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FCC
R&D on RF (SRF and high η)

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The Context

- LHC to run for 20+ years → we must keep key technologies in house!
- A future large machine (FCC or other) will need key technologies:
  - high field magnets,
  - efficient power conversion,
  - RF systems (normal conducting or superconducting)
    - normal conducting: pulsed – superconducting: CW (requires also efficient cryogenics)
- European Strategy for Particle Physics (2013):
  - *Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine…*
  - *CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron positron high-energy frontier machines. These design studies should be coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures, in collaboration with national institutes, laboratories and universities worldwide.*
- Collaboration: This is a global effort: what can partners provide – what should be concentrated at CERN?
  - → Keep the R&D @ CERN **complementary** to the successful global R&D program!

The CERN Context

- We have an ongoing SRF program for LHC and HL-LHC!
  (Highest priority, includes 400 MHz crab cavities as baseline (32 + spares), 200 MHz and 800 MHz harmonic & subharmonic cavities as options)
- We have an ongoing SRF program for HIE Isolde (High priority, 20 cavities 100 MHz, QWR, Nb-on-Cu, for radioactive isotope post-acceleration)
- Since LHC has to run 20+ years, we're building/processing LHC spare cavities/cryomodules and FPCs!
- There is the **FCC SRF R&D programme** described here.
- And also we have an ongoing SRF R&D program covering interesting R&D that is not focused on FCC (e.g. High Gradient test cavities 704 MHz in collaboration with ESS, alternative compact crab cavity study using Nb-on-Cu, cold diagnostics studies, new forming, joining and cleaning techniques, SRF theory …)

There is a certain synergy – which is by all means intentional/welcome!
But infrastructures and services have to be shared!

The Strategy

- Long term goals: significant performance improvement for future accelerators with better …
  - …overall energy efficiency
  - …reliability
  - …performance reach (accelerating gradient, intensity, brilliance, size …)
  - Reaching these goals will have impact on other accelerators, e.g. medical & light sources, and on society at large.
  - The R&D itself will have a positive societal impact (academic interest – training – excellence).
- R&D must be **fundamental and basic** – not incremental!
  - We must dare to do things that are very different! The risk is high – but also the potential.
  - We must understand the underlying physics – this requires time and contemplation as well as systematic studies.
  - I believe CERN is an excellent place to do this – where else?

Initial Choices for FCC

- Frequency: 400 MHz (and 800 MHz)
  - FCC-hh: similar to LHC (strong synergy) – single-cell cavities, total <50 MV (about 40 systems)
  - FCC-he: e-beam: ERL very attractive (800 MHz, 5-cell, high Q_0, about 1000 cavities)
  - FCC-ee-Z: 1.5 A beam current, 2.5 GV total voltage – dominated by HOM excitation (about 700 cavities)
  - FCC-ee-$t\bar{t}$: 11 GV total voltage! Option: add 800 MHz system to boost voltage! (additional 700 cavities)
- Technology: focus on thin films (Huge potential! Complementarity).
- Operation at 4.5 K with Nb-Cu sputtered cavities ? Cryo to optimize!
- RF Power: focus on BAC klystron – but keep surveying solid-state!

Some areas of R&D

- SC Materials
- Cavity optimum shape (fields, Q_0, MP, k_{loss}, mode spectrum …)
- Coating techniques/technology
- Intrinsic and extrinsic performance limits (flux trapping & expulsion, vibrations, thermo-electric currents, impurities, …)
- Fabrication techniques (spinning, rapid forming, additive, …)
- CM construction techniques (cryo economy, magnetic hygiene)
- Novel diagnostic methods (Surface analysis, T, B, quench localization, …)
- HOM damping
- HOM and impedance mitigation with fast feedback systems
- FPC study and optimization
- Highest efficiency klystrons & modulators
- …

The work packages (draft)

#		name	topics / objectives
WP 1	Collaboration Agreement "KE2722/BE/FCC"	P. Chiggiato	• 6 GHz: Nb/Cu performances + diagnostics • 800 MHz: fabrication of seamless cavities • 400 MHz: feasibility study (fabrication)
WP 2	Cavity Design (+ cavity impedance and HOMs)	R. Calaga	• 400 MHz: low loss factor cavities for FCC-ee • 800 MHz: for 2nd harmonic system
WP 3	Cavity Material and Performance	W. Venturini Delsolaro	• Preparation, diagnostics & measurements @ CERN • Bulk Nb, Nb/Cu & Nb_3Sn at low frequencies
WP 4	Cavity Fabrication	K. Schirm	• Collaboration with JLab? BINP? Mainz?? • High velocity forming of cavities (EN/MME)
WP 5	Cryomodule Challenges	K. Schirm	• CM design & architecture (SPL?, JLab, CEA Saclay) • CM assembly (CEA Saclay) • Auxiliaries (tuning, FPC, etc)
WP 6	LLRF System	W. Hofle	• Fast cavity feedbacks, cavity trip handling, impedance mitigation
WP 7	High Efficiency Power Systems	N.N.	• Super-efficient klystrons • ...

Next target: FCC week in Rome, April 16

Progress to be reported in Rome:

- Convergence towards FCC RF parameters (locations, staging scenarios ...)
- Initial cavity designs compatible with the different requirements
- Launch of R&D program – structure, WBS – international players
- First results of R&D program!
- First results of very high efficiency klystron prototypes

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