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# PERFORMANCE OF BEAM-BEAM COUNTER IN 1985 RUN

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## ABSTRACT

The beam-beam counter (BBC) system is one of the components of the trigger system for the Collider Detector at Fermilab. The BBC consists of 2 modules, each having 16 scintillation counters. In September-October run, a total of 28 counters were avilable. The performance was examined, using 26 beam-beam events at $\sqrt{s} = 1.6$ TeV, including 3 probable beam-beam events. The position (time) resolution and reconstruction efficiency were found to be 5.6 cm (0.19 nsec) and 91 +/- 6 %, respectively. In a Monte Carlo simulation, the efficiency is expected to be 96 %. The total charge collected in each module was equivalent to about 60 minimum ionizing particles per event. It was extremely large compared to 10 particles in Monte Carlo simulation. The difference seems to come from the particles generated by the interaction of the collision particles with beampipe.

## 1. Introduction

In the September-October run of Tevatron I, the Collider Detector at Fermilab (CDF) had detected 1.6 TeV beam-beam events. The beam-beam counter (BBC) system was used as one of the components of the trigger system for CDF. The BBC consists of 2 modules, called West and East modules. The trigger condition was

(BBC*L1) + MUON,

where

BBC = E*W with 30 nsec beam-beam gate width

L1 = Calorimeter at Level 1 {
- Single Tower 1.4 GeV
- Tot Et (EM) 1.5 GeV
- Tot Et (Had) 1.5 GeV
- Tot Et 3.1 GeV
- Summer C

MUON = Central muon (+/- 50 mRad of incident angle in phi)

A total of 886 events were triggered in Runs 489, 493, and 494. The 26 of 886 events were recognized by Vertex TPC (VTPC) to be beam-beam events, including 3 probable beam-beam events, i.e. the interaction position was outside the VTPC. Using 26 events, the performance of the beam-beam counter (BBC) is reported in the present note, i.e. efficiency of BBC for beam-beam events and position resolution of interaction point. The position resolution is very sensitive to the timing correction of each counter, and it is also limited by the statistic of calibation data used for the timing correction.

## 2. Setup of Beam-Beam Counter System

The BBC system was set up as one of the trigger systems for CDF. The system consists of 2 BBC modules, i.e. West and East modulues, FASTBUS/CAMAC system hardwares, and gating logic.

The West and East modules had 15 and 14 scintillation counters, respectively, during the September-October run. A complete system should have 16 counters for each module. The modules were placed at the forward (east) and backward (west) position of 581.6 cm (19.4 nsec) from the origin of CDF coordinate system. The counters are classified into four types, called types 0, 1, 2, and 3, according to the size. The size and the tube type attached at the both ends are tabulated in Table 1 [CDF Note 250].

The time and charge of the tube pulse were digitized with LeCroy 2228A TDC and LeCroy 1885N ADC, respectively. A total of 9 TDC and 1 ADC modules were driven by FASTBUS. The TDC's were especially driven with a FASTBUS branch driver (STRUCK model 320). The digitization was performed in 44 ps/count and 50 fC/count nominally. The calibration for each channel was performed within 1 % and 1.5 % for TDC and ADC respectively.

Each tube voltage was set to give 10 - 15 pC (2000 - 3000 ADC counts) of charge for a fast charged particle passing through the counter.

The block diagram of the trigger electronics is shown in Figure 1. The counter hits by particles within beam-beam gate and beam-gas (halo) gate were recorded in a latch module (STRUCK model 136). The latch information was sent to a fast logic board, which makes various OR'ed and AND logics (e.g. E*W, E*W*(No Halo) ).

The gating logic served to control TDC and ADC starts, latch gate, and the clearing of the TDC, ADC, LATCH channels of BBC system. The gating was given by the master clock system. The TDC start was set to come at about 30 nsec before the beam crossing.

## 3. Timing Correction in BBC-TDC

Two kinds of timing corrections for each TDC channel were made in the offline analysis, using the TDC data of 886 events taken in Runs 489, 494, and 494:

(1) Timing between 2 tubes in a counter,
(2) Timing between counters in a module.

In the item (1), the distribution of the time diffrence in 2 tubes was investigated and the spread of the transit time in phototube was estimated. The investigation is important to reject a non-physical hit for the counter, because the time difference is limited by the physical size of the counter. After the investigation, the mean time in a counter was fit to a function of the pulse height in the item (2). Then the timing was determined to give the same timing in a module. Notice that the events used for the fitting were statistically independent of the 26 beam-beam events. The detail descriptions are given below.

### 3.1 Spread of Transit Time in Phototube

We first adjusted the timing between two tubes attatched at the both ends of each counter. To select TDC data which a single particle hit a counter, the distribution of the time difference checked with ADC cut (200 - 4000 per tube) after subtracting the pedestal. The timing was determined to be a distribution around zero. The analysis of the adjustment was performed for Runs 489, 493, 494.

Assuming a uniform distribution of single particle hits, the spread can be expressed as

$$\sqrt{W^2 / 12 + 2\,\mathrm{Sigma(tube)}^2} , \qquad W = 2\,L ,$$

where L = length of counter, Sigma(tube) = spread of transit time in a tube. The length is expressed in units of nsec using that the refractive index of the scintillator is 1.58. The size and specification for Sigma(tube) are tabulated in Table 1. If a single particle hit was perfectly selected by ADC cut, the distribution should be uniform, which are smeared by the spread of the transit time. The distribution is actually like a Gaussian. Therefore, the spread of the distribution was estimated by using Gaussian. The above relation gives Sigma(tube) = 0.77 nsec for counter types 1 - 3, 0.41 nsec for type 0 as shown in Table 2 and Figure 2.

The time resolution for one counter (two phototubes) is then

$$0.41 / \sqrt{2} = 0.29 \text{ nsec} \quad \text{(for type 0)},$$

$$0.77 / \sqrt{2} = 0.54 \text{ nsec} \quad \text{(for types 1 - 3)},$$

using the mean time. If N counters per module catch the collision partilcles, the position resolution should be

$$0.29 / \sqrt{2N} \quad \text{(0.21 nsec for N = 1) ; type 0},$$

$$0.54 / \sqrt{2N} \quad \text{(0.38 nsec for N = 1) ; types 1 - 3},$$

The estimate takes into account the spread of transit time, and neglect contributions from both variations of the pulse height and the photon collection time in the scintillator.

### 3.2 Timing Correction of TDC by ADC

After above mentioned adjustment, the timing correction for each counter was performed using the TDC and ADC data by same protons in a bucket, i.e. particles at beam-gas time in West and beam-beam time in East. The counter information was selected with 200 < ADC < 4000 counts. A total of 221 events remained after ADC cut. The result is listed in Table 3. In the data, the time difference between West and East modules should be equal to the distance between modules (38.8 nsec). The timing should depend on the pulse height:

$$T = a + b / \sqrt{Q} ,$$

where T and Q are the mean time and charge in counter. The timing correction was performed to set the intercept (b) to the time when the protons in the bucket pass through each module. Therefore, the difference of the values of intercept between West and East is around 38.8 nsec. The correction, however, is limited by statistic of the data. If the intercept (b) is determined within an accuracy of 0.1 nsec, a total of 2000 events will be needed for the calibration.

# 4. Event Analysis

## 4.1 Procedure of Event Analysis

After making correction of the timing for each counter, the event analysis was perfomed according to the following procedure:

(1) Select the counters latched in beam-beam gate.

(2) Check ADC values of both tubes of the counter to select single particle hit in the counter; 200 < ADC < 4000 counts above the pedestal.

(3) Search for timing clusters for West and East modules with bin size of 0.5 nsec because the time resolution for a counter 0.54 nsec for types 1 - 3 as estimated in Section 3.

(4) Select a cluster with the most number of counters for module which has 2 or more clusters. The time in type 3 was often apart from the cluster. The next section gives a consideration on background with respect to the clustering.

(5) Calculate the time difference between two clusters in West and East modules for interaction position, the average time for interaction time, and the cluster size in Z-T plane:

$$Zint = \sum_{i,j} Zij \ / \ (Nw \cdot Ne) \ ,$$

$$Tint = \sum_{i,j} Tij \ / \ (Nw \cdot Ne) - TO \ ,$$

$$Tdev^2 = \sum_{i,j} [Zij - Zint]^2 \ / \ C^2 + \sum_{i,j} [Tij - Tint]^2 \ ,$$

where

$Zij = C \ (Wi - Ej) \ / \ 2$ ,
$Tij = (Wi + Ej) \ / \ 2$ ,
TO = a half of distance from West to East (19.4 nsec) ,
Wi = mean time (nsec) for counter "i" in West module,
Ej = mean time (nsec) for counter "j" in East module,
Nw = number of counters in cluster for West ,
Ne = number of counters in cluster for East ,
C = light velocity .

To estimate the position resolution, the information of the vertex from VTPC is used. In the present note, the event passed the above procedure is called <u>BBC event</u>.

### 4.2 Cluster Selection

We experienced a broad distribution in TDC of West counters compared to East counters. Figure 3(a) shows the scatter plot between West and East TDCs in any combination of counters for BBC events without halo. The combination was made for the counters which are selected in the analysis procedure in Section 4.1. There were 224 of 886 events, which includes a total of 104 events in the region of 30 < T(West) < 65 nsec and 45 < T(East) < 60 nsec. The figure is compared to Figure 3(b) in 23 beam-beam events. Notice that 3 of 26 beam-beam events were missed in the analysis procedure. The efficiency of BBC is described in Section 5.1 in detail.

The TDC distributions in West and East counters are shown in Figures 4(a) and 4(b) for 104 events including 23 beam-beam events. The West module seems to recieve many particles which comes earlier than the collision particles. Note that even beam-beam events gave the broad distribution of 5.2 nsec in rms to West and there seems to be 3 peaks, each having about 2 nsec of width in rms. Some consideration on the broad TDC distribution is given in Section 5.2.

Without clustering, the frequency of counters with a single hit in each counter type were

| | West Module | | East Module | |
|---|---|---|---|---|
| Type | Background 81 events | Beam-Beam 23 events | Background 81 events | Beam-Beam 23 events |
| 0 | 6 (0.07) | 41 (1.78) | 71 (0.88) | 26 (1.13) |
| 1 | 12 (0.15) | 12 (0.52) | 86 (1.06) | 21 (0.91) |
| 2 | 25 (0.31) | 6 (0.26) | 40 (0.49) | 12 (0.52) |
| 3 | 77 (0.95) | 6 (0.26) | 43 (0.53) | 7 (0.30) |
| | 120 (1.48) | 65 (2.82) | 240 (2.96) | 66 (2.86) |

*) The value in parenthesis is normalized by the event number, which means the hit frequency per event.

*) For type 0, the number of available counters for West and East were 3 and 2, respectively. Therefore, the number of events per counter (type 0) seems to be statistically same in 23 beam-beam events.

The value in each parenthesis for background events might be used as an indicator of unreliability of the counter by the background event. If the timing between the collision paticle and background coincides within 1 nsec, it hard to separate them because the spread of transit time of the tube is of order of 0.8 nsec estimated in Section 3. When 2 or more clusters were found in a module, one cluster with many smaller counters was selected.

## 5. Results

The characteristics of 26 beam-beam events from BBC are tabulated in Table 4 with the information from VTPC (i.e. Zint(VTPC) and event classification number). The table gives the following results.

### 5.1 Reconstruntion Efficiency

The reconstruntion efficiency of beam-beam counter was examined for 26 beam-beam events which include 3 probable beam-beam events. To recognize the beam-beam events by BBC system, several conditions with TDC, ADC, and latch information were set. The number of events selected after each analysis cut is listed below:

| Condition | Events selected | Comments |
|---|---|---|
| No cut | 886 (23/26) | All events in Runs 489,493,494 |
| 1 | 387 (21/23) | BBC events (w/ halo, w/o halo) |
| 2 | 224 (21/23) | BBC events w/o halo |
| 3 | 36 (21/23) | Latch information used |
| 4 | 23 (21/23) | VTPC added |

*) Number in each parenthesis is number of beam-beam events in the format (BB/BB+BB*), where BB* means probable beam-beam event.

Each condition number means:

(1) Select events with good TDC and ADC data in BBC, called <u>BBC events</u> in the obove comments.

(2) Select BBC events without halo.

(3) Check the number of counters latched within beam-beam gate:

$$N_{west} \geq 5 \text{ for West module,}$$
$$N_{east} \geq 5 \text{ for East module.}$$

The number, 5, is set to pass all the beam-beam events as shown in Figures 5(a) and 5(b).

(4) Check the diffrence of Zint between BBC and VTPC with 4-sigma cut, assuming the position resolution of Zint(BBC) is 10 cm.

The BBC missed 2 BB events and 1 BB* event after ADC cut at the analysis condition 1: After ADC cut, the BB* event was missed because of no candidates for counters having a single particle hit in East, while 2 BB events were missed because of no counters in West. The efficency for beam-beam events by BBC was

91.3 $\pm$ 5.8 % for 23 BB events.
(88.5 $\pm$ 6.3 % for 26 BB+BB* events)

A total of 500 events of simulation data at minimum bias were analyzed by using the same analysis procedure. The data were generated by LUND program. The efficency was 96.2 % for complete BBC system, 95.6 % in BBC system with 3 missing counters (8W, 4E, and 8E) and 1 dead TDC channel (2E). Note that the simulation data doesn't include any background and any interaction of the collision particles with the beampipe.

## 5.2 Interaction Position and Time

### A. Resolution

In 23 events after all cuts, the position (time) resolution was estimated. Figure 6 shows the distribution of Zint(BBC) - Zint(VTPC). The mean and rms values are -1.5 cm and 5.6 cm (0.19 nsec), respectively. The correlation plot between Zint(BBC) and Zint(VTPC) is also shown in Figure 7.

The average number of counters per module after cuts was about 2/event, and the smaller counters of types 0 and/or 1 were always included. If only two counters of type 0 (or 1) is used for calculating the position, then the position (time) resolution is expected to be 4.5 cm (or 8.1 cm) from spread of transit time in phototube. They are consistent with the experimental data. In 23 events, the number of counters for each type after cuts is listed below.

| Type | West | East |
|---|---|---|
| 0 | 37 (1.61) | 26 (1.13) |
| 1 | 10 (0.43) | 18 (0.78) |
| 2 | 1 (0.05) | 11 (0.48) |
| 3 | 0 (0.00) | 3 (0.13) |
| Total | 48 (2.09) | 58 (2.52) |

*) The value in parenthesis is normalized to by event number, which means the hit frequency per event.

In Monte Carlo simulation data, the average number of counters was about 4/event for each module. If 4 counters of type 0 (or 1) can be expected in the future run, the position resolution of 3 cm (or 6 cm) will be achieved. The difference is probably caused by the following: (1) Only 5 of 8 counters in counter type 0 were available in the run. (2) We experienced increasing pulse heights in the BBC as the counter size increased. The small counters (types 0 and 1) always remained after the analysis cuts.

### B. Correlation between Zint and Tint

Figure 8 shows the correlation between Zint and Tint in 23 events after all cuts. As shown in Figure 8, the scatter plots can be decomposed to 3 groups: One group on the left hand side in the figure comes from the events in Run489 before cogging antiprotons, the middle group mainly from Run494, and the right hand side one includes the event in Run489 after cogging antiprotons toward East. Since the beam crossing time given by the master clock system was the time when the center of mass of the proton bucket pass through Z = 0, the actual crossing position should move to East after the cogging and the interaction time should delay as much as the movement. It was also found that the slope C*dT/dZ was around unity in Figure 8.

Such situation can be explained by a schematic view in Figure 9. Antiprotons moved by several meters toward East after cogging during Run489 [CDF Note 402]. Then the interaction position (time) shifted by half the movement to East. The interaction time may depend on the interaction position as shown in Figure 8 and the slope C*dT/dZ will be unity. The shift of the interaction position was calculated to be 170 cm. Therefore those antiprotons seem to be cogged by 340 cm from BBC information. The figure also explains that the TDC distribution in West was broader that that in East.

## 5.3 Latch Information

Latch information of beam-beam counter (BBC) had a strong correlation with beam-beam (BB), beam-gas (BG) events as shown in Figures 5(a) and 5(b). The BBC events can be classified as follows:

| Number of counters latched in BB gate | | |
|---|---|---|
| West | East | Event Type |
| $\geq$ 5 | $\geq$ 5 | BB |
| $\leq$ 5 | $\geq$ 10 | BG by Proton |
| $\geq$ 10 | $\leq$ 5 | BG by Antiproton |

It seems to be powerful tool for selecting beam-beam events at the zero-th order. At higher luminosity in the future run, a narrower gate and a selection in the number of counters latched in the gate will be required to provide an effective trigger for a relatively unbiased beam-beam event. Assuming 10 nsec of full width of TDC distribution for beam-beam events, the gate width will be 20 nsec owing to an insensitive interval of about 5 nsec near both edge of the beam-beam gate in the latching.

## 5.4 Multiplicity of Charged Particles

Here the multiplicity of charged particles was estimated by using ADC information. We set the tube voltage to give about 2000-3000 ADC counts for a charged particle. A sum of ADC counts devided by 2500 ADC counts approximately gives the number of minimum ionizing particles (MIP) in BBC. In the beam-beam events, the average number (multiplicity) was about 60 for each of the modules. The multiplicity for each event is listed in

Table 4. However, the simulation data from LUND and ODORICO gave 10 and 12, respectively.

In Figure 10, the multiplicity in West and East modules is shown for 23 beam-beam events and 81 background events in the region of 30 < T(West) < 65 nsec and 45 < T(East) < 60 nsec. The source of the high multiplicities might be the secondary particles from the interaction of collision particles with beampipe since the counters take approximately equal bites in units of rapidity and the multiplicities are higher for larger counters.

From Figures 4 and 10, there seems to be the following background source: The West module received the background at some time before the collision particles and/or the secondary particles which were generated by the interaction with beampipe. It gave no effect in East, because it arrived at 40 nsec or more after the collision particles arrived at East. It gave the broader TDC distribution and low multiplicity in West.

On the other hand, the background gave the high multiplicity in East module, but the timing was the same as the collision particles. This indicates it seems to be associated with the proton bucket which created the collision particles.

It can be explaned by the beam-gas event having a few and slow beam-gas particles scattered backward and many fast beam-gas particles along with the proton bucket. Therefore, the TDC distribution in West is more broader than that of East and the multiplicity in East was higher than that in West. A full detail of the events is given in CDF Note 407.

### 5.5 Candidates for Beam-Beam Events from BBC

We are also interested in the 13 of 36 events at analysis condition 3, which are only selected by BBC. The event characteristics are tabulated in Table 5. A total of 4 events with the mark # in Table 5 indicate the candidates for beam-beam events from BBC information. The BBC calculated the interaction positions to be around 220 cm in Run489 (before cogging) and 340 cm in Run494 as listed in Table 5. The multiplicity of each event is also consistent with that of the beam-beam event. The events seem to come from later satellite antiproton colliding with the promary proton. The schematic view is shown in Figure 9.

In the 4 events, the aspects of the tracks by VTPC are shown in Figures 11(a), 11(b), 11(c) and 11(d). Each figure shows that the particles comes from East and the interaction seems to be in the region of Z > 140 cm. Note we are still sceptical of the event as seen in Figure 11(c).

## 6. Summary

The number of counters latched within beam-beam gate (30 nsec) was correlated to beam-beam events and it was a powerful tool for separating beam-beam and beam-gas events at the zero-th order. There were many particles passing through BBC in the gate, which were created by beam-beam collision and interaction of collision particles with beampipe. The average multiplicity of charged particles was estimated to be 60 per module from ADC information.

The several timing clusters in a module were often observed owing to the background. The clustering algorithm was needed to select one cluster with true information. There was no change in the BBC efficiency for the beam-beam events by using the cluster algorithm. The efficiency was 91 +/- 6 %.

The position (time) resolution of 5.6 cm (0.19 nsec) was achieved after the timing correction for each counter. The average number of counters in the cluster was 2/event for each module. The resolution agreed with the estimate from the spread of the transit time in phototube.

The background seems to be beam-gas events having both (1) a few and slow beam-gas particles scattered backward and (2) many fast beam-gas particles along with the proton bucket. The first one gave the broader TDC distribution and low multiplicity in West. On the other hand, the second gave the high multiplicity in East module, but the timing is almost same as the collision particles, that is, the TDC distribution is more narrow than that of West.

The BBC had 4 more candidates for the beam-beam events whose interaction positions were outside VTPC. The aspect of tracks reconstructed in the region of VTPC seem to be same among 4 events.

The parameters of BBC are summarized in Table 6. The table also shows the parameters expected in future run.

This experiment would have been impossible without the very successful operation of the Tevatron Collider whose staffs and coordinators we gratefully acknowledge for their collective effort.

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## Figure Captions

1 Block diagram of the trigger electronics in BBC system.

2 Spread of the time difference between tubes in a counter, which is normalized by the length of the counter. The average value of 8 counters for each type are indicated with the open circle. The vertical bar is the rms value for 8 counters. The dotted line is expected in the case that the spread of the transit time is 0.77 nsec. Also shown is the horizontal dotted line is in the case of no spread of the transit time.

3 Scatter plot of TDC values in nsec for West and East counters with 200 < ADC < 4000 counts over the pedestal.
(a) 224 BBC events without halo. The 104 of 224 BBC events are included in the region of 30 < T(West) < 65 nsec and 45 < T(East) < 60 nsec.
(b) 23 beam-beam events (including 2 probable BB events). Note that 3 of 26 beam-beam events were missed in the analysis procedure described in Section 4.1.

4 TDC distribution for BBC events without halo in the region of 30 < T(West) < 65 nsec and 45 < T(East) < 60 nsec. A total of 104 events are included in the region. For comparison, the distribution for 23 beam-beam events is also shown in the figure. The rms widths in West and East for 23 beam-beam events are 5.2 nsec and 1.3 nsec.
(a) West module
(b) East module

5 Number of counters latched in beam-beam gate (30 nsec wide).
(a) 224 BBC events without halo,
(b) 23 beam-beam events (including 2 probable BB events).

6 Position resolution of Zint in BBC. The distribution of Zint(BBC) - Zint(VTPC) is shown in 23 beam-beam events, including 2 probable BB events. The mean and rms values are -1.5 cm and 5.6 cm.

7 Correlation plot between Zint(VTPC) and Zint(BBC) in 23 Beam-Beam events (including 2 probable events).

8 Correlation plot between Tint(BBC) and Zint(BBC). Note the slope C*dTint/dZint is about 1, where C is light velocity.

9 Schematic view of proton-antiproton collision in Z-T plane.

10 Multiplicity plot of minimum ionizing particles between West and East modules. The multiplicity was estimated by BBC-ADC information. The difference between beam-beam event and background event is very clear.

11 Display of tracks reconstructed by VTPC in each candidates for the beam-beam event from BBC information. A total of 4 candidates were found as listed in Table 5.

Table 1. Specification of Beam-Beam Counter

| Counter | | | Phototube (Hamamatsu Photonics) | | | |
|---|---|---|---|---|---|---|
| Type | Width (cm) | Length (cm) | Type | Rise Time (ns) | Transit Time (ns) | Transit Spread (ns) |
| 0 | 3.13 | 12.92 | R2083 | 1.3 | 14 | 0.36 |
| 1 | 6.07 | 25.06 | R1828-01 | 1.3 | 28 | 0.55 |
| 2 | 11.76 | 48.87 | R1828-01 | 1.3 | 28 | 0.55 |
| 3 | 22.70 | 93.98 | R1828-01 | 1.3 | 28 | 0.55 |

Table 2. Spread of Transit Time

| Counter | | Phototube | |
|---|---|---|---|
| Type | Length (ns) | Spread of Transit (ns) Catalog | Measurement |
| 0 | 0.681 | 0.36 | 0.41 |
| 1 | 1.321 | 0.55 | 0.77 |
| 2 | 2.576 | 0.55 | 0.77 |
| 3 | 4.953 | 0.55 | 0.56 |

*) Refractive index of scintillator is 1.58

Table 3. Time Correction Parameter by Charge

| Counter | Slope (ns/pC) | Intercept (ns) | N.O.D.F |
|---|---|---|---|
| 0W | 2.941 +/- 3.829 | 31.93 +/- 0.69 | 50 |
| 1W | 19.315 +/- 8.946 | 32.04 +/- 1.22 | 35 |
| 2W | 9.118 +/- 8.250 | 31.62 +/- 1.33 | 48 |
| 3W | 16.434 +/- 6.089 | 32.08 +/- 0.99 | 57 |
| 4W | 10.206 +/- 11.991 | 32.07 +/- 1.71 | 13 |
| 5W | 13.017 +/- 5.745 | 31.95 +/- 0.81 | 62 |
| 6W | 10.384 +/- 5.138 | 31.99 +/- 0.72 | 64 |
| 7W | 21.904 +/- 5.221 | 31.94 +/- 0.82 | 81 |
| 8W | 0.000 +/- 0.000 | 0.00 +/- 0.00 | 0 |
| 9W | 22.562 +/- 4.916 | 31.99 +/- 0.77 | 49 |
| 10W | 13.002 +/- 5.976 | 31.91 +/- 0.88 | 50 |
| 11W | 15.885 +/- 5.146 | 31.97 +/- 0.84 | 64 |
| 12W | 10.195 +/- 4.602 | 31.98 +/- 0.72 | 77 |
| 13W | 5.332 +/- 8.631 | 32.02 +/- 1.02 | 51 |
| 14W | 17.099 +/- 3.752 | 32.03 +/- 0.58 | 81 |
| 15W | 10.761 +/- 4.683 | 32.28 +/- 0.72 | 97 |
| 0E | 6.116 +/- 3.734 | 71.06 +/- 0.62 | 67 |
| 1E | 6.244 +/- 5.661 | 70.97 +/- 0.79 | 49 |
| 2E | 0.000 +/- 0.000 | 0.00 +/- 0.00 | 0 |
| 3E | 53.582 +/- 20.412 | 68.35 +/- 2.34 | 12 |
| 4E | 0.000 +/- 0.000 | 0.00 +/- 0.00 | 0 |
| 5E | 3.544 +/- 6.366 | 70.88 +/- 0.82 | 60 |
| 6E | 10.671 +/- 5.821 | 70.89 +/- 0.75 | 71 |
| 7E | 2.574 +/- 8.068 | 70.84 +/- 0.92 | 48 |
| 8E | 0.000 +/- 0.000 | 0.00 +/- 0.00 | 0 |
| 9E | 4.688 +/- 6.299 | 71.06 +/- 0.78 | 48 |
| 10E | 7.889 +/- 8.715 | 71.09 +/- 1.05 | 41 |
| 11E | 2.642 +/- 8.556 | 71.04 +/- 1.02 | 47 |
| 12E | 7.154 +/- 3.207 | 71.05 +/- 0.53 | 110 |
| 13E | 2.061 +/- 4.135 | 71.02 +/- 0.59 | 72 |
| 14E | 21.867 +/- 8.474 | 71.03 +/- 0.99 | 47 |
| 15E | 16.487 +/- 6.966 | 71.06 +/- 0.88 | 49 |

*) The slope (b) and intercept (a) are defined as

$$T = a + b / \sqrt{Q} .$$

## Table 4. Scan List of Beam-Beam Events from VTPC

***** Analysis mode in BBC :        13 (Hex) *****
Bit 0 - Latch in time
Bit 1 - TDC check on class 0 ( 20 - 2047, Tdiff cut)
Bit 4 - ADC check on class 0 (200 - 4000)

Zint      - Interaction position in cm
Tint      - Interaction time in nsec
Tdev      - Cluster size in nsec
M.I.P.    - Number of minimum ionizating particles
RUN TIME - 94 kHz scaler counts in min
CLASS     - Classification number of event by VTPC

| | Number of Counters | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | IN TIME | | GOOD | | | | | M.I.P. | | | | VTPC | |
| EVENT | WEST | EAST | WEST | EAST | Zint | Tint | Tdev | WEST | EAST | RUN TIME | | Zint | CLASS |
| ///// RUN 489 ///// | | | | | | | | | | | | | |
| 424 | 15 | 14 | 1 | 2 | -108.0 | 29.8 | 0.1 | 139 | 67 | 233.1 | | -110.5 | 12 |
| 430 | 13 | 14 | 2 | 2 | -108.7 | 27.8 | 0.1 | 90 | 68 | 237.0 | | -110.2 | 12 |
| 434 | 15 | 13 | 3 | 1 | -91.4 | 30.1 | 0.3 | 106 | 71 | 239.9 | | -89.4 | 12 |
| #439 | 15 | 14 | 3 | 0 | ***** | **** | **** | 121 | 81 | 243.7 | | 145.0 | 20 |
| 446 | 15 | 14 | 3 | 4 | 2.0 | 32.7 | 0.4 | 109 | 70 | 248.2 | | 5.8 | 12 |
| 479 | 15 | 13 | 3 | 5 | -108.9 | 30.0 | 0.5 | 100 | 16 | 272.4 | | -104.6 | 12 |
| 485 | 6 | 13 | 2 | 3 | -115.4 | 30.3 | 0.4 | 7 | 25 | 278.3 | | -105.0 | 9 |
| 487 | 15 | 14 | 2 | 2 | -65.2 | 30.7 | 0.1 | 113 | 57 | 279.6 | | -59.1 | 12 |
| 491 | 13 | 14 | 2 | 3 | -48.2 | 32.5 | 0.1 | 72 | 57 | 282.5 | | -52.3 | 9 |
| #497 | 15 | 11 | 3 | 3 | 123.0 | 39.1 | 0.2 | 109 | 8 | 284.9 | | 131.0 | 10 |
| 498 | 15 | 14 | 2 | 2 | -112.2 | 30.7 | 0.2 | 49 | 71 | 285.3 | | -108.2 | 12 |
| 503 | 15 | 14 | 3 | 2 | -73.0 | 29.7 | 0.1 | 135 | 85 | 293.2 | | -73.0 | 9 |
| 509 | 12 | 14 | 3 | 2 | 124.1 | 36.3 | 0.2 | 41 | 94 | 298.2 | | 123.2 | 11 |
| 538 | 14 | 14 | 2 | 1 | 5.5 | 35.5 | 0.2 | 56 | 74 | 313.5 | | 5.4 | 12 |
| ///// RUN 493 ///// | | | | | | | | | | | | | |
| 11 | 10 | 14 | 1 | 6 | 128.4 | 35.5 | 0.6 | 23 | 14 | 11.3 | | 125.9 | [illegible] |
| 15 | 10 | 10 | 2 | 2 | -20.2 | 32.0 | 0.3 | 10 | 15 | 12.2 | | -19.9 | 12 |
| ///// RUN 494 ///// | | | | | | | | | | | | | |
| 203 | 13 | 13 | 1 | 1 | -15.0 | 31.9 | 0.0 | 53 | 55 | 76.9 | | -17.7 | 12 |
| 223 | 14 | 14 | 1 | 2 | 54.0 | 34.1 | 0.2 | 123 | 80 | 89.8 | | 42.0 | 20 |
| 226 | 13 | 14 | 0 | 1 | ***** | **** | **** | 50 | 82 | 91.5 | | 73.4 | 12 |
| 227 | 15 | 14 | 0 | 1 | ***** | **** | **** | 151 | 93 | 92.2 | | -44.5 | 12 |
| 244 | 11 | 14 | 2 | 2 | -34.4 | 32.9 | 0.2 | 11 | 20 | 99.4 | | -22.1 | 12 |
| 246 | 15 | 14 | 2 | 2 | -16.0 | 34.3 | 0.1 | 56 | 82 | 101.1 | | -15.3 | 12 |
| 247 | 15 | 14 | 2 | 3 | 27.9 | 32.8 | 0.3 | 83 | 53 | 101.2 | | 23.0 | 12 |
| 257 | 14 | 14 | 1 | 2 | -30.3 | 33.6 | 0.2 | 58 | 55 | 105.2 | | -30.2 | 12 |
| 271 | 15 | 14 | 3 | 2 | 2.2 | 35.0 | 0.3 | 124 | 89 | 113.4 | | 2.1 | 12 |
| #276 | 15 | 13 | 2 | 4 | 33.0 | 34.5 | 0.3 | 112 | 19 | 116.1 | | 45.5 | 12 |

*) A mark # indicates a probable beam-beam event in the VTPC information.
*) Antiprotons was cogged by 1.5 m toward East at Run489 Event 506.

Table 5. Candidates for Beam-Beam Events from BBC

***** Analysis mode in BBC : 13 (Hex) *****
Bit 0 - Latch in time
Bit 1 - TDC check on class 0 ( 20 - 2047, Tdiff cut)
Bit 4 - ADC check on class 0 (200 - 4000)

Zint - Interaction position in cm
Tint - Interaction time in nsec
Tdev - Cluster size in nsec
M.I.P. - Number of minimum ionizating particles
RUN TIME - 94 kHz scaler counts in min
CLASS - Classification number of event by VTPC

///// RUN 489 /////

| | Number of Counters IN TIME | | GOOD | | | | | M.I.P. | | | VTPC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EVENT | WEST | EAST | WEST | EAST | Zint | Tint | Tdev | WEST | EAST | RUN TIME | Zint | CLASS |
| 4 | 6 | 9 | 1 | 4 | -306.5 | 30.6 | 0.2 | 6 | 18 | 9.8 | 0.0 | 8 |
| 338 | 8 | 0 | 2 | 2 | 37.8 | 33.0 | 0.3 | 5 | 32 | 194.8 | ***** | 20 |
| 431 | 15 | 7 | 3 | 4 | 463.3 | 30.5 | 0.5 | 123 | 5 | 237.9 | ***** | 20 |
| #437 | 15 | 14 | 4 | 1 | 231.2 | 38.6 | 0.2 | 86 | 115 | 241.3 | ***** | 20 |
| 441 | 15 | 7 | 2 | 4 | 193.2 | 20.9 | 0.3 | 141 | 3 | 244.9 | 3.3 | 8 |
| #474 | 14 | 14 | 1 | 1 | 204.4 | 38.0 | 0.0 | 55 | 35 | 269.2 | -86.6 | 7 |
| #499 | 8 | 14 | 4 | 1 | 217.3 | 39.3 | 0.3 | 8 | 76 | 288.7 | ***** | 2 |

///// RUN 494 /////

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 58 | 11 | 11 | 2 | 2 | -25.6 | 31.9 | 0.2 | 26 | 15 | 35.8 | 134.4 | 8 |
| 66 | 8 | 11 | 1 | 4 | -24.7 | 32.6 | 0.4 | 9 | 15 | 37.5 | -132.1 | 7 |
| 67 | 6 | 6 | 2 | 2 | -117.3 | 34.8 | 0.2 | 4 | 8 | 37.5 | 17.7 | 7 |
| 74 | 11 | 7 | 6 | 1 | -33.2 | 33.0 | 0.3 | 10 | 12 | 39.3 | -128.4 | 8 |
| 201 | 9 | 8 | 3 | 1 | 582.9 | 33.1 | 0.2 | 63 | 11 | 75.2 | ***** | 20 |
| #265 | 6 | 14 | 2 | 4 | 340.7 | 42.7 | 0.2 | 24 | 31 | 112.1 | ***** | 20 |

*) Antiprotons was cogged by 1.5 m toward East at Run489 Event 506.
*) A mark # indicates a candidate for a beam-beam event from the BBC information. The event seems to come from the satellite antiproton colliding with primary proton. The others seems to be background.

Table 6. Parameters of BBC

| | | 1985 | 1986 (expected) |
|---|---|---|---|
| Position Resolution (Time) | | 5.6 cm (0.19 ns) | 3 - 6 cm (0.10 - 0.2 ns) |
| Efficiency | | 89 +/- 6 % | 96 % |
| Beam-Beam Gate | | 30 ns | 20 ns |
| Electonics | TDC | LRS 2228A (44 ps/count) | LRS 2228A (44 ps/count) |
| | ADC | LRS 1885N (50 fC/count) | LRS 1885N (50 fC/count) |
| # Counters available | | | |
| Type 0 | | 5 | 8 |
| 1 | | 8 | 8 |
| 2 | | 7 | 8 |
| 3 | | 8 | 8 |
| Total | | 28 | 32 |
| # Events used for timing correction | | 221 | 2000 |

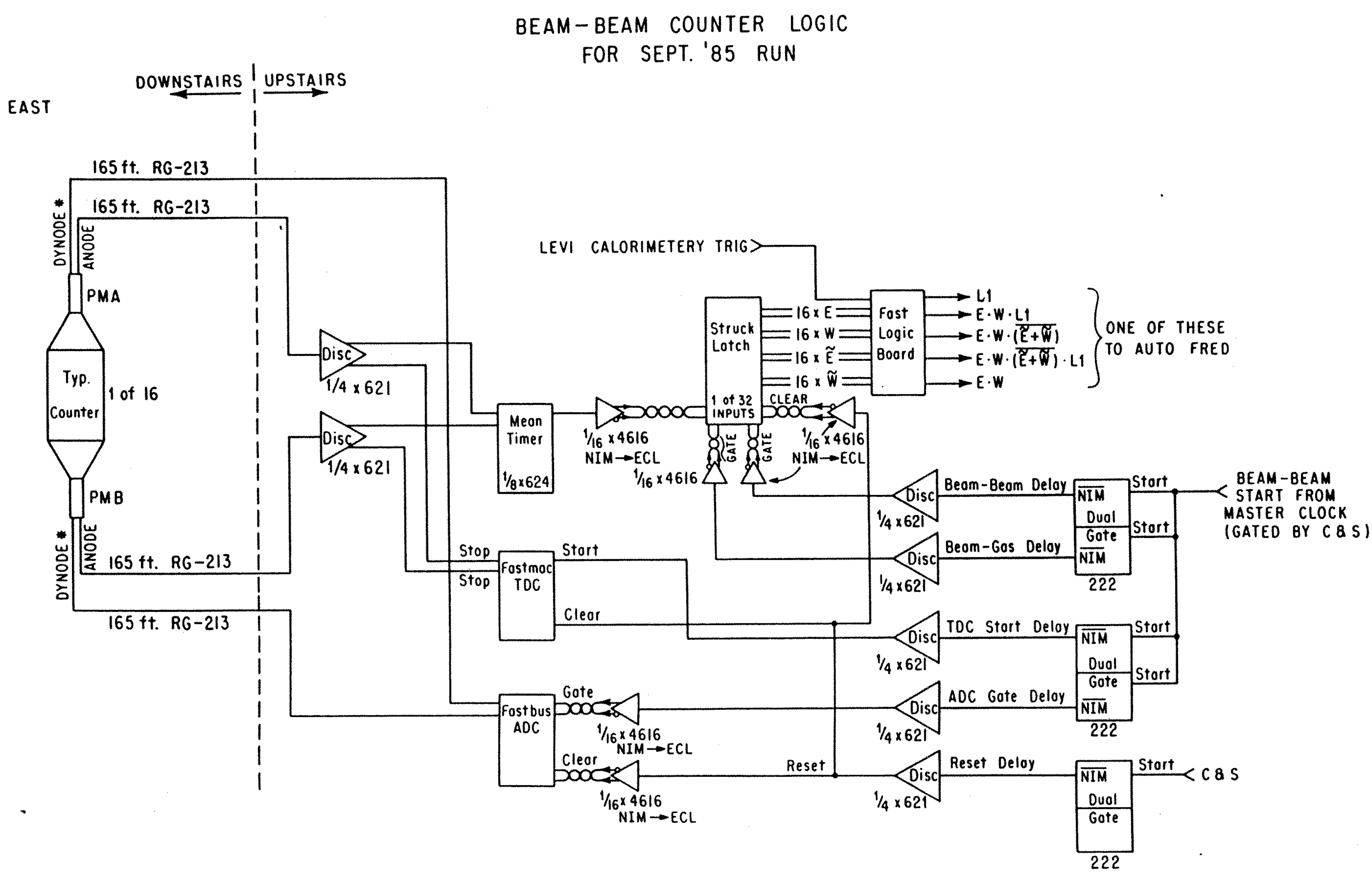

BEAM-BEAM COUNTER LOGIC
FOR SEPT. '85 RUN
EAST
DOWNSTAIRS
UPSTAIRS
165 ft. RG-213
165 ft. RG-213
165 ft. RG-213
165 ft. RG-213
DYNODE *
ANODE
PMA
Typ. Counter
1 of 16
PMB
ANODE
DYNODE *
Disc
1/4 x 621
Disc
1/4 x 621
Mean Timer
1/8 x 624
1/16 x 4616
NIM → ECL
1/16 x 4616
Struck Latch
1 of 32 INPUTS
CLEAR
GATE
GATE
1/16 x 4616
NIM → ECL
LEVI CALORIMETERY TRIG
16 x E
16 x W
16 x Ẽ
16 x W̃
Fast Logic Board
L1
E·W·L1
E·W·(Ẽ+W̃)
E·W·(Ẽ+W̃)·L1
E·W
ONE OF THESE TO AUTO FRED
Stop
Stop
Fastmac TDC
Start
Clear
Fastbus ADC
Gate
Clear
1/16 x 4616
NIM → ECL
1/16 x 4616
NIM → ECL
Reset
Disc
Beam-Beam Delay
1/4 x 621
Disc
Beam-Gas Delay
1/4 x 621
Disc
TDC Start Delay
1/4 x 621
Disc
ADC Gate Delay
1/4 x 621
Disc
Reset Delay
1/4 x 621
NIM
Dual Gate
NIM
222
Start
Start
NIM
Dual Gate
NIM
222
Start
Start
NIM
Dual Gate
222
Start
BEAM-BEAM START FROM MASTER CLOCK (GATED BY C & S)
C & S

Fig. 1

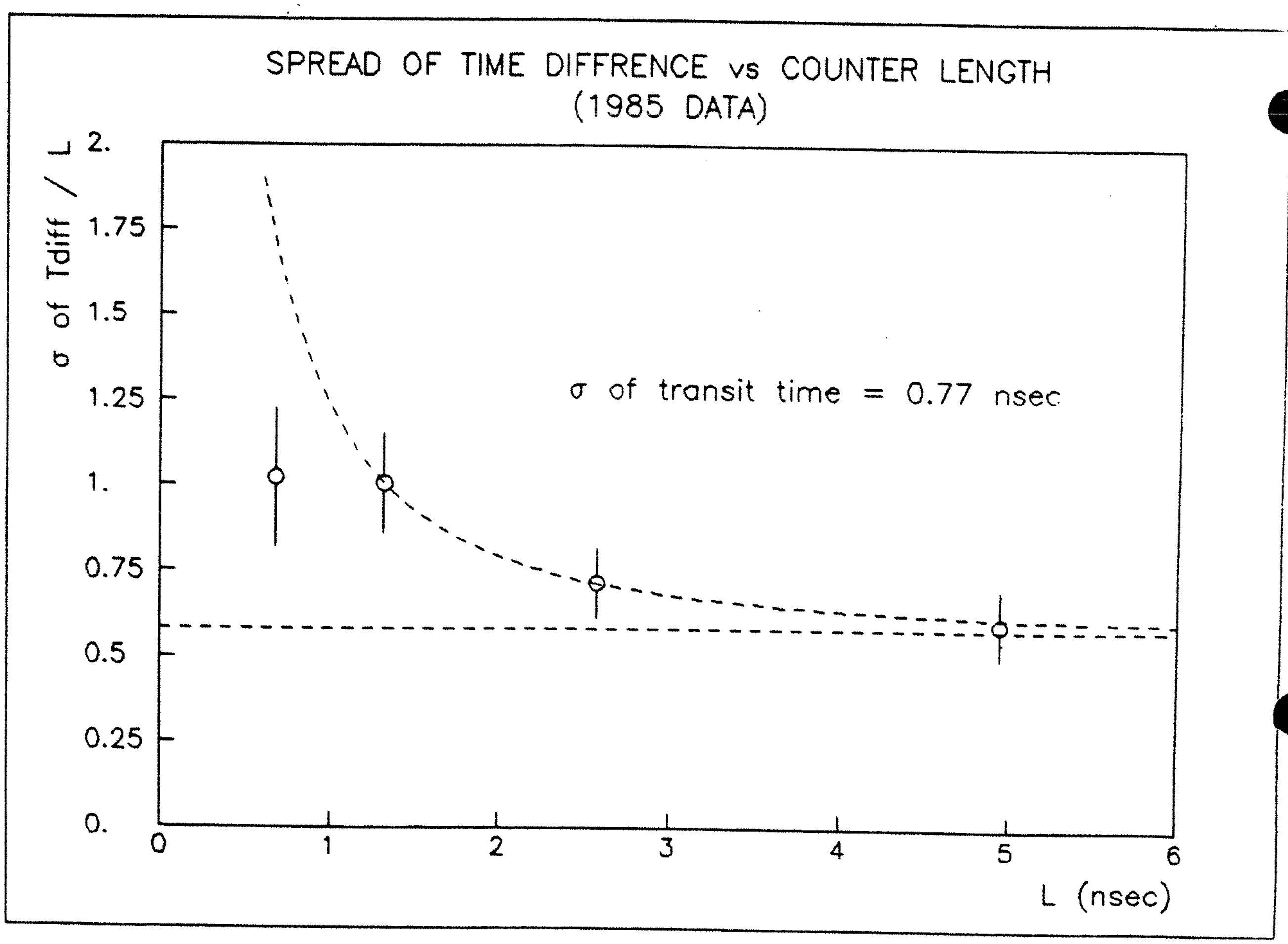

SPREAD OF TIME DIFFRENCE vs COUNTER LENGTH
(1985 DATA)
σ of Tdiff / L
2.
1.75
1.5
1.25
1.
0.75
0.5
0.25
0.
σ of transit time = 0.77 nsec
0
1
2
3
4
5
6
L (nsec)

Fig. 2

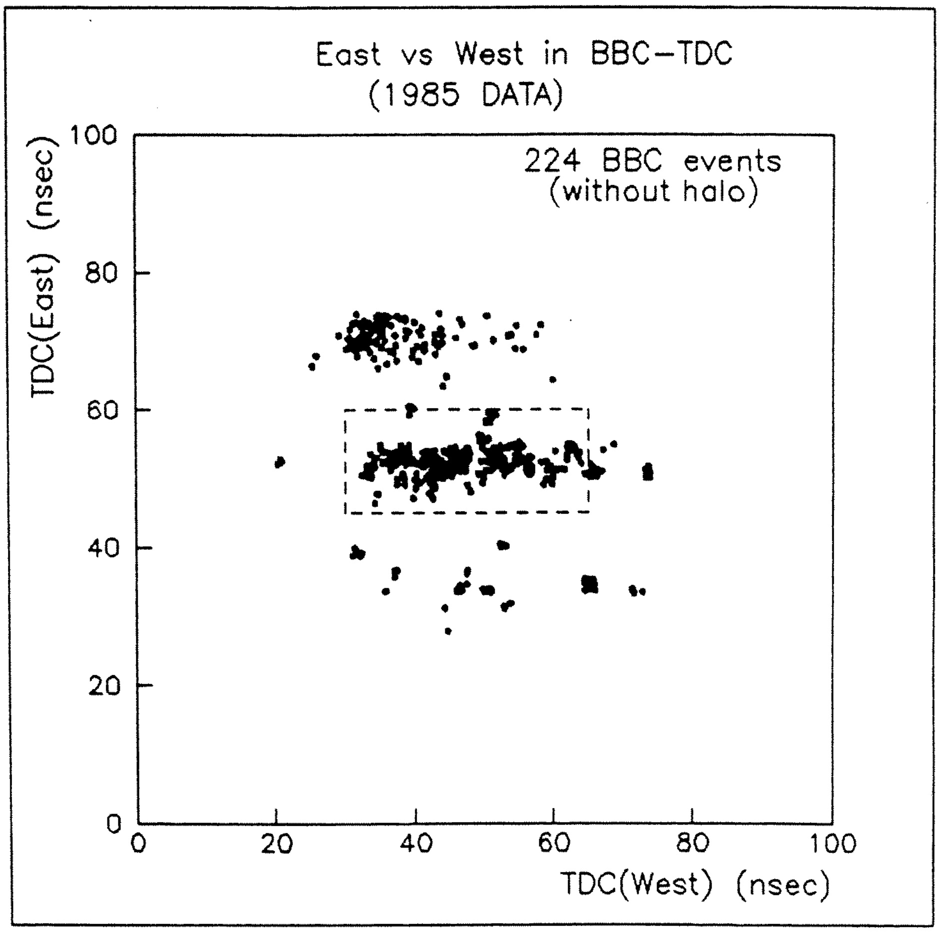

East vs West in BBC-TDC
(1985 DATA)
224 BBC events
(without halo)
TDC(East) (nsec)
TDC(West) (nsec)
0
20
40
60
80
100

Fig. 3(a)

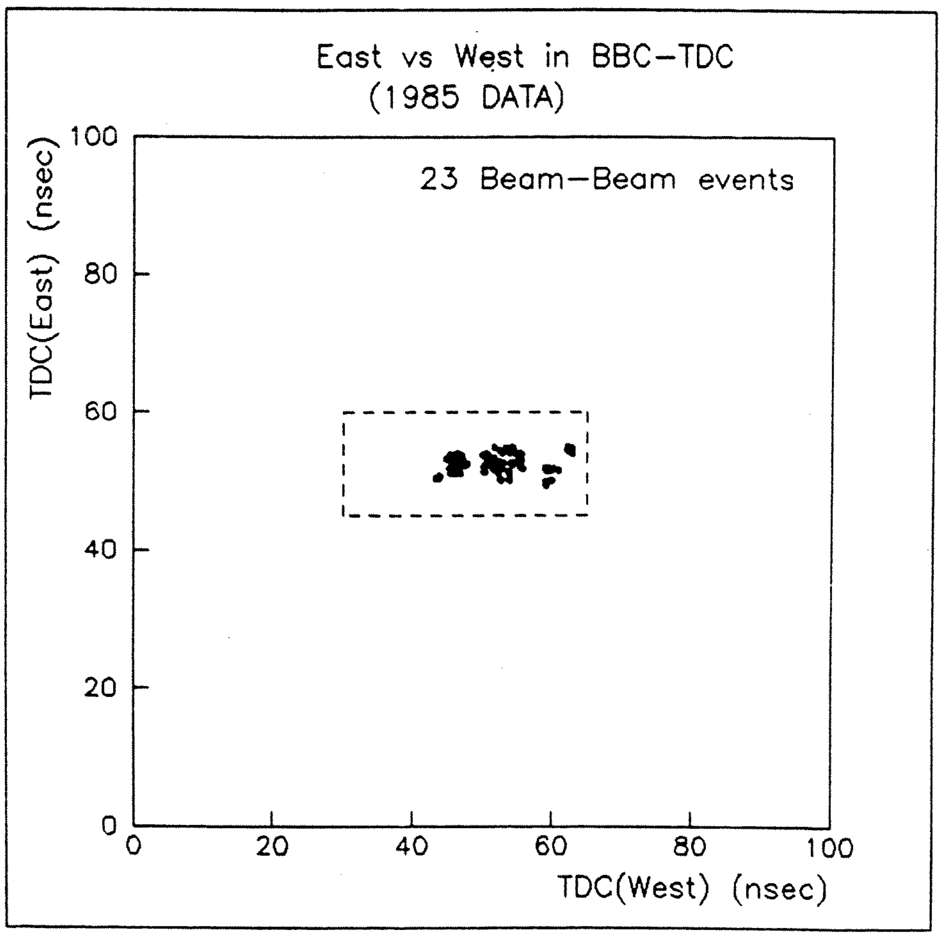

East vs West in BBC-TDC
(1985 DATA)
23 Beam-Beam events
TDC(East) (nsec)
TDC(West) (nsec)
0
20
40
60
80
100

Fig. 3(b)

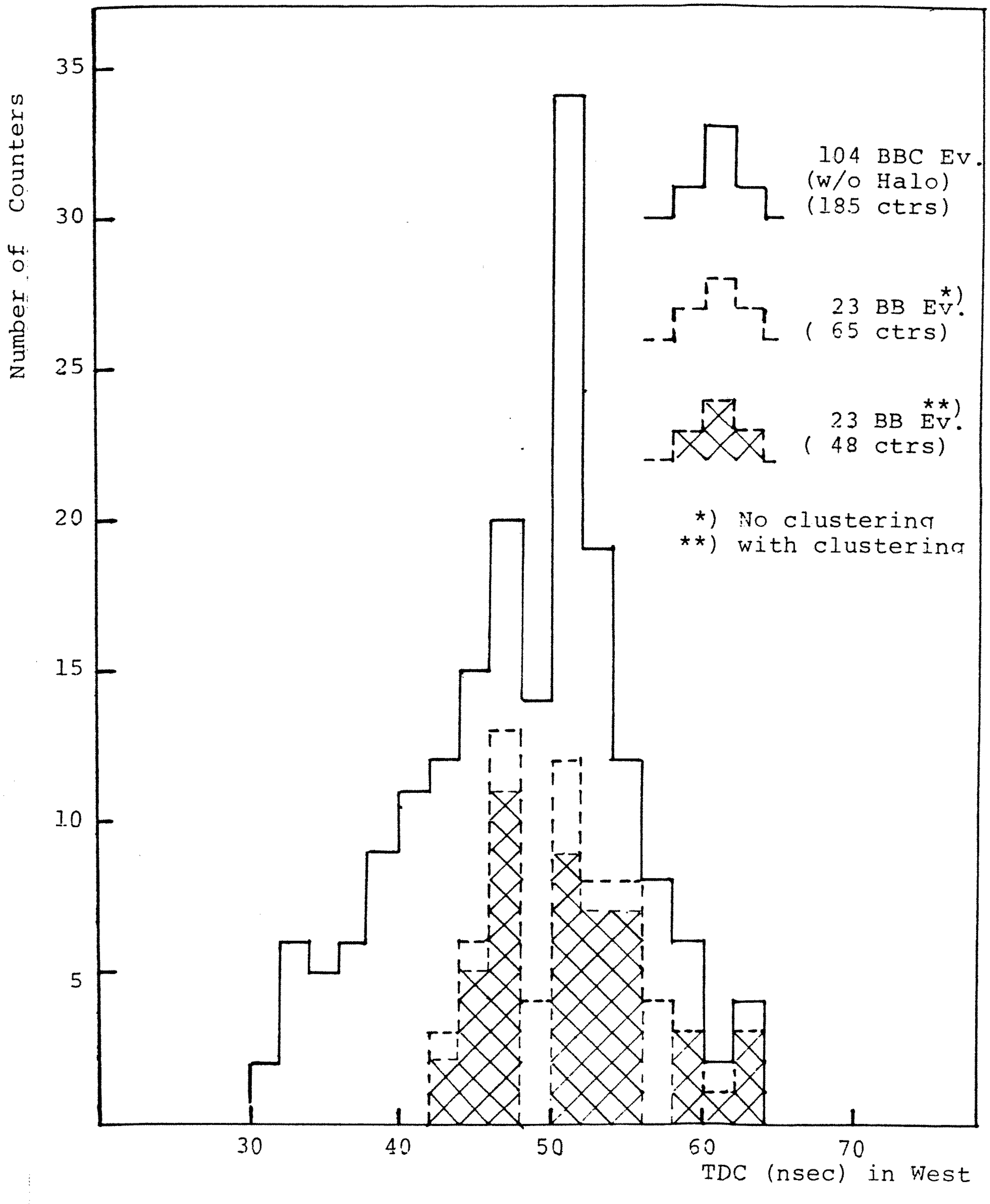
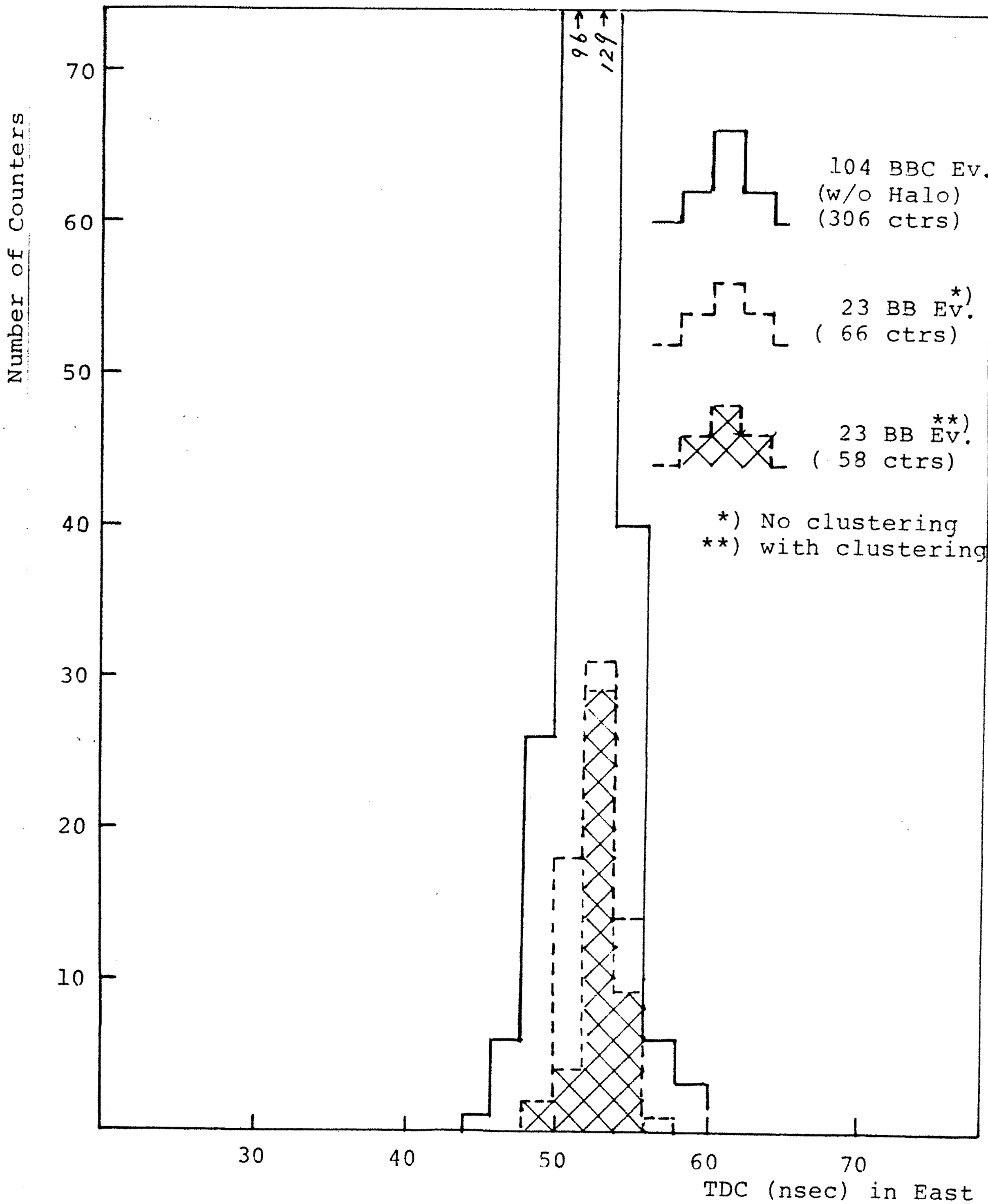

Number of Counters
35
30
25
20
15
10
5
30
40
50
60
70
TDC (nsec) in West
104 BBC Ev.
(w/o Halo)
(185 ctrs)
23 BB Ev.*)
( 65 ctrs)
23 BB Ev.**)
( 48 ctrs)
*) No clustering
**) with clustering

Fig. 4(a)



Number of Counters
70
60
50
40
30
20
10
96
129
104 BBC Ev.
(w/o Halo)
(306 ctrs)
23 BB Ev.*)
( 66 ctrs)
23 BB Ev.**)
( 58 ctrs)
*) No clustering
**) with clustering
30
40
50
60
70
TDC (nsec) in East


Fig. 4(b)

Neast(LATCH) vs Nwest(LATCH)
( 1985 Data)

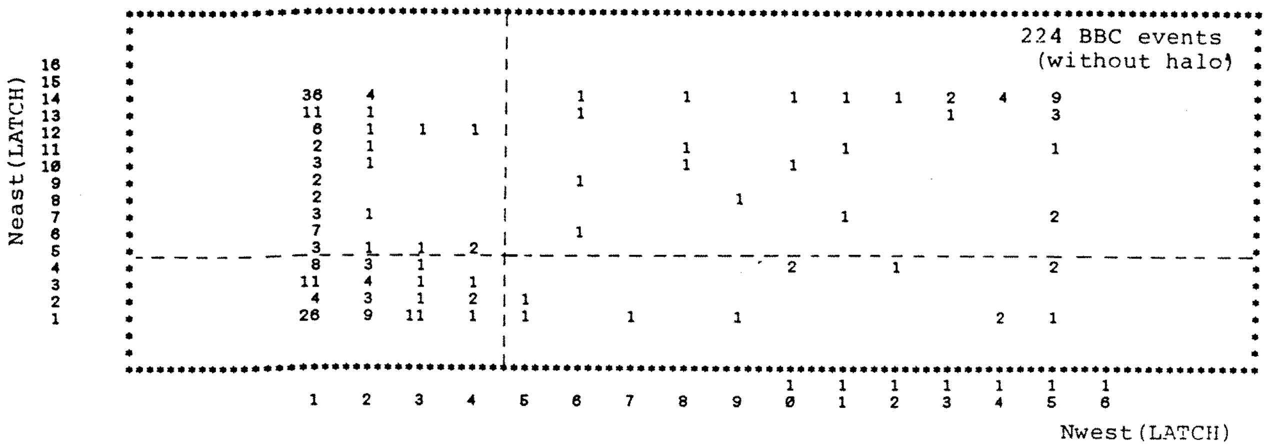



Fig. 5(a)

Neast(LATCH) vs Nwest(LATCH)
( 1985 Data)

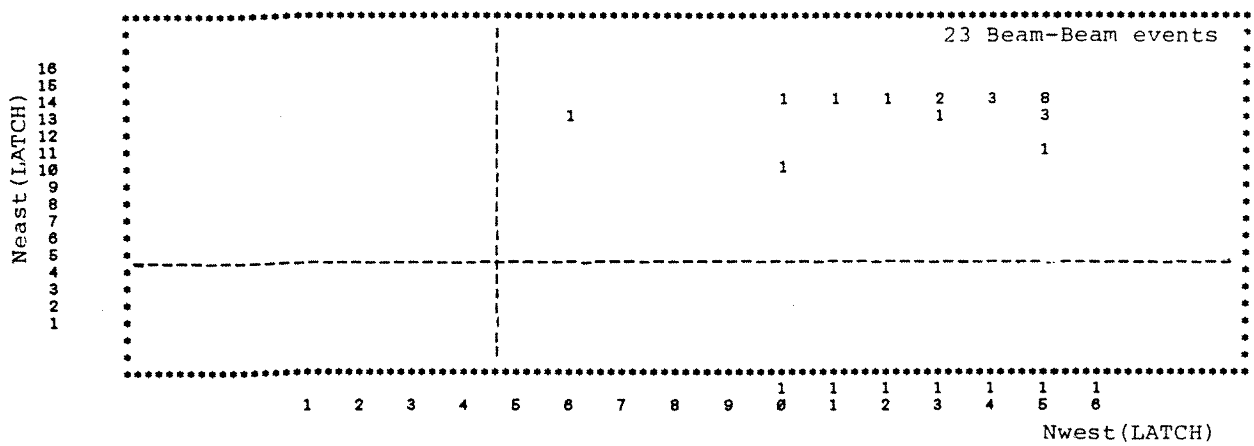
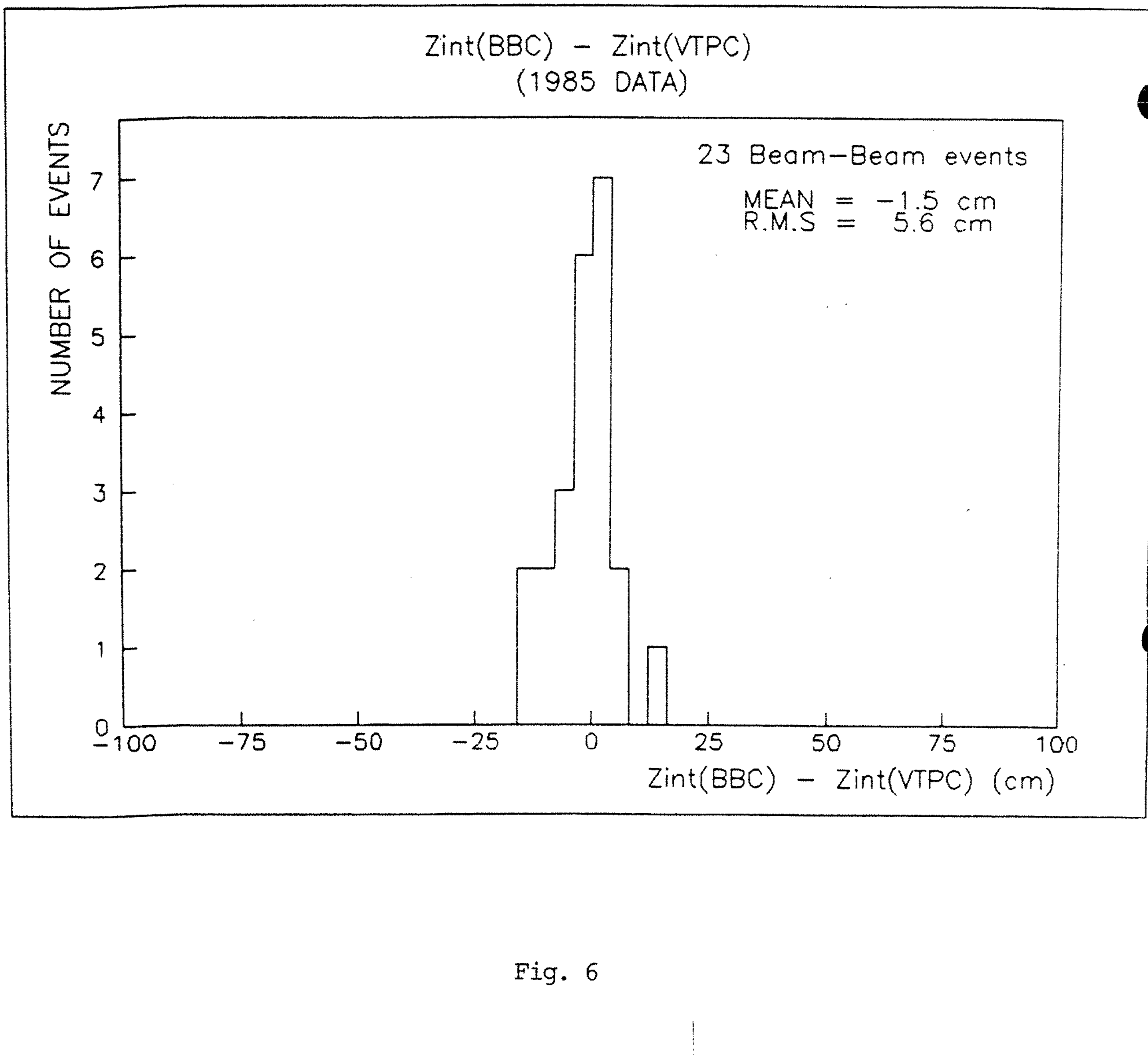



Fig. 5(b)



Zint(BBC) – Zint(VTPC)
(1985 DATA)
23 Beam–Beam events
MEAN = –1.5 cm
R.M.S = 5.6 cm
NUMBER OF EVENTS
0
1
2
3
4
5
6
7
–100
–75
–50
–25
0
25
50
75
100
Zint(BBC) – Zint(VTPC) (cm)


Fig. 6

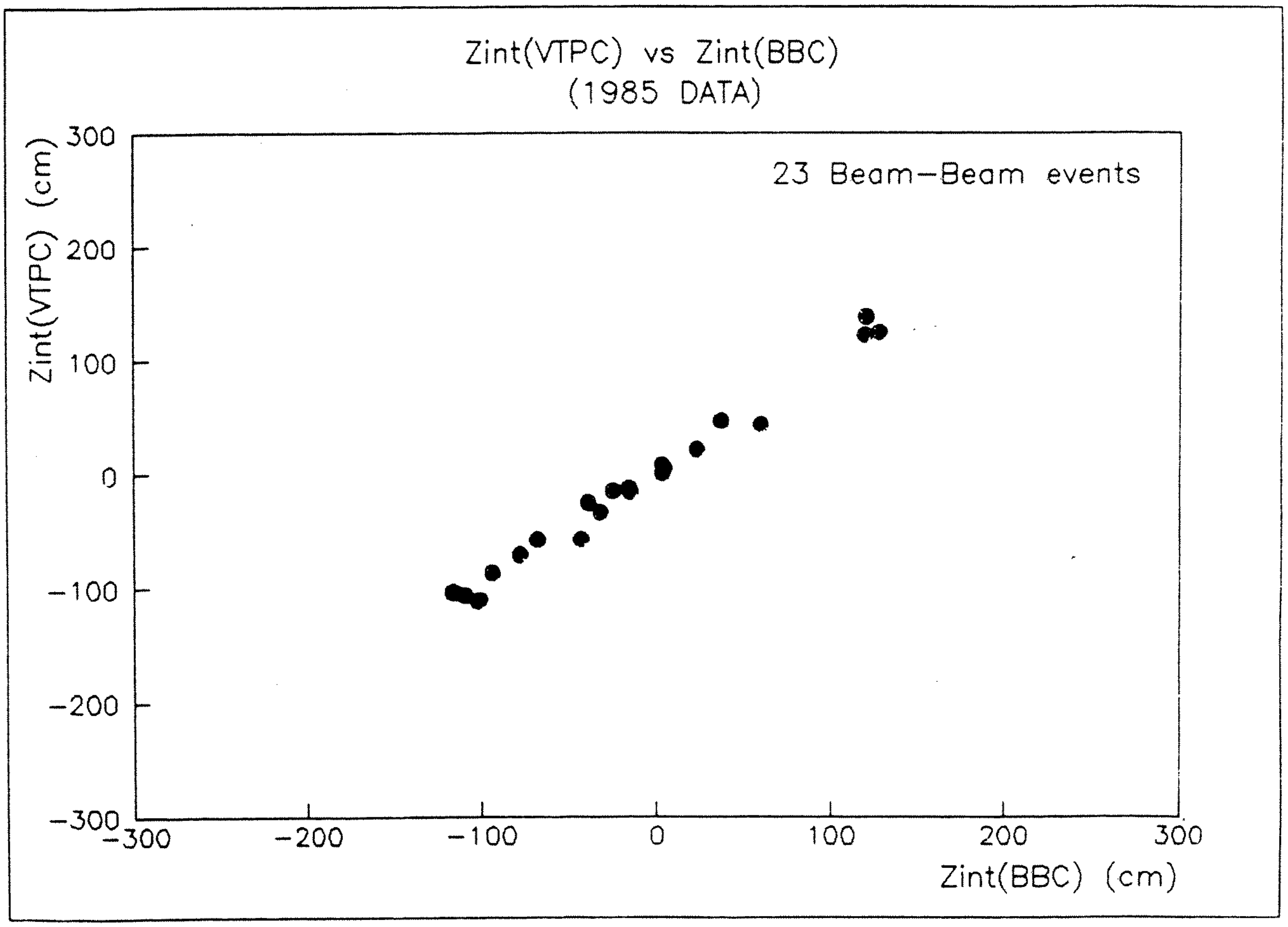
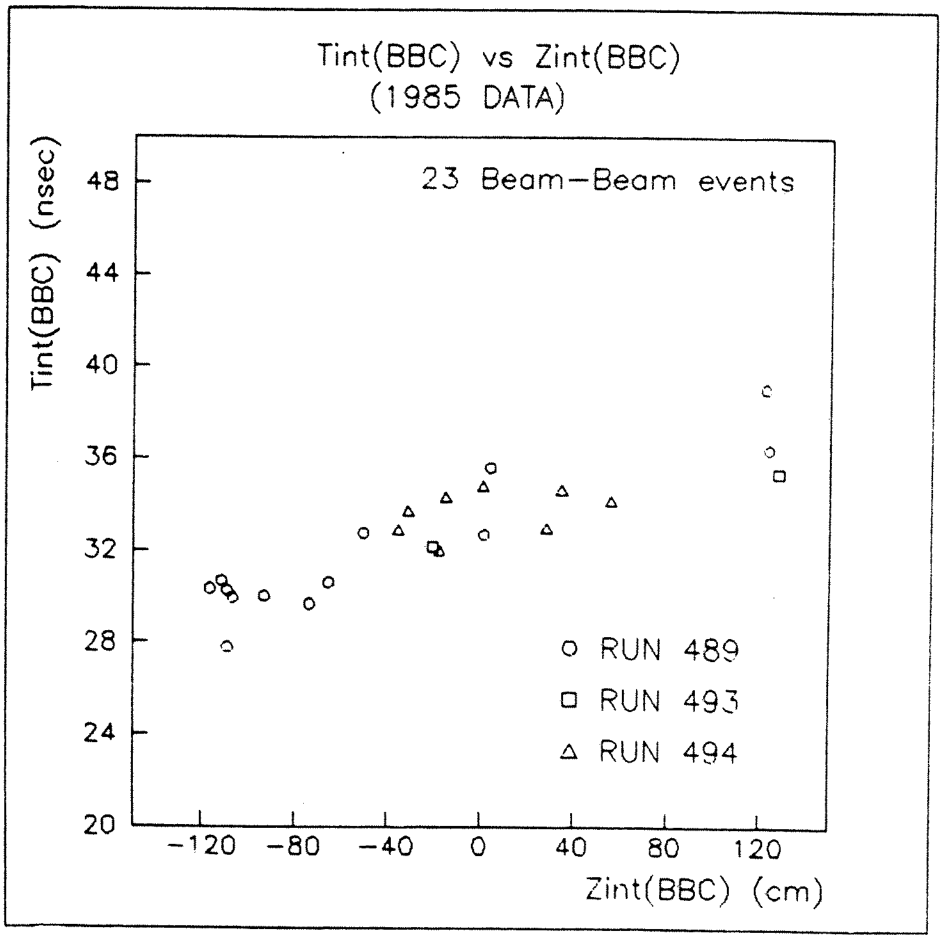

Zint(VTPC) vs Zint(BBC)
(1985 DATA)
23 Beam—Beam events
Zint(VTPC) (cm)
300
200
100
0
−100
−200
−300
−300
−200
−100
0
100
200
300
Zint(BBC) (cm)

Fig. 7



Tint(BBC) vs Zint(BBC)
(1985 DATA)
23 Beam–Beam events
Tint(BBC) (nsec)
48
44
40
36
32
28
24
20
−120
−80
−40
0
40
80
120
Zint(BBC) (cm)
RUN 489
RUN 493
RUN 494


Fig. 8

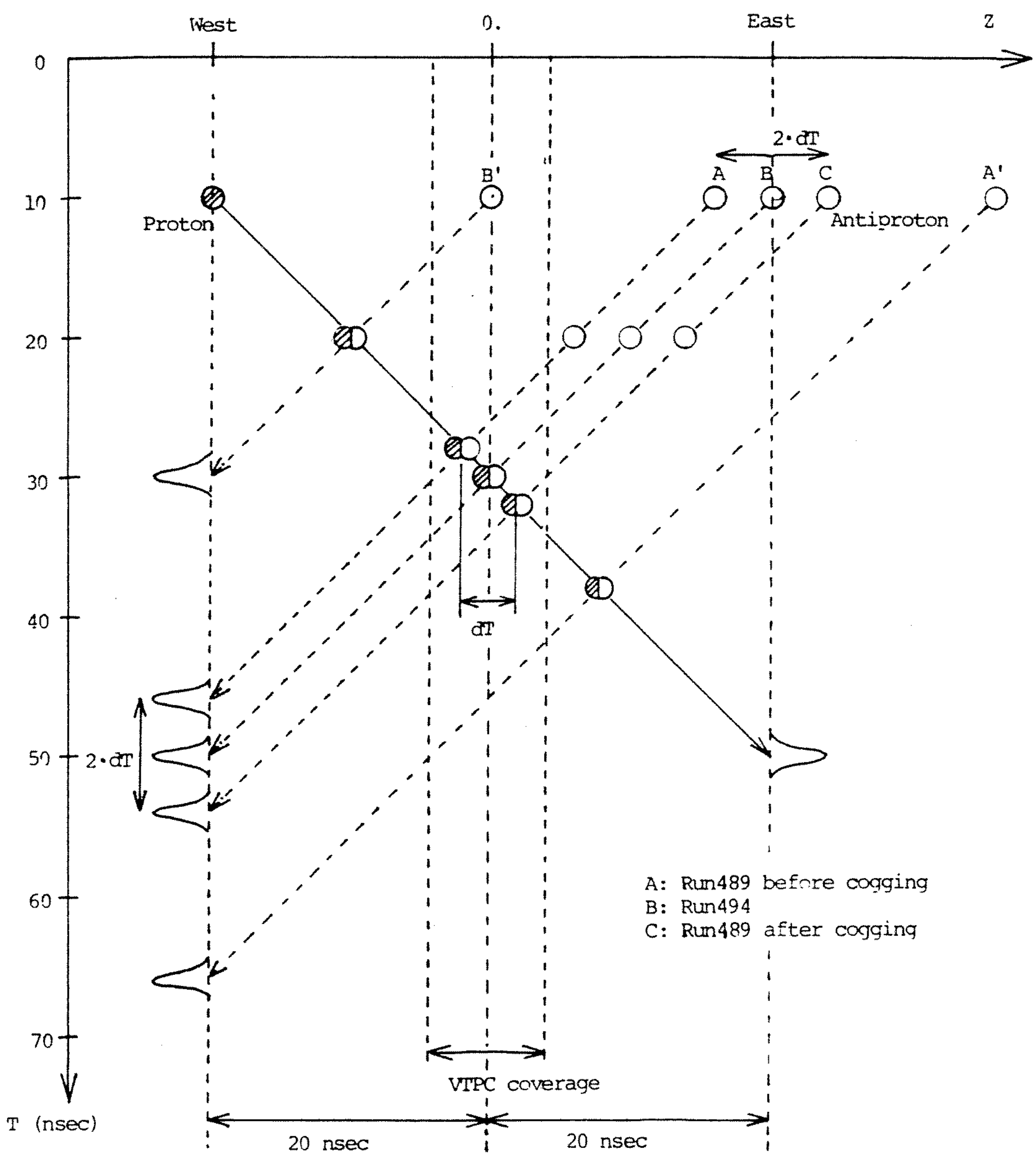

West
0.
East
Z
0
10
20
30
40
50
60
70
T (nsec)
2·dT
B'
A
B
C
A'
Proton
Antiproton
dT
2·dT
A: Run489 before cogging
B: Run494
C: Run489 after cogging
VTPC coverage
20 nsec
20 nsec

Fig. 9

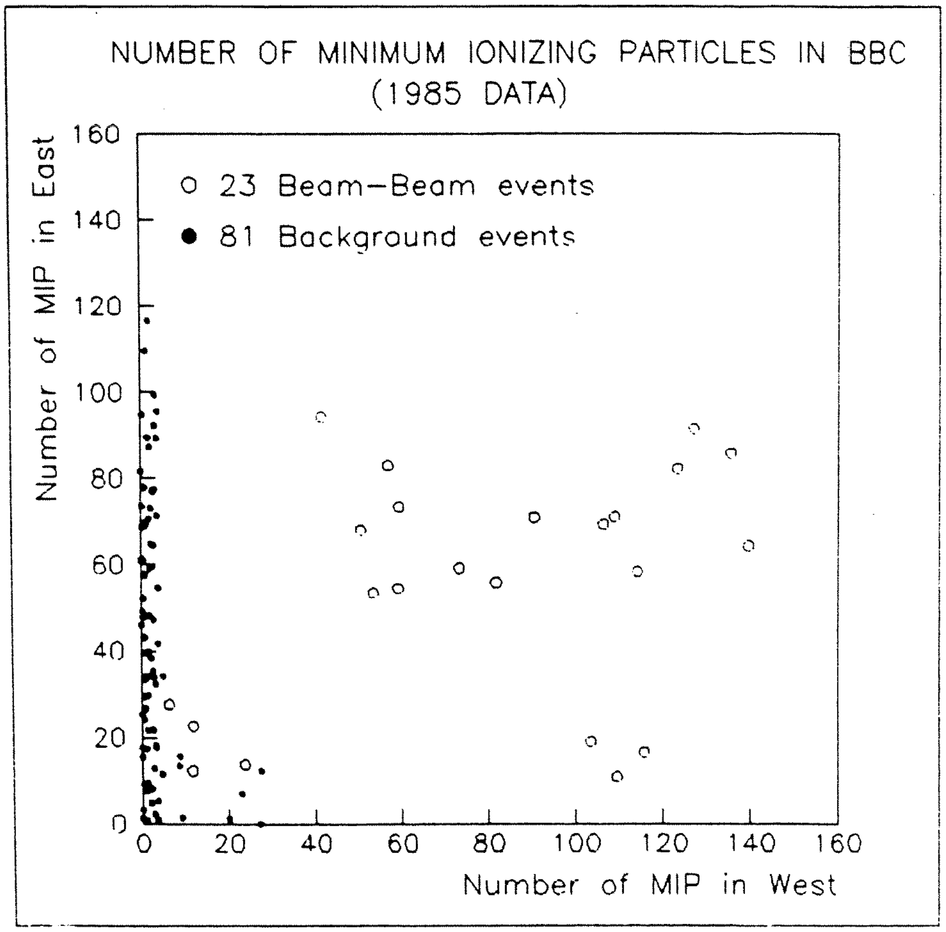
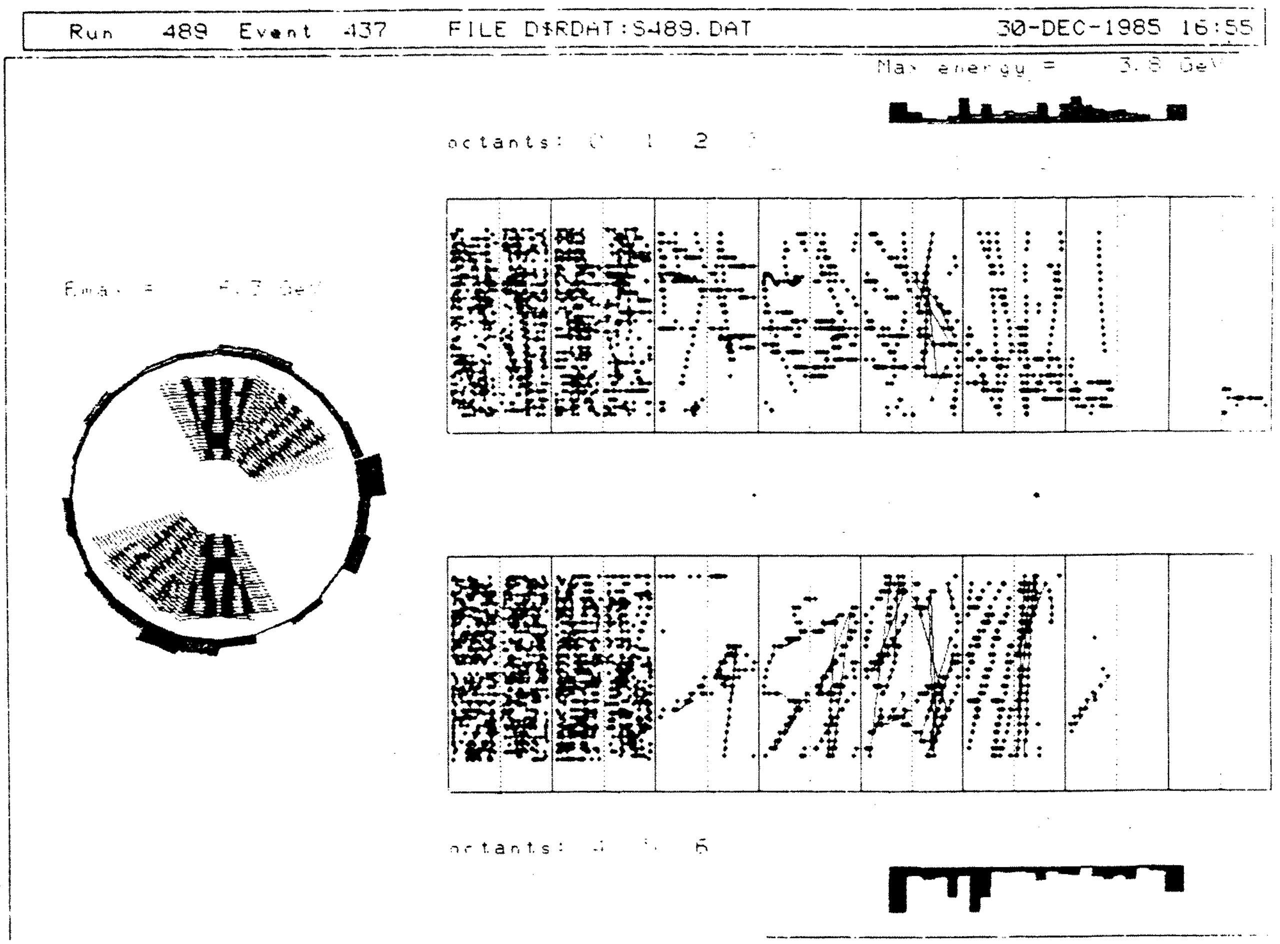

NUMBER OF MINIMUM IONIZING PARTICLES IN BBC
(1985 DATA)
23 Beam–Beam events
81 Background events
Number of MIP in East
Number of MIP in West
0
20
40
60
80
100
120
140
160

Fig. 10



Run 489 Event 437 FILE D$RDAT:S489.DAT 30-DEC-1985 16:55
octants:


Fig. 11(a)

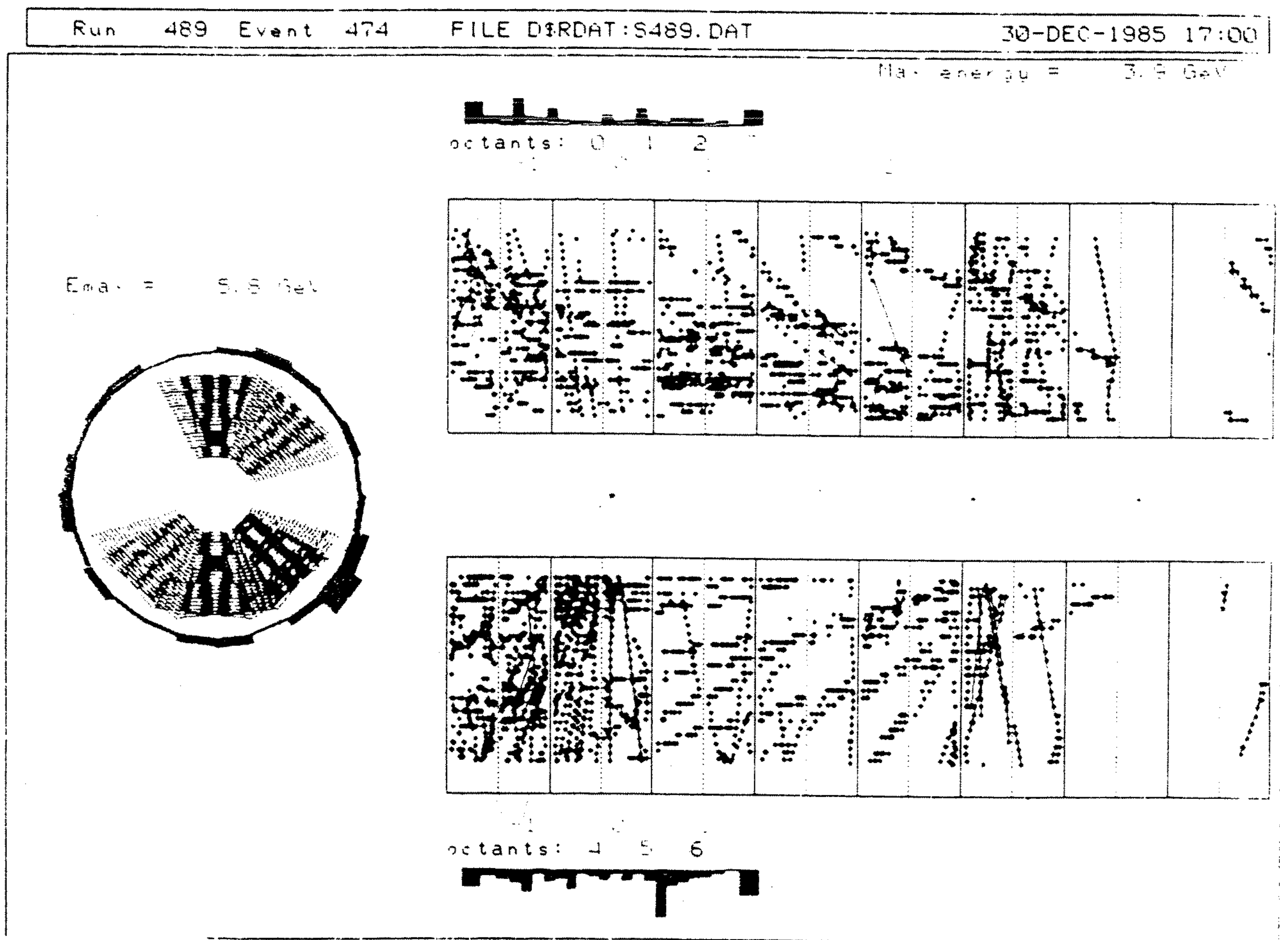

Run 489 Event 474 FILE D$RDAT:S489.DAT
30-DEC-1985 17:00
octants: 0 1 2
Emax = 5.8 GeV
octants: 4 5 6

Fig. 11(b)

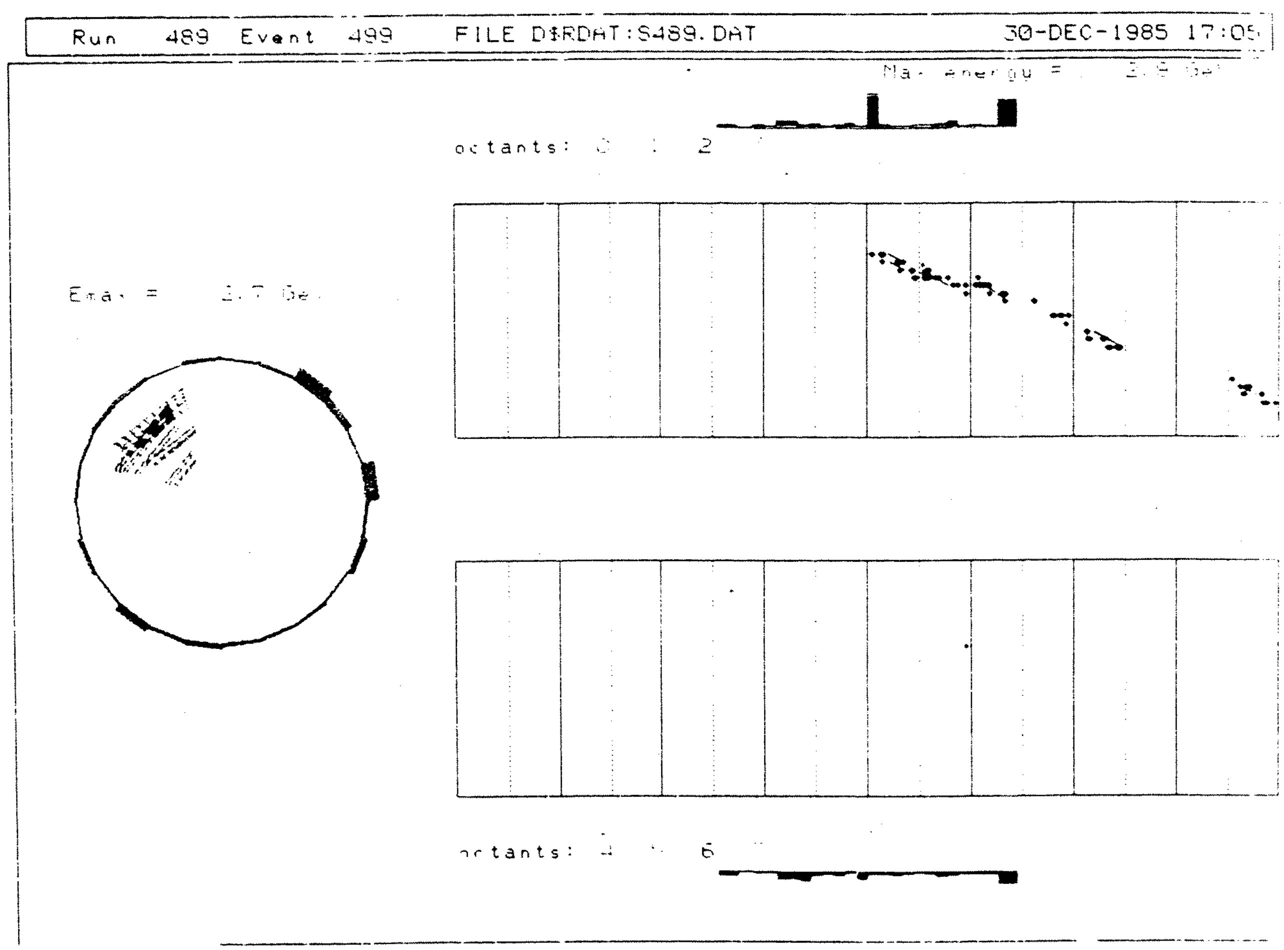

Run 489 Event 499 FILE D$RDAT:S489.DAT 30-DEC-1985 17:05
octants: 0 1 2
octants: 4 5 6

Fig. 11(c)

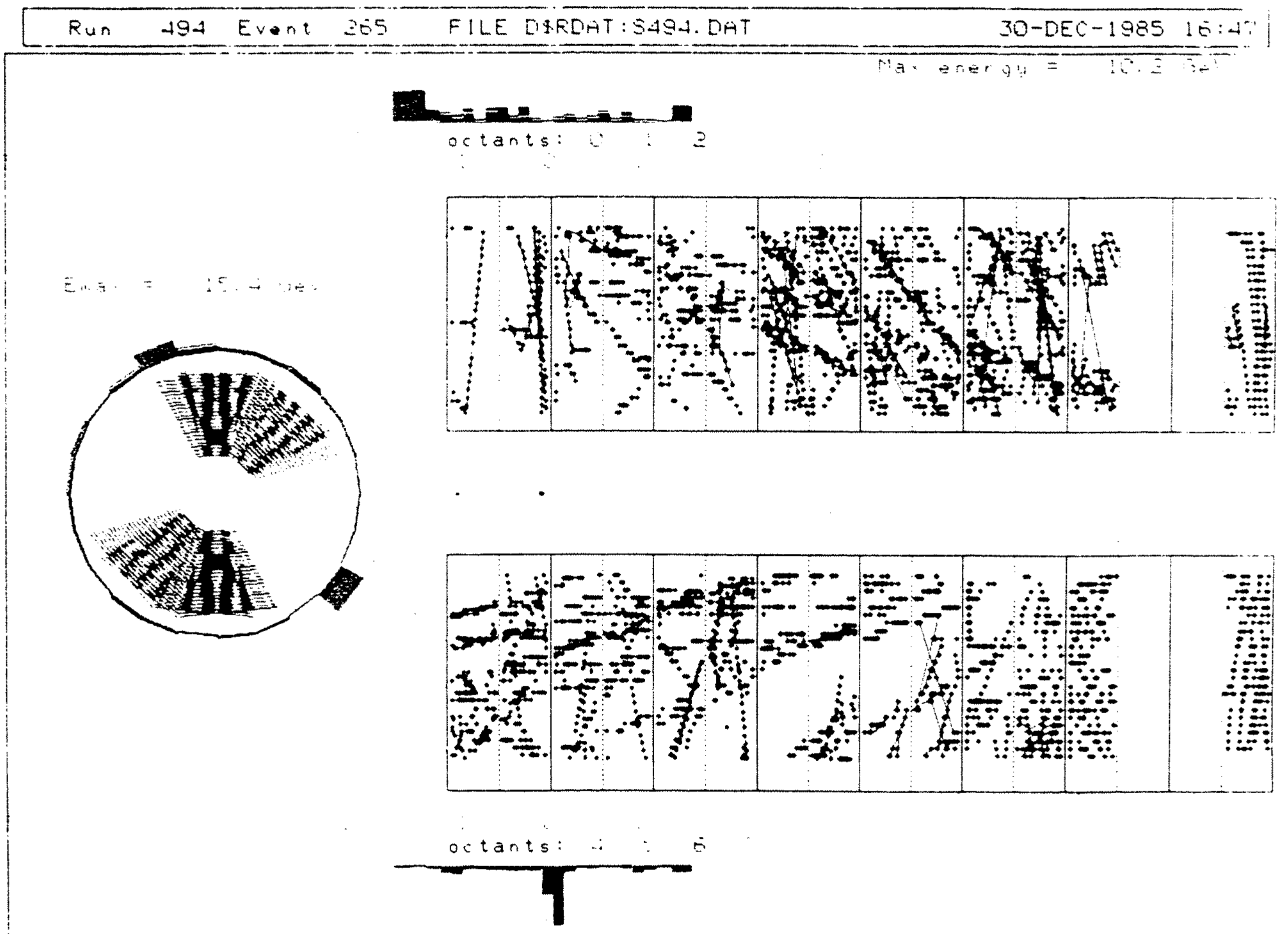

Run 494 Event 265
FILE D$RDAT:S494.DAT
30-DEC-1985
octants:
octants:

Fig. 11(d)