Electron beam energy analysis for the Spring 16 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 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 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 refer to the value reported by this measurement. Those can be real energy changes or artifacts of the measurement. This document tries to disentangle the two possibilities.

A conclusion from this study is that epics value HALLD:p should not be use on a (slow control) event-per-event basis since it displays many outlying values that do not correspond to the actual beam energy. Rather, a database listing the approximate beam energies for given periods, and a condition that the energy does not jump too far from the approximate value, would be more adequate.

Time (start, end)	energy (HALLD:p) (MeV) (uncorrected)	energy (corrected)	offset (MeV)	Notes
02/13 13:00 02/15 11:00	12025±8	12022±5	0	True drifts by -5 MeV during the first 10h. 5 MeV spikes at $t = 13.7$h are real. Other changes are artifacts.
02/15 17:00 02/16 8:30	12031±7	12031±7	0	02/16: 0:00 to 8:30am: Continuous +13MeV up drift is probably real.
02/17 11:00 02/20 8:00	12040±8	12040±8	0	Many energy drifts and jumps. Most as presumably real.
02/20 14:00 02/22 4:19	$12040\pm^{25}_{10}$ $t < 30h$ 12012±4 $t > 30h$	12044±4 12012±4	0	The jumps from 12050 to 12033 MeV at $t \simeq 11$h and from 12032 to 12040 MeV are artifacts. The jump from 12039 to 12012 MeV is real.
02/22 20:00 02/23 8:30	12135±3	12014±2	-120 -118	Beam down for 16h. Came back at 12133 MeV. Hall A pass change (now 1 pass) occurred after 120 MeV jump.
02/23 18:00 02/25 10:00	$12133\pm^{14}_{7}$	$12015\pm^{14}_{7}$	-118	
02/25 10:00 02/26 9:00	$12055\pm^{20}_{14}$	12020±10	-35	Artificial -83 MeV jump on 02/25 at 10:17am. Artif. jump of +12 MeV at the end of the period.
02/27 15:00 02/29 16:35	12101±3	12061±3	-13 -40	Beam was down for 30h. Came back with a +27 MeV offset. Can't assess if real. We arbitrarily assume for now that it is real. There is a -60 MeV shift the last few hours, then back.
02/29 17:00 03/01 9:00	12104±8	$12064\pm^{8}_{2}$	-34	Genuine +13 MeV drift at the start. Artificial -6 GeV shift at the end.
03/02 18:00 03/05 10:55	12098±8	12059±7	-39	Artif. +5 MeV jump.
03/05 20:10 03/06 16:10	12102±6	12063±6	-39	+5 MeV jump for 2h.
03/06 20:00 03/07 18:00	12097±5	12057±5	-36	Should add +3 MeV for $t > 19$h.
03/07 18:00 03/08 9:00	12085±11	12065±11	-20	Two energy jumps. 1st one (16 MeV) is an artifact. 2nd one appears real.
03/08 9:00 03/09 14:40	12090±5	12068±4	-18	Apparently genuine 15 MeV jump occurred between previous period and this one
03/27 13:00 03/28 9:41	$12094\pm^{14}_{3}$	$12094\pm^{14}_{3}$	$\equiv 0$	18 days down time $\Longrightarrow$ cannot relate energy scale of this period to previous one $\Longrightarrow$ Offset set to 0 arbitrarily. Genuine drift of 17 MeV up and then down.
03/28 19:10 03/30 10:10	12103±8	12103±8	-1	Genuine drift of 16 MeV. +1 MeV artif. jump in middle of period.

Table 1: Hall D electron beam energy binned in periods of approximate energy stability. The vertical error bars are not measurement uncertainties but bracket the systematic drift range during the time period. The second column provides the energy uncorrected for any 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
03/30 10:10 04/01 1:10	12116±7	12115±7	-1	Genuine drift of 13 MeV.
04/02 1:50 04/04 7:50	12120±11 $t < 25h$ 12120±11 $25 < t < 47h$ 12120±11 $t > 47h$	12121±5 12110±4 12103±4	-8	Large energy fluctuation (20 MeV) appears real apart for a +17 MeV offset.
04/07 14:00 04/09 8:00	12097±6	12097±6	0	Beam down for 3 days. Came back at 12096 MeV. Unclear if the -8 MeV shift between this period and previous one is real. We arbitrarily assume so.
04/09 8:00 04/11 00:00	12095±4	12095±4	0	
04/11 00:00 04/12 7:00	12095±1 $t <$ 9h 12115±2 $t >$ 9h	12095±1 12095±2	0 -20	Beam down for 6h. Came back at 12115 MeV. The change seems to be due to a re-tune after a Hall A pass change. The shift seems to be an artifact.
04/13 1:50 04/15 8:50	$12115\pm^{3}_{5}$	$12095\pm^{3}_{5}$	-20	
04/15 8:50 04/17 15:26	$12097\pm^{2}_{3}$	$12097\pm^{2}_{3}$	-20	
04/17 18:00 04/20 2:50	12121±6	12101±6	-19	Beam went down on 04/17 15:23. Came back at 12121 MeV, less stable, with overall systematic up drift and many artif. spikes.
04/20 6:00 04/20 16:00	12124±8	12105±8	-19	Real +4 MeV jump between this period and previous one, after 4h15 down time.
04/20 21:00 04/22 11:00	12115±6	12096±6	-19	Two artif. +5 MeV jumps at $t \simeq$ 3h and $t \simeq$ 23h
04/22 19:10 04/25 6:06	12118±5	12099±5	-19	

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 results 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 (anti)correlate, although not systematically, with the changes seen in arc energies and with the Hall A energy. However, the anticorrelation may be a problem: if the energy changes through linac energy drifts we expect the linac, Hall A and Hall D energies to be correlated.

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. 17. 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 an artificial jump in the HALLD:p readout. 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

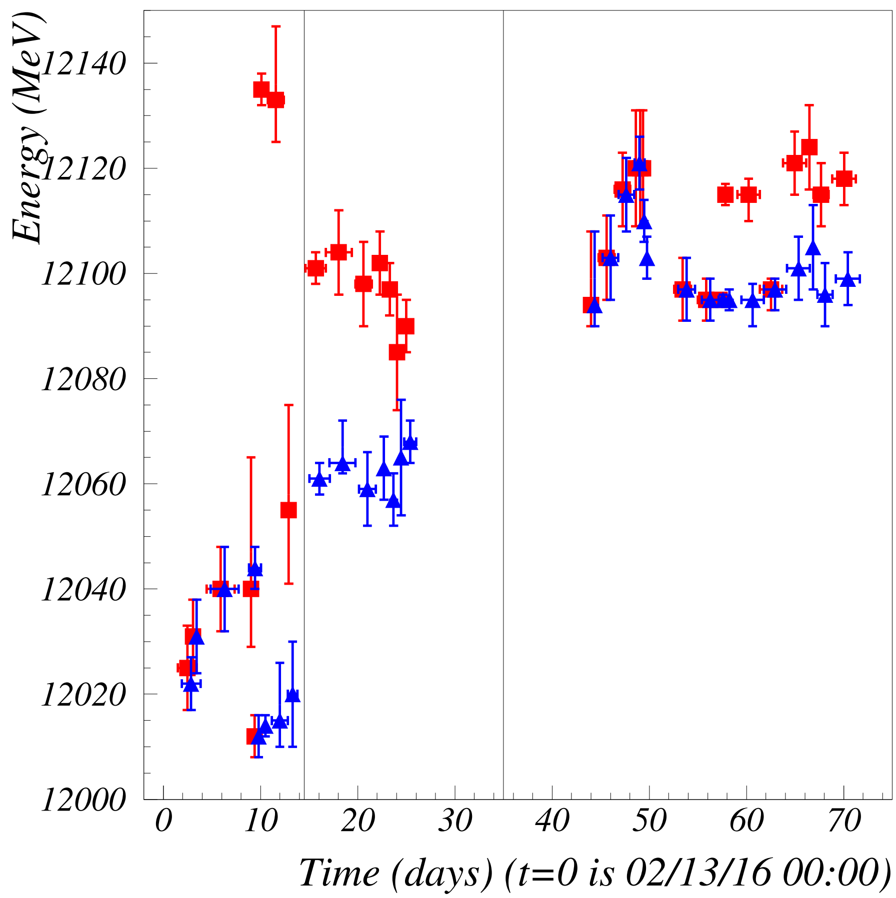
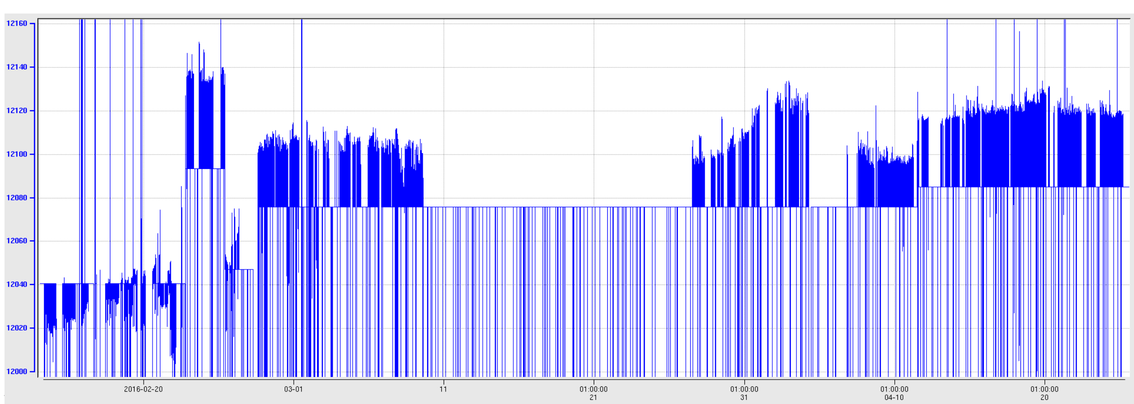


Figure 1:
Hall D electron beam energy binned in periods of approximate energy stability. The vertical error bars are not measurement uncertainties but bracket the systematic drift range during the time period. The horizontal error bars provide the time range over which the energy is averaged. The values given by the red squares are uncorrected for the artificial energy jumps, while the blue triangles are corrected for the artificial jumps. The time for the blue triangles is artificially shifted by 0.4 days for visual clarity. The two vertical black lines separate domains between which the absolute vertical scale could not be established, i.e. constant offsets may exist between these periods.



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

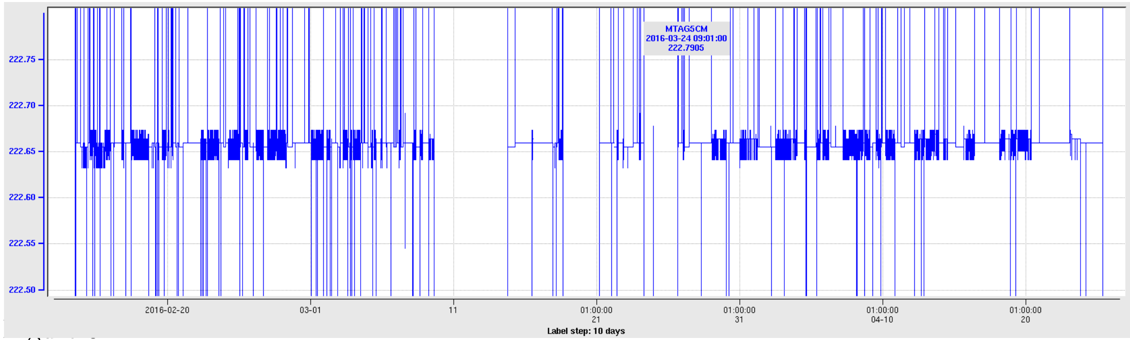


Figure 3: Tagger current during the Spring 2016 run.

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. 24 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.

There is a correlation between the vertical position of the beam after and before the tagger magnet, given by BPM 5C11-y, 5C11A-y, 5C11B-y, AD00-y and AD00C-y. This suggests that the jumps are due to vertical beam motions that are erroneously translated into energy changes by the magnetic energy measurement in the Hall D ramp.

Todd Satogata suggested that these artifacts may be coming from automatic gain switching of the BPMs. I am checking with Trent Allison and Mike Tiefenback.

4 Energy changes after long beam down times

These reasons listed in the previous sections cannot be applied to other energy changes that occur after a long beam down time, since the orbit of the beam may have changed. Any energy changes seen after a long beam downtime may be real.

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 readback is MTAG5CM, and the setpoint 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. These are given relatively to the initial energy at the start of the run, April 13, or to the periods after a beam retune, see Fig. 1.

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 3±0.5 MeV/mm, but it sometimes changes significantly. 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. Finally some of the jumps (equivalent in mm to a $\sim$ 3 MeV change) can come from inserting radiators of different thicknesses, see Section 9.

Period	$a \times AD00Cx + cst$ (uncorrected for offsets)
02/13-02/15	3.1x+12021.5
02/15-02/16	9.8x+12027.7
02/17-02/20	11x+12010$\pm^{4}_{13}$
02/20-02/22 start & end: middle	5.7$\pm$1.5x+11992$\pm$11 12.5x+11998.5 then 10.5x+11999.5
02/22-02/23	3.5x+12125.5$\pm$1
02/23-02/25	4.2x+12124.3
02/25-02/26	-
02/27-02/29 start end	3.2x+12094.0 $\sim$ 6x+12035
02/29-03/01 start end	3.1x+12093.5 3.3x+12086.4
03/02-03/05 start middle end	2.9x+12087.5 5.7x+12085.0 4.2x+12087.5
03/05-03/06 start middle end	2.9x+12089.0 5.0x+12085.0 4.5x+12082.0
03/06-03/07	4.5x+12083$\pm$2
03/07-03/08	4.7x+12082.5
03/08-03/09	4.7x+12081.5
03/27-03/28	3.2x+12096$\pm$5
03/28-03/30	2.9x+12095.7
03/30-04/01 Energy$<$12108 MeV 12108$<$E$<$12115 E$>$12115 MeV	2.6x+12096.6 2.9x+12095.5 4.5x+12084.5
04/02-04/04	2.5x+12119 or 2.5x+12131 or 3.9x+12091.5
04/07-04/11	2.5x+12093.5
04/11-04/12 Before 20 MeV jump after jump	2.5x+12093.5 2.5x+12111.5$\pm$4.5
04/13-04/15	2.3x+12112.3
04/15-04/17	2.5x+12113.7
04/17-04/20	2.6x+12114.1 $\pm$1.3
04/20-04/20	2.9x+12112.5$\pm^{3}_{1}$
04/20-04/22	2.7x+12114.5$\pm$2
04/22-04/25	2.6x+12113

9 Beam energy losses due to radiator thickness

Difference of radiator effective thicknesses will shift the beam energy and thus introduce an offset in the energy vs AD00C-x correlation. This is a small effect: the difference of effective thickness between para and perp configurations for the 50 μm diamond is 7×10^{-5} RL (this may depend on time since the lower effective RL of the perp configuration is due to the beam missing part of the diamond). Thus, the relation $energy = 2.6x + cst$, see previous table, would make approximately a 0.3 mm shift on AD00C-x. A difference between no-radiator and the 3.4×10^{-4} radiator would result in a 1.6 mm shift.

We verified this effect for the April 24 08:10am → April 25 1:24am period[1] during which the beam was stable and radiators were switched a number of times. The data can be seen on Fig. 4. On the bottom left panel, we see that HALLD:p and AD00C-x are positively correlated, as expected (facing downstream, x should point to the left). The colors correspond to different radiators: red is for the 50 μm diamond in para configuration (3.4×10^{-4} RL), purple is for the 3.4×10^{-4} Al. radiator and blue is for the 50 μm diamond in perp configuration ($\sim 2.7 \times 10^{-4}$ RL. Its effective RL is less than in the para configuration because the beam was missing part of the diamond). The blue data are systematically shifted to the positive-x, as expected since the beam energy loss was smaller. It can be seen more clearly in Fig. 5 where the HALLD:p vs AD00C-x correlation has been taken out. The top left plot is for all the data during the 40h period. The three other plots on the figure are for different time periods during which we ran several radiators. They verify that the effect is systematic. This verifies the correlation between HALLD:p and energy loss, i.e. that the sign of the variation of HALLD:p is correct, without relying on coordinate system conventions. It also verifies that the sign for AD00C-x is correct and provides a measurement of the effective radiation length of the diamond at that time. The RL for the 50 μm diamond in para configuration is confirmed to be 3.4×10^{-4}RL: its red histogram overlaps perfectly with the 3.4×10^{-4} Al. radiator purple histogram. Given the 0.175 mm shift between these histograms and the blue one, we deduce that the RL for the 50 μm diamond in perp configuration was 3.0×10^{-4}RL at that time.

10 Signs of the fluctuations

The anti-correlation between HALLD:p and HALLA:p as well as the ARC energies suggests that either the sign of the variation of HALLD:p is not correct or that the signs for Hall A and the ARC is wrong. This could come from a confusion in the coordinate system of the dispersive BPM used to extract the energy information. However, as discussed in Section 9, the sign of the Hall D fluctuations appears to be correct. (This check does not rely on coordinate system conventions.) Furthermore, the position of the photon energy spectrum was checked (J. Stevens) for two close runs of significantly different energy according to HALLD:p:

1. Run 10857, 03/08/2016 1:45am, with HALLD:p reading about 12091 MeV (blue in Fig. 6)
2. Run 10867, 03/08/2016 8:20am, with HALLD:p reading about 12074 MeV (red in Fig. 6)

As can be seen on Fig. 6, the coherent edge is around 8.98 GeV and is offset by 1-2 counters for the two runs, that is about 15 MeV, as expected from HALLD:p. The other structures on the spectrum are due to counter inefficiencies and are matching perfectly, as it should, for the two runs. The coherent edge of the lower energy run 10867 (red) is at lower energy, confirming the sign verification in Section 9. Again, this additional check does not rely on coordinate system conventions.

11 Conclusions

The Hall D electron beam energy varied over a $\sim$1% range during the Spring 2016 run. Some of these variations are genuine and some are artifacts of magnetic energy measurement method. One can usually distinguish between both cases, but sometimes, the nature (real or artifact) of the variation is ambiguous. The origin of the artificial drifts is unclear for the moment. One criterium to check if the variation is real or not is to compare dispersive an non-dispersive BPMs in Hall D ramp. However, the non-dispersive BPM sometimes correlates with energy fluctuations that are assessed by other means to be genuine.

The Hall D energy is systematically anti-correlated with the Hall A and Arc energies. We verified using several means that the sign of the Hall D energy variation is correct. The reason for such anti-correlation is unknown.

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.

[1]We also attempted to verify this using the Feb. 25-26, March 02-03 or Apr. 11th data but the beam position was not good stable enough.

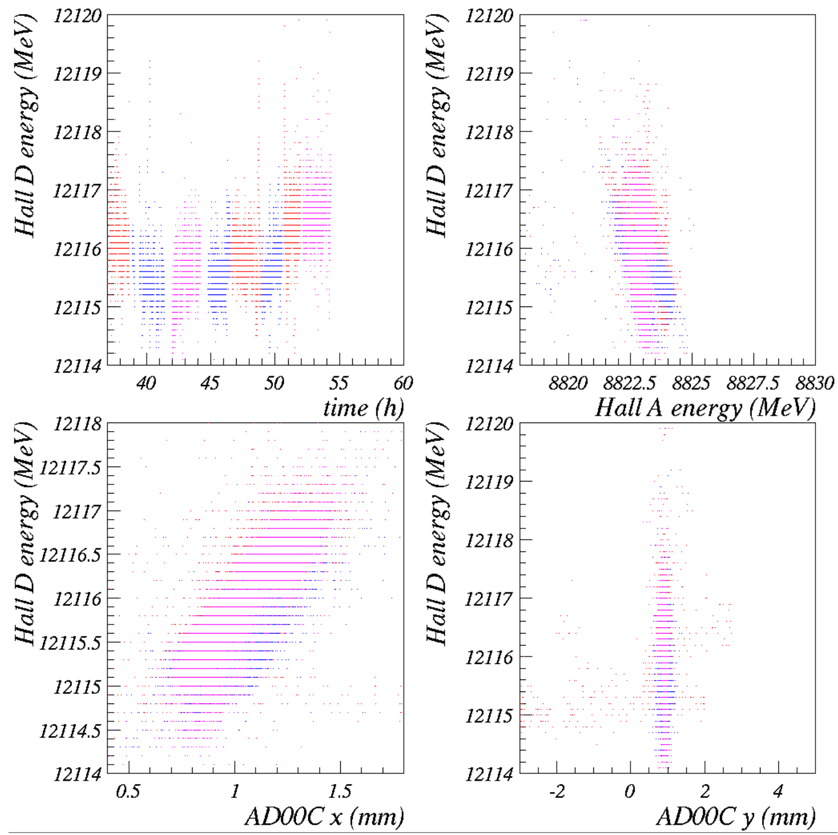


Figure 4:

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.

The data are for the April 24 08:10am → April 25 1:24am period (time=37h corresponds to April 24 08:10am). The colors correspond to different radiators, see main text.

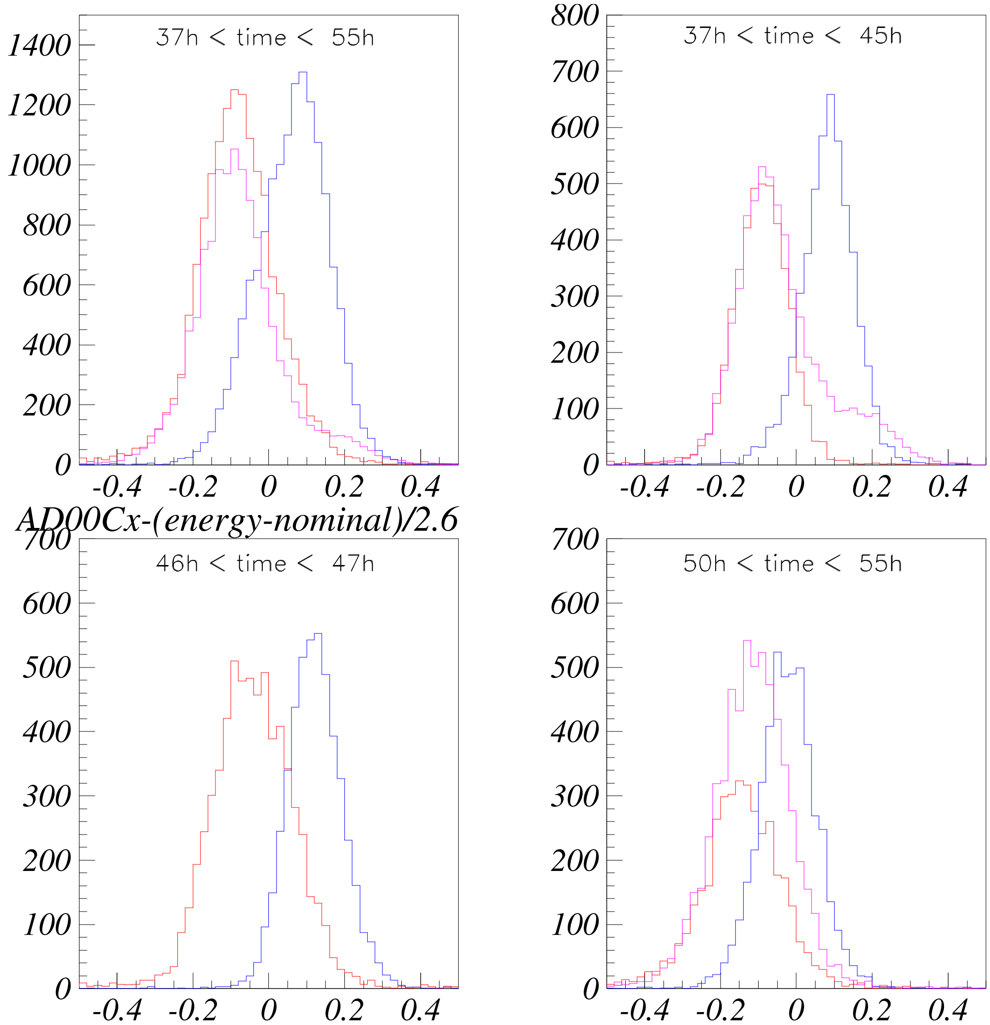
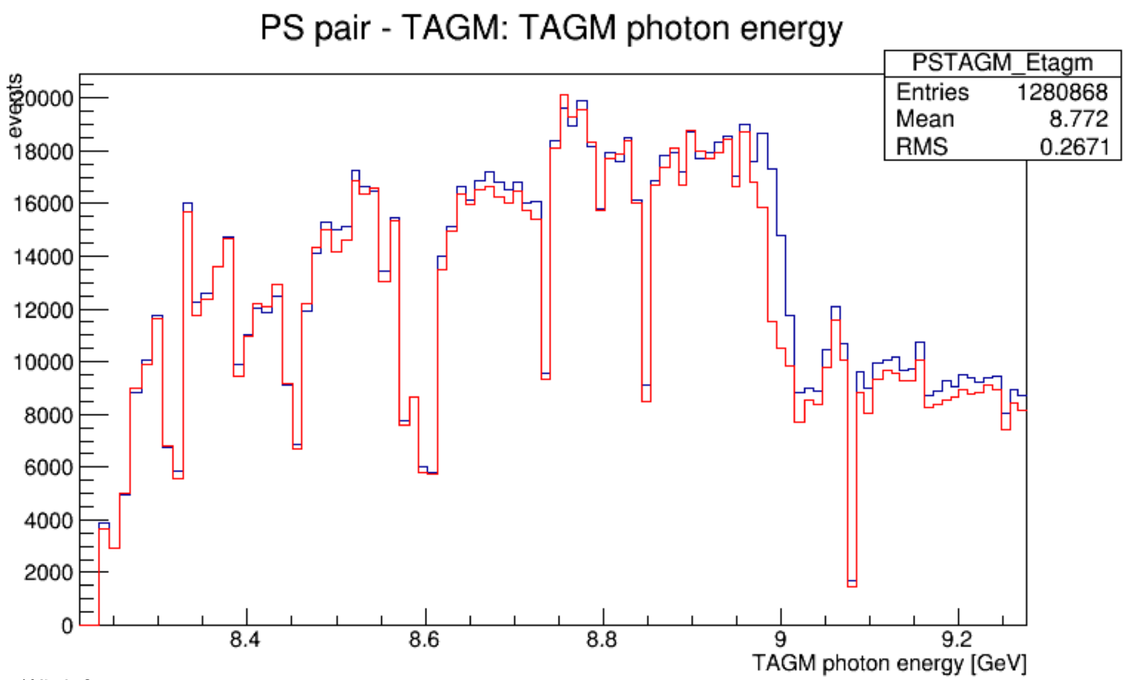


Figure 5:
x beam-position at AD00C. The colors correspond to different radiators, see main text.



Tagger microscope counter signals for runs 10857 (red) and 10867 (blue) vs *photon* beam energy. The coherent edge is around 8.98 GeV.

12 Appendix: Detailed analysis of the individual periods

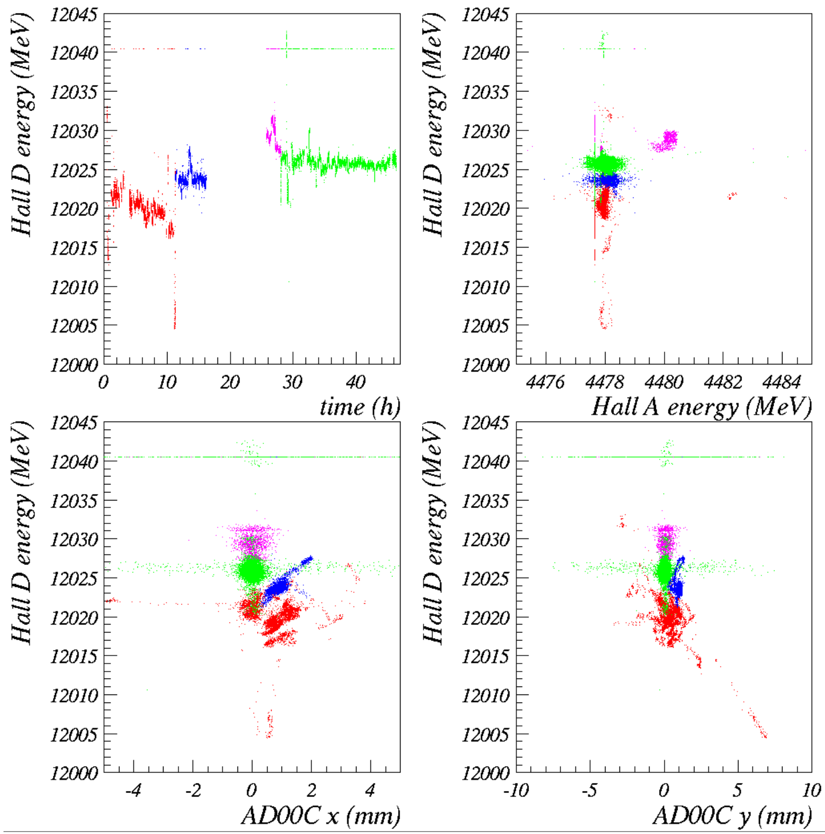


Figure 7:
Beam energies and beam x-y positions at the AD00C BPM (Hall D tagger dump). The top left panel displays the time evolution of the Hall D electron energy. The top right plot displays the correlation between the Hall A and Hall D energies. The bottom left plot displays the correlation between 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.
The data are for the Feb. 13 13:00 → Feb 15 11:00am period. The colors correspond to different slices of time.

12.1 Feb. 13 13:00 → Feb 15 11:00am

The small drift down by 5 MeV for $0 < t < 5$ h is real: There is a correlation between AD00C-x and the energy drift. Then, the 12 MeV drop at $t \simeq 11$h is an artifact: there is no correlation for x but a significant one for y. The 5 MeV spike occurring at t=13.7 is real. The energy drift shown in purple on the figure seems to be an artifact. Because of the 9 hours down time in the middle of this period, it is unclear whether the 2 MeV increase between the blue period and green one is real. It is likely an artifact. The energy jumps during the green periods are artifacts.

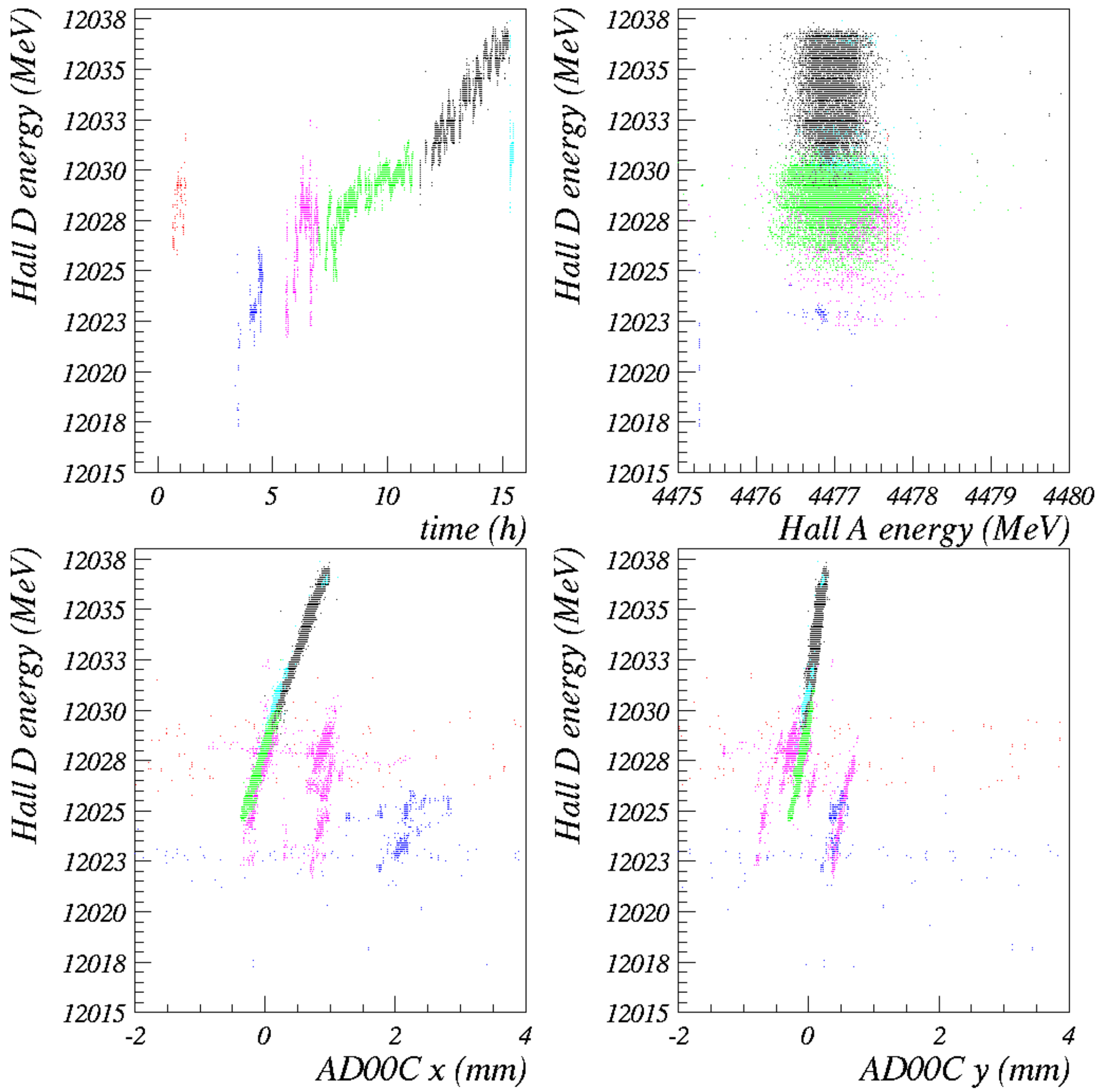


Figure 8:
Same as Fig. 7 but for the Feb. 15 17:00 → Feb 16 8:30am time period.

12.2 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.

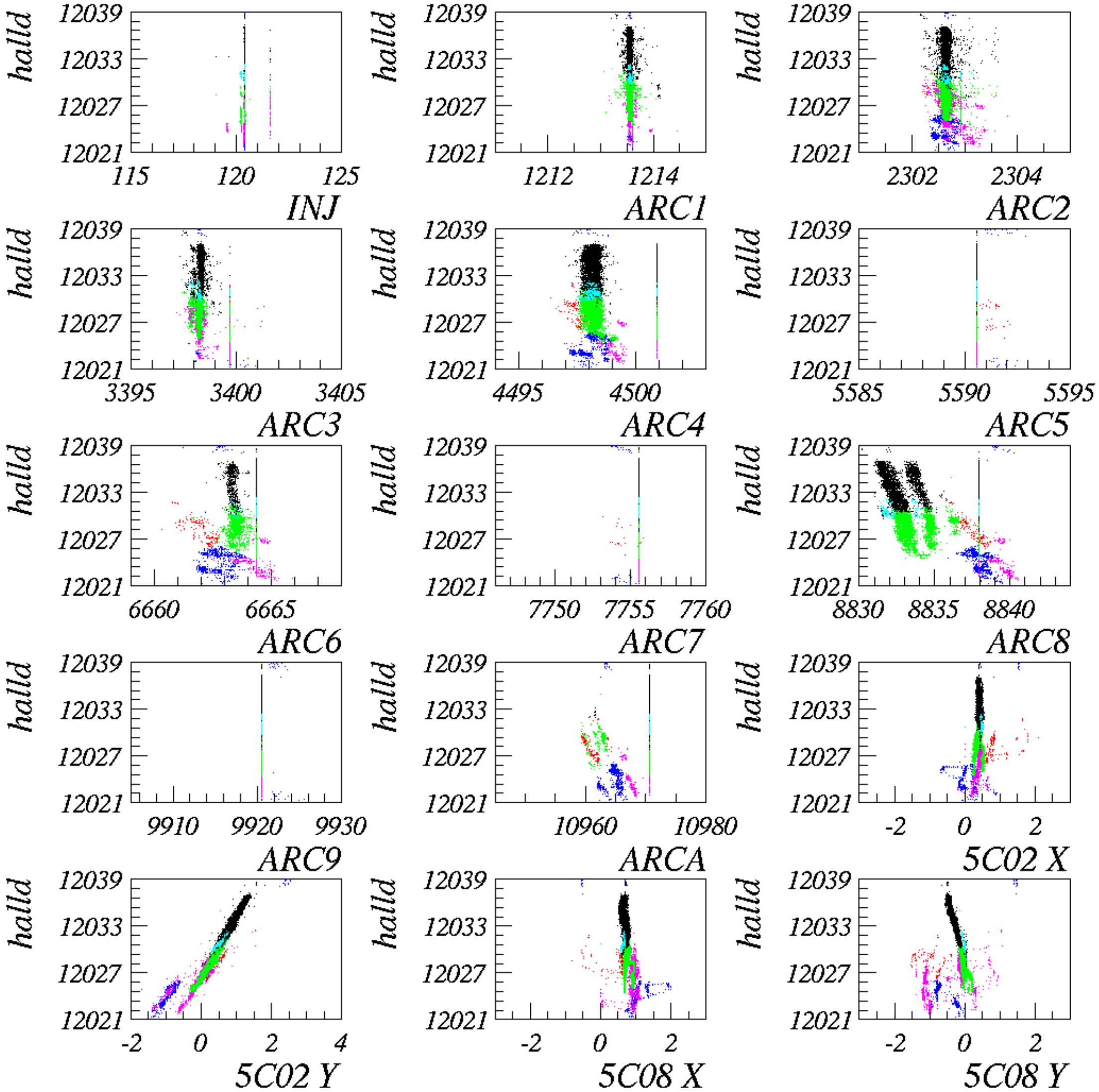


Figure 9:
Correlations between the Hall D electron beam energy and the beam energy at the injector and various arcs (first 11 plots), and between the Hall D energy and BPM 5C02 and 5C08 (last 4 plots). The data are for the Feb. 15 17:00 → Feb 16 9:00am time period.

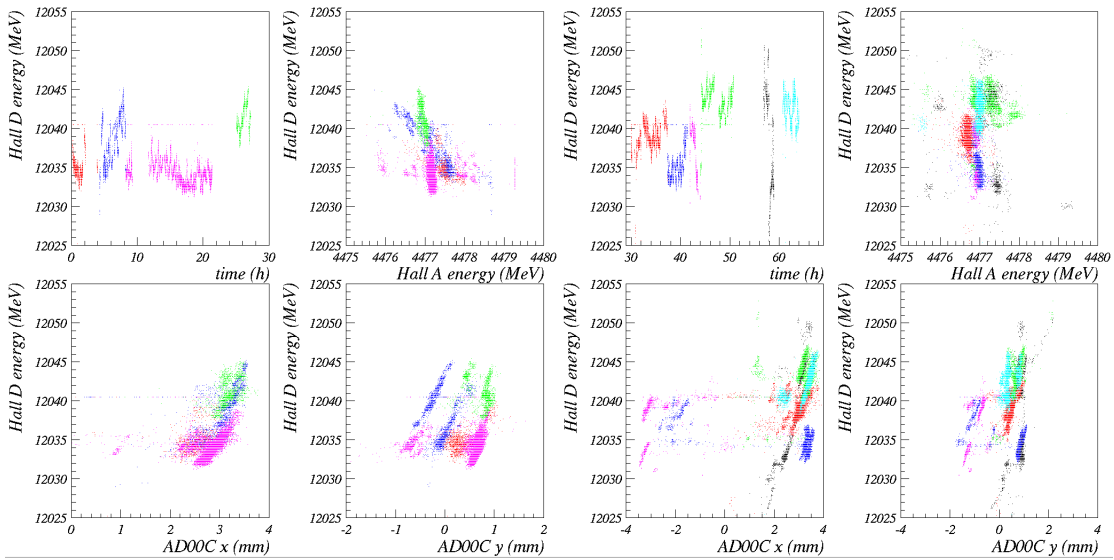


Figure 10: Same as Fig. 7 but for the Feb. 17 11:00am → Feb 18 21:00 time period (left) and Feb. 18 21:00 → Feb 20 8:00am time period (right).

12.3 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 first 4-panel figure, the first period (shown in red) has a 4 MeV Hall D energy decrease correlated with Hall A, and AD00C-x (but not -y). This indicates a true energy drift. The 4 MeV increase at the end of the red period is correlated only with AD00c-y, indicating an artifact. The next two periods (blue and magenta) display correlations between the Hall D energy and Hall A energy, AD00C-x and -y, as seen previously (Feb. 15 17:00 → Feb 16 9:00am time period). Thus, it is unclear whether the energy drifts are real or not. The last period (green) has a weaker AD00C-x correlation. The blue period shows a stronger correlation with Hall A energy, while the purple one is similar to the green one. We tentatively assume that the purple slow drift is a real energy changes. The jumps between the blue and magenta, and then magenta and green follow the same correlation pattern, so are probably real.

The same problem with correlation appearing both in AD00C-x and -y is seen on the second 4-panel figure. The drifts and jumps are assumed real, except for the 5 MeV decrease between the red and blue period, the 6 MeV decrease during in the magenta period, the 3 decrease during the green period and the 10 MeV decrease during the black period.

Correlations of the Hall D energy with arcs and BPM 5C02 and 5C08 are shown on Fig. 22. Non-dispersive BPM 5C08-y unexpectedly shows an anti-correlation with energy of the same magnitude as the 5C02-y correlation. This would suggest vertical-drifts of the beam rather than energy drift.

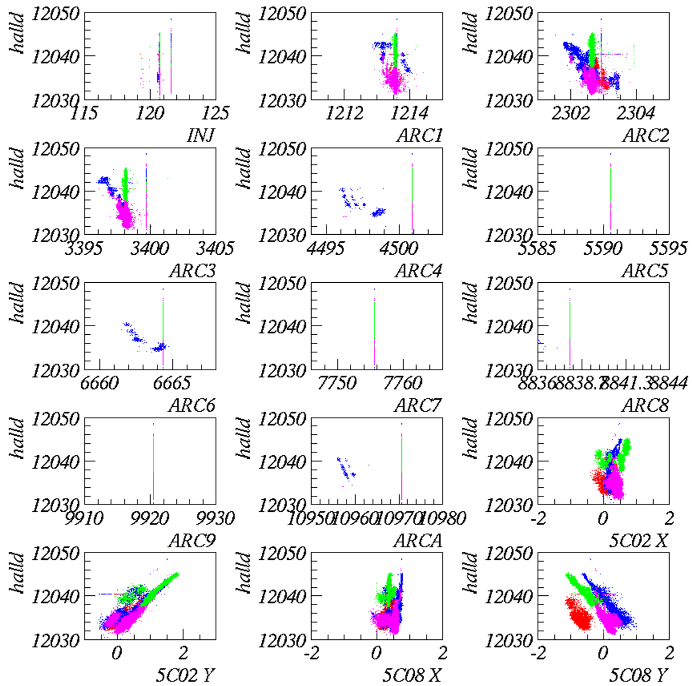
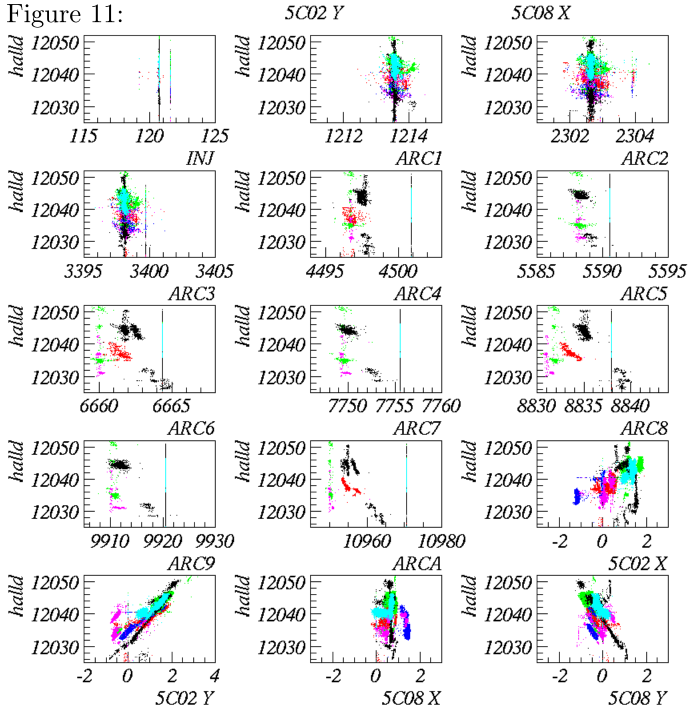


Figure 11:



Same as Fig. 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).

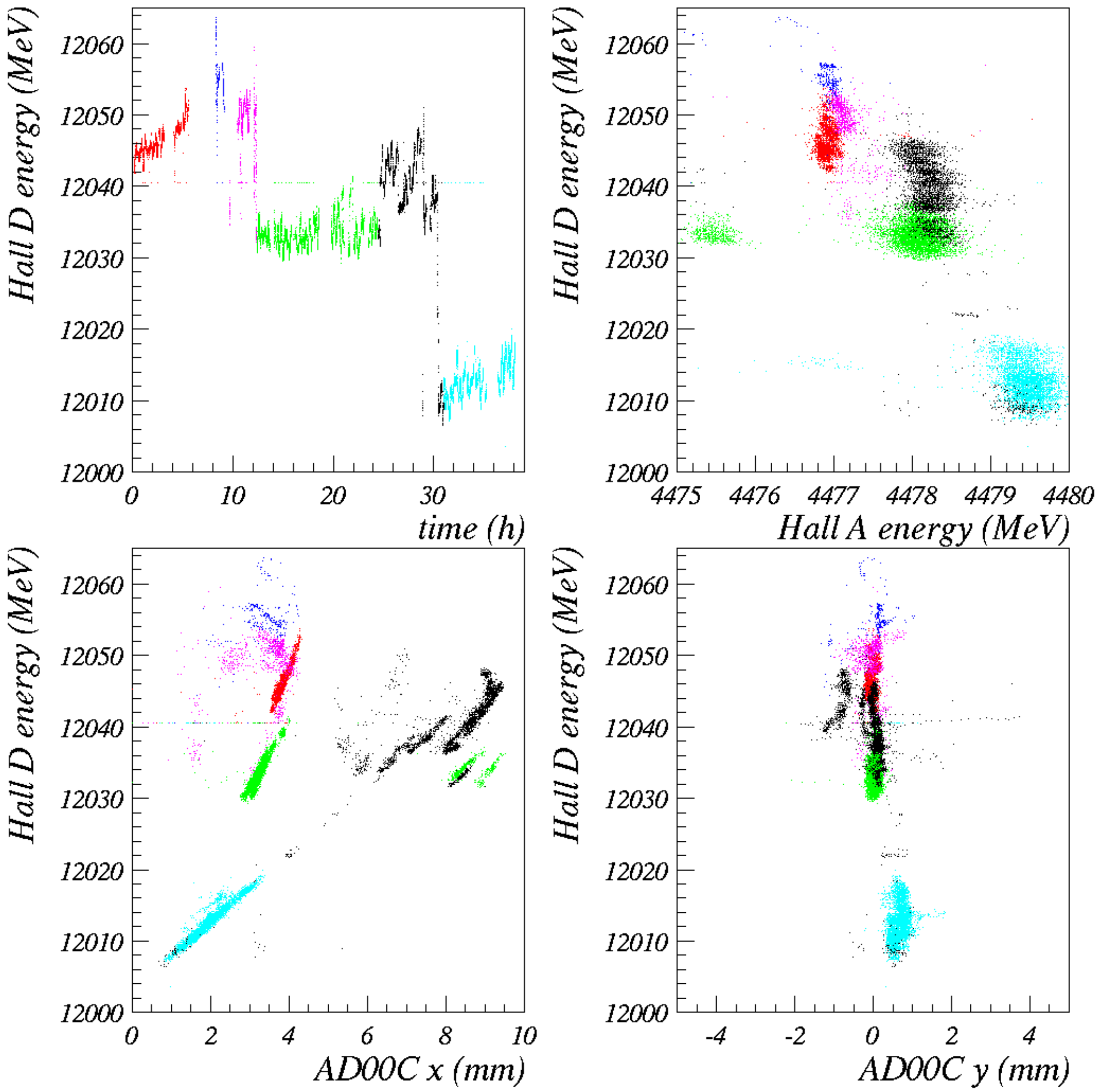


Figure 12:
Same as Fig. 7 but for the Feb. 20 14:00 → Feb 22 4:19am time period.

12.4 Feb. 20 14:00 → Feb 22 4:19am

All energy changes are real, apart from the energy jumps sandwiching the green period and the drifts during the blue and magenta periods.

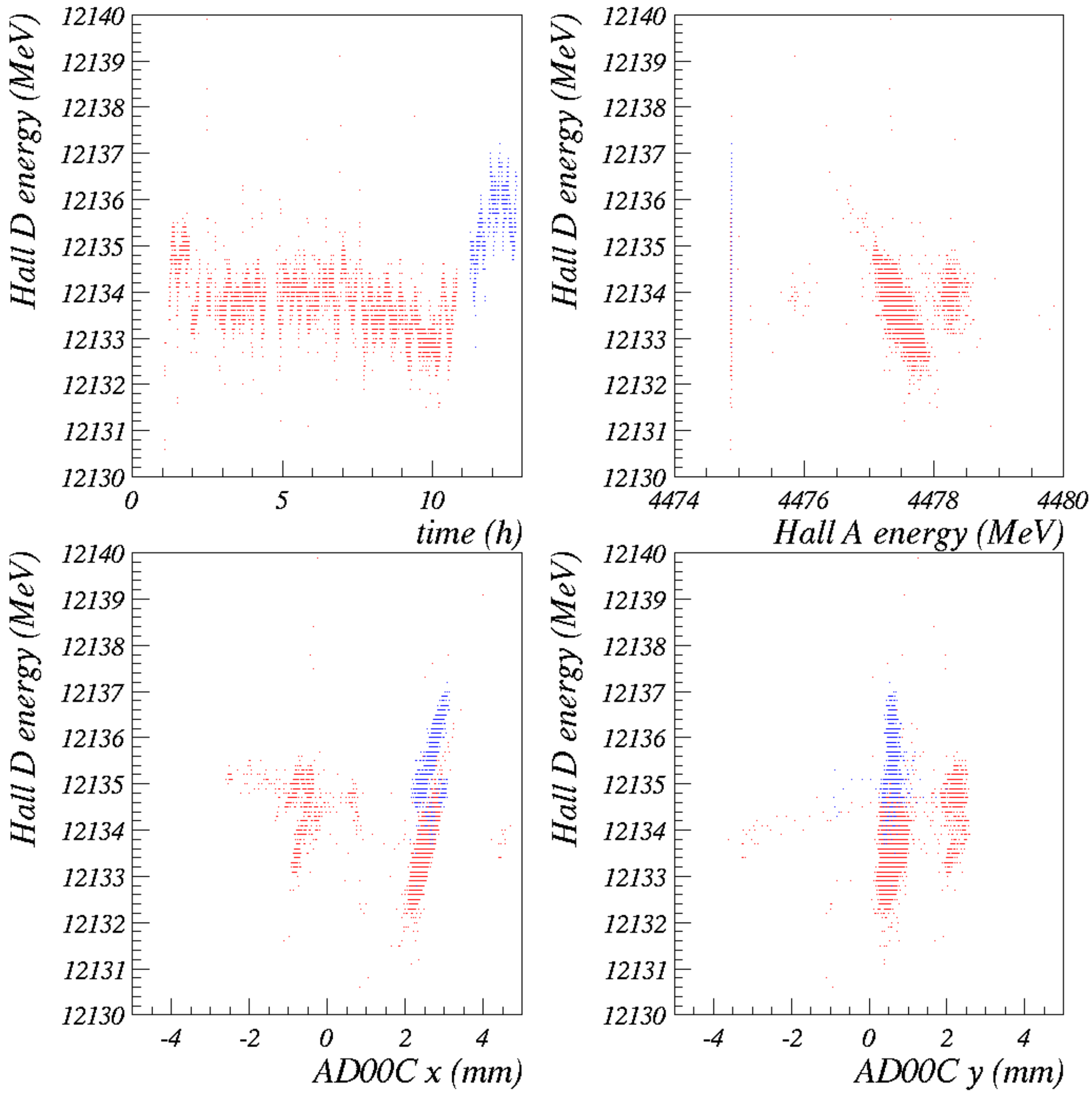


Figure 13:
Same as Fig. 7 but for the Feb. 22 20:00 → Feb 23 8:30 time period.

12.5 Feb. 22 20:00 → Feb 23 8:30

The energy drifts are real except for the jump between the red and blue period. There is a large increase of 120 MeV between the former period (Feb. 20 14:00 → Feb 22 5:00am) and this period (Feb. 22 20:00 → Feb 23 18:00). It is presumably an artifact (same AD00C-x position, about 2 mm). The reported Hall A energy moved only by 2 MeV.

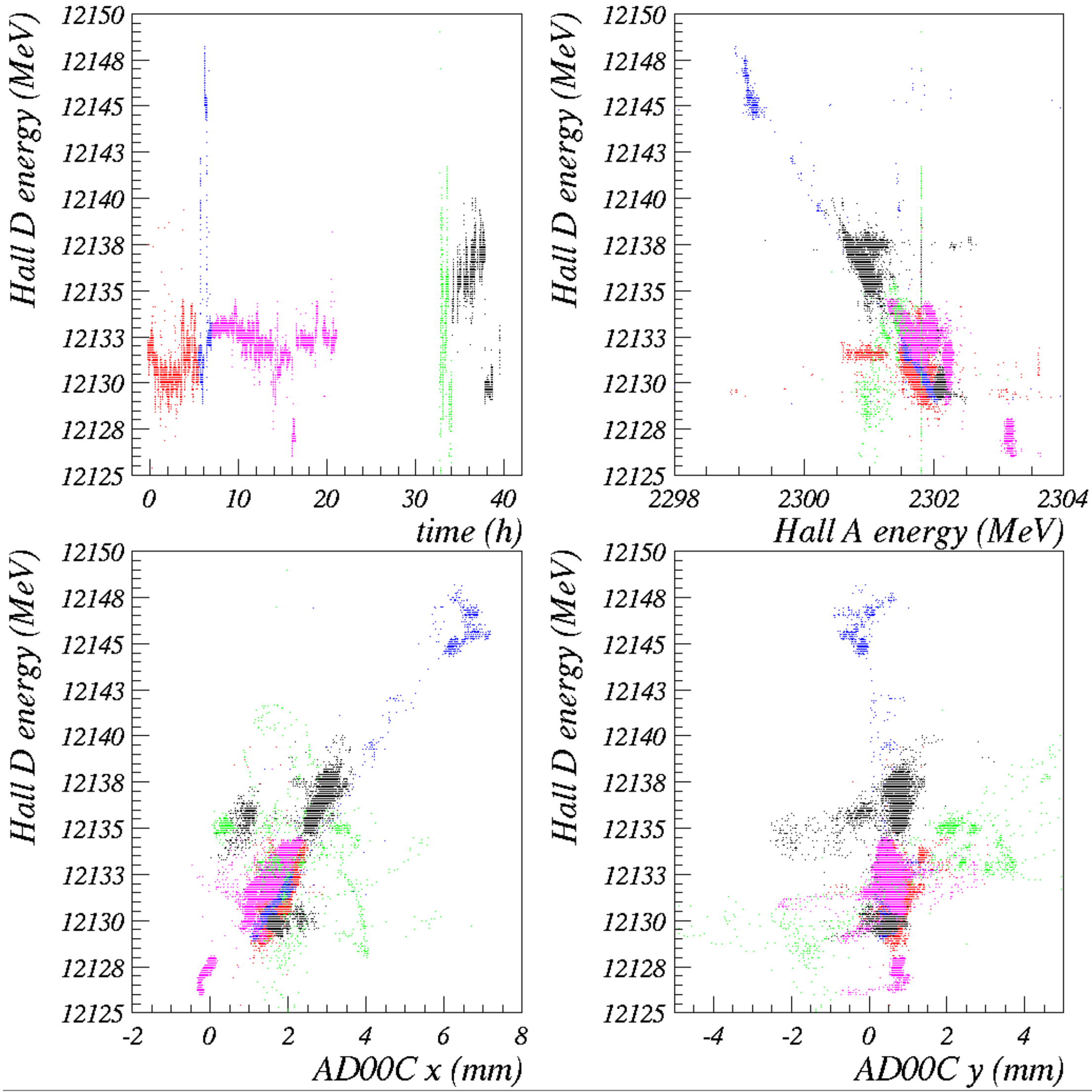


Figure 14:
Same as Fig. 7 but for the Feb. 23 18:00 → Feb 25 10:00am time period.

12.6 Feb. 23 18:00 → Feb 25 10:00am

The energy drifts are real except for the period shown in green. (Hall A is now at 1 pass).

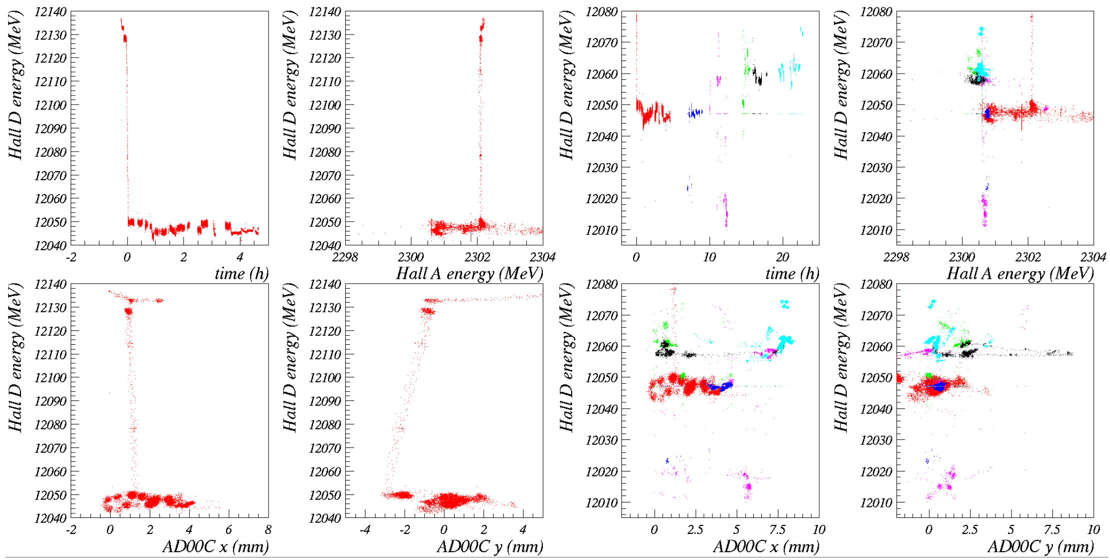


Figure 15: Same as Fig. 7 but for the Feb. 25 10:00am → Feb 26 9:00am time period.

12.7 Feb. 25 10:00am → Feb 26 9:00am

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. Then, the beam position becomes unstable, which complicates the assessment of whether the energy changes are real or not. The fluctuations during the red period seem mostly real. The blue energy at 12020 MeV is an artificial shift, and so are the magenta values near 12015 MeV. The shift from the blue period at 12046 MeV to the magenta one at 12958 is real. The small increase between the magenta and black periods is an artifact, as are the small shifts down occurring during the green period. The last jump of +12 MeV at $t = 22.5$h is an artifact.

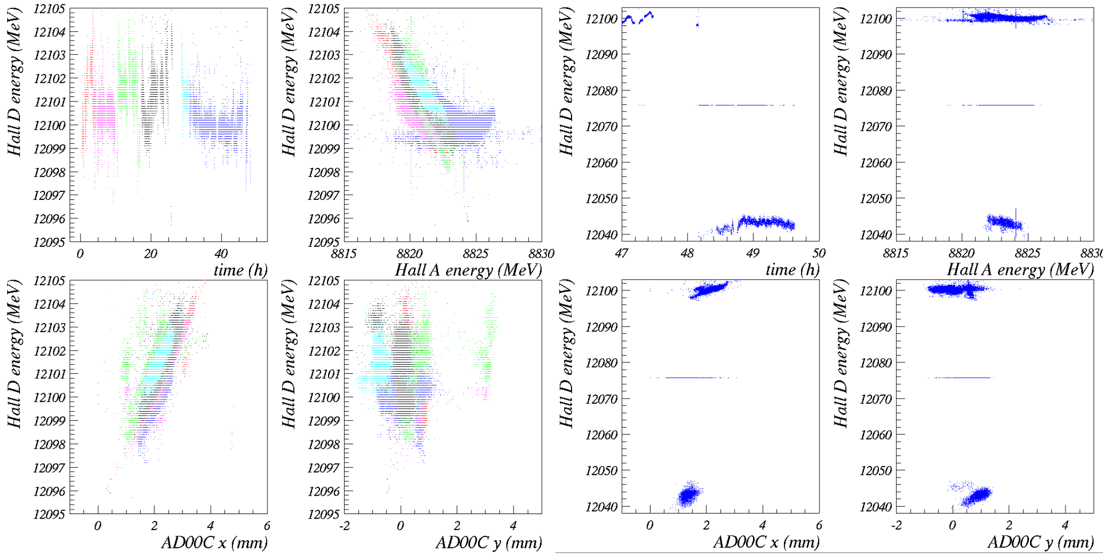


Figure 16:
Same as Fig. 7 but for the Feb. 27 15:00 → Feb 29 16:35 time period.

12.8 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). The Hall D electron beam energy came back 27 MeV higher than the previous period. We cannot assess whether this change is real or not. Apart for possible artificial jumps of 1 MeV or less (e.g. between the cyan and blue periods), which overall effect can be neglected, all energy fluctuations up to $t = 48$h (02/29 14:45) seem real during this period: They display a correlation with Hall A energy as well with AD00c-x but not AD00c-y (4-panel figure on the left). 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.

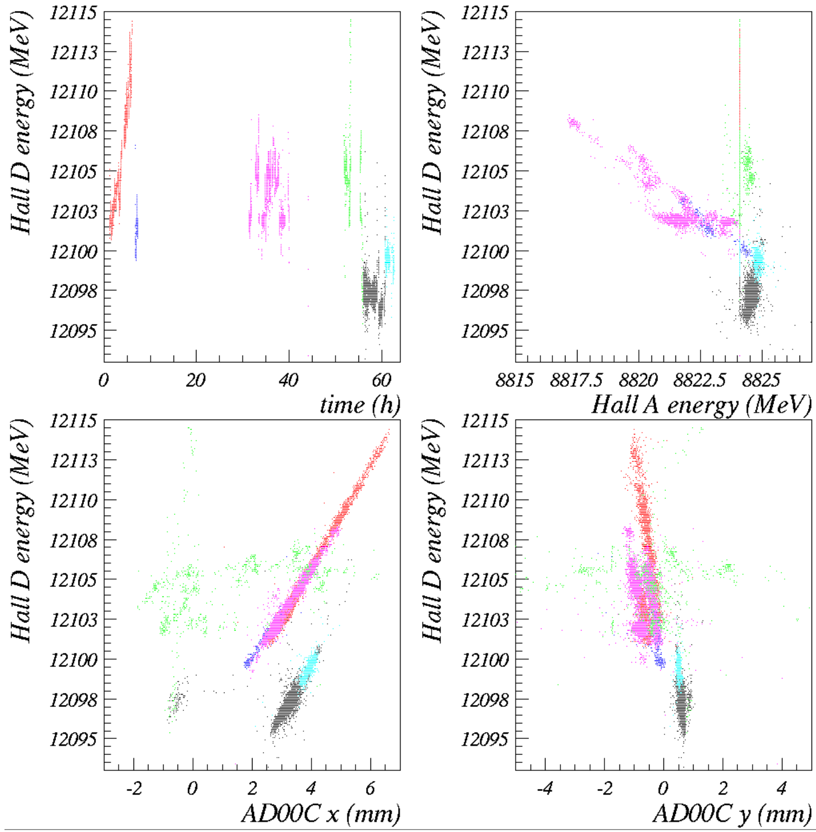


Figure 17: Same as Fig. 7 but for the Feb. 29 17:00 → Mar 03 9:00am time period.

12.9 Feb. 29 17:00 → Mar 03 9:00am

The energy fluctuations appear real except for the jump between the green and black periods (artifact) and for the green period for which the beam positions instability forbid to draw conclusions. Correlation of the Hall D energy with arcs and BPM 5C02 and 5C08 are shown on Fig. 22. 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.

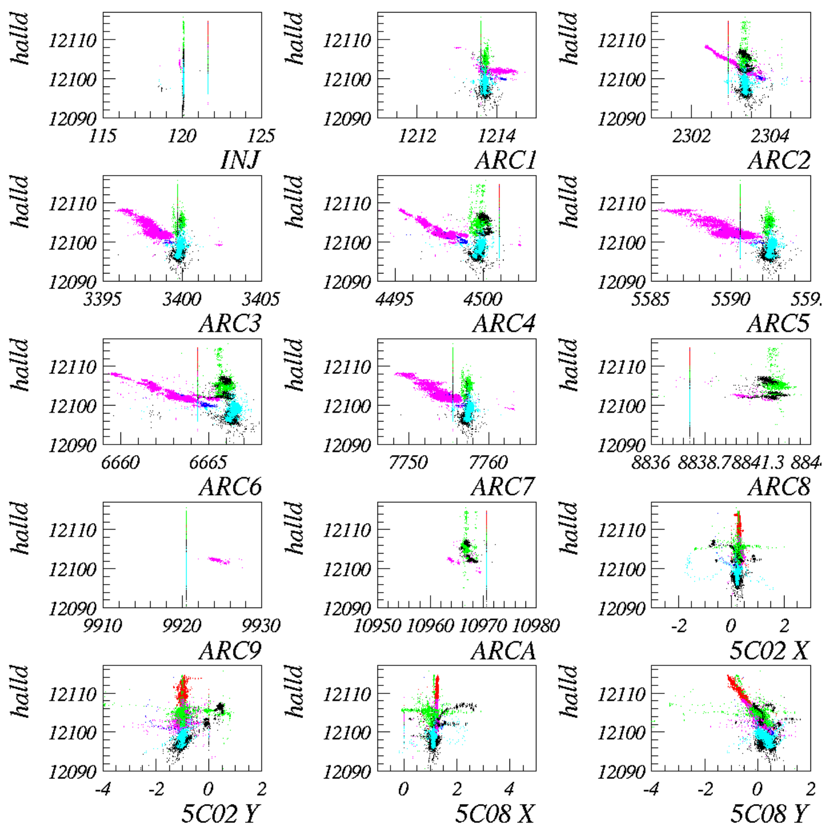


Figure 18:
Correlations between the Hall D electron beam energy and the beam energy at the injector and various arcs (first 11 plots), and between the Hall D energy and BPM 5C02 and 5C08 (last 4 plots). The 11th panel shows the Hall D vs Hall A energies. The data are for the Feb. 29 17:00 → Mar 03 9:00am time period.

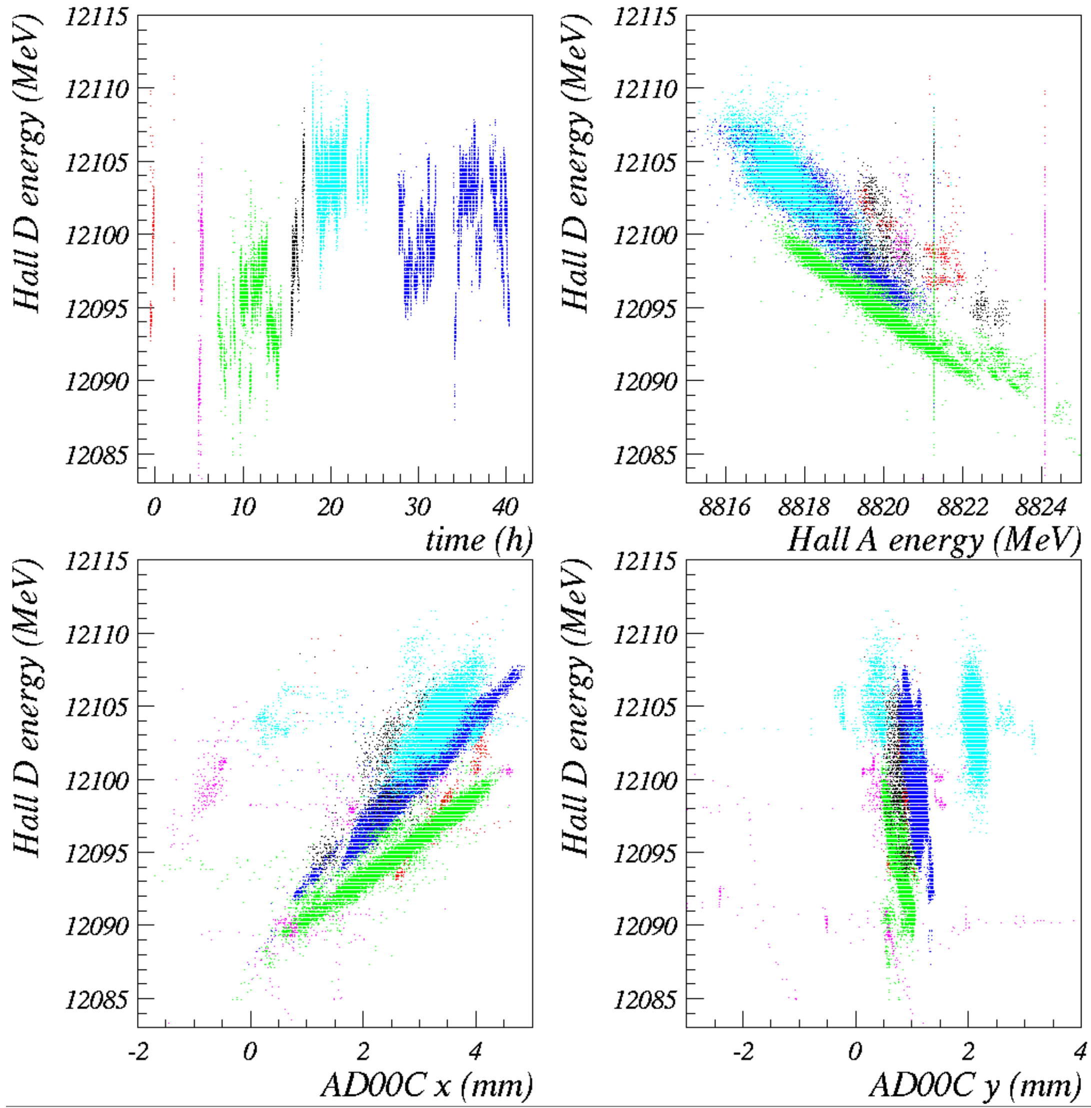


Figure 19:
Same as Fig. 7 but for the March 03 18:00 → March 05 10:55am time period.

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

The energy fluctuations appear real except for the +5 MeV jump during the blue period around $t \sim 15$ h.

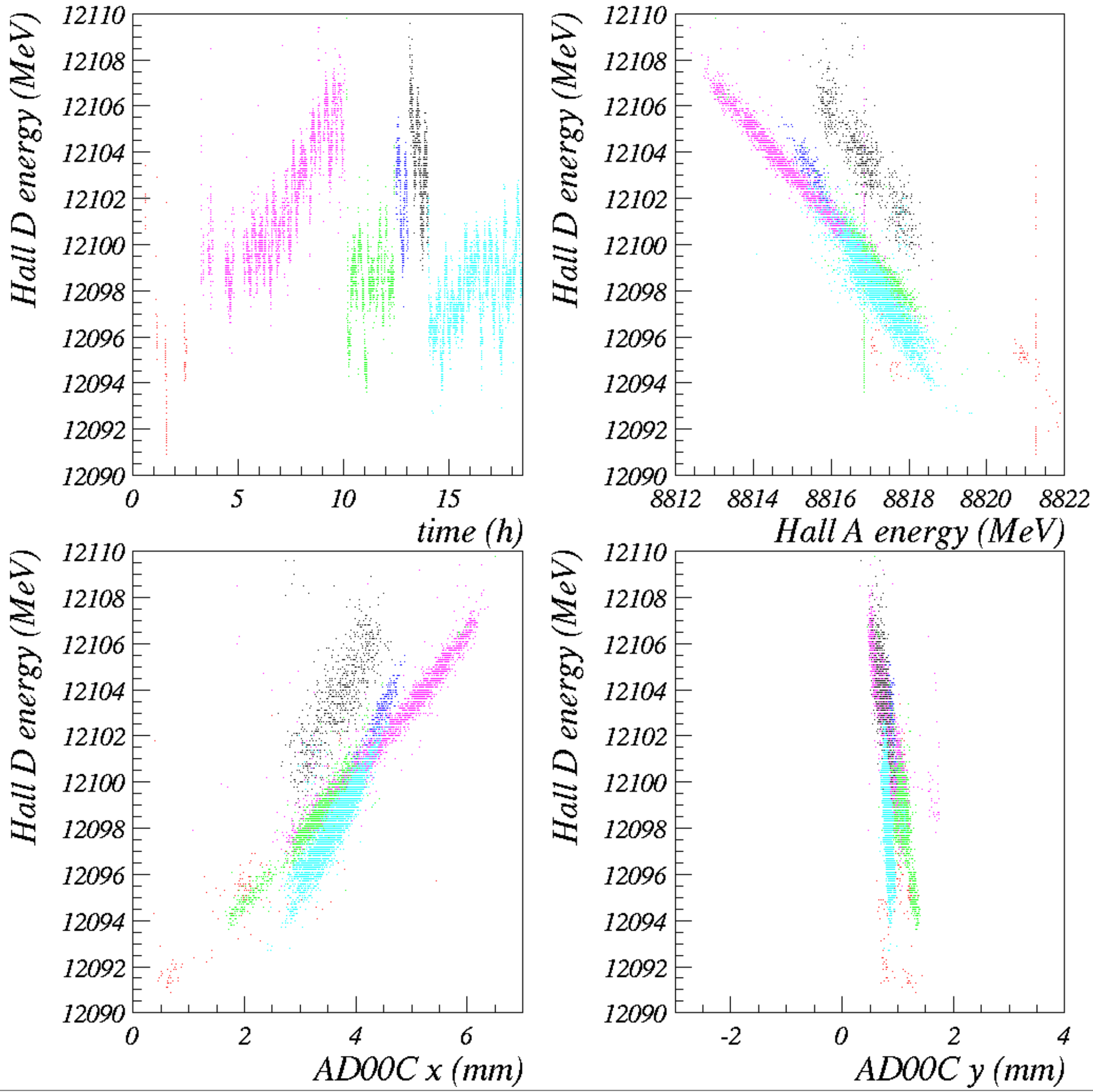


Figure 20:
Same as Fig. 7 but for the March 05 22:00 → March 06 16:00 time period.

12.11 March 05 22:10 → March 06 16:10

The energy fluctuations appear real apart for the temporary +3 MeV jump corresponding to the black period.

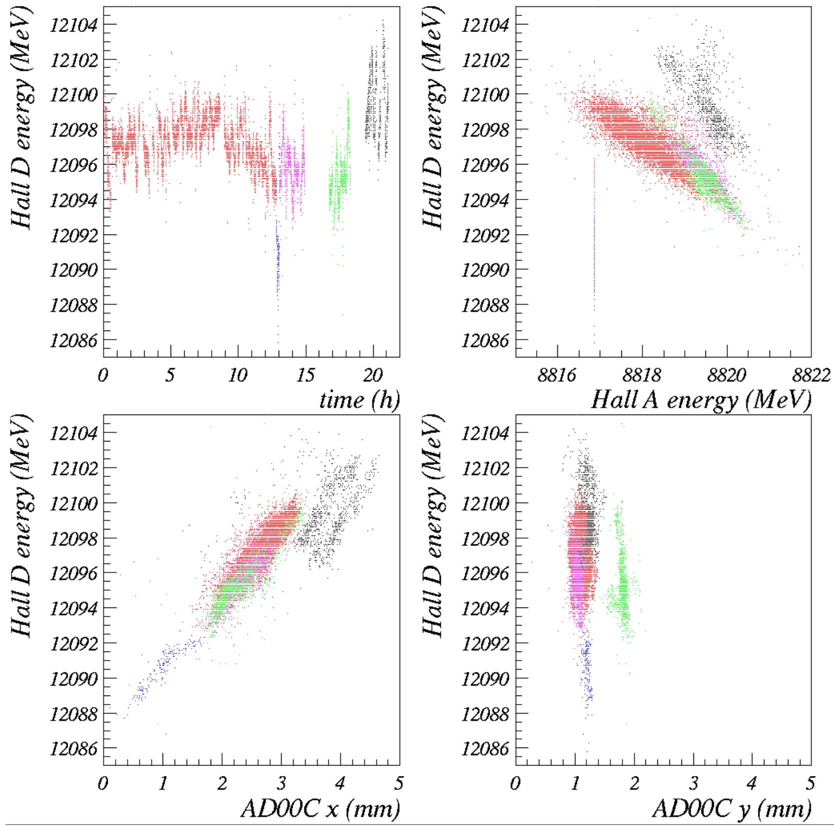


Figure 21: Same as Fig. 7 but for the March 06 20:00 → March 07 18:00 time period.

12.12 March 06 20:00 → March 07 18:00

The energy fluctuations appear real. The misalignment between the black period and the others in the AD00C-x vs energy correlation plot suggests that the energy during the black period should be higher by 2 or 3 MeV with respect to the other periods. Correlation of the Hall D energy with arcs and BPM 5C02 and 5C08 are shown on Fig. 22. BPM 5C02-y shows the expected correlation. However, some dispersion is also seen for 5C08-y, which should be insensitive to energy drifts.

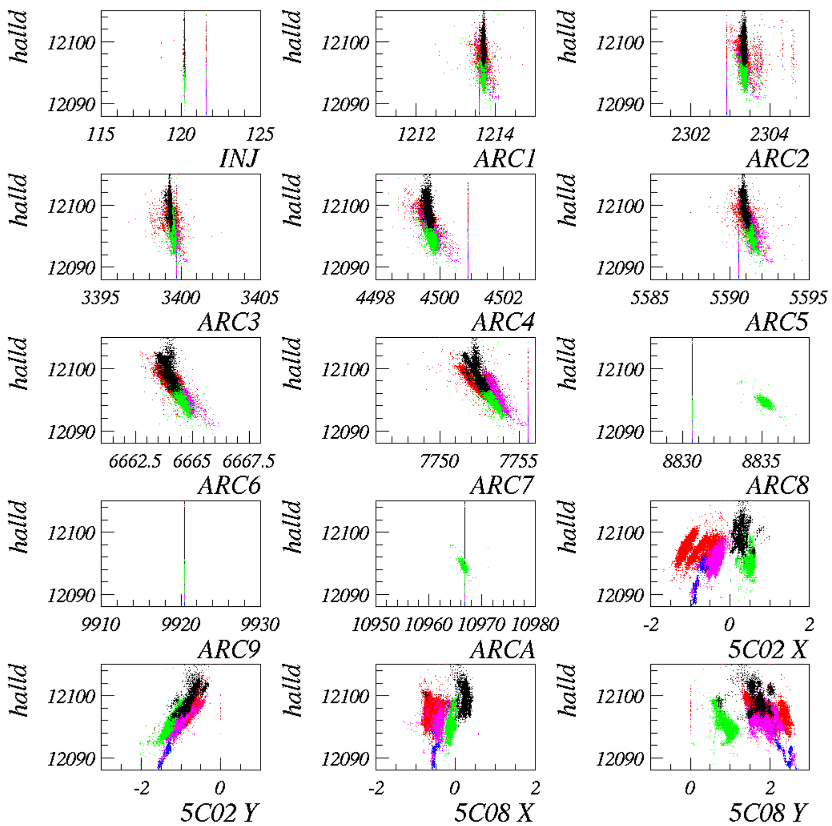


Figure 22:
Correlations between the Hall D electron beam energy and the beam energy at the injector and various arcs (first 11 plots), and between the Hall D energy and BPM 5C02 and 5C08 (last 4 plots). The 11th panel shows the Hall D vs Hall A energies. The data are for the March 06 20:00 → March 07 18:00 time period.

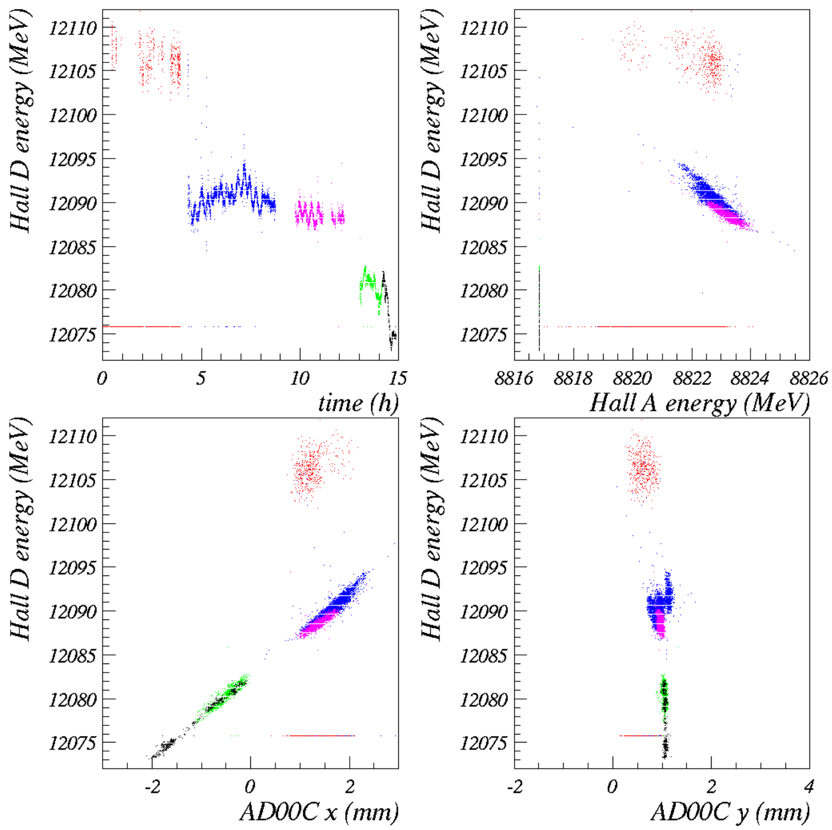


Figure 23:
Same as Fig. 7 but for the March 07 18:00 → March 08 9:00am time period.

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

The energy fluctuations appear real, except for the energy jump between the red and blue periods, that appears to be an artifact. 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.

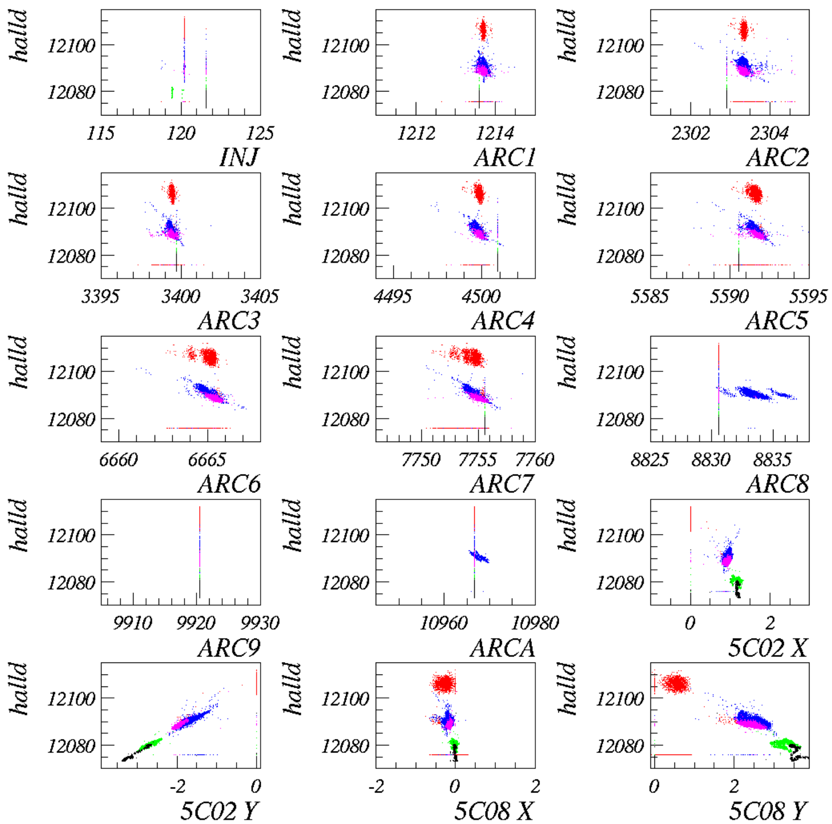


Figure 24:
Same as Fig. 9 but for the March 07 18:00 → March 08 9:00am time period.

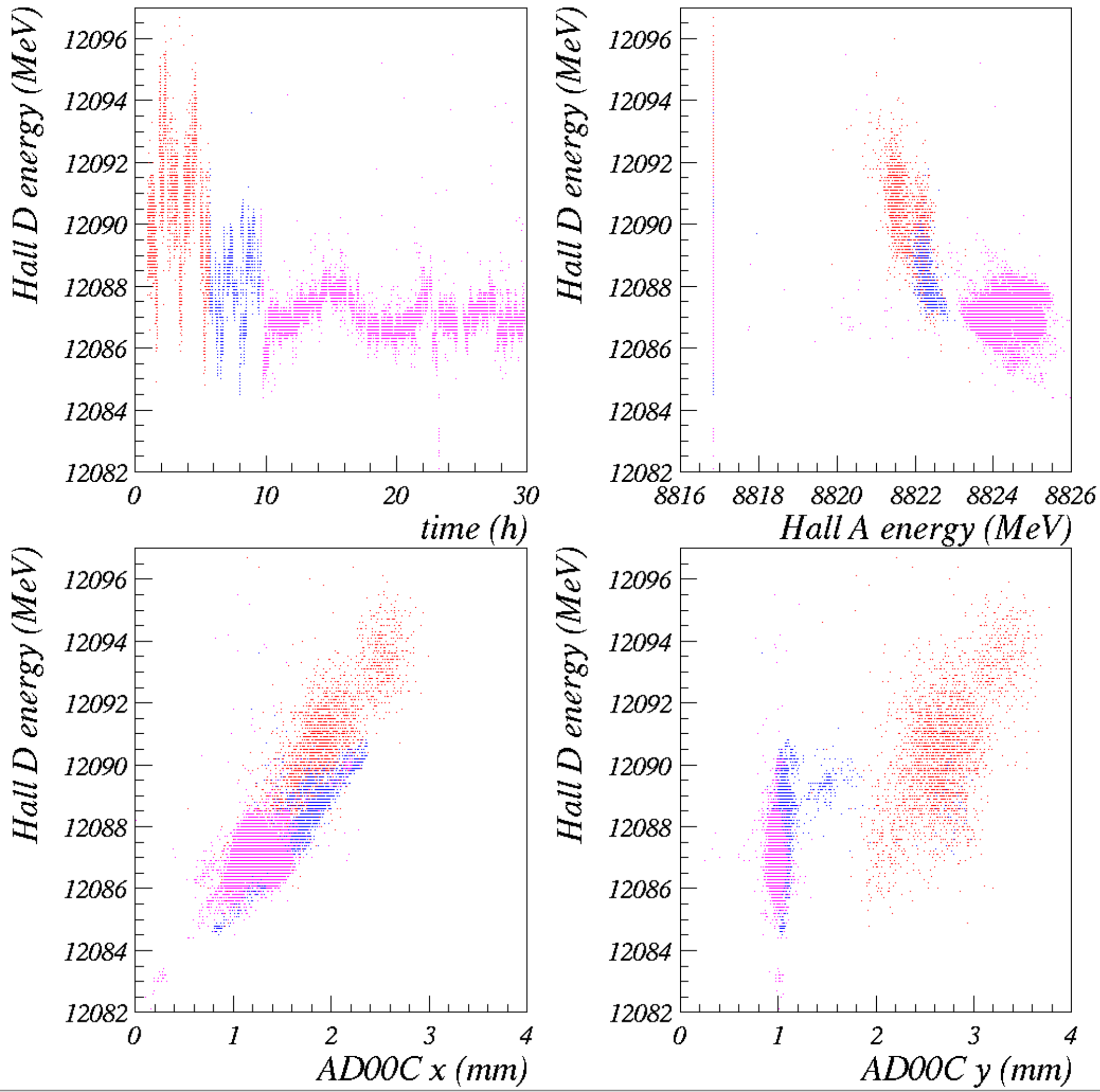


Figure 25:
Same as Fig. 7 but for the March 08 9:00am → March 09 14:40 time period.

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

There was a +15 MeV jump between this period and the March 07 18:00 → March 08 9:00am time period. It appears to be genuine: the energy vs AD00C-x correlation for the two periods follows the same pattern. The energy fluctuations during this period appear real, except for the +2 MeV energy jump between the red and blue periods, that appears to be an artifact.

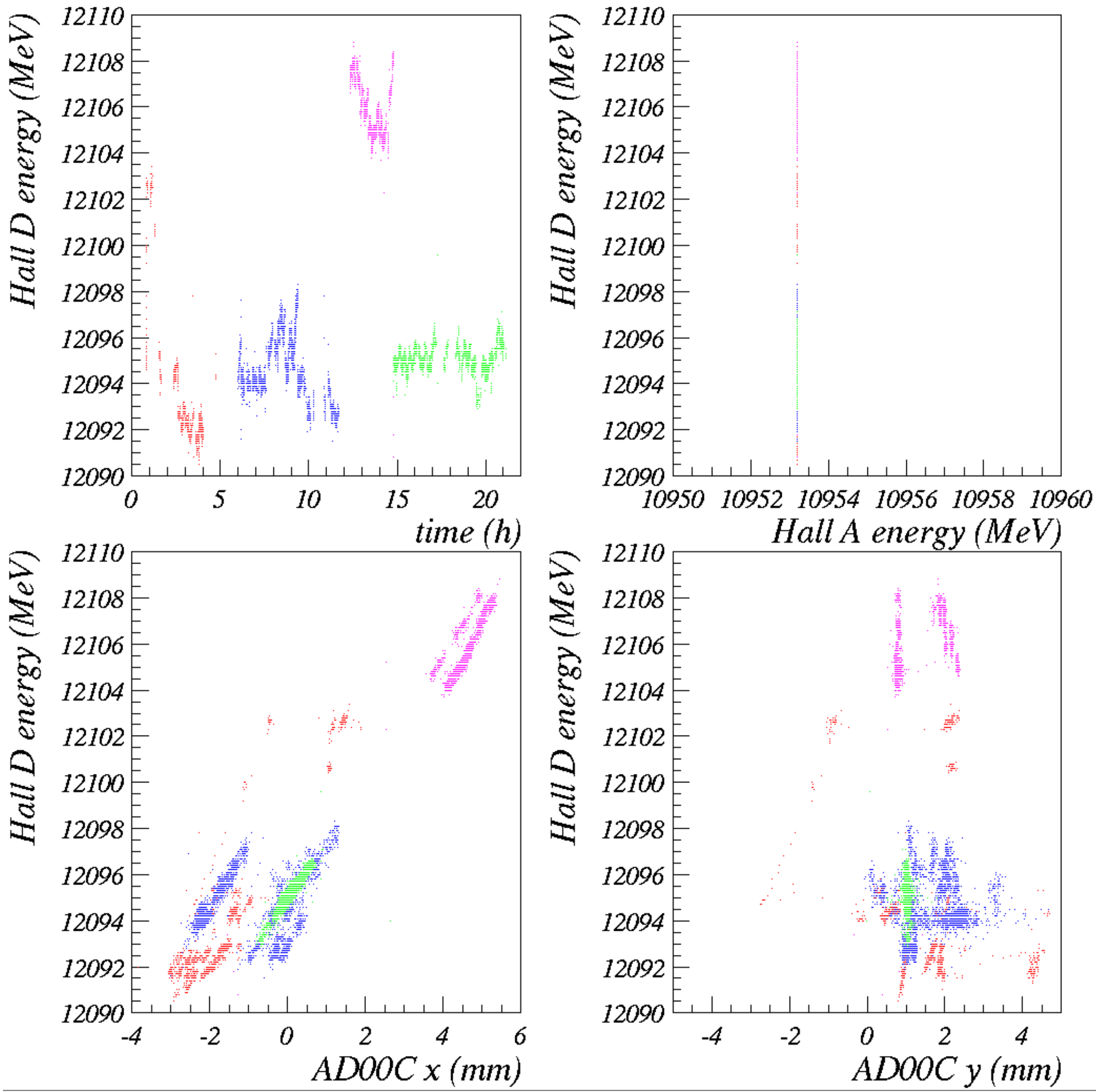


Figure 26: Same as Fig. 7 but for the March 27 13:00 → March 28 9:41am time period.

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

This period starts after a major beam down time of 18 days for CHL maintenance. It is thus uncertain how to relate the absolute scale of this period to the previous ones. Consequently, we take the energy scale at face value. The Hall A energy readout is frozen (Hall A down?). The energy fluctuations appear real, including the transition between the red and blue periods.

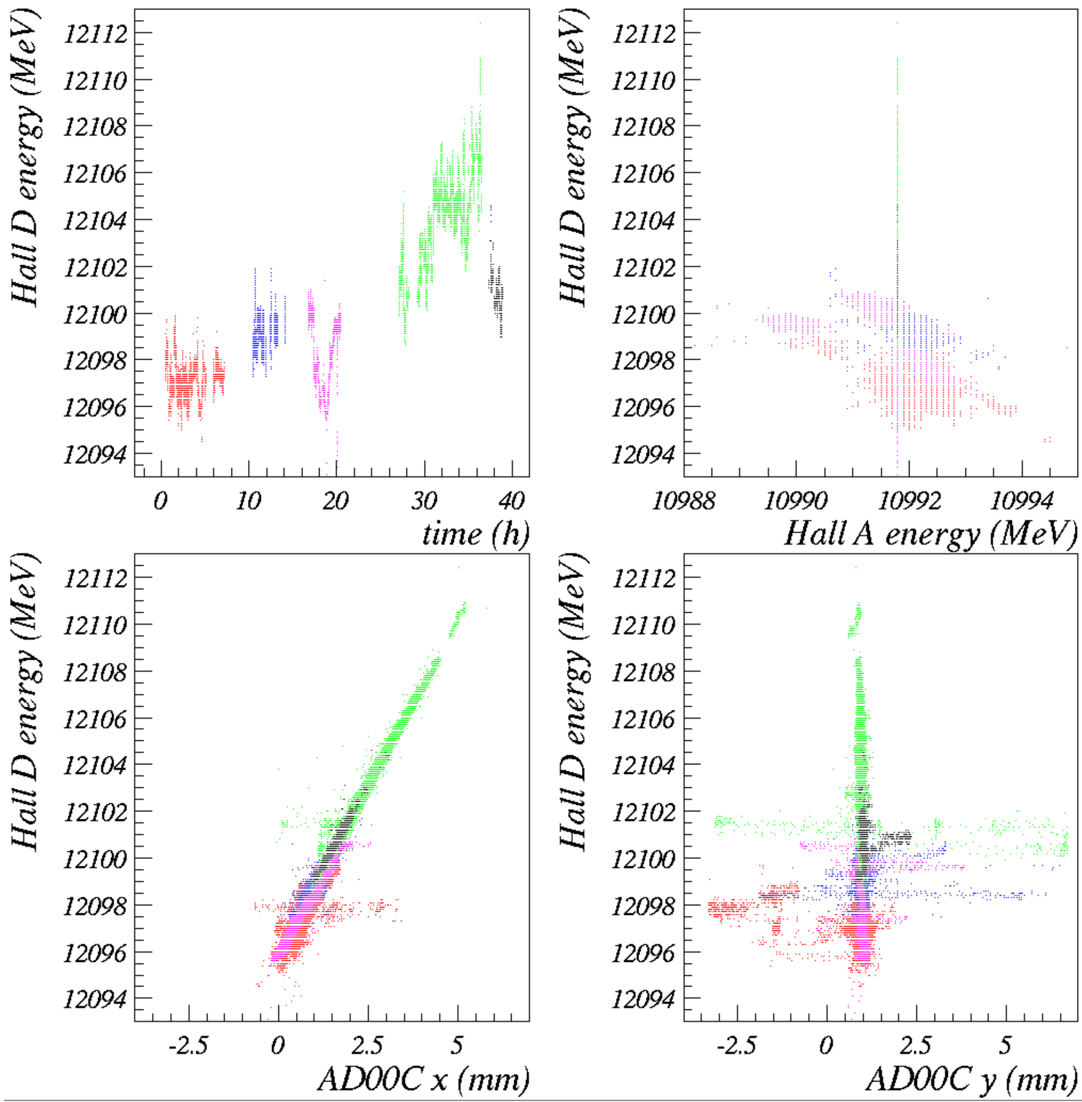


Figure 27:
Same as Fig. 7 but for the March 28 19:10 → March 30 10:10am time period.

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

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

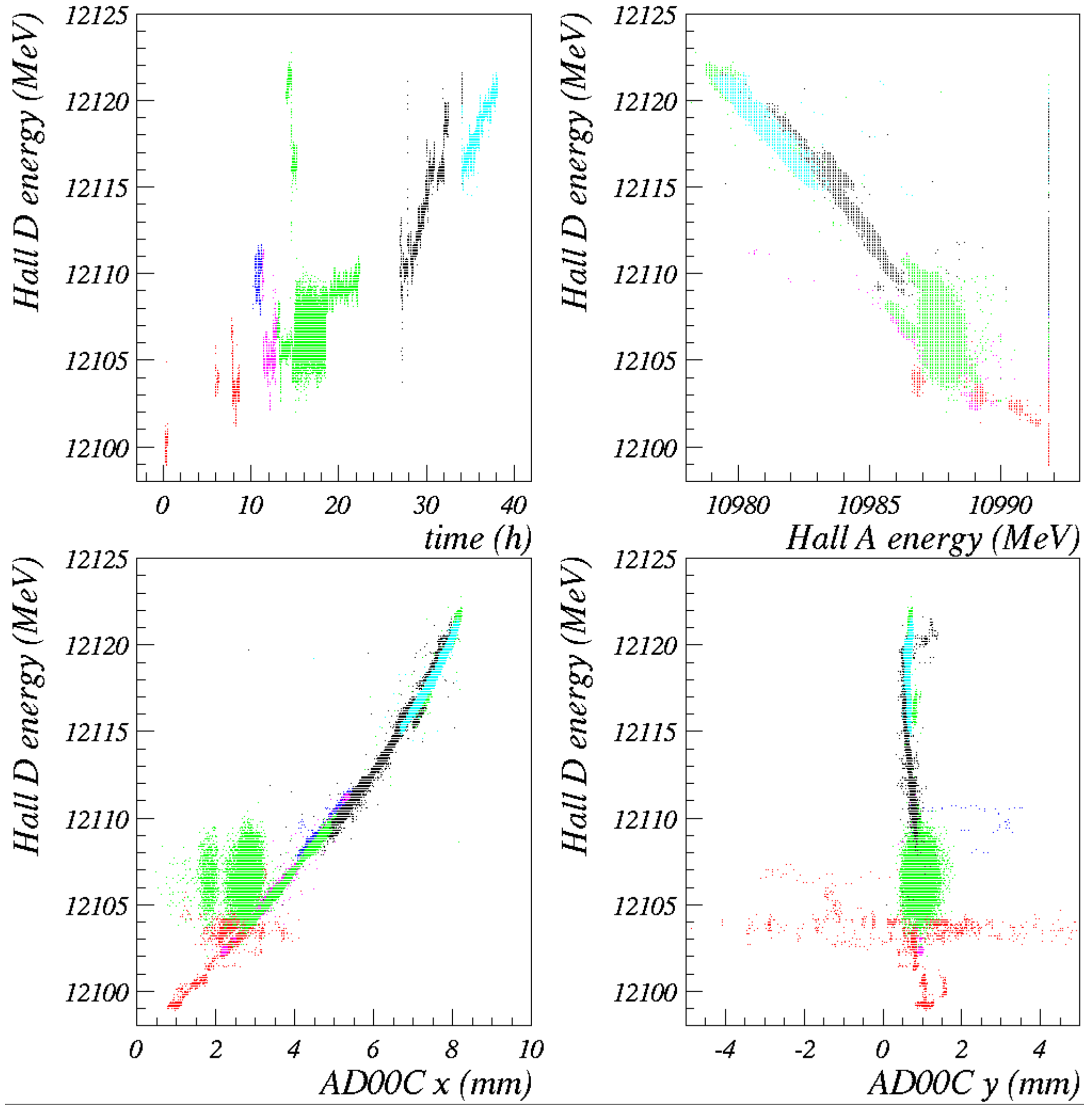


Figure 28:
Same as Fig. 7 but for the March 30 10:10 → April 4 1:10am time period.

12.17 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. Notice the non-linearity of the (AD00C-x vs energy) relation, in particular during the green period (compare the 12107 and 12120 MeV energies during this period).

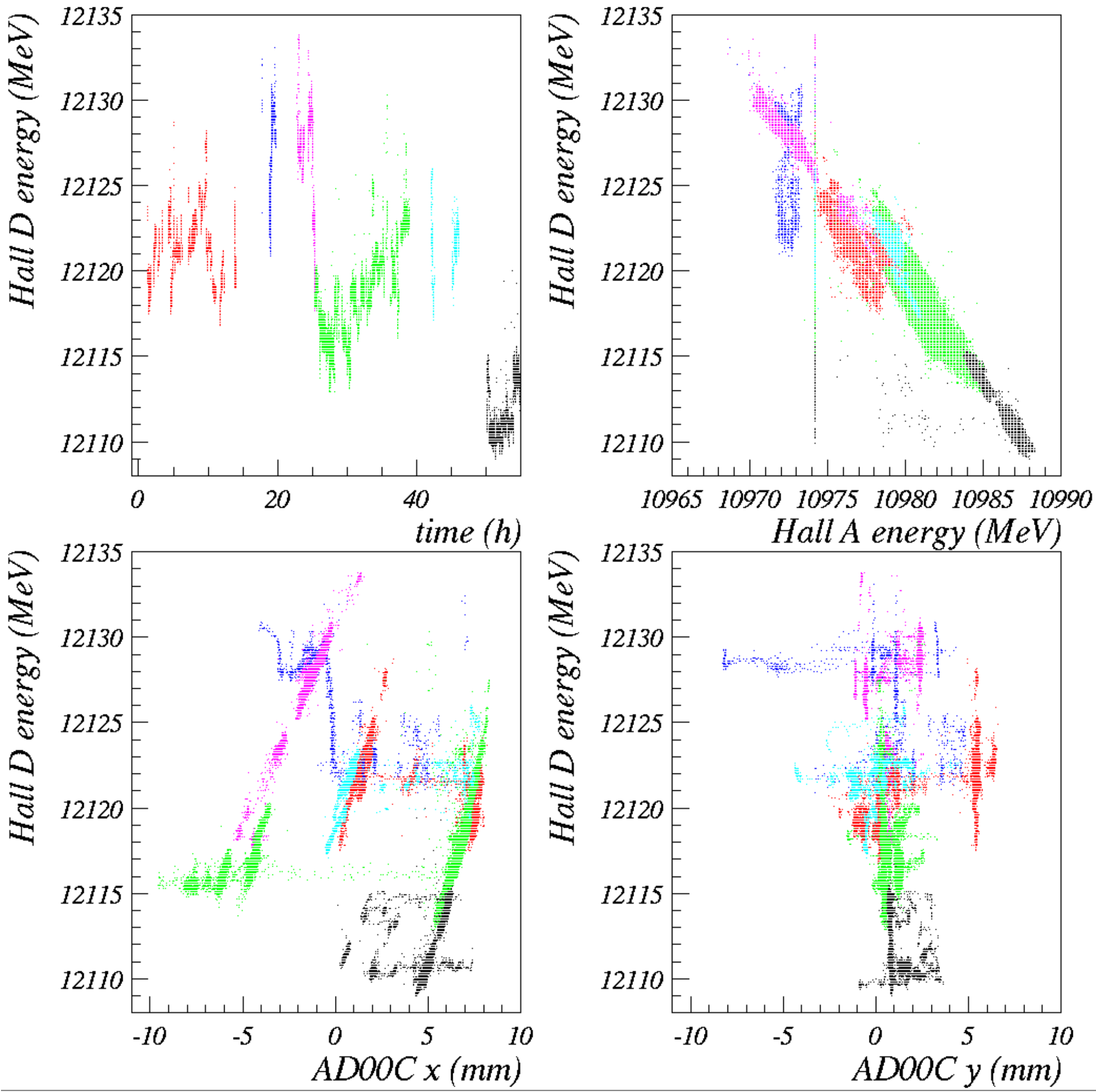


Figure 29:

Same as Fig. 7 but for the April 02 1:50am → April 04 7:50am time period.

12.18 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-position of the beam was unstable during this period.

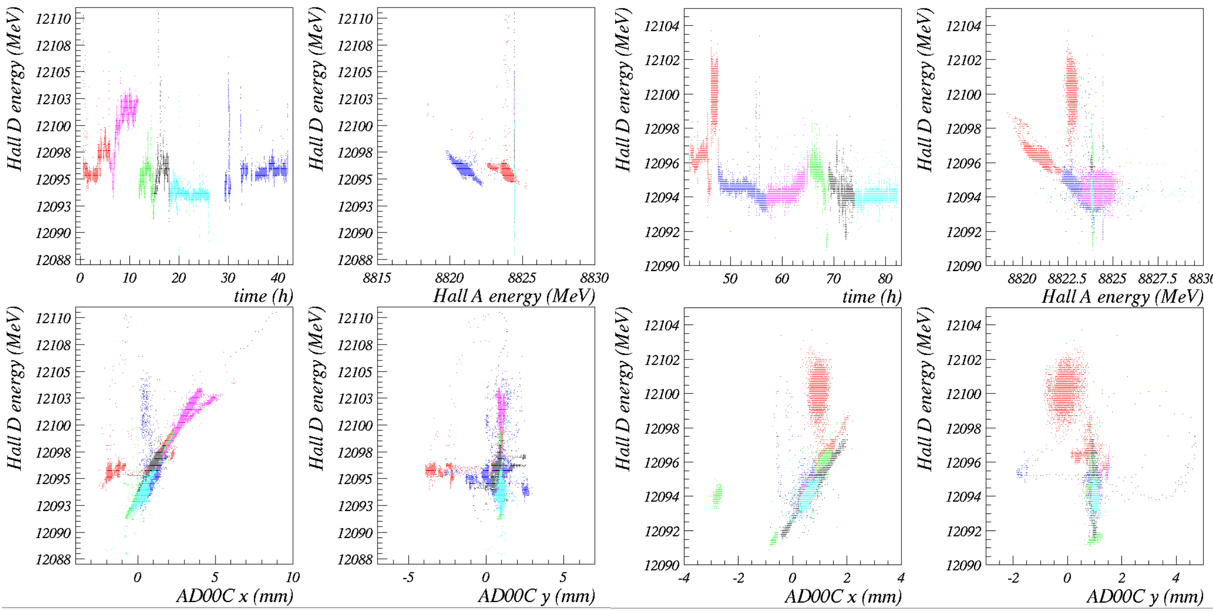


Figure 30:
Same as Fig. 7 but for the April 07 14:00 → April 11 00:00 time period.

12.19 April 07 14:00 → April 11 00:00

Beam was down for 3 days before this period. It is unclear if the -8 MeV shift between the energy at the end of the last period (12114 MeV) and the beginning of this one (12096 MeV) is real. We assume it is an artifact.

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 $t \simeq 46.5$h during the red period and the $\sim$ 9 MeV spike at $t \simeq 55$h during the blue period.

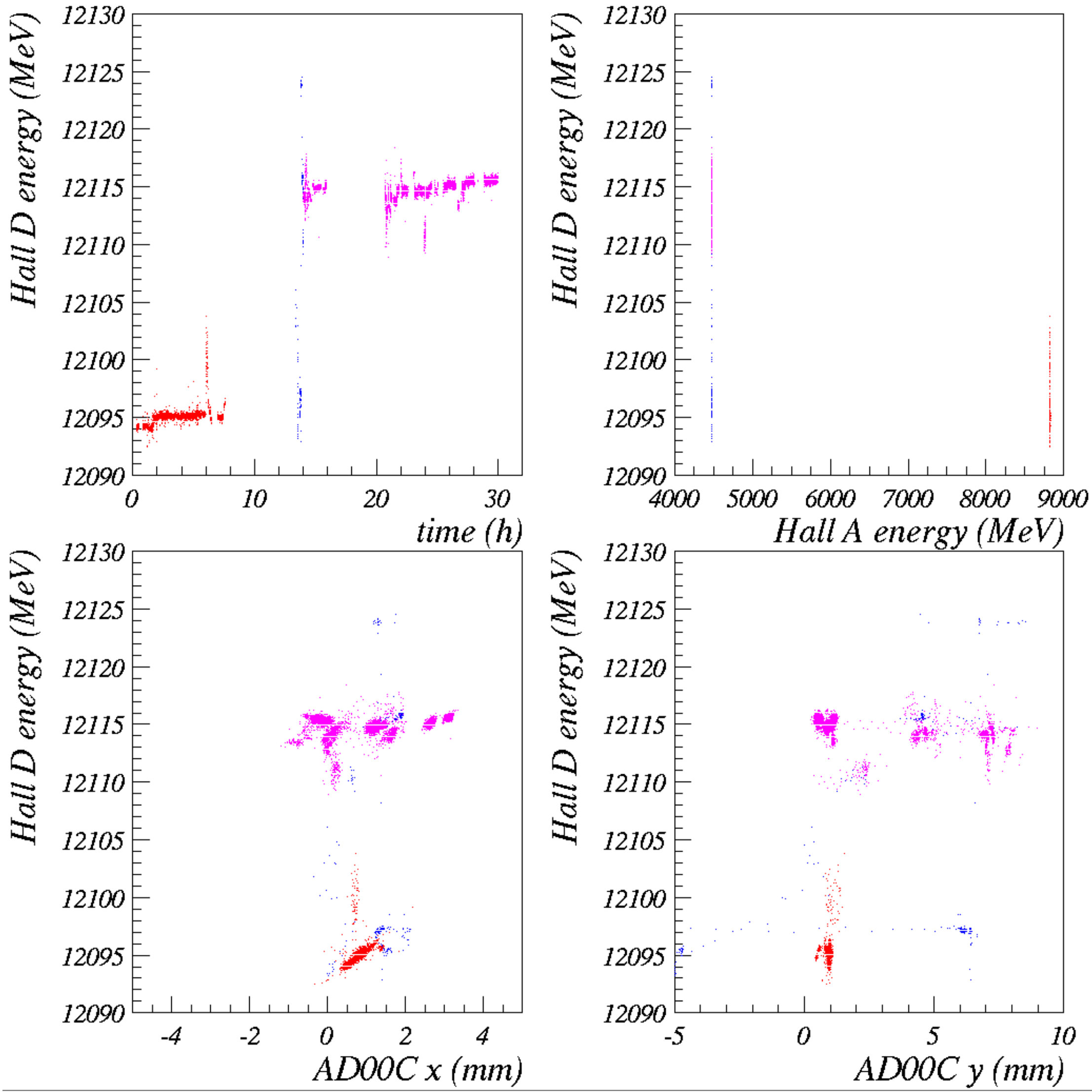


Figure 31:
Same as Fig. 7 but for the April 11 00:00 → April 12 7:00am time period.

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

The spike at $t \simeq 6$h is an artifact. An increase of 20 MeV in the Hall D energy readout occurred on 04/11/16, 13:31, from about 12095 MeV to 12125 MeV. The beam energy then went down after about 1 min to 12115 MeV. The shift occurred soon after a 6h down time due to pass change in Hall A. However, the beam was restored at about 12097 MeV and shifted up 25 min after beam restoration. We assume that this is due to a change of the beam orbit: There is no correlation between AD00C-x and the energy shift. There is a significant correlation for AD00C-y: it moved from about -5mm to +4.6mm during the transition. The brief energy drop of 4 MeV at $t \simeq 24$h is an artifact.

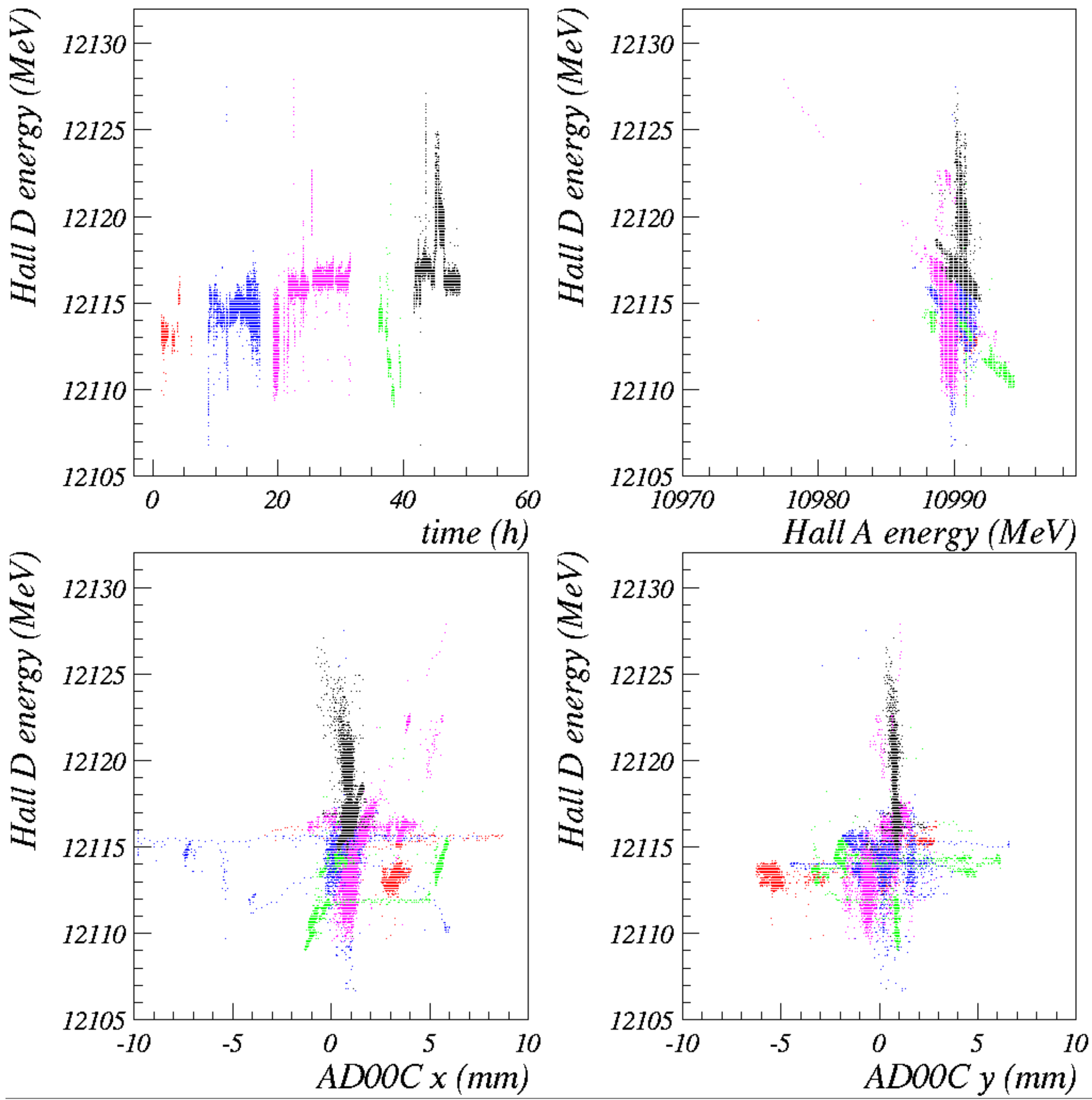


Figure 32:
Same as Fig. 7 but for the April 13 1:50am → April 15 8:50am time period.

12.21 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. This indicates that they are artifacts. The smaller fluctuations (up to 5 MeV) seem genuine.

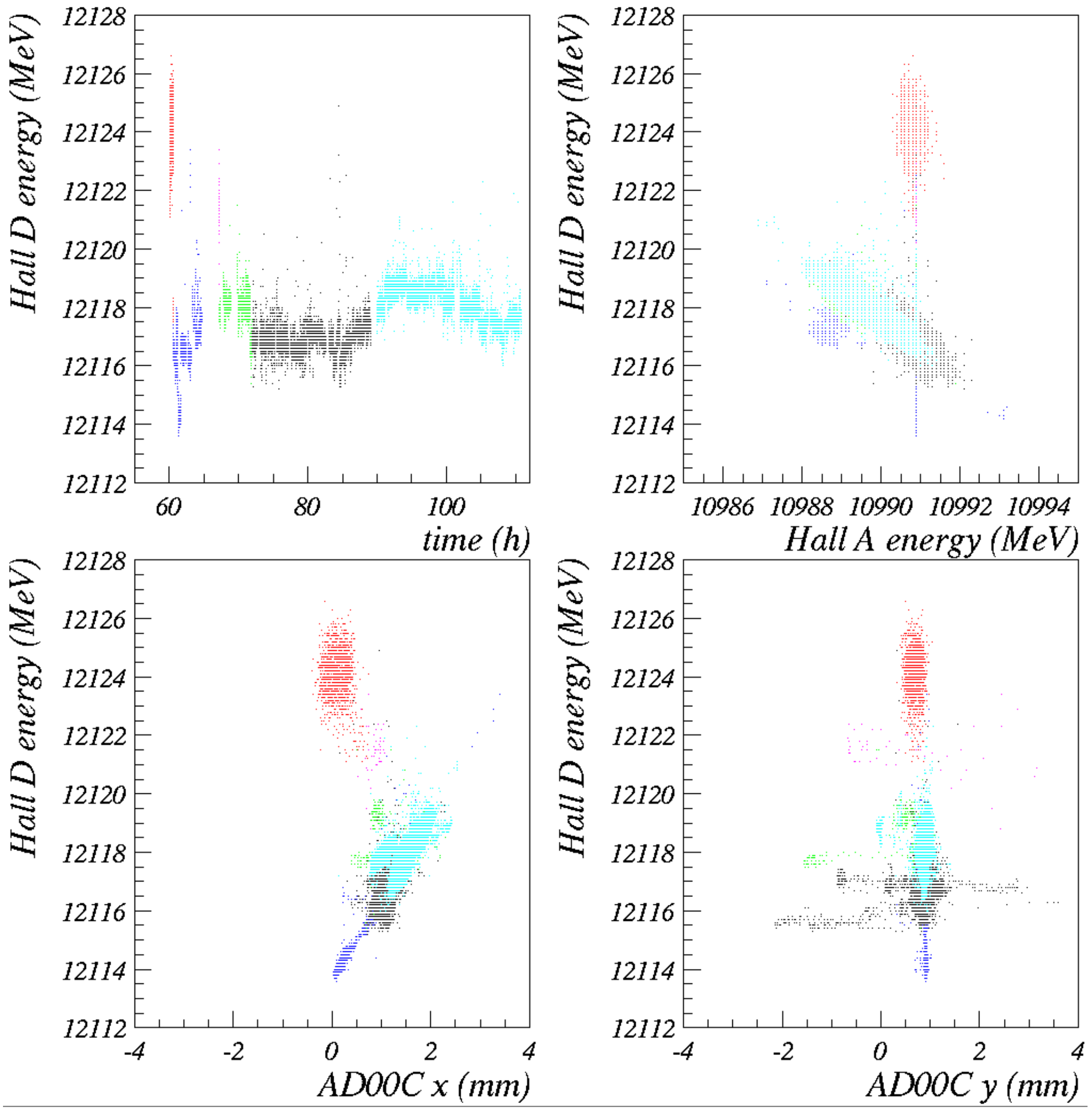


Figure 33: Same as Fig. 7 but for the April 15 8:50am → April 17 15:26 time period.

12.22 April 15 8:50am→ April 17 15:26

The energy fluctuations for this period seem genuine expect for the red and magenta periods.

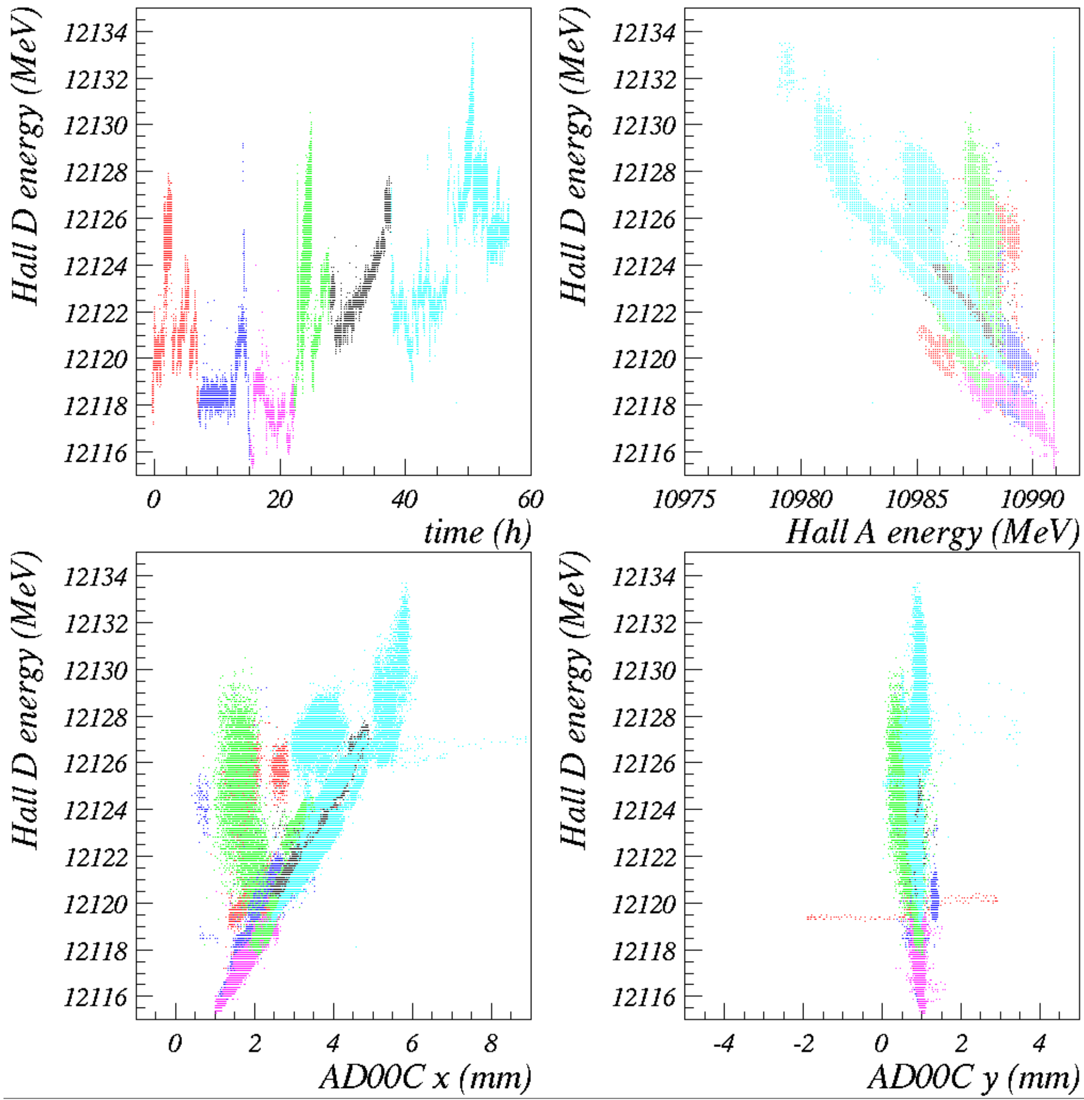


Figure 34: Same as Fig. 7 but for the April 17 18:00am → April 20 2:50am time period.

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

The fastest fluctuations (red, blue, green and cyan) display no AD00c-x correlation. This indicates that they are artifacts. The slower drifts seem genuine.

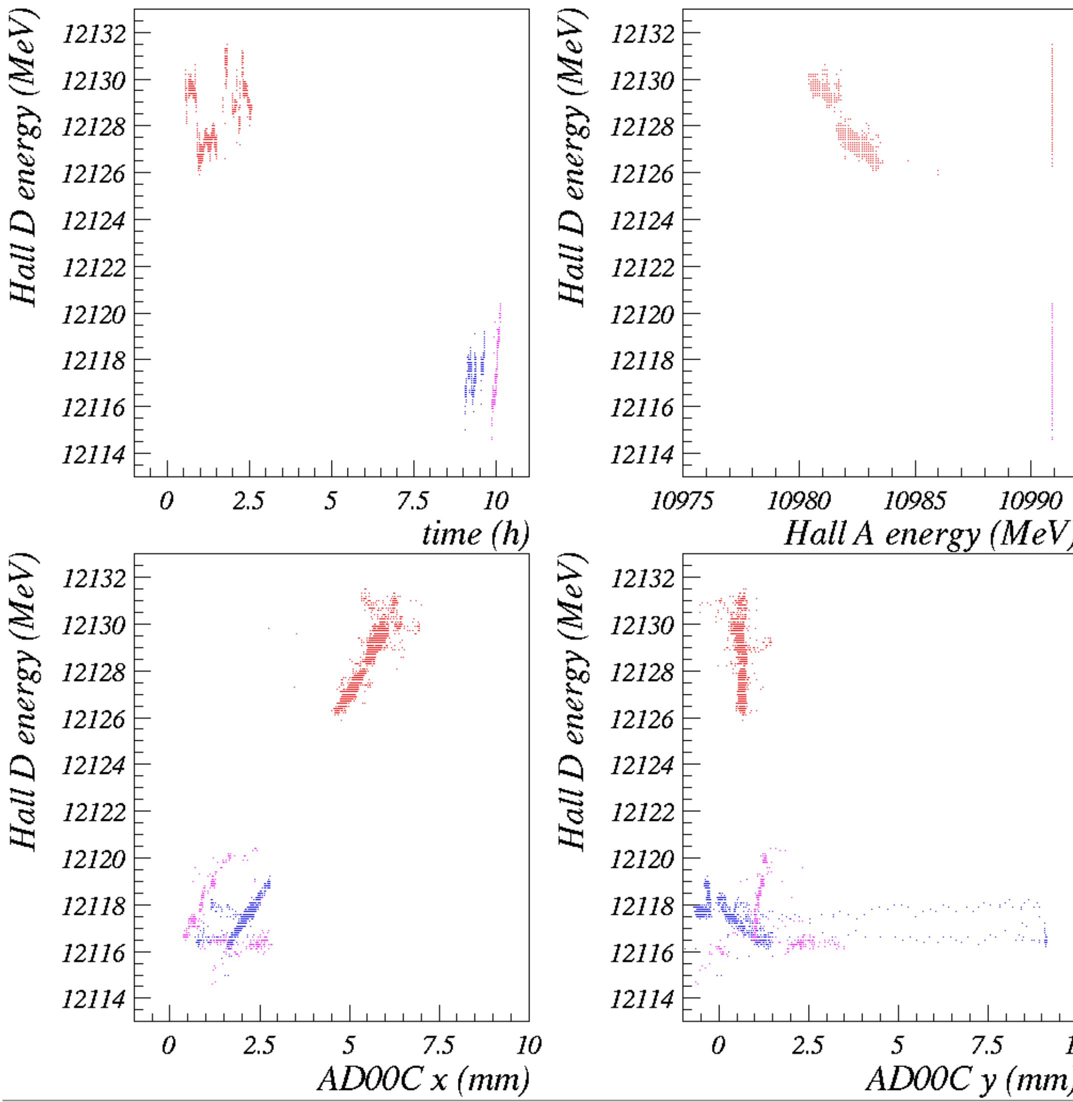


Figure 35:
Same as Fig. 7 but for the April 20 6:00am → April 20 16:00 time period.

12.24 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.

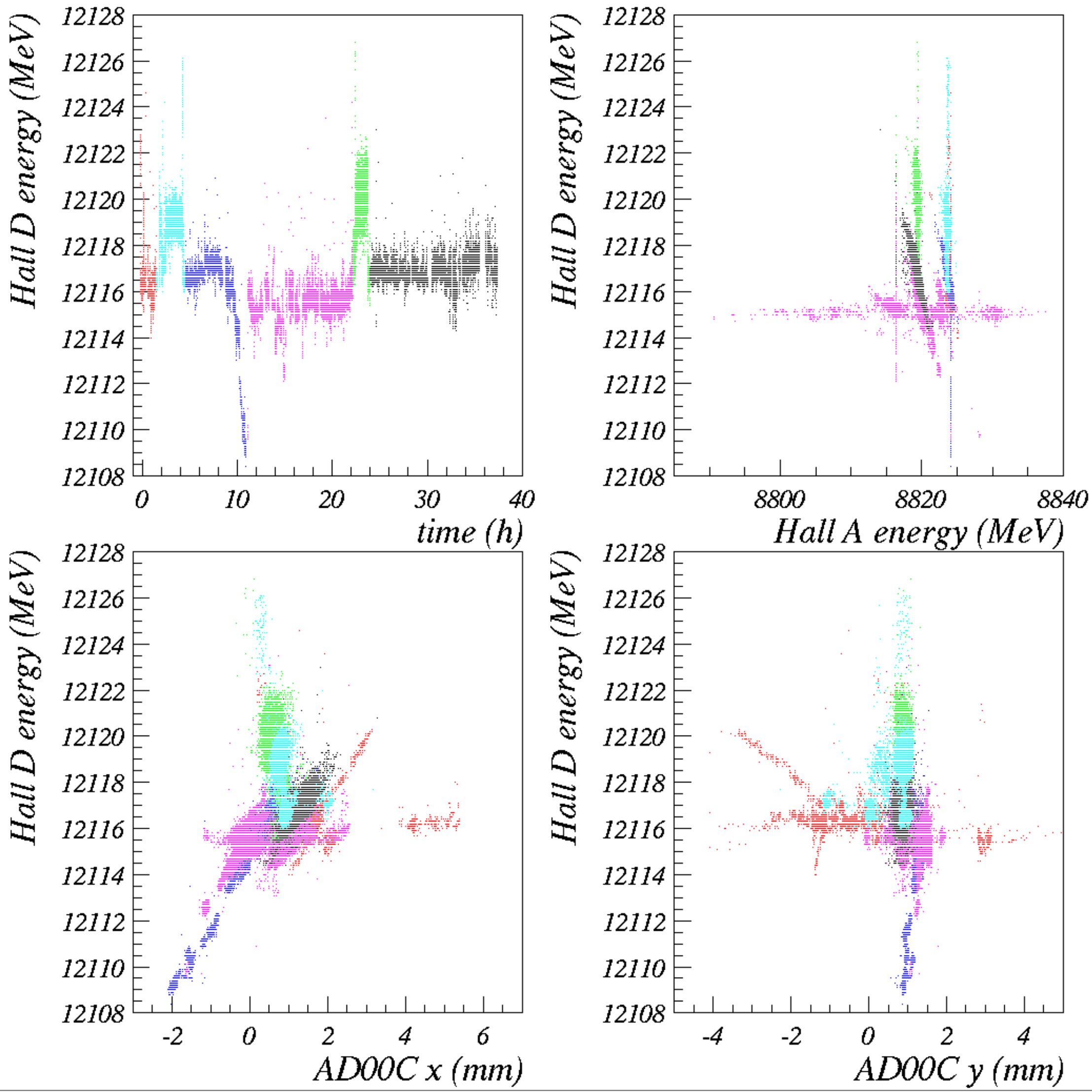


Figure 36: Same as Fig. 7 but for the April 20 21:00 → April 22 11:00am time period.

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

The energy fluctuations appear real, except for the cyan and green periods that appears to be artifacts.

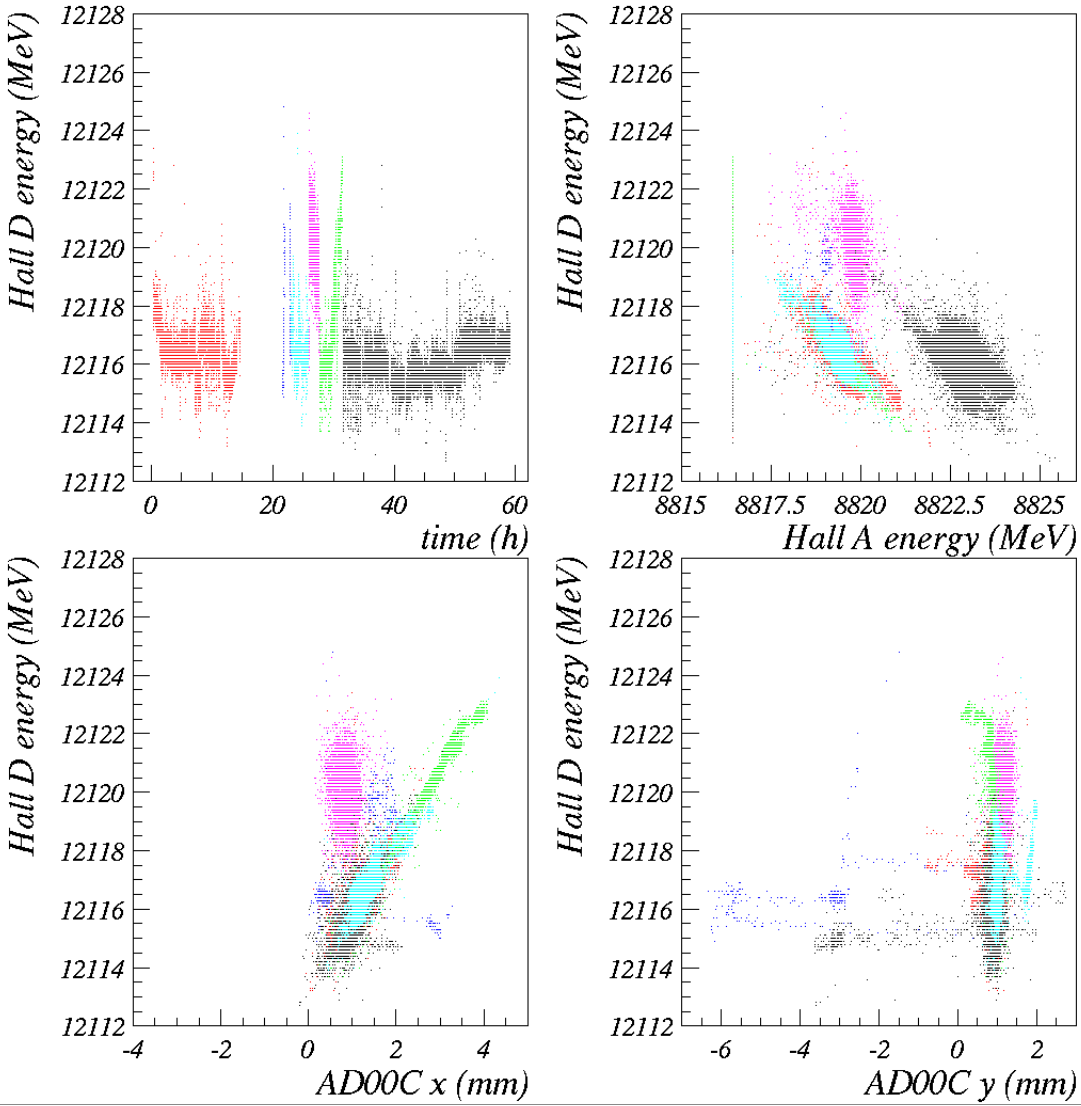


Figure 37: Same as Fig. 7 but for the April 22 19:10 → April 25 6:06am time period.

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

The energy fluctuations appear real, except for the magenta period, and probably the blue period, that appears to be artifacts.