BPM Data Acquisition System for KEK e-/e+ Injector Linac (Previous, Current, and Future System)

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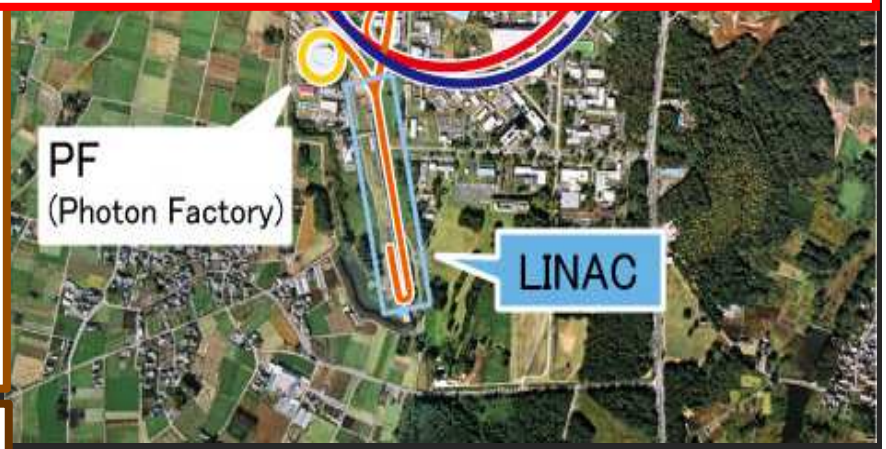
Overview of Linac Beam Operation

Accelerator Complex in KEK Tsukuba Campus

- Linac
  - 600-m-long e-/e+ injector

Four rings share one injector linac

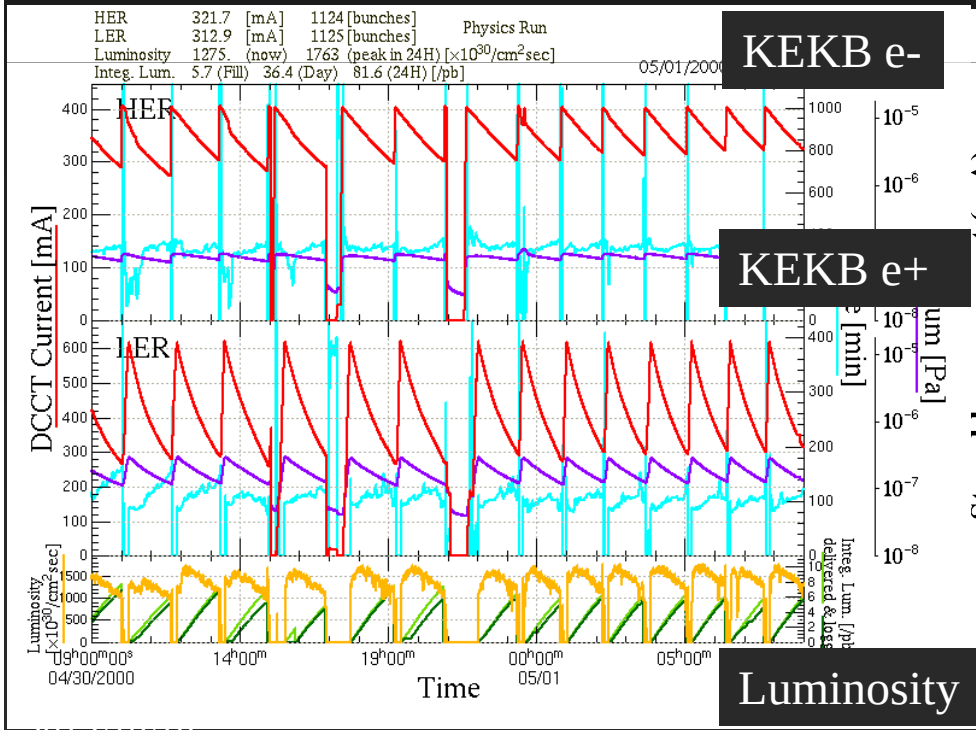
  - KEKB (shutdown in 2010)
    8 GeV e- 1 nC x2 bunch
    3.5 GeV e+ 1 nC x2
    (10 nC primary e–)



- Two Light Sources:
  - PF 2.5 GeV e- 0.1 nC
  - PF-AR 3 GeV e- 0.2 nC

Original Beam Operation for KEKB e-/e+, PF

- KEKB e-/e+ : every 90 min.
- PF (PF-AR) : twice daily

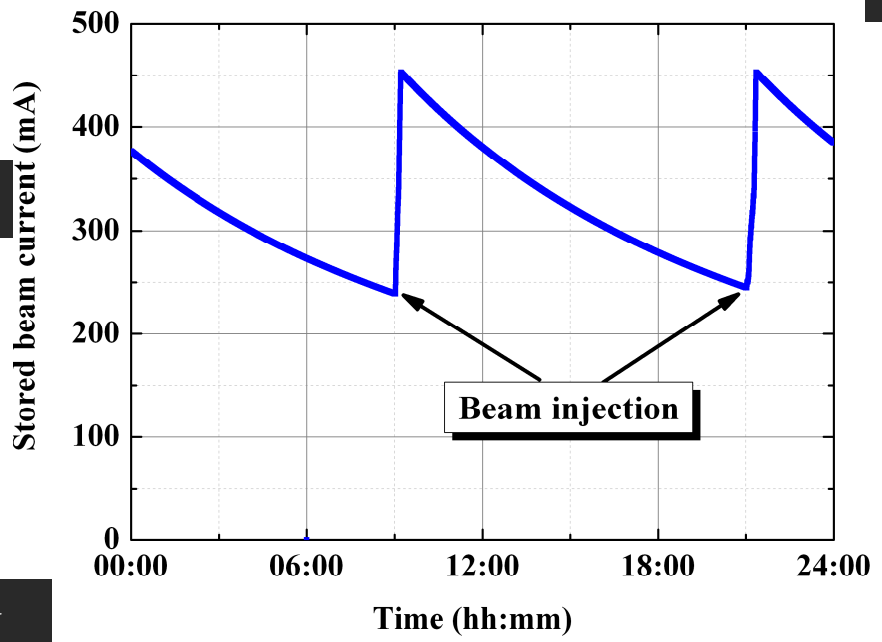


KEKB e-

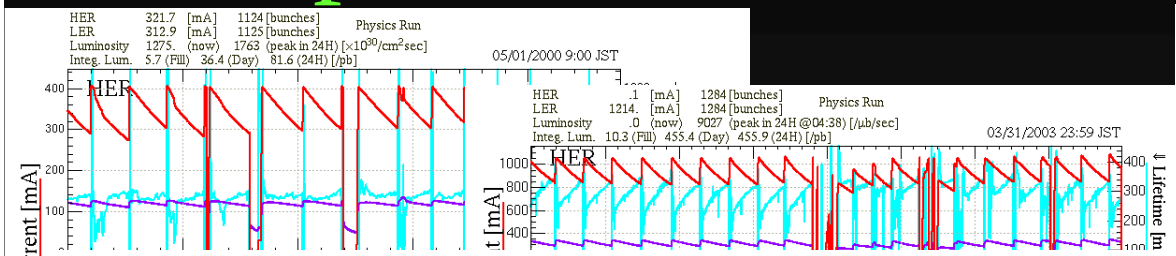
KEKB e+

Luminosity

PF



Improvement of KEKB Injection



Continuous inj.

(2005)

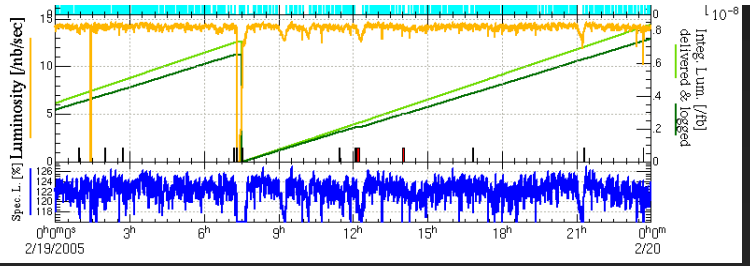
- Further stability of stored current
- KEKB and PF top-up at the same time

90 min.

(2000)

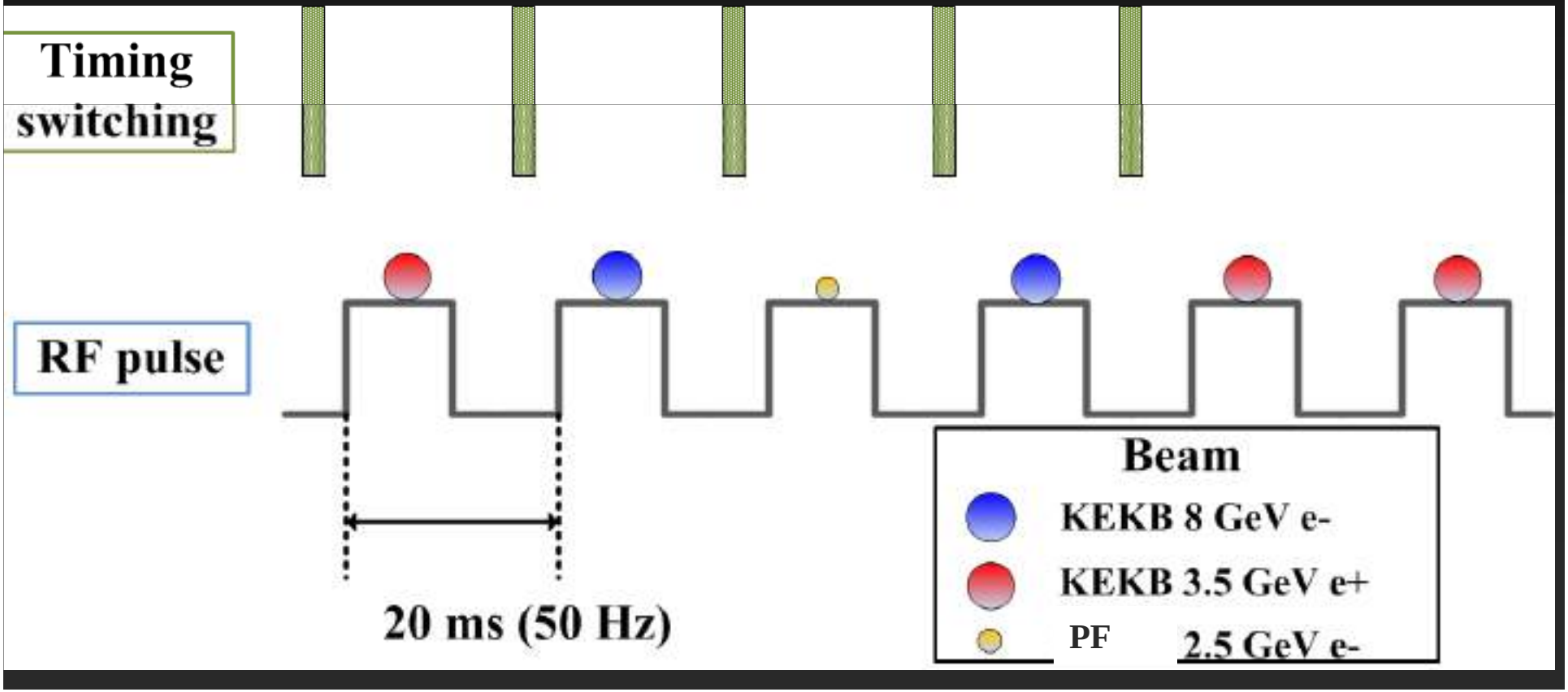
2 bunch inj.

(2003)



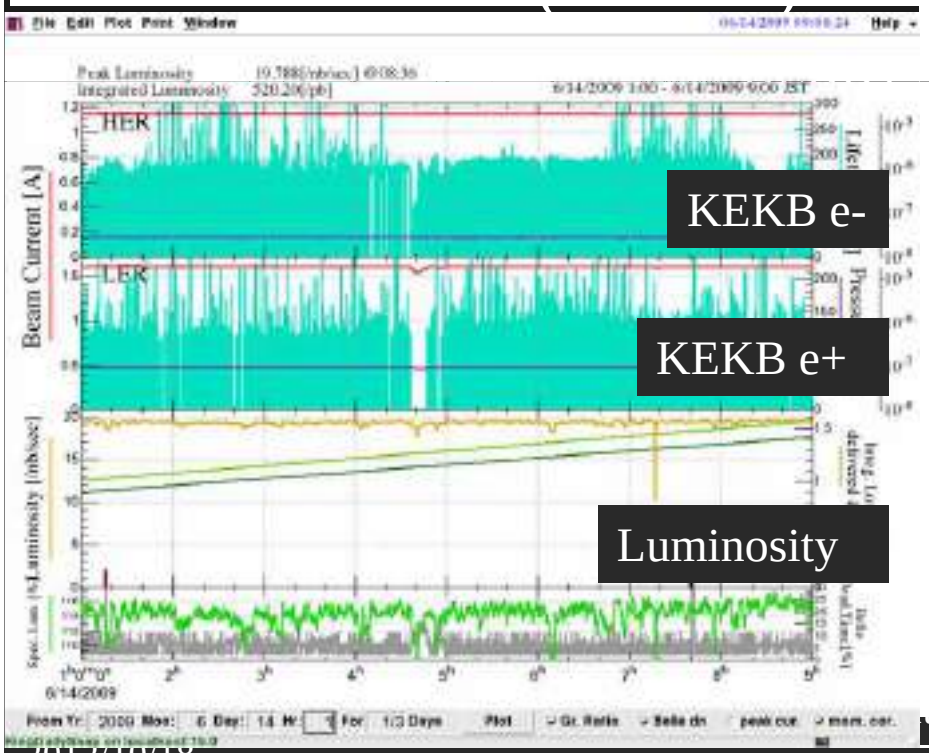
Fast Linac Parameter Switching

- Common DC magnet setting for different beam mode
- Several pulsed steering magnet
- Event-based timing system and fast LLRF phase control

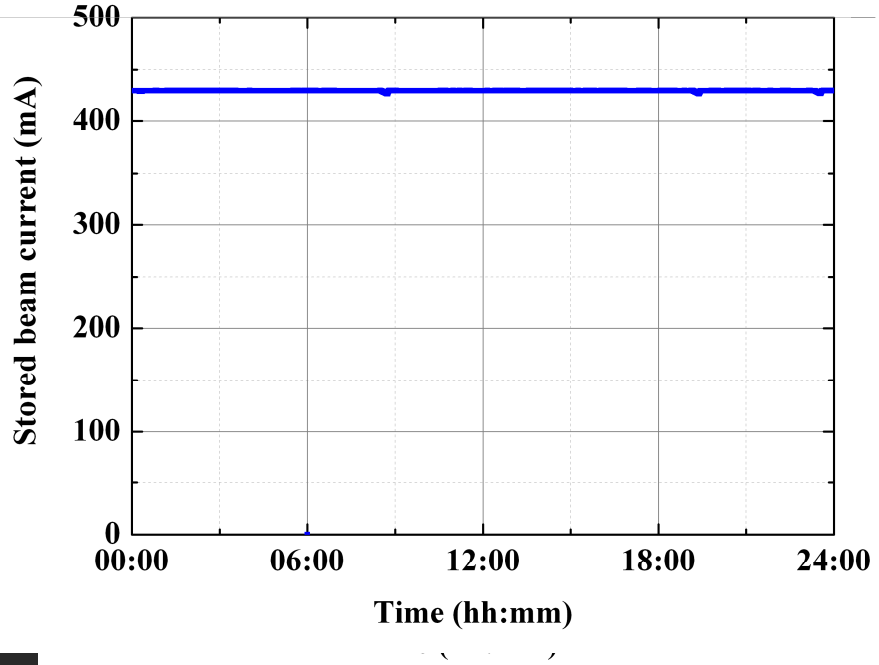


Simultaneous Top-up Injection

- Stored beam current stability since Apr. 2009
  - KEKB: 1 mA (~ 0.05%) : e-: 12.5 Hz, e+: 25 Hz
  - PF: 0.05 mA (~ 0.01%) : 0.5 Hz



PF



BPM and Previous DAQ System

Linac BPM System

- BPM x 100 for 600-m-long Linac
  - Stripline-type (four electrodes)
  - Installed at Quad
  - Position and Charge measurement
  - Orbit and Energy Feedback

- DAQ System
  - x 20 DAQ Stations

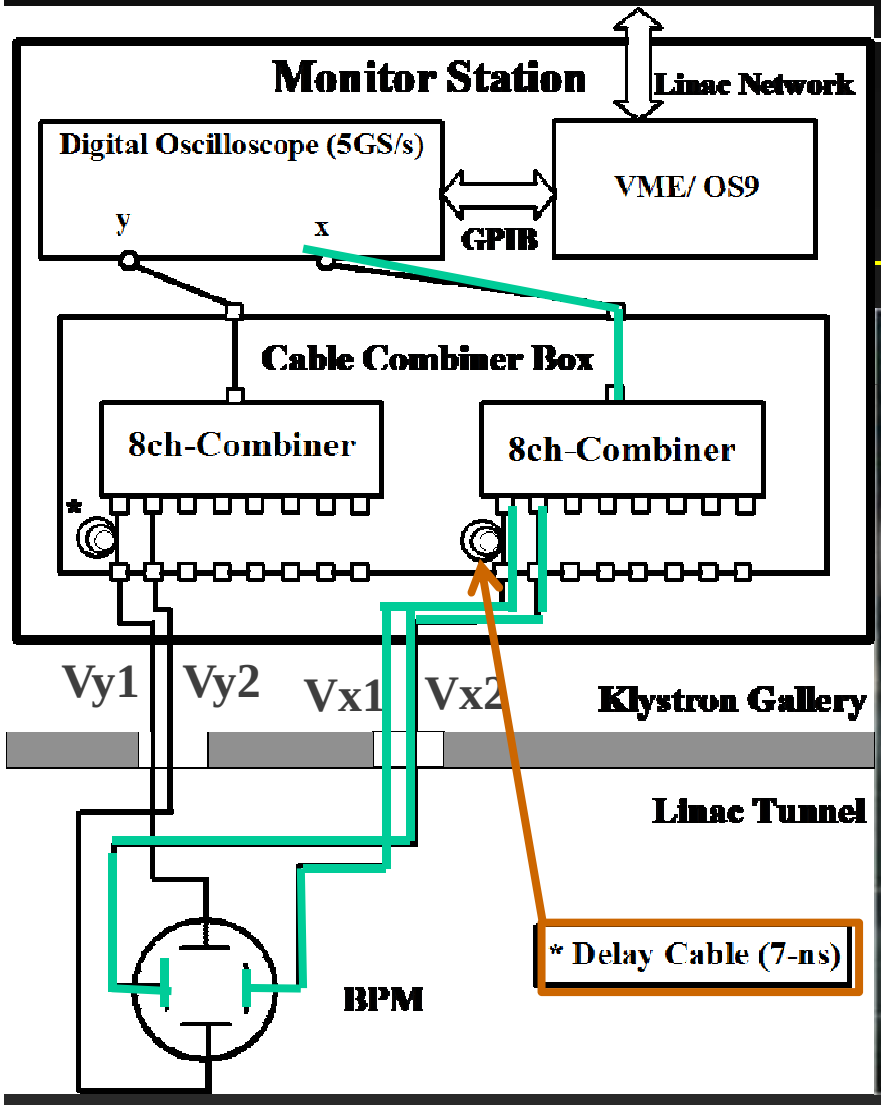
  (One DAQ station typically handle BPMx4)

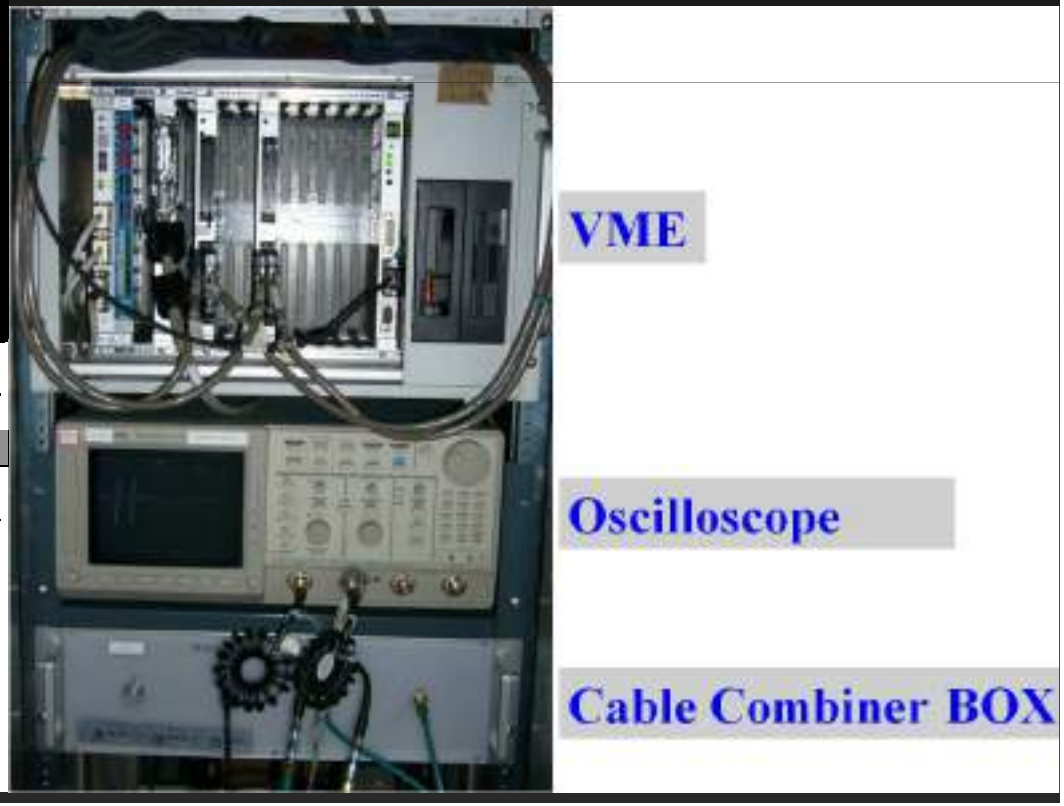
– Oscilloscope (Tektronix TDS680B)

– VME CPU (OS-9/ MC68060 50 MHz)

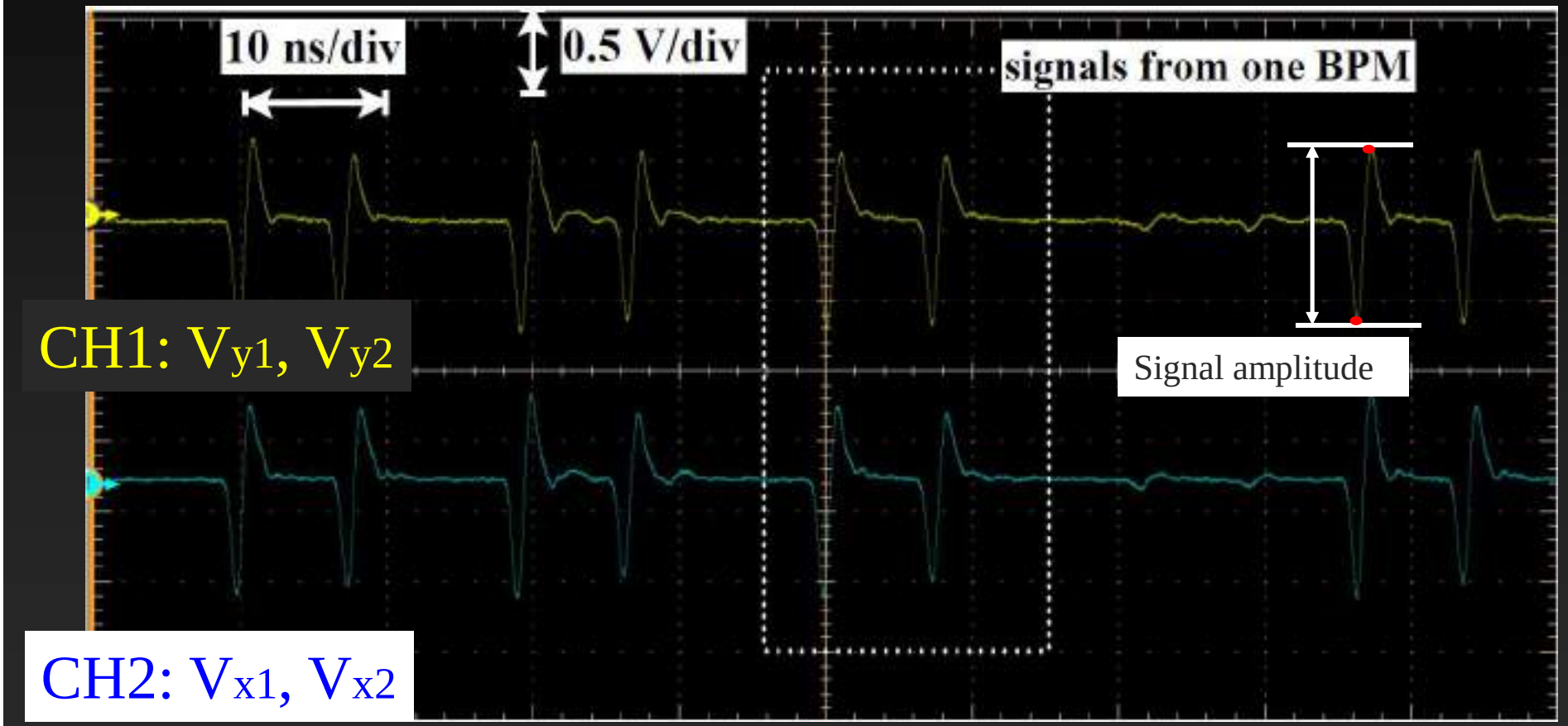
– 5 GSa/s, 8 bit, 2ch, 1 GHz BW, GPIB (low noise immunity)

– DAQ rate: ~1 Hz



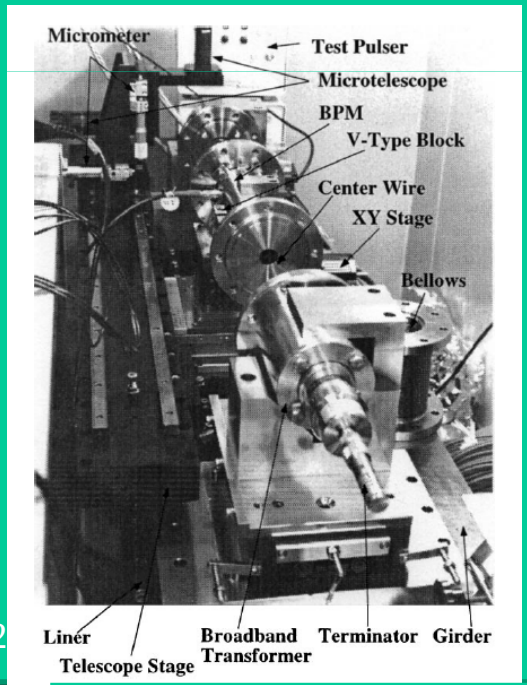


Analog signal from BPM

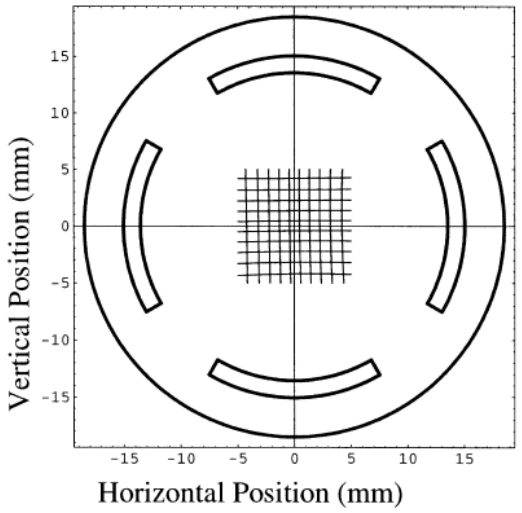


Beam Position Calculation

- Measured amplitude is used
- Ordinary Δ/Σ method
- Third order polynomial from mapping data
- Beam charge: sum of amplitude and calibration coefficient
- Position measurement precision (3-BPM): σx,y ~ 100 μm



Mapping data measurement



$$x = \sum_{i,j=0}^{3} a_{ij}(\Delta_x/\Sigma_x)^i(\Delta_y/\Sigma_y)^j$$

$$y = \sum_{i,j=0}^{3} b_{ij}(\Delta_x/\Sigma_x)^i(\Delta_y/\Sigma_y)^j$$

$$Q = G\sum_{k=1}^{4} g_k V_k \,.$$

Here,

$$\Delta_x = g_1 V_1 - g_3 V_3, \quad \Sigma_x = g_1 V_1 + g_3 V_3$$

$$\Delta_y = g_2 V_2 - g_4 V_4, \quad \Sigma_y = g_2 V_2 + g_4 V_4$$

T. Suwada et al., NIM A 440 (2000) pp.307-319

3-BPM for precision evaluation

- Synchronized measurement of three BPMs by changing beam orbit

- Using multiple linear regression analysis
  - Determine coefficients A, B, C from measured position (X1 ~ X3)

$$x_3 = Ax_1 + Bx_2 + C$$

  - Compare measured X3 and predicted X3 from above Eq.

$$\sigma_{\mathrm{BPM}} = \left(\frac{1}{N-1} \cdot \frac{\sum_i^N (x_{3,i} - (Ax_{1,i} + Bx_{2,i} + C))^2}{1 + A^2 + B^2} \right)^{1/2}$$

T. Suwada et al., NIM A 440 (2000) pp.307-319

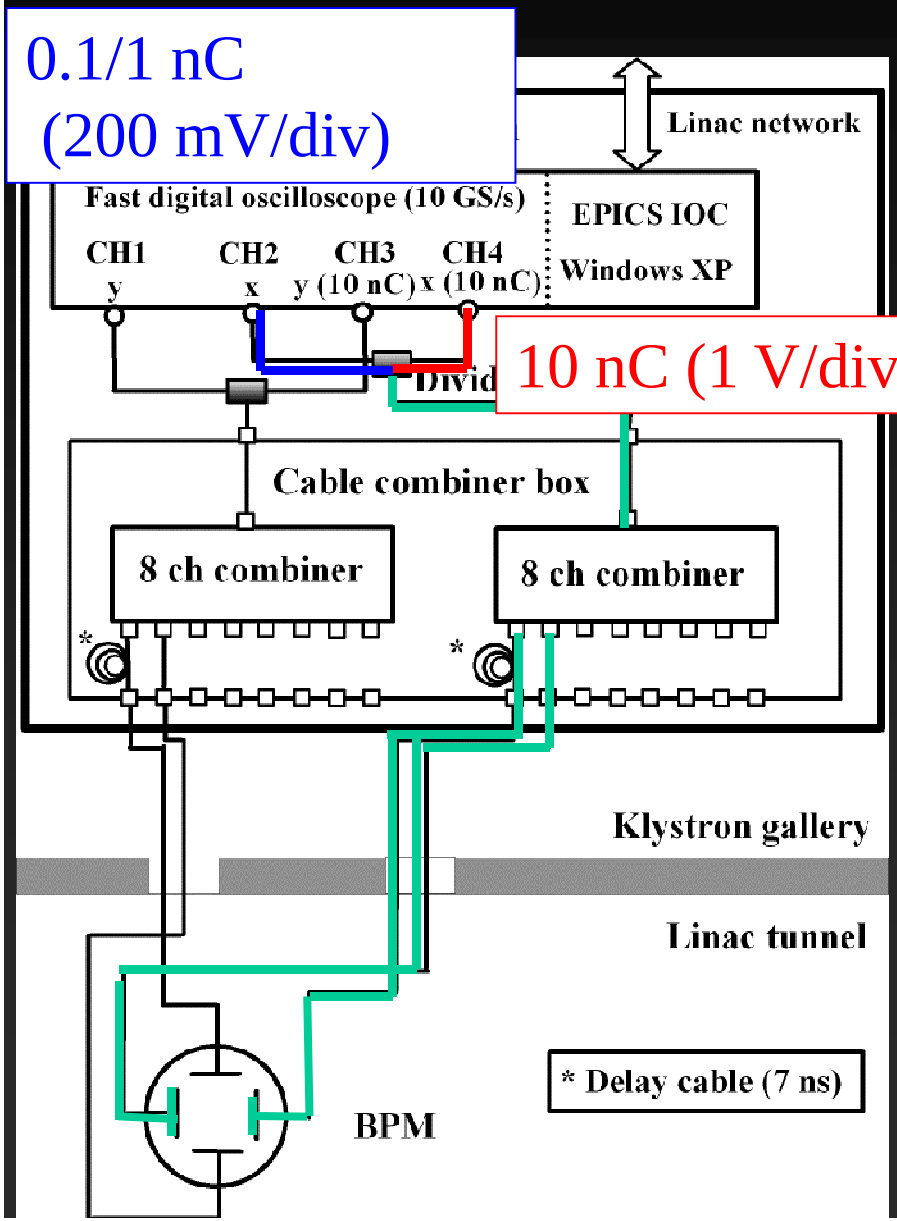
Current DAQ System (WindowsXP-based Oscilloscope)

BPM DAQ Upgrade

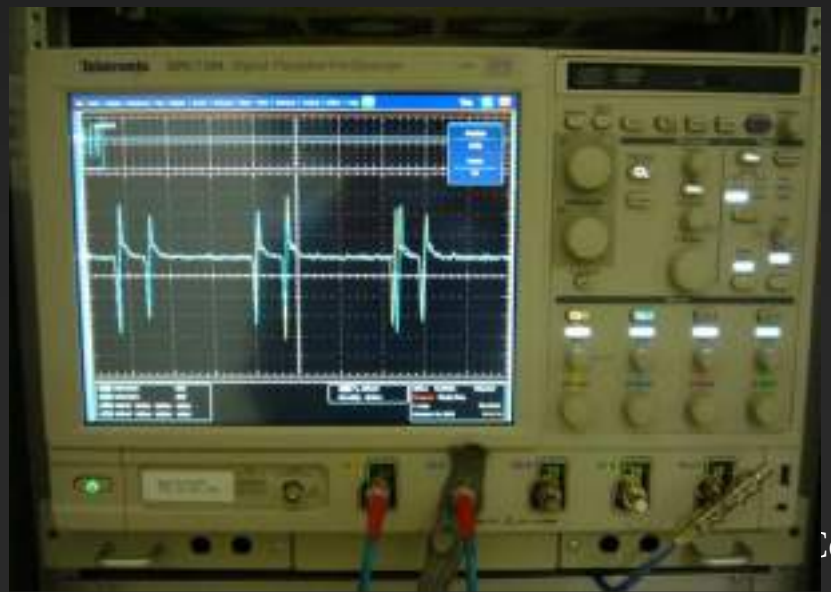
- Difficulty of maintenance (Old oscilloscope/VME)
- **Fast DAQ is strongly required (50 Hz) for simultaneous top-up operation**

- Old system has been replaced by new one in summer 2008

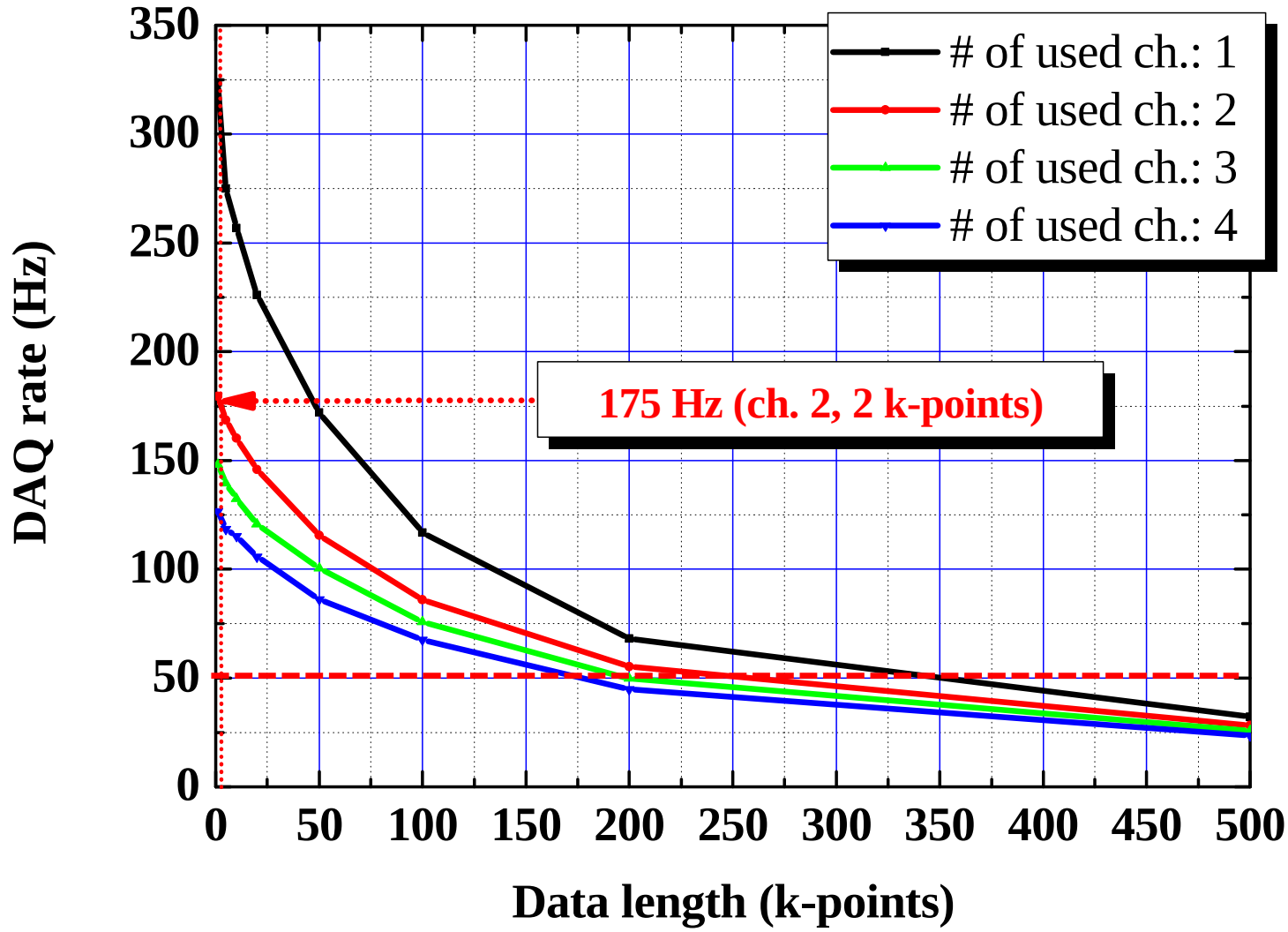
– WindowsXP-based Oscilloscope (Tektronix DPO7104)



- 10 GSa/s, 8 bits, 4ch, 1 GHz BW, Ethernet connection
- DAQ rate: > 50 Hz
- EPICS IOC running on Oscilloscope (R3.14.9)



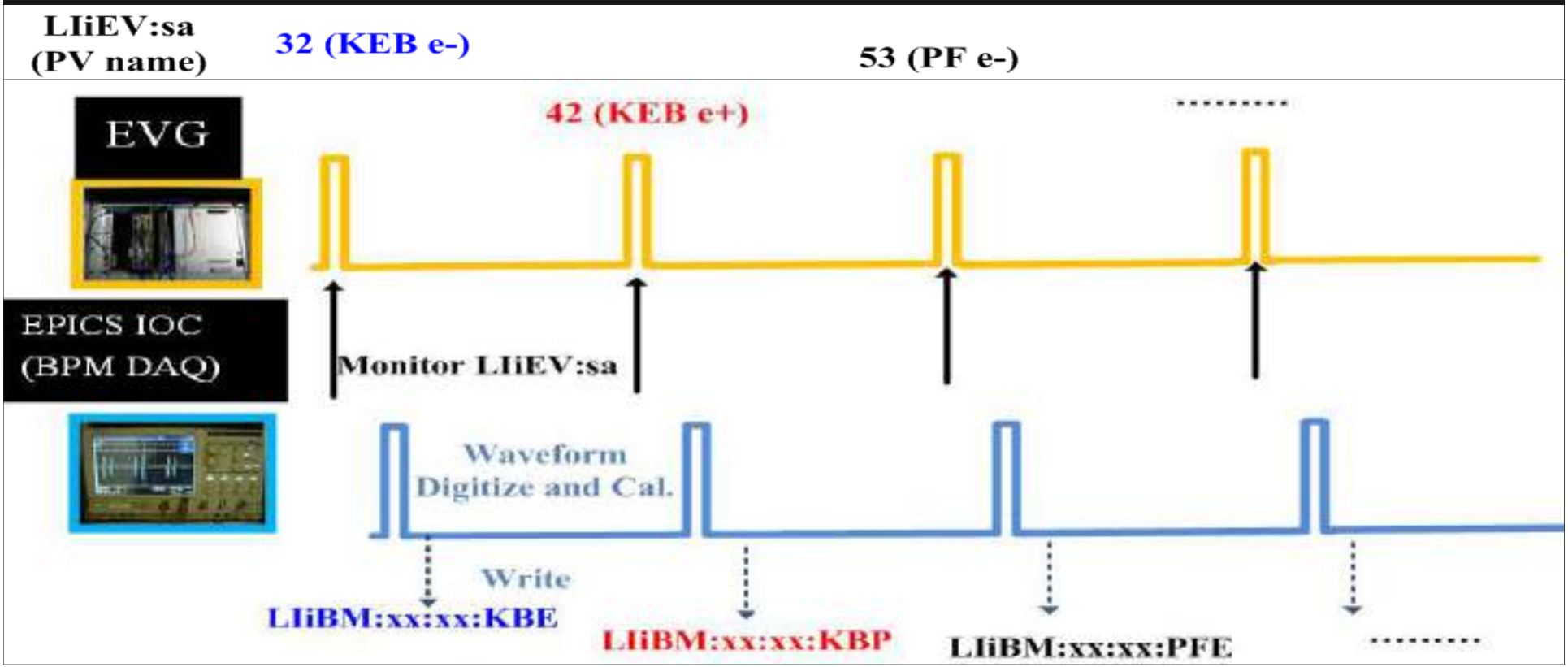
Oscilloscope performance



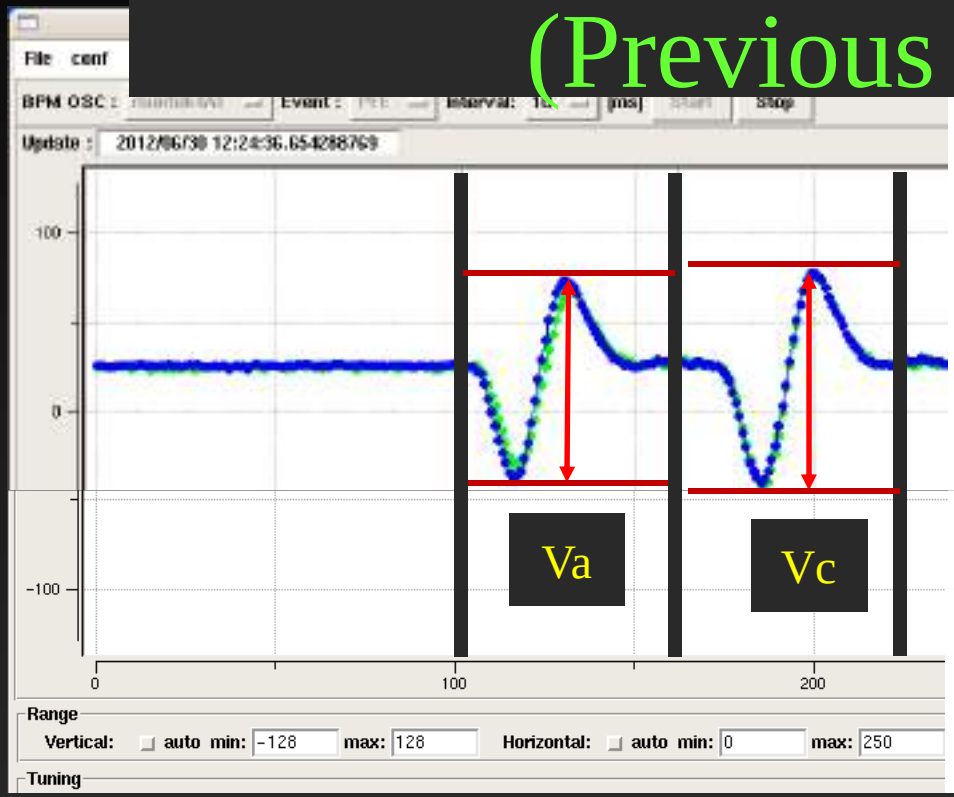
Synchronization w/ Event system

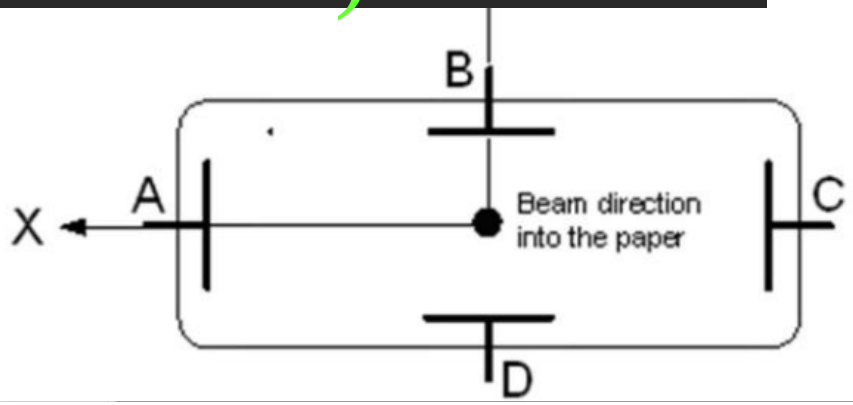
Beam mode	KEKB e-	KEKB e+	PF e-	PF-AR e-	…
LIiEV:sa	32	42	52	62	…

EPICS PV name @ Event generator



Beam position calculation (Previous software)





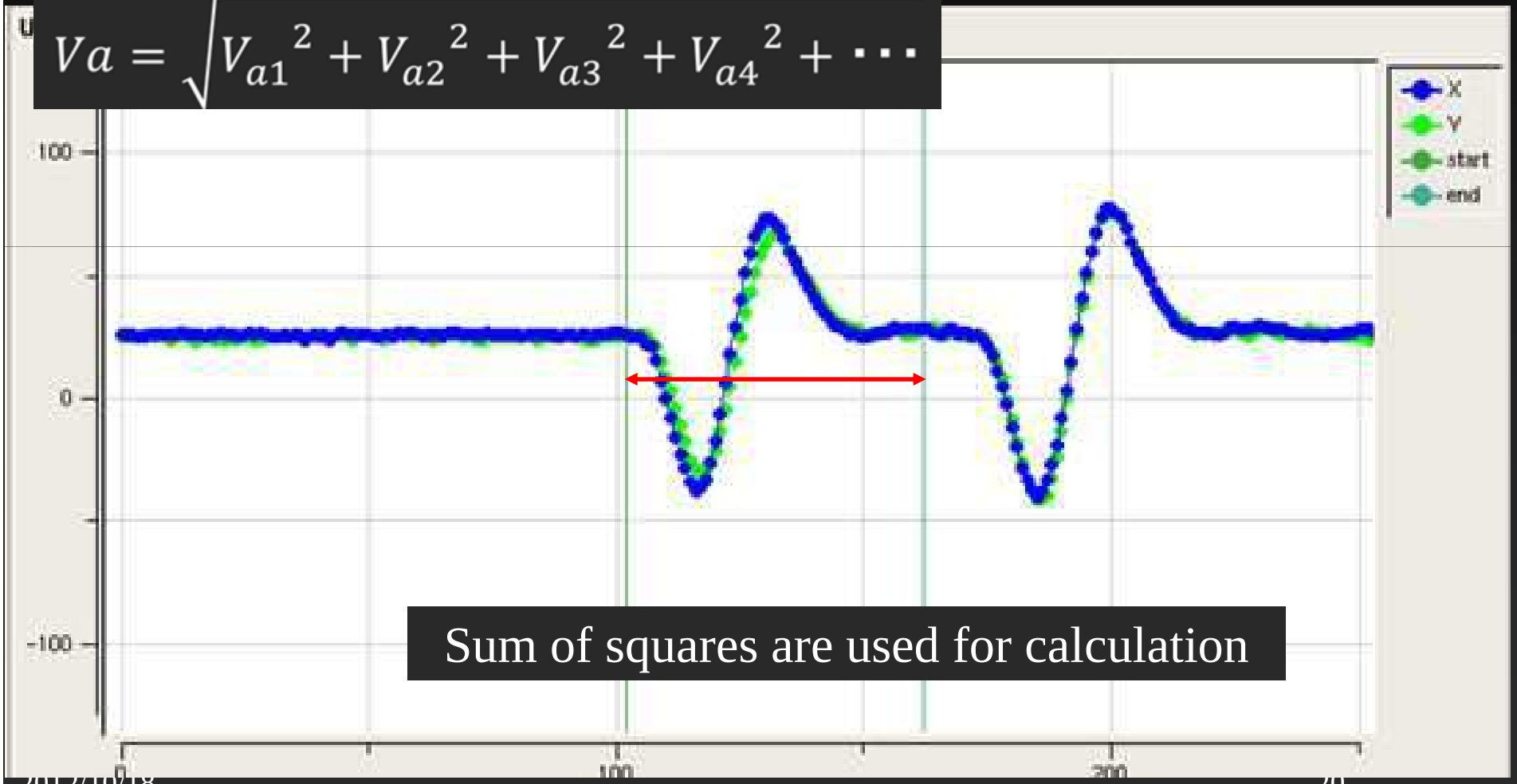
Maximum and minimum values are used for calculation

$$X = K_X \frac{(V_A' - V_C')}{(V_A' + V_C')} - X_{OFFSET}$$

$$Y = K_Y \frac{(V_B' - V_D')}{(V_B' + V_D')} - Y_{OFFSET}$$

Beam position calculation (Current software)

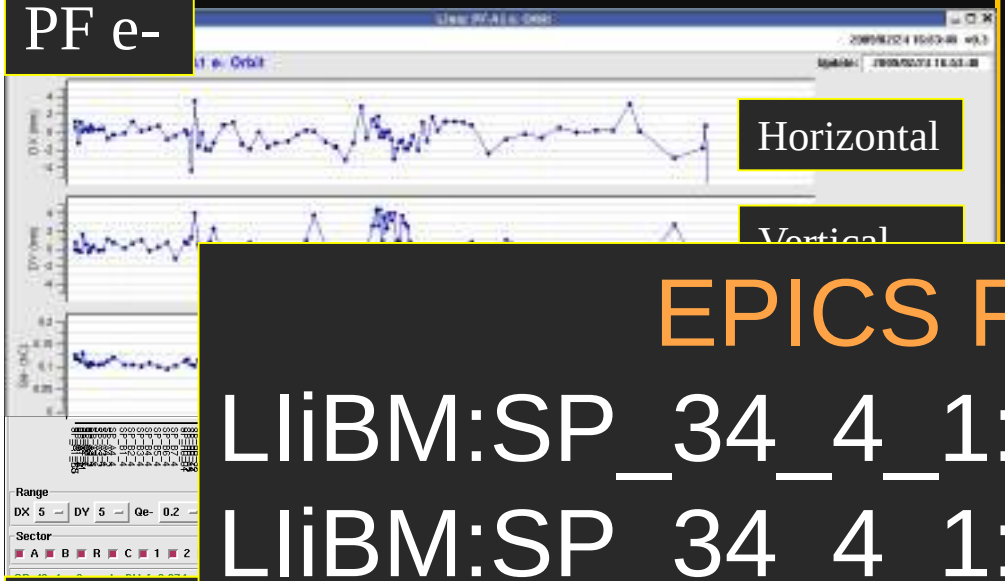
$$Va = \sqrt{V_{a1}{}^2 + V_{a2}{}^2 + V_{a3}{}^2 + V_{a4}{}^2 + \cdots}$$



Sum of squares are used for calculation

OPI for each beam mode

PF e-



- 3-BPM result

  $\sigma_{x,y}$ ~ 50 μm

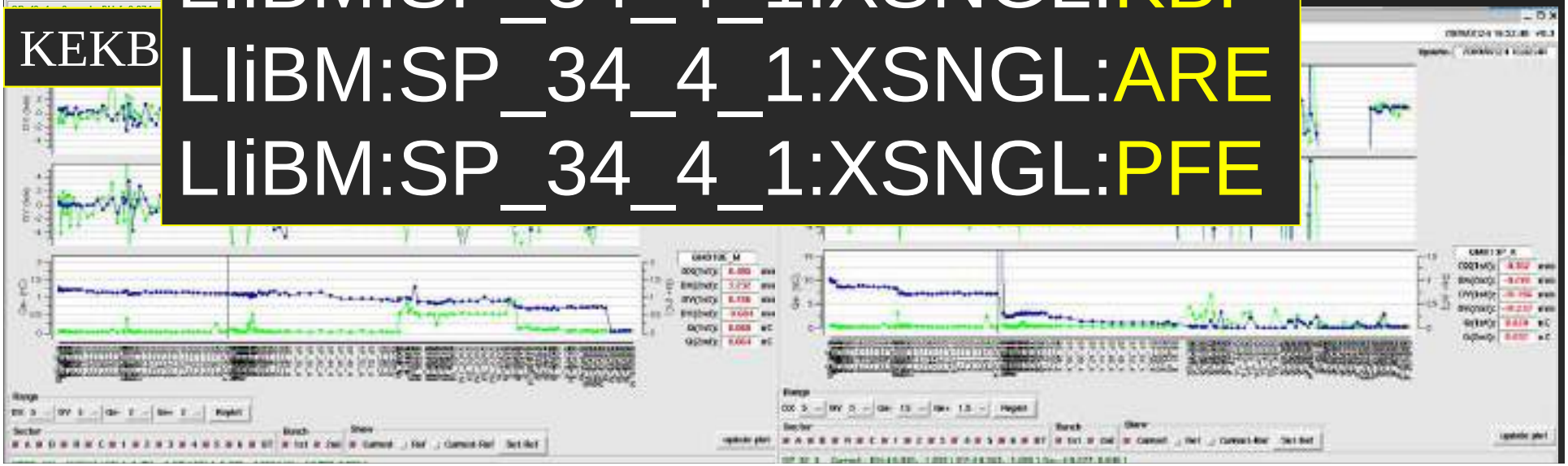
  (previous system : 100

  s utilized

KEKB

EPICS PVs

LIiBM:SP_34_4_1:XSNGL:KBE
LIiBM:SP_34_4_1:XSNGL:KBP
LIiBM:SP_34_4_1:XSNGL:ARE
LIiBM:SP_34_4_1:XSNGL:PFE



Future System towards SuperKEKB project

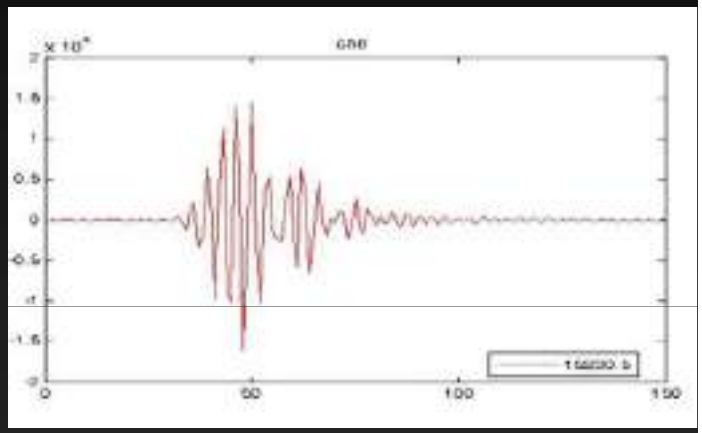
Issue for future system (SuperKEKB)

- Beam injection for SuperKEKB: Oct. 2014

- Low emittance electron beam w/o DR

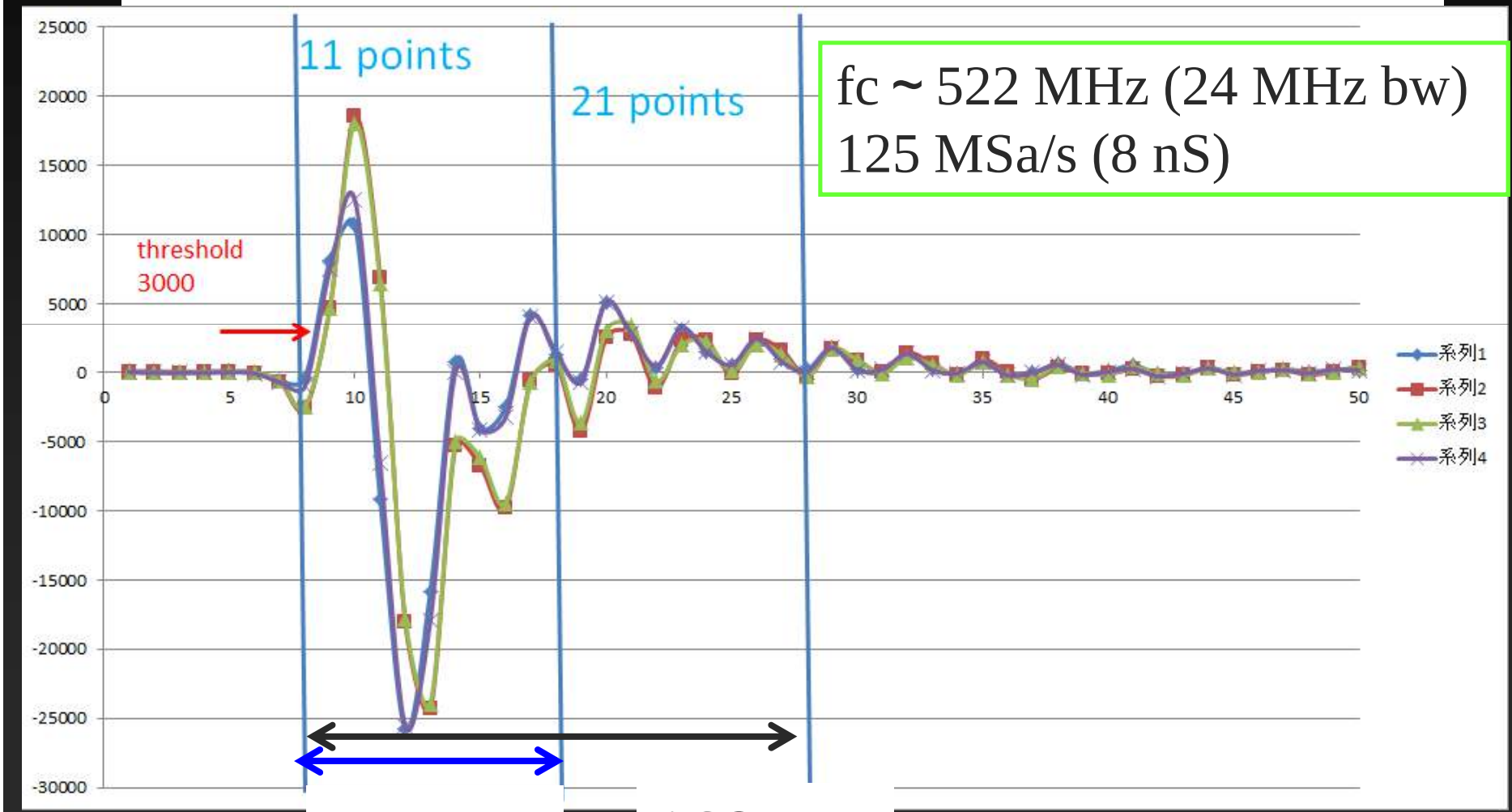
  $\varepsilon_{nx,y} < 20$ mm·mrad, 5 nC (KEKB: 100 mm·mrad, 1 nC)
- High precision beam orbit control
  - –Beam position measurement precision ~ 10 μm
  - –Current system ~ 50 μm
- Libera Single Pass Brilliance was tested last year.

- Libera Single Pass Brilliance: $\sigma_{x,y}$ ~ 10 μm (original performance)
- System requirements for SuperKEKB Linac
  - 2 banch beam measurement (96 ns interval)
  - Filter specification
    - SAW filter: fc ~ 522 MHz
    - BW: 24 MHz
    - A/DC: 125 MSa/s, 16 bit
  - Fast attenuator control in every 20 ms



- Evaluation result:
  - $\sigma_{x,y}$ ~ 20 μm (3-BPM)
  - $\sigma_{x,y}$ ~ 10 μm (test pulser)
  - Sometimes attenuator control failed (due to network traffic)

Digitized data by A/DC

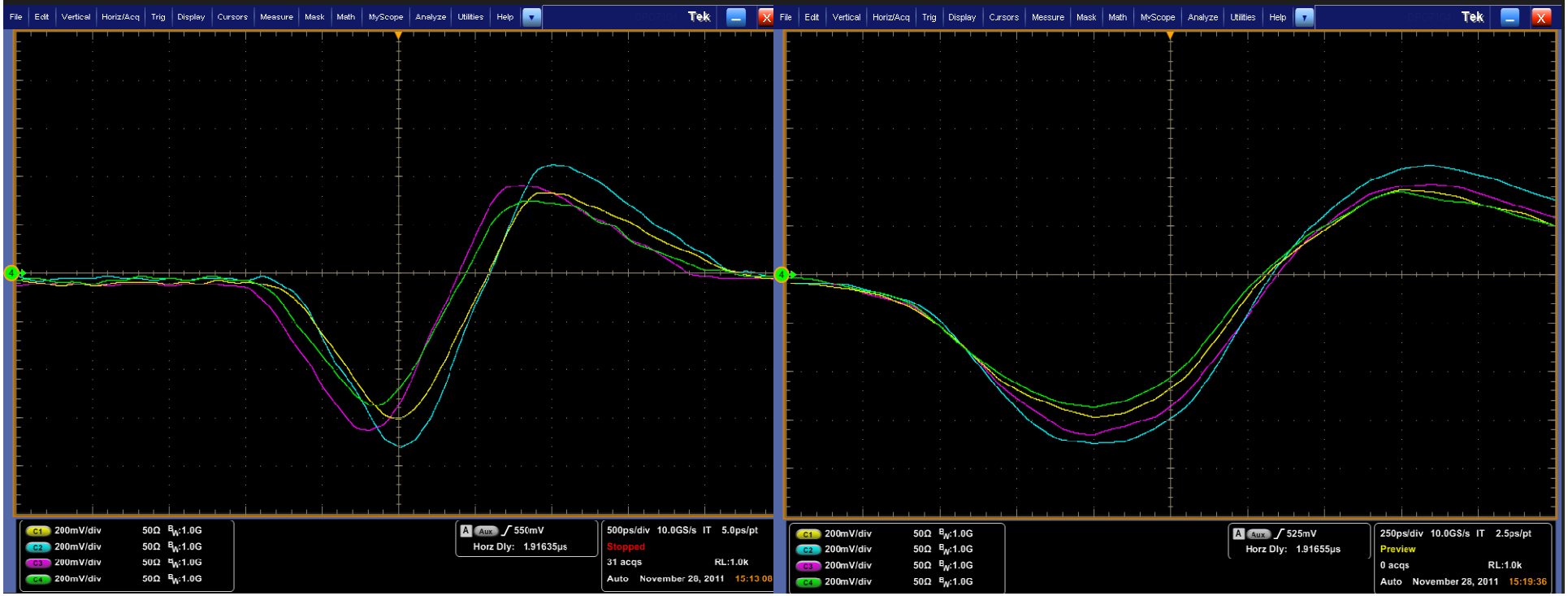


Phase matching is required
(SMA connector insertion)

SP_34_4

Before
(1.5 ns)

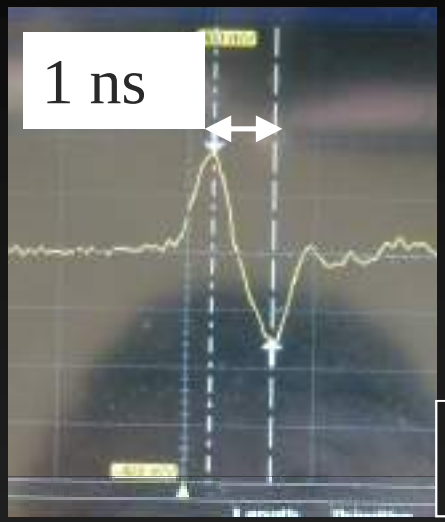
After
(100 ps)



Current Status:

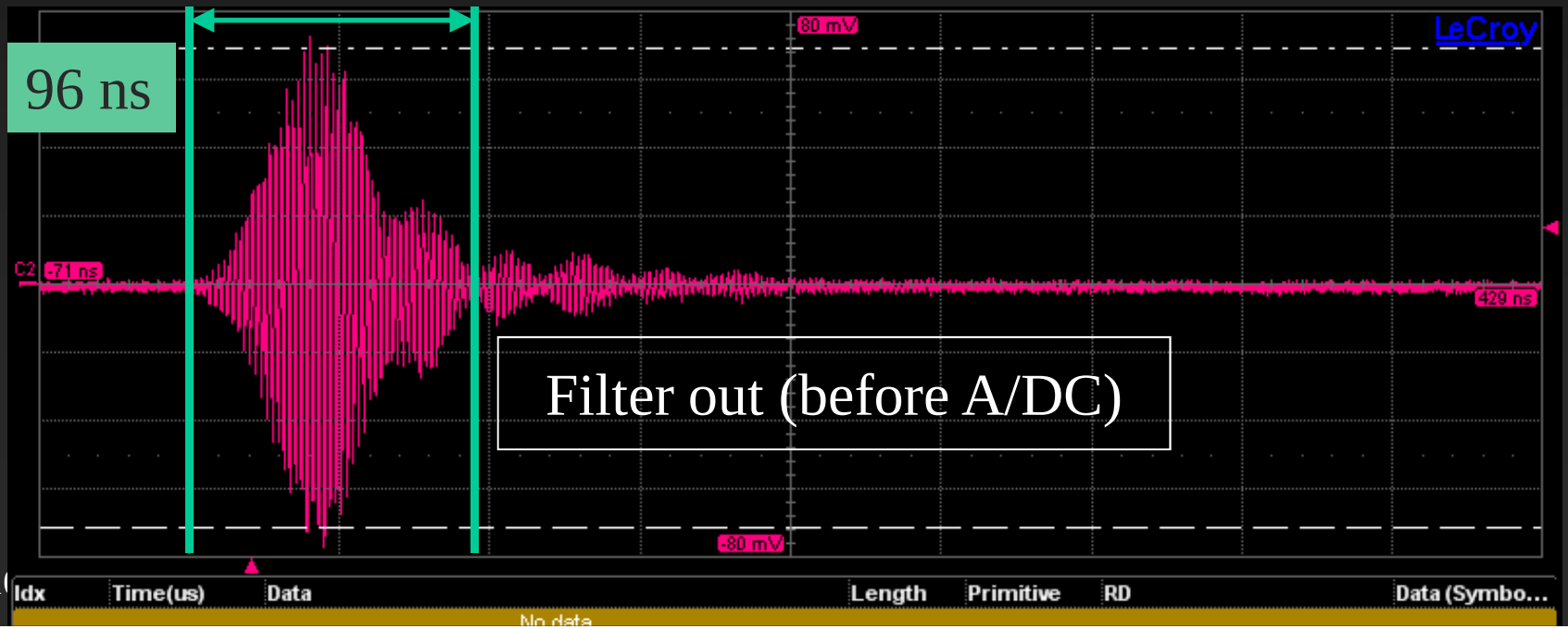
- Libera Single Pass E based:
  - A/DC was replaced: 125 MSa/s => 160 MSa/s
  - Target precision < 10 μm
    - Test pulser result at iTech ~ 2.5 μm
  - ○ Event based attenuator control in 50 Hz via SFP
  - ○ Phase shifter inside for phase matching
  - Basic test and beam test will be started soon at KEK

Pulser test



Leakage signal of 1st bunch may affect 2nd bunch beam position.

Input signal



Summary

- Current BPM DAQ System:
  - EPICS IOC (WindowsXP-based digital oscilloscope)
  - Old system (20) has been replaced by new one (24)
  - Successful in stable beam position measurement
    - 50 Hz, 2 bunch measurement
    - Synchronization with beam mode via EVG PV
  - Similar system is used for KEKB-BT
- Towards to SuperKEKB, New System is Required:
  - Higher position measurement precision (< 10 μm)
  - Libera Single Pass E based one is candidate.
    - Evaluation will be started soon.

Thank you for your attention!