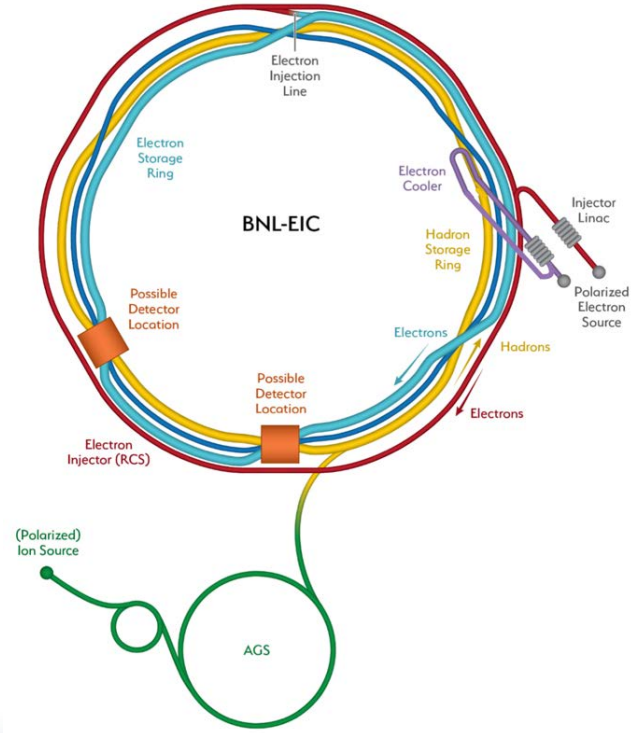
EIC Detector R&D Project

Peter Jones, University of Birmingham
Daria Sokhan, University of Glasgow/CEA Saclay

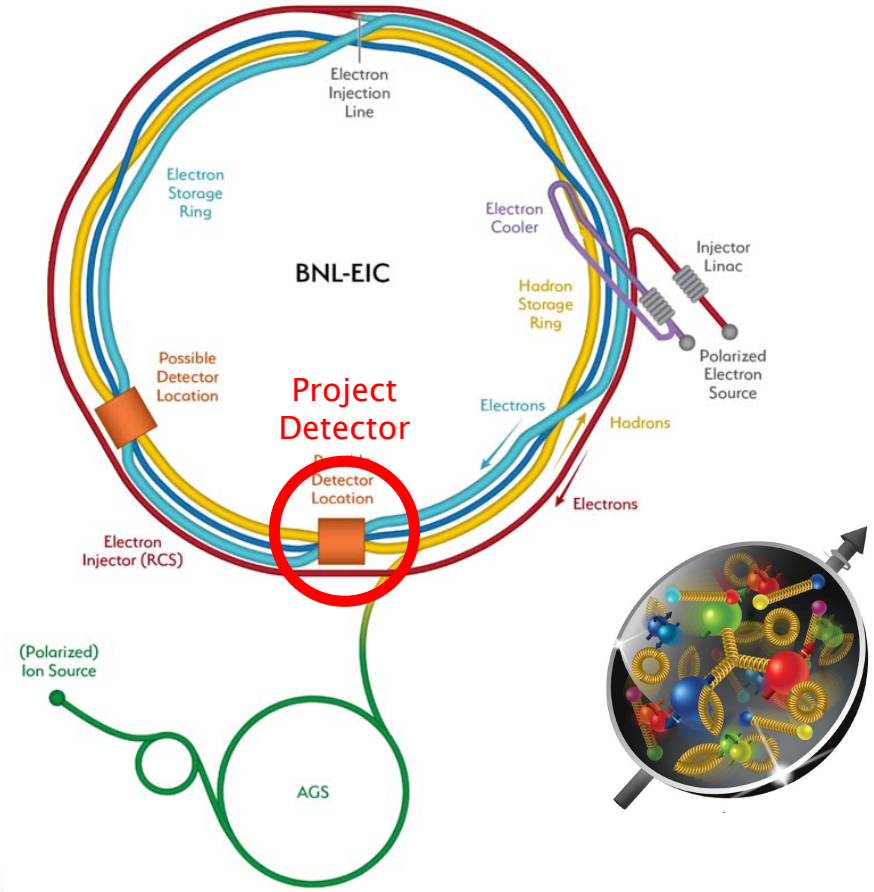


Daresbury Laboratory
Rutherford Appleton Laboratory

Electron-Ion Collider (EIC)

- Overview of the facility

  Incorporates the Relativistic Heavy Ion Collider 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?

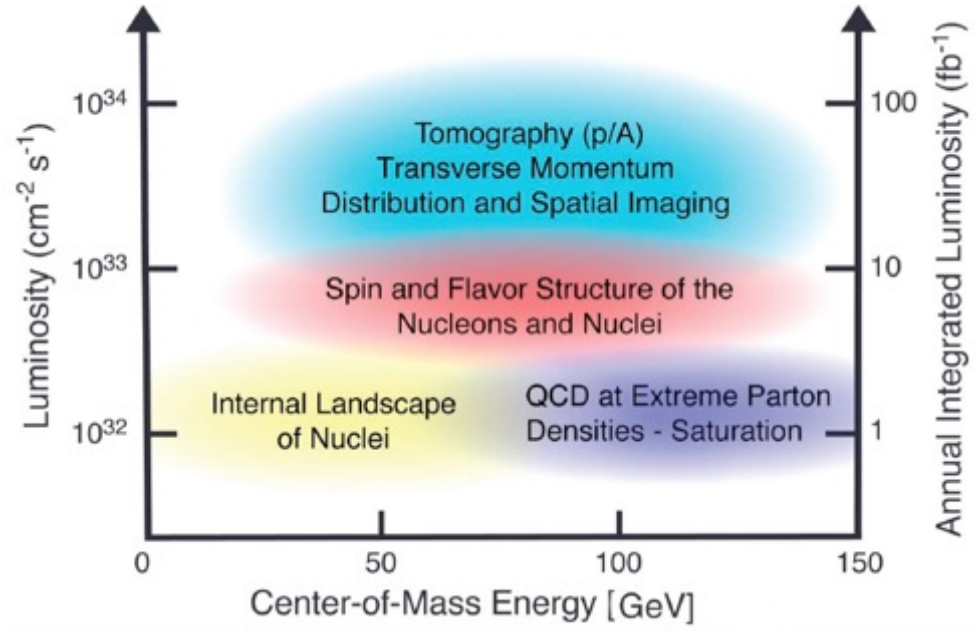
- Key features

  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

  Total Project Cost = $2.4B
  Start of Operations in 2032

EIC Science Overview

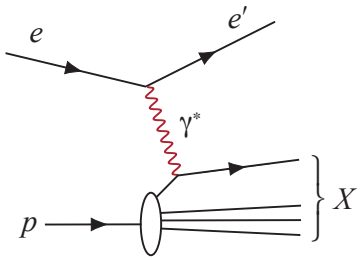


Mass of the nucleon

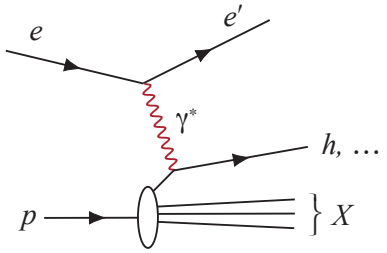
Spin of the nucleon

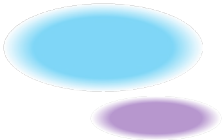
Gluons in nuclei

Inclusive DIS

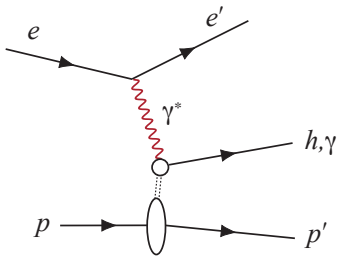


Semi-inclusive DIS

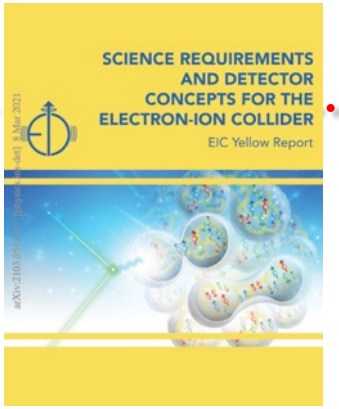




Exclusive DIS



EIC Recent Timeline



- 2020 Jan – CD-0 Approve Mission Need

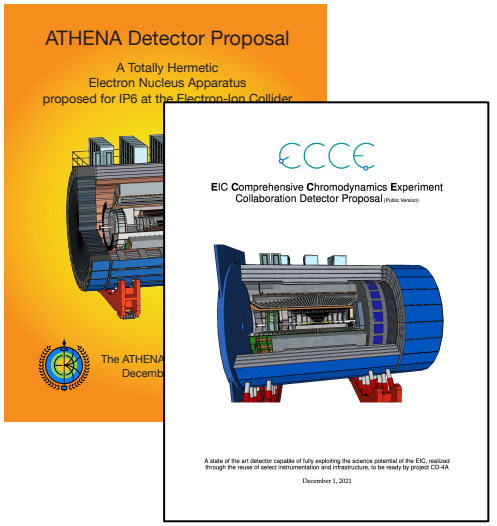
  BNL chosen to host the facility

- 2021 Mar – EIC Yellow Report published

  Ended a 15-month design study that had strong UK involvement and leadership

- 2021 Mar – Call for Detector Proposals
- 2021 Jun – CD-1 Approve Alternative Selection and Cost Range
- 2021 Dec – Submission deadline for Detector Proposals

  ATHENA – A Totally Hermetic Electron Nucleus Apparatus
  ECCE – EIC Comprehensive Chromodynamics Experiment
  CORE – Compact detector for the EIC
  UK had strong involvement and leadership in both ATHENA and ECCE



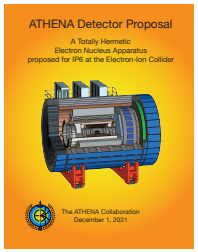
- 2022 Mar – Decision on the Project Detector – ECCE chosen as reference design

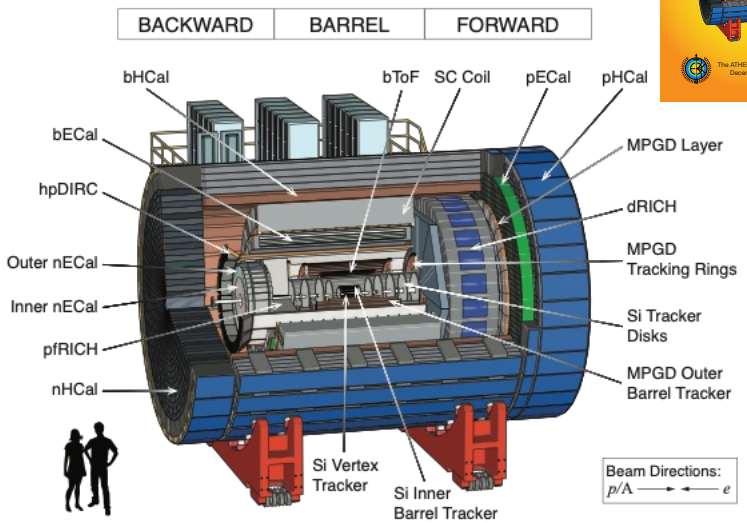
  Merger of ATHENA and ECCE to form the ePIC detector and collaboration

- 2025 Jan – CD-2 Approve Performance Baseline (Preliminary Design Review)
- 2025 Apr – CD-3 Approve Start Construction (Final Design Review)

EIC Detector Proposals

- ATHENA

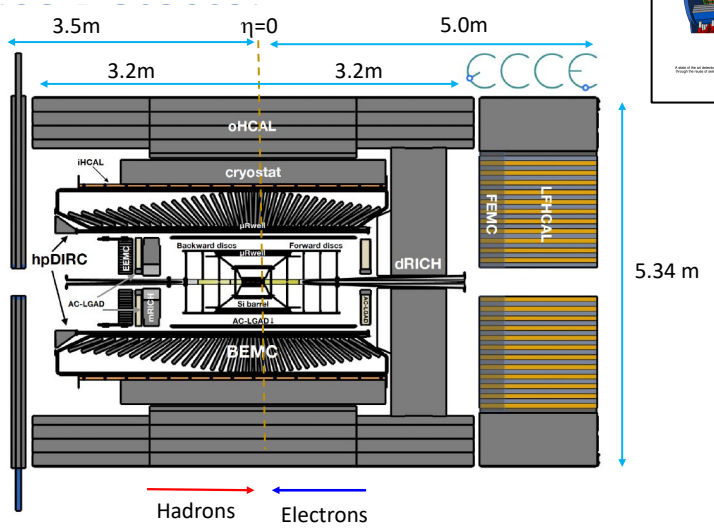




- New 3T solenoid
- Large bore; optimised performance
- Designed for IP6

Laura Gonella (BHM) – Tracking DWG
Paul Newman (BHM) – Inclusive PWG
Daria Sokhan (GLA) – Exclusive/tagging PWG
Peter Jones (BHM) – Proposal Committee

- ECCE



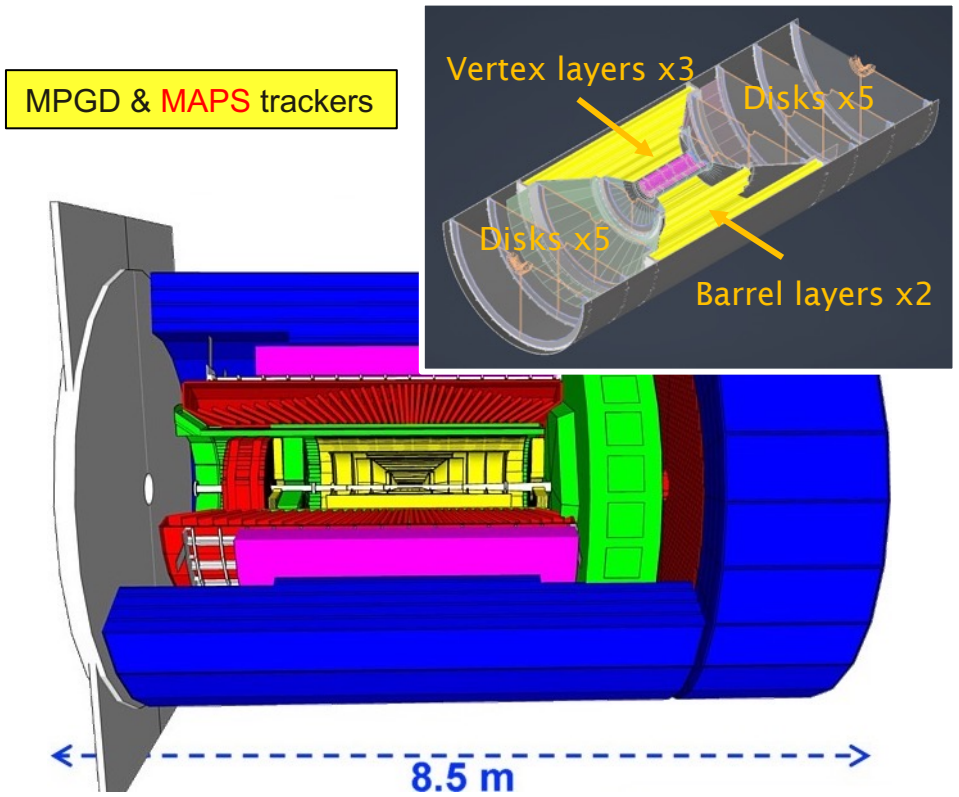
- Existing 1.5T solenoid (BaBar)
- Low-risk; cost effective
- Designed for IP6 or IP8

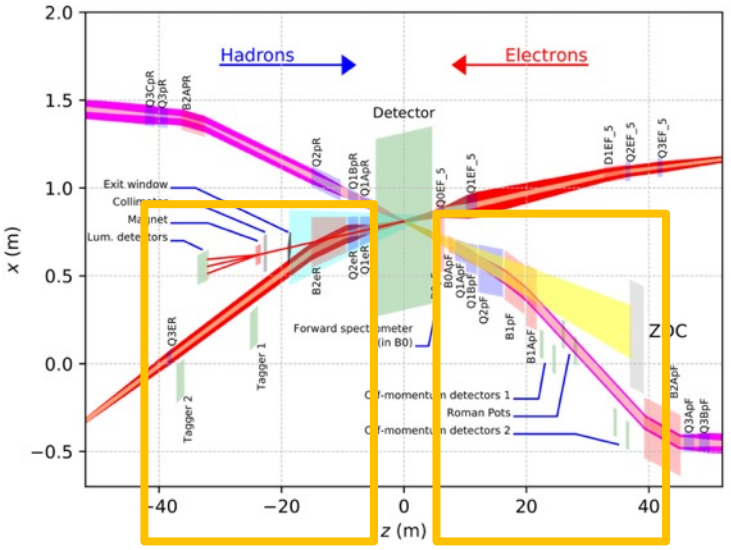
Nick Zachariou (YRK) – Far Backward DWG
Claire Gwenlan (OXF) – Inclusive PWG
Rachel Montgomery (GLA) – Exclusive PWG

UK-led Detector R&D

- ATHENA + ECCE = ePIC: central detector and ancillary detectors

WP1: MAPS

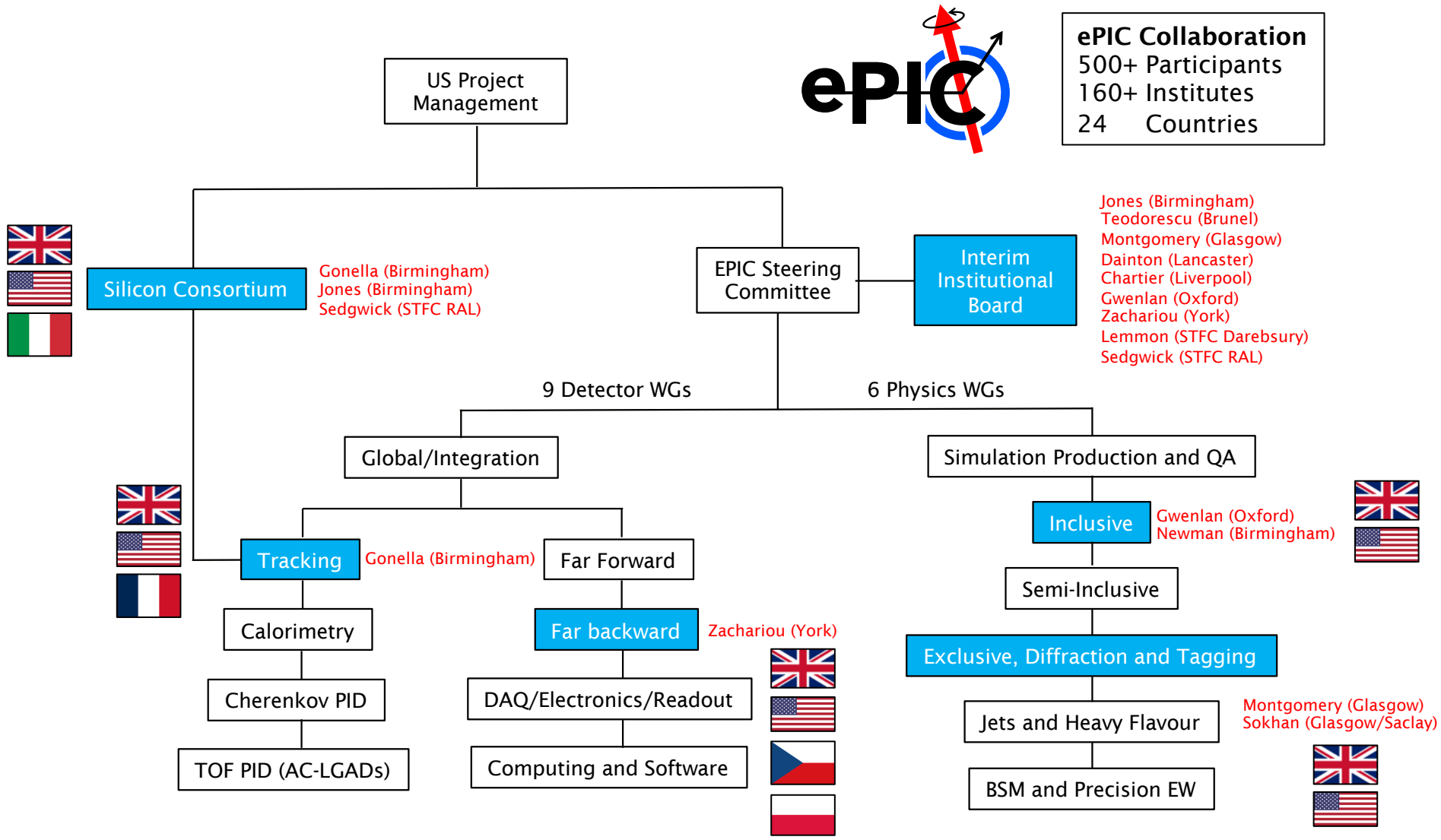




far backward far forward

WP2: Timepix WP3: Polarimetry

ePIC Collaboration



UK Project Overview

- UKRI Infrastructure Fund

  EIC Detector R&D awarded £2.97m

  Duration 2.5 years (Oct 2021 – Mar 2024)

  Three detector work packages: MAPS, Timepix, Polarimetry

  Funded institutes: Birmingham, Brunel, Glasgow, Lancaster, Liverpool, York, STFC DL, STFC RAL (TD and PPD)

  Current award is a Preliminary Activity or Scoping Project
  Aims of this phase are:
  (i) Establish/maintain technical and scientific leadership
  (ii) Define the size and scope of the UK's contribution to detector construction

  Preparing to submit a Full Infrastructure Project bid in July 2023

- Track Record

  Collaboration has a strong record in developing detector technologies. Relevant examples include: ALICE ITS2; ATLAS ITk; CLAS12 Forward Tagger; MAMI nucleon polarimeter

WP1 – MAPS (Birmingham, Brunel, Lancaster, Liverpool, STFC DL, STFC RAL)

- Central tracking and vertexing

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

Leadership grows out of UK involvement in the US-funded, EIC Generic R&D programme

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

Proposed ITS3 sensor meets EIC needs

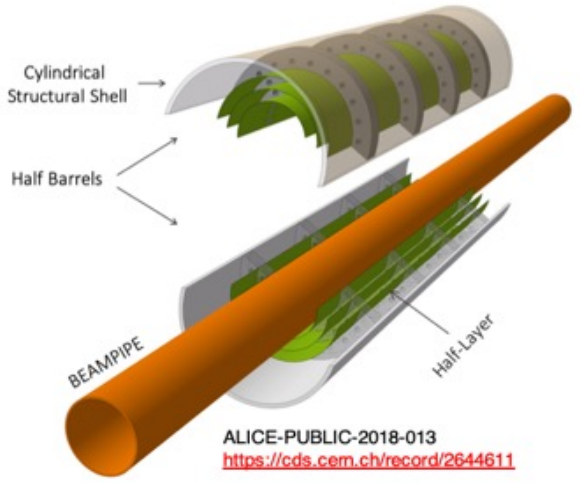
- Partnership with CERN minimises risk

EIC will use same concept for vertex layers

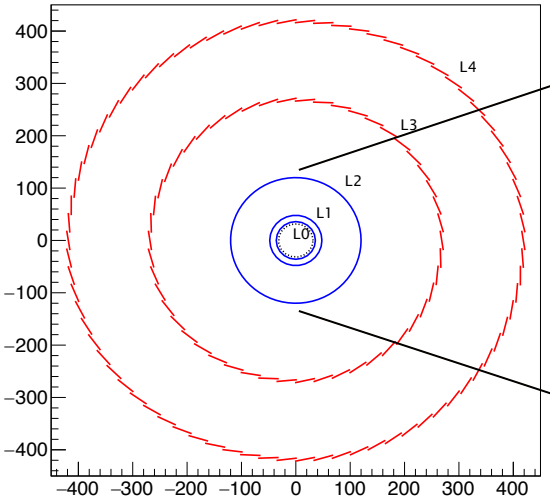
- Wafer-scale, stitched sensors, thinned and bent around the beam pipe

EIC specific development needed for the barrel layers and disks:

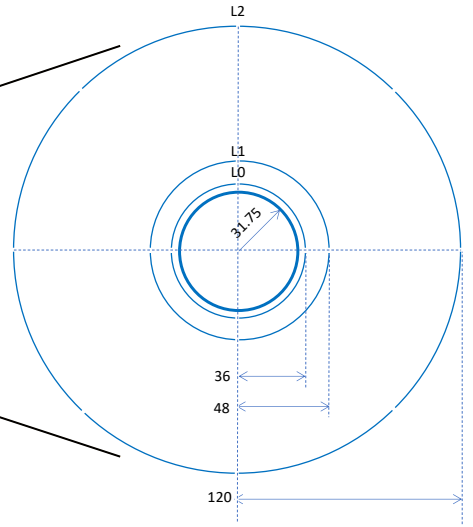
- large area stitched sensor (not wafer scale), and "conventional" low mass support structures



ALICE-ITS3 development



ePIC-SVT Vertex and Barrel layers



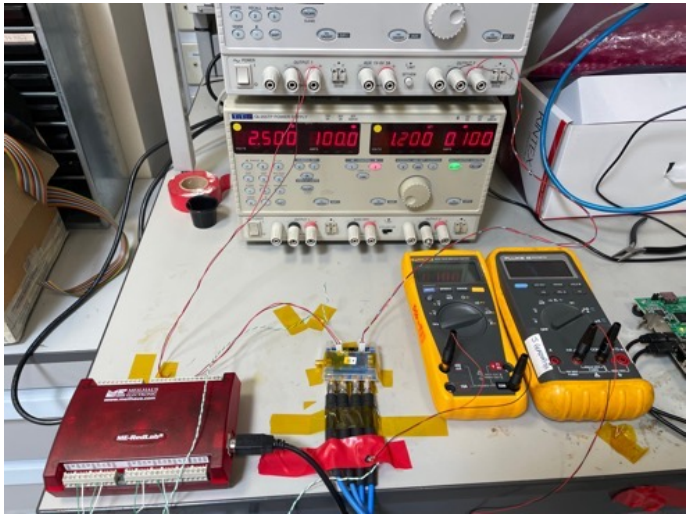
ePIC-SVT Vertex layers

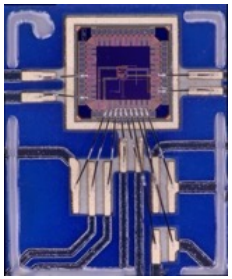
WP1– Sensor Characterisation

- MLR (Q4 2020) – RAL IP Block

  Test setup for RAL IP block: functional blocks for high-speed data transmission

  Chips bonded to carrier boards at Birmingham and Liverpool





RAL chip in new test system by DL/BHAM/LIV

  X-ray irradiations carried out at CERN by Daresbury (Sep 22)

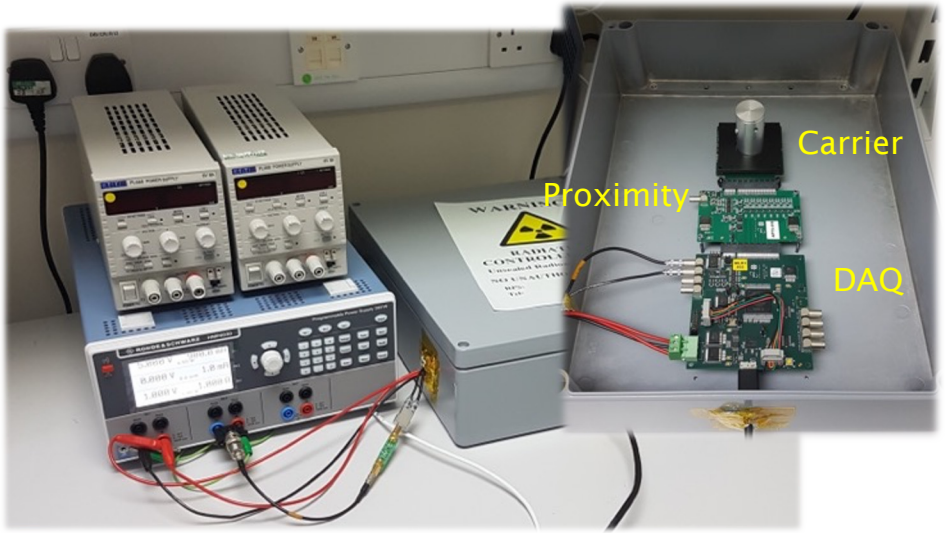
  Tests performed at Daresbury before/after irradiation; analysis on-going

- MLR (Q4 2020) – APTS / DPTS

  MLR contains Analogue Pixel Test Structures (APTS) and Digital Pixel Test Structures (DPTS) designed by ITS3 groups

  Birmingham and Liverpool have bonded chips to carrier boards for ITS3

  Both institutes have now received and commissioned APTS test setups



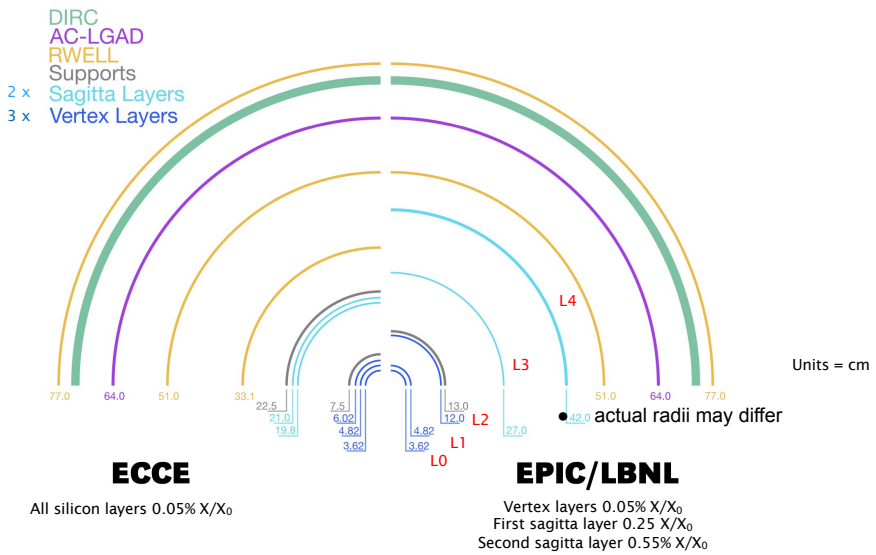
APTS test setup at Liverpool

  Expect to receive DPTS test setups for Daresbury and RAL in Dec 22.

WP1– Performance Evaluation

- Barrel tracking layers

  Evolution of ECCE design with more realistic assumptions on material thickness



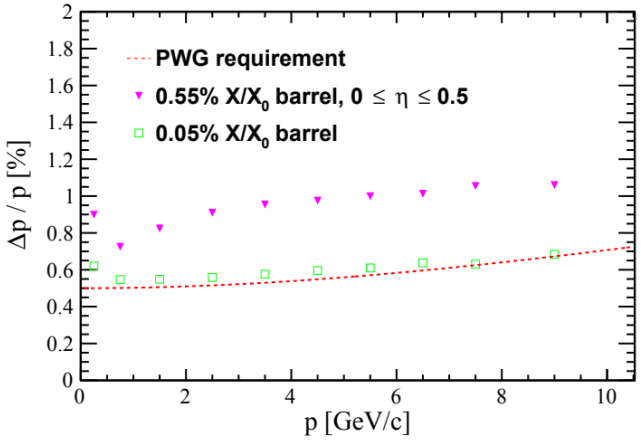
For reference 0.05 X/X_0 is equivalent to 50 μm of silicon

1. Outer barrel layers (L3 and L4) require conventional support structures

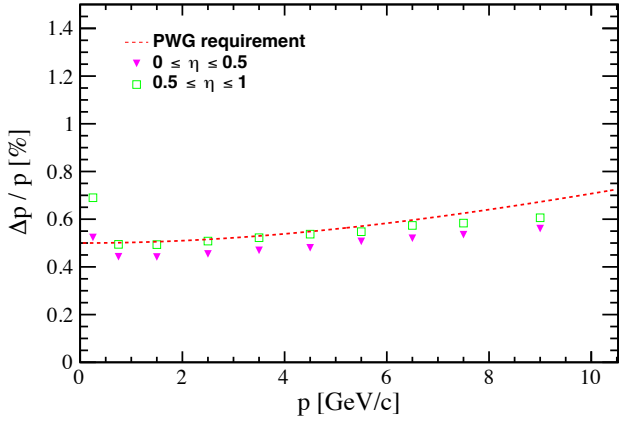
2. Radial positions adjusted to optimize momentum resolution

- Simulation studies

  Momentum resolution with updated material fails to meet requirement



After optimization with B = 1.7 T field



Demonstrated need for a <u>new</u> solenoid

Work by Stephen Maple (UoB PhD student)

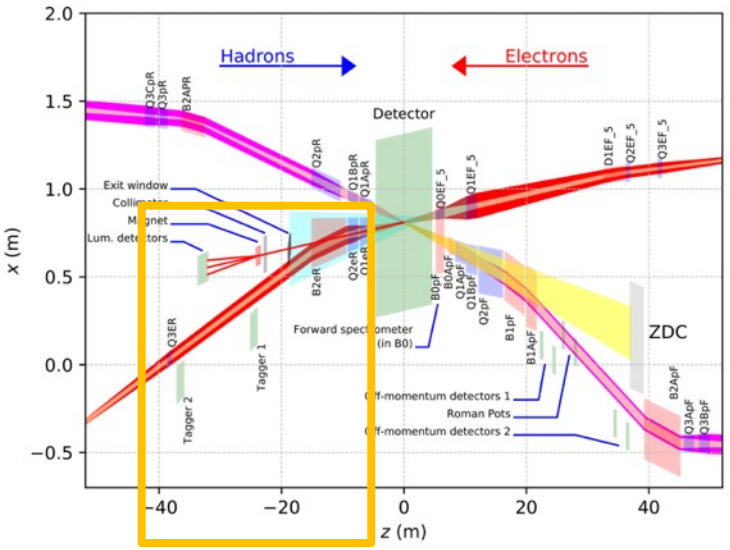
WP2 – Timepix (Glasgow, STFC DL)

- Low-Q^2 tagger with Timepix tracker

We have demonstrated:

1. Strong physics case for low-Q^2 tagger; emphasised by workshop on exotic heavy meson spectroscopy
2. Low-Q^2 tagger needs pixel-based tracking detectors in the beam pipe
3. A calorimeter is not required
4. Acceptable data rate ~10 Gbps

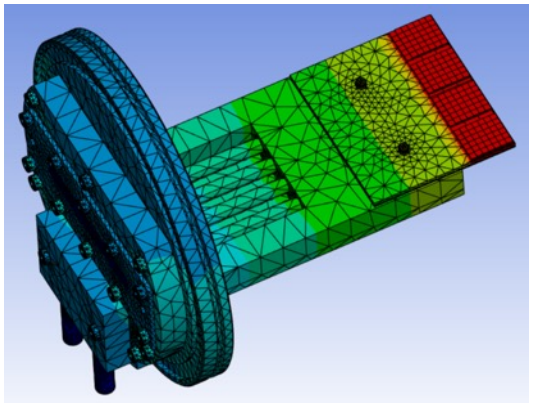
JINST paper in preparation with co-authors from far-backward detector working group

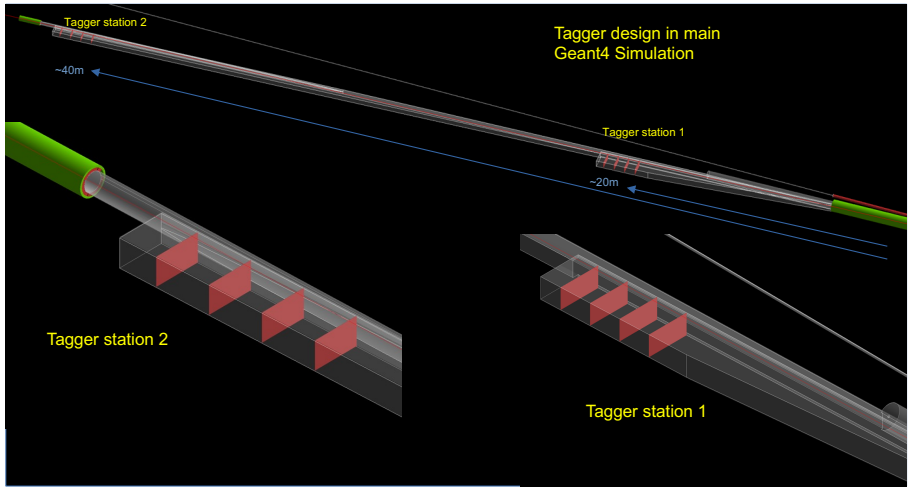


far backward far forward

Detector prototype design using 4x Timepix3 sensors is well advanced

Figure shows results of thermal modelling





WP3 – Polarimetry (York)

- Recoil nucleon polarimeter

  Central task to develop polarised active scattering media/detectors

  New concept to access polarimetry information from spin-spin correlations (rather than diminishing spin-orbit)

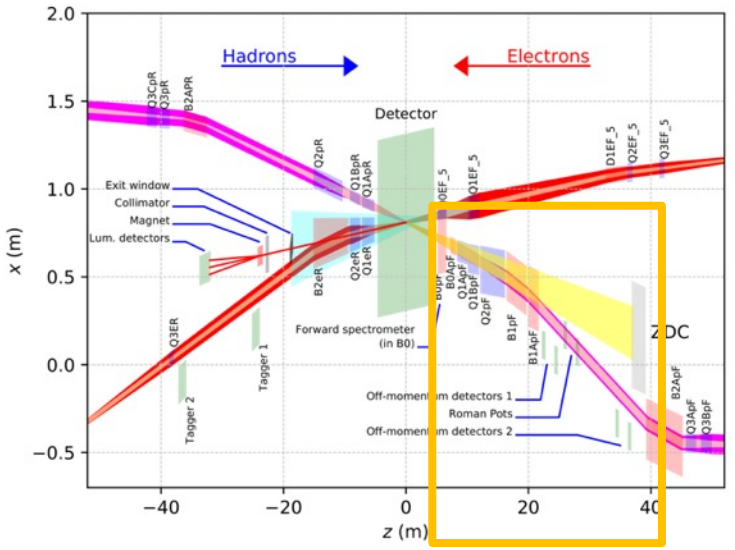
  Use Chemical HyperPolarisation (ChHP) of liquid media – involves substrate, catalyst, slowly bubbled para-hydrogen

  Prototype tests with pyradine (C_5H_5N) look promising

  Simulations indicate best to place detector is in front of the Zero Degree Calorimeter

  Golden channel: $e^- + {}^{208}Pb \rightarrow J/\Psi + N$

  Other EIC work:
  ePIC Far-backward DWG – Zachariou
  Also leading the design of the electron beam luminosity monitor pair spectrometer



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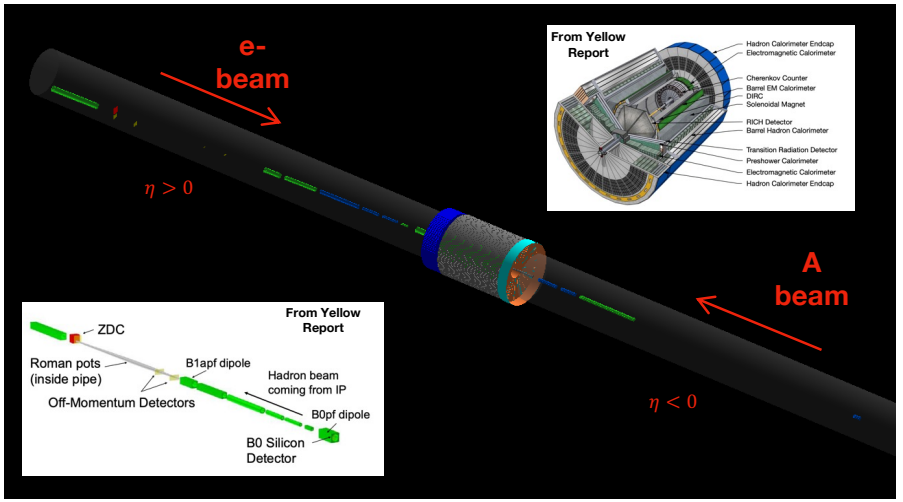
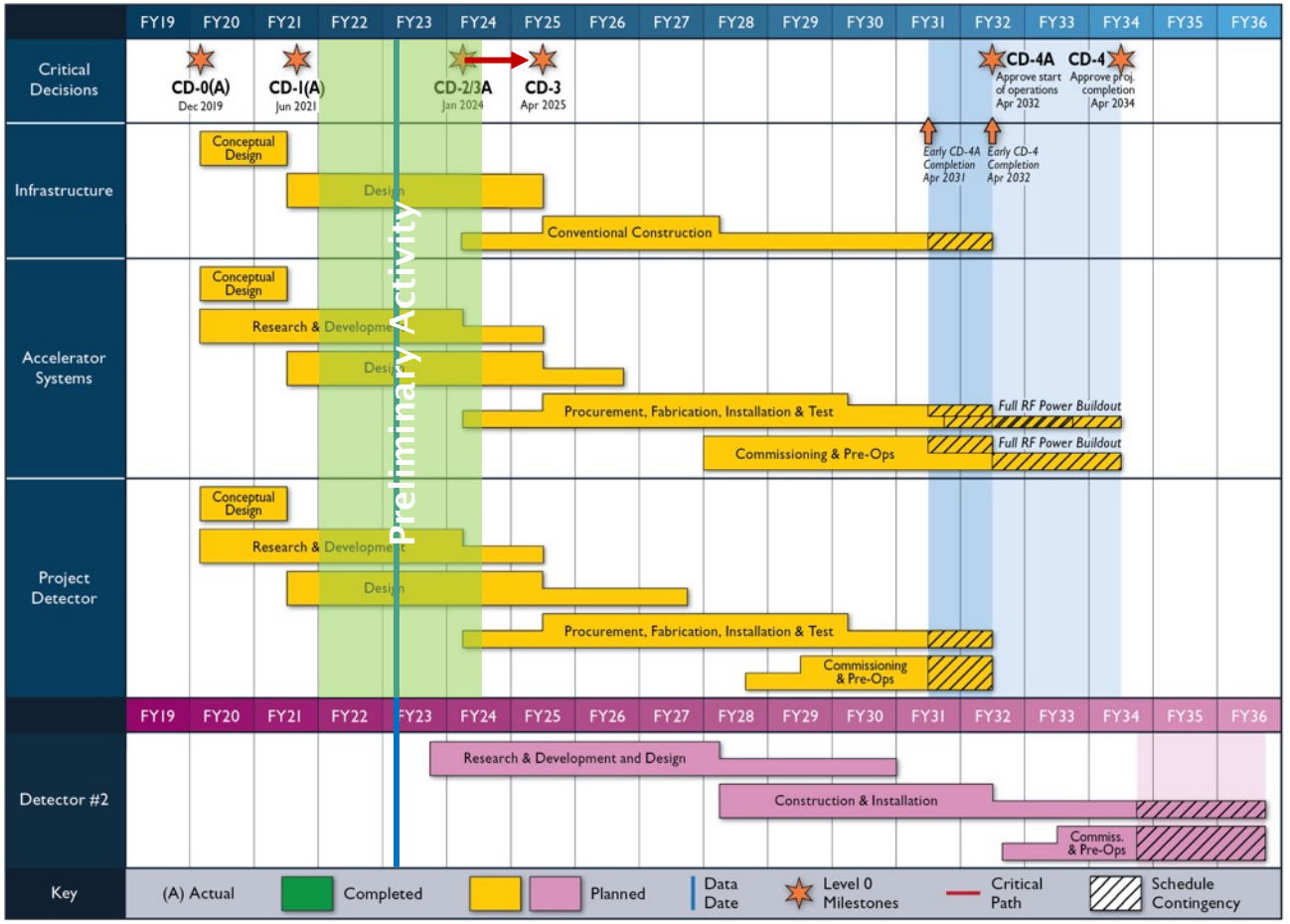


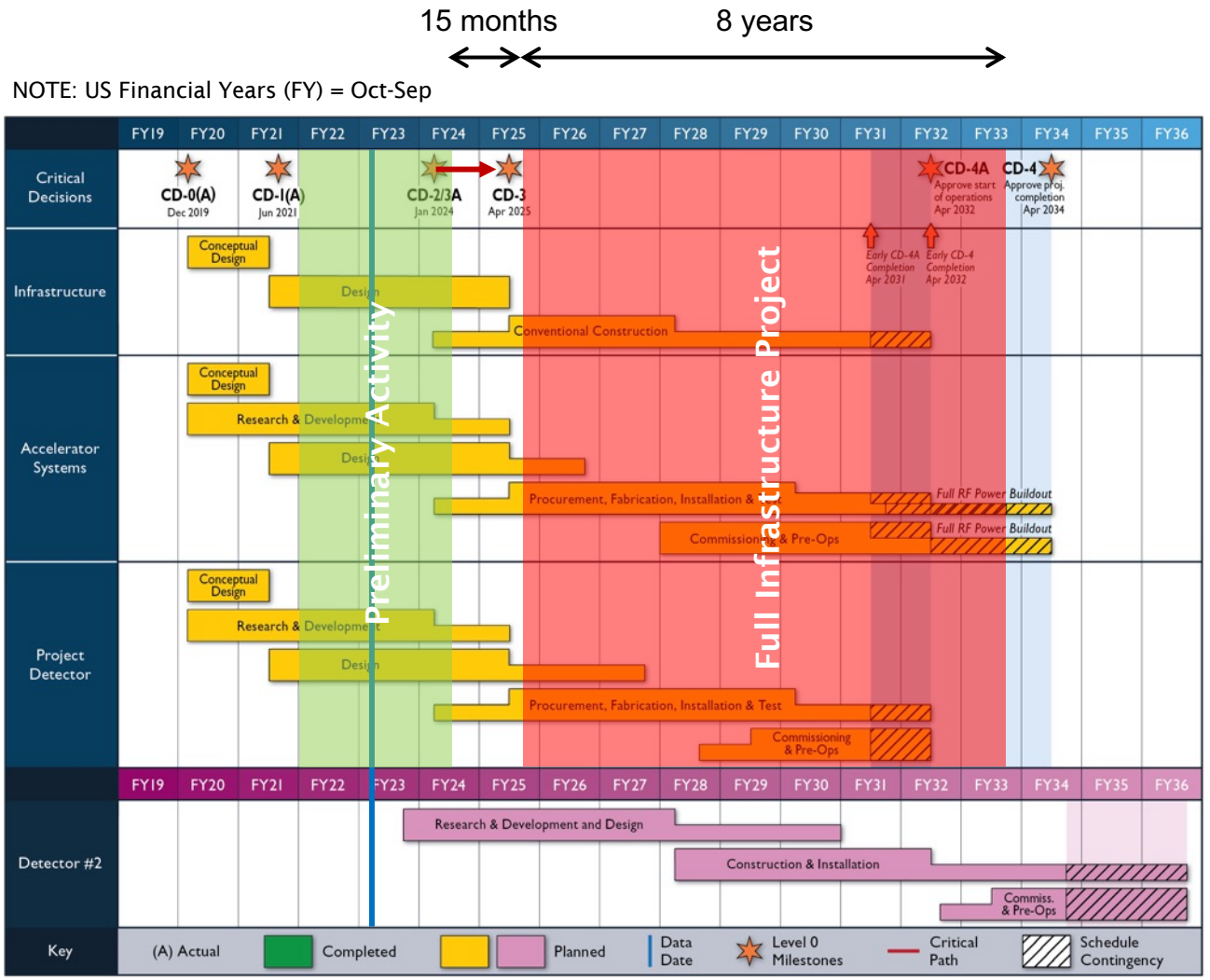
International Project Schedule and Full Infrastructure Project

NOTE: US Financial Years (FY) = Oct-Sep



UK-EIC Detector R&D Project

International Project Schedule and Full Infrastructure Project



UK-EIC Detector R&D Project

UK-EIC Detector Construction Project

Full Infrastructure Project Bid

- WP1 – MAPS: 65 nm (wafer-scale) stitched sensors; developed in partnership with ALICE-ITS3. Build ~33% of central tracker – two barrel layers. Technology already adopted in baseline detector.

  Institutes: Birmingham, Brunel, Lancaster, Liverpool, STFC RAL (PPD & TD), STFC DL, Oxford

- WP2 – Timepix: low-Q^2 tagger using pixel sensors in vacuum. Build two tracking stations in far backward region. Detector is baseline. Timepix4 is the preferred technology.

  Institutes: Glasgow, STFC DL

- WP3 – Polarimetry: current activity is exploring use of novel polarised scattering media using chemical hyperpolarization. Also, leading design of the baseline electron beam luminosity monitor. Contribution to luminosity monitor plus option to build a polarimeter when technology is proven.

  Institutes: York

- WP4 (NEW) – Accelerator options: SRF modules (possibly crab cavities); crab cavity LLRF synchronisation; EO-BPM instrumentation; ERL simulation and design.

  Institutes: CI (Lancaster, Liverpool, ASTeC), JAI (Oxford, Royal Holloway) and STFC DL (TD)

- Estimated total cost: £30m-£35m

Backup

US Project Overview

- Project costs

  The accelerator complex and *most* of one detector falls within the scope of the US DOE-funded project (originally $2.2B; now $2.4B)

  DOE Total Project Cost = $2,249m
  DOE Performance Measurement Baseline = $1,606m
  Contingency = $2,249 - $1,606m = $643m (40%)

- Accelerator partnerships ~5-10% in-kind

  Project cost = $1,406m; in-kind contribution = $70m – $140m (plus contingency)

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

  GPD estimated cost = $300m
  Project cost = $200m; in-kind contribution = $100m (plus contingency)
  2 x GPDs and 2nd IR = $400m-$500m in-kind contribution

- In-kind contributions

  Total in-kind contributions = $170m – $640m (plus contingency)
  For the baseline facility (1 GPD) = $350m (including contingency)
  UK Full Infrastructure Project = £35m ($42m) ≈ 12% contribution

UK Accelerator Capability

- Superconducting RF Systems

  Lancaster, Daresbury (TD) and ASTeC

  Experience from HL-LHC, ESS and PIP-II

HL-LHC cryomodule at Daresbury

- Low-level RF and Feedback

  Oxford and Lancaster

  Oxford has experience of beam-based feedback for colliders based on beam offsets post-IP

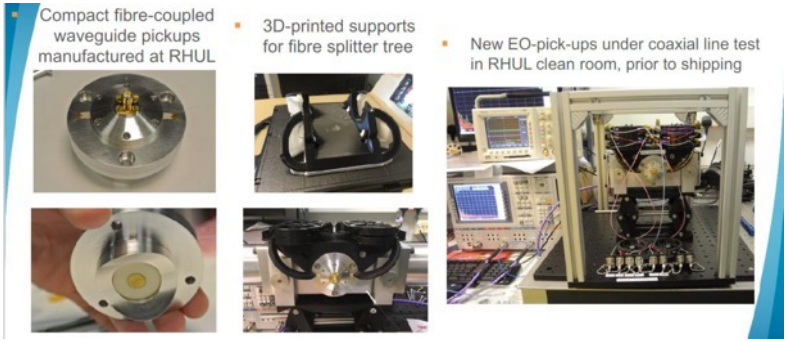
  Lancaster has experience of RF interferometers for RF synchronization in crab cavities

  EIC crabbing system will need both

- Electro-optic beam position monitors

  Royal Holloway

  Building on experience from HL-LHC, these unique devices are capable of measuring crabbing angle on proton or ion beams



- ERL modelling and design

  Lancaster and Liverpool

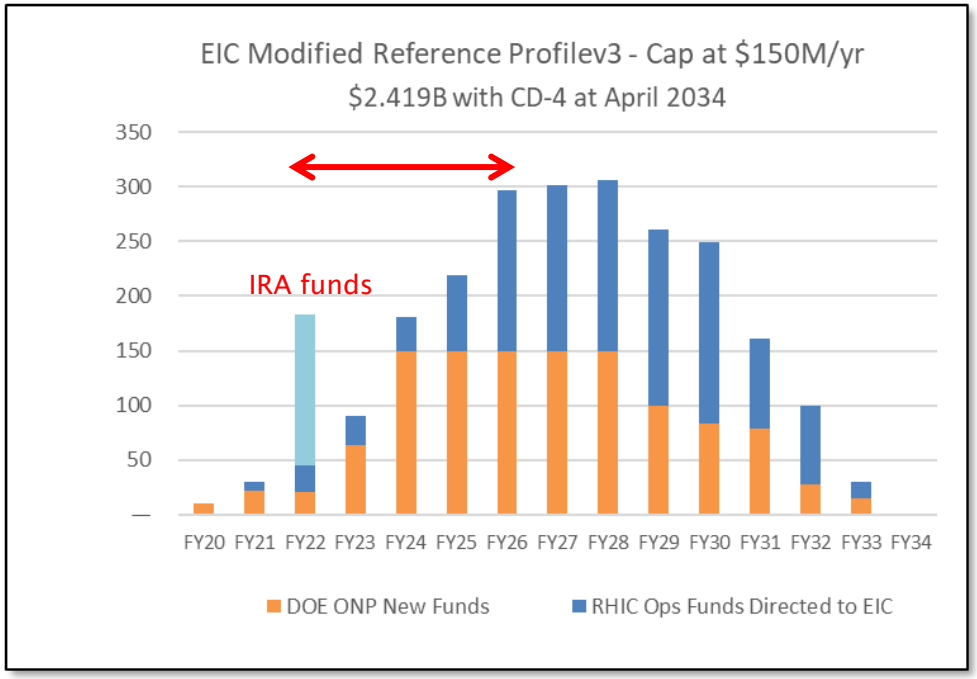
  Have been studying ERL filling pattern effect on RF and beam stability

  Only study of its type; most assume all bunches are identical

  We show the differences are critical

EIC Project News

- US Project Funding
  - Now on a firmer footing due to Inflation Reduction Act (IRA)
  - Settlement of $217m to DOE/NP, of which $138m awarded to EIC in FY23
  - IRA funds need to be spent by FY27; does not increase the Total Project Cost
  - Updated project schedule (next slide) – expect CD-2/3A review in October 2023
- EIC Funding Profile



Note: RHIC Operations stop in FY25, which coincides with CD-3: Approve Start Construction