First operational experience with the BCCM

251st Machine Protection Panel meeting

31/05/24

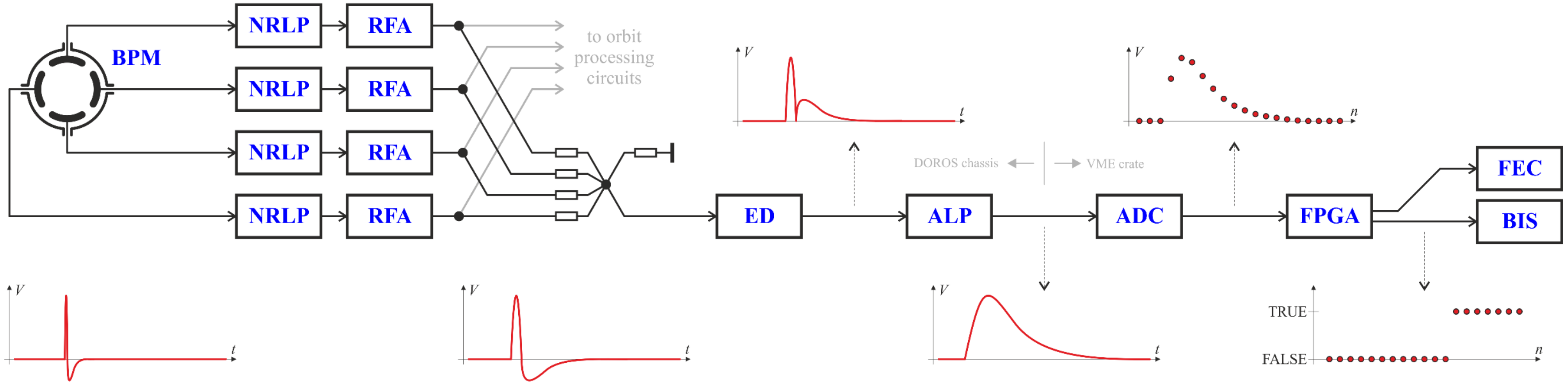
Marek Gasior, Tom Levens

SY-BI-IQ

BCCM (dI/dt) system

shared BPMs:

system A: BPMYA.5R4.B1+B2
system B: BPMYA.6R4.B1+B2



NRLP – Non-Reflective Low-Pass (≈ 80 MHz)

RFA – RF Amplifier

ED – Envelope Detector

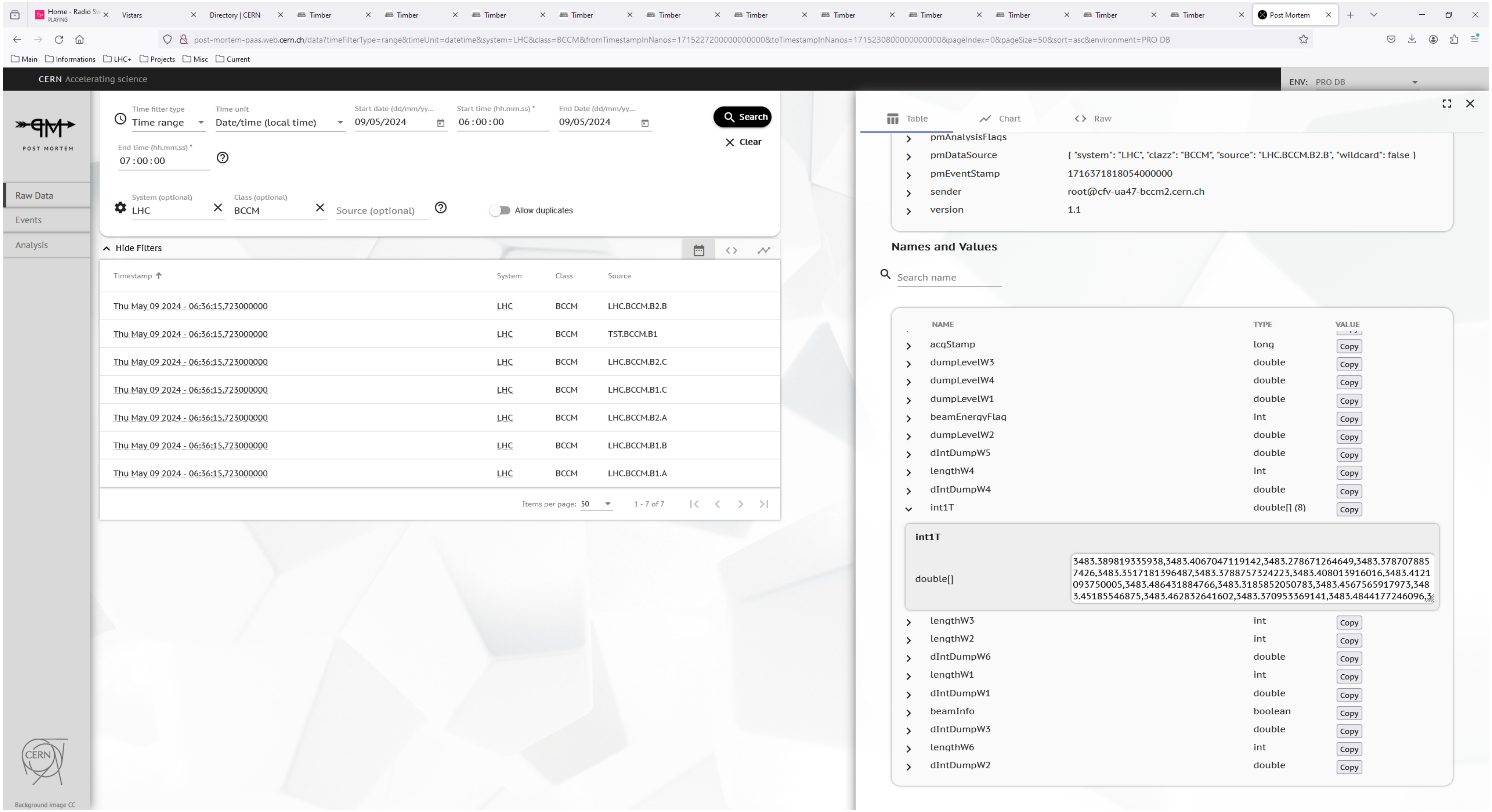
ALP – Active Low-Pass (≈ 2 MHz)

- BCCM uses BPM signals with the position dependency removed by summing the electrode signals
- Extensive analog processing to make the signals as slow as possible, allowing digitization with the highest possible resolution: low-pass filtering, amplification, envelope detection/rectification, further filtering
- Two operational redundant systems in UA47 (A + B) + one R&D not connected to the BIS in UA43 (C) + one R&D in the lab (TST)
- The BCCM dump triggers were unmasked on 8 April (connection to BIC in September 2018)

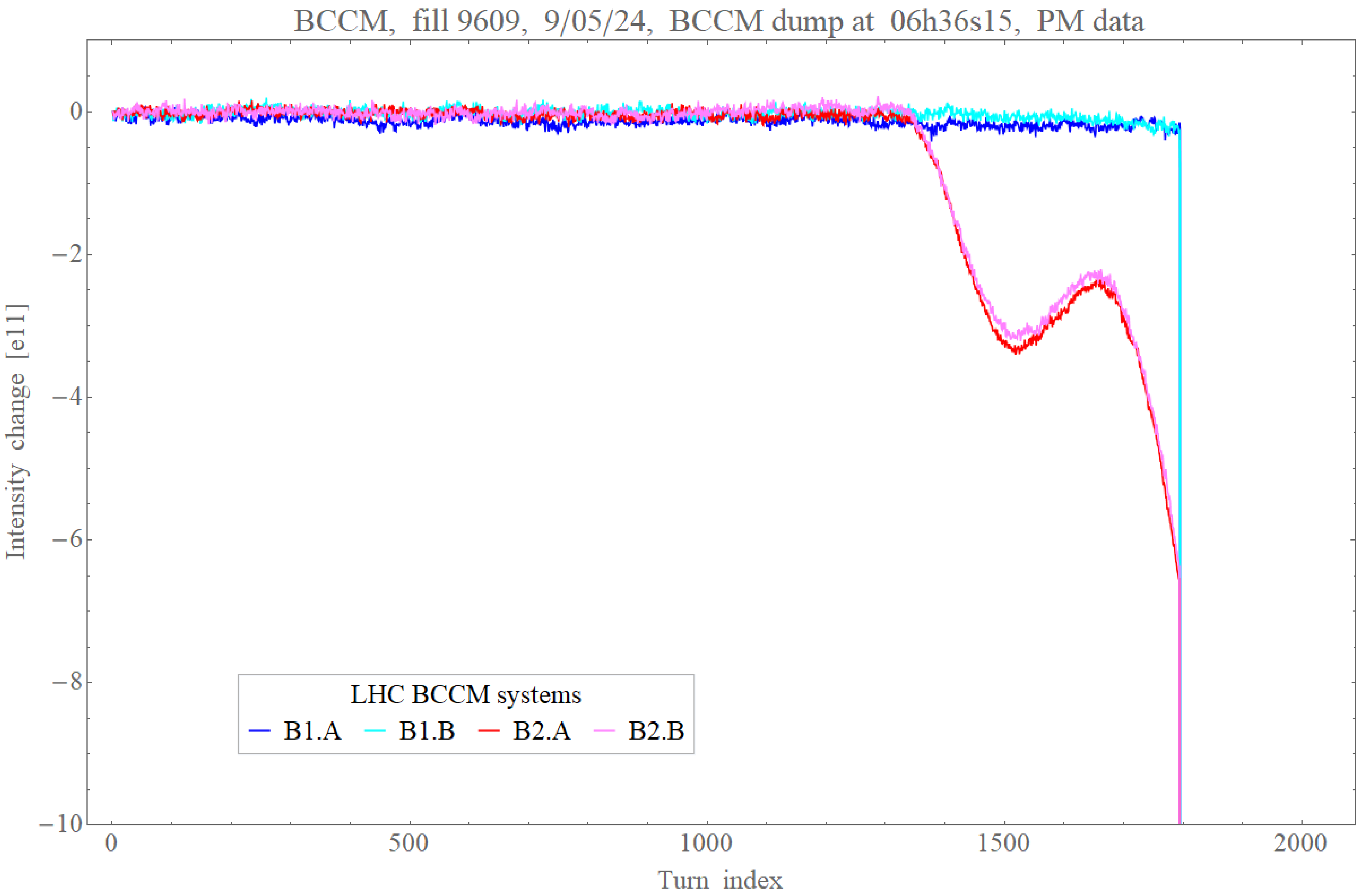
Window [turn]	1	4	16	64	225	1125
< 0.5	6	6	6	6	6	10
≥ 0.5	3	3	3	3	5	10

Energy [TeV] Losses [1e11]

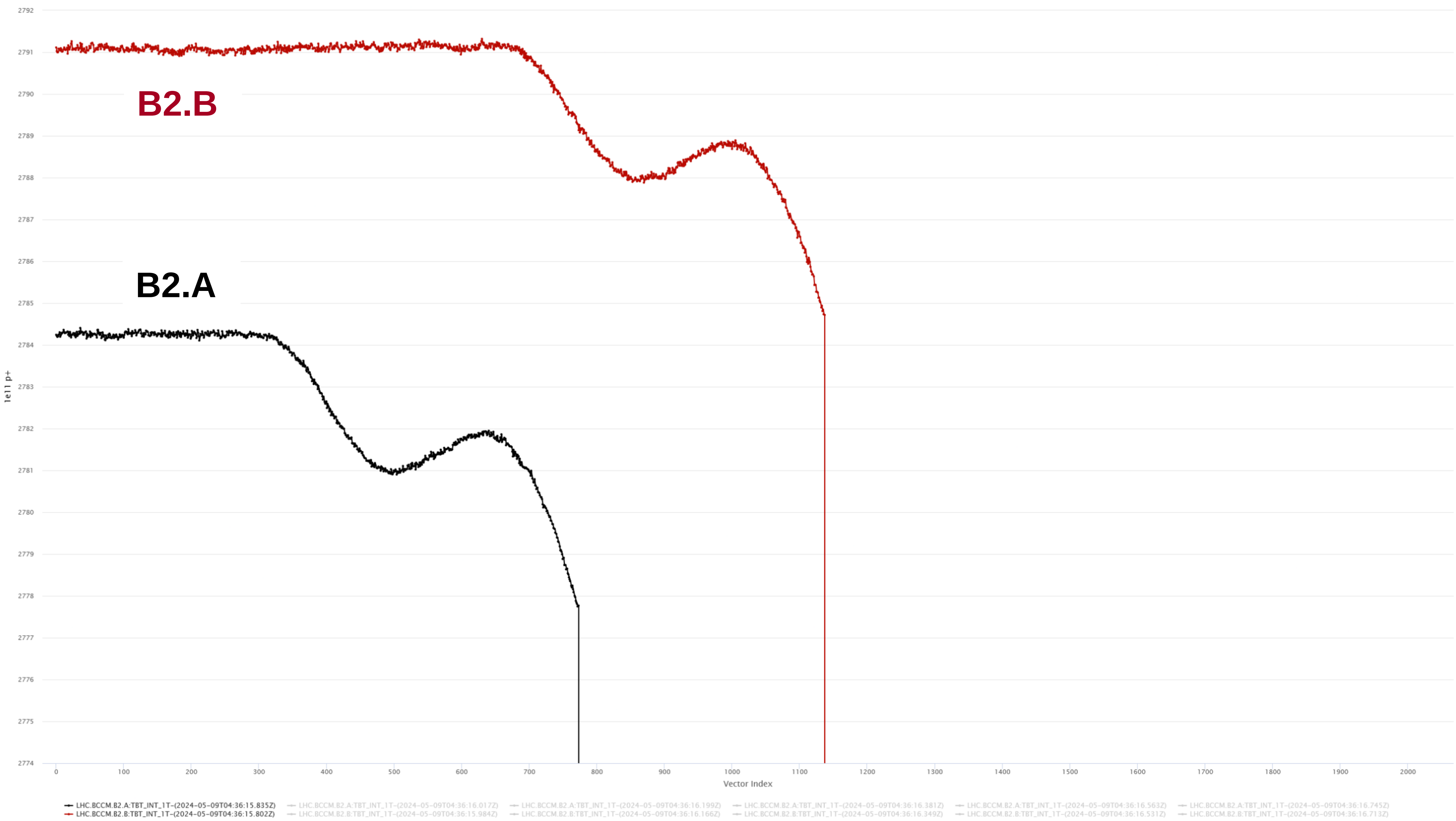
BCCM in service: first dump on 9 May (fill #9609)



BCCM in service: first dump on 9 May (fill #9609)



Dump #1: TbT intensity from the (continuous) logging



Dump #1: summary from the PM data

window	W1	W2	W3	W4	W5	W6
length [turns]	1	4	16	64	225	1125
dump level [e11]	3	3	3	3	5	10

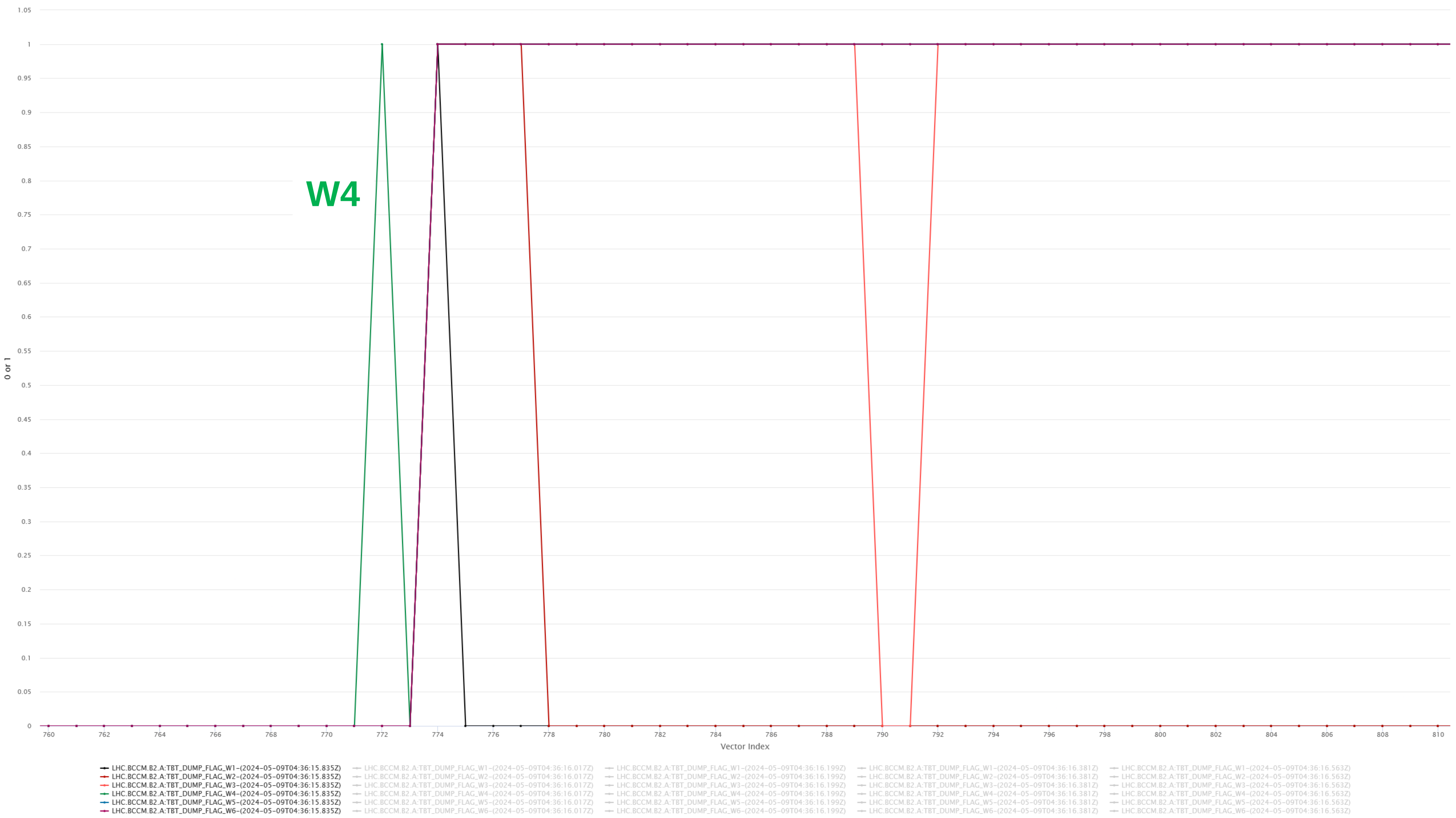
dtDumpFlag [turn]

B1.A	3	3	3	3	3	3
B2.A	2	2	2	**0**	2	2
B1.B	3	3	3	3	3	3
B2.B	2	2	2	2	2	2

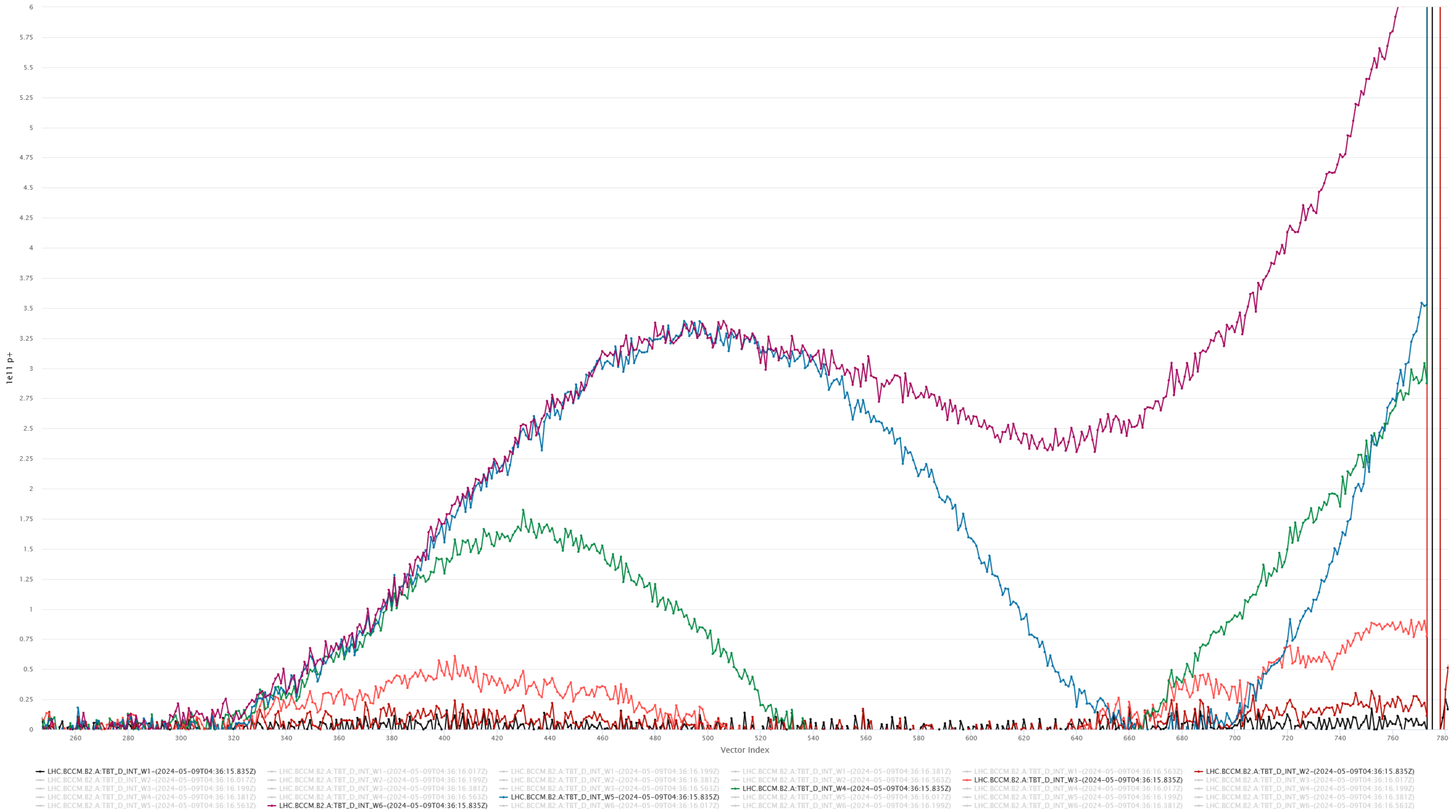
dIntDump [e11]

B1.A	2694.3	2694.4	2694.3	2694.5	2694.4	2694.4
B2.A	2684.9	2685.0	2685.7	**3.04**	2688.4	2691.3
B1.B	2704.8	2705.4	2705.5	2705.6	2705.7	2705.5
B2.B	2700.0	2700.1	2700.7	2702.8	2703.5	2706.3

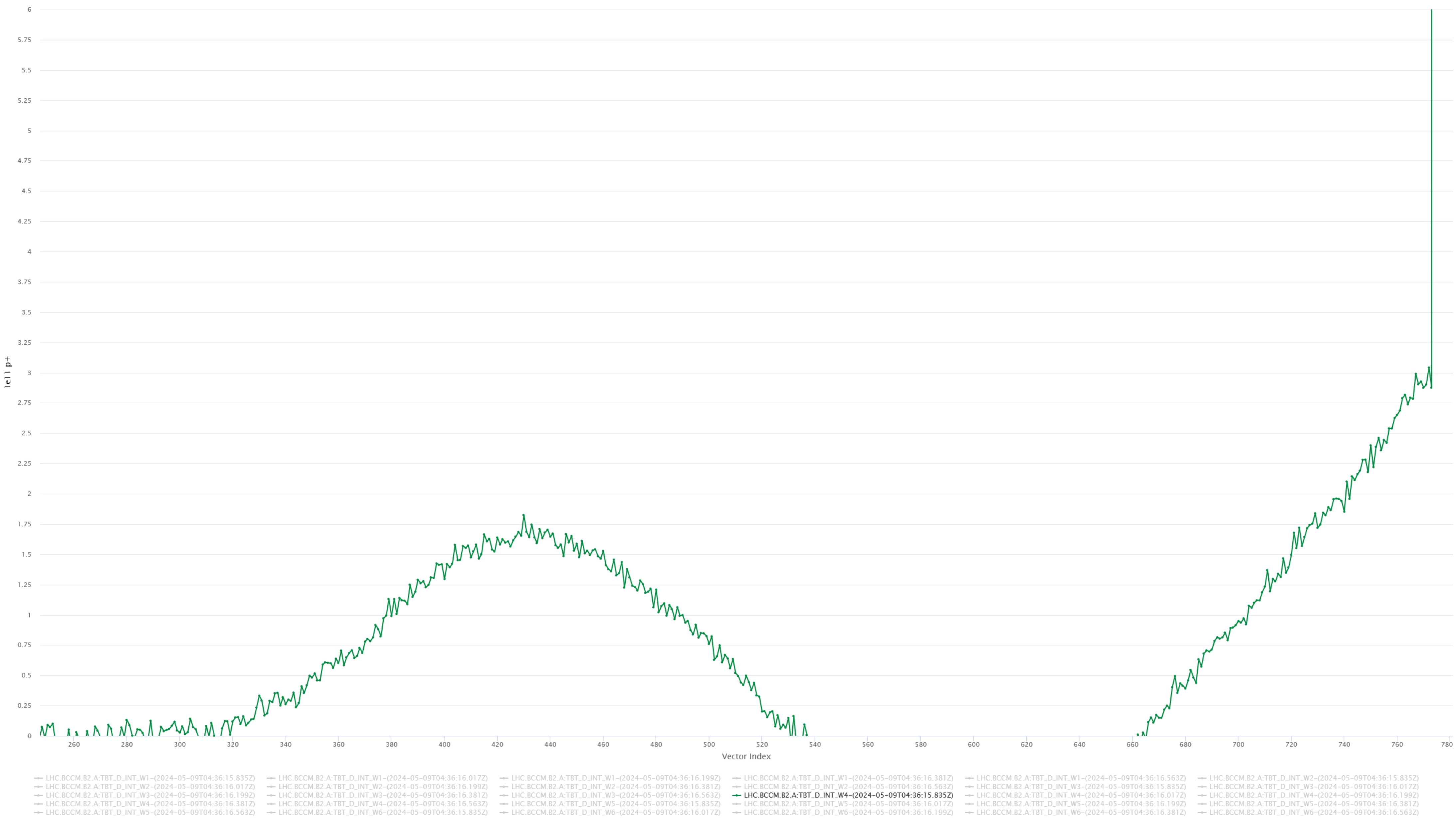
Dump #1: dump flags for system B2.A (TbT logging)



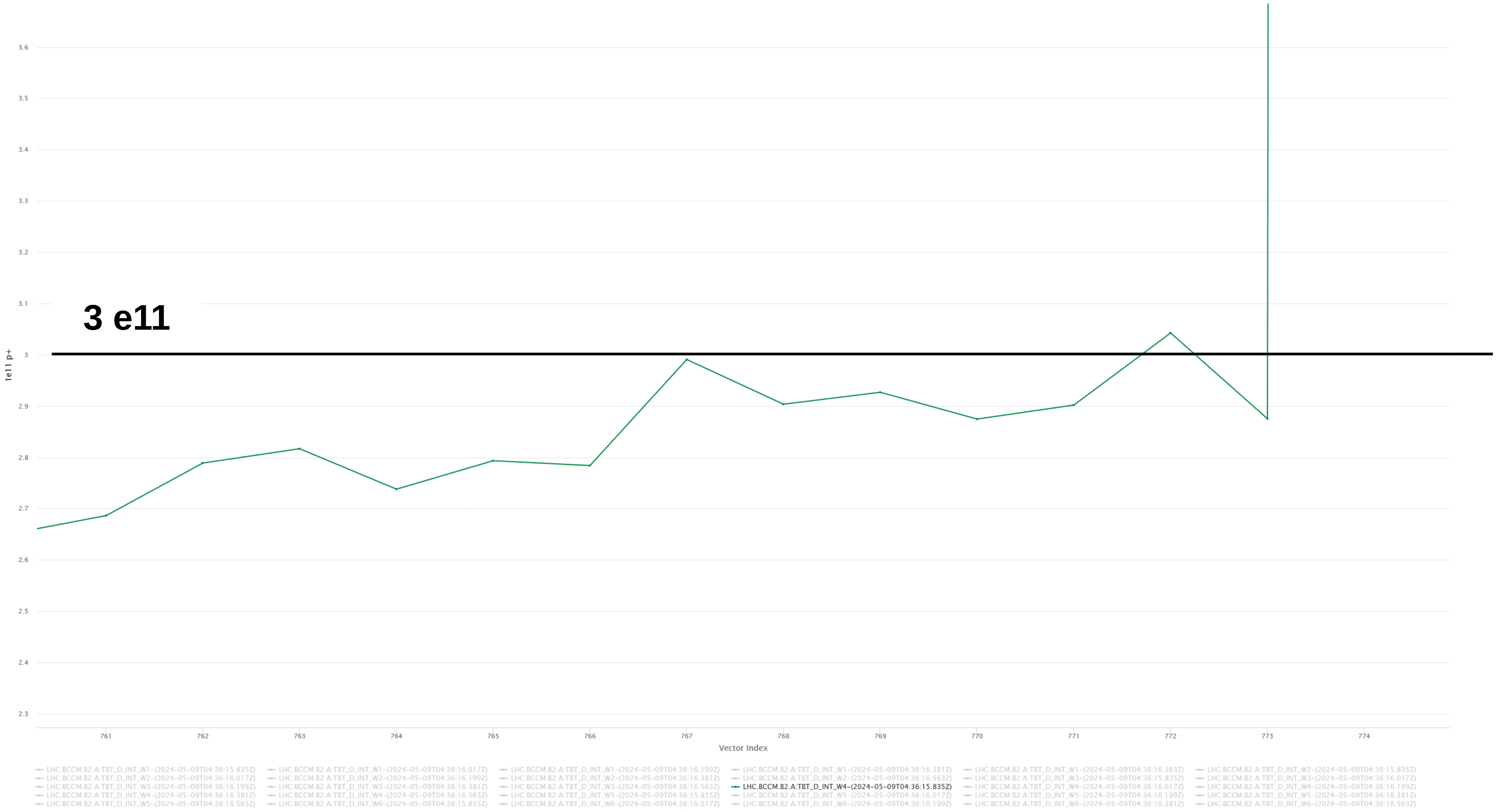
Dump #1: running sums for system B2.A (TbT logging)



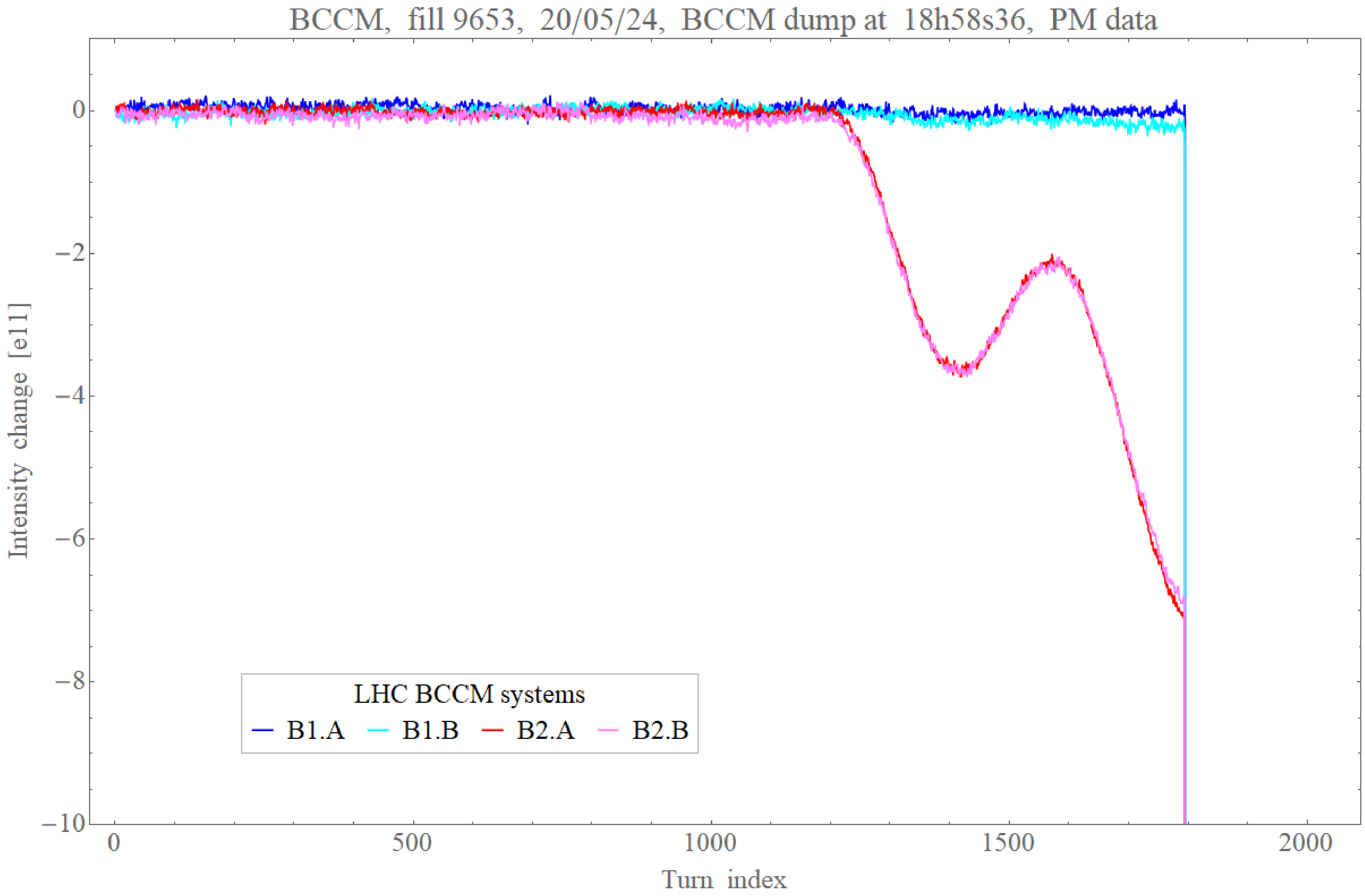
Dump #1: B2.A W4 running sum



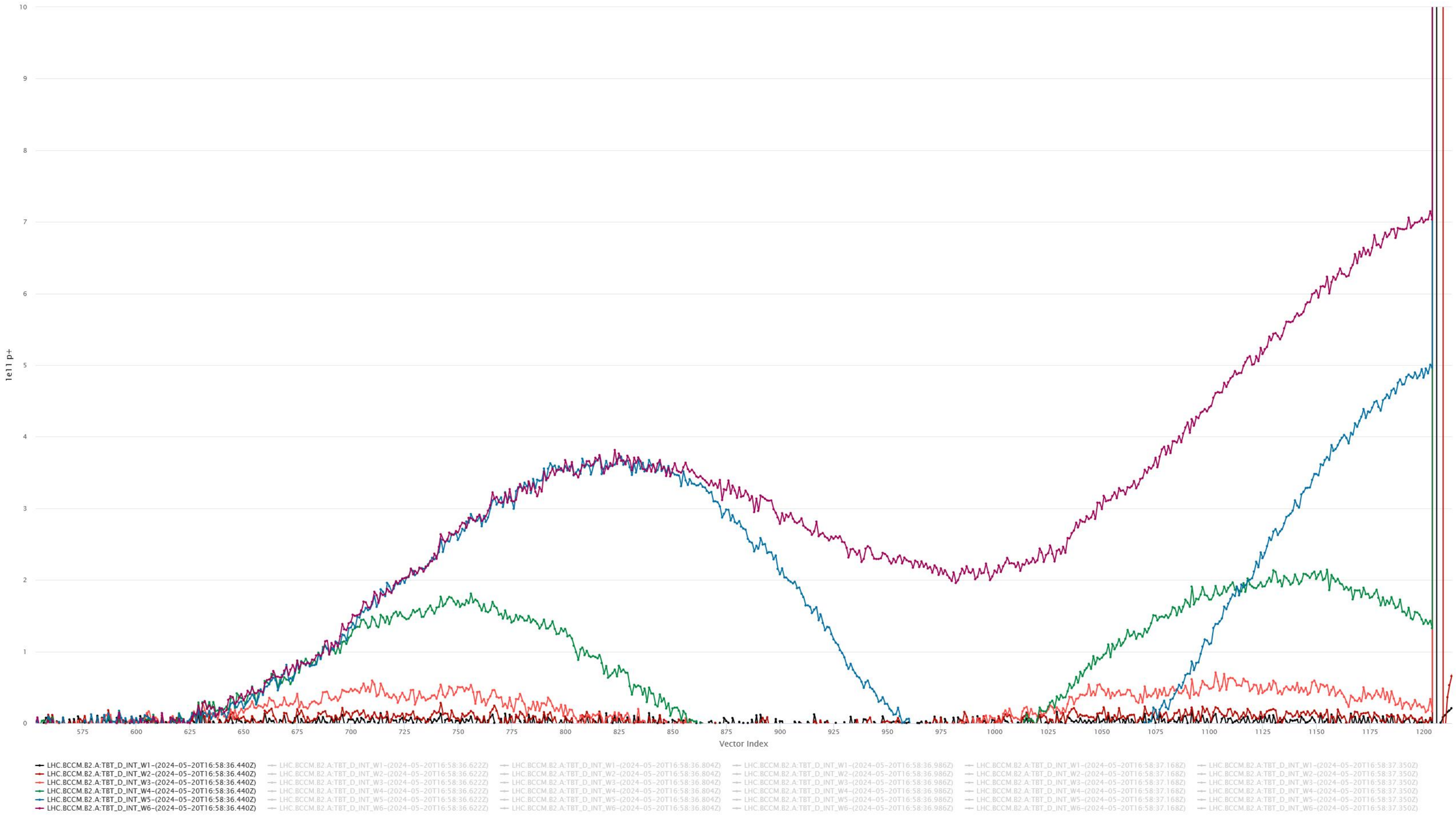
Dump #1: B2.A W4 running sum – zoom



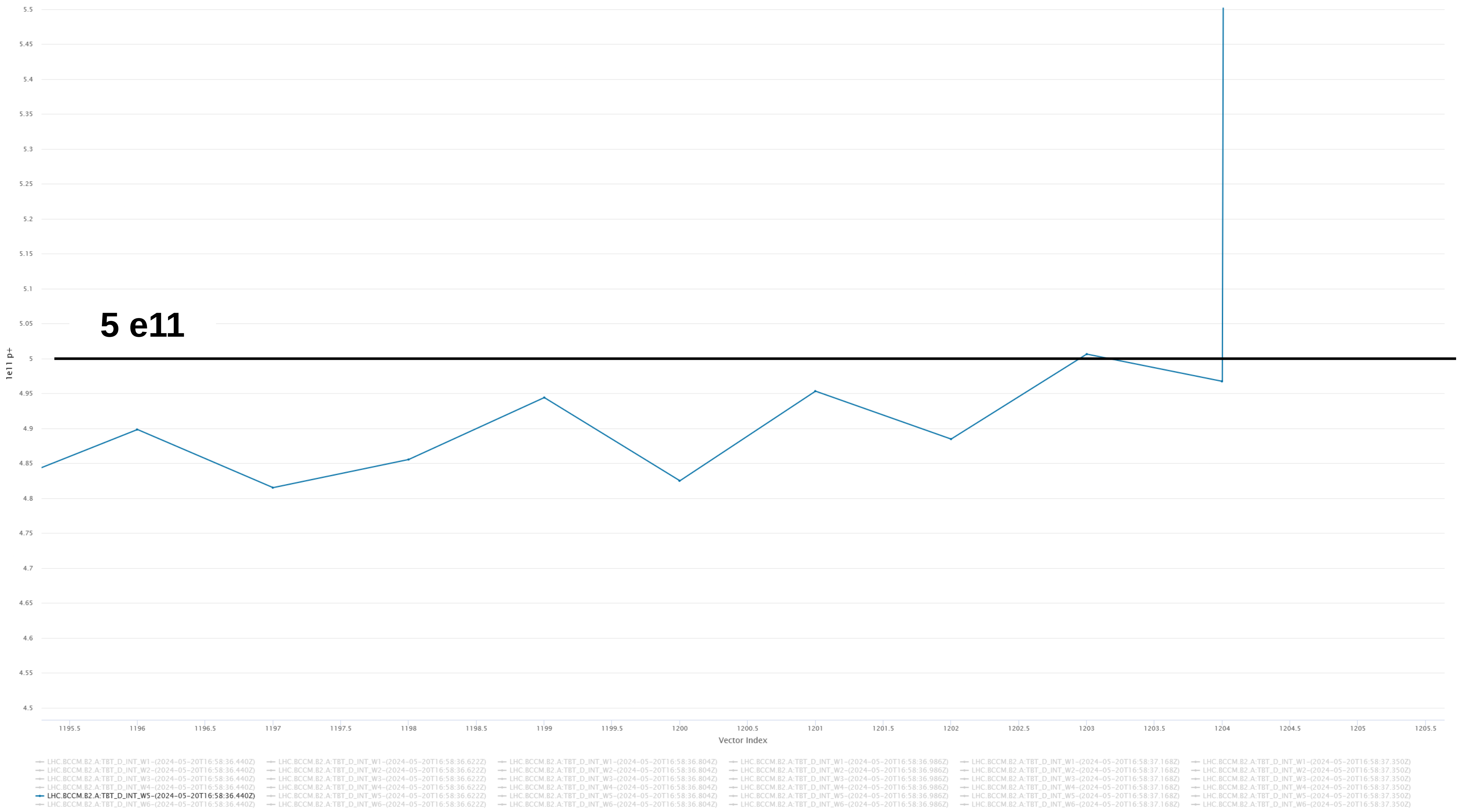
Dump #2 on 20 May (fill #9653)



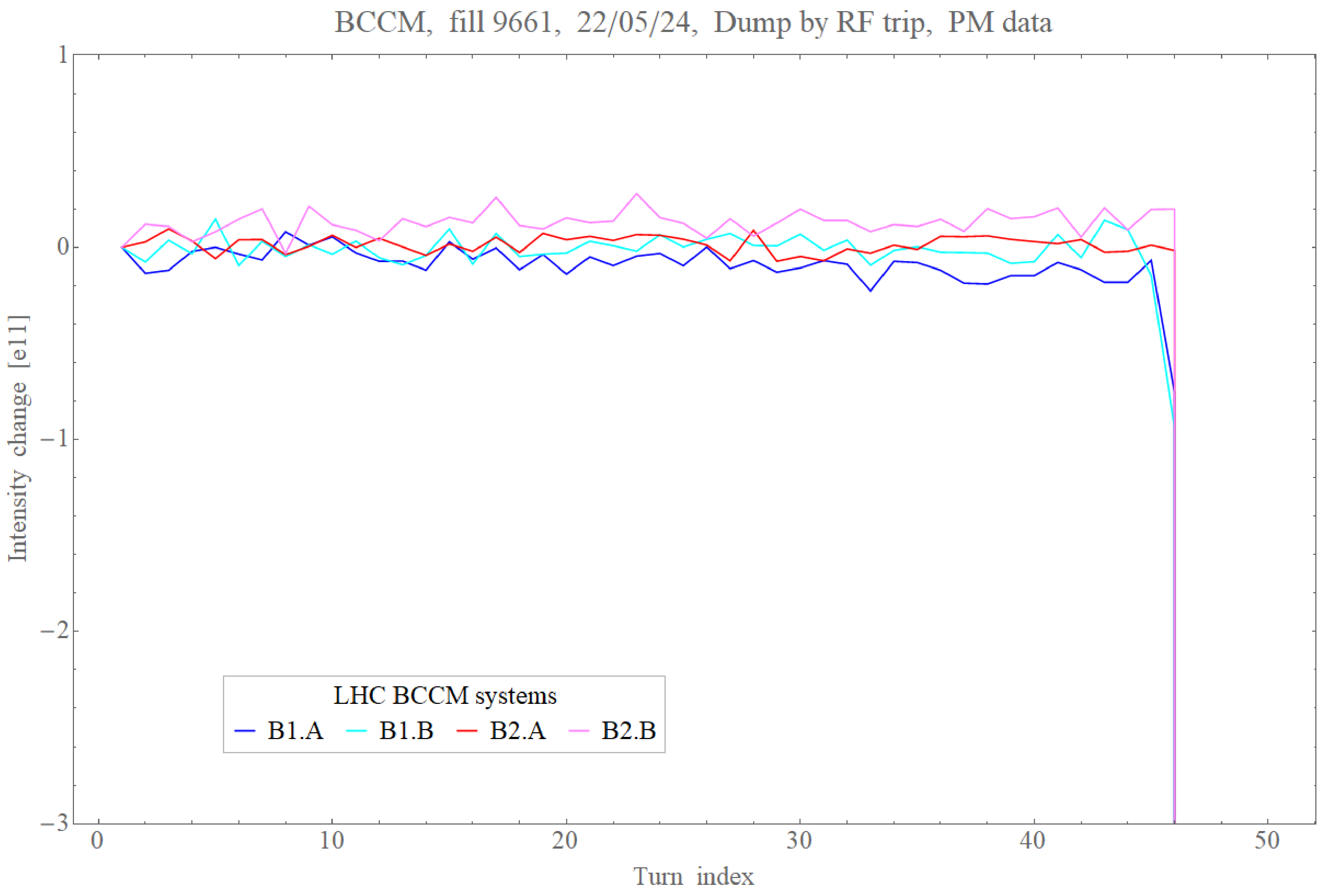
Dump #2: running sums for system B2.A (TbT logging)



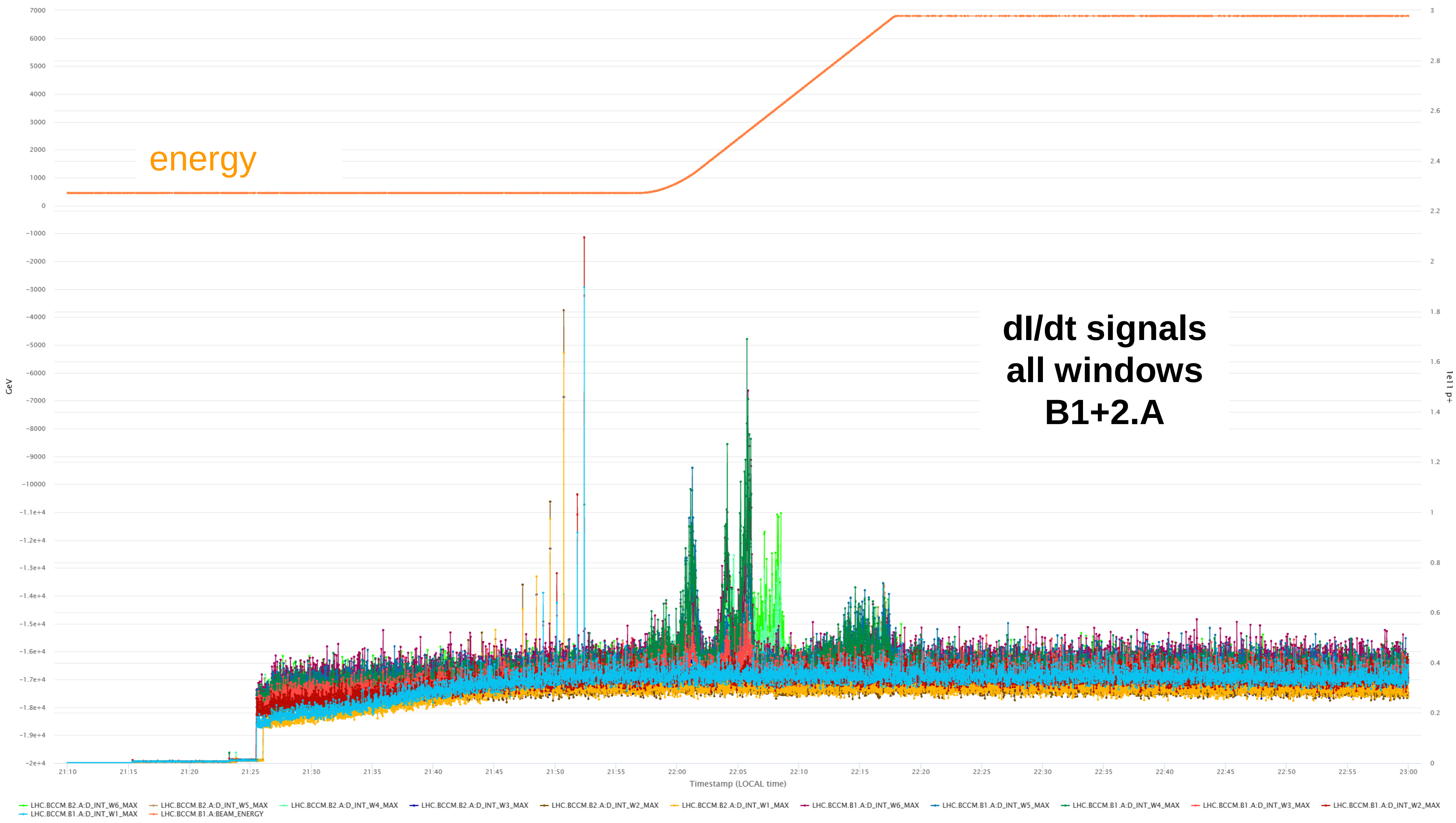
Dump #2: B2.A W5 running sum – zoom



RF trip on 22 May (fill #9661)

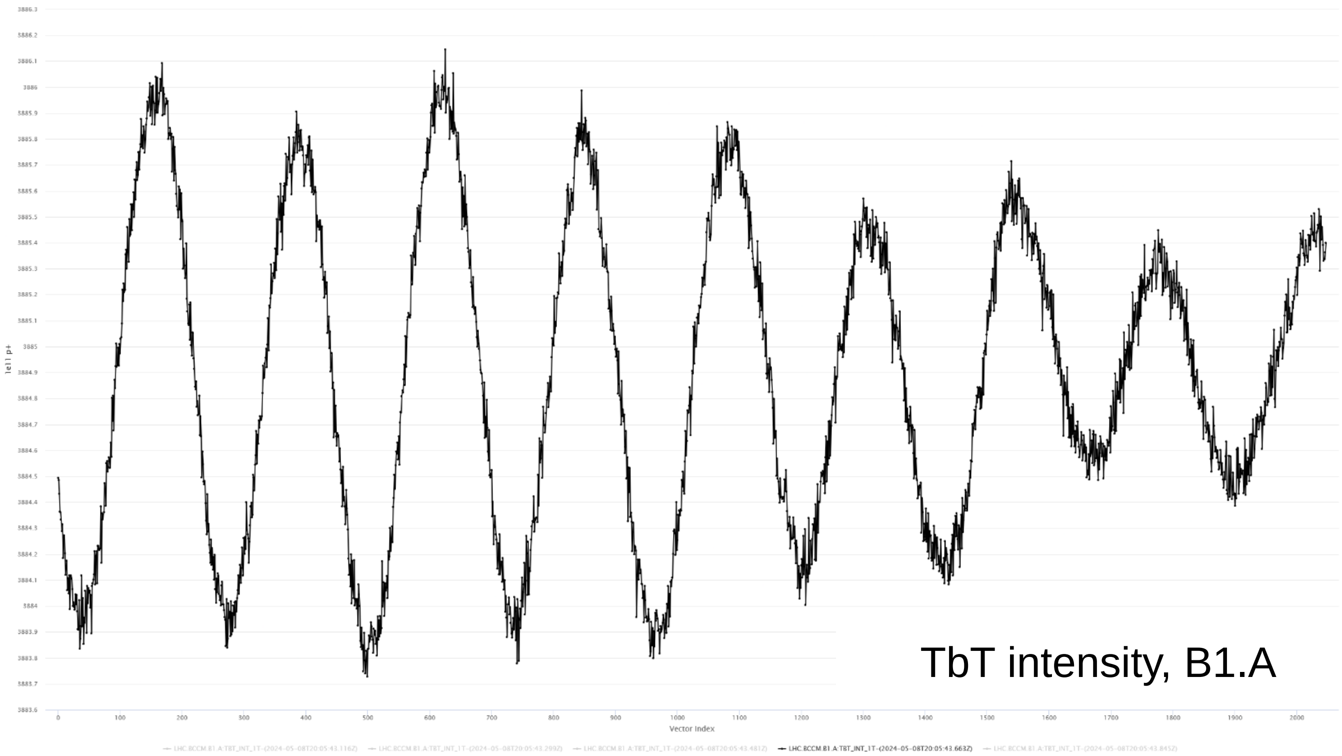


Weakness #1: sensitivity to the bunch length (oscillations)



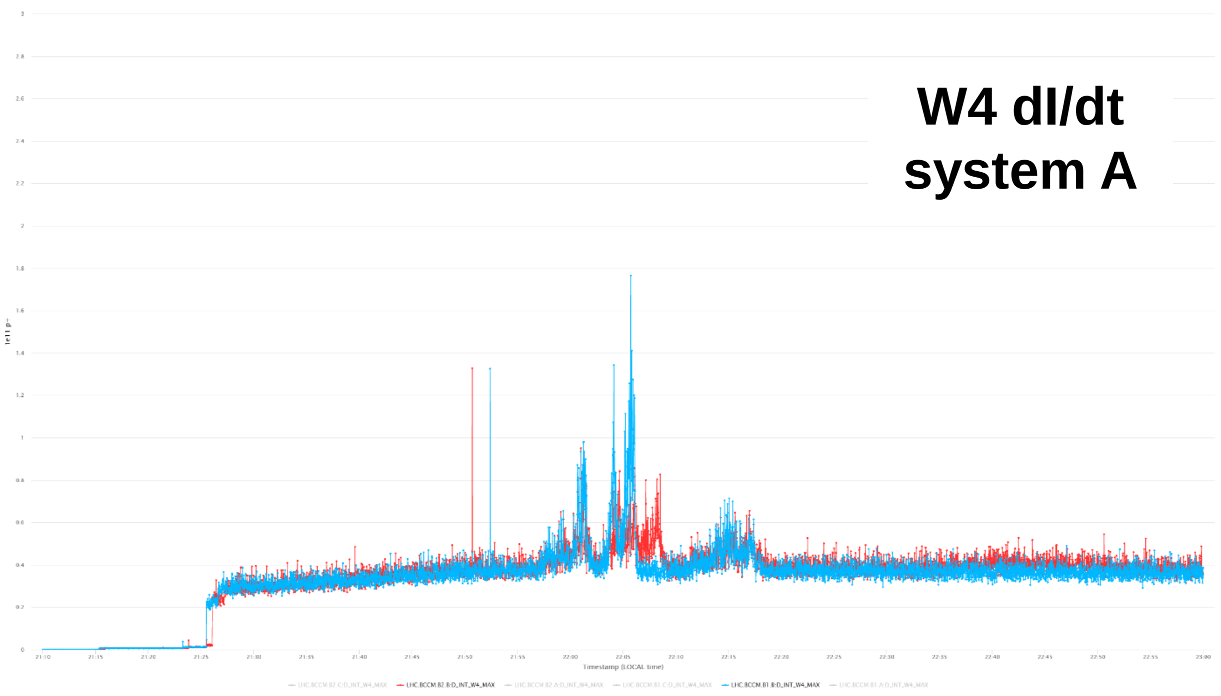
Weakness #1: sensitivity to the bunch length (oscillations)

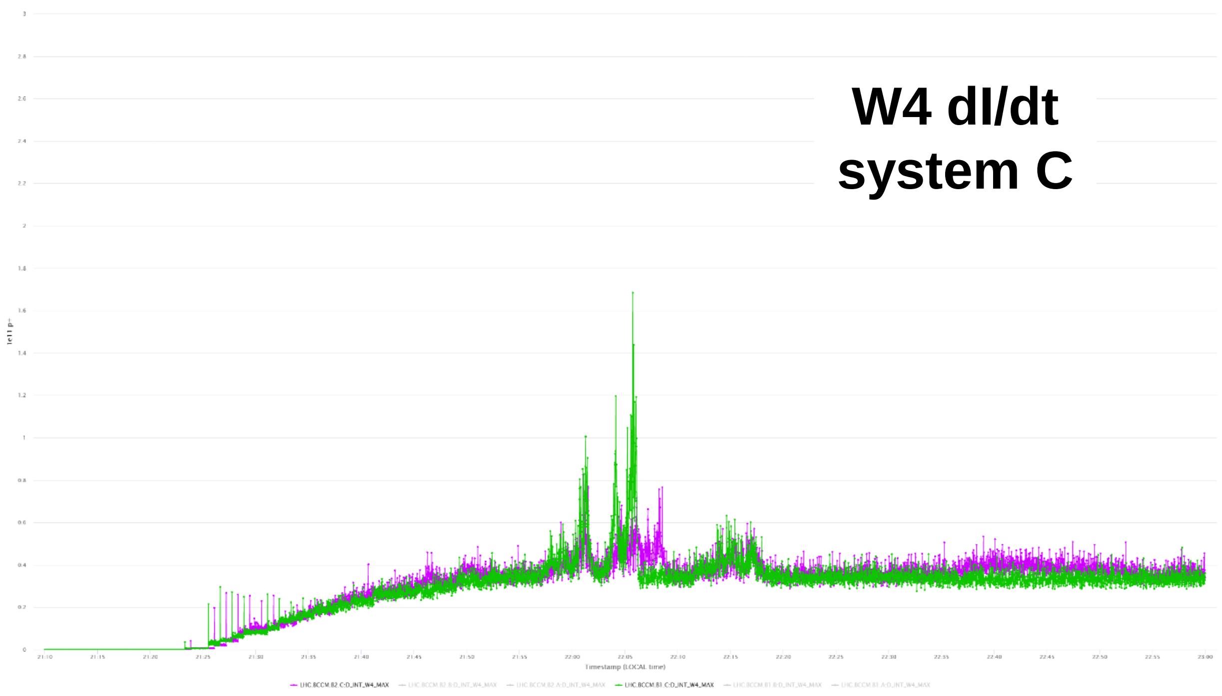
- Largest (TbT) intensity oscillations are during the RF longitudinal blowup
- Oscillations ≈ 2.5 e11 peak-peak on intensity ≈ 3900 e11, i.e. ≈ 0.06 %, which is a very small imperfection for analogue signal processing



- Beam signals are taken from BPMs, which are first order high-pass systems
- The current performance has been achieved with flattening the system frequency characteristic in the range ≈ 20 – 80 MHz, which was done at the expense of sacrificing ≈ 75 % of the beam signal
- FBCT signals were also used for tests, but with much worse results, despite the flat bandwidth ≈ 1 kHz – 80 MHz
- After LS3 BCCM is planned to have dedicated BPMs, resulting in larger beam signals, which may allow extending the system bandwidth with flat frequency response. The wider flat response MAY reduce the bunch length sensitivity.

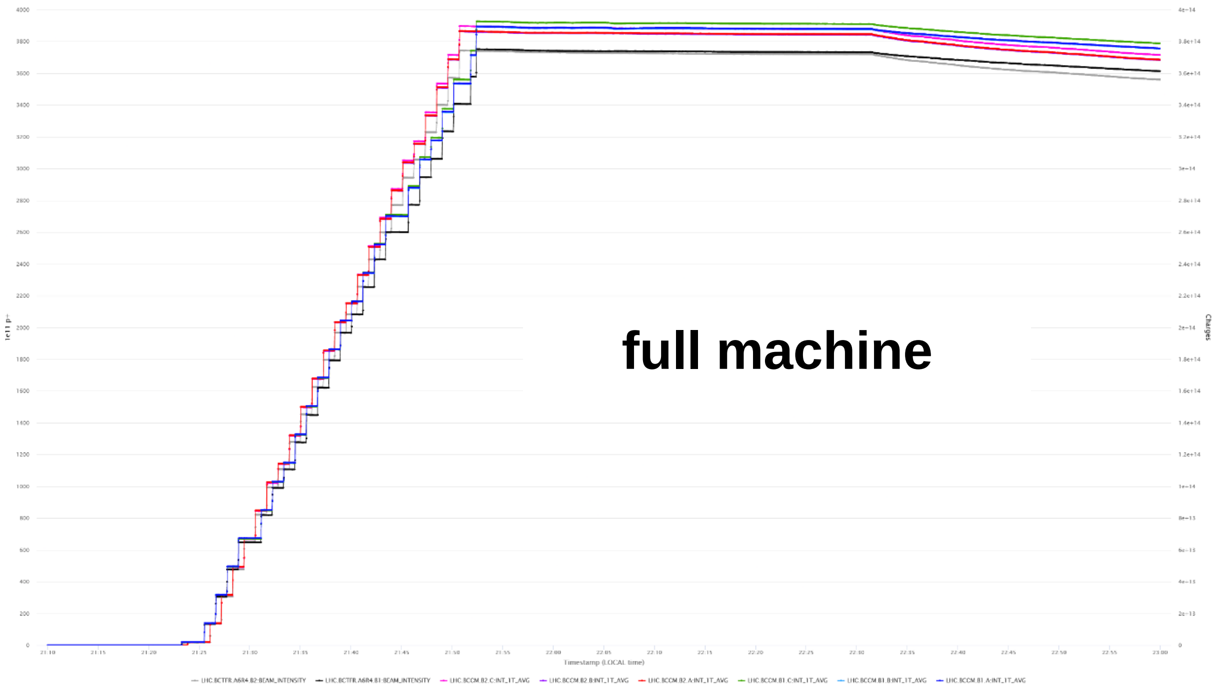
Weakness #2: spurious dI/dt signals during injections

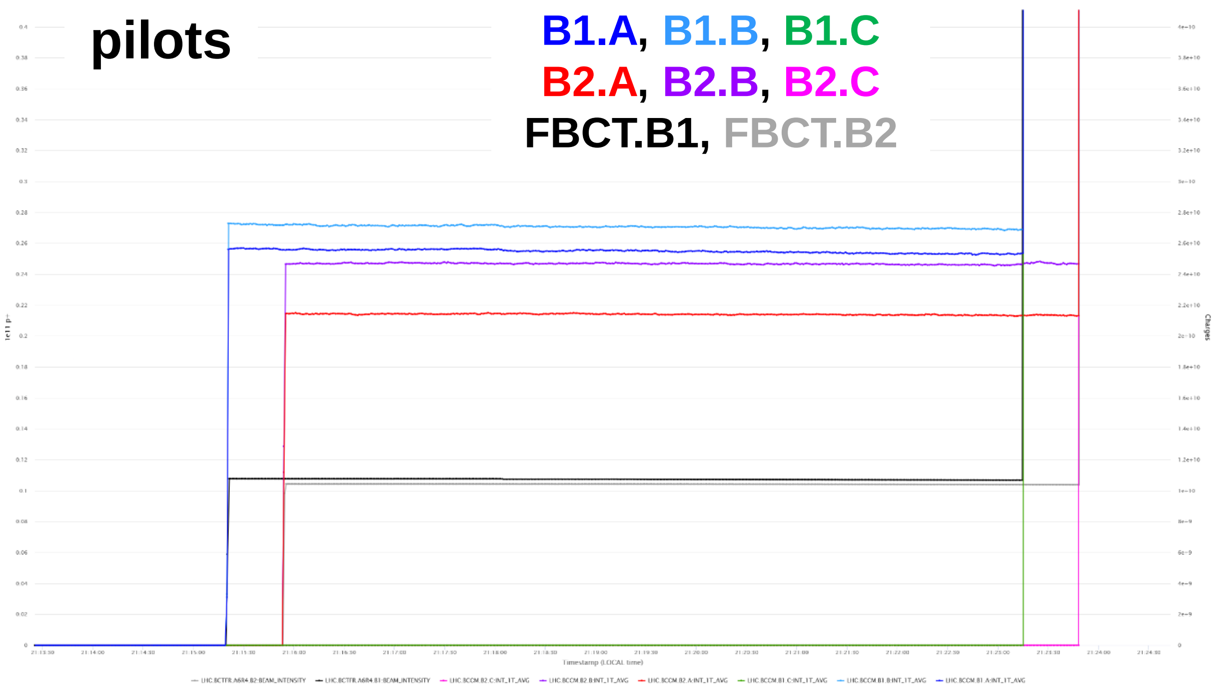




- Related to baseline shifts caused by the signal duty cycle increasing during the filling of the machine
- Special settings on R&D system C allowed almost complete reduction of the spurious signals,
  at the expense of very unfavourable settings for small intensities (pilots not seen at all)
- Ongoing FPGA code development to allow more flexible settings, which should be optimal for all intensities
- Hope to deploy the new code on system C during TS1 and test it during the rest of the run.
  Then we report the results to decide whether the new code should be used operationally during the 2025 run.

Weakness #3: Intensity overestimation for larger bunch spacing





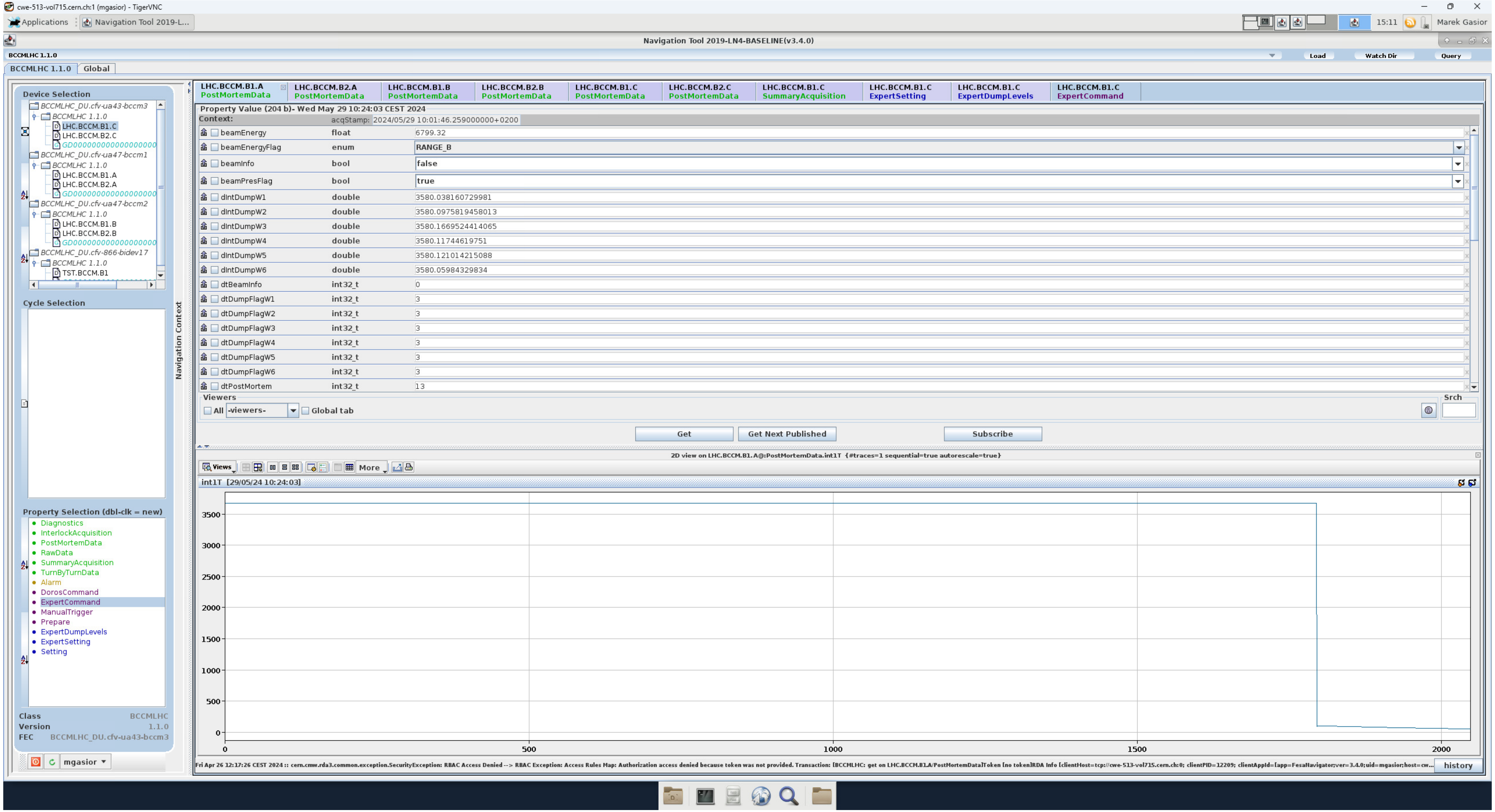
- Related to “unconventional” usage of a key RF component (an envelope detector chip), which, however, cannot be replaced by anything else without deteriorating the system performance
- Ongoing long-term hardware development to use the critical component in a different way, involving much faster sampling (completely new 16-bit acquisition with 200 MHz sampling, different filtering and amplification)

Conclusions and outlook

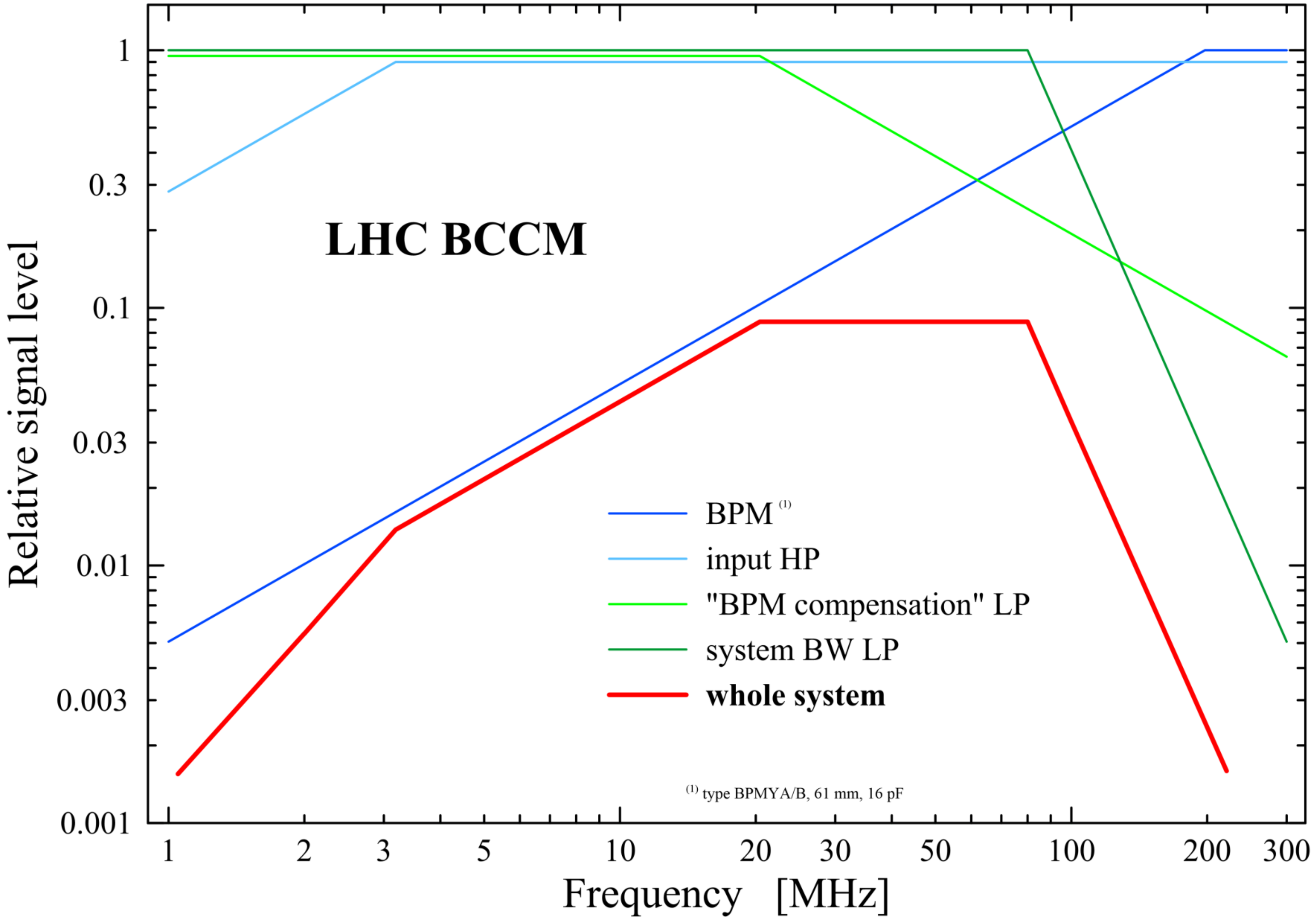
- BCCM is operational and reliable
- Two dumps triggered so far, both related to beam debunching after an RF trip.
  In both cases the system acted as ~~expected~~ designed.
- During physics fills the 64-turn window (W4) is typically the closest to the dump trigger level,
  with the highest values of ≈ 60 % during the RF longitudinal blowup
- System has not undergone a thorough testing with beam.
  Dedicated beam time is needed.
- PM automatic analysis module is being discussed
- Weaknesses of the system:
  - Spurious dI/dt during injections:
    being addressed in the FPGA code, deployment potentially for the startup 2025
  - Intensity overestimation for larger bunch spacing:
    ongoing development to increase the sampling rate to 200 MHz, to be able to relax filtering on the envelope detector block; some hope to test with beam on system C before LS3
  - Sensitivity to the bunch length oscillations:
    potentially addressed after LS3, with larger signals from dedicated new BCCM BPMs

Spare slides

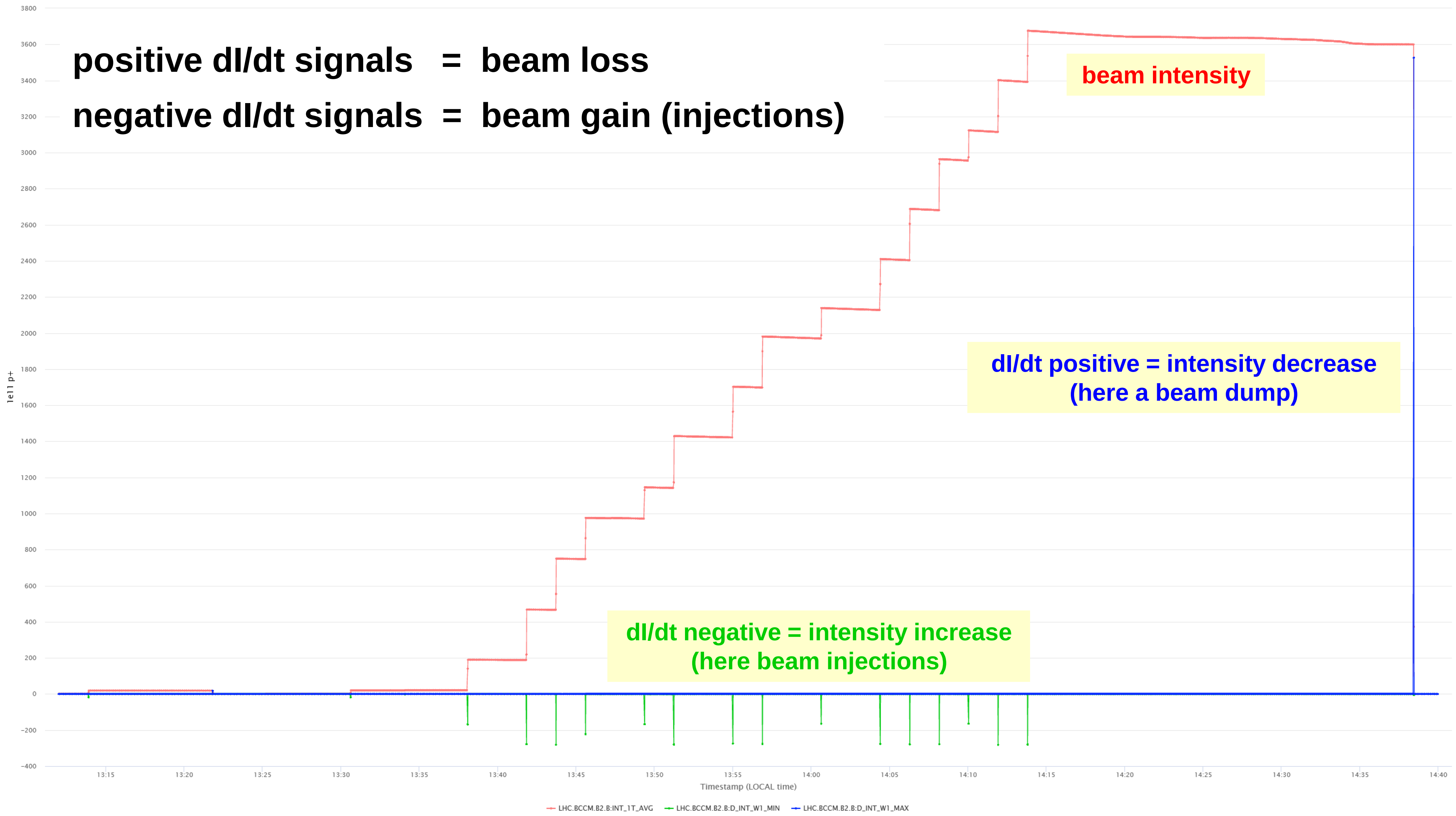
BCCM FESA post-mortem



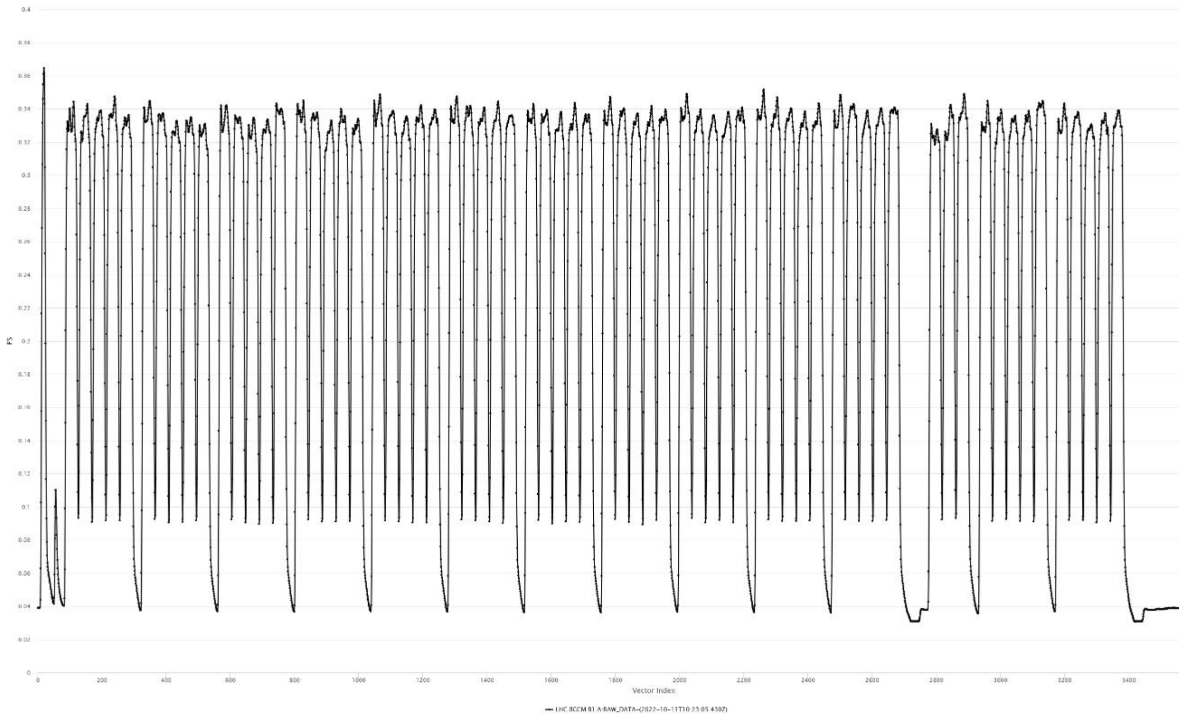
BCCM bandwidth



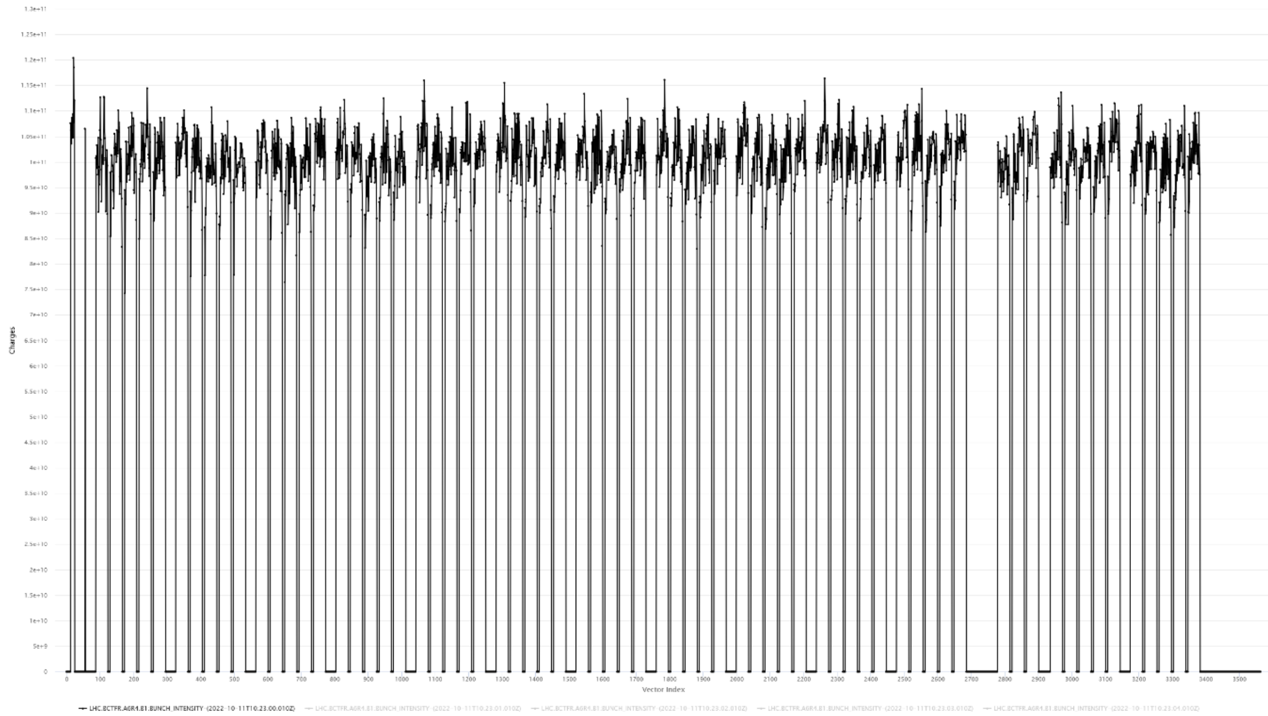
BCCM (– dI/dt) polarity convention



25 ns data: BCCM vs FBCT



one turn of BCCM data with full machine



one turn of FBCT data with full machine

Dump threshold levels

Window [turn]	1	4	16	64	225	1125
< 0.5	6	6	6	6	6	10
≥ 0.5	3	3	3	3	5	10
Energy [TeV]	Losses [1e11]					

Window [turn]	1	4	16	64	225	1125
< 0.5	1	1	1	1	1	1.7
≥ 0.5	0.5	0.5	0.5	0.5	0.8	1.7
Energy [TeV]	Relative losses [‰] (FS = 6e14)					

BCCM (dI/dt) system

shared BPMs:

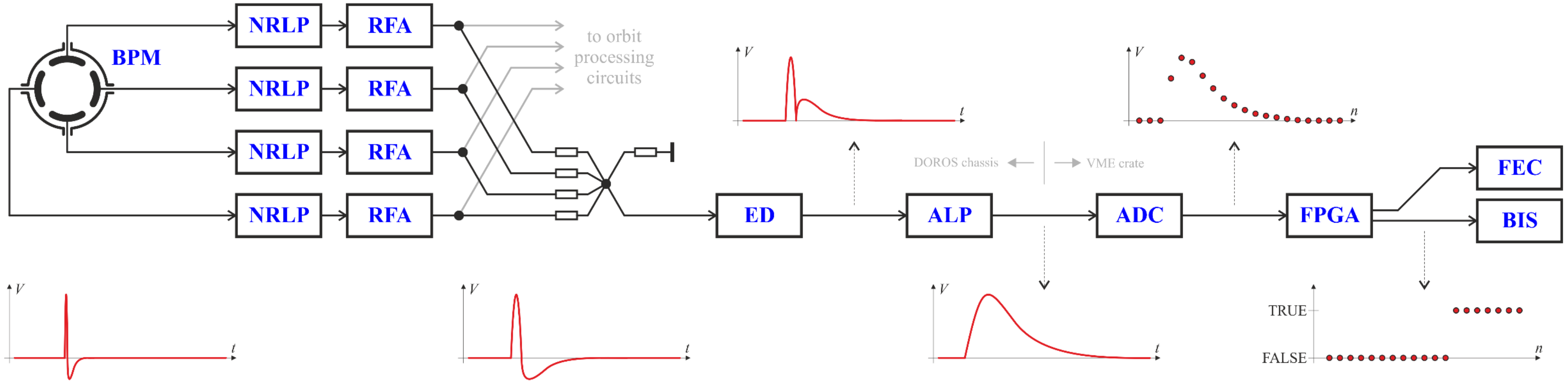
system A: BPMYA.5R4.B1+B2
system B: BPMYA.6R4.B1+B2

NRLP – Non-Reflective Low-Pass (≈ 80 MHz)

RFA – RF Amplifier

ED – Envelope Detector

ALP – Active Low-Pass (≈ 2 MHz)



- The system is based on BPM signals shared with the LHC beam position measurement system (passive RF splitters)
- The beam position dependence is removed by summing the four electrode signals
- Analog operations on the signals: low-pass filtering, amplification, envelope detection + rectification + level shifting, low pass filtering
- Digitization: 16-bit, 40 MHz sampling synchronous to the circulating beam (one revolution period is exactly 3564 ADC clocks).
  The 40 MHz ADC B1 and B2 clocks are derived from the 400 MHz RF frequencies received by optical fibers from the RF system.
- One turn "raw intensity" is a sum of ADC samples above a "beam presence threshold" minus "no beam offset", selected from one turn 3564 samples
- One turn "raw dI/dt signal" is a difference of the one turn raw integrals from two consecutive turns
- "Raw dI/dt signals" in the five other integration windows are calculated as running sums of the one-turn "raw dI/dt signals"
- Every turn each of the "raw dI/dt signals" are compared to its corresponding raw dump threshold level and potential beam dump triggers are generated.
  All real-time calculations are done in the FPGA in an integer arithmetic.
- The BCCM absolute intensities in elementary charges are calculated by scaling the "raw intensities" using a "BCCM/BCT scaling factor".
  The factor is a constant for each system and is obtained by matching the beam intensity evaluated by the BCCM to the corresponding BCT readings.
- The absolute dump thresholds in elementary charges are translated into "raw dump thresholds" using the same "BCCM/BCT scaling factor".