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VSAT energy calibration for 1995 minibunch data

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Abstract

In 1995 LEP operated with a new minibunch scheme, using 3 minibunches. In the VSAT data, high energy Bhabha events of minibunch 3 were wrongly assigned minibunch number 2 in modules B2 and F2. The calibration constants required for correcting the resulting distributions were obtained by iteration procedures, which are presented in this report. Extensive use has been done of macros and FORTRAN subroutines to be run from PAW.

Contents

1 Introduction

1.1 Minibunch operation of LEP

In 1995 period 2 a new energy scan of the Z^0 peak took place. For this run LEP had modified its previous mode of single bunch operation to a scheme of tightly spaced bunch-trains, i.e. instead of having one bunch crossing every 25 μs there were 2 to 4 bunch crossings within a fraction of a μs every 25 μs. Most of the scan data taking was done with 3 minibunches separated by about 250 ns. The electronics of the VSAT had not been properly modified to adjust to this scheme, which meant that elaborate off-line corrections to the data taken had to be applied, as described in this note. Practically constant energies have been assumed for peak-2, peak and peak+2 operation; the error of the LEP energy neglecting gravitational tide effects, the water level of Lac Leman and the TGV train schedule is of the order 10 MeV.

1.2 VSAT electronics 1995

Each VSAT module has an independent system for reading pulse heights, which allows for signals from different minibunches to be read in the four modules after the same beam crossing. Fig. 1 shows how the readout is done [1]. A fixed time (dt1) after a beam crossing (BCO), a signal from Pandora (WNG1) enables a gate generator. The width of each gate is about 50 ns. During this time a sensor is active and checks whether the sum of the FAD signals is above threshold. If this is the case, a HOLD is sent to the FADs when the peakfinding gate is closed. This gate is adjusted so that it should be on the top of the analog sum. A second HOLD is sent to the strips a fixed time later (dt2). If no signal is found above threshold during the gates, another signal from Pandora (WNG2) disables the gate generator after time dt3 and the HOLDs are generated. The minibunch number assigned to the signal is determined by the first gate during which the pulse was above threshold.

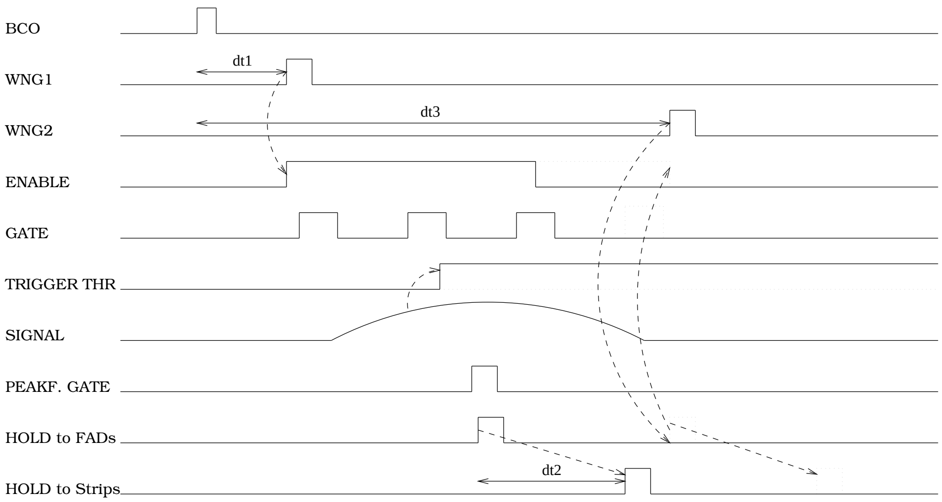

Figure 1: *Minibunch scheme signals when there is a hit in the module (full lines) and when there is no hit in the module (dotted lines).*

1.3 Radiation accident

On September 15, 1995 a low intensity electron beam was lost due to incorrect tuning of certain quadrupoles. The electrons hit modules B2 and B1 from the back, which caused an increase in the bias currents of these modules from 12 to 40 μA [2]. The incident was visible in the off-line in terms of a sudden decrease in the uncalibrated energies of modules B2, B1 for fills>3000 (fig. 2a). Table 1 shows a step of about 2% for module B2 and 1% for B1. There is no significant effect in modules F2, F1 (fig. 2b). Because of this event, we had to divide the analysis into two periods, before and after the accident.

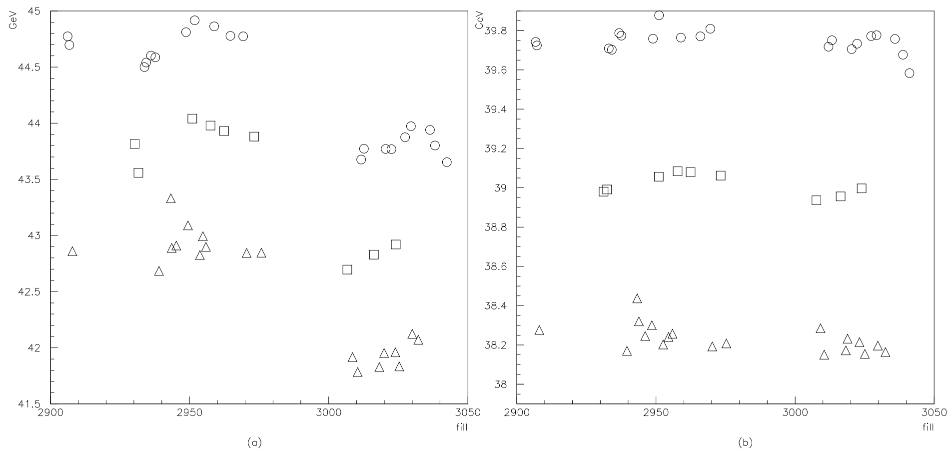

Figure 2: *Uncalibrated energy averages for (a) module B2 and (b) the diagonal module F1 at the three beam energies: peak+2 (circles), peak (squares) and peak-2 (triangles).*

		peak+2		peak		peak-2	
		before	after	before	after	before	after
B2	mb1	44.71	43.80	43.86	42.82	42.92	41.93
	mb2	44.22	43.33	43.38	42.33	42.47	41.47
	mb3	43.28	42.51	42.41	41.60	41.60	40.78
B1	mb1	40.67	40.28	39.98	39.50	39.18	38.71
	mb2	39.99	39.60	39.30	38.84	38.53	38.08
	mb3	39.36	38.97	38.69	38.19	37.93	37.43
F2	mb1	39.77	39.72	39.04	38.96	38.26	38.20
	mb2	39.15	39.12	38.42	38.38	37.68	37.61
	mb3	38.06	38.02	37.39	37.31	36.64	36.59
F1	mb1	39.92	39.88	39.10	39.07	38.30	38.26
	mb2	39.35	39.34	38.59	38.56	37.75	37.73
	mb3	38.78	38.77	38.01	38.01	37.20	37.19

Table 1: *Uncalibrated average energy values per minibunch for period 2 before and after the radiation accident.*

1.4 Mismatches

The off-line calibration programs produce (uncalibrated) energy distributions per module and per minibunch number. They also examine the cases where the diagonal modules have given different minibunch numbers. The identity of such events has been checked from correlation plots and it has been established that they are Bhabha events [3]. In total, we consider eight cases per module, as shown in table 2[1] for a typical fill at peak+2.

module	mb	entries	emean GeV	average GeV	opposite module status	
B2	1	155	46.45	47.45	mb(F1)>1	
	1	-				mb(F1)<1
	2	3969	49.10	49.03	mb(F1)>2	
	2	344	33.11			mb(F1)<2
	3	9	42.97		mb(F1)>3	
	3	265	36.89			mb(F1)<3
	4	-			mb(F1)>4	
	4	67	28.98			mb(F1)<4
B1	1	-				mb(F2)<1
	1	51	35.59		mb(F2)>1	
	2	391	39.05	39.73		mb(F2)<2
	2	37	48.52		mb(F2)>2	
	3	17818	38.33	38.92		mb(F2)<3
	3	5	37.55		mb(F2)>3	
	4	-				mb(F2)<4
	4	1	39.25		mb(F2)>4	
F2	1	390	49.28	50.43	mb(B1)>1	
	1	-				mb(B1)<1
	2	16795	46.38	46.38	mb(B1)>2	
	2	38	36.35	44.01		mb(B1)<2
	3	-			mb(B1)>3	
	3	61	34.60	37.50		mb(B1)<3
	4	-			mb(B1)>4	
	4	-				mb(B1)<4
F1	1	-				mb(B2)<1
	1	117	41.04	39.97	mb(B2)>1	
	2	384	33.93	34.27		mb(B2)<2
	2	115	44.97	47.42	mb(B2)>2	
	3	4316	38.30	38.96		mb(B2)<3
	3	6	39.08		mb(B2)>3	
	4	32	31.29	31.85		mb(B2)<4
	4	-			mb(B2)>4	

Table 2: *Histogram mean values and gaussian fit averages before calibration for mismatched events of fill 3029 .*

We see that B2 and F2 have many mismatched events of minibunch 2, for which the

[1]Fit statistics are neglected if sigma exceeds the rms of the histogram.

opposite module had minibunch number greater than 2. These correspond to minibunch 3 events in modules F2 and F1. By comparing those four distributions with the good assignment distributions of minibunch 2 and 3 in the same module, we have come to the conclusion that the correct minibunch number is 3 [3]. The statistics of the good assignments are given in table 3.

module	mb	entries	average GeV
B2	1	42003	43.97
	2	41232	43.52
	3	31729	42.66
B1	1	44116	40.29
	2	43625	39.65
	3	20025	38.96
F2	1	43727	39.77
	2	43167	39.15
	3	20467	38.07
F1	1	41942	40.00
	2	41390	39.45
	3	31598	38.86

Table 3: *Energy averages before calibration for good assignments of fill 3029.*

The reason why minibunch 3 events in modules B2 and F2 are assigned minibunch number 2 comes from the fact that they have too high energy. The mechanism of the wrong assignment is shown in fig. 3.

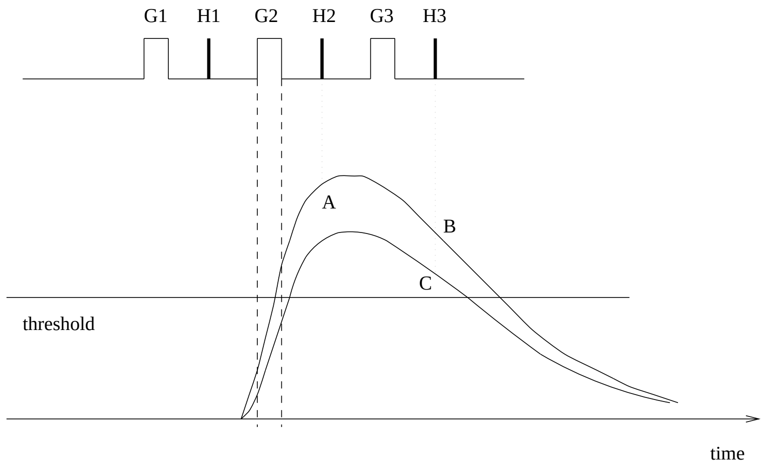

Figure 3: *Mismatched high energy event of minibunch 3.*

A low energy pulse is above threshold during gate G3, thus being assigned the correct minibunch number. The energy is read out at C when the corresponding hold is given. The high energy pulse, however, is above threshold during gate G2 as well, which will assign a minibunch number 2 to the event. The pulse height taken as the bhabha energy will then be that at point A instead of point B, which shifts the spectrum of the mismatches to higher energies. The minibunch 3 spectrum is thus split into two distributions (fig. 4).

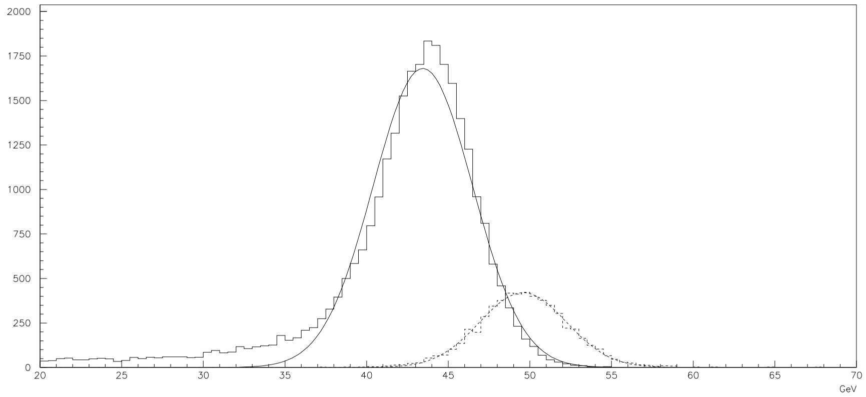

Figure 4: *Mismatched high energy events (dashed line) and remaining spectrum (full line) of minibunch 3 in module B2 at peak+2 before calibration.*

For calibration purposes, a gaussian fit to the energy distribution is normally done (as in fig. 4) and the average of the fit is used to calculate the calibration constant. However, this is not possible in the case of fig. 4 because both distributions have averages which have been shifted to lower energies (full line) or higher energies (dashed line). In the following sections we will describe a method to extract calibration constants for the two spectra. The rest of the mismatches of table 2 are not dealt with in this report.

2 Equidistant distributions

We have to calibrate pairs of distributions at three nominal energies and for two different modules (B2, F2). Furthermore, as was already mentioned, we have to split the analysis into two periods (before and after fill 3000) because of the radiation accident. In the following, we will examine the spectra of module B2 at peak+2 before the accident.

The first assumption that was checked was that the distributions of subsequent minibunch numbers should have equidistant averages [4]. Let g_1, g_2 and g_3 be the gaussian fit averages of the minibunch 1, 2 and 3 spectra, accordingly. What we expect to see in the uncalibrated data is that g_2-g_3 will be greater than g_1-g_2 because the minibunch 3 distribution has lost its high energy tail (fig. 5a).

Under the assumption of equidistant distributions, a suitable calibration constant for the minibunch 3 spectrum would be $g = \frac{enom}{2g_2 - g_1}$. The calibration constant of the mismatched distribution was taken to be $b = \frac{enom}{(2g_2 - g_1) * shift}$, where shift is greater than one. The way we determine the value of shift is described in Appendix A. The averages of the total calibrated distribution are plotted versus fill in fig. 5b. It is evident that this assumption cannot give acceptable results. Since no other assumption can be made about the value of the calibration constant, it will be taken as $g = \frac{enom}{g_3 + step}$, where step is a positive quantity to be determined. The above analysis was however useful in the sense that it determined the lower limit for step, $(2g_2 - g_1) - g_3$. The upper limit should clearly be $g_2 - g_3$. These values are given in table 4.

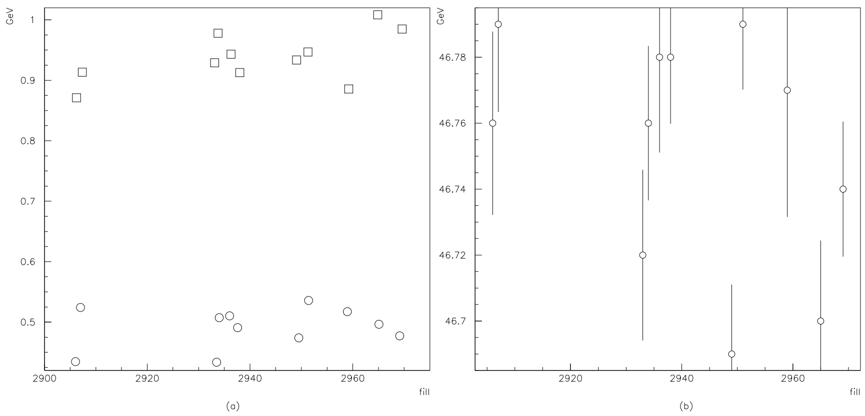

Figure 5: *(a) Differences of uncalibrated averages: minibunch 1 - minibunch 2 (circles) and minibunch 2 - minibunch 3 (squares); (b) Calibrated average values of minibunch 3 spectra at peak+2 under the assumption of equidistant distributions.*

fill	g_2-g_3	$(2g_2$-$g_1)$-g_3
2906	.87600	.44100
2907	.91600	.39000
2933	.92500	.49001
2934	.97200	.46300
2936	.94700	.43400
2938	.91300	.42599
2949	.93300	.46100
2951	.94500	.41000
2959	.88600	.36600
2965	1.0100	.51400
2969	.98700	.51100

Table 4: *Limits for step.*

3 Assumption of constant step

We now examine the possibility of adding a constant factor to g_3 in order to calculate the calibration constant. As an example, we try 15 different values for step to calibrate fill 2951. For each of these values, we determine the value of shift (see Appendix A) and thereafter the (calibrated) averages of the minibunch 3 distribution, $< 3 >$, mismatch distribution, $< mism >$, total distribution, $< 3{+}mism >$, and all minibunch distribution, $< mod >$. From the results we choose step = 0.695 GeV. We then calibrate the rest of the fills with calibration constant $g = \frac{enom}{g_3+0.695}$. The results are given in table 5.
The nominal energy for all fills is 46.51 GeV apart from fill 2965 (46.50 GeV)[2] .From table 2, we see that two fills (2949 and 2959) have $< 3 + mism >$ outside one standard deviation. A fit by a constant to the $< 3{+}mism >$ and $< mod >$ versus fill distributions

[2]We assume an error of 3 MeV for the nominal energies.

fill	shift	$<3>$ GeV	$<mism>$ GeV	$<3+mism>$ GeV	$<mod>$ GeV	per. %
2906	1.0378	45.770 ± .027	50.304 ± .050	46.517 ± .028	46.507 ± .015	16.93
2907	1.0411	45.773 ± .026	50.157 ± .049	46.487 ± .027	46.502 ± .013	16.61
2933	1.0399	45.776 ± .024	50.293 ± .046	46.503 ± .026	46.502 ± .014	16.74
2934	1.0424	45.768 ± .022	50.249 ± .041	46.516 ± .023	46.507 ± .012	17.21
2936	1.0411	45.774 ± .027	50.307 ± .052	46.520 ± .029	46.507 ± .015	17.12
2938	1.0436	45.773 ± .019	50.176 ± .036	46.490 ± .020	46.501 ± .011	16.73
2949	1.0446	45.770 ± .021	49.934 ± .040	46.470 ± .021	46.493 ± .012	16.95
2951	1.0399	45.768 ± .019	50.237 ± .036	46.512 ± .020	46.507 ± .011	16.84
2959	1.0296	45.773 ± .037	50.725 ± .075	46.516 ± .040	46.505 ± .019	16.28
2965	1.0423	45.764 ± .024	50.173 ± .043	46.524 ± .024	46.502 ± .012	17.30
2969	1.0394	45.774 ± .020	50.287 ± .036	46.567 ± .021	46.524 ± .010	17.95

Table 5: *Calibration results for step = 0.695 GeV.*

gives[3]:

$$<3+mism>= (46.511 \pm .007)\ GeV,\ \chi^2 = 1.341,\ CL = .99935$$

$$<mod>= (46.506 \pm .004)\ GeV,\ \chi^2 = .4934,\ CL = .99999$$

In the last column of table 5 we give the percentage of mismatched events. If we compare $<3+mism>$ with the nominal energy and the percentage of the fill in question with 16.84 %, we observe that we would need a greater step for fills with greater percentage and a smaller step for fills with smaller percentage (fills 2949 and 2959 do not agree with such a behaviour). This leads to the assumption of a increasing relation between step and percentage, which will concern us in the next section.

4 Dependence of step on mismatch percentage

We repeat the step determination procedure we have followed for fill 2951 (see previous section) for another four fills: 2934, 2969, 2938 and 2959. We plot the steps we find versus the mismatch percentage in fig. 6 , where we have chosen to do a linear fit for simplicity. According to the fit, there should exist the following relation between step (in GeV) and mismatch percentage

$$step = 0.017235 \cdot percentage + 0.40577 \tag{1}$$

We apply eq. (1) to calculate steps and averages for all eleven fills (fig. 7).
The results seem to be better than those of a constant step, since only fill 2949 is now outside one standard deviation. A fit by a constant to the $<3+mism>$ and $<mod>$ versus fill distributions now gives:

$$<3+mism>= (46.502 \pm .007)\ GeV,\ \chi^2 = .9693,\ CL = .99985$$

$$<mod>= (46.503 \pm .004)\ GeV,\ \chi^2 = .3538,\ CL = .99999$$

[3]For confidence level estimations, see Appendix C

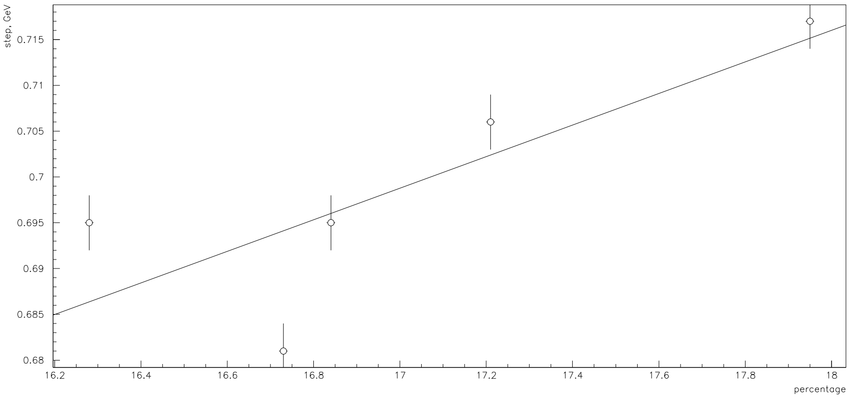

Figure 6: *An increase in the percentage of mismatched events would reduce the average of the remaining minibunch 3 distribution thus requiring a greater step to compensate for it; we assume that the relation is linear.*

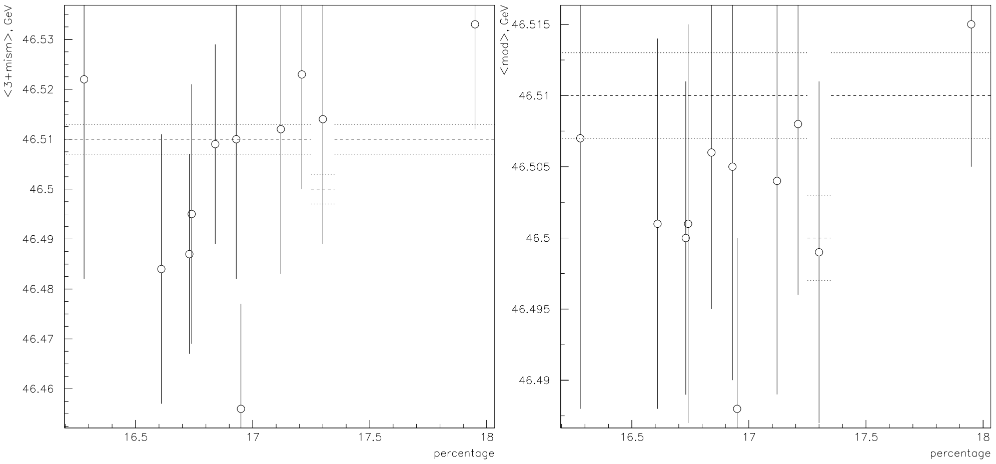

Figure 7: *Calibrated averages of total minibunch 3 distribution and all minibunch distribution; the steps are calculated from a fit to five data points.*

5 Check of linear relation assumption

The fit in fig. 6 has confidence level .04394 so we need another check for the relation between step and percentage. Eq. (1) gives for fill 2951:

$$step = .6960\ GeV,\ shift = 1.0406$$

$$< 3 + mism >= (46.509 \pm .020)\ GeV,\ < mod >= (46.506 \pm .011)\ GeV$$

We 'calibrate' the minibunch 3 and the mismatch distribution according to these values of step and shift and then we add them to obtain the uncalibrated total minibunch 3 distribution (see gauss.kumac, Appendix B). The average and σ of that distribution are:

$$emean = 44.494\ GeV,\ sigma = 3.066\ GeV.$$

We introduce these values in a program (see Appendix B) which assumes that above a certain energy threshold the events are assigned minibunch number two. We vary the value of the threshold so that we will cover a mismatch percentage range from 16% to 18% . For each value of threshold, we then calculate the step required and the mismatch percentage. In total, we obtained 31 values, which are plotted in fig. 8. The fit gives the

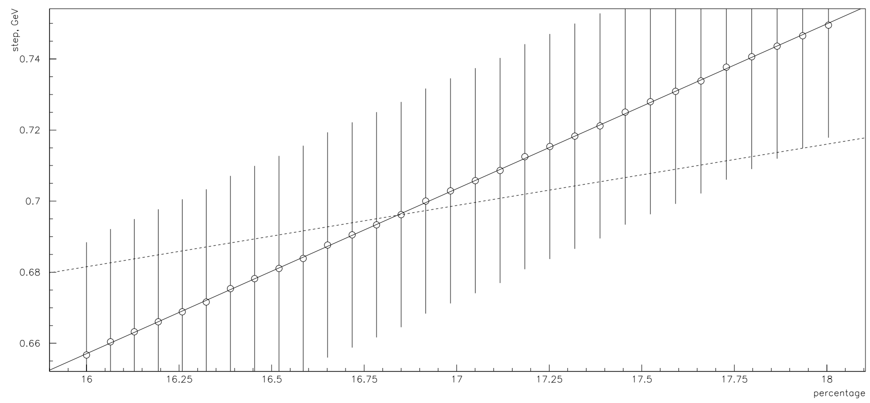

Figure 8: *Prediction for the step-percentage relation (full line); the line of fig. 6 (fit to five data points) is shown dashed.*

following equation:

$$step = 0.046383 \cdot percentage - 0.085046 \qquad (2)$$

and confirms the assumption of linear relation with $\chi^2 = .9161 \cdot 10^{-4}$.

The purpose of the program was to look for a relation between step and percentage and it was not meant to provide calibration constants. However, we have applied eq. (2) for calibration, mostly as a cross check. The results are shown in fig. 9. The fits by a constant now give us:

$$< 3 + mism >= (46.495 \pm .007)\ GeV,\ \chi^2 = 1.044,\ CL = .99979$$

$$< mod >= (46.501 \pm .004)\ GeV,\ \chi^2 = 0.3622,\ CL = .99999$$

We note that the use of eq. (1) to calculate step and shift values to be used in gauss.kumac does not induce any restrictions on the output of the program. Any values which give reasonable results for $< 3 + mism >$ and $< mod >$ could have been used, as has been the case during the analysis.

6 Conclusion

The same procedure as above has been followed for the 9 fills at peak+2 after the accident. In fig. 10 we plot the average values of the total minibunch 3 distribution for the data fit

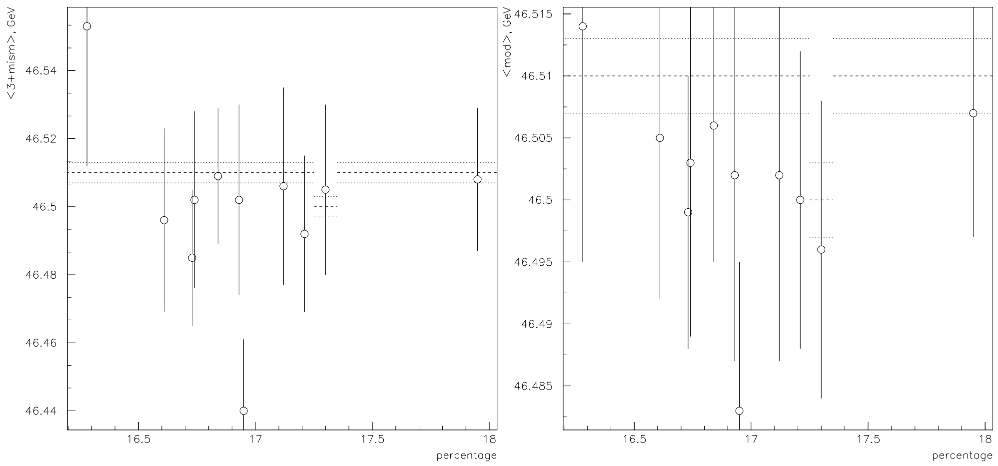

Figure 9: *Calibrated averages of total minibunch 3 distribution and all minibunch distribution; the steps are calculated from a program.*

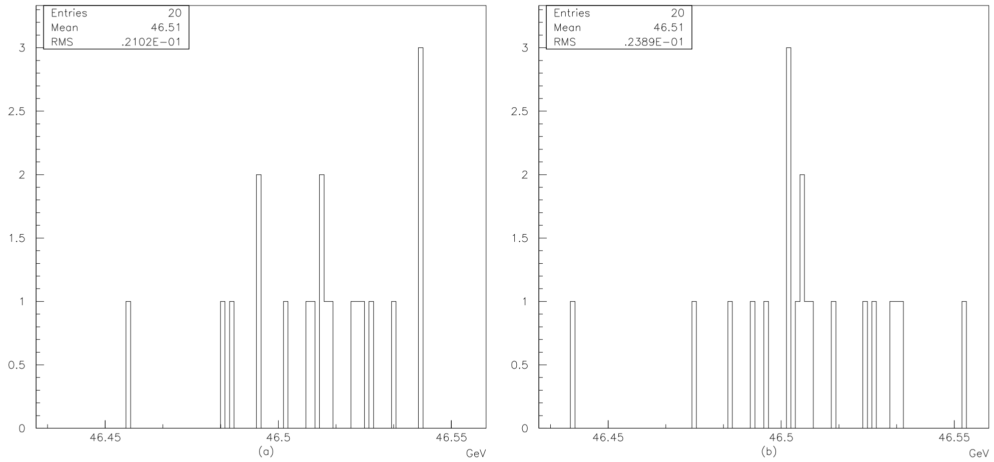

Figure 10: *Calibrated averages of total minibunch 3 distribution for calibration from fit (a) to data points, (b) to program points.*

calibration and for the program calibration for all 20 fills at peak+2 (module B2). We see that the two distributions have a similar spread.

A A minimum χ^2 method for shift determination

❧ **Step 1:** For each value of minibunch 3 calibration constant, g, we calibrate the mismatched distribution by using the calibration constant $b = \frac{g}{shift}$, where shift should be greater than one, since the mismatch distribution comes from the high energy tail of the total minibunch 3 distribution. The shift-1 values are written in the file e.kumac.

```
*------------------------------------------------------------------------------
*
* File: ~/calp2b/e.kumac
* Purpose: calls test71102 for 20 values of shift-1
* Input: [1] = fill number
* Parameters: none
* Created: 25 mar 96 - Ch. Jarlskog
*
*------------------------------------------------------------------------------
 macro e

   exec test71102 [1] .1
   exec test71102 [1] .095
   exec test71102 [1] .09
   exec test71102 [1] .085
   exec test71102 [1] .08
   exec test71102 [1] .075
   exec test71102 [1] .07
   exec test71102 [1] .065
   exec test71102 [1] .06
   exec test71102 [1] .055
   exec test71102 [1] .05
   exec test71102 [1] .045
   exec test71102 [1] .04
   exec test71102 [1] .035
   exec test71102 [1] .03
   exec test71102 [1] .025
   exec test71102 [1] .02
   exec test71102 [1] .015
   exec test71102 [1] .01
   exec test71102 [1] .005

   return
*------------------------------------------------------------------------------
```

❧ **Step 2:** Upon execution of e.kumac, the macro test71102 is called. It reads the averages of the (uncalibrated) ditributions of minibunches 1, 2 and 3 from text files and opens the histogram file ecal_fill_b.out, which includes them. The histograms have 100 bins of width .5 GeV and they range from 20 GeV to 70 GeV. At this stage we cannot calibrate event by event (as in the off-line programs), so we proceed as follows: the contents of the histograms are read into vectors and then written in text files. These files are used as input for the subroutines shift1.f and shift2.f, which will be described in the following steps. New histograms (1, 2, 3) are booked to be the calibrated spectra of the the old ones (61101, 61102 and 61103, respectively). The new histograms have the same binning but a wider energy range (from 0 to 100 GeV). The calibration constants are then calculated for the three minibunches of module B2: cb21, cb22 and cb23 and shift1.f is called to calibrate the three spectra. The mismatch distribution is calibrated by a call to shift2.f.

```
*-------------------------------------------------------------------------
*
* File: ~/calp2b/test71102.kumac
* Purpose: calibration of mb 1, 2, 3, mismatch distr. of module B2.
* Input: [1] = fill number, [2] = shift-1
* Parameters: g1* = gaussian fit average of uncalibrated mb * distr.
*             ebeam = nominal energy
* Created: 25 feb 96 - Ch. Jarlskog
*
*-------------------------------------------------------------------------

 macro test71102

  vec/create fill(3042)
  vec/create ebeam(3042)
  vec/create g11(3042)
  vec/create g12(3042)
  vec/create g13(3042)

  vector/read ebeam '.ebeam.txt' ! ! !
  vector/read g11 '.g11.txt' ! ! !
  vector/read g12 '.g12.txt' ! ! !
  vector/read g13 '.g13.txt' ! ! !

  opt stat
  opt fit

  close 1
  hi/file 1 ecal_[1]_b.out


*         GOOD ASSIGNMENTS


* 61101 (minibunch 1 distribution)

  vec/create one(100)
  hist/get_vect/contents 61101 one
  vec/write one 'one.txt' '100(1x,i10/)'
  hi/del 1
```

```
  1d 1 ' 61101 calibrated' 200 0. 100.
  cb21 = ebeam([1])/g11([1])
  call shift1.f(1,[cb21])

* 61102 (minibunch 2 distribution)

  vec/create two(100)
  hist/get_vect/contents 61102 two
  vec/write two 'two.txt' '100(1x,i10/)'
  hi/del 2
  1d 2 ' 61102 calibrated' 200 0. 100.
  cb22 = ebeam([1])/g12([1])
  call shift1.f(2,[cb22])

* 61103 (remaining minbunch 3 distribution)

  vec/create three(100)
  hist/get_vect/contents 61103 three
  vec/write three 'three.txt' '100(1x,i10/)'
  hi/del 3
  1d 3 ' 61103 calibrated' 200 0. 100.
* cb23 = ebeam([1])/( 2*g12([1])-g11([1]) )
  cb23 = ebeam([1])/( g13([1])+0.695 )
  call shift1.f(3,[cb23])


*                    BAD ASSIGNMENTS


* 71102 (mismatch distribution)

  vec/create fifteen(100)
  hist/get_vect/contents 71102 fifteen
  vec/write fifteen 'fifteen.txt' '100(1x,i10/)'
  call shift2.f(15,3,[cb23],[2],[1])
  zone 1 2
  hi/pl 9000
  hi/pl 10000 s
  hi/pl 3 s
  hi/pl 2000
  selnt 1
  itx 15 10 [2]
  itx 15 9 [cb23]
  return

*-------------------------------------------------------------------------
```

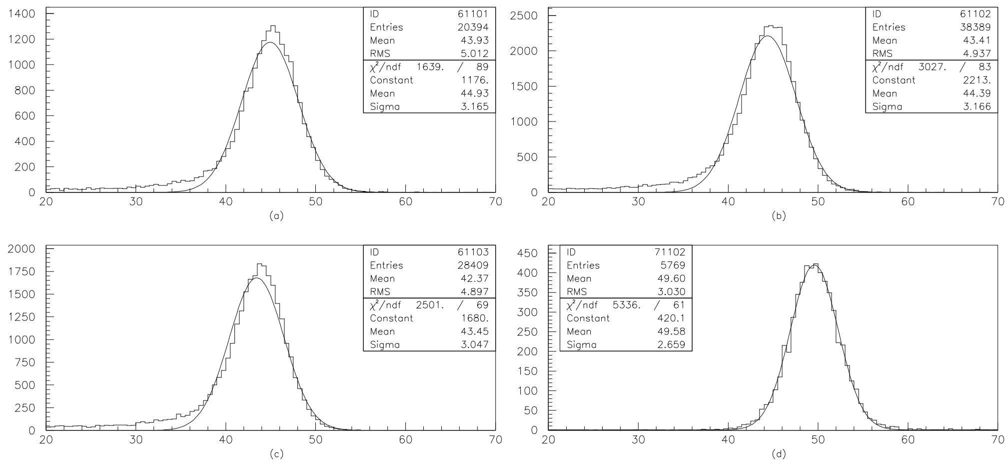

Figure 11: *Uncalibrated energy distributions (fill 2951) for (a) good assignment minibunch 1, (b) good assignment minibunch 2, (c) good assignment minibunch 3 and (d) mismatched events of minibunch 3.*

❧ **Step 3:** From each channel of the uncalibrated spectra 10 new ones are created, containing one tenth of the content of the original channel. This procedure is used as a substitute for the event by event calibration. We 'fill' the first new channel in the middle, i.e. at energy 20+(.5/10)/2 GeV= 20.025 GeV. The next channel will be 'filled' at (20.025+.05) GeV, since .05 GeV is the new binning and so on. These energy values (of the middle of the new channels) are calibrated by being multiplied by the calibration constant. The 1000 entries are then filled into the new histogram, which is thought of as the calibrated distribution.

```
*-----------------------------------------------------------------------
*
* File: ~/calp2b/shift1.f
* Purpose: calibrates the minibunch 1, 2 and 3 distributions
* Input: id = id of the calibrated histogram to be filled
*        cal = calibration constant required
* Parameters: enecor = uncalibrated energy
*             enecal = calibrated energy
*             content = contents of uncalibrated distributions
*             cont = contents of calibrated distributions
* Created: 26 feb 96 - Ch. Jarlskog
*
*-----------------------------------------------------------------------

        subroutine shift1(id,cal)

        dimension content(100),enecor(1000),enecal(1000)
        dimension cont(1000)
```

```
if (id.eq.1) open(1,file='one.txt',status='old')
if (id.eq.2) open(1,file='two.txt',status='old')
if (id.eq.3) open(1,file='three.txt',status='old')
if (id.eq.4) open(1,file='four.txt',status='old')
if (id.eq.5) open(1,file='five.txt',status='old')
if (id.eq.6) open(1,file='six.txt',status='old')
if (id.eq.7) open(1,file='seven.txt',status='old')
if (id.eq.8) open(1,file='eight.txt',status='old')
if (id.eq.9) open(1,file='nine.txt',status='old')
if (id.eq.10) open(1,file='ten.txt',status='old')
if (id.eq.11) open(1,file='eleven.txt',status='old')
if (id.eq.12) open(1,file='twelve.txt',status='old')
if (id.eq.13) open(1,file='thirteen.txt',status='old')
if (id.eq.14) open(1,file='fourteen.txt',status='old')
if (id.eq.16) open(1,file='sixteen.txt',status='old')
if (id.eq.17) open(1,file='seventeen.txt',status='old')
if (id.eq.18) open(1,file='eighteen.txt',status='old')
if (id.eq.19) open(1,file='nineteen.txt',status='old')
if (id.eq.20) open(1,file='twenty.txt',status='old')
if (id.eq.21) open(1,file='twentyone.txt',status='old')
if (id.eq.22) open(1,file='twentytwo.txt',status='old')
if (id.eq.23) open(1,file='twentythree.txt',status='old')
if (id.eq.24) open(1,file='twentyfour.txt',status='old')
if (id.eq.25) open(1,file='twentyfive.txt',status='old')
if (id.eq.26) open(1,file='twentysix.txt',status='old')
if (id.eq.27) open(1,file='twentyseven.txt',status='old')
if (id.eq.28) open(1,file='twentyeight.txt',status='old')
if (id.eq.29) open(1,file='twentynine.txt',status='old')
if (id.eq.30) open(1,file='thirty.txt',status='old')
if (id.eq.32) open(1,file='thirtytwo.txt',status='old')
if (id.eq.33) open(1,file='thirtythree.txt',status='old')
if (id.eq.34) open(1,file='thirtyfour.txt',status='old')
if (id.eq.35) open(1,file='thirtyfive.txt',status='old')
if (id.eq.36) open(1,file='thirtysix.txt',status='old')
if (id.eq.37) open(1,file='thirtyseven.txt',status='old')
if (id.eq.38) open(1,file='thirtyeight.txt',status='old')
if (id.eq.39) open(1,file='thirtynine.txt',status='old')
if (id.eq.40) open(1,file='fourty.txt',status='old')
if (id.eq.41) open(1,file='fourtyone.txt',status='old')
if (id.eq.42) open(1,file='fourtytwo.txt',status='old')
if (id.eq.43) open(1,file='fourtythree.txt',status='old')
if (id.eq.44) open(1,file='fourtyfour.txt',status='old')

do 10 i=1,100
  read(1,11) content(i)
  cont(i*10)=content(i)/10
  cont(i*10-1)=content(i)/10
```

```
          cont(i*10-2)=content(i)/10
          cont(i*10-3)=content(i)/10
          cont(i*10-4)=content(i)/10
          cont(i*10-5)=content(i)/10
          cont(i*10-6)=content(i)/10
          cont(i*10-7)=content(i)/10
          cont(i*10-8)=content(i)/10
          cont(i*10-9)=content(i)/10
 10     continue
 11     format(1x,i10)

        enecor(1) = 20.025
        enecal(1) = 20.025*cal

        do 20 i=2,1000
          enecor(i) = enecor(i-1)+.05
          enecal(i) = enecor(i)*cal
 20     continue

        do 30 i=1,1000
         call hfill(id,enecal(i),0.,cont(i))
 30     continue

        end
*-----------------------------------------------------------------------
```

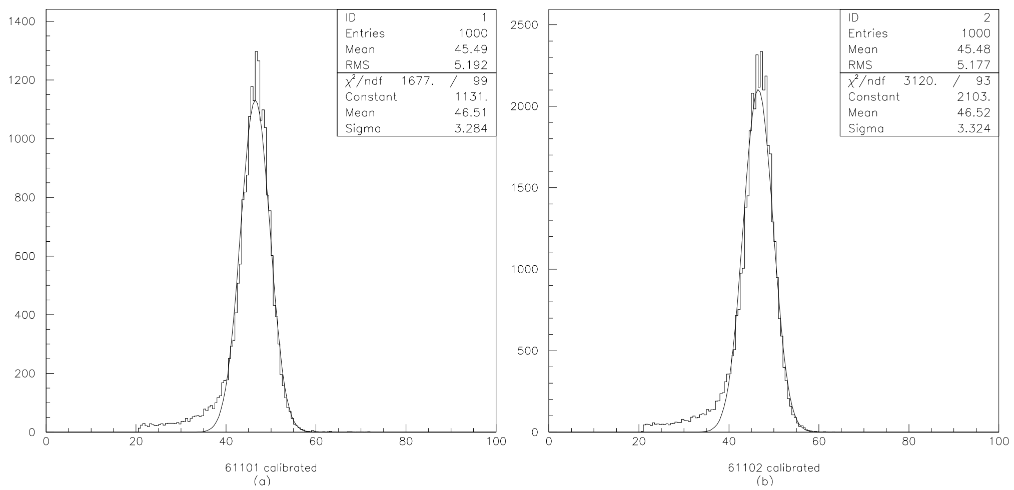

Figure 12: *Calibrated energy distributions (fill 2951) for (a) good assignment minibunch 1 and (b) good assignment minibunch 2.*

➢ **Step 4:** We calibrate the mismatch spectrum in the same way as we did for minibunches 1, 2 and 3. The id of the calibrated distribution is newid = 10000. The calibration constant is $b = g/shift = cal/shift$ called also cal in the program. The sum of the mismatch and minibunch 3 (calibrated) distributions has idsum = 9000. A restricted version of this plot is given in histogram 2000, which does not include the first 80 channels of 9000, i.e. it starts at $80 \cdot .5$ GeV= 40 GeV. The next step is to do a gaussian fit to 9000 and 2000 and to write the values of their averages and χ^2's in the file 'statistics' (together with the value of shift).

```
*------------------------------------------------------------------------
*
* File: ~/calp2b/shift2.f
* Purpose: calibrates the distribution of mismatched events
* Input: id = index specifying the module (15 = B2, 31 = F2)
*        idgood = id of the mb 3 (remaining) calibrated spectrum
*        cal = calibration constant for minibunch 3
*              the same name is used for the mismatch cal. constant
*        xstep = shift-1
*        ifill = fill number
* Parameters: enecor = uncalibrated energy
*             enecal = calibrated energy
*             content = contents of uncalibrated distributions
*             cont = contents of calibrated distributions
* Created: 28 feb 96 - Ch. Jarlskog
*
*------------------------------------------------------------------------

        subroutine shift2(id,idgood,cal,xstep,ifill)

        dimension content(100),enecor(1000),enecal(1000)
        dimension cont(1000)
        dimension utor1(300),utor2(300),var(300),err(300)
        dimension varnew(300),errnew(300)

        if (id.eq.15) open(1,file='fifteen.txt',status='old')
        if (id.eq.31) open(1,file='thirtyone.txt',status='old')
        open(2,file='statistics',status='unknown')
        open(3,file='check',status='unknown')

        do 10 i=1,100
          read(1,11) content(i)
          cont(i*10)=content(i)/10
          cont(i*10-1)=content(i)/10
          cont(i*10-2)=content(i)/10
          cont(i*10-3)=content(i)/10
          cont(i*10-4)=content(i)/10
          cont(i*10-5)=content(i)/10
          cont(i*10-6)=content(i)/10
          cont(i*10-7)=content(i)/10
```

```
          cont(i*10-8)=content(i)/10
          cont(i*10-9)=content(i)/10
  10    continue
  11    format(1x,i10)

         shift = 1.+xstep
         newid = 10000
         idsum = 9000

* use following command when running test71102.kumac
         cal = cal/shift
* use following command when running gauss.kumac
*        cal = 45.934/49.583

        call hdelet(newid)
        call hdelet(idsum)
        call hbook1(newid,'71102/71302 calibrated',200,0.,100.,0.)
        call hbook1(idsum,'sum of 71102/71302 and 3/9',200,0.,100.,0.)
        call hbook1(2000,'sum of 71102/71302 and 3/9 (restr.)'
     &              ,28,40.,54.,0.)

        enecor(1) = 20.025
        enecal(1) = 20.025*cal

        do 20 i=2,1000
          enecor(i) = enecor(i-1)+.05
          enecal(i) = enecor(i)*cal
  20    continue

        do 30 i=1,1000
         call hfill(newid,enecal(i),0.,cont(i))
  30    continue

c------------- add the histograms

        do 31 i=1,300
           utor1(i) = 0.
           utor2(i) = 0.
           var(i) = 0.
           varnew(i) = 0.
           err(i) = 0.
           errnew(i) = 0.
  31    continue

        call hunpak(idgood,utor1,' ',0)
        call hunpak(newid,utor2,' ',0)
        do 32 i=1,200
```

```
          var(i)=utor1(i)+utor2(i)
          varnew(i) = utor1(i+80)+utor2(i+80)
          err(i)=sqrt(utor1(i)+utor2(i))
          errnew(i)=sqrt(utor1(i+80)+utor2(i+80))
 32     continue
        call hpak(idsum,var)
        call hpak(2000,varnew)
        call hpake(idsum,err)
        call hpake(2000,errnew)

c------------- do the fit
        call hfitga(idsum,height,aver,sd,chi2,2,sig)
        call hfitga(2000,height,aver2,sd2,chi22,2,sig2)
        write(2,40) shift,aver,chi2,aver2,chi22
        write(3,45) ifill,aver,sd
 35    CONTINUE
 40    format(1x,f10.5,2(1x,f10.6,1x,f15.8))
 45    format(1x,i4,1x,2f15.8)
        end

*---------------------------------------------------------------------
```

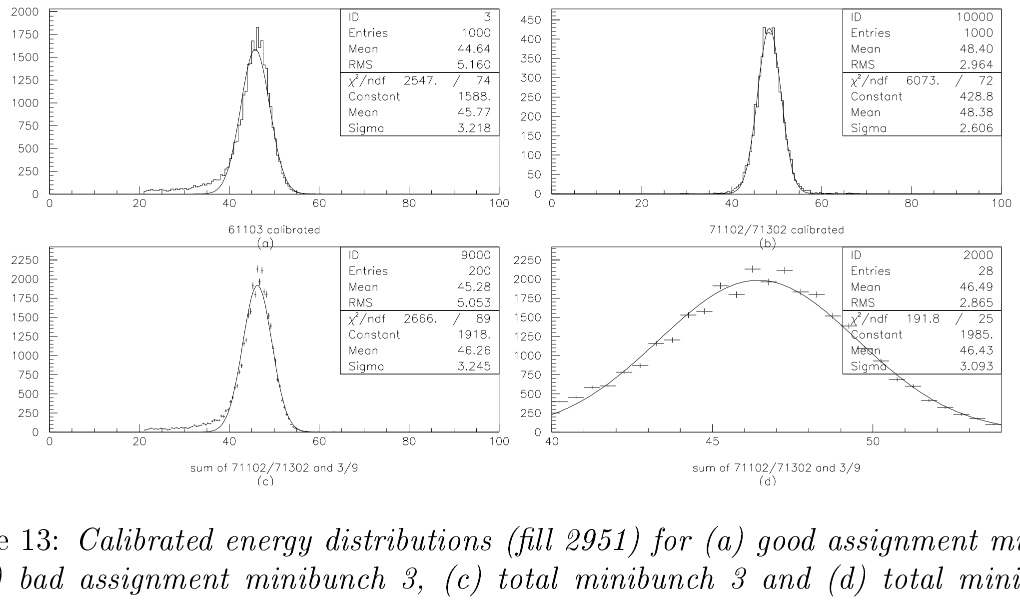

Figure 13: *Calibrated energy distributions (fill 2951) for (a) good assignment minibunch 3, (b) bad assignment minibunch 3, (c) total minibunch 3 and (d) total minibunch 3 restricted (step=0.695 GeV, shift=1.08).*

Step 5: The twenty values of shift and of average and χ^2 of the fit of histogram 2000 are read from the file statistics. Two new histograms are filled: the distribution of χ^2 versus shift and the distribution of (average - nominal energy) versus shift. A fit of third degree polynomial is then done to the χ^2 versus shift distribution. From the parameters of the fit, we calculate the value of shift at which the fit has a minimum. The minimum

χ^2 is supposed to signify that the minibunch 3 and mismatch spectra have been calibrated and fitted together in the best possible way [5].

```
*------------------------------------------------------------------------
*
* File: ~/calp2b/makehisto_peakp2.f
* Purpose: calculates the optimum shift value, r
* Input: none
* Parameters: none
* Created: 28 feb 96 - Ch. Jarlskog
*
*------------------------------------------------------------------------

          subroutine makehisto_peakp2

          dimension par(4),step(4),pmin(4),pmax(4),sigpar(4)
          dimension shift(20),chi22(20),energy(20)

          open(1,file='statistics',status='old')

          do 5 i=1,20
            read(1,7) shift(i),energy(i),chi22(i)
            energy(i)=energy(i)-46.51
  5       continue
  7       format(1x,f10.5,1x,f10.6,30x,f13.8)

          call hbook1(100,'71102+3, chi2 versus shift',20,1.0,
     &    1.105,0.)
          call hbook1(200,'71102+3, energy versus shift',20,1.0,
     &    1.105,0.)

          do 10 i=1,20
            call hfill(100,shift(i),0.,chi22(i))
            call hfill(200,shift(i),0.,energy(i))
  10      continue

       call hfithn(100,'p3',' ',3,par,step,pmin,pmax,sigpar,chi2)

       a=par(3)**2-3*par(4)*par(2)
       b=3*par(4)
       r=(-par(3)+sqrt(a))/b
       da=-1/b+a**(-.5)*par(3)/b
       db=3*par(3)/b**2-.5*a**(-.5)*par(2)/par(4)-r/par(4)
       dc=-.5*a**(-.5)
       dr=sqrt((da*sigpar(3))**2+(db*sigpar(4))**2+(dc*sigpar(2))**2)
       write(*,*) 'shift = ',r
       write(*,*) 'with error = ',dr
```

```
       close(1)
       end

*-----------------------------------------------------------------------
```

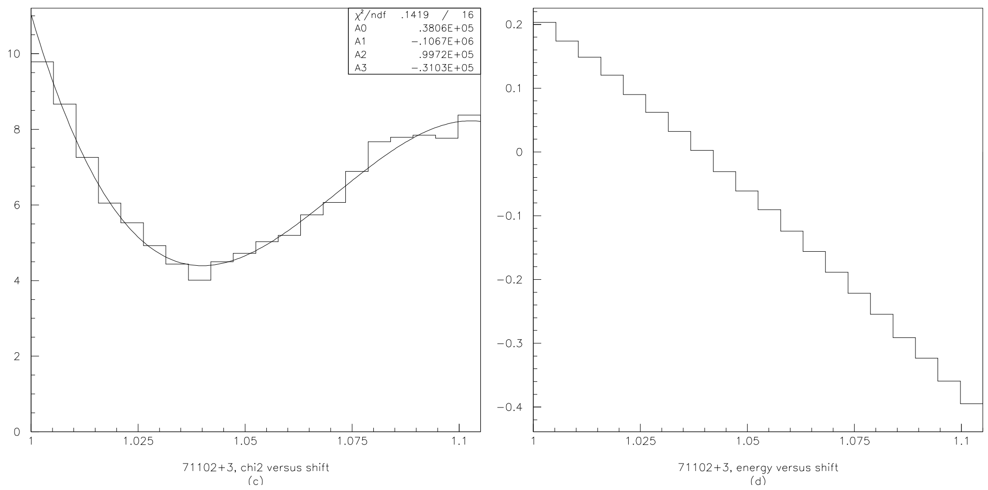

Figure 14: *(a) χ^2 vs shift distribution and p3 fit and (b) (calibrated average energy - beam energy) vs shift for step=0.695 GeV and 20 values of shift (fill 2951). The shift value at the minimum is 1.0399.*

❧ **Step 6:** The results are checked by plotting all calibrated distributions to note their (average ± error) and see whether the nominal energy is within one standard deviation. If not, a new value for the calibration constant of minibunch 3 spectrum should be found.

```
*-----------------------------------------------------------------------
*
* File: ~/calp2b/exe.kumac
* Purpose: prints calibrated distributions
* Input: [1] = fill number
*        [2] = (optimum) shift - 1
* Parameters: none
* Created: 5 mar 96 - Ch. Jarlskog
*
*-----------------------------------------------------------------------

macro exe

exe test71102 [1] [2]
hi/fit 9000 g
wait
hi/fit 3 g
```

```
wait
hi/fit 10000 g
wait
hi/fit 1 g
 wait
 hi/fit 2 g
wait
hi/oper/add 1 2 90
hi/oper/add 9000 90 9
hi/fit 9 g

return

*----------------------------------------------------------------
```

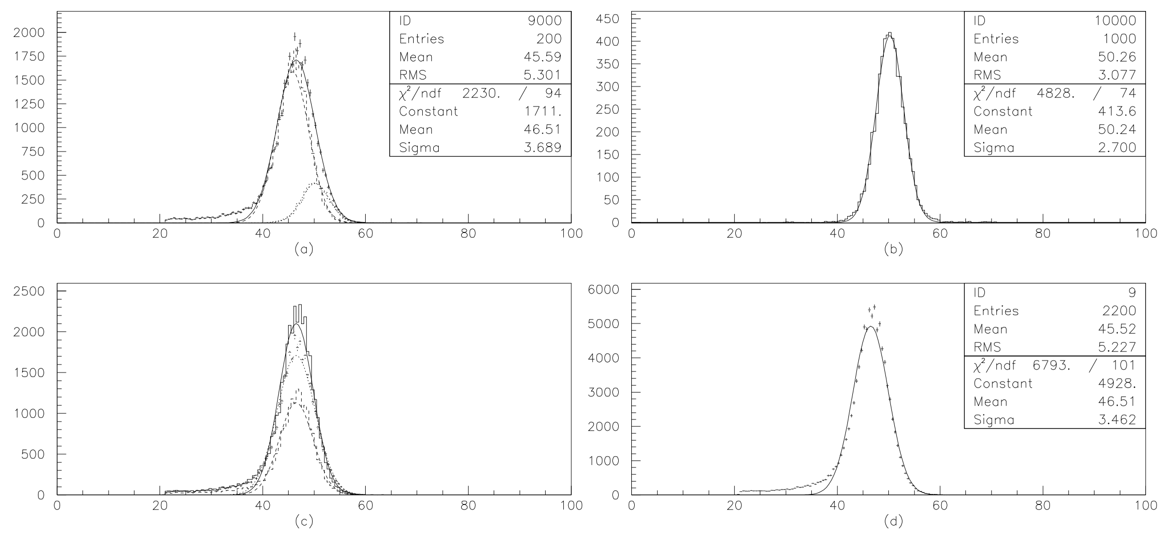

Figure 15: *Calibrated distributions for fill 2951, step=0.695 GeV and shift=1.0399: (a) total minibunch 3 spectrum (full line), good assignment minibunch 3 spectrum (dashed line) and mismatched minibunch 3 events (dotted line); (b) mismatched minibunch 3 events; (c) good assignment minibunch 2 spectrum (full line), good assignment minibunch 1 spectrum (dashed line) and total minibunch 3 spectrum (dotted line); (d) the sum of the distributions in (c).*

B Investigation of step-percentage relation

```
*-----------------------------------------------------------------------
*
* File: ~/calp2b/gauss.kumac
* Purpose: Reconstruction of total mb 3 spectrum before the tail mismatch
* Input: [1] = fill number
* Parameters: none
* Created: 25 mar 96 - Ch. Jarlskog
*
*-----------------------------------------------------------------------

 macro gauss

* copy of test71102.kumac
  opt stat
  opt fit
  close 1
  hi/file 1 ecal_[1]_b.out

*         GOOD ASSIGNMENTS

* 61103
  vec/create three(100)
  hist/get_vect/contents 61103 three
  vec/write three 'three.txt' '100(1x,i10/)'
  hi/del 3
  1d 3 ' 61103 calibrated' 200 0. 100.
  cb23 = 44.142/43.446
  call shift1.f(3,[cb23])

*                    BAD ASSIGNMENTS

* 71102
  vec/create fifteen(100)
  hist/get_vect/contents 71102 fifteen
  vec/write fifteen 'fifteen.txt' '100(1x,i10/)'
  call shift2.f(15,3,[cb23],.0,[1])
  zone 1 2
  hi/pl 9000
  hi/pl 10000 s
  hi/pl 3 s
  hi/pl 2000

 return

*-----------------------------------------------------------------------
```

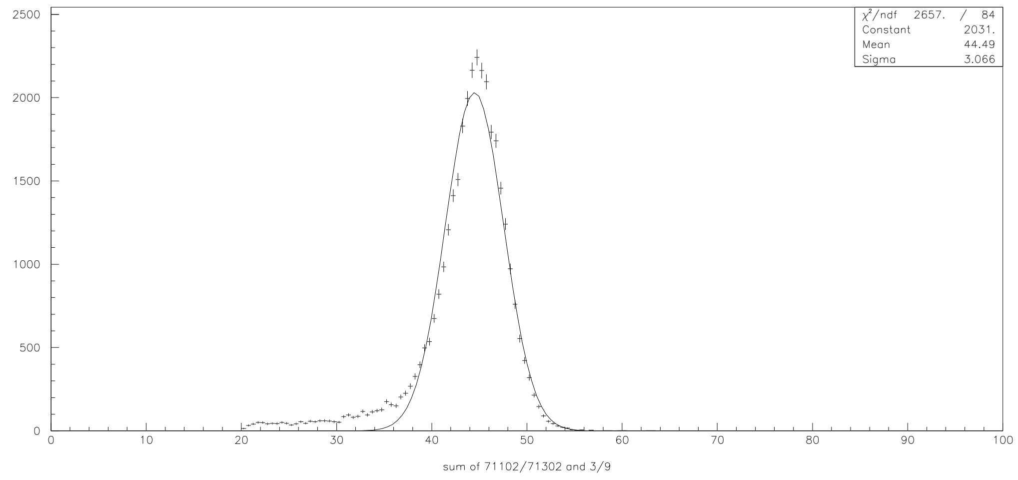

Figure 16: *Output of gauss.kumac for fill 2951: uncalibrated total minibunch 3 spectrum before the tail was assigned minibunch number 2.*

```
C===========================================================================
C
C      This program is looking for a relation between mismatch
C      percentage and step in calibration constant for the high
C      energy events of minibunch 3, module B2.
C
C      Author: Christina Jarlskog              Created: 12-Apr-96
C      Last modif.: 16-Apr-96
C
C===========================================================================

      PROGRAM GAUSS

      DOUBLE PRECISION A,B,RELTOL,ABSTOL,EVTOT,ERR,
     &                 F,SIGMA,EMEAN,FMEAN,MEANTOT,ERRM,
     &                 TOTNUM
      COMMON /PARAM/EMEAN,SIGMA,TOTNUM
      COMMON /INTEG/A,B,NSEG,RELTOL,ABSTOL
      EXTERNAL F
      EXTERNAL FMEAN

C-- Fit parameters corresponding to real data mb 3 complete spectrum

c    a) module B2, peak+2, before accident (fill 2951)

      SIGMA = 3.066
      EMEAN = 44.494
      TOTNUM = 33869.
```

```
C-- Integration limits and AGQ parameters

      A = 20.
      B = 70.

      NSEG = 1000
      RELTOL = .0000001
      ABSTOL = .000001

C-- Calculate number of bhabhas and average of total distribution

      CALL DADAPT(F,A,B,NSEG,RELTOL,ABSTOL,EVTOT,ERR)
      CALL DADAPT(FMEAN,A,B,NSEG,RELTOL,ABSTOL,MEANTOT,ERRM)
      WRITE(*,*)
      WRITE(*,*) '-------------------------- Main '
      WRITE(*,*)
      WRITE(*,*) ' TOTAL NUMBER OF BHABHAS = ',EVTOT
      WRITE(*,*) ' MEAN OF TOTAL DISTRIBUTION = ',MEANTOT

C-- Do test run

*     CALL TEST

C-- Do the analysis

      CALL ANAL

      STOP
      END

C---------------------------------------------------------------------------

C                                 TEST

C---------------------------------------------------------------------------

      SUBROUTINE TEST
      DOUBLE PRECISION THRES,A,B,RELTOL,ABSTOL,EVMIS,ERRMIS,PERCENT,
     &                 EVTOT,ERR,MEAN_LOW,RMS_LOW,MEAN_HIGH,RMS_HIGH,
     &                 ERROR_LOW,ERROR_HIGH
      CHARACTER OPT
      COMMON /INTEG/A,B,NSEG,RELTOL,ABSTOL
      EXTERNAL F

C-- Threshold above which signals are assigned mb number 2.
```

```
c    a) module B2, peak+2, before accident (fill 2951)
      THRES = 47.4394

C-- Calculate mismatched number of events

      CALL DADAPT(F,THRES,B,NSEG,RELTOL,ABSTOL,EVMIS,ERRMIS)
      CALL DADAPT(F,A,B,NSEG,RELTOL,ABSTOL,EVTOT,ERR)
      PERCENT = 100*EVMIS/EVTOT

C-- Do the energy plots below and above threshold and extract the mean
C-- values

      IND = 0
      DATA OPTION/'N'/
      CALL PLOT(IND,OPT,THRES,MEAN_LOW,RMS_LOW,MEAN_HIGH,RMS_HIGH)
      ERROR_LOW = RMS_LOW/SQRT(EVTOT-EVMIS)
      ERROR_HIGH = RMS_HIGH/SQRT(EVMIS)

C-- Print the results of test run

      WRITE(*,*)
      WRITE(*,*) '-------------------------- Test Run '
      WRITE(*,*)
      WRITE(*,*) ' NUMBER OF MISMATCHED EVENTS = ',EVMIS
      WRITE(*,*) ' MISMATCH PERCENTAGE = ',PERCENT
      WRITE(*,*) ' MEAN OF LOW ENERGY EVENTS = ',MEAN_LOW
      WRITE(*,*) '                WITH ERROR   ',ERROR_LOW
      WRITE(*,*) ' MEAN OF MISMATCHED EVENTS = ',MEAN_HIGH
      WRITE(*,*) '                WITH ERROR   ',ERROR_HIGH
      RETURN
      END

C---------------------------------------------------------------------------

C                    COMMENTS ON THE RESULTS OF TEST

C---------------------------------------------------------------------------
c     The test run gave the following results for 2951, B2:
c
c                                  program          real value
c
c  TOTAL NUMBER OF BHABHAS       33869.49947326066       33869
c  MEAN OF TOTAL DISTRIBUTION    44.49465616236851      44.494
c  NUMBER OF MISMATCHED EVENTS   5702.276597715748        5702
c  MISMATCH PERCENTAGE            16.8360226351074     16.8355
c  MEAN OF LOW ENERGY EVENTS      43.56680297851562     43.446
c                  WITH ERROR    1.436479630497880E-02  1.8155E-02
```

```
c  MEAN OF MISMATCHED EVENTS      49.07419967651367     49.583
c                 WITH ERROR     1.825471741540843E-02  3.5213E-02
c
C---------------------------------------------------------------------------

C                                ANAL

C---------------------------------------------------------------------------

      SUBROUTINE ANAL
      DOUBLE PRECISION THRES(31),A,B,RELTOL,ABSTOL,EVMIS(31),ERRMIS(31),
     &                 PERCENT(31),EPERCENT(31),THR,
     &                 EVTOT,ERR,MEAN_LOW,RMS_LOW,MEAN_HIGH,RMS_HIGH,
     &                 ERROR_LOW(31),CORF,ECORF,ML(31),EML(31),
     &                 STEP(31),ESTEP(31),H(31),
     &                 THR_INIT,THR_STEP,ERR_PERC,D_MEAN,ED_MEAN
      CHARACTER OPT
      COMMON /INTEG/A,B,NSEG,RELTOL,ABSTOL
      EXTERNAL F

C-- Initialization

c    a) module B2, peak+2, before accident (fill 2951)
      THR_INIT = 47.3
      THR_STEP = .0081
      ERR_PERC = .001
      CORF = 43.446/43.567
      ECORF = .0005
      D_MEAN = 44.142
      ED_MEAN = .018

C-- Threshold above which signals are assigned mb number 2.

      DO 50 II=1,31
      THRES(II) = THR_INIT+THR_STEP*(II-1)

C-- Calculate percentage of mismatched events

      CALL DADAPT(F,THRES(II),B,NSEG,RELTOL,ABSTOL,EVMIS(II),ERRMIS(II))
      CALL DADAPT(F,A,B,NSEG,RELTOL,ABSTOL,EVTOT,ERR)
      PERCENT(II) = 100*EVMIS(II)/EVTOT
      EPERCENT(II) = SQRT((100/EVTOT)**2*(ERRMIS(II)**2+(EVMIS(II)*ERR/
     &               EVTOT)**2)+ERR_PERC**2)

C-- Do the energy plots below and above threshold and extract the mean
C-- values
```

```
      THR = THRES(II)
      DATA OPT/'U'/
      CALL PLOT(II,OPT,THR,MEAN_LOW,RMS_LOW,MEAN_HIGH,RMS_HIGH)
      ERROR_LOW(II) = RMS_LOW/SQRT(EVTOT-EVMIS(II))

C-- Correct mean value of good assignments (program inefficiency)

      ML(II) = MEAN_LOW*CORF
      H(II) = MEAN_LOW
      EML(II) = SQRT((ERROR_LOW(II)*CORF)**2+(MEAN_LOW*ECORF)**2)

C-- Calculate the step

      STEP(II) = D_MEAN - ML(II)
      ESTEP(II) = SQRT( ED_MEAN**2 + EML(II)**2 )

 50   CONTINUE

C-- Diagnostic printout (to check the results in case of bad binning)

      WRITE(*,*)
      WRITE(*,*) '-------------------------- Diagn. printout from Anal'
      WRITE(*,*)
      WRITE(*,*) '     Threshold            Mean_low             Ml'
      WRITE(*,*)
      DO 75 K=1,31
      WRITE(*,70) THRES(K),H(K),ML(K)
 75   CONTINUE
 70   FORMAT(3(1X,F20.17))

C-- Write the results in graph.txt to be used by graph.kumac

      OPEN(1,FILE='graph.txt',STATUS='NEW')
      DO 51 J=1,31
         WRITE(1,60) STEP(J)
 51   CONTINUE
      DO 52 J=1,31
         WRITE(1,60) ESTEP(J)
 52   CONTINUE
      DO 53 J=1,31
         WRITE(1,60) PERCENT(J)
 53   CONTINUE
      DO 54 J=1,31
         WRITE(1,60) EPERCENT(J)
 54   CONTINUE
 60   FORMAT(1X,F13.10)
      RETURN
```

```
      END

C-----------------------------------------------------------------------

C                                PLOT

C-----------------------------------------------------------------------

      SUBROUTINE PLOT(INDEX,OP,THR,MEAN_LOW,RMS_LOW,MEAN_HIGH,RMS_HIGH)
      DOUBLE PRECISION THR,F,ENE,MEAN_LOW,RMS_LOW,
     &                 MEAN_HIGH,RMS_HIGH
      CHARACTER OP
      EXTERNAL F

      PARAMETER (NWPAWC = 50000)
      COMMON /PAWC/HMEMOR(NWPAWC)
      CALL HLIMIT(NWPAWC)

      CALL HBOOK1(200+INDEX,'Distribution below threshold',
     &            20000,20.,70.,0.)
      CALL HBOOK1(300+INDEX,'Distribution above threshold',
     &            20000,20.,70.,0.)

      DO 5 I=1,20000
          ENE = 20.+.0025*I
          Y = F(ENE)
          EENE = ENE
          IF (ENE.LT.THR) CALL HFILL(200+INDEX,EENE,0.,Y)
          IF (ENE.GE.THR) CALL HFILL(300+INDEX,EENE,0.,Y)
  5   CONTINUE

C-- Save the histograms

      CALL HRPUT(0,'histo',OP)

      MEAN_LOW = HSTATI(200+INDEX,1,' ',0)
      RMS_LOW = HSTATI(200+INDEX,2,' ',0)
      MEAN_HIGH = HSTATI(300+INDEX,1,' ',0)
      RMS_HIGH = HSTATI(300+INDEX,2,' ',0)
      RETURN
      END

C-----------------------------------------------------------------------

C                                 F

C-----------------------------------------------------------------------
```

```
      FUNCTION F(X)
      DOUBLE PRECISION EMEAN,SIGMA,F,X,TOTNUM
      COMMON /PARAM/EMEAN,SIGMA,TOTNUM
      F = TOTNUM*(1/(SIGMA*SQRT(2.*3.1415)))*EXP(-(X-EMEAN)**2./
     &    (2.*SIGMA**2.))
      RETURN
      END

C-----------------------------------------------------------------------

C                                 FMEAN

C-----------------------------------------------------------------------

      FUNCTION FMEAN(X)
      DOUBLE PRECISION EMEAN,SIGMA,FMEAN,X,TOTNUM
      COMMON /PARAM/EMEAN,SIGMA,TOTNUM
      FMEAN = X*(1/(SIGMA*SQRT(2.*3.1415)))*EXP(-
     &       (X-EMEAN)**2./(2.*SIGMA**2.))
      RETURN
      END

C=======================================================================
```

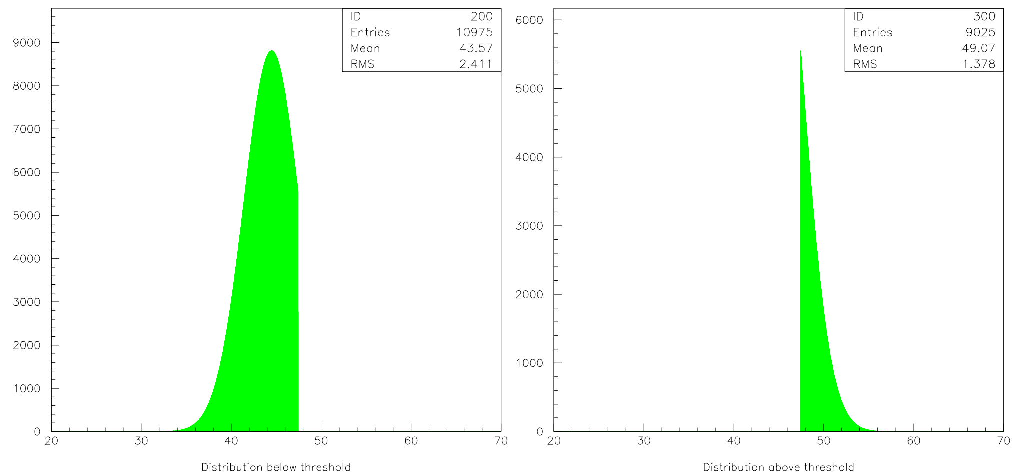

Figure 17: *Output of subroutine test for fill 2951: uncalibrated total minibunch 3 spectrum below and above threshold. The distribution above threshold is supposed to have been assigned minibunch number 2 in the data.*

C Confidence level estimation

```
C===========================================================================
C
C     This program calculates the confidence level of a fit, see
C     V. Hedberg, 'Error Analysis'.
C
C     Created: 6 apr 96 - Ch. Jarlskog
C
C===========================================================================

      PROGRAM CONLEV

      DOUBLE PRECISION DF,CHISQ,A,B,RELTOL,ABSTOL,
     &                 RES,ERR,COEF,CL,CLERROR,F,
     &                 DGAMMA,G
      COMMON /PARAM/DF
      EXTERNAL F

      DF = 4.
      CHISQ = 9.8

      A = CHISQ
      B = 100.
      NSEG = 1000
      RELTOL = .00001
      ABSTOL = .0001
      EPS = .000000001

C-- Calculate integral according to Adaptive Gaussian Quadrature

      CALL DADAPT(F,A,B,NSEG,RELTOL,ABSTOL,RES,ERR)

C-- Calculate Gamma Function

      G = DGAMMA(DF/2.)

C-- Calculate Confidence Level

      COEF = 2.**(DF/2.)
      CL = RES/(COEF*G)
      CLERROR = ERR/(COEF*G)

      WRITE(*,*) 'CONFIDENCE LEVEL = ',CL
      WRITE(*,*) 'WITH ERROR = ',CLERROR

      STOP
```

```
      END

C-- External function

      FUNCTION F(X)
      DOUBLE PRECISION DF,F,X
      COMMON /PARAM/DF
      F = X**(DF/2.-1.)*EXP(-X/2.)
      RETURN
      END

C===========================================================================
```

Acknowledgements

I would like to thank V. Hedberg for providing me with detailed documentation on statistics, especially for giving me the opportunity to take advantage of his paper 'Error Analysis', where conlev.f can be found in an almost identical form. Special thanks go to O. Smirnova for help with the libraries, to U. Egede for latex advice and to O. Bärring for fortran bug detection.

References

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