PERSPECTIVES FOR GLUEBALLS SEARCH AT FUTURE GSI ANTIPROTON FACILITY*

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The present status of glueballs search is shortly reviewed, with special emphasis on search in proton-antiproton annihilation. The lattice QCD predictions for glueball mass spectrum are presented. We discuss the main requirements for the detector for glueball searches with the planned High Energy Storage Ring (HESR) at GSI Darmstadt. The parameters of the HESR are also given.

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1. Introduction

In the framework of the quantum field theory of strong interactions, quantum chromodynamics (QCD), mesons are interpreted as quark–anti-quark ($q\bar{q}$) bound states. The understanding of meson spectra is based on six flavours of quarks having a new degree of freedom — colour. The three lightest quarks are the starting point of the SU(3) flavour classification. According to this classification, mesons form nonets ($3 \times \bar{3}$) with the same value of spin, parity and charge conjugation. The QCD postulates that only colour-singlet ("colourless") objects can be observed. The QCD introduces

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eight gauge vector fields (vector bosons), the gluons (g), which are also colour-charged. Interactions between gluons are possible and non-Abelian nature of QCD allows therefore to build new, bound, colourless states consisting of two or more gluons — the glueballs (gg or ggg). The observation of glueballs and the precise measurement of their properties would be very important for understanding of dynamics of low-energy QCD, where perturbative methods cannot be applied, because the coupling constant becomes too large at low-momentum transfer.

2. Glueballs mass spectrum from lattice QCD

At present, the most reliable predictions on the glueballs mass spectrum come from the lattice QCD calculations. In this approach, the continuous theory of QCD is transformed to Euclidian space, then discretized, and placed in a finite box. Quarks are placed in sites whereas gluons live on links. By increasing the lattice volume and decreasing the lattice spacing to zero, "discrete" becomes "continuous". The lattice QCD calculations are performed assuming infinite quark masses *i.e.* neglecting $q\bar{q}$ loops.

This approximation implies that glueball states are not mixed with $q\bar{q}$ states. We may expect that the mixing with ordinary $q\bar{q}$ states, having the same quantum numbers, may change the glueballs mass spectrum. Fig. 1 shows the glueballs mass spectrum from lattice QCD calculations in quenched

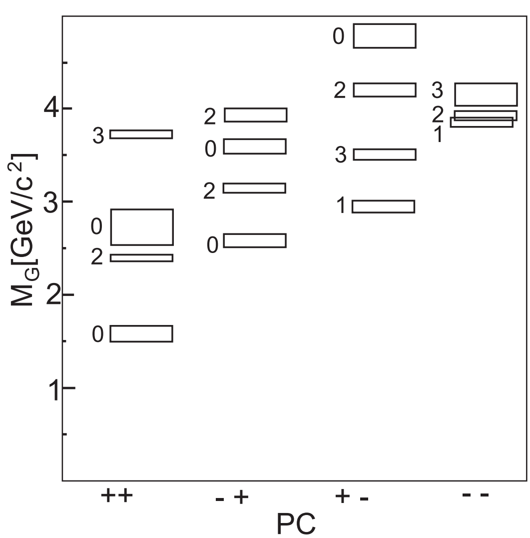

Fig. 1. The glueball mass spectrum from lattice QCD calculations in quenched approximation *i.e.* neglecting $q\bar{q}$ loops. (adopted from Ref. [1]).

approximation. As one can see, most of the low-lying glueball states have quantum numbers accessible also for ordinary $q\bar{q}$ states and therefore can be mixed with them. Such states can be identified as glueballs, or states having large gluonic content, by fulfilling meson nonets and looking for extranumerous states. Also careful inspection of their decay pattern may indicate on their nature. The quantum numbers of the $J^{\rm PC}{=}2^{+-}$ state are forbidden for $q\bar{q}$ states, therefore its identification can be more straightforward.

3. Present status of glueballs search

So far the prime glueball candidate is the scalar state $f_0(1500)$. It has been observed in central collisions [2, 3], J/ψ radiative decays [4] and $\bar{p}p$ annihilations [5,6] *i.e.* in glue-rich environment, and is not present in $\gamma\gamma$ collisions [7]. There are five isoscalar scalar resonances: $f_0(400$–$1200)$, $f_0(980)$, $f_0(1370)$, $f_0(1500)$ and $f_0(1710)$, whereas the meson nonet can only host four. The Crystal Barrel collaboration analyzed high statistics data from $\bar{p}p$ annihilations at LEAR and measured $f_0(1500)$ decays into $\pi^0\pi^0$, $\eta\eta$, $\eta\eta'$, K_LK_L and $4\pi^0$. Also other scalar states have been observed in this experiment. The small $f_0(1500)$ width and decay branching ratios support its interpretation as the glueball state mixed with quarkconia. However, the final classification of scalar nonet states is still a matter of debates.

The second lowest glueball state predicted by lattice QCD calculations is the tensor state with a mass of about 2.4 GeV/c^2. In this mass region an extremely narrow (width$\sim$ 20MeV/c^2) state $\xi(2230)$ has been seen in Mark III [8] and BES [9] experiments. However DM2 collaboration [10] failed in finding $\xi(2230)$ resonance in J/ψ radiative decays. Also a high resolution search for a tensor glueball in the mass region 2.23 GeV/c^2 in $\bar{p}p$ annihilations gave negative result [11]. No signal has been observed in $\bar{p}p \to \eta\eta$ cross section which could have been associated with a glueball formation. Therefore, one can conclude that the suspicion of the glueball nature of the $\xi(2230)$ state needs farther studies.

4. General layout of the HESR and detector for hadron spectroscopy

The Superconducting Synchrotrons SIS100/200, the Collector Ring, the New Experimental Storage Ring, the Super Fragment Separator, the proton liniac and High Energy Storage Ring (HESR) are planned as a new GSI facility [12]. It will be a unique opportunity to perform a broad spectrum of research: nuclei far from stability, hadron spectroscopy, compressed nuclear matter, high energy density in bulk matter and ion-matter interactions. The proton-antiproton ($\bar{p}p$) annihilation is well known glue-rich environment, and therefore the glueball searches, as a part of broad hadron spectroscopy research program, can be done with HESR.

TABLE I

General parameters of HESR. High luminosity mode uses stochastic cooling, whereas high resolution mode electron cooling. The high resolution mode is foreseen for antiproton beam momenta of up to 8 GeV/c.

Parameter	value
Beam momentum	1.5–15.0 [GeV/c]
Production rate L_R	10^7/s
Number of stored antiprotons	5×10^{10}
Luminosity	$2 \times 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ — high luminosity mode
	$10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ — high resolution mode
Relative momentum spread $\Delta p/p$	$\sim 10^{-4}$ — high luminosity mode
	$\sim 10^{-5}$ — high resolution mode

Table I summarizes the main HESR parameters. The usage of internal antiproton beam and hydrogen cluster/pellet target is foreseen. In order to realize the hadron spectroscopy research the planned detector should: cover nearly full solid angle, allow for good particle identification and accept high rate of annihilation events (total cross section of 100 mb). Measurements of processes with nb cross sections will require efficient trigger system. Magnet surrounding the detector will allow for tracking of charged particles. They will be identified with ring imaging Cerenkov detector. Photons will be measured in calorimeter. All these components form an "onion-like" structure of the detector, whereas muon counters and hadron calorimeter are parts of the forward spectrometer. There is a justifiable believe that glueball states will be observed with a new detector operating on HESR.

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