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QCD confinement and the GlueX experiment at Jefferson Lab*

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Abstract An understanding of the confinement mechanism in QCD requires a detailed mapping of the spectrum of hybrid mesons. Understanding confinement means understanding the role of gluons and it is in hybrid mesons that the gluonic degrees of freedom are manifest. High statistics searches for such states with π and p beams have resulted in some tantalizing signals. There is good reason to expect beams of photons to yield hybrid mesons with J^{PC} quantum numbers not possible within the conventional picture of mesons as $q\bar{q}$ bound states. Meager data currently exist on the photoproduction of light quark mesons. This talk represents an overview of the available data and what has been learned. In looking toward the future, the GlueX experiment at Jefferson Laboratory represents a new initiative that will perform detailed spectroscopy of the light-quark meson spectrum. This experiment and its capabilities will be reviewed.

Key words GlueX, exotics, flux tube

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1 QCD and exotic hybrid mesons

The specific goal of the GlueX collaboration at Jefferson Laboratory is to better understand the detailed nature of confinement. The nature of this mechanism is one of the great mysteries of modern physics, and in order to shed light on this phenomenon, we must better understand the nature of the gluon and its role in the hadronic spectrum. Confinement within the theory of strongly interacting matter, Quantum Chromodynamics (QCD), arises from the postulate that gluons can interact among themselves and give rise to detectable signatures within the hadronic spectrum. These signatures are expected within hadrons known as hybrids, where the gluonic degree of freedom is excited and can provide for a more detailed understanding of the confinement mechanism in QCD.

Gluonic mesons represent a $q\bar{q}$ system in which the gluonic flux-tube contributes directly to the quantum numbers of the state. In terms of the constituent quark model, the quantum numbers of the meson are determined solely from the quark and antiquark. However, QCD indicates that this simple picture is incomplete. Lattice QCD calculations predict that hybrid states with the flux-tube carrying angular momentum should exist, as well as purely gluonic states (called glueballs). Modern lattice calculations for mesons show that indeed a string-like chromoelectric flux-tube forms between distant static quark charges as shown in Fig. 1(a). The non-perturbative nature of the flux-tube leads to the confinement of the quarks and to the well-known linear inter-quark potential from heavy-quark confinement with $\mathrm{d}V/\mathrm{d}r \sim 1$ GeV/fm (see Fig. 1(b)). These calculations predict that the lowest lying hybrid meson states are roughly 1 GeV more massive than the conventional meson states. This provides a reference point for the mass range to which experiments must be sensitive.

1.1 Photoproduction of hybrids

Photon beams are expected to be particularly favorable for the production of exotic hybrids. The reason is that the photon sometimes behaves as a virtual vector meson (a $q\bar{q}$ state with the quark spins parallel, adding up to total quark spin S=1). When the flux tube in this S=1 system is excited to its first

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level, both ordinary and exotic J^{PC} are possible. In contrast, when the spins are antiparallel (S=0) as in pion or kaon probes, the exotic combinations are not generated. To date, almost all meson spectroscopy experiments in the light quark sector have been done with incident pion, kaon, or proton probes or in $p\bar{p}$ annihilations. High flux photon beams of sufficient quality and energy have not been available, so there are virtually no data on the photoproduction of mesons with masses below 3 GeV. Thus, up to now, experiments have not been able to search for exotic hybrid mesons precisely where they are expected.

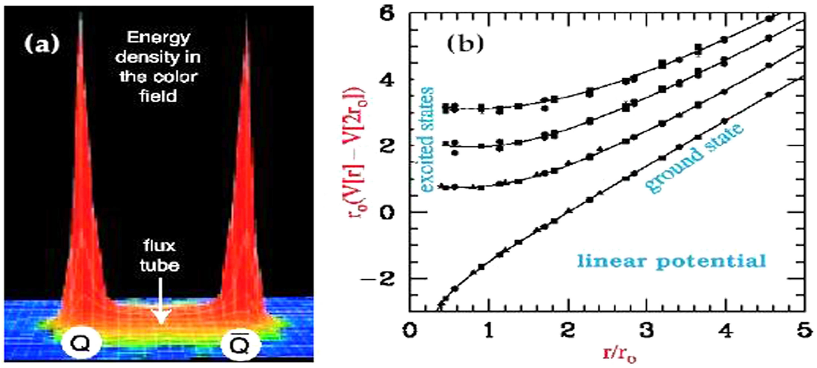

Fig. 1. (color online). Lattice calculation of the hybrid potential [1].

1.2 Evidence for gluonic excitations

There are some tantalizing hints that gluonic excitations have been observed experimentally. Three exotic states, each with $J^{PC} = 1^{-+}$, have been reported by the E852 collaboration at Brookhaven Laboratory and confirmed in independent experiments. The first state reported has a mass of 1.4 GeV/c^2 and decays into $\eta\pi^-$ [2]. The interpretaion of the data leading to this conclusion is not without controversy. The second state reported has a mass of 1.6 GeV/c^2 and decays into $\rho^\circ\pi^-$ [3]. In both cases the exotic signal is several percent of the more dominant signals observed in the two modes. For example in the $\eta\pi^-$ channel, the dominant signal is the $a_2(1320)$ and in the $\rho^\circ\pi^-$ channel the dominant signals are the $a_1(1260)$, $a_2(1320)$ and $\pi_2(1670)$. The third state reported is perhaps on firmer ground and has a mass of 2.0 GeV/c^2 and decays into $f_1\pi$ [4] and $b_1\pi$ [5]. The presence of the exotic signal is not at all evident by a simple examination of the effective mass spectrum of these states. A partial wave analysis (PWA) must be performed. Such an analysis involves a decomposition of the mass sepctrum into partial waves. The identification of a resonant wave depends on both the line shape (amplitude) and the phase motion (interference of a particular wave with other waves) as a function of mass. Application of the PWA technique to identify small signals puts stringent requirements on the detector. Exclusive events must be kinematically identified implying the need for a hermetic detector with excellent resolution and particle identification capability. With incident photons, maximum PWA information comes from using linearly polarized photons.

2 The GlueX experiment

2.1 Linearly polarized photon beam

The GlueX experiment will use a beam of tagged, linearly polarized photons. The photon beam is generated through coherent bremstrahlung from the primary electron beam provided by the accelerator by passing it through a 20 μm diamond radiator. The crystalline structure of the diamond produces linearly polarized photons with enhancements in the energy spectrum that can be tuned by adjusting the angle of the diamond w.r.t the electron beam. For the GlueX experiment, the peak will be tuned to E_γ=9 GeV which results in a polarization of approximately 40% after collimation.

The photons in the beam are “tagged” by measuring the residual energy of the post-bremstrahlung electron via a 1.5 T dipole magnet. The electron is detected using 2 different arrays of scintillator detectors, one courser with wider energy coverage, and the other finer with better energy resolution, but covering a smaller energy range. The “Fixed Array” hodoscope consists of 192 scintillators covering the 3.0-11.7GeV range with each counter spanning a 30 MeV energy bite. In the energy range below 9 GeV, gaps between detectors exist such that there is only 50% coverage. Above 9 GeV, there is 100% coverage. The microscope array is made of 2 mm×2 mm fibers which form a 11×5 grid. The fibers span 8MeV energy bites leading to about an 800 MeV range in energy coverage. The microscope tags photons in the 8.3-9.1 GeV range for the GlueX experiment, it is designed to be relocatable in order to modify the energy range for additional measurements.

2.2 GlueX detector

The GlueX detector uses a geometry based on solenoidal magnetic field, this is ideal for a fixed-target photoproduction experiment (Fig. 2). The solenoidal magnetic field traps low energy electromagnetic backgrounds (e^+e^- pairs) generated in the target inside a cone around the beam. It also allows for effective instrumentation of calorimeters to achieve very high acceptance for photons. The superconducting solenoid produces a 2.25 T field. A tagged, $\approx$9 GeV, linearly polarized ($\sim 40\%$) photon beam is incident on a 30 cm long liquid-hydrogen target that is surrounded by a start counter which is used in triggering. Next is a cylindrical tracking chamber, the CDC, and then a cylindrical electromagnetic calorimeter, the BCAL. Downstream of the CDC are four packages of circular planar drift chambers, FDC, followed by a time-of-flight wall, TOF. This is followed by a circular planar electromagnetic calorimeter, the FCAL. Space has been reserved between the downstream end of the magnet and the TOF for a possible particle identification (PID) system. This design provides for nearly 4π acceptance for both charged particles and photons.

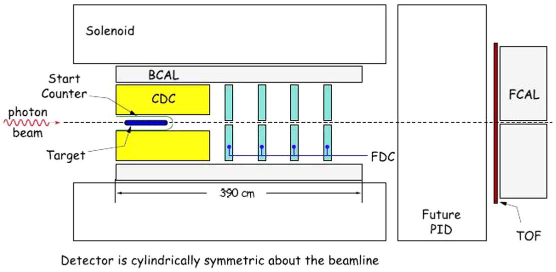

Fig. 2. (color online). Schematic of the GlueX detector.

2.3 Electronics and data rates

The GlueX experiment will consist of digitization electronics which are fully pipelined with front-end memory capable of buffering over 3 μs of data which allows 3 μs in which to make and distribute a level 1 trigger decision. The pulse height information will be digitized using 125 MHz and 250 MHz flash ADC modules and the high resolution timing information will be digitized using a F1TDC module with 60 ps least count capability. All digitization electronics will be VME based.

For high luminosity running, the integrated data rate from the front end modules will be 3 GB/s. A level 3 trigger farm will be used to filter out about 90% of the events leaving a final data rate to tape of 300 MB/s resulting in about 3PB/yr going to mass storage.

3 Conclusions

Understanding confinement requires an understanding of the glue that binds quarks into hadrons. Hybrid mesons are perhaps the most promising laboratory to study the nature of the glue. However, since their first observation, their existence has been controversial, but a number of experimental results have provided tantalizing hints for the existence of these mesons. Future studies, such as will be performed with the GlueX experiment at JLab, provide the hope for improved experimental results and interpretations. Here photoproduction promises to be rich in hybrids, starting with those having exotic quantum numbers where little or no data exist. The GlueX experiment that will take place at the energy-upgraded Jefferson Laboratory, will employ photon beams of the necessary flux, duty factor, and polarization, along with an optimized state-of-the-art detector. This experiment will provide for the detailed spectroscopy necessary to map out the hybrid meson spectrum, which is essential for an understanding of the confinement mechanism and the nature of the gluon in QCD.

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