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GlueX: The search for gluonic excitations

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Abstract. The phenomenon of confinement in QCD remains a fundamental, unanswered question, and so does the significance of hybrid mesons in understanding QCD in the confinement region. The GlueX experiment will search for all hybrid exotic and non-exotic mesons in the mass range up to 3.0 GeV/c^2. This contribution deals exclusively with the search for exotic hybrid mesons.

PACS. 12.38.-t Quantum chromodynamics – 12.38.Aw General properties of QCD (dynamics, confinement, etc.) – 12.38.Qk Experimental tests – 29.30.-h Spectrometers and spectroscopic techniques

1 Introduction

The physics motivating the search for hybrid mesons, and their significance in terms of our understanding QCD in the confinement region, has been presented in detail by T. Barnes (this issue, p. 489). Although GlueX will also search for all hybrid mesons and other non-exotic mesons (such as $\bar{s}s$) in the mass range up to 3.0 GeV/c^2, the flagship experiment in GlueX is the search for exotic hybrid mesons. In this context, exotic hybrid mesons are hybrids with a gluonic excitation resulting in J^{PC} combinations which are not possible with $q\bar{q}$-mesons. This presentation, then, will address this part of the GlueX program exclusively.

2 Physics goals

In the "normal", meaning $q\bar{q}$, mesons, the gluons connecting the two quarks do not contribute to the J of the system. The quantum numbers of the normal mesons, then, are defined by the total spin S of the two quarks and their radial L which combine to form specific values and signs of J, P and C. These combinations can only lead to certain values, for example: $J^{PC} = 0^{-+}, 1^{+-}, 2^{-+}$. One of the promising theoretical models of quark-gluon interactions in the confinement region, the Flux Tube Model (FTM), treats the gluon field as self-interacting strings forming a tube anchored on q and $\bar{q}$, respectively. This tightly contained flux of the gluonic field forms the "tube"-like conduit, thus the name of the model. Lattice Gauge Theory (LGT) also predicts a "tube"-like field on the lattice.

The notion of string-like interaction, that has a constant force as a function of radial distance between q and $\bar{q}$, while its potential energy increases linearly with the same, naturally leads to confinement. The FTM, then, if proven correct, will lead to a new understanding of the mechanism leading to confinement. In this model, excitation of the flux tube, which is in its ground state in a normal meson, will contribute an additional quantum degree of freedom, that of the J of the tube itself. In its first-excited state, $J = 1$. This, combined with the J, L of the quarks can lead to combinations of J^{PC} not possible in normal mesons. Such combinations are the fingerprints of gluonic excitations and a confirmation of the non-trivial role of the glue in the system. Mesons with $J^{PC} = 0^{+-}, 1^{-+}, 2^{+-}$ are such states of hybrid mesons with exotic quantum numbers, thus the term exotic hybrids.

In order for exotic quantum states to be populated with $J^{PC} = 0^{+-}, 1^{-+}, 2^{+-}$, the spin of the incident probe must be $S = 1$. If pions, for example, are used as probes, hybrids may be created but only with the same combinations of $J^{PC} = 0^{-+}, 1^{+-}, 2^{-+}$ as normal mesons. It is possible that, with a spin-flip of one of the quarks in the pion during the interaction, exotic combinations may be populated. Clearly, this is a weaker process; therefore $S = 0$ probes have a greatly suppressed probability of exciting exotic numbers compared to $S = 1$ probes. Photons, then, of appropriate energy, are the ideal probes to lead to exotic-hybrid-meson production.

While hybrid mesons can have J^{PC} combinations identical to those of $q\bar{q}$-mesons, and therefore they can mix with them, exotic hybrids do not. Identification of exotic J^{PC} combinations isolates hybrid mesons from all other mesons, which may or may not be hybrid. In order to do this, Partial-Wave Analysis (PWA) of the data

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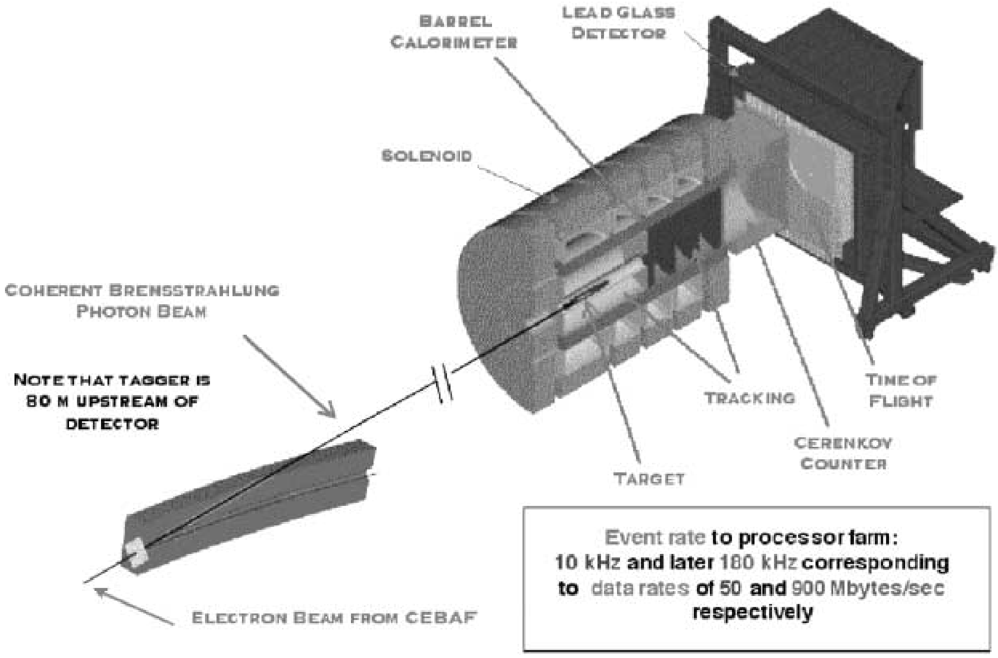

Fig. 1. A schematic diagram of the GlueX detector, not to scale. The super-conducting magnet solenoids are elements of the LASS/MEGA detector while the Pb-glass array also exists and is from the BNL E852 experiment.

is required. This, in turn, dictates a hermetically designed detector that is capable of good four-momentum resolution for charged as well as neutral particles. The experiment should also satisfy the requirements of excellent statistics, so that a binning in t will help the identification of the production mechanism and spectral shape deconvolution. Furthermore, beam polarization, while not a necessity in physics arguments, becomes, nevertheless, a requirement to further delineate the reaction mechanism. Excellent statistics means intense beams of good emittance. All these requirements combine to make the 12 GeV energy upgrade at JLab the facility of choice. Finally, the beam energy and detector parameters should be such that masses up to 3 GeV/c^2 are accessible, since this is the area of interest based on both FTM and LGT results.

3 The Hall D detector

The Hall D Collaboration was formed in order to pursue GlueX and beyond. The Collaboration consists of 25 institutions representing the US, Canada, Russia and the UK with nearly 100 physicists and engineers involved. Theoretical contributions to the overall effort are significant as are software physicists' contributions. With the proposed 12 GeV energy upgrade, Hall D will consist of a new beam line, taking advantage of the full 12 GeV electron beam energy, a tagged coherent bremsstrahlung photon beam optimized for 8-9 GeV energy and flux approximately $10^8\gamma$/s.

The detector, radiator and tagger are shown schematically in fig. 1. The distance between the radiator and the target is approximately 80 m. The radiator will consist of diamond wafers 20 μm thin of superior crystalline quality to produce coherent bremsstrahlung photons of 40% linear polarization and the flux required.

The detector consists of a system of four superconducting solenoid elements with an inner diameter of approximately 95 cm and total length of 4.5 m. The axial central field is approximately 2.2 T. Tracking within the magnetic field will be provided by a series of drift chambers and a system of scintillating fibers (SciFi) surrounding the production target, which also provide some timing information. The barrel calorimeter (BCAL) completes the detector elements within the solenoid volume and it will consist of Pb/SciFi matrix of approximately 25 cm of thickness. The diameter of the SciFi strands will be 1 mm, while the thickness of each layer of Pb will be 0.5 mm. It is modeled after the KLOE calorimeter at DAΦNE, with significant improvements and modifications.

Outside the strong magnetic-field region, forward particle identification will be provided by a gas Čerenkov counter, a time-of-flight array of plastic scintillator counters with proven excellent timing resolution and the forward Pb-glass calorimeter. The latter has been employed successfully at BNL E852 that has reported the first exotic-hybrid-meson results. Significant efforts in shielding the PMTs from the strong stray field are continuing. Upstream of the solenoid, a veto counter will be employed to suppress charged particles entering (and leaving) the active volume of the BCAL. The overall design provides the required 4πSr solid angle with the energy and timing resolution to successfully pursue PWA.

Extensive MC simulations and PWA exercises have been made. One of the most important was the simulation of the system's response to an admixture of seven non-exotic signals corresponding to well-defined and understood processes and an exotic (weak) signal of $J^{PC} = 1^{-+}$ from experiment E852 ($\pi^- p \to \pi^- \pi^- \pi^+ p$) at BNL. The PWA, with input the resolutions and statistics expected from GlueX, successfully extracted the input signal with excellent agreement in $m_{\pi^-\pi^-\pi^+} = m_{\pi_2}$ and Γ_{π_2} with the inputs into PWA. This is a "worst-case scenario" because, as stated earlier, exotic hybrid production via pion beams is suppressed. With photons, the ratio of exotic to non-exotic meson production will be substantially higher than in E852.

4 The GlueX experiment

The Hall D Collaboration has been pursuing an active and aggressive schedule of preparations in the past four years. A number of reviews have been conducted by expert panels on the physics and the technical feasibility of GlueX. All reviews have been extremely positive. As a result of these reviews, particularly that of the Cassel Committee report, an ambitious R&D program has been pursued in the last three years and significant progress on studies, prototyping and in-beam testing, has led to the last version (v4) of the conceptual design report (CDR.v4) submitted by the Collaboration. The best source of references and detailed information, beyond the scope and space available to this contribution, can be found at `www.gluex.org`.

Finally, one has to address also the dreaded question: what if no exotic signal is extracted after some months of running GlueX? Even though tantalizing evidence for exotics has been provided by the E852 and Crystal Barrel experiments at BNL and CERN, respectively, there is always the possibility that a more precise and sensitive experiment, like GlueX, turns out negative results. This can lead to several important conclusions regarding the present understanding of gluon-quark dynamics by the FTM and LGT. First, if the masses of the expected exotic hybrid mesons, for example the π_2 (1^{-+}), are outside the range of GlueX capabilities ($m_{\pi_2} \geq 3$ GeV/c^2), whereas both theoretical models predict masses slightly below 2 GeV/c^2, the result will be a radical restructure of the models, if not outright rejection. Second, if the combination of production cross-section and width is such that the PWA cannot extract the signal from the background, it will mean that our theoretical understanding of QCD processes at such energies is out by several orders of magnitude. The conclusions will be similar to the scenario above. In either case, a negative result on exotic hybrids by GlueX will be a clear signal that fundamental aspects of quark-gluon interactions, and thus confinement, remain outside our understanding and radically new ideas need to be put forward.