A Study of the Performance of the Gas Transmission Monitor of the PHENIX Hadron Blind Detector

B.Azmoun, R.P.Pisani, S.Stoll, C.Woody

Abstract—**For the successful operation of the Hadron Blind Detector (HBD) of the PHENIX Experiment at RHIC, it is essential that the radiator gas quality be continuously monitored. This is accomplished through the use of a gas transmission monitor, which is based on a customized McPherson 234/302 VUV spectrometer. After studying the performance characteristics of the spectrometer at the completion of RHIC Run9, a number of improvements were implemented to greatly improve its performance during Run10, including the replacement of all of the system optics. Following this upgrade, the transmission monitor was successfully used to monitor the gas quality of the HBD for the most recent Au+Au run at RHIC. With the aid of the transmission monitor, the absolute integrated transmittance of the detector was used to determine an absolute measure of the HBD detector efficiency throughout the run.**

I. Introduction

THE PHENIX HBD is a proximity focused Cherenkov detector which uses CF_4 gas as a radiator to detect electron pairs in heavy ion and polarized proton collisions at RHIC. The "blindness" of the HBD refers to its ability to reject signals from incident hadrons during heavy ion collisions by exploiting the fact that electrons produce Cherenkov light while hadrons do not. Further, the HBD must have the capacity to distinguish single hits from two overlapping hits in order to successfully identify and reject signals from background electrons pairs which traverse the image plane of the detector with a very small pair opening angle.

The ability to differentiate between single and double hits is in direct proportion to the size of the incident light signal from the electrons. Thus, the success of the HBD is highly dependent upon the degree to which losses in the primary photon signal can be mitigated due to absorption by impurities within the gas. In addition, since the photocathode material of the detector (CsI) is hygroscopic, there is also motivation here to operate the detector at very low water levels. As such, a rather sophisticated gas handling system, equipped with a gas monitoring and a gas scrubbing system has been put in place to deliver very high purity gas to the detector vessels, as well as to continuously monitor and maintain the quality of the gas.

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II. Setup

The layout for the HBD gas system is shown in Fig. 1. It is made of roughly 100% stainless steel and incorporates a recirculation system in order to conserve gas and reduce cost. While very purity gas, at the level of a few ppm's is delivered to the detector vessels at a substantial flow of about 5 liters per minute, upon each cycle through the system, the gas must be purified by water and oxygen scrubbers since the detector vessels themselves introduce about 25ppms of water and 3ppms of oxygen to the return gas. As illustrated in the figure, the gas monitoring system consists of gas analyzers as well as a gas a transmission monitor on both the input and outputs of the vessels. The gas transmittance provides a direct measure of signal losses suffered within the radiator gas and also ensures that high purity gas is continuously delivered to the detector vessels.

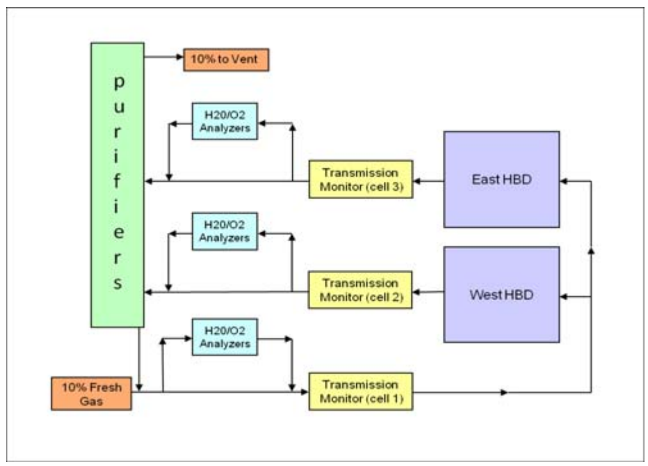


Figure 1: Schematic diagram of HBD gas system.

The transmission monitor is shown in Fig.2 and is comprised of a vacuum ultraviolet spectrometer, which sends a collimated beam of light into a vessel that houses two mirrors. One mirror "picks" off about half of the beam and sends it to a PMT that monitors the intensity of the light source. The other half of the beam intersects the surface of a mirror which steers the beam down one of three gas "cells", each of which has a PMT mounted on the end, as depicted in the illustration. This mirror is mounted on a rail system that moves to three different positions in order to send the beam through the three gas cells in succession, which then impinges one of the three PMT's. The first cell has flowing through it the gas that is delivered to the HBD vessels, and the other two have flowing through them

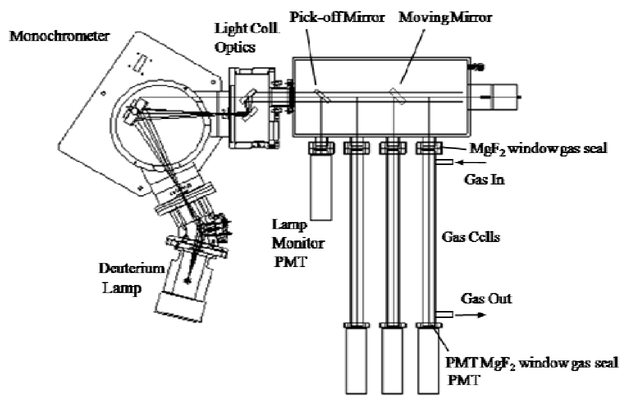


Figure 2: Schematic diagram of the PHENIX HBD Gas Transmission monitor.

the gas that is returned from either the East or West half of the detector.

The gas transmittance is defined as the residual flux intensity after partial absorption through the gas medium, divided by the initial flux intensity before absorption. Thus, since the PMT current is proportional to the incident flux intensity, by taking the ratio of the PMT current while gas is flowing through a cell and the PMT current while the cell is under vacuum, the transmittance may be calculated. Further, to correct for any changes in the light source intensity between the gas and the vacuum reference scans, the ratio of the monitor PMT currents is incorporated into the transmittance, where the following double ratio is computed:

$$T = \{I_{gas}(Cell)/I_{vac}(Cell)\}/\{I_{gas}(Mon.)/I_{vac}(Mon.)\}.$$

The resulting transmittance Vs wavelength plot may be fit to the following theoretical curve of the transmittance, based on the known photon interaction cross section values for the most prevalent gas contaminants, water and oxygen, as described in Ref [1]:

$$T = exp\{-NL(p_H\sigma_H + p_O\sigma_O)\},$$

where N is the particle density, L is the radiator length, and p and σ are the ppms and photon interaction cross sections for

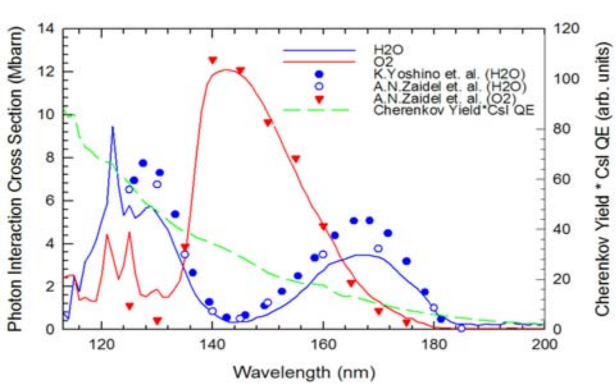


Figure 3: Measured photon interaction cross sections compared to values obtained the literature. The product of the Cherenkov yield and the CsI QE is also plotted to serve as a measure of the sensitivity of the HBD to impurities.

water and oxygen respectively. From such transmittance plots, and the measured cross sections for water and oxygen, shown in Fig. 3, the ppms of water and oxygen contaminants may be ascertained by performing the aforementioned fit, while setting the ppms of each contaminant as the free parameters of the fit. By integrating the area under this curve, an absolute measure of the gas transmission integrated over the produced Cherenkov light spectrum may be computed.

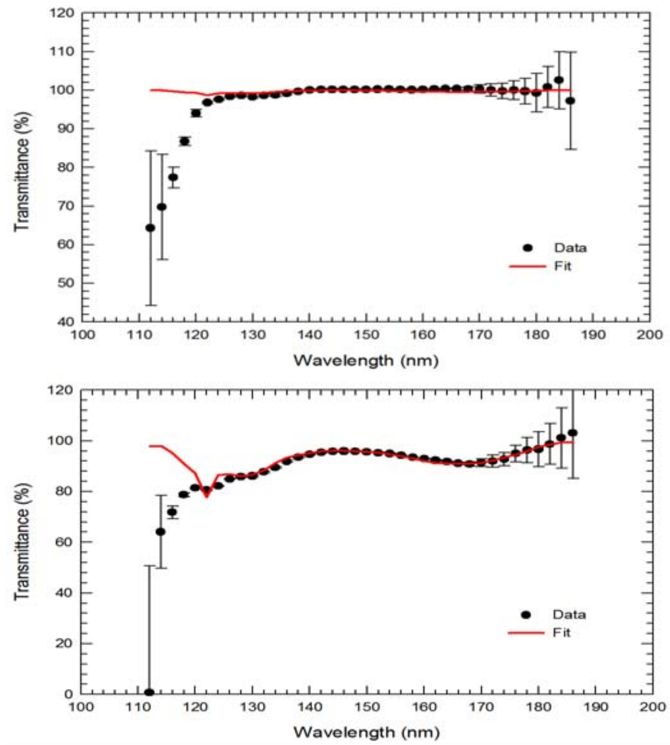


Figure 4: Typical CF_4 transmittance Vs. wavelength plot for HBD during RHIC Run10 for the input and output gas respectively. The red curve is a theoretical fit to the data (Fit region: 114-185nm).

Fig. 4 shows examples of typical transmittance curves from the most recent Au+Au run at RHIC (Run10), where there is excellent agreement between the data and the fit. Typically, the transmittance results correspond to about 2-3ppm's of water and oxygen in the input gas and about 25ppm's of water and about 3ppm's of oxygen for the return gas, as discussed above. Furthermore, the dynamic range of the instrument extends far into the deep VUV, down to 110nm, where the cutoff wavelength for CF_4 is easily visible. Most importantly, the range of the measurement exactly overlaps the wavelength range over which the HBD is sensitive, i.e., 110-190nm, thereby allowing for an absolute measure of the true integrated transmittance of the HBD gas. By utilizing the theoretical expression for the transmittance and integrating over the product of the Cherenkov yield and the CsI quantum efficiency, a relationship may derived between the level of water and oxygen impurities and the number of primary photoelectrons expected from the HBD, as shown in Fig. 5.

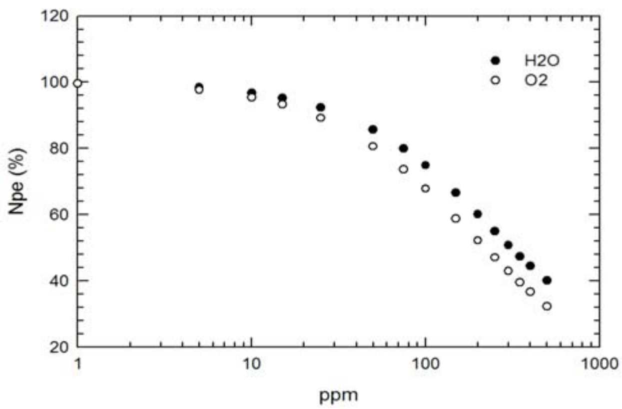


Figure 5: Relationship between the expected primary signal of the HBD and the level of impurities within the gas. In the HBD, for levels below 100ppm, roughly 1 photoelectron is lost for every 10ppm's of either impurity present within the gas.

III. Performance

The precision of the transmittance measurements obtained during Run10 was greatly improved compared to previous runs. As a comparison, Fig. 6 provides an example of a transmittance measurement performed at the end of Run9, which clearly shows the improved sensitivity of the apparatus when compared to Fig. 4. Fig. 7 shows the raw spectrum of the deuterium lamp from the end of Run9 and from Run10. From simple inspection of the raw PMT currents as a function of wavelength, it is clear that the cause for the limited range in the Run9 transmittance measurements was due to the loss of signal at the tail ends of the source spectra.

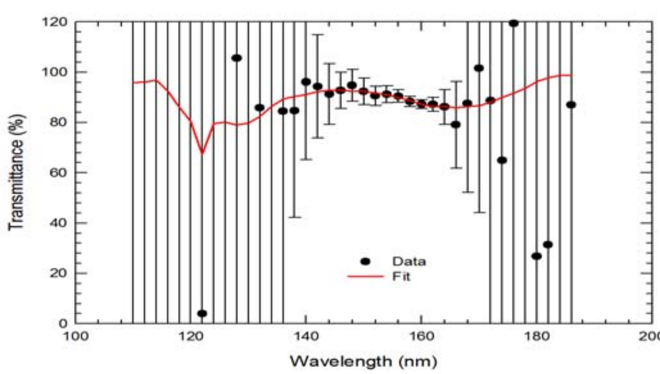


Figure 6: Transmittance plot measured at the end of Run9, before any improvements were made to the system. The useful range of the measurement has deteriorated to 145-165nm.

The cause of this loss of intensity required an intensive investigation. Aging of the lamp itself was ruled out by direct comparison with a different lamp. Upon close examination, a significant discoloration of a collimating optic near the source lamp was observed which led to a hypothesis that out-gassing components were gradually coating the surfaces of all the reflective and transmissive optics of the system.

Although replacing one or two optics within the system produced measurable changes, it wasn't until all six optics were replaced that a dramatic improvement was seen in the signal intensity at the spectrum tails, as seen in Fig.7 which compares the spectrum before and after the installation of all new optics, just as Run10 was starting. It is apparent that out-gassing of components under vacuum within the spectrometer was responsible for this contamination. As a result, high purity argon gas is now continuously purged through the spectrometer vessel in order to flush away the out-gassing material that would otherwise accumulate on the optical surfaces in vacuum.

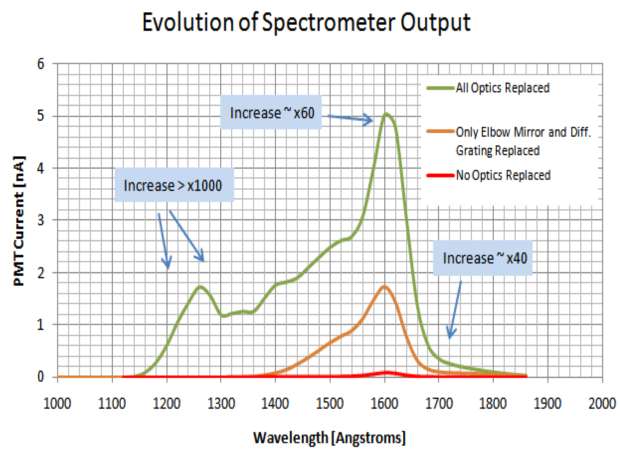
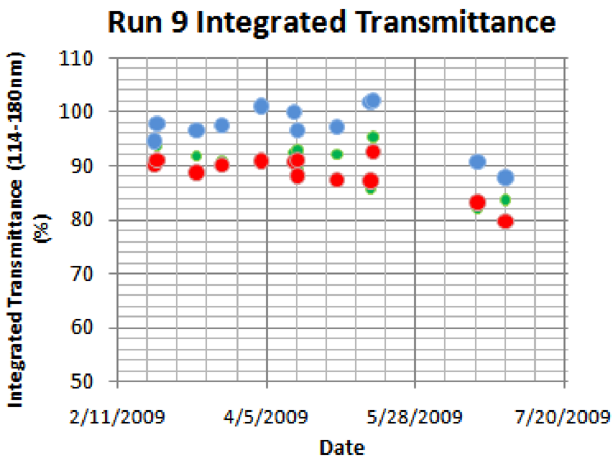


Figure 7: Comparison of VUV spectrum from end of Run9 (no optics replaced) to Run10, after replacing all optics within the system. An intermediate curve is also shown where only two of six optics were replaced.

It must be noted that since the start of the Ar purge, there has only been about a 10% deterioration in the lamp intensity over a period of 8 months where the spectrometer was operated with the lamp on for about 400-500 hours. Normally, with the spectrometer under ultra-high vacuum, the lamp window would have to be polished twice a month, after the intensity had dropped to well below 50-60% of the initial intensity.

As mentioned earlier, it is critical to the operation of the HBD that the radiator gas quality be continuously monitored. By studying and upgrading the system with new optics and implementing a new mode of operation, the signal to noise ratio of the transmittance measurement has improved by several orders of magnitude at the tails of the source spectrum and has thereby allowed a reliable and reproducible measure of the ppm levels of contaminants and signal losses within the detector gas. To wit, the uncertainty in the derived ppms levels of impurities has improved from about ±50 to ±3ppm, thus making a determination of the integrated transmittance significantly more precise than during Run9.

Fig. 8 shows the history of the integrated transmittance of the HBD during Runs 9 and 10, where the input gas delivered to the HBD remains reasonably flat at around 95%, and the outputs are flat at around 90%. The downward excursions seen in the integrated transmittance serve as warning signs and were in fact used (as intended) during the run to aid in identifying instances of deteriorating gas quality.



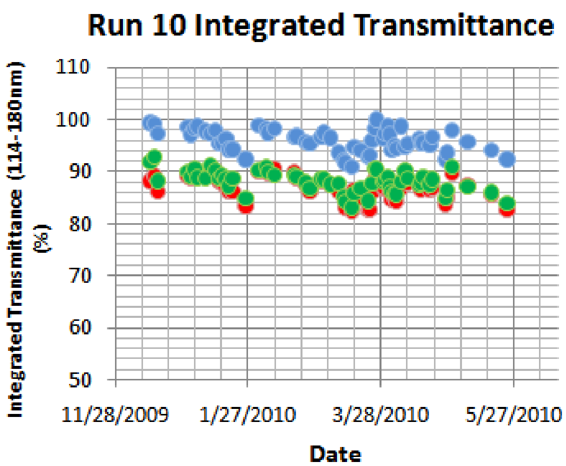


Figure 8: History of integrated Transmittance of HBD during RHIC Run 9 and 10. Blue: Input gas, Red: West Return gas, Green: East Return gas.

In one case, when the water analyzers failed, the transmittance measurement became the sole measure of the quality of the gas and served to alert experts of problems with the gas system, which was immediately attended to and remedied. Several other examples may also be cited which serve to illustrate the role of the transmittance monitor. In one instance, warmer weather sped up the out-gassing of water from the interior surfaces of the plumbing leading to the detector vessels, thus reducing the integrated transmittance. In another instance, the scrubbers of the system failed, which led to a gradual decline in the gas purity and a noticeable drop in the integrated transmittance. In both cases, data from the transmittance monitor was used to identify the problem which was promptly fixed, thus enabling the detector to continue to produce high quality data.

As mentioned, the transmittance monitor has also enabled a precise measure of the primary photoelectron signal expected from the HBD. As outlined in the following formula, by integrating, with respect to wavelength, the product of the Cherenkov yield, the CsI quantum efficiency, the gas transmittance, and other known detector efficiencies, one arrives at a value of about 22pe for the average number of detected photoelectrons (Npe) for the HBD. This value is in

$$N_{pe} = \int Y_{CH}(\lambda) * QE_{CsI}(\lambda) * T(\lambda) * \varepsilon_C(\lambda)\, d\lambda = N_0 L \langle \sin 2\ \theta_{CH} \rangle$$

excellent agreement with what was actually measured using Run10 data (within a few percent), and verifies the fact that the HBD is being operated at its maximum theoretical potential.

IV. Conclusion

In summary, the improvements to the transmission monitor have greatly improved the sensitivity and precision in determining the levels of impurities in the HBD gas during Run 10, which were crucial to the optimal and successful operation of the detector during this physics run. It further provided a greater understanding of the true photoelectron yield and showed that the detector was being operated near its theoretical limits of efficiency. Further details on the modifications and improvements to the transmission monitor and how the measurements were used to determine these optimal operating parameters for the HBD during Run 10 will be given in an article that will be submitted to the journal: Transactions on Nuclear Science.

V. References

[1] S.Stoll et.al., "A VUV Gas Transmission Monitor and Recirculating Gas System for the PHENIX Hadron Blind Detector", Conference Record Proceedings, 2007 IEEE NSS/MIC, Oct 28 - Nov 3 2007, Honolulu, Hawaii.