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| Cassandra  EIC Systems Engineering Group |
| Requirements ad Interfaces for the EIC Hadron Polarimeters |
| EIC System management document EIC-DET-02 |

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# Acronyms

|  |  |
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| **Acronym** | **Description** |
| CDR | Conceptual Design Report |
| DET | EIC Detector |
| EIC | Electron Ion Collider |
| ESR | Electron Storage Ring |
| FRD | Functional Requirements Document |
| GRD | Global Requirements Document |
| HSR | Hadron Storage Ring |
| ICD | Interface Control Document |
| IDD | Interface Definition Document |
| IP | Interaction Point |
| IR | Interaction Region |
| IRD | Interface Requirement Document |
| PRD | Physics Requirements Document |
| RCS | Rapid Cycling Synchrotron (Electron Injection) |

# Reference documents

|  |  |  |
| --- | --- | --- |
| **Ref #** | **Reference** | **Document #** |
| [1] | National Academies of Sciences, Engineering, and Medicine,  "An Assessment of U.S.-Based Electron-Ion Collider Science",  The National Academies Press, Washington, DC, 2018. | doi:10.17226/25171. |
| [2] | Dept Of Energy EIC mission need CD-0 approval | [Mission Need Statement for the EIC](https://brookhavenlab.sharepoint.com/sites/eic-document-center/DOE%20Project%20Records/Forms/AllItems.aspx?sortField=Modified&isAscending=true&id=%2Fsites%2Feic%2Ddocument%2Dcenter%2FDOE%20Project%20Records%2FEIC%2DMission%20Need%20Statement%5F2018%5FFINAL%5Fapproved%20%28002%29%2Epdf&parent=%2Fsites%2Feic%2Ddocument%2Dcenter%2FDOE%20Project%20Records) |
| [3] | EIC Conceptual Design Report CD-1 | BNL-221006-2021-FORE |
| [4] | EIC Usergroup Yellow Report | [arXiv:2103.05419](https://arxiv.org/abs/2103.05419) |
| [5] | Electron Ion Collider L1 Requirements  (Global Requirements Document) | EIC-ORG-PLN-010 |
| [6] | Requirements Management for Detector Systems | EIC-SEG-02-1 |
| [7] | Systems Engineering Plan | EIC-SEG-03 |
| [8] | Area Manager Responsibility | EIC-SEG-04 |
| [9] | Interface Management Plan | EIC-SEG-05 |
| [10] | EIC MAD lattice files for beamline details | To be added |
| [11] | EIC Key Parameter tables | To be added |

# Scope

This document presents the Requirements for the EIC hadron polarimeters, specifically the hydrogen-jet polarimeter and the pCarbon polarimeters including the one in the interaction region. The document is a requirement of the Systems engineering process see [6,7,8,9].

# Detector Summary

The physics program of an EIC requires that both beams, electrons and light hadrons, are polarized. To measure the polarization requires high precision polarimetry. This document discusses the hadron polarimetry in the hadron storage ring (HSR) of the EIC.

There are three types of polarimeters in the HSR

1. An absolute polarimeter in RHIC using a polarized hydrogen jet target (Hjet), see Figure 1
2. Two fast proton-carbon (pC) polarimeters in RHIC giving relative polarization measurements and determining the polarization profile as well as the polarization lifetime through a fill, see Figure 2
3. Local pC polarimeters to measure the spin orientation at the experiments;

# The fast polarimetry in RHIC is based on very small angle polarized proton-carbon (pC) elastic scattering in the Coulomb-Nuclear Interference (CNI) region. Typically 50-100 million events are collected in 30 seconds, giving a 3-4% relative uncertainty measurement of the beam polarization. Zero dead time readout waveform digitizers (WFD) is desirable to record the data. The pC polarimeters will provide the polarization normalization for the experiments for each fill. Measurements before and after the acceleration ramp are used to look for any polarization loss, particularly during studies of acceleration to the highest energies. i.e 100 and 275 GeV. Each measurement sweeps a small carbon ribbon target across the beam, providing the transverse polarization profile. Measurement will be made every 2-3 hours throughout a EIC fill, providing the polarization lifetime.

# The hydrogen jet polarimeter uses a polarized hydrogen target to provide the absolute polarization scale, with relative asymmetries for target and beam spin states used to determine the beam polarization. The measurements are limited statistically by the diffuse nature of the jet target, resulting in statistical uncertainties of 3-4% per typical fill (~8 hours).

# The detectors in both polarimeter systems exist of Silicon strip detectors. Carbon fiber targets with the most robust specifications, as learned from experience from RHIC, will be installed. The target holders to be designed to minimize electromagnetic fields near the attachment points, motivated by simulations of the beam in the scattering chamber.

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| Figure 1: The RHIC H-Jet target to be placed in the HSR of EIC | | |

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| Diagram, schematic  Description automatically generated |
| Figure 2*:* The RHIC pC polarimeter to be placed in the EIC HSR |

Measuring polarization of He-3 beams additionally requires forward taggers to veto breakup of the He-3 in collisions with the H-Jet, and a dipole downstream of the H-jet to separate the breakup products: deuterons, protons and neutrons. A schematic description of the tagging setup is shown in Figure 3. The neutrons pass undeflected through the dipole; the protons and deuterons, with approximately 2/3 and 4/3 of the beam rigidity, respectively, follow different trajectories. Sufficient drift space after the dipole is required to allow placement of the taggers outside of the beampipe. An example dipole is the RHIC DX magnet. 6 m after the DX, the d, p and n would be separated from the beam by approximately 5, 7 and 15 cm, respectively.

The pC polarimeter must be placed close to the H-Jet, at a location where the spin polarization vector is the same at both devices.

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|  | Figure 3: Schematic setup of the forward tagging system to measure the He-3 breakup products d, p, and n. |

# Hadron Polarimetry General Requirements

Table 1: General requirements for the HSR H-jet polarimeter WBS 6.10.14.02

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *Type* | *SubSystemID* | *Index* | *RequirementID* | *Description* |
| G | DET-POL-HPOL | 1 | G-DET-POL-HPOL.1 | The EIC hadron polarimeter system should provide a measurement of the absolute beam polarization in the HSR, the polarization lifetime and the transverse bunch polarization profile |
| G | DET-POL-HPOL-HJET | 1 | G-DET-POL-HPOL-HJET.1 | The HJET polarimeter measures the absolute beam polarization for light hadron beams. |
| G | DET-POL-HPOL-pC | 1 | G-DET-POL-HPOL-pC.1 | The pC polarimeter measures the relative polarization loss at flattop energy during a store and the transverse polarization profile of the hadron bunches. |
| G | DET-POL-HPOL-pC | 2 | G-DET-POL-HPOL-pC.2 | The pC polarimeter near the experimental IR measures the orientation of the polarization vector (local polarimetry). |

# Hadron Polarimetry Functional Requirements

*Table 2 Functional requirements for the HSR H-jet polarimeter WBS 6.10.14.02*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *Type* | *SubSystemID* | *Index* | *RequirementID* | *Description* |
| F | DET-POL-HPOL | 1 | F-DET-POL-HPOL.1 | Silicon detectors measure elastic reoil particles from the polarimeter target. |
| F | DET-POL-HPOL | 2 | F-DET-POL-HPOL.2 | The Si detector energy response is calibrated with two alpha sources (Am & Gd). |
| F | DET-POL-HPOL | 3 | F-DET-POL-HPOL.3 | Particle identification uses the time of flight and the energy of hits in Si strips. |
| F | DET-POL-HPOL | 4 | F-DET-POL-HPOL.4 | A second layer of Si is used to reject background from punch-through particles. |
| F | DET-POL-HPOL-HJET | 1 | F-DET-POL-HPOL-HJET.1 | The HJET polarimeter measures the polarization throughout a whole hadron store (about 8 hours) |
| F | DET-POL-HPOL-HJET | 2 | F-DET-POL-HPOL-HJET.2 | Silicon detectors are located to the left and right of the beam direction (in the accelerator plane). |
| F | DET-POL-HPOL-HJET | 3 | F-DET-POL-HPOL-HJET.3 | The atomic target is polarized through a set of hyperfine transitions and the target polarization is monitored in a Breit-Rabi unit. |
| F | DET-POL-HPOL-HJET | 4 | F-DET-POL-HPOL-HJET.4 | The unpolarized molecular fraction of the target is continously monitored with a beam gas analyzer. |
| F | DET-POL-HPOL-HJET | 5 | F-DET-POL-HPOL-HJET.5 | A Zero Degree Calorimeter is located downstream of the HJET (separated by a 10-12 Tm dipole magnet). |
| F | DET-POL-HPOL-pC | 1 | F-DET-POL-HPOL-pC.1 | Six silicon detectors are located to the left and right of the beam and under 45 degrees with respect to the accelerator plane. |
| F | DET-POL-HPOL-pC | 2 | F-DET-POL-HPOL-pC.2 | The pC polarimeters are equipped with ultra-thin fiber targets which scan the beam profile horizontally and vertically. |
| F | DET-POL-HPOL-pC | 3 | F-DET-POL-HPOL-pC.3 | The pC polarimeter target stations carry enough fiber targets to last throughout a year of EIC operations. |
| F | DET-POL-HPOL-pC | 4 | F-DET-POL-HPOL-pC.4 | The bias current of the detectors is constantly monitored. |

# Hadron Polarimetry Performance Requirements

*Table 3 Performance requirements for the HSR H-jet polarimeter WBS 6.10.14.02*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *Type* | *SubSystemID* | *Index* | *RequirementID* | *Description* |
| P | DET-POL-HPOL | 1 | P-DET-POL-HPOL.1 | Each detector consists of 12 vertical Si strips (1.375 mm pitch). |
| P | DET-POL-HPOL | 2 | P-DET-POL-HPOL.2 | The energy resolution is 25 keV or better. |
| P | DET-POL-HPOL | 3 | P-DET-POL-HPOL.3 | The time resolution of the waveform digitizers is 0.5 ns or better. |
| P | DET-POL-HPOL-HJET | 1 | P-DET-POL-HPOL-HJET.1 | The relative uncertainty of the beam polarization measurement is required to be 1% or less. |
| P | DET-POL-HPOL-pC | 1 | P-DET-POL-HPOL-pC.1 | The pC devices measure the relative beam polarization within 30 seconds with an uncertainty of 2% or less. |
| P | DET-POL-HPOL-pC | 2 | P-DET-POL-HPOL-pC.2 | The pC polarimeter is able to measure the bunch-by-bunch polarization for a single store. |

# Hadron Polarimetry Interfaces

Table 4: Interfaces for the HSR H-jet polarimeter WBS 6.10.14.02

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *Prefix* | *SubSystemID* | *Index* | *InterfaceID* | *Type* | *RelatedSystem* | *Role* | *Owner* | *Dependency* |
| I | DET-POL-HPOL-HJET | 1 | I-DET-POL-HPOL-HJET.1 | PHYS | Infrastructure | REQUESTER | REMOTE | There should be a vertical space in a straight section of the HSR of 4 m (actual size is 3.8m == 147") and a longitudinal and transverse space of 2m ( 72 ") . |
| I | DET-POL-HPOL-HJET | 2 | I-DET-POL-HPOL-HJET.2 | BEAM | Hadron Ring | REQUESTER | REMOTE | The spin direction at the location of the H-Jet should be vertical |
| I | DET-POL-HPOL-HJET | 3 | I-DET-POL-HPOL-HJET.3 | PHYS | Hadron Ring | REQUESTER | REMOTE | There should be a dipole of 10 -12 Tm next to the H-jet to separate the decay products from the He-3 from the core of the beam |
| I | DET-POL-HPOL-HJET | 4 | I-DET-POL-HPOL-HJET.4 | PHYS | Hadron Ring | REQUESTER | REMOTE | There has to be 1.5 m longitudinal and 20 cm transverse space for the taggers to measure the He-3 breakup particles |
| I | DET-POL-HPOL-HJET | 5 | I-DET-POL-HPOL-HJET.5 | PHYS | Hadron Ring | REQUESTER | REMOTE | There needs to be drift space from the dipole to the He-3 taggers 6 m to have enough separation of the beam and decay particles, beam optics and beam-size are critical to determine the exact number |
| I | DET-POL-HPOL-pC | 1 | I-DET-POL-HPOL-pC.1 | BEAM | Hadron Ring | REQUESTER | REMOTE | The beam size at the pC polarimeters should be X mm in x and Y mm in Y |
| I | DET-POL-HPOL-pC | 2 | I-DET-POL-HPOL-pC.2 | BEAM | Infrastructure | REQUESTER | REMOTE | There needs to be 2.5 m longitudinal and 2 m transverse space to integrate a dual pC polarimeter as shown in Fig 2. |
| I | DET-POL-HPOL | 1 | I-DET-POL-HPOL.1 | PHYS | Hadron Ring | REQUESTER | REMOTE | The polarisation direction between the H-Jet location and pC location cannot rotate |
| I | DET-POL-HPOL | 2 | I-DET-POL-HPOL.2 | SIG | Pre-Operations | PROVIDER | SHARED | The polarisation measurements need to be started remotely by the main control room |
| I |  |  |  |  |  |  |  |  |