Beam motion studies

H. Egiyan[1], R. Paremuzyan[2], and S. Stepanyan[1]

[1]Thomas Jefferson National Accelerator Facility, Newport News, VA 23606
[2]University of New Hampshire, Durham, NH 03824

September 11, 2015

The goal of this work is to study whether there is any significant beam motion at the microsecond/millisecond level. Such fast motion can arise, for example, from a RF trip, when one of RF cavities fails, causing a change of the electron energy. This energy change will change the beam trajectory to the hall and if dispersion allows will change the beam position at the detector. Beam trajectory and the position at the detector can change also if some of magnetic elements will fail, however this will be much slower motion.

If there is a slow beam position drifts, order of a second or so, the feedback system (known as orbit locks) based on Beam Position Monitors (BPMs) and a set of corrector magnets should be able to handle it, keeping the beam steady at the detector within the reasonable limits (during HPS spring run this system kept beam position steady within 50 μm). In case this system fails or the beam motion is too fast for it, there are other safeguards one of which is so called machine Fast ShutDown (FSD) system that takes as an input rates of halo counters and will initiate machine shutdown if these rates will exceed given threshold within set integration time (order of milliseconds). For example if beam motion is sufficiently large (orders of mm) beam can hit a beam-pipe or other beamline elements and will cause high rates in halo counters and/or beam loss monitors (BLMs) that will initiate the FSD. The slow beam motion can be studied through MYA archiver, by correlating for example BPM positions with rates on Halo counters.

The fast beam motions (orders of microseconds or milliseconds) cannot be handled or studied with BPMs due to limited bandwidth of BMP readout amplifiers. The halo counters rates that are stored in MYA are also updating slow (mostly updated every 2 sec in HPS run period). In order to study beam motion at the microsecond level a system based on Struck SIS 3800 scaler was developed that allowed to buffer counter rates with 15 μs dwell time.

1 Connections and characteristics of Struck scalers

The system consisted of a hardware IOC with one Struck scaler (SIS 3800). A buffered readout of the scaler was organized in EPICS that allowed to write the buffer to a root file. Each buffer has 60000 elements, each element corresponds to the integrated rate in that channel with 15 μs dwell time. When the buffer is filled it takes about 1.1 s to write them into a file. During that time scaler is blocked, doesn't count. Along with the 60 K long buffer it also writes the time-stamp with a nano-second precision for each buffer that corresponds to the local time of the 1-st element of the buffer. Schematically the readout is presented in Fig.1.

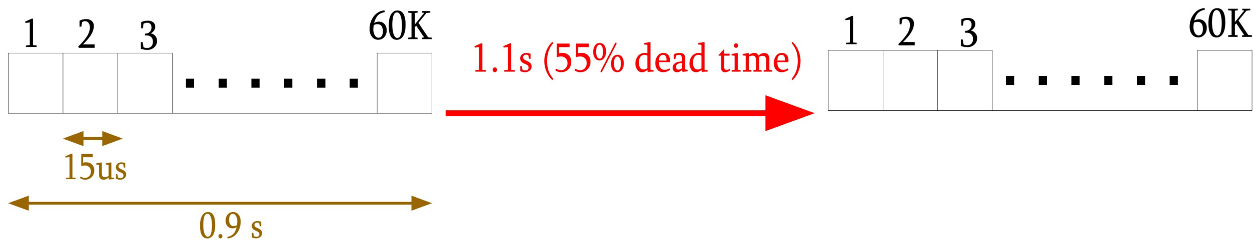


Figure 1: Readout of Struck scaler

Channel 0	25 MHz clock
Channel 1	"HPS-SC" + ECal crystal
Channel 2	"Tagger-top" + "Upstr.-Right" + ECal crystal
Channel 3	"HPS-R" + ECal crystal
Channel 4	ECal crystal

Table 1: Correspondence between scaler channels and signal sources.

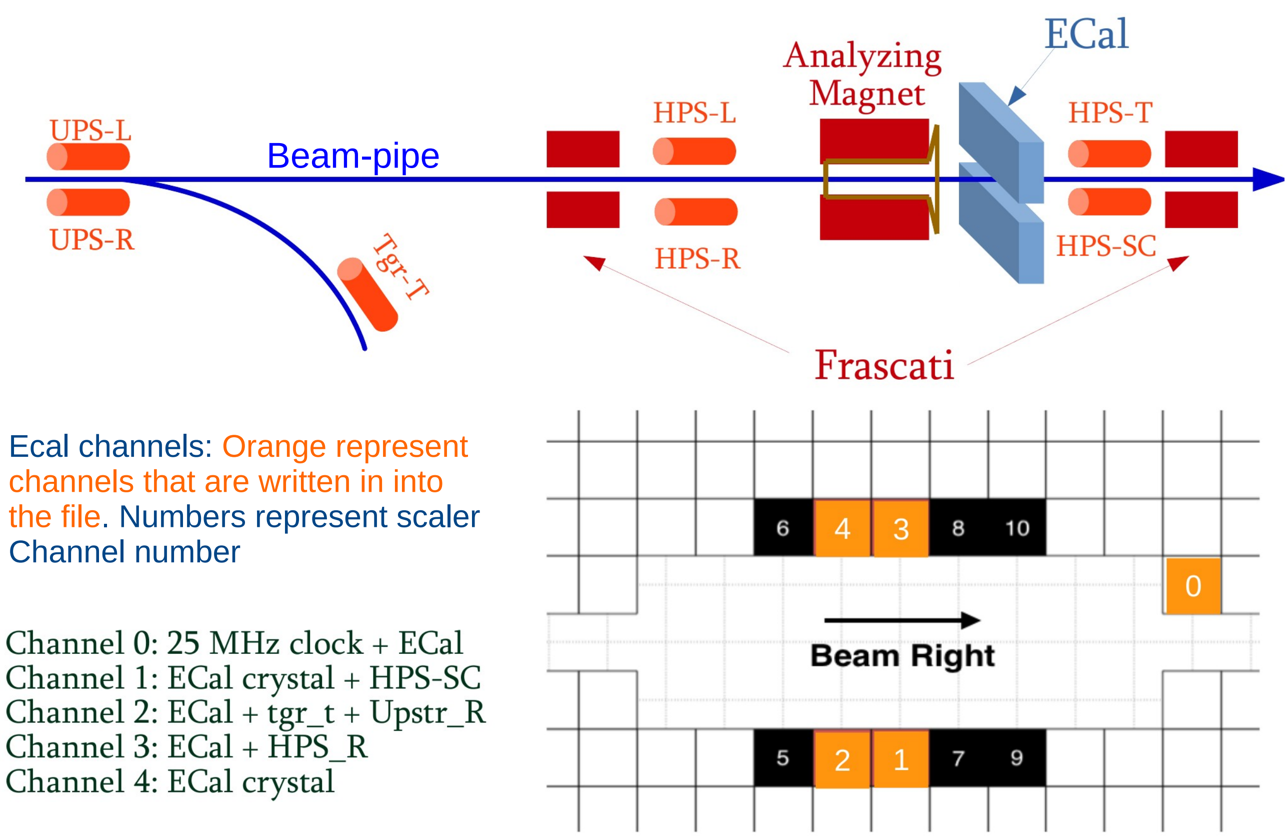


Figure 2: Schematic picture of connections: shown locations of all counters that are connected to scaler.

Only the first 5 inputs of the scaler were used to readout a 25 MHz pulser, HPS calorimeter modules, and a set of beam halo counters, see Table 1. In Fig.2 schematic view of the locations of counters is shown. The channel-0 of the scaler was connected to the 25 MHz pulser to be able to check whether the scaler reads and writes data properly. In Fig.3 the distribution of counts in channel-0 as a function of time. The

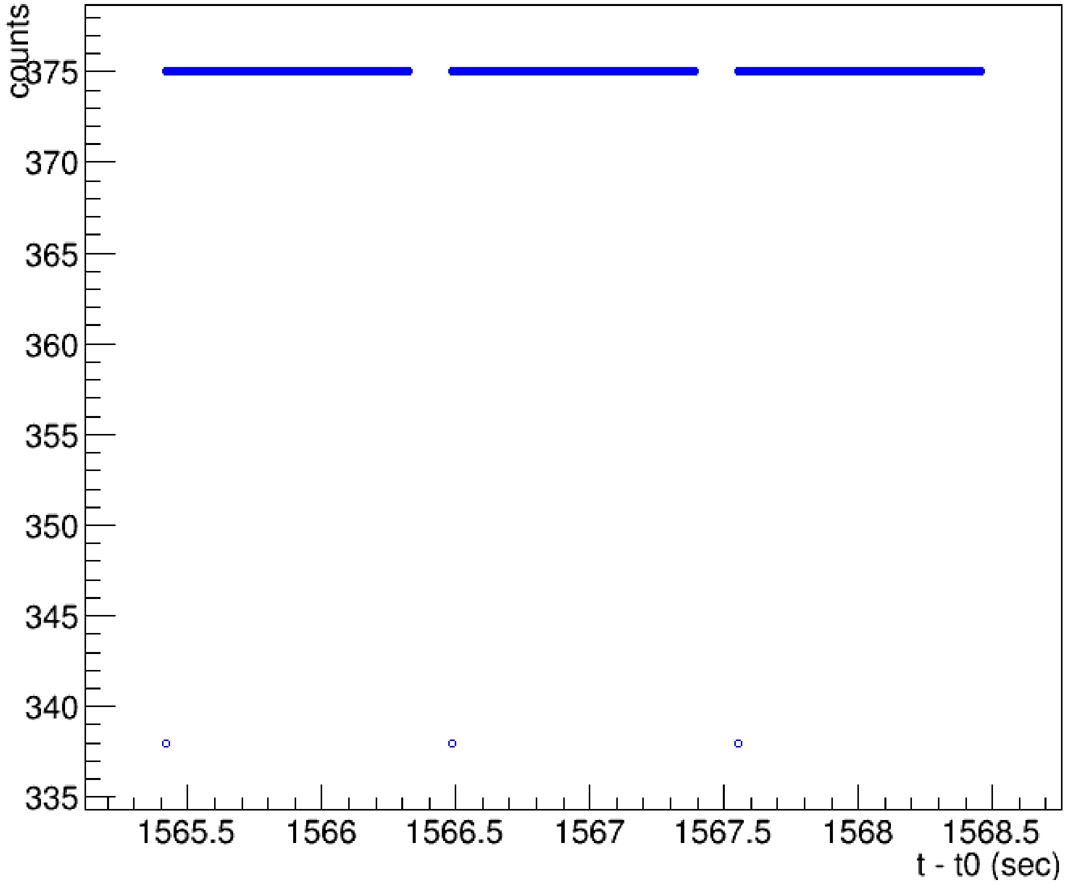


Figure 3: The 3 consequent buffers of 25 MHz pulser. In 15 μs interval it corresponds to 375 counts. The gap between readings is the dead time, when scaler writes out the buffered data.

25 MHz in 15 μs time interval corresponds to 375 counts. The gap between readings is the dead time, when scaler writes out the data into the file. It should be noted that the time-stamps from buffer-to-buffer are not correct, the actual dead time is about 1.1 s, while in the Fig.3 it appears as ≈ 150 ms.

2 Testing the system with beam in the tagger dump

The first test of the system with the beam was done on March 14 and 15. For that tests beam was directed to the Hall-B tagger dump. At that time upstream BPMs were not calibrated yet. Since the dwell time is quite small (15 μs), one need to have a sufficient rates in the counters to be able to observe rate change over the small time interval. Therefore only upstream halo counters that are directly on the electron beamline can be used (scaler channel #2). To get count rate high enough to be visible in the Struck readout the 1 mm thick iron wire on the "tagger harp" that is parallel to the X axis was moved close to the beam to create about 3 MHz rates in the halo counters ("Upstr-R" and "Tgr-T" together).

In Fig.4 about 4 minute snapshot of various beam parameters during the tests from MYA archiver is shown. In the figure brown line is the beam current as measured on 2C24 nA-BPM, the green line is the Y-position of the bam on 2C24 and the red line rate on "Upstr-R" halo counter. As one can see the beam current in that period is quite stable, while the beam vertical position oscillates with a period of about 30 s, and the rate in upstream halo counter oscillate with it. When beam moves up, and consequently touches the wire, rates quickly rise up to few MHz.

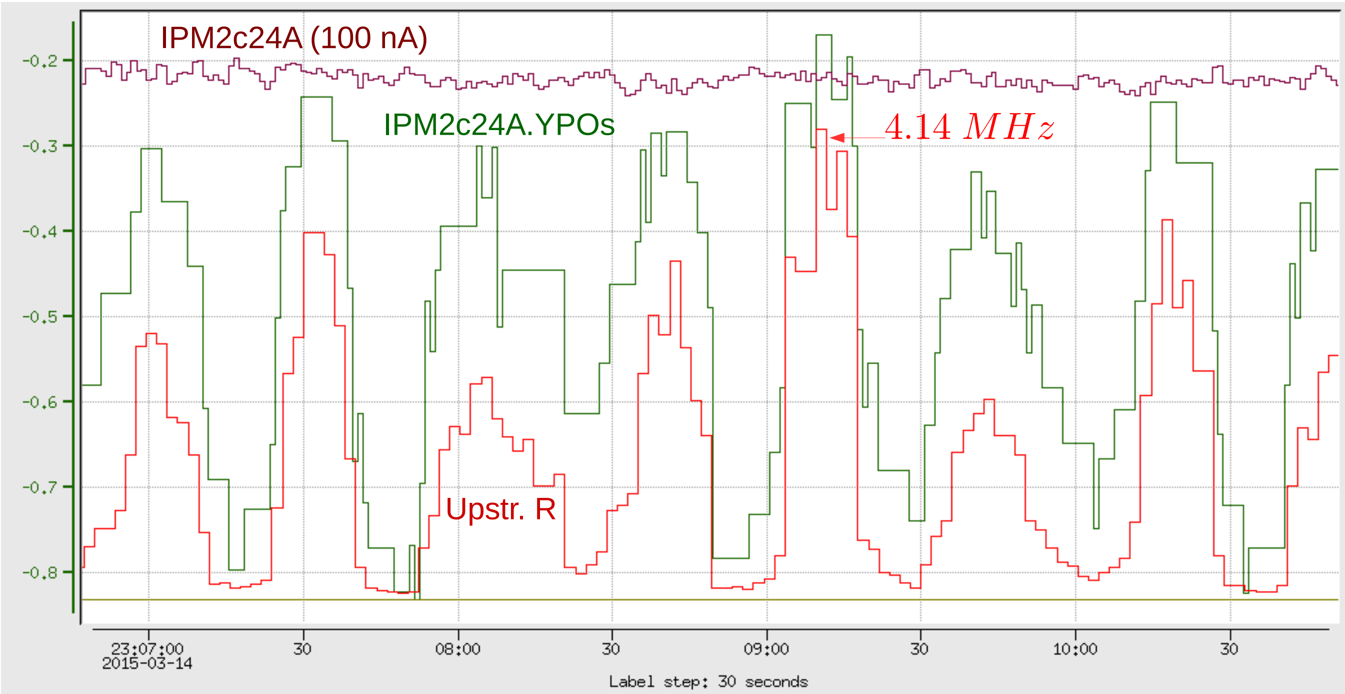


Figure 4: A figure showing periodic variation of rates on Upstr-R halo counter, when harp thick horizontal wire is touching the beam from the top. It is directly related to the beam Y position change at 2C24A.

The fast beam motion studies using the Struck scaler system was done with above beam conditions. In Fig.5 an example of one buffer with 60K readings from scaler channel #2 is shown. As one can see rates on scaler oscillate a lot. Rates vary from 0 up to 140, where 140 counts in 15 μs correspond to about 9 MHz. Taking into account that 9 MHz is the sum of two counters "Upstr-R" and "Tgr-t" and that these two counters count roughly equal, the maximum rate in each counter would correspond to about 4.5 MHz. The rate of oscillations isn't appear to be constant, but it is mostly within 60 Hz to 100 Hz. So taking into account above mentioned one can conclude that, there exist two beam motion components, one is fast, within 60 Hz to 100 Hz, another is slow with about 30 sec period. According to BPMs beam motion at 2C24 is about 500 μm. (One should note, however, that this doesn't mean that the beam motion will be the same order at the HPS detector, since the optics is such that beam has the largest spatial size at 2C24, whereas it is around 40 μm in the 2H02A.)

3 Beam motion studies at HPS

The next set of beam motion studies with Struck scalers were performed on April 27. Similar to the upstream case the 1 mm thick wire of the 2H02A harp 2H02 was placed close to the beam to create sufficient rates to on Struck scalers (in Ecal crystals and the HPS halo counters). In Fig.6 beam vertical position at 2H02 BPM (red) and the rate in HPS_SC (green) are shown. This shows that the BPM noise level is around 50 μm. Looking carefully to the picture, one can notice that on top of BPM position fluctuations (the noise), there is also a small (w.r.t. BPM noise) position variations that are correlated with rates on HPS_SC.

Looking rates with Struck scaler, we see a similar behavior as in the upstream case. In Fig.7 rate of channel #1(HPS_SC) as a function of time is shown for 100 ms time interval. We see there is a clear oscillations of rates. Oscillations are not occurring by a constant period, but it is mainly between 50 to

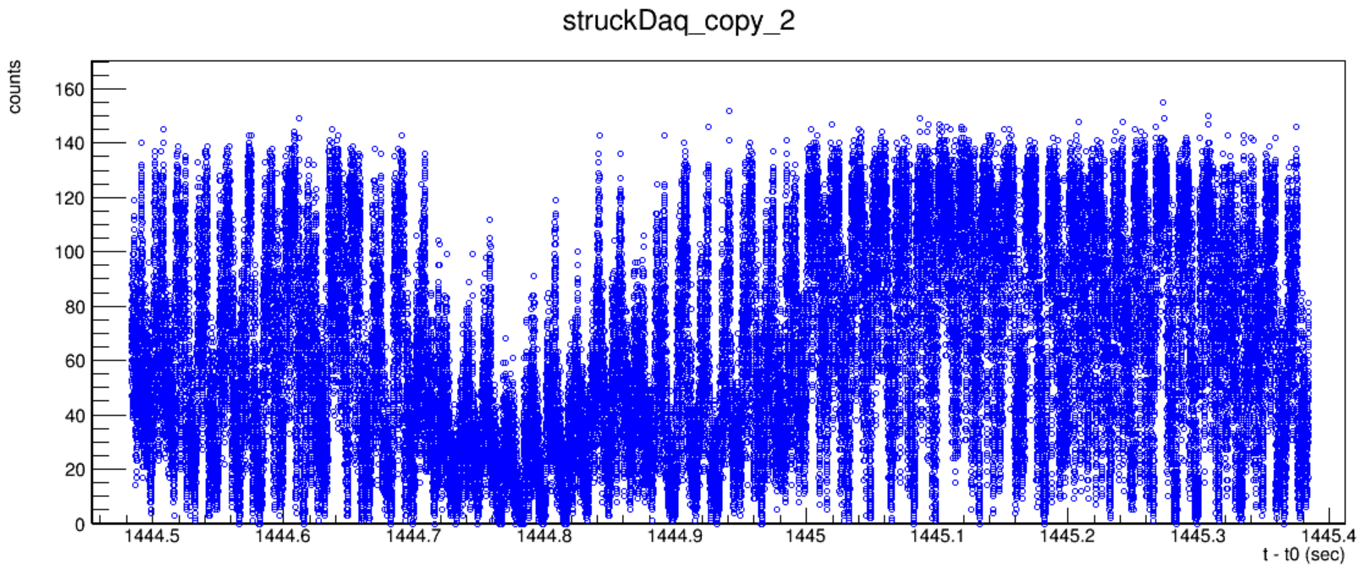


Figure 5: An example of one buffer with 60K readings from scaller channel 2.

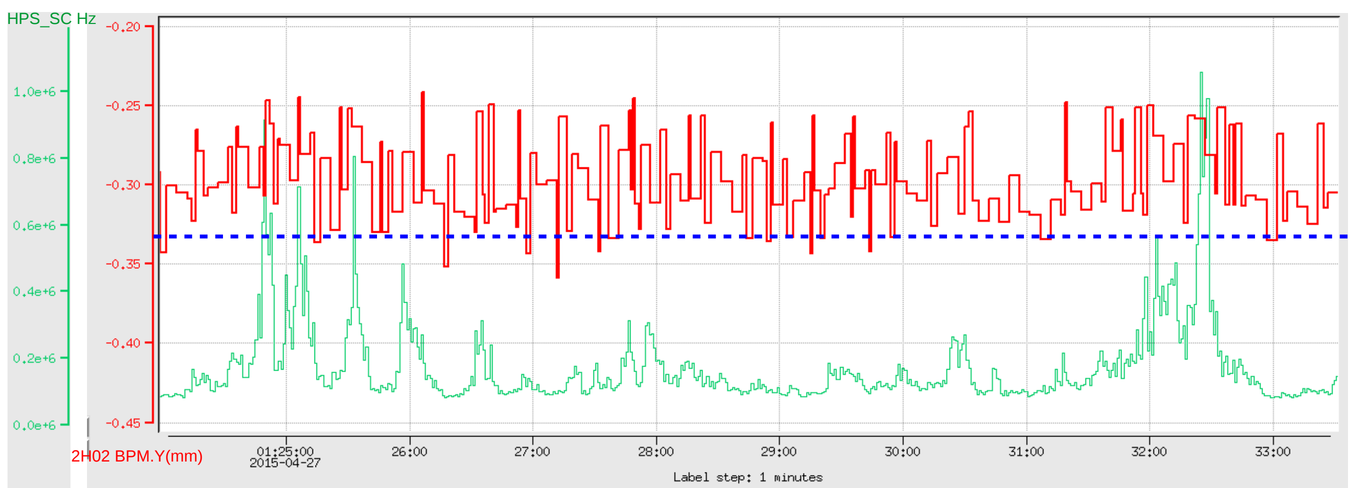


Figure 6: Stripchart representing Rates on HPS_SC (green) and 2H02 BPM_Y (red) when 2H02A 1 mm vertical wire is touching the beam from the top

100 Hz. From Fig.6 we learnt that at 2H02 BPM beam motion is less than 50 μm beam and the rate in HPS_SC changes by $\approx$ 6 times. In Fig.7 rate oscillations are the same order, about $5-6$ times between min and max values, therefore beam fast motion also should be within 50 μm. So behavior of the beam at upstream and at the HPS look similar. Both have slow and fast components, however the motion amplitude is much smaller, by factor of 10, at the HPS (less than 50 μm).

Using the Struck data we also studied beam motion during the beam trips to see whether there is an increase of rates just before the trip. During the owl shift on April 27 we didn't observe any increase of rates before the trip. One example of the scaler rate when trip happened is shown in Fig.8. As one can see that rates just go down to 0 within few μs.

3.1 Some exception

There were few instances when significant beam motion of the order of few hundreds of microns has

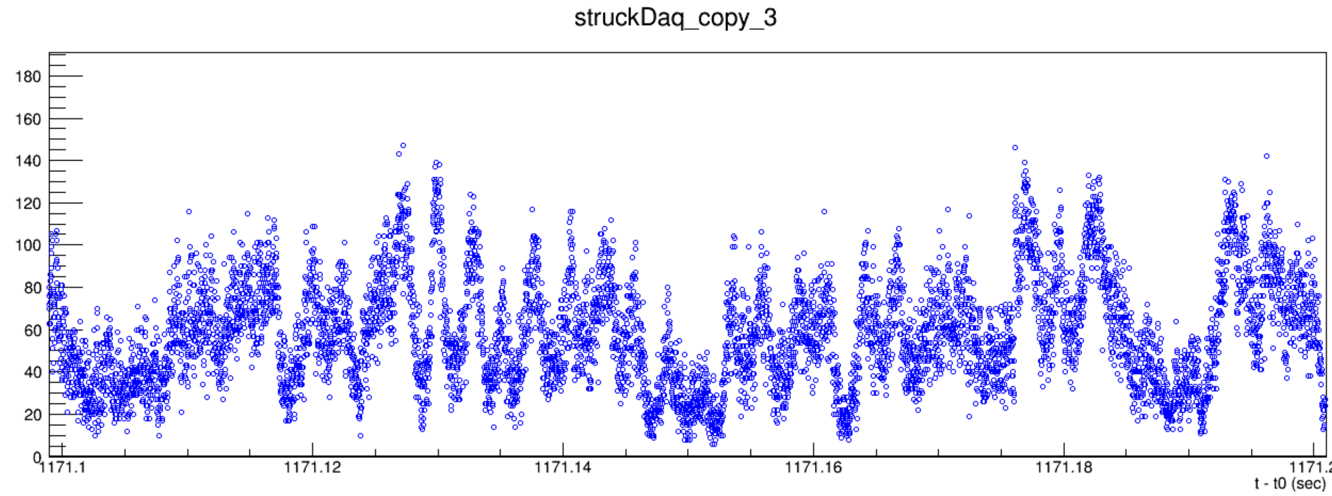


Figure 7: Counts as a function of time for Struck scaler channel 1 (HPS_SC) in 100 ms time interval. Each point represents counts in a 15 μs time interval.

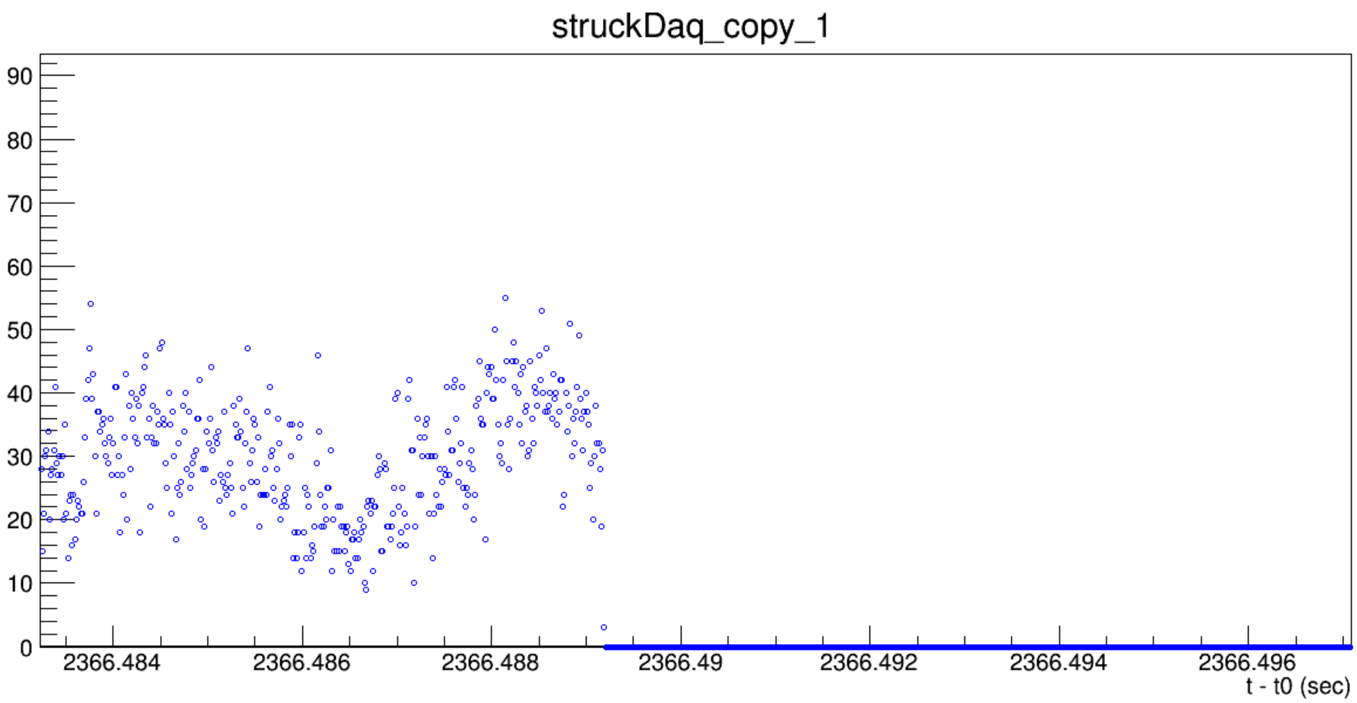
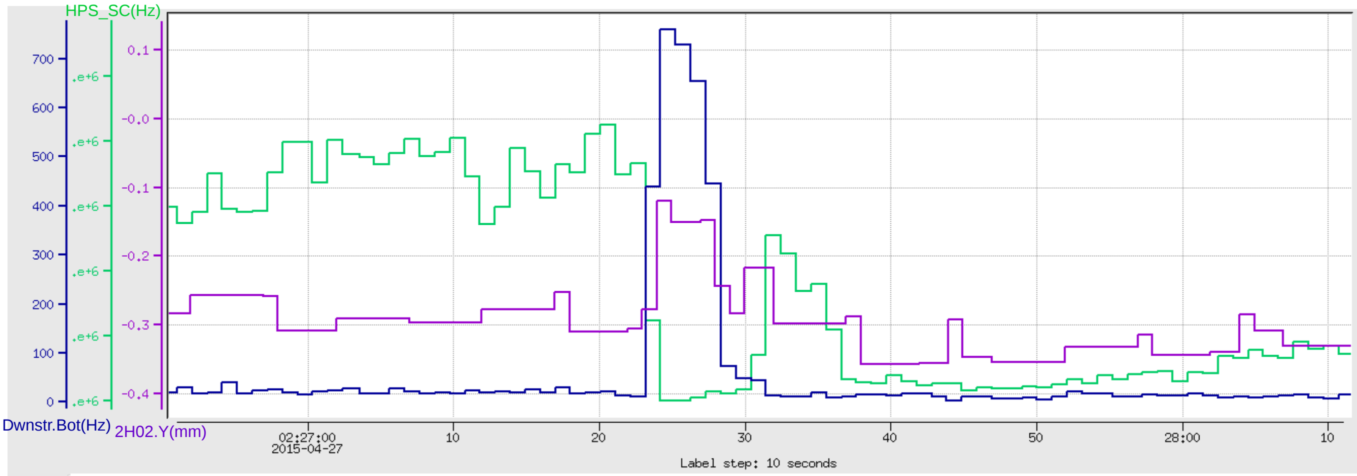
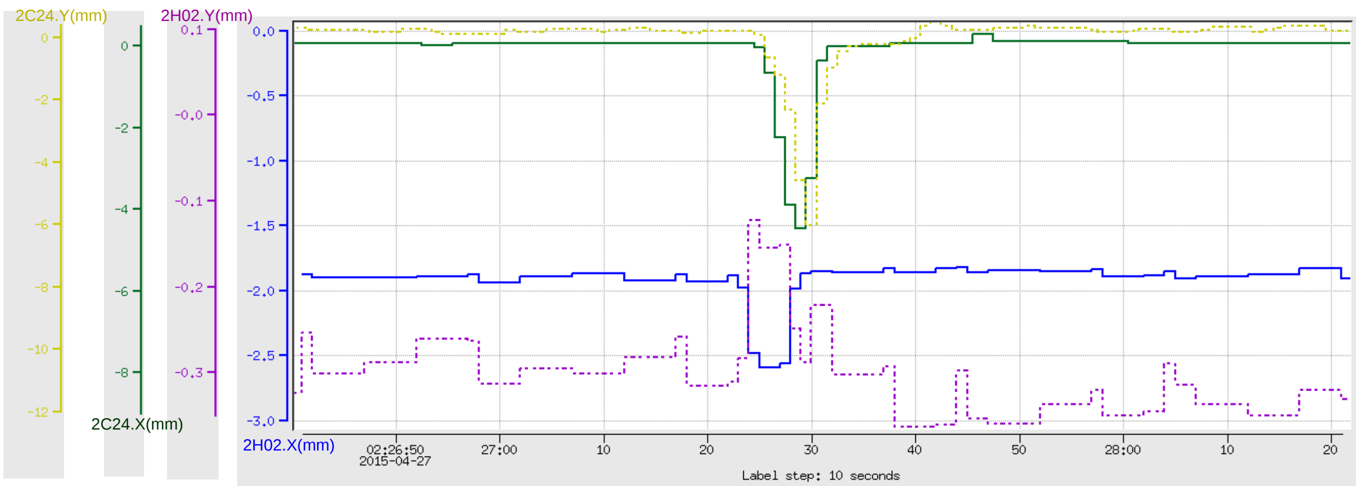


Figure 8: Counts on HPS_SC from Struck scaler as a function of time. No increase of rates is observed during the trip.

been observed. One example is depicted in Fig.9, where one can notice correlation between BPM position readings and the rates on halo counters, i.e. HPS_SC is saturated while downstream counter shows a clear peak during the beam movement. While at HPS beam movement is $\approx$ 150 μm in vertical direction and $\approx$ 500 μm in horizontal, on 2C24 BPM the beam position change in X is on oder few mm's. The fact that there is a big difference in beam motion amplitude between upstream of the orbit lock system (upstream of the 2H00 girder) indication that the movement is coming from the accelerator and the Hall-B orbit locks are able to compensate it.



(a)

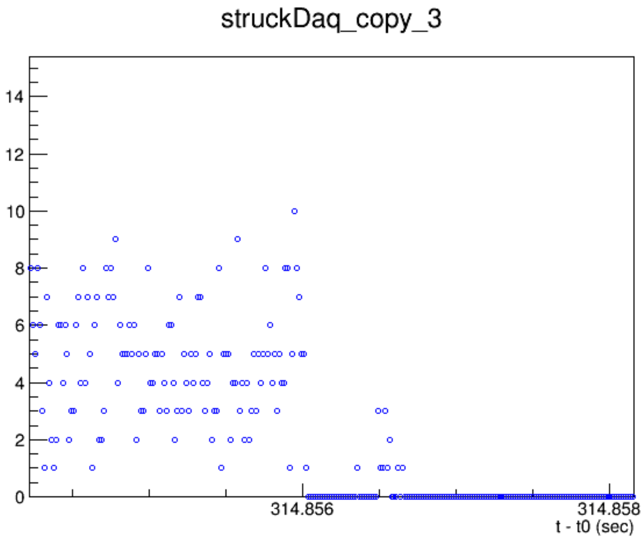


(b)

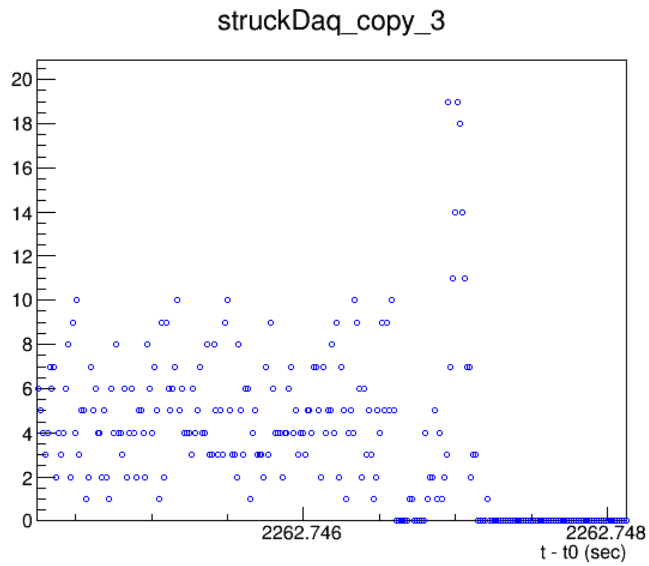
Figure 9: Strip chart showing a significant beam movement for a few seconds. a) rates on HPS_SC (green), 2H02.Y (pink) and rates on Downstream-bot (blue). b) Beam X and Y positions at 2C24 (green and yellow respectively), and at 2H02 (blue and pink respectively).

3.2 Studies with the target "IN"

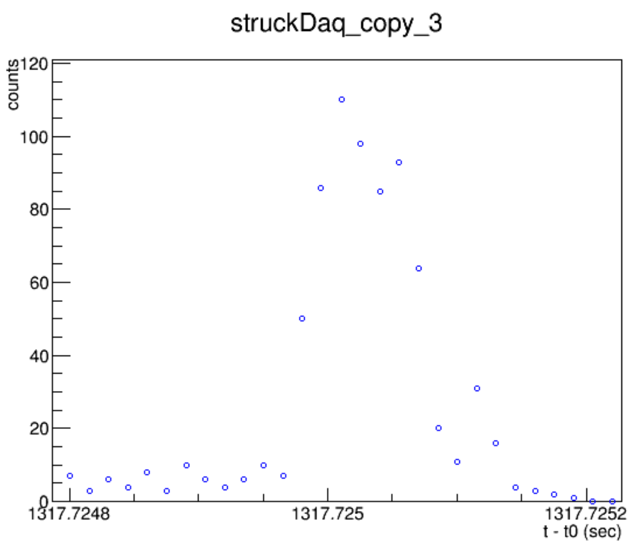
We took some parasitic data too with Struck scaler, i.e. during production running when target was on the beam. Of course there will be a high rates present in the downstream halo counters that is coming from the target, but if beam moves and hits some thick/dense material then one should expect to see much higher rates on the halo counters. In Fig.10 different scenarios of beam trips with the presence of the target are shown. In Fig.10a beam trip is smooth, no rate increase before beam was completely off indicating that the beam didn't move enough to hit anything. In Fig.10b counts were increased twice than normal by about 150 μs then went to 0. This is likely due to the beam-tail interaction with some material, otherwise as wee saw before rates would increase more than 10 times. In Fig.10c we see more than 10 times increase of rates again in a short ($\approx$ 150 μs) time interval. The same as in previous case, beam had somewhat stronger interaction with some material before being completely off. The scenario in Fig.10d is quite rear in sense that the time period with high rates is about 600 μs whereas it is usually



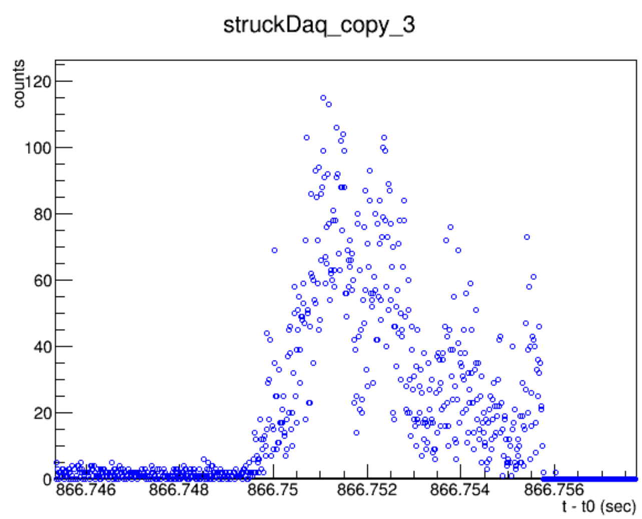
(a)



(b)



(c)



(d)

Figure 10: Different scenarios of beam trips, when target was "IN". a) Trip is quiet, b) rates slightly increased before the trip. c) in ≈ 100 μs rates increased by ≈ 10 times before the trip, d) rates increased by ≈ 10 times before the trip, then after ≈ 600 μs beam is tripped.

less than $100 - 200$ μs. During almost all trips the trip type also has been recorded. We didn't observe any correlation between the trip type and the behavior of halo counters, e.g. for the RF trip sometimes beam goes off quietly without making high rates on the halo counters, sometimes rates may increase, jump by an order of magnitude before the trip. Same thing is with the BLM trips or other types of trips. We should stress that the increase of rates doesn't necessarily mean that the beam has interacted with the HPS collimator or with something around the HPS. We already saw from MYA and Struck data several instances where the beam has moved away upstream causing the rate increase every where.

4 Testing of the FSD system

It is clear from the above discussed that even large beam motions are not avoidable. To keep SVT from being exposed by the beam, signals from all HPS halo counters (HPS_L(R, SC, t)) have been summed up and sent to CEBAF Fast Shut Down (FSD) system. The working principal of the FSD board is quite simple, during some time window called integration time, it counts number of pulses on the input, and if it is higher than a certain threshold, it sends a signal to the injector to shut down the beam. The integration time and the threshold level can be set by the user. Of course smaller the integration time better it is. But, in order to run with small integration times one should have an input to the system that will have sufficient counts in order to avoid frequent trips due to statistical fluctuations. The FSD card that was used has two limitations, integration time cannot be shorter than 1 ms and the rates during the integration time can not be less than 1 kHz.

To test the FSD system we ran the 2H02A harp wire through the beam and recorded the rates with Struck scaler. Since the integration time is in order of milliseconds, we increased the dwell time of Struck to be 300 μs, which allowed to have larger number of counts in each time bin. In Fig.11 rates of halo counters are shown when harp wire crossed the beam, the FSD was masked. In the figure the constant background around 70 counts at the beginning and at the end are due to beam- target interactions, while starting at $t - t_0 \approx 80\ s$ beam is hitting the wire and consequently creating higher rates in the counters. So, one should expect that if the FSD system was not masked this rate increase should have tripped the beam.

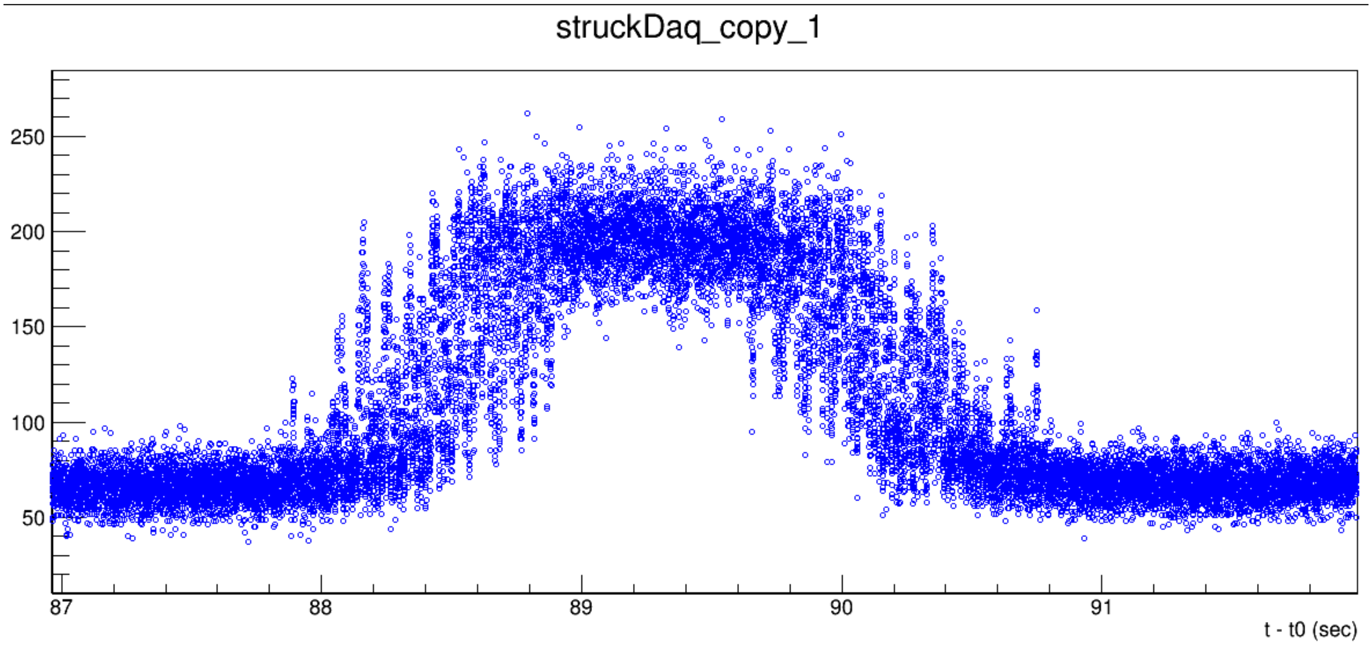
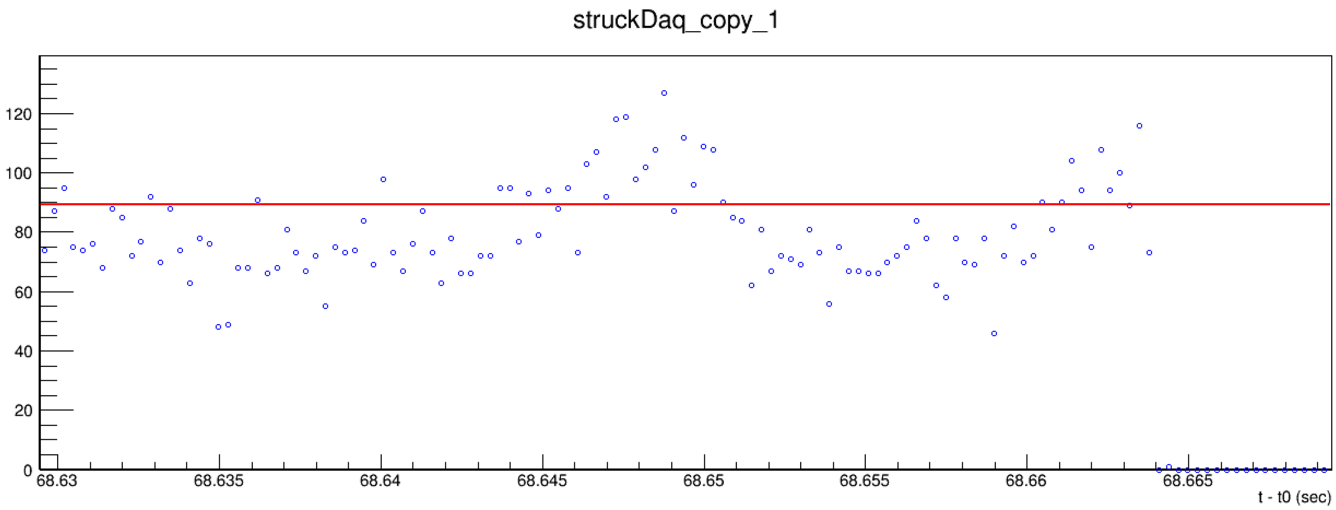
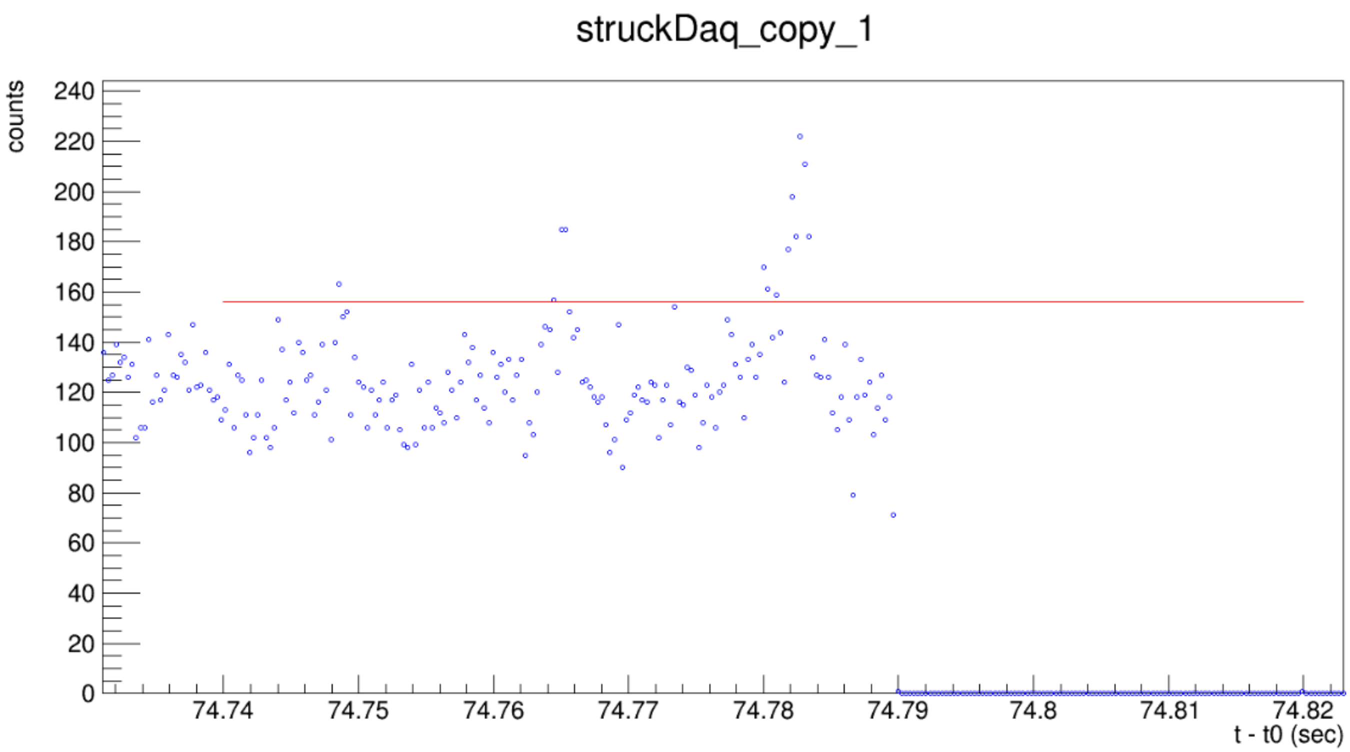


Figure 11: Rates on HPS_SC as a function of time when FSD was masked.

First we tested the 10 ms integration time. The threshold that we put is 3000 counts in 10 ms. This corresponds to 300 KHz input rate, which translates into 90 counts in 300 μs time interval on the Struck. In Fig.12 two trips recorded with two integration times 10 ms (top) and 5 ms (bottom) are shown. Red line is the translated threshold that would be if integration time is equal to the dwell time of the Struck scaler (300 μs). One can see that the time between threshold crossing and beam shutdown is consistent with the integration time. We repeated this test several times with both 5 ms and 10 ms integration times, and observed consistent results.



(a)



(b)

Figure 12: HPS_SC rates as a function of time. In top FSD integration time is 10 ms and the the beam current is 30 nA. In the bottom graph FSD integration time is 5 ms and the the beam current is 50 nA.

5 To summarize

- Two types of beam motions were observed, fast (roughly 100 Hz) and slow ($\sim$ 0.03 Hz) that BPMs can detect. The latter one was handled by the feedback system (orbit locks).
- With engaged orbit locks the vertical beam motion at HPS is mainly within 50 μm.

- Orbit locks keep the beam quite stable, however sometimes it happens that during the trip, or even without the trip beam moves by more than 100 μm at HPS.
- The exact reason for the beam motion during the trip is not clear. Analyzes of different trips didn't find any correlations between the trip types and the behavior of halo counters.
- The FSD system was tested, and it seems to work properly.