Future hadron physics programme

Peter Jones

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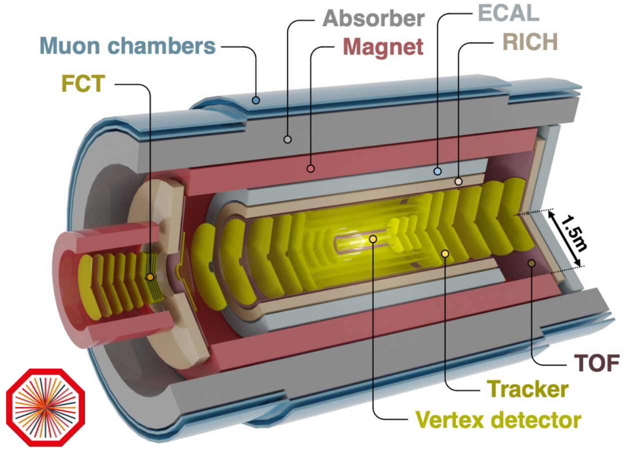
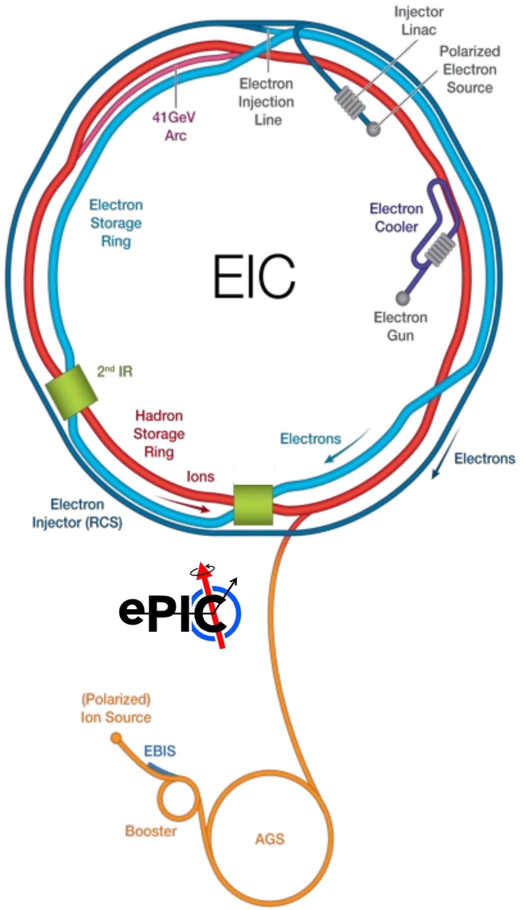
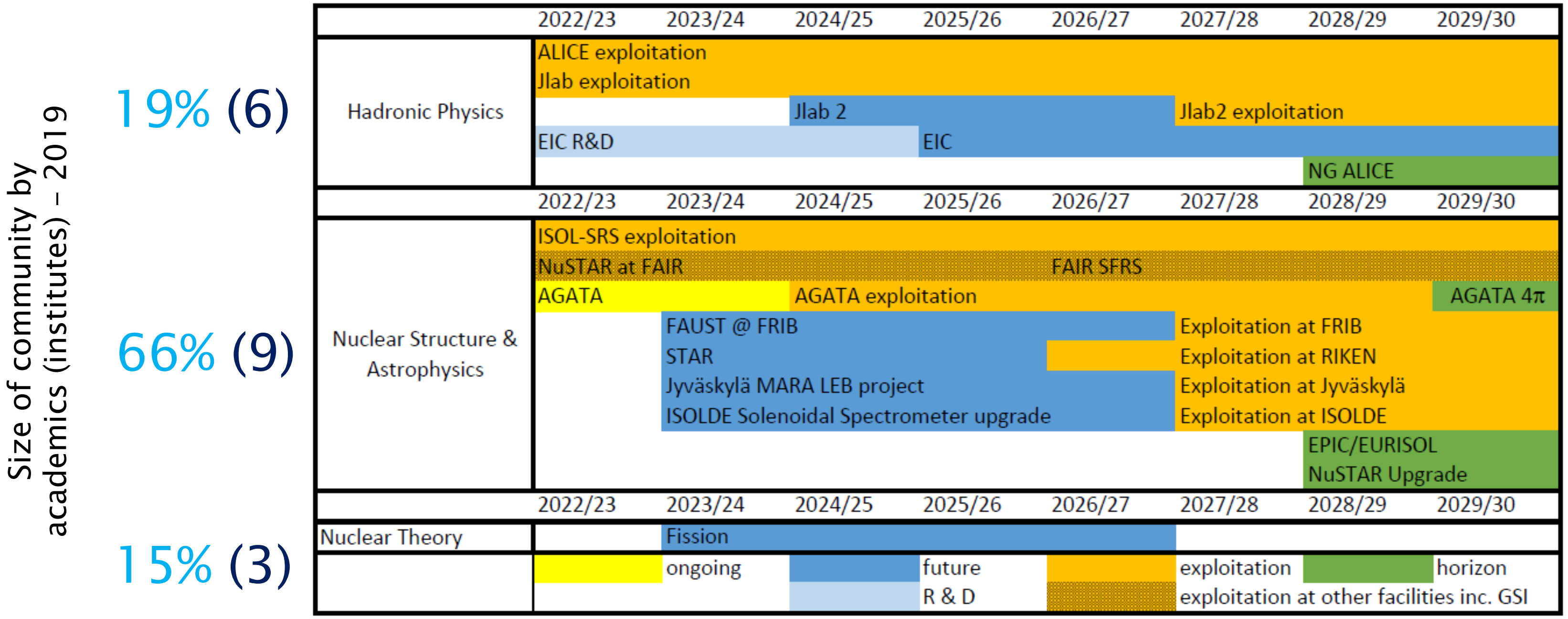




UNIVERSITY OF BIRMINGHAM | Brunel University London | UNIVERSITY OF DERBY | University of Glasgow | Lancaster University
UNIVERSITY OF LIVERPOOL | UNIVERSITY OF OXFORD | UNIVERSITY of York | UKRI Science and Technology Facilities Council
Daresbury Laboratory
Rutherford Appleton Laboratory

Nuclear Physics Roadmap

- Hadron Physics Theme



- Hot versus cold QCD: heavy-ions with ALICE at the LHC and electron-beam physics at Jlab.
- Smaller involvement in other projects e.g., AMBER/NA66 and ELSA at Bonn
- Focus of this talk will be future ALICE (ALICE-3) and the Electron-Ion Collider (EIC)

Hot QCD – ALICE

- Physics of the QCD Phase Transition

  A quark-gluon plasma (QGP) is created in heavy-ion collisions due to colour charge screening

  What are the properties of the QGP and how do they emerge from strong-interaction physics?

- Key Measurements

  Heavy quark propagation and hadronisation

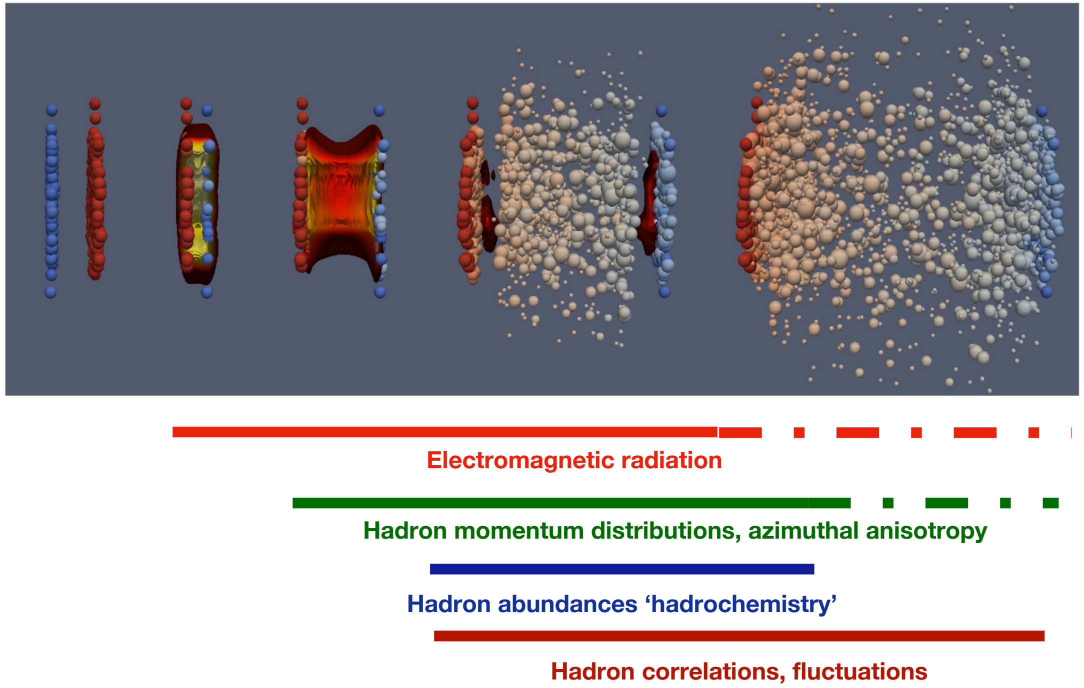
    Energy loss – correlations via tagged jets
    Multi-charm baryons
    Beauty production and flow

  Di-lepton production

    Temperature evolution of the QGP
    Chiral symmetry restoration

  Heavy-ion collisions as a QCD factory

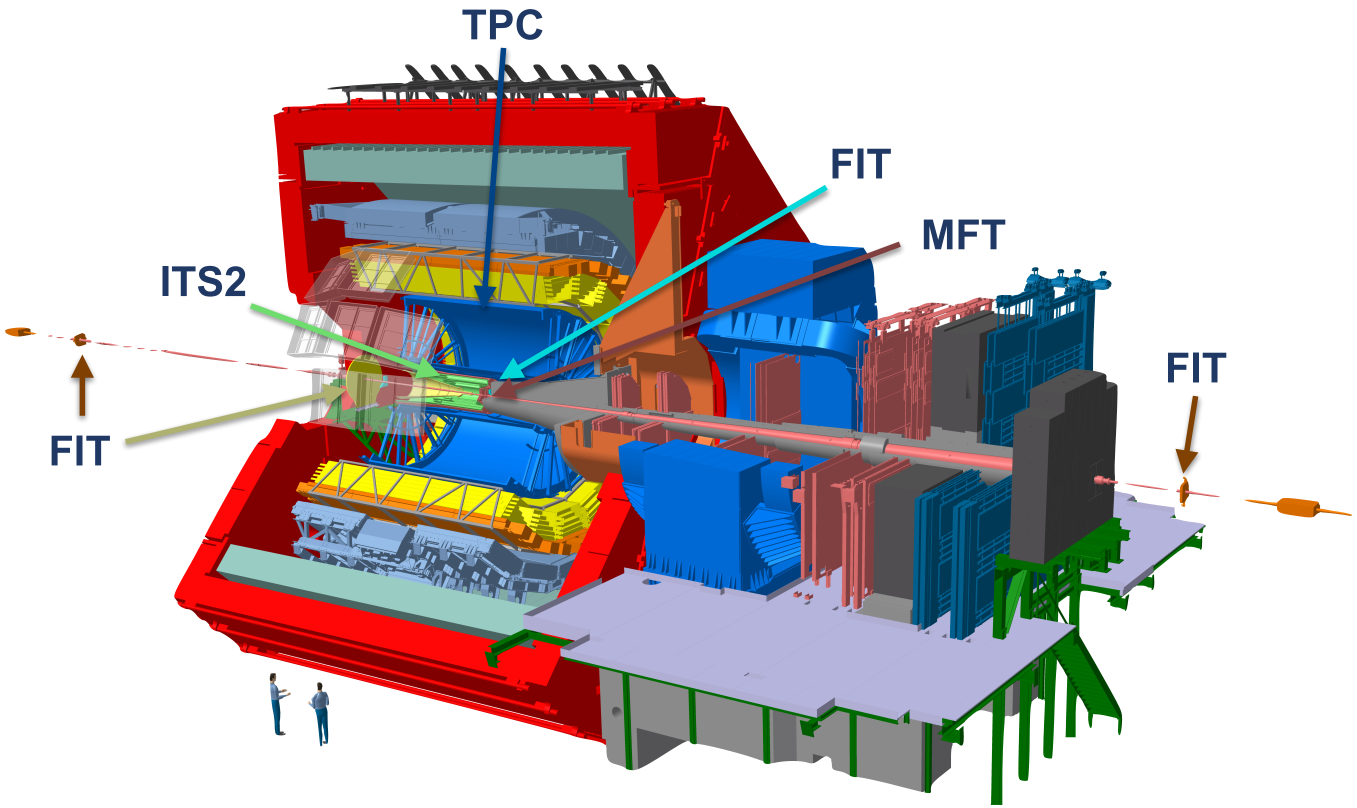
    Light anti-nuclei, Y-N potentials, etc.



Requires higher rate capability and improved detector performance

Current – ALICE-2

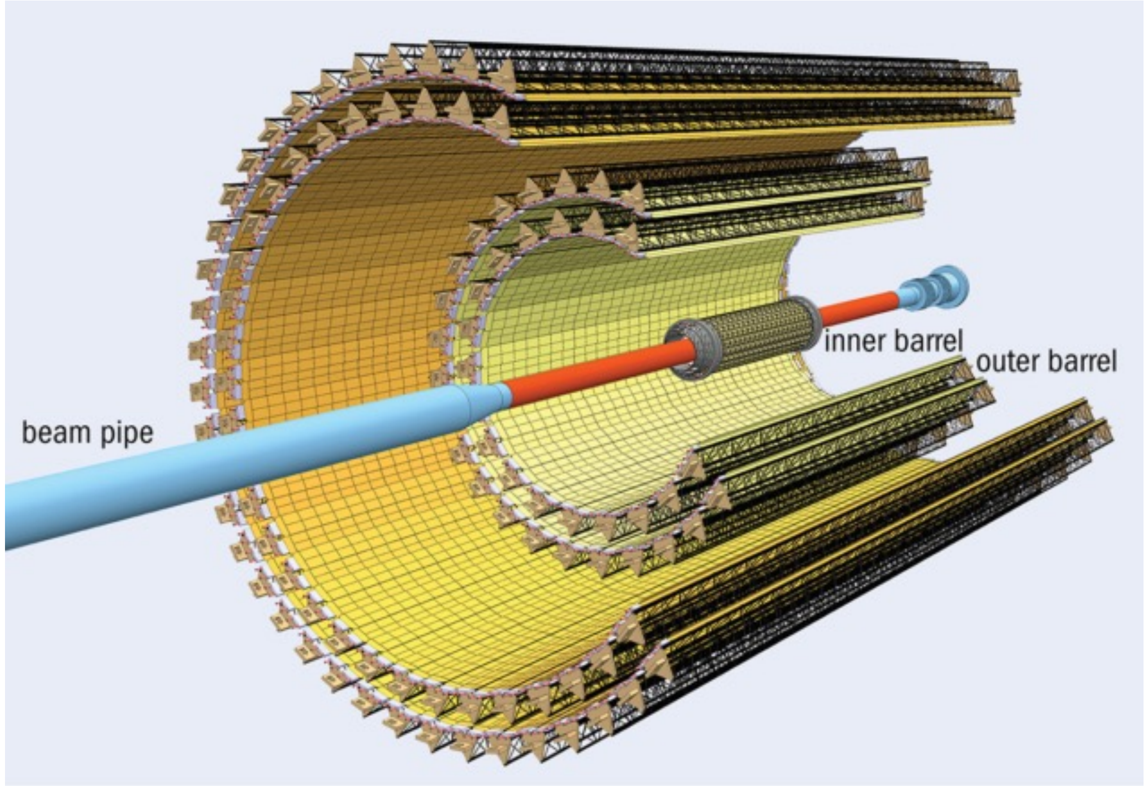
- Major upgrade during LS2
  - New Inner Tracking System (ITS2)
  - New Muon Forward Tracker (MFT)
  - New TPC Readout Chambers
  - New Fast Interaction Trigger (FIT) Detectors
  - Readout upgrade
  - Integrated Online-Offline system
- Motivation
  - High-precision rare probes at low p_T
  - Readout all Pb-Pb collisions (50 kHz)
  - Improved vertex reconstruction and tracking
- UK Institutes
  - Birmingham, Derby, Liverpool, Daresbury



UK leadership in the trigger and
track record in Si detector design & construction

Current – ALICE-2

- ITS2 Layout
  - Monolithic Active Pixel Sensors (MAPS)
  - 180 nm CMOS imaging process (TPSCo)
  - 7 layers: 3 inner, 2 middle, 2 outer
  - 10 m^2 active silicon
  - Total of 192 staves: 48 + 54 + 90
  - Material: 0.35% X_0 (IL) and 1.1% X_0 (ML/OL)
- Construction
  - 10+ institutes worldwide
  - Outer barrel module production at Liverpool
    - 650 modules
  - Outer layer stave production at Daresbury
    - 22 staves



Medium-term – ALICE-2

- Replace inner 3 tracker layers with ‘ITS3’

  65 nm CMOS (TPSCo) – larger wafer

  Wafer-scale stitched sensors

  Thin, flexible sensor bent round beampipe

  Modified beampipe (smaller radius; thinner)

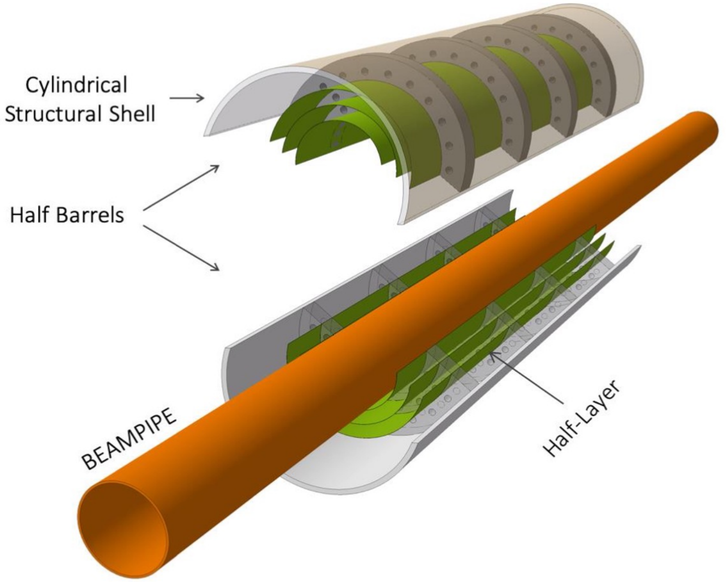
- Key benefits

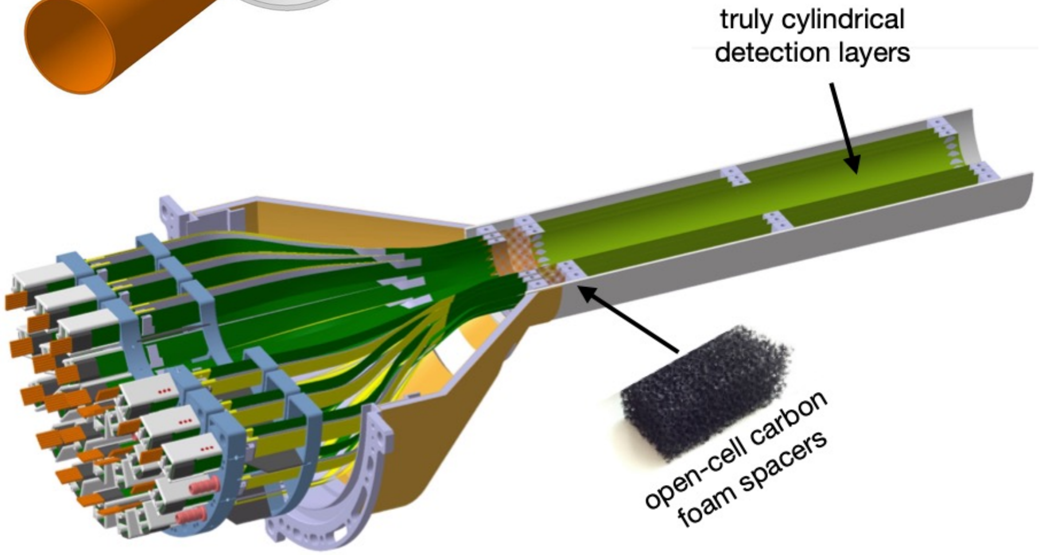
  Low material budget 0.07% X_0 per layer

  Homogenous material distribution: negligible systematic error from this source

  Improved (x2) pointing resolution

- In place for 2029-32 (Run 4)





UK involvement in sensor design, prototyping, simulation, test beam

Future ALICE – ALICE-3 (2035+)

- Novel and innovative detector concept

  Compact and lightweight all-silicon tracker

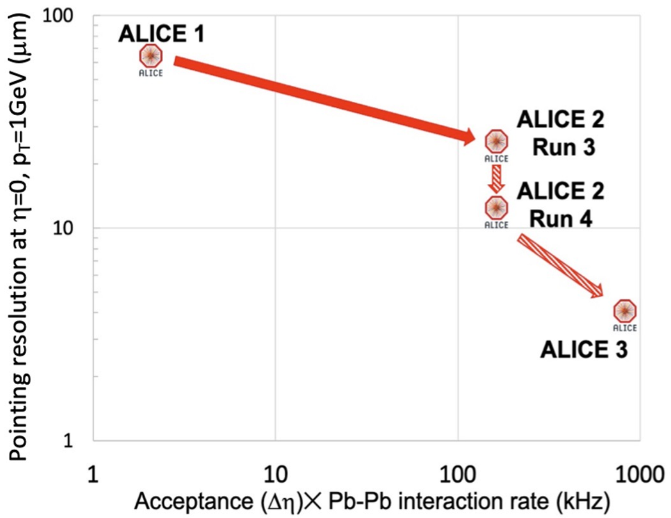
  Retractable vertex detector

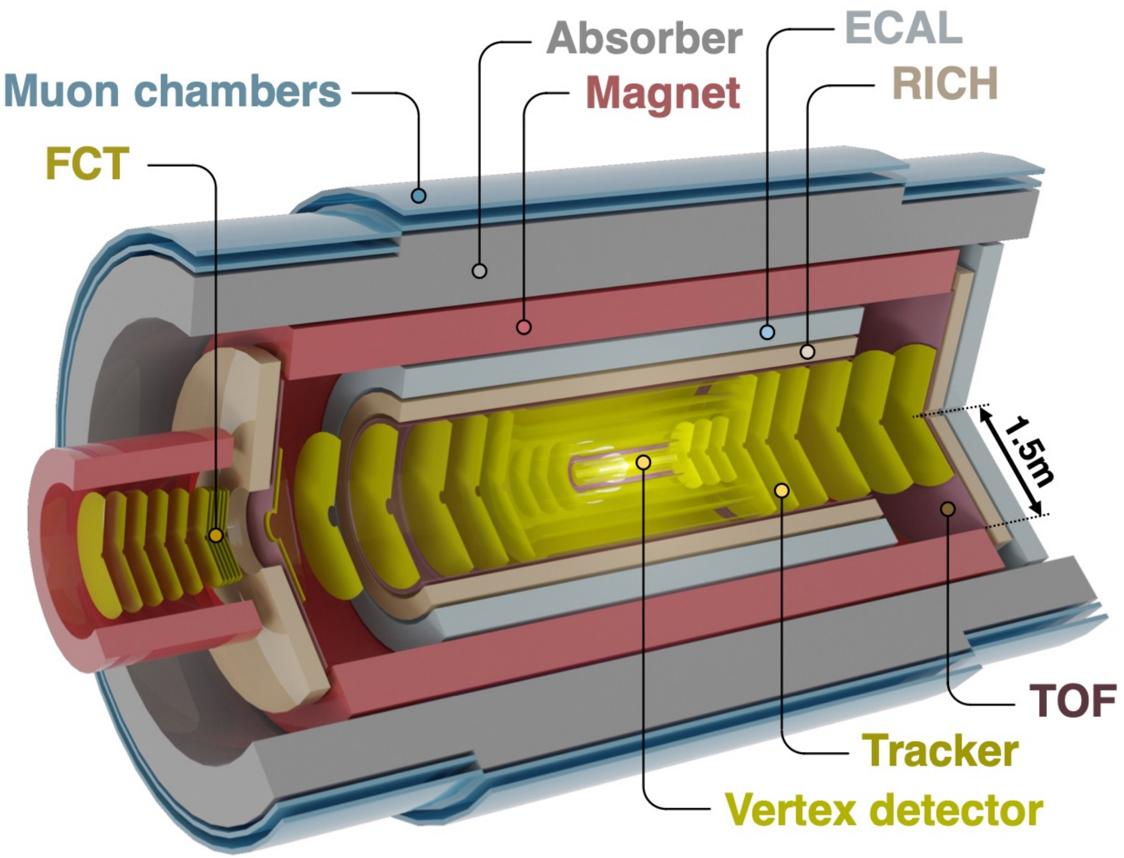
  Extensive particle identification capability

  Larger pseudorapidity acceptance

  Superconducting magnet system

  Continuous readout and online processing





Proposed UK involvement in **outer tracker** and **triggering**

Cold QCD – Electron-Ion Collider

- Facility Overview

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

  World's first collider of polarised electrons with heavy-ions

- 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?

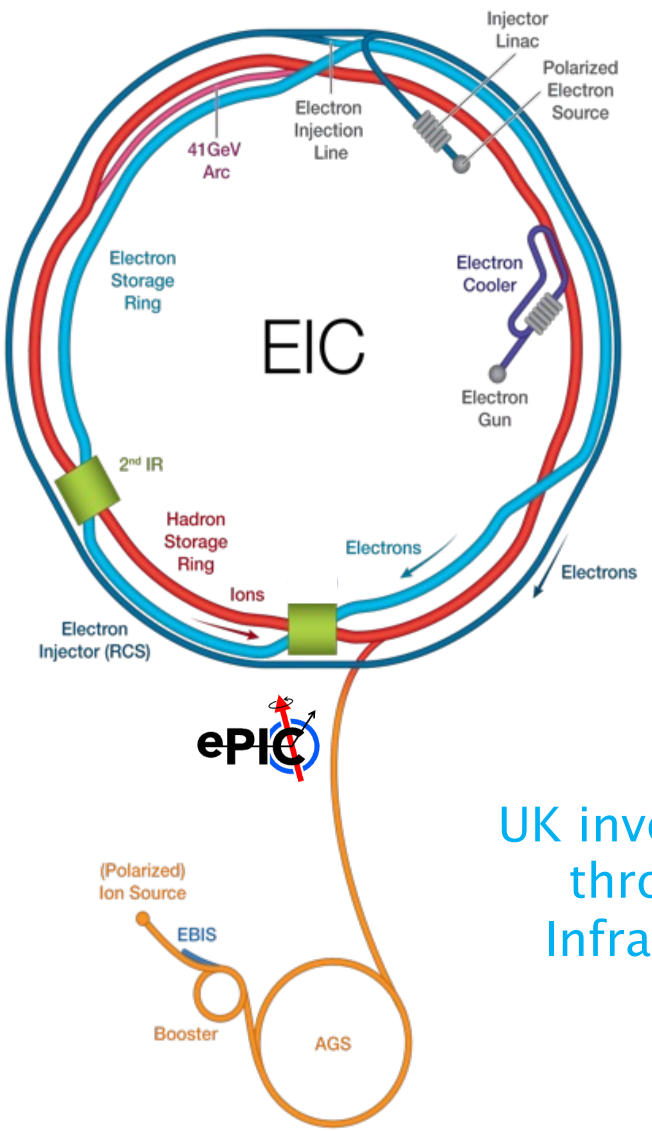
- US Project Overview

  Total Project Cost = $2.4B incl. contingency

  Currently in R&D and design phase

  Expect construction approval in 2025

  Expect start of operations in 2034



UK involvement funded through the UKRI Infrastructure Fund

EIC Design Goals

- Facility

  High luminosity: 10^{33}–10^{34} $cm^{-2}s^{-1}$

  Integrated luminosity: 10–100 fb^{-1}/year

  Highly polarised beams (e/p/light ions): 70%

  Wide range of CMS energies: 20–140 GeV

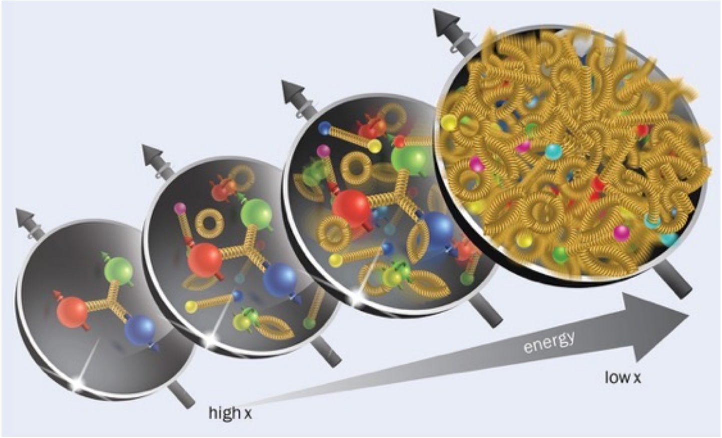
  Wide range of ion species: p–U

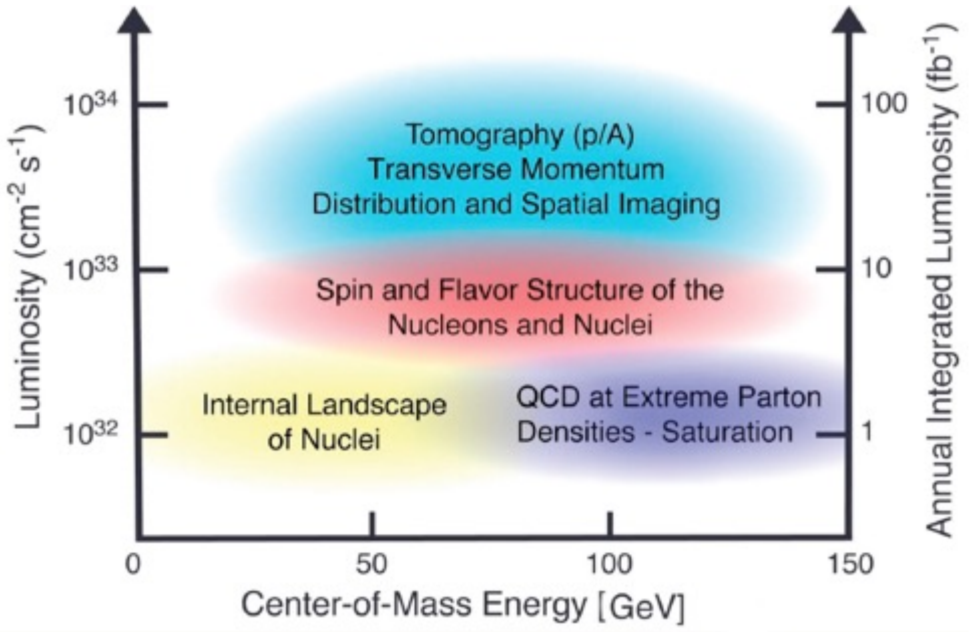
- Science

  The EIC will provide unprecedented access to the internal structure of protons and nuclei

  A highlight will be the spatial and momentum imaging of quarks and gluons

  Providing new insight into the spin structure of the proton and the origins of hadronic mass





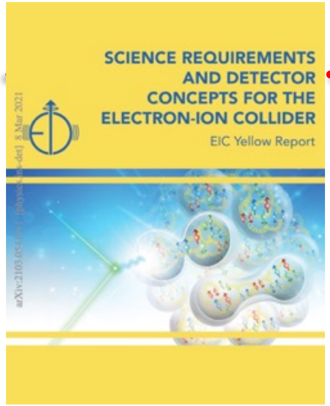
Mass of the nucleon

Spin of the nucleon

Gluons in nuclei

EIC Detector Requirements

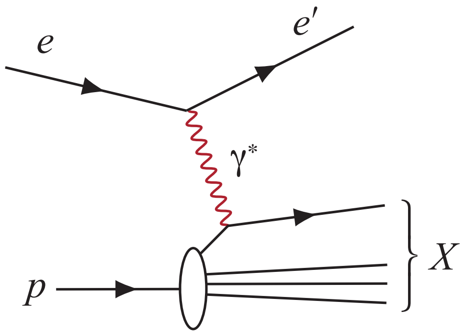
2021



EIC Yellow Report

- Deep Inelastic Scattering (DIS)

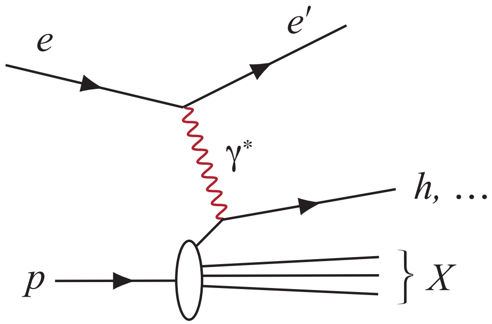
Inclusive DIS



Parton distributions in nucleons and nuclei

- High performance electron identification and reconstruction

Semi-inclusive DIS



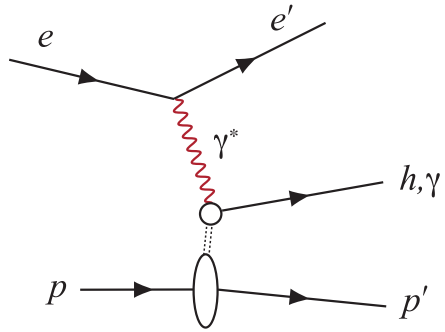
Tomography
Transverse Momentum Distributions

Spin and flavour structure of nucleons and nuclei

+

- Precision tracking and vertexing
- Hadronic calorimetry
- Hadronic particle identification

Exclusive DIS



Tomography
Spatial Imaging

QCD at extreme parton densities – Saturation

+

- Recoil proton tagging
- Electromagnetic calorimetry
- Maximum acceptance coverage

EIC Project Detector

Compact central detector
Asymmetric design
Solenoidal field (B = 1.7 T)
Magnet bore 2.84 m
Streaming readout

Hadronic Calorimeters (HCAL)

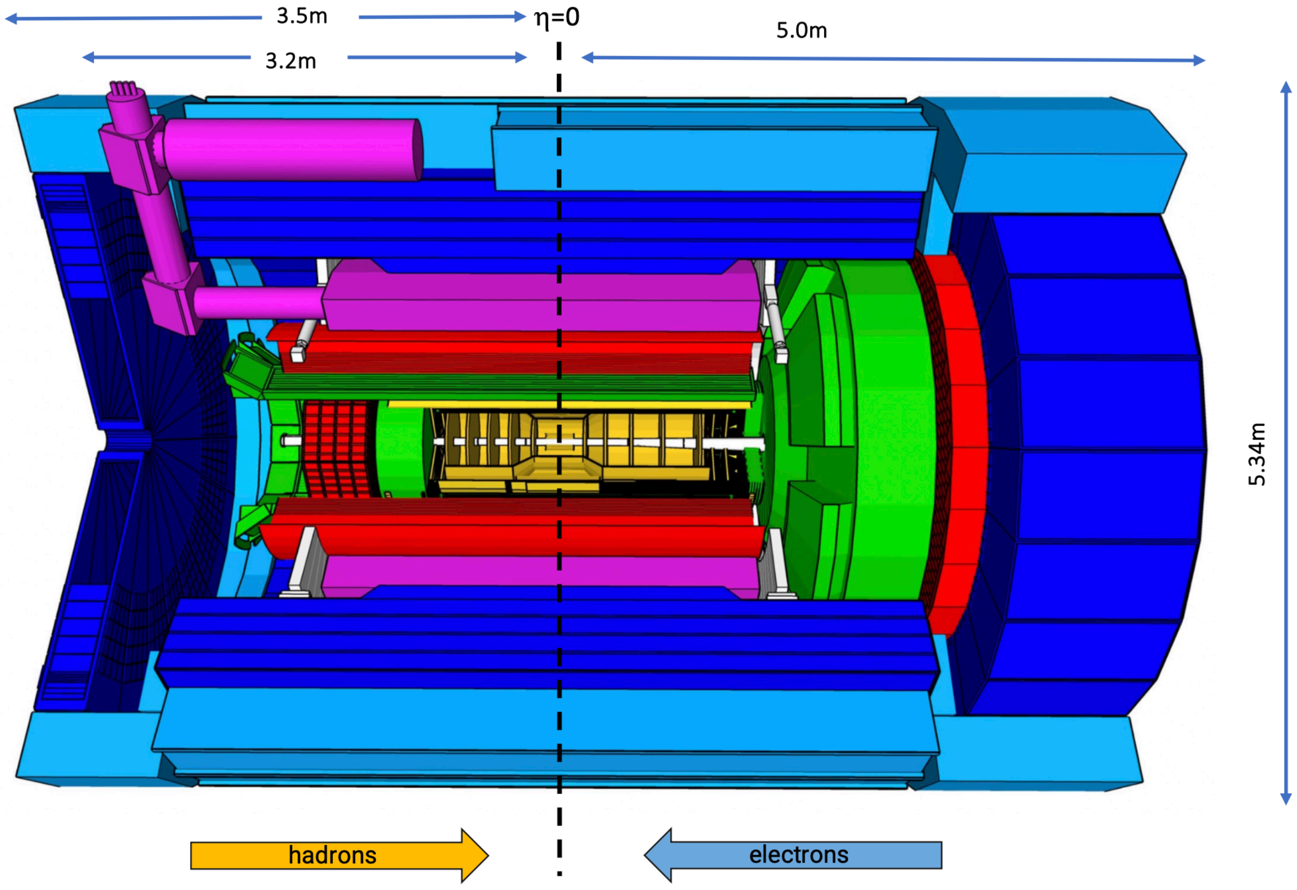
Solenoidal Magnet

E/M Calorimeters (ECal)

Time.of.Flight (ToF), DIRC, RICH detectors

MPGD trackers

MAPS tracker

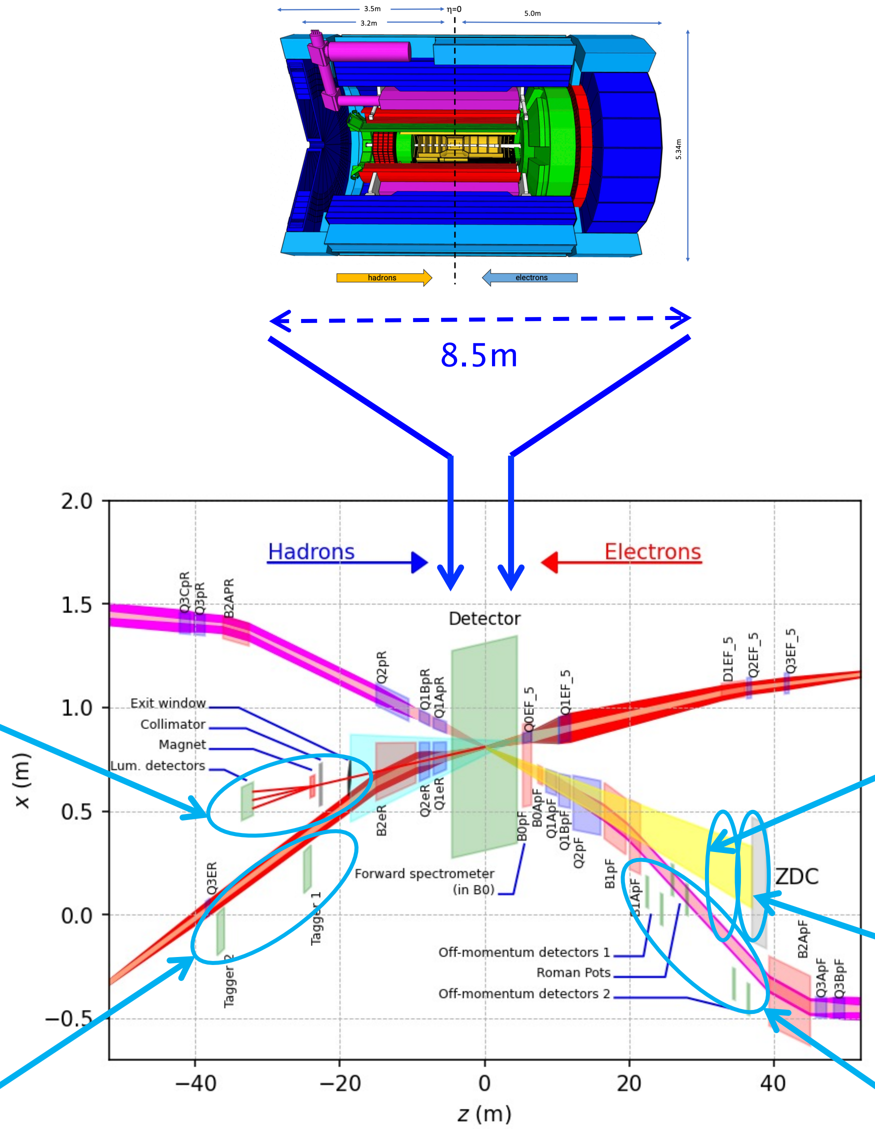


Beam energy [GeV]	5 x 41	5 x 100	10 x 100	10 x 275	18 x 275
L [$10^{33}cm^{-2}s^{-1}$]	0.44	3.68	4.48	10	1.54
DIS ep rate [kHz]	12.5	129	184	500	83

EIC Conceptual Design Report, Table 3.3

EIC Project Detector

Beamline instrumentation is essential to deliver the EIC science programme



In addition, there will be a UK contribution to the accelerator: cavity design and cryomodule fabrication for the Energy Recovery Linac that is part of the hadron beam cooler

Luminosity Monitor

Electron Tagger

Recoil Neutron Polarimeter*
(*potential future upgrade)

Zero Degree Calorimeter

Off-momentum Detectors

Silicon Vertex Tracker

- Based on ALICE-ITS3 sensor

  Proposed ALICE-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

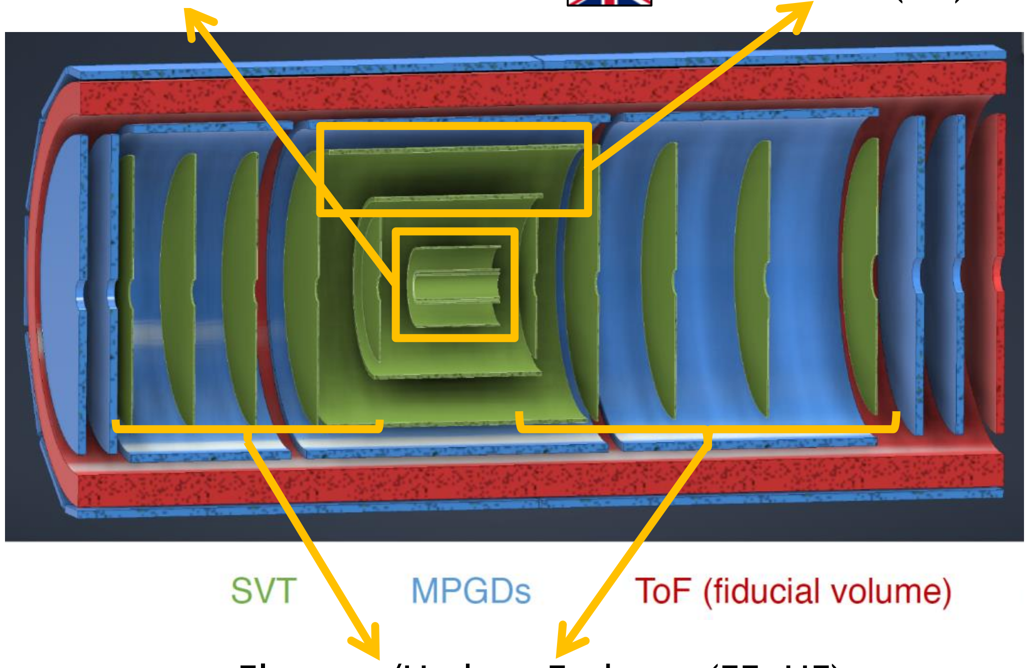
  EIC-specific development needed for the outer barrel layers and endcaps (disks):

  - Large area sensors (but not wafer scale), plus "conventional" low-mass support structures

  8 m^2 active silicon area (OB = 37%)

- UK institutes

  Birmingham, Brunel, Liverpool, Oxford, Daresbury, RAL



ePIC SVT target specifications	
Spatial resolution	~ 5 μm
Power	< 40 mW/cm^2
Frame rate	≤ 2 μs
Material budget (per layer)	IB: 0.05% X/X_0 OB: 0.25, 0.55% X/X_0 EE/HE: 0.25% X/X_0

Hadron Physics – Projects Timeline

- Future Programme

EIC has been awarded a UKRI Full Infrastructure Project grant (£58.8m)

This is a joint nuclear physics and particle physics project

EIC exploitation will be a major focus from 2034+

ALICE-3 is at the pre-approval stage; gathering funding agency commitments

ALICE exploitation remains a high priority; potential hardware contribution to ALICE-3

Tentative schedule from ALICE 3 LoI

ALICE 3	R&D + Design	Construction & Pre-commissioning	Contingency	Installation & Commissioning	Ops

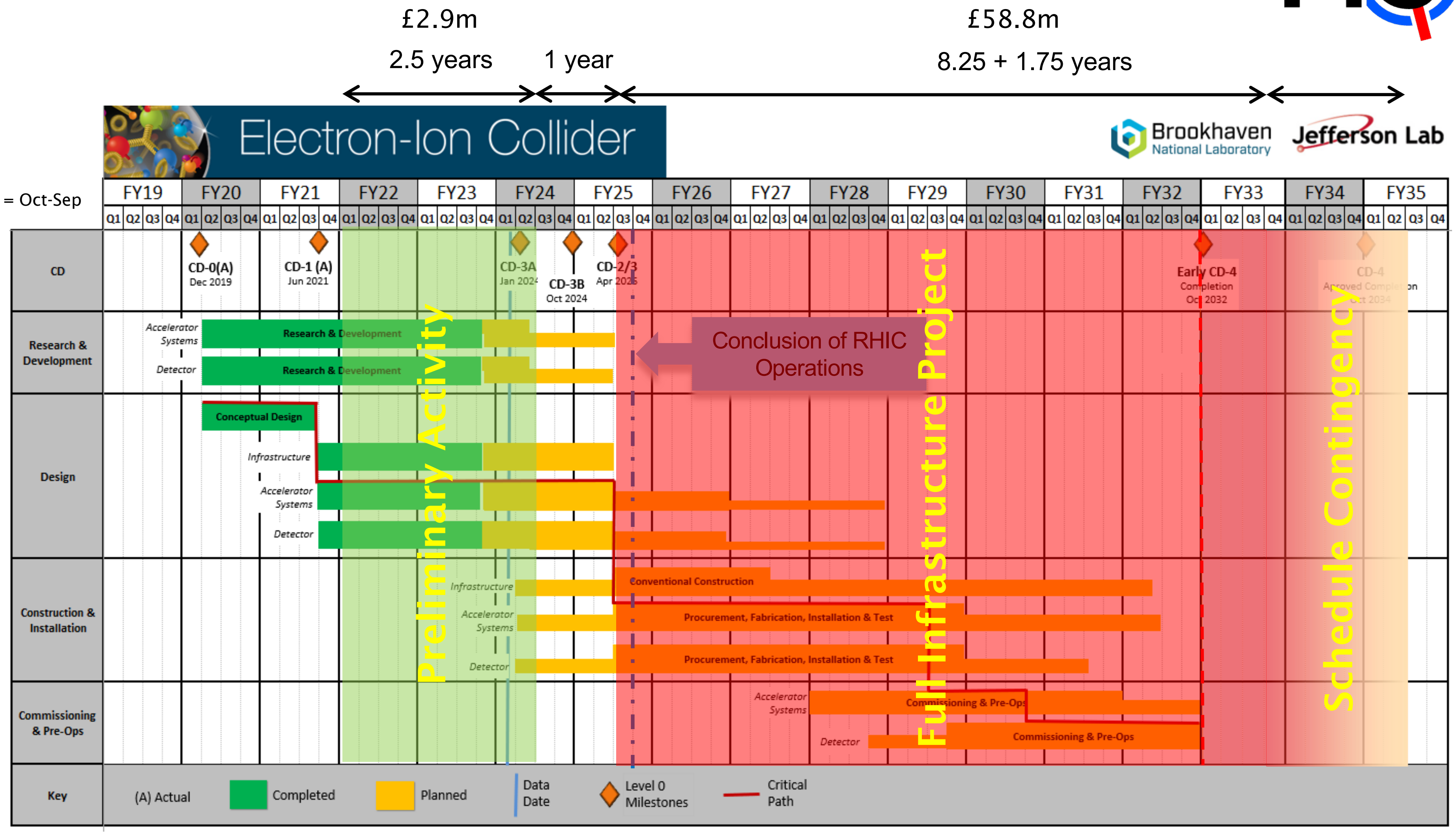
LHC Schedule	Run 3	LS3	Run 4	LS4	Run 5

Year	2025				2026				2027				2028				2029				2030				2031				2032				2033				2034				2035			
Q		2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
nQ		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
CD milestone		2/3																														4e								4				

UK EIC Project	R&D + Design ↔	Construction ↔	Installation & Commissioning ↔	Contingency

Transition to operations

Backup – EIC Project – Schedule



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–4 Approve Project Completion

Upcoming Project Milestones

CD-2/3 review – Q4 2024
CD-4 (EF) – Q4 2032
CD-4 – Q4 2034

UK-EIC Detector R&D Project
UK-EIC Detector Construction Project

Backup – EIC Full Infrastructure Project – Deliverables

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

  65 nm stitched monolithic active pixel sensors; developed in partnership with CERN/ALICE

  Deliverable: Build the two outer barrel layers of the central silicon tracker (~37%)

  Institutes: Birmingham, Brunel, Liverpool, Oxford, STFC RAL, STFC DL
- WP2 – Electron Tagger: Precision tracking of low-Q^2 scattered electrons

  Low-Q^2 tagger using Timepix pixel sensors

  Deliverables: Build the two tracking stations needed in the far backward region

  Institutes: Glasgow, STFC DL and Lancaster
- WP3 – Luminosity Monitor: Precision 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

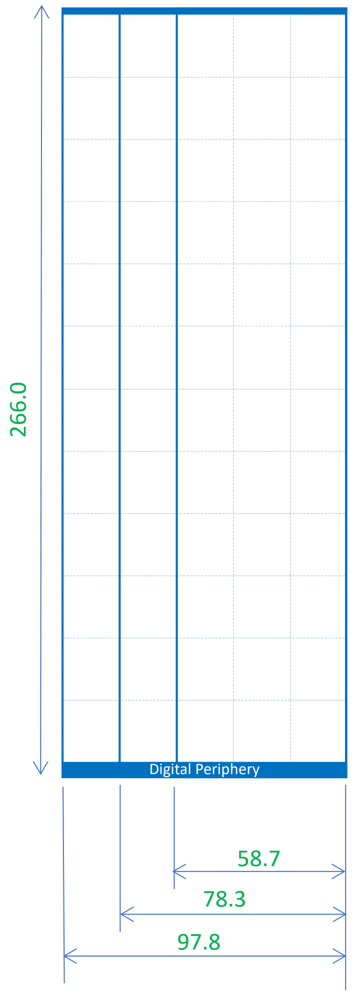
  Institutes: York
- WP4 – Accelerator: ERL cavity design and cryomodule fabrication

  Cavity design and cryomodules fabrication for the Energy Recovery Linac (ERL) hadron beam cooler

  Deliverables: Build two cryomodules for the ERL cooler

  Institutes: Lancaster and STFC DL

Backup – Silicon Vertex Tracker – Inner Barrel Layers

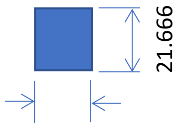


ePIC - SVT
Use same 3 sensor formats
for the inner barrel layers:

L0 sensor = 3 x 12 RSUs
L1 sensor = 4 x 12 RSUs
L2 sensor = 5 x 12 RSUs
L0 & L1 = 4 sensors
L2 = 8 sensors

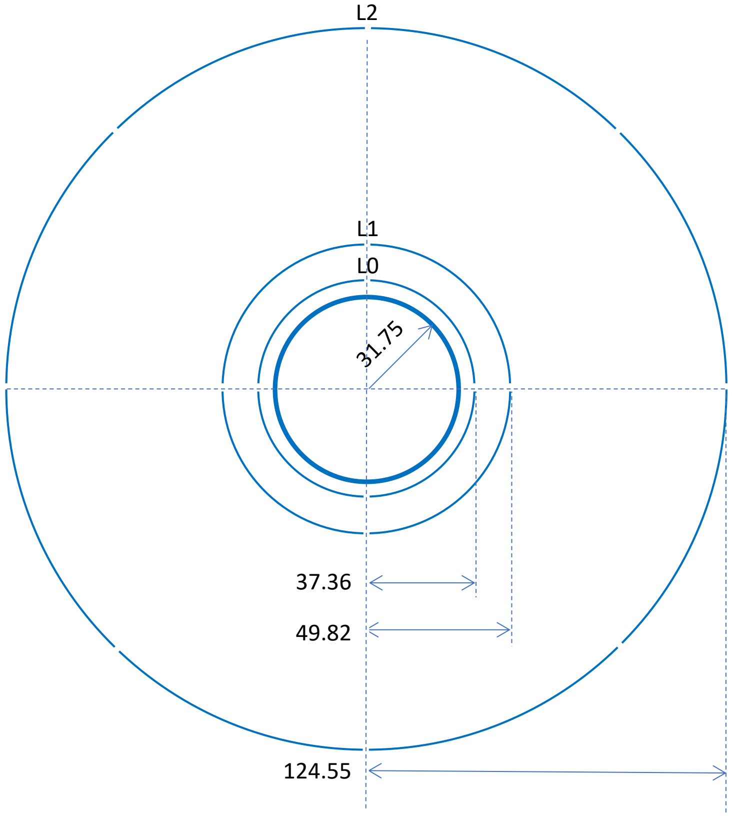
L0 = 4 x 58.692; R = 37.36
L1 = 4 x 78.256; R = 49.82
L2 = 8 X 97.820; R = 124.55

RSU



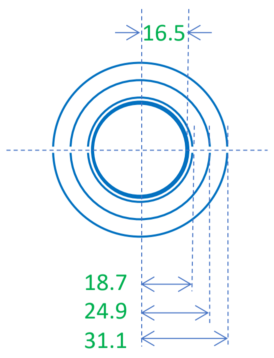
ePIC – SVT

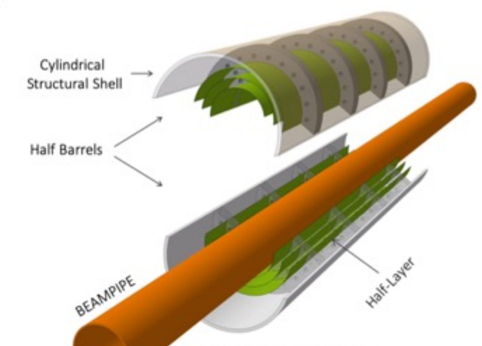
Dimensions are mm



ALICE – ITS3

Dimensions are mm

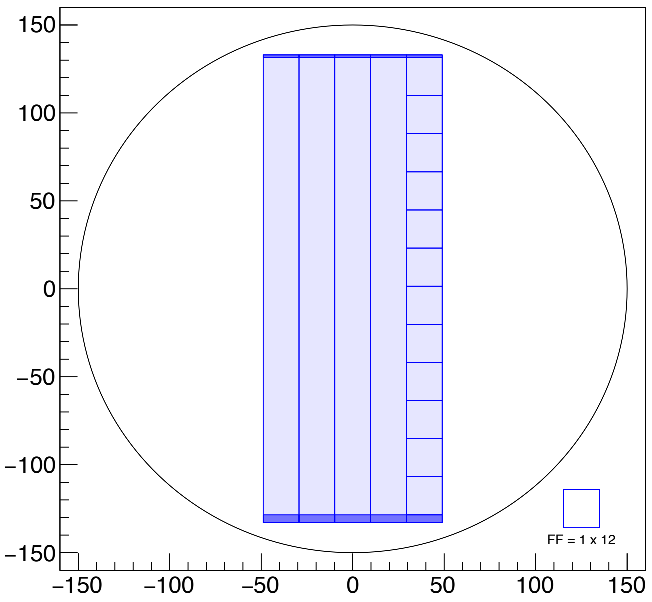




ALICE-PUBLIC-2018-013
https://cds.cern.ch/record/2644611

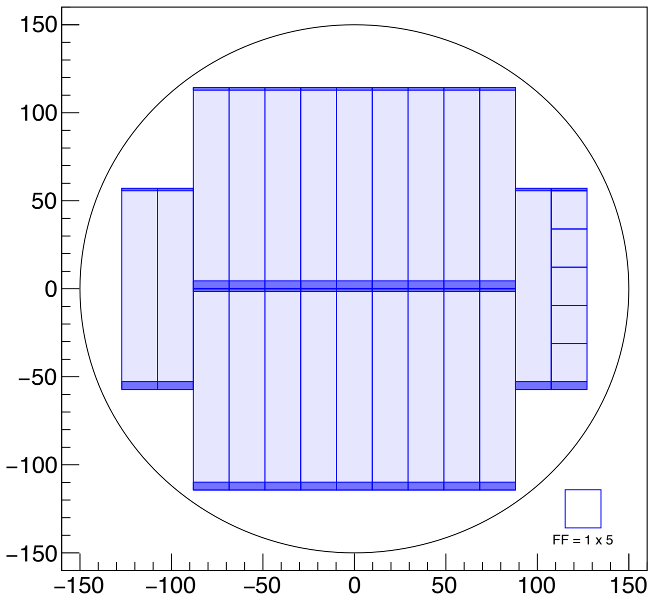
Backup – Silicon Vertex Tracker – Outer Barrel Layers

ITS3 – Wafer Scale Sensor



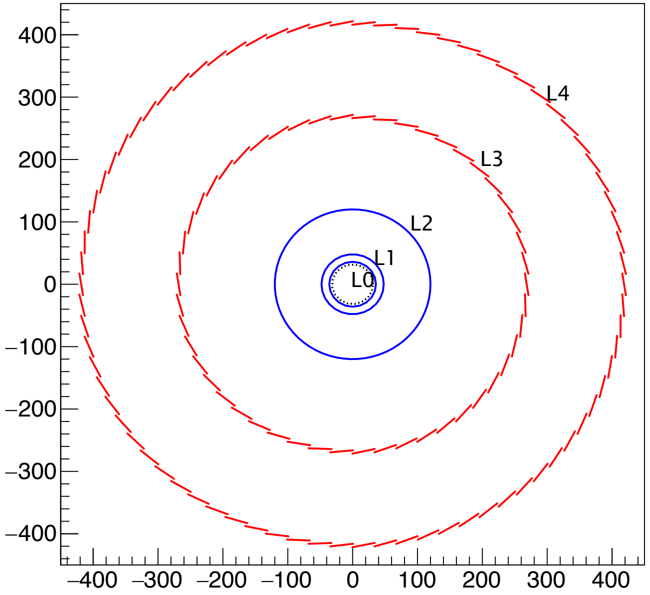
Total 60 RSUs

EIC – Large Area Sensor



Total 110 RSUs

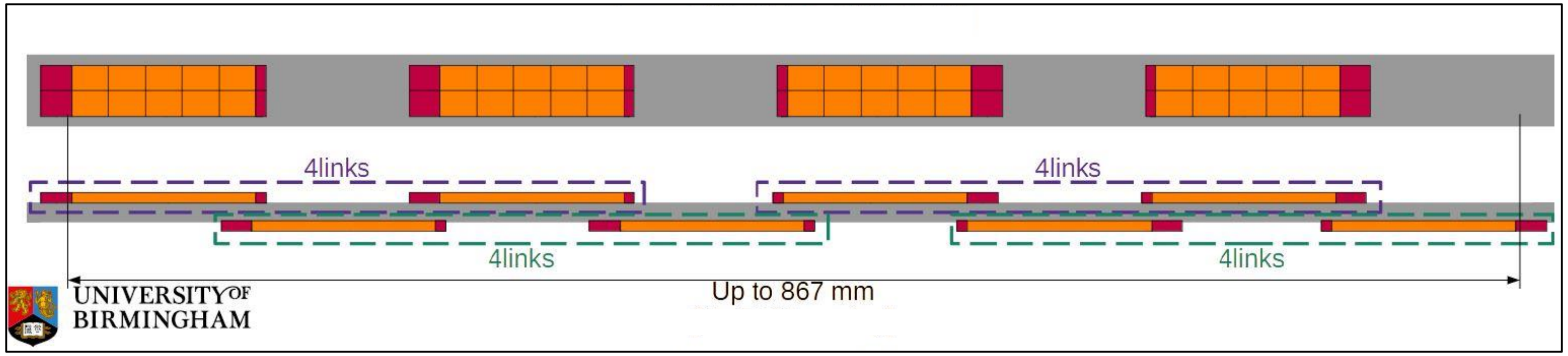
Outer Barrel Stave Layout



Stave Conceptual Design

PWR in

Data out



PWR in

Data out

ePIC Collaboration – International Leadership

Working Groups

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S. Dalla Torre (INFN), Deputy Spokesperson

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PID
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Thomas Ulrich (BNL)

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Nathaly Santiesteban (UNH)

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Thomas Britton (JLab)

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Dmitry Kalinkin (Kentucky)

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Chao Peng (ANL)

RECONSTRUCTION
Shujie Li (LBNL)
Derek Anderson (ISU)

ANALYSIS TOOLS
Kong Tu (BNL)
TBD

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Claire Gwenlan (Oxford)

EXCLUSIVE, FRACTION AND TAGGING
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Rachel Montgomery (Glasgow)

SEMI-INCLUSIVE PHYSICS
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BSM AND PRECISION EW
Ciprian Gal (JLab)
Michael Nycz (Virginia)

Paul Newman (Birmingham) – EXECUTIVE BOARD
Nick Zachariou (York) – CONFERENCES AND TALKS COMMITTEE

Detector Subsystem Collaborations

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hpDIRC
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DSTC (B0): Zvi Citron (Ben-Gurion)
DSTC (Roman Pots/OMD): Alex Jentsch (BNL)
DSTC (ZDC): Yuji Goto (RIKEN)

LUMINOSITY
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Co-DSL: Krzysztof Piotrzkowski (AGH Krakow)
DSTC (Pair Spectr.): Dhevan Gangadharan (Houston)

FAR BACKWARD HIGH RATE TRACKER
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DSTC: Simon Gardner (Glasgow)

Si TRACKERS
DSL: Ernst Sichtermann (LBL)
DSTC: Laura Gonella (Birmingham)

BACKWARDS ECAL
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DSTC: Carlos Munhoz (IJCLab)

BACKWARDS HCAL
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BARREL HCAL
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Co-DSL: Megan Connors (GSU)

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Co-DSL: Huan Huang (UCLA)

FORWARD HCAL
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Deputy DSL/DSTC: Miguel Arratia (UCR)

AC-LGAD TOF
DSL: Zhenyu Ye (LBL)
Deputy DSL: Satoshi Yano (Hiroshima)

GASEOUS TRACKERS
DSL: Kondo Gnanvo (LBL)
DSTC: Maxence Vendenbroucke (Saclay)

Backup – ALICE-3 – Tracker

- 60 m² silicon pixel detector (MAPS)

  Larger coverage: |η| < 8 units

  Compact: r_{outer} = 80 cm, z = ±3.5 m

  High-spatial resolution ~ 10 μm

  Low material density, material budget

- R&D

  Concept of module ~10x10 cm² production which can be standardized for industry

  Reduce/eliminate interdependence between modules (to allow replacement)

- Status

  Currently at pre-approval stage, gathering funding agency commitments etc.