CLAS-NOTE 2011-022

A complement to the ODU study of the reaction $\gamma p \rightarrow pK_S(K_L)$ in the CLAS g11 Data and the search for structure in the pK_L system.

November 10, 2008

M. Bellis

Abstract

This study is a parallel study of an effort undertaken by the ODU group in a search for evidence of a resonance in the pK^0 spectrum for the title reaction. Initially the goal was to verify the mass distributions detailed by the group in their note posted at `http://www.jlab.org/Hall-B/secure/e1/gavalian/SecurePLP/`. The relevant mass distribution is reproduced with a slightly different approach to identifying the final state and agreement is shown with the ODU analysis. However, varying the ODU physics cuts removes any evidence of a peak and suggests that any structure seen is not so much a resonant state, but an artifact of the chosen kinematic cuts.

1 Data selection

The reaction to be looked at is $\gamma p \rightarrow p\pi^+\pi^-$ where the $\pi^+\pi^-$ come from a K_s and the missing mass is consistent with a K^0. Both ODU and myself use the entire g11 dataset. The ODU group used the SEB PID scheme and the standard ntuples produced during cooking. I use the PART PID scheme and the CMU compressed files from the 2+1- skim.

I use the CMU tagger and momentum corrections as well as the standard g11 `eloss` package to account for energy losses in the target. I applied the energy loss correction using the detached vertex when appropriate, though this was found to have almost no effect on the final mass spectra. While I do not use kinematic fitting for the bulk of this note, when it is used to make data selection cuts, the CMU kinematic fitter, detailed in CLAS note 2004-0017, is used. I always plot the prefit quantities. Whenever vertices or DOCA are calculated, I use the standard `MVRT` package in the CLAS repository. For common plots, I have used the mass ranges and binning detailed in the ODU note mentioned in the abstract.

2 Initial analysis and ODU comparison

It is useful to describe some of the quantities which I will be plotting and detail exactly what they mean.

1. **M($\pi^+\pi^-$)**: Invariant mass of the $\pi^+\pi^-$ system.

2. K_S: Three-vector of the $\pi^+\pi^-$ system, constrained to have the mass of the K_S.

3. **Missing mass**: Missing mass off the pK_s system.

4. K_L: Three-vector of the missing mass, constrained to have the mass of the K_L. While this track is not expressly required to be a K_L, because I will be cutting around the ϕ-meson and in order to be consistent with the ODU discussion, I refer to this as a K_L.

5. **ϕ-meson**: The four-vector for the $K_S K_L$ system.

6. pK_S: The four-vector for the pK_s system.

7. pK_L: The four-vector for the pK_L system.

8. E_γ: Initial photon energy (GeV) after tagger corrections.

9. **DOCA**: Distance of closest approach for the two pions.

10. **DIST**: I define a primary vertex as the point of closest approach between the proton track and photon beam. I define a secondary vertex as the point of closest approach between the two pions. DIST is the distance between these two quantities.

11. **Collinearity**: This is a requirement that the K_S momentum is parallel to the spatial line connecting the primary and secondary vertices. I cut on $\cos(\theta)_{col}$, where the angle is defined to be the angle between the K_S momentum vector and the spatial vector connecting the primary and secondary vertex.

12. $-t_{pKL}$: $-(proton + mm - target)^2$ Here I chose to use the missing mass 4-vector instead of the idealized K_L in order to be consistent with the ODU group. When we cut on this quantity, the cuts are broad enough that any small difference in how it is calculated will be negligible.

To begin cleaning up the signal I used a few minimal cuts:

- The number of charged tracks measured for an event is exactly three. This is to maintain consistency with the ODU study, though it was later found that when successive cuts are applied to select the proper topology, this cut is extraneous.

- Timing cut. I required *at least* one of the final state particles has a start counter time within $\pm$1ns of the photon time. I did not have any requirement on the number of photons which can satisfy this cut.
- Energy cut. Because the ODU group is hypothesizing that a possible resonance in the pK_L system could be amplified by interference with the ϕ-meson, it makes sense to choose an energy range where there is overlap between the K_SK_L system in the region of the ϕ mass and the pK_L mass of interest, around 1.550 MeV/c^2. For this reason, my initial cut is $1.7 < E_\gamma < 2.4$ GeV.

At this point the data is dominated by two-π photoproduction, though the K_S and K_L can be seen in the mass distributions. The state of the data at this early set of cuts is shown in Fig. 1. Though I am not cutting on it, I show the confidence level from a fit requiring a missing neutral kaon, and that the 2 pions come from a K_S.

The ODU group used a set of *experimental data cuts* to isolate the pK_SK_L system from the $p\pi^+\pi^-X$ background and a set of *physics cuts* to search for the intermediate states of interest. The cuts are listed below and the the effect of the sum of these cuts on the data is shown in Fig. 2. Note the first plot is the one of interest, the invariant mass of the pK_L system. A dotted line is drawn at 1.55 GeV/c^2. Fig. 3 shows this plot next to a figure of the same distribution with the same cuts taken from the ODU note referenced at the beginning of this document. While there are subtle differences most likely due to different PID schemes, momenta/tagger corrections and 4-vector calculations, it is reassuring that the plots essentially agree as we are looking at the same data with hopefully similar tools.

- Experimental data cuts
  - **# charge** : Number of charged particles = 3.
  - Δt : At least one track's start counter vertex time is within 1ns of a photon vertex time. No limitation is made on the number of photons which can satisfy this cut
  - Vertex cuts
    - DOCA < 2.0 cm
    - DIST > 1.5 cm
    - Collinearity cut: $\cos(\theta) > 0.95$
  - Mass cuts
    - $0.49 < M(\pi^+\pi^-) < 0.51$ GeV/c^2
    - $0.480 <$ Missingmass < 0.515 GeV/c^2
- Physics cuts
  - $\mathbf{E}_\gamma$: $1.8 < E_\gamma < 1.9$ GeV
  - **ϕ-meson** : $1.005 < M(\phi) < 1.035$ GeV/c^2
  - **t-cut** : $0.35 < -t_{pKL} < 0.45$ GeV^2/c^4

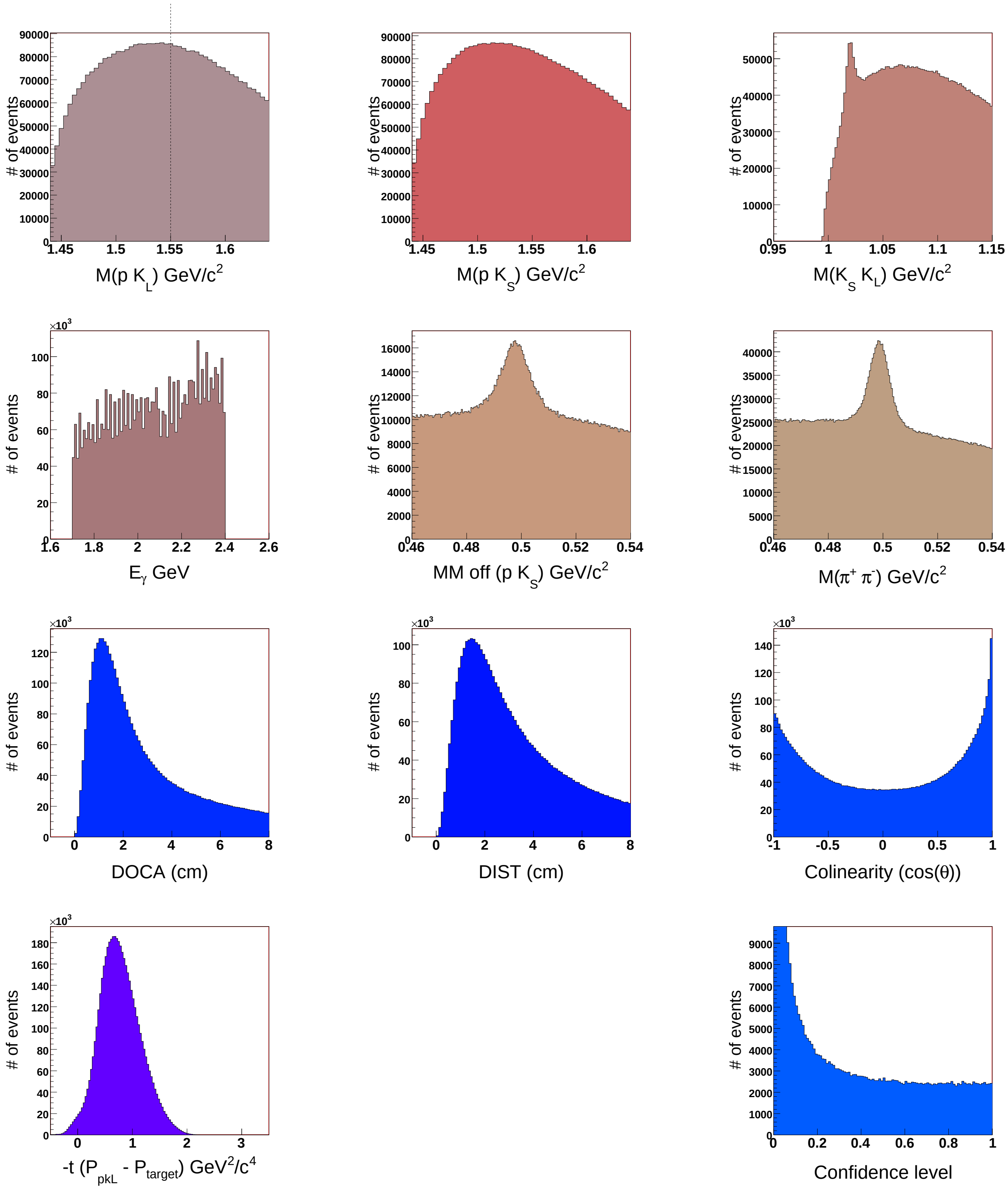

Figure 1: Data with only minimal cuts: # charged = 3, Δ timing cut.

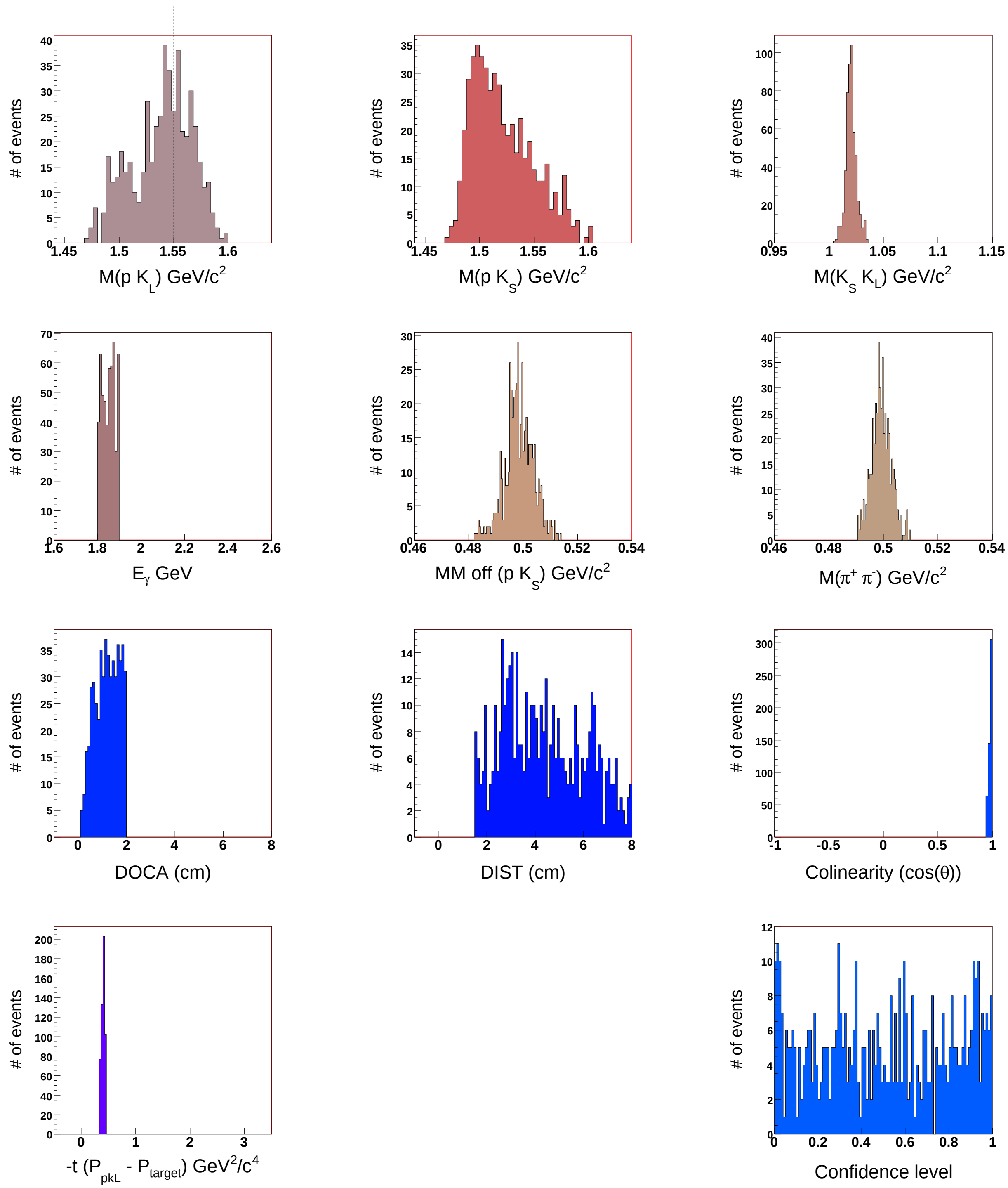

Figure 2: Data with full ODU cuts: # charged, mass cuts, vertex cuts, E_γ, ϕ, t-cut.

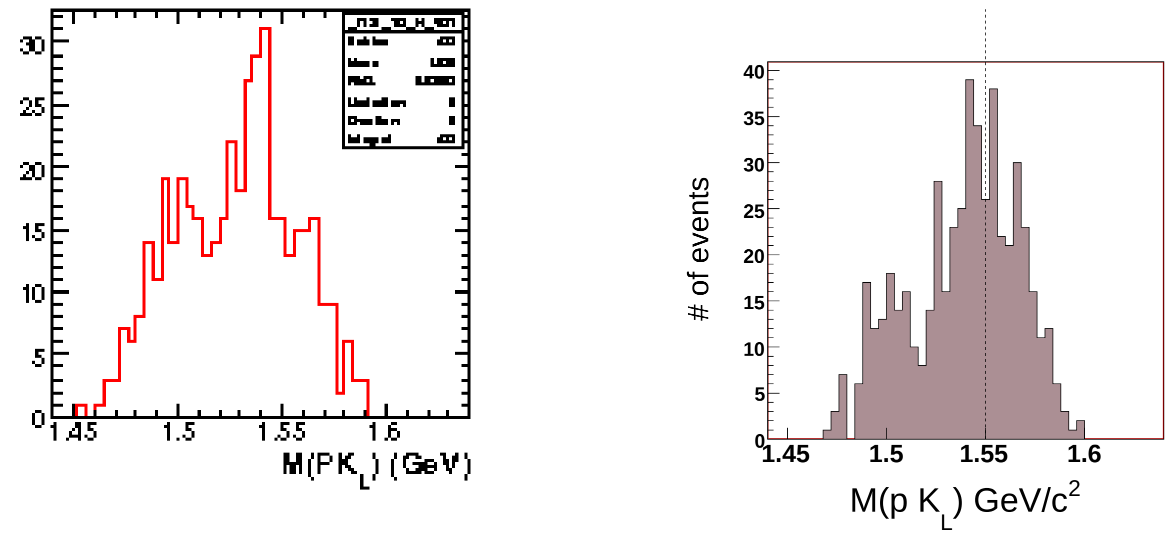

Figure 3: Invariant mass of pK_L with full ODU cuts: # charged, mass cuts, vertex cuts, E$_\gamma$, ϕ, t-cut. The left plot is from the ODU note and the right plot is from this analysis.

3 Further analysis and varying the cuts

After this first sanity check, the cuts were varied in order to test the robustness of the peak and the validity of the cuts. The concern is that the peak is merely carved out by the cuts and the peak seemingly enhanced by statistical fluctuations when event count is small due to unnecessary cuts.

I start by backing the some cuts off. First, I eliminate the t cut, keeping the photon energy cut and ϕ mass cut. I also back off the collinearity cut to $\cos(\theta) > 0.50$. These are two of the harsher cuts in terms of possibly cutting out signal events. The effect of this is shown in Fig. 4.

The first thing I notice, is that after the basic cuts to clean the data the confidence level looks very good. David Tedeschi has been using the kinematic fitter for this channel in studying ϕ-production and has gotten very good results with it for both data and Monte Carlo (private communication). So I keep only the very basic data cuts (# charged, Δ-timing) and mass cuts while discarding the vertex (DIST, DOCA, Collinearity) cuts and use a 10% confidence level cut to clean the data. I keep the physics cuts and show the results in Fig. 5.

The physics cuts are designed to select a particular process for the production of this state, but by relaxing the vertex cuts, I wind up with almost 10x as much data. The shape of the pk_L spectrum is roughly similar to the original ODU plot, though perhaps slightly shifted to lower masses. *I see no sign of the original "peak" with this set of cuts.* It is possible the vertex cuts are selecting some subset of the data. Because the ϕ has very little break-up momentum, the two-K's must be moving with roughly the same momentum. The vertex cuts are designed to clean up the K_S signal, but if there are errors which are not well understood, this could select particular momenta distribution of the K_S which would map onto selecting a similar momenta distribution for the K_L and reflect in the pK_L mass spectrum. This is only conjecture at this stage and has not been explored.

What I can next do however, is test the robustness of the peak with the original ODU cuts, but vary the energy and t-cuts. Fig. 6 shows the pK_S mass spectrum with all of the ODU experimental cuts and the ϕ-mass cut and t cut, but varying the photon energy in staggered 100 MeV bins. Fig. 7 is the same except I have changed the t-cut so it is not a slice, but merely an upper limit ($-t_{pKL} < 0.45$ GeV^2/c^4. Fig. 8 replaces the ODU experimental cuts with the confidence level cut from the kinematic fit but uses the full ODU physics cuts. Fig. 9 uses the ODU experimental cuts, the ϕ-mass cut, the original photon energy cut (1.8-1.9 GeV), but varies the t-cut in staggered 100 MeV^2/c^4 bins. The structure previously seen with one particular E$_\gamma$ and t-cut is not robust when these cuts are varied.

4 Varying the collinearity cut

In this section I look at the effects of the collinearity cut and the validity of the ODU cut on $\cos(\theta) > 0.95$. Figs.10-13 show this variation and are each laid out the same. I take a moment to describe the plot grid for these figures.

- Columns
    1. $\cos(\theta)$ of the collinearity angle.
    2. Invariant mass of the $\pi^+\pi^-$ system.
    3. Missing mass off the pK_S system.
    4. Invariant mass of the K_SK_L system.
    5. Invariant mass of the pK_L system.
- Rows
    1. Cuts: $1.8 < E_\gamma < 1.9$ GeV, DOCA, DIST, masses in the plotted ranges.
    2. Cuts: Collinearity cut for that given figure: 0.95, 0.90, 0.75, 0.50
    3. Cuts: ODU mass cut on $\pi^+\pi^-$ and missing mass.
    4. Cuts: ODU cut on ϕ mass.

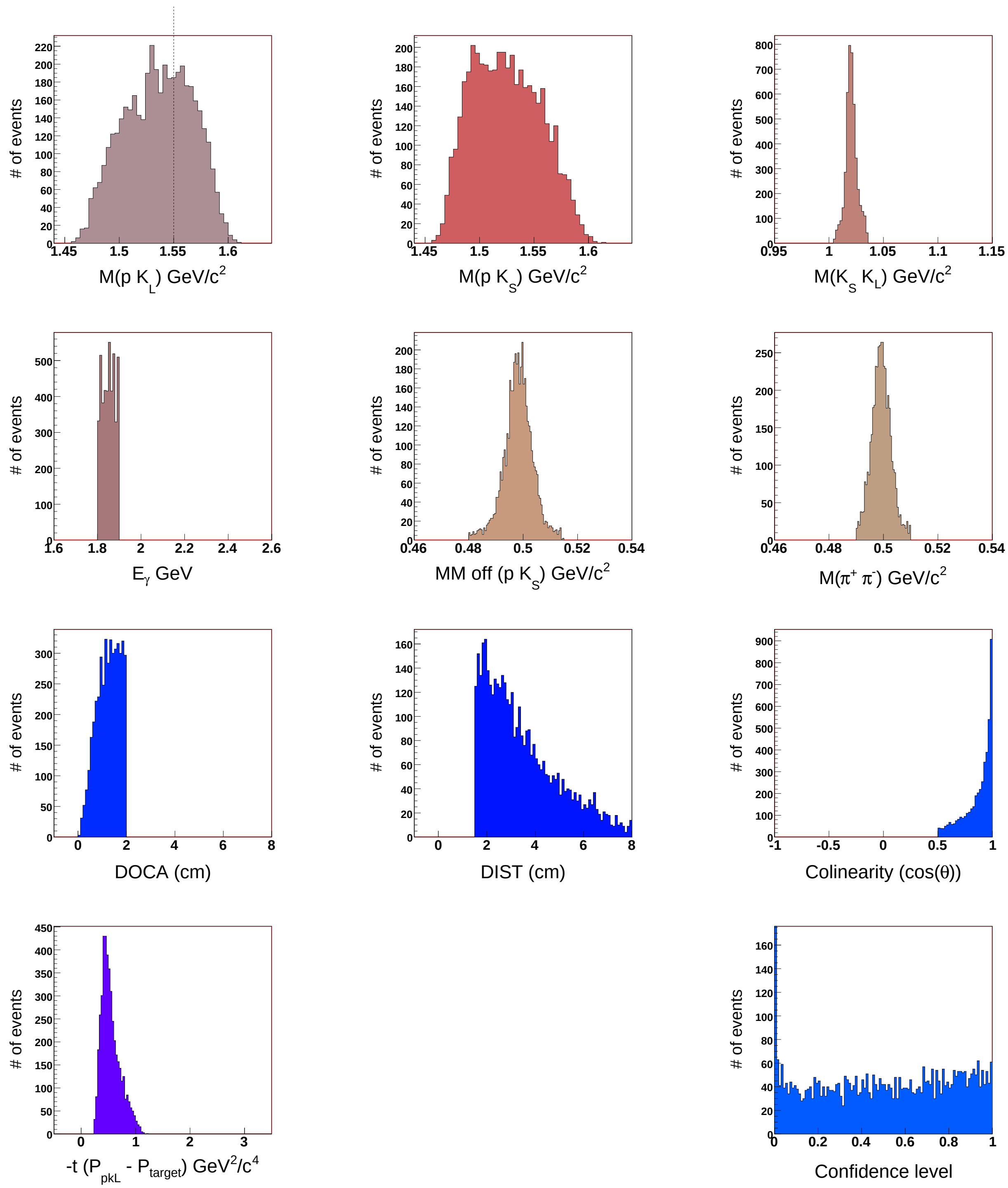

Figure 4: Invariant mass of pK_L with scaled back ODU cuts: # charged, mass cuts, DIST, DOCA, Collinearity $\cos(\theta) > 0.50$, E_γ, ϕ.

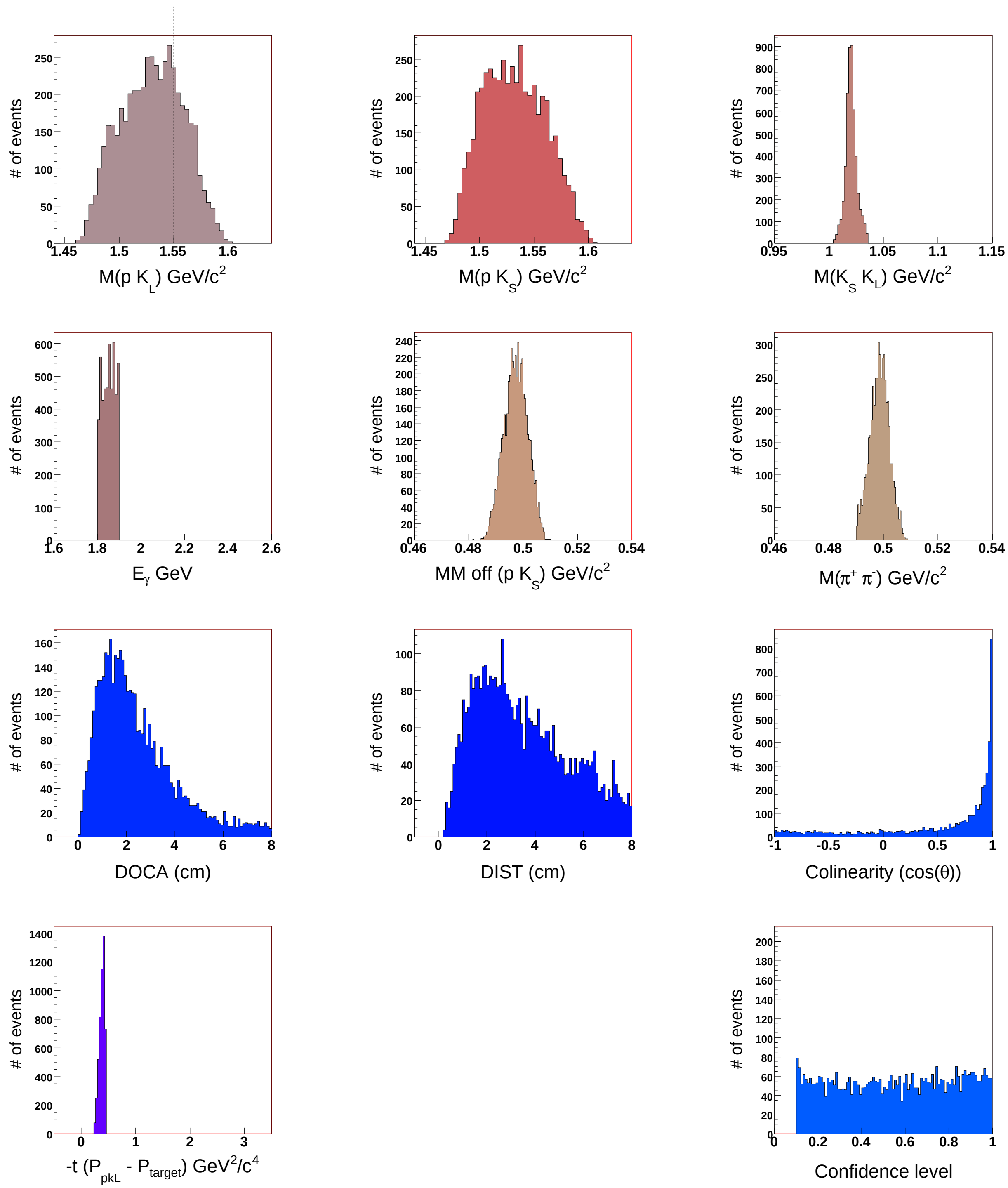

Figure 5: Data with ODU physics cuts, but using the kinematic fit and confidence level to clean the data: # charged, mass cuts, E_γ, ϕ, t-cut, CL>10%.

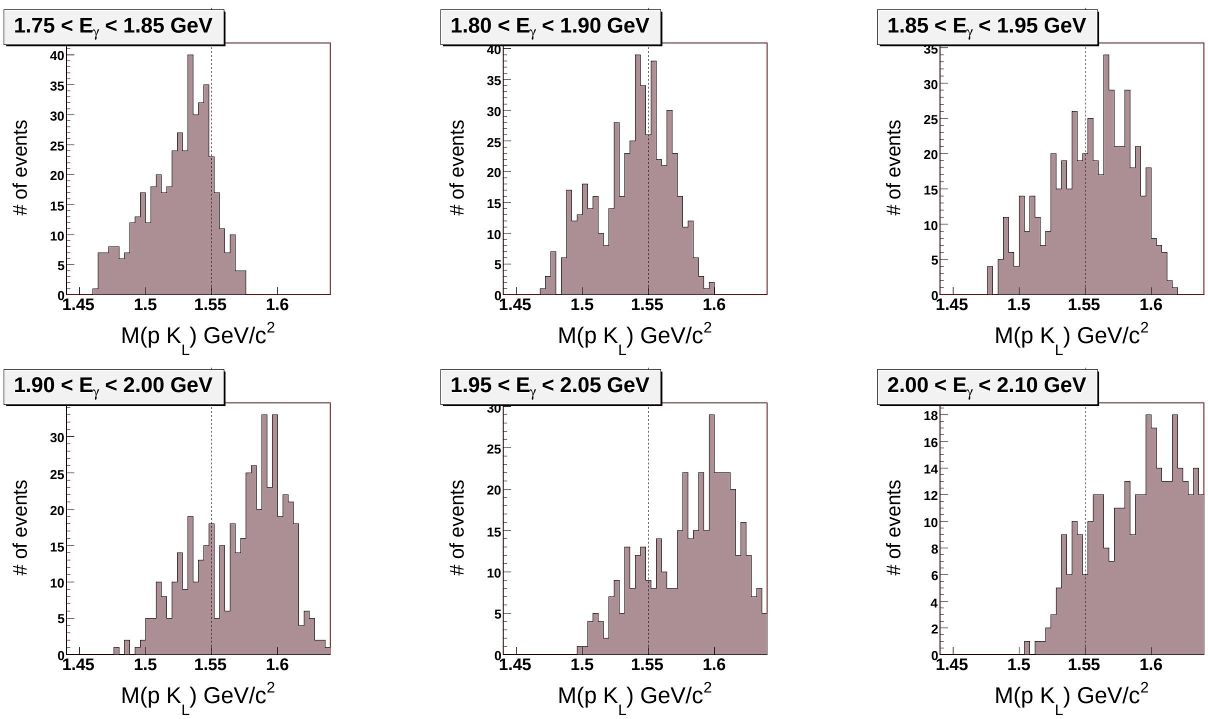

Figure 6: Invariant mass of pK_L system with full ODU cuts: # charged, mass cuts, vertex cuts, ϕ, t-cut and varying E_γ.

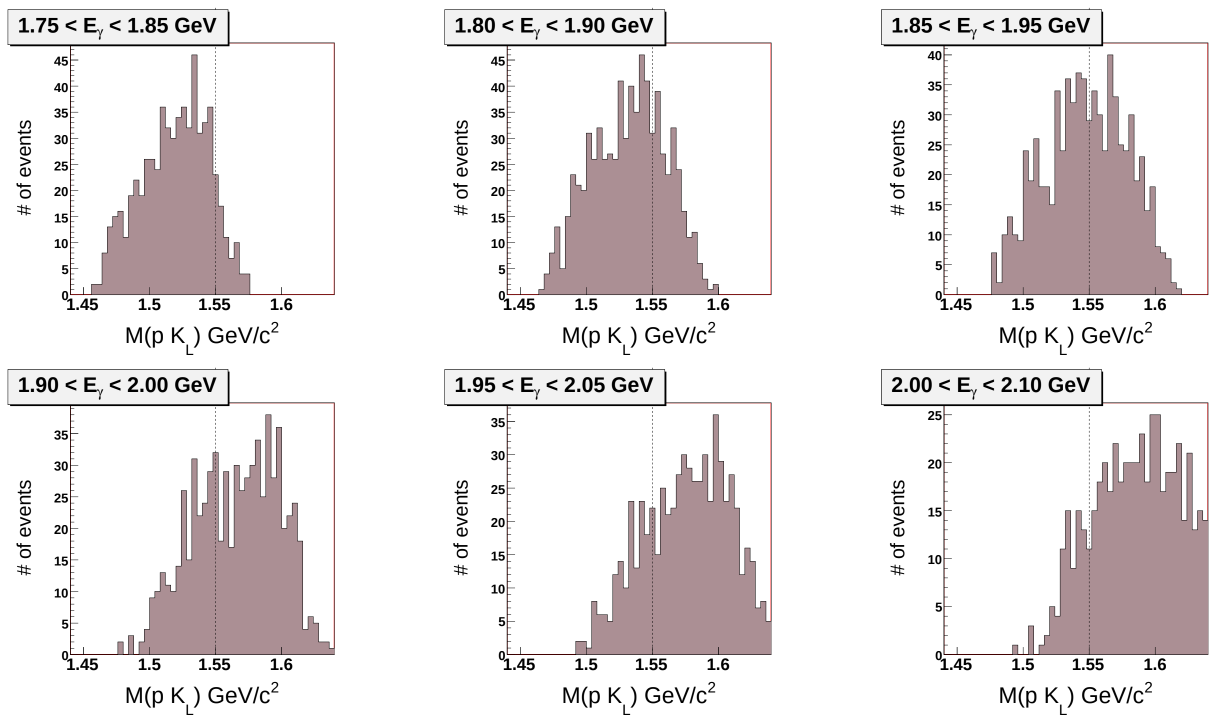

Figure 7: Invariant mass of pK_L system with some ODU cuts: # charged, mass cuts, vertex cuts, ϕ, t-cut changed to < 0.45 GeV^2/c^4 and varying E$_\gamma$.

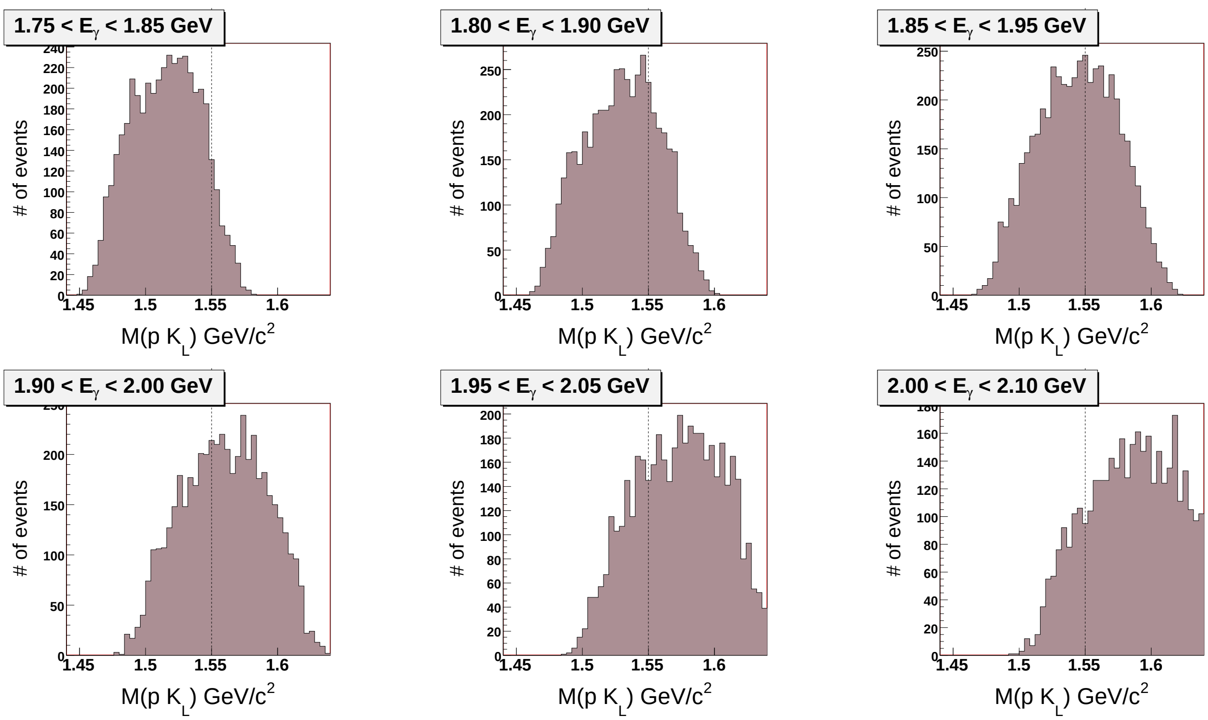

Figure 8: Invariant mass of pK_L system with ODU physics cuts, but using the kinematic fit and confidence level to clean the data: # charged, mass cuts, ϕ, t-cut, CL>10% and varying E$_\gamma$.

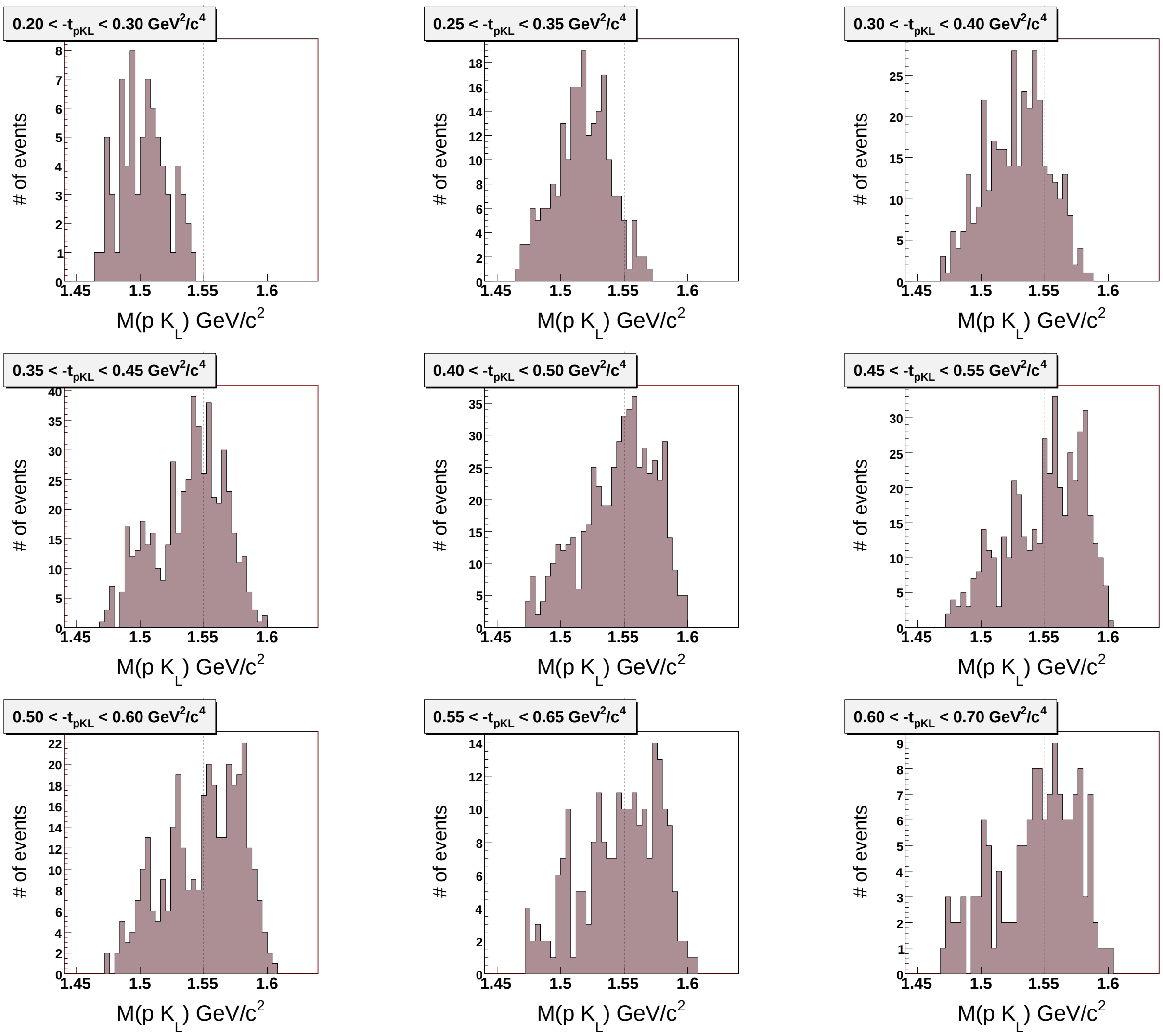

Figure 9: Invariant mass of pK_L system with full ODU cuts: # charged, mass cuts, vertex cuts, ϕ, E$_\gamma$ and varying t_{pKL}.

The successive figures loosen the collinearity cut from the initial ODU cut. Loosening this cut does not seem to add any appreciable background under the K_S, the distribution which it is meant to clean up. There is slight changes to the K_L and ϕ spectra, but nothing significant, especially by the time we make the K_S and K_L mass cuts. Instead it merely reduces the overall signal. When very tight cuts are made and the statistics *artificially decreased*, the chances of spurious fluctuations giving rise to apparent peaks will increase. A sound statistical analysis of the structures will handle this appropriately, but the danger is that the eye will pick out structure that is not there and so bias can be inadvertantly introduced.

To check the amount of background left over after the cuts, I focus on the K_S and K_L reconstruction, as it is here that PID issues could manifest themselves. Again, I work with the original ODU cuts, DIST, DOCA, $1.8 < E_\gamma < 1.9$ GeV, $0.35 < -t_{pKL} < 0.45$ GeV^2/c^4, except that I vary the collinearity cut and I do not make the K mass cuts yet, so I can extract the background. The results for the K_S are shown in Fig. 14. The background makes up between 8% and 11% of the total spectrum for any of the collinearity cuts, while the total amount decreases by a factor of two. Fig. 15 shows the missing mass with the K_L after the same set of cuts, but also *after* we cut on the K_S from 0.49-0.51 GeV/c^2. For all collinearity cuts the background is about 7% of the total event count under the standard ODU cuts for this spectrum.

5 Conclusion

This document makes no claim about statistical significance of any of the perceived peaks or structures in the mass distributions. While it may be that one can make a quantitative statement regarding a peak at 1.55 GeV/c^2 in the pK_L mass spectrum using the cuts developed at ODU, it seems that *this peak is not robust and varying these cuts in a reasonable fashion removes the appearance of a peak.* This is not consistent with an actual resonance in the pK_L system, but rather an artificial shape in the data due to the particular selection of cuts. The effects of these types of cuts is further discussed in CLAS note 2007-12, *"Generation of Peaks Using Tight Kinematic Cuts"* by Meyer and Bellis. Furthermore, the tight collinearity cut appears to cut out more signal than it does actually reducing the background. In this way, statistical fluctuations in the mass spectra which give the appearance of peaks become more likely.

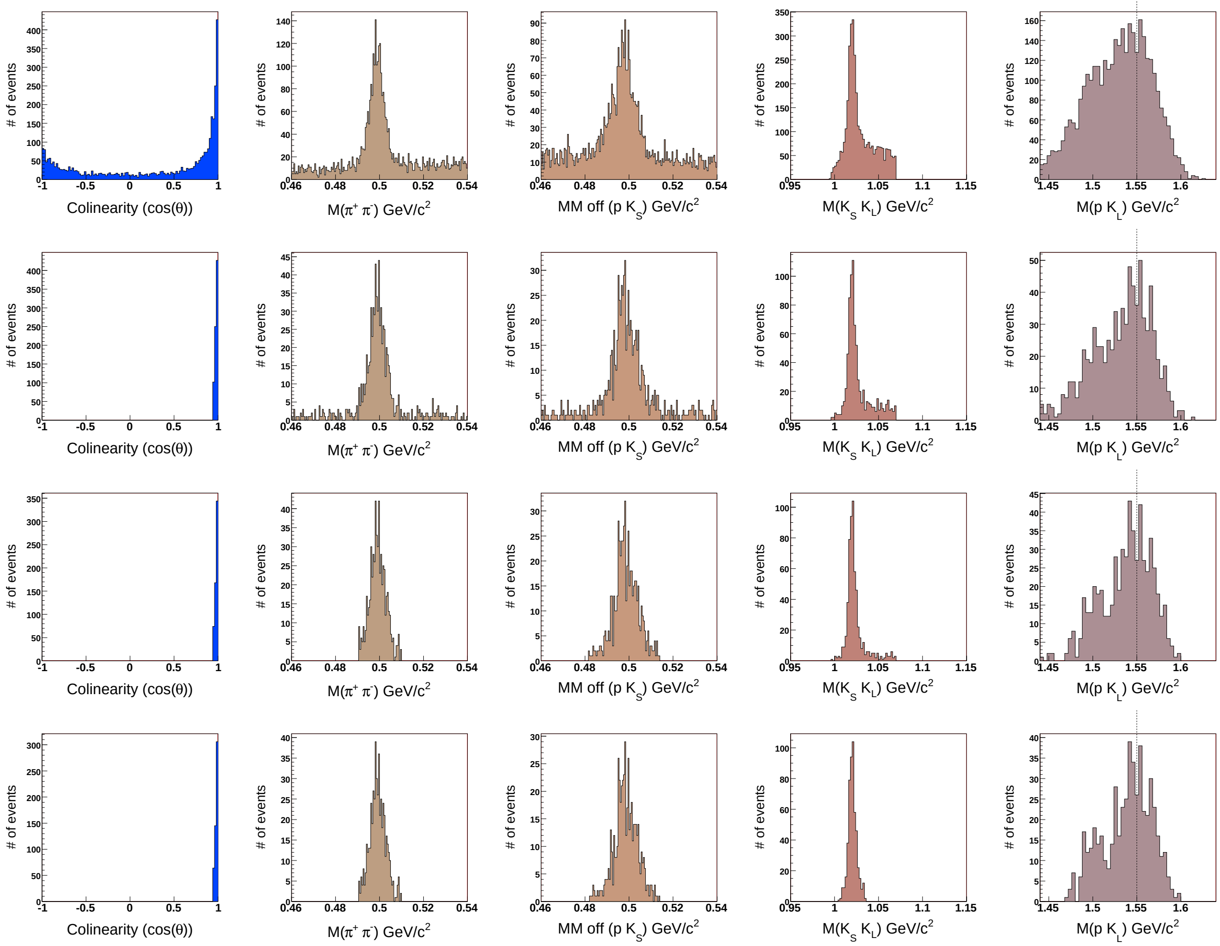

Figure 10: Collinearity cut: $\cos(\theta) > 0.95$. Other details of this figure can be found in the text

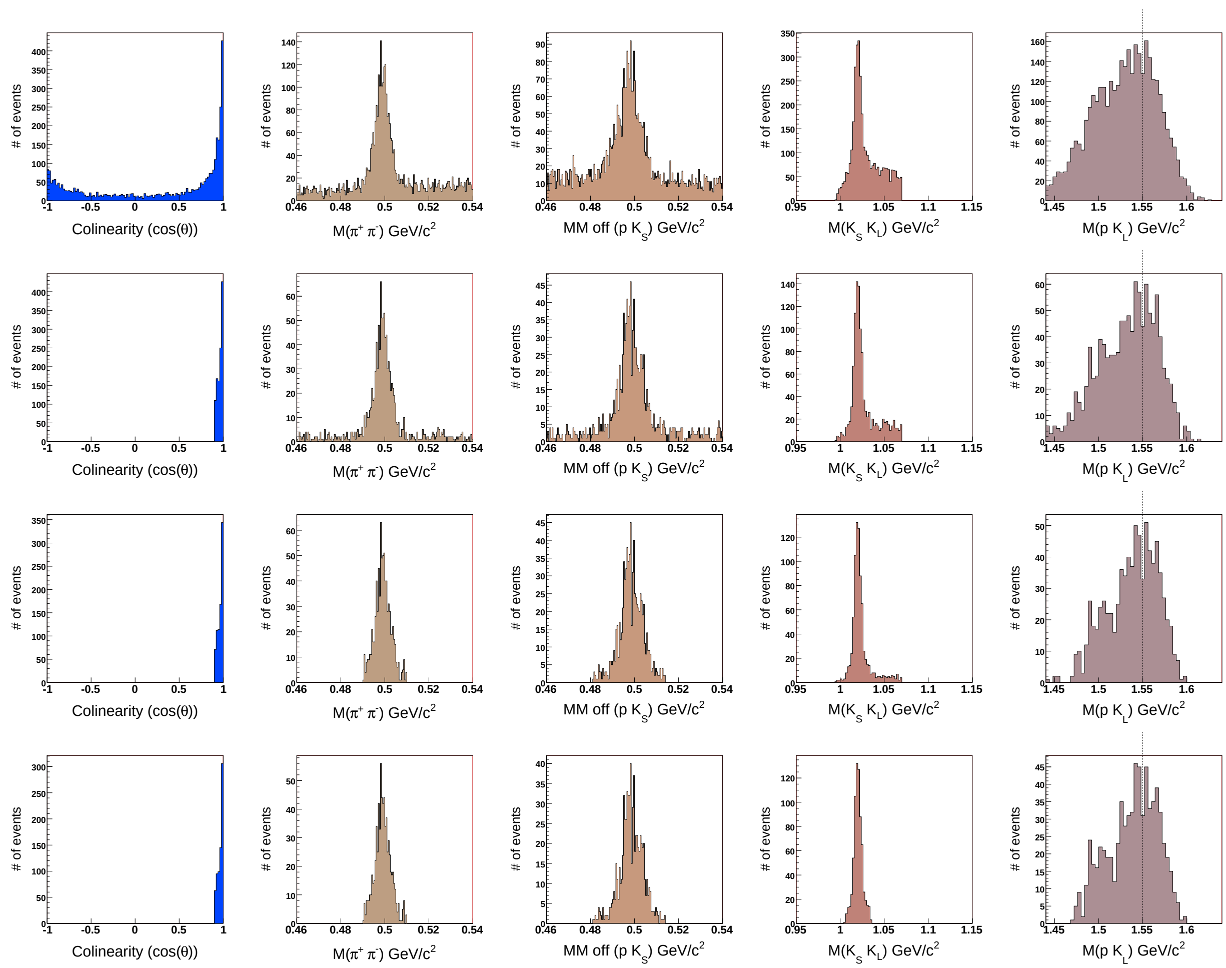

Figure 11: Collinearity cut: $\cos(\theta) > 0.90$. Other details of this figure can be found in the text

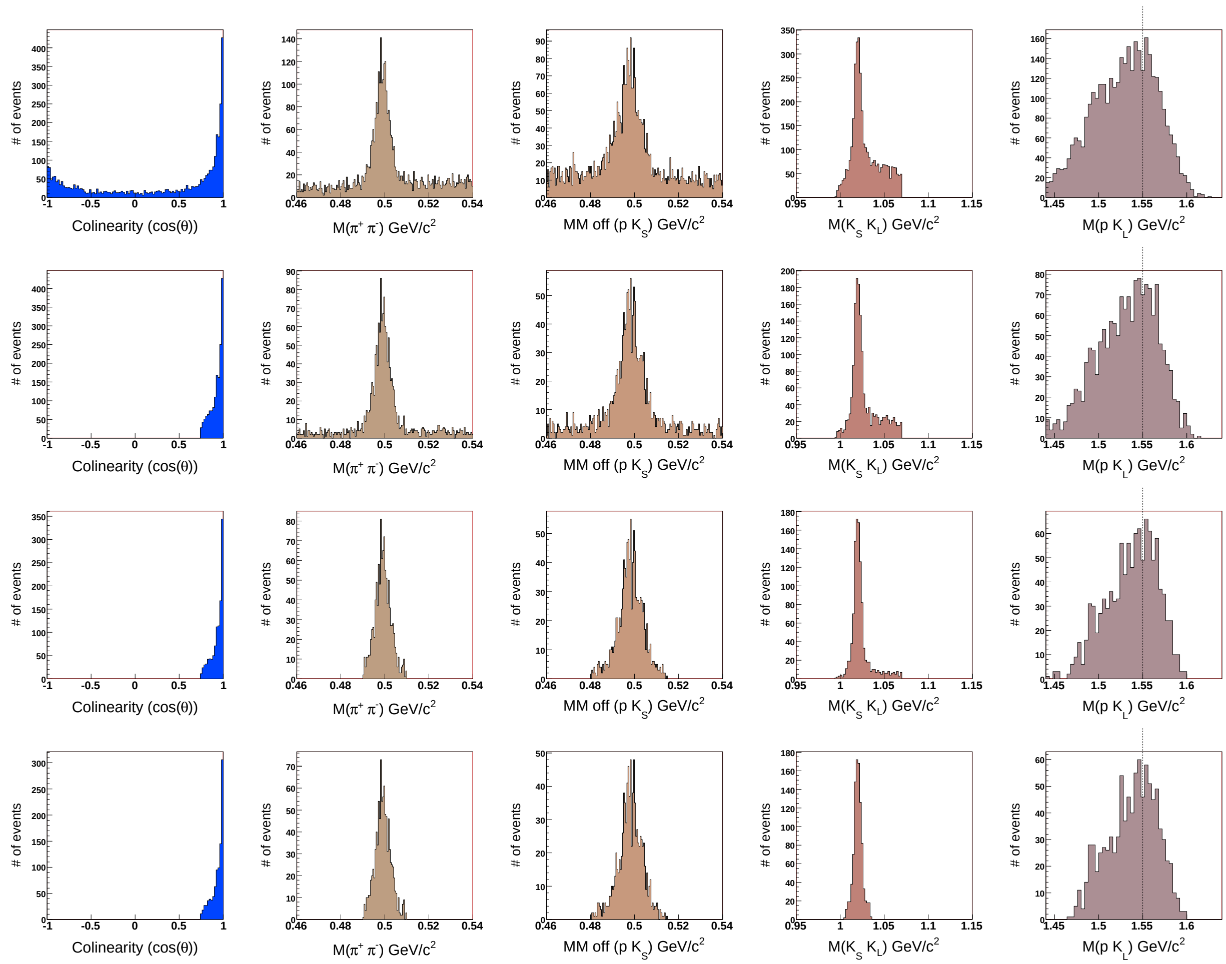

Figure 12: Collinearity cut: $\cos(\theta) > 0.75$. Other details of this figure can be found in the text

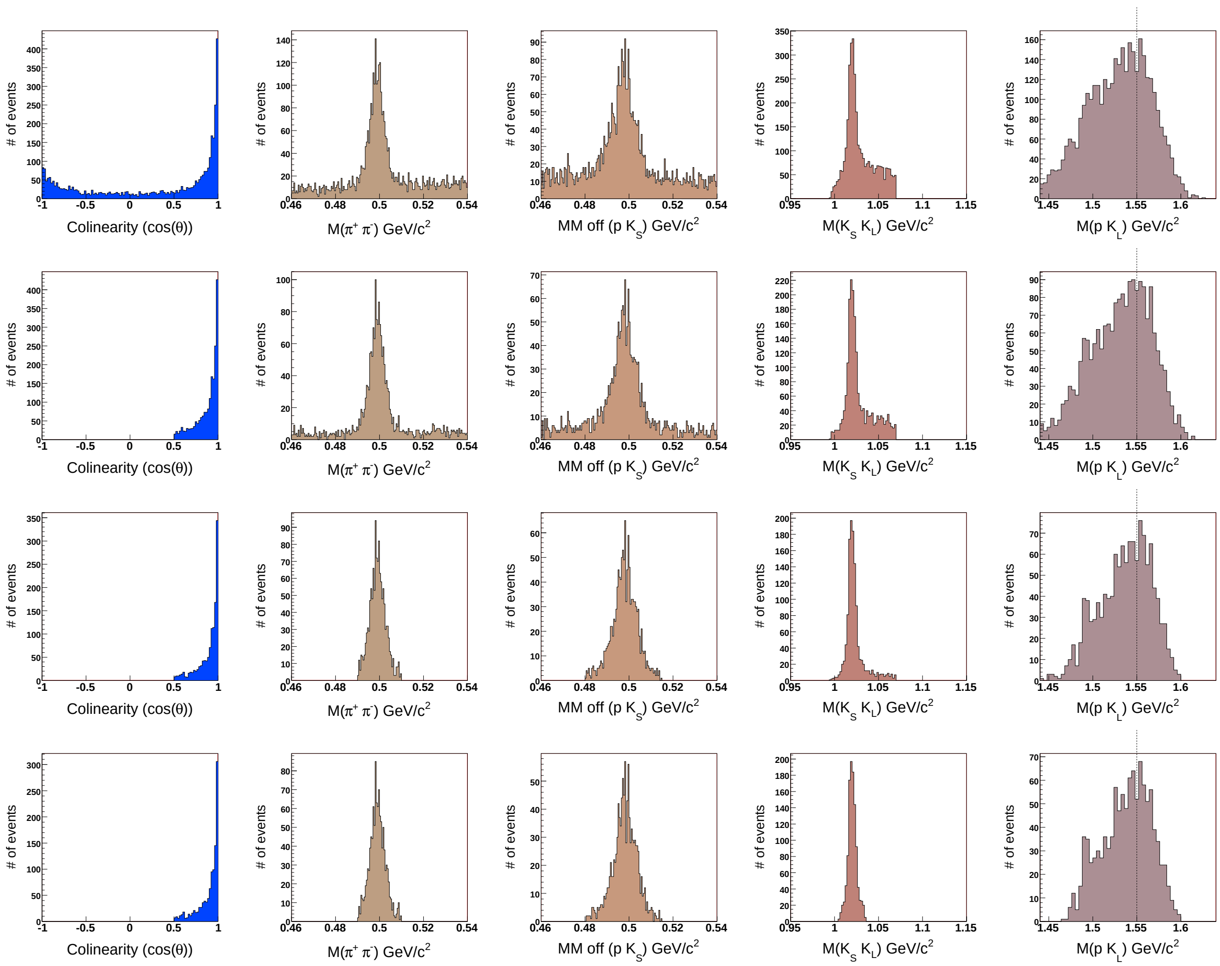

Figure 13: Collinearity cut: $\cos(\theta) > 0.50$. Other details of this figure can be found in the text

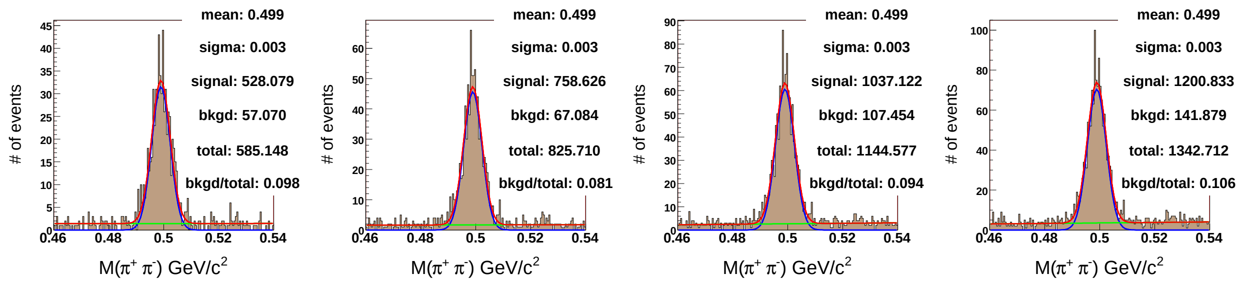

Figure 14: Effects of collinearity cut on K_S. The cuts go from 0.95, 0.90, 0.75, 0.50, from left to right. The other cuts are: DIST, DOCA, $1.8 < E_\gamma < 1.9$ GeV, $0.35 < -t_{pKL} < 0.45$ GeV^2/c^4. The spectra are fit to a Gaussian and a linear background over the full range of the plot. The respective functions are integrated over the range 0.49-0.51, the standard ODU cuts for this mass spectrum. The background is around 8-11% of the total signal.

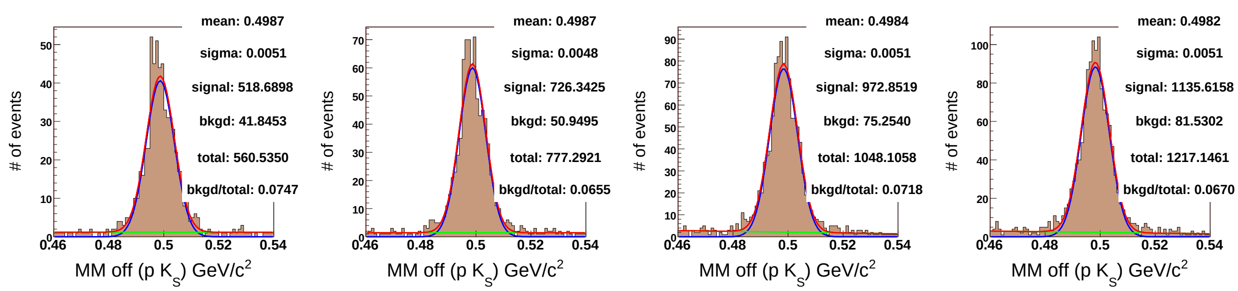

Figure 15: Effects of collinearity cut on K_L. The cuts go from 0.95, 0.90, 0.75, 0.50, from left to right. The other cuts are: DIST, DOCA, $1.8 < E_\gamma < 1.9$ GeV, $0.35 < -t_{pKL} < 0.45$ GeV^2/c^4. I also cut on the $\pi^+\pi^-$ mass around the K_S from 0.49-0.51. The spectra are fit to a Gaussian and a linear background over the full range of the plot. The respective functions are integrated over the range 0.480-0.515, the standard ODU cuts for this mass spectrum. The background is around 7% of the total signal for all collinearity cuts. Note that the binning is coarser for this set of plots than the previous one. With the lower statistics, the finer binning was affecting the fits adversely leading to high χ^2/ndf.