Electron beam energy analysis for the Spring 2016 run

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1 Introduction

In this document we analyze the Hall D electron beam energy during the 2016 spring run. The energy appears to drift with time, typically by tens of MeV over a day. It also sometimes jumps from one value to another within a few minutes. Overall, the Hall D electron beam energy -as given by the epics energy variable HALLD:p- seems to have varied by about 140 MeV during the spring run. Fig. 1 and Table 1 summarize the average energy binned in periods of approximate energy stability. (For a finer binning, one may refer to the Appendix where the energy plots and discussions about energy drifts are provided for each period.) The vertical error bars in Fig. 1 are not uncertainties in the measurement but they bracket the systematic fluctuations of the beam during the time period.

The Hall D beam energy is obtained from the magnetic field and the vertical beam positions in the ramp leading to the Hall D tagger. The epics name for this measurement is HALLD:p. In this document, energy instability/drift/jump refers to the value reported by this measurement. Those can be real energy changes or artifacts of the measurement. This document disentangles the two possibilities.

After the run (and the first version of this document), it was found that there was two sign mistakes in the computation of HALLD:p. The beam energy (or equivalently momentum) is computed from:

$$P = P_0(1+\delta_{steering})(1+\delta_{orbit}) \simeq P_0(1+\delta_{steering}+\delta_{orbit})$$

where P_0 is the baseline momentum obtained from the nominal magnetic field settings of the dipoles in the Hall D ramp, while assuming a perfectly centered beam ($x = 0$, $y = 0$). $\delta_{steering}$ is the correction due to any quadrupoles and changes in the magnetic beam transport in the ramp. δ_{orbit} is the correction for $y \neq 0$. Since the ramp is vertical, y is the dispersive variable and the δ_{orbit} correction comes from $y \neq 0$. However, there was a sign mistake for y (the mistake comes from the fact that the coordinate system of the accelerator is left-handed while the one of the beam transport model is right-handed. This difference was mistakenly accounted for with ($x \to -x$, $y \to -y$) rather than the correct ($x \to -x$, $y \to y$)). Consequently, the sign of δ_{orbit} was wrong. Consequences are that:

- Each time the baseline P_0 changed, P jumped artificially by $2\delta_{orbit}$.
- The sign of the energy drift was wrong, with the Hall D energy fluctuations displaying a negative correlation with Hall A or ARCs energy fluctuations.
- Similarly, the sign of the Hall D energy correlation with the beam x position after the (horizontally bending) tagger magnet was wrong.

It appears that to make the several baseline change corrections consistent, the sign of $\delta_{steering}$ needs also to be flipped. We assumed this correction as well. This additional wrong sign has now been confirmed by the accelerator BEM group. Hence, the correction we used is:

$$E_{cor} = E_{HALLD:p}\frac{(1-\delta_{steering}-\delta_{orbit})}{(1+\delta_{steering}+\delta_{orbit})} \tag{1}$$

The corrections $\delta_{steering}$ and δ_{orbit} can be obtained from the EPICS variables HALLD:dpp_bpm and HALLD:dpp_corr, respectively.

In this note, we show the data both with the original values of the energy according to HALLD:p (uncorrected energy) and the corrected energy.

With the above corrections, the epics variable HALLD:p for the Spring 16 run, can be used on a (slow control) event-per-event basis.

Time (start, end)	energy (HALLD:p) (MeV) (uncorrected)	energy (corrected)	offset (MeV)	Notes on energy (once it is corrected)
02/13 13:00 02/15 11:00	12025±8	12057±4	0	Beam instable. Artificial energy jumps. The last 15h is artificially offset by -2 MeV.
02/15 17:00 02/16 8:30	12031±7	12051±7	0	Artificial energy jump of 2 MeV at the beginning. 02/16: 0:00 to 8:30am: Continuous -13MeV up drift is probably real.
02/17 11:00 02/20 8:00	12040±8	12043±9	0	Many energy drifts and jumps but all appears real.
02/20 14:00 02/22 4:19	$12040\pm^{25}_{10}$ $t < 30h$ 12012±4 $t > 30h$	12037±13 12069±7	0 0	Genuine and sudden jump from 12037 to 12069 MeV at the end.
02/22 20:00 02/23 8:30	12053±2	12053±2	-1	Beam down for 16h. Came back very stable but with a large baseline change. Possible artificial jump of -1 MeV at end of period.
02/23 18:00 02/25 10:00	$12133\pm^{14}_{7}$	12051±2	0	
02/25 10:00 02/26 9:00	$12055\pm^{20}_{14}$	12048 ± 212034 ± 6	0	Beam seem to have genuinely drift down by 15 MeV at the end of the period.
02/27 15:00 02/29 16:35	12101±3	12050±3	0	Beam was down for 30h. Came back with a +17 MeV offset. Can't assess if real. We assume that it is real.
02/29 17:00 03/01 9:00	12104±8	12045±8	(-15?)	Genuine -13 MeV drift at the start. Artificial +15 GeV shift at the end? This happened during TAC run, see logbook entry #3386965. Low current (2nA) makes BPM, i.e. energy meas. unreliable.
03/02 18:00 03/05 10:55	12098±8	12053±11	0	Genuine -15 MeV drift during the first half. Compensates for the +15 GeV shift at the end of previous period. Suggests that this -15 MeV was real?
03/05 20:10 03/06 16:10	12102±6	12052±9	0	Artificial -5 MeV jump for 2h. This happened around 11am. Nothing special to report at that time, see logbook entry #3388565.
03/06 20:00 03/07 18:00	12097±5	12056±4	-4	Should add +4 MeV for $t > 19$h. Due to optics adjustment: see logbook entry #3388964
03/07 18:00 03/08 9:00	12085±11	12064±11	-4	Artificial energy instability for the first 4h due to low current (BPM unreliable). Strong but real energy drift of 14 MeV during last 2h.
03/08 9:00 03/09 14:40	12090±5	12058±5	-4	Genuine -12 MeV drop occurred between previous period and this one.

Table 1: Hall D electron beam energy binned in periods of approximate energy stability. The error are not measurement uncertainties but bracket the systematic drift range during the time period. The second column provides the energy uncorrected for the δ_{orbit} and $\delta_{steering}$ sign mistakes or any other artificial jumps of the HALLD:p measurement, while column 3 attempts to provide a corrected number. The 4th column provides the offsets used for the correction.

Time (start, end)	energy (HALLD:p) (MeV) (uncorrected)	energy (corrected)	offset (MeV)	Notes
03/27 13:00 03/28 9:41	$12094\pm^{14}_{3}$	Mostly 12057±3 3h of 12045±3	0?	18 days down time $\Longrightarrow$ Offset set to 0 arbitrarily. Genuine jump down and then up of 17 MeV for 3h.
03/28 19:10 03/30 10:10	12103±8	12049±8	-1?	Genuine drift of 16 MeV. Probably a +1 MeV artif. jump in middle of period. Happened after RF separator work, see logbook entry #3393171
03/30 10:10 04/01 1:10	12116±7	12042±12	-1	Long genuine drift down seen in previous period continue for 23 MeV.
04/02 1:50 04/04 7:50	12120±11 $t < 22h$ 12120±11 $22 < t < 25h$ 12120±11 $25 < t < 47h$ 12120±11 $t > 47h$	12029±6 12021±4 12027±7 12038±2	-3	Large energy fluctuation (20 MeV) appears real apart for a possible +2 MeV offset occurring in the middle of the period. Happened during tuning struggle, see logbook entry #3394648
04/07 14:00 04/09 8:00	12097±6	12052±7	-3	Beam down for 3 days. Came back with $\sim$ 8 MeV offset. Unclear if this is real. We tentatively assume so.
04/09 8:00 04/11 00:00	12095±4	12055±4	-3	
04/11 00:00 04/12 7:00	12095±1 $t <$ 9h 12115±2 $t >$ 9h	12056±2	-3	Beam down for 6h. Several artificial spikes due to HARP scans.
04/13 1:50 04/15 8:50	$12115\pm^{3}_{5}$	12053±5	-3	Multiple artificial spikes. (HARP scans)
04/15 8:50 04/17 15:26	$12097\pm^{2}_{3}$	$12050\pm^{4}_{2}$	-3	Several artificial spikes. (HARP scans)
04/17 18:00 04/20 2:50	12121±6	12045±5	-3	Beam went down on 04/17 15:23. Came back less stable, with overall systematic up drift and many artif. downward spikes. (HARP scans)
04/20 6:00 04/20 16:00	12124±8	12039±3 12048±3	-3	Real +4 MeV jump between this period and previous one, after 4h15 down time. The beam energy increased by 9 MeV during the run.
04/20 21:00 04/22 11:00	12115±6	$12053\pm^{9}_{2}$	-1	Two artif. downward spikes at $t \simeq$ 3h and $t \simeq$ 23h. +2 MeV offset occurring 2h after the start of the period. Happened during retuning, see logbook entry # 3401251
04/22 19:10 04/25 6:06	12118±5	12051±5	-1	Artif. downward spikes at $t \simeq$ 27h. (HARP scans)

Table 1 (cont.)

2 Slow drifts and fast variations

Energy drifts can occur over periods of hours and shift the energy by 10s of MeV. Those are believed to be real energy variations for the following reasons:

- They correlate with the x-position of the beam after the tagger magnet (AD00c BPM in the tagger beam dump) but they do not correlate with the y-position. The tagger magnetic field is horizontally bending and thus serves as an electron momentum analyzer. A change in beam energy would result in a x-displacement after the tagger magnet, but no y-displacement.
- Likewise, they correlate with the y-position of BPM 5C02-y in the vertical ramp up to the tagger, but not with 5C02-x.
- They correlate, although not systematically, with the changes seen in arc energies and with the Hall A energy.
- Apart for their signs, they are not affected by the corrections for the δ_{orbit} and $\delta_{steering}$ sign mistakes.

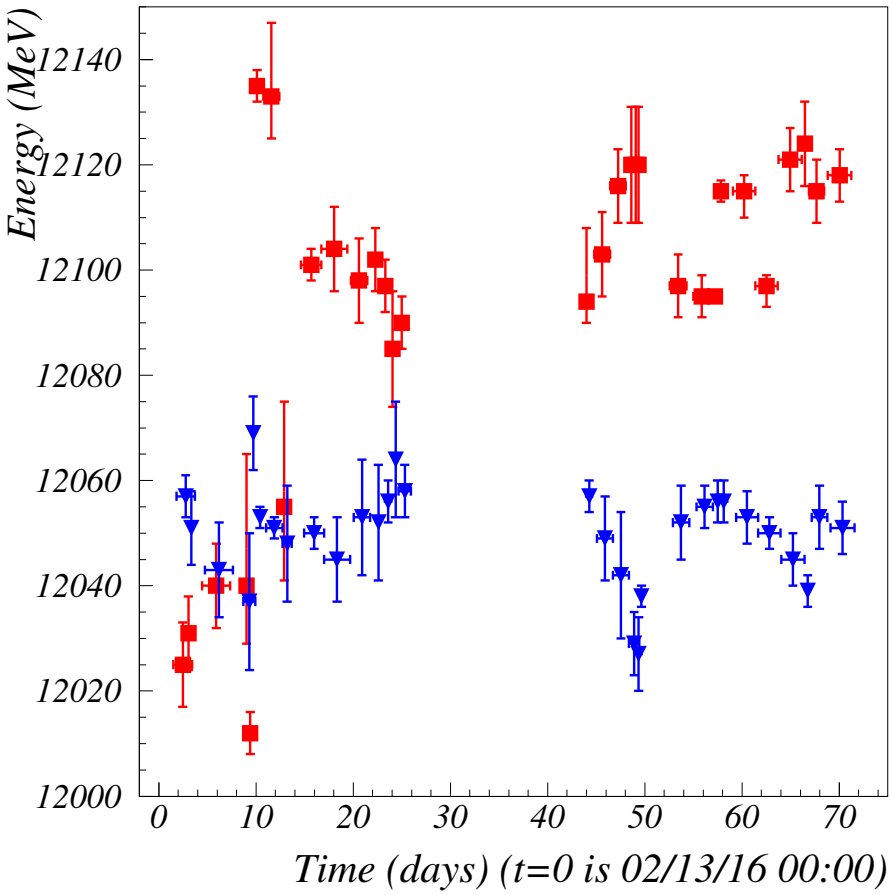


Figure 1:
Hall D electron beam energy binned in periods of approximate energy stability. The vertical error bars are not measurement uncertainties but bracket the range of the systematic drift during the time period. The horizontal error bars provide the time range over which the energy is averaged. The values given by the red squares are uncorrected for the artificial energy jumps. The blue triangles are corrected for the artificial jumps. The time for the blue triangles is artificially shifted by 0.3 days for visual clarity.

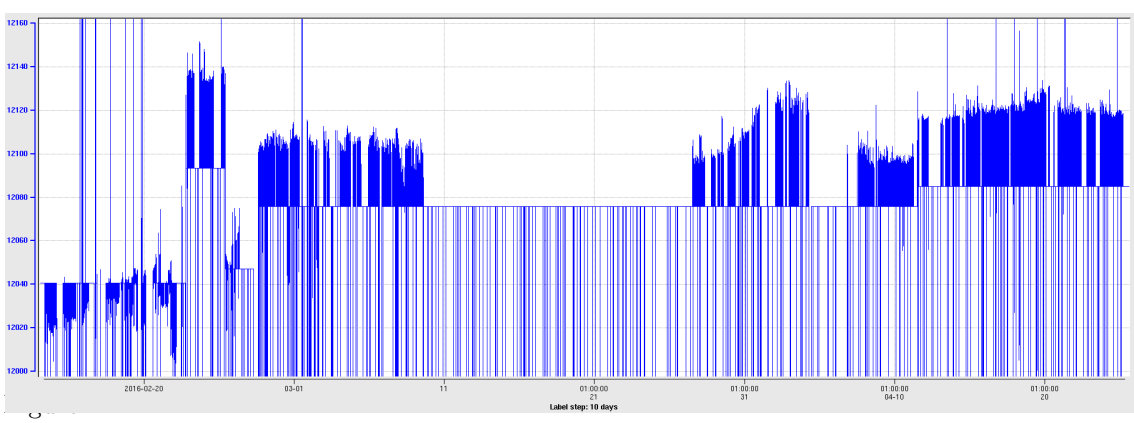


Figure 2: Uncorrected Hall D electron beam energy (HALLD:p) during the Spring 16 run, from MyaViewer.

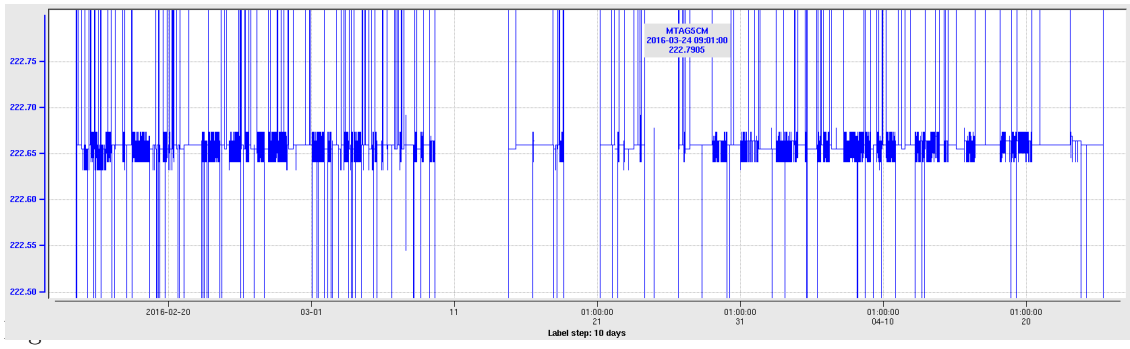


Figure 3: Tagger current during the Spring 2016 run.

Faster oscillations of the energy, typically with a period of a few minutes and amplitude of a few MeV seem real too for the same reasons as listed above.

An example of clear real energy drift can be seen for the Feb. 29 17:00 → Mar 03 9:00am period, see Fig. 23. However, at the end of the period, a shift occurred on the AD00c-x vs energy plot. This could be interpreted as either an artificial energy drop of about -5 MeV or a genuine x-displacement of the beam of -2mm. In this document, we will generally assume that the beam position was stable and that the change is a change in HALLD:p. The reason for this choice is because the beam position and angle were locked, starting Feb. 19th, with PID locks on BPM 5C11b and on the active collimator. When it is necessary to establish unambiguously if the change is genuine, we also analyze the 5C11, 5C11a, 5C11b beam position data before the tagger magnet, as well as 5C02 (a vertically dispersive BPM which should correlate with energy drifts) and 5C08, a non-dispersive BPM which should not correlate. However, we often found cases where both 5C02-y and 5C08-y are correlated to beam energy. This can be seen clearly on Fig. 34 where the beam energy drifts are clearly genuine from the AD00C BPM (apart for a period shown in red), but for which both 5C02-y and 5C08-y also correlate with beam energy.

3 Energy jumps during beam delivery

The largest jumps (30 to 100 MeV) are believed to be artifacts for the following reasons:

- The beam pipe size could not accommodate the change in beam orbit that would follow such jumps.
- There is no correlation between these energy changes and the beam x-position after the tagger.
- They disappear after corrections for the δ_{orbit} and $\delta_{steering}$ sign mistakes.

4 Beam current

The BPMs provide the input for calculating HALLD:p. They are not reliable bellow 40 nA and thus the HALLD:p information is also unreliable. An example can be seen in March. 7th 18:00-22:30, see Fig. 35, Hall D logbook entry # 3389136.

5 Tagger field stability

The tagger magnetic field is used to analyze the energy of the beam after it hits the radiator. The tagger current was stable over the entire runs (except when it was ramped down because there was no beam) at a value of 222.660±0.010 V, see Fig. 3. (The epics variable for the read-back is MTAG5CM, and the set-point is MTAG5C.S)

6 Absolute value of the beam energy

This study is concerned with energy changes. We do not know the accuracy on the absolute value of the energy. In Table 1, we corrected for the energy jumps that are identified as artifacts. The energies are given relatively to the initial energy at the start of the run.

7 Energy jitter from AD00C-x

This analysis is not sensitive to any high frequency ($>$ Hz) jitter. These contributions at 60 Hz and 10-20 Hz (microphonics) are known to be present (Todd Satogata). The low frequency jitter ($<$ Hz) is typically of $\sigma \lesssim 0.5$ MeV.

8 Correlation coefficient

Since the field of the tagger magnet was constant and since the BPM calibration should be stable, the correlation coefficient between AD00C and the beam energy should be constant throughout the run. The following table lists the approximate linear relation $energy = a \times AD00Cx + cst$ (note: the uncertainty sometimes quoted corresponds to discrete systematic variations). The coefficient is usually stable around -2.6±0.5 MeV/mm, in good agreement from the expectation -2.4 MeV/mm from D. Sober, but it sometimes changes significantly, see table below and Fig. 4. It may be due to calibration changes of the BPM in the ramp or in the dump. Some of the variation of the offset could be due to x-position/angle change of the beam, although we expect this to be small due to the slow locks that were implemented starting on Feb. 19th. Assuming a uniform and constant tagger field and no correlation between beam motion and (genuine) energy drift, the slope should be independent of such events. However, these locks were not systematically turned on.

Period	$a \times AD00Cx + cst$ (uncorrected for offsets)
02/13-02/15	-3.1x+12060.
02/15-02/16	-10.3x+12053.5
02/17-02/20	(-9±1)x+12057±2
02/20-02/22 start, middle, end	 -13.0x+12085 -10.5x+12082. -4.8x+12078
02/22-02/23	-3.9x+12062.0±0.5
02/23-02/25	-2.8x+12059.5
02/25-02/26	-
02/27-02/29	-2.8x+12057
02/29-03/01 start end	 -3.0x+12057.7 -3.5x+12066.0
03/02-03/05 start middle end	 -3.0x+12071.0 -7.0x+12064.5 -4.0x+12063.0
03/05-03/06 start end	 -2.9x+12063.0 -5.0x+12071.0
03/06-03/07	-4.3±0.8x+12064±2
03/07-03/08	-4.7x+12069.0
03/08-03/09	-4.7x+12070.0
03/27-03/28	-3.x+12055±5
03/28-03/30	-2.8x+12055.5
03/30-04/01 AD00c-x$\lesssim$6mm AD00c-x$\gtrsim$mm	 -2.8x+12055.5 -4.9x+12067.
04/02-04/04	-2.4x+12021 or -2.9x+12033 or -4.5x+12063.
04/07-04/11	-3.0x+12059. -1.2x+12055.
04/11-04/12	-3.0x+12059.
04/13-04/15	-3.0x+12057.
04/15-04/17	-2.7x+12056.5
04/17-04/20	-2.7x+12057.5
04/20-04/20	-2.7x+12056.5
04/20-04/22	-2.7x+12056.5
04/22-04/25	-2.7x+12057.5

9 Conclusions

The epics variable providing the Hall D electron beam energy indicates that it varied over a ∼1% range during the Spring 2016 run. Some of these variations are genuine and some are artifacts of the magnetic energy measurement method. One can usually distinguish between both cases, but sometimes, the nature (real or artifact) of the variation is ambiguous. The Hall D energy is systematically anti-correlated with the Hall A and arcs energies. The origin of the artificial drifts and negative correlation is due to sign mistakes in the program generating the epics variable (BEM -beam energy monitor- program). Once those are corrected for, these problems disappear and the Hall D energy appears to be stable within 50 MeV.

Real drifts of up to 20 MeV over a periods of tens of hours can occurs, as well as large sudden change (30

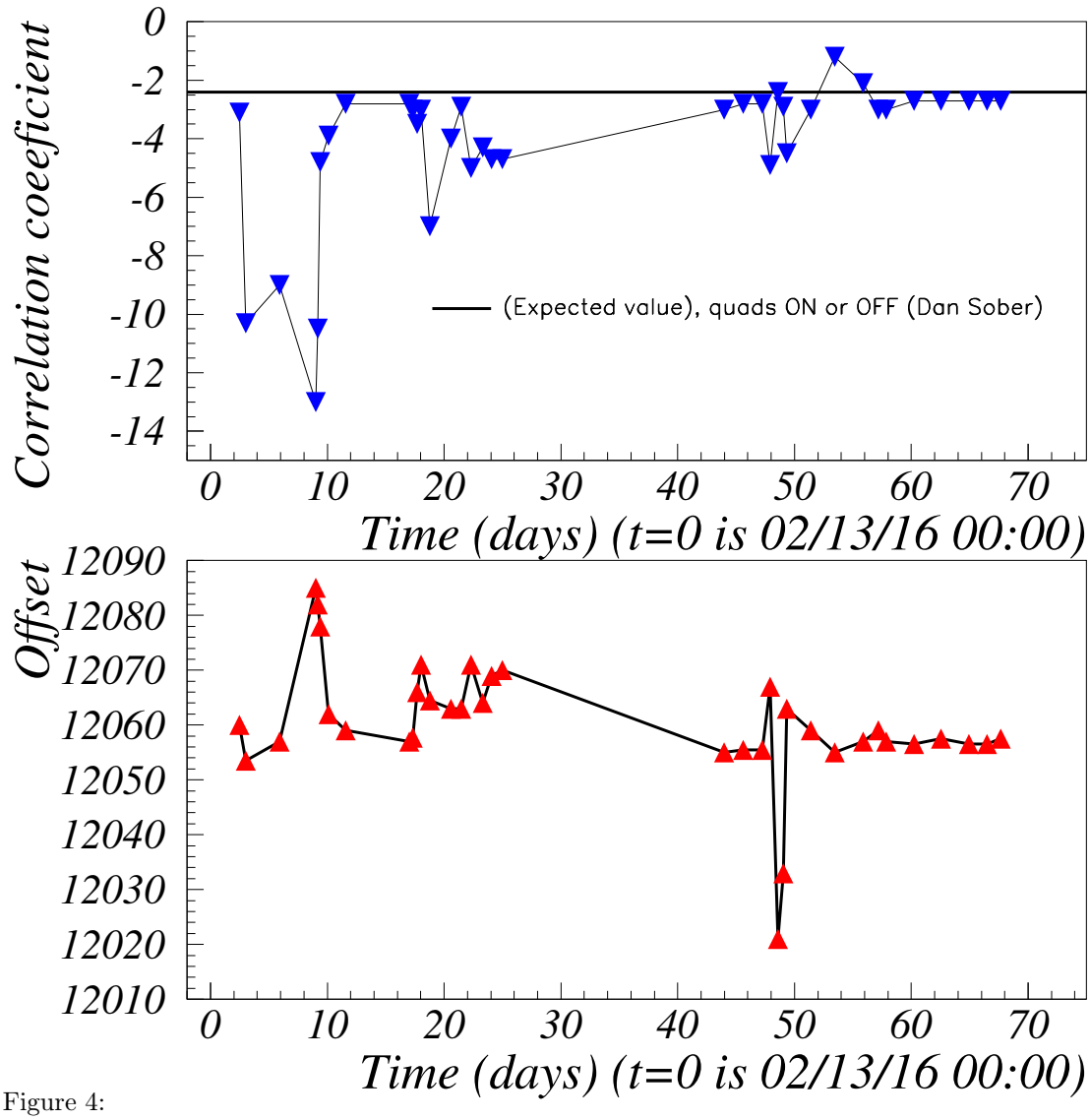


Figure 4:
Coefficient values for the $energy = a \times AD00Cx + cst$ fit during the Spring 2016 run. Top plot: coefficient a. The plain line is the expectation -2.4 MeV/mm from D. Sober. Bottom plot: coefficient cst.

MeV) of energy. Other mis-readings of the energy occur but they can be traced back to low beam current ($\lesssim$50 nA) operations, machine tuning, or in case of energy spikes, to harp scans.

With the sign correction given by Eq. (1), epics data can be used on a event-per-event basis.

This document provides the average energy (corrected for artificial shifts) in time periods of approximate energy stability. Values with finer time binning are also available from the Appendix.

The accuracy of absolute energy is not presently known.

10 Appendix: Detailed analysis of the individual periods

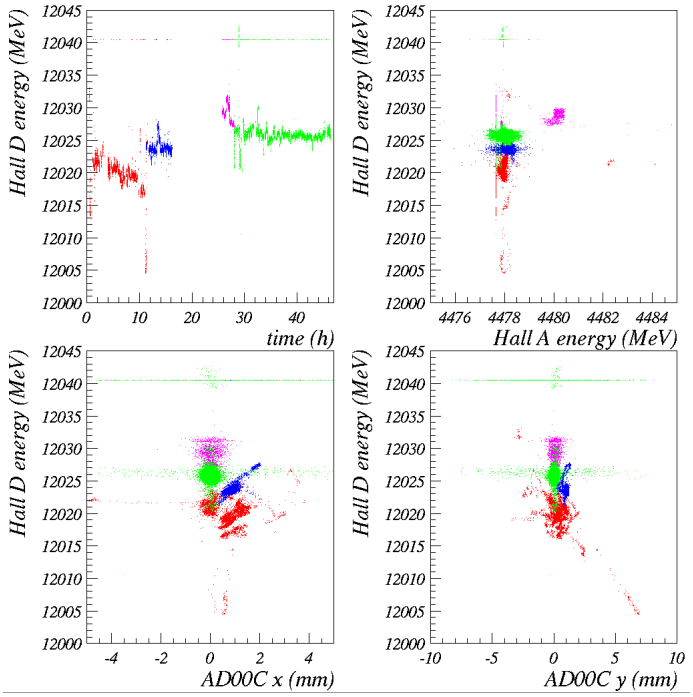


Figure 5: Uncorrected beam energies and beam x-y positions at the AD00C BPM (Hall D tagger dump). The top left panel displays the time evolution of the Hall D electron energy. The top right plot displays the correlation between the Hall A and Hall D energies. The bottom left plot displays the correlation between the Hall D energy and the x beam-position at AD00C. The bottom right plot is for the correlation between the Hall D energy and the y beam-position at AD00C. **(uncorrected beam energies)**
The data are for the Feb. 13 13:00 → Feb 15 11:00am period. The colors correspond to different slices of time.

10.1 Feb. 13 13:00 → Feb 15 11:00am

Fig, 6 displays the corrected energies while Fig, 5 displays the uncorrected one. The following discussion and all subsequent ones for different time period refer to the Figure giving the corrected energies.

Beam was instable during that period. The jumps between the time periods coded by colors seem to be artificial: they do not fall in the AD00C-x vs energy correlation pattern. Likewise, the two spikes at $t \simeq 0$ and $t \simeq 11$h are artifacts: there is no correlation for x but a significant one for y. The only correlation indicating genuine energy changes is during the purple period.

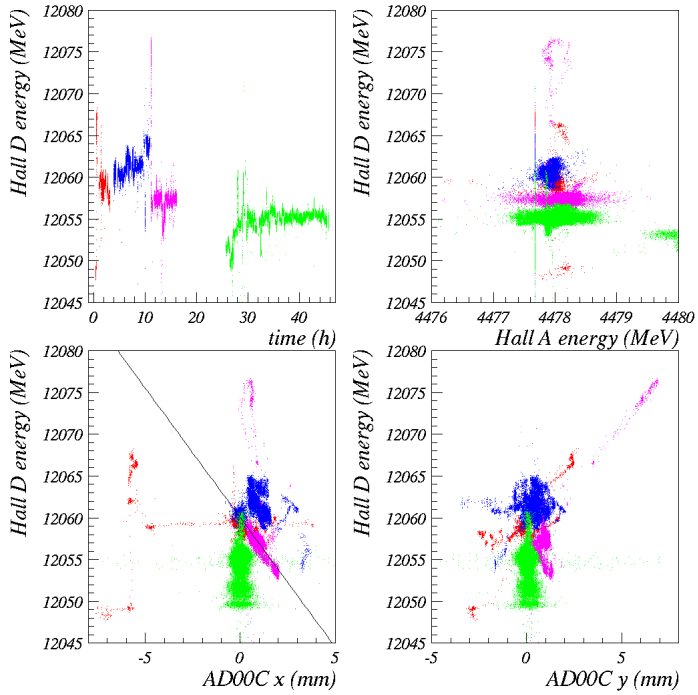


Figure 6:
Same as Fig. 5 but with the energies corrected for the $\delta_{steering}$ sign mistake. The line on the bottom left panel is the fit used to extract the coefficients given in the table of Sec. 8. **(corrected beam energies)**

10.2 Feb. 15 17:00 → Feb 16 8:30am

There is a correlation between AD00C-x and the energy drift, which usually signals a genuine energy change. However, AD00y also displays a (smaller) correlation, which is atypical. There is no correlation between the Hall D drift and the Hall A energy. The origin of the drift is unclear: the energies measured past arc 4 (arc 2 during the early magenta period), when measured, display a correlation (see Fig. 9). This, along with the facts that 5C02-y is strongly correlated with the Hall D energy but 5C08-y is not, indicates that the 13 MeV drift is real, with probably a smaller y drift of the beam. The initial +2 MeV jump between the red and blue periods is artificial (no correlation with AD00Cx). However, the one between magenta and green is real, as it fall in the AD00cx vs energy correlation pattern.

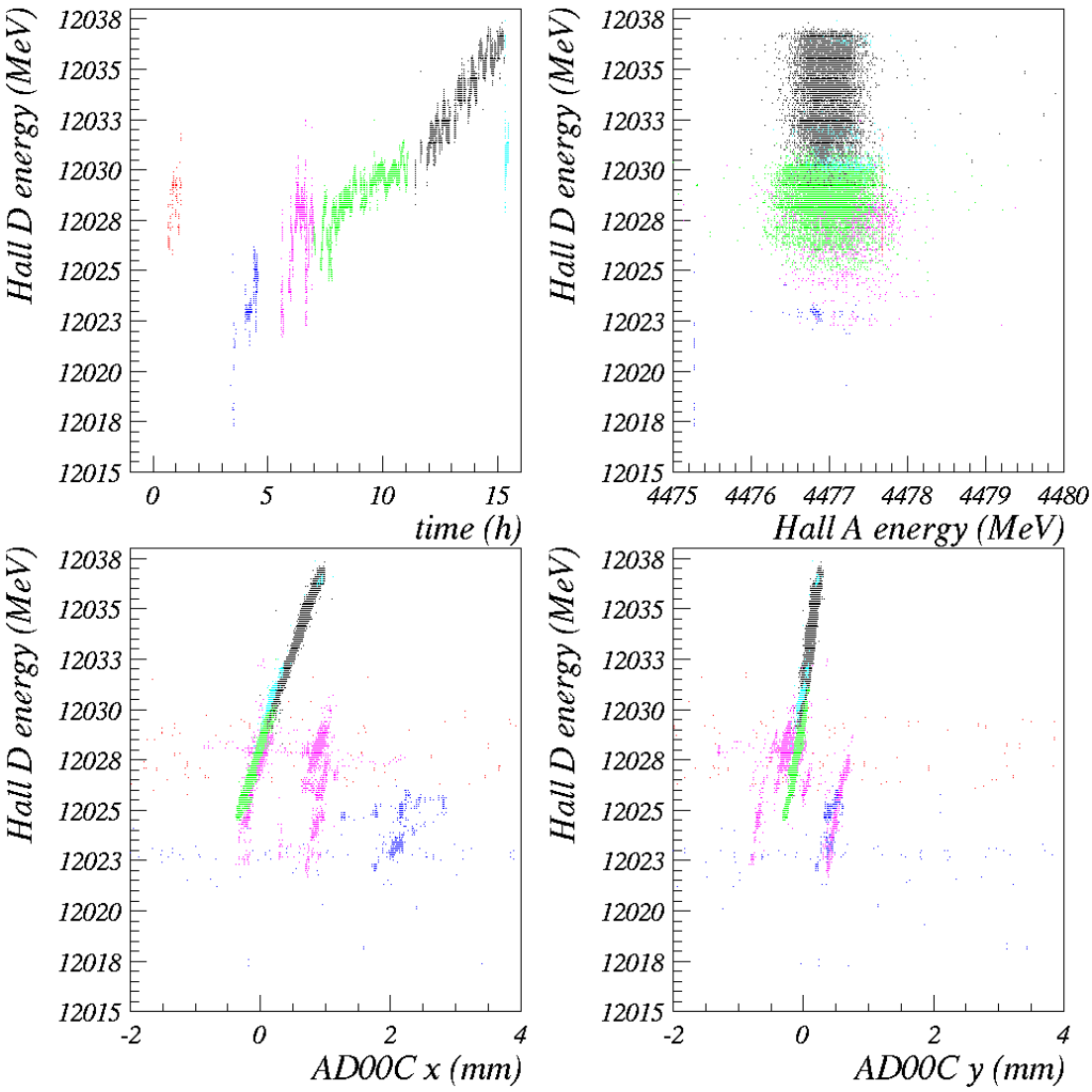


Figure 7:
Same as Fig. 5 but for the Feb. 15 17:00 → Feb 16 8:30am time period. **(Uncorrected beam energies)**

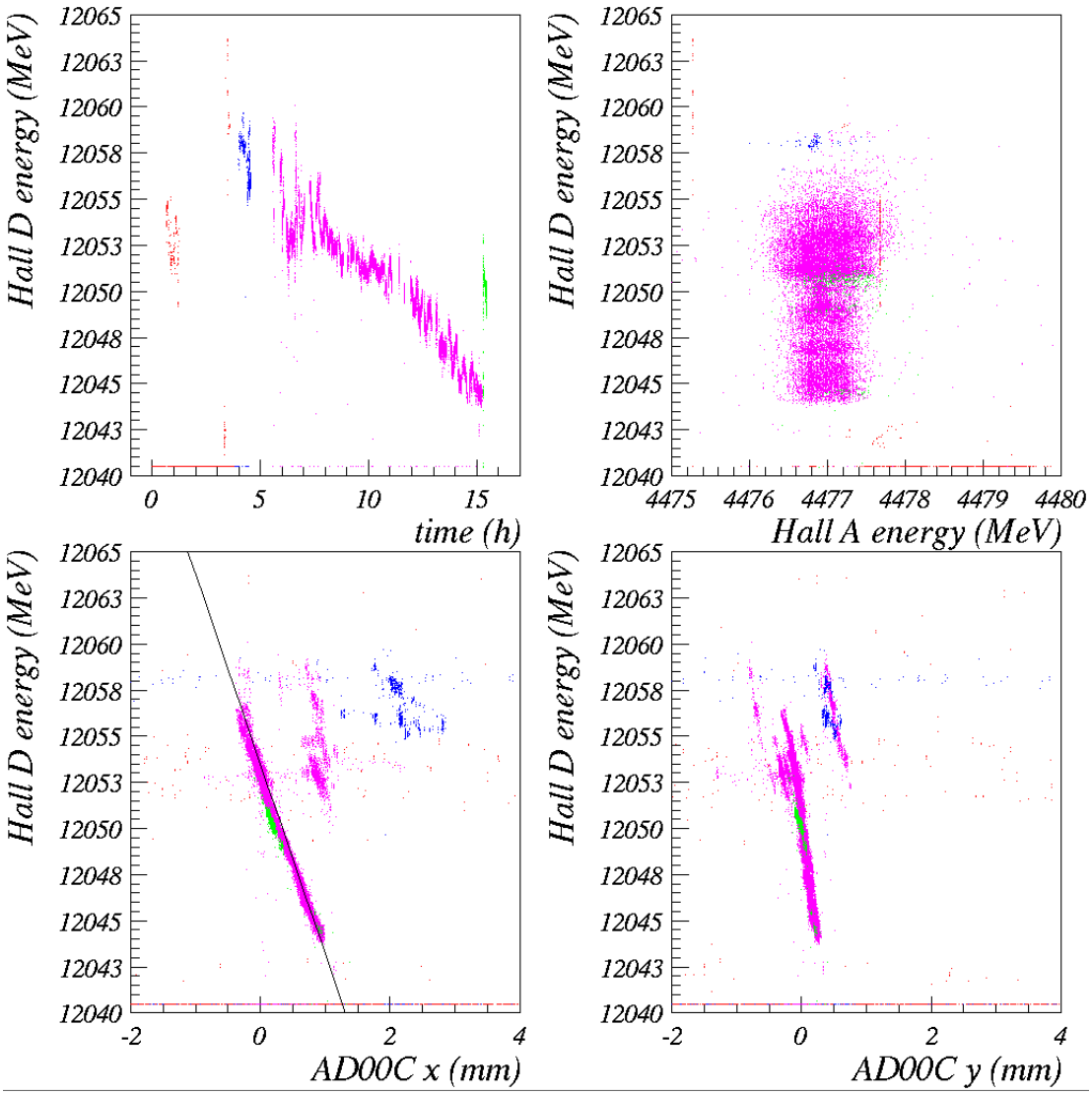


Figure 8: Same as Fig. 6 but for the Feb. 15 17:00 → Feb 16 8:30am time period. **(Corrected beam energies)**

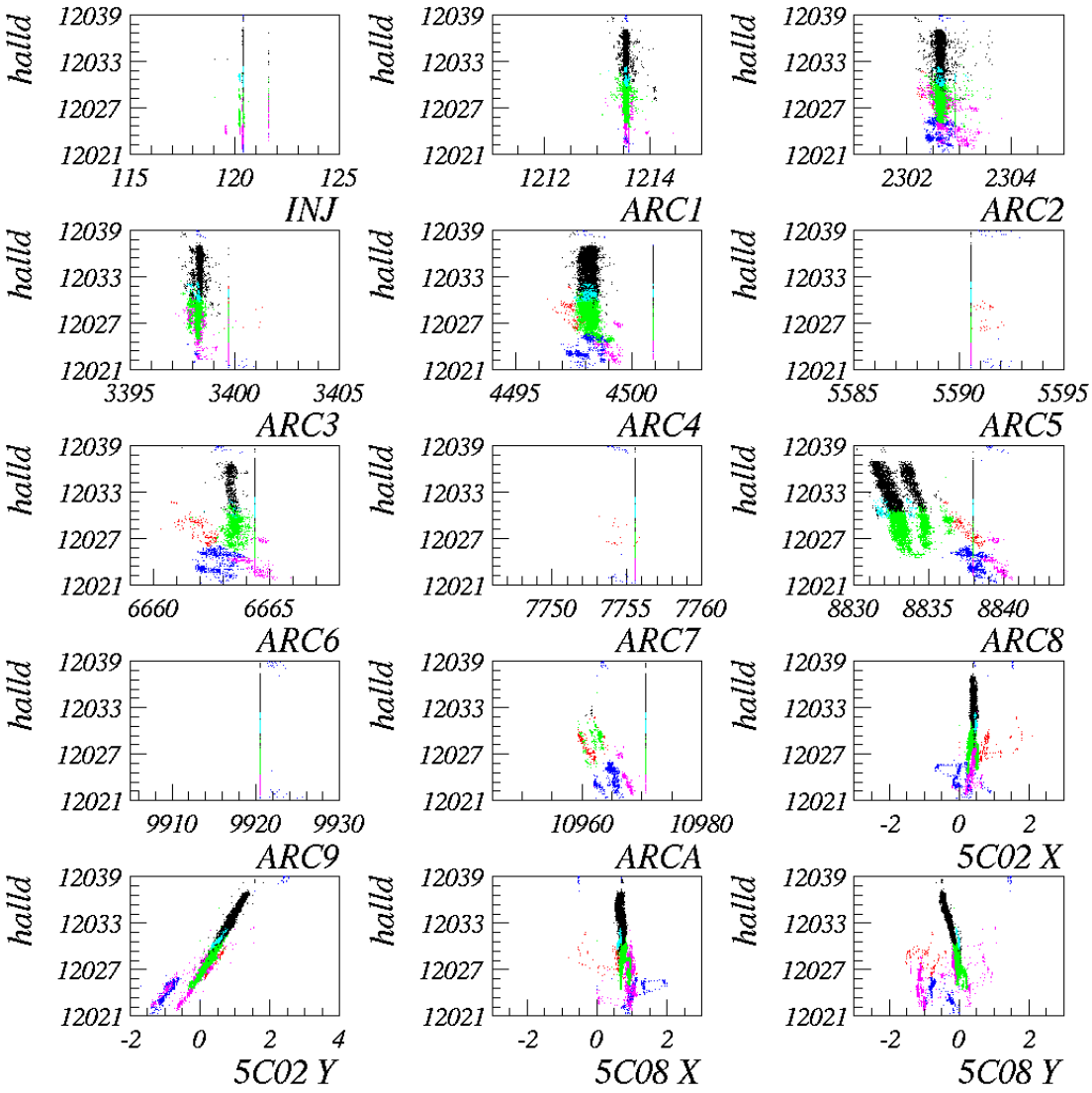


Figure 9:
Correlations between the uncorrected Hall D electron beam energy and the beam energy at the injector and various arcs (first 11 plots), and between the Hall D energy and BPM 5C02 and 5C08 (last 4 plots). The data are for the Feb. 15 17:00 → Feb 16 9:00am time period.

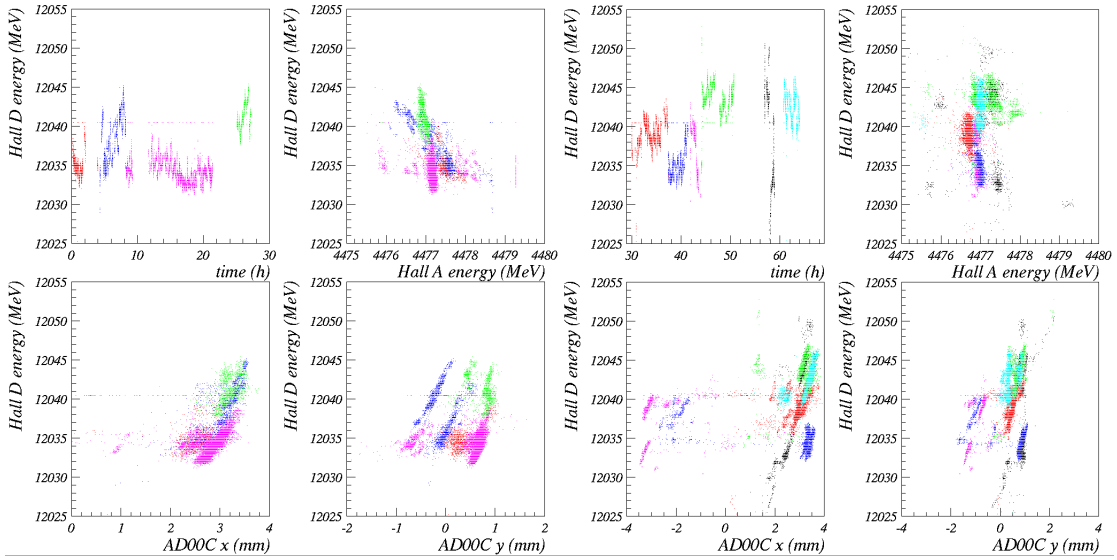


Figure 10: Same as Fig. 5 but for the Feb. 17 11:00am → Feb 18 21:00 time period (left) and Feb. 18 21:00 → Feb 20 8:00am time period (right). **(Uncorrected beam energies)**

10.3 Feb. 17 11:00am → Feb 20 8:00am

There is a significant energy instability during this period. We split it in two parts for clarity (see figure 10).

On the left 4-panel figure (first 30h), the energy fluctuations during the time periods coded are real: they fall in the correlation pattern with AD00C-x. Correlation are present for both in AD00C-x and -y.

The instability is greater during the second part, $t > 30$h. The same problem with correlation appearing both in AD00C-x and -y is seen on the second 4-panel figure. It is difficult to say whether the apparently artificial jumps for the magenta and blue period are not due instead to BPM drifts, as clearly seen for the green period.

Correlations of the Hall D energy with arcs and BPM 5C02 and 5C08 are shown on Fig. 31. Non-dispersive BPM 5C08-y unexpectedly shows a negative correlation with energy of the same magnitude as the 5C02-y correlation. This would suggest vertical-drifts of the beam rather than energy drift.

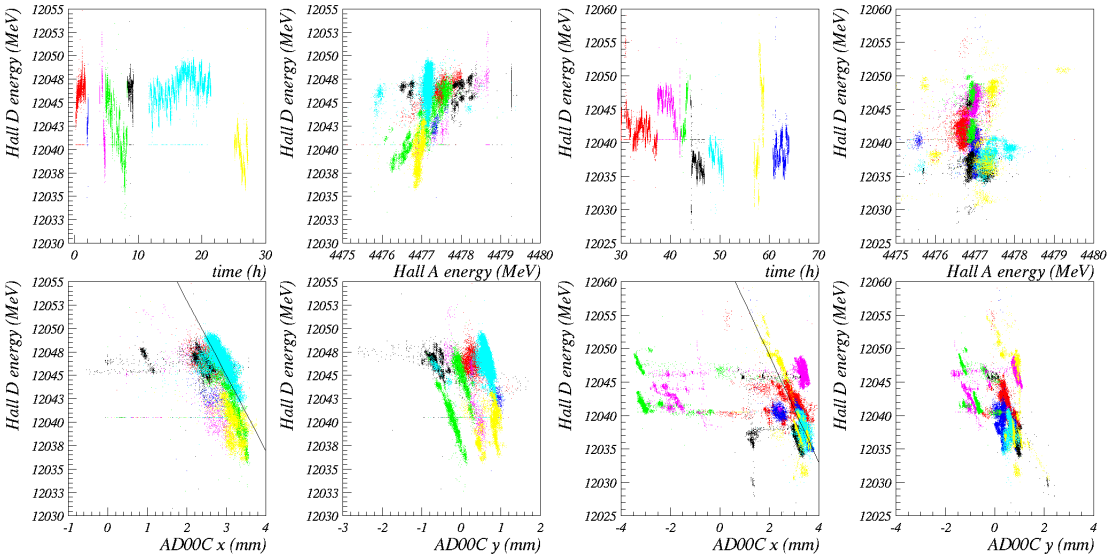


Figure 11:
Same as Fig. 6 but for the Feb. 17 11:00am → Feb 18 21:00 time period (left) and Feb. 18 21:00 → Feb 20 8:00am time period (right). **(corrected beam energies)**

10.4 Feb. 20 14:00 → Feb 22 4:19am

All energy changes are real, including from the energy jumps after the blue and after the green periods, as they fall in the AD00C-x vs energy correlation pattern. The reason for true energy jump near t=30h (Feb. 21, 20:37) is unknown. The beam current changed from about 55 nA to 40 nA (see logbook entry 3382425).

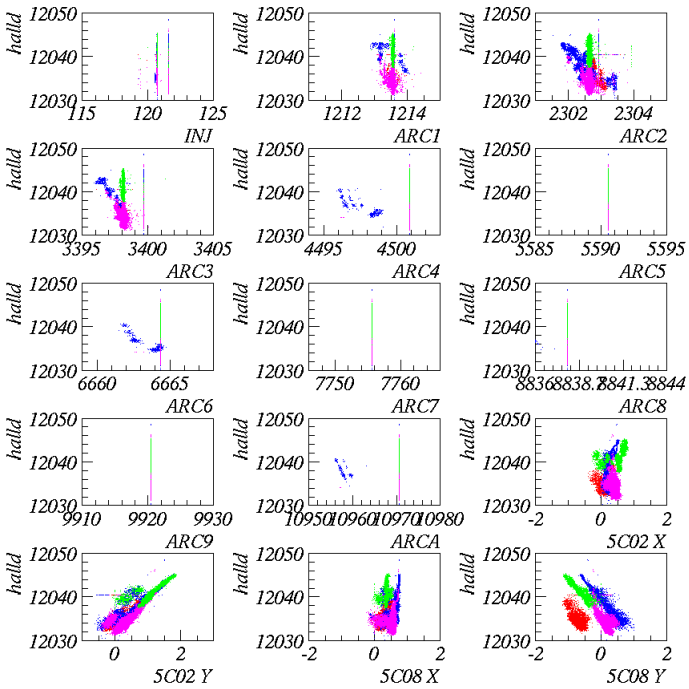
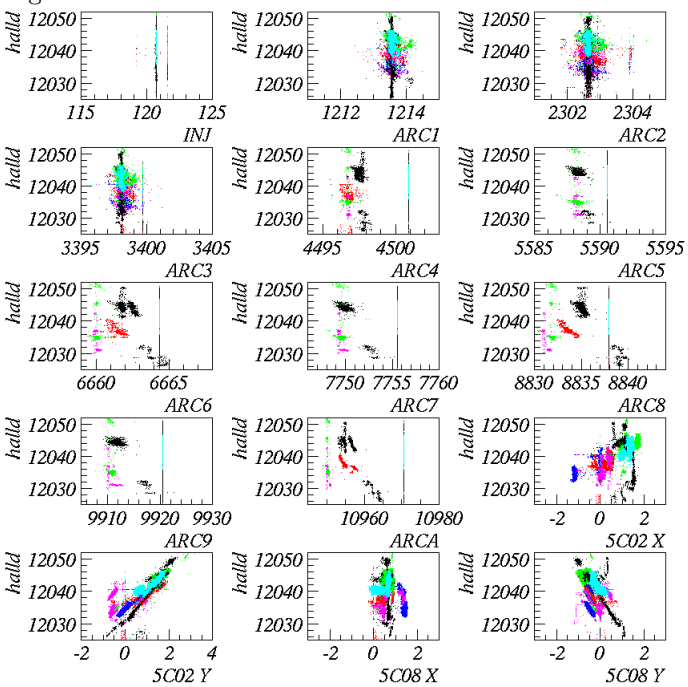


Figure 12:



Same as Fig. 9 but for the Feb. 17 11:00am → Feb 18 21:00 time period (first set of panels) and Feb. 18 21:00 → Feb 20 8:00am time period (second set of panels). **(Uncorrected beam energies)**

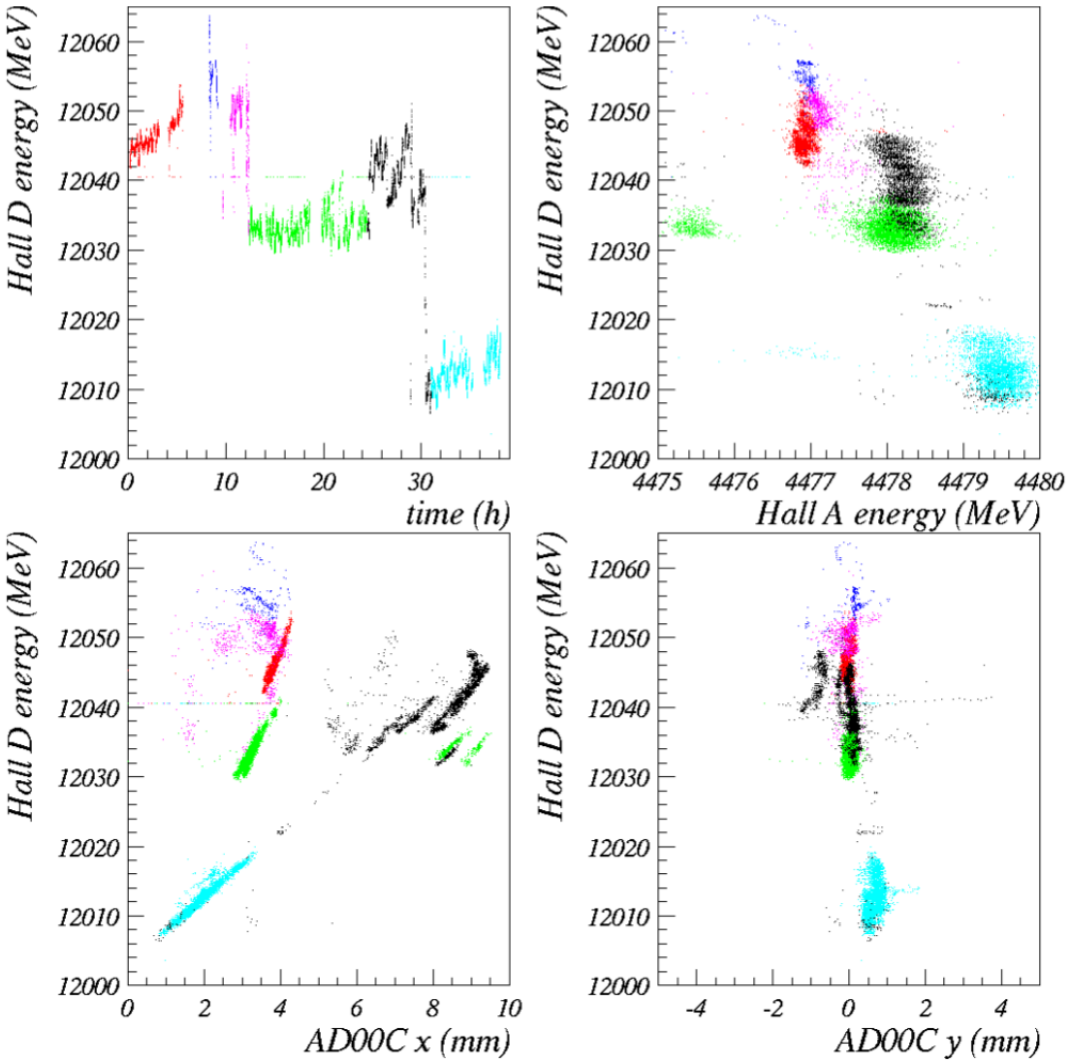


Figure 13:
Same as Fig. 5 but for the Feb. 20 14:00 → Feb 22 4:19am time period. **(Uncorrected beam energies)**

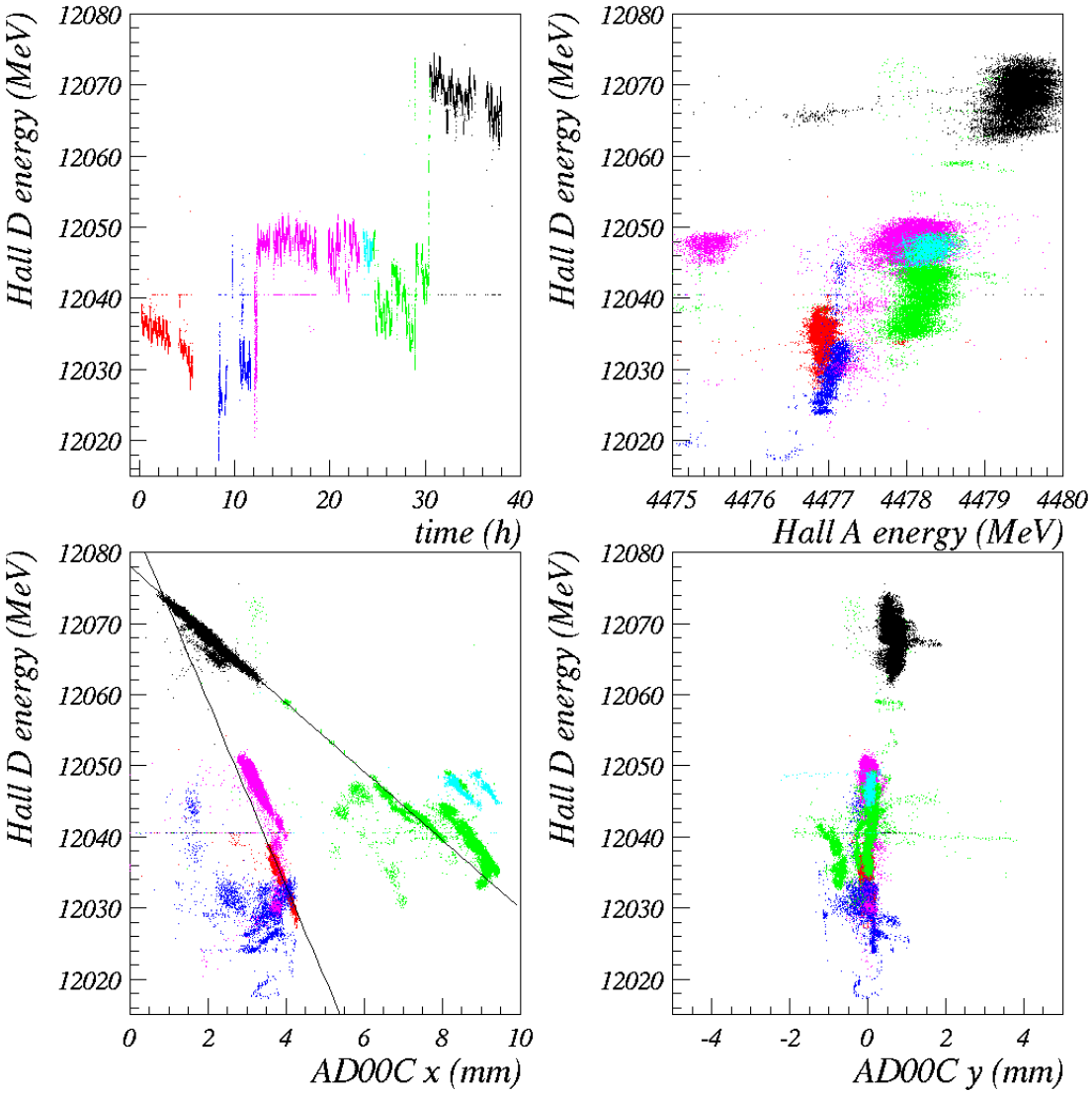


Figure 14:
Same as Fig. 5 but for the Feb. 20 14:00 → Feb 22 4:19am time period. **(corrected beam energies)**

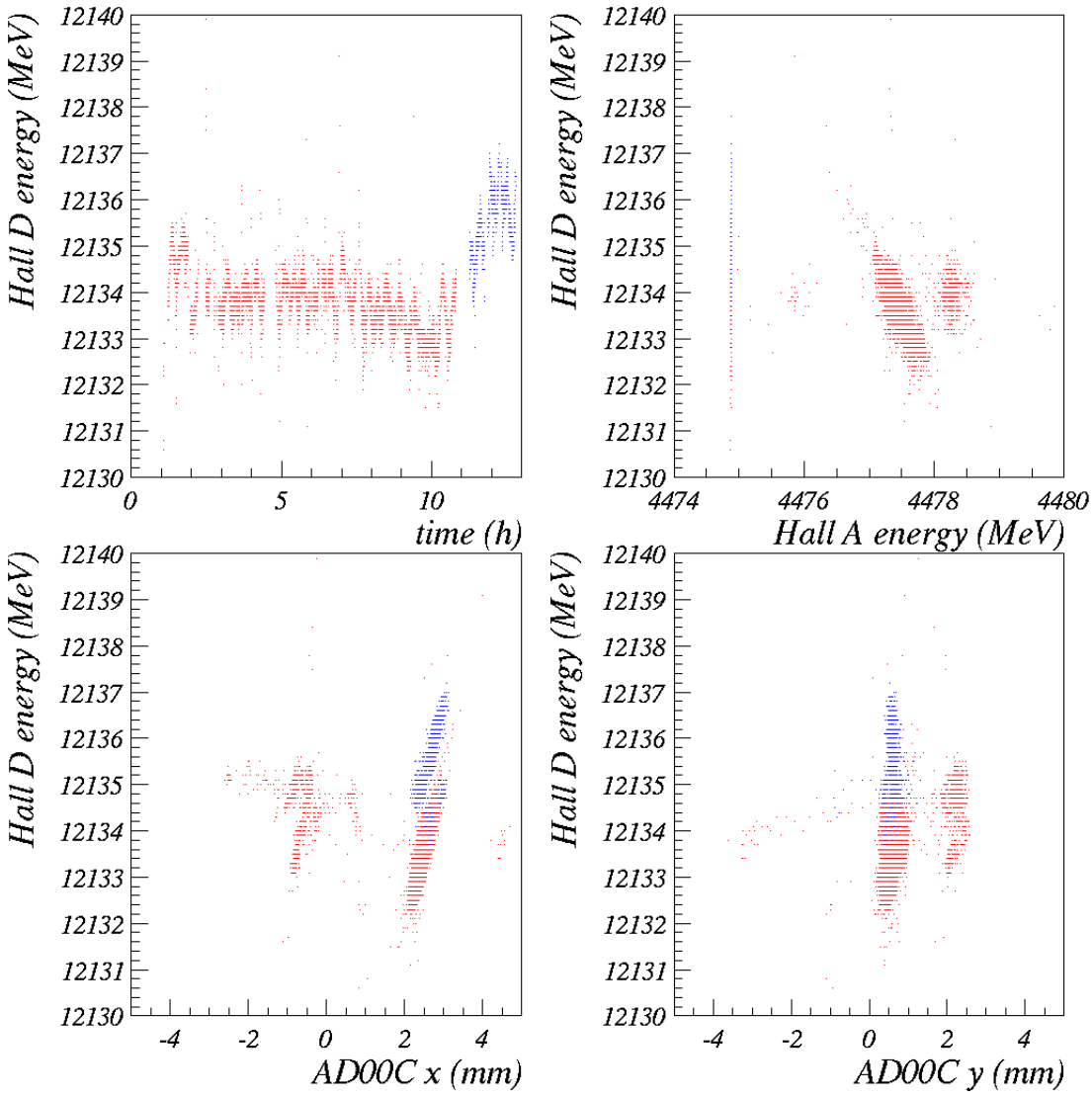


Figure 15:
Same as Fig. 5 but for the Feb. 22 20:00 → Feb 23 8:30 time period. **(Uncorrected beam energies)**

10.5 Feb. 22 20:00 → Feb 23 8:30

The energy drifts are real. There used to be a large increase of 120 MeV in HALLD:p between the former period (Feb. 20 14:00 → Feb 22 5:00am) and this period (Feb. 22 20:00 → Feb 23 18:00) due to a large baseline change. It is well corrected for by correcting the sign of $\delta_{steering}$. There is possibly a small artificial energy jump of -1 MeV between the blue and magenta period.

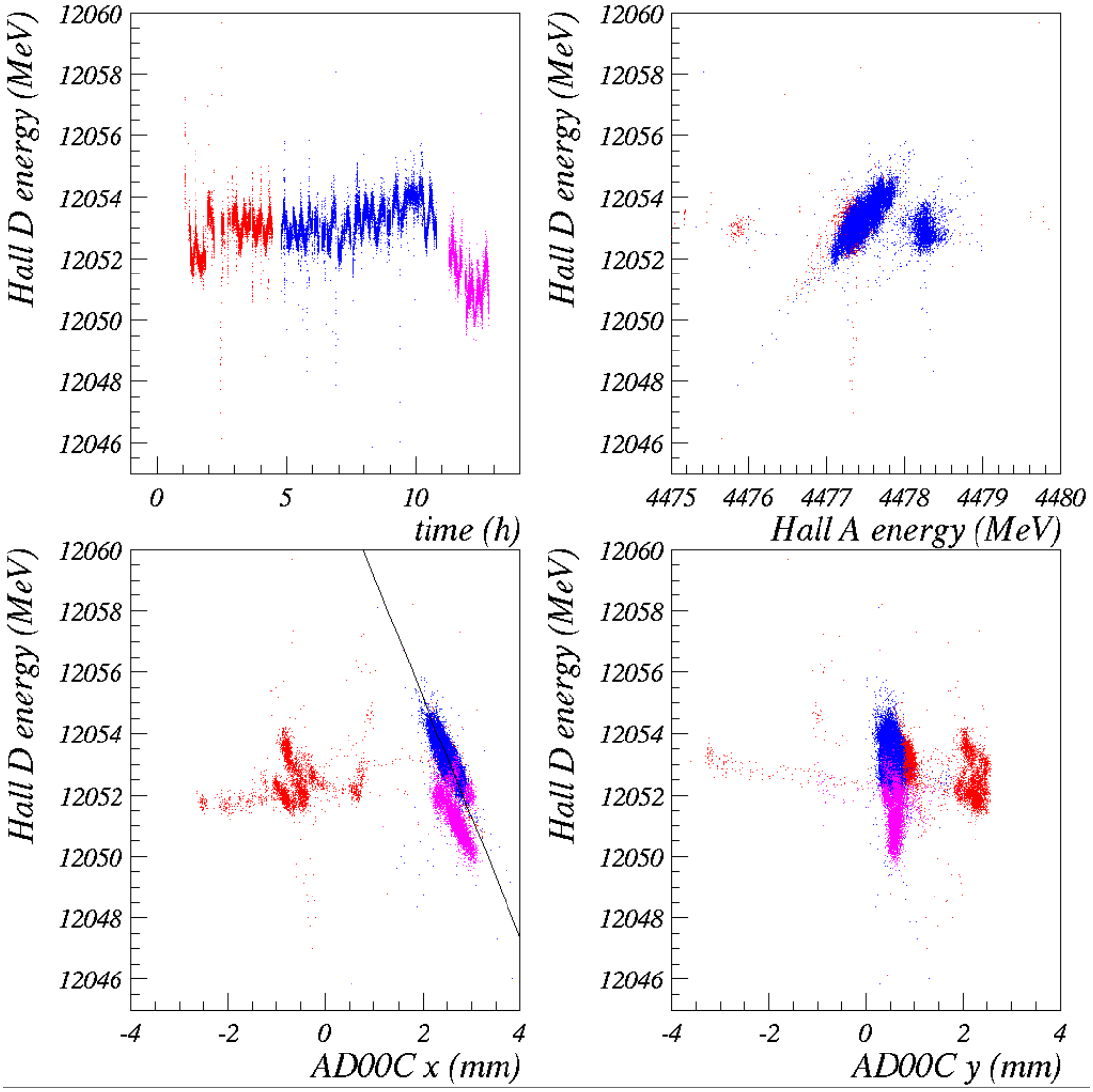


Figure 16: Same as Fig. 5 but for the Feb. 22 20:00 → Feb 23 8:30 time period. **(corrected beam energies)**

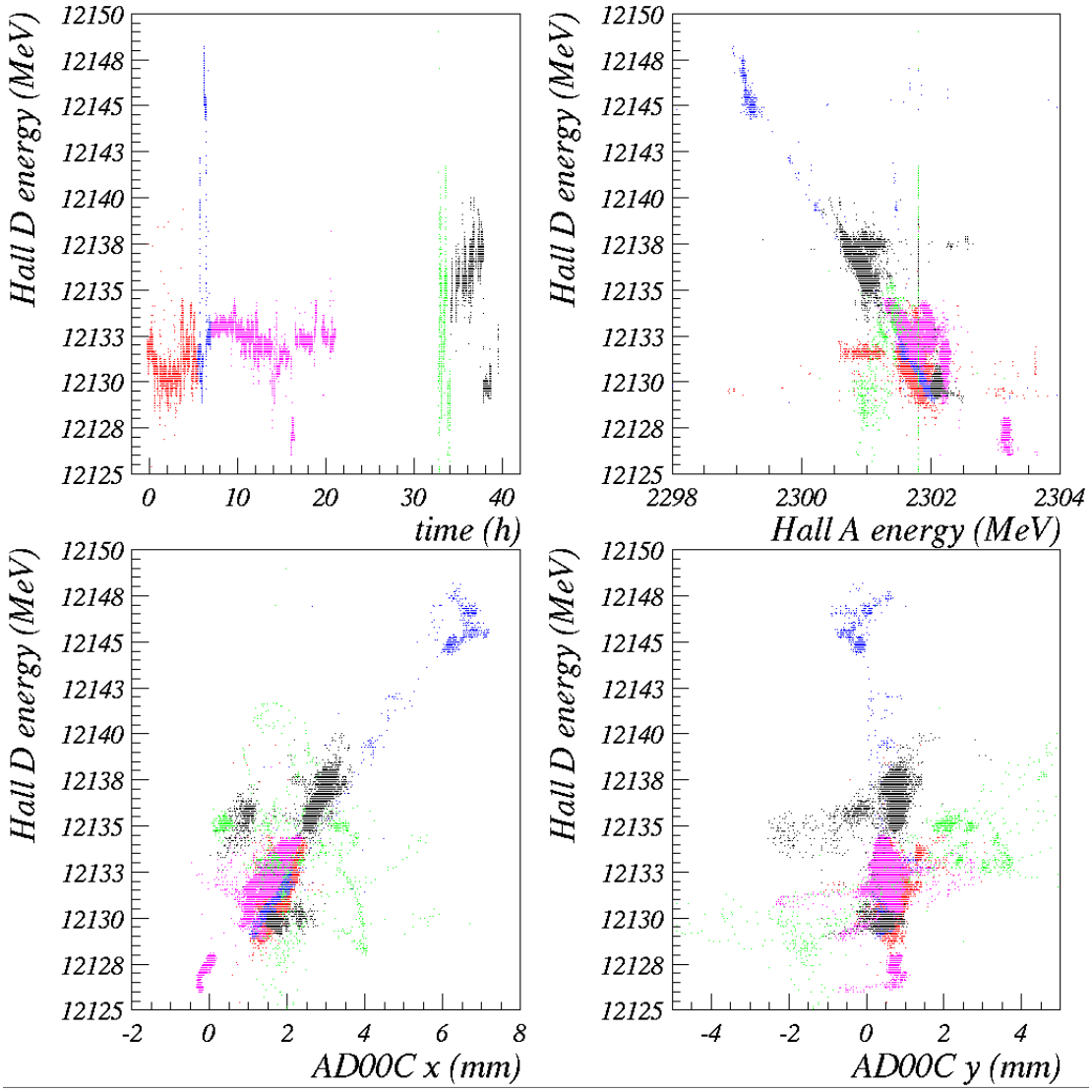


Figure 17: Same as Fig. 5 but for the Feb. 23 18:00 → Feb 25 10:00am time period. **(Uncorrected beam energies)**

10.6 Feb. 23 18:00 → Feb 25 10:00am

The energy drifts are real except for the large excursions during the blue, green and black periods. (Hall A is now at 1 pass).

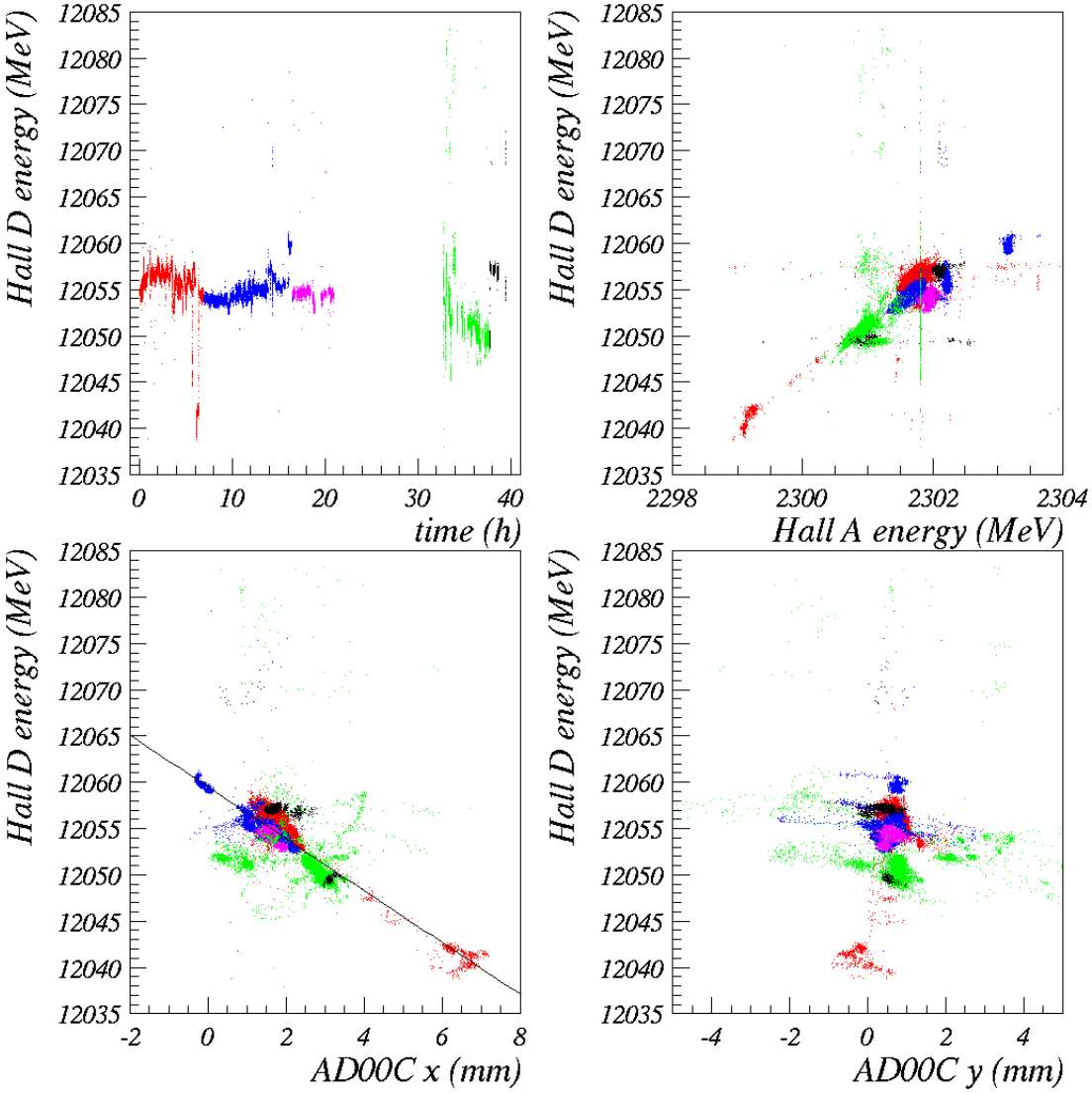


Figure 18:
Same as Fig. 5 but for the Feb. 23 18:00 → Feb 25 10:00am time period. **(Corrected beam energies)**

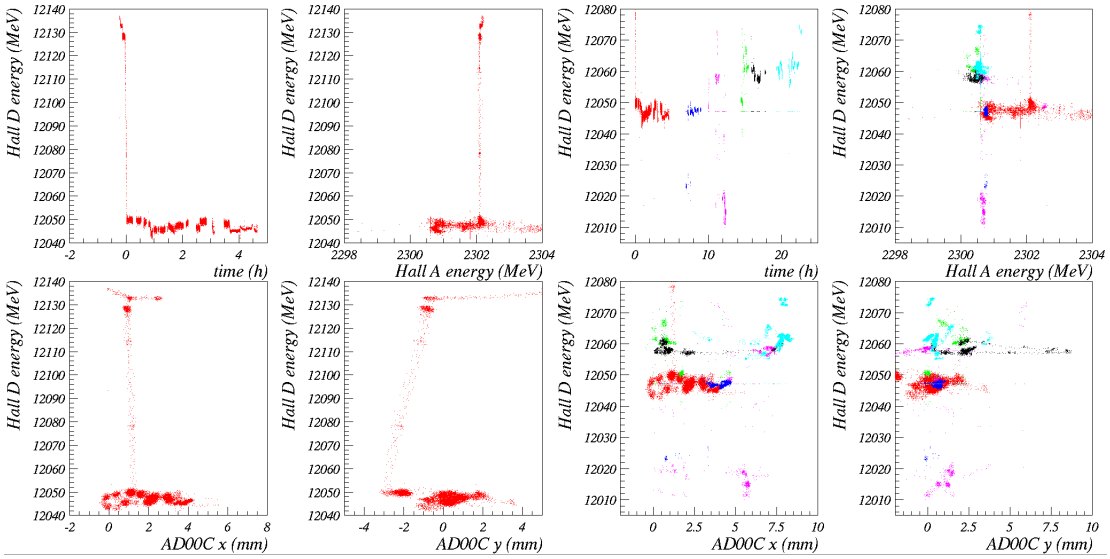


Figure 19: Same as Fig. 5 but for the Feb. 25 10:00am → Feb 26 9:00am time period. There is an artificial decrease by 83 MeV occurring at $t \simeq 0.0$ (02/25, 10:17 am). It is shown on the first set of 4 panels in the figure. **(Uncorrected beam energies)**

10.7 Feb. 25 10:00am → Feb 26 9:00am

The effect of large baseline change seen in the uncorrected beam energy (+83 MeV jumps) near $t = 0$ and the jump of +12 MeV at $t = 22.5$h are well corrected for by correcting the sign of $\delta_{steering}$. The beam is unstable during this period, displaying little correlation with AD00Cx during the red period but clear one with AD00Cy. Then, the expected AD00Cx correlation appears, although there are still correlation with the y-component. The drop of energy between ∼12047 MeV and ∼12034 MeV seems to be real since the green and yellow periods fall in the AD00C-x vs energy correlation pattern. The large green excursion is an artifact.

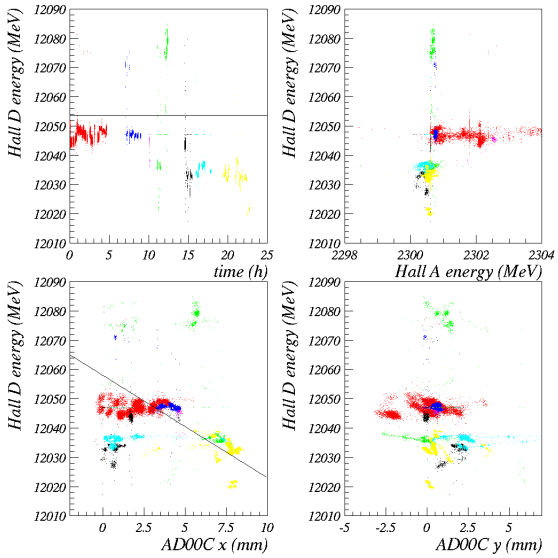


Figure 20:
Same as Fig. 5 but for the Feb. 25 10:00am → Feb 26 9:00am time period. **(Corrected beam energies)**

10.8 Feb. 27 15:00 → Feb 29 16:35

The beam was down for 30h before this period. A Hall A energy change was done (now at 8.8 GeV). Correcting the sign of $\delta_{steering}$ partly took care of the apparent 27 MeV higher energy than the previous period, reducing it to +17 MeV, and fully took care of an artificial -60 MeV shift 48h $< t <$ 50h. All remaining variations of the corrected energy are real.

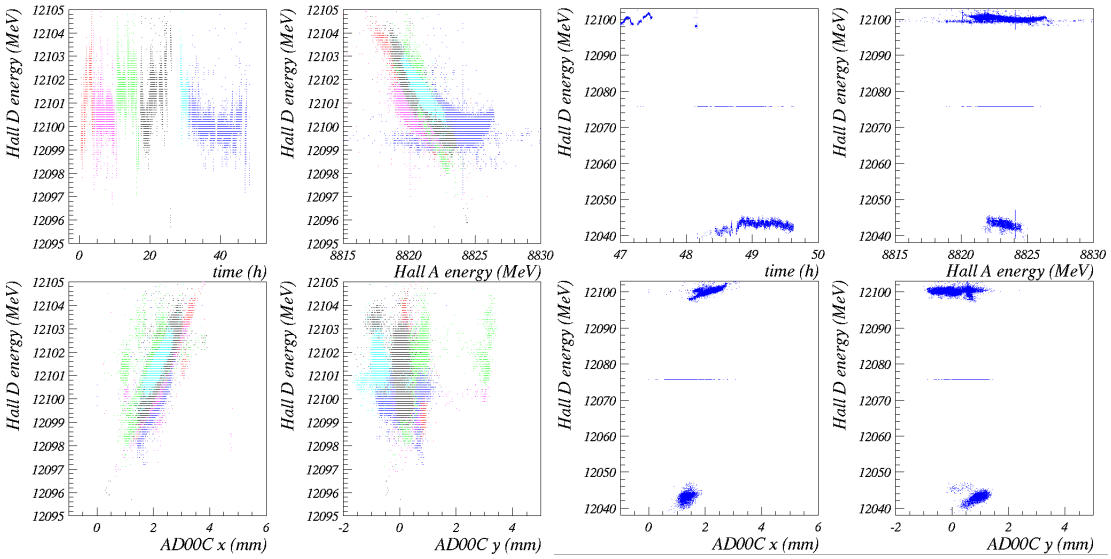


Figure 21:
Same as Fig. 5 but for the Feb. 27 15:00 → Feb 29 16:35 time period. The uncorrected Hall D electron beam energy seemed to have come back 27 MeV higher than the previous period uncorrected energy. There is an artificial -60 MeV shift 48h $< t <$ 50h (4-panel figure on the right) at the end of the period, followed by a +60 MeV shift between this period and the next one.**(Uncorrected beam energies)**

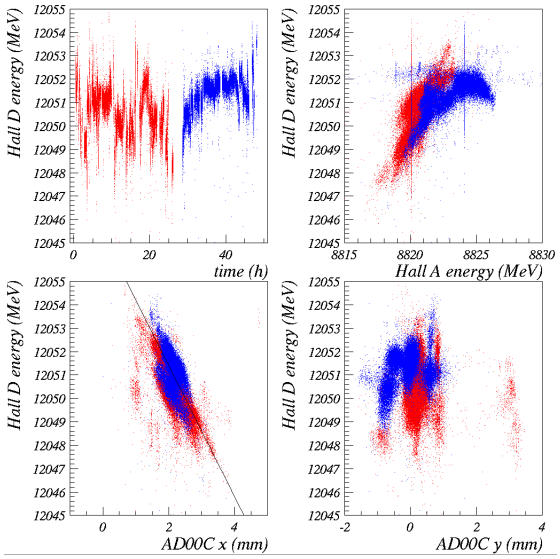


Figure 22:
Same as Fig. 5 but for the Feb. 27 15:00 → Feb 29 16:35 time period. **(Corrected beam energies)**

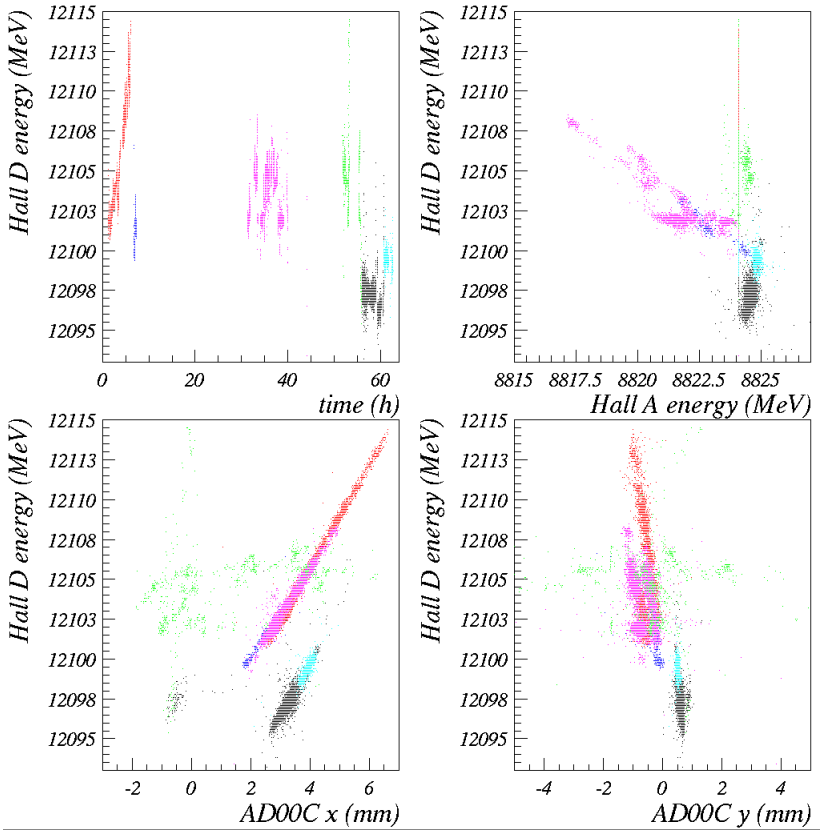


Figure 23: Same as Fig. 5 but for the Feb. 29 17:00 → Mar 03 9:00am time period. **(Uncorrected beam energies)**

10.9 Feb. 29 17:00 → Mar 03 9:00am

The energy fluctuations appear real except for part of the green period. The jump of energy just before the black period seems artificial.

Correlation of the Hall D energy with arcs and BPM 5C02 and 5C08 are shown on Fig. 31. Non-dispersive BPM 5C02-y unexpectedly shows no correlation with energy, while a significant one is seen for 5C08-y while it should be insensitive to energy drifts. From 5C08-y one would conclude that the energy variation seen during the green period is artificial. However this conclusion would also apply to the other periods (except the black one) where it is clear that the energy drifts are genuine (see especially the red period). Consequently, we cannot draw conclusions from the 5C02-y and 5C08-y data.

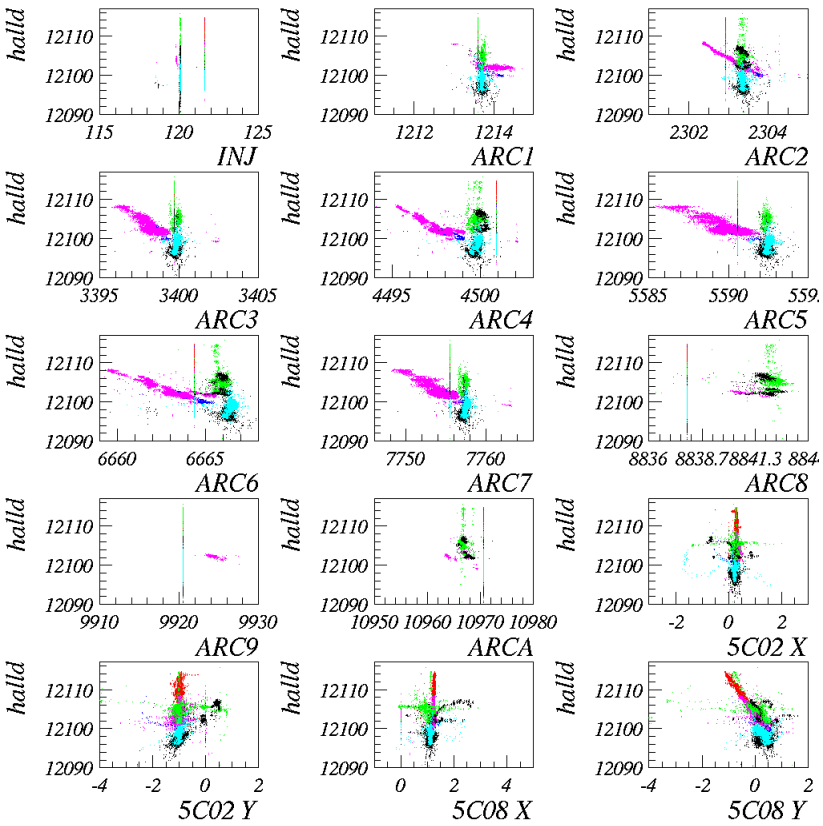


Figure 24:
Correlations between the uncorrected Hall D electron beam energy and the beam energy at the injector and various arcs (first 11 plots), and between the Hall D energy and BPM 5C02 and 5C08 (last 4 plots). The 11th panel shows the Hall D vs Hall A energies. The data are for the Feb. 29 17:00 → Mar 03 9:00am time period. **(Uncorrected beam energies)**

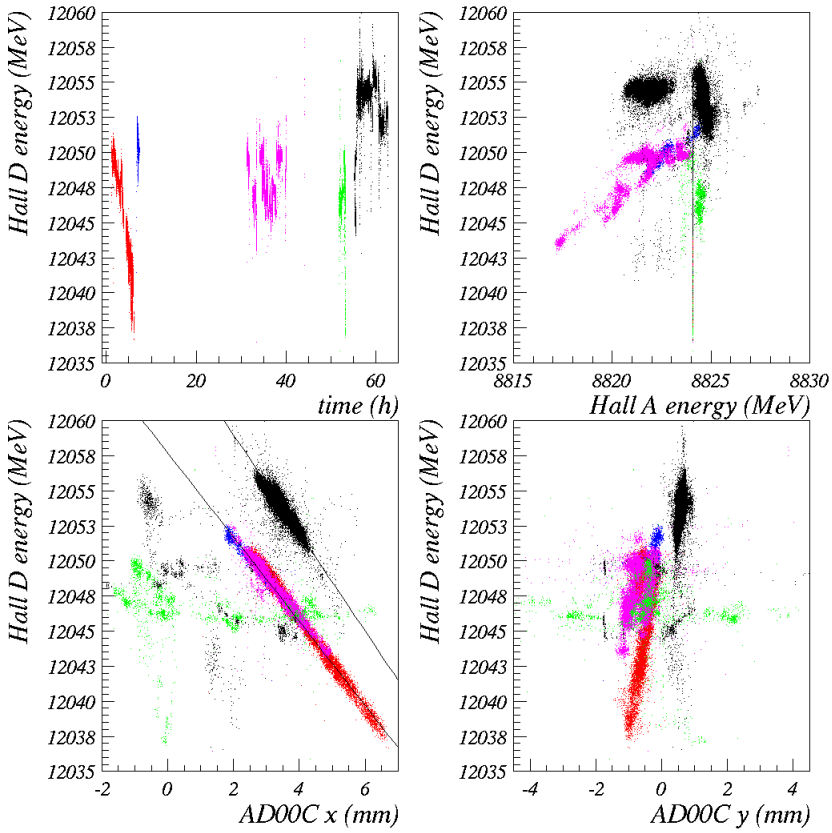


Figure 25:
Same as Fig. 5 but for the Feb. 29 17:00 → Mar 03 9:00am time period. **(Corrected beam energies)**

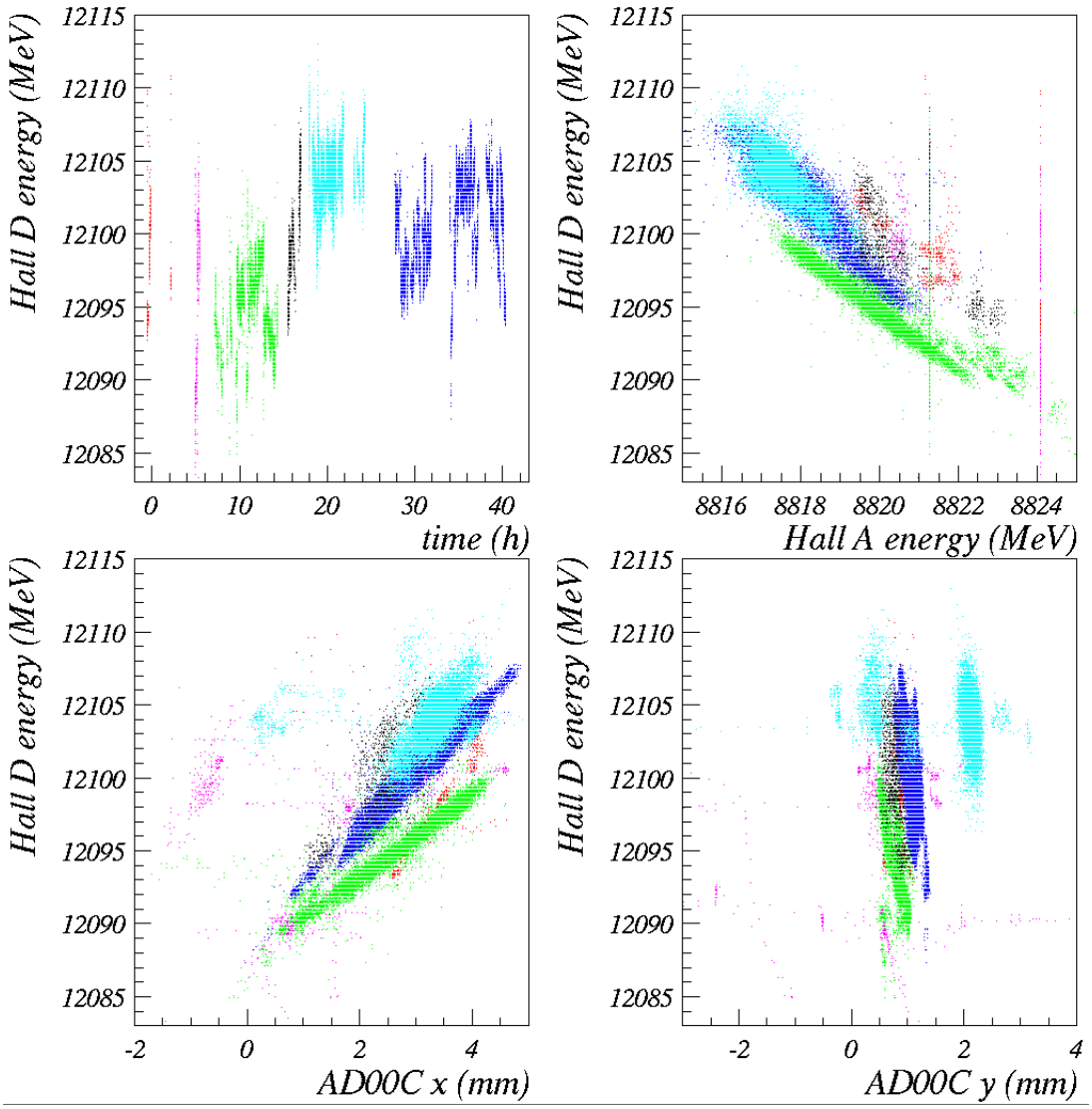


Figure 26: Same as Fig. 5 but for the March 03 18:00 → March 05 10:55am time period. **(Uncorrected beam energies)**

10.10 March 03 18:00 → March 05 10:55am

All the energy fluctuations appear real.

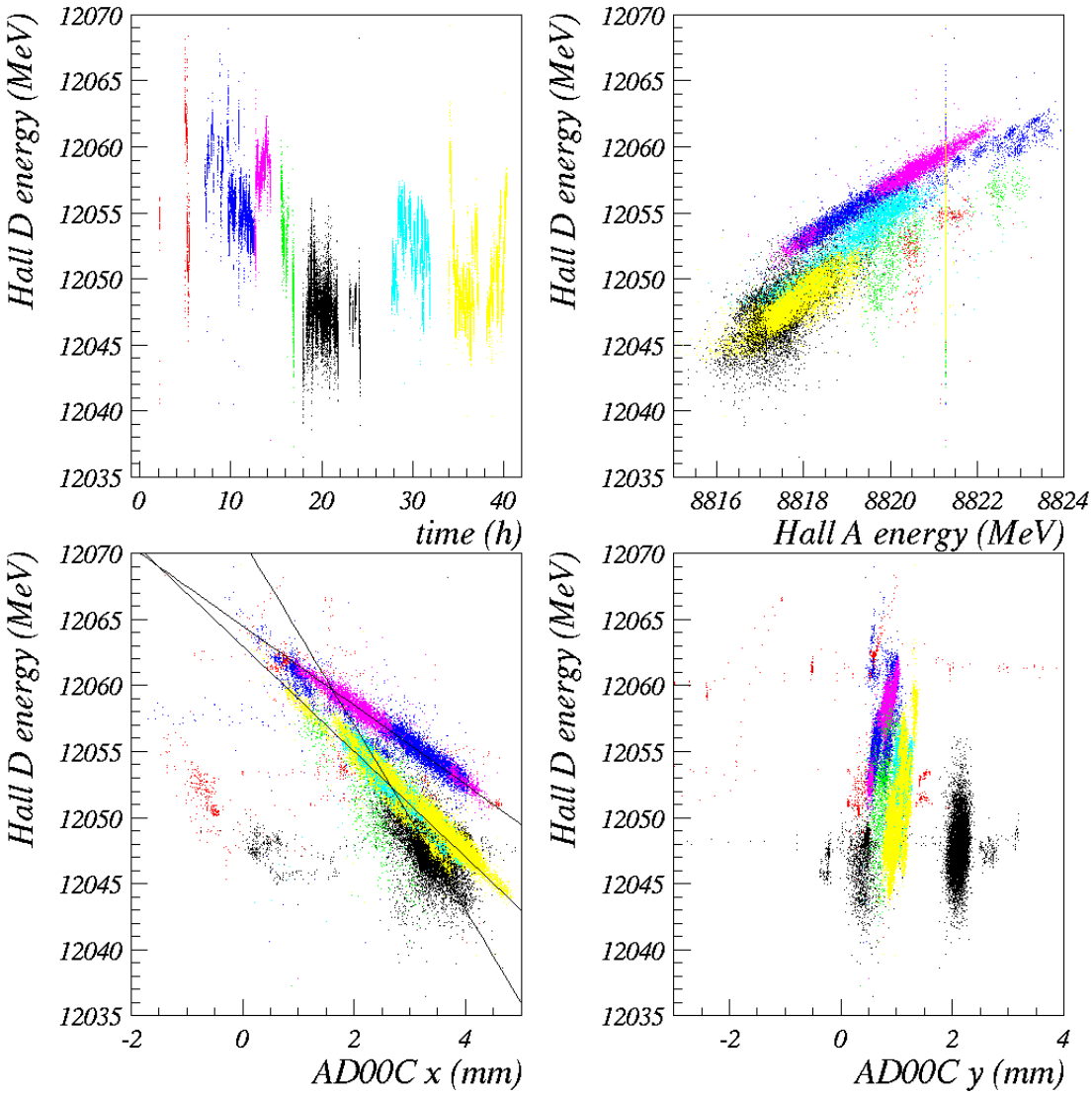


Figure 27:
Same as Fig. 5 but for the March 03 18:00 → March 05 10:55am time period. **(Corrected beam energies)**

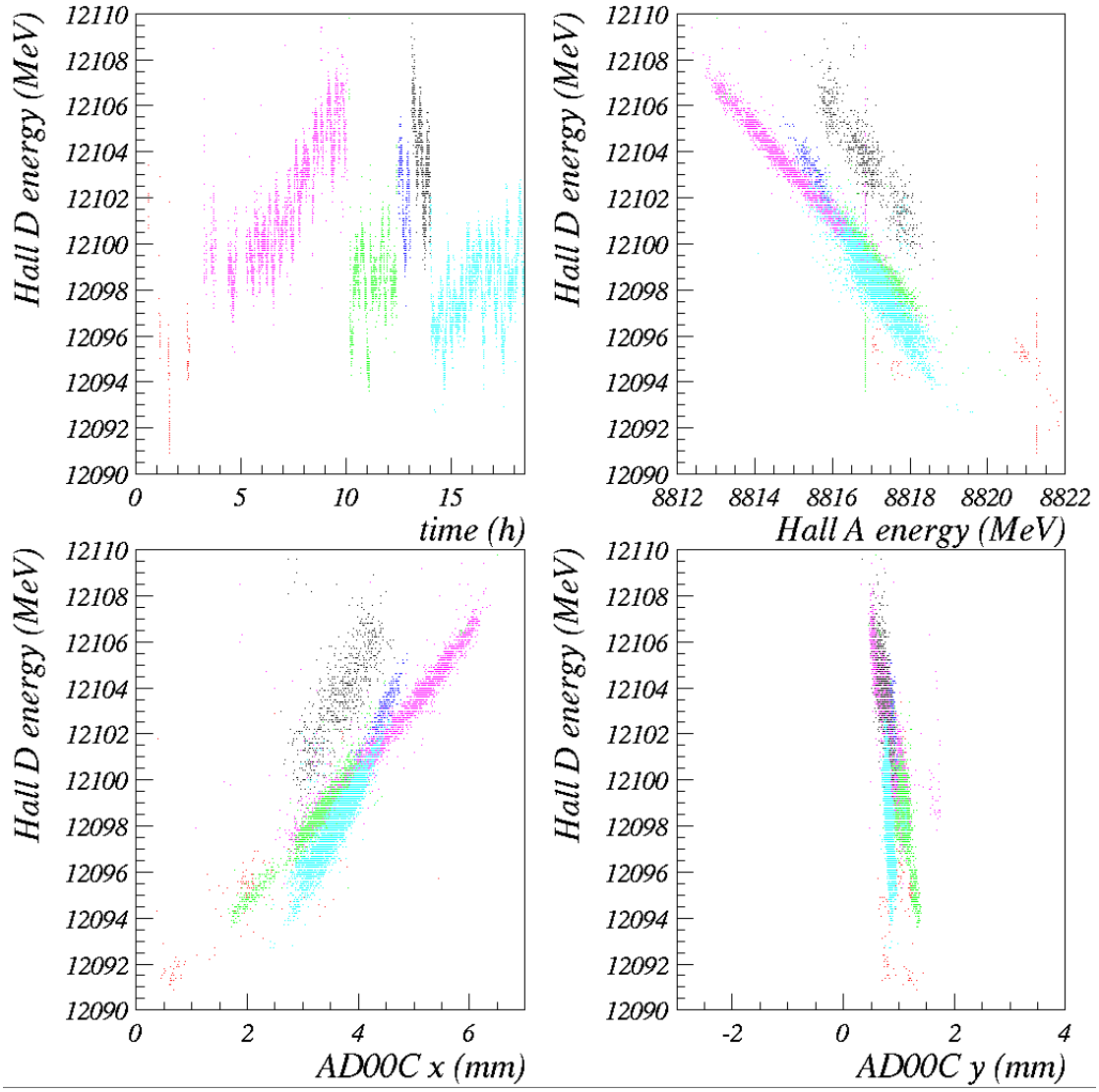


Figure 28: Same as Fig. 5 but for the March 05 22:00 → March 06 16:00 time period. **(Uncorrected beam energies)**

10.11 March 05 22:10 → March 06 16:10

The energy fluctuations appear real, including the jump between the magenta and green period that are perfectly matching the AD00C-x vs energy correlation pattern. However, the temporary -3 MeV jump corresponding to the cyan period appears to be an artifact.

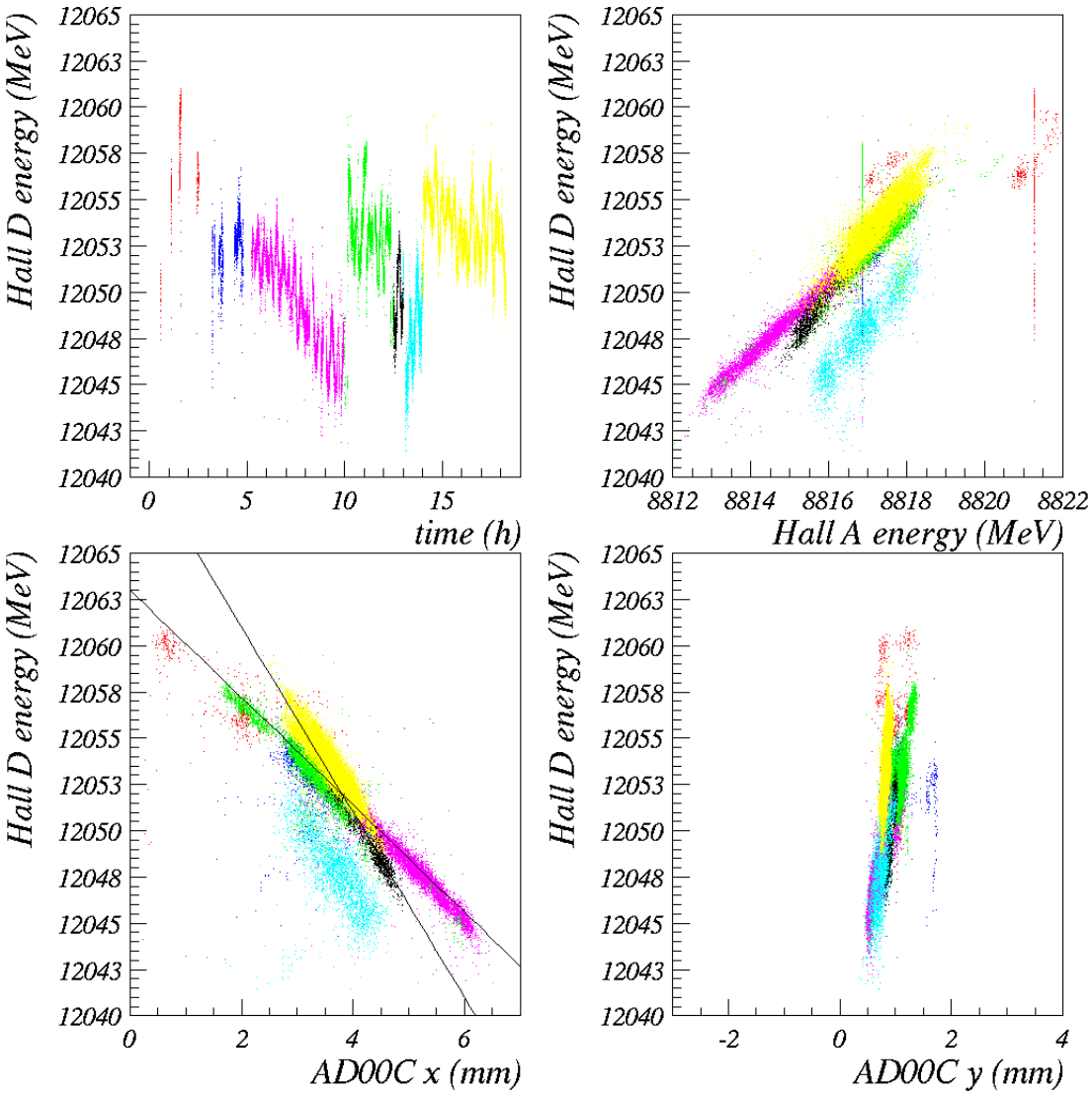


Figure 29:
Same as Fig. 5 but for the March 05 22:00 → March 06 16:00 time period. **(Corrected beam energies)**

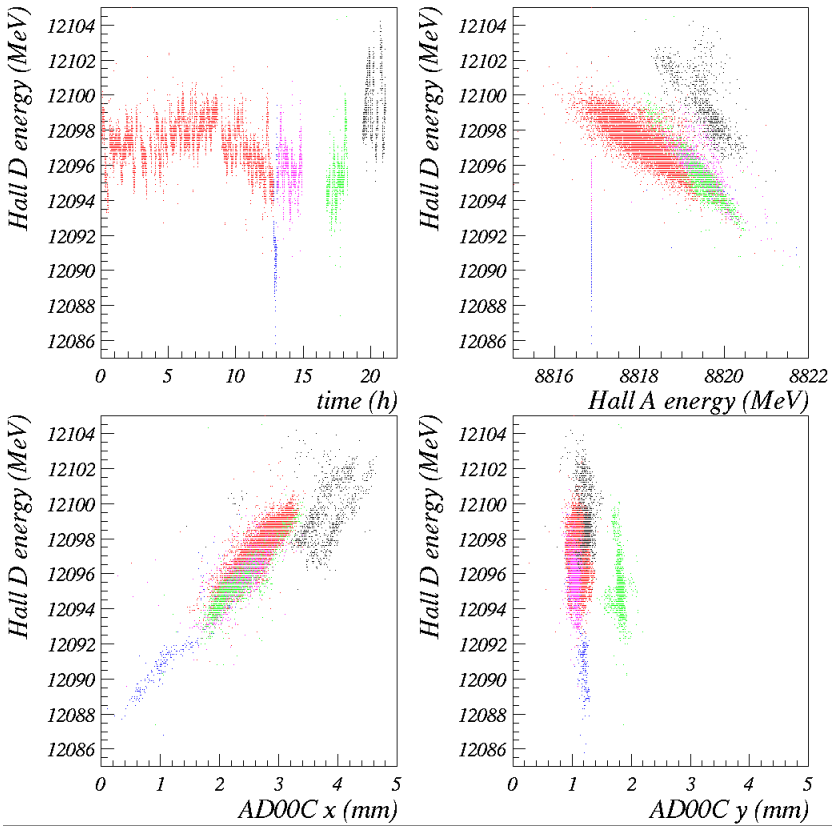


Figure 30: Same as Fig. 5 but for the March 06 20:00 → March 07 18:00 time period. **(Uncorrected beam energies)**

10.12 March 06 20:00 → March 07 18:00

The energy fluctuations appear real. The misalignment between the magenta period and the others in the AD00C-x vs energy correlation plot suggests that the energy during the magenta period should be higher by 4 MeV with respect to the other periods. Correlation of the Hall D energy with arcs and BPM 5C02 and 5C08 are shown on Fig. 31. BPM 5C02-y shows the expected correlation. However, some dispersion is also seen for 5C08-y, which should be insensitive to energy drifts.

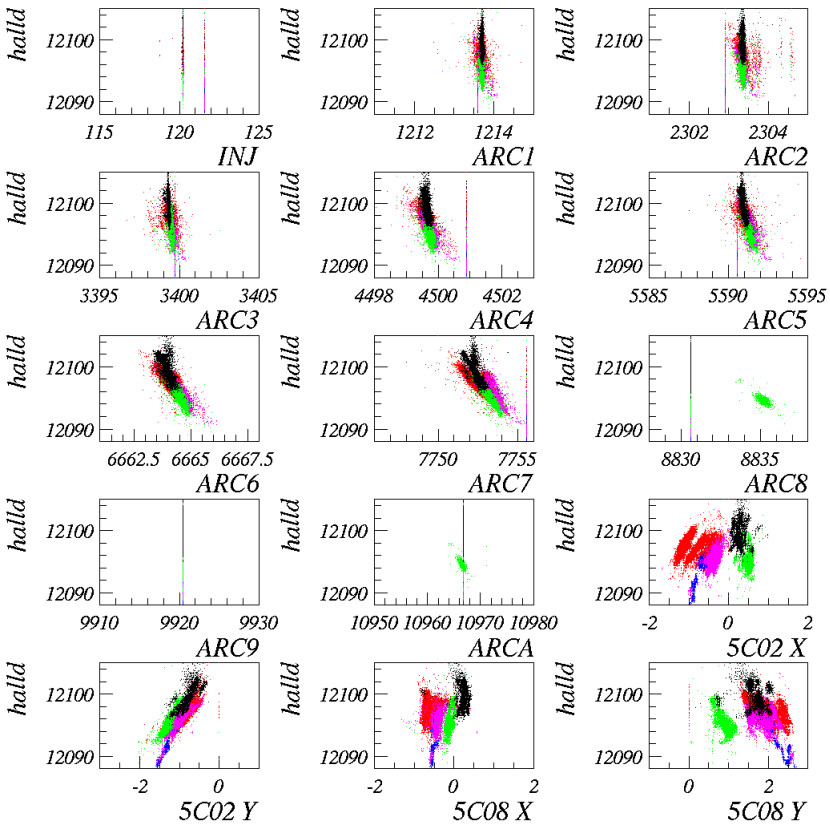


Figure 31:
Correlations between the Hall D electron beam energy and the beam energy at the injector and various arcs (first 11 plots), and between the Hall D energy and BPM 5C02 and 5C08 (last 4 plots). The 11th panel shows the Hall D vs Hall A energies. The data are for the March 06 20:00 → March 07 18:00 time period. **(Uncorrected beam energies)**

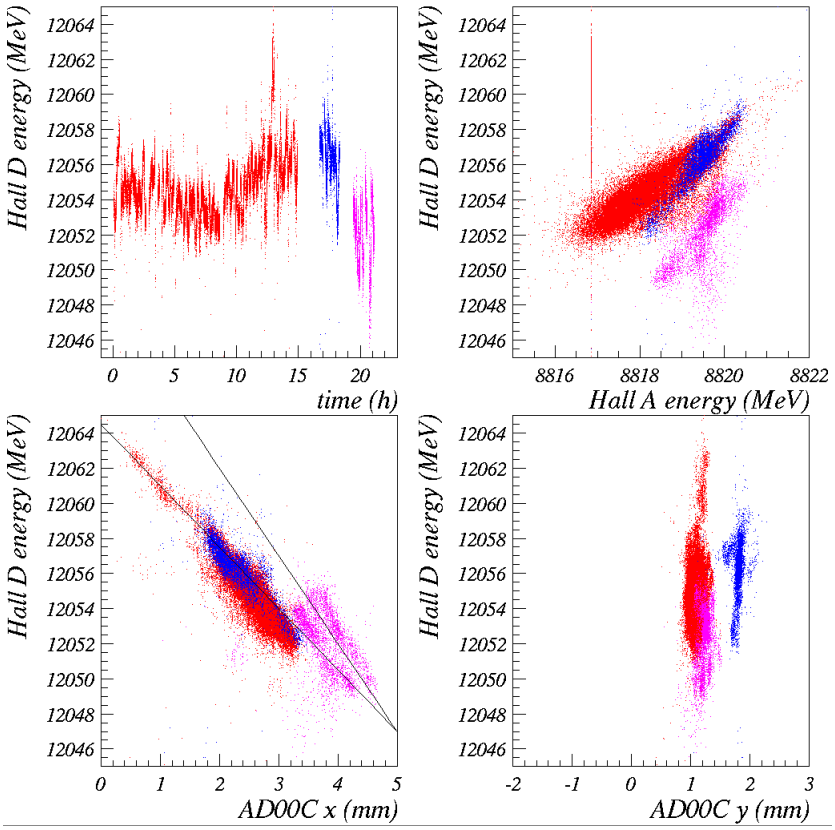


Figure 32: Same as Fig. 5 but for the March 06 20:00 → March 07 18:00 time period. **(Corrected beam energies)**

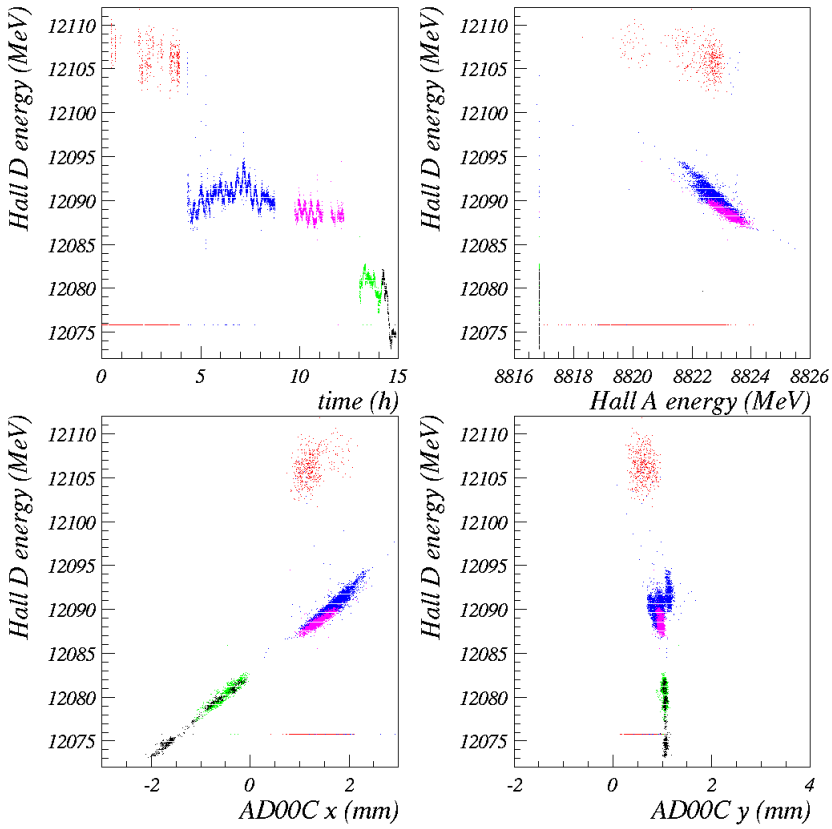


Figure 33:
Same as Fig. 5 but for the March 07 18:00 → March 08 9:00am time period. **(Uncorrected beam energies)**

10.13 March 07 18:00 → March 08 9:00am

The energy readings for the first 4h are incorrect. This is because of operation at very low current (2-5 nA, TAC run, see logbook entry 3389136) The energy variations after 4h appear real. We note that there is no 5C02-y data for the red period. As for the March 06 20:00 → March 07 18:00 period, BPM 5C02-y shows the expected correlation. However, an unexpected strong dispersion is also present for 5C08-y.

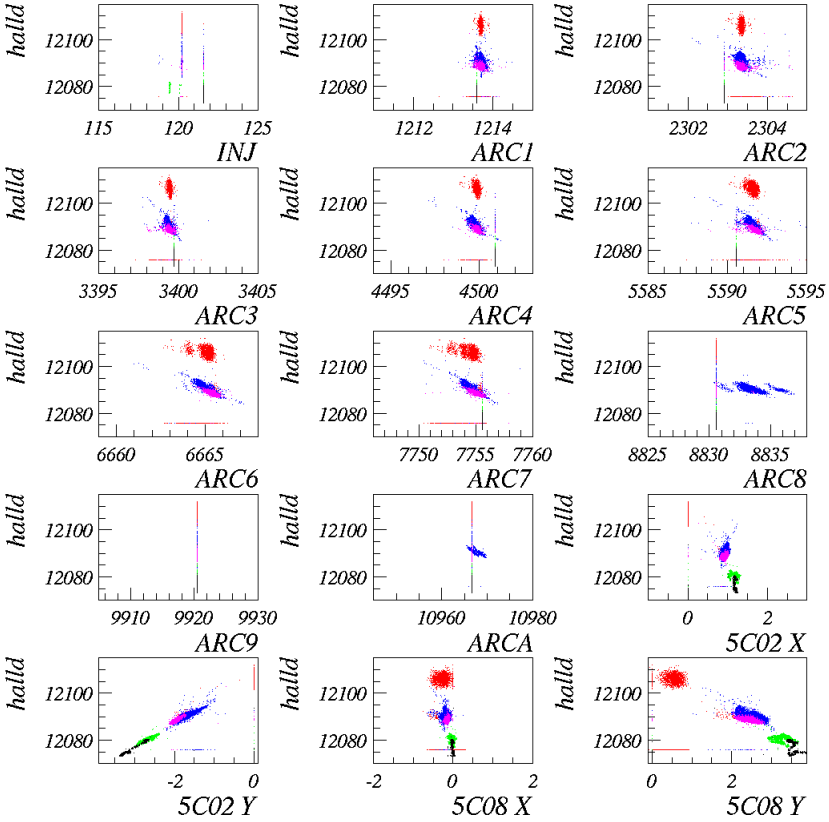


Figure 34:
Same as Fig. 9 but for the March 07 18:00 → March 08 9:00am time period. **(Uncorrected beam energies)**

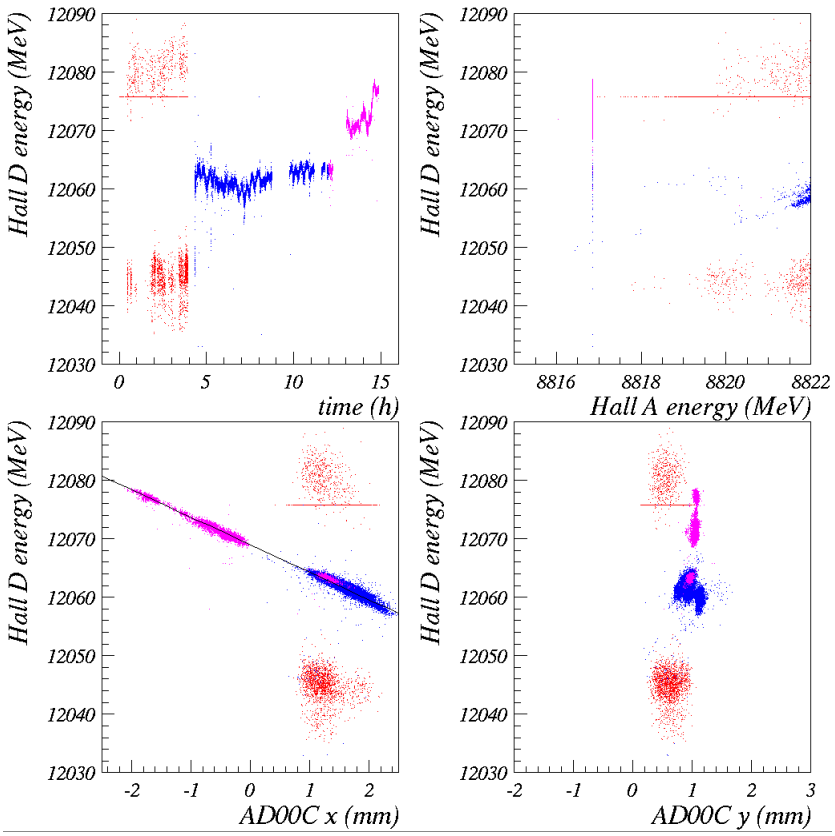


Figure 35: Same as Fig. 5 but for the March 07 18:00 → March 08 9:00am time period. **(Corrected beam energies)**

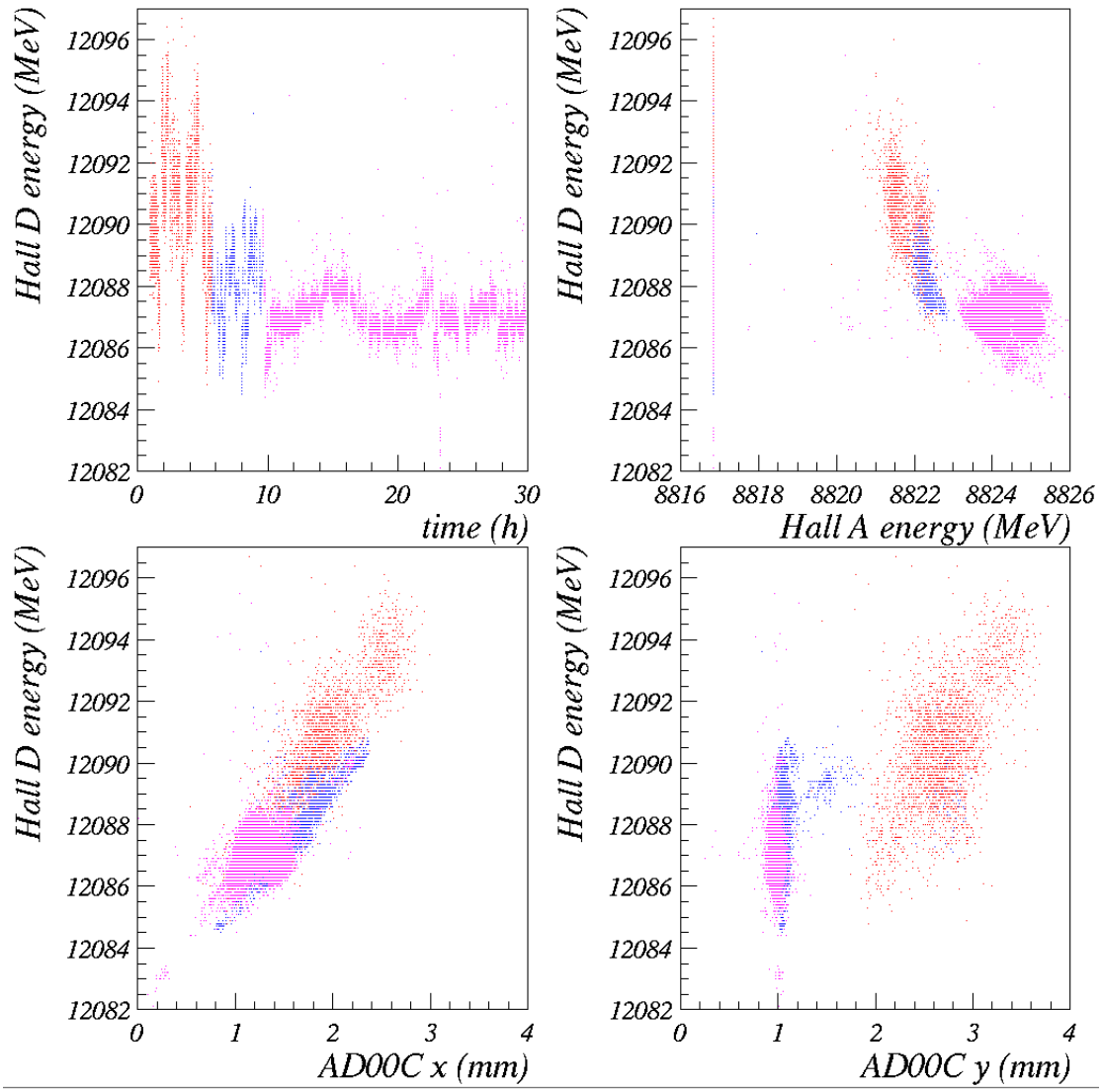


Figure 36: Same as Fig. 5 but for the March 08 9:00am → March 09 14:40 time period. **(Uncorrected beam energies)**

10.14 March 08 9:00am → March 09 14:40

All energy fluctuations are real, including the -12 MeV jump between this period and the March 07 18:00 → March 08 9:00am time period: the early red period starts at 12074 MeV and then drops to 12062. It appears to be genuine: the energy vs AD00C-x correlation for the two periods follows the same pattern.

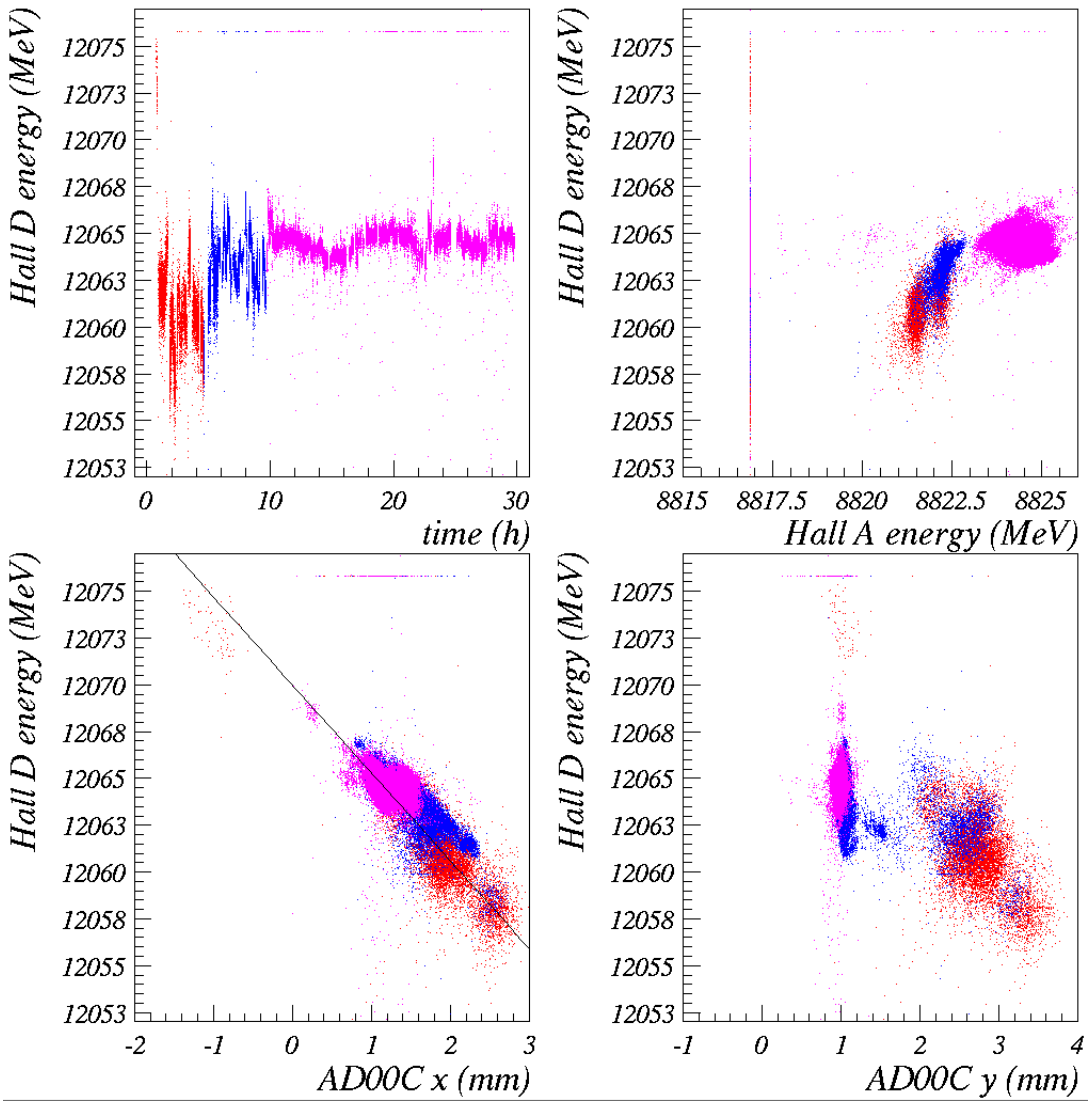


Figure 37: Same as Fig. 5 but for the March 08 9:00am → March 09 14:40 time period. **(Corrected beam energies)**

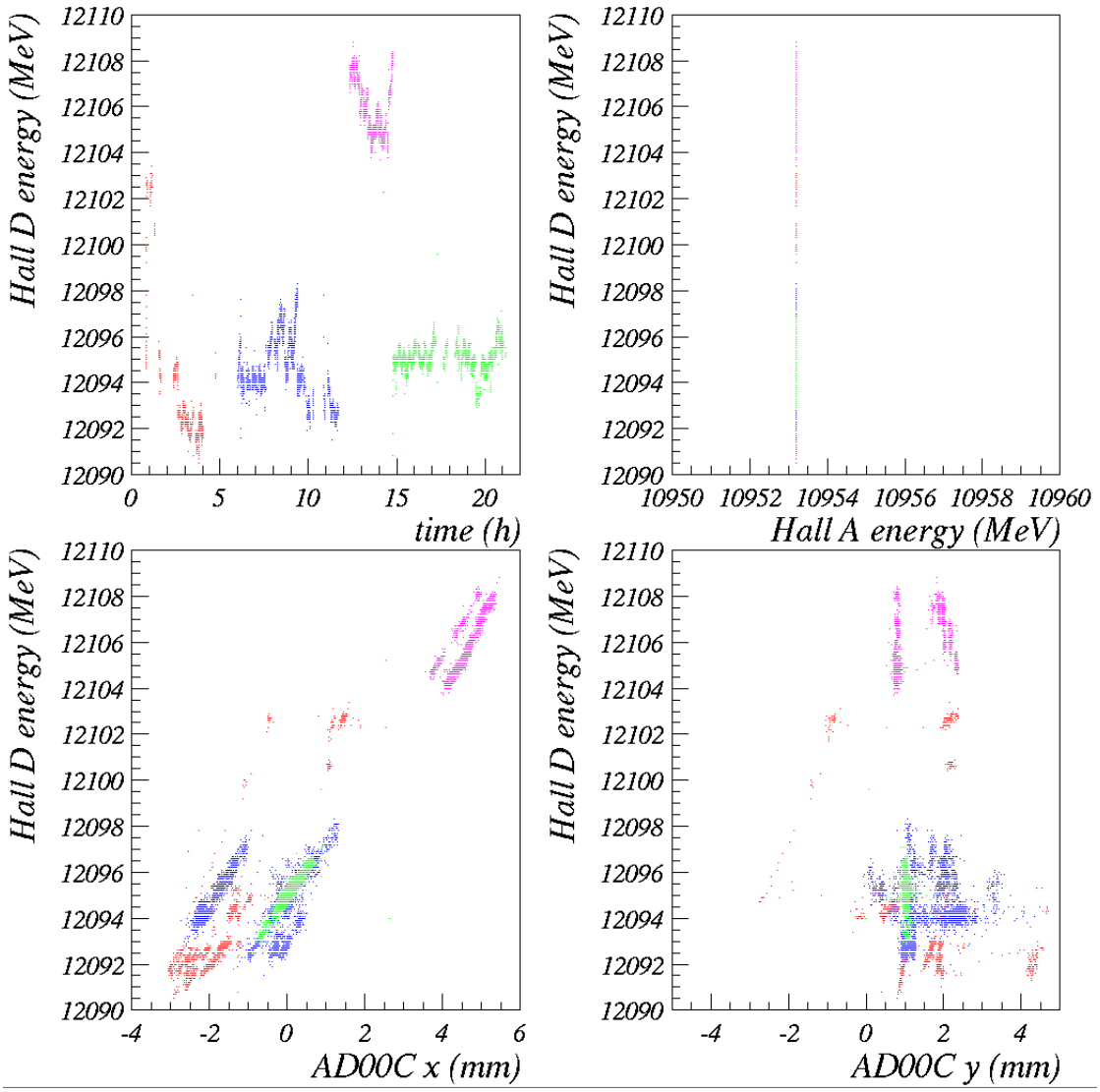


Figure 38: Same as Fig. 5 but for the March 27 13:00 → March 28 9:41am time period. **(Uncorrected beam energies)**

10.15 March 27 13:00 → March 28 9:41am

This period starts after a major beam down time of 18 days for CHL maintenance. The Hall A energy readout is frozen (Hall A down?). The energy fluctuations appear real, including the transition between the red and blue periods and around the green period.

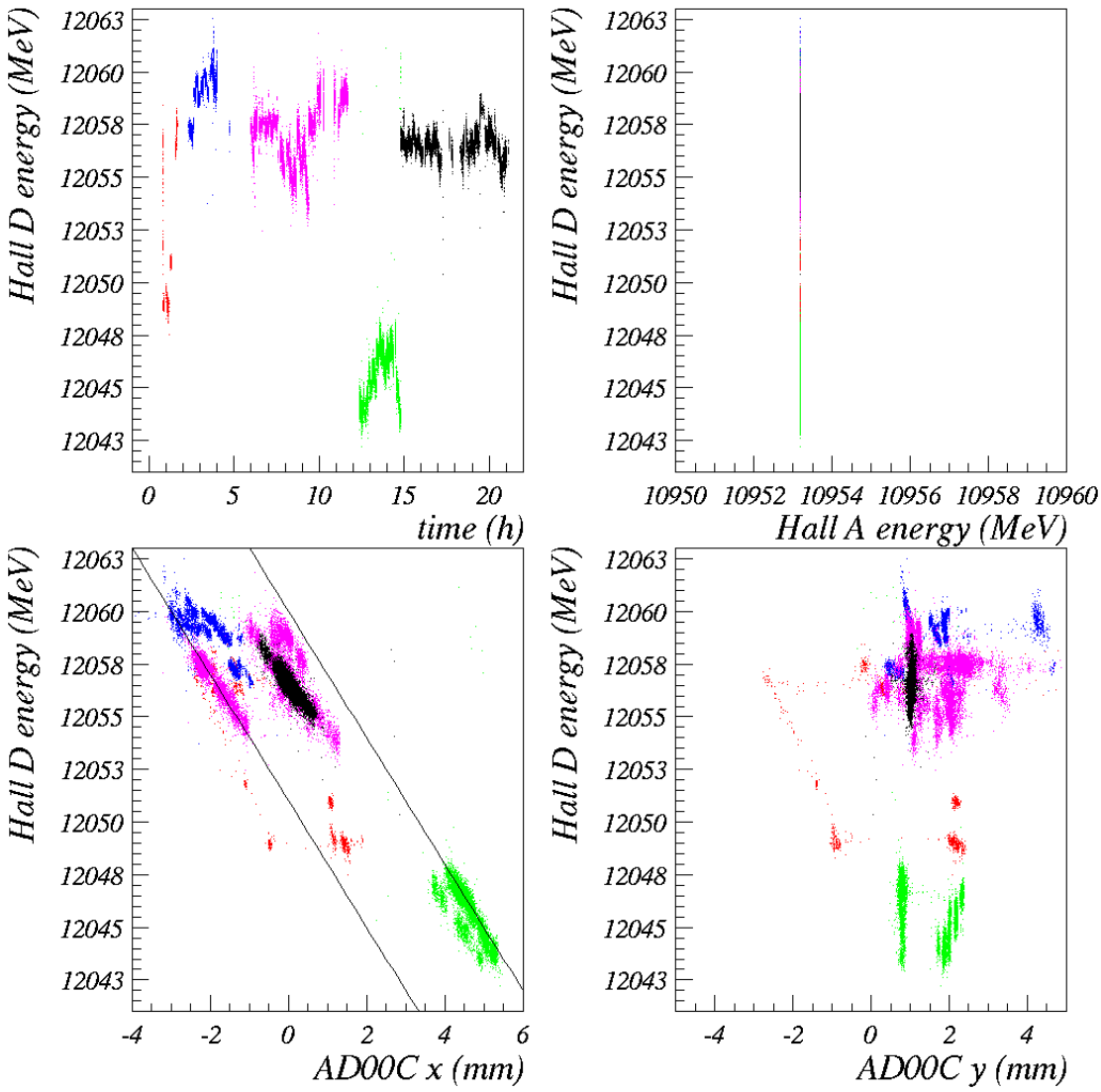


Figure 39:
Same as Fig. 5 but for the March 27 13:00 → March 28 9:41am time period. **(Corrected beam energies)**

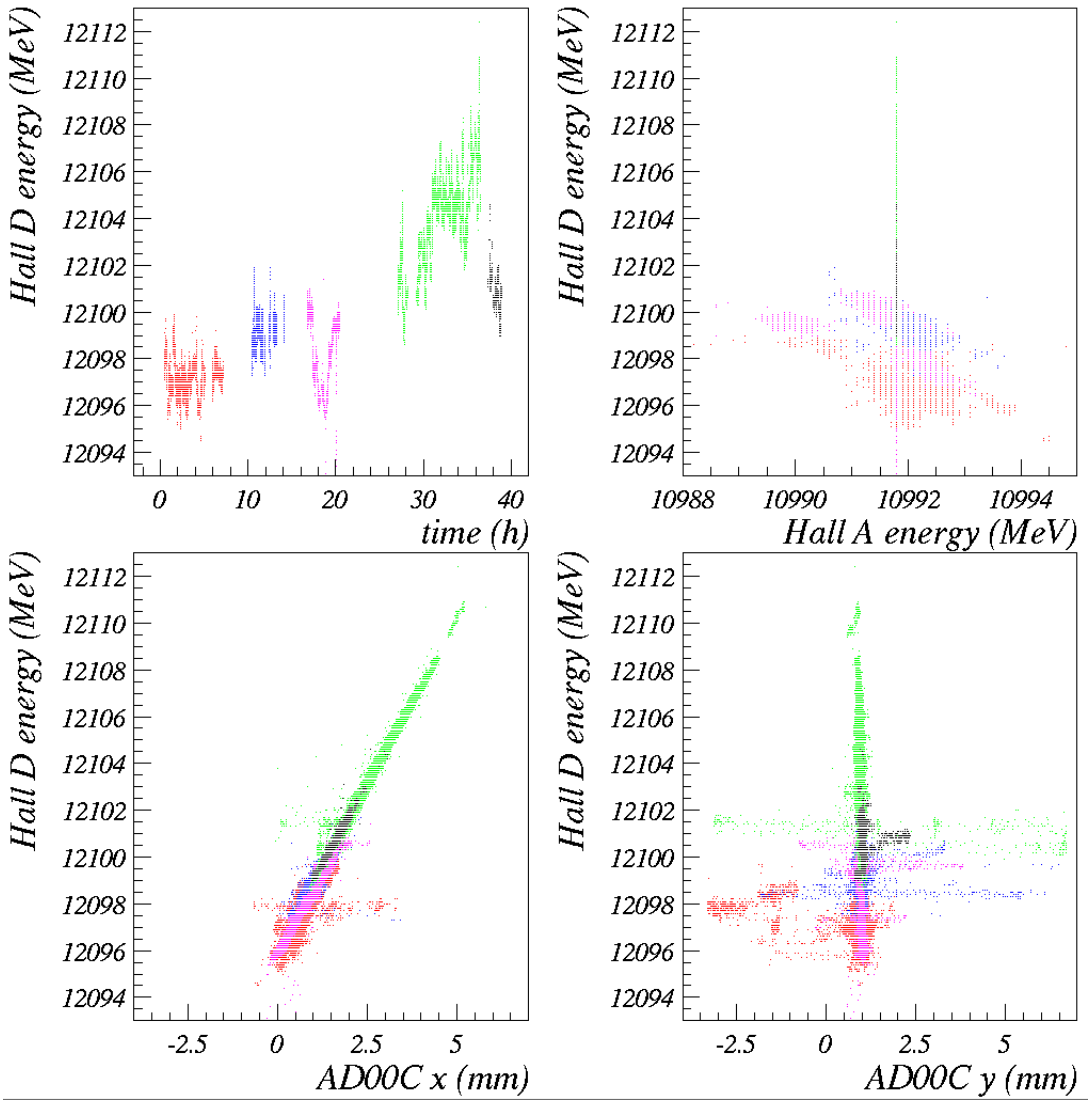


Figure 40: Same as Fig. 5 but for the March 28 19:10 → March 30 10:10am time period. **(Uncorrected beam energies)**

10.16 March 28 19:10 → March 30 10:10am

The energy fluctuations appear real, except for a possibly small 1 MeV energy jump between the magenta and green periods, that appears to be an artifact.

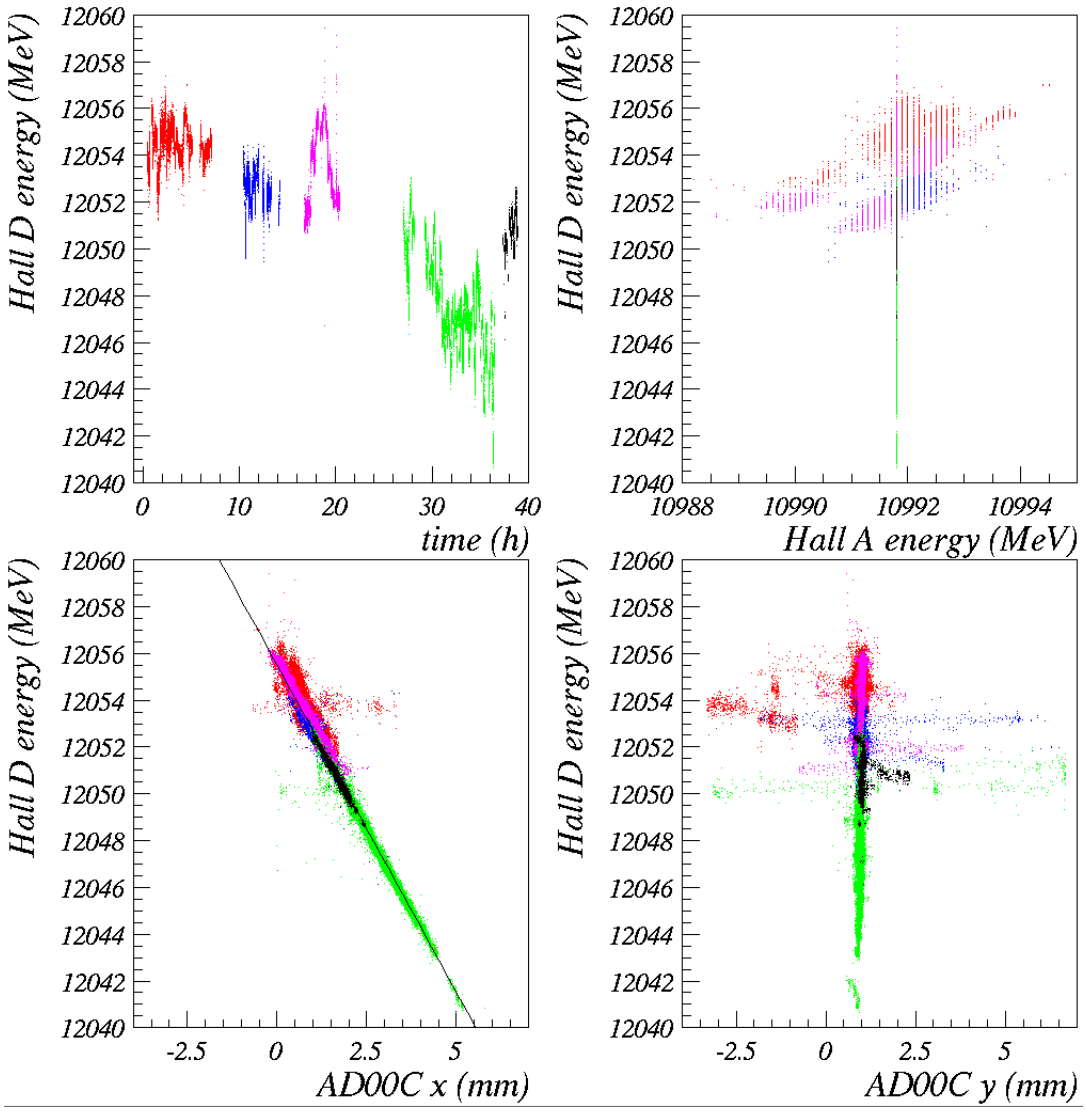


Figure 41: Same as Fig. 5 but for the March 28 19:10 → March 30 10:10am time period. **(Corrected beam energies)**

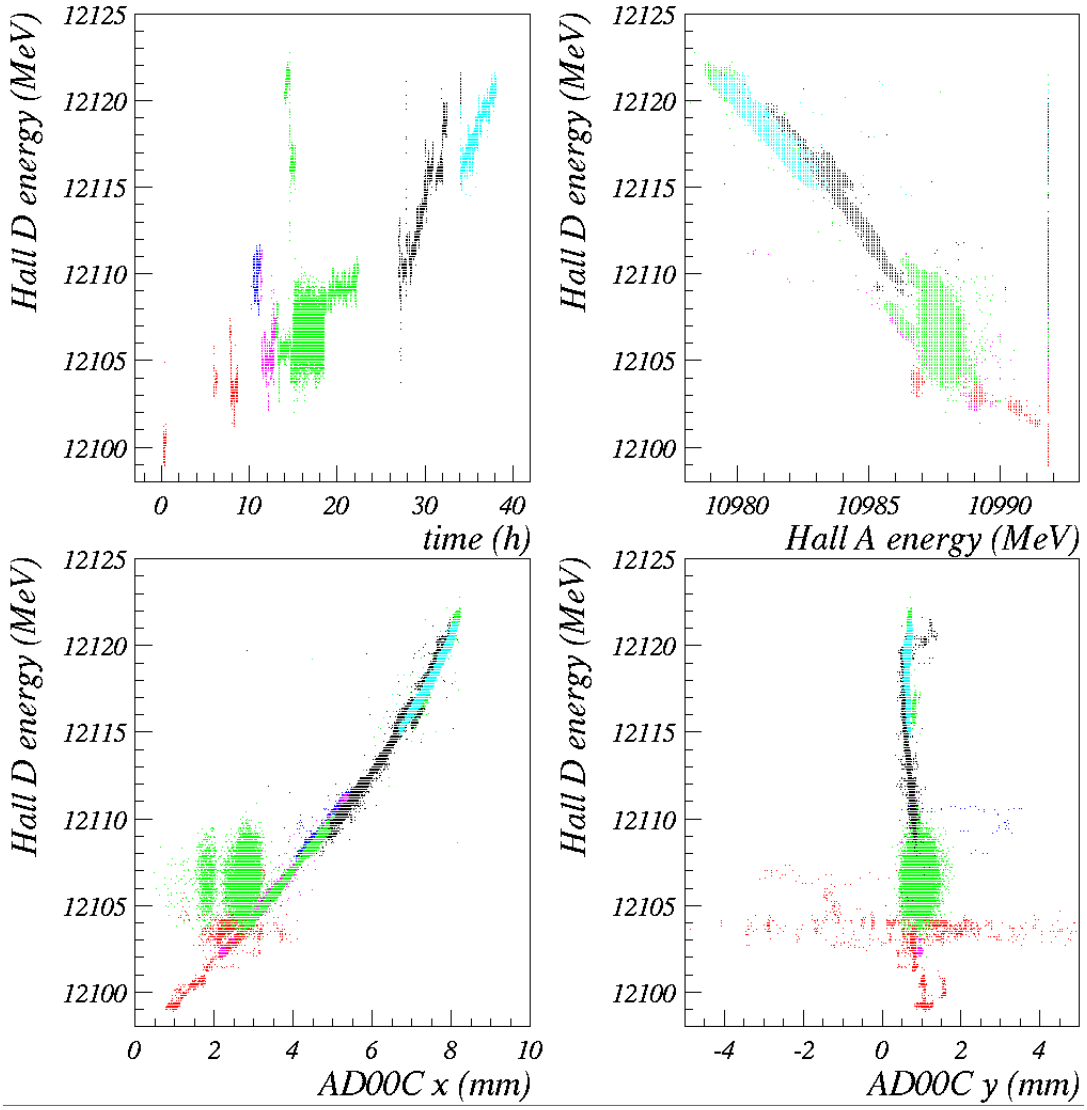


Figure 42: Same as Fig. 5 but for the March 30 10:10 → April 4 1:10am time period. **(Uncorrected beam energies)**

10.17 March 30 10:10 → April 1 1:10am

The energy fluctuations appear real, except for the 5 MeV energy jitter between 14.4h and 18.4h, that appears to be an artifact. This occurred during a low current run (5nA, see logbook entry # 3393698). Notice the non-linearity of the (AD00C-x vs energy) relation, in particular during the cyan period. It could be due to the beam going outside of the uniform field of the tagger magnet or of the beam angle/position on the radiator being correlated with energy.

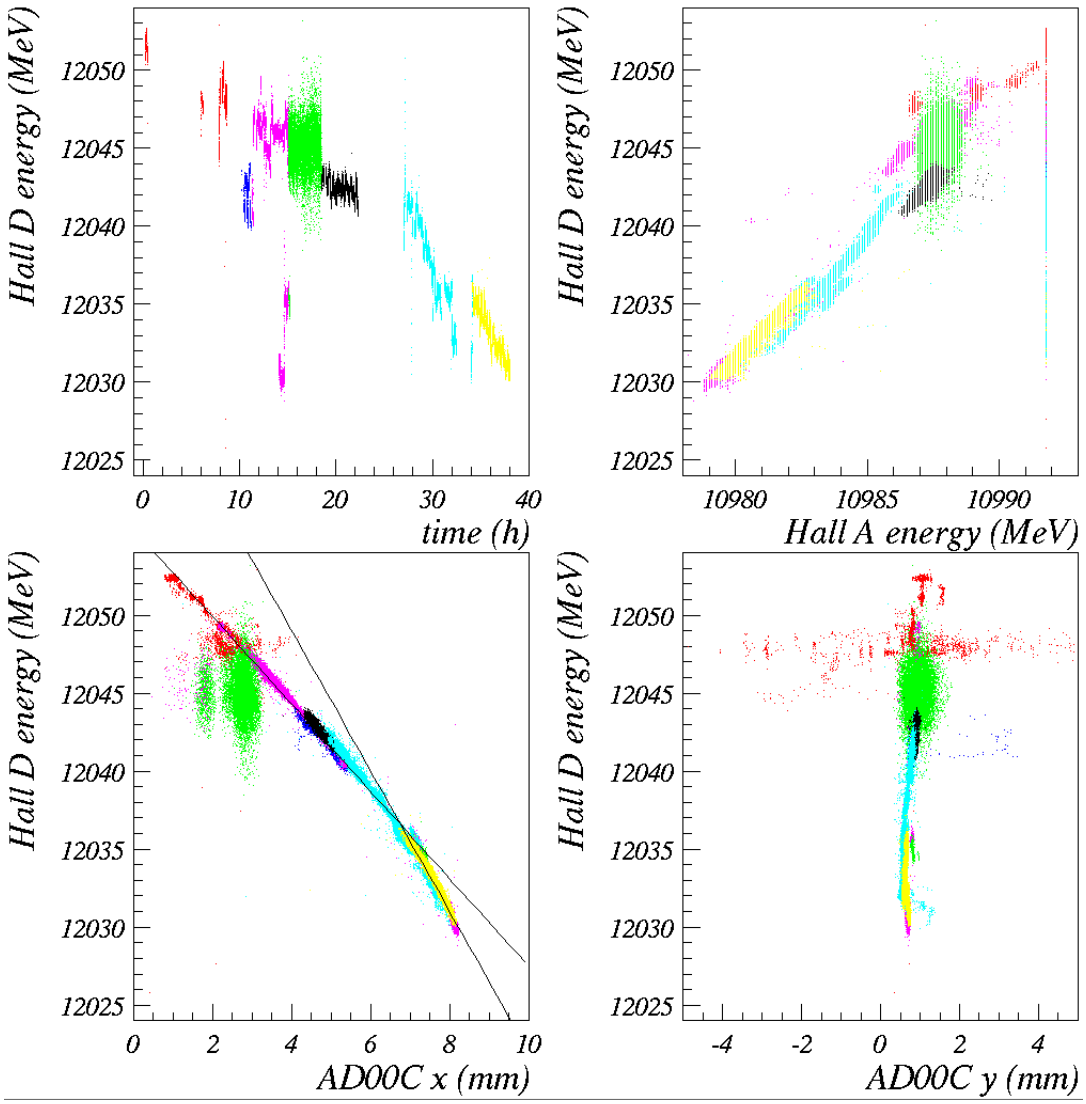


Figure 43: Same as Fig. 5 but for the March 30 10:10 → April 1 1:10am time period. **(Corrected beam energies)**

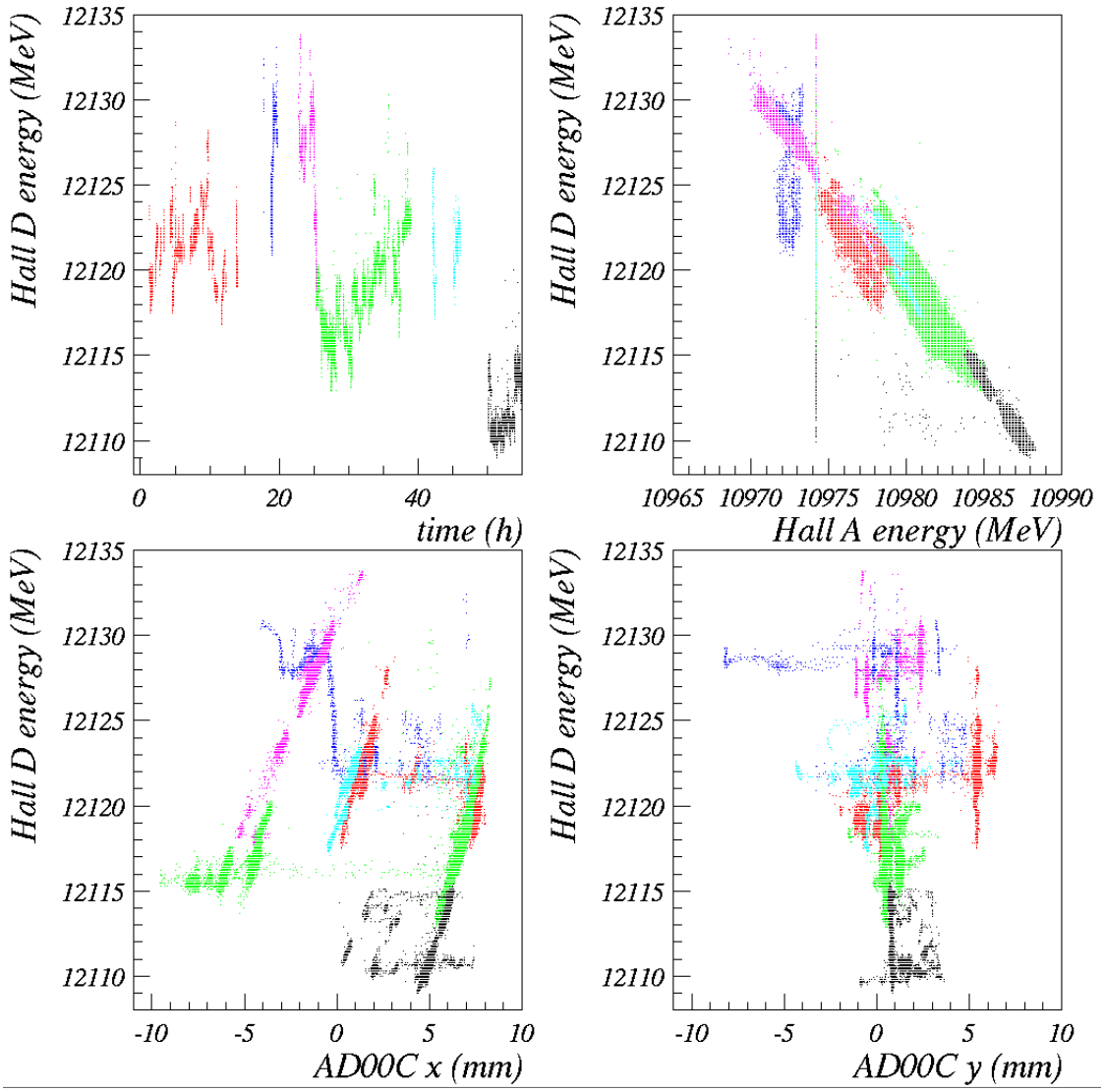


Figure 44: Same as Fig. 5 but for the April 02 1:50am → April 04 7:50am time period. **(Uncorrected beam energies)**

10.18 April 02 1:50am → April 04 7:50am

The energy fluctuations appear real, except for the +7 MeV energy jump at the beginning blue period, that appears to be an artifact. The x- and y-position of the beam were unstable during this period. It is possible that the beam energy shifted by +2 MeV after the magenta period (best seen on the Hall D vs Hall A energy correlation plot).

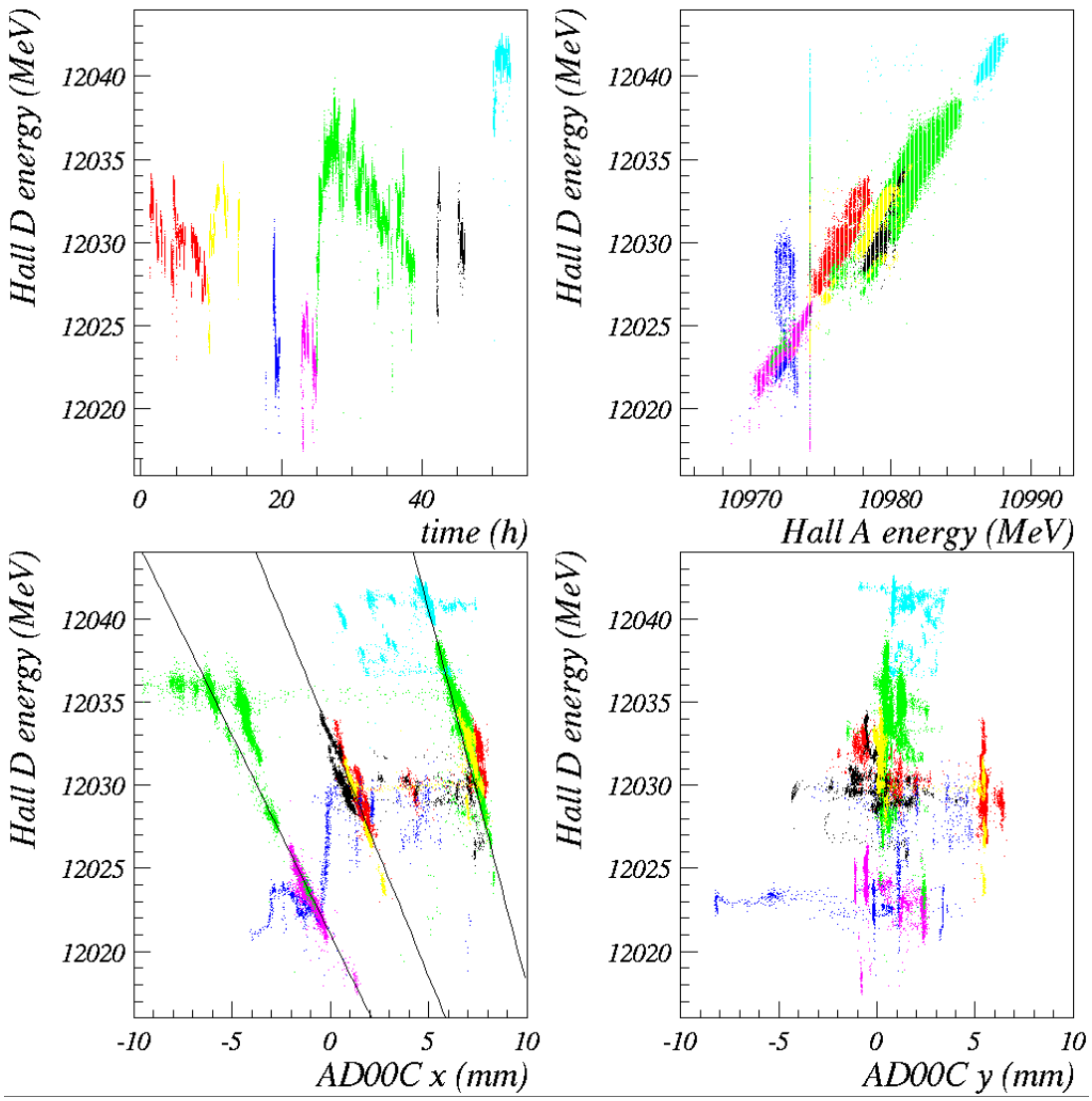


Figure 45: Same as Fig. 5 but for the April 02 1:50am → April 04 7:50am time period. **(Corrected beam energies)**

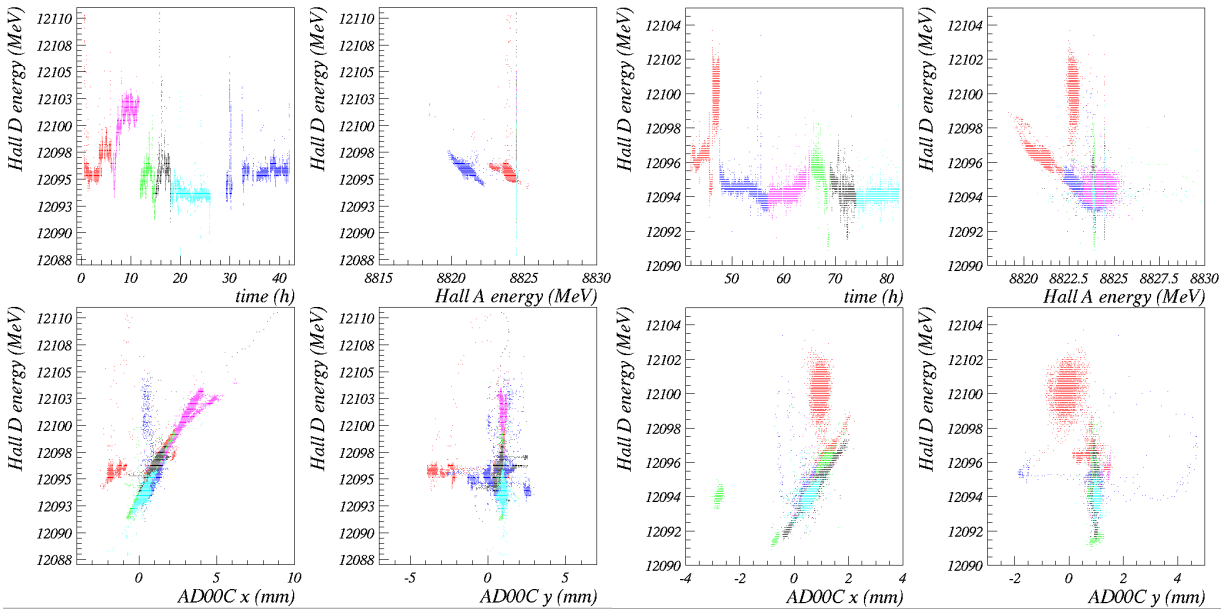


Figure 46: Same as Fig. 5 but for the April 07 14:00 → April 11 00:00 time period. We split the period into two, for better clarity. For the first part (four panels on the left), all fluctuations appear genuine except the $\sim$ 15 MeV spike at the very beginning of the red period and the two $\sim$ 10 MeV spikes during the blue period. For the second part (four panels on the right), all fluctuations appear genuine apart for the $\sim$ 6 MeV increase at $t \simeq$ 46.5h during the red period and the $\sim$ 9 MeV spike at $t \simeq$ 55h during the blue period. **(Uncorrected beam energies)**

10.19 April 07 14:00 → April 11 00:00

Beam was down for 3 days before this period. It is unclear if the +15 MeV shift between the energy at the end of the last period (12114 MeV) and the beginning of this one (12096 MeV) is real. It roughly falls in the AD00Cx vs beam energy pattern. We assume the shift is real. There was several baseline changes during the period. All are well accounted for by correcting for the sign of $\delta_{steering}$ and δ_{orbit}.

We split the period into two, for better clarity. For the first part (four panels on the left), all fluctuations appear genuine. For the second part (four panels on the right). Except for the magenta period (April 9th, 11:57-13:21, correspond to a diamond alignment using 5nA current, see# 3396779) in the second panel, all energy fluctuations seems real. During the red period of the first panel (April 7th, 14h-18h), beam was been tuned, including x and y Act. Col. scans (logbook entries # 3395991, 3396138)

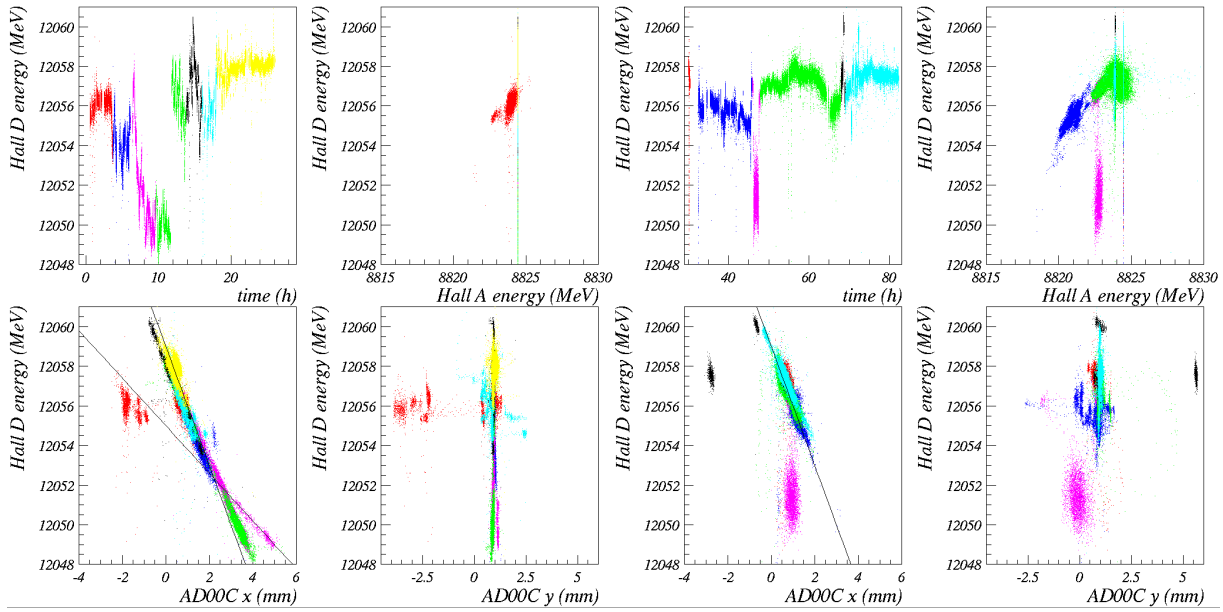


Figure 47: Same as Fig. 5 but for the April 07 14:00 → April 11 00:00 time period. **(Corrected beam energies)**

10.20 April 11 00:00 → April 12 7:00am

The important baseline change is well accounted for by correcting for the signs of $\delta_{steering}$ and δ_{orbits}. The spikes at $t \simeq 6$h, (Apr. 11, 5h38-5h48) 13.3h (Apr. 11, 13h31-13h45), 20.9h (Apr. 11, 20h25-20h30) and 23.9h are artifacts. They are not associated with low current operations but due to harp scans, see logbook entries # 3397378, 3397540, 3397749.

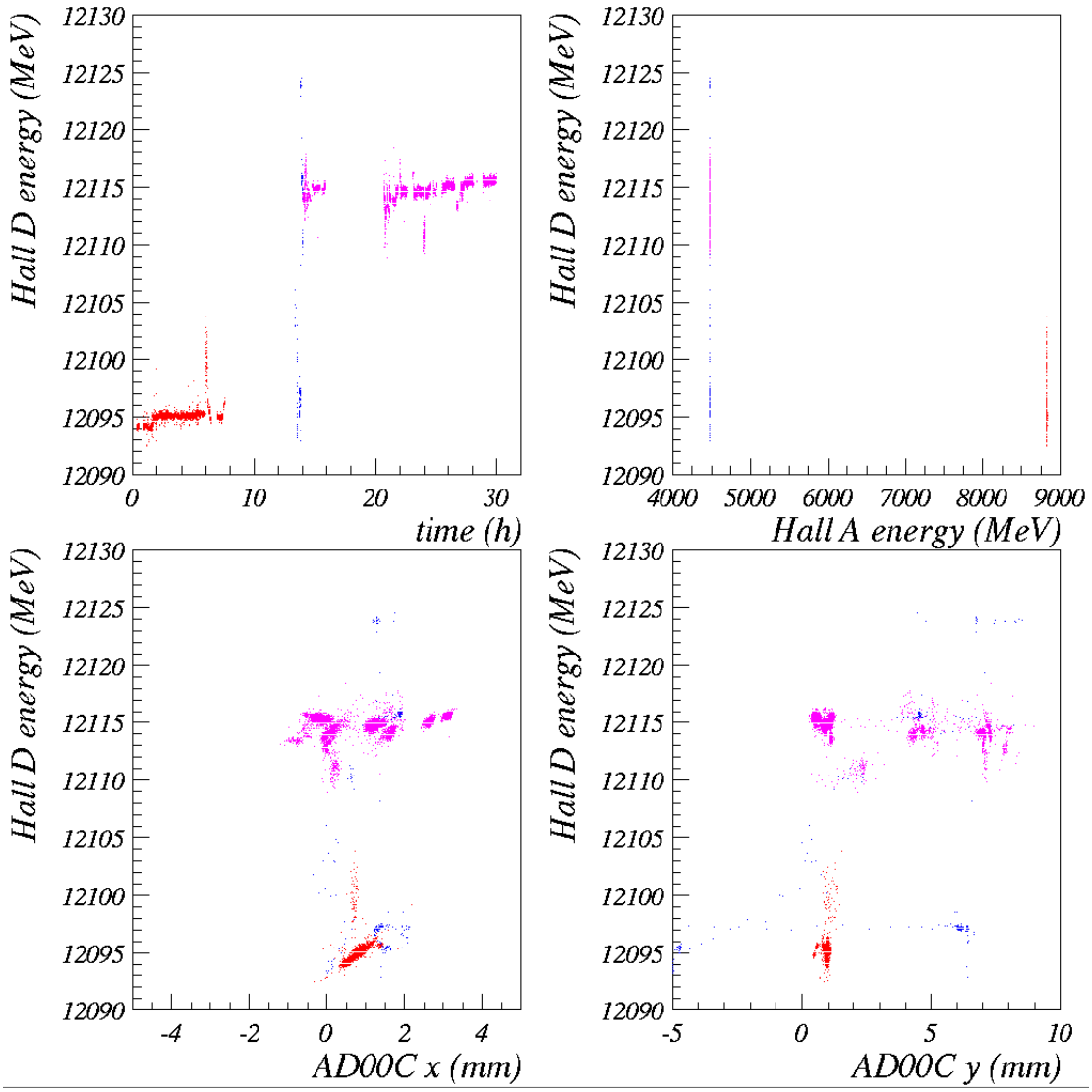


Figure 48: Same as Fig. 5 but for the April 11 00:00 → April 12 7:00am time period. **(Uncorrected beam energies)**

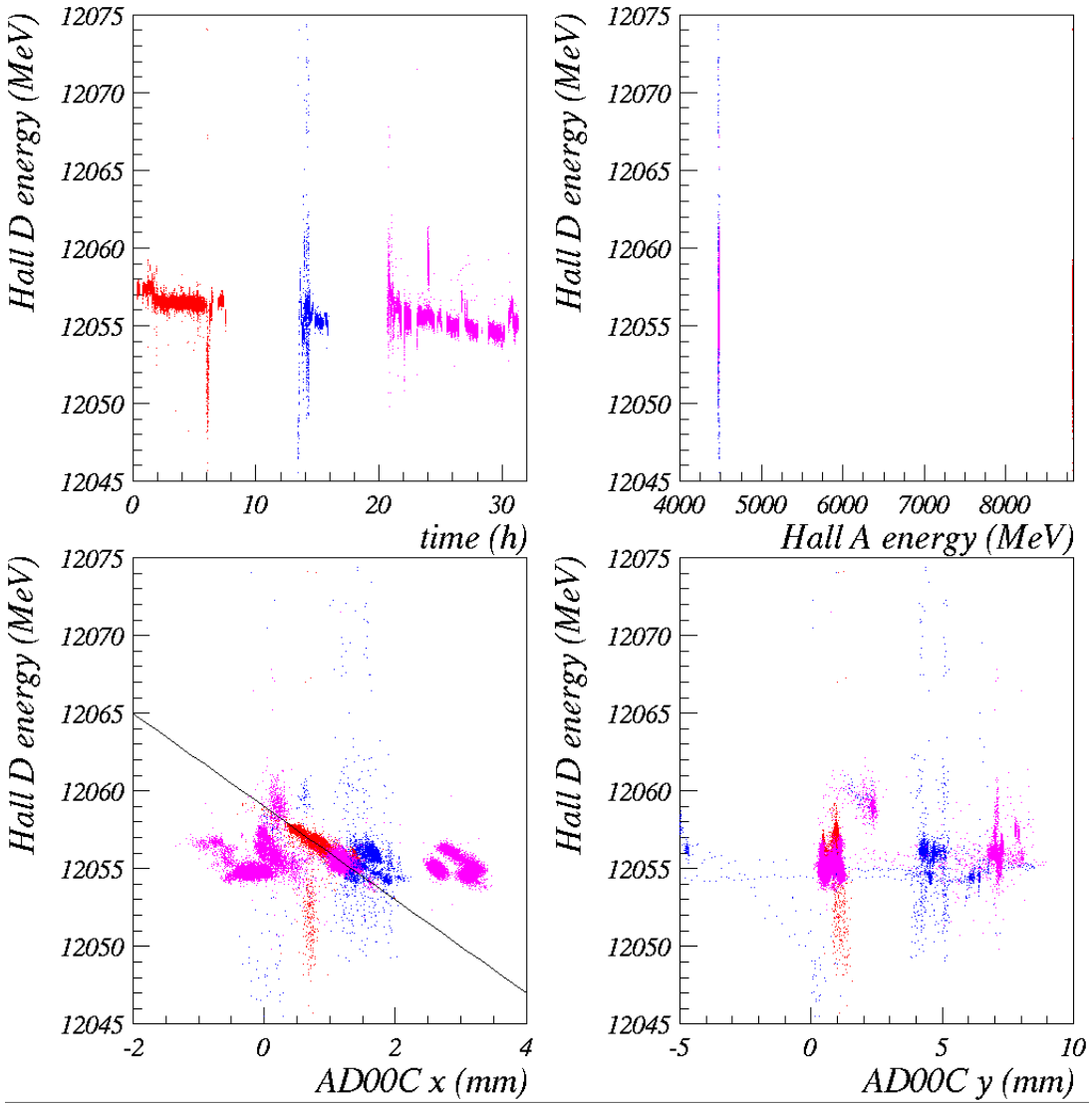


Figure 49: Same as Fig. 5 but for the April 11 00:00 → April 12 7:00am time period. **(Corrected beam energies)**

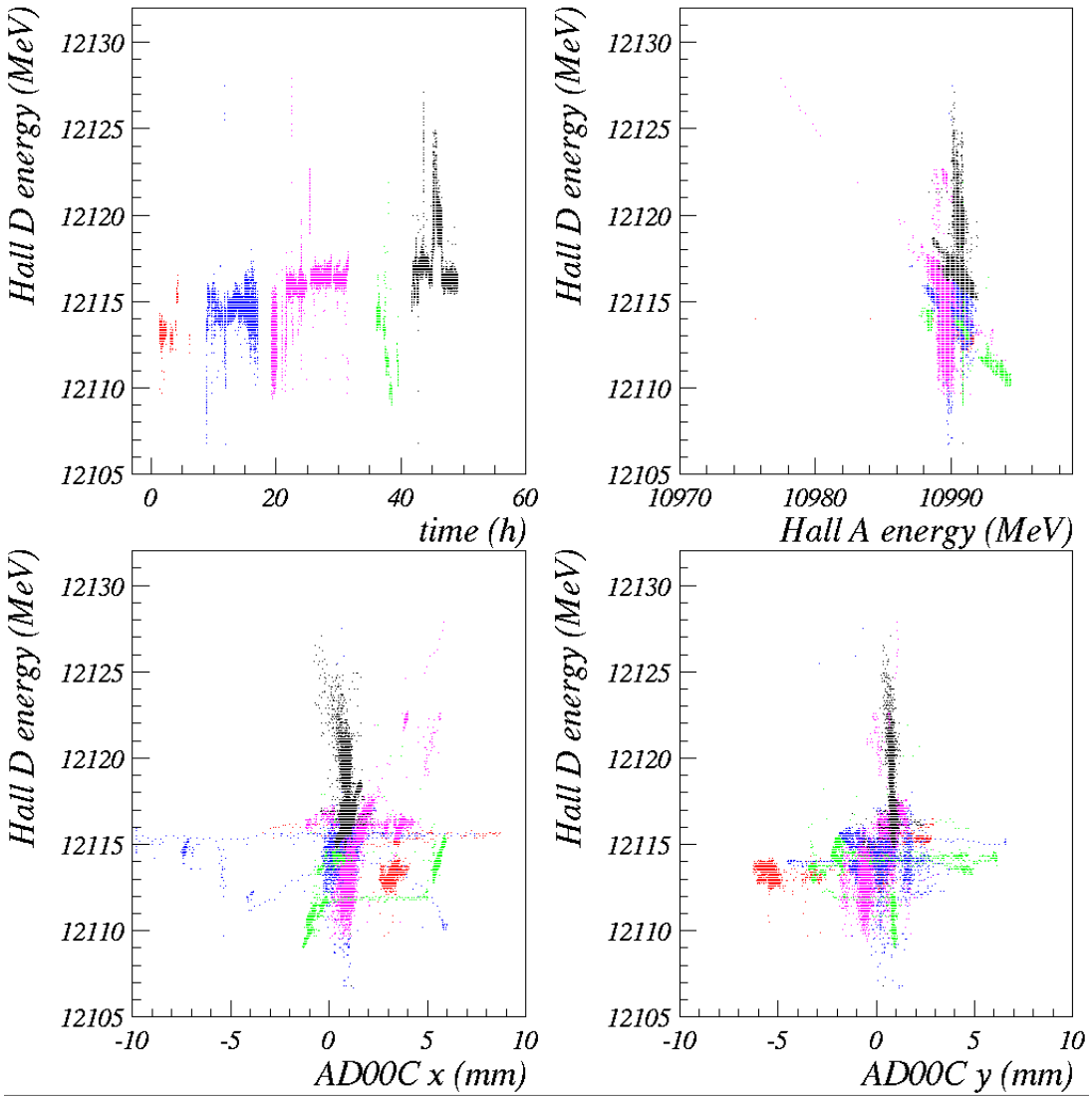


Figure 50: Same as Fig. 5 but for the April 13 1:50am → April 15 8:50am time period. **(Uncorrected beam energies)**

10.21 April 13 1:50am → April 15 8:50am

The large (5-10 MeV) fluctuations display no AD00c-x correlation but are located at different values of AD00c-y. These period correspond to low current runs (11 nA at the beginning of the magenta period, 22 nA during the cyan period). This indicates that they are artifacts. The smaller fluctuations (up to 5 MeV) seem genuine.

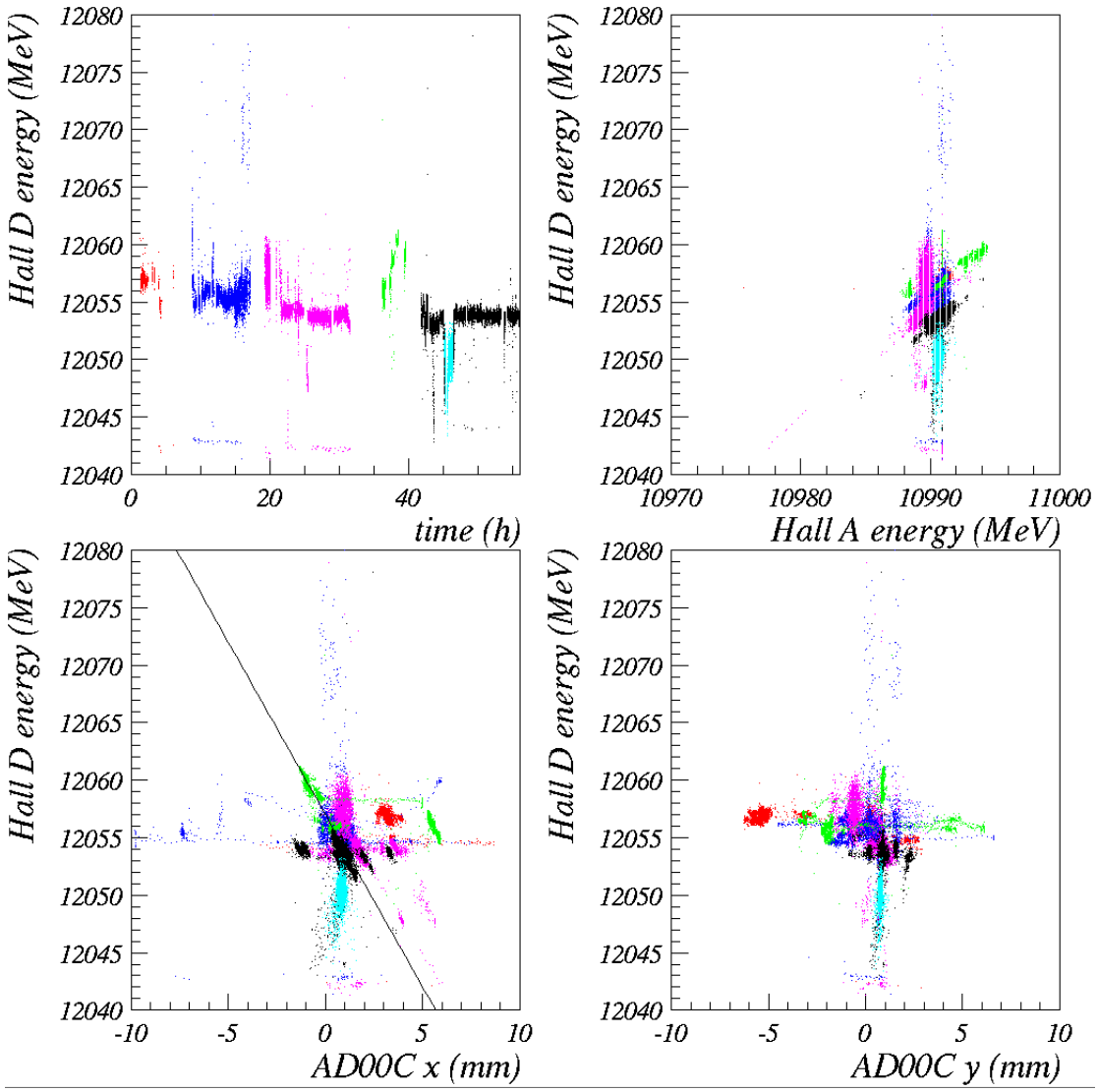


Figure 51: Same as Fig. 5 but for the April 13 1:50am → April 15 8:50am time period. **(Corrected beam energies)**

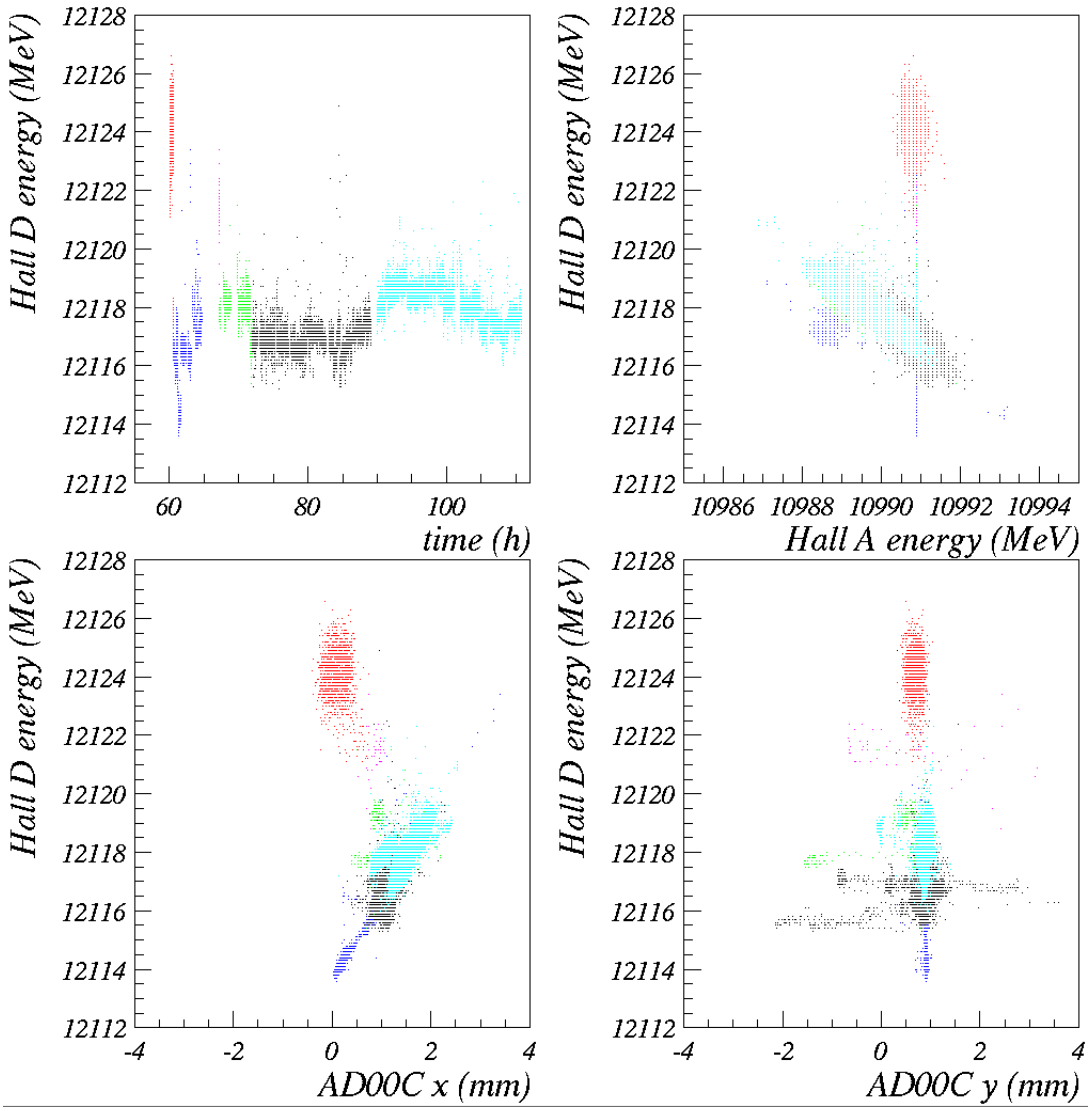


Figure 52: Same as Fig. 5 but for the April 15 8:50am → April 17 15:26 time period. **(Uncorrected beam energies)**

10.22 April 15 8:50am→ April 17 15:26

The energy fluctuations for this period seem genuine expect for the red, blue and magenta spikes toward lower energies. The red and blue are associated with a low current run (22nA and then 6nA)

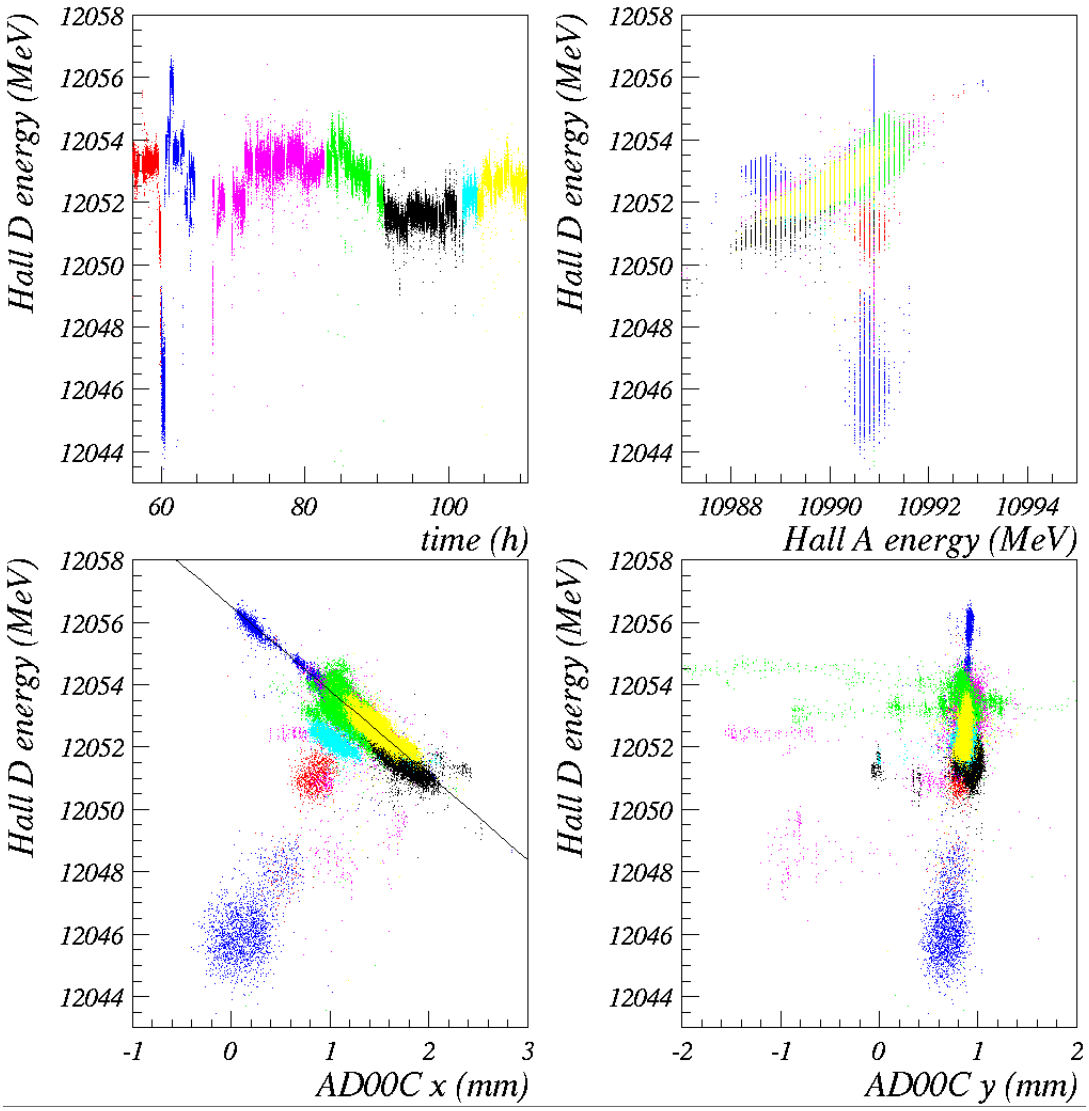


Figure 53: Same as Fig. 5 but for the April 15 8:50am → April 17 15:26 time period. **(Corrected beam energies)**

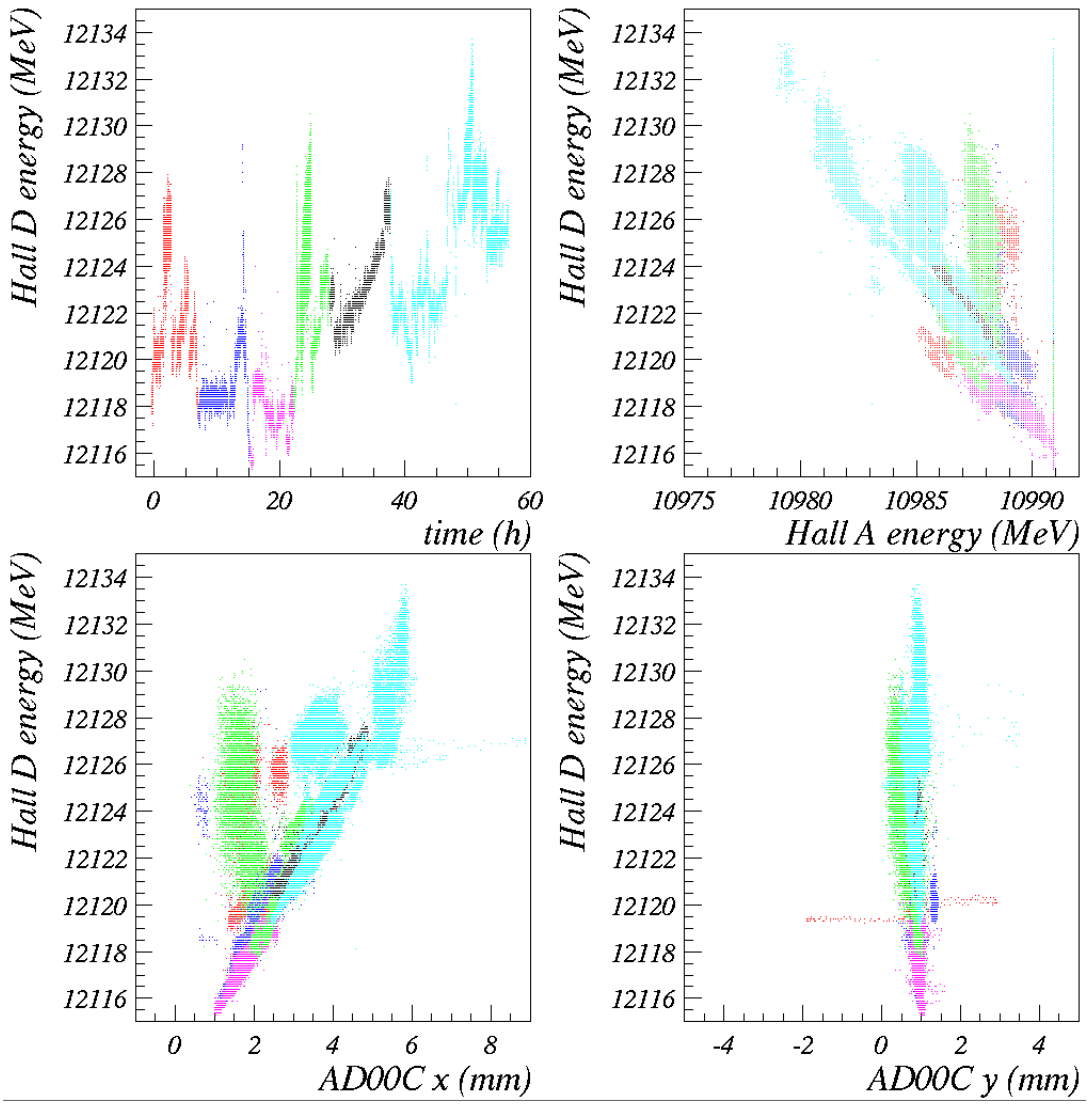


Figure 54: Same as Fig. 5 but for the April 17 18:00am → April 20 2:50am time period. **(Uncorrected beam energies)**

10.23 April 17 18:00am → April 20 2:50am

The fast downward fluctuations for the red (near 12045 MeV), green (near 12046 MeV), all the black, and yellow (see correlation pattern with AD00C-x) display no AD00c-x correlation. This indicates that they are artifacts. Except for the green near 12046 MeV (04/17, 23h50. I=200 nA), they are all due too low beam currents runs: The red near 12045 MeV ran at 10nA, the black at 50 nA, and yellow at 22 nA. The other drifts are genuine.

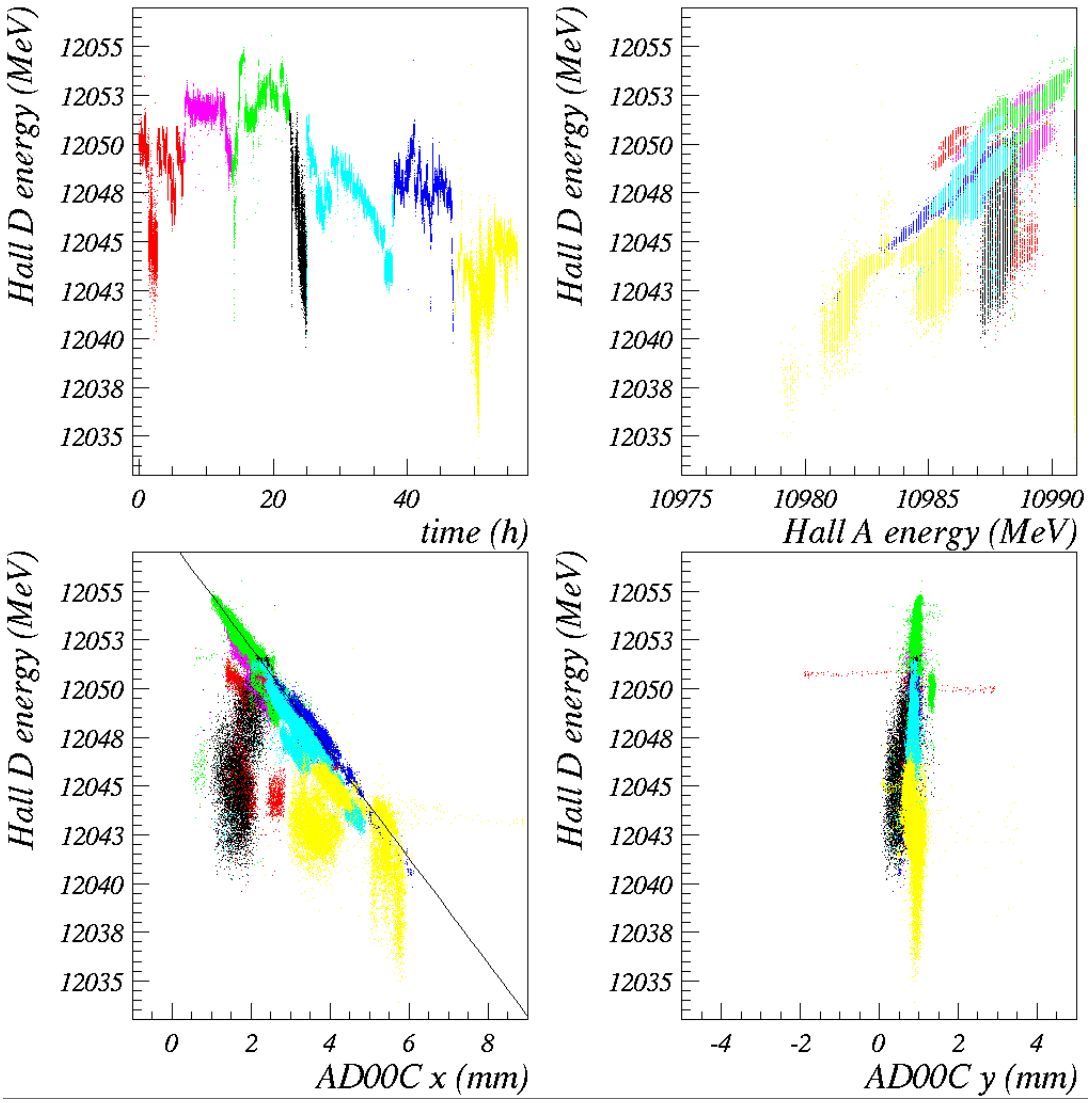


Figure 55: Same as Fig. 5 but for the April 17 18:00am → April 20 2:50am time period. **(Corrected beam energies)**

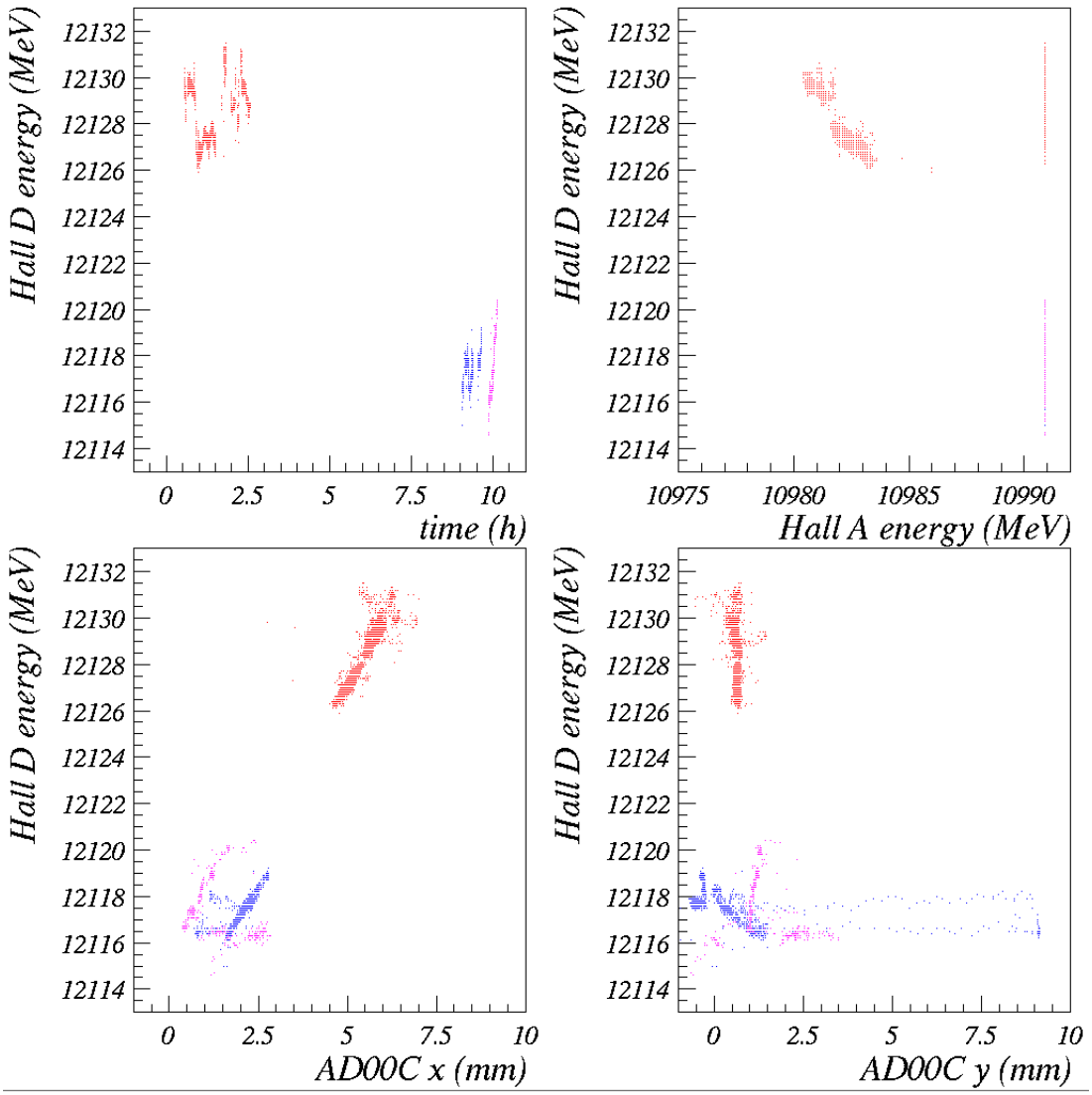


Figure 56: Same as Fig. 5 but for the April 20 6:00am → April 20 16:00 time period. **(Uncorrected beam energies)**

10.24 April 20 6:00am → April 20 16:00

The energy fluctuations for this period seem genuine. There is a +4 energy jump between this period and the previous one. It seems real comparing the AD00C-x position of this period and the previous one: the correlations fall well in line. The beam was off during the middle period because of beam studies (see logbook entry #3401053).

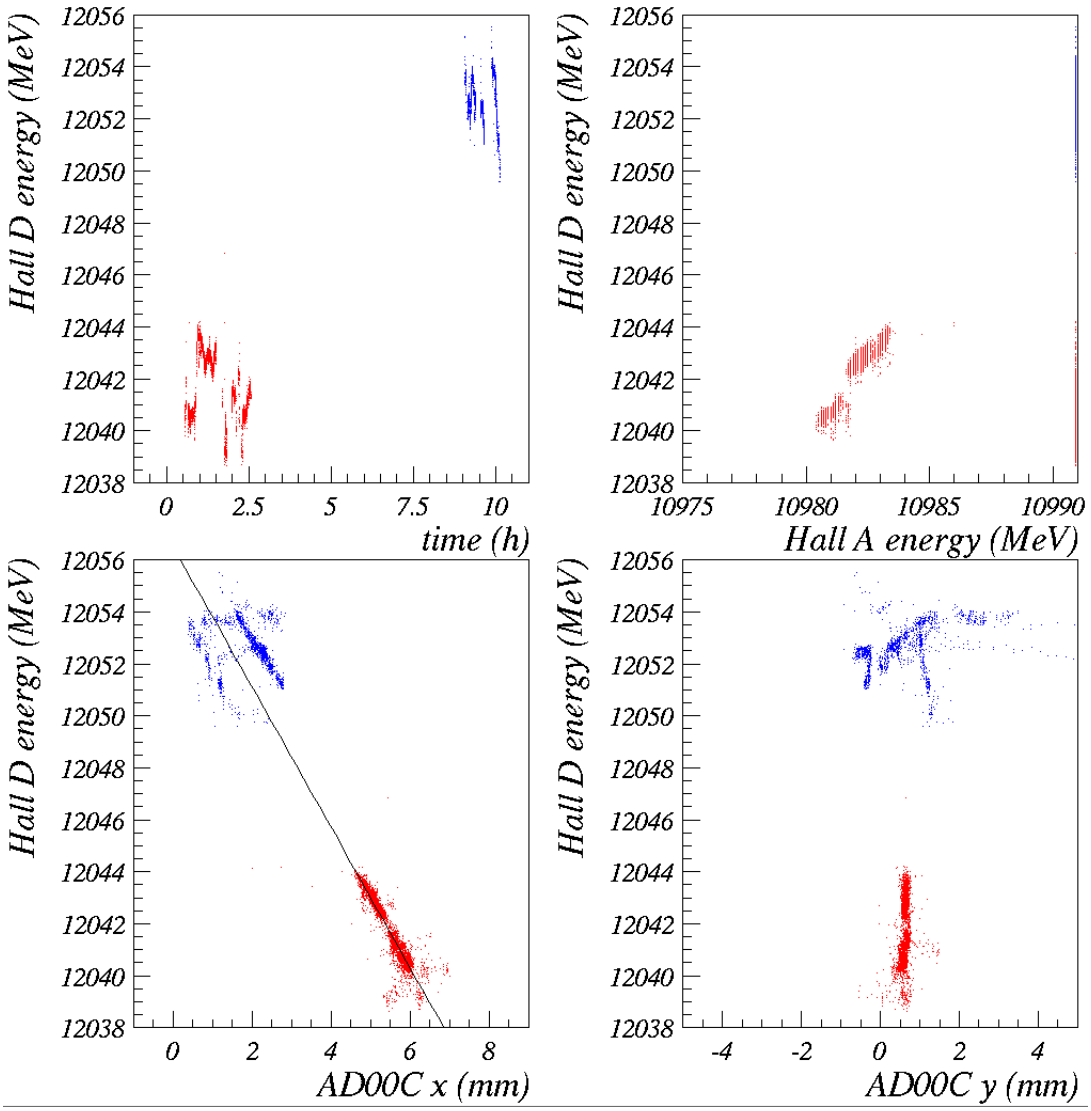


Figure 57: Same as Fig. 5 but for the April 20 6:00am → April 20 16:00 time period. **(Corrected beam energies)**

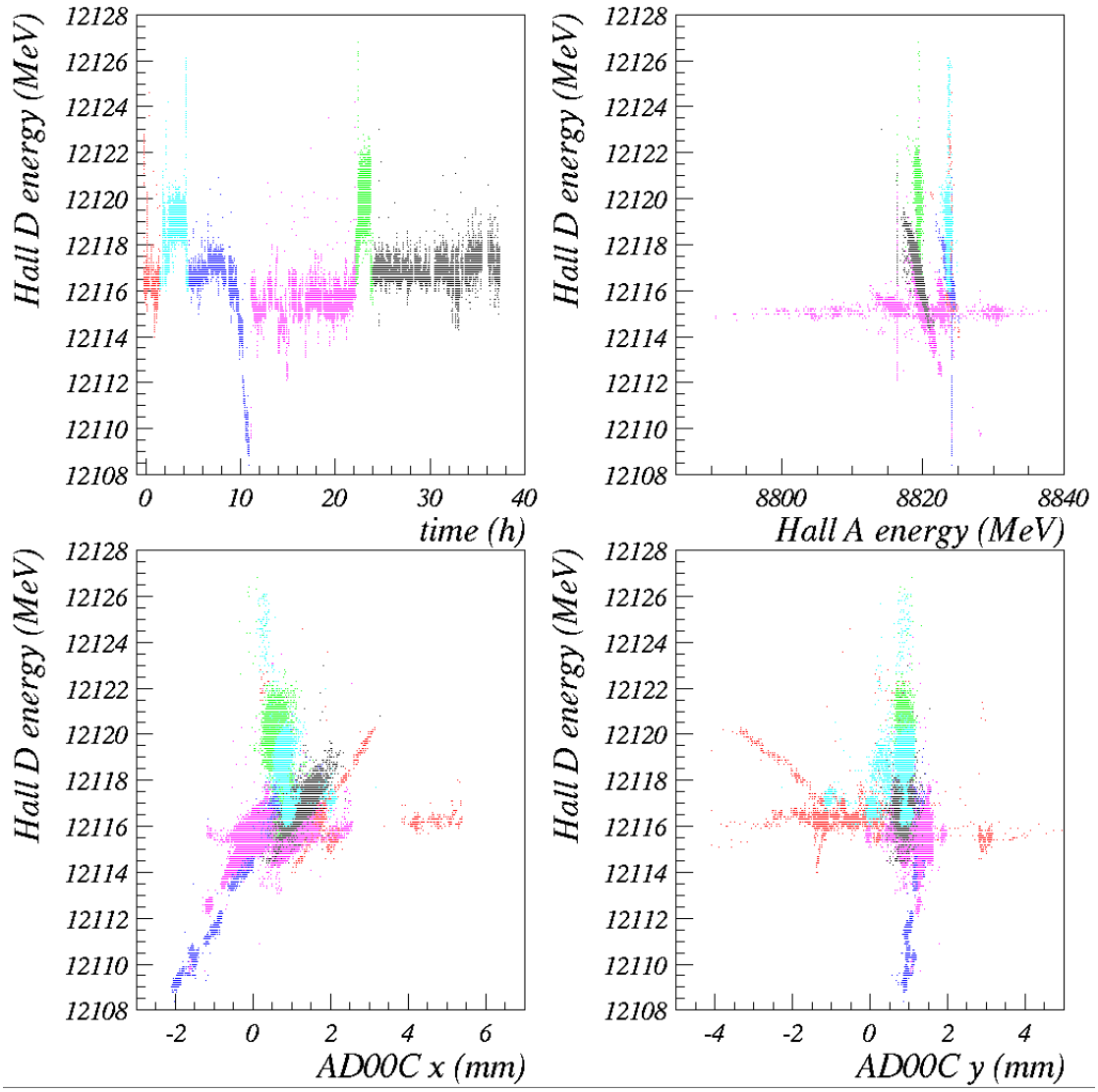


Figure 58: Same as Fig. 5 but for the April 20 21:00 → April 22 11:00am time period. **(Uncorrected beam energies)**

10.25 April 20 21:00 → April 22 11:00am

The energy fluctuations appear real, except for the cyan and green periods that are artifacts. They are associated with low current runs (cyan: 27 nA, green briefly at 24nA and then mostly at 12nA). There may be an artificial shift of -2 MeV after the red period.

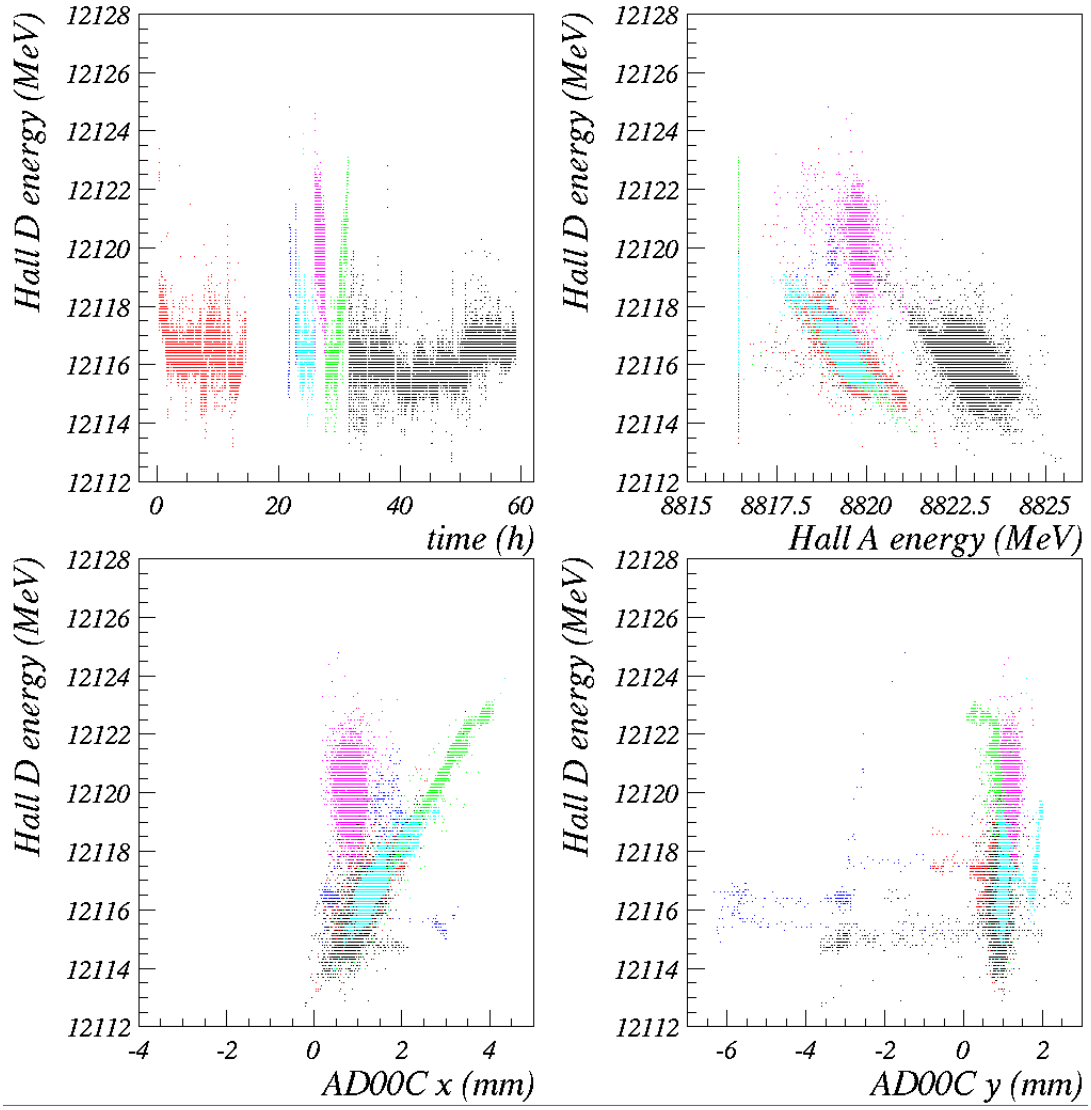


Figure 59: Same as Fig. 5 but for the April 22 19:10 → April 25 6:06am time period. **(Uncorrected beam energies)**

10.26 April 22 19:10 → April 25 6:06am

The energy fluctuations appear real, except for the magenta period and some rare instances during blue period, that appears to be artifacts.

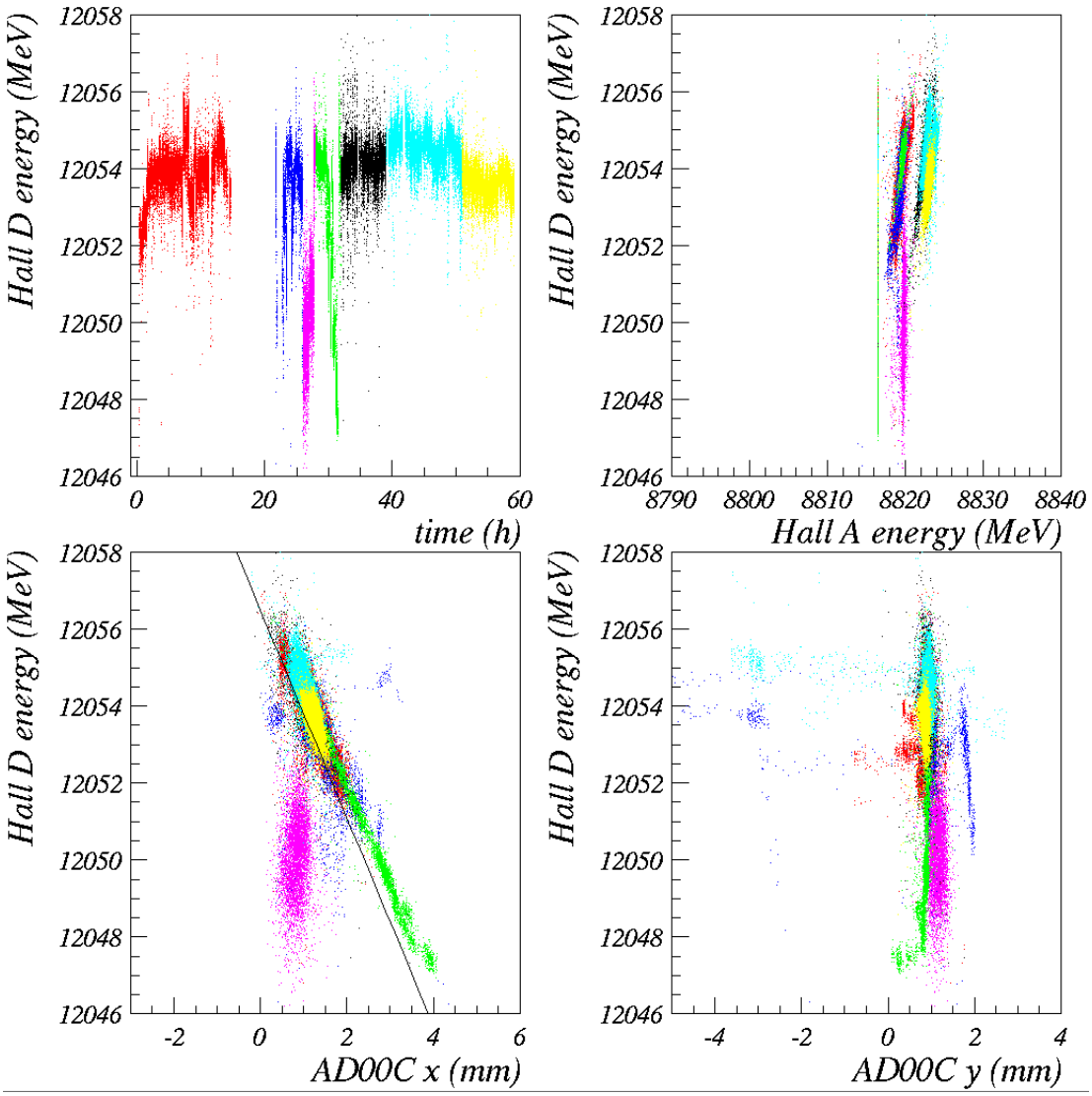


Figure 60: Same as Fig. 5 but for the April 22 19:10 → April 25 6:06am time period. **(Corrected beam energies)**