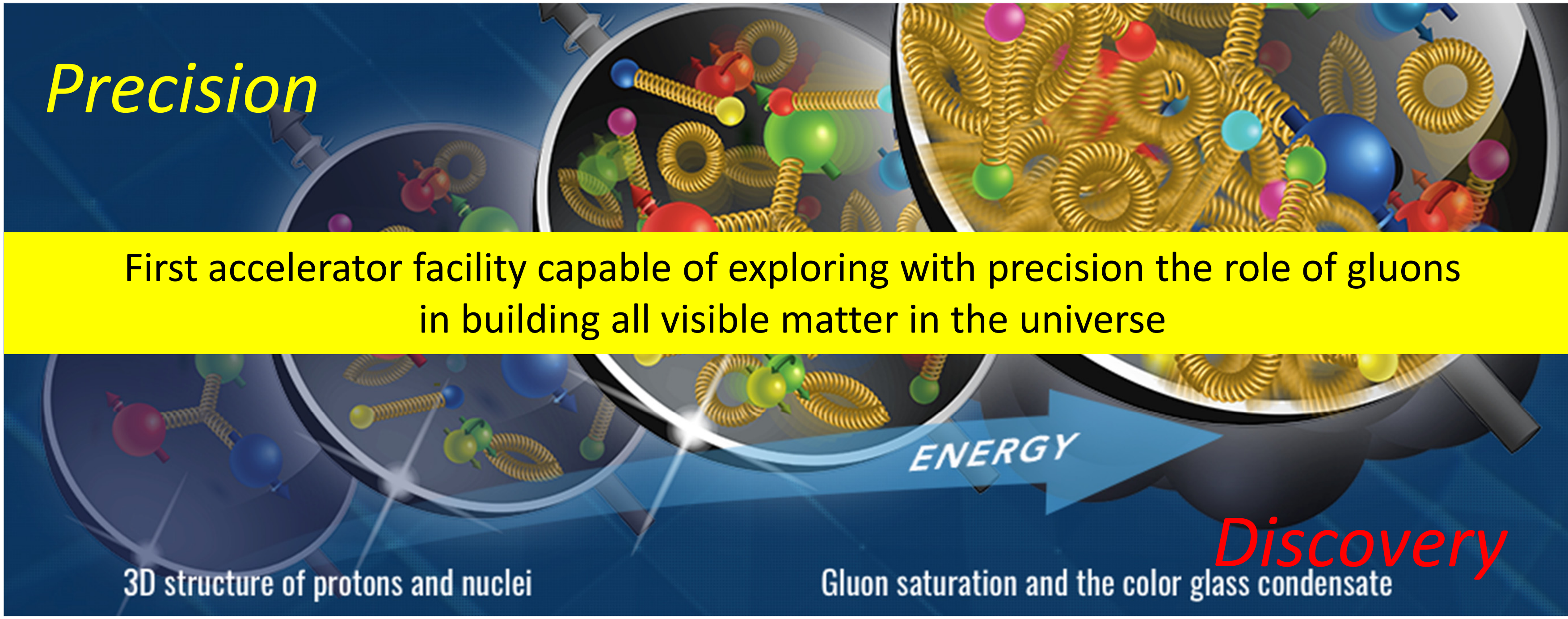
Modern view of the nucleus



The goal of the EIC is to provide us with an understanding of the internal structure of the proton and more complex atomic nuclei that is comparable to our knowledge of the electronic structure of atoms themselves, which lies at the heart of modern technologies.

EIC: Compelling Science Case



First accelerator facility capable of exploring with precision the role of gluons in building all visible matter in the universe

NAS Study of the Science Case for a U.S. based EIC

In summary, the committee finds a compelling scientific case for such a facility. The science questions that an EIC will answer are central to completing an understanding of atoms as well as being integral to the agenda of nuclear physics today. In addition, the development of an EIC would advance accelerator science and technology in nuclear science; it would as well benefit other fields of accelerator based science and society, from medicine through materials science to elementary particle physics.

Requirements for the EIC

Requirements for an Electron-Ion Collider are defined in the White Paper:

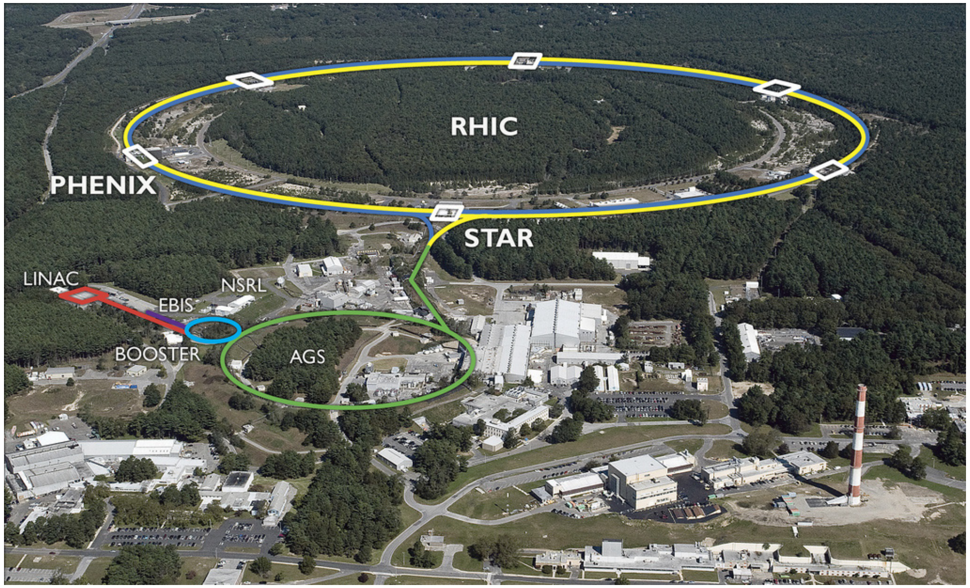
- High luminosity: L = 10^{33} to 10^{34} $cm^{-2}sec^{-1}$ - factor 100 to 1000 beyond HERA
- Large range of center-of-mass energies E_{cm}= 20 to 140 GeV
- Polarized beams with flexible spin patterns
- Favorable condition for detector acceptance such as p_T =200 MeV
- Large range of hadron species: protons ….Uranium
- Collisions of electrons with polarized protons and light ions (↑^{3}He, ↑d,…)

➔

eRHIC meets or exceeds the requirements formulated in the White Paper on EIC

RHIC

- Two superconducting 4T storage rings
- 3.8km circumference
- Energy up to 255GeV protons, or 100GeV/n gold
- 110 bunches/beam
- Ion species from protons to uranium

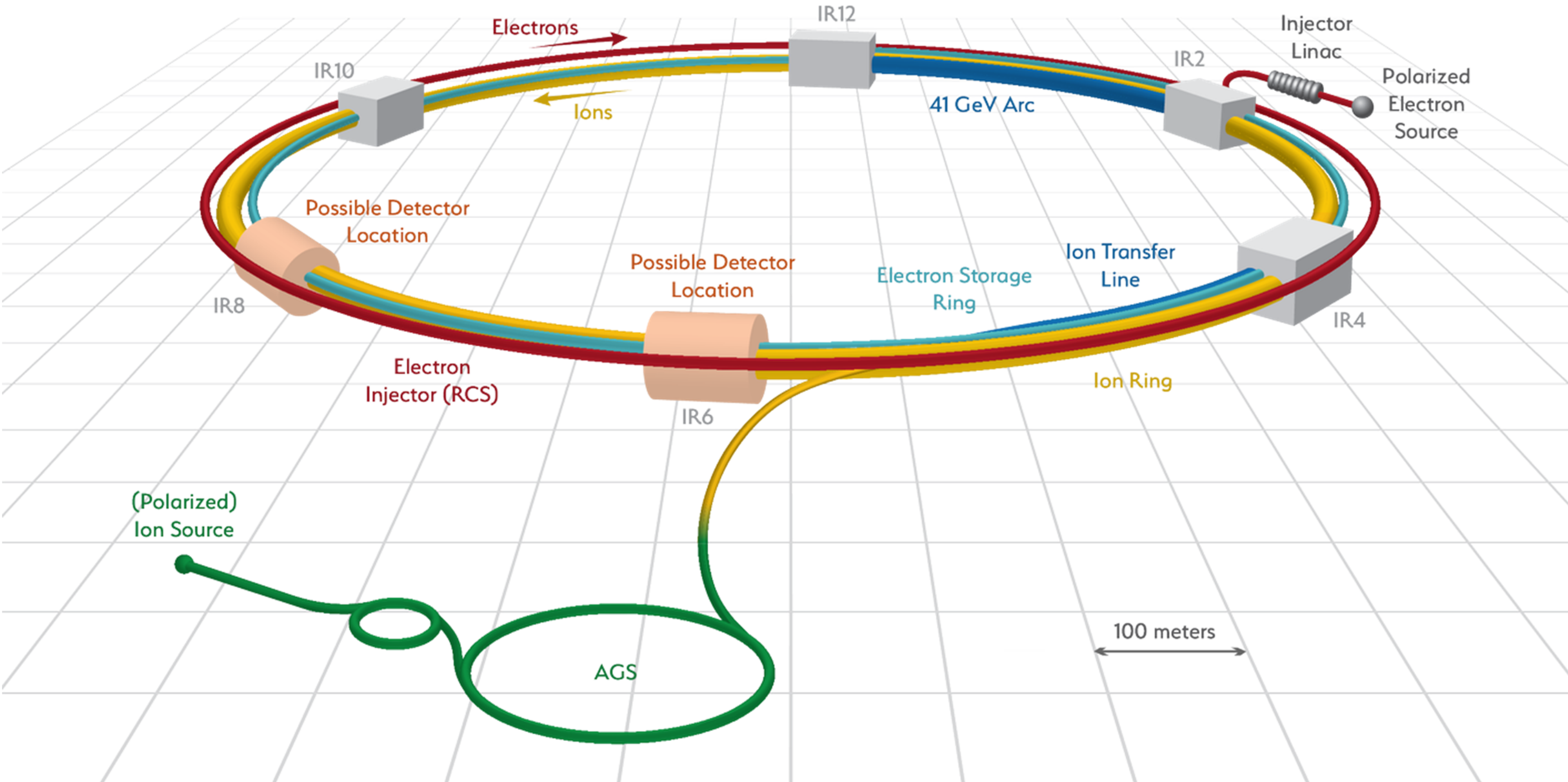


- 60% proton polarization – world's only polarized proton collider
- Exceeded design luminosity by factor 44 - unprecedented
- 6 interaction regions, 2 detectors
- In operation since 2001

eRHIC Design Concept

- Take one RHIC ring ("Yellow") with its entire injector complex as the eRHIC hadron ring
- Add electron cooling to lower emittance and counteract IBS
- Modify the hadron ring to be suitable for eRHIC beam parameters
- Add an electron storage ring in the existing tunnel
- Use a spin-transparent rapid-cycling synchrotron as full-energy polarized electron injector for rapid bunch replacement to counteract depolarization
- Build a high luminosity interaction region that fulfills acceptance requirements

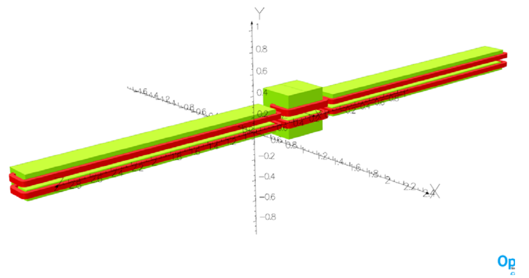
Facility layout

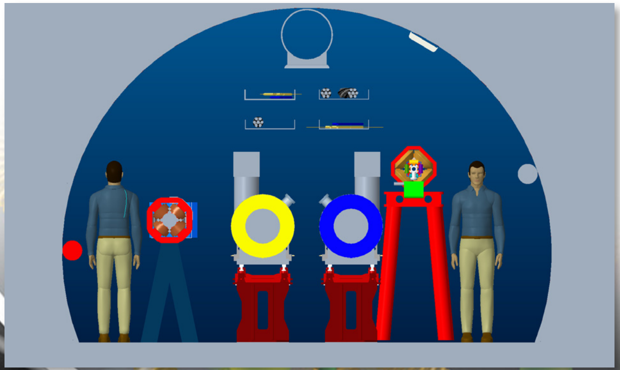


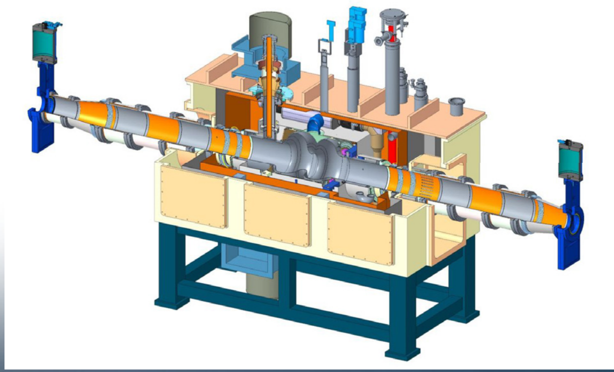
Electron complex to be installed in existing RHIC tunnel – cost effective

Electron Storage Ring

- Composed of six FODO arcs with 60º /cell for 5 to 10 GeV
  90º /cell for 18 GeV
- Super-bends for 5 to 10 GeV for emittance control
- 5 straight sections with simple layout, plus IR straight
- Radiate approx. 10 MW for maximum luminosity para 10GeV
- 14 superconducting 2-cell 591 MHz RF cavities
- Optimization yields 20σ transverse dynamic aperture, 12σ momentum acceptance at 10 GeV
- Spin tracking predicts 70% average polarization at 18 GeV, more at lower energies







Hadron Storage Ring Modifications

- “Yellow” RHIC ring will serve as eRHIC hadron ring
- In-situ beam pipe coating with copper and amorphous carbon to improve conductivity and reduce SEY
- Four additional Siberian snakes for polarized deuterons and helions; will also increase proton polarization to ~80 percent
- “Blue” arc from IR6 to IR4 as transfer line extension to new injection area
- “Blue” inner arc between IRs 12 and 2 for circumference matching during 41 GeV low-energy operation
- (Energy range from 100 to 275 GeV can be covered by radial shift)

Parameters for Highest Luminosity

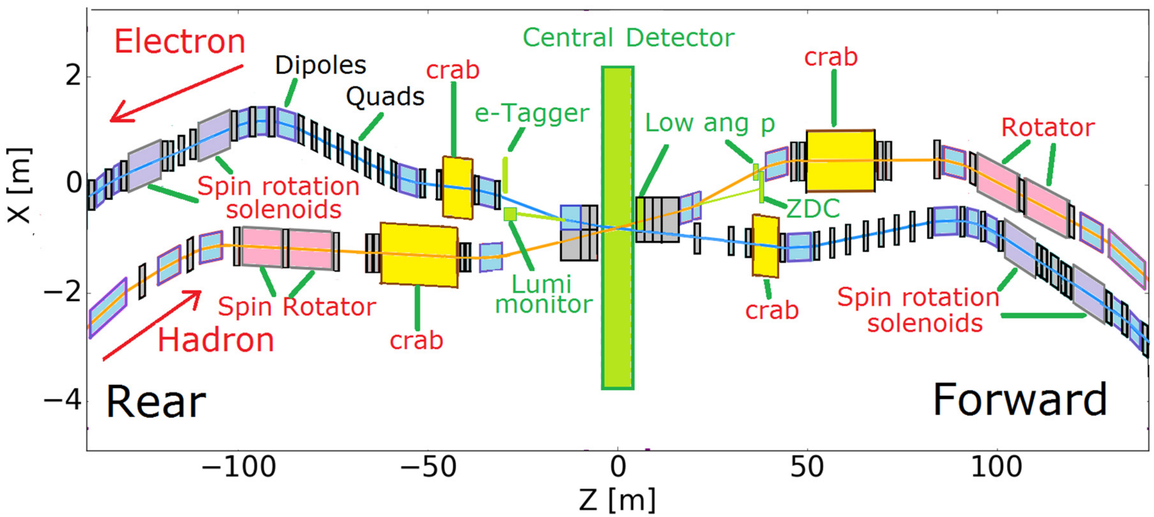
	proton	electron
no. of bunches	1160	
energy [GeV]	275	10
bunch intensity [10^{10}]	6.9	17.2
beam current [A]	1.0	2.5
ϵ_{RMS} hor./vert. [nm]	9.6/1.5	20.0/1.2
$\beta^*_{x,y}$ [cm]	90/4	43/5
b.-b. param. hor./vert.	0.014/0.007	0.073/0.100
σ_s [cm]	6	2
$\sigma_{\mathrm{d}p/p}$ [10^{-4}]	6.8	5.8
τ_{IBS} long./transv. [h]	3.4/2.0	N/A
L [$10^{33}\,\mathrm{cm}^{-2}\mathrm{sec}^{-1}$]	10.05	

- Hadron beam parameters similar to present RHIC, but smaller vertical emittance and many more bunches
- 2 hour IBS growth time requires strong hadron cooling
- Electron beam parameters resemble a B-Factory

Alternative to Strong Hadron Cooling

- 2 hour IBS growth time requires strong cooling
- Hadron beam cooling at full energy is very challenging
- Use existing BLUE ring as full-energy injector (requires polarity reversal of quench protection diodes)
- Cool proton bunches at (or slightly above) 25 GeV injection energy in the BLUE ring – much easier due to strong energy dependence of cooling force
- Ramp BLUE ring and replace entire fill every ~hour (< IBS growth time of 2h). Average luminosity is >90 percent of peak luminosity

Interaction Region



- +/- 4.5 m machine-element free space for central detector
- 25 mrad total crossing angle
- Transverse momentum acceptance down to 200 MeV/c
- Peak magnetic fields below 6T (NbTi sufficient)
- Most magnets direct-wind; few collared magnets

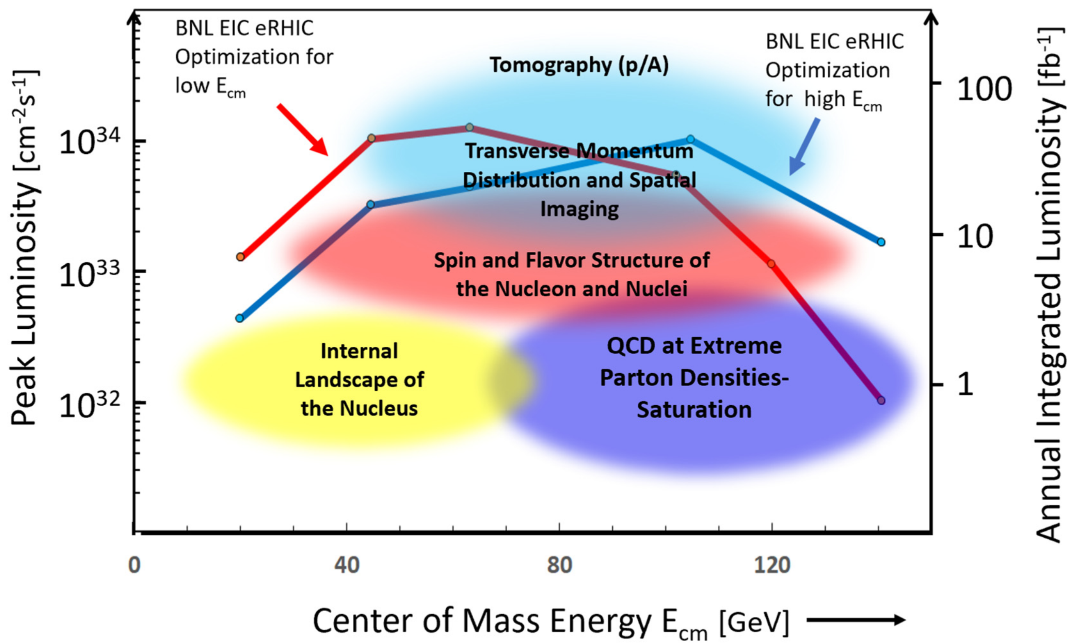
Optimization at Lower CoM Energies

- Lower beam energies allow magnet placement closer to IP due to larger scattering angles
- Larger crossing angle for early separation
- Lower beam energies allow larger magnet apertures for same focusing strength
- Lower bunch intensities, more bunches to limit IBS and space charge
- Electron cooling much easier due to lower hadron beam energy

	Low CM Energy	High CM Energy
CM energy [GeV]	63	105
Crossing angle [mrad]	50	25
Max. β-function [m]	2700	1800
τ_{IBS} long./transv. [h]	0.4/0.4	3.4/2.0
Luminosity [$10^{33}\,cm^{-2}sec^{-1}$]	12.4	10.0

Luminosity Curves

Optimizations at 63 GeV and 105 GeV CoM energy



Either optimization spans entire energy range, with different emphasis depending on physics goals

Summary

- eRHIC design reaches a peak luminosity of

$$\mathbf{L= 1.05 \cdot 10^{34} cm^{-2} s^{-1}}$$

- However, this can only be achieved with strong hadron cooling, which is beyond state of the art (highest energy electron cooling so far was achieved in 8 GeV FNAL Recycler Ring, with DC beam), and is a topic of ongoing R&D.
- An alternative scheme using a full-energy injector exists that needs electron cooling at 25 GeV injection energy only – much easier
- High acceptance IR design based on NbTi magnet technology with 6 T peak field. Mostly direct wind magnets, only few collared ones
- Simulations yield sufficient dynamic aperture (at 10 GeV) and 70% polarization (at 18 GeV) in the electron ring
- Luminosity optimization at lower energy yields $\mathbf{L= 1.2 \cdot 10^{34} cm^{-2} s^{-1}}$ at 63 GeV CoM energy

eRHIC at NAPAC'19

- IR Design: TUZBA2
- Beam-beam: TUPLO06, TUPLO07
- Fast Ion Instability: TUPLM11, TUPLM25
- Bunched Beam Electron Cooling: THZBA5
- Hadron Abort System: TUPLO03