EIC - UK Accelerator WP

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Projects & Mechanical Engineering Group
STFC Daresbury Laboratory

EIC UK Gathering
University of Birmingham
19th Nov24

Electron-Ion Collider

Accelerator Work Package Plans

Who?

Where?

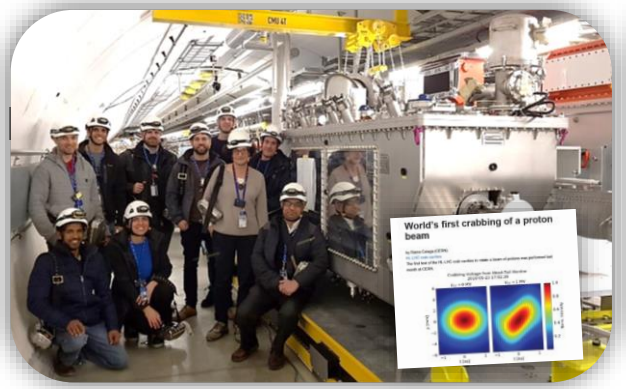
Why?

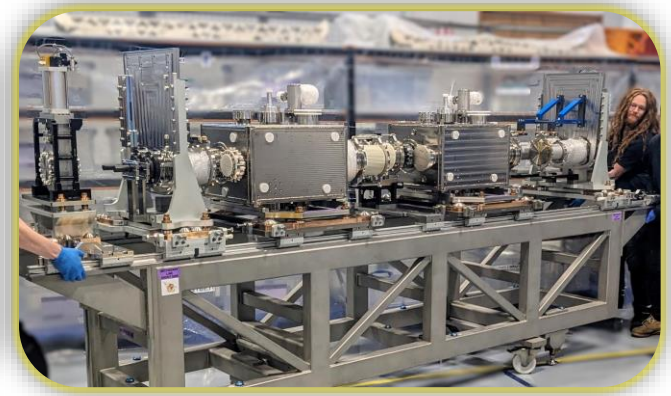
What?

TBD…

About Me

- Project & Mechanical Engineer
- WP-Lead UK Crab Cavity Cryomodules for Hi Lumi
- →WP-Lead EIC – UK Accelerators





2012 — 2025

Mechanical Engineering (MEng)

UNIVERSITY OF LIVERPOOL

Joined STFC

Science & Technology Facilities Council

Placement DESY Zeuthen

DESY.

Placement CERN

CERN

APM PMQ

apm PROJECT MANAGEMENT QUALIFICATION PMQ

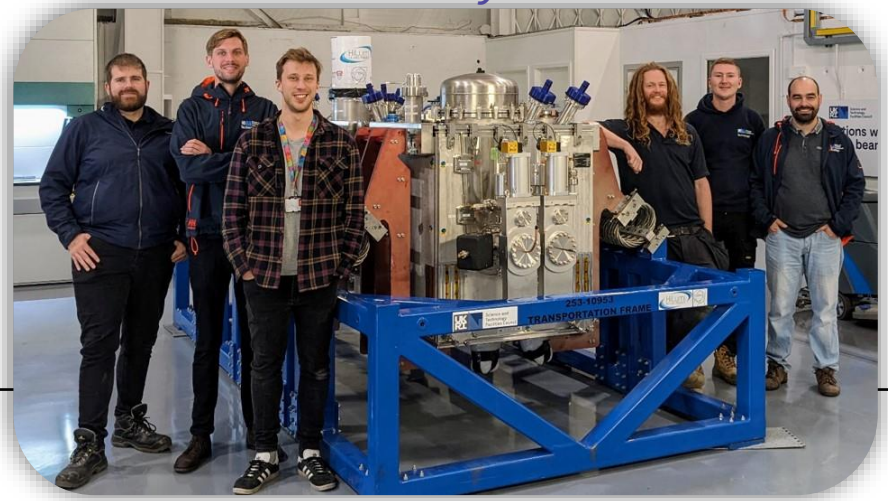
CEng IMechE

Institution of MECHANICAL ENGINEERS CEng ESTD 1847

DQW-SPS Cryomodule

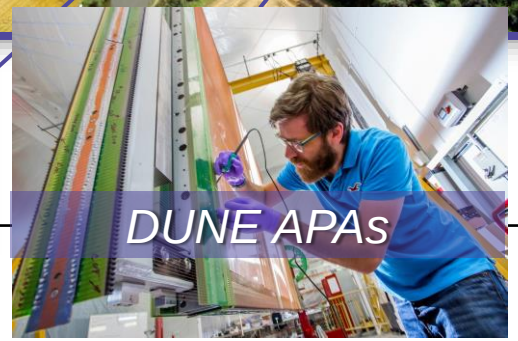
DQW-LHC Cavity String (1st of 4)

RFD-SPS Cryomodule



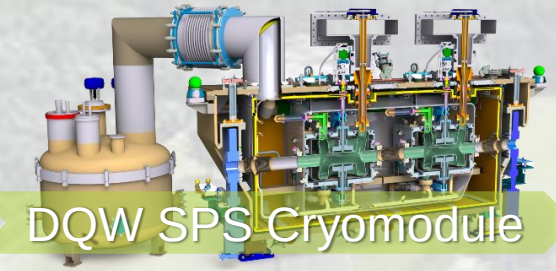
Daresbury Laboratory

- Accelerator Physics
- Supercomputing
- Nuclear Physics
- Detector Systems
- SRF Engineering



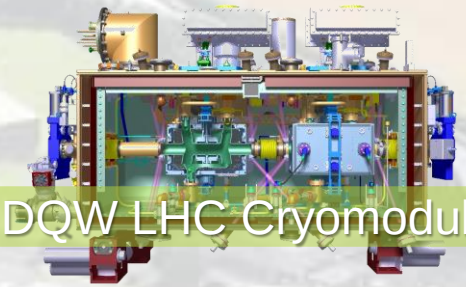
Daresbury Lab - SRF Roadmap

HI LUMI CRAB CAVITIES



DQW SPS Cryomodule

RFD SPS Cryomodule

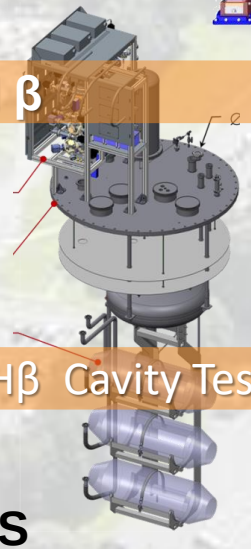


DQW LHC Cryomodules

EIC Accelerators

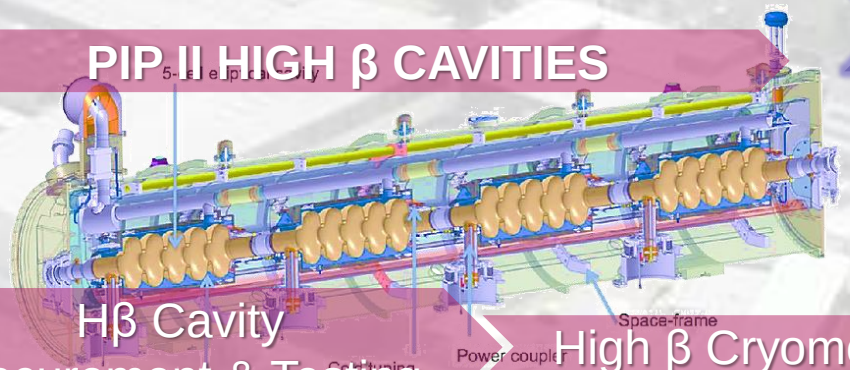
ESS HIGH β

Hβ Cavity Procurement



Hβ Cavity Testing

PIP II HIGH β CAVITIES



Hβ Cavity Procurement & Testing

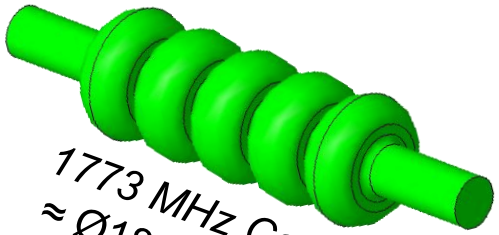
High β Cryomodules

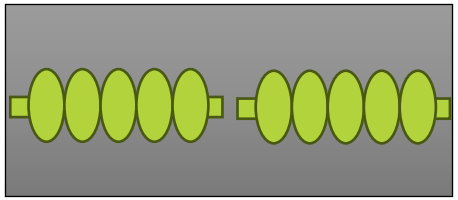
DL SRF CAPABILITIES

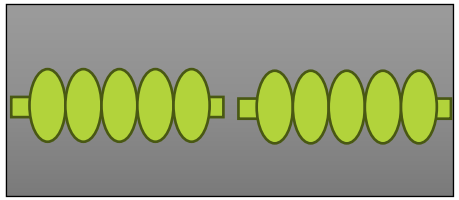
- ✓ Vacuum vessels
- ✓ Cryogenic engineering
- ✓ Thermal screens
- ✓ Magnetic shielding
- ✓ MLI
- ✓ Cavity procurement
- ✓ Cavity testing
- ✓ High Pressure Rinse (HPR)
- ❑ Cavity mech design
- ❑ Coupler mech design
- ❑ Tuner design
- ❑ Cryomodule testing

(Original) Accelerator WP Grant

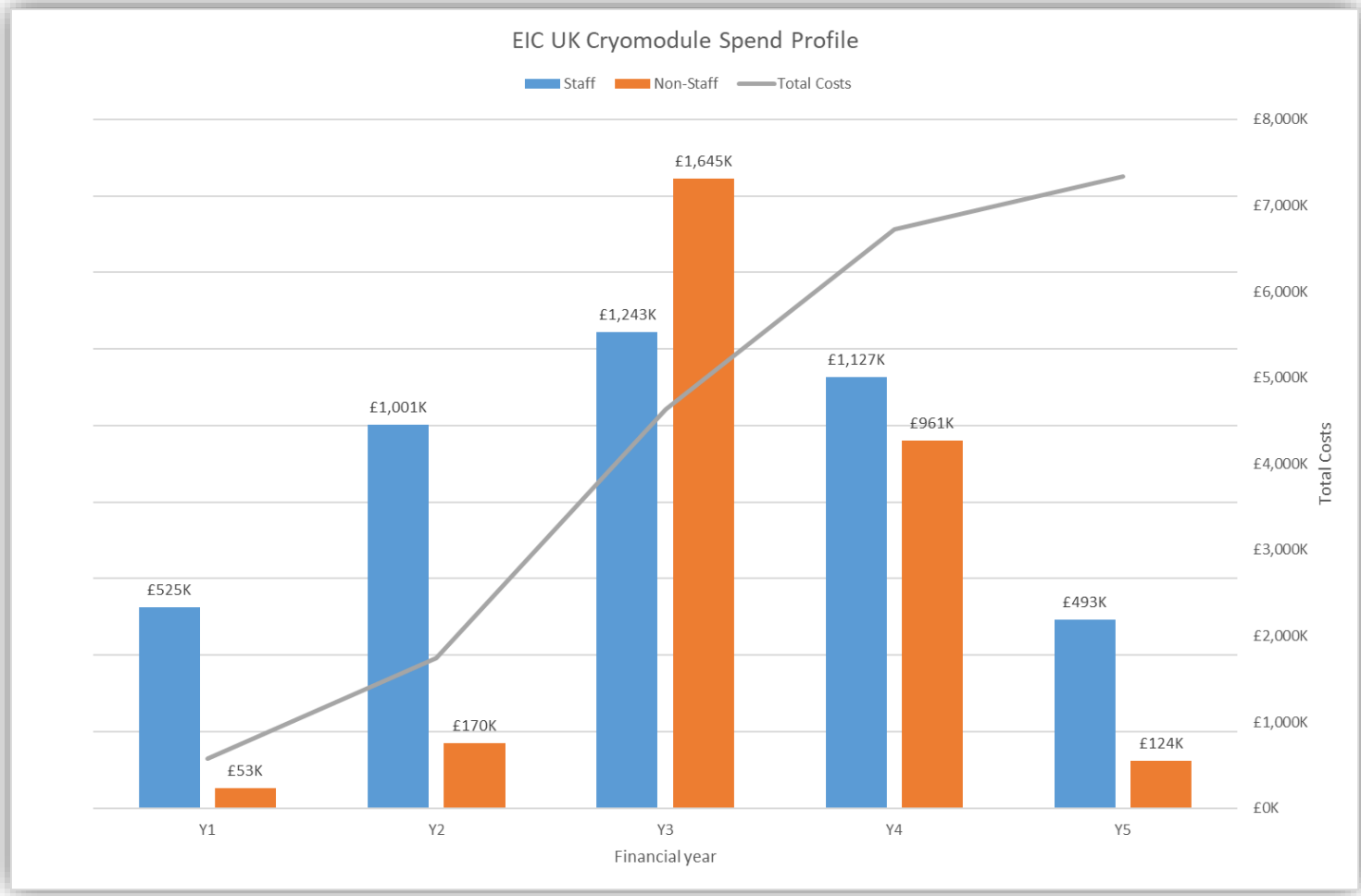
- 5-year project Starting Apr26
- Budget £5.4M Incl. ~33 FTE (yrs)
- 2x 1773MHz Cavity Cryomodules
  - 2 cavities per CM
- Part of Energy Recovery Linac (ERL)
- ***De-scoped following kick-off mtg Jun24***







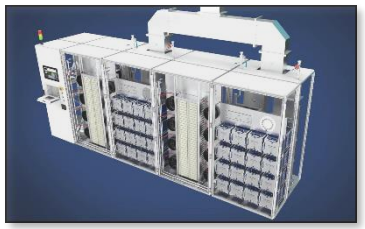
Design & Development → Procurement → Delivery



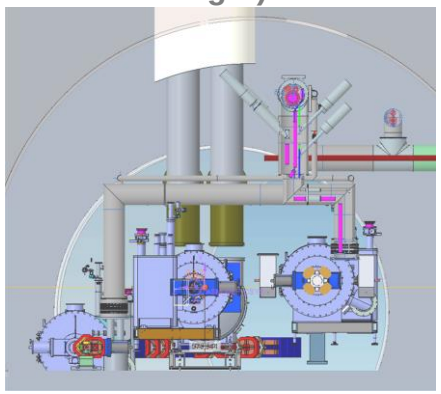
EIC – RF Systems

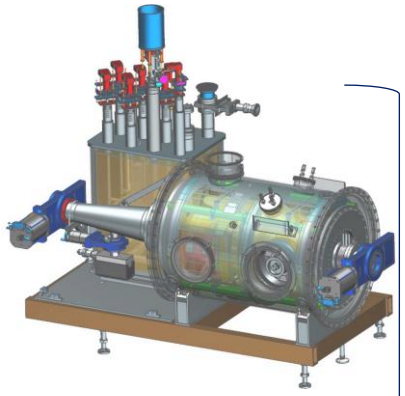
The Project is pre-CD2 and in the design phase. Many systems are still developing.

400 kW Amplifier

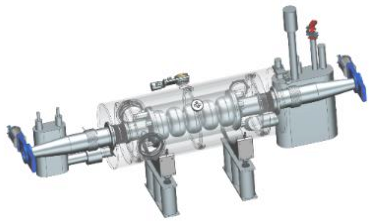


IR10 Tunnel with RCS, HSR and ESR (Left to Right)

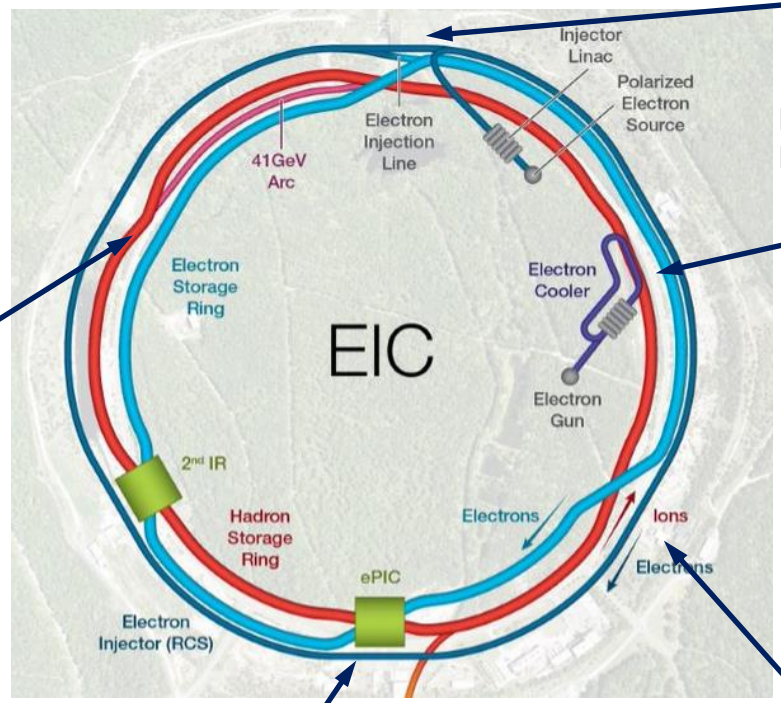




Electron Storage Ring & Hadron Storage Ring
591 MHz 800 kW 2 K
1-Cell Cavity Cryomodules
ESR = 17 CMs, IR10
HSR = 5 CMs, IR10



Rapid Cycling Synchrotron
591 MHz Five-Cell Acceleration Cavity Cryomodule
3 CMs, IR10



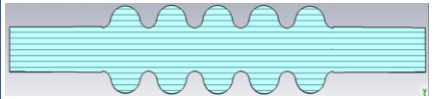
First Article 197 MHz Crab Cavity

Interim Project

New WP

Crab Cavities (per IR)	HSR (Cavities /CMs)	ESR (Cavities /CMs)
197 MHz	8/4	–
394 MHz	4/4	2/2

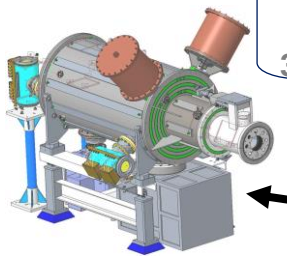
RCS injection harmonic RF kicker, **IR12**



Hadron Cooling – 10 591 MHz acceleration cavities &
4 **1773 MHz 3rd Harmonic** Cavities (Not shown)
Electron Cooler, IR02

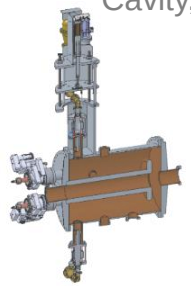
OG Grant

6 ea 197 QWR, 3 ea 591 SC Cavities (Not shown)
3 CMs, ERL Injector, IR02

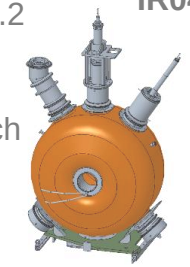


Hadron Storage Ring
24.6 MHz Accelerating Cavity, IR04

HSR – 24.6 MHz acceleration cavity **IR04**



HSR – 49.2 MHz and 98.5 MHz bunch splitter cavities **IR04**



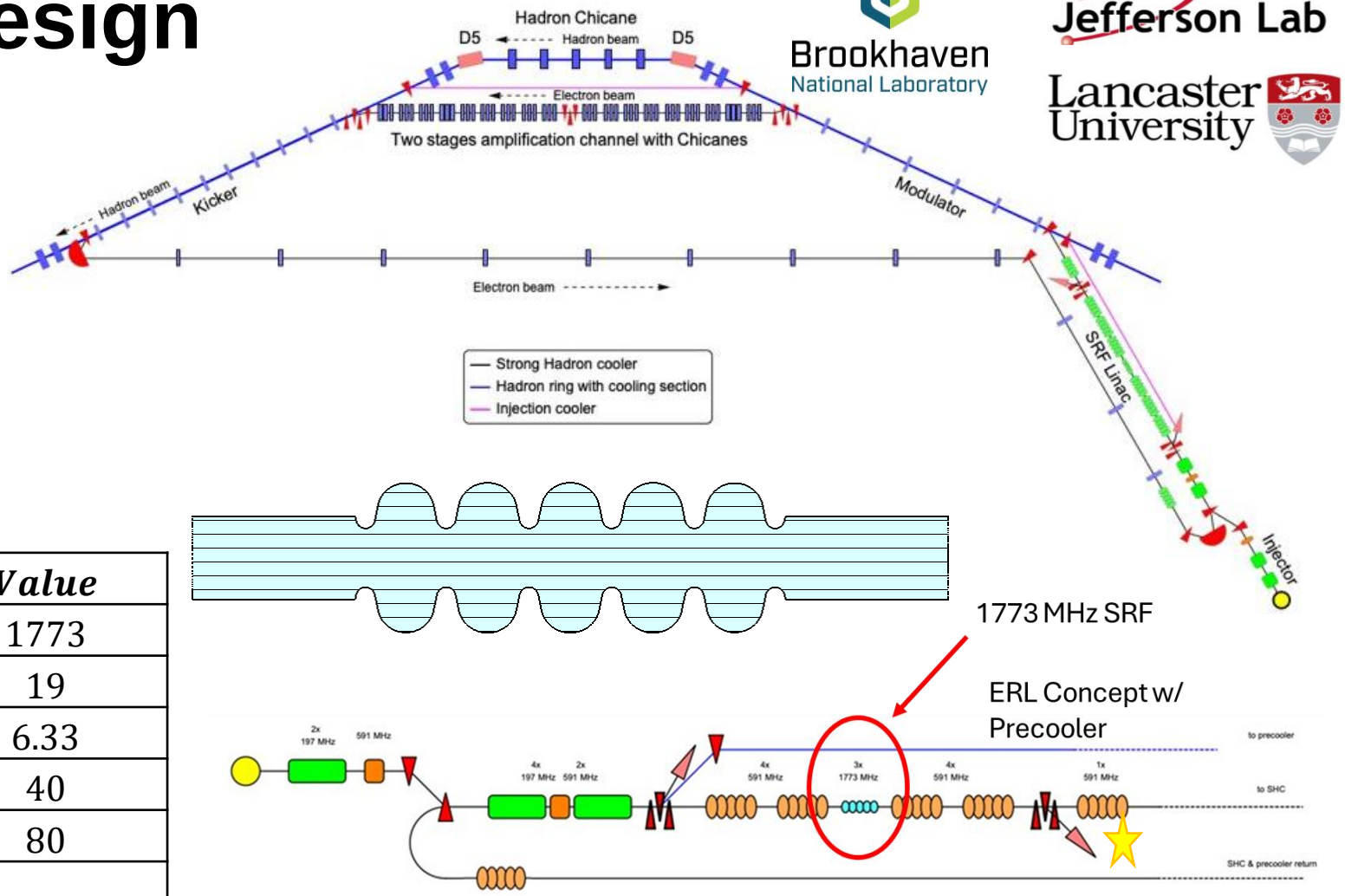
HSR - 197 MHz bunch compression cavity **IR04**

1773 MHZ Cavity Design

SHC-ERL: Precooler

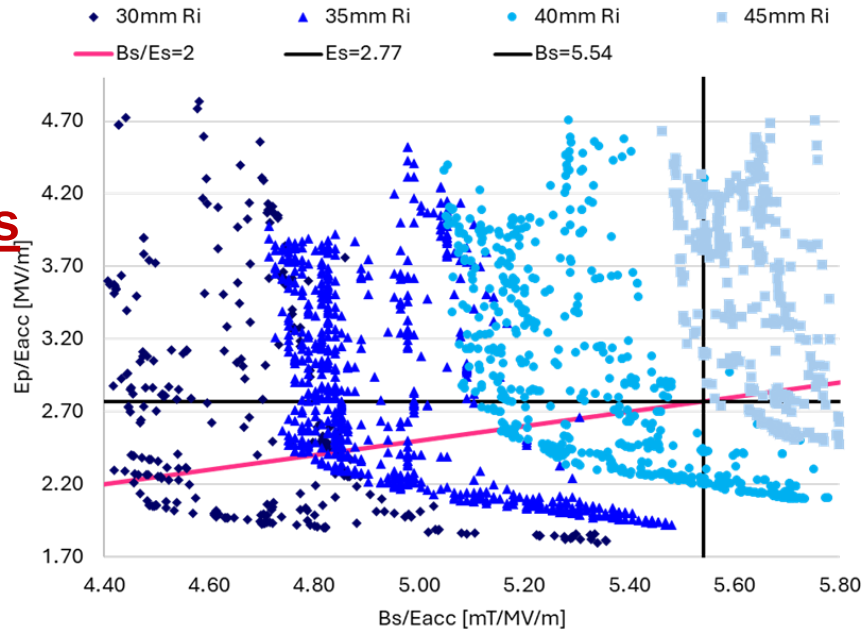
- The main linac is a 5-cell, 591MHz SRF cavity complimented by our 1773MHz Third Harmonic SRF cavities
  - ➢ 3rd harmonics provide bunch lengthening, or linearisation of the electron bunch phase space

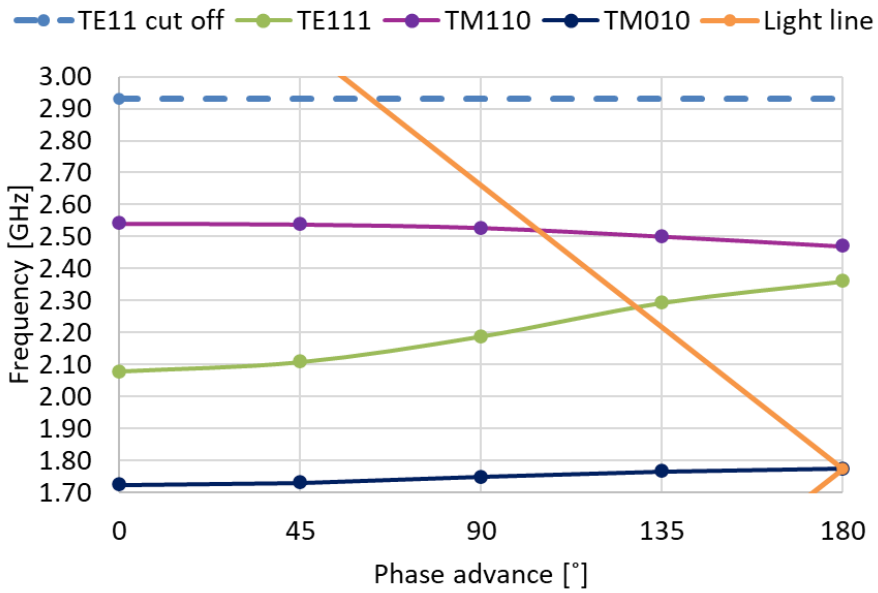
Figure of Merit	***Unit***	***Value***
f_0	$[MHz]$	1773
V_{cryo}	$[MV]$	19
V_{cav}		6.33
$E_p(6.33MV)$	$[MV/m]$	40
$B_p(6.33MV)$	$[mT]$	80
$E_p/Bp(6.33MV)$	$[MV/m\ /\ mT/MV]$	2.0
R_a	$[mm]$	≥ 30



1773 MHz – Single Cell Optimisation

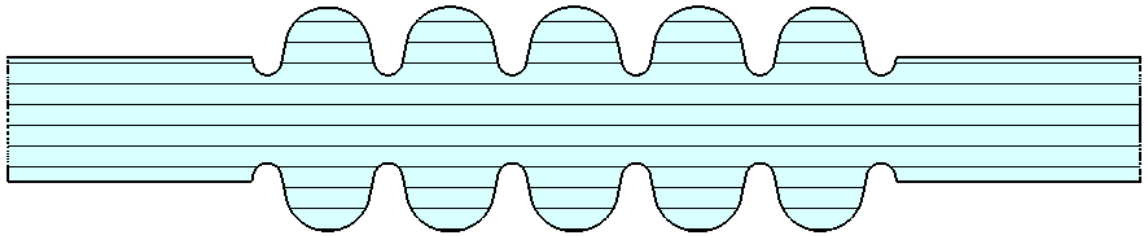
Small iris aperture allow higher gradients

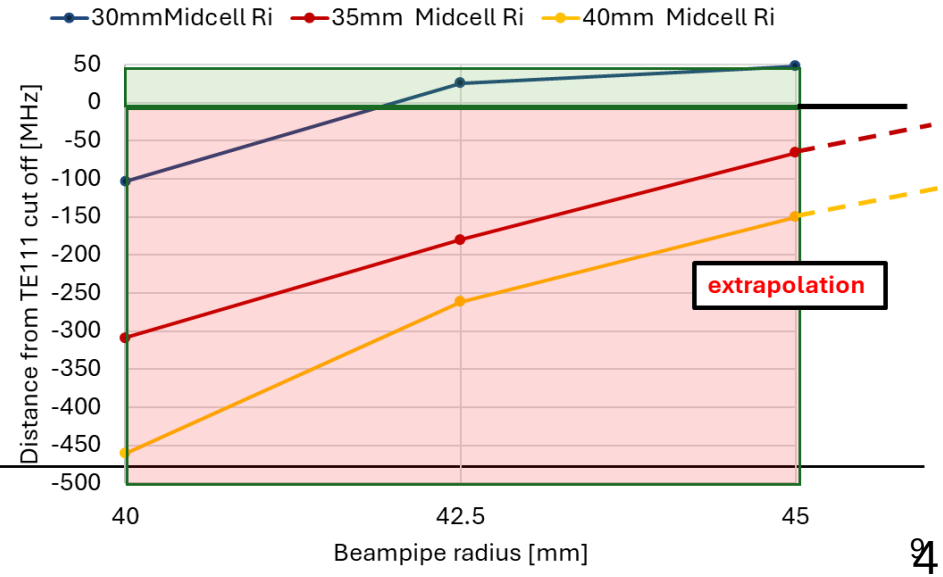




Large beampipe apertures are good for propagating out higher order modes but large apertures in the iris push down the dipole mode frequency

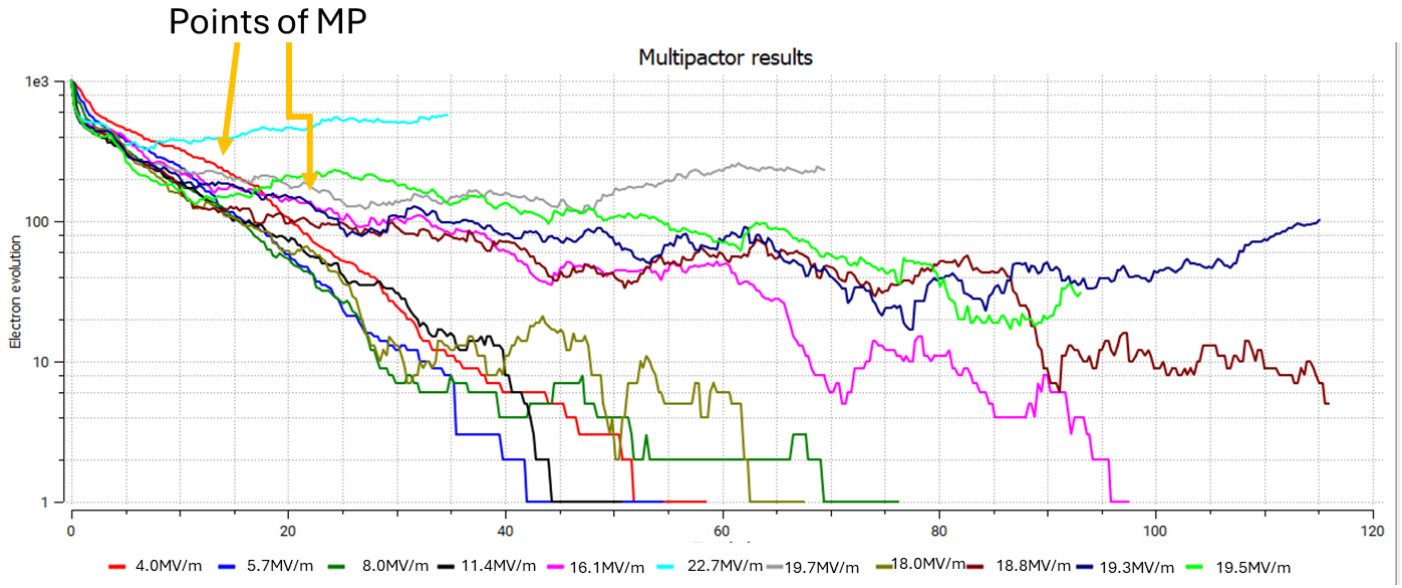
Solution: mid-cell radius < beampipe radius

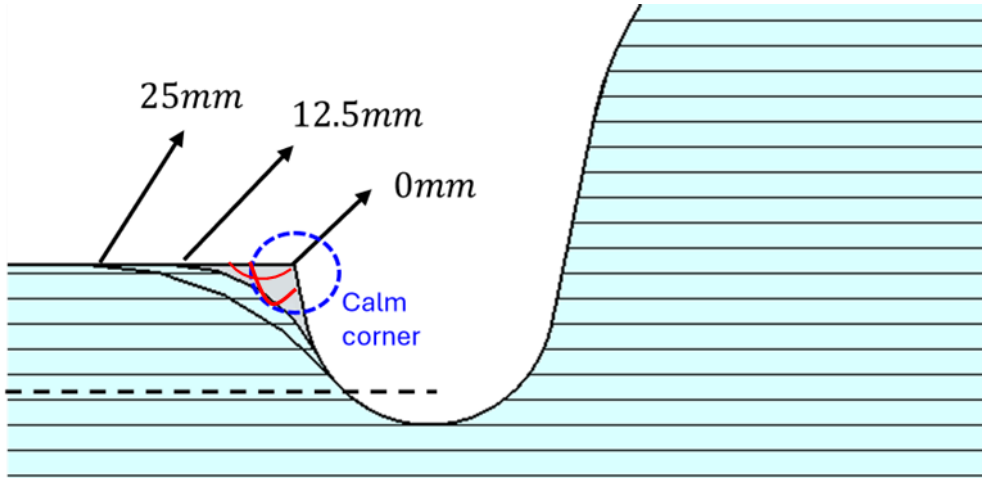




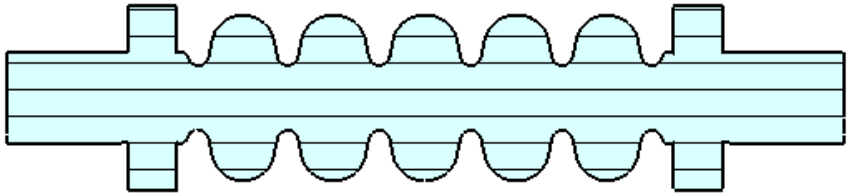
Sara Toole & Graeme Burt

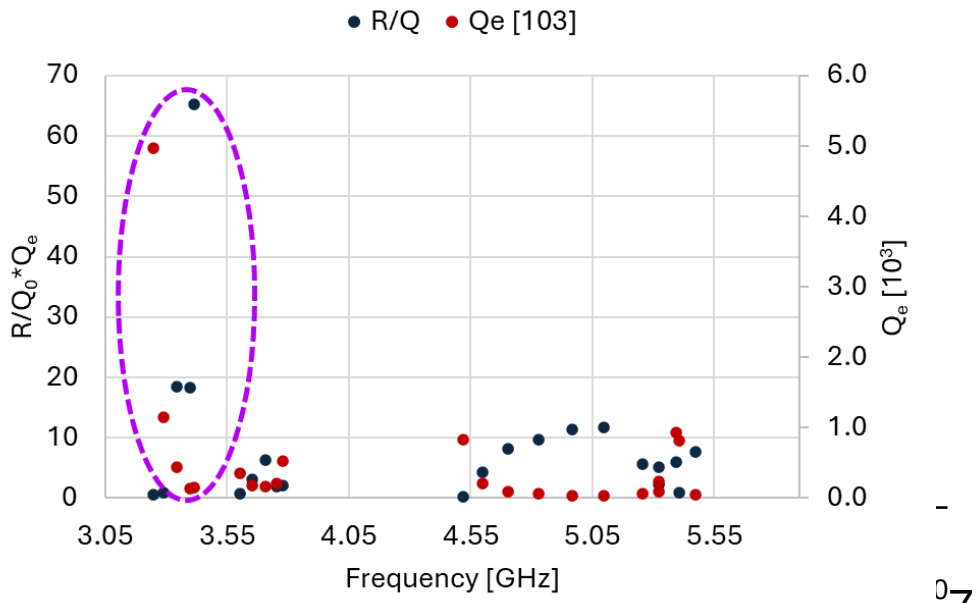
1773 MHz - Lip optimisation Multipacting & HOMs





Initial design showed multipacting due to a field null behind the lip, this can be removed by smoothing the corner.
We are now optimising higher order mode dampers to meet the very tight ERL impedance limits.





Sara Toole & Graeme Burt

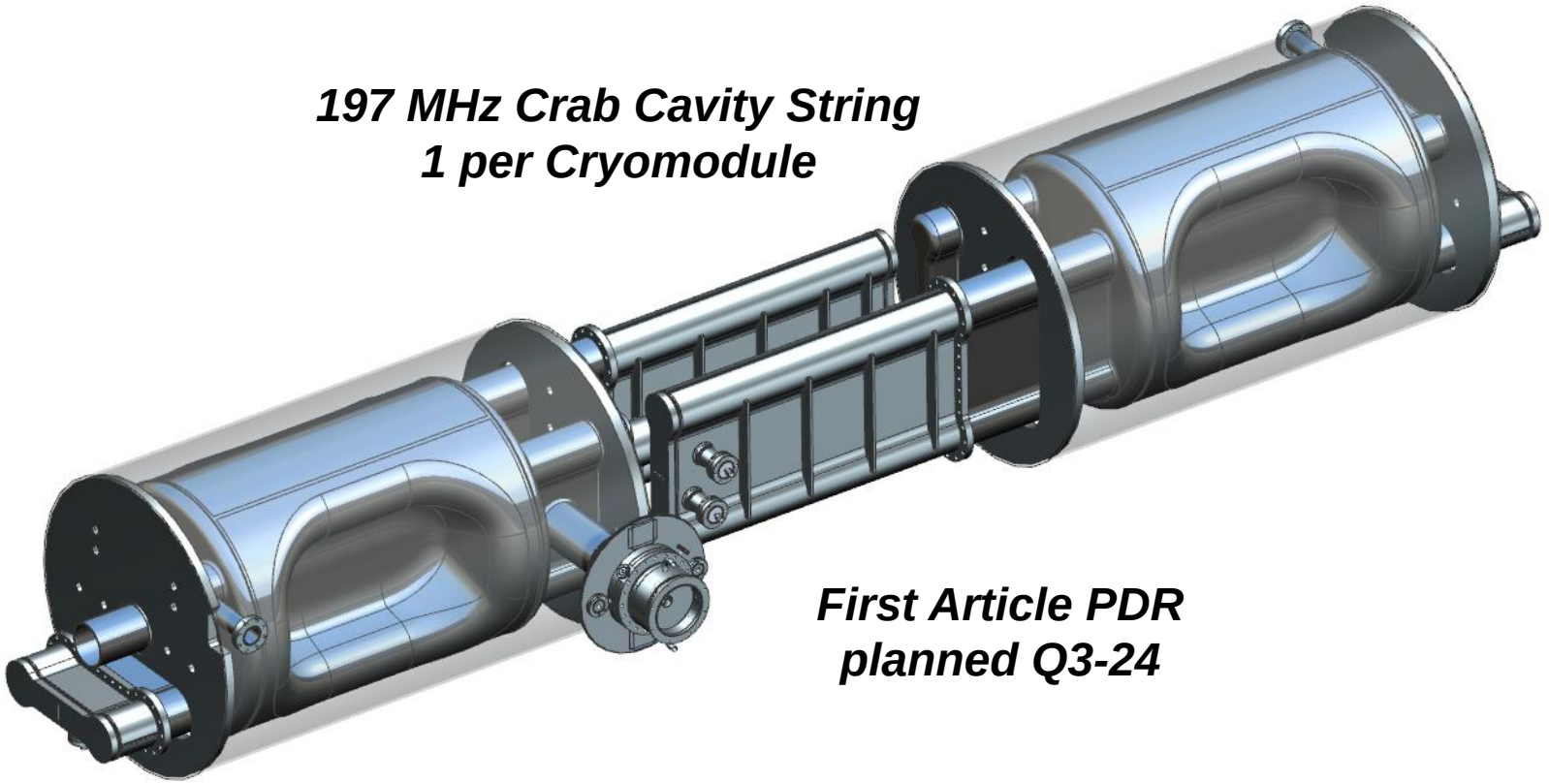
197 MHz Crab Cavity Cryomodule First Article

- 1yr interim project start: Apr’25
- £220k
- mechanical design only

Scope & Deliverables

- ❑Cavity-string assembly design for Preliminary Design Review (PDR)
- ❑PDR recommendations
- ❑Other cryomodule sub-system designs, as determined by the PDR
- ❑Detailed design & handovers

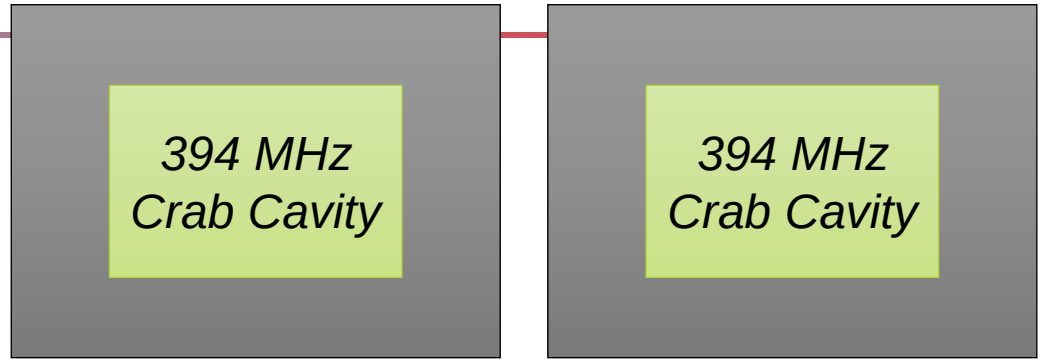
197 MHz Crab Cavity String
1 per Cryomodule



First Article PDR planned Q3-24

394 MHz Crab Cavity Cryomodules
Electron Storage Ring (ESR)

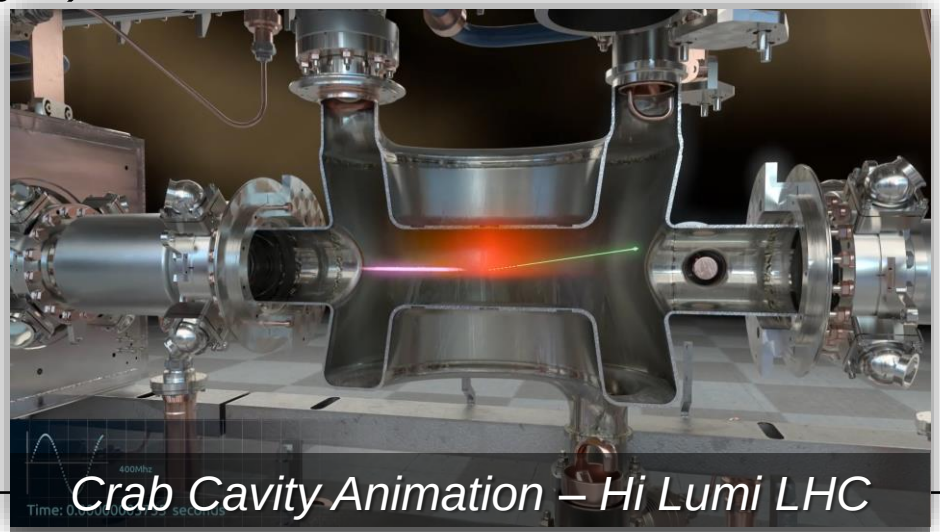
- UK to deliver (2x) single-cavity-cryomodules
- Phase1 grant: £5.4M
- JLAB match funding up to 150% (including in-kind)



Sub-WPs

1. Cavity & Coupler Design *(25 FTE-yrs across 2 yrs)*
2. Cavity Manufacture & Cold Testing *(£2M + 3 FTE-yrs management)*
3. Cryomodule Manufacture & Assembly *(£3.3M + 11 FTE-yrs)*
4. Cryomodule Infrastructure *(tbd)*

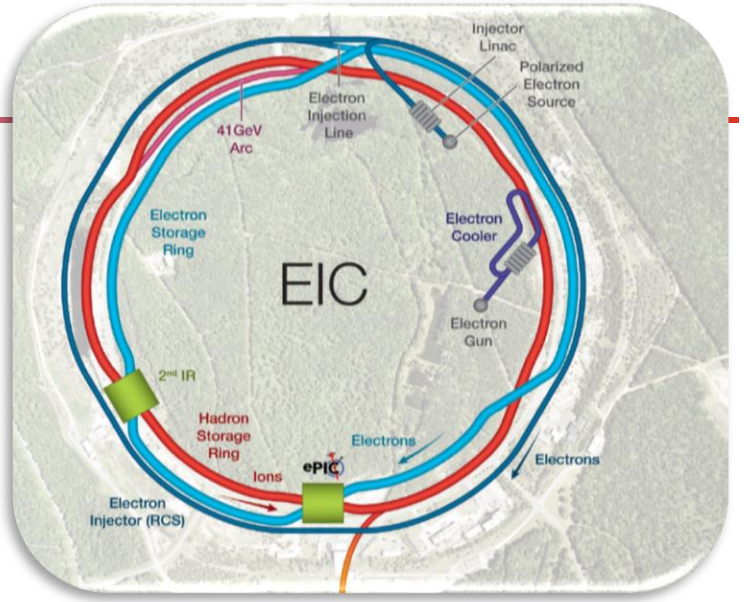
New plan & scope - *in-work*


Crab Cavity Animation – Hi Lumi LHC Double Quarter Wave (DQW)

Transition crossing for the EIC

Collaboration between University of Huddersfield & Brookhaven National Lab
H. Lovelace[1,2] , S. Peggs[2] , A. Drees[2], R. Seviour[1], B. Lepore[2], G. Robert-Demolaize[2]

(1) University of Huddersfield (UK)
(2) Brookhaven National Lab (USA)



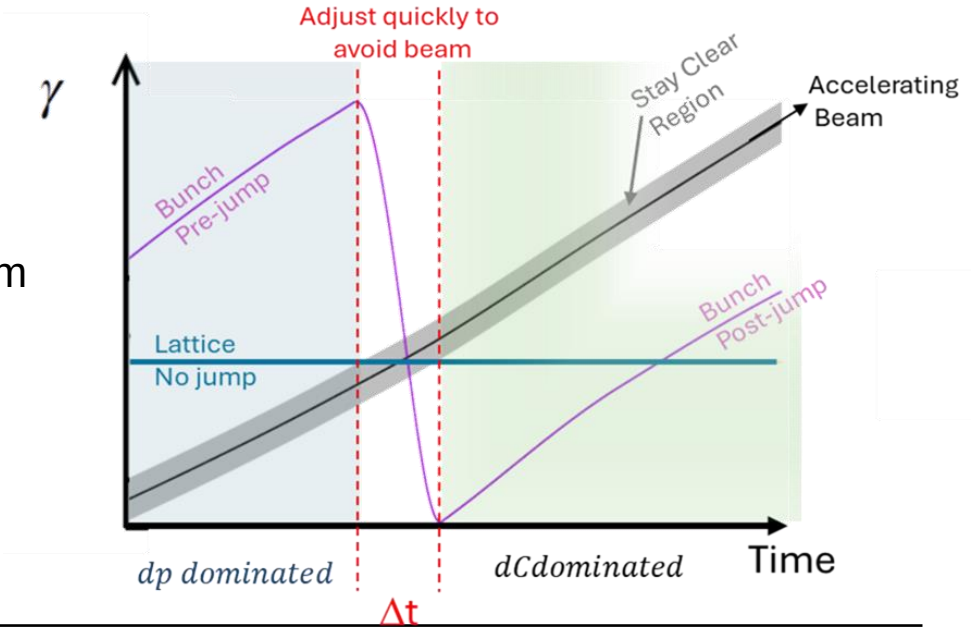
In a circular machine increasing energy of electron bunches creates competing increases in **velocity** & **trajectory** length.

Below the ***transition*** energy the velocity increases faster than the length.

Above ***transition*** energy, the opposite is true.

At the ***transition*** energy, variation in velocity is compensated by variation in trajectory.

Crossing transition energy involves a perturbation of the longitudinal beam dynamics enhanced by space charge and chromatic effects.



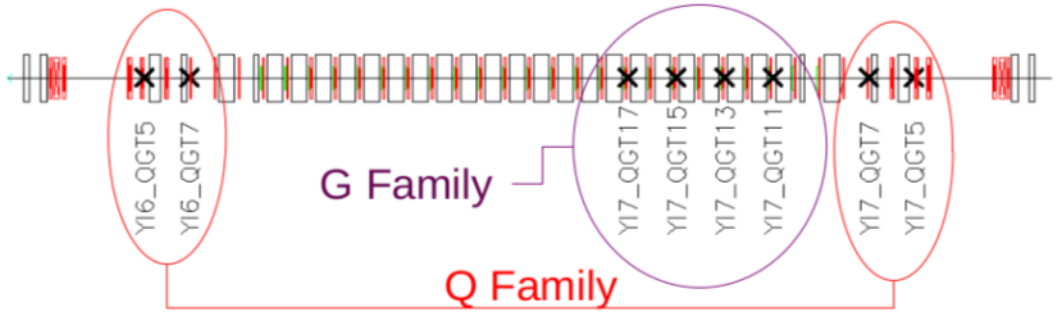
Transition crossing for the EIC

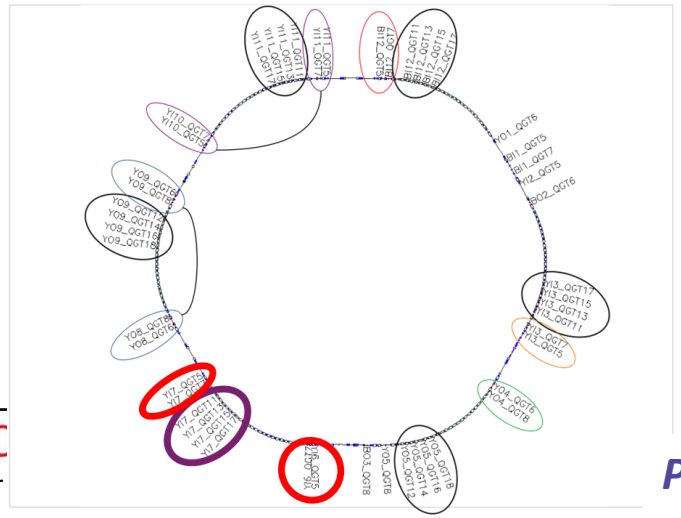
How to control transition crossing

Solution: tweak two families of quads

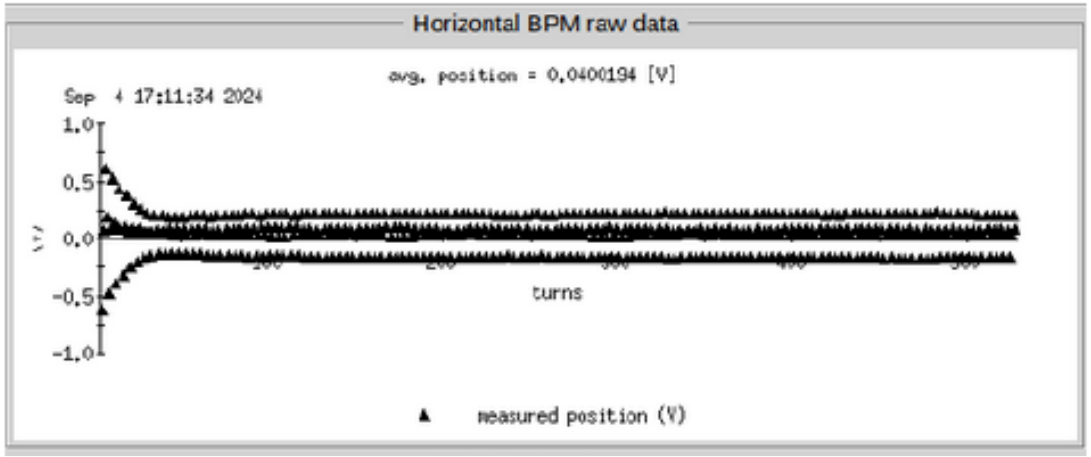
1. the G family at high η locations changes γ_T
2. the Q family at low η locations keeps $\Delta Q_H \simeq 0$

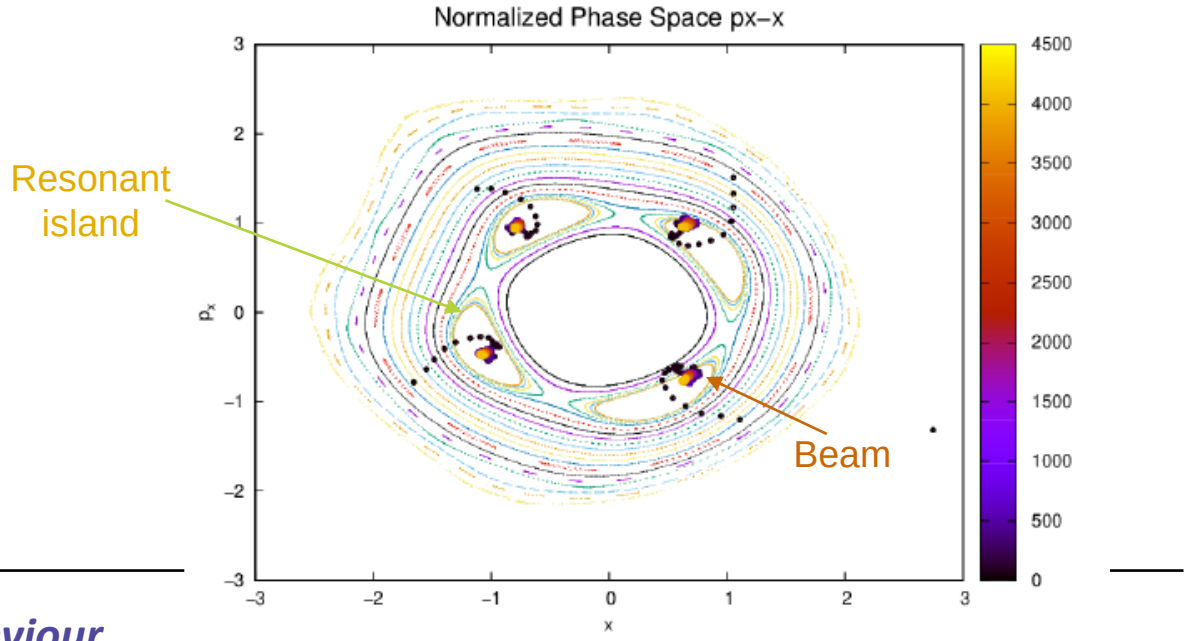
Each RHIC arc has 2 jump power supplies:





Sept 2024 APEX BPM measurements showing 4 island formation





Thanks! Questions?

Niklas Templeton **CEng MEng MIMechE**
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University of Birmingham
19th Nov24

Electron-Ion Collider

more info: https://www.bnl.gov/eic/explore/

197 MHz Crab Cavity Prototype

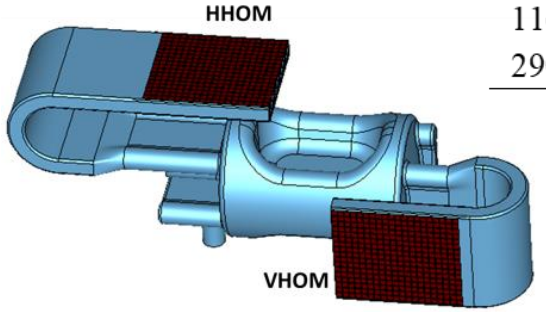
Courtesy of Zack Conway & Naeem Huque

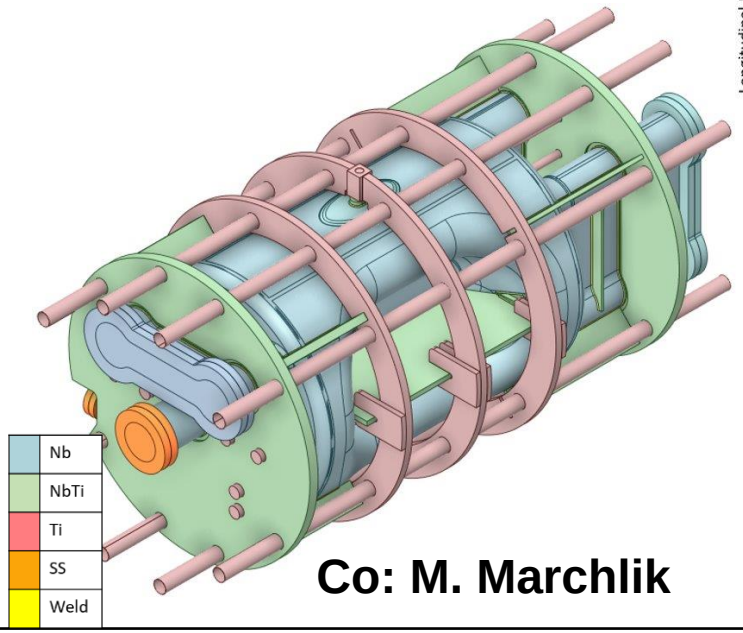
- **Not the First Article.**
- **Building a prototype cavity, Finish 2025.**
- **Demonstrate that we can build it, process it and it can achieve the basic RF parameter set.**

Al Part Fabrication Co: N. Huque and JLab

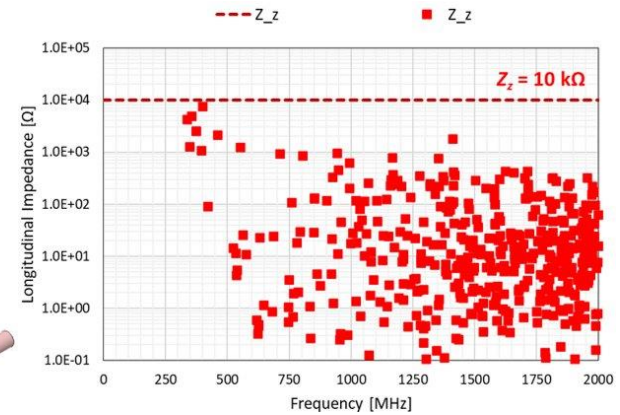
Prototype cavity, HOM Power, and Coupling Impedance to Beam: B. Xiao & S. De Silva

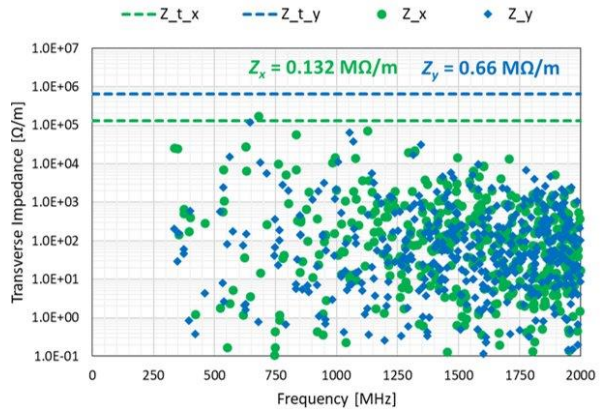
Filling Scheme	P_z	P_t	Total P
1160 bunches	2.91 kW	156 W	3.07 kW
290 bunches	3.00 kW	258 W	3.26 kW





Co: M. Marchlik

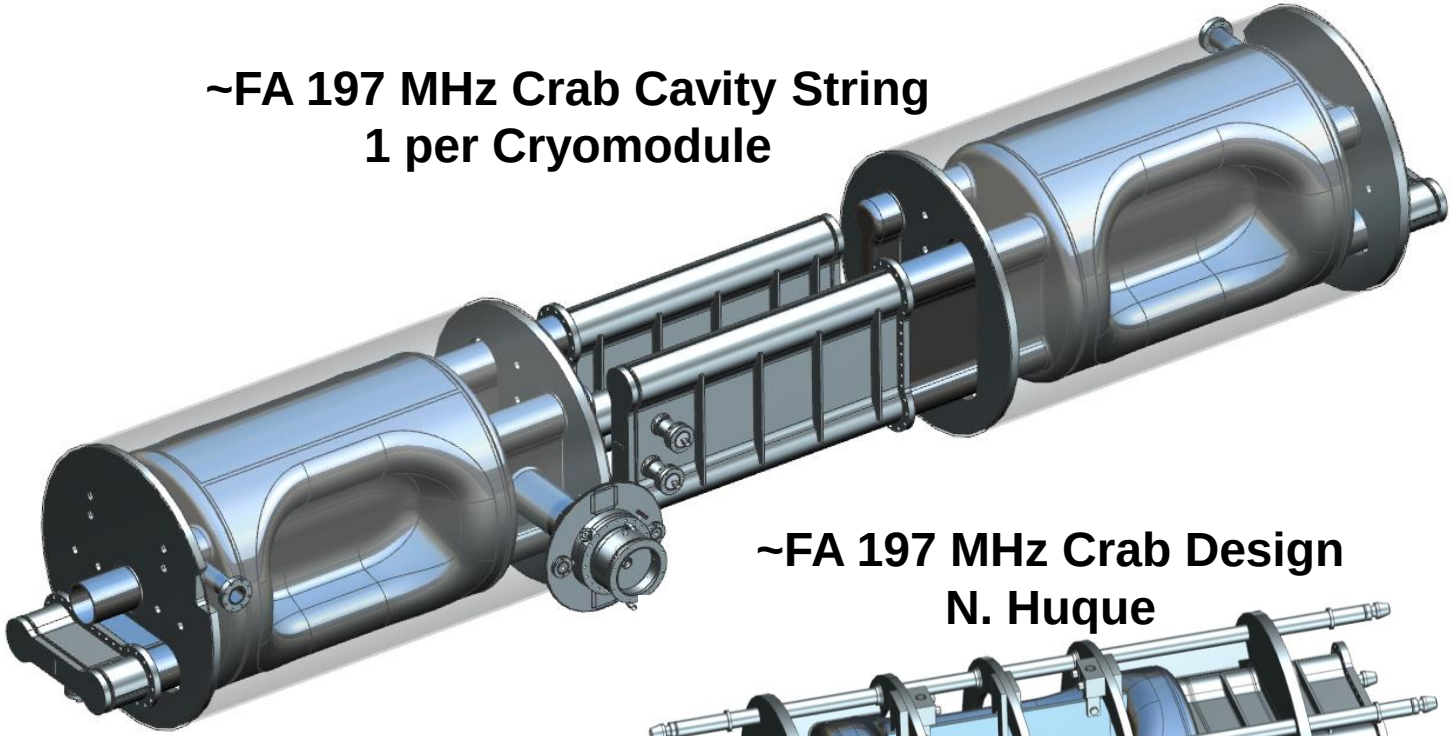




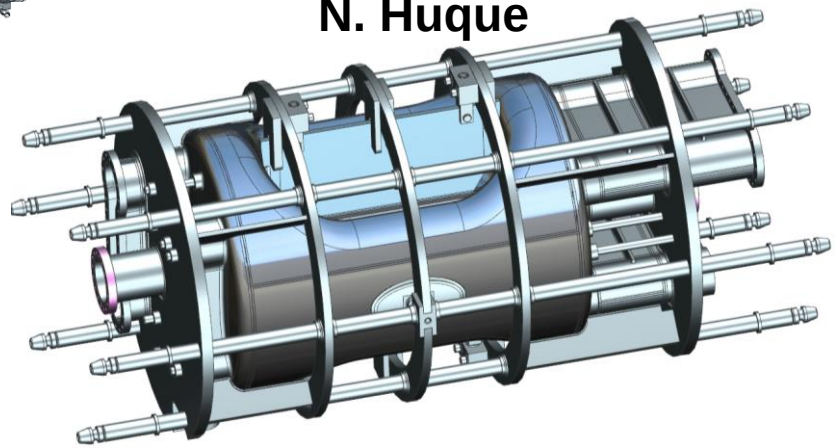
197 MHz Crab Cavity Cryomodule First Article

Courtesy of Zack Conway & Naeem Huque

~FA 197 MHz Crab Cavity String
1 per Cryomodule



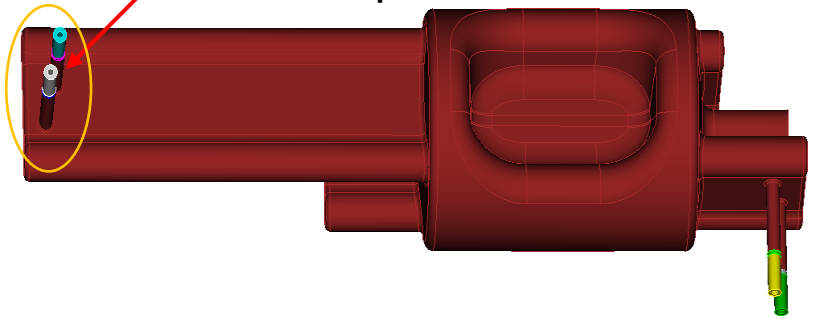
~FA 197 MHz Crab Design
N. Huque

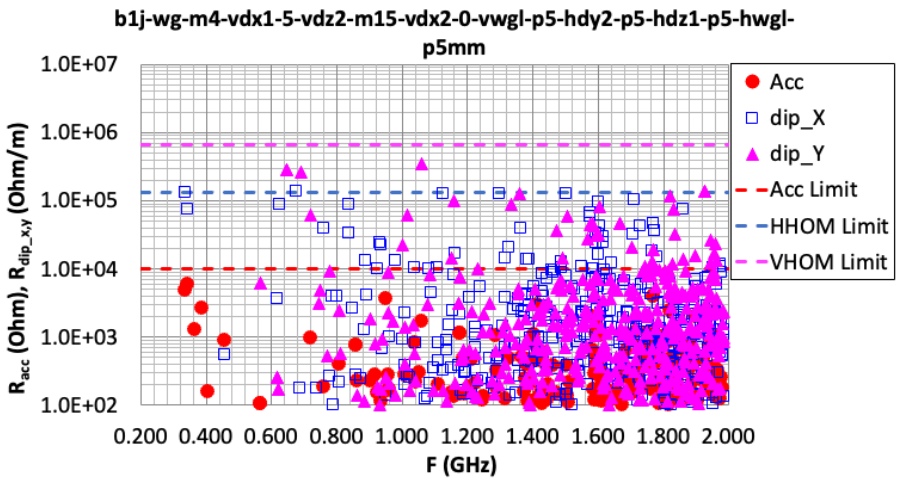


First Article PDR
planned May 2024

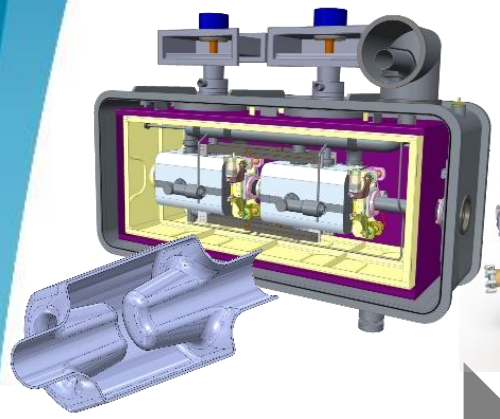
First Article Cavity Optimization
Z. Li (SLAC, B. Xiao (BNL), S. De Silva (ODU)

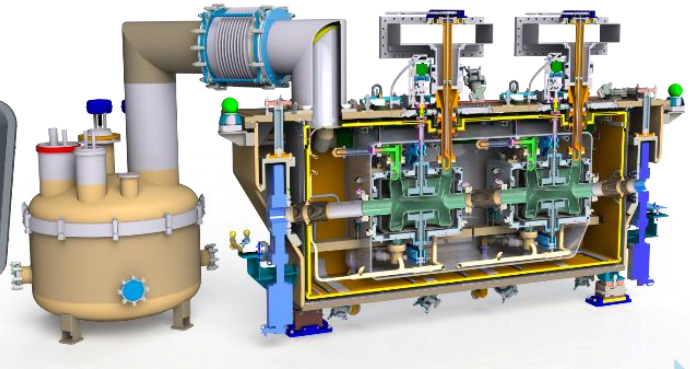
Position optimized

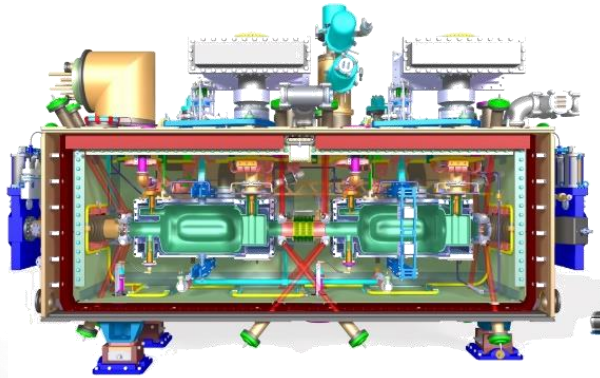


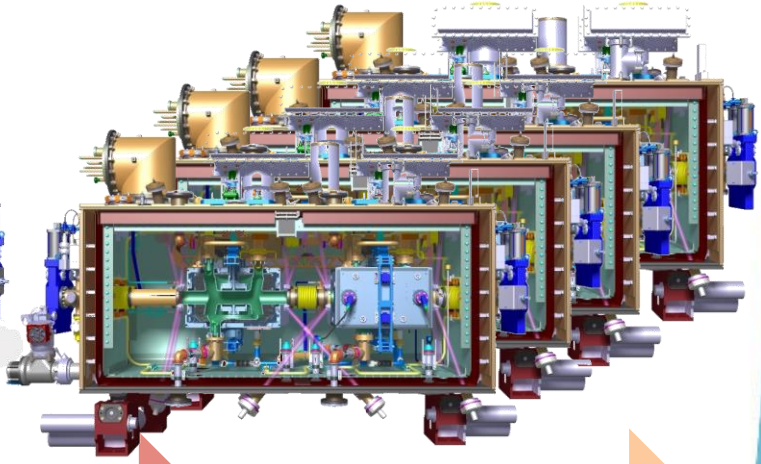


Hi Lumi Crab Cavities – UK Collaboration

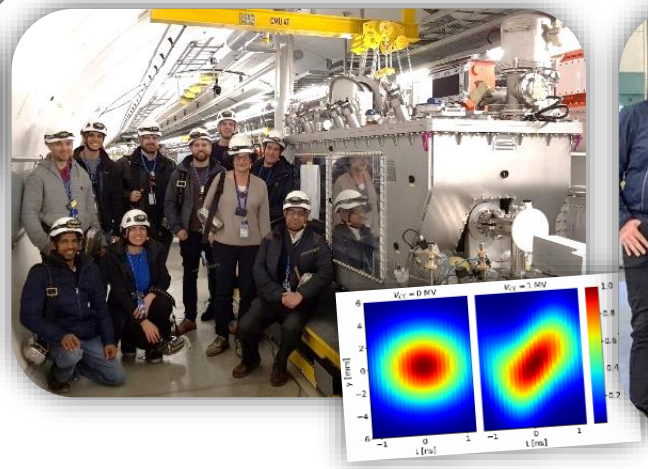


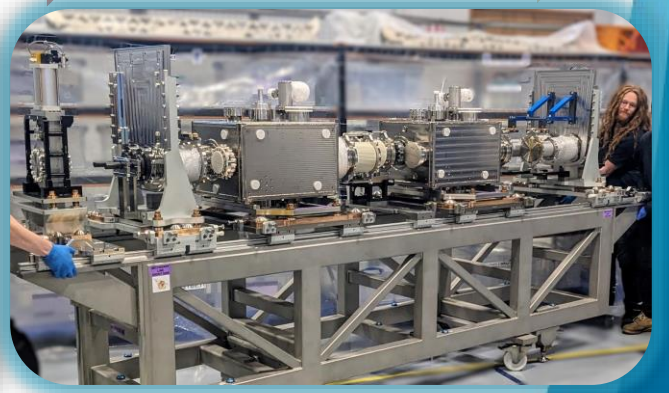






2011 — UK 4-Rod Crab Cavity → DQW Prototype CM → RFD-SPS CM → DQW-LHC CMs — 2027





HL-LHC-UK