Does the Tensor Glueball ξ(2230) Exist?

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Abstract We show that the ξ(2230) must have a width much broader than the reported 20MeV. A broader width does not necessarily rule out the ξ(2230) as a glueball, but it does explain why the meson cannot be seen in $p\bar{p}$ experiments. Therefore, the controversy between different experimental results does not rule out the existence of the tensor glueball ξ(2230).

Key words tensor glueball, pp scattering, $p\bar{p}$ scattering

Gluons, with the property of self-interaction, were proposed long before quarks[1], in order to explain the strong interaction. In 1972, Fritzch and Gell-Mann[2] pointed out that "if the quark-gluon field theory indeed yields a correct description of the strong interactions, there must exist glue states in the hadron spectrum", and Frizch and Minkowski[3] presented a detailed discussion of the phenomenology of the glueball ("glue-states") spectrum.

Glueballs are bosons with baryon number and isospin equal to zero ($B = I = 0$). They are $SU(3)$ singlets, but only to the extent to which $SU(3)$ breaking effects can be neglected[3]. As color singlets, two-gluon glueballs have the same quantum numbers as two-photon systems, i.e, $J^{PC} = 2n^{++}, (2n+1)^{++}$ and $2n^{-+}$, with $n = 0, 1, 2, \cdots$.

The existence of glueball has been predicted in many QCD based models, and on the Lattice calculations. For example, MIT bag model[4] and its variant, the constituent gluon model[5], Flux-tube model[6], QCD sum rule[7], and Lattice Calculations[8]. Serious pursuits of glueball are now on.

In 1986, MARK Ⅲ at SLAC, investigating radiative decays of 5.8×10^6 J/ψ, reported an abnormally narrow enhancement[9], dubbed ξ(2230), in the K_SK_S channel ($M_\xi = 2230 \pm 10$MeV, $\Gamma_\xi = 18^{+23}_{-15} \pm 10$MeV) and K^+K^- channel ($M_\xi = 2230 \pm 15$MeV, $\Gamma_\xi = 26^{+20}_{-16} \pm 17$MeV). They reported allowed $J^{PC} = (\text{even})^{++}$. The upper limits (90% CL) were also set for decays of ξ(2230) into ππ and $p\bar{p}$ at the level $B(J/\psi\to\gamma\xi)B(\xi\to X) < 2\times10^{-5}$. At nearly the same time, Alde et al. also reported[10] a relatively broad enhancement ($\Gamma \leqslant 150$MeV) at $M_\xi = 2220$MeV in the reaction $\pi^- p\to nX, X\to\eta\eta'$. The legend of a 2^{++} glueball was born.

Unfortunately, in 1988, DM2 at ORSAY reported[11] on the radiative decays of a sample of 8.6×10^6 J/ψ, and concluded that in "neither channel K^+K^- or K_SK_S is ξ(2230) seen". The upper limits (95% CL) for both decays were lower than the branching ratios reported by MARK Ⅲ by a factor of two. They did, however, observe a broad enhancement ($\Gamma \approx 201 \pm 51$MeV) in the

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region ($M = 2197 \pm 17$MeV). It appeared that the legend of the narrow $\xi(2230)$ was dead.

Between 1987 and 1993, a number of attempts were made to look for the narrow $\xi(2230)$ in the $p\bar{p} \to K_S K_S$ and K^+K^- formation experiments[12]. None reported any success.

The legend of $\xi(2230)$ was revived by BES at BEPC in 1996 with a report[13] of the observation of $\xi(2230)$ in the radiative decays of 8.0×10^6 J/ψ. They claimed the observation of $\xi(2230)$ not just in the $K_S K_S$ and the K^+K^- channels, but also in the $\pi^+\pi^-$ and the $p\bar{p}$ channels, with masses in all channels between 2230 and 2235 MeV, width between 15 and 20 MeV, and the branching ratios $B(J/\psi \to \gamma\xi)B(\xi \to X)$ between 1.5×10^{-5} and 5.6×10^{-5}. In a subsequent publication[14], BES also reported the observation of $\xi(2230) \to \pi^0\pi^0$ at a 3.6σ significance level and 90% confidence limits at $B(J/\psi \to \gamma\xi)B(\xi \to \eta\eta) < 5.6 \times 10^{-5}$ and $B(J/\psi \to \gamma\xi)B(\xi \to \eta\eta') < 2.2 \times 10^{-3}$ in Ref.[15]. It appeared that $\xi(2230)$ is very much alive, perhaps even narrow than 20 MeV, and the reported width in each channel is almost exactly equal to the experimental resolution width.

However, more recent measurement[16] concluded that none of the two-body decays of $p\bar{p} \to \phi\phi$, $K_S K_S$, $\pi^0\pi^0$, $\eta\eta$ showed any evidence for the existence of the narrow $\xi(2230)$, i.e, in the proton-antiproton annihilation experiments no evidence is found for the existence of $\xi(2230)$, the much heralded candidate for the tensor glueball.

Does the tensor glueball exist? In this note we try to answer this question. We study high energy proton-proton elastic scattering in the framework of the Pomeron exchange model, which corresponds to $p\bar{p}$ scattering in the t-channel. The Pomeron has been thought of as being a Reggeized tensor glueball $\xi(2230)$[17] with quantum numbers $I^G J^{PC} = 0^+ 2^{++}$. In the present work, we use this assumption and assume the pp elastic scattering proceeds through the tensor glueball exchange mechanism. The partial decay width given by our present analysis shed light on the understanding of the unsettled experimental situation.

Our results obtained from applying the theory of tensor glueball formation and decay in the tchannel to fitting simultaneously the pp total cross section and to the diffraction peak of the pp elastic differential cross sections are tabulated in Table 1, where λ_s and λ_t are cut-off masses of the form factor used in this calculation[17]. g_1 and g_3 are coupling constants of P-and F-waves, respectively. $\Gamma_{f_2 \to p\bar{p}}$ is the partial decay width of f_2 meson into $p\bar{p}$ channel.

Table 1. Predicted partial decay widths to the $p\bar{p}$ channel from the pp scattering at $\sqrt{s}$ = 53GeV and 62GeV.

mesons	$\sqrt{s}$/GeV	λ_s/GeV	λ_t/GeV	g_1	g_3	$\Gamma_{f_2 \to p\bar{p}}$/MeV
$f_2(2230)/\xi$	53	0.65—0.67	3.79—3.82	1.70—1.72	0.00—0.02	1.94—1.99
	62	0.66—0.68	3.74—3.79	1.67—1.70	0.00—0.01	1.88—1.94
$f_2(2150)$	53	0.66	3.88—3.99	1.53—1.56	0.00—0.04	1.88—1.94
	62	0.67	3.89—3.96	1.49—1.55	0.00—0.05	1.41—1.53
$f_2(2010)$	53	0.66—0.67	3.42—4.35	1.04—1.18		0.54—0.70
	62	0.67	3.94—4.18	1.12—1.15	0.00	0.62—0.65

We see from Table 1 that the partial decay widths of all f_2 mesons, $\Gamma_{f_2 \to p\bar{p}}$, are extremely narrow. Furthermore, $g_3 \ll g_1$, which indicates the F-wave ($L = 3$) component of the vertex is negligeable. These results are due to the fact that the masses of these mesons are very close to the $p\bar{p}$ threshold. The narrowness of the partial width indicates that the $p\bar{p}$ decay channel must be a small part of the total decay width of these f_2 mesons.

The BES collaboration reported similar branching ratios (BR) for $\xi \to p\bar{p}$, K^+K^-, $K_S^0 K_S^0$, $\pi^+\pi^-$ decay modes. Later, they published[15,18] the observation of $\xi \to \pi^0\pi^0$, $\eta\eta$, $\eta\eta'$, $\eta'\eta'$. It is indicated that the BR for $\pi^0\pi^0$ is similar to that for $\pi^+\pi^-$. However, in Ref.[18] the width Γ_ξ^{tot} was not given by the analysis but was fixed at 20 MeV. As to the BR for $\eta\eta, \eta\eta', \eta'\eta'$, a much higher upper bound was given[15]. Assuming equal BRs for all these 8 decay modes and taking from Table 1 the average value of $\Gamma_{\xi\to p\bar{p}} = 1.94$MeV, we obtain $\Gamma_\xi^{tot} = 16$MeV. Considering the experimental uncertainty of the width given in Ref.[14] a width of 16 MeV has already reached the observed value. This implies that there are no other unobserved decay modes left. This is a very unlikely possibility.

It was also reported in Ref.[14] that the BR of ξ decaying into $\pi^+\pi^-$ is equal to or less than 2%. Assuming again equal BR, then the 2% fraction and $\Gamma_{\xi\to p\bar{p}} = 1.94$MeV imply that $\Gamma_\xi^{tot} = \Gamma_{\xi\to p\bar{p}}/0.02 = 97$MeV, which is very large compared with the $\Gamma_\xi^{tot} \approx 20$MeV given in Ref.[14]. In order to obtain 20 MeV, the 2% fraction would require that the predicted $\Gamma_{\xi\to p\bar{p}}$ should be reduced by a factor of 5, i.e, reducing the coupling constant g_1 by a factor of $\sqrt{5}$. We could not find such a solution in our analysis.

A broad width is also consistent with the non-observation of a resonance structure in the 2.23 GeV region in the $p\bar{p}$ experiment[16]. We recall that there are many broad f_2 resonances in the neighborhood of 2.23 GeV. Consequently, all these resonances contribute simultaneously to the $p\bar{p}$ reaction and the corresponding differential cross section is then given by

$$\left(\frac{d\sigma}{dt}\right)_{a'a} = \left|\sum_j \frac{C_{a';j}C_{j;a}f(t)}{S - M_j^2 + iM_j\Gamma_j^{tot}}\right|^2, \quad (1)$$

where S and t are the total energy and the momentum transfer, $f(t)$ the t-dependence of the differential cross section. The indices a and a′ denote, respectively, the initial ($p\bar{p}$) and the final ($\bar{h}h$) channels, with $C_{j;a} \propto \Gamma_{j\to a}^{1/2}$ and $C_{a';j} \propto \Gamma_{j\to a'}^{1/2}$ being the couplings of the initial and final states to the resonance j, respectively. The partial decay widths, $\Gamma_{f_2\to p\bar{p}}$, are theoretical predictions based on fitting simultaneously the pp total cross section and to the diffraction peak of the pp elastic differential cross section (see Ref.[17] for details) and given in Table 1. Clearly, a resonant structure will not show up in the energy dependence of the cross section if $C_{j;a} = 0$, i.e, if the resonance j does not exist. However, we advocate that even if the resonance does exist, the structure still may not be seen in the data.

We have examined the general feature of the energy dependence of the $p\bar{p}\to hh$ reaction by firstly considering a case where all the numerators in Eq.(1) are set to be equal, and take the published values for their respective $\Gamma_{f_2}^{tot}$, but treat Γ_ξ^{tot} as a variable. That is, we take the $f_2(1950)$, $f_2(2010)$, $f_2(2150)$, $f_2(2230)$/ξ and $f_2(2300)$ resonances into account. Our calculation shows that the shape of this energy dependence is very sensitive to the value of Γ_ξ^{tot}. A resonance peak can be clearly seen in the mass region 2200 to 2500 MeV when Γ_ξ^{tot} is narrower than 50 MeV. However, the peak is no longer significant when Γ_ξ^{tot} is 75 MeV, and disapears when Γ_ξ^{tot} reaches ~ 100MeV. The last two values are in line with the 97 MeV deduced from Refs.[13,14] that the BR of ξ decaying into $\pi^+\pi^-$ is equal to or less than 2% as mentioned previously.

We also consider an extreme case in which the numerator of the $f_2(2230)$/ξ term is reduced by a factor of 5 with respect to the other resonances. We note that even with this reduction, there is still a very clear resonance structure if $\Gamma_\xi^{tot} = 22$ MeV. However, the peak is no longer statistically significant when the width is 50 MeV, and completely disappears when the width is 75 MeV.

In conclusion, we claim that the $p\bar{p}$ experiment of Ref.[16] only scanned the mass region of 2222.7 to 2239.7 MeV, and consequently, can only confirm the existence of a narrow $f_2(2230)$/ξ resonance. In other words, no observation of the resonance structure in Ref.[16] is not a sufficient reason for rejecting the existence of ξ(2230), but may just indicate that ξ(2230) has a broad width. Our analysis puts, therefore, a lower bound of ~100 MeV for Γ_ξ^{tot}. The broader width does not necessarily rule out the ξ as a glueball, but it does explain why the meson cannot be seen in the p $\bar{p}$ experiments of Ref.[16].

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张量胶子球ξ(2230)存在吗?*

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摘要 指出了张量胶子球ξ(2230)的宽度要比文献中所报告的20MeV宽. 这个大的宽度并不能排除ξ(2230)作为一个胶子球的存在. 但是,它解释了为什么在p $\bar{p}$实验中看不到ξ(2230)存在的原因. 因此,在p $\bar{p}$实验中没观测到张量胶子球ξ(2230)存在的实验结果并不能排除张量胶子球的存在.

关键词 张量胶子球 pp散射 p $\bar{p}$散射

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