CLAS12 High Threshold Cerenkov Counter (HTCC)

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Abstract

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1. Overview

The CLAS12 spectrometer has been designed and built for the comprehensive experimental studies of matter, using primarily a high energy electron beam. Due to the experiments with which this spectrometer is involved it must be capable of detecting scattered electrons within the entirety of its acceptance range and at the highest possible efficiency with low background. The High Threshold Cerenkov Counter (HTCC) in CLAS12 exists to fulfill such goal—to detect scattered electrons in conjunction with the other systems and to generate a fast trigger signal. The distinguishing features of the detector were influenced by its location in front of the drift chambers. Its location required that the HTCC incorporate a minimum amount of material in front of the tracking detectors and, at the same time, since the HTCC is a single module system it uses very limited space inside of CLAS12. Consequently, the construction requirements—including transportation to the hall and installation into the nominal location of the detector—were all equally important for its structural design.

2. Requirements

The core requirements that needed to be met are summarized in the Table 1.

Based on these necessary general conditions we derived the corresponding more specific and essential compulsory demands that had to be taken into consideration. As a result it was necessary to spend time on the R&D of scaled prototype mirror facets. In order to provide minimal light collection loses, i.e. maximal signal strength, the construction of an ellipsoidal multifocal mirror was chosen and this necessitated a significant upgrade of available machines for manufacturing parts. The R&D goals formulated covered both properties of mirrors and the equally important choice of construction technology. It must be mentioned that any polishing of working surfaces were excluded from consideration in the first place due to very high cost and time consuming procedures that would have been involved otherwise.

Another critical stipulation in regards to the combined mirror was the demand not to use any mirror support structure within the working acceptance of the HTCC. One of the problems that was addressed was finding a way to assemble the mirror to make it a self-supporting and light weight structure. Thus, in this case, the mirror design was such that it could not provide a means of individual mirror adjustment. Therefore the construction and assembly procedures had to be precise enough to guarantee the geometrical specifications of the multifocal mirror. The multifocal mirror can then be adjusted only as a whole unit. Since the assembly of the detector directly in the experimental hall was impossible for several reasons and the HTCC being a single unit detector (covering all 6 sectors of CLAS12) should have been by definition thought of having large size and at the same time be very fragile, than space available for assembly, its corresponding infrastructure and following final transportation to the hall also been regulated beforehand to avoid possible crucial difficulties. Environmental concerns—such as what gases would be in use, the inside/outside temperature of the detector, the humidity of the air, as well as quality of pavement along transportation routes—have also been addressed. Additional requirements with regards to detector maintenance and year-round controls were applied to the HTCC by using the experience acquired with the Low Threshold Cerenkov Counter built for CLAS6.

3. Design

htcc design description

Table 1: Core Requirements

PARAMETER	DESIGN VALUE
Working Gas	CO_2@1 atm, 25°C
Angular Coverage	$\vartheta = 5° - 35°$; $\varphi = 0° - 360°$
Threshold	15 MeV/c (electrons)
Threshold	4.9 GeV/c (charged pions)
Rejection of charged pions	0.5×10^3 (~ 99% electron detection efficiency)
Overall Dimensions	≥ 15 ft and L = 6 ft along beam direction
Mirror Type	Combined, self-supporting
Mirror Substrate Structure	Composite
Mirror Thickness	200 mg/cm^2
Number of Channels	$(12 \times 4) = 48$
Photomultiplier Tubes	Photocathode of ~5 inch in diameter
Number of Reflections	1 (in most cases)
Environment	Magnetic Field of 35 Gauss (along PMT axis)

4. Hardware Components and Constructions

The multifocal ellipsoidal mirror is the most critical component of the detector. For the purpose of addressing all the key requirements and to find possible solutions a special comprehensive R&D was conducted. This R&D was to test and verify the entire possible technological chain of building mirror prototypes on a 1:2 scale. All core parameters of the detector have been checked and/or derived from results of MC simulations.

One of the requirements was to have no mirror support structure so as to not introduce additional material within the working acceptance, i.e. in front of the drift chambers. The lack of a mirror support structure was an absolutely necessary requirement, and the the only design solution to satisfy this requirement was to glue mirror facets all together along their edges and to build a self-supporting combined multifocal mirror.

This method led to several problems. One of them was to define contact surfaces of adjacent mirror facets that would allow for final assembly without any shape adjustments. The analytical solutions of system of two second order equations that describe two intersecting ellipsoidal surfaces lead to an equation of the fourth order in general form. The solutions for any two intersecting ellipsoidal mirrors of different parameters have been used directly in the design. This includes the fact that the line along which two ellipsoidal surfaces intersect is "a flat line of second order", i.e. the line entirely belongs to one particularly well defined plane. This plane coincides with edge of each of two adjacent facets that had to be glued together.

A R&D goal was to test this core idea above by building several mirror facets of required shape and size at high manufacturing accuracy. These were then glued together to form a 75% portion of one half-sector. It was unavoidable that one had to find solutions for the appropriate high accuracy tooling, mechanical processing equipment, establishing the assembly procedure and testing the entire chain of construction and final testing. Usually the manufacturing of mirrors of relatively large size, e.g. 8 to 9 feet in diameter, is too labor intensive and time consuming due to polishing process. This process also makes the manufacturing of large mirrors very expensive.

Another of the R&D goals was to exclude any polishing. It seemed to be possible because the constructed mirror facets were designed to just to work as efficient light collectors and not to get sharp images. Thus we have been looking only for radical solutions of completely avoiding any polishing. The plan was to build 12 identical half-sectors of the combined mirror, which would consist of 48 ellipsoidal mirror facets. It was absolutely necessary to have high manufacturing accuracy because, once assembled, the facets of the combined mirror cannot be adjusted at all. Since most of the mirror facets had 4 contact surfaces to be glued this would then necessitate the development of the facet trimming technology by "one shot" to exclude or, at least, minimize the errors introduced while resetting the facets or while cutting the four edges under combined angles.

It has been estimated that any deviation in designed dimensions of more than ~0.005" would make the assembly of so many mirror substrates together impossible because any post manufacturing adjustment of any of these mirror substrates was simply not an option. The facets in no way could be overlapping nor leave significant gaps. The gaps could be as thick as the thickness of a regular glue joint obtained by simple contact pressure. Otherwise these gaps would reduce working acceptance and lead to additional inefficiency that is hard to control or fix.

Additional aspects to be addressed was to choose between gluing or mechanical plug pin assembly procedures. Clearly gluing introduces deformations due to the shrinkage of any glue joint. On the other hand assembly using location pins is more complicated because this method requires a high precision processing of very lightweight and mechanically weak plastic parts to deal with. Moreover, if any joint deformation happens to be observed after the first attempt of assembly then many parts involved (including mirror facets) could not be remanufactured or used again.

All mirror facets have the same composite (sandwich) structure: Acryl Film (0.01") + Foam (0.6") + Acryl Film (0.01"). The mirror substrate was made of ROHACELL PMI (polymethacrylimide) foam. Acryl films were of optical quality and also covered with thin protection film. Thus the face of the mirror substrate did not require any processing before deposition of a reflector material. The total thickness of the mirror is 130 to 135 mg/cm^2. The films were glued to both sides of substrates to cancel deformation due to the unavoidable shrinkage effect of the epoxy glue. This completely eliminated any long term problems with the mirror shape. All critical mirror fabrication steps have been performed in the Clean Room (GRADE TBD). Thermal and mechanical processing was done either with protection films covering the face or encapsulated in the gas tight volume to prevent dust and any other unwanted depositions damaging working surface or otherwise compromising mirror reflectance.

5. Electronics

htcc electronics description

6. Signals and Readout

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7. Calibration

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8. Reconstruction

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9. Simulation

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10. Performance

htcc performance description

11. Acknowledgements

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12. Conclusion

13. References

References