Fermi National Accelerator Laboratory

FN-524

Embedded e^+e^- Pairs in Heavy Flavor Photoproduction*

J. A. Appel, J. Busenitz and S. Gourlay
Fermi National Accelerator Laboratory
P.O. Box 500
Batavia, Illinois 60510

October 1, 1989

* Talk given by J. Busenitz at "Physics at Fermilab in the 1990's," Breckenridge, Colorado, August 15-24, 1989.

Operated by Universities Research Association Inc. under contract with the United States Department of Energy

Embedded e^+e^- Pairs in Heavy Flavor Photoproduction

J. A. Appel, J. Busenitz, and S. Gourlay

1 October 1989

I. Introduction

Bethe-Heitler e^+e^- pairs comprise a copious background to photoproduction experiments studying hadronic final states. Even for light-nucleus targets, e.g. H_2 or Be, the Bethe-Heitler pair rate is two to three orders of magnitude greater than the total hadronic production rate. Experiments now being considered for the future aspire to hadronic interaction rates approaching 100 kHz, which implies pair production rates of O(100 MHz). At such rates and assuming gate widths which are at least tens of nanoseconds, several pair events, on average, will occur in the same gate-length interval as a hadronic event.

Below we report the results of studies carried out to understand the degree to which these so-called "embedded pairs" affect the reconstruction of heavy-flavor states. Though the presence of multiple embedded pairs impacts on many aspects of the reconstruction, we have focused on the effects on track finding and particle ID. In particular, we address two questions. First, supposing that tracking detector efficiencies can be maintained at high pair rates and that nothing is done to baffle Cerenkov light from pairs, how is the reconstruction affected as a function of the number of embedded pairs in the event? Second, what is the effect on the acceptance of deadening chamber wires in the pair region and inserting baffles into the Cerenkov counters?

II. Simulation and Event Reconstruction

To estimate the effects of multiple pairs on heavy flavor detection, we chose to study the reaction $\gamma p \rightarrow \Lambda_c D^- X$ occurring in conjunction with n photons converting to pairs. The Λ_c was forced to subsequently decay into $pK\pi$ and the charged D into $K\pi\pi$. (The charmed reaction products were charge-conjugated in 50% of the events.) The charm production model chosen was photon-gluon fusion followed by δ(z-1) fragmentation. (Use of the more realistic Petersen fragmentation function would increase the acceptances quoted below by roughly a factor of 1.1.) The photon initiating the charm production was drawn from a bremsstrahlung spectrum between 50 and 350 GeV and was targeted according to the E687 beam profile in the 1987-88 run. Each of the n conversion photons was also targeted according to the E687 beam profile but its energy was drawn from a 1/k spectrum between 1 and 350 GeV.

For the detector simulation and event reconstruction, we used essentially the current E687 Monte Carlo and reconstruction programs. To be more precise, we used the E687 programs, as is, to obtain the results reported in Section III, but modified them, as described in Section IV, to obtain the results for the case where baffles are built into the Cerenkov counters and chamber wires lying within the pair region have been deadened. The tasks carried out by the reconstruction program, in any case, were track-finding from hits in the SSD's, track-finding from the hits in the MWPC's, particle ID using the Cerenkov counters, vertex-finding using the SSD tracks and the PWC tracks separately, reconstruction of V^0's, and linking of SSD tracks to PWC tracks.

III. Reconstruction: No Dead Wires and No Baffles

We first generated samples with no pairs, 3 pairs/event, and 5 pairs/event, respectively, using the E687 Monte Carlo and reconstructed the simulated data using the current E687 reconstruction program.

Table 1 lists the mean MWPC track multiplicity, the mean SSD track

multiplicity, and the average event reconstruction time on a VAXstation 3200 for each of these samples. The change in MWPC multiplicity as the number of pairs/event is increased is somewhat less than twice the change in number of pairs because there is an effective momentum cutoff of about 2 GeV/c for particles to make it past the first magnet into the MWPC system. The SSD reconstruction program reconstructs most of the pairs as single tracks, due to the small opening angle between the members of the pairs, which explains why the change in the SSD multiplicity goes approximately as the number of pairs. Most striking in Table 1, but not totally unexpected, is the strong dependence of the reconstruction time on the number of pairs. In going from 0 pairs/event to 5 pairs/event, for example, the average reconstruction time increases by an order of magnitude.

It must be mentioned that SSD track-finding algorithm failed on about 5% of the events in the 5-pair/event sample in the sense that it did not find any tracks at all. The reason for this failure was that the number of tracks formed, prior to the stage in which arbitration is carried out to remove duplicates, exceeded 150. Without having investigated these failures in detail, we cannot say whether these failures can be avoided by the increasing the maximum number of pre-arbitration tracks allowed or whether they indicate an irrecoverable breakdown in the track-forming process. We have determined, however, that these "failed" events do not make a disproportionately large contribution to the difference in average reconstruction time between the 3-pair/event and 5-pair/event samples.

Before discussing the effects of embedded pairs on acceptances, we show how the occupancy/event for various detector elements changes as the number of embedded pairs is increased. Figure 1a shows the mean MWPC wire occupancy for the four views P0X, P0V, P4X, and P4V in the case of 0 pairs/event and Figure 1b shows the corresponding occupancies for 5 pairs/event. P0 is the most upstream MWPC station and P4 is the last MWPC station; the X wires run vertically, in the same direction as the magnet kicks, while the V wires make an angle of 11.3 degrees with respect to the horizontal. The wire spacing in P0 is 2 mm and for P4X and P4V it is 3 mm and 2mm, respectively. The pair "spikes" in the P0X and P4X are between 4 and 5 cm wide at the base. The occupancy peak in the P0V view is noticeably sharpened by the addition of the pairs, but the highest

occupancy is less than about 0.2. The emergence of the sharp peak in the P4V view for 5 pairs/event is due to the fact that the kicks of the two E687 analyzing magnets are set to focus the Bethe-Heitler pairs onto the beam hole of the inner electromagnetic calorimeter, which is less than a meter downstream of P4.

Figures 2a and 2b show the mean Cerenkov cell occupancy for 0 pairs and 5 pairs, respectively. C1 and C2 lie between the two analysis magnets while C3 lies downstream of the second. The very high occupancy of two C3 cells in the 5-pair/event sample is also due to the pair focusing already mentioned in connection with P4V.

We now sketch the effects of the embedded pairs on the detection efficiency of the charm states. Tables 2 and 3 list the integrated acceptances for $D \rightarrow K\pi\pi$ and $\Lambda_c \rightarrow pK\pi$, respectively, as a function of an increasing number of requirements. The minimum requirement, denoted by "PWC" in the table, is that all daughters of the respective charm decay be found in the MWPC's. The second set of requirements, denoted by "Cerenkov" in the table, is that the daughters be reconstructed in the MWPC's and that the kaon be identified as K definite or K/p ambiguous and that the proton, if any, be identified as p definite or K/p ambiguous. The final set of requirements, labeled "SSD", is that the tracks be reconstructed in the MWPC's and SSD's and that the kaon and proton be identified as indicated above. The "rel." column gives the acceptance for the current requirements normalized to the number of events which passed the previous set of requirements while the "cum." column is the acceptance normalized to the total number of events in the sample.

From the results listed in the "rel." columns, we see that MWPC, SSD, and particle ID efficiencies alike are degraded by the embedded pairs. The degradation between 0 pairs and 5 pairs is 5-10% for the MWPC and SSD reconstruction efficiencies and 10-15% for particle ID. (Recall that the SSD degradation includes about 5% from failures in the 5-pair sample.) The cumulative efficiencies after all cuts decrease between 20 and 30% in going from no pairs to 5 pairs/event.

The losses in SSD and PWC reconstruction can be attributed to the fact that the additional hits due to the pairs makes pattern recognition more difficult for tracks in the pair region. (If one plots the individual PWC track

reconstruction efficiency as a function of the track's projection in x to the bend plane of the second magnet, the efficiency is independent of the number of pairs except around x=0, where a dip occurs, the depth and width of which increases with the number of pairs.) The decrease in heavy particle ID efficiency occurs mainly because the pairs increase the frequency with which cells in the pair region are "confused" , i.e. overlapped by more than one track. There is also a secondary effect contributing to ID inefficiencies which follows from inefficiency in the PWC track reconstruction, namely, Cerenkov light from unreconstructed tracks which is mis-associated to a reconstructed track.

IV. Reconstruction: Dead X Wires and Cerenkov Baffles

In building a detector to take pair rates in the range of 100 MHz, it is reasonable to consider deadening the X view wires which lie in the pair region and also to baffle the Cerenkov counters in the same region. The argument for deadening the X wires is essentially that they cannot be made efficient anyway at such rates and will just draw a lot of current. (In principle, it would not be necessary to completely deaden an X wire which overlaps the pair region but just that portion of the X wire which takes most of the rate. This has the clear advantage of maintaining a significant amount of X view sensitivity over the range in x populated by the pairs. For the sake of simplicity, however, our study takes the entire X wire to be deadened, which is the worst case.) Placing narrow vertical baffles in the Cerenkov counters would eliminate most of the confusion due to pairs and avoid problems such as baseline shifts due to pile-up one would probably otherwise have for cells with high occupancy.

In order to estimate the effects of deadened X wires and Cerenkov baffles on the charm detection efficiency, we modified the E687 Monte Carlo and reconstruction program as follows. In the Monte Carlo program we added vertical baffles to each Cerenkov counter; each baffle was 5 cm wide and centered on the beam. The particle ID algorithm of the reconstruction program was also modified to take into account the baffles when calculating

light yield predictions. The first attempt at putting dead X wires into the acceptance calculation consisted of dropping all X hits in the pair region before calling the MWPC reconstruction routine. The MWPC reconstruction efficiency in this scheme came out surprisingly low and appeared to depend largely on the fact that one Y view was inefficient and that no more than 5 hits were allowed to be missing. Rather than modify the reconstruction program to better optimize it for missing X hits, we instead called the MWPC track finding routine without having first dropped the X hits and then, before carrying out any further reconstruction involving the MWPC tracks, deleted those MWPC tracks whose reconstruction had depended critically upon X hits in the pair region. The bands of X wires effectively deadened varied in width chamber-to-chamber between 4 and 6 cm. The effect of this *ad hoc* procedure to account for dead X wires was to reduce the individual track reconstruction efficiency from 97% in the pair region to about 90%. (The reason that the efficiency does not go to zero in the pair region is that one still has information on the track from the V, U, and Y views.)

Tables 4 and 5 show the measured acceptances for a sample with 0 pairs and and a sample with 3 pairs/event. (Lack of time precluded studying a 5-pair sample.) As far as the MWPC and particle ID efficiencies are concerned, there is very little change in going from 0 pairs/event to 3 pairs/event, i.e. in this scenario there appears to be very little dependence on the number of pairs in the event. By comparing column 1 of Tables 4 and 5 with column 1 of Tables 2 and 3, respectively, we see that the efficiency for finding all 3 charm daughters in the PWC's is reduced by an average factor of 0.95 as a result of deadening the X wires and that the efficiency for correctly identifying the daughters is re-scaled by an average factor of 0.9 through the addition of baffles.

V. Summary and Final Comments

Taking the E687 detector as a model and assuming that the E687 reconstruction program is reasonably optimized for reconstructing events with embedded pairs, we have seen that the efficiency for reconstructing daughters of secondary charm decays and identifying the heavy daughters cor-

rectly does depend on the number of embedded pairs in the event. The ratio of the efficiency in the case of 5 pairs/event to that in the case of no pairs is in the range of 0.7 to 0.8. Deadening X wires and baffling Cerenkov counters in the pair region greatly weakens the dependence of the efficiency of the MWPC track finding and particle ID on the number of embedded pairs but at a cost up front of 10-15% in efficiency. Moreover, it is important to keep in mind our observation that the average time required to reconstruct an event increases rapidly with the number of pairs. This observation still holds if X wires are selectively deadened and Cerenkov baffles installed. It is well worth further investigation to understand in detail the dependence of the reconstruction time on the number of embedded pairs, in case changes are possible which can significantly moderate that dependence without sacrificing reconstruction efficiency.

Overall, the above results indicate that multiple embedded pairs do not threaten major losses to the efficiency for reconstructing heavy flavor states. This is true in any case if the average number of embedded pairs does not greatly exceed 5 pairs/event and, as far as MWPC track-finding and particle ID efficiencies are concerned, it would appear to be true for a wide range of pair multiplicities if X wires in the pair region are deadened and Cerenkov counters baffled. It must be kept in mind, however, that detector noise, a problem which becomes more acute with higher rates, was not simulated by our Monte Carlo, and also that we assumed that the efficiencies of views other than the X view are unaffected by high rates. Furthermore, we have clearly limited our study to the effects of multiple embedded pairs on *average* efficiencies; for efficiencies in restricted regions of phase space, e.g. high x_F, the effects of pairs may be significantly more severe than for the average.

Table 1
Dependence of Multiplicity and
Average Event Reconstruction Time
on Embedded Pairs

	PWC Multiplicity	SSD Multiplicity	Reconstruction Time (VS3200 seconds)
0 pairs	6.3	7.1	0.7
3 pairs	10.9	11.1	3.0
5 pairs	14.4	13.4	7.5

Table 2
Dependence of $D^{\pm} \rightarrow K\pi\pi$ Acceptance on
Embedded Pairs

	0 pairs		3 pairs		5 pairs	
Cut	rel.	cum.	rel.	cum.	rel.	cum.
PWC	0.69	0.69	0.67	0.67	0.65	0.65
Cerenkov	0.68	0.47	0.66	0.44	0.62	0.40
SSD	0.89	0.41	0.85	0.37	0.79	0.32

Table 3
Dependence of $\Lambda_c \rightarrow pK\pi$ Acceptance on
Embedded Pairs

	0 pairs		3 pairs		5 pairs	
Cut	rel.	cum.	rel.	cum.	rel.	cum.
PWC	0.77	0.77	0.76	0.76	0.73	0.73
Cerenkov	0.67	0.51	0.60	0.45	0.54	0.40
SSD	0.90	0.46	0.88	0.40	0.82	0.33

Table 4
Dependence of $D^{\pm} \rightarrow K\pi\pi$ Acceptance on
Embedded Pairs
(Deadened X Wires + Baffle)

	0 pairs		3 pairs	
Cut	rel.	cum.	rel.	cum.
PWC	0.66	0.66	0.66	0.66
Cerenkov	0.63	0.42	0.64	0.42
SSD	0.90	0.39	0.86	0.36

Table 5
Dependence of $\Lambda_c \rightarrow pK\pi$ Acceptance on
Embedded Pairs
(Deadened X Wires + Baffle)

	0 pairs		3 pairs	
Cut	rel.	cum.	rel.	cum.
PWC	0.72	0.72	0.72	0.72
Cerenkov	0.60	0.43	0.59	0.43
SSD	0.90	0.39	0.86	0.37

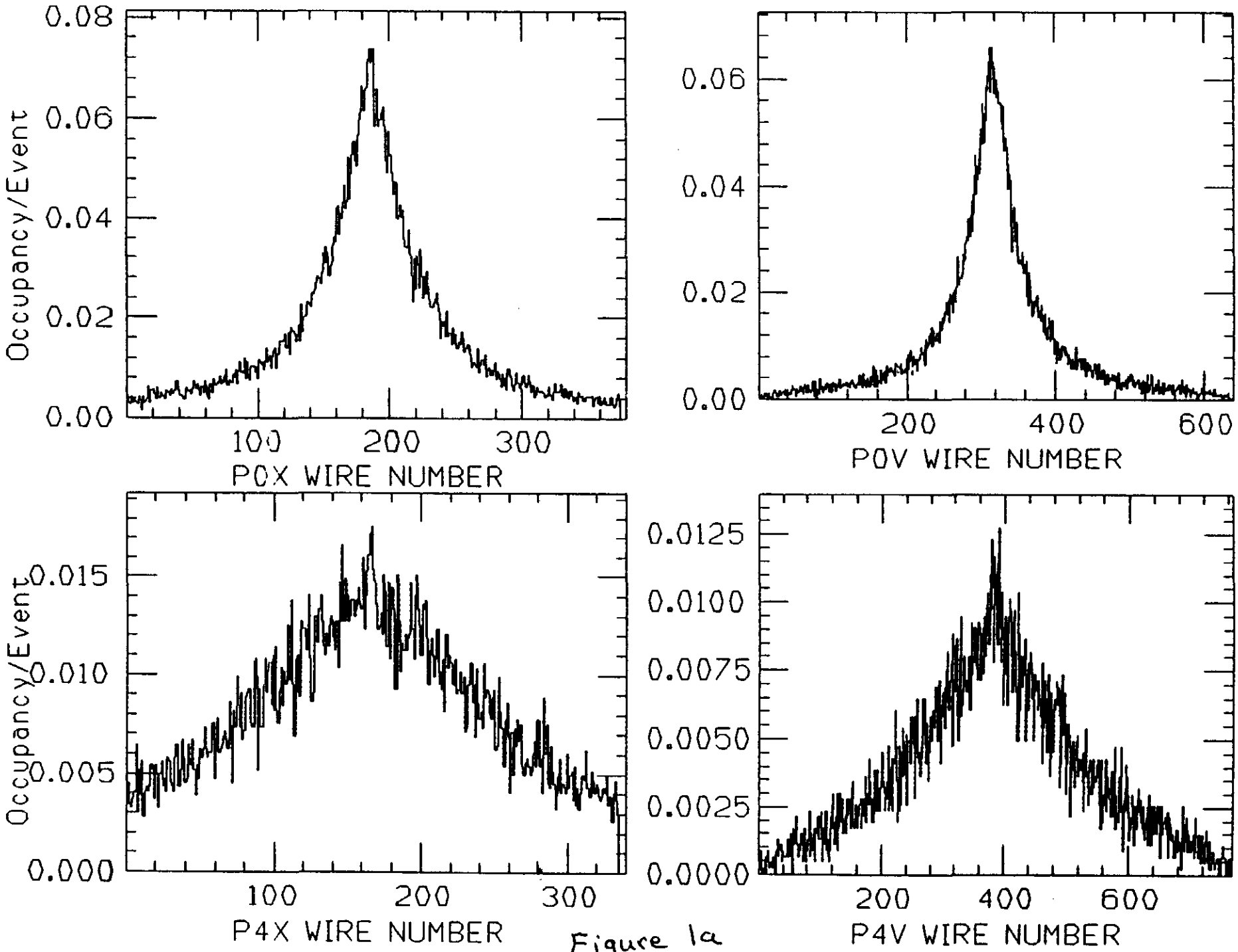

0.08
0.06
0.04
0.02
0.00
Occupancy/Event
100
200
300
P0X WIRE NUMBER
0.06
0.04
0.02
0.00
200
400
600
P0V WIRE NUMBER
0.015
0.010
0.005
0.000
Occupancy/Event
100
200
300
P4X WIRE NUMBER
0.0125
0.0100
0.0075
0.0050
0.0025
0.0000
200
400
600
P4V WIRE NUMBER

Figure 1a

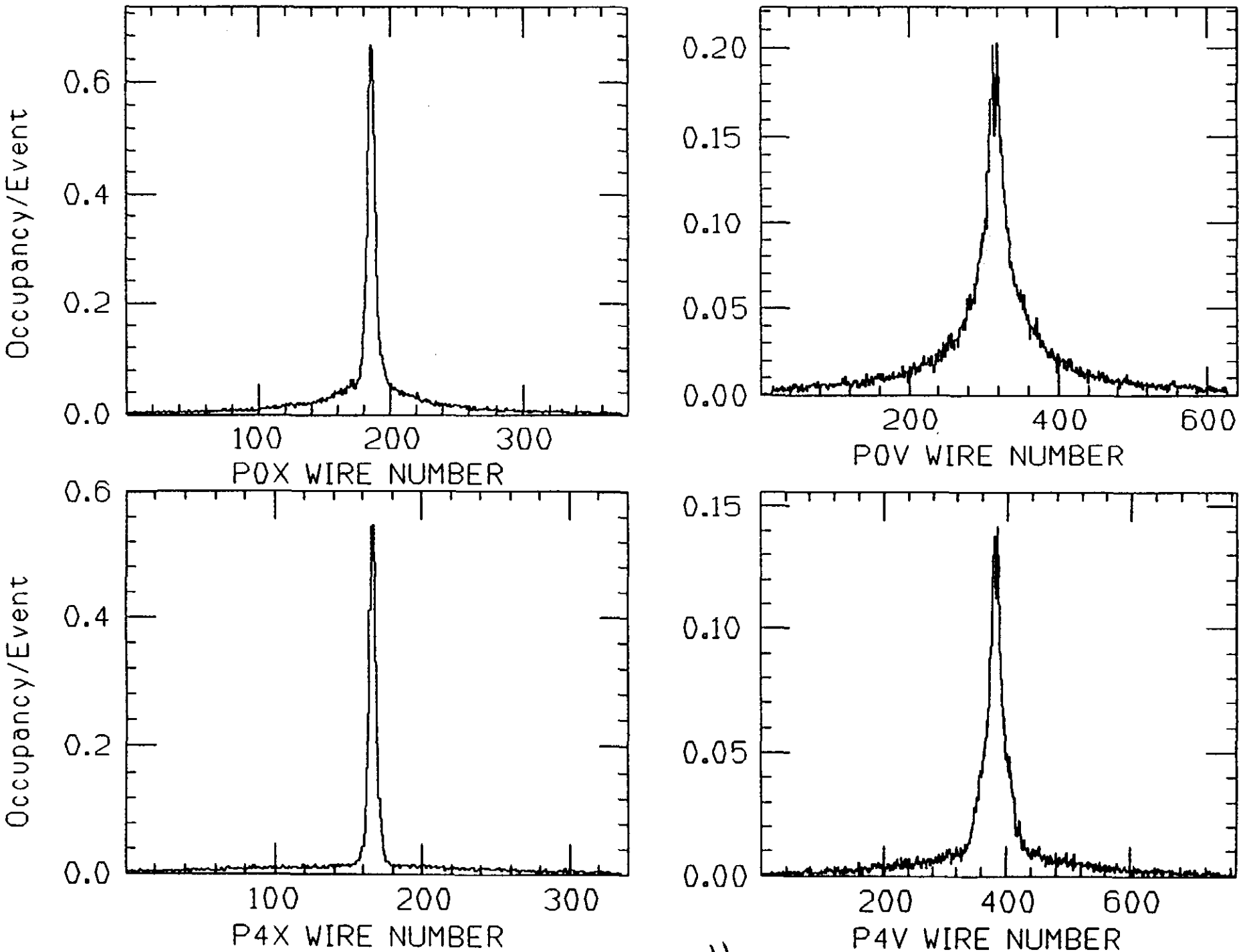
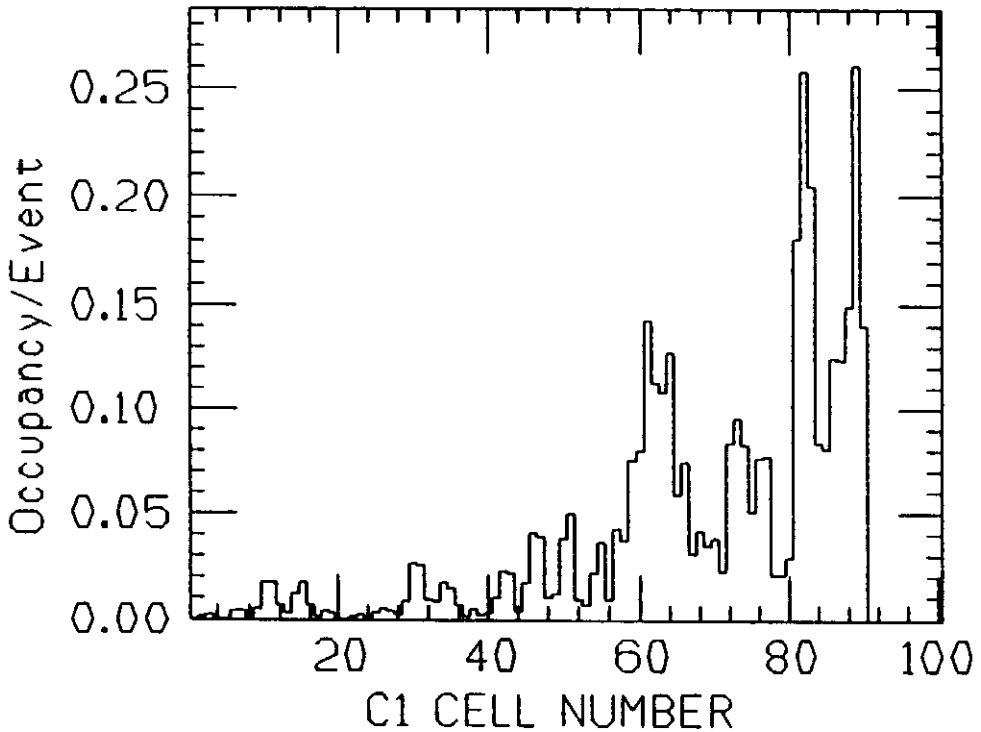
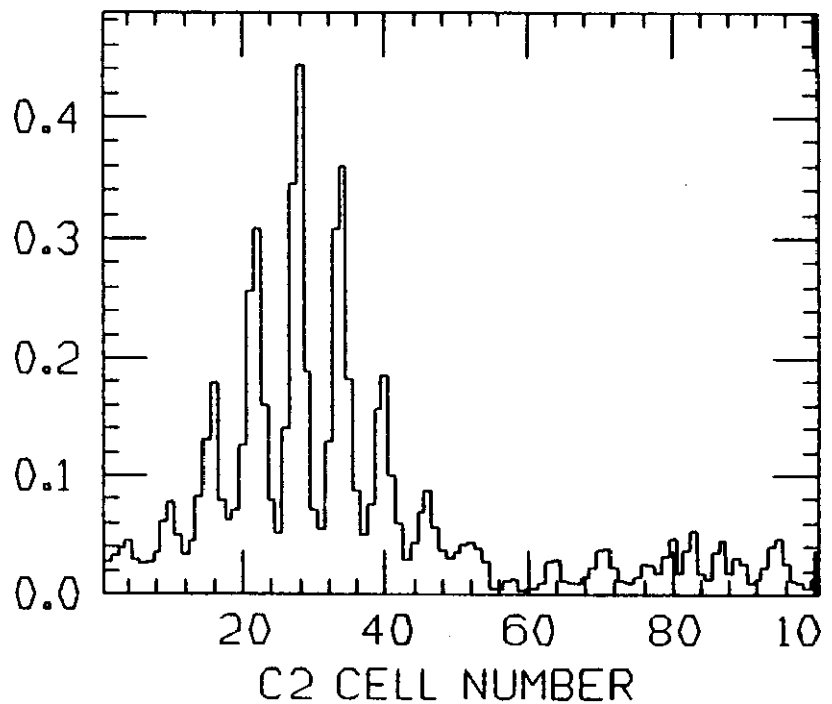

Occupancy/Event
0.6
0.4
0.2
0.0
100
200
300
P0X WIRE NUMBER
0.20
0.15
0.10
0.05
0.00
200
400
600
P0V WIRE NUMBER
Occupancy/Event
0.6
0.4
0.2
0.0
100
200
300
P4X WIRE NUMBER
0.15
0.10
0.05
0.00
200
400
600
P4V WIRE NUMBER

Figure 1b


Occupancy/Event
0.25
0.20
0.15
0.10
0.05
0.00
20
40
60
80
100
C1 CELL NUMBER


0.4
0.3
0.2
0.1
0.0
20
40
60
80
10
C2 CELL NUMBER

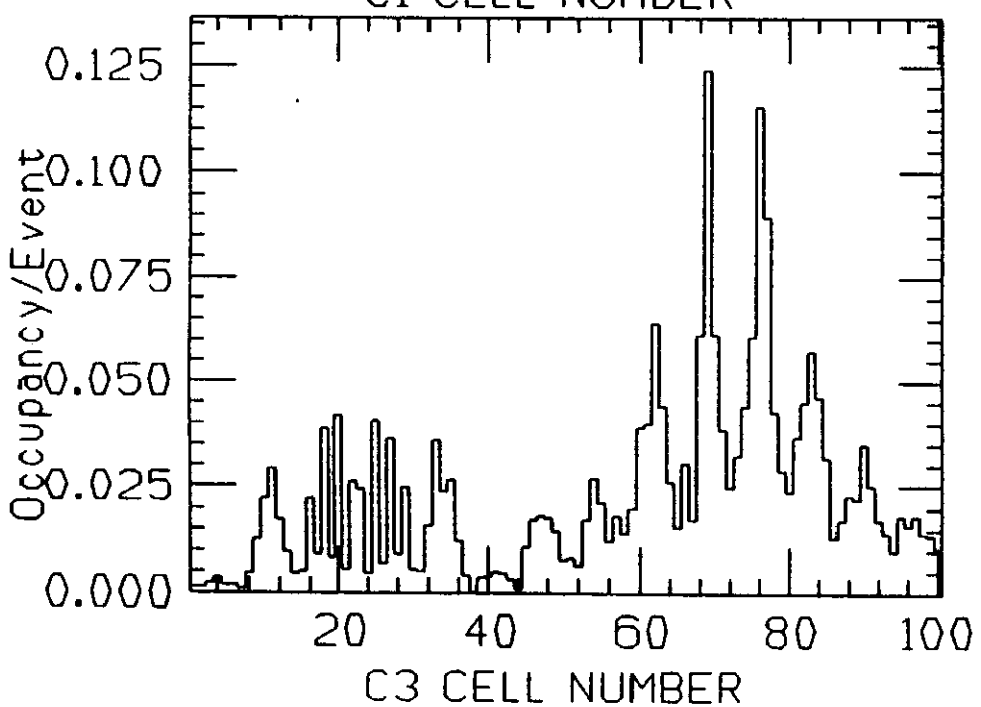
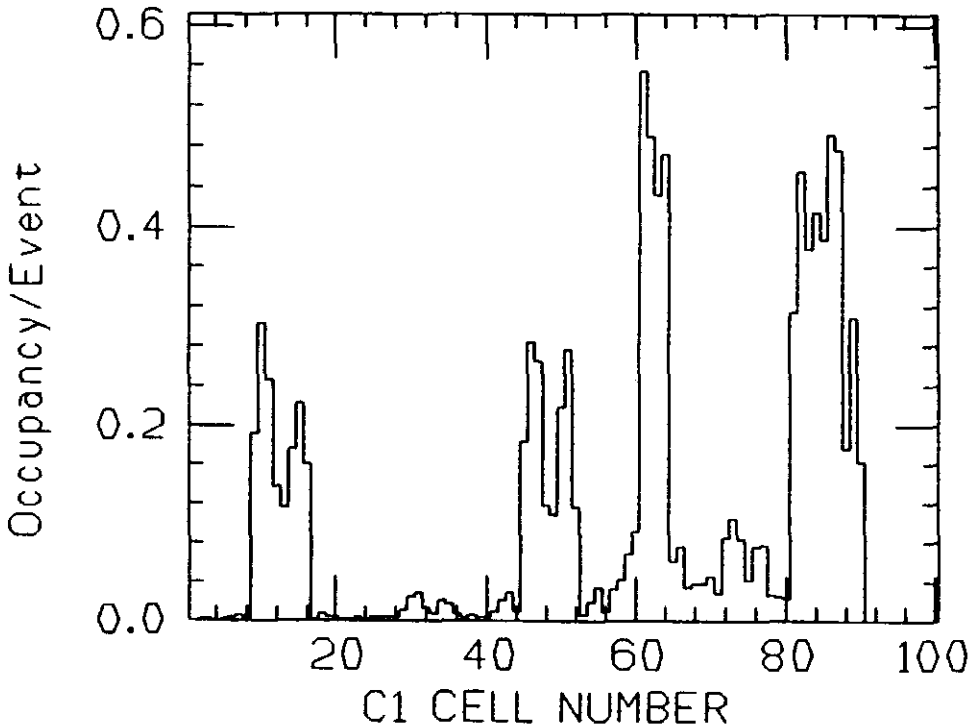
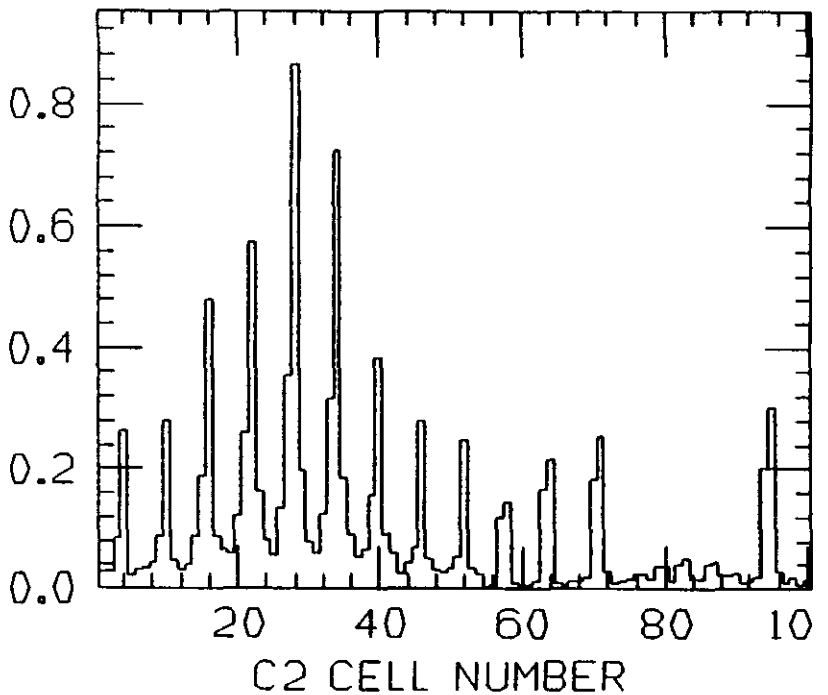

Occupancy/Event
0.125
0.100
0.075
0.050
0.025
0.000
20
40
60
80
100
C3 CELL NUMBER

Figure 2a


0.6
0.4
0.2
0.0
Occupancy/Event
20
40
60
80
100
C1 CELL NUMBER


0.8
0.6
0.4
0.2
0.0
20
40
60
80
10
C2 CELL NUMBER

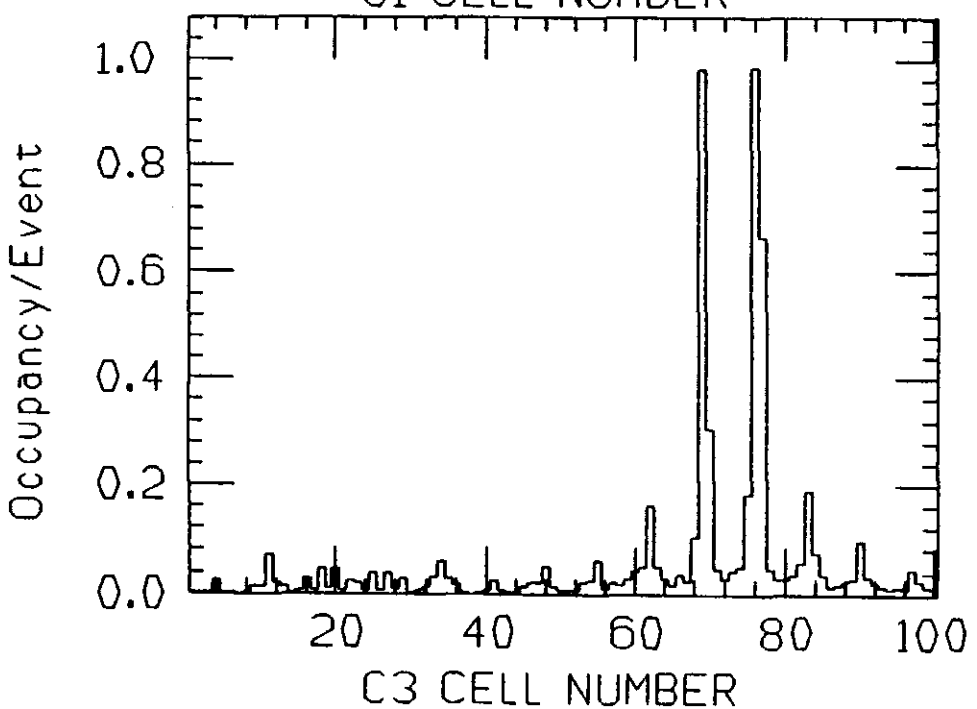

1.0
0.8
0.6
0.4
0.2
0.0
Occupancy/Event
20
40
60
80
100
C3 CELL NUMBER

Figure 2b