CB Report no. 336
Addendum on In-Flight Normalisation

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Abstract. This report gives technical details of some further investigation of in-flight normalisation. There are no dramatically new developments, simply some fine-tuning. Results for the fine-scan momenta are now included and agree closely with neighbouring momenta. The conclusion is that the strong rate-dependence reported previously is definitely present, and our analyses of physics channels must be based on this normalisation.

Technically two things have changed. Firstly, Klaus Peters alerted us to a deadtime we did not know about. For every trigger, there is a 4 μs deadtime while the final layers of the JDC are interrogated. We now include this explicitly in the calculations. Its magnitude is such as to generate a rate-dependent correction of typically 4%, much smaller than the observed effects. Deviations from linearity are tiny, so there is negligble change is earlier results due to this correction.

Secondly, in CB report 335, there was a minor defect in data processing. There are occasional runs where the beam scaler overflows and we failed to notice this. When this happened, blocks of 1000 events were corrupted. The beam scaler gave too low a reading, and the plot of events/beam was always too high. One can see this for example in Fig. 7 of report 335, where a few points lie systematically above the trend of the great majority of points. When this is corrected, the extrapolation to zero rate looks cleaner and therefore more convincing. We had previously ignored these high points by eye, so it leads to very little change. At two momenta, we now find very small increases in the normalisation, but within the previously quoted errors.

Thirdly, Kamal Seth and others have argued that one should not consider data at beginnings and ends of spills, because of the possibility of poor beam conditions. We have made a number of checks on this hypothesis. (a) An investigation of scaler readings provides no evidence for bad beam at beginnings and ends of spills; indeed, there is definite evidence that beam quality improves there. Two ratios of scalers are helpful. Firstly, the quantity $K/K.Si_C$ monitors the amount of beam counting in Ken's chamber but not in Si_C and should be sensitive to beam quality. We find that this ratios varies from a minimum of 1.22 to values as large as 2.0 without any change in measured cross sections. At the beginnings and ends of spills, this ratio always decreases by about 0.10. This change is not enough to have a significant effect, but it is in the sense that MORE beam goes through Si_C, i.e. the beam improves. Secondly. the ratio $S(OR)$/K monitors the amount of beam going through the four quadrant counters. At beginnings and ends of spills, it always drops by about 10% of its value; this again indicates that beam quality improves at beginnings and ends of spills. (b) we have searched out runs where the beam rate varies inside a spill without any significant change in beam conditions, as monitored by LU, LD, RU and RD. These runs show precisely the same rate dependence, within errors, as data at beginnings and ends of spills. (c) Conversely, we have searched out BAD runs, where there was obvious beam steering. Some show the normal rate dependence, but some show a LOSS of events, as one would expect if beam misses Si_C, with the result that the rate is underestimated and the correction for rate dependence needs increasing. But no beam-steering is ever observed to INCREASE cross sections. In view of these three tests, the hypothesis is untenable that poor beam conditions lead to the observed INCREASE of the number of events at low rates. It is anyway hard to believe that poor beam conditions would lead to an *increase* in the number of reconstructed events. The variations observed in LU, LD, RU and RD at beginnings and ends of spills are very small and are at least one order of magnitude less than variations when the beam is steered in bad runs.

Fourthly, Wolfgang Duennweber has argued that there is no rate dependence because fine-scan data give the same cross sections at significantly different beam rates. However, we now verify the presence of significant rate-dependence within those fine-scan momenta where data exist over a reasonable range of rates. For data with high beam rate, the slope of the extrapolation is smaller than that at low beam rate. Both give the same intercept within errors. The same effect is observed at three other momenta.

One other point was not fully documented in the previous report, and we now correct this omission. The way in which we have processed data is to fit 43 physics channels to the data. We keep all events satisfying a kinematic fit to any of these channels with confidence level $> 10^{-4}$. What we mean by the quantity $\sigma(4\gamma)$ is the cross section for any of these 43 channels containing 4γ, with a confidence level $> 10\%$. Likewise for 5, 6, 7 or 8γ. These cross sections are slightly different from what one would get by simply fitting $n\gamma$, since we have imposed the additional requirement that the events ALSO fit one of our 43 channels with $CL > 10^{-4}$. Apologies that we omitted this detail previously.

A general point is that the order of magnitude of the rate-dependence is in accordance with pile-up due to the time-constant of $100\mu s$ of CsI. The beam intensity was typically 3×10^5/s. For a total cross-section of 100 mb, the interaction rate in the target is 5500/s. With a time constant of $100\mu s$, we expect pile-up of order 50%. That is just what is observed.

Most of this report takes the form of graphs plus a running commentary.

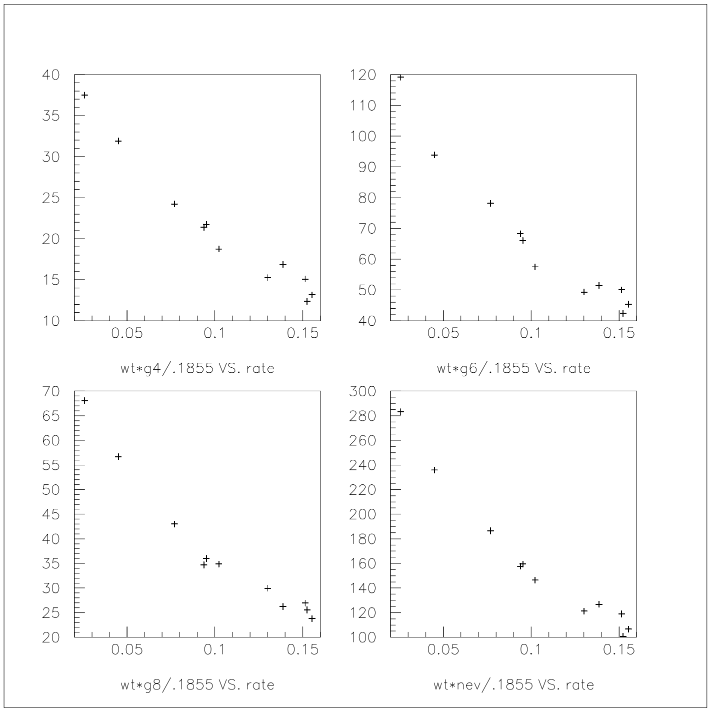


Fig. 1

1 Results at individual momenta

1.1 600 MeV/c

Here the rate dependence has always been exceedingly obvious. We have data over a wide range of intensities, and whole runs were taken with widely different rates. Two examples illustrate these effects.

Fig. 1 shows data from runs 39044/5, where the beam intensity varied from 0.025 MHz to 0.155 MHz (horizontal axis). The top-left panel shows $\sigma(4\gamma)$ in μb v. rate. The top-right panel shows $\sigma(6\gamma)$ v. rate. The lower two panels show $\sigma(8\gamma)$ and $\sigma(4+5+6+7+8\gamma)$ v. rate. In all cases, the rate dependence is very obvious. Fig. 2 shows results from whole runs up to run 39070 at 600 MeV/c. Again the rate dependence is obvious.

At 600 MeV/c, data from runs above 39070 are considerably different to those up to run 39070. The upper panel of Fig. 3 shows groups of 1000 events from runs up to 39070. The line is the one which was fitted in CB report 335 to data at rates < 0.05 MHz. The lower panel shows corresponding results for runs above 39070. The upper line is fitted to these data and extrapolates to the same intercept within errors, although the upper panel obviously gives a more reliable intercept. The lower line on the lower panel repeats the line from

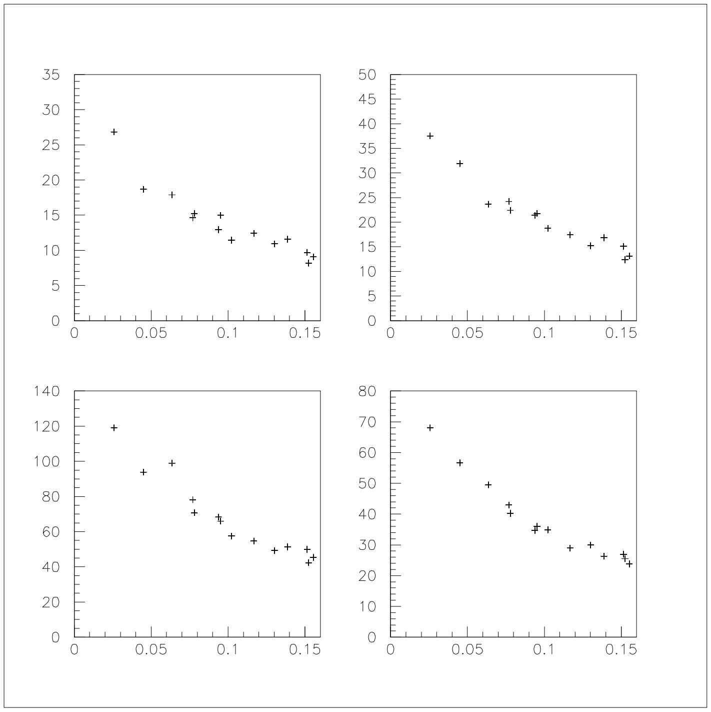

0 5 10 15 20 25 30 35
0 5 10 15 20 25 30 35 40 45 50
0 20 40 60 80 100 120 140
0 10 20 30 40 50 60 70 80
0 0.05 0.1 0.15

Fig. 2

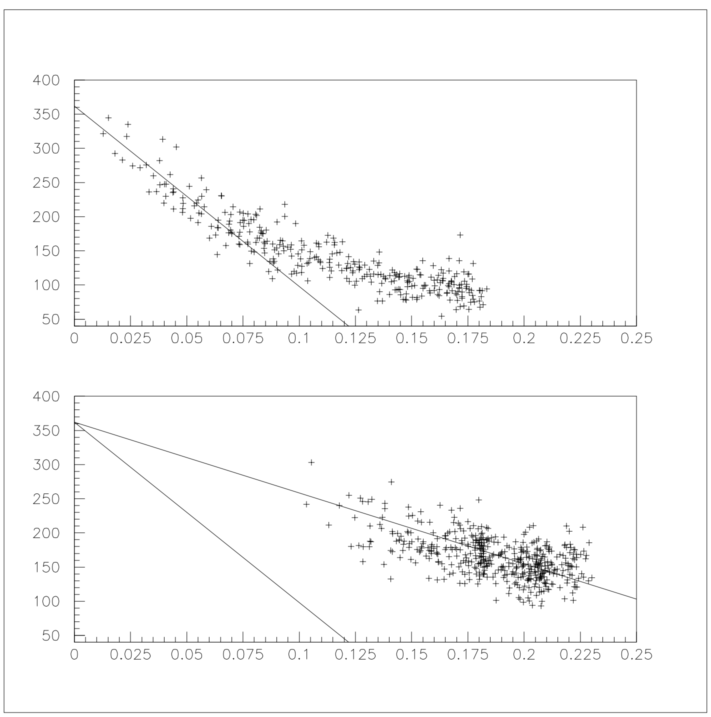

50 100 150 200 250 300 350 400
0 0.025 0.05 0.075 0.1 0.125 0.15 0.175 0.2 0.225 0.25

Fig. 3

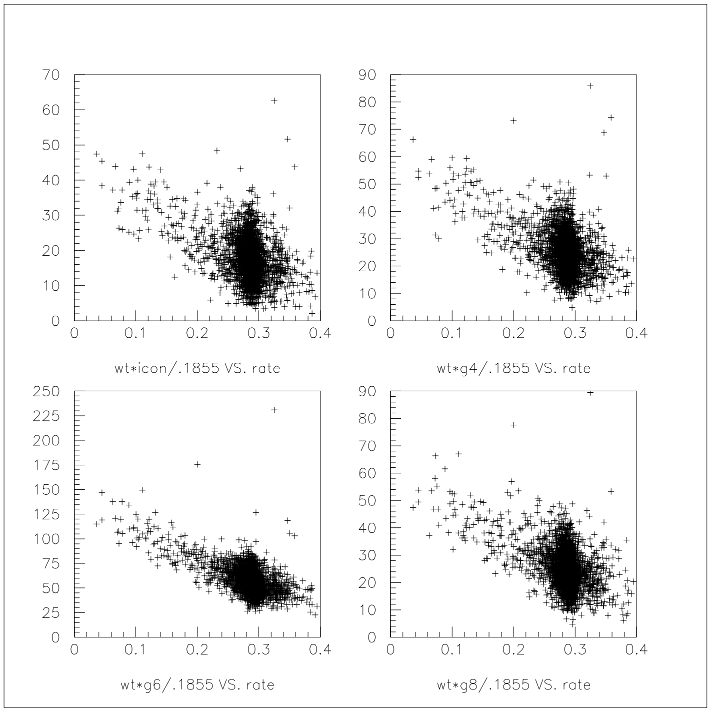


Fig. 4

the upper panel, so as to make the difference in slope obvious.

1.2 900 MeV/c

Fig. 4 shows, for runs 41400-41650, the rate dependence for $\sigma(2\pi^0)$ (top-left), $\sigma(4\gamma)$ (top right), $\sigma(6\gamma)$ (bottom left), and $\sigma(8\gamma)$ (bottom right). In all cases the vertical axis is in μb and the horizontal axis in MHz.

Fig. 5 shows $\sigma(4+5+6+7+8\gamma)$ in μb v. rate in MHz, after cleaning up the data by correcting those runs where scalers overflowed. The picture is cleaned up significantly compared with Fig. 8 of report 335. We now assess a slightly higher intercept of 340 μb, compared with the previous 332 μb. However, this change of 2.5% is well within the previously quoted error of $\pm 6\%$.

The upper part of Fig. 6 shows runs 40560 to 40600. The lower half shows data from runs > 40600. The slopes of the extrapolations are very different, but the intercepts are the same within errors. The extrapolation in the upper figure is longer and there is one high point at low rate, but with error $\pm 7\%$. We prefer to rely on the lower figure for the intercept.

We have examined ratios of $\sigma(4\gamma)$ to $\sigma(4+5+6+7+8\gamma)$ for the two groups of runs having the very different slopes in Fig. 6. Results are shown in Fig. 7 and

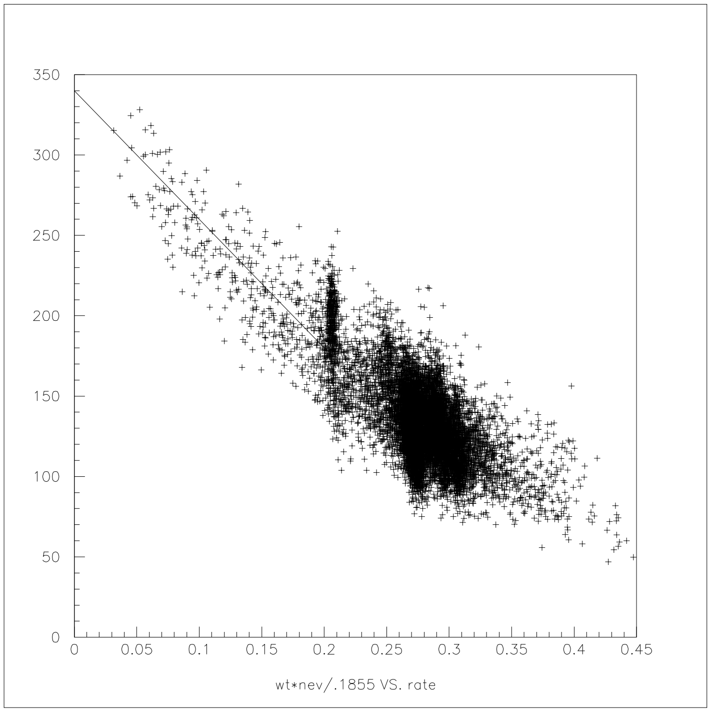


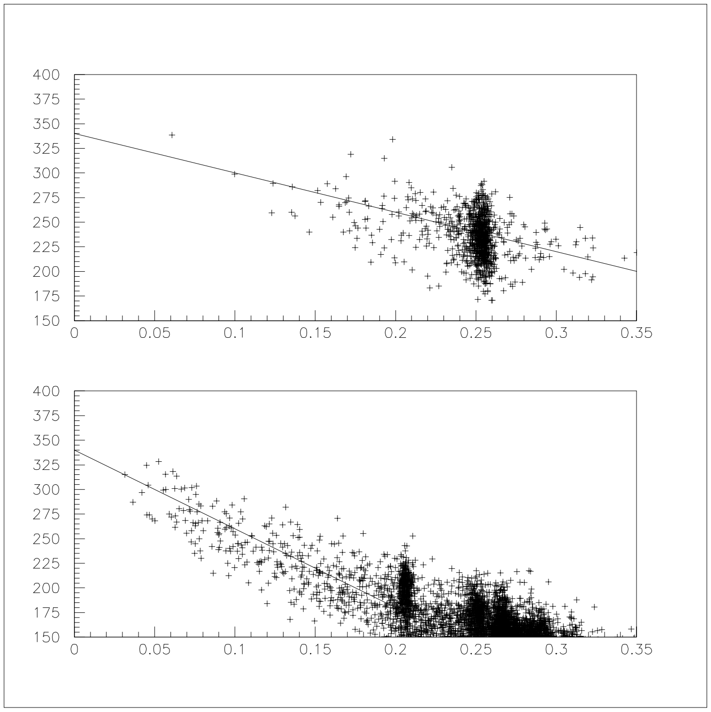
Fig. 5

agree within errors. We have likewise examined the ratios of $\sigma(\pi^0\pi^0)$, $\sigma(6\gamma)$ and $\sigma(8\gamma)$ to $\sigma(4+5+6+7+8\gamma)$ at this momentum and all others. We observe no significant variations anywhere, except at 1050 MeV/c for tapes $GK0483_1$, $GK0483_2$ and GK0484; the explanation was reported in CB Report 335 - the threshold of Tony's box was set too high, and these tapes are unreliable for absolute magnitudes of cross sections.

1.3 1050 MeV/c

Fig. 8 shows $\sigma(2\pi^0)$ (top left), $\sigma(4\gamma)$ (top right), $\sigma(6\gamma)$ (bottom left), and $\sigma(8\gamma)$ (bottom right) using groups of 1000 events for selected runs in which the beam rate varies widely over the whole run, but without any evidence for beam steering. These runs are 38923, 38925, 38942, 39953, 38972, 38983 and 38769. The rate dependence is obvious and is not tied to beginnings or ends of spills.

Fig. 9 shows the extrapolation to zero rate after cleaning out runs where the beam scaler reset. The fitted line is identical to that used previously in CB report 335.


400
375
350
325
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275
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225
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175
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0.05
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0.3
0.35

Fig. 6

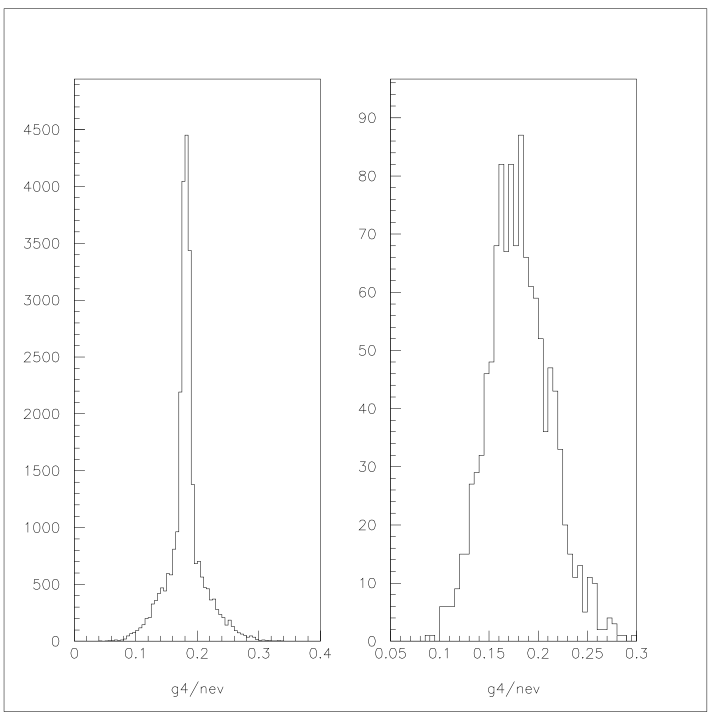

4500
4000
3500
3000
2500
2000
1500
1000
500
0
0.1
0.2
0.3
0.4
g4/nev
90
80
70
60
50
40
30
20
10
0.05
0.15
0.25
g4/nev

Fig. 7

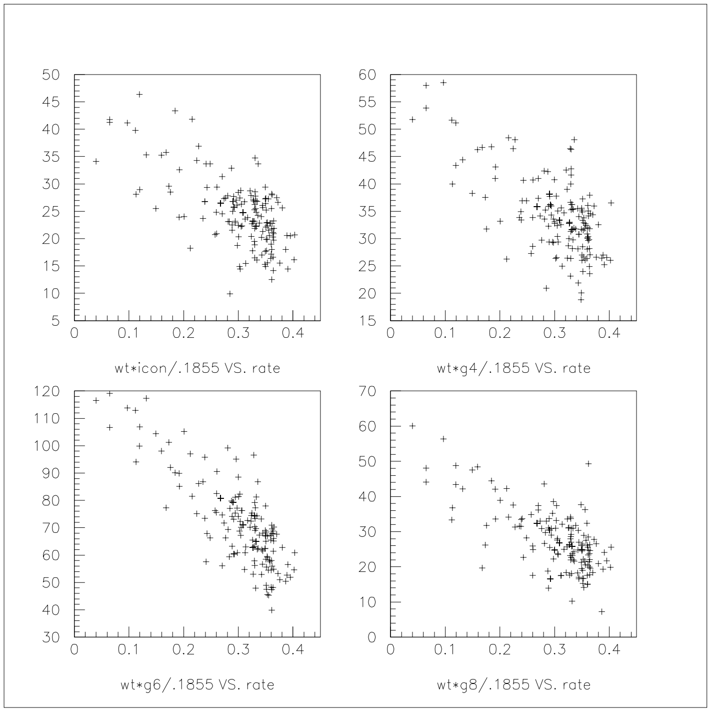

wt*icon/.1855 VS. rate
wt*g4/.1855 VS. rate
wt*g6/.1855 VS. rate
wt*g8/.1855 VS. rate

Fig. 8

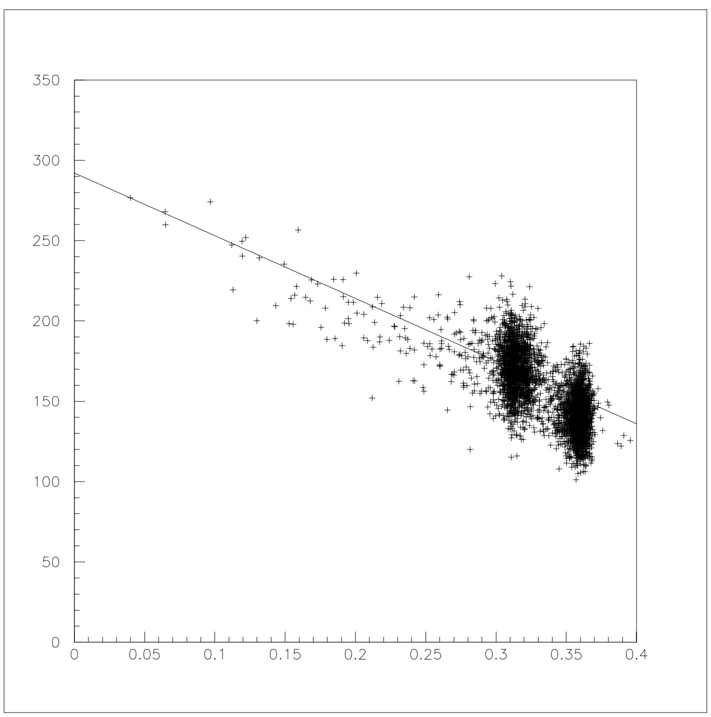


Fig. 9

1.4 1350 MeV/c

Fig. 10 shows $\sigma(4+5+6+7+8\gamma)$ (top left), $\sigma(4\gamma)$ (top right), $\sigma(6\gamma)$ (bottom left), and $\sigma(8\gamma)$ (bottom right) using groups of 1000 events for selected runs in which the beam rate varies widely over the whole run, but without any evidence for beam steering. These runs are 39404, 39474, 39480, 39500, 39631, 39746, 39750, 39881 and 39906. The rate dependence is obvious and is not tied to beginnings or ends of spills. Fig. 11 shows the extrapolation of $\sigma(4 + 5 + 6 + 7 + 8\gamma)$ to zero rate for whole runs above 30385. The extrapolation is longer than for groups of 1000 events, shown below in Fig. 12, but agrees. The line on both figures is identical to that of CB report 335.

At 1350 MeV/c, there are very different extrapolations for runs up to 39380 and runs 38385 upwards. The top panel of Fig. 12 shows beam rate v. run number. There is a large change of rate between runs 39380 and 39385. On the right-hand half of this panel one sees a 'curtain' of points at low rate, usually at the beginnings and ends of spills, but not in the runs listed above for Fig. 10. The second panel shows the extrapolation to zero beam rate for runs above 39385. The bottom panel shows runs below 39380. The slope fitted to the second panel is reproduced on the third as the upper line. The lower line extrapolates to the same intercept but with a very different slope. Fig. 13 shows this extrapolation somewhat more clearly from the few runs where beam rate varies over the whole spill. These are runs 39160, 39322 and 39380.

1.5 1525 MeV/c

Run 43121 is a remarkable run where the beam intensity varies from 0.07 to 0.38 MHz with no visible beam steering. Presumably LEAR operators were manipulating the stochastic extraction. Successive groups of 1000 events have the rates shown in Table 1. Results for $\sigma(4+5+6+7+8\gamma)$ are shown in Fig. 14. The rate dependence is very obvious.

There are further runs which show less dramatic variations of rate over the whole run. Results for runs 43302, 43323, 43121, 43357, 43392, 43399, 43408, 43190 and 43208 are compared in Fig. 15 with the line fitted to all data, Fig. 16.

1.6 1642 MeV/c

Fig. 17 shows the extrapolation of $\sigma(4 + 5 + 6 + 7 + 8\gamma)$ to zero rate for all runs. The line is the same as that in CB report 335.

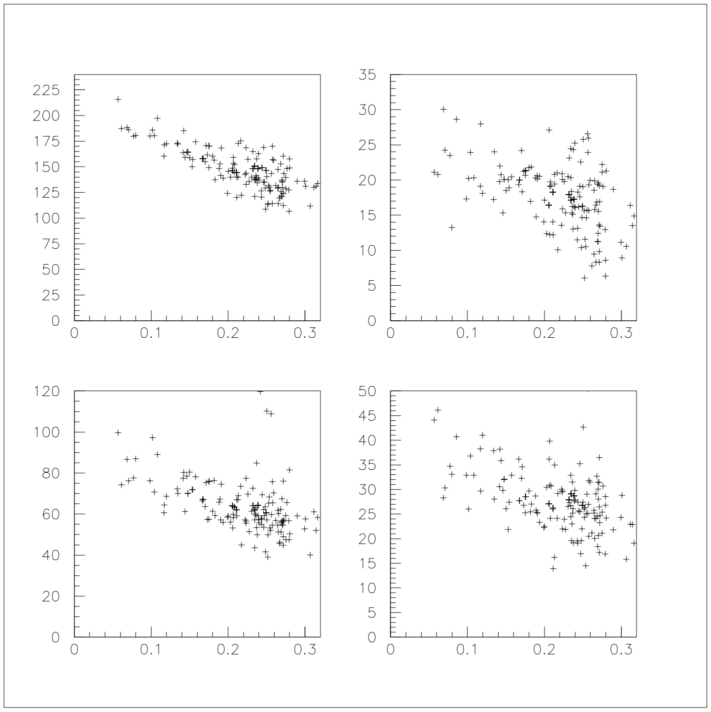


Fig. 10

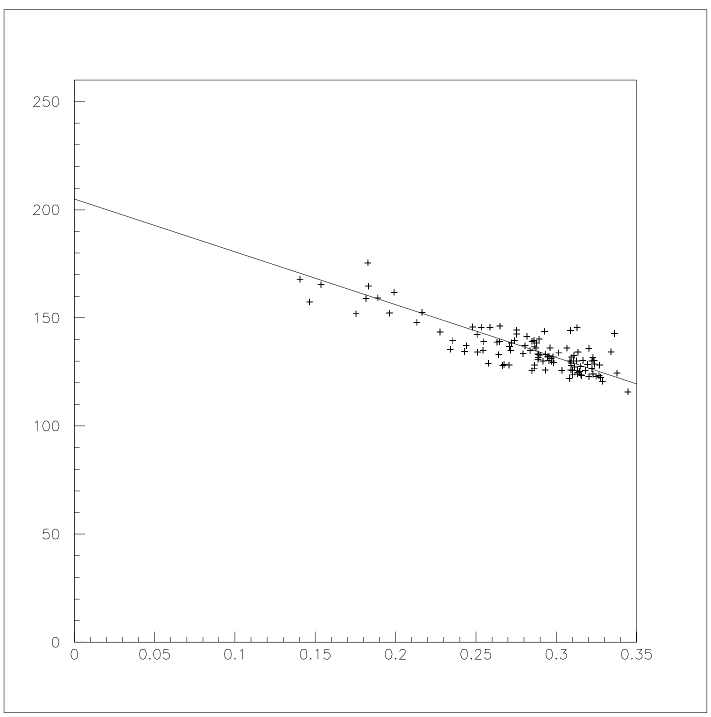


Fig. 11

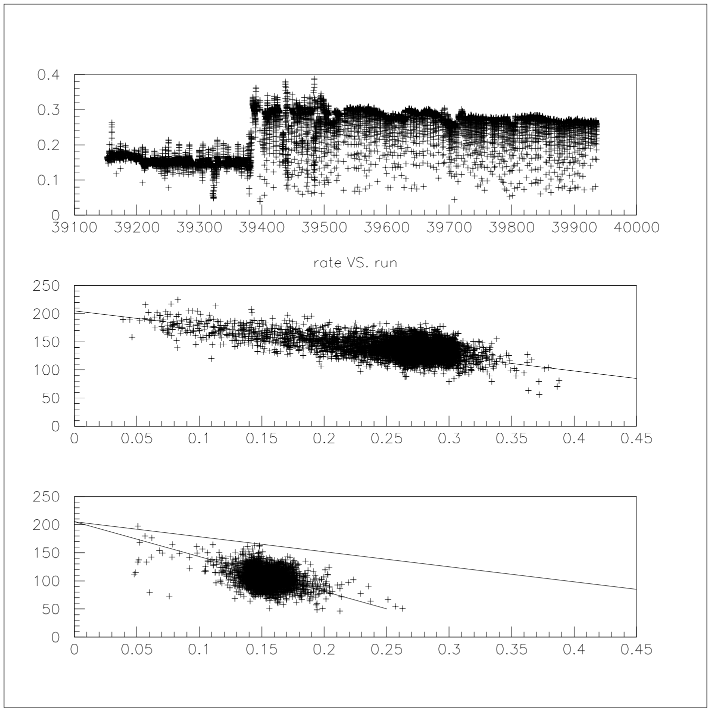


Fig. 12

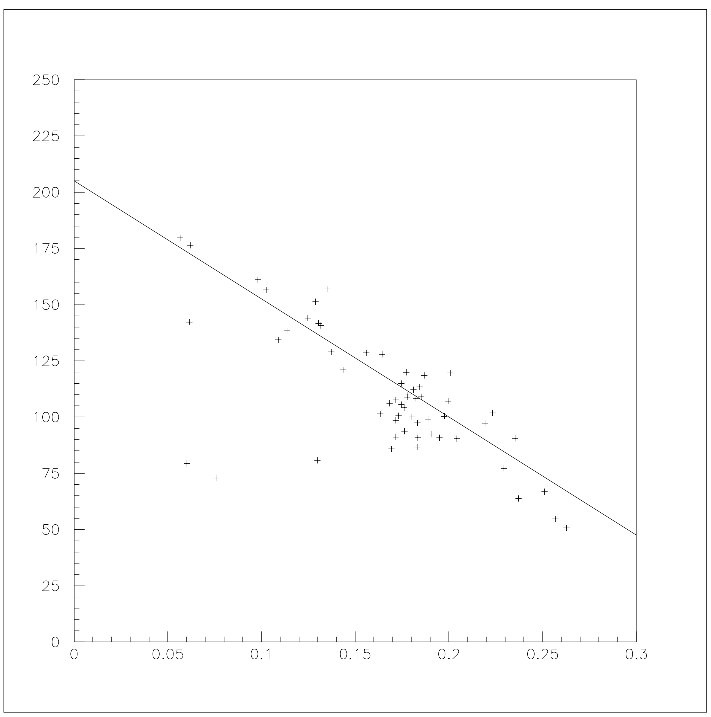


Fig. 13

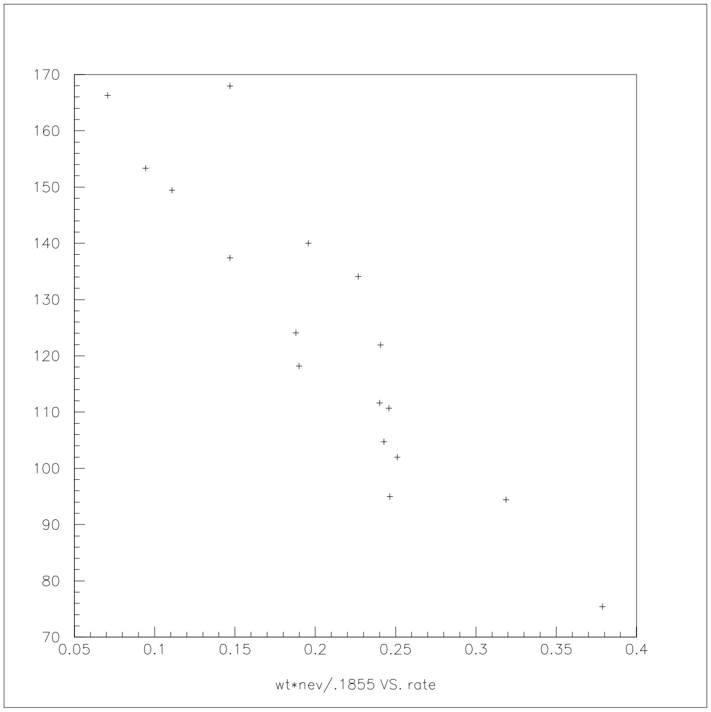


Fig. 14

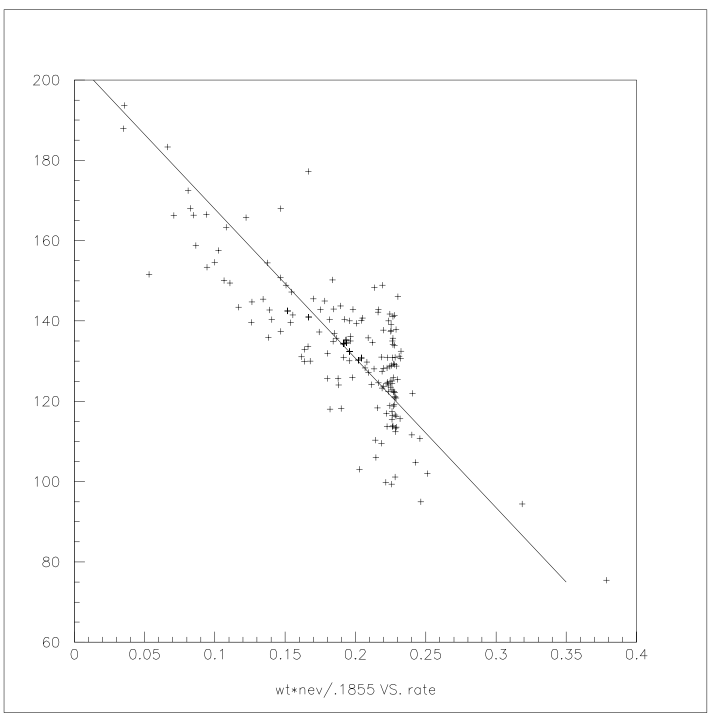
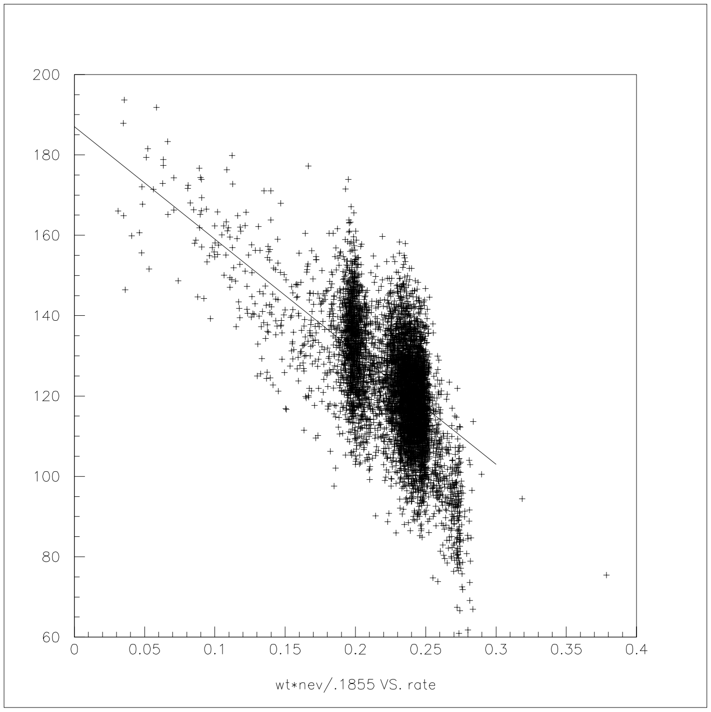


Fig. 15


200
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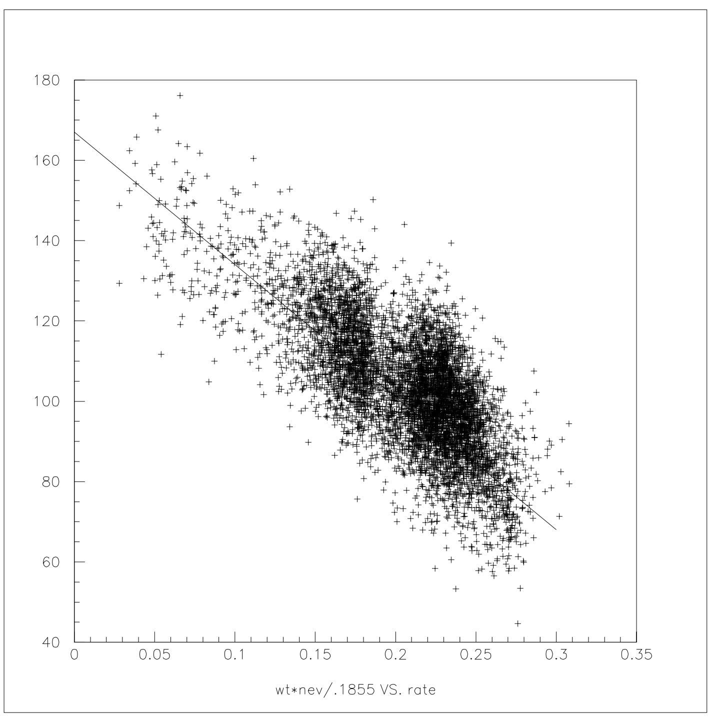
0.4
wt*nev/.1855 VS. rate

Fig. 16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0.25
0.3
0.35
wt*nev/.1855 VS. rate

Fig. 17

Batch	Rate(MHz)
1000	0.250
2000	0.248
3000	0.249
4000	0.255
5000	0.072
6000	0.339
7000	0.407
8000	0.194
9000	0.112
10000	0.252
11000	0.234
12000	0.095
13000	0.195
14000	0.260
15000	0.201
16000	0.150
17000	0.149

Table 1
Rate for successive blocks of 1000 events in Run 43121

1.7 1800 MeV/c

Fig. 18 shows $\sigma(4+5+6+7+8)\gamma$ for selected runs 41171, 40744, 40821 and 41012 where there is a significant variation of rate through the runs. Fig. 19 shows the extrapolation of $\sigma(4+5+6+7+8\gamma)$ for all runs. Here, we have revised our earlier extrapolation slightly to give an intercept of 125 μb compared with the earlier result of 121 μb. The change is due to cleaning up the picture by removing groups of events where the beam scaler reset. The change is roughly equal to the previously quoted error.

After correcting for the 2.45% of $\pi^0 \to \gamma e^+ e^-$, the revised Table 1 of CB report 335 is as follows.

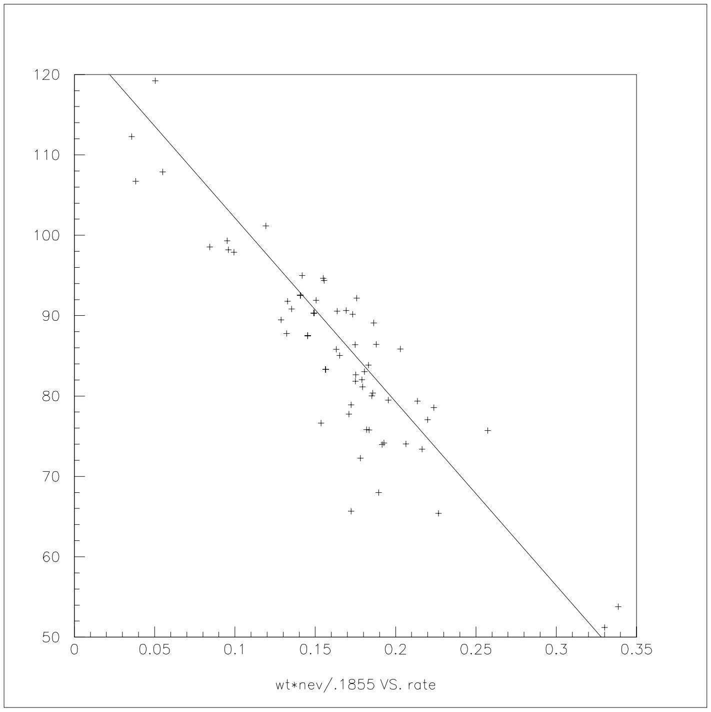


Fig. 18

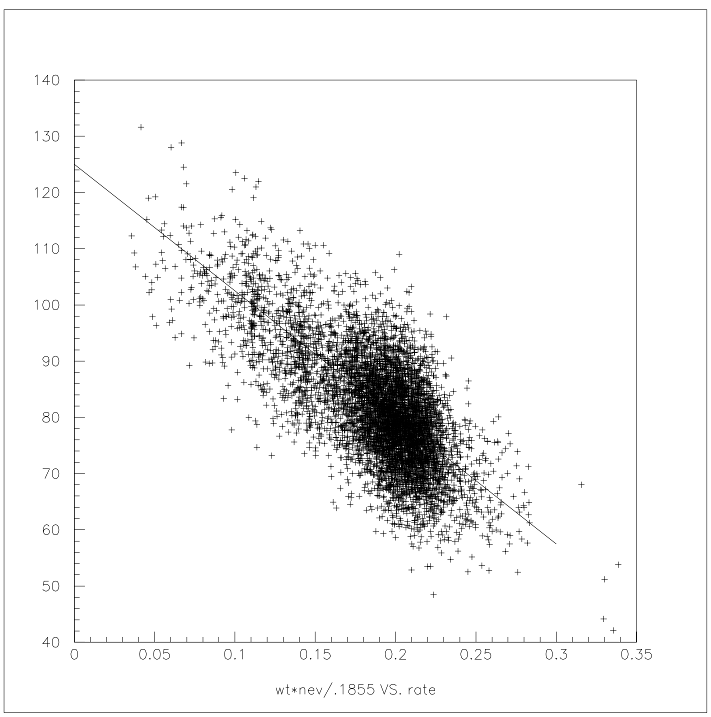


Fig. 19

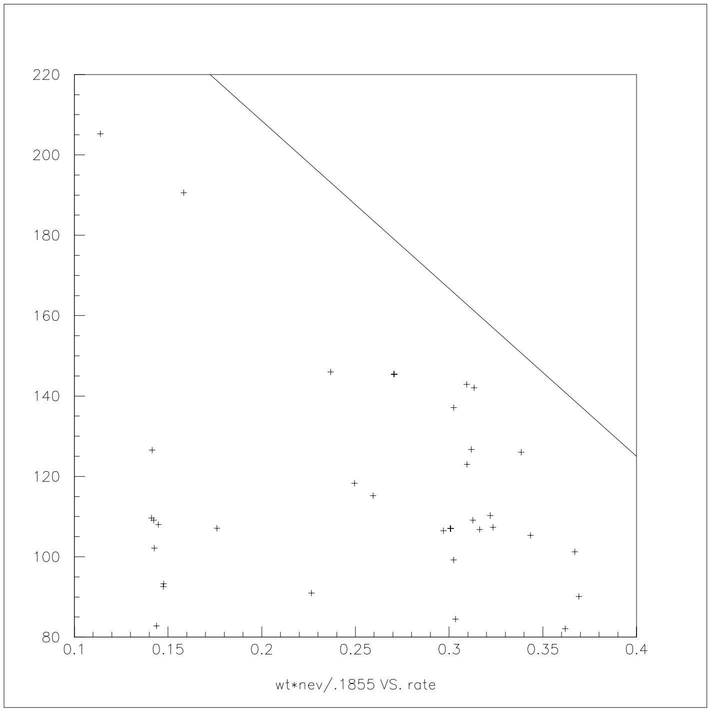
Momentum (MeV/c)	'$\sigma(4-8)\gamma$' (μb)	'$\sigma(\pi^0\pi^0)$' (μb)	'$\sigma(\pi^0\pi^0)$' (μb)
600	372.0 ± 19.1	34.0	51.2 ± 2.3
900	348.3 ± 20.2	45.3	72.2 ± 4.1
1050	291.9 ± 8.4	44.6	72.0 ± 2.2
1200	248.5 ± 10.8	34.1	65.3 ± 2.8
1350	205.1 ± 8.8	25.4	50.6 ± 2.8
1525	191.4 ± 6.1	18.5	40.8 ± 1.2
1642	167.2 ± 7.9	13.9	33.0 ± 1.0
1800	128.0 ± 4.0	8.8	23.0 ± 0.7
1940	97.9 ± 9.4	6.23	18.6 ± 1.8

Table 2
Corrected cross sections v. beam momentum

2 Beam Steering

We have searched for runs where there was obvious beam steering, to see if this affects the measured $\sigma(4+5+6+7+8\gamma)$. We identify such runs from large changes in the quadrant counters LU, LD, RU and RD. In some cases there is no visible effect on $\sigma(4+5+6+7+8\gamma)$. In others, it drops visibly. Our conclusion is that in the latter case, a significant amount of beam has missed Si_C and the beam rate it measures is too low, hence an increased rate-dependent correction is required. Where the steering has no apparent effect, the beam presumably remains within Si_C.

Examples are as follows. Fig. 20 compares the effect of beam steering at 1050 MeV/c for runs 38731, 38732 and 38746 with the standard extrapolation. There is an obvious REDUCTION in the number of reconstructed events. At 1350 MeV/c, in runs 39473, 39474 and 39475–39485, Fig. 21 shows a possible effect at the highest rates due to beam steering, again a reduction in the number of reconstructed events. At 1525 MeV/c, runs 43115 and 43704 show a reduction in the number of reconstructed events in Fig. 22. At 1642 MeV/c, runs 42609 and 42610 show no significant effect in Fig. 23 in runs where there is definite beam steering. In NO case do we observe an INCREASE in the number of events due to beam steering. This rules out the hypothesis that beam shifts at beginning and ends of spills are responsible for the observed rate dependence.


220
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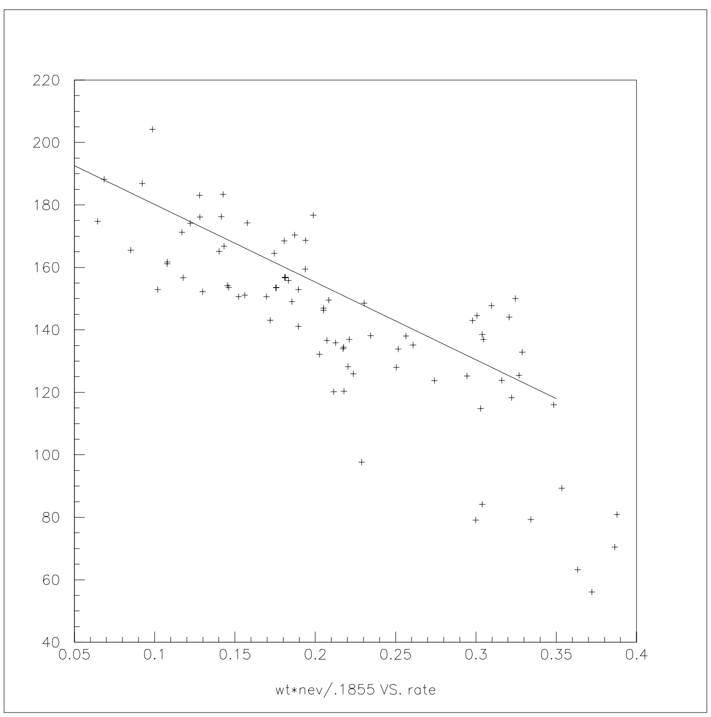
wt*nev/.1855 VS. rate

Fig. 20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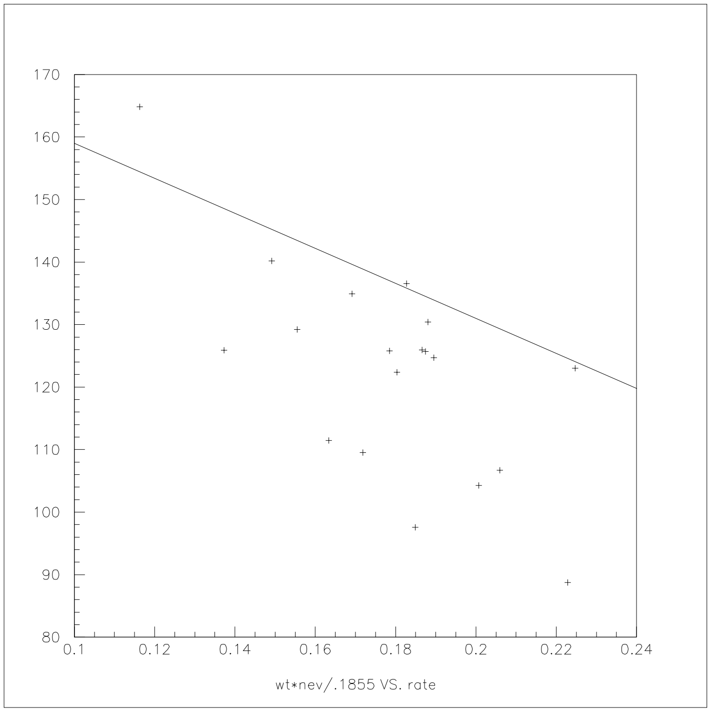
wt*nev/.1855 VS. rate

Fig. 21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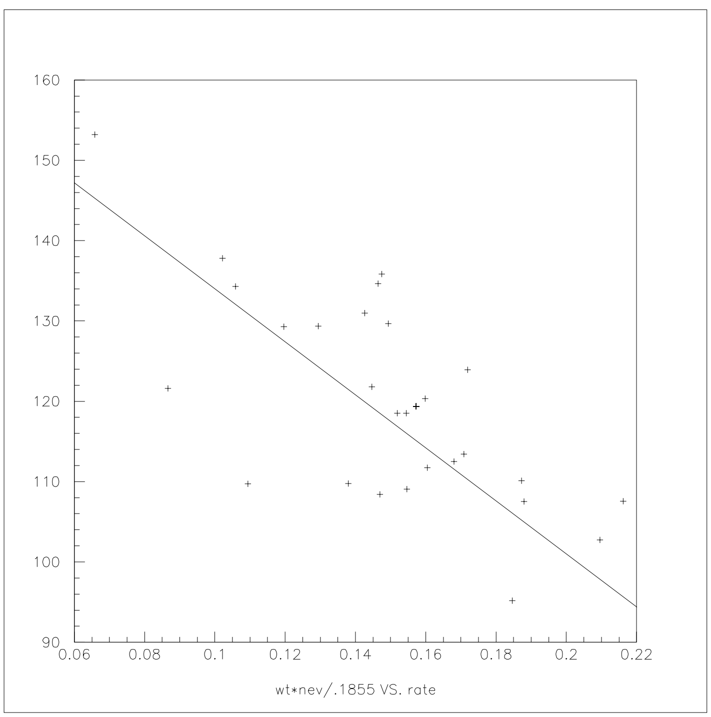
wt*nev/.1855 VS. rate

Fig. 22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0.12
0.14
0.16
0.18
0.2
0.22
wt*nev/.1855 VS. rate

Fig. 23

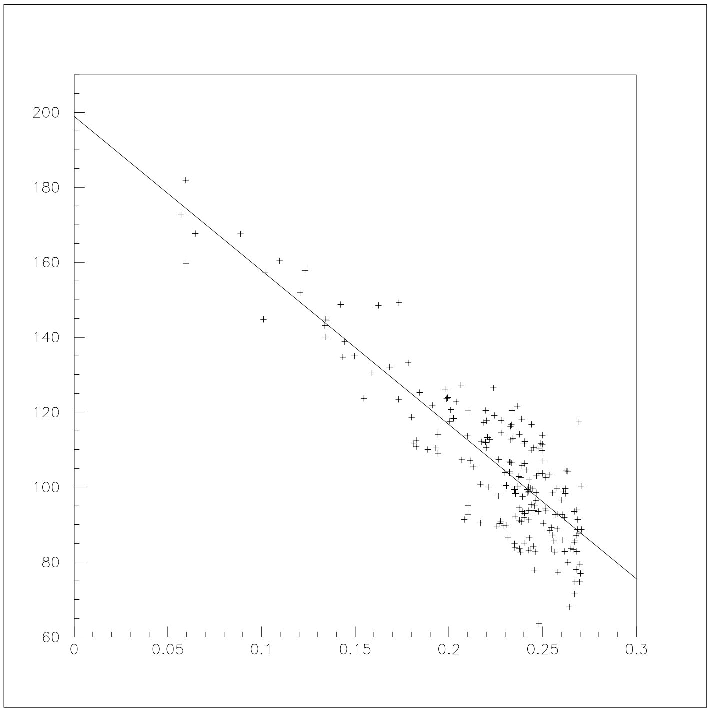


Fig. 24

3 Results for fine-scan runs

Here statistics are more than an order of magnitude lower than for the main in-flight momenta, and the rate dependence is correspondingly harder to observe. It is not really visible in $\sigma(\pi^0\pi^0)$, because of low statistics. But it is clearly visible for $\sigma(4+5+6+7+8\gamma)$, as shown in the following figures. In all (except Fig. 27), the vertical axis shows the cross-section in microbarns and the horizontal axis shows the rate in MHz.

The clearest rate dependence is at 1429 MeV/c. There, it is fortunate that there are MANY runs with a big variation of beam intensity. In the early stages of this momentum, there was some beam tuning. There is a rather nice illustration of a change of beam condistions during run 42169. Before and after this, there are significantly different slopes to the extrapolation, but intercepts agree within errors. A nice feature is that run 42169 itself shows an intermediate slope between earlier runs and later runs. The beam tuning is not recorded in the log-book, but from scaler readings it obviously took place between events 11000 and 14000 in run 42169.

Fig. 24 shows $\sigma(4-8)\gamma$ for runs > 42169. The line fitted to the data goes through points (0,198.0) and (0.35,55). Here the intercept is obtained from linear interpolation between 1350 and 1525 MeV/c. Our judgement is that a free fit would give instead a line through (0,193.9) and (0.35,55). The difference

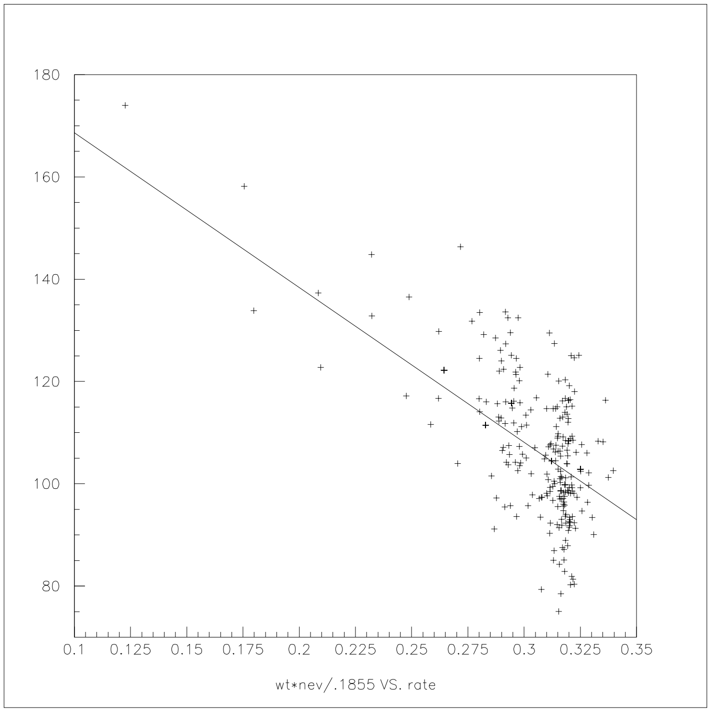


Fig. 25

of roughly 2 percent in the intercept (193.9 or 198.0 microbarns) is a measure of the error.

This plot was actually made from the following runs, which all show a nice variation of beam intensity: runs 42081, 42083, 42186, 42188, 42191, 42197, 42199, 42202, 42204 and 42207. Remaining runs show little variation of intensity, but are consistent with the others.

Fig. 25 shows runs 42157 to 42168. Fig. 26 shows four panels. The top left repeats runs 42157 to 42168; the top right panel repeats ALL runs > 42169; the bottom left shows run 42169 - data lie between full and dashed lines fitted to the previous two panels. The bottom right panel shows runs up to 42156. In these runs, there was major beam tuning, and the panel displays nicely the consequent variation of reconstructed events (a big scatter, from which it is hard to deduce anything).

Fig. 27 shows: (a) top left the ratio of $2\pi^0$ events to all events as a function of rate; (b) top right 4γ/all events, (c) bottom left 6γ/all events, (d) bottom right 8γ/all events. All are constant within errors.

At other momenta, the rate dependence is less obvious, for the simple reason that there are fewer runs where there is a significant variation of rate. At some momenta, the people on shift seem to have made a special effort to AVOID taking data as the rate varied, and this of course makes the extrapolation

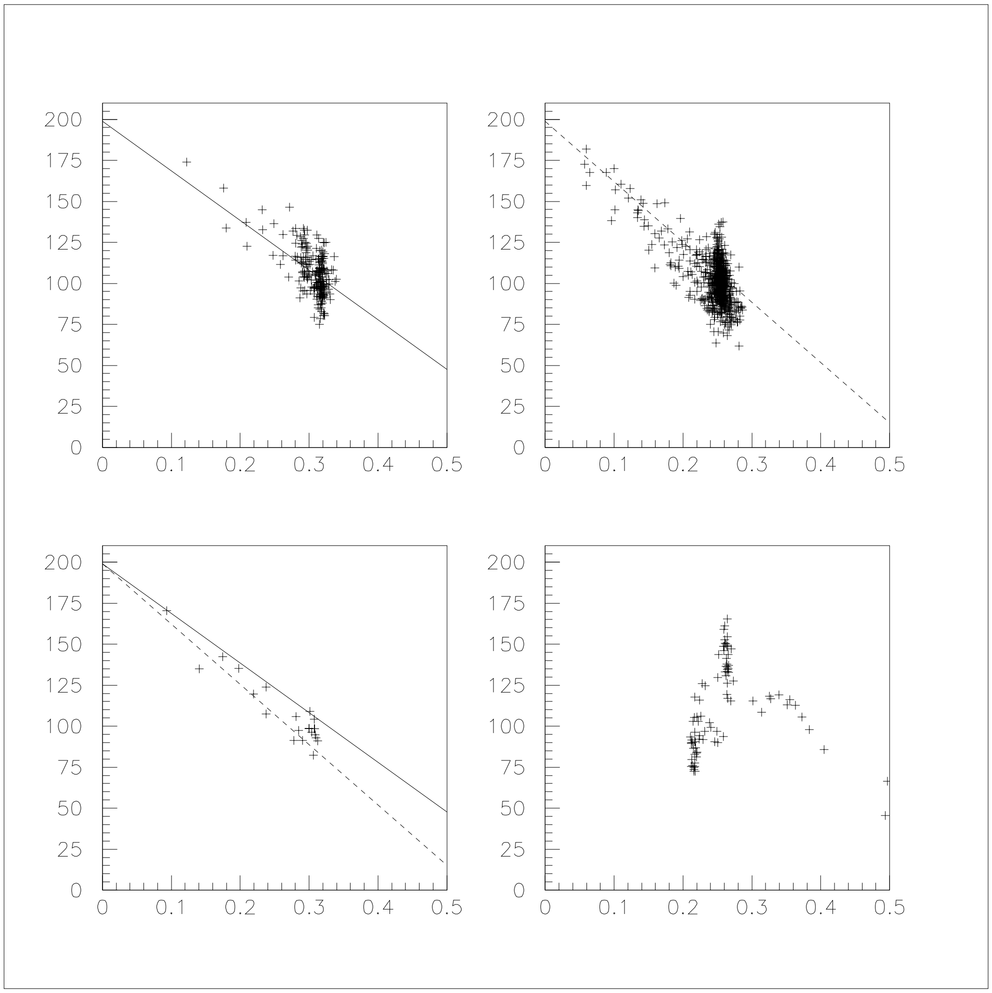


Fig. 26

difficult or impossible.

At 1412 MeV/c, runs showing a useful variation are 42053, 42058, 42060. The rate dependence is shown in Fig. 28. It is fitted by a line through the points (0,197) and (0.35,142). This is a free fit, and compares with the interpolated intercept 200.2 (different by 1.3 percent). Ratios 4γ/all and 8γ/all are independent of rate, but no judgement is possible for $2\pi^0$/all or 4γ/all because of low statistics. The rate dependence is obviously present at this momentum, but the precise slope is not well defined because of a few low 'wild' points.

At 1416 MeV/c, there are rather few runs with significant rate variation: 42088, 42092 and 42109. Results from these runs are shown on Fig. 29. A free fit gives a line through (0,210) and (0.4,100). The interpolated result here is $199.3\mu b$, so the discrepancy between free fit and interpolation is 5%. This is within the rather large errrors.

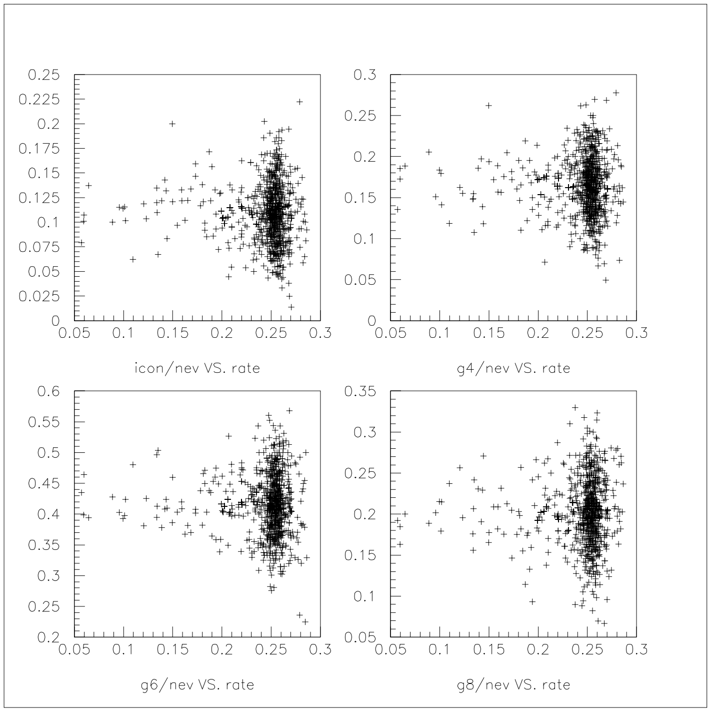


Fig. 27

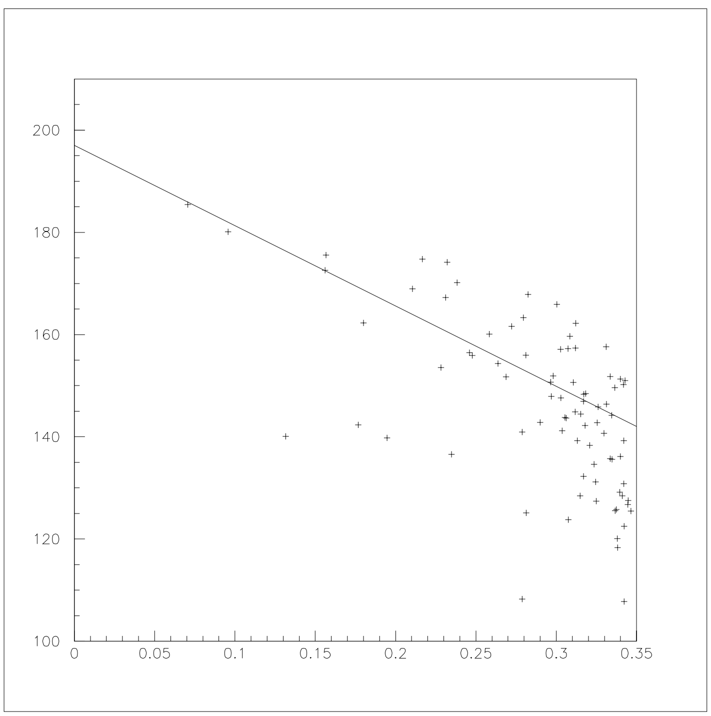


Fig. 28

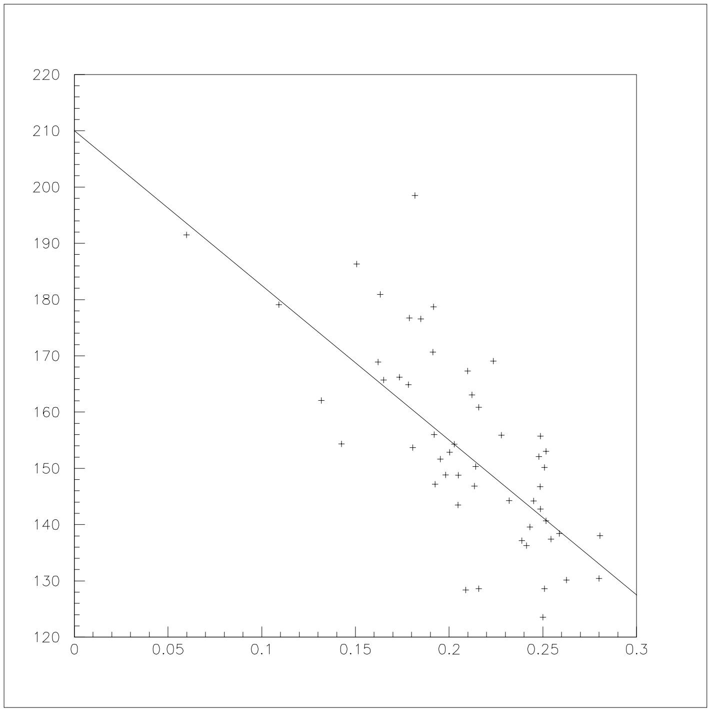
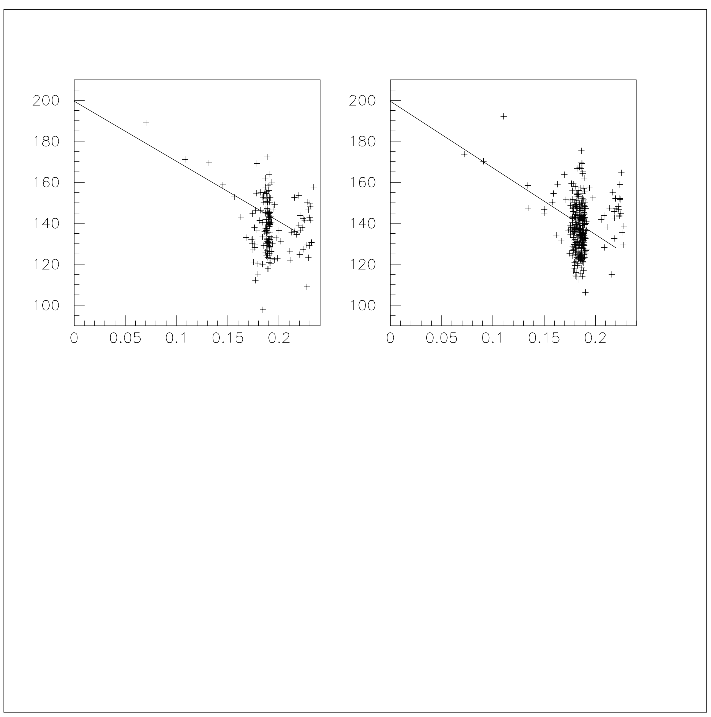

220
210
200
190
180
170
160
150
140
130
120
0
0.05
0.1
0.15
0.2
0.25
0.3

Fig. 29


200
180
160
140
120
100
0
0.05
0.1
0.15
0.2
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180
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140
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100
0
0.05
0.1
0.15
0.2

Fig. 30

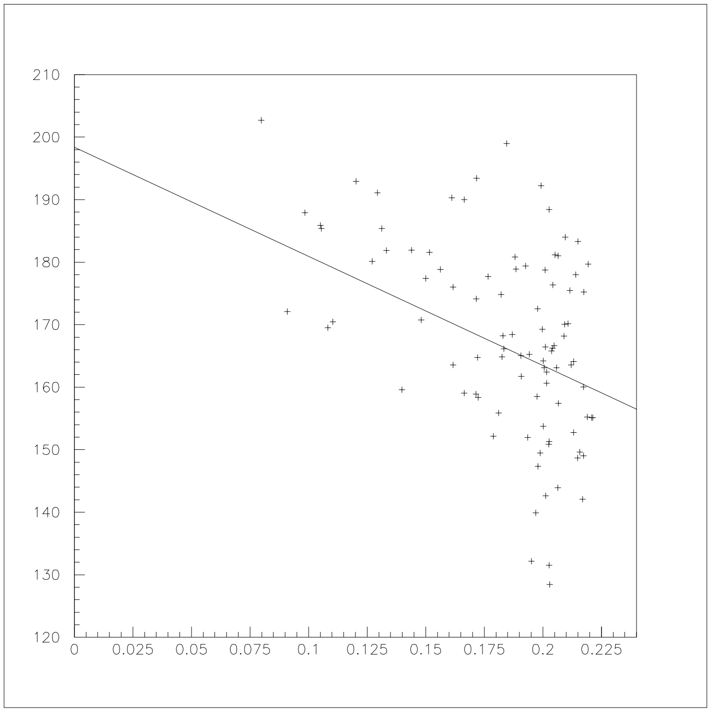

Fig. 31

Fig. 30 shows results at 1422 MeV/c. Runs 42124 and 42125 suffer from beam steering, and there is a noticeable change of slope between (i) runs < 42124 where a line through (0,199.5) and (0.22,135) fits with the intercept determined by the interpolation between 1350 and 1525 MeV/c, (ii) runs > 42125, where the fit is through points (0,199.5) and (0.22,128).

At 1436 MeV/c, results are not very definitive, because of a rather large scatter of the points. Some rate-dependence is obviously required. The runs showing the greatest variation of rate are 42412, 42424, 42441, 42449 and 42459. From these runs, results are shown on Fig. 31. The fitted line uses the intercept 198.37 interpolated between 1350 and 1525 MeV/c. It lies centrally amongst the points.

At 1443 MeV/c, there are very few runs (only 19) and only one has any variation of rate, and even then rather little. So it is not really possible to get a meaningful measure of the rate dependence at this momentum. A satisfactory result is obtained using an interpolation between 1350 and 1525 MeV/c and a slope from 1436 MeV/c. We do not bother to show this here, but it has been supplied to Willi Roethel.

At 1454 MeV/c, runs 42539, 42552 and 42558 give a useful determination of rate dependence. The fitted line on Fig. 32 is through points (0,203) and (0.2,150), compared with a value interpolated between 1350 and 1525 MeV/c of 197.0. The difference between free fit and interpolation is 2.5%.

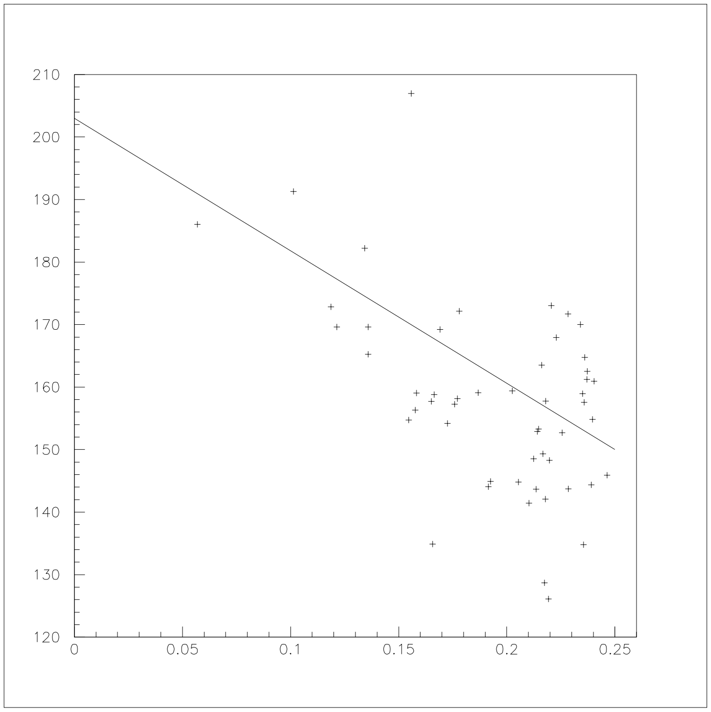
210
200
190
180
170
160
150
140
130
120
0
0.05
0.1
0.15
0.2
0.25

Fig. 32

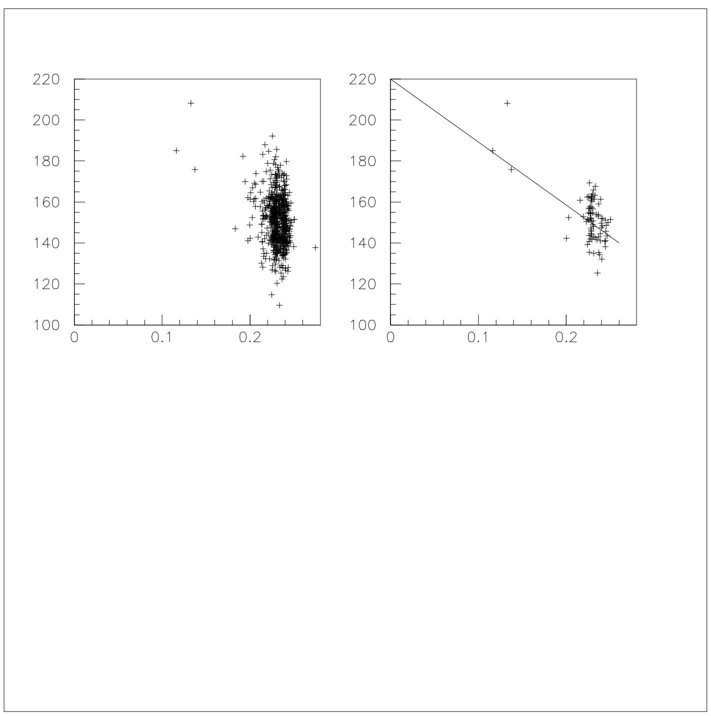
220
200
180
160
140
120
100
0
0.1
0.2
220
200
180
160
140
120
100
0
0.1
0.2

Fig. 33

At 1461 MeV/c, there are almost NO data determining the rate dependence. All data in included in the left-hand panel of Fig. 33. The best runs, 42576, 42588 and 42596 are shown on the right-hand panel. The fitted line is through (0,220) and (0.26,140), compared with an interpolated value of 196.4μb. The discrepancy between fit and interpolation is over 10 percent, but this is simply due to the absence of runs with significant rate variation.

4 Conclusions

The rate-dependence reported in the previous Technical Report is confirmed with further detail. It is definitely present also for momenta of the fine-scan. Within errors, relative rates of each channel to the total are independent of rate.