Document Title:	**Detailed Specification of Cold section BPM Detector SIS100**
Description:	This document is the Detailed Specification that describes the Detector part of the cold sections SIS100 Beam Position Monitor (BPM), comprising all BPM components to be integrated in quadrupole doublet module (QDM).
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Abstract

This document is the Detailed Specification that describes the Detector part of the SIS100 BPM, comprising all its components to be integrated within the quadrupole doublet modules. This document covers all items of PSP-code 2.8.6.2.1.1.1

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1. Purpose and classification of the document

The purpose of this document is to specify the technical requirements for the production of the Beam Diagnostic (BD) component ‘cold sections BPM detector’ for the heavy-ion synchrotron SIS100 [1]. In this document the term 'detector part' comprises all BPM components to be integrated into the SIS100 quadrupole module. The detailed specification of the full BPM system is given in F-DS-BD-22e [20]. However, the items described in the present document are a subset of the full BPM system.

Important note:

Because of the diversity of components to be delivered, the contribution has been split up into three separate work packages (WP1 – WP3). This separation allows that the ‘detector part’ described in this document can be delivered by up to three different Contractors.

All work packages can be offered by the same bidder as different options.

Section 2.2 provides more technical details on the contents of each work package.

This Detailed Specification gives an overview of the required functionalities of the beam diagnostic component ‘cold sections BPM detector’ and explains the scope of the instrument.
Whenever regulations and requirements are specified in the General Specifications [2], Common Specifications for Beam Diagnostics [3], Detailed Specifications [20-99] and Technical Guidelines [100-199] they are only referenced in the present document. The related documents are listed in section 7. No legal or contractual conditions are treated in this document. All related information is given in the corresponding contract.

1.1 Abbreviations, terms and Definitions

Table 1. Abbreviation, terms and definitions.

Abb., Term	Definition
US	Upstream
DS	Downstream, Detailed Specification
BD	Beam Diagnostic
DAQ	Data Acquisition
ELR	Electronic Room
BPM	Beam Position Monitor
FAT	Factory Acceptance Test
FAIR	Facility for Antiproton and Ion Research
COL	Collimator (cryogenic ion catcher)
GSI	GSI Helmholtzzentrum für Schwerionenforschung GmbH
GUI	Graphical User Interface
LAN	Local Area Network
LNA	Low Noise Amplifier
ST	Steerer (closed orbit corrector)
QD	Defocusing Quadrupole
F1/F2	Focusing Quadrupole Magnet of type 1/type 2
CV/CH	Chromaticity sextupole Magnet vertical/horizontal
PSP	Project Structure Plan (code number in cost book)
QA	Quality Assurance
CWT	Cold Warm Transition
CAP	Cryogenic Adsorption Pump
QDM	Quadrupole Doublet Module
RF	Radio Frequency
SAT	Site Acceptance Test
SIS 18	„SchwerIonenSynchrotron“ at GSI
SIS 100	„SchwerIonenSynchrotron“ at FAIR
SNR	Signal to Noise Ratio
TDR	Technical Design Report, Time-Domain Reflectometer
TG	Technical Guideline
PU	Pick-Up
PCB	Printed Circuit Board
QIPP	Quality-Inspection and Production Plan

1.2 Definition of the Detector Parameters

The **displacement of the beam center** with respect to the center of the vacuum chamber can be calculated from the difference voltage $U_{\Delta} = U_{left} - U_{right}$ or $U_{\Delta} = U_{up} - U_{down}$ for orthogonal plates. Normalizing to the sum signals $U_{\Sigma} = U_{left} + U_{right}$ the horizontal displacement Δx can be obtained via:

$$\Delta x = K_x \frac{U_{left} - U_{right}}{U_{left} + U_{right}} + \delta_x \qquad \textbf{(horizontal) Equation 1}$$

and:

$$\Delta y = K_y \frac{U_{up} - U_{down}}{U_{up} + U_{down}} + \delta_y \qquad \textbf{(vertical) Equation 2}$$

respectively. The variables K_x and K_y are the horizontal and vertical **position sensitivities**, respectively. They are expressed in units of [K] = mm. Position sensitivity is the most fundamental BPM parameter that depends on the geometrical arrangement of electrodes, guard ring etc. and was maximized during BPM design optimization.

The **offsets** δ_x and δ_y represent the misalignment of the electric center of the pick-up with respect to the geometrical one. This is a convolution of the all production tolerances and offset due to e.g. different capacitance of the electrodes with respect to ground. The optimization of the parameters mentioned above for the SIS100 BPMs is described more precisely in [201]-[203].

Accuracy: defined as the ability of absolute position reading with respect to any absolutely known axis, e.g., to the symmetry axis of a quadrupole magnet. The accuracy is mainly influenced by the pick-up mechanical tolerances and the long-term stability of the mechanical alignment. In the particular case of SIS100 BPM installed in the cryogenic environment the **mechanical stability** (that is understood as position reproducibility after a number of cold-warm cycles) affects the accuracy. Moreover, the accuracy can suffer from temperature fluctuations of the quadrupole yoke. The accuracy of the beam position determination is a convolution of the mechanical adjustment of the BPM, displacement sensitivity and overall resolution of the readout (including e.g. amplification noise, digitalization resolution, etc.).

Resolution: This is the smallest possible beam displacement variation that can be detected by the BPM system. In contrast to accuracy, relative values are compared here. The resolution usually is roughly ten times better than the accuracy. The averaging procedure, typically over 1000 subsequent turns, increases the accuracy by a factor of 100.

Dynamic range: means the range of beam current to which the system has to respond. In the case of SIS100 BPM the signal adoption is done by an amplifier with switchable

amplifier stages at the input stage of the electronics processing chain (see also [20]). For the present specification only the highest expected signal is relevant as limitation for e.g. the breakdown voltage for the signal feed-through.

For more information please refer to [201].

2. Scope of the technical System

2.1 Full System Overview

Please note: For better orientation this section gives an overview of the full BPM system, including the 'Detector Part' embedded in the full BPM setup. However, the purpose of this Detailed Specification is to specify the deliveries for the Detector Part only.

The Beam Position Monitors described here are intended for usage in the synchrotron SIS100 of FAIR.

Throughout the FAIR project individual technical components are unambiguously identified by their unique PSP-code (project structure plan). Moreover, the sub-structure of beam diagnostic equipment is also reflected by detailed PSP-codes for BD sub-components.

The Beam Position Monitor (BPM) system allows the non-intercepting determination of the transverse position of the bunched ion beam. The primary measurand is the transverse position of the bunched beam, or precisely speaking: position of the center of gravity of the transverse charge distribution within the bunch. For further details see [20].

A schematic diagram of the full BPM system is shown in Figure 1. The full BPM system consists of (a more detailed parts list is given in section 2.2):

BPM (location: beam Line)

- Pick-up electrodes and appropriate guard rings shaped in the metal coated ceramic pipe
- Pick-up chassis being a part of the beam pipe
- UHV signal feed-throughs for the electrical connection between the UHV region and insulating vacuum.
- Impedance matching transformer installed inside the insulating vacuum
- Cryogenic cables interconnecting UHV signal feed-throughs with insulation vacuum signal feeds.
- Insulation vacuum feed-throughs
- high quality, low dispersion, air filled coax cables toward preamplifiers

Detector Part (delivery)

Amplifier (location: tunnel niches)

Dedicated niches in the inner concrete wall of the synchrotron are foreseen. In these niches the radiation level is reduced by more than one order of magnitude. BPM amplifiers will be positioned in those niches and mounted in a standard half-height electronic rack.

- Amplifier with switchable amplifier stages and switchable attenuator chain
- Cables and interconnections
- External power supply
- Radiation tolerant design is required.

Data acquisition and control (location: supply area)

- ADC – FPGA DAQ unit with GPIO
- timing receiver board
- attenuator control unit (I/O)
- calibration signal source
- power supplies for all electronic components in the beam line

This specification and delivery is restricted only to these components which will later be integrated in the cryomodule of the quadrupole doublet (N.B.: The effort for **integration of the BPM into the cryostat is NOT part of the work packages WP1-WP3** described in this specification). These items are called 'Detector Part' throughout this specification.

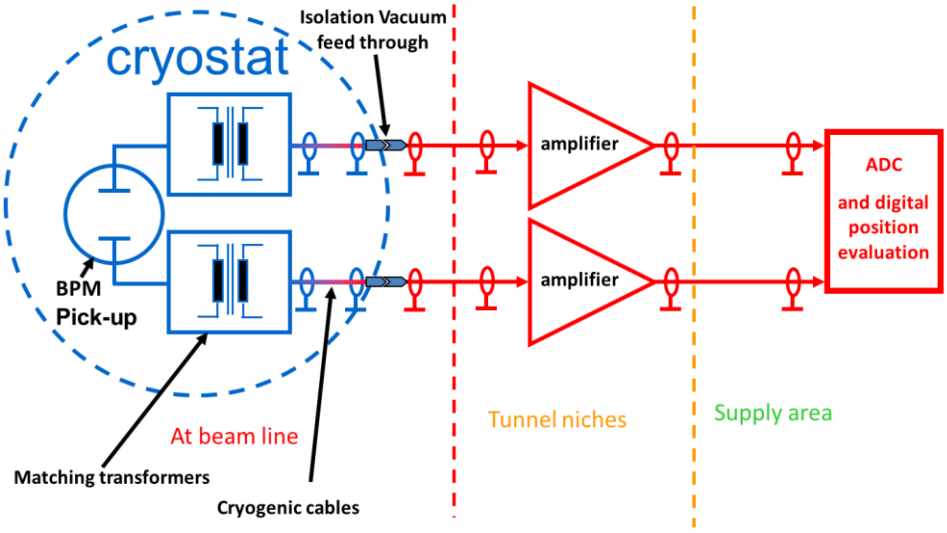


Figure 1: Schematic diagram of the entire BPM system. Components that are operated at cryogenic conditions, i.e. the Detector Part, are marked blue.

All cold section BPM pick-ups (PU) will be installed inside the cryostats and attached to main quadrupole magnets, see Figure 2. Since the amplifier power losses generate an unacceptable heat source, the amplifiers have to be installed outside the cryostat.

The length of the signal lead (cryogenic cables) inside the vacuum vessel has to be matched to overcome the distance between the BPM and cryostat cable ports. In addition, the cable length has to be sufficiently long to reduce the heat flow through signal leads.
For reflection free signal transport in long signal lines an impedance matching close to the BPM plates by a passive transformer is necessary.

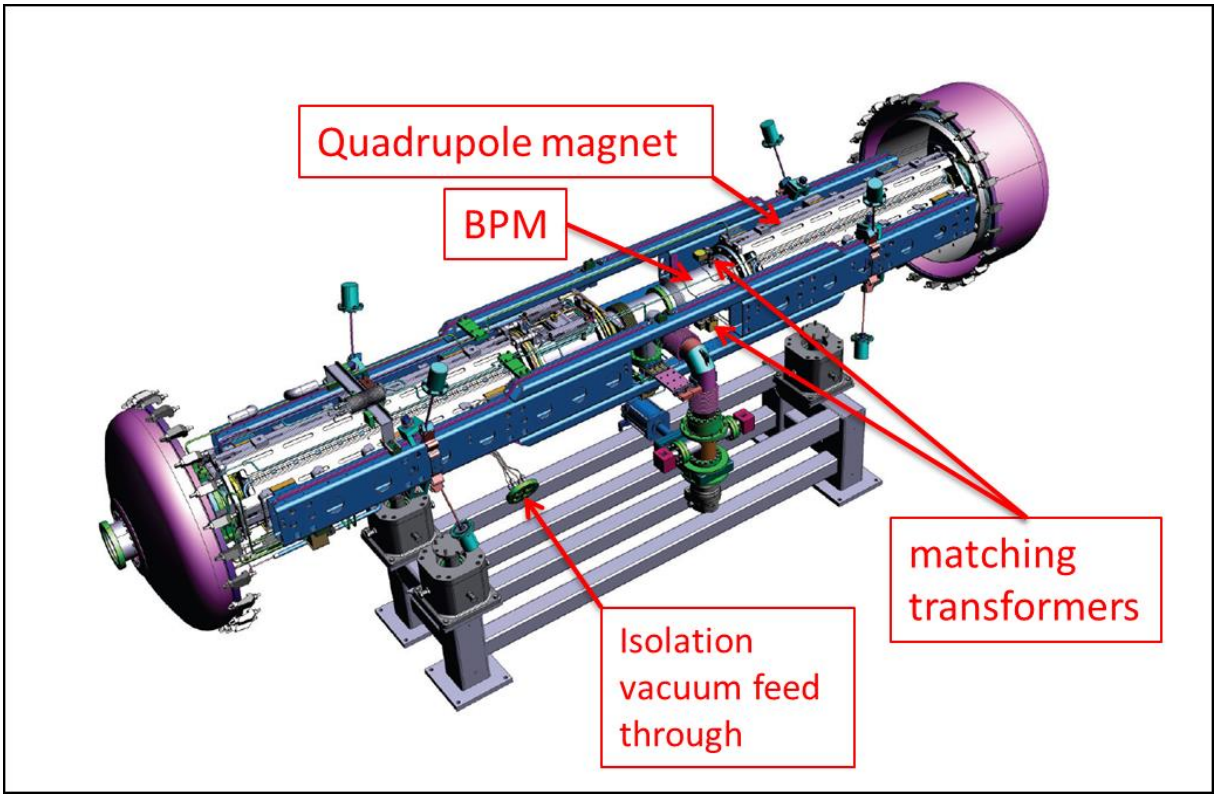


Figure 2: Exemplary location of the BPM pickup in Quadrupole Doublet Module (QDM). This picture shows only a rough position of the components. More accurate description of the BPM components is described later on.

2.2 Content of Delivery by the Contractor(s)

This section gives an overview of the constituents of the Detector Part of the BPM, including a detailed parts list. (The deliveries by the Company to the Contractor are separately listed in section 2.3).

Each of the SIS100 BPM detectors shown in Figure 3 and Figure 4 consists of the following components:

Work package 1 – Contractor 1 (items 1-3, 5, 8, 11)

1. **Main flange** being the main reference plane that after welding becomes an integral part of the quadrupole chamber
2. **Metal coated ceramic pipe** with electrodes and appropriate guard rings
3. **BPM Chassis**
5. **Feedthrough contacts**
8. **RF contacts** in form of CuBe ribbons
11. **Insulation vacuum signal feed-throughs** (the DN100CF vacuum flange shown in Figure 4 is NOT part of the delivery)

Company (items 4, 9)

4. **UHV signal feed-throughs** interconnecting electrically the UHV region with the insulating vacuum region
9. **Compensation below and adapter flange**

Work package 2 - Contractor 2 (items 6, 7)

6. **Matching transformers and 90° N-type adapter** installed in the insulating vacuum
7. **Supporting plate** that supports the transformer chassis

Work package 3 - Contractor 3 (item 10)

10. **Cryogenic cables**

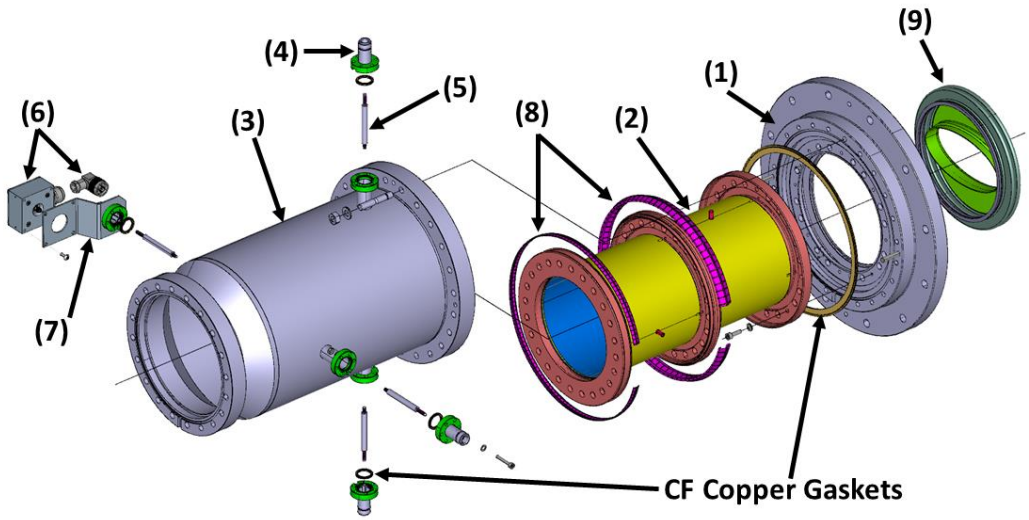


Figure 3: SIS100 BPM pick-up, see description in text.

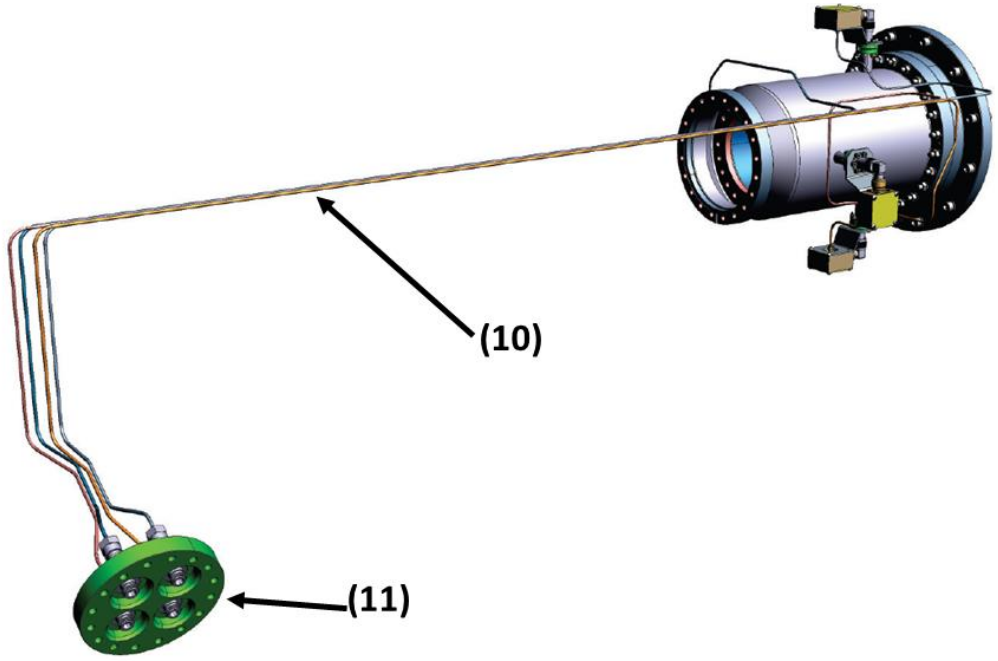


Figure 4: SIS100 BPM components installed inside the Quadrupole Doublet Module

As listed in Table **2** the deliveries for the SIS100 BPM Detector Part are organized in three independent work packages:

WP1: Mechanics,

WP2: Matching Transformers and

WP3: Cryogenic Cables.

The bidder shall distinguish in his offer these three work packages as independent options. All three work packages may be offered by a single bidder. However, a bidder may decide to offer only one of the three work packages.

Each bidder has to clearly indicate, which work package is covered by his individual offer.

Table 2 Delivery packages and required quantities for the SIS100 BPM Detector Part

Work Package	Item No. (see Fig.3 and Fig.4)	Component Name	Quantity	Remark
WP1: Mechanics	No. 1	Main flange	84	
	No. 2	Metal coated ceramic pipe	84	
	No. 3	BPM Chassis	84	
	No. 4	UHV signal feed-throughs	336	(3)
	No. 5	Feedthrough contacts	400	
	No. 8	RF contact (CuBe ribbon)	168	
	No. 11	Insulation vacuum feed through	84	
WP2: Matching Transformers	No. 6	Matching transformer	672	(1)
	No. 6	90° N-type adapter	336	
	No. 7	Supporting plate	336	
WP3: Cryogenic Cables	No. 10	Cryogenic Cables	336	(2)

(1) The given number of matching transformers is twice the number of transformers actually required for installation at the BPM feed-through. This is necessary since matching transformers have to be selected and pairwise matched with respect to their rf properties in order to reach the strong requirements for precise beam position measurement.

(2) The total number of cryogenic cables is 4 times 84 cables. This number is divided into 2 families and each family consists of 4 different cables (same length, same connectors, but different shape, see description in section 3.1.14).

(3) The indicated number of UHV signal feedthroughs will be provided by the Company to the Contractor.

2.2.1 Spare Parts

As part of the delivery each Contractor has to prepare a detailed list of proposed spare parts needed to ensure only short periods of downtime in case of failures – during the period of warranty and extrapolated for the system's lifetime (30 years of beam operation). This list of proposed items is seen as an enhancement of the list of minimum required spare parts, see below. The list has to consider the restocking/replacement time of the components.

Table 3 summarizes the minimum required spare parts that have to be delivered by the contractors for WP1, WP2 and WP3, respectively.

Table 3: Minimum required spare parts to be delivered by Contractors.

Work Package	Component Name	Minimum Number of Spare Parts
WP 1: Mechanics	Main flange	3
	Metal coated ceramic pipe	3
	BPM Chassis	3
	UHV signal feed-throughs (*)	*12*
	Feedthrough contacts	12
	Insulation vacuum feed through	4
	RF-contact	8
WP2: Matching Transformers	Matching transformer	See section 2.2, remark (1)
	90° N-type adapter	12
	Supporting plate	12
WP3: Cryogenic Cables	Cryogenic signal cables	2 x each family

(*) The indicated number of spare parts for UHV signal feedthroughs will be provided by the Company. Spare parts for UHV signal feedthroughs stay at the Company site.

2.3 Content of Delivery by the Company

The following parts will be provided by the Company to the Contractor:

- UHV signal feed-throughs (item No. 4 of
- Table 2)

[N.B.: Spare parts for UHV signal feed-throughs (quantity given in Table 3) are available at the Company site and will not be sent to the Contractor.]

3. System Specification

The diagnostic component as specified in the present document is the product of R&D work within GSI Beam Instrumentation department. It is important to note that minor changes of the parameters given here might become necessary during the course of project realization. More precisely, design changes are possible only as a result of the Conceptual Design Review (CDR, see section 4.1) or the Final Design Review (FDR, see section 4.2). The contractor shall account for the fact that limited alterations of the technical realization as described here will be communicated by GSI Beam Instrumentation department (see section 3) as soon as the modification is approved by GSI and agreed upon by the responsible persons at FAIR.

3.1 Parameter Requirements (functional requirements)

In this section the subcomponents of the BPM, their locations, main boundaries and key parameters are described.

Please note: information given in the following sections is not equally important for all work packages (WP1-WP3), but it provides the technical background to understand how the various components are embedded in the full BPM system. At the beginning of each section the relevance for the work packages is explicitly indicated.

BPM Detector components are divided into two groups depending on the regions with significantly different vacuum requirements. The ceramic pipe with electrodes and the corresponding guard rings and signal feed-throughs will be installed in the beam pipe. The PU chassis being the ground for the electrodes is also a part of the beam pipe. Other in-cryostat components, like matching transformers and cryogenic signal cables, will be installed in the insulating vacuum between beam pipe and outer wall of the cryostat, see Figure 2. The system requirements are defined in section 3.2.

3.1.1 Basic Component Parameters (relevant for **WP1-WP3, part of the delivery**)

Table 4: Technical Parameter List of the BPM detector

Number of elements	84	
Overall length	mm	400
Length of the metal coated ceramic pipe (active plates including the guard rings)	Mm	300
Horizontal aperture	mm	135
Vertical aperture	mm	135
Pick-up bandwidth	MHz	0.4 – 95
Resolution	mm	0.1
Absolute accuracy	mm	0.5
Min. bunched beam current for given resolution	$\mu A_{(rms)}$	10
Max. bunched beam current	A	< 150
Max. expected voltage on electrodes	kV	1.8
Min. voltage withstand	kV	2

3.1.2 BPM Pick-Up (relevant for **WP1**: Mechanics, part of the delivery)

All BPMs are equipped with electrodes for both horizontal and vertical beam position measurement. All SIS100 pick-ups are installed inside the quadrupole doublet cryostats and are attached directly to the yoke of the preceding or following quadrupole (see also section 3.3). Since pick-ups are operated at the temperature of liquid helium, i.e. at 4.2 K, all components of the BPM have to be manufactured from materials with similar contraction coefficient unless the compensation of the different contraction is guaranteed by e.g. sliding RF contacts, bellows etc.

The BPM detector is of the linear-cut type. The PU design is based on metal-coated ceramic tubes, see Figure 5. The ceramic tube is coated on its internal side. The shapes of the electrodes, diagonal cuts and separating guard rings have to be formed in the

metal coating by removing a part of the coating material using e.g. blasting method. The guard rings have to be made (by brazing) as an integral part of metal coated ceramic pipe and must be made from titanium.

The BPM Pick-Up and Chassis has to be produced according to GSI documentation defined in Table 5. The company will provide 3-D models and a complete set of the technical drawings.

Table 5: Technical drawing relevant for WP1.

Drawing number and parts list number	Drawing name and parts list name
BD-1029728-A-000 (-)	**Beam Position Monitor SIS100 Production**

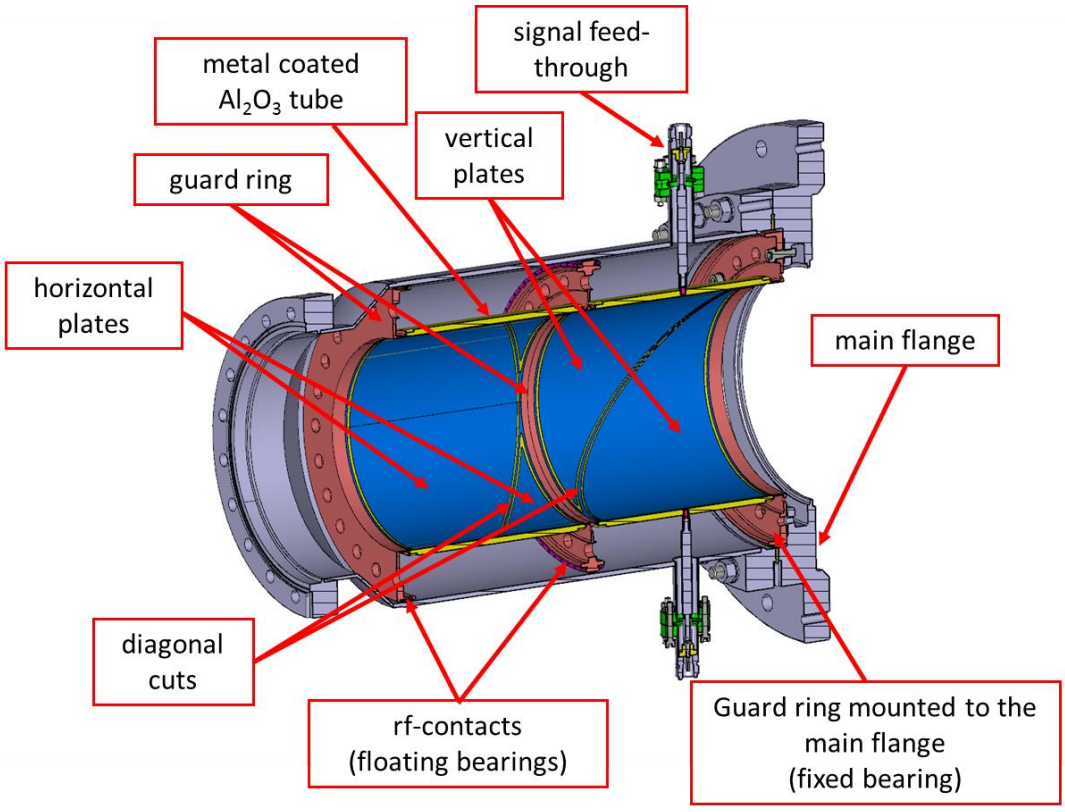


Figure 5: Schematic Drawing of the SIS100 BPM pick-up.

The length of the BPM chamber and BPM clearance are given in **Table 4**.

All components installed within the beam pipe have to satisfy UHV and cryogenic requirements, see section 3.2.

[Background information: a special challenge is the expected dynamic range of the signal amplitude, see **Table 4**. All components including feed-throughs and metal coated ceramic pipe are designed to fulfill this requirement. In particular the relative distances between electrodes, guard rings and chamber elements are designed with sufficiently large clearance to prevent discharges.]

The ceramic pipe has only one fixed bearing at the side of the main flange, see Figure 6. The other two guard rings slide on the inner part of the BPM chassis on the copper-beryllium RF contacts. These floating bearings are necessary for compensation of the contraction differences between stainless steel and ceramics.

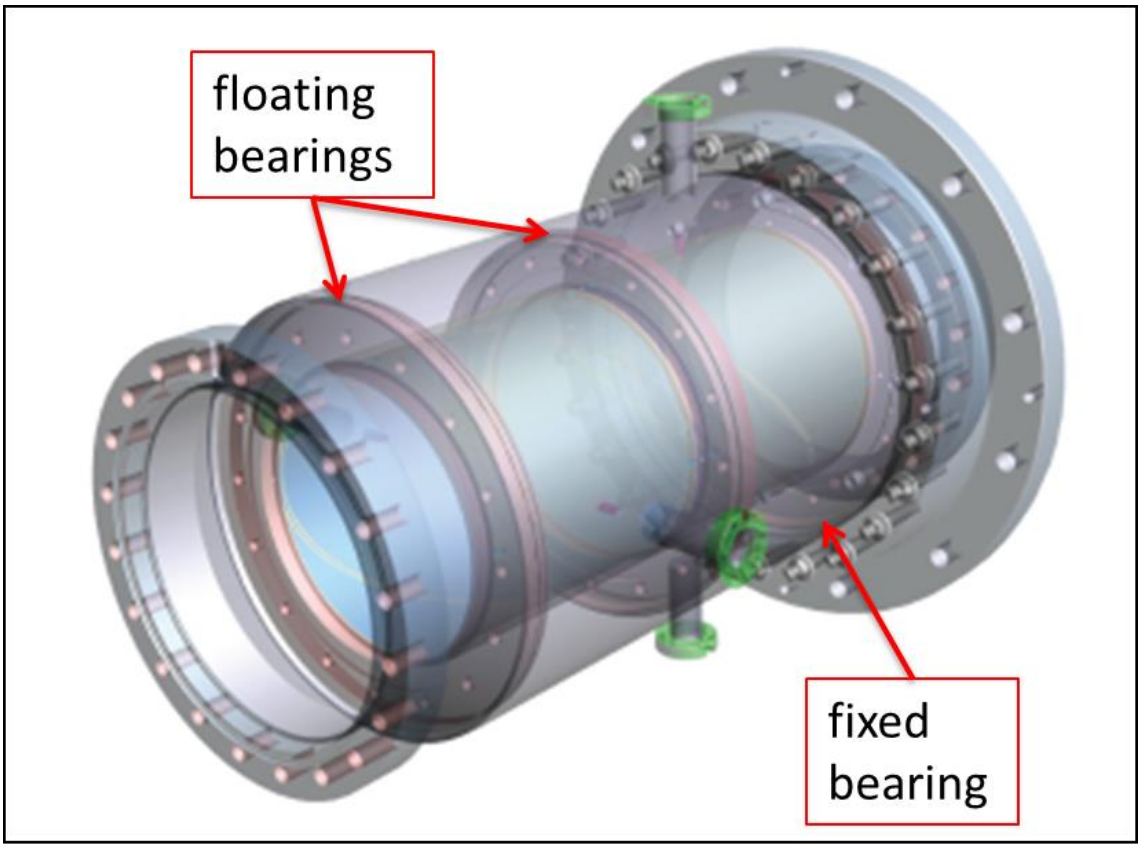


Figure 6: Fixation of the metal coated ceramic pipe inside the SIS100 BPM pick-up.

3.1.3 Exemplary realization

(relevant for **WP1**: Mechanics, not part of the delivery)

The present BPM design is a result of extensive development made by the GSI. The prototype shown in Figure 7 was tested at GSI under cryogenic conditions. All eventual changes of the concept, production methods or chosen materials have to be approved by the Company in the frame of the Conceptual Design Review.



Figure 7: Prototype of the ceramics based SIS100 BPM pick-up

3.1.4 Special requirements for assembly of the BPM chassis
(relevant for **WP1**: Mechanics, part of the delivery)

Since any incline of the chassis with respect to the main reference flange can exceed tolerances between guard rings and inner part of the BPM chassis, special attention has to be paid during assembly.

- fastening of the screws holding chassis (see Figure 8) must strictly follow technical guide line F-TG-V-13.1e [124]
  - ➲ Exception: screws, washers and screw nuts have to comply with technical guideline F-TG-V-2.37e [106]
  - ➲ **Exception for last fastening: torque must not exceed 22 Nm.**
- The slit of the CF 200 connection between chassis and main flange (see Figure 8) has to be controlled using a slip gauge (thickness gauge). **The maximum difference measured along the whole circumference must not exceed 0.1 mm (see drawings).**

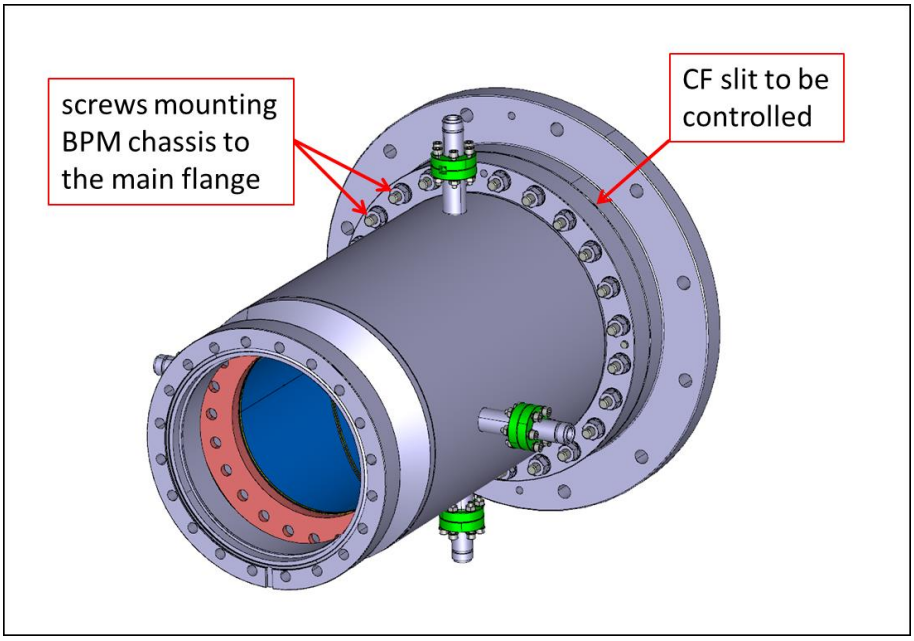


Figure 8: Screws mounting BPM chassis to the main flange and slit to be controlled, see description in text.

3.1.5 Determination of misaligned axes

(relevant for **WP1**: Mechanics; for information only, not part of the delivery)

One of the most fundamental issues for the beam position measurement is the proper absolute positioning of the BPM pick-up to an absolutely known reference frame. For the closed orbit correction most appropriate is the knowledge of the BPM position with respect to the magnetic axis of a neighboring quadrupole magnet. The accuracy is mainly influenced by the pick-up mechanical tolerances and the long-term stability of the mechanical alignment. In the particular case of SIS100 BPM installed in the cryogenic environment the mechanical stability (that is understood as position reproducibility after cool-down cycles) affects the accuracy. The accuracy of the beam position determination is a convolution of the mechanical adjustment of the BPM, displacement sensitivity and overall resolution of the readout (including e.g. amplification noise, digitalization resolution, etc.).

The main flange of the pickup will be mounted directly to the yoke interface flange of the preceding quadrupole (see section 3.3) and will be treated as a reference plane for whole BPM and particularly for the ceramic pipe of the pickup. The reproducibility of the positioning will be realized by dowel pins installed between main flange and magnet yoke.

Conceptually there is no alignment possibility given to BPM. However, the accuracy of the BPM is obtained by surveying of the misalignments, tolerances

and intrinsic offsets of the quadrupole as well as the tolerances of the BPM and subtracting them when calculating the beam position.

To calculate δ_x and δ_y and in Eq.1 and Eq.2, one needs to do three measurements of the offsets defined in Figure 9:

- Measurements of the magnetic axis of the quadrupole and its offset δ_{QM} with respect to geometrical center. These transfer measurements are foreseen as FAT and SAT of the quadrupole units. They deliver information about position of the magnetic axis with respect to the quadrupole magnet fiducials (**task of magnet manufacturer**).
- Measurements of the offset δ_{BPM} between electrical and geometrical center of the BPM. These measurements (see section 3.1.7) will be performed at GSI for each individual BPM Pick-up by means of a dedicated calibration test stand (**task of the Company**).
- Surveying of misalignment δ_{miss} between geometrical axes of the BPM and of the quadrupole described later on in this section (**task of the QDM integrator**).

Another important limiting factor for the BPM accuracy is the fact that all survey measurements will be done in warm conditions only. Dislocations due to e.g. differences in the contraction coefficients of the complex geometry of the QDM are not completely known in cryogenic condition. However, due to direct mounting of the main flange to the quadrupole yoke this effect will be minimized: the BPM will tend to move together with the quadrupole, whereas their relative position should remain almost unchanged.

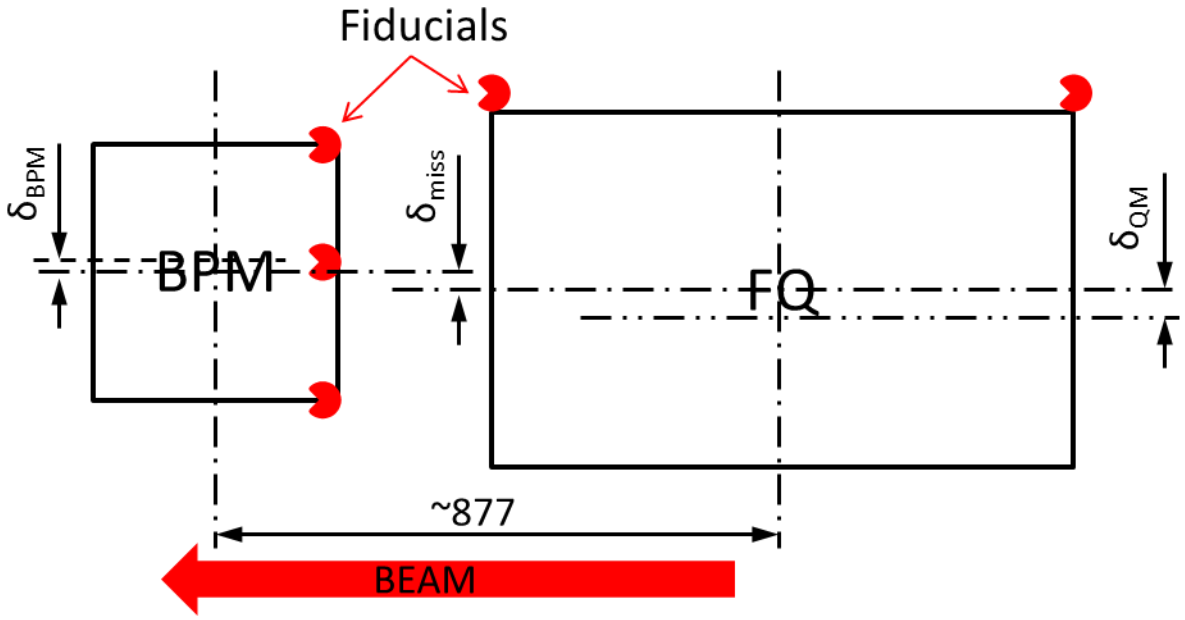


Figure 9: Definition of the offsets between geometrical axes (dashed-dotted line), electrical center of BPM (dashed line) and magnetic axis of the neighboring quadrupole magnet (dashed-double-dotted line).

Surveying has to be done by the QDM integrator and is neither part of WP1 nor WP2 nor WP3 (for assembly procedures please refer to detailed specification F-DS-MT-107e [22]).

3.1.6 Main reference plane and fiducials

(relevant for **WP1**: Mechanics, part of the delivery)

At the main flange the interface plane to quadrupole (see section 3.3) is treated as reference plane for all tolerances of the whole BPM. Position of this reference plane is shown in Figure 10. To reach the desired BPM accuracy (see definition in section 1.2) contractor of WP1 must guarantee special non-threaded H7 reference bore holes and worked-over reference planes at the positions specified in Figure 10. These have to be prepared according to the technical drawing defined in Table 5.

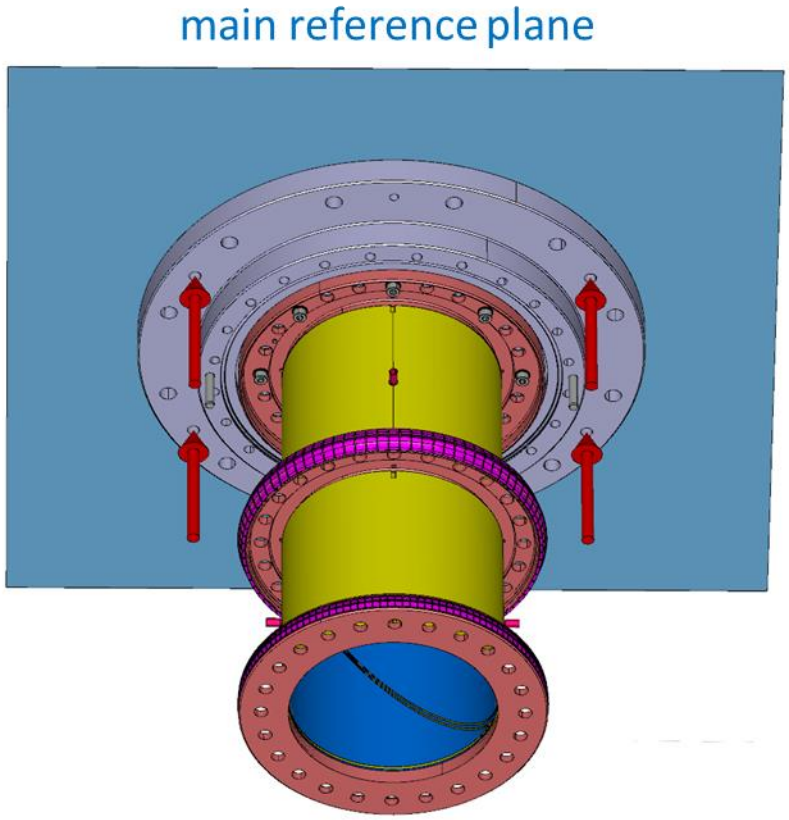


Figure 10: Position of the referenced holes and/or worked-over planes for fiducials on the main flange and ceramic cylinder.

3.1.7 Calibration of the BPM position sensitivity and offset between electrical and geometrical center

(for information only, not part of the delivery)

This calibration bases on the so called stretched wire method. The BPM is fixed to heavy and stable support. BPM position is aligned with the reproducibility of 0.02 mm by means of dowel pins installed between the main flange and support table. The metal wire with a diameter in the order of 0.1 mm is stretched inside the BPM and is mounted to stable and exactly positioned frame. The frame will be moved on the x-y cross table and positioned with the absolute accuracy of 0.02 mm. An eventual incline of the wire will be detected by the optical position detection system. An electrical signal will be applied to the wire and the response will be measured in the BPM. These measurements will be performed within the SAT described in section 5.3.

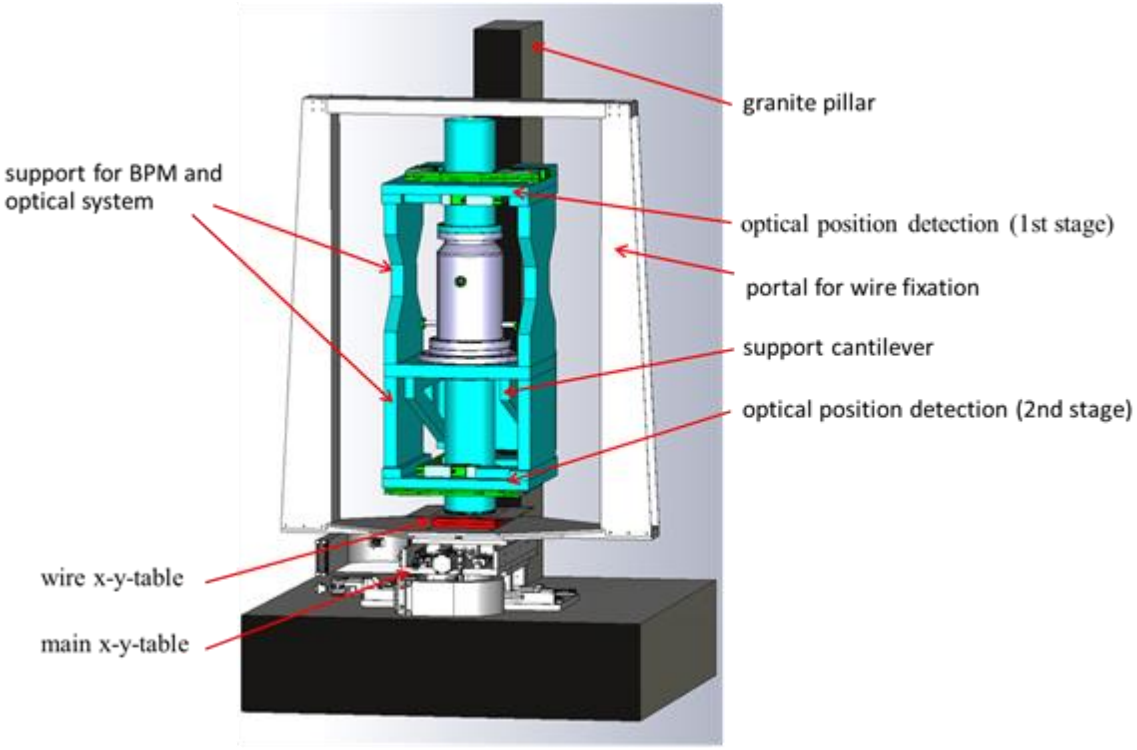


Figure 11: Schematic view of the calibration test stand for the SIS100 BPMs.

3.1.8 Electrical test of the BPM detector

(relevant for **WP1**: Mechanics, part of the delivery)

After the assembly of BPM Pick-up the capacitances of the BPM electrodes against ground and between two opposite electrodes have to be measured by means of LRC-

meter or Network Analyzer (NWA). The reference values are specified in Table 9. This procedure proves the proper assembly and BPM structure integrity:

a. Connect the LRC-meter to one of the four N-type signal feeds of BPM

b. Terminate all other feeds with 50 Ohm

c. Measure the capacitance against ground

d. Repeat measurement for all other feeds

e. Connect the LRC-meter to two opposite N-type signal feeds of BPM

f. Terminate all other feeds with 50 Ohm

g. Measure the capacitance between two opposite electrodes

h. Repeat measurement for other two feeds

If a 4-port NWA is used this measurement can be done in one single measurement, whereas the capacity has to be extracted from S11-scattering parameter. If the capacitance measured at any feed-through diverges from the values specified, the connections of the signal pins to the feed-through have to be rechecked and the measurements have to be repeated.

3.1.9 High-voltage test of the BPM detector
(relevant for **WP1**: Mechanics, part of the delivery)

High-voltage tests of the pickup part of the BPM detector are required up to the minimum withstand voltage denoted in Table 9. The electrical insulation test has to be carried out as a direct current resistance test, performed for all combinations of two signal feedthroughs and signal feedthrough vs. BPM chassis.

3.1.10 Characteristic Impedance test of the feed-through
(relevant for **WP1**: Mechanics, part of the delivery)

The values of the characteristic Impedance Z_0 of both, the UHV and insulation vacuum feed-throughs have to be measured and documented individually for each feed-through. The measurements have to be performed with a state-of-the-art TDR measurement (by means of TDR reflectometer or Network Analyzer). The measured value of Z_0 has to meet the requirements given in Table 10 and Table 11.

3.1.11 High-voltage test of the feed-through

(relevant for **WP1**: Mechanics, part of the delivery)

High-voltage tests of feed-throughs of the BPM detector are required up to the minimum withstand voltage denoted in Table 10 and Table 11, respectively. The electrical insulation test has to be carried out as a direct current resistance test between middle pin and slave of the feed-through.

3.1.12 Matching Transformers

(relevant for **WP2**: Matching Transformer, part of the delivery)

For reflection free signal transport in such long signal lines an impedance matching using to 50 Ohm close to the BPM plates by a passive transformer is necessary. Matching transformers with the winding ration N_{pri}/N_{sec} =18:2 based on toroidal cores made from nano-crystalline material will be used. **The matching transformer has to be produced according to GSI documentation defined in Table 6. The company will provide 3-D models and a complete set of the technical drawings.**

Table 6: Technical drawing relevant for WP2.

Drawing number and parts list number	Drawing name and parts list name
MG-1008892-A-000 (-)	BPM Impedance matching unit

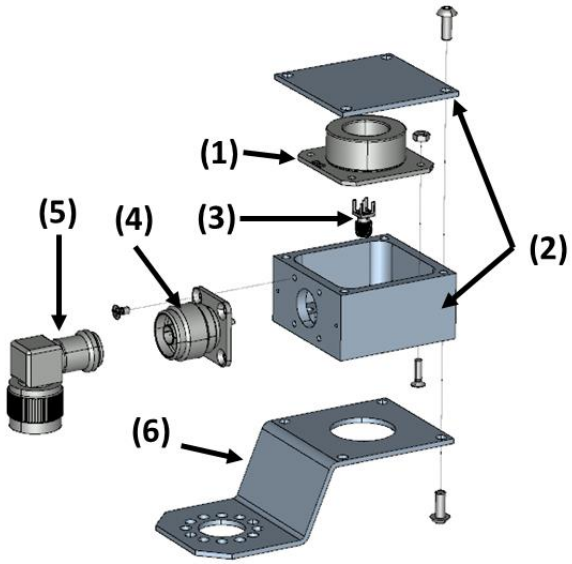


Figure 12: Impedance matching unit, see description Table 7

Table 7: Constituents of the WP2 .

Work Package	Item No. (Fig. 12)	Component Name

WP2: Matching Transformer	No. 1	PCB with Matching transformer
	No. 2	Housing
	No. 3	Output Connector
	No. 4	Input Connector
	No. 5	90° N-type adapter
	No. 6	Supporting plate

The transfer function is the most important MT parameter and has to be measured by a vector network analyzer by measurements of the scattering parameter S21 for each individual matching transformer. The transfer function has to be flat (within 0.1 dB) in the bandwidth from ~ 0.1 MHz to 55 MHz [3]. An example of the measurement is shown in Figure 13. The reference transfer function will be delivered to the contractor by the company. To minimize the offset of the BPM position determination the MTs have to be pairwise balanced within ±0.1 dB.

Due to possible geometry changes during thermal cycling, the transformer windings have to be stabilized using epoxy resin. The epoxy material has to be suitable for insulation vacuum and for cryogenic conditions, see section 3.2.

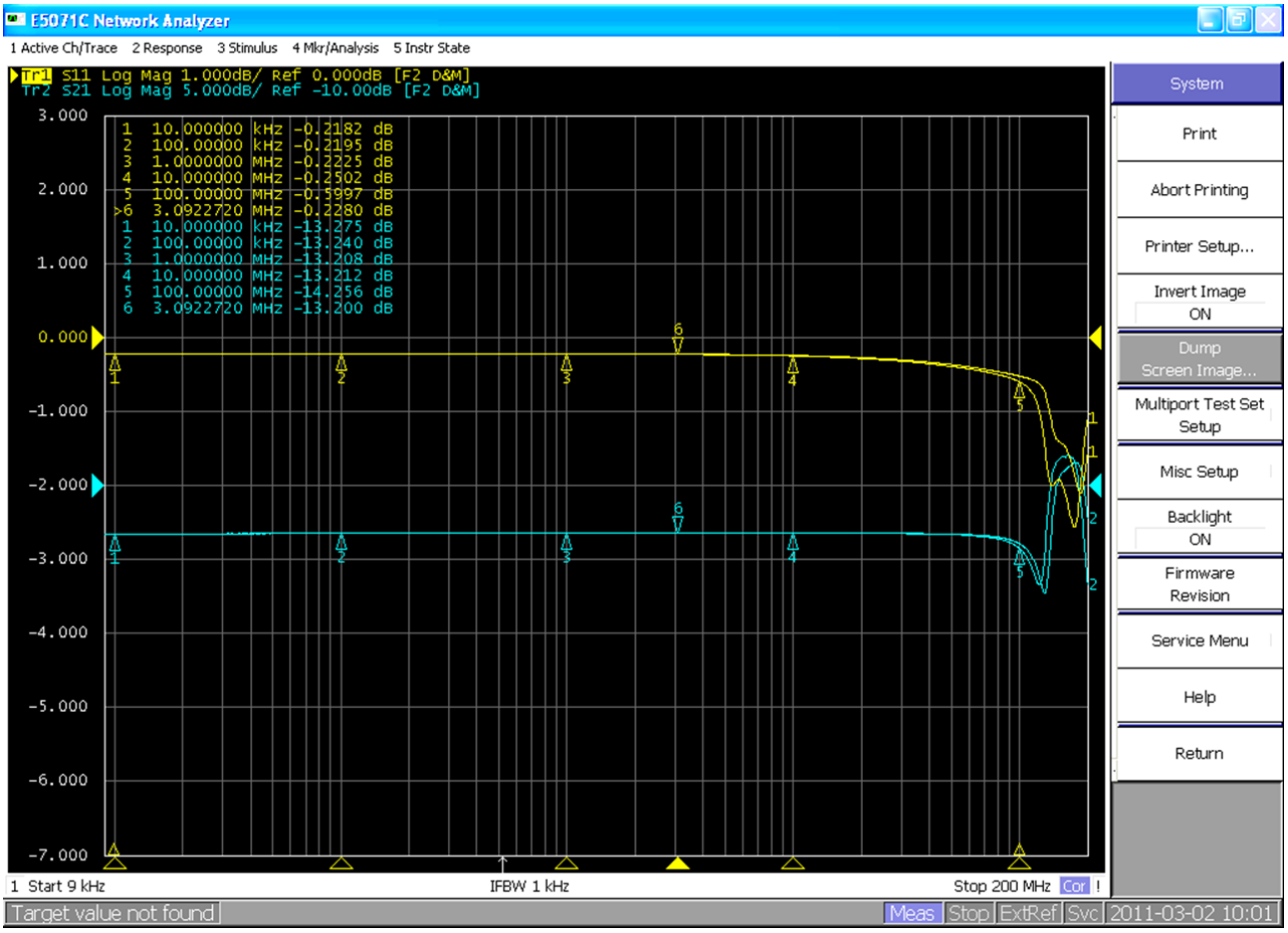


Figure 13: Example of the transfer function of the matching transformer measured using a network analyzer

The Stycast 2850 KT or Stycast 2850 GT mixed with Catalyst 24 LV as a second compound has to be used. Great attention has to be paid in preparation of the epoxy resin following strictly the vendor prescription. After filling with epoxy, the matching transformer's encapsulations, must be kept at least 10 min. in a 0.1 mbar vacuum for outgassing. Additional admixture of Antifoam 88 is to be used to reduce the surface tension and to remove air bubbles from epoxy material. After filling the encapsulation with epoxy the transformers are to be stored in a temperature controlled oven as specified in the epoxy documentation. **The temperature of the matching transformers at any time must not exceed 80 deg. Celsius (otherwise the magnetic properties of the toroid material are changed irreversibly).**

The technical requirements for the matching transformers are specified in section 3.4.5. The cryogenic suitability of the encapsulation will be tested in LHe within the Site Acceptance Tests, see section 5.3.4.5.

3.1.13 BPM installation locations

(relevant for: **WP3**: Cryogenic Cables, for information only, not part of the delivery)

A total number of 84 BPM stations will be distributed over the circumference of SIS100, comprising 6 sectors. This corresponds to 14 BPM locations per sector. All BPM pick-ups will be installed inside the Quadrupole Doublet Module (QDM) cryostats. A Quadrupole Doublet is an assembly of 2 quadrupole units within the same cryostat, see Figure 14. Each QDM has two quadrupole vacuum chambers and one middle vacuum chamber or collimator (COL) installed between two quadrupole units. Within the QDM the defocusing quadrupole (QD) is always on the upstream side; the second is a focusing quadrupole of type F1 or F2. There are 11 different configurations of the QDM depending on their location in the SIS100 lattice. An overview of the module types can be found in Fair Detailed Specification F-DS-MT-74e SIS100 Design Quadrupole Modules [20].

In the arcs the BPMs will be located at the down-stream (DS) or up-stream (US) end of the cryostat see Figure 14 and Figure 15, respectively. On the contrary, in the straight sections the BPMs will be installed in the middle of the quadrupole doublet, see Figure 18. **There are only two cable families foreseen: one for arcs and one for straight sections, as described later on in section 3.1.14.**

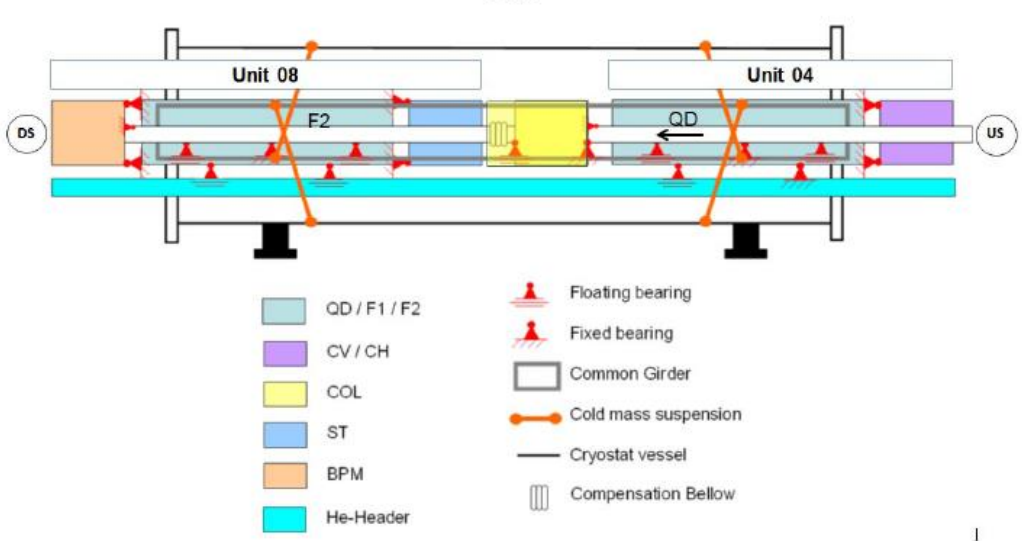


Figure 14: Location of BPM in the arc QDM of configuration 2.5 (schematics). Note the beam direction depicted by an arrow (US and DS stand for up-stream and down-stream, respectively). Other abbreviations are defined in section 1.1.

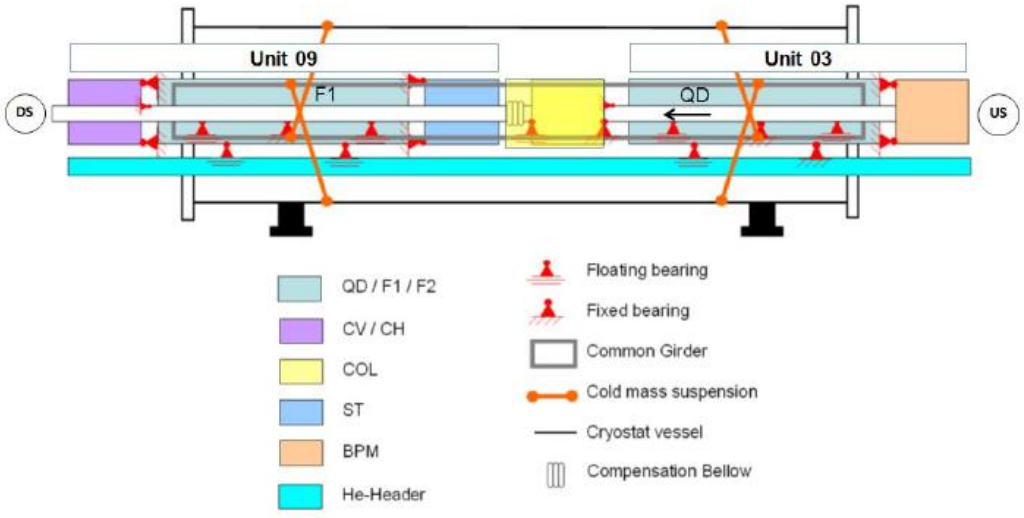


Figure 15: Location of BPM in other QDM configuration in arc (e.g. 1.6).

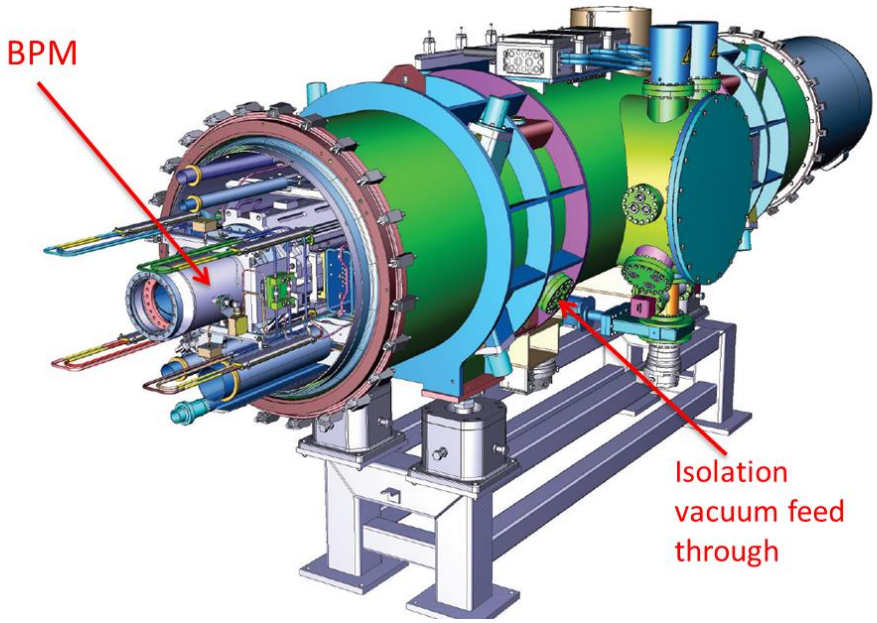


Figure 16: Position of BPM in the arc module (configuration 2.5).

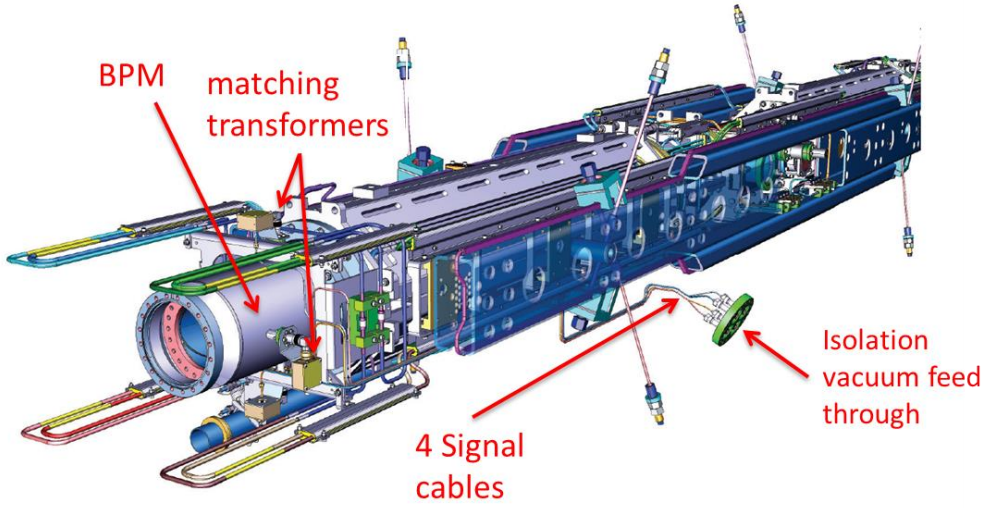


Figure 17: Position of BPM in the configuration 2.5. Note: several cryostat components were removed for a better visibility

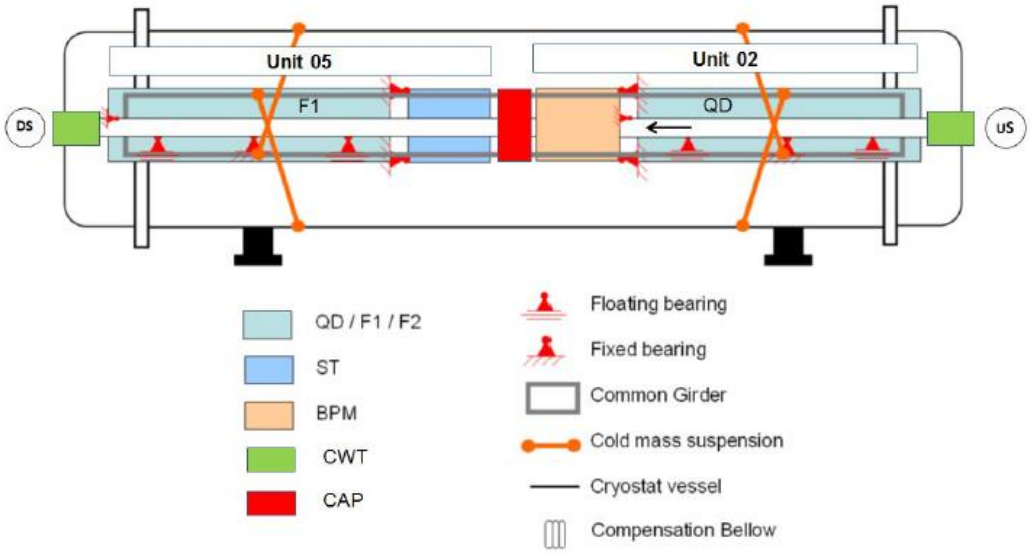


Figure 18: Location of BPM in one of the 18 straight sections QDM (schematics)

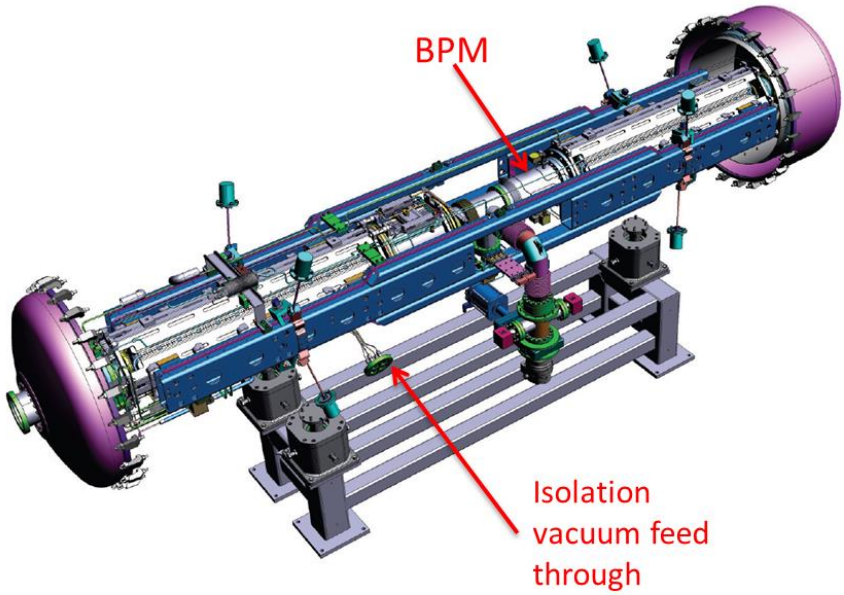


Figure 19: Position of BPM in one of the 18 straight sections QDM

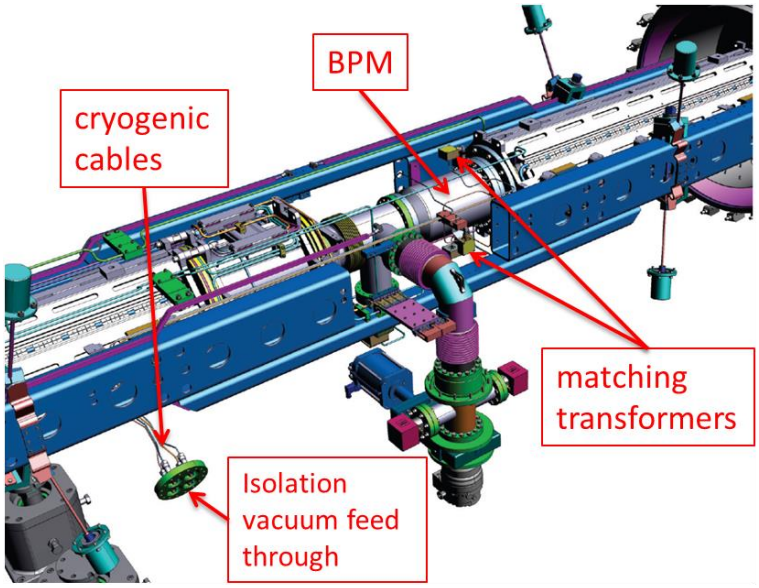


Figure 20: Same as Figure 19, but here several cryostat components were removed for a better visibility.

3.1.14 Cryogenic cables

(relevant for: **WP3**: Cryogenic Cables, part of the delivery)

The cryogenic signal cables lead the signals from the pick-up toward the outside the cryostat. The length of the signal lead (cryogenic cables) inside the vacuum vessel has to be about 2.5 m – on the one hand – to overcome space between the BPM and cryostat cable ports and – on the other hand – to keep the heat flow through all four signal leads below 0.5 W per single BPM. The cryogenic cables have to be radiation hard. The solution based on copper-coated stainless steel coaxial cable filled with $Si0_2$ powder is preferred. Usage of stainless steel based cables allows for keeping the heat flow through all four signal leads below 0.5 W per single BPM.

- Cryogenic cables have to be made from stainless steel conductors and have to be filled with SiO2 as dielectric.
- The cables have to be delivered formed in the final shape, matched to the same electric length and confectioned.
- Each BPM configuration needs 4 cryogenic cables with different geometric shape but with same total length.
- At the moment only two BPM configurations are foreseen: One for all arc QDMs and one for QDMs in straight sections. This implies that two cable families have to be build, each consisting of 4 different cables.

The cryogenic cables have to be produced according to GSI documentation defined in Table 8. The company will provide 3-D models and a complete set of technical drawings.

Table 8: Technical drawing relevant for WP3.

Drawing number and parts list number	Drawing name and parts list name	No. of cables	
		Arc QDM	Straight QDM
MG-1008907-A-000 (A)	INNER BPM CABLE	66	18
MG-1008900-A-000 (A)	LOWER BPM CABLE	66	18
MG-1008903-A-000 (A)	OUTER BPM CABLE	66	18
MG-1008905-A-000 (A)	UPPER BPM CABLE	66	18

Technical requirements for cryogenic cables are specified in section 3.4.6.

3.1.15 Hermeticity test of cryogenic cables

(relevant for: **WP3**: Cryogenic Cables, part of the delivery)

The Contractor has to check and document the hermeticity of the cryogenic cables, by measuring the outgassing rate of a cable inside an evacuated chamber. The outgassing rate may not exceed the value given in Table 13.

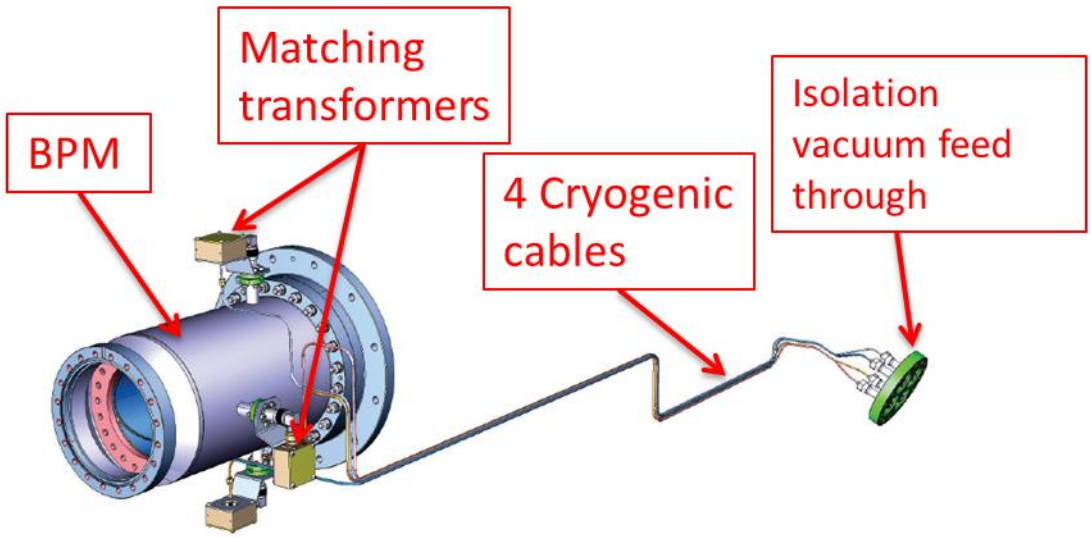


Figure 21: Cryogenic cables for the arc Quadrupole Doublet Module (QDM)

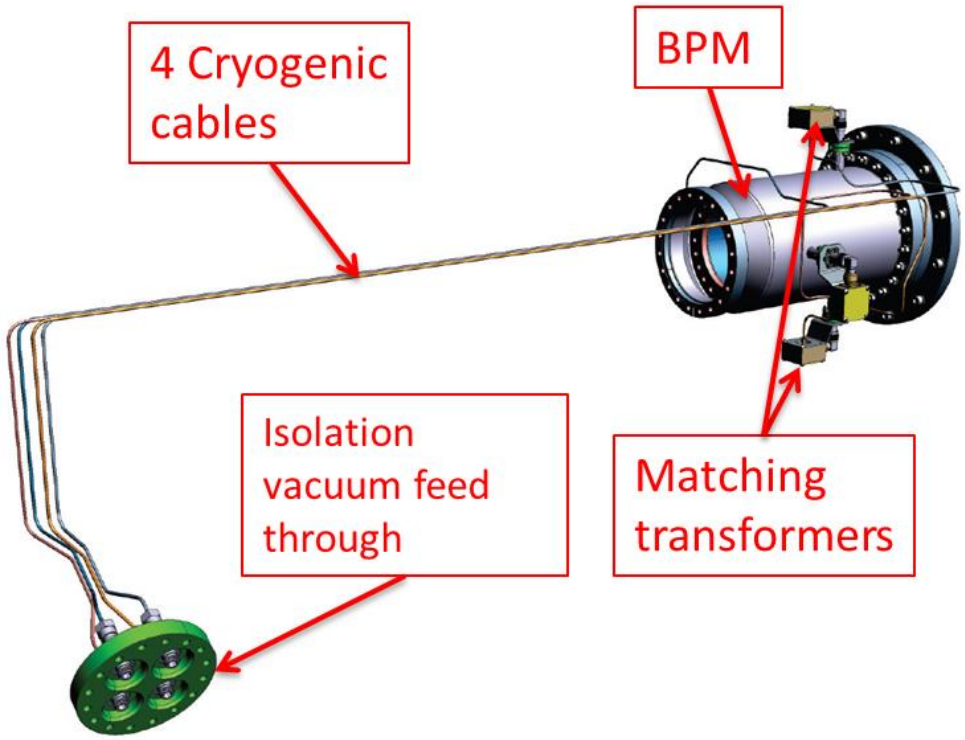


Figure 22: Cryogenic cables for the straight section QDM

3.2 System Environment and Constraints
(relevant for: **WP1**, **WP2** and **WP3, part of the delivery**)

BPM Detector components are divided into two groups depending on the significantly different vacuum environments. The ceramic pipe with electrodes and the corresponding guard rings and signal feed-throughs will be installed in the beam pipe. The PU chassis, being the ground for the electrodes, is simultaneously a constituent of the beam pipe. All components mentioned above have to be suitable for UHV conditions and operation at a temperature of 4.2 K (see F-TG-V-7.25e Vacuum Properties Acceptance Tests for Cryogenic Beam Vacuum Components [139]).

Other in-cryostat components, like matching transformers and cryogenic signal cables, will be installed in the insulating vacuum between beam pipe and outer wall of the vacuum vessel. These elements have to be compatible with typical insulation vacuum requirements at a pressure of 1e-7 mbar.

3.3 Mechanical interfaces

(relevant for: **WP1**: Mechanics, for information only, not part of the delivery)

The interface to the UHV vacuum system is the welded connection to the quadrupole vacuum chamber on the BPM quadrupole side, and CF160 on the opposite side. The main flange is mounted to the quadrupole chamber via a compensation bellow and the adapter flange (see Figure 23 and cross-section in Figure 24). The connection between an adapter flange and the quadrupole chamber is sealed by lip welding. Main flange after welding becomes an integral part of the quadrupole chamber. The BPM chassis after assembly becomes a part of the beam pipe. A bellow and an adapter flange belong to the delivery package of the QDM vacuum chamber (indicated as 'quadrupole vacuum chamber' in the center of Figure 23). The assembly procedure is described more precisely in the detailed specification of QDM Integration F-DS-MT-107e [23].

The BPM main flange is mounted on the yoke interface flange of the quadrupole magnet, see Figure 25 and Figure 26. The space surrounding the plate houses the ends of quadrupole coils and chamber cooling pipes. This interface plate serves as a mechanical support for the whole BPM; there is no other support needed. The plane in-between interface and main flange is the reference plane for the BPM, see section 3.1.6. The reproducibility of the connection is given by the dowel pins installed between the main flange and interface plate, see Figure 26.

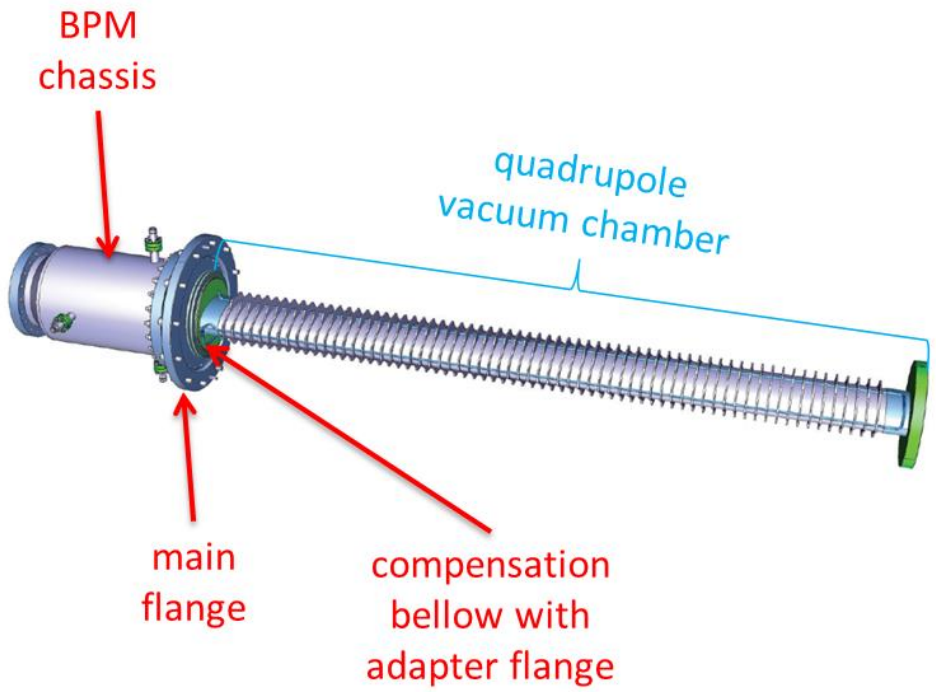


Figure 23: Interface between BPM and the quadrupole vacuum chamber, see description in text.

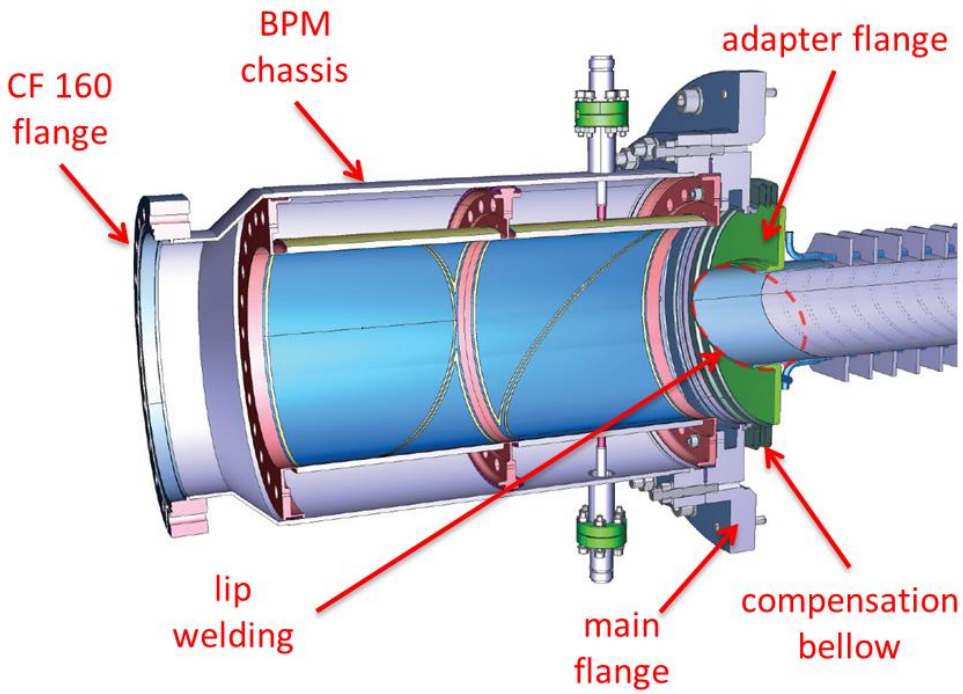


Figure 24: Cross-section of the interface between BPM and the quadrupole vacuum chamber.

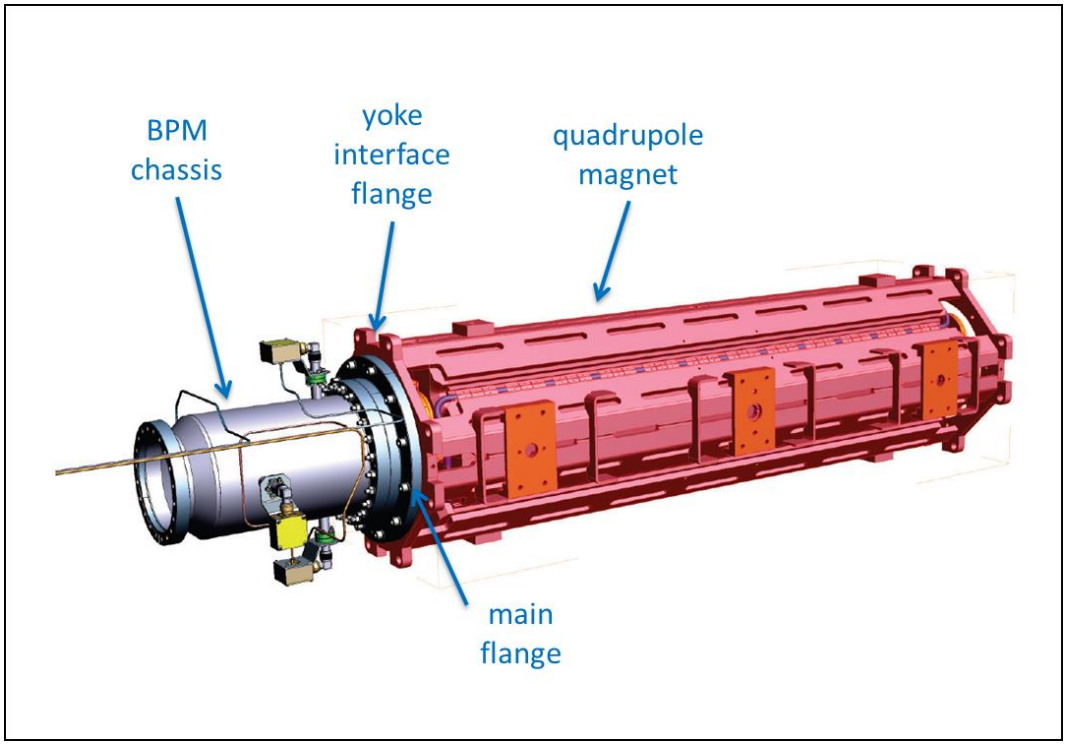


Figure 25: Interface between BPM and the neighboring quadrupole, see description in text.

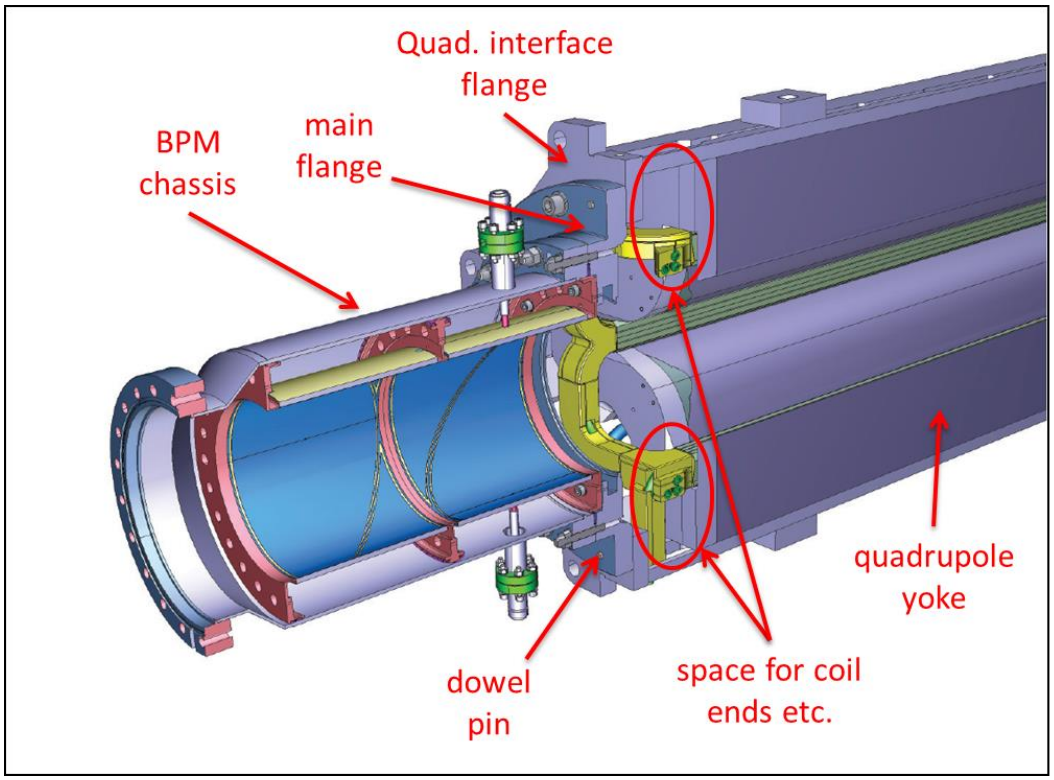


Figure 26: Cross-section of the interface between BPM and the neighboring quadrupole.

3.4 System components (technical requirements)

In this section the technical parameters of the BPM detector are summarized.

3.4.1 Pickup

(relevant for: **WP1**: Mechanics)

Table 9: Technical requirements for the BPM detector

Design principle	Capacitive, diagonal-cut type pick-up. Construction based on the pipe made from Al_2O_3 ceramic and coated from inner part with metallization. 4 electrodes and relevant guard rings are formed by cutting of the metallization. Pick up chassis is a part of the beam pipe
Active component length	300 mm
Transversal clearance	135 mm
Pick-up freq. range (min.)	0.4 MHz-95 MHz
Capacitance between electrode and ground	85 ± 5 pF
Capacitance between two electrodes of same plane	10 ± 2 pF
High Voltage withstand	2 kV
Working pressure	See F-TG-V-7.25e [139]
Integral leak rate	<=1E-10 mbar*l/s
Working temperature	4.2 K

All metal parts have to be produced from the materials specified in the parts lists of the related technical drawings. Isolators have to be made from Al2O3 ceramics. The choice of the ceramic material and cleaning is regulated by the FAIR Technical Guidelines F-TG-V-2.7e Ceramics for Vacuum Applications [134] and F-TG-V-6.4e Cleaning of Ceramics for Use in Vacuum [134].

Moreover, all vacuum parts have to be produced according the relevant technical guidelines for vacuum installations:

F-TG-V-2.7e Ceramics for Vacuum Applications [108]

F-TG-V-2.19e Additives for TIG Welding of StainlessSteel [101]

F-TG-V-2.25e Forged Blanks for Vacuum Applications Material 1.4429 / ESU [104]

F-TG-V-2.28e Stainless Steel for Beam Vacuum Chambers at Cryogenic Temperatures [105]

F-TG-V-2.37e Bolts, Studs, Nuts and Washers for Cryogenic UHV Components [106]
F-TG-V-2.6e Material for bakeable CF-flanges [135]

F-TG-V-3.1e Constructive Design of Welding Seams for Vacuum Chambers [137]
F-TG-V-5.1e Surface Properties of Vacuum Chambers [112]
F-TG-V-6.1e Cleaning of UHV Components of Stainless Steel [113]
F-TG-V-6.2e Cleaning of Standard Vacuum Components [114]
F-TG-V-6.4e Cleaning of Ceramics for Use in UHV [115]
F-TG-V-7.1e Mechanical Acceptance Test for Beam Vacuum Components [117]
F-TG-V-7.15e Record for Factory Acceptance Test (FAT) of Vacuum Components [118]
F-TG-V-7.25e Vacuum Properties Acceptance Test for Cryogenic Beam Vacuum Components [119]
F-TG-V-9.1e Transport and Packaging of Vacuum Components [122]
F-TG-V-9.12e Sealing Cap for CF Flanges [123]
F-TG-V-13.1e Assembly Instructions for Knife-Edge UHV Flanges [124]

3.4.2 UHV Signal feed-through (including DN16CF flange)

(relevant for: **WP1**: Mechanics, for information only, not part of the delivery)

Four signal feed-troughs for the Pick-up chassis shall have a line impedance of 50 Ohm and have to be embedded in DN16CF flange. The flange must be made from stainless steel of grade 1.4429 ESU following the Fair Technical Guideline F-TG-V-2.6e Material for Bakeable and Cryogenic CF Flanges [135]. The isolator should be made out of Al_20_3 ceramics. All technical requirements for UHV signal feed-throughs are listed in Table 10.

3.4.3 UHV signal feed-through contacts

(relevant for: **WP1**: Mechanics, part of the delivery)

UHV signal feed-through contacts shall be made from titanium. Contact springs shall be made out of blank copper-beryllium (they must not be plated with gold or similar). All technical requirements for UHV signal feed-through contacts are listed in Table 10.

Table 10: Technical requirements for UHV signal feed-throughs and Feedthrough contacts

Parameter	Value
UHV Feed-through	
Pcs. / BPM	**4**
Flange type	NW16 CF-F (ISO/TS 3669-2)
Flange material	Stainless Steel 1.4429 ESU
Middle pin material	Titanium
Slave material	Titanium
Characteristic impedance	50 ± 2 Ohm
Min voltage withstand	2 kV
UHV-side connector	4 mm cylindrical hole
Output connector	N-type
Isolator material	Al203
Working pressure	See F-TG-V-7.25e [139]
Integral leak rate	See F-TG-V-7.25e [139]
Working temperature	4.2 K
Feedthrough contacts	
Pcs. / BPM	**4**
Pin material	titanium
Contact spring material	CuBe blank (no coating)
Working pressure	See F-TG-V-7.25e [139]
Working temperature	4.2 K

3.4.4 Insulation vacuum feed-through (including DN16CF flange)

(relevant for: **WP1**: Mechanics, part of the delivery)

Insulation vacuum feed-troughs shall have a line impedance of 50 Ohm and have to be embedded in DN16CF flange. The flange must be made from stainless steel of grade 1.4429 ESU following the Fair Technical Guideline F-TG-V-2.6e Material for Bakeable and Cryogenic CF Flanges [135]. The isolator should be made out of Al_20_3 ceramics.

Insulation vacuum feed-throughs shall be equipped with N-type female connectors on both, the inner and outer side. All technical requirements for insulation vacuum feed-throughs are listed in Table 11.

For information: The insulation vacuum feed-throughs will be mounted inside one vacuum flange DN100CF at the outer cryostat wall. This DN100CF vacuum flange is NOT part of the delivery.

Table 11: Technical requirements for Insulation vacuum Feedthrough

Parameter	**Value**
Insulation vacuum -feedthrough	
Pcs. / BPM	**1**
Flange type	NW16 CF-F (ISO/TS 3669-2)
Flange material	Stainless Steel 1.4429 ESU
Middle pin material	Titanium
Slave material	Titanium or stainless steal
Characteristic impedance	50 ± 2 Ohm
Min voltage withstand	2 kV
Vacuum-side connector	N-type
Air-side connector	N-type
Isolator material	Al203 or SiO2 glass ceramics
Working pressure	See section 3.2
Integral leak rate	<= 1e-9 mbar*l/s
Working temperature	Room Temperature

3.4.5 Matching transformers

(relevant for: **WP2**: Matching transformers)

Table 12: Technical requirements for matching transformers

Parameter	Value
Pcs. / BPM	**4**
Winding ratio	18:2
Toroid material	Vitroperm 500F
Toroid Dimensions	
Outer radius	15 mm
Inner radius	10 mm
height	10.5 mm
Epoxy resin for filling	
first compound	Stycast 2850 GT or KT
second compound	Catalyst 24 LV
outgassing ratio	3.6e-8 mbar (after 100 hours)
Housing material	see technical drawing (Table 6)
Support plate material	see technical drawing (Table 6)
Frequency range	0.4 - 95 MHz
Max. insertion loss	-0.5 dB
Input impedance	4 kOhm
Output impedance	50 Ohm
Max. input voltage	2 kV
Max. output voltage	200 V max
Input connector (pick-up side)	N-type male (suitable for insulation vacuum, see section 3.2)
Output connector	SMA female (suitable for insulation vacuum, see section 3.2)
Max. outgassing rate (integral, per MT)	1e-8 mbar*l/s

3.4.6 Cryogenic cables

(relevant for: **WP3**: Cryogenic Cables)

Table 13: Technical requirements for cryogenic cables

Parameter	Value
Characteristic impedance	50 Ohm
Max. insertion loss @100MHz	- 0.5 dB
Materials:	
Inner conductor	Stainless steel copper coated on outer side.
Inner conductor	Stainless steel copper coated on inner side.
Dielectric	SiO2 fiberglass stabilized
Maximal length (stretched)	2.5 m
Minimal length	2.0 m
Cable shape	as defined in Table 8
Connector standards	N-Type and SMA (suitable for insulation vacuum, see section 3.2), additional holes for fixing under cryogenic conditions
Electric length matching within cable family	Better than 10 ps
Min. radiation hardness	1 MGy
Min. voltage withstand	2 kV
Max. outgassing rate (integral, per cable)	1e-8 mbar*l/s

4. Procedure

This chapter presents the procedure of the BPM detector realization. This covers almost fully finished design phase, production phase and testing.

4.1 Design phase

Design of the BPM detector has been processed in extensive test at the Company and is almost completed. Only some eventual minor changes concerning pickup design can be expected. For all relevant questions concerning BPM and its requirements contractors should refer to section 1.2 of this specification.

All the design work has to be documented as complete 3-D models in the Conceptual Design Report (CDR) by the Contractor. After the Company has given approval to the CDR, it is considered that the design of the whole system is fixed. This design will not be altered without grave reasons and only with permission by the Company. Any work

started before release of the CDR might be refused. The costs have to be carried by the Contractor.

If, after CDR approval passed, the Contractor proposes a change from the provided drawings and specifications, the Contractor must submit a change request document to the Company, which describes the requested change in detail and the reason for the change request.

4.2 Final Design Review phase

The Contractors of WP1, WP2 and WP3 have to deliver a Quality-Inspection and Production Plan (QIPP) to the Company. Production steps, procedures and tests differ depending on the work package and are listed in the following subsections.

In the Final Design Review Phase the contractor has to accomplish the following tasks:

- Overall production concept of the component that meets the functional requirements with list of components to be manufactured by Contractor and list of “standard” components
- Establishing manufacturing documents for the components to be prepared by Contractor
- Verification of the provided set of production drawings
- Final Design Review (FDR)

4.3 Production phase

Successful finalization of the Final Design Review (FDR) is the pre-requisite for the Contractor to start the Production Phase. The Contractors have to carry the full responsibility for the manufacturing documentation, production planning, manufacturing and testing of all components. They must provide all necessary equipment, material, tools, instruments, facilities and labor to engineer, and manufacture, test and deliver these components.

In the Production Phase the contractor has to accomplish the following tasks:

- Successful completion of the FDR
- Manufacturing of the components
- The short specifications or/and relevant test protocol of each component have to be provided
- Transportation of the component to the Company’s site
- Factory Acceptance Test (FAT)

- Instruction of FAIR personnel
- Documentation

The subcontractors have to take all measures to ensure the quality of all components and though the functionality of the complete system within these requirements at his efforts.

An installation of the complete system at the company's site and integration of all components into quadrupole doublet modules (QDM) is out of scope of this specification. This will be carried out by an Integrator following detailed specification for QDM Integration F-DS-MT-107e [22].

4.3.1 Work Package WP1: Mechanics

In the following list all steps to be performed by the Contractor are indicated with [Contractor], all steps performed by the Company are indicated with [Company]:

- [Contractor] Quality-Inspection and Production Plan is prepared and sent to GSI
- [Company] UHV-Feed-throughs are delivered to contractor
- [Contractor] Production of the First Of Series (FOS) is finished for all components of WP1
- [Contractor] Preliminary assembly of FOS Pick-up is finished
- [Contractor], [Company] Approval of FOS within Factory Acceptance Test (FAT) (HV test, production check dimensions, test report), see section 5.2
- [Contractor] FOS sent to GSI (including test report) for Site Acceptance Test (SAT)
- [Contractor], [Company] Test of FOS in SAT at GSI (HV test, test report, cryogenic test)
- [Company] FOS calibration No.1 is done at GSI, see section 3.1.7
- [Company] FOS disassembly, and QIPP and production check dimensions are proven
- [Company] FOS calibration No. 2 is done at GSI and compared with calibration No.1 (reproducibility)
- [Company] FOS is sent to integrator for integration into the FOS-Quadrupole Module
- [Company] FAT and SAT of FOS-Quadrupole Module is finished
- [Contractor] Start series production of BPM components
- [Contractor] Assign unique serial number (component ID, CID) to each component of the BPMs (CIDs are defined by the Company). A QR code tag according to TG-B-0.5e must be attached on stainless steel housing of each BPM

unit. The QR code must contain the CID (Component ID number) and may additionally also contain the individual serial number.

- [Company] Select BPM pickup components and assign them to a particular BPM
- [Contractor] From this point in time, the parts must not be interchanged between any of the BPMs. Complete test documentation has to be assigned to a particular BPM and followed during the next steps.
- [Contractor] Series Items have to be produced and delivered to GSI in **4 charges**
- [Contractor], [Company] FAT and SAT for series item are performed (same as for FOS)

4.3.2 Work Package WP2: Matching Transformer

- [Contractor] Quality-Inspection and Production Plan is prepared and sent to GSI
- [Contractor] Production of 10% of total number of pieces
- [Contractor] 10% of series is proven within Factory Acceptance Test (FAT) (proof of transfer function, insertion loss, outgassing rate of epoxy resin, test report).
- [Contractor] 10% of series is sent to GSI (including test report) for Site Acceptance Test (SAT)
- [Contractor], [Company] 10% of series is tested in SAT at GSI (proof of transfer function, insertion loss, outgassing rate of epoxy resin, cryogenic tests, test report).
- [Contractor] Series Items are produced and FAT are finished
- [Contractor] Assign an unique serial number (component ID, CID) to each component (CIDs as defined by the Company, according to TG-B-0.5e)
- [Contractor] Series Items are sent to GSI
- [Contractor], [Company] SAT is performed at GSI for rest of series
- [Company] Selection and pairing of matching transformers is done at GSI
- [Company] Series is sent to integrator for integration in the QDM

4.3.3 Work Package WP3: Cryogenic Cable

- [Contractor] Quality-Inspection and Production Plan is prepared and sent to GSI
- [Contractor] Production of FOS item of all cable type (2 families time 4 cables each) is finished
- [Contractor], [Company] FOS is proven within Factory Acceptance Test (FAT) (proof of insertion loss, electric length, hermeticity test, test report).
- [Contractor] FOS is sent to GSI (including test report) for Site Acceptance Test (SAT)

- [Contractor], [Company] FOS is tested in SAT at GSI (proof of insertion loss, electric length, vacuum tightness, cryogenic tests, test report)
- [Company] FOS is sent to integrator for integration in the FOS Quadrupole Module
- [Company] FAT and SAT of FOS Quadrupole Module is finished
- [Contractor] Series production is started
- [Contractor] Assign an unique serial number (component ID, CID) to each component (CIDs as defined by the Company, according to TG-B-0.5e)
- [Contractor] Series production of cryogenic cables
- [Contractor] Series is sent to integrator for integration in the Quadrupole Module

4.4 Documentation

The following table presents a list of mandatory documentation.

Table 14: Mandatory documentation.

		Design	Production	Acceptance
WP 1: Mechanics	**DS**	[3],[20],[21],[22]	[22]	[3],[22]
	TG	[100],[103],[104],[121], [128],[129]	[101],[102],[107],[110], [111],[112],[113],[130], [134],[135],[136]	[117],[118],[120] [121],[124],[138][139]
WP:2 Matching transformers	**DS**	[20],[22]	[22]	[3],[22]
	TG	[125],[204]	[204]	[139]
WP3: Cryogenic cables	**DS**	[20],[21] [22]	[22]	[3],[22]
	TG			

Additionally the following documentation has to be considered:

- General information BPM design and measurements: [201]-[204]
- General information FAIR: [1], [2], [200]
- Documentation and data exchange: [126], [127]
- Transportation and installation: [130], [131], [132], [133]

5. Quality Assurance, Tests, and Acceptance

General descriptions of the Factory Acceptance Test (FAT) and Site Acceptance Test (SAT) for all Beam Instrumentation components are described in Common Specification Beam Diagnostics for FAIR [3] and in the references therein.

This document describes the most relevant quality assurance procedures for the SIS100 BPM detector that have to be carried out and documented before, during and after production of the QDM. The procedures described here are to be considered as a contribution to Quality Assurance Plans for QDM.

In order to assure the demanded quality and to gain a common understanding the following procedures have to be applied as described in the present chapter. All

acceptance tests described in this chapter shall be carried out and documented for the BPM mechanics.

5.1 Quality Assurance system of the contractor

A list of tools to perform FAT has to be prepared by Contractor. The Company has to approve the list formally and only then the FAT test can be done.

The General Specification [2] applies. Special attention must be paid to chapter 5 on quality assurance and to chapter 6 on documentation.

5.2 Factory Acceptance Test (FAT)

Prior to shipment the Factory Acceptance Test (FAT) must be carried out by the contractor. The contractor is responsible for the preparation of the inspection plan. This plan has to be approved by GSI. All tests must be documented and the results made available for inspection.

FAT procedures differ slightly depending on the component and are listed below.

If the FAT fails, it will be in the responsibility of the Contractor to prepare and carry out any necessary rectification. In general, no rework on the BPM mechanics is allowed without the written permission of the Company.

The following rectifications are allowed to be performed only:

- repair of scratches or knife-edges,
- re-cleaning of the BPM mechanics

Manufacturing failures of BPM mechanics which require a repair in form of

- re-welding or mechanical re-alignment
- rectification of welding seams or of flanges

cannot be accepted. BPM mechanics with such manufacturing errors must not be reworked and have to be rejected.

If any rework is required, the written approval of the Company is mandatory. In case of return to the Contractor's premises the full set of Factory Acceptance Tests must be repeated prior to subsequent delivery.

5.2.1 Visual Inspection

Check that components are produced according to the design report and all parts are included. Upon completion of the BPM mechanics, the manufacturer shall inspect the vacuum parts on the inner as well on the outer side. It shall be proven that there are no defects which might render it unfit for UHV application. Particular attention shall be paid

to the form and state of the inner surfaces of the vacuum chamber, the quality of welding and brazing seams on the ribs and on the sealing surfaces of flanges. All welding regions must be scale-free, free from voids, blow holes, etc., and there should be no visible evidence of inclusions. Any trace of colored oxide is not acceptable. All internal surfaces must be free from scratches, dents, inclusions and other superficial contaminations. The sealing flanges must be inspected. Knife edges must be free from any scratches. All welding seams have to undergo a visual inspection by a certified person according to DIN EN ISO9712 (Non-destructive testing – Qualification and certification of Non-Destructive Testing (NDT) personnel). The basis of evaluation is DIN EN ISO 5817 quality class B. Transport and packing of the components must satisfy technical guideline F-TG-V-9.1e [141].

5.2.2 Mechanical Acceptance Test

The Mechanical Acceptance Tests are described in Fair Technical Guideline F-TG-V-7.1e Mechanical Acceptance Test for UHV Components [112]. The labeled check dimensions and position tolerances have to be checked and documented in the form of a measurement report.

5.2.3 Vacuum Acceptance Tests

Detailed vacuum acceptance tests have to be carried out for the BPM mechanics, which include helium leak test, ultimate pressure measurement, residual gas analysis, surface out-gassing rate. All measurements have to be documented.

The vacuum acceptance tests must be carried out according to F-TG-V-7.25e [139]. Prior to carrying out the vacuum acceptance test the procedure as well the test set-up must be submitted to and approved by the Company. Note that the Company will not provide any additional vacuum pumps, gauges, controllers or power supplies for vacuum acceptance tests.

The required vacuum tests are described in:

F-TG-V-7.25e Vacuum Properties Acceptance Tests for Cryogenic Beam Vacuum Components [139]
F-TG-V-7.15e Record for FAT Vacuum Components [111].

For all vacuum tests the BPM mechanics has to be closed with metal sealed blind flanges.

F-TG-V-3.42e Copper Gaskets for ConFlat® Flanges [104]

All acceptance tests have to be documented and sent as part of the delivery.

5.2.4 Component Specific Factory Acceptance Tests

5.2.4.1 BPM detector

(**WP1**: Mechanics, technical requirements: see Table 9**)**

- HV test
- Capacitance test using a network analyzer or LRC-meter, see section 3.1.8

5.2.4.2 UHV signal feedthrough

(technical requirements: see Table 11**)**

- characteristic impedance check using network analyzer is performed for each of feed through
- Leak test of the 10% random of series is proven to be below 1e-10 mbar*l/sec
- rest of series is proven for the leak-test for <=1e-9 mbar*l/sec
- HV tests are performed

5.2.4.3 Insulation-vacuum feedthrough

(**WP1**: Mechanics, technical requirements: see Table 11)

- each of series is proven for the leak-test for <=1e-9 mbar*l/sec
- HV tests are performed
- characteristic impedance check using network analyzer is performed for each of feed through

5.2.4.4 Matching transformer

(**WP2**: Matching Transformer, technical requirements: see Table 12)

- The outgassing rate of the epoxy resin will be checked for 10% of the delivery (random sample).
- Transfer function and insertion loss has to be measured for each transformer using a network analyzer, see section 3.1.12. Measurement protocols have to be prepared for each item

5.2.4.5 Cryogenic Cables

(**WP3**: Cryogenic Cables, technical requirements: see Table 13)

- The electrical length of the cables must be proven to be identical for all 4 cables of the same family
- Transfer function and impedance is measured using network analyzer and TDR
- Hermeticity of cable is proven

5.3 Site Acceptance Test (SAT)

The final and formal acceptance of the delivered BPM units will be declared only after successful completion of the Site Acceptance Tests (SAT) at the Company's premises. In general, the Company reserves the right to completely or partially repeat all Factory Acceptance Tests.

Site acceptance tests are described in [3]. They are spilt into two parts A and B, test prior to installation in the final location and tests after installation.

Immediately after delivery, all components must pass the incoming-goods inspection (SAT Aa). Prior to installation, all component tests must be repeated in a dedicated test area to assure proper function and obtain the permission for on-site installation. This test area must have access to the accelerator control system infrastructure in order to allow for system integration tests.

This SAT Ab process is finished and the approval for installation is given, if all test measurements are successful.

After installation, the sequence of tests without beam (SAT Ba) is identical to the one of SAT Ab.

The sequence of tests is given in the following sections.

Important note: Of course, the Company reserves the right to test all parts of the delivery against all technical parameters as given in the specifications and technical guidelines.

5.3.1 Visual Inspection

After delivery, an internal and external visual inspection of the chamber will be carried out to ensure that there are no chamber defects. Particular attention will be paid to the form and condition of the inner surface of the vacuum chamber, the quality of welding seams and on the sealing surfaces of flanges. All internal surfaces must be free from

scratches and dents. The sealing flanges will be inspected intensively. All knife edges must be free from any scratches.

5.3.2 Mechanical Acceptance tests

The Mechanical Acceptance Tests are described in F-TG-V-7.1e Mechanical Acceptance Test for UHV Components [112]. The labeled dimensions and position tolerances have to be checked and documented.

5.3.3 Vacuum Acceptance Tests

Detailed vacuum acceptance tests have to be carried out and documented for the BPM mechanics, which include helium leak test, ultimate pressure measurement, residual gas analysis & surface out-gassing rate measurements.

The Vacuum Acceptance tests are described in:

− F-TG-V-7.25e Vacuum Properties Acceptance Tests for Cryogenic Beam Vacuum Components [139]

− F-TG-V-7.15e Record for FAT Vacuum Components [111]

5.3.4 Component Specific Site Acceptance Tests

5.3.4.1 BPM detector

(technical requirements: see Table 9**)**

- Mechanical tolerances are proven especially the check dimensions for FOS and 10% random sample of delivery
- HV test
- Capacitance test using a network analyzer or LRC-meter, see section 3.1.8
- Cryogenic tests of entire preassembled FOS BPM pick-up

5.3.4.2 UHV signal feedthrough

(technical requirements: see Table 10**)**

- proof of check dimensions is performed for 10% of series
- characteristic impedance check using network analyzer is performed for each of feed through
- HV tests are performed
- Leak test of the 10% random of series is proven to be below 1e-10 mbar*l/sec

- Cryogenic test combined with leak test is performed for same 10% of feeds.
- Leak test is repeated for the same 10% of series
- rest of series is proven for the leak-test for <=1e-9 mbar*l/sec

5.3.4.3 Insulation-vacuum feedthrough

(technical requirements: see Table 11)

- leak-test for each piece of series is proven
- HV tests are performed
- characteristic impedance check using network analyzer is performed for each of feed through

5.3.4.4 Matching transformer

(technical requirements: see Table 12)

- The outgassing rate of the epoxy resin will be checked for 10% of the delivery (random sample).
- For 10% the transfer function and insertion loss is compared with measurement protocol
- 10% of series is tested in cryogenic tests at LHe temperatures.

5.3.4.5 Cryogenic cable

(technical requirements: see Table 13)

- The electrical length of the cables must be proven to be identical for all 4 cables of the same family.
- Hermeticity of cable is proven
- Transfer function and impedance is measured using network analyzer and TDR.

5.3.5 Packaging and transport (WP 1: Mechanics)

I. Once each BPM mechanics has successfully passed FAT (see section 5.2) and was vented using dry N2 (at least 99.995% purity = nitrogen 4.5), it must be packaged carefully and contained in such a way that each unit remains clean and free from any damage and contamination at all times (see F-TG-V-9.1e [122]). This requires a stable, weather-proof packaging. It is recommended to pack and store each BPM mechanics within an appropriate plastic foil and to keep each BPM mechanics in a separate wooden box.

II. For shipping and storing, each BPM mechanics shall be sealed with a suitable blank aluminum end cap using an appropriate gasket, i.e. no DN160CF or DN200CF blank flanges shall be used. The technical drawings of these aluminum end caps can be found

in F-TG-V-9.12e [123]. Prior to mounting to the CF-type flanges each aluminum end cap must be thoroughly cleaned according to F-TG-V-6.5e [116] .

6. Documentation

In general the Contractor has to deliver all documents requested in the General Specification F-GS-F-01e [2]. As a supplement the following documents have to be delivered by the Contractor:

- Test plans
- Quality-Inspection and Production Plan
- Test reports

7. Related Documents

The first paragraph contains all design reports and the General and Common Specifications of FAIR and the GSI Beam Instrumentation department. The second paragraph is devoted to the Detailed Specifications of the Beam Diagnostics work package, whereas the third paragraph lists all relevant Technical Guidelines. Paragraph four contains documents that are specific for the present Detailed Specification. The mandatory documentation reference which has to be followed by Contractor during each project stage is referenced in Table 14.

General Documents [1..19]

[1] TDR-SIS100-Dec2008.pdf, FAIR Technical Design Report SIS100
[2] F-GS-F-01e-General_Specification_v1_2.pdf, General Specification (General Specification for the FAIR Accelerator Facility Project), EDMS No 1365092 v. 1
[3] F-CS-BD-01e_Beam_Diagnostics_v3.1.pdf, Common Specification Beam Diagnostics for FAIR
[4] FAIR Baseline TR, H. H. Gutbrod et al, 09.2006, EDMS: tba

Detailed Specifications [20..99]

[20] F-DS-BD-22e_Pos+BPM_1S_v2.3.pdf
[21] F-DS-MT-74e_SIS100_Design_Quadrupole_Modules_v1.1.pdf
[22] F-DS-MT-107e_SIS100_QDM_Cryostat_Construction_Module_Integration
[23] F-CS-K-03e_Common_Specification_Cryogenic

Technical Guidelines [100..199]

[100] F-TG-V-2.1e_Stainless_Steel_for_Beam_Vacuum_Chambers_20121203.pdf
[101] F-TG-V-2.19e_Additives_for_TIG_Welding_of_Stainless_Steel_20100512.pdf
[102] F-TG-V-2.23e_Bolts_Studs_Nuts_Washers_for_bakeable_UHV_Components_20100624.pdf
[103] F-TG-V-2.24e_Materials_in_UHV_20100512.pdf
[104] F-TG-V-2.25e_Forged_Blanks_for_Vacuum_Applications_Material_1.4429_ESU_20100512.pdf
[105] F-TG-V-2.28e Stainless Steel for Beam Vacuum Chambers at Cryogenic Temperatures (2015-02-24)
[106] F-TG-V-2.37e Bolts, Studs, Nuts and Washers for Cryogenic UHV Components (2014-10-20)
[107] F-TG-V-2.5e_Vacuum_Firing_for_Hydrogen_Degassing_of_Materials_and_UHV_Chambers_20140406.pdf
[108] F-TG-V-2.7e Ceramics for Vacuum Applications (2014-11-11)
[109] F-TG-V-3.9e_Welding_of_CF_Flanges_on_Tubes_v.1.2.pdf
[110] F-TG-V-3.42e_Copper_Gaskets_for_CF_Flanges_v1.2.pdf
[111] F-TG-V-3.4e_Manufacturing_of_CF-Knife_Edge_Flanges_20110706.pdf
[112] F-TG-V-5.1e_Surface_Conditions_of_Vacuum Chambers_20101012.pdf
[113] F-TG-V-6.1e_Cleaning_of_UHV_Components_Stainless_Steel_20121203.pdf
[114] F-TG-V-6.2e Cleaning of Standard Vacuum Components (2014-04-03)
[115] F-TG-V-6.4e Cleaning of Ceramics for Use in UHV (2014-04-09)
[116] F-TG-V-6.5e Cleaning of Aluminium Components (2014-04-09)
[117] F-TG-V-7.1e_Mechanical_Acceptance_Test_for_UHV_Components_20121203.pdf
[118] F-TG-V-7.15e_Record_for_Factory_Acceptance_Test_(FAT)_of_Vacuum_Components_v.1.2.pdf
[119] F-TG-V-7.25e Vacuum Properties Acceptance Test for Cryogenic Beam Vacuum Components (2014-04-05)
[120] F-TG-V-7.3e_Vacuum_Properties_Acceptance_Test_with_Bakeout_20130604.pdf
[121] F-TG-8.3e_Recommended_Guidelines_for_Purchase_of_Vacuum_Chambers_with_Bakeout_20100624.pdf

[122] F-TG-V-9.1e Transport and Packaging of Vacuum Components (2014-04-05)
[123] F-TG-V-9.12e Sealing Cap for CF Flanges (2015-06-30)
[124] F-TG-V-13.1e_Assembly_Instructions_for_Knife-Edge_UHV_Flanges_20100414.pdf
[125] F-TG-B-01e_Material_Selection_Radiation_20110617.pdf
[126] FAIR Technical Guideline, F-TG-B-02e DARL-T1 20130228, “Datenaustauschrichtlinie”
[127] FAIR Technical Guideline, F-TG-B-03e DARL-T2 20130228, “Datenaustauschrichtlinie”
[128] FAIR Technical Guideline, F-TG-B-04e KRL 20120228, “Konstruktionsrichtlinie”
[129] FAIR Technical Guideline, F-TG-S-2.17e General construction norms 20100412
[130] F-TG-T-01e_Transport_v1.1.pdf
[131] F-TG-T-02e_Existing_Infrastructure_20101101.pdf
[132] F-TG-T-03e_Installation_v1.1.pdf
[133] F-TG-B-0.5e_Permanent_Tagging_and_Labelling_of_Components.pdf
[134] F-TG-V-6.4e_Cleaning_of_Ceramics_for_Use_in_UHV_20140409.pdf
[135] F-TG-V-2.6e_Material_for_Bakeable_CF_Flanges_v1.3.pdf
[136] F-TG-V-3.9e_Welding_of_CF_Flanges_on_Tubes_v.1.2.pdf
[137] F-TG-V-3.1e_Constructive_Design_of_Welding_Seams_for_Vacuum_Chambers_v.2.1.pdf
[138] F-TG-V-9.1e_Transport_and_Packaging_of_Vacuum_Components_20140405.pdf
[139] F-TG-V-7.25e_Vacuum_Properties_Acceptance_Tests_for_Cryogenic_Beam_Vacuum_Components
[140] F-TG-V-2.28e_Stainless_Steel_for_Beam_Vacuum_Chambers_at_Cryogenic_Temperatures
[141] F-TG-V-9.1e_Transport_and_Packaging_of_Vacuum_Components

Special Documents and Technical Notes [200...]

[200] V. R. Schaa, F. Peldzinski, M. Kühne and Bayer, Wolfgang, "System for Nomenclatures of Accelerator Devices at FAIR & GSI," [Online]. Available:https://www-acc.gsi.de/wiki/Accnomen.
[201] P. Forck et al., CAS “Beam Diagnostics”, Dourdan (2008)
[202] P. Kowina et al., Proc. EPAC’06, Edinburgh (2006)
[203] P. Kowina et al., Proc. DIPAC’07, TUPB16, Venice (2007)
[204] P. Kowina et al., Proc. DIPAC’11, Hamburg (2011) and references therein
[205] f-tn-bd-002e_leak-check-grove_v2_0.pdf