The Electron-Ion Collider

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Outline

- Introduction: some open questions of QCD and Electron-Ion Collider
- Key measurements at EIC
- Collider concepts
- Status of EIC project
- Summary

Some open questions of QCD

One of central goals of nuclear physics is to understand the structure of the nucleon and nuclei in terms of *quarks* and *gluons*.

After decades of experiments at SLAC, CERN, Fermilab and DESY that explored the structure of hadrons, there are several open questions:

- What is the gluon momentum distribution in nuclei?
- What are the properties of high-density gluon matter?
- How do fast partons interact as they traverse nuclear matter?

- How do partons contribute to the spin structure of the nucleon?
- What is the spacial distribution of partons in the nucleon?
- How do hadronic final states form in QCD?

Open questions and Electron-Ion Collider

The Electron-Ion Collider (EIC) is proposed new facility to collide high-energy *electrons* with *nuclei* and *polarized protons/light ions*, which will address the above open questions.

Two broad classes of goals of the future EIC are reflected in two physics groups:

- **eA program**: explore strong gluon fields in nuclei

- **ep program**: precisely image the sea quarks and gluons in the nucleon

Basic requirements for EIC

- **Lepton beam**

  provides clean and well-understood probe

- **High and variable energy**

  -- $\sqrt{s}$ up to 90 GeV (more on this later)

  -- variable energy to access $F_L(x,Q^2)$

- **High luminosity**

  desired luminosity $L > 10^{33}\ cm^{-2}\ s^{-1}$

- **Polarized beam**

  to study nucleon spin structure; polarized D or He3 for Bjorken sum rule

- **Nuclear beams (from D to U)**

-- light nuclei to probe spin and flavor-separated parton distributions

-- heavy nuclei to probe nuclear PDFs and high-density gluon matter

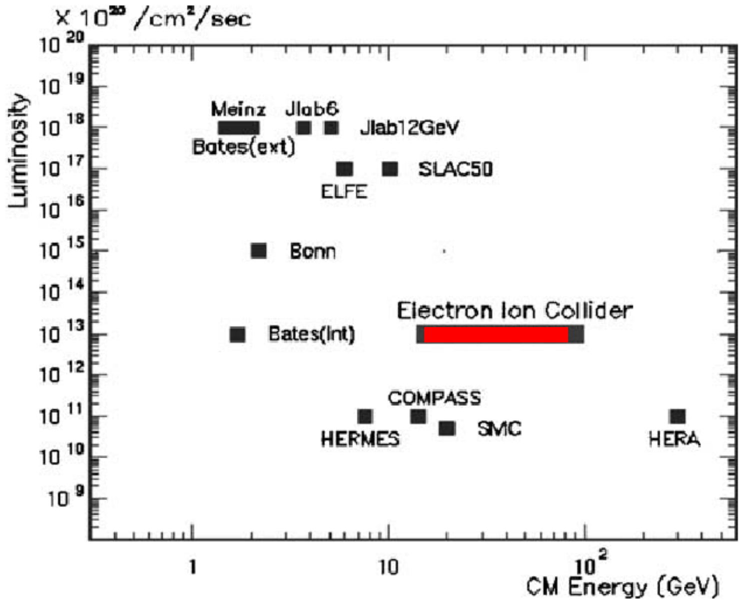


Figure 1 The center-of-mass energy vs. luminosity of the proposed Electron-Ion Collider eRHIC compared to other lepton scattering facilities.

Key measurements at EIC: unpolarized DIS

- Inclusive DIS structure functions $F_2(x,Q^2)$ and $F_L(x,Q^2)$

  - $F_2(x,Q^2)$ probes quarks directly and gluons via scaling violations
  - $F_L(x,Q^2)$ access gluons directly
  - nuclear shadowing and antishadowing and EMC effect

- Charmed structure functions $F_2^c(x,Q^2)$ and $F_L^c(x,Q^2)$

  - access to charm quark PDFs and gluons

- Light and heavy jets in DIS

  - complimentary measurements of quark and gluon PDFs
  - cleanest environment to study nuclear modification of hadron production
  - simultaneous studies of light and heavy quark jets will test models of hadronization (energy loss vs. absorption) in cold nuclear matter (relevant for RHIC and LHC)

- Semi-inclusive DIS

Color coding: eA ep

Key measurements at EIC: diffractive DIS

- Inclusive diffractive DIS
  - diffraction in DIS with nuclei has never been measured, nature of Pomeron?
  - diffractive structure function F_2^D is much more sensitive to saturation (large gluon densities) than inclusive $F_2(x,Q^2)$

- Jets in diffractive DIS
  - complimentary to inclusive measurement, probes gluon diffractive PDFs

- Exclusive diffraction: DVCS, electroduction of mesons
  - DVCS, electroproduction of neutral vector mesons will probe singlet quark and gluon GPDs, transverse image, relevant for pp at LHC
  - color transparency
  - nuclear shadowing and saturation enhanced
  - **Non-diffractive** electroproduction of π, ρ^+, K probes non-singlet quark PDFs, valence structure

Key measurements at EIC: polarized DIS

- Inclusive DIS
  - ΔG from scaling violations, global fits of polarized PDFs
  - ΔG from open charm and di-jet production via photon-gluon fusion

- Semi-inclusive DIS
  - flavor separation of polarized PDFs
  - measurement of transverse momentum dependent PDFs, spin-orbit correlations

- Exclusive processes

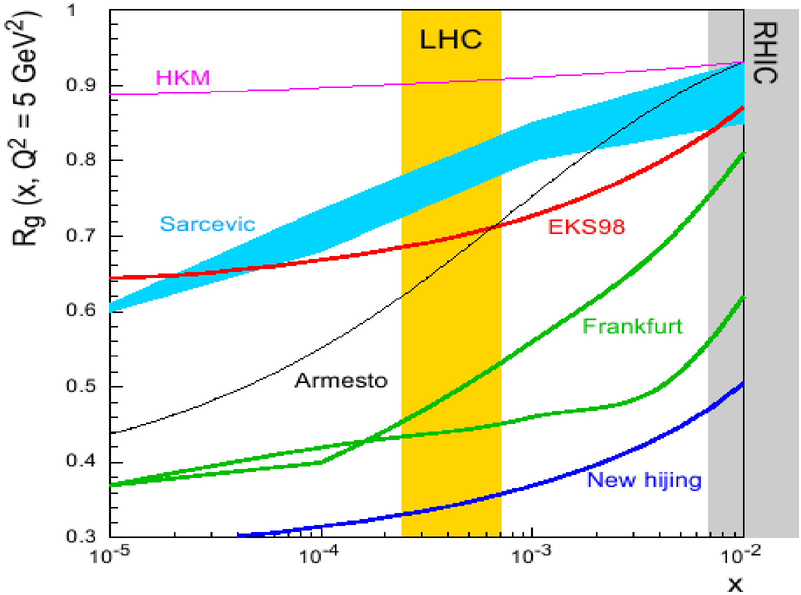
- ......

One example: nuclear PDFs at EIC

Nuclear parton distributions (nPDFs), especially gluon nPDFs, are poorly known at small Bjorken x.

$$R_g = \frac{g_A(x, Q^2)}{A g_N(x, Q^2)}$$

- Nuclear PDFs are measured in DIS on fixed nuclear targets
- In fixed-target kinematics, small x are either unaccessible or correspond to low Q^2 (HT effects?)
- Large uncertainties in extrapolations to low x
- Gluons are only through scaling violations

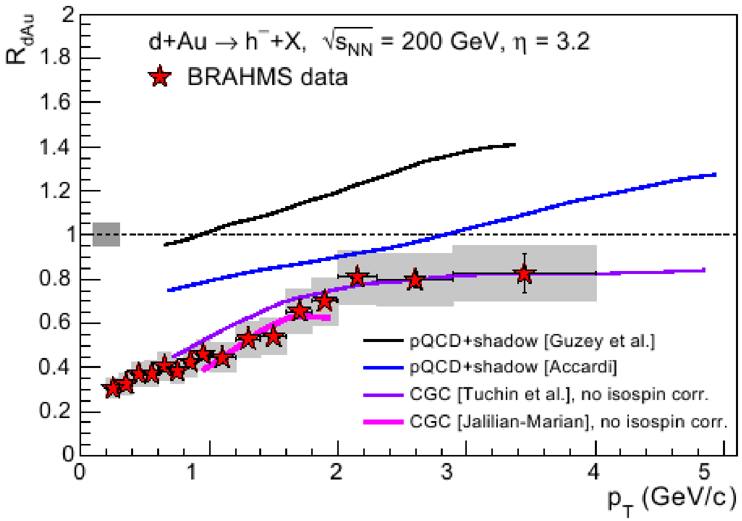


One example: nuclear PDFs at EIC (Cont.)

Nuclear PDFs at small x are interesting and important because:

• nPDFs test theoretical models of nuclear shadowing and saturation

• essential for pQCD analysis and interpretation of RHIC and LHC data



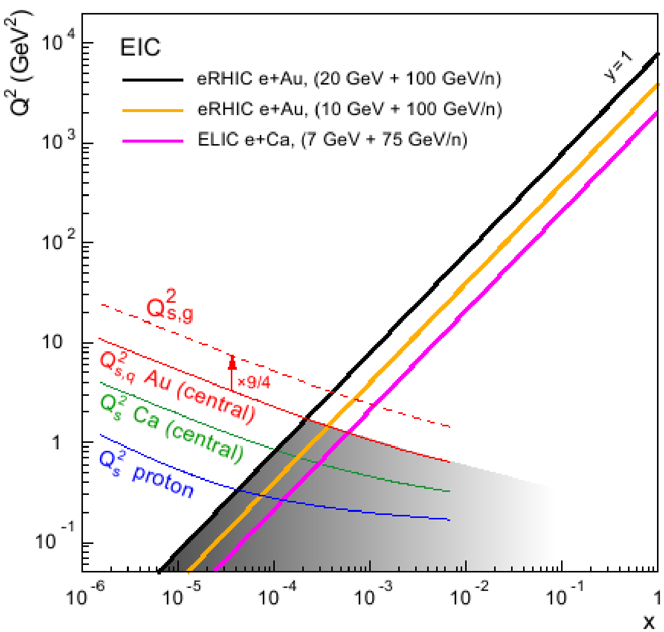
Note that saturation effects at forward rapidities at RHIC will appear at midrapidities at the LHC

• Energy loss and hadronization in hot nuclear matter: precise nuclear PDFs are needed to separate the initial state effects from final state effects (parton energy loss) and test different models of fragmentation.

One example: nuclear PDFs at EIC (Cont.)

The future EIC with a wide kinematic coverage will allow to determine gluon nPDFs at small x using several complimentary measurements:

- scaling violations of $F_2(x,Q^2)$
- longitudinal structure function $F_L(x,Q^2)$
- charm and jets



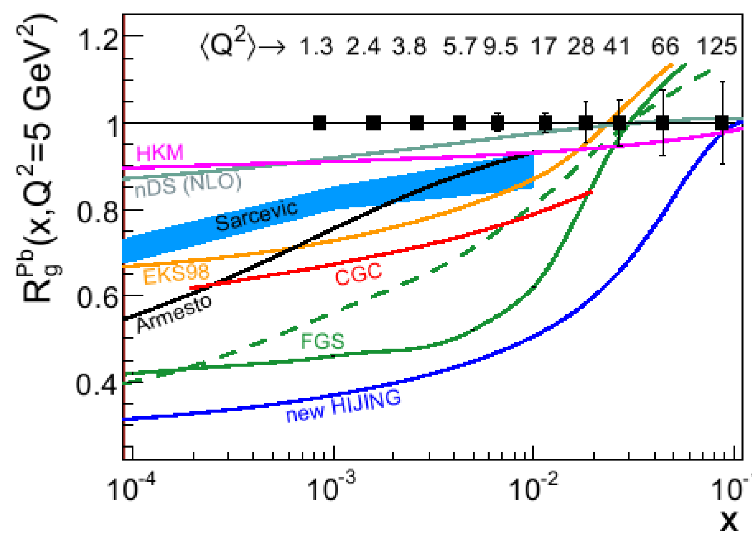


Figure 5: *The ratio of gluon distributions in Pb nuclei to those in deuterium extracted from the ratio of the respective longitudinal structure functions F_L. The filled squares and error bars correspond respectively to the projected kinematic reach and statistical uncertainties for this measurement (for 10/A fb^{-1}) with the EIC. A large range of model predictions are shown which differ widely in this kinematic region.*

Concepts of Electron-Ion Collider

eRHIC (BNL): Add energy recovery linac to RHIC

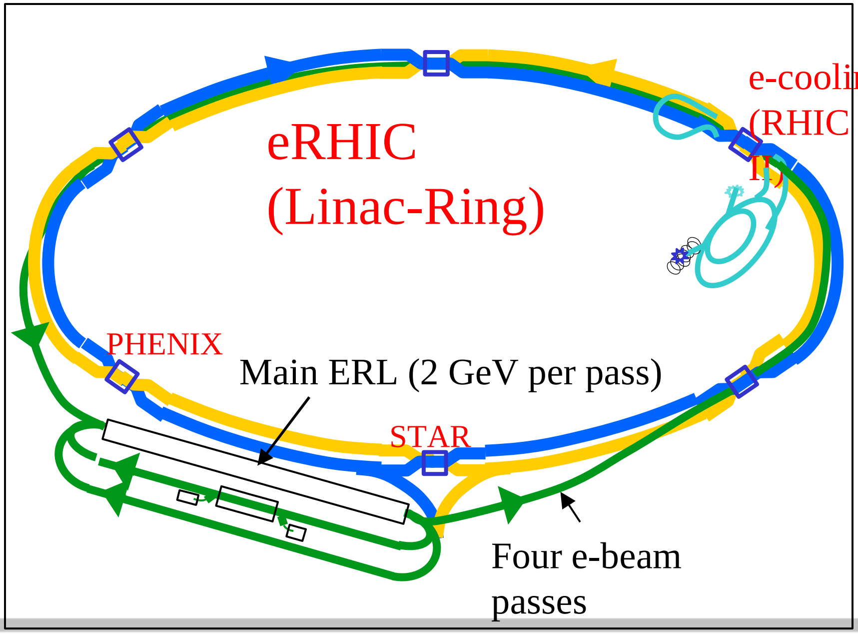
- higher energy, lower luminosity

E_e=10 (20) GeV

E_A=100 GeV (up to U)

$\sqrt{s_{eN}}$=63 (90) GeV

L_{eAu}(peak)/n=2.9•10^{33} cm^{-2} s^{-1}



ELIC (JLab): Add hadron beam facility to existing CEBAF

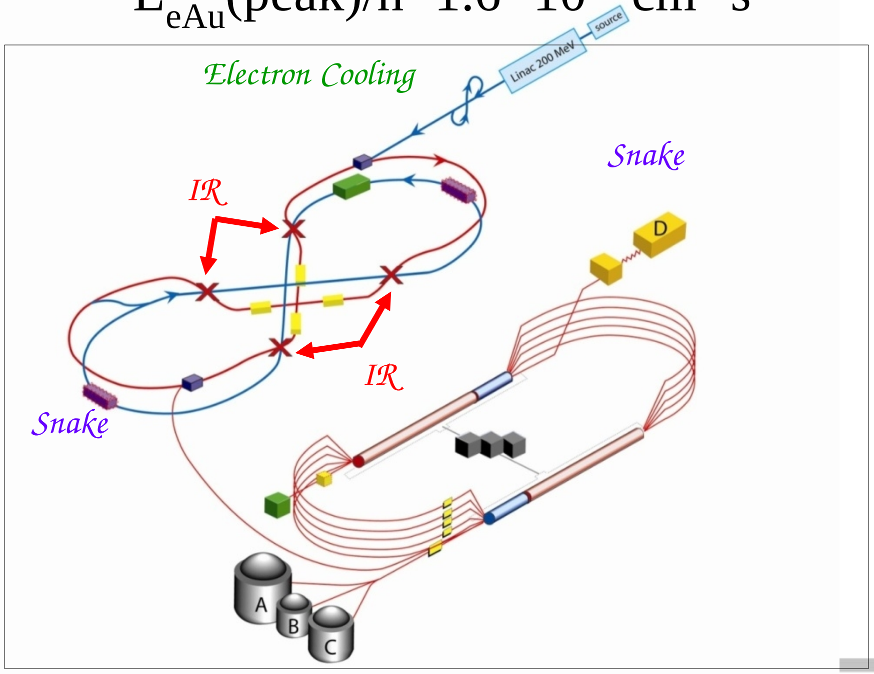
- lower energy, higher luminosity

E_e=9 GeV

E_A=90 GeV (up to Au)

$\sqrt{s_{eN}}$=57 GeV

L_{eAu}(peak)/n=1.6•10^{35} cm^{-2} s^{-1}



Concepts of Electron-Ion Collider (Cont.)

	High Energy Setup		Low Energy Setup	
	Au	e	Au	e
Energy, GeV (or GeV/n)	100	20	50	3
Number of bunches	166		166	
Bunch spacing (ns)	71	71	71	71
Bunch intensity (10^{11})	1.1	1.2	1.1	1.2
Beam current (mA)	180	260	180	260
95% normalized emittance (π mm mrad)	2.4	115	2.4	115
Rms emittance (nm)	3.7	0.5	7.5	3.3
β x/y (cm)	26	200	26	60
Beam-beam parameters (x/y)	0.015	1.0	0.015	1.0
Rms bunch length (cm)	20	0.7	20	1.8
Peak Luminosity/n (10^{33} cm^{-2}s^{-1})	2.9		1.5	
Luminosity integral/week /n (pb^{-1})	580		290	

Table 1: *Luminosities and main beam parameters for e+Au collisions at eRHIC.*

Ion	Ion Energy E_A (GeV/n)	Luminosity at $E_e = 7$ GeV (cm^{-2}s^{-1})	Luminosity at $E_e = 3$ GeV and $E_A/5$ (cm^{-2}s^{-1})
Proton	150	$7.8 \cdot 10^{34}$	$6.7 \cdot 10^{33}$
Deuteron	75	$1.6 \cdot 10^{35}$	$1.3 \cdot 10^{34}$
$^3H^{+1}$	50	$2.3 \cdot 10^{35}$	$2.0 \cdot 10^{34}$
$^3He^{+2}$	100	$1.2 \cdot 10^{35}$	$1.0 \cdot 10^{34}$
$^4He^{+2}$	75	$1.6 \cdot 10^{35}$	$1.3 \cdot 10^{34}$
$^{12}C^{+6}$	75	$1.6 \cdot 10^{35}$	$1.3 \cdot 10^{34}$
$^{40}Ca^{+20}$	75	$1.6 \cdot 10^{35}$	$1.3 \cdot 10^{34}$

Table 2: *ELIC luminosities per nucleon for e+A collisions.*

e+A White Paper, EIC Collab. April 2007

Concepts of Electron-Ion Collider (Cont.)

Recent developments: staged approach

- lower energies (2-4x100 GeV for eA and 2-4x250 GeV for ep)
- smaller price tag
- the physics is under consideration

Workshop "Physics at a high energy EIC"
October 19-23, 2009, INT, Seattle, WA

Even more recent development:

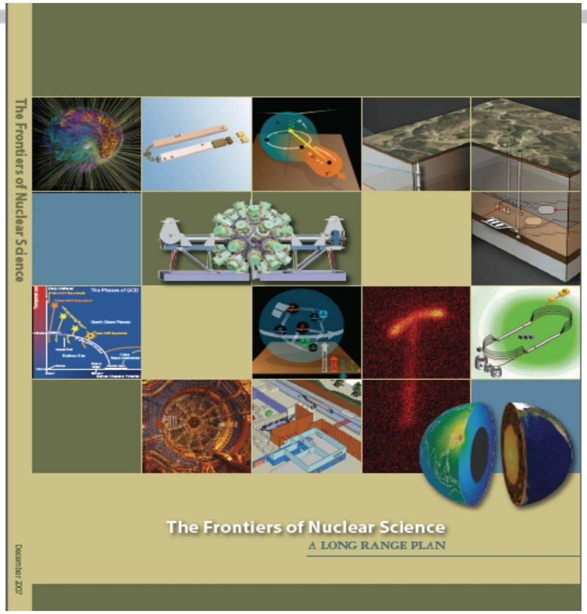
Low/medium energy EIC at JLab (5x30-5x60 GeV)

- key issues in nucleon structure (transverse imaging, flavor-decomposition)

favor smaller energies and more symmetric energies

For more details, see
C. Weiss, DIS2009,
http://www.jlab.org/meic/

EIC project: Timeline and Status



- NSAC Long Range Plan 2007
  - Recommendation: $6M/year for 5 years for machine and detector R&D

- Goals for Next Long Range Plan 2012
  - high-level recommendation for construction

- EIC Roadmap
  - finalize detector requirements from physics 2009
  - conceptual detector designs 2010
  - EIC design decision 2011

The EIC Collaboration

- ~100 Scientists, 30 Institutions, 9 countries

- 4 Working Groups:
  - accelerator - detector
  - ep - eA

- Publications:
  - The Electron Ion Collider (EIC) White Paper
  - The GPD/DVCS White Paper
  - Position paper: e+A Physics at an Electron-Ion Collider
  - The eRHIC Machine: Accelerator Position Paper
  - ELIC Zeroth Order Design Report

- More info: http:web.mit.edu/eicc (general)
  http://www.eic.bnl.gov (eA WG)

Summary

• The proposed Electron-Ion Collider (EIC) is a new high-energy and high-luminosity electron-ion and electron-polarized proton (light ion) collider.

• The EIC physics program has two main goals:

- explore strong gluon fields in nuclei

- precisely image the sea quarks and gluons in the nucleon (including spin)