HL-LHC-UK

G. Burt, Lancaster University

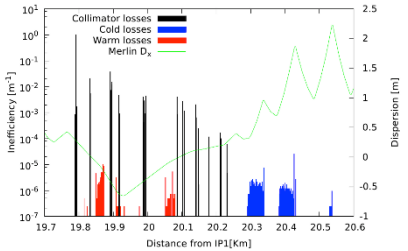
HiLumi-LHC : Science and leadership

The Cockcroft Institute of Accelerator Science and Technology

Manchester
Lancaster
ASTeC

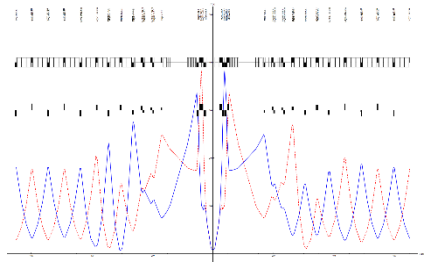
Crab Cavities

Manchester
RHUL



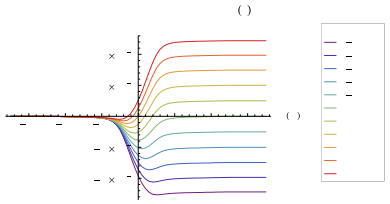
Collimation

Manchester
Liverpool
ASTeC

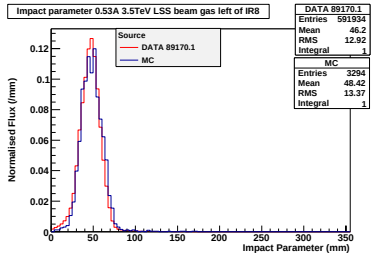


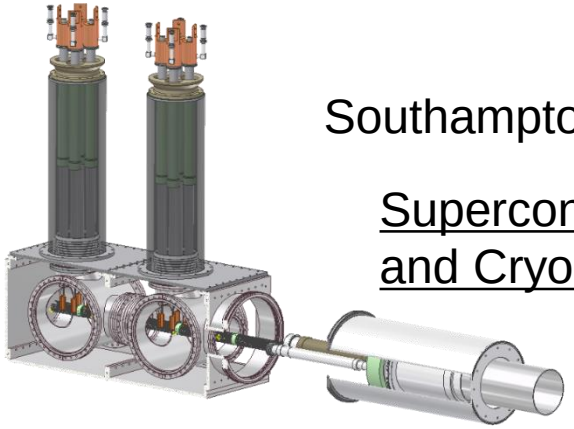
Beam dynamics

Manchester
Liverpool
ASTeC



HiLumi-LHC
UK





Southampton

Superconductivity and Cryogenics

Liverpool
RHUL

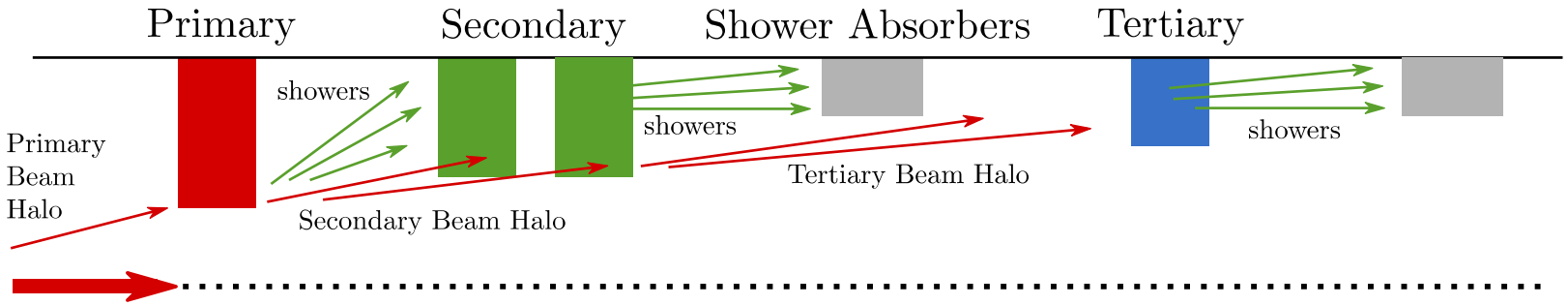
Diagnostics

Manchester

Machine-detector interface

Challenge 1 : Collimation

Beam collimation has been considered one of the most critical aspects for the LHC
- Cleaning challenge vs quench (fundamental for this target luminosity)
- Small gaps challenge, impedance



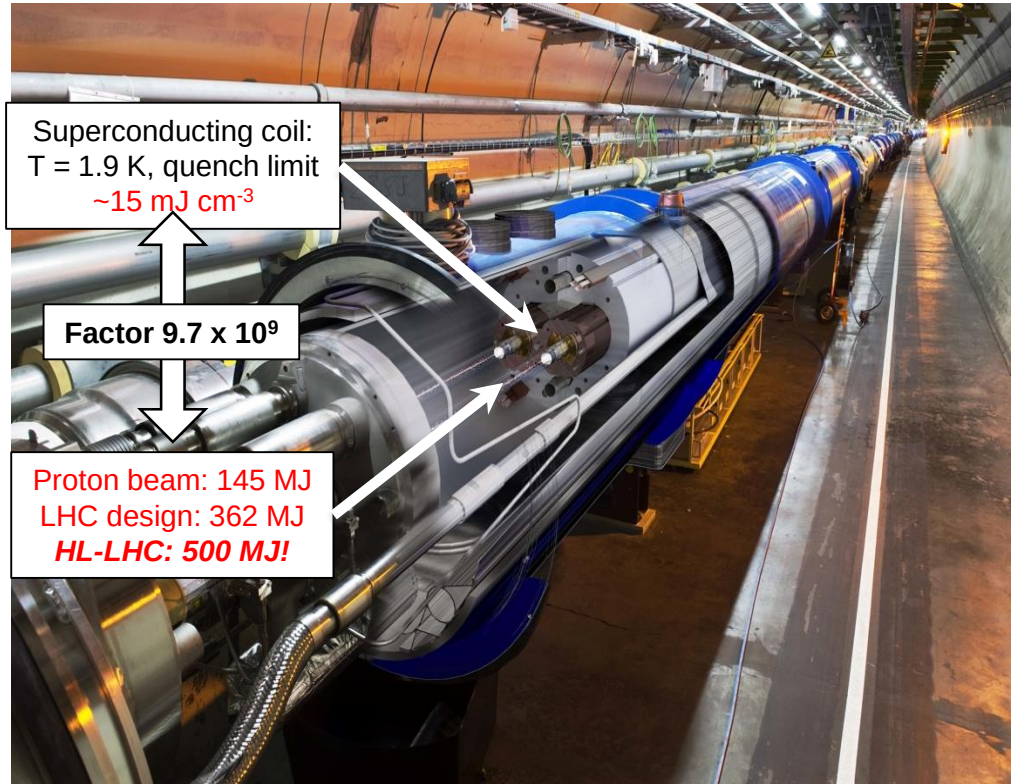
> 500 MJ of stored energy per beam

➔ requires collimation during all operation stages!

➔ requires careful design/study and exploitation of the run 2 beam

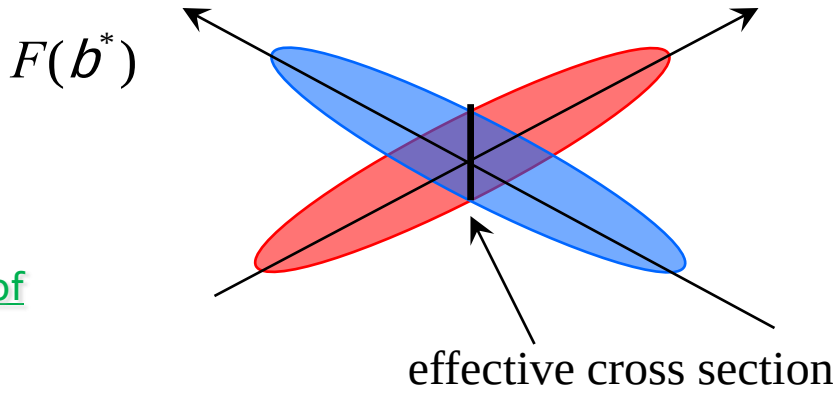
➔ requires novel collimation solutions

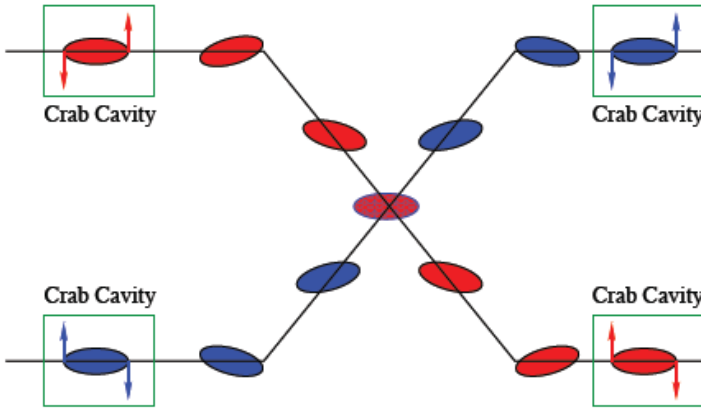
➔ HL-LHC luminosity implies higher leakage from IP & requires additional collimators and collimator diagnostics



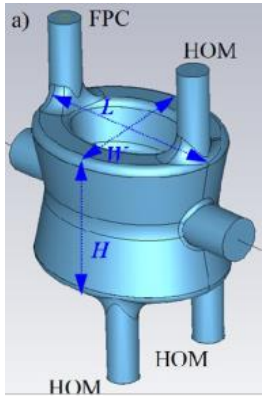
Challenge 2 : Crab Cavities

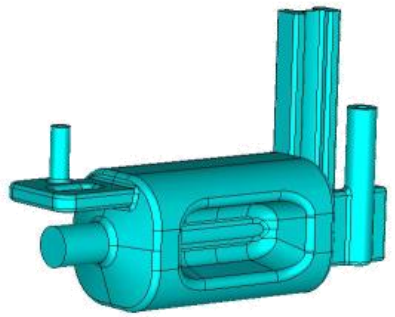
- Crab cavities are proposed to provide bunch rotation to give a geometric overlap with the required crossing angle at HL-LHC
- Without crab cavities the beam would lose 50% of the luminosity and would have a greater pile-up density.
- they have not been tested on hadron beams.





- The SRF crab cavities need 3MV per cavity and 32 cavities are required.
- A proof of principle test is envisioned on the SPS beam at CERN before LS2. To understand cavity behaviour, beam dynamics, LLRF and machine protection issues.
- A pre-series prototype is then planned to the LHC specification.



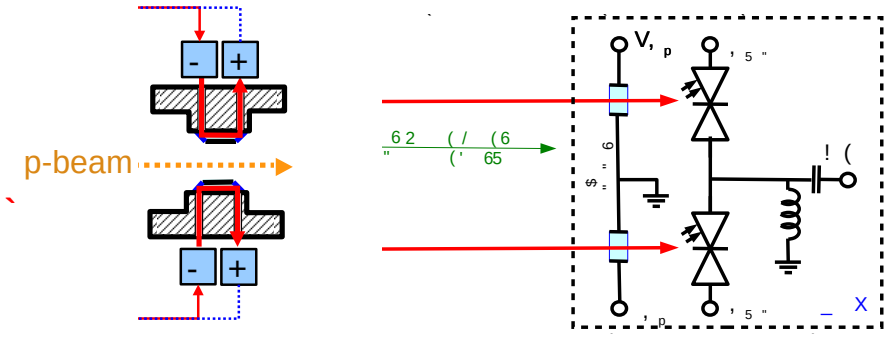


Challenge 3 : Diagnostics

Precise measurement of beam parameters is essential. The LHC is equipped with an extensive array of beam diagnostics that has played a major role in commissioning, rapid intensity ramp-up and safe and reliable operation of the accelerator. The HL-LHC presents new challenges:

Challenge 1:

- Crab-cavities will rotate the bunches
- *A method to accurately measure the bunch rotation is required.*
- Conventional BPMs have insufficient bandwidth for single pass, intra-bunch measurements.
- *A new technology is needed:*



Electro-optic crystals as the BPM pickup

The electric field of the passing bunch induces a polarization change in the crystal that is readout with <50ps time resolution to derive the transverse position along the bunch.

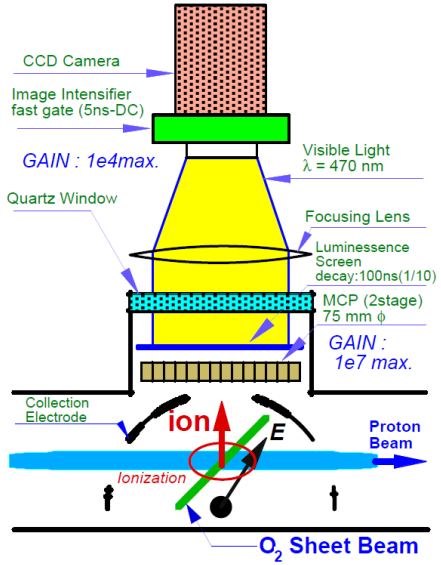
Challenge 2:

- The unprecedented stored beam energy would damage conventional diagnostics and/or disrupt the particle beam.
- *Non-invasive diagnostics are required to measure the beam profile and beam halo.*

Gas-jet based beam profile monitor

A supersonic jet of neutral gas is shaped into a thin sheet and injected with a 45º tilt across the particle beam.

Ions produced accelerate toward a phosphor screen, to monitor profile



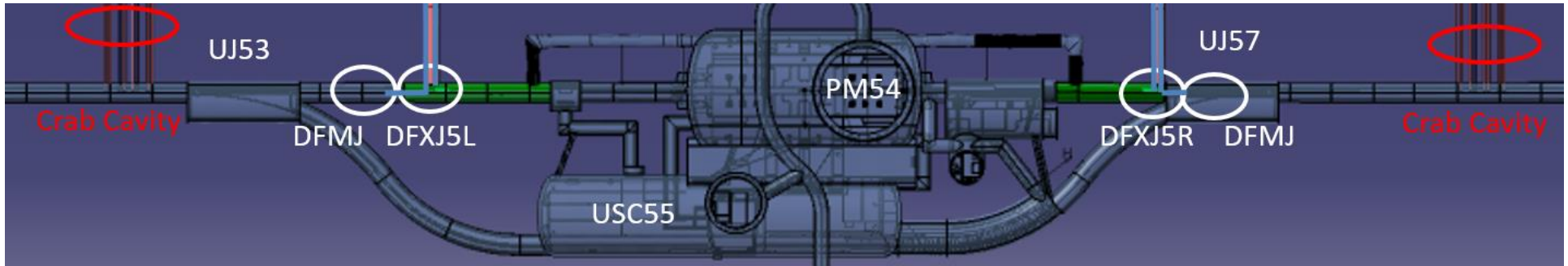
Challenge 4 : Cold Powering

1. Transport of **unprecedented high-currents ($|I_{tot}|$ ~ 200 kA)** via superconducting electrical transmission lines (SC-Links) consisting of **HTS/MgB_2** cables

2. **Developing a novel Cold Powering Systems** relying on cooling with He gas

3. Required for powering the **HL-LHC Triplets** and the **Matching Sections** at P1/P5
   - ❑ Four high power SC-Link (200kA-5 kV, total individual cables up to 20kA)
   - ❑ Allows power converters to be located at surface or in the new underground cavern for Hi-Luminosity equipment

4. **Long term and sustainable solution** of R2E problems by remote powering
   - ❑ Increasingly relevant to higher luminosity at higher energy
   - ❑ Towards a full ALARA approach for radiation protection



WP 2 : Crab Cavities
Science, tasks, dependencies

- WP2 will focus on simulation, production and testing related to the crab cavities for HL-LHC. The leader is Graeme Burt (Lancaster)
  - Task 1: Testing crab cavities in SM18 & SPS (Burt), Lancs
  - Task 2: Pre-series cryomodule (Pattalwar), STFC, Lancs
  - Task 3: Beam dynamics and RF noise (Newton), Liv, Man, Lancs

- Task 1 will perform testing and validation of the crab cavity prototypes, including components, cavities, cryomodules and beam tests.
- Task 1 has 6 PhD student/PDRA-years of effort + academic time

- Task 2 will design, manufacture, and assemble one of the two pre-series crab cryomodules required for HL-LHC
- Task 2 has 11.5 Technician/STFC Staff/PDRA-years of effort + academic time

- Task 3 will simulate beam dynamics and LLRF issues related to crab cavities and analyse relevant data from the SPS test. This will be used to develop the LLRF system for the crab cavities for LHC.
- Task 8 has 11.5 PDRA-years of effort + academic time

Task 1: Testing crab cavities at SM18/SPS

- Will help plan testing of FPC, HOM couplers, cavities and cryomodules in SM18/SPS.
- Covers SPS and Pre-series systems
- Lancaster will base a student at CERN and send a PDRA on long term attachment to take part in testing.
- Will then analyse data (in collaboration with Task 3)

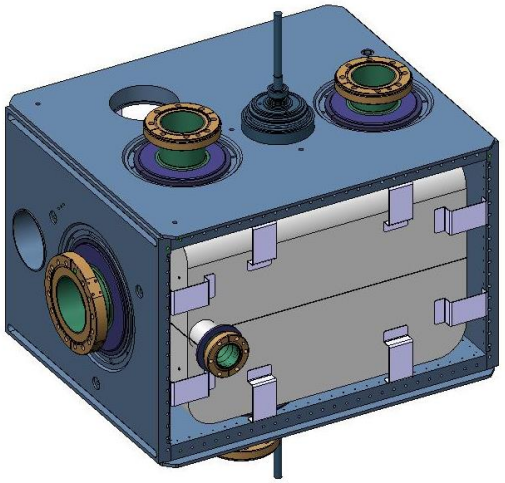
Milestones and Deliverables (note some are CERN milestones which UK will support rather than lead)

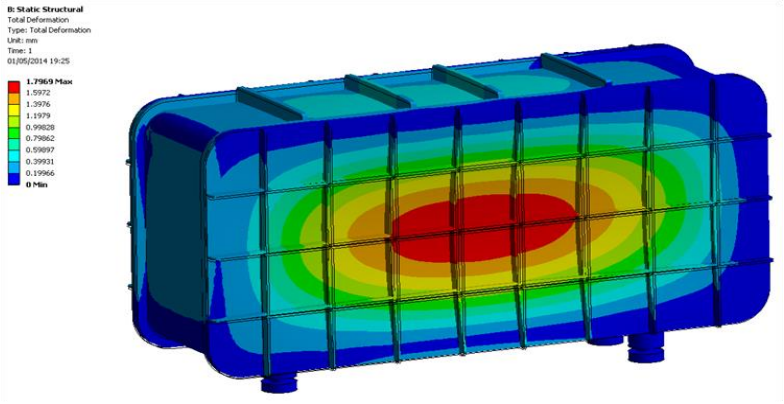
- M2.1 Impedance testing plan and construction of required infrastructure (M6) - Dr G Burt
- M2.2 Design of a LLRF system for SPS tests (M12) - Dr A Dexter
- M2.3 SPS Cryomodule RF and cryogenic testing in SM18 (M24) - Dr G Burt
- M2.5 SPS Cavity and Cryomodule beam testing (M36) - Dr G Burt
- D2.1 Report on HOM coupler testing (M12 - Report) - Dr G Burt
- D2.3 Report on SPS test results (M 40 - Report) - Dr G Burt

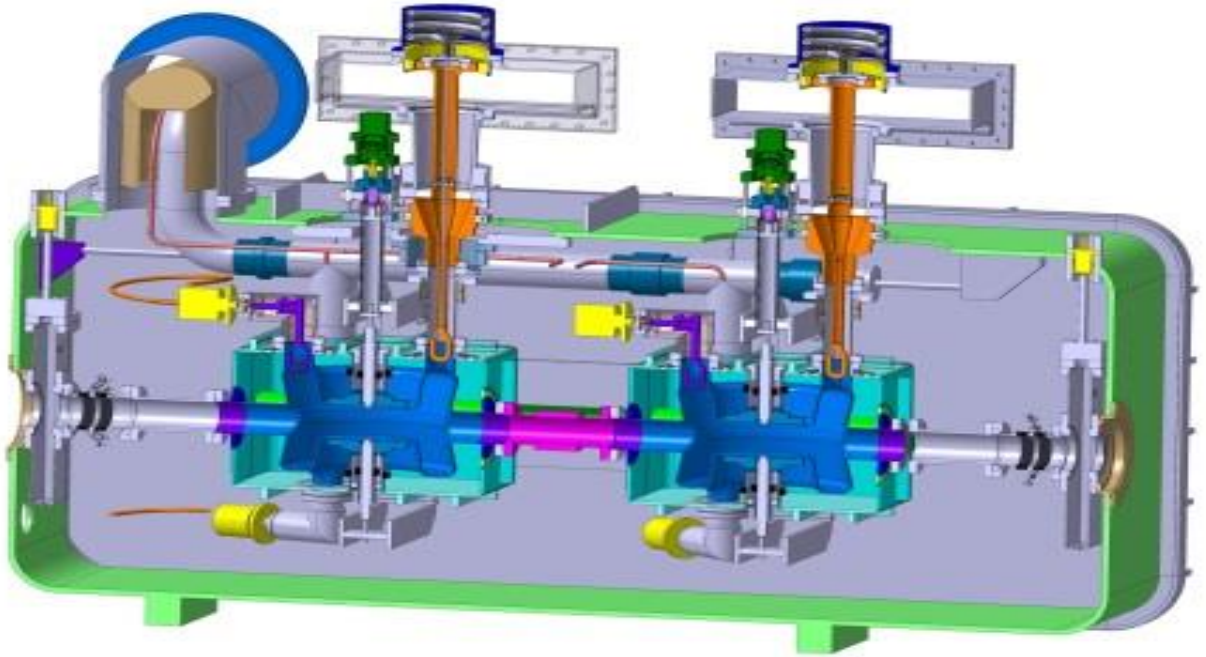
Task 1 Posts

- PDRA 1, Kaveh Delfanizari will spend 50% of his time at CERN participating in the various testing at CERN. He will lead testing on the UK cryomodule at SM18 and will be heavily involved in SPS tests. He is split between tasks 1 and 2.
- PhD student, Adam Tute (already in post) is based at CERN and will focus on SM18 testing, FPC and HOM couplers. He will also be involved in the SPS tests. A. Macpherson will be his CERN supervisor.

WP 2.2 : Cryomodule







- The key goal of this WP is to deliver a UK-led pre-series cryomodule to CERN for testing.
- Also covers the mechanical design of components for the SPS cryomodule.

Task 2: Design and assembly of the pre-series prototype

- Design of Pre-series cryomodules with CERN
- Create drawings for one type of cryomodule
- Purchase 50% of the cryomodule parts (equivalent to one cryomodule)
- Assemble cryomodule and integrate cavities at Daresbury

Milestones and Deliverables

- M2.4 Pre-series cryomodule design review (M24) - Mr S Pattalwar
- D2.2 Design of a pre-series cryomodule for HL-LHC crab cavity (M30 - Drawings) - Mr S Pattalwar
- D2.4 Production of a pre-series cryomodule for HL-LHC crab cavity (M48 - Hardware) - Mr S Pattalwar

Task 2 Posts

- PDRA 1, Kavh Delfanizari, Lancaster will focus on combined EM/mechanical design tasks and thermal analysis. As he will spend 50% of his time at CERN he will be a line of communication with CERN.
- S. Pattalwar will project manage the cryomodule assembly and will lead cryogenic instrumentation, and cold cycling tests.
- Post 4 (N. Templeton) will focus on mechanical design and creating drawings
- Post 5 (T. Jones) will oversee and assist post 4.
- 3 Technicians are required to complete assembly.

Task 3: **Beam dynamics and RF noise studies**

The studies will aim at understanding the impact of crab cavities on beam dynamics in HL-LHC, including:

- instabilities driven by higher (and lower) order modes;
- impact on dynamic aperture and beam lifetime ;
- tolerances on amplitude, and phase set by beam quality specifications.
- Analysis of Crab Cavity RF fault scenarios for LHC and SPS.

Number	Description	Responsibility	Deadline
D1	Report detailing results of benchmarking of crab cavity beam dynamics models against beam tests in SPS.	PDRA	Month 30
D2	Report details SPS crab cavity measurement simulations	PDRA	Month 30
D3	Report detailing estimates of instability thresholds and growth rates in HL-LHC from crab cavity impedance.	PDRA	Month 33
D4	Report describing impact of crab cavities on dynamic aperture in HL-LHC.	PDRA	Month 36
D5	Specification of tolerances on amplitude and phase stability in different operational scenarios.	PDRA	Month 36

Milestones

Number	Description	Relevant Deliverables	Deadline*
M1	Report summarising calculation of transfer functions from electromagnetic models of the crab cavities.	D1, D3, D4	Month 6
M3	Report summarising calculation of crab cavity wake fields/impedance.	D1, D2	Month 9
M2	Report describing representation of transfer functions in a form suitable for implementation in a tracking code (for dynamic aperture studies, or strong-strong beam-beam simulations), including effects of amplitude jitter and phase noise.	D1, D3, D4	Month 12
M4	Report describing implementation of crab cavity wake fields/impedance in models of SPS and HL-LHC.	D1, D2	Month 18
M5	Report summarising beam dynamics results of crab cavity beam tests in SPS.	D1	Month 24

Task 3 Posts

- Post 2 will investigate combined RF/beam dynamics effects and will provide RF support to the other posts
- Post 3 will be a LLRF engineer and will look at LLRF implications of this task.
- Post 6 will look at the effect of beam dynamic models on SPS and HL-LHC
- Post 7 will develop beam dynamics models to be used by post 6.

Resources

The Cockcroft Institute of Accelerator Science and Technology

Also doing a part-time PhD giving an extra 10-15% of his time on HL-LHC

Name	Institute	Type	FY 15/16 Effort	FY 16/17 Effort	FY 17/18 Effort	FY 18/19 Effort	FY 19/10 Effort
G. Burt	Lancaster	Ac	0.1	0.2	0.2	0.2	0.1
A. Dexter	Lancaster	Ac	0	0.03	0.03	0	0
K. Delfanazi	Lancaster	PDRA	0.5	1	1	0.5	0
R. Apsimon	Lancaster	PDRA	0.1	0.2	0.2	0.1	0
Post 3	Lancaster	PDRA	0	0.5	0.5	0	0
S. Pattalwar	STFC	Staff	0	0.5	0.5	0.5	0.5
N. Templeton	STFC	Staff	0	0.9	0.9	0.4	0.7
T. Jones	STFC	Staff	0	0.1	0.1	0.1	0.1
Technician 1	STFC	Staff	0	0	1	1	0.35
Technician 2	STFC	Staff	0	0	1	1	0.35
Technician 3	STFC	Staff	0	0	0.45	0.45	0
R.B. Appleby	Manchester	Ac	0	0.05	0.05	0.05	0.0
Post 6	Manchester	PDRA	0	1	1	1	0
A. Wolski	Liverpool	Ac	0	0.05	0.05	0.05	0
Post 7	Liverpool	PDRA	0	1	1	1	0

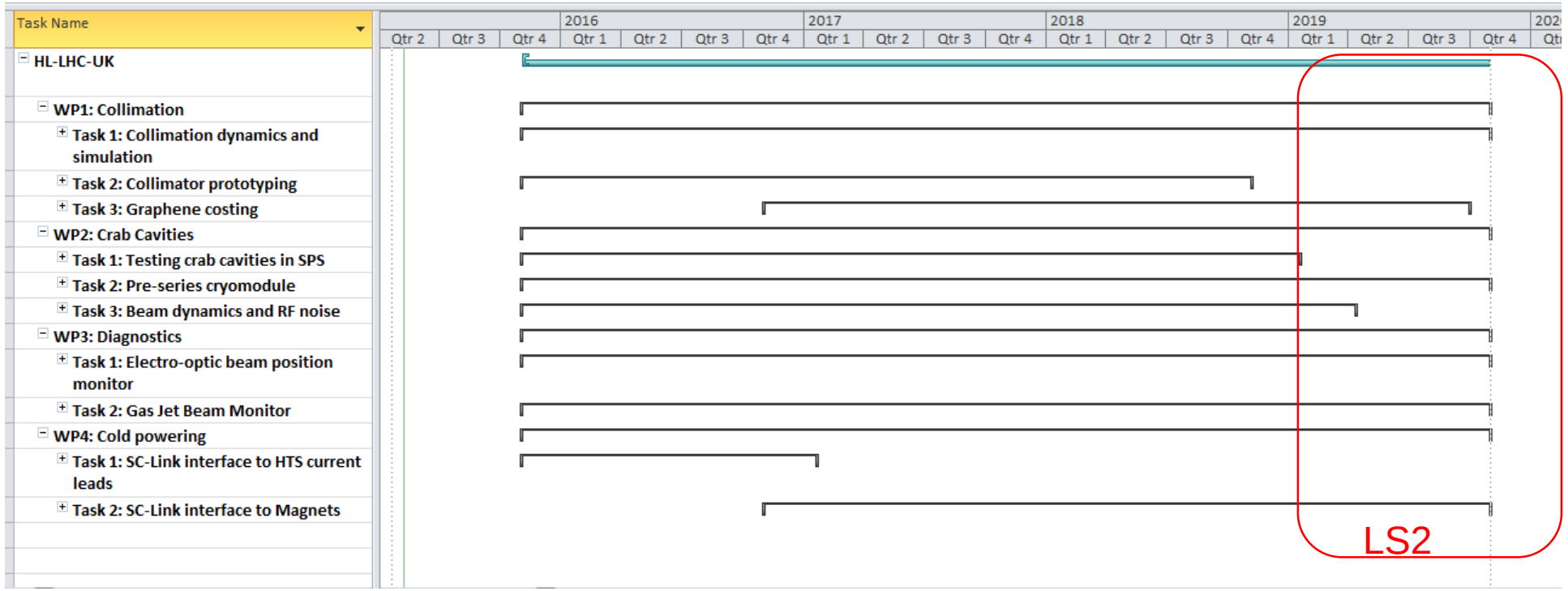
Staff = 17 staff-years + 5.6 technician years
Staff = Task 1 (1.5 years + PhD student), Task 2 (7.9 years + 5.6 technician), Task 3 (7.6 years)
Capital £900,000 for the pre-series cryomodule (Task 2)
Travel = £60k travel + £25k LTA to CERN (pro rata with staff)
PhD students = (2.5 years based at CERN) – (Task 1)

Funding

- Proposal has been recommended for full funding by both the peer review panel and the accelerator board in the UK and by the STFC programmes office
- At this point the proposal is 95% guaranteed funding barring a major reduction of science funding in the UK
- Final decision will be Nov/Dec but is very positive

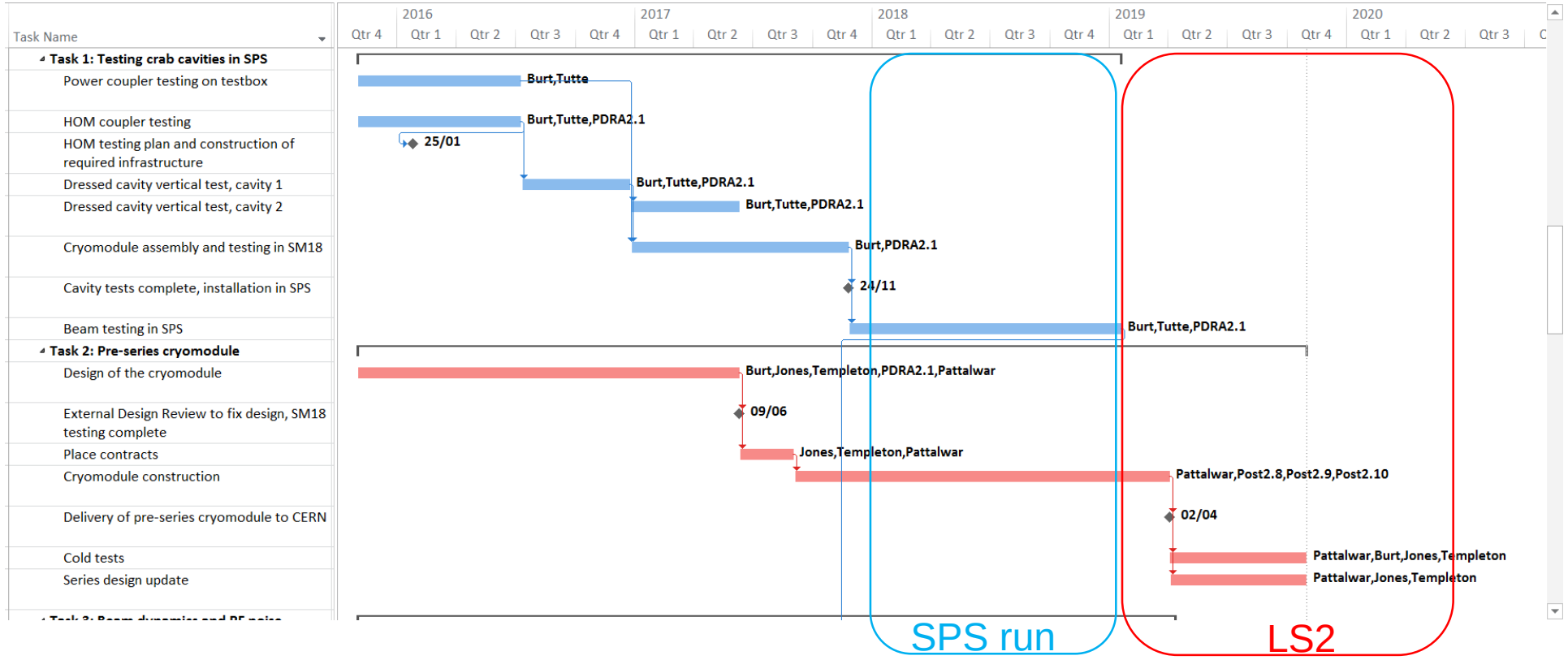
Gantt Chart
and critical path Overall

- The programme is expected to commence on the 1st April 2016 and last 4 years (note this is a 6 month delay from below).
- May need to extend a bit at the end due to pre-series delay



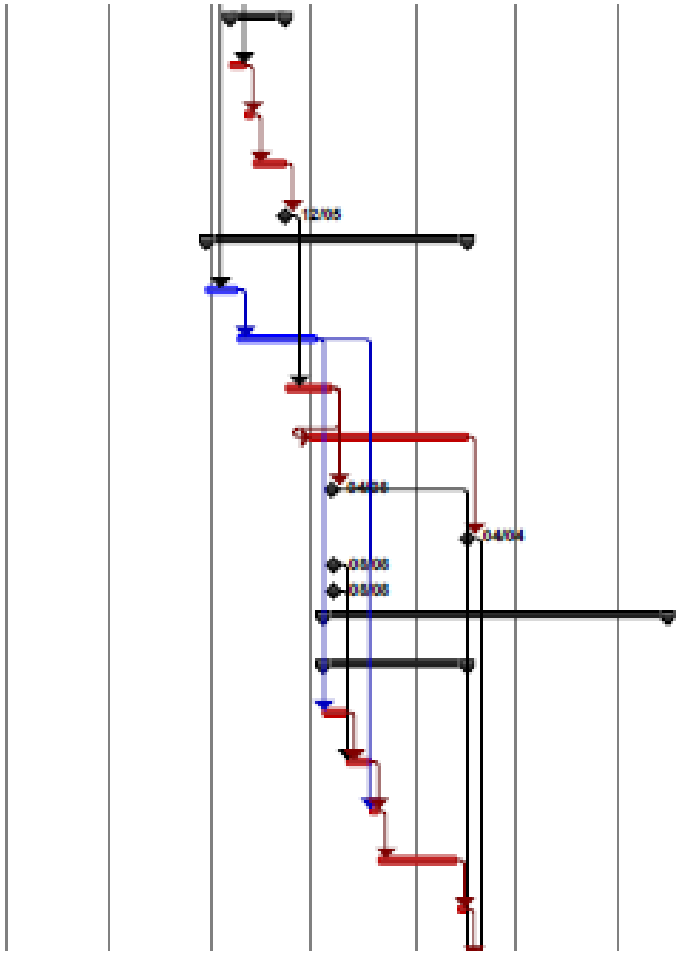
Gantt Chart to WBS2 and critical path WP2

- The gantt chart has been updated to level 2 including participant names.



Detailed WP2 Assembly Plan

General Assembly Tooling	70 days	Fri 03/02/17	Fri 12/05/17		
Lessons learnt from SPS module build and test	20 days	Fri 03/02/17	Thu 02/03/17	30	
Review General Assembly procedure	10 days	Fri 03/03/17	Thu 16/03/17	32	
Modify external tooling design	40 days	Fri 17/03/17	Fri 12/05/17	33	
Tooling design complete	0 days	Fri 12/05/17	Fri 12/05/17	34	
Cryomodule component procurement and manufacture	330 days	Fri 23/12/16	Wed 04/04/18		Graeme Burt,Niklas Templeton,Shrikant Pattalwar,Thomas
Procurement/Tender exercise for components and tooling for Cleanroom Build	40 days	Fri 23/12/16	Thu 16/02/17	26	
Manufacture components and toolingfor Cleanroom Build	100 days	Fri 17/02/17	Fri 07/07/17	37	
Procurement/Tender exercise exercise for outer module components and tooling	60 days	Mon 15/05/17	Fri 04/08/17	35	
Manufacture outer module components and tooling	200 days	Mon 26/06/17	Wed 04/04/18	39FS-30 days	
Crymodule component procurement complete	0 days	Fri 04/08/17	Fri 04/08/17	39	
Cryomodule component manufacture complete	0 days	Wed 04/04/18	Wed 04/04/18	40	
Dressed cavities delivered fully tested to DL	0 days	Tue 06/06/17	Tue 06/06/17		Graeme Burt,Peter Mc
Conditioned coupled delivered fully tested at DL	0 days	Tue 06/06/17	Tue 06/06/17		Graeme Burt,Peter Mc
Assembly of Cryomodule	436 days	Thu 20/07/17	Fri 25/01/19		Assembly manager,N
Cleanroom assembly	182 days	Thu 20/07/17	Wed 04/04/18		
Dry run of assembly procedure with dummy cavity and coupler	30 days	Thu 20/07/17	Thu 31/08/17	38	
Cleaning of beamline components	30 days	Fri 01/09/17	Thu 12/10/17	47,43,44	
Cleaning of helium tank and cavity	10 days	Fri 13/10/17	Thu 26/10/17	38,48	
Cavity string assembly in cleanroom	100 days	Fri 27/10/17	Fri 16/03/18	49	
Final leak check	10 days	Tue 20/03/18	Mon 02/04/18	50	



Conclusion

- HL-LHC-UK is a £8M programme covering crabs, collimators, cold powering and diagnostics
- Funding is very likely to be approved but with a 6 month delay (april16 start)
- For crabs we focus on testing (@CERN), construction of one pre-series cryomodule
- Beam dynamics and LLRF for SPS and for HL-LHC crabs.