Comment on the narrow baryon peak reported by Amaryan *et al.*

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Abstract

The purpose of this note is to lay out the reasoning why the CLAS Collaboration as a whole did not approve the analysis of the narrow baryon peak claimed by Amaryan *et al.*. Here, we show that a broader analysis of all data, before restrictive kinematical cuts are applied, appears to be inconsistent with the statistical significance claimed by those authors.

Introduction

A paper was recently circulated by M.J. Amaryan *et al.* [1] with an analysis of the reaction $\gamma p \rightarrow pK_SK_L$ using data from the CLAS detector. The paper claims to observe a narrow peak in $M(pK_L)$, the mass of the pK_L system (measured via the missing mass of the K_S for events where a p is also detected, and the K_L is measured via missing momentum of the γpK_S system), at a mass of about 1.54 GeV, with a width of about 6 MeV. The statistical significance of the peak is claimed [1] to be 5.9 standard deviations (5.9-σ) above a background that varies markedly about the region of the peak. This peak, if real, would be consistent with the existence of an exotic baryon particle called the Θ^+. This same paper states that no peak is seen in the $M(pK_S)$ spectrum, where one would expect a peak at the same mass if the Θ^+ were real.

The above analysis uses data from the CLAS data set called $g11$, with the standard CLAS software for particle identification, momentum corrections, *etc.* The K_S particle is reconstructed from the 4-vectors of a pair of $\pi^+\pi^-$ mesons, measured in the CLAS detector, and the K_L particle is reconstructed via momentum and energy conservation (a technique called missing mass, M_X). In addition, the reconstructed vertex positions of the final state particles are used to improve the event selection. Overall kinematic restrictions are that $M_X(p)$, the missing mass of the proton, be at the mass of the

ϕ-meson ($1.01 < M_X(p) < 1.03$ GeV) and that the photon energy be below 2.6 GeV ($E_\gamma < 2.6$ GeV). The former cut is motivated by theoretical reasons of enhancing a possible pentaquark amplitude by interference with a strong ϕ-meson amplitude having the same final state [2]. The restriction on E_γ has no effect in the mass region of interest (the narrow peak in Ref. [1] is near missing mass $M_X(K_S) \simeq 1.54$ GeV, and due to other kinematic restrictions, photons above 2.6 GeV contribute only to masses $M_X(K_S) > 1.65$ GeV.)

Additional kinematic restrictions in Ref. [1] are: (a) a restriction on $t_\Theta = (p_\gamma - p_{K_S})^2$, the momentum transfer from the photon to the pK_L system; (b) $M(pK_S)$, the mass of the pK_S system. The use of these additional constraints in that analysis, and in particular the t_Θ constraint, raises some important concerns. Reasons motivating these constraints are given in Ref. [1] but there are also reasons why one should be critical of their use. Applying these constraints significantly reduce the background but also is expected to reduce some counts in the peak, so that the the statistical significance of the peak is not improved according to internal-collaboration review studies [3] and the reasons described below.

The purpose of this note is to lay out the reasoning why the CLAS Collaboration as a whole has rejected the analysis of Ref. [1]. First, some history of the review process within the CLAS Collaboration is presented. Next, some statistical anomalies in the application of the t_Θ-cut are examined. Finally, past experience is reviewed, where higher-statistics experiments failed to reproduce other mass peaks associated with the purported Θ^+ particle.

CLAS Collaboration Internal Reviews

The CLAS Collaboration has a policy that all papers published as collaboration results (stating CLAS Collaboration below the author list) must be approved by an analysis review committee followed by approval by a paper committee, and as a final step the entire collaboration is asked to review the paper. In the case of Ref. [1], the analysis review report [3] stated that there were concerns regarding the event selection (also called analysis "cuts" or "kinematic constraints") used in the data analysis for the above reaction. In particular, the motivation for a cut on the Mandelstam variable t_Θ (the momentum transfer from the photon to the pentaquark) is weakly supported. As shown in the next section, without a highly restrictive cut on t_Θ (which reduces the event selection to about 25% of the parent distribution), the statistical significance of the narrow peak in the mass spectrum of Ref. [1] (corresponding to the pentaquark mass) is severely eroded.

The analysis shown in Ref. [1] underwent extensive internal review by the CLAS Collaboration, which is documented on an internal website, spanning nearly four years. This was not a simple exercise, either for the authors of

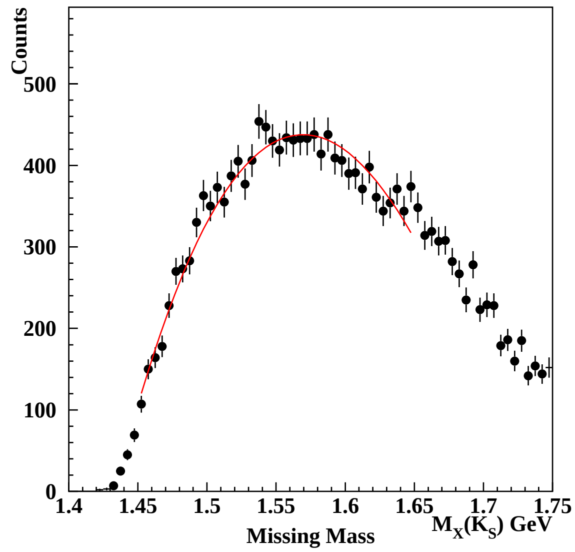

Figure 1: The data of Figs. 6a and 8a of Ref. [1] with a polynomial fit to the background. The reduced χ^2 of the fit is 1.2.

Ref. [1] or for the review committees, and many years of effort have been spent examining this data analysis. At the request of the lead author of Ref. [1], presentations were made at a CLAS Collaboration meeting by both the authors and the review committee, followed by discussions and a vote on whether to publish this result as a collaboration paper. The vote failed.

Some of the reasons for the failure of this analysis to be accepted by the CLAS Collaboration are described below; other reasons are documented in the report of the analysis review [3].

Statistical Anomalies

In this section, we present a qualitative discussion of the statistical significance claimed for the narrow peak seen in Ref. [1], and argue that the real statistical significance is smaller. One unconvincing aspect of the statistical analysis in Ref. [1] is that significance of their peak is extracted only for very restrictive cuts on the full kinematic phase space (see Figs. 8, 9 and 10 of that paper). For example, there is no justification for the *particular* value of the cut on the Mandelstam variable t_Θ used in Ref. [1]. One must be very careful to deduce the statistical significance of a peak when cuts are not rigorously justified in advance.

If the peak is real, we should also expect to see a peak in the spectra before the cuts, albeit perhaps with a reduced signal-to-noise ratio (due to more background under the peak). Suppose that we start with a parent distribution consisting of 150 counts in a peak on top of a large background. If one can find the perfect kinematic cut which removes background without reducing counts in the peak, we expect 150 counts in the peak on a smaller background after the cut is applied. Said another way, barring any unusual fluctuations of the background, if there are 150 counts seen in the peak after the cut, there should be 150 counts in the peak before the cut is applied.

Here, we focus on Fig. 8a of Ref. [1], which is before any cuts (and is identical to Fig. 6a). In Fig. 1, we fit a smooth curve to the background and estimate the number of counts above the curve. The curve shown is a reasonable fit, with a reduced χ^2 of 1.2, which is close to the ideal value of 1.0. In Fig. 1, using only three bins where the peak is expected (see Figs. 9 and 10 of Ref. [1]), there are a total of 1331 counts in this mass region just below 1.55 GeV, with a gaussian error of $\sqrt{1331} = 36.5$ counts. The integral of the curve in the same region is about 1260 counts, giving a signal of $(1331 - 1260) = 71$ counts above the background. The statistical significane of this peak is about 2-σ.

Now looking at Fig. 9 of Ref. [1], the number of counts above the background, is about 120-150 counts for the same mass region (the same three bins below 1.55 GeV), depending on the background shape used.

Clearly, the t_Θ-cut applied to the data to obtain Fig. 9 of Ref. [1] cannot *increase* the number of counts in the peak; the cut can only *reduce* the background under the peak (and perhaps reduce some of the counts in the peak as well). Hence, there is an inconsistency between the number of counts in the peak before and after the t_Θ-cut is applied in Ref. [1]. A reasonable explanation is that the background undergoes some unusual fluctuations in the region of the peak due to the t_Θ-cut.

If the background shape used in Ref. [1] is correct, the number of counts in the peak of their Fig. 9 (after the t_Θ-cut) should be consistent with the number of counts shown in Fig. 1 As described above, this is not the case (about 71 ± 36 counts before the t_Θ-cut and 120-150 counts after the t_Θ-cut). This should give one pause when considering whether the peak is real, or at the very least that its significance is compromised by statistical fluctuations.

Furthermore, while the t_Θ-cut of Fig. 8c of Ref. [1] makes the peak look more prominent, the t_Θ-cuts at lower and higher values shown in Figs. 8b and 8d, respectively, hardly show any unique structure above background. Fig. 8d even suggests multiple structures, with low significance, most likely due to statistical fluctuations.

Although the present note does not rule out the possibility that the peak in the mass spectra of Ref. [1] could be real, our conclusion is that the statistical significance of the peak in Ref. [1] appears to be over-estimated.

This over-estimate is not due to any mathematical error, but might be due to the choice of background shape from the Monte Carlo simulations used in Ref. [1]. A small change in the background shape will change the number of counts in the peak, and hence change its statistical significance.

Reproducibility

We note that the importance of the background shape has already been demonstrated in Refs. [4] and [5], where the latter re-measured the same reaction as the former with more than 10 times the statistics. The result is that the apparently reasonable peak seen in Ref. [4] with an estimated 5-σ significance turned out to be a 3-σ statistical fluctuation when compared with the real shape of the background, which was measured (with no apparent peak) in Ref. [5]. From this history, we should be very careful with the estimates of statistical significance based on unknown background shapes.

Ultimately, the real scientific test is whether the results are reproducible. There is already a new data set from CLAS, the g12 run, with even more statistics than the g11 run used for the analysis of [1]. Both g11 and g12 were taken under similar (but not identical) conditions. If the claims of Ref. [1] are correct, then the peak should be reproduced in the analysis of the g12 data as well. So far, the g12 data has not been presented to the CLAS Collaboration under the same analysis conditions as in Ref. [1]. A preliminary analysis of this same reaction using the g12 data, carried out by an independent group within the CLAS Collaboration, was not aboe to resproduce the narrow peak of Ref. [1]; however further work is necessary before this preliminary study can become fully vetted.

A further concern is why the peak only shows up in the missing mass of the K_S. The Θ^+, if it exists, must decay into a $p\bar{K}^0$, followed by the $\bar{K}^0$ becoming either a K_S or a K_L. Again, Ref. [1] reports no peak in the invariant mass of the pK_S system. The authors claim that this is due to degredation of experimental resolution in this channel, but this is disputed by others in the CLAS Collaboration. If the peak is real, one would expect to see it in both pK_S and pK_L spectra.

Conclusions

Using a simple comparison of the spectra shown in Ref. [1], before and after kinematic constraints are applied, the statistical significance of the peak does not behave as expected. In particular, there appear to be fewer counts in the peak of the parent distribution and more counts in the daughter distribution (after the constraint is applied). A reasonable explanation for this behavior is that there are unusual statistical fluctuations in the background, and if there is a peak, it has a much smaller statistical significance than the 5.9-σ result quoted in Ref. [1].

Based on past experience, as shown in Ref. [5], a peak of modest statistical significance on top of an unknown background shape is not sufficient evidence to prove that a new particle exists. If the peak is real, then it should be reproducible using the already-existing g12 data set. Also it should be seen in the mass spectra of the pK_S system. Neither of these criteria have been demonstrated in Ref. [1].

References

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