Physics and Detector Overview at the Electron-Ion Collider (EIC)

Part II

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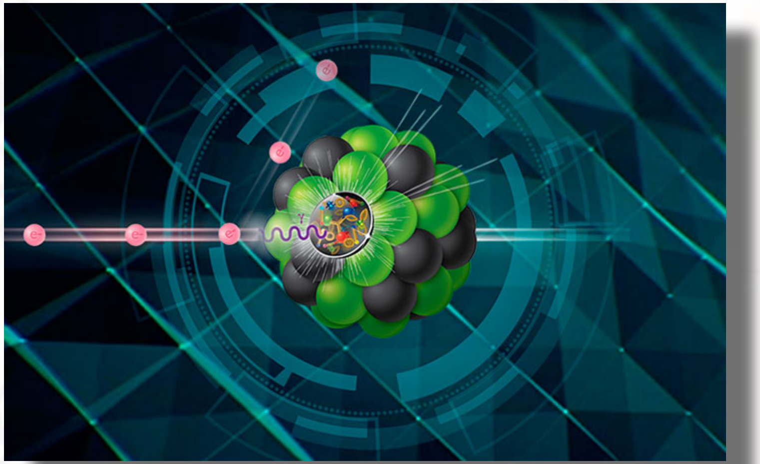

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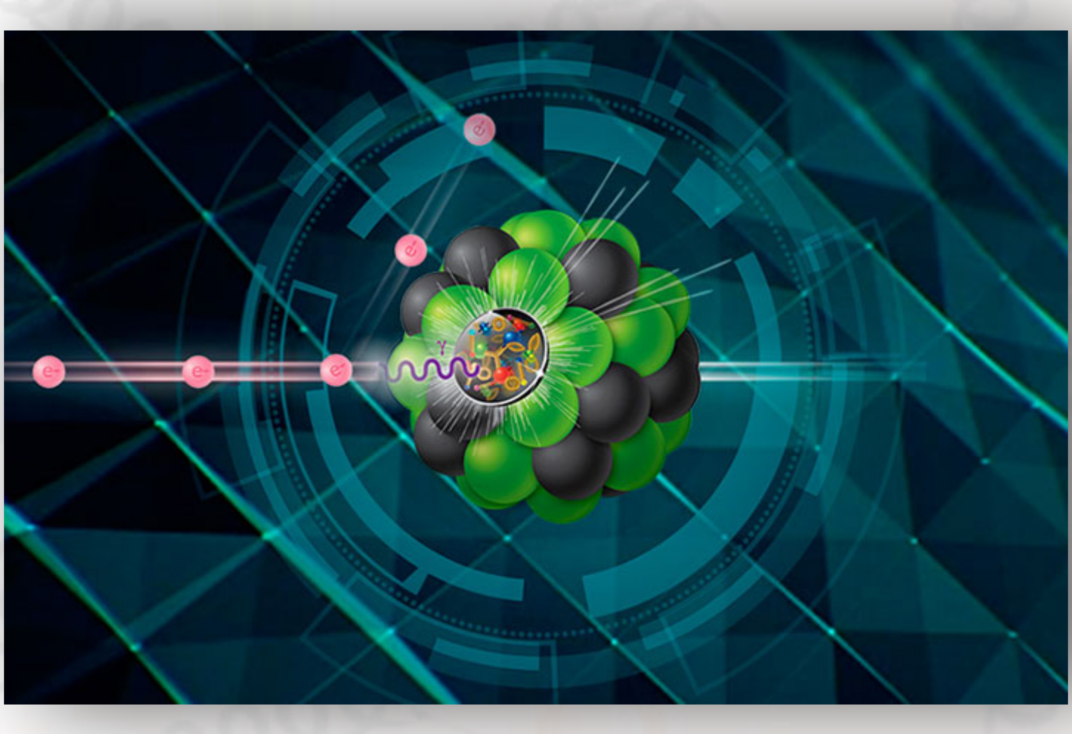
DOE NP contract: DE-SC0013405

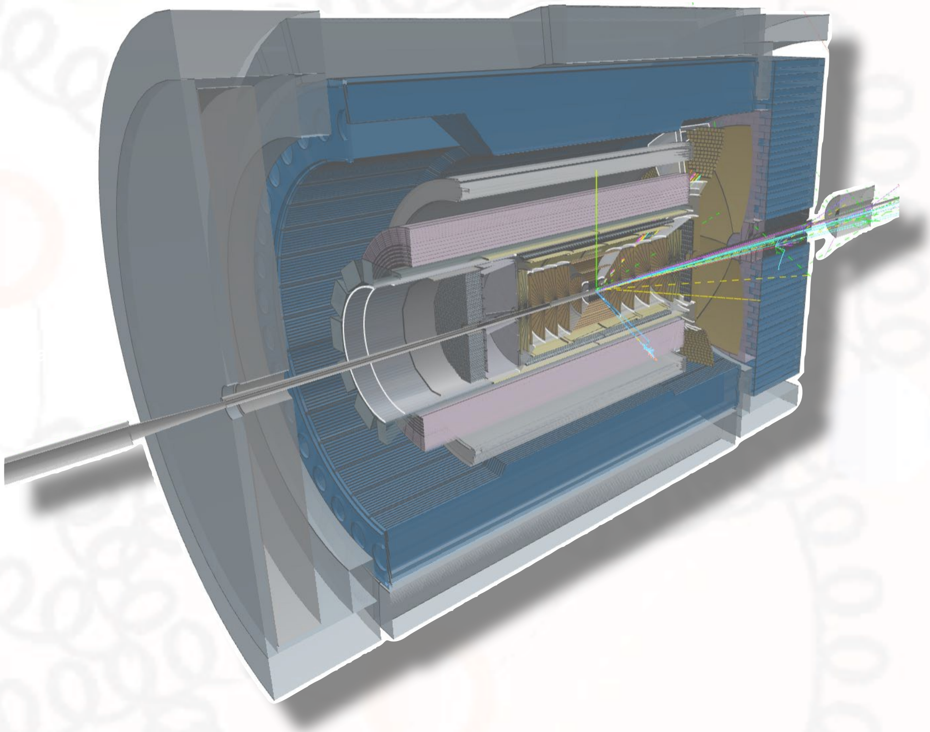
Orientation of Part 1 / Part 2

- Part 1: DIS Basics and Experimental Aspects
- Part 2: EIC Physics and Detector Realization
- Summary



Outline - Part 2

- ☐ Theoretical foundation EIC
- ☐ EIC physics case development
- ☐ Selected EIC Physics Pillars
  - ○ Global properties: Mass & Spin
  - ○ Nucleon 3D structure
  - ○ Low-x physics
- ☐ Experimental Realization
- ☐ Summary

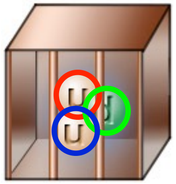


ePIC event display by Dmitry Romanov (JLab)

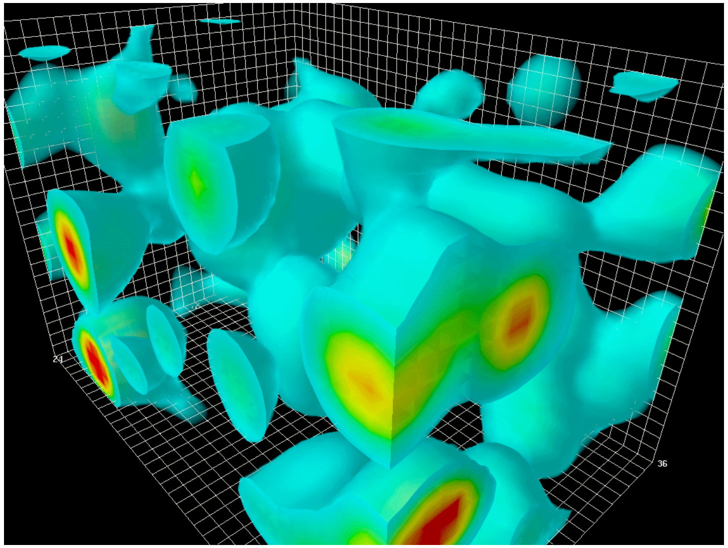
Theoretical foundation

- ☐ EIC - A QCD lab to explore the structure and dynamics of the visible world

$$\mathcal{L}_{QCD} = \sum_{j=1}^{n_f} \bar{\psi}_j \left(i D_\mu \gamma^\mu - m_j \right) \psi_j - \frac{1}{4} \mathrm{Tr}\, G^{\mu\nu} G_{\mu\nu}$$



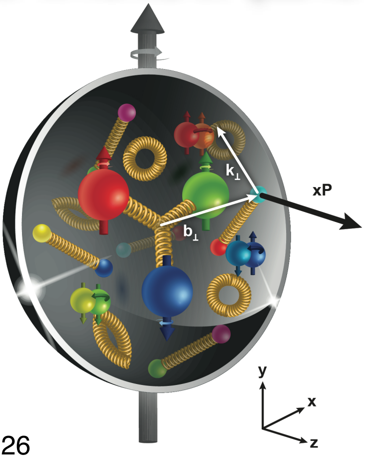
- ○ Interactions arise from fundamental symmetry principles: SU(3)$_c$
- ○ Properties of visible universe such as mass and spin (e.g. proton): Emergent through complex structure of the QCD vacuum



D. Leinweber: Quantum fluctuations in gluon fields

Major goal:

Understanding QCD interactions and emergence of hadronic and nuclear matter in terms of quarks and gluons



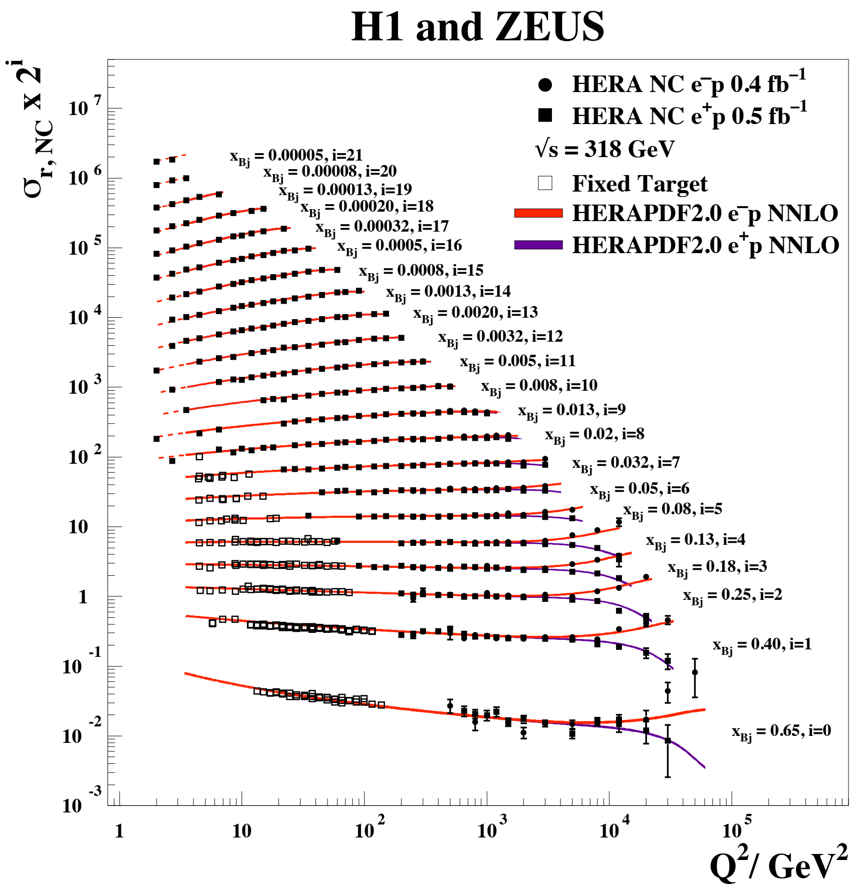
Essential elements looking forward:

1) Tomography of hadrons and nuclear matter in terms of quarks and gluons
2) Synergy of experimental progress and theory

Theoretical foundation

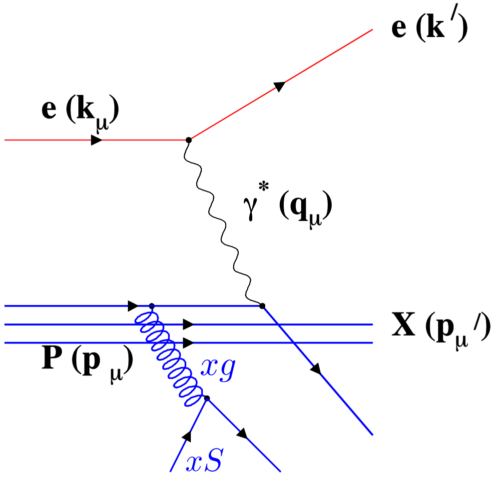
☐ DIS - Parton structure: Unpolarized

H1 and ZEUS Collaborations (H. Abramowicz et al.), Eur.Phys.J. C75 (2015) no.12, 580.

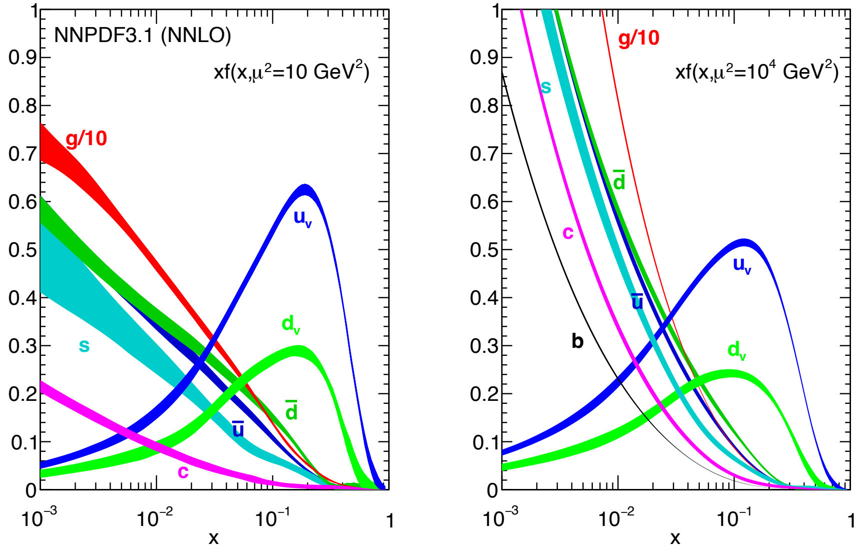


$$d\sigma_{eP} \propto F_2^P = \sum_i e_i^2 \, x \, (q_i + \bar{q}_i)$$

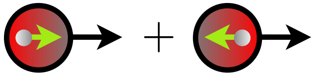
1990: J. I. Friedman, H. W. Kendall and R. E. Taylor: “for their pioneering investigations concerning deep inelastic scattering of electrons on protons and bound neutrons, which have been of essential importance for the development of the quark model in particle physics.”



R. D. Ball et al., EPJ C77 (2017) 663.



$f(x) =$



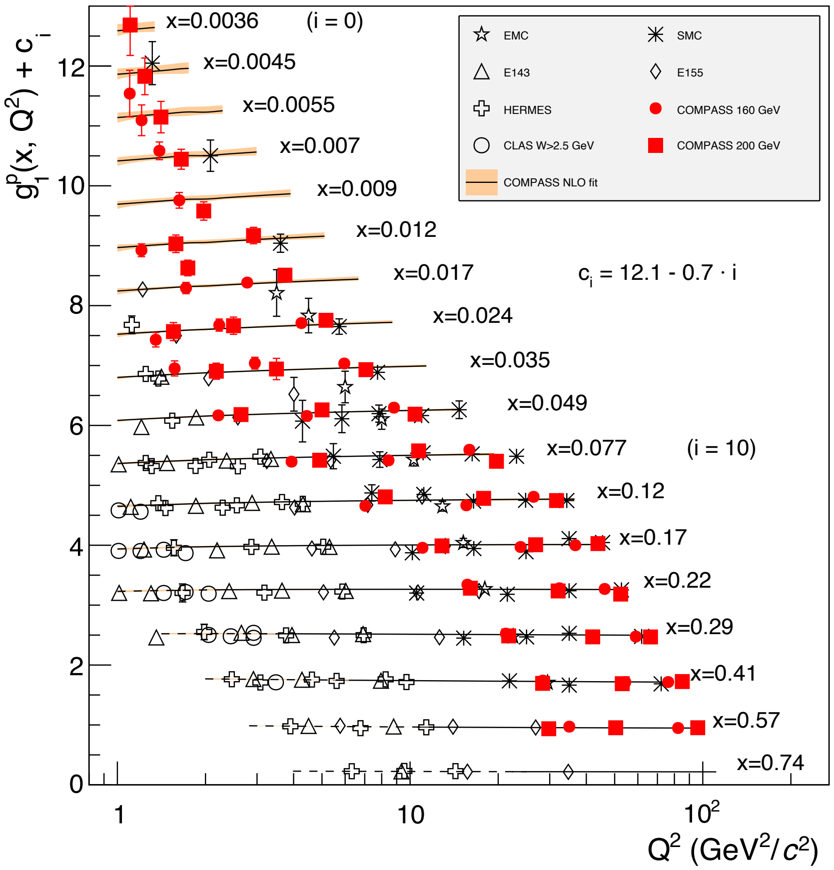
$$\underbrace{f^{+}(x) + f^{-}(x)}$$

Measure of probability to find parton f with longitudinal momentum fraction x

Theoretical foundation

☐ DIS - Parton structure: Polarized

COMPASS Collaboration (C. Adolph et al.), Phys.Lett. B753 (2016) 18.



$$g_1^P = \frac{1}{2}\sum_i e_i^2\left(\Delta q_i + \Delta\bar{q}_i\right)$$

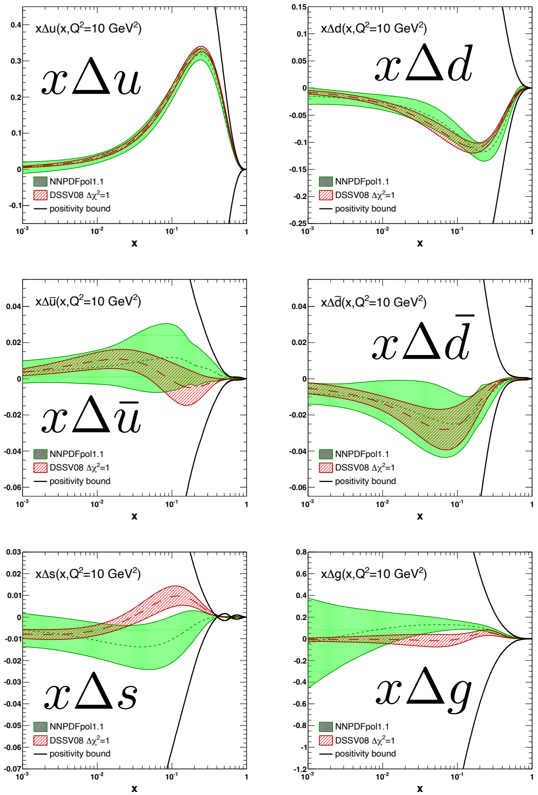
$$\boxed{\frac{1}{2} = \overbrace{\langle S_q \rangle}^{\frac{1}{2}\Delta\Sigma} + \underbrace{\langle S_g \rangle}_{\Delta G} + \langle L_q \rangle + \langle L_g \rangle}$$

(R.L. Jaffe and A. Manohar, Nucl. Phys. B337, 509 (1990))

$$\Delta\Sigma = \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}$$

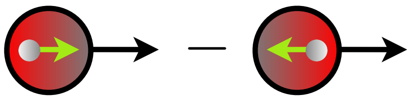
$$\Delta q_i(Q^2) = \int_0^1 \Delta q_i(x, Q^2)dx$$

$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2)dx$$



NNPDF Collaboration (Emanuele R. Nocera et al.), Nucl.Phys. B887 (2014) 276-308

$$\Delta f(x) =$$



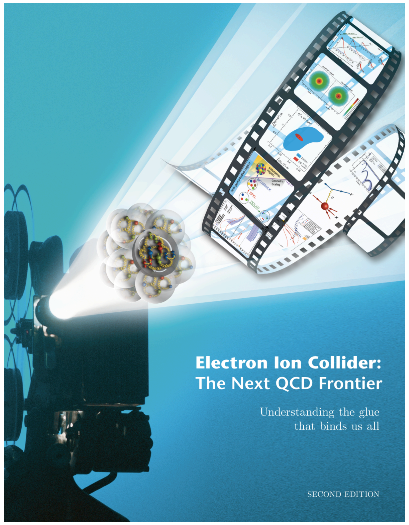
$$\underbrace{f^+(x) - f^-(x)}$$

Measure of probability to find parton f with spin aligned to anti-anti-aligned to proton spin at momentum fraction x

EIC physics case development

- Critical steps over the last couple of years - 1
  - INT Workshop series / Documentation of Physics Case - Whitepaper: "Understanding the glue that binds us all!"
    - INT Workshop: 2010
    - WP: 2012, updated in 2014 for LRP
  - 2015 Long-range plan (LRP):

arXiv:1212.1701

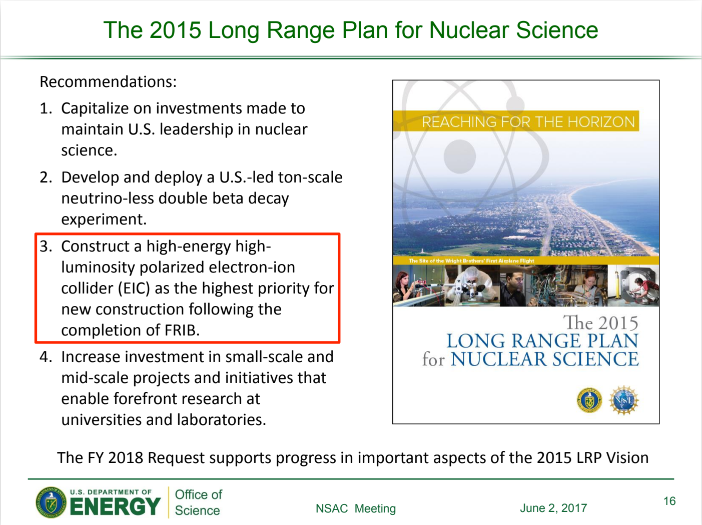

Electron Ion Collider: The Next QCD Frontier

Understanding the glue that binds us all

SECOND EDITION

Understanding the glue that binds as all!

T. Hallman


The 2015 Long Range Plan for Nuclear Science

Recommendations:

1. Capitalize on investments made to maintain U.S. leadership in nuclear science.
2. Develop and deploy a U.S.-led ton-scale neutrino-less double beta decay experiment.
3. Construct a high-energy high-luminosity polarized electron-ion collider (EIC) as the highest priority for new construction following the completion of FRIB.
4. Increase investment in small-scale and mid-scale projects and initiatives that enable forefront research at universities and laboratories.

REACHING FOR THE HORIZON

The 2015 LONG RANGE PLAN for NUCLEAR SCIENCE

The FY 2018 Request supports progress in important aspects of the 2015 LRP Vision

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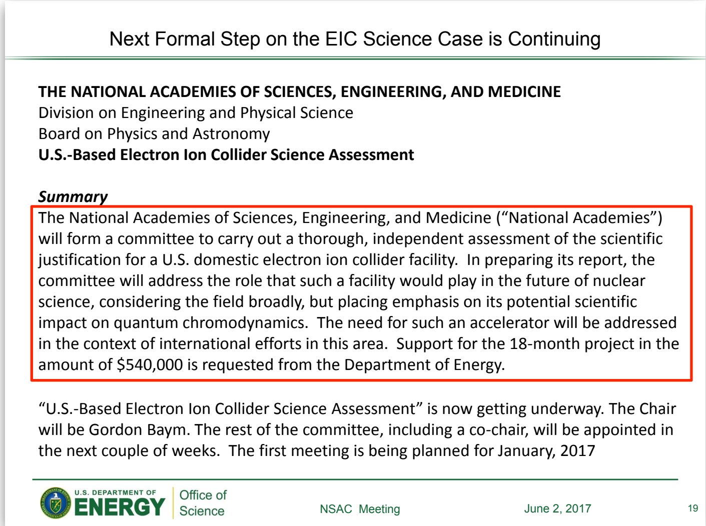
T. Hallman


Next Formal Step on the EIC Science Case is Continuing

THE NATIONAL ACADEMIES OF SCIENCES, ENGINEERING, AND MEDICINE
Division on Engineering and Physical Science
Board on Physics and Astronomy
U.S.-Based Electron Ion Collider Science Assessment

Summary

The National Academies of Sciences, Engineering, and Medicine ("National Academies") will form a committee to carry out a thorough, independent assessment of the scientific justification for a U.S. domestic electron ion collider facility. In preparing its report, the committee will address the role that such a facility would play in the future of nuclear science, considering the field broadly, but placing emphasis on its potential scientific impact on quantum chromodynamics. The need for such an accelerator will be addressed in the context of international efforts in this area. Support for the 18-month project in the amount of $540,000 is requested from the Department of Energy.

"U.S.-Based Electron Ion Collider Science Assessment" is now getting underway. The Chair will be Gordon Baym. The rest of the committee, including a co-chair, will be appointed in the next couple of weeks. The first meeting is being planned for January, 2017

U.S. DEPARTMENT OF ENERGY | Office of Science NSAC Meeting June 2, 2017 19

-
  - Request to review EIC Science Case by National Academy of Sciences, Engineering, and Medicine (NAS)

EIC physics case development

- NAS Webinar and NAS report release: 07/24/2018

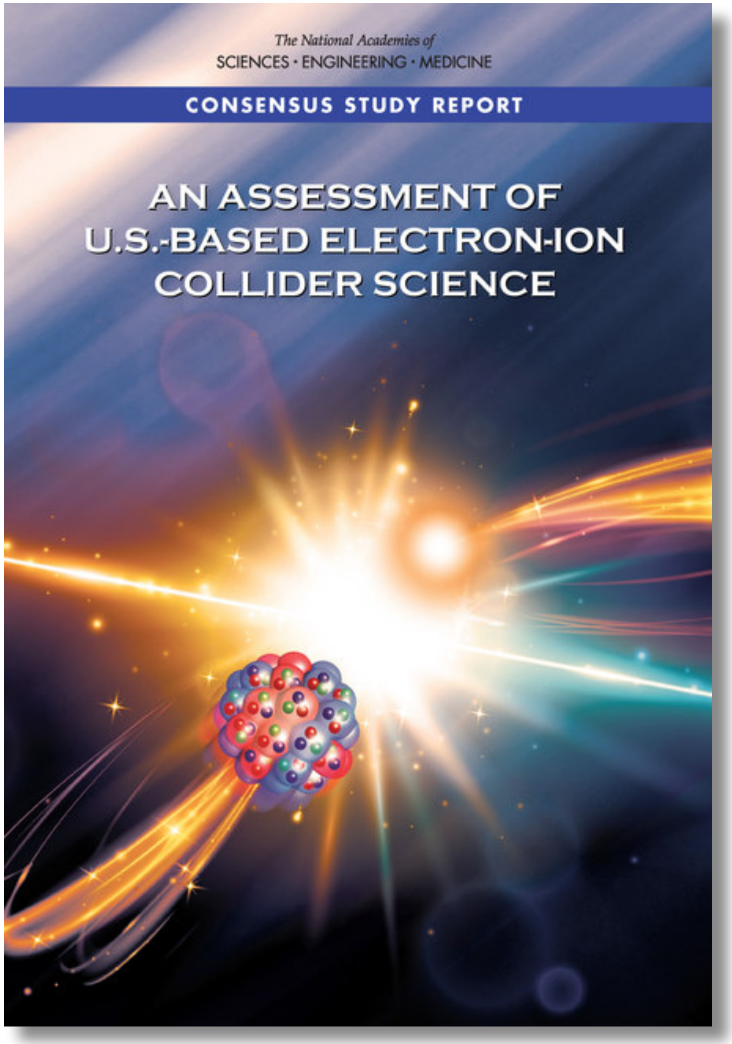
https://www.nap.edu/catalog/25171/an-assessment-of-us-based-electron-ion-collider-science

- Webinar on Tuesday, July 24, 2018 - Public presentation and report release
- Gordon Baym (Co-chair): Webinar presentation

> "The committee finds that the science that can be addressed by an EIC is compelling, fundamental and timely."

- Slides from Webinar: https://www.nap.edu/resource/25171/eic-public-briefing-slides.pdf
- Glowing" report on a US-based EIC facility!

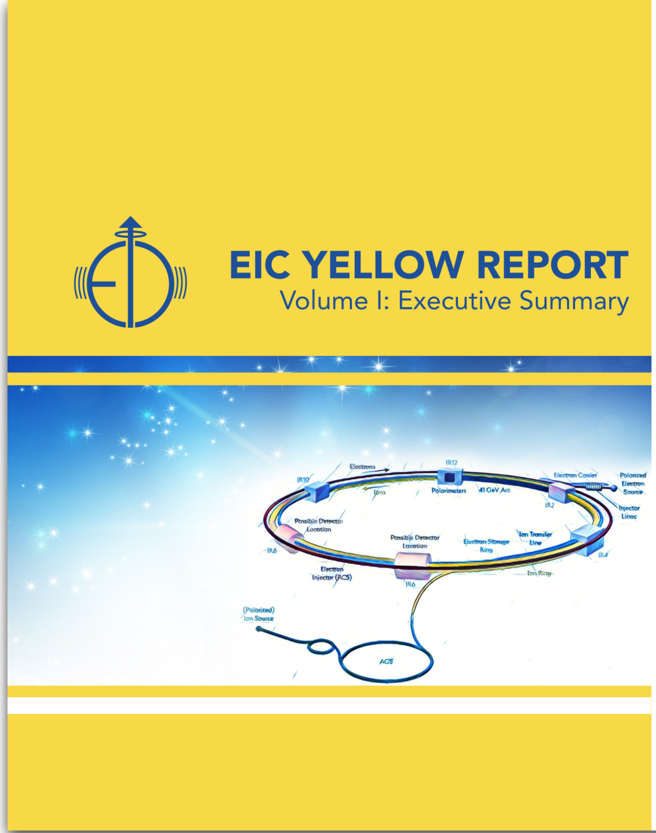
Download pdf-file of final report!

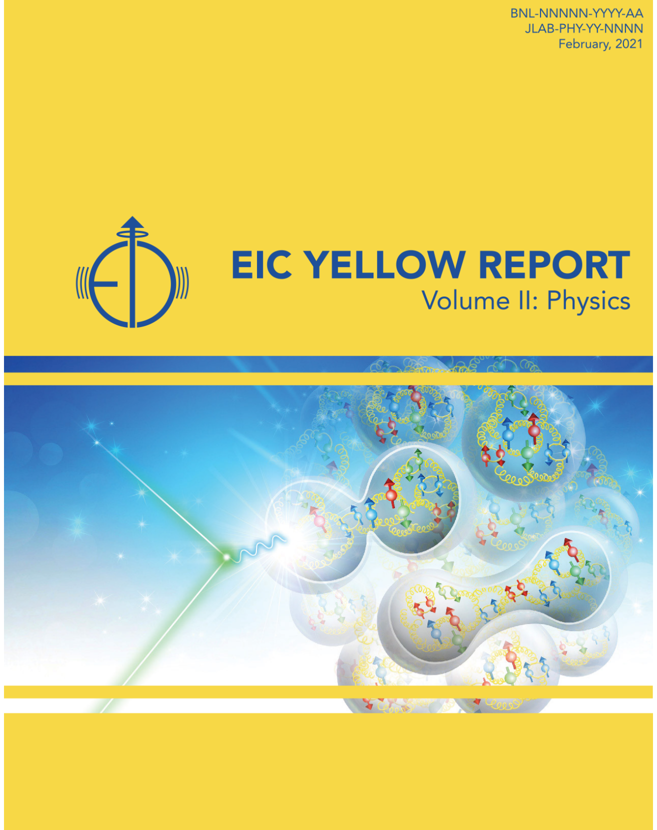


EIC physics case development

- ☐ Volume 1-3: Executive Summary / Physics / Detector

arXiv:2103.05419


EIC YELLOW REPORT
Volume I: Executive Summary


BNL-NNNNN-YYYY-AA
JLAB-PHY-YY-NNNN
February, 2021

EIC YELLOW REPORT
Volume II: Physics

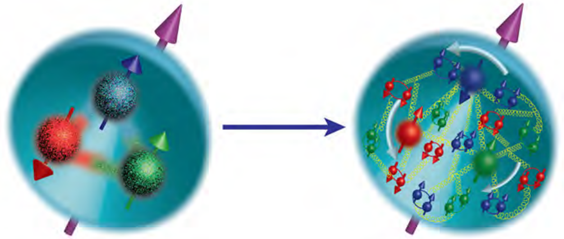

BNL-NNNNN-YYYY-AA
JLAB-PHY-YY-NNNN
February, 2021

EIC YELLOW REPORT
Volume III: Detector

- ○ ~400 authors / ~150 institutions / ~900 pages with strong international contributions!
- ○ Review: Community review within EICUG and external readers (~30) worldwide covering physics and detector expert fields!
- ○ Available on archive: Nucl. Phys. A 1026 (2022) 122447 / https://arxiv.org/abs/2103.05419

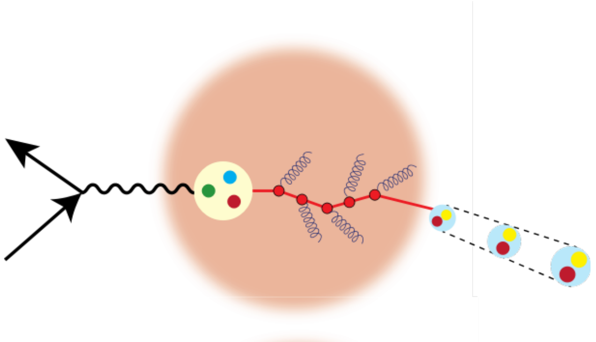
EIC Physics Pillars

☐ Motivation - EIC program



How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?

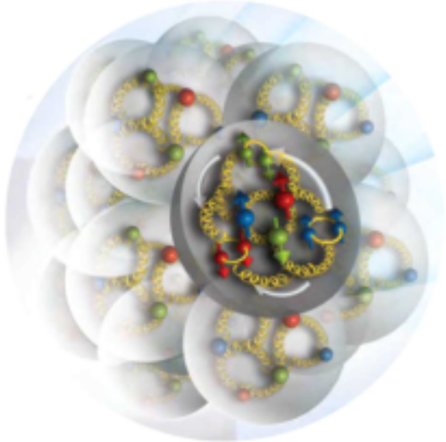
How do the nucleon properties emerge from them and their interactions?



How do color-charged quarks and gluons, and colorless jets, interact with a nuclear medium?

How do the confined hadronic states emerge from these quarks and gluons?

How do the quark-gluon interactions create nuclear binding?



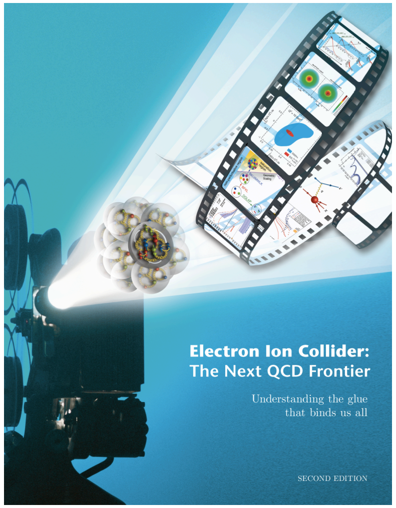
How does a dense nuclear environment affect the quarks and gluons, their correlations, and their interactions?

What happens to the gluon density in nuclei? Does it saturate at high energy, giving rise to a gluonic matter with universal properties in all nuclei, even the proton?

EIC Physics Pillars

- ☐ EIC: Study structure and dynamics of matter at high luminosity, high energy with polarized beams and wide range of nuclei
- ☐ Whitepaper:

arXiv:1212.1701

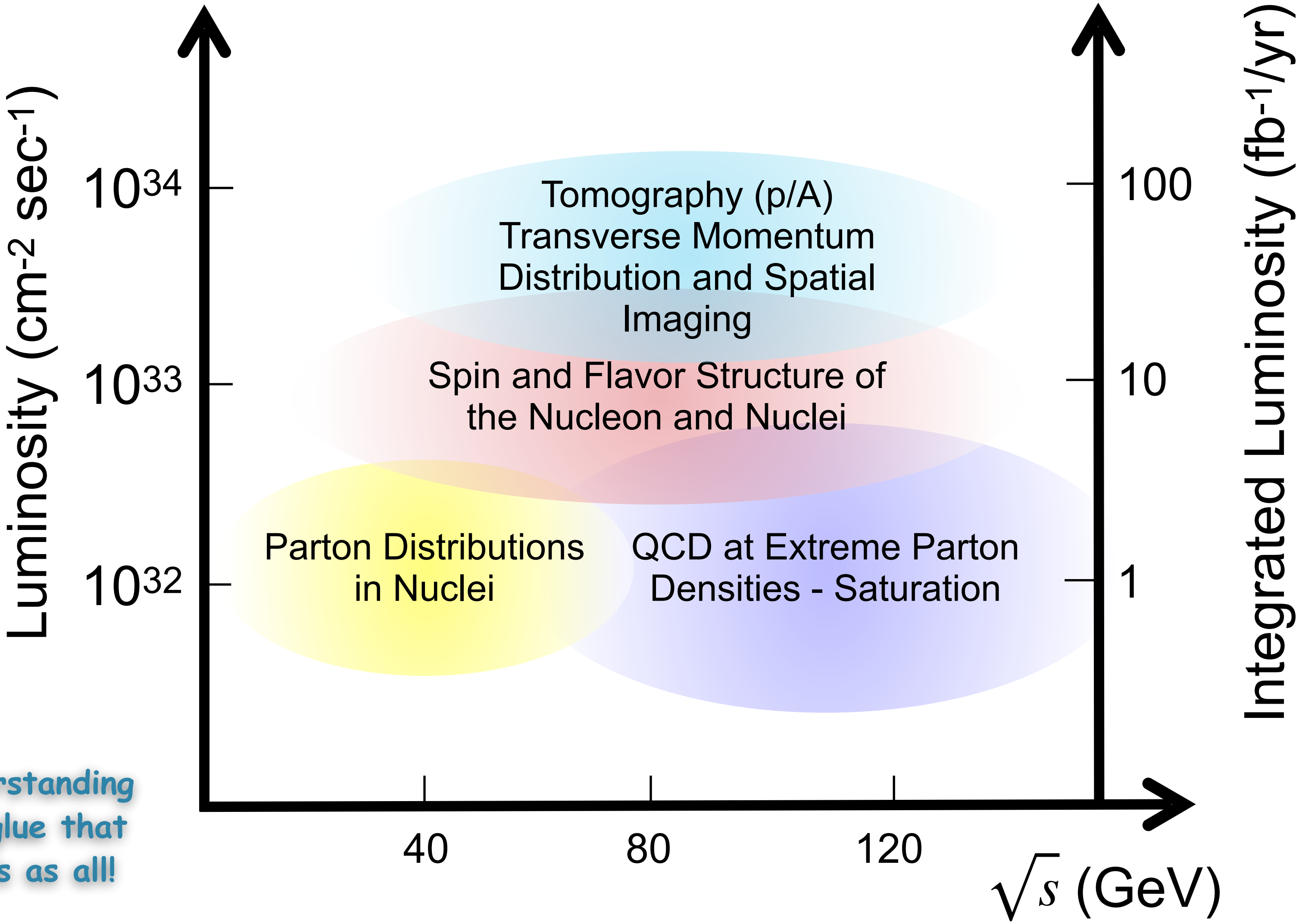


Electron Ion Collider: The Next QCD Frontier

Understanding the glue that binds us all

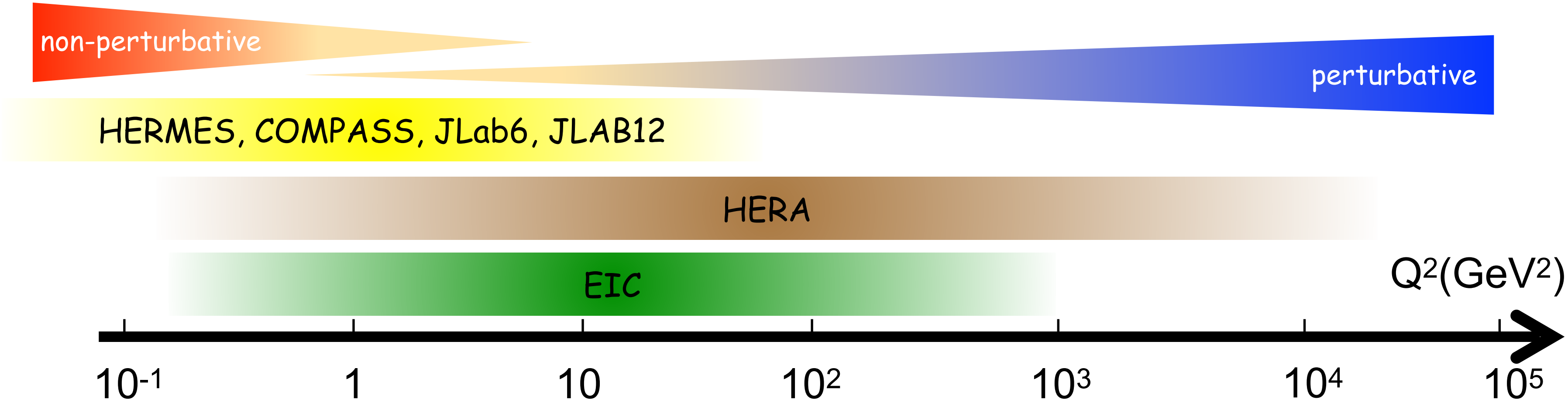
SECOND EDITION

Understanding the glue that binds as all!



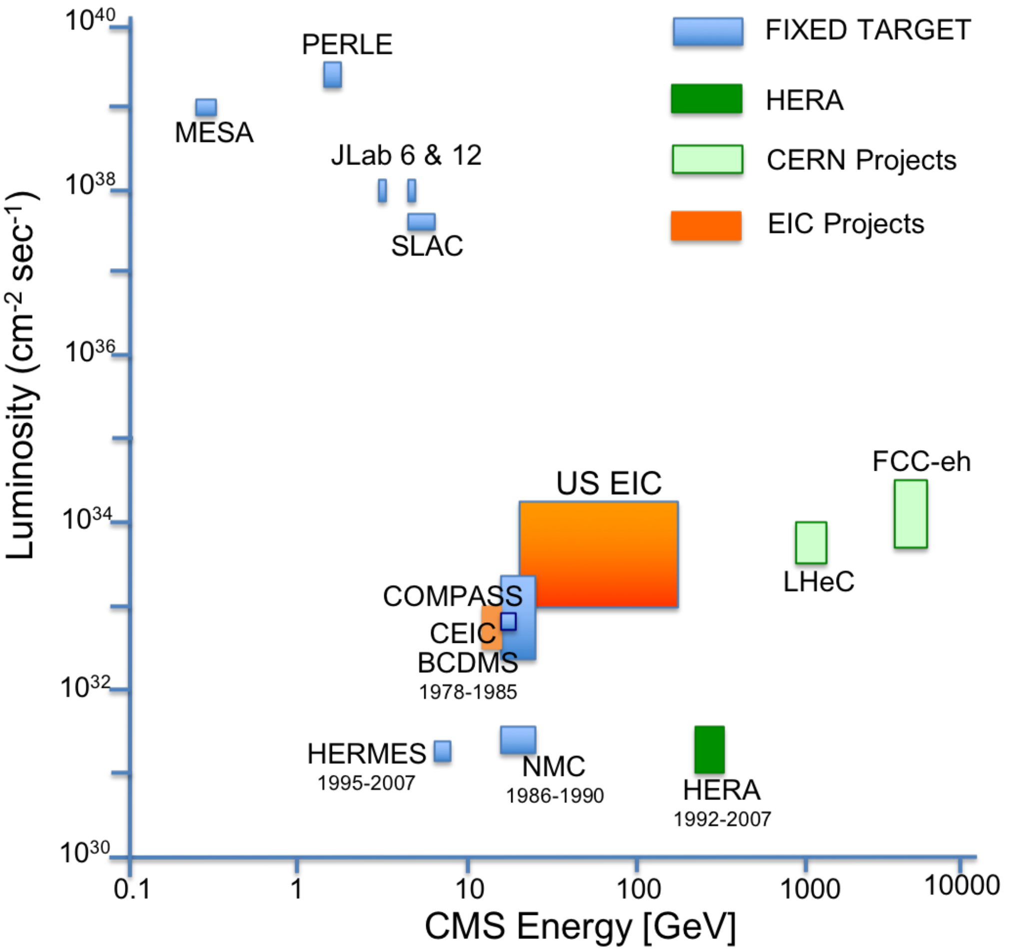
EIC Physics Pillars

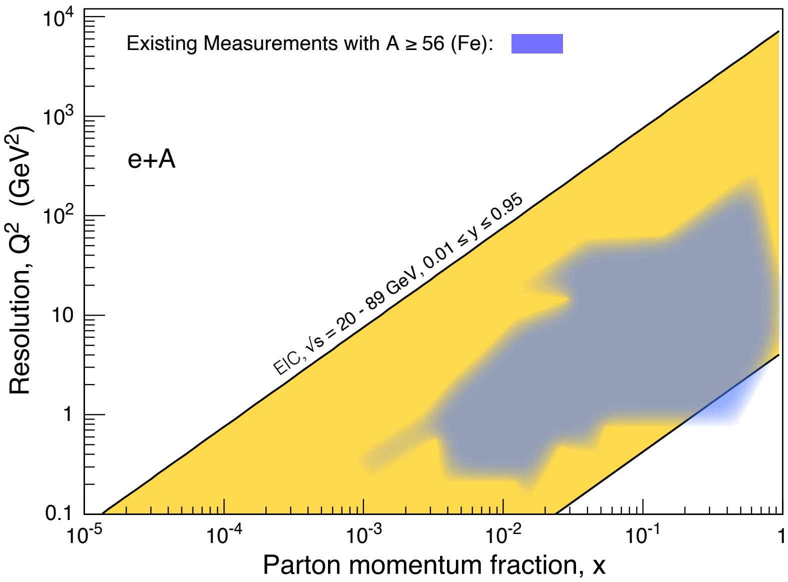
- Requirements
  - Machine:
    - High luminosity: $10^{33}\text{cm}^{-2}\text{s}^{-1}$ - $10^{34}\text{cm}^{-2}\text{s}^{-1}$ / 10-100 fb^{-1}/year
    - Flexible center-of-mass energy $\sqrt{s} = \sqrt{4\,E_e\,E_p}$: Wide kinematic range $Q^2 = s\,x\,y$
    - Highly polarized electron (0.7) and proton / light ion (0.7) beams: Spin structure studies
    - Wide range of nuclear beams (d to Pb/U): High gluon density
  - Detector:
    - Wide acceptance detector system including particle ID (e/h separation & π, K, p ID - flavor tagging)
    - Instrumentation for tagging of protons from elastic reactions and neutrons from nuclear breakup: Target / nuclear fragments in addition to low Q^2 tagger / polarimetry and luminosity (abs. and rel.) measurement



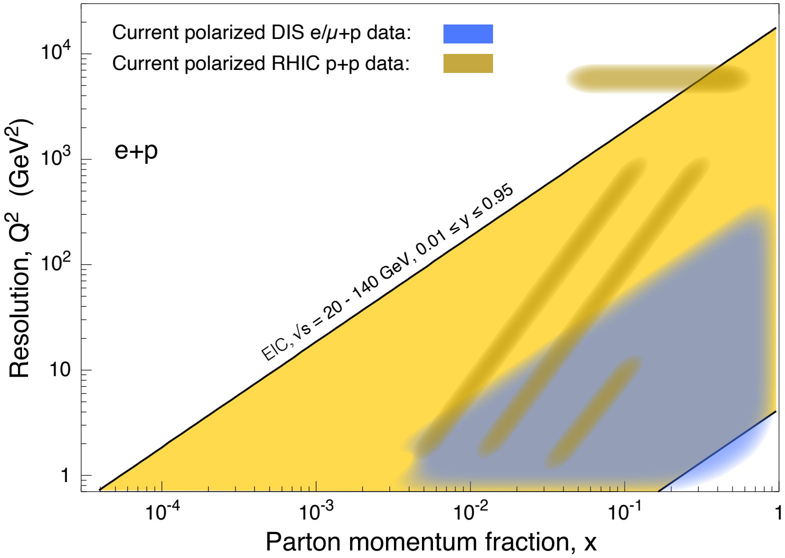
EIC Physics Pillars

- Luminosity / $\sqrt{s}$ / Kinematic coverage





eA



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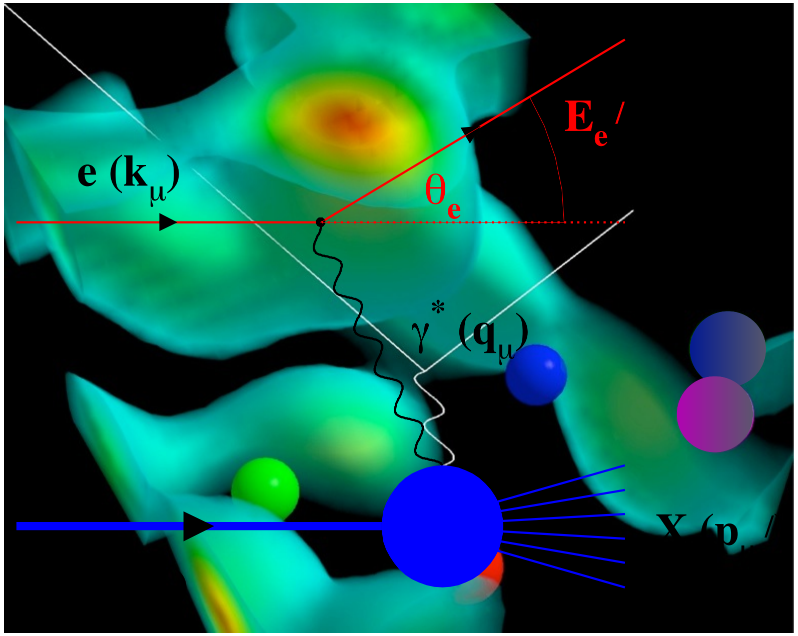
EIC Physics Pillars

☐ DIS - Kinematics

$$k = \begin{pmatrix} E_e \\ 0 \\ 0 \\ -E_e \end{pmatrix}$$

$$p = \begin{pmatrix} E_P \\ 0 \\ 0 \\ E_P \end{pmatrix}$$



$$k' = \begin{pmatrix} E'_e \\ E'_e \, \sin\theta'_e \, \cos\phi'_e \\ E'_e \, \sin\theta'_e \, \sin\phi'_e \\ E'_e \, \cos\theta'_e \end{pmatrix}$$

$$p' = \begin{pmatrix} \sum_h E_h \\ \sum_h p_{X,h} \\ \sum_h p_{Y,h} \\ \sum_h p_{Z,h} \end{pmatrix}$$

$$Q^2 = -(k-k')^2 = -q^2$$

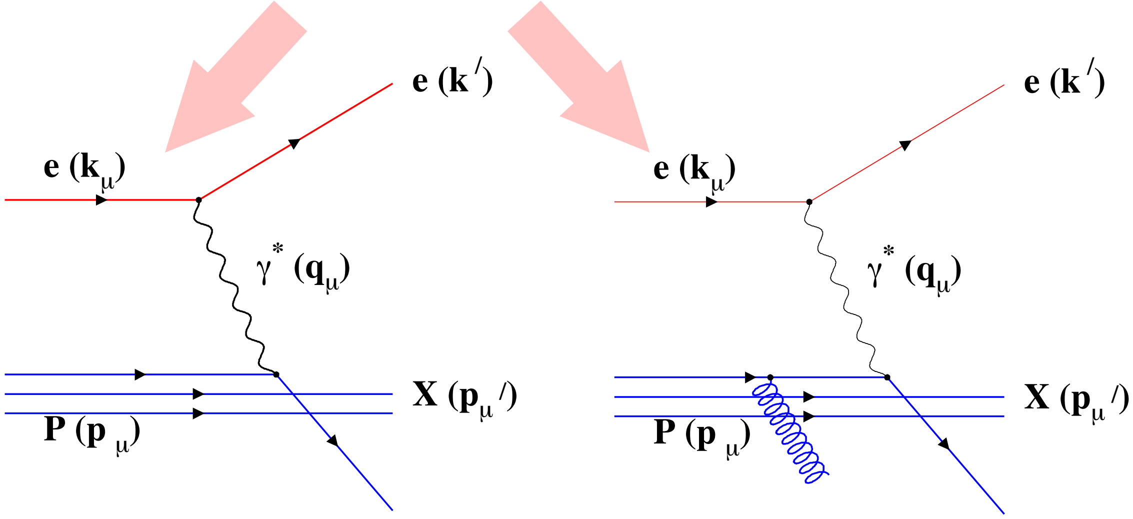
Measure of resolution power

$$x = \frac{Q^2}{2(p \cdot q)}$$

Measure of momentum fraction by struck quark

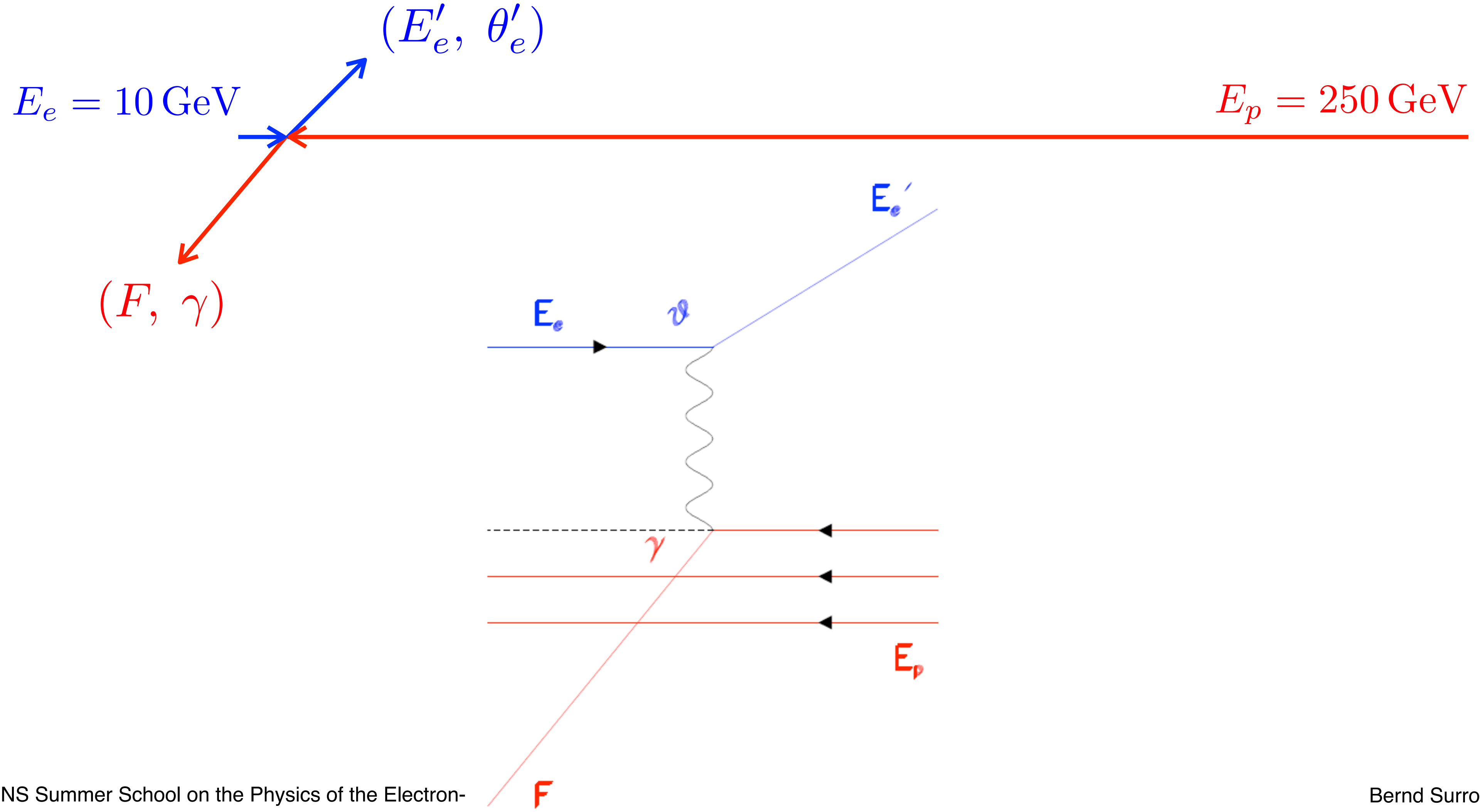
$$y = \frac{p \cdot q}{p \cdot k}$$

Measure of inelasticity



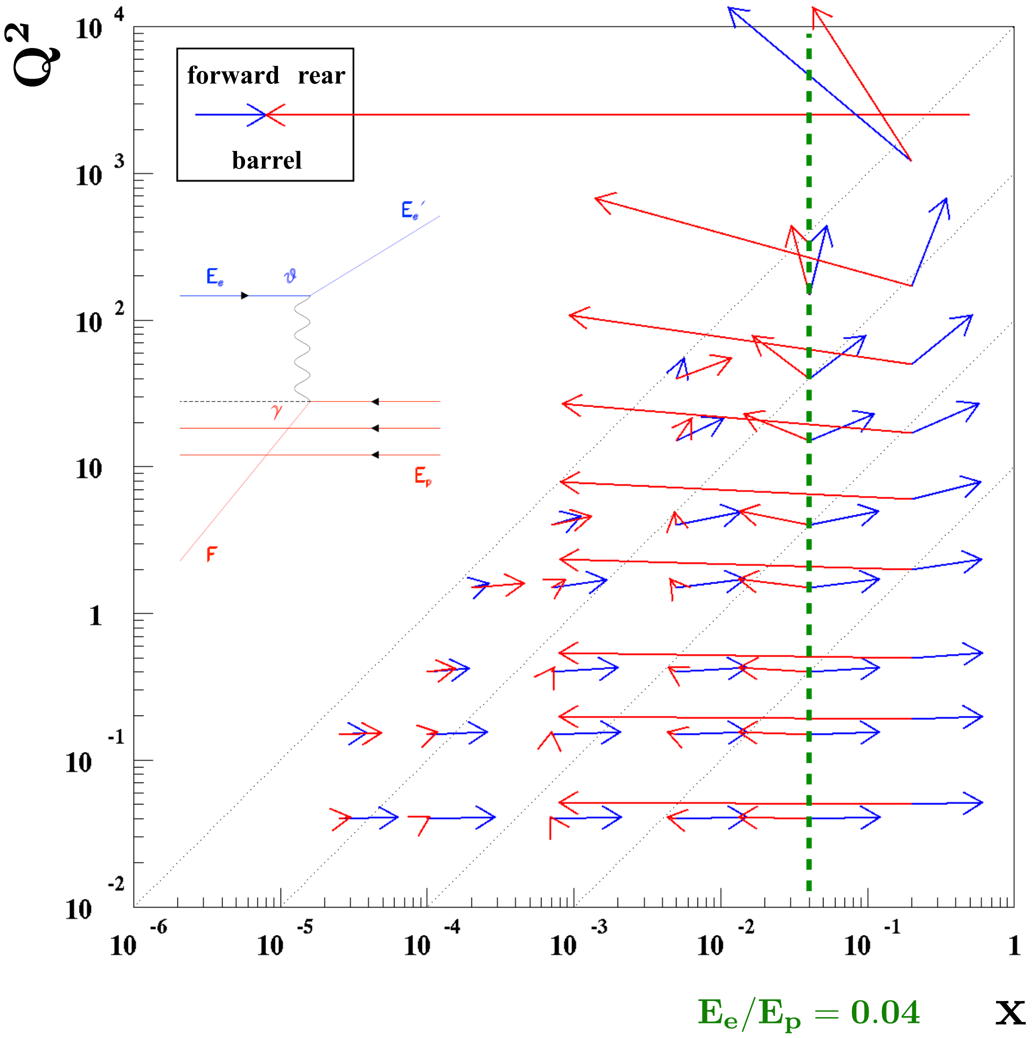
EIC Physics Pillars

- EIC kinematic considerations: E_e=10GeV X E_p=250GeV ($\sqrt{s}$=100GeV)



EIC Physics Pillars

- EIC kinematic considerations: E_e=10GeV X E_p=250GeV (√s=100GeV)



Kinematic peak location!

EIC Physics Pillars

- EIC kinematic considerations: E_e=10GeV X E_p=250GeV ($\sqrt{s}$=100GeV)

$$Q^2[x,E'_e] = \frac{xs\left(1-\frac{E'_e}{E_e}\right)}{1-\frac{xs}{4E_e^2}}$$

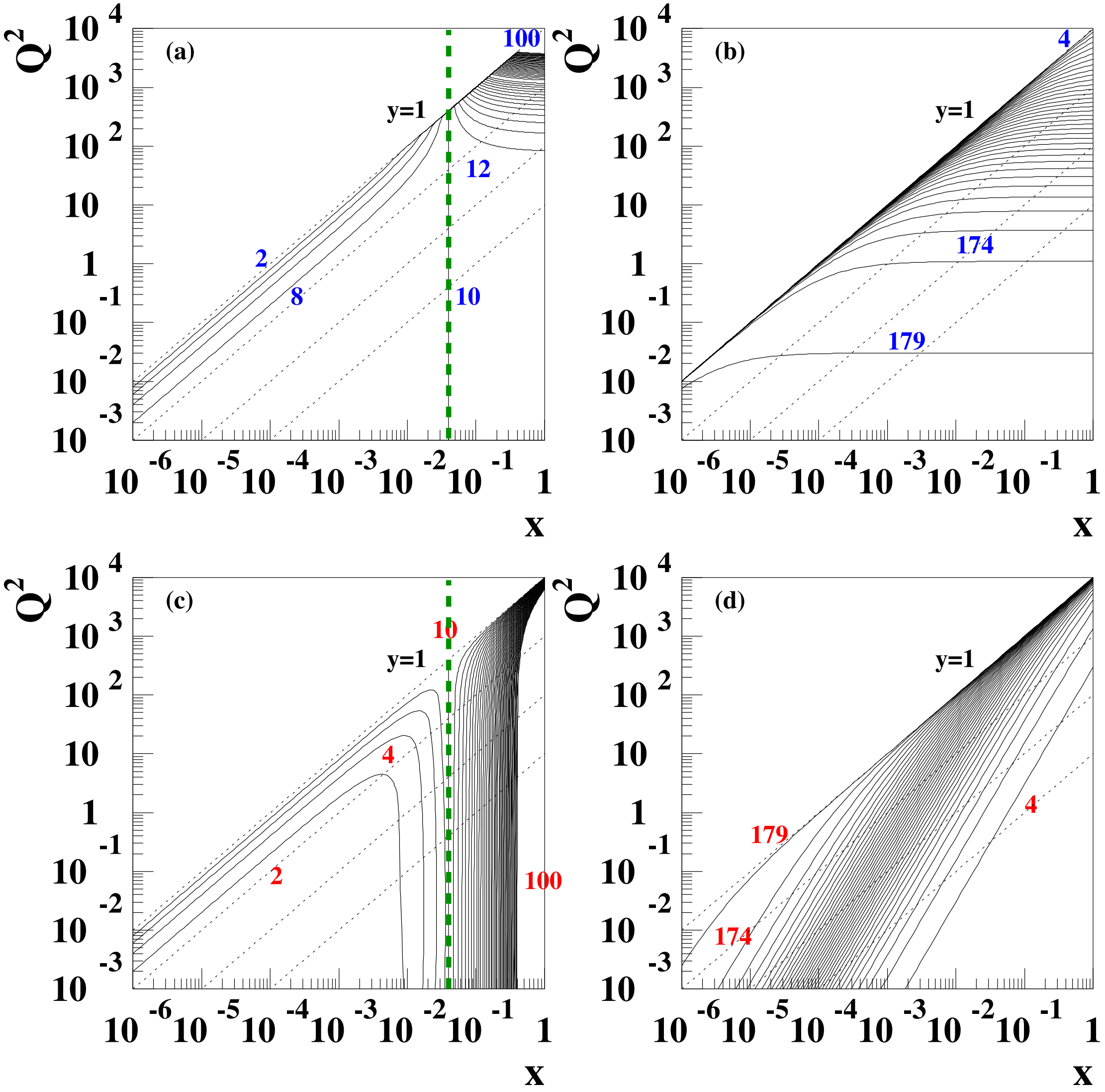
Fixed E'_e

2GeV steps:
2GeV-100GeV

$$Q^2[x,\theta'_e] = \frac{xs}{\frac{xs}{4E_e^2}\tan^2\frac{\theta'_e}{2}+1}$$

Fixed θ'_e

5° steps: 4°-179°



Fixed F

2GeV steps:
2GeV-100GeV

$$Q^2[x,F] = \frac{4E_eF - sx}{\frac{4E_e^2}{sx}-1}$$

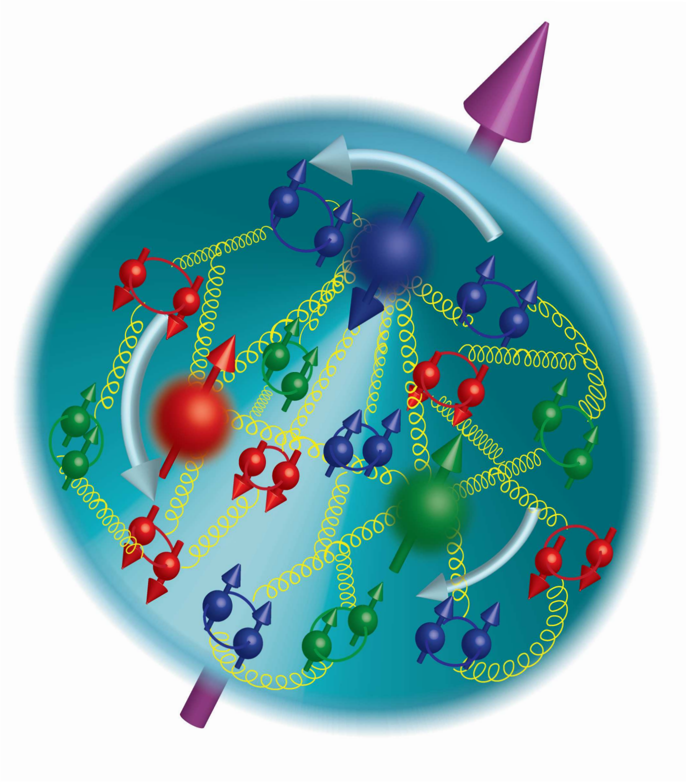
Fixed γ

5° steps:
4°-179°

$$Q^2[x,\gamma] = \frac{sx}{\frac{4E_e^2}{sx}\cot^2\frac{\gamma}{2}+1}$$

EIC Physics Pillars

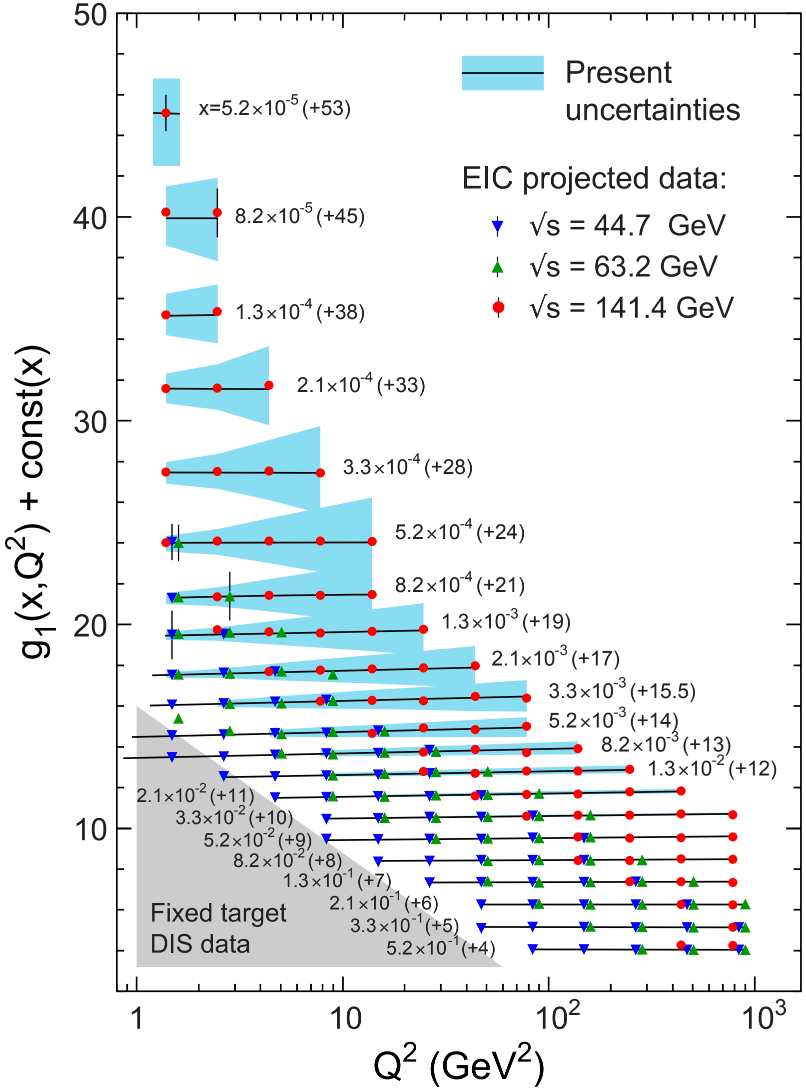
Global properties: Spin

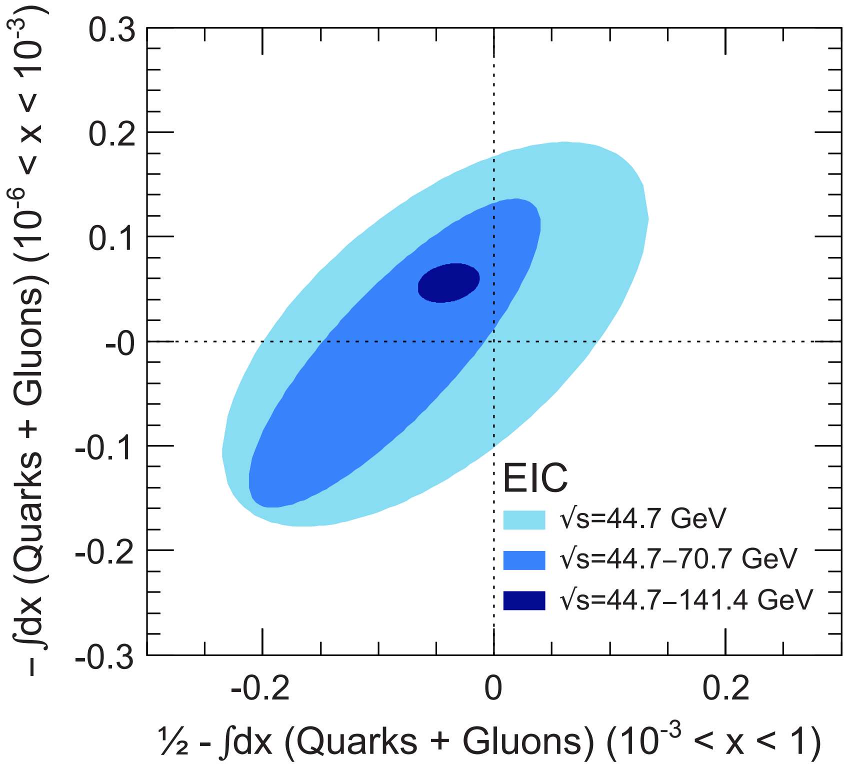


EIC Physics Pillars

- ☐ Spin and Flavor Structure of the Nucleon

arXiv:1708.01527



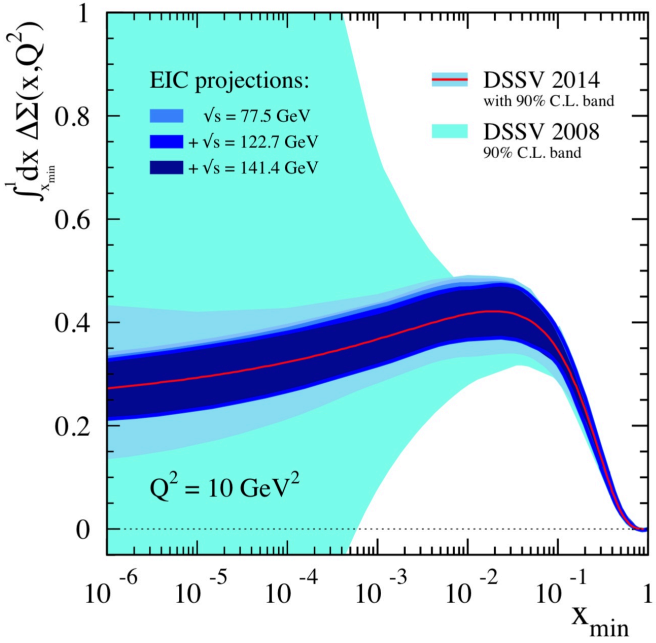


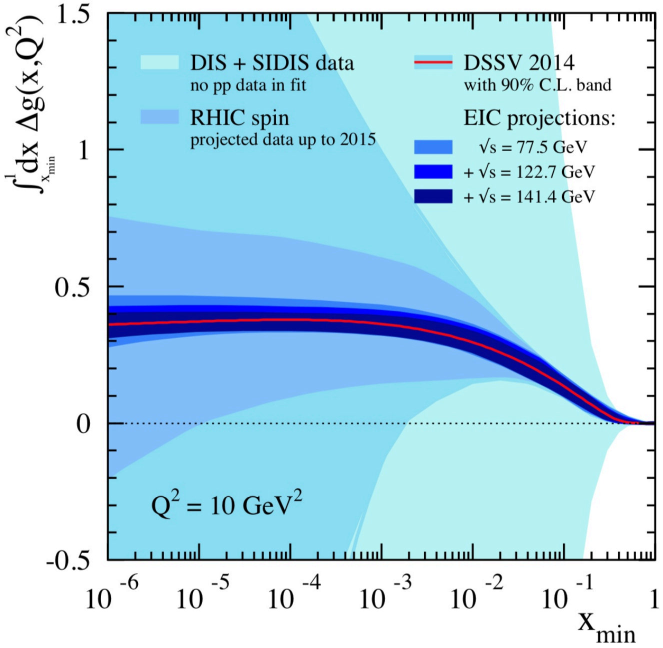
- ○ g_1 stat. uncertainty projections for $10 fb^{-1}$ for range of CME in comparison to DSSV14 predictions incl. uncertainties
- ○ EIC impact on the knowledge of the integral of the quark + gluon spin contribution vs. orbital angular momentum

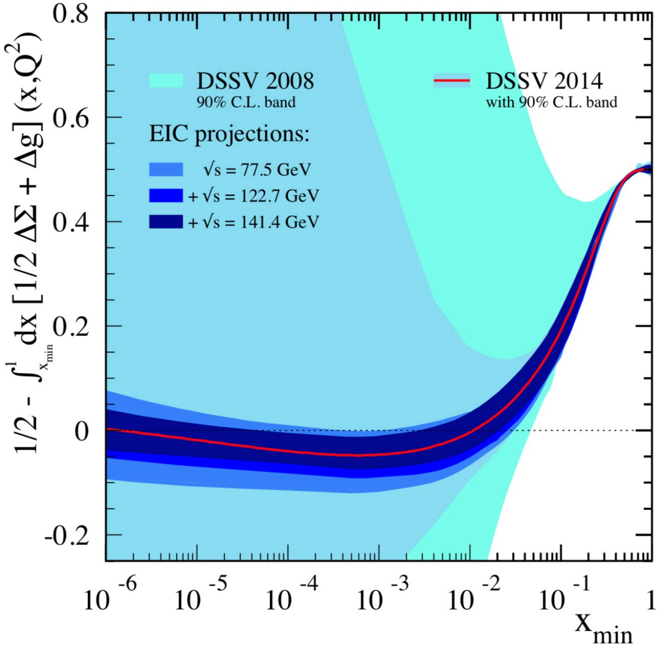
EIC Physics Pillars

- Impact on proton spin

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







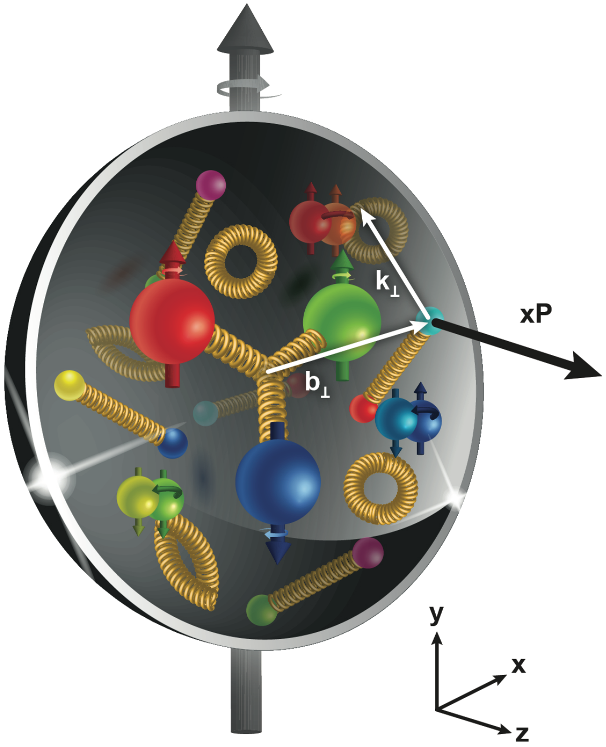
Quark Spin

Gluon Spin

Orbital Angular Momentum

EIC Physics Pillars

Nucleon 3D structure



EIC Physics Pillars

☐ Transverse Momentum Distribution and Spatial Imaging

arXiv:1212.1701

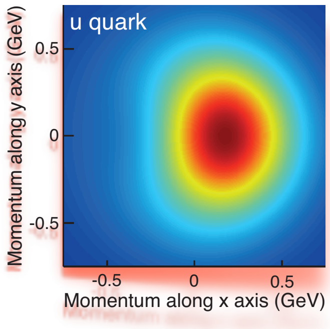
$f(x,k_T)$ 1+2D $\int d^2b_T$ $W(x,b_T,k_T)$ $\int d^2k_T$ $f(x,b_T)$ 1+2D

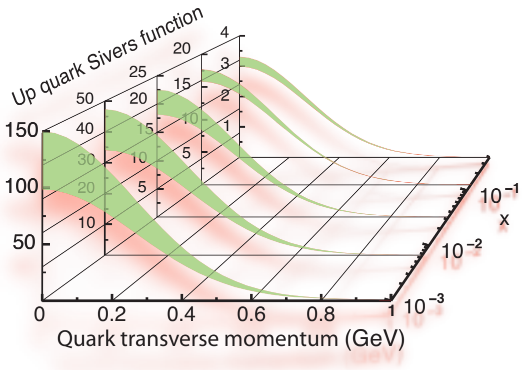
Transverse Momentum Distribution (TMD)

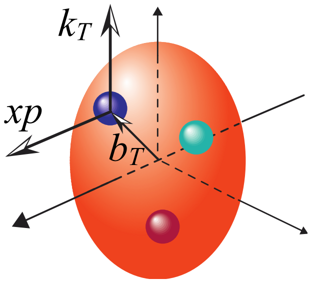
Wigner Distribution

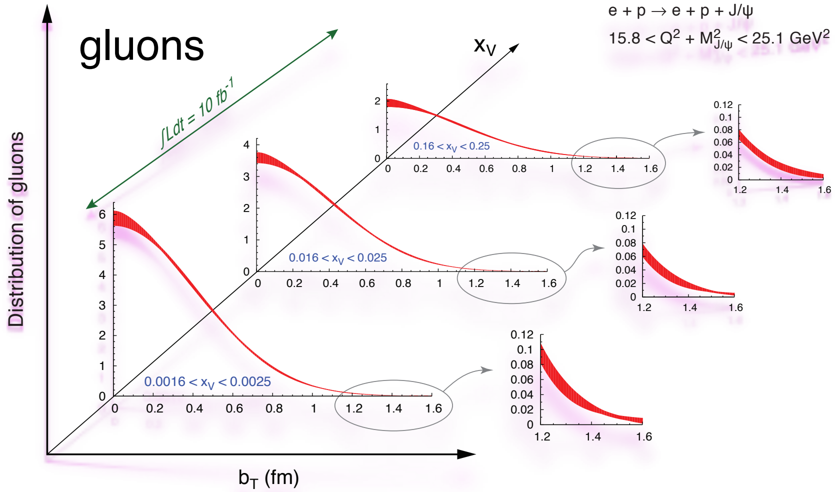
Impact Parameter Distribution

quarks









- ○ Spin-dependent 1+2D momentum space (transverse) images from semi-inclusive scattering
- ○ Spin-dependent 1+2D impact parameter (transverse) images from exclusive scattering

Fourier transf.
$b_T \longleftrightarrow \Delta$: $t = -\Delta^2$

$H(x,0,t)$

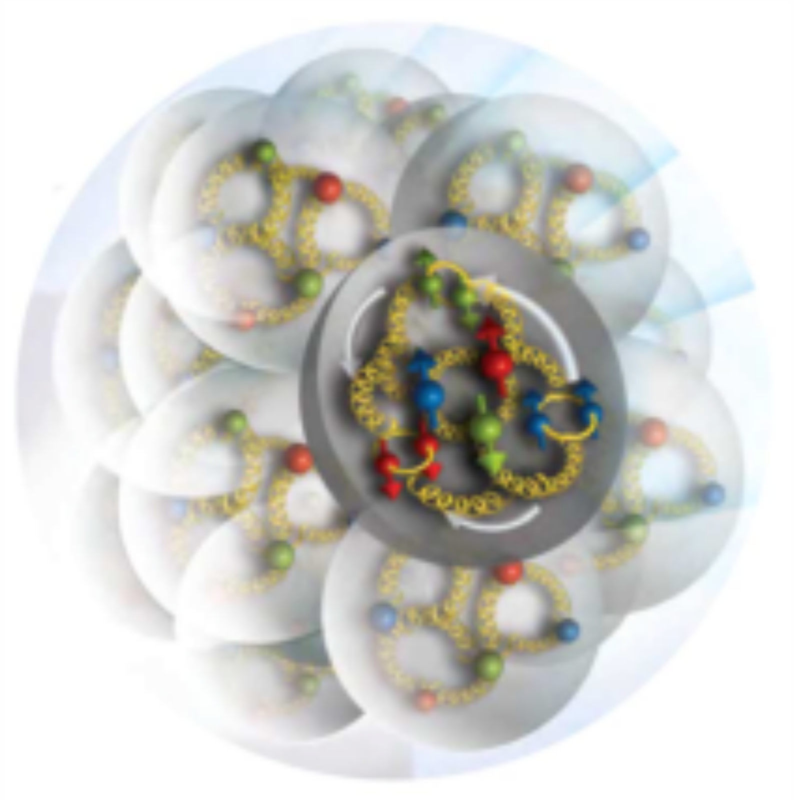
$\xi = 0$

$H(x,\xi,t)$

Generalized Parton Distribution (GPD)

EIC Physics Pillars

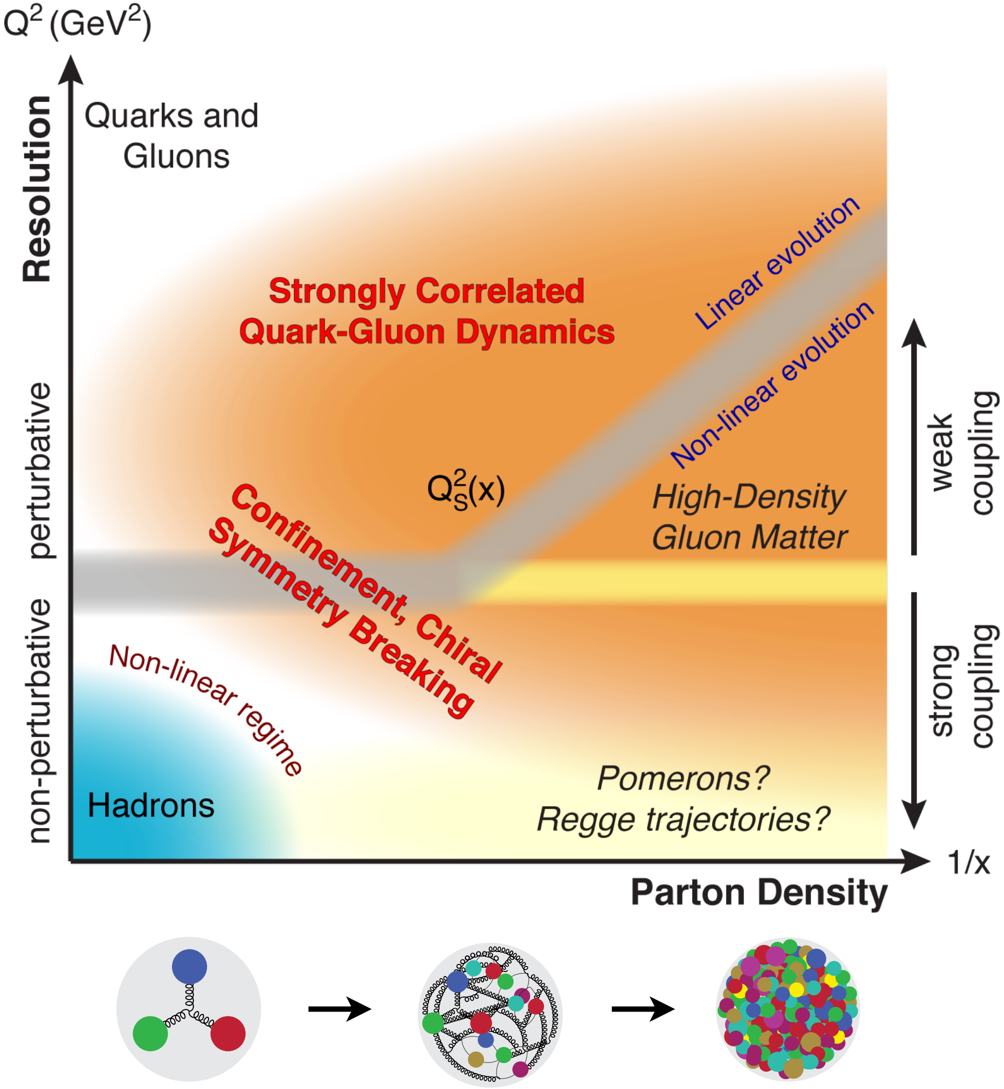
Low-x physics



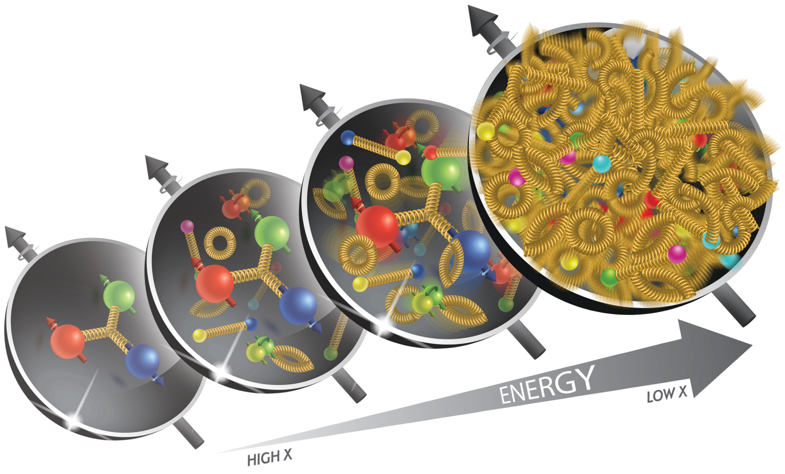
EIC Physics Pillars

- QCD dynamics

arXiv:1708.01527



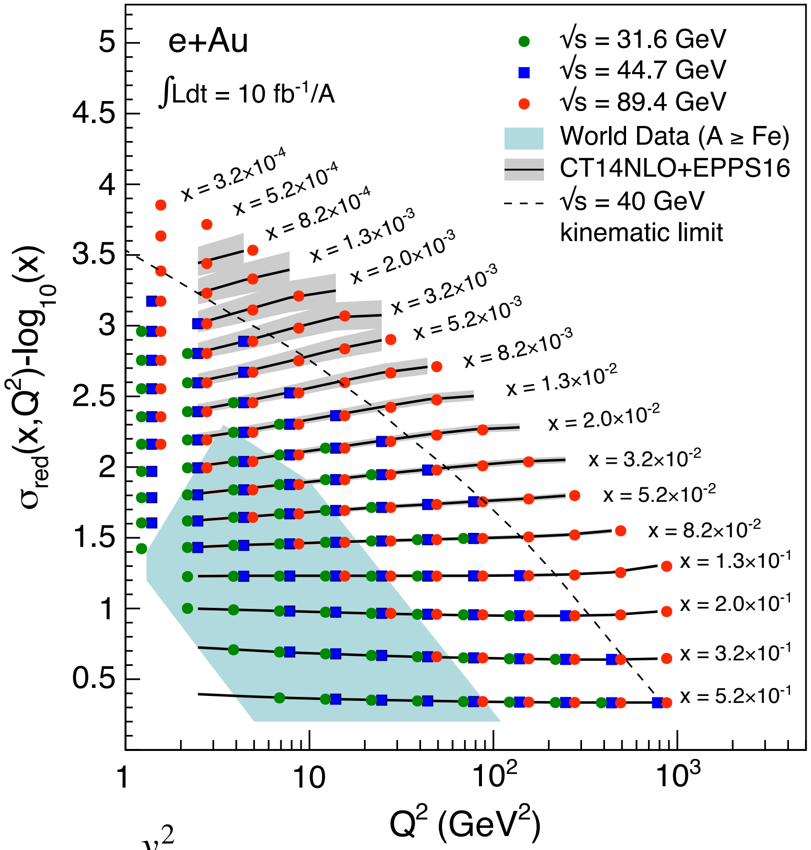
- Explore QCD landscape in various aspects over a wide range in x and Q^2
- Heavy nuclei at high energy critical to explore high-density gluon matter!

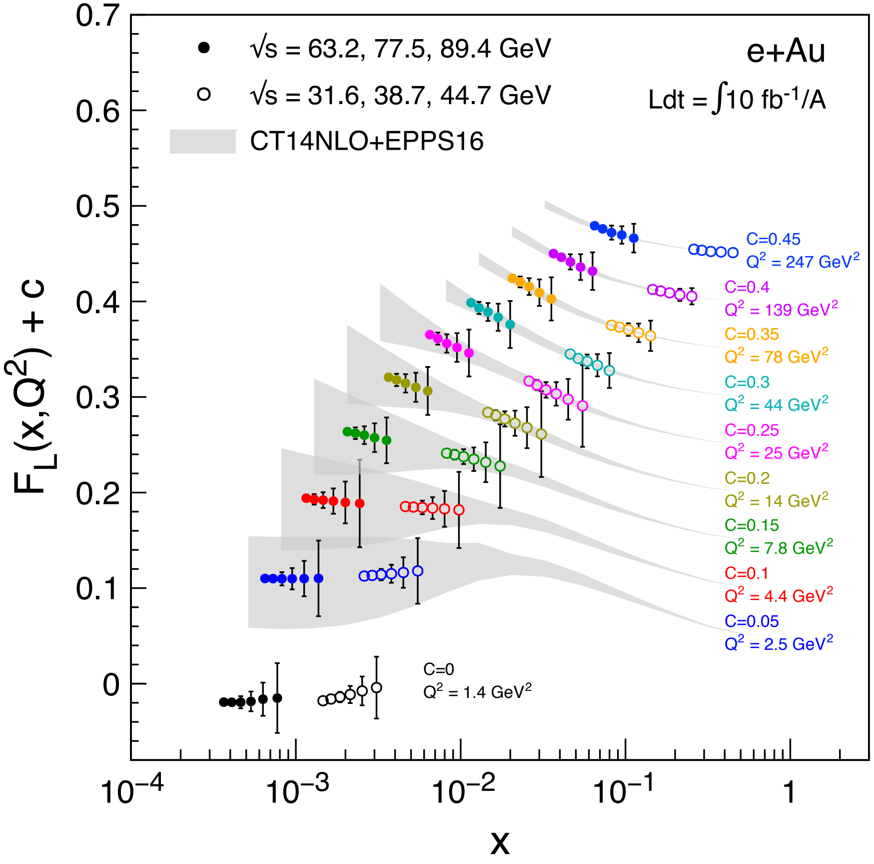


EIC Physics Pillars

- Inclusive eA scattering measurements

arXiv:1708.01527





$$\sigma_{\rm red} = F_2 - \frac{y^2}{Y_+}F_L$$

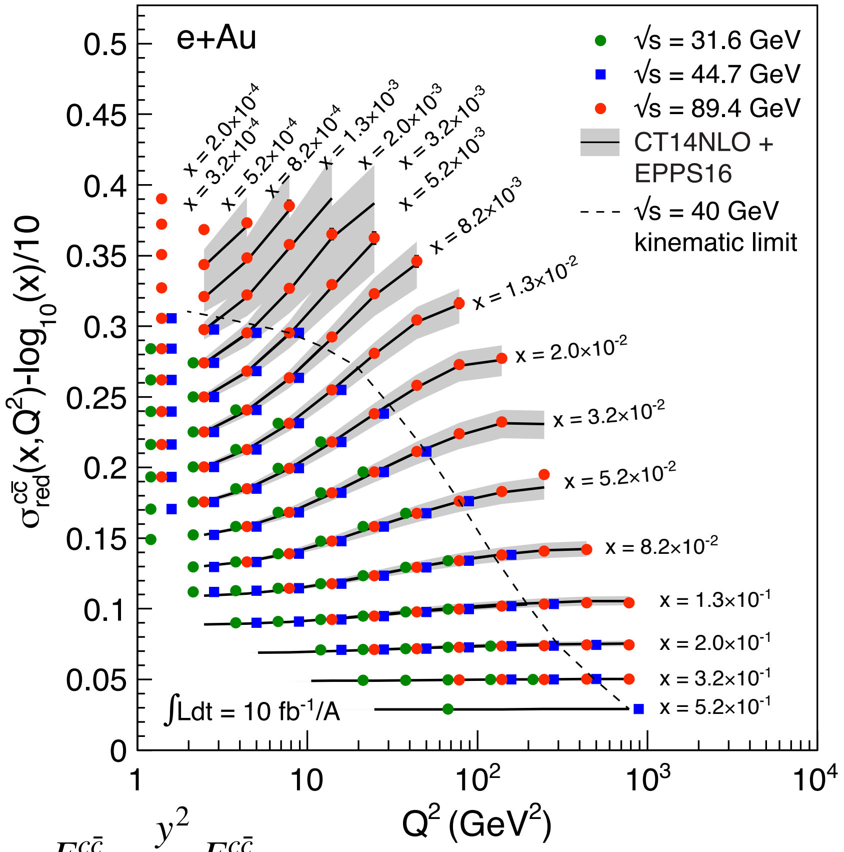
$$\left(\frac{d^2\sigma}{dx\,dQ^2}\right) = \frac{2\pi\alpha^2 Y_+}{xQ^4}\left(F_2 - \frac{y^2}{Y_+}F_L\right)$$

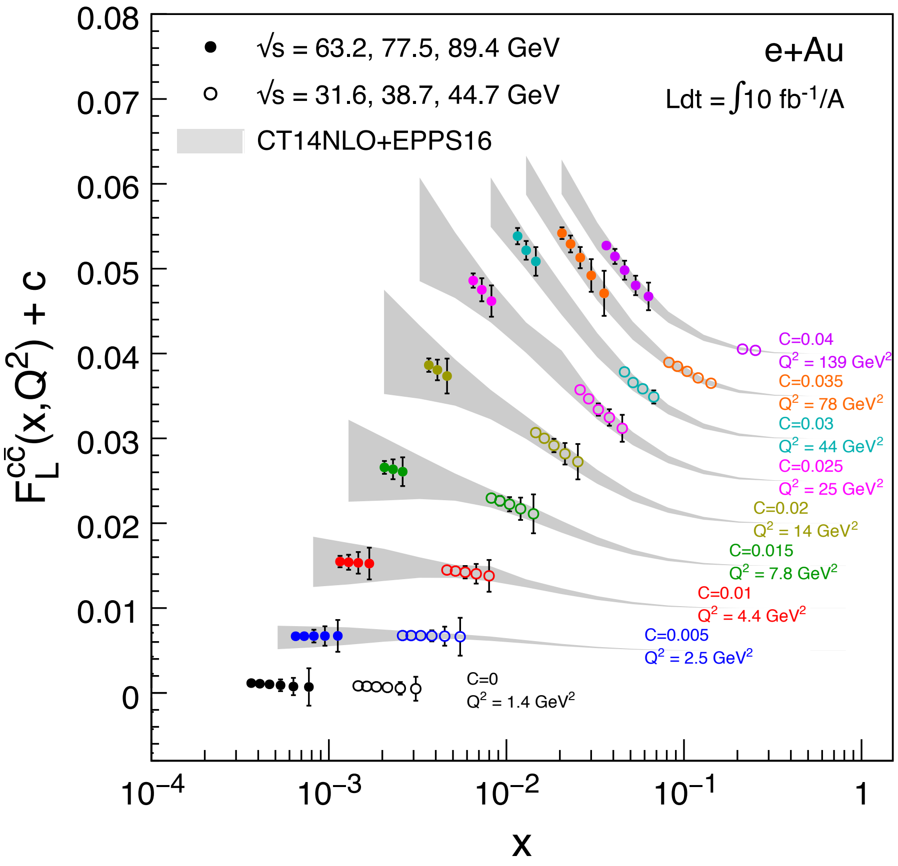
$$Y_+ = 1 + \left(1 - y\right)^2$$

EIC Physics Pillars

- ☐ Charm-associated eA scattering measurements

arXiv:1708.01527





$$\sigma_{\mathrm{red}}^{c\bar{c}} = F_2^{c\bar{c}} - \frac{y^2}{Y_+} F_L^{c\bar{c}}$$

$$\left(\frac{d^2\sigma}{dx\,dQ^2}\right)^{c\bar{c}} = \frac{2\pi\alpha^2 Y_+}{xQ^4}\left(F_2^{c\bar{c}} - \frac{y^2}{Y_+}F_L^{c\bar{c}}\right)$$

$$Y_+ = 1 + \left(1-y\right)^2$$

EIC Physics Pillars

- ☐ Impact on nuclear gluon behavior in eA scattering

arXiv:1708.01527

Modifications of

nuclear

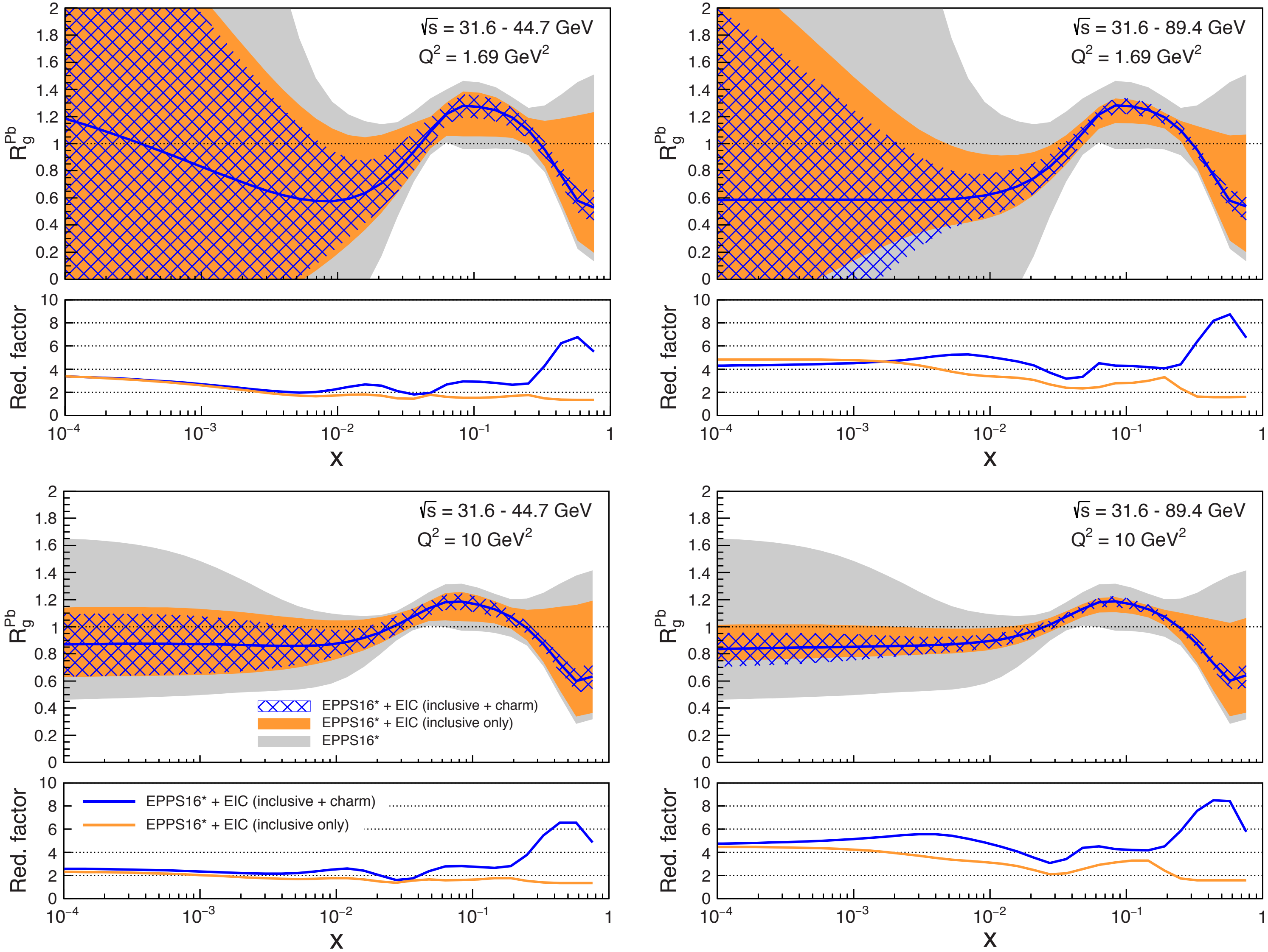
environment:

R_g^{Pb}

Ratio of gluon

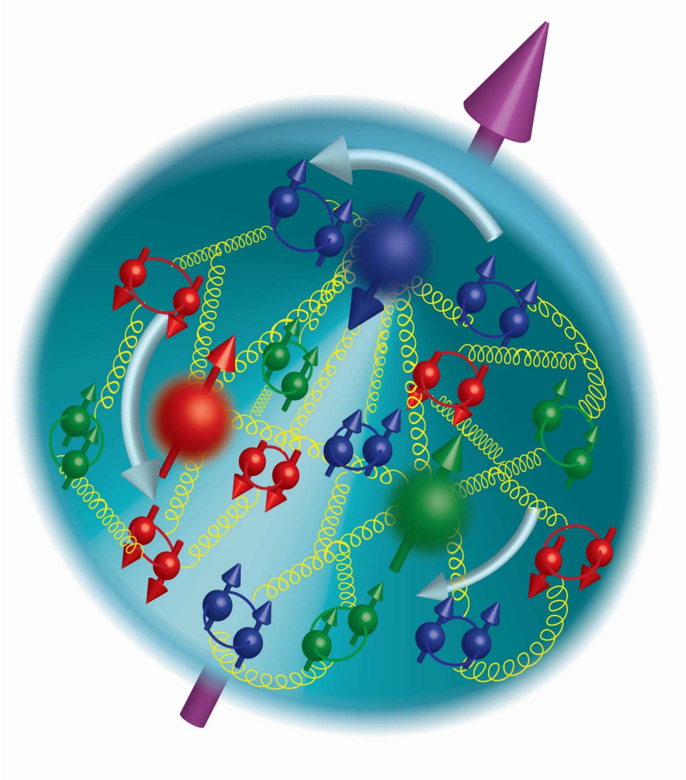
distribution in Pb

compared to proton



EIC Physics Pillars

Global properties: Mass



EIC Physics Pillars

- Mass

A. Metz, Priv. com.

  - Proton mass M - Relation to Energy-Momentum Tensor (EMT) $T^{\mu\nu}$

$$M = n\langle T^{\mu}_{\mu}\rangle = n\langle T^{00}\rangle\Big|_{P=0} \text{ with } n = \frac{1}{2M}$$

  - Forward matrix element of $T^{\mu\nu}_{i\ \ R}$ (i=q,g): $\langle T^{\mu\nu}_{i\ \ R}\rangle = 2P^{\mu}P^{\nu}A_i(0) + 2M^2 g^{\mu\nu}\overline{C}_i(0)$

with gravitational form factors $A_i(0)$, $\overline{C}_i(0)$ at t=0. Conservation of EMT implies:

$$A_q(0) + A_g(0) = 0 \quad \overline{C}_q(0) + \overline{C}_g(0) = 0$$

  - In the forward limit, $\langle T^{\mu\nu}_{i\ \ R}\rangle$ fully determined by two numbers!

EIC Physics Pillars

- Nucleon mass

A. Metz, Priv. com.

  - Different sum rules based on a decomposition of T^{μ}_{μ} or T^{00}:
    - 2-term sum rule by Hatta, Rajan, and Tanaka : Decomposition of T^{μ}_{μ}

$$M = n\left(\langle (T_{q,\,R})^{\mu}_{\mu}\rangle + \langle (T_{g,\,R})^{\mu}_{\mu}\rangle\right)$$

Hatta, Rajan, Tanaka, JHEP 12 (2018) 008 /
Tanaka, JHEP 01 (2019) 120

    - 2-term sum rule by Lorcé: Decomposition of T^{00}

$$M = n\left(\langle (T_{q,\,R})^{00}\rangle + \langle (T_{g,\,R})^{00}\rangle\right)$$

Lorcé, EPJC 78, 120 (2018)

    - 3-term sum rule by Rodini, Metz, Pasquini: Decomposition of T^{00}

$$M = n\left(\langle (\mathscr{H}_{q}\rangle + \langle (\mathscr{H}_{m}\rangle + \langle (\mathscr{H}_{g}\rangle\right)$$

Rodini, Metz, Pasquini, JHEP 09 (2020) 067 /
Metz, Rodini, Pasquini, PRD 102 (2020) 114042

    - 4-term sum rule by Ji: Decomposition of T^{00}

$$M = n\left(\langle (\mathscr{H}_{q[Ji]}\rangle + \langle (\mathscr{H}_{m}\rangle + \langle (\mathscr{H}_{g[Ji]}\rangle + \langle (\mathscr{H}_{a}\rangle\right)$$

Ji, PRL 74, 1071 (1995) /
PRD 52, 271 (1995)

Formulation in terms of two independent parameters reflecting

a) Parton momentum fraction and

b) Quark mass terms / relation to trace anomaly.

EIC: Constrain anomaly contribution (Gluon contr. to trace anomaly) through heavy quarkonium production!

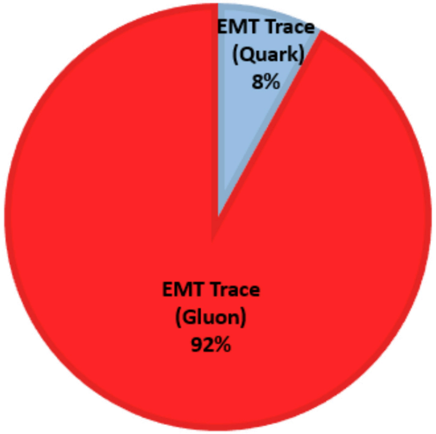
EIC Physics Pillars

☐ Comparison of different mass sum rules: D2 renormalization scheme

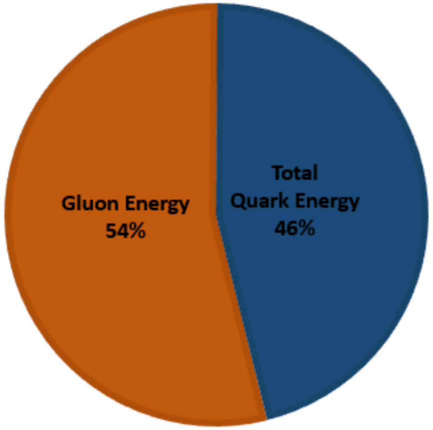
A. Metz, Priv. com.

2-term sum rule by Hatta, Rajan, and Tanaka

2 terms $T^{\mu}{}_{\mu}$



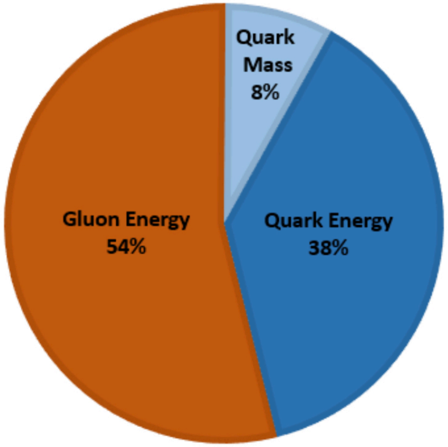
2 terms T^{00}



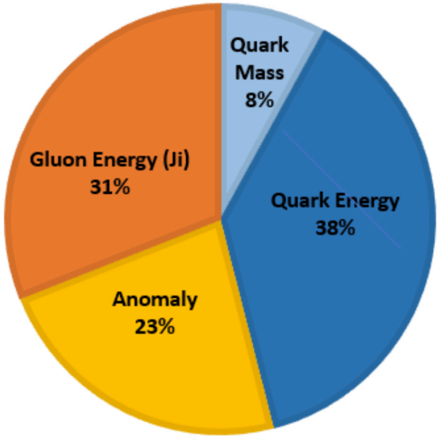
2-term sum rule by Lorcé

3-term sum rule by Rodini, Metz, Pasquini

3 terms T^{00}



4 terms T^{00}

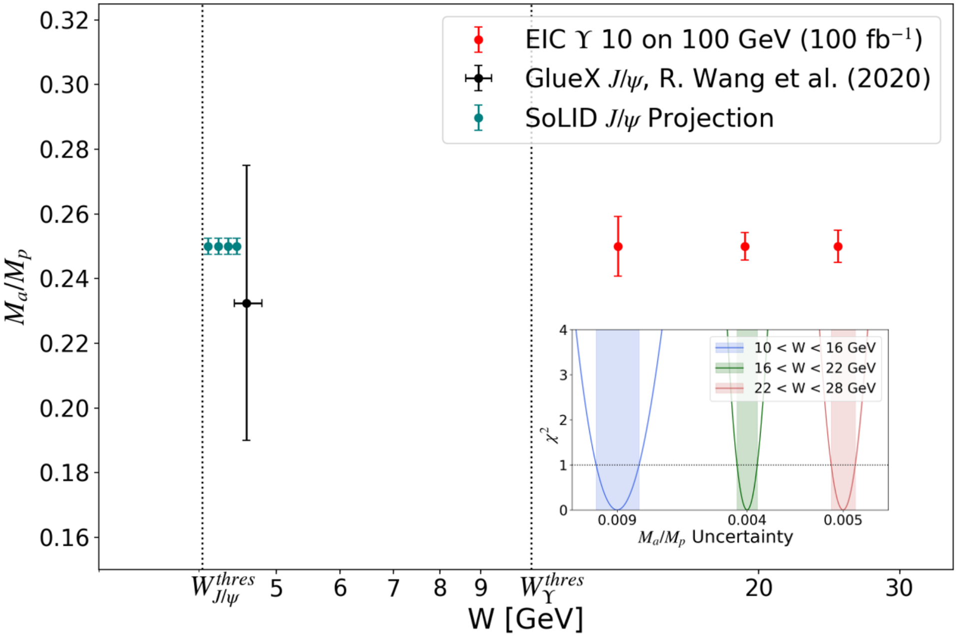


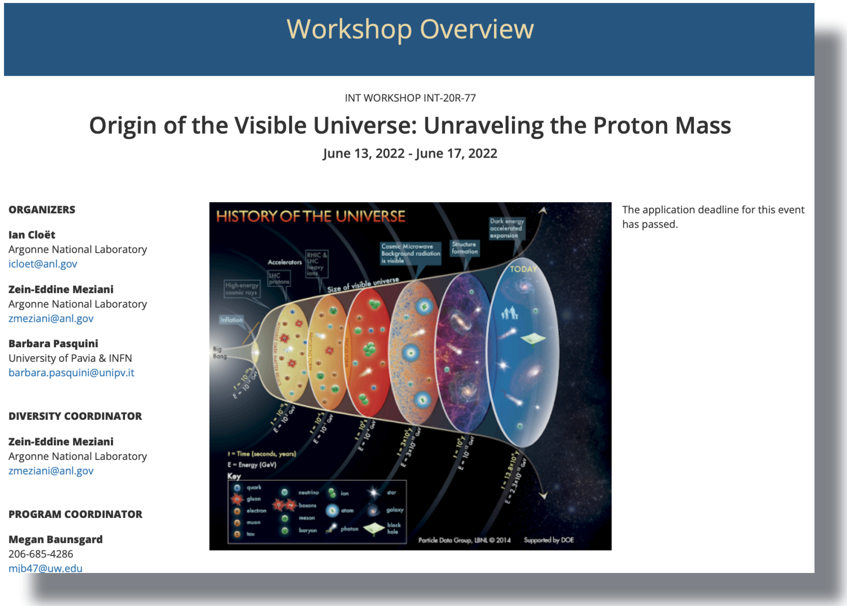
4-term sum rule by Ji

EIC Physics Pillars

- EIC constraint of anomaly to nucleon mass

arXiv:2103.05419





Workshop Overview

INT WORKSHOP INT-20R-77

Origin of the Visible Universe: Unraveling the Proton Mass

June 13, 2022 - June 17, 2022

ORGANIZERS

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PROGRAM COORDINATOR

Megan Baunsgard
206-685-4286
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The application deadline for this event has passed.

- First results from GlueX and anticipated SoLID experiment!

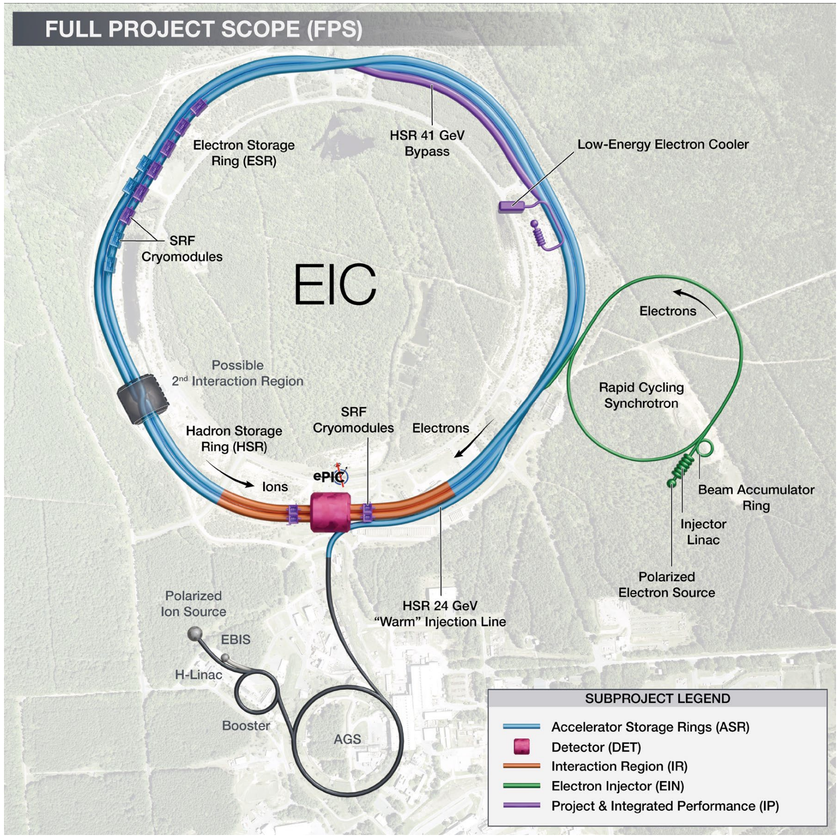
- INT workshop: "Origin of the Visible Universe: Unraveling the Proton Mass" June 13-17, 2022

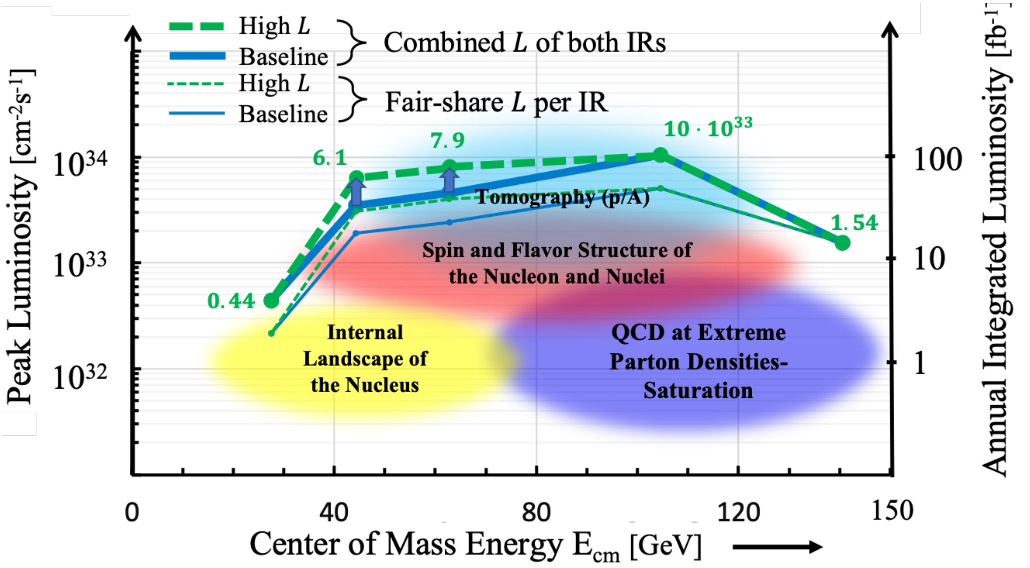
  https://www.int.washington.edu/programs-and-workshops/20r-77

Experimental Realization

- EIC accelerator design

Center of Mass Energies:	20GeV - 140GeV
Luminosity:	10^{33} - 10^{34} cm^{-2}s^{-1} / 10-100fb^{-1} / year
Highly Polarized Beams:	70%
Large Ion Species Range:	p to U
Number of Interaction Regions:	Up to 2!

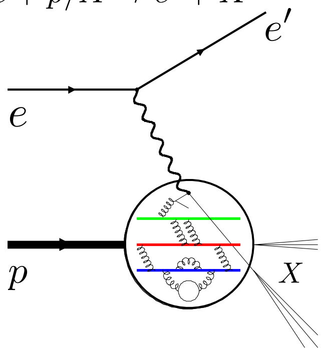




ePIC Detector Layout

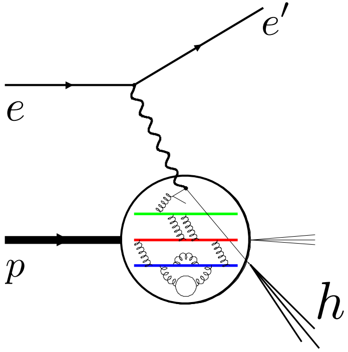
☐ Overview of processes and final states

$e + p/A \rightarrow e' + X$

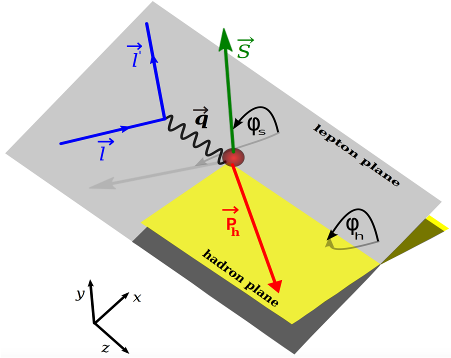


Inclusive DIS

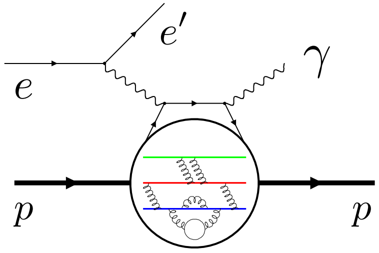
$e + p/A \rightarrow e' + h + X$



Semi-Inclusive DIS (SDIS)



$e + p/A \rightarrow e' + N'/A' + \gamma/m$



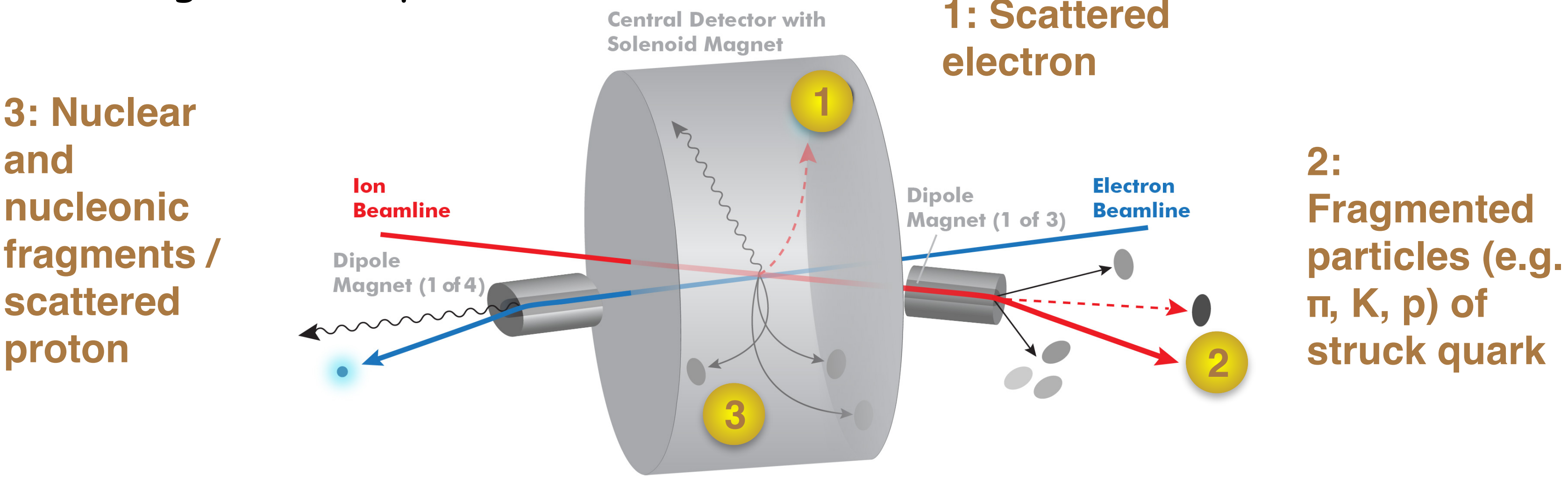
Deeply-Virtual Compton Scattering (DVCS)

- Inclusive: Unpolarized $f_i(x,Q^2)$ and helicity distribution $\Delta f_i(x,Q^2)$ functions through unpolarized and polarized structure function measurements (F_2, F_L, g_1)
- Define kinematics (x, y, Q^2) through electron (e-ID and energy+angular measurement critical) / hadron final state or combination of both depending on kinematic x-Q^2 region
- SDIS: Flavor tagging through hadron identification studying FF / TMD's (Transverse momentum, k_T, dependence) requiring azimuthal asymmetry measurement - Full azimuthal acceptance
- Heavy flavor (charm / bottom): Excellent secondary vertex reconstruction
- Exclusive: Tagging of final state proton using Roman pot system studying GPD's (Impact parameter, b_T, dependence) using DVCS and VM production
- eA: Impact parameter determination / Neutron tagging using Zero-Degree Calorimeter (ZDC)

ePIC Detector Layout

- Overview of general requirements

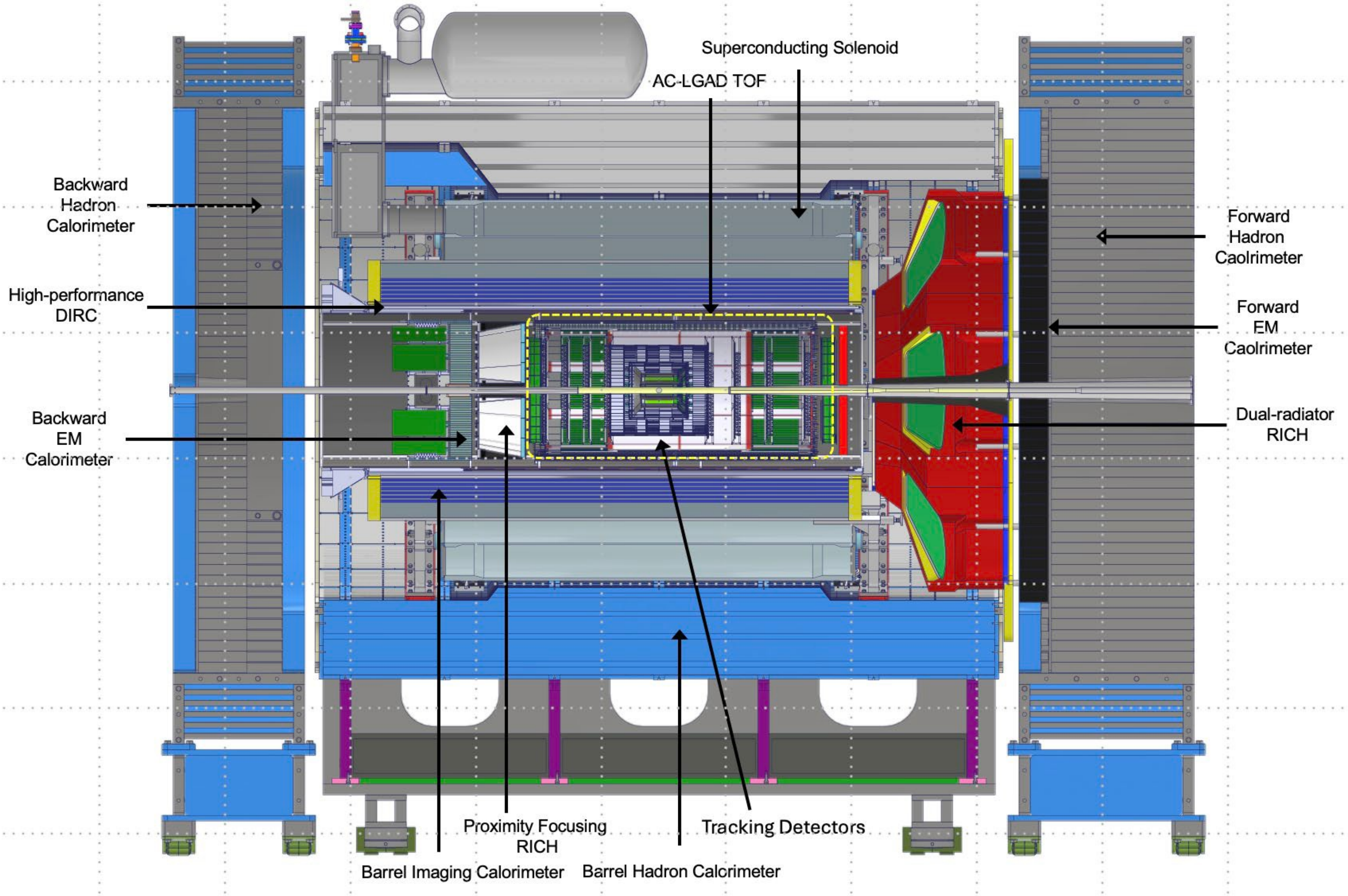
arXiv:1212.1701



- Acceptance: Close to 4π coverage with a η-coverage (η = -ln(tan(θ/2)) of approximately η < |3.5| combined calorimetry (EM CAL and hadron CAL at least in forward direction) and tracking coverage
- Low dead material budget in particular in rear direction (~10% X/X_0)
- Good momentum resolution Δp/p ~ few %
- Electron ID for e/h separation varies with θ / η at the level of $1:10^4$ / ~2-3%/√E for η<-2 and ~7%/√E for -2<η<1
- Particle ID for π/K/p separation over wide momentum range (Forward η up to ~50GeV/c / Barrel η up to ~4GeV/c / Rear η up to ~6 GeV/c)
- High spatial vertex resolution ~ 10-20µm for vertex reconstruction
- Low-angle taggers:
  - Forward proton / A fragment spectrometer (Roman pots)
  - Low Q^2 tagger
  - Neutrons on hadron direction
- Luminosity (Absolute and relative) and local polarization direction measurement

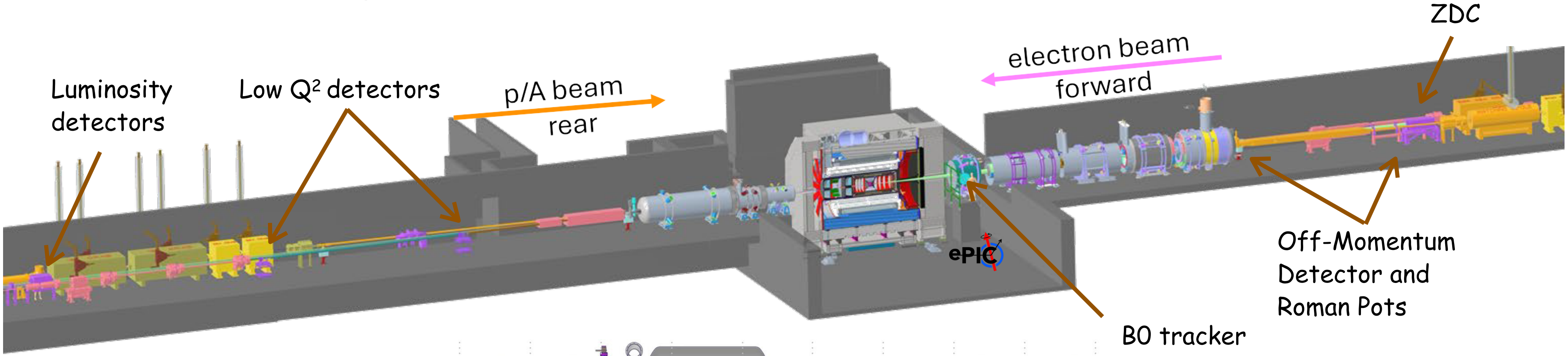
ePIC Detector Layout

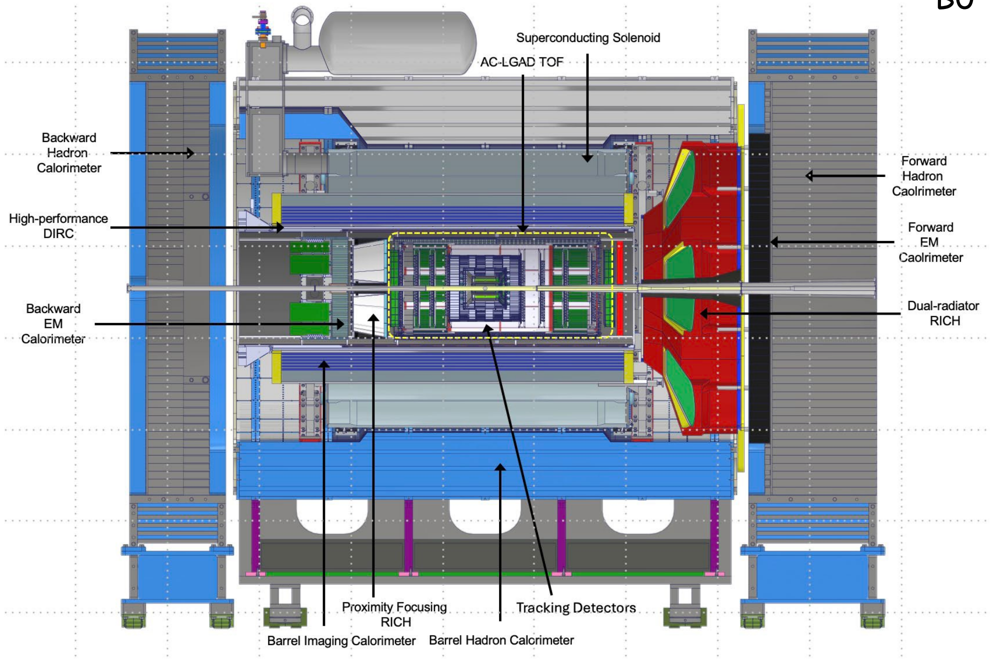
- Global ePIC design overview



ePIC Detector Layout

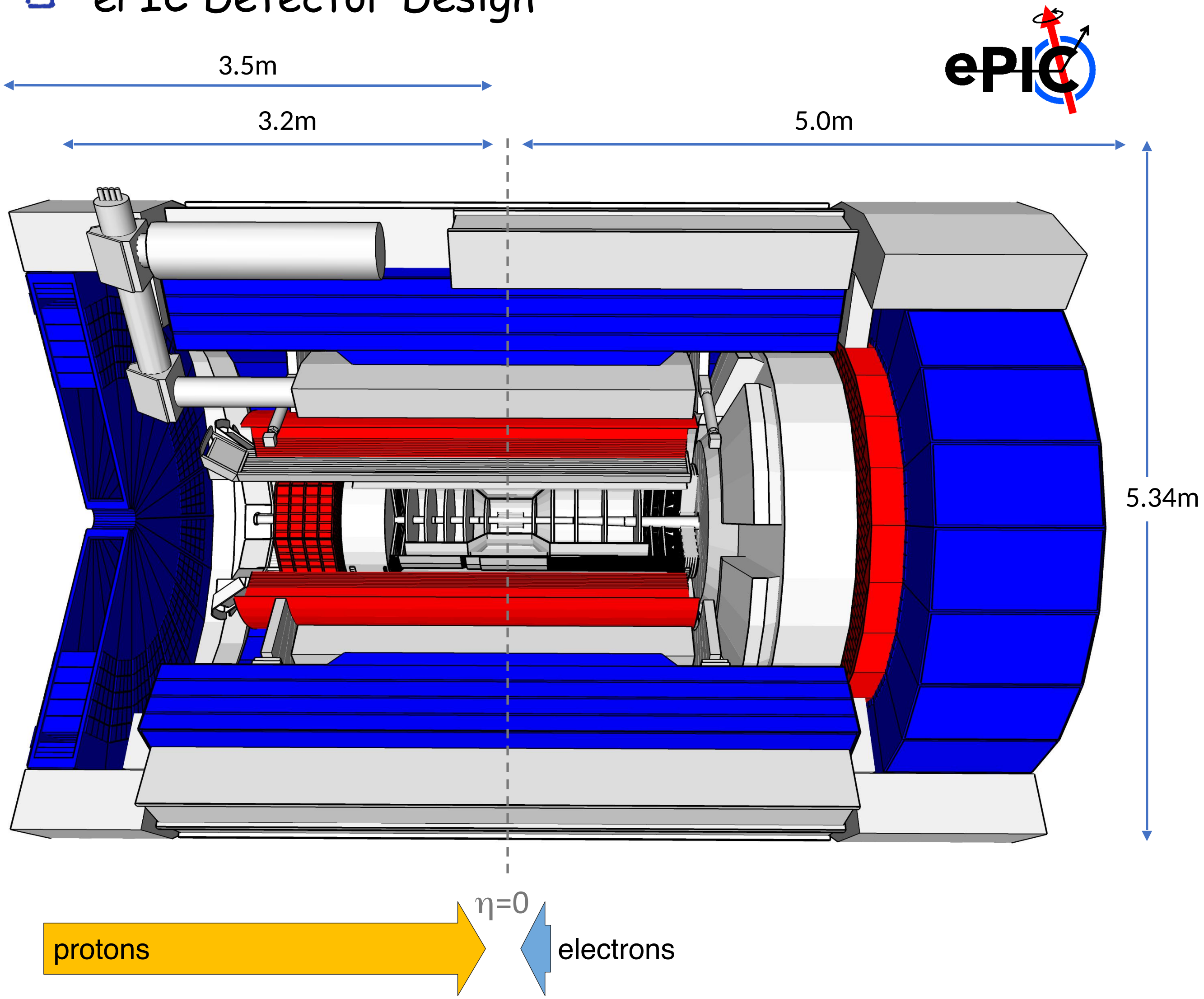
- Global ePIC design overview





ePIC Detector Layout

☐ ePIC Detector Design



Tracking:

- New 1.7T solenoid
- Si MAPS Tracker
- MPGDs (μRWELL/μMegas)

PID:

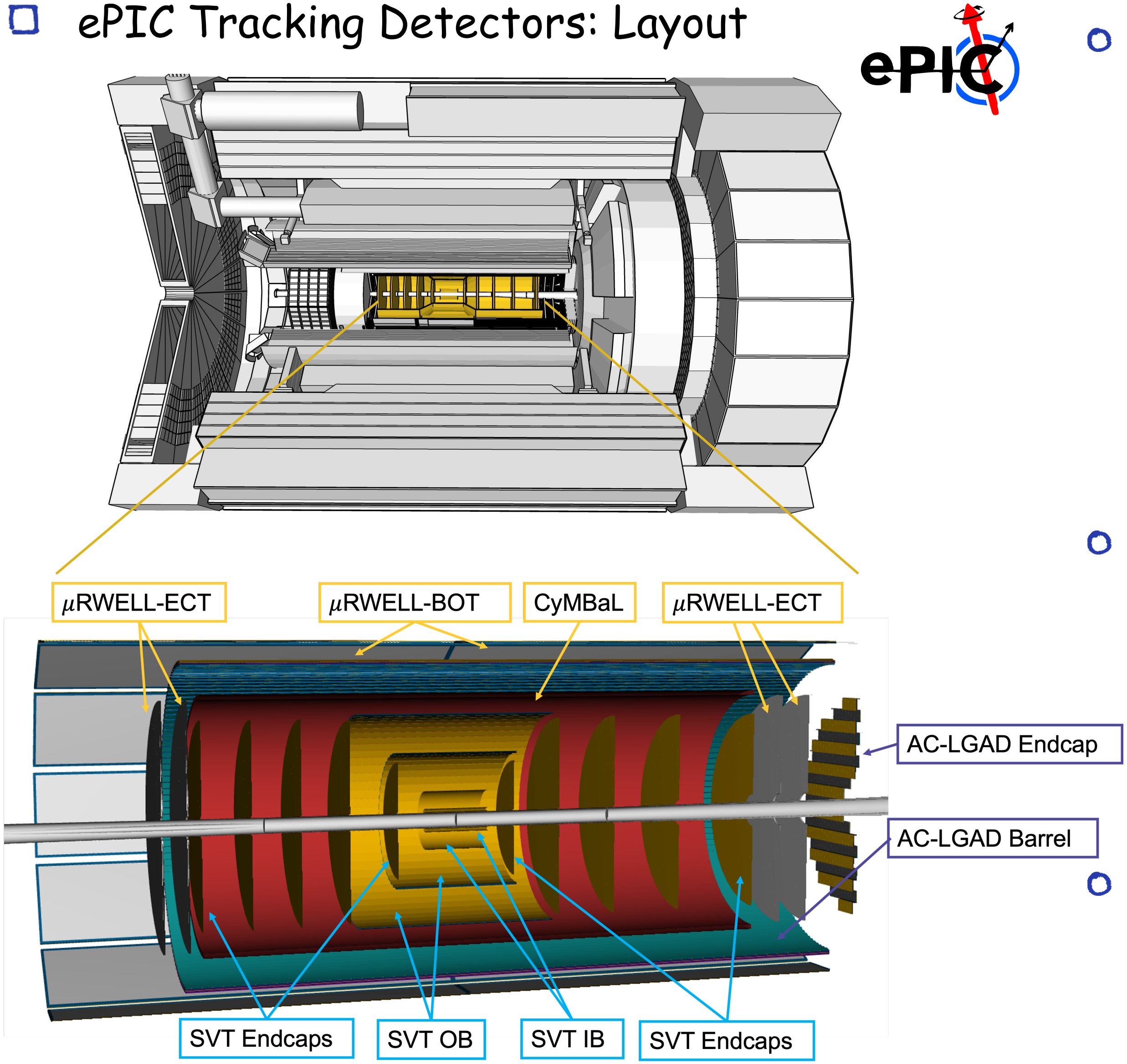
- hpDIRC
- pfRICH
- dRICH
- AC-LGAD (~30ps TOF)

Calorimetry:

- Imaging Barrel EMCal
- $PbWO_4$ EMCal in backward direction
- Finely segmented EMCal +HCal in forward direction
- Outer HCal (sPHENIX re-use)
- Backwards HCal (tail-catcher)

ePIC Detector Layout

ePIC Tracking Detectors: Layout



- MAPS Tracker:
  - Small pixels (20 μm), low power consumption (<20 mW/cm²) and material budget (0.05% to 0.55% X/X_0) per layer
  - Based on ALICE ITS3 development
  - Vertex layers optimized for beam pipe bake-out and ITS-3 sensor size
  - Forward and backward disks
- MPGD Layers:
  - Provide timing and pattern recognition
  - Cylindrical μMEGAs
  - Planar μRWell's before hpDIRC - Impact point and direction for ring seeding
- AC-LGAD TOF and AstroPix (BECAL):
  - Additional space point for pattern recognition / redundancy
  - Fast hit point / Low p PID

ePIC Detector Layout

☐ ePIC Tracking Detectors: Performance

Technology:

ITS3 MAPS based Si-detectors:

- ☐ O(20 μm) pitch, $X/X_0 \sim 0.05 - 0.55\%$/ layer

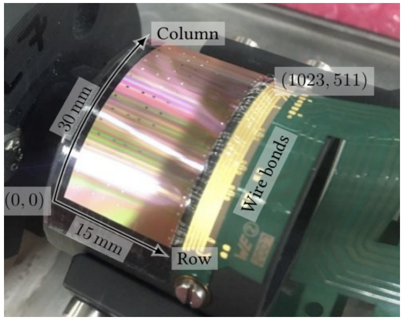
Gaseous tracker:

- ☐ σ = 150 μm, $X/X_0 \sim 0.5 - 2.0\%$/layer

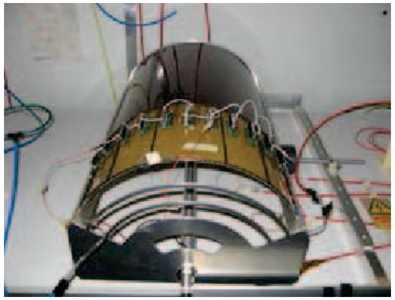
AstroPix outer tracker layer:

- ☐ 500μm pixel pitch (σ = 144 μm)

First “μITS3” assembly at CERN

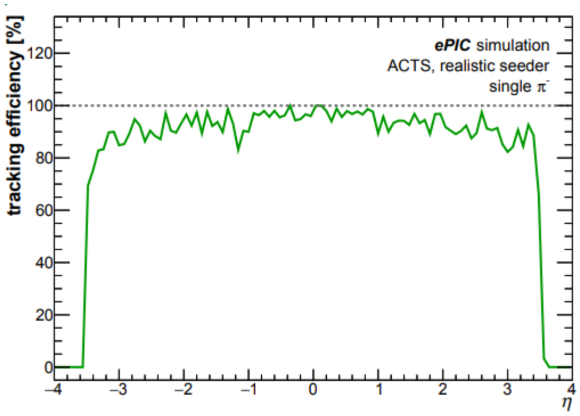


Cylindrical MicroMegas detector

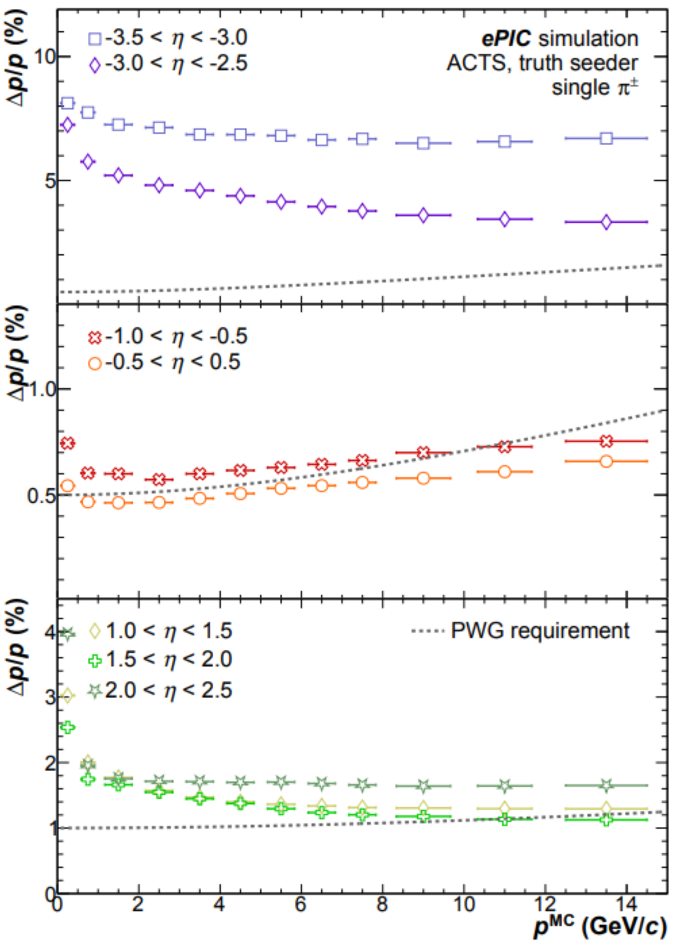


Simulated performance:

F. Bock, Hard Probes 2023



F. Bock, Hard Probes 2023

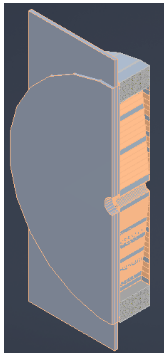


E. Yeats, R. Cruz-Torres, N. Schmidt, S. Maple

- ☐ Meets EICUG Yellow Report design requirements
- ☐ Backward momentum resolution complemented by calorimetric resolution

ePIC Detector Layout

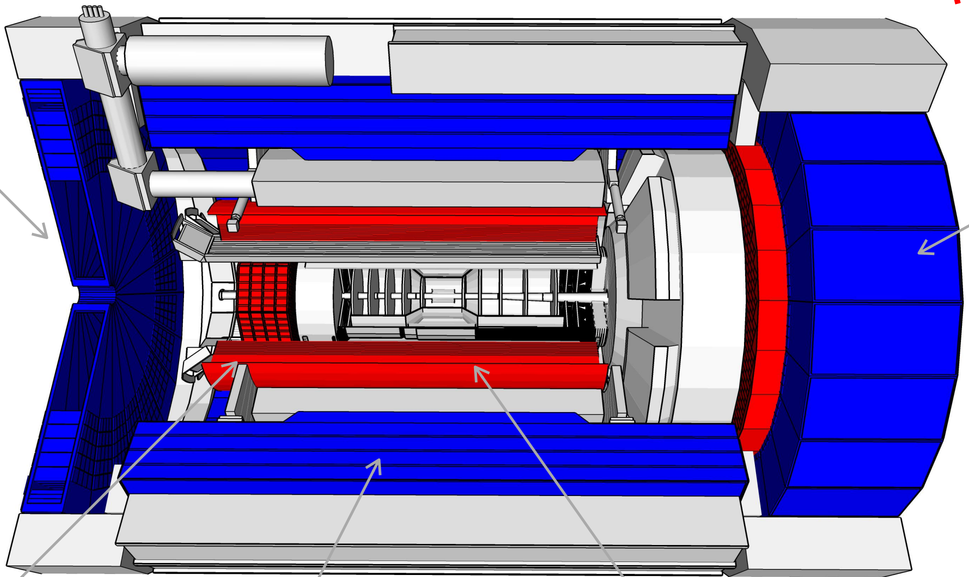
☐ ePIC Calorimeter Detectors: Layout

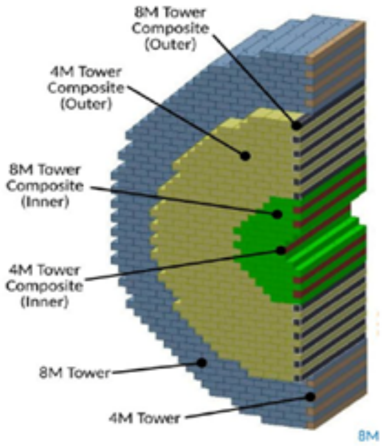


Backwards HCal

Steel/Sc Sandwich tail catcher

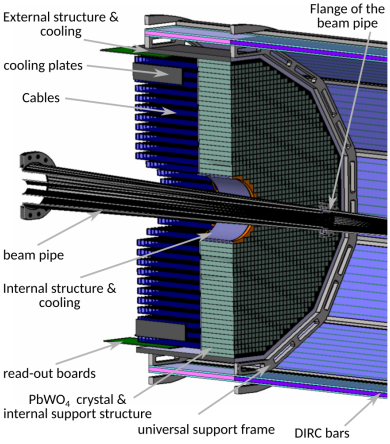
ePIC





High granularity W/SciFi **EMCal**

Longitudinally separated **HCAL** with high-η insert

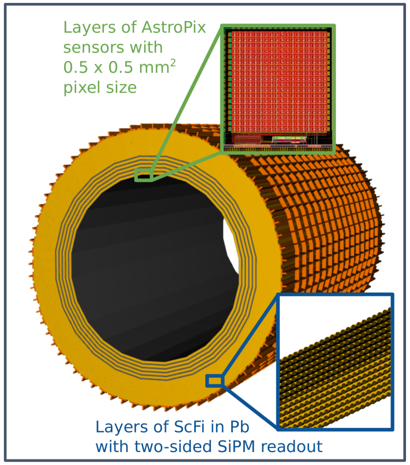


Backwards EMCal

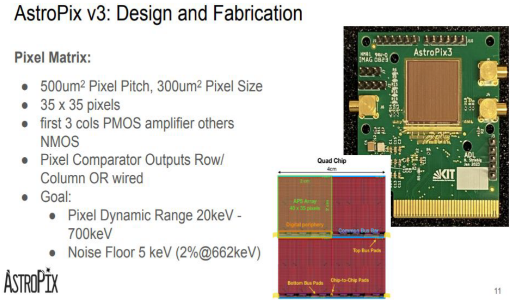
$PbWO_4$ crystals, SiPM photosensor

Barrel HCAL

(sPHENIX re-use)



Barrel BECAL



AstroPix v3: Design and Fabrication

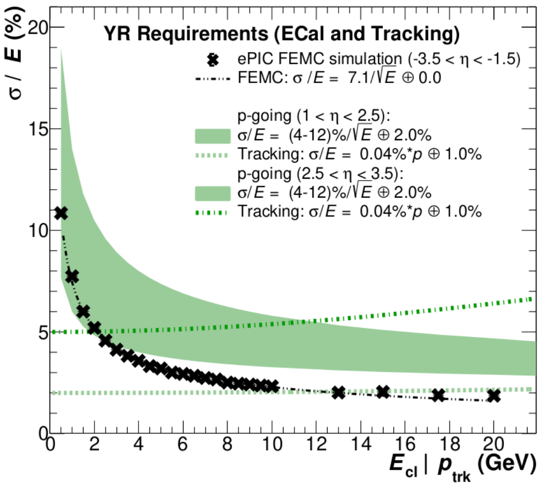
Pixel Matrix:

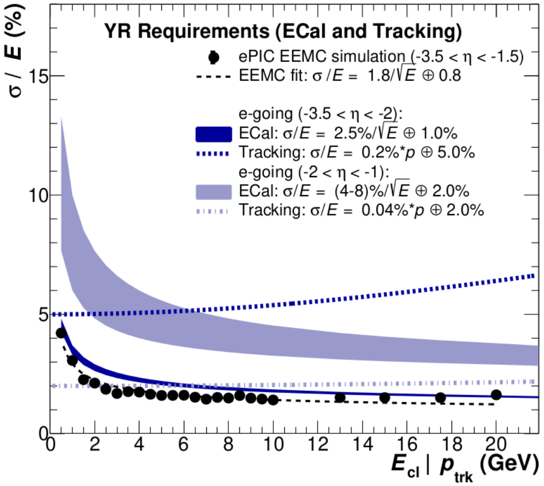
- 500um² Pixel Pitch, 300um² Pixel Size
- 35 x 35 pixels
- first 3 cols PMOS amplifier others NMOS
- Pixel Comparator Outputs Row/ Column OR wired
- Goal:
  - Pixel Dynamic Range 20keV - 700keV
  - Noise Floor 5 keV (2%@662keV)

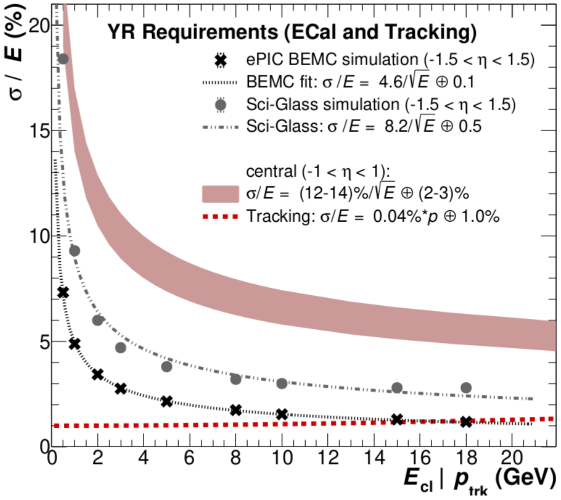
ePIC Detector Layout

ePIC Calorimeter Detectors: Performance

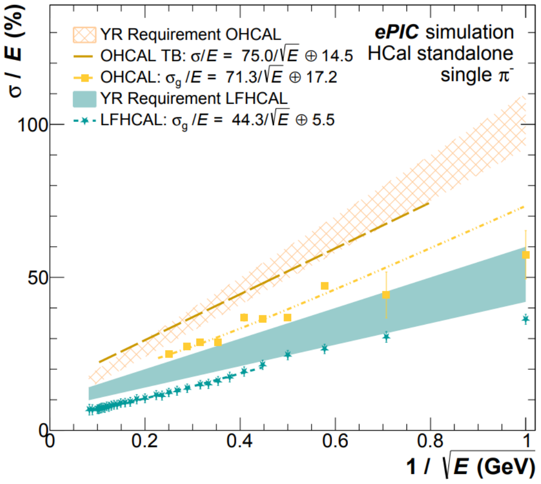
N. Schmidt







F. Bock, Hard Probes 2023



Performance on energy resolution and matching:

- Technologies fulfill YR requirements for energy resolution
- Ongoing simulation studies related to overlaps between different η regions for calorimetry and reconstruction algorithms

Ongoing work on Monte-Carlo validation:

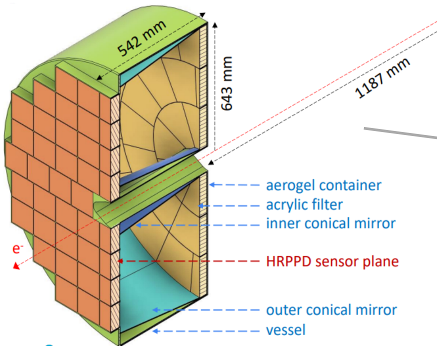
- Validation for high Z absorbers

ePIC Detector Layout

ePIC PID Detectors: Layout

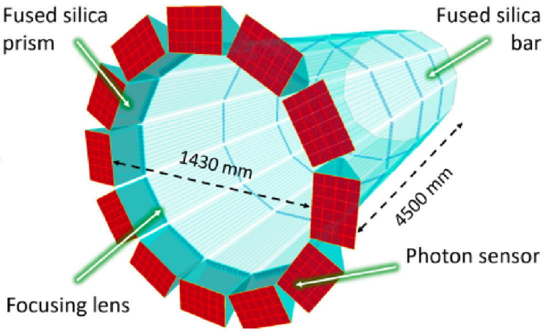
Proximity Focused (pfRICH)

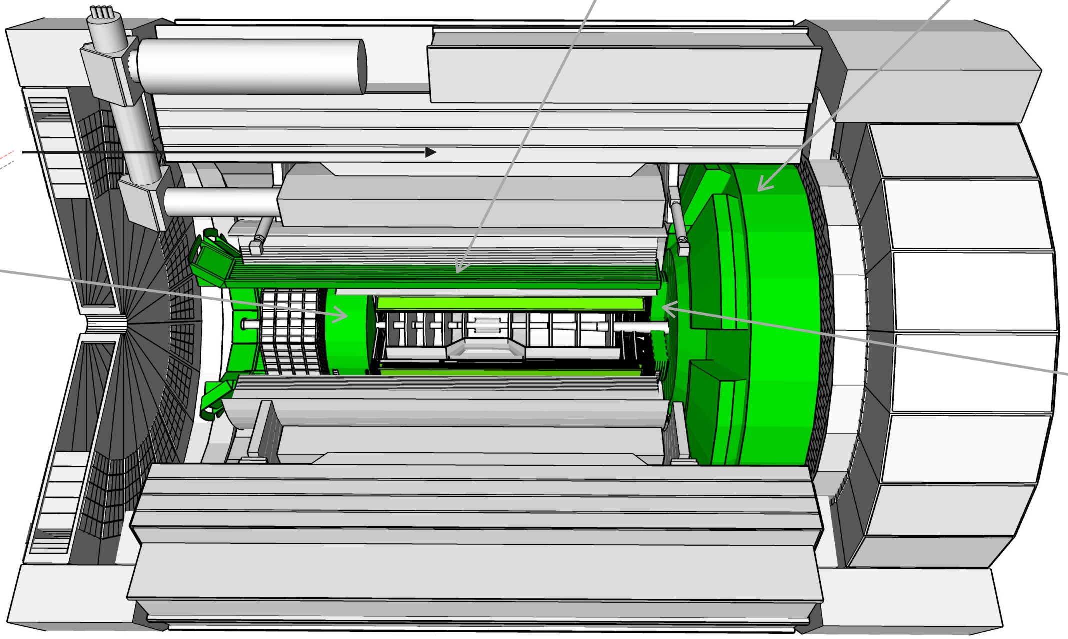
- Long proximity gap (~40 cm)
- Sensor: LAPPDs
- up to 9 GeV/c 36 π/K sep.



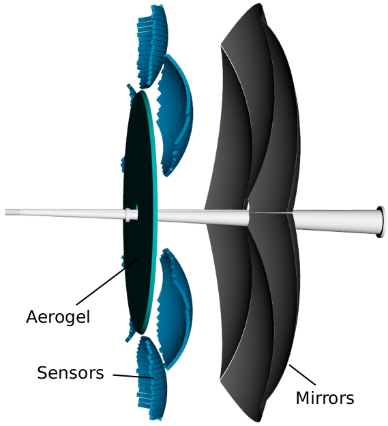
High-Performance DIRC

- Quartz bar radiator (BaBAR bars)
- light detection with MCP-PMTs
- Fully focused
- π/K 36 separation at 6 GeV/c



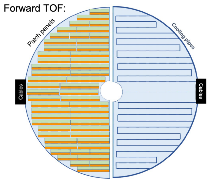


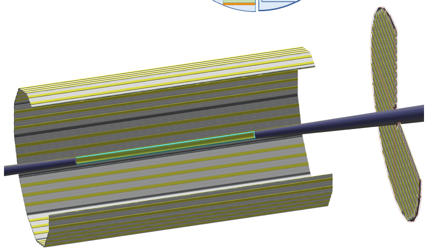
Dual-Radiator RICH (dRICH)



- C_2F_6 Gas Volume and Aerogel
- Sensors tiled on spheres (SiPMs)
- π/K 3σ sep. at 50 GeV/c

AC-LGAD TOF (~30ps)





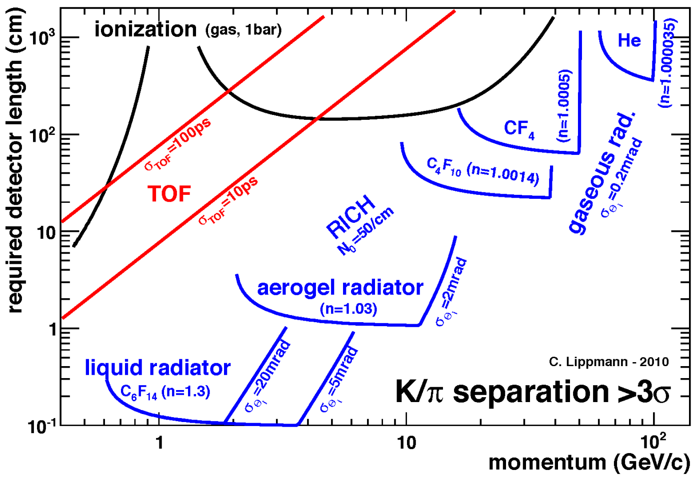
- Accurate space point for tracking / Low p PID
- Forward disk and central barrel

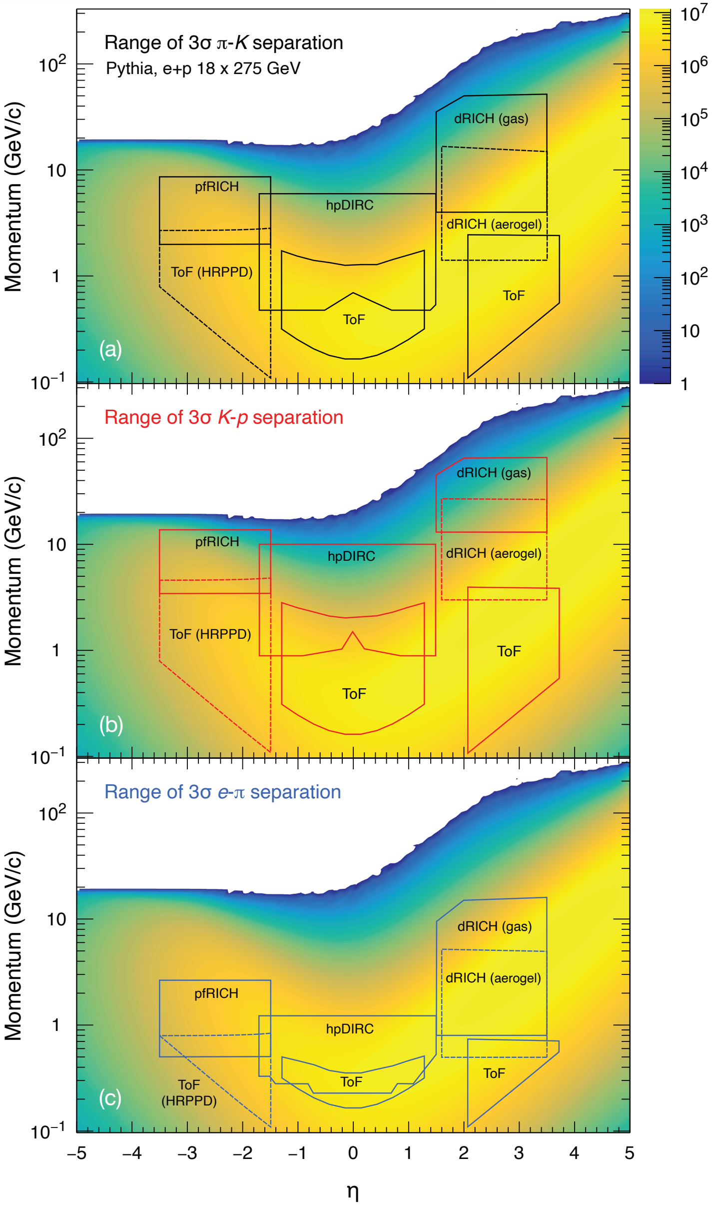
ePIC Detector Layout

ePIC PID Detectors: Performance

Particle IDentification needs:

- Electrons from photons ➜ 4π coverage in tracking
- Electrons from charged hadrons ➜ mostly provided by calorimetry and tracking
- Charged pions, kaons, and protons from each other on track level ➜ Cherenkov detectors, complemented by ToF

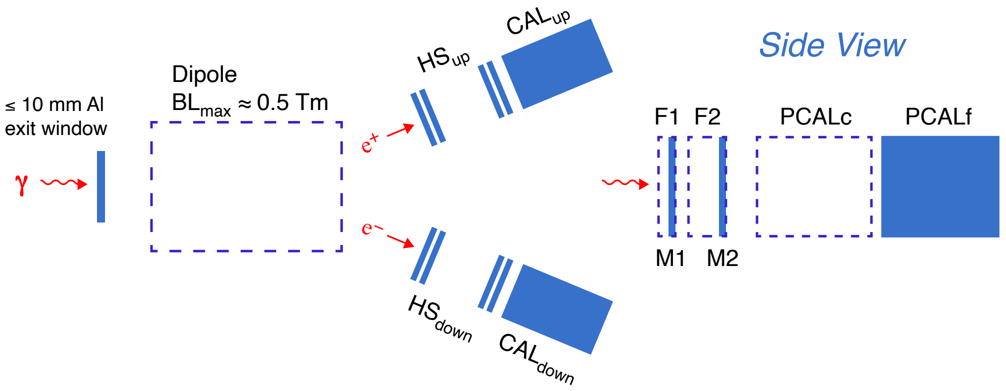


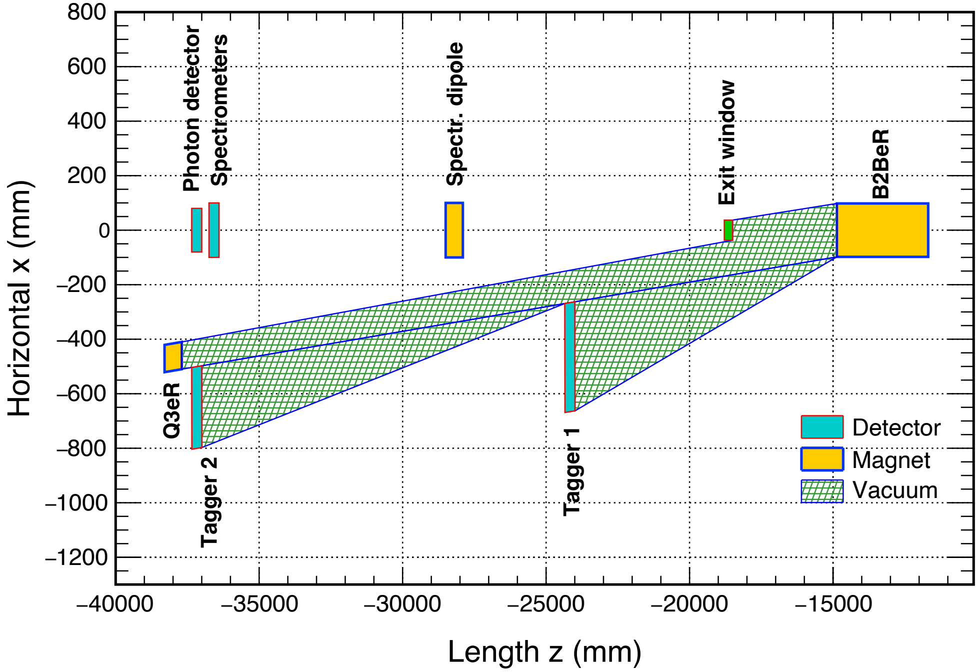


Critical: Need more than one technology to cover the entire momentum ranges at different rapidities!

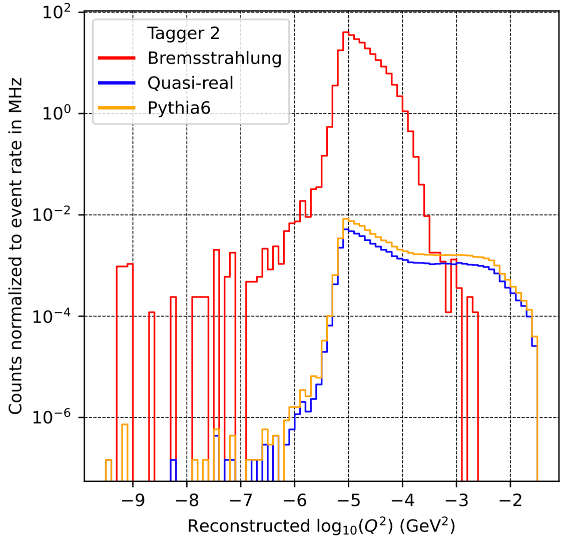
ePIC Detector Layout

- FarBackward system



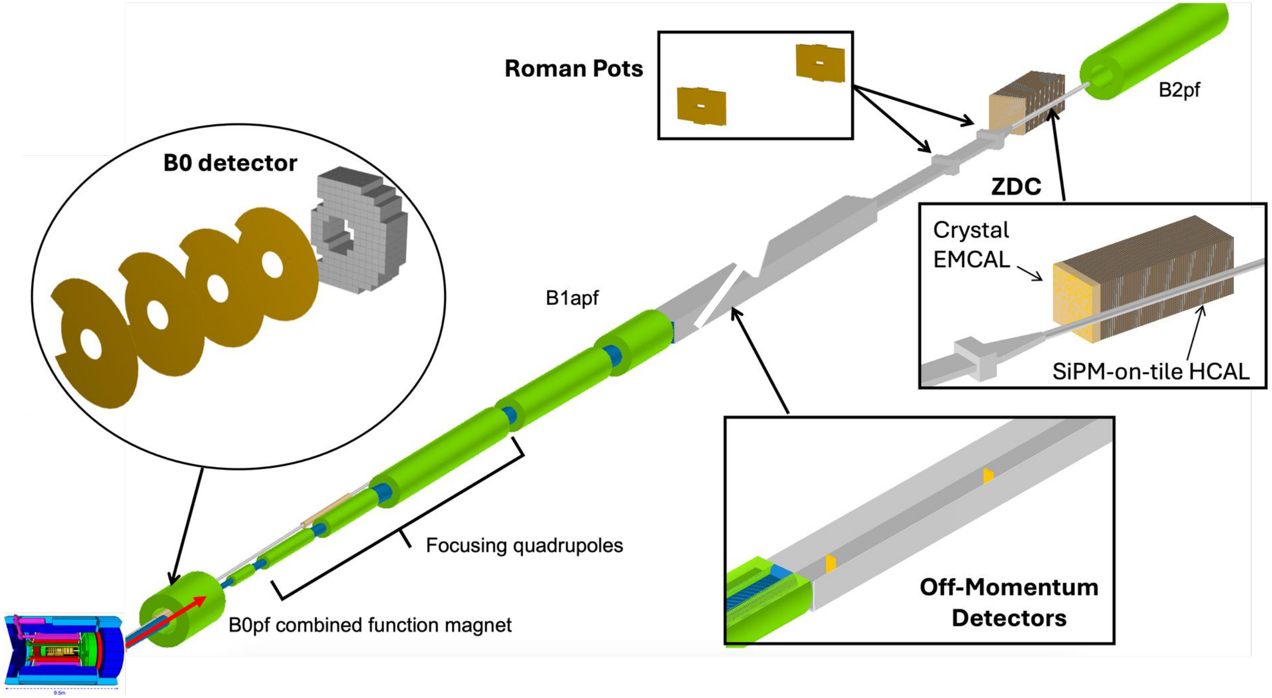


- High precision luminosity measurement at 1% level for absolute luminosity and 0.01% for relative luminosity measurement using several methods based on the Bremsstrahlung process:
  1. Counting photons converted in thin exit window using dipole field and measuring e^+e^- pairs
  2. Energy measurement of unconverted photons
  3. Counting of unconverted photons
- Low Q^2 taggers - PHP tagger



ePIC Detector Layout

- FarForward detector system
  - FarForward detector system to measure very forward neutral and charged particle production: 4 detector systems
  - B0 system: Measures charged particles in the forward direction and tags neutral particles
  - Off-momentum detectors: Measure charged particles resulting from decays
  - Roman pot detectors: Measure charged particles near the beam
  - Zero-degree calorimeter: Measures neutral particles at small angles



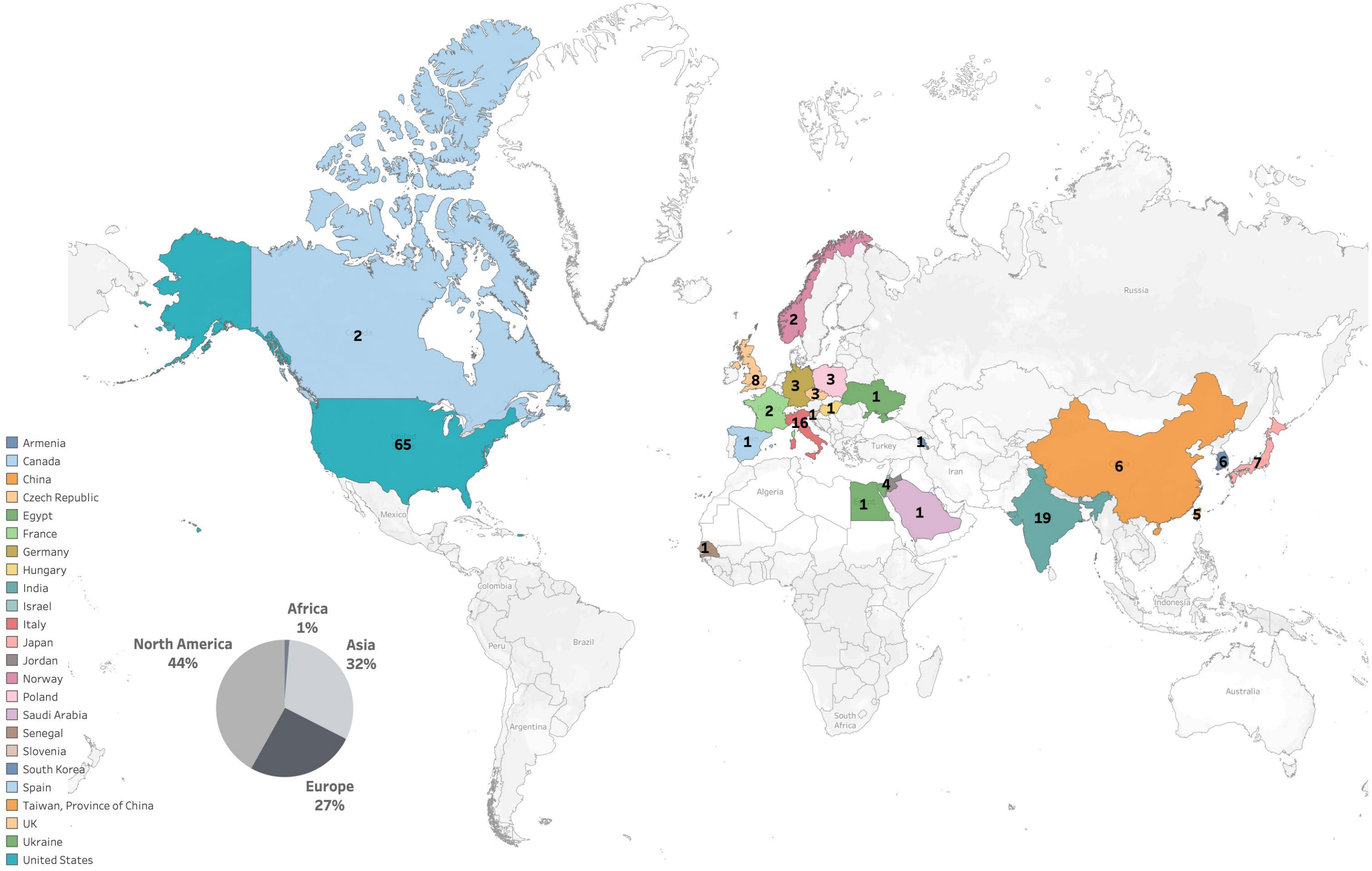
Detector	θ accep. [mrad]	Rigidity accep.	Particles	Technology
B0 tracker	5.5–20.0	N/A	Charged particles Tagged photons	MAPS AC-LGAD
Off-Momentum Detector	0.0–5.0	45%–65%	Charged particles	AC-LGAD
Roman Pots	0.0–5.0	60%–95%*	Protons Light nuclei	AC-LGAD
Zero-Degree Calorimeter	0.0–4.0	N/A	Neutrons Photons	W/SciFi (ECal) Pb/Sci (HCal)

ePIC Collaboration

- World Map - Institutions

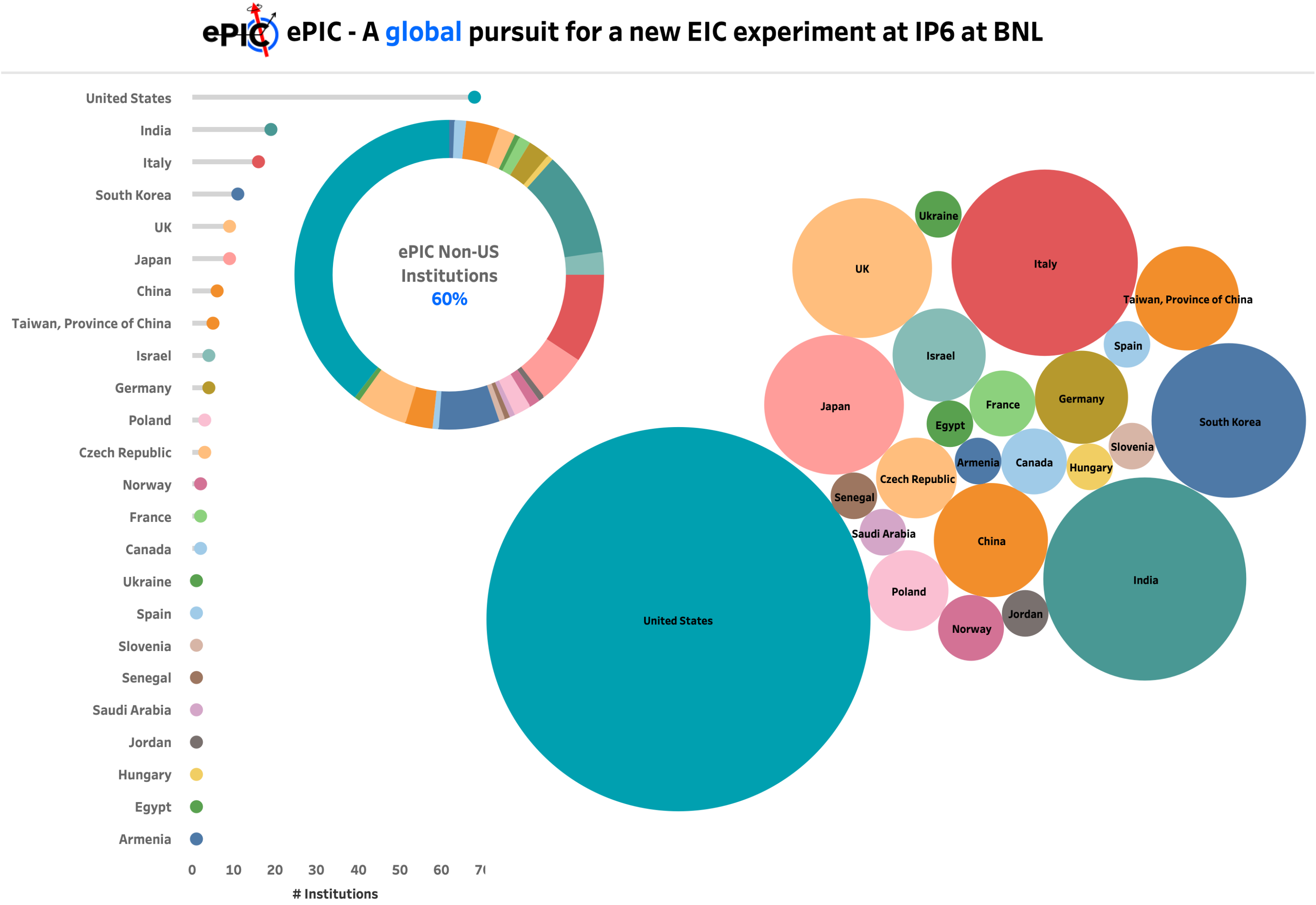
ePIC - A global pursuit for a new EIC experiment at IP6 at BNL

ePIC Institutions	ePIC Countries	ePIC World Region
160	24	4



ePIC Collaboration

- Number of Institutions



ePIC Collaboration

- ☐ Collaboration

JLab, January 2023

Warsaw, July 2023

Lehigh, July 2024

ANL, January 2024

Frascati, Jan 2025

- ○ Vibrant ePIC community on physics and detector studies
- ○ World-wide ePIC collaboration meetings

Summary and Next Steps

- Over two decades, the nuclear physics community has developed the scientific and technical case for the Electron-Ion Collider, to push the frontiers of human understanding of the fundamental structure and dynamics of matter ➜ Emergent phenomena in QCD!
- Enormously profit from a diverse set of experiences among experimentalists and theorists at numerous institutions worldwide ➜ Critical for a broad EIC scientific program
- Successful merging of several proposal efforts, forming a new collaboration in 2022/2023: ePIC collaboration
- A 2nd experiment is strongy supported by the EIC community - Not part of the EIC project / Longer timescale!
- A very exciting time is ahead of us to explore the structure and dynamics of matter at a new ep/eA collider facility following years of preparation - Join us!

Thank you!

Thank you to my friends and faculty colleagues

Andreas Metz and Alexey Prokudin

for numerous EIC physics discussions!

Andreas
Metz

Alexei
Prokudin