

# Future Plans for Electron-Ion Colliders

**Outline:** • A Science Case • Concepts • Selected Projections • Status • User Group • Closing Words

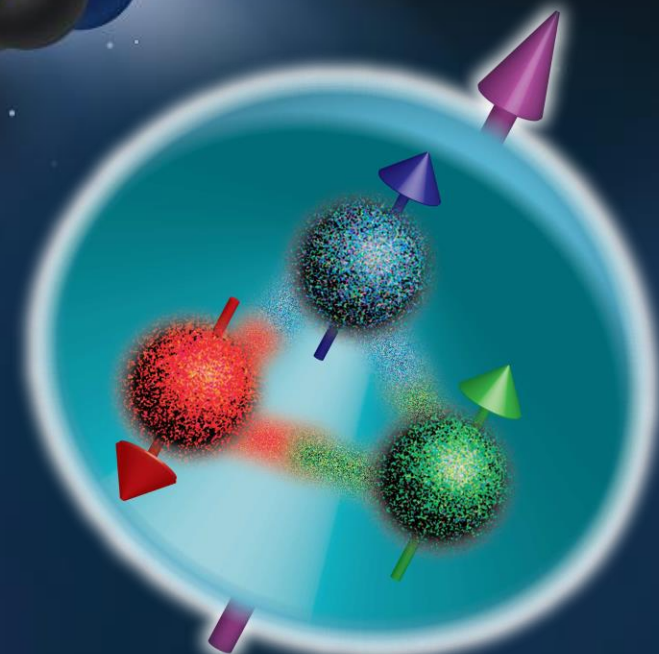
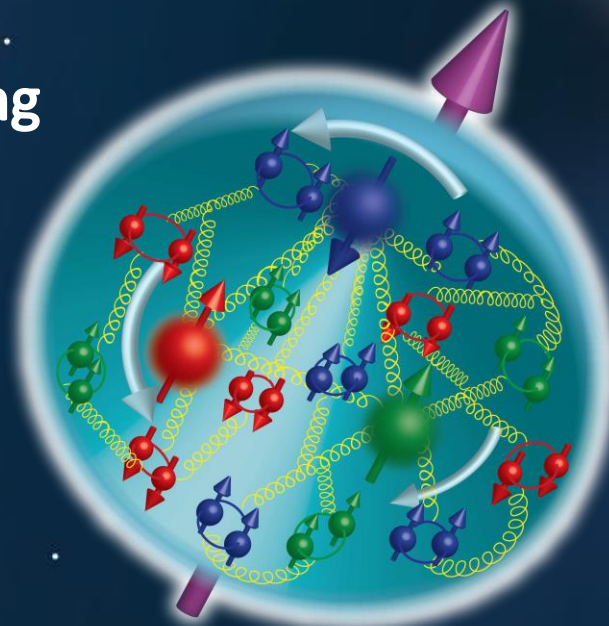
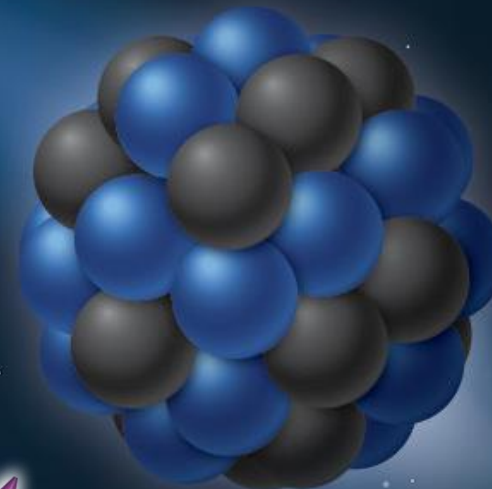
Jin Huang

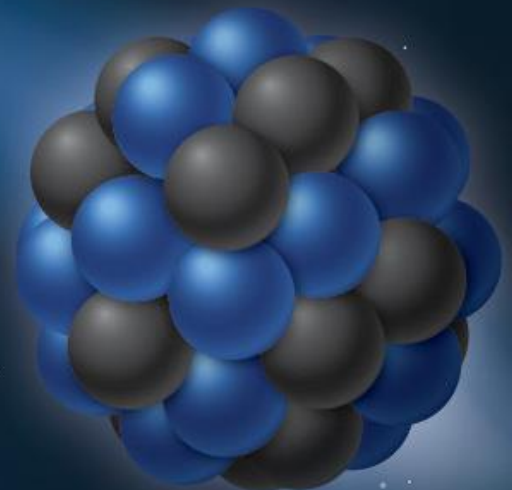
Brookhaven National Lab



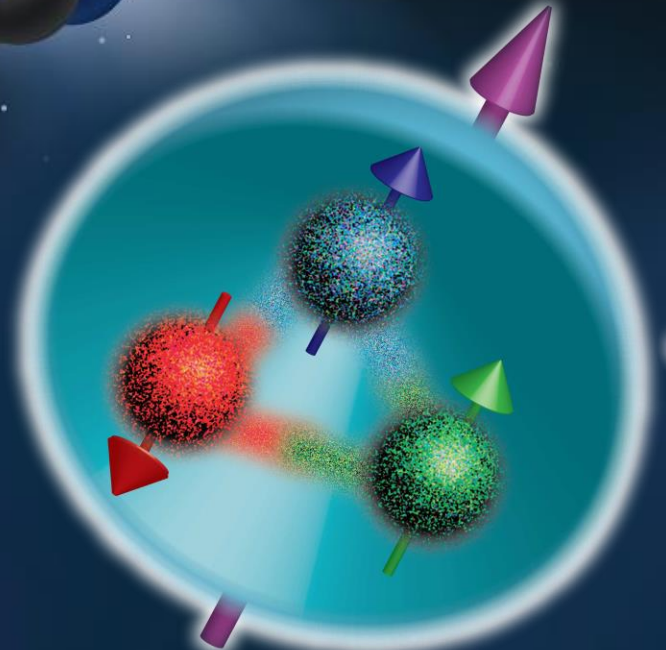
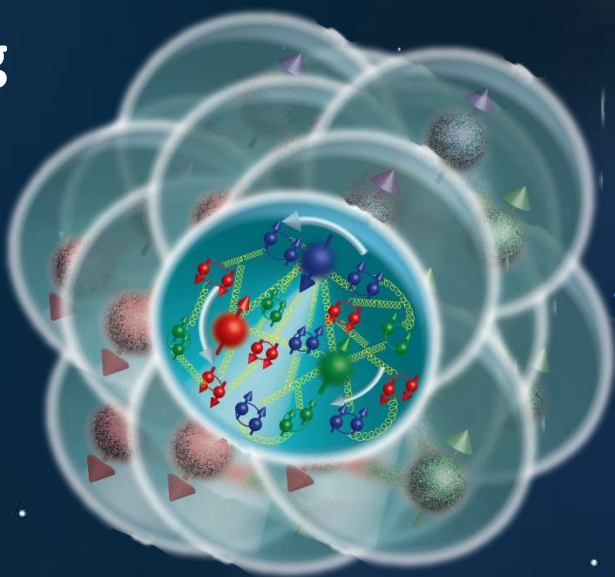
*Special thanks* to the valuable inputs from Christine **Aidala**, Abhay **Deshpande**, Jan Fiete **Grosse-Oetringhaus**, Tom **Hemmick**, Max **Klein**, Dave **Morrison**, Berndt **Mueller**, Jianwei **Qiu**, Bernd **Surrow**, Thomas **Ullrich**, Raju **Venugopalan**, and Rikutarō **Yoshida**

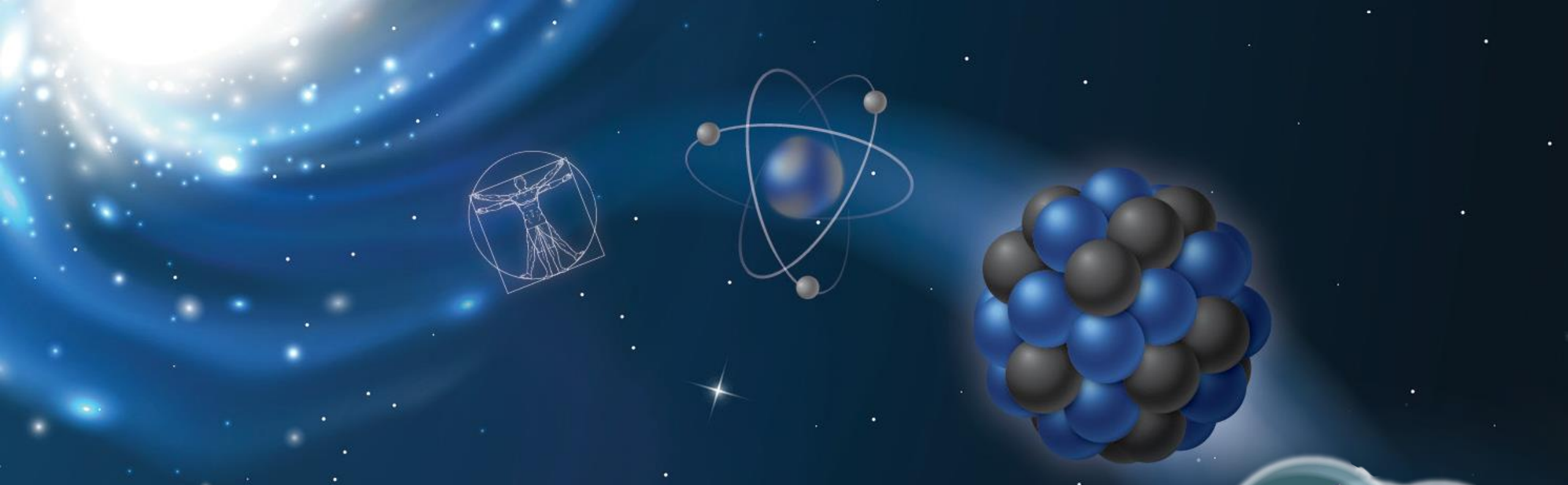
- **QCD** is expected to describe building blocks of visible matter (nucleons) and their binding in nuclei
- Strongly interacting non-abelian gauge theory; implications are far from fully understood





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- Strongly interacting non-abelian gauge theory; implications are far from fully understood

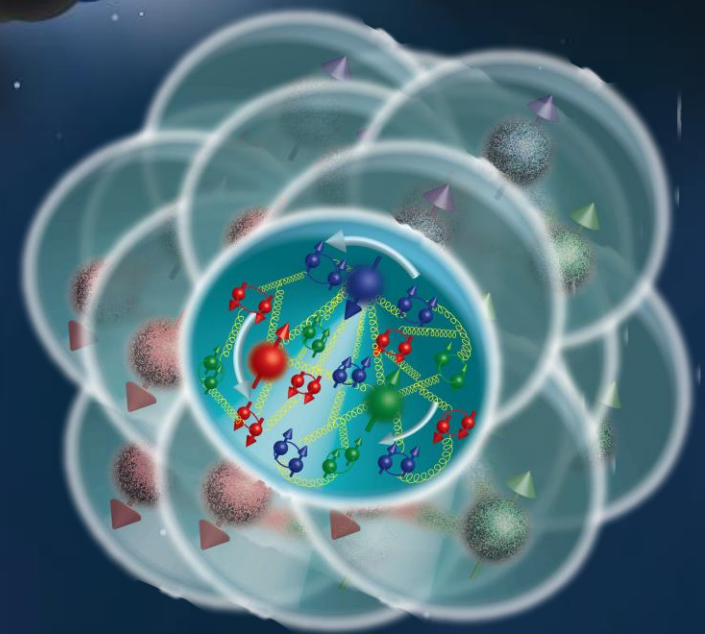




Story for an early morning talk:

Say the secret of the universe is locked in a watermelon ...

And I want to learn about it ...

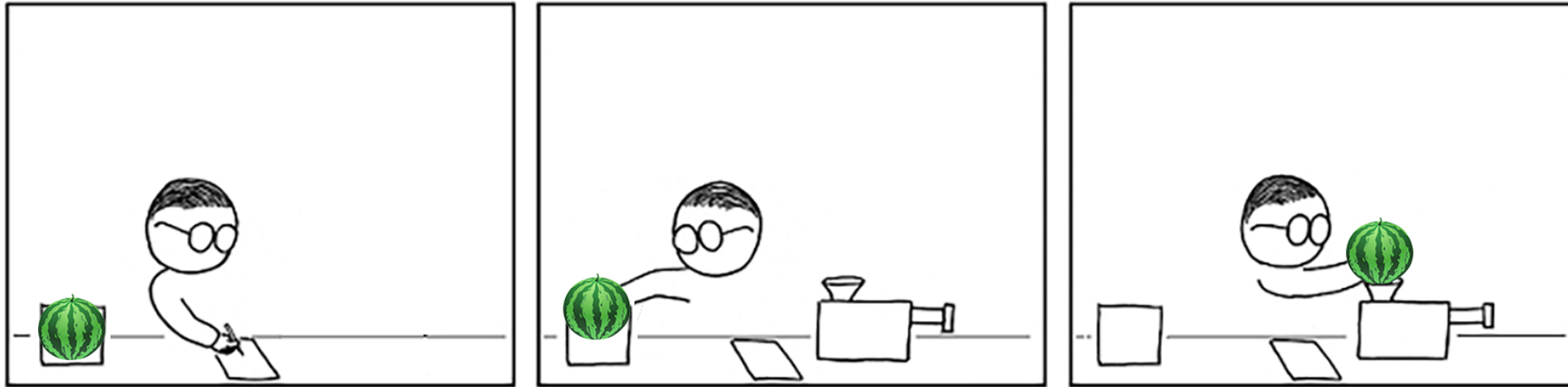


# As a high energy nuclear physicist....



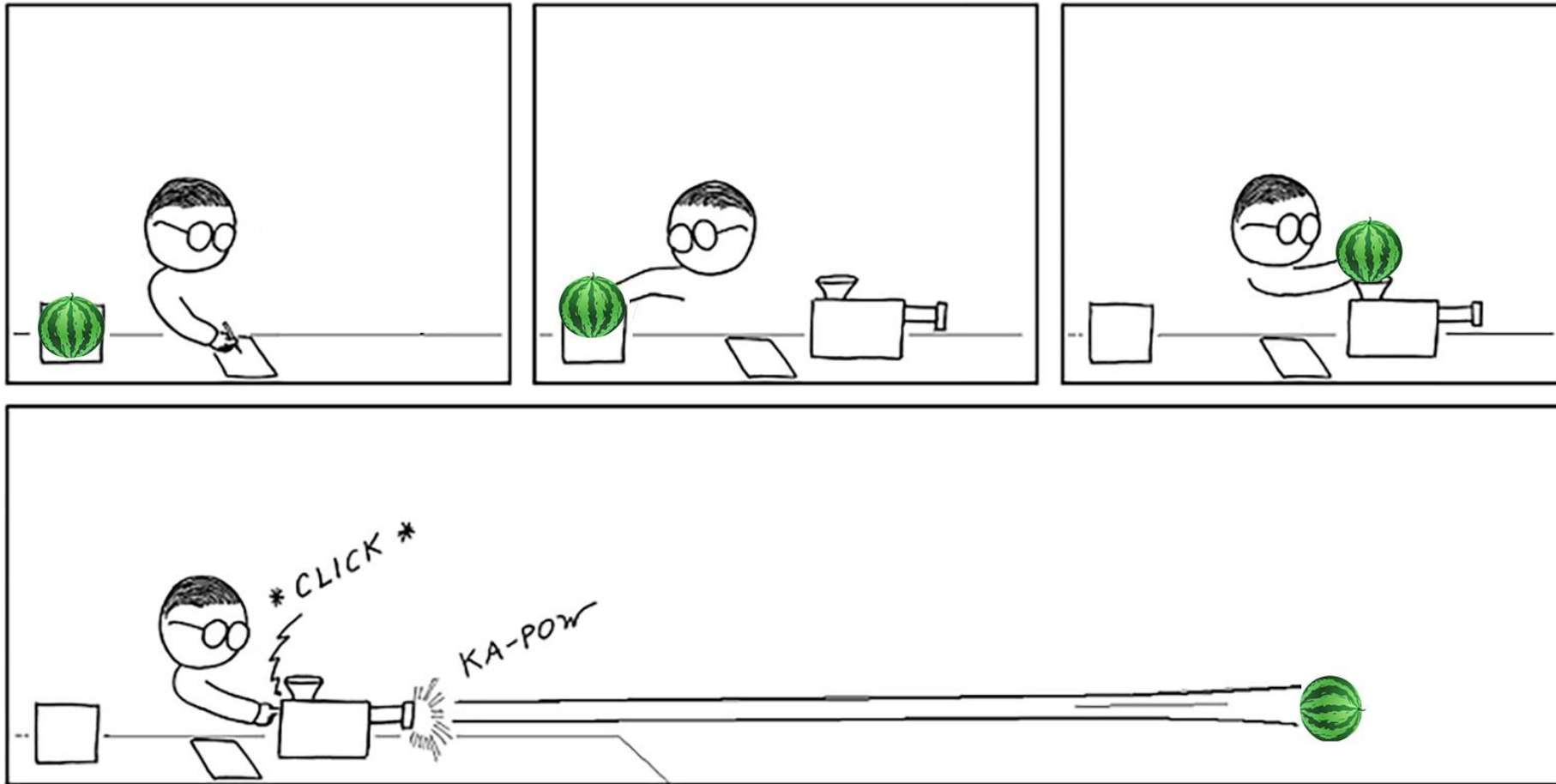
Original creation: 全玄鴻 <http://abstrusegoose.com/156>

# As a high energy nuclear physicist....



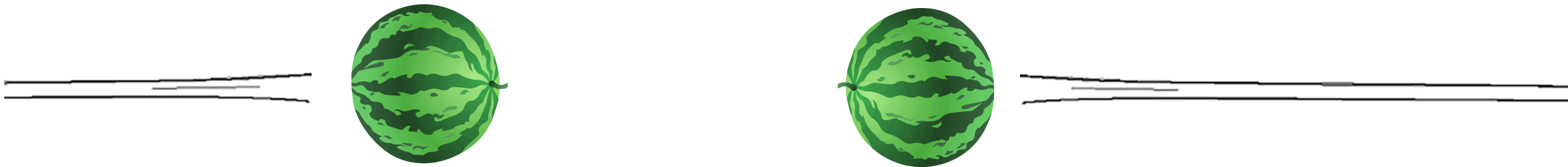
Original creation: 全玄鴻 <http://abstrusegoose.com/156>

# As a high energy nuclear physicist....



Original creation: 全玄鴻 <http://abstrusegoose.com/156>

# With help from genius accelerator friends ...





# We have had many exciting discoveries !

Collectivity

Jet production and quenching

Heavy flavor and photon production



Also many more questions remain:

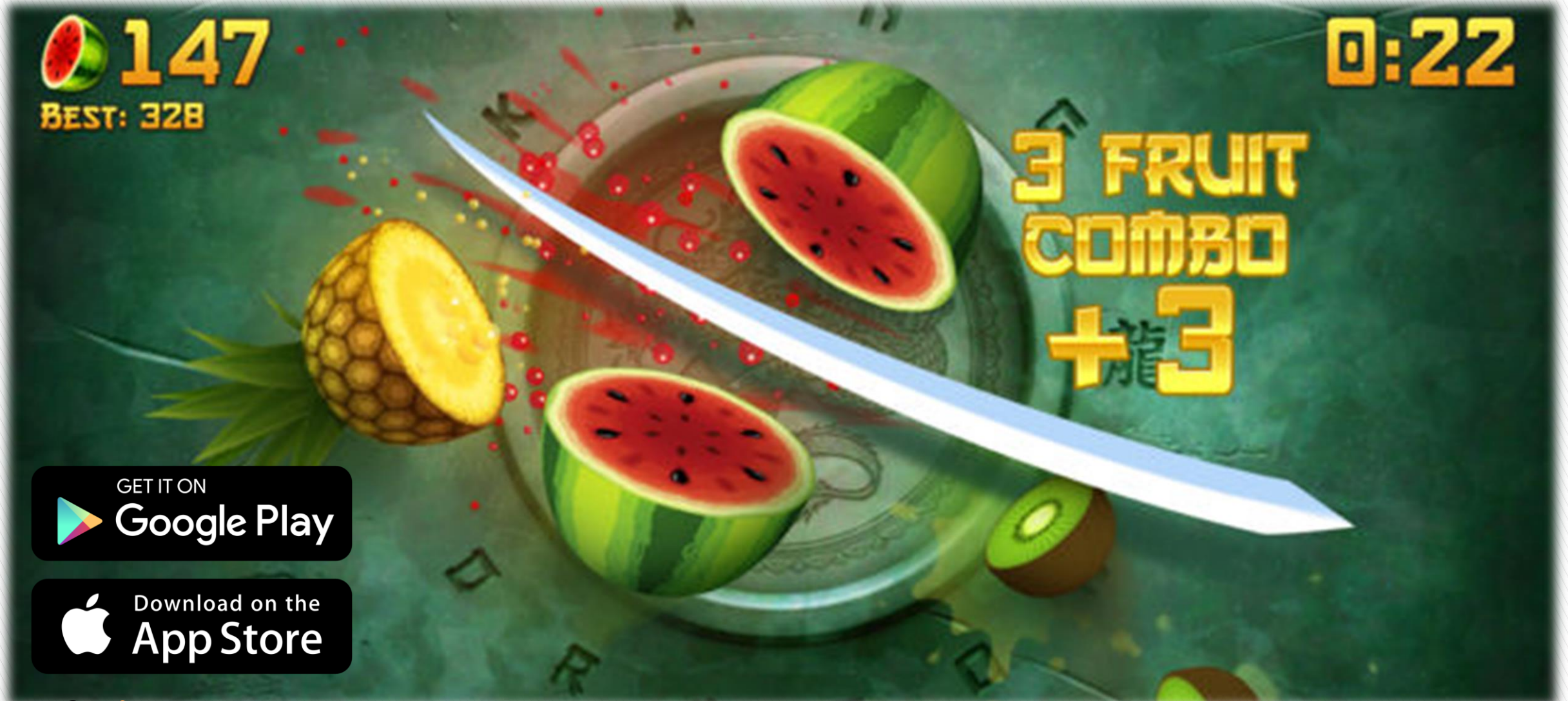
- Initial state
- How it binds together
- Internal structure / dynamics

Plasma formation

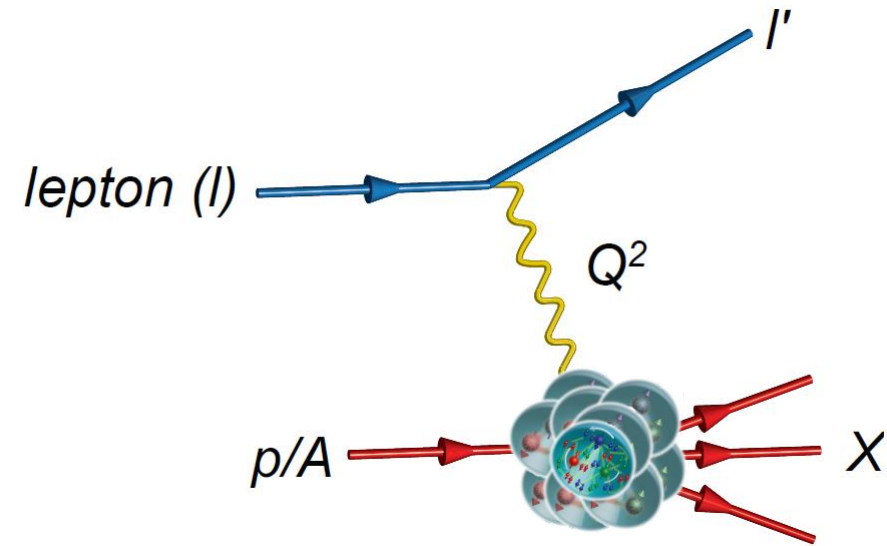
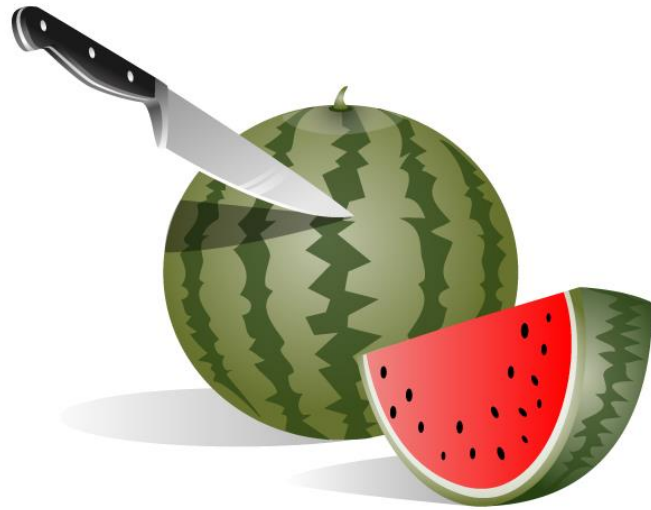
Viscosity

Transport properties

# Alternative approach ... Fruit Ninja!



# “cut open” the nucleon/nucleus with DIS



- ▶ Deep inelastic scattering (DIS) cuts open a hadron with a snapshot in momentum space
- ▶ Tag the quark kinematics, flavor and spin
- ▶ Launch a tagged parton through nuclear matter

DIS enables us to look into

- Gluon momentum distribution in nuclei
- Energy loss in cold nuclear matter (CNM) and emergence of hadrons
- Parton spin in nucleons/nuclei
- Dynamics of a bound QCD system

# A modern approach ... NMR

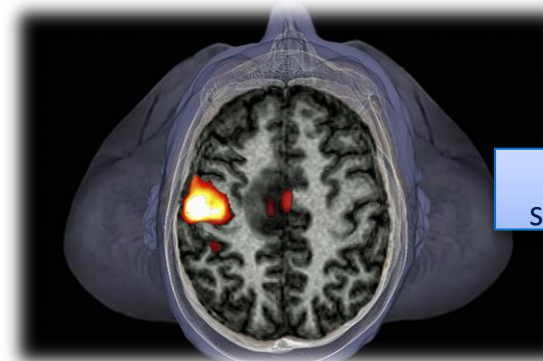


Watermelon in NMR



- ▶ If the object is dynamic and delicate, you might prefer a non-destructive approach, such as nuclear magnetic resonance imaging
- ▶ Modern imaging allows one to build up a 3-D model of selected activity in object

Brain in functional NMR



Dynamics of brain in 3D

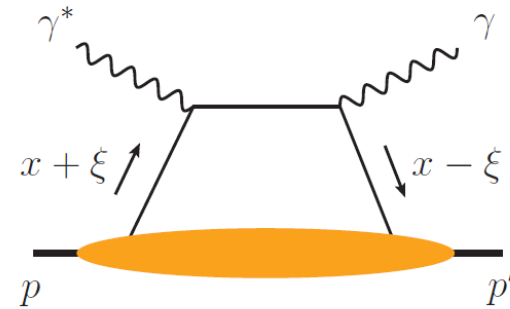


Stack in space time

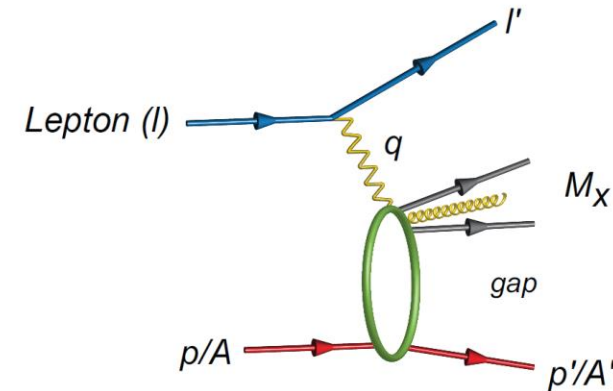
# Non-destructive imaging of nucleons/nuclei



NP exp. →



Exclusive diffractive processes (e.g. DVCS)



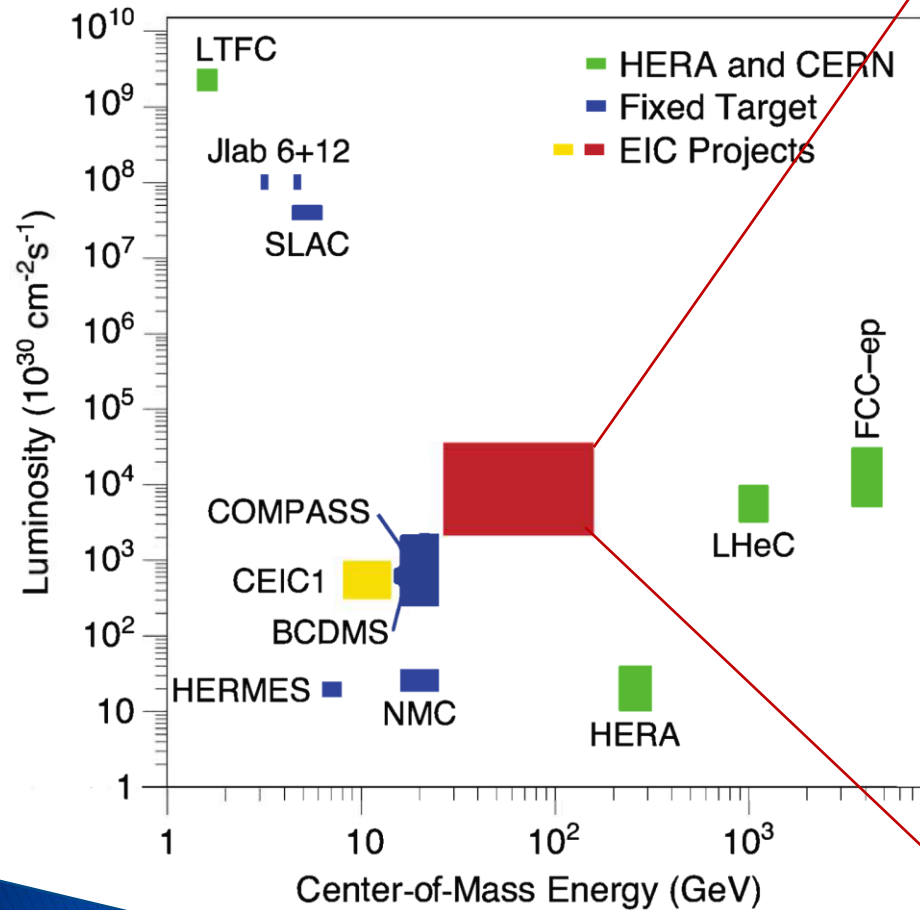
Inclusive diffractive processes

Nuclear matter can be imaged in electron-ion collisions via diffractive processes

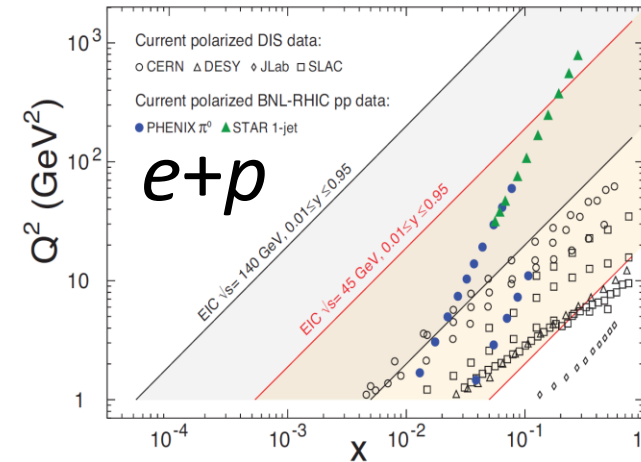
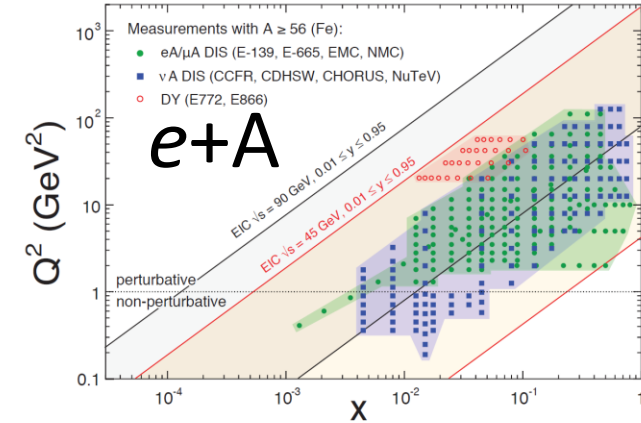
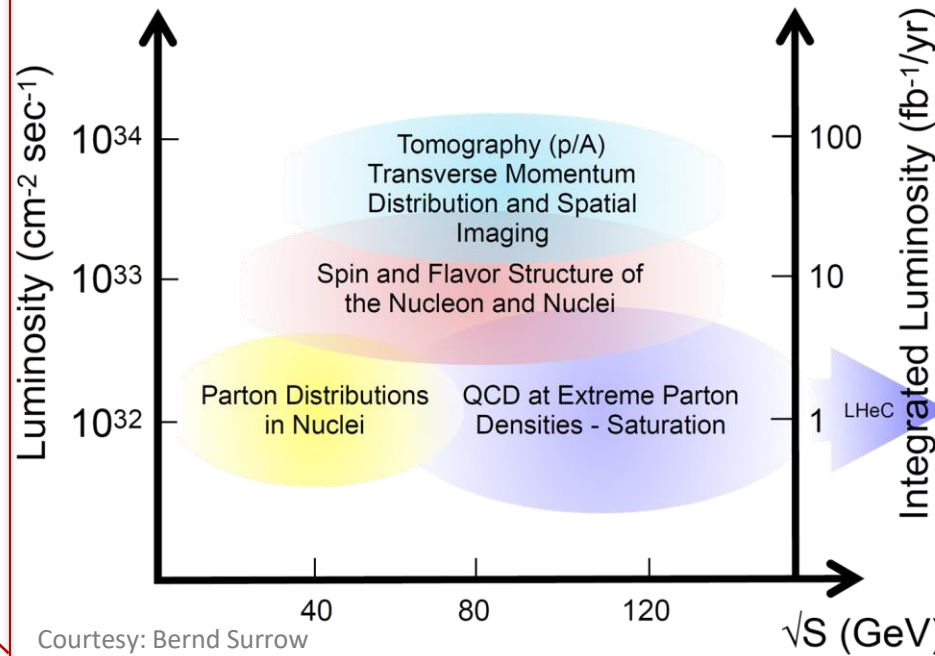
- Imaging gluon distribution
- Gluon saturation w/ boosted color density
- Orbital motion of partons in nucleons

# Explore QCD landscape with Electron-Ion Collider (EIC)

Simplified based on work of M. Klein, R. Ent, U. Klein



- ⇒ Nuclear beam
- ⇒ Polarized hadron beam
- ⇒ 1000x HERA luminosity

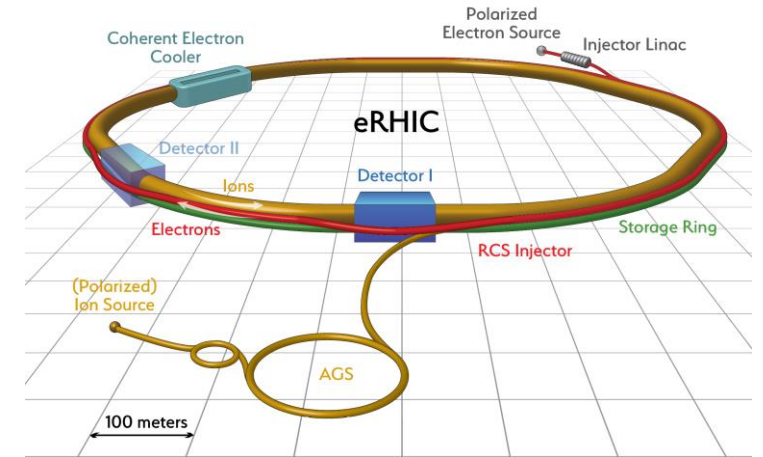


DOI: 10.1140/epja/i2016-16268-9

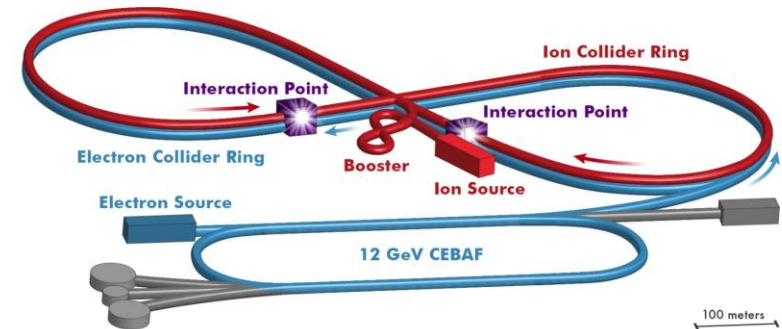
# Electron-Ion Collider (EIC) concepts

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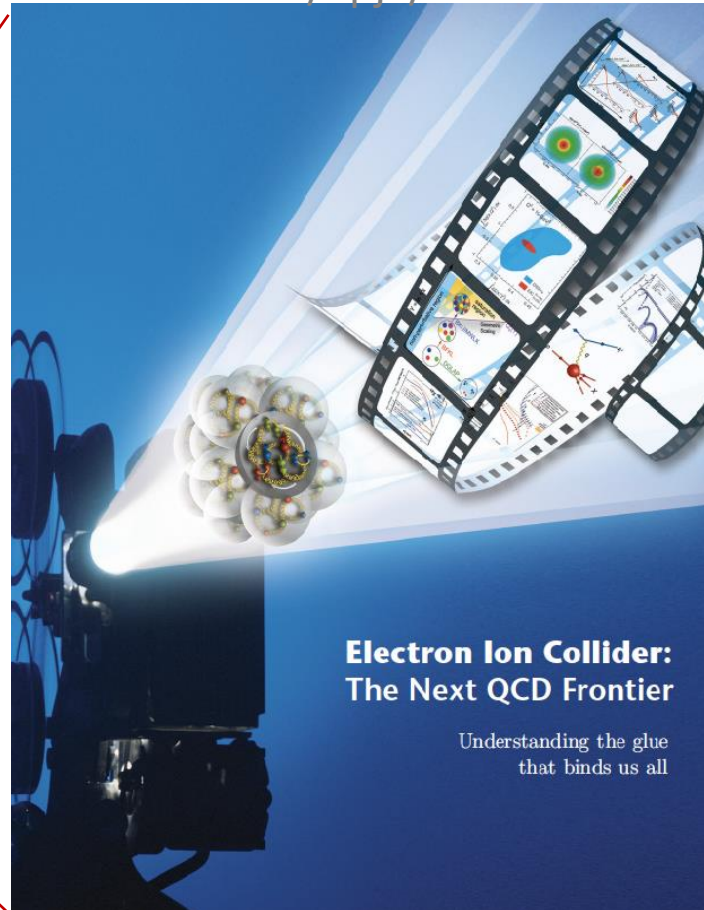
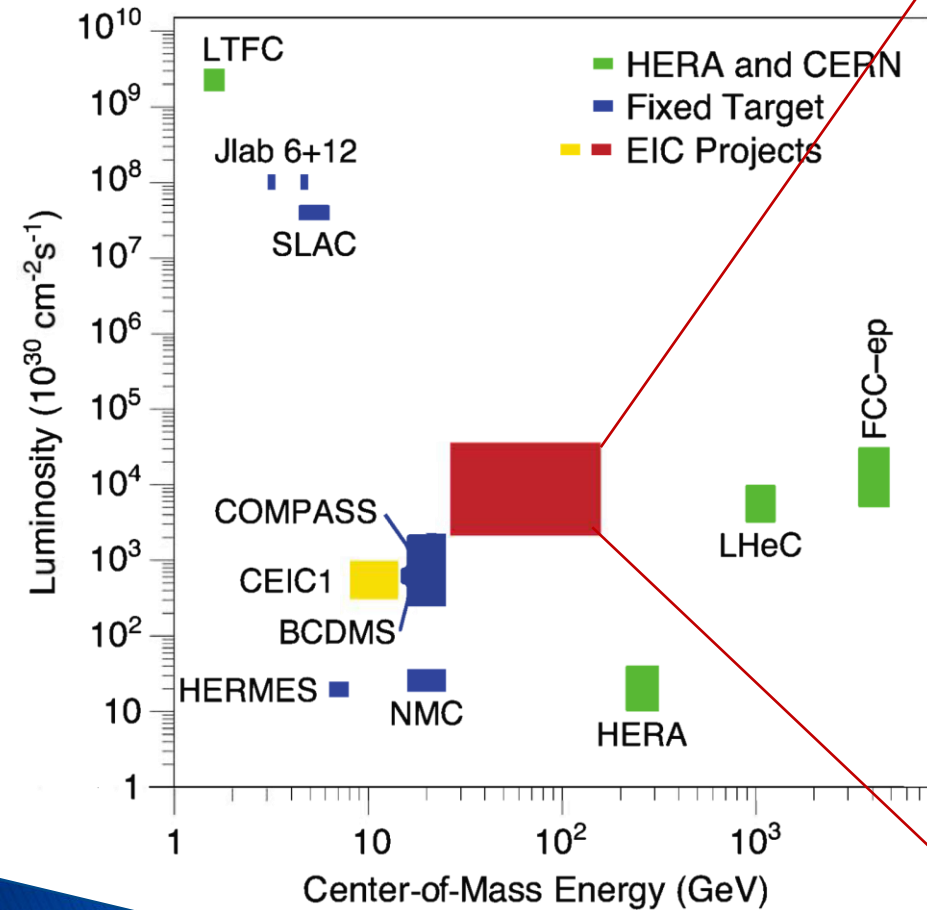
## eRHIC Concept, BNL, NY



## JLEIC Concept, Jefferson Lab, VA

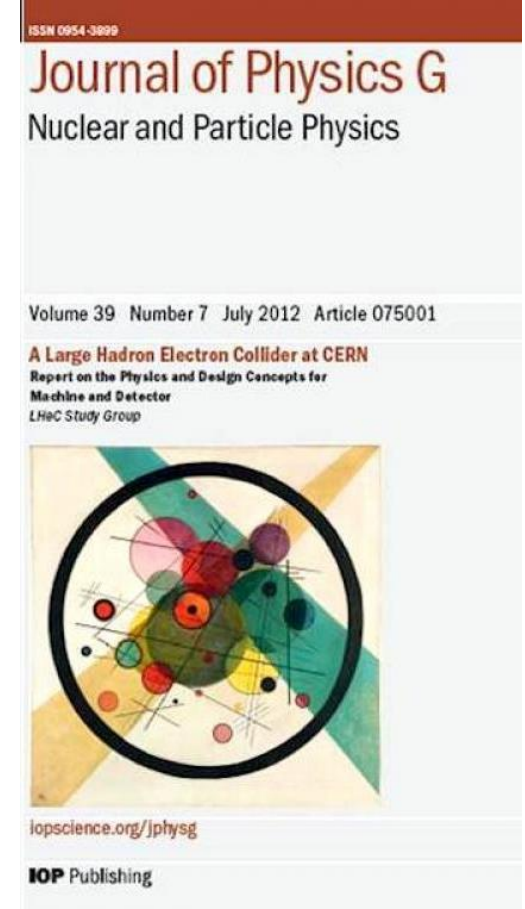
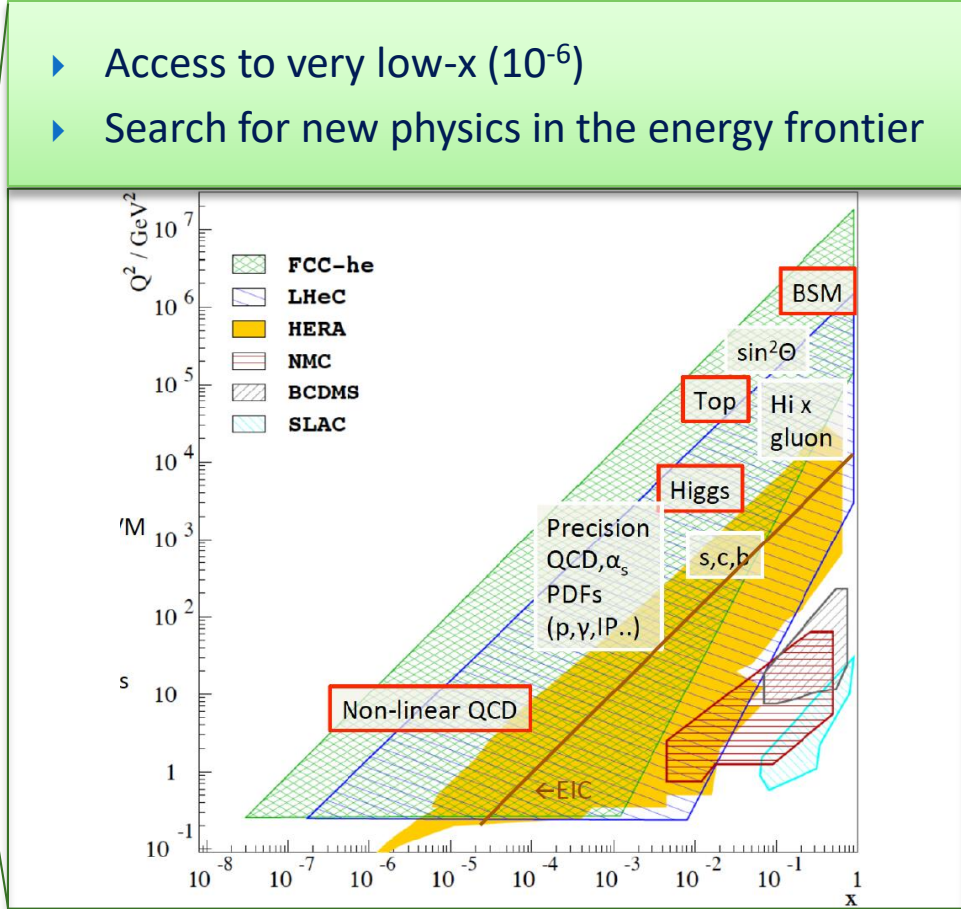
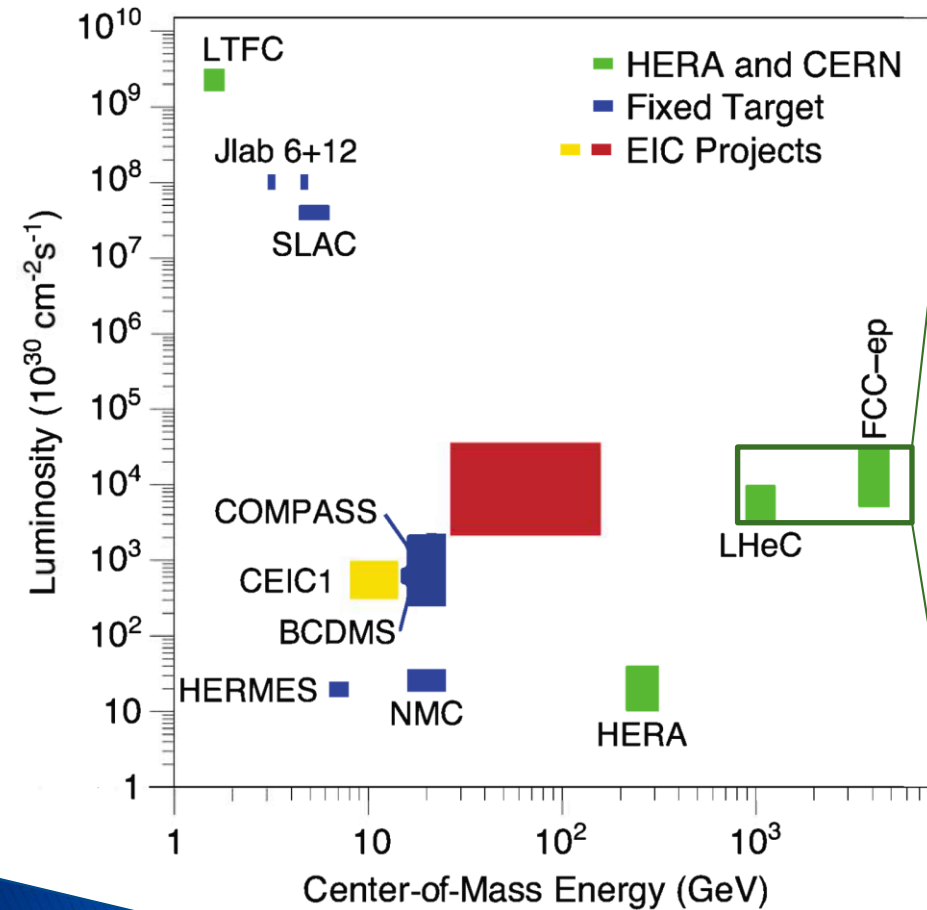


Simplified based on work of M. Klein, R. Ent, U. Klein



# Energy frontier: LHeC

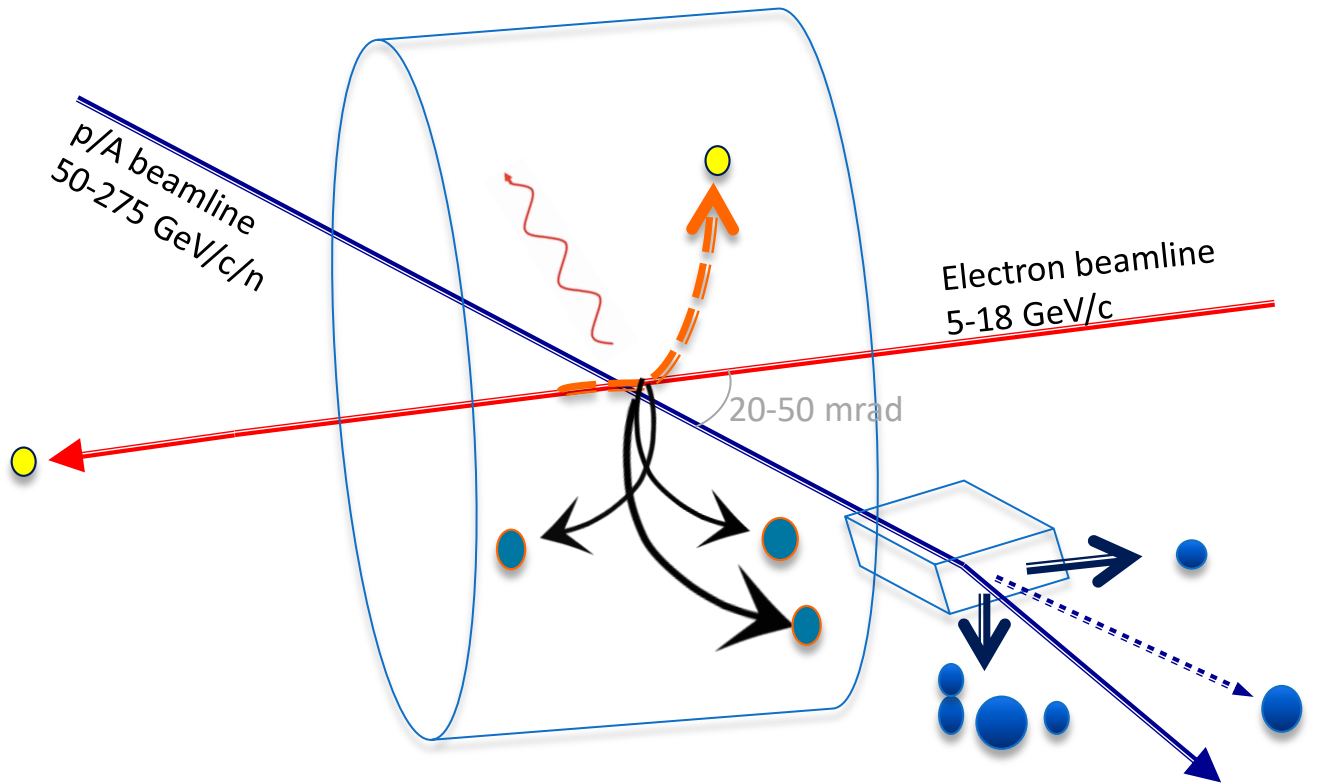
Simplified based on work of M. Klein, R. Ent, U. Klein



<http://lhec.web.cern.ch/> and LHeC CDR: DOI: 10.1088/0954-3899/39/7/075001



# EIC collision and detector



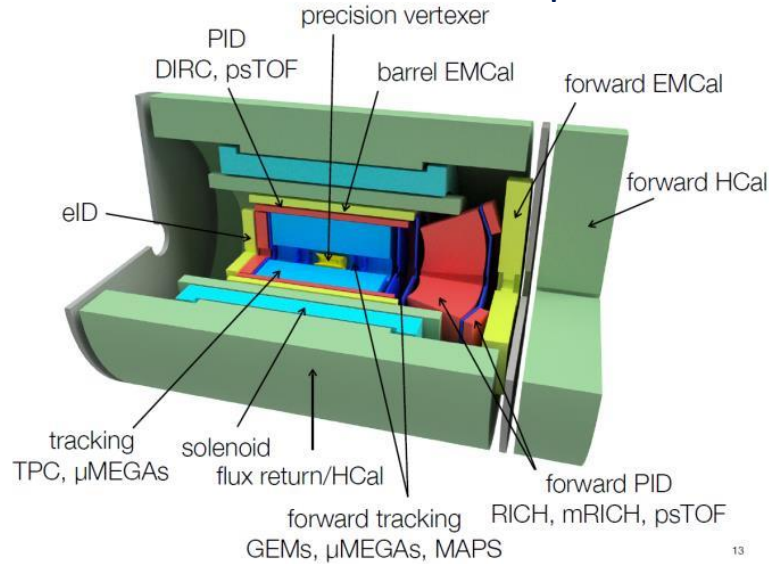
Courtesy: Rik Yoshida

Detection: electron, hadrons (w/PID), photons, nuclear fragments, beam polarization/lumi

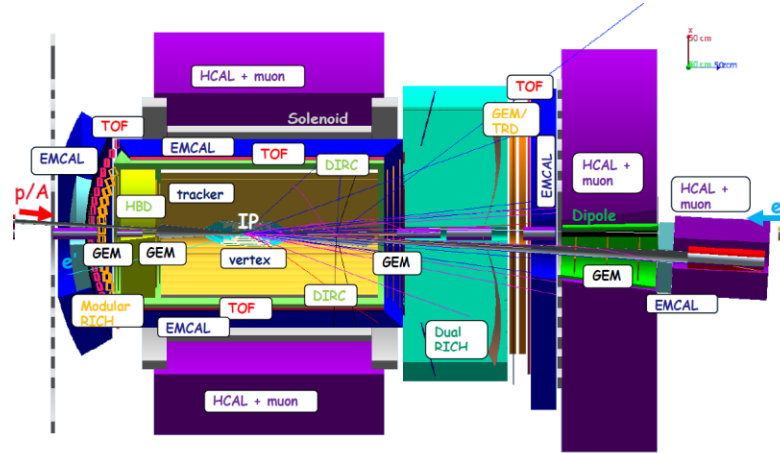
- ▶ Detector very tightly integrated with IR and beam line design
- ▶ Importance of systematics control, hermiticity, and particle ID
- ▶ Active detector and accelerator R&D program is attacking these challenges early on
- ▶ High lumi  $\neq$  high rate
  - Cross section proportional to  $\alpha_{EM}^2$   
 $\rightarrow 0.1 \times$  RHIC p+p collision rate  
(0.5 MHz @  $L=10^{34} \text{cm}^{-2}\text{s}^{-1}$ )
  - A modern high throughput DAQ (such as sPHENIX/LHC/CBM) may allow one to streaming record all EIC detector signal hits

# Detector concepts : many opportunities open!

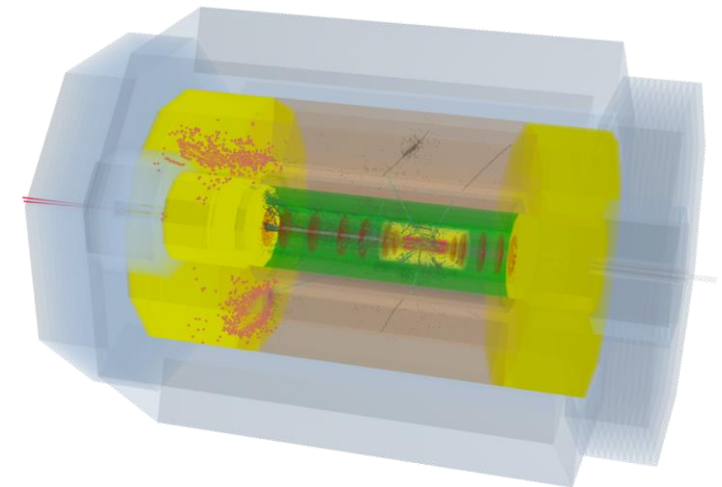
sPHENIX-based concept



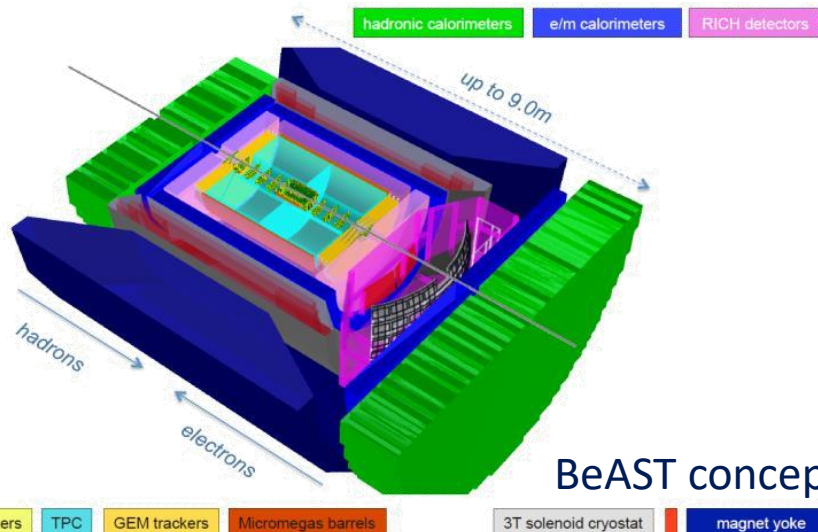
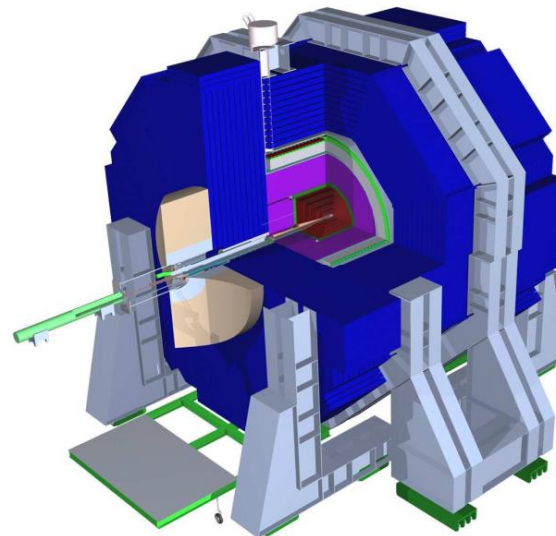
JLEIC concept



LHeC detector concept



TOPside concept

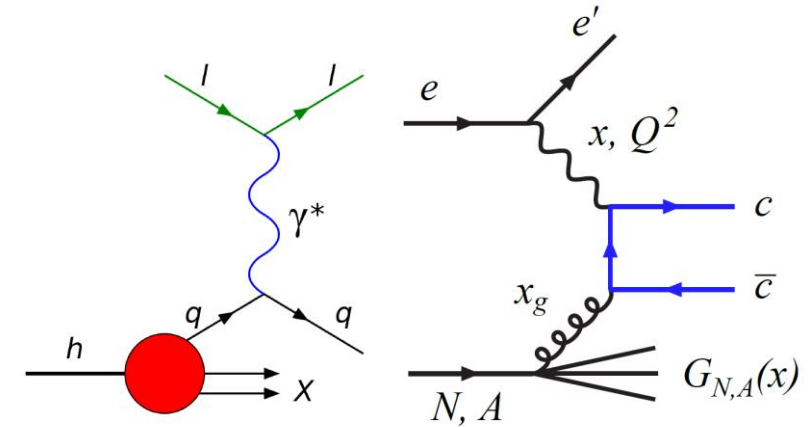


References reports :

- LHeC CDR: DOI:10.1088/0954-3899/39/7/075001
- ePHENIX LOI: arXiv:1402.1209
- eRHIC design report: arXiv:1409.1633
- MEIC (JLEIC) design summary: arXiv:1504.07961
- On-going development and updates

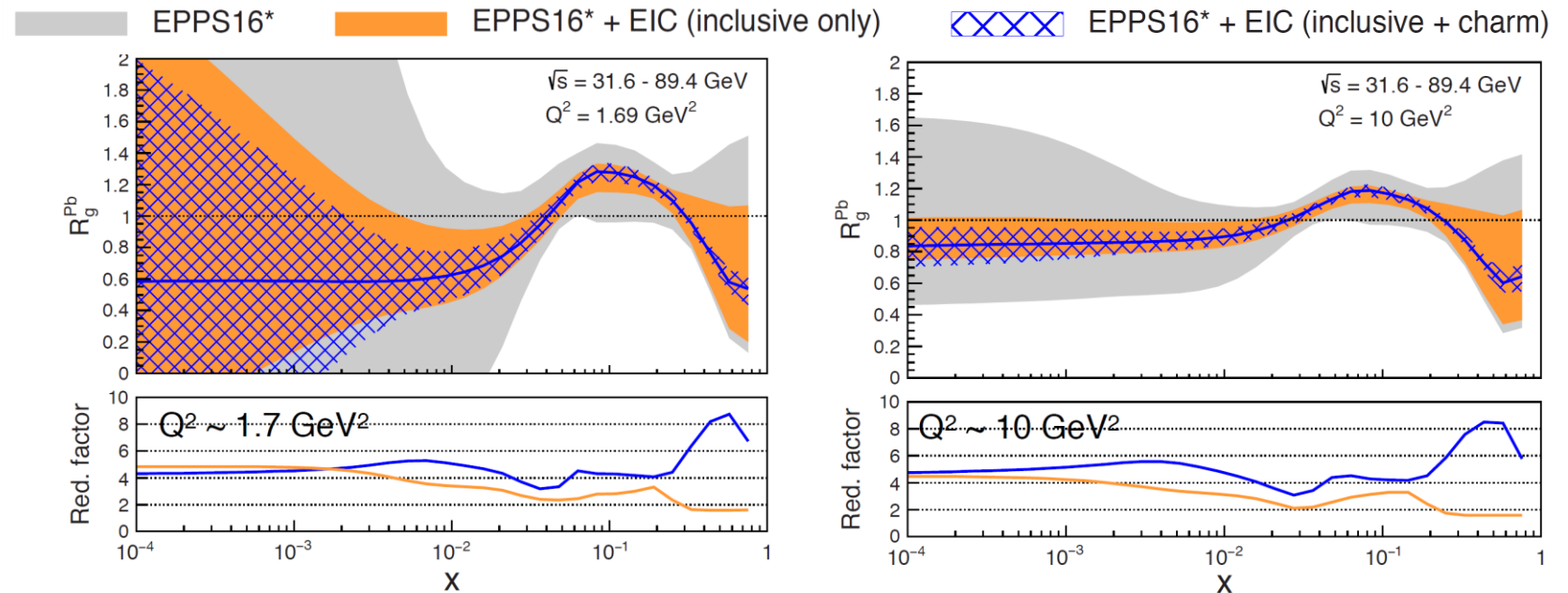
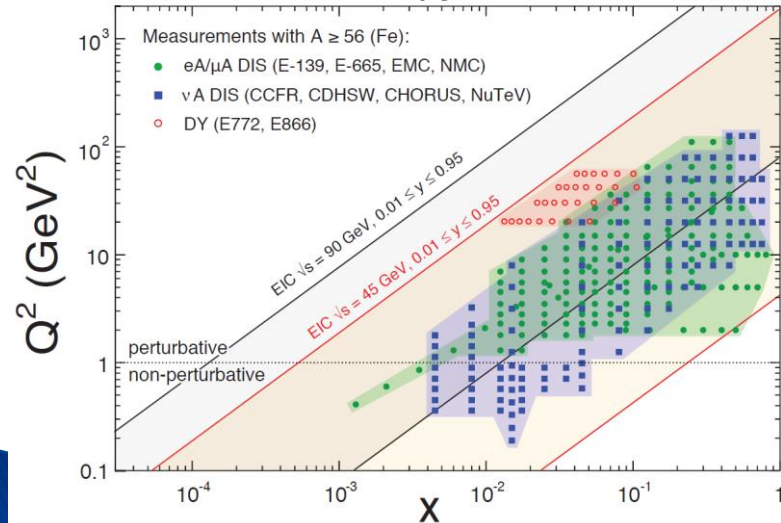
# Selected EIC impact: the knowledge of nPDFs

- ▶ EIC  $e+A$ :  
Significantly reduces sea/gluon nPDF uncertainties
- ▶ Reaching down to  $x \sim 10^{-4}$  for EIC and  $10^{-6}$  for LHeC
- ▶ HF in  $e+A$  collision constraints at large- $x$  gluon



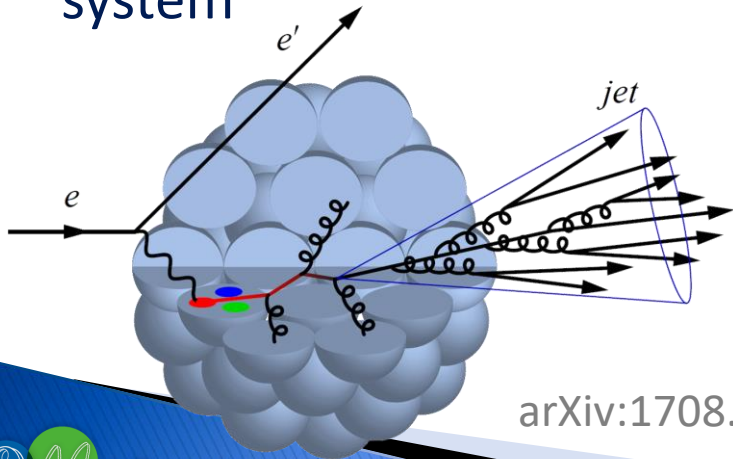
arXiv:1708.01527

DOI: 10.1140/epja/i2016-16268-9



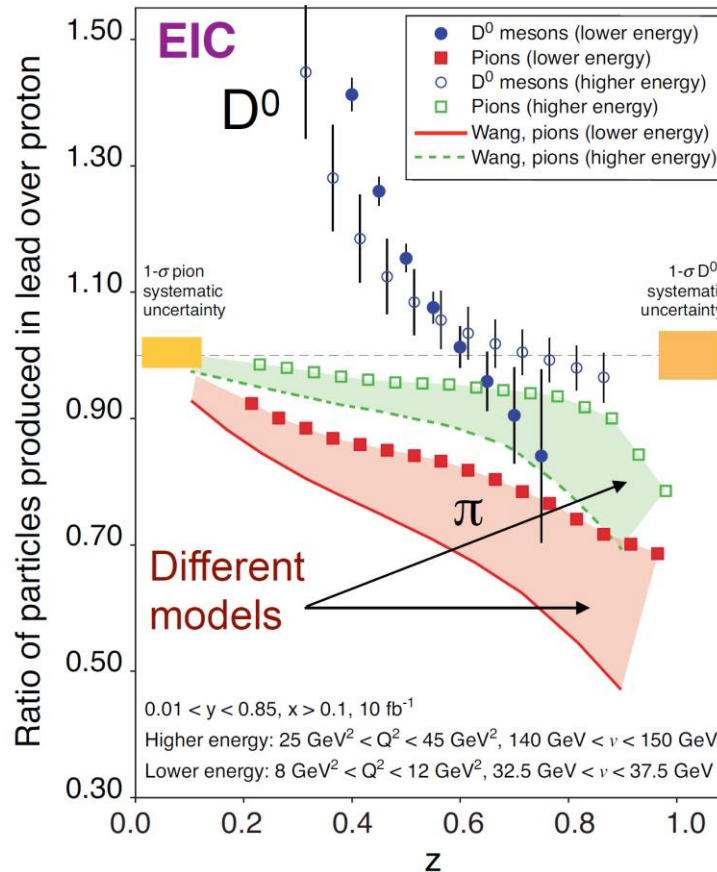
# Selected EIC impact: formation of hadrons and CNM

- ▶ DIS on Nuclei:
  - E-loss in cold nuclear matter
- ▶ Varying A-size and initial parton energy in e-A collision
  - control length in fragmentation
- ▶ Target fragmentation
  - Underlying event in small system



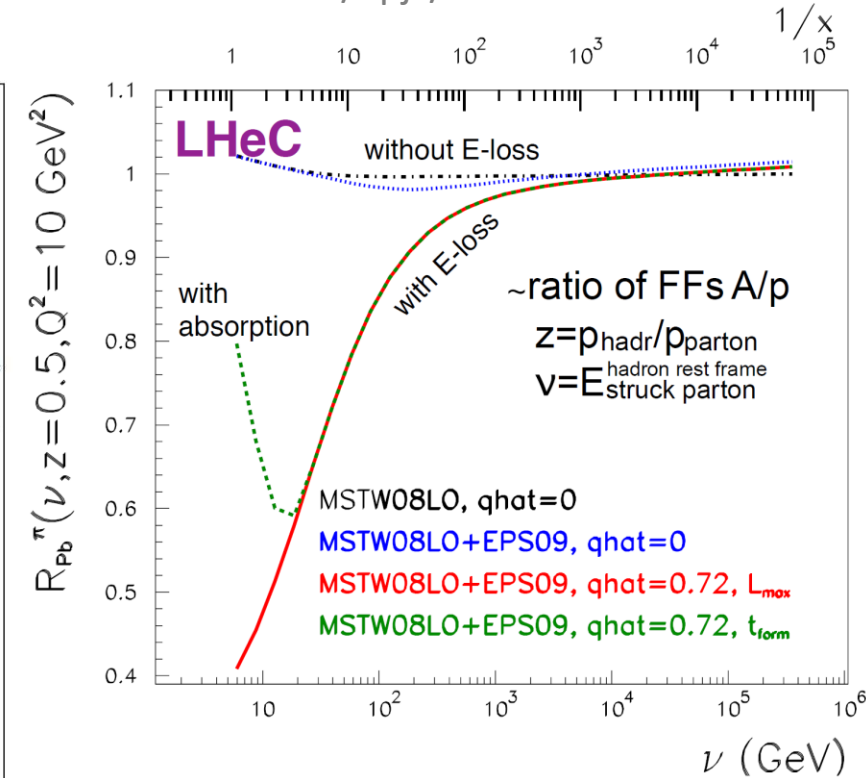
arXiv:1708.01527

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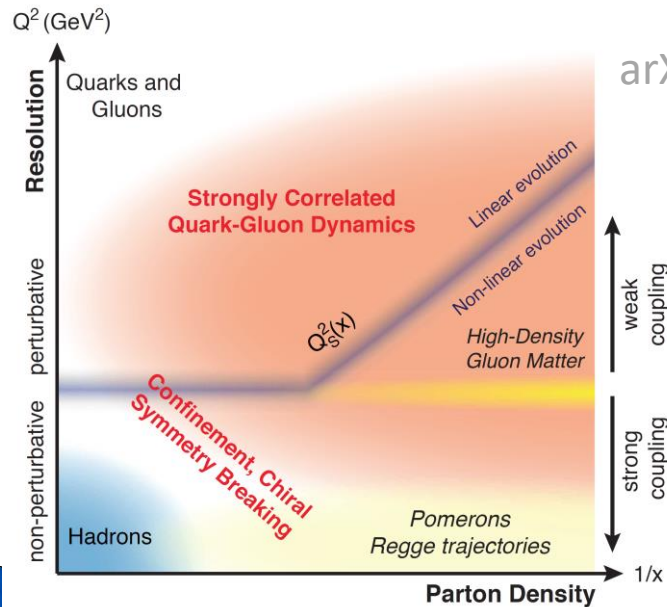
DOI: 10.1140/epjc/s2003-01289-x



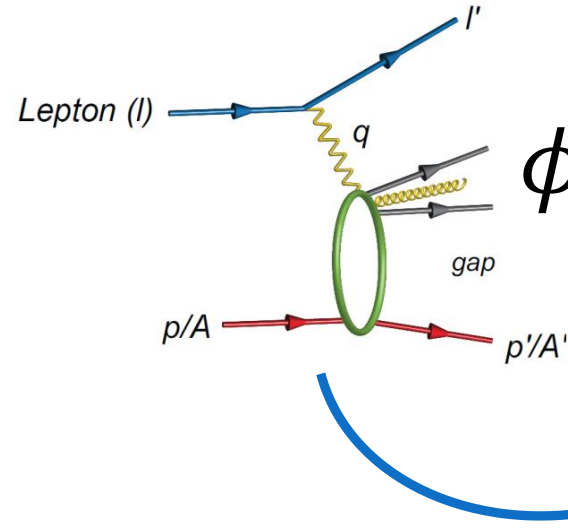
See also: Wed 4PM Sievert/Vitev  
 (Substructure of jets in e+A)

# Selected EIC impact: high density gluon matter

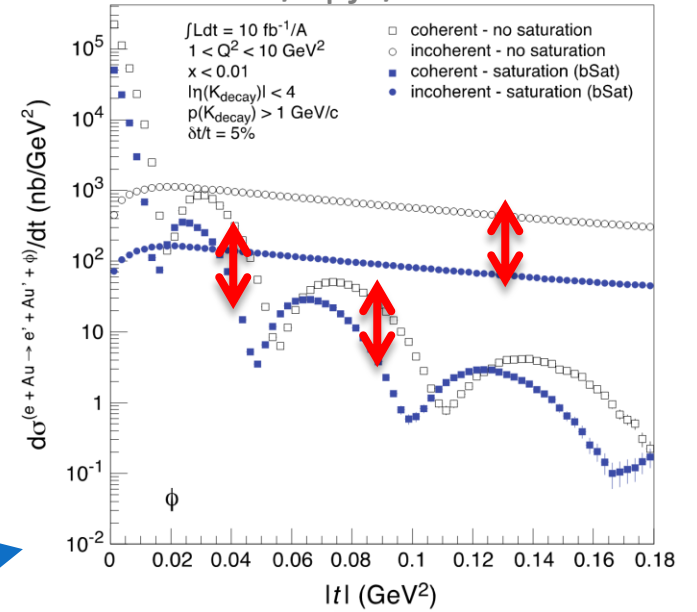
- ▶ Enhanced color density with nuclear targets at EIC, accessing the non-linear evolution in the high gluon density region via nuclear diffraction
- ▶ Accessing much lower  $x$ -region ( $10^{-6}$ ) allowed by LHeC



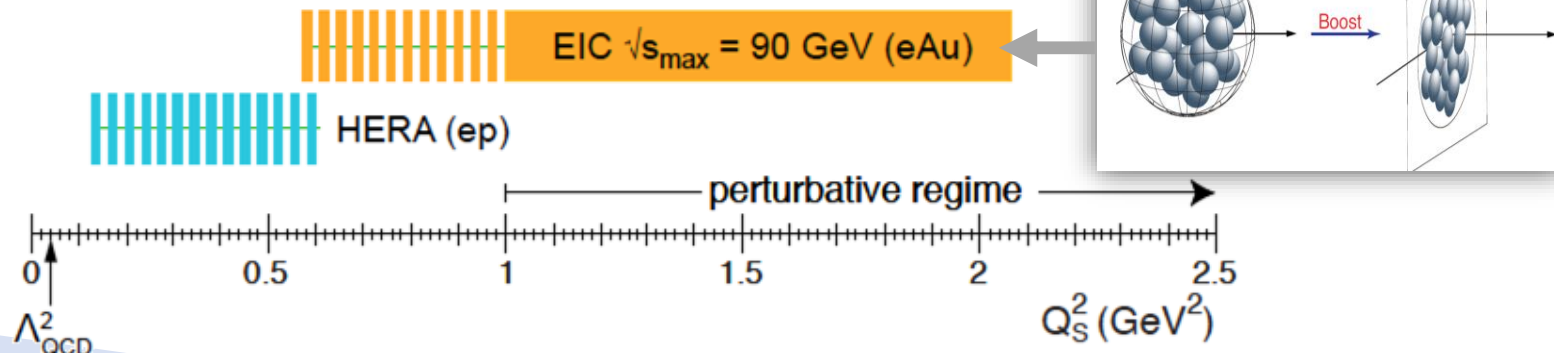
arXiv:1708.01527



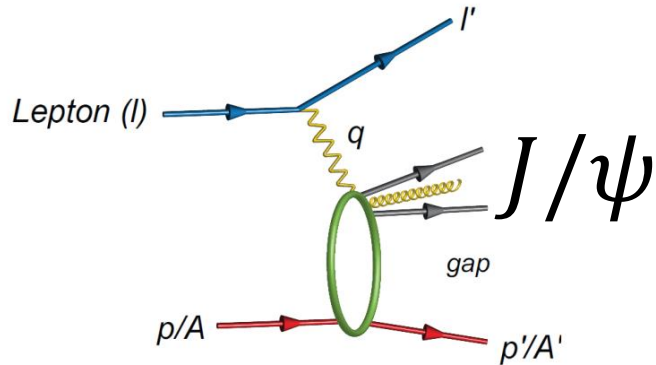
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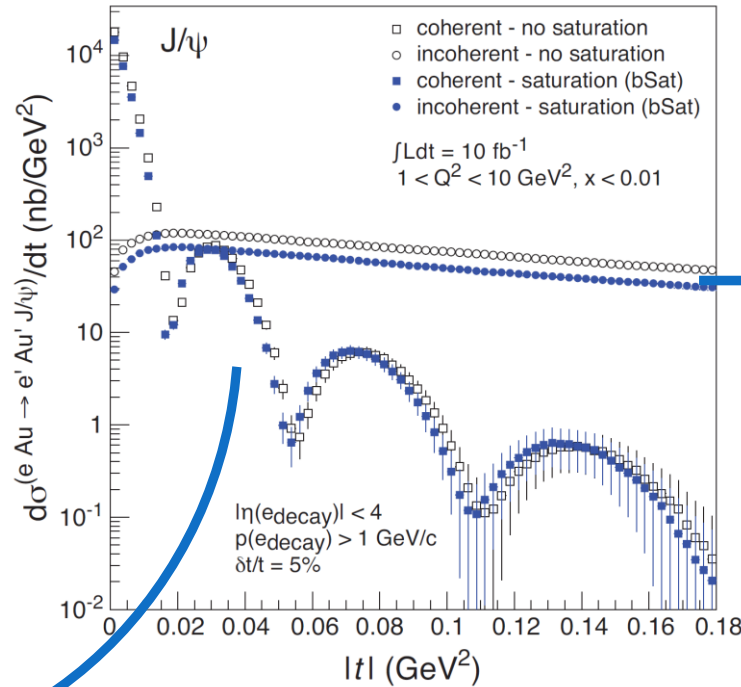
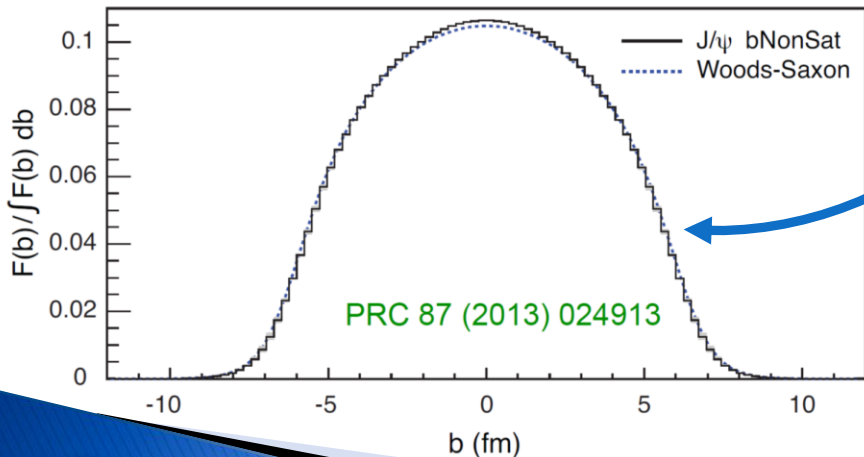
For  $x < 0.01$  in  $e$ - $p/A$  collisions:



# Selected EIC impact: imaging of gluons



Coherent  $\rightarrow$  gluon distribution



See also:

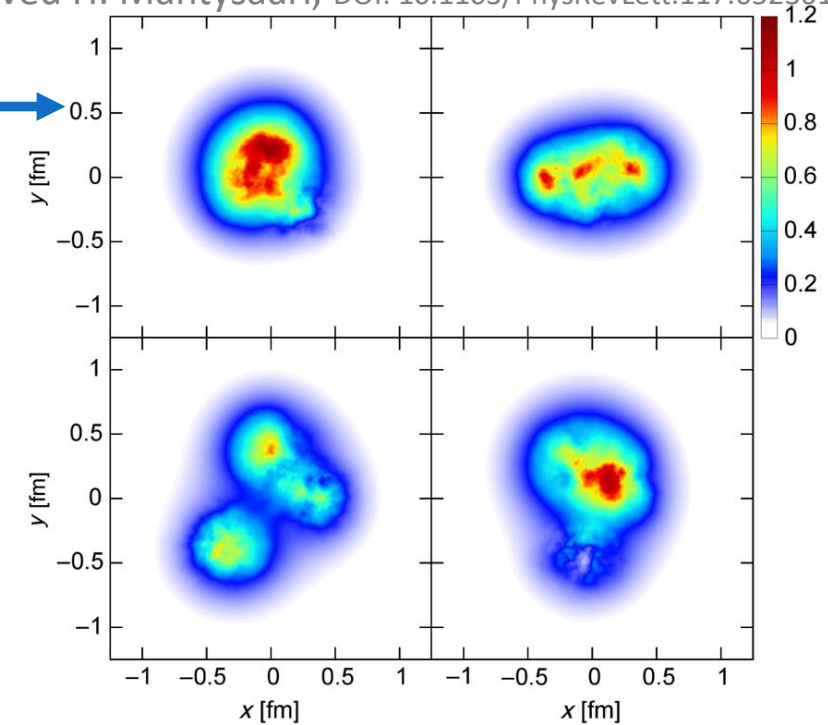
Tue M. Murray, Y.J. Li  
 Thu Y. Li, M. Strickland  
 Fri A. Angerami

Incoherent

$\rightarrow$  Initial stage gluon fluctuations!

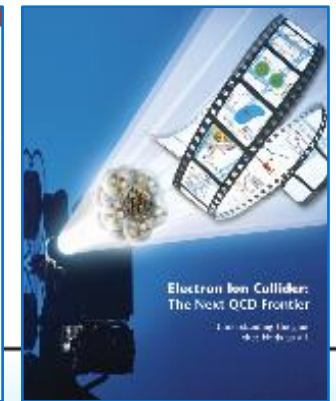
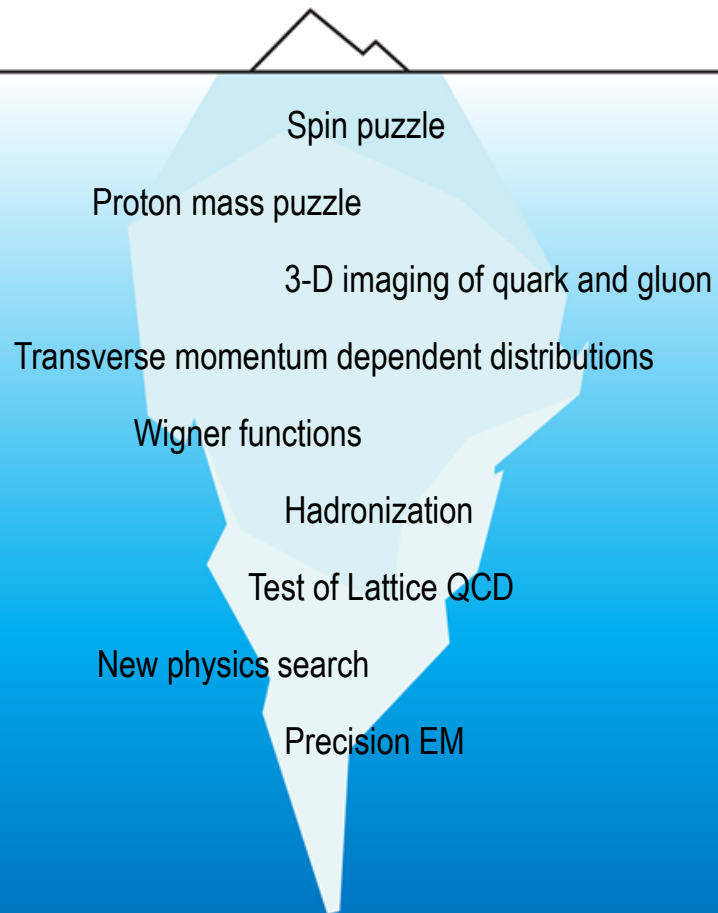
$\rightarrow$  Origin of  $v_3$  in  $p+A$

Wed H. Mäntysaari, DOI: 10.1103/PhysRevLett.117.052301



Tue Y.-J. Lee, J. Onderwaater: no collectivity signal found yet in  $e-e / e-p$   
 In EIC: can we detect flow signal in  $e-A$  DIS?  
 $e-A$  DIS  $\approx$  collide of VM and nucleus with a controllable  $Q^2$  handle

# And that is just tip of the iceberg in the QCD ocean ...



Unknown emergent phenomena of QCD

# Dramatically simplified timeline of the past decade

2011

2012

2013

2014

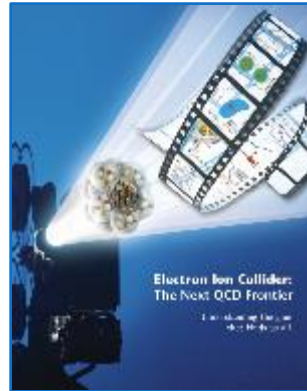
2015

2016

2017



arXiv:1108.1713



arXiv:1212.1701

arXiv:1206.2913



REACHING FOR THE HORIZON

The Site of the Wright Brothers' First Airplane Flight

The 2015  
LONG RANGE PLAN  
for NUCLEAR SCIENCE

## RECOMMENDATION III

*Gluons, the carriers of the strong force, bind the quarks together inside nucleons and nuclei and generate nearly all of the visible mass in the universe. Despite their importance, fundamental questions remain about the role of gluons in nucleons and nuclei. These questions can only be answered with a powerful new electron ion collider (EIC), providing unprecedented precision and versatility. The realization of this instrument is enabled by recent advances in accelerator technology.*

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





# Towards the future

## ▶ US EIC Project

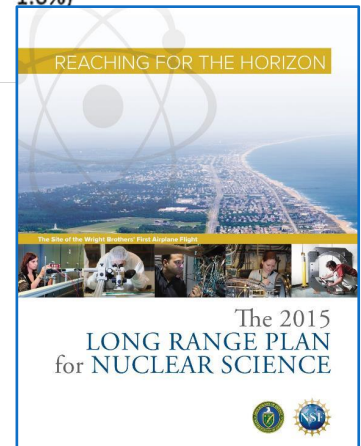
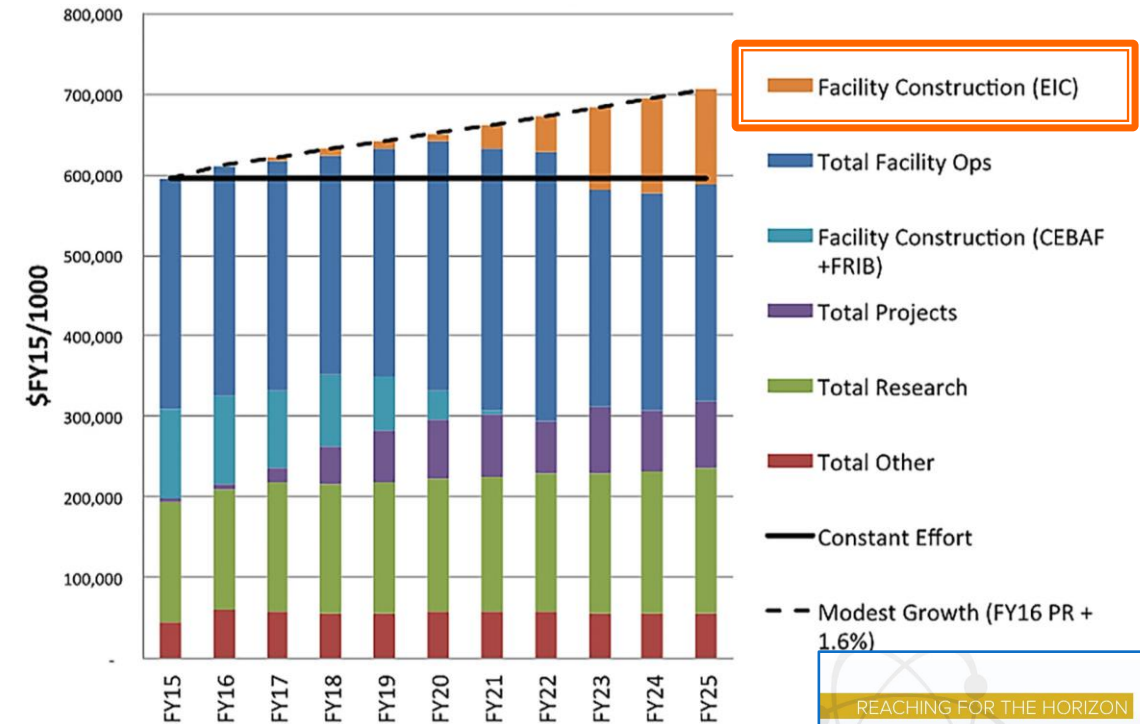
- Now: EIC scientific case is under review by US National Academy of Sciences.
  - Report expected very soon (June/July 2018)!
  - Positive result would establish a key part of the scientific requirement for US DOE CD-0 (Approve Mission Need)
- Key accelerator and detector R&D is on-going
- EIC funds may start as early as FY20-FY23
- Completion of construction as early as late-2020s, timeline depends on US budget and international contributions

## ▶ LHeC:

- Depending on consensus from the LHC community
- As project being considered in the on-going 2020 European Strategy for Particle Physics. Many active efforts in advancing the case.

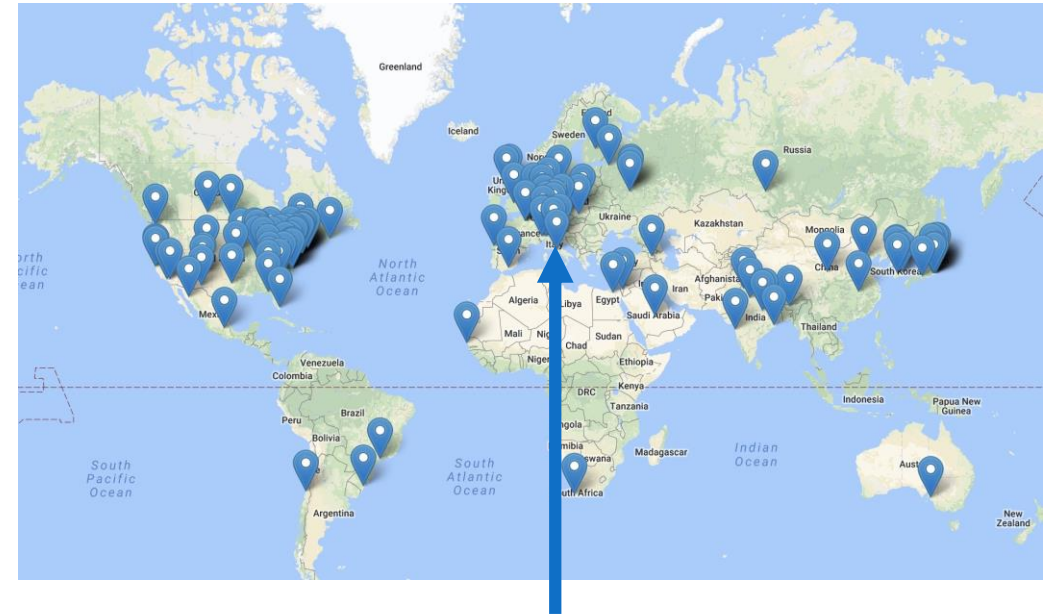
## ▶ EIC @ China and its energy upgrade are proposed

US DOE budget in FY 2015 dollars for the Modest Growth scenario



# EIC user group

- ▶ EIC science case and development
- ▶ EIC user group established in summer 2016
- ▶ 788 members 169 institutions in 29 countries



Sign up: [eicug.org](http://eicug.org)

2017 EIC user group meeting : Trieste, Italy, organized by INFN-Trieste and University of Trieste



# EIC Physics Centers

- ▶ Center for Frontiers in Nuclear Science (CFNS)
  - New funds from Simons' Foundation and NY State for the next 10 years, and in kind support from Stony Brook University and BNL. Initial focus on realization of EIC in the US, later develop into a broad center for Nuclear Science in the US
  - Workshop programs, bi-weekly seminar, postdoctoral fellows/visitors, EIC summer school
  
- ▶ EIC Center at Jefferson Lab (EIC<sup>2</sup>@Jlab)
  - Consolidation of EIC related activities under the umbrella of a Center for JLEIC at JLAB. Particular emphasis is on the close connection of EIC science to the current 12 GeV CEBAF program.
  - Weekly meetings, LDRD projects, HUGS Summer School, student/postdoctoral fellows



[www.stonybrook.edu/cfns](http://www.stonybrook.edu/cfns)



[www.eiccenter.org](http://www.eiccenter.org)

# Coming EIC/LHeC User Events



June 2018

July 2018

Later in 2018

## POETIC 8

8th International Conference on Physics Opportunities at an Electron-Ion Collider  
19-23 March 2018, University of Regensburg

**Local Organizing Committee:**  
Dimitris Alexopoulos  
Ralf Bräse  
Tina Eder  
Andreas Krieger (Chair)  
Andreas Schäfer

**International Advisory Committee:**  
Nicolle Amato-Im, IN2P3, France  
David Boal, University of Colorado, USA  
Maurice Cozzani, INFN, Italy  
Wolfgang Engel, DESY, Germany  
Maurice Hatzioftalidis, University of Liverpool, UK  
Hans-Joachim Drescher, DESY, Germany  
Ting Thomas, University of Adelaide, Australia  
Thomas Weir, SLAC, USA  
Raj Venkatesh, IIT, India

**Topics:**  
• Physics of various hadron production mechanisms  
• Experimental and theoretical studies of the proton structure  
• QCD in high particle densities and nuclear medium  
• Progress in heavy ion collisions and nuclear matter

## Electrons for the LHC

LHeC/FCCeh and PERLE Workshop  
June 26-29, 2018  
LAL-Orsay, France

**Organizing Committee:**  
Nestor Armento (USC)  
Oliver Brüning (GERN)  
Walid Kaabi (LAL)  
Uta Klein (Liverpool)  
Zhiqing Zhang (LAL)

**Advisory Committee:**  
Yong-Mu Kim (Chung-Ang Univ., Korea)  
Sergey Kuznetsov (JINR, Dubna, Russia)  
Pavel Kratochvíl (JINR, Dubna, Russia)  
Johannes Knipfing (LAL, France)  
John Krieger (LAL, France)  
John Krieger (LAL, France)  
John Krieger (LAL, France)

**Physics Co-Chairs:**  
Nestor Armento (USC)  
Oliver Brüning (GERN)  
Walid Kaabi (LAL)  
Uta Klein (Liverpool)  
Zhiqing Zhang (LAL)

<https://indico.cern.ch/event/698368/>

**Center for Frontiers in Nuclear Science**  
4-6 June 2018  
CFNS Stony Brook  
US/Eastern timezone

Next-generation GPD studies with exclusive meson production at EIC

June 4 @ CFNS

## EICUG 2018

Electron Ion Collider User-Group Meeting 2018  
July 30 - August 2, 2018  
Catholic University of America  
Washington, DC

The Electron Ion Collider (EIC) is a proposed facility to study hadron physics at high energy recommended by the 2015 Long Range Plan for Nuclear Science by the NSAC. The EIC User Group (EICUG) promotes the realization of the EIC and its science, and consists of over 700 scientists. The meeting will discuss the outcome of the National Academic of Science study and the path forward for the Electron Ion Collider, as well as recent developments and progress on novel physics ideas and technical plans for the collider and detectors.

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[www.jlab.org/conferences/eicug18](http://www.jlab.org/conferences/eicug18)

July 30 @ CUA

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**Programs & Workshops**

- **2017 Programs**
  - **Toward Predictive Theories of Nuclear Reactions Across the Isotopic Chart (INT-17-14)**  
February 27 - March 21, 2017  
J.E. Eberke, Ch. Elster, K.D. Launey, D. Lee
  - **Precision Spectroscopy of QGP Properties with Jets and Heavy Quarks (INT-17-15)**  
May 1 - June 8, 2017  
S.A. Bass, A. Mazumder, J. Putschke, L. Ruan
  - **Neutrons Double beta Decay (INT-17-2a)**  
June 13 - July 14, 2017  
J. Engel, J. Gerden, Y. Orlandini
  - **Electromagnetic Signatures of R-process Nucleosynthesis in Neutron Star Binary Mergers (INT-17-2b)**  
July 24 - August 18, 2017  
R. Fernández, D. Kasen, G. Martínez-Pinedo, B.D. Metzger
  - **Spatial and Momentum Tomography of Hadrons and Nuclei (INT-17-3)**  
August 28 - September 28, 2017  
I. Cloet, K. Hofels, Z.E. Meziani, B. Paschos
  - **2017 Workshops**
    - **Probing QCD in Photon-Nucleus Interactions at RHIC and LHC: The Path to EIC (INT-17-65W)**  
February 13 - 17, 2017  
J.D. Tapia Takai, C.A. Bertulani, S.R. Klein, T. Lappi, M. Strikman
    - **BNL 2017 International Workshop on the Big Problems in QCD and Beyond (INT-17-64W)**  
March 20 - 24, 2017  
J. Carlson, S. Chandrahasan, K. Daniele, C. Gethinger, D. Kaplan, U.-J. Wiese
    - **Letter QCD Input for Neutrons Double- $\beta$  Decay (INT-17-67W)**  
July 6 - 7, 2017  
Z. Davoudi, W. Detmold, A. Nicholson, M.J. Savage
    - **The Flavor Structure of Nucleon Sea (INT-17-68W)**  
October 2 - 13, 2017  
C. Adami, W. Detmold, J. Gu, W. Vogelsang
    - **Neutron-Antineutron Oscillations: Appearance, Disappearance, and Baryogenesis (INT-17-69W)**  
October 23 - 27, 2017  
K. Babu, Z. Berezhiani, Y. Kamyshov, B. Kerbikov
  - **2018 Programs**
    - **Nuclear  $\alpha$ -Indo Theories and Neutrino Physics (INT-18-1)**  
February 26 - March 26, 2018  
C. Bertulani, O. Benhar, A. Galindo-Urrutia, A. Lovato, J. Menéndez
    - **Multi-Scale Problems Using Effective Field Theories (INT-18-2)**  
May 7 - June 1, 2018  
E. Braaten, N. Brambila, T. Schaefer, A. Vario
    - **Fundamental Physics with Electroweak Probes of Light Nuclei (INT-18-3a)**  
June 12 - July 13, 2018  
S. Bacca, R. J. Holt, S. Pastore, O. Phillips
    - **Advances in Monte Carlo Techniques for Many-Body Quantum Systems (INT-18-3b)**  
July 20 - September 7, 2018  
F. Pastore, B. Clark, C. Gandolfi, M.J. Savage
    - **Probing Nucleons and Nuclei in High Energy Collisions (INT-18-3)**  
October 1 - November 16, 2018  
Y. Hatta, Y. Kurokawa, C. Marquet, A. Prokudin

Oct @ INT Program

## POETIC Series

## PIEIC2018

Workshop on Pion and Kaon Structure at an Electron - Ion Collider  
May 24-25, 2018  
The Catholic University of America  
Washington, D.C.

**Circular**

This workshop will explore opportunities provided by the Electron - Ion Collider to study the quark and gluon structure of the pion and kaon. It follows and will stake stone of the progress since the earlier June 1-2, 2017 workshop at Argonne National Lab: <http://www.phy.anl.gov/theory/peiic2017>

**Organizing Committee**

Ian Cloet - ANL  
Tanja Horn - CUA  
Cynthia Keppel - Jlab  
Craig Roberts - ANL

May 24 @ CUA

2018 Quark Matter

## 2018 Workshop on Probing Quark-Gluon Matter with Jets

Hosted at Brookhaven National Laboratory  
July 23-25, 2018

**2018 Workshop Registration (Deadline: July 23, 2018 11:59 PM)**  
GSI Submission Form (Deadline: July 9, 2018 12:00 AM) What is GSI?

[Begin Workshop Registration](#)

**Motivation**

Observables involving QCD jets have proven to be effective in probing the hot nuclear medium created in heavy ion collisions. In the last decade important theoretical and experimental advances have been achieved towards understanding jet evolution in QCD media, stimulated by jet measurements at RHIC and LHC.

Novel substructure techniques that were developed recently within the high-energy physics community have also drawn much attention in the context of heavy ion collisions and are currently being investigated. While the latter efforts are mainly attempting to describe final-state interactions, jets in electron-ion collisions constitute comprehensive tools for probing the nuclear structure.

The workshop aims at bringing together leading experts from the heavy ion and the high energy physics communities, both theorists and experimentalists, to review the latest progress in jet physics in the various subfields, share their respective expertise and discuss the related technical challenges. The goal is to provide a platform to assess the new jet observables whose scope is probing quark-gluon matter.

The program will consist of a workshop with contributed talks for three days, July 23-25, 2018, for which you can register through this website. The workshop will be followed by a

**Workshop Dates**  
July 23-25, 2018

**Event ID**  
38779

**Workshop Venue**  
Brookhaven National Laboratory  
Upton, NY 11973 USA

**Workshop Location**  
Physics Department (Bldg. 110)  
Large Seminar Room

**Map and Directions To Event** | In Brookhaven Lab

**Workshop Coordinator**  
Dorothy Davis  
☎ (631) 344-2524  
✉ (631) 344-7561  
✉ [gdavis@bnl.gov](mailto:gdavis@bnl.gov)

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July 23-25 @ BNL

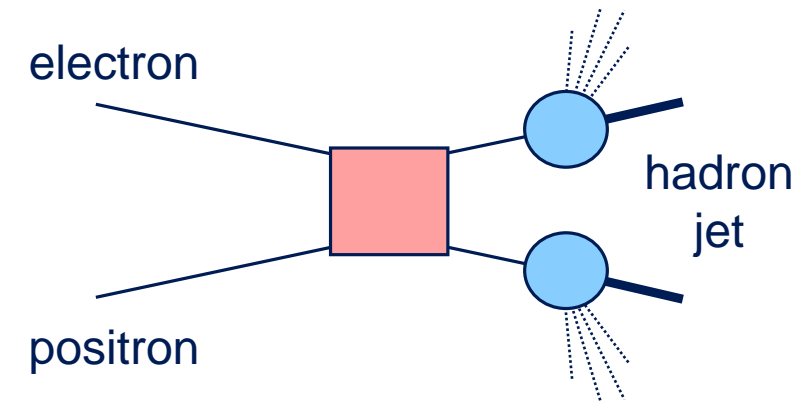
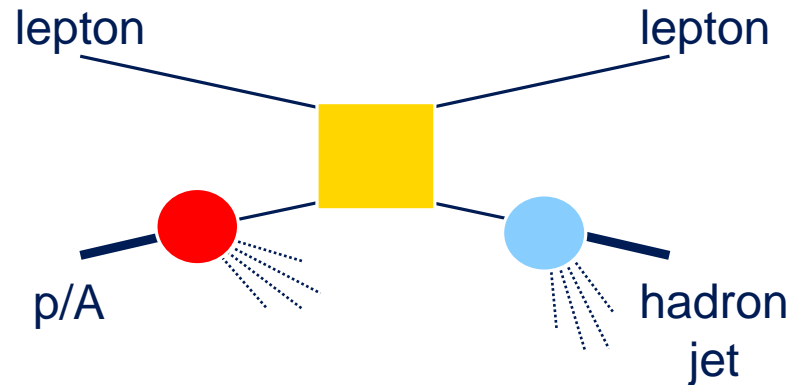
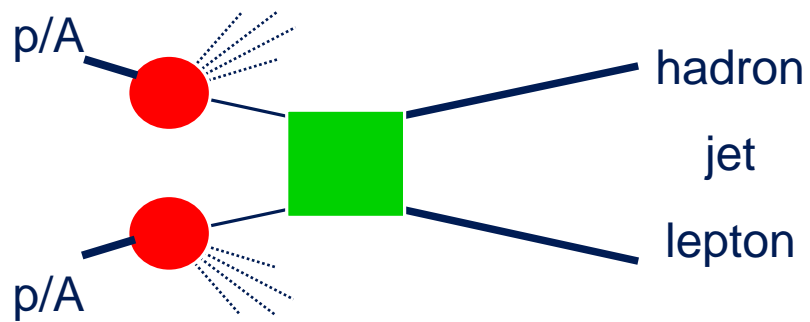
Jin Huang <jhuang@bnl.gov>

September 5-7 2018	Short-range nuclear correlations at an Electron-Ion Collider Brookhaven National Lab
September 10-12 2018	Studies of Entropy And Entanglement At The EIC Stony Brook: Peter Paul Seminar Room (C-120, Physics Building)
November 28-30 2018	CFNS Inaugural Meeting Stony Brook and Brookhaven National Lab
November 30 2018	CFNS International Advisory Committee Review Stony Brook: Peter Paul Seminar Room (C-120, Physics Building)

Future Plans for EICs

# Closing remarks 1: Continuity of research

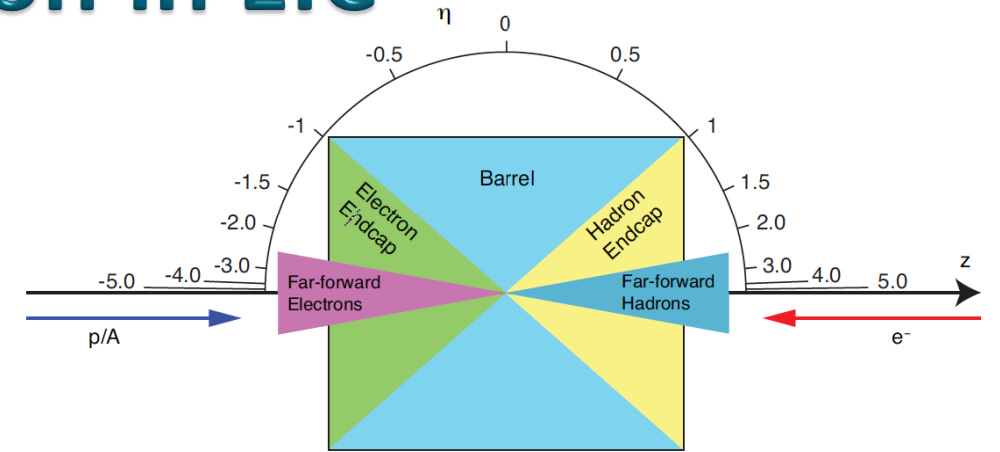
- ▶ We are just scratching the surface of the collective behavior in QCD and the role of gluons. Expecting more discovery of emergent phenomena of QCD
- ▶ This quest will involve  $h-h$ ,  $h-e$ ,  $e-e$  facilities, each carries a piece of the puzzle
- ▶ EIC/LHeC represents a convergence of heavy ion and DIS communities; equal importance for Accelerator physics and Detector physics
- ▶ In US, QCD communities (JLAB/RHIC) work jointly on EIC physics



# Closing remarks 2: Participation in EIC

- ▶ For junior audience:  
New generation of experiments is an opportunity for new generation of physicists, to design our own experiment, build it, take data, and make discoveries over the next years
  - Contact me if want to try reconstructing an EIC event in simulation
- ▶ Sign up for user group: [eicug.org](http://eicug.org)
- ▶ A vibrant detector R&D program with many connections to Heavy Ion experiments

This session/ future HI exp  
Tetyana Galatyuk  
Jan Fiete Grosse-Oetringhaus



Courtesy: Thomas Ullrich

## Generic detector R&D programs

Current and recently completed projects

- eRD1: Calorimeter Development
- eRD2: Magnetic-Field Cloaking Device
- eRD3: Fast and Lightweight Forward Tracking
- eRD6: The EIC Tracking and PID Consortium
- eRD12: Polarimeter, Luminosity Monitor and Low Q<sup>2</sup>-Tagger for Electron Beam
- eRD14: An Integrated Program for Particle Identification for an EIC Detector
- eRD15: R&D for a Compton Electron Detector
- eRD16: Forward Silicon Tracking
- eRD18: Precision Central Silicon Tracking and Vertexing for the EIC
- eRD17: BEAGLE: A tool to Refine Detector Requirements for eA Collisions
- eRD20: Developing Simulation and Analysis Tools for the EIC
- eRD21: EIC Background Studies and Impact on the IR and Detector design
- eRD22: GEM based Transition radiation detector and tracker



[https://wiki.bnl.gov/conferences/index.php/EIC\\_R%25D](https://wiki.bnl.gov/conferences/index.php/EIC_R%25D)

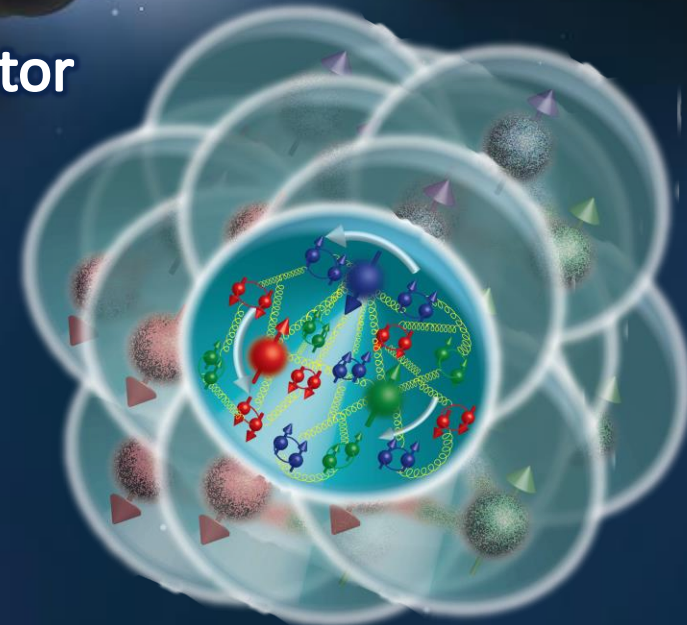
# Summary



- Broad impact from EIC and LHeC: for the first time, precisely image gluons in nucleons and nuclei, explore a new QCD frontier of ultra-dense gluon fields , reveal the origin of the nucleon spin
- Active community in development on fronts of accelerator, detector and theory, so we would be ready to meet the challenge of constructing such frontier e-p/A facility in the coming decade

I would like to use this opportunity to thank

- Developers of EIC theory, accelerator and detectors
- Funding agencies who guide/support us along the way





## Bridge to Color Land

QM18 Outing, May 17, 2018, Burano, Venice

*Jin Huang*