New Spectroscopy

I. INTRODUCTION AND PLAN

Although the Standard Model of elementary particles is well established, QCD, the fundamental theory of strong interactions, provides a quantitative comprehension only of phenomena at very high energy scales, where the perturbation theory tool is effective due to asymptotic freedom.

The description of hadron dynamics below the QCD dimensional transmutation scale is therefore far from being a problem under full theoretical control.

Systems that include heavy quark-antiquark pairs (quarkonia) are an ideal and unique laboratory to probe both the high energy regimes of QCD, where an expansion in terms of the coupling constant is possible, and the low energy regimes, where nonperturbative effects dominate.

For this reason, quarkonia have been studied for decades in great detail. The actual level of understanding of the quarkonia mass spectra is such that a particle mimicking quarkonium properties but not fitting any quarkonium level is most likely to be considered of a different nature.

In particular, in the past few years B-Factories, and Tevatron, have provided evidence for states that do not match the conventional mesonic interpretation and that instead could be made of a larger number of constituents [1]. While this possibility has been considered since the beginning of the quark model [2], the actual identification of such states would represent a major revolution in the panorama of elementary particles. It would also imply the existence of a large number of states that have never been observed until now.

Finally the study of the strong bound states could be of relevance to the comprehension of the Higgs boson in case it turns out to be itself a bound state as predicted by several technicolor models (with or without extra dimensions) [3]

The currently most credited possible states beyond the mesons and the baryons are

- **hybrids:** bound states of a quark-antiquark pair and a number of *constituent* gluons. The lowest lying state is expected to have a quantum numbers $J^{PC} = 0^{+-}$. The impossibility of a quarkonium state to assume these quantum numbers (see below) makes this a unique signature for hybrids. Alternatively a good signature would be the preference to decay into a quarkonium and a state that can be produced by the excited gluons (e.g. $\pi^+\pi^-$ pairs); see e.g. [4].
- **molecules:** bound states of two mesons, usually represented as $[Q\bar{q}][q'\bar{Q}]$, where Q is the heavy quark. The system would be stable if the binding energy would set the mass of the states below the sum of the two meson masses. While this could be the case for when $Q = b$, this does not apply for $Q = c$, where most of the current experimental data are. In this case the two mesons can be bound by pion exchange. This means that only states decaying strongly into pions can bind with other mesons (e.g. there could be D^*D states, but that the bound state could decay into it's constituents [5].
- **tetraquarks:** a *bound* quark pair neutralizing its color with a *bound* antiquark pair, usually represented as $[Qq][\bar{q}'\bar{Q}]$. A full nonet of states is predicted for each spin-parity, i.e. a large amount of states is expected. There is no need for these states to be close to any threshold [6].

In addition, before the panorama is not fully clarified there is always the lurking possibility that some of the observed states are misinterpretations of threshold effects: a given amplitude might be enhanced when new hadronic final states become possible, even in absence of resonances. Since the tetraquark model is the most robust and complete one in understanding the recent findings, we will show how the SuperBF data could verify or falsify it and distinguish it with respect to the other ones. In case the correct model proves to be a different one, we believe the arguments in this document will hold anyhow, since the modes to be explored and the required statistics for them cannot be significantly different.

Current experimental knowledge points to some good candidates for unconventional states, but on one side the overall picture is not complete and needs confirmation, on the other side discrimination among the above mentioned alternative explanations is needed. To pursue this program a much larger dataset than currently available is needed at several energies, all within the reach of the SuperBF.

Finally, bottomonium decays also allow direct searching for physics beyond the Standard Model in regions of the parameters space which have not been reached by LEP. In particular running at the center of mass of $Y(3S)$ for a relatively little portion of the SuperBF program would have a large sensitivity to a possible light Higgs boson, expected in extensions of the MSSM [7], via $Y(nS) \to H, A + \gamma$ decays, and to possible dark matter candidates, such as neutralinos, in $Y(nS) \to \chi_0\chi_0 \to$ invisible decays.

The full argumentation of the physics case for SuperB is in the works and will include the following:

- **The foundations of the tetraquark model: light meson spectroscopy**

  The tetraquark model originates and has its current best test bench in light meson spectroscopy, in particular the scalar nonet. We will summarize the evidences in this land and introduce the reason of interest of the recently discovered $Y(2175)$. We will then show the need for very high luminosity to fully understand this particle which could show all the three possible decay mechanisms of a light-light diquark-antidiquark state (quark exchange between diquarks, instanton induced quark rearrangement, diquark-antidiquark color string breaking).

  Also, the only current direct and strong evidence that the $f0(980)$ particle is a tetraquark comes from dispersion relation analysis in Ref. [8] and we argument which statistics is needed to explore the possibility, long discussed but never proven in a robust way, that the $f_0(1500)$ is indeed a glueball.

  Scalar mesons could play also a role in the high precision determination of CKM angles, think to the $B \to \rho\pi$ channel used to measure α [9].

- **Charmonium: current hints for a new spectroscopy**

  This section will review the experimental searches at the BF that lead to the identification of at least four tetraquark candidates decaying into charmonium.

- **Charmonium: observables at SuperB**

  The interpretation of the current tetraquark candidates still competes with other models. Further studies are needed to discriminate among them, all requiring an extremely high luminosity. Furthermore, in case strong interactions really favor the diquark aggregation a large wealth of new states are predicted and only a statistics much higher than currently available could complete the experimental picture.

- **Bottomonium spectroscopy**

  Bottomonium is much less known than Charmonium, some of the fundamental states not having been observed at all. Furthermore, the new possibilities of aggregation would still broaden the number of expected states: for instance just recently data from Belle have hinted to the existence of a tetraquark with mass close to the $Y(5S)$ itself. Potentialities of the SuperBF to search for the missing Bottomonium states and the new predicted ones will be discussed.

- **Search for Physics Beyond the Standard Model in Bottomonium decays**

  In spite of intensive searches performed at LEP [10], the possibility of a light non-standard Higgs boson has not yet been ruled out in several scenarios beyond the Standard [7, 11, 12]. Moreover, the LHC might not be able to find a signal from a light Higgs boson whose mass is below the $B\bar{B}$ threshold. A Super B factory should play an important and complementary role in this regard if systematics were under control. Testing lepton universality in Υ radiative decays to the few percent level or below [13] would probe the existence of a light pseudoscalar Higgs boson A^0 (preferred versus a scalar light Higgs H^0 by theory arguments based on Peccei-Quinn and R-symmetries) mainly decaying into taus: $\Upsilon(nS) \to \gamma A^0(\to \tau^+\tau^-)$ [14, 15]. Finally, let us also stress the relevance of invisible quarkonium decays for searches of light dark matter at a SuperB factory [16].

  This section will review the experimental sensitivities and translate them in search potentiality for these modes.

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