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Functional Specification

LHC IP1/IP5 FRONT QUADRUPOLE ABSORBERS (TAS)

Abstract

The front quadrupole absorbers (TAS) are required to absorb the flux of forward high energy charged and neutral particles that are produced at the high luminosity IPs 1 and 5 of the LHC. These particles are thereby prevented from quenching the inner triplet superconducting quadrupoles and the induced activation is localized to the absorber and surrounding shielding. The aperture of the TAS is the limiting physical aperture in IRs 1 and 5 so the TAS also protects the inner tracking elements of the ATLAS and CMS detectors from loss of beam particles in the IRs. The TAS absorbers are an integral part of the forward shielding of ATLAS and CMS. This specification describes the function of the front quadrupole absorbers and related requirements and parameters.

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History of Changes

Rev. No.	***Date***	***Pages***	***Description of Changes***
0.1	1999-02-16	15	First version submitted for approval
0.2	2000-03-30	17	Modifications added after first approval circulation.
			Second version submitted for approval
1.0	2000-06-15	1-17	First version released.
2.0	2000-06-15		Reviewers' comments to the first version incorporated.
		8	Lattice requirements clarified.
		9,10	Changes to vacuum requirements.
		5	Absorber weight corrected.
		9	Support and adjustment clarified.
		9	Crane limits corrected.
		3, 6, 10, 11	Misc. text corrections
2.1	2000-07-31	10	Beam tube straight and tapered section facing IP mechanical tolerance of +/- 0.4 mm becomes +/- 0.5 mm
			Beam tube in the absorber section mechanical tolerance of +/- 0.3 mm becomes +/- 0.5 mm
			Beam tube tapered section away from the IP mechanical tolerance of 0.4 mm becomes +/- 0.5 mm
3.0	2002-04-05	6-9, 18-21	Updated all Figures and added opposite side Figures to show latest design
		10,12,14	Removed references to 20 mm radius commissioning Vacuum beam tube.
		10	Changed text to indicate only Q1 transition instead of both ends.
		9-11	Update nomenclature: TAS2, TAS3 become TAS A and TAS B
		11	Add reference to current optics and layout version 6.4.
			Corrected radial tolerance from 0.3 mm to 0.5 mm and the tolerance stackup from 1.2 mm to 1.4 mm.
			Added descriptive text for the 0.5 mm tolerance.
		13	Updated Vacuum beam tube lengths: CMS from 2450 mm to 2130 mm and ATLAS from 2500 mm to 2130 mm
		14	Updated IP flange design to 240 mm OD telemanipulator version Updated flange bond from braze to explosion bond Updated Q1 flange design to 114 mm OD rotatable CF Removed the taper reference on tube facing the IP.

Rev. No.	***Date***	***Pages***	***Description of Changes***
		15	Updated beam tube taper away from IP: added half angle dimension of 10° Updated distance from front surface of absorber to IP flange from 450mm (ATLAS) and 400 mm (CMS) to 50 mm for both. Updated distance from rear surface of absorber to Q1 flange from 250 mm to 280 mm for both. # of detector slots changed from 1 to 2
		22	Updated flange bond from braze to explosion bond, removed reference to TAN
		24	Added references to CERN vacuum chamber drawings, added references to LBNL Engineering Notes and the TAS Interface Spec.
		24	Corre cted references 17 to read TIS-TE-MB-lj instead of TIS-TE-MB-1j
	2002-05-28	all	Submission for approval process

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1. OVERVIEW

When the 7 TeV proton beams of the LHC are in collision at the high luminosity IPs 1 and 5, approximately 1kW of collision products leaves the IPs in each direction at the design luminosity of $10^{34}cm^{-2}sec^{-1}$ [1] [2] [3]. Special purpose absorbers are needed to protect superconducting magnets from this radiation to prevent them from quenching [4]. The absorbers also localize the induced activation to the absorbers and surrounding shielding. The function of the TAS is to absorb the charged and neutral particles leaving the IPs, primarily charged pions and photons, that would otherwise impinge on the front face of the inner triplet superconducting quadrupole Q1. Since the beam tube aperture of the TAS is the limiting physical aperture in the IRs, the TAS absorbers also provide protection of the inner tracking elements of the ATLAS and CMS detectors from loss of beam particles in the IRs. Forward shielding is needed around the TAS absorbers to reduce the background radiation in the detectors due to the interactions taking place in the TAS[5]. The TAS absorbers are designed to be an integral part of the forward shielding of ATLAS and CMS.

For IP1 and IP5, the proposed designs of the TAS surrounded by the forward shielding cones of the ATLAS and CMS experiments are shown in Figure. 1 and 2. The TAS itself consists of the innermost copper absorber, the beam tube, the adjustable supports and alignment rods.

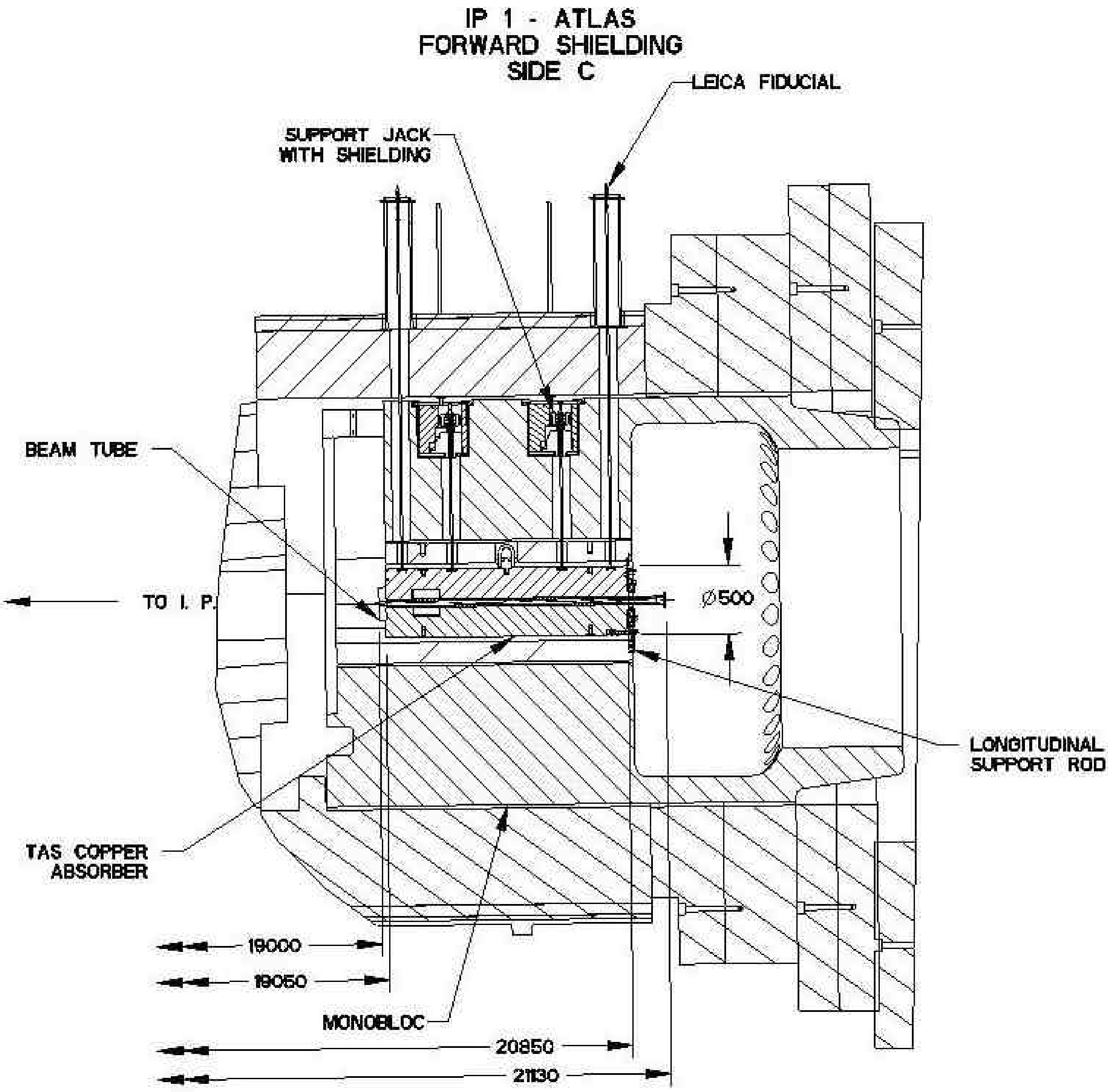

Figure 1A TAS Design for ATLAS – SIDE C – Elevation View

(View is from the inside of the ring looking out)

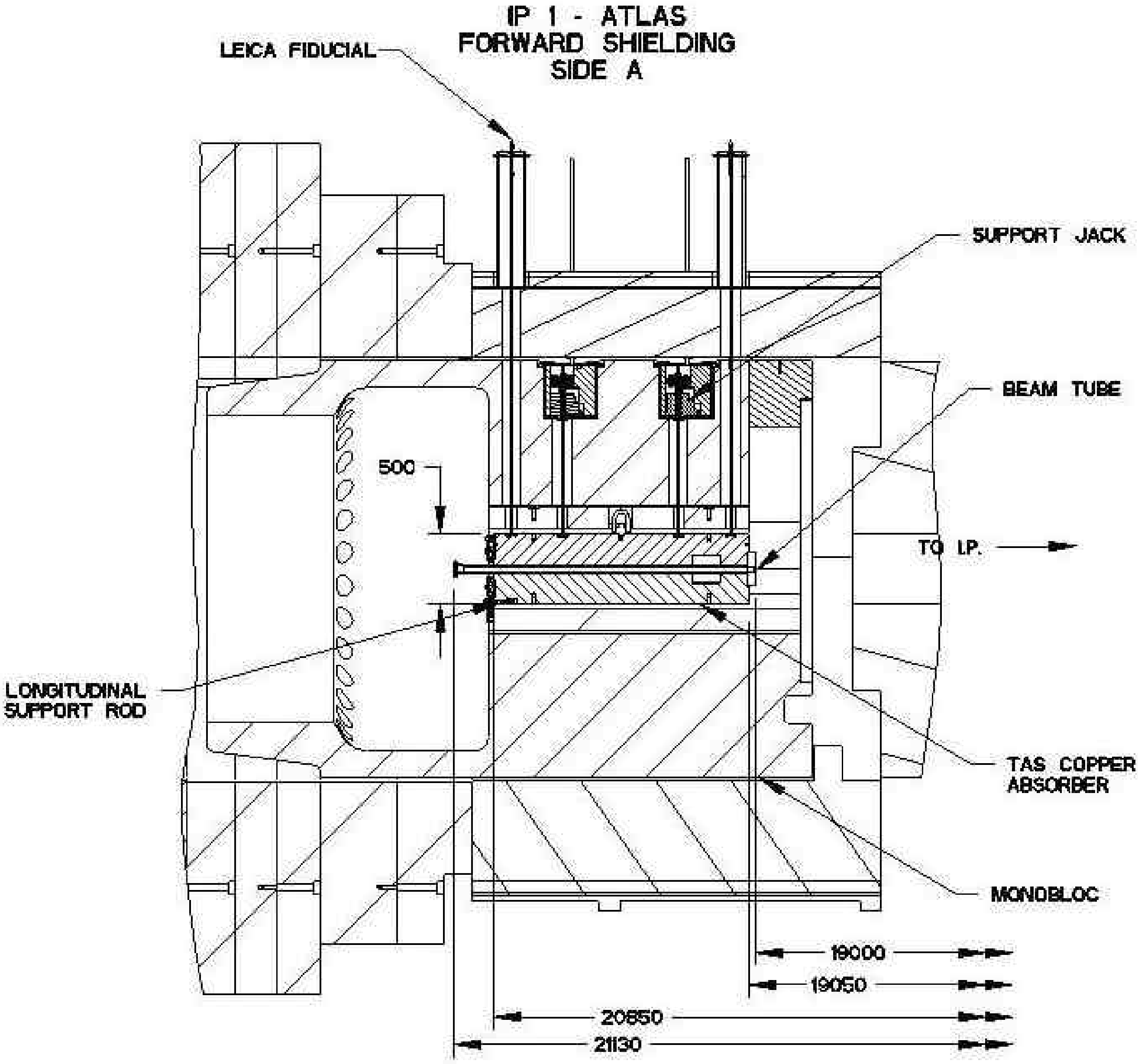

Figure 1B TAS Design for ATLAS – SIDE A – Elevation View

(View is from the inside of the ring looking out)

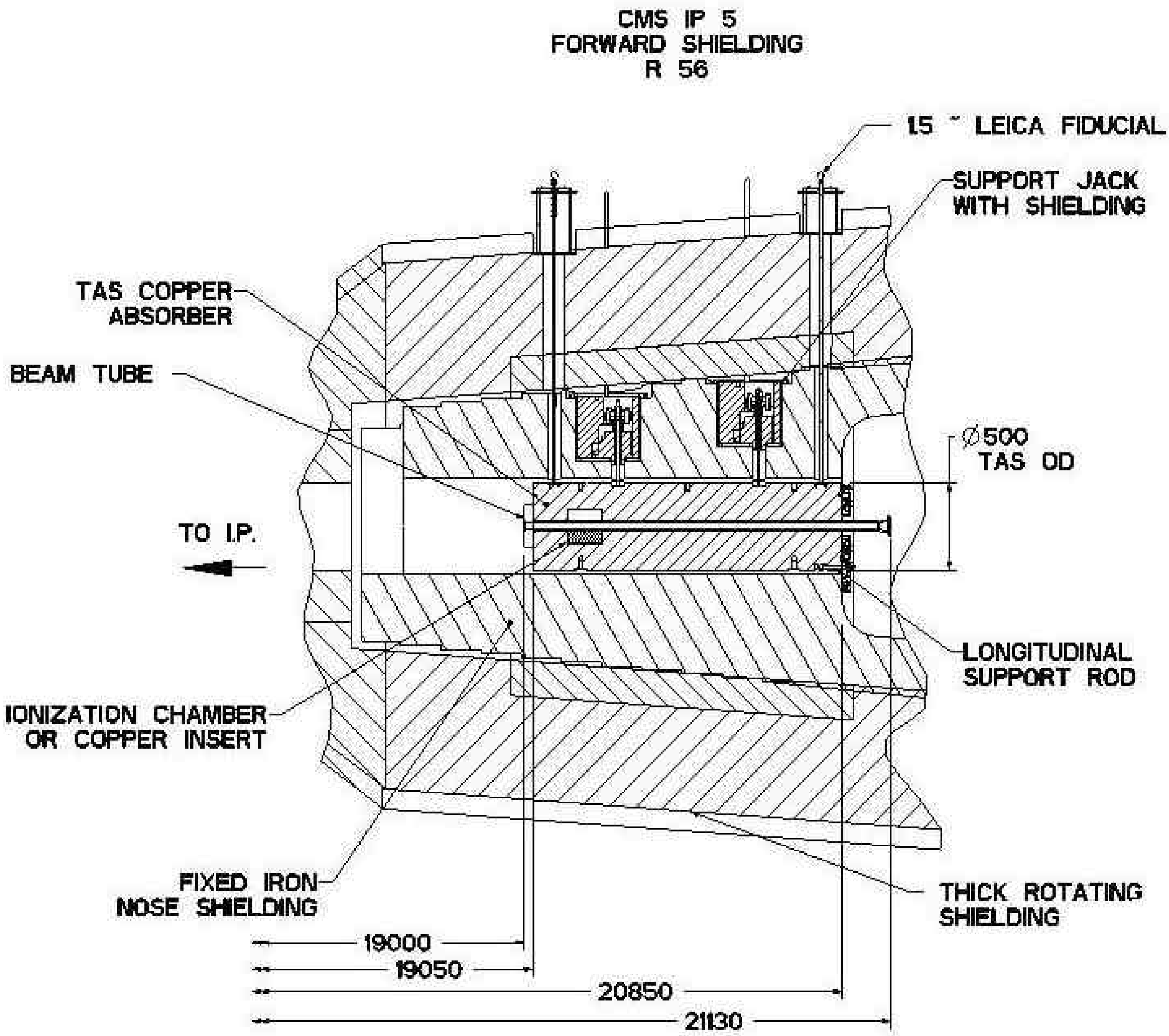

Figure 2A. TAS Design for CMS – R56 – Elevation View

(View is from the inside of the ring looking out)

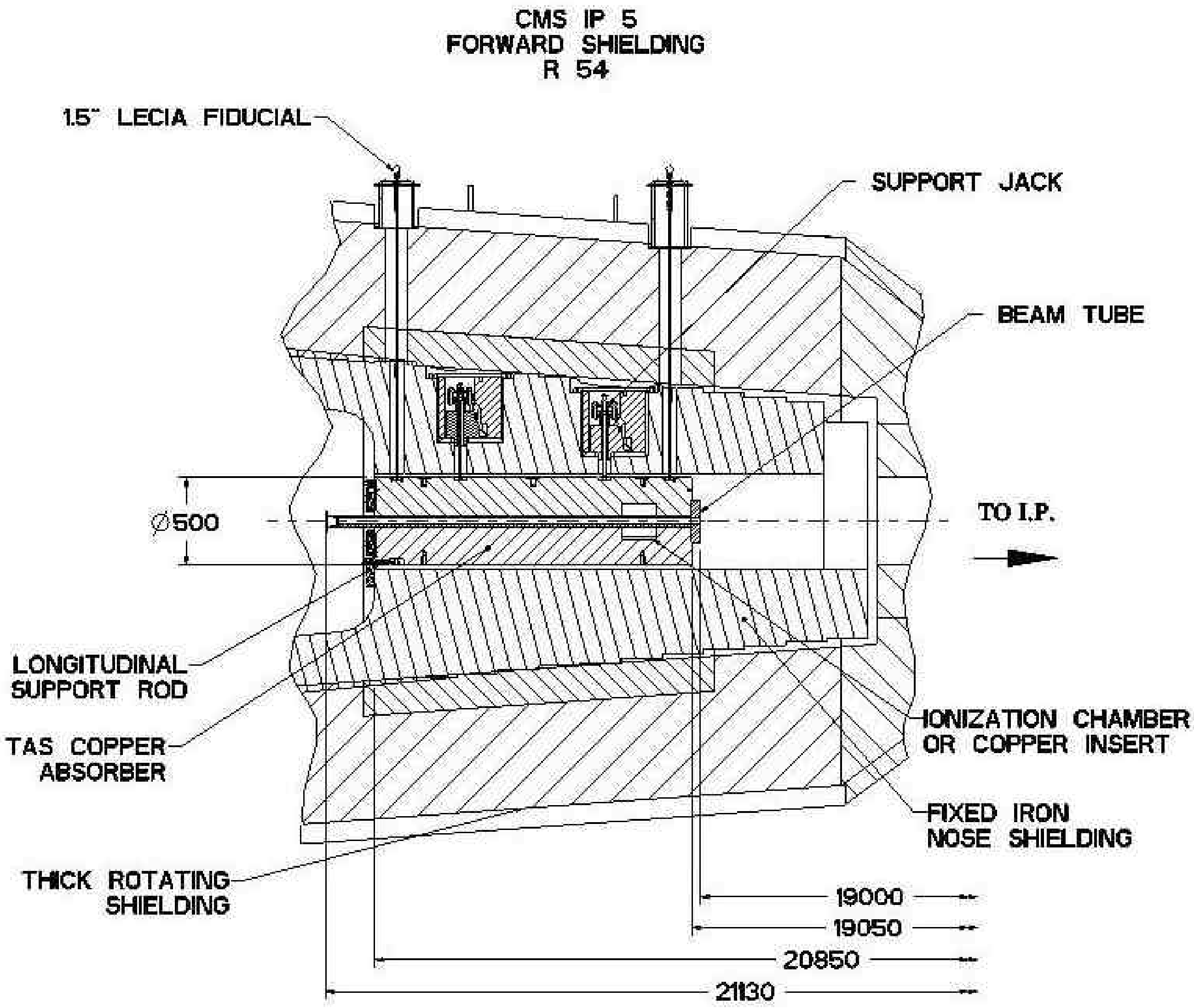

Figure 2B Design for CMS – R54 – Elevation View

(View is from the inside of the ring looking out)

The TAS is located just in front of the first inner triplet superconducting quadrupole Q1. There are two TAS each at IP1 and IP5. At design luminosity $10^{34}cm^{-2}s^{-1}$, each TAS absorbs approximately 220 W. As described in the Yellow Book [1] the luminosity averaged over a fill and storage cycle is reduced to about sixty per cent of its peak value or $0.6x10^{34}cm^{-2}s^{-1}$. The power absorbed by a TAS is likewise reduced from 220 W to 130 W when averaged over a fill and store cycle. For calculations of total absorbed radiation dose and temperature rise of the TAS and surrounding shielding it is important to allow for this averaging. At design luminosity $10^{34}cm^{-2}s^{-1}$ the TAS, in combination with the TAS A and TAS B absorbers internal to the Q1-Q3 cryostat, must attenuate power due to collision fragments so that the total power density transmitted to the conductor of the inner triplet superconducting quadrupoles is less than 0.4 W/kg to protect them from quenching. The TAS A and TAS B absorbers internal to the Q1-Q3 cryostat are necessary to achieve < 0.4 W/kg absorbed power in the conductor of Q1-Q3 due to power passing through the back beam tube aperture of the front quadrupole TAS and incident on the beam tube wall of Q1-Q3. The TAS A and TAS B absorbers will be described in a separate Functional Specification and are not part of this specification. The radiation deposition calculations being performed for the TAS and the internal absorbers are done self consistently to assure the total power density transmitted to Q1-Q3 is < 0.4 W/kg.

The total weight of the TAS is expected to be approximately 3.2 Tonnes and it will be installed as a single unit inside the forward iron shielding that protects the experiments ATLAS and CMS from particles leaving the TAS due to backscattering or activation.

The beam tube of the TAS is an ultra high vacuum component and will be OFHC copper. The TAS will be designed with all metal seals and provision for in-situ vacuum bakeout to 200 C. Strip heaters and internal thermocouples will be provided for the bakeout. The transitions of the TAS beam tube to the external beam tubes on the Q1 end will be designed to minimize the impedance subject to aperture and space constraints. The inside diameters of the TAS beam tubes will be designed to match smoothly to the adjacent beam tubes provided by CERN. The front flanges of the TAS will become too activated for normal access and will be designed for rapid remote assembly and disassembly.

Measurement of the power absorbed by the TAS can be used for accelerator operations and monitoring machine parameters - luminosity, beam-beam separation, beam size beam-beam crossing angle and transverse position of the IP[7]. Slots will be provided at one axial location in the TAS for instrumentation that measures the power deposition near the shower maximum. The instrumentation will surround the beam tube and be segmented into quadrants. This and similar instrumentation for the TAN will be described in a separate Functional Specification.

2. TECHNICAL REQUIREMENTS AND DESIGN PARAMETERS

2.1 DISCUSSION

The technical requirements and design parameters for the front quadrupole absorbers (TAS) are tabulated in Section 2.2. The TAS technical requirements include functional, lattice, tunnel, vacuum, alignment, radiation and electrical requirements. The TAS design parameters are separated into vacuum and absorber parameters. The remainder of this section discusses the background behind several of the requirements and parameter values.

The maximum radiation power that can be deposited in an LHC magnet without quenching it is normally taken to be 1.2 W/kg [8]. The TAS together with the internal IR quadrupole absorbers TAS A and TAS B are specified to transmit a maximum 0.4 W/kg to the conductor of Q1-Q3 at design luminosity $10^{34}cm^{-2}s^{-1}$. Even at ultimate luminosity $2.5x10^{34}cm^{-2}s^{-1}$ the conductor power density would be less than the maximum allowed value 1.2 W/kg.

The geometrical acceptance requirement for the TAS expressed in terms of primary radial aperture and normalized to the rms beam size according to the prescription of Jeanneret and Risselada is n_1 > 7 with allowances for mechanical tolerances, alignment and closed orbit error [9] [10]. This is the same as the global requirement for all apertures in the machine with the exception of the primary and secondary apertures of the beam cleaning collimators. Specific beam orbit calculations are carried out in order to check the consistency of this requirement with the specifications of beam tube aperture and mechanical tolerances. These calculations are done by CERN within the Apertures Working Group. The aperture calculations for LHC optics version 6.1 are reported in reference [11]. (Conditions with respect to the TAS are identical in version 6.1 and the current version 6.4.) Figures. 8 and 11 in ref. [11] show that the 34 mm ID TAS satisfies the n_1 > 7 requirement in collision and injection optics. The tolerances that were assumed for this calculation that are relevant to this specification are a radial mechanical tolerance of 0.2 mm and an alignment tolerance of the center of the TAS beam tube of 0.5 mm. The worst case is the right side of an IP in collision optics for which n_1 = 7.5 for the TAS, so there is a margin of 0.5 σ in radial aperture. For v6.1 collision optics the rms beam size at the TAS is σ = 0.6 mm, so the radial aperture margin in physical units is 0.3 mm. In this specification the radial mechanical tolerance of the deliverable item is specified as 0.5 mm (a stackup of tolerances for tube radius, out of roundness, and straightness [25]). At the time of submission of this specification, the CERN alignment group is stating that the center of the TAS beam tube will be surveyed relative to the alignment fiducial system with a tolerance of 0.9 mm. [12] Taken in sum then the radial mechanical tolerance plus the alignment tolerance is 1.4 mm compared to 0.7 mm for the calculations in ref. [11]. Under these assumptions n_1 = 6.3 in the worst case, falling slightly below the goal of n_1 > 7; in physical units the radial aperture of the TAS is 0.4 mm inside the allowable radius. By the time the LHC is approaching design it may be possible to reduce the 4 mm allowance for closed orbit errors in the interaction regions to achieve n_1 > 7.

Because the small radius of the TAS beam tube limits the conductance to the pumping stations at both ends of the TAS, there is a question about susceptibility of the TAS beam tube vacuum to the ion desorption instability. This problem has been analyzed and there is a rather large safety margin for stability (> 10) even at the ultimate current of 0.85 A per beam[13]. The estimated stability assumes that a procedure of preconditioning with Argon glow discharge cleaning followed by in situ baking of the beam tube [14] or of coating with the recently developed low activation temperature NEG films [15] is followed. Preconditioning by Argon glow discharge cleaning or coating with NEG film will be done by CERN before installation.

2.2 TAS TECHNICAL REQUIREMENTS

2.2.1 FUNCTIONAL REQUIREMENTS($10^{34}CM^{-2}SEC^{-1}$)

Absorbed collision power at $L=10^{34}cm^{-2}sec^{-1}$	220 W
Absorbed collision power averaged over a fill and store cycle	130 W
Maximum beam power transmitted to IR quad coils in combination with the internal IR quad absorbers at $L=10^{34}cm^{-2}sec^{-1}$	<0.4 W/kg

2.2.2 LATTICE REQUIREMENTS

Geometrical acceptance (n_1)	> 7
Beam tube inner radius (19.05<|s|<20.85 m)	17.0 mm
Maximum beam tube half angle	10 degrees
Absorber (TAS) length	1800 mm
Distance from the IP to the TAS front surface	19 050 mm

2.2.3 TUNNEL/CAVERN REQUIREMENTS

TAS locations [16]	In the fixed shielding assemblies at the ends of the ATLAS/CMS caverns just in front of Q1
Cavern shielding layouts	Shown on CERN drawings: ATLJ____00012B for IP1 (ATLAS) LHCTX5S_0014, LHCTX5S_0015, LHCTX5S_0017 – LHCTX5S_0020 for IP5 (CMS)
Nominal beam height from tunnel floor @ Q1	1100 mm at IP1 950 mm at IP5
Nominal longitudinal tunnel/cavern slope	+1.236 % at IP1 -1.236 % at IP5
Nominal transverse tunnel/cavern slope	0 % at IP1 0 % at IP5
TAS horizontal earthquake loading [17]	0.15 g
TAS vertical earthquake loading	0.11 g
TAS support and adjustment	4 radial adjustable rods, 2 horizontal and 2 vertical, in a flexure arrangement, 1 axial initially-adjustable rod. Adjustments provided by jacking systems, manual but upgradable to remote operation
Crane limit at TAS locations in caverns [18]	65 T to 18.4 m from IP1 10 T to 21.7 m from IP1 20 T to 21.1 m from IP5 5 T to 23.6 m from IP5

2.2.4 VACUUM REQUIREMENTS

Beam tube material	Oxygen free high purity copper (OFHC)
Copper alloy options for the beam tube (Copper Dev. Assoc. Alloy numbers) [19]	C10100 through C10800
TAS flange to flange length (ATLAS) [20]	2130 mm
TAS flange to flange length (CMS) [20]	2130 mm
Flange types [20,21]	Q1: CERN Rotatable ConFlat– 114 mm OD IP: Custom Stainless Telemanipulator Flange- 240 mm OD
Flange modifications [20,21,22]	OFHC ring explosion bonded into 316LN flange to attach copper beam tube
Copper surface preparation [23]	LBNL Engr. Spec. M735
Stainless steel surface preparation [24]	LBNL Engr. Note M7024
Fabrication methods (attaching beam tubes to one another or a beam tube to a flange)	Electron beam welding
Vacuum qualification leak rate	7.5×10^{-11} Torr-l/sec in a 100 % helium atmosphere for 2 minutes
Vacuum qualification base pressure	5×10^{-10} Torr
CERN vacuum processing	Glow discharge cleaning or NEG Getter coating at CERN
Maximum beam tube operating temperature ($2.5 \times 10^{34} cm^{-2} s^{-1}$)	75C
In-situ beam tube bakeout temperature	200C
Minimum time to reach bakeout temperature	24 hrs
Bakeout heater and thermocouple redundancy	Factor of 2

2.2.5 VACUUM CHAMBER PARAMETERS

The tolerances given below are 3 sigma values.

Beam tube straight sections facing IP	
Inner radius	17.0 mm IR
Mechanical tolerance (radius)[25]	+/- 0.5 mm
Beam tube in the absorber section	
Inner radius	17.0 mm IR
Mechanical tolerance (radius)	+/- 0.5 mm
Beam tube tapered section away from the IP	
Inner radius	17.0 to 63.0 mm IR
Half Angle	10°
Mechanical tolerance (radius)	+/- 0.5 mm

Distance from the front surface of the TAS absorber to the IP flange face	50 mm (ATLAS) 50 mm (CMS)
Distance from the rear surface of the TAS absorber to the Q1 flange face	280 mm

2.2.6 ABSORBER DESIGN PARAMETERS

Absorber material	ETP Copper(C11000)
Number of detector slots	2
Absorber radius	250 mm
Total weight (1 assembly)	3 tonne
Absorber construction	Bolted assembly
Supports range of motion	+/- 30 mm horiz. and vert. at installation (ATLAS). +/- 20 mm horiz. and vert. at installation (CMS). +/- 10 mm with stops when operational.
Absorber cooling	Ambient cooling for design luminosity, water cooling for ultimate luminosity

2.2.7 ALIGNMENT REQUIREMENTS

Alignment concept	TAS alignment referenced to the stretched wire alignment system [12]– fiducials to provide vert., horiz., pitch and yaw information
Number of fiducials	4
Fiducial type [26]	38.1 mm dia. spheres with holder mounted on a two piece Invar rod that penetrates the shielding and contacts the TAS
Fiducial locations	Two each penetrate the shielding horizontally and vertically, contacting the ends of the TAS

2.2.8 RADIATION REQUIREMENTS

Radiation environment guidelines at CERN [27]

Condition	Exposure limit
No access	$\geq$ 20 mSv/hr
Emergency access	1-2 mSv/hr
Maximum per person per job	< 1 mSv
Ok to walk past	<0.2 mSv/hr
Ok to stand in the region	<0.1 mSv/hr
No concern	<0.01-0.02 mSv/hr

Assembly	Minimize the number of components and assembly procedures

2.2.9 ELECTRICAL REQUIREMENTS

Heater voltage rating [28]	230 volt operation.
Thermocouple type	Type E
Electrical terminations	Ceramic terminal strips in a metal enclosure

2.3 TAS CROSS SECTION

Transverse cross-sections of the ATLAS and CMS TAS designs are shown in Figure. 3 and 4; material of the surrounding inner forward shielding is cross hatched. For ATLAS, the TAS is inserted into a thick wall, steel circular cylinder and this assembly is inserted into the stationary shielding. The steel cylinder serves to reduce exposure to surface activation of the TAS when removed. Likewise for CMS, the TAS is inserted into a shielding block that is installed and removed as a unit with the TAS. The sides of the shielding block extend over the TAS to form a base for supporting the unit either on the floor when it is removed or on the mating piece of the forward shielding when it is installed. The removable shielding block also reduces exposure to surface activation of the TAS when the unit is removed. The thick wall steel cylinder and the shielding block are supplied by CERN.

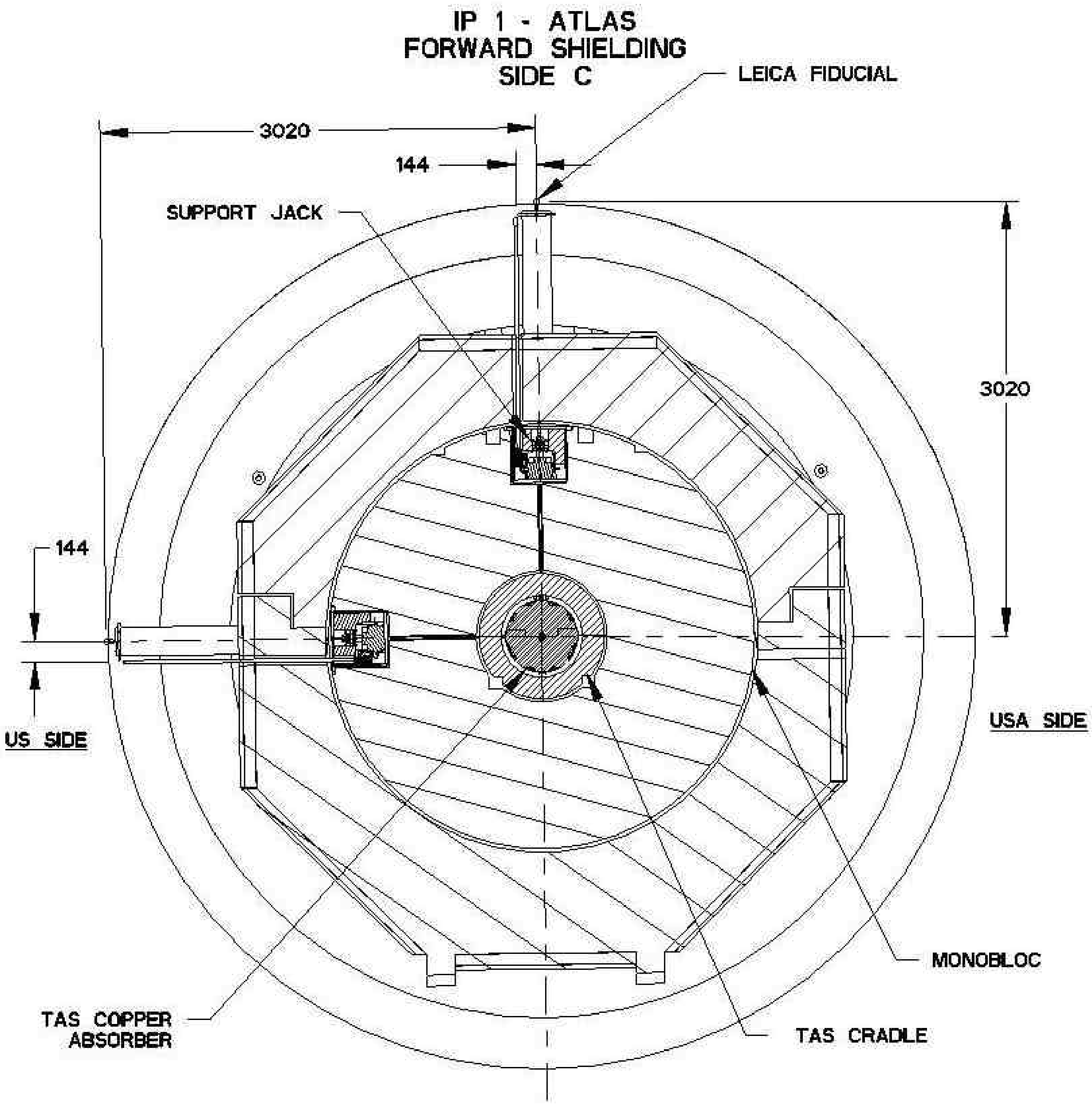

Figure 3A TAS Transverse Cross-section in ATLAS – SIDE C

(View is from the IP looking clockwise)

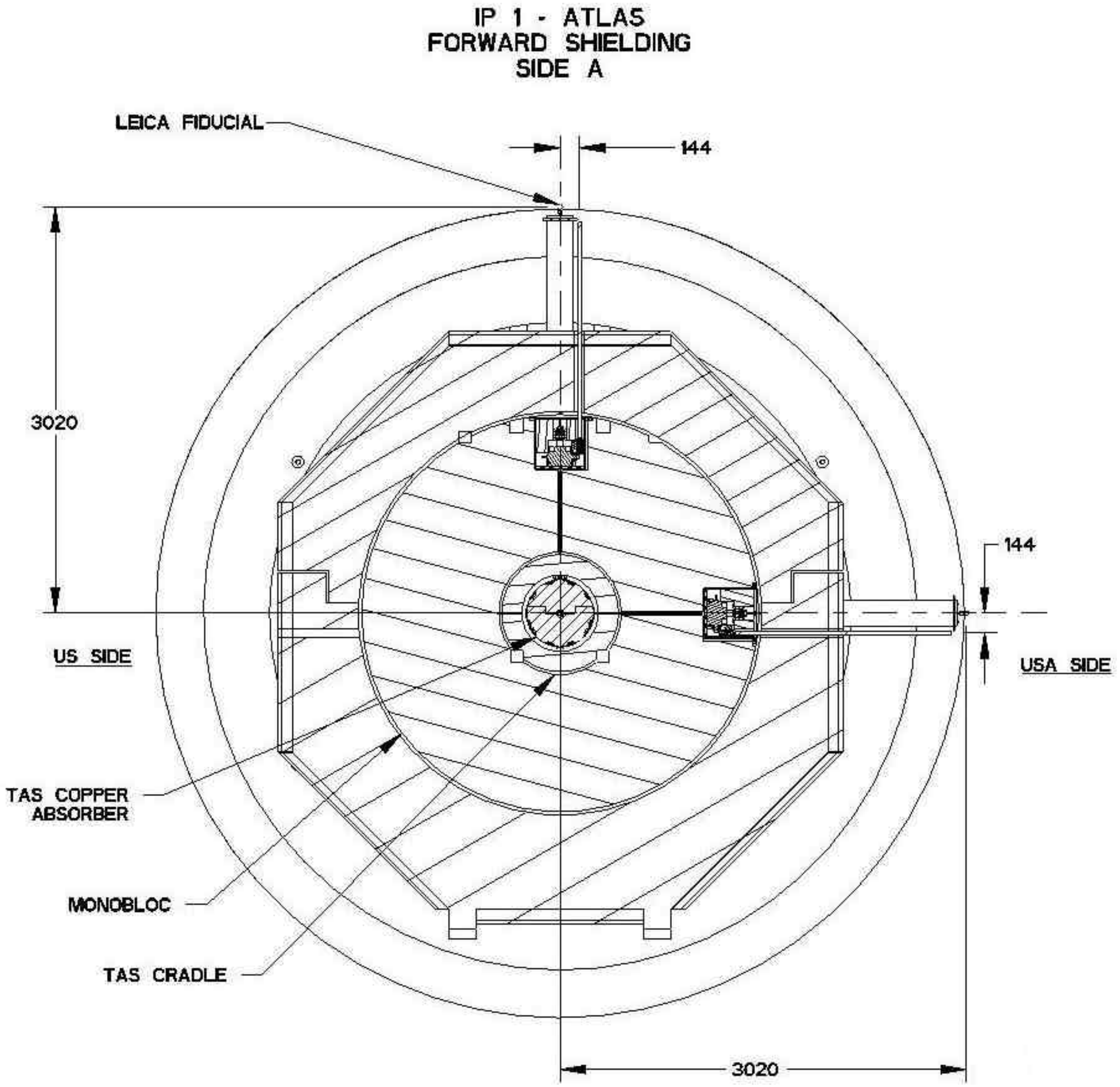

Figure 3B TAS Transverse Cross-section in ATLAS – SIDE A

(View is from the IP looking counter-clockwise)

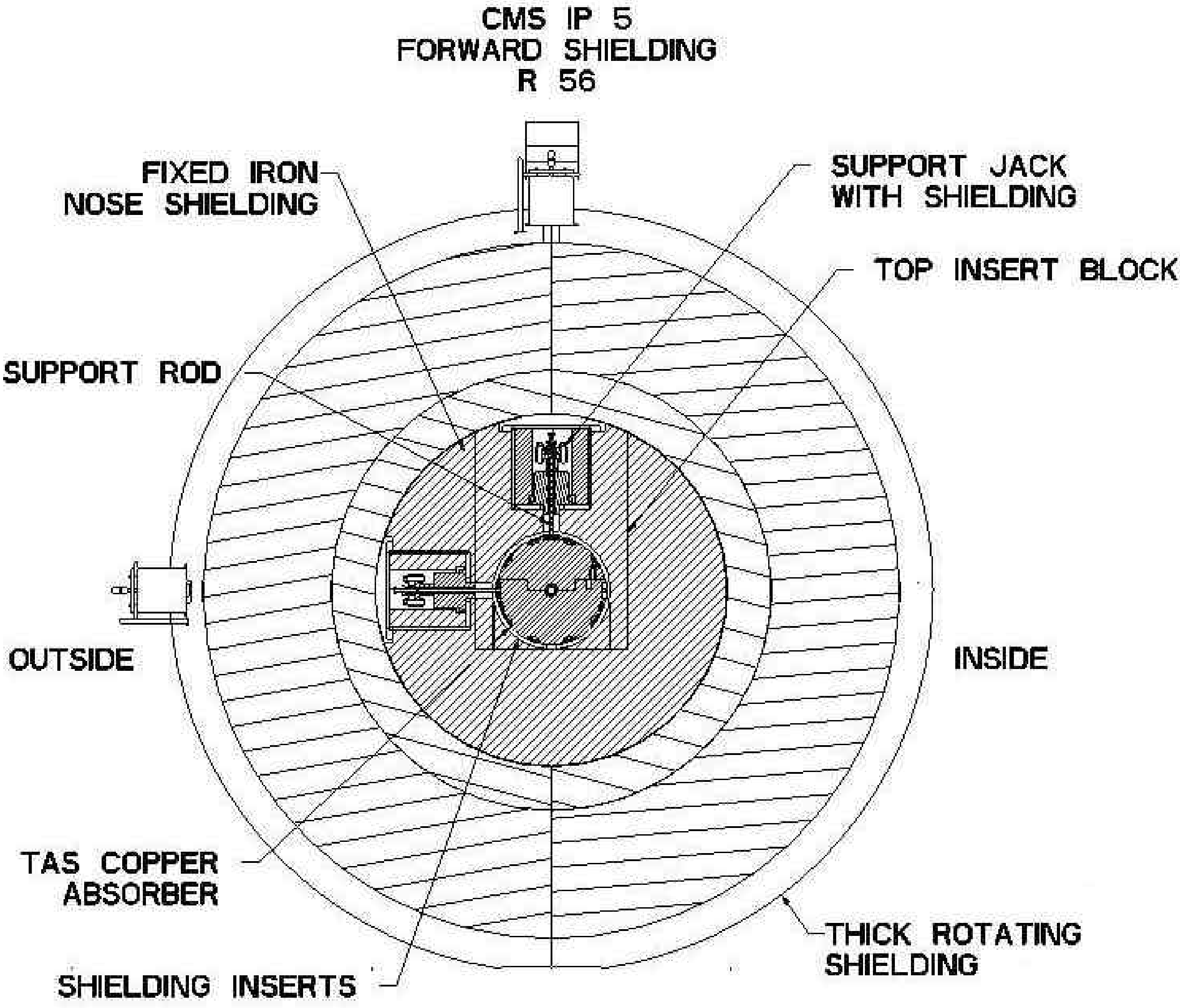

Figure 4A TAS Transverse Cross-section in the CMS – R56

(View is from the IP looking clockwise)

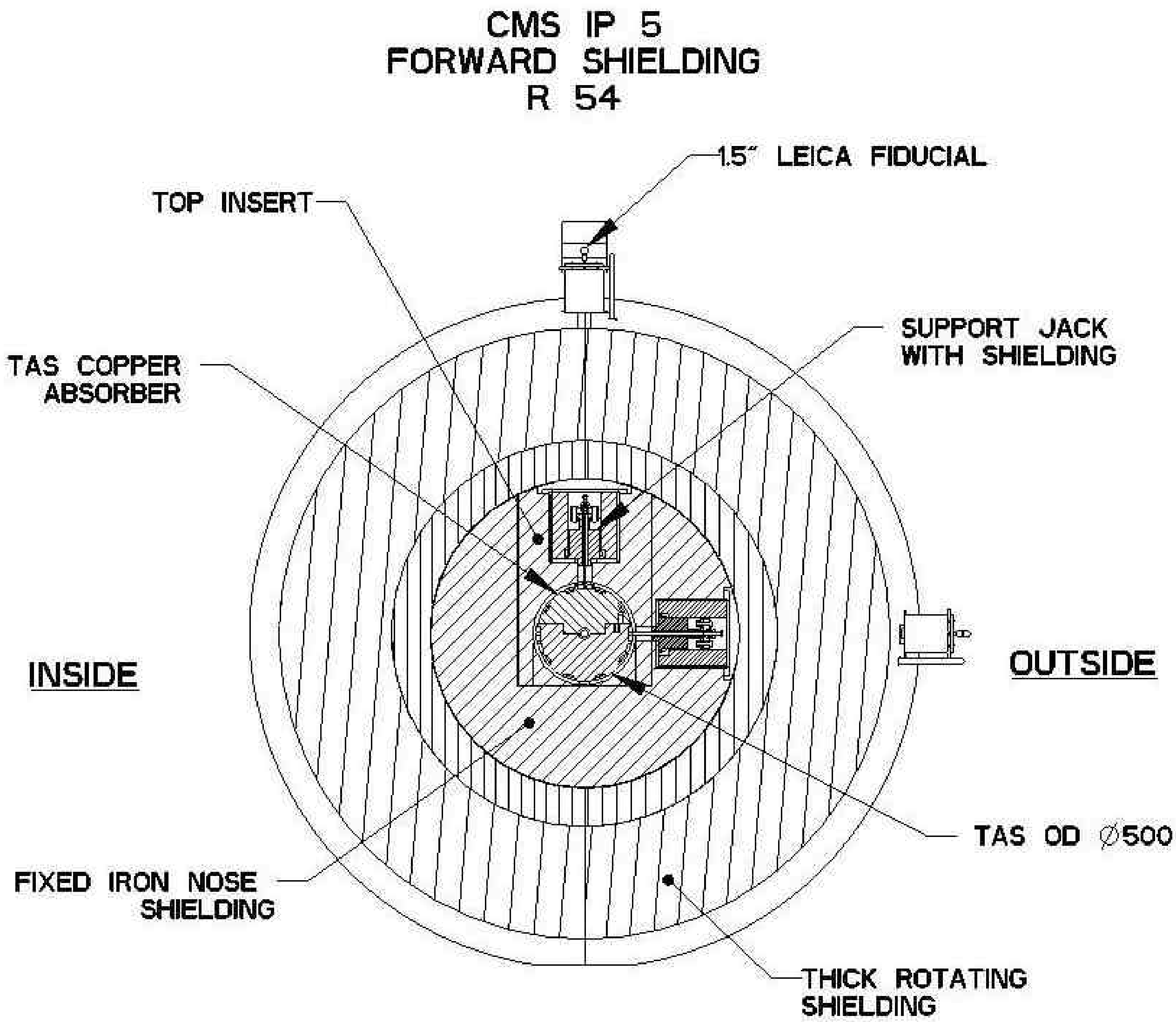

Figure. 4B TAS Transverse Cross-section in the CMS – R54

(View is from the IP looking counter-clockwise)

3. RELIABILITY, AVAILABILITY AND MAINTAINABILITY REQUIREMENTS

The TAS contains an ambient temperature beam tube that requires in situ bakeout whenever exposed to atmospheric pressure. Internal thermocouples and heating elements are provided for this purpose with a factor of two redundancy to allow for component failure. Alignment fiducials and adjustable supports are provided for periodically checking and correcting alignment of the beam tube apertures.

The TAS will be designed to be water cooled with a maximum internal beam tube temperature of 75C at ultimate luminosity 2.5×10^{34} $cm^{-2}s^{-1}$. The thermocouples provided for in situ vacuum bakeout will be used for monitoring the maximum internal temperature of the TAS.

When the TAS is removed or taken apart after it has been activated, special handling procedures will need to be followed to avoid exposing the workers to excessive radiation. The pieces of the TAS will be designed for assembly with a minimum number of procedures.

There are several explosion bonded or e-beam weld joints in the TAS beam. If these joints fail it would be necessary to disassemble the TAS and replace the beam tube. To minimize the possibility of failure the joints will be inspected with x-ray radiography prior to assembly of the TAS.

4. SAFETY AND REGULATORY REQUIREMENTS

The TAS design must meet the safety guidelines put forward by the CERN Technical Inspection and Safety Commission (TIS). TIS has issued safety documents and the guidelines in these documents need to be incorporated into the TAS design. For the TAS, the appropriate TIS safety documents are:

4.1 D1 Safety Code for lifting equipment 1997 [29].

4.2 F Protection Against Ionizing Radiation – Radiation Safety Manual 1996 [30].

4.3 IS 41 The Use of Plastic and other Non-Metallic Materials at CERN with respect to Fire Safety and Radiation Resistance 1995 [31].

4.4 NS 16 Rules concerning the transport of radioactive material 1988 [32].

4.5 TIS-TE-MB-98-74
CERN/LHC-US/LHC MOU on Accelerator Mechanical Safety [33]

5. CALCULATIONS REQUIRED

The following calculations have been carried out during the design of the TAS:

5.1 Radiation deposition, activation and shielding calculations corresponding to the dimensions of the as designed front quadrupole TAS. The calculations must be done self consistently with calculations for the absorbers internal to the Q1-Q3 cryostat to assure that the total power absorbed by the conductor of Q1-Q3 is less than 0.4 W/kg at design luminosity 10^{34} $cm^{-2}s^{-1}$. Radiation and activation calculations have already been completed for the TAS [2]

5.2 The temperature distributions inside the TAS have been calculated based on the simulation of radiation power deposition with ambient and water cooling [34].

5.3 Thermal calculations have been carried out to determine the size of heaters needed to raise the TAS and beam tube to 200C for in-situ vacuum bake out [35].

5.4 TAS component sizes and weights have been tabulated [36].

5.5 Stress and deflection calculations have been carried out on the support system mechanical design[37].

6. REFERENCE DOCUMENTS

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Layout of Long Straight Section, IR1 Right, Cells C1.R1 to C7.R1, LHCLSX__0002;
Layout of Long Straight Section, IR5 Left, Cells C1.L5 to C7.L5, LHCLSX__0009;
Layout of Long Straight Section, IR5 Right, Cells C1.R5 to C7.R5, LHCLSX__0010.

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