IN2P3 Scientific Council

October 21 & 22, 2024

CNRS/IN2P3 in-kind contribution to the Electron Ion Collider (EIC)

Supply of 4 cryomodules to the Rapid Cycling Synchrotron

1. Summary

We present, in this document, the latest version of the IN2P3/IJCLAB in-kind contribution to the construction of the EIC Rapid Cycling Synchrotron (RCS), which is presently being built at Brookhaven National Laboratory (BNL). RCS is an important part of the accelerator complex (Fig.1) and will accelerate polarised electron beams from 400 MeV to a maximum energy of 18 GeV and will inject them into the EIC Electron Storage Ring (ESR).

The scope of the in-kind contribution consists of delivering, 4 tested cryomodules ready to be installed into the RCS tunnel. IJCLAB is, as of today, the main and only laboratory[1] from IN2P3 which is involved in this contribution.

In the following chapters, we will outline the background of this in-kind contribution and how it has drawn up for a year, then, we will describe in more details the technical activities and how they are planned as well as the associated human resources and cost.

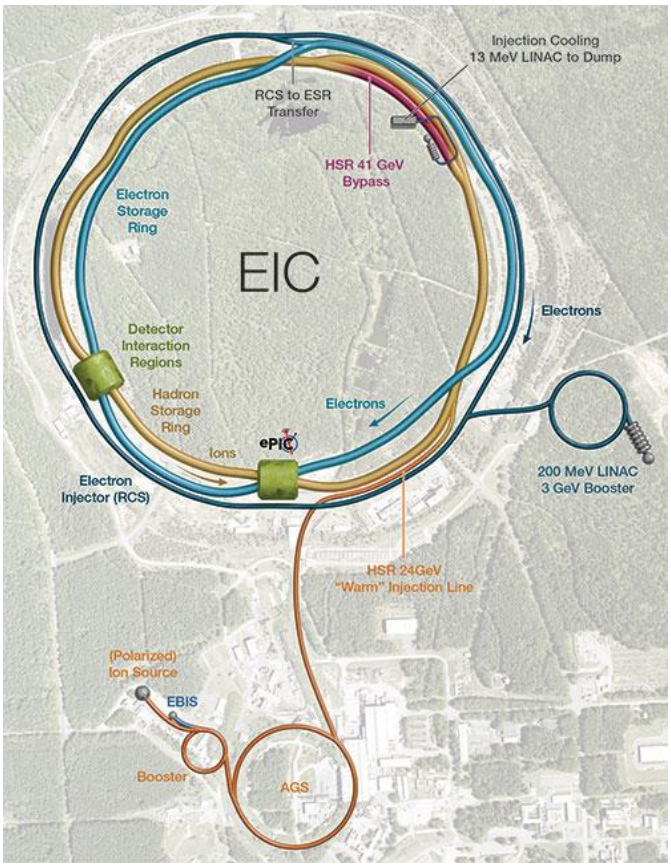


Figure 1: Schematic of the EIC complex (Valerie Lentz/Brookhaven National Laboratory)

Nota bene: This IJCLAB proposal, developed jointly with IN2P3 management, has not been the subject of detailed discussions or further iterations with the EIC team, in particular with the JLAB people responsible for designing the cryomodule. The content of this contribution may also change in 2025 after it has been submitted to the Ministry.

[1] *For the transport of the cryomodules, IJCLAB will call on the CNRS logistics unit ULISSE.*

2. Context

a. IJCLAB: accelerator builder

IJCLAB is a well-known actor in accelerator community and had major contributions to the construction of accelerators such as LHC, XFEL, SPIRAL2, MYRRHA, ESS or PIP2. In particular, more than 100 people spread across the Supratech platform[2], the Engineering division and the Accelerators division of the laboratory have built up expertise in, for example: beam dynamics, cryogenics, Superconducting RF technologies, ultra-high vacuum techniques, Low Level RF systems, mechanical design of cryostat, preparation of cavities, RF conditioning of fundamental power couplers, cavity string assembly in ISO 4 clean, qualification test in vertical cryostat,…These people bring together all the skills needed to manufacture, prepare, assemble and test SRF cryomodules for accelerators.

Hereafter are listed a few examples of major contributions:

- Cryostat design and production follow-up of short straight sections for the LHC.
- Design, fabrication, assembly and test of the 7 high-beta cryomodules for SPIRAL2.
- Clean room preparation and RF conditioning of 800 power couplers for XFEL.
- Design, fabrication, assembly and test of the prototype Spoke cryomodule for MYRRHA.
- Design, fabrication and assembly of the 13 series Spoke cryomodules for ESS.
- Co-design and test of the prototype and series Single Spoke Resonator 2 (SSR2) for PIP2.

Capitalising on this valuable experience, IJCLAB has been leading, for many years, an international collaboration which aim at building a new compact multi-MW Energy Recovery Linac (ERL), so called PERLE. Following a period of design studies, PERLE has been granted two major financial supports (iSAS project[3] and ERL4ALL[4]) giving the project a tremendous boost. PERLE has entered a construction phase which. Without giving too many details not useful in the context of the EIC project, the first PERLE cryomodule was founded thanks to the European iSAS project and IN2P3 matching funds. It became the baseline and starting point of the reflexion to the IN2P3 in-kind contribution to EIC accelerator described hereafter.

b. Background of the contribution

Beginning of 2023, the PERLE collaboration took a major decision by choosing a new basic design for the cryomodule of PERLE linac cryomodule. It was decided to switch from the SPL cryomodule design to the ESS one (Figure 2). This technical choice (followed by its funding through the iSAS project), obviously had many advantages for PERLE, but also had the indirect effect of strengthening synergies between PERLE and the EIC complex, where an ERL cooler based on SRF cryomodules had been identified at the time.

The first contacts between IJCLAB and the EIC management team occurred in spring 2023. With the support of Accelerator Deputy Scientific Director of IN2P3 and IJCLAB management, IJCLAB raised up the idea to produce of 2 cryomodules “in the PERLE/ESS style”. Optimized to the EIC requirements,

[2] Supratech is a labelled research platform by IN2P3. https://platforms.in2p3.fr/platform/697/details
[3] https://isas.ijclab.in2p3.fr/ https://www.in2p3.cnrs.fr/fr/cnrsinfo/projet-isas-vers-des-accelerateurs-de-particules-plus-economes-en-energie
[4] https://isas.ijclab.in2p3.fr/news/2024/09/06/related-topic-erl4all-to-extend-the-reach-of-isas.html

each cryomodule composed of 4 cavities, were supposed to replace the 8 single-cavity cryomodules planned. This solution would most likely have considerably reduced costs (less space needed in the tunnel) and guaranteed greater reliability (well-known and proven design).

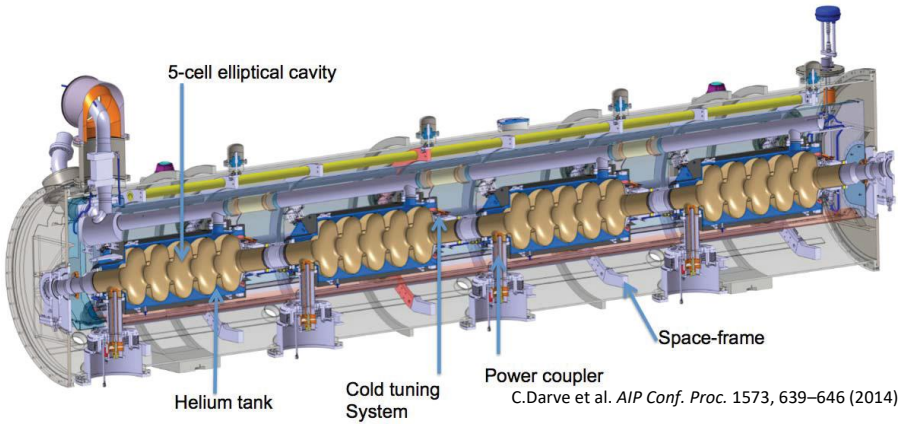


Figure 2 : The ESS elliptical cavity cryomodule

IJCLAB has started working on that solution and was about to complete the first draft proposal, but in February 2024, IJCLAB was said that the ERL cooler based on SRF cryomodules was no longer on top of the list of the EIC roadmap. IJCLAB team started to think about a new proposal related to the needs expressed by the EIC management for the RCS. IJCLAB, again supported by IN2P3, built up the new proposal which is the subject of this document and submitted it to IN2P3 end of April 2024.

The proposal has been presented by IN2P3 during the EIC Resource Review Board meeting (RRB) in May 2024 and was well received and accepted.

c. Status as of today

As a common effort to the EIC accelerator and ePIC detector, IN2P3 and CEA are currently preparing a request for funding to the French ministry.
In parallel, two international Cooperative Research and Development Agreement (iCRADA) are being prepared between IN2P3 and JLAB then IN2P3 and BNL to provide a framework to the IN2P3 in-kind contribution (Figure 3).
The IN2P3/JLAB iCRADA has been received in September and is being proofread. It includes *"the design, procurement, fabrication and testing of the 591 MHz 5-cell cryomodules for the EIC Rapid Cycling Synchrotron (3 required + 1 spare)".*
The second one between IN2P3 and BNL is being drafted and should be received soon. It will cover the shipping and delivery of the 4 cryomodules between IJCLAB/Orsay and BNL/Brookhaven.
The signature of those iCRADAs are expected end of 2024. Next step in 2025 will be the drawing up of the Project Planning Documents (PPDs) which are requested.

This summer, EIC moved towards establishing an Institutional Collaboration Board (ICB) which consists of representatives appointed by institutions interested in contributing to the EIC accelerator. In September, Guillaume Olry has been nominated as the IN2P3 representative et the ICS.

Country - Agency	Milestone	Target Date
Canada – TRIUMF	JLab iCRADA (for Crab CMs) drafted	✓ Since end 2023
Canada – TRIUMF	BNL iCRADA (for Crab CMs) drafted	✓ Jun 2024
UK	JLab iCRADA (for 1773 MHz 5-Cell CMs) drafted	✓ Aug 2024
UK	BNL iCRADA (for 1773 MHz 5-Cell CMs) drafted	Aug 2024
France – IN2P3	JLab iCRADA (for 591 MHz 5-Cell CMs) drafted	✓ Sep 2024
France – IN2P3	BNL iCRADA (for 591 MHz 5-Cell CMs) drafted	Sep 2024
Canada – TRIUMF	iCRADAs signed	Dec 2024
UK	iCRADAs signed	Dec 2024
France – IN2P3	iCRADAs signed	Dec 2024
	PPDs preparation could start at the end of drafting the iCRADA and completed in 2025	**May-June 2025 Ready to be signed**
	DOE CD-2 and Status OPA Review	**Late 2025**

Figure 3: In-Kind Collaboration iCRADA status (Luisella Lari, EIC Advisory Board, 2 August 2024)

3. The project: In-kind contribution to EIC RCS

a. Scope

The main goal is to procure, test and deliver to EIC 4 cryomodules (3 required and 1 spare) for the EIC RCS. Each cryomodule (Figure 3) is composed of one 591MHz 5-cell SRF cavities equipped with its ancillaries' systems (HOM couplers, fundamental power coupler, tuning system, warm beam loss absorbers and cold box).

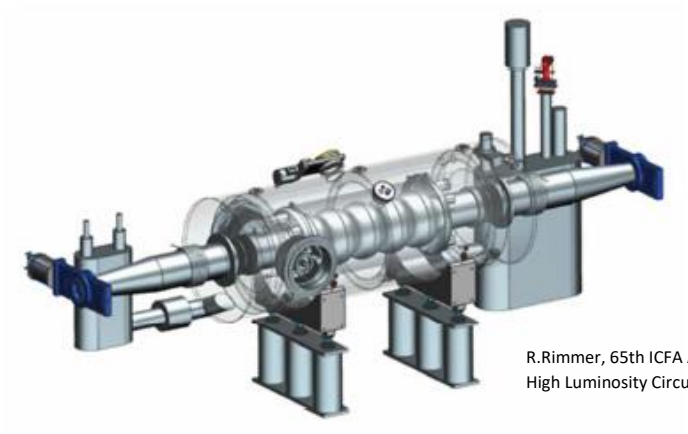


Figure 4 : Conceptual design of the cryomodule for use in the RCS

EIC duties:

The overall cryomodule design responsibility lies primarily with EIC teams. Nevertheless, IJCLAB will also work on the final design along with them and will take part in all reviews before procurement, manufacturing, testing and shipping.

In addition, EIC will also provide IJCLAB with all the RF equipment (RF station, RF network, LLRF system) needed to perform the RF conditioning of the power couplers at warm temperature and the final test of the cryomodules.

IJCLAB will be in charge of:

- The design of all tooling needed for the assembly and test of the cryomodules
- The procurement and follow-up of all components
- The test of each critical component (SRF cavities, power couplers and tuning systems) before their assembly in the cryomodules.
- The cryomodule assembly
- The final test of the cryomodules
- The shipping of the cryomodules to BNL

b. Description of the work (incl. planning and human resources)

The duration of this contribution has been estimated at 66 months (from January 2026 to mid-2031). We assumed that the start of the contribution begins on 1 January 2026 after the CD-3 decision

scheduled end of 2025 (Figure 4). The year 2025 should be dedicated to the finalisation of the iCRADAs agreements, the drafting of the PPDs and the start of the first technical exchanges.

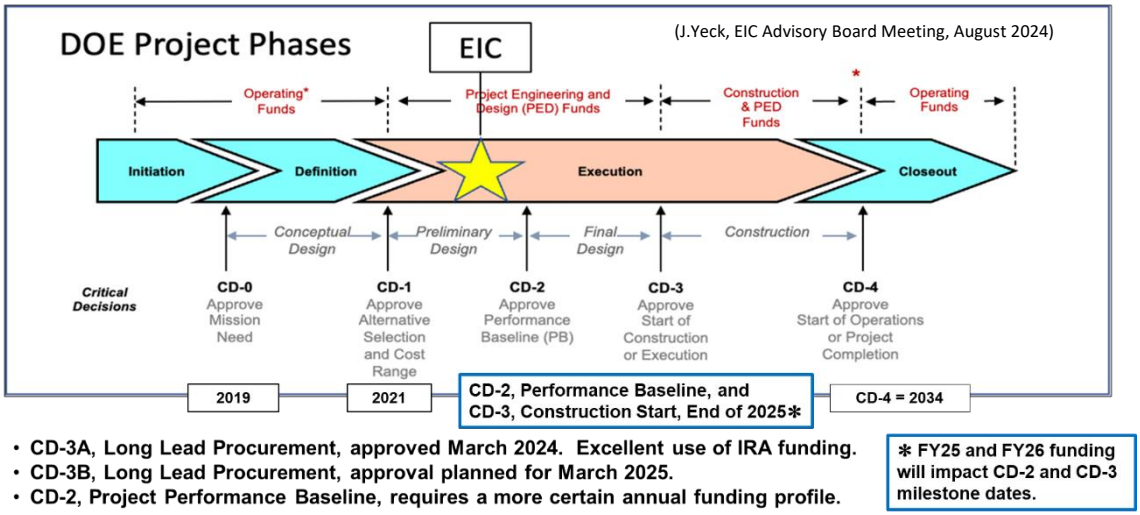
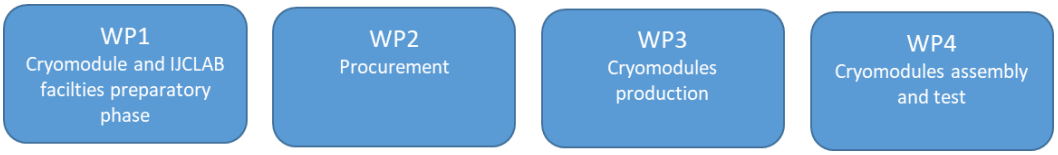


Figure 5: EIC Project Critical Decisions and Plans

The project has been divided in 4 main Work Packages. The planning is presented in figure 6 and will be detailed in the sections hereafter.



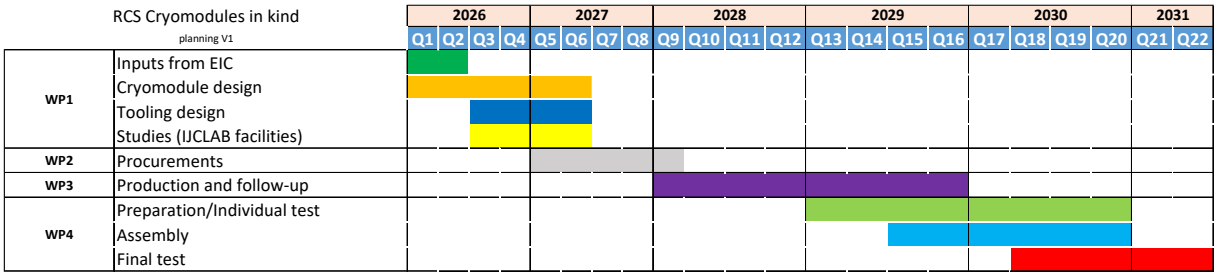


Figure 6: Planning of the IN2P3 contribution

Nota bene:

- *The present planning has been established without taking into account any constraints from EIC and does not include contingencies.*
- *It reflects the present IN2P3/IJCLAB capabilities to fulfil the contribution.*
- *The balance between permanent/non-permanent staff is estimated 60%/40%. Permanent staff is not yet allocated to the project, so no name will be given in this document.*

- *No risk analysis has been conducted so far but 2 risks have been identified since the beginning: the time and human resources required for the procurement phase and possible difficulties in recruiting non-permanent staff.*

WP1: Cryomodule design and studies to prepare assembly and testing sites (18 months).

In this WP1, IJCLAB will participate with JLAB to the final design of all cryomodule components, will design all the tooling needed for the assembly of the cryomodules and will carry out the studies needed to adapt the IJCLAB facilities to host the individual tests of cavities/power couplers/tuning systems and perform the final test of the cryomodules in a dedicated test-stand area.

			2026				2027			
			Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
WP1	Inputs from EIC	Resp projet, Pôle Acc (IR)	25%	25%						
	Cryomodule design	Resp projet, Pôle Acc (IR)	50%	50%	50%	50%	50%	50%		
		Resp Design CM, Bureau d'études (IR)	75%	75%	75%	75%	75%	75%		
		Projeteur n°1, Bureau d'études (IE, CDD)	100%	100%	100%	100%	100%	100%		
		Ingénieur cryo, Service Cryo (IR)	50%	50%	50%	50%	50%	50%		
		Ingénieur C&C/Instrumentation, Service Cryo? (IE/IR)	15%	15%	15%	15%	15%	15%		
	Tooling and studies (IJCLAB facilities)	Resp Design CM, Bureau d'études (IR)			25%	25%	25%	25%		
		Projeteur n°2, Bureau d'études (AI/IE, CDD)			100%	100%	100%	100%		
		Resp sites de test, ? (IR/IE)			50%	50%	50%	50%		
		Projeteur n°3, Bureau d'études (AI/IE)			50%	50%	50%	50%		
		Resp Supratech (IR)			20%	20%	20%	20%		
		Opérateur salle Blanche (AI), Supratech			10%	10%	10%	10%		
		Opérateur chimie (T/AI), Supratech			10%	10%	10%	10%		
		Opérateur tests cavités (AI), Supratech			10%	10%	10%	10%		
		Resp QA/QC (IR), CeQMAP			40%	40%	40%	40%		

Figure 7: Detailed WP1 human resources breakdown (non-permanent staff in red)

Task 1.1: Inputs from EIC (6 months, 1.5 man.month)

A 6-month period is allocated to finalise with the EIC teams the requirements, the technical specifications, the Quality Assurance plan, the test plan for the critical components (cavities, power couplers…).

Nota bene: this task may be started before January 2026 depending on the finalisation/signature of the IK agreement between DOA/EIC and IN2P3/IJCLAB.

Task 1.2: Cryomodule design (18 months, 52.5 man.month)

As the overall cryomodule design is the responsibility of JLAB, we don't know today how advanced the design is. That's why we took as a starting point the cryomodule conceptual design already presented by EIC and, based on the ESS experience, we considered an 18-month period to complete all design of the cryomodule and its ancillaries and go through all the necessary reviews before starting the procurement phase. A global design review is planned Q6/2027.

Task 1.3: Tooling design (12 months, 15 man.month)

This task is important and will start as soon as possible in parallel to the task 1.2. The work includes the design of tooling needed for the cavity and power couplers individual testing and of course for the cryomodule assembly (in clean room in particular). The task 1.3 must be realised in parallel to task 1.4 as the tooling must be adapted to the Supratech equipment which will be used @ IJCLAB (clean room, vertical cryostat, assembly hall, chemical room…).

Task 1.4: Studies to adapt the Supratech equipment (12 months, 24 man.month)

IJCLAB has a unique platform called Supratech which is fully dedicated to the R&D and production of SRF components for accelerators (Figure 8). Most of the present equipment (clean room, assembly halls, power coupler assembly clean room…) are almost fully compatible with the need of EIC RCS cryomodules preparation and assembly and will require only minor modifications. In another hand, we have identified some equipment that requested major modifications and/or upgrades: the 1250mm diameter vertical cryostat (not shown in Figure 8), the tuner testing cryostat, the RF conditioning test bench and the cryomodule test stand.

Nota bene: some of the work can be brought forward to before Q3/2026, depending on the progress of activities relating to the design of the tooling.

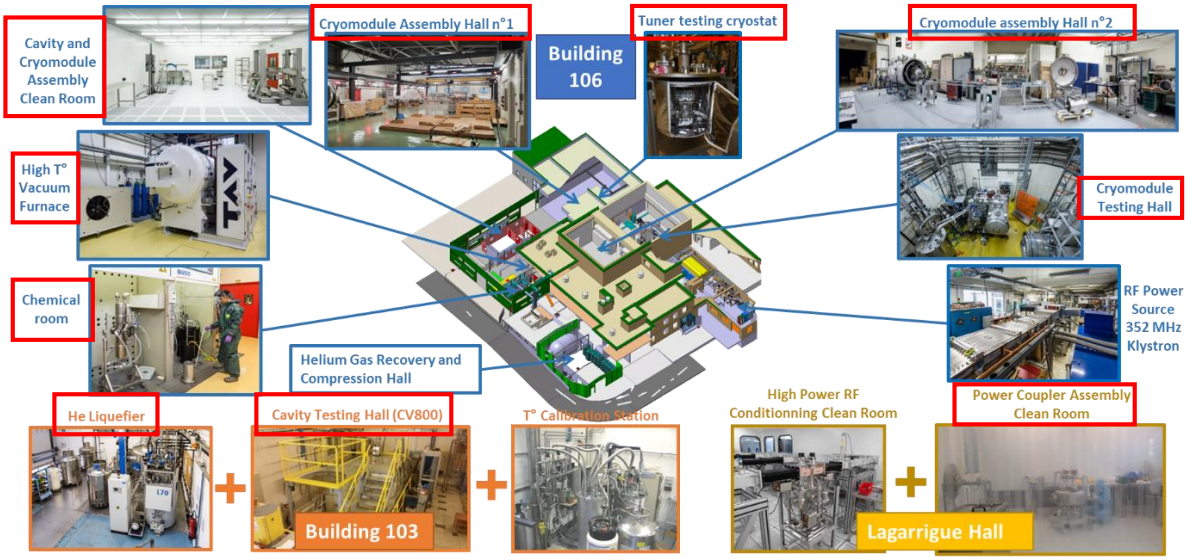


Figure 8: Supratech platform overview with equipment needed for EIC circled in red (D. Longuevergne, CS IJCLAB, May 2024)

The total human resources is estimated to 93 man.month for this WP1, with 30 man.month of non-permanent staff.

WP2: Procurements (15 months)

The number of international call for tenders has been estimated to circa 10. For those kind of tenders above the public procurement threshold (>143k€ in 2024), IJCLAB will have to delegate the procedure to the regional delegation (DR4 at Gif sur Yvette). For this particular task and mitigate the risk of delay, IJCLAB plans to hire a non-permanent person who will work at the regional delegation on the tenders for EIC RCS cryomodules. In parallel, IJCLAB will deal with around 100 orders to complete the procurement phase.

For the follow-up of the fabrication, a dedicated full time engineer is foreseen.

			2027				2028			
			Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
WP2	Procurement	Resp projet, Pôle Acc (IR)	20%	20%	20%	20%	20%			
		Resp "produits" (IR), ?	100%	100%	100%	100%	100%			
		Resp QA/QC (IR), CeQMAP	25%	25%	25%	25%	25%			
		Resp service financiers/achats	15%	15%	15%	15%	15%			
		Gestionnaire commandes/PUMA (AI, CDD)	75%	75%	75%	75%	75%			
		Resp bureau des marchés pour prépa A/O + PUMA	25%	25%	25%	25%	25%			
		DR4 Acheteur bureau des marchés (AI, CDD)	*50%*	*50%*	*50%*	*50%*	*50%*			

Figure 9: Detailed WP2 human resources breakdown (non-permanent staff in red)

The total human resources is estimated to 46.5 man.month for this WP2, with 19 man.month of non-permanent staff.

Nota bene: we think that some orders could be done before Q5/2027 and before the completion of the cryomodule design: the Niobium material, the SRF cavities, some components (i.e. temperature sensors) and some equipment for the Supratech upgrade.

WP3: Fabrication/follow-up and preparation of test sites (24 months)

This 2-year period of time will be dedicated to the follow-up of the fabrication of all components and also the preparation and upgrade of the Supratech platform equipment.

			2028				2029			
			Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16
WP3	Production and follow-up	Resp projet, Pôle Acc (IR)	50%	50%	50%	50%	50%	50%	50%	50%
		Resp "produits" (IR), ?	100%	100%	100%	100%	100%	100%	100%	100%
		Gestionnaire commandes/PUMA, Div Adm (AI)	25%	25%	25%	25%	25%	25%	25%	25%
		Resp service financiers/achats	10%	10%	10%	10%	10%	10%	10%	10%
		Suivi de fabrication + plans sites de test, Bureau d'études (AI, CDD)	100%	100%	100%	100%	100%	100%	100%	100%
		Ingé pour Suivi de fabrication, ? (IE/IR)	50%	50%	50%	50%	50%	50%	50%	50%
		Resp QA/QC (IR), CeQMAP	100%	100%	100%	100%	100%	100%	100%	100%
		C&C/Instrumentation (IR/IE)					50%	50%	50%	50%
		C&C/Instrumentation (AI, CDD)					50%	50%	50%	50%
		Systèmes Cryo (IR)			75%	75%	75%	75%	75%	75%
		Systèmes Cryo (AI, CDD)					50%	50%	50%	50%
		Systèmes RF (IR)					25%	25%		
		Systèmes RF (AI, CDD)					25%	25%		

Figure 9: Detailed WP3 human resources breakdown (non-permanent staff in red)

Task 3.1: Follow-up (24 months, 104.4 man.month)

A full time QA/QC engineer is plan during this period who will work with the engineer in charge of the follow-up (resp “produits” in the Figure 10).

Task 3.2: Supratech platform: preparation of test sites (12 months, 66 man.month)

This task is important and is planned over 1 year. It will involve a lot of non-permanent staff for the installation phases (dedicated to the C&C/instrumentation, cryogenics and RF equipment).

The total human resources is estimated to 170.4 man.month for this WP3, with 54 man.month of non-permanent staff.

WP4: Inspection, assembly and test (30 months)

Finally, one of the most critical WP which may impact a lot the EIC schedule in case of delays.

			2029				2030				2031	
			Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q22
WP4	Inspection Preparation Individual test	Resp projet, Pôle Acc (IR)	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
		Resp QA/QC (IR), CeQMAP	**25%**	**25%**	**25%**	**25%**	25%	25%	25%	25%	25%	25%
		Resp réception (IE/IR), ?	50%	50%	50%	50%	50%	50%	50%	50%		
		Opérateur 1, Supratech (AI)	100%	100%	100%	100%	100%	100%	100%	100%		
		Opérateur 2, Supratech (AI, CDD)	100%	100%	100%	100%	100%	100%	100%	100%		
		Opérateur 3, Supratech (AI, CDD)	100%	100%	100%	100%	100%	100%	100%	100%		
	Assembly	Resp assemblage (IE/IR), ?			100%	100%	100%	100%	100%	100%		
		Opérateur 1 Salle Blanche, Supratech (AI)			100%	100%	100%	100%	100%	100%		
		Opérateur 2 Salle Blanche, Supratech (AI, CDD)			100%	100%	100%	100%	100%	100%		
		Opérateur 1 Hors Salle Blanche, Bureau d'études (AI, CDD)			100%	100%	100%	100%	100%	100%		
		Opérateur 2 Hors Salle Blanche, Bureau d'études (AI, CDD)			100%	100%	100%	100%	100%	100%		
	Final test	Resp test (IR), ?						100%	100%	100%	100%	100%
		Expérimentateur 1 Test (AI), Supratech						100%	100%	100%	100%	100%
		Expérimentateur 1 Test (AI, CDD), Supratech						100%	100%	100%	100%	100%

Figure 10: Detailed WP4 human resources breakdown (non-permanent staff in red)

As we did for the ESS Spoke cryomodules in-kind, we plan to have almost 50% of the team with non-permanent staff dedicated to specific operations (especially technicians for the clean room and cryostating phases).

Task 4.1: inspection, preparation and test of the critical components; cavities, tuning systems and power couplers (24 months, 90 man.month)

Each cavity will be tested at 2K in our vertical cryostat. Each tuning system will be individually tested into our dedicated tuner test cryostat and the RF power couplers will be conditioned at warm temperature.

Nota bene: there are no spare components to mitigate any contingencies.

Task 4.2: Cryomodules assembly (18 months, 96 man.month)

The cavity strings will be assembled in the cleanroom one after the other (parallel assembly of 2 cavity strings is not possible). For the cryostating phase outside the clean room, we plan to use only one cryomodule assembly hall. To mitigate any problem, it is possible to move to the cryomodule assembly hall n°2 which is located in the same building.

Task 4.3: Final cryomodules tests (15 months, 51 man.month)

Up to now, we have identified 2 possible testing areas at IJCLAB for the EIC RCS cryomodules and the choice will be made in 2025.

The total human resources is estimated to 237 man.month for this WP4, with 117 man.month of non-permanent staff.

Total human resources for the contribution

546.9 man.month with 220 man.month (~40%) of non-permanent (equivalent of 45.6 FTE with 18.3 non-permanent FTE)

c. Cost estimate

The cost of the material has been estimated mainly thanks to our passed experience on the in-kind for ESS. All prices that we got in 2015 have been increased by 50% (except for the SRF cavities by 100%). Including the budget needed for all the individual tests and the final tests of the 4 RCS cryomodules, a total cost of 13.45 M€ has been estimated.

For the human resources, as we haven't yet appointed the people who will work on the project in 2026, we took an average value of 8k€ for 1 man.month. This leads to a cost of 4.375 M€ for the human resources

In total, IN2P3's contribution to the construction of the RCS was estimated at 17.825 M€.

	WP1	WP2	WP3	WP4	Total (k€)
Human resources (k€)	744	372	1363	1896	4375
Components & Tests (k€)	0	10650	0	2800	13450