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The mirror system of COMPASS RICH-1

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Abstract

The architecture and the properties of the mirror system of the COMPASS RICH-1 detector, composed by 116 spherical VUV reflecting units supported by a lightweight mechanical structure, are described.

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Keywords: COMPASS; RICH; VUV mirrors

1. Introduction

COMPASS (NA58) is a double-spectrometer, installed at CERN SPS for fixed-target experiments, to study hadron structure and spectroscopy [1]. Particle identification is based on magnetic analysis and two RICH detectors: RICH-1, already in operation, is the large acceptance partner, described in Ref. [2]. It employs a 3 m long, high purity C4F10 gaseous radiator [3], and MWPC with CsI photocathodes as VUV (165–200 nm) photon detectors. The optical system for image focalisation, described in the following sections, consists of two spherical mirror surfaces.

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2. Mirrors

The RICH-1 optical system (Fig. 1) is formed by two VUV reflecting spherical surfaces ($R = 6600$ mm, total area ~ 21 m^2) with centres vertically displaced, up and down, by 1600 mm with respect to the beam axis, so to focalise the image outside the spectrometer acceptance. The plane photon detectors are placed outside the spectrometer acceptance, above and below the beam; their surface is a raw approximation of the spherical focal surface. This arrangement results in a geometrical aberration of 0.32 mrad for images produced by particles incident at small angles and larger for particle incident at large angles. The two surfaces are a mosaic type composition of spherical mirror units: most of them are regular hexagons (side length 261 mm) and 48 are pentagons of six different size, to avoid saw-teeth patterns on the surface borders. The clearance left between adjacent mirrors results in a 4% loss of reflecting surface (Fig. 2).

At the design level, the main parameters of the mirrors were requested to be:

- radius of curvature, $R = 6600$ mm, $\pm 1\%$
- "spot diameter" D, i.e. the diameter of the smallest circle containing 95% of the power associated with the image of a point-like source, < 3.5 mm
- roughness, r.m.s. < 1.6 nm
- reflectance $r > 80\%$, for wavelengths in the interval 160–200 nm
- substrate thickness: $< 6\%$ of radiation length (minimum material is required also for the mechanical structure of the mirror wall).

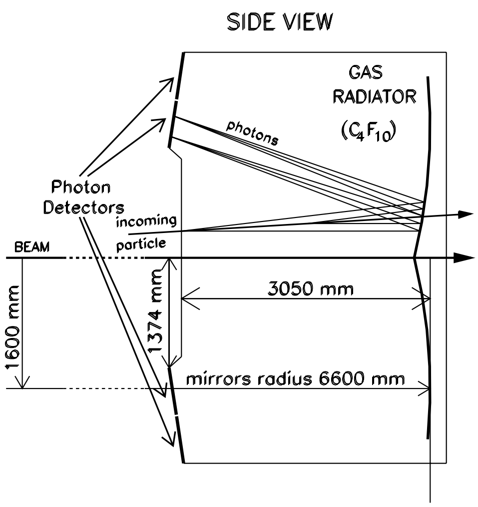

Fig. 1. Scheme of COMPASS RICH-1 geometrical arrangement.

Fig. 2. COMPASS RICH-1 mirror wall; the picture has been taken during mirror alignment procedure inside the RICH vessel.

The mirror substrates are borosilicate glass, 7 mm thick; their stiffness is confirmed by a F.E.M. calculation [4].

The 126 (10 spare units) substrate, produced by IMMA [6], have been visually inspected and individually characterised by measuring the radius of curvature, R, and the 'spot diameter', D [5]. For the 126 substrates, the average values are: $R_{av} = 6606$ mm ± 20 mm and $D_{av} = 1.65$ mm ± 0.45 mm. The roughness of the polished surfaces has been checked on a sampling base: the measured roughness r.m.s. was in all cases <1.6 nm (average value: 1.26 nm ± 0.11 nm). The first element of the mechanical support, a stesalite disk, 46 mm diameter, is glued on an annulus of 290 mm^2, at the centre of the mirror substrates, rear face. The substrates have a 6 mm diameter hole at their centre, to allow an extra fixation, by a nylon screw, to the stesalite disk.

To obtain a good reflectance in the VUV region the reflecting layer (Al, about 80 nm) and the protective layer (MgF_2, about 30 nm) have to be deposited with a carefully tuned and controlled procedure. Some crucial requirements are: very good vacuum (10^{-7} mbar), high deposition rate (2–4 nm/s) and rapid rotation of the mirror. For the procedure tuning, feedback to the manufacturer [7] was provided by making use of the CERN reflectometer facility [8], later used to measure the reflectance of each mirror at the centre and at the edge. The coated mirrors must be carefully protected against humidity at all time.

The measured reflectance is good (Fig. 3) (only four mirrors had to be re-coated) and the mean value of the reflectance for wavelengths in the useful interval (160–200 nm) is always in the range 83–87%. Repeated measurements of the reflectance after 1 and 2 years permanence in RICH vessel indicate, after the expected short term degradation, stable reflectance values above 165 nm (Fig. 3).

The hexagons were divided into two sets, according to their R values (> or <6607 mm). For each surface, the best mirrors (R nearest to the nominal value) were used to fill the central region, around the beam, and going farther, sequences of mirrors minimising R-variation were chosen. In the case of pentagonal mirrors, the alternatives were limited by their different sizes.

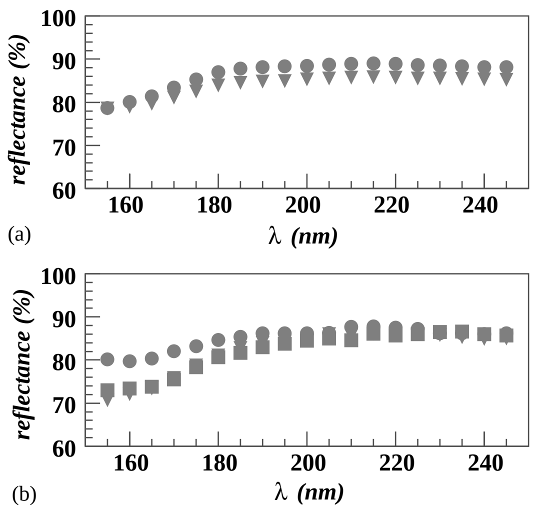

Fig. 3. (a) Mean value of the reflectance measured for the 126 mirror units at the centre (dots) and at the edge (triangles). (b) Reflectance of one mirror unit immediately after production (dots), after one year (squares) and after two years (triangles) permanence in RICH vessel.

3. The mechanics of the mirror wall

For the mechanical supporting structure of the mirror wall, we have chosen a net-like configuration in which the nodal points, where the mirrors are suspended to, lay on a sphere with a very high mechanical precision; as a consequence, only angular adjustment of the mirror units is needed (radial adjustment is suppressed to reduce the amount of support material).

The (thermally controlled) aluminium structure (Fig. 4) is formed by:

- a rectangular (6.05×4.85 m^2) stiff outer frame, which lies outside the acceptance of the spectrometer (stiffness checked with F.E.M. calculation) screwed on the rear flange of the radiator gas vessel

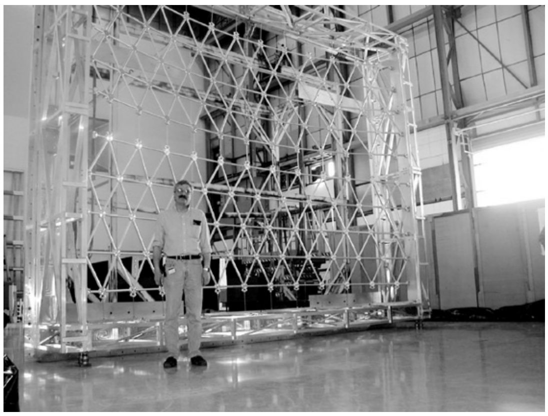

Fig. 4. The mechanical structure of the mirror wall.

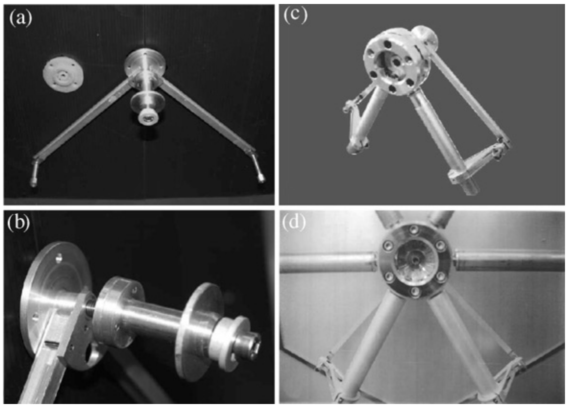

Fig. 5. (a) and (b) A mirror joint; (c) the mirror joint mounted on a prototype portion of the mirror supporting structure; (d) a mirror (rear face) mounted on the supporting structure.

- a double-spherical structure of high mechanical precision, with connection points to which the mirrors will be anchored (Figs. 4, 5)
- the joints, i.e., mechanisms connecting the mirrors to the above mentioned structure and allowing for mirror alignment, rotating around two orthogonal axes (Fig. 5); they permit angular adjustments via converting the translational push (or pull) of a micrometric screw (pitch 0.5 mm) against one end of a rigid bar (200 mm long) into a rotation at the other end of the bar constrained to a pivot anchor; the angular resolution is 2.5 mrad/turn with very good linearity, practically no hysteresis and a negligible (0.01 mrad) cross-talk. Their unit weight is 112 g.

For the assembling of the spherical surfaces a dedicated mould was manufactured using a five-axis miller. After assembling, the mirror-wall support has been carefully surveyed and found to be fully satisfactory: the centres of the front faces of the 'nodes' actually lie, within ± 1 mm, at the designed positions on two spherical surfaces. The equivalent thickness of the mirror supporting wall, including the joints, is 2.5% of a radiation length.

4. Mirror mounting and alignment

Mirror mounting and alignment took place within the RICH vessel; during operations the air was continuously filtered and dried (humidity between 10% and 30% was measured, varying with the presence/absence of operators inside). First, each mirror was equipped with its joint and then mounted at its own place on the mirror-wall. After mounting all the mirrors onto the supporting wall, they were aligned. As the loci of the centres of the spherical surfaces are outside the vessel volume, the following alignment procedure was adopted: the coordinates of the two sphere centres are known in the vessel reference frame, the coordinates, respect to the same reference frame, of a theodolite are measured and its axis oriented along the straight line joining the centres of the sphere and of the theodolite (reference line). If the mirror which is just in front of the theodolite is perfectly aligned, the normal to the mirror surface, at the intersection point with the reference line, will also lie along this line. If it is not aligned, the normal and the reference line will be at an angle, and the image from the mirror of a reticle will be seen displaced: the mirror is rotated to make them coincide. At the end, the residual misalignment angle of the mirror is measured and accepted if it is less than 0.1 mrad, the precision with which is defined the 'reference line'. To allow the positioning of the theodolite in front of every mirror, special scaffoldings, minimising vibrations, have been built inside the vessel and removed at the end of the alignment exercise.

5. Conclusions

Two spherical VUV reflecting surfaces of total area $> 21\ m^2$ are implemented in the COMPASS RICH-1. In spite of the strict and somewhat conflicting requirements for mirrors and support mechanics, the design figures have been obtained.

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