CERN
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the
Future
Circular
Collider
project

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Work Package Description

FUTURE CIRCULAR COLLIDER

RF R&D ACTIVITIES

Abstract

Superconducting radiofrequency (SRF) accelerating structure is a key technology for future colliders at the energy frontier, for which the wall-plug efficiency will be one of the biggest challenge.
This document describes the FCC SRF Work Package. The objective of this WP is to identify the ultimate limits, the showstoppers and define the R&D topics that need to be addressed in order to optimize the SRF technology for large superconducting RF system.
This document compiles the sub-WP items with definition of scope, deliverables and milestones. CERN resource impact has been evaluated in order to provide feedback to potential international partners.

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History of Changes

Rev. No.	***Date***	***Pages***	***Description of Changes***
0.0	2015-03-24	All	Initial submission
0.1	2015-04-27	All	Rama’s comments& corrections added
0.2	2015-05-05	10	Eric’s WP description added
0.3	2015-05-20	All	Reshuffled after discussion with Erk and Karl
0.4	2015-06-05	1-2	CERN-STFC-LNL Collaboration Agreement WP1
0.5	2015-09-18		CAVITY FABRICATION -HIGH VELOCITY FORMING OF SUPERCONDUCTING RF STRUCTURES transferred from STP WP

Table of Contents

1 COLLABORATION AGREEMENT "KE2722/BE/FCC" (P. CHIGGIATO)

1.1 FRAMEWORK FOR SCIENTIFIC COLLABORATION IN SUPERCONDUCTING RF CAVITIES TECHNOLOGY						
Participant	CERN	STFC	LNL			
Person months						
Type	All types					

Objectives

1) Establish a framework for scientific collaboration in Superconducting RF cavities technology with the aim to combine expertise, to achieve scientific goals and to develop common specialized knowledge
2) Investigate innovative cavity fabrication techniques and evaluate the ultimate performance of 800 MHz 5 cell cavities

Description of Work

The FCC RF system will be made up of a large number of accelerating cavities. Cavity design, fabrication and performance are key R&D topics.

The contributions to the collaboration are defined as follow:

Task 1 (CERN):

a) RF design of the 5-cell 800 MHz cavities.
b) The supply of the High Purity OFHC Copper material required for the cavity forming in the size required by INFN.
c) Development of the full infrastructure for the niobium sputter-coating of 5-cell 800 MHz copper cavities:
   a) The design, manufacturing and operation of a surface processing bench for the chemical and/or electropolishing of 5-cell 800 MHz copper cavities prior to coating.
   b) The design, manufacturing and operation of a coating bench for such cavities, based on current the state of the art for magnetron niobium coatings of elliptical cavities.
   c) The design, manufacturing and operation of a cryogenic RF test bench for such cavities.

   To these purposes CERN will execute all relevant studies, material procurement and analyses, prototyping and tests as seen fit for the purpose.

Task 2 (INFN):

a) The fabrication of four seamless 800 MHz 5-cell copper cavities
b) The development of surface processing and coating techniques on seamless 6 GHz cavities, in view of a possible application to 800 MHz cavities, including: the role of the microstructure of niobium at the interface between copper and niobium, the effect of the high deposition temperatures on SRF properties of niobium, the study of improved

deposition magnetron sources for the niobium deposition, and the study of thermal boundary resistance between copper and liquid helium.

c) INFN will also investigate the possible application of either spinning, back-extrusion or alternative seamless fabrication techniques for the production of a single-cell 400 MHz cavity. For these initial investigations the technical drawings of the LHC 400 MHz cavity will be provided by CERN. In collaboration with CERN an optimisation of the cavity design (HOM coupler, FPC, etc.) will be considered. These investigations should be summarised in a feasibility report including first estimates of tooling cost and providing the basis for prototyping activities
d) For the achievement of these goals, INFN will be free to subcontract part of the work to Consorzio Futuro in Ricerca (CFR). CFR has been traditionally collaborating for years with INFN, through the support and coordination of students, scientific fellows, young researchers and foreign experts, that have contributed to the performance of R&D on superconducting cavities, in the framework of a Master Programme called "Surface Treatments for Industrial Applications" promoted by INFN and the University of Padua.RF design of the 5-cell 800 MHz cavities.

Task 3 (STFC):

a) Microscopic and surface characterization of samples produced by the other parties, representing either routine or innovative surface preparation processes or coating.
b) Development of in-house 3D Nb/Cu coating capabilities.

Deliverables	**Month**
D1: - 6 GHz cavities: delivery of 15 units completed - 800 MHz cavities: toolings for 800 MHz production ready	**M12**
D2: - 6 GHz vacities: delivery of units 16 to 28 completed - 800 MHz cavities: first 800 MHz cavity module ready - 400 MHz feasibility study: intermediate report on study status	**M24**
D3: - 6 GHz vacities: delivery of units 29 to 32 completed - 800 MHz cavities: all 4 800 MHz cavity modules ready - Feasibility study for 400 MHz production available	**M48**
CERN Resources (Manpower) [Person. Months (PM)]	
STAFF	
FELL/PJAS	
PhD	
CERN Resources (Material) [kCHF]	
Total budget (details in KE2722/BE/FCCAnnex 2): *Year 1* *Year 2* *Year 3*	**xx** *xx* *xx* *xx*

Year 4 *to INFN (450 000 EUR)* *To STFC (104000 GBP)*	*xx* *470 000* *150 000*

2 CAVITY DESIGN (R. CALAGA)

2.1 CAVITY DESIGN						
Participant						
Person months						
Type						
Objectives						

Define a viable cavity design for the FCC-ee and FCC-hh RF system to cover the requirements for both the highest accelerating gradient and very high beam currents with the same machine. A possible design and layout of a 2^{nd} harmonic cavity system to provide landau damping or bunch profile manipulation.

Description of Work

Detailed study on the RF scenarios, optimum gradient and staging, RF frequency choice, cavity shape and aperture optimization, number of cells and cavities/c ryomodule layout, and cryogenic loads. Study of variable Qext fundamental power couplers would seem to be desirable for energy efficiency

Task 1: Evaluate and detail the requirements for the possible scenarios
Task 2: Study cavity design and HOM damping and power extraction concepts
Task 3: Study FPC concepts and options (fixed vs variable couplers)

Deliverables	**Month**
D1: Concepts and parameters	**M12**
D2: Cavity and layout design	**M24**
D3: Document results	**M48**
CERN Resources (Manpower) [Person. Months (PM)]	
STAFF A. Butterworth R. Calaga	**9** *1* *2*
FELL/PJAS	**36**
PhD	**0**
CERN Resources (Material) [kCHF]	
Total budget: *Travels* *Material budget for PHD student*	**20** *10* *10*
Arbitration decision	

2.2 CAVITY IMPEDANCE AND HOMS						
Participant						
Person months						
Type						

Objectives

Impedance estimates from RF cavities and stability limits for the different lepton and hadron schemes.

Description of Work

Cavity impedance and HOMs are expected to be a major issue at the Z pole, and might dictate to a large extent the RF system design. Therefore, comprehensive impedance estimates for the different cavity layouts and staging of the RF system, HOM charaterization and power calculations including tapers and other cold to warm transitions are necessary. The conformity of the RF structures within the stability limits with adequate HOM damping should be verfied.

Task 1: Define the impedance budget for both broadband and narrowband impedances
Task 2: Evaluate longitudinal and transverse impedance spectra for cavities with damping
Task 3: Evalaute the effects of large HOM power losses

Deliverables	**Month**
D1: Concepts and parameters	**M12**
D2: Impedance budget and stability criteria for various scenarios	**M24**
D3: Document results	**M48**
CERN Resources (Manpower) [Person. Months (PM)]	
STAFF	**9** *1* *2*
FELL/PJAS	**36**
PhD	**0**
CERN Resources (Material) [kCHF]	
Total budget:	**20** *10* *10*
Arbitration decision	

3 CAVITY MATERIAL AND PERFORMANCE (WALTER VENTURINI DELSOLARO)

3.1 SUPERCONDUCTING MATERIAL DEVELOPMENTS

Participant	CERN	UNIGE	HZB	TUW	TRIUMF?	JLAB?
Person months						
Type						

Objectives

Investigation of classical and novel materials for their RF performance limits at moderate to high fields, at frequencies in the 400–800 MHz range.
Study of BCS and extrinsic sources of RF loss (surface preparation prior to RF test, thermal treatments, flux expulsion, thermal currents).

The method followed will be to systematically characterize the material parameters influencing the surface resistance (microstructure, chemistry, l, λ, ξ, Hc1, etc), and relate them to the RF performance and to the production and test parameters.

A key objective is to mitigate the Q-slope in SC thin films up to 10-15 MV/m.
The final goal is coating FCC cavities with competitive performance/cost as compared to the bulk Nb technology.

Description of Work

SC thin films: the Nb-Cu technology is the Laboratory hallmark for SRF cavities. After the era of LEP2 and LHC based on magnetron sputtering, it has been revived for the HIE-ISOLDE post accelerator, where a bias sputtering method was used. The community is presently focusing on energetic condensation methods, of which HIPIMS is favorite at CERN. The initial baseline material choice for FCC is Nb-Cu.

Beyond Nb-Cu, alternative materials (A15, multilayers) are promising in the timeframe of FCC and will therefore be actively researched.

Bulk-Nb: the workhorse of SRF worldwide is a mature technology, with some novel developments coming on the stage recently (Ti and N doping).
The measurement techniques, analysis methods and underlying SRF physics are largely common to SRF thin films.
In the framework of SRF for FCC the scope for bulk Nb is limited to establish state of the art infrastructures and performances, providing a standard to enable comparisons with novel materials.

The WP is structured into the following tasks:

Task 1: Cu surface preparation prior to coating
Task 2: DC and AC sample characterization
Task 3: RF measurements and diagnostic tools
Task 4: Nb-Cu coatings

Task 5: Alternative materials: A15 coatings
Task 6: Preparation and test of bulk Nb surfaces

Deliverables	**Month**
D1a: Document on Cu surface preparation protocols	**M22**
D1b: Tumbling system (tbc)	**?**
D2a: Document on l, λ, ξ, Tc, Hc1, and microstructure measurements	**M22**
D2b: Inductive Tc/RRR measurement bench at CERN with cryocooler	**M26**
D2c: Nb-Cu sample studies: DC/AC vs coating parameters correlations	**M32**
D3a: Document on RF surface impedance measurements	**M22**
D3b: Digital multi frequency LLRF system for high Q measurements	**M26**
D3c: Variable coupler system for vertical cryostat tests	**M26**
D3d: Test bench for monocell 800 MHz FCC type cavity	**M32**
D3e: Temperature mapping system for FCC cavites	
D3f: Magnetic field mapping system for FCC cavites	**M32**
D4a Nb-Cu and bulk Nb sample studies: DC/AC vs RF correlations	**M32**
D4b: Commissioning of refurbished 1.3 GHz coating bench (DC magnetron cavity test)	**M24**
D4c: Measurement of first bias-HIPIMS 1.3 GHz cavity	**M26**
D4d: Optimized biased HIPIMS for 1.3 GHz cavites (finalized protocol with coating parameters and procedures, supported by RF tests)	**M30**
D4e: Installation and commissioning of coating bench for FCC cavities	**M34**
D4f: Coating of a single cell FCC Nb-Cu cavity (800 MHz)	**M47**
D4g: Measurement of a single cell FCC Nb-Cu cavity (800 MHz)	**M48**
D4h: Measurement of a prototype FCC cavity (400 MHz)	**M48**
D5a: Sputtering A15 onto copper samples with good superconducting dc properties	**M20**
D5b: Sputtering of A15 on copper substrate for Quadrupole Resonator	**M26**
D5c: Coating of FCC single cell cavity with A15	**M38**
D5d: Coating FCC cavity with A15	**M48**
D6a: test of monocell 1.3 GHz bulk Nb (reference cavity)	**M24**
D6b: test of monocell FCC cavity bulk Nb (reference cavity)	**M30**

CERN Resources (Manpower) [Person. Months (PM)]	
STAFF	**70** *0* *0*
FELL/PJAS	**108**
PhD	**36**
CERN Resources (Material) [kCHF]	
Total budget estimate:	**600** *0* *0*

Arbitration decision

4 CAVITY FABRICATION (KARL SCHIRM)

4.1 HIGH VELOCITY FORMING OF SUPERCONDUCTING RF STRUCTURES

Participant	CERN	Bmax (FR)				
Person months	**56**					
Type	All types					

Objectives

1. Thorough understanding of the electro-hydraulic forming process applied to copper and niobium geometries for Superconducting RF structures.
2. Characterisation and modelisation of copper and niobium for fast forming.
3. Production of a niobium functional structure.

Description of Work

Superconducting RF (SRF) structures are traditionally fabricated from sheet metal formed using a wide range and combination of techniques: spinning, deep drawing, necking and hydroforming. The metals involved are pure niobium as well as Oxygen free OFE copper typically used for preliminary trials. Geometries used for SRF cavities can be axisymmetric (e.g. LHC, ILC, SPL) or non-axisymmetric (e.g. HL-LHC crab cavities). Electron-beam welding is typically used to join formed structures to obtain the final geometry.

The possible forming techniques can be compared along different characteristics of merit: complexity of set-up, equipment and dies, precision of formed geometry, regularity of formed thickness, metallurgy, reproducibility of results, cost.

High-velocity forming is a potentially alternative process. It involves a high-strain rate deformation, through a process lasting a few milliseconds, that allows reaching higher formability (larger plastic deformation, smaller springback). Applications to copper and niobium have only recently been started using electro-hydraulic forming (EHF). Advantages are expected in metallurgy, geometrical precision, reproducibility, suitability for economic, large series production.

The project proposal aims to study and apply this technology initially for the application to HL-LHC crab cavities, combining the competences at CERN of EN/MME (the Engineering Department / Mechanical and Materials Engineering Group) and BE/RF (the Beams Department/Radio-Frequency Group) with the industrial partner Bmax (in Toulouse, France). EHF could allow the design of the crab cavity – as well as developing Future Circular Collider (FCC)-type SRF structures - to be optimised using fewer parts and welds positioned in lower field areas.

EN-MME, will use its internal resources in:

- Engineering and mechanical design
- Numerical modelling and simulation of the EHF process relying on the experience gained with explicit FEM methods and hydrocodes like LS-Dyna and Autodyn.
- Materials, metallurgy, SEM/FIB analysis

- Mechanical testing including high-strain rate characterization of the materials (possibly exploiting the agreement between CERN and Politecnico di Torino which is leader in this field).
- CMM metrology
- Machining and sheet metal forming
- Electron beam welding to assemble the final structure

EN-MME would work closely in collaboration with BE-RF physicists and engineers.

Bmax would also perform advanced simulation and modelling work, and contribute their specific know-how in electro-hydraulic forming.

The result of the study is expected to be a thorough understanding of the process and the identification and influence of its parameters on copper and niobium, as well as a complete HL-LHC crab cavity prototype (in copper and/or niobium). In particular, the development of microstructure and of physical (e.g. Residual Resistivity Ratio, RRR) and mechanical properties induced by the regime of strain rates associated to the EHF process will be investigated as a function of the process parameters in the whole temperature range relevant for the application.

It should allow to introduce high velocity forming as a qualified, referenced alternative for the forming of accelerating structures throughout laboratories world-wide.

Task 1: learning period, first simple EHF tests on copper and simple geometries
Milestone 1: Identification of key project issues and required contributions.
Deliverable 1: Report on the state of sheet metal forming for SRF applications, potential of EHF, state-of-the-art, detailed project plan for numerical simulation, forming, testing.

Task 2: project programme
Milestone 2: production of simulations and formed components
Deliverable 2: Report covering EHF tests, comparisons with numerical simulations, testing and qualification of produced structures in copper and niobium.

Task 3: application of know-how to structural components
Milestone 3: production of a functional, complex geometry SRF component in niobium
Deliverable 3: Final structural component, summary report of findings.

Deliverables	**Month**
D1. First simple EHF tests	**M6**
D2. Project programme	**M24**
D3. Application of know-how to structural components	**M6**
CERN Resources (Manpower) [Person.Months (PM)]	
STAFF 5 PM/year	**20**
FELL/PJAS (starting mid-2015)	**36**
PhD	**0**
CERN Resources (Material) [kCHF]	
Total budget estimate for test bench, PCBs, components and FSU *Year1* *Year2*	**275** *50* *50*

Year3 *Year4*	*100* *75*
Arbitration decision	
Transferred form STP to RF as part of the "SPL" activities. Resolutely takes up a technological challenge for the production of large series of cavities. Fellow -> Nov '15	

5 CRYOMODULE CHALLENGES (KARL SCHIRM)

5.1 CRYOMODULE DESIGN						
Participant						
Person months						
Type						
Objectives						
- Cavity/Cryomodule Layout (Number of cavities, cold-to-warm transitions) - Cryogenic budget estimate (static/dynamic) - Helium vessel and interfaces, tuning system, magnetic/thermal shielding - Vacuum vessel design, structural support, alignment						
Description of Work						

Deliverables	**Month**
D1: ..	**M12**
D2: ..	**M24**
D3: Document results	**M48**
CERN Resources (Manpower) [Person. Months (PM)]	
STAFF	**0** *0* *0*
FELL/PJAS	**0**
PhD	**0**
CERN Resources (Material) [kCHF]	
Total budget estimate:	**0** *0* *0*
Arbitration decision	

5.2 FUNDAMENTAL POWER COUPLERS						
Participant						
Person months						
Type						

Objectives

Define a design for the FCC-ee RF system to cover the requirements for both the highest accelerating gradient and very high beam currents with the same machine.
How to build a variable coupler covering the Qext range ?
Do we have to have two different fixed couplers ?

Description of Work

Detailed study on the RF FPC:
How to build a variable FPC covering the Qext range ?
Do we have to have two different fixed couplers ?

Task 1: Study FPC concepts and options, fixed vs variable couplers

Deliverables	**Month**
D1: RF Simulations	**M24**
D2: 3D model	**M48**

CERN Resources (Manpower) [Person. Months (PM)]	
STAFF E. Montesinos A. Boucherie	**12** *6* *6*
FELL (1 x TTE)	**30**
PhD	**0**

CERN Resources (Material) [kCHF]	
Total budget estimate: Travels Mockups	**60** *10* *50*

Arbitration decision

5.3 TUNING SYSTEM AND AUXILIARIES						
Participant						
Person months						
Type						

Objectives
-
Description of Work

Deliverables	**Month**
D1: Concepts and parameters	**M12**
D2: Components and design	**M24**
D3: Document results	**M48**
CERN Resources (Manpower) [Person. Months (PM)]	
STAFF	**9** *1* *2*
FELL/PJAS	**36**
PhD	**0**
CERN Resources (Material) [kCHF]	
Total budget estimate:	**20** *10* *10*
Arbitration decision	

6 LLRF SYSTEM (W. HOFLE)

6.1 FAST CAVITY FEEDBACKS FOR COUPLED BUNCH MODES. CAVITY TRIP HANDLING – IMPEDANCE MITIGATION						
Participant						
Person months						
Type						
Objectives						
-						
Description of Work						
Strong RF feedback will be necessary for Z pole running to suppress coupled bunch modes driven by the fundamental cavity impedance						

Deliverables	**Month**
D1: Concepts and parameters	**M12**
D2: Components and design	**M24**
D3: Document results	**M48**
CERN Resources (Manpower) [Person. Months (PM)]	
STAFF	**0** *0* *0*
FELL/PJAS	**0**
PhD	**0**
CERN Resources (Material) [kCHF]	
Total budget estimate:	**20** *10* *10*
Arbitration decision	

7 POWER SYSTEM (TBD)

7.1 POWER DISTRIBUTION SYSTEM FOR FCC-EE						
Participant						
Person months						
Type						

Objectives

- Conceptual design of the RF power distribution for FCC-ee

Description of Work

The possible RF power distribution scenarios shall be elaborate and detailed in the light of the results of WP 1.1.
In particular a review of the existing technology shall be presented:

- Solid state amplifiers
- IOT's
- Klystrons

Task 1: Evaluate and detail the possible scenarios (including estimation/comparison of cost & efficiency)
Task 2: Simulate, design and built a movable l/4 WG transformer (prototype)

Deliverables	Month
D1: Concepts and parameters	**M12**
D2: Components and design	**M24**
D3: Document results	**M48**
CERN Resources (Manpower) [Person. Months (PM)]	
STAFF	**3**
FELL/PJAS	**36**
PhD	**0**
CERN Resources (Material) [kCHF]	
Total budget estimate:	**50** *0* *0*
Arbitration decision	
Second priority. To be reassessed when RF system is defined.	

7.2 HIGH VOLTAGE CHALLENGES FOR THE HIGH POWER RF SYSTEM

Participant						
Person months						
Type						

Objectives

Modernize aging technology and develop robust and reliable HV equipment for the HPRF system (e.g. klystron modulators, fast protection system)

Description of Work

Work ongoing for LHC – to be reassessed at a later stage

Deliverables	**Month**
D1:	**M12**
D2:	**M24**
D3:	**M48**

CERN Resources (Manpower) [Person. Months (PM)]

STAFF	
FELL/PJAS	**0**
PhD	**0**

CERN Resources (Material) [kCHF]

Total budget estimate:	**0** *0* *0*

Arbitration decision

Addressed in the framwork of the LHC operation

7.3 DEVELOPMENT OF VERY HIGH EFFICIENCY KLYSTRONS

Participant						
Person months						
Type						

Objectives	
Development of klystrons with ultimately high - 90% RF power production efficiency	
Description of Work	
Using new bunching theory 90% (at least in simulation) looks possible for FCC/CLIC/ESS klystrons Low voltages achievable No new technology, simply a design breakthrough Prototypes and further validation required International collaboration at work	
Deliverables	**Month**
D1: Concepts and parameters	**M12**
D2: Components and design	**M24**
D3: Document results	**M48**
CERN Resources (Manpower) [Person. Months (PM)]	
STAFF	**0** *0* *0*
FELL/PJAS	**0**
PhD	**0**
CERN Resources (Material) [kCHF]	
Total budget estimate:	**0** *0* *0*
Arbitration decision	
Addressed in the framwork of the CLIC project	

7.4 SOLID STATE AMPLIFIERS

Participant						
Person months						
Type						

Objectives	
High power solid state amplifiers technology – start of the art, advances & perspectives	
Description of Work	
Deliverables	**Month**
D1:	**M12**
D2:	**M24**
D3:	**M48**
CERN Resources (Manpower) [Person. Months (PM)]	
STAFF	**0** *0* *0*
FELL/PJAS	**0**
PhD	**0**
CERN Resources (Material) [kCHF]	
Total budget estimate:	**0** *0* *0*
Arbitration decision	
Second priority. To be reassessed	

7.5 INDUCTIVE OUTPUT TUBE (IOT)

Participant						
Person months						
Type						

Objectives

IOTs designed for various applications
Series production has been < 100 kW
ESS requires 1.2 MW plus overhead

Future machines require:
More power another factor of 10?
Better efficiency
Better reliability
Smaller footprint, etc

Description of Work

Deliverables	**Month**
D1: Concepts and parameters	**M12**
D2: Components and design	**M24**
D3: Document results	**M48**

CERN Resources (Manpower) [Person. Months (PM)]

STAFF	**0** *0* *0*
FELL/PJAS	**0**
PhD	**0**

CERN Resources (Material) [kCHF]

Total budget estimate:	**0** *0* *0*

Arbitration decision

Addressed in the framwork of the SPL/ESS study. Collaboration with ESS.

ANNEX A: MANDATE OF FCC SRF WP

The mandate of the FCC Radio Frequency (SRF) Work Package has been defined as follow:

- Study the RF technologies including conceptual aspects required for the FCC accelerator and identify the possible design and performance limitations for the accelerator.
- Identify challenges, opportunities for technological breakthroughs and set the R&D program.
    - Understand impacts of technologies
    - Prioritize R&D topics
    - Define scope, schedule, cost guidelines
    - Reporting on Specific Technologies R&D Programs
- Set up collaborations to address standard FCC issues and R&D opportunities

- The R&D activities will then be followed in the frame of the Accelerator R&D Work Package which is sub-divided in three Sub-Work Packages:

    - High field Magnet Program
    - Superconducting RF Program
    - Special Technology Program (all except Magnet and RF)

ANNEX B: SRF WBS STRUCTURE (DRAFT)

To ease understanding the organisation of the different items, the WBS struture has been rearraged accordingly:

Energy driven

-

Power driven

-

Beam driven

-

Reliability driven

-

Radiation driven

-

Accelerator driven

-

ANNEX C: RESPONSIBLE PERSONS

The following Table aims at easing contacts with CERN Sub-Tasks Coordinators

WP #	Description	Contact Person
1	COLLABORATION AGREEMENT "KE2722/BE/FCC"	P. CHIGGIATO (CERN)
2	CAVITY DESIGN	R. CALAGA (CERN)
3	CAVITY MATERIAL AND PERFORMANCE	WALTER VENTURINI DELSOLARO (CERN)
4	CAVITY FABRICATION	KARL SCHIRM (CERN)
5	CRYOMODULE CHALLENGES	KARL SCHIRM (CERN)
6	LLRF SYSTEM	W. HOFLE (CERN)
7	POWER SYSTEM	TBD

ANNEX D: CERN RESOURCES (PERSONNEL & MATERIAL)

ANNEX E: ARBITRATION: FELL, DOCTS & MATERIAL