Future Plans for Electron-Ion Colliders

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

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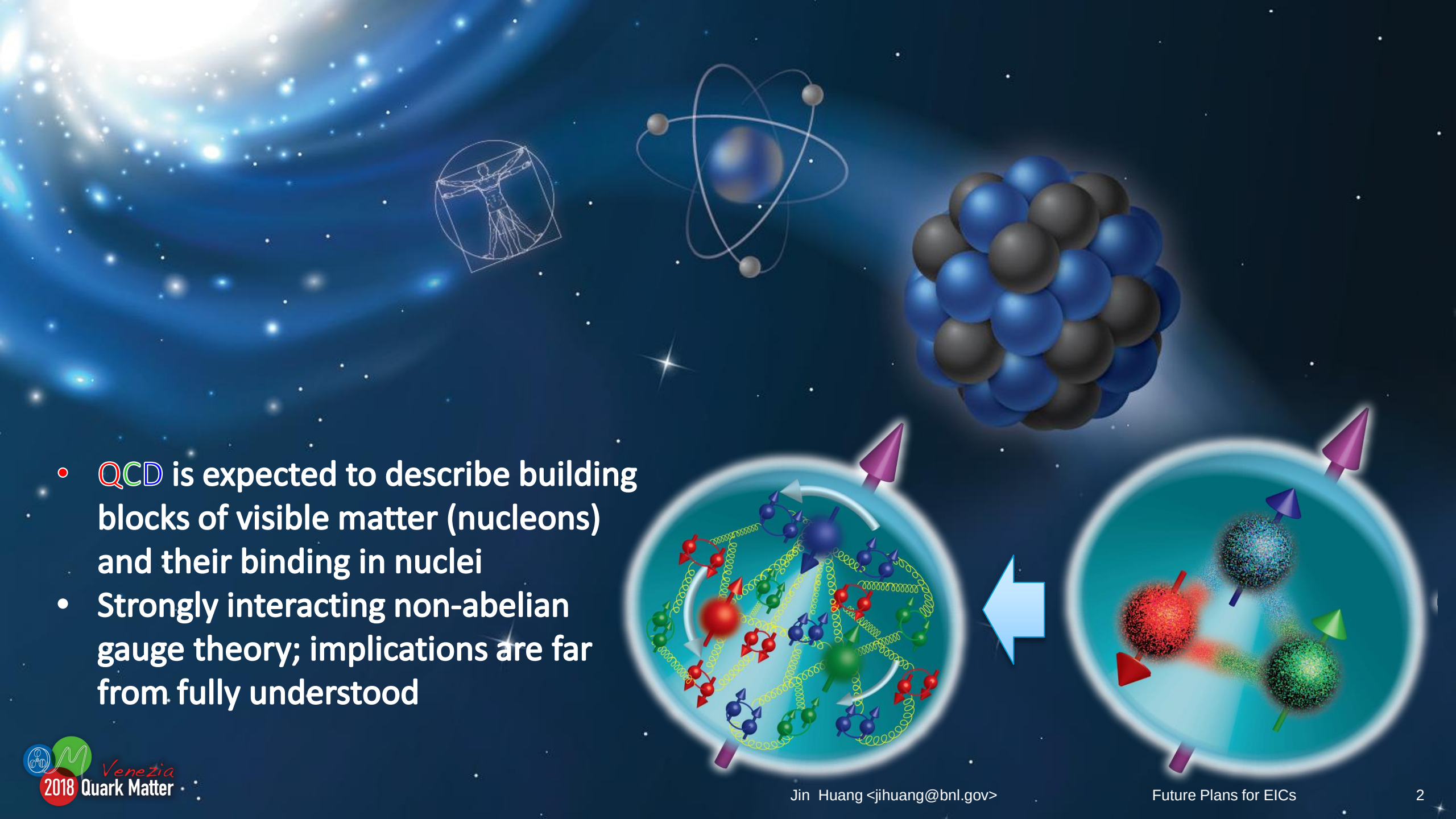
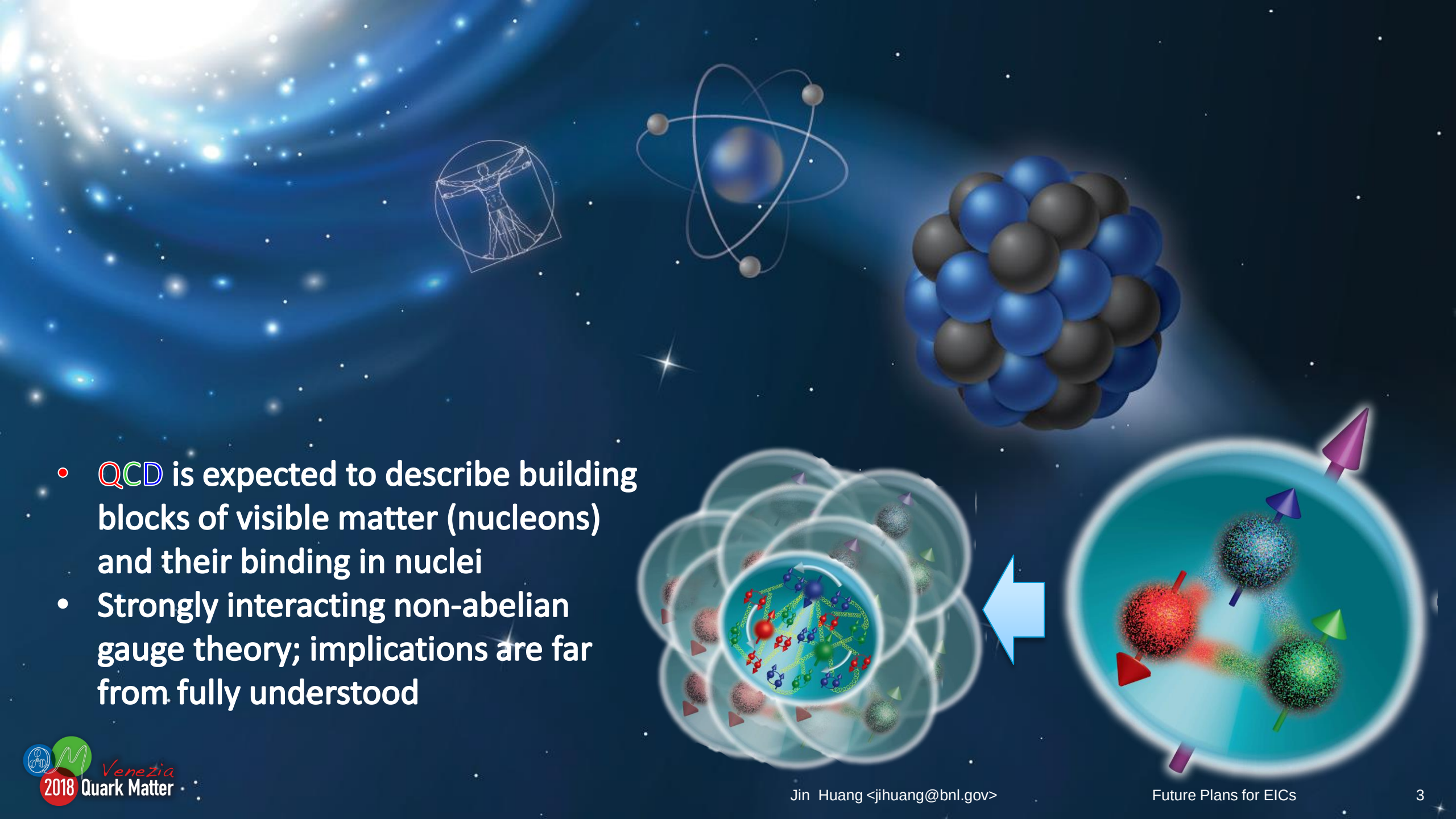
Special thanks to the valuable inputs from Christine **Aidala**, Abhay **Deshpande**, Jan Fiete **Grosse-Oetringhaus**, Tom **Hemmick**, Max **Klein**, Dave **Morrison**, Berndt **Mueller**, Jianwei **Qiu**, Bernd **Surrow**, Thomas **Ullrich**, Raju **Venugopalan**, and Rikutaro **Yoshida**



- 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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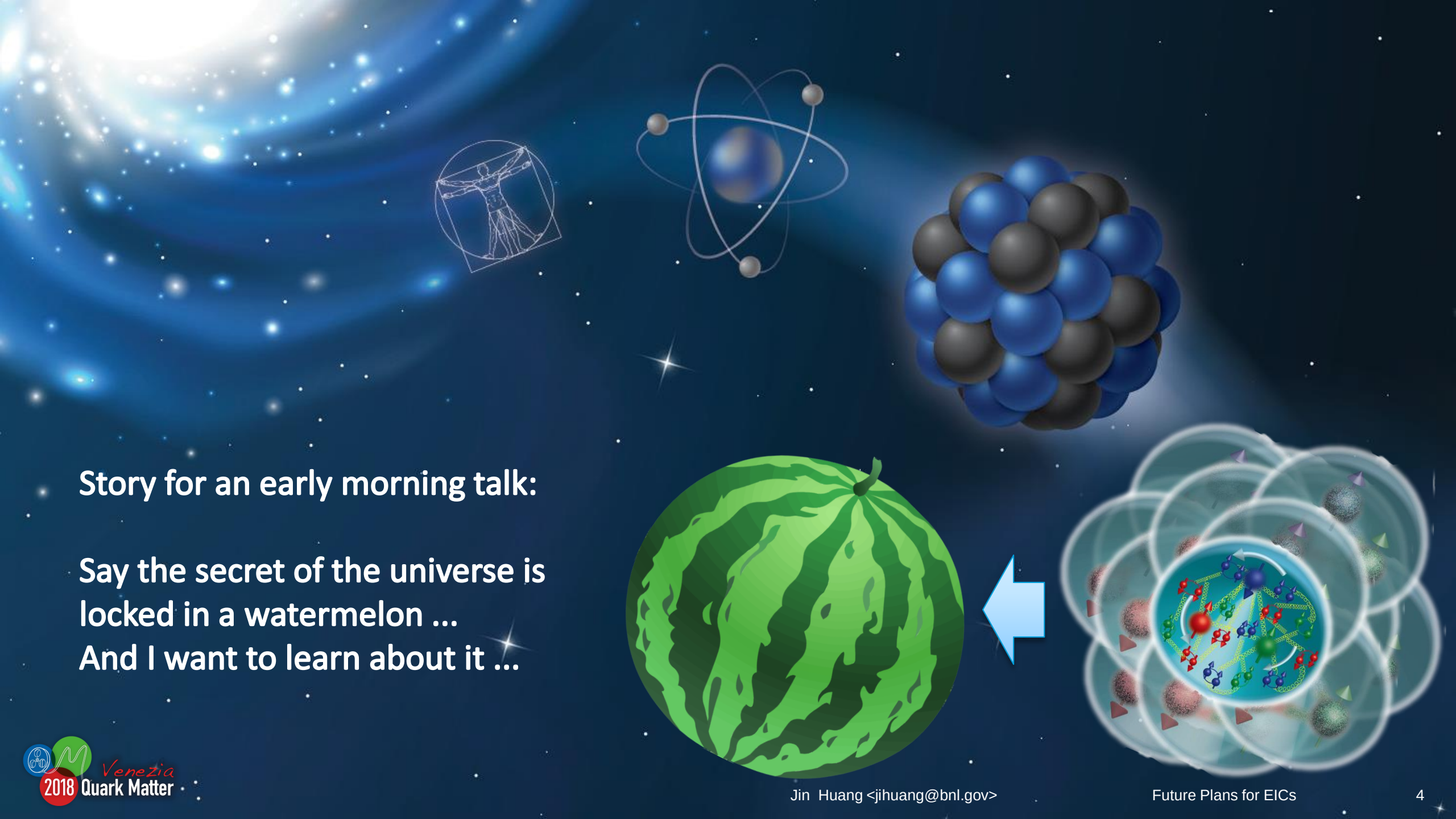
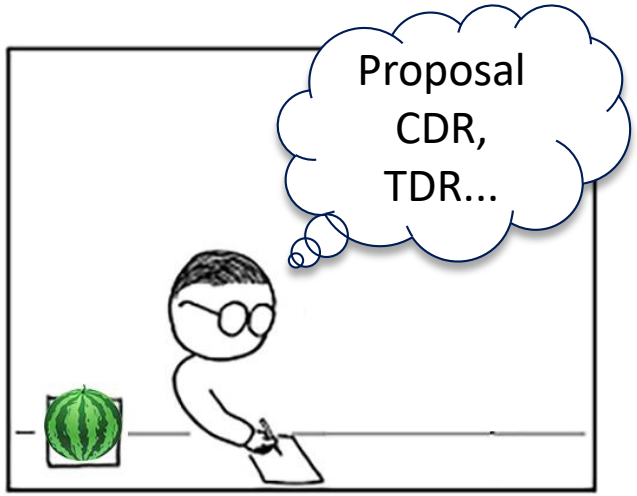


Story for an early morning talk:

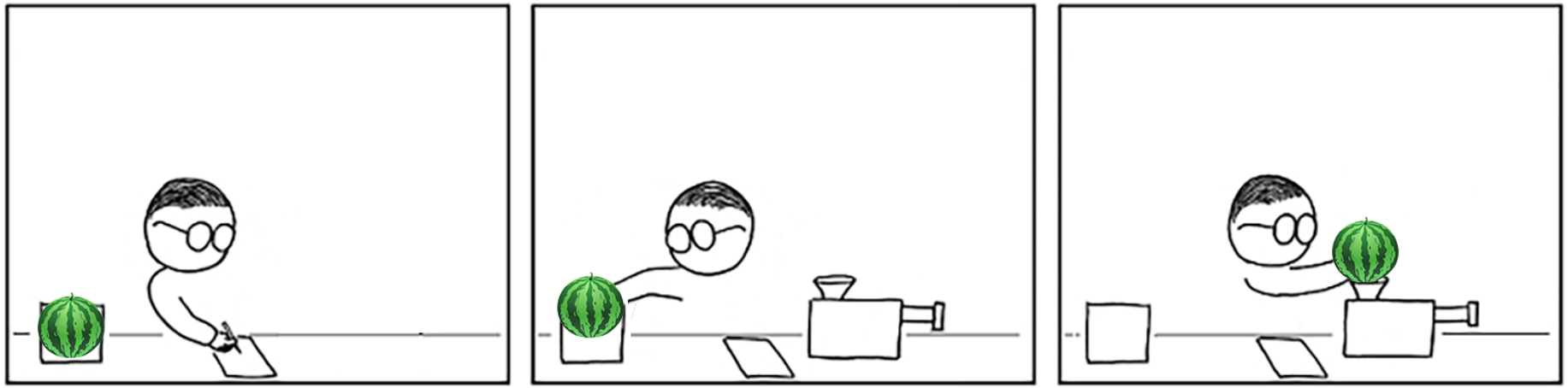
Say the secret of the universe is locked in a watermelon …
And I want to learn about it …

As a high energy nuclear physicist....



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

As a high energy nuclear physicist....



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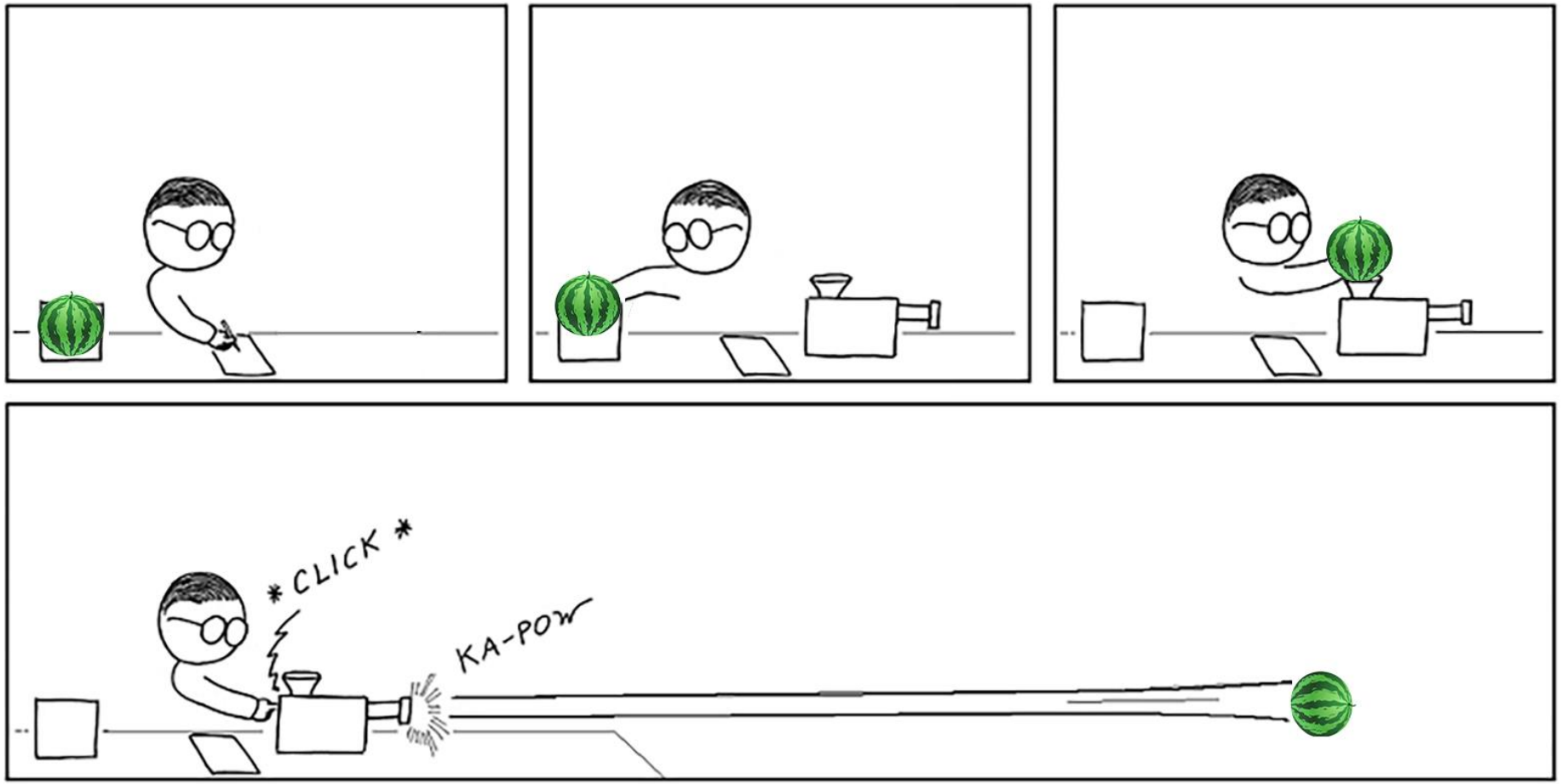
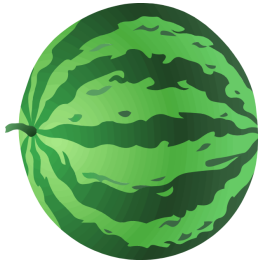
As a high energy nuclear physicist....



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

With help from genius accelerator friends …

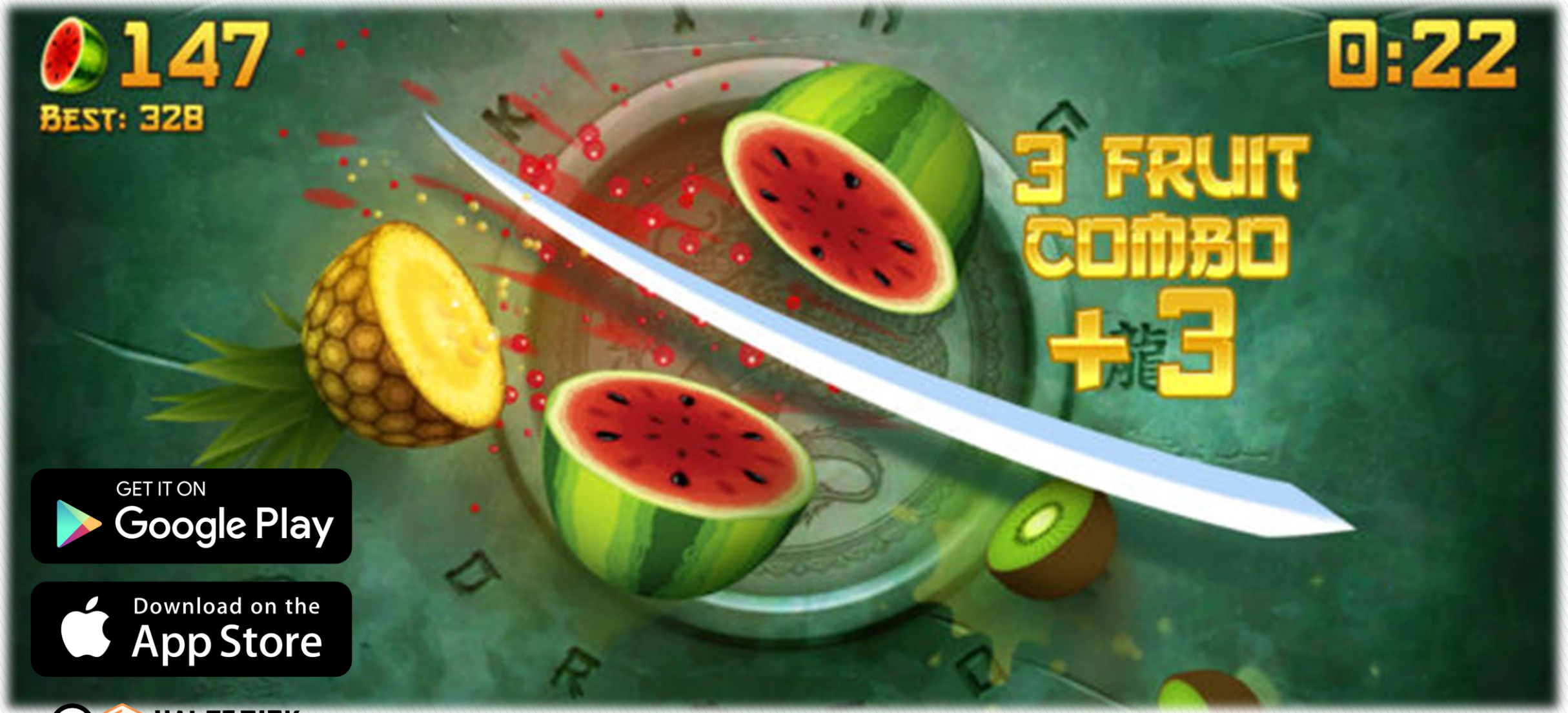


We have had many exciting discoveries !

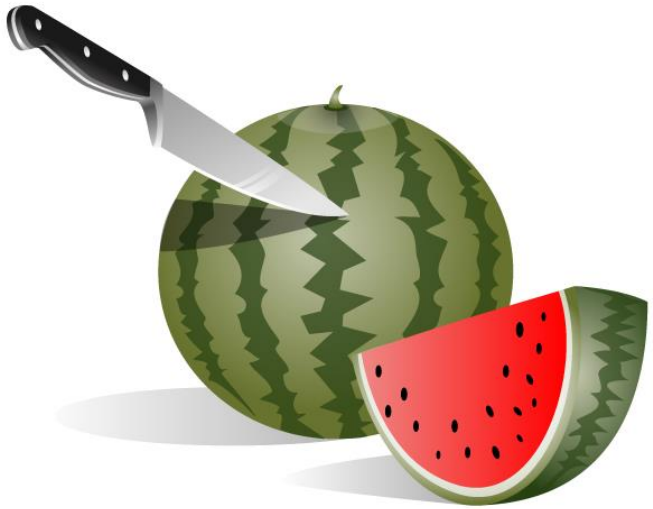
Also many more questions remain:

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

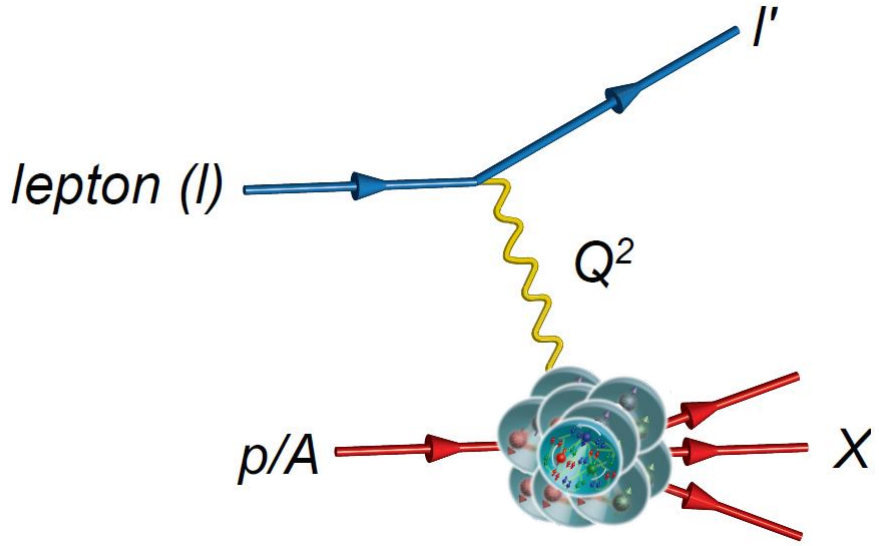
Alternative approach ... Fruit Ninja!



“cut open” the nucleon/nucleus with DIS



Exp. NP



- 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

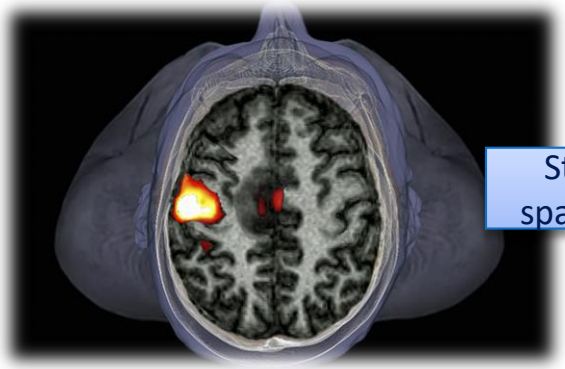
- Gluon momentum distribution in nuclei
- Energy loss in cold nuclear matter (CNM) and emergence of hadrons
- Parton spin in nucleons/nuclei
- Dynamics of a bound QCD system

A modern approach … NMR

Watermelon in NMR

- If the object is dynamic and delicate, you might prefer an 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

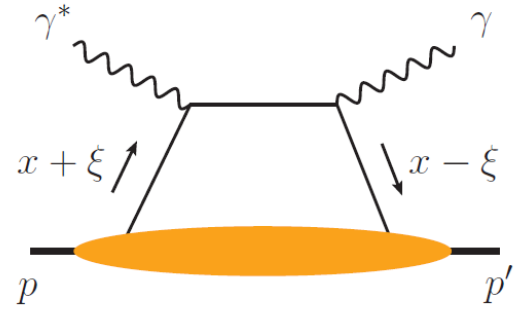


Stack in space time

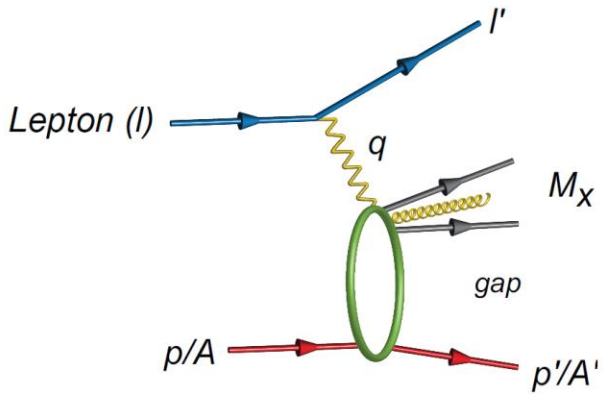
Dynamics of brain in 3D

Non-destructive imaging of nucleons/nuclei

NP exp.



Exclusive diffractive processes (e.g. DVCS)



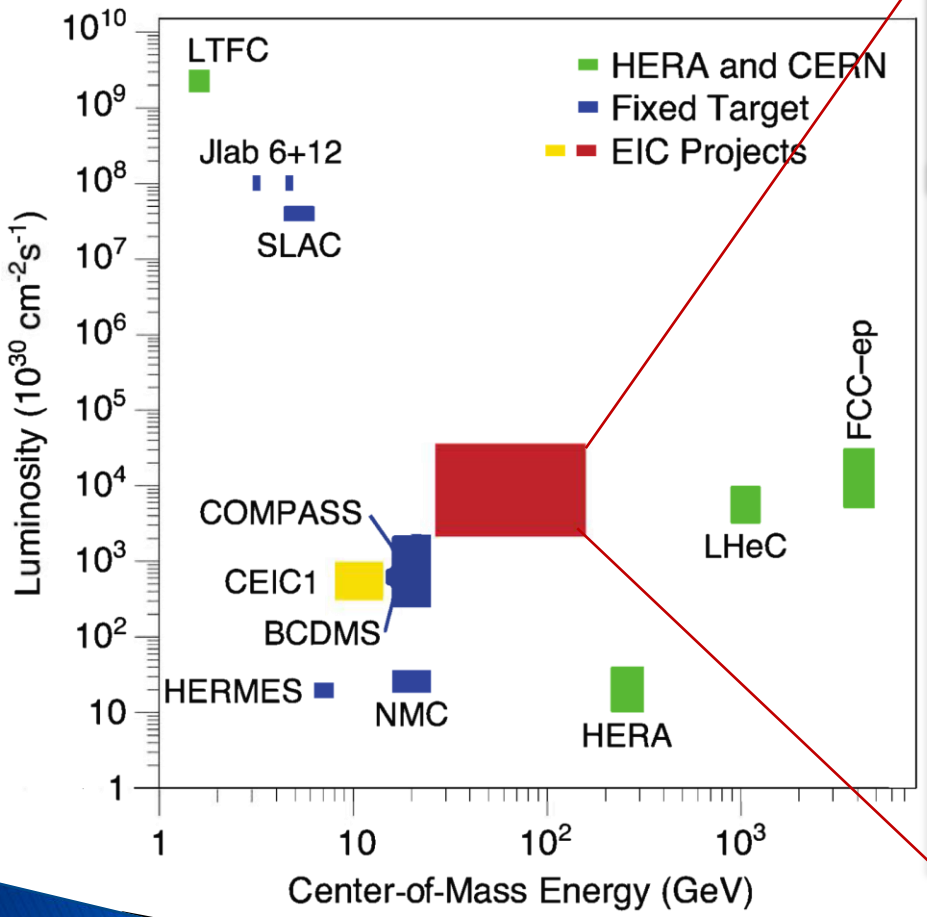
Inclusive diffractive processes

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

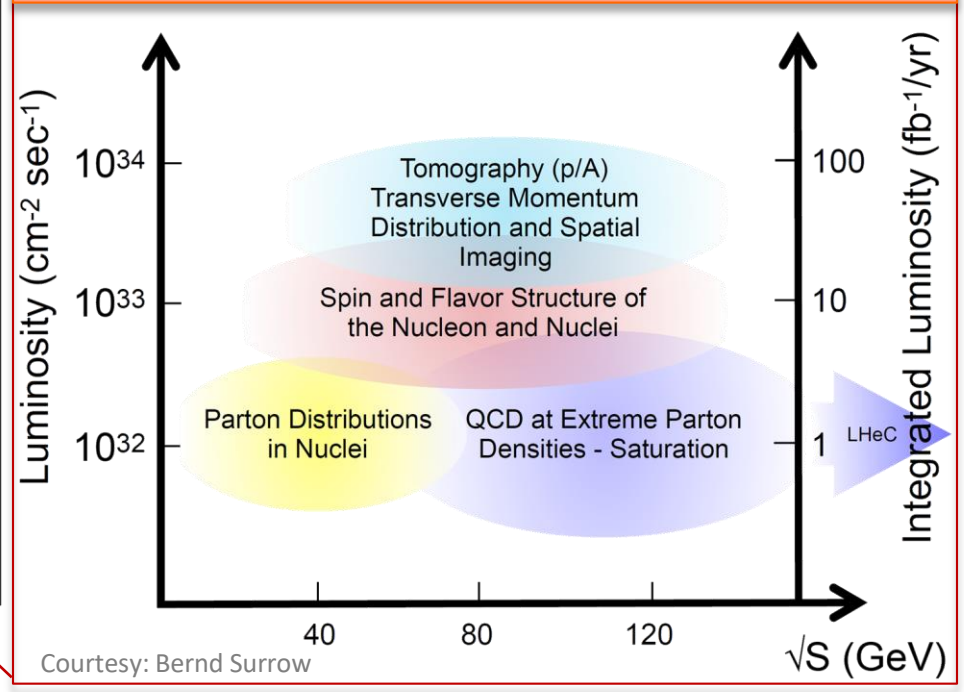
- Imaging gluon distribution
- Gluon saturation w/ boosted color density
- Orbital motion of partons in nucleons

Explore QCD landscape with Electron-Ion Collider (EIC)

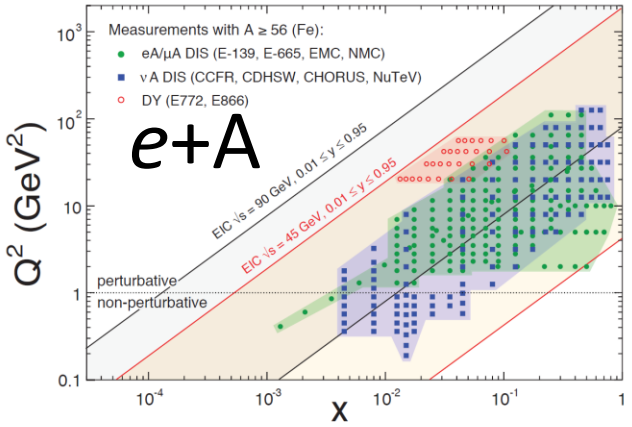
Simplified based on work of M. Klein, R. Ent, U. Klein

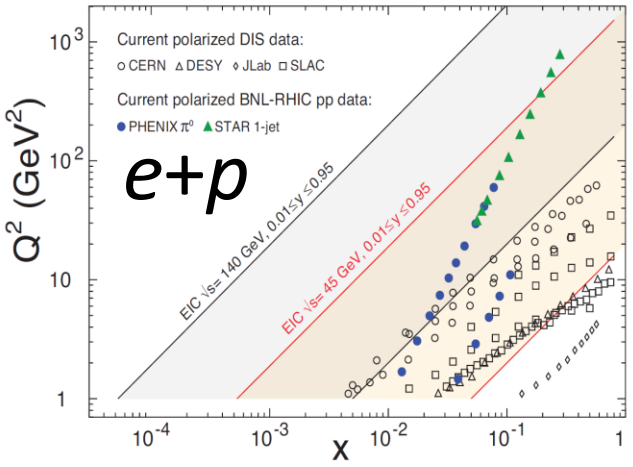


- Nuclear beam
- Polarized hadron beam
- 1000x HERA luminosity



Courtesy: Bernd Surrow



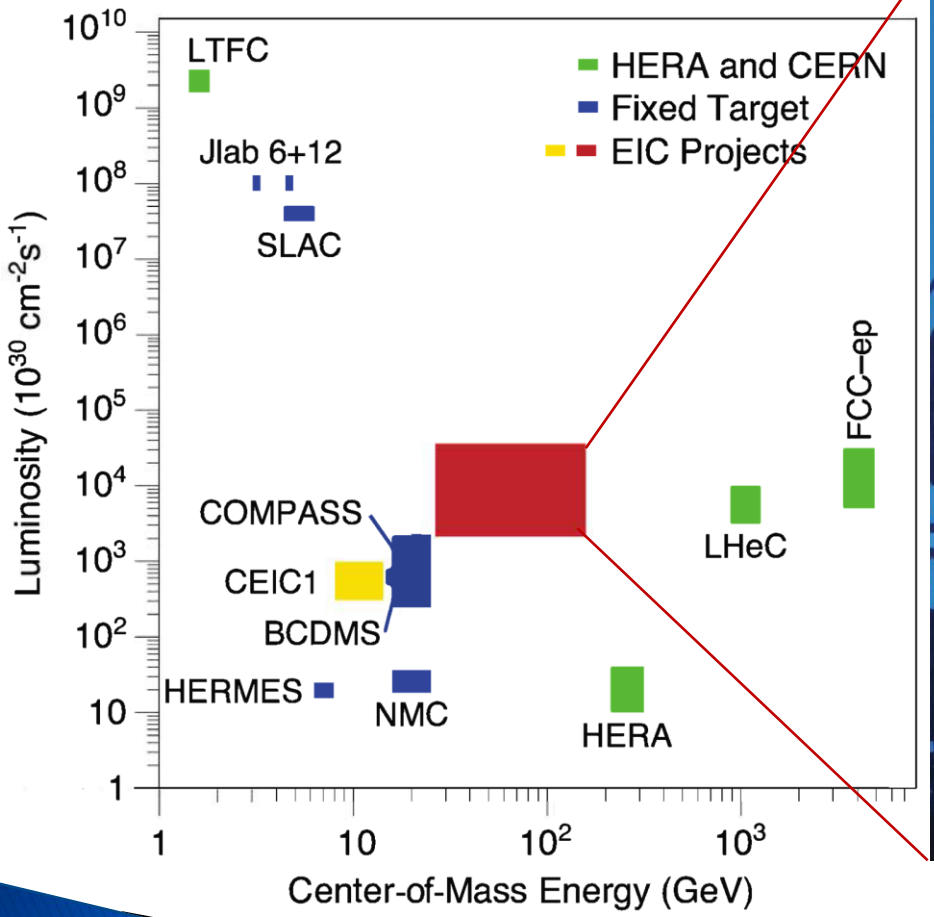


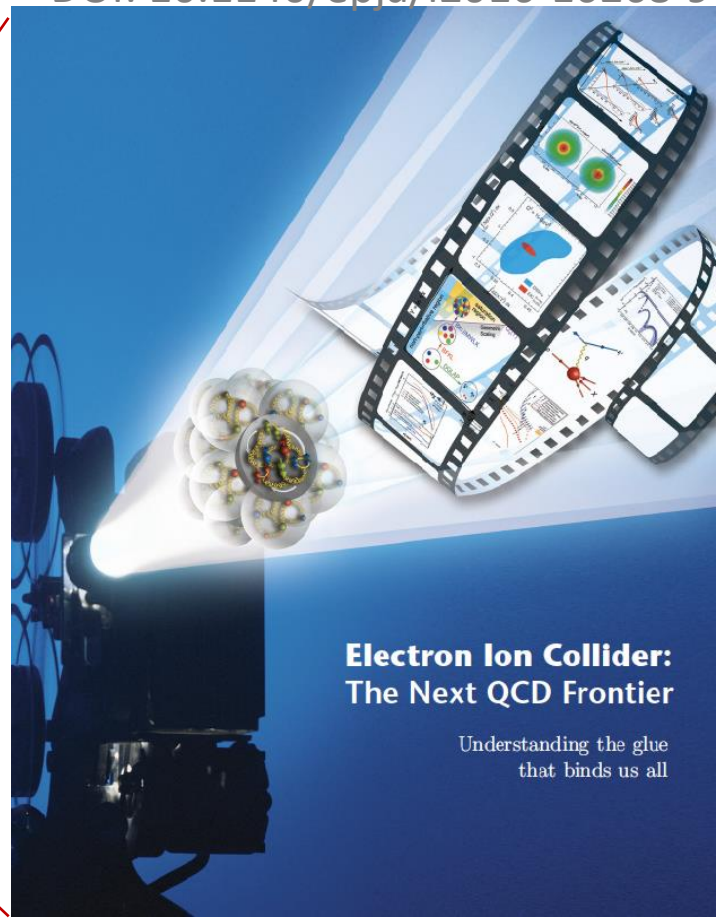
DOI: 10.1140/epja/i2016-16268-9

Electron-Ion Collider (EIC) concepts

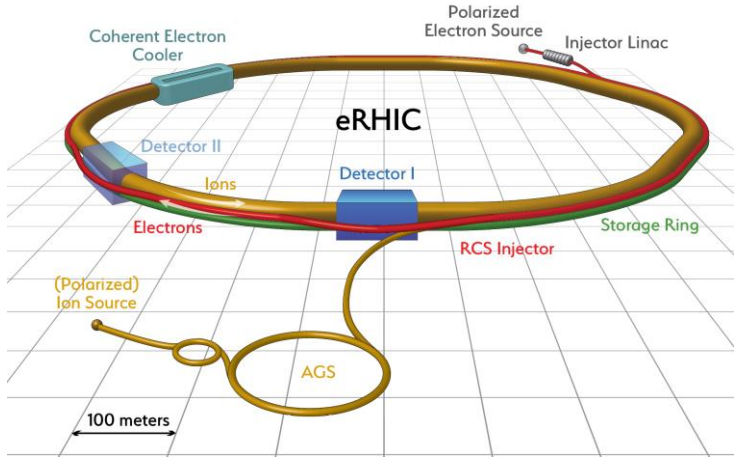
DOI: 10.1140/epja/i2016-16268-9

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

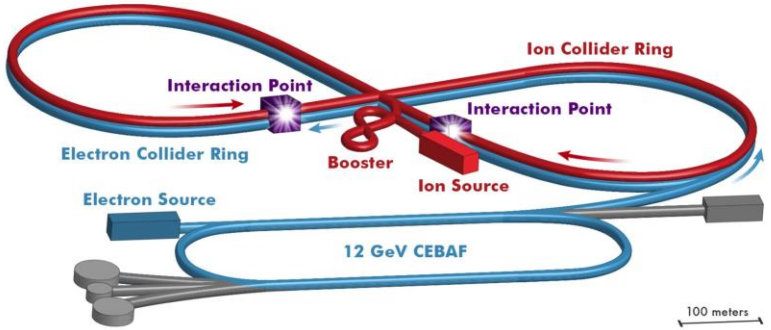




eRHIC Concept, BNL, NY

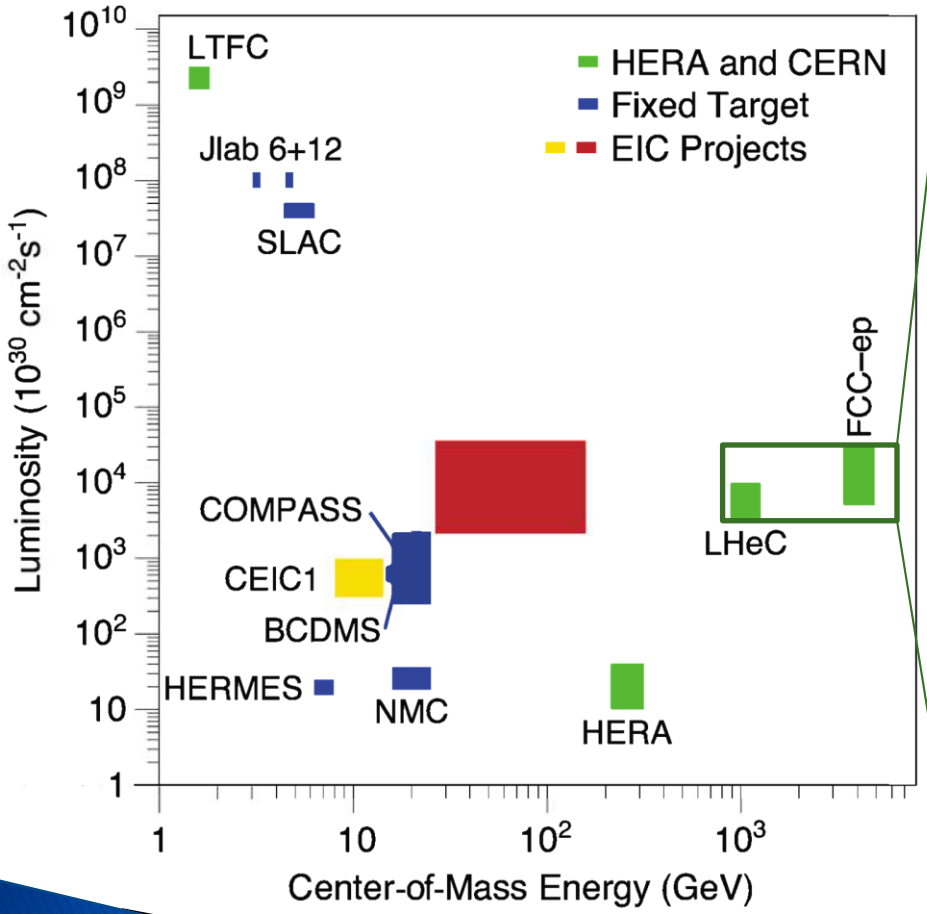


JLEIC Concept, Jefferson Lab, VA

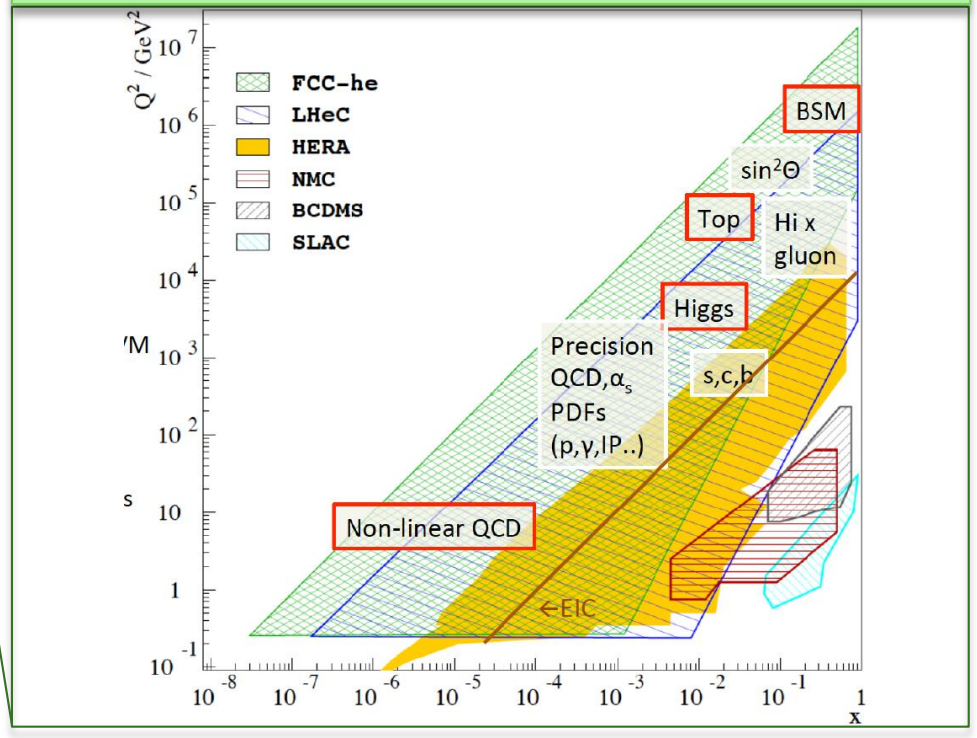


Energy frontier: LHeC

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

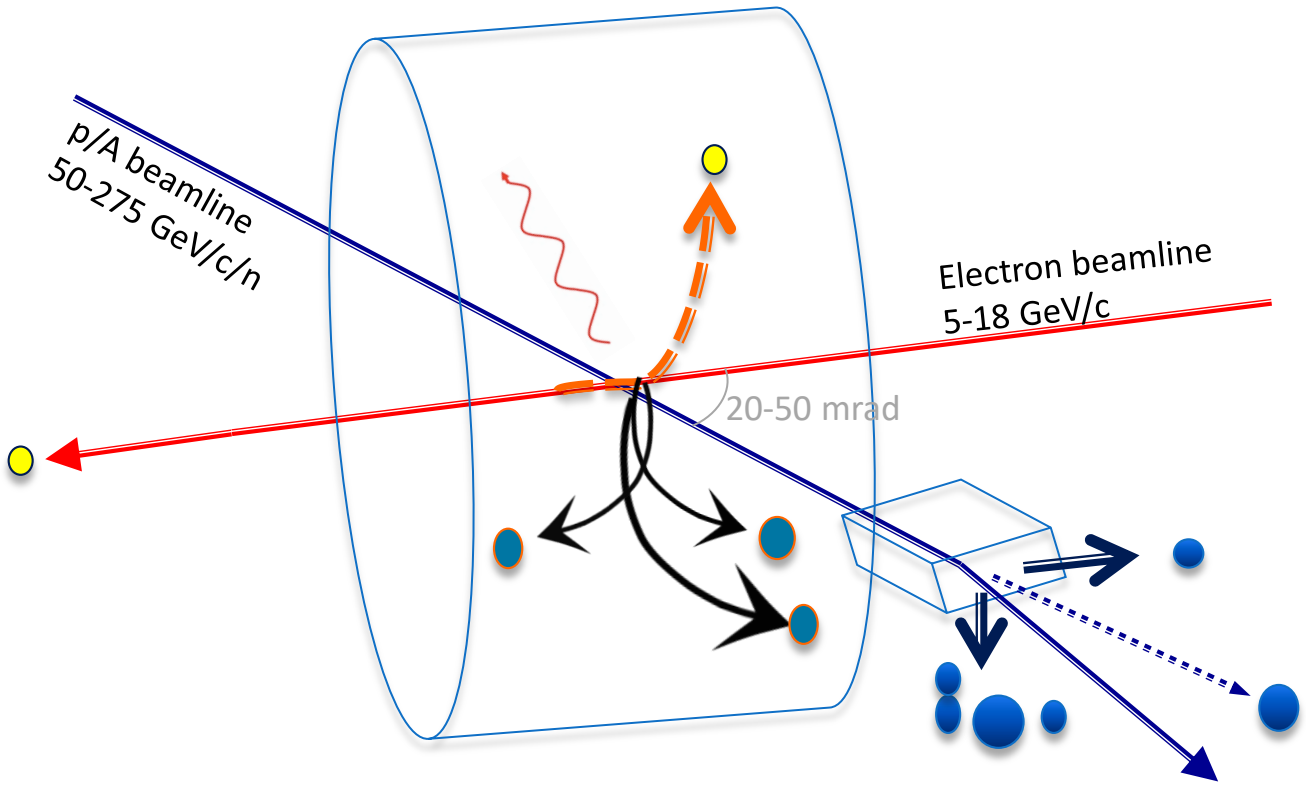


- Access to very low-x (10^{-6})
- Search for new physics in the energy frontier



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

EIC collision and detector



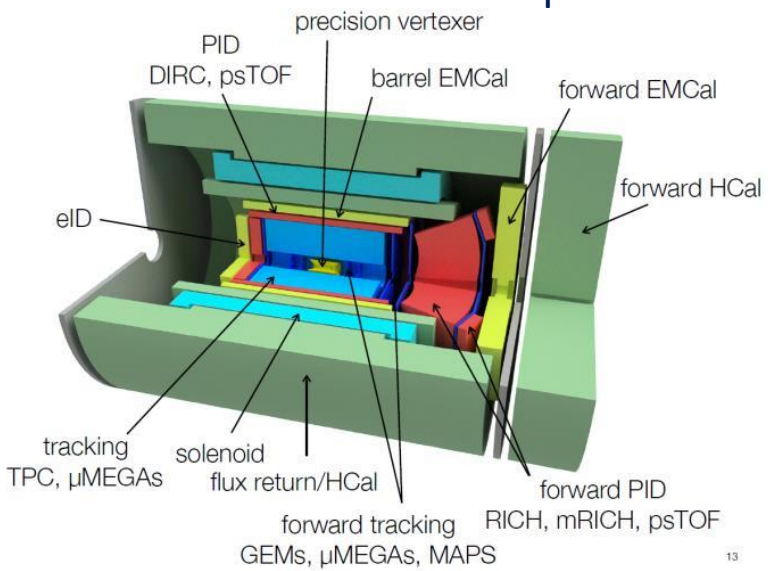
Courtesy: Rik Yoshida

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

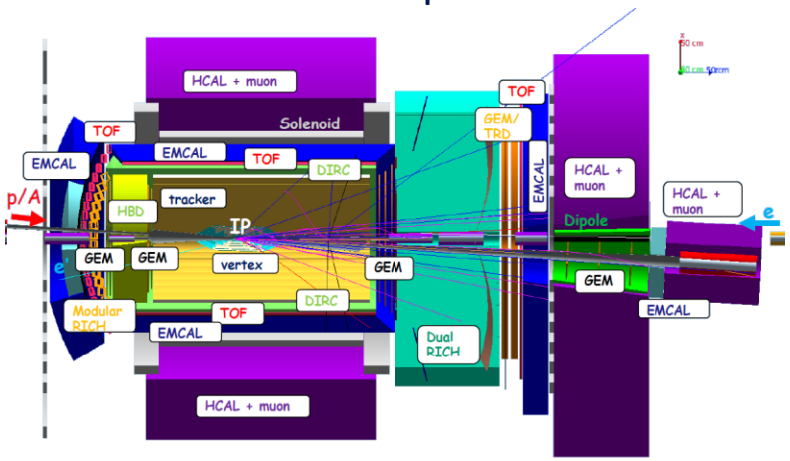
- Detector very tightly integrated with IR and beam line design
- Importance of systematics control, hermiticity, and particle ID
- Active detector and accelerator R&D program is attacking these challenges early on
- High lumi ≠ high rate
  - Cross section proportional to α_{EM}^2
    → 0.1 x RHIC p+p collision rate
    (0.5 MHz @ L=10^{34}cm^{-2}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!

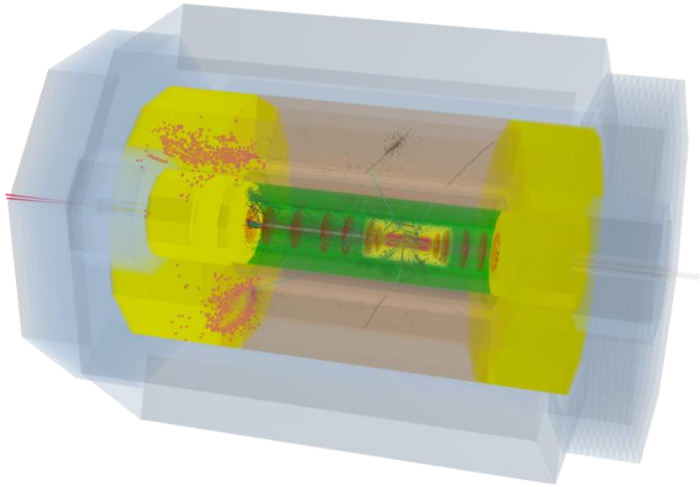
sPHENIX-based concept



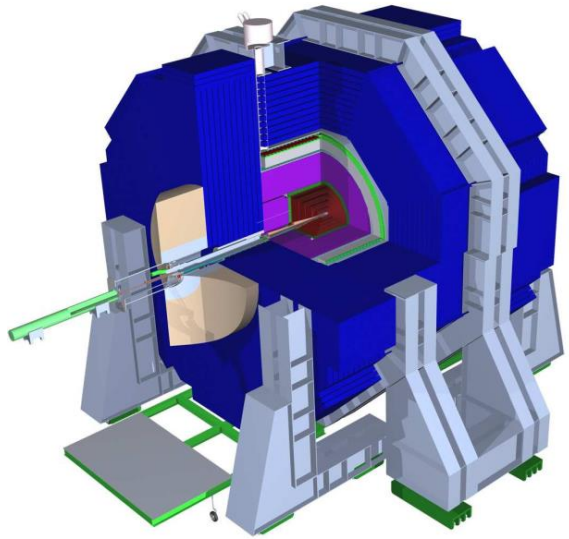
JLEIC concept



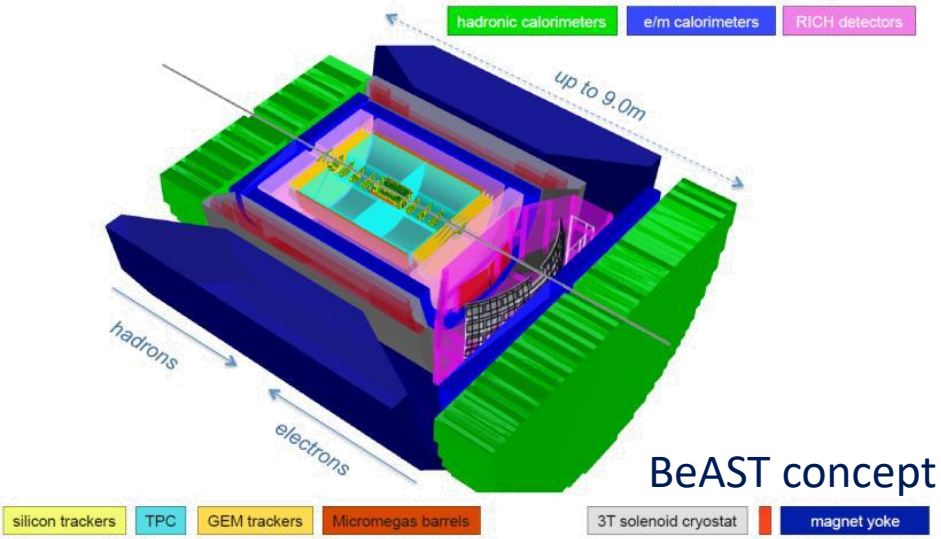
LHeC detector concept



TOPside concept



BeAST concept

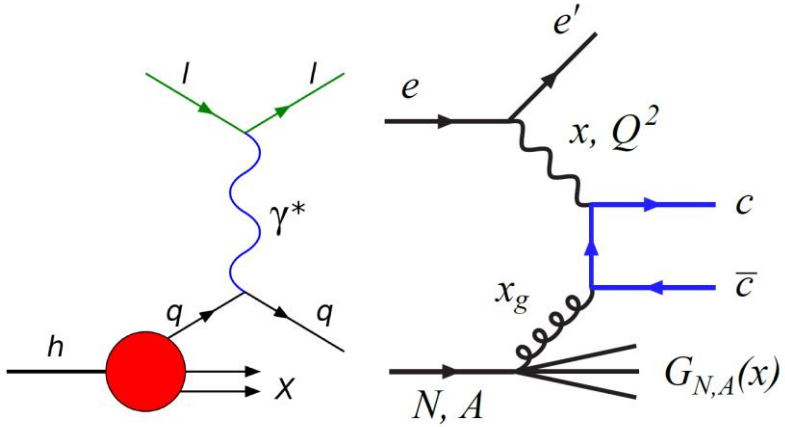


References reports :

- 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

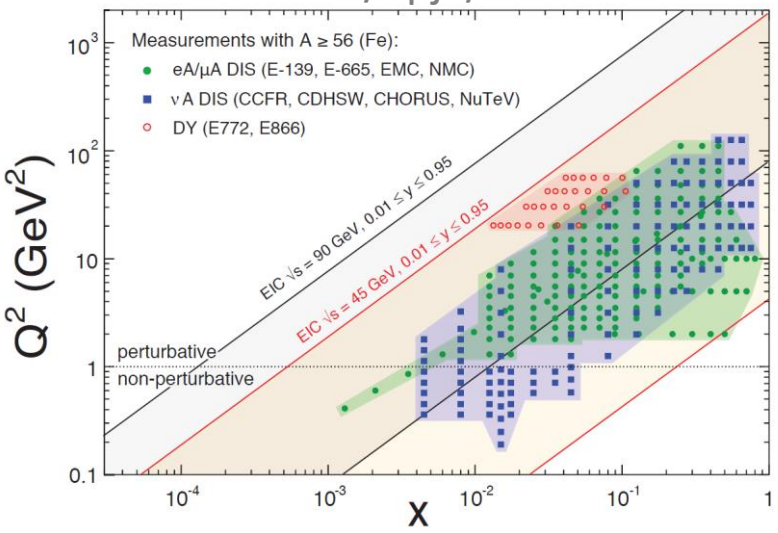
Selected EIC impact: the knowledge of nPDFs

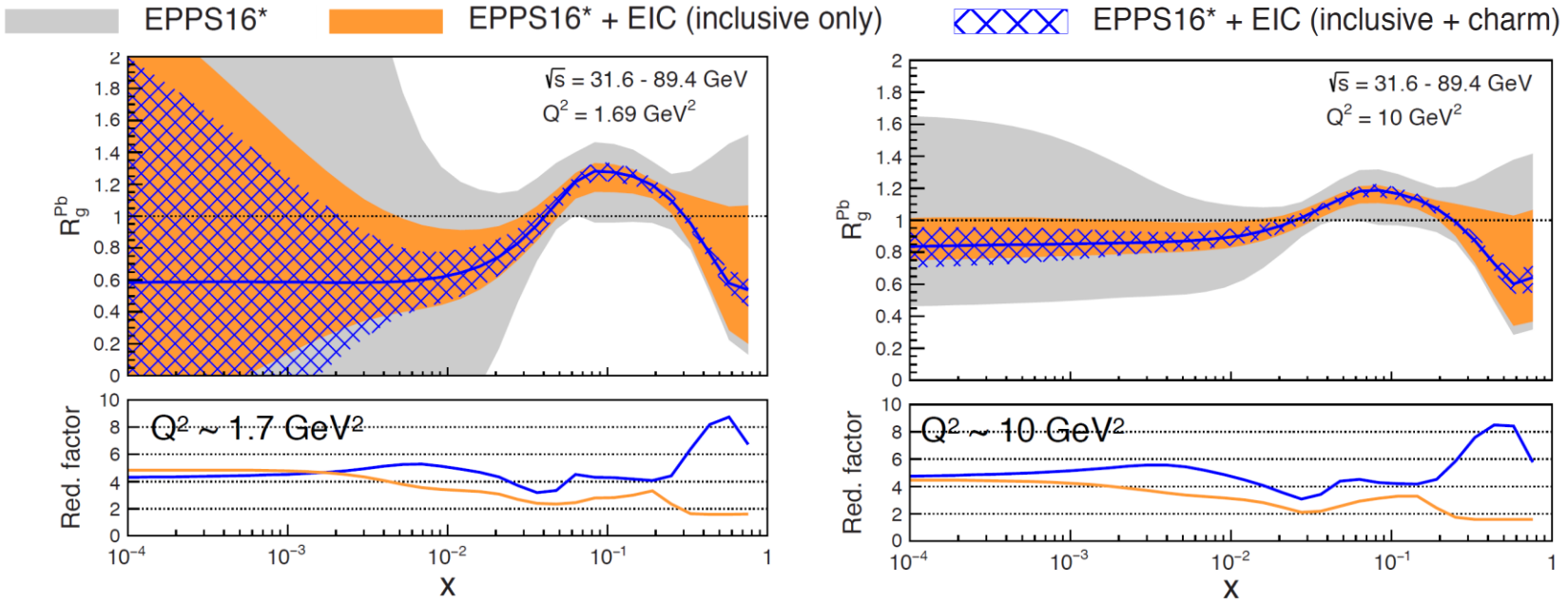
- EIC *e*+A:
  Significantly reduces sea/gluon nPDF uncertainties
- Reaching down to x~10^{-4} for EIC and 10^{-6} for LHeC
- HF in *e*+A collision constraints at large-*x* gluon



arXiv:1708.01527

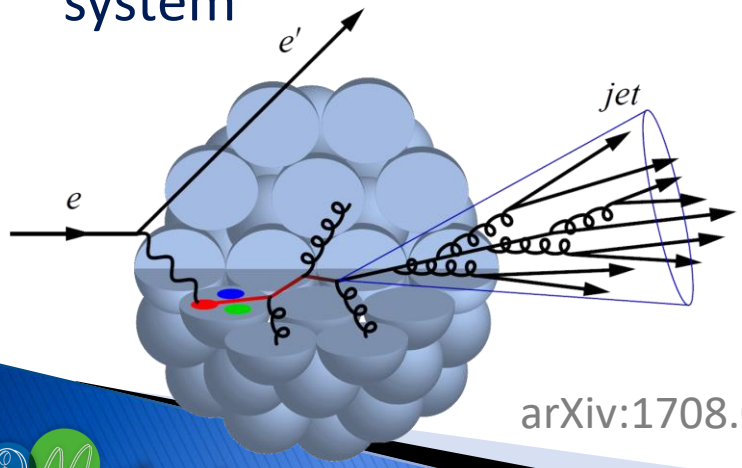
DOI: 10.1140/epja/i2016-16268-9





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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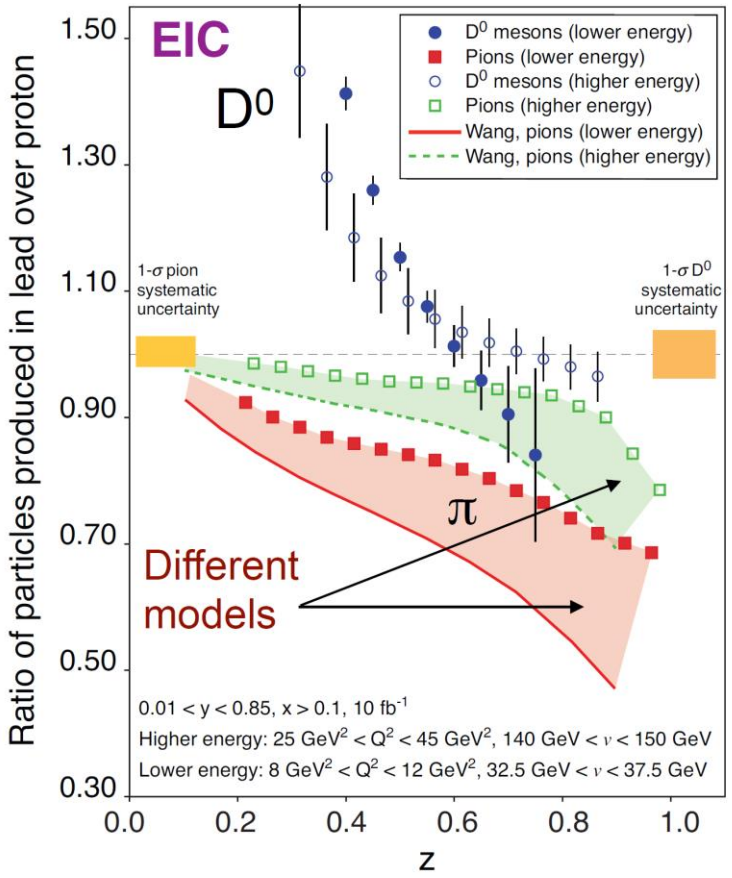

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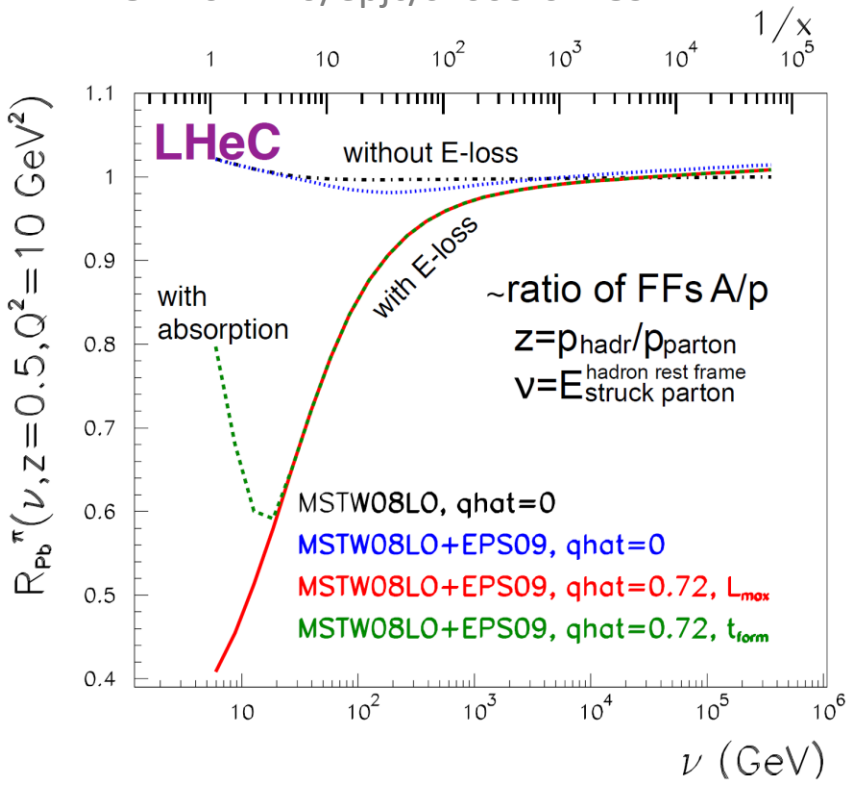
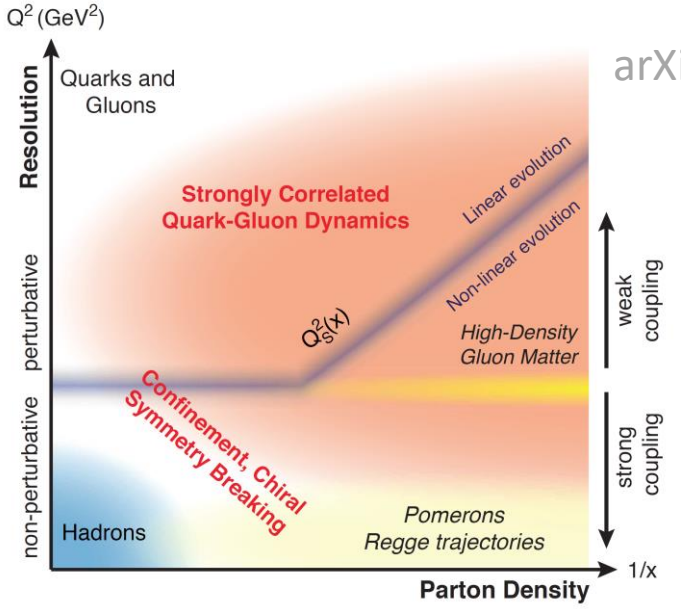
DOI: 10.1140/epjc/s2003-01289-x



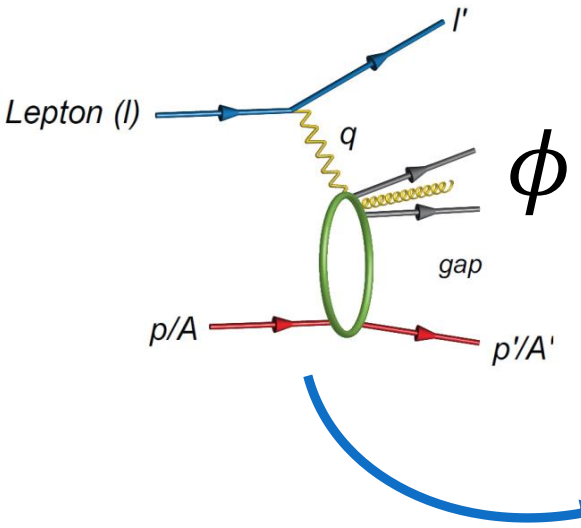
See also: Wed 4PM Sievert/Vitev
(Substructure of jets in *e*+A)

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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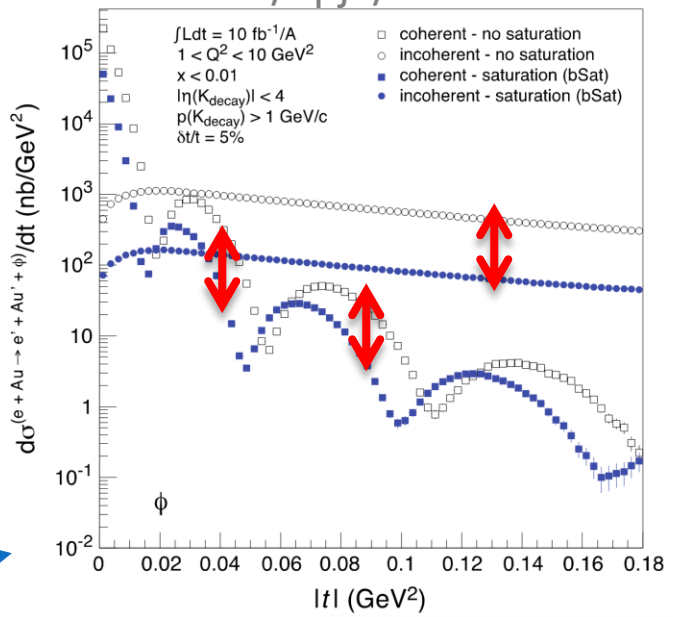
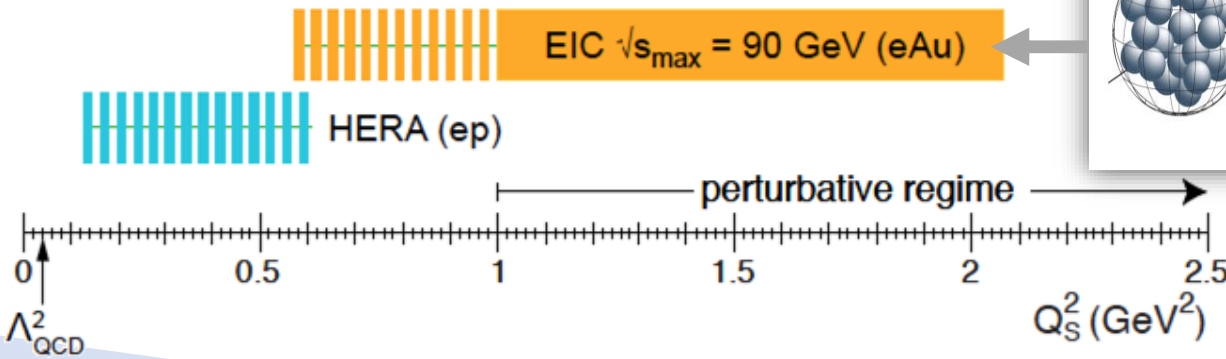
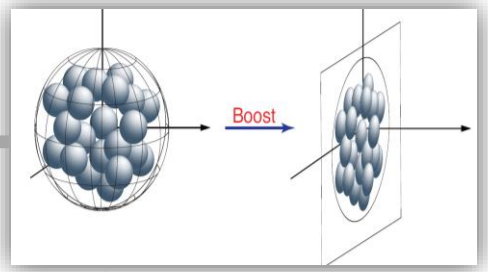
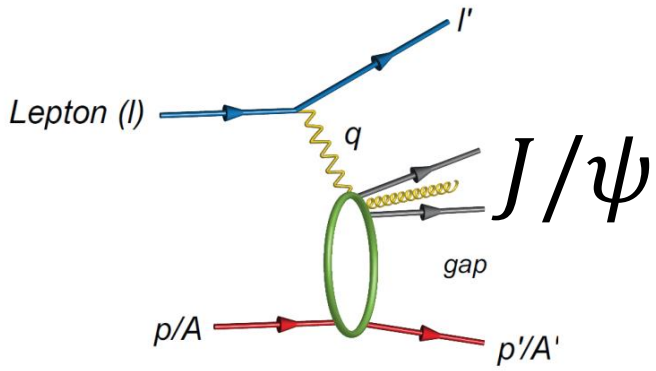


For x<0.01 in e-p/A collisions:

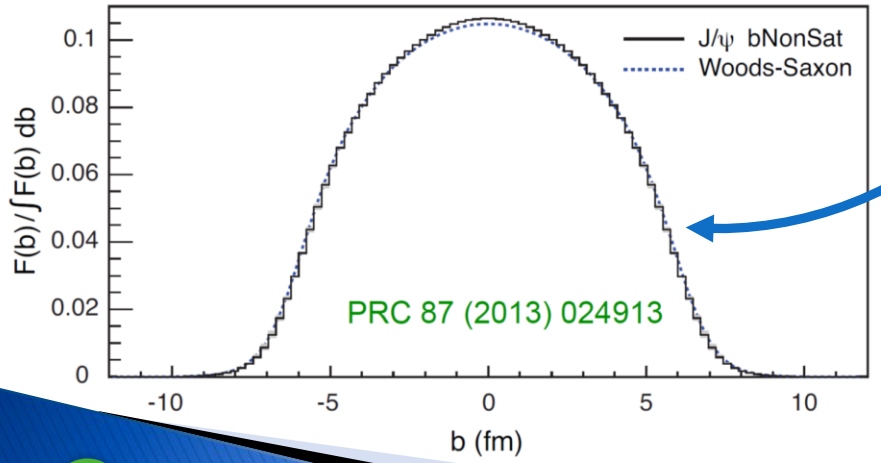


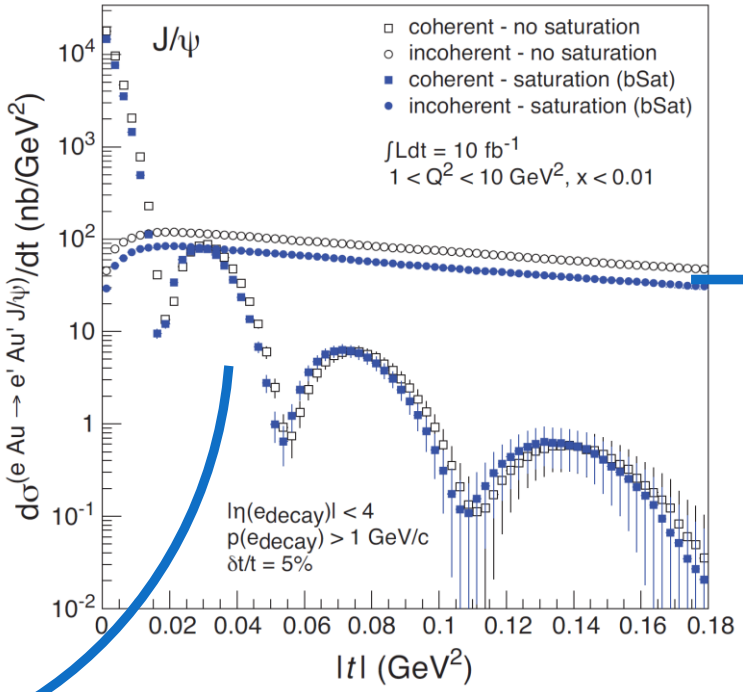


Selected EIC impact: imaging of gluons



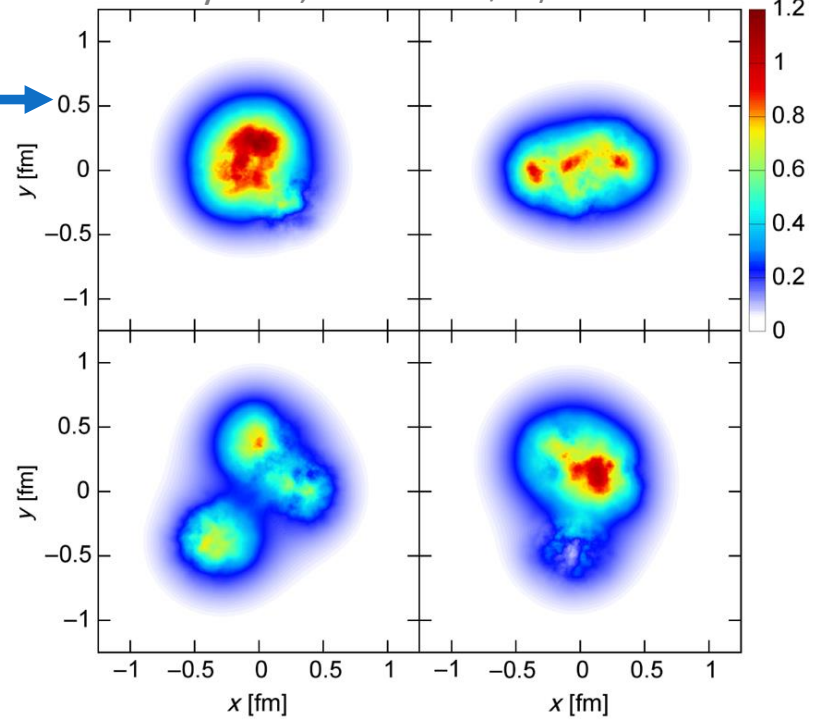
Coherent → gluon distribution





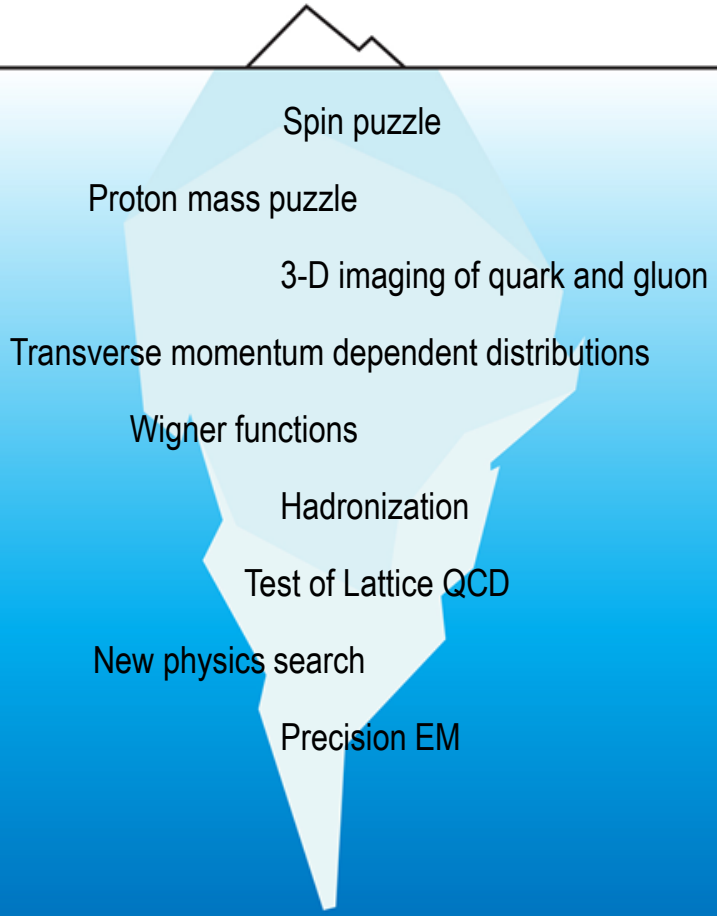
See also:
Tue M. Murray, Y.J. Li
Thu Y. Li, M. Strickland
Fri A. Angerami

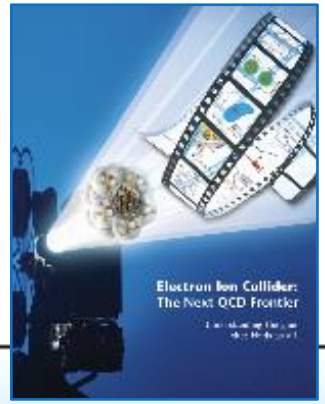
Incoherent
→ Initial stage gluon fluctuations!
→ Origin of v_3 in p+A
Wed H. Mäntysaari, DOI: 10.1103/PhysRevLett.117.052301



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 ≈ collide of VM and nucleus with a controllable Q^2 handle

And that is just tip of the iceberg in the QCD ocean …





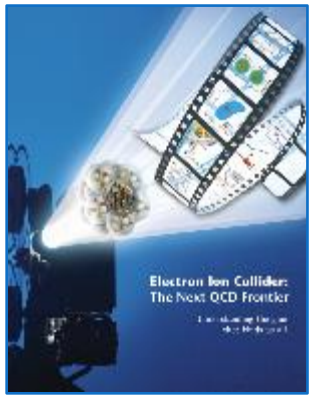
Unknown emergent phenomena of QCD

Dramatically simplified timeline of the past decade

2011 2012 2013 2014 2015 2016 2017

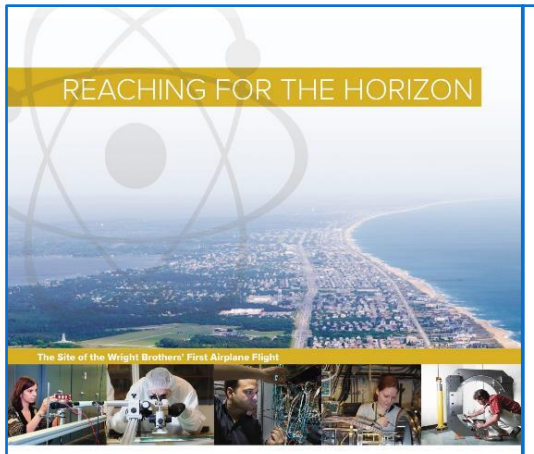
Review by US National Academy of Sciences

arXiv:1108.1713



arXiv:1212.1701

arXiv:1206.2913



RECOMMENDATION III

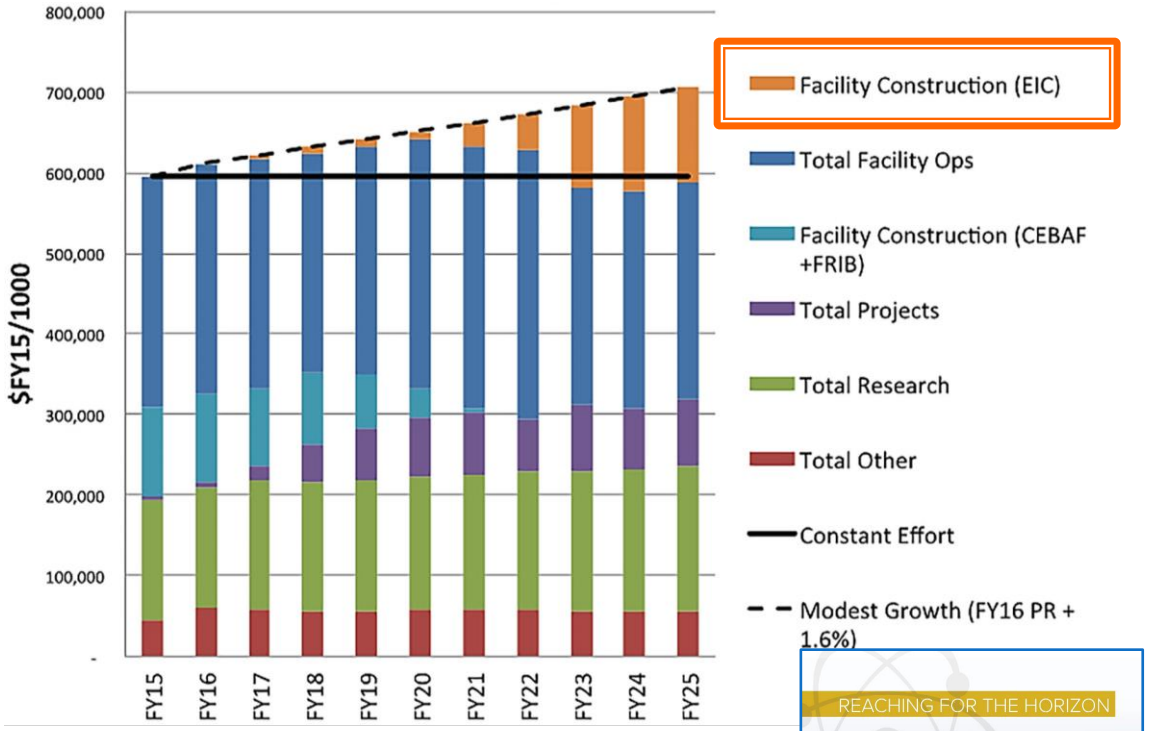
Gluons, the carriers of the strong force, bind the quarks together inside nucleons and nuclei and generate nearly all of the visible mass in the universe. Despite their importance, fundamental questions remain about the role of gluons in nucleons and nuclei. These questions can only be answered with 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.

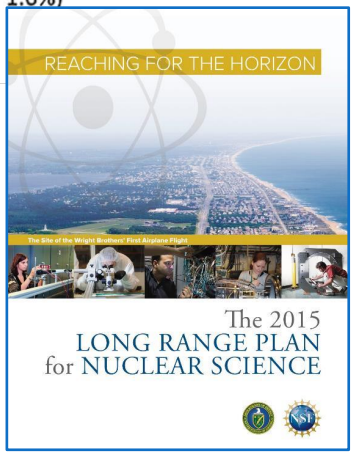
We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB.

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

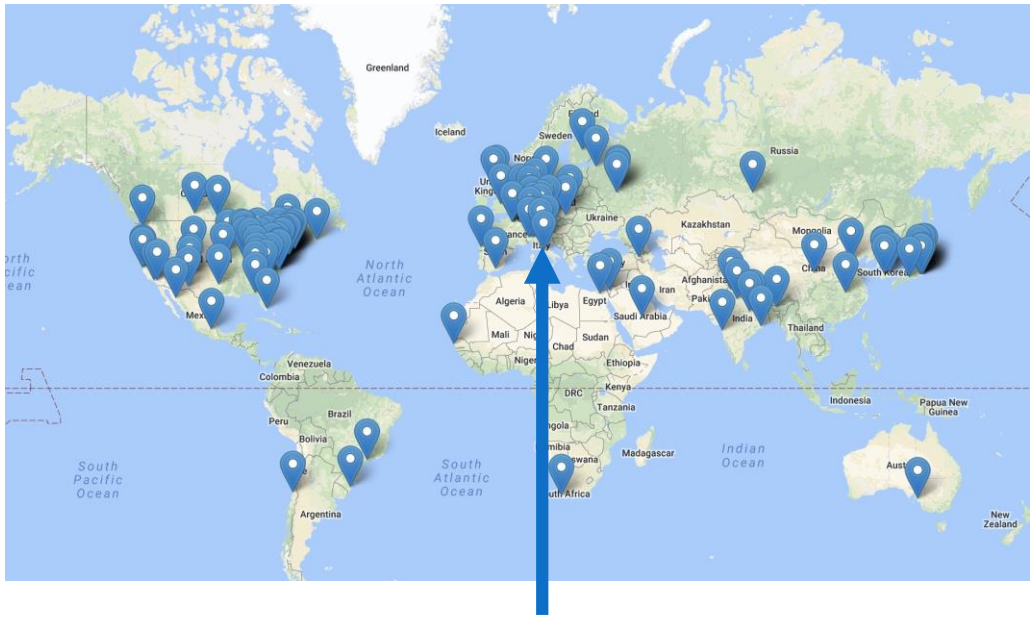
US DOE budget in FY 2015 dollars for the Modest Growth scenario





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

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 Stonybrook 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

Center for Frontiers in Nuclear Science

www.stonybrook.edu/cfns

- EIC Center at Jefferson Lab (EIC^2@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

EIC^2 EIC Center at Jefferson Lab

www.eiccenter.org

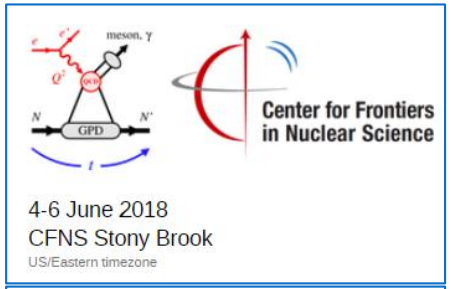
Coming EIC/LHeC User Events

2018 Quark Matter, Venezia

June 2018 | July 2018 | Later in 2018

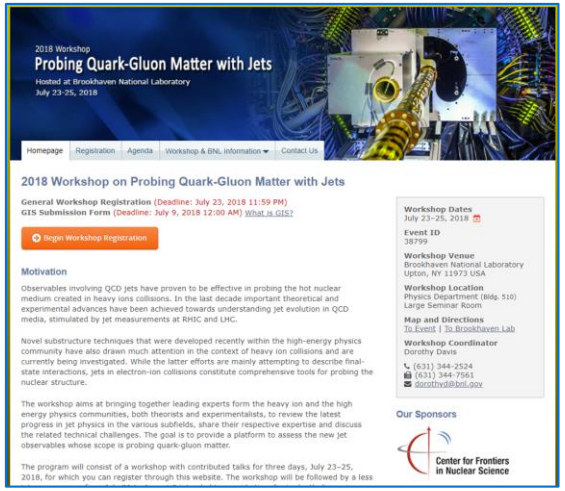
POETIC Series

June 27
@ LAL-Orsay

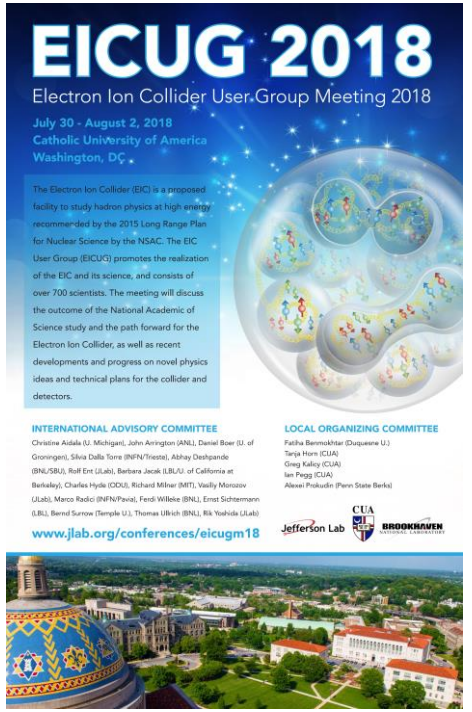


Next-generation GPD studies with exclusive meson production at EIC

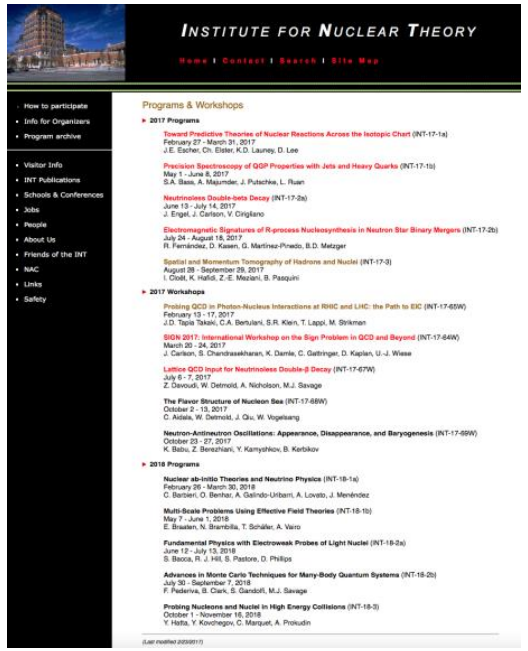
June 4 @ CFNS



July 23-25 @ BNL



July 30 @ CUA



Oct @ INT Program

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 stock of the progress since the earlier June 1-2, 2017 workshop at Argonne National Lab: http://www.phy.anl.gov/theory/pieic2017

Organizing Committee

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

May 24 @ CUA

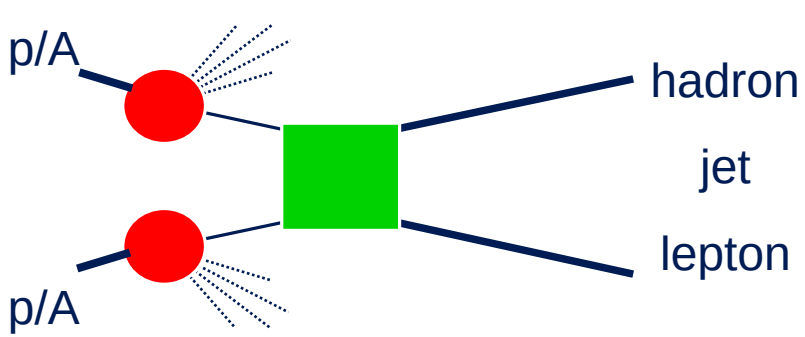
Center for Frontiers in Nuclear Science

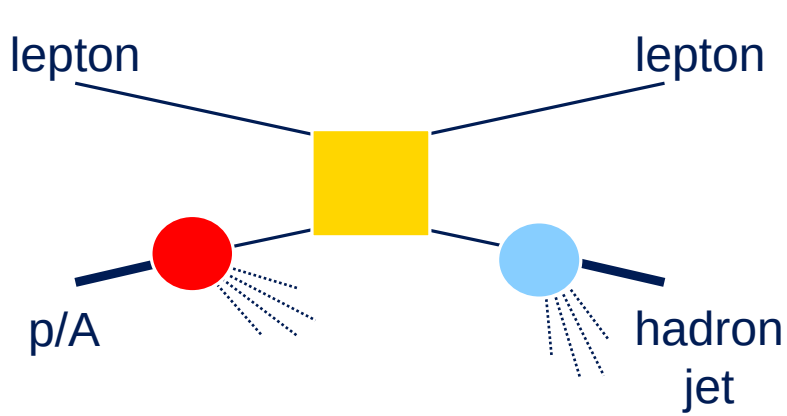
Later in 2018

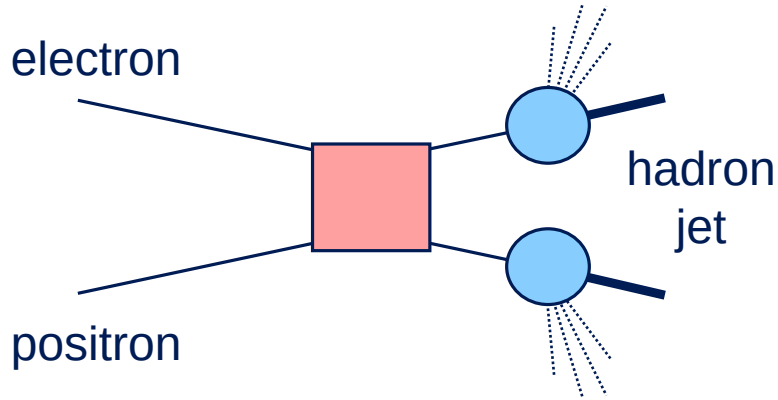
September 5-7 2018	Short-range nuclear correlations at an Electron-Ion Collider Brookhaven National Lab
September 10-12 2018	Studies Of Entropy And Entanglement At The EIC Stony Brook: Peter Paul Seminar Room (C-120, Physics Building)
November 28-30 2018	CFNS Inaugural Meeting Stony Brook and Brookhaven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

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



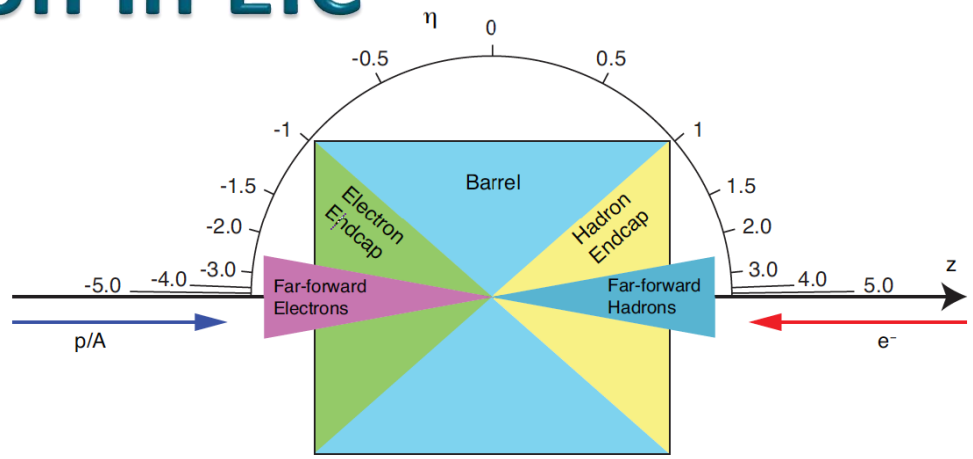




Closing remarks 2: Participation in EIC

- 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
- 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

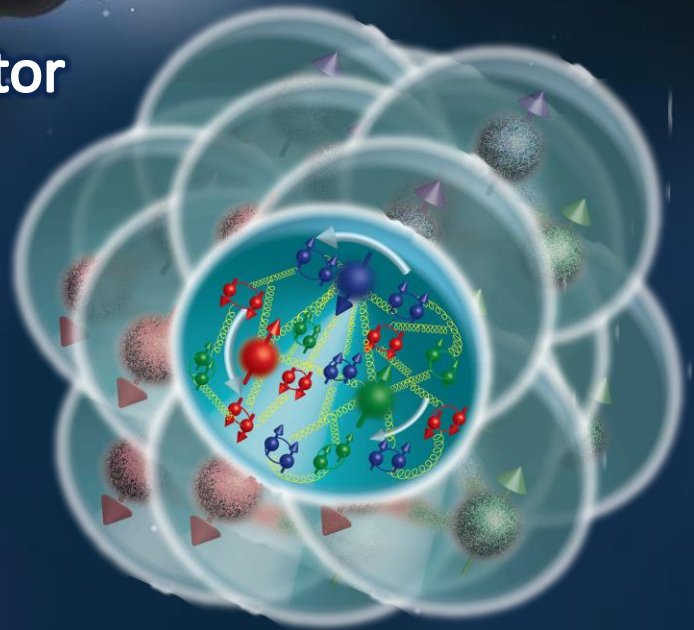
Current and recently completed projects

- 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 Q2-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

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