Optical charge measurements at PETRA III

Development of a online bucket resolved charge measurement based on synchrotron radiation

DEELS 2024

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HELMHOLTZ

DESY.

Agenda

01 PETRA III and partly PETRA IV basics

02 Task and Motivation

03 System description

- Description of optical setup
- Description of readout system
  - Closer look: Custom Firmware
  - Closer look: Servers

04 System performance

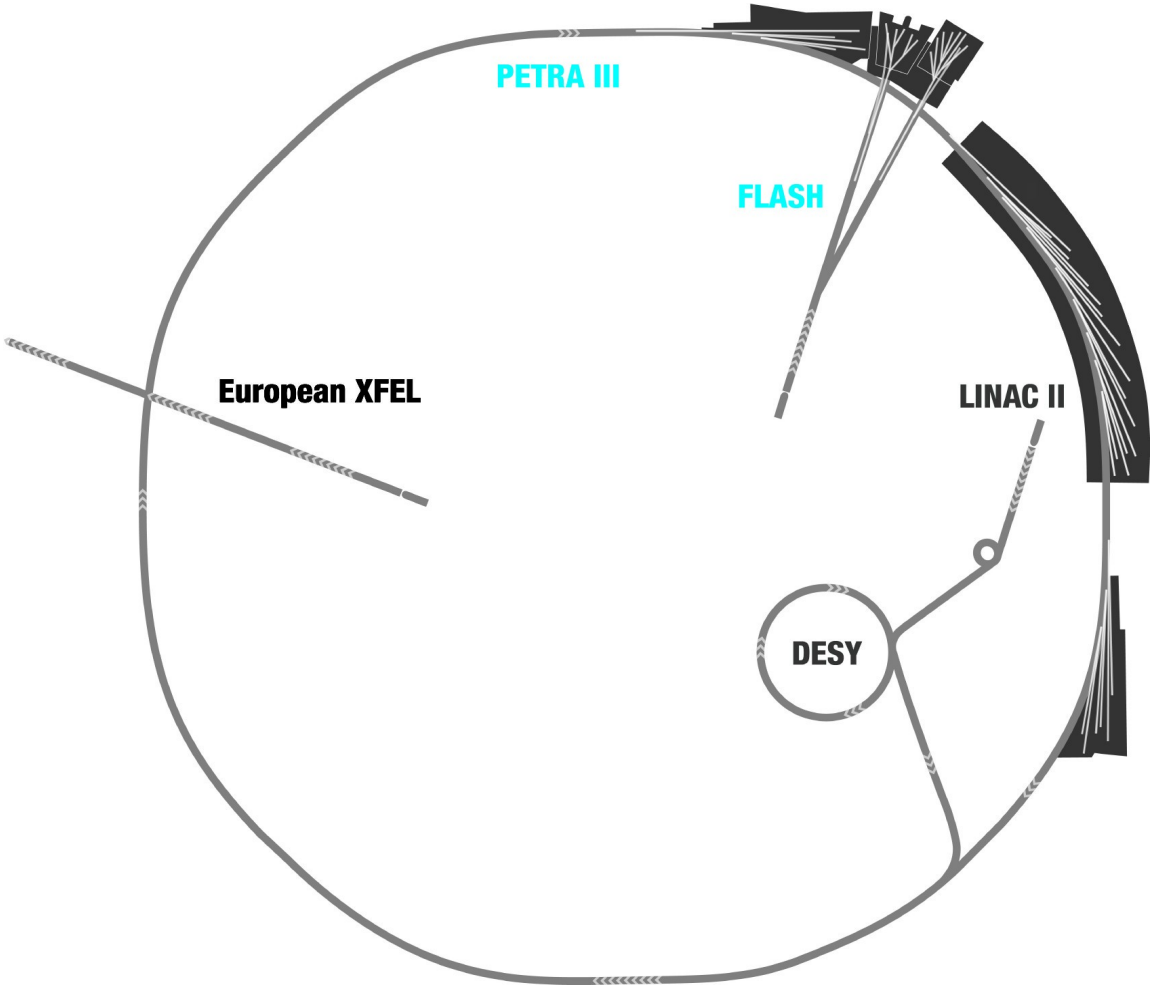
- Short term measurements
- Baseline deviations
- Long term drifts of intensity

05 Results and outlook

Overview PETRA III and mostly PETRA IV

Main parameters for this talk

- Circumference: 2304 m
- Energy: 6 GeV
- Current: 100 mA / 120 mA
- No. Bunches in user operation: 40/480
- RF frequency: ~500MHz
- Num of buckets: 3840
- Bunch spacing: ~2ns
- Revolution frequency: ~130.1 kHz



Task and Motivation

1. Find and validate second source of charge per bunch information

- Actual FCTs show excessive heating even in PETRA III operation
- Development of second source to have a fallback solution
- Shrink width of monitor pulse down to about 1ns → bucket resolved measurement#

- => Idea: Use synchrotron radiation

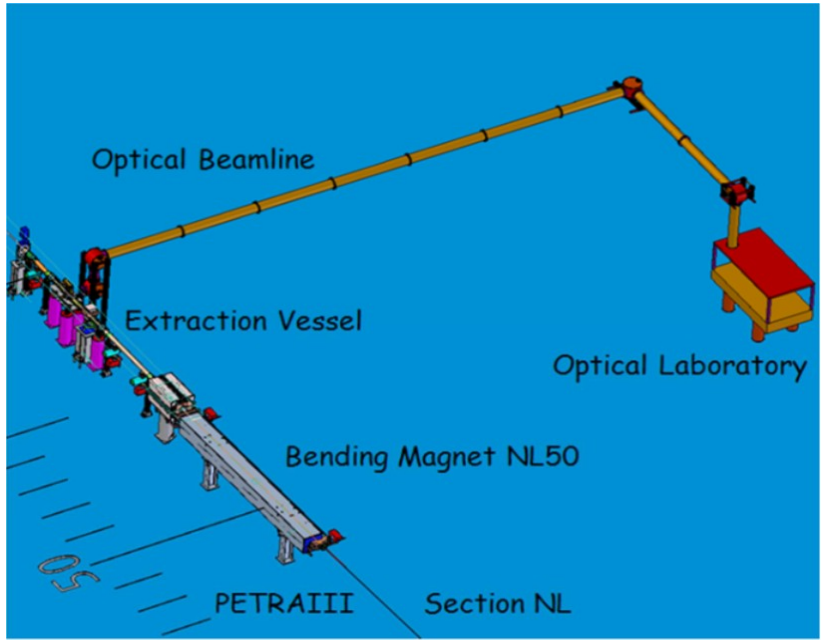
2. Update and Upgrade the bunch resolved measurement

- Actual system is capable to measure 8ns spacing (4 buckets)
- Upgrade to MTCA 4 hardware to replace PXI system in preparation of PETRA IV
- Side effect: develop system that gives bunch and turn resolved data with various signals (FCT, Detectors, BPMs,...)

System description

Optical setup – beam generation

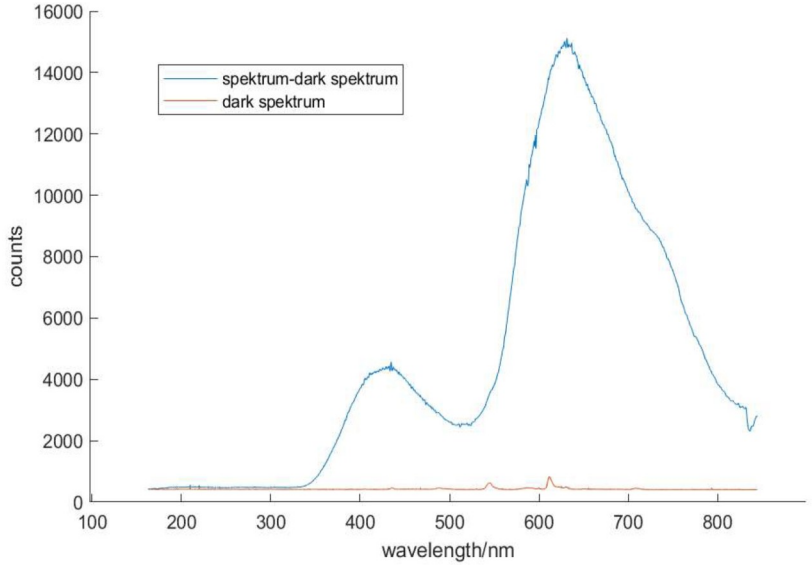
- Use optical beamline developed for streak camera measurements



- Synchrotron radiation hits cooled mirror/ absorber and visible and near infrared part is mirrored out

- Beam is transported with 5 mirrors and two relais lenses to optical hutch

- Spectrum of light with maximum at 650nm (red) but reaches from about 380nm (violett) till 850nm (near infread)

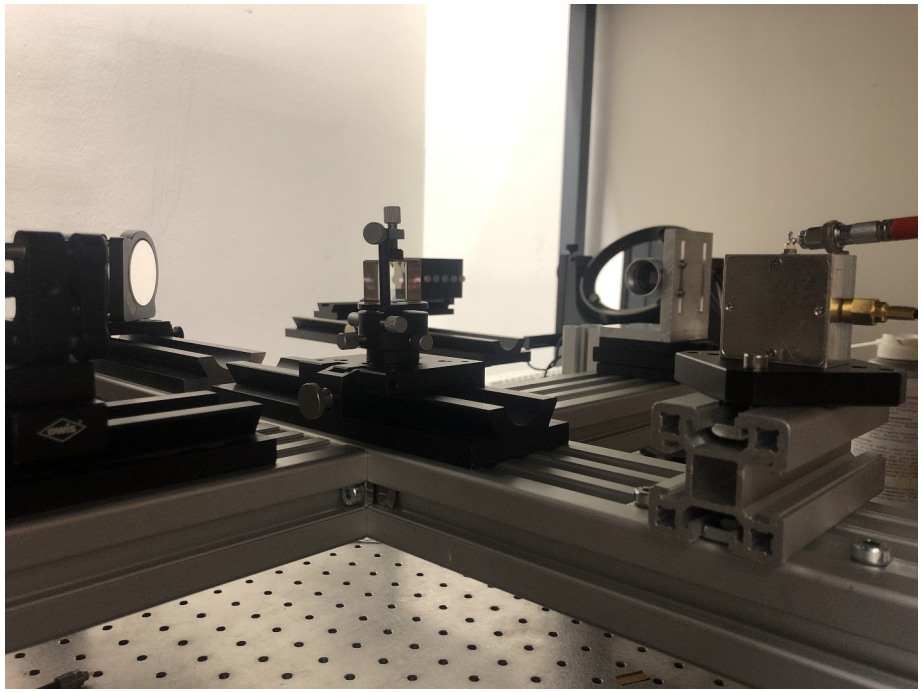


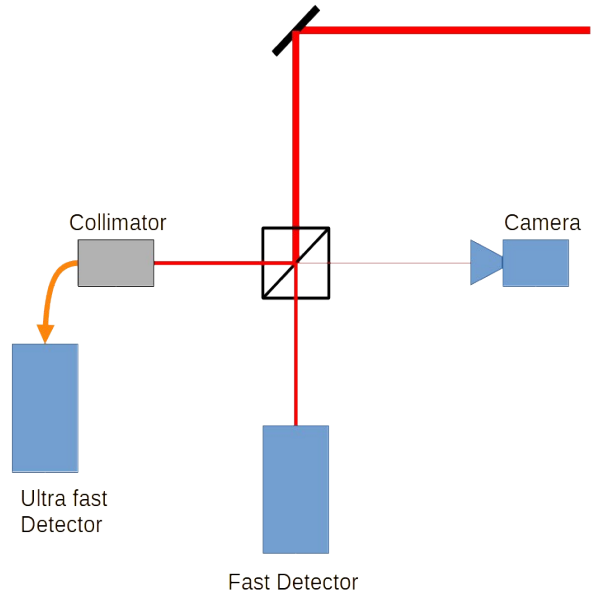
System description

Optical setup – scheme

- Beam is sent through an 50:50 beam splitter cube

- Direct beam is used for intensity eg. charge measurement





- Second port is used for further analysis like faster or slower measurements

- Third, normally not used port: used for beam observation with camera for stabilization

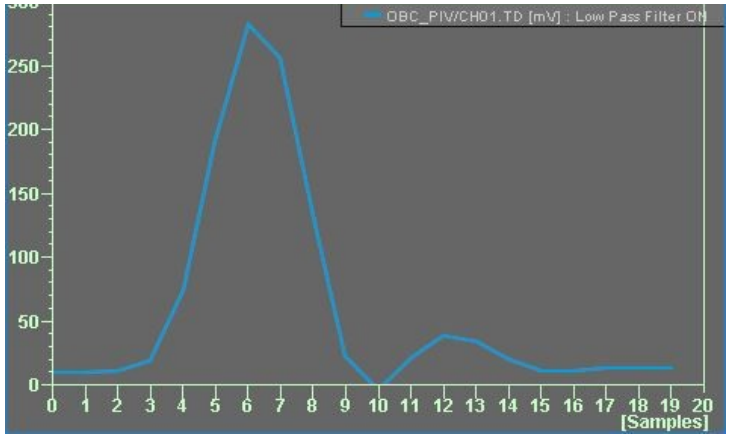
System description

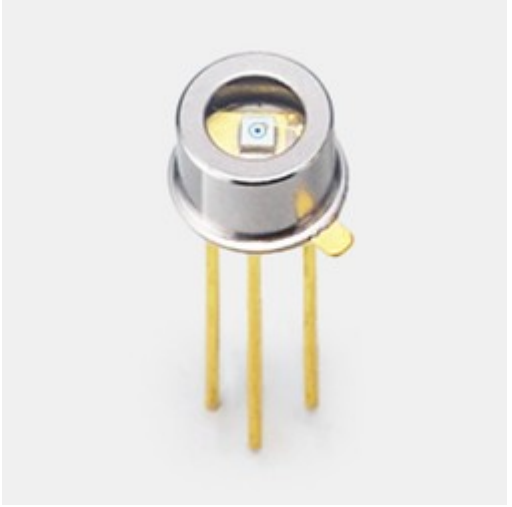
Optical setup – detector

- Different detectors tested:
  - Hamamatsu S5973 (bare diode, free space, 1GHz nom.)
  - Thorlabs FDS02 (fiber coupled with 400um MM fiber and collimator, tr = 47 ps / tf= 246 ps)
  - Thorlabs DET025AFC/M (biased detector, fiber coupled,tr/tf = 150ps, 2GHz nom.)
- Result: Easier setup and more stable signal with fiber coupled detector

https://www.thorlabs.com/images/TabImages/Fiber_Photodiode_A1-780.jpg

https://www.thorlabs.com/images/large/16630-lrg.jpg





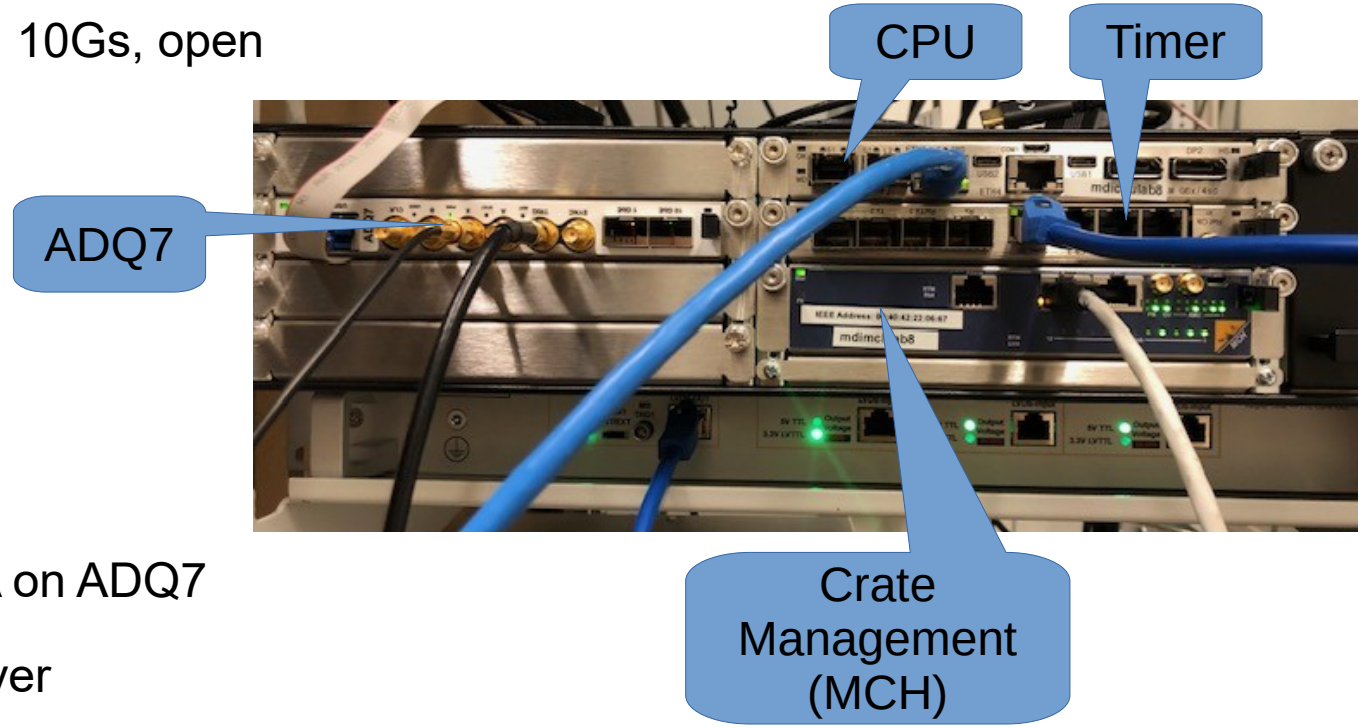
https://www.hamamatsu.com/content/dam/hamamatsu-photonics/sites/images/03_SSD/03_01_Product_photo/k_s5973_pp_xx.jpg.thumb.252.252.jpg

System description

Readout system overview

Hardware

- SPDevices ADQ7 in MTCA form factor (14 Bit, 10Gs, open FPGA)
- AM G64/471 CPU
- X2Timer for synchronisation



Signal path

- Raw signal is processed in user logic in FPGA on ADQ7
- Transfer to CPU over PCIe with Low level server
- DOOCS server for control system connection
- JDDD control panels for setup and operation

System description

Readout system - firmware

- RF is not exact 500MHz
- Number of buckets is 3840 with length of about 2ns
- 10GHz sampling frequency gives us 20 samples per bucket
- To be independent as possible only a turn trigger is used but no external clock reference from timing system

- Adapt to varying RF
- Estimate the pulse high per bucket and remove baseline
- Scale the result to µA or multiples for direct processing
- Enumerate buckets and align to global timing system
- Handle external events like beam loss or injection
- Goal: transfer 3840 scaled values per turn to CPU
- For reference: ~ 1GB/s plus overhead

System description

Readout system – servers

Low level server

- Written in C
- runs independent from control system server
- Uses ADQAPI for communication with ADQ7 over PCIe
- Uses shared memory as interface to DOOCS server, python scripts, …
- Takes data from ADQ7 and pushes it to RAM for further processing

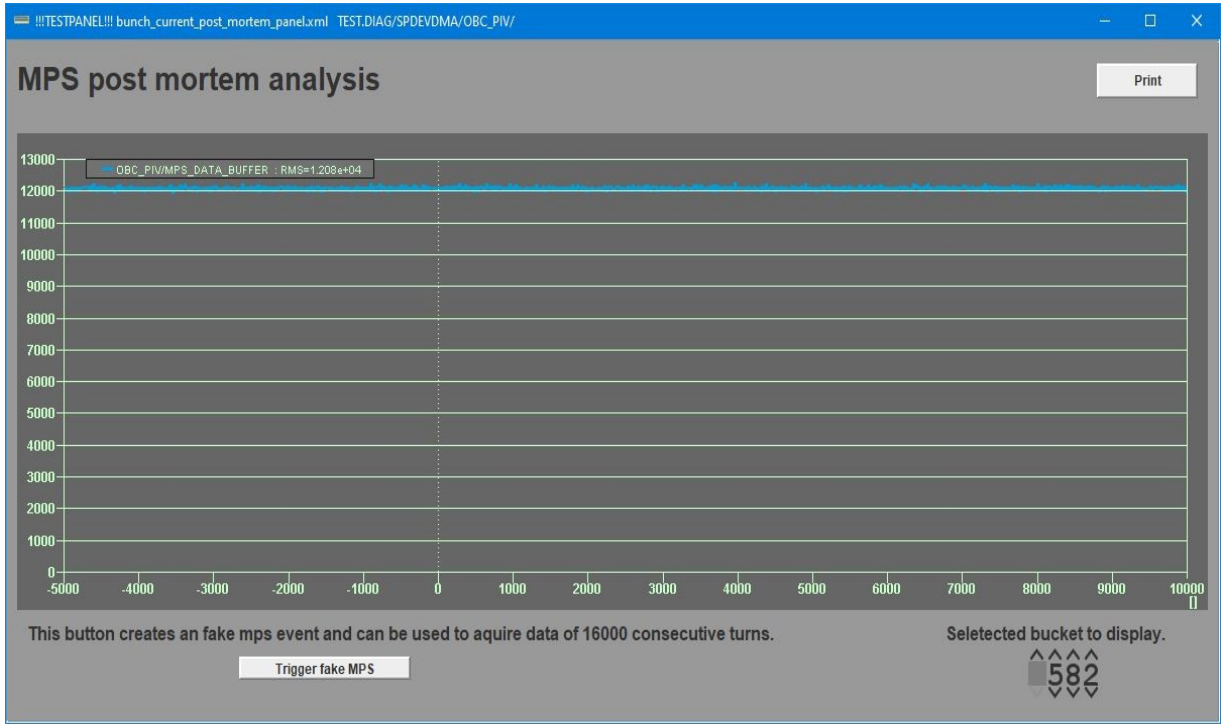
DOOCS server

- takes care of network communication and does higher level calculations
- controls the low level server
- Calculates the baseline and overall current
- detects filled and unfilled buckets
- calculates lowest and highest charge in filled buckets
- takes care of turn by turn data, writes to disk, shows selected data to user

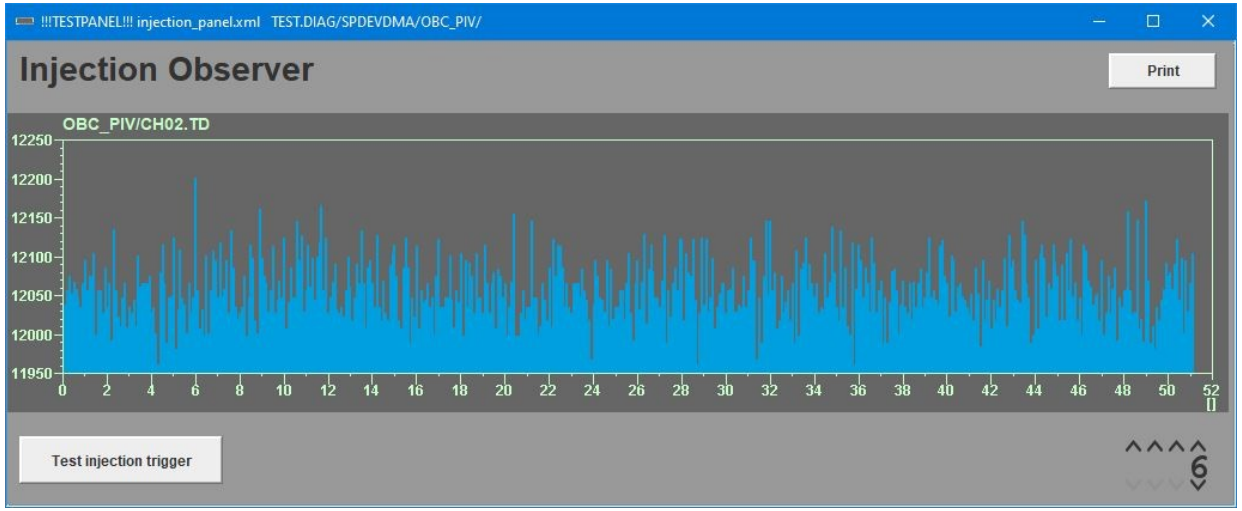
System description

Special diagnosis

- Special diagnosis: Takes 15.000 full turns on request or external trigger (Beam loss, kicker excitation, …)



- Special diagnosis: Takes data for one bucket with higher rep rate (Injection,…)

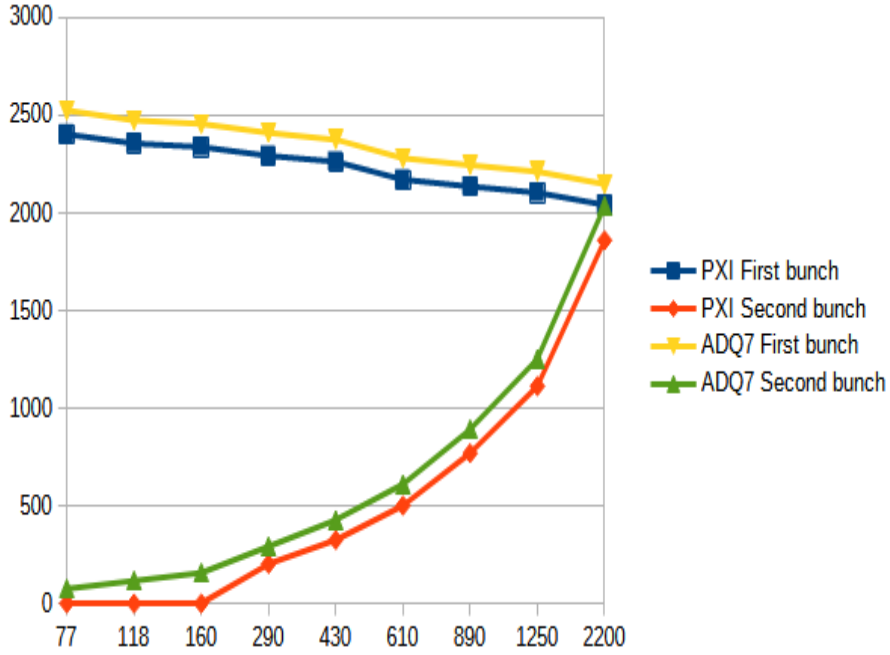


Performance

Results of 24/7 operation

Short term measurements

- Shows identical results like actual system – with better resolution
- One turn is not very valid, average over multiple turns is necessary
- Basic and special functions working well



Baseline deviations

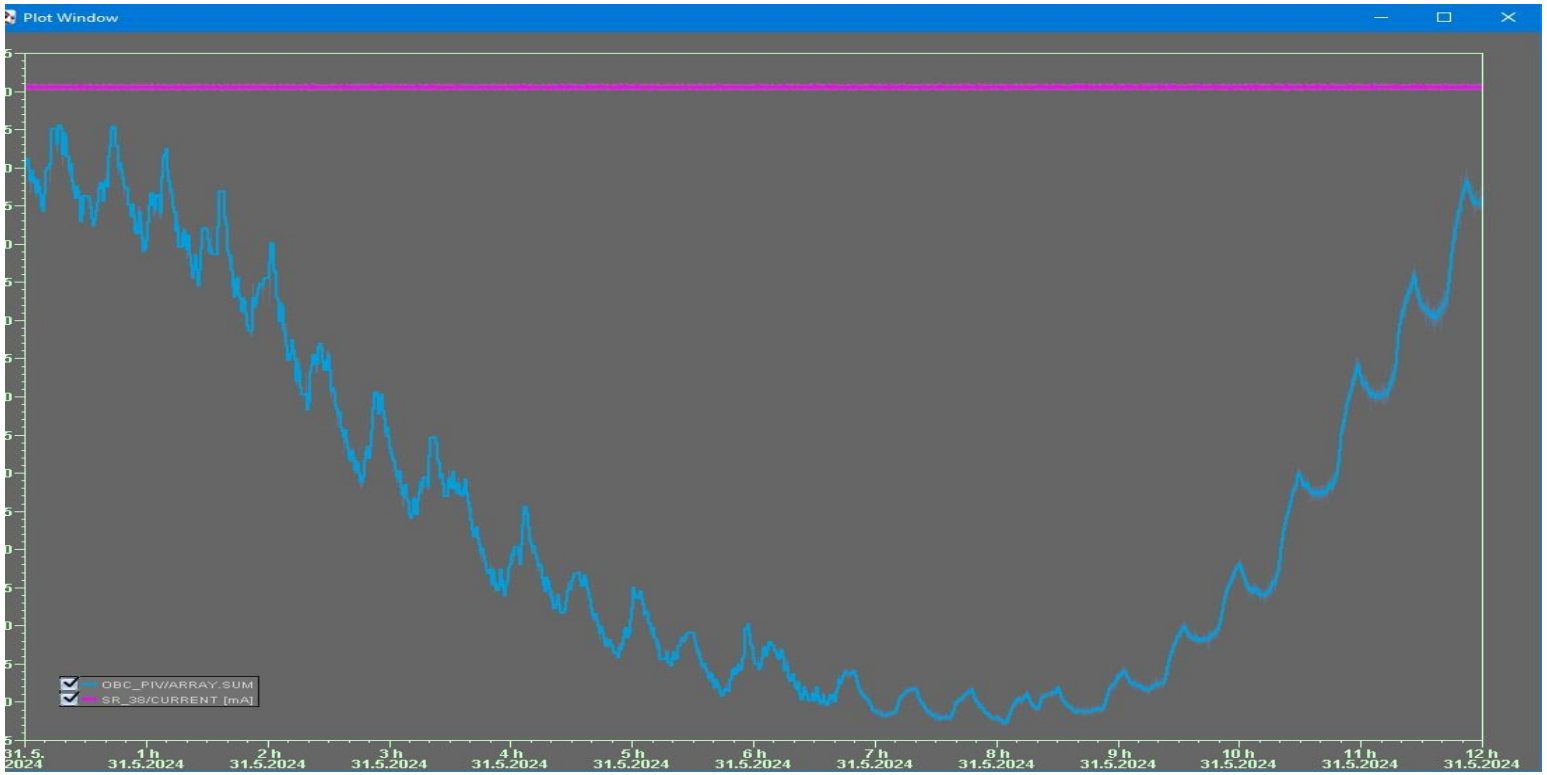
- Were not an issue with more than 8ns spacing
- Baseline removal in server is good for even filled machine
- As FCTs have an overshoot baseline is wrong for partly filled machine
- Solution: calculate baseline per bucket in firmware

Performance

Results of 24/7 operation

Long term drifts of intensity

- Caused by thermal movement of beamline
- Can be in range of milimeter at detector position (diameter about 250µm)
- Effect can be reduced by usage of collimator
- Okay for relative measurement scaled to DCCT but not for standalone system



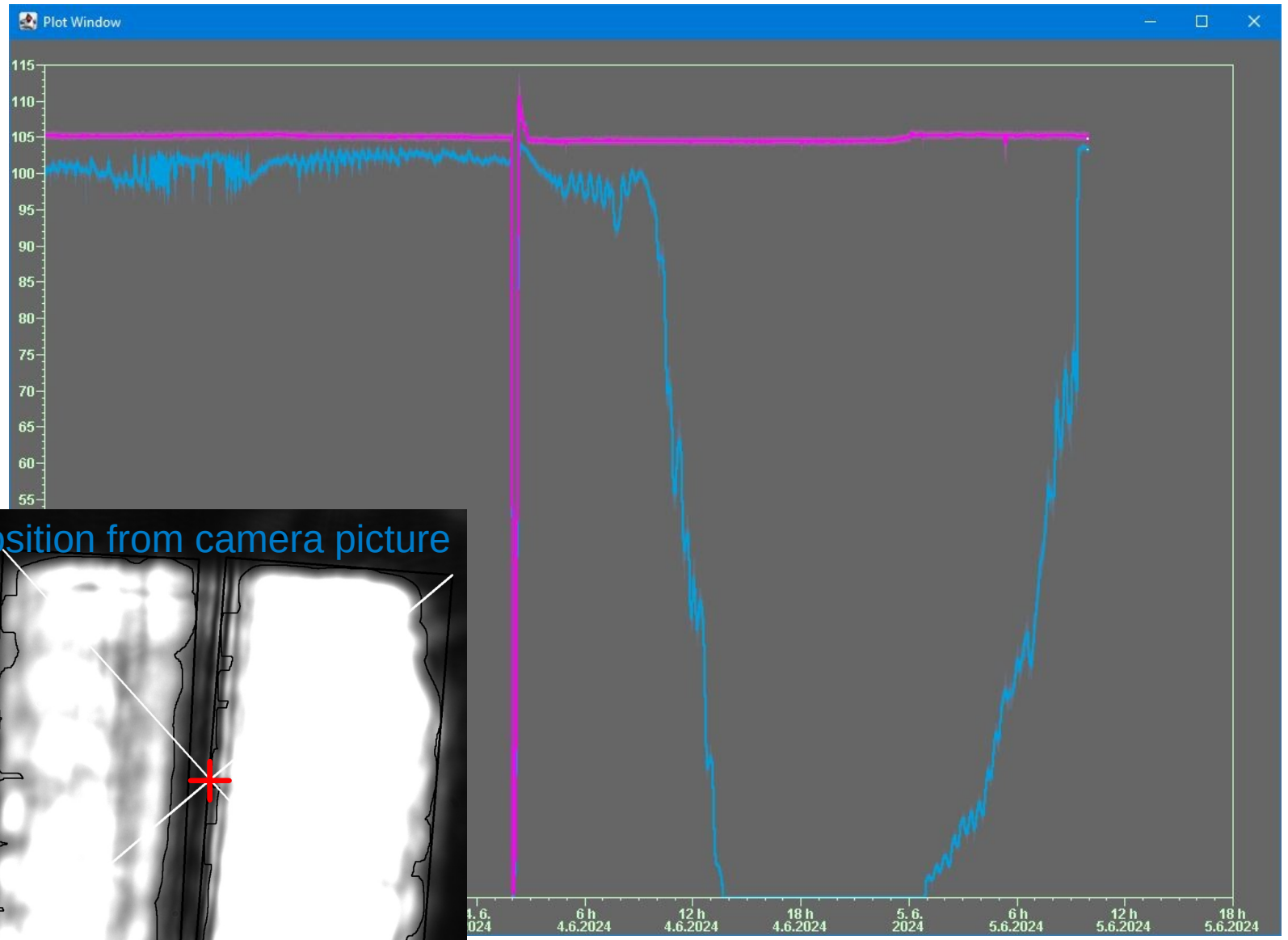
=> Solution: Active stabilization

- Use camera to observe position changes
- Use last mirror of beamline to stabilize the beam
- Movement can be reduced to ±15um
- Uses python script for image processing, feedback and DOOCS server for archiving and control

Beam Stabilization

Results

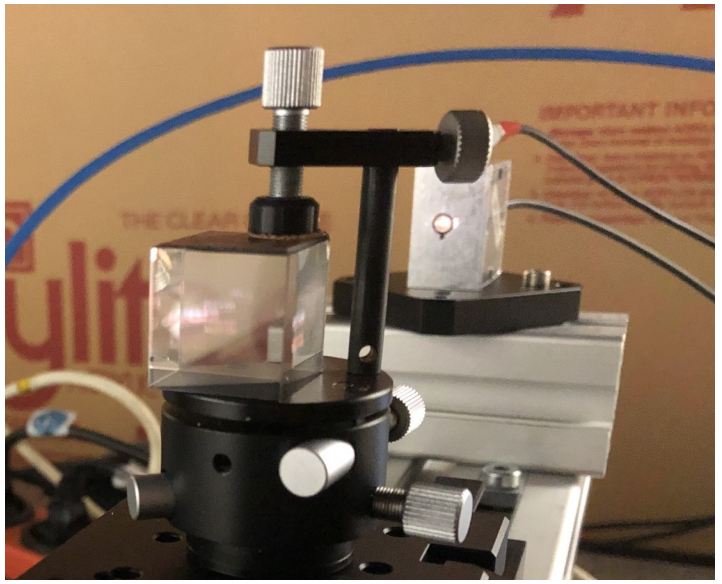
- Trace over about 2.5 days
- Left of vertical violet line: Stabilization is running
- Right side: stabilization is off
- Deviation in the range if 6%, can be reduced further with better alignment

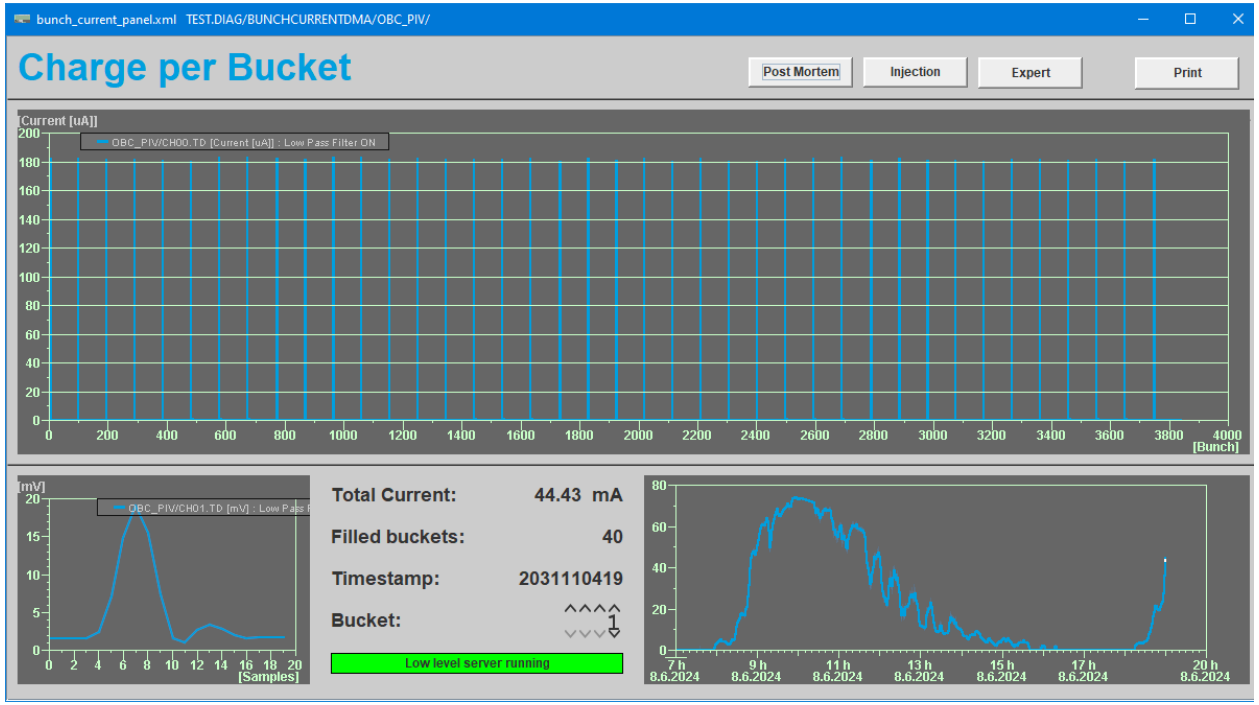


Results and outlook

Whats working, whats not

- Principle is working in general
- Readout system is nearly finished, some minor bugs have to be fixed and maybe implement some new functionalities
- Optical setup can be improved for sure → I would like to hear your recommendations and ideas
- Stabilization has to be improved to make it more fail save





Contact

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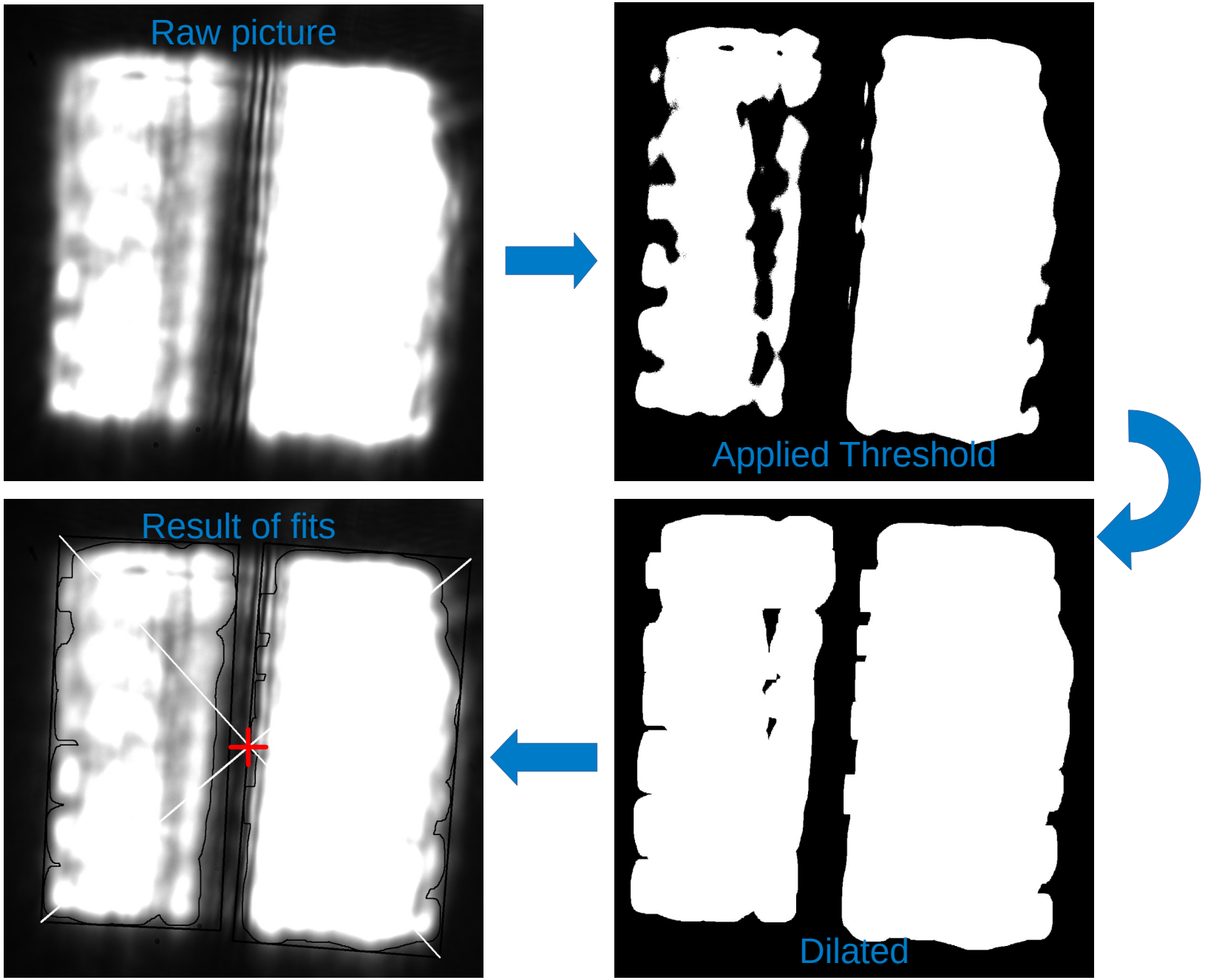
Beam Stabilization

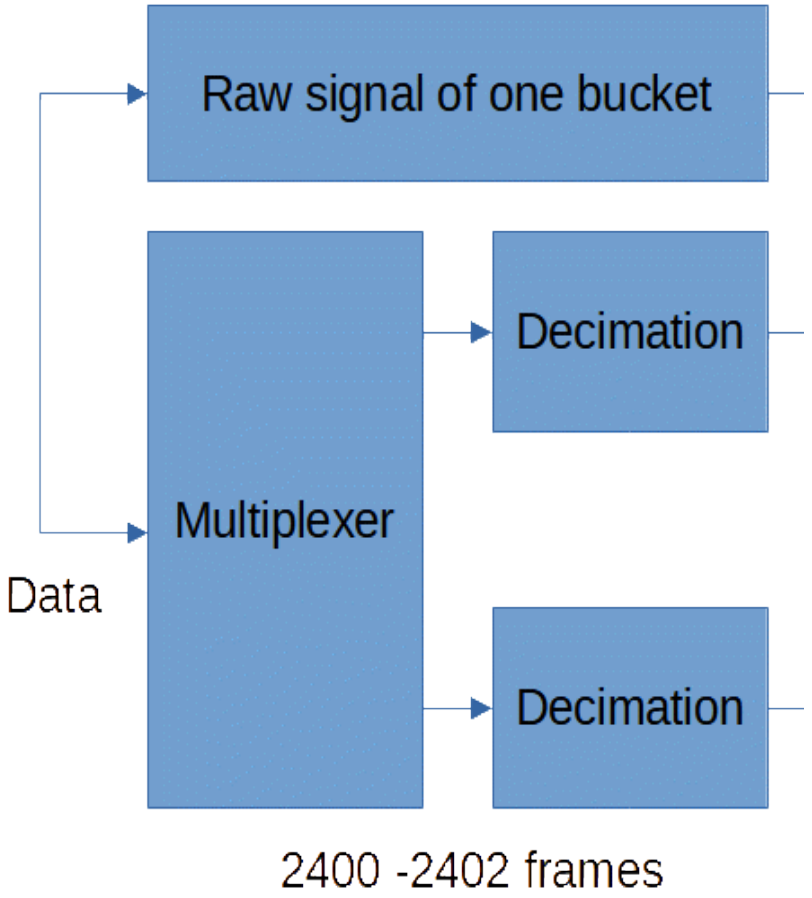
- Apply threshold
- Dilate 20 times to remove holes
- Find Contours (hopefully only two)
- Fit an minimum area rectangle to each contour
- Find two crossing lines from upper left to lower right and from upper right ro lower left corner of the structure
- Find crossing point of the two lines => position



System description

Readout system – user logic 1

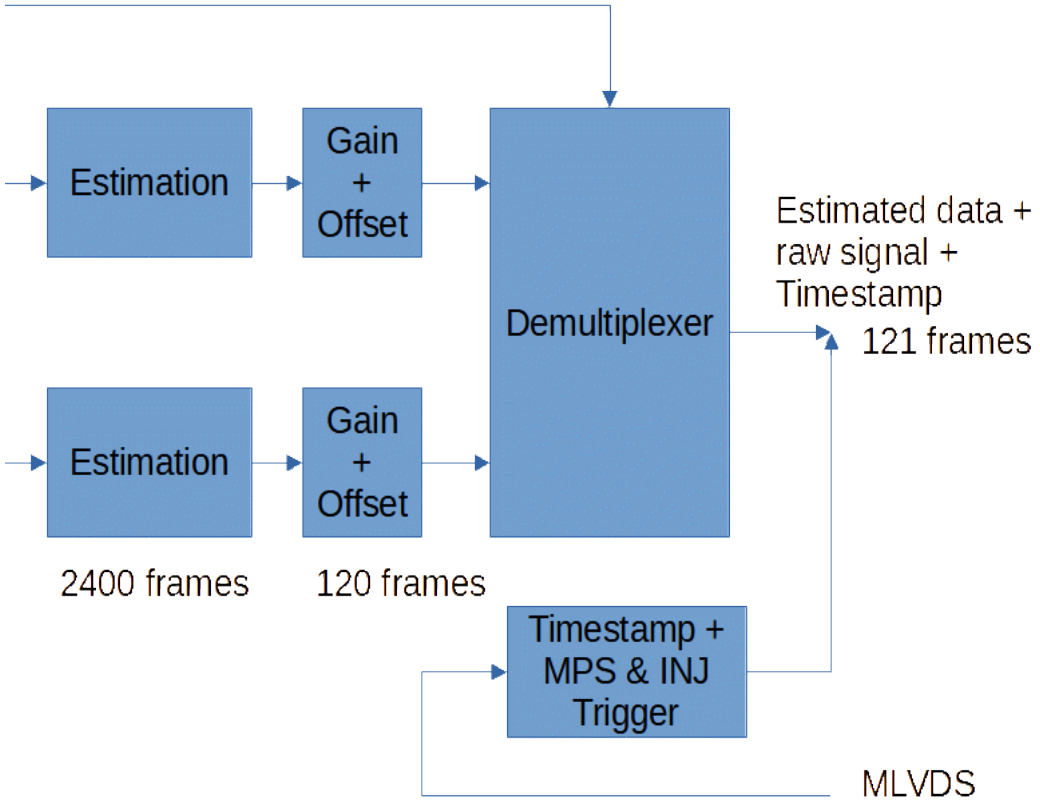
- Processing is triggered by master turn trigger from timing system
- Data comes in frames of 32 samples in parallel
- One turn is 2400 to 2402 frames long (difference in RF)
- Data of consecutive frames overlaps in first and last frame → two processing channels
- Decimation: remove up to 64 samples to reach exact 20 samples per bucket



System description

Readout system – user logic 1

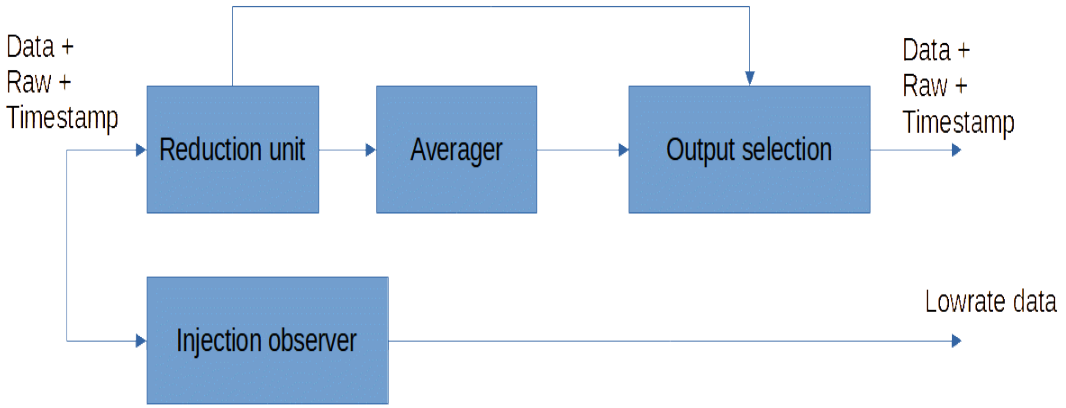
- Estimation: divide data stream in buckets, compute maximum or integral and baseline per bucket
- Gain +Offset: Scale to μA and remove baseline
- Timestamp: Global timing is tranfered over backplane → used to enumerate buckets and turns
- MPS and INJ Trigger: Used to acquire turn and bucket resolved data sets



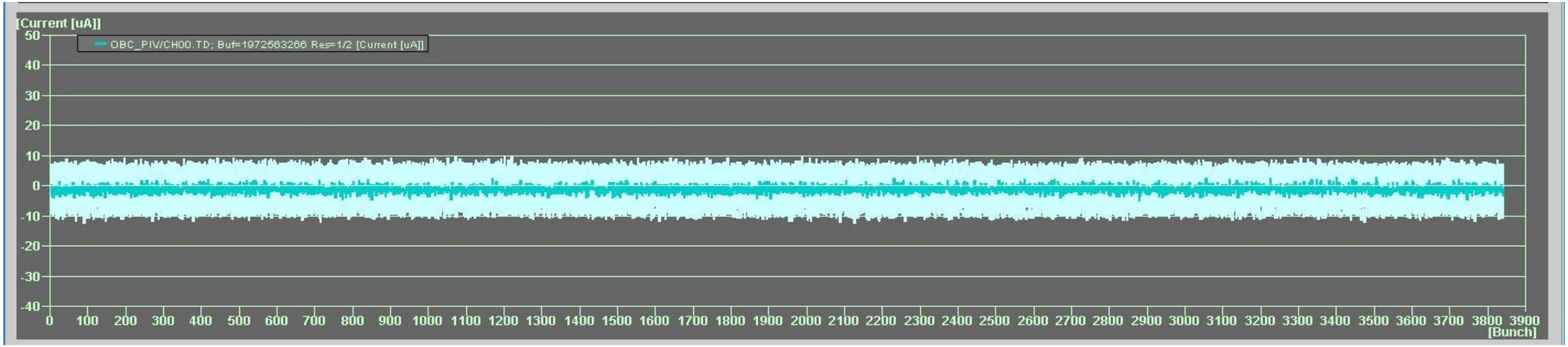
System description

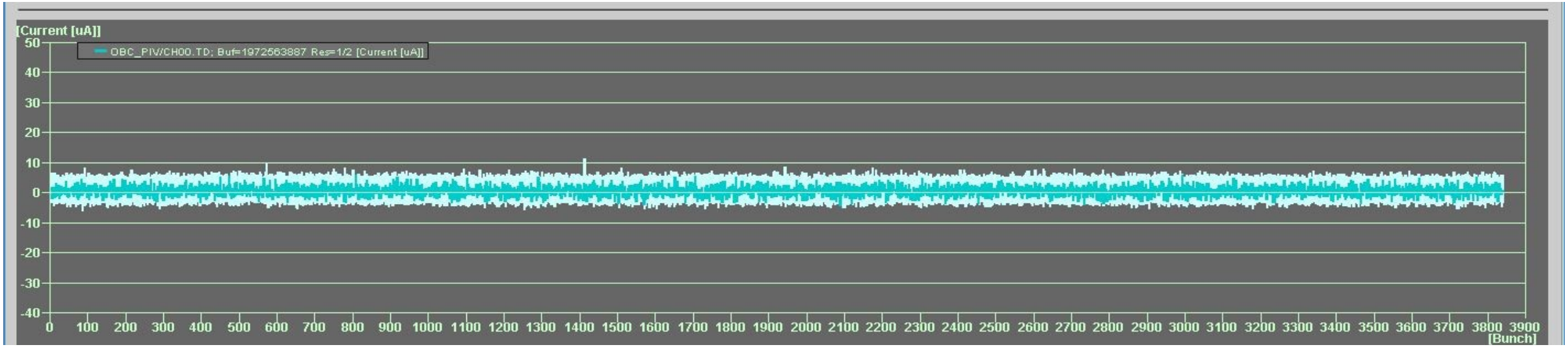
Readout system – user logic 2

- Reduction unit: skips turns to reduce transfer load to CPU
- Averager: moving average filter unit to get more stable results, changeable length
- Injection Observer: Collects to result of one bucket over 256 turns



Backing slides – dynamic baseline

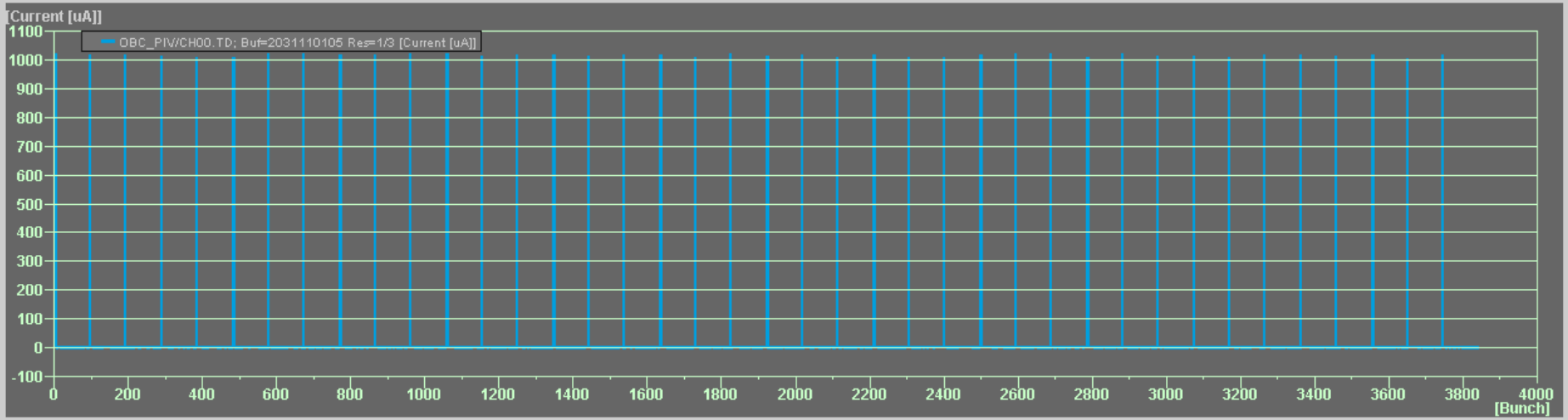




bunch_current_panel_expert.xml TEST.DIAG/BUNCHCURRENTDMA/OBC_PIV/

Charge per Bucket - EXPERT

BKR | Movement | Post Mort... | Injection | x2timer | Watchdog | Print



Tick only, if you know what you are doing! ☑ SETUP

User Logic | Transfer/Readout | Clock + Front | Trigger

Clock settings

Clock source: Internal

Clock impedance: 50 Ohm

Clock delay (ps): 0

External REF freq: 10.00

Frontend

Analog Offset: +600

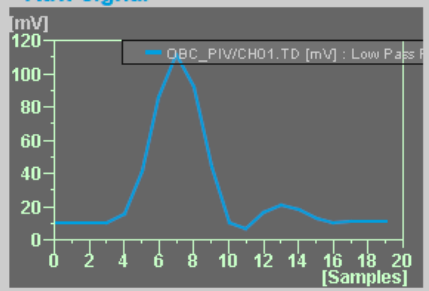
Digital Gain: +1124

Target Sample Rate: 10000.00

Firmware

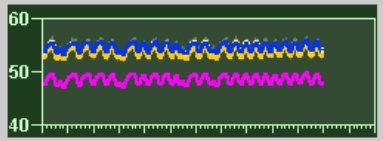
Data Rate_IN:	130121
Data_Rate_OUT	130121
Decimation:	3306
Frames_IN_a:	65060
Frames_OUT_a:	65061
Frames_IN_b:	65061
Frames_OUT_b:	65060
Timestamp:	2031110103
Sub-Timestamp:	1851
Timestamp MPS:	2009337240
Sub-Timestamp:	8535

Raw signal



Digitizer

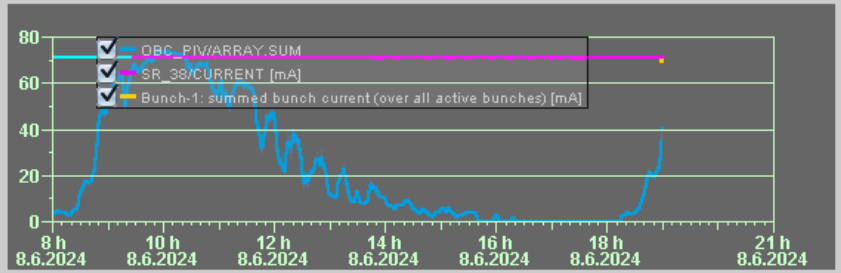
FPGA:	53.5 °C
PCB:	47.8 °C
ADC 0:	53.0 °C
ADC 1:	53.9 °C



Start | Stop

LL server running

Summed charge over time



Server

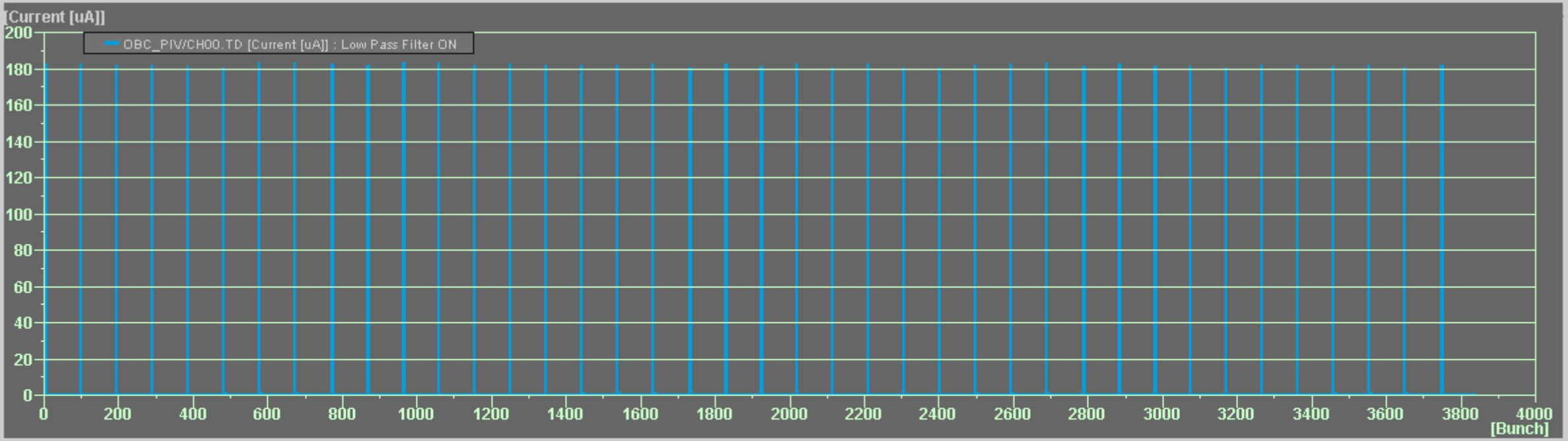
Total Current:	40.41 mA
Maximum:	1021 µA
in bucket:	960
Minimum:	1004 µA
in bucket:	1728

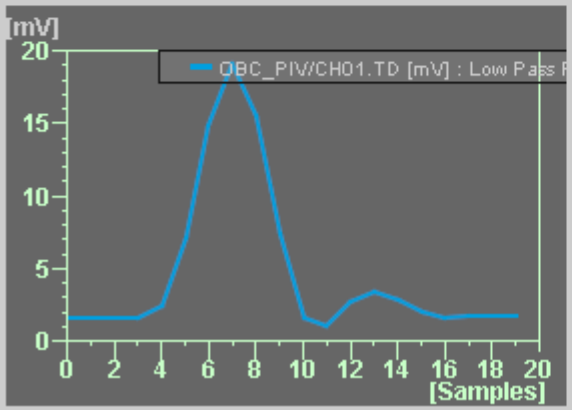
Selected Bucket: 1

bunch_current_panel.xml TEST.DIAG/BUNCHCURRENTDMA/OBC_PIV/

Charge per Bucket

Post Mortem | Injection | Expert | Print





Total Current: 44.43 mA

Filled buckets: 40

Timestamp: 2031110419

Bucket: 1

Low level server running