HZB BESSY II Light Source

Bumpless Transition to New Orbit Feedback in BESSY II and MLS using Libera Spark ERXR

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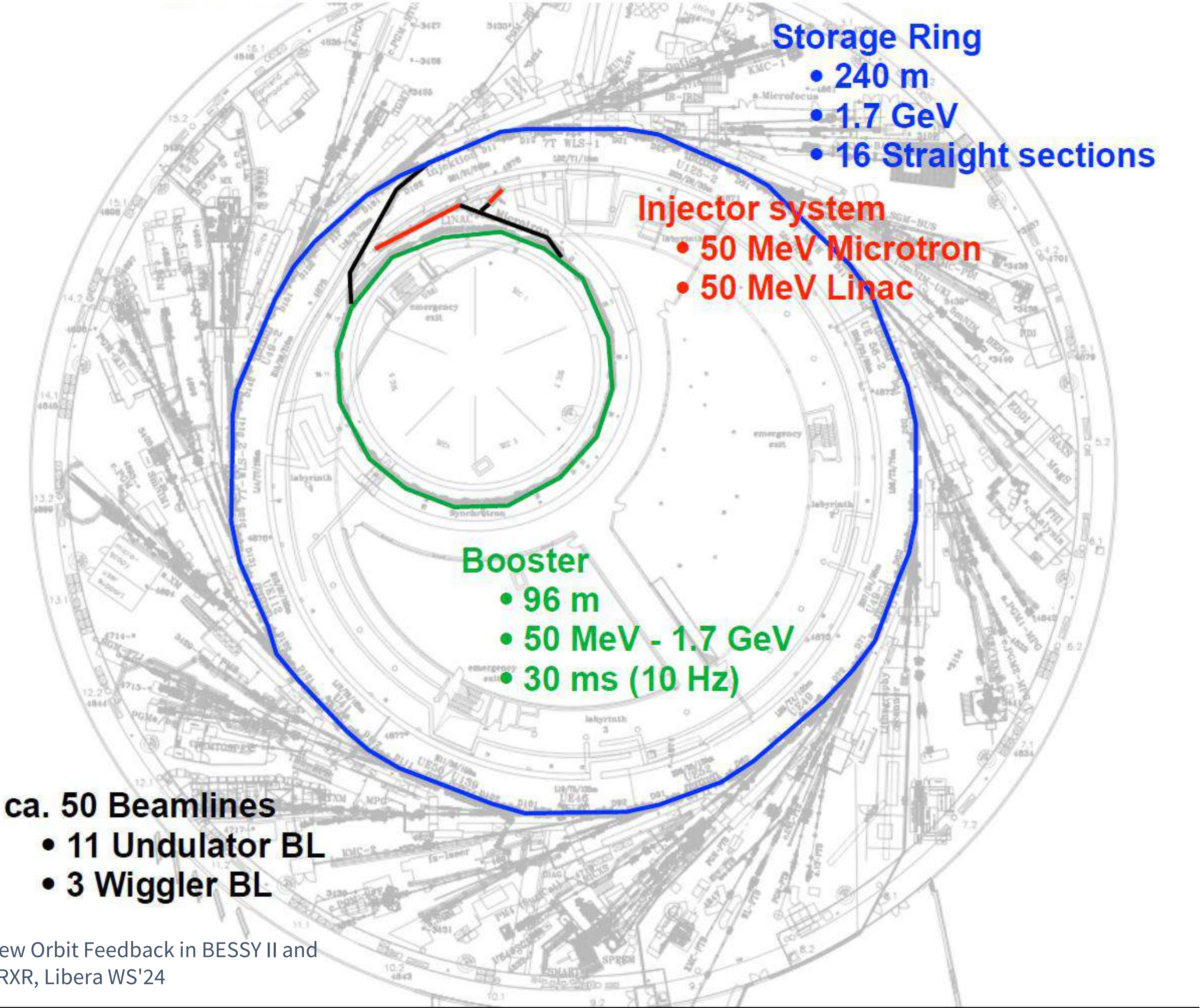
New eyes for mature machines

BESSY II

In operation since 1998

$\epsilon_x = 5$ nm rad

$\epsilon_y \approx 50$ pm rad



Storage Ring
- 240 m
- 1.7 GeV
- 16 Straight sections

Injector system
- 50 MeV Microtron
- 50 MeV Linac

Booster
- 96 m
- 50 MeV - 1.7 GeV
- 30 ms (10 Hz)

ca. 50 Beamlines
- 11 Undulator BL
- 3 Wiggler BL

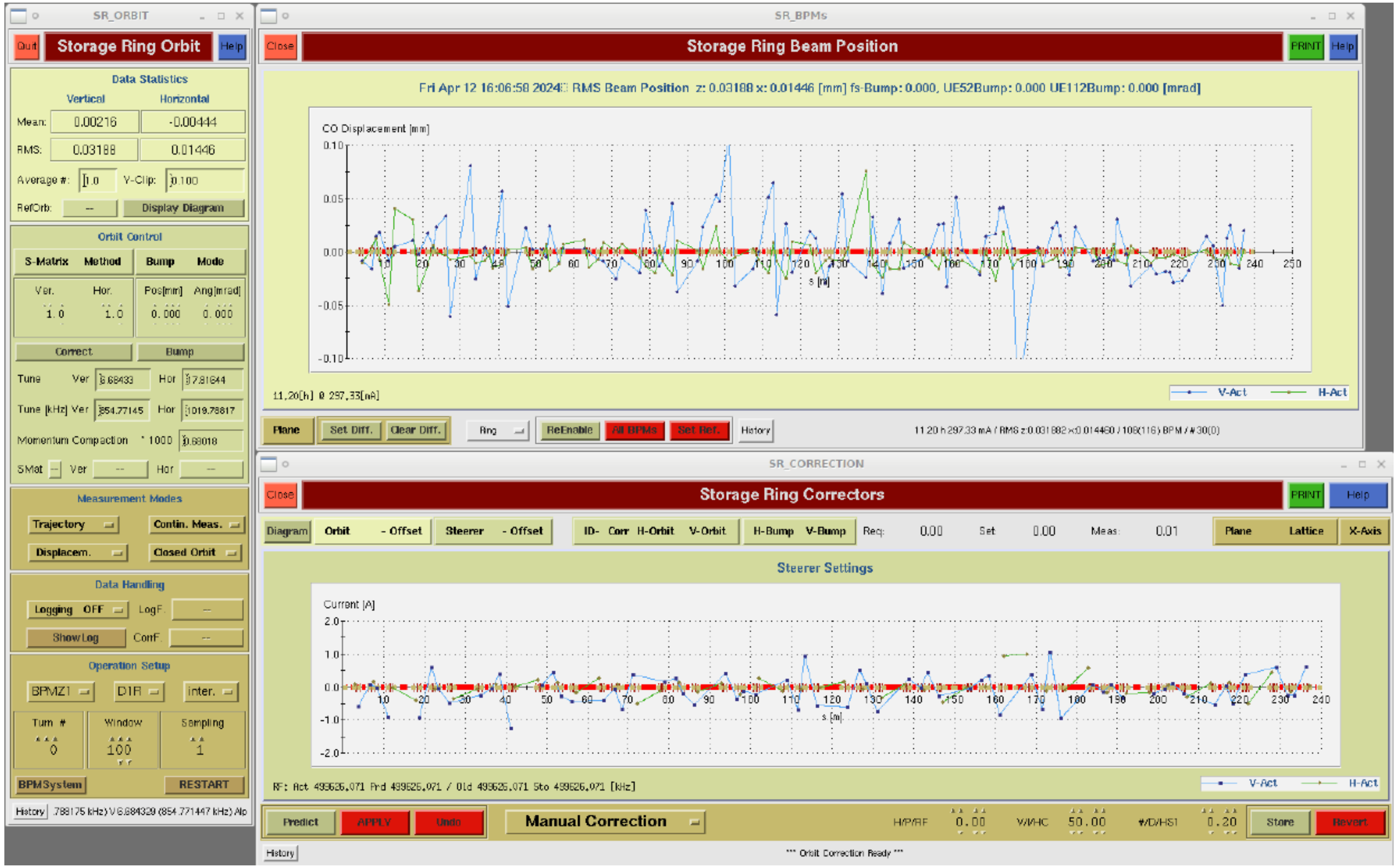
EXISTING BPM ELECTRONICS

- **Original BESSY II BPMs:**
  - Single channel multiplexing
  - Analogue processing of X,Y and S
  - 1kHz analogue output bandwidth
  - Digitisation in VME, EPICSs PVs output at 0.5Hz rate
- **Issues:**
  - LO drift or poor amplitude, no spare parts
  - TbT not usuable
  - Power supply failures
  - Other old age electronics issues

BPM-HF and BPM-AD, mid 1990s in-house design and build

EXISTING SLOW ORBIT FEEDBACK

- EPICS to BPMs and corrector PSUs
- Corrections at 0.5 Hz
- In operation since dawn of BESSY II
- Monolithic Tcl/Tk tool
- Disabling of individual BPMs and correctors
- Used during startup and maintenance
- **Continue use during transition**
- **Replace after transition**



	Vertical	Horizontal
Mean:	0.00216	-0.00444
RMS:	0.03188	0.01446

Average #: 1.0 V-Clip: 0.100

RefOrb: --

Ver.	Hor.	Pos[mm]	Ang[mrad]
1.0	1.0	0.000	0.000

Tune Ver 6.68433 Hor 17.81644

Tune [kHz] Ver 854.77145 Hor 1019.78817

Momentum Compaction * 1000 0.68018

SMat -- Ver -- Hor --

Logging OFF LogF. --

ConF. --

Turn #	Window	Sampling
0	100	1

.788175 kHz) V 6.684329 (854.771447 kHz) Alp

Fri Apr 12 16:06:58 2024 RMS Beam Position z: 0.03188 x: 0.01446 [mm] fs-Bump: 0.000, UE52Bump: 0.000 UE112Bump: 0.000 [mrad]

11,20[h] @ 297,33[mA]

11.20 h 297.33 mA / RMS z:0.031882 x:0.014460 / 108(116) BPM / #30(0)

Req: 0.00 Set 0.00 Meas: 0.01

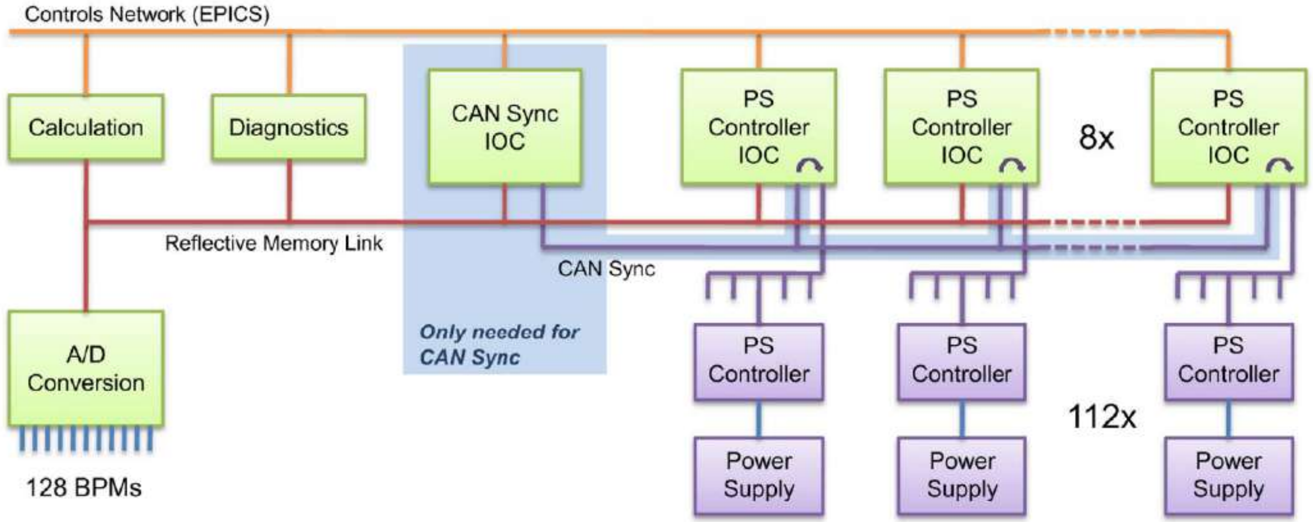
RF: Act 499626.071 Prd 499626.071 / Old 499626.071 Sto 499626.071 [kHz]

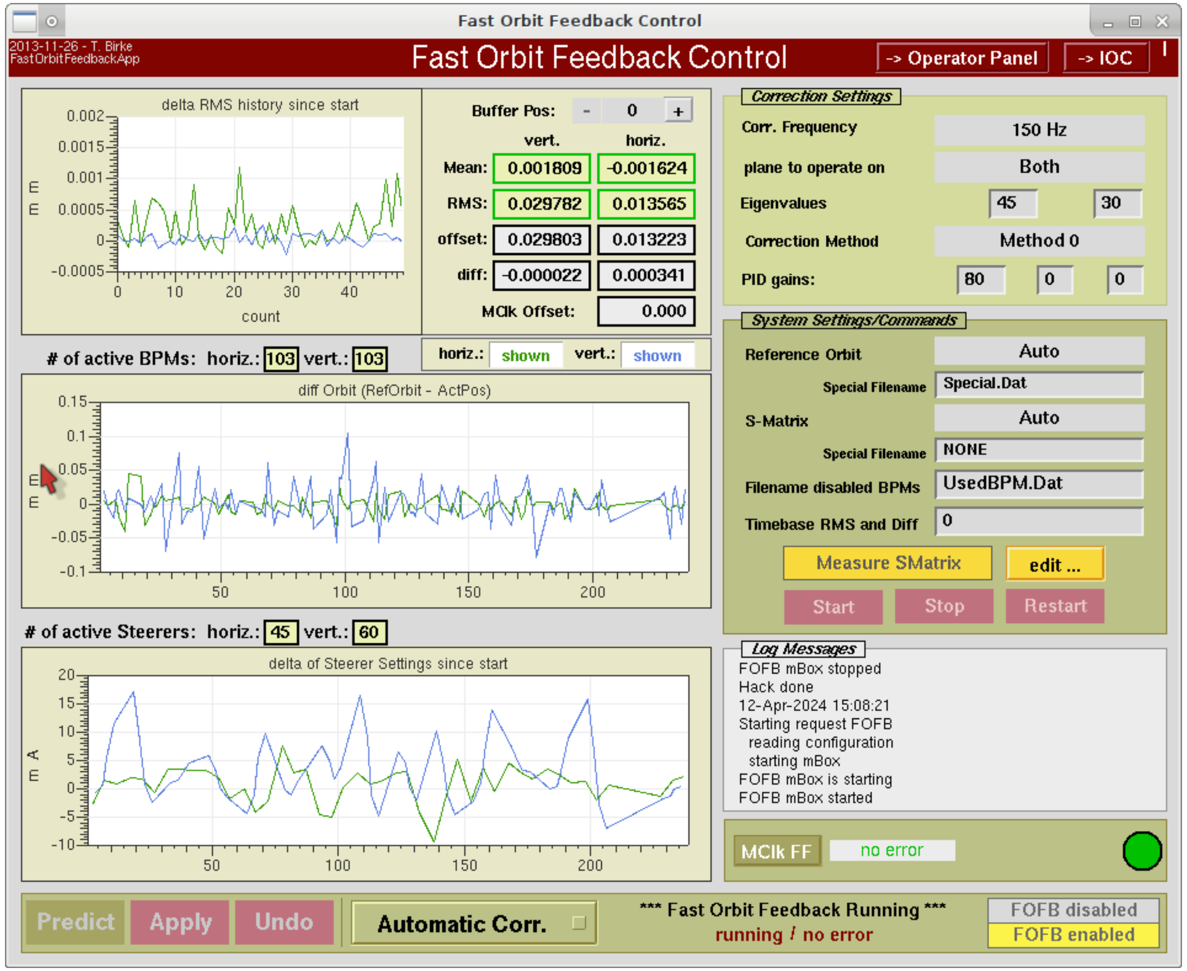
H/P/RF 0.00 V/I/HC 50.00 #/D/HS1 0.20

*** Orbit Correction Ready ***

EXISTING FAST ORBIT FEEDBACK

- In operation since 2012
- Runs at 150 Hz update rate, limited by large latency
- Uses reflective memory to distribute BPM data and corrector data
- Bottleneck is large latency in CAN bus (>3ms)
- **Continue use during transition**
- **Replace after transition**





Buffer Pos: - 0 +

	vert.	horiz.
Mean:	0.001809	-0.001624
RMS:	0.029782	0.013565
offset:	0.029803	0.013223
diff:	-0.000022	0.000341
MClk Offset:		0.000

# of active BPMs: horiz.: 103 vert.: 103

horiz.: shown vert.: shown

# of active Steerers: horiz.: 45 vert.: 60

Correction Settings

Corr. Frequency	150 Hz		
plane to operate on	Both		
Eigenvalues	45	30	
Correction Method	Method 0		
PID gains:	80	0	0

System Settings/Commands

Reference Orbit	Auto
Special Filename	Special.Dat
S-Matrix	Auto
Special Filename	NONE
Filename disabled BPMs	UsedBPM.Dat
Timebase RMS and Diff	0

Log Messages

```
FOFB mBox stopped
Hack done
12-Apr-2024 15:08:21
Starting request FOFB
  reading configuration
  starting mBox
FOFB mBox is starting
FOFB mBox started
```

MClk FF no error ●

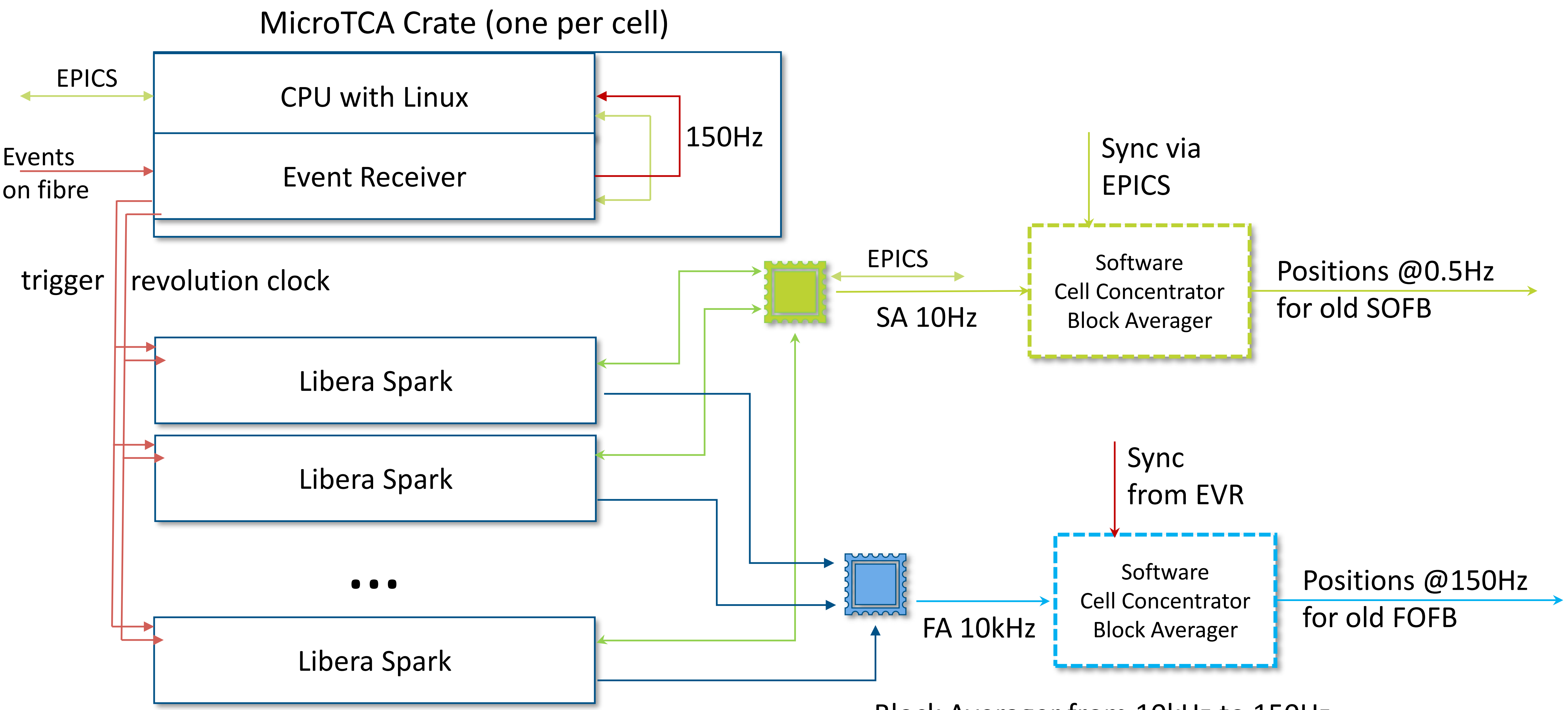
*** Fast Orbit Feedback Running ***
running / no error

FOFB disabled
FOFB enabled

BPM and Orbit Feedback Upgrade Plan

1. Install new BPMs cell by cell
   - Operate SOFB (0.5Hz) and FOFB (150Hz) with hybrid BPM population
   - Need to produce relevant data at original rates and in sync
2. Replace old SOFB with new Python routine
   - Headless server, communicates with users solely through EPICS
   - Will also be able to communicate with new FOFB
3. Replace old FOFB with new routine using FA data at full rate
   - Transfer to compuational node through GBE and 10 GBE
   - GBE Receiver for cell corrector values produces DAC values for PSU

TIMING OF NEW BPMS AND HYBRID ORBIT FEEDBACK (PLAN 2023)

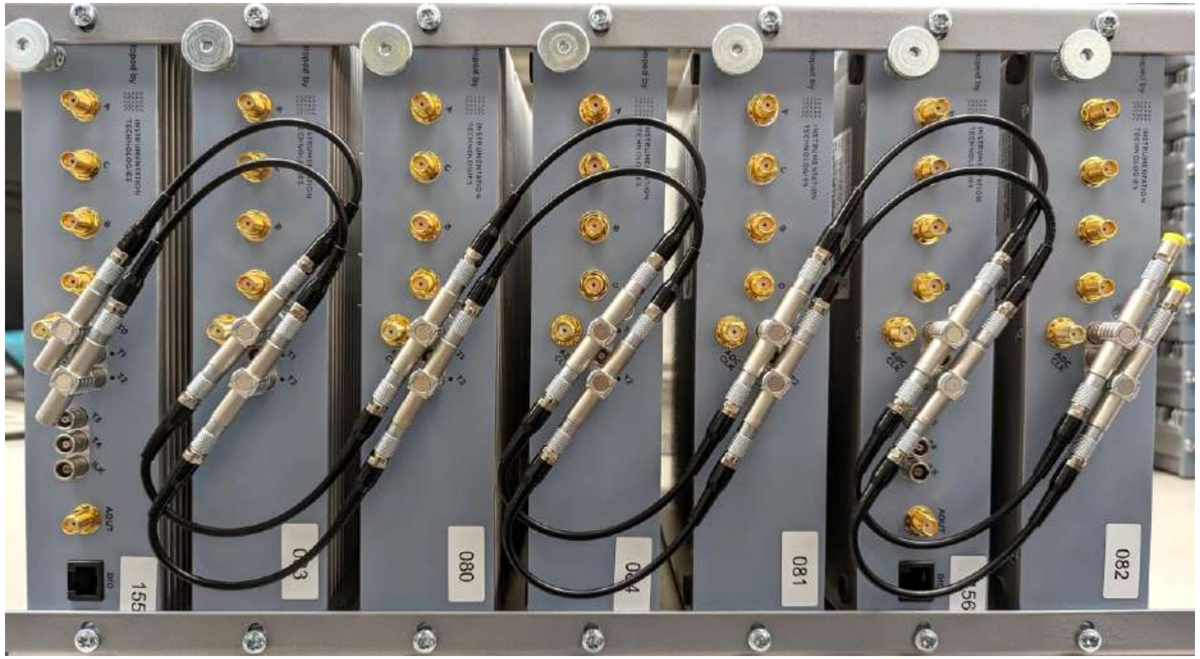


Block Averager from 10kHz to 150Hz:

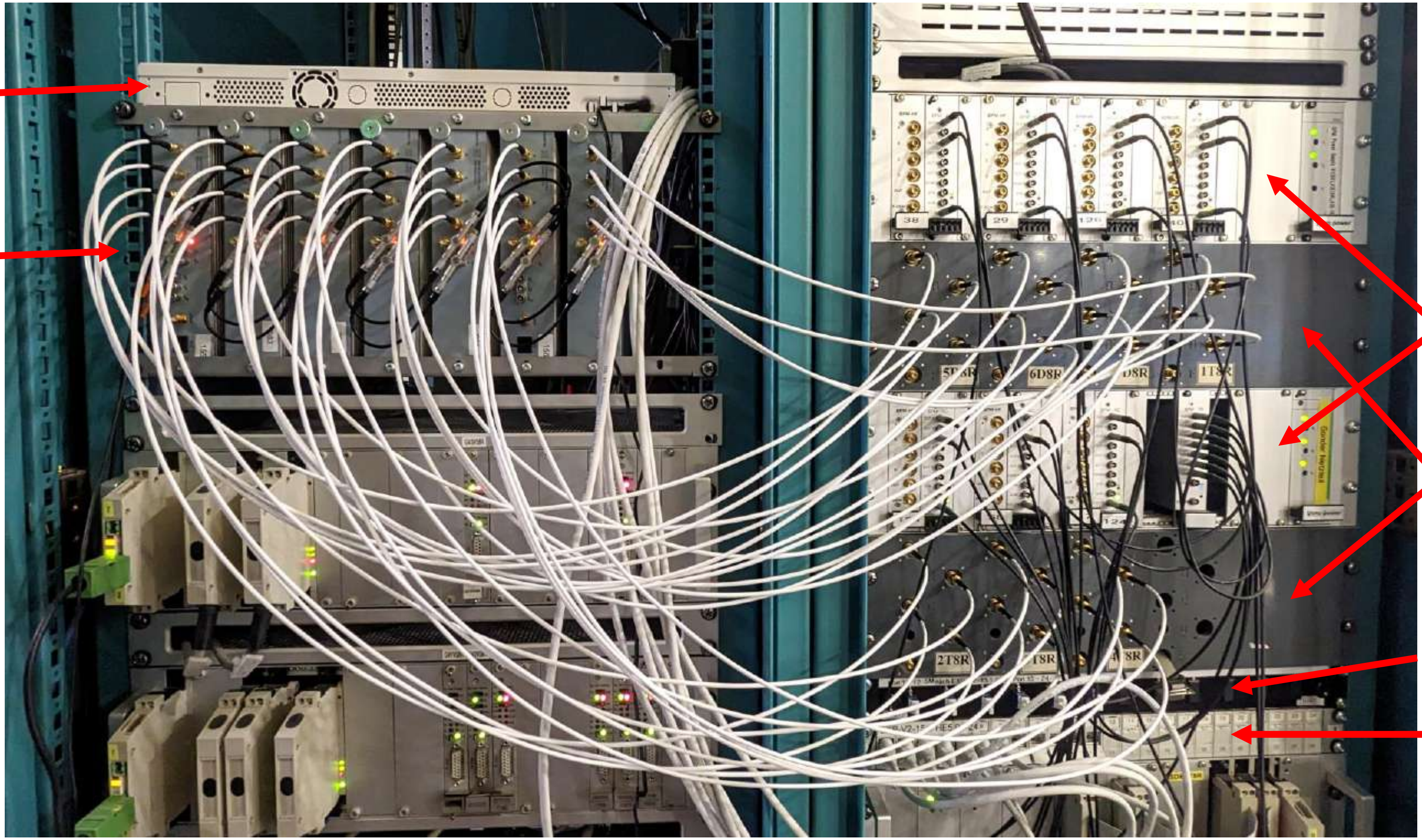
- Software in MTCA CPU
- Firmware in Libera Spark

DECEMBER 2023: DELIVERY COMPLETE

- All Spark ERXR units delivered
- All units passed quick in-house test
- Begin to group units for assembly in cells
- Route MC clock and Trigger signals per group
- New features in 2023 vintage of Spark ERXR:
  - Additional 0/5/10/15dB attenuator in RF chain
  - Ability to supply sample clock externally
  - Firmware/Software 2.0,
  - Support of Neon FPU in Arm Processor
  - EPICS IocStats included
  - Pre-installed ssh-key in authorized_keys



FEBRUARY 2024: FIRST TEST IN ONE CELL



FA data switch output on 10GBE

Temporary location for Sparks

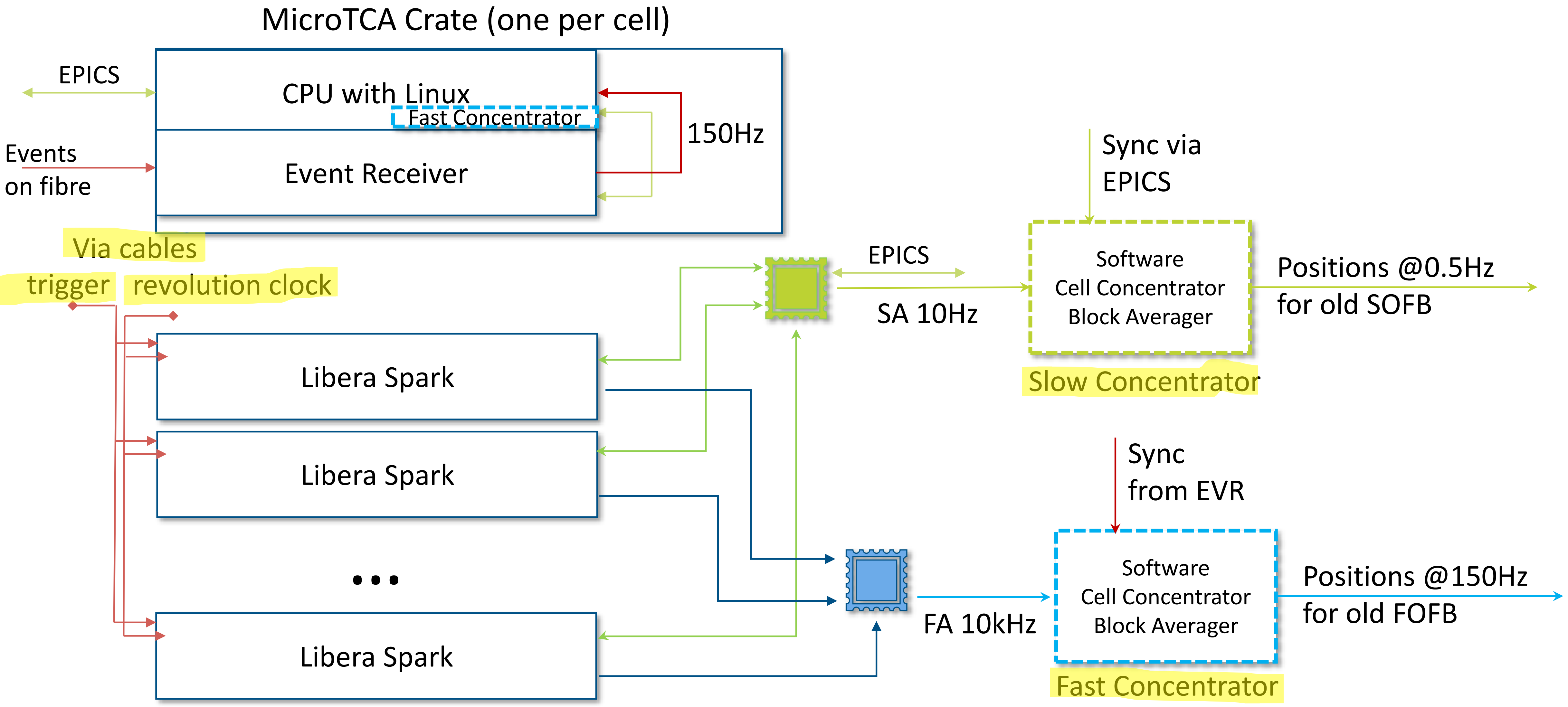
Old BPMs

Button patch panels

Timing Fibres

Network with PoE

TIMING OF NEW BPMS AND HYBRID ORBIT FEEDBACK (CURRENT)

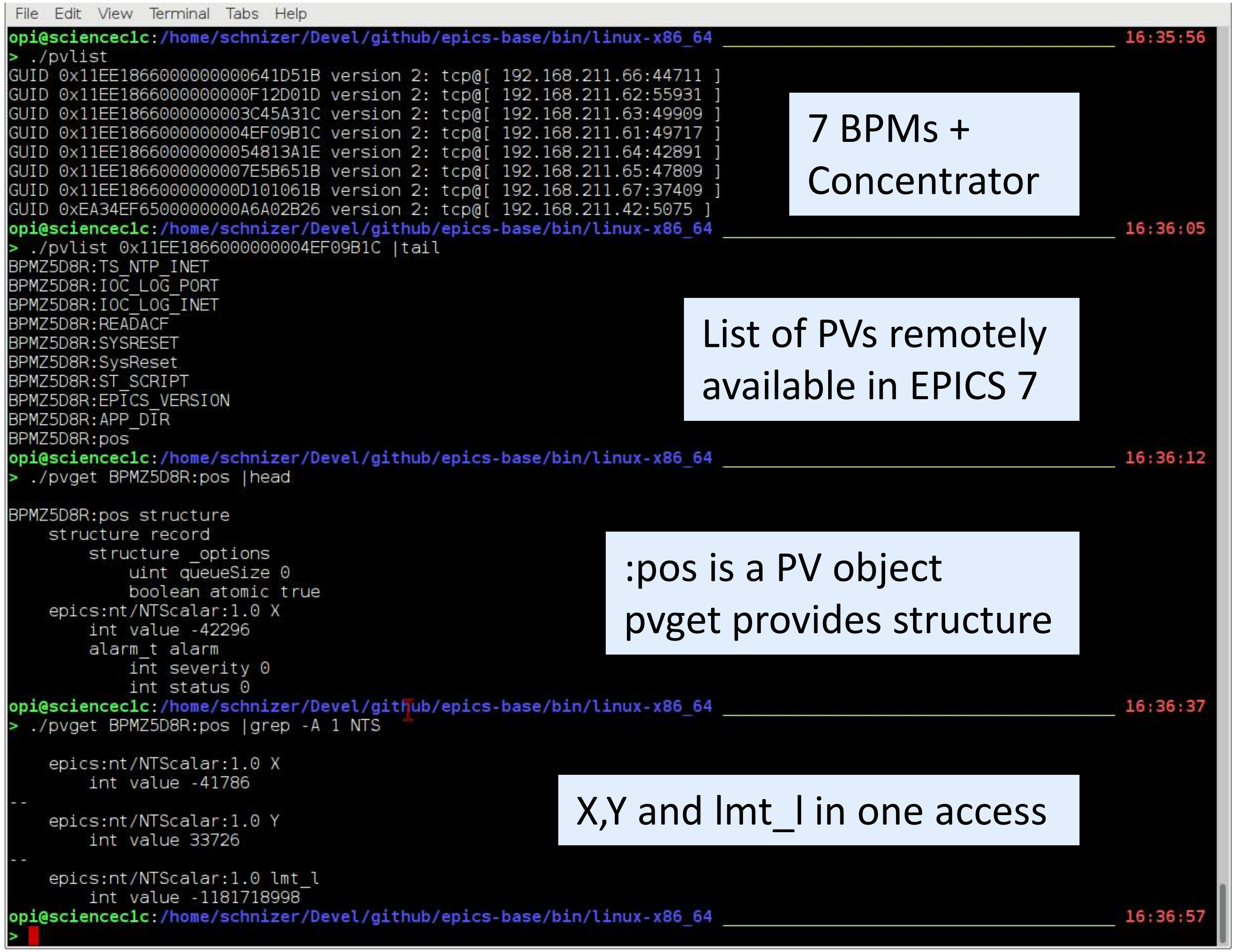


Block Averager from 10kHz to 150Hz:

- Software in MTCA CPU

MARCH 2024: SLOW CONCENTRATOR USING EPICS7 (1)

- Instrumentation Technologies offer EPICS3 and EPICS7
- EPICS7 is missing „qsrv“
- Required for construction of PV objects
  - ➢ Compile EPICS7 IOC at HZB using supplied virtual machine
- Ammendment of database file on Spark
  - ➢ Now PV object provides X,Y, timestamp in **one access**
- Software changes roled out through DHCP, TFTP, NFS



```
opi@sciencec1c:/home/schnizer/Devel/github/epics-base/bin/linux-x86_64 ____________ 16:35:56
> ./pvlist
GUID 0x11EE186600000000641D51B version 2: tcp@[ 192.168.211.66:44711 ]
GUID 0x11EE18660000000F12D01D version 2: tcp@[ 192.168.211.62:55931 ]
GUID 0x11EE186600000003C45A31C version 2: tcp@[ 192.168.211.63:49909 ]
GUID 0x11EE186600000004EF09B1C version 2: tcp@[ 192.168.211.61:49717 ]
GUID 0x11EE18660000000054813A1E version 2: tcp@[ 192.168.211.64:42891 ]
GUID 0x11EE186600000007E5B651B version 2: tcp@[ 192.168.211.65:47809 ]
GUID 0x11EE1866000000000D101061B version 2: tcp@[ 192.168.211.67:37409 ]
GUID 0xEA34EF650000000A6A02B26 version 2: tcp@[ 192.168.211.42:5075 ]
opi@sciencec1c:/home/schnizer/Devel/github/epics-base/bin/linux-x86_64 ____________ 16:36:05
> ./pvlist 0x11EE186600000004EF09B1C |tail
BPMZ5D8R:TS_NTP_INET
BPMZ5D8R:IOC_LOG_PORT
BPMZ5D8R:IOC_LOG_INET
BPMZ5D8R:READACF
BPMZ5D8R:SYSRESET
BPMZ5D8R:SysReset
BPMZ5D8R:ST_SCRIPT
BPMZ5D8R:EPICS_VERSION
BPMZ5D8R:APP_DIR
BPMZ5D8R:pos
opi@sciencec1c:/home/schnizer/Devel/github/epics-base/bin/linux-x86_64 ____________ 16:36:12
> ./pvget BPMZ5D8R:pos |head

BPMZ5D8R:pos structure
    structure record
        structure _options
            uint queueSize 0
            boolean atomic true
    epics:nt/NTScalar:1.0 X
        int value -42296
        alarm_t alarm
            int severity 0
            int status 0
opi@sciencec1c:/home/schnizer/Devel/github/epics-base/bin/linux-x86_64 ____________ 16:36:37
> ./pvget BPMZ5D8R:pos |grep -A 1 NTS

    epics:nt/NTScalar:1.0 X
        int value -41786
--
    epics:nt/NTScalar:1.0 Y
        int value 33726
--
    epics:nt/NTScalar:1.0 lmt_l
        int value -1181718998
opi@sciencec1c:/home/schnizer/Devel/github/epics-base/bin/linux-x86_64 ____________ 16:36:57
>
```

7 BPMs + Concentrator

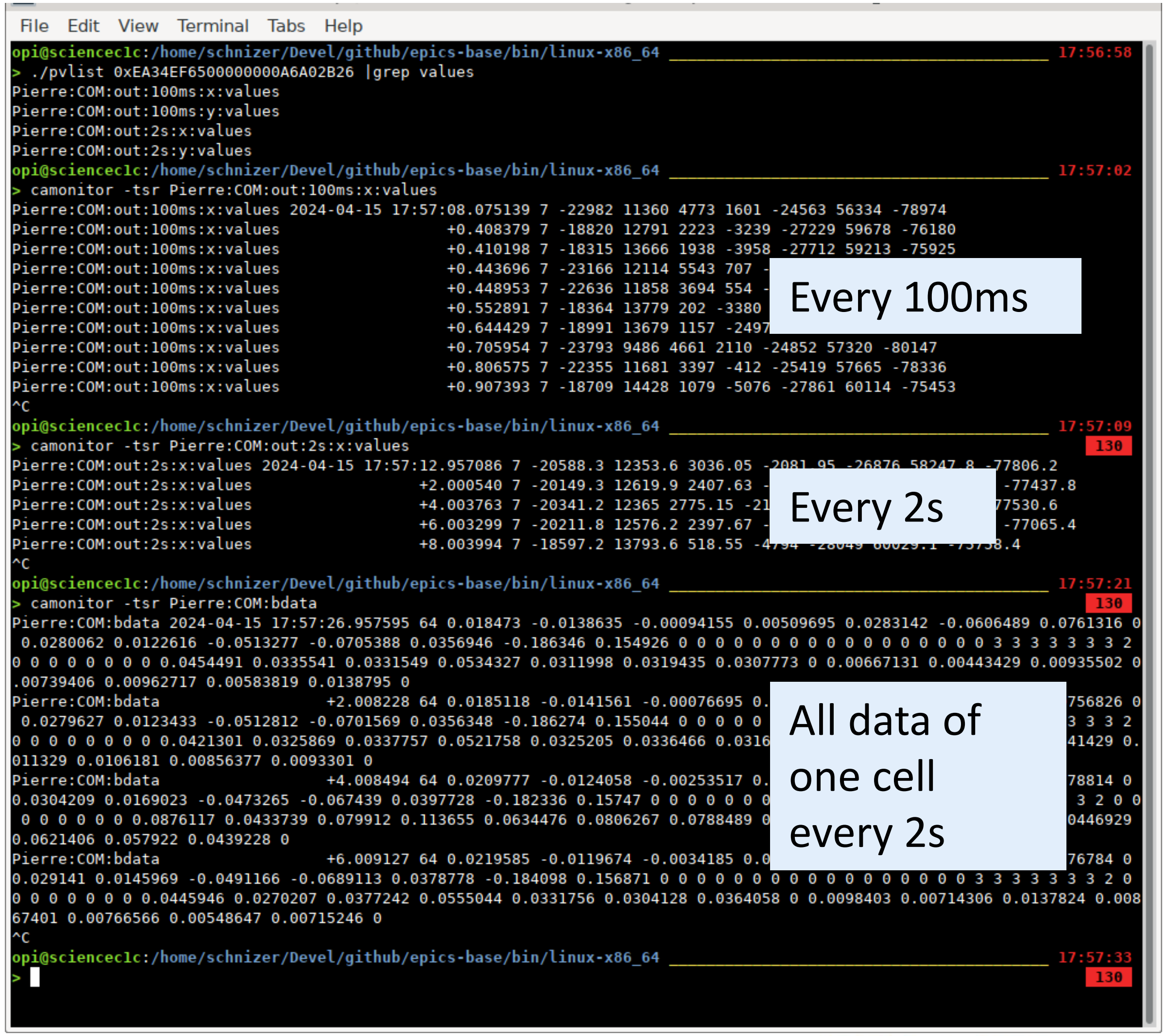
List of PVs remotely available in EPICS 7

:pos is a PV object
pvget provides structure

X,Y and lmt_l in one access

MARCH 2024: SLOW CONCENTRATOR USING EPICS7 (2)

- Slow Concentrator produces collected values at two rates: every 100ms and every 2s
- Format of previous hard IOC is reproduced to replace one cell
- „bdata“ contains all information from one cell



```
opi@sciencec1c:/home/schnizer/Devel/github/epics-base/bin/linux-x86_64 ________________________ 17:56:58
> ./pvlist 0xEA34EF6500000000A6A02B26 |grep values
Pierre:COM:out:100ms:x:values
Pierre:COM:out:100ms:y:values
Pierre:COM:out:2s:x:values
Pierre:COM:out:2s:y:values
opi@sciencec1c:/home/schnizer/Devel/github/epics-base/bin/linux-x86_64 ________________________ 17:57:02
> camonitor -tsr Pierre:COM:out:100ms:x:values
Pierre:COM:out:100ms:x:values 2024-04-15 17:57:08.075139 7 -22982 11360 4773 1601 -24563 56334 -78974
Pierre:COM:out:100ms:x:values                  +0.408379 7 -18820 12791 2223 -3239 -27229 59678 -76180
Pierre:COM:out:100ms:x:values                  +0.410198 7 -18315 13666 1938 -3958 -27712 59213 -75925
Pierre:COM:out:100ms:x:values                  +0.443696 7 -23166 12114 5543 707 -
Pierre:COM:out:100ms:x:values                  +0.448953 7 -22636 11858 3694 554 -
Pierre:COM:out:100ms:x:values                  +0.552891 7 -18364 13779 202 -3380
Pierre:COM:out:100ms:x:values                  +0.644429 7 -18991 13679 1157 -2497
Pierre:COM:out:100ms:x:values                  +0.705954 7 -23793 9486 4661 2110 -24852 57320 -80147
Pierre:COM:out:100ms:x:values                  +0.806575 7 -22355 11681 3397 -412 -25419 57665 -78336
Pierre:COM:out:100ms:x:values                  +0.907393 7 -18709 14428 1079 -5076 -27861 60114 -75453
^C
opi@sciencec1c:/home/schnizer/Devel/github/epics-base/bin/linux-x86_64 ________________________ 17:57:09
> camonitor -tsr Pierre:COM:out:2s:x:values                                                          130
Pierre:COM:out:2s:x:values 2024-04-15 17:57:12.957086 7 -20588.3 12353.6 3036.05 -2081.95 -26876 58247.8 -77806.2
Pierre:COM:out:2s:x:values                  +2.000540 7 -20149.3 12619.9 2407.63 -                 -77437.8
Pierre:COM:out:2s:x:values                  +4.003763 7 -20341.2 12365 2775.15 -21                 77530.6
Pierre:COM:out:2s:x:values                  +6.003299 7 -20211.8 12576.2 2397.67 -                 -77065.4
Pierre:COM:out:2s:x:values                  +8.003994 7 -18597.2 13793.6 518.55 -4794 -28049 60029.1 -75758.4
^C
opi@sciencec1c:/home/schnizer/Devel/github/epics-base/bin/linux-x86_64 ________________________ 17:57:21
> camonitor -tsr Pierre:COM:bdata                                                                    130
Pierre:COM:bdata 2024-04-15 17:57:26.957595 64 0.018473 -0.0138635 -0.00094155 0.00509695 0.0283142 -0.0606489 0.0761316 0
 0.0280062 0.0122616 -0.0513277 -0.0705388 0.0356946 -0.186346 0.154926 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 3 3 3 3 3 3 3 2
0 0 0 0 0 0 0 0 0.0454491 0.0335541 0.0331549 0.0534327 0.0311998 0.0319435 0.0307773 0 0.00667131 0.00443429 0.00935502 0
.00739406 0.00962717 0.00583819 0.0138795 0
Pierre:COM:bdata                  +2.008228 64 0.0185118 -0.0141561 -0.00076695 0.                756826 0
 0.0279627 0.0123433 -0.0512812 -0.0701569 0.0356348 -0.186274 0.155044 0 0 0 0 0                3 3 3 2
0 0 0 0 0 0 0 0 0.0421301 0.0325869 0.0337757 0.0521758 0.0325205 0.0336466 0.0316               41429 0.
011329 0.0106181 0.00856377 0.0093301 0
Pierre:COM:bdata                  +4.008494 64 0.0209777 -0.0124058 -0.00253517 0.                78814 0
0.0304209 0.0169023 -0.0473265 -0.067439 0.0397728 -0.182336 0.15747 0 0 0 0 0 0 0               3 2 0 0
 0 0 0 0 0 0 0.0876117 0.0433739 0.079912 0.113655 0.0634476 0.0806267 0.0788489 0               0446929
0.0621406 0.057922 0.0439228 0
Pierre:COM:bdata                  +6.009127 64 0.0219585 -0.0119674 -0.0034185 0.0                76784 0
0.029141 0.0145969 -0.0491166 -0.0689113 0.0378778 -0.184098 0.156871 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 3 3 3 3 3 3 3 2 0
0 0 0 0 0 0 0 0.0445946 0.0270207 0.0377242 0.0555044 0.0331756 0.0304128 0.0364058 0 0.0098403 0.00714306 0.0137824 0.008
67401 0.00766566 0.00548647 0.00715246 0
^C
opi@sciencec1c:/home/schnizer/Devel/github/epics-base/bin/linux-x86_64 ________________________ 17:57:33
>                                                                                                    130
```

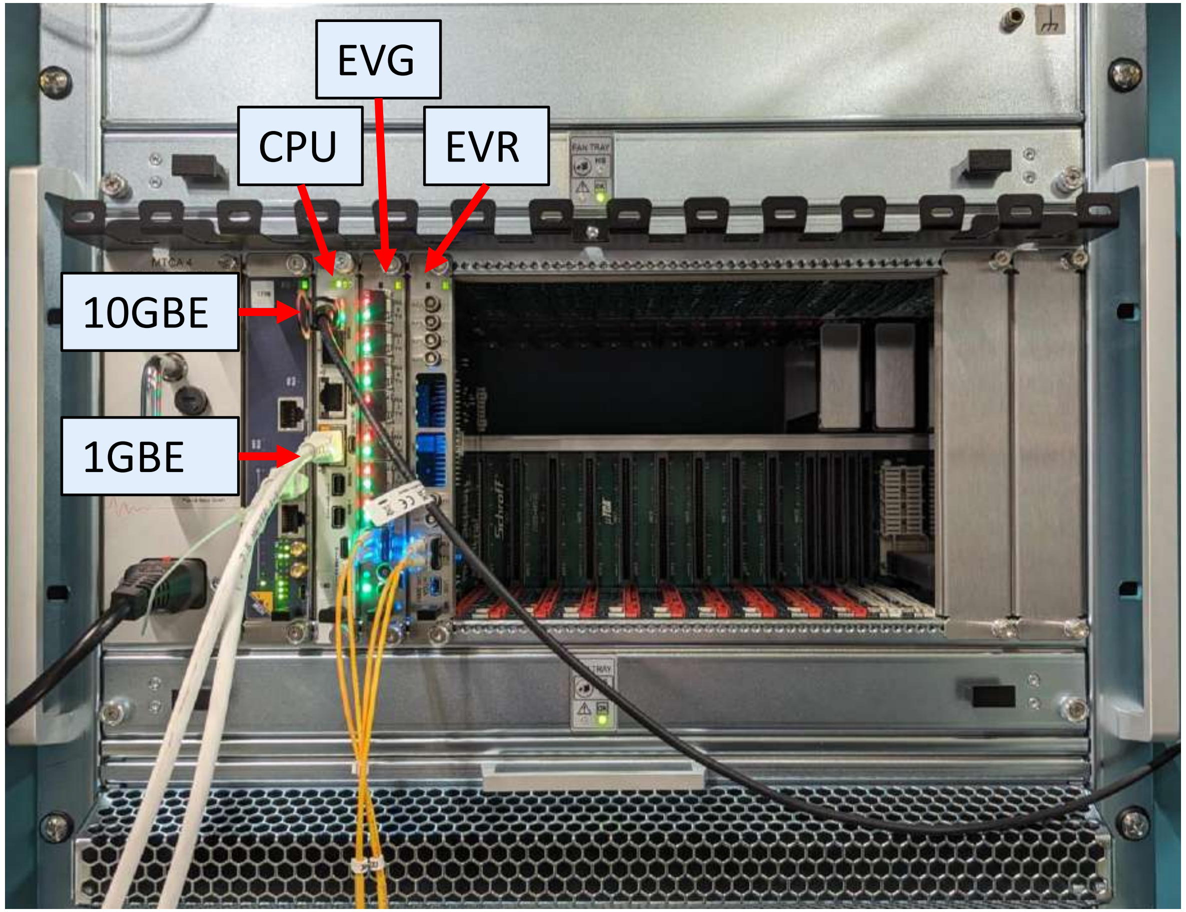
Every 100ms

Every 2s

All data of one cell every 2s

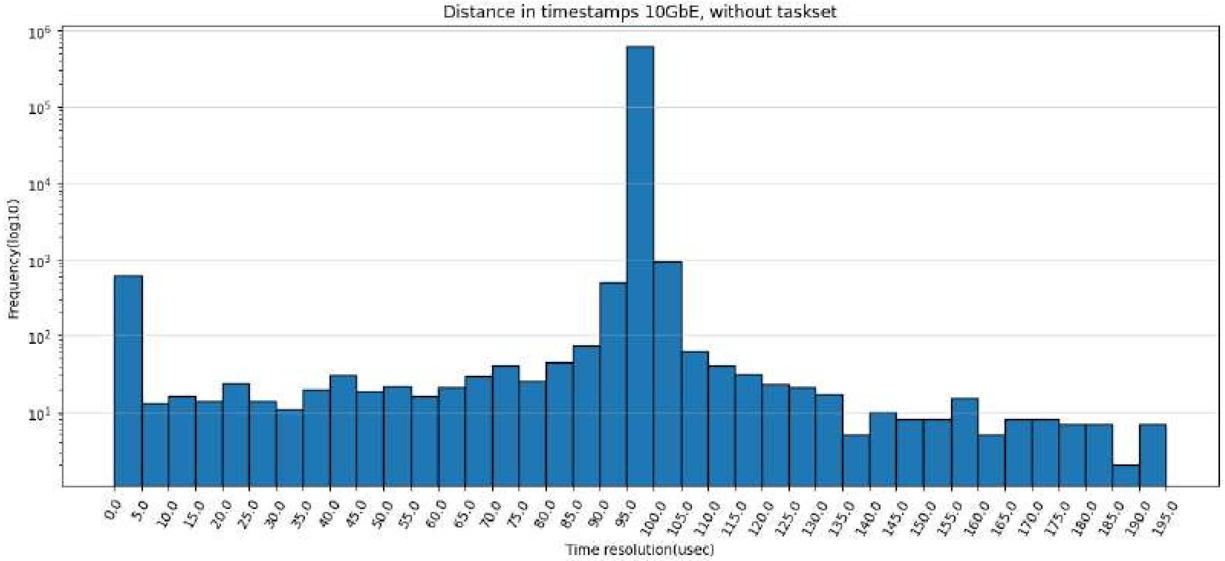
APRIL 2024: FAST CONCENTRATOR USING LOW-LATENCY TUNED LINUX (1)

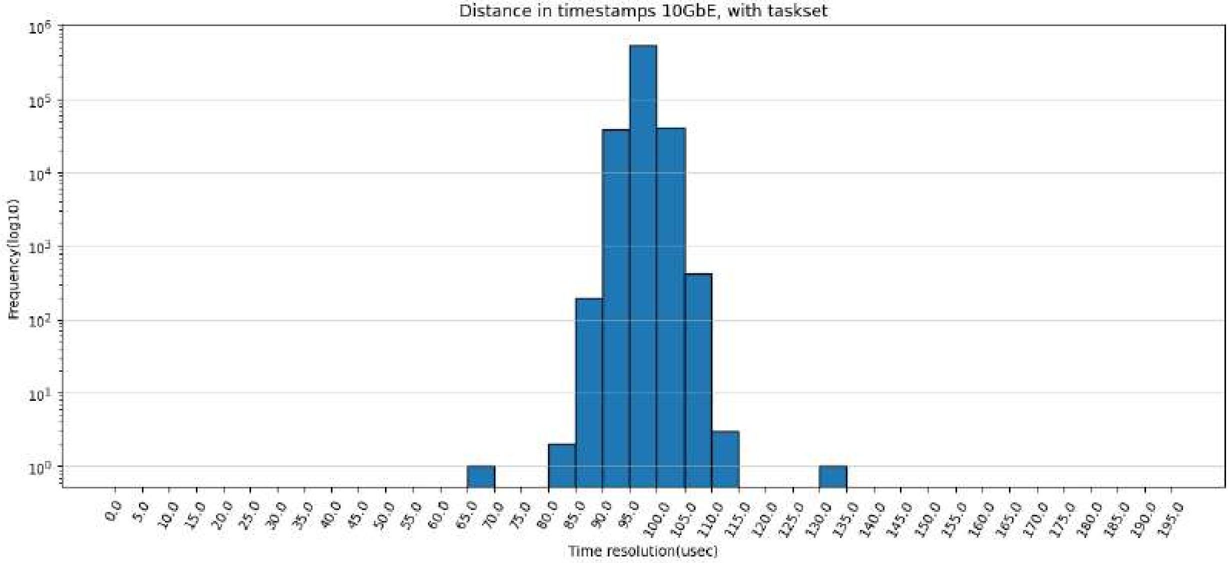
- MTCA crate, power supply, MCH
- AMC-CPU with 4 core Xeon, MRF-EVG/EVR
- One cell of UDP FA packets received in CPU
- Incoming data on 10GBE
- Outgoing temporarily on 1GBE, parallel with EPICS
- EVG (temporarily here) creates 150Hz event rate
- EVR receives event, fires PCIe interrupt on CPU
- On interrupt, all received FA packets are averaged
- New UDP packet sent in compressed format forward towards FOFB compute node
- Also to be replicated in all 16 cells, but only one EVG



APRIL 2024: FAST CONCENTRATOR USING LOW-LATENCY TUNED LINUX (2)

- Standard Linux tuned using mostly using run-time configuration
- Worked well enough on Ubuntu, Fedora, Debian and various kernels
- Verified by timestamping using monotonic clock
- No significant impact of 24port GBE Switch and 10GBE output

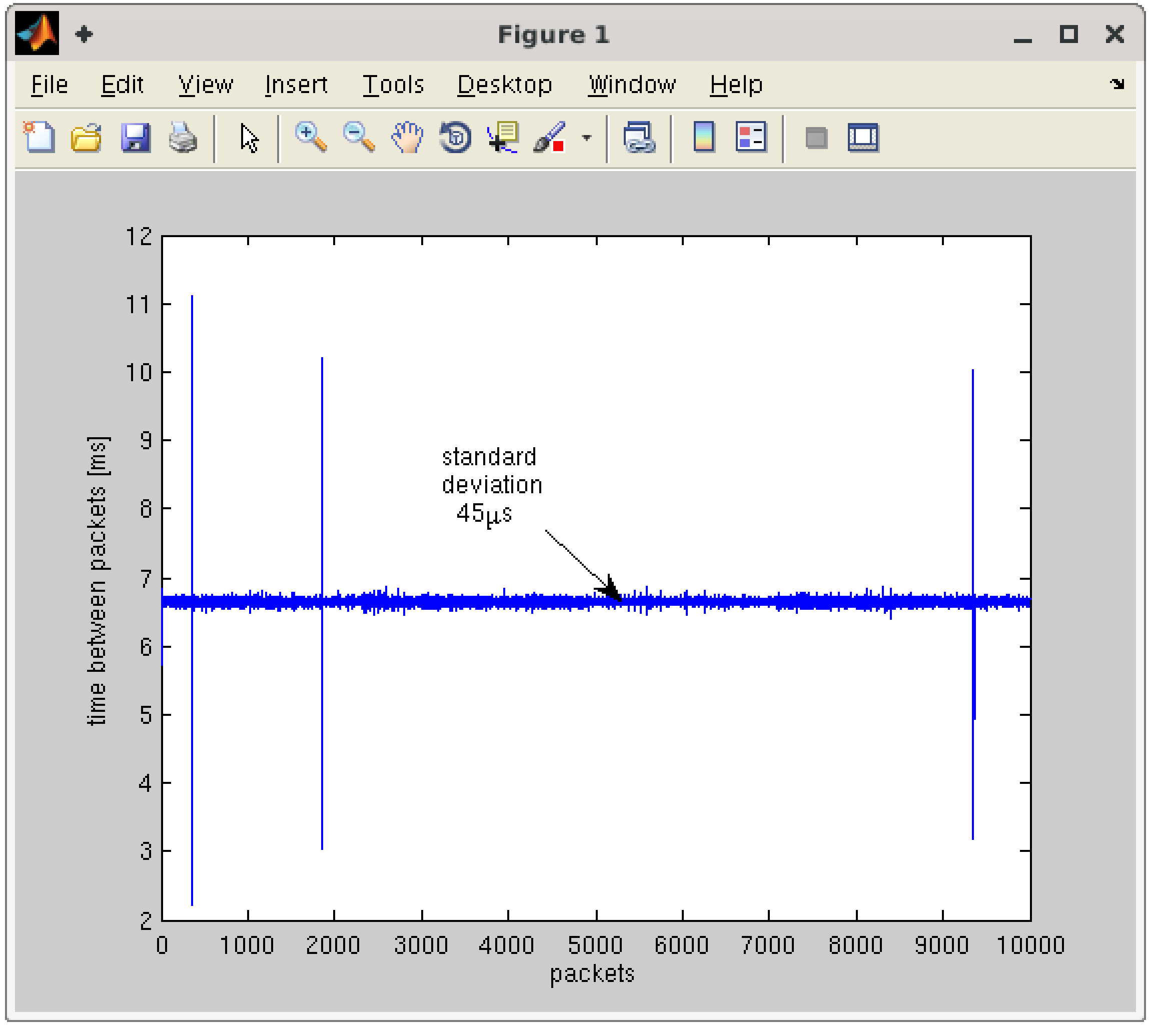

Distance in timestamps 10GbE, without taskset


Distance in timestamps 10GbE, with taskset

APRIL 2024: RECEIPTION OF COMPRESSED UDP PACKETS IN MATLAB

- Current FOFB application runs in MATLAB
- Reception using MEX-file written in C
- Tested time between received UDP packets
- Acceptable standard deviation found
- Occasional glitches need to be addressed
  - ➢ Linux Low-Latency tuning required!

- Next steps:
  - ➢ Share orbit trigger between old and new BPMs
  - ➢ Integrate UPD and RFM receiption in FOFB



Summary

Spark ERXR with custom modifications received

First Cell replaced

Integrated on SA rate through EPICS

Integrated on FA rate using software averager

UDP packets received successfully in MATLAB

Thank you for your attention!

Questions?