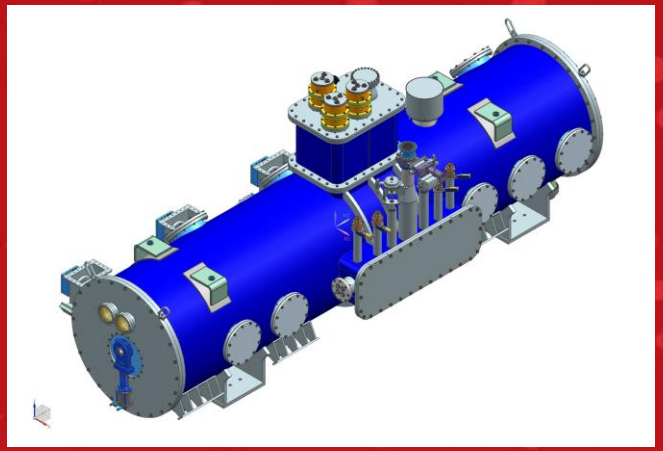
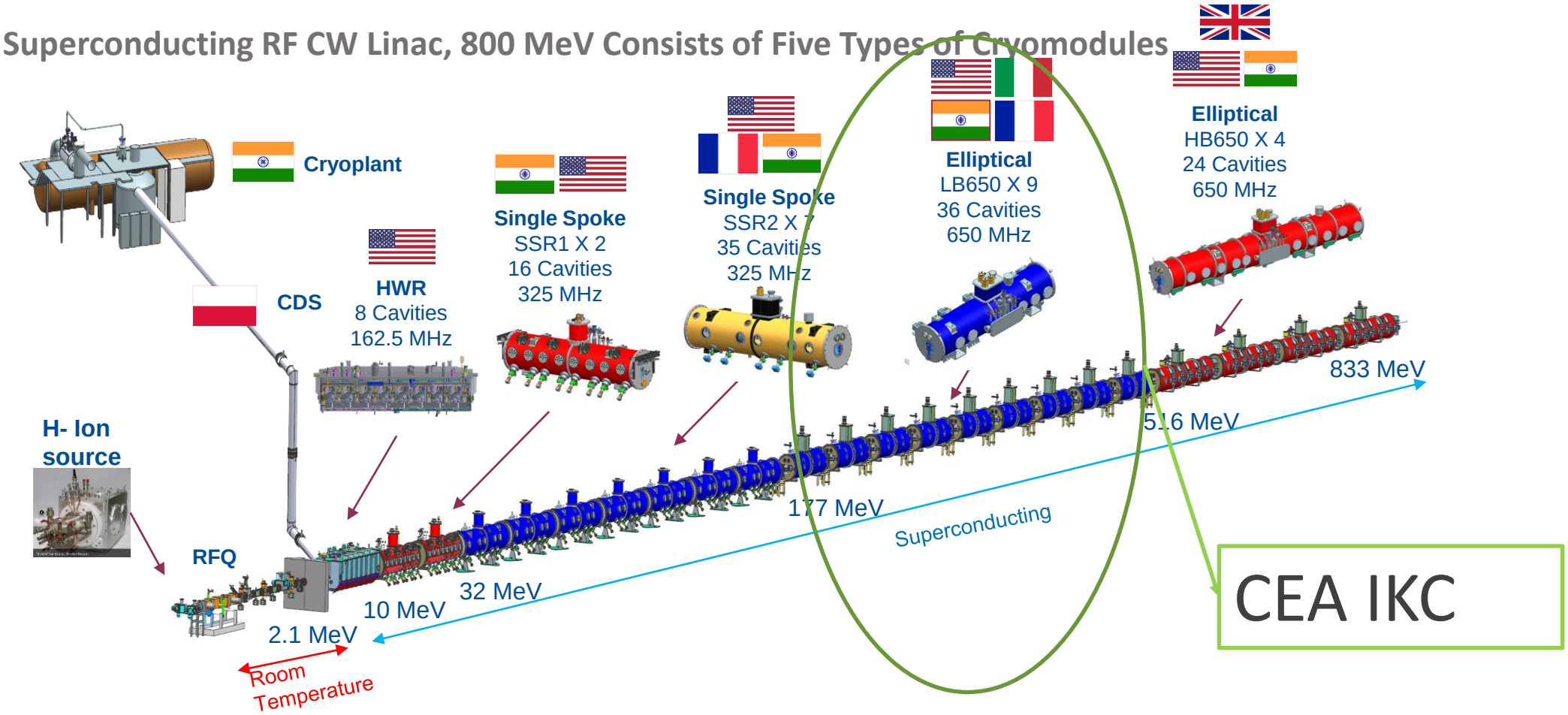
DE LA RECHERCHE À L'INDUSTRIE

CEA Contribution to PIP-II

Olivier Napoly

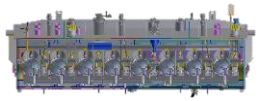
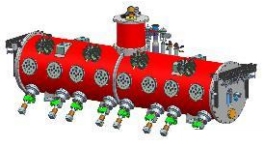


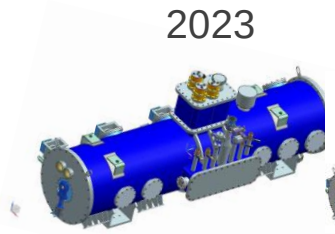
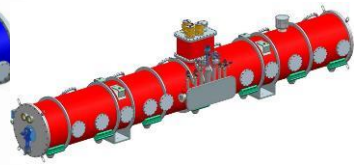
PIP-II Superconducting RF CW Linac, 800 MeV Consists of Five Types of Cryomodules



PIP-II is the world's highest energy and power CW proton linac, and the U.S. first accelerator project to be built with major international contributions

2023 2023 2021-22

HWR ✓ SSR1 ✓ SSR2 LB650 HB650

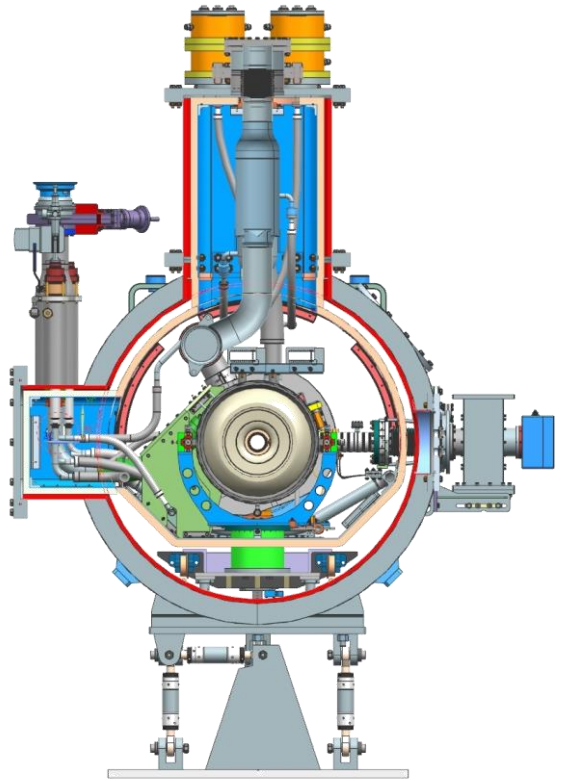
Cryomodule	CM #	Cavity #	String Assy.	CM Length [m]	Q_0 @ 2K	R_s [Ω]	Q_L [x10^6]
HWR	1	8	8 x (SC)	5.93	8.5E9	5.6	2.3
SSR1	2	8	4 x (CSC)	5.3	8.2E9	10.2	3.0
SSR2	7	5	SCCSCCSC	6.5	8.2E9	14.0	5.1
LB650	9	4	CCCC	5.52	2.4E10	8.0	10.4
HB650	4	6	CCCCCC	9.92	3.3E10	7.9	9.9

C = Cavity, S = Solenoid

23 Cryomodules + 4 Prototypes, 14 Cryomodules will be transported between Europe and US

CEA Scope of Work

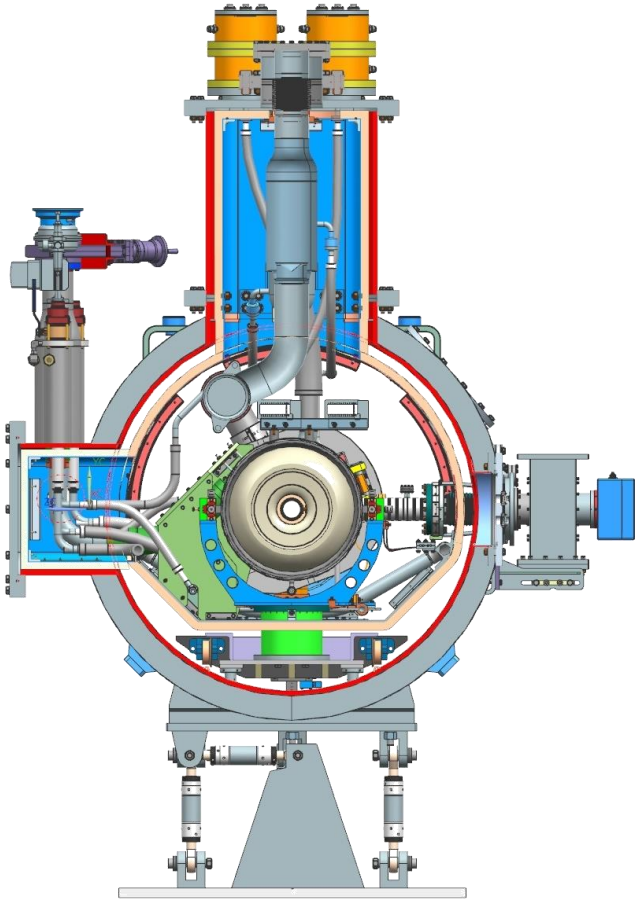
- **In July 2020, the French research ministry approved the involvement of CEA in the PIP-II Linac construction and defined its budget envelope.**
- **Within this envelope, the Scope of Work of CEA includes:**
  - the design of the LB650 cryomodules (1 pre-production + 9 production)
  - the procurement of cryomodule components*
  - the assembly of the LB650 cryomodules (1+9), including all necessary tooling
  - the RF tests of the LB650 cryomodules (1+9), including cryogenics and RF equipment
  - the system acceptance reviews of the LB650 cryomodules (1+9)
  - the licensing of the LB650 cryomodules (1+9)
  - the design of the LB transport frame, fabrication of 2 units, and road tests
  - the disassembly (warm couplers, cryogenic cap) and preparation of LB650 cryomodules for shipment.



* Many components are provided by Fermilab (cf. next page).

CEA Scope of Work

- **The cryomodule components procured by CEA include:**
  - the inter-cavity bellows and cold-warm beam line transitions
  - the hardware, fasteners and gaskets for string assembly
  - the strong-backs, cavity posts and supports, and C-blocks
  - the cold and warm magnetic shields
  - the 50 K thermal shields
  - The 2K, 5K and 50 K Helium circuit pipes and bellows
  - the superinsulation blankets
  - the vacuum vessels
  - the hardware, fasteners and seals for module assembly
- **The cryomodule components provided by Fermilab include:**
  - the RF cavities equipped with their Helium jacket including bi-metallic transition and di-phasic tee, and their pick-up antenna
  - the RF couplers equipped with their vacuum gauge and electron pick-ups
  - the beamline gate valves
  - the frequency tuners with step-motor, piezo-mechanisms, electric cables and end-switch
  - the RF cables, thermal sensors, and pick-up cables
  - the instrumentation flanges equipped with connectors
  - the alignment instrumentation such as HBCAM tool kit, HBCAM optical target subassemblies
  - the cryogenics equipment such as valves, heat exchangers, bayonets, Helium guards and relief stack columns



This contribution relies on a strong and fully open collaboration model between Fermilab and CEA.

1. Fermilab, as 'end-user' of the LB650 cryomodules, specifies the LB650 **Requirements** while CEA delivers the monthly **Reporting** of the LB650 activity progress. Currently:
   - CEA reports at the 650 MHz collaboration fortnightly meetings (650 all-partners)
   - CEA convenes a monthly LB650 Cryomodule Design meeting (Fermilab-CEA)

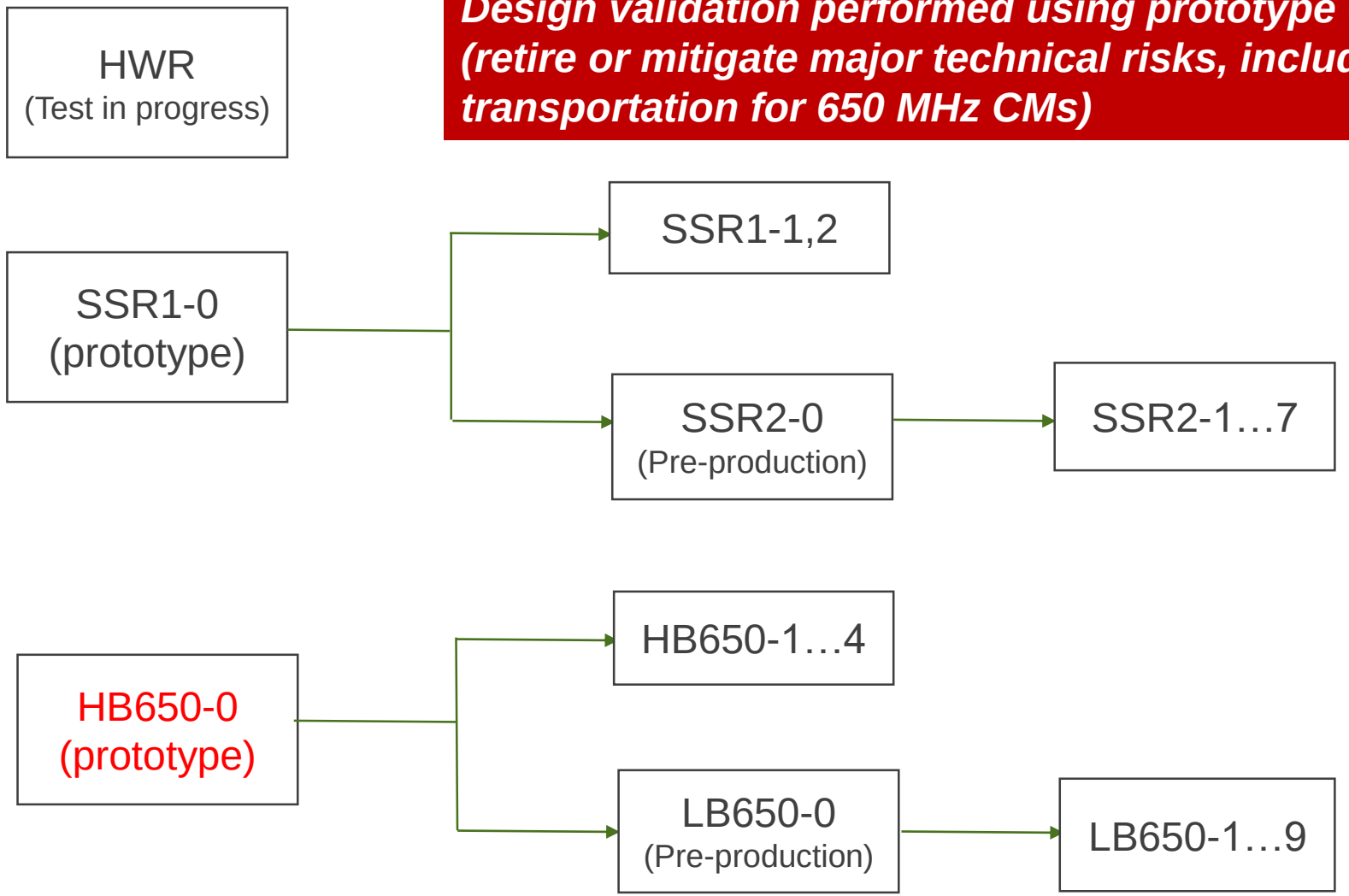
   A series of Reviews (design, system acceptance, transportation) are defined in the 'Project Planning Documents' that will serve as technical annexes to PIP-II CEA-DoE Agreement.
2. The fabrication of the HB650 prototype cryomodule (pCM) is a critical precursor, by about 2 years, of the LB650 activity, in terms of design, assembly and tests.
   - Regarding design: the project strategy is to maximize the common components, e.g. couplers, tuners, cavity supports, endgroups, valves, etc. and also to have a direct filiation of the scalable parts, e.g. strongback, thermal shield, magnetic shield, piping, etc.
     - ➢ CEA team joined the HB650 pCM design team and was responsible for the strongback design

Cryomodule Development Plan

Charge 1e, 2c

PIP-II

Design validation performed using prototype CMs (retire or mitigate major technical risks, including transportation for 650 MHz CMs)



CEA-Fermilab Collaboration

- Regarding assembly: CEA will make the most both from its current ESS experience, e.g. industrial contractor, clean room tooling, etc., and from the HB650 pCM assembly at Fermilab
  - CEA team was responsible for the design of the endcap closing tool, a direct descendant from the ESS tool.
  - CEA team will observe, and possibly participate in, the HB650 pCM assembly at Fermilab
- Regarding cold RF testing: Fermilab and CEA are collaborating on the Acceptance Criteria List and the Test Plan of the HB650 pCM. Experience from LCLS-II and ESS is shared openly, e.g. Xray detectors, RF operation, etc.
  - CEA team will 'scale' the LB650 Acceptance Criteria List and Test Plan from the HB650 pCM documents
  - CEA plans to participate in the HB650 pCM testingg.

In a nutshell, CEA regards the HB650 pCM construction at Fermilab as a test-bed and risk-lifting prototype for its future LB650 cryomodule design, construction and testing activities.

The fabrication and test of the '*pre-production*' LB650 cryomodule (ppCM) will serve as a second validation, mostly for the CEA procedure and infrastructure specifics.

3. Transfer of Title of LB650 cryomodules will take place at CEA-Saclay, before shipment.
4. Fermilab plans to repeat the RF testing of the LB650 ppCM and first 3 CMs, at Fermilab after transportation.

- **This shared scope of work implies many interfaces of organizational and physical natures with a potential strong impact on cost, schedule, risk, and responsibilities.**
- **To name a few:**
  - Supply chains
  - Identification of components
  - Acceptance of components
  - Software and drivers
  - Choice of CM 4-cavity sets
  - Codes and norms
  - Tests procedures and equipment
  - Title transfers
  - Acceptance of cryomodules

CEA-Fermilab Interfaces Relevant to this Preliminary Design Review

- **Physical and organizational interfaces with components provided by Fermilab:**
  - 3D models of cavities, tuners, couplers
  - Instrumentation and RF cables routing and insulation
  - Acceptance and Quality Control
  - Cavity fiducialization and alignment methodology
- **Validation of LB650 cryomodule Final Design by Fermilab**
  - The Final Design Review must be formally endorsed by Fermilab
- **Licensing and certification**
  - Work in progress in understanding ASME versus PED for pressurized vessels and piping.
- **Transportation**
  - The transport frame design must be validated by Fermilab
  - Road test instrumentation must be identical in France and in the USA (roads aren't)
- **System Acceptance Reviews:** assembly→ SAR1→ RF test→ SAR2→ title transfer→ shipment
  - Joint review procedures are needed.

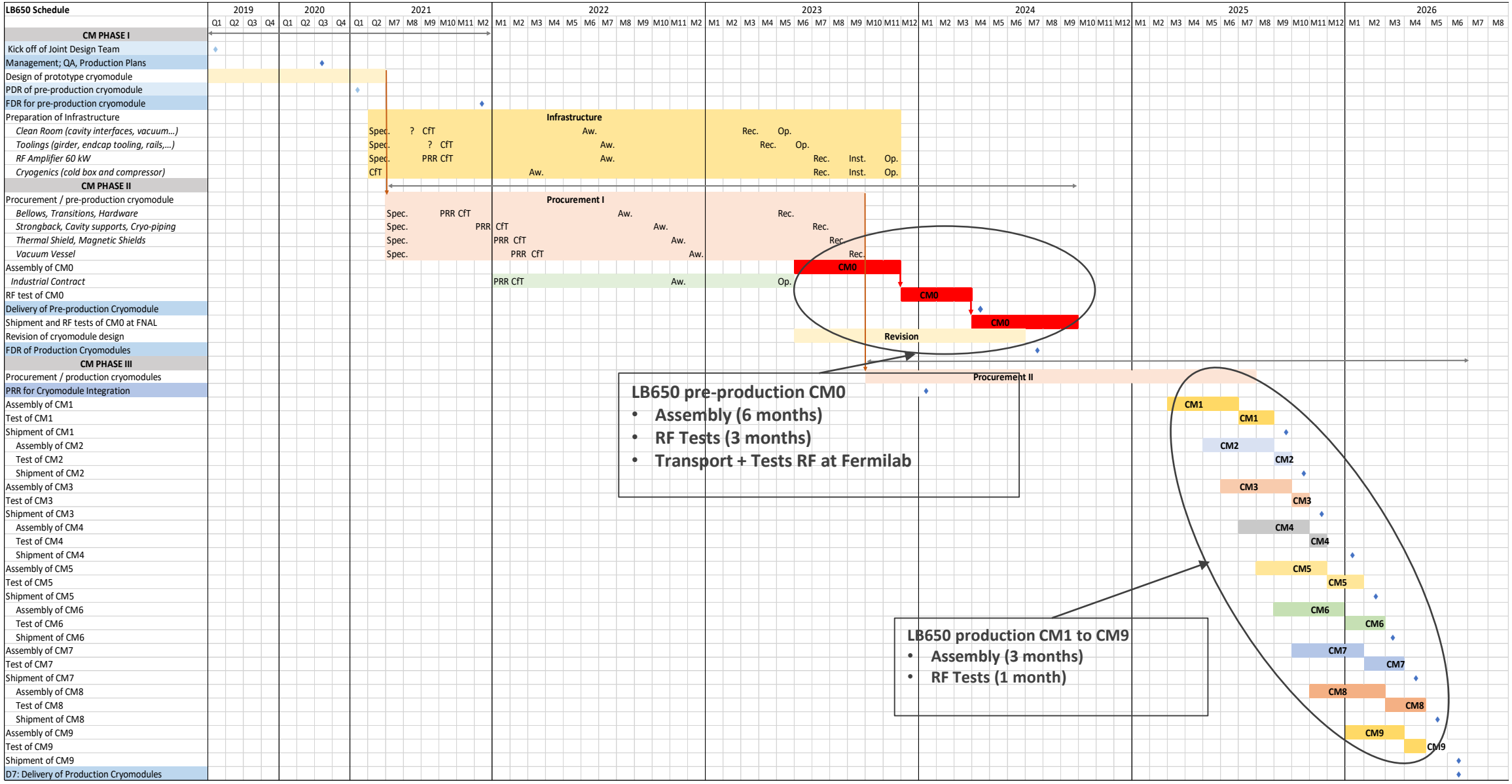
CEA-Fermilab Interfaces Relevant to this Preliminary Design Review

- **A lot of information and lessons learnt with be gathered from the HB650 prototype cryomodule design, fabrication, assembly and testing.** CEA intends to 'participate' to assembly and testing.

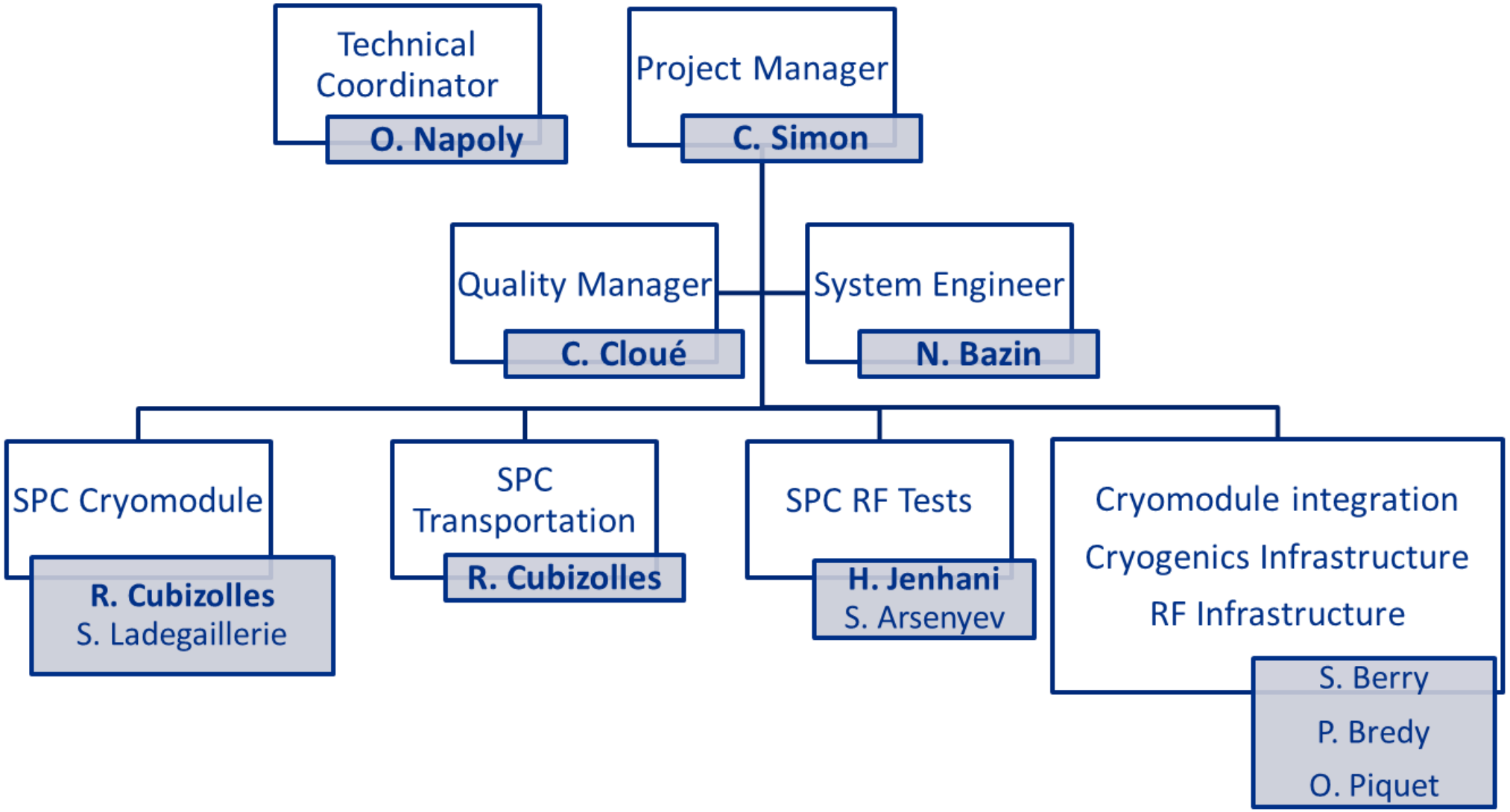
- **Some of these interface issues will be addressed during the Preliminary Design Review,** e.g. common parts, instrumentation, cryo-distribution, certification, etc.

- **All these interfaces need to be thoroughly understood and solved in time of the Final Design Review.**

LB650 Schedule: P6 compatible



CEA PIP2-LB650 Organization Chart



Risk Analysis

Risk Types	Impact	Mitigation	Comment
Risks imported by CEA			
HB650 pCM qualification delay	Schedule		Currently March 2022
Supply chain shortage	Cost, Schedule		RF cavities, RF couplers
Longer RF testing cycle	Schedule		RF testing is the bottleneck of the CEA chain
Risks internal to CEA			
Conflicts with other CEA projects	Schedule	Second clean room ISO5, Alternate assembly hall	ESS is the direct precursor, SARAF is 2 years earlier
Delays in equipment readiness	Schedule	Planning	RF amplifiers, cryoplant
Cryomodule underperformance	Cost, Schedule	QC, external expertise	Repairs at CEA
Risks exported by CEA			
Assembly delays	Schedule	Emergency workstations	Impact on installation
Transportation failure	Cost	Road test, LB650 ppCM overseas transport	HB650 pCM round trip

Concluding Remarks

- CEA team is experienced, with involvement in the preceding and ongoing projects like XFEL, IFMIF, ESS, SARAF
- The PIP2 design team is being reinforced with the ongoing recruitment of one Quality engineer, one assembly engineer and two draftmen.
- The current design effort is in line with issuing components specifications and launching procurement beginning of 2022.