Technical specifications for the SIRIUS Cryogenic Permanent Magnet Undulator – CPMU14.2

LNLS, July 10th, 2025

1. Introduction

The bare lattice parameters for the SIRIUS storage ring, where the Cryogenic Permanent Magnet Undulators (CPMU) will be installed, are given in **Table 1**. Specific parameters of low-beta straight sections are given in **Table 2**.

Table 1: Beam parameters in the center of the SIRIUS low beta straight sections.

Beam energy	3	GeV
Ring circumference	518.4	m
Nominal beam current	350	mA
Natural energy spread (rms)	0.084	%
Natural horizontal emittance	250	pm.rad
Vertical emittance @ 1% coupling	2.5	pm.rad
Beam height above floor	1400	mm

Table 2: Beam parameters in the center of the SIRIUS low beta straight sections.

Low beta:		
Horizontal betatron function @ straight center	1.5	m
Vertical betatron function @ straight center	1.4	m
Horizontal dispersion function	0.0	m
Horizontal beam size (rms) @ straight center	19.3	µm
Horizontal beam divergence (rms) @ straight center	12.9	µrad
Vertical beam size (rms) @ straight center	1.9	µm
Vertical beam divergence (rms) @ straight center	1.3	µrad

2. Scope of supply

The scope of this supply consists of 1 unit of the following CPMU, to be installed in a low-beta straight section.

- Hybrid cryogenic permanent magnet undulator CPMU14.2 producing vertical magnetic field, designed, fabricated, assembled, and tested at the supplier site, delivered and tested at LNLS site, according to specifications contained in this document.
- Cryogenic cooling system, including internal components, transfer lines and control system.

- Undulator vacuum chamber assembled, including internal components, valves, gauges, ion pumps, NEG pumps, controllers, thermocouples, and bake out parts and controllers.
  - The transitions to connect the CPMU to the standard Sirius vacuum chamber will be manufactured by CNPEM.
  - The CPMU must be delivered to CNPEM filled with dry pure nitrogen at a pressure slightly above atmospheric pressure.
- Steering correctors assembled on the device or the transitions.
- Motion system assembled, motor drives mounted and delivered in a rack.
- Control system with PLC and EPICS IOC implementation.
- Full set of documentation, as described in section 4.3.

3. Reference design for the CPMU14.2

The reference design represents a theoretical calculation model to serve as a guideline for suppliers. It is based on a CPMU of the hybrid type, at LN2 temperature, where the permanent magnet is based on *PrFeB* and the pole piece material is based on *FeCoV.*

Table 3: Design parameters for CPMU14.2

Period	mm	14.2
Br @ 80K	T	1.71
Vertical Clear Aperture (VCA)	mm	3.6
Nominal Magnetic Gap	mm	3.8
B_{eff}	T	1.38
K_{eff}	-	1.83
Number of full periods	-	141

4. Contract management

4.1. Conceptual Design Review

After award of the contract, a detailed Conceptual Design Review Meeting shall be conducted with the LNLS and the supplier's technical personnel in attendance. A CDR document shall be provided by the supplier to LNLS at least one week before the CDR review meeting, including but not limited to:

a) Overall layout of the system with a technical description of a preliminary undulator design meeting the specifications of this document.

b) Magnetic simulation results of the proposed undulator design including:
   - On-axis field profiles for a full strength, central period and an end period,
   - Transverse field profiles of a full-strength pole,
   - Field maps for an (x, y, z) grid that contains the entire good field region, i.e. -4.5 mm < x < 4.5 mm and –1.8 mm < y < 1.8 mm, for the whole longitudinal extension of the undulator.
   - Field integral plots with end sections,
   - Other field plots showing compliance with the magnetic specifications of this document.

c) Specifications, drawings, bill of materials, and supplier list of long lead items.

d) Design of the mechanical frame, vacuum chamber with tolerances, structural analysis for pressure load, thermal analysis for the tapers, bake-out system and temperature monitoring system.

e) Conceptual drawings for the internal flexible taper, including cooling system with electrical and hydraulic connectors.

f) Detailed schedule for the design, fabrication, and assembly work for the first and the second devices.

g) Description of the magnetic measurement facility, measurement plan, and vacuum assembly.

h) Concept of the LN2 cryogenic system and integration.

i) List of vacuum equipment.

j) List of proposed spare parts.

4.2. Final Design Review

A similar Final Design Review Meeting will be held to review and approve detailed design of the components. An FDR document shall contain at least:

a) Magnetic measurement procedures, fiducial procedure

b) Detailed design of the mechanical structure, vacuum chamber and tolerances

c) Detailed design of the vacuum system: gas loads; materials to be used in vacuum environment; pressure distribution inside CPMU; final pressure analysis; flanges with detailed technical drawings Design of the transition chamber, flexible taper and taper cooling.

d) Detailed design of internal tapers with cooling (if necessary) and detailed technical drawings

e) Layout drawing with main dimensions of the entire CPMU including weight and center of gravity

f) Detailed drawings of legs and feet
g) Description of motion system, encoders, motors, including all pin configurations
h) Description of plugs and connectors including electrical connectors, cooling water connections, greasing points
i) Extensive list of vacuum equipment describing vendors and warranty
j) Detailed design of the bake-out strategy, mechanical strategy to accommodate chamber's expansion during bake-out, bake-out parts list, thermocouples, communication protocol, safety against overshoot temperatures that could damage the magnets and undulator components.
k) Indication of fiducial points located at the chamber for the positioning and alignment during assembly.
l) Parts List and supplier of commercial equipment as well as external suppliers of parts.
m) Detailed description of the LN2 cryogenic system including integration aspects.

4.3. Documentation

Upon delivery of the undulator, the supplier shall deliver to LNLS: copies of all drawings, instructions and procedures listed below:

a) Mechanical detail and assembly drawings
b) Electrical schematics
c) Assembly and installation instructions
d) Alignment procedures
e) Test procedures and data
f) Recommended routine maintenance procedures
g) All magnetic measurement procedures and data record, including measurement data and conditions (calibrations, temperature, etc)
h) Operation manuals for: undulator control; cryogenic system; baking procedure

4.4. Factory Acceptance Test

The supplier shall perform a FAT with all necessary testing and measurements required to demonstrate compliance with the specifications prior to shipping and delivery. The FAT shall compromise the following measurements:

a) Magnetic performance before and after bake out and cool down.
    - Magnetic properties of the permanent magnet blocks (Br [T], HcB [kA/m], HcJ [kA/m], BH max [kJ/m^3])
    - Magnetic property of the pole pieces (Bmax [T])

- Keff-values at gaps: 3.6 mm, 4.0 mm, 4.5 mm, 5.0 mm, 5.5 mm, 6.0 mm, 6.5 mm, 7.0 mm, 7.5 mm, 8.0 mm, 10 mm, 12 mm, 14 mm, 16 mm, 18 mm, 20 mm, 24 mm.
- Phase error at gaps: 3.6 mm, 4.0 mm, 4.5 mm, 5.0 mm, 5.5 mm, 6.0 mm, 6.5 mm, 7.0 mm.
- Multipoles at gaps: 3.6 mm, 4.0 mm, 4.5 mm, 5.0 mm, 5.5 mm, 6.0 mm, 6.5 mm, 7.0 mm, 7.5 mm, 8.0 mm, 10 mm, 12 mm, 14 mm, 16 mm, 18 mm, 20 mm, 24 mm.
- Skew multipoles at gaps: 3.6 mm, 4.0 mm, 4.5 mm, 5.0 mm, 5.5 mm, 6.0 mm, 6.5 mm, 7.0 mm, 7.5 mm, 8.0 mm, 10 mm, 12 mm, 14 mm, 16 mm, 18 mm, 20 mm, 24 mm.
- Magnetic field profile (on-axis) at gaps: 3.6 mm, 3.8 mm, 4.0 mm, 4.5 mm, 5.0 mm, 5.5 mm, 6.0 mm, 6.5 mm, 7.0 mm, 7.5 mm, 8.0 mm, 10 mm, 12 mm, 14 mm, 16 mm, 18 mm, 20 mm, 24 mm.
- Field maps with off-axis measurements at gaps: 3.6 mm, 3.8 mm, 4.0 mm, 4.5 mm, 5.0 mm, 5.5 mm, 6.0 mm, 6.5 mm, 7.0 mm, 8 mm, 10 mm, 12 mm. The field map grid (x, y, z) must contain the entire good field region. The x values for the field map grid are: 0.0 mm, ± 0.5 mm, ± 1.0 mm, ± 1.5 mm, ± 2.0 mm, ± 2.5 mm, ± 3.0 mm, ± 3.5 mm, ± 4.0 mm, ± 4.5 mm, ± 5.0 mm, ± 6.0 mm, ± 7.0 mm, ± 8.0 mm, ± 9.0 mm, ± 10.0 mm, ± 11.0 mm, while the y values for the grid are: 0.0 mm, ± 0.5 mm, ± 1.0 mm.
- First and second field integrals at gaps: 3.6 mm, 3.8 mm, 4.0 mm, 4.5 mm, 5.0 mm, 5.5 mm, 6.0 mm, 6.5 mm, 7.0 mm, 7.5 mm, 8.0 mm, 10 mm, 12 mm, 14 mm, 16 mm, 18 mm, 20 mm, 24 mm.

b) Vacuum performance
- Absolute pressure after pumping down and after bakeout.
- Helium leak rate before and after bakeout (including background level).
- RGA scan before and after bakeout.
- Record of bakeout temperature and pressure.

c) Mechanical performance
- Frame accuracy test
- Test and record of rotary encoder and linear encoder readings vs. gap of the fully assembled undulator (with assembled magnets). All encoder readings shall be compared to ceramic gauge measurements at 4mm, 5mm, 6mm, 10mm gap (based on linear encoder reading) of the fully assembled undulator.
- Test of limit switches and verification of their positions in relation to the rotary and linear encoder readings with magnets and liner assembled.

- Verification of hard stop positions in relation to rotary and linear encoder readings with magnets assembled
- Motion accuracy
- Measurement record of installation geometric dimensions (overall length, length of the vacuum chamber, dimension of up- and downstream flanges, etc.)

d) Fiducialization report with description of the orientation and position of the reflectors with reference to the coordinate system, and with respect to the magnetic center of the device.

4.5. Site Acceptance Test

Upon delivery, mechanical measurements and vacuum testing will be performed at LNLS site, prior to installation of the two CPMUs in the storage ring. The SAT shall also approve the vacuum and mechanical performance at FAT.

5. General Technical Requirements

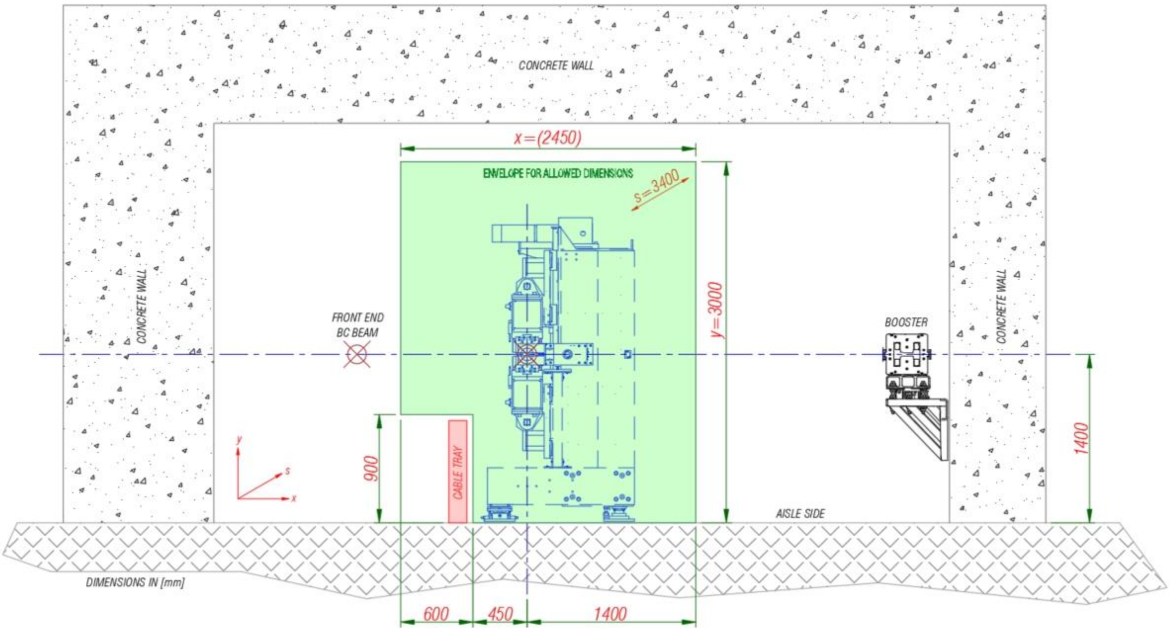
5.1. Coordinate system

For the coordinate system employed in this specification, the longitudinal axis of the undulator, in the electron beam travel direction, shall be positive Z-axis. The positive Y axis shall be vertically up, away from the floor, with Y=0 on the undulator centerline. The X axis is horizontal with positive toward the outside of the ring. The coordinate system convention is right-handed

5.2. Undulator envelope

The SIRIUS accelerators tunnel houses the 3 GeV storage ring close to the outer tunnel wall, and the full energy booster installed on the inner tunnel wall. The CPMUs shall be installed in two straight sections of the storage ring facing the outer wall of the tunnel.

The overall dimensions of the CPMU shall remain within a longitudinal envelope of ΔZ=3400mm and transverse envelope as shown in the figure below. The horizontal envelope of ΔX=1400mm from the beam axis towards the aisle side of the tunnel can be discussed if more space is needed.



5.3. Undulator Installation

To install the undulator, an aperture at the tunnel ceiling will be opened and the undulator will be lowered into the tunnel using a crane. For this reason, the device shall have lift points accessible from above. The crane maximum capacity is 20 tons.

Inside the accelerator tunnel, floor transportation shall be done using fork-lift or air cushions.

6. Magnetic Requirements

6.1. CPMU Magnetic Parameter Requirements

The magnetic parameters requirements for the CPMU are described in **Table 4**. The integrated quadrupole, sextupole and octapole fields, as well as the peak field roll-off, may exceed the values on Table 3, as long as the simulations of the model/measured 3D field profiles show acceptable impact on the Sirius beam dynamics.

Table 4: Magnetic Requirements

Parameter	Value	Unit	Description/Comments
Magnetic field direction	-	-	Vertical
Undulator type	-	-	Permanent magnet hybrid
Undulator symmetry	-	-	Anti-symmetric or symmetric
Magnetic period, λ_u	14.2	mm	
Number of full periods	141	-	

Nominal Vertical Clear Aperture (VCA)	ΔY = 3.6	mm	Vertical aperture including wake current sheets
Minimum VCA	3.5	mm	VCA smaller than nominal for future testing possibilities
Deflection parameter K_{eff} at nominal VCA	≥ 1.9	-	
VCA actuation range	3.5 – 24.0	mm	The maximum range corresponds to the standard SIRIUS vacuum chamber diameter
VCA range for field requirements	3.6 − 12.0	mm	**Not including RMS phase error**
VCA range 1 for phase error requirements	3.6 − 5.0	mm	Phase error < 3 degrees
VCA range 2 for phase error requirements	5.0 – 7.0	mm	Phase error < 5 degrees
Magnetic width for field requirements (GFR)	-4.5 < X < +4.5	mm	Given by the low-beta hor. BSC.
Wake current sheet maximum thickness	ΔY ≤ 100	µm	Cu/Ni-foil
Pole material	-		V-Co-Fe alloy; to meet B_{eff} and field requirements; coated for UHV
PM type	PrFeB	-	Radiation-hard PrFeB; coated for UHV
PM remanent field, B_r	≥ 1.70	T	T = 80 K
1st horiz. field integral, GFR	≤ 100	G.cm	Without steering corrector, @ all gaps
1st vert. field integral, GFR	≤ 100	G.cm	Without steering corrector, @ all gaps
2nd horiz. field integral, GFR	≤ 20000	$G.cm^2$	Without steering corrector, @ all gaps
2nd vert. field integral, GFR	≤ 20000	$G.cm^2$	Without steering corrector, @ all gaps
Integrated quadrupole field, GFR	≤ 300.0	G	@ all gaps, WAMs
Integrated sextupole field, GFR	≤ 500.0	G/cm	@ all gaps, WAMs
Integrated octupole field, GFR	≤ 1000.0	G/cm^2	@ all gaps, WAMs
Peak field roll-off, |X| ≤ 4.5 mm	$< 1 \times 10^{-3}$	-	@ gap 3.80 mm
Height of electron beam above floor	1400	mm	
Maximum total weight	20	ton	

6.2. Permanent magnets

The permanent magnets used for the magnet arrays and end sections shall be Praseodymium-Iron-Boron. The supplier shall adopt adequate surface treatment (coating) to reduce the outgassing rate and for radiation protection. The treatment process shall not affect the magnetic properties of the magnet blocks. The supplier shall provide a copy of the coating procedure for review. The PM B-H characteristics (remanent field, permeabilities, coercivity, intrinsic coercivity, temperature coefficient), magnetization uniformity, and magnetization angle tolerance shall be such that the magnet requirements are met. Property variations between blocks shall be limited so that sorting methods may be employed to meet the field integral and phase requirements. As needed, the individual PM blocks shall be characterized using Helmholtz coil measurements or other means.

6.2.1. Coercivity, radiation resistance, thermal processing

High intrinsic coercivity, H_{ci}, ensures the PM will not demagnetize during vacuum bake and will have good radiation hardness, resistant to radiation induced demagnetization. The H_{ci} (at RT) shall be sufficiently high to ensure the radiation hardness of the material, so that the device meets the specified magnetic performance over a 10-year operation period, after exposure to $2x10^{13}$ electrons lost per year. All PM blocks shall be thermally stabilized (aged) in the open circuit condition after magnetization at a minimum temperature of 140°C to enhance their resistance to demagnetization and radiation hardness. During vacuum bake, with the PM held at 120°C max., there shall be no irreversible loss of intrinsic induction. The intrinsic coercivity for a PrFeB formulation will be such that $H_k \geq 1000$ kA/m, at 150° C (see Figure 1). Chamfers may be added to the PM blocks in order to avoid regions with high demagnetizing fields.

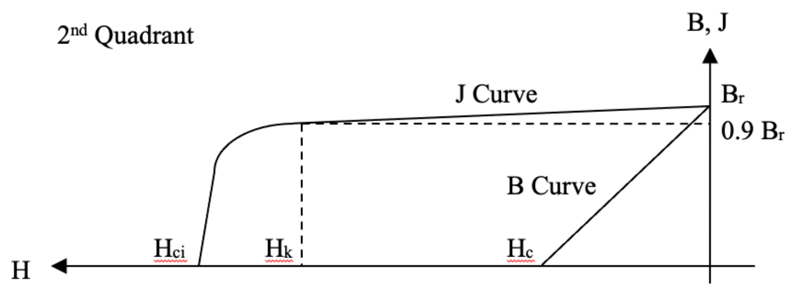


Figure 1: Magnetization curve.

6.2.2. B, J vs. H Curves and PM Testing Requirements

The supplier shall provide B-H curves representative of the grade of material used for the device. These curves shall be generated at room temperature and at least two elevated temperatures up to and including 150° ± 10° C. Additionally, testing of the material lots used to produce the PM blocks for the device is required. A material lot shall be defined as material that has experienced identical processing conditions which define the magnetic properties (e.g. metallurgical composition, powder metallurgy processes, and heat treatment). For each lot of material used, a B-H curve shall be generated at RT. The curve shall be generated after thermal stabilization and confirm that the lot meets the coercivity requirements.

The supplier shall provide a measurement record of the magnetic properties of each single magnet including the magnetic dipole direction and the deviation angle of the magnetic dipole moment.

The supplier shall provide a record of the measured magnet block dimensions (length, width, height) including the manufacturing tolerance. This record shall include the length, width and height of each magnet block and pole piece with a precision of X × Y × Z (±0.05 × 0.00-0.05 × ±0.05 mm).

6.3. End pole sections

The end sections (up- and downstream) design shall be arranged to have the electron beam trajectory coinciding with the magnetic axis of the undulator. The end pole sections may be actively corrected using electromagnetic correction coils.

6.4. Wake current sheet

The wake current sheets shall be fabricated by the supplier for assembly to the magnet poles to reduce beam impedance. Each Cu-Ni foil shall be at maximum 100 µm thick and the maximum slope angle ratio of the wake current sheets at the up- and downstream ends of the vacuum chamber is 1:20. The flexible wake current sheets lie flat against the magnet poles and should provide RF continuity for the electron beam image current and reduce the resistive wall impedance.

6.5. Transition chambers

Transition chambers between the SIRIUS vacuum chamber and the undulator wake current sheets will be fabricated and installed at LNLS. The interfaces between the transition chamber, undulator chamber, wake current sheets, and photon absorber shall be discussed at the conceptual design review and finalized at the final design review.

6.6. Corrector Coils

A set of vertical and horizontal steering/corrector coils must be designed by the manufacturer and must be assembled on both ends of the insertion device or on the transitions to the storage ring vacuum chamber. Each corrector coil field integrals must be I_{cor} > 100 G.cm for each direction, using a maximum operation current of 5A.

7. Motion Control Requirements

The system of driven axes shall include three modes of leveling and alignment: the first to center the magnets on the electron beam axis (gap midplane), the second to correct gap taper (relative pitch of magnet arrays), the third to correct overall pitch to the mechanical tolerances for the full range of operational gap values.

All axes shall be designed with a high-precision motion control system (preferably based on Beckhoff or Delta Tau). The ideal motor configurations shall use four motors for gap/taper/tilt/elevation adjustment. The resolution for gap monitoring shall be 1 nanometer with a 0.5 micrometer required repeatability for encoders on all driven axes. There shall be no more than 5 G.cm above background stray field from any combinations of motor and brake fields within an 8 mm by 24 mm window of the magnetic centerline (electron beam path) anywhere throughout the CPMU.

The taper of the CPMU shall be variable on demand to at least 100 μrad and controlled to 1 μrad for gaps in the range 3.60 to 20.00 mm to allow for harmonic broadening and to preserve the intensity for the high harmonics at zero taper.

Step scans of the gap with minimum deadtime are essential for the undulator. In this case the motion settling time must be properly optimized to deliver a deadtime between two gap positions to be less than 1 second during step scans in addition to the time needed to move the gap (minimum velocity of 0.001 mm/s). This requirement shall be applied to the entire control pipeline (CLP, EPICS IOC and GUI).

The design of the gap drive system shall allow gap speeds in the range from 0.001 mm/s to 0.5 mm/s. The maximum allowable tolerance for velocity (deltav/v) jitter is 1%. Following position errors during motion shall not exceed 0.5 microns. The referred tolerances and errors do not apply during transient motion (start/stop). The speed range is intended for scans during experiments.

The gap following error shall respect the specified tolerances across different scanning modes: fly scans at constant gap speed or constant energy variation speed (see section **Erro! Fonte de referência não encontrada.**).

Integration between undulator and monochromator shall consider two topologies for fly scans: (1) the pure gap reference signal employed by the motion controller shall be broadcasted via UDP at high resolution (≤ 5 nm) and refresh rate (~kHz) to allow the monochromator motion system to follow; (2) the undulator motion controller shall accept gap trajectory files (see section **Erro! Fonte de referência não encontrada.**) with step transitions commanded by an external trigger source (slave mode) and/or executing the trajectory autonomously while generating low jitter (~100 μs) triggers to command the monochromator and other motion/detector systems.

Table 5: Motion Control Requirements Summary

Parameter/Feature	Value	Units	Comments
Gap drive actuation type	Servo	-	-
VCA actuation range	3.5 – 24.0	µm	-
Tapering actuation range	> -100 to 100	µrad	-
Tapering resolution	1	µrad	-
Gap drive repeatability, over gap range – Δgap	≤ 0.5	µm	-
Gap drive step size, max.	0.1	µm	Full motor step
Gap drive speed range	0.001 – 0.5	mm/s	-
Working modes for experiment	Step scan Constant Gap speed Constant Energy speed	-	Require special signal interfaces to the beamline control system
Max. allowed settling time for gap steps	1	s	-
Gap indirect transduction type	Rotary absolute encoders	-	Purpose: speed control loop
Gap and magnetic taper direct transduction type interface	BISS protocol	-	Absolute encoder
Gap direct transduction resolution	1	nm	-
Magnetic taper resolution	1	µrad	

8. Vacuum System Requirements

The following section describes the main vacuum requirements that must be fulfilled by the supplier of the CPMU.

The vacuum system of the CPMU must operate in Ultra High Vacuum condition respecting the defined final pressure, cleanliness procedure, outgassing and residual gas analysis demands.

Table 6 describes the vacuum demands to be respected by supplier. The CPMU must operate with a vacuum level compatible to the vacuum of the storage ring. Design pressure of Sirius storage ring with electron beam is equal or lower than 1×10^{-9} mbar.

Table 6 – Main vacuum requirements for operation.

Final pressure after bake-out (mbar)	$\leq 1 \times 10^{-9}$
Maximum allowable leak rate (mbarL/s)	2.10^{-10}
Maximum allowable specific desorption rate (mbarL/scm²)	1.10^{-12}

All materials selected for the construction of the CPMU must be compatible with Ultra High Vacuum. A list of selected materials must be provided in the CDR for approval of the vacuum group. This requirement applies for greases and other non-metallic materials used.

The relative magnetic permeability of the vacuum chamber and other stainless steel parts must be less than 1.05 ($\mu_{rel} < 1.05$).

Water cooling connections and coupling must be swagelok type, inch sizes.

The supplier must provide a detailed report describing the cleaning process which will be adopted. The report must be approved by LNLS in written.

The cleaning and pumping procedures must be carefully chosen in order to avoid any contamination with halogens.

The supplier should specify in CDR the technical specifications of vacuum pumps necessary for the safe vacuum operation of the CPMU. Vacuum calculation should be performed and presented in Detailed Design Report. CNPEM encourages the use of the same pumps already selected for the Sirius vacuum system (Agilent StarCell). Pumps controllers, cables and spare parts must also be considered.

To avoid NEG coating contamination, dry pumps must be used as the backing pump for turbomolecular pumps. The dry pump must not have the tip seal due to fluorine composition (i.e. Scroll Pump is not allowed).

Pressure monitoring must be done using cold cathode gauges and Pirani gauges approved by CNPEM Vacuum Group. The supplier shall propose the amount and location of the gauges and present the lay-out at the CDR. The final pressure of 1.10-9 mbar must be achieved by all cold cathode sensors assembled at the CPMU.

The vacuum gauges must be installed in DN 40 CF Conflat TM Type. The right-angle valves must be installed in DN 40 or DN 63 CF Conflat TM Type.

Temperature of external chamber and internal components must be measured by thermocouples to guarantee a safe operation during bake-out. Supplier shall define the amount and position of thermocouples and it should be written at the CDR. The communication protocol must be defined by supplier in agreement to CNPEM staff.

The maximum output voltage of the bake-out heaters should be equal or below 50 V, if possible.

After cleaning and bake-out, the residual gas analysis must be done to check for contamination and leaks in the vacuum system.

The RGA must have a pressure sensitivity of $1.3x10^{-14}$ mbar and mass range of 1 - 100 amu.

Final pressure and partial pressure measurements must be done after 12 hours the system is in ambient temperature. The steps bellow must be considered for the residual gas analysis:

- Monitor partial pressure of H2, CH4, H2O, Ar, CO, CO2, Hidrocarbons (molar weight higher than 50 amu) and Halogens
- Set the H2 ion current peak as 100%
- Check that partial pressure (ion current) for CH4, H2O and CO (amu 16, 18 and 20, respectively) are bellow 10% of the peak value defined for H2
- Check that partial pressure (ion current) for CO2 (44 amu) are bellow 5% of the peak value defined for H2
- Check that partial pressure (ion current) for Hydrocarbons with atomic weight higher than 50 amu are bellow 0.1% of the peak value defined for H2

- Halogen contamination is strictly forbidden since it is incompatible with the NEG-coated vacuum chambers of the Sirius storage ring

Vacuum flanges for the entrance and exit of the CPMU must be DN100 CF Conflat TM Type and follow the standard ISO 3669:2020. Flange design must be agreed to CNPEM Vacuum Group requirements aiming the proper assembly at the storage ring as well as a smooth path to reduce impedance issues. Gasket dimensions must follow the standard ISO 3669:2020.

The entrance and exit flanges of the CPMU must have a machined “race-track” shape of 50 mm in horizontal direction and 24 mm in Vertical direction, centered at the flange.

Figure 2 illustrates a schematic view of the flange.

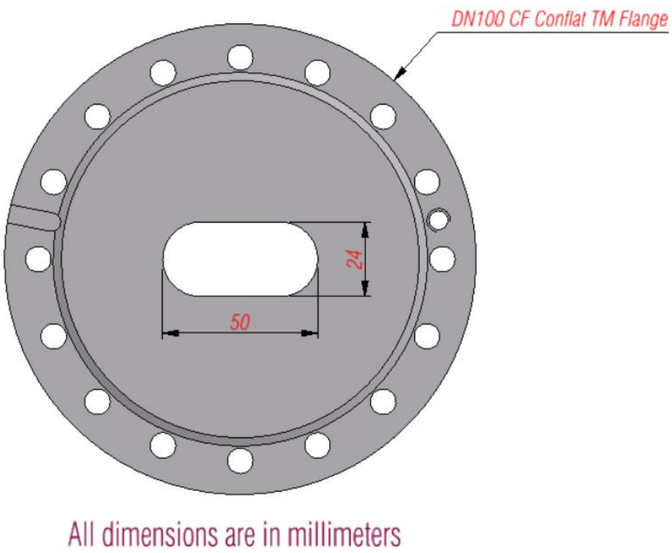


Figure 2: CPMU flange schematic view.

The supplier must design, fabricate and assembly the internal flexible tapers. The tapers should be cooled due to RF induced heating (if necessary). The desired aspect ratio to be respected in design should be 1:20 to reduce impedance budget. The internal flexible tapers must not be heated by Synchrotron Radiation beam, then the design and simulations must be done with CNPEM team support.

9. Utility systems

- Main power: 3-phase electrical power lines (220 / 380 VAC; 60 Hz).
  Socket and plug standard: IEC 60309-1/2/4.
- Compressed air pressure: 5 bar
- Cooling water circuit (demineralized):

  - Temperature: 21 ± 1 ºC
  - Pressure drop: < 2.5 bar
  - Max pressure: 8 bar
  - Conductivity: < 1 μS/cm
- Ambient temperature in the tunnel: 24 ºC, stabilized to ± 0.1 ºC
- Alignment: Alignment of the CPMU shall be made using laser tracker. The fiducial marks on the CPMU should be compatible with laser tracker targets.

10. Cryogenic System

The cryogenic system must guarantee the operation temperature with stability high in temperature and pressure. CNPEM encourages the use of the same systems already selected for other Sirius applications (Axilon ChillAX). The choice and full details of the cryogenic system, including its necessary components for integration of the cryogenic system with Sirius LN2 shall be discussed during the CDR phase. The cryogenic system must be compliant with specifications on Table 7 and must include:

- LN2 chiller including all internal components and reservoirs.
- Complete PLC and control system, assembled in a rack, including cabling.
- LN2 Transfer line with at least 15 m from chiller to the CPMU.
- LN2 Filling line for connection with Sirius LN2 circuit.
- LN2 feedthroughs and connections compatible with the chosen cryocooler system.

Table 7: Requirements for the cryogenic cooling system.

Parameter	**Value**	**Unit**
Cooling liquid	LN2	
Operation Temperature	~ 80	K
Temperature Gradient	1.5	K/m
Heat load	>= 1000	W
Input Pressure	5.0	bar
Pressure Stability RMS	< 1.0	mbar
Leak Rate	$< 1 \times 10^{-8}$	$Pa.m^3/s$
Air Consumption	1.5	L/min