ATHENA
A new detector proposed at the Electron-Ion Collider

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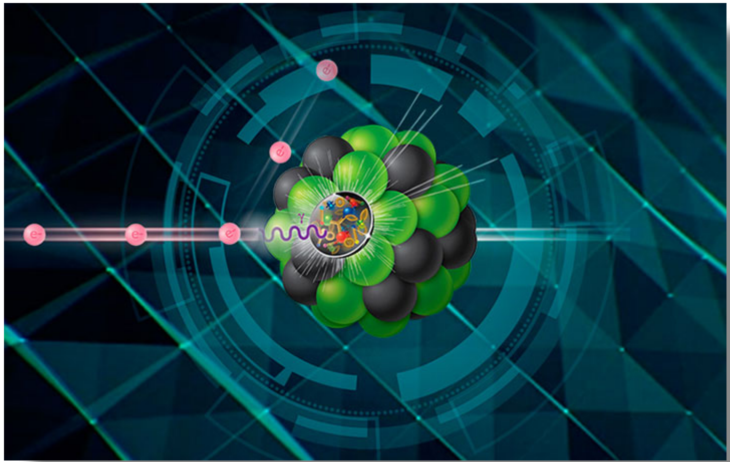
TEMPLE UNIVERSITY

INFN Trieste

On behalf of the ATHENA Collaboration

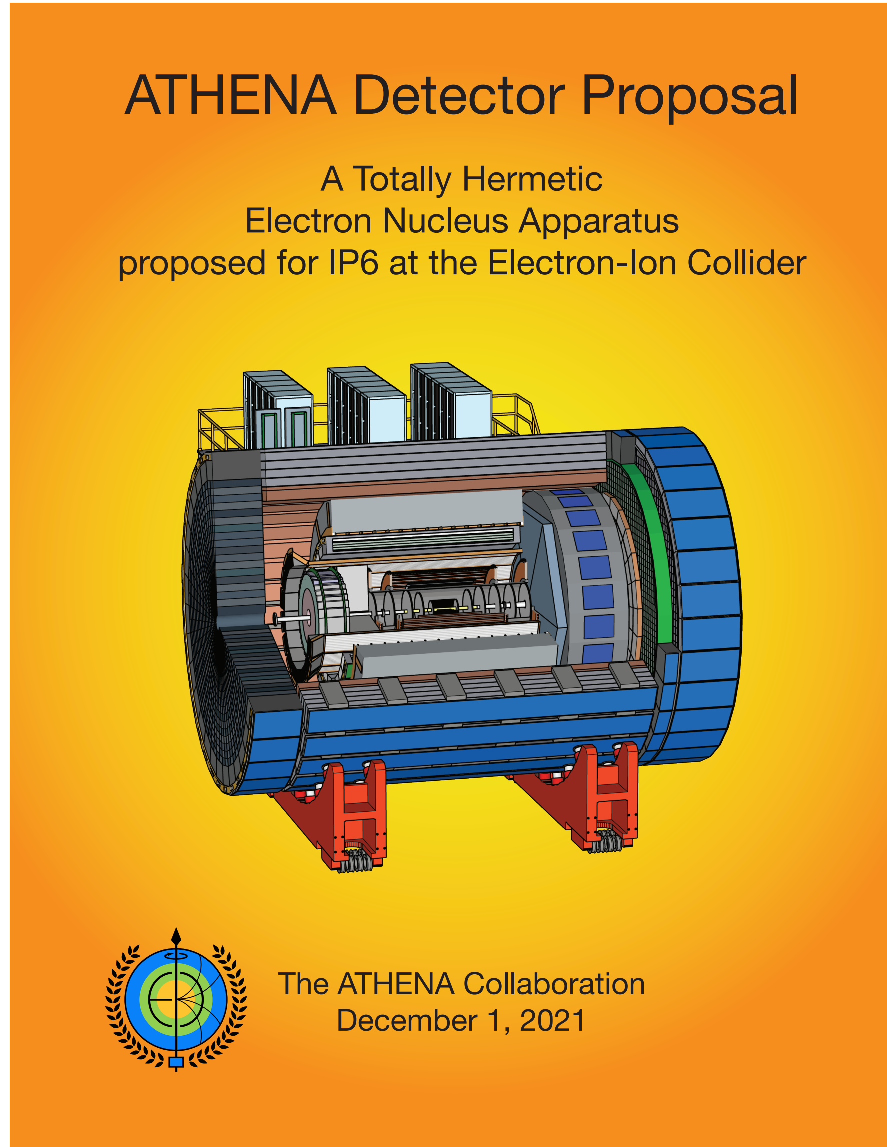


U.S. DEPARTMENT OF ENERGY | Office of Science

DOE NP contract: DE-SC0013405

Outline

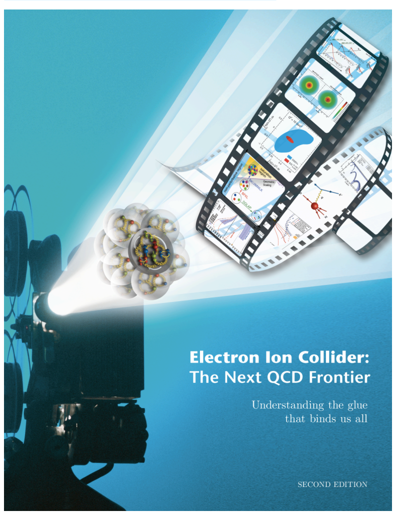
- Introduction
- ATHENA
  - Physics Highlights
  - Detector Layout
- EIC Project status
- Summary



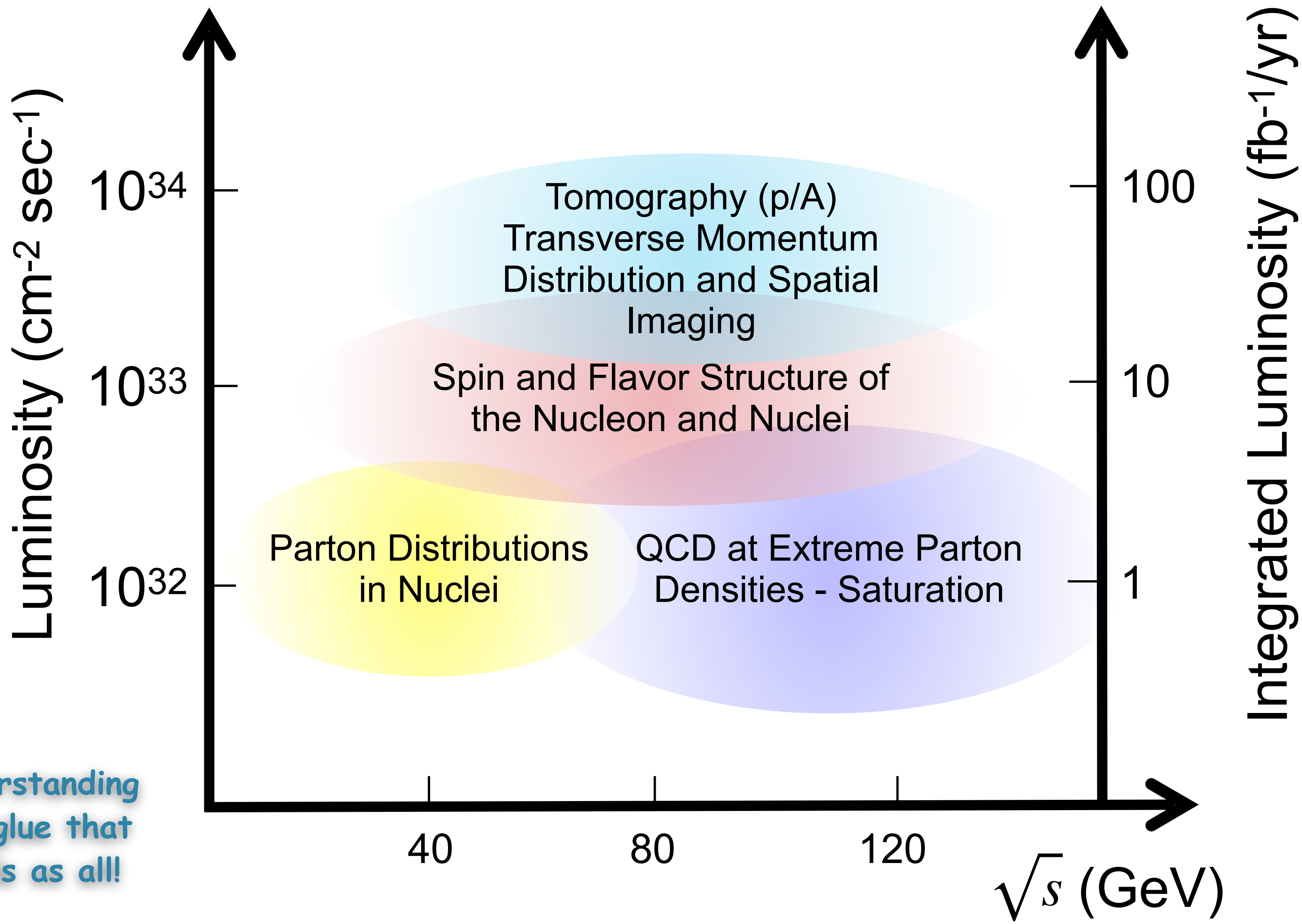
Introduction

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

arXiv:1212.1701

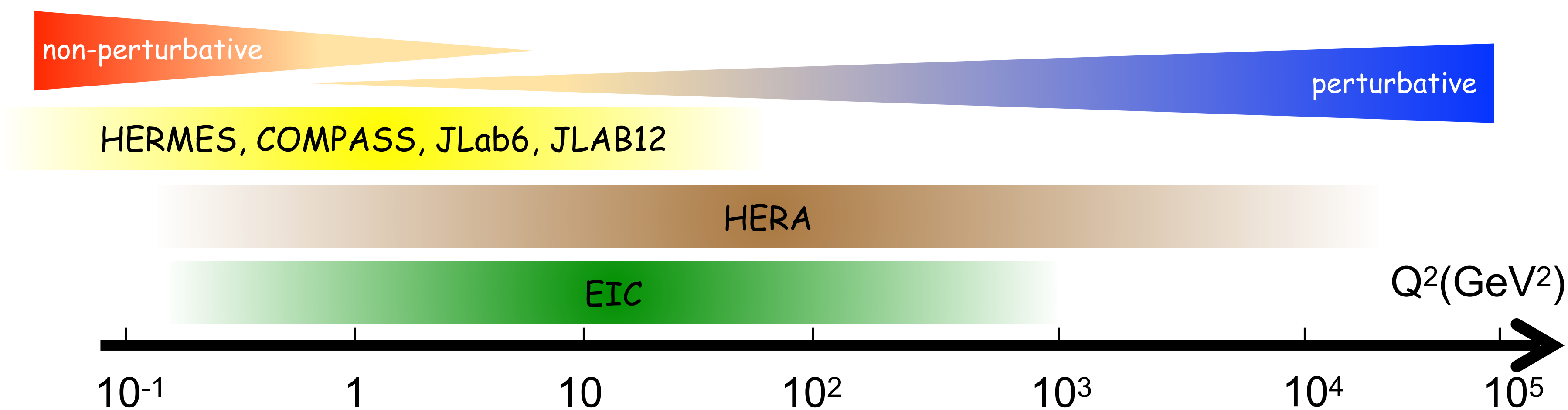


Understanding the glue that binds as all!



Introduction

- Requirements
  - Machine:
    - High luminosity: $10^{33}\text{cm}^{-2}\text{s}^{-1}$ - $10^{34}\text{cm}^{-2}\text{s}^{-1}$
    - 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



Introduction

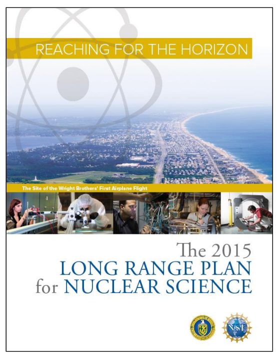
- Critical steps over the last couple of years - 1
  - INT Workshop series / Documentation of Physics Case - Whitepaper: "Understanding the glue that binds us all!"
    - INT Workshop: 2010
    - WP: 2012, updated in 2014 for LRP
  - 2015 Long-range plan (LRP):

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.

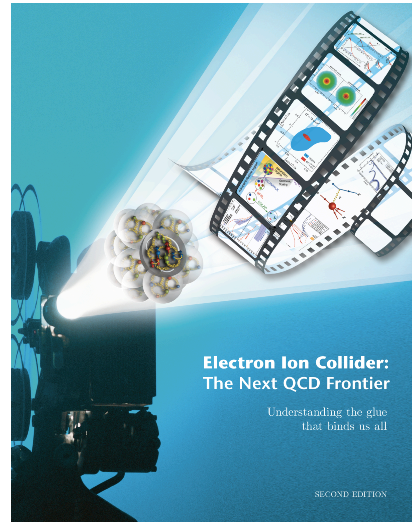


The FY 2018 Request supports progress in important aspects of the 2015 LRP Vision

U.S. DEPARTMENT OF ENERGY | Office of Science   NSAC Meeting   June 2, 2017   16

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

arXiv:1212.1701



Understanding the glue that binds as all!

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

Introduction

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

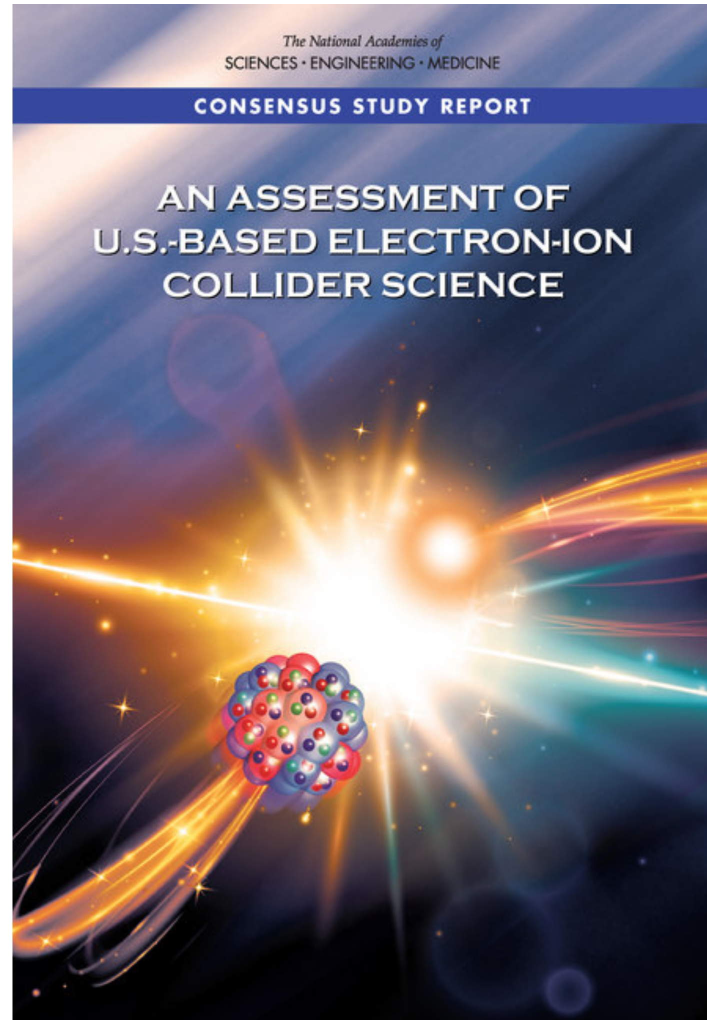
https://www.nap.edu/catalog/25171/an-assessment-of-us-based-electron-ion-collider-science

Download pdf-file of final report!

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

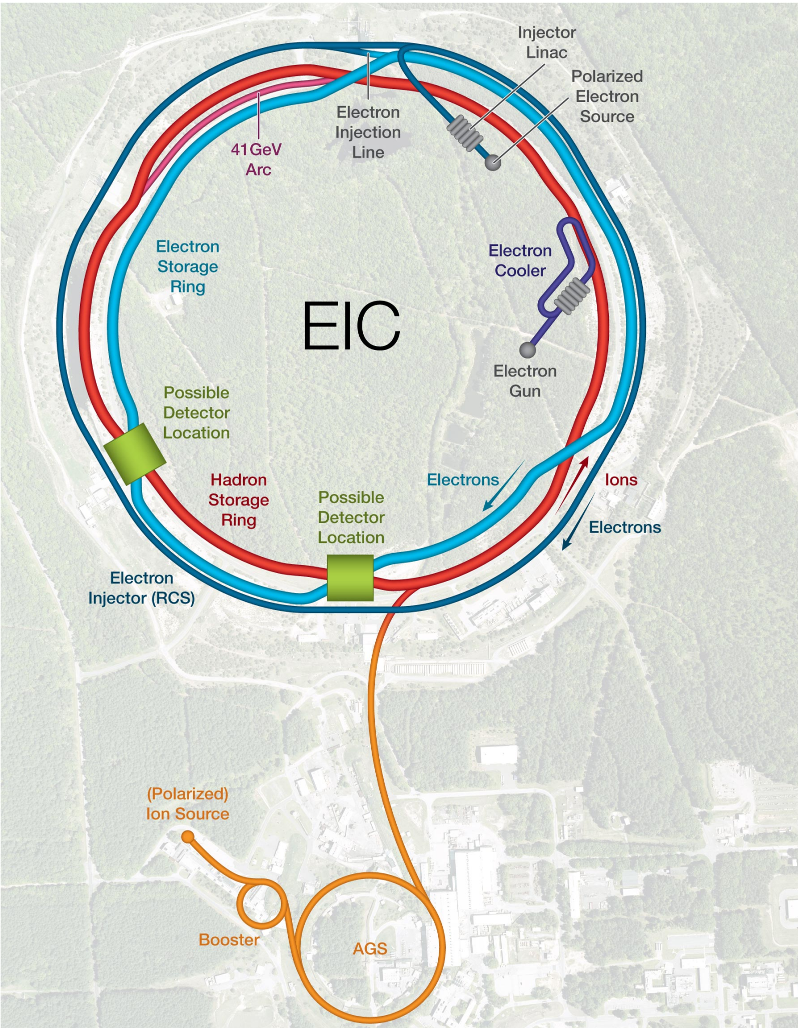
"The committee finds that the science that can be addressed by an EIC is compelling, fundamental and timely."

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

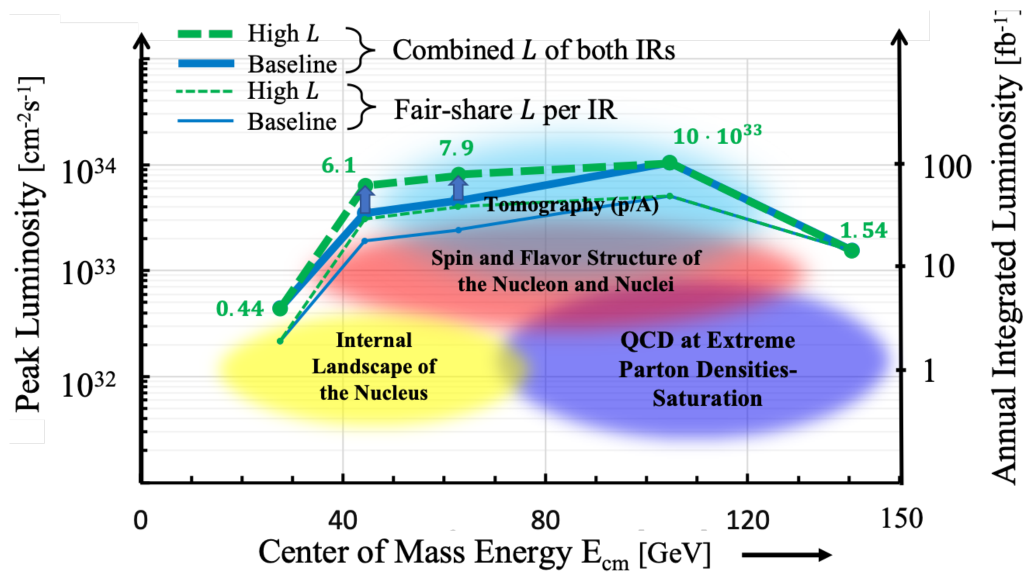


Introduction

- EIC accelerator design



Center of Mass Energies:	29GeV - 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!



Introduction

- Site Selection and award of DOE Critical Decisions 0 (CD-0) and 1 (CD-1)

https://www.energy.gov/articles/us-department-energy-selects-brookhaven-national-laboratory-host-major-new-nuclear-physics

Department of Energy

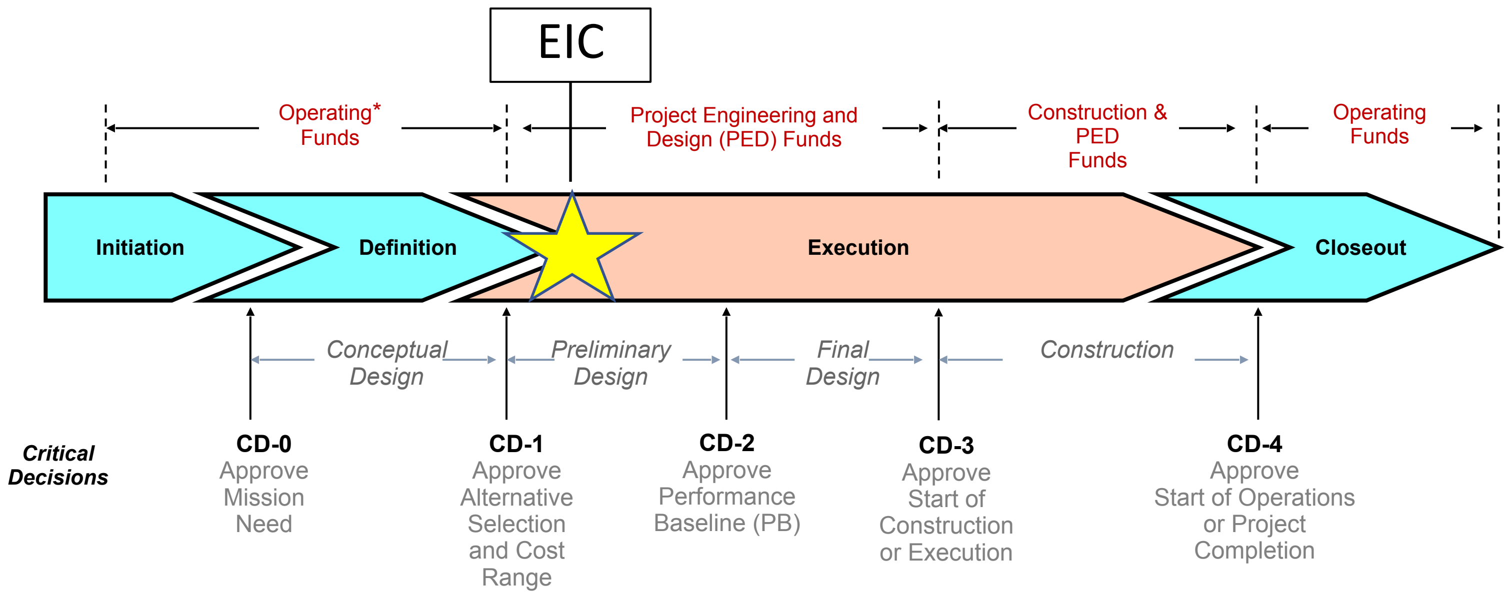
U.S. Department of Energy Selects Brookhaven National Laboratory to Host Major New Nuclear Physics Facility

JANUARY 9, 2020

WASHINGTON, D.C. – Today, the U.S. Department of Energy (DOE) announced the selection of Brookhaven National Laboratory in Upton, NY, as the site for a planned major new nuclear physics research facility. The Electron Ion Collider (EIC), to be designed and constructed over ten years at an estimated cost between $1.6 and $2.6 billion, will smash electrons into protons and heavier atomic nuclei in an effort to penetrate the mysteries of the “strong force” that binds the atomic nucleus together.

Critical Decision-0 (CD-0), “Approve Mission Need”, approved for the EIC on December 19, 2019.

Critical Decision-1 (CD-1), “Approve Alternative Selection and Cost Range”, was awarded for the EIC on June 29, 2021.



Introduction

- Press release by JLab and BNL

JEFFERSON LAB TO BE MAJOR PARTNER IN ELECTRON ION COLLIDER PROJECT

The Department of Energy announced that Jefferson Lab will collaborate on plans to build a future Electron Ion Collider in New York

NEWPORT NEWS, VA – The Department of Energy announced that it has taken the next step toward construction of an Electron Ion Collider (EIC) in the United States. DOE announced on Thursday that the collider will be sited at DOE's Brookhaven National Laboratory in Upton, N.Y. In addition, DOE's Thomas Jefferson National Accelerator Facility will be a major partner in realizing the EIC, providing key support to build this next new collider, which will be the most advanced particle collider of its type ever built.

https://www.jlab.org/news/releases/jefferson-lab-be-major-partner-electron-ion-collider-project

U.S. Department of Energy Selects Brookhaven National Laboratory to Host Major New Nuclear Physics Facility

January 9, 2020

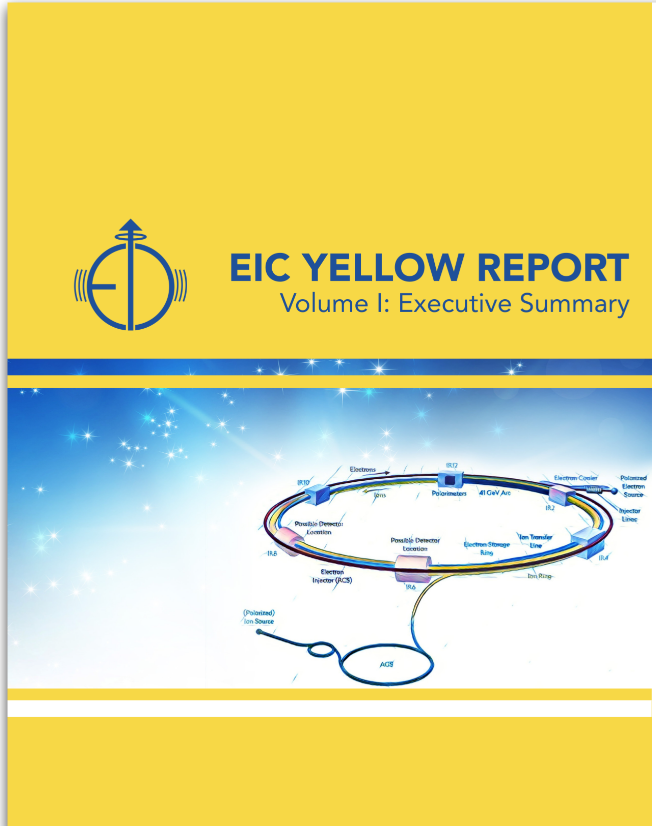
The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory will provide crucial infrastructure for the new Electron Ion Collider. + ENLARGE

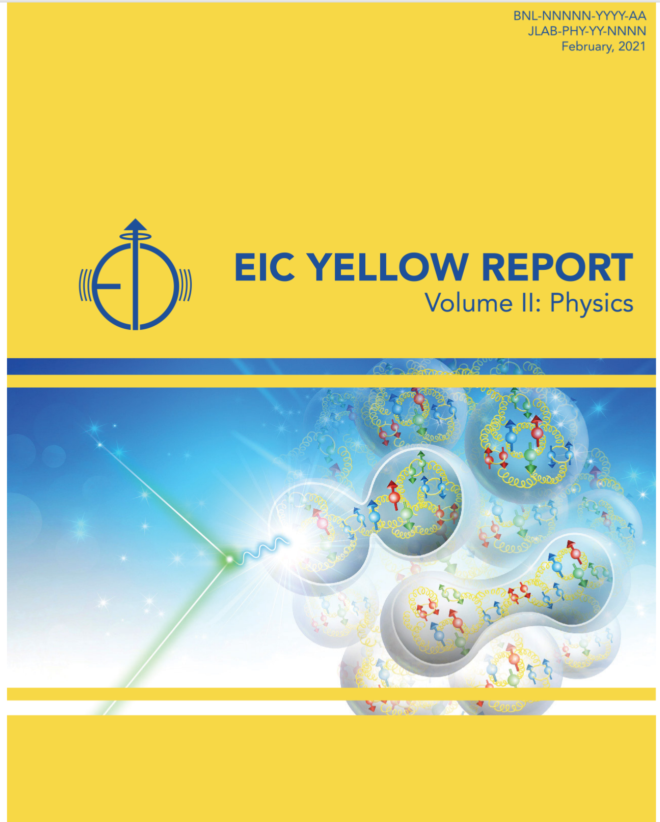
WASHINGTON, D.C. – Today, the U.S. Department of Energy (DOE) announced the selection of Brookhaven National Laboratory in Upton, NY, as the site for a planned major new nuclear physics research facility.

https://www.bnl.gov/newsroom/news.php?a=116996

Introduction

- Yellow Report Activity - Critical EIC Community activity for CD-1



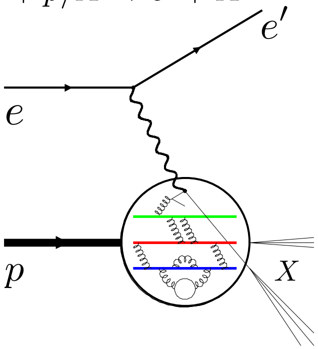


- ~400 authors / ~150 institutions / ~900 pages with strong international contributions!
- Review: Community review within EICUG and external readers (~30) worldwide covering physics and detector expert fields!
- Available on archive: https://arxiv.org/abs/2103.05419

Introduction

Overview of processes and final states

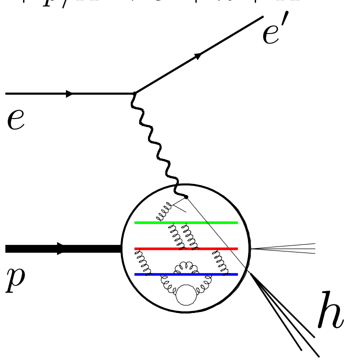
$e + p/A \rightarrow e' + X$

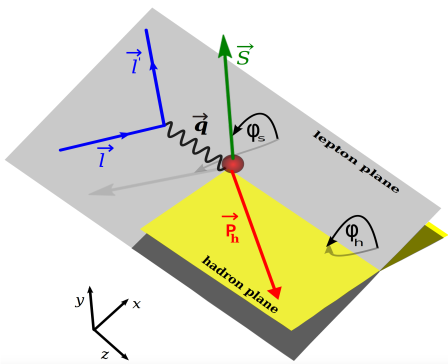


Inclusive DIS

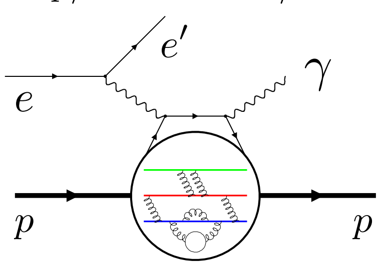
Semi-Inclusive DIS (SDIS)

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





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



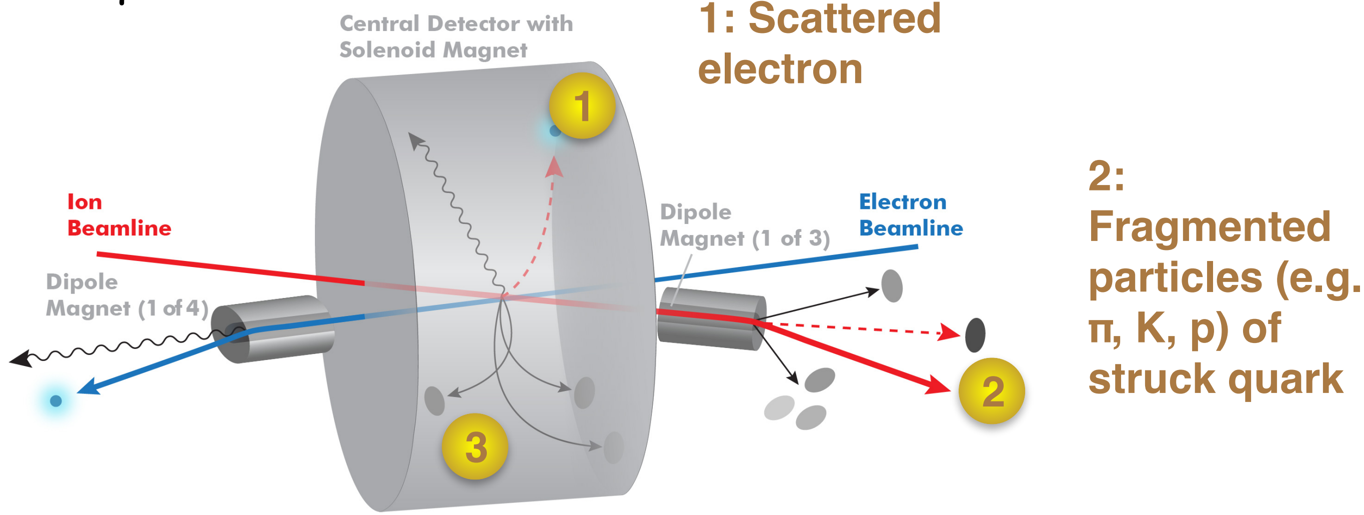
Deeply-Virtual Compton Scattering (DVCS)

- 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)

Introduction

Overview of general requirements

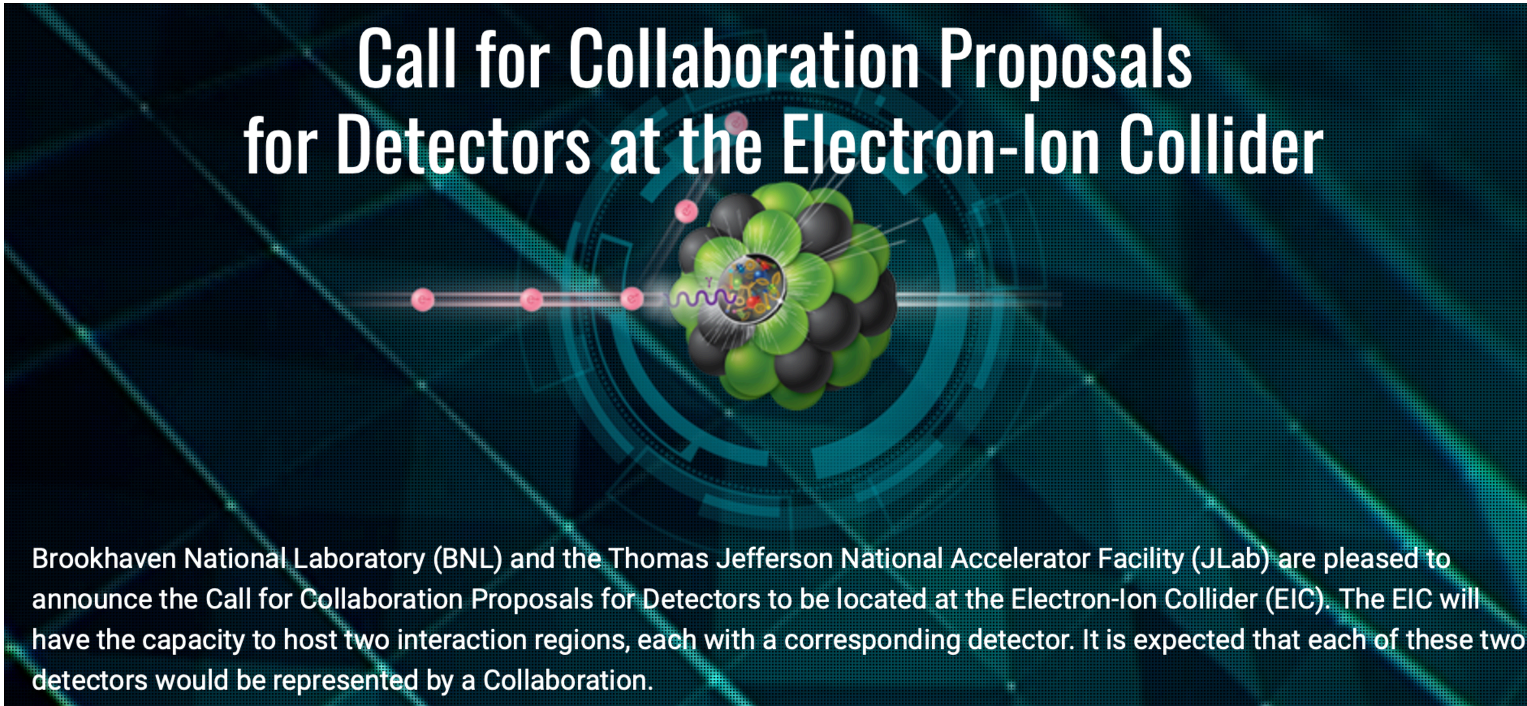
arXiv:1212.1701



- Acceptance: Close to 4π coverage with a η-coverage ($\eta = -\ln(\tan(\theta/2))$) of approximately $\eta < |3.5|$ combined calorimetry (EM CAL and hadron CAL at least in forward direction) and tracking coverage
- Low dead material budget in particular in rear direction (~5% X/X_0)
- Good momentum resolution $\Delta p/p$ ~ few %
- Electron ID for e/h separation varies with θ / η at the level of $1:10^4$ / ~2-3%/$\sqrt{E}$ for $\eta<-2$ and ~7%/$\sqrt{E}$ for $-2<\eta<1$
- 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-angel 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

Introduction

- Open Call for Detector Proposals



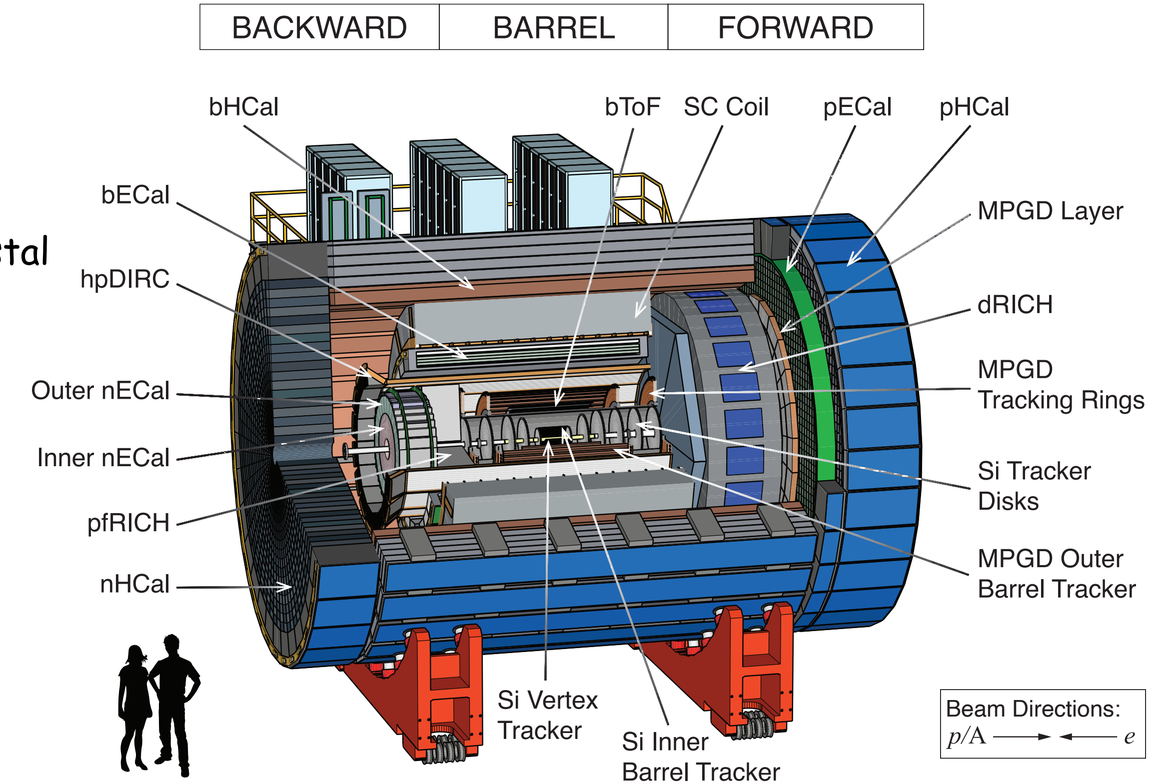
ATHENA: A Totally Hermetic Electron-Nucleus Apparatus
Concept: General purpose detector inspired by the YR studies based on a new central magnet of up to 3T
WWW-page: https://www.athena-eic.org

CORE: COmpact detectoR for the Eic
Concept: Nearly hermetic, general-purpose compact detector, 2T baseline
WWW-page: https://userweb.jlab.org/~hyde/EIC-CORE/

ECCE: EIC Comprehensive Chromodynamics Experiment
Concept: General purpose detector based on 1.5T BaBar magnet
WWW-page: https://www.ecce-eic.org

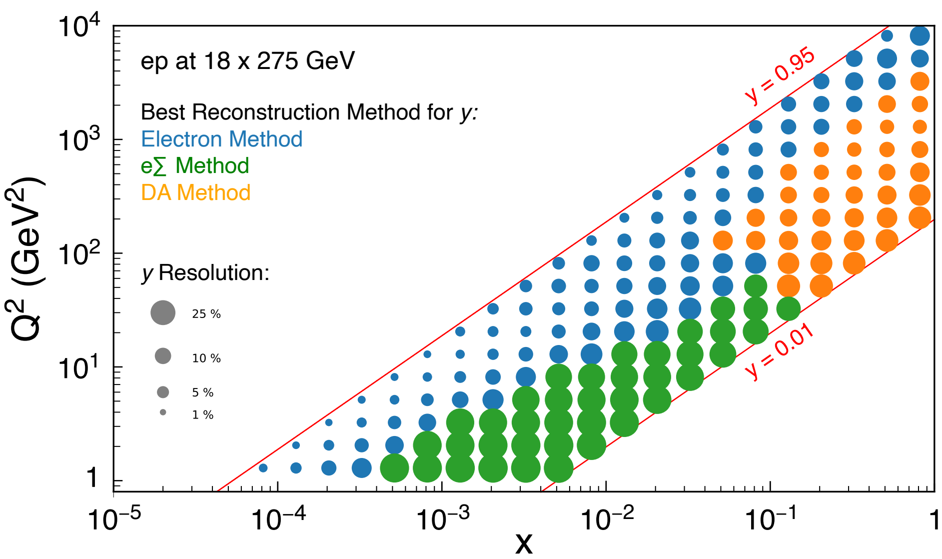
ATHENA - Overview

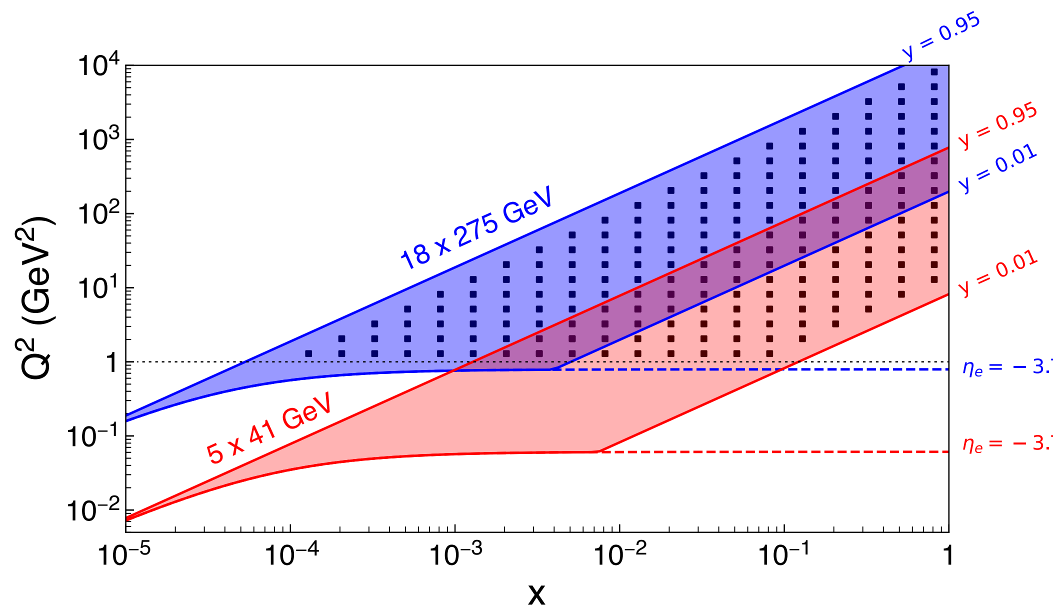
- Highlights of ATHENA design
  - Large-bore 3T solenoid
  - Hybrid tracking: Silicon pixel sensors and state-of-the-art MPGDs
  - Calorimetry: Backward high-resolution crystal calorimeter / Barrel novel hybrid imaging/ sampling EM calorimeter / Forward high-energy jet reconstruction
  - PID: Large bore allows for layered, complementary, state-of-the-art PID technologies
  - Dedicated FarBackward (Luminosity and low-Q^2 tagger) and FarForward detector systems



ATHENA - Physics Highlights

Kinematic Acceptance



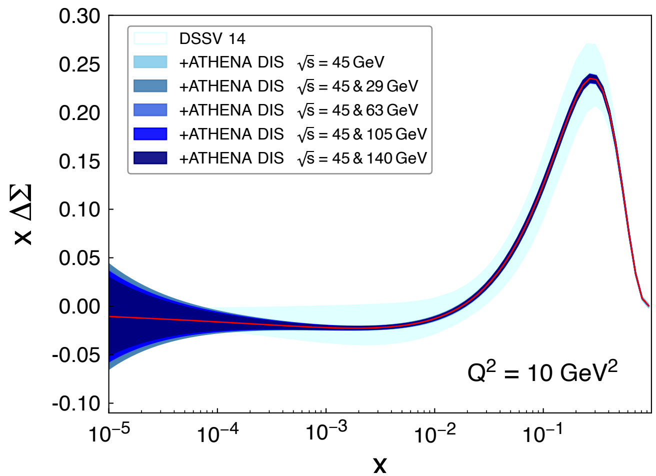


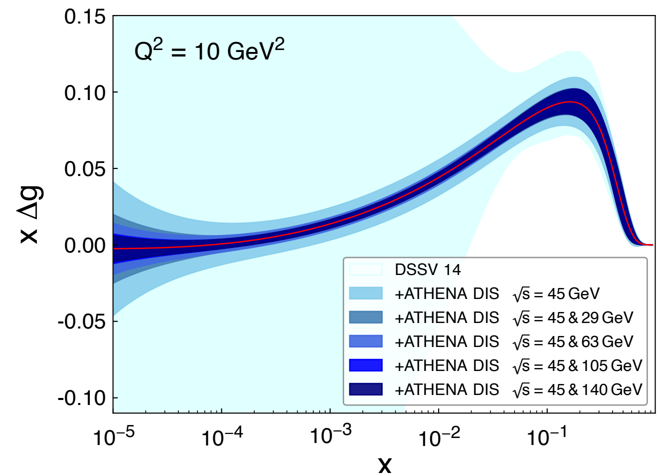
- Kinematic coverage and y-resolution studies
- Optimized reconstruction methods

- Kinematic coverage for the largest (18GeV X 275GeV) and smallest (5GeV X 41GeV) center-of-mass energies
- Simulated measurements shown for $Q^2 > 1\text{GeV}^2$ and $0.01 < y < 0.95$

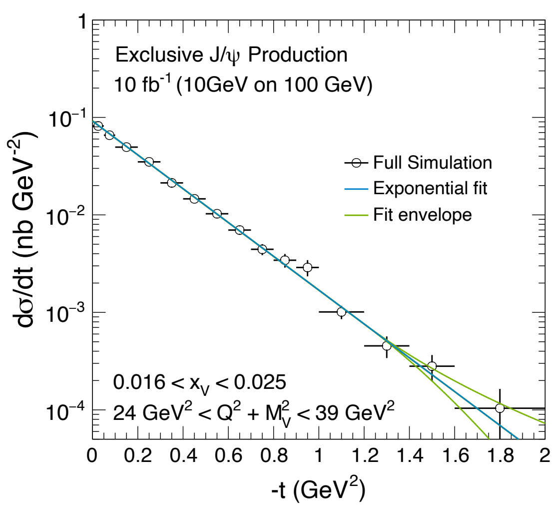
ATHENA - Physics Highlights

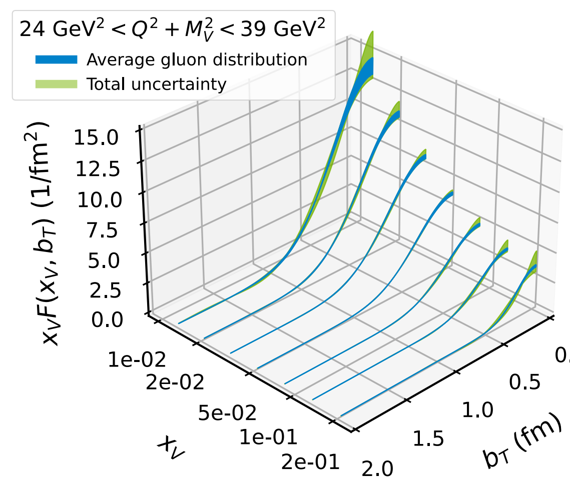
- Helicty measurements: Singlet quark distribution and Gluon helicity distribution





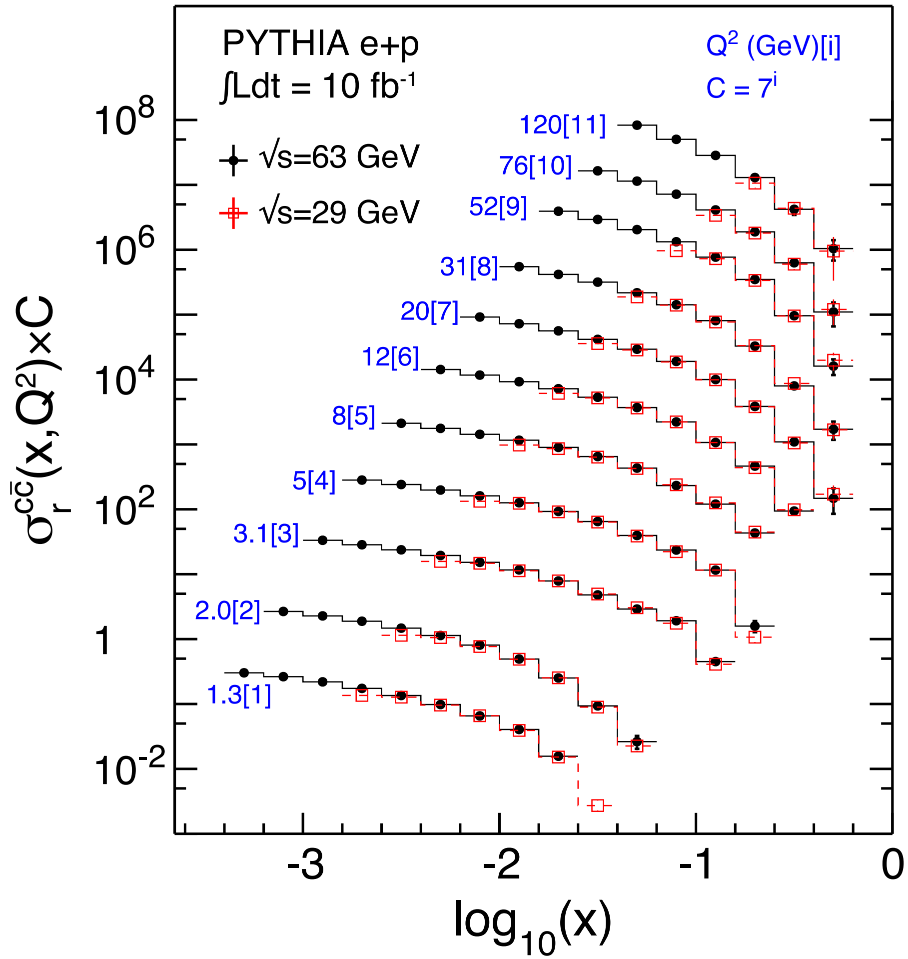
- GPD measurements through elastic electroproduction of J/Psi measurements

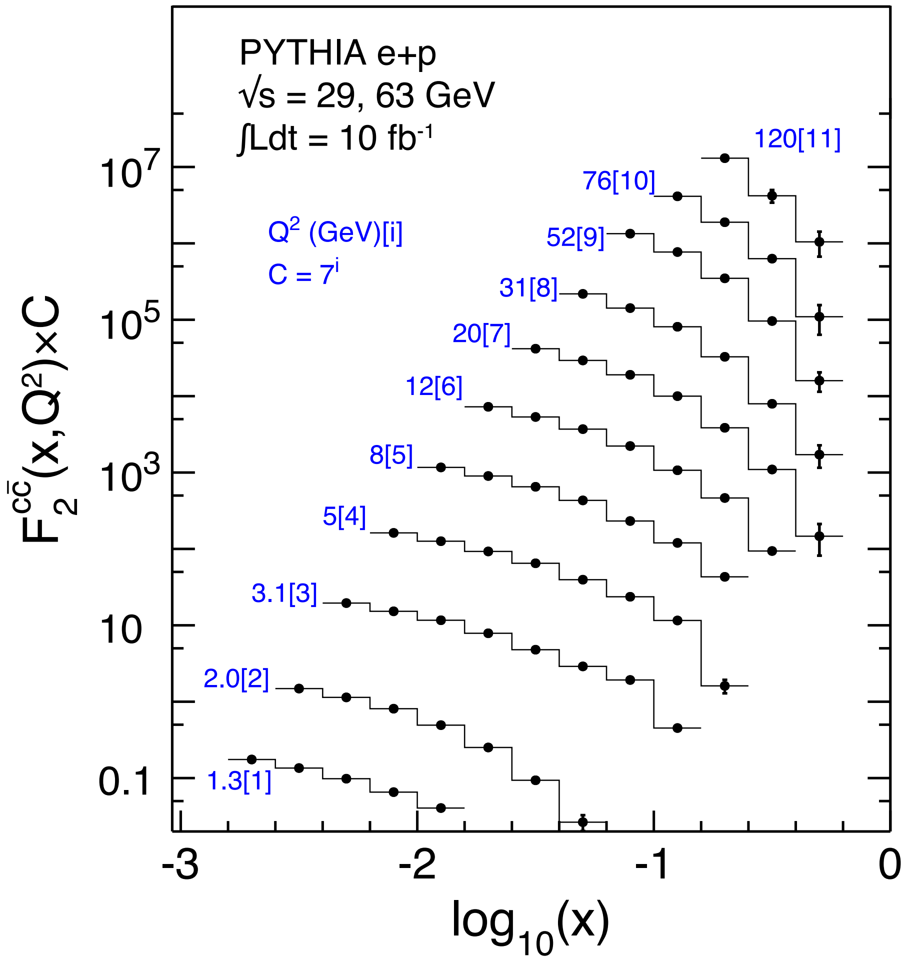




ATHENA - Physics Highlights

- Reduced charm cross-section and F_2 - Gluon density probe for ep (Shown!) vs. eA





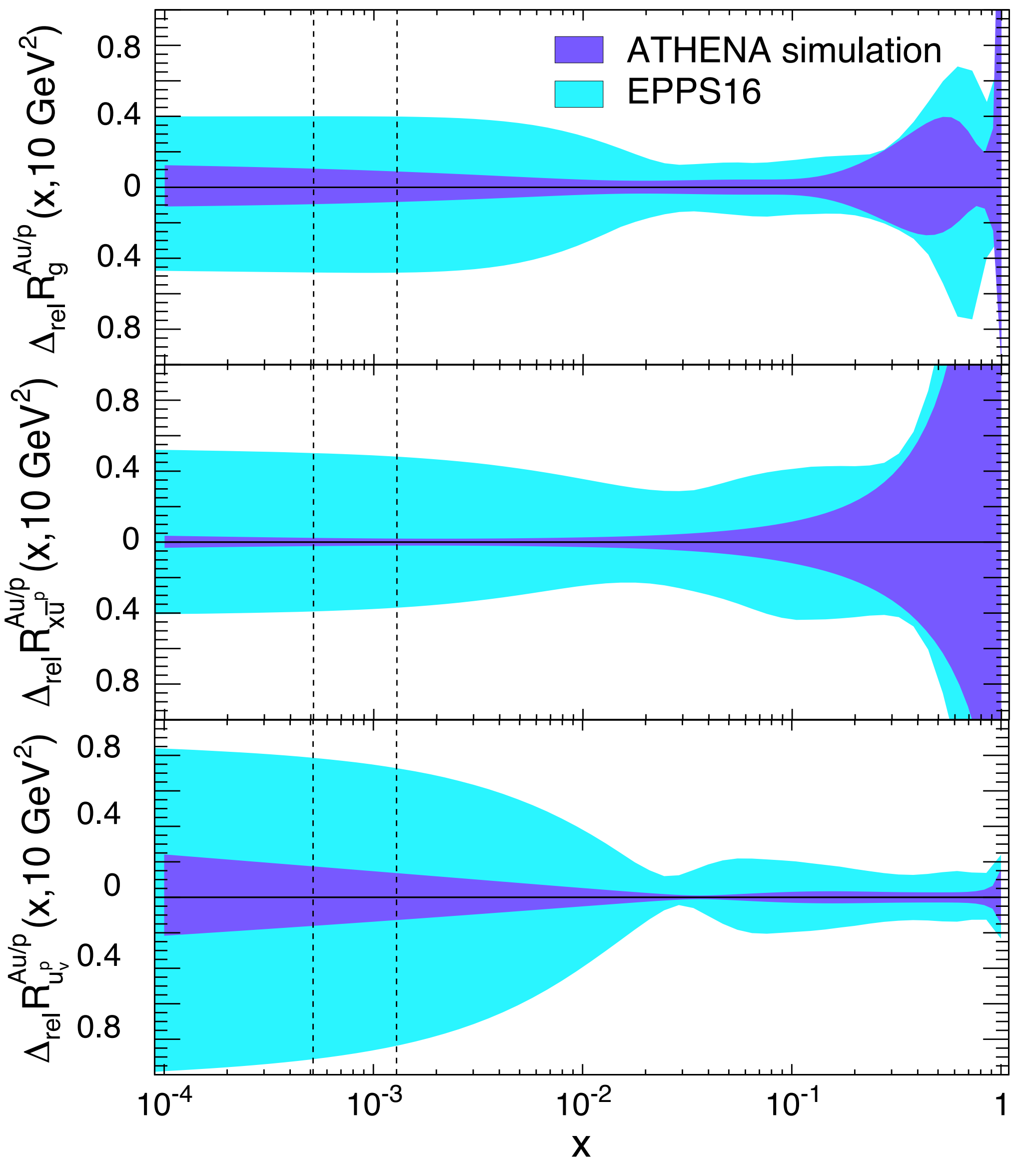
ATHENA - Physics Highlights

- Probing nuclear pdf's

Gluons

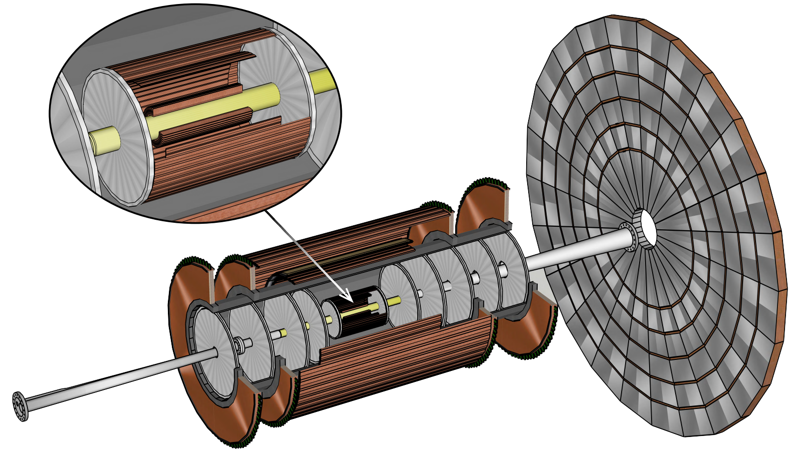
Sea u-quarks

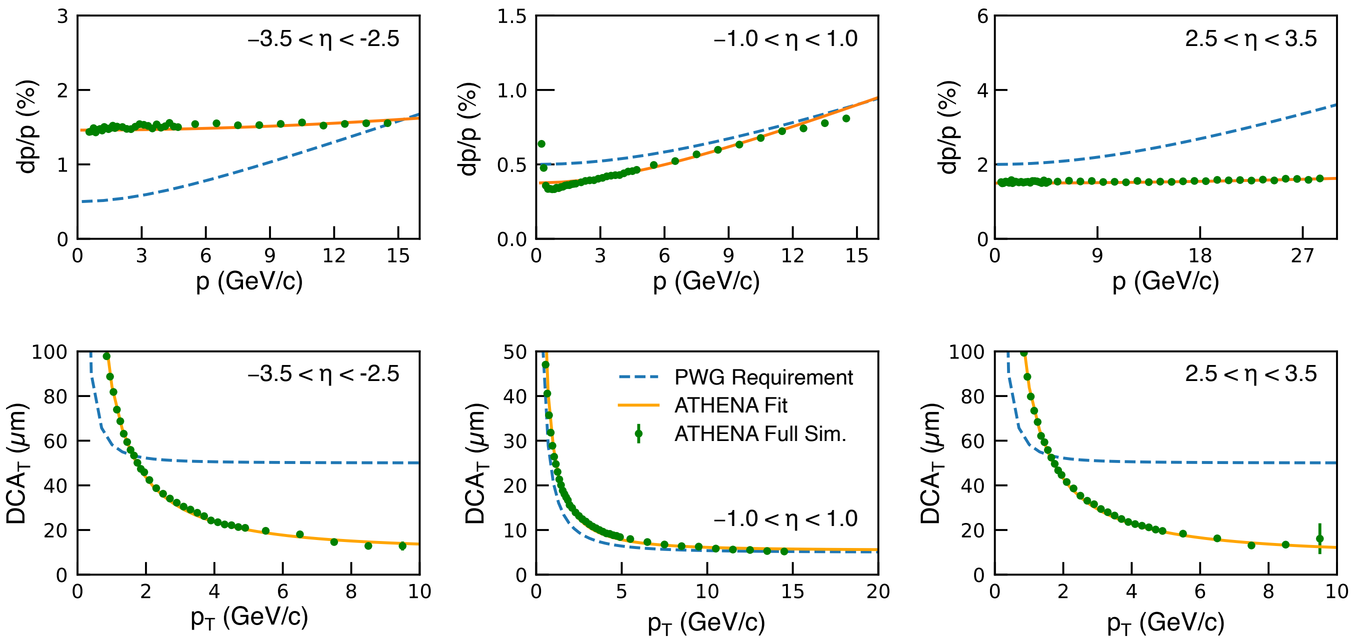
Valence u-quarks



ATHENA - Detector Layout

- ATHENA Tracking
  - Complimentary silicon and MPGD technologies: Cost-effective with high momentum, angular, and vertex resolution / Large acceptance
  - Backward tracker: 5 Si disks / 2 micro RWell rings
  - Barrel tracker: 3 Si vertex layers / 2 Si barrel layers / 2 X 2 MicroMegas layers
  - Forward Tracker: 6 Si disks / 2 micro RWell rings / 1 Large micro RWell tracker behind dRICH

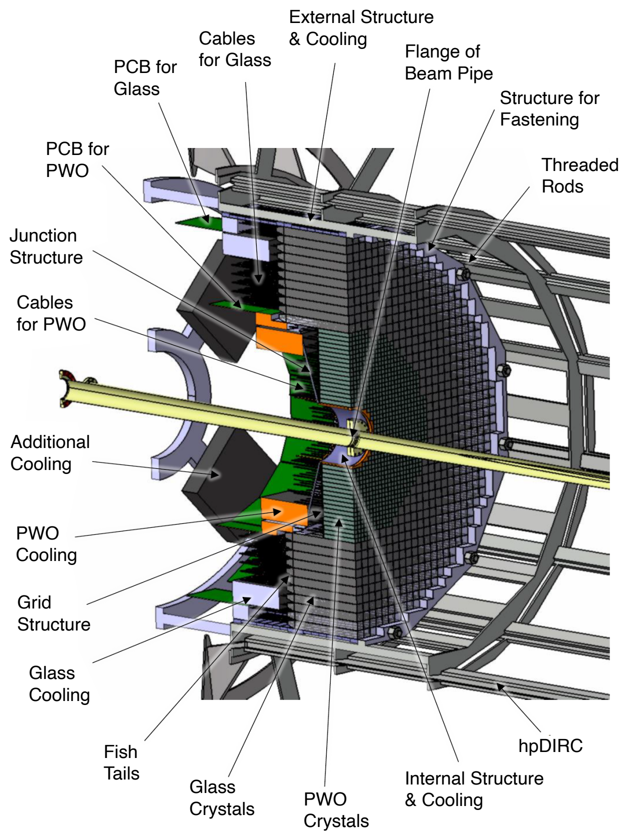


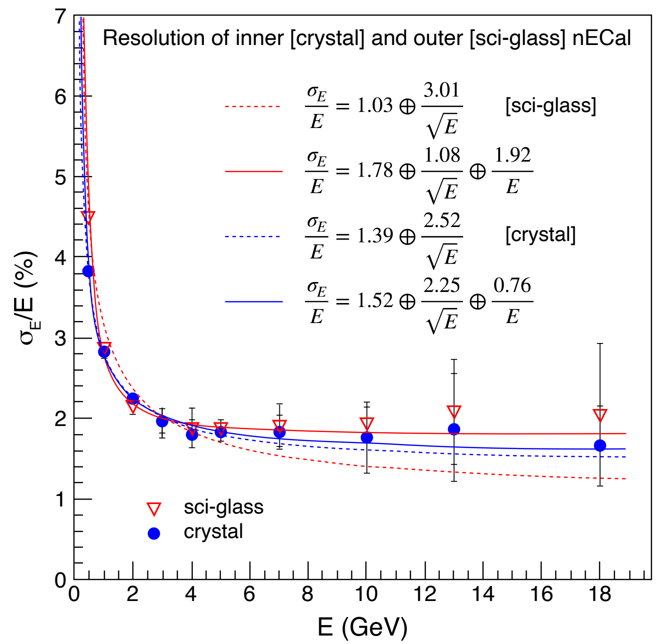


ATHENA - Detector Layout

ATHENA Calorimetry

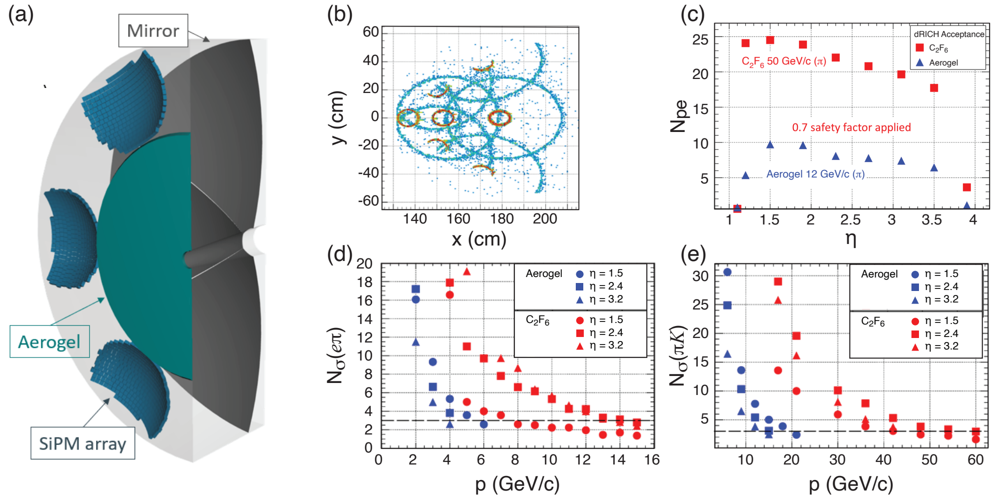
- **Backward calorimetry**: EMCAL Hybrid $PbWO_4$ inner crystals / SciGlass outer blocks - Readout via SiPMs and HCAL (Fe/Sci)
- **Barrel calorimetry**: EMCAL Hybrid design of Pb/ScFi layers and imaging silicon sensors and HCAL (Fe/Sci)
- **Forward calorimetry**: EMCAL W powder embedded with ScFi and HCAL (STAR forward HCAL)

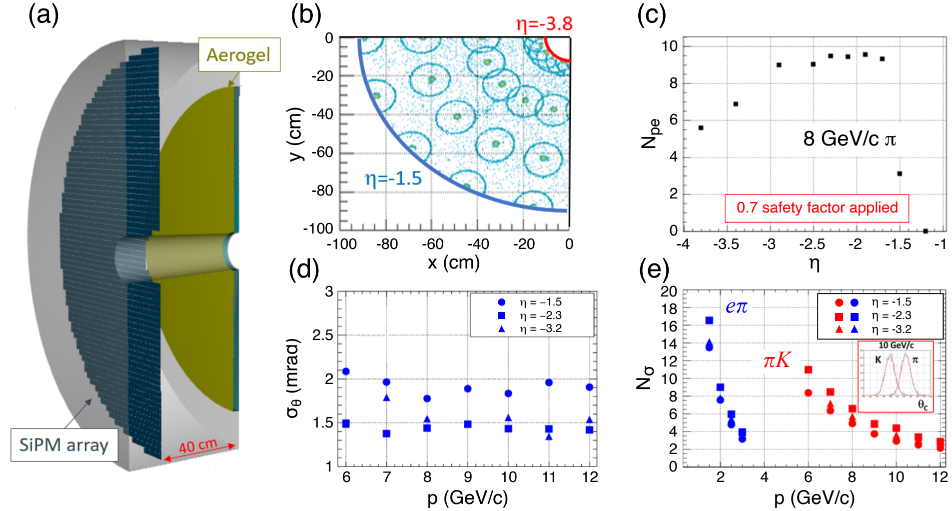




ATHENA - Detector Layout

ATHENA PID

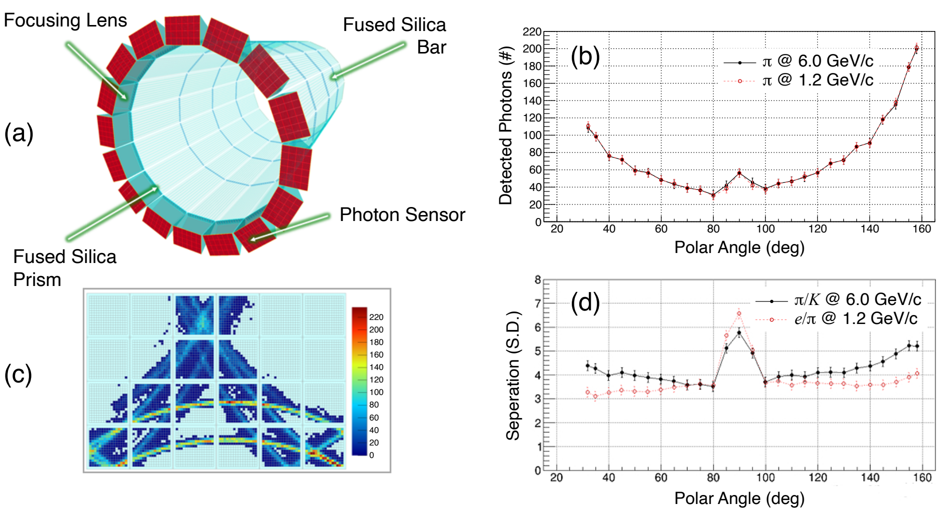


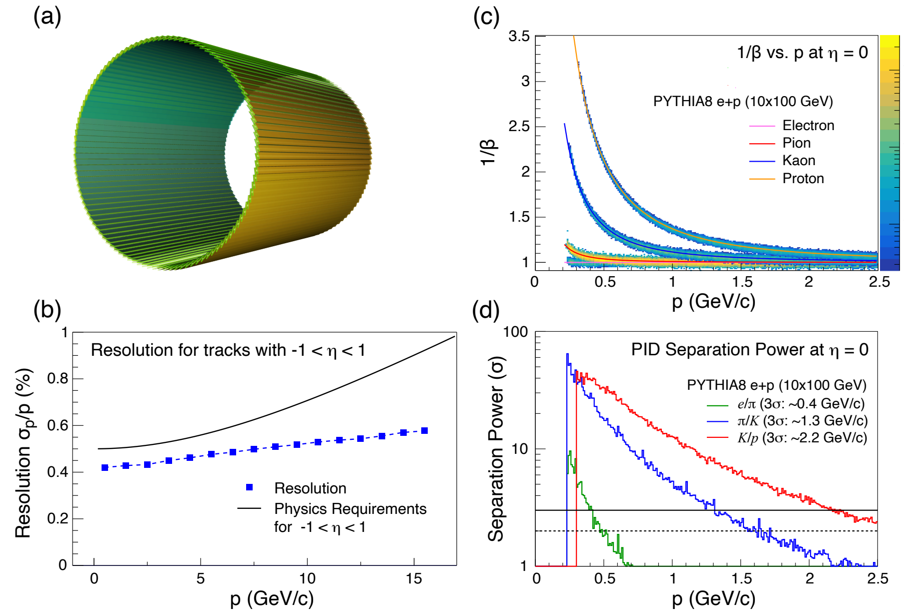


- Forward PID: Dual-radiator RICH (dRICH) utilizing aerogel and gas radiators focused by mirrors onto a focal plane instrumented with SiPMs
- Backward PID: Proximity-focusing aerogel RICH (pfRICH) featuring minimal material budget, easy pattern recognition, large acceptance

ATHENA - Detector Layout

ATHENA PID

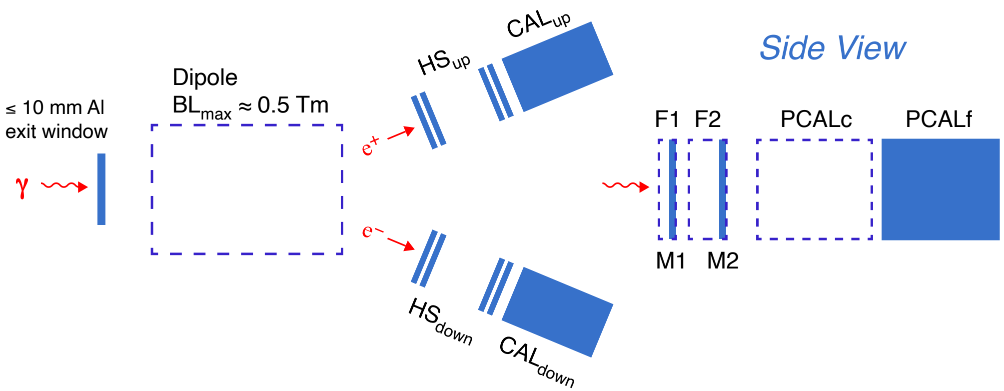


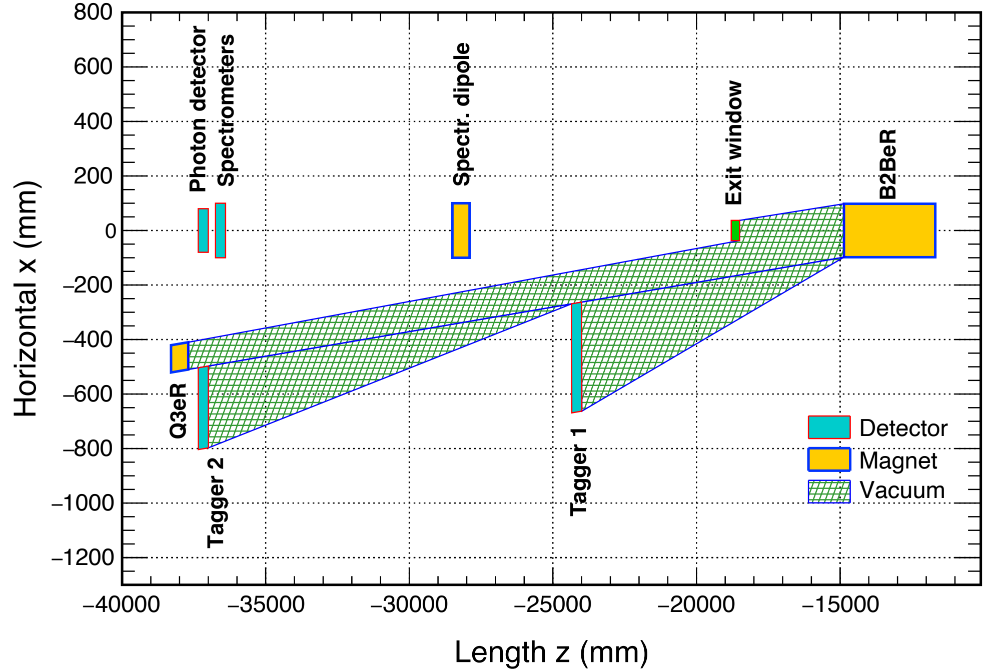


- Barrel PID: 100-cm radius high-performance DIRC (hpDIRC) with re-use of Babar bars, complemented by a
- Barrel PID: AC-LGAD Tof detector at 52.5cm radius

ATHENA - Detector Layout

ATHENA FarBackward system





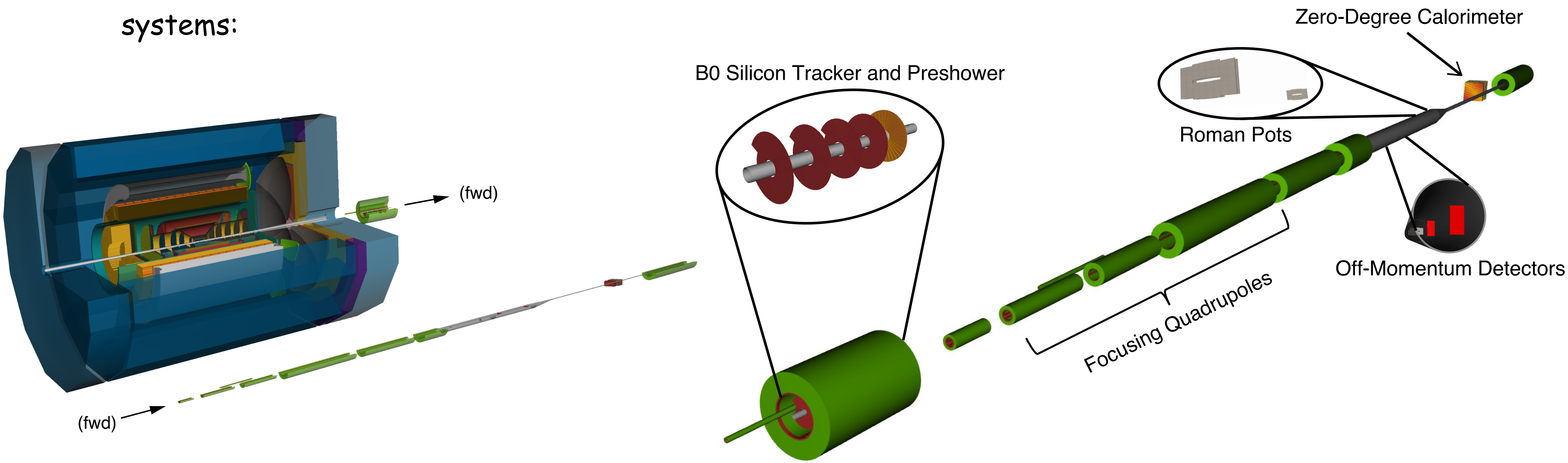
- High precision luminosity measurement at 1% level for absolute luminosity and 0.01% for relative luminosity measurement using several methods based on the Bremsstrahlung process:
  1. Counting photons converted in thin exit window using dipole field and measuring e^+e^- pairs
  2. Energy measurement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

2. Two low Q2 taggers

ATHENA - Detector Layout

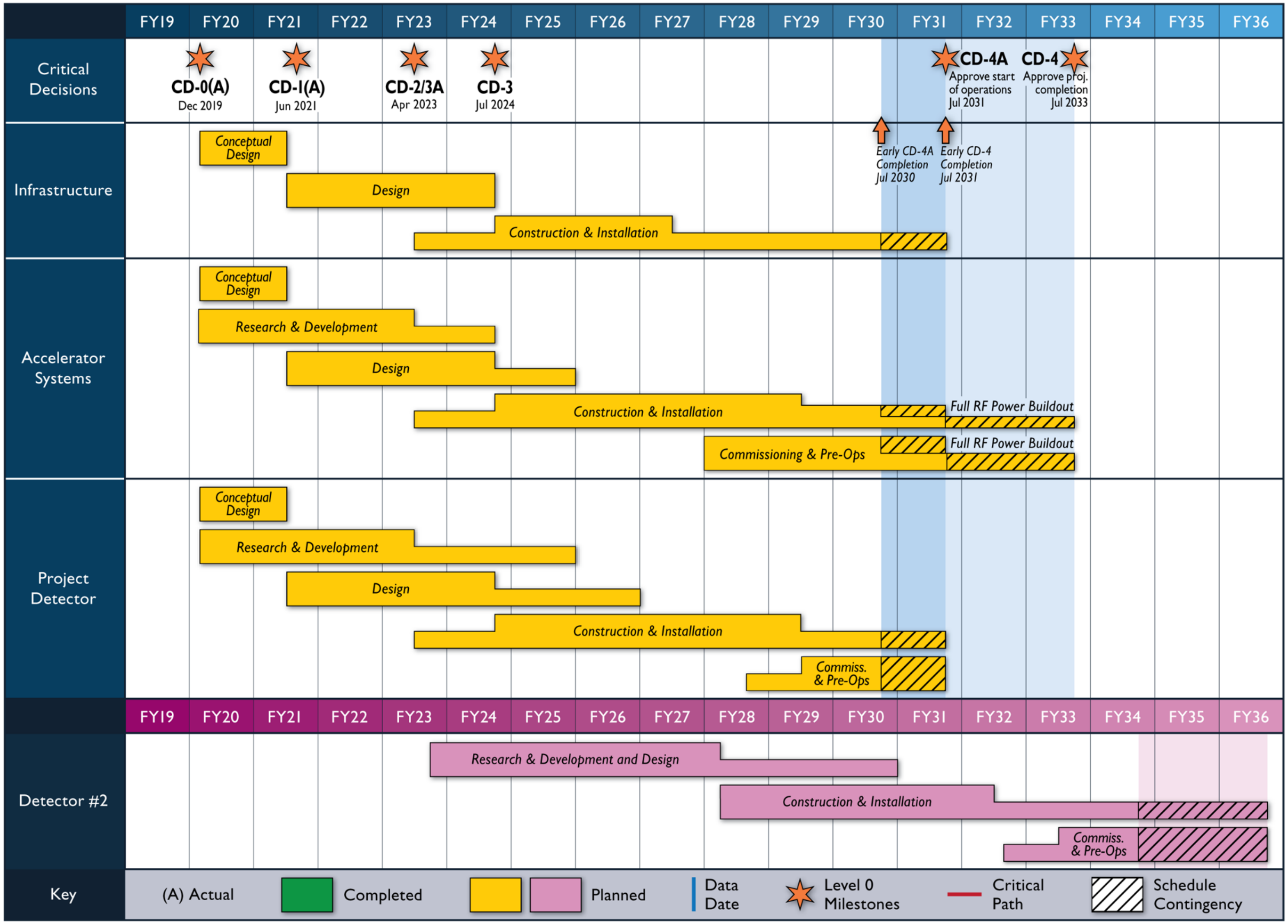
- ATHENA FarForward system
  - FarForward detector system to measure very forward neutral and charged particle production: 4 detector systems:

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)



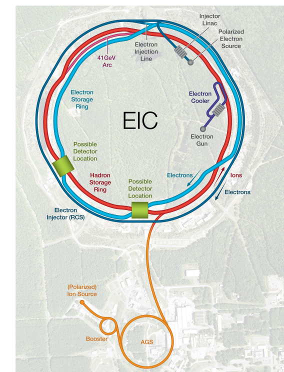
EIC Project Status

- Schedule



Summary and Next Steps

- Review of EIC detector proposals concluded in March 2022
- Merging of ATHENA and ECCE proposal efforts forming a new collaboration (DETECTOR 1) - Ongoing process!
- 2nd experiment (DETECTOR 2) planned on a different timescale, e.g. CORE proposal!
- Preparation of CD-2/3A:
    - Review (expected) requires pre-TDR: ~October 2023*
    - Award: ~January 2024*
- CD-3 (expectation): ~April 2025*



- 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!

* Taking into account constraints from Continuing Resolution of US budget discussions!