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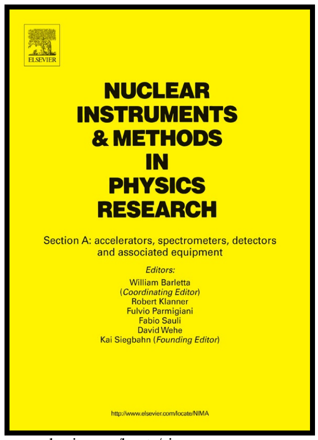

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PII: S0168-9002(17)30112-2
DOI: http://dx.doi.org/10.1016/j.nima.2017.01.054
Reference: NIMA59609

To appear in: *Nuclear Inst. and Methods in Physics Research, A*

Received date: 2 November 2016
Revised date: 20 January 2017
Accepted date: 23 January 2017

Cite this article as: F. Barbosa, J. Bessuille, E. Chudakov, R. Dzhygadlo, C Fanelli, J. Frye, J. Hardin, J. Kelsey, M. Patsyuk, C. Schwarz, J. Schwiening, J Stevens, M. Shepherd, T. Whitlatch and M. Williams, The GlueX DIRC Detector, *Nuclear Inst. and Methods in Physics Research, A* http://dx.doi.org/10.1016/j.nima.2017.01.054

The GlueX DIRC Detector

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Abstract

The GlueX DIRC (Detection of Internally Reflected Cherenkov light) detector is being developed to upgrade the particle identification capabilities in the forward region of the GlueX experiment at Jefferson Lab. The GlueX DIRC will utilize four existing decommissioned BaBar DIRC bar boxes, which will be oriented to form a plane roughly 4 m away from the fixed target of the experiment. A new photon camera has been designed that is based on the SuperB FDIRC prototype. The full GlueX DIRC system will consist of two such cameras, with the first planned to be built and installed in 2017. We present the current status of the design and R&D, along with the future plans of the GlueX DIRC detector.

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

1. Introduction

The GlueX [1, 2, 3] experiment is a key element of the Jefferson Lab 12 GeV upgrade. It is located at the end of the new beamline from the Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab in the new experimental area, Hall D. Electrons with an energy of 12 GeV produce coherent bremsstrahlung on a thin diamond wafer forming a tagged photon beam. The GlueX experiment, schematically shown in Fig. 1, utilizes the photon beam and a target filled with liquid hydrogen. The primary goal of the 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.

Commissioning of the baseline GlueX detector was completed in Spring 2016 [5]. The particle identification (PID) capabilities of the GlueX detector in the forward region are illustrated in Fig. 2. The time-of-flight (TOF) detector approached its design specifications and provides π/K separation up to the momentum of about 2 GeV/c. An initial physics program to search for and study hybrid mesons which decay to non-strange final state particles begins in Fall 2016. However, an upgrade of the PID capabilities is needed to fully exploit the discovery potential of the GlueX experiment by studying the quark flavor content of the potential hybrid states.

The proposed PID upgrade for GlueX is based on the DIRC (Detection of Internally Reflected Cherenkov light) principle citeAdam2005281. Charged particles emit Cherenkov light while traveling inside fused silica. A fraction of the light cone is trapped inside the radiator and transported to the photon camera, where it is expanded and imaged on a pixelated photodetection plane. The resulting hit pattern provides information about the velocity of the charged particle given the momentum vector reconstructed by the tracking system.

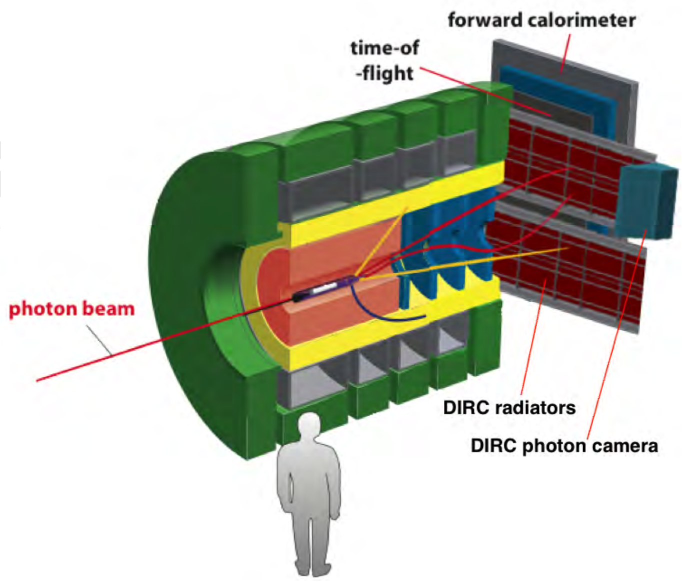

Figure 1: A schematic view of the GlueX detector with the DIRC, which consists of four radiator boxes and two photon cameras.

The GlueX DIRC [6] will reuse four existing BaBar DIRC [7] bar boxes filled with long and narrow radiators ($1.725 \times 3.5 \times 490$ cm^3) without any modifications. Each pair

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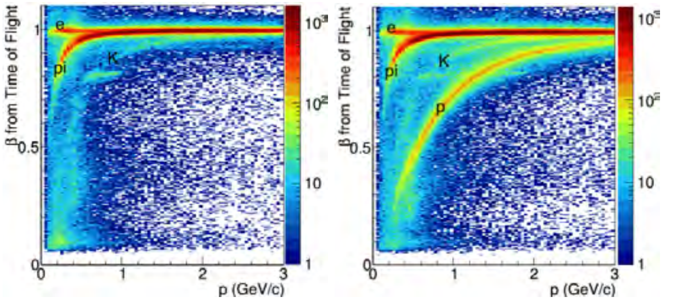

Figure 2: The charged particle β as determined from both time-of-flight (TOF) and path-length measurements in the GlueX detector versus the reconstructed particle momentum, for negatively charged particles (left) and for positively charged particles (right). Since the TOF detector has exactly the same acceptance as the DIRC, the plots illustrate the GlueX PID capabilities in the forward region.

of boxes will be attached to a new compact photon camera, inspired by the SuperB FDIRC prototype [8]. The GlueX DIRC design is described in detail in Ref. [9] and summarized in the next section. The current GlueX DIRC design should provide clean separation between kaons and pions with at least three standard deviations for momenta up to 4 GeV/c.

2. GlueX DIRC Design

The GlueX DIRC covering the polar angle range from 2° to 11° is located about 4 m away from the target directly upstream of the TOF detector. Two unaltered BaBar bar boxes forming a wall above the beam pipe will be attached to a photon camera located to the left of the beam. Another pair of the unaltered BaBar bar boxes covering the acceptance below the beam pipe will be attached to the second photon camera located to the right of the beam. An array of multi-anode photomultipliers (MaPMTs) will read out the cameras. The support structure of the DIRC will allow the pairs of bar boxes to swap out of the active area of the detector for experiments requiring minimal material budget in front of the forward calorimeter.

The design of the photon camera is based on the SuperB FDIRC prototype[1] developed at SLAC (see Fig. 3). The FDIRC photon camera design was based on compact focusing blocks made of fused silica, one for each bar box in a barrel. For the GlueX planar orientation one common camera, filled with distilled water, will be used for two bar boxes together. This design with wider cameras (the width is approximately 1 m) reduces the fraction of photons reflecting off the sides, simplifying the hit pattern and removing ambiguities in the reconstruction.

Another important modification of the photon camera design is the approximation of a cylindrical mirror by three flat segments for simplicity in alignment and construction. The optimized radius of the mirror approximated by three flat segments allows using fewer photosensors, which is the main cost driver for GlueX DIRC. The resolution on the Cherenkov angle is approximately the same for the designs with the cylindrical and

[1]FDIRC was designed to be the successor of the BaBar DIRC, but the SuperB project was canceled in 2012

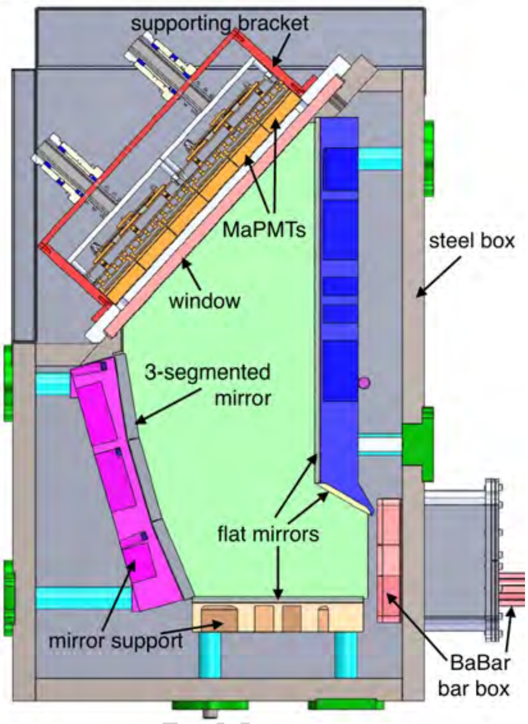

Figure 3: Schematic diagram of the cross-section of the photon camera, which will be filled with distilled water. The attached bar boxes are shown on the bottom right. The bottom flat mirror is aligned with the radiators.

the three-segmented mirrors. An example of the hit pattern for 5 GeV/c charged pions and incident direction defined by the polar angle $\theta = 4°$ and $\phi = 40°$ (x axis is parallel to the floor of the experimental hall) is shown in Fig. 4. The effect of the three segmented mirror is the vertical shift of individual arches in the hit pattern with respect to each other.

A conservative estimate of the GlueX DIRC detector resolution is based on the performance of the SuperB prototype with required corrections for the camera material and differences in the optical system. The necessary Cherenkov angle resolution (σ_{θ_C}), defined as

$$\sigma^2_{\theta_C} = \sigma^2_{corr} + \frac{\sigma^2_\gamma}{N_\gamma}, \tag{1}$$

should be better than 2.5 mrad. We expect to detect between 20−30 photons per track (N_γ), and the correlated error (σ_{corr}) is about 1.5 mrad. The single photon Cherenkov angle resolution (σ_γ) is estimated to be about 7.3 mrad (individual contributions to σ_γ are described in Ref. [9]). Better photon yield and more accurate tracking resolution will improve the GlueX DIRC performance, and the DIRC's impact on the GlueX physics program should be even larger than previously expected.

To test different design options and evaluate the detector performance, two independent simulations are being used: a full Geant4-based Monte Carlo [10] and an analytical algorithm called FastDIRC [11]. In the latter approach the photons are traced through radiators analytically, therefore it is four orders of magnitude faster than Geant. FastDIRC includes reconstruction based on kernel density estimation (KDE) and look-up tables (LUTs). The KDE method reconstructs the separation between different particle species based on difference in log of the likelihoods, formed from two hypotheses. The likelihood is obtained from a probability density function (PDF) for the distribution of photons expected on the photodetector plane for each charged-particle hypothesis. The PDFs are determined numerically using kernel density estimation.

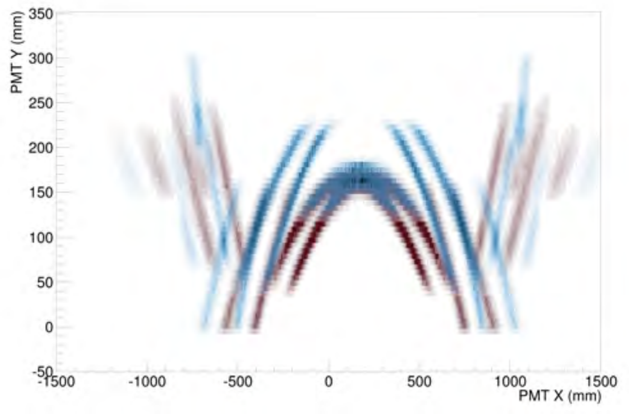

Figure 4: Hit pattern on the virtual uniformly pixelated photodetection plane for charged pions with momentum of 5 GeV/c and incident angles $\theta = 4^\circ$ and $\phi = 40^\circ$. The width of the virtual photodetection plane is 3 m (the width of the real photodetection plane is 90 cm), so that photons expand without reflections on the sides of the photon camera. The plot shows a general shape of the hit pattern, which gets folded differently depending on which bar was hit by the charged particle. Photons which go directly to the readout end of the radiator are marked in red, photons reflected off the flat mirror on the other end of the radiator are marked in blue.

The second reconstruction approach is similar to the one used for the BaBar DIRC [7]. For this a large number of photons is generated from a single point at the readout end of the radiator bar and tracked to the photodetector plane. A LUT entry for a given pixel contains possible photon directions at the radiator face, which could have led to a photon hitting the pixel. The reconstructed Cherenkov angle is then defined using the LUT information together with the charged track direction provided by the tracking system. Plotting the cumulative distribution of reconstructed Cherenkov angles for all photons associated to a charged particle provides the means for determining the Cherenkov angle for the particle.

We plan to use H12700 [12] 64-channel MaPMTs from Hamamatsu for the read-out system. Each photon camera is equipped with a grid of 6×17 photosensors. The electronics design is based on the CLAS12 RICH [13], since it has similar specifications. The expected timing resolution is about 1 ns.

Optimization of the photon yield includes optical coupling of the photosensors to the photon camera. We are considering using silicone cookies [14] similar to the ones utilized in Belle II TOP [15]. The FDIRC prototype used direct coupling of the photosensors to the window of the photon camera. This effectively implied an air gap. According to the simulation, a large difference in the refractive index between fused silica and air could cause photon loss of about 15 – 35 % in the GlueX acceptance compared to the ideal case, where photons go from the window of the photon camera directly into the photosensor. Silicone pads ensure good optical coupling and reduce photon loss to 2 – 4 % compared to the ideal case. The use of the silicone pads requires constant pressure applied to the MaPMTs. A special bracket shown in Fig. 3 in red was developed to safely apply the force to the photosensors.

The transport of the BaBar components from SLAC to Jefferson Lab is a special challenge as the bar boxes are very fragile, especially the glue joints. Moreover, they are more than 15 years old, exposed to radiation, and were not designed for transportation. The value of the bar boxes is priceless, therefore, a detailed plan including a special environment, monitoring during the trip, and testing upon arrival at Jefferson Lab has been developed. It is planned to bring one BaBar bar box from SLAC to JLab first, and then take a second trip to deliver another three.

3. Summary and Outlook

The ability to reconstruct kaon final states is absolutely critical to maximizing the physics potential of the GlueX experiment. Upgrade of the PID system using DIRC doubles the momentum range, where kaons can be separated from pions, to $p \leq 4$ GeV/c. The GlueX DIRC is going to reuse the decommissioned components of the BaBar DIRC. The design of the new expansion volumes based on the SuperB FDIRC prototype is being finalized. Construction has been started. The calibration system is being studied. Preparations for transporting the bar boxes from SLAC to Jefferson Lab are underway. An initial installation of two bar boxes and one photon camera in Hall D is planned for 2017.

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