Upsilon Decays into $f_J(2220)$

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Abstract

The purpose of this study is to either show conclusively the existence of the $f_J(2220)$ or place an upper limit on its radiative branching fraction to Υ(1S). I looked into the decay mode of $\Upsilon \to \gamma X^0$ where $X^0 \to \pi^+\pi^-/K^+K^-$. I found one $f_J(2220)$ candidate for $\gamma\pi\pi$, as well as one candidate for γKK which allowed me to get an upper limit of 7.55×10^{-6} for $\Upsilon \to \gamma f_J \to \gamma\pi^+\pi^-$ and 9.59×10^{-6} for $\Upsilon \to \gamma f_J \to \gamma K^+K^-$ with 90% CL.

Glueballs and the $f_J(2220)$

QCD predicts the existence of glueballs, bound states of gluons. Unlike QED, which does not allow for bound states of $\gamma\gamma$ due to the fact that γ binds to charge and is itself charge-less charge-less , gluons bind to color and at the same time possess color and therefore can bind to each other. A pure glueball is thought to possess a narrow width, flavor symmetric decays, and a large production cross section in glue-rich environments [1]. With that said the question is why should we look for the glueball? The answer to this is that it is believed that the discovery of the tensor glueball spectrum would greatly increase our understanding of the strong force at the hadronic scale.

The $f_J(2220)$, sometimes referred to as the $\xi(2230)$, is a possible glueball candidate due to its narrow width, its observations in glue-rich environments (radiative J/ψ decays), its proximity to the mass obtained in lattice QCD predictions [9] of the tensor glueball as well as its non-observation in $\gamma\gamma$ interactions [3]. This resonance was first reported by the Mark III collaboration in radiative J/ψ decays to K^+K^- and $K_s^0K_s^0$ [2]. The BES experiment also confirmed the existence of the $f_J(2220)$ in the J/ψ radiative decays into $K\overline{K}$ as well as three non-strange decay modes into $\pi^+\pi^-$, $\pi^0\pi^0$, and $p\overline{p}$ [1] (see Figure 1).

Analysis Strategy

In this analysis I was looking for $\Upsilon \to \gamma f_J$. The $f_J(2220)$ can only be seen with our detector through its decay products. The decay products I was looking for were $\pi^+\pi^-$ and K^+K^-. By reconstructing the decay products I was able to see if they came from a γxx system with a mass of 9.46 GeV/c^2. If this requirement was met I then looked into the xx invariant mass to determine if they could have come from an f_J decay.

To understand the results that I obtained it is important to understand the number of events that were expected. The calculated branching fractions $B(\mathrm{J}/\psi \to \gamma f_J)\times B(f_J \to xx)$ obtained in the BES experiments were on the order of 4×10^{-5}. That tells us that out of 400,000 J/ψ decays, statistically one will decay as $f_J \to \pi\pi$ / KK / $p\overline{p}$. Using simple scaling arguments, one would predict a branching fraction $B(\Upsilon \to \gamma f_J)\times B(f_J \to xx)$ of $1/40\times4 \times 10^{-5} = 10^{-6}$. That means that out of 1,000,000 Υ(1S) events one will decay this way. CLEO has currently working accumulated 1.5×10^6 Υ(1S) events at a luminosity of 61.3 pb^{-1} [4]. So one would not expect to see more than a handful of possible f_J candidates.

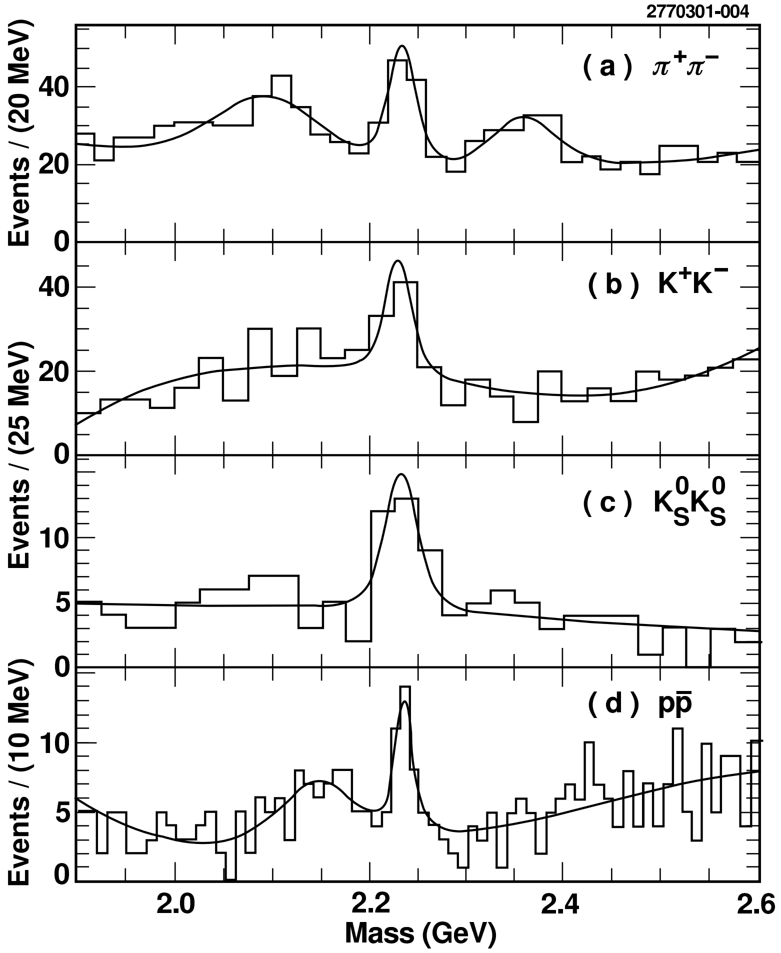

FIGURE 1. The fitted invariant mass spectra from the BES detector showing their $f_J(2220)$ signal. Fitted invariant mass spectra of (a) $\pi^+\pi^-$,(b) K^+K^-, (c) $K_s^0K_s^0$, and (d) $p\overline{p}$ [10]. Note that the peaks are not very prominent and therefore the results obtained need verification.

But even without a distinct signal it is still possible to place an upper limit on the product branching fraction $B(\Upsilon \rightarrow \gamma f_J)\times B\ (f_J \rightarrow xx)$.

The Code

Using Driver I was able to write a code that analyzed the events. Here I only outline the most interesting cuts that were applied. The outline of the code is relatively simple (although debugging it never seemed to be). The code looks first at the event and checks to see that certain requirements are met. It must pass the skim cuts, general cuts that were placed on the data tapes to skim out useless events for the analysis, as well as some other restraints, namely that there was only one hard photon (> 4 GeV) per event and that the ELTRACK trigger fired. The second thing the code does is cycle through all of the bumps (energy deposits in the calorimeter) and check to see that the bump is not garbage from a particle shower, and that it looks like a photon bump. Third, it cycles through the tracks two at a time and checks to make sure that they were not muons and that at least one of the tracks was in the fiducial volume (the region of the detector not including the end caps: $\cos\theta < 0.707$). It also uses an E/p cut to minimize QED events with final state electrons, as well as check to make sure that the cosine of the opening angle between tracks is reasonable according to the kinematics of the event. The code then looks to make sure that the system energy as well as the system momentum is consistent with that of an $\Upsilon(1S)$ decay. The code does not contain any dE/dx cuts or time of flight cuts for the $\pi\pi$ or KK systems, so there is no actual particle identification within those modes. They were left out because in these modes there is little background. We do however plan to use dE/dx and time of flight cuts for the $p\overline{p}$ analysis. Below is a break down of all of the cuts used. The cuts are nested inside of each other (i.e. bump cuts comes only if event cut requirements are met). *itk* refers to a track id index, *ib* refers to a bump id index, and *icr* refers to a connected region id index.

Skim

- There was two tracks (NTRKCD = 2), OR all tracks pass trackman.
- There is only one bump in the calorimeter with more than 4 GeV.

Event

- There is exactly one photon candidate that has energy in excess of 4 GeV and no other photon candidate with energy in excess of 0.5 GeV.
- ELTRACK trigger fires.

Bump

- Minimize probability that the bump is from a fragment shower (IBSTOP(ib) = 0).
- The shape of the bump is consistent with what is expected for a photon (E925U(ib)> C92501(ib))
- Eliminate all "matched" showers (ANGCRT(icr) > 15.0).
- The connected region has a round shape which will further suppress showers from charged particles (RMO(icr) > 0.40).
- The bump energy is in excess of 4 GeV (EBUMP(ib) > 4.0).
- The photon is in the good barrel region (RDBUMP(ib,3) < 0.707).

Track

- E/p cut to minimize QED events with final state electrons: $|\text{E}/p - 1)| > 0.15$.
- There are two tracks, each satisfying the standard TRKMNG requirement (TRACKMAN(itk) ≥ 0.
- The angle from the track to the nearest bump is < 15 degrees (ANGTB(itk) < 15.0).
- The GCFIND algorithm has determined that the tracks are not from a photon conversion.

- There are no muons in the final state and at least one of the tracks was in the fiducial volume ($|\cos(\theta) < 0.7$ AND NMUTR = 0).
- The tracks have equal and opposite charge.
- The $\cos(\theta_1 2)$ is > -0.95.

Kinematics

- $|E_{\gamma xx} - E_{beam}| < 0.02$.
- $\mathrm{p}_{\gamma xx} < 0.405$.

Signal Monte Carlo

The data tapes that were analyzed were taken using five different trigger configurations. Therefore it was necessary to use five different Monte Carlo simulations to accurately extract efficiencies that pertain to each trigger setting. The Monte Carlo simulations produced only events of the decay process $\Upsilon \to \gamma f_J \to \gamma xx$ where xx was either exclusively $\pi^+\pi^-$ or K^+K^-. I have included tables 1 and 2 that illustrate the efficiencies obtained. The luminosity weighted average efficiencies are 36% for $\pi\pi$ and 28% for KK

TABLE 1. $\gamma\pi\pi$ efficiencies. The cuts are nested

cut	1s1 early	1s1 late	1s2 early	1s2 late	1s3
Event	53%	51%	68%	69%	66%
Skim	81%	80%	80%	92%	79%
Only 1 hard γ	78%	78%	77%	78%	76%
ELTRACK trigger	67%	65%	87%	87%	86%
Bump	92%	91%	91%	92%	93%
Track	95%	92%	92%	92%	91%
$\lvert E/p - 1\rvert > 0.15$	97%	97%	97%	97%	97%
No muons and 1 track in fiducial	73%	74%	74%	74%	73%
cos(track1,track2) > -0.95	99%	99%	99%	99%	99%
Kinematics	93%	93%	92%	92%	92%
$\lvert E_{\gamma\pi\pi} - E_{beam}\rvert < 0.02$	93%	91%	92%	92%	93%
$\mathrm{p}_{\gamma\pi\pi} < 0.405$	97%	97%	97%	97%	97%
Final	30%	29%	38%	38%	36%

Figure 2 is a plot of various invariant mass reconstructions for the Monte Carlo 1s2 late trigger setting. The top left of Figure 2 is a plot of the $\gamma\pi\pi$ system invariant mass. The peak between 9 and 10 GeV/c^2 is the Υ(1S). This shows that if there are Υ in the data that I am investigating then I should see them. The top right of Figure 2 is a plot of the γKK system invariant mass. The peak between 9 and 10 GeV/c^2 is again the Υ. The bottom left of Figure 2 is a plot of the $\pi\pi$ system invariant mass. The peak at 2.220 GeV/c^2 is the f_J. Again, if there are any f_J in the data then the code should find them. The bottom right

TABLE 2. γKK efficiencies.The cuts are nested.

cut	1s1 early	1s1 late	1s2 early	1s2 late	1s3
Event	49%	49%	67%	67%	65%
Skim	81%	80%	81%	81%	78%
Only 1 hard γ	78%	78%	78%	78%	76%
ELTRACK trigger	62%	63%	85%	85%	85%
Bump	93%	93%	92%	92%	93%
Track	89%	89%	88%	88%	88%
$\lvert E/p-1\rvert > 0.15$	97%	97%	97%	97%	97%
No muons and 1 track in fiducial	66%	66%	63%	64%	63%
cos(track1,track2) > -0.95	100%	100%	100%	99%	100%
Kinematics	90%	90%	91%	91%	90%
$\lvert E_{\gamma KK} - E_{beam}\rvert < 0.02$	91%	91%	91%	91%	90%
$p_{\gamma KK} < 0.405$	95%	95%	96%	95%	95%
Final	24%	24%	30%	30%	28%

of Figure 2 is a plot of the KK system invariant mass. The peak at 2.220 GeV/c^2 is the presence of the f_J.

1S Data

The data I analyzed contained 494,985 skimmed events. Again this data was taken over a period of time in which five different trigger configurations were utilized. The left of Figure 3 shows the $\gamma\pi\pi$ invariant mass reconstruction. The right of Figure 3 shows the γKK invariant mass reconstruction. The shaded regions in the plots are the Υ(1S) after using E$_{sum}$ and p$_{sum}$ cuts. These regions were then analyzed for $f_J \to \pi^+\pi^-$ and $f_J \to KK$ candidates.

After requiring that the γxx invariant mass was consistent with that of an Υ(1S) I reconstructed the invariant mass of the xx system to see if they could have come from an f_J. The left of Figure 4 is the mass reconstruction after assuming that the tracks were pions. The peak around 0.5 GeV/c^2 can be explained by $e^+e^- \to \gamma\phi \to \gamma K^+K^-$ where the kaons are missassigned with the pion mass. The large peak at around 0.770 GeV/c^2 is $e^+e^- \to \gamma\rho$. The peak around 1.25 GeV/c^2 is presumably $\Upsilon \to \gamma f_2 \to \gamma\pi^+\pi^-$ [5]. The right of Figure 4 is a blown up view around 1.5 to 3.0 GeV/c^2. The lines around 2.23 GeV/c^2 enclose the 2σ signal box centered at 2.234 GeV/c^2. This central value was obtained by taking the average of the BES masses for the four decay modes [6]. Notice there is one event at 2.220 GeV/c^2. This is the single $f_J \to \pi^+\pi^-$ candidate (Woohoo!). The event picture is shown in Figure 6. Before I had finished the KK analysis I studied whether some of the other events between 1.6 and 2.0 GeV/c^2 could be $f_J \to K^+K^-$ where the tracks were kaons with missassigned pion masses. I created a “toy” Monte Carlo simulation that stepped through the angle of flight of x from the f_J trajectory from 0 to 90 degrees (within the f_J rest frame). It then calculated the mass of the xx system as a function of that angle. It turns out that if the kaons came from an f_J and are missassigned with a pion mass then they produce a mass sum between 1.2 and 2 GeV/c^2 (see Figure 5).

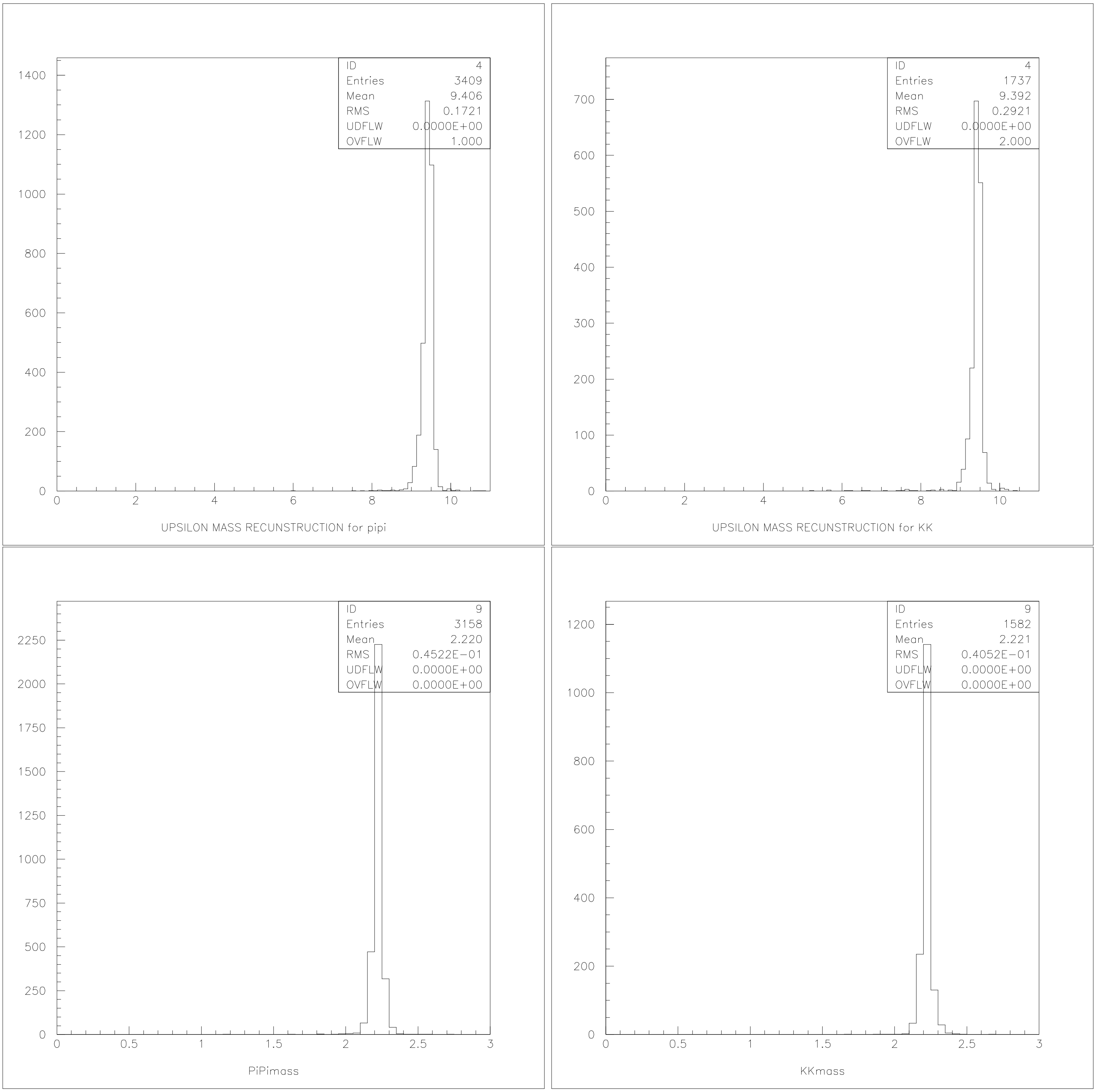

FIGURE 2. Using 1s2 late Trigger settings: $\gamma\pi\pi$ Invariant Mass (Top Left), γKK Invariant Mass (Top Right), $\pi\pi$ Invariant Mass (Lower Left) KK Invariant Mass (Lower Right).

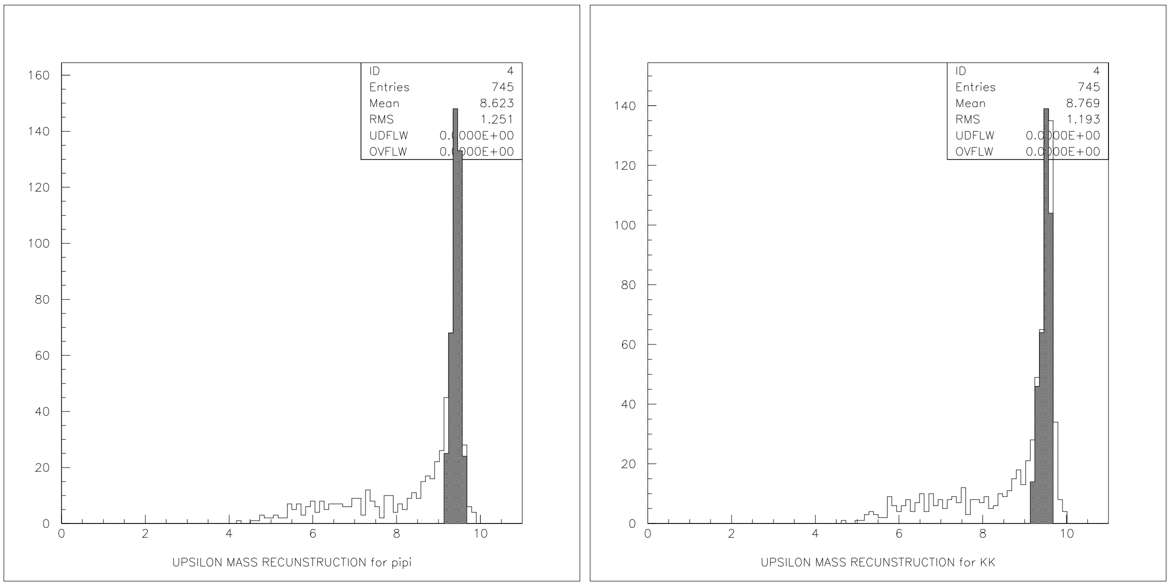

FIGURE 3. Data taken from 494,985 skimmed events. $\gamma\pi\pi$ invariant mass reconstruction (Left). γKK invariant mass (Right). The shaded regions are the Υ(1S) (after E_{sum} p_{sum} cuts)which were analyzed for f_J production.

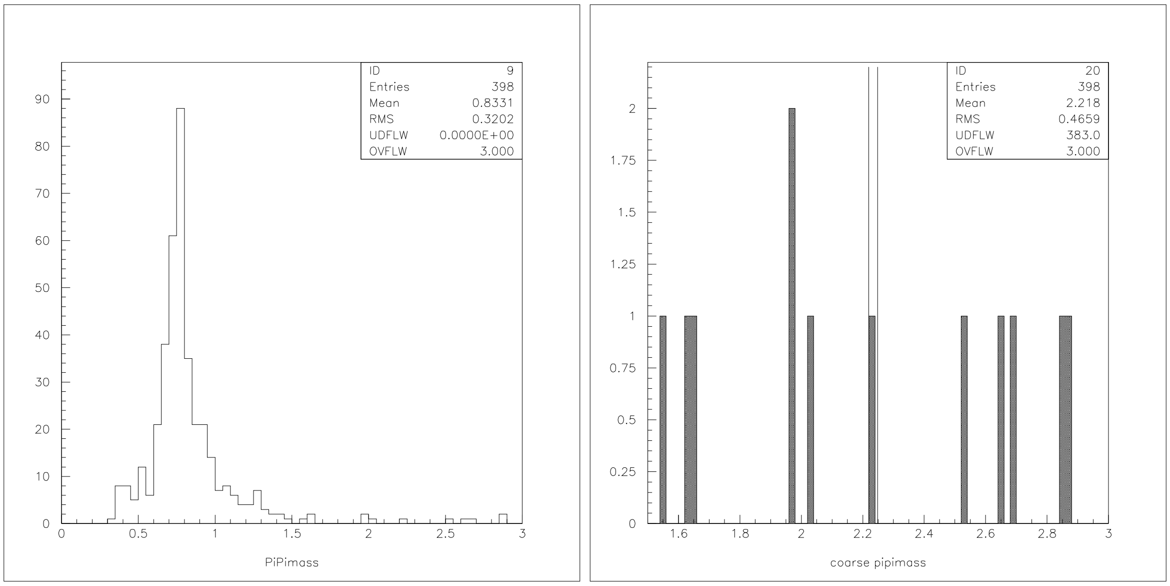

FIGURE 4. Data taken from 494,985 skimmed events. $\pi^+\pi^-$ invariant mass reconstruction (Left). $\pi^+\pi^-$ invariant mass between 1.5 and 3.0 GeV/c^2 (Right). Notice the one $f_J \rightarrow \pi^+\pi^-$ candidate within the 2σ signal box (Woohoo!).

After doing the analysis of the tracks under the assumption that they had pion masses I did the analysis again under the assumption that the tracks had kaon masses. The left of Figure 7 is the xx invariant mass. The right of Figure 7 is the same plot between 1.5 and 3.0 GeV/c^2. Notice I have one $f_J \rightarrow K^+K^-$ candidate within the 2σ signal box at 2.24 GeV/c^2 (Woohoo!). The event picture is provided in Figure 6.

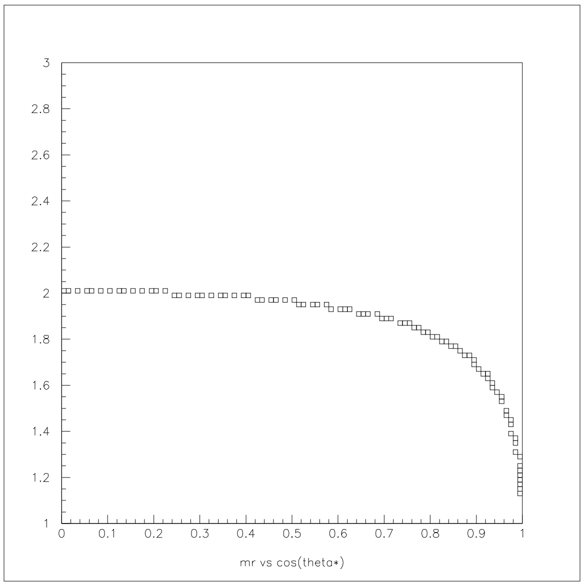

FIGURE 5. The Invariant mass of kaon pairs with missassigned pion masses as a function of the cosine of the angle of flight of the kaon from the f_J trajectory (within the f_J rest frame).

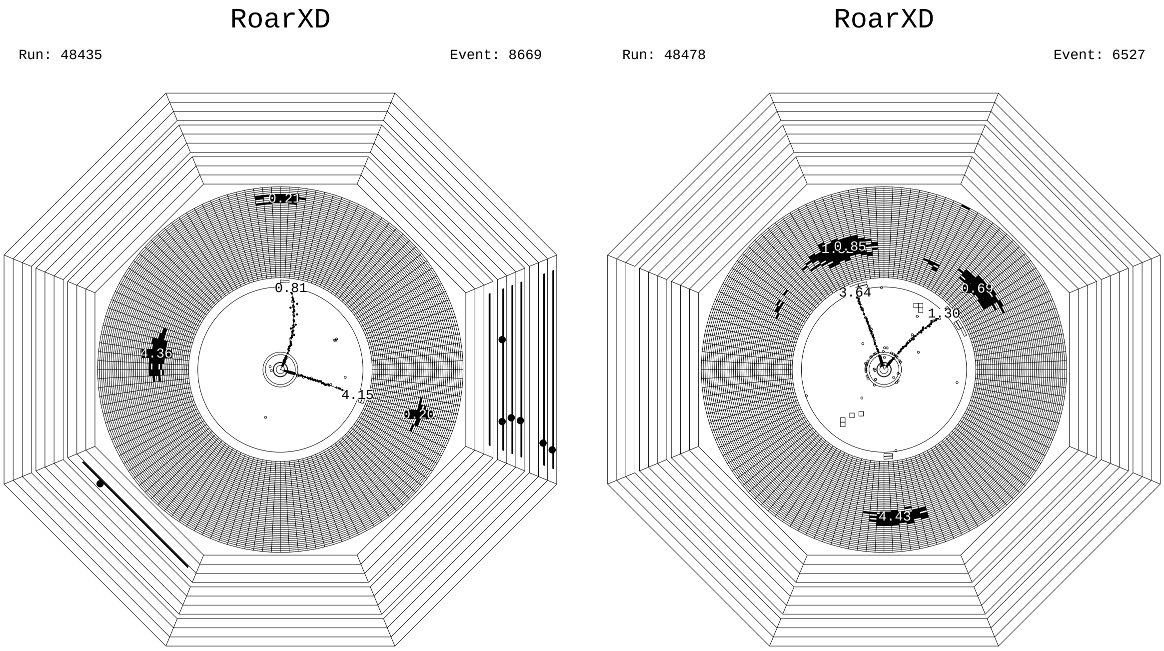

FIGURE 6. The $f_J \to \pi^+\pi^-$ candidate (Left). Run 48435 Event 8669 with a $\pi\pi$ mass of 2.23GeV/c^2. The $f_J \to K^+K^-$ candidate (Right). Run 48478 Event 6527 with a KK mass of 2.24 GeV/c^2.

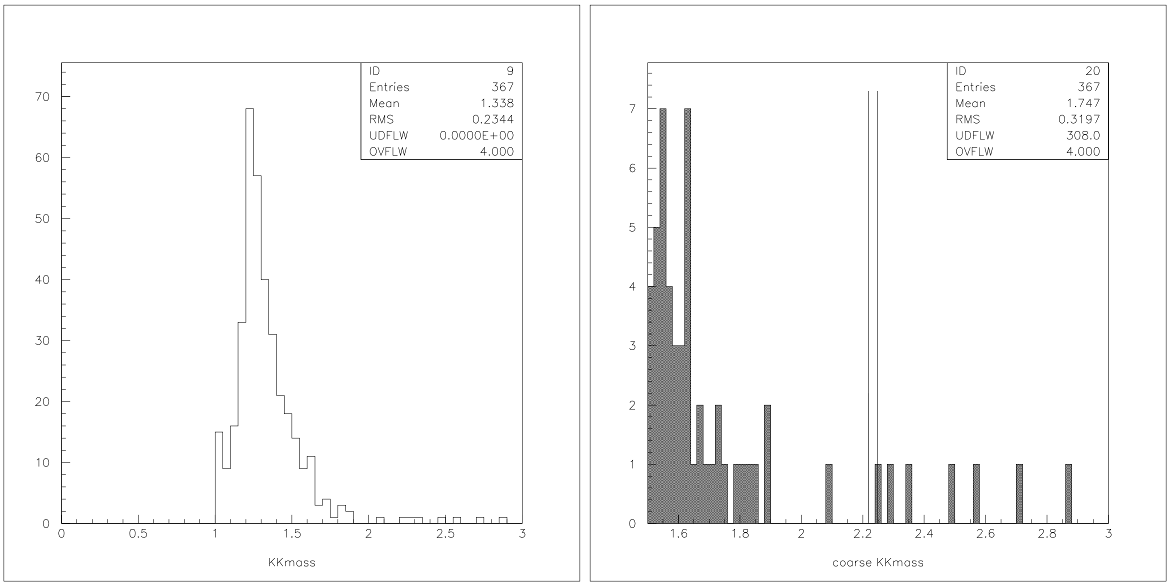

FIGURE 7. Data taken from 494,985 skimmed events. K^+K^- invariant mass reconstruction (Left). K^+K^- invariant mass between 1.5 and 3.0 GeV/c^2 (Right). Notice the $f_J \to K^+K^-$ candidate within the 2σ signal box (Woohoo!).

Background

Even with these two $f_J(2220)$ candidates, no matter how exciting they were to find, I did not have enough evidence to claim to have conclusively found the elusive glueball candidate. So, instead, I went in search of background events within the $\Upsilon(4s)$ data. I used skims from the 4s2, 4s4, and 4sG datasets. These tapes were skimmed using the same requirements as the $\Upsilon(1S)$ data. In the end 32 tapes were skimmed resulting in a luminosity of 838 pb^{-1}. This is 13.6 times more luminous than the 1S data.

I searched for background within a 10σ signal box centered at 2.234 GeV/c^2. There were 6 background events in the $\pi\pi$ analysis, and 10 in the KK analysis. Figure 8 contains the xx mass spectrum from 1.5 to 3.0 GeV/c^2 for the $\pi\pi$ (left) and KK (right) analysis.

$$n_{background} = \frac{n_{(bkg\ in\ 10\sigma)}}{5} \times \frac{\mathcal{L}_{1S}}{\mathcal{L}_{4s}} \tag{1}$$

After scaling using Eq. (1) I obtained a background count of 0.08 for the $\pi\pi$ mode and 0.14 for the KK mode.

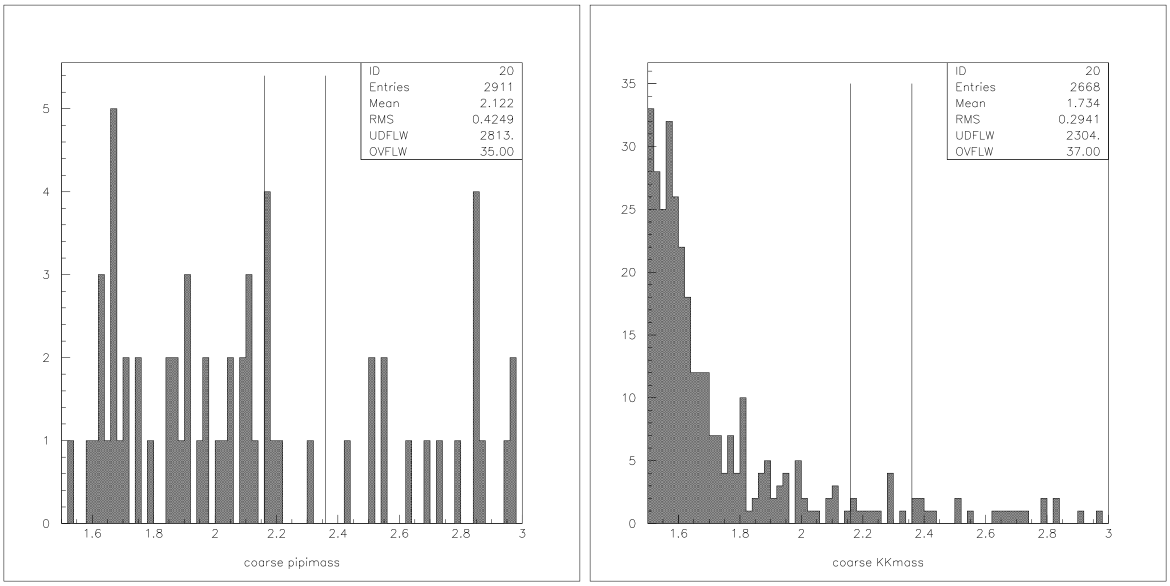

FIGURE 8. Data taken from 4.5×10^6 4s skimmed events. $\pi\pi$ invariant mass reconstruction (Left). K^+K^- invariant mass reconstruction (Right). The two lines in the plots are the 10σ signal region.

Results

Using this background count as well as some Poisson statistics I was able to determine the upper limit on the number of events I should have seen within 90% CL [7]. For $\pi^+\pi^-$ I quote an upper limit of 4.2 events for the data sample. For KK I quote an upper limit of 4.0 events for the data sample.

$$\mathcal{B}(\Upsilon \to \gamma f_J) \times \mathcal{B}(f_J \to xx) \leq \frac{n_{limit}}{n_\Upsilon \times \epsilon} \tag{2}$$

Using Eq. (2) we were able to extract the upper limit on $B(\Upsilon \to \gamma f_J)\times B\ (f_J \to \pi^+\pi-)$ and $B(\Upsilon \to \gamma f_J)\times\ B(f_J \to K^+K^-)$ were n_{limit} is the upper limit on the number of events we should have seen, ϵ is the total efficiency, and n_Υ is $(1.451\pm0.034)\times10^6$ [8].

I obtained $B(\Upsilon \to \gamma f_J)\times B\ (f_J \to \pi^+\pi-) \leq 7.55\times10^{-6}$ and $B(\Upsilon \to \gamma f_J)\times B\ (f_J \to K^+K^-) \leq 9.59\times10^{-6}$ at 90% CL.

Conclusions

In conclusion, I have have observed one $f_J \to \pi^+\pi^-$ candidate and one $f_J \to K^+K^-$ candidate. I was not able to use this to conclusively declare the existence of the decay mode $\Upsilon \to \gamma f_J$. I was however able to place an upper limit on the branching fractions of $B(\Upsilon \to \gamma f_J)\times B(f_J \to \pi^+\pi-)$, and $B(\Upsilon \to \gamma f_J)\times B(f_J \to K^+K^-)$ of 7.55×10^{-6} and 9.59×10^{-6} respectively. This allows us to place an upper limit on the simple scaling ratio of 1/40 stated above. $\pi^+\pi^- < 7/40$ and $K^+K^- < 9/40$.

I have started studying the uncertainties within my results. I have not obtained all of the uncertainties yet so I have not talked about them in this report at all. I will finish this study of the uncertainties. I also plan to continue the search within the decay mode of $p\overline{p}$. This is proving to be more difficult than the $\pi^+\pi^-$ and K^+K^- modes because of the shift of the $\gamma\rho$ peak right on top of the f_J mass spectrum. I have thus far looked into the consequences of dE/dx and time of flight cuts. Including both we still obtain one signal event within the 2σ signal box. So it looks as if it might be promising. This project has gone very well and if I keep pace it may go into publication in a physics journal.

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