Upgrade of Pohang Light Source (PLS) Linac

for PLS-II

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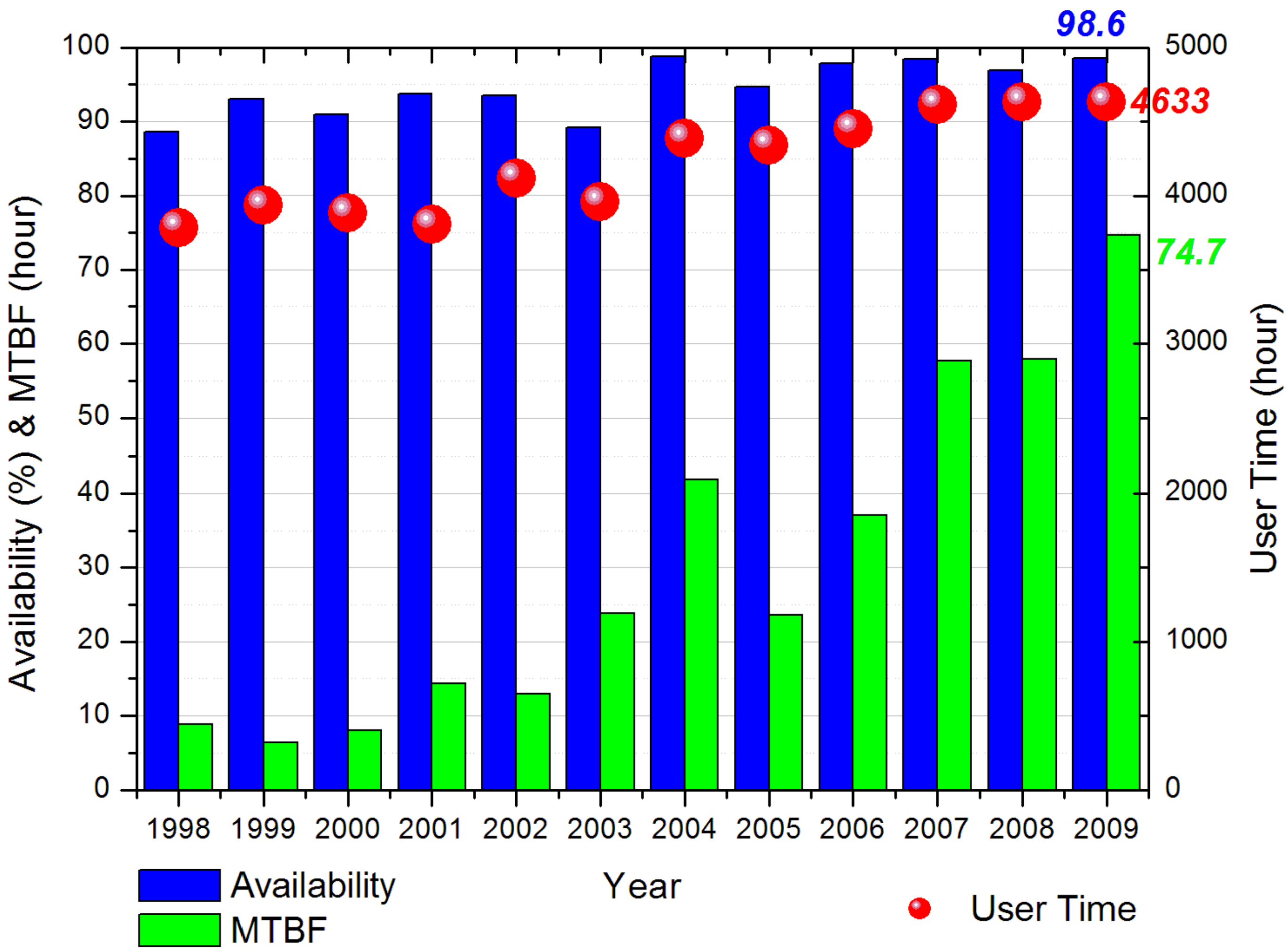
Pohang Light Source (PLS)

Beam energy (GeV)	2.5
Frequency (MHz)	2,856
Energy spread (%)	0.26
Bunch length (ps)	13
Beam current (A)	33
Normalized emittance (um)	150
Number of klystrons	12
Klystron power (MW)	80
SLED Gain	1.6
No. of accelerating columns	44
Total length (m)	160

	Designed Value	Achieved Value
Energy (GeV)	2(2.5)	2(2.5)
Stored current (mA)		
Multibunch	300(150)	305(182)
Single Bunch	10	26
Emittance (nm rad)	12.1(18.9)	≤11(13)
Lifetime(hr)		
100mA in 400 bunch		28(42)
10mA in single bunch		1
Bunch length (psec)	16.8	21.2
RF Voltage (MW)		1.6
Betatron Tunes		
Horizontal (V_x)	14.28	14.28(14.258)
Vertical (V_y)	8.18	8.187(8.147)
Synchrotron Tune	0.0109	0.0109

PLS Operation Statistics



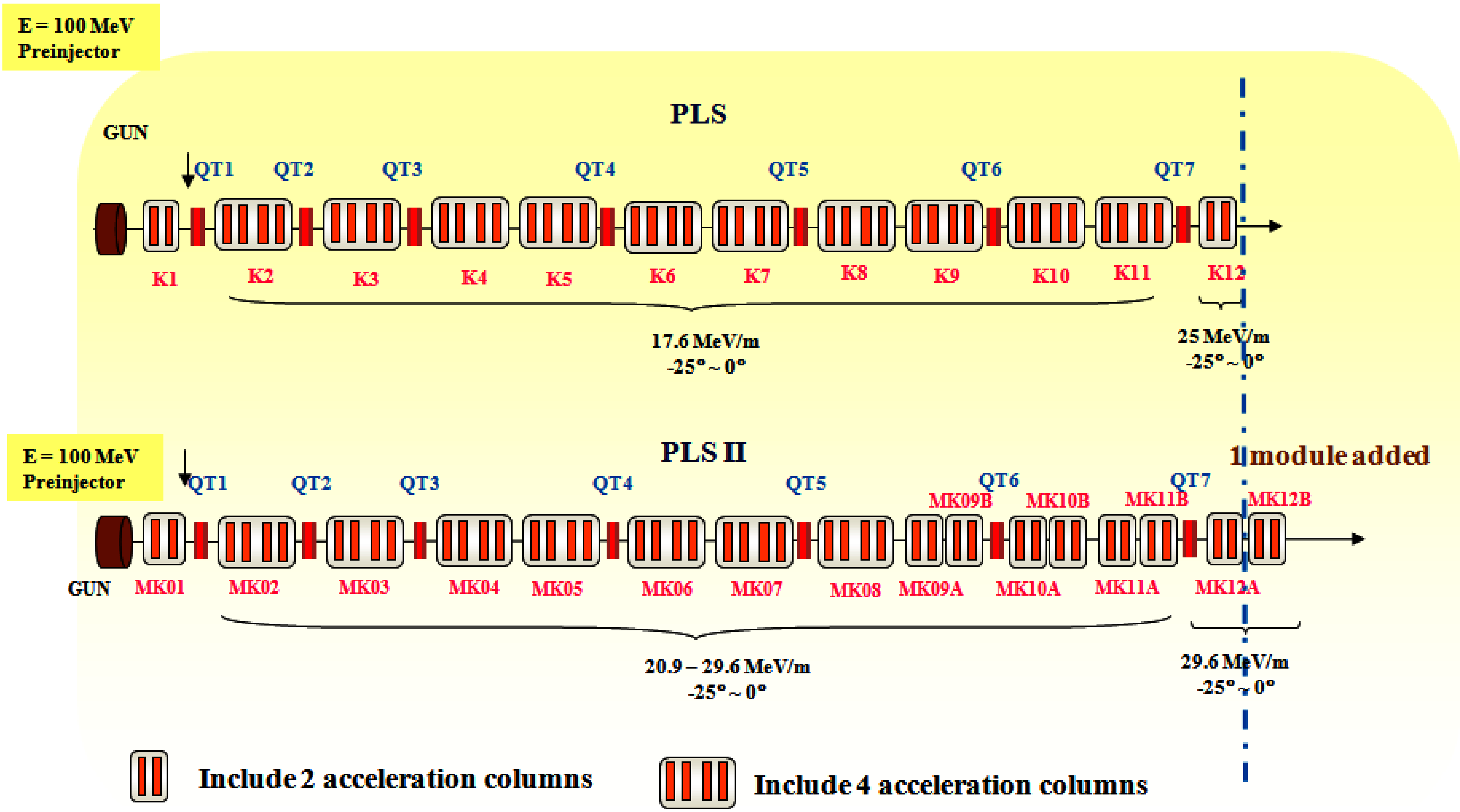
Past, Present and Future of PAL

Past	I. PLS			
	▪ Project started	Apr.	1	1988
	▪ Ground-breaking	Apr.	1	1991
	▪ 2-GeV Linac commissioning	Jun.	30	1994
	▪ Storage ring commissioning	Dec.	24	1994
	▪ User's service started	Sep.	1	1995
	▪ 1st PLS Upgrade Complete	Nov.	1	2002
	✓Energy ramping to 2.5 GeV	Sep.	1	2000
	✓ 2.5-GeV injection	Nov.	1	2002
Present	II. 2nd Major Upgrade of the PLS (PLS-II)			
	▪ 3.0-GeV PLS-II Upgrade begin	Jan.		2009
	▪ Top-Up Operation in PLS	Oct.		2010
	▪ 3.0-GeV PLS-II Upgrade Complete	Dec.		2011
Future	III. Proposal of PAL XFEL			

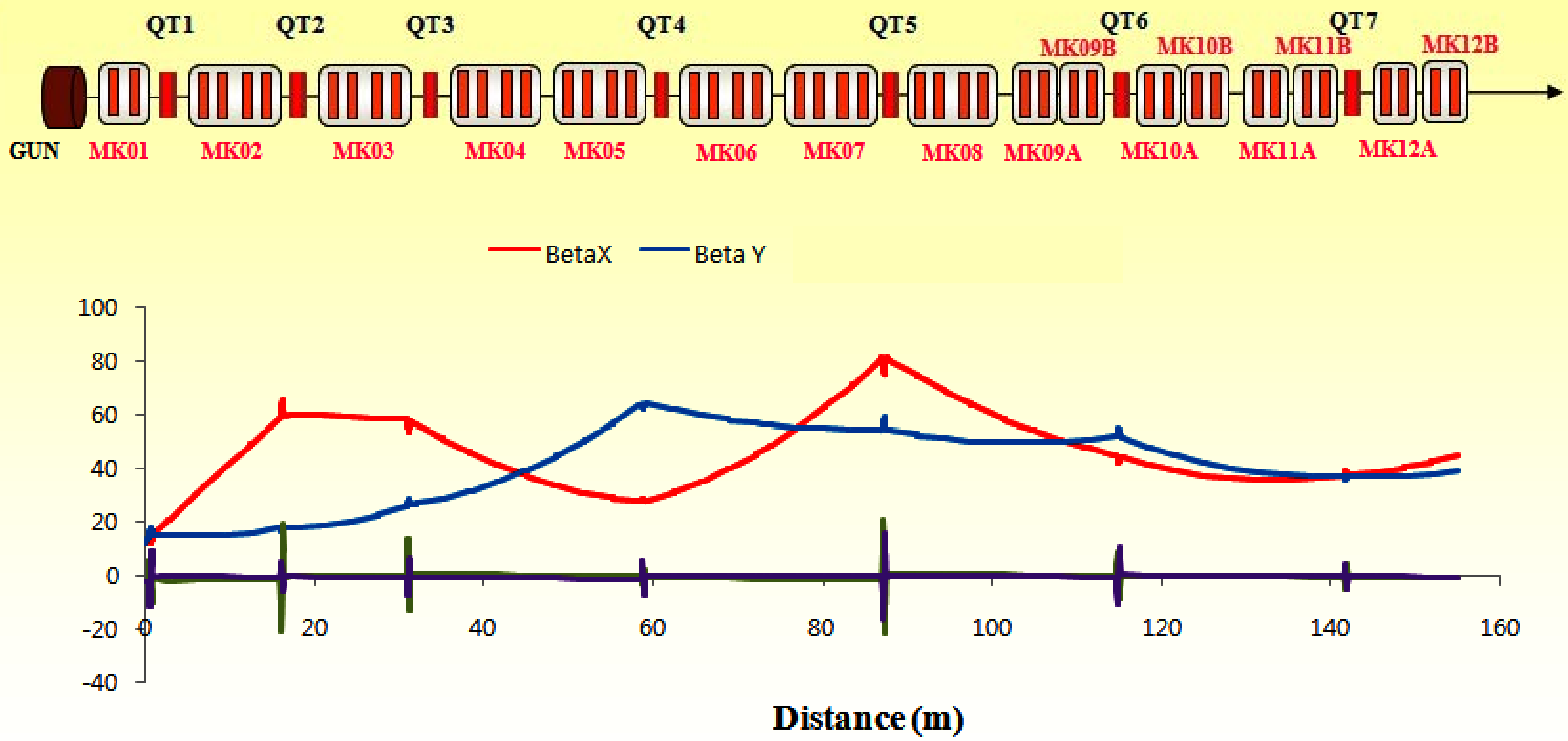
PLS-II Linac Parameters

Beam Energy	3 GeV
Normalized Transverse Emittance	150 mm·mrad
Required Energy Spread for S.R.	< 0.2 %
Operating RF Frequency	2856 MHz
Beam Pulse Length	< 1 ns
Beam Peak Current	~ 1 A
Machine Length	160 m
No. of Accelerating Columns	46 (4 x 7 + 2 x 9)
No. of Klystrons	16 (7 + 9)
SLED Energy Gain	~1.5

Lattice Layouts of PLS and PLS-II Linacs



Beta Functions in Linac



Comparison of Linac Parameters for PLS and PLS-II

PLS

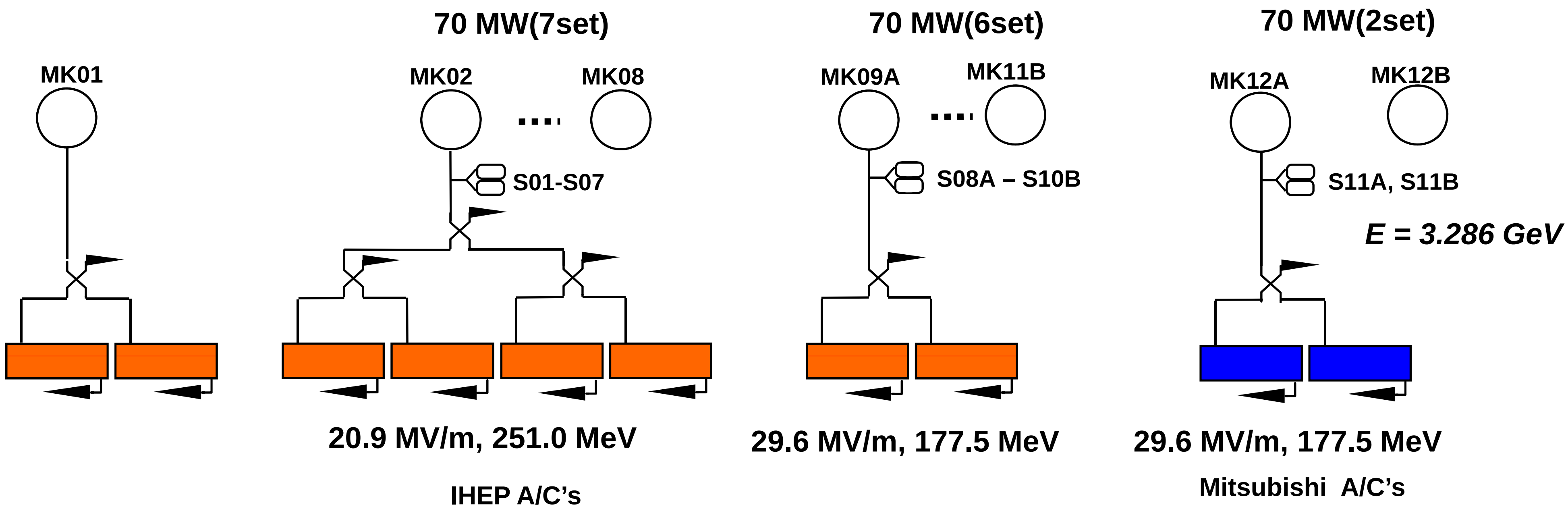
	MK1(1set)	MK2 - MK11(10set)	MK12(1set)
RF Power	55 MW	55 - 58 MW	56 MW
Klystron	SLAC5045	Toshiba E3712	
A/C	IHEP		Mitsubishi
SLED Gain	-	1.5	1.5
Gradient	17.6 MeV/m	17.6 MeV/m	25 MeV/m
Energy	105.8 MeV	224.5 MeV per module	150 MeV
Number of A/C's	2	40	2

PLS-II

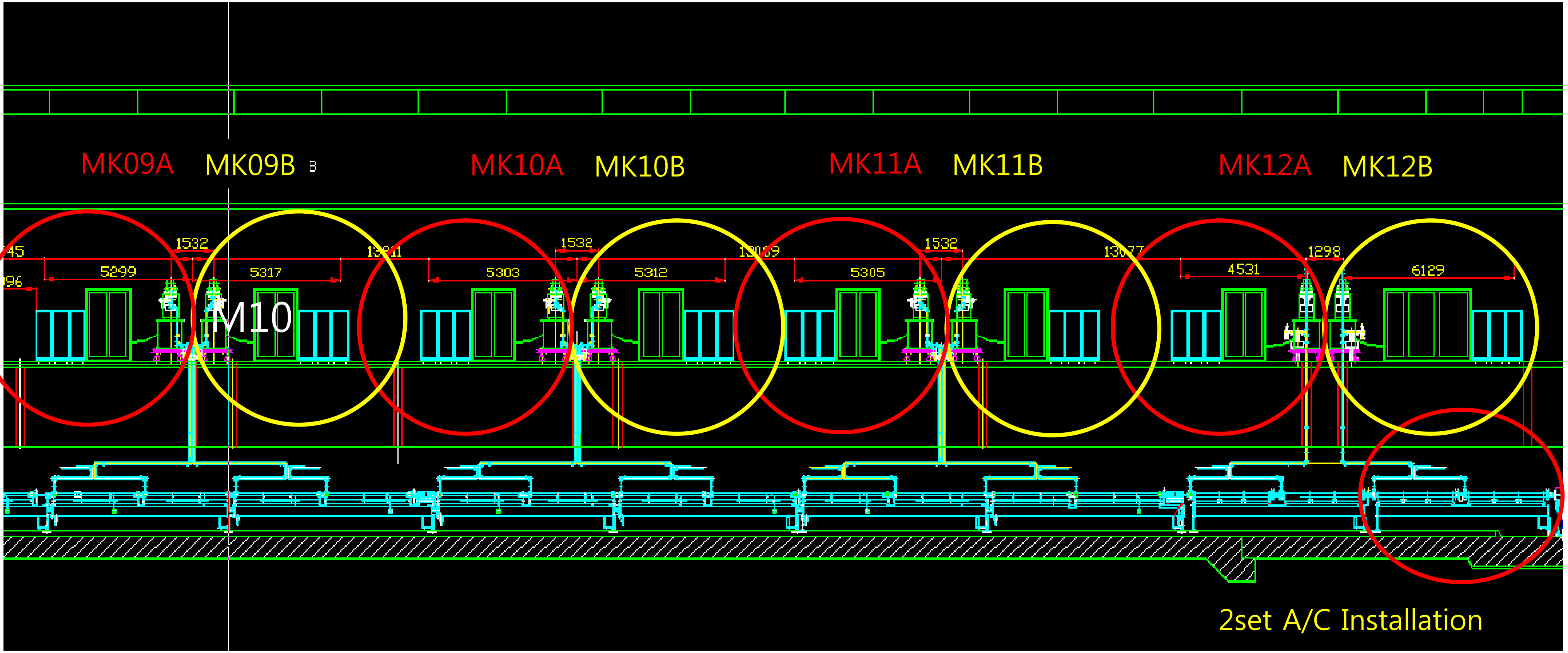
	MK1(1set)	MK2 – MK08(7set)	MK09A-MK11B(6set)	MK12A-MK12B(2set)
RF Power	60 MW	70MW	70 MW	70 MW
Klystron	SLAC5045	Toshiba E3712		
A/C	IHEP			Mitsubishi
SLED Gain	-	1.5		1.5
Gradient	18.3 MeV/m	20.9 MeV/m	29.6 MeV/m	29.6 MeV/m
Energy	105.8 MeV	251.0 MeV per module	177.5 MeV per module	177.5 MeV
Number of A/C's	2	28	12	4

Energy Upgrade Plan (1/2)

- 1st Stage (2010 Summer): Double RF Station for MK11 Unit.
- 2nd Stage (2010 Winter – 2011 Spring): Double RF Stations for MK09, MK10 , and MK12. Add two A/C's at Linac End (MK12B)



Energy Upgrade Plan (2/2)



- **Red color : Adding New Modulators, W/G Network, A/C**
- **Yellow color : Replaced Modulators and W/G Network**

Energy Stability Analysis (1/3)

- Energy Jitter vs. RF Power Source Jitter -

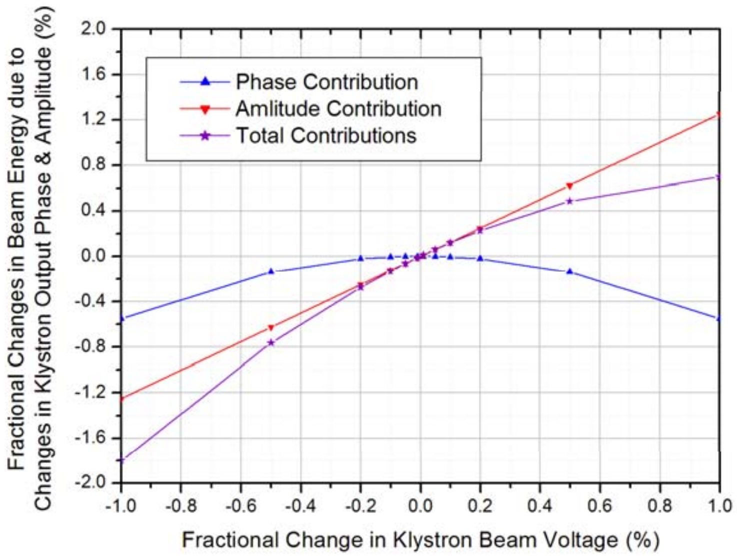
Phase Contribution

$$E = E_0 \cos(\delta\theta) \approx E_0 (1 - \frac{1}{2}\delta\theta^2),$$

$$\frac{\delta E}{E_0} = \frac{E - E_0}{E_0} = -\frac{1}{2}\delta\theta^2$$

$$\delta\theta_k = A_k \frac{\delta V_k}{V_k}$$

$$A_k = \frac{2\pi f L_k}{c} \frac{eV_k}{m_0 c^2} [(1 + \frac{eV_k}{m_0 c^2})^2 - 1]^{-\frac{3}{2}}$$



Amplitude Contribution

$$P_{rf} = \eta P_B = \eta V_B I_B = \eta k V_B^{5/2}$$

$$\frac{\delta V_{rf}}{V_{rf}} = \frac{5}{4} \frac{\delta V_k}{V_k}$$

$$\frac{\delta E}{E_0} = -\frac{1}{2}\delta\theta^2 + \frac{5}{4}\frac{\delta V_k}{V_k} = -\frac{1}{2}(A_k \frac{\delta V_k}{V_k})^2 + \frac{5}{4}\frac{\delta V_k}{V_k}$$

Energy Stability Analysis (2/3)

- Multiple RF Sources -

Parameter Definitions

$v_j = (\frac{\delta V_k}{V_k})_j$ = Fractional klystron voltage change in j-th rf station,

$\delta\theta_j$ = Phase change in j-th rf station,

$\delta\theta_b$ = Jitter in beam injection phase to main linac,

θ_j = Operating beam phase in j-th station,

N = Total number rf stations,

$\frac{\delta E_j}{E_j}$ = Fractional energy change in j-th rf station.

$$\frac{\delta E_j}{E_i} = -\frac{1}{2}\delta\theta_j^2 + \frac{5}{4}v_j$$

$$-\delta\theta_i \tan\theta_i$$

$$\delta\theta_i = A_k v_i + A_k v_1 + \delta\theta_b$$

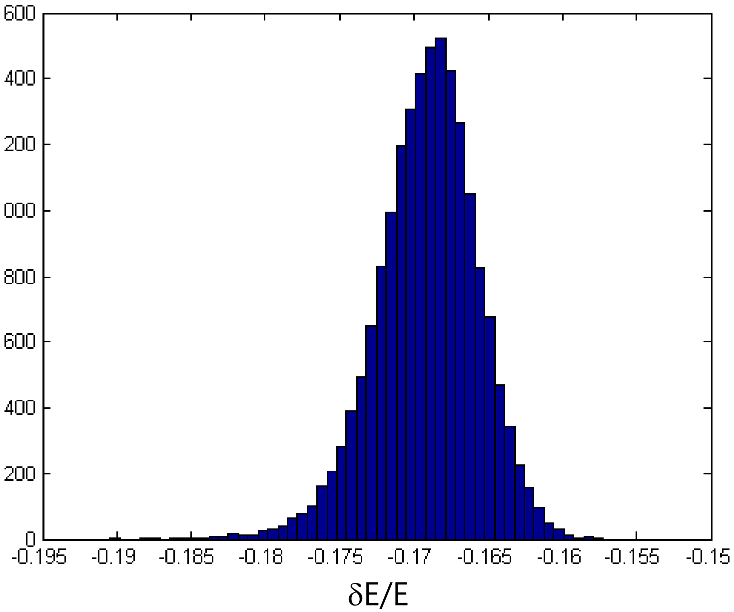
$$\frac{\delta E}{E} = \sum_i^N k_j \frac{\delta E_j}{E_j}$$

$$\boxed{\frac{\delta E}{E} = \sum_{j=2}^N k_j \left(-\frac{A_k^2(v_j^2 + v_1^2) + \delta\theta_b^2}{2} + \frac{5}{4}v_j\right) + k_1 \delta e_1}$$

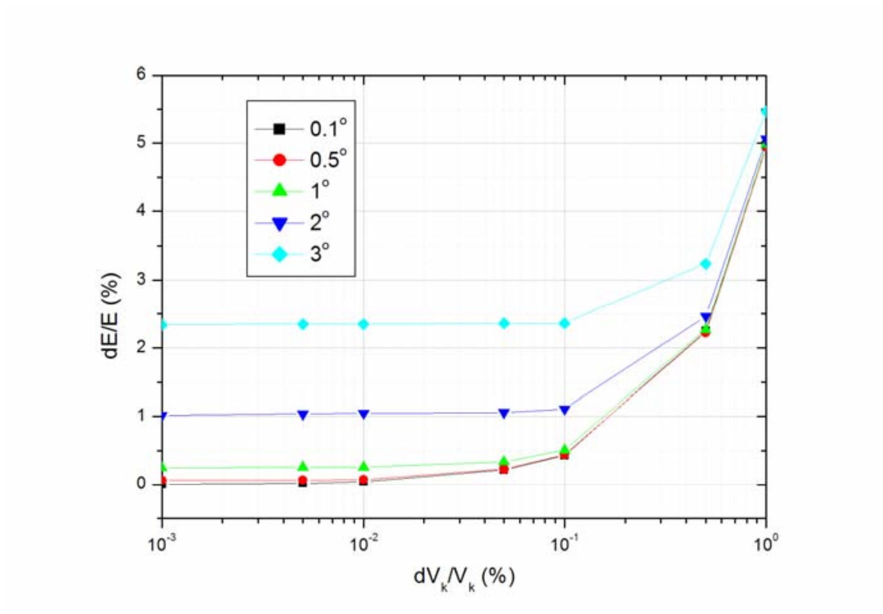
$$\delta e_1 \approx -(A_k v_1 + \delta\theta_b)\tan\theta_1$$

Energy Stability Analysis (3/3)

- Numerical Calculation for PLS Linac -



Numerical Calculation of δE/E distribution for PLS Linac. Standard Deviation = 0.34%



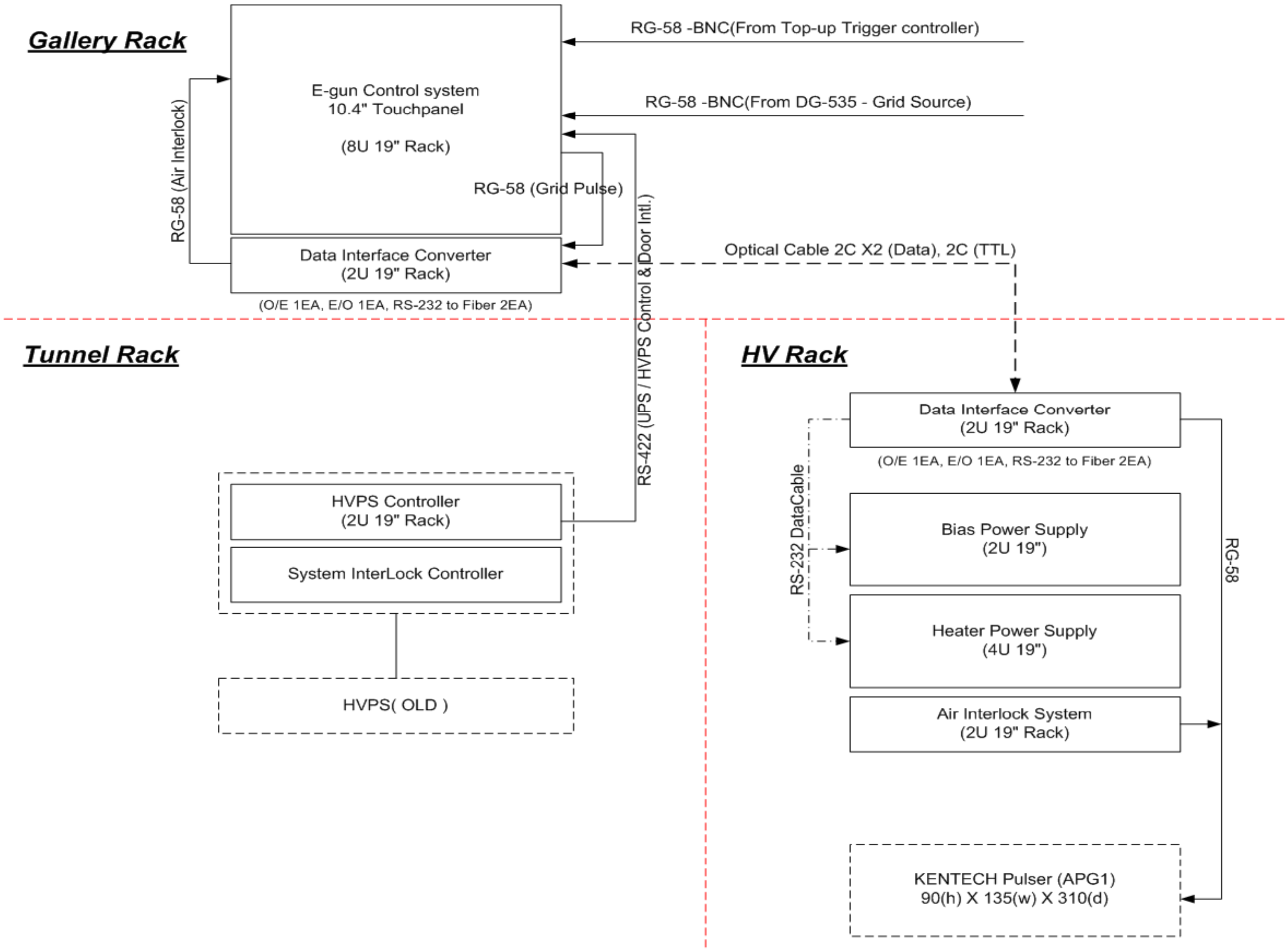
$\delta E/E$ versus various combinations of v_j and $\delta\theta_b$
N = 12, θ_j = 0° (for all j's)

Linac Upgrade Activities during

2010 Summer Shutdown

Electron Gun Upgrade (1/2)

[Electron Gun Control Block Diagram]

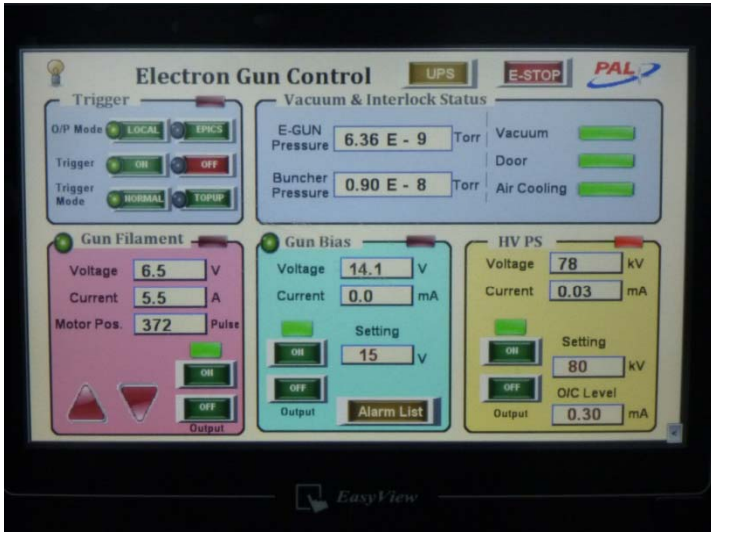


Electron Gun Upgrade (2/2)

[Old Control room(Tunnel)]

[New Control room(Tunnel)]

[Old Control Systems(Gallery)]



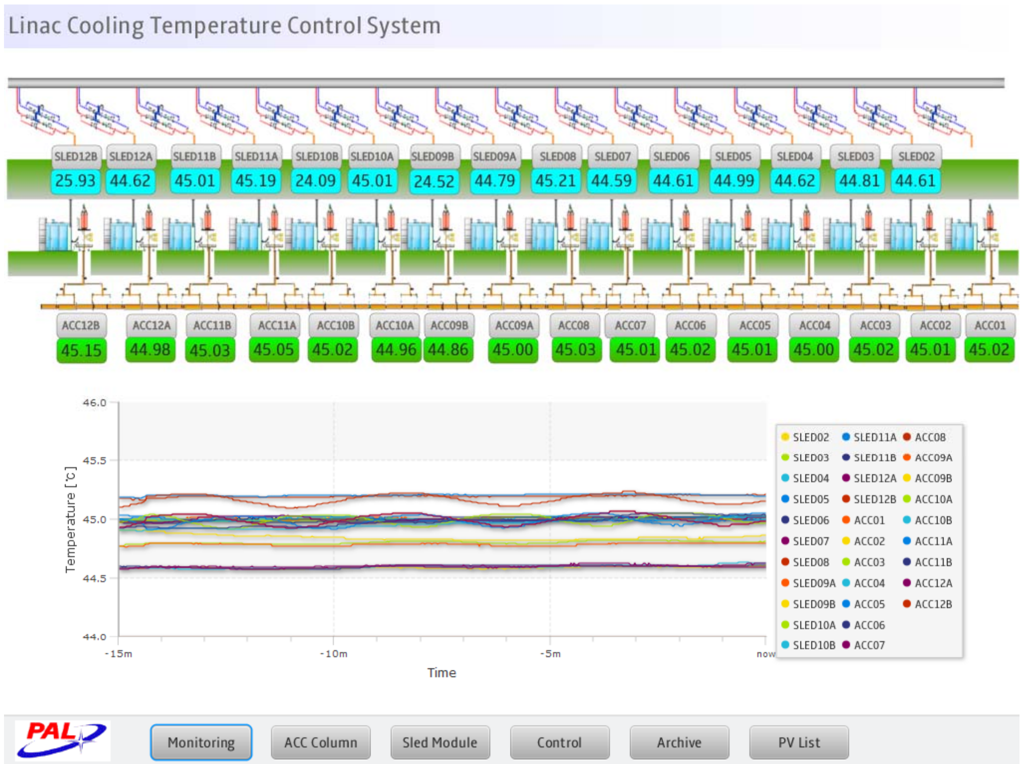
[New Control Systems(Gallery)]

Cooling Upgrade

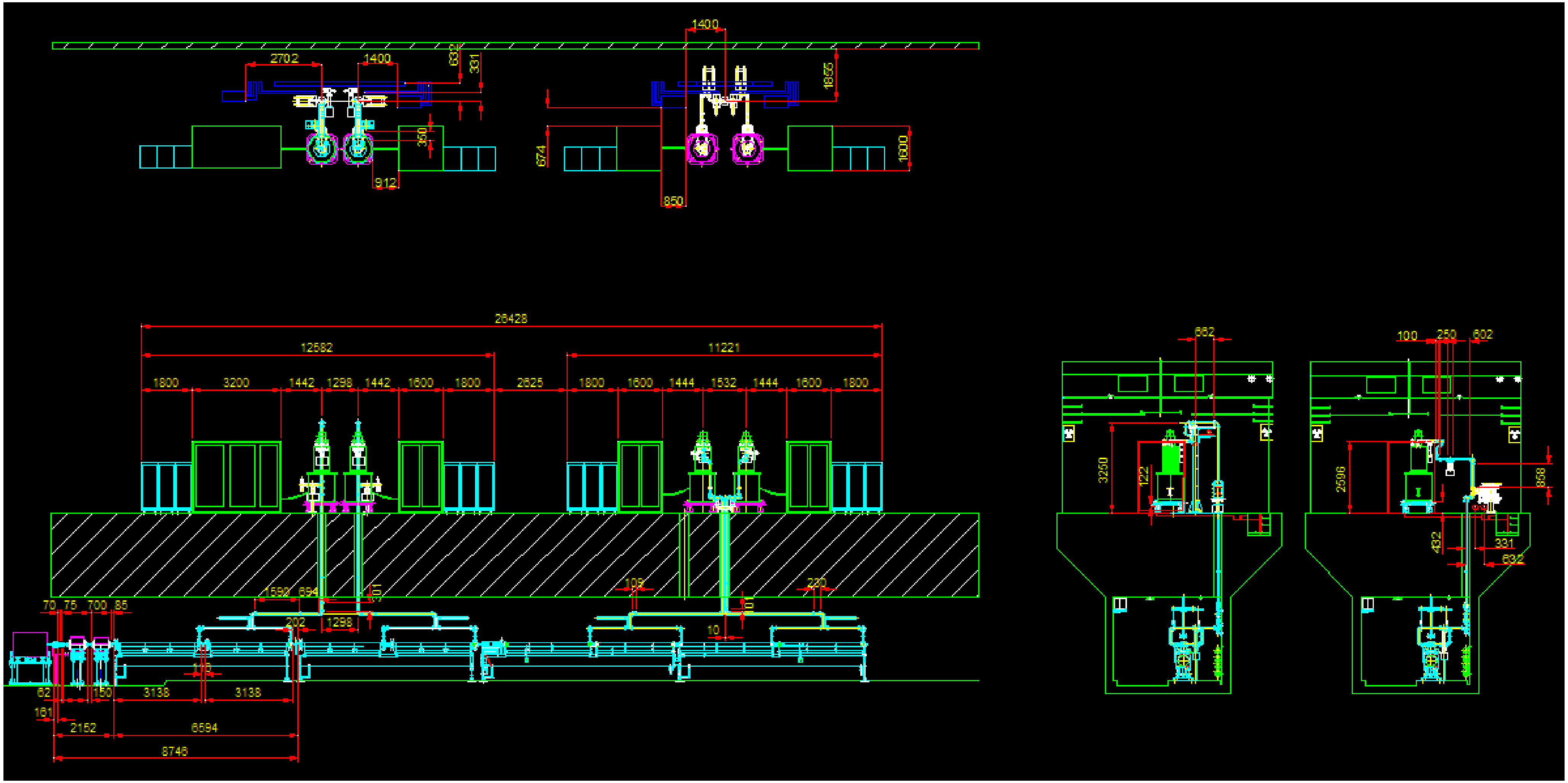
Temperature Sensitivities for
PLS Linac RF Devices

Device Parameters	Sensitivities	Utility Parameters
SLED output phase	3°/°C	Air temperature
SLED output phase	10°/°C	Cooling water temperature
Klystron output phase	1°/°C	Cooling water temperature

We have independent temperature controls for each SLED cavities to obtain temperature stability < +/- 0.1 °C



Doubling MK11 RF Source

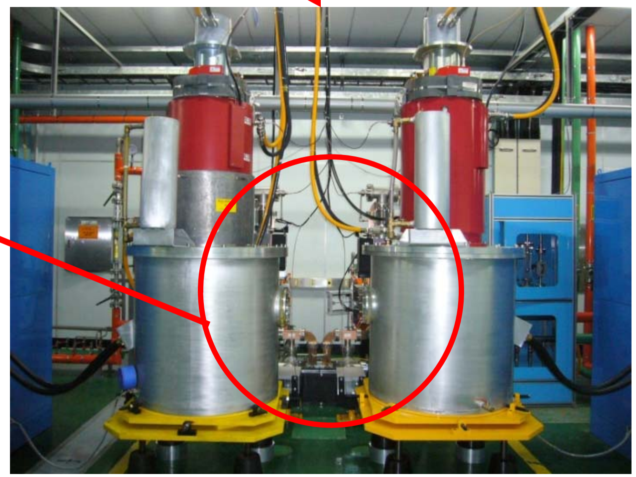


Doubling MK11 RF Source Power

Before

After

	Before	After
Modulator & Klystron	One	Two
SELD	One	Two
A/C	Four	Each Two

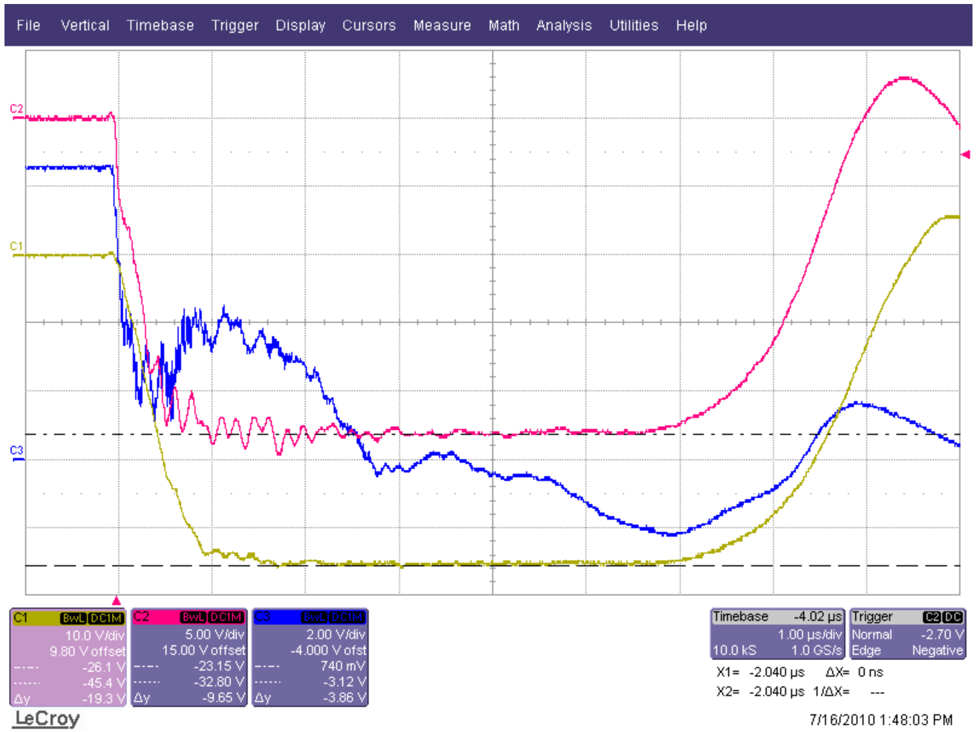


Lab-Test of New Modulators

MK11A Modulator(Pulse width : 8 μs)

CH1: 100 kV/div
CH2: 100 A/div
CH3: 10 kV/div

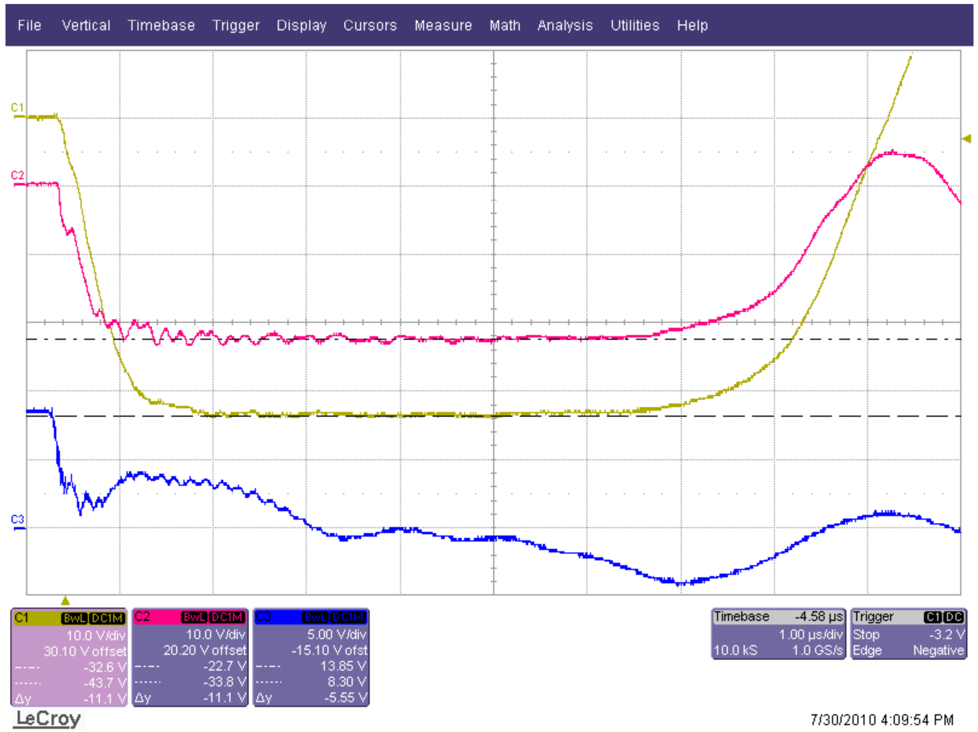
V_{beam}(Yellow) : 400 kV
I_{beam}(Red) : 463 A
V_{PFN} : 43 kV



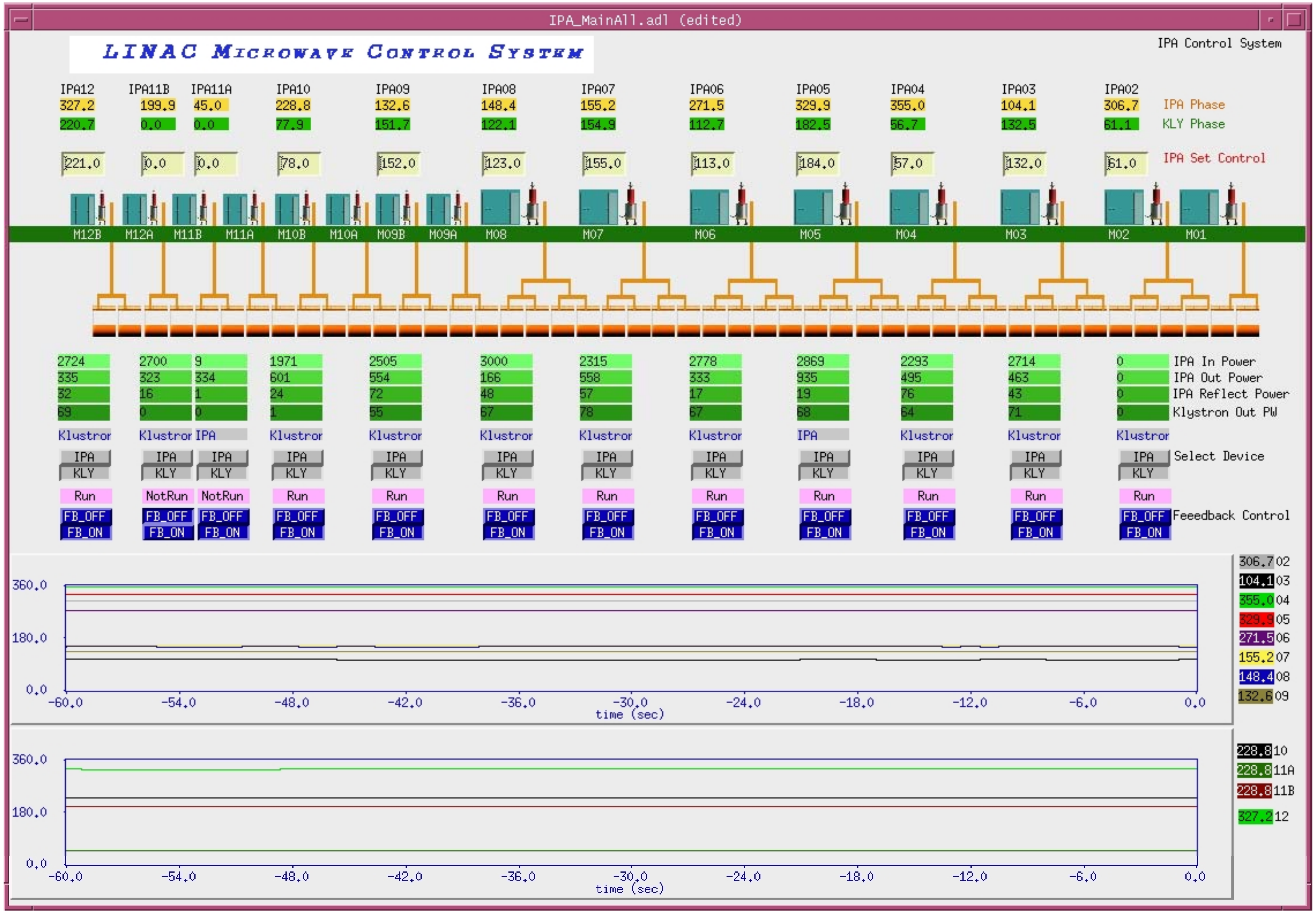
MK11B Modulator(Pulse width : 8 μs)

C1: 100 kV/div
C2: 200 A/div
C3: 30 kV/div

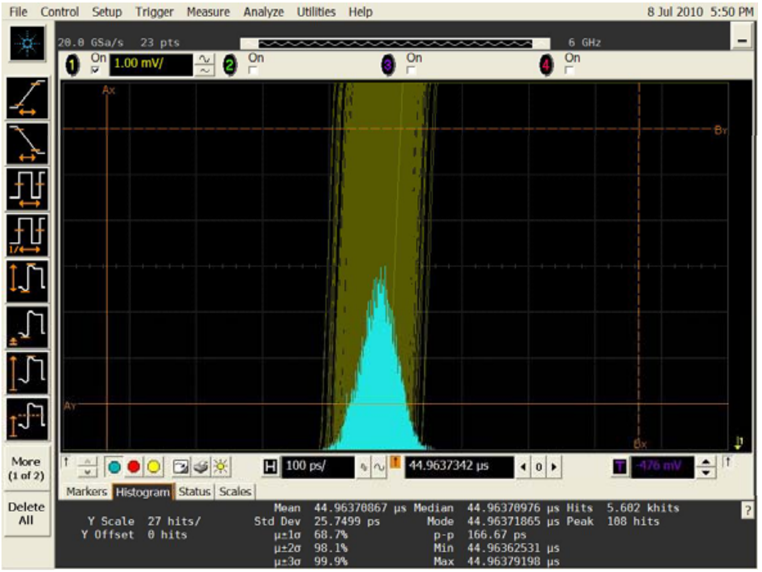
V_{beam}(Yellow) : 394 kV
I_{beam}(Red) : 454 A
V_{PFN} : 44 kV



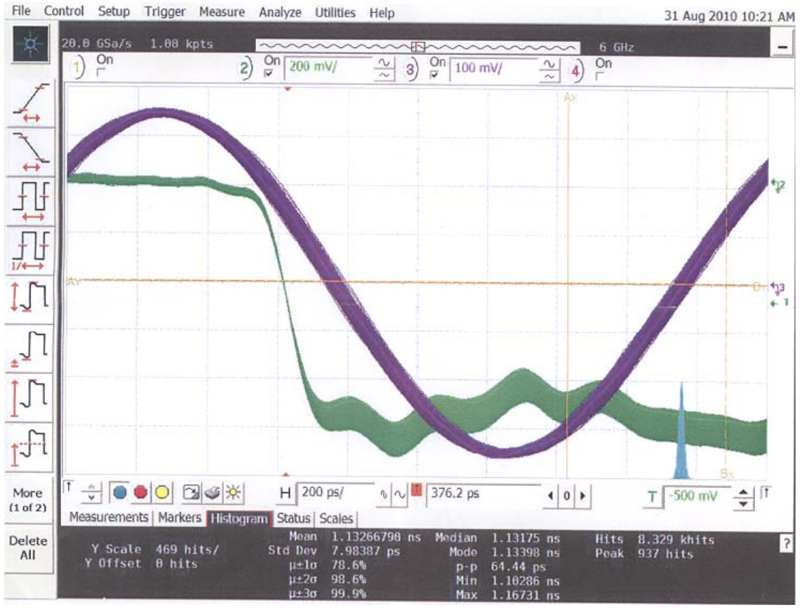
LLRF Upgrade



Timing System Upgrade



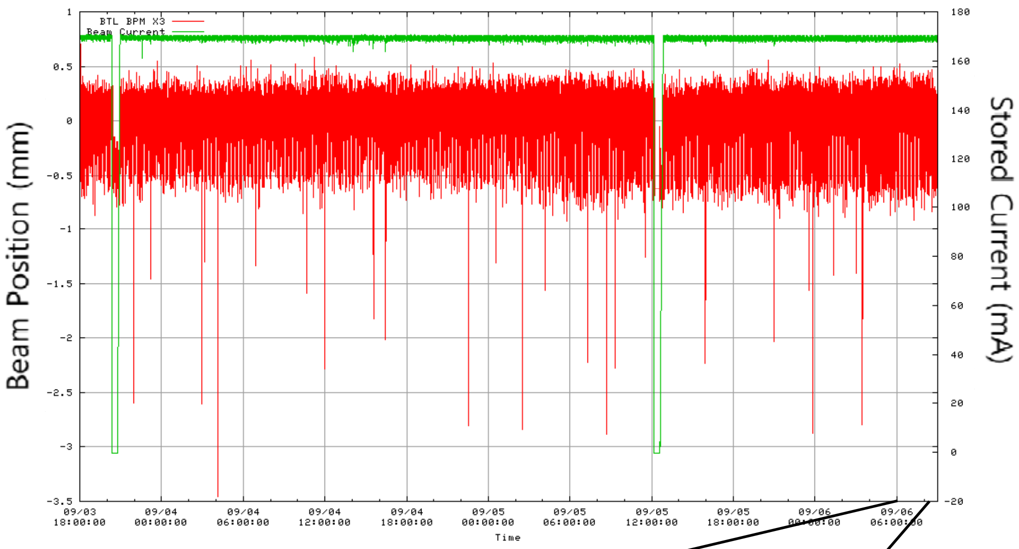
PLS Timing System

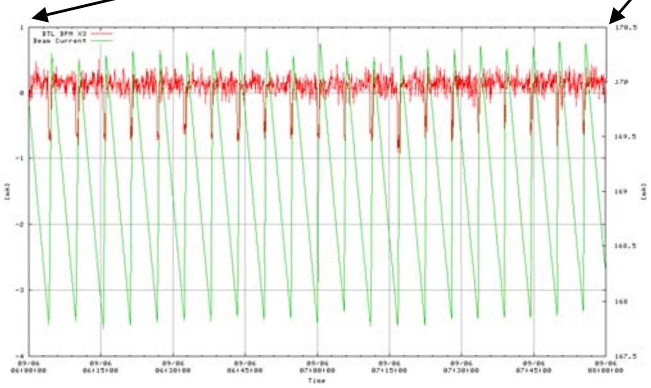


Event Trigger System
Provided by the SSRF

2010 September Top-Up Test Operation

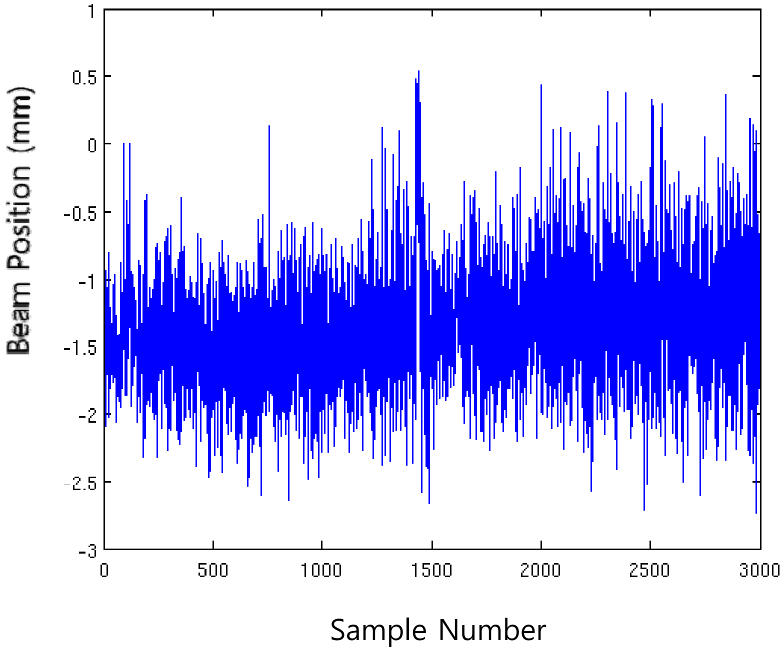
(9/3 18:00 – 9/6 09:00)

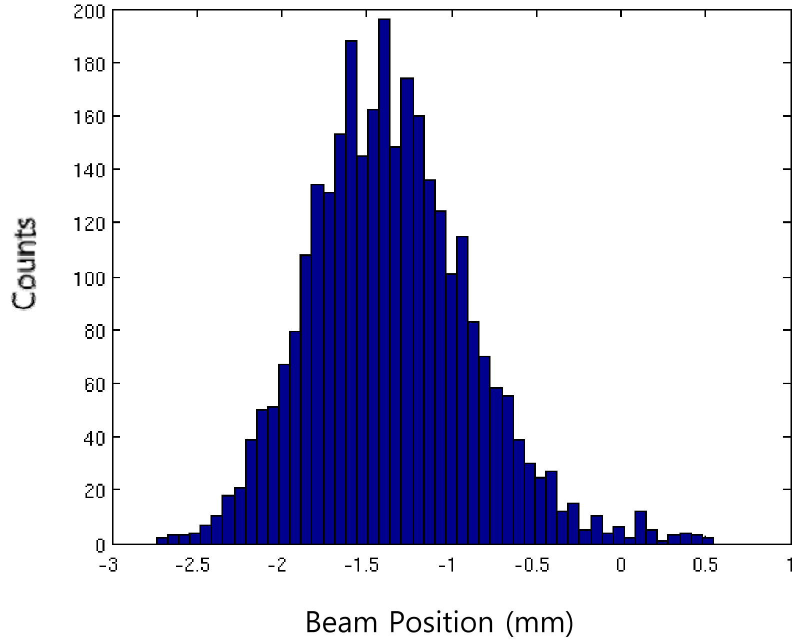




Total Operation Time [hr]	63
Total Down Time [hr]	2
Availability [%]	96.8
Total Number of Beam Dumps	2
Total Number of Linac Faults during injection	25
Average Time for an Injection [sec]	33
Linac Energy Variation (during Normal Operation)	pk-pk ~10 MeV (0.4%)

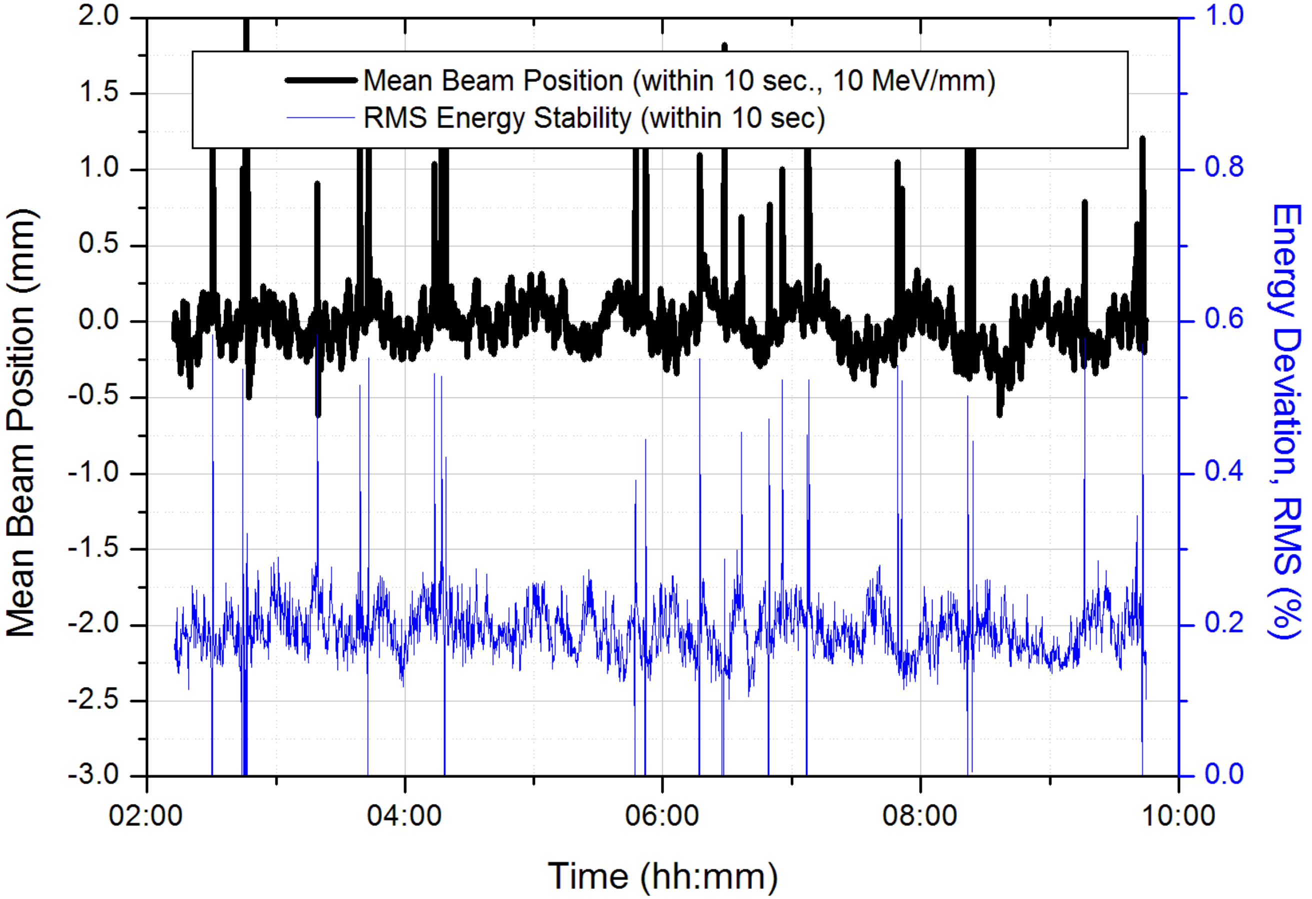
Energy Jitter
(Measured by Digital BPM @ BAS3, 9/9/2010)



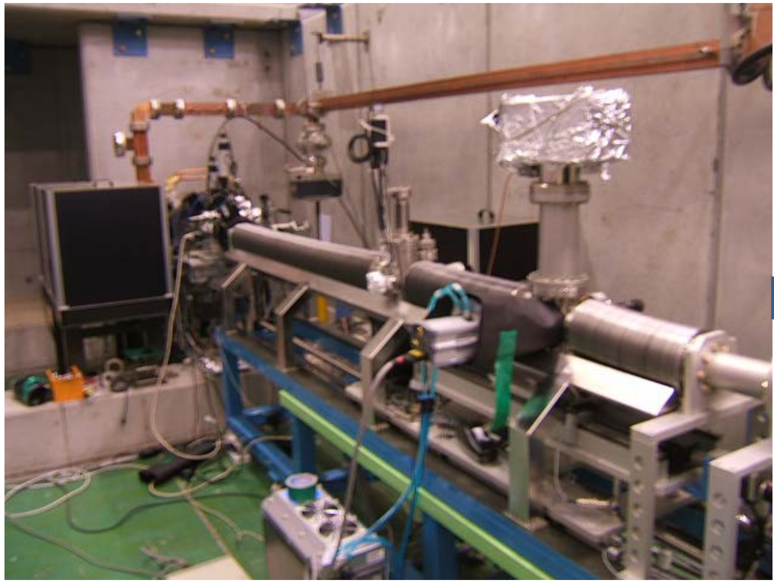


- 3000 samples (beam repetition rate = 10Hz)
- Dispersion = 250 mm (10 MeV/mm)
- RMS Jitter = 0.19% (cf. 0.36% measured on 7/12/2010)

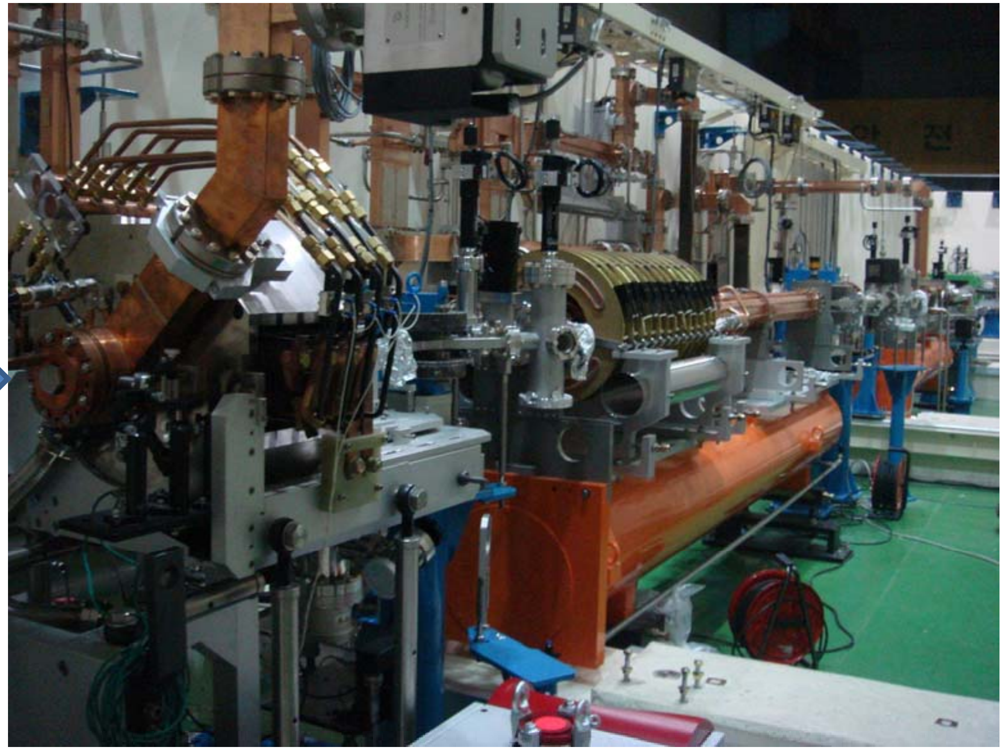
Long-Term Energy Stability
(Measured by Digital BPM @ BAS3)



High-Brightness R&Ds



Photocathode RF Gun
Test Stand (2004 - 2006)



Fs-THz Source Facility (2008 -)

Summary

1. A major upgrade to the Pohang Light Source (PLS), the PLS-II is well progressing.
2. The PLS Linac is being upgraded to 3 GeV to be within existing building.
3. In 2010 summer one acceleration unit (MK11) was successfully modified to double the RF power.
4. Upgrades of cooling system and installation of digital IPA system greatly improved the energy stability.
5. Test of top-up operation for the PLS storage ring and linac proved excellent linac energy stability.
6. High-brightness source R&Ds have been done to promise the bright future of the Pohang Accelerator Laboratory