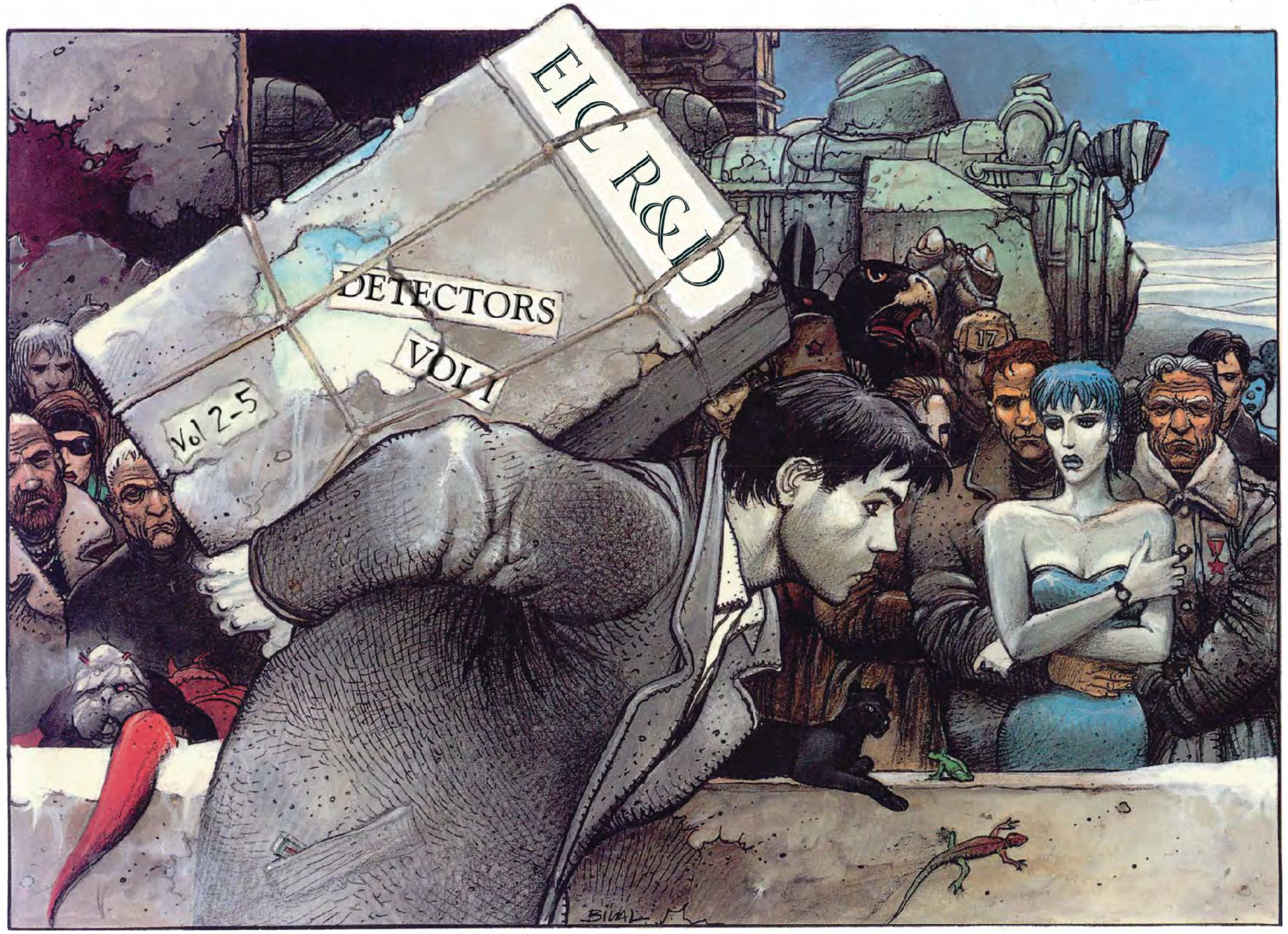
Electron-Ion Collider:
➡ Generic Detector R&D Program
➡ Benefits of Two Detectors



based on drawing by Enki Bilal

Thomas Ullrich

2022 NSAC Long-Range Plan Town Hall Meeting on Hot and Cold QCD

MIT, September 23, 2022

Thanks to Dave Mack for help
in preparing the generic R&D part

BROOKHAVEN NATIONAL LABORATORY

Detector R&D in Nuclear Physics

- NP has no general detector R&D subprogram
  - compare to HEP that fosters research on the physics of particle detection as part of their Advanced Technology R&D subprogram
- NP detector R&D was and is centered around specific projects
  - Implies that R&D funding is tied to timeline of project
  - Example RHIC:

Detector R&D Funding Summary

R&D Effort	FY 90 $	FY 91 $	FY 92 $	FY 93 $	FY 94 $	FY 95 Plan	Total
Total Generic	1,121,437	1,620,751	215,000	20,000	50,000		3,027,188
Total STAR			1,125,000	1,267,000	1,467,365	1,100,000	4,959,365
Total PHENIX			1,200,523	1,463,984	1,147,300	1,000,000	4,811,807
Total PHOBOS				288,000	340,000	200,000	828,000
Total Allocations	1,121,437	1,620,751	2,540,523	3,038,984	3,004,665	2,300,000	13,626,360
Administration & BNL Support	228,563	331,249	269,477	376,016	450,335	296,000	1,951,640
R&D Total	1,350,000	1,952,000	2,810,000	3,415,000	3,455,000	2,596,000	15,578,000

Source:
T. Ludlam, RHIC Detector R&D:
A History and Summary (1994)

- We knew quite early that an EIC detector is too complex to wait with R&D until EIC matures and becomes a DOE project
  - Recognized in 2007 LRP: We recommend the allocation of resources to develop […] detector technology necessary to lay the foundation for a polarized Electron-Ion Collider.

World-Wide R&D Efforts with Potential Impact on EIC

- CERN R&D program with partial match with EIC needs (e.g. RD51 Micro-Pattern Gas Detectors Technologies)
  - prominent and strong R&D program in the past, now restructured
- LHC Experiments R&D for phase-I upgrades, especially ALICE (TPC, ITS, SAMPA) and LHCb (RICH, triggerless DAQ).
  - LHC related R&D not very strong on PID and forward/backward instrumentation
  - much emphasis on radiation hardness
- R&D at Belle-II and Panda (crystals, DIRC, …)
- ILC related R&D (TPC w/ MMG)
  - Rate and precision requirements compatible
  - Less emphasis on forward/backward instrumentation
- Laboratory Directed Research & Development Programs (LDRDs) at National Labs in the US (ANL, BNL, JLAB, LANL, LBNL, ORNL)
  - kicked in after ~2015

Generic EIC Detector R&D Program (2011-2021)

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

- Goals of Effort
  - Enable successful design and timely implementation of an EIC experimental program
  - Quantify the key physics measurements that drive instrumentation requirements
  - Develop instrumentation solutions that meet realistic cost expectations
- Stimulate the formation of user collaborations to design and build experiments

motivates software/ simulation projects

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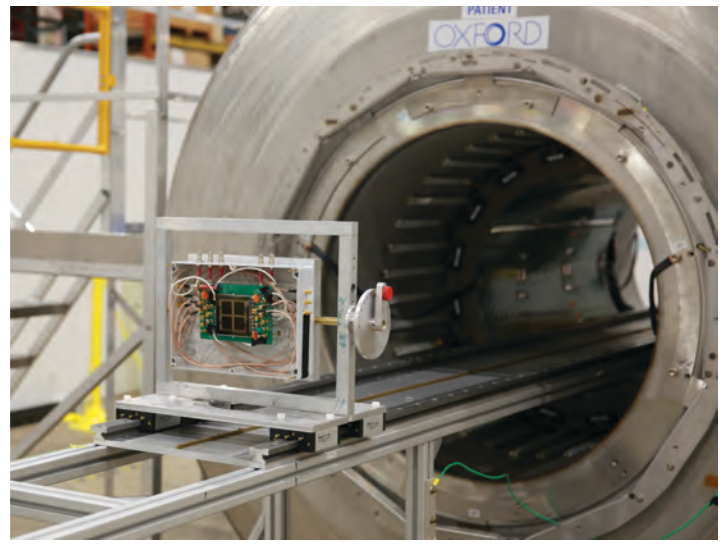
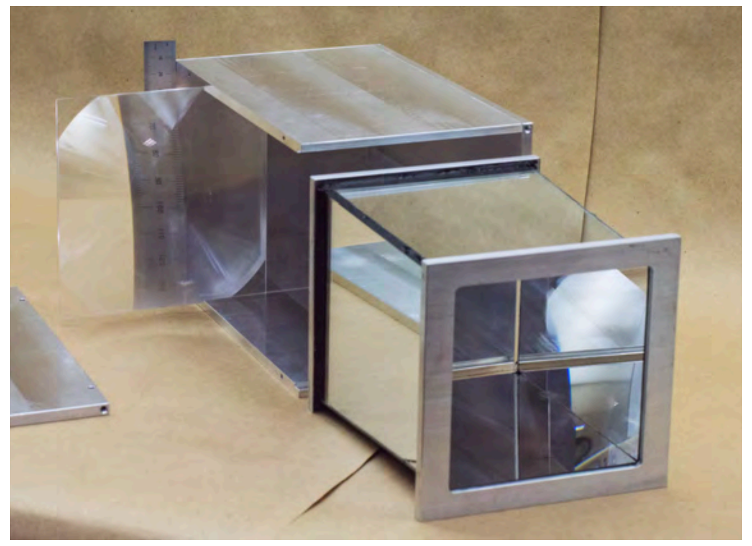
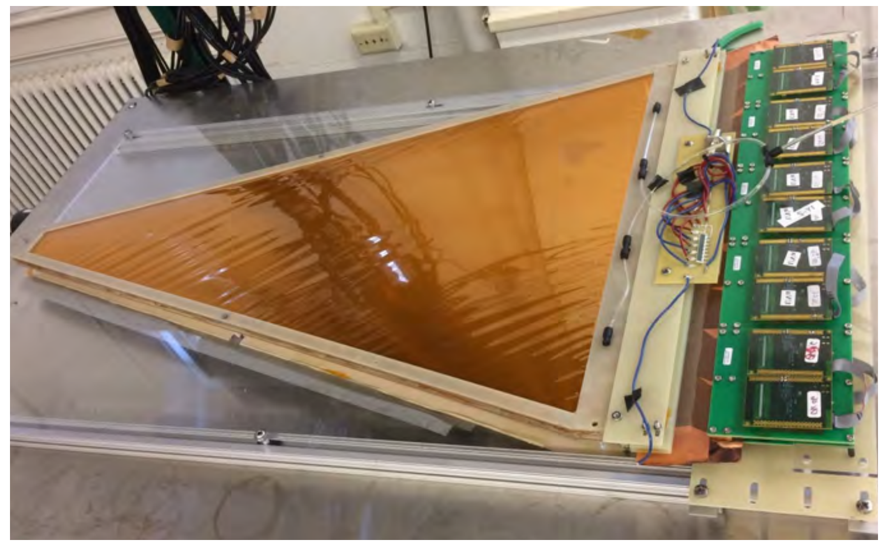
this was absolute key - at least as important as R&D itself

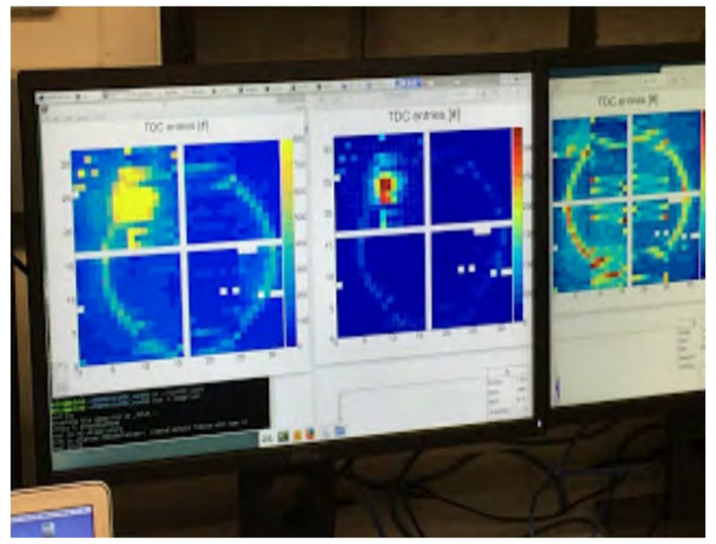
motivates software/ simulation projects

First Generic EIC Detector R&D Program

- Started in 2011 by BNL in association with JLab and the DOE Office of NP
- Funded by DOE through RHIC operations funds
- Program explicitly open to international participation
- Standing EIC Detector Advisory Committee consisting of internationally recognized experts in detector technology
- Typical 10-11 projects supported per year
- Over 281 participants from 77 institutions (37 non-US)
- Many of the subsystems in EPIC were developed and matured in the program
- Many PIs and participants of this program now active in EPIC detector working groups
- With start of project R&D, the first generic program ended (2021)





On the web: `https://wiki.bnl.gov/conferences/index.php/EIC_R%25D`

Generic R&D Projects 2014-2021

Project	Topic
eRD1	EIC Calorimeter Development
eRD2	A Compact Magnetic Field Cloaking Device
eRD3	Design and assembly of fast and lightweight forward tracking prototype systems
eRD6	Tracking and PID detector R&D towards an EIC detector
eRD10	(Sub) 10 Picosecond Timing Detectors at the EIC
eRD11	RICH detector for the EIC's forward region particle identification - Simulations
eRD12	Polarimeter, Luminosity Monitor and Low Q2-Tagger for Electron Beam
eRD14	An integrated program for particle identification (PID)
eRD15	R&D for a Compton Electron Detector
eRD16	Forward/Backward Tracking at EIC using MAPS Detectors
eRD17	BeAGLE: A Tool to Refine Detector Requirements for eA Collisions in the Nuclear Shadowing/Saturation Regime
eRD18	Precision Central Silicon Tracking & Vertexing
eRD19	Detailed Simulations of Machine Background Sources and the Impact to Detector Operations
eRD20	Developing Simulation and Analysis Tools for the EIC
eRD21	EIC Background Studies and the Impact on the IR and Detector design
eRD22	GEM based Transition Radiation Tracker R&D
eRD23	Streaming Readout for EIC Detectors
eRD24	Silicon Detectors with high Position and Timing Resolution as Roman Pots at EIC
eRD25	Si-Tracking
eRD26	Pulsed Laser System for Compton Polarimetry
eRD27	High Resolution ZDC
eRD28	Superconducting Nanowire Detectors
eRD29	Precision Timing Silicon Detectors for combined PID and Tracking System

Tracking | PID | Calorimetry | Software/Simulations | Other

The Need for Continuing Generic R&D

- EIC Specific
  - EIC project R&D only supports R&D to reduce risk and optimize technologies used in project detector (EPIC)
  - Need to continue developing technologies that are not ready for day-1 (CD-4a timeline) but that would offer superior technologies down the road
  - Support some higher risk items that, if successful, could be ready for day-1
  - R&D for complementary technologies that could be used in a 2nd EIC detector
  - Develop technology for future upgrades keeping the EIC on cutting-edge in the future and built on past investments
- Broader Impact
  - develop more environmental-friendly technologies (e.g. fluorocarbon)
  - brings benefit for other programs in NP, HEP, and medical application (e.g. PET w/ ToF)

The NEW Generic EIC Detector R&D Program

We were heard: Generic program reconstituted starting this year

- funded by DOE
- coordinated by JLab (Dave Mack)
- `https://www.jlab.org/research/eic_rd_prgm`
- total of **27** proposals were received on July 25, 2022

The large amount of good proposals on vital technologies shows clearly the need for generic R&D within the community

CSGlass for hadron calorimetry at the EIC
A proposal for MPGD-based transition radiation detector/tracker
Precise Timing with a Micro Pattern Gaseous Detector
BeAGLE, a tool to refine IR and detector requirements for the EIC
Continued Development and Evaluation of a Low-Power High-Density High Timing Precision Readout ASIC for AC-LGADs (HPSoC)
A new radiation tolerant low power Phase-Locked Loop IP block in a 65 nm technology for precision clocking in the EIC frontend electronics
Refined Methods for Transfer Matrix Reconstruction Using Beamline Silicon Detectors for Exclusive Processes at the EIC
TOMATO (end-TO-end siMulation fAst deTectOrs): An end-to-end simulation framework for fast detectors at the EIC
Z-Tagging Mini DIRC
Implementation of a gain layer in Monolithic Active Pixel Sensor (MAPS) for high resolution timing application
Development of a Generic, Low-power and Multi-channel Frontend Readout ASIC for Precision Timing Measurements at EIC
Development of a Novel Readout Concept for an EIC DIRC
Simulations of the physics impact of a solenoid-based compensation scheme for the field of the main detector solenoid in IR8
Tracking and PID with a GridPIX Detector
Particle identification and tracking in real time using Machine Learning on FPGA
Development of High Precision and Eco-friendly MRPC TOF Detector for EIC
Machine Learning for Detection of Low-Energy Photons in the EIC ZDC
Superconducting Nanowire Detectors for the EIC
EIC KLM R&D Proposal
High Quantum Efficiency III-nitrides photocathodes and hybrid photon detectors for EIC
Exclusive and Semi-inclusive reactions in the muonic channel, and development of muon detectors in the far forward region
Injection Molding of Large Plastic Scintillator Tiles at Optical Quality
Development of Thin Gap MPGDs for EIC Trackers
Simplified LGAD structure with fine pixelation
Imaging Calorimetry for the Electron-Ion Collider
Silicon Tracking and Vertexing Consortium
Combined design of a projective tracker and PID system for the EIC Detector-1 with the assistance of Artificial Intelligence

Suggested Input for LRP

- The next Long Range Plan should
  - detail the need for continuing generic detector R&D
  - encourage DOE to continue their support and funding
- Relevant question: should one push for NP-wide R&D program?
  - gain broader support
  - allow for cross-fertilization between NP communities on advanced technologies
  - possible overlap with HEP program (synergy)?
- Supporting text needs to be part of the EIC White Paper and the topic needs to be promoted in the LRP resolution meeting

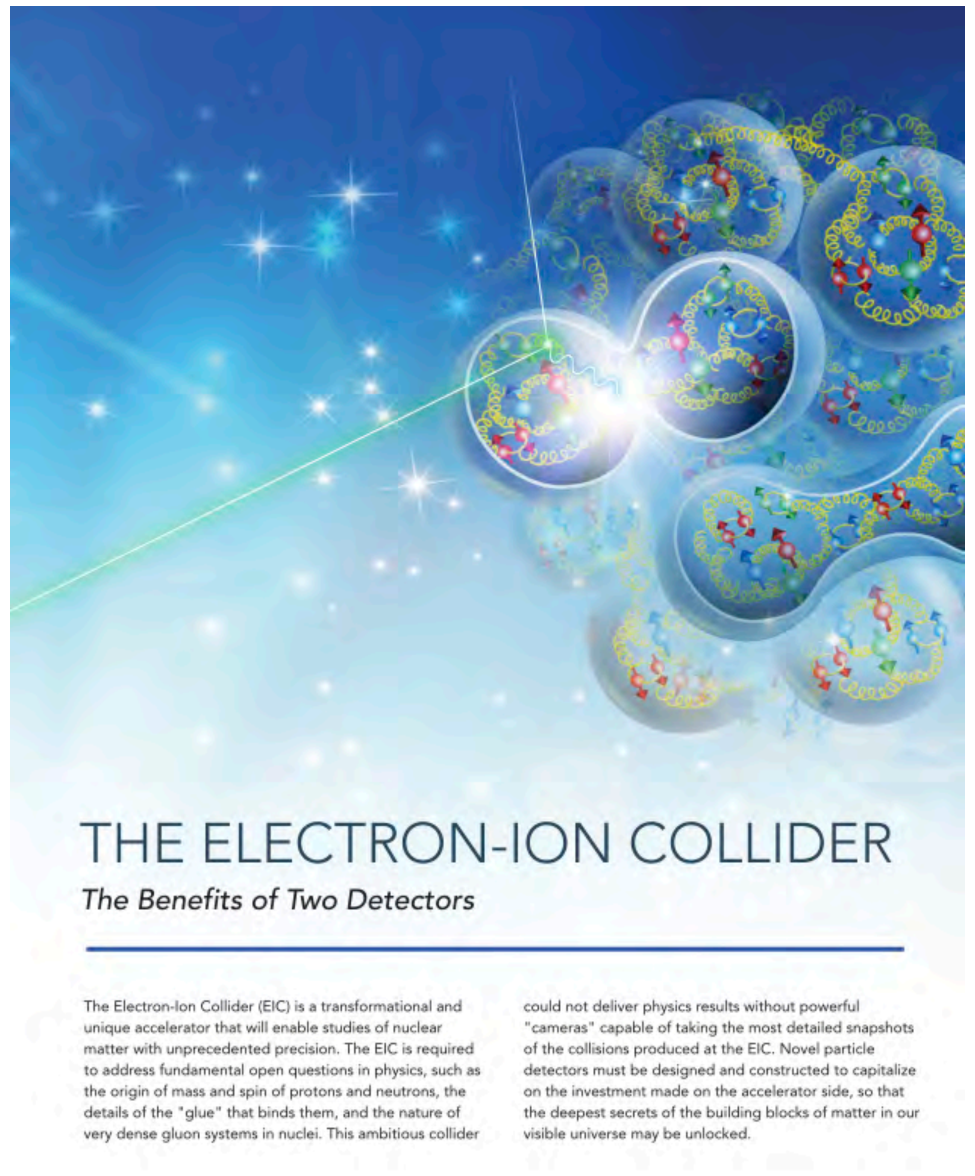
- For the EIC, this effort is connected to the long term future of the program addressing future detector upgrades and technology choices of a potential 2nd EIC detector

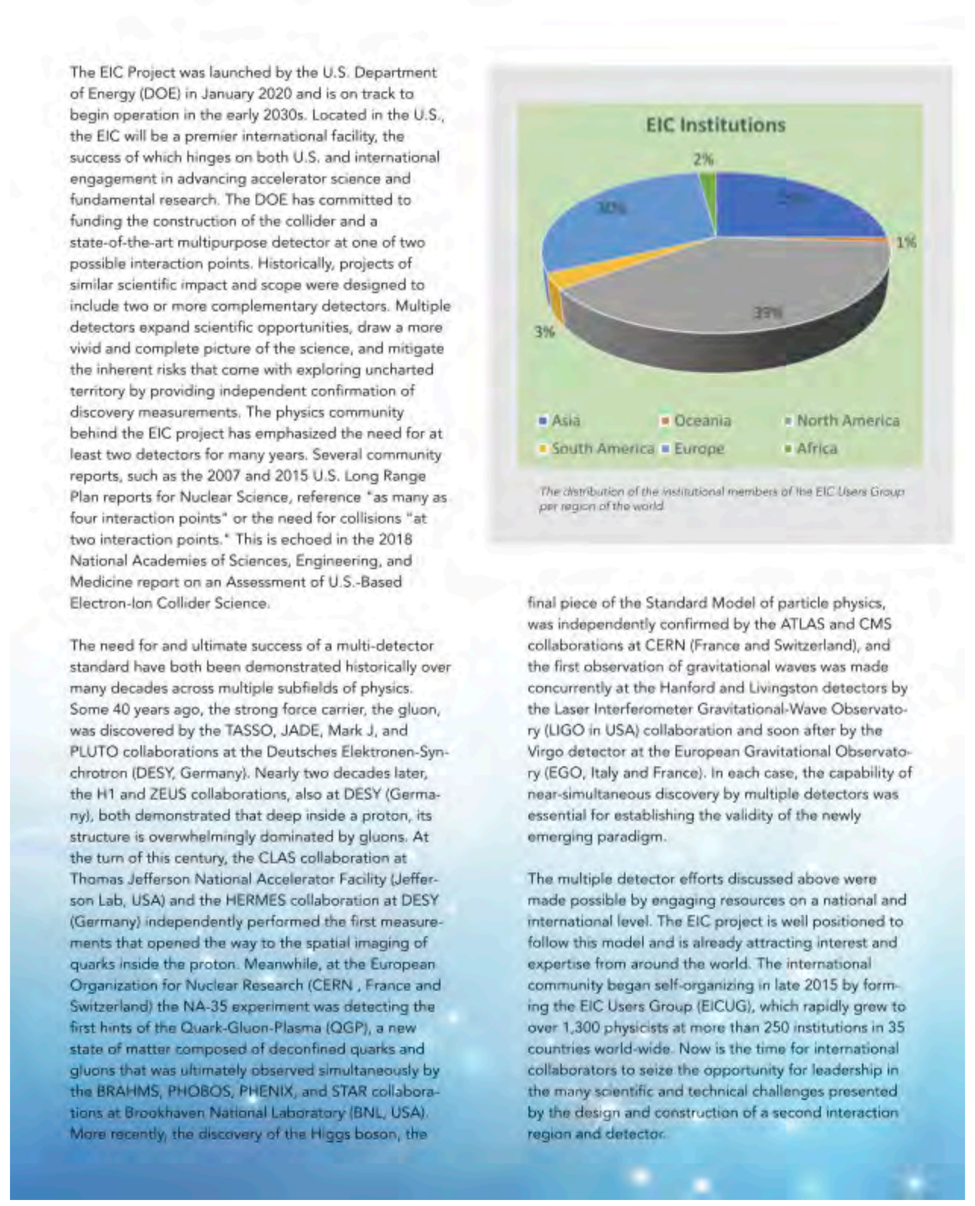
Opportunities With a Second EIC Detector

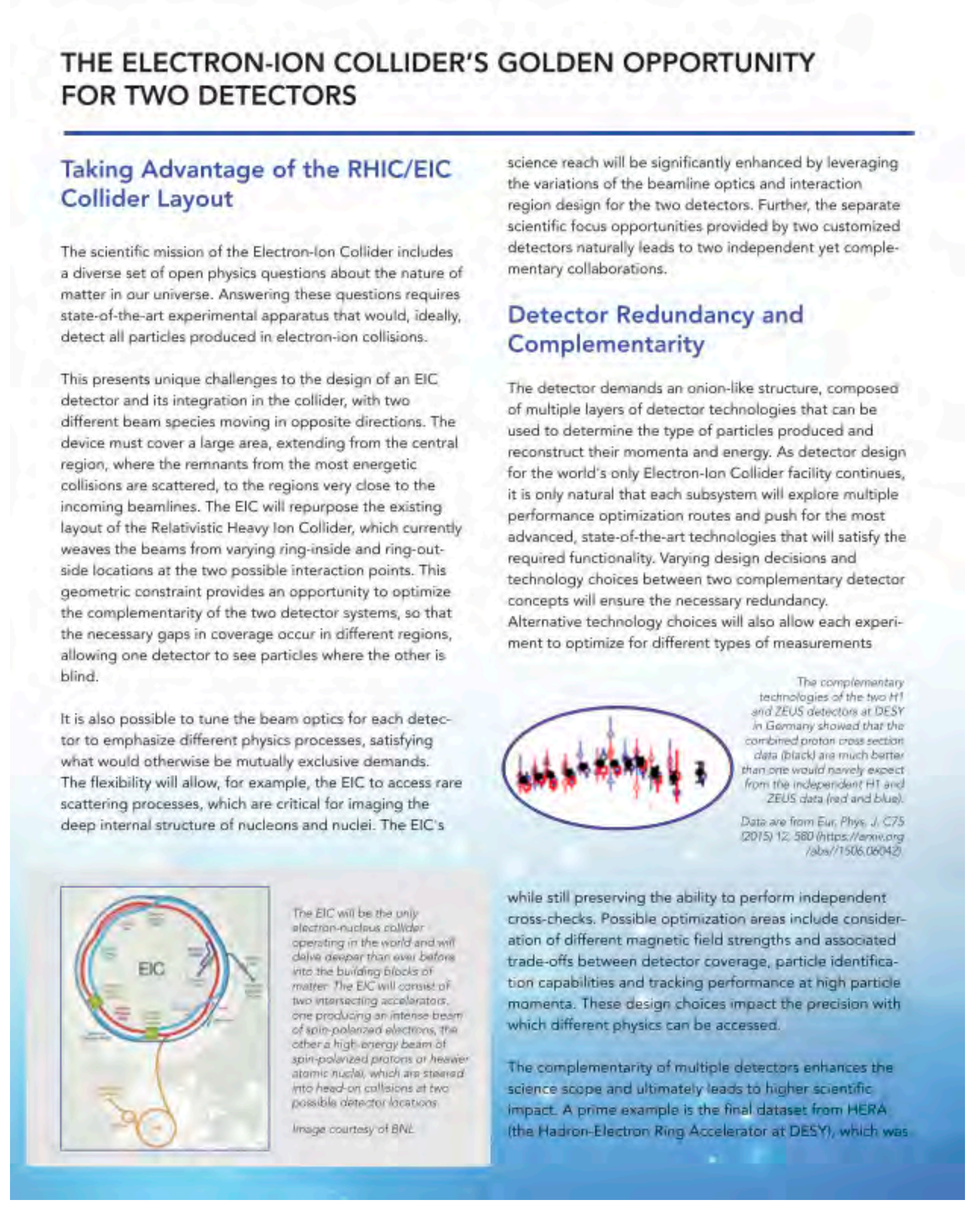
Only one detector is in scope of EIC project

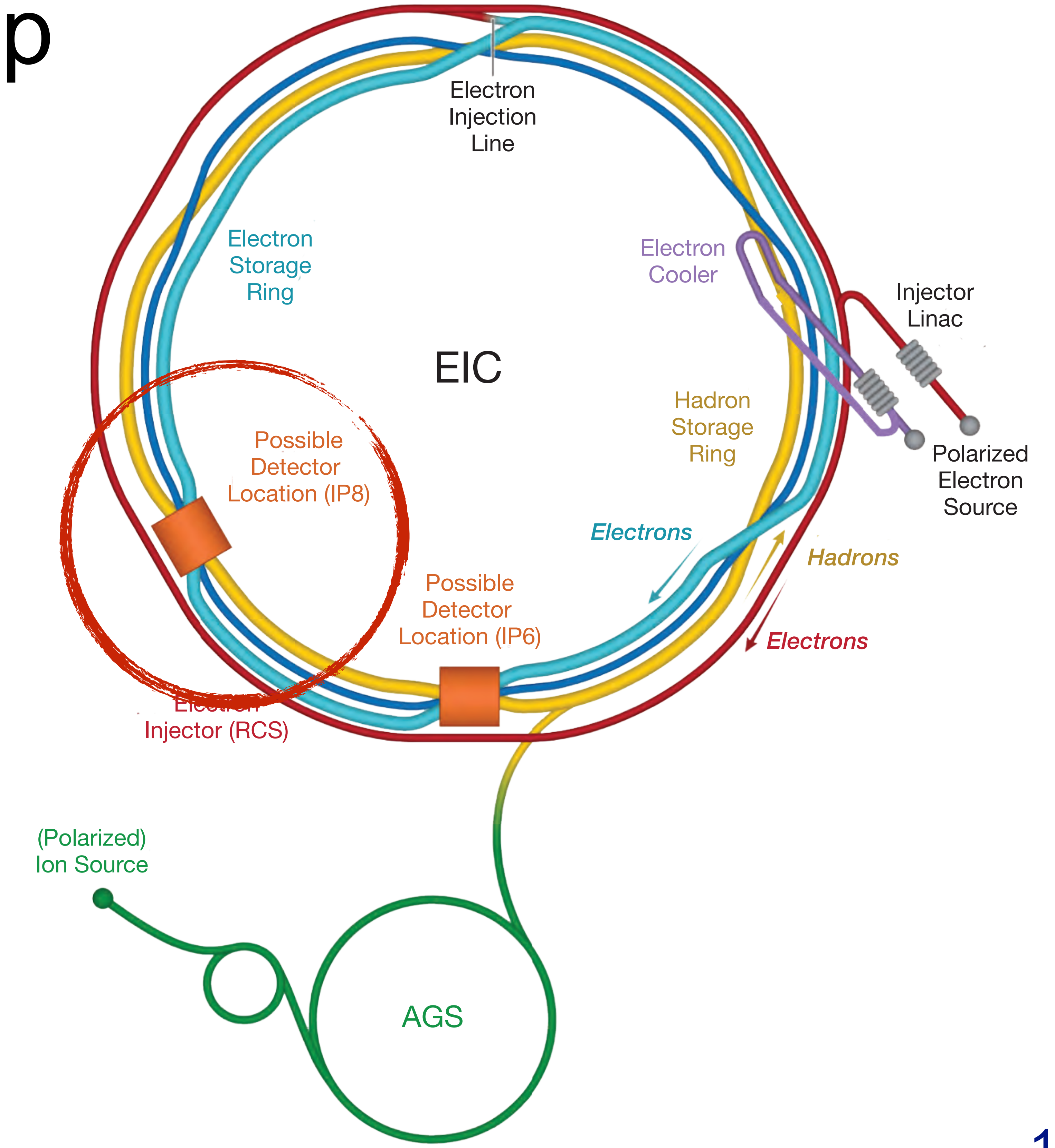
The EIC community is *strongly* in favor of a second detector

- Dedicated chapter in Yellow Report: “Two Complementary Detectors”
- New flyer to outline the benefits of a second detector
- EIC User Group formed a Detector-II Working Group









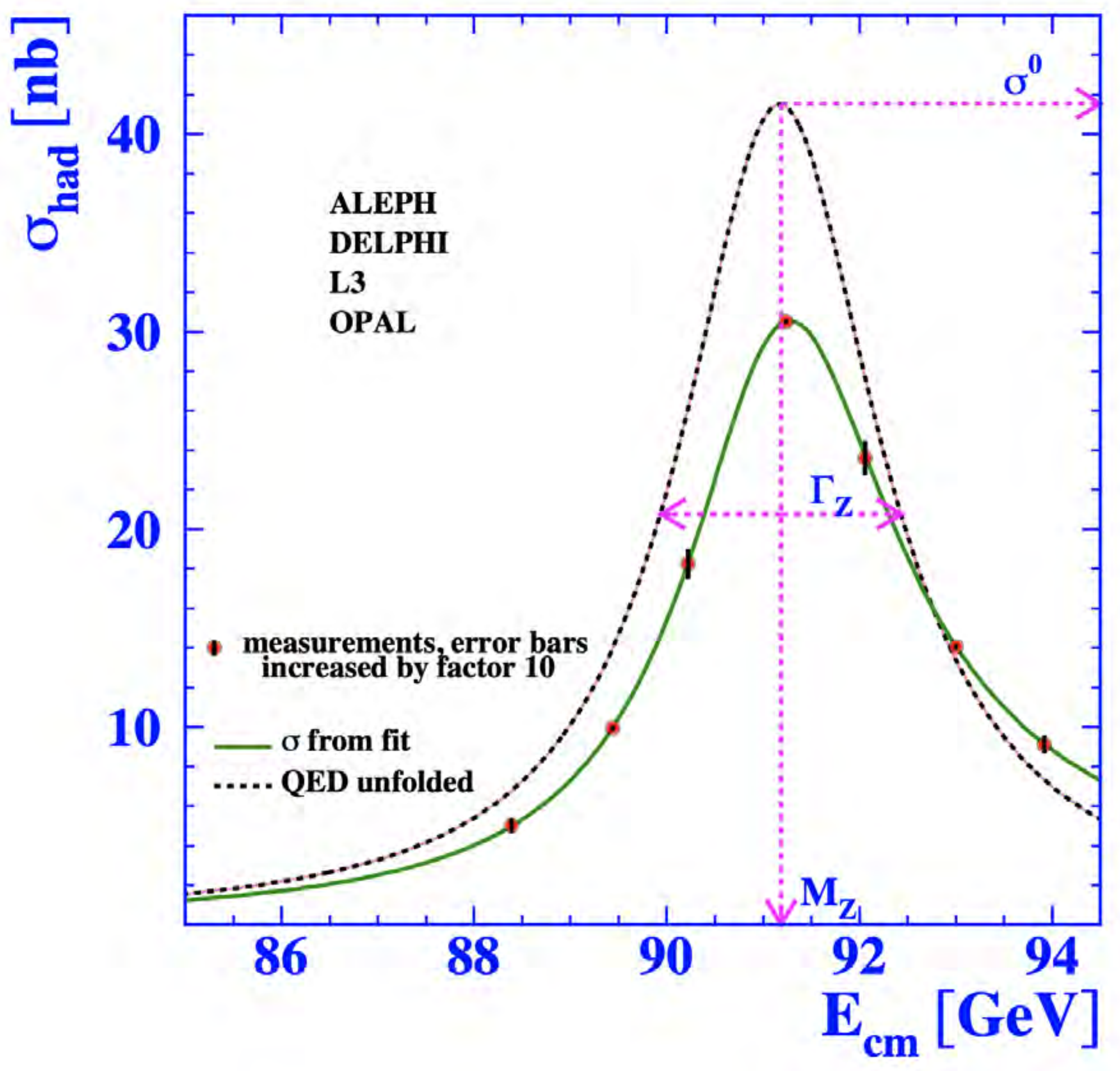
get flyer at eicug.org web site

Arguments for a Second EIC Detector

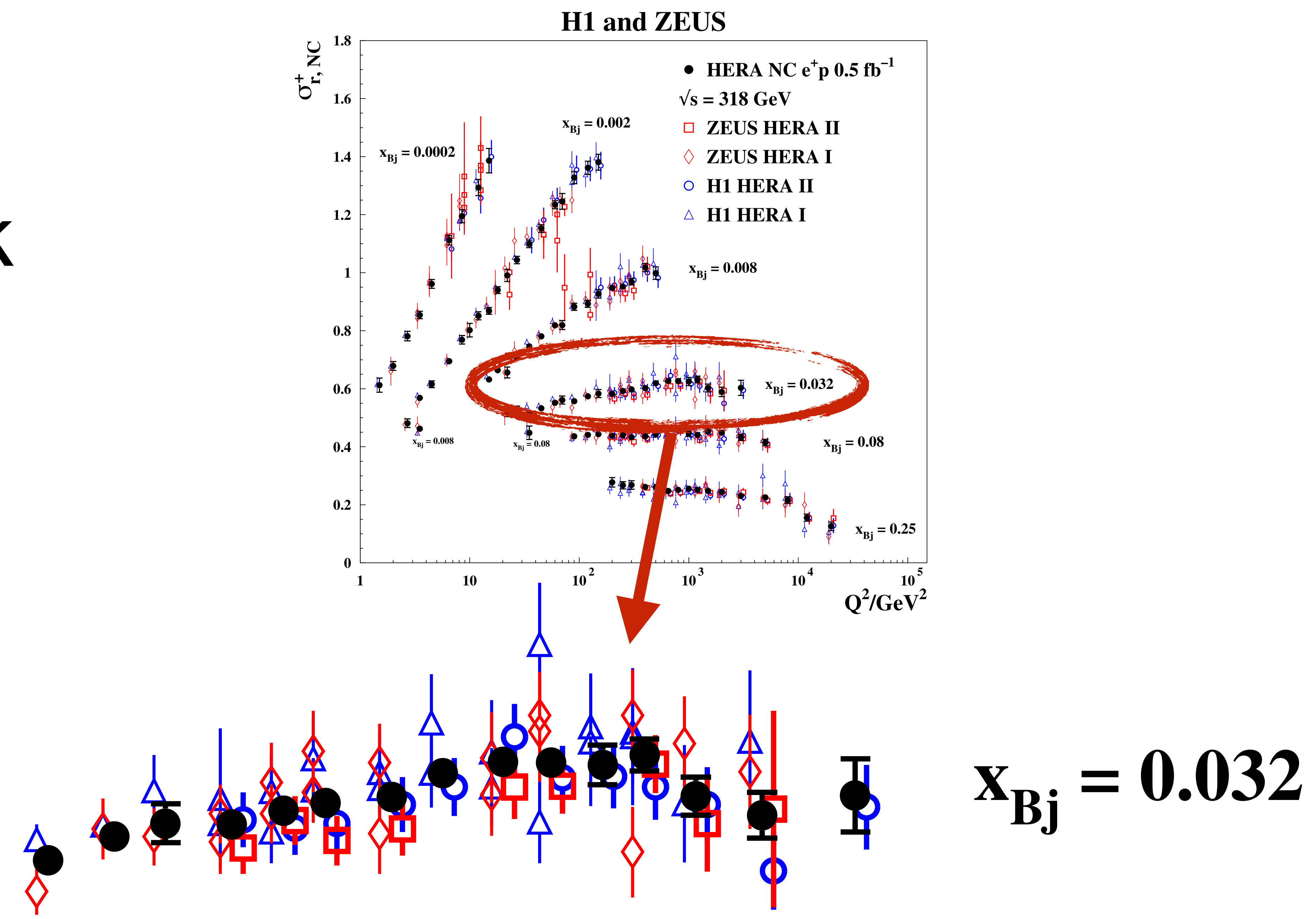
- EIC has unusual broad physics program
  - runs gamut from detailed investigation of hadronic structure to explorations of new regimes of strongly interacting matter.
  - EPIC covers full NAS program but impossible to *optimize* the full program in a single detector
  - Examples of Opportunities and Complementarity:
    - secondary focus in IP8 (improve diffractive physics, tagging)
      - greatly enhances the low-p_T and low-x (large-x_L) acceptance of recoiling target system in exclusive reactions on the proton and in coherent scattering by nuclei
      - provides an unprecedented detection of nuclear fragments with magnetic rigidities close to that of the beam, including heavy ions that have lost only one nucleon (A-1 tagging).
    - alternative subdetector technologies
    - enhanced p_T and/or PID acceptance in areas of phase space
    - more emphasize on μ detection
    - different B field
    - …

Arguments for a Second EIC Detector (cont.)

- Cross-checking
  - Many examples of wrong turns in history
  - Analysis mistakes, instrumental malfunctions, or inevitable statistical fluctuations
- Cross-calibration
  - A good example is offered by LEP (ALEPH, DELPHI, L3,OPAL) HERA (H1, ZEUS)
    - Improvements well beyond $\sqrt{N}$ statistical improvements
    - Make use of different dominating systematics (not all optimal solutions have to be in one detector)
- Technology redundancy and mitigating of overall risk
  - by applying different technologies and philosophies to similar physics aims
  - mitigate risk of reduced performance or failure of detector sub-component
  - mitigate risks of unforeseen backgrounds
  - differently optimize precision and systematics



hep-ex/0101027: "The technical precision of the adopted combination procedure is around 5 % of the combined errors."



A Second EIC Detector and R&D

Requires efforts and support to

- study and document a *broadened physics* program
- provide a realistic detector concept that is *complementary* to the current project detector in terms of physics reach, precision, and systematics

A potential 2nd detector is optimally realized with a 3-5 year delay to the first detector opening new opportunities:

- new technologies that are not mature enough or too risky for the 1st detector can be considered to provide full complementarity
- this needs a well-thought-out R&D program that will be guided and inspired by efforts on Detector-II (also EPIC upgrades)
- making full use of the reinstated generic EIC detector program (next slides)

Suggested Recommendation for LRP

(on behalf of the EICUG LRP Task Force)

Initiative: We recommend targeted efforts to enable the timely realization of a second, complementary detector at the Electron-Ion Collider

The EIC is a transformative accelerator that will enable studies of nuclear matter with unprecedented precision. The EIC encapsulates a broad physics program with experimental signatures ranging from exclusive production of single particles in ep scattering to very high multiplicity final states in eA collisions. High statistical precision matched with a similar or better level of systematic precision is vital for the EIC and this can only be achieved with carefully optimized instrumentation. A natural and efficient way to reduce systematic errors is to equip the EIC with two complementary detectors. Two detectors will expand the scientific opportunities, draw a more complete picture of the science, and mitigate the inherent risks that come with exploring uncharted territory by providing independent confirmation of discovery measurements. The second detector effort will rely heavily on the use of generic detector R$\&$D funds and accelerator design effort to integrate the detector into the interaction region. The design and construction of such a complementary detector and interaction region are interwoven and must be synchronized with the current EIC project and developed in the context of a broad and engaged international EIC community.

Backup Slides

Project R&D

Project R&D (> 2022)

- aims at achieving the maturity required to carry out final design and construction of EPIC
- support only projects that perform R&D on technologies used in EPIC
- Guided by Detector Advisory Committee (DAC)
- `https://wiki.bnl.gov/conferences/index.php?title=General_Info`

FY22/FY23

Project	Topic
eRD101	mRICH / aerogel RICH
eRD102	dRICH
eRD103	hpDIRC
eRD104	Service reduction
eRD105	SciGlass
eRD106	Forward EMCAL
eRD107	Forward HCAL
eRD108	Cylindrical & Planar MPGD
eRD109	ASICs/Electronics
eRD110	Photosensors
eRD111	Si-Tracker (no sensors)
eRD102	ToF with AC-LGAD
eRD103	ITS3/MAPS

Tracking PID Calorimetry Sensors Electronics