GlueX a new facility to search for gluonic degrees of freedom in mesons.

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Abstract. The GlueX detector facility in Hall-D at Jefferson lab in Newport News is part of the 12 GeV upgrade and dedicated to the search for gluonic degrees of freedom in mesons by scattering high energy linearly polarized real photons of up to 9 GeV from nucleon targets. Civil construction of the Hall-D complex has started as well as the construction of the various detector components. The current status of the project is outlined here.

Keywords: GlueX, exotics, hybrids, flux tube

INTRODUCTION

While gluonic degrees of freedom in nucleons are well established in experimental measurements their counterpart in mesons, a quark-anti-quark system, has not been confirmed. The quantum numbers of mesons are expressed in terms of the quantum numbers of their constituents, the spin and angular momentum, and can be attributed to quark degrees of freedom only for mesons observed so far in various experiments. The quantum numbers of a meson are labeled as $J^{PC}$ with $J$ the total angular momentum of all the constituents, $P$ the parity of the meson system and $C$ the charge-parity of the system. If only the two fermions contribute we find the following possible combinations of quantum numbers: $0^{++}, 0^{-+}, 1^{++}, 1^{--}, 2^{++}, \ldots$. In particular combinations of quantum numbers like $0^{--}, 0^{+-}, 1^{+-}, 2^{+-}$ can not be generated by the degrees of freedom of two fermions only. An Additional degrees of freedom is necessary for a meson to have such quantum numbers. Hence such quantum numbers are called exotic quantum numbers. A natural candidate for an additional degree of freedom in mesons is the gluon. Mesons with such gluonic excitations are called hybrid mesons. Experiments searching for such hybrid mesons are looking for mesons with exotic quantum numbers. Most of these experiments use pion beams on proton or nuclear targets [1] [2] [3] or a real photon beam[4]. These experiments reported results of partial wave analyses with a possible candidate for a meson with exotic quantum numbers in the mass range of about 1.6 GeV/$c^2$.

Lattice QCD calculations have improved significantly over the last decade and provide us with results that suggest the lowest lying mass state of such hybrid mesons to be in the region of 2 GeV/$c^2$ with quantum numbers $1^{--}$ [5]. In the most naive assumption of the $1^{--}$ state carrying one unit of gluon excitation with the spins of the quark and anti-quark parallel it can be advantageous to use a real photon beam to produce such a state because the hadronic structure of the photon is a $q\bar{q}$ state with their spin already parallel. This means that helicity flip amplitudes are not required in the production of such a meson as they would be with a pion beam. More importantly the polarization direction provides an additional reference axis that can help in a partial wave analysis to disentangle the different amplitudes.

THE GLUEX EXPERIMENT

The GlueX experiment will use a linearly polarized high energy photon beam impinging on a liquid hydrogen target. The data acquisition will record any possible reaction of sufficient high energy providing an unbiased data sample. The produced multi-particle final states are then searched for mesons with exotic quantum numbers applying partial wave analyses. This general approach requires a hermitian detector system that is capable of recording all final state particles in a reaction with sufficiently high efficiency.
The photon beam is generated through coherent bremsstrahlung from a primary electron beam provided by the CEBAF accelerator in passing it through a 20 µm thick diamond radiator. The crystal structure of the diamond causes linearly polarized photons in the process of coherent bremsstrahlung. The polarization can be optimized by adjusting the crystal axis with respect to the electron beam direction. For the GlueX experiment an incident electron beam energy of 12 GeV will lead to a coherent bremsstrahlung peak at a photon energy of about 9 GeV with a polarization of approximately 40%. The full photon beam spectrum as a function of photon energy is shown in figure 1. The photon beam is separated from the electron beam by a vertical 1.5 T dipole field. This magnet is also used to momentum analyze the electrons that underwent bremsstrahlung by detecting them in two arrays of scintillation detectors located in the focal plane of the dipole magnet. A fixed array hodoscope consisting of 192 scintillators covers the photon energy range between 3.0 GeV and 11.7 GeV. Each counter covers a ∼30 MeV energy bite. In the low energy region these detectors cover about 50% of the focal plane while in the high energy region they cover 100%. A second scintillator array, the “microscope”, covers the region of the coherent bremsstrahlung peak around 9.0 GeV. This detector system is made of 2 mm x 2 mm x 20 mm fibers arranged in a matrix of 120x5 with the long dimension parallel to the focal plane. The fiber width covers an energy bite of ∼8 MeV covering the photon energy spectrum between 8.3 GeV and 9.1 GeV. This is the main part of the coherent bremsstrahlung peak. The exact shape of this peak is a measure of degree of polarization of these photons. A collimation system in combination with a long base line streamlines the photon beam by reducing significantly the number of photons from incoherent bremsstrahlung [6]. This behavior is due to the fact that the angular distribution of coherent bremsstrahlung photons is much more forward peaked than incoherent bremsstrahlung. Figure 1 shows the effect of the collimator reducing the initial beam intensity labeled as “rate in tagger” to the final photon beam intensity after the collimator, labeled as “rate on target”. Also shown is the polarization of the photons as a function of energy.
GlueX detector

The necessity to detect multi-particle final states and full reconstruct each event a hermitian spectrometer is required. This is achieved with a 2 T superconducting solenoidal magnet in combination with detectors in the bore and downstream of the magnet as shown in figure 2. A 30 cm long liquid hydrogen target is located on the central axis of the solenoid surrounded by a thin scintillator hodoscope to provide timing information. A cylindrical straw tube chamber and cathode strip wire chambers provide position information for tracking charge particles while two electromagnetic calorimeters one inside the magnet bore and one down stream of the magnet provide the necessary energy measurements of charged and neutral particles. Downstream in front of the forward calorimeter a scintillator hodoscope will provide additional timing information on charged tracks for particle identification.

Charged Particle Tracking

The GlueX detector has two types of tracking chambers, a cylindrical straw tube wire chamber (CDC) located around the target and four packages of cathode strip wire chambers (FDC) downstream of the target. The CDC consists of 3522 straw tubes of 150 cm length. They are located at radial distances between 10 cm and 55 cm around the target and are arranged in packages of 4 layers either parallel or with a ±6° stereo angle with respect to the beam axis. In total there are 12 axial layers and 16 stereo layers. The tubes have a diameter of 1.6 cm with a 20µm diameter gold plated tungsten wire at its central axis. The operating gas is an Argon CO₂ mixture. Studies with a prototype chamber using cosmic rays achieved a position resolution of \( \sigma_r = 150\mu m \). The combination of axial and stereo layers will provide additional information on the axial coordinate of the tracks along the beam line. The FDC are packages of planer wire chambers with the cathode planes on each side of the wire plane segmented in strips of 4 mm width with a pitch of 5 mm. These strips are oriented at ± 75 degree with respect to the wire orientation.
on each side of the wire plane. The wire planes have 20\(\mu\)m diameter gold plated tungsten sens wires and 80\(\mu\)m gold plated copper-beryllium field wires separated by 5 mm leading to a cell size of 1 cm. Each wire plane has 96 sens wires with two cathode planes of 216 copper strips each. A total of 6 such chambers form one package of which there are four in total. In a given package each successive wire plane is rotated by 60° with respect to the previous one. The additional information from the cathode strips improve the pattern recognition in particular for multi-track events. Cosmic ray test with a prototype chamber have shown a position resolution of \(\sigma_r = 200\mu m\) perpendicular to the wire from the drift time information and \(\sigma_l = 200\mu m\) along the wire from the cathode strip information.

Calorimetry

There are two electromagnetic calorimeters in the GlueX detector. The barrel calorimeter (BCAL) is in the bore of the magnet around the target while the forward calorimeter (FCAL) is about 5 m downstream of the target. The BCAL is a sampling calorimeter built as a matrix of scintillating fibers and lead. It is a cylinder with 48 segments. Each segment is a wedge of 380 cm length with thickness of 22.5 cm resulting in 15.5 radiation lengths. It covers the angular region between 11° and 125°. The scintillation light will be detected on both ends of the barrel with silicon photo multipliers (SiPM). Each of these SiPMs has an active area of about 1.2 cm x 1.2 cm and is made up of 16 cells of 3 mm x 3 mm silicon pads. These newly available sensors will operate in the high magnetic field region of the solenoid avoiding the necessity long light guides. Timing information will allow the determination of the shower position along the barrel. Beam tests with full scale prototype of one wedge indicate an expected relative energy resolution of \((\sigma_E/E = 5.54/\sqrt{E+1.6})\)% with a position resolution along the barrel of \(\sigma_z = 5.0/\sqrt{E}\) mm. This is consistent with results by the KLOE experiment for a similar calorimeter[7].

The FCAL is a lead glass calorimeter covering an angular range between 1° and 11° located about 5 m downstream of the target center. 2800 lead glass blocks of 4 cm x 4 cm x 45 cm are stacked in a circular shape. Each block is optically isolated and coupled to a 1 inch diameter photo multiplier (PMT) through a plastic light guide. Due to the large fringe fields of the solenoid each PMT requires sufficient iron shielding for operation. The PMTs are powered by Cockcroft-Walton bases that generate the necessary high voltage locally eliminating costly high voltage cables. A very similar arrangement with the same lead glass blocks was used in the E852 experiment at Brookhaven National Lab [8]. Due to the better light collection using light guides as compared to E852 a relative energy resolution of \((\sigma_E = 5.7/\sqrt{E+2.0})\)% is expected with a position resolution of the shower of \(\sigma_{xy} = 6.4/\sqrt{E}\) mm.

Particle Identification

In the forward region of the GlueX detector a time of flight scintillator hodoscope provides the necessary information in combination with the particle trajectory to determine the particle type. This method is applicable to particles with momenta below 2.5 GeV/c covering the angular range between 1° and 11°. The combined timing resolution of planes of scintillator hodoscopes is expected to be better than 80 ps [9]. Similarly the timing information from the BCAL can be used to determine the particle type for momenta below 0.5 GeV/c. In addition the measured energy loss dE/dx of particles in the CDC in combination with its momentum can be used to determine the particle type at momenta below 0.5 GeV/c.

As indicated in figure2 some space is available in front of the FCAL for a potential upgrade of the GlueX detector system with a detector based on the Cerenkov effect that covers high momentum particles above 2.5 GeV/c for particle identification.

Readout Electronics

The front end electronics for digitization and read out is developed at JLab and based on the VME crates with a VXS back plane architecture. The signal pulse height is recorded with flash ADCs at a rate of 250 MHz for the calorimeters and at 125MHz for the cathode wire chambers. Sums of the calorimeter signal amplitudes are calculated on board at the sampling rate of 250MHz and shipped via the VXS back plane to a trigger processor in the center of the crate that calculates amplitudes sums of the entire crate from which it is shipped to a global trigger crate where the energy deposition of complete detectors are calculated, all this at the same rate of 250MHz. At this stage a trigger decision
is made and a possible trigger signal is distributed back to all crates via fiber optics. The ADCs and TDCs are read out by a read out controller through the VME back plane. The maximum trigger rate is 200kHz. Timing information is recorded with the F1TDC, a multi-hit TDC with 60 ps timing resolution. The memory size of these modules allows for a latency of up to 3µs between the occurrence of an event and the trigger decision. At high luminosity operation of $10^8$γ/s in the coherent region a data rate of 3GB/s is expected. A level 3 trigger farm will reduce this data by 90% to about 300MB/s on tape leading to about 3PB/year data on mass storage.

**STATUS**

At the time of writing (January 2010) construction of the HallD complex at Jefferson Lab is continuing with the floor base of HallD ready for concrete poring. At the same time construction of the BCAL has begun and the first module is finished with 47 more to go. The hall is expected to be ready for detector installation by August 2011 and beam on target by April 2014.

**ACKNOWLEDGMENTS**

**REFERENCES**