VCS-E93050

Experimental Offsets Determination for DA1 and DA2 datasets

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This note reports a study of the experimental offsets for DA1 and DA2 datasets in VCS-E93050 experiment at JLab. This document aims to contain updated values of offsets that will be used in the final analysis (values which cannot be found in the thesis works).

1 What are the Experimental Offsets

these are : 1) geometrical offsets in spectrometer positioning, 2) offsets in particle energies and angles. These two kind of offsets are decorrelated, and hence are determined by quite different methods.

1.1 Offsets in geometrical positioning

These are the spectrometer mispointings. The origin of the problem is that these offsets, as calculated from the LVDT readings, are not fully reliable. So we have determined them by software methods when possible (i.e. independently of the LVDTs).

1.2 Offsets in particle energies and angles

We have considered the existence of offsets on the seven variables which enter the computation of the missing mass squared: [1]

beam energy	E_0	$\rightarrow$ offset dE_0
scattered electron momentum	P_e	$\rightarrow$ offset dP_e
outgoing proton momentum	P_p	$\rightarrow$ offset dP_p
horizontal angle reconstructed in E-arm	ϕ_{tg}=PhiE	$\rightarrow$ offset dPhiE
horizontal angle reconstructed in H-arm	ϕ_{tg}=PhiH	$\rightarrow$ offset dPhiH
vertical angle reconstructed in E-arm	θ_{tg}=ThetaE	$\rightarrow$ offset dThetaE
vertical angle reconstructed in H-arm	θ_{tg}=ThetaH	$\rightarrow$ offset dThetaH

[1] the spectrometer angles θ_{HRS} also enter the computation, via the sum $(\theta_{HRS} + \phi_{tg})$.

It is well known that by optimizing only the missing mass squared, one cannot fix the seven offsets in a unique way. Including both ($ep \to ep\gamma$) and ($ep \to ep\pi^0$) events helps to get a reliable solution, but it is still not enough. First, the two offsets dThetaE and dThetaH are determined in a correlated way. Second, the optimization of the five other offsets is not always possible, in the sense that such a fit does not always converge to a reasonable solution. So one has interest to *fix* a certain number of offsets. This is a major guideline in the present study.

1.3 Origin of offsets

• Mispointing: hardware offset of spectrometers.
• Beam energy: unreliable nominal energy from MCC (4045 MeV).
• Momenta and angles measured by the spectrometers: software offsets *mainly due* to systematic biases in the optic databases. Two databases have been used: one for DA1 data, one for DA2 data. They correspond to two different sets of optic coefficients, except for the Hadron Arm (θ, ϕ) coefficients which are the same in both databases.

1.4 Other possible Offsets

These are relative to the beam position on target: the centroid as well as the amplitude of *beamx* and *beamy* may have to be corrected. We have chosen to neglect such corrections, estimating that the determination of beam position in the latter version of Espace-E93050 is reliable enough. A cross-check for *beamx* is the the correlation slope between *twoarmx* and *beamx*, always found close to one.
We have also neglected the beam angles, which are always very small (< 0.2 mr).
We have not fitted any offset in y_{tg}, because they are redundant with other position offsets.

1.5 DA1 data: previous work

The following offsets were optimized in year 2000 using OFFSET code: dE_0, dThetaE and position offsets: dY_{tg} and beam centroid and amplitudes. (N.B. a change in *beamy* induces some change in the dispersive variables θ_{tg} and $\delta p/p$ via the extended target corrections of Espace). The resulting position of experimental missing mass peaks did not always agree well with the simulated ones, ⇒ need of a new determination of offsets.

1.6 DA2 data: previous work

The seven offsets of section 1.2 have been determined previously. One problem was that the distribution of simulated missing mass for ($ep \to ep\pi^0$) was not realistic, due to the use of a constant cross section in VCSSIM. Also, the study was done with an earlier version of the present code, not including the visual check of simulation compared to experiment ⇒ need of a new determination of offsets.

2 Offsets in position

2.1 The method

1. E-arm mispointing. We center the spectrum of Z_V= the vertex point coordinate along beam axis, on the target nominal survey. Z_V is obtained event/event by crossing the beam trajectory and the scattered electron trajectory. The obtained distribution shows well-defined edges that are adjusted on the surveyed position of the target endcaps. The adjustment fixes the offset $X_{OffsetE}$, and hence $Z_{OffsetE} = -X_{OffsetE} * \tan\theta_{HRSE}$.

Normally, one should use single-E-arm triggers for this study. Indeed, at nominal angles of 15°(DA1) and 23°(DA2) the E-arm sees the full length of the 15 cm target. On the contrary, the H-arm in general does not see the full target length [2], so true coincidences are useless. However in the *accidental coincidences* one recovers the full target acceptance of the E-arm, and thus the Z_V study can still be performed on the T5 triggers, including accidentals.
For DA1, several types of events were used (T1 by Natalie, T5 by Helene), leading to very similar results in terms of $X_{OffsetE}$. For DA2 this study was done on T1 triggers (Stephanie).

2. H-arm mispointing. from clean double-arm triggers (i.e. true coincidences sitting in the γ and π^0 missing mass peaks) we center the reconstructed variable $d = (twoarmx - beamx)$ on zero, where $twoarmx$ is obtained by crossing the trajectories measured in the two spectrometers. This fixes the offset $X_{OffsetH}$, and hence $Z_{OffsetH} = +X_{OffsetH} * \tan\theta_{HRSH}$.

3. the spectrometer angles are then calculated, from [angle mark + vernier + horiz. mispointing + inclinometers + temperature], using e.g. Javier Gomez's code.

4. offsets in vertical positioning: for $Y_{OffsetE}$ and $Y_{OffsetH}$ we do not have such simple determination by software, so we simply take the value computed from vertical LVDT reading.

2.2 results for DA1: horizontal spectrometer mispointing

The results are summarized in Table 1.

set	XoffsetE (calset0) mm	XoffsetE (calset1) mm	XoffsetE (new) mm	angleHRSE (new) deg.	XoffsetH (LVDT) mm	XoffsetH (new) mm	angleHRSH (new) deg.
8	4.07	0.55	4.0	15.389	-0.57	-0.57	51.994
9	4.06	0.55	4.1	15.389	+0.86	+0.86	49.509
11	4.09	0.64	4.4	15.389	+1.41	+0.80	44.507
10	4.10	0.66	4.4	15.389	+1.74	-0.35	46.997
14	4.10	0.68	4.6	15.389	+1.73	+0.70	44.517
13	4.09	0.67	4.7	15.389	+1.65	-0.80	47.518
12	4.08	0.58	4.6	15.391	+1.57	-0.70	50.494
15	4.06	0.54	4.9	15.385	+1.58	-0.80	50.000
16	4.07	0.62	5.0	15.382	+1.62	-0.80	48.492
17	4.09	0.58	5.0	15.384	+1.68	-0.60	46.502
3	4.07	0.59	5.0	15.382	+1.67	+0.04	46.996
2	4.08	0.64	4.9	15.383	+1.58	-0.70	49.997
1	4.09	0.62	4.9	15.383	+1.49	-0.91	52.988
4	4.09	0.62	4.9	15.383	+1.49	-0.79	52.989
5	4.11	0.68	4.9	15.385	+1.56	-0.14	50.498
6	4.11	0.67	5.0	15.384	+1.63	+0.55	48.007

[2] H-arm angular settings are: $\theta_{HRSH} = 44.5 - 53°$ (DA1), $\theta_{HRSH} = 37.5 - 42.5°$ (DA2).

7	4.12	0.74	5.1	15.384	+1.75	+1.50	45.017

Table 1. "set" is the setting number. Columns 2 and 3 are the E-arm horizontal mispointing given by [LVDT+calibation set "0" or "1"]. Column 4 is our software determination of this quantity, and column 5 the deduced E-arm spectrometer angle. Column 6 is the H-arm horizontal mispointing given by LVDT. Column 7 is our software determination of this quantity, and column 8 the deduced H-arm spectrometer angle.

Conclusion: the new E-arm offset is close to the "calset0" reading (up to $\sim$ 1 mm) and the new H-arm offset differs from the LVDT reading by up to 2.5 mm. The uncertainty in the determination of X_{offset} by our method is estimated to be $< \pm$ 0.2 mm in both arms. But remember there is an overall uncertainty in the surveyed target position, of $\pm$ 2 (? maybe 5 ?) mm.

2.3 results for DA2: horizontal spectrometer mispointing

The results are summarized in Table 2.

set	XoffsetE (calset0) mm	XoffsetE (calset1) mm	XoffsetE (new) mm	angleHRSE (new) deg.	XoffsetH (LVDT) mm	XoffsetH (new) mm	angleHRSH (new) deg.
1 (*)	4.67	3.03	4.00	22.971	1.79/1.84	1.79/1.84	42.012
4	5.00	4.00	4.00	22.977	2.13	+1.10	42.521
5	5.00	4.03	4.00	22.977	2.23	+2.23	39.520
6	5.02	4.05	4.00	22.970	2.31	+1.70	37.521
2(*)	5.00/4.73	4.02/3.20	4.00	22.972	2.22/2.67	+1.30	40.021
3	4.74	3.23	4.00	22.972	2.76	+2.00	38.025
14	4.75	3.25	4.00	22.972	2.76	+2.00	38.025
13	4.74	3.23	4.10	22.977	2.74	+1.40	38.512
10(*)	4.75/4.80	3.27/3.41	4.05	22.977	1.86/1.76	+0.30	40.003
11	4.80	3.40	4.00	22.972	1.79	+1.00	39.018
12	4.81	3.44	4.00	22.982	1.97	+1.70	37.518
9	4.81	3.44	4.00	22.982	2.00	+1.70	37.117
8(*)	4.95	3.88	4.00	22.976	-0.05	-0.55	39.289
7	4.94	3.81	4.00	22.976	-0.07	-0.01	41.398

Table 2. same conventions as in Table 1. The (*) represent four main interruptions that took place during DA2 data taking, between settings or during a setting. This implies that some offsets may have changed within one setting (see e.g. setting 2).

3 Offsets in energies and angles

3.1 The tool: missing mass optimization code

We have used a code devoted to, and only to, missing mass optimization. See the manual In Appendix 1 where the principle of the minimization is explained. The code needs a clean experimental sample of events (see next section), and makes use of interactive graphics to have a visual control of the optimization process at each iteration.

- **Summary of how the code works:**

in a directive file you type the main choices, i.e.:

- the fit windows for each channel: ($ep \rightarrow ep\gamma$) and ($ep \rightarrow ep\pi^0$)
- the offsets to optimize (up to 7 items)
- the desired position of the *mean value* in each fit window (this value is the one entering the χ^2)

Then you run the code. It is necessary to iterate the minimization, as new events enter the fit windows at each iteration. You can iterate up to 10 times in one execution and check the numerical convergence of the offsets. You can also judge visually the agreement between experiment and simulation at each iteration with interactive graphics: experimental missing mass spectrum is plotted together with the parametric function fitted from the simulation (see figure 1).

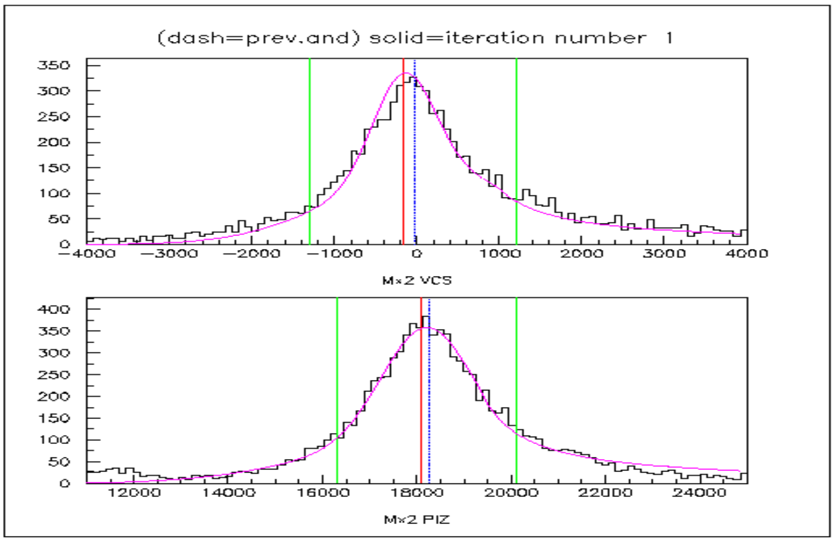

Figure 1: Missing mass squared in MeV^2 for offsets optimization code: example of setting DA1-12. Histogram = experimental, curve = simulation. Top/Bottom= γ and π^0 regions. Fit windows are defined by the most left and right vertical lines on each plot.

3.2 Fabrication of event samples

EXPERIMENTAL SAMPLE: to make the best use of the code, one must provide a sample of experimental events as clean as possible, containing ($ep \rightarrow ep\gamma$) and ($ep \rightarrow ep\pi^0$) events in roughly equal proportions. Such a sample is made by Titanic. Event cuts are the standard analysis cuts + a narrow cut in d and a narrow cut in *tccor*. The latter cut is chosen because accidentals are not subtracted in the optimization code [3].

SIMULATED SAMPLE: it is made by VCSSIM, with the same cuts as in EXP (except *tccor*). Realistic cross sections are used: BH+Born for VCS, MAID2000 for π^0. The latter cross

[3] This is a default. It could be improved, but it may not be worth as the accidental rate is very small for DA2, and rather small for DA1.

section changes quite a lot the π^0 missing mass width and position. Then we make a fit of simulated missing mass spectra by a parametric function. This function serves only as a visual reference during the optimization process.

3.3 The optimization sequence

As we cannot fit all the offsets in a unique way, we have chosen a *definite optimization sequence.* There is a part of arbitrariness in this choice. As usual, it is a compromise: it may introduce biases, however it gives a quite reasonable solution.

- **which offsets can we fix?**

in DA1 or DA2, the E-arm is kept fixed in angle and momentum. So the offsets dP_e, dPhiE, dThetaE should be *fixed numbers* [4]. In the Hadron arm it is not so simple, as this spectrometer has been moved in momentum and/or angle for each setting. Regarding the beam energy, we have little constraint; the only guess is that it varied more or less smoothly during the experiment, and by no more than "a few" MeV.

Our procedure is the following:

1. fix the offset in P_e by fine tuning the E-arm momentum run/run
2. make a study *setting per setting*, with the 6 other offsets unconstrained.
3. from this study, draw conclusions in order to constrain some offsets (*fix* them or *limit their range of variation*)
4. make a second study *setting per setting* with "constrained offsets", yielding the final set of values.

3.4 Results for DA1: Offsets in energies and angles

Below is given the ($ep \to ep\gamma$) experimental statistics for each DA1 setting [5] in missing mass range (-3000,+3000) MeV^2. Line #1 is the setting number, line# 2 the number of events within cuts, line # 3 and # 4 are the first and last run number of each setting.

8	9	11	10	14	13	12	15	16	17	3	2	1	4	5	6	7
5k	10k	4.0k	3.8k	2.4k	1.9k	9.4k	14k	9.8k	7.0k	1.9k	2.7k	1.6k	2.1k	2.4k	3.1k	2.8k
1563	1566	1584	1600	1627	1634	1642	1655	1666	1676	1686	1712	1726	1736	1743	1755	1765
1565	1579	1599	1613	1633	1640	1649	1661	1675	1685	1711	1725	1734	1741	1753	1763	1780

3.4.1 E-arm absolute momentum calibration

The E-arm field setting has never been changed during DA1 data taking, so we should be able to fix the offset dPe to a constant value.

[4] there may be exceptions, for example if the optics database has systematic biases which are not constant throughout the (θ, ϕ_{tg}) phase space, and different settings fill very different parts of this phase space. But this is generally not the case.

[5] Total= 84k events. Accidentals unsubtracted.

Procedure: the present headerfiles contain as E-arm dipole field ("B_{low}") two different sets of values: B $\sim$ 12.6449 kGauss and B $\sim$ 12.6495 kGauss, depending if B_{low} was read from EPICS or recalculated from B_{high}. This induces a fake relative change in momentum P_e of 3.6e-4, i.e. 1.24 MeV/c at central momentum 3415 MeV/c.
We consider that the true B_{low} was kept to **12.6449 kG** during DA1 data taking, and we add an offset in P_e run per run, when necessary, i.e. to correct for when the B_{low} in the headerfile is not equal to 12.6449 kG.
Further, we apply a rescaling of the E-arm gamma factor: in our analysis, we use and will keep using Γ_e=270.1 MeV/kG, whereas the most precise value determined by N.Liyanage is 270.2, inducing a relative change of P_e of 3.7e-4, or 1.26 MeV/c at central momentum 3415 MeV/c.
Having done these two corrections run/run in the fabrication of the experimental sample by Titanic, we then fix the residual offset **dP_e=0** before starting the offset studies.

3.4.2 DA1 study # 1: unconstrained offsets

The offsets dE_0, dP_p, dPhiE, dPhiH, dThetaE and dThetaH are allowed to vary freely. The optimization sequence is the following: [6]

1. we fit the triplet (dE_0, dPhiE, dPhiH). These offsets play a major role in the centering of the missing mass peaks. The fit never diverges if the two peaks (γ and π^0) are included.
2. for DA1, the events show an obvious distortion of M^2_{miss} versus ThetaE, whereas it is not the case for M^2_{miss} versus ThetaH. So we fit dThetaE alone. If we fit dThetaH afterwards, there is almost no offset left, as the two offsets in vertical angles are correlated (see Table 3).
3. we re-do steps 1 and 2 if a big dThetaE was found, in order to stabilize the convergence.
4. we then fit dP_p. N.B: we should iterate on steps 1 and 4 but sometimes this sequence diverges. So this last step is done only once, and it just gives an indicative offset in hadron momentum.

Results are reported in Table 3 and figure 2.

file da1-off-3

T	set	dE0	dPe	dPp	dPhiE	dPhiH	dTheE	dTheH	VCS	minVC	maxVC	PIZ	minPI	maxPI
		MeV	...MeV/c..		.....mr.....		.....mr....		.....MeV2......			.....MeV2......		
1	8	-10.2	0.00	-0.068	-0.41	-0.84	-1.87	0.02	0	-1600	1600	18540	16500	20400
2	9	-10.6	0.00	-0.076	-0.07	-2.19	-1.68	0.00	-50	-2300	2300	18340	15400	20800
3	11	-11.6	0.00	0.014	+0.26	-2.54	-1.90	-0.02	-280	-2400	2300	18280	15500	20700
4	10	-11.6	0.00	-0.050	+0.15	-2.99	-1.91	0.02	-210	-2200	2200	18320	16100	20400
5	14	-13.7	0.00	-0.023	+0.28	-2.28	-1.94	0.01	-200	-2000	2000	18100	15500	20500
6	13	-12.3	0.00	-0.011	-0.01	-1.61	-2.01	-0.03	-70	-2200	2200	18280	15500	20500
7	12	-11.6	0.00	-0.004	-0.17	-1.75	-1.38	0.06	-20	-1300	1200	18280	16300	20100
8	15	-13.3	0.00	0.005	-0.06	-1.84	-1.77	0.02	+20	-1000	1000	18100	16000	20000
9	16	-14.4	0.00	0.000	+0.15	-1.99	-1.26	0.02	-70	-1100	1000	18130	16300	19900
10	17	-14.9	0.00	0.001	+0.29	-2.99	-1.04	0.00	-150	-1500	1300	18100	16500	19800
11	3	-7.9	0.00	0.021	+0.87	-0.46	-1.34	0.02	-370	-2300	2100	18370	16100	20200
12	2	-7.6	0.00	-0.138	+0.69	-1.80	-1.23	0.00	-180	-2300	2200	18300	16100	20300
13	1	-10.6	0.00	-0.483	+0.12	+0.10	-1.43	-0.06	-20	-2300	2600	18500	16000	20700
14	4	-11.9	0.00	-0.144	-0.25	-1.23	-1.56	0.02	+20	-2200	2400	18540	16000	20700

[6] for each step, one iterates as many times as needed to reach convergence.

15	5	-9.7	0.00	-0.063	+0.19	-1.67	-1.57	0.00	-100	-2300	2200	18390	15800	20600
16	6	-10.6	0.00	0.091	+0.41	-0.87	-1.55	0.01	-360	-2300	2200	18390	15900	20500
17	7	-8.3	0.00	0.012	+0.84	+1.86	-1.59	-0.01	-400	-2200	2000	18320	16100	20100

Table 3: T is a time index. "set" is the setting number. "VCS minVC maxVC" are mean value and fit windows for the VCS sample. "PIZ minPI maxPI" are the same for the π^0 sample. Offset in beam energy is relative to the nominal 4045 MeV of the headerfiles.

- **Conclusions from this study # 1:**

1) VERTICAL ANGLES: The offset found in ThetaE is almost constant, with a spread < 1 mr. The average over the 17 settings, each setting being weighed by its own statistics, is -1.56 mr. We consider it as a constant offset of the optic database used in the DA1 analysis, and we will fix **dThetaE to -1.60 mr**. Similarly we will fix **dThetaH to 0.**

2) HORIZONTAL ANGLES: remember that what is optimized is actually the sum $(\theta_{HRS}+\phi_{tg})$. So together with an offset of the optic database we may find variations due to the spectrometer rotations from one setting to the other (H-arm).

E-arm: we find dPhiE quite small (<0.5 mr except for a few settings). [7] This spectrometer has not been moved at all during DA1 data taking, so the offset in PhiE should be constant. We will fix the offset **dPhiE=+0.09 mr** = the weighed average over the 17 settings.

H-arm: there is a definite negative offset dPhiH, with a weighed average of -1.77 mr and quite large fluctuations around this value. For the following we will allow the offset dPhiH to vary in the range: -1.80 ± 0.5 mr (to allow an offset in spectrometer angle), i.e. the range **[-2.3, -1.3] mr**[8].

3) MOMENTA: In the H-arm, the dipole field has been changed may times. Furthermore the gamma factor is not very well known (cf. N.Liyanage). So we may consider some offset in P_p, and it may change with time. We will allow the offset dP_p to vary in the range of ± 1.e-3 (relative), i.e. **±1 MeV/c** in absolute, at central momentum 1 GeV/c.

4) BEAM ENERGY: from this study we find an offset in the range **[-14.9,-7.6] MeV**.

3.4.3 DA1 study # 2: constrained offsets

According to the previous study, we decide to fix or constrain several offsets:
E-arm: dPhie=+0.09 mr, dThetaE=− 1.60 mr.
H-arm vertical angle: dThetaH=0.
H-arm momentum: dP_p in the range [-1,+1] MeV/c.
H-arm horizontal angle: dPhiH in the range [-2.30, -1.30] mr.

The results of this second optimization are shown in Table 4 and figure 3

```
file da1-off-6
-------------------------------------------------------------------------------------
 T set  dE0   dPe    dPp    dPhiE  dPhiH  dTheE dTheH  VCS minVC maxVC   PIZ minPI maxPI
        MeV   ...MeV/c..    .....mr.....  .....mr....  .....MeV2......   .....MeV2......
```

[7]These settings: 3,2,7, have the highest accidental rates, about 10-15 % under the *tccor* peak. As the accidental are left unsubtracted, the code may have some difficulty to optimize the offsets.

[8]Instead, one could strictly fix dPhiH to -1.8 mr. This would change the beam energy offset by a small amount only: less than 0.5 MeV.

1	8	-8.6	0.00	+1.000	+0.09	-1.30	-1.60	0.00	0	-1600	1600	18540	16500	20400
2	9	-10.0	0.00	+0.700	+0.09	-1.91	-1.60	0.00	-50	-2300	2300	18340	15400	20800
3	11	-12.0	0.00	-0.892	+0.09	-2.20	-1.60	0.00	-280	-2400	2300	18280	15500	20700
4	10	-11.5	0.00	-0.559	+0.09	-2.30	-1.60	0.00	-210	-2200	2200	18320	16100	20400
5	14	-14.4	0.00	-1.000	+0.09	-2.30	-1.60	0.00	-200	-2000	2000	18100	15500	20500
6	13	-11.8	0.00	+0.355	+0.09	-1.31	-1.60	0.00	-70	-2200	2200	18280	15500	20500
7	12	-10.8	0.00	+1.000	+0.09	-1.53	-1.60	0.00	-20	-1300	1200	18280	16300	20100
8	15	-12.6	0.00	0.800	+0.09	-1.61	-1.60	0.00	+20	-1000	1000	18100	16000	20000
9	16	-14.7	0.00	-0.501	+0.09	-2.17	-1.60	0.00	-70	-1100	1000	18130	16300	19900
10	17	-14.9	0.00	-0.046	+0.09	-2.30	-1.60	0.00	-150	-1500	1300	18100	16500	19800
11	3	-12.2	0.00	-1.000	+0.09	-2.30	-1.60	0.00	-370	-2300	2100	18370	16100	20200
12	2	-10.8	0.00	-1.000	+0.09	-2.30	-1.60	0.00	-180	-2300	2200	18300	16100	20300
13	1	-9.5	0.00	-0.904	+0.09	-1.30	-1.60	0.00	-20	-2300	2600	18500	16000	20700
14	4	-10.0	0.00	+1.000	+0.09	-1.30	-1.60	0.00	+20	-2200	2400	18540	16000	20700
15	5	-10.1	0.00	-0.632	+0.09	-1.84	-1.60	0.00	-100	-2300	2200	18390	15800	20600
16	6	-12.1	0.00	-1.000	+0.09	-1.38	-1.60	0.00	-360	-2300	2200	18390	15900	20500
17	7	-12.7	0.00	-1.000	+0.09	-1.30	-1.60	0.00	-400	-2200	2000	18320	16100	20100

Table 4. same conventions as in Table 3.

- **Conclusions from this study # 2:**

BEAM ENERGY: the offset is found in the range **[-14.9, -8.6] MeV** with an average value around -12 MeV, i.e. an incident beam energy of 4033 MeV.

4 Results for DA2

Generally speaking, the offset optimization is more difficult on DA2 data than on DA1 data. There are less statistics, and the results show more fluctuations. Furthermore there have been several long interrupts in this data taking, during which -among other things- the E-arm setting has been modified (in momenta and angle). Nevertheless we will adopt exactly the same optimization method as in DA1.

Below is given the $(ep \to ep\gamma)$ experimental statistics for each DA2 setting [9] in missing mass range (-3000,+3000) MeV^2 and run numbers.

1	4	5	6	2	3	14	13	10	11	12	9	8	7
0.6k	0.8k	1.0k	0.9k	0.5k	0.3k	4.5k	7.5k	7.0k	4.7k	4.4k	1.5k	1.7k	5.2k
1920	1996	2010	2015	2027	2084	2117	2123	2129	2167	2190	2199	2206	2269
1934	2009	2014	2022	2083	2095	2122	2127	2166	2189	2198	2205	2267	2273

4.1 E-arm absolute momentum calibration

We consider that the true B_{low} was kept to **10.8624 kG** during DA2 data taking, and we add an offset in P_e run per run, when necessary, i.e. to correct for when the B_{low} in the headerfile is not equal to 10.8624 kG. We also apply the same rescaling of the E-arm gamma factor as in DA1; and then we fix the residual offset $\mathbf{d}P_e\mathbf{=0}$ before starting the offset studies.

[9] Total= 41k events. The rate of accidentals is negligible.

4.2 DA2 study # 1: unconstrained offsets

There is no visible distortion of the missing mass squared versus any vertical angle, contrary to the case of DA1. If we fit the two offsets dThetaE and dThetaH together, the fit does not diverge but results are scattered over ± 5 milliradians, which is not helpful. Knowing that the hadron arm (θ, ϕ) optics is the same in the two databases (db-DA1 and db-DA2), we then fix **dThetaH=0** as in DA1, and we fit only dThetaE.

Results are reported in Table 5 and figure 4.

file da2-off-2

T	set	dE0	dPe	dPp	dPhiE	dPhiH	dTheE	dTheH	VCS	minVC	maxVC	PIZ	minPI	maxPI
		MeV	...MeV/c..		.....mr.....		.....mr....		.....MeV2......			.....MeV2......		
1	1	-02.7	0.00	-0.084	+0.91	-0.79	-1.08	-0.00	0	-3000	3500	18900	15500	22000
2	4	-14.2	0.00	-0.051	-0.35	-0.15	-0.48	+0.00	+40	-2100	2100	18530	15200	21800
3	5	-19.3	0.00	-0.220	-0.35	-4.96	-0.81	+0.00	+170	-2400	2500	18230	15100	21400
4	6	-13.2	0.00	+0.170	+0.50	-0.42	-0.41	-0.00	-400	-3500	3500	18800	15600	21200
5	2	-10.5	0.00	+0.036	+0.43	-1.85	-0.59	-0.00	-80	-4000	4000	19000	15000	23000
6	3	-16.4	0.00	+0.074	+0.12	-2.77	-0.51	-0.00	-250	-4000	3500	18900	15000	23000
7	14	-17.6	0.00	-0.001	+0.02	-1.23	-0.88	+0.00	-100	-1400	1400	18100	16400	19600
8	13	-18.5	0.00	+0.009	+0.03	-1.97	-0.71	+0.00	-70	-1300	1300	18070	16200	19800
9	10	-16.1	0.00	-0.066	-0.24	-1.80	-0.52	+0.00	+0	-1100	1100	18040	15500	20500
10	11	-15.8	0.00	-0.011	+0.02	-0.75	-0.35	+0.00	-80	-1400	1400	18200	16000	20100
11	12	-17.1	0.00	-0.012	+0.08	-1.95	-0.55	+0.00	-70	-2000	2000	18120	16000	20000
12	9	-16.2	0.00	+0.015	-0.03	-2.27	-0.56	-0.00	-120	-2400	2600	18390	15400	21200
13	8	-15.4	0.00	-0.034	-0.06	-1.86	-0.26	+0.00	-60	-1700	1700	18240	15400	20800
14	7	-14.2	0.00	-0.055	-0.40	-1.00	-0.19	-0.00	-20	-1300	1300	18170	15800	20300

Table 5: same as in tables 3 and 4.

- **Conclusions from this study # 1:**

1) HORIZONTAL ANGLES: we observe the same trend as in DA1, i.e. dPhiE is generally small [10] and dPhiH tends to be negative. The weighed averages are: dPhiE= -0.06 mr and dPhiH=-1.59 mr. In the following we will fix **dPhiE= -0.06 mr** and we will allow dPhiH in the range **-1.60 ± 0.5 mr**. Note that this latter value is very close to the one found in the DA1 study (dPhiH ≃ -1.80 mr), as expected since it's the same optics in the two cases.

2) VERTICAL ANGLES: the fitted dThetaE is small. In the following we will fix it to its weighed average: **dThetaE=-0.54 mr**.

3) MOMENTA: we will allow the H-arm momentum to vary by ± 1.e-3 in relative, i.e. in the range **[-1.5,+1.5] MeV/c** at central momentum 1.5 GeV/c.

4) BEAM ENERGY: the fitted offset is in the range [-19.3,-10.5] MeV except for setting 1 which has a correlated problem in dPhiE.

4.3 DA2 study # 2: constrained offsets

According to the previous study, we decide to fix or constrain several offsets:
E-arm: dPhie=-0.06 mr, dThetaE=$-$ 0.54 mr.
H-arm vertical angle: dThetaH=0.

[10] except for setting 1, which has one of the lowest statistics.

H-arm momentum: dP_p in the range [-1.5,+1.5] MeV/c.
H-arm horizontal angle: dPhiH in the range [-2.10, -1.10] mr.

The results of this second optimization are shown in Table 6 and figure 5.

file da2-off-4

T	set	dE0	dPe	dPp	dPhiE	dPhiH	dTheE	dTheH	VCS	minVC	maxVC	PIZ	minPI	maxPI
		MeV	...MeV/c..		.....mr.....		.....mr....		.....MeV2......			.....MeV2......		
1	1	-11.1	0.0	-1.50	-0.06	-1.10	-0.54	0.00	-240	-3000	3500	19200	15500	22000
2	4	-11.9	0.0	-1.50	-0.06	-1.10	-0.54	0.00	+40	-2100	2100	18530	15200	21800
3	5	-16.4	0.0	+1.50	-0.06	-2.10	-0.54	0.00	+120	-2400	2500	18210	15100	21400
4	6	-16.7	0.0	-1.50	-0.06	-1.17	-0.54	0.00	-400	-3500	3500	18800	15600	21200
5	2	-14.0	0.0	-1.50	-0.06	-2.10	-0.54	0.00	-170	-4000	4000	19060	15000	23000
6	3	-16.8	0.0	-1.50	-0.06	-2.10	-0.54	0.00	-300	-4000	3500	18950	15000	23000
7	14	-18.2	0.0	-0.79	-0.06	-1.31	-0.54	0.00	-100	-1400	1400	18100	16400	19600
8	13	-19.1	0.0	-0.73	-0.06	-2.10	-0.54	0.00	-70	-1300	1300	18070	16200	19800
9	10	-15.1	0.0	+1.13	-0.06	-1.55	-0.54	0.00	+0	-1100	1100	18040	15500	20500
10	11	-16.6	0.0	-0.93	-0.06	-1.10	-0.54	0.00	-80	-1400	1400	18200	16000	20100
11	12	-18.0	0.0	-1.45	-0.06	-2.10	-0.54	0.00	-70	-2000	2000	18120	16000	20000
12	9	-16.2	0.0	+0.10	-0.06	-2.10	-0.54	0.00	-120	-2400	2600	18390	15400	21200
13	8	-15.3	0.0	-0.06	-0.06	-1.84	-0.54	0.00	-60	-1700	1700	18240	15400	20800
14	7	-12.9	0.0	-0.27	-0.06	-1.10	-0.54	0.00	-20	-1300	1300	18250	15800	20300

Table 6. same conventions as in previous tables.

- **Conclusions from this study # 2:**

The beam energy variations are smoother than in study # 1, and results for setting 1 are now OK. The offset is found in the range **[-19.1, -11.1] MeV** with an average around -16 MeV, i.e. an incident beam energy of 4029 MeV.

5 Conclusions

We propose to take for the final analysis of DA1 and DA2 data the set of offsets obtained from the constrained studies, i.e. the sets of Tables 4 and 6. For the resonance data, which uses the same optic database as DA1, the suggestion would be to fix the offsets dPhiE, dThetaE, dPhi, dThetaH, dPe and dPp to the values (or bounds) of Table 4, and just fit the beam energy run/run or setting/setting.

From the practice of the optimization code we estimate the following uncertainties in the determination of offsets (in r.m.s.):

- uncertainty in vertical angles: dThetaE, dThetaH $< \pm$ 0.5 mr
- uncertainty in horizontal angle: d(θ_{HRSE}+PhiE) $< \pm$ 0.3 mr
- uncertainty in horizontal angle: d(θ_{HRSH}+PhiH) $< \pm$ 0.6 mr
- uncertainty in beam energy: $< \pm$ 4 MeV.

Thanks to all the analysis groups at Clermont, Gent and ODU for helpful discussions on the matter.

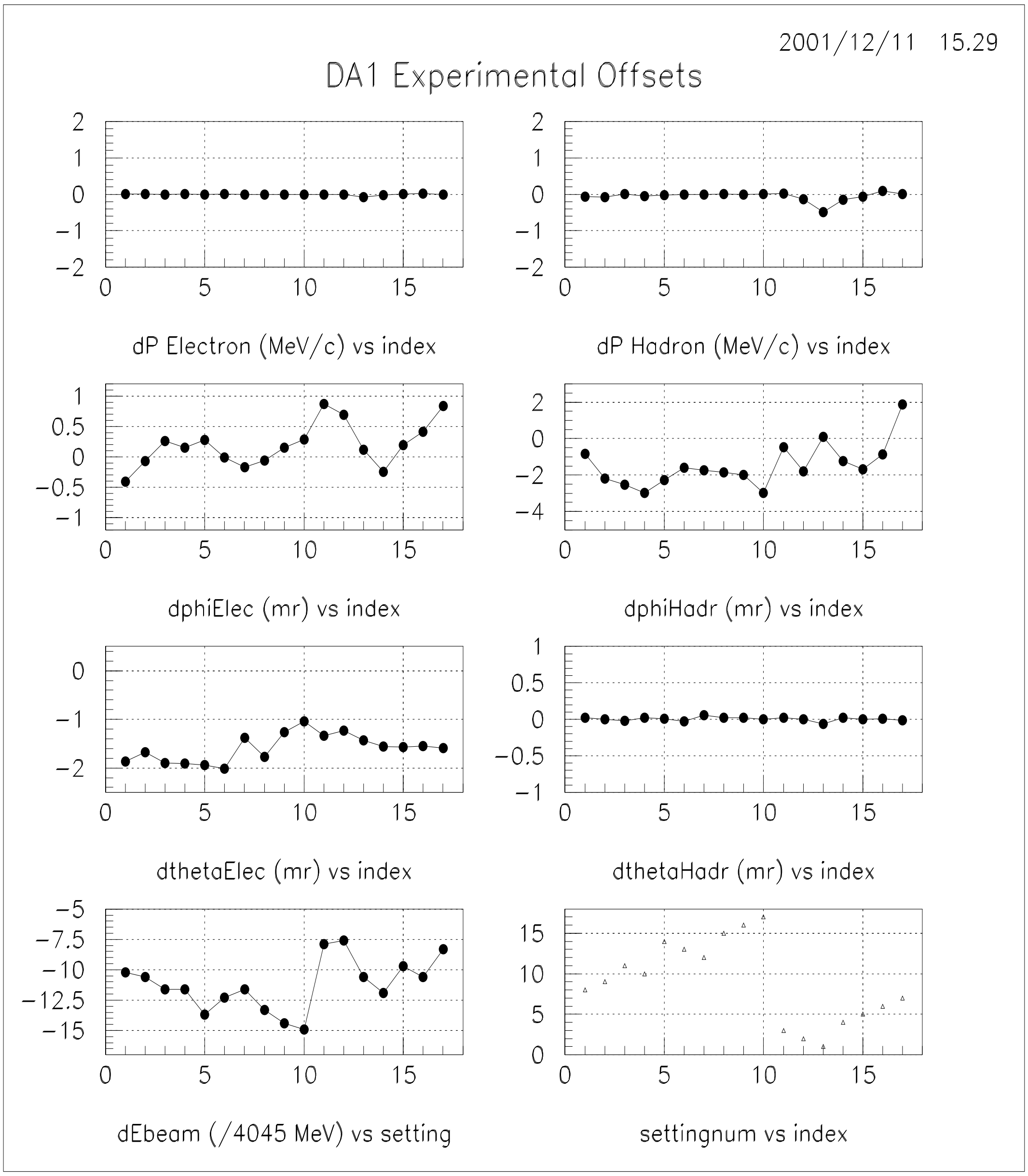

Figure 2: DA1 offset study # 1. In abscissa is the time index T of Table 3.

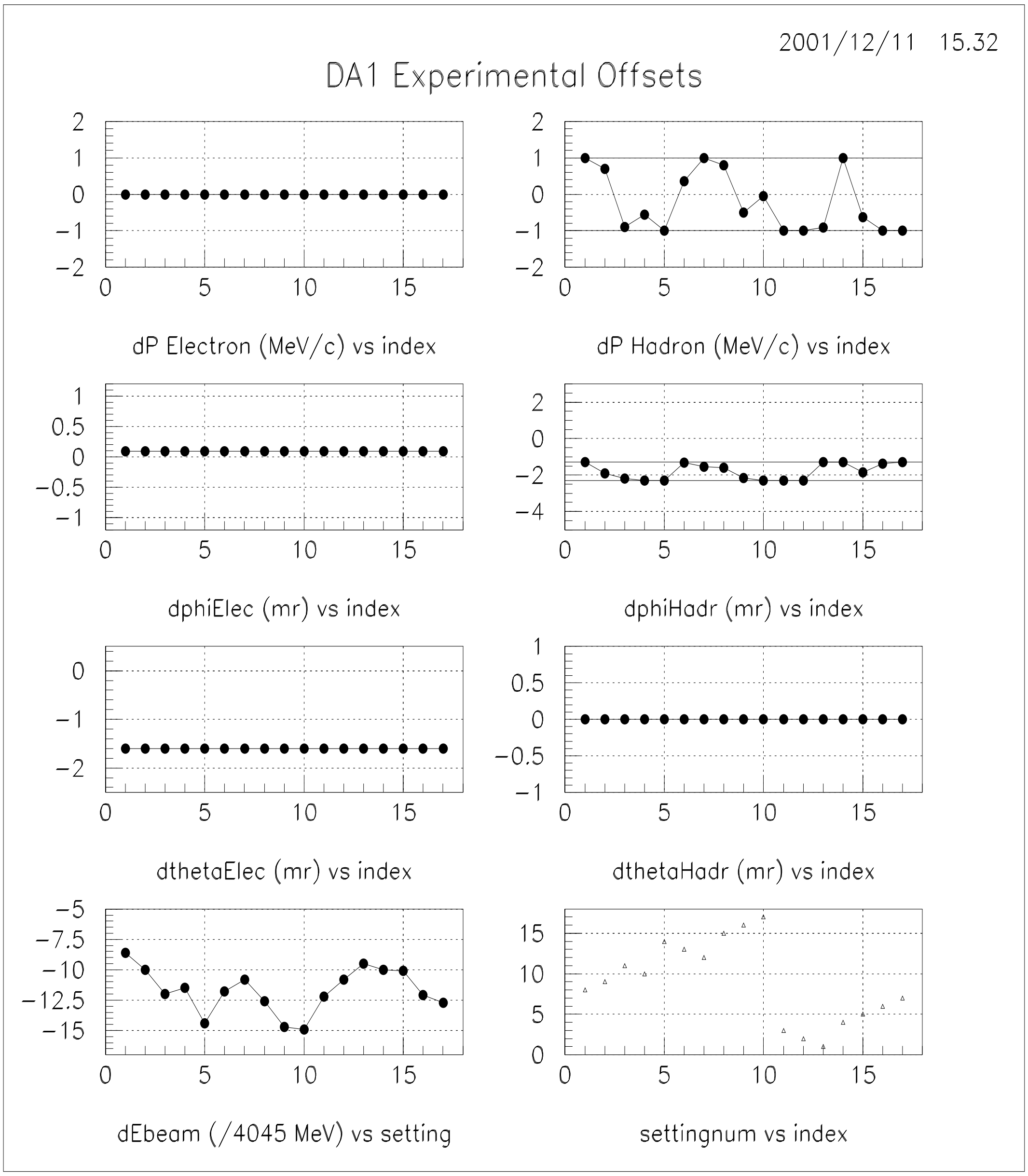

Figure 3: DA1 offset study # 2. In abscissa is the time index T of Table 4. Horizontal lines in plots 2 and 4 represent the bounds of the allowed range for the offset.

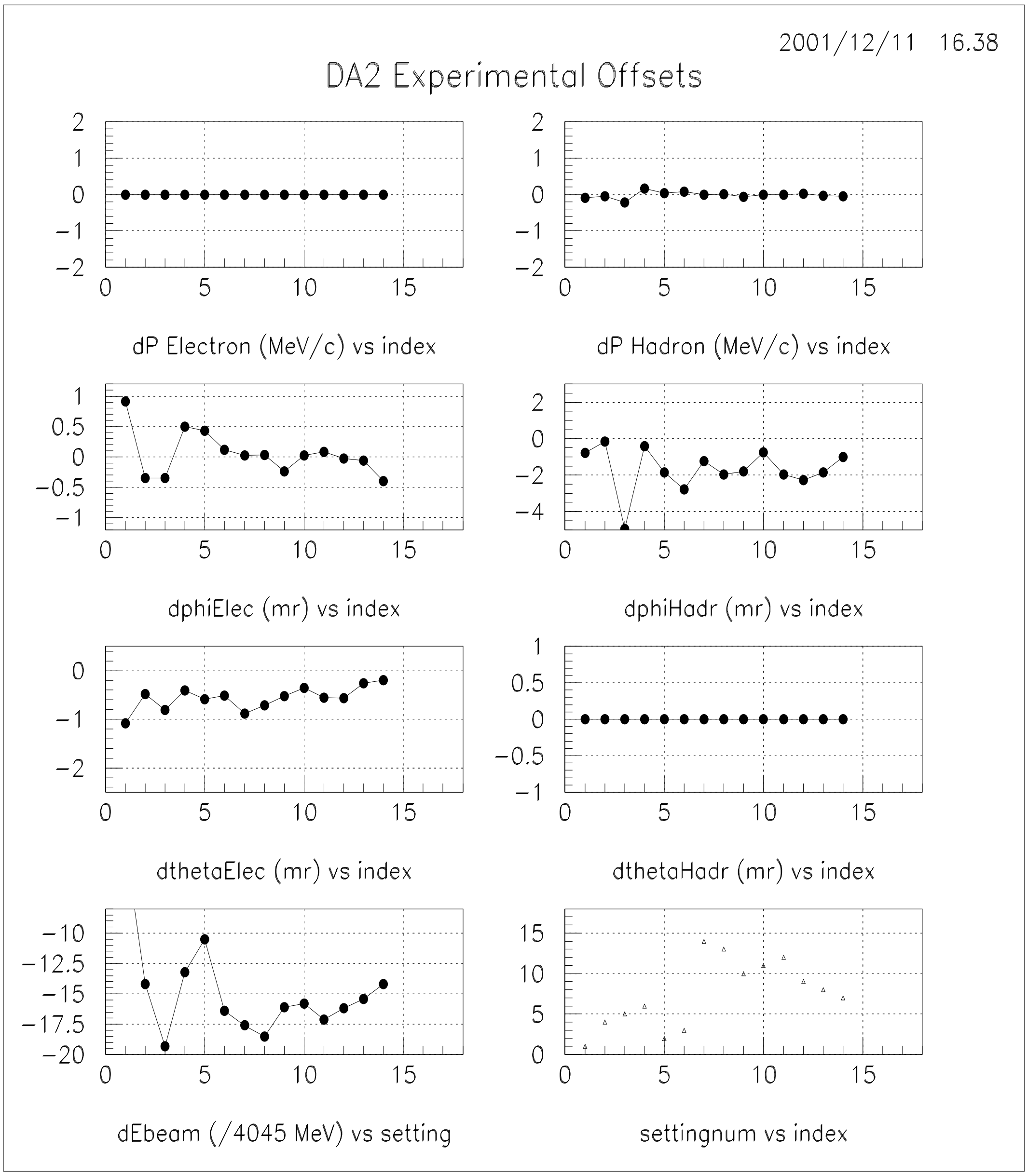

Figure 4: DA2 offset study # 1. In abscissa is the time index T of Table 5.

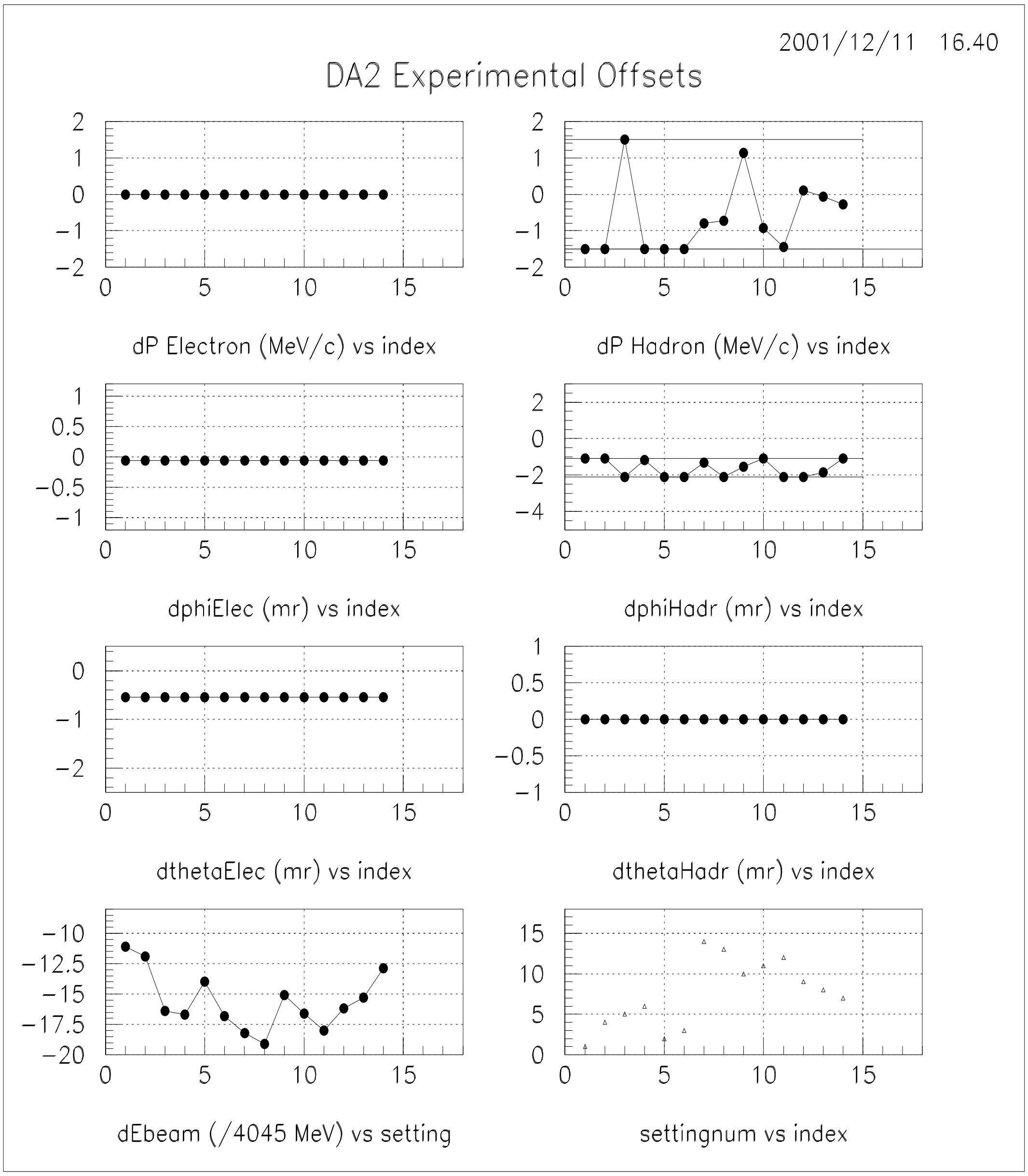

Figure 5: DA2 offset study # 2. In abscissa is the time index T of Table 6. Horizontal lines in plots 2 and 4 represent the bounds of the allowed range for the offset.

APPENDIX 1

```
************************************************************
*                       VCS-E93050
*             Short MANUAL for Optim Code:
*             Minimization of Missing Mass Squared
*             to find offsets in energies and angles.
************************************************************
H.Fonvieille, LPC-Clermont \ November 2000 \ Revised October 2001

Description:
============

This code finds offsets in the variables on which the Missing mass
squared (Mmiss2) depends.
It is a "shortened" version of Offset code of Geraud: it does less things
(Geraud's code is able to optimize many more parameters) but it is easier
to handle (less input files etc).

Mmiss2 depends on energies and angles. i will neglect the beam angles, so
we are left with seven event variables entering the missing mass formula:
    Ebeam  = incoming beam energy at vertex
    Pe     = energy of scattered electron, at vertex
    Pp     = energy of outgoing  proton,   at vertex
    PhiE   = horizontal angle measured in E-arm (spectrometer frame)
    PhiH   = horizontal angle measured in H-arm (spectrometer frame)
    thetaE = vertical   angle measured in E-arm (spectrometer frame)
    thetaH = vertical   angle measured in H-arm (spectrometer frame)
    (+ nominal angle of spectrometers)

if there is an offset on these variables in experimental data, the missing
mass is shifted or degraded. the goal is to find these offsets by minimizing
a chisquare built on Mmiss2. the chisquare is of the type:

      chi2= sum_{events} [( Mmiss2(event) - Mmiss2(theo) )**2]/(w)

where:
      Mmiss2(event) is the missing mass squared for event i,
      built from the seven variables listed above:
      Ebeam, Pe, Pp, PhiE, PhiH, thetaE and thetaH

      Mmiss2(theo) is a fixed theoretical value, constraining the fit.
      it can be taken e.g. as the center of the Mmiss2 peak given
      by VCSSIM, or any other value that will make the convergence go
      where you want.


      w is the weight of the event, i.e. the variance of Mmiss2,
      event per event. it is computed using a reslution on each
      of the seven event variables.


suppose each of the 7 variables has an offset:

      Ebeam_true= Ebeam + dEbeam,
      .....
```

```
      thetaE_true=  thetaE + dthetaE
```

```
the minimization is written as a set of seven equations:

      d(chisquare)/dEbeam=0
      .....
      d(chisquare)/dthetaE=0

the system is linear w.r.t. the offsets, to 1st order. one just
has to calculate the partial derivatives of Mmiss2 w.r.t. the
seven variables.
as the problem is treated to 1st order only, several iterations of
the minimization process may be necessary. the code iterates up to
10 times in a single execution.
```