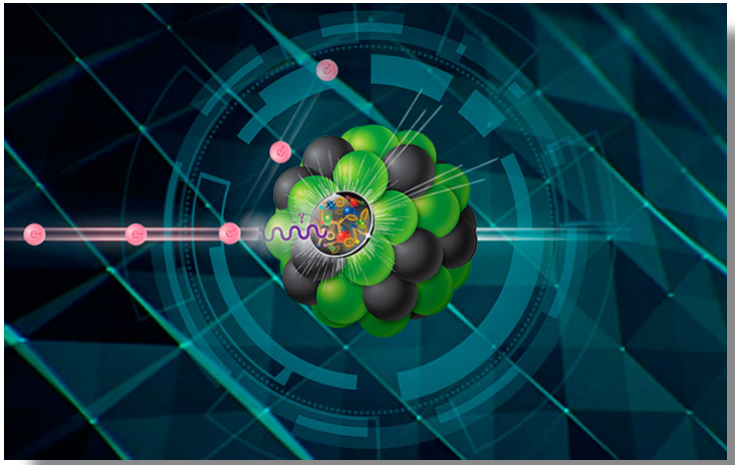
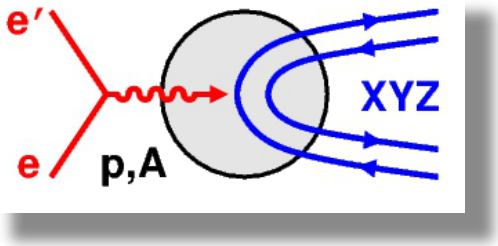
ePIC Detector Overview at the Electron-Ion Collider

Bernd Surrow

TEMPLE UNIVERSITY

On behalf of the ePIC Collaboration



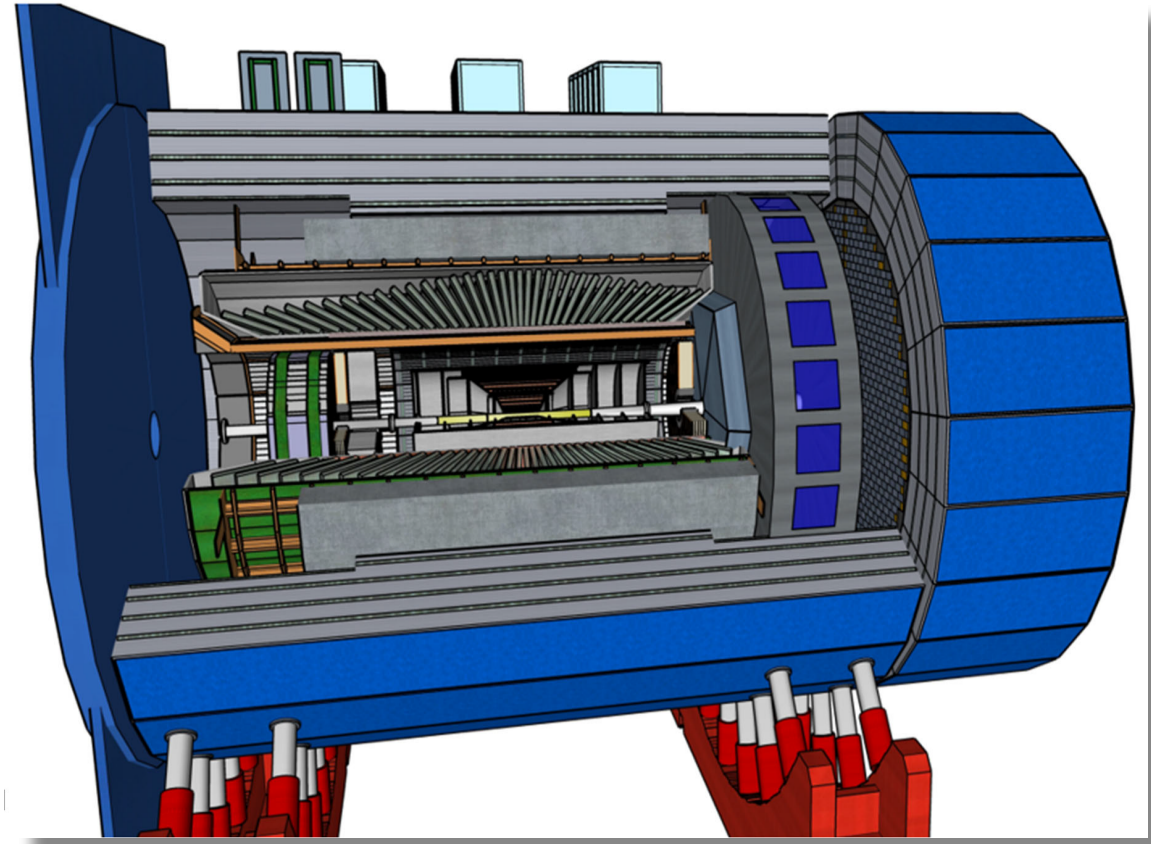


U.S. DEPARTMENT OF ENERGY | Office of Science

DOE NP contract: DE-SC0013405

Outline

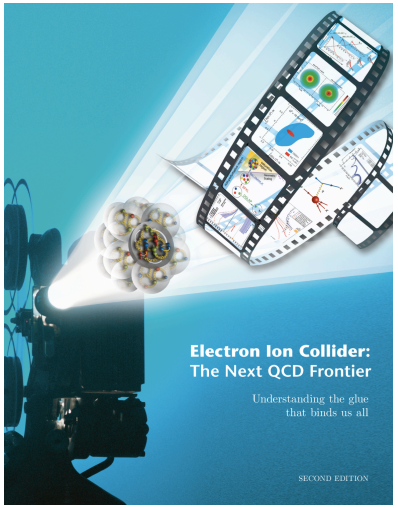
- Introduction
- ePIC detector
  - Layout
  - Collaboration
  - Overview of Sub-systems
- EIC Project status
- Summary



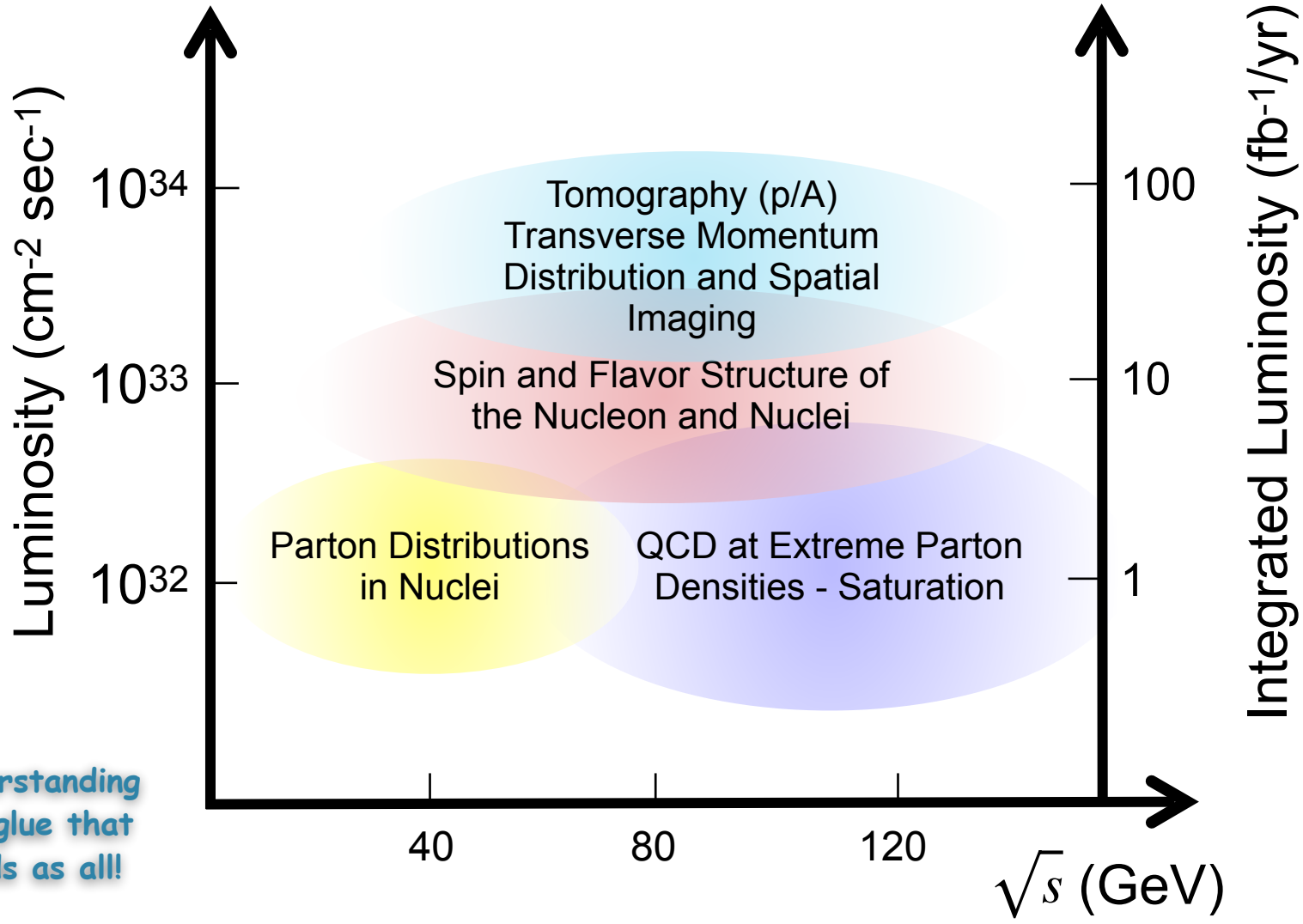
EIC Physics Pillars

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

arXiv:1212.1701

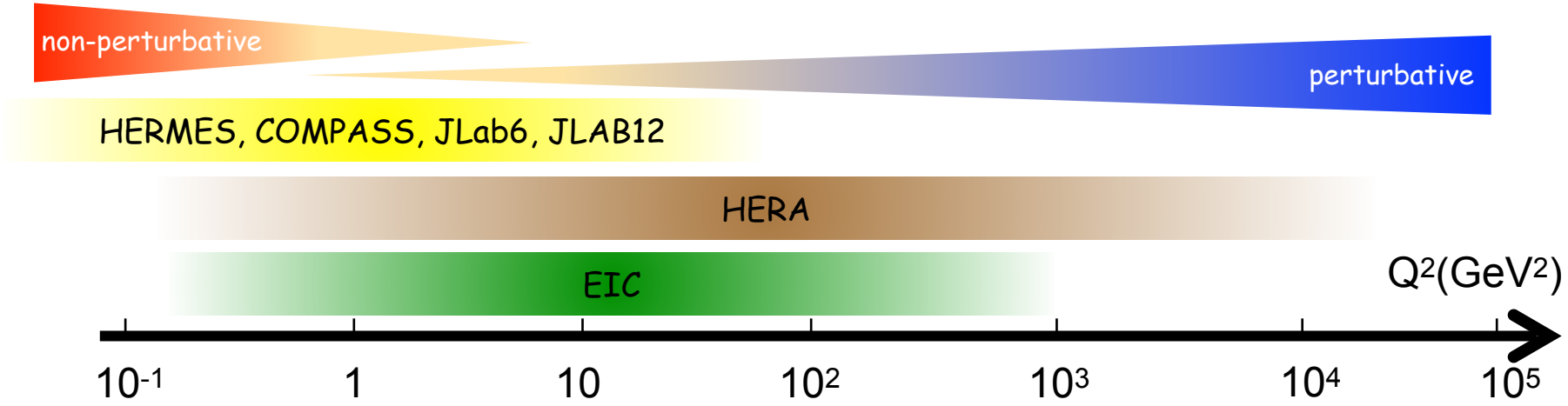


Understanding the glue that binds as all!



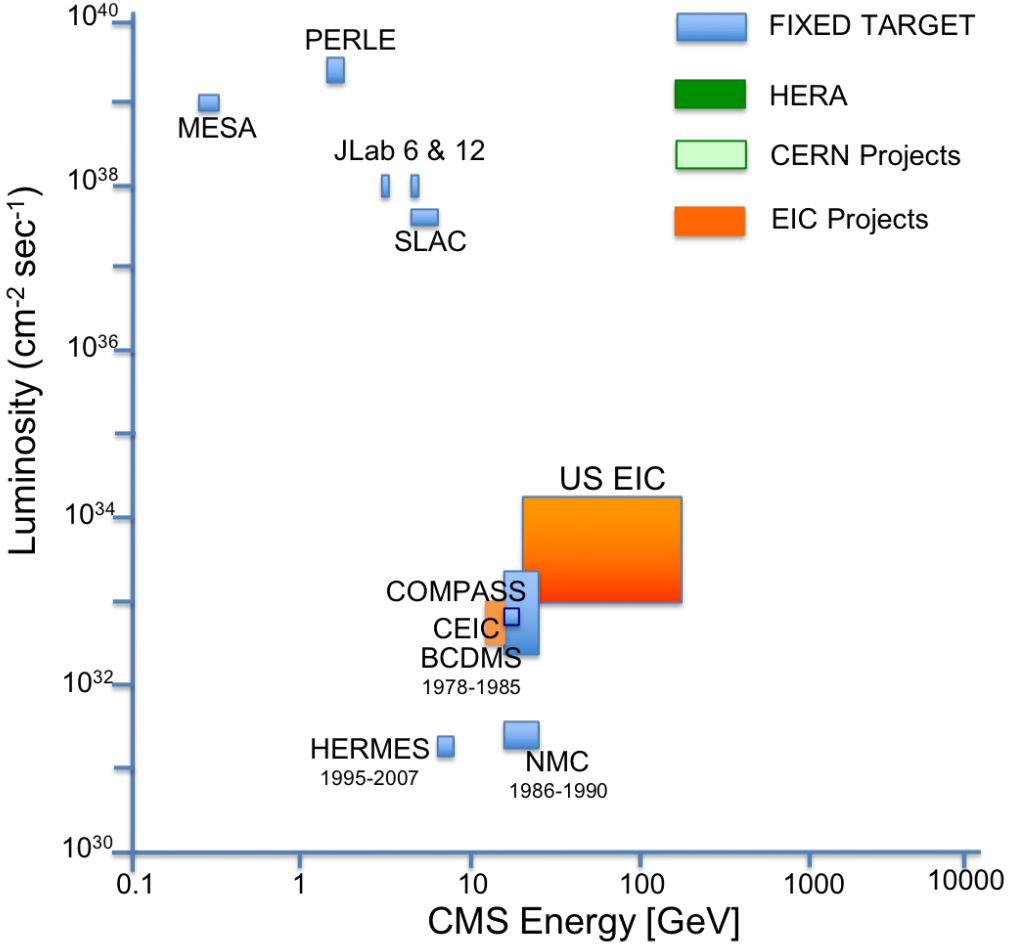
EIC Physics Pillars

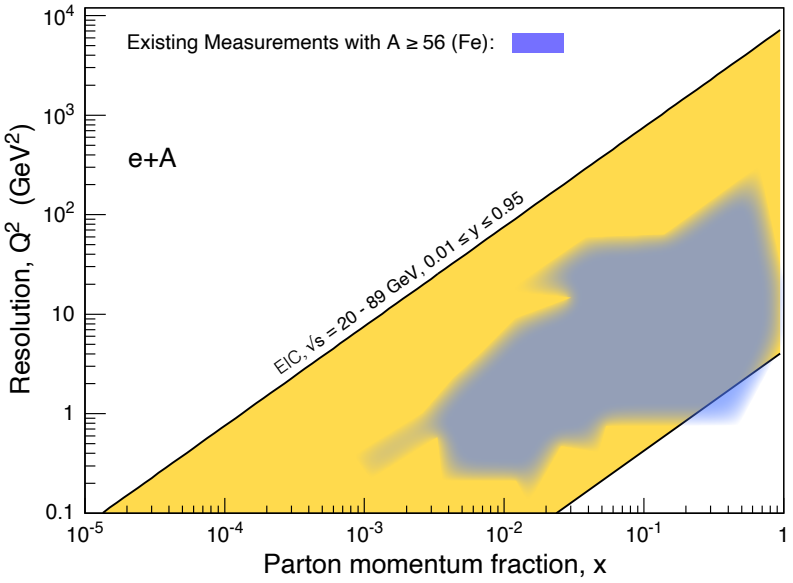
- Requirements
  - Machine:
    - High luminosity: $10^{33}cm^{-2}s^{-1}$ - $10^{34}cm^{-2}s^{-1}$
    - Flexible center-of-mass energy $\sqrt{s} = \sqrt{4\,E_e\,E_p}$: Wide kinematic range $Q^2 = s\,x\,y$
    - Highly polarized electron (0.8) and proton / light ion (0.7) beams: Spin structure studies
    - 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



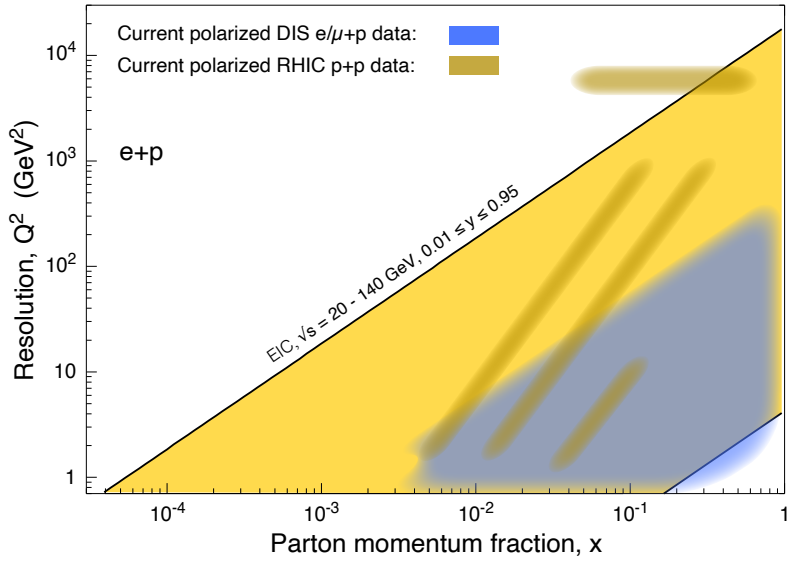
EIC Physics Pillars

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





eA

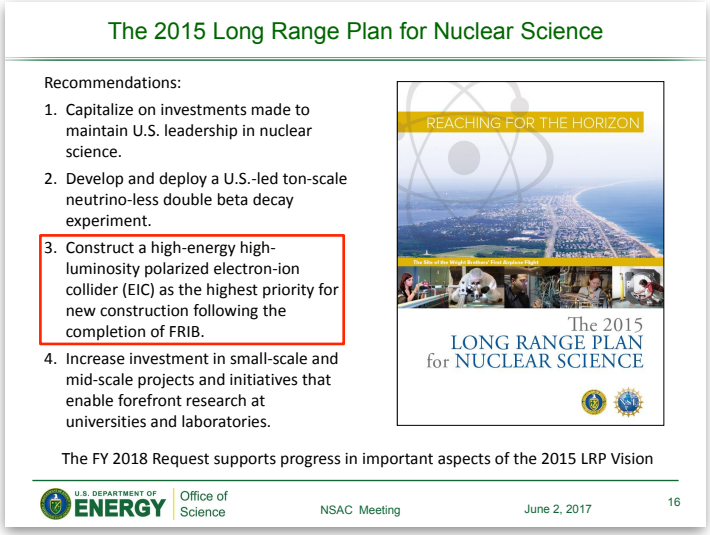


ep

EIC project development

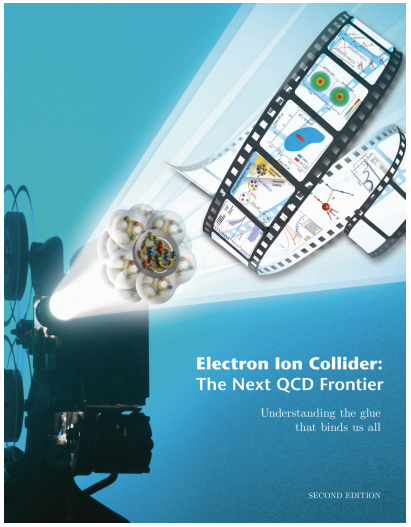
- Critical steps over the last couple of years - 1
  - INT Workshop series / Documentation of Physics Case - Whitepaper: "Understanding the glue that binds us all!"
    - INT Workshop: 2010
    - WP: 2012, updated in 2014 for LRP
  - 2015 Long-range plan (LRP):

T. Hallman



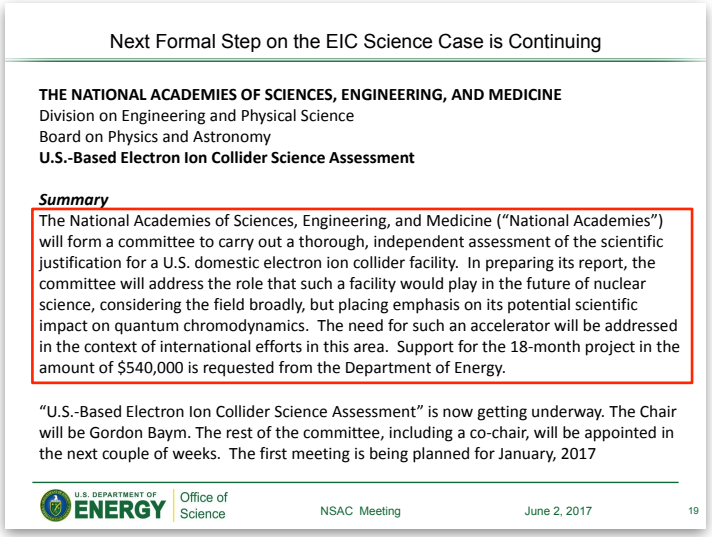
  - Request to review EIC Science Case by National Academy of Sciences, Engineering, and Medicine (NAS)

arXiv:1212.1701



Understanding the glue that binds as all!

T. Hallman

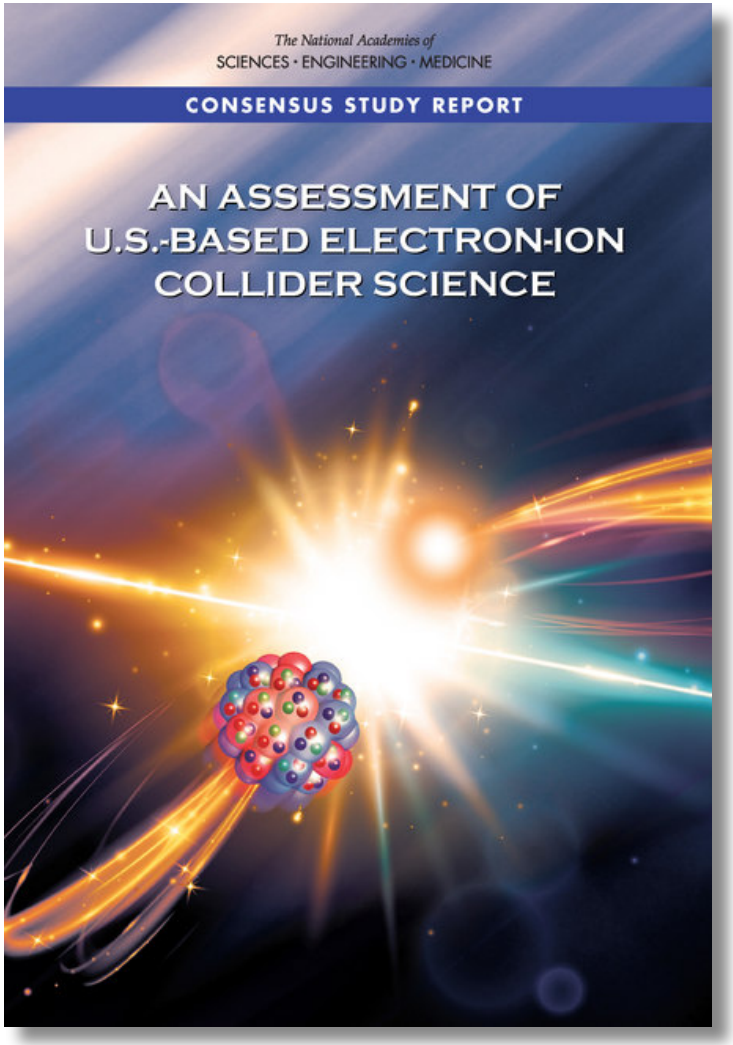


EIC project development

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

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

Download pdf-file of final report!



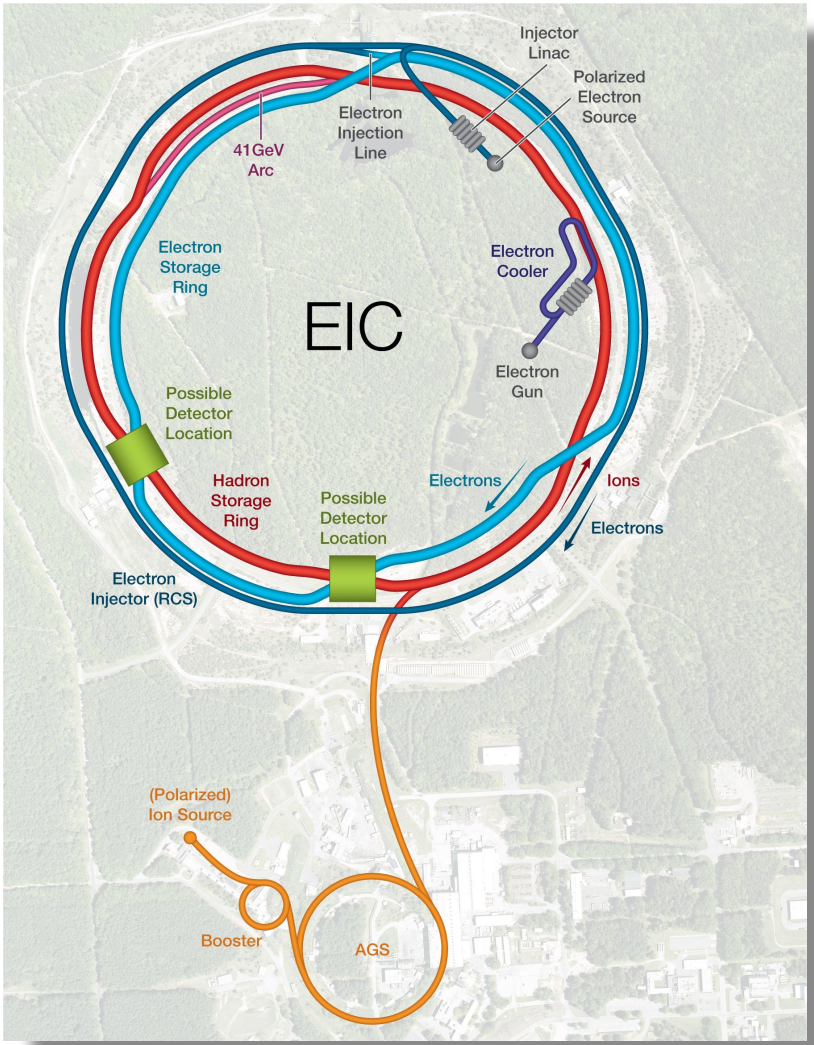
- Webinar on Tuesday, July 24, 2018 - Public presentation and report release
- Gordon Baym (Co-chair): Webinar presentation

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

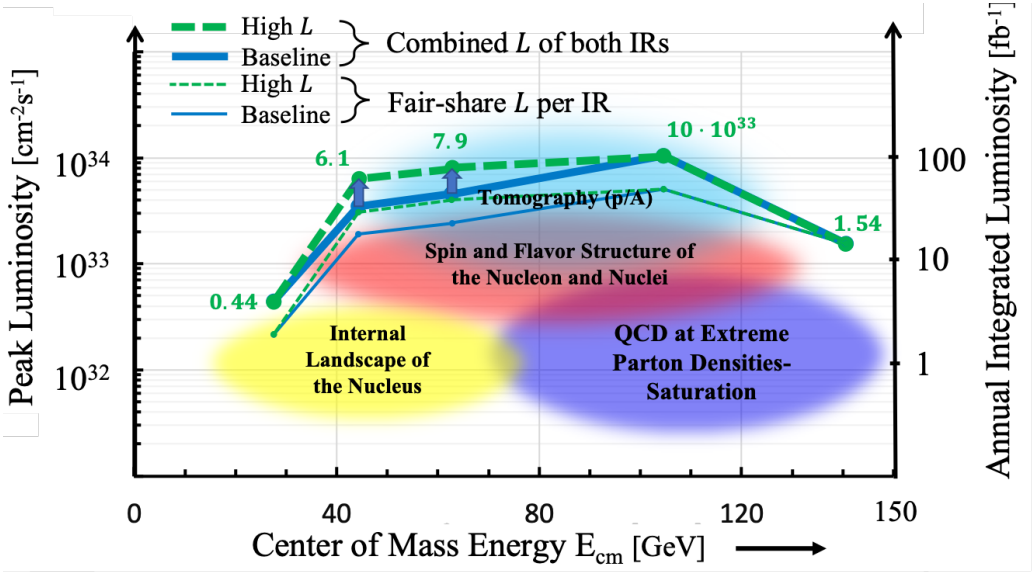
- Slides from Webinar: https://www.nap.edu/resource/25171/eic-public-briefing-slides.pdf
- Glowing" report on a US-based EIC facility!

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

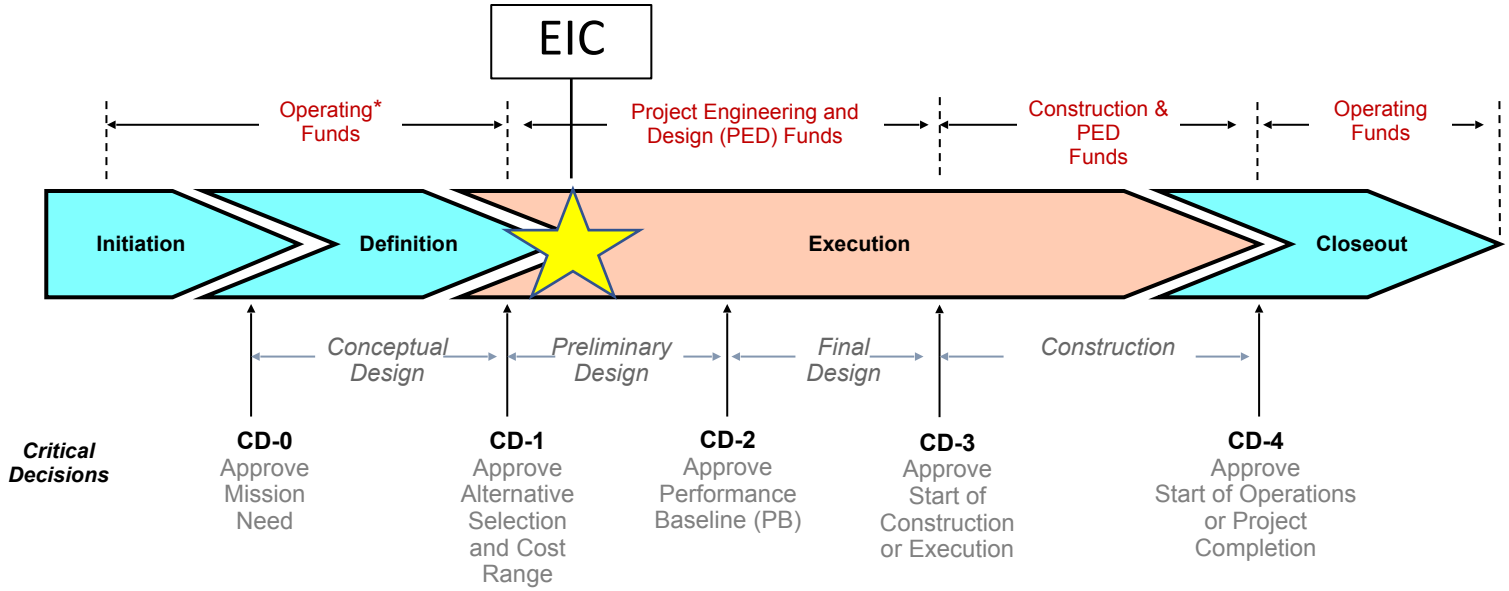
U.S. Department of Energy Selects Brookhaven National Laboratory to Host Major New Nuclear Physics Facility

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

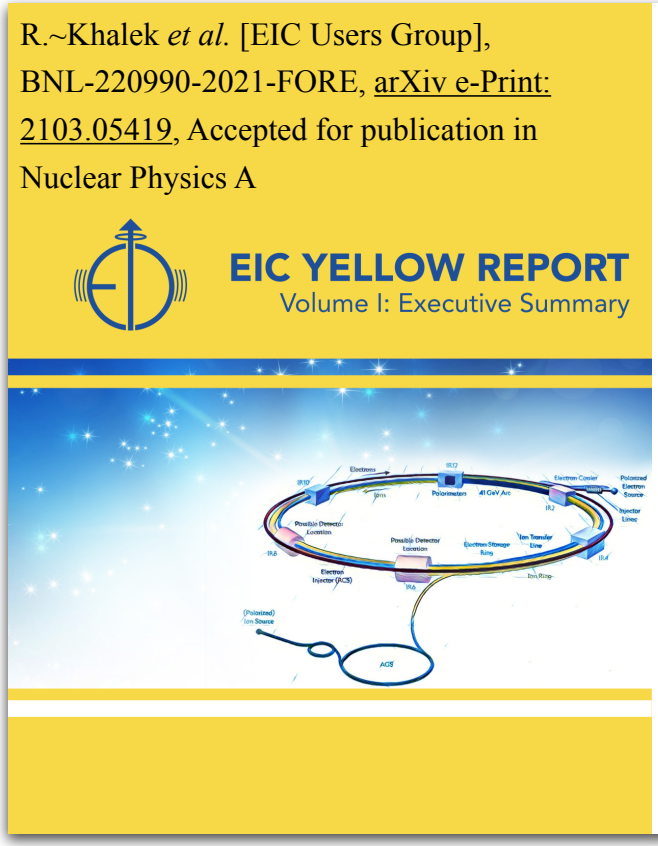
WASHINGTON, D.C. – Today, the U.S. Department of Energy (DOE) announced the selection of Brookhaven National Laboratory in Upton, NY, as the site for a planned major new nuclear physics research facility.

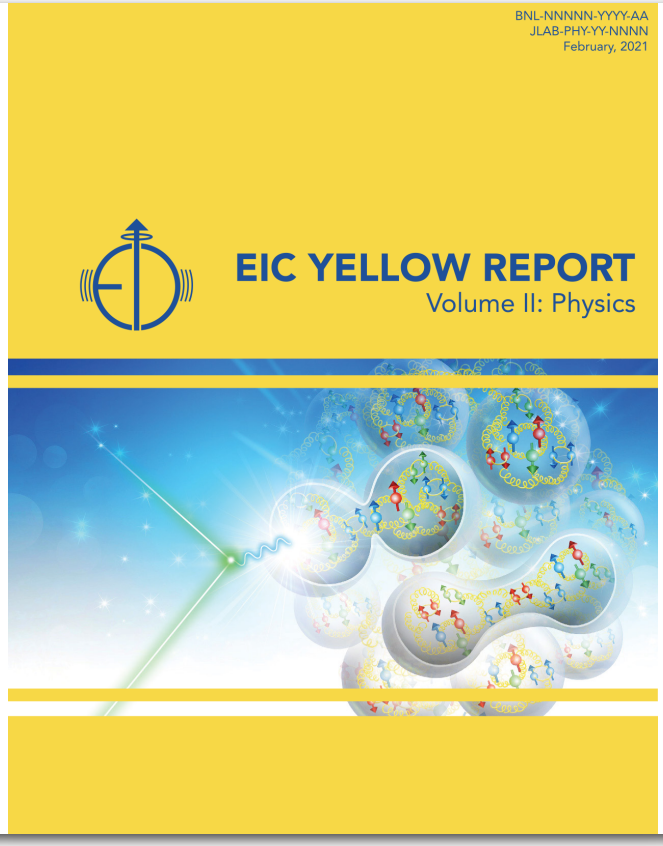
https://www.bnl.gov/newsroom/news.php?a=116996

Introduction

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

R.~Khalek *et al.* [EIC Users Group], BNL-220990-2021-FORE, arXiv e-Print: 2103.05419, Accepted for publication in Nuclear Physics A



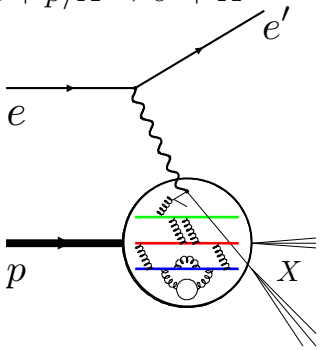


- ~400 authors / ~150 institutions / ~900 pages with strong international contributions!
- Review: Community review within EICUG and external readers (~30) worldwide covering physics and detector expert fields!
- Available on archive: https://arxiv.org/abs/2103.05419

The EIC Detector Requirements and R&D

Overview of processes and final states

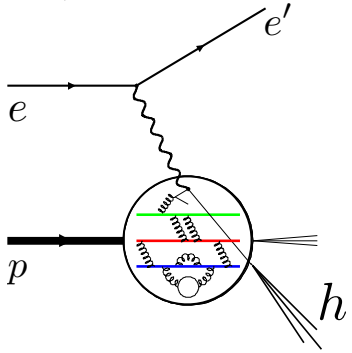
$e + p/A \rightarrow e' + X$



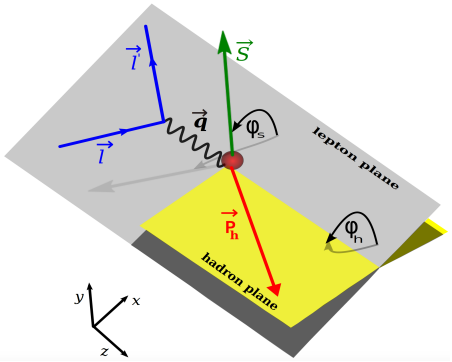
Inclusive DIS

- 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

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

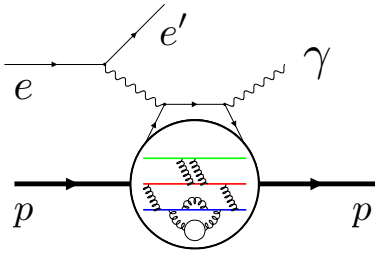


Semi-Inclusive DIS (SDIS)



- 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

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



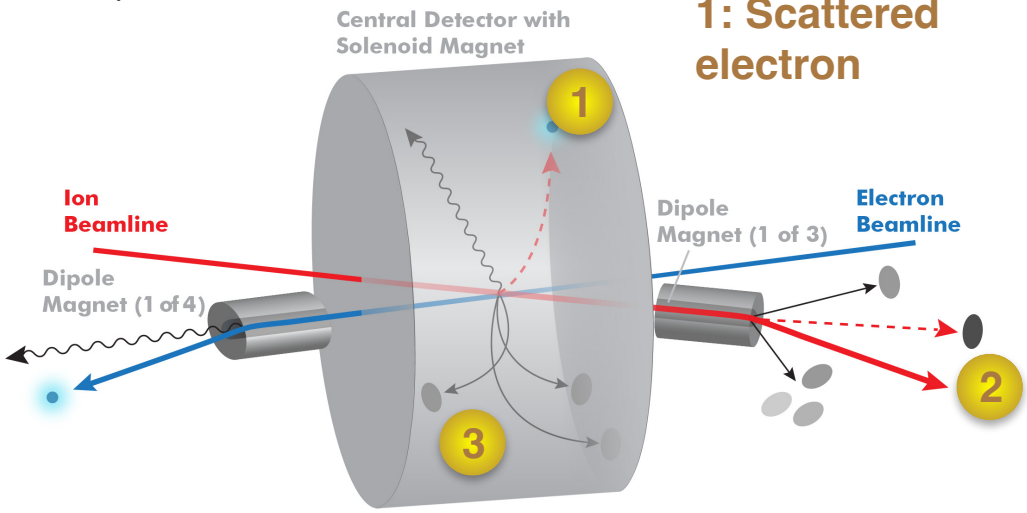
Deeply-Virtual Compton Scattering (DVCS)

- 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)

The EIC Detector Requirements and R&D

- 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 (~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%/√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-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

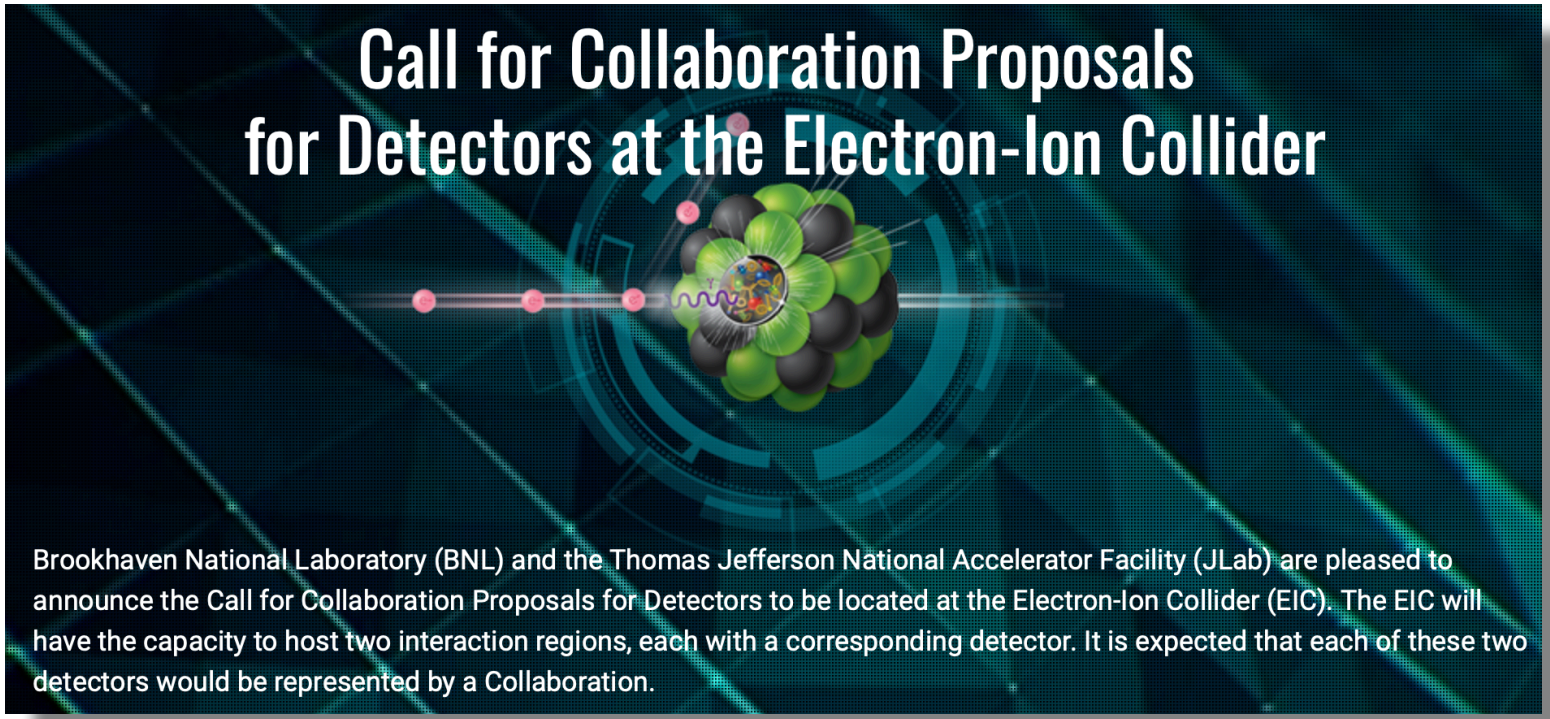
Introduction

- Generic Detector R&D program for an EIC
  - In January 2011, BNL, in association with JLab and the DOE Office of NP, announced a generic detector R&D program to address the scientific requirements for measurements at a future EIC facility.
  - Goals:
    - Enable successful design and timely implementation of an EIC experimental program
    - Develop instrumentation solutions that meet realistic cost expectations
    - Stimulate the formation of user collaborations to design and build experiments
  - Peer-reviewed program funded by DOE and managed by BNL with $1M/year to $1.5M/year Initiated and coordinated by Tom Ludlam (BNL) until 2014 / Since 2014 coordinated by Thomas Ullrich (BNL)
  - Key to success: Standing EIC Detector Advisory Committee
    - Current members: Marcel Demarteau (ANL), Carl Haber (LBNL), Peter Krizan (Ljubljana), Ian Shipsey (Oxford), Rick van Berg (UPenn), Jerry Va'vra (SLAC) and Glenn Young (JLab)
    - Past members: Robert Klanner (Hamburg) and Howard Wieman (LBL)
  - Wide range of R&D programs: Calorimetry / Tracking (GEM, MicroMegas, TPC) incl. silicon / Particle ID (TRD, Dual-RICH, Aerogel RICH, DIRC, TOF) / Polarimetry / Background / Simulation Tools /

https://wiki.bnl.gov/conferences/index.php/EIC_R%25D

Introduction

- Open Call for Detector Proposals



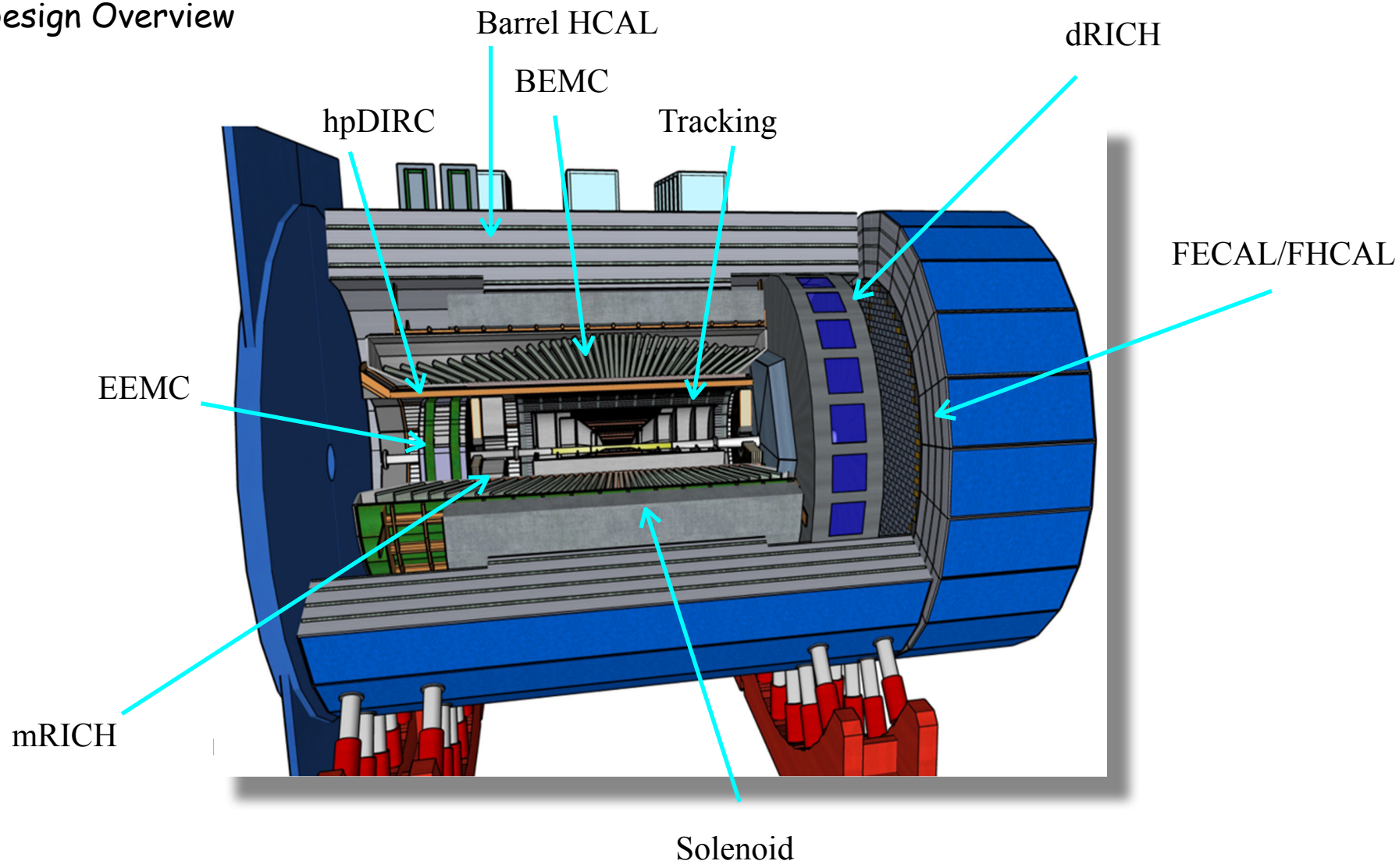
ATHENA: A Totally Hermetic Electron-Nucleus Apparatus
Concept: General purpose detector inspired by the YR studies based on a new central magnet of up to 3T
WWW-page: https://www.athena-eic.org

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

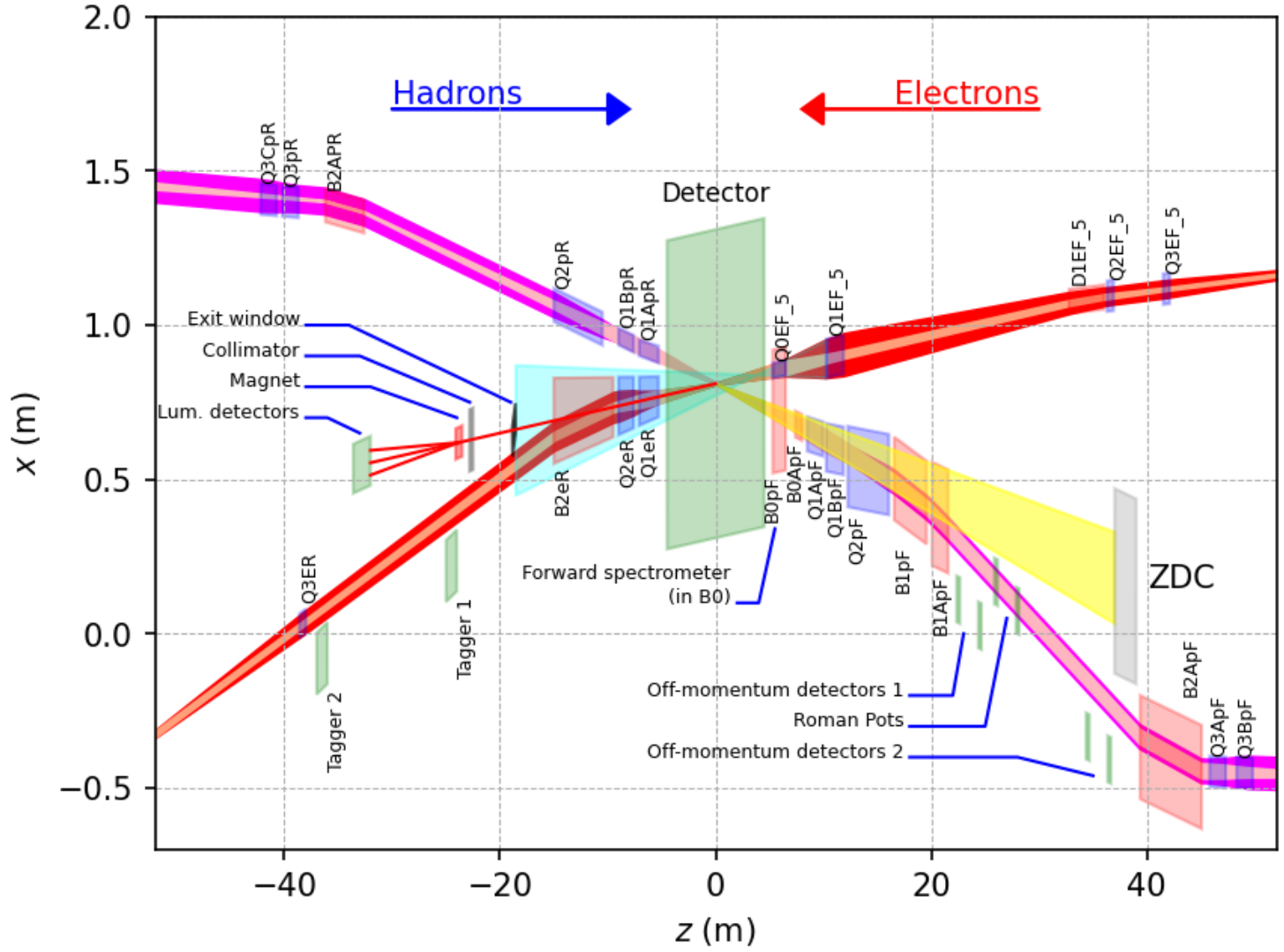
ePIC detector

- Design Overview



ePIC detector

- Design Overview



ePIC detector

- Consolidation and optimization of detector design ongoing:
  - Starting point for reference detector design: ECCE concept
  - Optimization of barrel tracking system: Achieve a low-mass design with good performance / MPGD selection µWell / MM
  - Addition of barrel HCAL under discussion/physics case
  - Two barrel EMCal solutions imply different physics emphasis
  - AC-LGAD tracking elements are new, unproven technology / Potential for risk reduction
  - PID in backward direction: Two competing technologies!
  - Magnet: Project plan based on a new magnet of 1.7T - BaBar solenoid listed as risk opportunity/mitigation
- Process is driven by physics performance, taking into consideration integration aspects / Interactive optimization process

ePIC detector

- Backward Calorimetry

EMCAL

Hybrid $PbWO_4$

inner

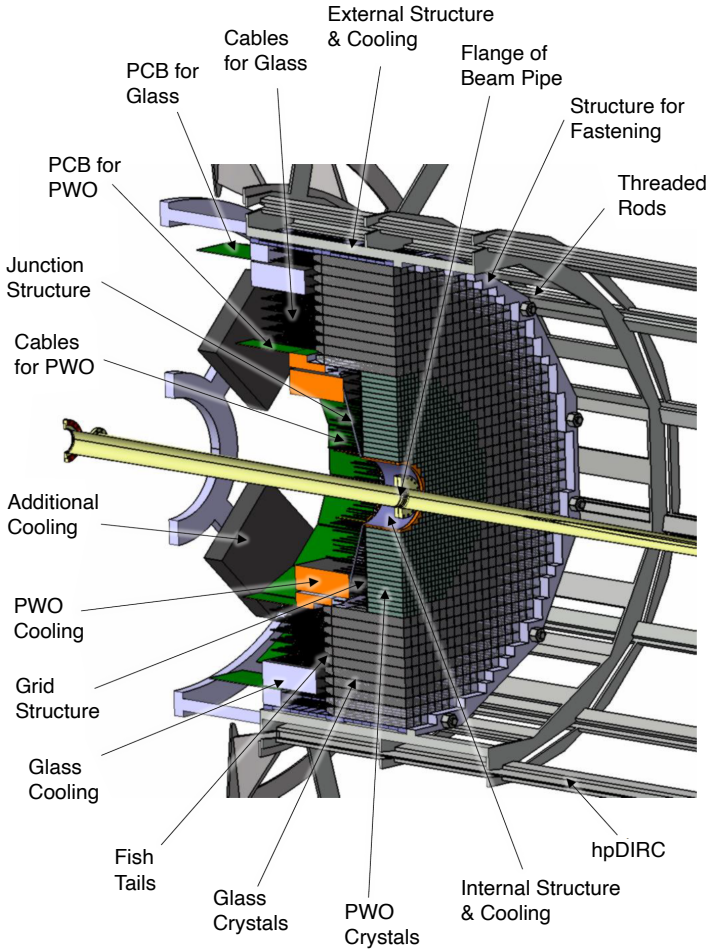
crystals /

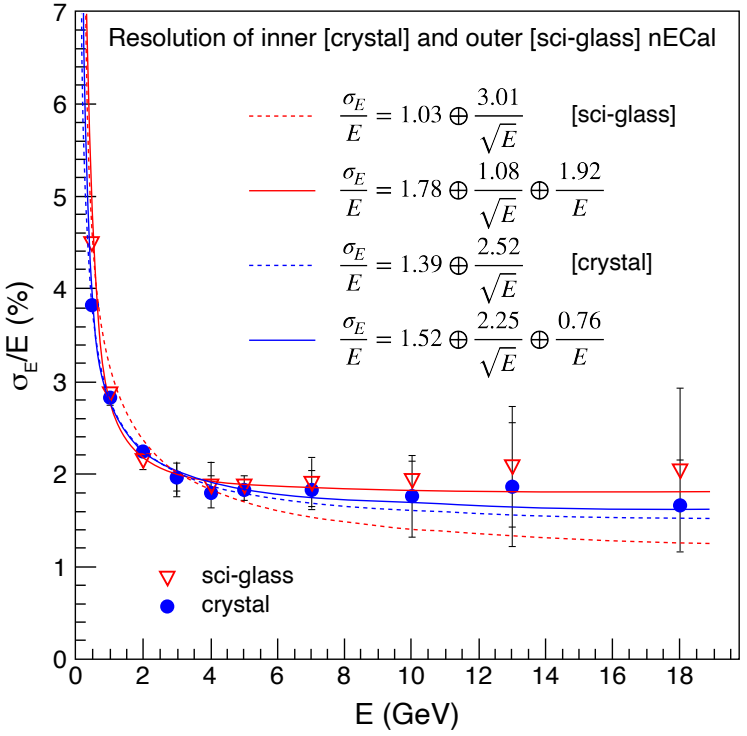
SciGlass outer

blocks -

Readout via

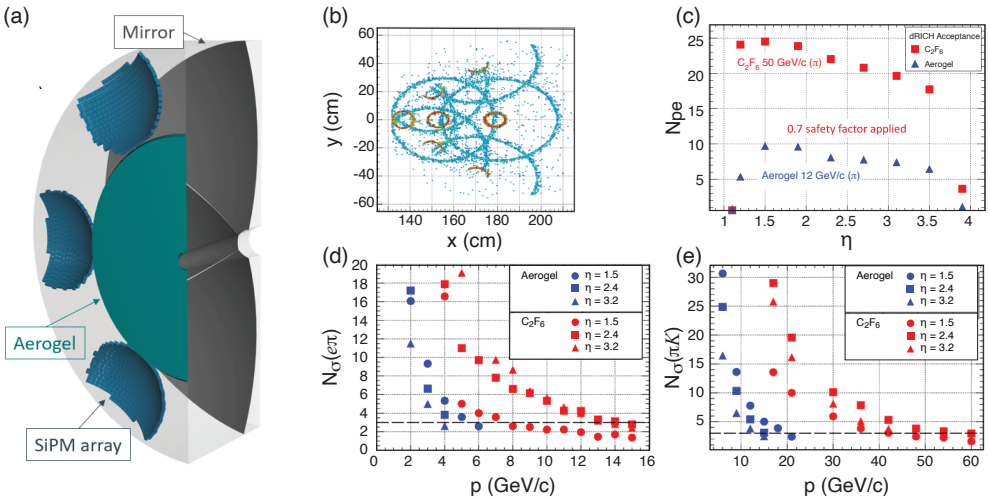
SiPMs

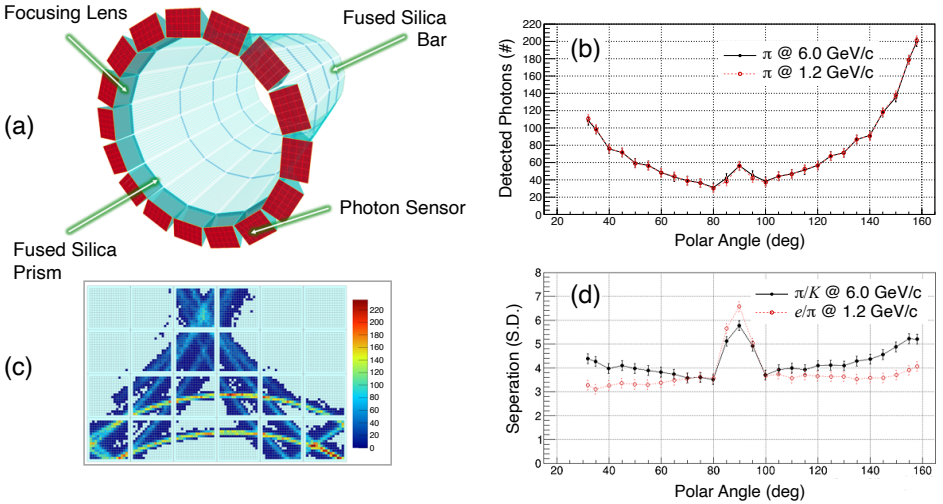




ePIC detector

PID

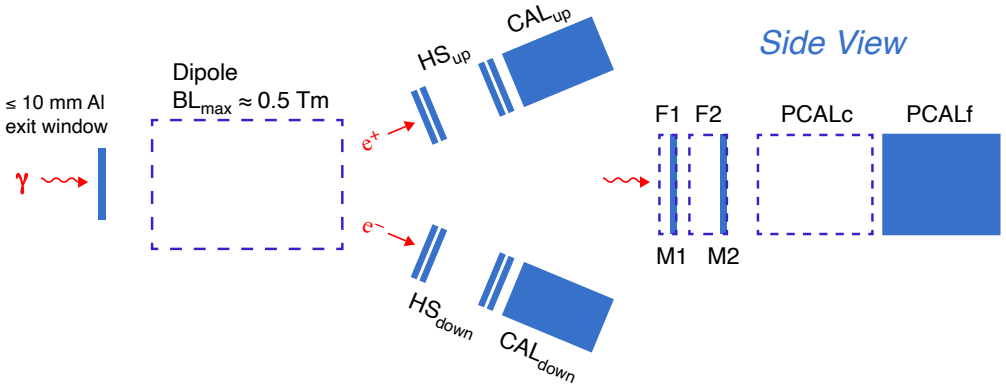


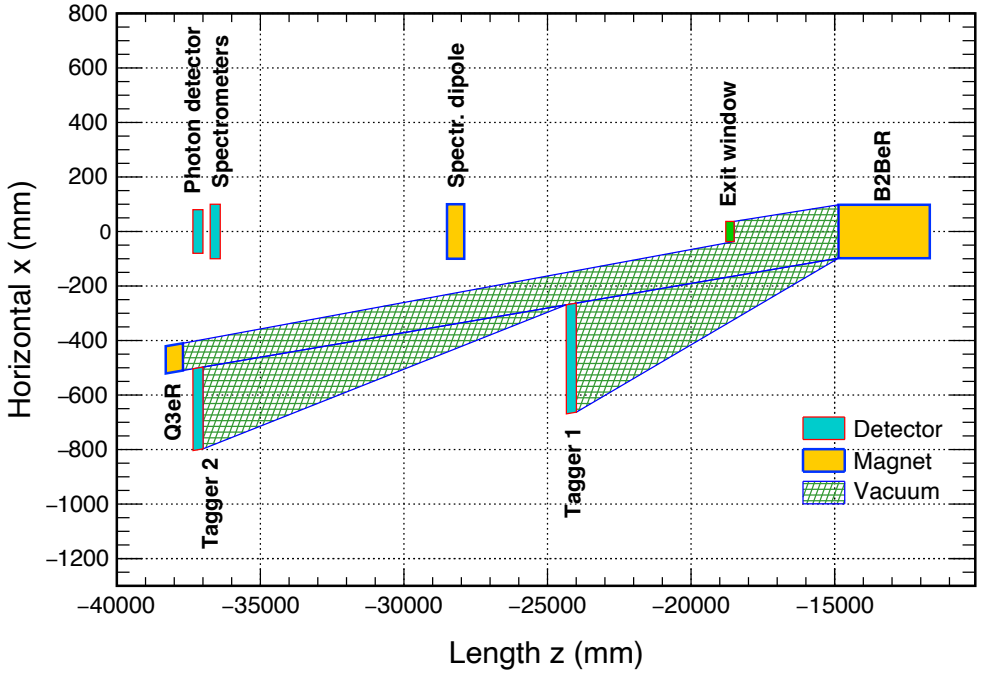


- Forward PID: Dual-radiator RICH (dRICH) utilizing aerogel and gas radiators focused by mirrors onto a focal plane instrumented with SiPMs
- Barrel PID: High-performance DIRC (hpDIRC) with re-use of Babar bars

ePIC detector

- FarBackward system



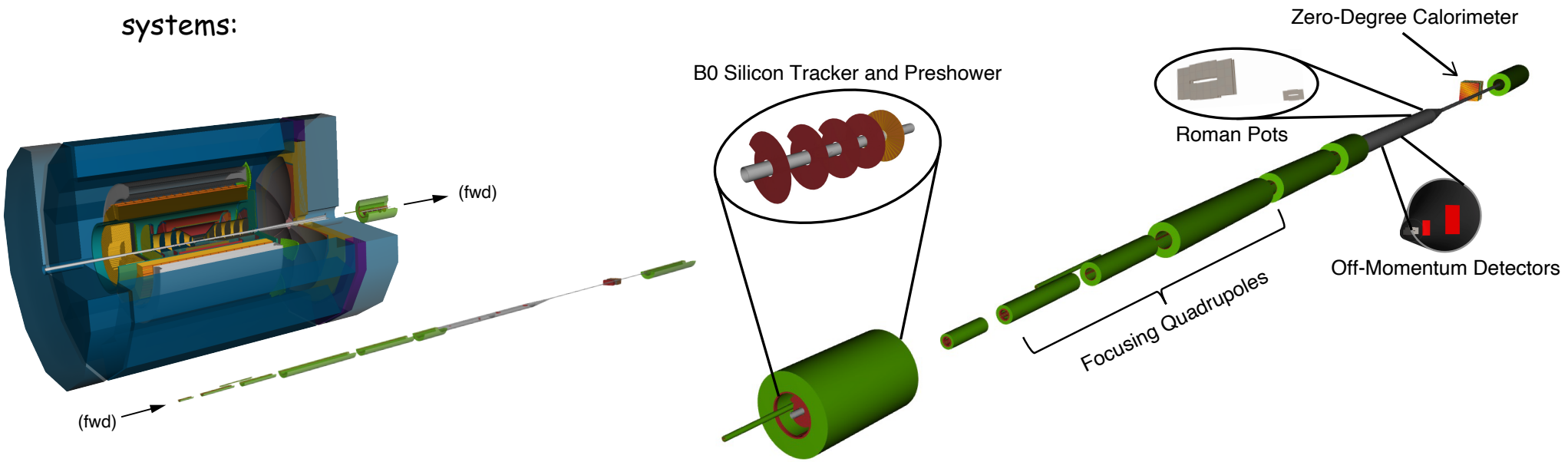


- High precision luminosity measurement at 1% level for absolute luminosity and 0.01% for relative luminosity measurement using several methods based on the Bremsstrahlung process:
  1. Counting photons converted in thin exit window using dipole field and measuring e^+e^- pairs
  2. Energy measurement of unconverted photons
  3. Counting of unconverted photons
2. Two low Q2 taggers

ePIC detector

- 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)



ePIC detector

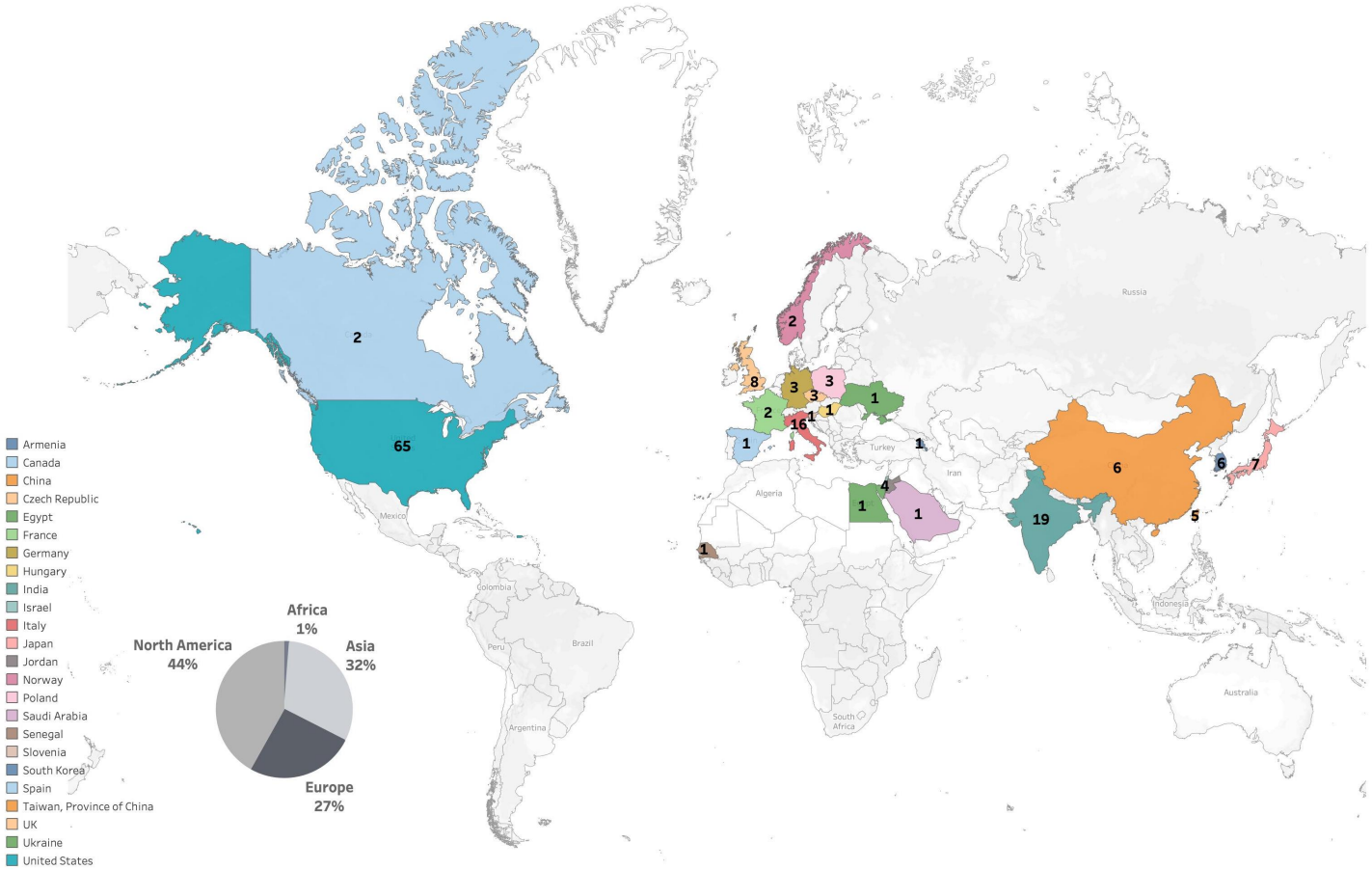
World Map - Institutions

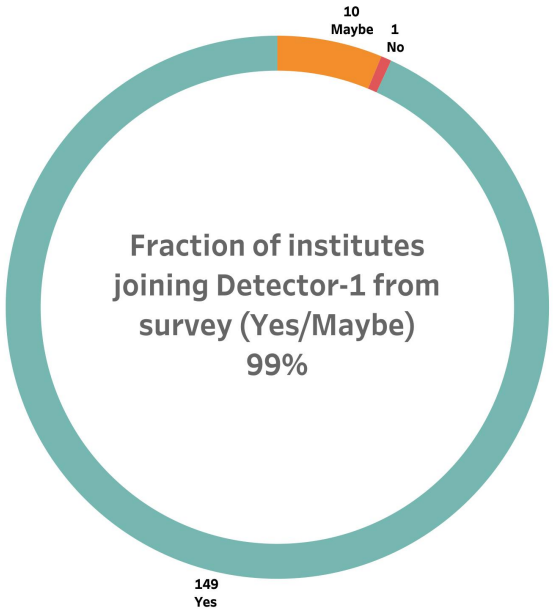
Detector-1 - A global pursuit for a new EIC experiment at IP6 at BNL

Detector-1 Institutions
160

Detector-1 Countries
24

Detector-1 World Region
4

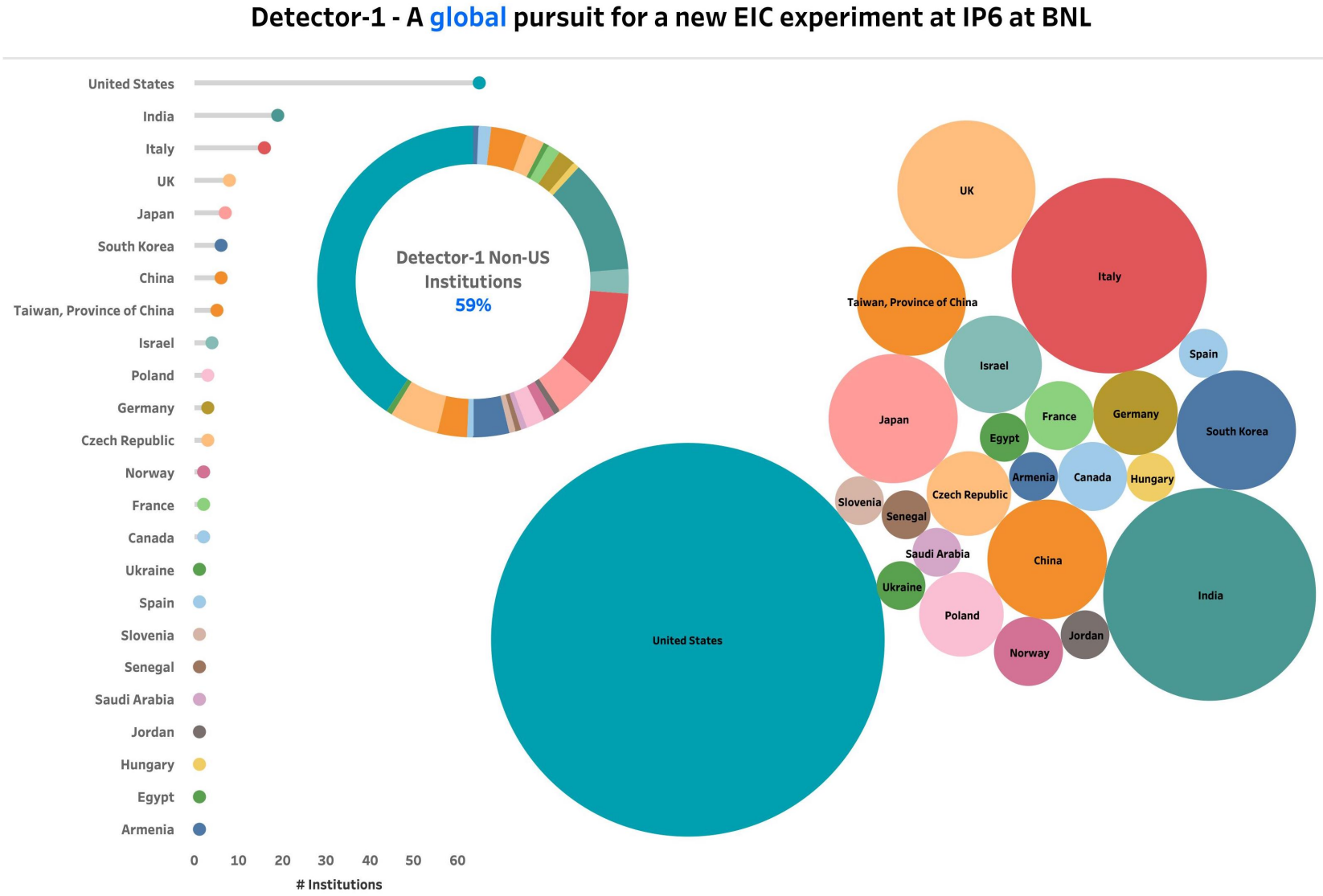




Interactive Tableau link

ePIC detector

Number of Institutions

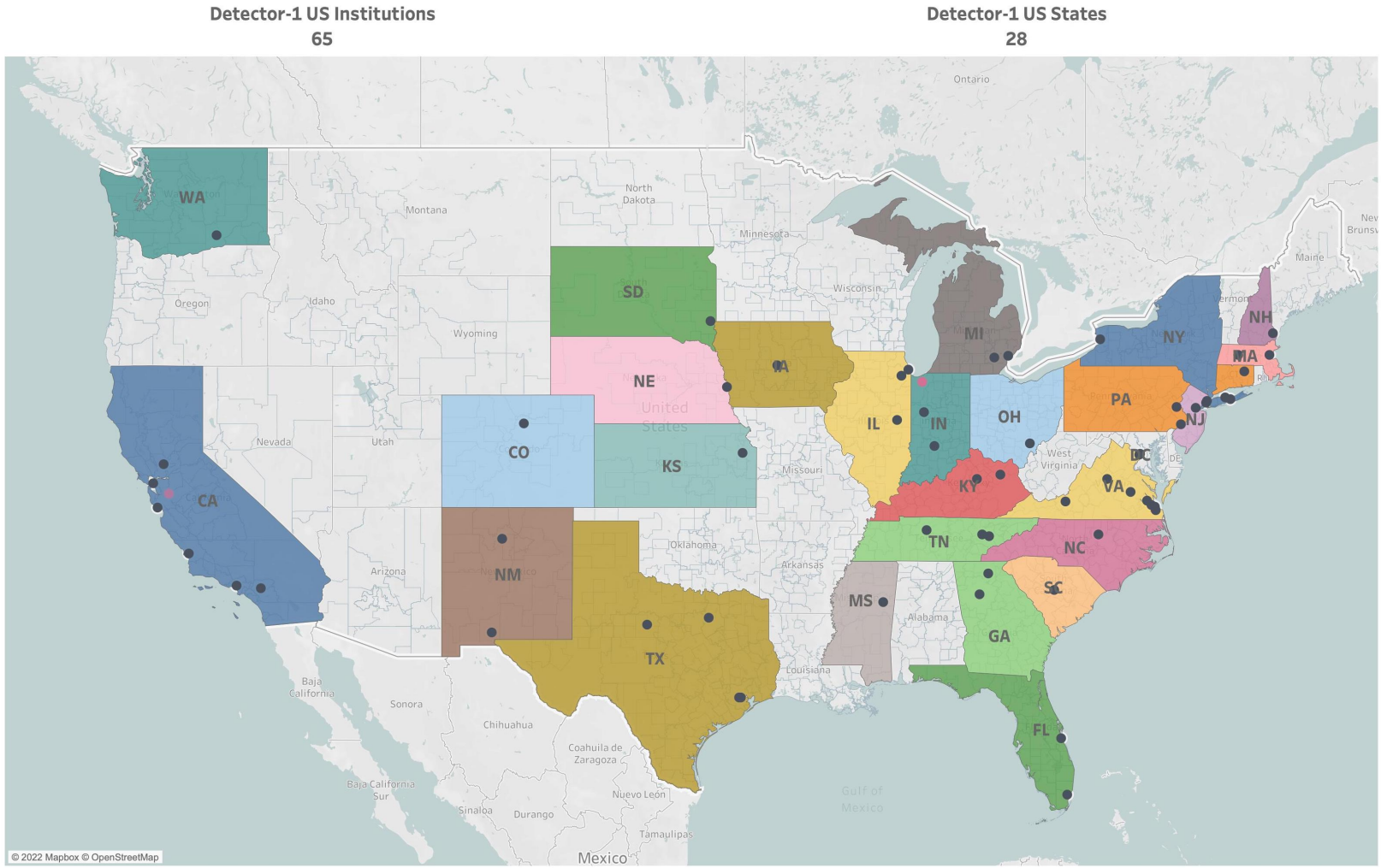


Interactive Tableau link

ePIC detector

- US map - Institutions

Detector-1 - A global pursuit for a new EIC experiment at IP6 at BNL

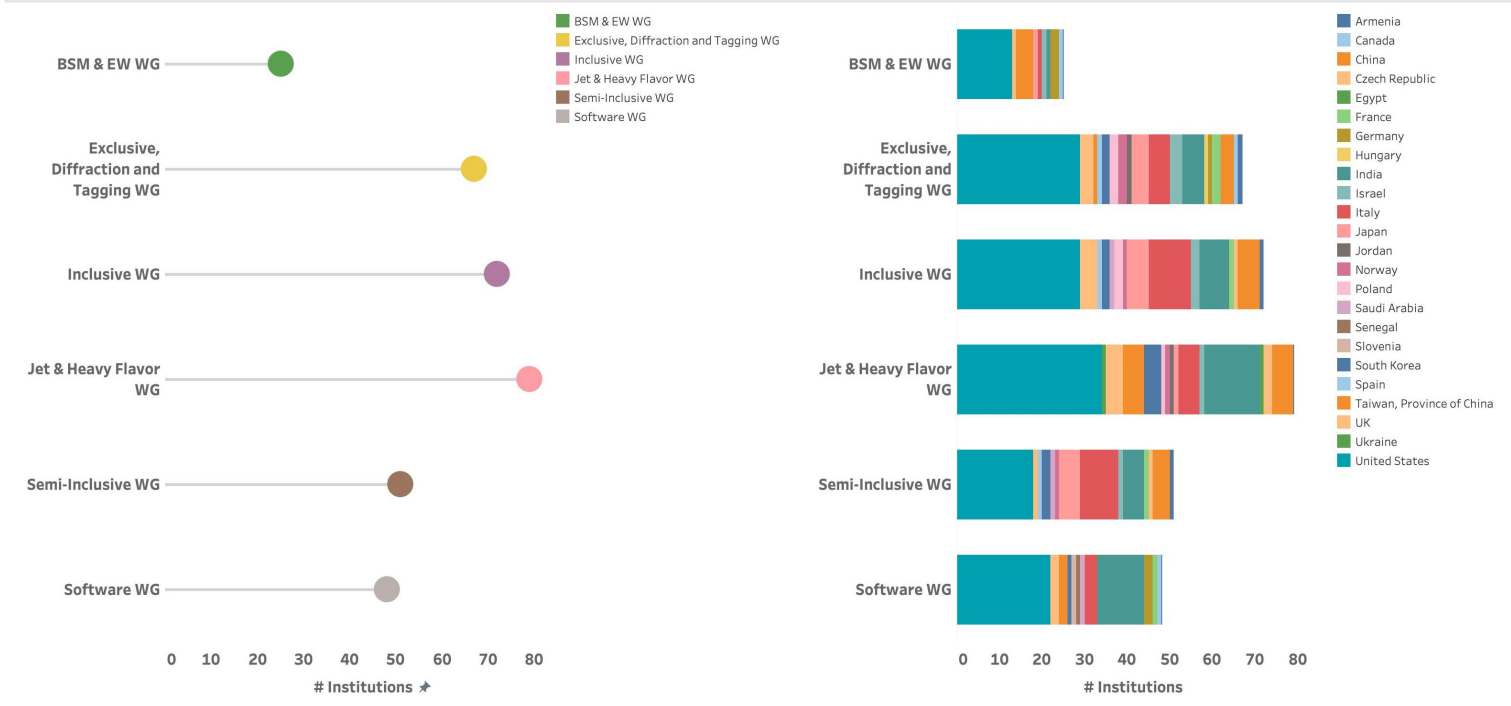


Interactive Tableau link

ePIC detector

Physics Interests - Institutions

Detector-1 - A global pursuit for a new EIC experiment at IP6 at BNL / Physics Interests



Select category (Detector WG / Country / Institution) from pull-down menu. Institutions fullfilling the chosen category are highlighted in the last column!

WG / Sub-system: Inclusive WG

Country: All

Institutions: All

Inclusive WG

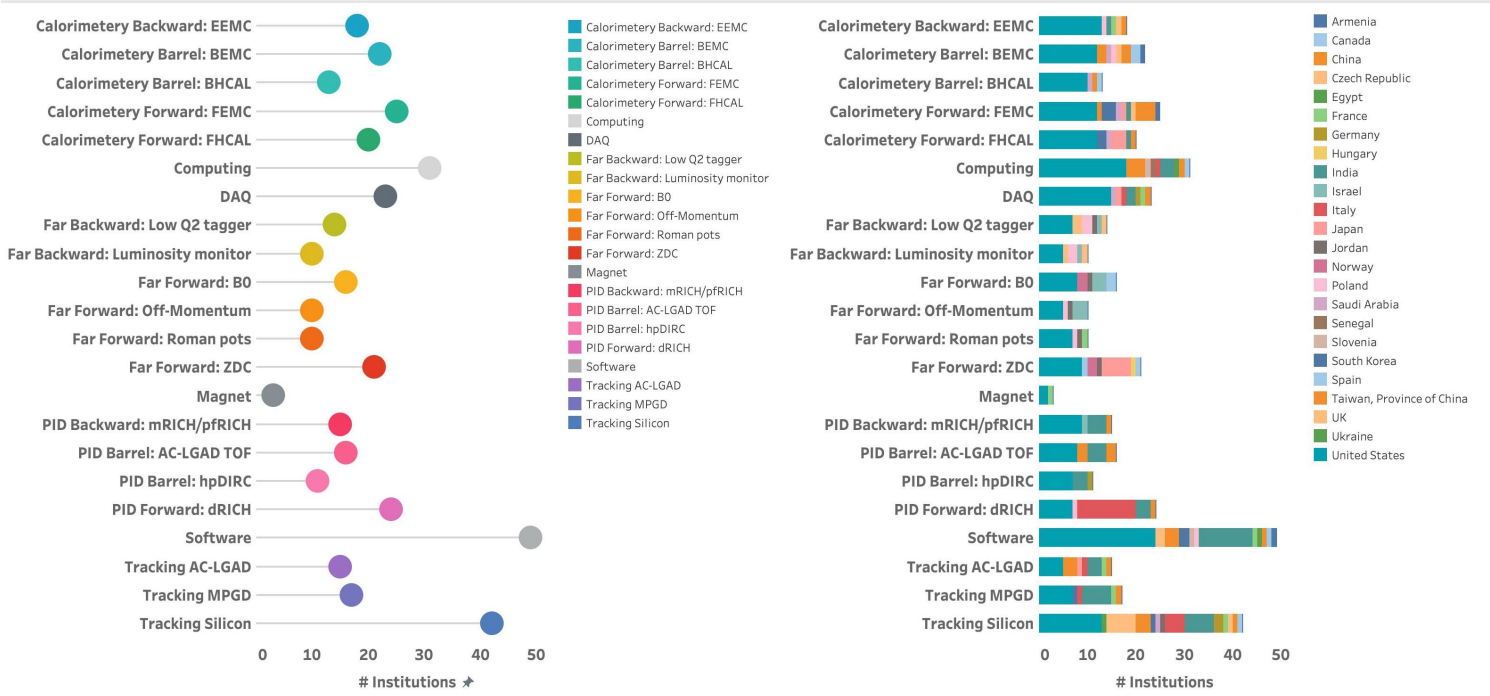
Institutions	City	Country	Contact Name	Email
A. I. Alikhantan National Science Laboratory	Yerevan	Armenia	Mkrtchyan, Hamlet	mkrtchyan@yerphi.am
Abilene Christian University	Abilene	United States	Daugherity, Michael	mike.daugherity@acu.edu
AGH University of Science and Technology	Krakow	Poland	Przybycien, Mariusz	mariusz.przybycien@agh.edu.pl
Aligarh Muslim University	Aligarh	India	Abir, Raktim	raktim.ph@amu.ac.in
Argonne National Laboratory	Lemont	United States	Meziani, Zein-Eddine	zmeziani@anl.gov
Augustana University	Sioux Falls	United States	Grau, Nathan	ngrau@augie.edu
Banaras Hindu University	Ajagara	India	Singh, B. K.	bksingh@bhu.ac.in
Baruch College, City University of New York	New York	United States	Bathe, Stefan	stefan.bathe@baruch.cuny.edu
Ben Gurion University of the Negev	Beer Sheva	Israel	Citron, Zvi	zhcitron@bgu.ac.il
Brookhaven National Laboratory	Upton	United States	Steinberg, Peter	peter.steinberg@bnl.gov

Interactive Tableau link

ePIC detector

Sub-system Interests - Institutions

Detector-1 - A global pursuit for a new EIC experiment at IP6 at BNL / Sub-System Interests



Select category (Physics WG / Country/Institution) from pull-down menu. Institutions fullfilling the chosen category are highlighted in the last column!

WG / Sub-system: Far Backward: Low Q2 tagger

Country: All

Institutions: All

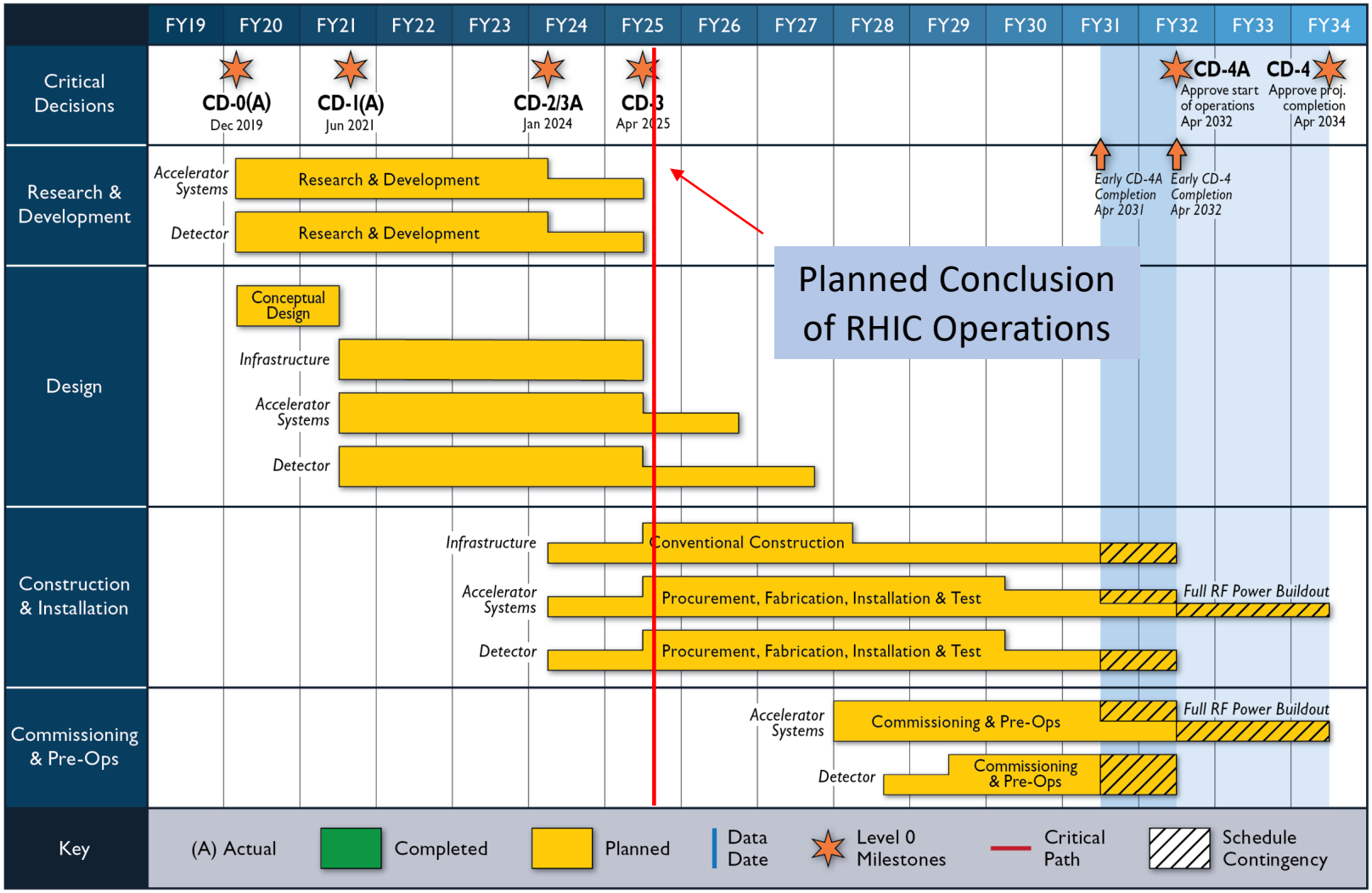
Far Backward: Low Q2 tagger

Institutions	City	Country	Contact Name	Email
A. I. Alikhantan National Science Laboratory	Yerevan	Armenia	Mkrtchyan, Hamlet	mkrtchyan@yerphi.am
Abilene Christian University	Abilene	United States	Daugherty, Michael	mike.daugherty@acu.edu
AGH University of Science and Technology	Krakow	Poland	Przybycien, Mariusz	mariusz.przybycien@agh.edu.pl
Aligarh Muslim University	Aligarh	India	Abir, Raktim	raktim.ph@amu.ac.in
Argonne National Laboratory	Lemont	United States	Meziani, Zein-Eddine	zmeziani@anl.gov
Augustana University	Sioux Falls	United States	Grau, Nathan	ngrau@augie.edu
Banaras Hindu University	Ajagara	India	Singh, B. K.	bksingh@bhu.ac.in
Baruch College, City University of New York	New York	United States	Bathe, Stefan	stefan.bathe@baruch.cuny.edu
Ben Gurion University of the Negev	Beer Sheva	Israel	Citron, Zvi	zhcitron@bgu.ac.il
Brookhaven National Laboratory	Upton	United States	Steinberg, Peter	peter.steinberg@bnl.gov

Interactive Tableau link

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 (ePIC) - Ongoing process!
- 2nd experiment (DETECTOR 2) planned on a different timescale, e.g. CORE proposal!
- Preparation of CD-2/3A (expectation): ~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!