Bench Tests of the Prototype Photon Beam Active Collimator for GlueX

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Abstract

A research and development project is underway at the University of Connecticut to build and test a prototype active collimator for the Hall D photon beam line at Jefferson Lab. This report describes the current status of this project as the collimator components are assembled and the electronics tested on the bench.

An active collimator has been designed by the University of Connecticut group for the Hall D photon beam line at Jefferson Lab [1]. The design was borrowed from SLAC, where a similar device was needed for monitoring the alignment of their high energy electron beam. This device is described by G. Miller and D. Walz [2] as a "tungsten pin cushion" detector. It takes advantage of the "knock-on" electrons produced in electromagnetic showers generated by the incident hard photon beam in the tungsten, which result in a net flow of electrons out of the tungsten plates.

Implementation of this technique requires optimization of the knock-on emission rate and amplification of the small currents they produce. The tungsten blocks are machined to resemble pin cushions: an array of pins erected on a solid tungsten base. The pins are directed downstream from the incident beam, and present a dense material for shower and knock-on production while at the same time allowing the knock-ons to escape in the spaces between the pins. Our design employs two rings of tungsten pin cushion wedges each divided into four independent sectors for a total of eight sectors. The two rings are coaxial with the beam axis, an outer ring for coarse positioning and an inner ring for fine positioning of the beam relative to the geometric axis of the collimator. The wedges are mounted on an insulating housing and seated within a conducting shell which serves as a Faraday shield and also as a collector to catch the emitted electrons and close the current loop.

1 Prototype construction

The design of the principal components of the active collimator has been developed and its performance simulated [1]. The need for good insulation and heat dissipation (critical for components exposed to the a high energy photon beam) simultaneously has been taken into account, leading to the use of boron nitrite. The aluminum collector has been designed to fit inside the cylindrical insulator, with electrically conducting walls that divide and isolate the two rings and four quadrants.

A full-scale boron nitride insulating support has been obtained from the firm Accuratus for use in the prototype. Careful attention was given to the choice of material for this purpose. The following quotation taken from the manufacturer's documentation explains the special properties and limitations of this material.

> Boron nitride is often referred to as *white graphite* because it is a lubricious material with the same platy hexagonal structure as carbon graphite. Unlike graphite, BN is a very good electrical insulator. It offers very high thermal conductivity and good thermal shock resistance. BN is stable in inert and reducing atmospheres up to 2800C, and in oxidizing atmospheres to 850C. Three grades are commonly used, including a boric oxide binder system, a calcium borate binder system, and a pure diffusion bonded grade. The boric oxide containing material (Grade BO) absorbs moisture which causes swelling and property degradation. The calcium borate containing material (Grade CA) is moisture resistant. The pure BN material (Grade XP) contains no binders and is used for extremes of temperature and where purity is important. The boric oxide material is the most commonly used grade.

The material used for the active collimator prototype used a calcium borate binder to avoid the problems with humidity-dependent dimension changes that affect the boric-oxide-based material.

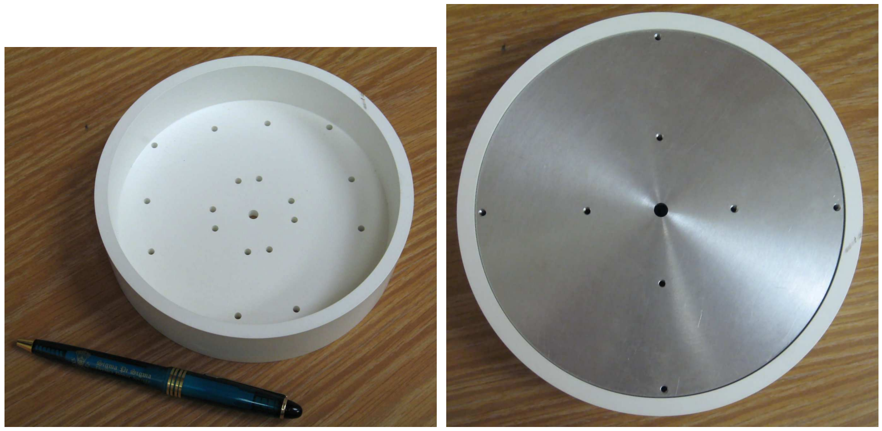

Figure 1: Photographs showing the boron nitride insulating support cylinder on which the tungsten pin cushion wedges will be mounted. Each wedge is supported by bolts that pass through the holes in the base of the support. The holes at the outer perimeter of the support are used to attach the aluminum quadrant divider insert to the insulating support shown in its attached position in the second panel.

The manufacturer machined the piece to our specifications, including the mounting holes that support the tungsten wedges. The reference surface for this piece is the outer cylindrical surface, which was specified to be cylindrical to within ± 50 μm. Two holes to support each tungsten wedge were placed with the same precision around the circumference of the two rings, and a central hole provided to allow the uncollimated beam to pass through without interaction. Photographs of this piece are shown in Fig. 1.

The tungsten wedges for the active collimator were fabricated starting from solid blocks of machinable tungsten material of composition 97%W : 2.1%Ni : 0.9%Fe by weight. This alloy was chosen because of of its machinability (Class 4 ROC 28) in contrast to pure tungsten that is too hard and brittle to machine at room temperature. Rows and columns of square pins pf dimension approximately 0.5×0.5 mm^2 by removing the material in between using a process called electric discharge machining (EDM). This work was done for us by the Physics Department machine shop at Florida State University, Tallahassee, FL. We are grateful to Prof. Paul Eugenio at Florida State for his assistance in the fabrication of these specialty components. Photographs of these pin cushion wedges are shown in Fig. 2.

Mechanical constraints due to the expected temperature variation have

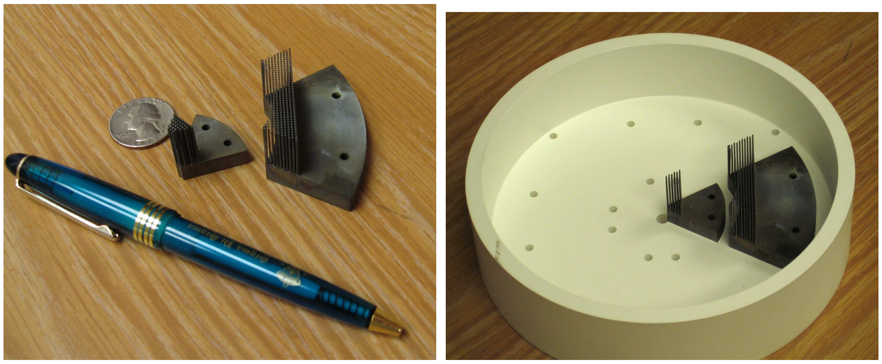

Figure 2: Photographs showing the tungsten pin cushion wedges and the boron nitride cylinder on which they will be mounted. The second panel shows one inner and one outer wedge in the positions where they will be mounted when the prototype is assembled.

been checked, showing that the assembly fits together without internal stress over the temperature range $0 - 40^o$ C.

2 Readout electronics

A plan for assembly and the connections to the readout electronics has been developed. Components necessary to complete the assembly have been ordered, including the grounded faceplate needed to mount coaxial cable jacks and shield the body of the collimator.

On the data acquisition side of the project, low and high-level software support for the DAQ cards has been explored within the framework of Labview. Various Labview virtual instruments have been made to test data acquisition. A screen shot of the prototype readout interface is shown in Fig. 3.

Two current-sensitive high-gain pre-amplifiers have been obtained for testing. These are the PMT-5R current-sensitive preamplifier made by Advanced Research Instruments Corporation. These devices support 7 different gain settings, from 10^{-6} A/V to 10^{-12} A/V. Expected currents from individual tungsten wedges under nominal GlueX running conditions at 10^8 tagged photons per second are on the order of several hundred nA near nominal beam alignment. It is important for the active collimator readout to be sensitive to currents at least an order of magnitude lower than this in order

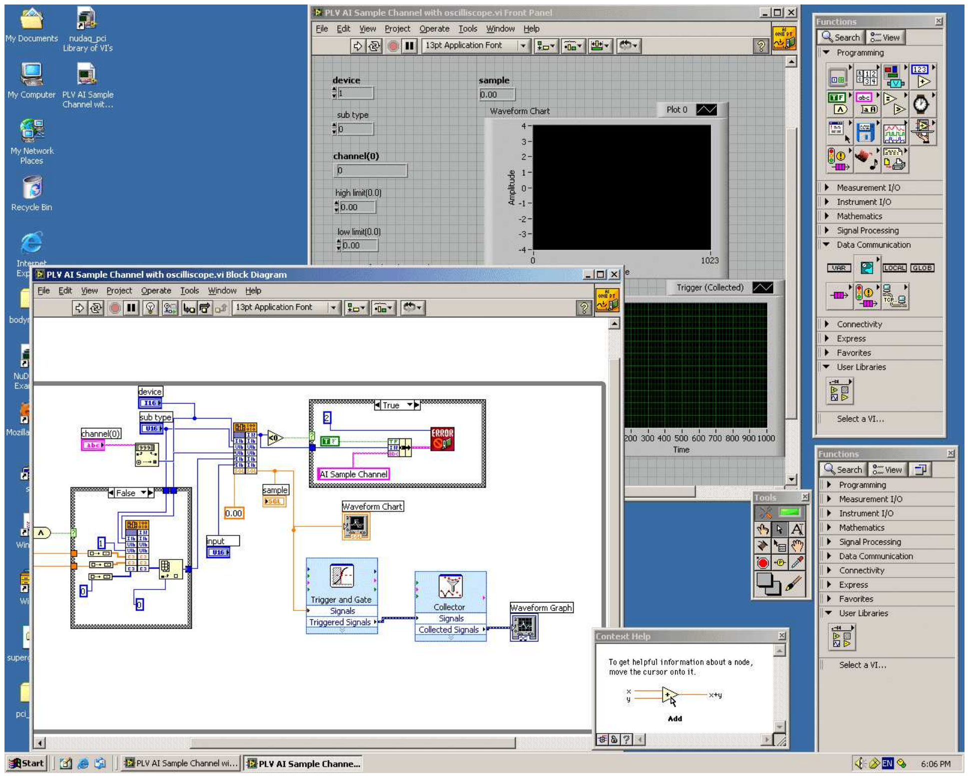

Figure 3: A screen shot of a Virtual Instrument in Labview. The window on the lower left provides a schematic of the data flow, including routines called, program flow control, triggering and the "back end" of the visual objects used to output the data. The window behind it shows the graphical run-time controls. The toolbars on the right are used to design the visual and back-end aspects of the virtual instruments.

for this device to be useful during beam line commissioning and early running at 10^7 γ/s. The position signal from this device is based on current differences between wedges, so the readout can benefit from common mode rejection in trying to control noise levels.

Ideally one would like the noise on individual channels to be of order 1 pA or less at a bandwidth of 1 KHz, with an order of magnitude further reduction using common mode rejection. The bandwidth of 1 KHz comes from an estimate of the maximum response frequency of a feedback loop in which an offset signal from the active collimator is used to correct the electron beam position upstream of the photon radiator. This noise level corresponds to roughly 5% in the asymmetry between opposing wedges, which corresponds to the required photon beam alignment accuracy of ± 200 μm at a beam intensity of 10^7 γ/s.

Bench tests were carried out of the PMT-5R preamplifiers using an unterminated 50Ω coaxial cable connected to the input. The results are shown in Fig. 4. We do not observe an output signal six orders of magnitude higher at the highest gain setting compared to the lowest as expected, but it must be noted that the dependence of pickup on amplification stages used in the preamplifier is not known. The results still demonstrate that the preamplifiers can boost pA currents almost two orders of magnitude above the noise floor. We conclude that the preamplifier is capable of measuring currents with gain and noise characteristics that match the active collimator requirements.

3 Future work

We are ready to assemble the active collimator pending completion of the coaxial connector face plate. The data readout component will be ready simultaneously, with the procurement of a new ADC card and the completion of tests on the amplifiers. At that point, we will be ready for a bench test of the fully assembled prototype, limited to two opposing quadrants and the simultaneous readout of two current channels. In this configuration it will be possible to use the prototype to measure one coordinate of the centroid of a photon beam, either using the coarse or the fine beam positioning pairs. This test will allow us full control of the amplifiers as well as a chance to characterize and calibrate the device.

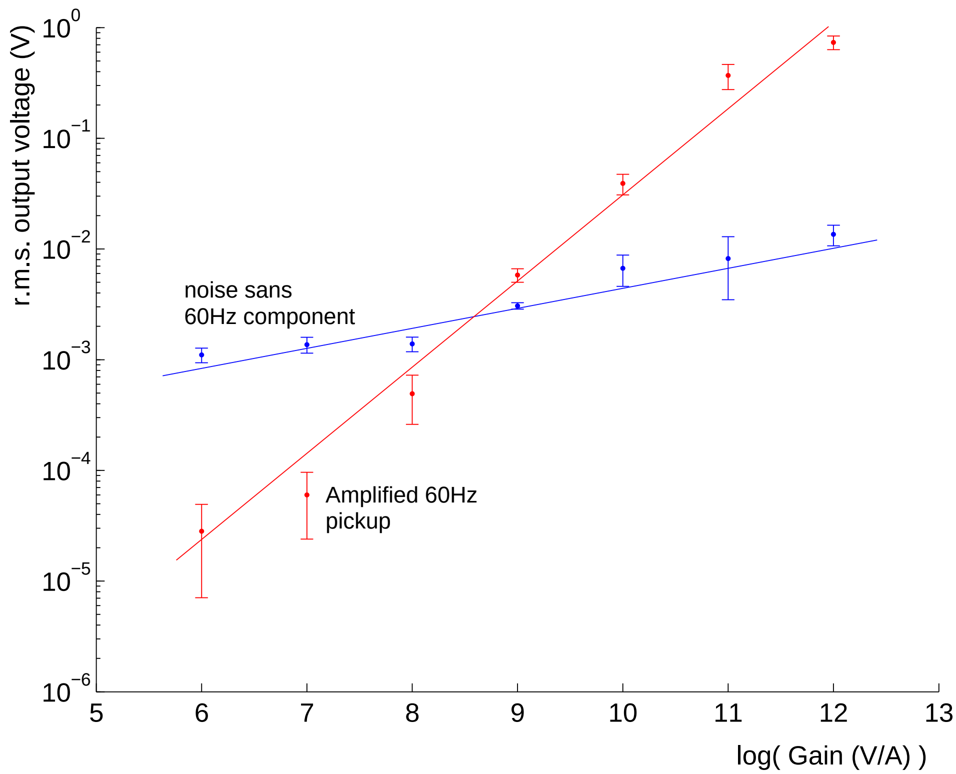

Figure 4: Noise as a function of gain is shown for both random noise and 60Hz pickup, collected with an unterminated coaxial cable attached to the input.

References

[1] C. Gauthier, "Simulation of a Position-Sensitive Tungsten Pin-Cushion Detector" *GlueX-doc-244* (2004).

[2] G. Miller and D.R. Waltz, Nucl. Instr. and Meth. **117** (1974) 33.