EIC Project and Experimental Program status Update

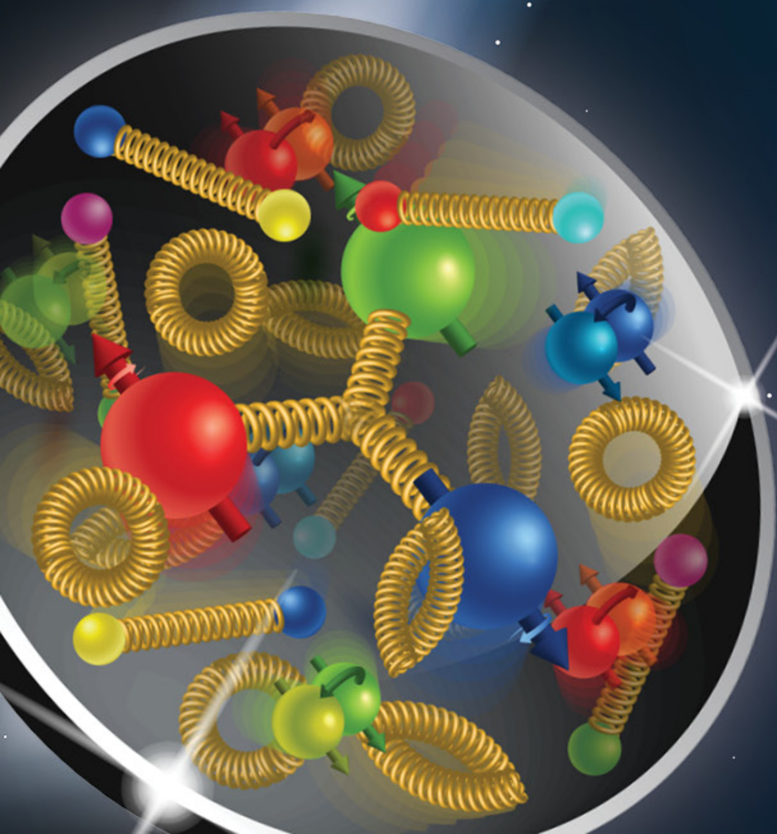
E.C. Aschenauer (BNL)

R. Ent (JLab)

Co-Associate Directors for the Experimental Program

EIC Meeting with Japanese Physics Society

May 12th, 2021



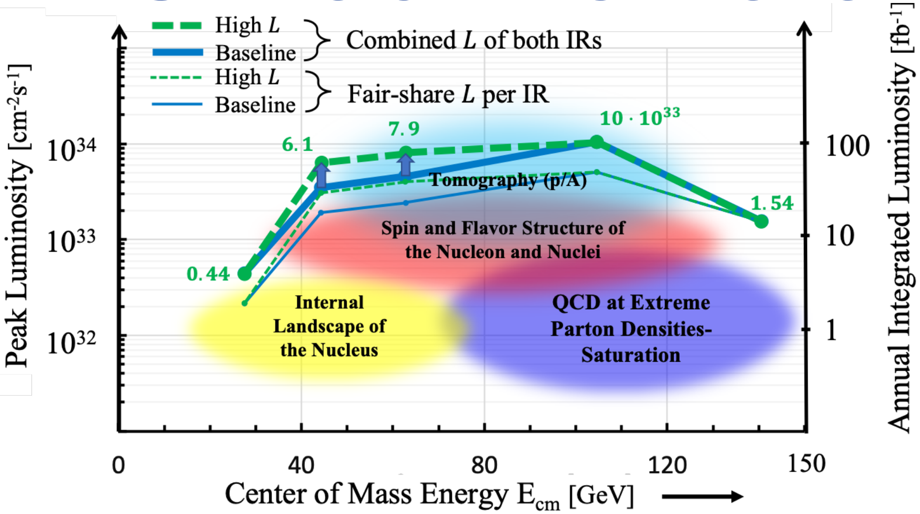
Electron-Ion Collider

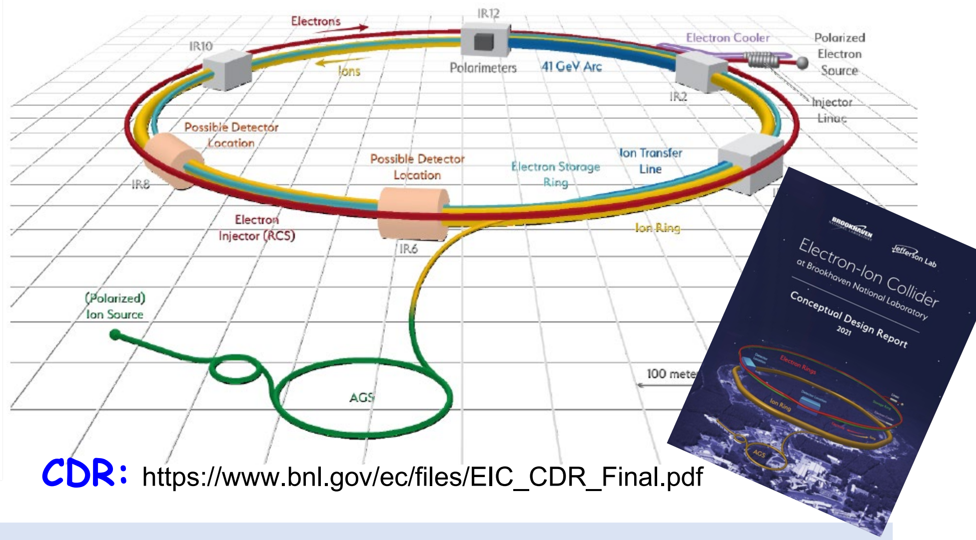
BROOKHAVEN NATIONAL LABORATORY

Jefferson Lab

U.S. DEPARTMENT OF ENERGY | Office of Science

EIC Machine Parameters





CDR: https://www.bnl.gov/ec/files/EIC_CDR_Final.pdf

Double Ring Design Based on Existing RHIC Facilities	
Hadron Storage Ring: 40 - 275 GeV	**Electron Storage Ring: 5 - 18 GeV**
RHIC Ring and Injector Complex: p to Pb	Many Bunches, Large Beam Current - 2.5 A
1160 bunces @ 1A Beam Current 9 ns bunch spacing	9 MW Synchrotron Radiation
Light ion beams (p, d, ^{3}He) polarized (L,T)	Polarized electron beams
Requires Strong Cooling: new concept → CEC	**Electron Rapid Cycling Synchrotron**
	Spin Transparent Due to High Periodicity
High Luminosity Interaction Region(s)	
25 mrad Crossing Angle with Crab Cavities	

EIC Recent History

Event	**Date**
DOE Mission Need Statement Approved	January 22, 2019
DOE Independent Cost Review	July 2019
DOE Electron Ion Collider Site Assessment	October 2019
Critical Decision – 0 (CD-0) Approved	December 19, 2019
DOE Site Selection Announced	**January 9, 2020**
BNL TJNAF Partnership Agreement	May 7, 2020
DOE Office of Science Status Review	September 9-11, 2020
Independent EIC Conceptual Design Review	November 16-18, 2020
DOE Office of Science CD-1 Review	January 26-29, 2021
DOE Independent Cost Review	January - February 2021
CD-1 Approval Target Date	***June 2021***

Project Organization

- BNL/TJNAF Partnership
  - BNL and TJNAF partnering agreement signed in May 2020.
  - Executive Management Team established that integrates BNL and TJNAF into project leadership roles.
  - EIC Council, chaired by BNL Director, established in June 2020. TJNAF Director is a founding member. Major international partners will also join the Council.

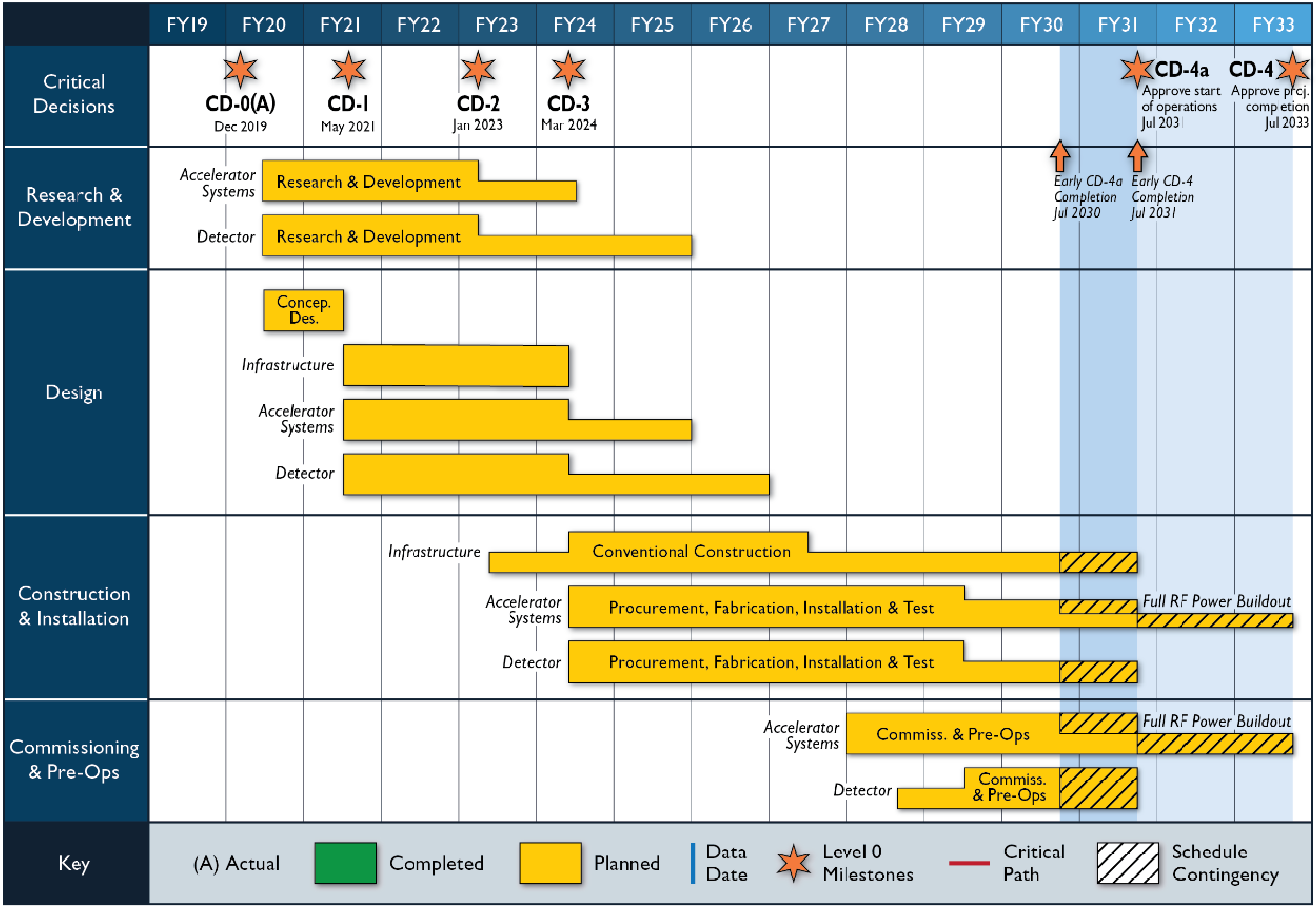
- Established standing advisory committees with international membership
  - Machine Advisory Committee: 08/26/20, *TBD Fall*
  - Project Advisory Committee: 08/27/20, 12/01/20, 04/29-30/21
  - Detector Advisory Committee: 09/28-29/20, 12/18/20, 03/24-26/21

CD-1 Reviews

- CD-1 Preparation Reviews
  - Independent Design Review – November 2020 ✔☐
  - Director's Review – December 2020 ✔☐

- DOE CD-1 Reviews
  - DOE Office of Science, Office of Project Assessment CD-1 Readiness Review – January 26-29, 2021 ✔☐
  - DOE Office of Project Management Independent Cost Review – Jan/Feb 2021 ✔☐

DOE reviews recommend proceeding with CD-1!



FY19
FY20
FY21
FY22
FY23
FY24
FY25
FY26
FY27
FY28
FY29
FY30
FY31
FY32
FY33
Critical Decisions
CD-0(A)
Dec 2019
CD-1
May 2021
CD-2
Jan 2023
CD-3
Mar 2024
CD-4a
Approve start of operations
Jul 2031
CD-4
Approve proj. completion
Jul 2033
Early CD-4a Completion
Jul 2030
Early CD-4 Completion
Jul 2031
Research & Development
Accelerator Systems
Research & Development
Detector
Research & Development
Design
Concep. Des.
Infrastructure
Accelerator Systems
Detector
Construction & Installation
Infrastructure
Conventional Construction
Accelerator Systems
Procurement, Fabrication, Installation & Test
Full RF Power Buildout
Detector
Procurement, Fabrication, Installation & Test
Commissioning & Pre-Ops
Accelerator Systems
Commiss. & Pre-Ops
Full RF Power Buildout
Detector
Commiss. & Pre-Ops
Key
(A) Actual
Completed
Planned
Data Date
Level 0 Milestones
Critical Path
Schedule Contingency

Key Milestones Proposed

DOE Critical Decision (CD)	CD-1 Review (2020)	Change (Months)	Proposed (03/21)
CD-1, Alternative Analysis	April 2021	+1	May 2021
CD-2, Performance Baseline	October 2022	+3	**January 2023**
CD-3, Construction Start	July 2023	+8	March 2024
		Construction Start to Early Ops = 6 ¼ Years	
Early Start of Operations (CD-4a)	July 2029	+12	**July 2030**
Late Start of Operations (CD-4a)	January 2031	+6	July 2031
CD-4 Early Project Completion	July 2031	=	July 2031
		Schedule Contingency = 2 Years	
CD-4 Late Project Completion	January 2033	+6	July 2033

- Revised funding profile including actual FY2021 ($30M vs $43M planned)
- DOE Total Project Cost now includes a 40% contingency budget
- Additional year of schedule contingency on project completion – 2 yrs total

Post CD-1 Timeline

Accelerator Technical Reviews	Spring/Summer 2021
Call for Detector Proposals	March 2021
Start Preliminary Design	April 2021
Detector Proposals Submitted	December 2021
Selection of Project Detector	March 2022
Start Earned Value Tracking	Summer 2022
Clarify In-kind Deliverables - Agreements	Summer/Fall 2022
Goal for CD-2 Approval	January 2023
Goal for CD-3 Approval	March 2024

Challenges and Opportunities

- Affordability – EIC is very large project for DOE Office of Nuclear Physics (NP) and Office of Science (SC)
  - Requires reprioritization of RHIC operations funding to EIC and new funding
  - Significant ramp up of project funding is required to maintain timeline for DOE Critical Decisions
  - Most cost-effective project follows closely to a technically driven schedule
- Partner Engagement – Expectations and Implementation
  - International engagement is highly desirable and widely expected
  - In-kind contributions to the accelerator and detector are being pursued
  - Partners must engage now given the EIC technically driven schedule

Experimental Program Preparation

- Call for Collaboration Proposals for Detectors launched after extensively soliciting input from DOE and EIC User community
- Jointly developed between EIC Project, JLab and BNL
- Appeared in the same week as the community Yellow Report (https://arxiv.org/abs/2103.05419)!

BNL and TJNAF Jointly Leading Process to Select Project Detector		
2020	Call for Expressions of Interest (EOI) https://www.bnl.gov/eic/EOI.php	May 2020
	EOI Responses Submitted	November 2020
	Assessment of EOI Responses	Finalized
2021	Call for Collaboration Proposals for Detectors https://www.bnl.gov/eic/CFC.php	March 2021
	BNL/TJNAF Proposal Evaluation Committee	Spring 2021
	Collaboration Proposals for Detectors Submitted	December 2021
✓	Decision on Project Detector	March 2022

Call for Collaboration Proposals for Detectors

- Call for proposals for
  - Detector 1 is within the scope of the EIC project and should be based on the "reference" detector and must address the EIC White Paper and NAS Report science case.
  - Detector 2 should address major parts of the science described in the EIC White Paper and possibly science beyond that and enable some complementarity to Detector 1.
- Evaluation Criteria:
  - science capabilities
  - risk, cost, and schedule of the proposed experiment, specifically for detector technology, design choices
  - strength of the collaboration
- Who Evaluates:
  - scientific-technical committee of renowned and independent subject matter experts in collaboration with members of the Detector Advisory Committee

Further from the Call: "The EIC Detector Advisory Committee will be asked to provide input on detector technology, design choices, and collaboration strength"

Other Considerations

It is understood that the process of collaboration formation is even more complex during a pandemic preventing face-to-face meetings and community building.

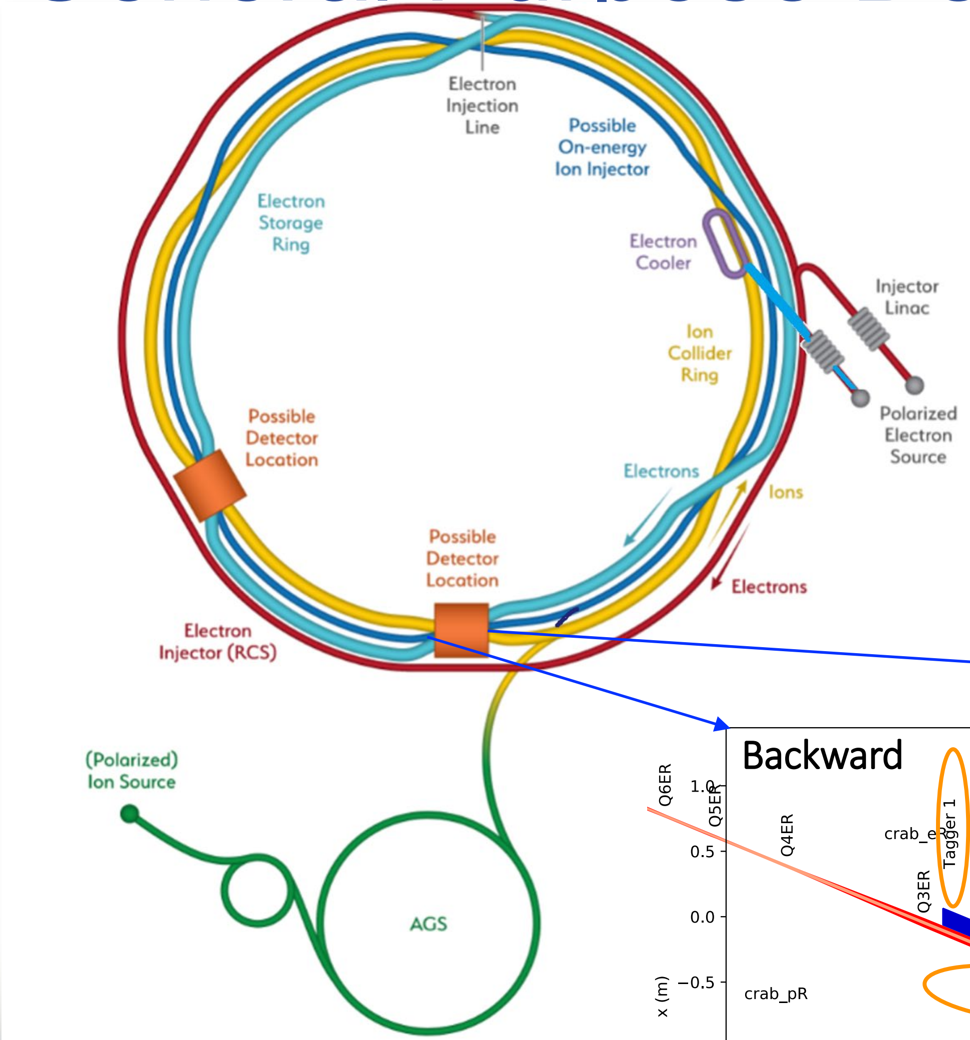
Thus, we use methods to remove uncertainties as much as possible and facilitate the process, e.g.,

- First round of FAQ (similar as what was done for the Expressions of Interest)
  - Collect further FAQ from user questions to eic-call-det-proposal-l@lists.bnl.gov
- In coordination with the EIC User Group (EICUG), schedule some workshops and organizational meetings to facilitate discussions and collaborations, and provide additional information.
  - Week-long Summer workshop/UGM co-hosted by VUU & UCR
  - Monthly "forums" with EICUG SC and proposal contacts, may lead to new FAQ.
  - Share EIC Detector Proposal Advisory Panel charge and review process beyond December 1 submission date in May at remote quarterly EICUG Meeting.
- Provide some assistance to the proto-collaborations with cost template, basis-of-estimate information, simulations, layouts, schedules, etc.

Guiding Principles:

- achieving a transparent and fair process
- Everybody has a place in the EIC experimental program

General Purpose Detector @ EIC

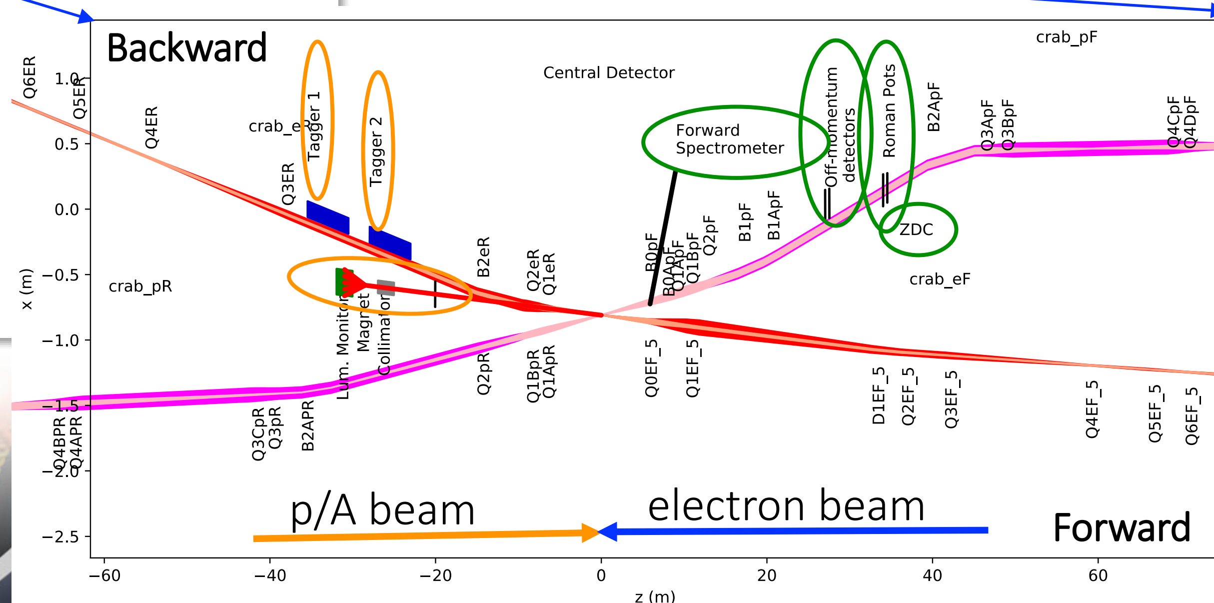


The **EIC facility is capable supporting a science program that includes two detectors and two interaction regions**

The DOE-NP supported **EIC Project includes one detector and one Interaction Region**

Two possible locations – IP6 and IP8 – for detectors and Interaction Regions.

IP6 is the planned detector location for the project detector



EICUG: Yellow Report (YR) Initiative

The EIC Users Group: EICUG.ORG
Report: https://arxiv.org/abs/2103.05419

Detector requirements and design driven by EIC Physics program and defined by EIC Community

Physics Topics → Processes → Detector Requirements

Physics Working Group:

- Inclusive Reactions
- Semi-Inclusive Reactions
- Jets, Heavy Quarks
- Exclusive Reactions
- Diffractive Reactions & Tagging

↔

Detector Working Group:

- Tracking + Vertexing
- Particle ID
- Calorimetry
- DAQ/Electronics
- Polarimetry/Ancillary Detectors
- Central Detector: Integration & Magnet
- Far- Forward Detector & IR Integration

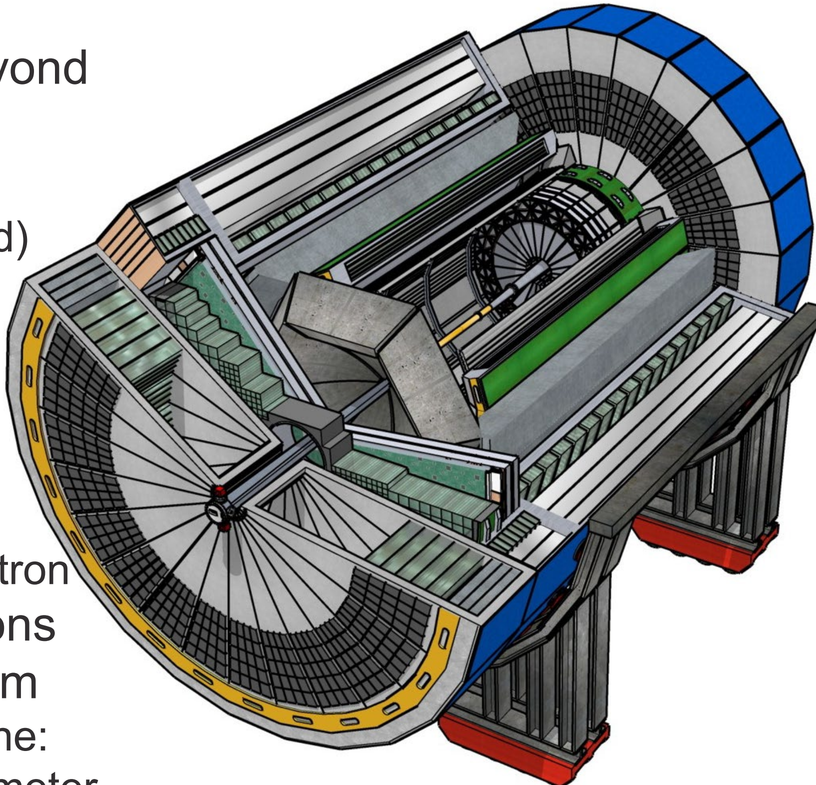
Provides **critical input for detector proposals** – handoff between Physics & Detector Working Groups in "**interactive detector matrix**": Collects physics requirements "real time", lists all technologies for a given region, and links to studies that established the numbers

EIC Experimental Equipment

Any general purpose EIC Detector is complex

Overall detector requirements:

- ❑ Large rapidity ($-4 < \eta < 4$) coverage; and far beyond in especially far-forward detector regions
- ❑ High precision low mass tracking
  - o small (μ-vertex) and large radius (gaseous-based) tracking
- ❑ Electromagnetic and Hadronic Calorimetry
  - o equal coverage of tracking and EM-calorimetry
- ❑ High performance PID to separate π, K, p on track level
  - o also need good e/h separation for scattered electron
- ❑ Large acceptance for diffraction, tagging, neutrons from nuclear breakup: critical for physics program
  - o Many ancillary detector integrated in the beam line: low-Q^2 tagger, Roman Pots, Zero-Degree Calorimeter, ….
- ❑ High control of systematics
  - o luminosity monitor, electron & hadron Polarimetry



Integration into the Interaction Region is critical

2^{nd} IR Progress and Status

- Position paper for 2^{nd} IR to define commitment of layout and compatibility verification, and trigger point for further work. Scope agreed upon.
- Basic concept of a 2^{nd} IR option fulfilling many RHIC boundary conditions (crossing angle can not be too large, < 50 mr, and not too small, > 25 mr) was presented by Vasiliy Morozov at 2^{nd} IR meeting.
    - In this lattice more space was required for positioning crab cavities, etc.
- Have now integrated this 2^{nd} IR design into the overall EIC layout, with as goal to minimize need for new magnets far away from the IP (J. Scott Berg) - reuse as much as possible of RHIC → this also constrains crab cavities to "existing" locations.
- Laid out two configurations
    - 35 mrad, beam lines converging on forward hadron side
    - 25 mrad, beam lines diverging on forward hadron side (i.e., extra beam kink)
- Ongoing work:
    - Fold in secondary focus – think this is doable within available lattice space.
    - First acceptance tests showed a "cut", and that some optimization of magnets and optics was required to obtain good acceptance. First order work has been done and we are rechecking acceptance.

We plan to pass things on to EICUG this month (May) for further discussion and physics simulations - we first need to ensure we have a quasi-stable optics layout and get the right acceptance.

Strategy for Detector 1 and 2nd IR/Detector 2

- EIC with two interaction regions and detectors
  - Ensures a robust EIC physics program and enhances the science reach.
- The DOE-NP supported EIC Project includes one detector and one IR
  - The included detector is ~70% scope as carried by the US-DOE EIC Project and ~30% international or in-kind scope.
  - The call for Expression of Interest was a crucial step to get guidance on the EIC detector scope.
- IR2 and detector concepts needed now
  - Informs strategies for achieving IR2 and detector
  - Influences project decisions on IR1 and detector
  - EIC project schedule is an important planning constraint
  - We do have a little more time for a 2nd EIC detector and IR – to be ready by CD-4
- Major effort needed to secure resources (~$500M)
  - Second detector may be opposite in scope, ~70% international or in-kind and ~30% possibly a DOE Major Item of Equipment (MIE) project
  - Significant international engagement is needed for 2nd detector and 2nd IR
  - Many bi-lateral meetings with potential partners underway to discuss opportunities in accelerator and experimental areas

EICUG Activities towards Collaboration Formation

EIC user community efforts on detector collaboration formation have started:

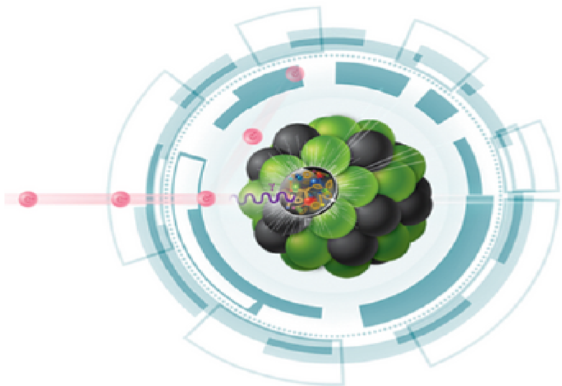
- The ECCE consortium had its first organizational meeting February 12th. ECCE is investigating a detector based on an existing 1.5T solenoid in both EIC interaction regions, ready for the beginning of EIC accelerator operation: https://www.ecce-eic.org

- EIC@IP6 (naming competition ongoing) had its organizational meeting March 12-13. EIC@IP6 is investigating a new EIC experiment at IP6 based on a 3 T magnet and the Yellow Report Reference Detector: https://sites.temple.edu/eicatip6/

- CORE had a "Kick-Off" Workshop on March 29-30 for an open collaboration for an EIC Detector proposal based on a new 2-4 T compact magnet at IP8: https://userweb.jlab.org/~hyde/EIC-CORE/

There is in addition a 2nd IR EIC Workshop series with a focus on Detector and IR complementarity (https://indico.bnl.gov/event/10677/timetable/) – First workshop had 400+ attendants, 2nd and 3rd workshop planned. They plan to submit a (draft) White Paper to the Proposal Detector Advisory Panel.

EIC Comprehensive Chromodynamics Experiment



The EIC Comprehensive Chromodynamics Experiment (ECCE) consortium is comprised of 64 institutions assembled around the idea of developing an EIC detector envisioned to offer full energy coverage and an optimized far forward detection region. The consortium includes institutions with wide-ranging world-class detector expertise, strong involvement with EIC physics, and an understanding of the DOE approach to project management. Our foundational principles are outlined in this talk from the first ECCE workshop.

ECCE shares the vision of the Nuclear Physics community that the EIC science mission is best served by two complementary detectors. In pursuit of that goal, ECCE is investigating a detector based on a 1.5T solenoid in both EIC interaction regions, ready for the beginning of EIC accelerator operation.

The ECCE consortium will thus respond to the EIC call for detector proposals with a plan to address the full range of EIC physics outlined in the NAS study and the Yellow Report, as the EIC project detector. To achieve complementarity we will investigate both IRs with the existing BABAR 1.5T solenoid and will show how ECCE will perform at either RHIC IP6 with its 25 mrad crossing angle or at IP8 with its ~35 mrad crossing angle.

We invite all interested institutions to join our effort!

Welcome

Following the site selection for construction of the U.S. Electron-Ion Collider research facility by the U.S. Department of Energy (DOE) in early 2020, the EIC Users Group led a year-long Yellow Report initiative to define the detector design criteria needed to realize the EIC physics described in the EIC White Paper, supported by the National Academy of Sciences. Using the Yellow Report as input, a Reference Detector concept was presented at the recently held DOE Critical Decision-1 review of the EIC.

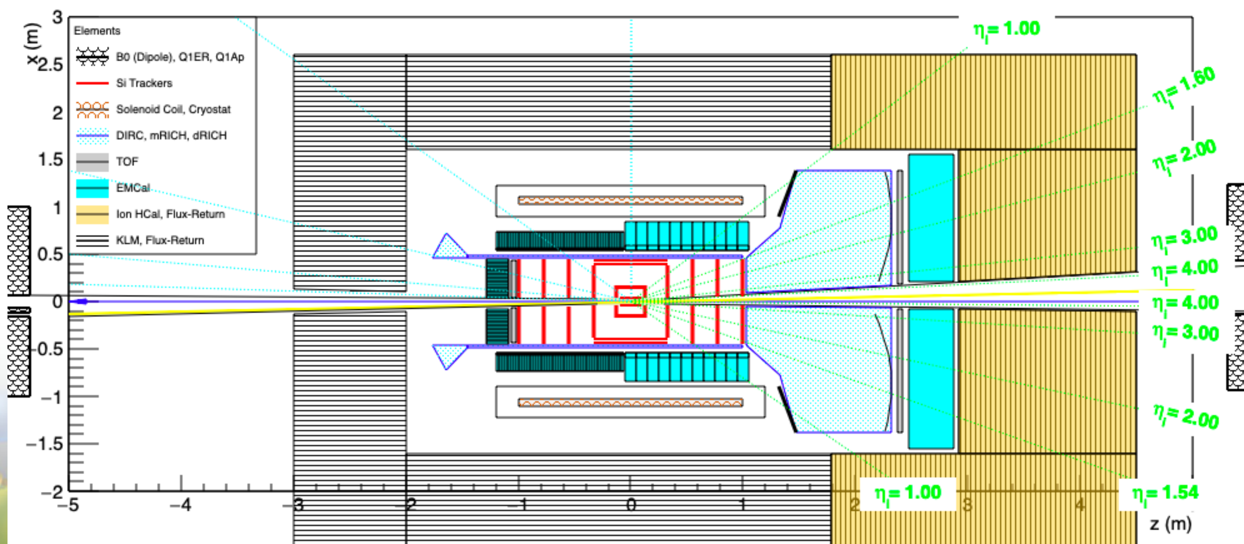
A Call for EIC Detector Proposals has been issued by DOE & BNL/JLab on March 6, 2021, with an expected proposal submission deadline on December 1st, 2021. The EICUG community's strong preference for two detectors has led to multiple exciting detector initiatives. We invite all interested groups and consortia to come together to plan for a detector inspired by the Yellow Report detector concept based on a new central detector magnet up to 3T. We are actively planning to evolve this effort into a concrete detector proposal and start the process of forming a new collaboration for IP6. Please contact us if you wish to join us!

COmpact detectoR for the Eic (CORE)

Specific choices driving the overall design:

- Small size enabled by all-Si central tracker (eRD25 design)
- Solenoid 2.5 m long and 0.9 m inner radius.
  - Baseline is 2 Tesla, but compact size enables consideration of fields up to 4 Tesla at moderate cost
- Radially compact high-performance barrel DIRC for $e/\pi/K/p$ PID (eRD14)
- Dual-radiator RICH with *outward-reflecting* mirrors in the ion endcap (eRD14)
- Extended PWO_4 EMcal coverage (up to 2π solid angle, $\eta < 0$).
- High performance Hadronic Calorimetry for (pseudo radipity) $1 < \eta < 4$
  - Modest HCal providing K_L, *muon* tagging for $-4 < \eta < 1$.
- Integrated with a 2nd Interaction Region design including a secondary high-dispersion focus (x-y) in the downstream ion-line.

Details of CORE at https://indico.bnl.gov/event/11053/



Proto-Collaborations at a Snapshot

- ECCE
  - Contacts: Or Hen (MIT), Tanja Horn (CUA), John Lajoie (Iowa State)
  - ~70 collaborating institutions
  - Includes institutions from Armenia, Chile, China, Czech, France/IN2P3, Germany, Israel, Japan, Korea, Russia, Taiwan, UK

- EIC@IP6
  - Coordinating Committee: Abhay Deshpande (BNL/SBU), Silvia Dalla Torre (INFN Trieste), Olga Evdokimov (UIC), Yulia Furletova (JLab), Barbara Jacak (LBL/UCB), Alexander Kiselev (BNL), Franck Sabatie (Saclay), Bernd Surrow (Temple)
  - ~96 collaborating institutions
  - Includes institutions from Canada, China, Czech, France, Italy, India, Poland, Rumania, UK

- CORE
  - Contacts: Charles Hyde (ODU) and Pawel Nadel-Turonski (SBU)
  - Smaller-scale effort, at present 20 active collaborators

Conclusion

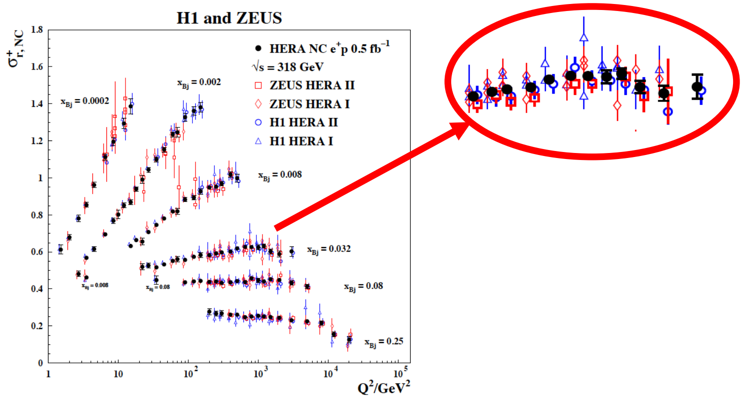
- The EIC User Community is strongly engaged in all parts of the EIC experimental program, *e.g.*, the EIC-related detector R&D program, the Yellow Report initiative to define requirements.
- The call for Expression of Interest was a crucial step to get guidance on the EIC detector scope.
- The Yellow Report was finalized: https://arxiv.org/abs/2103.05419
- Next phase: Collaboration Proposals for Detectors: https://www.bnl.gov/eic/CFC.php
  - ➢ Critical to have excellent detector proposals with science and technology complementarity integrated
- Strong community and international engagement efforts – goal is to have DOE ONP, EIC project and EIC User Group to go hand in hand.
  - ➢ Semi-annual DOE NP International Funding Agencies Meetings (most recent one on March 12, 2021, where we discussed project status, international engagement of accelerator and detector, governance model and user activities)

BACK UP

2^{nd} Detector: Complementary is Key

What do we want from "Complementary"

- **Cross-checking important results (obvious!)**
  - Many examples of wrong turns in history of nuclear and particle physics.
  - Independent cross checks (detector, community, analysis tools) are essential for timely verifications and corrections

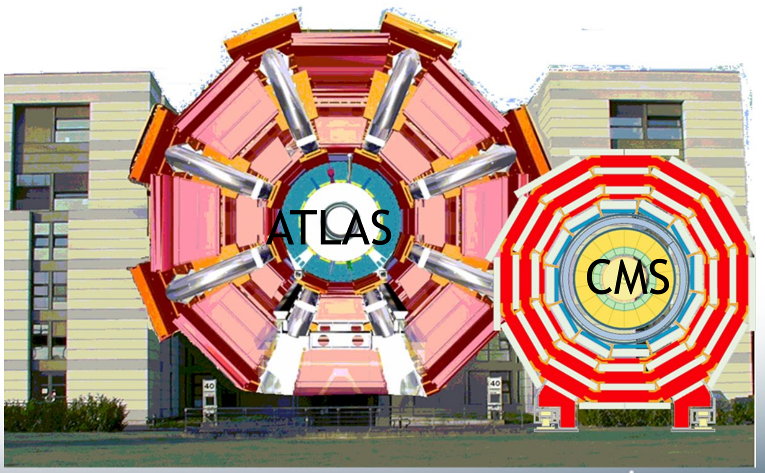


- **Cross Calibration**
  - Combining data gave well beyond the √2 statistical improvement …
  - Different dominating H1, ZEUS systematics…
  - Effectively use H1 electrons with ZEUS hadrons

  … not all optimal solutions have to be in one detector…

- **Technology Redundancy**

  ... by applying different detector technologies and philosophies to similar physics aims
  - mitigates technology risk vs. unforeseen backgrounds
  - differently optimises precision and systematics



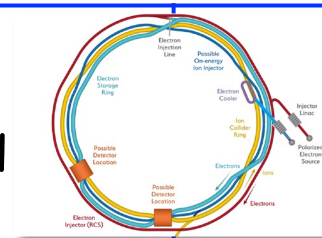
- **Different primary physics focuses**

  ... EIC has unusually broad physics program (from exclusive single particle production to high multiplicity eA or gA with complex nuclear fragmentation)

  → Impossible to optimize for the full program in a single detector.

Complementarity for 1st-IR & 2nd-IR

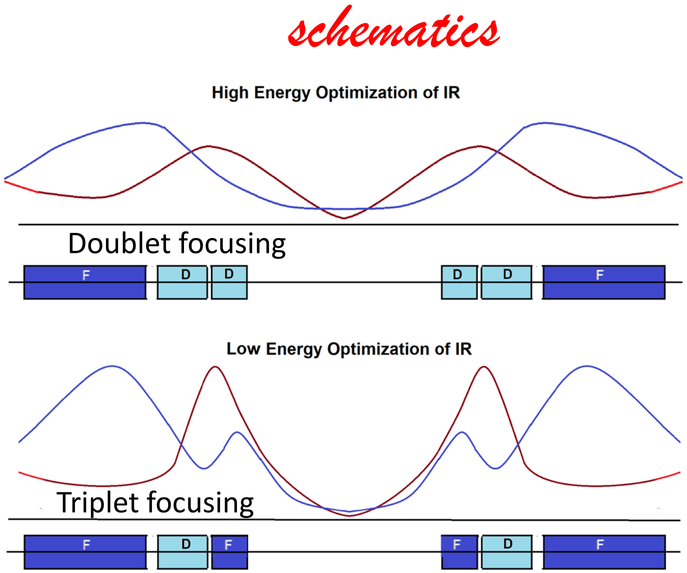
Since CD-1 we made significant progress in the preliminary design for the 2nd IR with a focus on complementarity

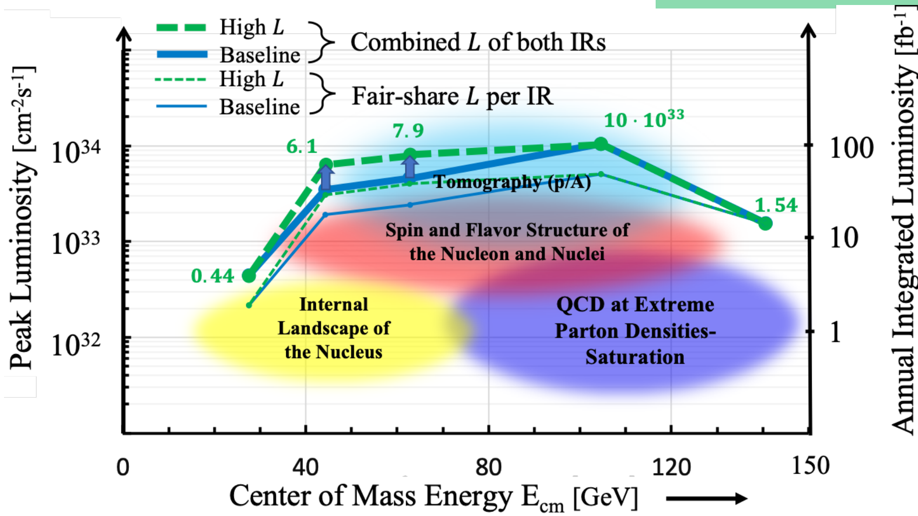


	1st IR (IP-6)	2nd IR (IP-8)
Geometry:	ring inside to outside	ring outside to inside
	tunnel and assembly hall are larger Tunnel: ⌀ 7m +/- 140m	tunnel and assembly hall are smaller Tunnel: ⌀ 6.3m to 60m then 5.3m
Crossing Angle:	25 mrad	35 mrad secondary focus
	different blind spots different forward detectors and acceptances different acceptance of central detector	
Luminosity:	more luminosity at lower E_{CM} optimize Doublet focusing FDD vs. FDF → impact of far forward p_T acceptance	
Experiment:	1.5 Tesla or 3 Tesla different subdetector technologies	

How to get more luminosity at lower E_{cm}?

F. Willeke,
V. Morozov





For hadrons, final focus lens is split into two.

- Doublet focusing for E_{cm} ~100-140 GeV.
- For low hadron beam energy (E_{cm} ~ 60 GeV) can rewire into triplet focusing, reduce β^* ➔ Increase L by factor of ~2.
- **Applicable at both IP6 and IP8**
- Luminosity E_{cm} ~ 40 – 60 GeV could be increased by factor of almost 2 **(work in progress!)**

But nothing is for free, there is a direct impact on the low p_T acceptance, e.g., for 100 GeV protons: p_T^{min} = 0.2 → 0.3 GeV