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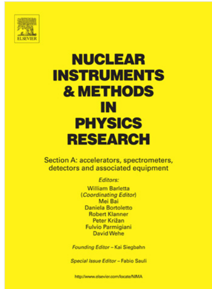


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# Status of the GlueX DIRC

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**Abstract**

This year we start assembling the DIRC detector to upgrade the particle identification capabilities in the forward region of the GlueX detector in Hall D at Jefferson Lab. The main components of the GlueX DIRC are the four bar boxes (reused from the decommissioned BaBar DIRC) and two photon cameras, which were designed based on the prototype for the SuperB FDIRC. The delicate bar boxes have already arrived at JLab from SLAC, where they have been stored for the last ten years. They will be attached to the newly built photon cameras and installed in Hall D already for the 2019 spring run. We present the status of the GlueX DIRC project including the ongoing R&D and the plan for the future.

*Keywords:* Particle Identification, Cherenkov Counter, Ring Imaging, DIRC

## 1. Introduction

The primary goal of the GlueX [1, 2, 3] experiment is to search for and ultimately study the properties of hybrid mesons, which contain an intrinsic gluonic component in their wave functions. Hybrid mesons, predicted by lattice QCD calculations [4], provide an opportunity to quantitatively test our understanding of the strong nuclear force in this non-perturbative regime. The GlueX physics program has two phases. The first phase, focused on the study of light quark mesons, is finishing this year. Next year GlueX starts the second phase, high luminosity run, with improved particle identification (PID) capabilities in the forward region. The new detector, based on the DIRC (Detection of Internally Reflected Cherenkov light) principle [5], was developed and is currently being installed in Hall D to provide clean separation between kaons and pions with at least three standard deviations for momenta up to 4 GeV/c.

The GlueX DIRC [6] consists of four BABAR DIRC bar boxes and two photon cameras based on the SuperB prototype [7]. Each bar box contains 12 long and narrow fused silica radiators ($1.725 \times 3.5 \times 490$ cm$^3$) with a small wedge attached to the end which is read out. Each of two photon cameras, described in [6], is attached to two bar boxes and is equipped with an array of Hamamatsu H12700 Multianode Photomultiplier Tubes (MaPMTs). The readout electronics boards are the same as for the CLAS12 RICH [8] in Hall B (Jefferson Lab).

## 2. Transportation of the Bar Boxes

One of the major challenges of the GlueX DIRC project was the transportation of the fragile radiators stored since 2008 at SLAC (California). The BABAR bar-box numbers 0, 1, 10, 11 (out of 12 total) were selected for GlueX and had to be brought over to Jefferson Lab (Virginia) by truck. To minimize the risk for the bars or glue joints, the transportation campaign was carefully prepared and included two stages: the first trip took only one bar box, and the remaining three boxes were brought in the second trip.

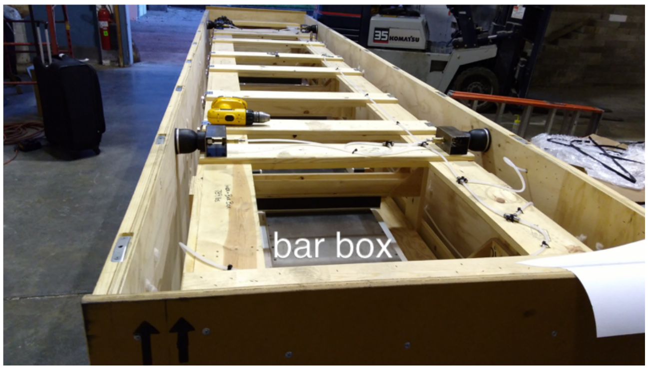


Figure 1: The transportation crate with a bar box inside.

Each bar box was packed in a special double layer crate (see Fig. 1), equipped with a number of accelerometers and temperature sensors. The radiator bars need nitrogen atmosphere to keep the surfaces clean and dry, therefore a constant purge was ensured for all four bar boxes not only while in storage, but also

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during the transportation. The temperature, stress, and nitrogen flow were continuously monitored on the road. The maximal stress requirements of 3 g in the up/down direction and 1.5 g along the radiators were defined based on the material properties, engineering studies, and expertise of the SLAC team.

The radiators were visually monitored throughout the whole trip in order to notice immediately if a bar or a glue joint were damaged, and link it to the road conditions or other actual circumstances. This was of particular importance for the first trip, which influenced the preparation for the second one. The idea of the inspection was to use the human eye to look at the kaleidoscopic pattern visible through the readout face of the bars (see Fig. 2) every several minutes and compare that to the reference picture taken before the trip. The human eye is sensitive to changes, which is a key feature for the inspection. Monitoring was done by a chase car, which received the wifi signal from cameras installed in front of the bar box window (see Fig. 3). Each bar box was equipped with four cameras, which resulted in four signals for the first trip and twelve signals for the second trip. The same type of truck and trailer was used for both trips. The first bar box arrived at JLab in November 2017, and the remaining three in June 2018. All bar boxes were inspected upon arrival. During the transportation, one bar box experienced a shock of 5 g vertically, and three bar boxes were under negative nitrogen pressure for three minutes while driving downhill, but that did not cause any visible damage.

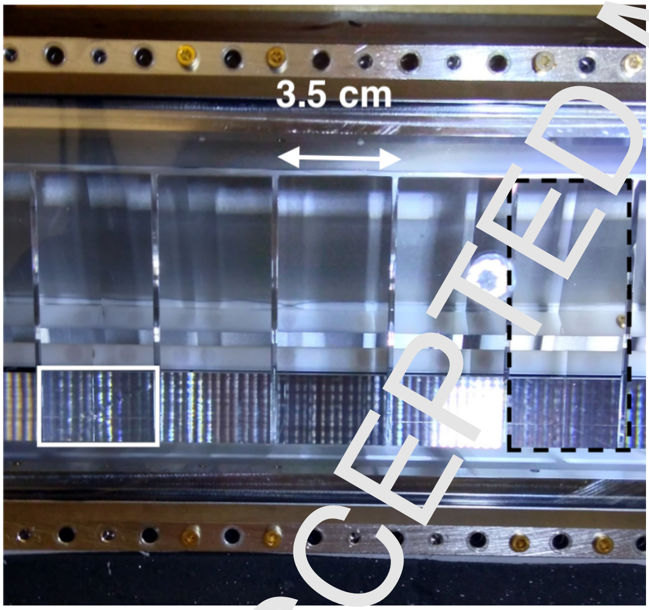


Figure 2: The interior view of the bar box through the window (for details of the bar box structure see [5]). A face of the small wedges is marked with a black dashed line. A readout face of the radiator is marked with a white solid line. The multiple reflections of the light off the long radiator sides result in the grid-like kaleidoscopic pattern visible in the readout faces of the bars. The picture was taken before the trip.

The experience gained during this transportation campaign is of great value and might be applied to the transportation of the remaining 8 bar boxes, when they are needed outside of SLAC.

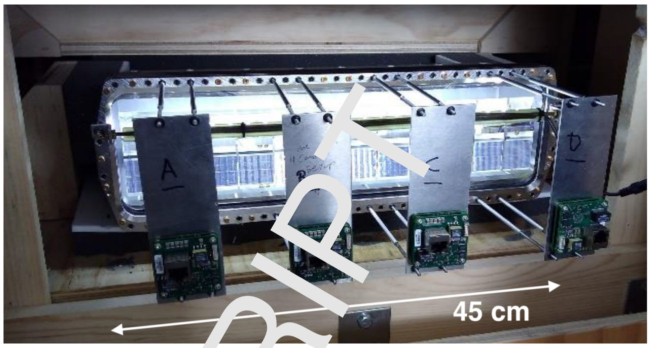


Figure 3: Four cameras on the support structure inspecting the interior of the bar box through the window. A strip of LED lights was used to ensure enough light for the cameras.

## 3. Simulation and Reconstruction

The DIRC detector was implemented into the GlueX Geant4-based software. The detector simulation has a detailed model of the optical system including description of the materials, realistic structure of the photosensors, implementation of the quantum efficiency of MaPMTs and reflection probability for the BABAR radiators based on the SLAC measurements. The DIRC support structure within the geometrical acceptance was implemented as well. There are three reconstruction methods which can be used for the DIRC.

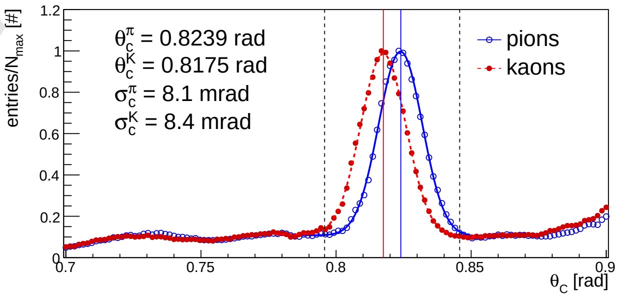


Figure 4: Cherenkov angles per photon for simulated 1000 kaons (red) and 1000 pions (blue) with momenta of 4 GeV/c and track direction defined by $\theta = 4°$ and $\phi = 90°$ angles[1]. The distributions are normalized to their peak values ($N_{max}$). The solid vertical lines show the expected values for the Cherenkov angles. The dashed lines define the range of values, where the reconstructed photon is considered to be signal.

The geometrical reconstruction method [9] based on the BABAR DIRC algorithm was implemented in the GlueX software and will be used for the commissioning and start of the DIRC operation. This method reconstructs the Cherenkov angle for each detected photon as an angle between the particle direction obtained from the tracking system and the estimator for the photon direction taken from a look-up table. The look-up table is created in advance using a simulation, where each

[1]The z axis in the GlueX coordinate system goes along the beam, i.e. perpendicular to the DIRC wall, the y axis is vertical, and the x axis is defined by the right handed system. The polar angle $\theta$ and the azimuthal angle $\phi$ are conventional for spherical coordinates.

pixel on the photodetection plane is associated to a set of photon directions at the exit from the bar, which could have lead to a photon ending up in that pixel. Each entry of the look-up table contains a radiator number, a pixel number, and a set of photon directions at the exit from the radiator together with a propagation time associated to each of that direction. The look-up table is stored as a root tree with the size of about 300 MB. The Cherenkov angle distribution (e.g. Fig. 4 shows a cumulative spectrum of reconstructed Cherenkov angle for 1k pions and 1k kaons) includes a number of solutions for each detected photon, which account for the possible reflections off the radiator bar sides and for possible photon paths inside the photon camera (from the look-up table), which explains the background under the peaks at the expected values of $\theta_C$ for pions and kaons. The width of the Cherenkov angle distribution can be used to determine the single photon Cherenkov angle resolution $\sigma_C$, which is a characteristic of the detector performance. The difference in log likelihoods, formed for two particle hypotheses, shows the separation power between kaons and pions (see Fig. 5a).

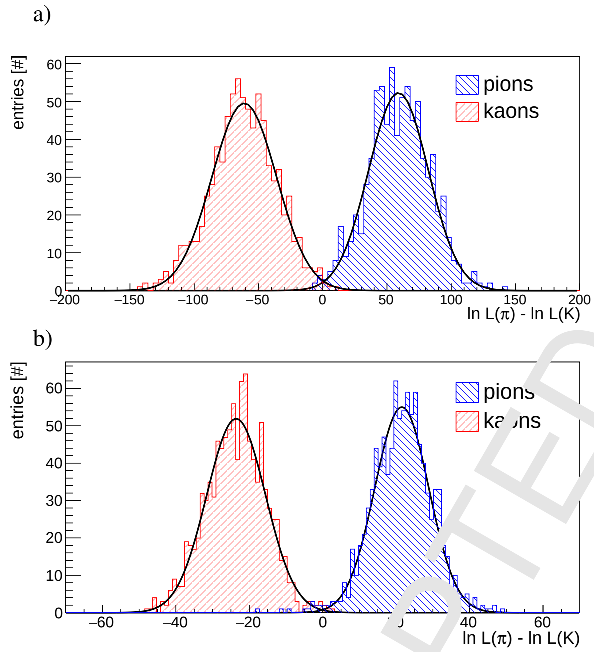


Figure 5: Log of likelihoods for pion (blue) and kaon (red) hypotheses for momentum of 4 GeV/c and track direction defined by $\theta = 4°$ and $\phi = 90°$[1]. The simulated sample includes 1000 particles of each type. The reference timing spectra for each pixel were created using $10^5$ pions and $10^5$ kaons with the same parameters. The separation power defined as the difference between log likelihoods is 4.95 s.d. for the geometrical reconstruction method (a) and 5.6 for the time-based imaging reconstruction assuming 1 ns single photon timing resolution (b).

The time-based imaging reconstruction is similar to the approach used by the Belle II TOP [10, 11]. The basic concept is that the measured arrival time of Cherenkov photons in each single event is compared to the expected arrival time for every particle hypothesis, yielding the PID likelihoods. The expected photon arrival time can be calculated analytically based on the charged particle direction and hit location on the photodetection plane. Alternatively, the full detector simulation can be used to produce timing spectra for each pixel. Since the DIRC signal depends on the particle mass, momentum, direction, and the position on the DIRC wall, the simulation of timing spectra for all charged particle configurations is computationally limiting. For the detector performance evaluation (see Fig. 5b) we used the simulated timing spectra and the single photon timing resolution of 1 ns, which is the value obtained during tests of the readout electronics. The design value for the single photon timing resolution is 600 ps.

In the FastDIRC [12] algorithm the photons are traced through the optical system analytically, which makes it four orders of magnitude faster than Geant. The FastDIRC reconstruction is based on kernel density estimation (KDE), which delivers the separation between different particle species based on difference in log likelihoods. The likelihood is obtained from a probability density function (PDF) for the distribution of photons expected on the photodetection plane for each charged particle hypothesis. The PDFs are determined numerically using kernel density estimation. The resolution of the reconstructed Cherenkov angle is about 30% better than for the geometric reconstruction method. Since the FastDIRC method is about 1000 times slower than the look-up table based reconstruction, we plan to use the FastDIRC algorithm offline for particular events, where the default method does not yield a clear identification.

Simulation studies showed that one edge row of 18 MaPMTs can be removed from each photon camera without loss in performace. Therefore the total number of MaPMTs needed to equip the GlueX DIRC decreased from 216 to 180 pieces. The vacant slots in the electronics boards will be filled with dummy blocks of the same size as MaPMTs (see Fig. 8).

## 4. Optical Coupling of MaPMTs

Special silicone pads were developed to couple the photo sensors to the fused silica window of the photon camera. The technology is based on the Belle II TOP [13] experience. The refractive index of RTV-615 (from Momentive) is close to that of adjacent materials: the fused silica window of the photon camera and the MaPMT window made of borosilicate glass. Coupling with a silicone pad minimizes the difference between the refractive indices of the adjacent materials and allows saving up to 20% of photons on that interface. The pads allow exchange of single PMTs if necessary, are robust, and have good transmittance (see Fig. 6).

One silicone pad with dimensions of 51×153×2 $mm^3$ is used for 3 MaPMTs matching the design of the electronics boards. The pads have flat surfaces and are produced using the softest mixing ratio for the two-component RTV-615 material. To maintain good optical coupling the pads need constant pressure, which is ensured by the clamping fixture shown in Fig. 7, which holds two electronics boards (six MaPMTs) forming one row of the 6 × 18 MaPMT array on the window of the photon camera. Two independent springs (inside blue cases in Fig. 7) transmit a force of 150 Newton to each of the two electronics boards, which push the MaPMTs and the silicone pads to the window

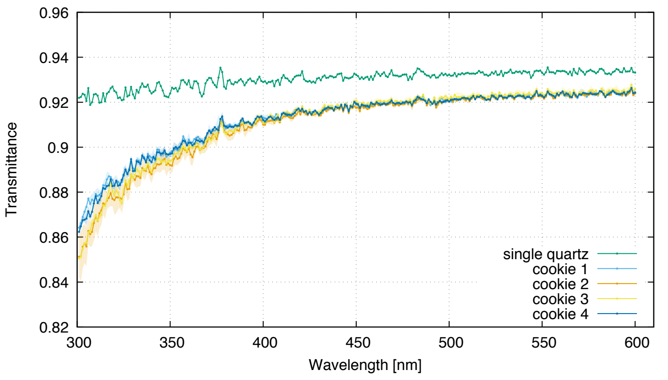


Figure 6: Transmittance as a function of wavelength for several custom-made silicone pads and a single quartz window (for comparison).

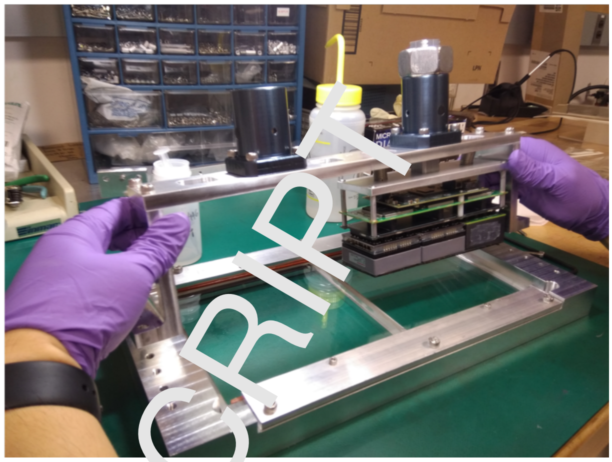

Figure 8: Test setup including a clamping fixture and a small window (mockup of the photon camera window). The clamping fixture is loaded with one electronics board attached to two MaPMTs and one dummy block.

of the photon camera. A special procedure of greasing and application of the silicone pads was developed using a test setup (see Fig. 8) to ensure stable optical coupling. About fifty silicone pads were produced, which is enough to equip the first photon camera.

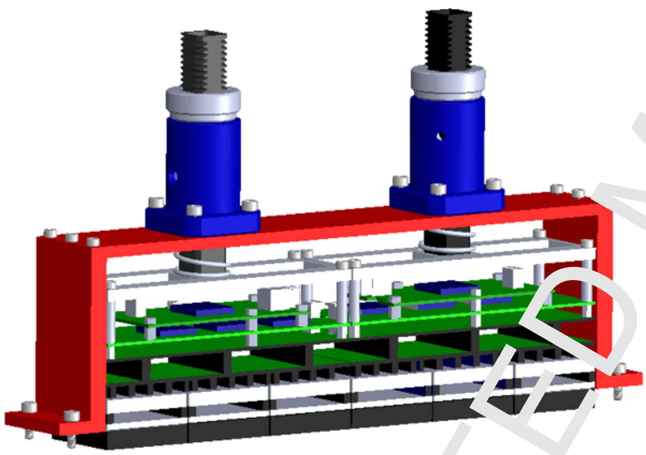

Figure 7: Technical drawing of the clamping fixture (shown in red) holding two electronics boards (shown in green). The two springs in the blue cases apply pressure to the boards, pushing the six MaPMTs to the window of the photon camera (not shown here).

## 5. Summary and Outlook

The GlueX experiment is about to start the second phase of its physics program aimed at studying exotic mesons with a strange component. The DIRC detector doubles the momentum range, where kaons can be separated from pions, to $p \leq 4$ GeV/c. The four BABAR DIRC bar boxes assigned to GlueX were safely transported from SLAC to JLab. Two of them are already installed on the DIRC support structure. The assembling of the DIRC started in July 2018 and is expected to finish the end of February 2019, so that the detector is ready for parasitic data taking in the upcoming run. The MaPMTs arrived at JLab and have been tested. The photon cameras will shortly be equipped with photo sensors using custom silicone pads.

The DIRC detector simulation is implemented into the global GlueX software. The baseline reconstruction algorithm based on the BABAR DIRC geometrical method is ready to be used in the beginning of operation. The time imaging reconstruction needs some development work, and the FastDIRC method awaits implementation into the GlueX software. The number of MaPMTs required for the DIRC was decreased by 17% without loss in performance.

One half of the DIRC including two bar boxes and one photon camera will be installed by early 2019. Then the DIRC will collect calibration data-sets with an LED pulser for timing offsets as well as HV and thresholds scans. The commissioning with the beam starts in February 2019. Later in 2019 a complete installation of four bar boxes and two photon cameras is planned. The GlueX physics program with the DIRC starts in autumn 2019.

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