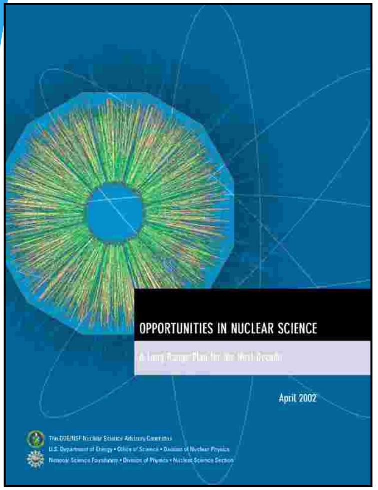
EIC status: User Group Perspective

Olga Evdokimov (University of Illinois at Chicago)

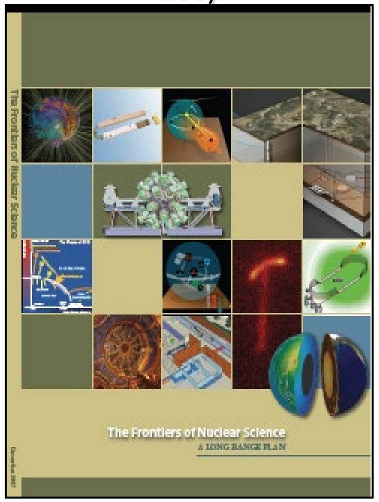
Scientific Case for the Electron-Ion Collider

- EIC: long time in the making and planning
- EIC potential and prospects are discussed in the US Long Rage Planning from 2002
- EIC is a key element of the Long-Range Plan in 2015

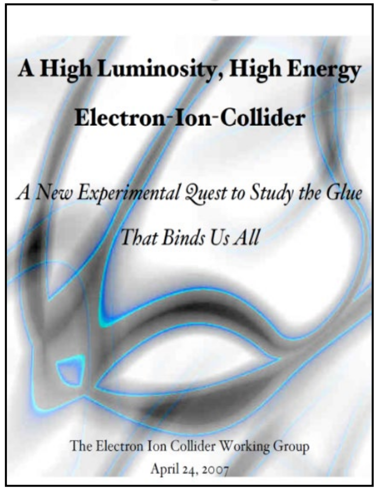
2002



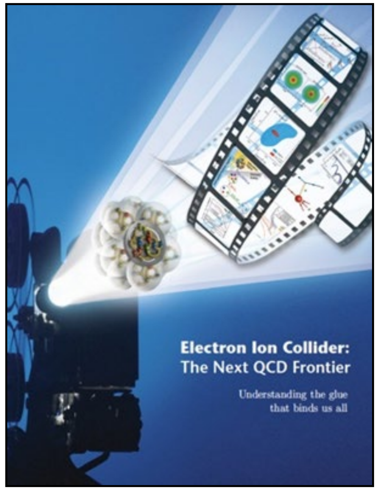
2007



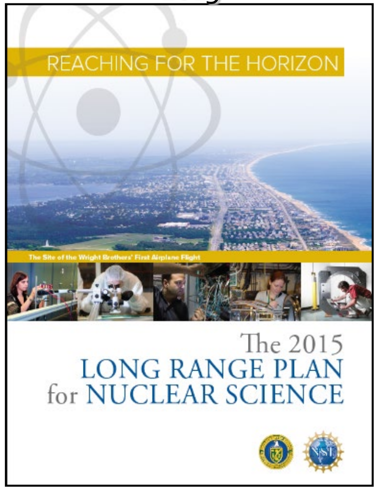
2009



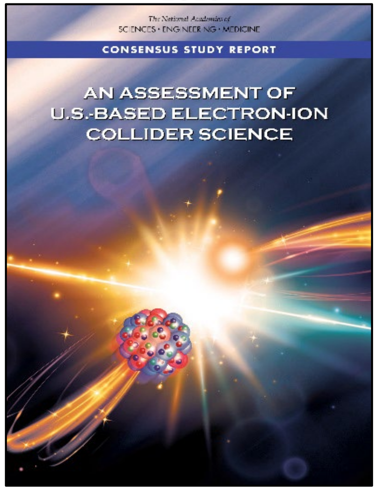
2012



2015



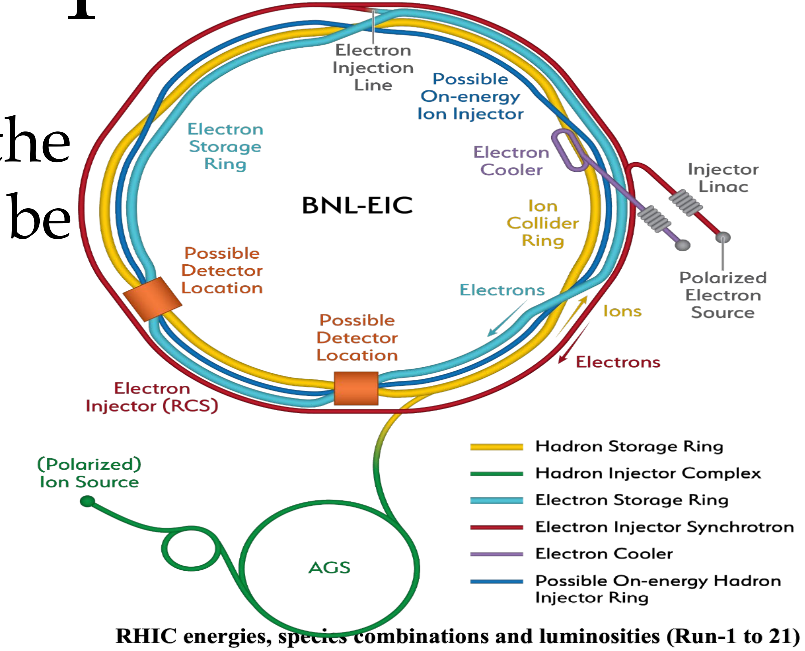
2018



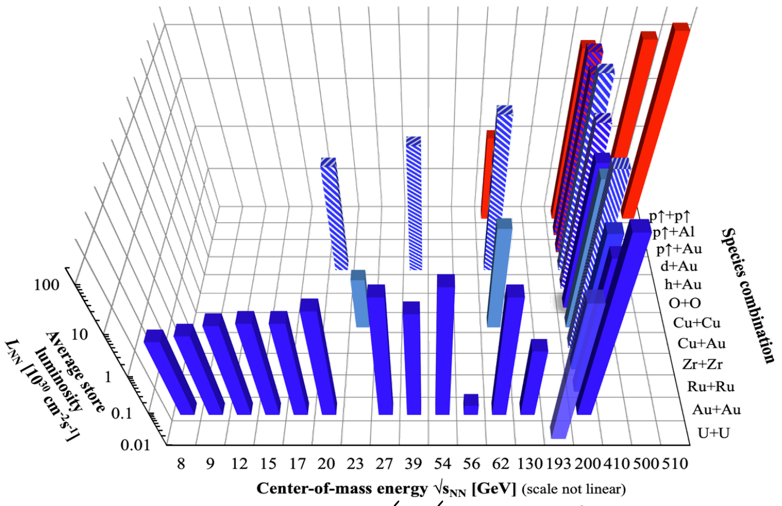
- NAS assessment: *"The committee finds that the science that can be addressed by an EIC is compelling, fundamental and timely."*

EIC Machine Design and Requirements

- NP Community and NSAC defined the requirements for the new facility which will be hosted by BNL in partnership with TJNAF
  - High luminosity (10^{33}– $10^{34}\ cm^{-1}s^{-1}$)
  - High polarization for electrons / light ions (70%)
  - Wide range of $\sqrt{s_{ep}}$ (20 – 140 GeV)
  - Variety of ion species (p to U)
- Hadron ring with 2 IRs exists and operational
  - Adding electron ring with beams 5 - 18 GeV
- CD-0: January 22, 2019, CD-1: July 6, 2021

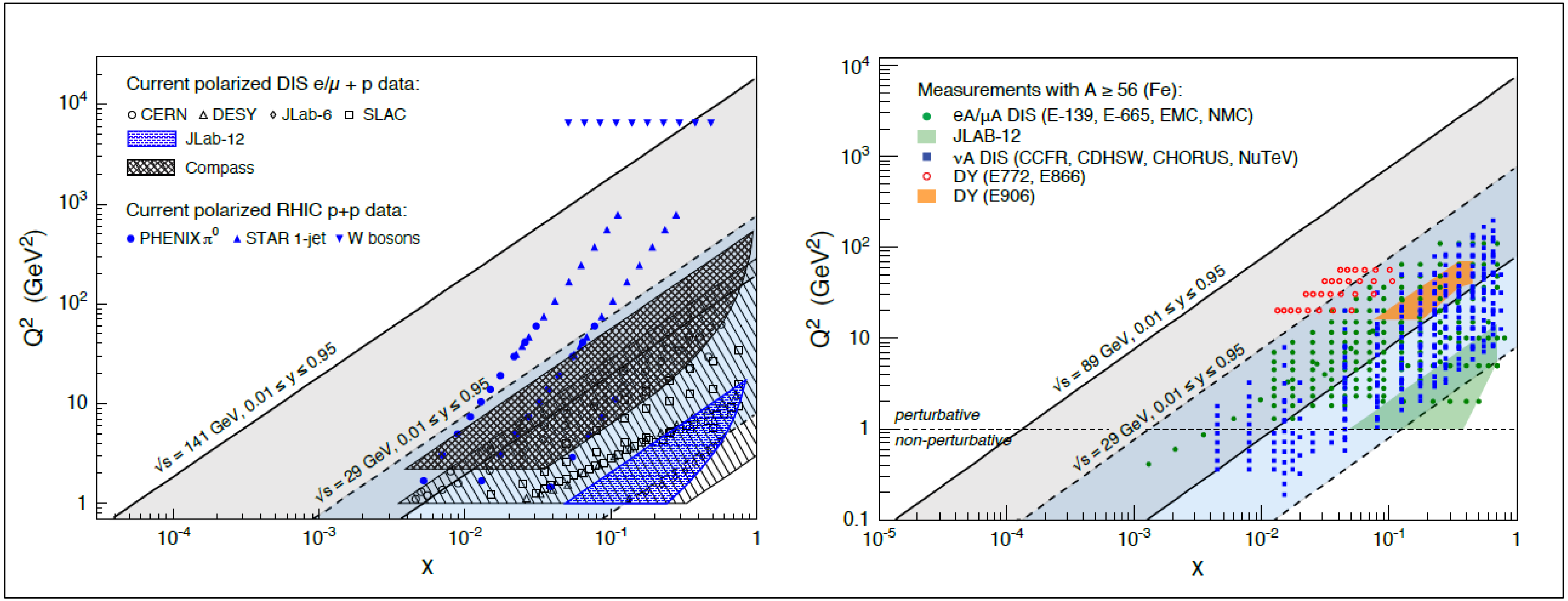


RHIC energies, species combinations and luminosities (Run-1 to 21)



www.eicug.org/web/sites/default/files/EIC_CDR_Final.pdf

EIC Kinematic Reach



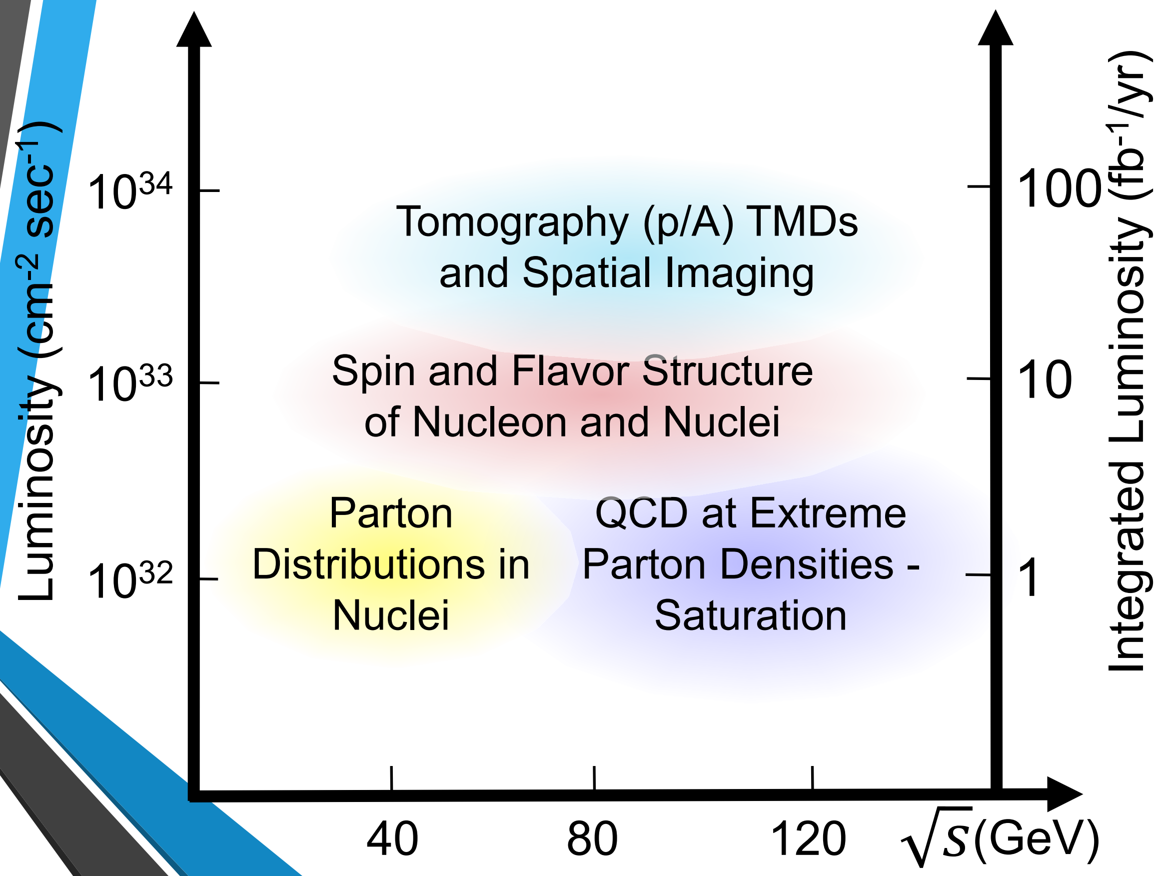
Polarized ep   Polarized eA

- Extension of existing polarized beam measurements:

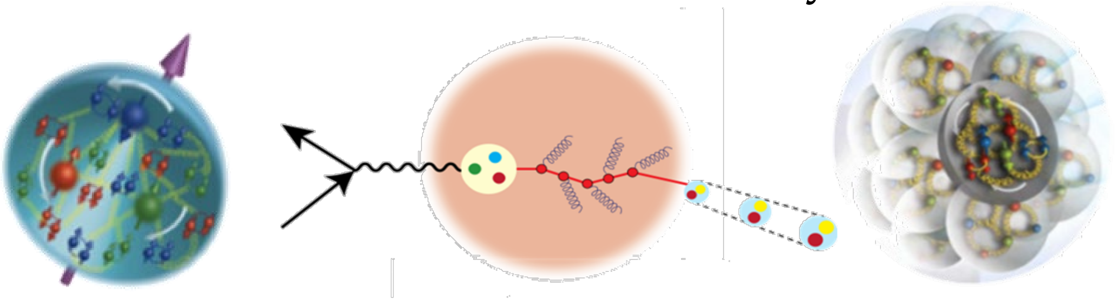
  × 100 in x at a fixed Q^2 and by × 100 in Q^2 at a fixed x

EIC – a New QCD Laboratory

EIC is envisioned as a premier facility to study the structure and dynamics of the visible matter

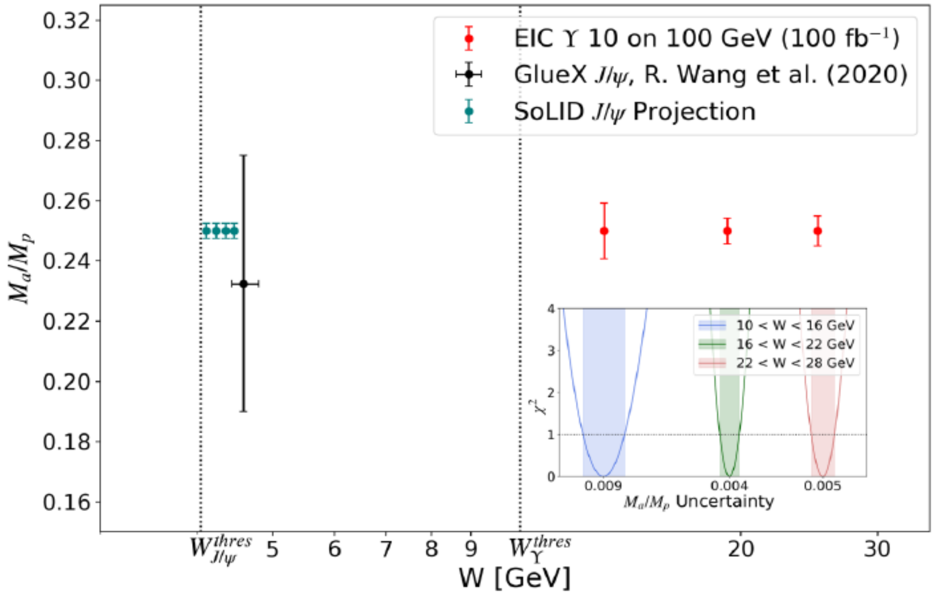


- Major physics goals:
  - Understanding the properties of hadrons (mass, spin)
  - Complete (3D) imaging of hadrons
    - PDF, TMD, GPD
  - Properties of QCD nuclear matter at high parton densities
  - Emergence of hadrons
    - Hadronization, universality tests



EIC Input on Proton Mass

- Possible decomposition of contributions:



Quantum fluctuations
Quark mass + Trace anomaly

$$M = E_q + E_g + \chi_{m_q} + T_g$$

Relativistic motion
Quark energy + Gluon energy

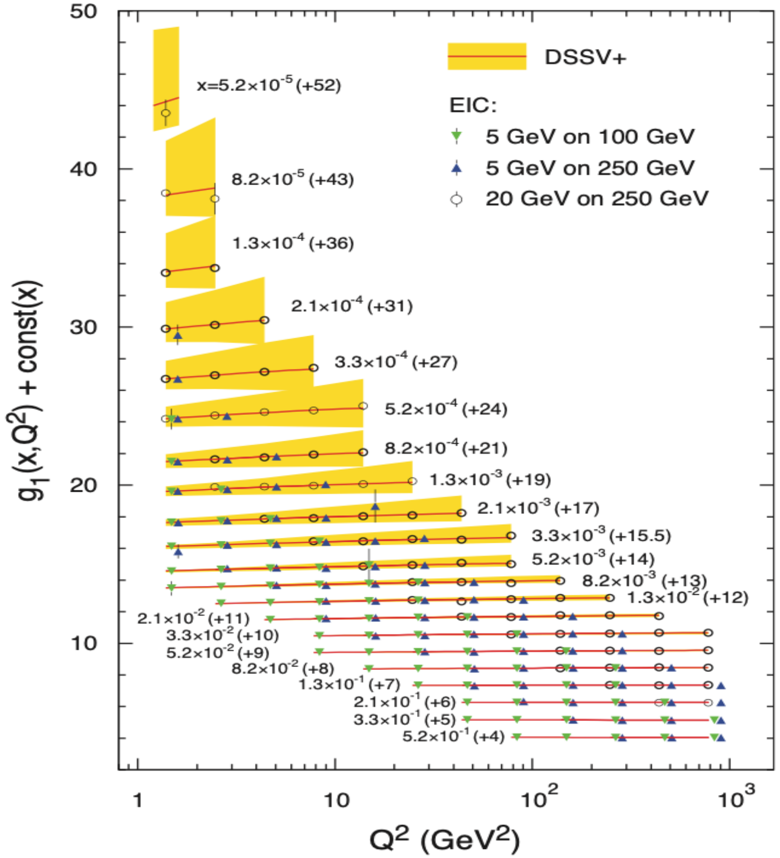
PRL121(2018)212001

quark condensate ~9%
quark energy ~32%
gluonic field energy ~37%
anomalous gluonic contribution ~23%

- EIC will deliver crucial input through dedicated measurements of exclusive production of J/ψ and Υ close to the production threshold
- Hadron mass through chiral-symmetry features will also be studied with light mesons (π, K, φ)

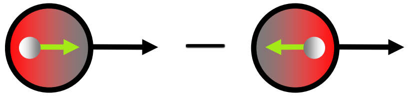
EIC Input on Proton Spin

arXiv:1212.1701

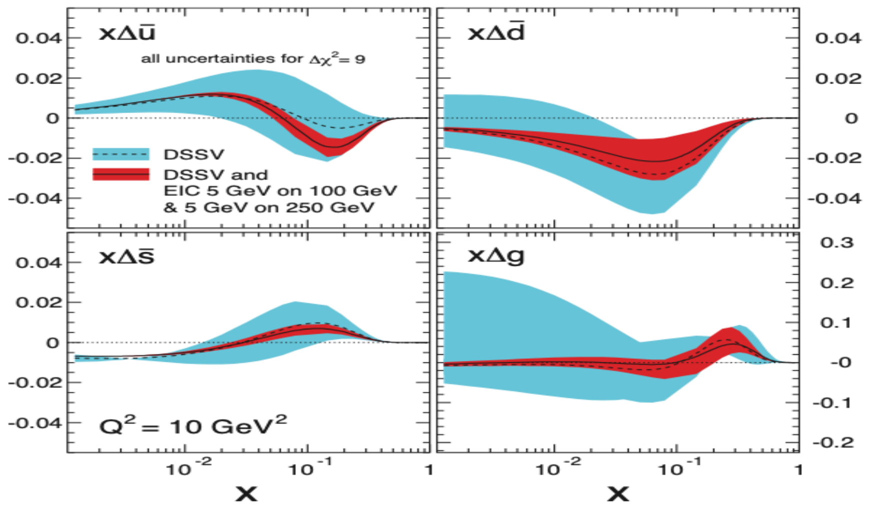


g_1 uncertainty projections for 10fb^{-1} for range of CME compared to DSSV+

- Contribution of quarks and gluons to the spin of the proton are constrained via x, Q^2 behavior of the cross-section difference g_1

$g_1(x)\sim$ 

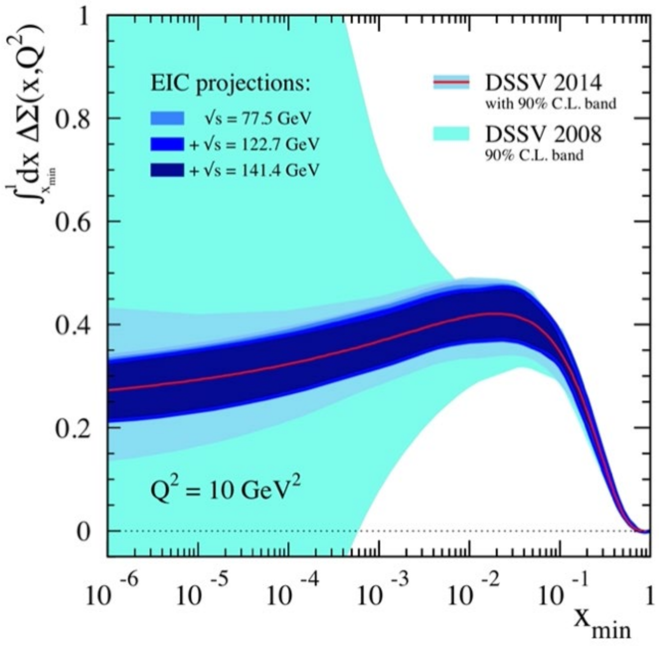
$f^+(x) - f^-(x)$

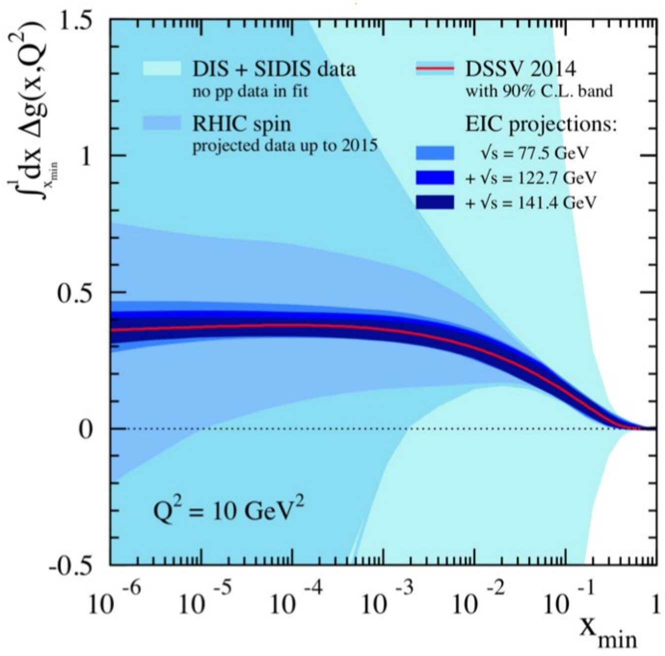


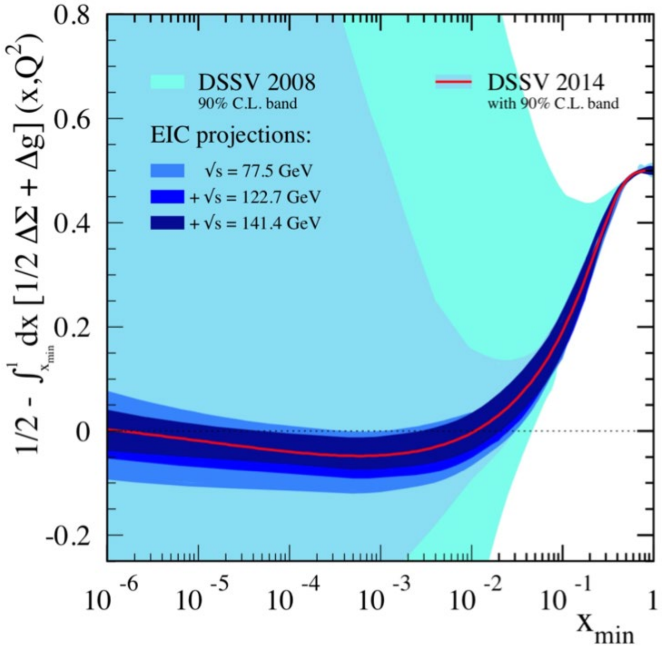
- EIC impact on spin and flavor structure of the proton through helicity distributions of sea quarks and gluons

EIC Expected Impact Example

E. Aschenauer, R. Sassot and M. Stratmann, Phys. Rev. D92 (2015) 094030.



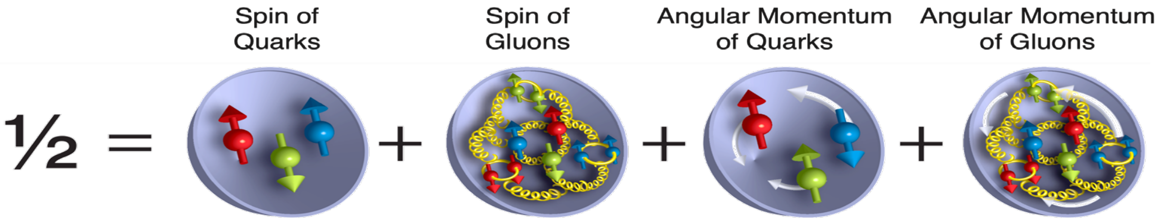


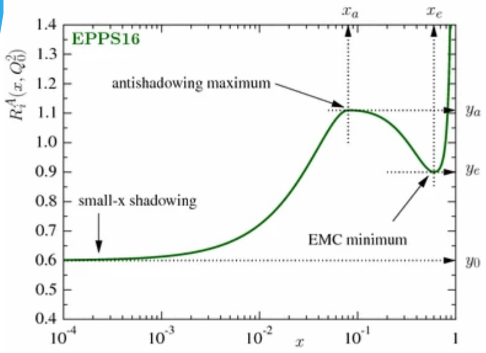


Quark Spin

Gluon Spin

Orbital Angular Momentum

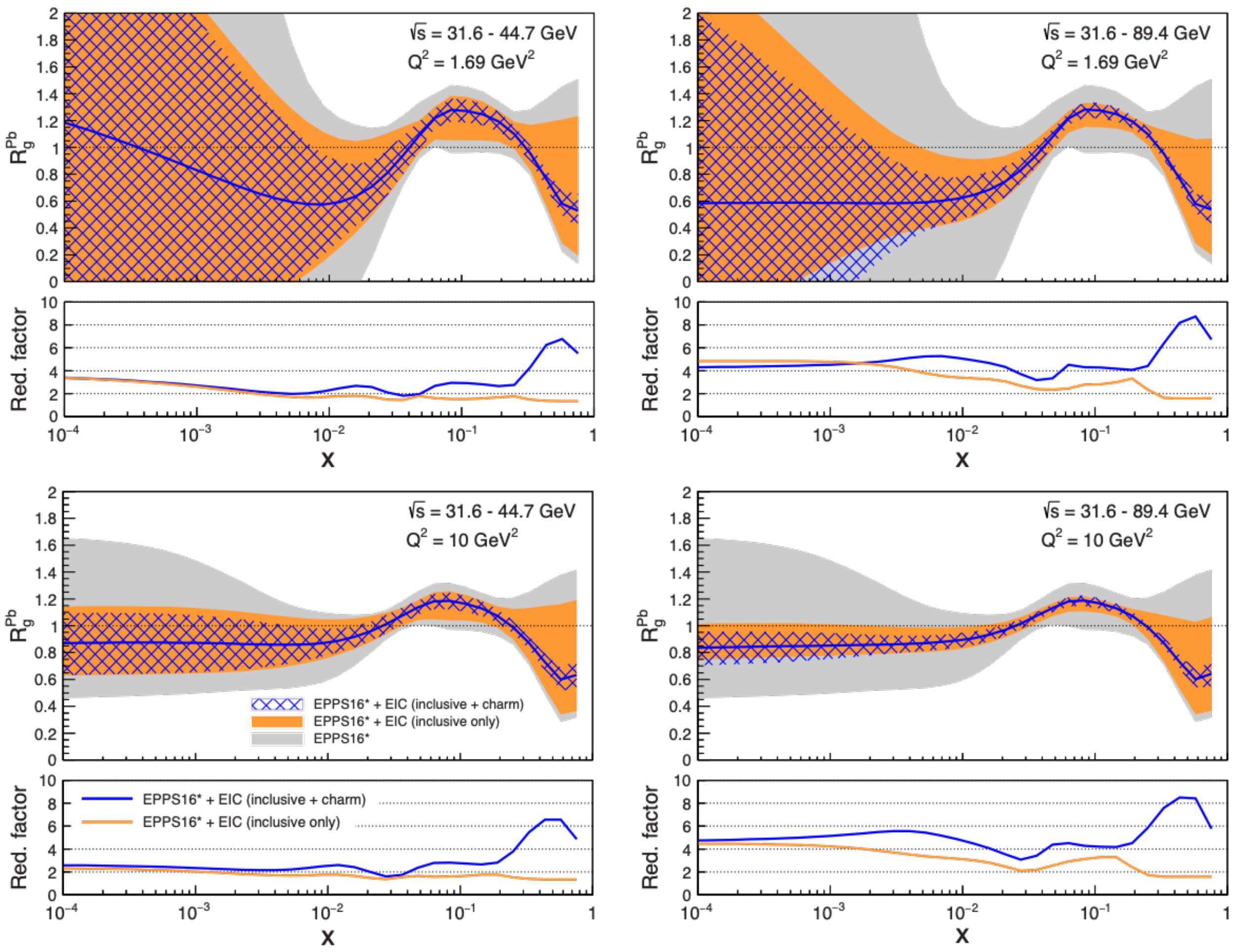




eA: Nuclear PDF effects

- Nuclear modification R_g^{Pb}: ratio of gluon distributions in Pb and in p
- Projected precision of EIC measurements allows for substantial reduction of nPDF uncertainties
- Complementary to RHIC and LHC pA data, and has no potential complications of disentangling initial and final state effects
- Provides critical input on initial state for heavy ion collisions

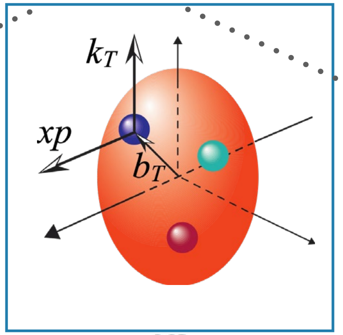
RPP 82 (2019) 2, 024301



PDF Complexity

EPJ A 52 (2016) 9, 268

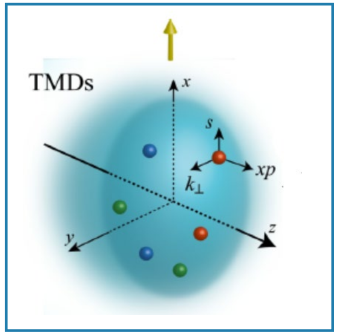
- Wigner Functions $W(x, k_T, b_T)$

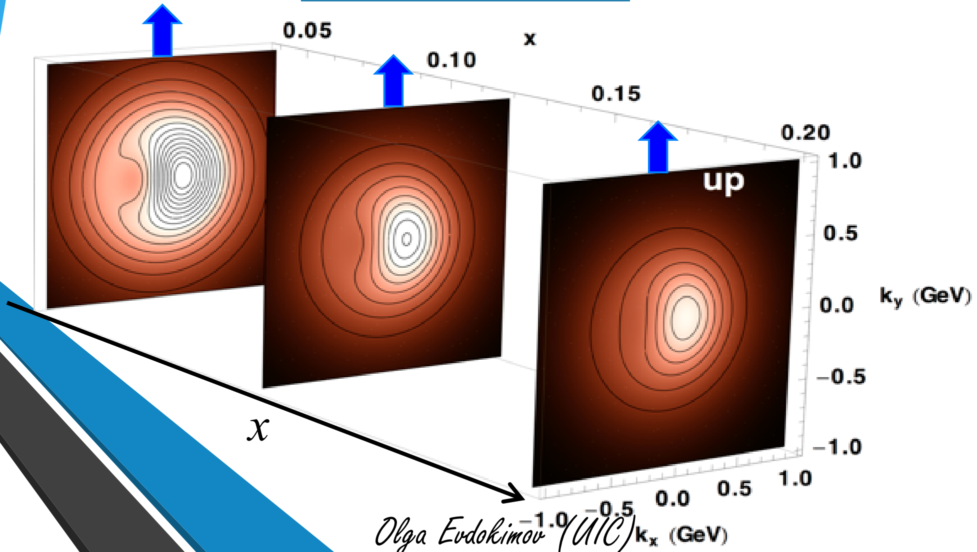


$\int d^2 b_T$

$\int d^2 k_T$

Transverse Momentum Dependent distributions

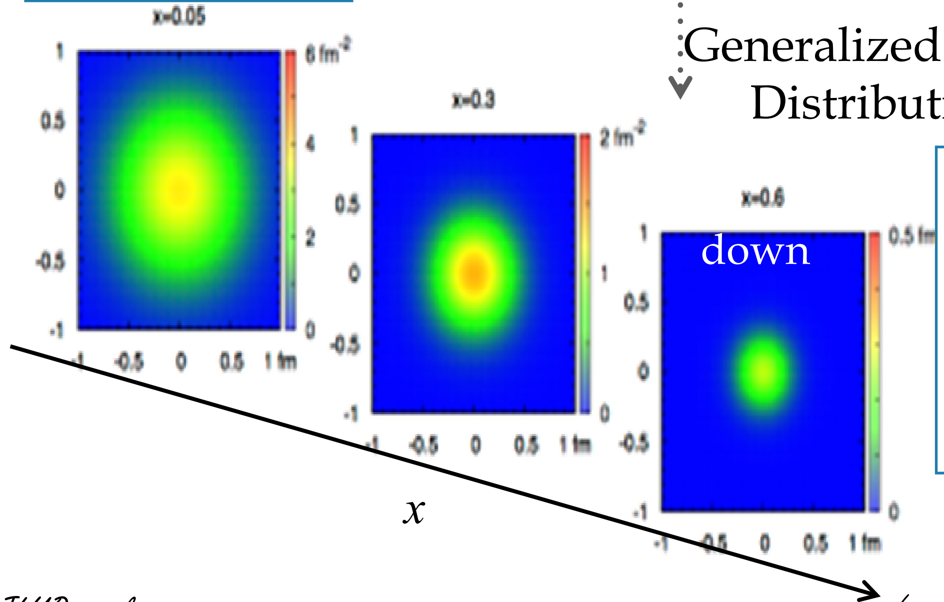


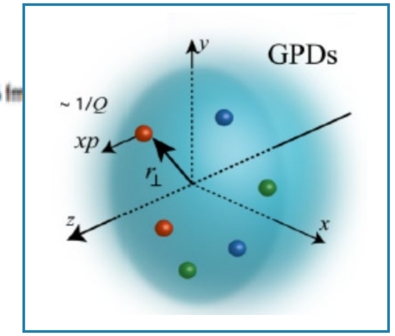


Impact Parameter Dependent distributions $f(x, b_T)$

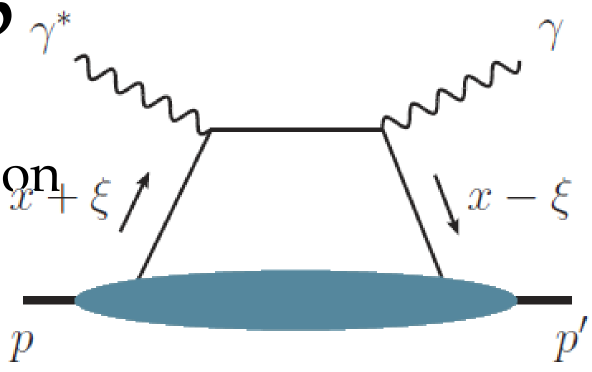
Fourier Transform

Generalized Parton Distributions





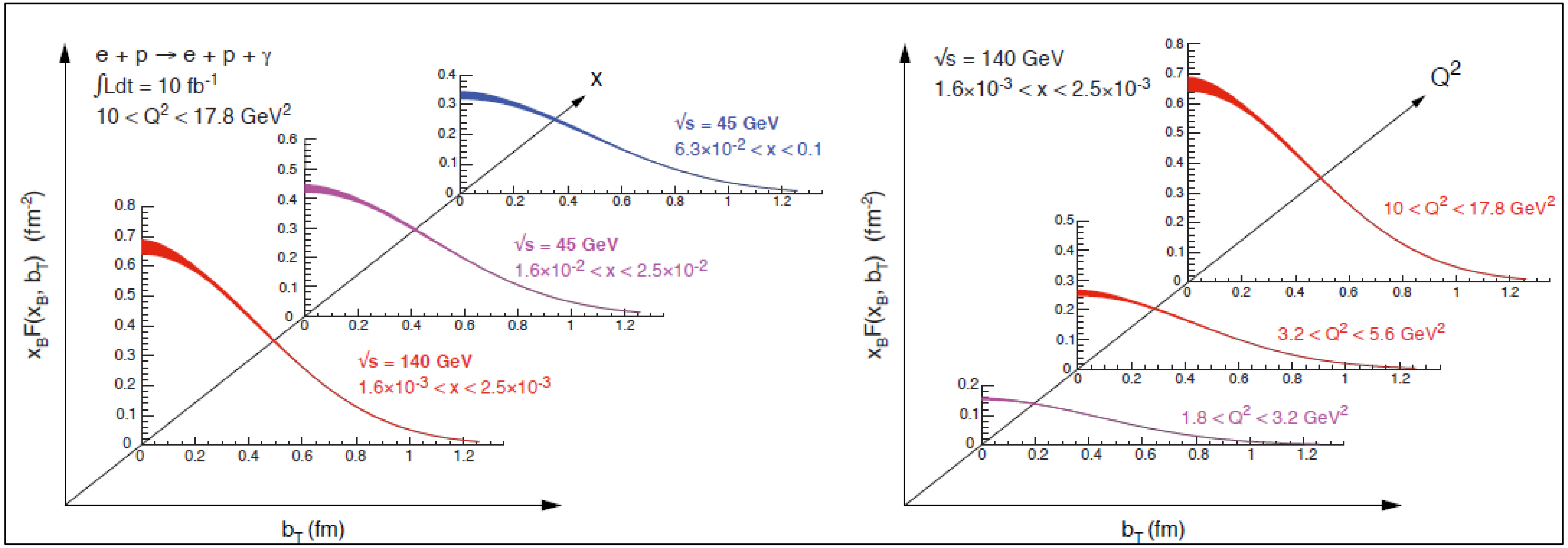
EIC: 2D Spatial Imaging



- EIC will enable precise mapping the spatial quark and gluon structure of the proton in (x, Q^2)
- GPDs "golden channel" – DVCS
- Also, together with direct helicity measurements for quarks and gluons, GPD provide additional insight into quark and gluon orbital momenta

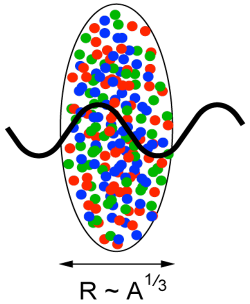
RPP 82 (2019) 2, 024301

Projected precision of the EIC GPDs from Fourier transform of the unpolarized DVCS cross-sections vs |t|



EIC eA: Gluon Saturation

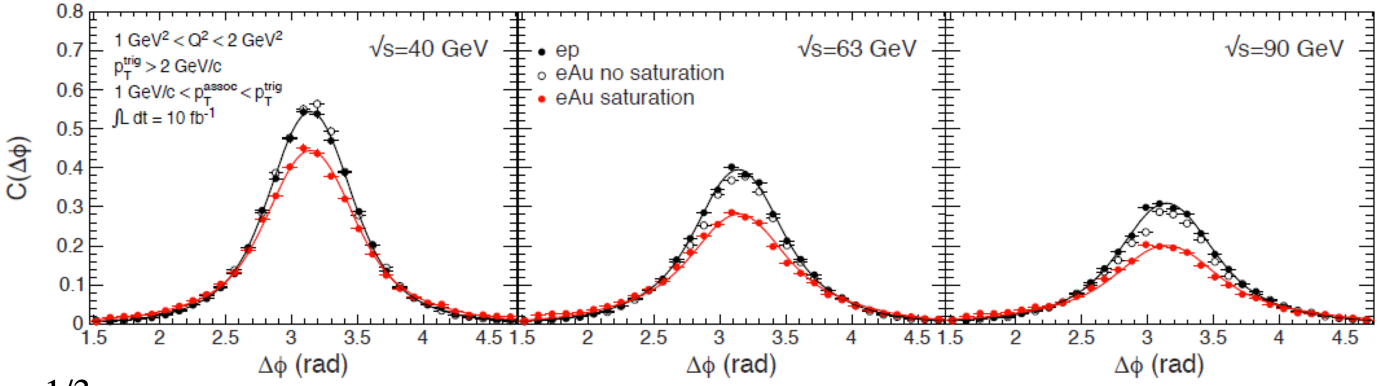
- Could the gluon density $G(x, Q^2)$ continuously grow?
- New idea: Non-Linear Evolution
  - Recombination compensates gluon splitting
  - New evolution equations
  - Saturation of gluon densities characterized by scale $Q_s(x)$
- Saturation → Color-Glass-Condensate (CGC)
- Experimentally, nucleus serves as Q_s amplifier



$$(Q_s^A)^2 \approx cQ_0^2\left(\frac{A}{x}\right)^{1/3}$$

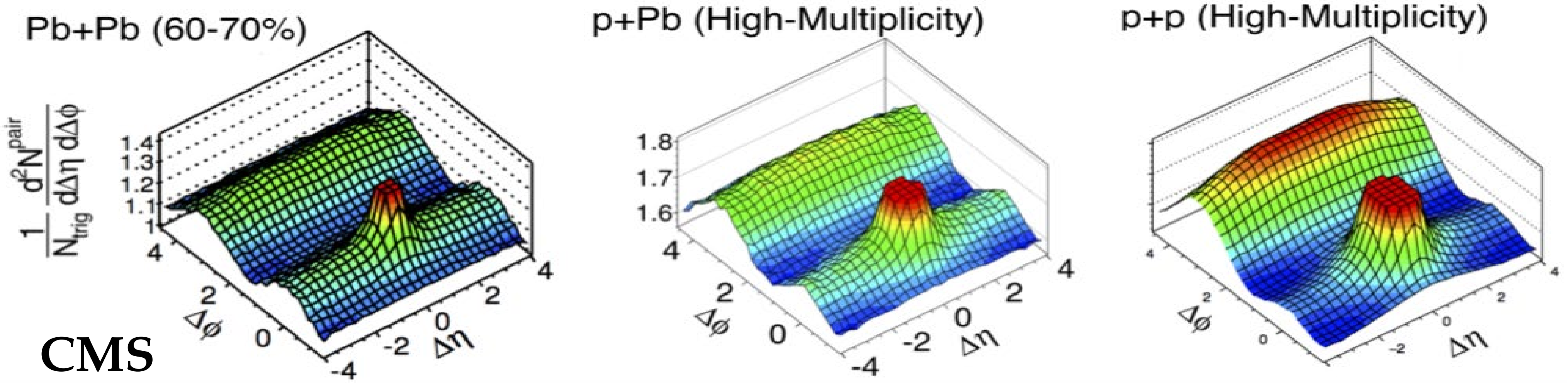
- Di-hadron correlations are sensitive to the transverse momentum dependence of the gluon distribution and gluon correlations

2→2 vs. 2→many

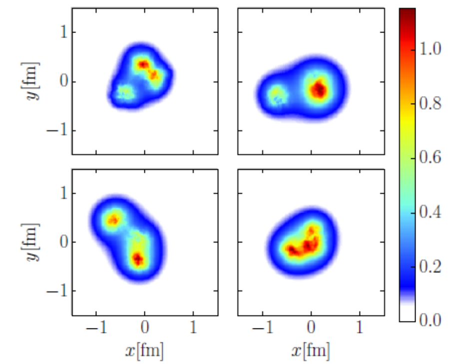


- EIC allows to study the evolution of Q_s with x

eA: Collective Phenomena in Small Systems



PRD 94(2016)034042



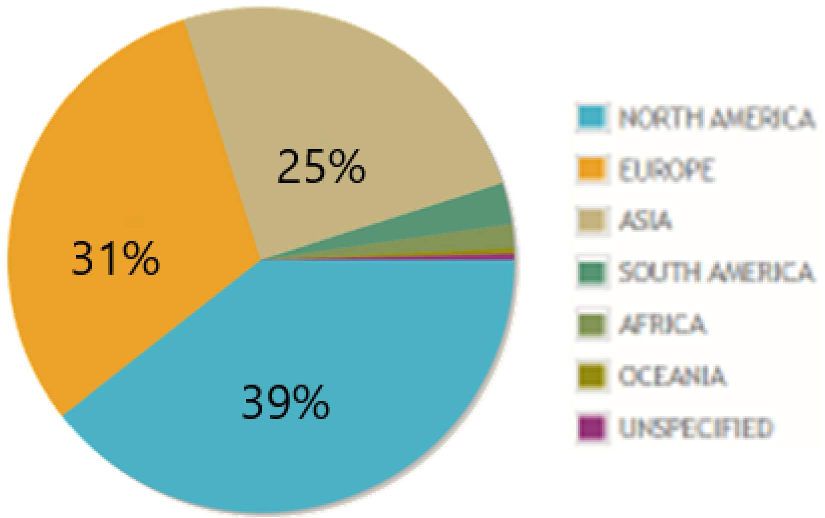
proton density
$x \sim 10^{-3}$

- Long range correlations: everywhere! AA collisions, pA, high multiplicity pp
  - Can the system that small reach an equilibrium?
  - Is this a manifestation of initial state phenomena? CGC?
- NOT reproduced in any established MC generators
- Understanding of proton structure is critical for testing QGP formation in small systems

EIC Users Group

- EICUG established in summer 2016
- Annual Meetings

2016 UC Berkeley, CA	2019 Paris, France
2016 Argonne, IL	2020 Miami, FL
2017 Trieste, Italy	2021 VVU/UCR
2018 Washington, DC	2022 SBU, NY



- New website: https://eicug.github.io/

Come Join Us!

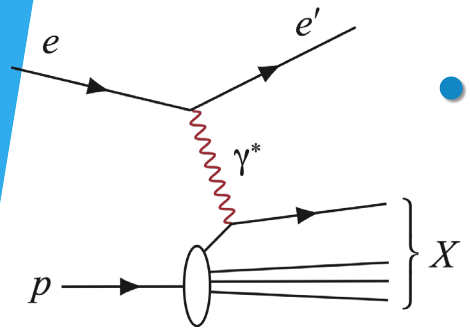
EIC User Group:

- 1330 members
- 266 institutions
- 36 countries (7 world regions)

Community Effort to Define EIC Detector

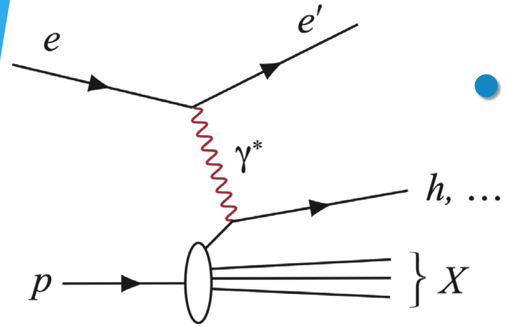
- ~400 authors / ~150 institutions / ~900 pages with strong international contributions!
- Review, community input, and editorial process completed: https://arxiv.org/abs/2103.05419
- Best reference guide for EIC detector requirements and technologies

EIC Detector Requirements



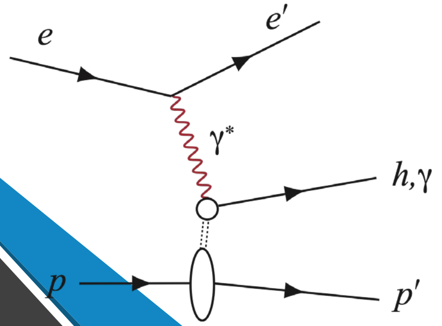
- **Inclusive:** fine binning in x, Q^2
- Hermetic coverage, e ID, reaching lowest x, Q^2

$1\ fb^{-1}$



- **SIDIS:** 5-dimensional binning in x, Q², z, p_T, θ
- Hadron PID over wide range is critical

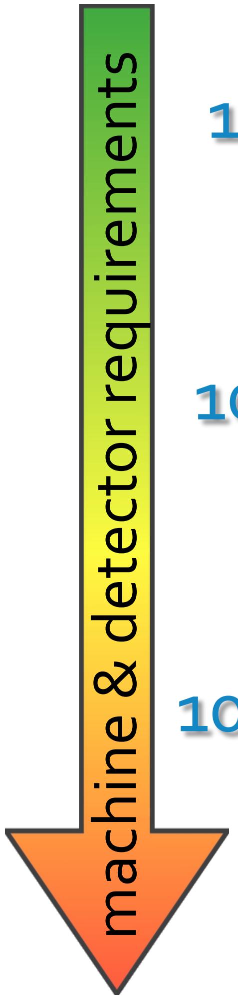
$10\ fb^{-1}$



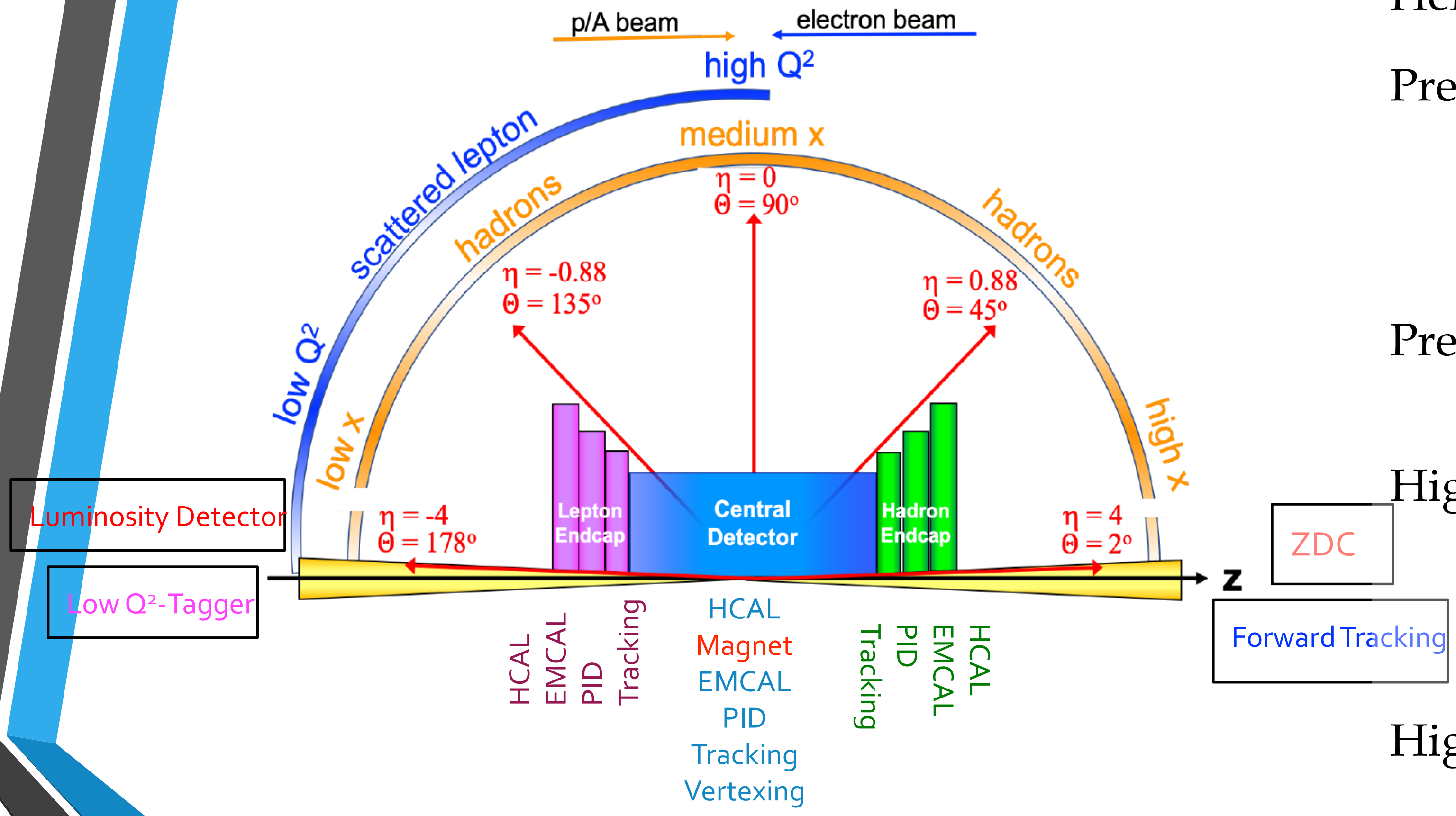
- **Exclusive:** 4-dimensional binning in x, Q^2, t, θ
- Forward, backward region is key

$10\text{-}100\ fb^{-1}$

$\int \mathcal{L}dt$



EIC General Purpose Detector Schematics



Hermetic coverage $-4.0 \lesssim \eta \lesssim 4.0$

Precision tracking:

$\sigma p_T/p_T(\%) = 0.05 p_T \otimes 0.5$ (central)
$\sigma p_T/p_T(\%) \approx 0.1 p_T \otimes 0.5$ (backward)
$\sigma p_T/p_T(\%) \approx 0.1 p_T \otimes 1–2$ (forward)

Precision vertexing:

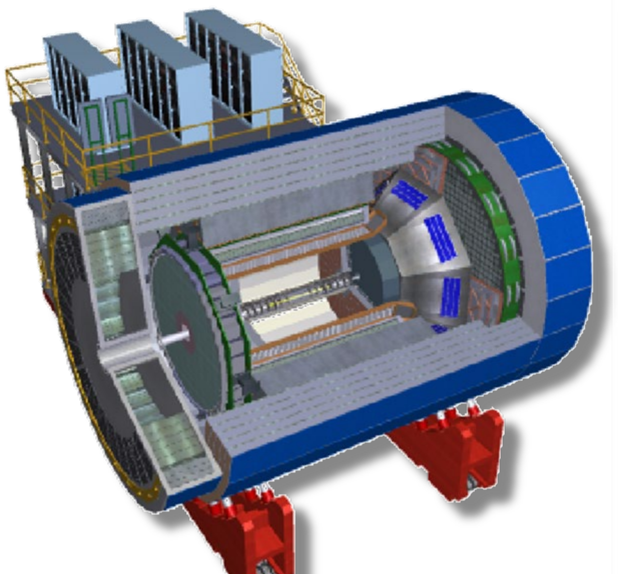
$\sigma_{xy} \sim 20/p_T \otimes 5$ µm

High-resolution calorimetry:

$\sigma(E)/E \approx 10\%/\sqrt{E} \otimes (1-3)\%$ (ECal, central)
$\sigma(E)/E \approx 2\%/\sqrt{E} \otimes (1-3)\%$ (ECal, backward)
$\sigma(E)/E \approx 50\%/\sqrt{E} \otimes 10\%$ (Hcal, forward)

High performance PID: $3\,\sigma$ π/K/p
up to 50GeV/c (forward)
up to 10GeV/c (central)
up to 7GeV/c (backward)

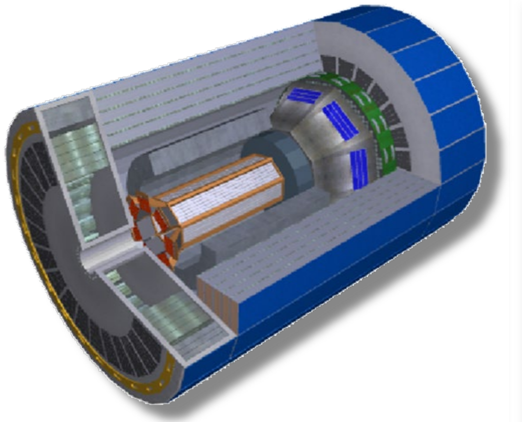
EIC Detector Proposals



ATHENA: **A** **To**tally **H**ermetic **E**lectron-**N**ucleus **A**pparatus

Concept: General purpose detector with a new central magnet of up to 3T

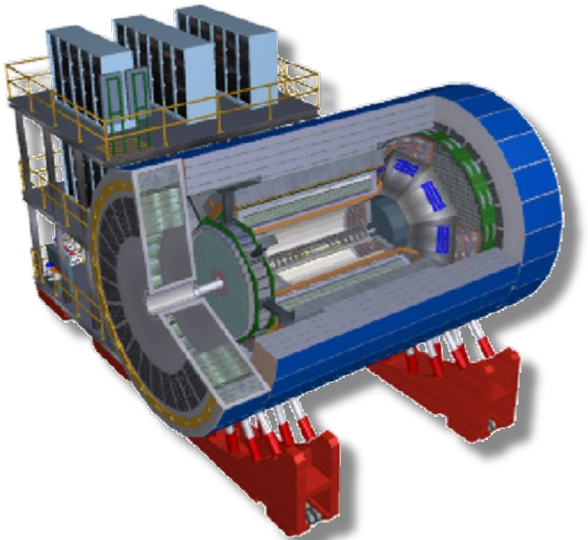
https://www.athena-eic.org



CORE: **CO**mpact detecto**R** for the **E**ic

Concept: Nearly hermetic, general-purpose compact detector, 2T baseline

https://userweb.jlab.org/~hyde/EIC-CORE/



ECCE: **E**IC **C**omprehensive **C**hromodynamics **E**xperiment

Concept: General purpose detector based on 1.5T BaBar magnet

https://www.ecce-eic.org

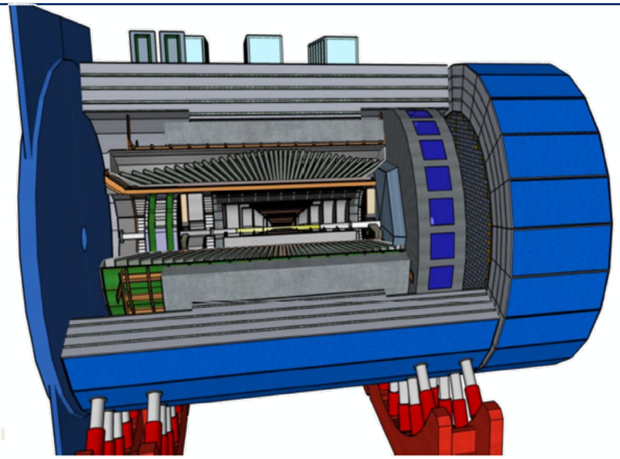
EIC Detector Proposal Advisory Panel

- The DPAP was set to advise host Laboratories on how to realize an optimal set of experimental equipment at the EIC utilizing the resources and expertise of the EIC user community.
- Panel evaluated the **scientific merit**, the expected **scientific performance**, **technical risk**, **cost**, and **schedule** of the experiment proposed as well as the **strength of the collaboration** and the **availability of resources**, addressing two primary charges:
  - **Identify the optimal approach to realize a detector system, designated Detector 1**
  - **Assess options for an alternate detector system, designated Detector 2**
- Chaired by Rolf Heuer (CERN) and Patricia McBride (FNAL)

Patricia McBride April 10, 2022 April APS Meeting

DPAP Final Report

Conclusions and Recommendations



- The panel finds that ECCE and ATHENA fulfill all requirements for a Detector 1.
  - ECCE has several advantages, in particular reduced risk and cost, and qualifies best for Detector 1.
  - CORE presented a more conceptual design and given the tight timeline for CD2/3a would generate a schedule risk for the EIC Project as Detector 1.
- The panel supports the case for a second EIC detector.
  - DOE resources to start a Detector 2 project will most likely be delayed for several years, or the resources would have to found from other sources. There is significant international participation in the proto-collaborations, however, the panel found the overall resources were insufficient to proceed with a second detector effort at this time.
- The EIC's project planning for Detector 1 should incorporate a period for integrating new collaborators and re-optimizing experiment conceptual design in advance of CD-2.

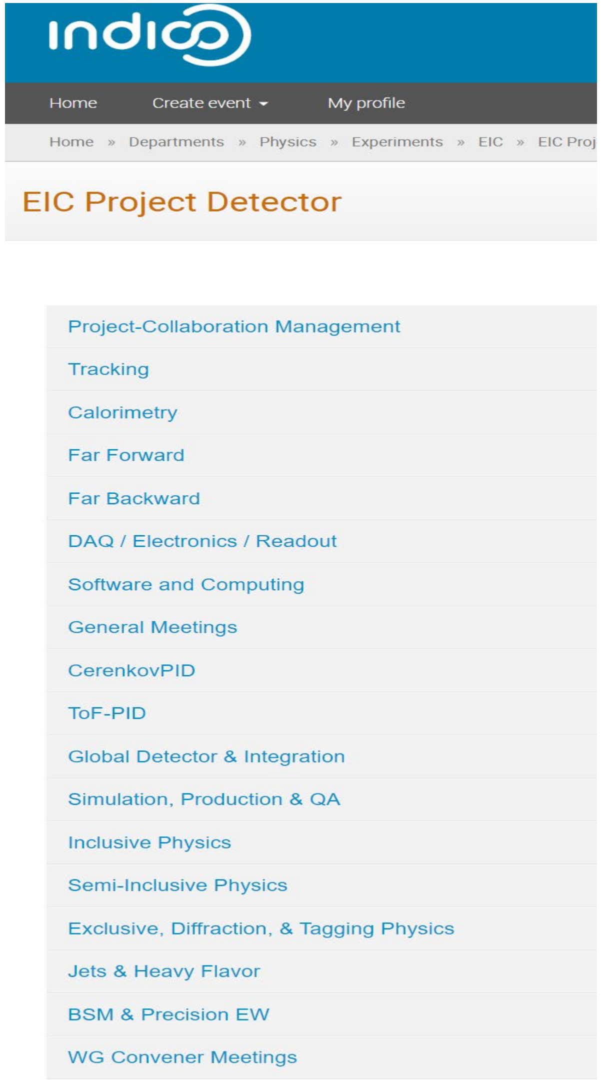
Panel Recommendations

- The panel unanimously recommends ECCE as Detector 1. The proto-collaboration is urged to openly accept additional collaborators and quickly consolidate its design so that the Project Detector can advance to CD2/3a in a timely way.
- The panel supports the case for a second EIC detector, however, given the current funding and available resources, the committee finds that a decision on Detector 2 should be delayed until the resources and schedule for the Project detector (Detector 1) are more fully realized.

https://www.bnl.gov/dpapanelmeeting/

Detector-1: Towards Realization

- The EICUG Steering Committee has been meeting regularly with Project Management and the three proto-collaborations
- The main priority for the EICUG community is to establish a strong collaboration for Detector 1
- Progress since the review:
  - A joint leadership team coordinates the efforts: Silvia Dalla Torre, Or Hen, Tanja Horn, John Lajoie, Bernd Surrow
  - Joint working Detector and Physics working groups established and operational
  - Institutional interest survey was completed for Institutional Board Formation
  - First in-person collaboration meeting collaboration is planned at the EICUG annual meeting



https://indico.bnl.gov/category/402/

Opportunities for Detector 2

- EICUG: There is strong support in the user community for two EIC detectors to realize fully scientific opportunities provide by the new collider.

- DPAP: “The panel supports the case for a second EIC detector, however, given the current funding and available resources, the committee finds that a decision on Detector 2 should be delayed until the resources and schedule for the Project detector (Detector 1) are more fully realized.”

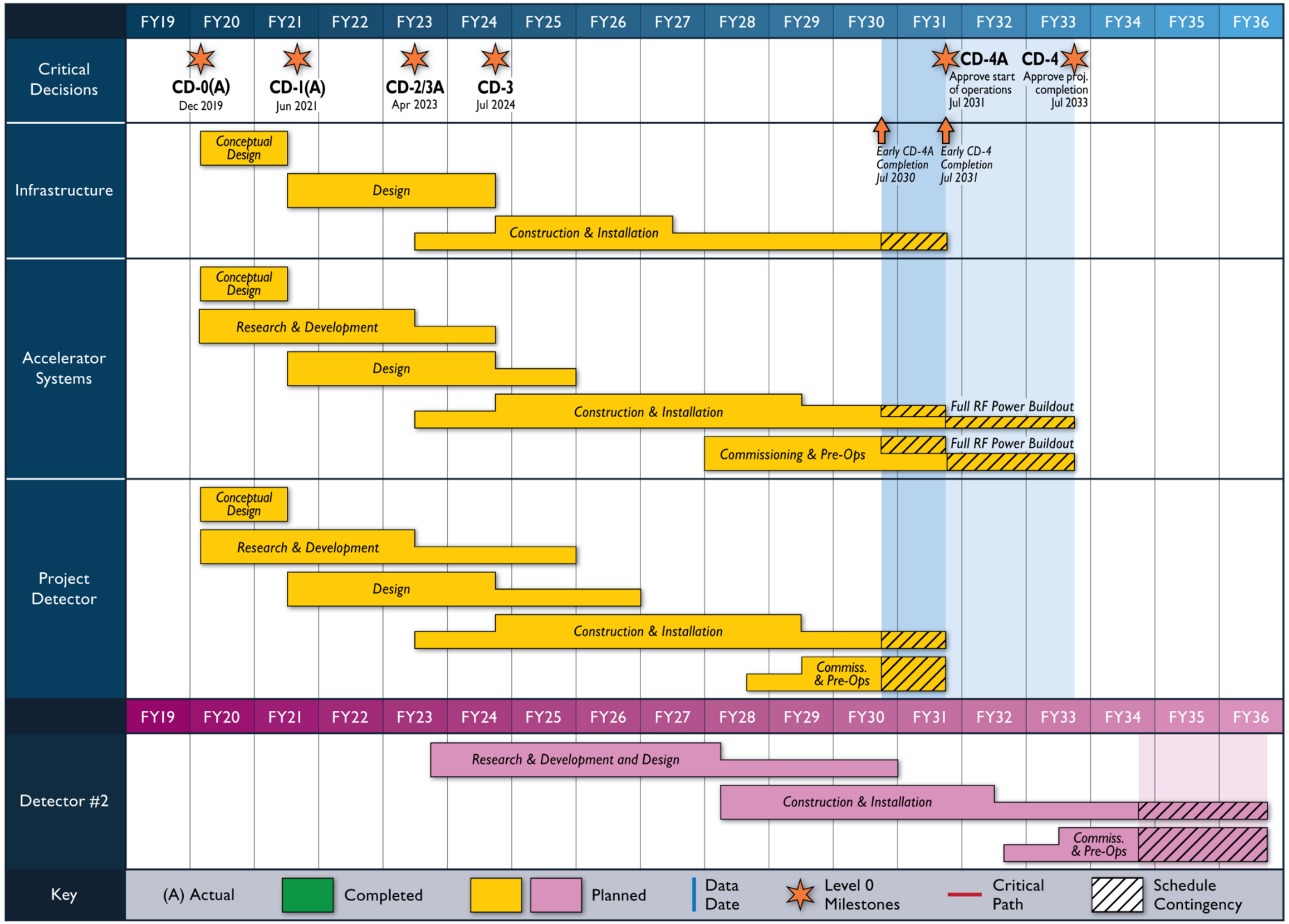
  - Detector-1 is clearly a priority, but careful balance/timing considerations are needed to make the Detector 2 feasible

THE ELECTRON-ION COLLIDER

The Benefits of Two Detectors

The Electron-Ion Collider (EIC) is a transformational and unique accelerator that will enable studies of nuclear matter with unprecedented precision. The EIC is required to address fundamental open questions in physics, such as the origin of mass and spin of protons and neutrons, the details of the "glue" that binds them, and the nature of very dense gluon systems in nuclei. This ambitious collider could not deliver physics results without powerful "cameras" capable of taking the most detailed snapshots of the collisions produced at the EIC. Novel particle detectors must be designed and constructed to capitalize on the investment made on the accelerator side, so that the deepest secrets of the building blocks of matter in our visible universe may be unlocked.

EIC Planning and Milestones



Elke Aschenauer and Rolf Ent

Co-Associate Directors for the Experimental Program

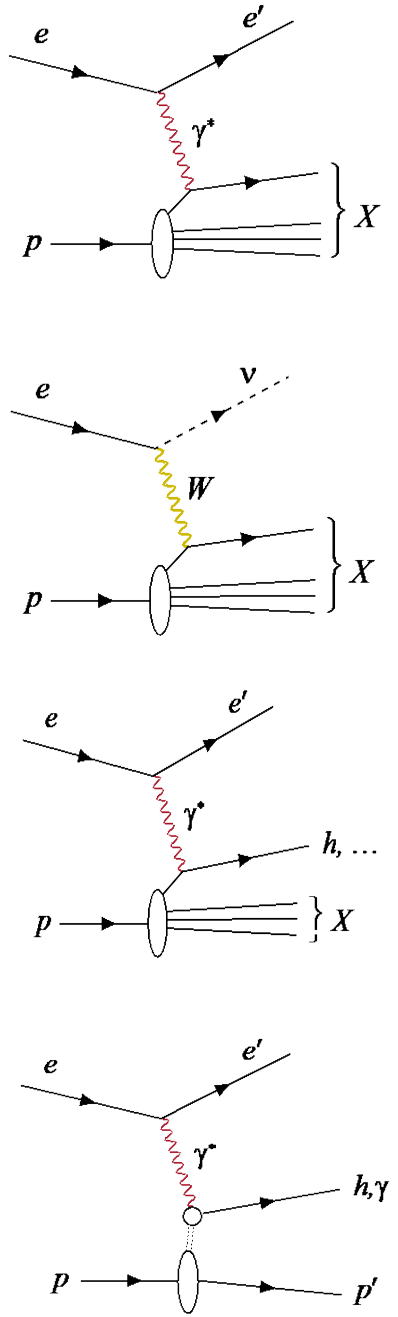
Detector-1 General Meeting, 5/13/22

- CD-2/3A review (expectation), requires pre-TDR ~October 2023
- CD-2/3A (expectation) ~January 2024
- CD-3 review (expectation) ~January 2025
- CD-3 (expectation), requires TDR ~April 2025

This reference schedule is now being revised for the long CR and FY22 actuals, expect CD dates to slip ~9 months.

Summary and Outlook

- The scientific case for the EIC has been firmly established by the efforts of nuclear physics community
- EIC facility has potential to revolutionize our knowledge of QCD
- Physics requirements and detector concepts developed for Yellow Report
- DPAP reviewed detector proposals and selected design for the project detector (Detector-1)
- Formation of Detector-1 collaboration is underway to refine the design and realize the first general-purpose EIC detector
- EIC R&D program is a vital part of the EIC efforts: many technologies at hand or within reach (many ideas for future)
- National and International participation is expected and welcome in all aspects of accelerator and detector developments



Thank you!

The UIC Group's work is supported by DOE-NP

Detector-1 project work planning

What is Needed for the Detector

Elke Aschenauer and Rolf Ent

Co-Associate Directors for the Experimental Program

Detector-1 General Meeting, 5/27/22

Between now and CD-2

- Form collaboration and define subsystem responsibilities
  → in-kind contributions need to be identified and agreements need to be in an advanced state (draft but not final)
- Integrate collaboration in WBS – structure of detector
- Define scope of EIC Project Detector → need to know all subsystem technologies
- All subsystem requirements and interfaces need to be defined
- Refine cost, schedule and labor needs for each subsystem
  - basis – of – estimates need to be well documented
- Agree on the Long Lead Procurement (LLP) items of the detector
- Bring level of design on average to 50-60%, with LLP items needing to be at final design stage (~90%)
- Produce pre-TDR*: 1st version of by May 2023
  → final version by October 2023

*TDR is needed by CD-3, about one year later