Search for Weakly Decaying Charmed Pentaquark States

Peter Cooper, Jurgen Engelfried
February 18, 2004

Abstract

We have searched for a pentaquark state $uudd\bar{c}$ decaying weakly into $pK^+\pi^-\pi^-$ for masses below $2807MeV/c^2$ where the strong decay pD^- is forbidden. Jaffe and Wilczek [1] have predicted this state at $2710MeV/c^2$. In general, we can set a 95% confidence level upper limit for the production cross-section $\times$ branching ratio of $< 1\%$ relative to the topologically identical $D^0 \to K^+\pi^+\pi^-\pi^-$ decay mode assuming the same lifetime and production properties as the D^0.

We find a 4σ excess at $2740 \pm 3.5MeV/c^2$ consistent with the simulated mass resolution for this final state of $7.5MeV/c^2$. This 13 event excess over a 12 event background is statically inadequate for a discovery claim. It may constitute "evidence for" the state predicted by Jaffe and Wilczek. Both the events in the mass region of this signal and the entire event sample have a average reduced proper lifetime of $80 \pm 25fsec$. A lifetime $\times 5$ smaller that the D^0 may be a challenge to the interpretation of this bump as a charmed pentaquark candidate.

1 Introduction

Jaffe and Wilczek [1] have predicted that the pentaquark states with heavy anti-quarks are sufficiently tightly bound to be stable against strong decay. Specifically they predict the state $uudd\bar{c}$ to have mass of about $2710MeV/c$. After a "wine & cheese" seminar by Jaffe at Fermilab on February 6,2004, where he repeated this prediction, one of us (psc) decided that contradicting this prediction with data was probably worth the effort. This note reports the results of that study.

2 Search Methodology

2.1 Data Set

We wish to search for 4 prong detached secondary vertices with particle PIDs consistent with $pK^+\pi^-\pi^-$. There were no reconstructions included in either pass with pK^+ track PIDs for the obvious reason these these are exotic baryons containing heavy anti-quarks. Jurgen recalled that we had saved partial secondary vertex reconstructions with $K^+\pi^-\pi^-$ (ID=62) and it's charged conjugate $K^-\pi^+\pi^+$ (ID=64). These recons were saved in the out2 stream of the PASS1 analysis. All of these analyzed data are in Enstore and available for reanalysis.

2.2 Event Analysis

The analysis chain we adopted was to restore all the *out*2 analyzed data files and strip events which contain either an ID=62 or ID=64 recon. There are 17.8M events containing 5.06M

ID=62 and 7.30M ID=64 recons in this data set. These files were copied to UASLP and reanalyzed on the Linux cluster there to include new 3 and 4 prong reconstructions. The relevant RECDF table entries are shown below.

```
#recdf      0     0 fill anal v01.20 04-Mar-1998 16:32 psc ! pass12 recon list
! pass11 production - add new charmed baryon modes + excited states + x1 recons
  id  name       from pr q  pid  ls_min ls_max mass_min mass_max   out !   frac
!
! Partial states
  62  k-2i        v2  3 +1  k-i+i+   5.  800.   0.750  1.500  $002002 !18 0.20
  64  k+2i        v2  3 -1  k+i-i-   5.  800.   0.750  1.500  $002002 !20 0.35

#recdf      0     0 fill anal v04.12 Feb 18 2004 14:31 je ! Jurgen's list
  id  name       from pr q  pid   ls_min ls_max mass_min mass_max   out !
! Exotic States
 951  jaffe       v2  4  0 p+k+i-i-    5.   800. 1.500 2.900 $000002
 952  ajaffe      v2  4  0 p-k-i+i+    5.   800. 1.500 2.900 $000002
 953  jaffe       v2  3 +1 p+k+i-      5.   800. 1.500 2.900 $000002
 954  ajaffe      v2  3 -1 p-k-i+      5.   800. 1.500 2.900 $000002
 955  jaffe       v2  5 +1 p+k+i-i-i+  5.   800. 1.500 2.900 $000002
 956  ajaffe      v2  5 -1 p-k-i+i+i-  5.   800. 1.500 2.900 $000002
 957  jaffe       v2  4 +2 p+k+i-i+    5.   800. 1.500 2.900 $000002
 958  ajaffe      v2  4 -2 p-k-i+i-    5.   800. 1.500 2.900 $000002
 959  jaffe       v2  2 +2 p+k+        5.   800. 1.500 2.900 $000002
 960  ajaffe      v2  2 -2 p-k-        5.   800. 1.500 2.900 $000002
 961  jaffe       v2  5 -1 p+k+i-i-i-  5.   800. 1.500 2.900 $000002
 962  ajaffe      v2  5 +1 p-k-i+i+i+  5.   800. 1.500 2.900 $000002
```

The resulting FTUPLES were copied back to Fermilab to permit further analysis at both institutions.

2.3 Sample Selection

We defined a basic set of sample selection cuts based on previously used Selex single charm selection criteria. There are:

1. $L/\sigma > 8$
2. $pvtx < 5$
3. $svx\_chi2 < 3$
4. $tk1\_pz > 90 \& proton\_pid > 0$

The first three of these cuts are demonstrated on the topologically identical ID=103 $D^0 \to K^+\pi^+\pi^-\pi^-$ decay mode in figure 1. Tightening cuts 2 and 3 relative to the CHARM2 sample definitions retain 75% of the D^0 signal events while retaining 27.5% of the background.

The fourth cuts is a tight proton definition requiring that the candidate proton track be above proton threshold in the RICH and be at least 1/10 as likely to be a proton as the most likely PID hypothesis. There is little difference in the results of this search if the proton is required to be the most likely PID hypothesis. Testing this cut with the CHARM2 ID=400 Λ_c^+ sample retains 51% and 32% of signal and background events respectively. Most of the losses to this cuts are just the removal of events where the proton is below the $90 GeV/c^2$ RICH threshold.

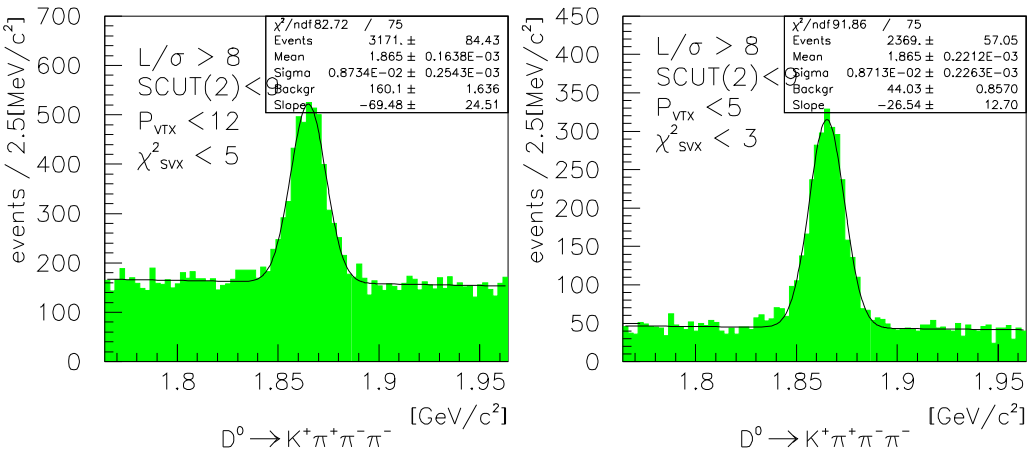

Figure 1: Sample defining cuts applied to the charm2 id=103 D^0 data.

ID	L/σ	P_{VTX}	χ^2_{SVX}	PID	signal		background		S/N
103	8	12	5	std	3171 ± 84	100%	160.1 ± 1.6	100%	1
103	8	5	3	std	2369 ± 57	75%	44.0 ± 0.9	28%	2.7
400	8	-	5	std	1435 ± 51	100%	65.1 ± 1.0	100%	1
400	8	5	3	std	1004 ± 48	70%	24.1 ± 0.6	37%	1.9
400	8	5	3	\$4	499 ± 32	35%	6.9 ± 0.3	11%	3.2

Table 1: Effect of sample defining cuts on charm signals.

The summary of the effect of appling the sample defining cuts to several of the charm signals are summarized in table 2.3

The K^+ is identified with the default Selex kaon identification; The kaon hypothesis is not less likely than the pion hypothesis.

These cuts define a sample of well reconstructed 4 prong vertices with very strong positive proton and kaon particle identification.

3 Search Results

3.1 Search plots

The search results for $uudd\bar{c} \to pK^+\pi^-\pi^-$ and $\overline{uudd}c \to \overline{p}^-K^-\pi^+\pi^+$ states in $10MeV/c$ mass bins are shown in figure 2. The bin width is chosen as $\sim 1.5\sigma$ (see below) so we expect any candidate signal to be an excess of events over background in two adjacent bins.

The olny features apparent in these spectra are in the $uudd\bar{c}$ plot. There is a 1 bin wide upward fluctuation with 12 events at $2500MeV/c^2$ and 2-3 bin wide structure near $2740MeV/c^2$. The probability of observing 12 or more events in one bin when the expected mean is 6 events is 2%. With 80 bins on this plot we expect one fluctuation of of at least this size.

The structure at $2740MeV/c^2$ is more interesting. This region is expanded and fit in

figure 3. The data in the region $2650 - 2900 MeV/c^2$ are fit to a Gaussian plus constant background with the resolution fixed to the simulation values of $7.5 MeV/c^2$. The fit is good and establishes a constant background level of 3.9 ± 0.4 events per bin. In the 3 bin region $2720 - 2750 MeV/c^2$ there are 25 events with a expected background of 11.6 events. This is an excess if $(25 - 11.6)/\sqrt{(11.6)} = 3.9\sigma$ excess. The possion probability of observing 25 or more with an expected mean of 11.6 is 4.2×10^{-4}. Evalauting the Possion excess probability as the product of the Possion excess probabilities in each of the 3 bins given a probability of this excess as 7.2×10^{-5}.

This structure fails to achieve a 5σ discovery threhold but, at the 4σ level, it is too signficiant to just ignore. It is robust against variations in the cuts. We can't seem to make it much more, or less, significant by cut variations which keep the total number of events in this sample about the same. This structure appears to be a classic case of "evidence for" something at $2740 \pm 3.5 MeV/c^2$. There is weak confirmnating information in the charged conjugate channel shown in green (grey) in figure 3. There is a 4 event excess over a 2.5 event background ($\sim 2.5\sigma$) at the same mass.

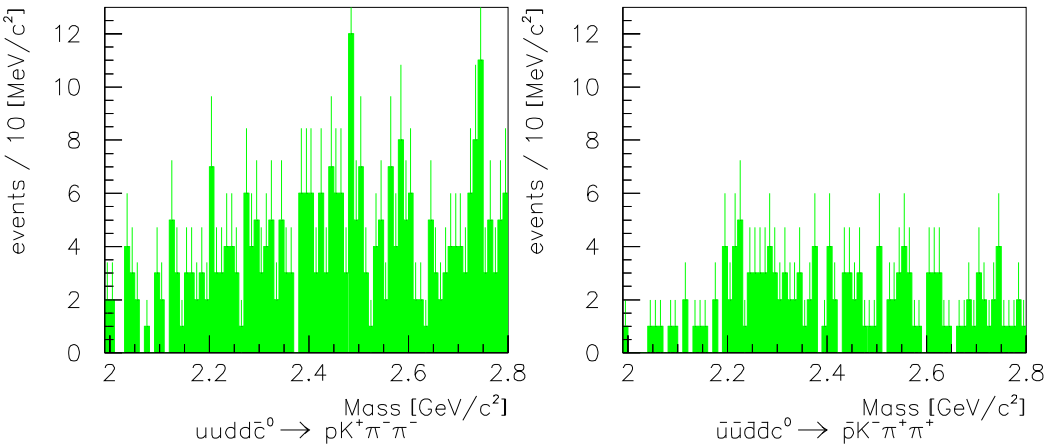

Figure 2: Search results for $uudd\bar{c}$ (left) and $\overline{uudd}c$ (right) states in $10 MeV/c$ mass bins.

3.2 Background sources

3.3 Upper Limits

4 Acceptance and Resolution

5 Conclusions

References

[1] R. L. Jaffe and F. Wilczek, Phys. Rev. Lett. **91**, 232003 (2003) [arXiv:hep-ph/0307341].

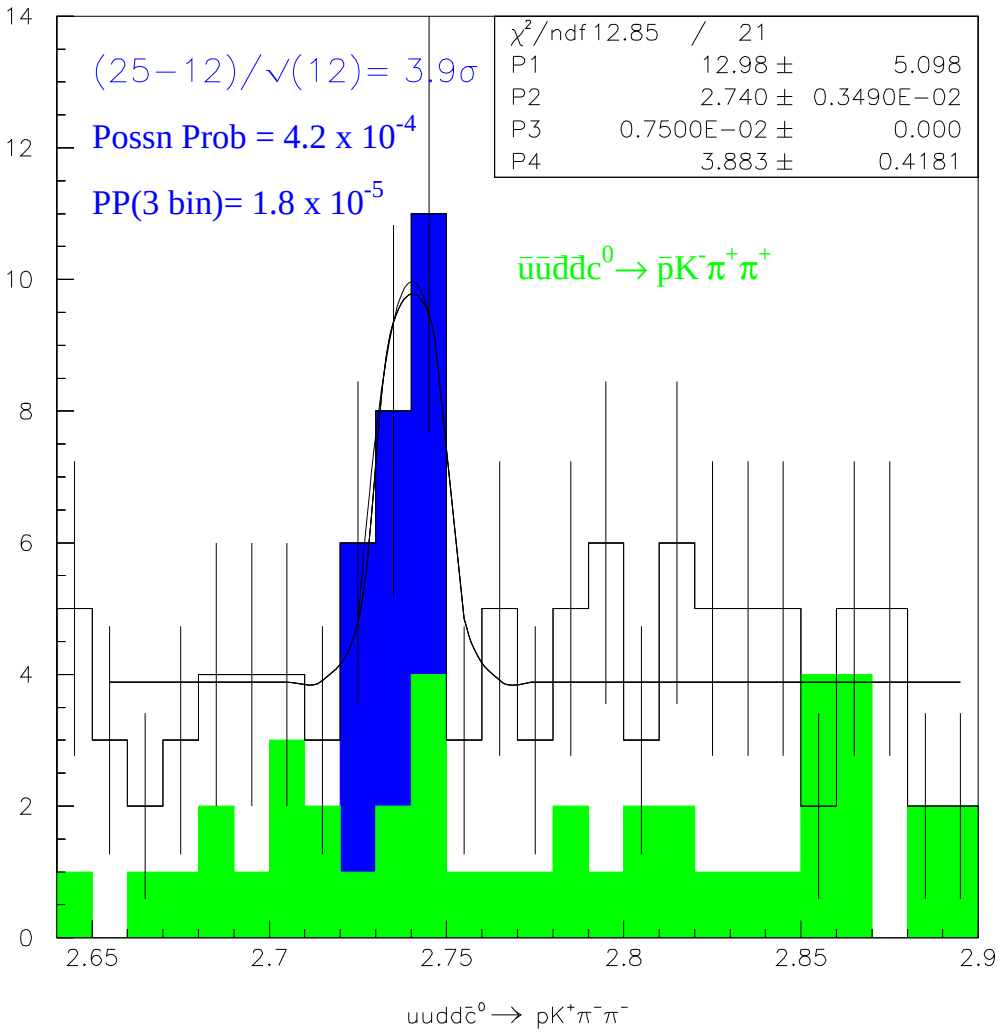

Figure 3: Candidate region fit with a fixed width Gaussian plus constant.

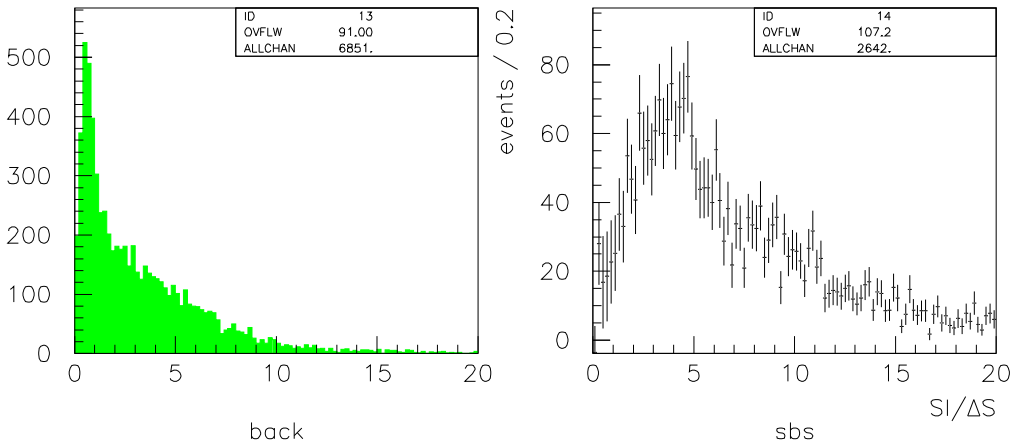

Figure 4: Primary vertex $|S|/\Delta S$ for π^+ track from ID=103 $D^0 \to K^+\pi^+\pi^-\pi^-$ events: Sidebands (left), Signal(right).

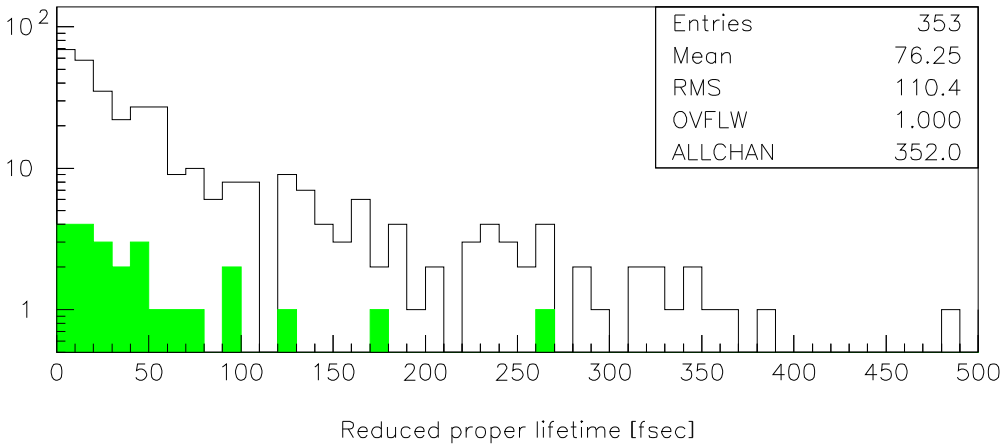

Figure 5: Reduced proper lifetime for whole sample (open) and candidate region (solid) events.