

IN2P3 contribution to PIP-II

1. Summary

The Proton Improvement Plan-II (PIP-II) encompasses a set of upgrades and improvements to the Fermilab accelerator complex aimed at supporting a world-leading neutrino program over the next several decades and more specifically at providing an intense neutrino beam to the future DUNE project (Deep Underground Neutrino Experiment). Fermilab is building a large collaboration with different partners experienced in the design and fabrication of accelerator components to support this very ambitious international project. The main partners are USA (FERMILAB, ANL), India (DAE, BARC, RRCAT), Italy (INFN), France (CNRS, CEA), England (UKRI-STFC) and Poland (WUST, WUT and TUL).

IN2P3 and particularly the Accelerator department of IJCLab is, since 2018 strongly involved in PIP-II project and more specifically on the design and development of accelerator components for a section of the superconducting linac named (SSR2: Single Spoke Resonator type 2). The expertise and experience of IJCLab in the conception of fully equipped cryomodules (including all accelerator components) is known worldwide through several past and present contributions in national, European and international projects like cryomodule series production (Spiral2, ESS), power coupler assembly and processing (XFEL) and cryomodule design and prototyping (SPL, MYRRHA).

Since 2018, the prototyping phase of SSR2 cryomodule has been initiated in close collaboration between FERMILAB and ICLab teams following the signature of an SoI (Statement of Interest) between DOE and IN2P3. Prototypes accelerator components (superconducting accelerating cavity, frequency tuning system and RF power coupler) have been jointly designed, optimized and are now under fabrication. IN2P3 is fully supporting the cost of development, fabrication and testing of some components meant to be installed in the SSR2 prototype cryomodule.

End of 2021, the production phase will be initiated and fully launched in 2022 after the validation in operating conditions of the prototype cryomodule at FERMILAB. The In-Kind contribution of IN2P3 to the production phase of PIP-II has been agreed at technical level and consists in:

- Supporting FERMILAB teams during fabrication and surface processing phases done in specialized companies.
- Validating the performances of the 33 SSR2 cavities in vertical cryostat.
- Shipping all components to FERMILAB ready to be integrated in cryomodules.

The IK contribution to the production phase will be official once the following documents will be signed by both DOE and IN2P3: Project Planning Document Part 1 and Part 2. These documents describe how the collaboration is managed (Part1) and what are the technical activities, deliverables and milestones (Part2).

Last deliverables are scheduled end of 2025.

2. Outline

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3. Scientific context

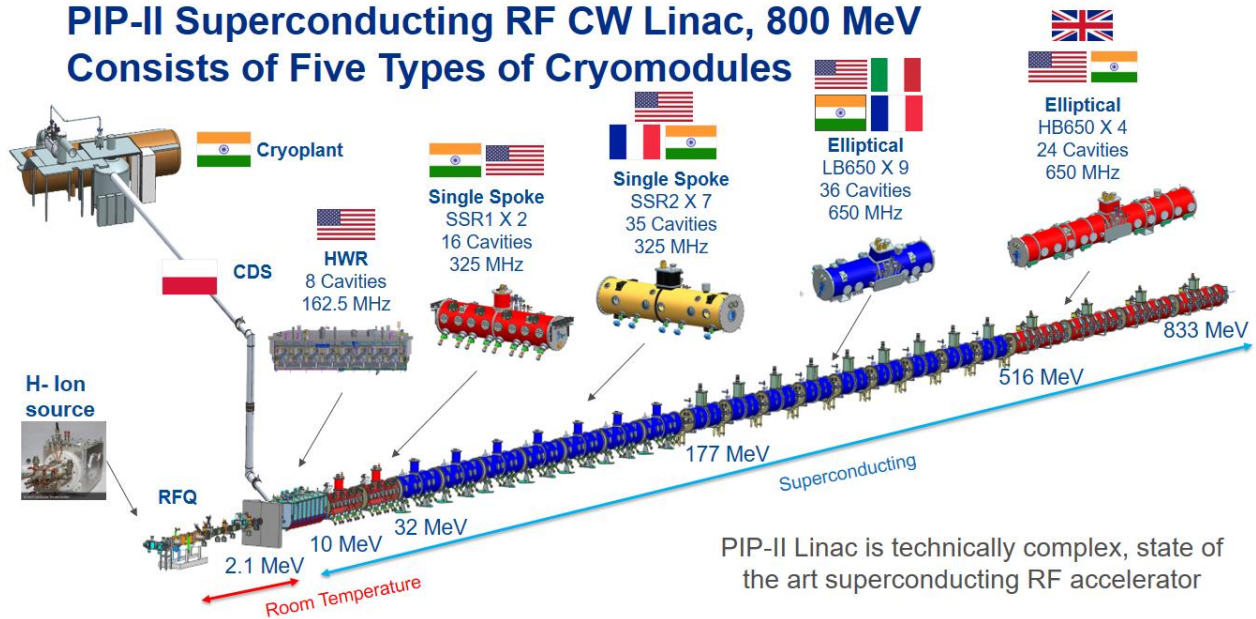
PIP-II is an integral part of the strategic plan for U.S. High Energy Physics as described in the Particle Physics Project Prioritization Panel (P5) report of May 2014 and formalized through the Mission Need Statement approved in November 2015. As an immediate goal, PIP-II is focused on upgrades to the Fermilab accelerator complex capable of providing proton beam power in excess of 1 MW on target at the initiation of the Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment (LBNF/DUNE) program. PIP-II is a part of a longer-term goal of establishing a high-intensity proton facility that is unique within the world, ultimately leading to multi-MW capabilities at Fermilab. The most challenging development of PIP-II project, for which Fermilab was looking for contribution and expertise of international partners, is the 800 MeV proton linear superconducting accelerator. PIP-II linac will be the first accelerator in the US with significant In-Kind Contribution from all over the world. France will contribute significantly to PIP-II and DUNE through the two major research institutes known for their expertise and experience in In-Kind Contributions:

- For PIP-II, CEA (IRFU) will be one of the main contributor to the elliptical section of the superconducting linac. It consists in integrating and fully validating the nine 650 MHz Low-Beta elliptical cryomodules. CNRS (IN2P3) will provide support to Fermilab during the fabrication of 33 Single Spoke Resonators type 2 (SSR2) and will validate their performance and re-process if required before shipment to Fermilab. The cavities will be ready to be integrated in their cryomodules
- For DUNE, IN2P3 will be strongly involved in the developments of detectors (double phase, single phase).

Both Institutions, CEA and CNRS, are financially supported by the French Ministry MESRI (Minister of Higher Education, Research and Innovation) and received TGIR grants respectively and separately for their contribution to PIP-II and DUNE.

The expertise and experience of IN2P3 and specifically of the accelerator department of IJCLab in the conception of fully equipped cryomodules (including all accelerator components) is known worldwide through several past and present contributions in national, European and international projects like cryomodule series production (Spiral2, ESS), power coupler assembly and processing (XFEL) and cryomodule design and prototyping (SPL, MYRRHA). Beside Fermilab, IJCLab is the most experienced lab in the world which has designed, produced and validated Spoke-type resonators. This advanced world-wide-recognized experience will be essential for the success of the project and to reach the very ambitious specifications required for SSR2 cavities. A nominal gradient of 11.4 MV/m (accelerating voltage of 5 MV/cavity) with a quality factor (Q_0) above $9E9$ (power dissipations in the helium bath below 9 Watts) have to be achieved, to be compared to ESS specifications ($Q_0=2E9$ at 9 MV/m).

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



PIP-II Linac is technically complex, state of the art superconducting RF accelerator

Last but not least, the opportunity to work in close collaboration with the world-leading accelerator laboratory Fermilab is of first interest for IN2P3 and for all technical people that are involved on PIP-II Project. The joint-design activities, R&D, prototyping programs and project management requirements have been defined accordingly to IN2P3 labs interests, expertise and will result in a significant skills improvement. Moreover, this contribution to PIP-II will serve the international DUNE experiment dedicated to neutrino science in which many French physicists, engineers and technician will be involved.

4. Genesis, timeline

PIP-II Project has been created following the strategic plan for U.S. High Energy Physics as described in the Particle Physics Project Prioritization Panel (P5) report of May 2014 and formalized through the Mission Need Statement approved in November 2015. The first version of the PIP-II Conceptual Design Report¹ has been issued in March 2017.

Fermilab and DOE contacted IN2P3 direction for the first time beginning of 2018 to start building a potential scientific and technical contribution. In June 2018, DOE and the PIP-II project technical team came in person at IJCLab to discuss and show their strong interest in IN2P3 expertise and experience in the design and production of superconducting Spoke resonator.

A detailed scientific and technical scope has been developed jointly and agreed between both teams (Fermilab and IJCLab) till end of 2018. R&D and design activities have been initiated in Autumn 2018 and was financially supported by IN2P3. A SoI (Statement of Interest) has been signed between DOE and IN2P3, officializing the contribution in December 2018. In Autumn 2019, the global French contribution to PIP-II and DUNE project shared between both research institutes (CNRS and CEA) has been presented to TGIR Council (Très Grand Infrastructure de Recherche).

At the end of summer 2020, MESRI (Minister of Higher Education, Research and Innovation) gave the feedback on the total financial support. At the sight of project priorities and the amount of available funds from France compared to scientific scopes, no support has been granted by MESRI for the contribution from CNRS/IN2P3. The CEA scope required the full amount of MESRI allocated funds.

¹ PIP-II CDR : https://pxie.fnal.gov/PIP-II_CDR/default.htm

IN2P3 decided to contribute to the PIP-II with a reduced scope described in section 3. This new contribution has been adapted to match funding capabilities of IN2P3 for the next five years and IJCLab expertise and scientific interest. Indeed, the contribution to PIP-II has been analyzed at the level of IJCLab following a review by a “Decision Committee” (CODEC) composed of the lab project management service and lab direction in October 2020.

Before signing any formal engagement (MoU) with Fermilab, IN2P3 would like the scientific council of IN2P3 to analyze the contribution and issue recommendations and approval. The signature of IN2P3 contribution is foreseen in Spring 2021.

The schedule of the contribution, appearing very challenging, has been developed jointly with Fermilab and is fully aligned and integrated in PIP-II project schedule. It consists in 2 main phases:

- R&D and Pre-production phase. This phase aims at developing and producing prototype components for the pre-production cryomodule. This phase has been initiated since the Sol signature and will finish end of 2022 after the full validation at Fermilab of the three main components fully assembled in operating conditions (Spoke Cavity+Frequency Tuner+Power Coupler).
- Production phase: this phase aims at qualifying production cavities in vertical cryostat (dedicated cryostat to test cavities in operating conditions) and if required to re-process the cavity surface if not meeting specifications. We can separate this phase into two sub-phases:
 - o Project deliverables: This phase will start in 2022 after full validation of pre-production components and will finish once all cavities will be delivered and accepted by Fermilab.
 - o Upgrade of IJCLab facilities: this upgrade consists in preparing and upgrading the testing area at IJCLab for the production phase. Indeed, the qualification rate of cavities needed for the project requires an upgrade of the testing facilities to improve the efficiency, reliability and quality of current infrastructure.

A detailed schedule is presented in appendix 1.

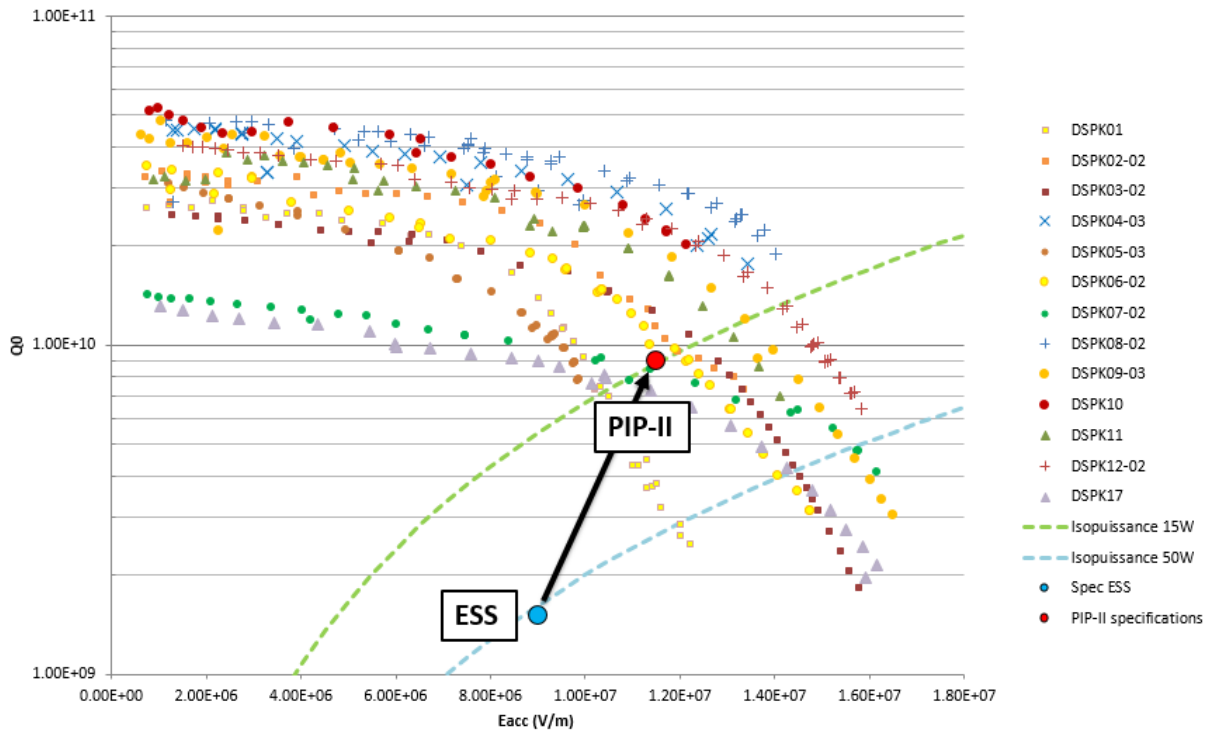
5. State of the art

The real challenge in this project is not scientific or technologic as no new technology is involved. Indeed, the type of resonator (Spoke) is not new even though the design of this cavity is very specific to meet the project requirements. Moreover, the use of bulk Niobium is required which is today mastered by several companies in term of production, forming and welding. The most challenging part is the level of technical specifications. The later have been already challenging to meet by design (mechanical properties and frequency stability) and are not conservative neither straightforward in term of accelerating gradient and quality factor for Spoke resonator. Some specific optimization of the surface treatments should be introduced and are today under study. This implies a very high level of quality for the surface processing. As an example, the first “Spoke” resonator production made by IJCLab is for ESS project aiming at a quality factor of $2E9$ at an operating gradient of 9 MV/m . PIP-II SSR2 resonators will operate at a gradient of 11.5 MV/m with a minimal quality factor of $9E9$. At the sight of the first validated cavities, most of them also meet PIP-II operating specifications but with a very limited margin. This margin will be improved:

- By design, the optimization process has been pushed further allowing peak surface electromagnetic field ratios (namely E_{pk}/E_{acc} and B_{pk}/E_{acc}) to be smaller. Moreover, ESS spoke cavities are double spoke resonators with a more complicated geometry limiting the efficiency of the surface treatment.
- By surface processing. The surface preparation of PIP-II Spoke resonators will integrate the experience and most recent developments of both labs Fermilab and IJCLab. Firstly, rotational chemical etching with BCP (Buffered Chemical Polishing) mixture will be studied. The implementation of rotation improves drastically the homogeneity and quality of surface polishing. Secondly, the heat treatment procedure aiming at degassing hydrogen contamination has been optimized allowing to reach very high quality factors as shown during studies carried out in the framework of European project MYRTE (MYRRHA Research and Transmutation Endeavour). Finally, cavities will be jacketed with a helium tank made of titanium to mitigate any problems of magnetic hygiene (any magnetized parts, mainly stainless steel, in the cavity vicinity during superconducting transition can affect significantly the quality factor).

All these improved processes will be investigated and consolidated during the prototyping phase on 4 cavities at IJCLab.

An additional challenge will be met during production phase. The improved surface processing will have to be transferred to the company in charge of cavity fabrication. These companies are already sensitized to surface processes as the latter already processed such cavities for previous projects like EU-XFEL or LCLS-II. The real challenge will be to work with companies to upgrade and adapt their facilities to process Spoke resonators.



	ESS	PIP-II
GEOMETRY : magnetic field distribution		
Accelerating gradient	9	11.5
Qo at operating gradient	1.5E9	9E9
Epk/Eacc	4.3	3.5
Bpk/Eacc	6.9	6.75
G	130	115

6. Description of scientific and technical activities (as detailed in PPD part 2)

PIP-II project activities can be divided into two main packages:

- Fermilab Package: All activities related to deliverable components to be shipped to Fermilab
- IJCLab Package: All activities related to the local infrastructure at IJCLab.

3.1 Technical Description of Femilab package

CNRS/IN2P3 plans to perform the fabrication follow-up (if procurement done by Fermilab is with a European company) and the validation in vertical cryostat of 33 (30 plus 3 yield) jacketed SSR2 single-spoke resonators. All the technical, administrative and coordination work is localized at IJCLab, one of the several laboratories supervised and managed by IN2P3.

The 33 SSR2 jacketed cavities and the niobium material required for their fabrication are planned to be procured by Fermilab. All cavities are planned to undergo room temperature checks and validation in a vertical cryostat using a Low Power Coupler (LPC) and a dedicated tuner (not production tuner) at IJCLab. The cavities are planned to be delivered to Fermilab under vacuum without any intermediate venting following the qualification in the vertical cryostat.

3.2 Detailed Project Activities for deliverable components

The following sections provide brief description of activities, leading to the milestones described later of this document. Project activities are organized according to the four Project Phases defined in PPD – Part 1.

3.2.1 Phase 1: Preliminary Design Phase

Phase 1, as described in PPD – Part 1, is the preliminary engineering design phase of the in-kind deliverables. It culminates in the completion of the system and component Preliminary Design Reviews (PDR) and the closure of any request for action generated by the reviews.

CNRS/IN2P3 contributed to the SSR2 cavity and tuner designs, developed by Fermilab and its partners including CNRS/IN2P3. The SSR2 cavity and tuner preliminary design reviews were completed in 2018. More recently, CNRS/IN2P3's contributed to address specific technical points to support the preliminary design of the 325 MHz power coupler prototype development.

Phase 1 starts upon first successful kick-off meeting and ends with the successful completion of the Preliminary Design Review (PDR) for the SSR2 cavities, tuners and power couplers. This phase is considered completed.

3.2.2 Phase 2: Final Design Phase

The Final Design Phase develops an engineering design of sufficient maturity to serve as the basis for procurement, fabrication, assembly and testing of the system or component. The final design is supported by a complete set of assembly drawings and engineering notes, accompanied by an acceptance testing plan. The Final Design Phase culminates in the completion of the system and component Final Design Reviews (FDR) and the closure of any requests for action generated by the reviews.

During Phase 2, CNRS/IN2P3 is expected to contribute to:

- pre-production detailed design activities for SSR2 cavities, tuners and power couplers;

- building pre-production parts to be installed in the pre-production cryomodule SSR2. The scope of the pre-production cryomodule is to meet all the PIP-II SSR2 specifications, but it is planned to be not installed in the superconducting linear accelerator (Linac)

In the context of detailed design activities, CNRS/IN2P3's work in this stage includes but it is not limited to:

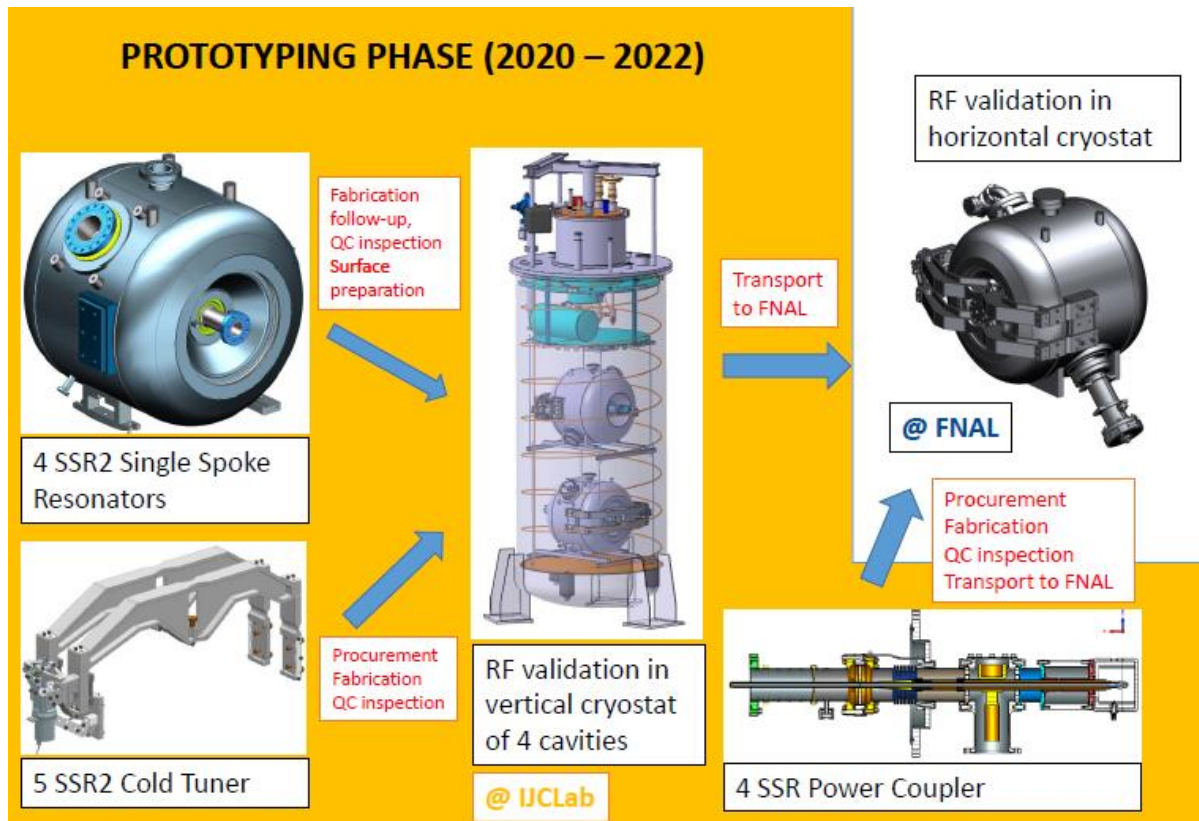
- Test specific heat treatments (Nitrogen infusion or doping, 120°C baking) to measure their positive and negative impact on SSR2 Spoke cavity performances and decide which could be integrated in the surface preparation procedure of the prototype and series production. This R&D activity has been started at IJCLab on 352 MHz Single Spoke Resonator from MYRRHA project and will be continued and refined on pre-production SSR2 Spoke cavities.
- Analysis of the sensitivity to magnetic trapped flux of SSR2 cavities. Calculations plan to be performed and compared to experimental data measured during vertical tests at IJCLab.
- Transportation study: aims at addressing cavity performances before and after shipment of the cavity and/or power coupler. This is expected also to help the optimization of the transportation box and procedure. This study plans to be done on a SSR cavity. At most 2 different type of transportation box will be studied (standard box and cable-spring damped box).
- Aging test on SSR1 tuner cartridge in the dedicated nitrogen cooled test bench at IJCLab, under availability of SSR1 tuner by Fermilab. This test plans to simulate several years of pulsed operation of the cold motor and piezo actuator. The performances of both motor and piezo actuators are planned to be monitored.
- Issue a report on the optimized recipe for cavity surface preparation (Q0 optimization) and how to reach frequency target of the dressed cavity (cavity + tuner + HPC) at 2K.
- CNRS/IN2P3 plans to be involved in the mechanical design optimization of the pre-production SSR2 spoke cavity and its helium tank. In such a context, CNRS/IN2P3 plans to perform, in collaboration with FERMILAB, the structural calculations required to comply with specifications written in the FRS and TRS documents.
- CNRS/IN2P3 plans to be involved in the SSR2 pre-production tuner design optimization in collaboration with Fermilab. CNRS/IN2P3 plans to contribute to the tuner system mechanical design optimization in compliance review with FRS and TRS.
- CNRS/IN2P3 plans to be involved in the SSR2 pre-production HPC design optimization (electrical, thermal and mechanical) in collaboration with Fermilab.

In the context of building pre-production parts to be installed in the pre-production cryomodule SSR2, CNRS/IN2P3 plans to cover the cost of pre-production tuners and power couplers fabrication, while the cost of Niobium and cavity fabrication (pre-production four units) are covered by FERMILAB. In select cases, FERMILAB is expected to supply components to CNRS/IN2P3 as specifically indicated below. CNRS/IN2P3's work in this stage includes but it is not limited to:

- For SSR2 Cavities:
 - o Support FERMILAB supplier selection and act as inspector (QC measurements, reporting to FERMILAB) during fabrication (if supplier is European) of 3 jacketed pre-production cavities.
 - o Assess the Niobium thickness distribution all over cavity walls at reception and after BCP etching of a bare cavity. So as to be representative of real operating conditions (chilled water running in the helium jacket), BCP etching of the bare cavity will be performed with a mock-up helium jacket allowing to simulate the water cooling during the chemical treatment.

- o Process (BCP, hydrogen degassing), prepare (HPR, clean room assembly), and evaluate parameters and sequence of each cleaning step to define final processing recipe.
- o Develop the ability of rotational BCP and address the benefits in term of material removal homogeneity and surface quality. This study will be performed on a bare cavity in parallel and jointly of the wall thickness distribution study.
- o Test the 4 jacketed pre-production cavities in vertical cryostat with 4 of the 5 pre-production tuners and Low Power Coupler (LPC). The cavity performances are planned to be measured ($Q_0=f(E_{acc})$, multipacting, field emission). This approach is to optimize test protocols and to define the final processing recipe.
- o Ship the 4 jacketed pre-production cavities to FERMILAB after qualification, including meeting PIP-II specifications. Cavities are planned to be shipped under vacuum without any venting after qualification in vertical cryostat.
- o Participate to the final design of the production cavities.
- For SSR2 Tuners:
 - o Procure 5 tuners.
 - o Perform QC inspection and room temperature tests.
 - o Test tuners in vertical cryostat assembled on the cavity. Tuner performance are planned to be measured (mechanical range, frequency sensitivity versus position, hysteresis).
 - o Ship to FERMILAB the 5 tuners (mechanical parts + piezo-electric actuators + stepper motors) with cavities but partly disassembled to ensure safe transportation of both the cavities and tuners.
 - o Participate to the final design of the production tuners.
- For SSR2 Power Couplers :
 - o Procure 4 HPCs including both cold and warm end assemblies. 2 HPCs of the 4 procured HPCs will have a TiN coating on the ceramic windows. Ceramic windows are procured and validated by FERMILAB prior to shipping to CNRS/IN2P3. CNRS/IN2P3 is expected a minimum of 6 8 ceramic windows to be shipped by FERMILAB.
 - o Choose and support the supplier during fabrication.
 - o Perform QC inspection and low power room temperature tests (S11, bias voltage). The 4 HPCs will be cleaned by the supplier following the standard cleaning procedure required for the cold end assembly (degreasing, baking and assembly in ISO 5 clean room). No RF conditioning and no RF power test are planned to be executed at CNRS/IN2P3.
 - o Ship all 4 HPCs together to FERMILAB
 - o Participate to the final design of the series power coupler

Phase 2 starts at the successful completion of the Phase 1 and ends with the successful completion of the Final Design Review (FDR) of the production SSR2 dressed cavities.



3.2.3 Phase 3: Procurement/Assembly/Fabrication Phase

During Phase 3, production systems and components are procured, manufactured, and verified. The product is planned to be verified by way of analysis and/or test and/or inspection and/or demonstration.

CNRS/IN2P3's contribution in Phase 3 is the production, assembly and tests of all the deliverables described in this document for the PIP-II Project. CNRS/IN2P3's work in this stage includes but it is not limited to:

- For SSR2 Cavities:
 - o Support supplier during fabrication and surface processing (BCP, heat treatment, HPR) provided that the supplier is a European company
 - o Test the 33 (30 plus 3 yield) cavities in vertical cryostat with 2 dedicated tuners (not production tuners) and low power coupler (LPC). The cavity performances are planned to be measured ($Q_0=f(E_{acc})$, multipacting, field emission)
 - o A maximum of 25% of the cavities (8 cavities) could be re-processed (BCP, HPR) and re-tested in vertical cryostat at IJCLab without impacting cost and schedule (already included in the baseline cost and schedule). Additional re-processing and testing are possible but will induce delays and cost increase.

Phase 3 starts upon successful completion of the cavity Final Design Reviews (FDRs). Phase 3 ends with the successful completion of the System Acceptance Review at CNRS/IN2P3 premises (SAR1).

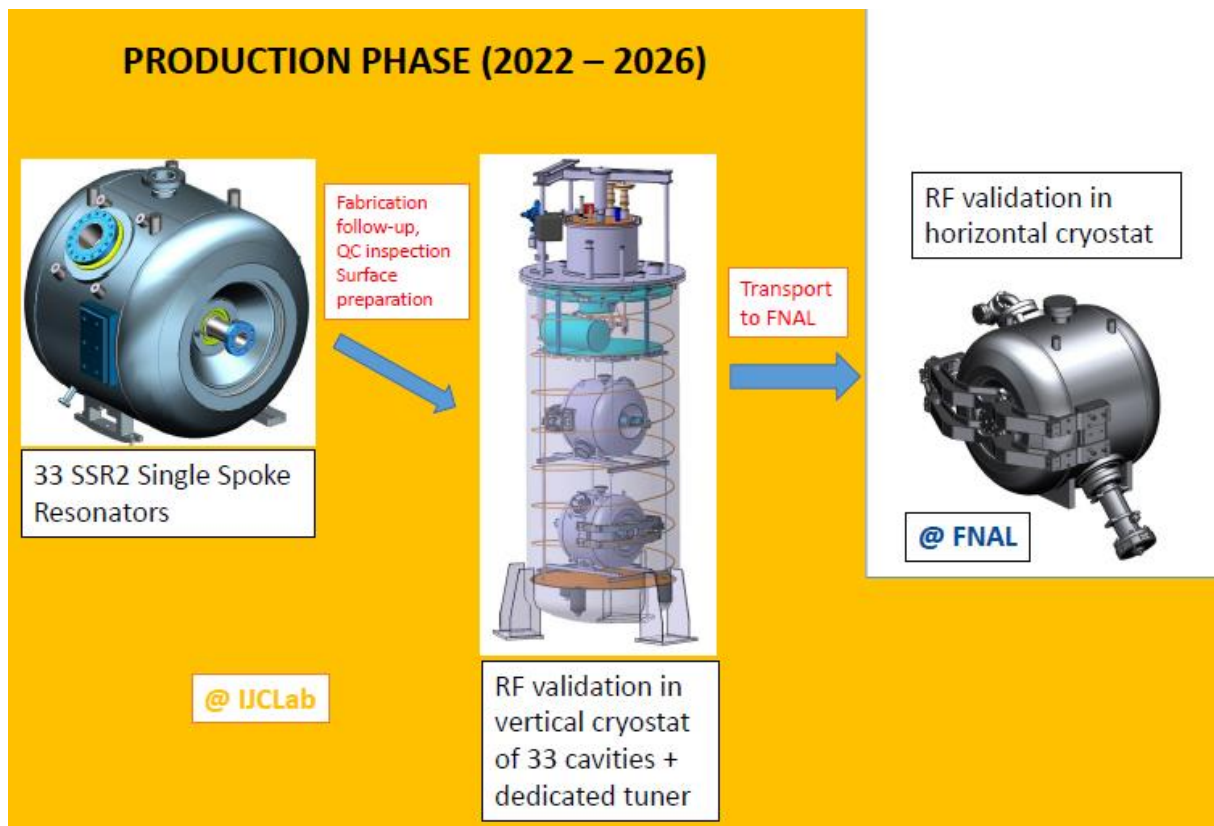
3.2.4 Phase 4: Delivery and Acceptance Phase

During Phase 4, CNRS/IN2P3 plans, after full qualification of all deliverables and if authorized by PIP-II project, to proceed with:

- Transport of SRF cavities according to PIP-II transportation requirements;
- Deliver to FERMILAB and proceed with SAR2 of each batch composed of 6 (or 5, or 7) jacketed Cavities under vacuum with vacuum valve and RF feedthroughs used for VTS qualification Support FERMILAB acceptance test of the first cavity batch in VTS.
- Resolve any non-conformity to follow mutually agreed remedial protocols, as defined in PPD – Part 1 and the Acceptance Test Plan.

Phase 4 starts at the successful completion of the Phase 3 System Acceptance Review 1 per each delivery batch, and ends with the successful completion of the Site Acceptance Review 2 at FERMILAB for each delivery batch.

The acceptance plan and acceptance criteria are detailed in the PIP-II-SRF-SSR2 Dressed Cavity Acceptance Plan and PIP-II-SRF-SSR2 Dressed Cavity Acceptance Criteria documents.



3.3 Technical description of IJCLab Package

This package includes all technical activities required to upgrade facilities to test production cavities in optimal conditions. A risk analysis exercise pointed out that the cryostat currently in operation is showing operating weaknesses for production activities (low reliability, non-optimal logistic of cryogenic fluids, ...) that could significantly impact the qualification rate.

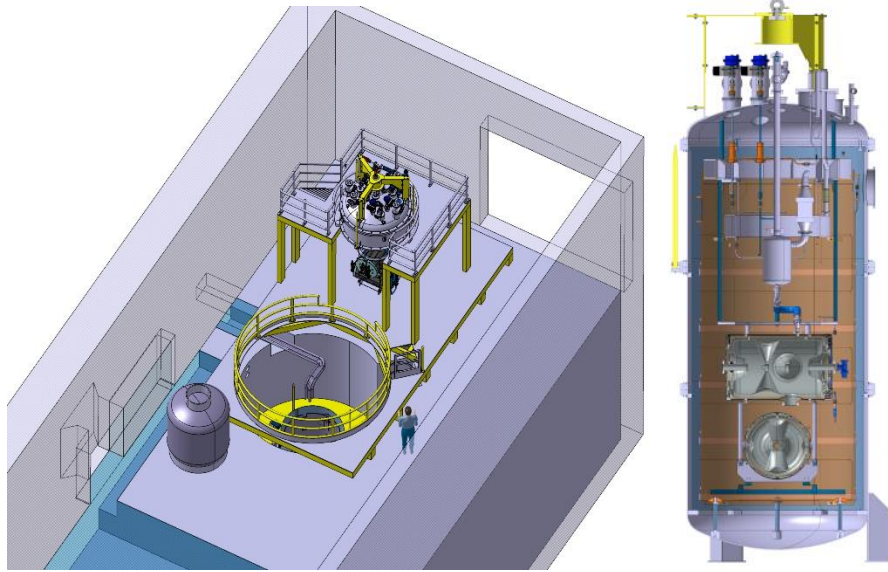
It mainly consists in finalizing the installation of a new cryostat (CV1250) on Supratech Platform. The next section will describe all work-packages and related activities.

It has to be noted that this new cryostat (CV1250) is not required for all testing activities during pre-production phase. Indeed, the cryostat currently in operation (CV800) will be available and well adapted for the small number of prototype cavities.

3.4 Detailed Project activities related to IJCLab facilities

All activities related to IJCLab facilities can be categorized in the following work-package

- Infrastructure:
 - o Procure and install secured platform for insert assembly
 - o Install cryostat inside the pit (scheduled in September 2021)
- Radioprotection:
 - o Upgrade security PLC
 - o Communicate changes to ASN and finalize authorization.
 - o Procure and install additional shielding (moving platform loaded with lead)
- Cryogenic distribution:
 - o Procure and install liquid helium vacuum-isolated distribution line between liquefier and buffer next to cryostat
 - o Procure and install helium buffer
 - o Procure and install liquid nitrogen distribution line between liquid nitrogen tank and cryostat
 - o Maintain or upgrade sub atmospheric helium pumps.
- RF distribution:
 - o Procure RF components and build Low Level RF system
 - o Procure additional RF components: RF amplifier, circulator, bidirectional coupler, RF cables, ...
 - o Upgrade software for command and control
- Vacuum distribution:
 - o Procure vacuum components for cavity volume: turbo-molecular pump, ionic pump, primary dry pump, valves, vacuum gauges, residual gas analyzer, ...
 - o Procure vacuum components for cryostat isolation: turbo-molecular and primary pumps, valves, ...
- Control & Command:
 - o Procure, install and program PLC for command and control of cryogenic fluids, pressure and helium level
 - o Procure and install temperature sensor read-out
- Instrumentation:
 - o Procure and calibrate cernox sensors
 - o Procure pressure gauge and butterfly valve
 - o Procure helium level sensors
 - o Procure magnetic sensors for residual magnetic field monitoring

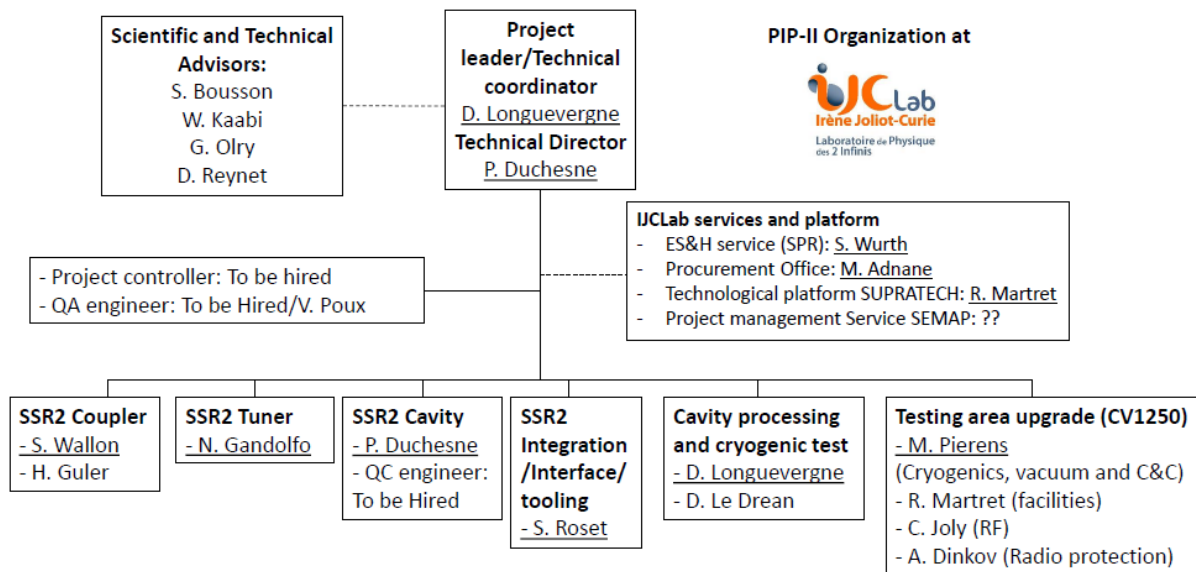


7. Human resources and project cost

Since 2018, IN2P3 is strongly involved in PIP-II project and especially in the design activities of accelerator components: cavities, tuner and couplers. These activities benefited both parts of the collaboration (“win-win” collaboration) as the design of accelerator components included experiences and lessons learned from both FNAL and IN2P3. This very active collaboration is rythmed by:

- regular (almost weekly during very active period) technical meetings between Fermilab and IN2P3.
- monthly “All partners” meeting involving Fermilab, DAE and IN2P3 to exchange on technical advances specifically on Spoke cryomodules (SSR1 and SSR2)
- trimestrial coordination meeting named P2PEB (PIP-II Project Executive Board) involving all partners of the collaboration and serving as a forum to exchange on project updates (technical advances, project management, ...) and as an international configuration change board.
- yearly technical workshop aiming at exchanging between all partner’s experiences and lessons learned on specific topics decided by technical coordinators and a scientific committee.
- Yearly review by IN2P3 direction (Entretien Annuel Projet) of project status, encountered difficulties, project forecast of following years.

The IN2P3 organization chart can be viewed below. Detailed organization charts of Fermilab and the international collaboration can be found in appendix.



IN2P3 team is composed today of a scientific and technical directors, 6 Sub-Project Coordinators and a QA engineer. The technical team is then divided into 6 work-packages: one per type of components (coupler, tuner and cavity) and three others for tooling and interfaces, cavity surface processing and testing and upgrade activities of the testing facilities. The local team is supported by IJCLab services and Supratech Platform which includes activities such as cavity inspection at reception, surface preparation and cavity testing in vertical cryostat. Supratech facilities are operating since more than 5 years and the team is well experienced in producing cavities for projects such as ESS or SPIRAL2. Advisors have been identified if any expertise are required.

During prototyping phase, the availability of IJCLab permanent workers is enough to handle the work load. For the production phase, starting in 2022 and for 3 years, the local team would need to be

reinforced especially for cavity testing and project management. In that sense, 3 temporary workers should be recruited to cover the work load during cavity quality check (QC) and cryogenic test activities and project management (project controller) and quality assurance.

The table below summarizes the human resources already required since 2018 and expected till the end of IN2P3 contribution. A total of 38 FTE has been estimated including 12 FTE of non-permanent staff.

Nom des personnes	Statut	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	Total (FTE)
IJCLab		0%	14%	42%	65%	65%	65%	50%	40%	30%	20%	3.91
D. Longuevergne	Responsable scientifique		14%	35%	50%	50%	50%	40%	30%	20%	10%	2.99
H. Guler	Expertise conditionnement coupleurs			7%	10%	10%	10%	5%	5%	5%	5%	0.57
W. Kaabi	Conseil coupleur				5%	5%	5%	5%	5%	5%	5%	0.35
TOTAL (FTE)		0.00	0.14	0.42	0.65	0.65	0.65	0.50	0.40	0.30	0.20	3.91

Human resources (physicists)

Nom des personnes	Statut	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	Total (FTE)
EQUIPE PIP-II		0%	17%	90%	180%	180%	160%	150%	145%	135%	70%	11.27
P. Duchesne	Responsable technique + lot cavité		12%	35%	50%	70%	70%	85%	90%	90%	50%	5.52
N. Gandolfo	Responsable Lot Tuner			15%	35%	35%	35%	15%	10%	10%	5%	1.60
S. Wallon	Responsable Lot Coupleur			15%	25%	25%	25%	5%	5%	5%	5%	1.10
D. Reynet	Ingénieur Système		5%	10%	10%	10%	10%	10%	10%	10%	5%	0.80
V. Poux	Responsable Qualité IJCLab			10%	10%	10%	10%	10%	10%	10%	5%	0.75
S. Roset	Conception outillage/mécanique			5%	50%	30%	10%	25%	20%	10%		1.50
PLATEFORME SUPRATECH		0%	0%	0%	0%	40%	140%	0%	95%	95%	0%	3.70
T. Pépin-Donat	Opérateur four et planning SUPRATECH					5%	25%		15%	15%		0.60
L. Renard	Opérateur Salle blanche SUPRATECH					10%	30%		25%	25%		0.90
N. Bippus	Opératrice Salle Blanche SUPRATECH					10%	30%		25%	25%		0.90
F. Rabehasy	Opérateur Salle Chimie SUPRATECH					5%	25%		15%	15%		0.60
L. My Vogt	Opérateur Salle Chimie SUPRATECH					10%	30%		15%	15%		0.70
SERVICE CRYO ET RF		0%	0%	0%	0%	100%	180%	200%	160%	100%	0%	7.40
F. Gallet	Opérateur Liquéfacteur + Upgrade CV1250					10%	20%	20%	20%	20%		0.90
M. Pierens	Opérateur Liquéfacteur + Upgrade CV1250					25%	40%	50%	40%	5%		1.60
F. Chatelet	Gestion cryo Cryostat					10%	20%	20%	20%	20%		0.90
G. Mavilla	Instrumentation + gestion cryo Cryostat + upgrade CV1250					25%	40%	40%	40%	30%		1.75
D. Le Dréan	Opérateur RF Cryostat					10%	20%	20%	20%	20%		0.90
S. Blivet	Infrastructure upgrade CV1250					10%	20%	20%	10%			0.60
TBD	Ingénieur radio-protection					10%	10%	10%				0.20
TBD	Ingénieur RF Upgrade CV1250					10%	10%	20%	10%	5%		0.55
CDD		0%	0%	0%	0%	0%	75%	325%	400%	325%	75%	12.00
TBD	Contrôleur projet						25%	100%	100%	75%		3.00
TBD	Ingénieur qualité						25%	100%	100%	75%		3.00
TBD	Instrumentation + gestion cryo Cryostat + QC						25%	100%	100%	75%		3.00
TBD	Instrumentation + test RF + QC							25%	100%	100%	75%	3.00
TOTAL (FTE)		0.00	0.17	0.90	1.80	3.20	5.55	6.75	8.00	6.55	1.45	34.37

Human resources (ITA=technical staff)

Initially, the IN2P3 contribution was meant to be financed by French Ministry MESRI as a TGIR. As explained earlier, the allocated money was drastically reduced and could only cover the CEA contribution that was for Fermilab the highest priority. Nevertheless, IN2P3 decided to maintain its contribution to PIP-II but with a reasonable and reduced scope as described in previous sections. It consists in keeping all activities where IN2P3 has a strong and unique expertise that couldn't be handled by any other international partners: cryogenic testing of Spoke resonators. This reduced scope has been financially evaluated and appears to be within IN2P3 budget for the next 4 years. Expenses have been smoothed as much as possible over the years. A minimum margin of 15% has been included for all well-known expenses and has been increased for instance to 50% for all activities/procurements showing high risks or with significant uncertainties (rough estimations not based on quotations): upgrade of Supratech facilities, cryogenic testing of prototypes.

The project cost is estimated at 5.7 million euros including FTE (permanent and non-permanent staff). The personnel cost is about 3 million euros including 900 k€ of non-permanent staff.

IN2P3 already engaged more than 500 k€ and 4 FTE for R&D and prototyping phase for PIP-II.

Somme de Cout (base+incertitude) Étiqu		+	+	+	+	+	+	+	+	
		2018	2019	2020	2021	2022	2023	2024	2025	Total général
Étiquettes de lignes										
+	WP1 management	16	13		14	29	29	29	29	158
+	WP2 Cavité	17	25	11	165	182	85	423	305	1214
+	WP3 Tuner		23	42	21	0	0			86
+	WP5 Coupler			370	35	0	0			405
+	WP6 Supratech (CV1250)				191	239	404			834
Total général		33	61	423	426	450	518	452	333	2696

Financial resources distribution already spent and required per year (in k€). Cost of personnel is not included

8. SWOT

Strengths:

- Team is well experienced in series production (ESS) of Spoke resonators
- Current facilities are fully compatible with PIP-II Spoke resonators
- Technology transfer (surface processing of Spoke resonator and power coupler) to industries with which a lot of projects/interactions are already going on
-

Weaknesses:

- Some facilities need to be upgraded (vertical cryostat) to handle efficiently the series production (risk mitigation).
- IN2P3 funding is tight and might have difficulties to ensure complete funding (non-permanent human resources + facilities upgrade)
- Profil of IN2P3 funding. Yearly funding will add uncertainties and difficulties to manage the project
- Too many key permanent staff: today human resources is sufficient but what about tomorrow in case of resignation?

Opportunities:

- Collaborate with Fermilab, one of the most experienced accelerator lab of the world, not only on PIP-II but also on R&D topics like Nitrogen doping/infusion.
- Collaborate with a lab very advanced in project managements methods
- Benefit from experience and lessons learned of the full collaboration
- Work on a world-class project with very high visibility
- Improve IJCLab's facilities for PIP-II and future projects.

Threats:

- On-going project ESS is delayed and could impact significantly PIP-II prototyping phase schedule
- Potential new projects (MYRRHA series production) could happen in the same period.
- Delays or extra cost due to export/import difficulties (VAT exemption)
- See risk analysis

9. Risk analysis

Risk identification and evaluation

The full local team and also lab technical support services, because of their expertise and experience, will be part of the risk identification and evaluation process. Risks identification will be not only based on existing risks portfolio (IN2P3 level) but also on the specificities of PIP-II team activities and lab facilities and environment. Risks of different nature (technical and scientific, external, human, organizational, costs, procurement, planning, transportation, ...) will be assessed and graded in term of likelihood and severity. The criticality (likelihood*severity) will be calculated and classified in 3 impacts levels (1: Low, 2: Medium and 3: High).

The risk impact scoring is summarized in the table below:

	Low Impact	Medium Impact	High Impact
Technical Impact	Somewhat sub-standard	Significantly sub-standard	Extremely sub-standard or KPP in jeopardy
	Can be repaired by the team	Can be repaired within IJCLab	Can be repaired only with external parties
Cost Impact	< 1% of project cost	1% - 5% of project cost	> 5% of project cost
	< 25 k€	25k€ - 100k€	> 100k€
Schedule Impact	< 2% of project duration	2 - 5 % of project duration	> 5 % of project duration
	<1 month	1 - 3 months	> 3 months

Table : Impact scoring of risks

The risk ranking matrix is distributing the risk impact versus the probability:

	Low Impact	Medium Impact	High Impact
Very High. 64-100%	Medium	High	High
High 39-64%	Medium	High	High
Medium 21-39%	Low	Medium	High
Low 9-21%	Low	Medium	Medium
Very Low 0-9%	Low	Low	Medium

Table: Risk ranking matrix

Risk management and mitigation:

The project controller will be responsible of coordinating the risk evaluation process and will generate preventive (risk level 2) and corrective (risk level 3) actions. Each action generated will aim at mitigating the risk criticality down to an acceptable level. Risks will be monitored and updated during the full project life time. A risk register will be built, fed and updated continuously. Actions generated by risk analysis process will be integrated in the action management process.

Depending on their nature, several processes could be used to mitigate risks criticality: expertise, reviews, strengthening of Quality Assurance (improvement of procedures, manufacturer follow-up, communications, infrastructure maintenance, ...), external support,

Preliminary Analysis

DESCRIPTION	Probability	Schedule impact (month)	Cost impact (k€)	P* schedule impact (months)	P* cost impact (k€)
Technical					
RF test forbidden due to ASN restrictions	5	6		0.3	0
Accident during BCP etching	5	2		0.1	0
Accident during cavity handling	5	1		0.05	0
Management					
Human resources not available due to other projects	25	1		0.25	0
Difficulties to hire temporary workers	25	3		0.75	0
Loss of a temporary worker (resignation)	25	3		0.75	0
funding lost because of delay in activities (yearly funding)	25	0	200	0	50
Cavity loss or damages during transportation to FNAL	1	1	150	0.01	1.5
Custom fees not waived on time because of incomplete procedure	10	0	50	0	5
External					
Increase of helium cost	50	0	50	0	25
Qualified vendors not available for production	10	6	0	0.6	0
More than 25% of production cavities have to be re-processed	50	4	50	2	25
Testing facilities not/partially available because of other projects	25	6	0	1.5	0
Clean room not/partially available because of other projects	25	6	0	1.5	0
CV1250 not operational	10	6	0	0.6	0

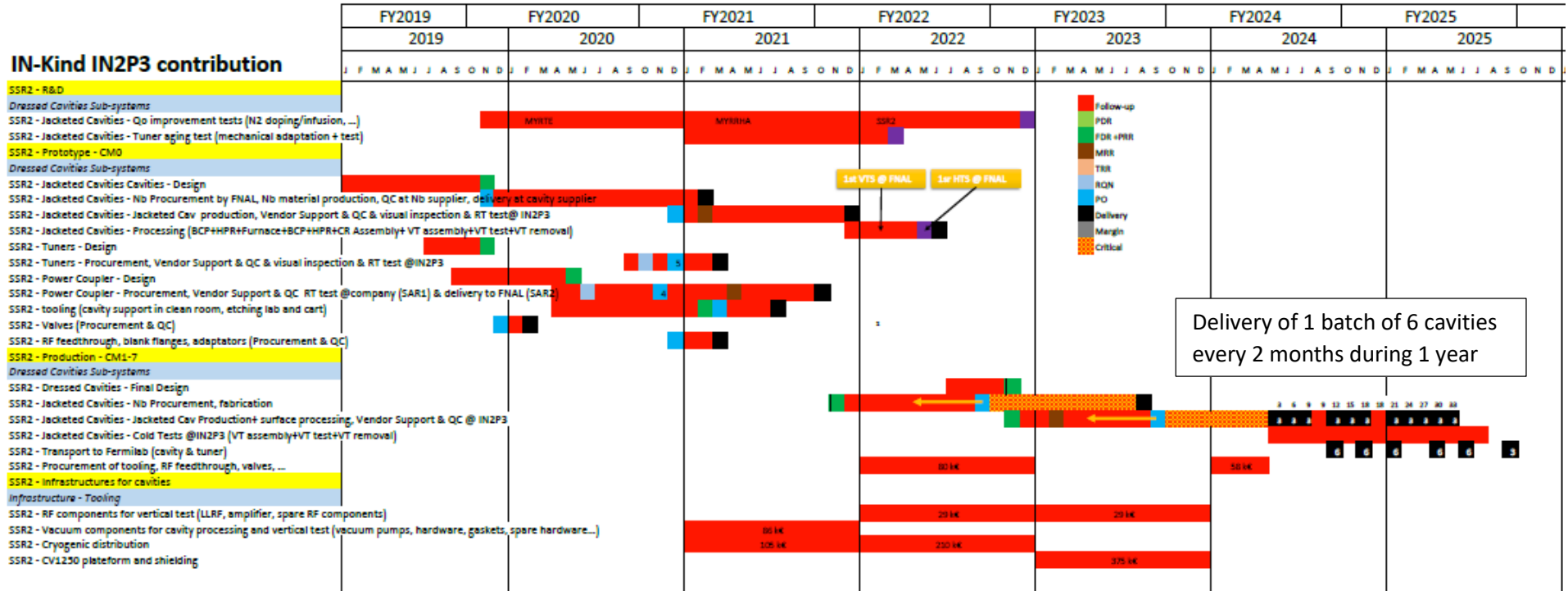
Table : Identified risks

Risk evaluation for production phase (preliminary)

Risks	Schedule (month)	Cost (k€)
Systemic	8.41	106.5
Technical (cavity)	5.185	155.34
TOTAL	13.6	261.8

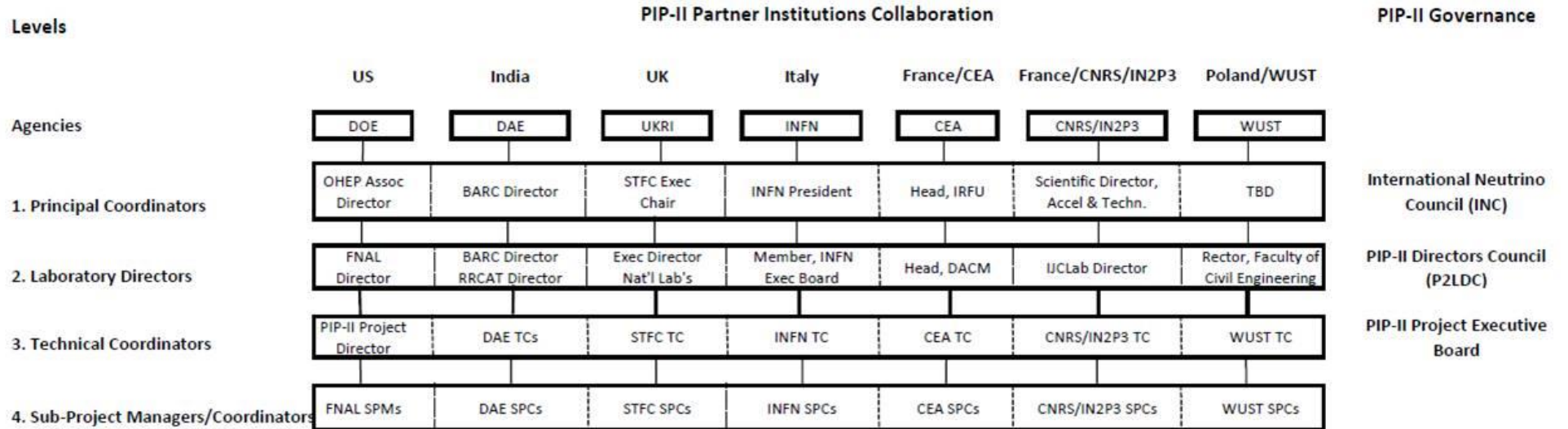
10. Appendix

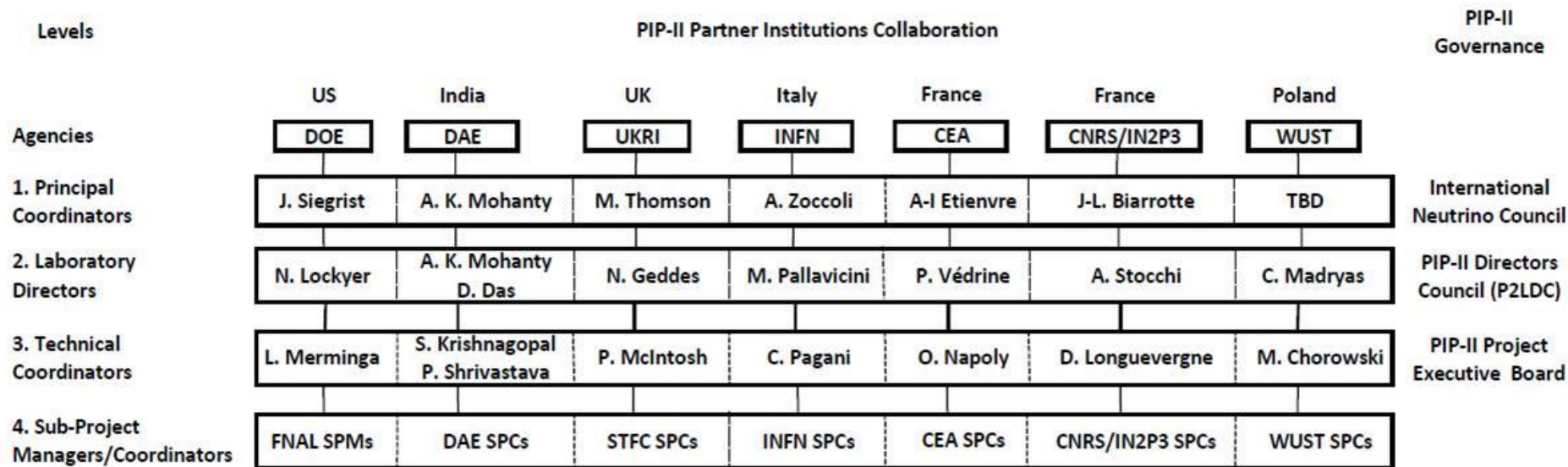
Simplified schedule (excel version)



MPP schedule :

PIP-II International Organization chart





Detailed cost

Somme de Cout (base+incertitude)		Étiquettes									
		2018	2019	2020	2021	2022	2023	2024	2025	2026	Total général
Étiquettes de lignes											
WP1 management		16	13	14	72	200	200	200	72		788
Pre-production		16	13	14	29						72
mission		16	13	14	29						72
Travels+meeting organization (semaines)		16	13	14	29						72
Production					43	200	200	200	72		716
CDD					43	172	172	172	43		601
IR QA&QC					21	86	86	86	21		300
IR Project Controller2					21	86	86	86	21		300
mission						29	29	29	29		115
Travels+meeting organization (semaines)						29	29	29	29		115
WP2 Cavité		17	25	11	165	198	162	546	427	31	1582
Pre-production		17	25	11	165	102					321
mission					23						23
Fabrication follow-up of cavity and QC test (jours)					23						23
Équipement IJCLab		17	21		92						130
Fabrication follow-up of cavity and QC test (endos)					35						35
Tooling for pre-prod cavity preparation and test					58						58
Cavity design (simulation code)			6								6
RF components for vertical test (Amplifier, coupler, circ)		17	3								20
Magnetic sensor for vertical test			12								12
Équipement Livrable			4	11	26						42
Cavity vacuum valves			2								2
Motors for moving coupler					14						14
RF feedthrough Qi et Qt and blank flange intermediate				11							11
RF feedthrough Qi et Qt and blank flange for final test					13						13
Cryogenic components for vertical test			2								2
Consommables					24	102					126
Cavity surface processing at IJCLab (BCP+Four+HPR)					14	41					54
Cavity validation in vertical cryostat (cryostat + hélium)					11	32					42
Transport FNAL						30					30
Production					96	162	546	427	31		1262
CDD					15	77	123	123	31		368
2 CDD cavité (1 AI, 1 IE pour inspection et tests cryo)					15	77	123	123	31		368
Équipement IJCLab							58				58
Tooling (duplicate)							58				58
Équipement Livrable					80						80
Cavity vacuum valves					25						25
RF feedthrough Qi and Qt					55						55
Consommables						85	366	305			755
Cavity surface reprocessing at IJCLab (reprocess + validation)							73	61			134
Cavity validation in vertical cryostat (cryostat + hélium)							158	131			289
Fabrication follow-up of cavity and QC test						85					85
Transport of cavity + tuner to FNAL (crate for cavity + transport)							135	113			248
WP3 Tuner			23	42	21						86
Pre-production			23	42	21						86
Équipement Livrable			23	42	15						80
Instrumentation piezo					12						12
Matériel fin de course					3						3
Tuner procurement (5)				37							37
Piezo actuator procurement for 5 Tuner			23								23
Specific screws for 5 tuners				5							5
Consommables					6						6
Aging test					6						6
WP5 Coupler				370	35						405
Pre-production				370	35						405
Consommables				370	35						405
Transport of coupler to FNAL					23						23
Coupler Procurement (4)				370							370
Outillage QC coupleur (transition type N-> guide d'onde)					12						12
WP6 Supratech (CV1250)					191	239	404				834
Production					191	239	404				834
Équipement IJCLab					191	239	404				834
Upgrade of IJCLab facilities (cryogenic lines for CV1250)					105	210					315
Upgrade of IJCLab facilities (infrastructure platform, shielding, C&C for CV1250)							375				375
Upgrade of IJCLab facilities (RF)						29	29				58
Upgrade of IJCLab facilities (vacuum components for CV1250)					86						86
Total général		33	61	423	426	508	766	746	628	102	3694