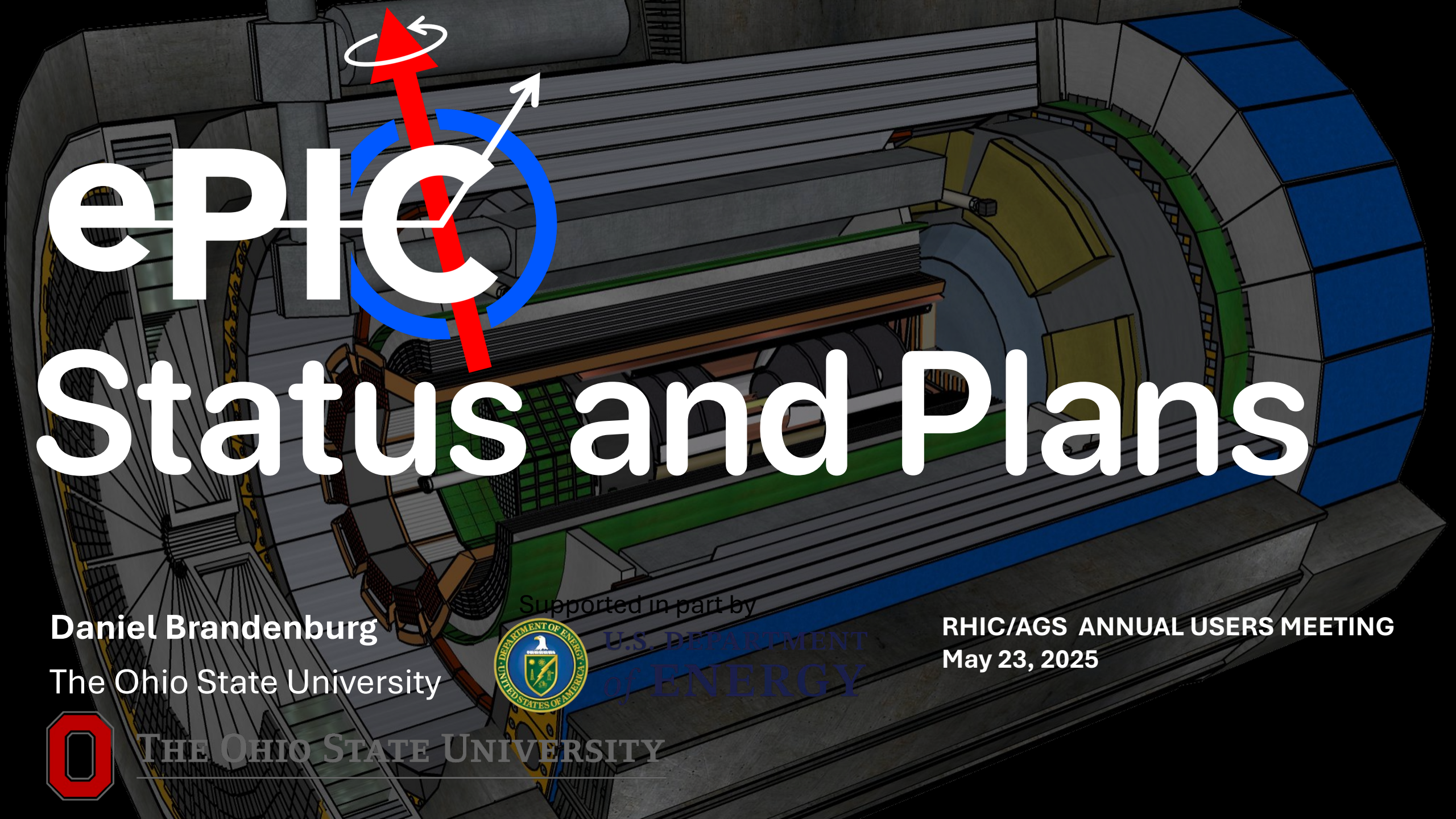


ePIC Status and Plans

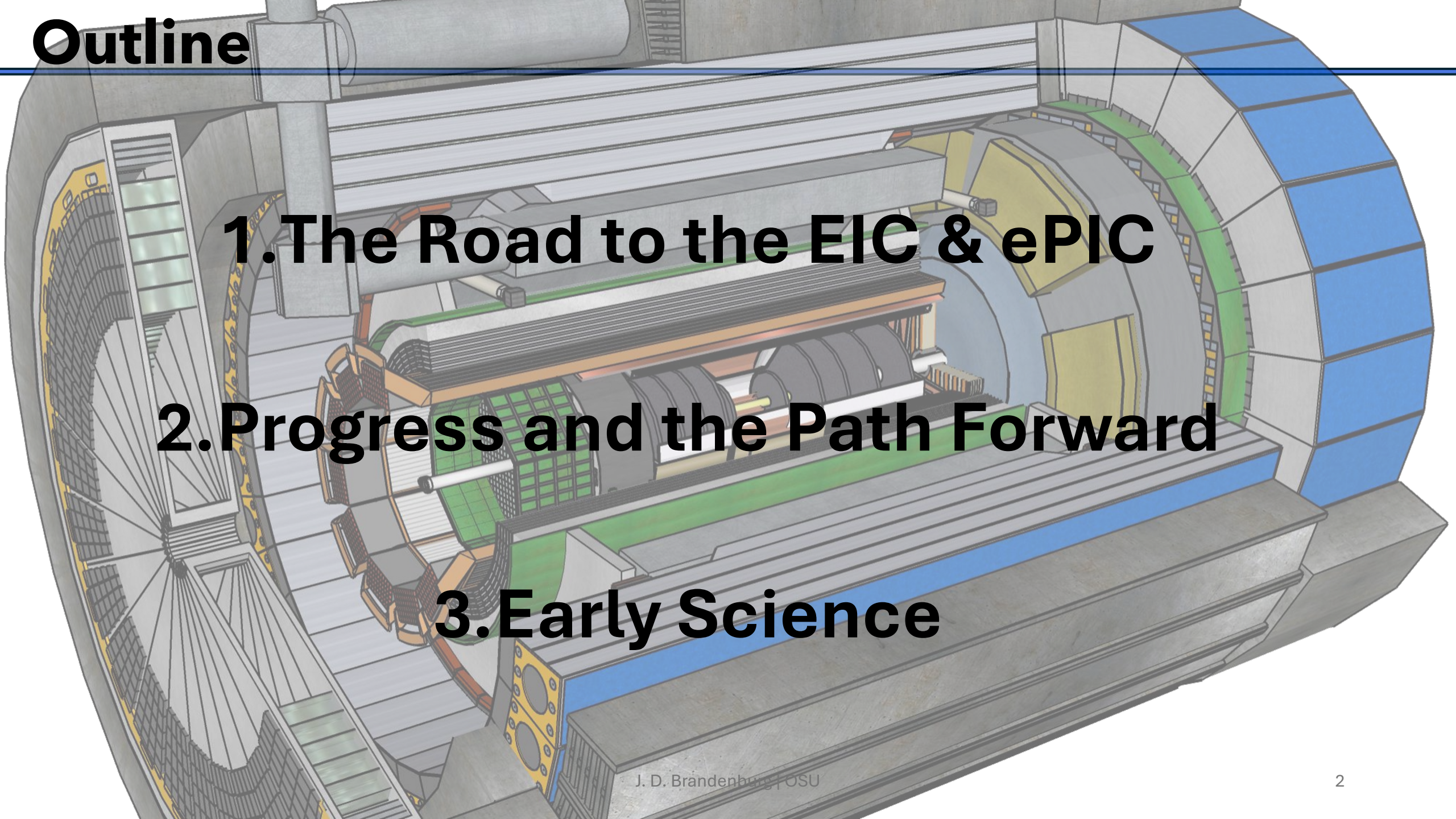
Daniel Brandenburg
The Ohio State University

Supported in part by
U.S. DEPARTMENT of ENERGY

THE OHIO STATE UNIVERSITY

RHIC/AGS ANNUAL USERS MEETING
May 23, 2025

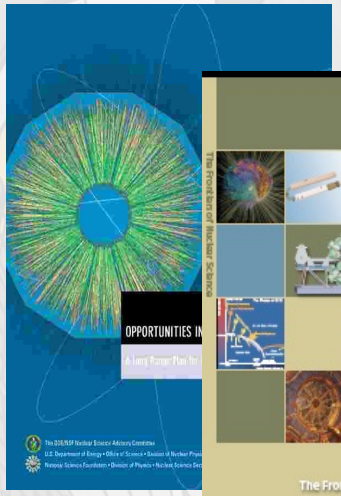
Outline



1. The Road to the EIC & ePIC
2. Progress and the Path Forward
3. Early Science

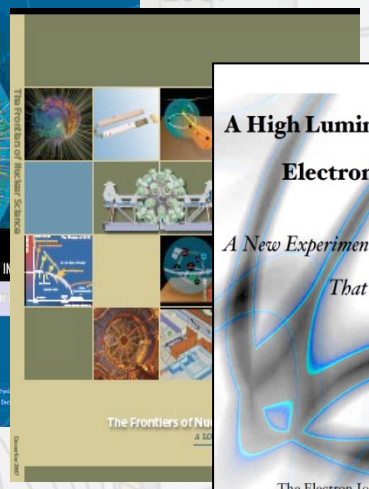
The Scientific Foundation for an EIC

2002



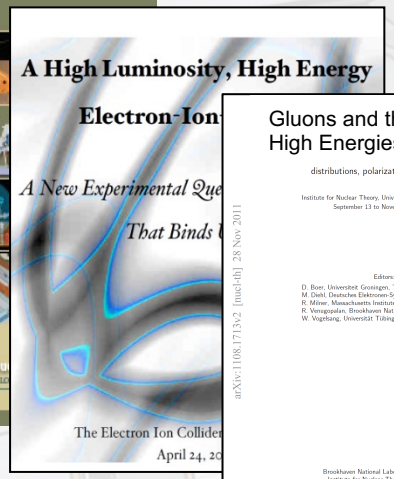
"…essential accelerator and detector R&D [for EIC] should be given very high priority in the short term."

2007



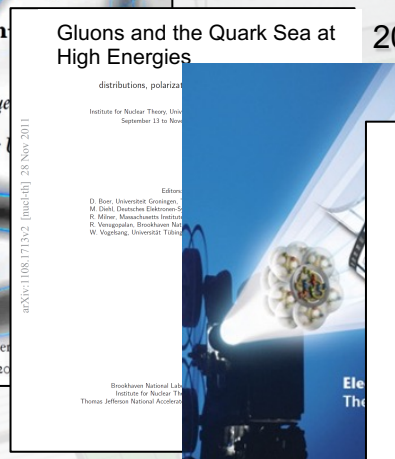
"We recommend the allocation of resources …to lay the foundation for a polarized Electron-Ion Collider…"

2009



"..a new dedicated facility will be essential for answering some of the most central questions."

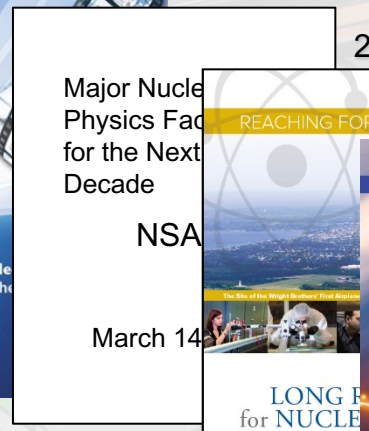
2010



"The quantitative study of matter in this new regime [where abundant gluons dominate] requires a new experimental facility: an Electron Ion Collider.."

2012

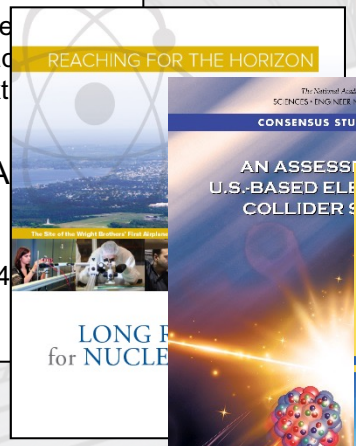
2013



Electron-Ion Collider..*absolutely central* to the nuclear science program of the next decade.

"a high-energy high-luminosity polarized EIC [is] the highest priority for new facility construction following the completion of FRIB."

2015



The science questions that an EIC will answer are central to completing an understanding of atoms as well as being integral to the agenda of nuclear physics today."

2018

Science Requirements and Detector Concepts for the EIC – Drives the requirements of EIC detectors

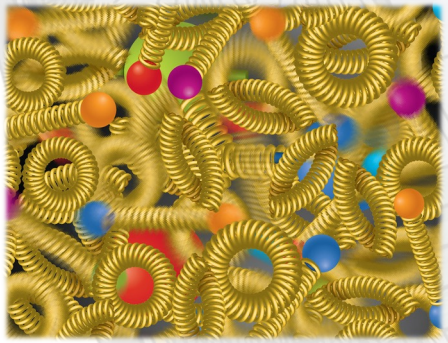
2021

2023

We recommend the expeditious completion of the EIC as the highest priority for facility construction.

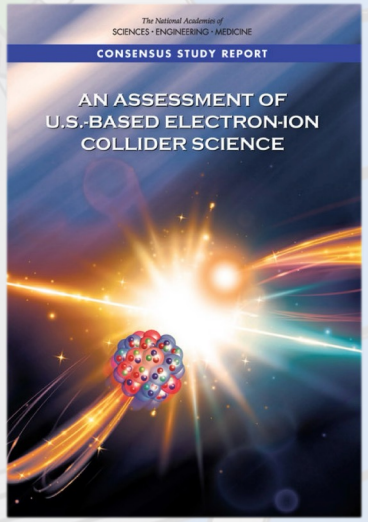
The Dynamic Nature of Nuclear Matter

An EIC can uniquely address profound questions about nucleons and how they assemble to form the nuclei of atoms



Figures courtesy of BNL

- How does the mass of the nucleon arise?
- How does the spin of the nucleon arise?
- What are the emergent properties of dense systems of gluons?



- What are the different contribution from the quarks, gluons and orbital angular momentum to proton spin
- Does the mass of visible matter emerge from quark-gluon interactions?
- How do the confined hadronic states emerge from quarks and gluons?

The Electron-Ion Collider

A Frontier Accelerator in the USA

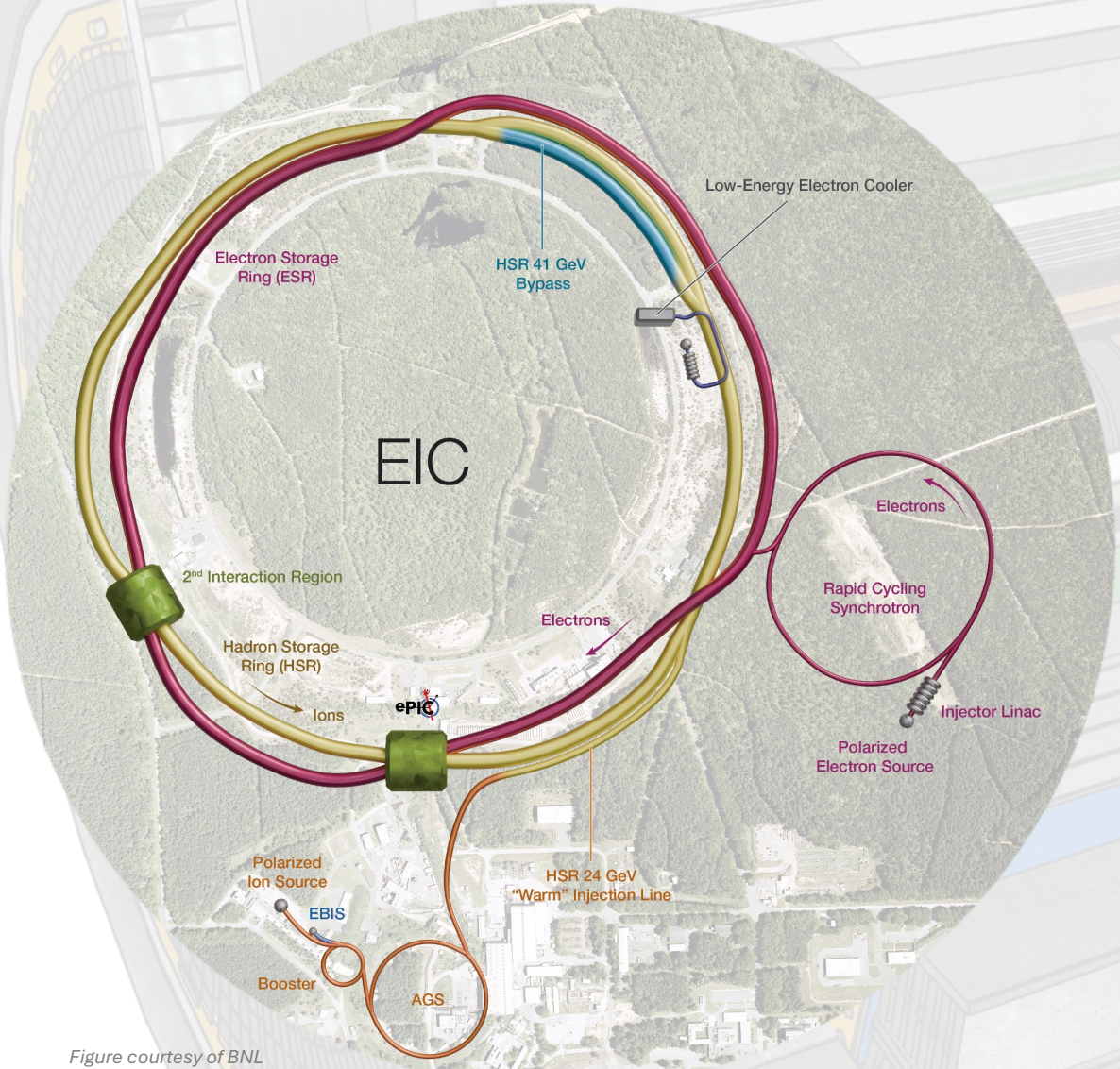


Figure courtesy of BNL

World's first collider of:

- Polarized electrons and polarized protons
- Polarized electrons and light ions (d, ^{3}He)
- Electrons and heavy ions (up to Uranium)

A versatile machine:

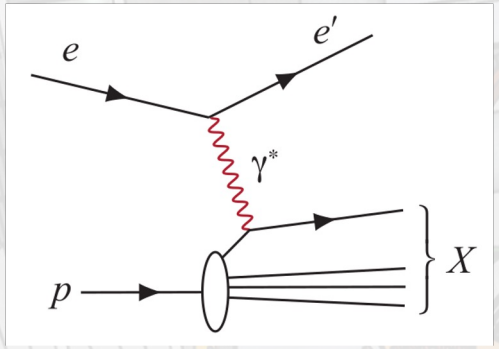
- Beam polarizations up to 70%,
- Versatile range of beam species
- Versatile range of center of mass energies, E_{cm} = 29 – 140 GeV

A high luminosity machine

- up to $\mathcal{L} = 10^{34}$ cm^{-2} s^{-1}
- At peak luminosity, the e-p signal event rate will be about 500 kHz

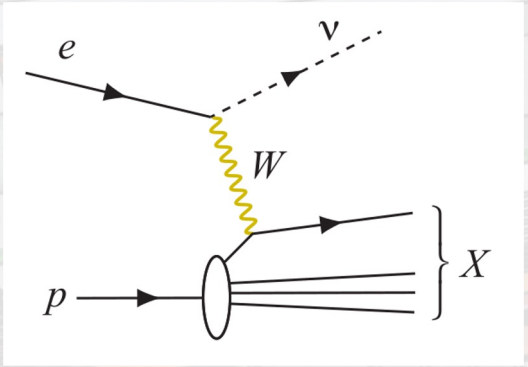
Experimental Processes to Access EIC Physics

DIS event kinematics - scattered electron or final state particles (CC DIS, low y)



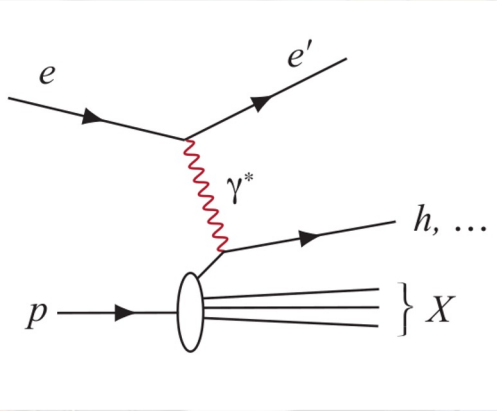
Neutral Current DIS

- Detection of scattered electron with high precision - event kinematics



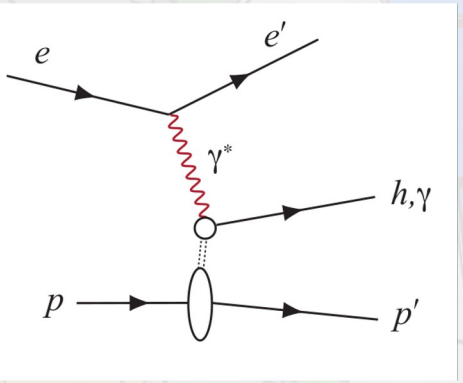
Charged Current DIS

- Event kinematics from the final state particles (Jacquet-Blondel method)



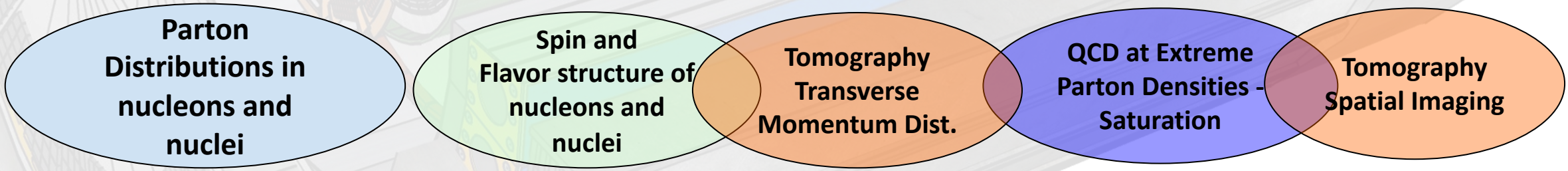
Semi-Inclusive DIS

- Precise detection of scattered electron in coincidence with at least 1 hadron



Deep Exclusive Processes

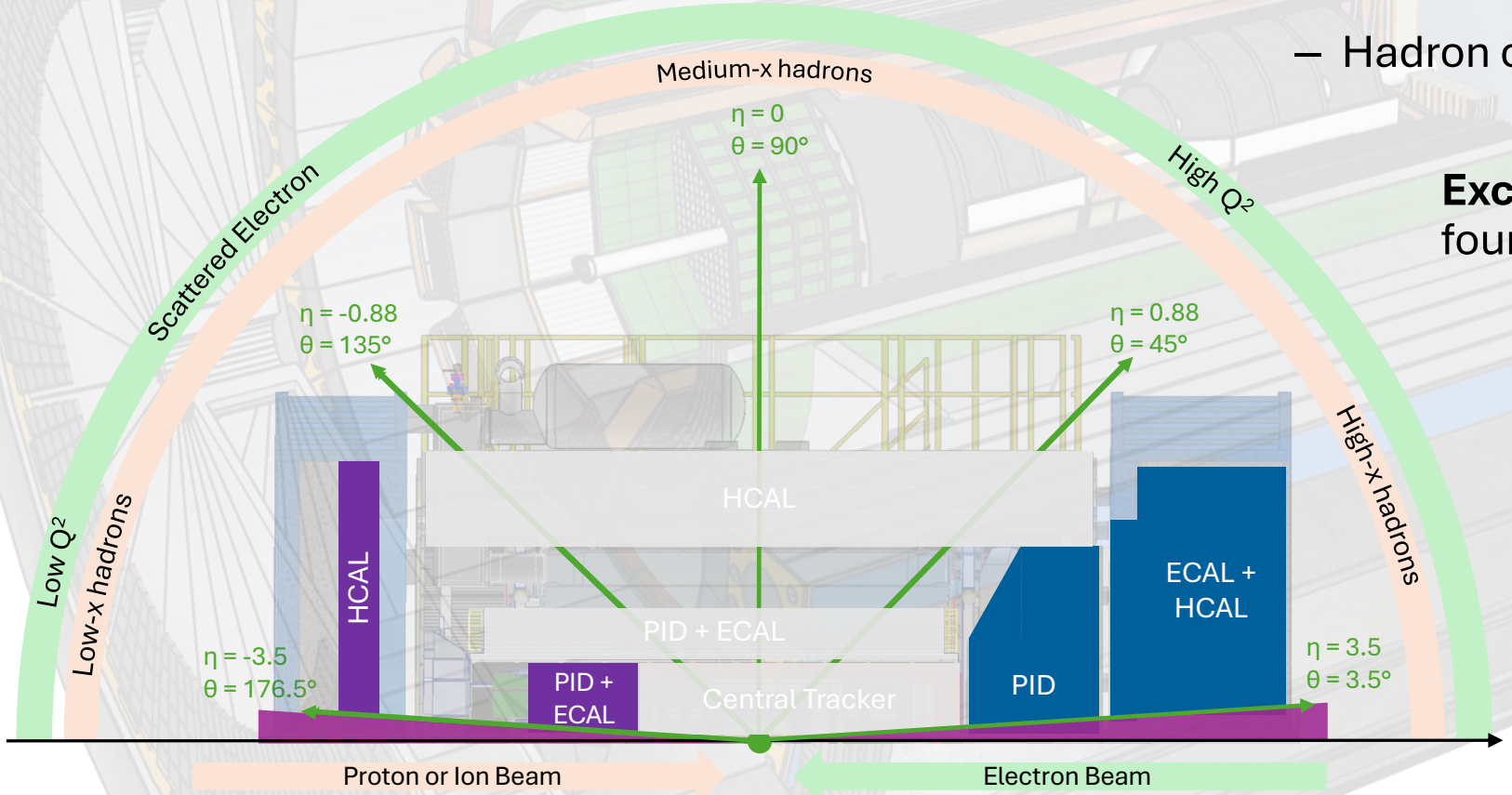
- Detection of all particles in event



Physics-Driven Detector Design

Inclusive DIS requires fine binning in x_B, Q^2:

- Large angular coverage for wide phase space reach
- Excellent EM-calorimetry with PID support for e/π separation, and good electron energy resolution
- Fine resolution tracking with low mass



Semi-inclusive DIS requires binning in five or more variables (x_B, Q^2, z, p_T, ϕ_h , ...):

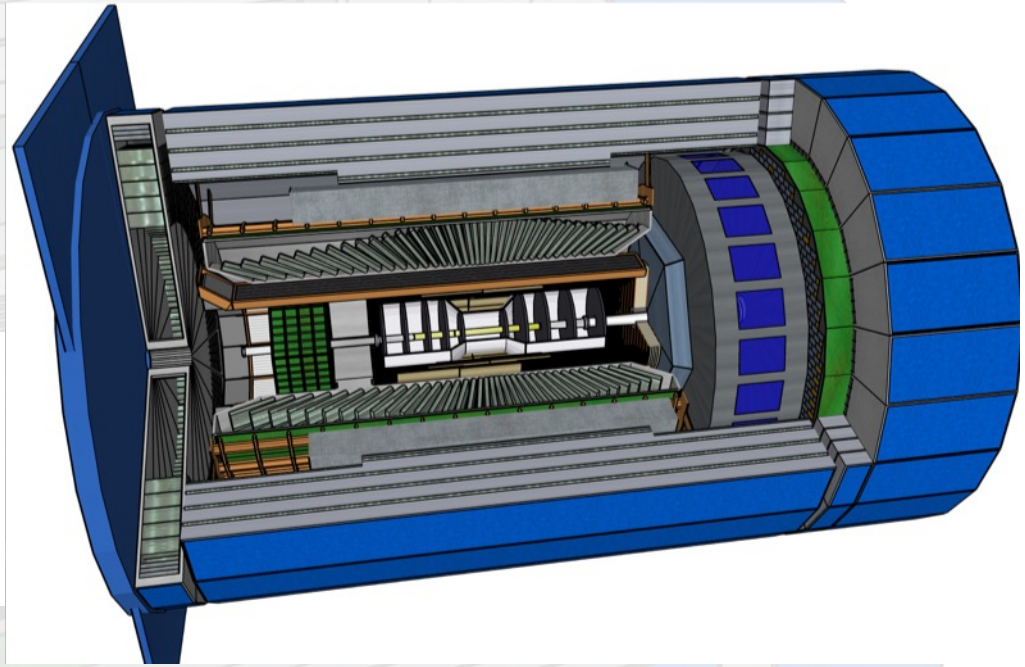
- Fine p_T resolution
- Extended PID systems for hadron identification
- Hadron calorimetry for jet physics

Exclusive processes require binning in four or more variables (x_B, Q^2, t, ϕ_h , ...):

- Extend acceptance at extremely small scattering angles by far forward detectors
- Fine vertex resolution by tracking
- Highly granular EM-calorimeters to separate γ/π^0

A Brief Timeline

- EICUG Yellow Report (2020-21)
- Call for proposals issued jointly by BNL and JLab in March 2021
  - Proposals due Dec. 1, 2021
  - ATHENA, CORE and ECCE proposals submitted
- Public DPAP meetings Dec. 13-15, 2021
  - Presentations from proto-collaborations
  - Panel-assigned homework questions
- Second DPAP session Jan. 19-21, 2022
- DPAP closeout March 8th, 2022
  - Final report available March 21st, 2022
  - ECCE proposal chosen as basis for Detector-1 reference design
- Spring/Summer 2022 – ATHENA and ECCE form joint leadership team
  - Joint WG's formed and consolidation process undertaken
  - Coordination with EIC project on development of technical design
- Collaboration formation process started July, 2022
  - First IB Meeting July 18th
  - Charter writing committee formed and active – DE&I built in from start!
- **First ePIC Collaboration meeting July 26-29, 2022**



ePIC Detector

- To be sited at IP6 (25mr crossing angle)
- Addresses EIC science program as outlined in the EIC white paper and NAS report
- Must be ready for Day-1 EIC operations
- Working towards pre-TDR and CD-2/3A

JLab, Jan. 2023


Frascati, January 2025


ANL, Jan 2024

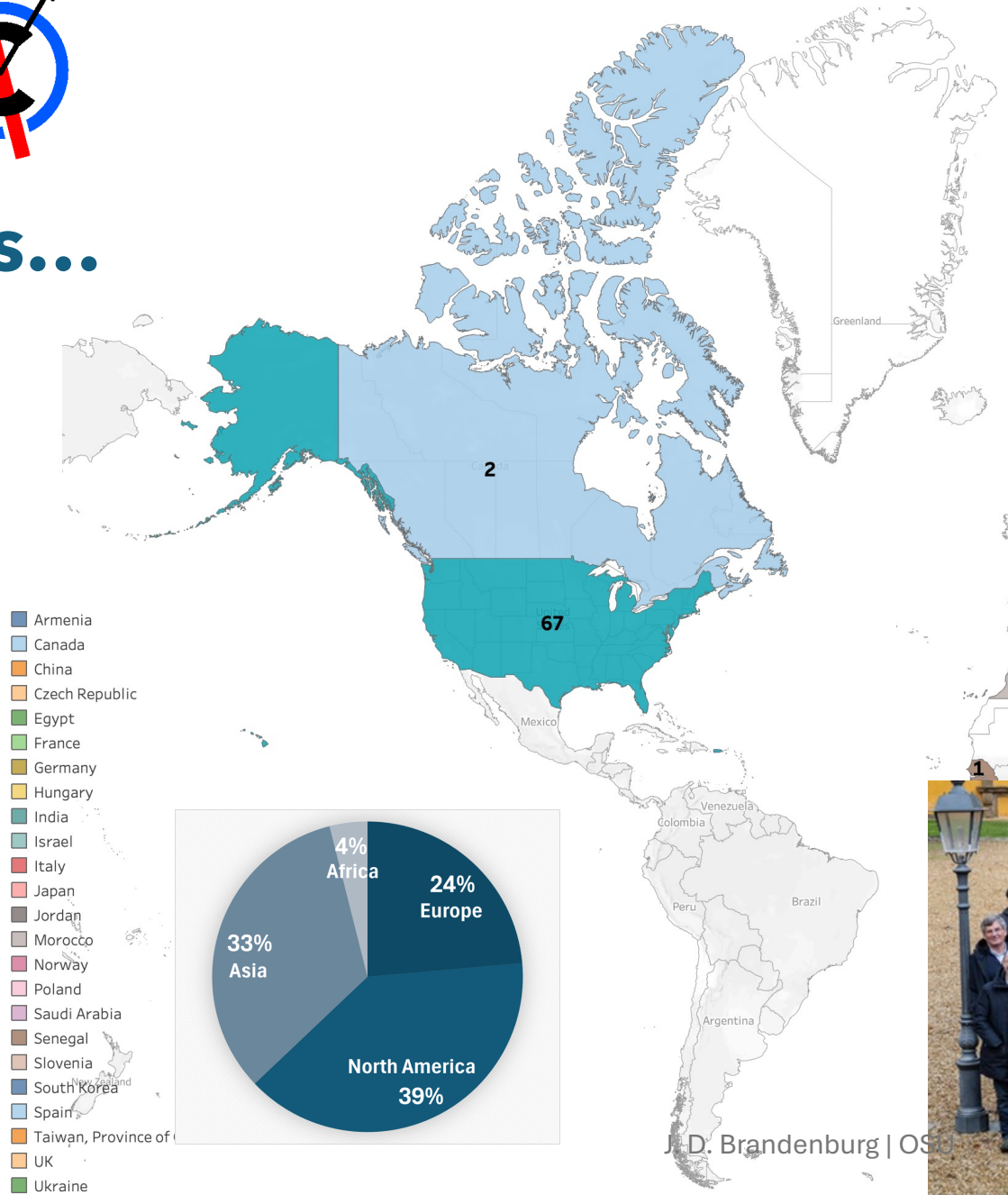
By the numbers…

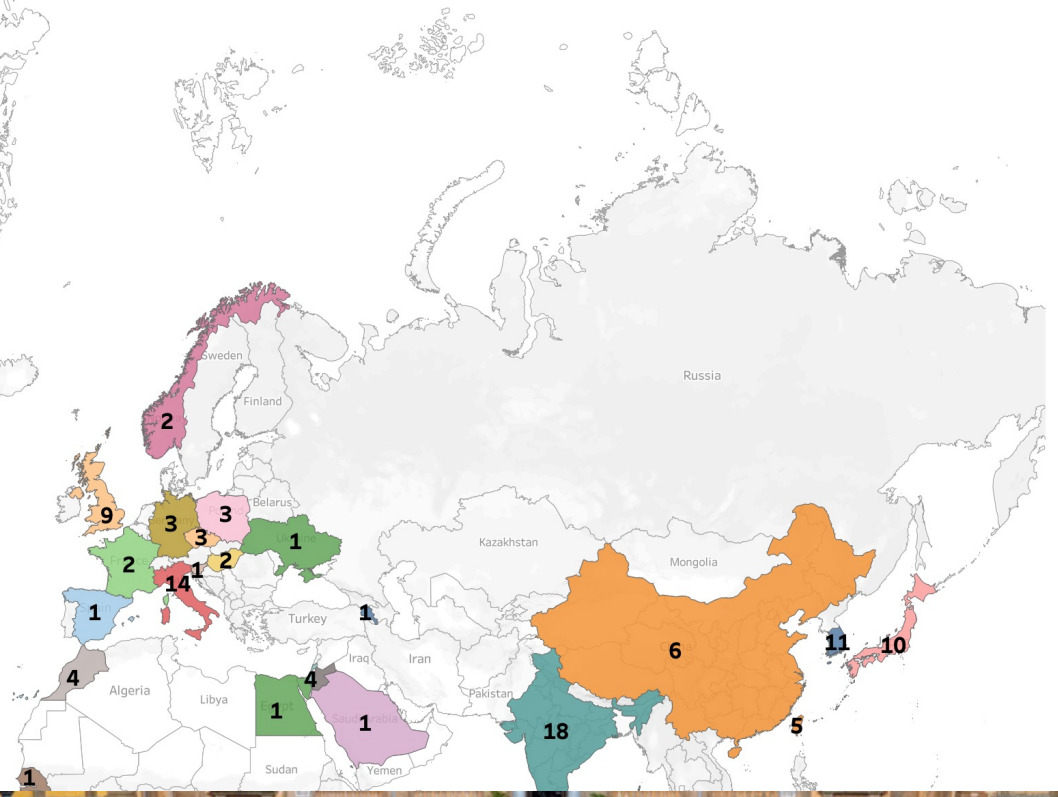
Currently: >1000 collaborators (from 2025 Institutional Survey)

ePIC Institutions
180

ePIC Countries
25

ePIC World Region
4





CERN Recognized Experiment Status: RE47

ePIC now appears in the CERN Grey Book database as RE47: https://greybook.cern.ch/experiment/recognized

Two steps to get ePIC Collaborators registered at CERN:

- CC Representative needs to register as team leader with CERN Users Office:
  - https://usersoffice.web.cern.ch/
  - https://usersoffice.web.cern.ch/team-leaders-corner
  - info@recognized-experiments.cern.ch
- CC member can then certify registrations of team members

Contact us if you run into problems!

Recognized Experiments

Teams and Participations include only people registered at CERN

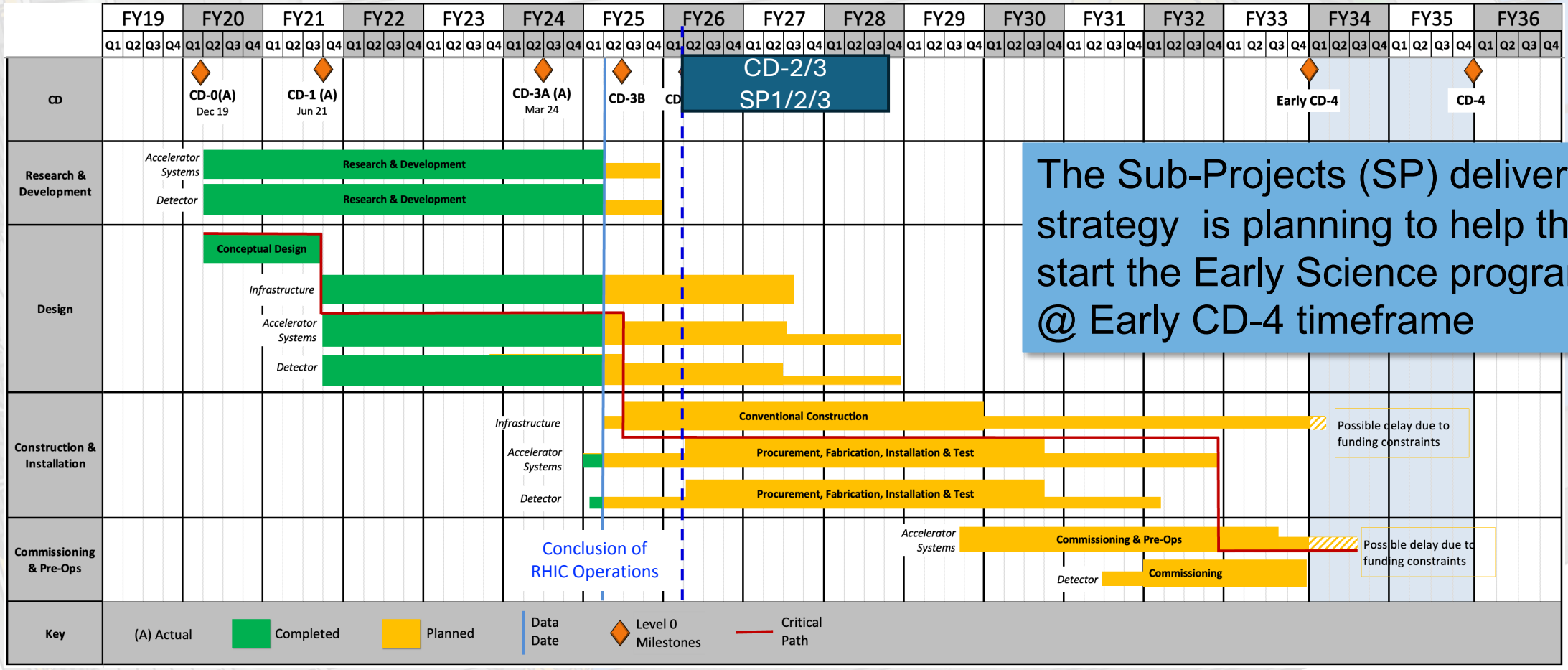
Search criteria: Search

Name	Synonym	Title	Program	Date of Approval	Status
RE35	SNO+	A diverse instrument for neutrino research	RE	08-03-2017	Preparation
RE36		Mu3e	RE	07-03-2018	Preparation
RE37		DarkSide-20k	RE	07-03-2018	Preparation
RE38		DAMIC-M	RE	05-03-2019	Preparation
RE39		sPHENIX	RE	05-03-2019	Preparation
RE40	POLAR-2	A COMPACT DETECTOR FOR GAMMA RAY BURSTS PHOTON POLARIZATION MEASUREMENTS	RE	11-03-2020	Preparation
RE41	COSINUS	Cryogenic Observatory for SIgnals seen in Next-generation Underground Searches	RE	17-03-2021	Preparation
RE42	CRESST	Cryogenic Rare Event Search with Superconducting Thermometers	RE	17-03-2021	Data Taking
RE43	Einstein Telescope	Einstein Telescope	RE	16-03-2022	Preparation
RE44	HERD	The High Energy cosmic Radiation Detection facility	RE	13-03-2023	Preparation
RE45	Hyper-K	Hyper-Kamiokande	RE	13-03-2023	Preparation
RE46	NUCLEUS	NUCLEUS	RE	13-03-2023	Preparation
RE47		electron-Proton/ion Collider	RE	19-03-2025	Preparation
RE6	ANTARES	Astronomy with a Neutrino Telescope and Abyss environmental Research	RE	09-12-1999	Data Taking
RE7	FERMI	The Fermi Gamma-ray Space Telescope	RE	15-06-2000	Preparation
RE8	LISA	The Laser Interferometer Space Antenna	RE	14-09-2000	Preparation

Rows per page: 20 21–36 of 36

EIC Schedule – Under Development

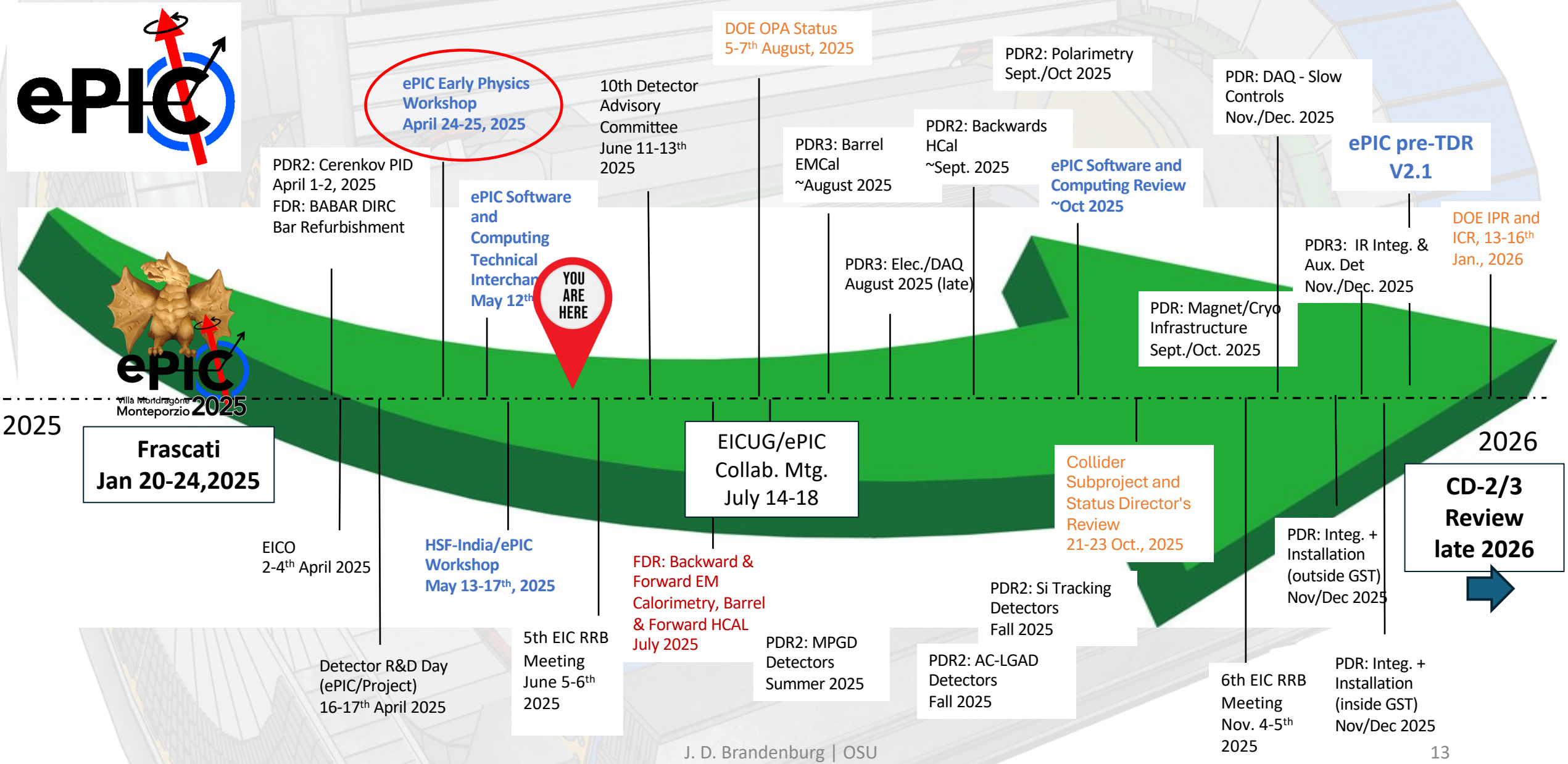
Schedule Update Underway - Mostly Technically Driven after FY2027



The Sub-Projects (SP) delivery strategy is planning to help the start the Early Science program @ Early CD-4 timeframe

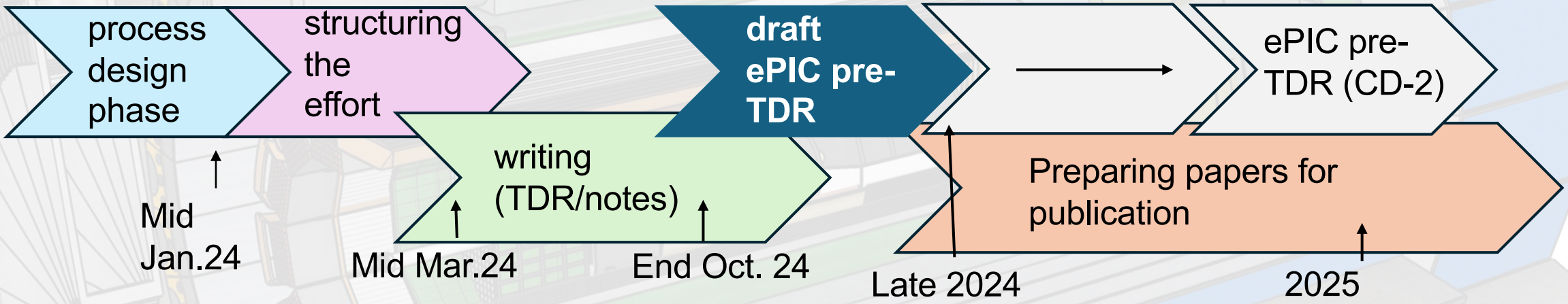
Since CD-1, the critical path is on the Accelerator systems.

Many Milestones in the next year!



(pre)TDR Strategy and Publications

The EIC (pre)TDR is the top priority for the ePIC Collaboration



Timeline driven by the EIC Project (CD-2/CD-3)

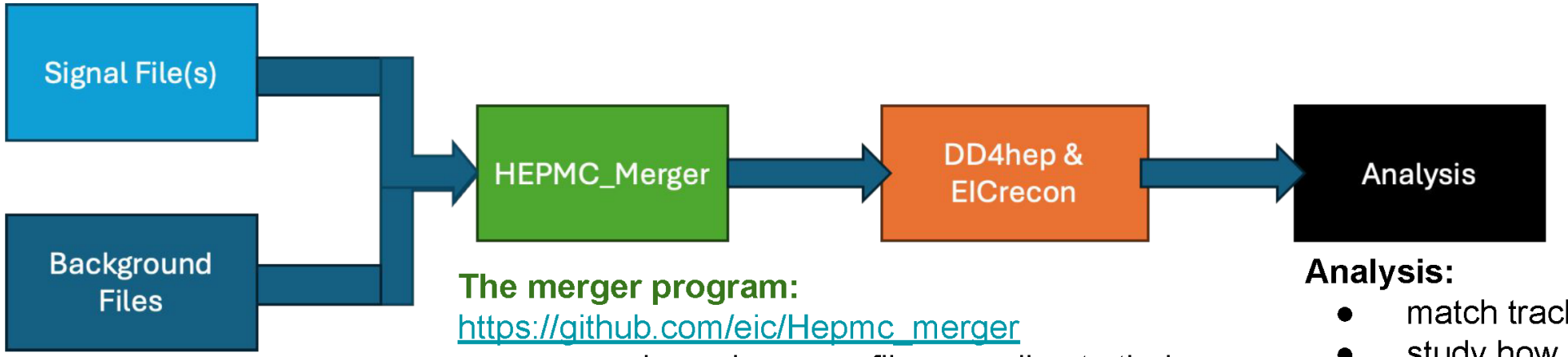
Extended versions of the sections on the detector, physics performance, and software & computing to be published in scientific journals

Priorities Moving towards the preTDR

Example: Demonstrate detector performance in a realistic background environment

In DIS+Background merged event (2us):

	DIS(Q2>1)	minBias (SIDIS)	Electron beam gas	Synchrotron radiation	Proton beam gas
# of events	0.002	0.9	6.4	28	0.7
# of particles	0.037	14.9	12.8	28	12.4



The merger program:
https://github.com/eic/Hepmc_merger

- sample each source file according to their frequency within a fixed-length (2us) time window
- Will be able to label each source particle with custom generator code in dd4hp v1.32

Analysis:

- match track to particles
- study how well we can reconstruct signal particles

Consistent Effort to Define the Early Science

- Jul. 2024: initial discussion at Coll. Meeting (Lehigh)
  https://indico.bnl.gov/event/20727/contributions/93191/
- Sep. 2024: kick-off workshop
  https://indico.bnl.gov/event/24432/
- Jan. 2025: plenary at Coll. Meeting (Frascati)
  https://agenda.infn.it/event/43344/sessions/31149/#20250122
- Apr. 24-25, 2025: workshop at SBU
  https://indico.cfnssbu.physics.sunysb.edu/event/410/
- Jul. 2025: plenary at Coll. Meeting (JLab)
  https://indico.jlab.org/event/934/overview
- ~ Sep. 2025: workshop
- Spring/summer 2026: final report

April 2025 Workshop

Thu, April 24

9:00 AM – 9:20 AM	**Address by the ePIC spokesperson** Contribution | Speaker: John Lajoie
9:20 AM – 9:40 AM	**Introduction by the Physics Analysis Coordinators** Contribution | Speakers: Salvatore Fazio, Rosi Reed
9:40 AM – 10:25 AM	**Mining for gluon saturation at the Electron-Ion Collider** Contribution | Speaker: Farid Salazar
10:25 AM – 10:35 AM	**Wellcome by the CFNS Director** Contribution | Speaker: Abhay Deshpande
11:05 AM – 11:50 AM	**Thoughts on early EIC running with in eA** Contribution | Speaker: Wim Cosyn
11:50 AM – 12:35 PM	**Key processes to access parton orbital angular momentum at the EIC** Contribution | Speaker: Shohini Bhattacharya
1:35 PM – 3:35 PM	**Discussion on scientific opportunities - (Driven by Yuri Kovchegov)** Session | Convener: Yuri Kovchegov

Fri, April 25

9:00 AM – 9:45 AM	**Studies and projections by the inclusive PWG & the BSM+EW PWG** Contribution | Speakers: Stephen Maple, Tyler Kutz
9:45 AM – 10:30 AM	**Studies and projections by the semi-inclusive PWG** Contribution | Speakers: Ralf Seidl, Stefan Diehl
11:00 AM – 11:45 AM	**Studies and projections by the exclusive+diffractive+tagging PWG** Contribution | Speaker: Zhoudunming Tu
11:45 AM – 12:30 PM	**Studies and projections by the jets+heavy-flavor PWG** Contribution | Speaker: Rongrong Ma
1:30 PM – 1:50 PM	**Presentation of the image_browser for sharing results** Contribution | Speaker: Torri Jeske
1:50 PM – 2:20 PM	**Beams effects and background in simulation** Contribution | Speaker: Alex Jentsch
2:20 PM – 3:05 PM	**Discussion on Simulation Needs and Coordination - led by SCC** Contribution | Speakers: Markus Diefenthaler, Sakib Rahman, Wouter Deconinck

Input and open discussion with theorists

Reports from ePIC Physics/Detector Working Groups, Software & Computing + Many individual contributions

Early Science Matrix

	Species	Energy (GeV)	Luminosity/year (fb-1)	Electron polarization	p/A polarization
YEAR 1	e+Ru or e+Cu	10 x 115	0.9	NO (Commissioning)	N/A
YEAR 2	e+D e+p	10 x 130	11.4 4.95 - 5.33	LONG	NO TRANS
YEAR 3	e+p	10 x 130	4.95 - 5.33	LONG	TRANS and/or LONG
YEAR 4	e+Au e+p	10 x 100 10 x 250	0.84 6.19 - 9.18	LONG	N/A TRANS and/or LONG
YEAR 5	e+Au e+3He	10 x 100 10 x 166	0.84 8.65	LONG	N/A TRANS and/or LONG

Note: the eA luminosity is per nucleon

The staged ramp-up of EIC to full capacity leads to discussion of early science
- First 5 years
- Double HERA ep luminosity + new eA data

ePIC: a series of plenary sessions and workshops to define meaningful and impactful ES measurements
- Tied to EIC science mission
- Physics working groups: simulation, analysis, precision projection

EIC Early Science Program

Year - 1

Start with Phase 1 EIC

New Capability:
Commission electron polarization in parallel

Run:
10 GeV electrons on 115 GeV/u heavy ion beams (Ru or Cu)

Physics:
- nPDF in unexplored low-x region
- Electric & magnetic form factors

Year - 2

Phase 1 EIC
+ electron polarization

New Capability:
Commission proton polarization in parallel

Run:
10 GeV polarized electrons on 130 GeV/u Deuterium

Physics:
- Free neutron structure

Run:
Last weeks 10 GeV electrons and 130 GeV polarized protons

Physics:
- PDF, structure function

Year - 3

Phase 1 EIC
+ electron polarization
+ proton polarization

New Capability:
Commission running with hadron spin rotators

Run:
10 GeV polarized electrons on 130 GeV transverse polarized protons

Physics:
- Hadron structure, hadron mass

Run:
Last weeks switch to longitudinal proton polarization

Physics:
- Baseline for saturation effect
- Proton spin structure at low x

Year - 4

Phase 1 EIC
+ electron polarization
+ proton polarization
+ operation of hadron spin rotators

New Capability:
Commission hadron accelerator to operate with not centered orbits

Run:
10 GeV polarized electrons on 100 GeV Au

Physics:
- Gluon spatial distribution
- Constrain nFF

Run:
10 GeV electrons on 250 GeV transverse and longitudinal polarized protons

Physics: …

Year - 5

Phase 1 EIC
+ electron polarization
+ proton polarization
+ operation of hadron spin rotators
+ operation of hadron beams with not centered orbits

Run:
10 GeV polarized electrons on 100 GeV Au

Physics:
- Nuclear effects, hadronization

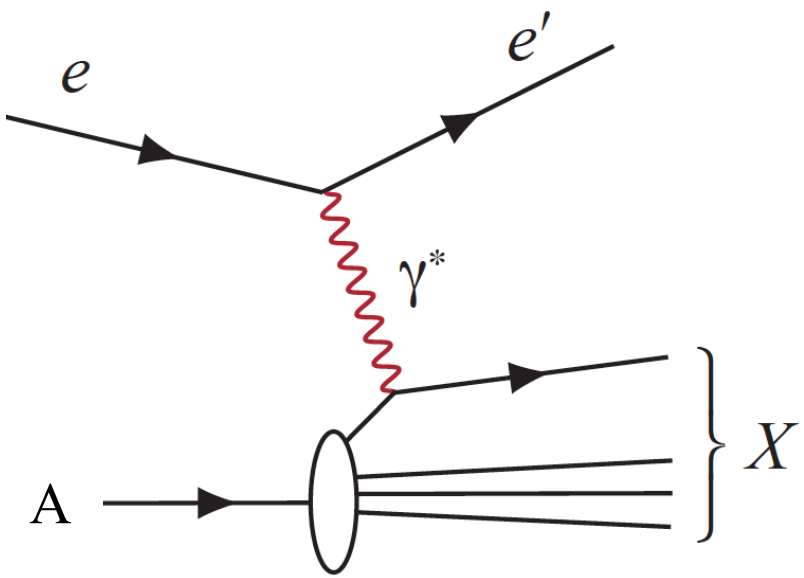
Run:
10 GeV electrons on 166 GeV transverse and longitudinal polarized He-3

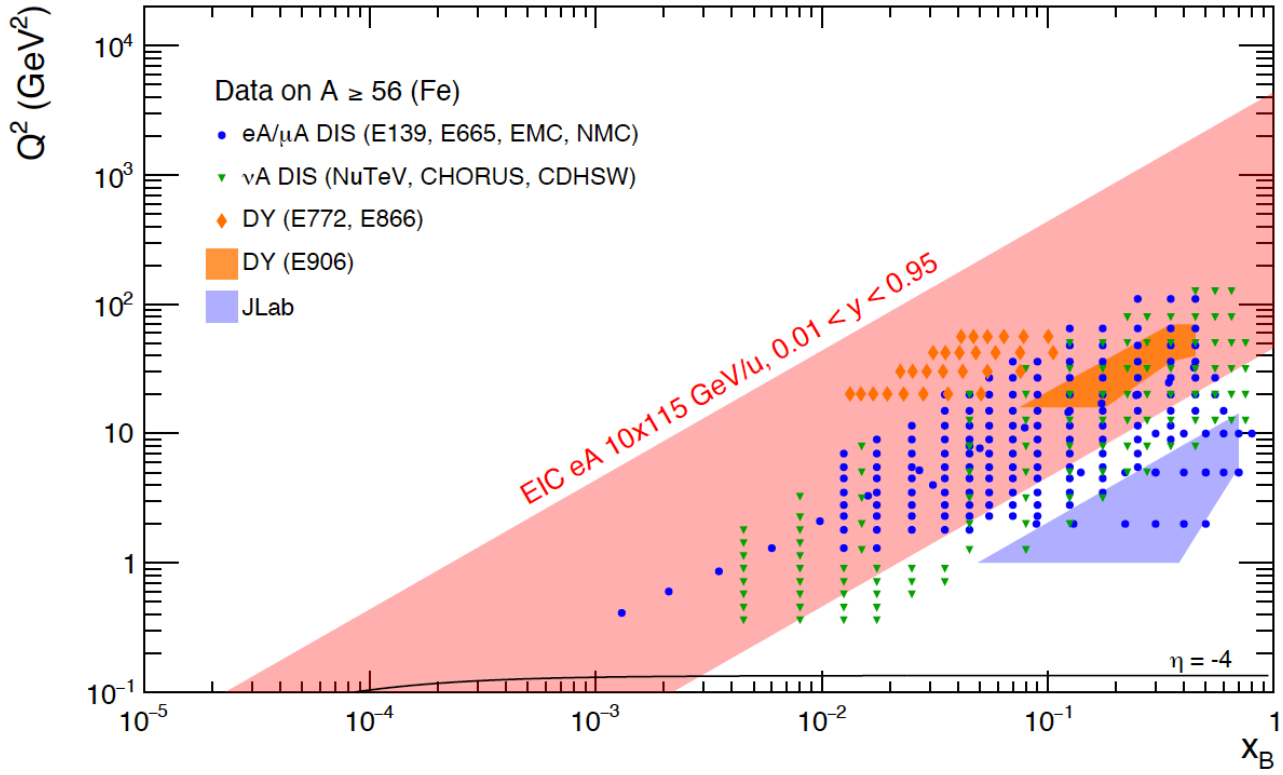
Physics:
- Quark orbital angular momentum

Time to install additional ESR RF and HSR PS to reach design Current and max. Energies

Year 1: e+Cu/Ru @ 10x115

- Total and differential DIS cross section
  → nPDF in unexplored low-*x* region

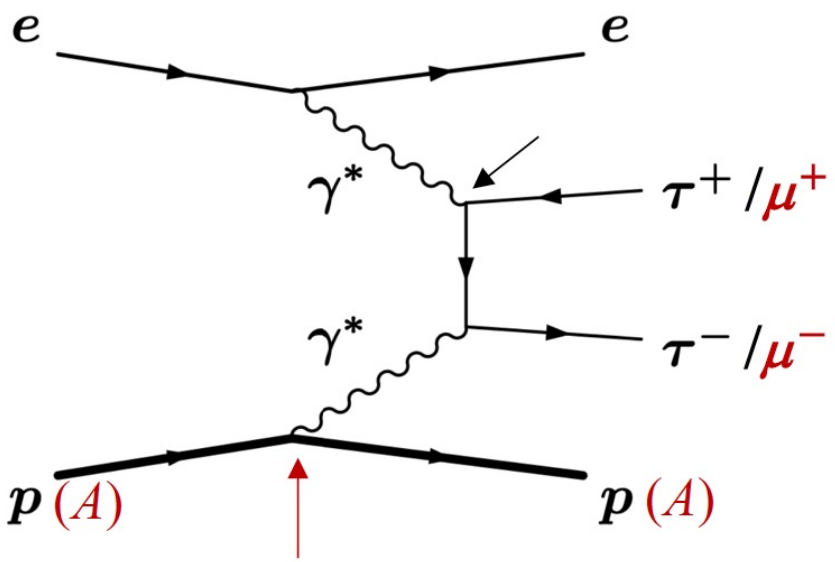


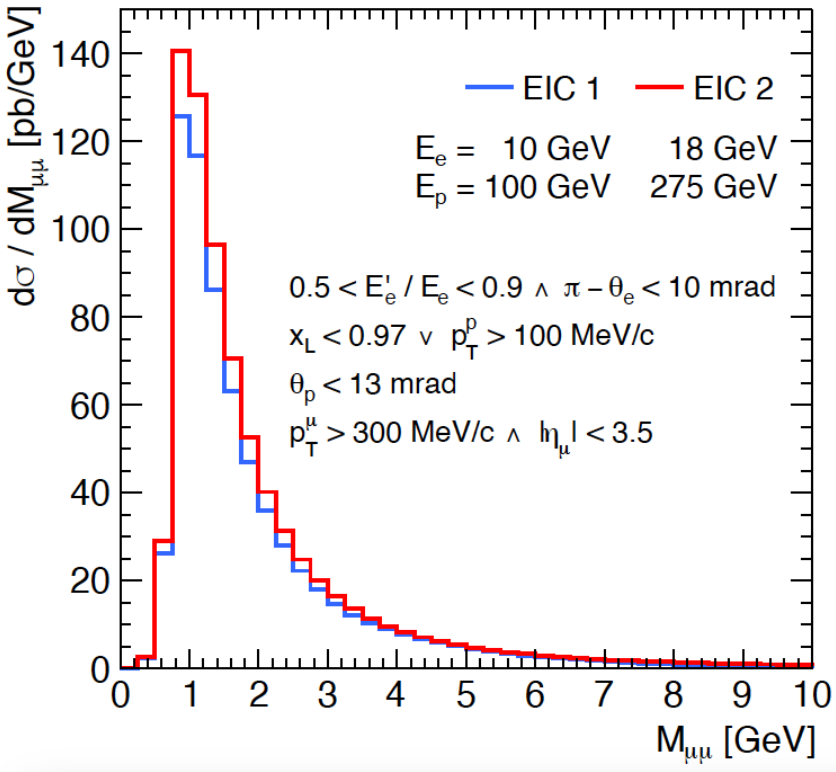


arXiv:2103.05419

Year 1: e+Cu/Ru @ 10x115

- Exclusive dimuon production in elastic interactions
  → Electric and magnetic form factors

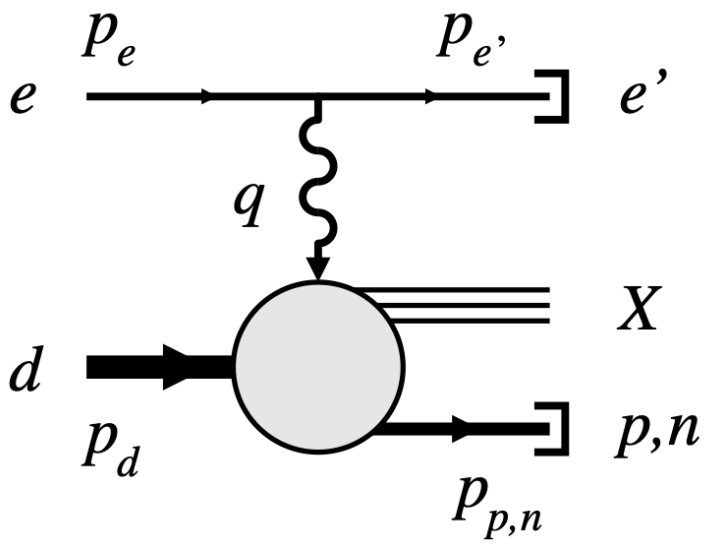


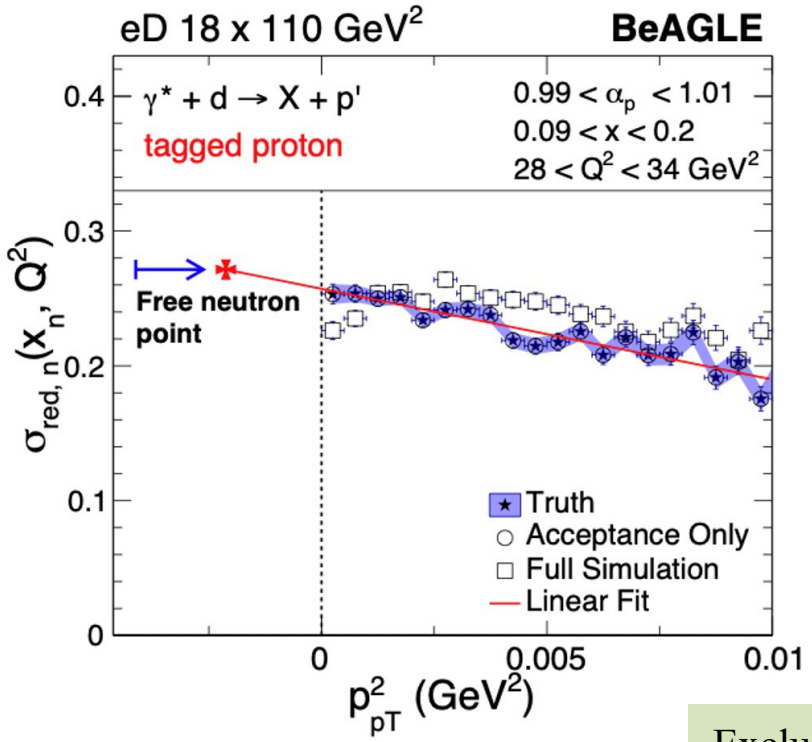


$\sigma_{Ru}(\gamma\gamma \to \mu\mu)$ per nucleon = $\mathcal{O}(10\ \text{nb}) \Rightarrow 10^7$ events!

Year 2: e+D @ 10x130

- Reduced cross section with proton tagging + pole extrapolation
  → Free neutron structure





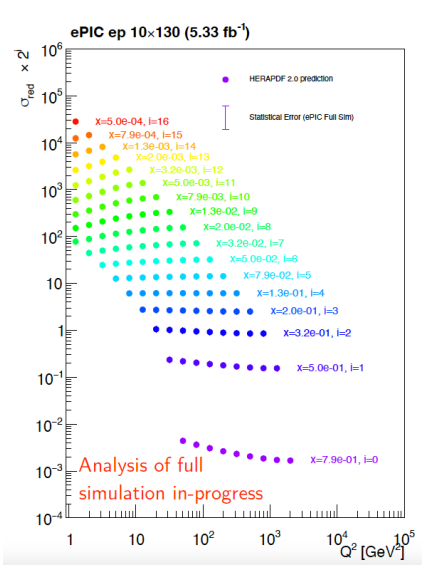
A. Jentsch, et. al., PRC 104 (2021) 065205

Exclusive WG (11:00)

Year 2/3/4: e+p @ 10x130, 10x250

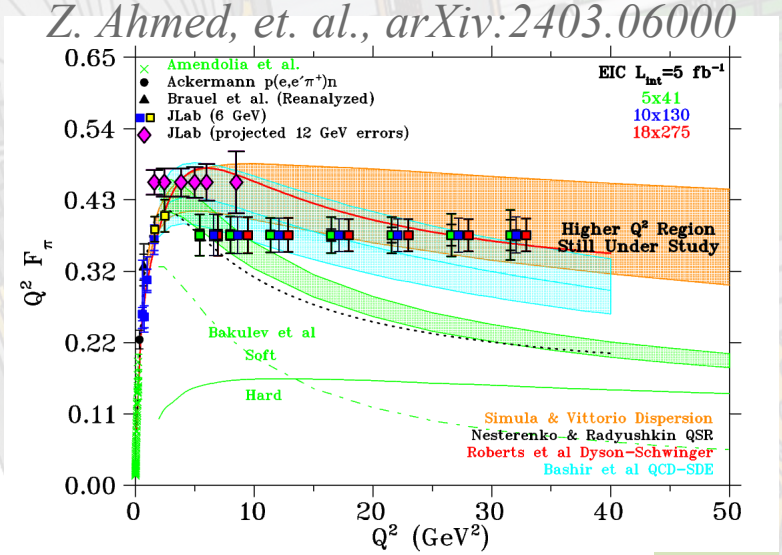
- PDF
- Structure Functions

  arXiv:2103.05419

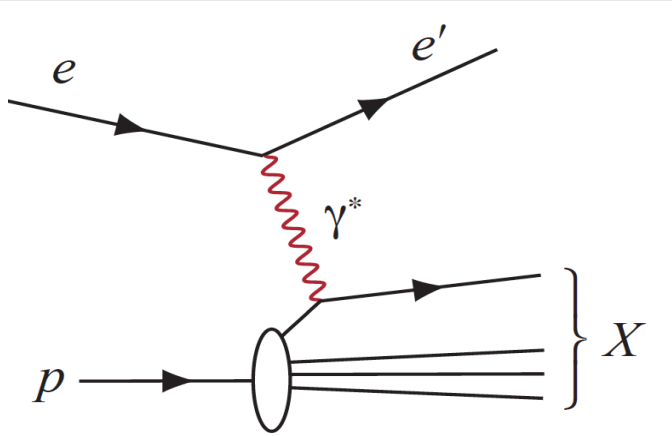


- Hadron structure; hadron mass

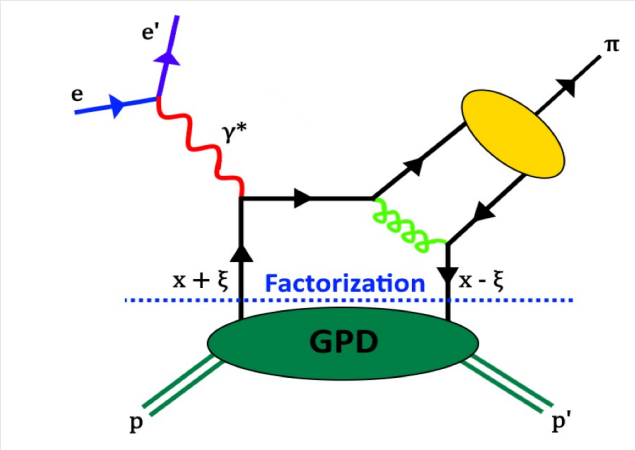
Z. Ahmed, et. al., arXiv:2403.06000



Total and differential DIS cross section

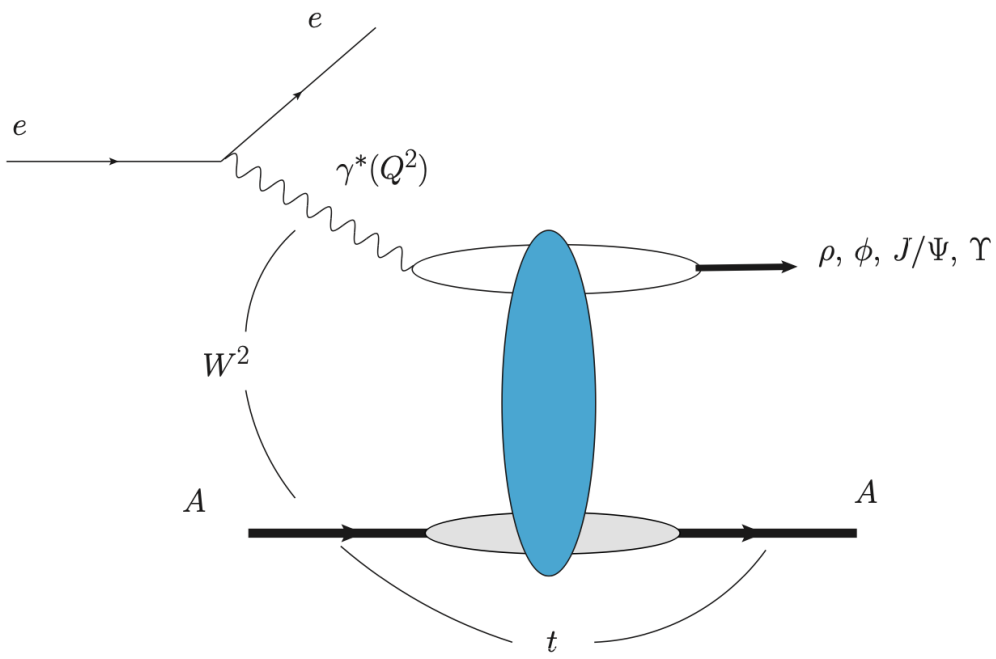


Deep Exclusive Meson Production (DEMP) for meson form factors

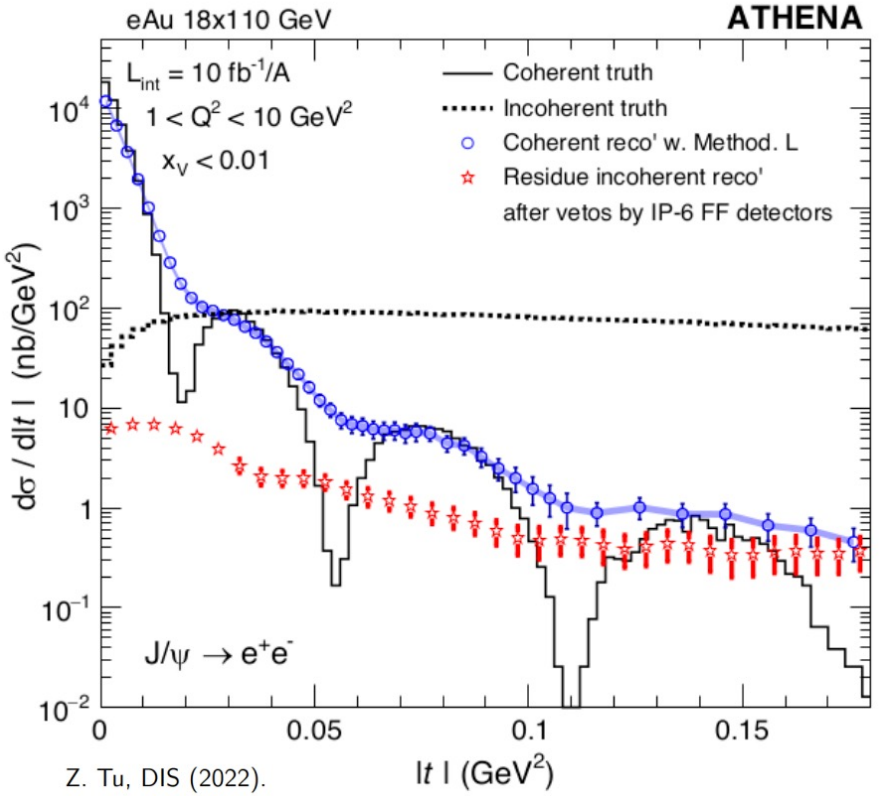


Year 4/5: e+Au @ 10x100

- Exclusive coherent vector meson production
  → Gluon spatial distribution



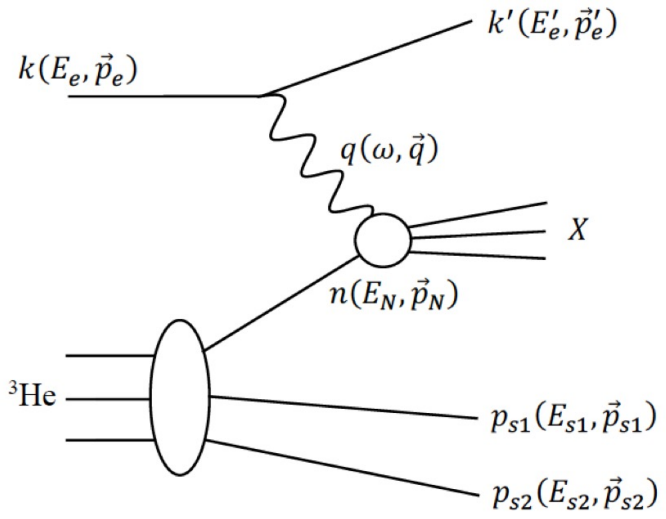
M. Krelina, et. al., NPA 989 (2019) 187



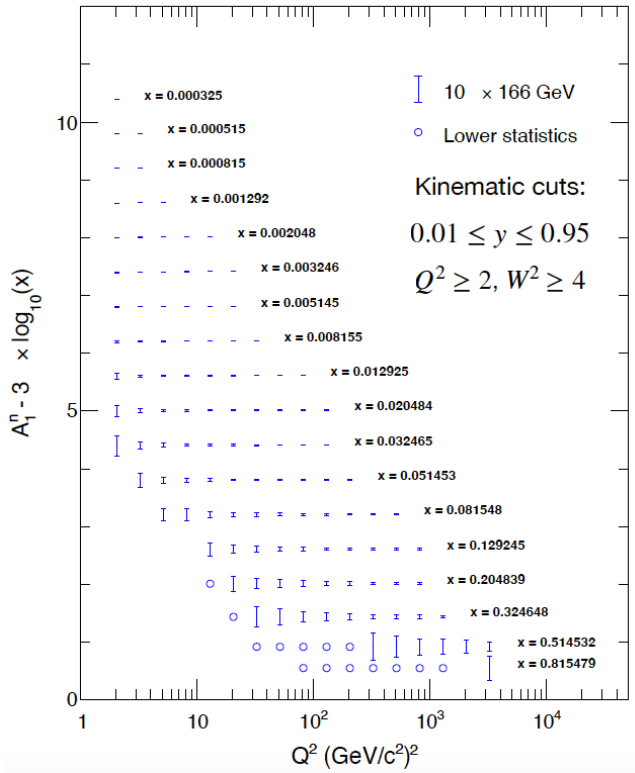
- Limited resolution in measuring $|t|$
- Overwhelming incoherent background

Year 5: e+3He @ 10x166

- Access to **neutron spin structure** (A_1^n) through double-spectator tagging
  → Quark orbital angular momentum



I. Friscic, et. al., PLB 823 (2011) 136726



- Wide range of acceptance in x and Q^2
- Good statistics at unexplored low x region

W. Lin (16:55)

The Path Forward

- The EIC Scientific Mission stands on 2 decades of preparation for **discovery physics**
- **The EIC itself is a World's First – Polarization, Collision Species, Versatility**
- The ePIC Collaboration is growing fast and growing stronger
  - 180 Institutions, 25 Countries, A truly international collaboration
  - CERN Recognized Experiment status
- The Year ahead:
  - Continue to develop the Early Science
  - Major reviews, preTDR milestones, Director's Reviews, etc.
  - Realistic performance in background
  - Invest in publications of early science program, detector developments,