Search for Gluonic Excitations in Hadrons with GlueX

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The GlueX experiment will employ a linearly polarized 9 GeV tagged photon beam incident on a liquid hydrogen target to search for exotic states in the light meson spectrum. Optimized for this purpose, the detector has a highly uniform acceptance over nearly 4π solid angle, with high efficiency for both neutral and charged final state particles. An overview of the physics motivation and detector design will be given.

1 Introduction

The firmly established states in the light meson spectrum have J^{PC} quantum numbers compatible solely with quark degrees of freedom. However, lattice QCD calculations have shown [1] [2] that the theory allows for *exotic states*: quantum numbers like 1^{-+} with mass near $2.0\,\mathrm{GeV/c^2}$. Such quantum numbers and others like 0^{--}, 0^{+-}, 2^{+-} are impossible with quark degrees of freedom alone and may require excitation of the "glue" between the quarks. Identification of these "hybrid mesons" allows direct investigation of the field's dynamics and would provide a novel test of QCD. So far, most of the searches for hybrid mesons have been carried out with pion beams [3] [4], accumulating evidence of a state around $1.6\,\mathrm{GeV/c^2}$.

In the flux tube model, it has been shown that hybrid mesons with exotic quantum numbers involve predominantly quarks in a spin-triplet state, as opposed to spin-singlet. This suggests that a pion probe requires a spin flip to access exotic states, something that would not be necessary for a photon. Lattice calculations of radiative decays of $c\bar{c}$ states [1] appear to support the flux-tube model in suggesting that photo-production of exotic hybrid mesons may have a relatively large cross-section. However, suppression of spin flip may be a feature of the heavy charm quark: current efforts at calculations with lighter quarks may be able to put these suggestions on firmer ground. A separate advantage of photo-production lies in being able to resolve the exchange mechanism (naturality) through linear polarization [5] [6]. To date, no experiment has been conducted with a high-energy polarized photon beam capable of achieving sufficient statistics to search for these novel meson states.

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2 The GlueX Experiment

Hall D, a new facility dedicated to photon beam experiments on a fixed target, is under construction in Jefferson Lab as part of the 12 GeV upgrade of the CEBAF accelerator. Photons will be produced from Coherent Bremsstrahlung (CB) of 12 GeV electrons in a diamond radiator and collimated 75 m downstream for effective filtering of the incoherent background photons. The coherent enhancements in the spectrum are tuned via radiator orientation. The primary peak of (9 GeV, 40% polarization fraction) was selected as the optimal balance between these parameters (the latter vanishes at the end point.) CB on 20 μm thick diamond radiator will yield a flux of 10^8 γ/s at $\sim 2\,\mu$A beam current, within the coherent peak 8.4-9.0 GeV. The photon beam is tagged with 8 MeV/channel within the primary peak. A pair spectrometer will be utilized for tagger calibration and online polarimetry.

A 30 cm liquid hydrogen target will be used for the primary program of the experiment. Around the target, a hermetic "GlueX" detector has been designed optimally for meson spectroscopy with efficient partial wave analysis. This requires a nearly 4π, highly uniform acceptance and good tracking and calorimetry to handle neutral and charged final state particles. Figure 1 shows the basic GlueX detector components. Most of the detector components are inside a 2.2 T solenoid, with coverage in the polar angle split into the barrel and forward areas.

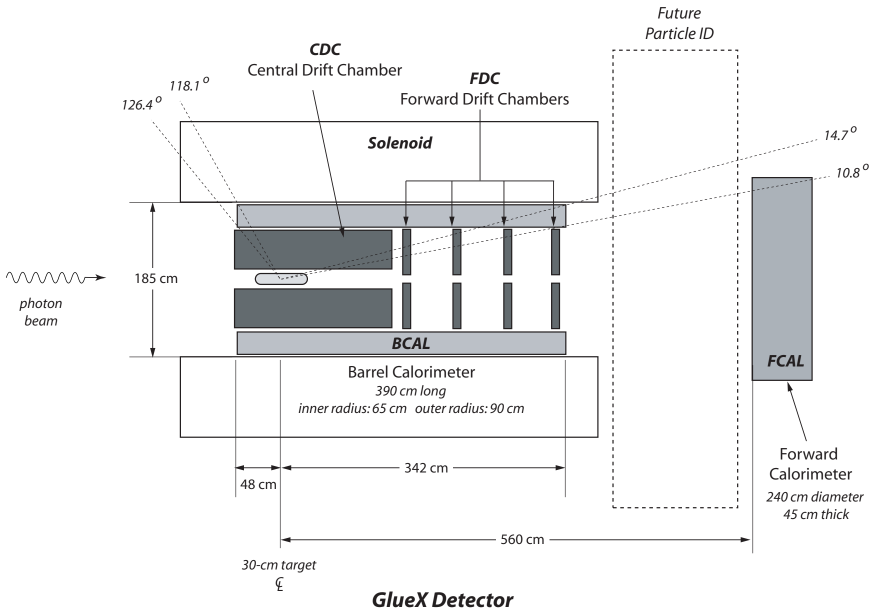

Figure 1: Simplified view of the GlueX detector: vertical cross-section along beam line. The tracking system is darkly shaded. Lightly shaded are the calorimeters. Not shown is the Start Counter around the target and the Time of Flight wall in front of the FCAL.

2.1 Tracking

The Central Drift Chamber (CDC) consists of 12 axial and 16, 6° stereo straw layers. Tests with cosmic rays have demonstrated resolution of $\sigma_r = 150\,\mu$m, $\sigma_z = 1.5$ mm and $\sigma_p/p = 1.5 - 3\%$. dE/dx information will be provided by this system to separate π, K and protons with momenta below 450 MeV/c.

Four Forward Drift Chambers (FDC) will be installed downstream. Each consists of 6 planes of 96 wires with a 1 cm pitch interleaved with cathode strips: 12 planes with 216 strips in each. Ghosting is minimized by reading out all of these electrodes and employing angular offsets between each plane. Spacial resolution of 200 μm is expected.

2.2 Calorimetry

The Barrel Calorimeter (BCAL) is of a 10% sampling "spaghetti" design with corrugated lead sheets interleaving 1 mm diameter scintillating fibers, read out by silicon photomultipliers devices (SiPMs). Resolutions $\sigma_E/E = 5.54/\sqrt{E} \oplus 1.6\%$, $\sigma_{\Delta t/2} = 70\,ps/\sqrt{E}$ have been demonstrated in a beam test [7]. dE/dx and time of flight information will be provided with a calculated 3σ time of flight-based separation of pions from protons below 0.75 GeV and kaon separation from pions and protons below 0.40 GeV and 0.55 GeV respectively.

The Forward Calorimeter (FCAL) is composed of 2800 F8-00 lead glass blocks with spacial segmentation of 4 cm. Used in the Brookhaven experiment E852 and RADPHI at JLab, this detector will be outfitted with light-guides to improve light collection. The resolutions are: $\sigma_E/E = 5.7/\sqrt{E} \oplus 1.6\%$ $\sigma_r = 5 - 6\,mm$ and $\sigma_t < 150\,ps$.

2.3 Time of Flight

Time of flight in the barrel region by the BCAL was described above. In the forward angles, a dedicated Time of Flight wall will be mounted in front of the FCAL. This device should achieve excellent separation between pions and protons at all energies relevant to the reactions of interest. A three sigma separation of kaons will be possible below 2-3 GeV. The prototype is close to achieving the required 100 ps resolution.

The complete time of flight system is assembled using a Start Counter around the target to identify the event with the beam bunch, information from the tagger and bunch timing from the accelerator. Additional particle identification detector components may be added between barrel and forward regions in the future.

3 Trigger, Electronics and Reconstruction

The expected initial rate of events within the tagged peak is 20 kHz. This will be achieved with a minimum-bias trigger using track multiplicity and a minimum energy cut. Eventually the beam intensity will be increased by an order of magnitude to 10^8 tagged photons/s on target, at which point the minimum-biased trigger will run at 200 kHz. This rate will be reduced to 20 kHz of events to tape using fast online reconstruction and keeping only events within the 8.4-9.0 GeV window. Simulations show effective reduction of low-energy events, 92% trigger efficiency above $\sim$ 6 GeV and a minimal effect on the important channels.

The readout needs of the detector are met with VMEx64/VXS, fully pipelined electronics such as the 250 MSPS flash ADC 16 channel module with 12 bit dynamic range and an 8 μs buffer, and the 32 channel F1TDC of better than 60 ps resolution and a 3.9 μs buffer (trigger latency: 3 μs.)

This high statistics experiment with the intensive Partial Wave Analysis (PWA) requires massive computing resources and efficient algorithms. Parallelization has been pursued at all levels: vectorized operations on CPUs, PWA on GPUs, and on-demand, fully threaded reconstruction and analysis. The computing resources of the collaboration are being integrated with the Open Science Grid (OSG) for opportunistic access to high-throughput resources.

4 Outlook

The civil construction of the new facility is almost finished, with detector installation beginning within months. Construction of major detector components is well underway. First beam is expected in 2014.

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