Electron-Ion Collider Project

Overview and Proposal Status

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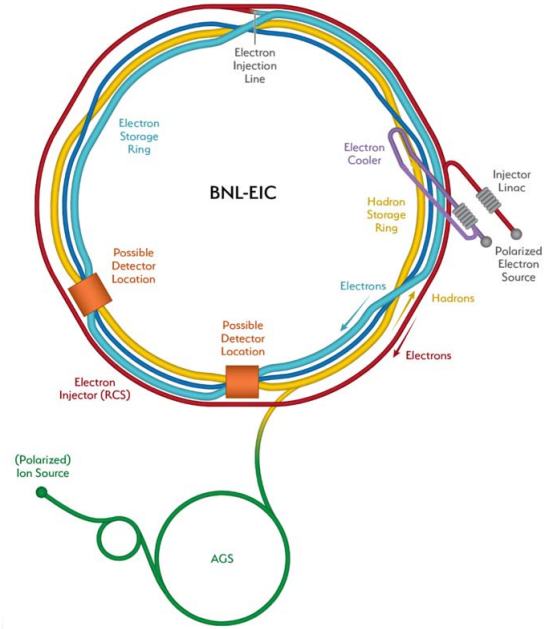


WP1 – MAPS Institutes

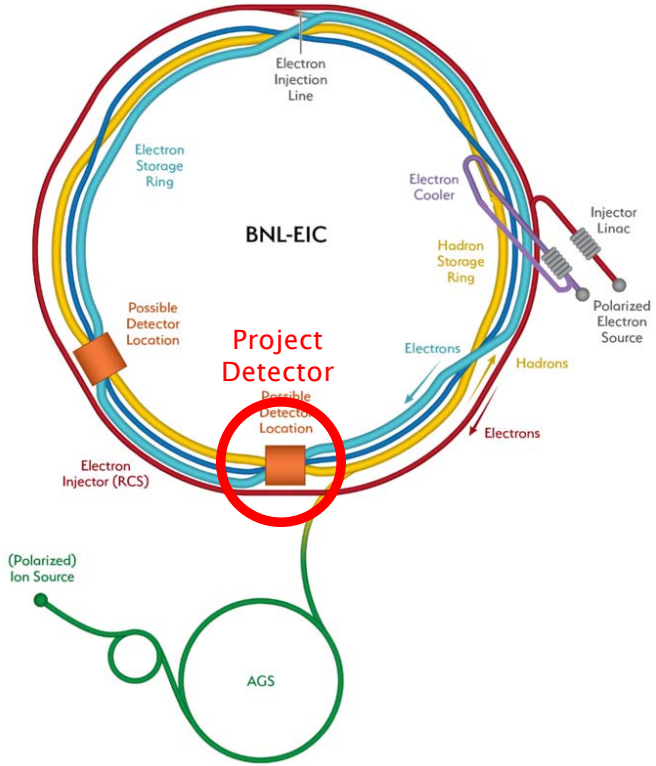
University of Birmingham, Brunel University London, Lancaster University, University of Liverpool, University of Oxford, Science and Technology Facilities Council

Daresbury Laboratory
Rutherford Appleton Laboratory

Electron-Ion Collider (EIC)

- Overview of the facility

  The EIC is to be built at the Brookhaven National Laboratory (BNL)



- Uniqueness

  World's first polarised electron, polarised proton/light-ion collider

  World's first polarised electron, heavy-ion collider

- Overarching science questions

  How does the mass and spin of the nucleon arise from its constituents?

  What are the emergent properties of dense systems of gluons?

- Key features

  High Luminosity: 10^{33}–10^{34} $cm^{-2}s^{-1}$
  Highly polarised beams: 70%
  Wide range of energy: 20-140 GeV
  Wide range of ion species: p-U

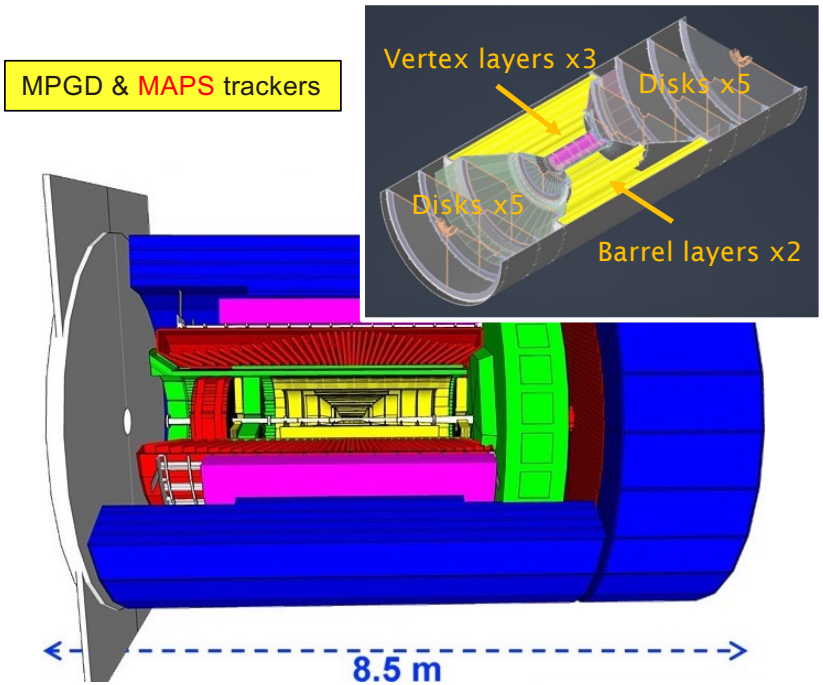
- US DOE Project Overview

  Total Project Cost = $2.4B
  Expected start of Construction in 2025
  Expected start of Operations in 2032

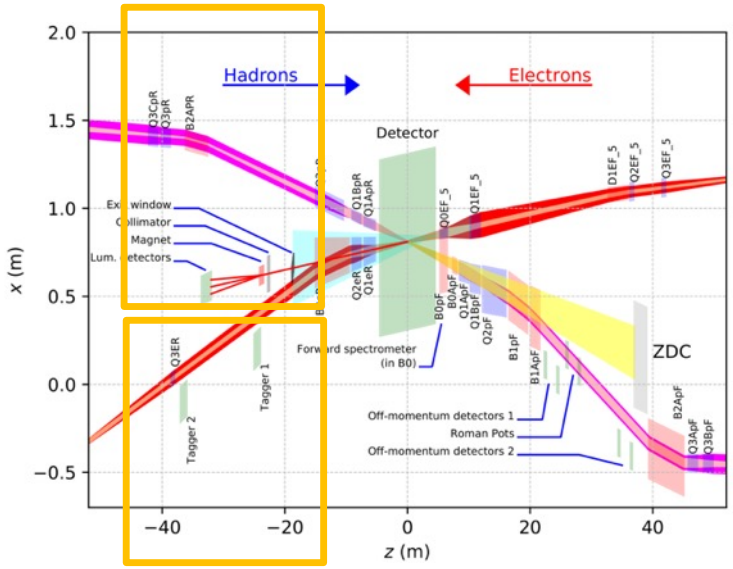
EIC Project Scope: Detector Work Packages

- ePIC Central Detector and Ancillary Detectors

WP1: Silicon Tracker



WP3: Luminosity monitor



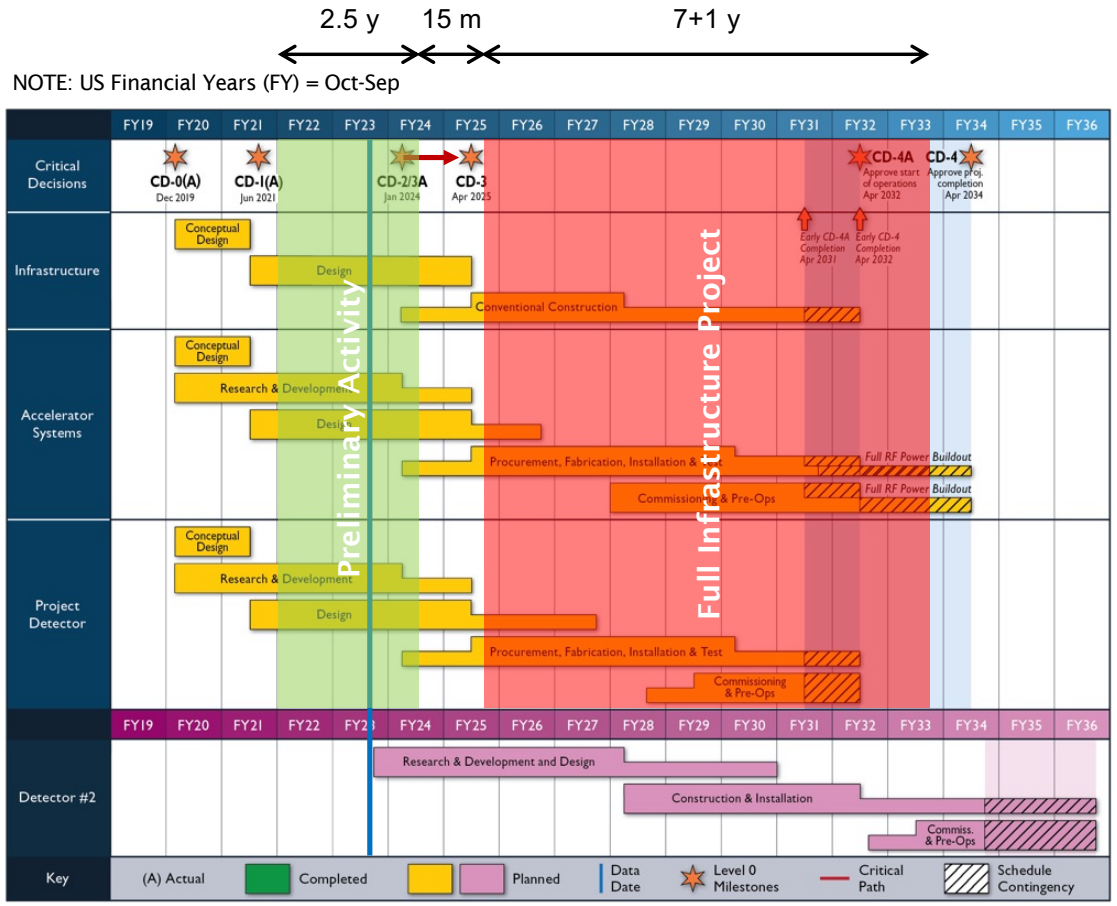
Far-backward region Far-forward region

WP2: Electron tagger

UK-led Detector R&D (stems from current UKRI Infrastructure Preliminary Activity)

International Project Schedule and Full Infrastructure Project

Critical Decision (CD) Milestones
CD-0 Approve Mission Need
CD-1 Approve Cost Range
CD-2 Approve Baseline Performance
CD-3 Approve Start Construction
CD-4A Approve Start of Operations
CD-4 Approve Project Completion



EIC Full Infrastructure Project – Deliverables

- WP1 – Silicon Tracker: Precision tracking and vertexing in the central detector

  Novel 65 nm stitched (wafer-scale) monolithic active pixel sensors; developed in partnership with CERN/ALICE-ITS3. Deliverable: Build ~33% of central silicon tracker – 2 x barrel layers.

  Institutes: Birmingham, Brunel, Lancaster, Liverpool, Oxford, STFC RAL, STFC DL

- WP2 – Electron Tagger: Precision tracking of low-Q^2 scattered electrons

  Low-Q^2 tagger using pixel sensors. Deliverable: Build two tracking stations in the far backward region. Timepix4 is the baseline technology.

  Institutes: Glasgow, STFC DL + Lancaster (beam impedance studies)

- WP3 – Luminosity Monitor: Bunch-by-bunch measurement of collision luminosity

  Design of the luminosity monitor comprising a pair spectrometer (PS) and photon detector (PD). Deliverables: Build the two calorimeters needed for the PS and half the modules needed for the PD.

  Institutes: York

- WP4 – Accelerator Deliverables:

  WP4.1 Cavity design and cryomodules for the ERL
  WP4.2 Design of crab cavity LLRF feedback system
  WP4.3 Design and delivery of EO-BPM instrumentation
  WP4.4 ERL simulation and design

  Institutes: Cockcroft Institute (Lancaster, Liverpool, ASTeC), John Adams Institute (Oxford, Royal Holloway) and STFC DL

EIC Full Infrastructure Proposal – Timeline

- Peer Review
  - Submitted standard proposal and cost justification – submitted 10th February
  - Peer Review Meeting – 22nd March
  - Feedback received – 31st March
- STFC Prioritisation
  - UKRI Proforma application (last year's version) – submitted 19th April
  - Internal Review by STFC departments (Estates, Digital Research Infrastructure, Finance, Impact, Sustainability)
  - Review by SB/TAAB followed by STFC Council and STFC Executive Board
  - Feedback received – 1st June
- UKRI Infrastructure Process
  - Preparation of final proposal using this year's UKRI Proforma
  - Submission to STFC EB – 30th June
  - Submission to UKRI IF – 24th July
  - Decision from UKRI IAC expected – November 2023

EIC Full Infrastructure Project – Feedback

- Peer Review

  Criteria: 1– Community Support and Demand; 2 – Research and Innovation Excellence; 3 – Impact Potential; 4 – Capability to Deliver; 5– Added Value; 6 – Budget Justification

  Rated very highly against criteria: 2 – Research and Innovation Excellence; 3 – Impact Potential; 5– Added Value

  Against criteria 1 – Community Support and Demand, panel commented on small community but recognized potential to grow.

  Main concerns fell within criteria 4 – Capability to Deliver and 6 – Budget Justification, largely due to the UK committing funding at a very early stage in the project.

  Main points: concern over level of contingency, uncertainty around future governance (e.g., subscription costs) and access arrangements affecting ability of new groups to join.

- STFC Prioritisation

  Descope accelerator work package to maximise fit to scope of Infrastructure Fund.

  Ensure sufficient provision for open access data and other computing requirements is costed into the proposal.

  Increase level of contingency to mitigate the risk of slippage in the international project schedule.

EIC Full Infrastructure Project – Costs

- Updated Costing Model

STFC Overheads now appear under Other UKRI Funding and is not a cost to the UKRI IF

HEIs will be funded at 100% FEC

After descoping WP4, total project cost has gone down from £59.6m to £51.8m

For WP1, the cost has gone down from £30.3m to £27.9m (Note that institute costs have gone up!)

			9 months							3 months		
Project Work Packages			**Cost £k (1 decimal place)**									**£m**
WP	**Breakdown**	**Description**	25/26	26/27	27/28	28/29	29/30	30/31	31/32	32/33	33/34	
1	Staff Costs	Academic Staff	437.1	665.9	689.7	690.8	684.8	664.7	792.0	190.1		
1	Staff Costs	PDRAs	571.1	785.3	762.7	848.4	674.3	608.7	692.0	166.9		
1	Staff Costs	Engineers	644.2	1096.9	1254.9	978.5	685.5	584.8	83.5	0.0		
1	Staff Costs	Technicians	230.5	376.0	556.9	677.0	680.1	546.4	47.1	11.8		
1	**Staff Costs**	**Total**	**1882.9**	**2924.0**	**3264.2**	**3194.7**	**2724.7**	**2404.7**	**1614.7**	**368.8**	**0.0**	**18.4**
1	Non-Staff Costs	Equipment	242.8	376.9	414.6	394.7	324.5	246.5	0.0	0.0		
1	Non-Staff Costs	Comsumables	291.4	452.3	497.5	473.6	389.4	295.9	0.0	0.0		
1	Non-Staff Costs	Travel	85.0	131.9	145.1	138.1	113.6	86.3	150.0	150.0		
1	Non-Staff Costs	Other	114.8	630.5	2934.5	143.9	111.0	73.4	71.8	0.0		
1	**Non-Staff Costs**	**Total**	**733.9**	**1591.5**	**3991.7**	**1150.3**	**938.5**	**702.1**	**221.8**	**150.0**	**0.0**	**9.5**
1	**Total**	**Total for Work Package**	**2616.8**	**4515.5**	**7255.9**	**4345.1**	**3663.2**	**3106.9**	**1836.4**	**518.8**	**0.0**	**27.9**

Description	**Work Packaage**	25/26	26/27	27/28	28/29	29/30	30/31	31/32	32/33	33/34	**£m**
STFC Overheads	WP1	432.7	733.1	872.0	736.2	554.5	374.1	61.8	0.0	0.0	3.8
STFC Overheads	WP2	13.7	17.6	23.5	19.6	9.8	9.8	0.0	0.0	93.9	0.2
STFC Overheads	WP4	185.7	388.5	475.8	426.2	189.4	0.0	0.0	0.0	0.0	1.7
STFC Overheads	WP5	52.4	72.4	74.9	77.5	80.2	83.1	86.0	21.5	0.0	0.5
STFC Overheads	**Total for Project**	**684.6**	**1211.5**	**1446.2**	**1259.6**	**834.0**	**467.0**	**147.7**	**21.5**	**93.9**	**6.1**

EIC Full Infrastructure Project – Contingency

- Contingency is work-in-progress

Currently, contingency includes: 1 – Extra year of staff effort; 2 – Indexation on the extra effort; 3 – Flat rate of 20% on Equipment and Consumables; 4 – 50% on silicon wafer costs; 5 – An extra percentage point on inflation

The US Project carries about 35% as contingency

UKRI will award half of the contingency as WA; half will be held by STFC

Profiling contingency is important: needs to appear where needed

Note: early CD-4A is April 2031, CD-4A is April 2032; project ends July 2032; with contingency July 2033

Adding an additional 6 months contingency, grants end in March 2034 (CD-4 + 2 years)

Staff costs WPs 1-3 & 5	2555.5	3775.6	4126.5	4025.3	3523.2	3191.4	2389.6	576.0	
Staff costs with delay			3775.6	4126.5	4025.3	3523.2	3191.4	2389.6	576.0
Surplus/Deficit			350.9	249.7	-252.4	-331.8	-801.7	-1813.7	-576.0

Contingency WPs 1, 2, 3 & 5	25/26	26/27	27/28	28/29	29/30	30/31	31/32	32/33	33/34			
Add 1 year staff effort; reprofile FY27/28+					252.4	331.8	801.7	1813.7	576.0	3.8		
Add indexation			132.1	144.4	140.9	123.3	111.7	83.6	20.2	0.8	1.035	Indexation
Equip & Cons	132.8	342.9	380.1	283.5	189.7	134.5	21.0	0.0	0.0	1.5	0.2	Scale
Silicon Costs			692.5	692.5						1.4	0.5	Yield
Indexation	0.0	63.1	184.4	175.8	193.5	209.7	172.6	47.7		1.0	1.01	
Total WPs 1, 2, 3 & 5	**132.8**	**342.9**	**1204.8**	**1120.5**	**583.0**	**589.6**	**934.4**	**1897.3**	**596.1**	**7.4**	**20%**	

Contingency WP 4	25/26	26/27	27/28	28/29	29/30	30/31	31/32	32/33	33/34	
Original estimate	**146.7**	**261.5**	**503.5**	**421.1**	**200.6**					1.5
Total WP4	**146.7**	**261.5**	**503.5**	**421.1**	**200.6**					**1.5**	**27%**

Backup

Full Infrastructure In-kind Contribution

- Detector partnerships ~30% in-kind (project detector)

  GPD estimated cost = $300m
  Project cost = $200m; in-kind contribution = $100m

- ATHENA costing

  $7.3m material, $13.7m staff effort = $21m total (with indexation $9.1m + $17.1m = $26.2m)

  At todays exchange rate ($1 = £0.78), ATHENA indexed cost is £7.1m + £13.3m = £20.4m

  UK bid appears high by comparison: £9.5m + £18.4 = £27.9m plus contingency

Project Delivery (Academics and Senior Research Fellows)

- Birmingham (NP/PP)

  Peter Jones (co-PI, WP1)
  Paul Newman (WP1)
  Laura Gonella (WP1)

- Brunel (PP)

  Liliana Teodorescu (WP1)

- Glasgow (NP)

  Daria Sokhan (co-PI, WP2)
  Ken Livingston (WP2 leader)
  Derek Glazier (WP2)

- Lancaster (PP/AP)

  Harald Fox (WP1)
  Graeme Burt (WP4 leader)
  Robert Apsimon (WP2)

- Liverpool (NP)

  Marielle Chartier (WP1)

- Oxford (PP)

  Georg Viehhauser (WP1 leader)
  Todd Huffman (WP1)
  Claire Gwenlan (WP1)

- York (NP)

  Dan Watts (WP3 leader)
  Nick Zachariou (WP3)
  Mikhail Bashkanov (WP3)

- STFC RAL (PP)

  Ian Sedgwick (WP1)
  Fergus Wilson (WP1)

- STFC DL (NP/AP)

  Roy Lemmon (WP1)
  Marcello Borri (WP1)
  Richard Smith (PM)
  Niklas Templeton (WP4)

Key
NP = Nuclear Physics
PP = Particle Physics
AP = Accelerator Physics
PM = Project Manager

WP1 – Silicon Tracker (BHM, BRU, LAN, LIV, OXF, STFC DL, STFC RAL)

- Central tracking and vertexing

Approximately 10 m^2 detector comprising vertex layers, barrel layers and disks

65 nm MAPS technology driven by physics requirements and validated with simulations

Proposed ITS3 sensor meets EIC needs

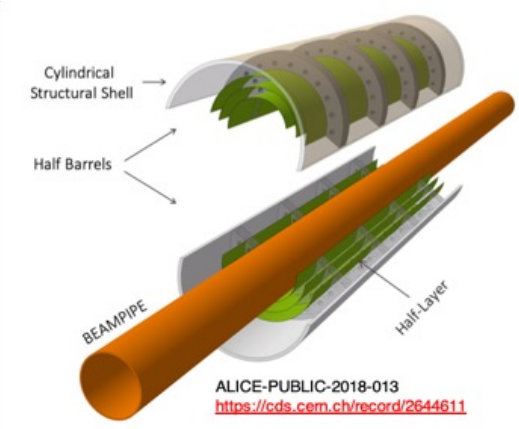
- Partnership with CERN minimises risk

EIC will use same concept for vertex layers:

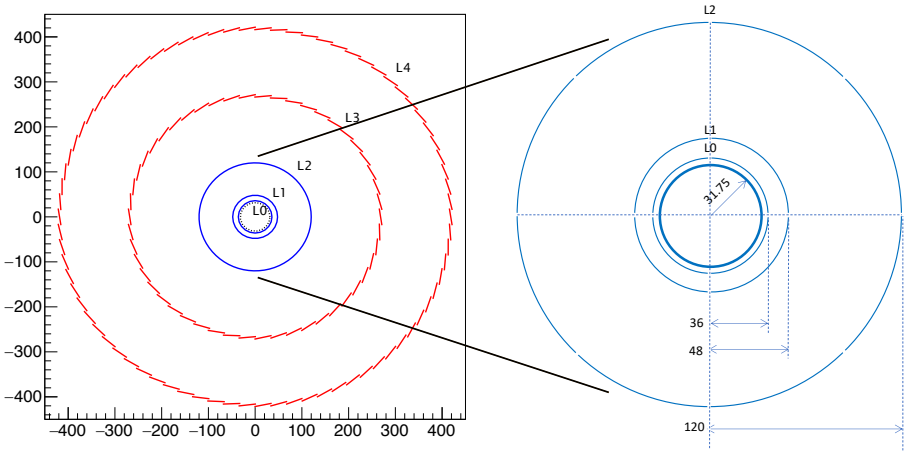
- Wafer-scale, stitched sensors, thinned and bent around the beam pipe

EIC specific development needed for the barrel layers and disks:

- large area stitched sensor (not wafer scale), and "conventional" low mass support structures

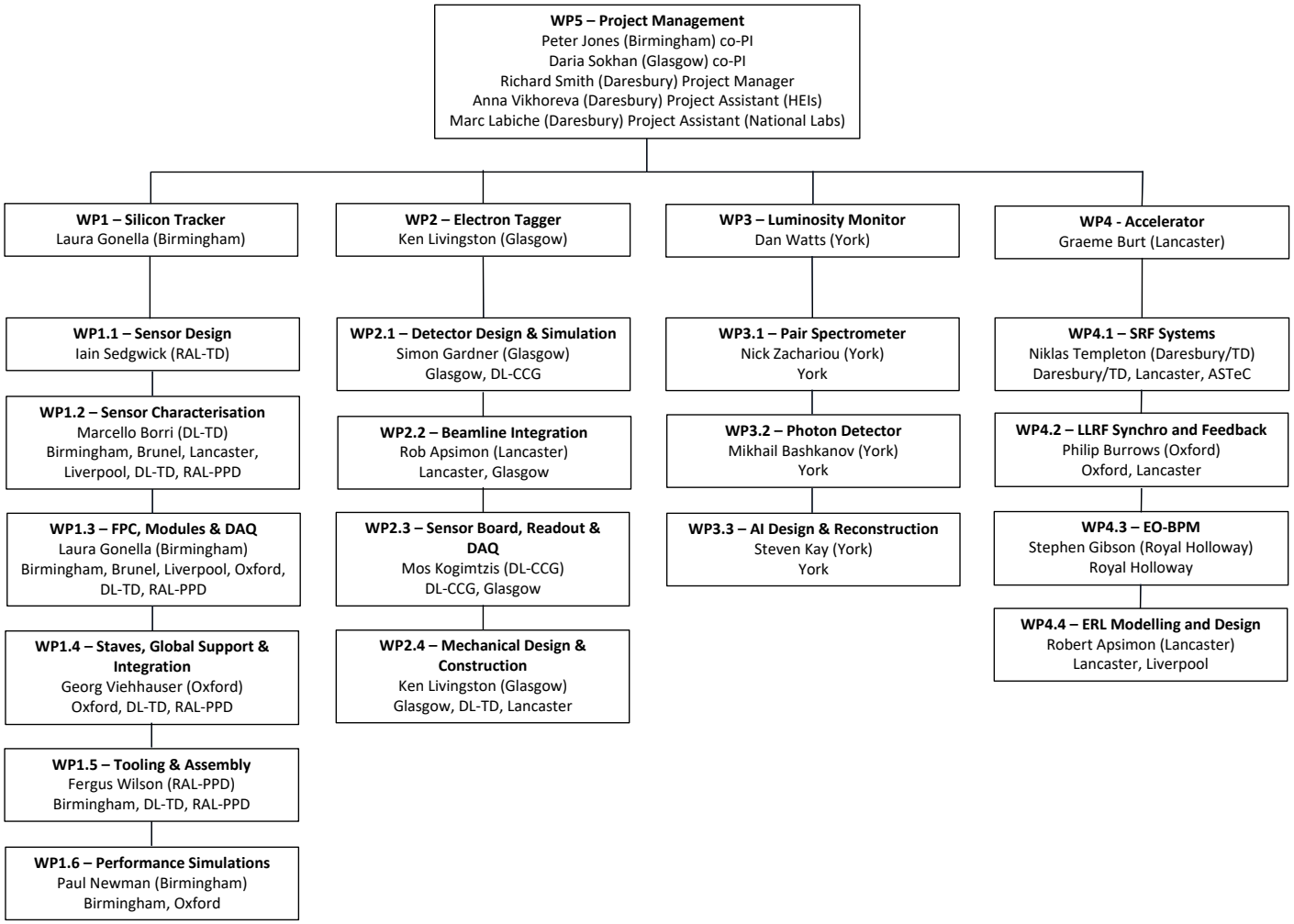


ALICE-ITS3 development



ePIC-SVT Vertex and Barrel layers ePIC-SVT Vertex layers

Project Delivery (Project Organisation)

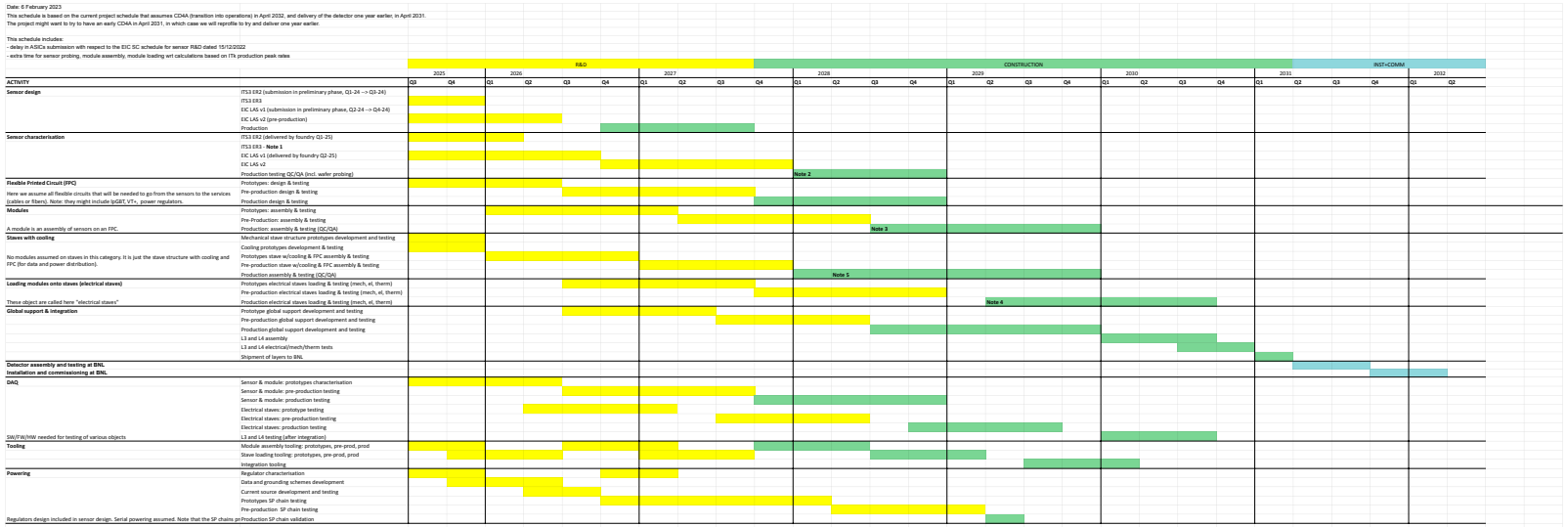


Cost Estimation – WP1 – Definition of Tasks/Responsibilities

NOTES		
Sagitta L3 = 11% Si area – 50 staves, 200 sensors Spares: 10 staves, 40 sensors		
Sagitta L4 = 26% Si area – 78 staves, 624 sensors Spares: 12 staves, 96 sensors		
TO BUILD: 150 staves, 960 sensors, 480 modules (w/o yield)		
Prototypes below mean multiple versions of an object during the R&D phase.		
We will work within the international collaboration and some of these development will be common/have overlap to work on disks, e.g. DAQ.		
Tasks in grey start, and in some cases complete, in the preliminary phase.		

ACTIVITY		INSTITUTES
Sensor design	ITS3 ER2 (submission in preliminary phase, Q1-24)	**RAL-TD**
	ITS3 ER3	**RAL-TD**
	EIC LAS v1 (submission in preliminary phase, Q2-24)	**RAL-TD**
	EIC LAS v2 (pre-production)	**RAL-TD**
	Production	**RAL-TD**
Sensor characterisation	ITS3 ER2 (delivered by foundry Q3-24)	**BHM DL-TD BRU LIV LAN**
	ITS3 ER3	**BHM DL-TD BRU LIV LAN**
	EIC LAS v1 (delivered by foundry Q4-24)	**BHM DL-TD BRU LIV LAN**
	EIC LAS v2	**BHM DL-TD BRU LIV LAN**
	Production testing QC/QA (incl. wafer probing)	**BHM BRU**
Flexible Printed Circuit (FPC)	Prototypes: design & testing	**DL-TD OX**
Here we assume all flexible circuits that will be needed to go from the sensors to the services (cables or fibers). Note: they might include lpGBT, VT+, power regulators.	Pre-production design & testing	**DL-TD OX**
	Production design & testing	**DL-TD OX**
Modules	Prototypes: assembly & testing	**BHM RAL-PPD (BRU) LIV**
A module is an assembly of sensors on an FPC.	Pre-Production: assembly & testing	**BHM RAL-PPD (BRU) LIV**
	Production: assembly & testing (QC/QA)	**BHM RAL-PPD (BRU) (LIV)**
Powering	Regulator characterisation	**BHM OX (RAL-PPD)**
Regulators design included in sensor design. Serial powering assumed. Note that the SP chains prototypes might be bricolaged but at some point SP will be fully implemented in the electrical staves so it will be tested with proto/pre-prod/prod electrical staves	Data and grounding schemes development	**BHM OX (RAL-PPD)**
	Current source development and testing	**BHM OX (RAL-PPD)**
	Prototypes SP chain testing	**BHM OX (RAL-PPD)**
	Pre-production SP chain testing	**BHM OX (RAL-PPD)**
	Production SP chain validation	**BHM OX (RAL-PPD)**
Staves with cooling	Mechanical stave structure prototypes development and testing	**OX DL-TD**
No modules assumed on staves in this category. It is just the stave structure with cooling and FPC (for data and power distribution).	Cooling prototypes development & testing	**OX DL-TD**
	Prototypes stave w/cooling & FPC assembly & testing	**OX DL-TD**
	Pre-production stave w/cooling & FPC assembly & testing	**OX DL-TD**
	Production assembly & testing (QC/QA)	**OX DL-TD**
Loading modules onto staves (electrical staves)	Prototypes electrical staves loading & testing (mech, el, therm)	**RAL-PPD DL-TD**
These object are called here "electrical staves"	Pre-production electrical staves loading & testing (mech, el, therm)	**RAL-PPD DL-TD**
	Production electrical staves loading & testing (mech, el, therm)	**RAL-PPD DL-TD**
DAQ	Sensor & module: prototypes characterisation	**DL-TD BRU LAN**
	Sensor & module: pre-production testing	**DL-TD BRU**
	Sensor & module: production testing	**DL-TD BRU**
SW/FW/HW needed for testing of various objects	Electrical staves: prototype testing	**RAL-PPD BHM**
	Electrical staves: pre-production testing	**RAL-PPD BHM**
	Electrical staves: production testing	**RAL-PPD BHM**
	L3 and L4 testing (after integration)	**RAL-PPD BHM**
Tooling	Module assembly tooling: prototypes, pre-prod, prod	**BHM**
	Stave loading tooling: prototypes, pre-prod, prod	**RAL-PPD**
	Integration tooling	**OX RAL-PPD**
Global support & integration	Prototype global support development and testing	**OX DL-TD (LIV)**
	Pre-production global support development and testing	**OX DL-TD**
	Production global support development and testing	**OX DL-TD**
	L3 and L4 assembly	**OX RAL-PPD**
	L3 and L4 electrical/mech/therm tests	**OX RAL-PPD**
	Shipment of layers to BNL	**OX RAL-PPD**

Cost Estimation – WP1 – Schedule



Note 1: ITS3 ER3 testing
The ITS3 ER3 sensor will be used for the vertex layers of the ePIC SVT
This testing will be QC/QA for vertex layers, not done by us, removed from schedule

Note 2: Wafer probing
Assume 240 wafers (incl. yield = 2, see silicon costing tab)
1 wafer/day, 2 probing sites
120 wafers/site
220 working day/year
Total time needed: ~6 months for probing **--> 1 year in the schedule**

Note 3: Module production
480 modules + yield (factor 1.2, estimated from ITk stip modules)= 576
Assume 2 sites (BHM RAL-TD)
~300 modules/ sites
For ITk 2 modules/day (incl. QC/QA, database uploads, shipments to stave loading site)
150 days/ site
Total time needed: ~8 months for assembly **--> 1.5 years in the schedule**

Note 4: Stave loading
ITk loads 2 staves per week, (13 modules per side), including wire bonding and testing
150 staves + yield = 180
2 sites
90 staves/site
45 weeks = one year **--> 1.5 years in schedule**

Note 5: Staves production
2 staves/week, 88 staves/years, 176 staves in 2 years

Gantt Chart

Gantt chart: EIC Full Infrastructure Project

Version: 2.0
Author: Peter Jones (p.g.jones@bham.ac.uk)

Starting date:	01/07/2025
Year:	2025
Quarter:	3

ID	Task	Start Time	End Time	Duration Q
	WP1 - Silicon Tracker			
1	Sensor Design	01/07/2025	30/09/2027	9
2	Sensor Characterisation	01/07/2025	31/12/2027	10
3	Sensor Production Testing (QC/QA)	01/01/2028	31/12/2028	4
4	Flexible Printed Circuits – Design and Testing	01/07/2025	30/09/2027	9
5	Flexible Printed Circuits – Production and Testing	01/10/2027	31/12/2028	5
6	Modules - Prototypes	01/01/2026	31/03/2027	5
7	Modules - Preproduction	01/04/2027	30/06/2028	5
8	Modules - Production	01/07/2028	31/12/2029	6
9	Staves - Prototypes	01/07/2025	31/12/2026	6
10	Staves - Preproduction	01/01/2027	31/12/2027	4
11	Staves - Production	01/01/2028	31/12/2029	8
12	Staves - Loading	01/04/2029	30/09/2030	6
13	Global Support and Integration - Design, Prototyping and Testing	01/07/2026	30/06/2028	8
14	Global Support and Integration - Production and Testing	01/07/2028	31/12/2029	6
15	Layers Assembly and Testing	01/01/2030	31/12/2030	4
15	Shipment to BNL	01/01/2031	31/03/2031	1
16	Installation and Commissioning	01/04/2031	30/06/2032	5
	WP2 - Electron Tagger			
1	Vacuum and Window Design	01/07/2025	30/06/2026	4
2	Prototype Development (2 x Timepix4)	01/07/2025	31/12/2026	6
3	Final Design	01/07/2025	31/12/2027	10
4	PCB for Prototype Tracking Layer (12 x Timepix 4)	01/01/2026	30/06/2028	10
5	Mechanics and Cooling	01/01/2027	31/12/2028	8
6	Construction	01/09/2028	31/12/2030	10
7	Delivery to BNL	01/01/2031	31/01/2031	1
8	Installation and Commissioning	01/04/2031	30/06/2032	5
	WP3 - Luminosity Monitor			
1	Pair Spectrometer - Design and Prototype	01/07/2025	31/03/2028	11
2	Pair Spectrometer - Construction and Testing	01/04/2027	31/03/2030	12
3	Pair Spectrometer - Delivery to BNL	01/04/2030	30/04/2030	1
4	Pair Spectrometer - Installation and Commissioning	01/07/2030	30/06/2032	8
5	Photon Detector - Design and Prototype	01/07/2025	31/03/2028	11
6	Photon Detector - Construction and Testing	01/04/2027	31/03/2030	12
7	Photon Detector - Delivery to BNL	01/04/2030	30/04/2030	1
8	Photon Detector - Installation and Commissioning	01/07/2030	30/06/2032	8
9	AI Development	01/07/2025	30/06/2032	28
	WP4 - Accelerator			
1	Cryomodule and Tooling Design	01/07/2025	01/05/2027	8
2	Acceptance testing of US cavities	01/01/2027	01/06/2028	6
3	Procument of cryomodule subsystems	01/01/2027	01/05/2028	6
4	Cryomodule Assemby	01/05/2027	01/06/2029	9
5	Final testing and shipping	01/06/2029	31/12/2029	3
6	Define scope of LLRF synchronisation and feedback task	01/07/2025	30/09/2025	1
7	Conceptual design of beam feedback system	01/10/2025	31/12/2026	5
1	Conceptual design of LLRF synchronisation system	01/10/2025	31/12/2026	5
2	Technical specification of LLRF synchronisation system	01/01/2027	31/12/2027	4
3	Technical specification of beam feedback system	01/01/2027	31/12/2027	4
4	Document integrated LLRF synchronisation and feedback system	01/01/2028	30/06/2028	2
5	Simulate and optimise design of EO BPM with EIC parameters	01/07/2025	31/12/2025	2
1	Build and bench test EO-waveguide prototype	01/01/2026	30/06/2026	2
2	Beam test EO prototype at EIC	01/07/2026	30/06/2027	4
3	Review results and finalise design	01/07/2027	31/12/2027	2
4	Technical design of EO-BPM for EIC	01/01/2027	30/06/2028	6
5	Model BBU thershold current for combined 1st and 3rd harmonic cavities for electron cooler and pre-cooler	01/07/2025	31/12/2026	6
6	Determine impedance budget for electron cooler and pre-cooler	01/01/2027	30/06/2029	10
7	Optimisation of bunch stretching schemes for cooler and pre-cooler at 100 GeV ant 275 GeV	01/10/2025	30/09/2027	8
7	Design of required tuneable beam lines to switch between operating modes	01/10/2027	31/12/2028	5