Pulsed magnet control system using COTS PXIE devices and LabVIEW

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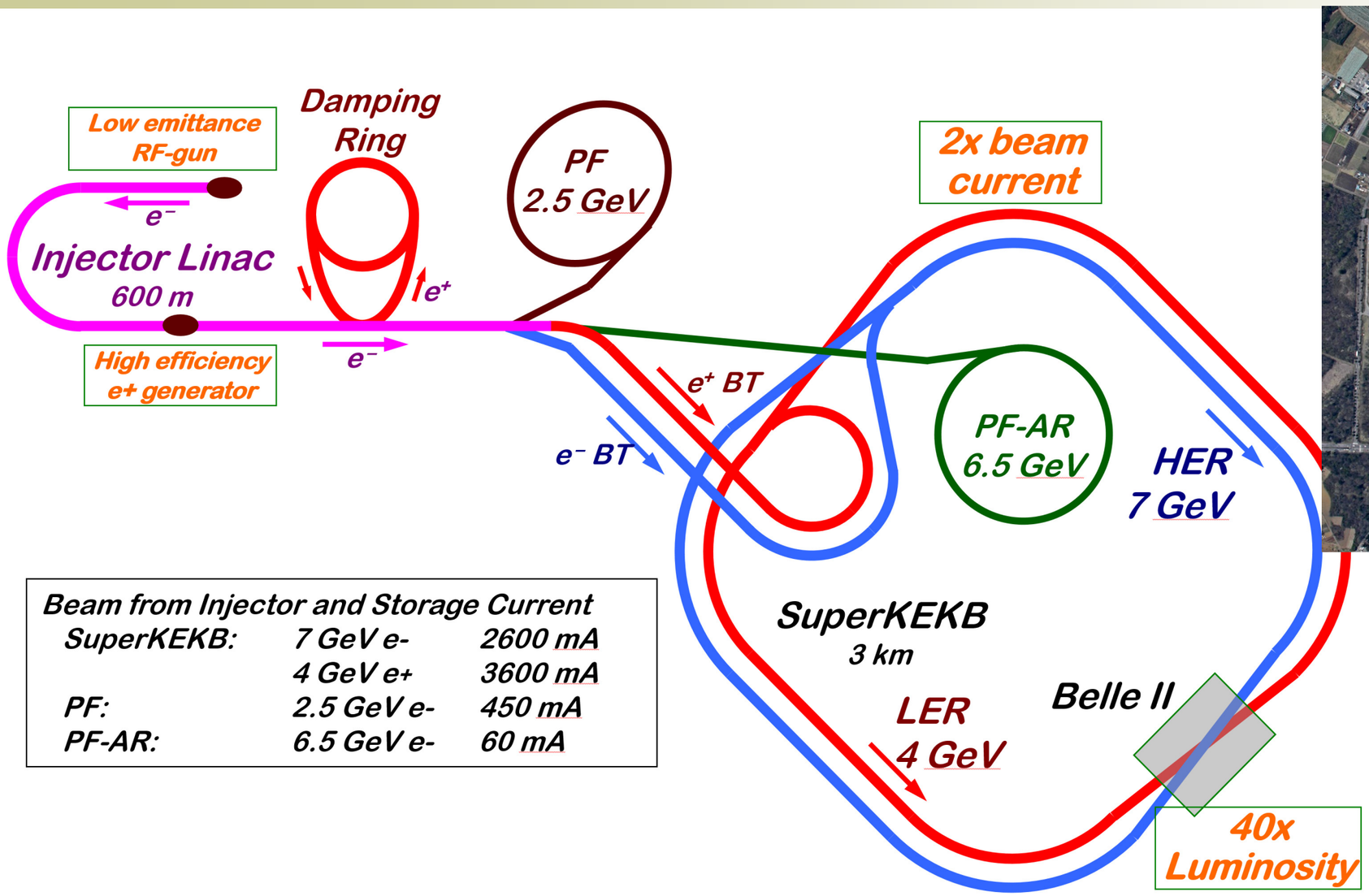
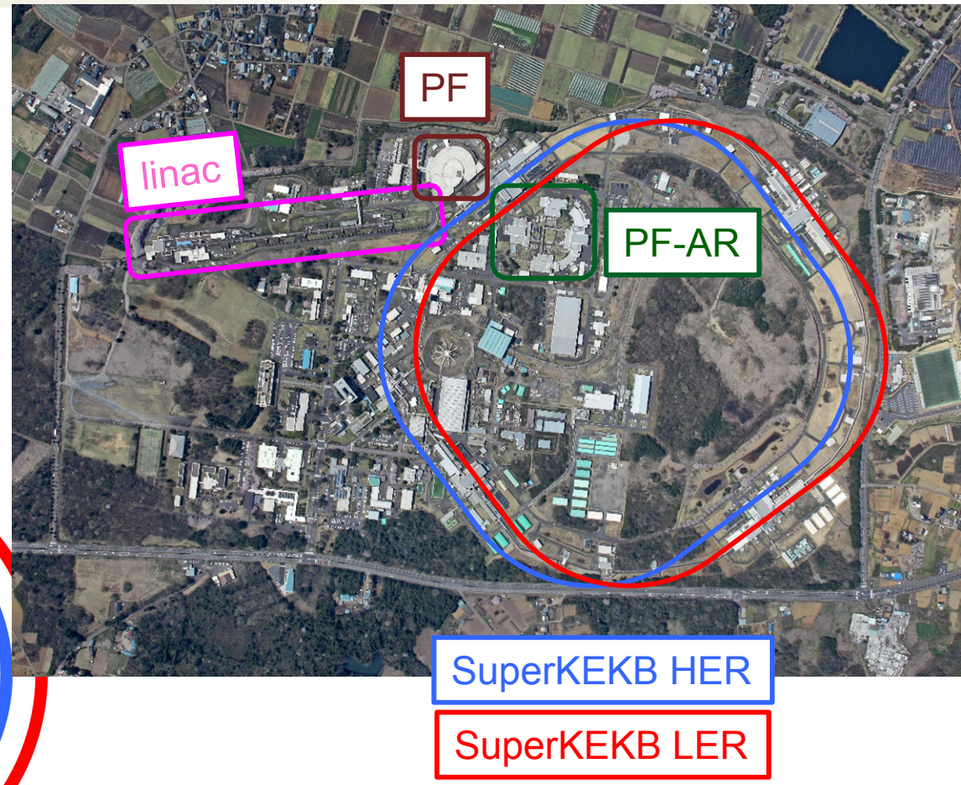
1. Introduction
2. Overview of the system
3. PXI / PXI express devices
4. Software
5. Evaluation and Operation
6. Summary

Key words : Event Timing System, EPICS, LabVIEW, PXI / PXI express

Accelerator complex in KEK Tsukuba



Beam from Injector and Storage Current		
SuperKEKB:	7 GeV e-	2600 mA
	4 GeV e+	3600 mA
PF:	2.5 GeV e-	450 mA
PF-AR:	6.5 GeV e-	60 mA



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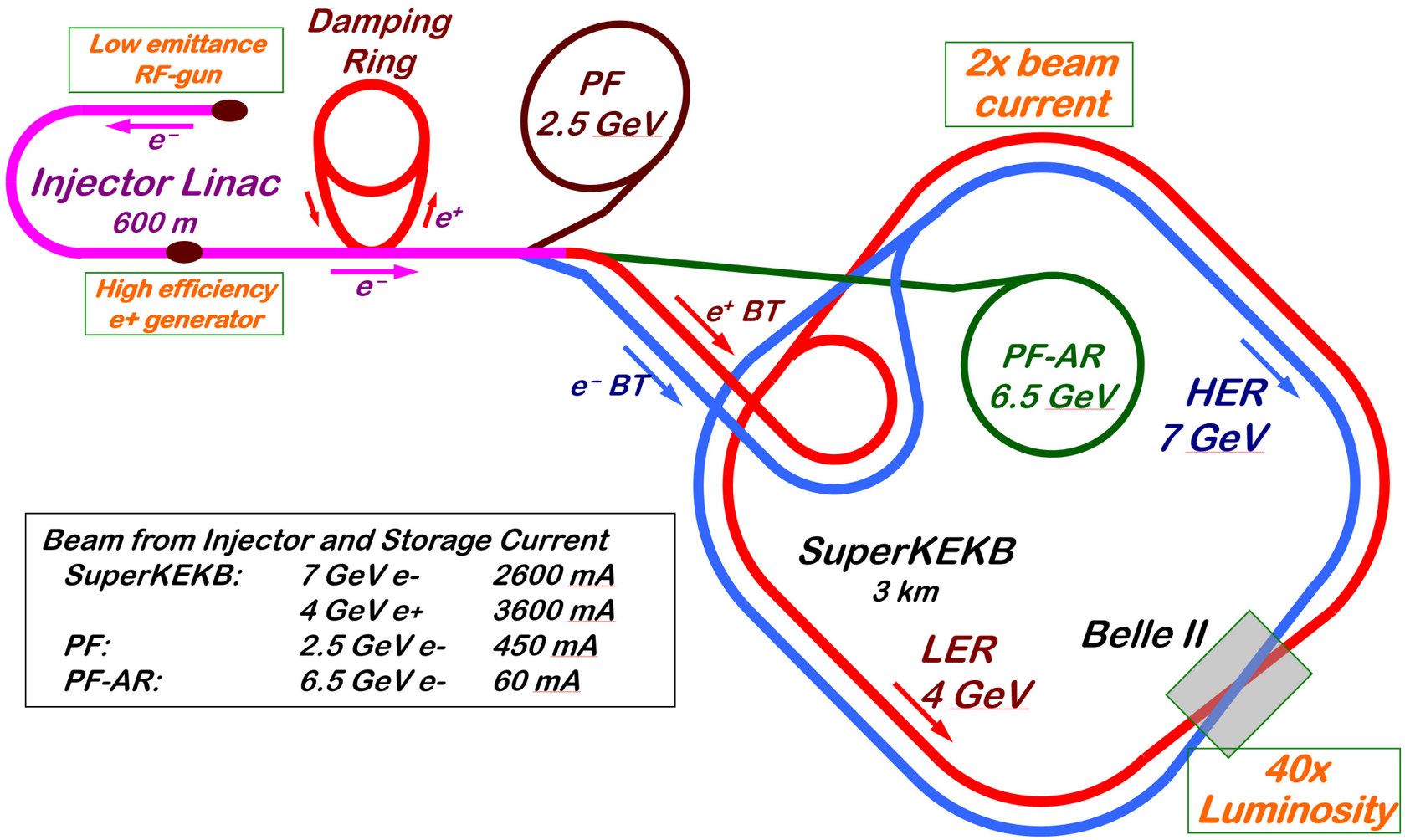

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- 4 rings and 1 linac
  - Two light source rings
    - PF, PF-AR
  - Two collider rings
    - SuperKEKB LER, HER
- Parallel configuration
  - No booster ring
- All storage rings
  - Full energy injection
- Top-up injection
- Two electron guns
  - RF gun for low emittance injection to SuperKEKB HER
  - Thermionic gun for high charge (10 nC) to produce large number of positrons
- Positron injection to LER

Our linac is an all-in-one injector

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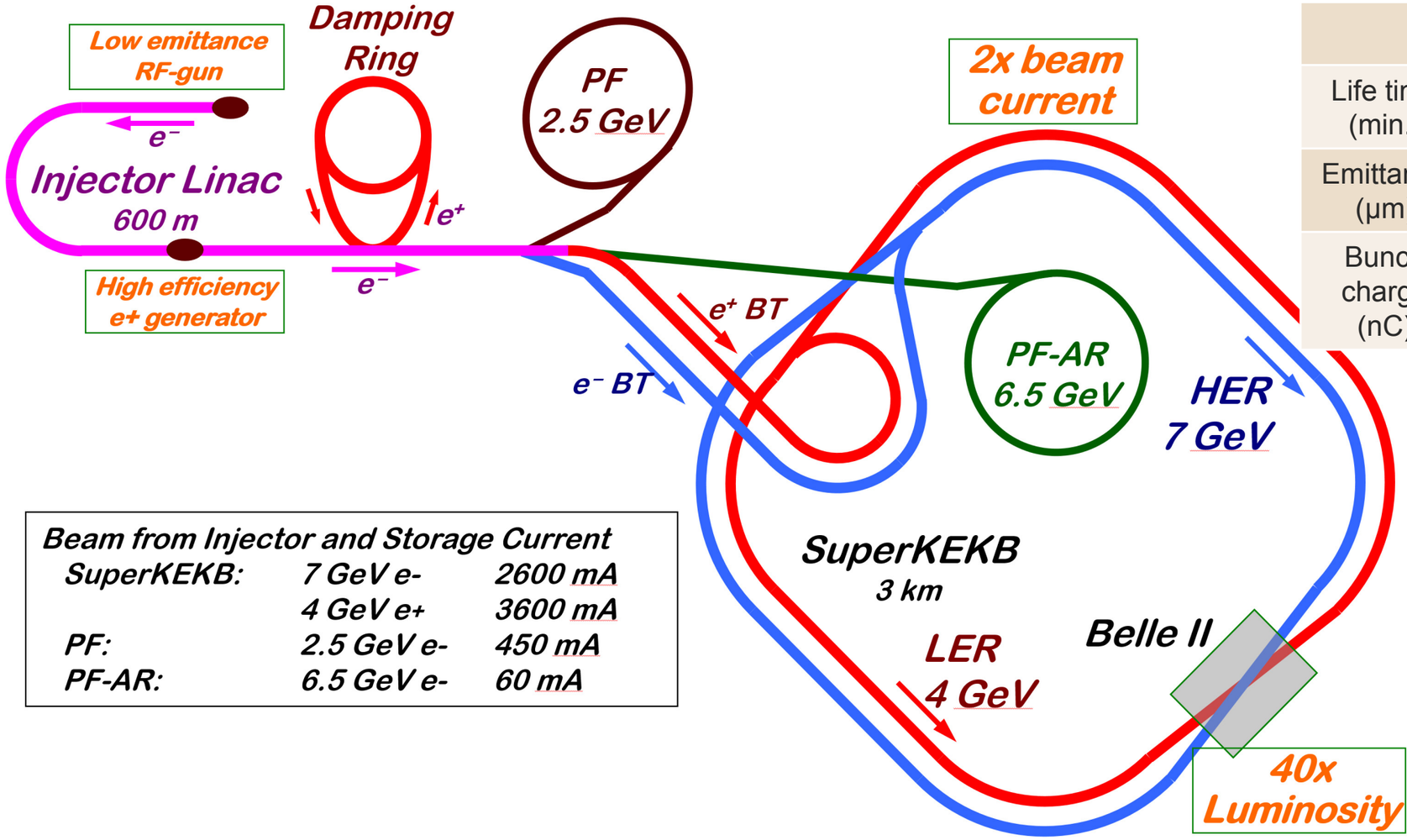

	KEKB		SuperKEKB	
	e^-	e^+	e^-	e^+
Life time (min.)	200	150	6	6
Emittance (μm)	310	1400	40/20 (H/V)	100/15 (H/V)
Bunch charge (nC)	1	1	4	4

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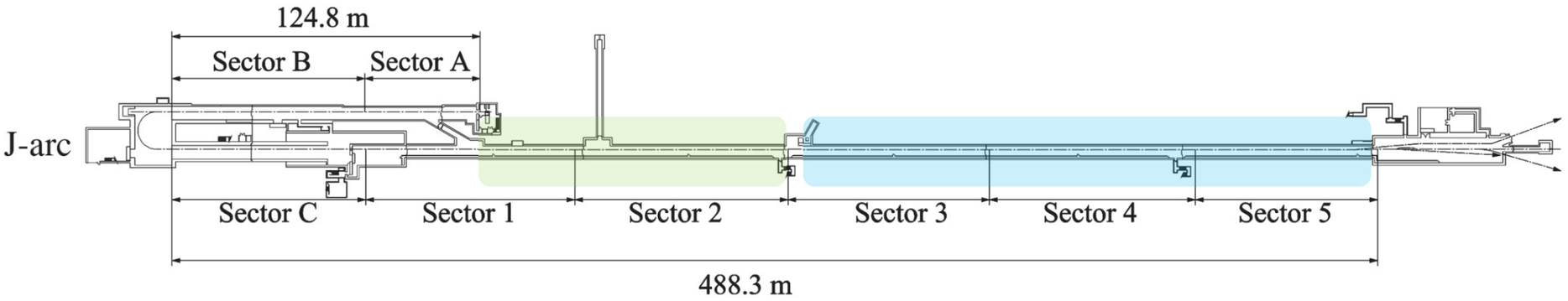
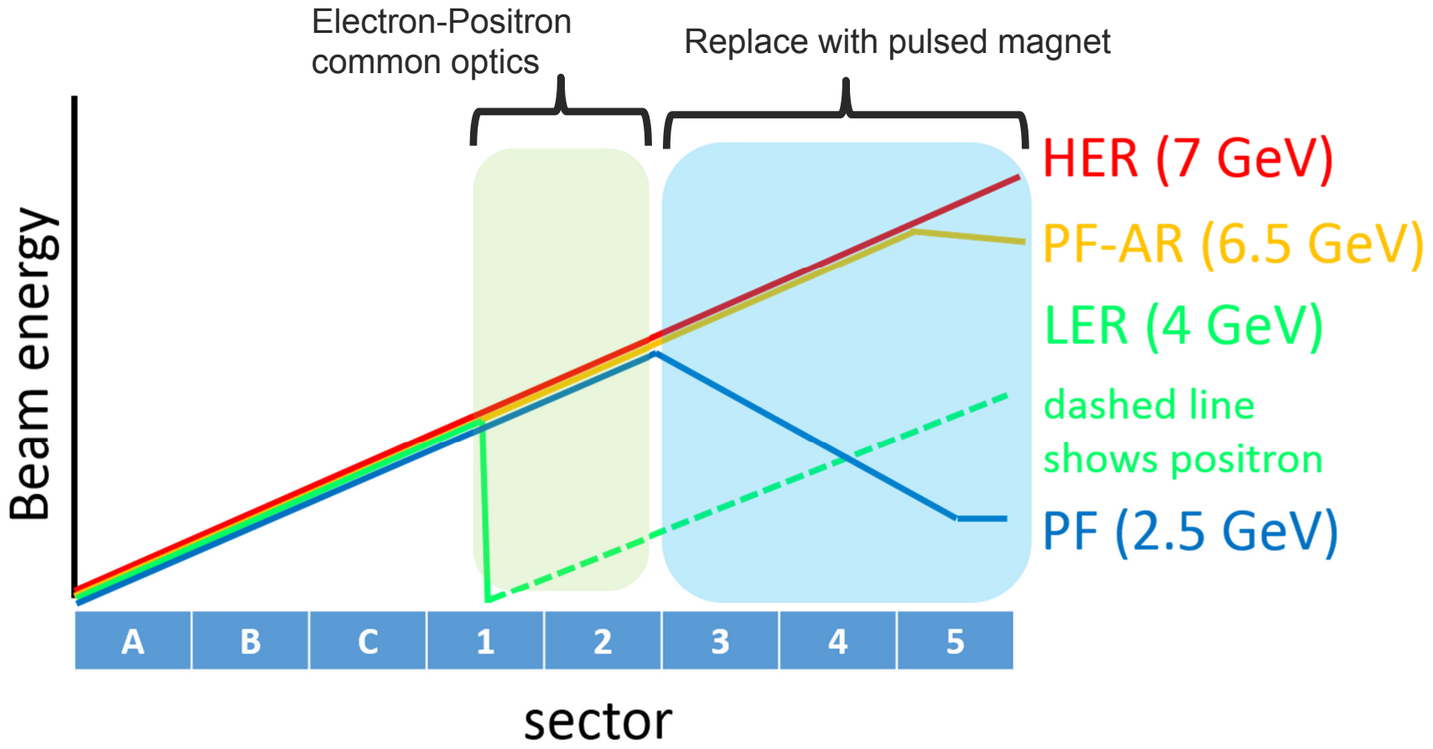
- very short life time
  - a few min. interruption of injection is not acceptable.
- small emittance and high bunch charge requirements
  - common parameter operation is no longer valid.

Simultaneous (shot by shot) injection with different magnet parameter at 50 Hz is necessary

Beam energy and structure of our linac





- 600 m long, 8 sectors
- Maximize common energy section to use DC magnets as much as possible
- Install pulsed magnets mainly in sector 3 to sector 5

Bend	2
Quadrupole	32
steering	58

How to realize?

- Requirements
  - Low cost and high reliability
    - We need 100 unit
  - Flexible setting
    - On / off control is not enough
  - Small size
    - compatible with old DC power supply
  - High efficiency
    - compatible with old DC power supply
  - MRF Event Timing System
    - Compatible with existent timing system
  - EPICS
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  - Use commercially available devices as much as possible for control system
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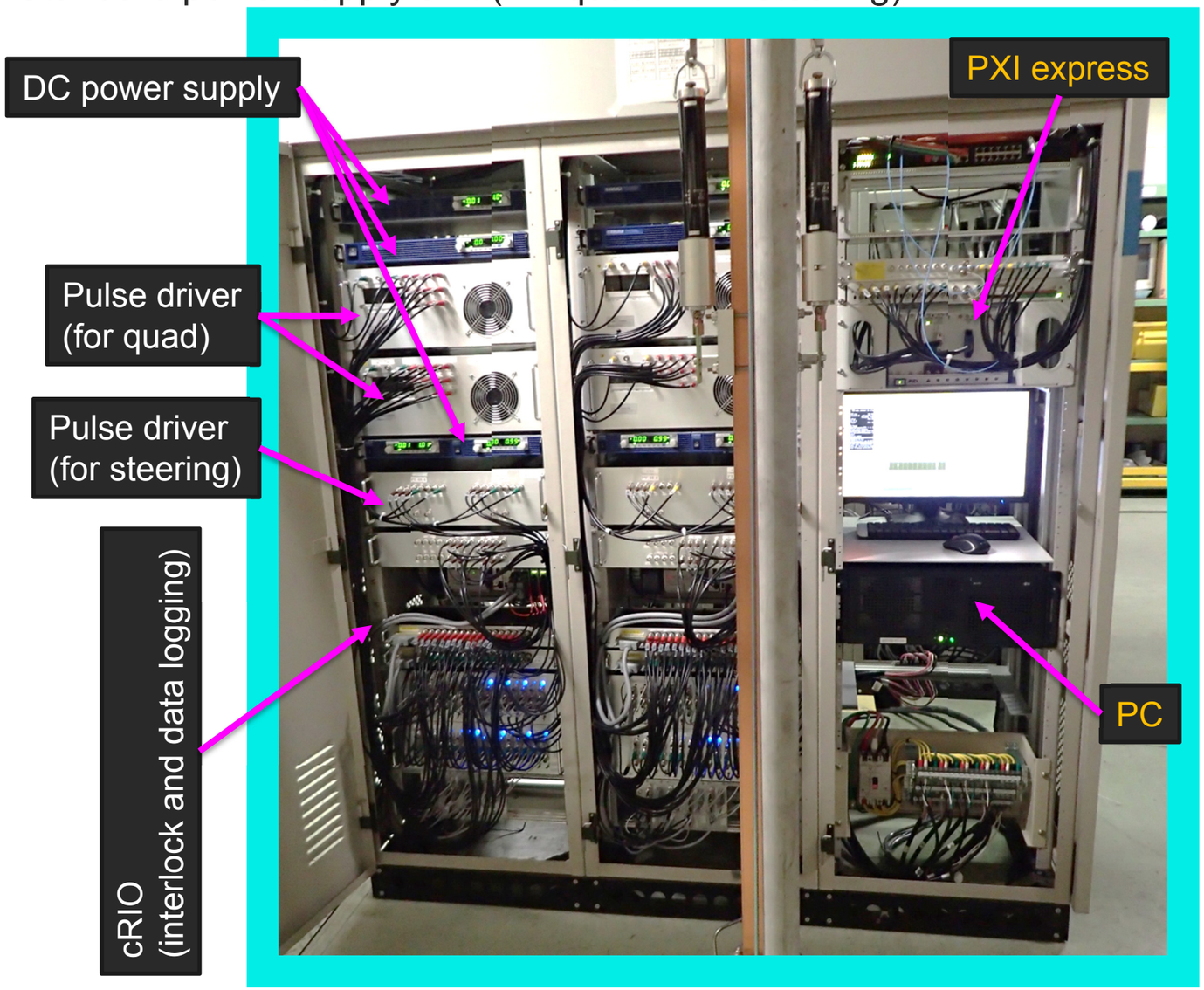
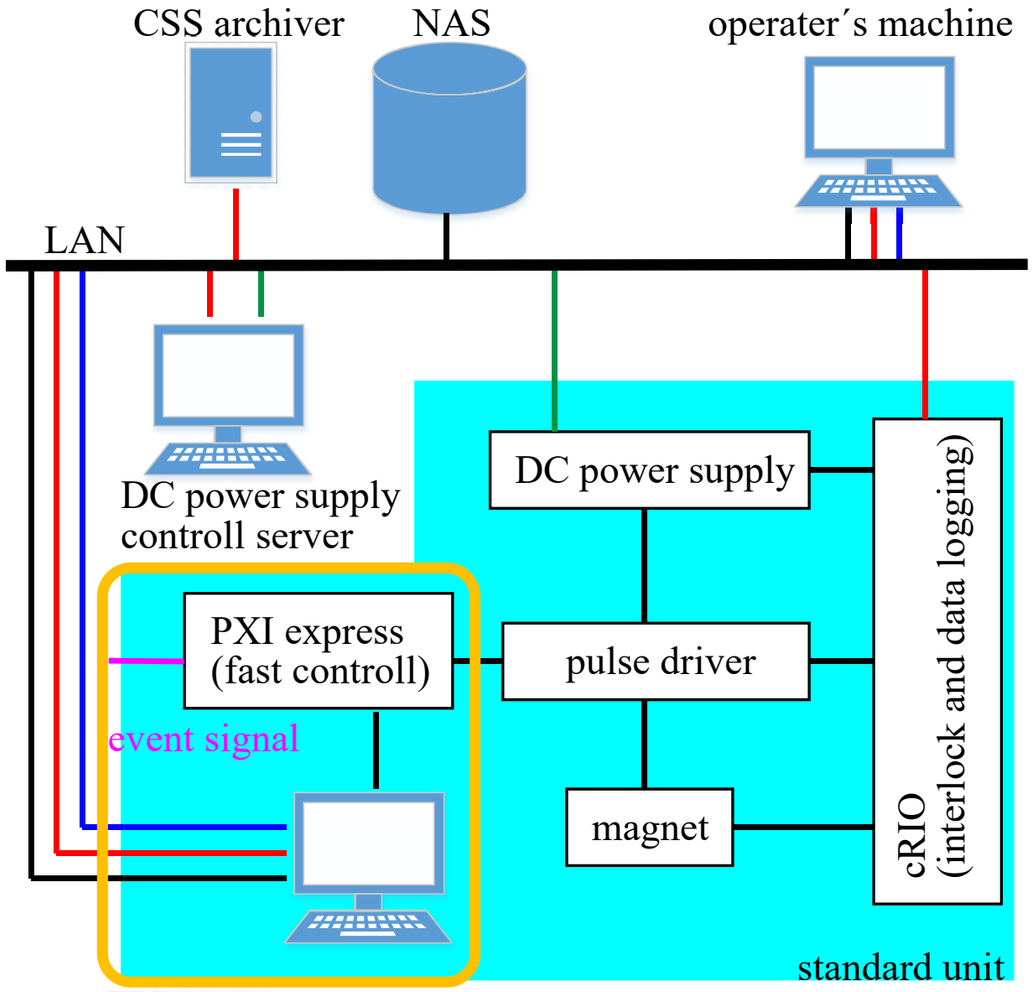
	Full custom		Catalog product
Suitable System scale	Large		Small
Development costs	High		Low
Development time	Long		Short
flexibility	High		Low

System configuration of the pulsed power supplies

Standard power supply unit (4 x quad + 4 x steering)



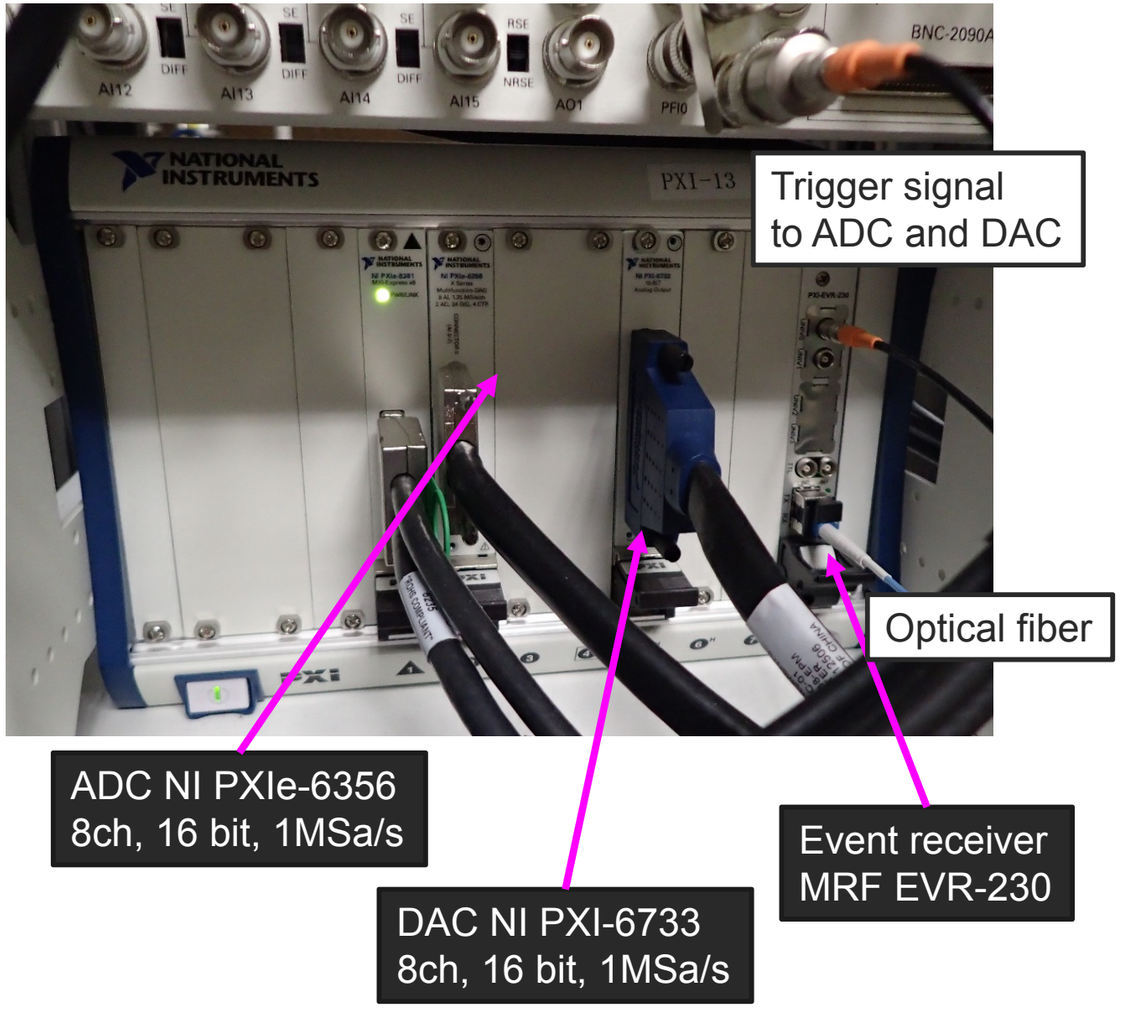


EPICS CA

LXI ver 1.3

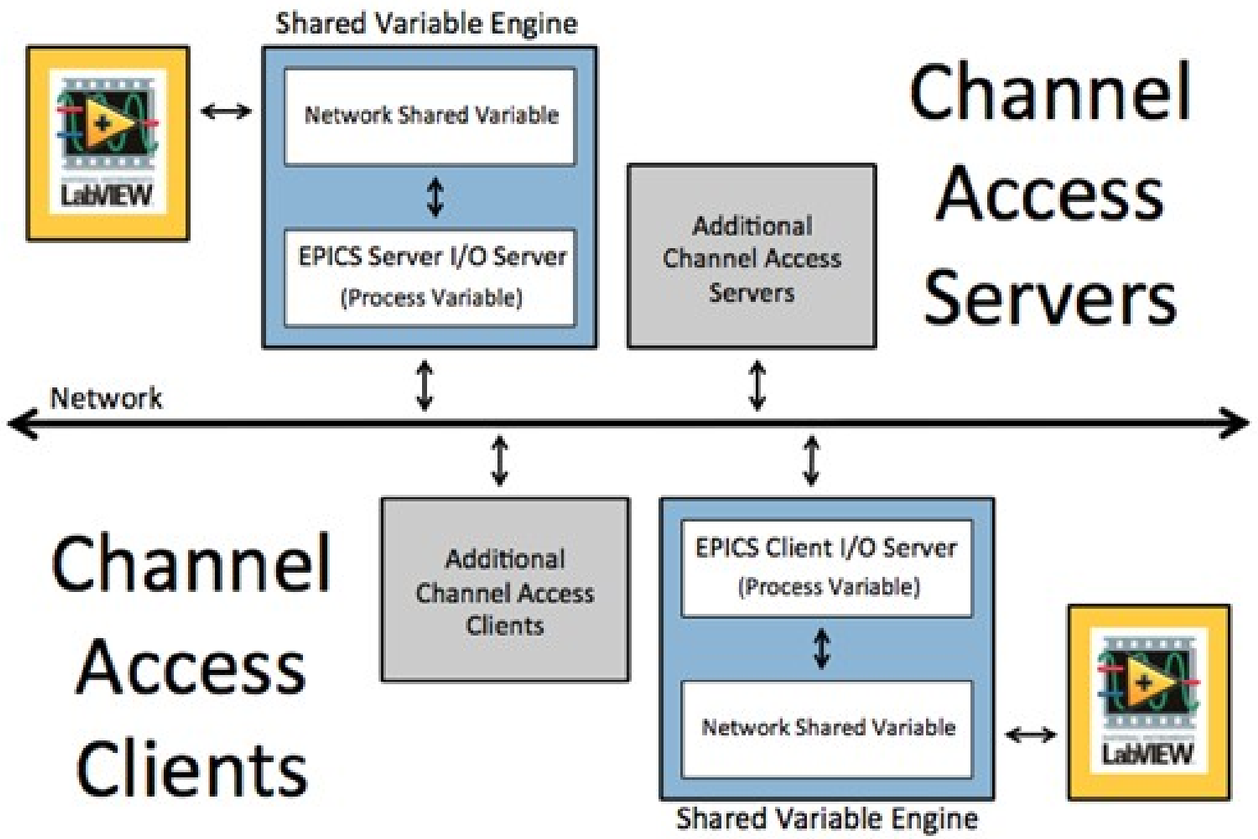
NI network shared variable

Timing and fast control

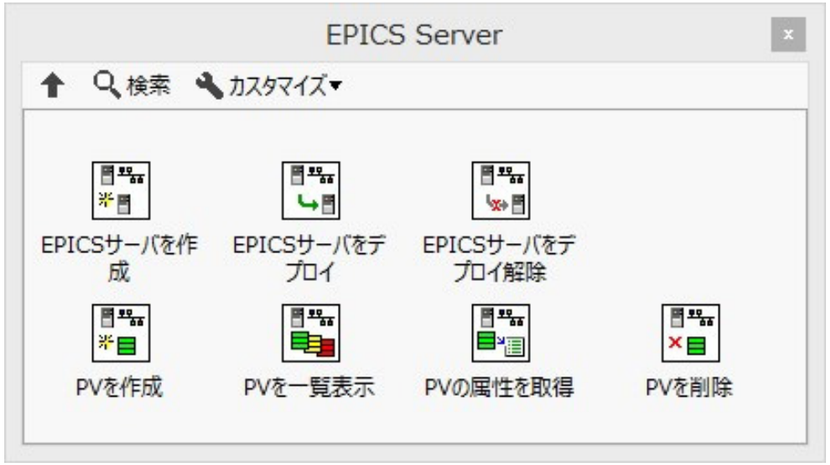


- PXI express system is adopted for fast control of the power supplies (8GB / s).
- All of the intelligent functions are processed by PXI express unit
  - Pulse driver works as a kind of power amplifier
  - Separation of control and power section makes it possible for us to flexible installation of different capacity of power supplies.
- MRF(Micro-Research Finland) event receiver with PXI form factor is used for timing control
  - MRF event timing system is used as a master timing system of our linac.
- Mode and shot ID information are sent to the event receiver via optical fiber
  - Mode determine the destination of the beam.
  - Shot ID is used for tagging the data.

EPICS and LabVIEW

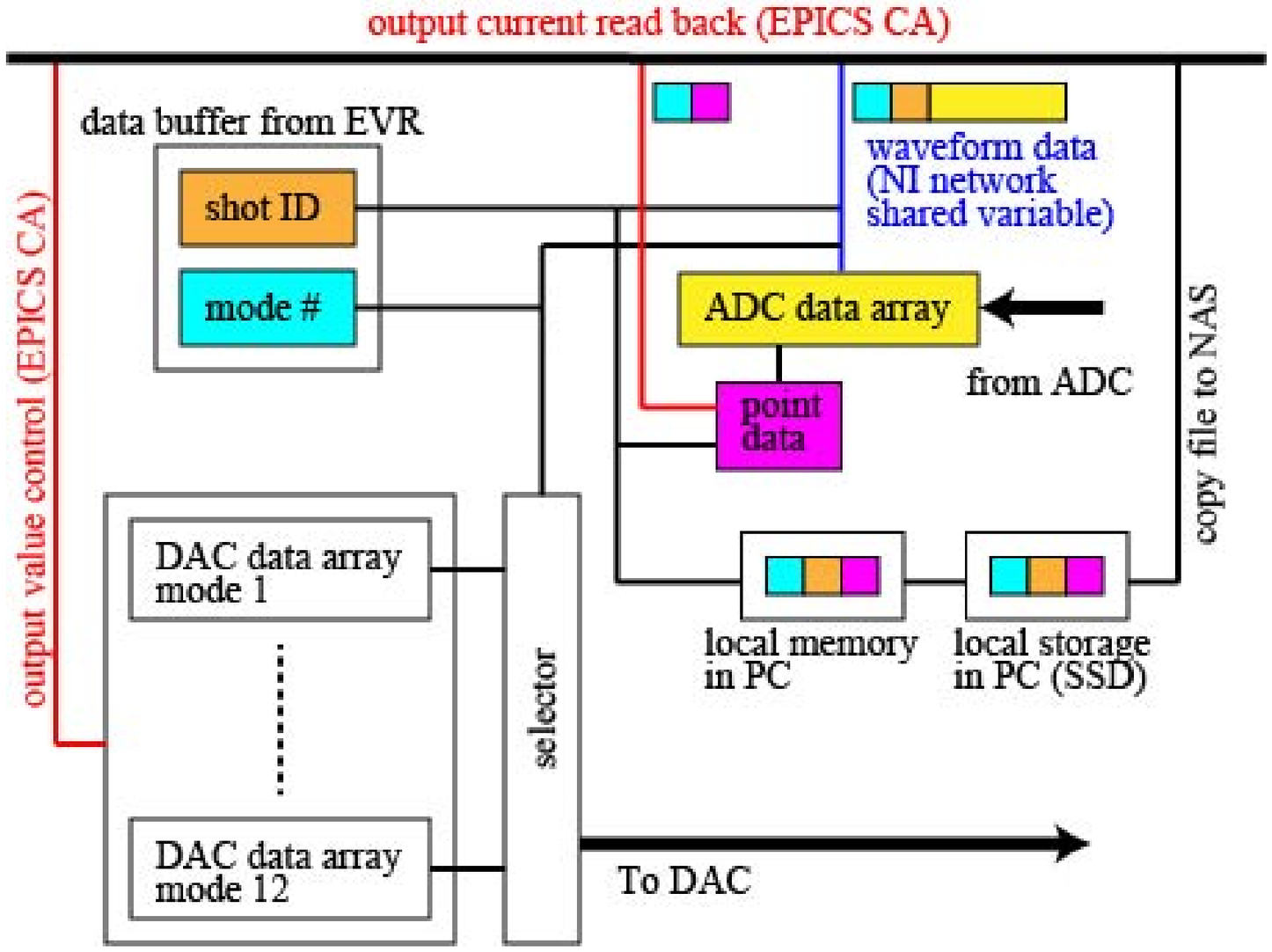


https://www.ni.com/ja-jp/innovations/white-papers/12/introduction-to-epics.html



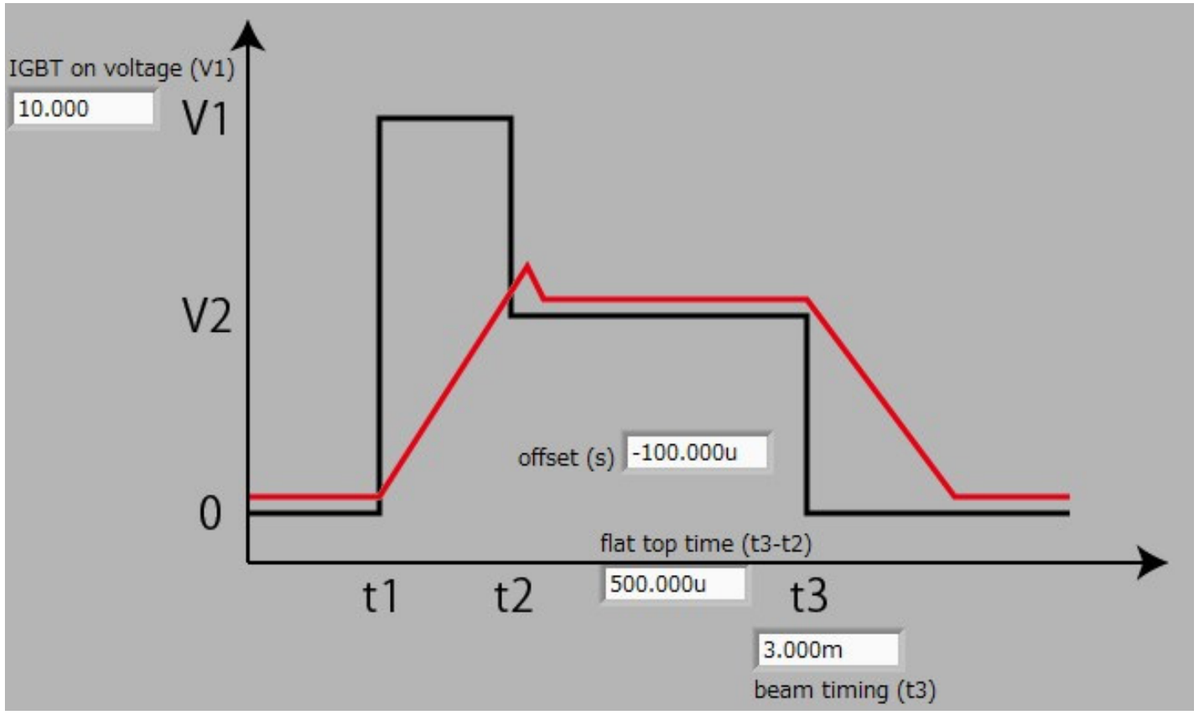
- Declare PVs
  - Dynamic declaration is possible only by LabVIEW running on Windows
- Get/put value
- Process by value change event

Data flow in main program

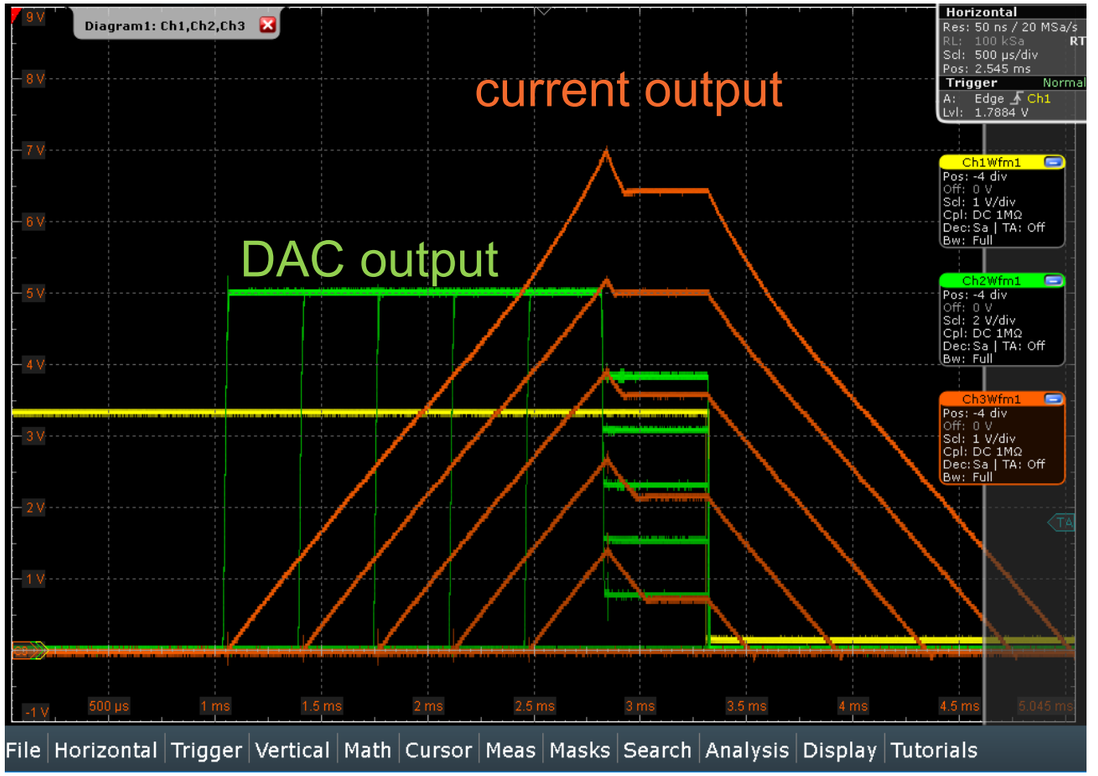


DAC output control

- Slew rate is limited by voltage of the power supply
- Beam timing t3 is fixed 3 ms after trigger pulse.
- Flat top width t2 is fixed 0.5 ms before t3
- V1 is always 10 V
- V2 is determined by value of output current
- t1 is calculated from other parameters
- DAC output is determined from these parameters



Minimize energy consumption



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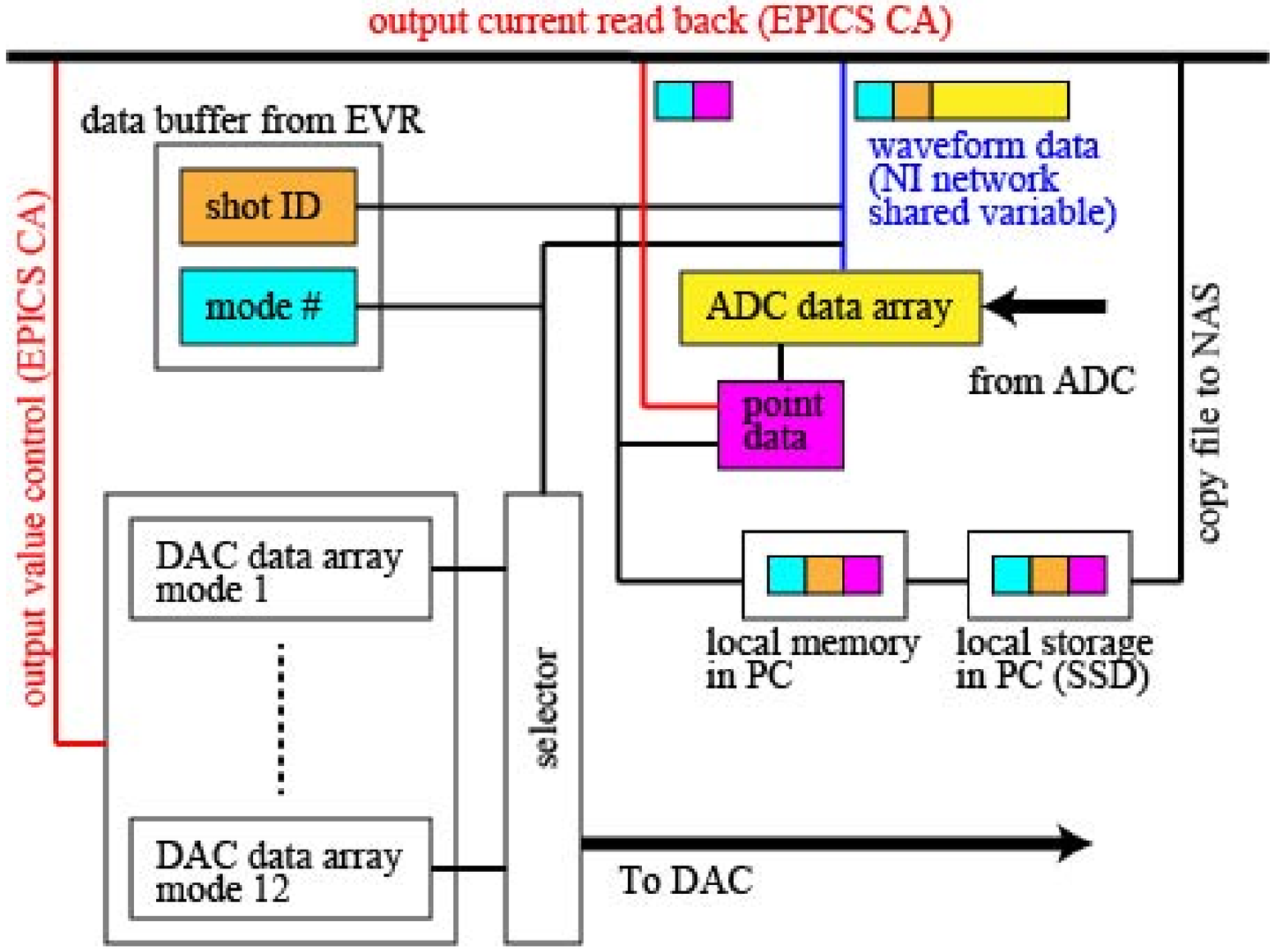

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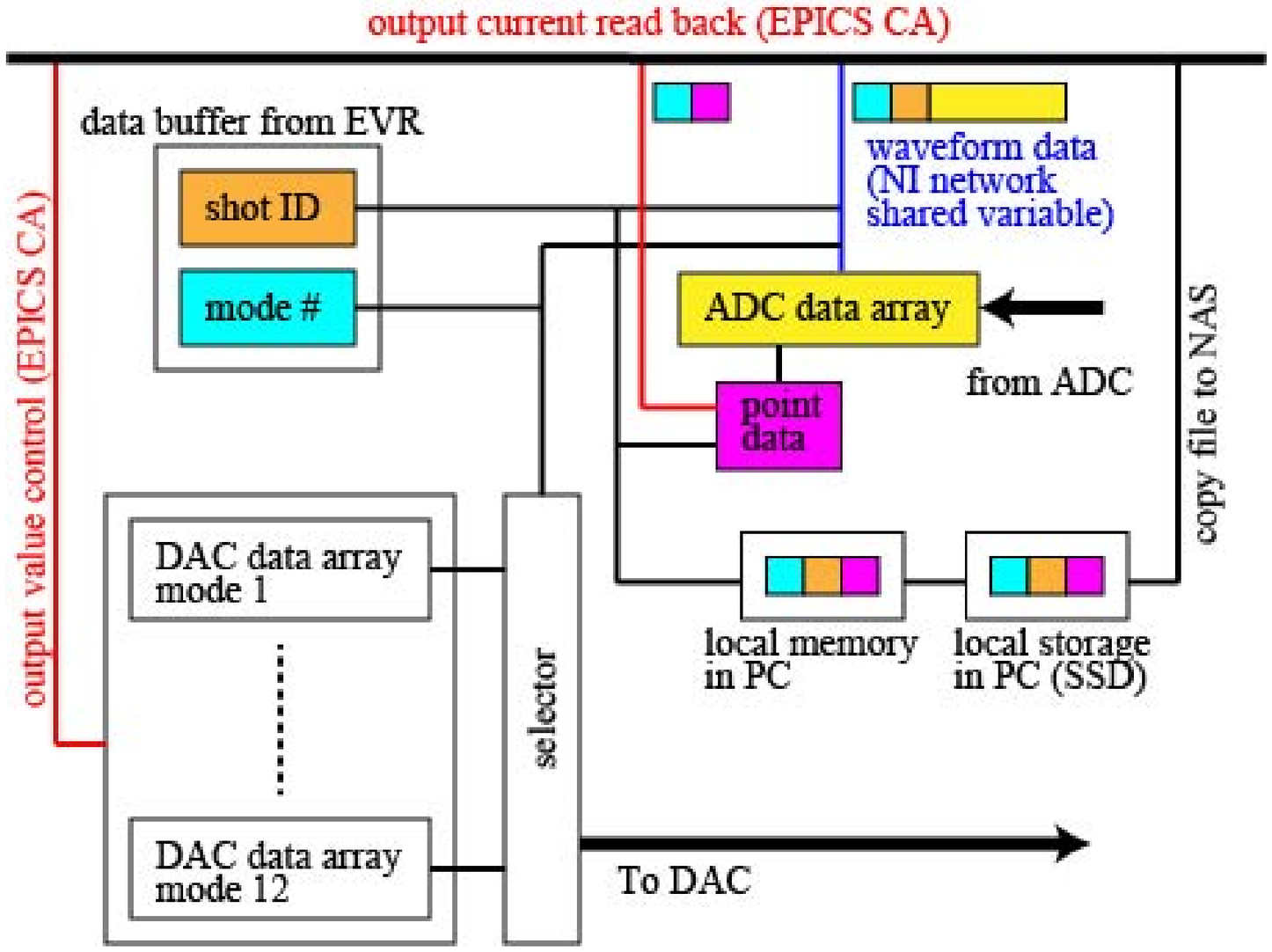

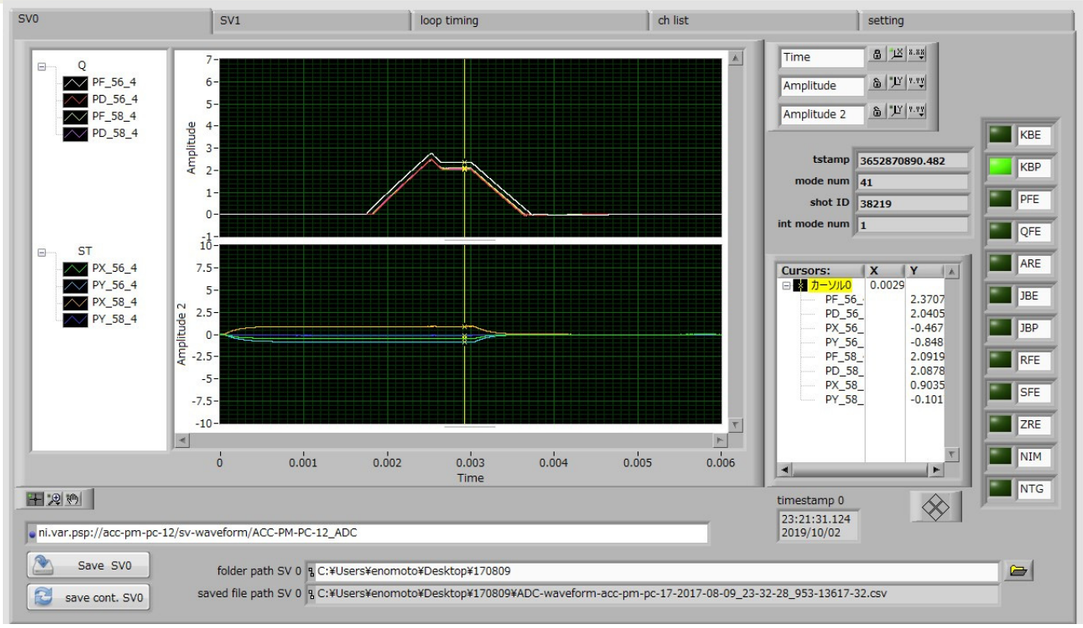

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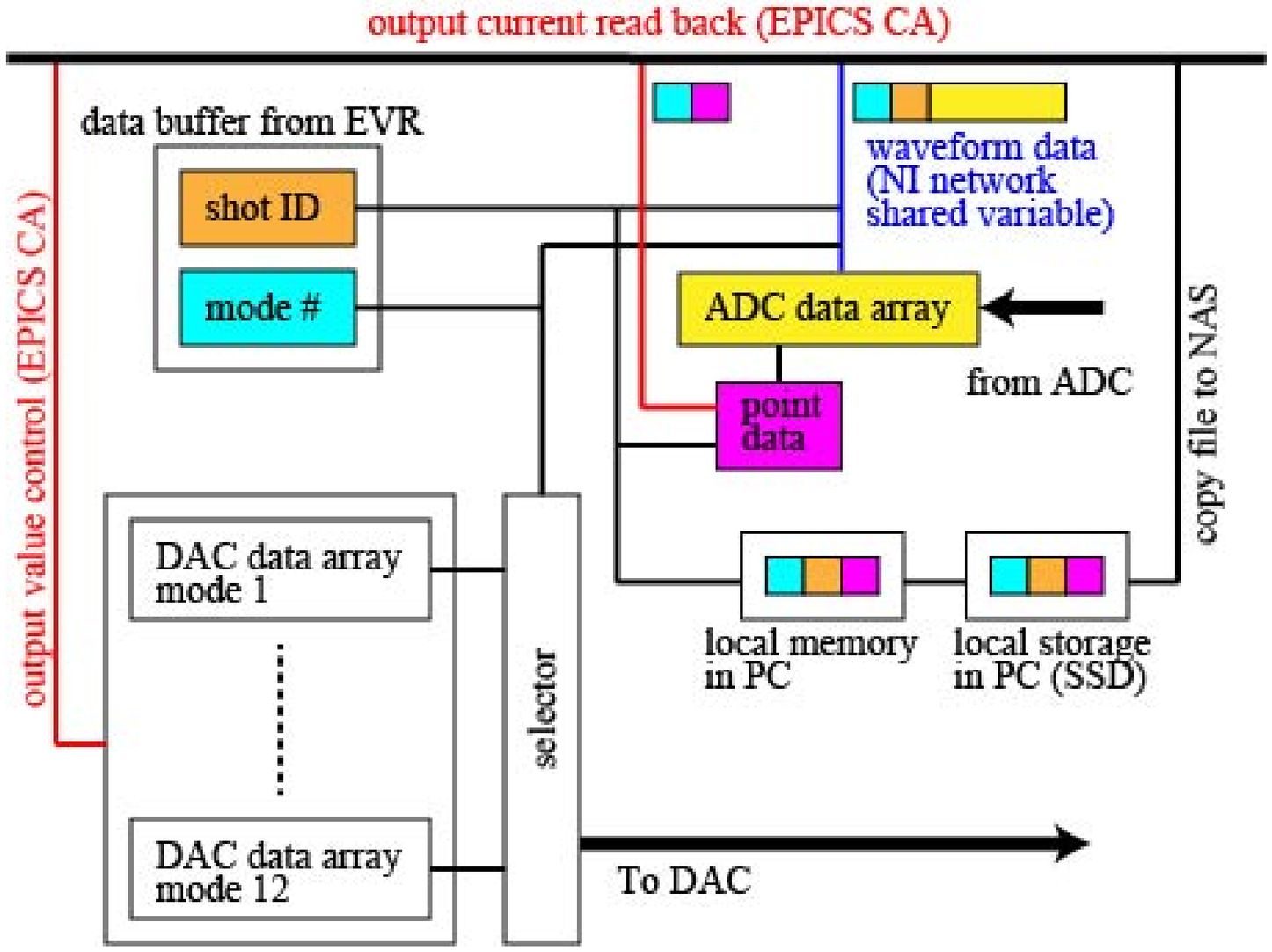

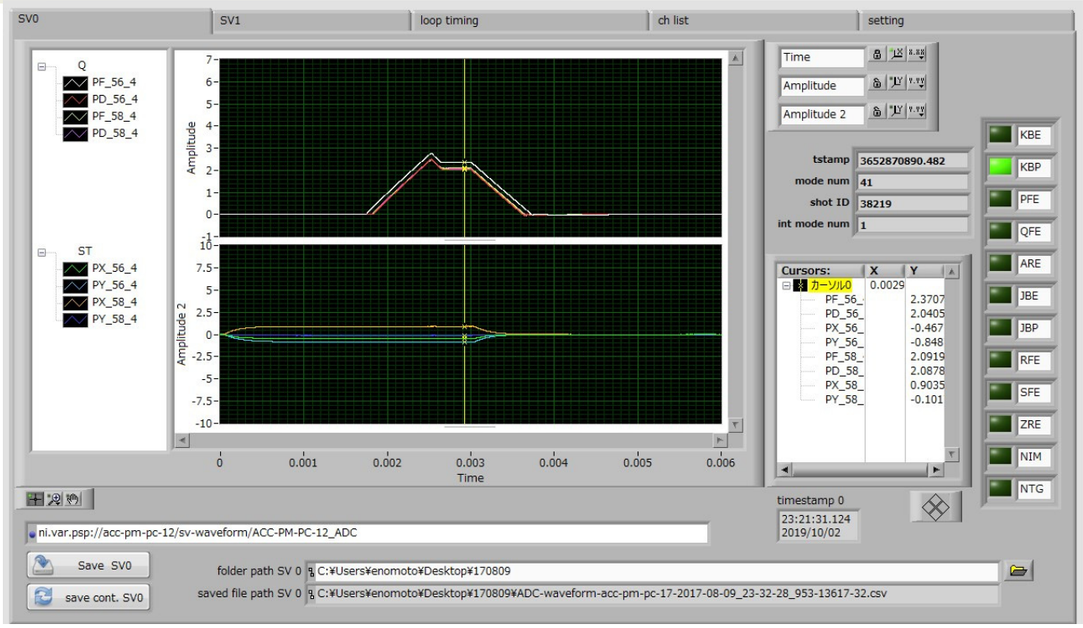

Point data (8 ch x 1 point @ beam timing) is extracted from ADC data array (8 ch x waveform) and stored in the PV with appropriate mode name

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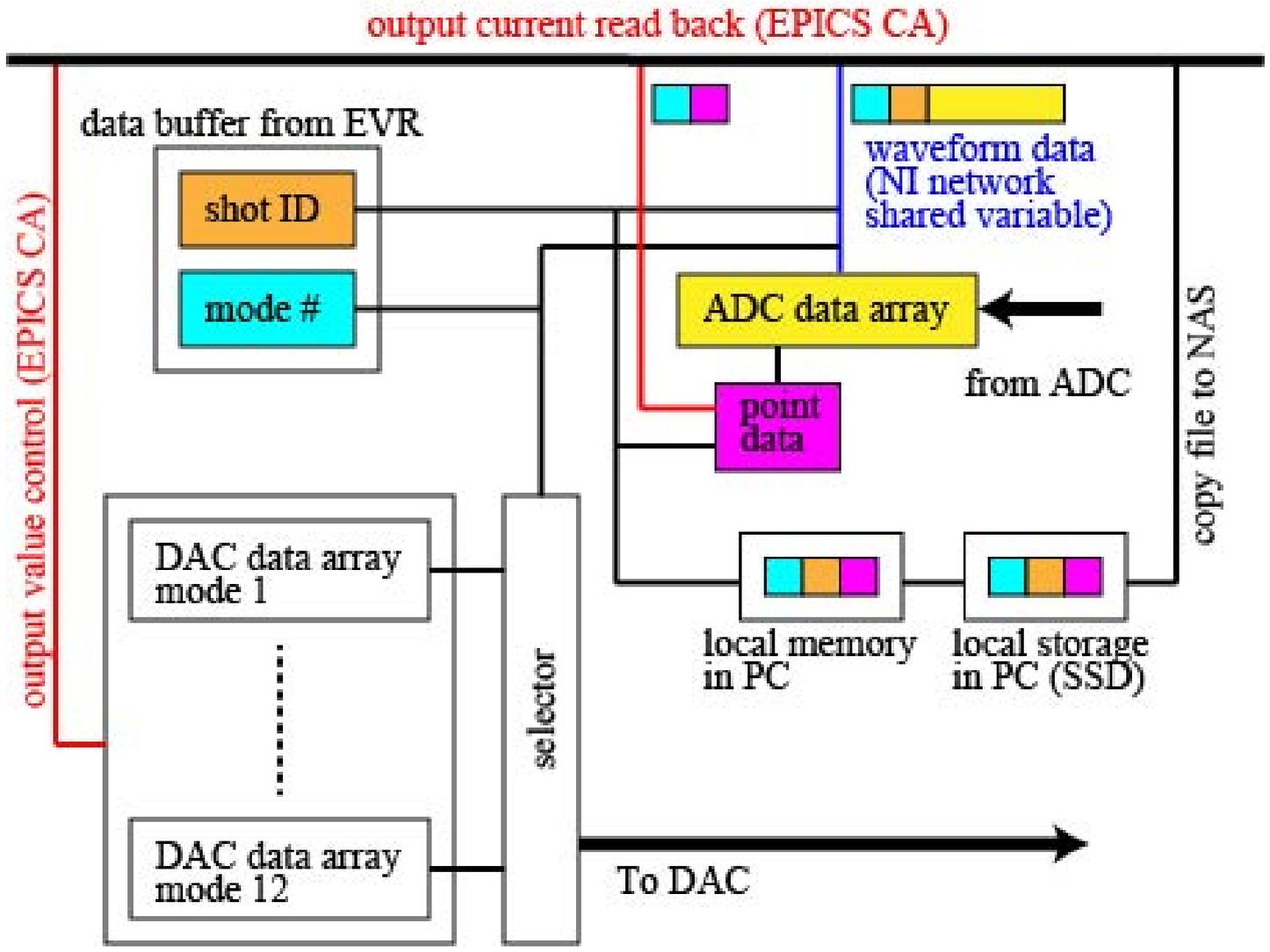

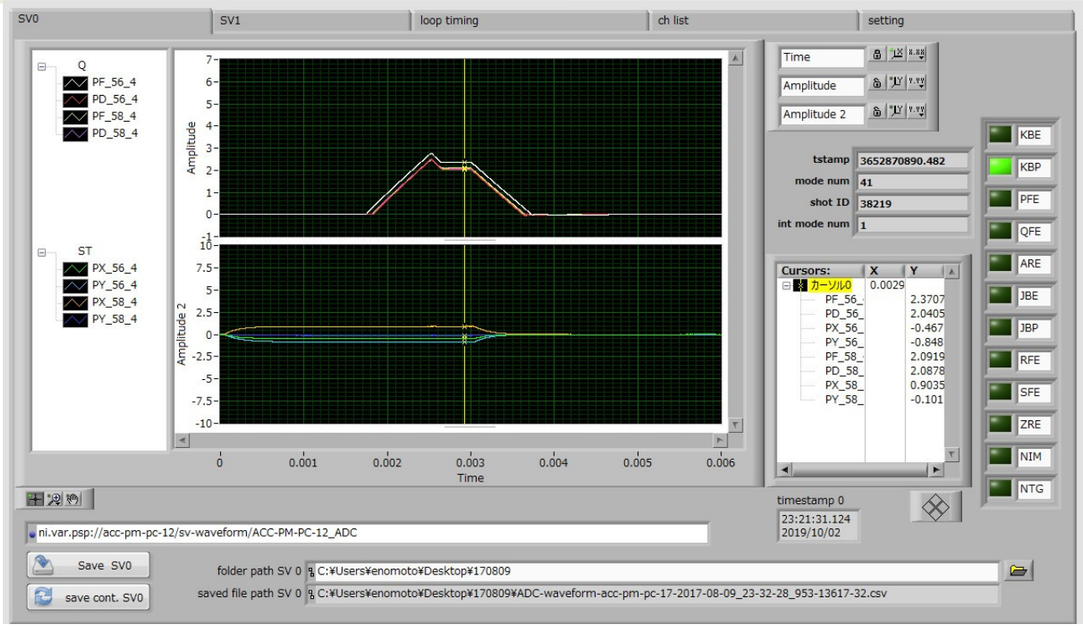

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Prefix:magnet name:type:mode
LIiMG:PF_32_4:IREAD_R:KBE
LIiMG:PF_32_4:IREAD_R:KBP
LIiMG:PF_32_4:IREAD_R:PFE
⋮

Data in log files

Mode number = destination of the beam

Current read back

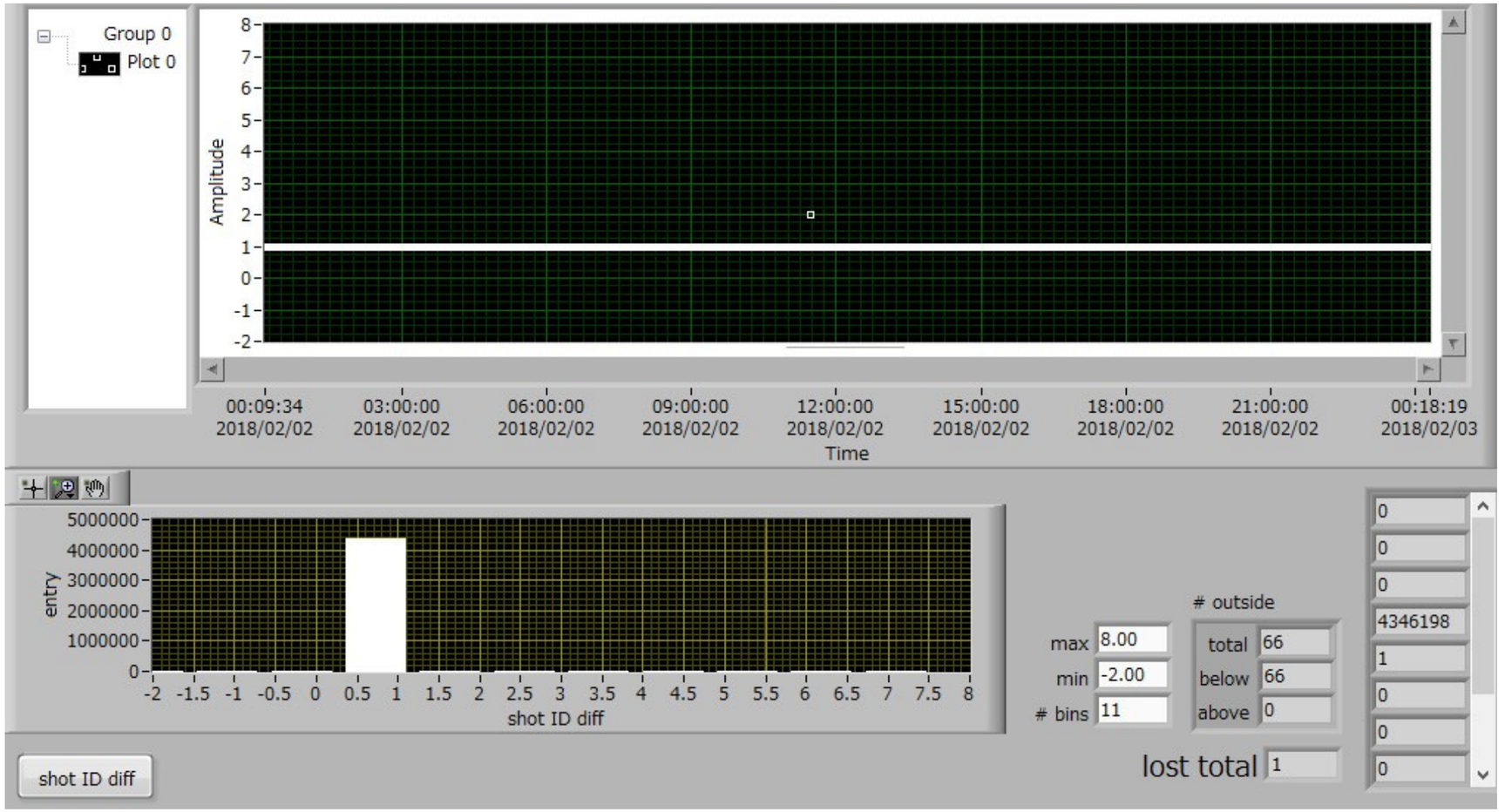
Current setting

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	tstamp	mode	shot_ID	internal_mode	ADC_ch0	ADC_ch1	ADC_ch2	ADC_ch3	ADC_ch4	ADC_ch5	ADC_ch6	ADC_ch7	DAC_ch0	DAC_ch1	DAC_
2	3652624504.919	181	39644	10	−0.0051	−0.0045	0.0002	0.0002	−0.0059	−0.001	−0.0006	−0.0007	−0.006	−0.0042	−0.
3	3652624504.940	181	39645	10	−0.0039	−0.0053	0	0.0003	−0.0059	−0.0011	−0.0009	−0.0011	−0.006	−0.0042	−0.
4	3652624504.959	181	39646	10	−0.0041	−0.0054	0.0001	0.0003	−0.006	−0.0009	−0.0006	−0.0005	−0.006	−0.0042	−0.
5	3652624504.979	41	39647	1	82.2347	82.2852	−2.9986	0.8595	86.363	88.5796	−1.6337	−0.2241	82.235	82.234	
6	3652624504.998	31	39648	0	158.9922	159.12	−2.5993	0.2494	169.0895	170.5758	−3.505	1.6445	158.79	158.79	
7	3652624505.020	181	39649	10	−0.0057	−0.0052	0.0003	0.0003	−0.0056	−0.0013	−0.0011	−0.0008	−0.006	−0.0042	−0.
8	3652624505.039	181	39650	10	−0.0035	−0.0052	−0.0001	0.0002	−0.0054	0.0008	−0.0011	−0.0007	−0.006	−0.0042	−0.
9	3652624505.059	181	39651	10	−0.005	−0.0054	0.0001	0.0004	−0.0048	0.0065	−0.0007	−0.0006	−0.006	−0.0042	−0.
10	3652624505.079	181	39652	10	−0.0047	−0.0052	0.0001	0.0003	−0.006	−0.0029	−0.001	−0.001	−0.006	−0.0042	−0.
11	3652624505.099	181	39653	10	−0.0026	−0.0056	0.0002	0.0003	−0.0056	0.0013	−0.0009	−0.0006	−0.006	−0.0042	−0.
12	3652624505.119	181	39654	10	−0.0047	−0.0053	0	0.0001	−0.0059	−0.002	−0.001	−0.0008	−0.006	−0.0042	−0.
13	3652624505.139	181	39655	10	−0.0047	−0.0059	0.0001	0.0002	−0.0059	−0.0027	−0.0007	−0.0007	−0.006	−0.0042	−0.
14	3652624505.159	181	39656	10	−0.003	−0.0056	−0.0001	0.0003	−0.0053	−0.0005	−0.0004	−0.0004	−0.006	−0.0042	−0.
15	3652624505.179	41	39657	1	82.223	82.2783	−2.9988	0.8593	86.3677	88.5721	−1.6339	−0.2243	82.235	82.234	
16	3652624505.198	31	39658	0	158.977	159.1255	−2.5993	0.2493	169.0817	170.5824	−3.5052	1.644	158.79	158.79	
17	3652624505.218	181	39659	10	−0.0048	−0.0053	0.0004	0.0005	−0.0055	−0.0008	−0.0014	−0.0009	−0.006	−0.0042	−0.

Each low contains information about each pulse.

A new file is created when the size of previous one is larger than 10 MB.
Data size is about 3 TB / year in total.

Trigger dropping rate



Difference of shot ID between adjacent pulses from log data for one day.

- A few drop per day for one unit
- 50 Hz x 24 hour x 3600 sec = 4.32 million
- Dropping rate is less than 1 ppm

Even though Windows in not a real-time OS, practically it works as we want.
This is a kind of brute-force solution.
Machine power and careful software writing is important.

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- Concern about long term stability of the LabVIEW on Windows. (I was asked by many people….)

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Not perfect but acceptable

There are many devices which is less stable than this one….

summary

- About 100 pulsed magnet were installed to realize simultaneous top up injection to 4 different storage rings
- Setting current and destination can be changed every 20 ms
- COTS devices are used for control system to reduce development cost and time
- PXI / PXI express with MRF's Event Timing System is adopted
- Software is written by LabVIEW with EPICS modules.
- Real-timeness and long term stability are not perfect but acceptable for present operation.

members

- K. Furukawa
  - Adviser, management of the project, timing system
- T. Kamitani
  - Magnet design
- F. Miyahara
  - Timing system
- T. Natsui
  - Energy recovery pulse driver
- M. Satoh
  - Timing and control system, software
- K. Yokoyama
  - Magnet design
- M. Yoshida
  - Energy recovery pulse driver
- S. Ushimoto
  - cRIO interlock and data acquisition system
- H. Satome
  - Device driver for event receiver

Thank you
for your attention!