Pohang Light Source

(http//:pal.postech.ac.kr)

Status and Research Activities

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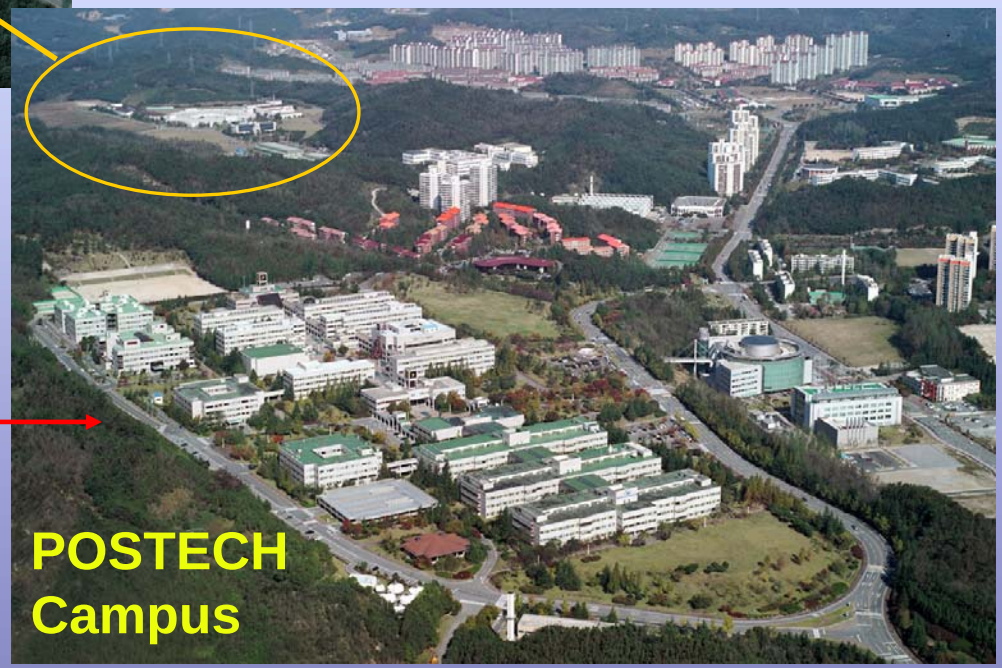
PAL(Pohang Accelerator Laboratory)
POSTECH

21 June 2007 Thomas Jefferson National Accelerator Laboratory

PAL: Chronology

- Project started Apr. 1 1988
- Ground-breaking Apr. 1 1991
- 2-GeV Linac commissioning June 30 1994
- Storage ring commissioning Dec. 24 1994
- User's service started Sept. 1 1995
- Energy ramping to 2.5 GeV Sept. 1 2000
- 2.5-GeV injection Nov. 1 2002
- 200mA injection Sep. 2004
- improved orbit FB < 2um Sep. 2005



Manpower and Budget

- Construction (1988. 4 ~ 1994. 12)
  - Total budget: 150.0 Bwon (~ 180M$)
  - Machine Cost: ~ 66M$

- Operation
  - 3 Divisions (12 Teams)
    - Accelerator
    - Beamline
    - Technical Support
  - Total Number of Staffs : 132
    - 73 Researchers (45 Ph.D.)
    - 42 Technicians
    - 17 Administrative Staffs
    - + 51 Temporary Employees

- 2006 Operation Budget: 22.8 BWon (~24M$)

Lab director: Prof. In Soo Ko
isko@postech.ac.kr

PLS Operation Status

2006 PLS Operation Schedule

PLS Operation (236days, 5664 hrs)
- User Beamtime (189days, 4536 hrs)
- Machine Turn-On & Machine Studies (47 days, 1128 hrs)
- Maintenance & Upgrade (114 days, 2736 hrs)
- No Operation (15 days, 360hrs)

	S	M	T	W	T	F	S	
1	1	2	3	4	5	6	7	
	8	9	10	11	12	13	14	
	15	16	17	18	19	20	21	
	22	23	24	25	26	27	28	
	29	30	31					

	S	M	T	W	T	F	S	
2				1	2	3	4	
	5	6	7	8	9	10	11	1
	12	13	14	15	16	17	18	
	19	20	21	22	23	24	25	
	26	27	28					2

	S	M	T	W	T	F	S	
3				1	2	3	4	
	5	6	7	8	9	10	11	
	12	13	14	15	16	17	18	3
	19	20	21	22	23	24	25	
	26	27	28	29	30	31		4

	S	M	T	W	T	F	S	
4							1	
	2	3	4	5	6	7	8	
	9	10	11	12	13	14	15	5
	16	17	18	19	20	21	22	
	23	24	25	26	27	28	29	6
	30							

	S	M	T	W	T	F	S	
5		1	2	3	4	5	6	
	7	8	9	10	11	12	13	7
	14	15	16	17	18	19	20	
	21	22	23	24	25	26	27	
	28	29	30	31				

	S	M	T	W	T	F	S	
6					1	2	3	
	4	5	6	7	8	9	10	8
	11	12	13	14	15	16	17	
	18	19	20	21	22	23	24	
	25	26	27	28	29	30		9

	S	M	T	W	T	F	S
7							1
	2	3	4	5	6	7	8
	9	10	11	12	13	14	15
	16	17	18	19	20	21	22
	23	24	25	26	27	28	29
	30	31					

	S	M	T	W	T	F	S
8			1	2	3	4	5
	6	7	8	9	10	11	12
	13	14	15	16	17	18	19
	20	21	22	23	24	25	26
	27	28	29	30	31		

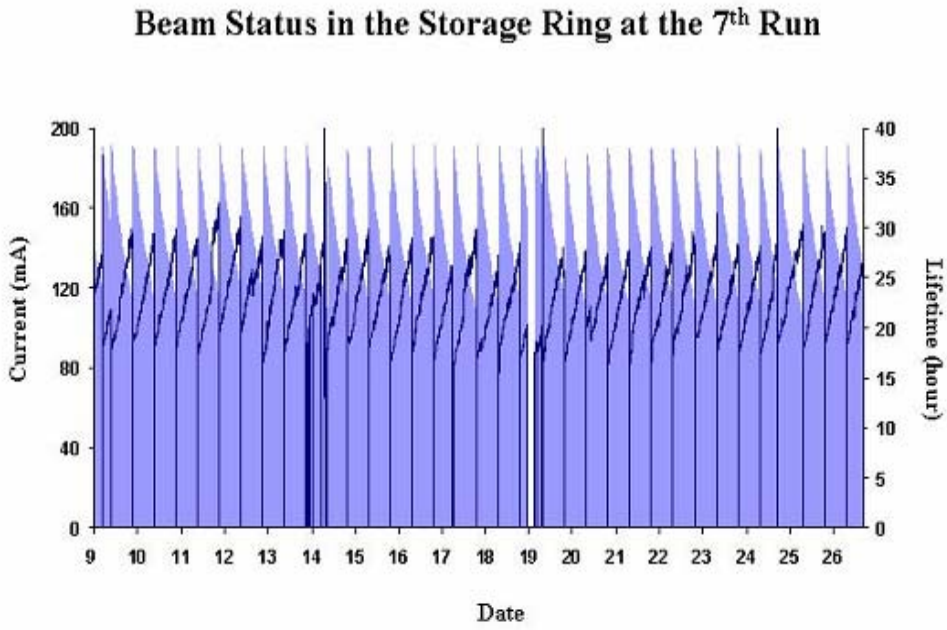
	S	M	T	W	T	F	S
9						1	2
	3	4	5	6	7	8	9
	10	11	12	13	14	15	16
	17	18	19	20	21	22	23
	24	25	26	27	28	29	30

	S	M	T	W	T	F	S
10	1	2	3	4	5	6	7
	8	9	10	11	12	13	14
	15	16	17	18	19	20	21
	22	23	24	25	26	27	28
	29	30	31				

	S	M	T	W	T	F	S
11				1	2	3	4
	5	6	7	8	9	10	11
	12	13	14	15	16	17	18
	19	20	21	22	23	24	25
	26	27	28	29	30		

	S	M	T	W	T	F	S
12						1	2
	3	4	5	6	7	8	9
	10	11	12	13	14	15	16
	17	18	19	20	21	22	23
	24	25	26	27	28	29	30
	31						

Typical Beam Current Pattern during one user shift



- **2006 Operation Summary**
  - **Max. stored beam current : ~ 195 mA**
  - **User beamtime: ~4450 hr /4560 hr (189days)**
    = 97% beam availability
  - **Slow global orbit feedback runs every 5 seconds**

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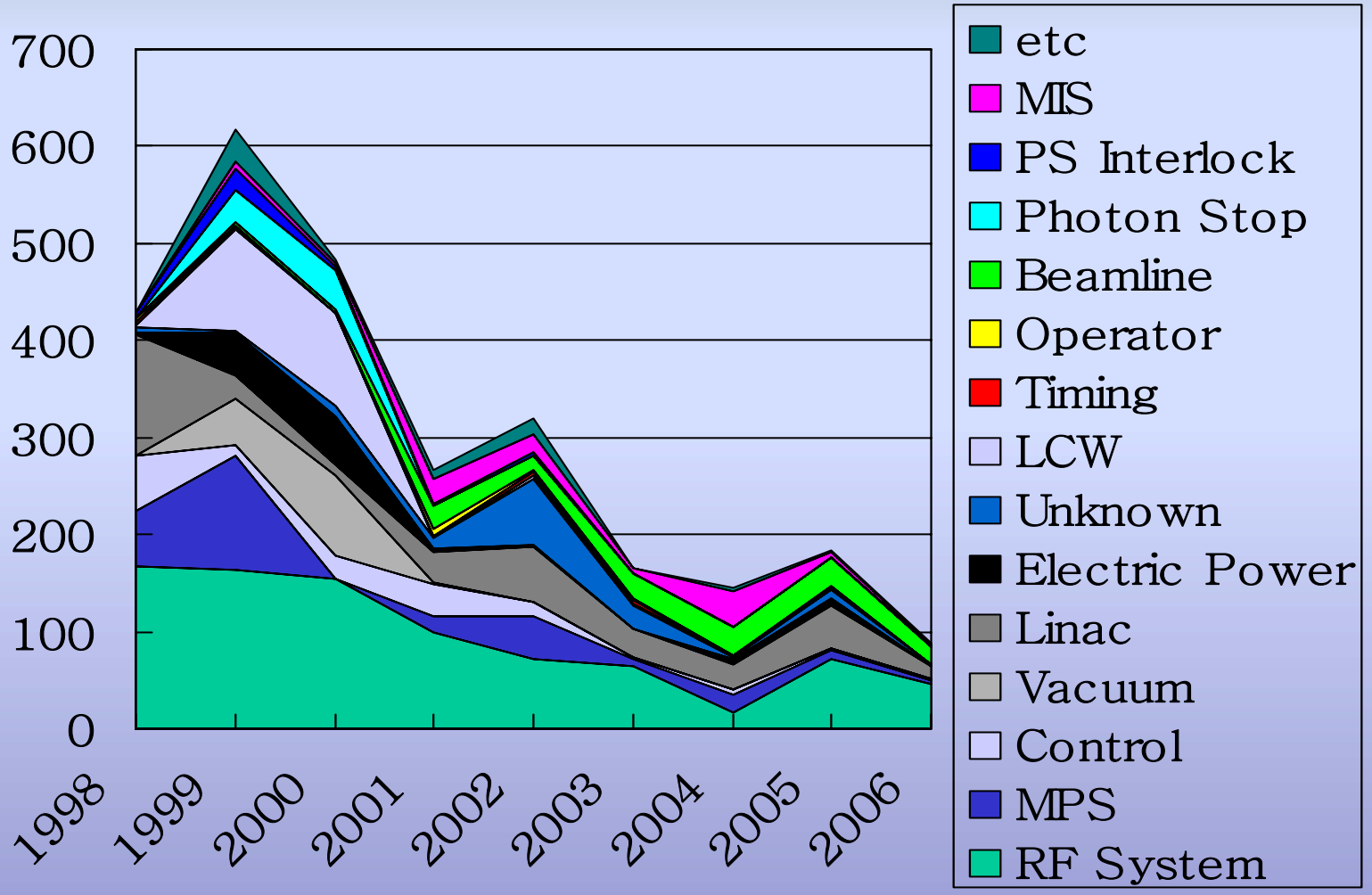
Machine Fault Summary



1999: 2.5 GeV Operation Started

2002: Full energy injection Started

2005: end-of-life failure increased

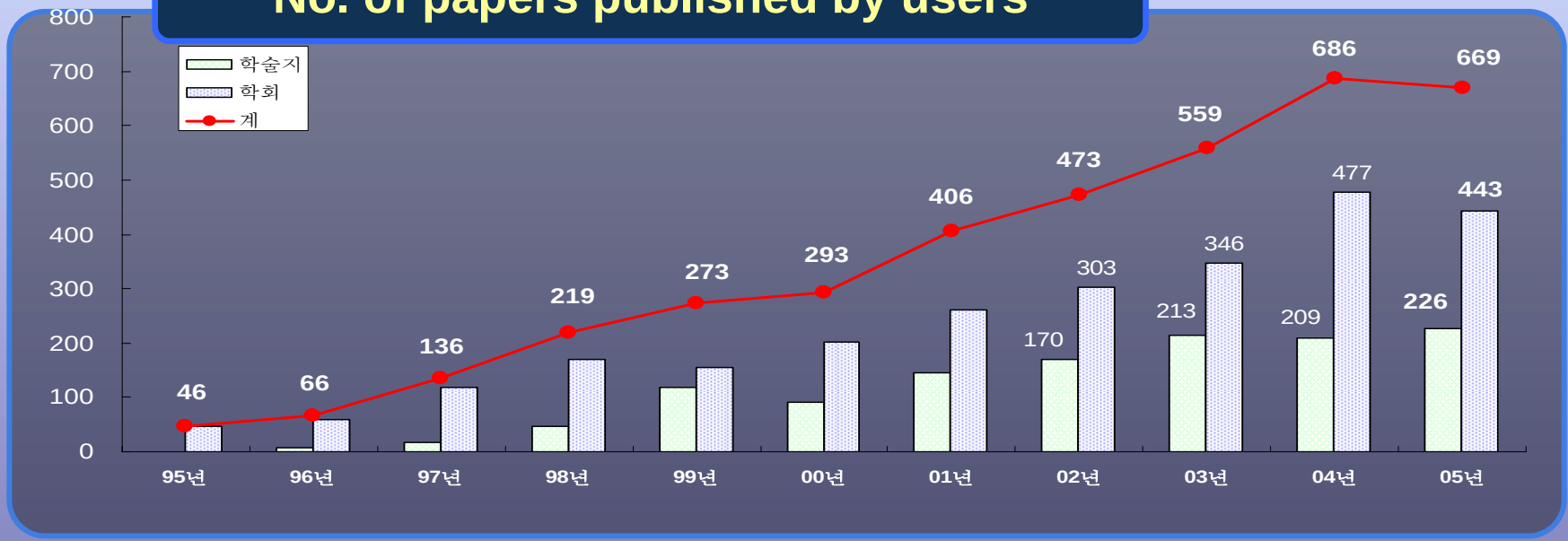
User statistics

– **No. of Users and Experiments**

*** 3,004 experiments by 10,138 users until 2005**

Year	‘95	‘96	‘97	‘98	‘99	‘00	‘01	‘02	‘03	‘04	’05	Sum
Application	58	124	173	171	255	322	408	467	531	631	797	3,937
Approved	18	69	139	130	156	237	270	310	382	489	648	3,004
No. of Users	78	283	577	646	659	883	1,071	1,197	1,321	1,466	1,957	10,138

No. of papers published by users



Machine Status

- 2.5GeV Linac
- 2.5GeV Storage Ring
- 70MeV Test Linac (nuclear data)
- 40MeV FIR source (in construction)
- 3.7GeV XFEL (in design work)

Operation Issues of PLS

LINAC

- Energy Stabilization and Feedback (top-up and FEL)
  - digital phase and amplitude feedback
  - Smart modulator
  - temperature control
- Replacement of End-of-life Component
  - Klystron development
  - energy doubler
  - power supplies
- Upgrade of Linac
  - uW phase feedback
  - diagnostics
  - beam optics

Storage Ring

- Beam stabilization
  - 80 digital MPS installed (2ppm)
  - T control for electronic racks
  - chamber(13m long) movement monitored for all BPMs
- Beam instability
  - longitudinal feedback (SLAC)
  - HOM cure by T-control
  - transverse feedback
- RF power (4 x 75kW, 500 MHz)
  - 5^{th} cavity to be installed
- Settlement of ground
  - ground move ~1.5mm/year
  - Source-beamline alignment
  - HLS around SR tunnel floor

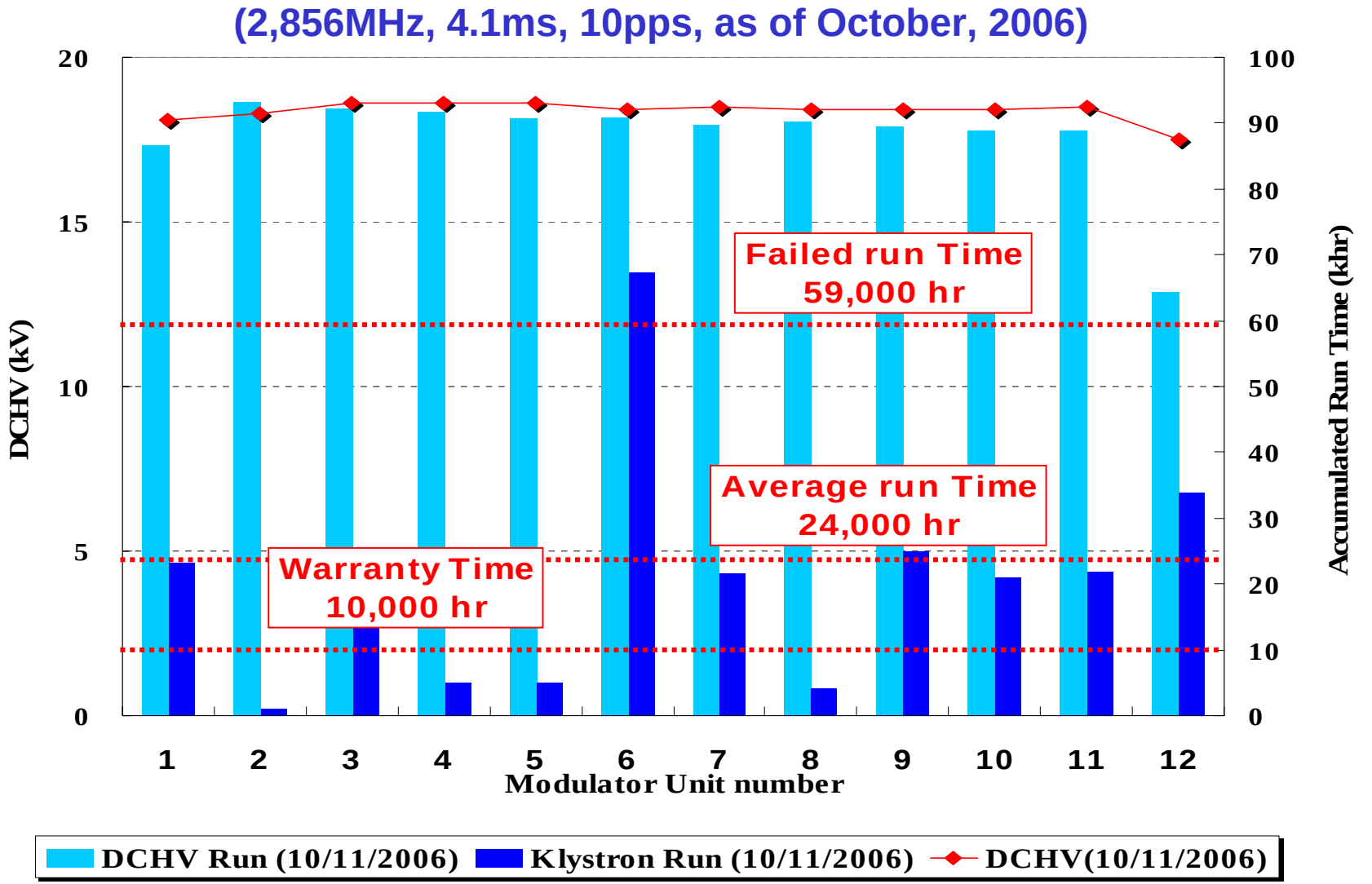
2.5 GeV Linac

Injector LINAC

- Length = 160m
- 2.5GeV, full energy injection
- 2,856 MHz (S-band)
- Normalized emittance: 150um
- 10Hz, 1.5 ns, 1A pulsed beam

- Thermionic Electron Gun
- 12 Pulse Modulators (200MW, 4us)
- 12 Klystrons (80 MW)
- 11 Energy Doublers (g=1.6)
- 44 x 3m Accelerating Sections (~ 20MeV/m)

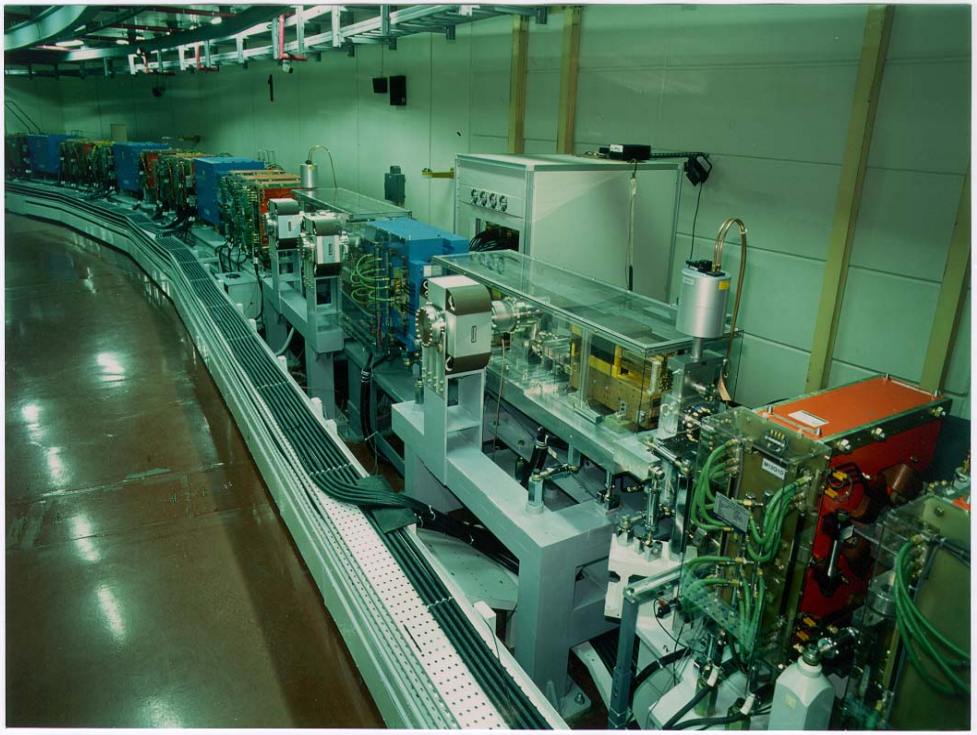
Operational Status of Modulator and Klystron



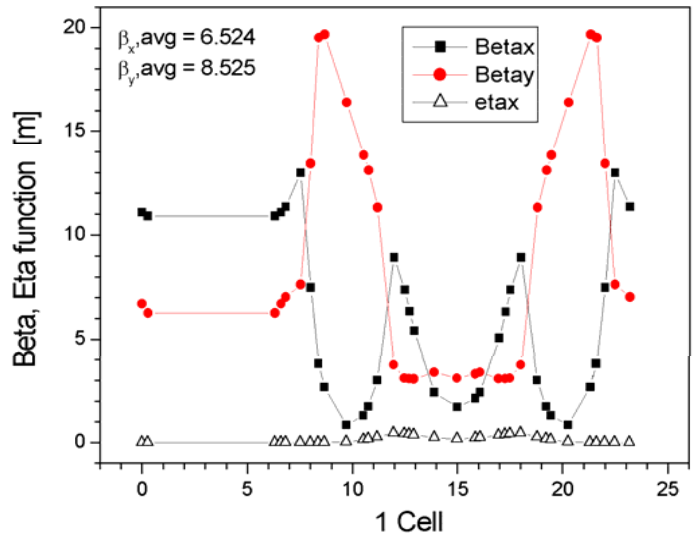
klystron lifetime records

Mod. No	Tube Type	Tube Serial No.	Magnet Serial No.	Heater Time (hr)	Problems	Failed Date
M02	E3712	PLS001	PLS001	18,833	Magnet coil short, Kly. Arc(13kV)	1995-08-12
M06	E3712	51005PLS	51005PLS	26,772	Kly. Arc, Mag. Noise, bucking	1997-02-25
M08	E3712	65008PLS	65008PLS	27,290	Heater internal short	1997-03-28
M12	E3712	93015PLS	93013PLS	28,463	Input cavity damage	2001-12-26
M09	E3712	41009PLS	41009PLS	68,300	Arcing, Capacitor divider damage	2003-03-07
M01	SLAC5045	511A	SM11A	72,123	life time of heater finished	2003-05-21
MK07	E3712	65007PLS	65007PLS	71,500	life time of heater finished	2003-08-04
MK11	E3712	77006PLS	77006PLS	71,518	life time of heater finished	2003-08-20
MK10	E3712	98010PLS	98010PLS	72,158	life time of heater finished	2003-10-17
MK03	E3712	PLS002	PLS002	80,844	life time of heater finished	2004-08-03
MK04	E3712	74003PLS	74003PLS	90,180	life time of heater finished	2005-12-26
MK05	E3712	89004PLS	89004PLS	89,465	life time of heater finished	2005-12-28
MK08	E3712	82013PLS	51005PLS	62,514	Tube collector leaks cooling water	2006-02-24
MK02	E3712	21011PLS	21011PLS	78,586	life time of heater finished	2006-08-22
MK06	E3712	14012PLS	14012PLS	67,675	life time of heater finished	2006-10-27

PLS Storage Ring



- Beam Energy 2.5GeV
- Beam Current 200mA
- Lattice TBA
- Superperiods 12
- Circumference 280 m
- # of bunches 300 (ooox fill)
- Emittance 18.9 nm-rad
- Tune 14.28 / 8.18
- RF Frequency 500 MHz
- harmonic # 468

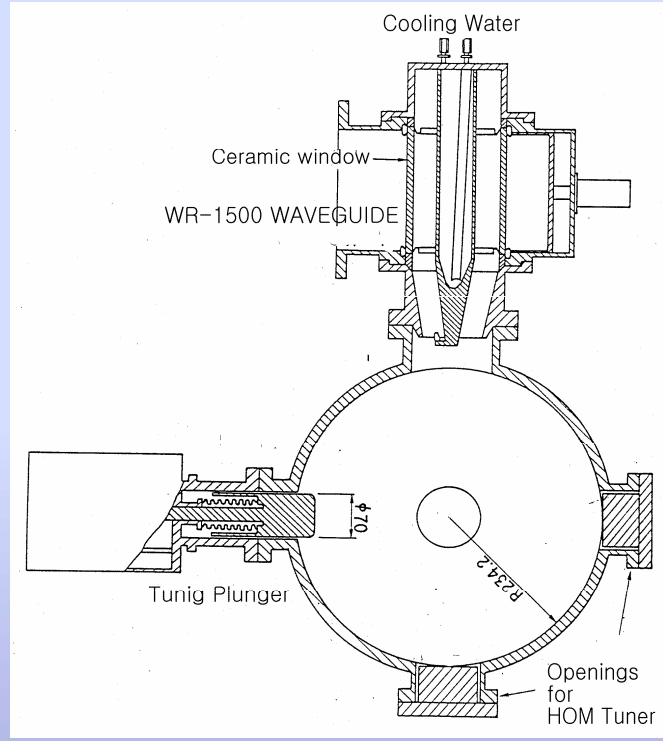


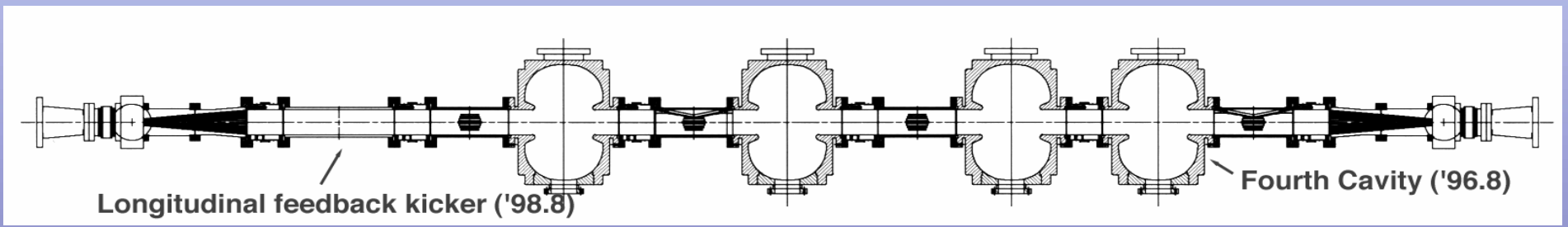
Major Components

- rf system: 75kW x 4 cavities
- Longitudinal CBI damping system
- magnet power supply (2ppm)
- orbit feedback system (2um)
- chamber-motion monitoring system
- ground-motion monitoring system

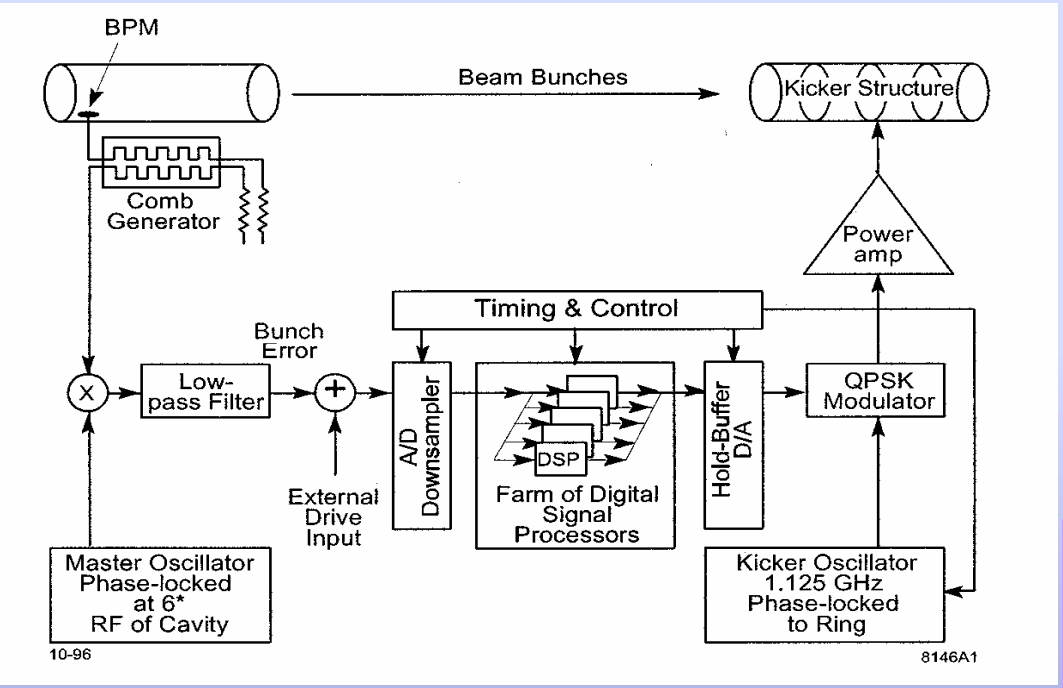
PLS RF System

RF Frequency	500.064 MHz
Number of Cavities	4
Total Cavity Voltage	1.6 MV
RF Cavity Shunt Impedance	8.5 MΩ
RF Cavity Quality factor	38,000
Number of Klystrons	4
Longitudinal damping time	4.2 ms





Longitudinal Feedback System



LFB System Setup

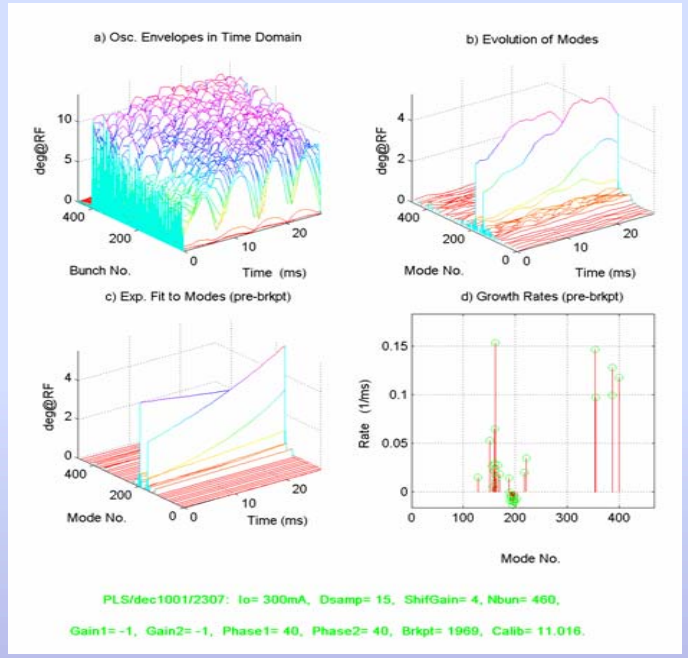
- **Bunch-by-bunch feedback system to suppress the longitudinal coupled bunch instability**
- **digital signal processing formalism to compute correction signals for each bunch**

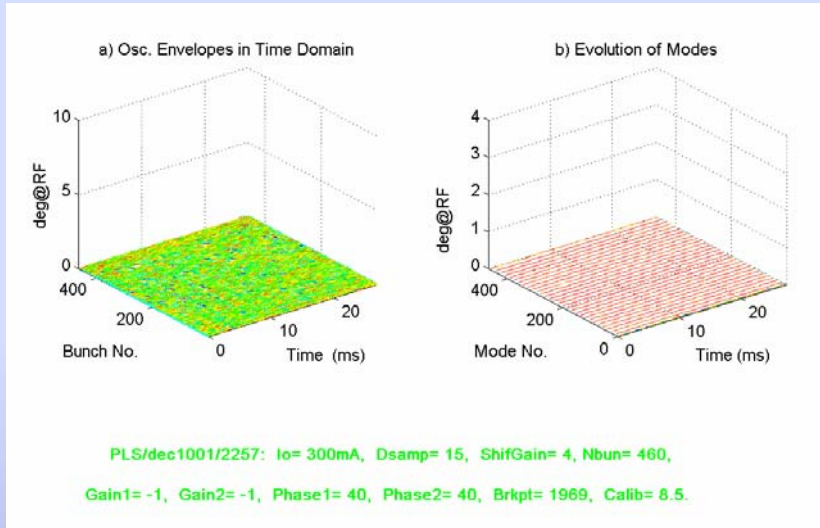
SLAC developed and PAL, DAΦNE, ALS, BESSY-II shares the same technology

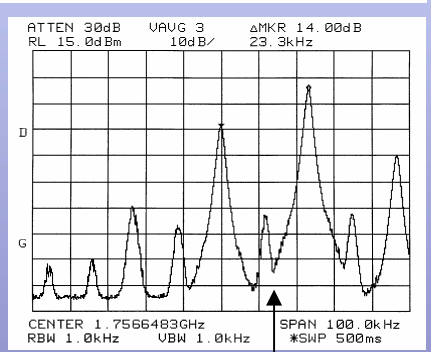
John Fox, SLAC

Suppression of CBI

LFS OFF **@ 2GeV/300mA** **LFS ON**

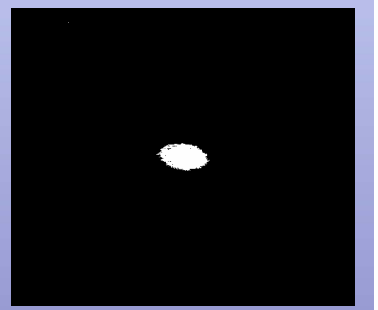




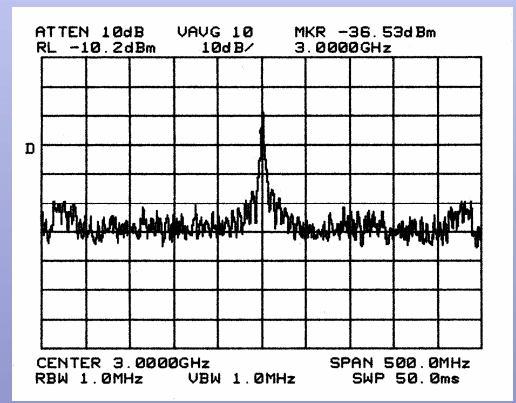


HOM: 758 MHz (TM011)
831 MHz (TM021)

Revolution harmonics



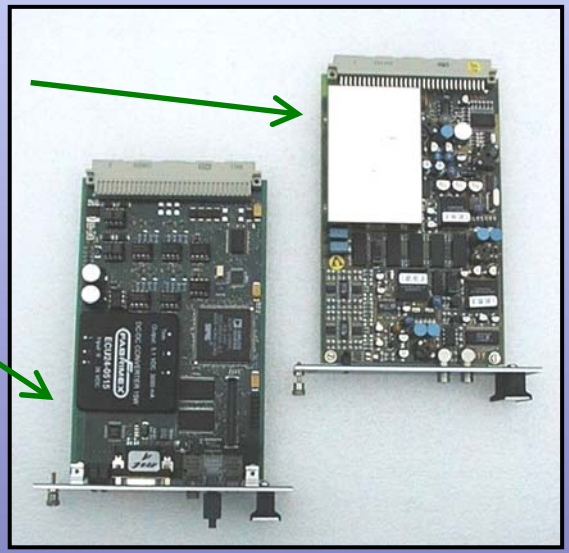
CBI Suppressed



Digital Corrector Power Supply

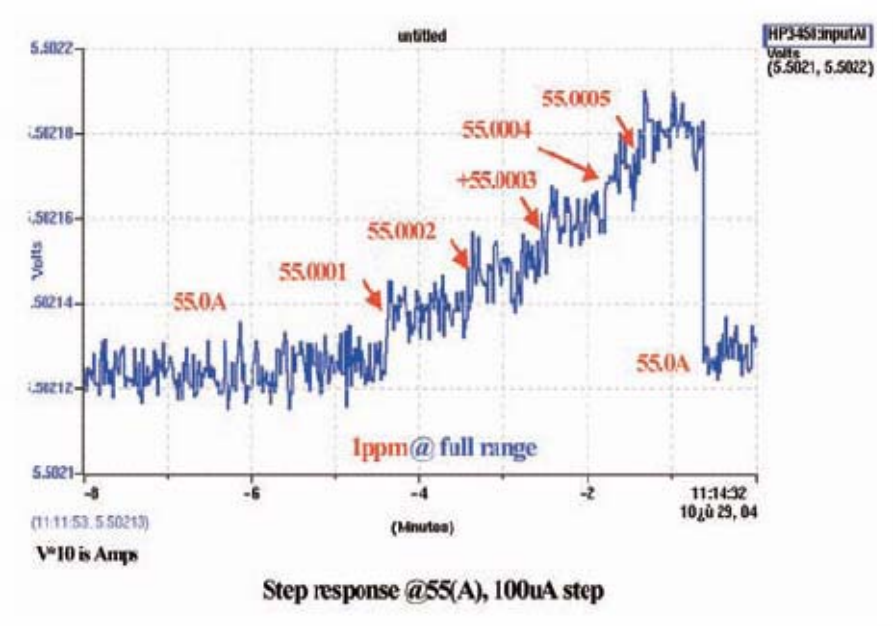
Analog- Digital-Converter

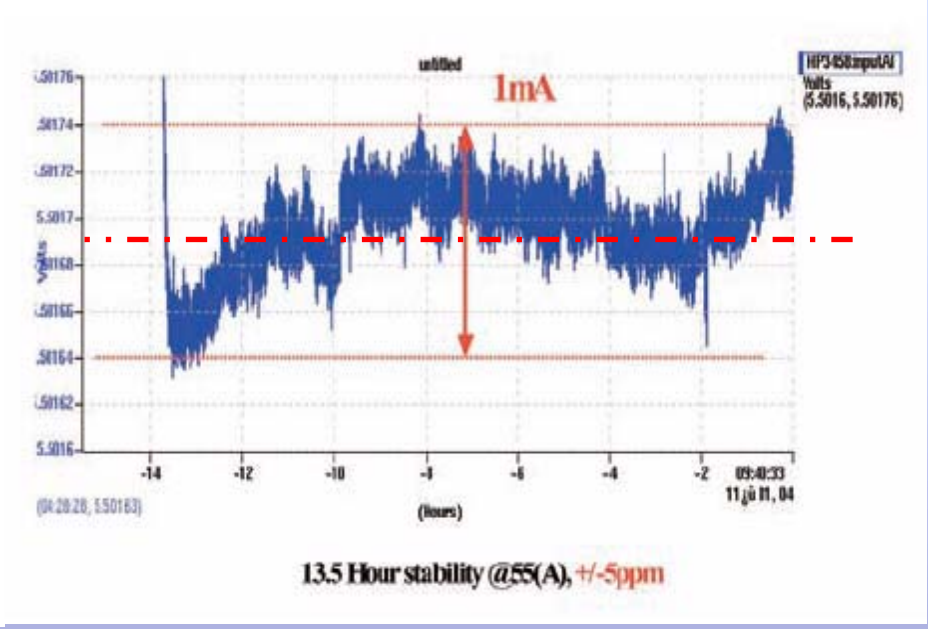
DSP-FPGA controller incl. PWM generator



	12bit Analog	16bit Analog	20 bit Analog	20bit Digital
Feedback control	Analog	Analog	Analog	Digital
Long-term (10d)stability	100 ppm	100 ppm	50 ppm	20 ppm (+/-5ppm)
Short-term stability	10 ppm	10 ppm	5 ppm	2 ppm
Feedback Controller	In house developed	In house developed	Euro-card developed by BESSY	DSP & FPGA developed by PSI
Switching frequency	2 kHz	16 kHz	50 kHz	25 kHz
Feedback scheme	current	current	Current	Current + voltage
Quantities geand Usa	All dismissed	48 ea Hor. Corrector	22 ea Hor. Corrector	70 ea Ver. Corrector

Performance of Power Supply



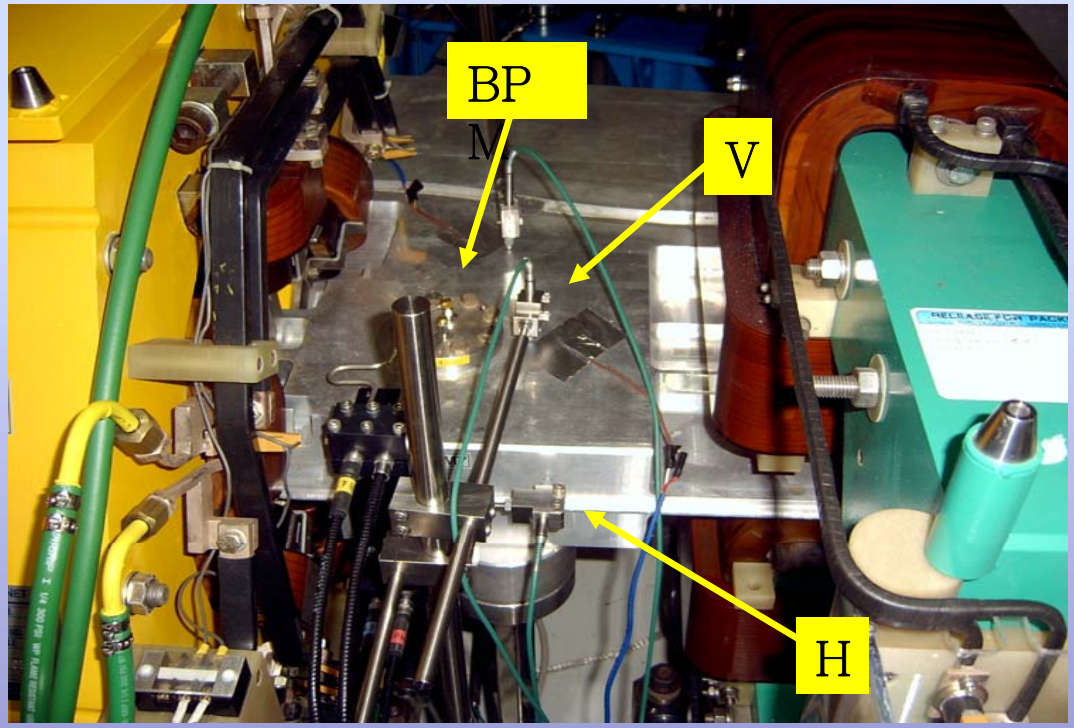


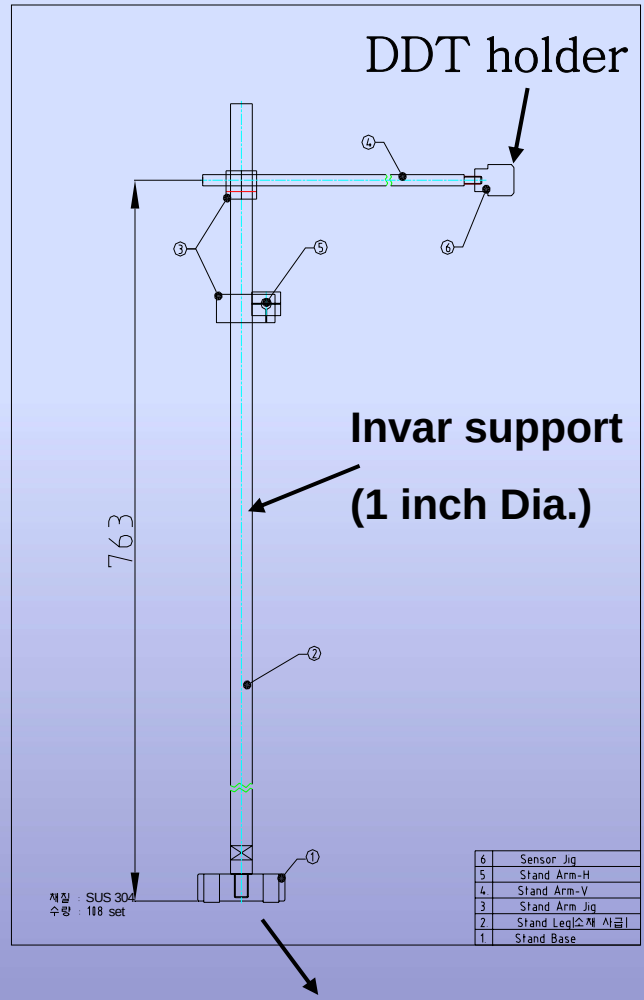
1 ppm step response

+/- 5ppm for 14 hr @55A

Measurement of BPM Chamber Motion

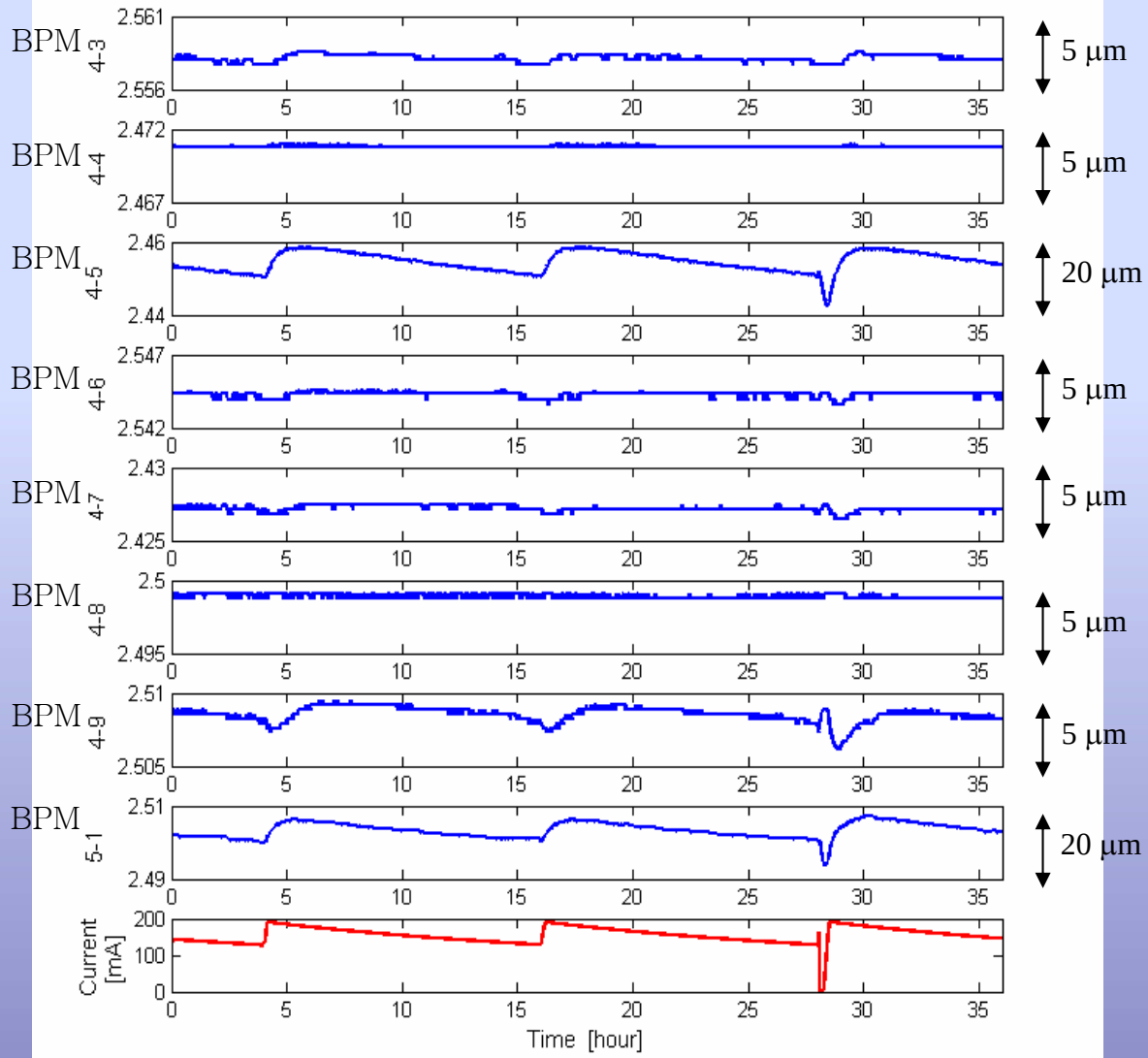
108 DDT(Digital Displacement Transducer) were installed in the vertical direction onto the vacuum chamber as close as possible to BPM in August 2005.



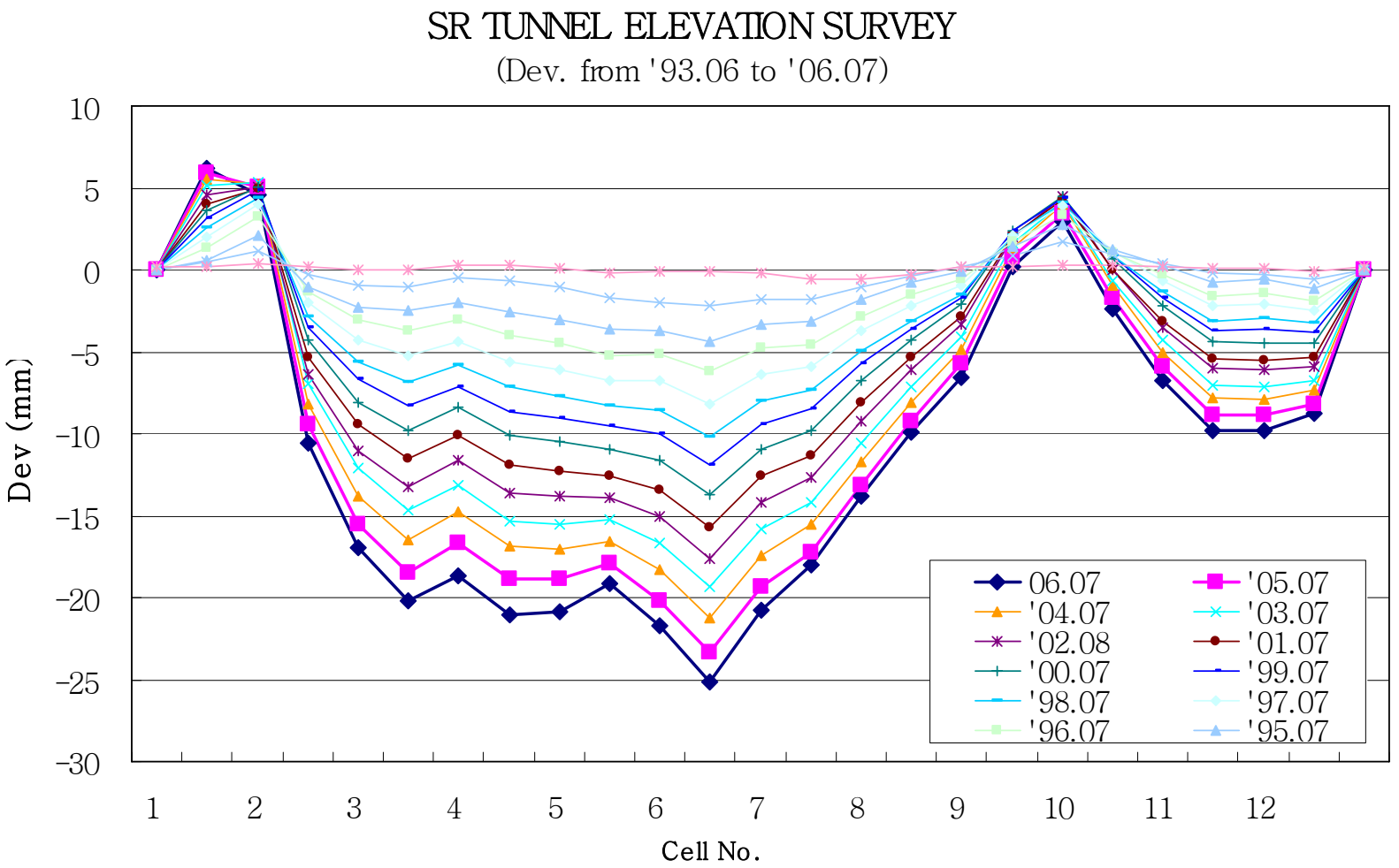


Model: SOLARTRON DP5
Stroke: 5 mm,
Reading accuracy: < 0.3 μm

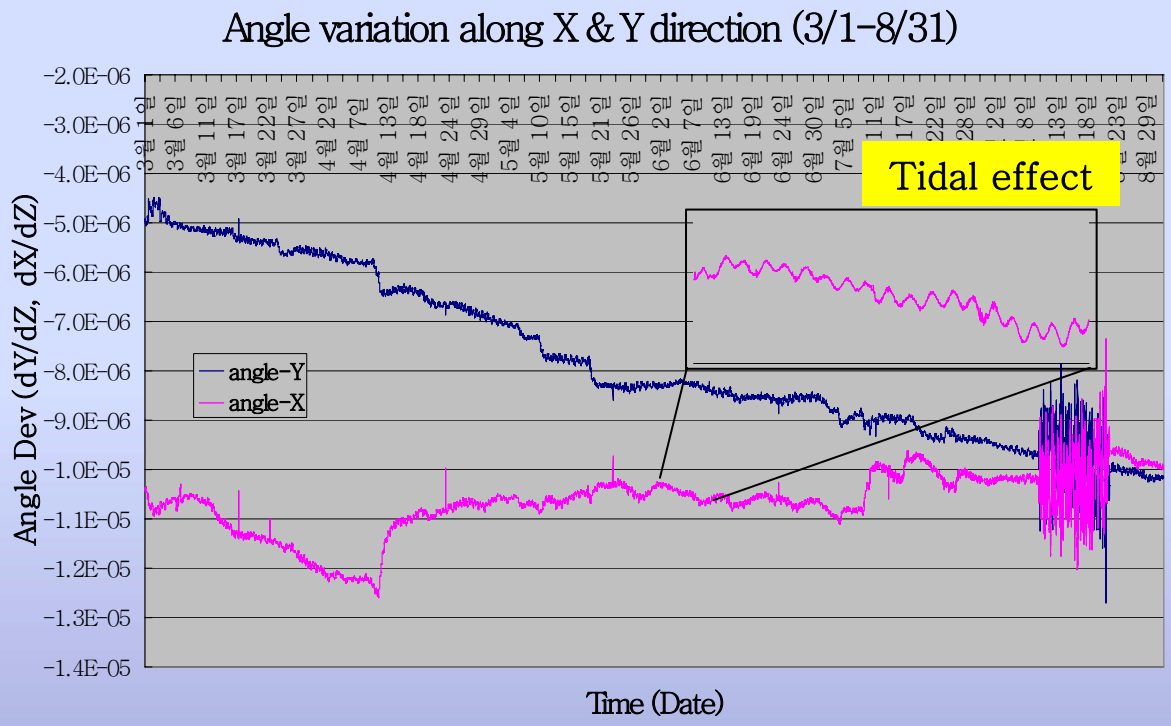
Measurement of Chamber Motion



Settlement of Tunnel Floor



Hydraulic Leveling System

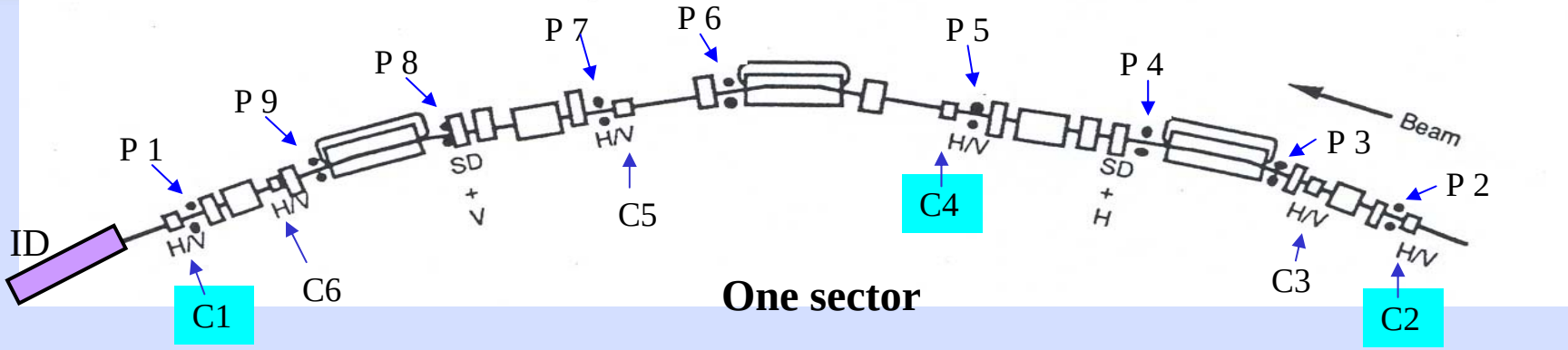


- Linear tiling movement along y direction
- Little tilting movement of x-direction from winter to summer

Beam Diagnostic System

- **Beam Position Monitors**
  - 112 units (108 in arc + 4 ID BPM)
  - Bergoz electronics
  - 1 um resolution
  - 483 MHz TE mode excitation is solved by (1110) filling pattern. (375MHz BPM)
- **Photon BPM**
  - 7 working units at beamline front-ends
- **Digital BPM**
  - Turn by turn measurement
  - High resolution (0.5 um), High band width
  - 1 unit with EPICS IOC

Correctors and BPMs (Orbit Feedback)



- **9 BPMs & 6 Correctors /sector → 108 BPMs and 70 correctors in each plane**
- **BPM electronics: Bergoz MUX BPM**
- **Insertion Devices (7)**
  - **Undulator: U7, EPU6, U6/U10, In-Vacuum Revolver (min. gap: 5 mm)**
  - **Multipole Wiggler: HFMX, HFMS**

◆ **SOFB uses**

20 bit resolution PS : 0.004 μrad/ 1 bit

- 2 correctors (C1, C2) / sector -> 22 correctors in each plane

- 6 BPMs / sector

- Beam current dependence table for BPM electronics

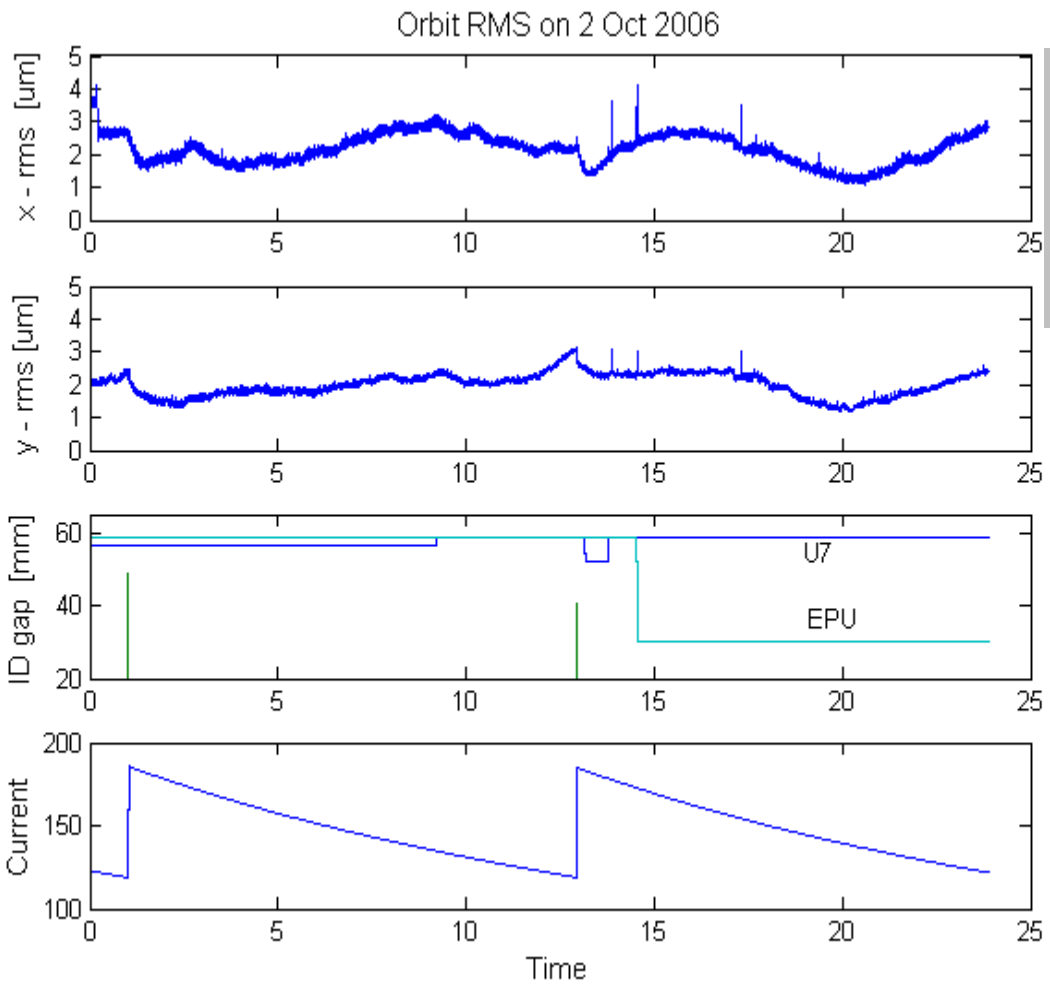
- chamber motion compensation

Orbit data for one day

RMS-x

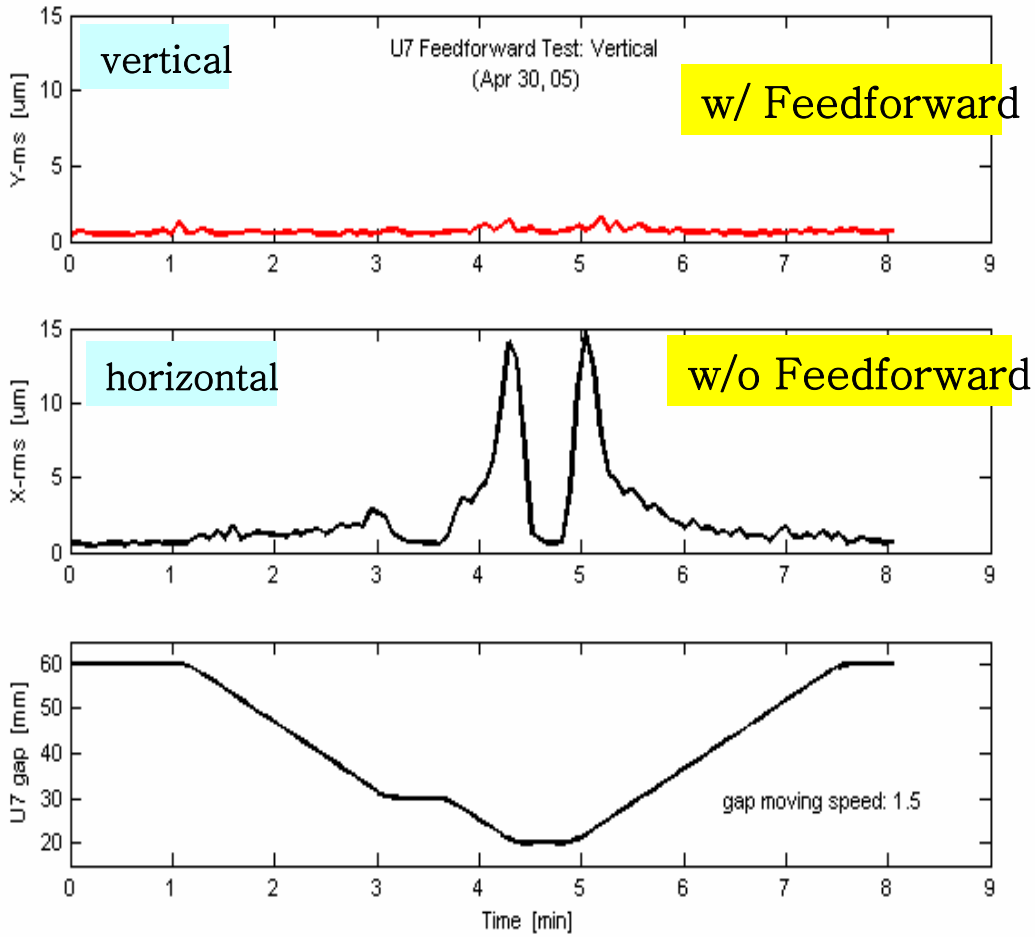
RMS-y

ID gap



- SOFB speed: 5 sec
- Feed-forward correction for ID is used (speed: 0.2 sec).

ID Feedforward correction



Beamline Status

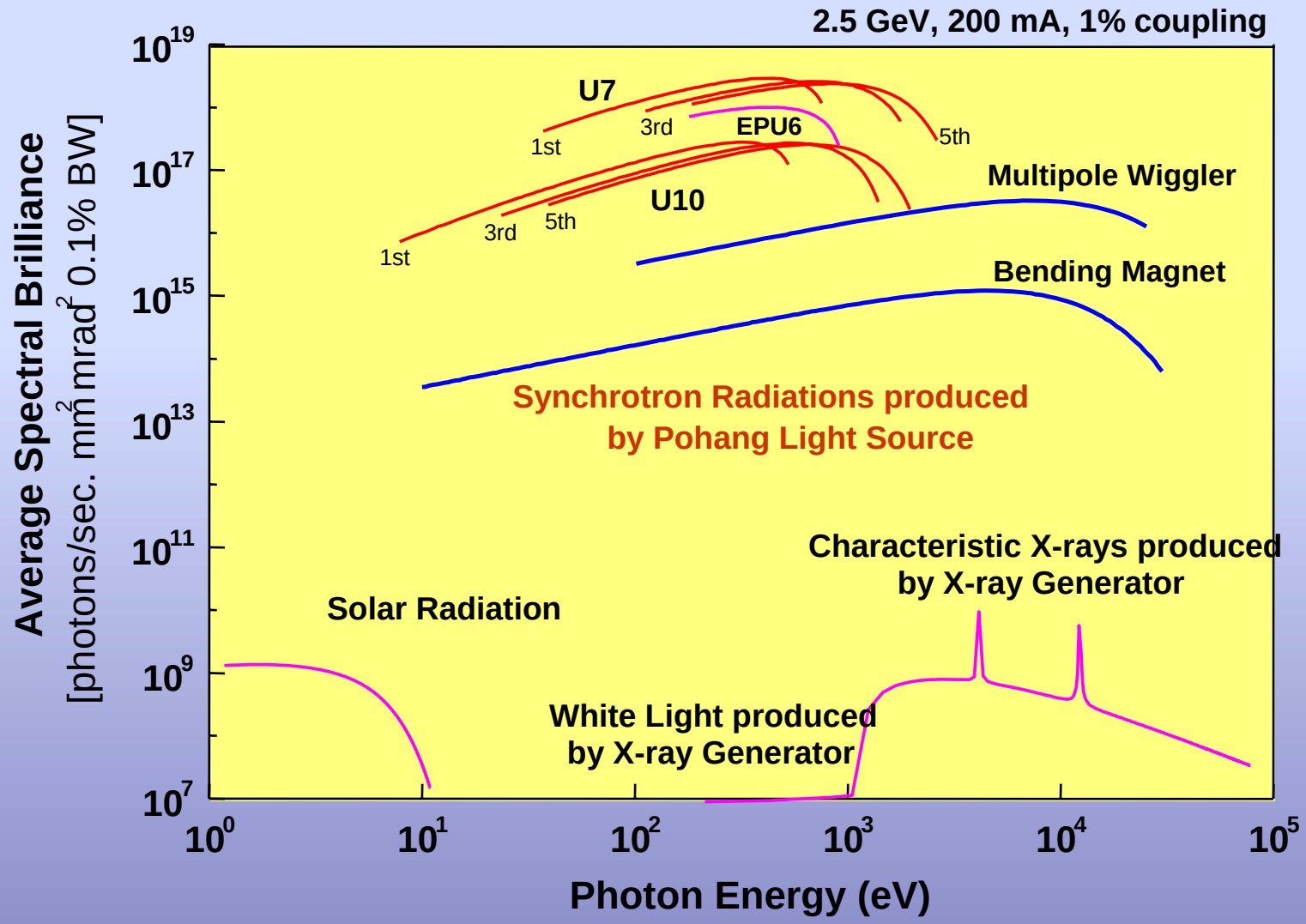
Statistics

- 26 beamlines in service
- 1 BL in commissioning
- 4 BLs in construction
  - 7 insertion devices
- >2000 users / year
- >700 experiments / year

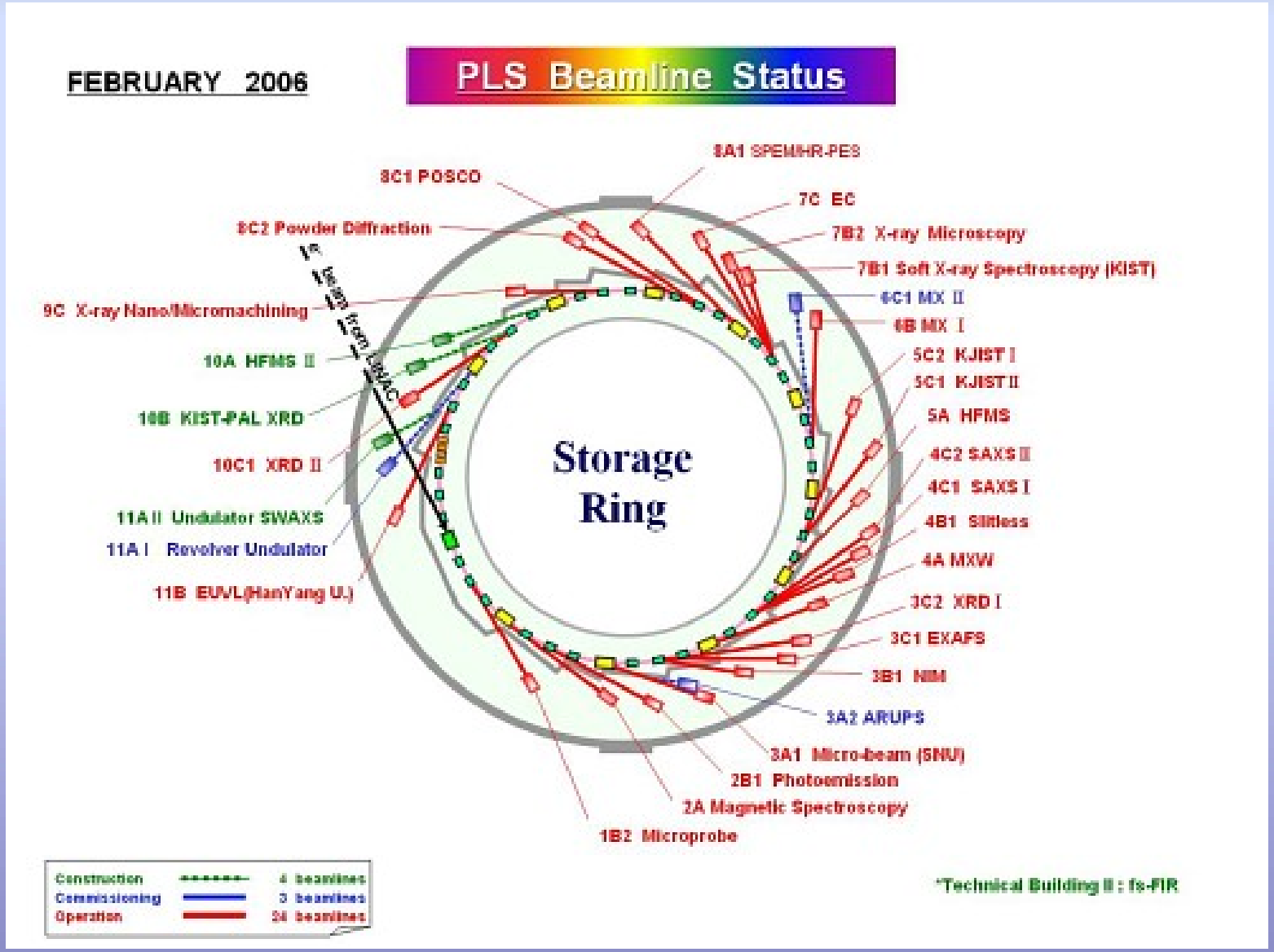
Sciences

- x-ray diffraction
- imaging: microscopy
- lithography
- spectroscopy
- spectromicroscopy
- magnetic spectroscopy
- Nanoscopy

Spectral Brilliance



PLS Beamline Status



IDs in PLS

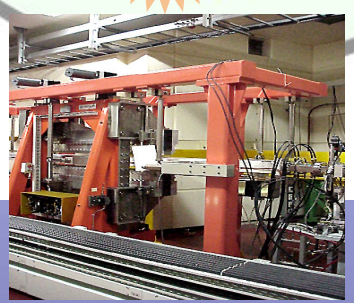
7 IDs installed in the ring.

In-vacuum Undulator

Out-vacuum Undulator

Out-vacuum Wiggler

6A : IVUN (MX)
7A : IVUN (Imaging)
9A : IVUN (SWAXS)
10A : WG (HFMS)



U6/U10

MPW14

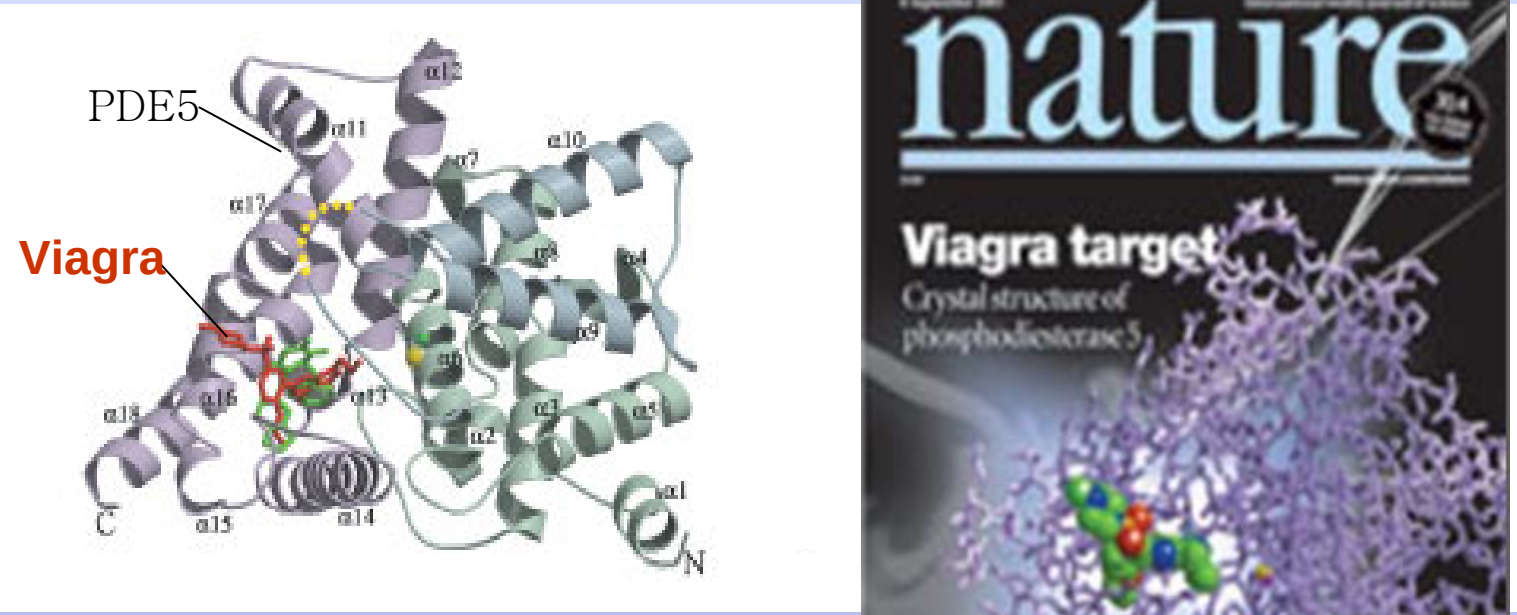
Beamline Experimental Hall

Sciences

- X-ray Diffraction
- Imaging: Microscopy
- Lithography
- Spectroscopy
- Spectromicroscopy
- Magnetic Spectroscopy
- Nanoscopy
- ……

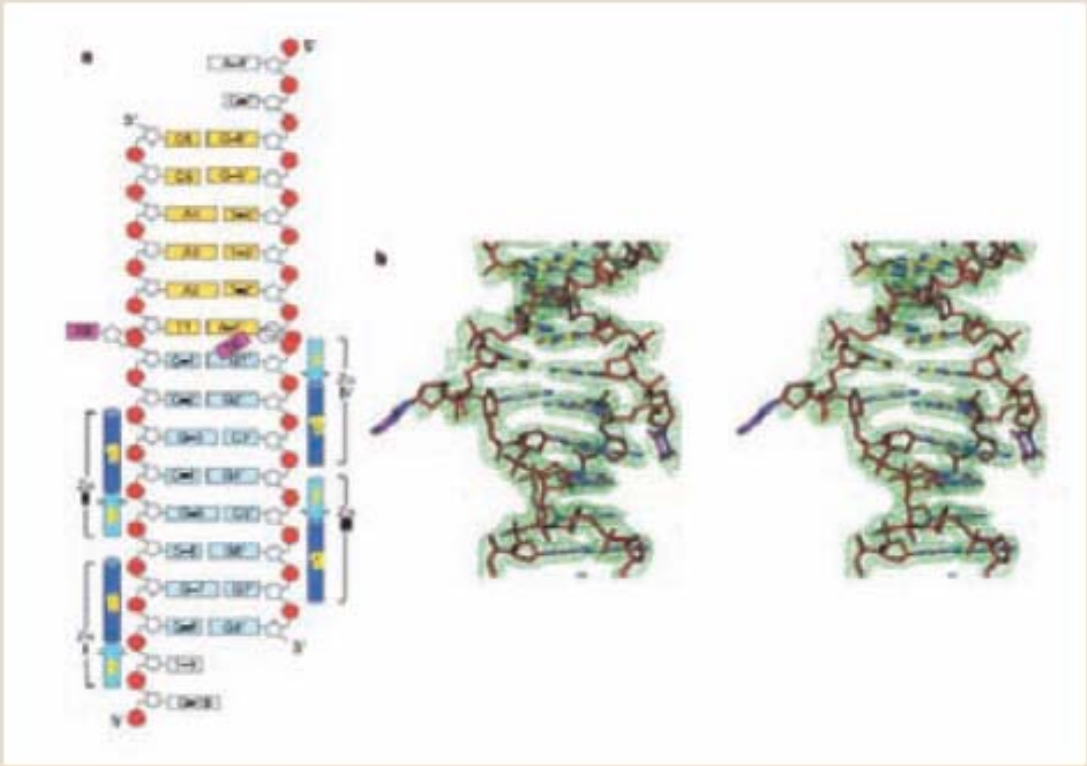
Two proudly cited works at PLS are …

Structure of the catalytic domain of human phosphodiesterase 5 with bound drug molecules



Nature (2003.9.4)

Left-handed meets right-handed DNA

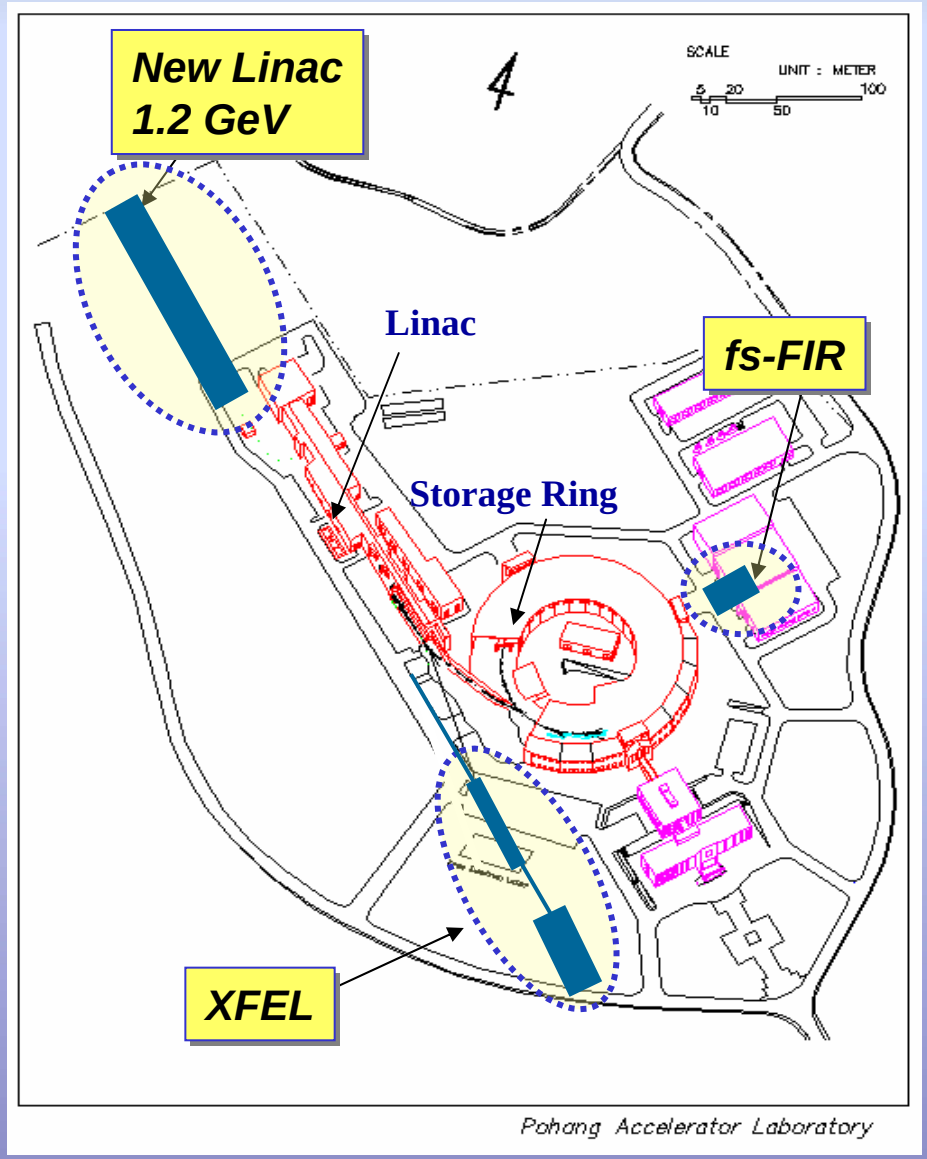


Nature (2005)

Ongoing projects

- 3.7GeV XFEL (in design work)
- Gun Test Facility
- 40MeV FIR source (in construction)
- 200MeV FEL test facility (in design)

PAL XFEL Project



- Need for science with fs x-ray pulse laser
- PAL has 2.5GeV LINAC as PLS injector
- XFEL machine is a good test facility for ILC
- Project period: 2005 – 2010 (delayed)
- Budget: 100 M$

PAL XFEL Project

- Energy: 1.2 – 3.7 GeV
  - WFEL: 2 ~ 5 nm
  - XFEL: 0.3 nm
    - (0.1 nm at 3rd harmonic)
- Budget: ~ 100 M$ total
  - 2005: 0.4 M$
  - 2006: 0.4 M$
  - 2007: 1.0 M$

No official approval from Government yet

XFEL Parameters

Parameters	Value	Unit
Electron energy	3.7	GeV
Peak current	3	kA
Normalized slice emittance	1	mm mrad
RMS slice energy spread	0.01	%
Full bunch length	80 (1 sigma ~110fs)	mm
Undulator period	1.5	cm
Undulator gap	4	mm
Undulator parameter, K	1.49	
Full undulator length	80 - 100	m
Radiation wavelength	0.3 (0.1nm 3rd har.)	nm
FEL parameter, ρ	5.7×10^{-4}	
Peak brightness	5×10^{31}	
Peak power	1	GW
1D gain length	1.2	m
Saturation length	60	m

Design Issues

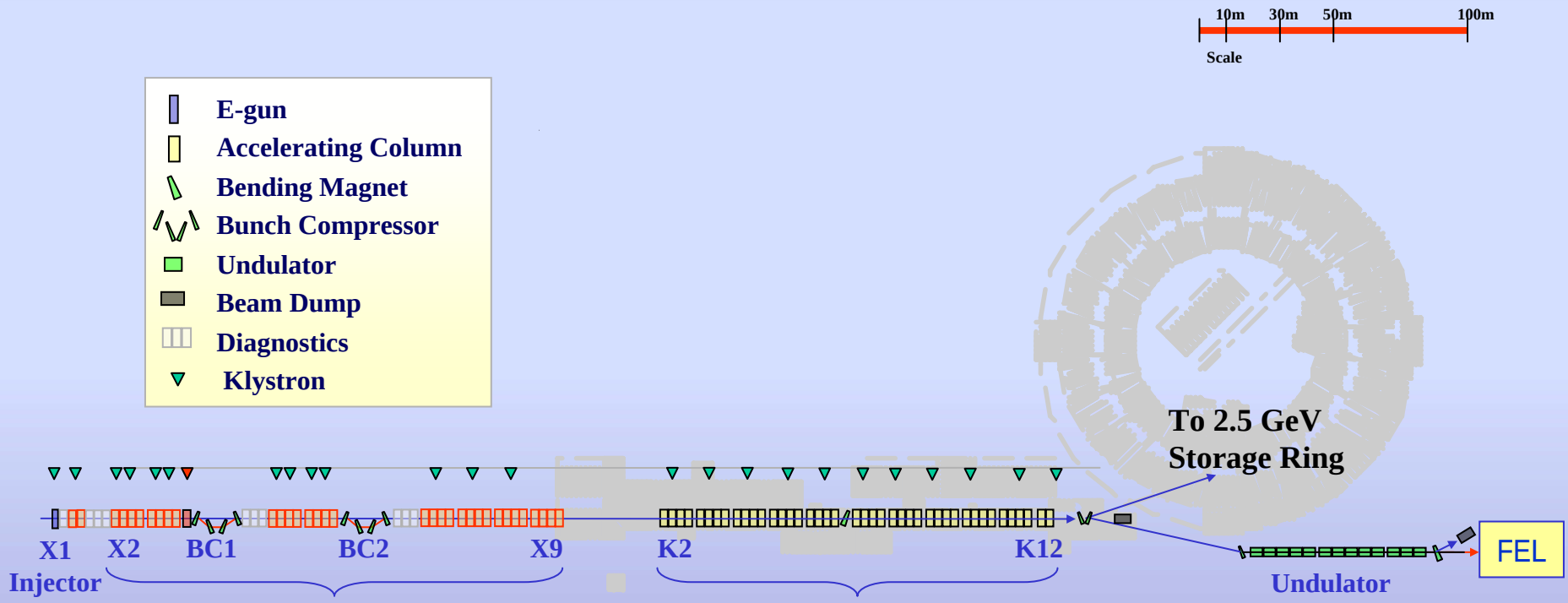
Accelerator

- Low-emittance (< 1 μmrad)
- High-peak-current(3.4 kA)
- Stability:
  energy, rf amplitude & phase
- Bunch compression: CSR
- Emittance preservation
- Upgrade of 2.5GeV LINAC

Undulator

- Segment separations
- Narrow gap: wakefield
- Strong focusing
- Beam-based alignment
- Spontaneous radiation
- Beam loss safety
- In-Vacuum Undulator

Layout of PAL XFEL



X – Linac (extending)

E_0=1.5 GeV

$\varepsilon_{nx}/\ \varepsilon_{ny}$ = 1.4/0.89 um rad

σ_δ=0.35%

K – Linac (existing)

E_0=2.2 GeV

$\varepsilon_{nx}/\ \varepsilon_{ny}$ = 1.43/0.89 um rad

σ_δ=0.025%

XFEL

λ_x = 0.3 nm

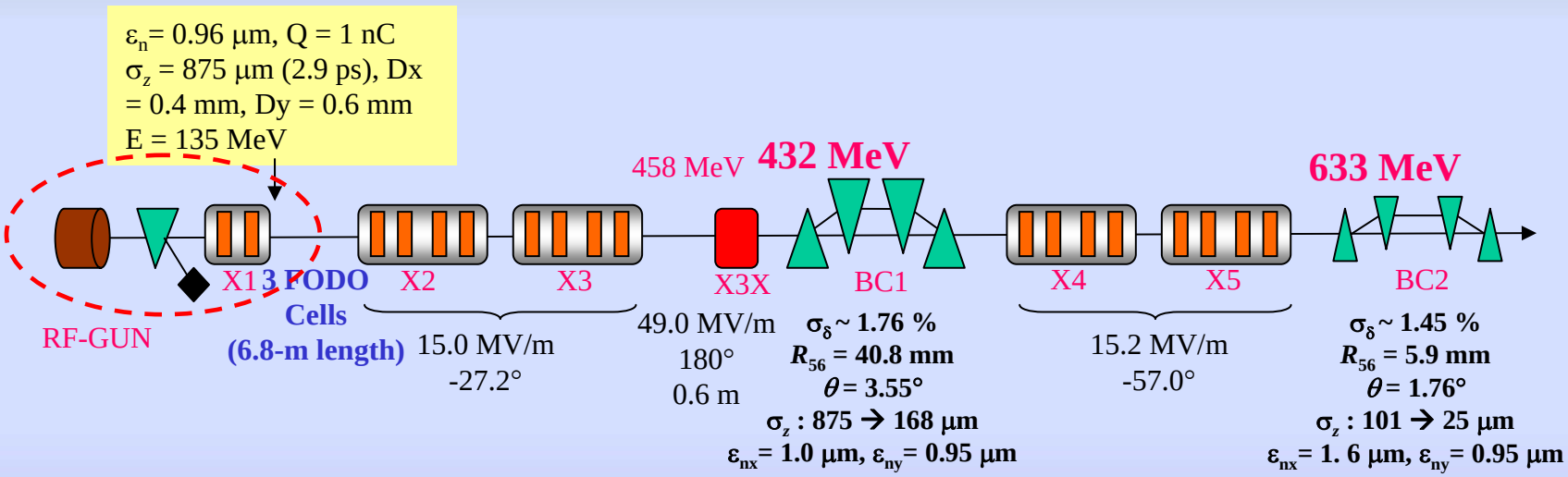
E_0 = 3.7 GeV

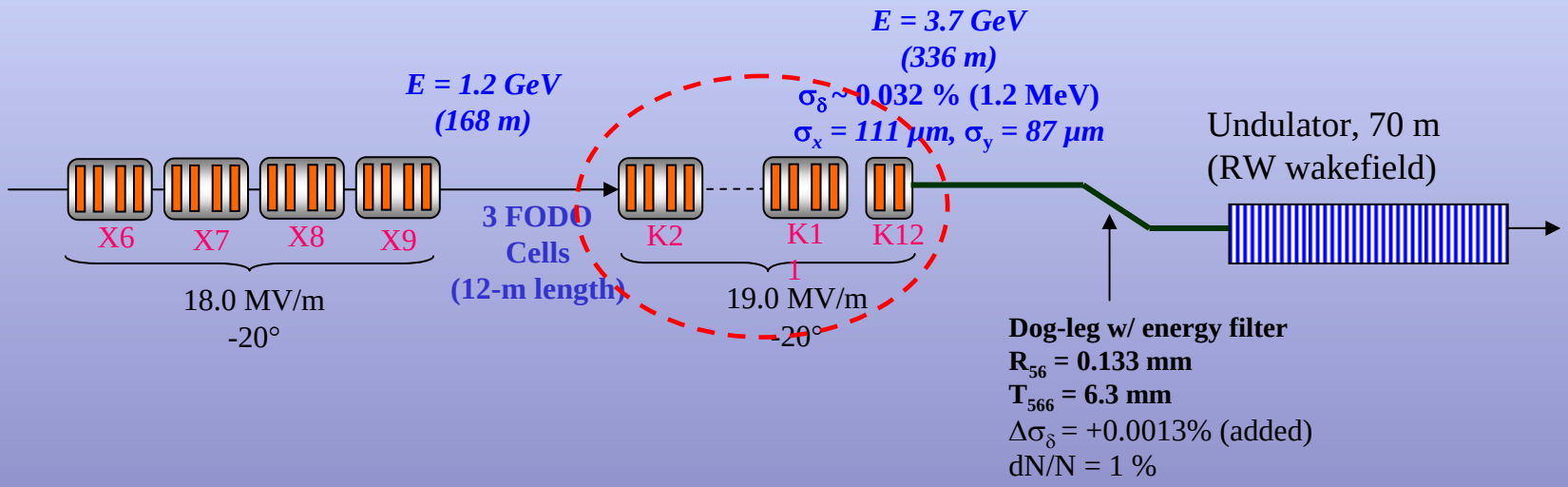
λ_U = 1.5 cm

g = 4 mm

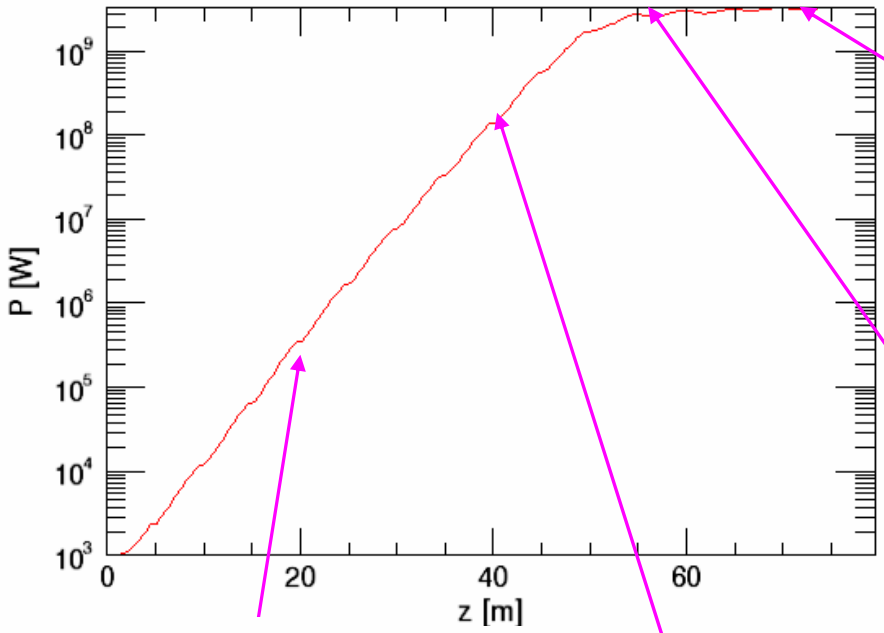
β = 10 m

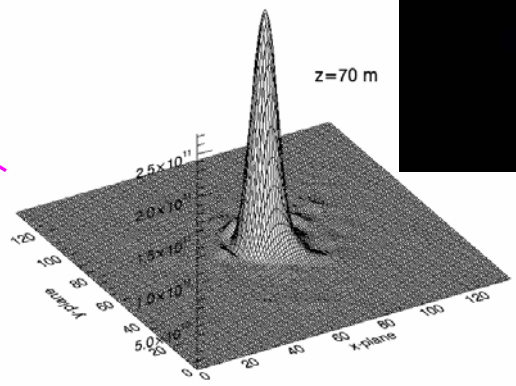
Design of PAL XFEL

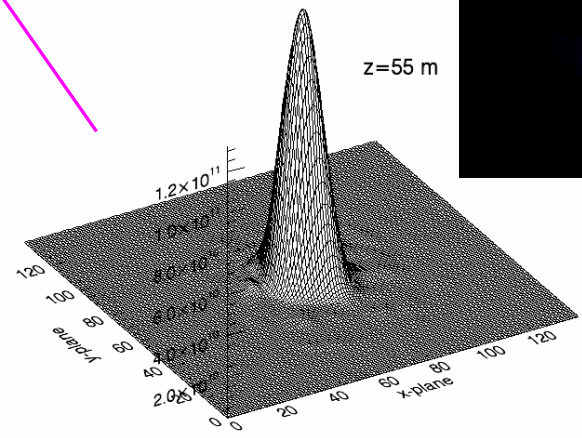


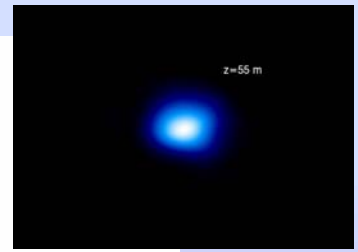


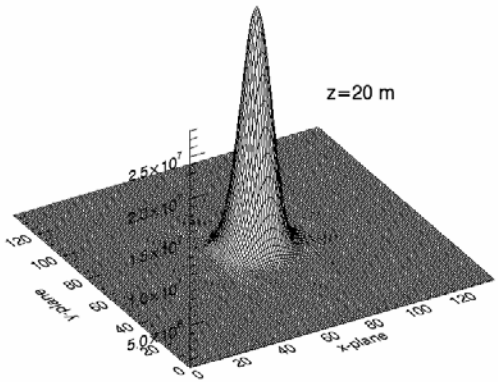
0.3 nm @ 3.7 GeV FEL lasing from Genesis

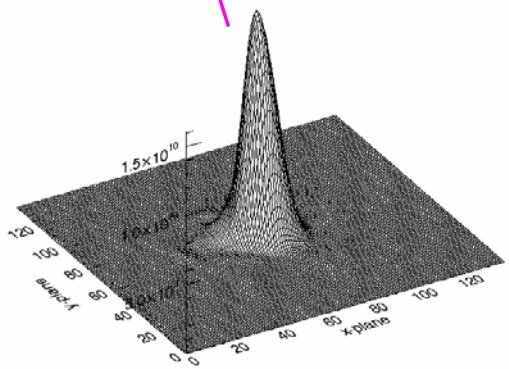


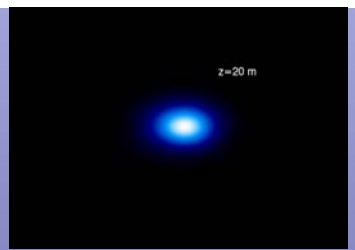


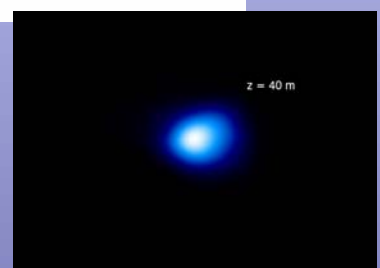












Gamma	7254.0
DELGAM	2.0
Period	15 mm
Gap	4 mm
Current	3.0 kA
Emittance	1.0 um

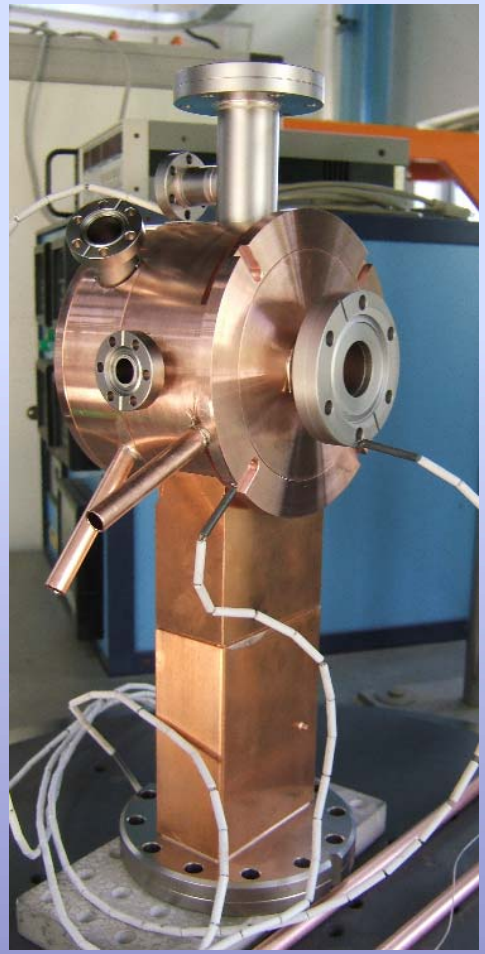
GTS Summary

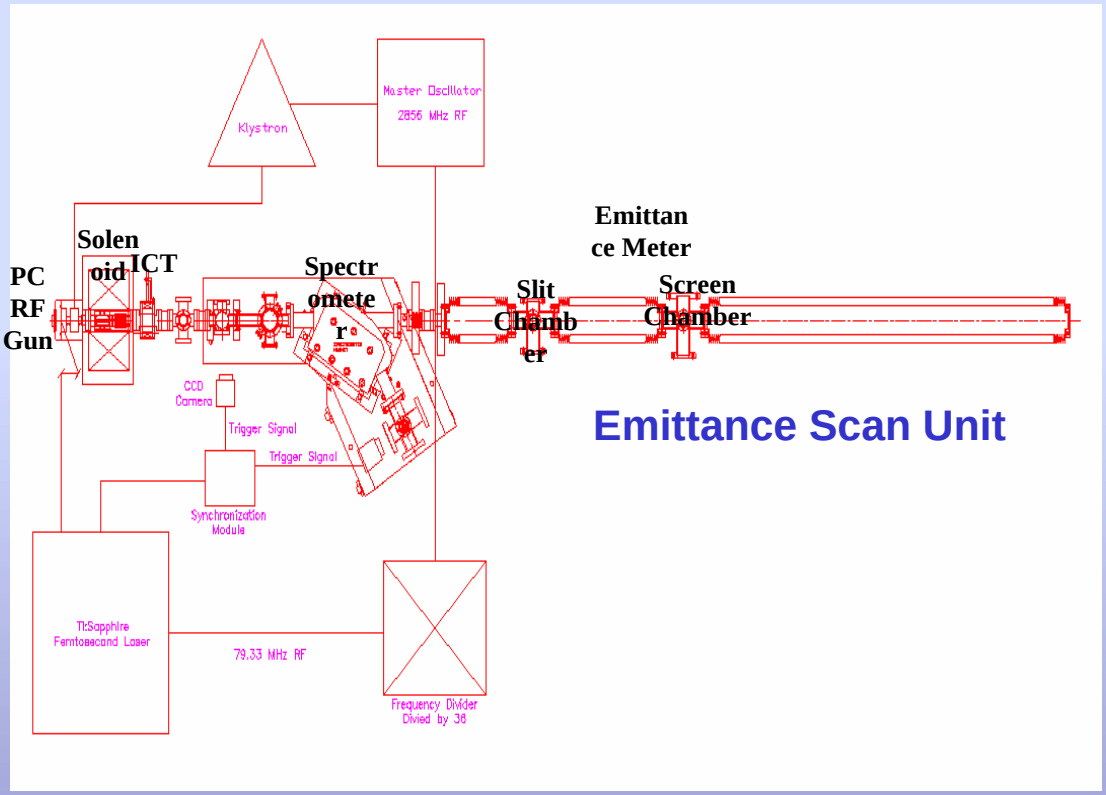
- Construction started in December, 2004. (BNL gun-IV)

- First beam was achieved on November 1, 2005.

- Best beam achieved as of October, 2006:
  - Energy 3.7 MeV (Goal 5MeV)
  - Initial phase = 30^{o}
  - Q = 350 pC (I nC)
  - Laser pulse length = 5 ps (FWHM)
  - Peak current = 70 A
  - Beam size at 1.46 m from cathode = 500 mm rms
  - Laser spot diameter at the cathode = 3 mm (hard edge)
  - Normalized rms emittance ~ 1.5 mm mrad (1 mm mrad)

Experimental Setup for GTS





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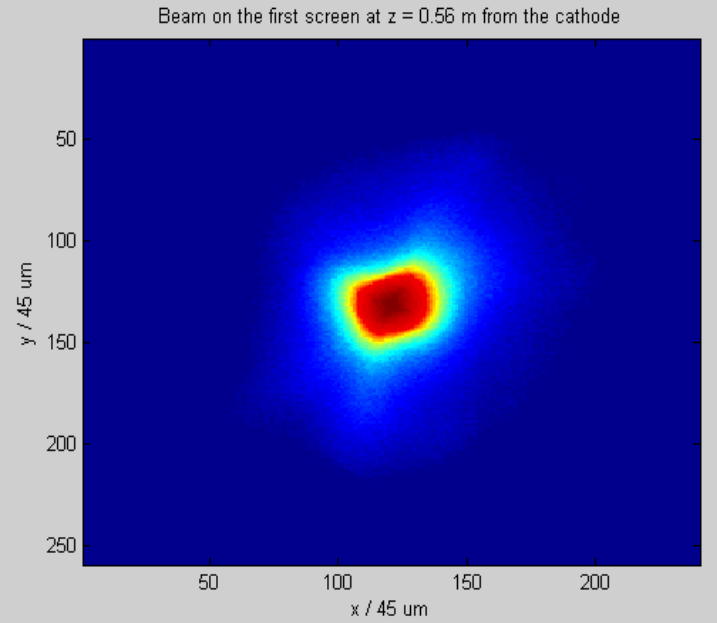
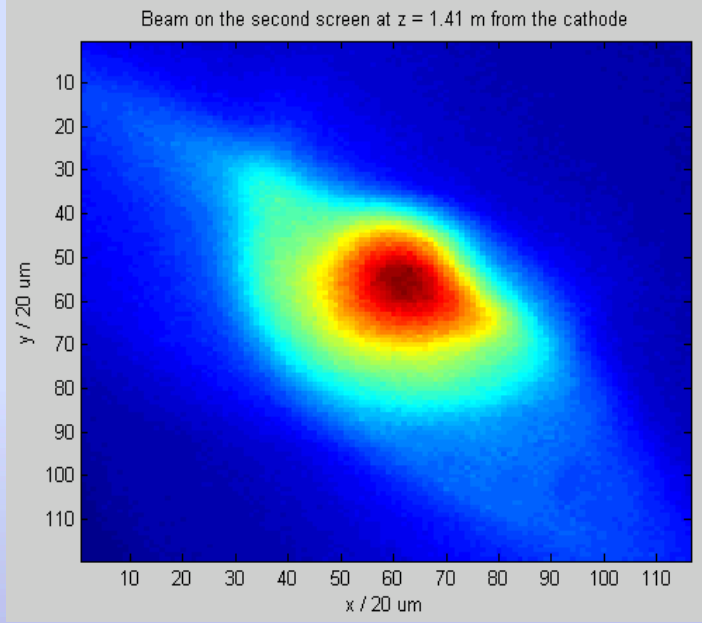
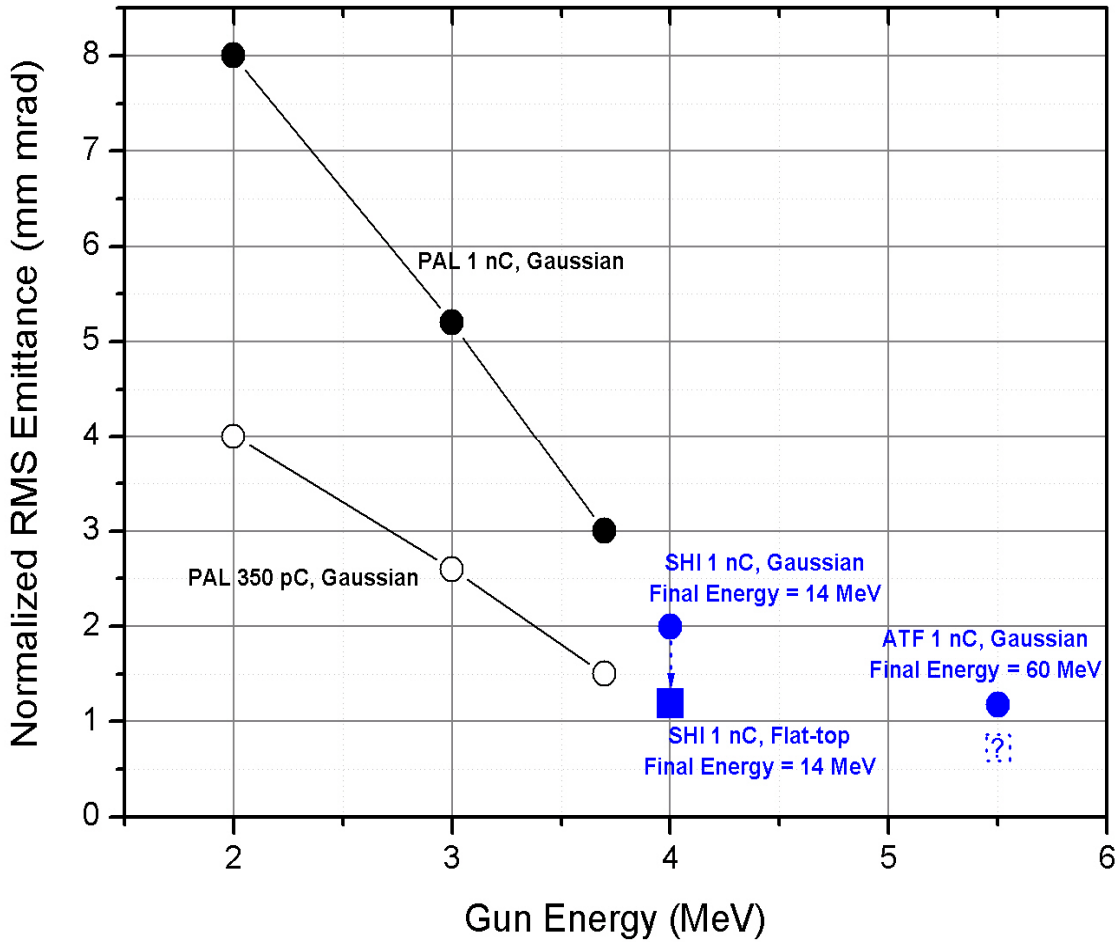
Beam Images on Phosphor Screen



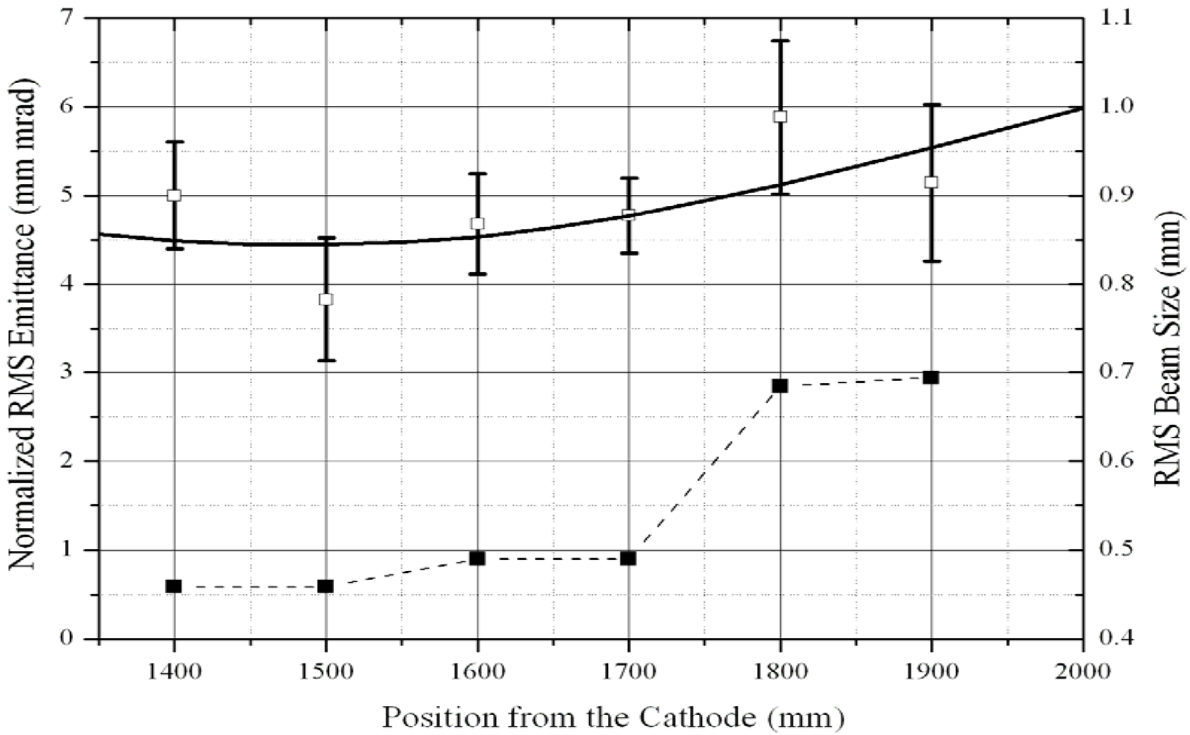


- **Beam energy ~ 2 MeV**
- **Initial phase = 30^{o}**
- **Charge = 320 pC**
- **Laser Spot Diameter (hard edge) = 3 mm, obliquely incident**
- **Laser Pulse Length (FWHM) = 6 ps**
- **Normalized rms emittance ~ 4 mm mrad**

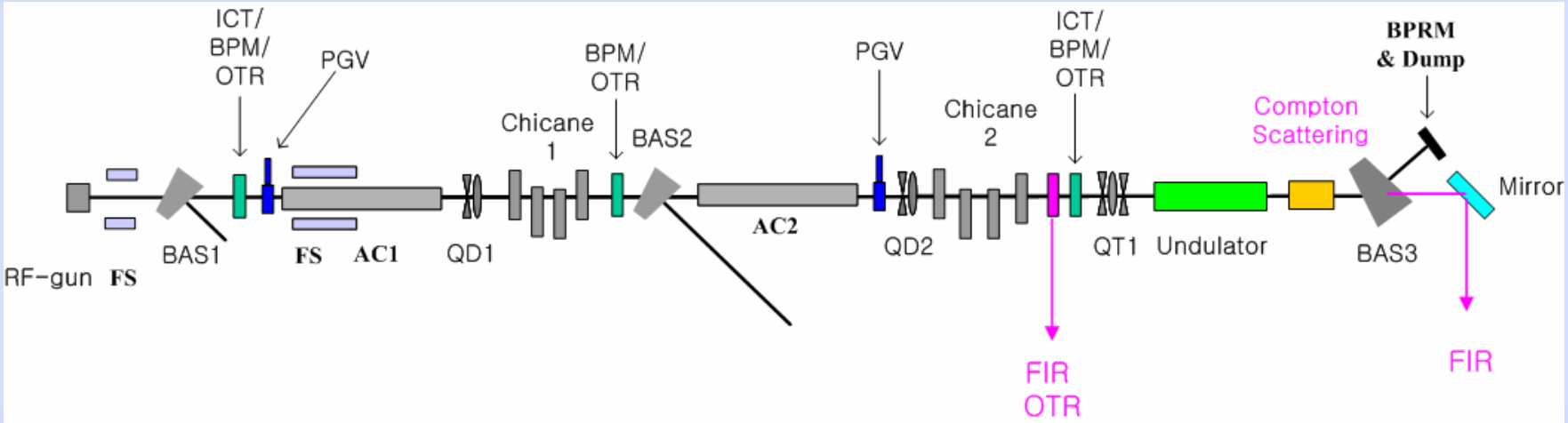
Emittance vs. Gun Energy



Emittance Evolution (2MeV)



fs FIR Linac Layout



OTR FIR

Undulator Radiation

- **Beam Energy : 60 MeV**
- **Beam Charge : 0.1 – 0.5 nC**
- **Beam Emittance: < 5 mm-mrad**
- **Beam Pulse Repetition rate: 30 Hz max.**
- **Bunch Length**
  - ✓ **Before chicane: 0.15 - 2 ps**
  - ✓ **After chicane: 20 - 200 fs**

Beam Charge	Bunch Length after RF-gun	Bunch Length after Chicane 2
0.2 nC	0.3 ps	< 50 fs
0.5 nC	1 – 2 ps	< 150 fs

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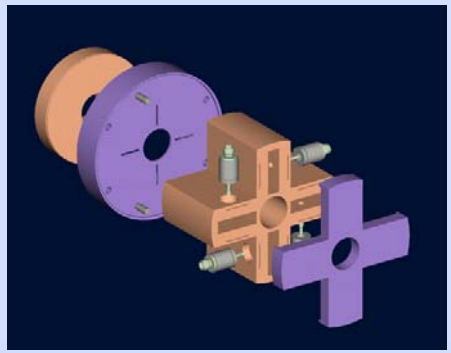
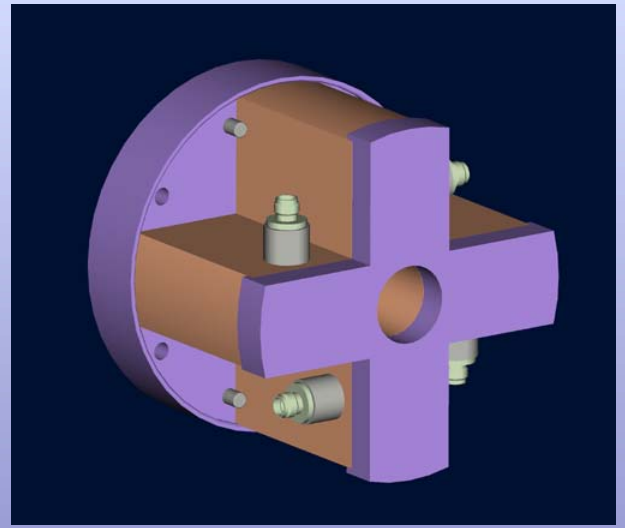
Cavity BPM for XFEL/ ILC





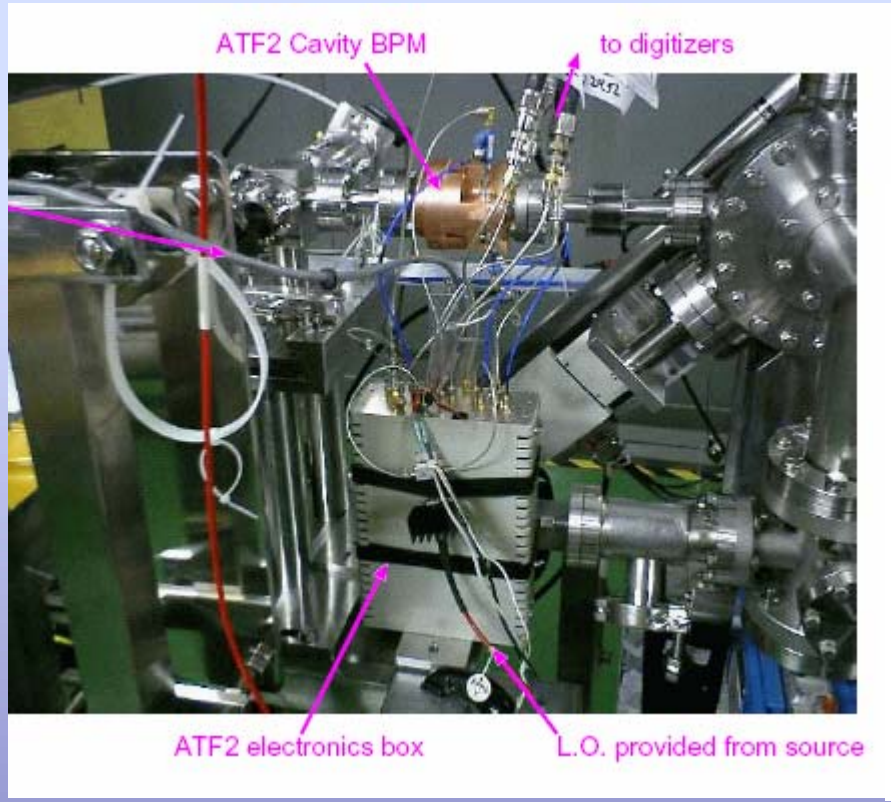
-2 prototypes made by PAL, tested at KEK
- Best resolution < 100nm

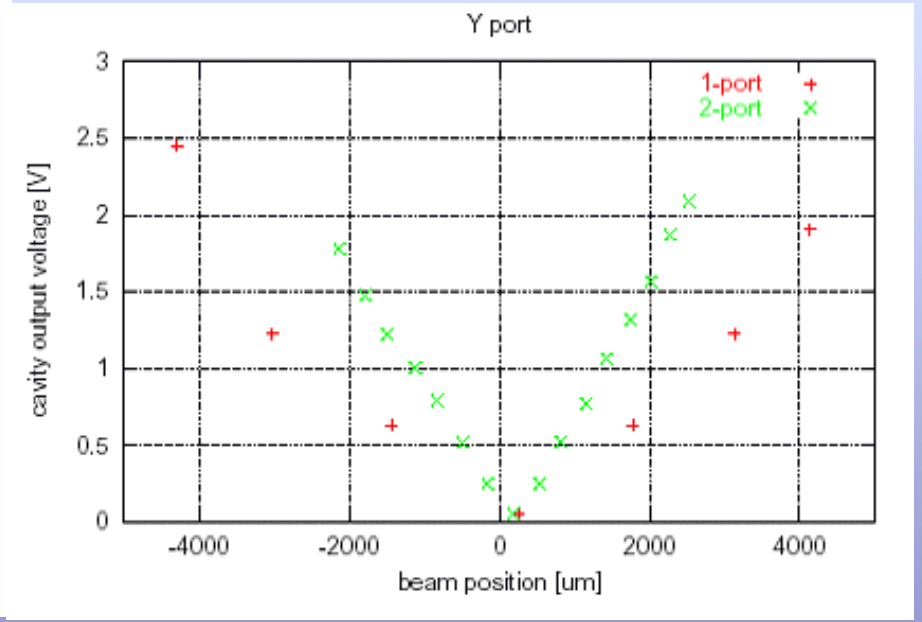
- 11 CBPMs fabricated and tuned by PAL and shipped to KEK by March 2006

- 28 units by March 2007

Cavity BPM under test at KEK

- **x-y isolation < -45dB**
- **sensitivity ~ 1mV/ μm /nC**
- **beam position resolution < 100 nm**





Thank you for Attention

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