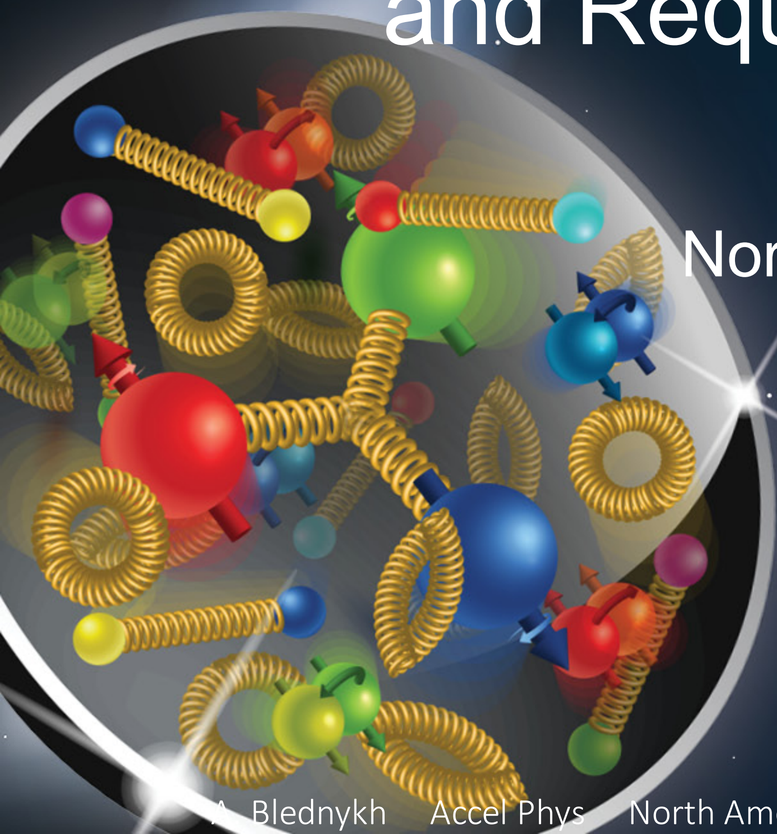
Developing Control System Specifications and Requirements for Electron Ion Collider



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Electron-Ion Collider

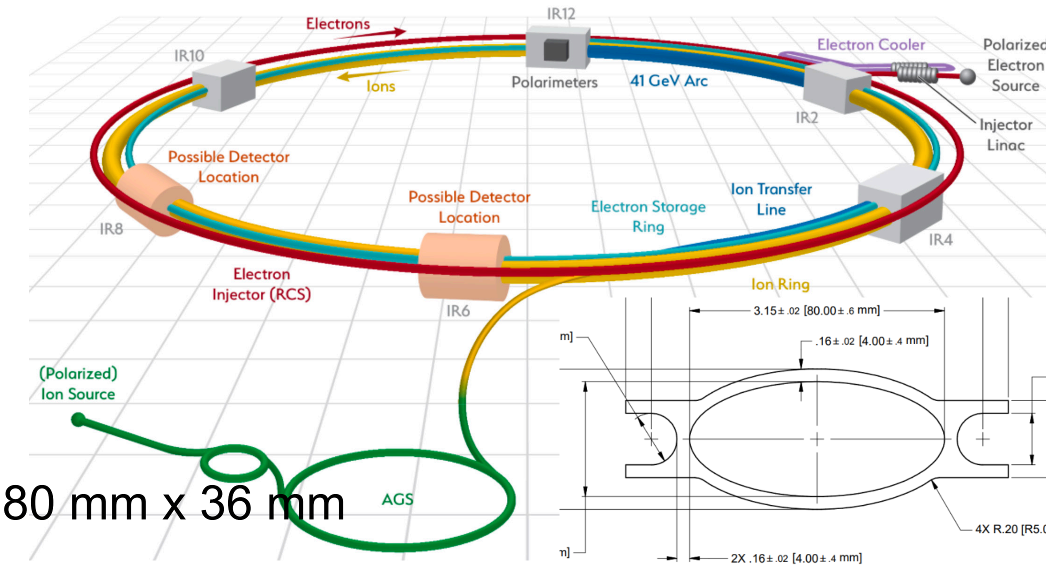
Outline

- **Introduction To The EIC Project**
- **Control System Architecture**
- **Control System Requirements and Specifications**
- **EIC Approach To Requirements**
- **Summary**

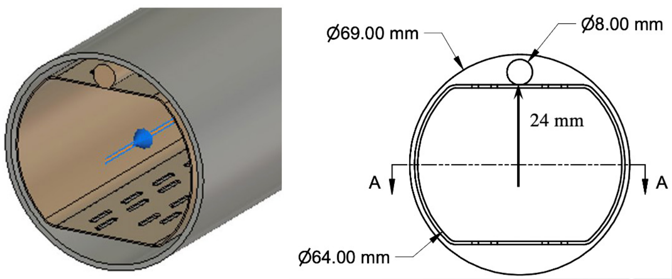
Electron-Ion Collider (EIC)

F. Willike – " Progress on the Electron-Ion Collider", NAPAC2022, MOYD1

- Electron Injection Scheme
  - LINAC, 400MeV
  - Rapid Cycling Synchrotron (RCS), 400MeV – 18GeV
  - Electron Storage Ring (ESR), 5GeV, 10GeV and 18GeV
    - $I_{av} = 2.5\ A$, $M = 1160$, $\sigma_s = 7\ mm$
    - Chamber: Elliptical of Cu, 80 mm x 36 mm



- Ion Injection Scheme 40-275 GeV (Present RHIC complex)
  - LINAC, 200MeV
  - Booster
  - Alternating Gradient Synchrotron (AGS)
  - Hadron Storage Ring (HSR)
    - $I_{av} = 0.7\ A$, $M = 290$, $\sigma_s = 60\ mm$
    - aC&Cu coated Stainless Steel beam screen chamber, actively cooled



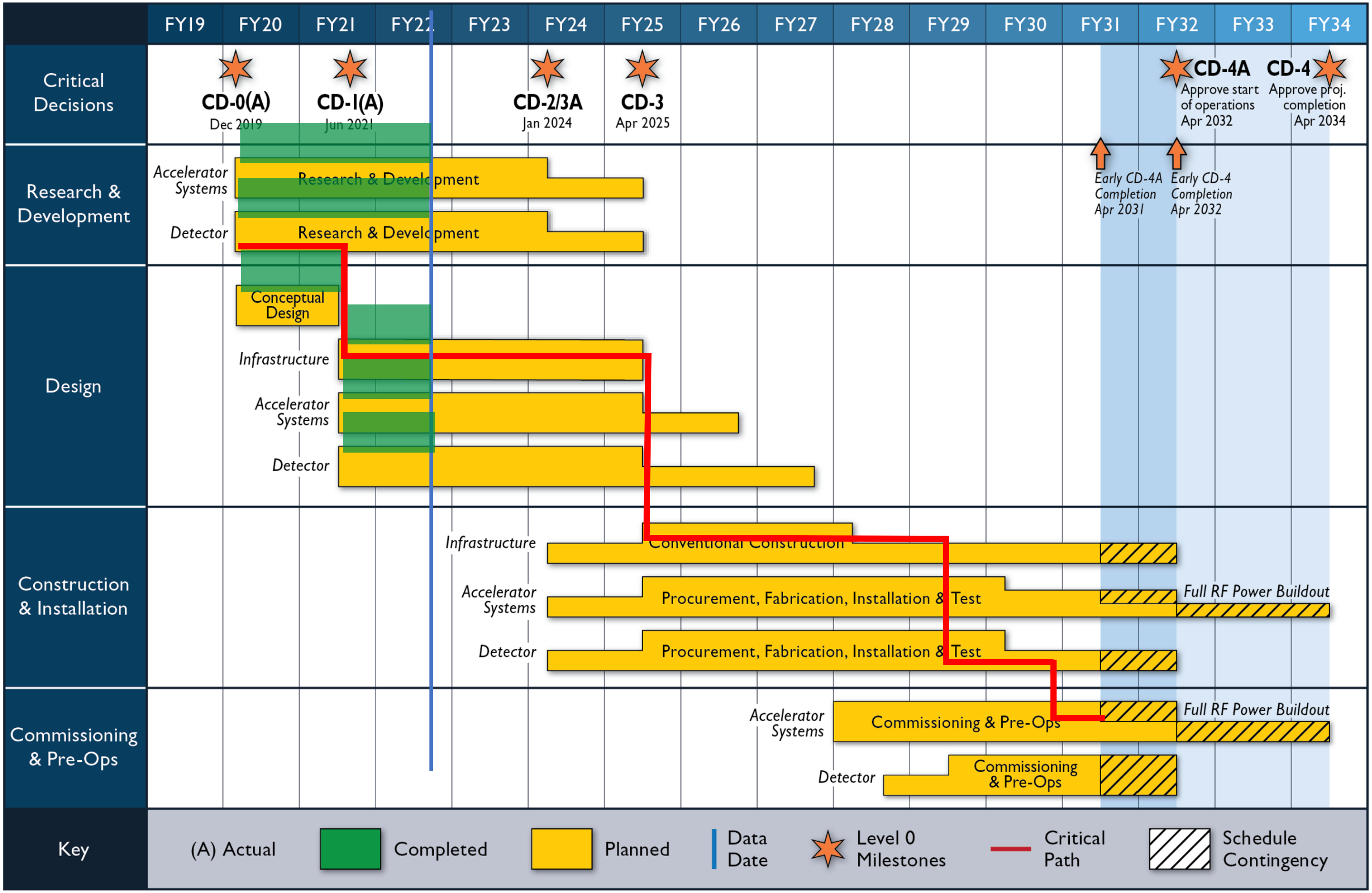
EIC Conceptual Design Report 2021, https://www.bnl.gov/ec/files/EIC_CDR_Final.pdf

Main EIC Parameters

Table 3.3: EIC beam parameters for different center-of-mass energies $\sqrt{s}$, with strong hadron cooling. High divergence configuration.

Species	proton	electron	proton	electron	proton	electron	proton	electron	proton	electron
Energy [GeV]	275	18	275	10	100	10	100	5	41	5
CM energy [GeV]	140.7		104.9		63.2		44.7		28.6	
Bunch intensity [10^{10}]	19.1	6.2	6.9	17.2	6.9	17.2	4.8	17.2	2.6	13.3
No. of bunches	290		1160		1160		1160		1160	
Beam current [A]	0.69	0.227	1	2.5	1	2.5	0.69	2.5	0.38	1.93
RMS norm. emit., h/v [μm]	5.2/0.47	845/71	3.3/0.3	391/26	3.2/0.29	391/26	2.7/0.25	196/18	1.9/0.45	196/34
RMS emittance, h/v [nm]	18/1.6	24/2.0	11.3/1.0	20/1.3	30/2.7	20/1.3	26/2.3	20/1.8	44/10	20/3.5
β^*, h/v [cm]]	80/7.1	59/5.7	80/7.2	45/5.6	63/5.7	96/12	61/5.5	78/7.1	90/7.1	196/21.0
IP RMS beam size, h/v [μm]	119/11		95/8.5		138/12		125/11		198/27	
K_x	11.1		11.1		11.1		11.1		7.3	
RMS $\Delta\theta$, h/v [μrad]	150/150	202/187	119/119	211/152	220/220	145/105	206/206	160/160	220/380	101/129
BB parameter, h/v [10^{-3}]	3/3	93/100	12/12	72/100	12/12	72/100	14/14	100/100	15/9	53/42
RMS long. emittance [10^{-3}, eV·s]	36		36		21		21		11	
RMS bunch length [cm]	6	0.9	6	0.7	7	0.7	7	0.7	7.5	0.7
RMS $\Delta p/p$ [10^{-4}]	6.8	10.9	6.8	5.8	9.7	5.8	9.7	6.8	10.3	6.8
Max. space charge	0.007	neglig.	0.004	neglig.	0.026	neglig.	0.021	neglig.	0.05	neglig.
Piwinski angle [rad]	6.3	2.1	7.9	2.4	6.3	1.8	7.0	2.0	4.2	1.1
Long. IBS time [h]	2.0		2.9		2.5		3.1		3.8	
Transv. IBS time [h]	2.0		2		2.0/4.0		2.0/4.0		3.4/2.1	
Hourglass factor H	0.91		0.94		0.90		0.88		0.93	
Luminosity [$10^{33}cm^{-2}s^{-1}$]	1.54		10.00		4.48		3.68		0.44	

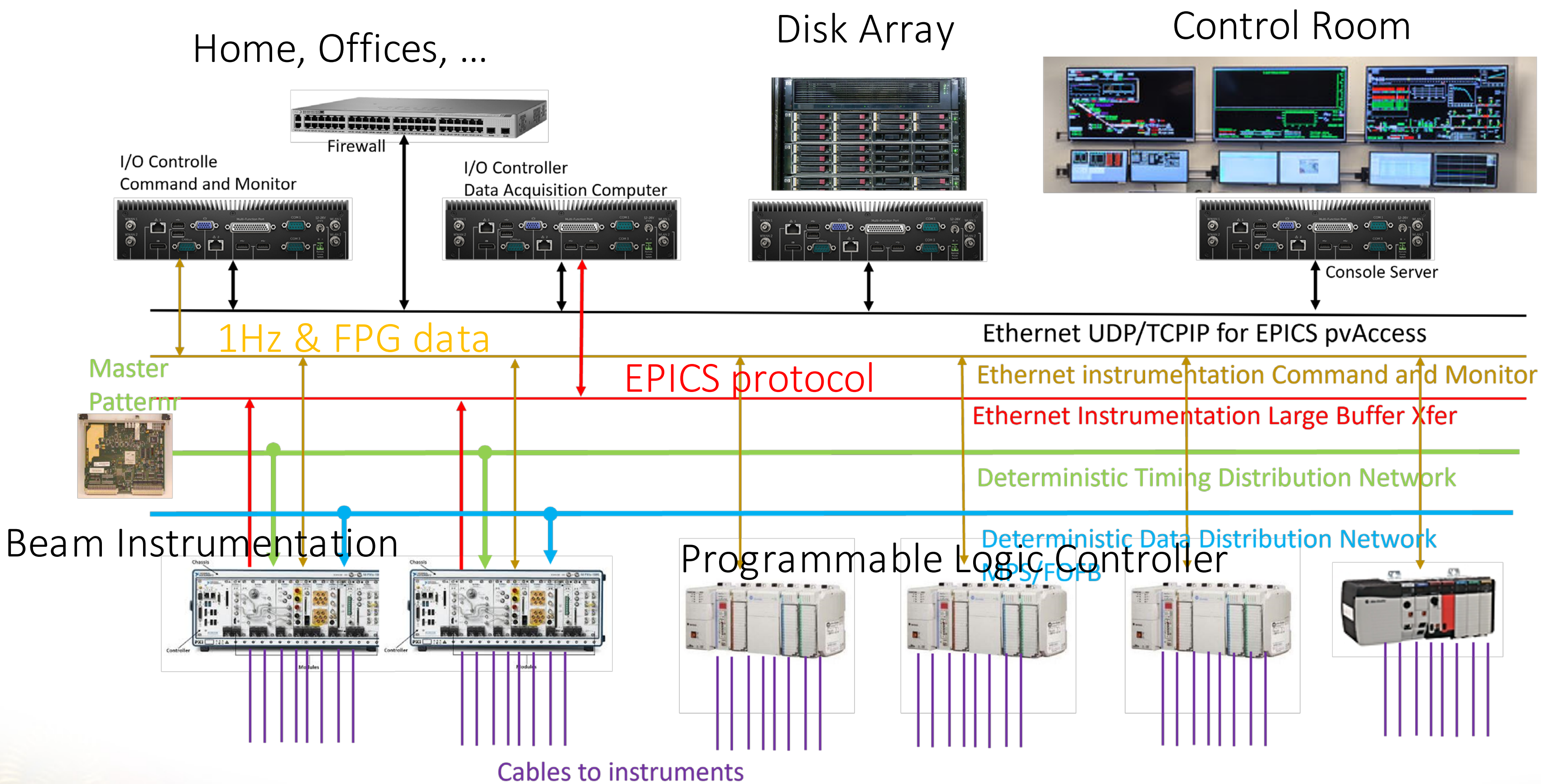
EIC Schedule



What is a Control System (CS)

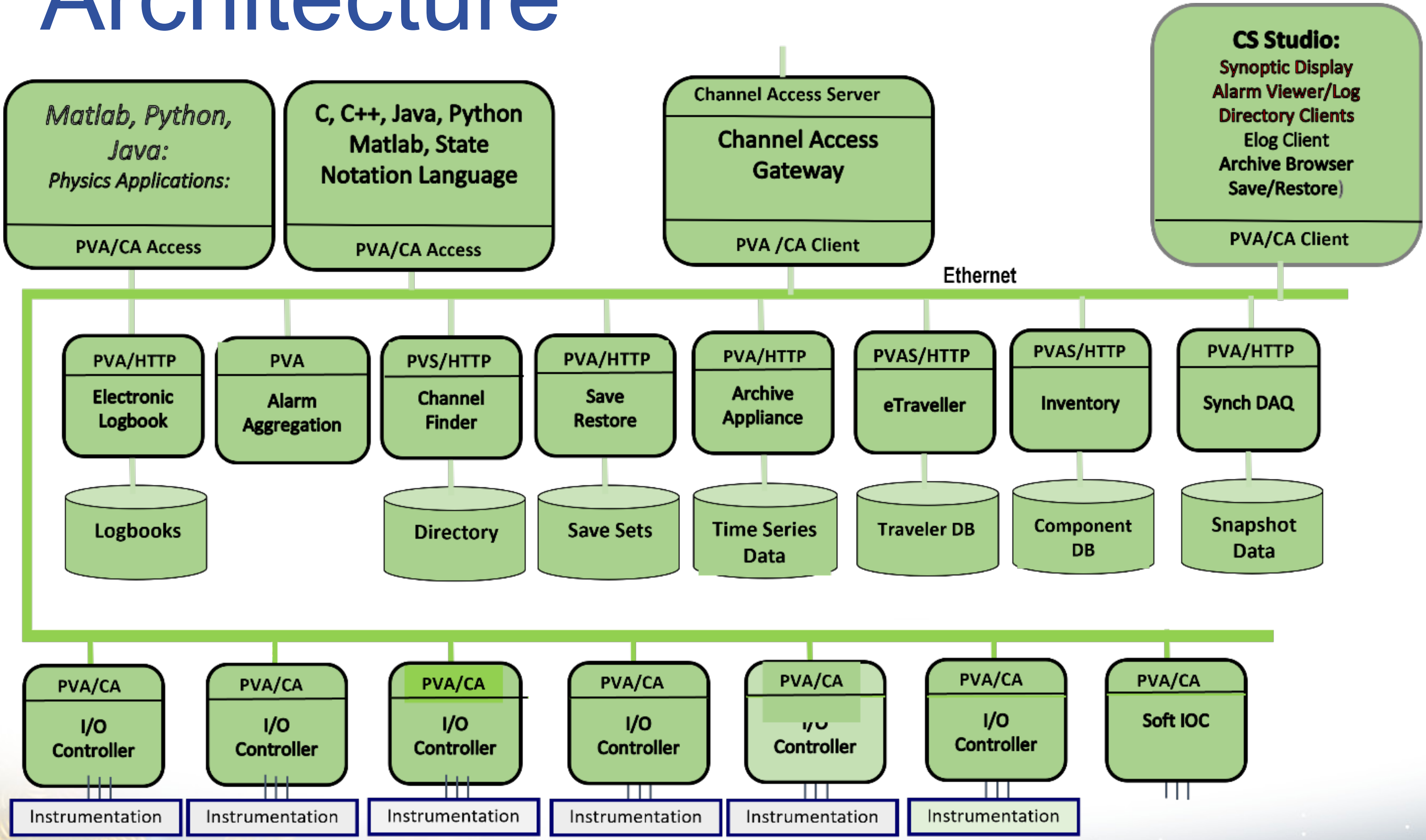
- **The control system** provides the tools, performance and capabilities for controlling and monitoring a complex machine with many interacting subsystems
- Electrical and computer interfaces to all instrumentation for control and monitoring
- Instrumentation bus, computers, networks, operator stations and storage to provide Supervisory Control and Data Acquisition functionality.
- Infrastructure to support the synchronization of control and data acquisition.
- **Application Programable Interfaces (APIs)** to provide access to all applications for test, commissioning, operations and maintenance.
- Services to manage configuration data, time series archive data, snap shot data, alarm logs, save/restore sets, directory, electronic logs, etc.…
- Clients to support the configuration, runtime viewing, and access to all service data.

CS Hardware Architecture



- The EPICS controls system architecture includes a broad range of functionality
- It consist from multilayer network connections

Control System Software Architecture



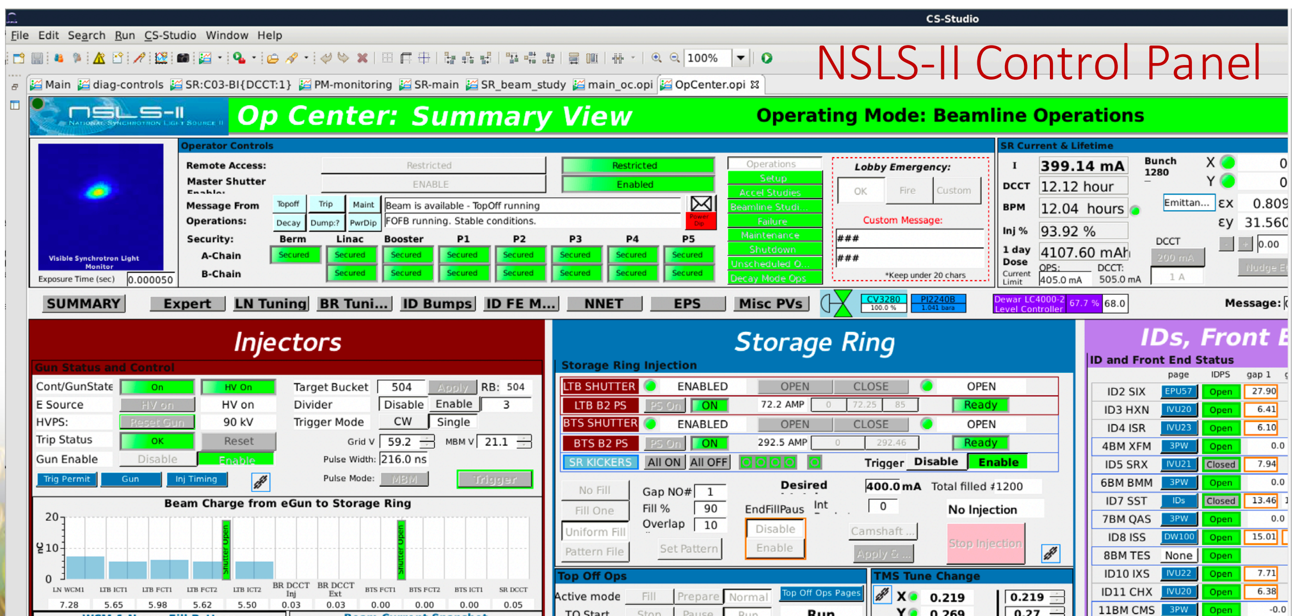
- EPICS needs to be integrated into present RHIC Controls Infrastructure (ADO)

Developing Specifications

- What is asked from the project?
- How do we provide the project with the capabilities to meet the Key Performance Parameters (KPP)?
- What has been achieved by recent similar projects?
- What has been learned and developed in the most recent projects?
- What has not been achieved by recent similar projects and what were the consequences?
- What can be reasonably accomplished as they have been demonstrated elsewhere?
- What approach provides the best solution with the given or likely resources?
- There are a limited number of resources in the scope of a construction project. What is absolutely required to meet the project goals

Source of Control System Requirements

- Accelerator Control and Monitoring -> Instrumentation -> Controls
- Physics Studies -> Instrumentation -> Controls
- Physics Applications -> Controls -> Instrumentation
- Operations -> Controls
- Facility Control and Instrumentation -> Controls



Main Engineering Specification

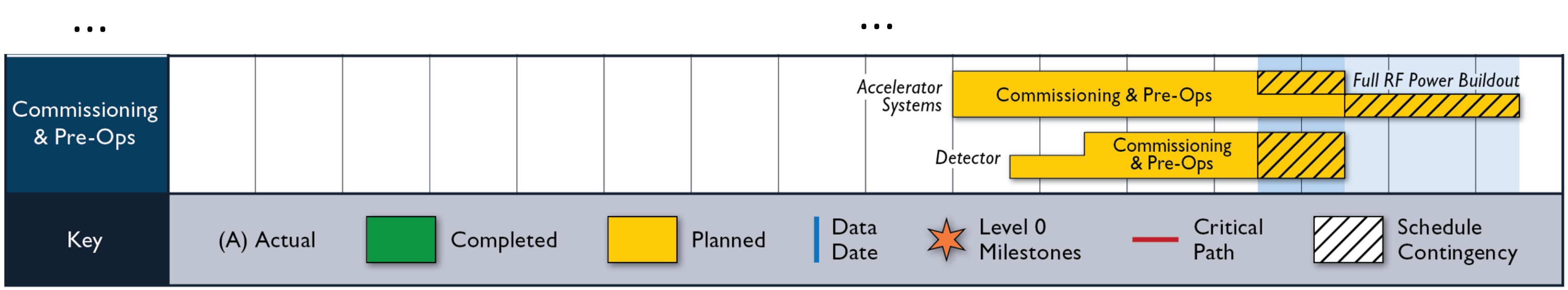
- Sampling BPM: Turn-By-Turn Data, 1kHz Machine Learning, Machine Protection / Fast Orbit Feedback ($100\mu s$), Operator 10Hz.
- Time Stamps: 48-bit value representing seconds/nanoseconds with a precision of microseconds, which may be augmented.
- Filling Pattern (ESR): h=7560 RF buckets at 591MHz, M=1160 (every 6^{th} RF bucket), bunch-by-bunch reading is 8GS/s with 16-bit.
- Machine protection time: Beam dump within 8 turns ($12.8\mu s$/turn).
- Feed back – spot size for collision: 80% noise suppression for steering magnet on controlling the interaction region, 3kHz data.
- Number of magnets and BPMs: ~1500 & 500 over C=3.833km (ESR)
- Machine Availability: RHIC Availability ~80%, and RHIC Time-at-Store ~60%. Failing and impacting them? Do we have redundant power supplies?
- CS Availability: 85%

Requirements - Priorities

- Must meet and support:
  - Project Key Performance Parameters
  - Construction, installation, integration and testing – Instrument Readiness Review (Turn ON the equipment) and Accelerator Readiness Review (Operation with beam)
  - Operations w/ basic controls, mean time to repair (MTTR), mean time between failures (MTBF), mean time to failure (MTTF).
  - Commissioning goals
- Want to limit and minimize/optimize
  - Commissioning schedule
  - Obsolescence (Software, FPGA, Network Hardware, …)
  - The costs of construction
  - Availability of control staff

When Are Requirements Needed

- New hardware boards require 3 years to develop
- New software tools require 2 years to develop
- Software Applications require 9 months to develop
- New device integration into a Supervisory control and data acquisition (SCADA) system requires 2 months



Examples of Use Cases

- Physics Use Case
  - Artificial Intelligence/Machine Learning - Collect all beam related instrumentation (3,000 PVs) continuously at 1 kHz.
  - Physics Applications – Revisit the existing HLA (HSR) and provide an AP interface to the control system that supports Physics Name reference to all control system Process Variables (PV)
- Operations Use Case
  - Machine Protection - Provide a protection system to dump the beam within 8 turns. (ESR&HSR)

EIC Approach To Requirements

- Bi-weekly meetings with representative of the Vacuum, Diagnostic, Collimator, Detector, RF, and Control groups on:
  - Requirements and specifications for control and data acquisition
  - HLA development
- Collecting the list of requirements & specifications
- Learning experience at other facilities:
  - Y. Hidaka – "Accelerator Physics Python HLA Development & Experiences at NSLS-II", BNL/NSLS-II
  - Y. Hu – "NSLS-II User Interface (UI) and Accelerator Physics High Level Applications (APHLA)", BNL/NSLS-II
  - A. Derbenev – "EPICS Through Time and Space", BNL/NSLS-II
  - G. Shen – "Use Case Study Online Model and Its Python Environment", ANL/APS

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https://docs.google.com/document/d/16wniLAvWjdE-1Xe4BWztDAj-SGQa0gfQ/edit

Summary

- **The EIC project is a complex facility.**
- **Collection of the CS requirements:**
  - **Needs Multi-Discipline contribution.**
  - **Must be done at earlier stage of the project, before CD2.**
- **Bi-weekly meetings on requirements and specifications for control and data acquisition helps to discuss and collect the list of the requirements and specification for different subsystem of the EIC project.**
- **Experience at other facilities is helpful in design of the EIC CS.**
- **We have a good start on requirements and specifications that support the design of the hardware and software architecture.**

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