International Review of the Crab Cavity System Design & Production Plan for the HL-LHC

- Close-out Presentation –

Review Panel:

Sebastien Bousson (IN2P3), Edward Daly (JLab), Carlo Pagani (INFN), Delio Duarte Ramos (CERN), and Akira Yamamoto (Chair, CERN-KEK)

To be held at CERN, 19-21 June, 2019

https://indico.cern.ch/event/787363/overview

Introduction:

- The **Crab Cavity (CC)** system is a critical equipment in the HL-LHC project.

- The **first tests** with proton beam in a CC were successfully **achieved** in the **SPS** during **2018,**
  - following the construction of the first HL-LHC CC cavities at CERN and in the US, and the crash program for the SPS DQW cavity cryomodule construction and installation in the new SPS facility,
- The ***system integration*** design, of CC and the complete cryomodule (CM), is **being finalized**, both for **DQW** (double quarter wave) and **RFD** (RF Dipole) types,
  - while the construction of a second complete CM prototype for RFD is under construction by CERN and UK.

- The **in-kind contributions** for CC and CM are **agreed** or in **final negotiation** stage from:
  - US-AUP (all dressed cavities of RFD type),
  - UK-STFC and Lancaster Univ. (4 DQW cryomodule assemblies) and
  - Canada-TRIUMF (5 RFD cryomodule assemblies).
- The **construction** of the **DQW** **jacketed cavities** by Industry for CERN is already **under way.**

Tasks given to Panel:

- The project management calls this review to assess:
  - Is the **present design** adequate to meet the required performance,
    - for the CC system integration with their cryomodules, HPRF, LLRF, and other services, including some updates since 2014?
  - Is the **production plan** well harmonized with due margin,
    - considering the complex scheme with many in-kinds in the HL-LHC schedule?

Mandate for the 2019 CC Review

summarized by R. Calaga, 190619

CQ	Subject
CQ1	SPS-CC experience & lessons learned to be implemented into HL-LHC CC
CQ2	SPS beam tests & extrapolation to HL-LHC, open questions ? Readiness of RFD pre-series cryomodule?
CQ3	Readiness for series production? Open points being addressed implying changes
CQ4	Status of HPRF, LLRF and other auxiliary components, do we need further attention over the coming years?
CQ5	Baseline schedule including collaborations w.r.t HL-LHC schedule? Management of in-kind and preparations for work framework – risks for production/testing ?
CQ6	Is CERN ready to finalize the agreements (status of acceptance criteria & procedures of different sub-components)
CQ7	QA/QC and risks for deliverables between partner labs

Responses to CQs are to be given in the Review Panel Report.

Executive Summary

- The international review of the Crab Cavity (CC) performance for HL-LHC was held at CERN on 19 – 21st June 2019. The Committee is very impressed with the significant progress and excellent reports of the international joint effort for excellent results in development of CC technologies being prepared for HL-LHC CC system construction.

- We sincerely congratulate the collaboration on outstanding progress with the DQW CC test at SPS, in particular for the first demonstration of crabbing of the proton beam, as the historical and very important milestone achieved with excellent team work in a very short period of time.

- We acknowledge that the international collaboration has been further reinforced and strengthened toward the HL-LHC CC construction stage in cooperation of CERN, US-AUP, UK, and Canada.

Comments – Preliminary (1/4)

- We agree with the current strategy and plan for CC system development employing two complementary CC designs, Double Quarter Wave (DQW) and RF Dipole (RFD), with an unified concept of the CryoModule (CM) design allowing common physical interfaces to RF, vacuum, instrumentation and cryogenics systems.
  - The approach meets complementary requirements for horizontal and vertical crabbing in the two interaction regions at the HL-LHC, allowing in principle to be exchanged in the future depending on physics requirements.
- The DQW cavity prototype in-house development at CERN and subsequent test results at SPS CERN demonstrated the crabbing capability and that there are no adverse affects on beam operations caused by the CC structures which can be made transparent to the beam.
  - This result is a crucial demonstration and retires a significant project risk.
- The RFD cavity prototype developed first with US-LARP and finally through AUP has been successfully demonstrated in vertical tests.

Comments – Preliminary (2/4)

- The CM design and development has made good progress in the CERN and UK collaboration. The effort will be reinforced with the Canada-TRIUMF participation.
- We recognize the very much impressive collaboration working very hard to proceed the cavity system development including CC with ancillary, CM, HPRF, LLRF, control, cryogenics, and further general services, and testing at SM18 and SPS.
- First demonstration of FSI system and non-contact survey/alignment technique is quite impressive. It enables observation of actual cold mass movement and eliminates need for sometimes complicated mechanical solutions.
- In many cases, CM designs presented are between preliminary and final design phases. Subsystem design development appears to be well-coordinated and integrated.

Comments – Preliminary (3/4)

- Performance testing of DQW and RFD cavity systems has been very good to date. Focus of tests includes both cavity intensive properties as well as gaining understanding of cavity system parameters.
- There is concern regarding the potential cause of tuner performance issues that were discovered during SPS CM testing.
- Progress on engineering analysis for several sub-systems was presented. In some cases, preliminary analyses don't necessarily include all operational conditions that can be expected (e.g. thermal and magnetic shields cool-down and warm-up).
- The proposed plan for RFD CM production ramp up includes using prototype dressed cavities for TCM-0 (mock up CM) at TRIUMF. This proposal may help to improve the RFD production CM delivery schedule.

Comments – Preliminary (4/4)

- The project goal in terms of number of components to produce is clear - for each CC type, four CMs at the nominal performances, that will be installed in LHC, and one additional of each type that will be a spare. We recognize it to be also ready ready to be installed during LS3, if needed.

- The overall project management approach and quality assurance plan instituted at CERN is well-organized. It contains elements that allow monitoring and maintaining technical, cost and schedule baselines. This is a good basis for project integration amongst the partners.

Recommendations – Preliminary (1/2)

- Validate RFD system performance with beam at SPS at the earliest practical opportunity after LS2.
- Perform full set of RFD CM tests at SM18 allowing sufficient time to consider all acceptance criteria.
- Extend testing of the already-installed DQW CM to validate the integrated CC system performance parameters in the SPS concentrating on technical aspects such as voltage reach and quench behavior with beam, and integrated cavity system testing.

- Perform analysis and testing on components, for the CC system, which have incremental design changes (e.g. change in HOM antenna material, 25 Ohm feedthroughs, etc.).

Recommendations – Preliminary (2/2)

- Complete thermo-mechanical analyses including warm-up and cool-down scenarios and detailed design, include lessons learned from SPS testing and then conduct internal design reviews prior to initiating procurements for CM components.
- Establish and agree on acceptance criteria (including how to measure) for parts, components and systems. This may require completion of technical specifications in some cases.
- Consolidate the plan to clearly establish how many components of each type will be produced in order to assess the risks to achieve nominal performance on all CMs (yield vs. spares for critical components).
- Evaluate possibility and implement for adding equipment (heaters, valves, etc.) to enable thermal cycle to de-gas CCs, so called “independent warm-up & cool-down”.
- Complete remaining high-level inter-laboratory agreements in order to formally identify in-kind contributions and scope of work.

Many thanks for your cooperation and warmest hospitality

Appendix

Agenda: 19-pm: General and SPS exp.

https://indico.cern.ch/event/787363/overview

	Subject	Reported by	Focused by
	* Executive Session		
1	Introduction and Overview	L. Rossi & O. Bruning	
2	Overview of WP4-CC in HL-LHC	Rama Calaga	
3	WP4 Strategy for CM	Ofelia Capatina	
4	WP4 Strategy for RF system	Eric Montesions	
5	WP4 Strategy for (SPS) Integr. & HL-LHC interface	Giovanna Vandoni	
	Coffee break		
6	US contribution to SPS CC prototype & Lessons Learned	Alessandro Ratti	
7	CERN-Crash Program for SPS-DQW CM	Marco Garlasche	
	* Discussions		

Agenda: 20-am: SPS lesson to outlook for HL-LHC

	Subject	Reported by	Focused by
11	Vacuum layout & experience from SPS	Chiara Pasquino	
12	Cryogenics experience from SPS	Krzysztof Brodzinski	
13	SPS experiment with beam	Lee Robert Carver	
13	HOM damping & SPS measurements	James Alexander Mitchell et al.	
	Group Photo and Coffee Break		
15	Freq. tuning system & lessons learned	Kurt Artoos	
16	LLRF experience for SPS & HL-LHC outlook	Philippe B audrenghien	
17	APA-CC operation challenges/Limitation & outlook for 2021	Rama Calaga	
18	Machine protection lessons learned from SPS	Daniel Wollmann	
	Discussions		

Agenda: 20-p: CC production and CM design

	Subject	Reported by	Focused by
21	CERN RFD-SPS cavity manufacturing status	Marco Garlashe	
22	CERN/RI DQW-Series Cavities for HL-LHC CC	Nuria Valverde Alonso	
23	US-AUP RFD Dressed Cavities for HL-LHC CC	Leonardo Ristori et al.	
24	CERN FPCs & Other Couplers for HL-LHC CC	Eric Montesinos	
25	US-AUP RFD Couplers for HL-LHC CC	tbd	
	Coffee Break		
26	HL-LHC CC Cryomodule Design	Teddy Capelli	
27	SPS-RFD & Series DQW Cryostating Plans	Thomas Joseph Jones	
28	Series RFD Cryostating for HL-LHC CC	Robert Laxdal	
29	Transport Aspects	Kurt Artoos et al.	
	Discussion		

Agenda: 21-am: Services

	Subject	Reported by	
31	SM18 Assembly and Testing Infrastructure	Katarzyna Turaj	
32	LHC Environment Constraints & Integration	Paolo Fessia	
33	Vacuum for HL-LHC CC	Germana Riddone	
34	Cryogenics for HL-LHC CC including sectorization	S. Claude, K. Brodzinski	
35	Alignment & Monitoring from SPS to HL-LHC	Mateusz Sosin	
	Discussion		
	Coffee Break		
36	RF Conditioning Strategy during HL-LHC	Eric Montesinos	
37	Tech. Spec. & Guidelines for Compl. w/ CERN Safety Rules	Luca Dassa	
38	WP4 QA/QC Status, Risks & Documentation	Isabel Bejar Alonso	
+	Coodination for HL-LHC CC construction and Int'l collab.	O. Bruning, R. Calaga	
	Discussions		

1) Rama Calaga

Past Reviews & Outcome

- **May 2014**: Cavity design review
  - Led to down selection to 2 cavities (DQW, RFD) for SPS/LHC
- Feb 2015: 1st HOM coupler review
- Mar 2015: Cost & Schedule review I
  - Study the effect of only ½ of system (16 instead of 32)
- May 2015: CERN-STFC Helium vessel review
- **Nov 2015**: SPS Cryomodule review
  - Develop minimum goal for SPS tests, review individual critical components, integrated production/test planning including infrastructure
- Oct 2016: Clean room assembly review
- Oct 2016: Cost & Schedule review II
  - Reduction to ½ system, HPRF 40 kW-CW
- Nov 2016: Operational safety review in SPS
- **April 2017**: Crab cavity performance review for HL-LHC
  - Perform SM18 tests prior to SPS with minimum success criteria, establish formal agreements, specifications, acceptance criteria and interfaces
- Mar 2018: Cost & Schedule review III
  - Endorsed with new strategy (UK, US-AUP, Canada)

HiLumi HL-LHC PROJECT CERN

Note: 2 SPS tests days jointly with WPs concerned for MD preparation

Review Panel Members and Link-Persons:

- **Panel members**:
  - Edward Daly (JLAB), Carlo Pagani (INFN), Sébastien Bousson (IN2P3), Delio Duarte Ramos (CERN), and Akira Yamamoto (Chair, CERN-KEK),

- **Link persons:**
  - R. Calaga (CERN), T. Jones (UK-STFC), B. Laxdal (TRIUMF), L. Ristori (US-AUP)