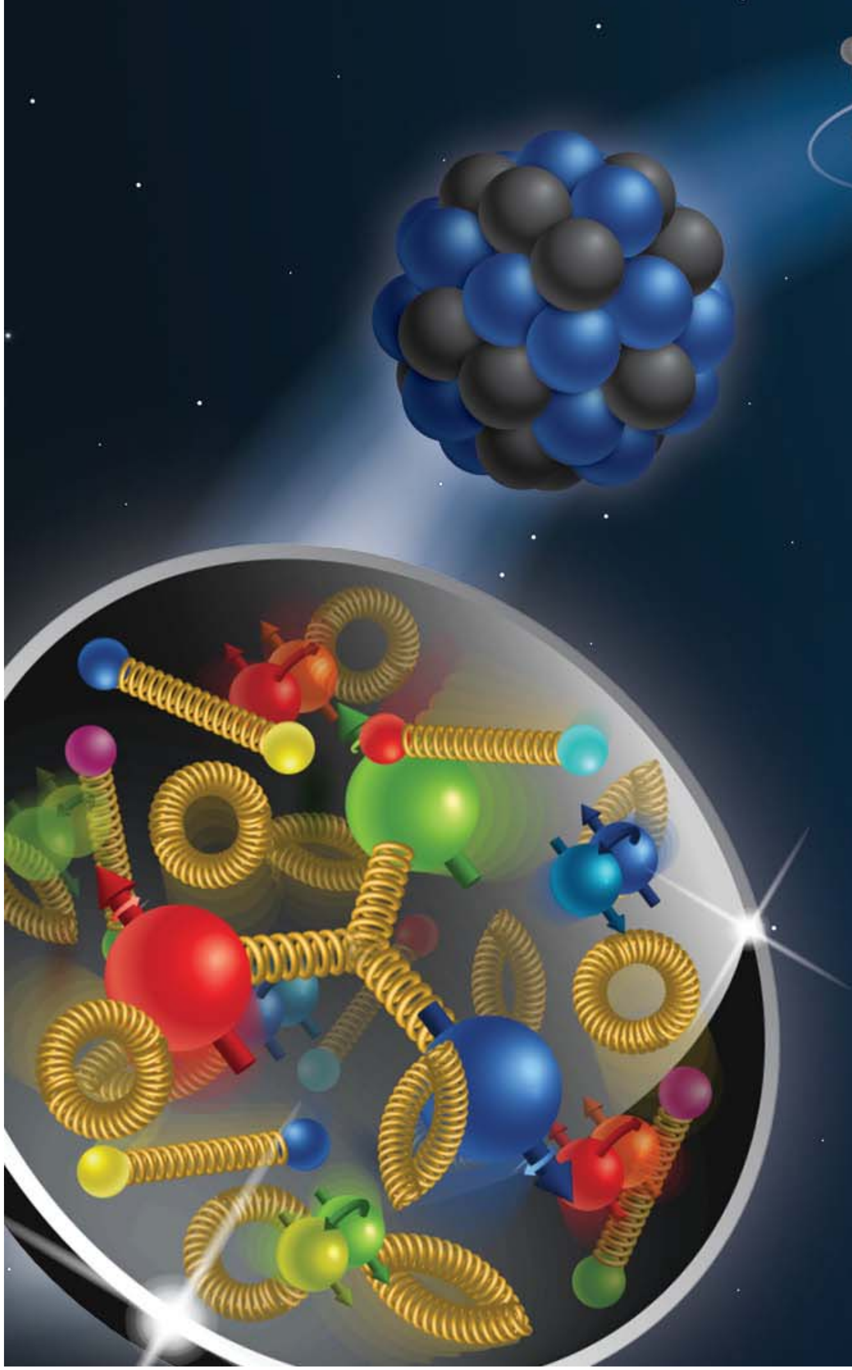


Update from BNL

Robert Tribble

2018 EIC Users Meeting

July 30, 2018

Electron Ion Collider – eRHIC

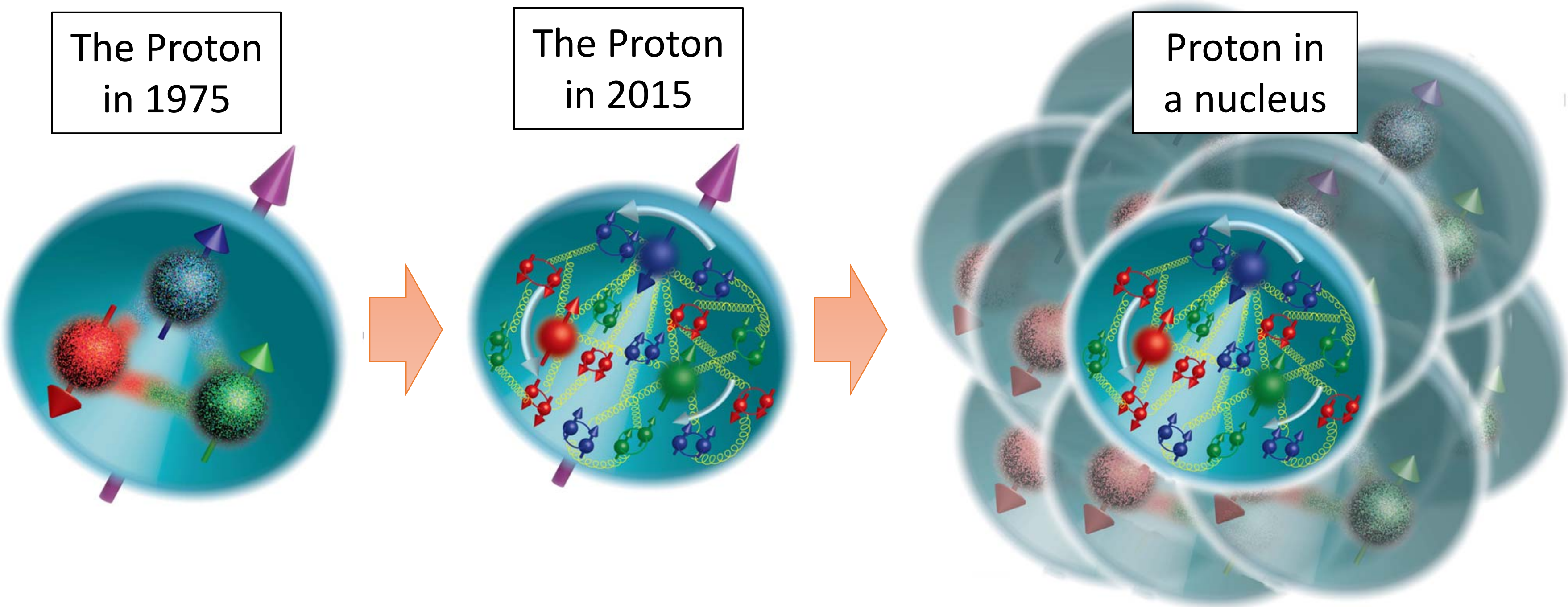
BROOKHAVEN NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

- Some Recent Updates to EIC Science
- Community Activities
- eRHIC Design
- eRHIC Machine and Detector R&D

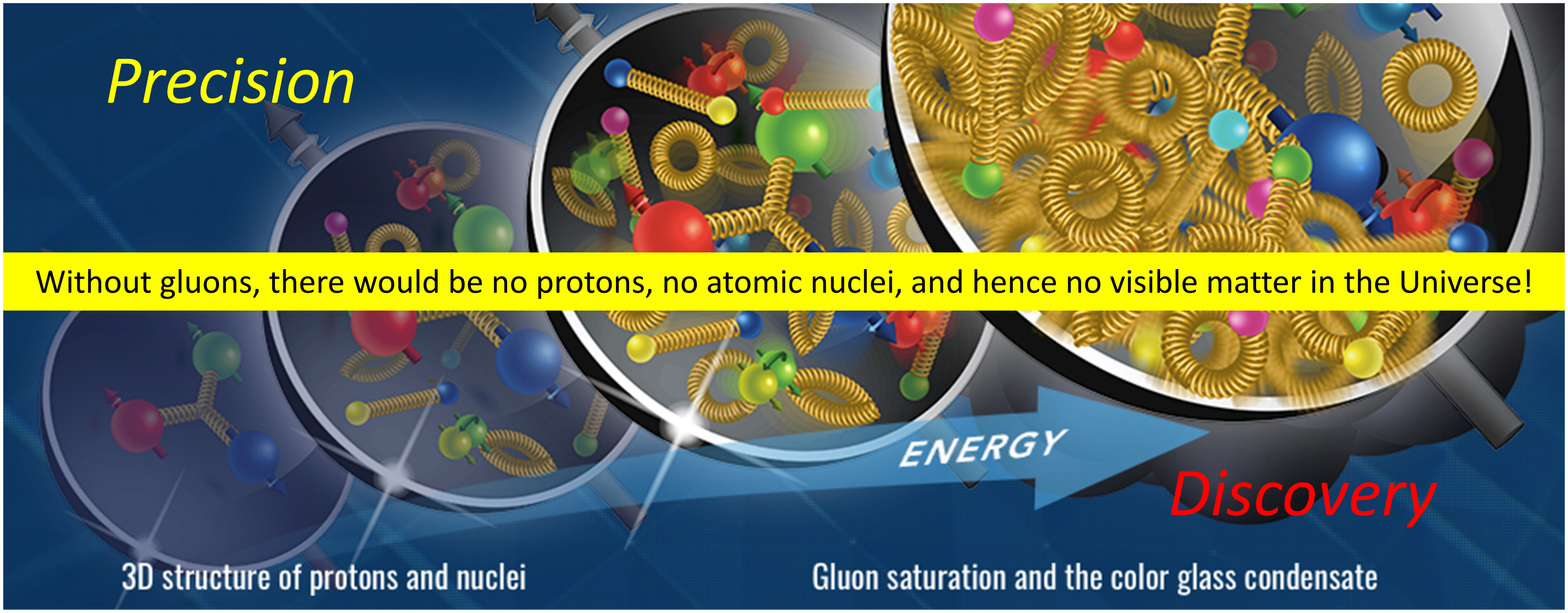
Thanks to many contributors who helped on all of these topics! In particular, I want to thank E. Aschenauer, A. Deshpande, V. Ptitsyn, and F. Willeke for their input.

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 Science Pillars



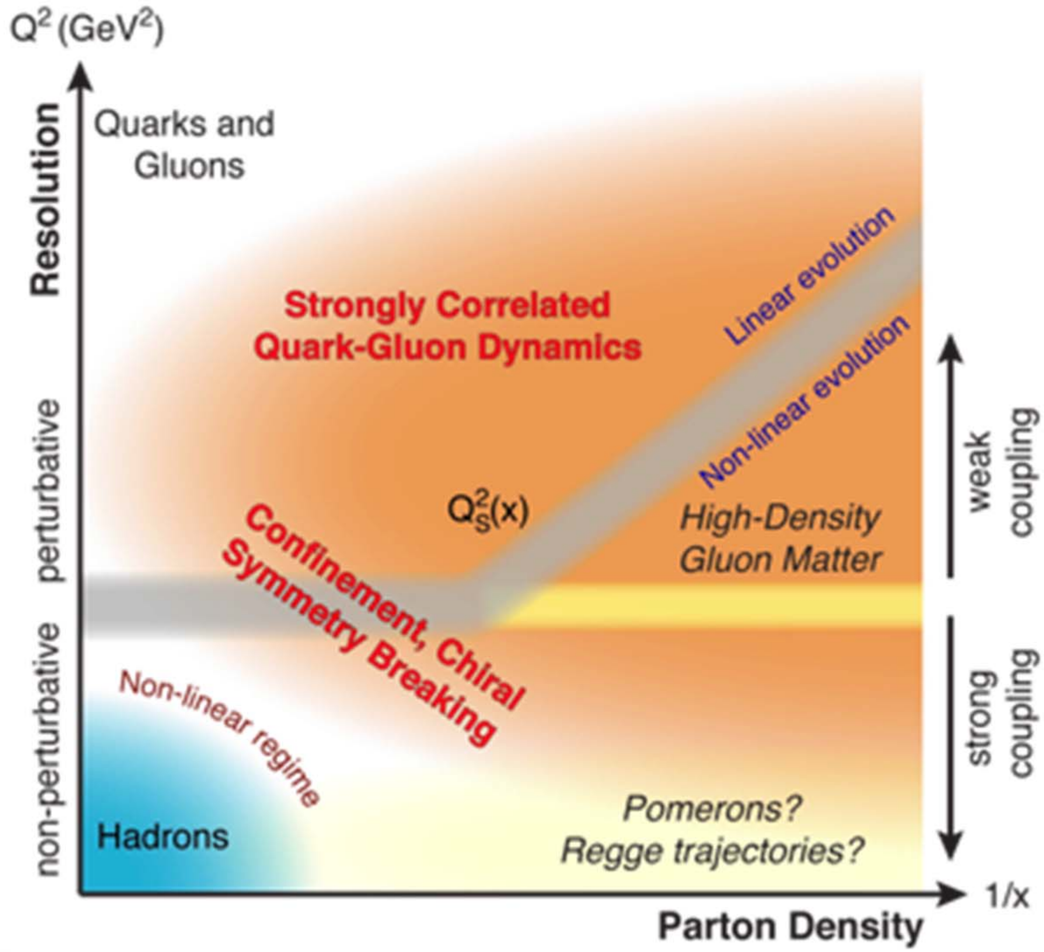
The EIC will collide high-energy electrons with high-energy protons or heavier atomic nuclei to produce "freeze-frame" snapshots of their inner structure, creating precise first-ever tomographic images of the "ocean" of gluons within. These images will tell us how gluons and quarks bind each other to form the particles that lie at the core of all atoms.

New experiments and advances in theory suggest that protons, neutrons, and nuclei appear as dense "walls" of gluons when probed at high energy, creating what are conjectured the strongest fields in nature. Discovering and studying this new form of matter, the "color glass condensate," will give us additional insight into why matter in this sub-atomic realm is stable.

… and much, much more! (see EIC White Paper)

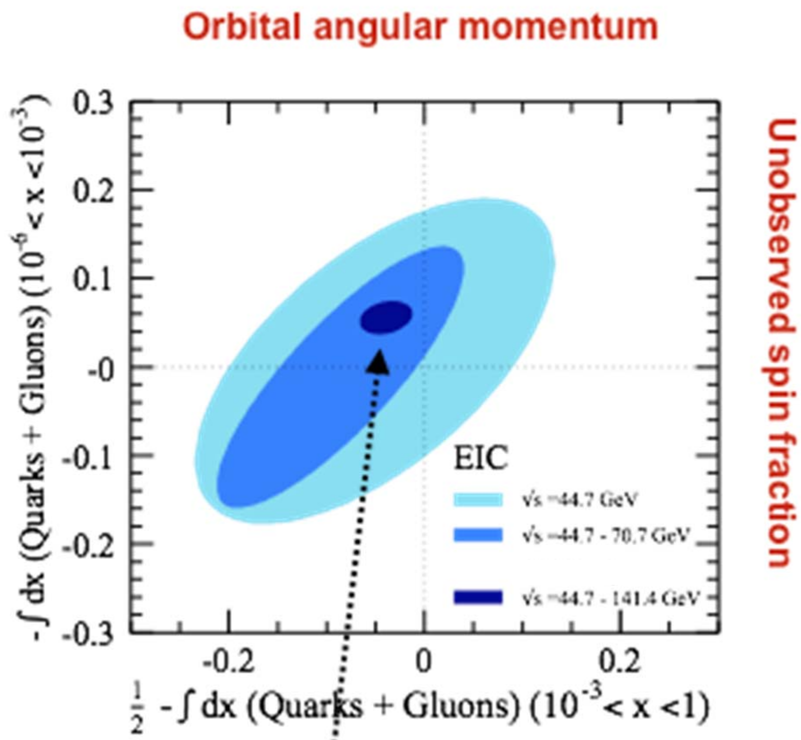
Ion Collider. – eRHIC

EIC and the QCD landscape

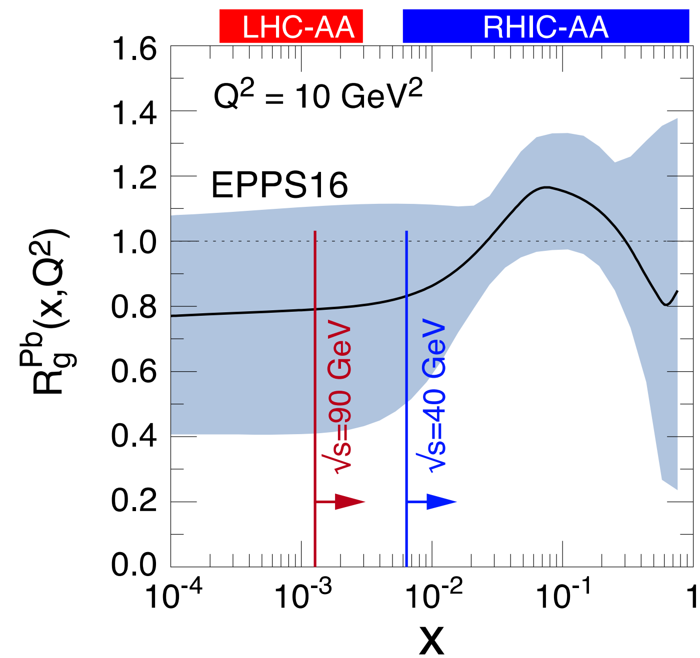


With its wide kinematic range, access to polarization and nuclei, the EIC will enable the exploration of the full cold QCD matter landscape.

Value of √s reach



Full eRHIC CM energy required to disentangle different contributions to the proton spin with less than 10% uncertainty (ΔJ < 0.05ħ)



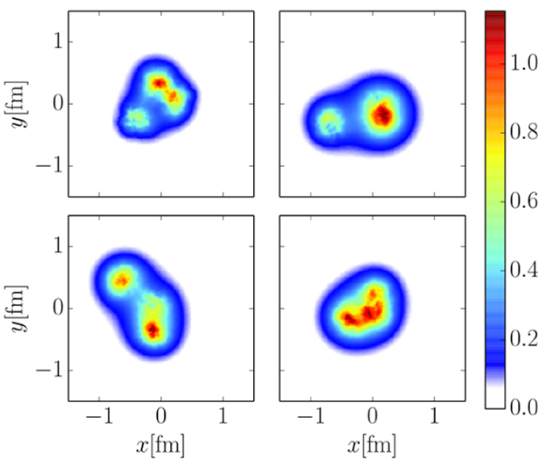
Full eRHIC CM energy required to constrain nuclear PDFs for the A+A and p+A programs at the LHC

Proton structure in pA, pp, and ep

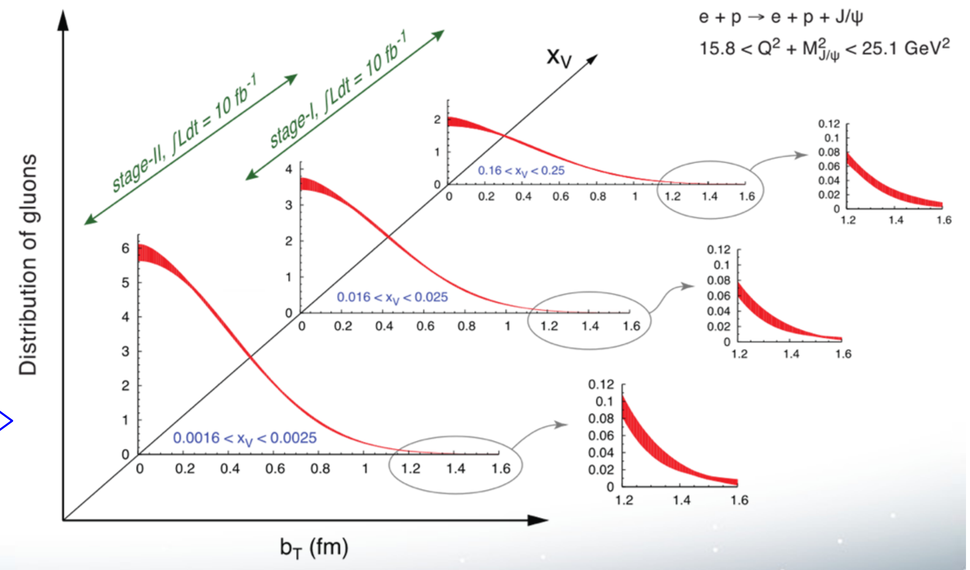
Data from pp and pA collisions at RHIC and LHC have shown that shape fluctuations of the proton at $x = 10^{-2} - 10^{-3}$ are essential to explaining the observed collective behavior of pA and pp

eRHIC will map out the spatial quark and gluon structure of the proton

Simulated proton density fluctuations at x ~ 10^{-3}

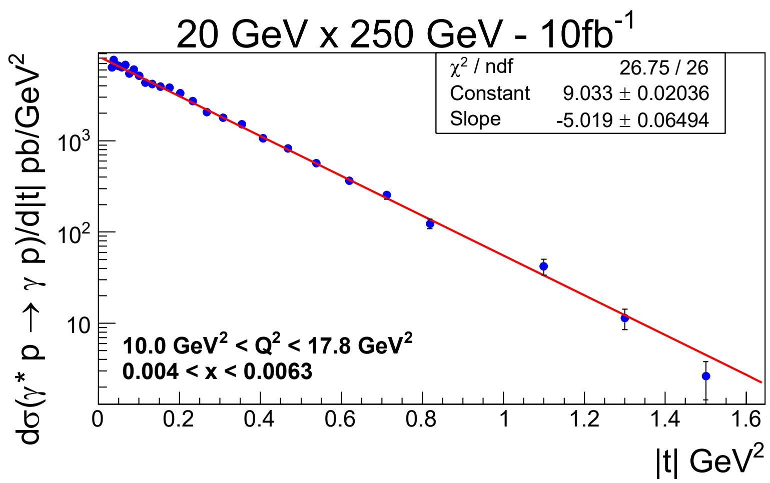


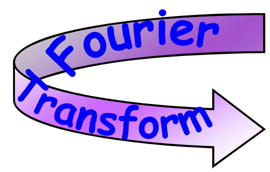
DVCS coherent and incoherent J/Ψ production

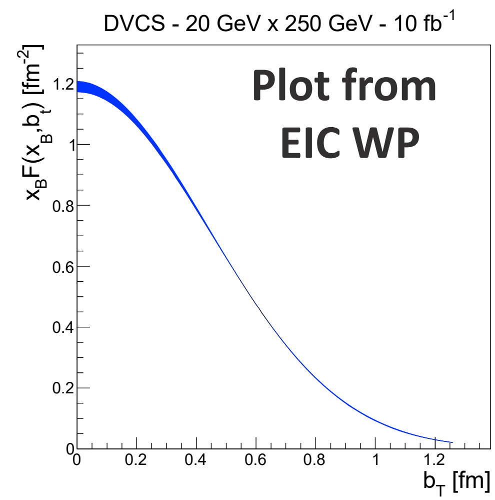


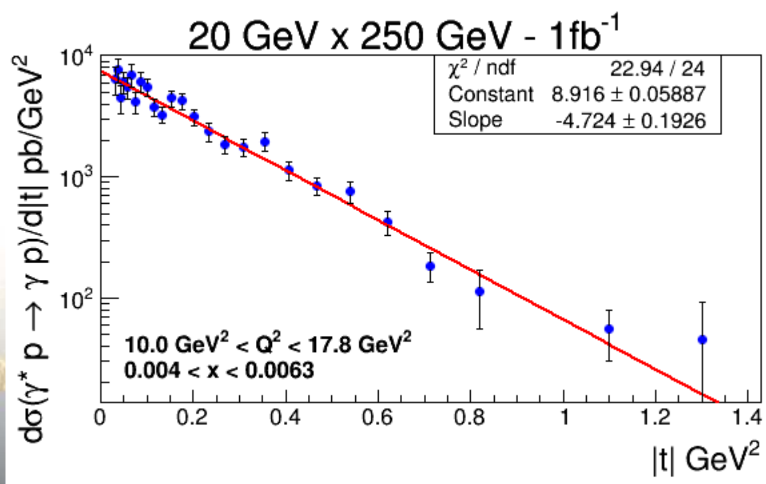
Impact of reduced luminosity

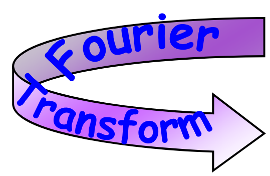
10 fb^{-1} → 1 fb^{-1} **0.18 < |p$_t$| (GeV) < 1.3**

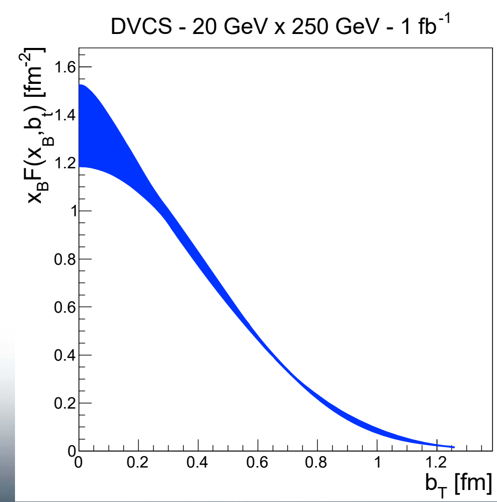






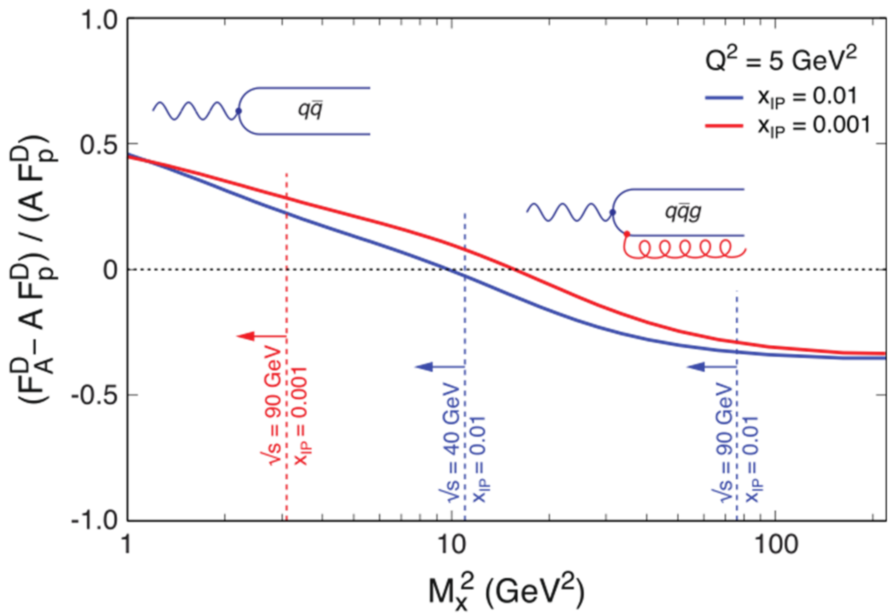




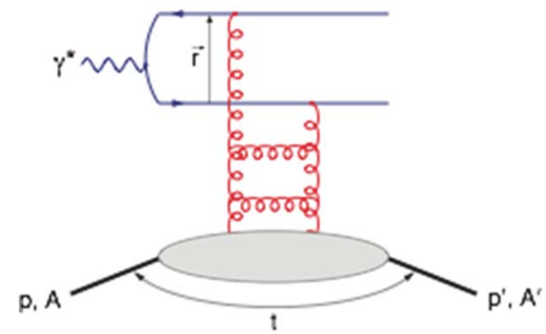


Nuclear opacity

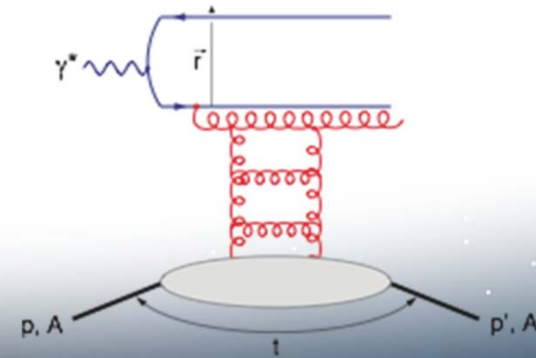
The sign Change in $\sigma_{diff}/\sigma_{total}$ is characteristic of gluon saturation



A nucleus is "blacker" than a proton. Elastic scattering probability of a $q\bar{q}$ dipole is maximal in the "black" limit



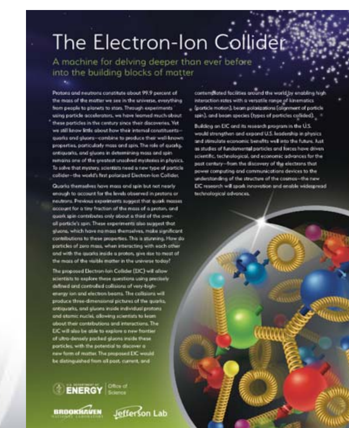
The $q\bar{q}g$ component vanishes in black disk limit

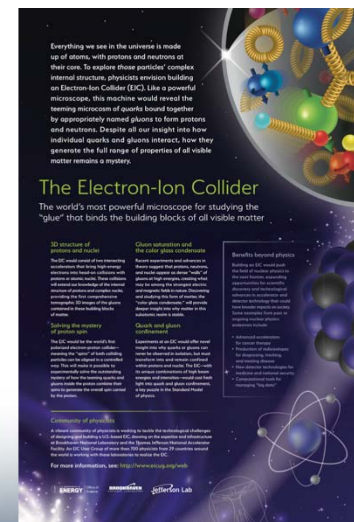


Observing the dependence on M_x, invariant mass of diffractive system, over a large range in x and Q^2 is crucial: Sufficiently wide √s range is key.

Community Activities

- BNL/SBU Center for Frontiers in Nuclear Science:
  - Rotating bi-weekly seminars
  - Joint workshops focused on new (and old) ideas
  - Several postdoc positions (some joint with universities)
  - Visitor program (2018) / Summer school (2019)
  - Support for EINN School, NNPSS, Gordon Conf.
- Outreach activities jointly with JLAB
  - EIC Web page
  - EIC Brochure
  - EIC Fact-sheet
  - EIC Poster





CFNS

http://www.stonybrook.edu/cfns

Center for Frontiers in Nuclear Science

Welcome to the Center for Frontiers in Nuclear Science

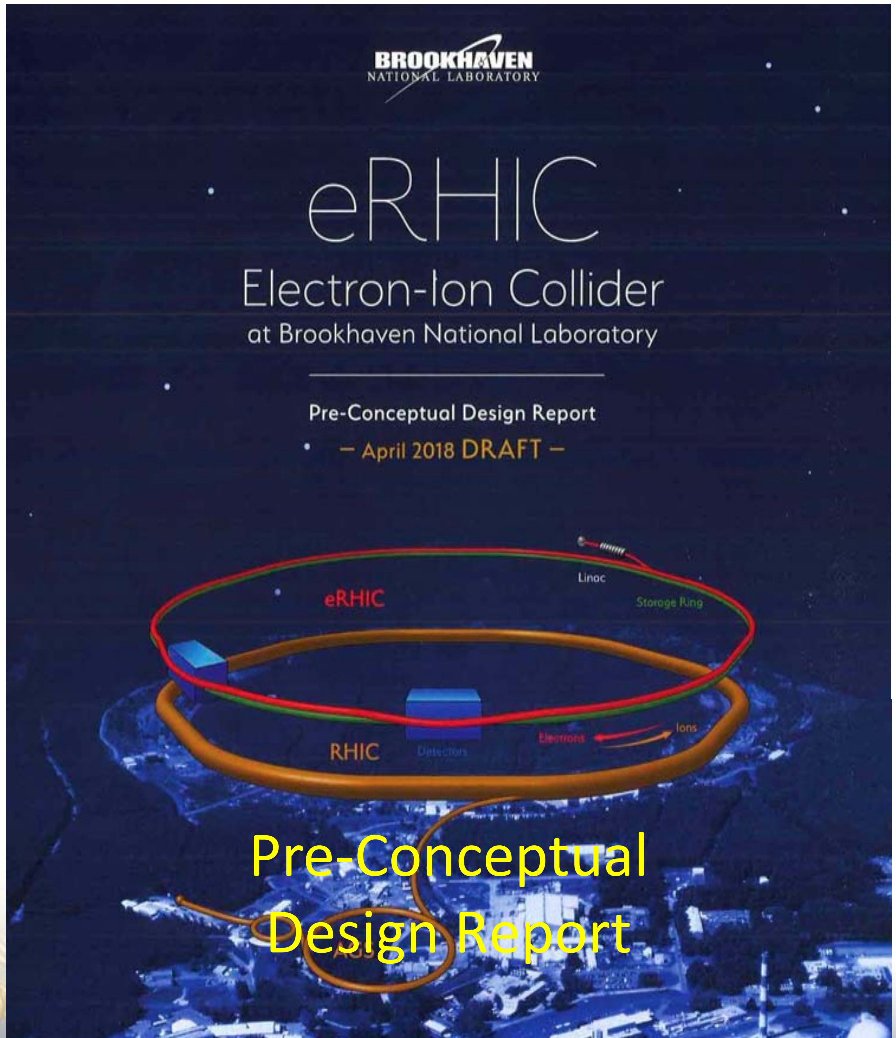
The Electron Ion Collider (EIC) is essential for our understanding of quantum chromodynamics (QCD) and in particular the role of gluons and sea quarks in the structure of nucleons and nuclei. The mission of this Center is to promote and facilitate the realization of the U.S. based EIC by enhancing the science case and collaborations amongst the scientists around the world interested in the EIC.

International Advisory Committee:
R. Milner (MIT), A. Caldwell (MPI), L. Elouadrhiri (Jlab), B. Jacak (LBNL), X. Ji (Shanghai), Y. Kovchegov (Ohio), Z. Mezziani (Temple), W. Nazarewicz (MSU), P. Newman (Birmingham), B. Pasquini (INFN Padua) F. Pilat (ORNL), J. Qiu (Jlab), Sterman (SBU-YITP), W. Vogelsang (Tuebingen)

EIC Workshops

- Joint with JLAB:
  - *EIC Accelerator Collaboration Meeting 2017* (Oct. 10-12, 2017)
- CFNS Workshops*:*
  - *Next-generation GPD studies with exclusive meson production at EIC* (June 4-6, 2018)
  - *Probing quarks and gluons with jets* (July 23-25, 2018)
  - *Short-range nuclear correlations at an EIC* (Sept. 5-7,2018)
  - *Quantum entanglement at collider energies* (Sept. 10-12, 2018)
  - *Forward Physics and instrumentation from colliders to cosmic rays* (Oct. 17-19, 2018)
  - *CFNS Inaugural Meeting* (Nov. 28-30, 2018)

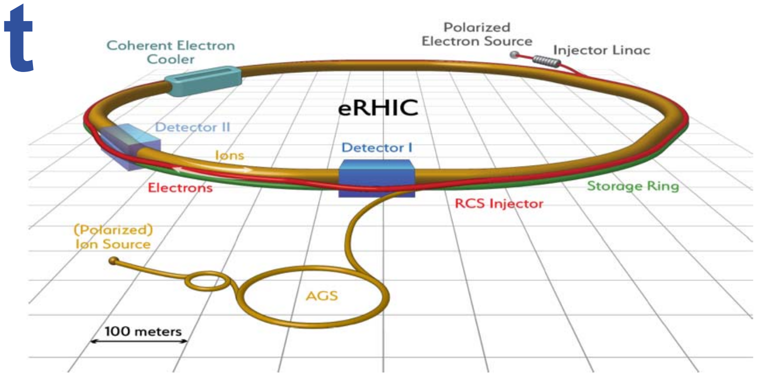
EIC Design



The BNL design team has completed a Pre-conceptual Design Report for a facility based on the Ring-Ring concept that is capable of addressing the full range of science covered in the EIC White Paper with a low-risk, cost-effective solution for the first phase:

- Polarized (~70%) electrons, protons, and light nuclei (↑^{3}He, ↑d),
- Ion beams from deuterons to the heaviest stable nuclei,
- Variable CM energies ~20–100 GeV, an easy upgrade to ~140 GeV (e-p),
- Collision luminosity ~$10^{33\text{-}34}$ $cm^{-2}s^{-1}$,
- Up to two interaction regions.

eRHIC Design Concept

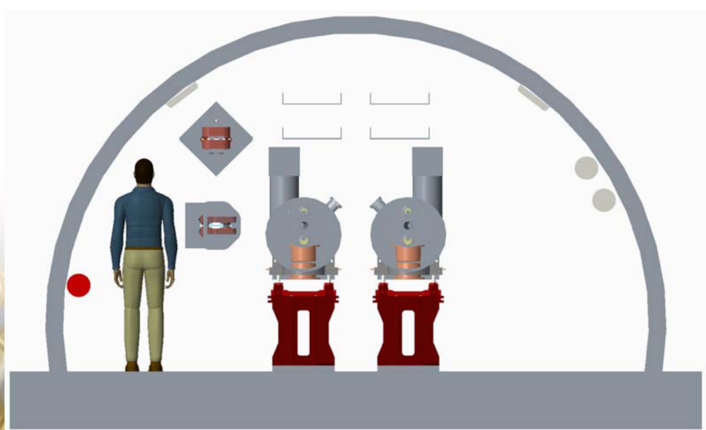


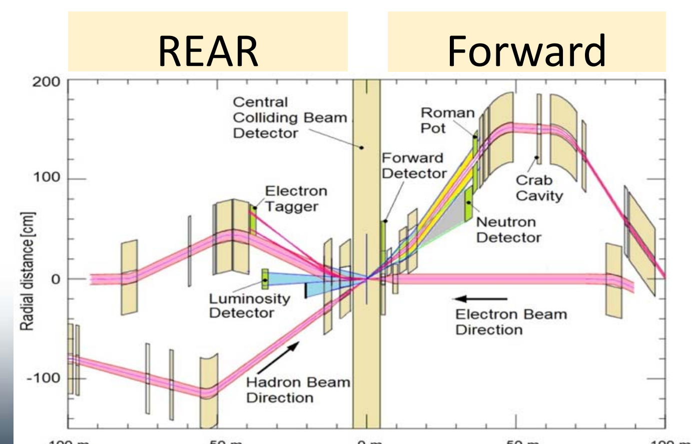
The eRHIC design goal has been adapted to reach the upper limit of the EIC White Paper luminosity range: **L= 10^{34} $cm^{-2}s^{-1}$** with strong hadron cooling

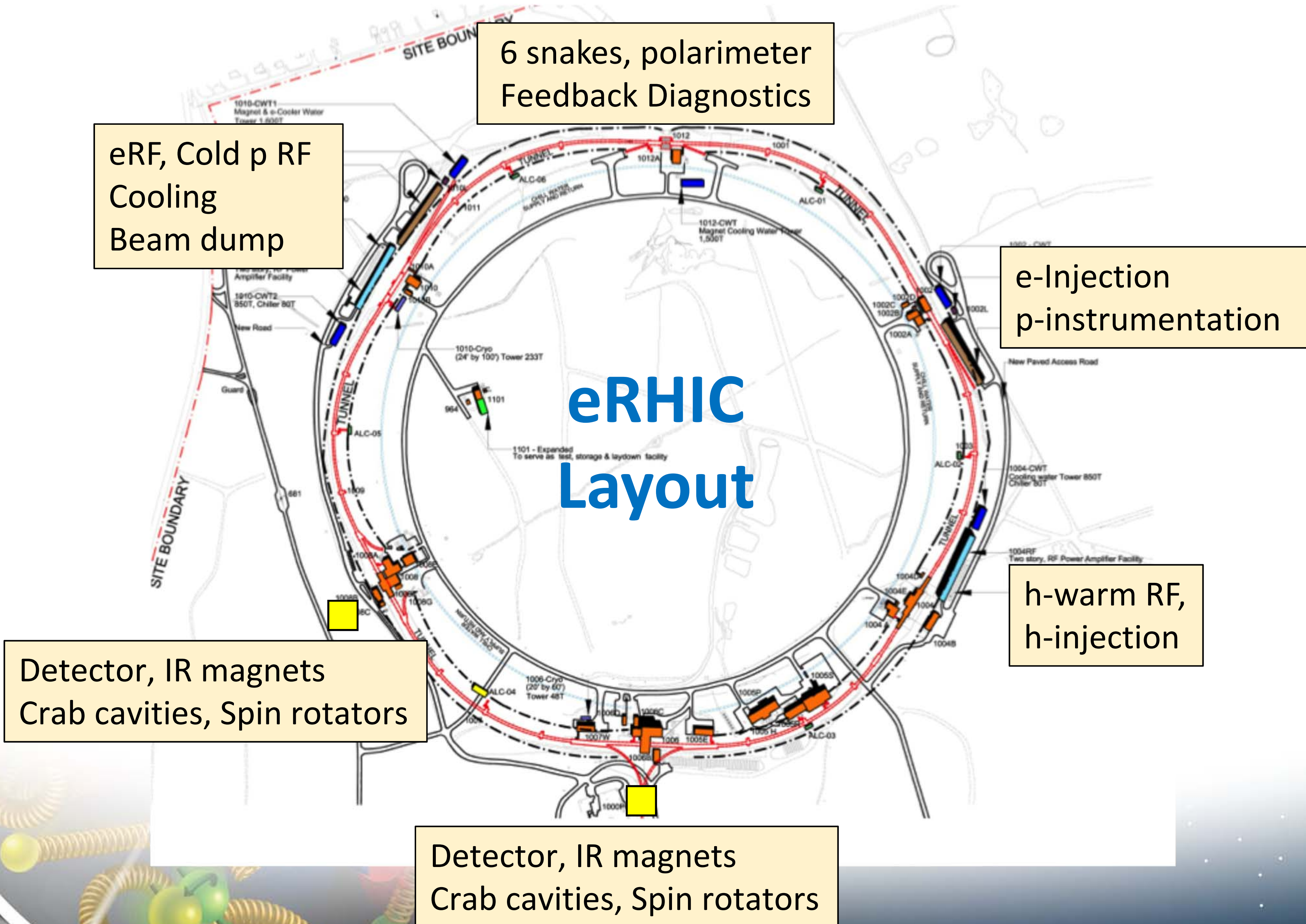
- eRHIC is based on the RHIC complex: Storage ring (Yellow Ring), injectors, ion sources, infrastructure, which need only relatively few modifications and upgrades
- A (5-18) GeV electron storage ring & its injectors are added to the RHIC complex ➔ E_{cm} = (20-140) GeV
- To minimize risk, the eRHIC design is optimized under the assumption that each beam will have the parameters (in particular beam-beam tune-shift) that have been demonstrated in collisions in other colliders
- The requirement to store electron beams with a variable spin pattern requires an on-energy, spin transparent injector
- The total power of synchrotron radiation of the electron beam is assumed to be limited to 10 MW. This is a design choice.

Key Additional Components

- **Electron Injector Synchrotron**
  - A comprehensive study resulted in the choice of a spin-transparent rapid cycling synchrotron in the RHIC tunnel
- **Electron Storage Ring**
  - Details given by Vadim – present plans call for a 10 MW limit on synchrotron radiation, which limits circulating current
- **IR Regions for Detectors**
  - Design satisfies requirements set by physics; uses 22 mr crab crossing and crab cavities






eRHIC
Layout
6 snakes, polarimeter
Feedback Diagnostics
eRF, Cold p RF
Cooling
Beam dump
e-Injection
p-instrumentation
h-warm RF,
h-injection
Detector, IR magnets
Crab cavities, Spin rotators
Detector, IR magnets
Crab cavities, Spin rotators
SITE BOUNDARY

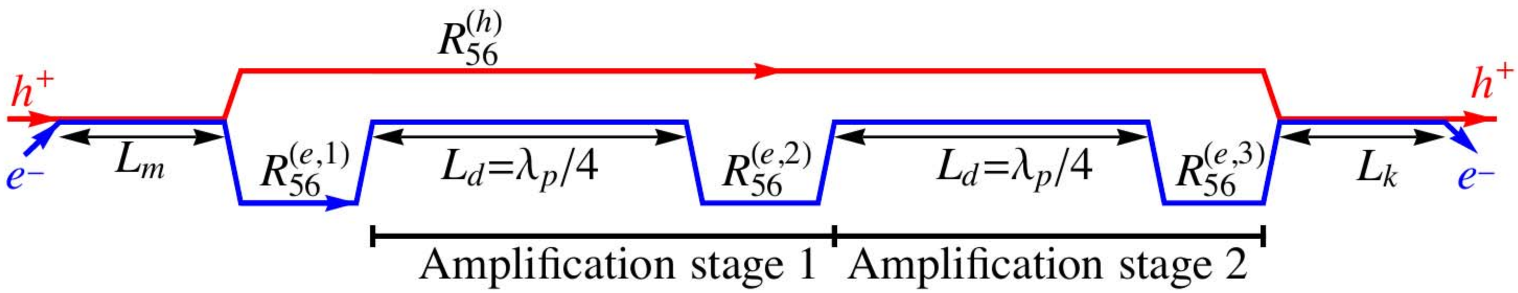
Strong Hadron Cooling

Necessary to reach highest luminosity in all EIC schemes.

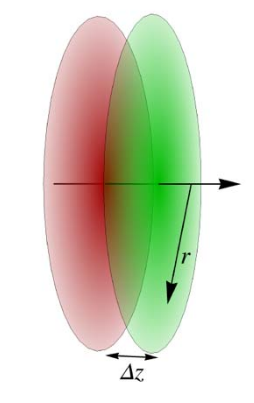
Several methods of strong hadron cooling have been studied:

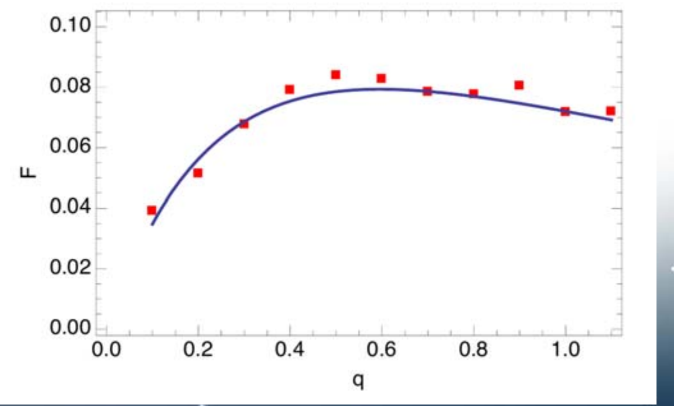
- Bunched Beam Electron Cooling with an electron storage ring
- Coherent electron cooling with FEL amplifier or micro-bunching amplifier

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



Achievable cooling rates with 100 mA electron current and flat beams are in the order of 1 h which would be sufficient for eRHIC.
Analytical calculation of the cooling rate agrees well with simulations within the 1-D model.





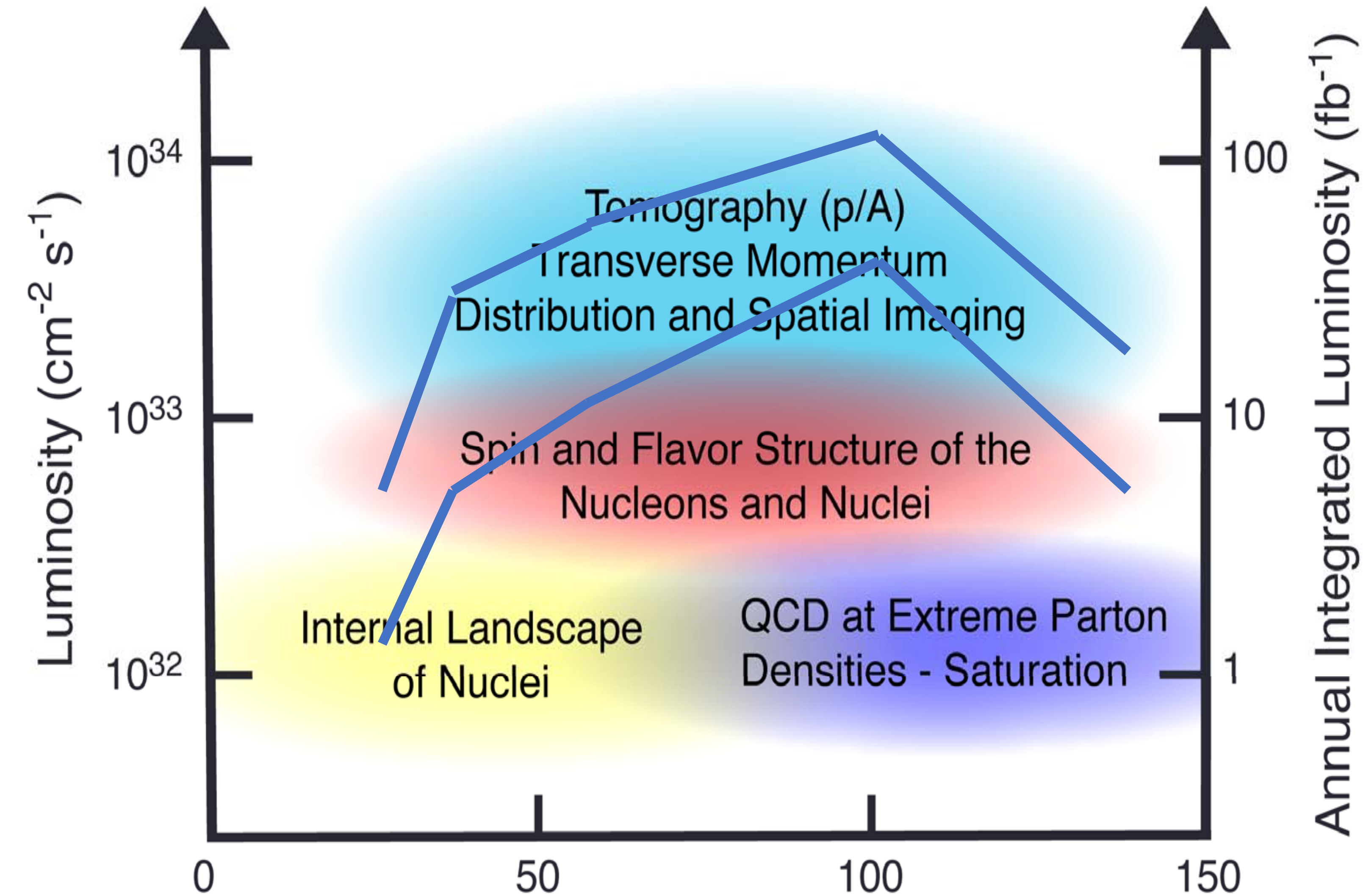
eRHIC pCDR

- The draft pre-CDR was reviewed April 24-25, 2018 by an international team of experts (chair: J. Seeman, SLAC)
- The pre-CDR is currently in the final stages of editing and proofreading
- Distribution will be coordinated with DOE
- A cost estimate for a facility based on the pre-CDR based on standard principles is being developed
- BNL (as well as JLAB) have been asked to submit preliminary cost & schedule estimates by August 20, 2018
- We are beginning work on a full CDR aiming at a late 2019 completion date

Estimates of Integral Luminosity

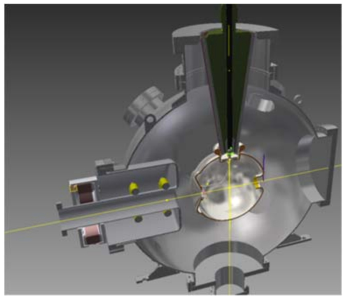
	eRHIC		
	Initial operation	Without cooling	Nominal
Peak L, 10^{33} cm^{-2} s^{-1}	1.05	4.4	10
Average store L calculated, 10^{33} cm^{-2} s^{-1}	0.93	3.85	9.95
Contingency of average store L evaluation	20%	20%	0
Store length, h	11	10	several days
Time in store, %	60%	60%	75%
Integral L/week, fb^{-1}	**0.27**	**1.12**	**4.51**
Average L in the Run, 10^{33} cm^{-2} s^{-1}	0.56	2.31	7.46
Average L/Peak L	0.53	0.53	0.75

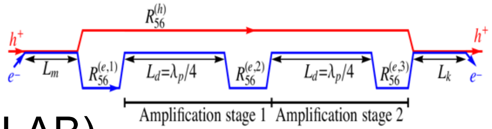
Luminosity versus CM Energy

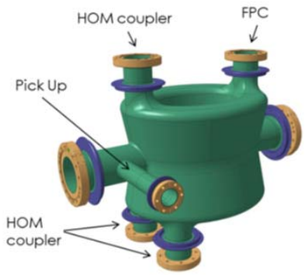


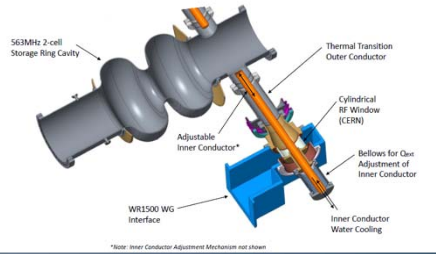
eRHIC R&D @ BNL

- Development of a **large cathode Inverted gun** for high average current, high bunch charge polarized electron beam
- Advanced coherent electron cooling with plasma amplification (in preparation)
- **Coherent electron cooling** with multi-staged microbunching is studied theoretically (Coll. BNL-JLAB-ANL-SLAC)
- **Development of simulation tools** for EIC (Coll. BNL-LBNL-MSU-JLAB)
- **Study of Spin transparency** mode in EIC (Collaboration with JLAB)
- **Crab-cavity in hadron ring:** SPS test (Coll. with JLAB & CERN)
- **High Gradient actively shielded quadrupole** (Coll BNL-LBNL-JLAB)
- **Development of ^{3}He ion source polarimetry** (Coll BNL-MIT)
- **Study of storage ring based electron cooling** (Coll. BNL-JLAB)
- **Development of 1 MW variable coupling input coupler** for electron storage ring superconducting cavity (LDRD)

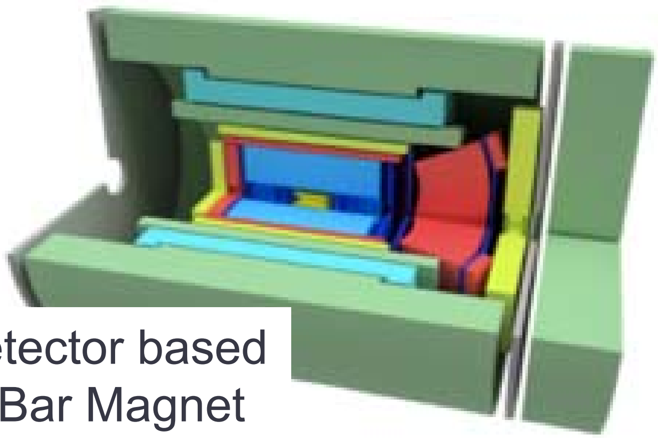




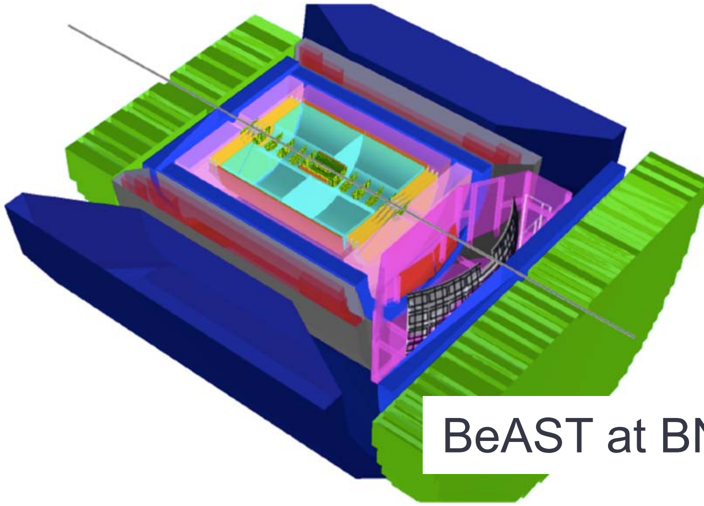




EIC Detector R&D



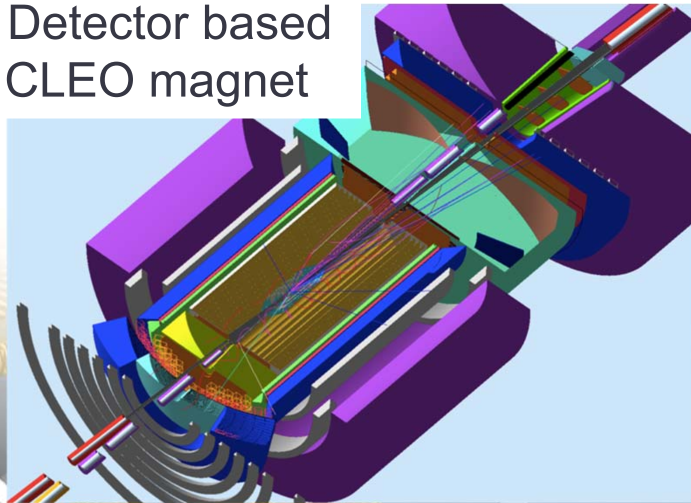
EIC Detector based on BaBar Magnet

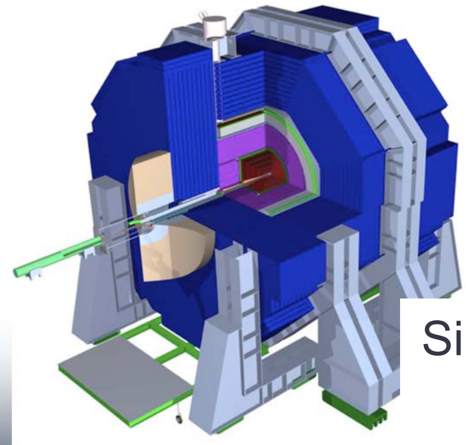


BeAST at BNL

Ongoing $1M Generic EIC Detector R&D Program managed by BNL

EIC Detector based on CLEO magnet

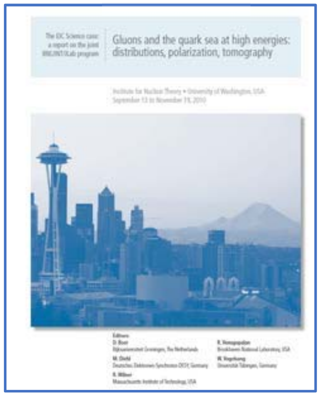


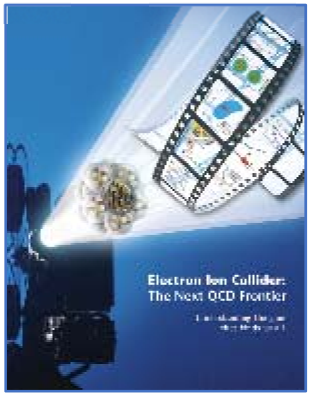


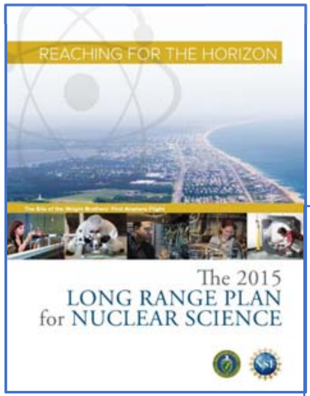
SiEIC Detector (ANL)

Timeline (Past & notional future)

2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017. | 2018







Review by US National Academy of Sciences

LRP RECOMMENDATION

We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB.

	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31
Critical Decisions	CD-0 Approve Mission Need Dec 2018			CD-1 Approve Selection and Cost Range Dec 2020	CD-2 Approve Selection Performance Baseline Dec 2021		CD-3 Approve Start of Construction Dec 2023						CD-4 Approve Project Completion Dec 2029	

Beam Energy Scan

sPHENIX

eRHIC ?

Summary & Outlook

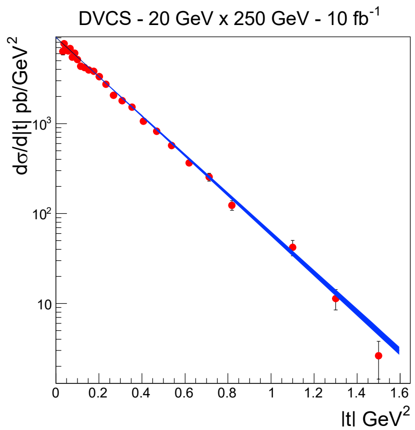
Over the past year, we have made significant progress in understanding the role of the energy range in realizing the full physics potential of an EIC. The new Center for Frontiers in Nuclear Science (CFNS) is supporting the effort by the EIC community to fully develop the EIC science program and train young scientists for their future role in it.

We have completed a pre-conceptual design report for the ring-ring version of eRHIC and are actively engaged in a broad program of EIC accelerator and generic detector R&D in close collaboration with many other institutions.

The energy and luminosity range of eRHIC would enable a robust physics program that addresses the goals of the 2015 NSAC Long Range Plan and the NAS report:

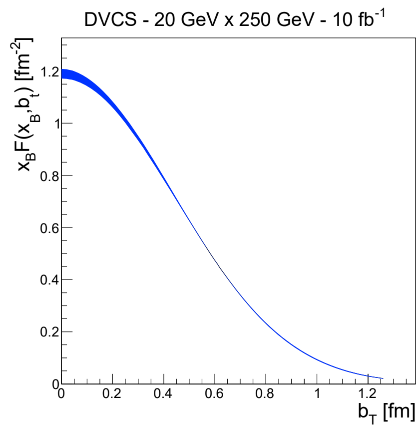
- fully access the sea-quark and gluon dominated regime
- reveal the dynamics of sea quarks and gluons in hadrons
- open up the phase space for new probes of nucleon / nuclear structure (jets, charge current, etc.)

IMPACT OF REDUCED ACCEPTANCE

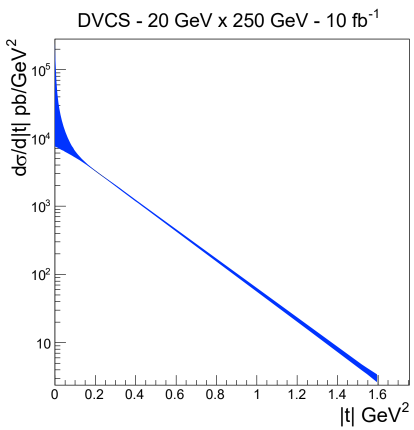


Plot from EIC WP:

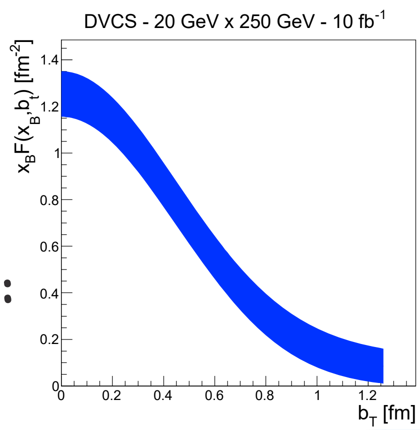
Fourier Transform



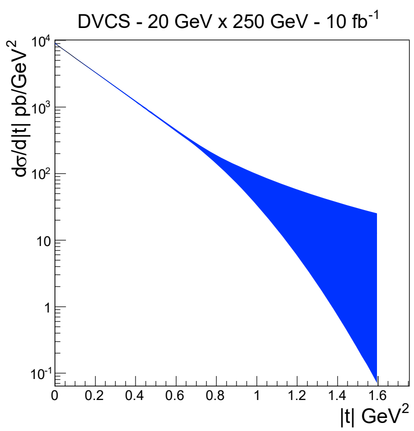
eRHIC with 20x250 GeV^2 and $\int L = 10 fb^{-1}$
$0.18 < p_t$ (GeV) < 1.3
$0.03 < |t|$ (GeV^2) < 1.6



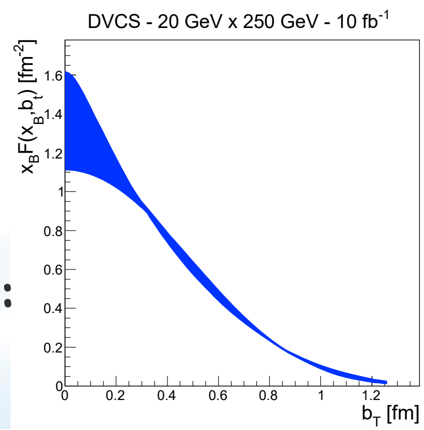
Plots with reduced lower p_t-acceptance:



eRHIC with 20x250 GeV^2 and $\int L = 10 fb^{-1}$
$0.44 < |p_t|$ (GeV) < 1.3



Plots with reduced high p_t-acceptance:



eRHIC with 20x250 GeV^2 and $\int L = 10 fb^{-1}$
$0.18 < |p_t|$ (GeV) < 0.8

BROOKHAVEN NATIONAL LABORATORY

E.C. Aschenauer