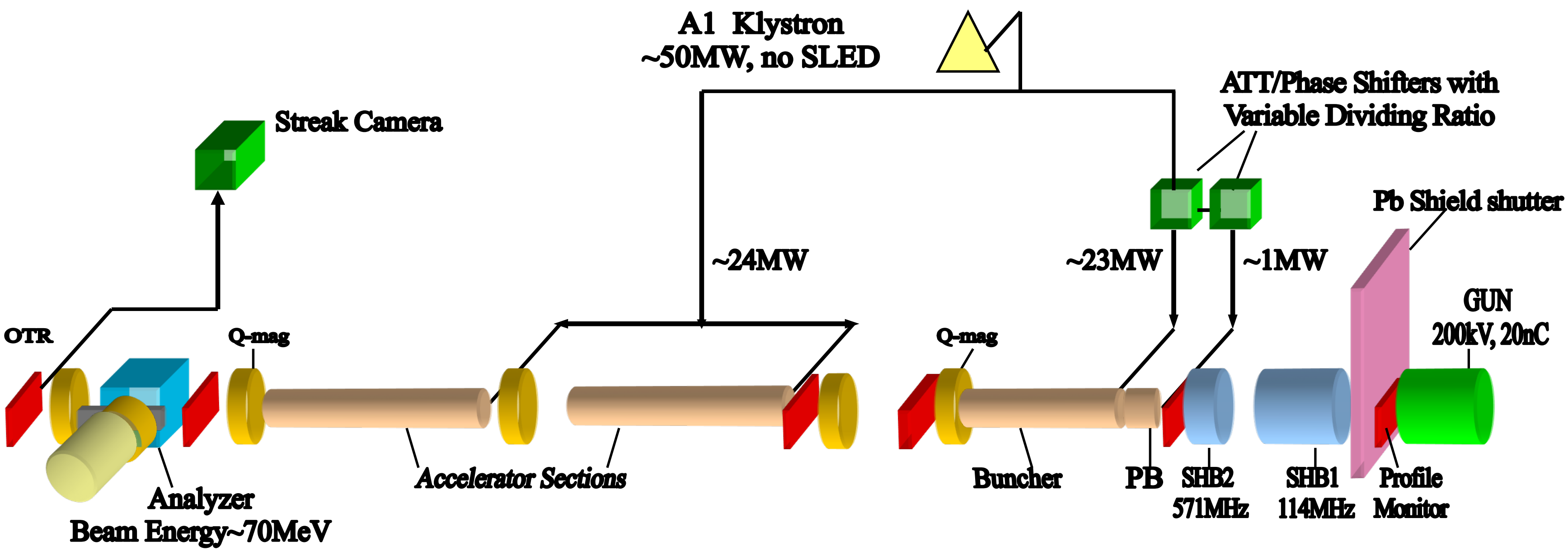
PF/KEKB入射器の熱電子銃とバンチング

2018/10/18

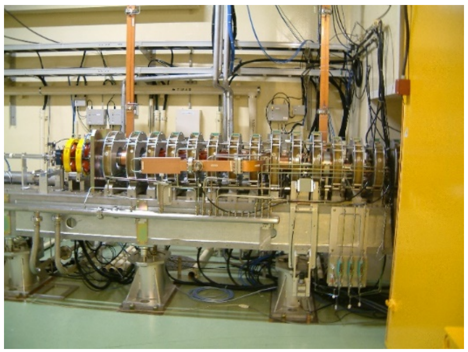
大澤　哲

KEKB当時のA1ユニットの構成



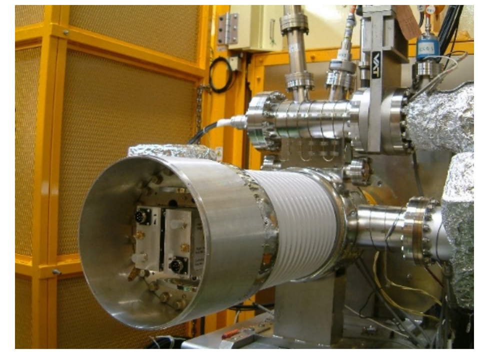
KEKB当時の入射部の様子

バンチャ部

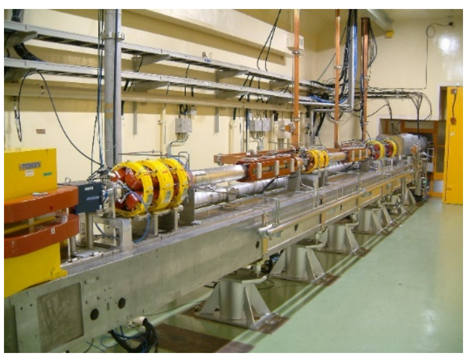


電子銃＆高圧ステーション

電子銃＆グリッド・パルサー(2台)



A1ユニット全景

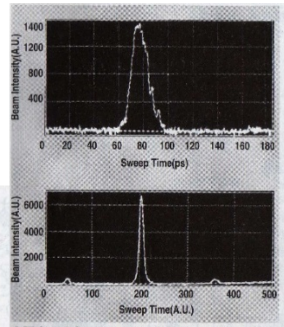


エネルギー分析系とOTRモニター

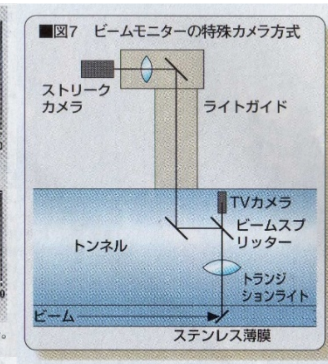
陰極部(Y-796)

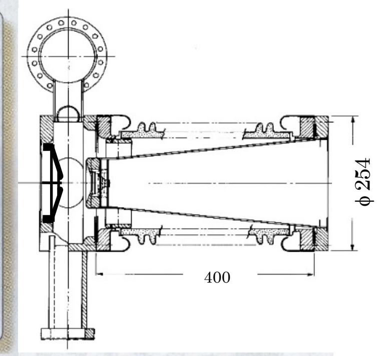
短パルスビームのバンチングの様子

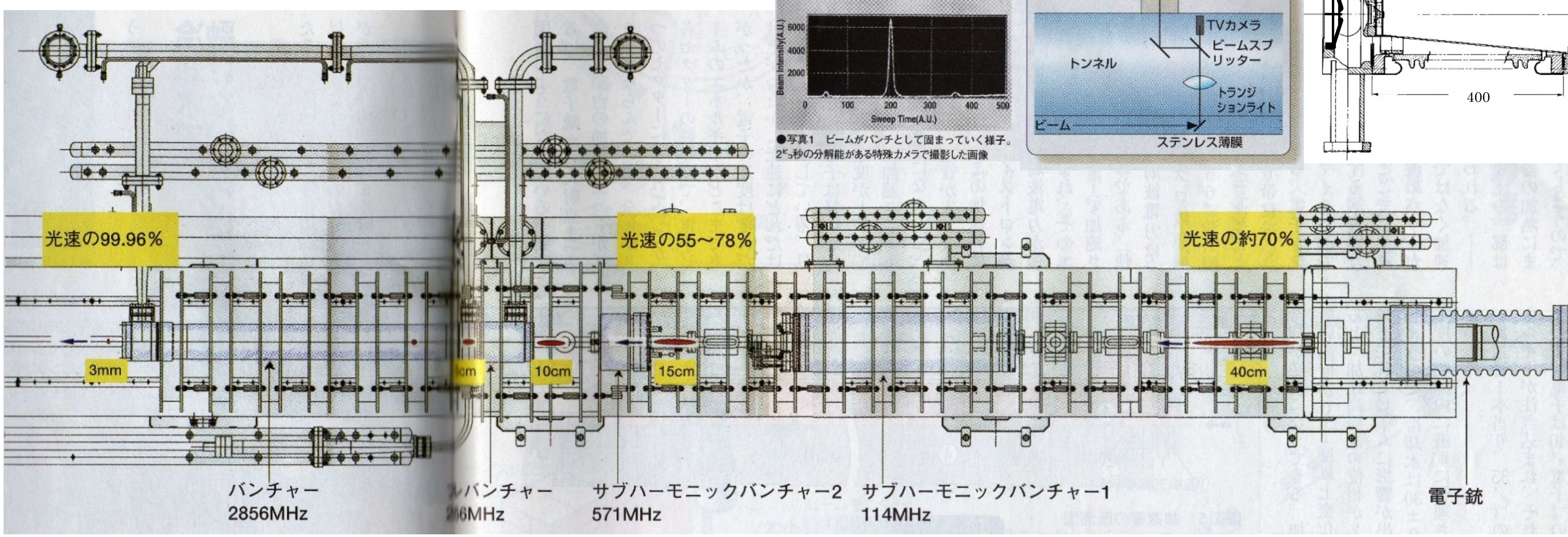
立花隆「消えた反粒子のナゾに迫る」May 2000サイアス122



●写真1　ビームがバンチとして固まっていく様子。
2ピコ秒の分解能がある特殊カメラで撮影した画像

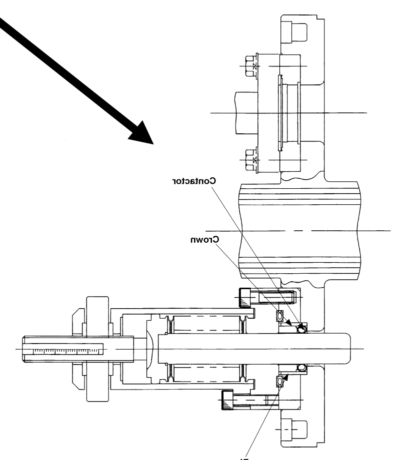






SHB1 of 114MHz

Input coupler



Tuner

Monitor Coupler

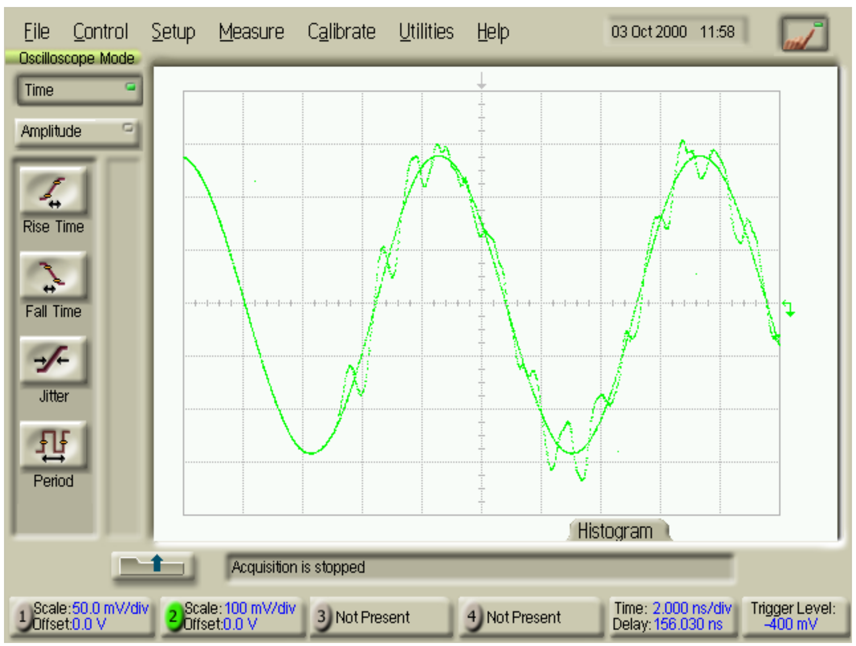
Beam induced field in SHB1

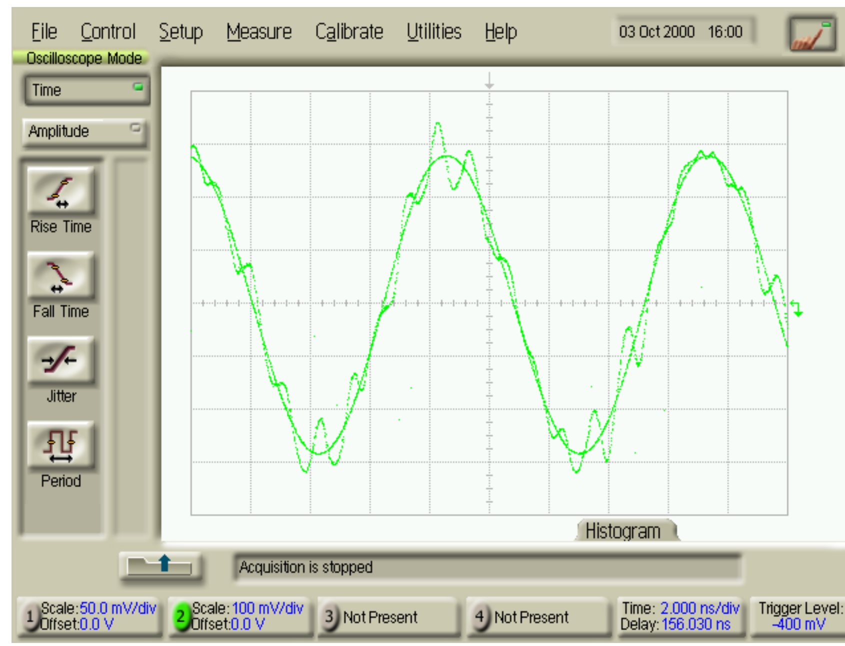
114MHz RF & induced fields by a single pulse beam of 10nC are shown

(1) just after the beam passed

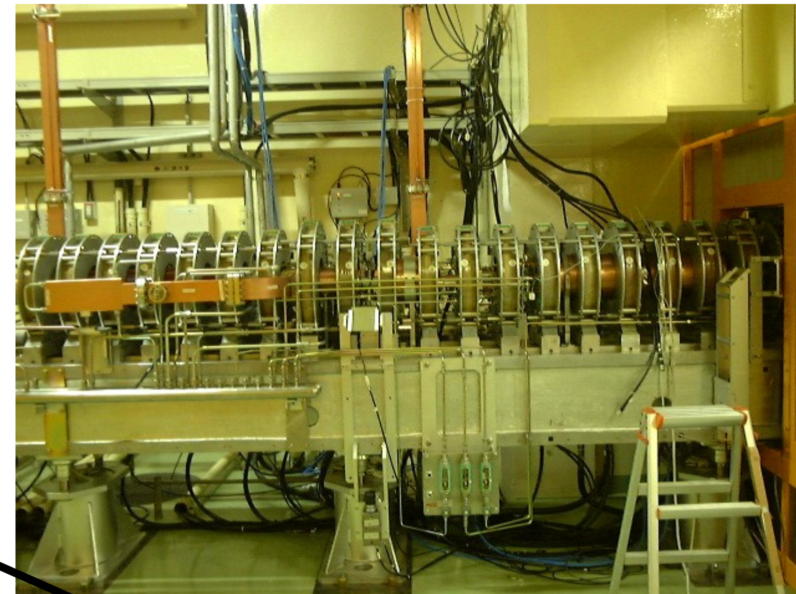
(2) after 96.2ns.

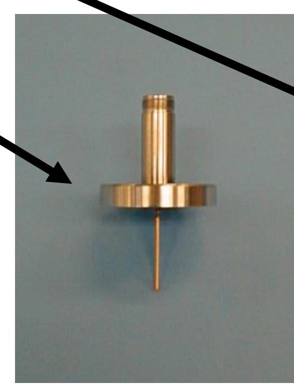
Field attenuation is not sufficient

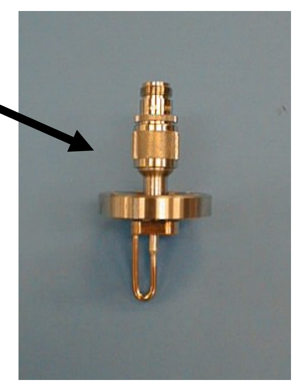




SHB2 of 571MHz





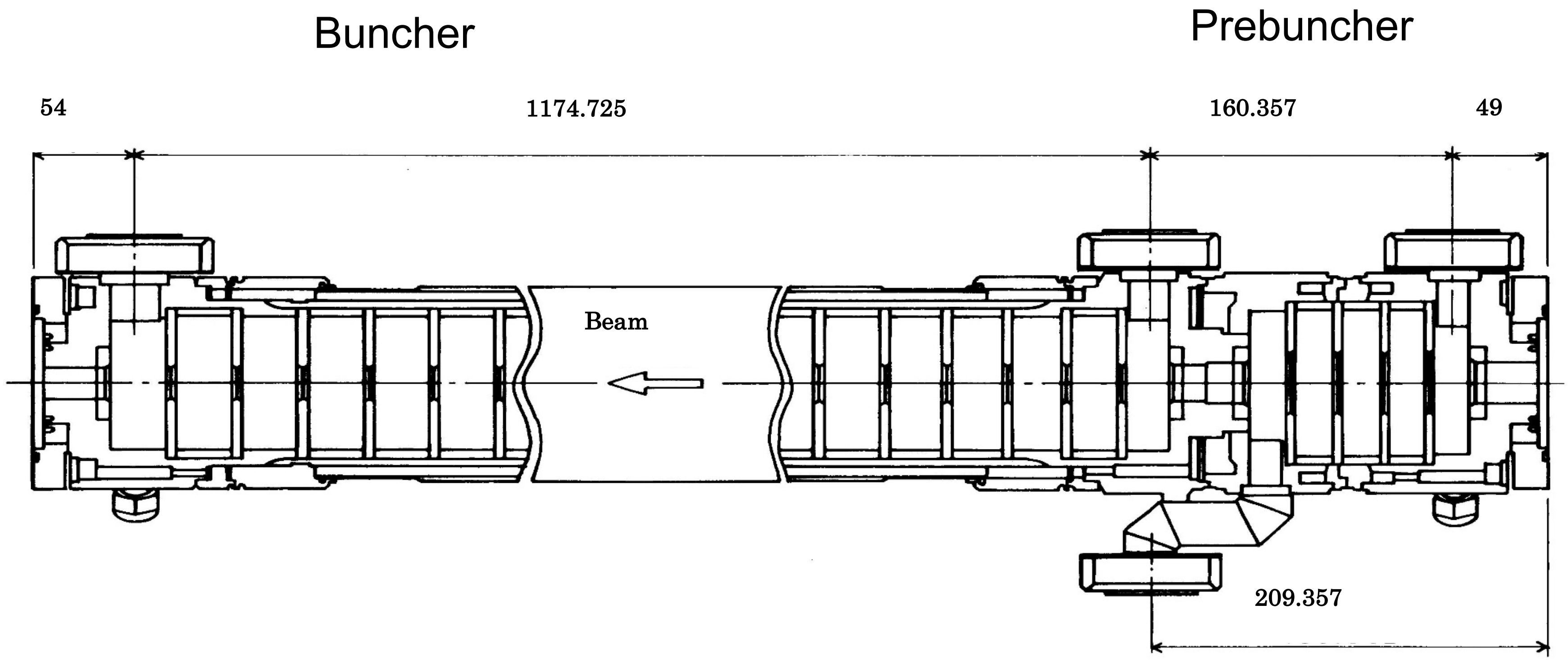


SHB2 Cavity

Monitor Coupler

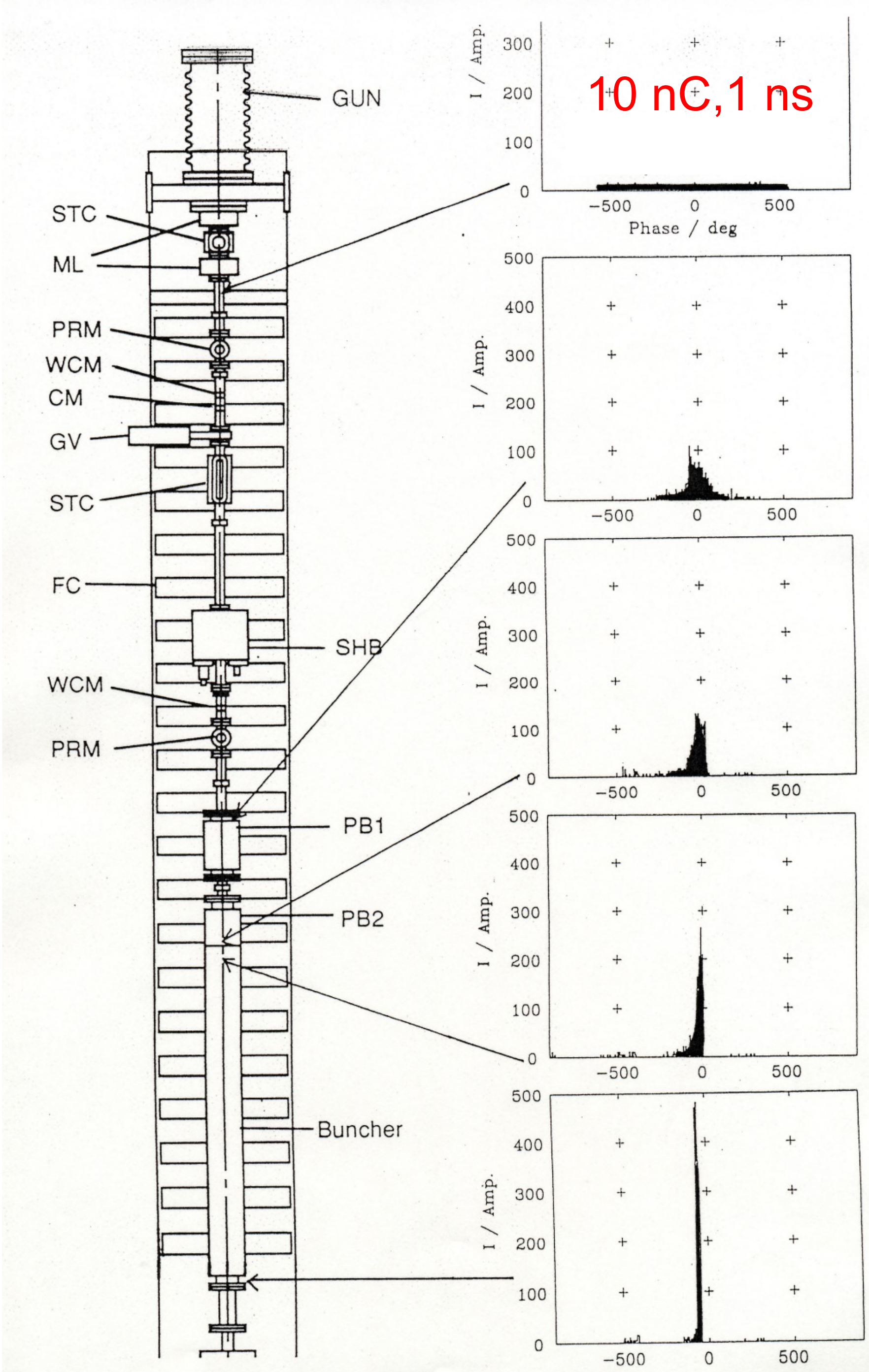
Input coupler

Prebuncher and buncher of pre-injector A

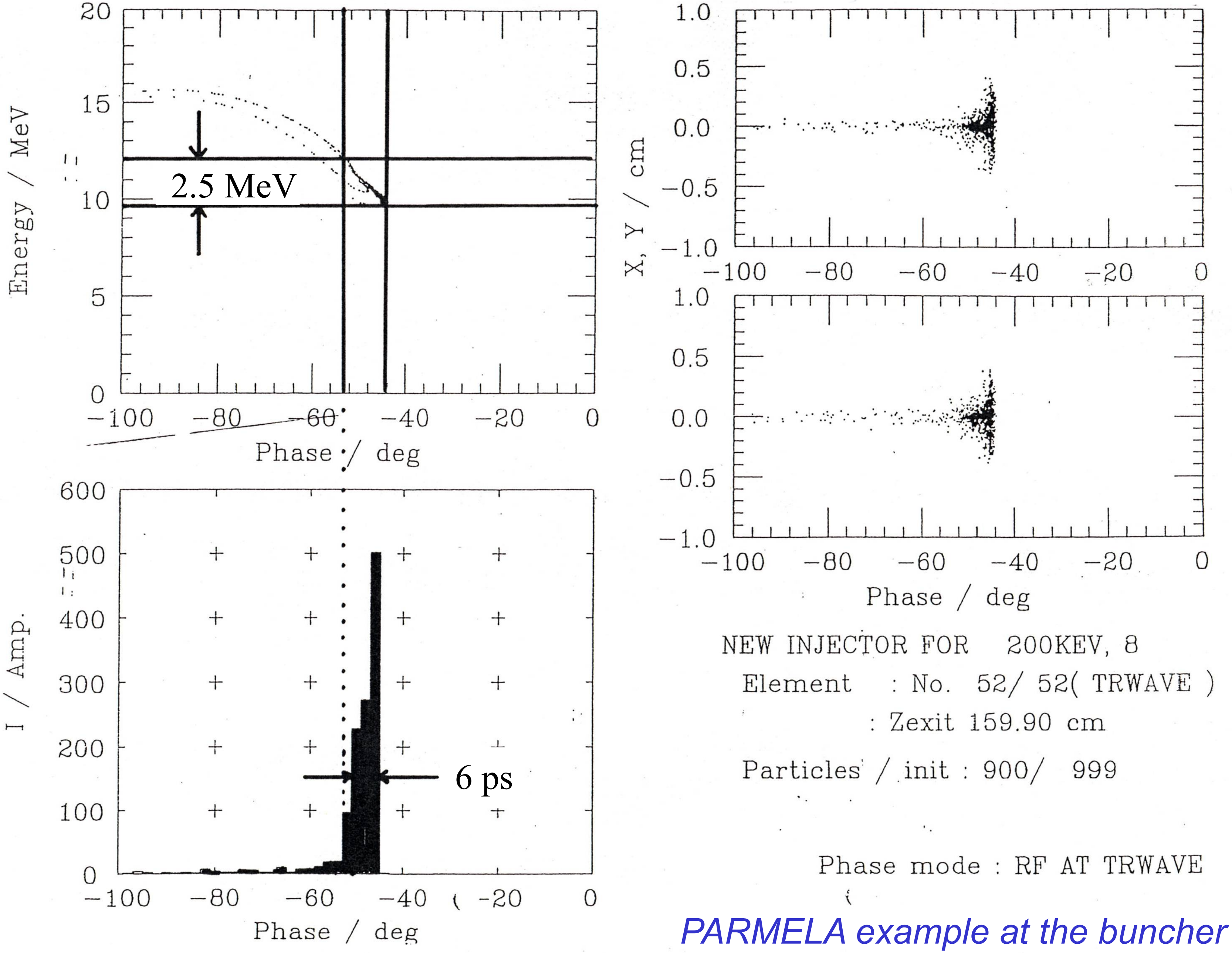


PALMERAによるシミュレーション例

Simulation by PARMELA

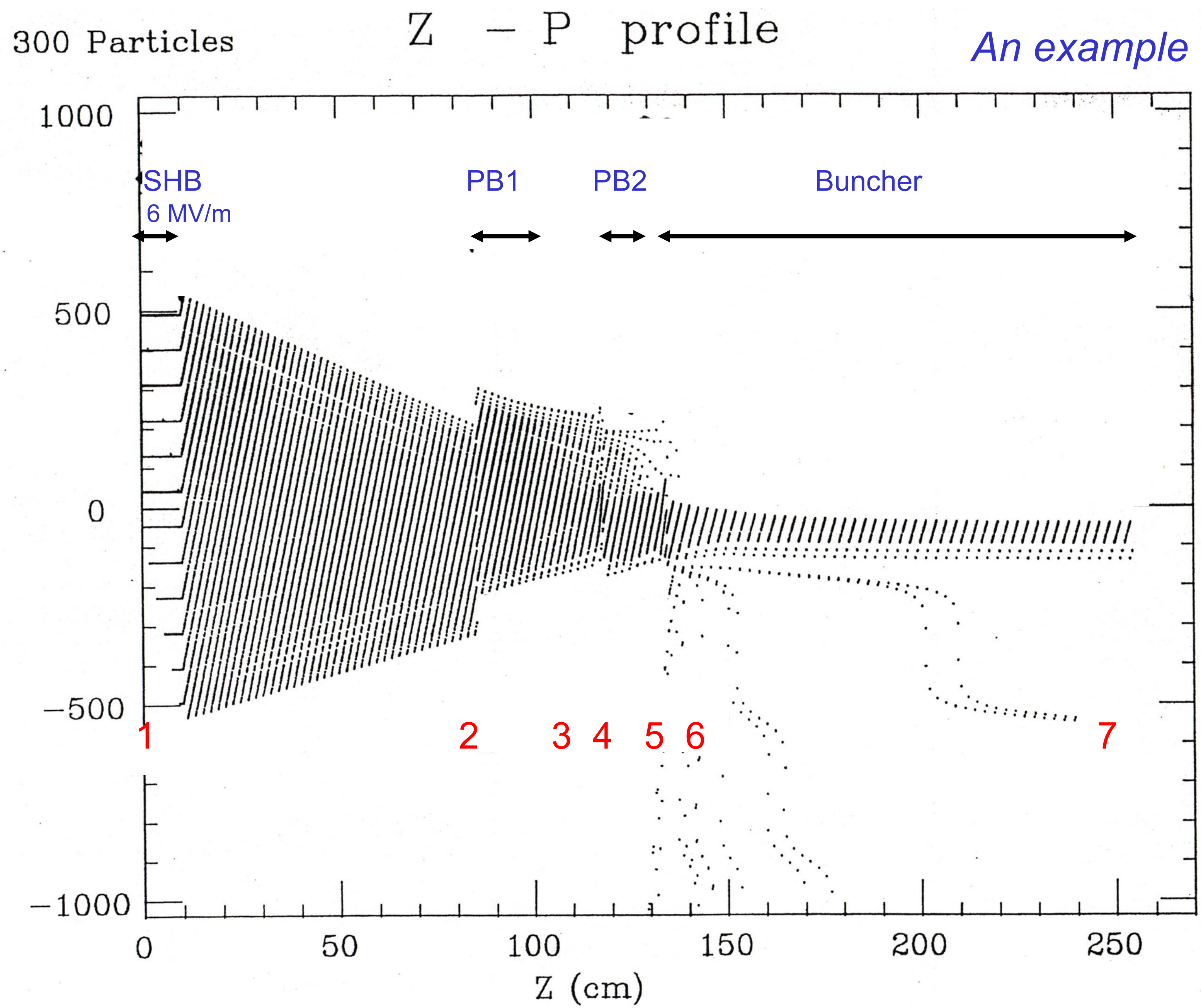


Gun	200 kV
SHB	476 MHz
PB1	2856 MHz
PB2	2856 MHz
Buncher	2856 MHz



PARMELA example at the buncher exit

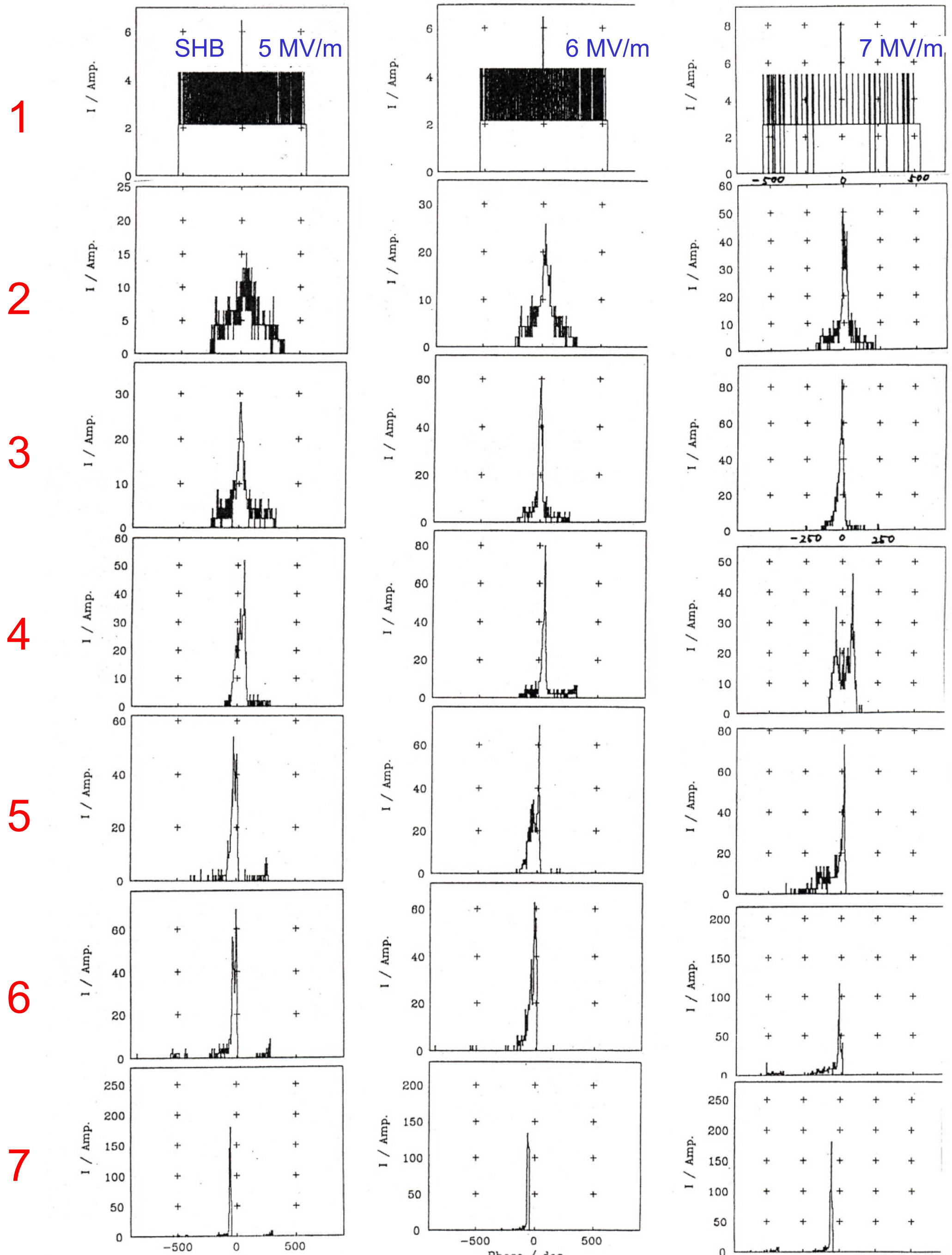
An example of PARMELA



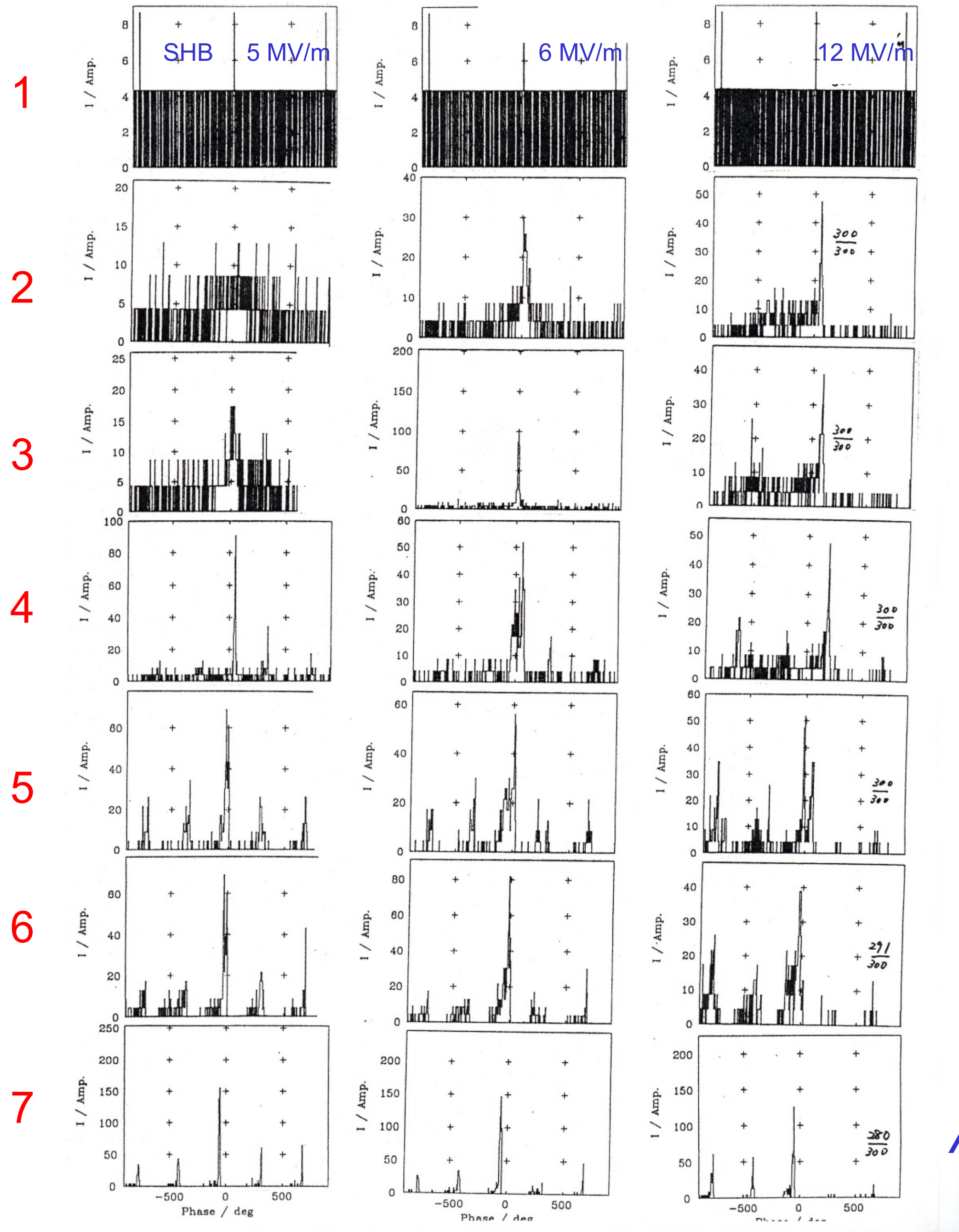
NEW INJECTOR FOR 200KEV. 3.0A, 6MV/m, 540DEG.

200kV, 3A, 1 ns

An example of PARMELA



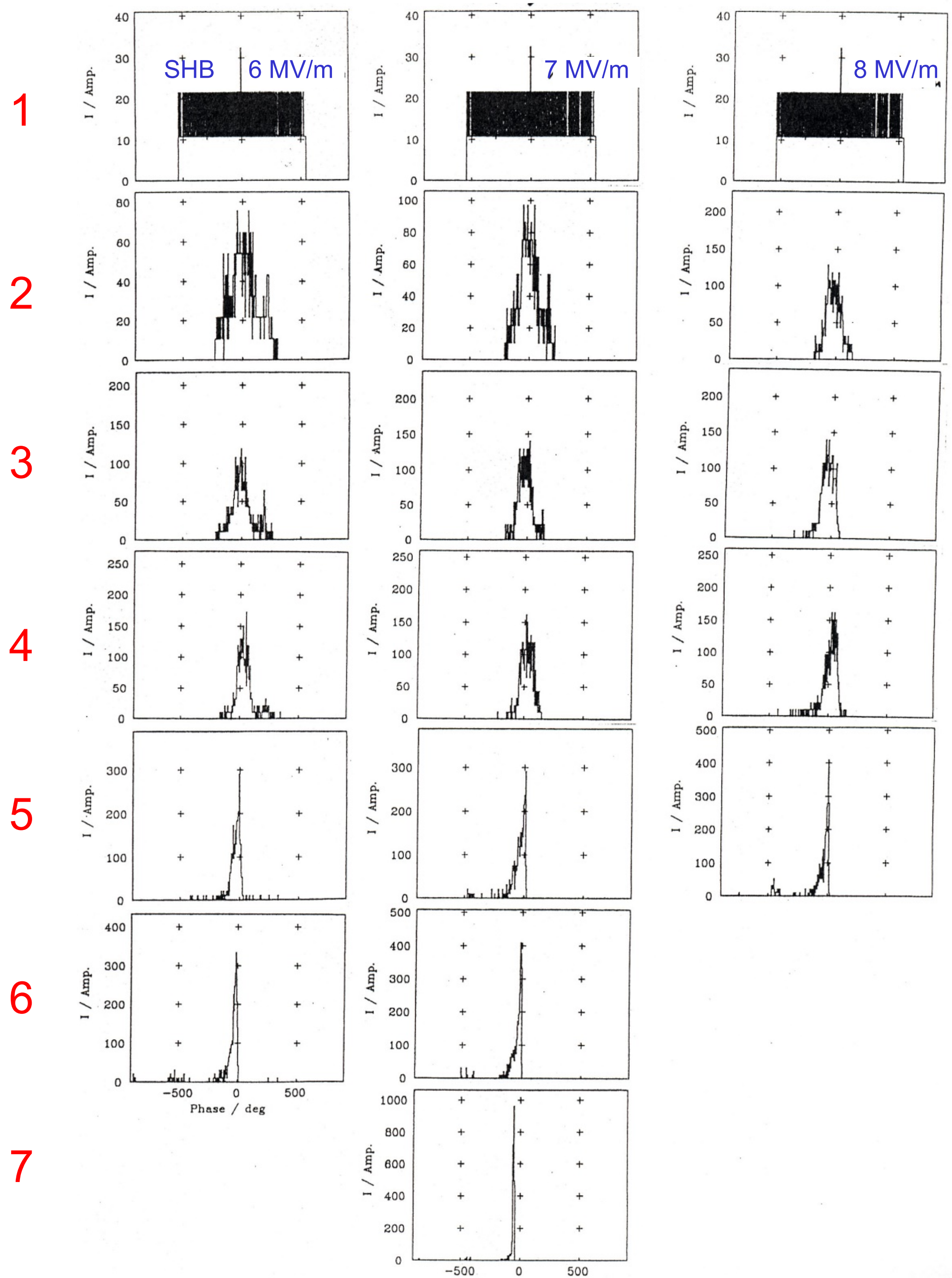
200 kV, 3A, 2 ns



An example of PARMELA

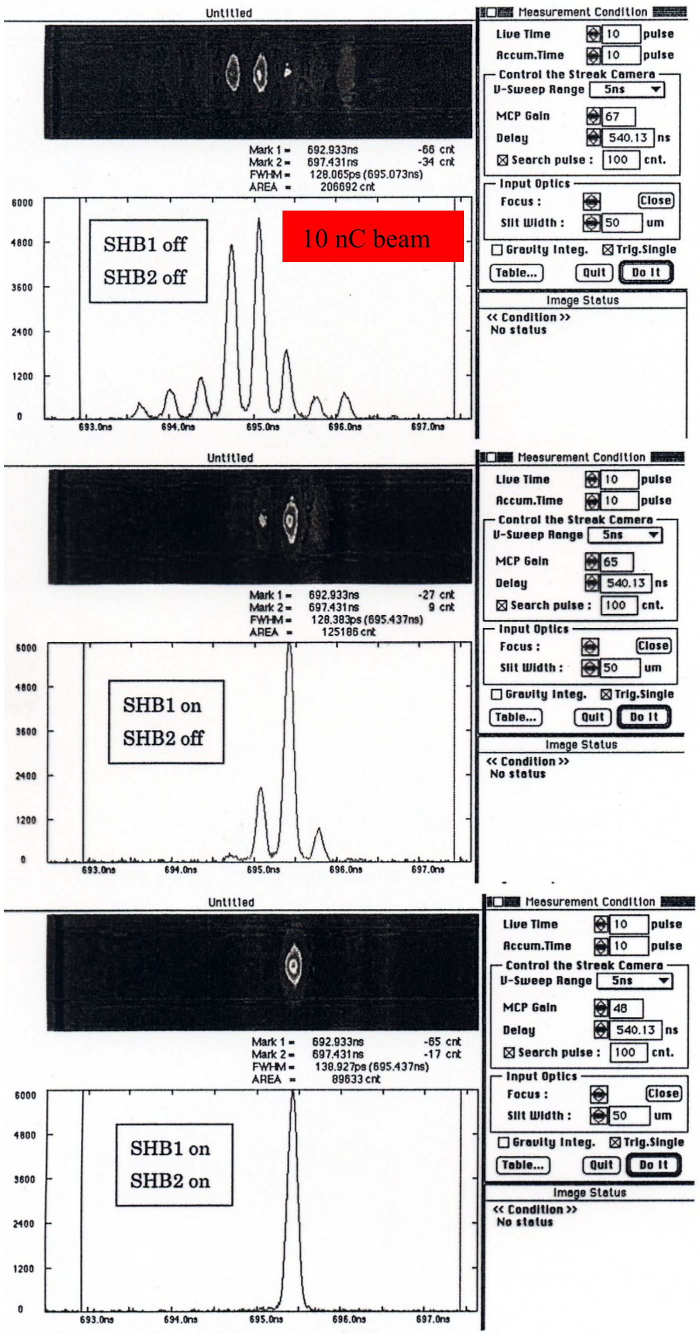
An example of PARMELA

15A, 1ns



ストリークカメラを用いたバンチング手順の具体例

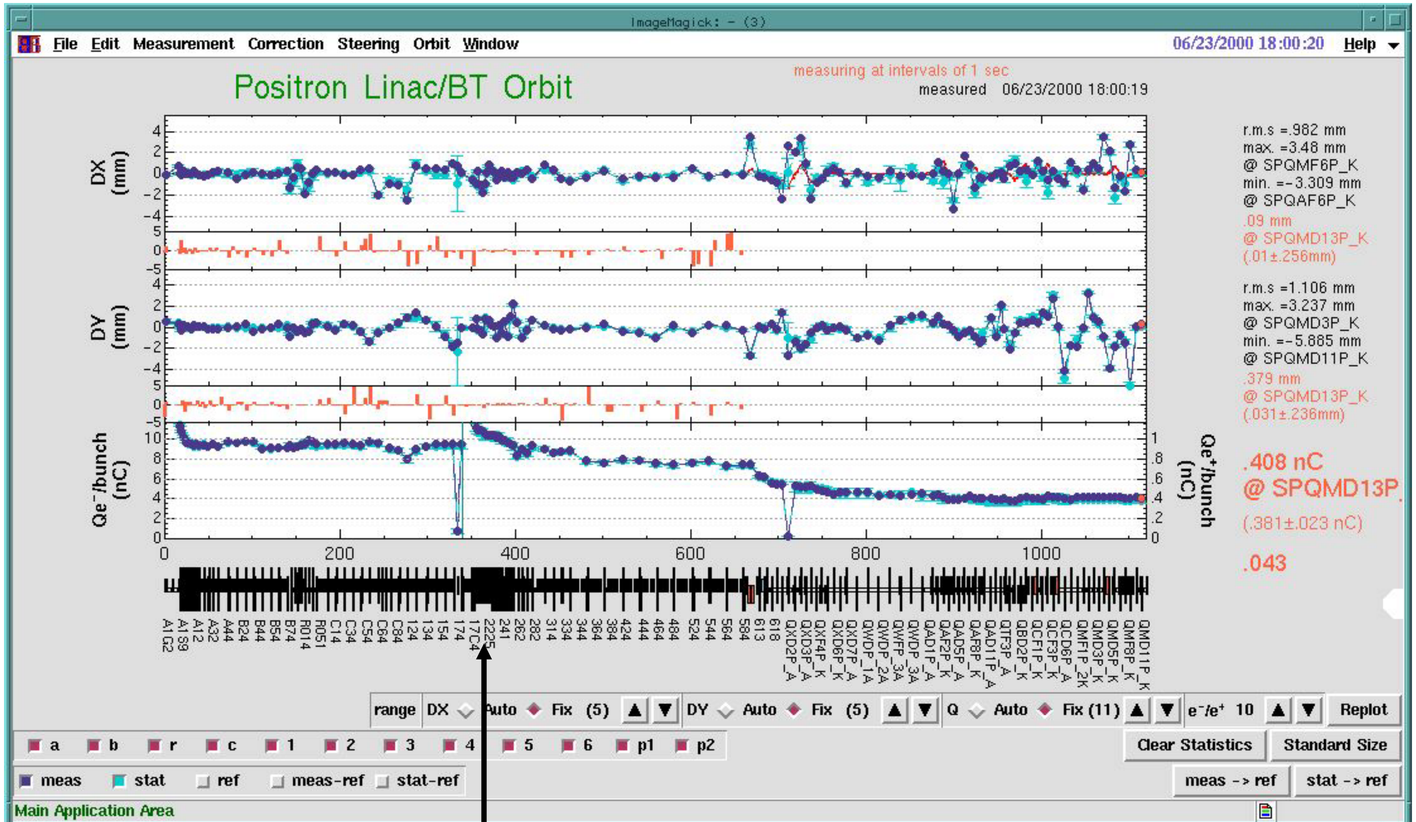
Bunch structure measured with a streak camera



Single bunch procedure

1. Turn off SHB1&2 power source, or delay rf pulse timings not to affect the beam.
2. Adjust the beam timing by changing the time delay of a grid pulser so that the central bunch peak becomes maximum.
3. Turn on only the SHB1 power source, or return the rf timing for modulating the beam.
4. Adjust the SHB1-rf phase so that the center bunch becomes the highest peak and maximum.
5. Turn on the SHB2-rf power source, or return the rf timing for modulating the beam.
6. Adjust the SHB1-rf phase so that the center bunch becomes maximum and satellite bunches become minimum.

Positron Linac/BT Orbit



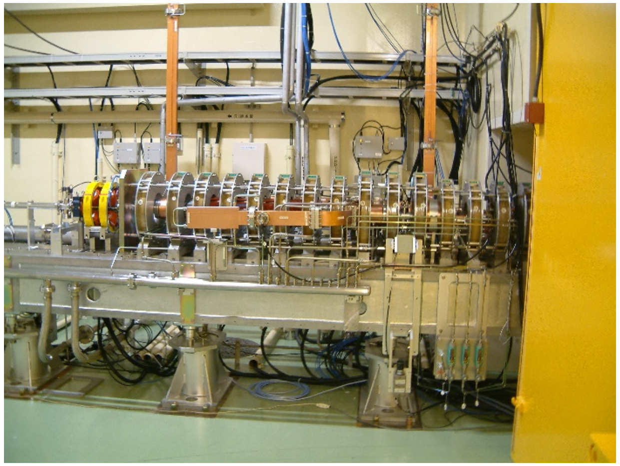
positron production target

The 10-nC electron/positron beams accelerated in the KEKB linac

RF-gunとそのバックアップ

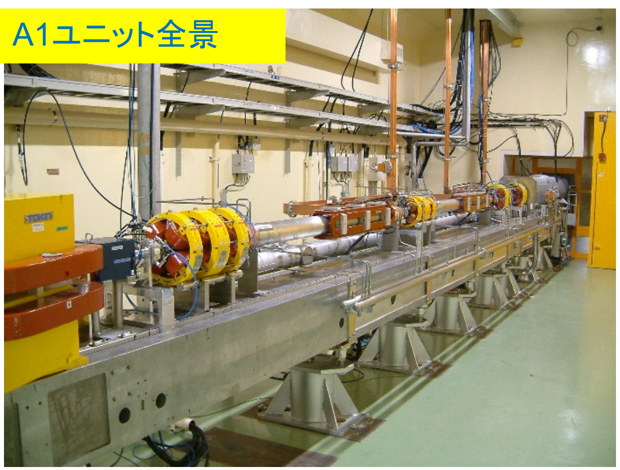
KEKB当時のA1 unit

Bunching System



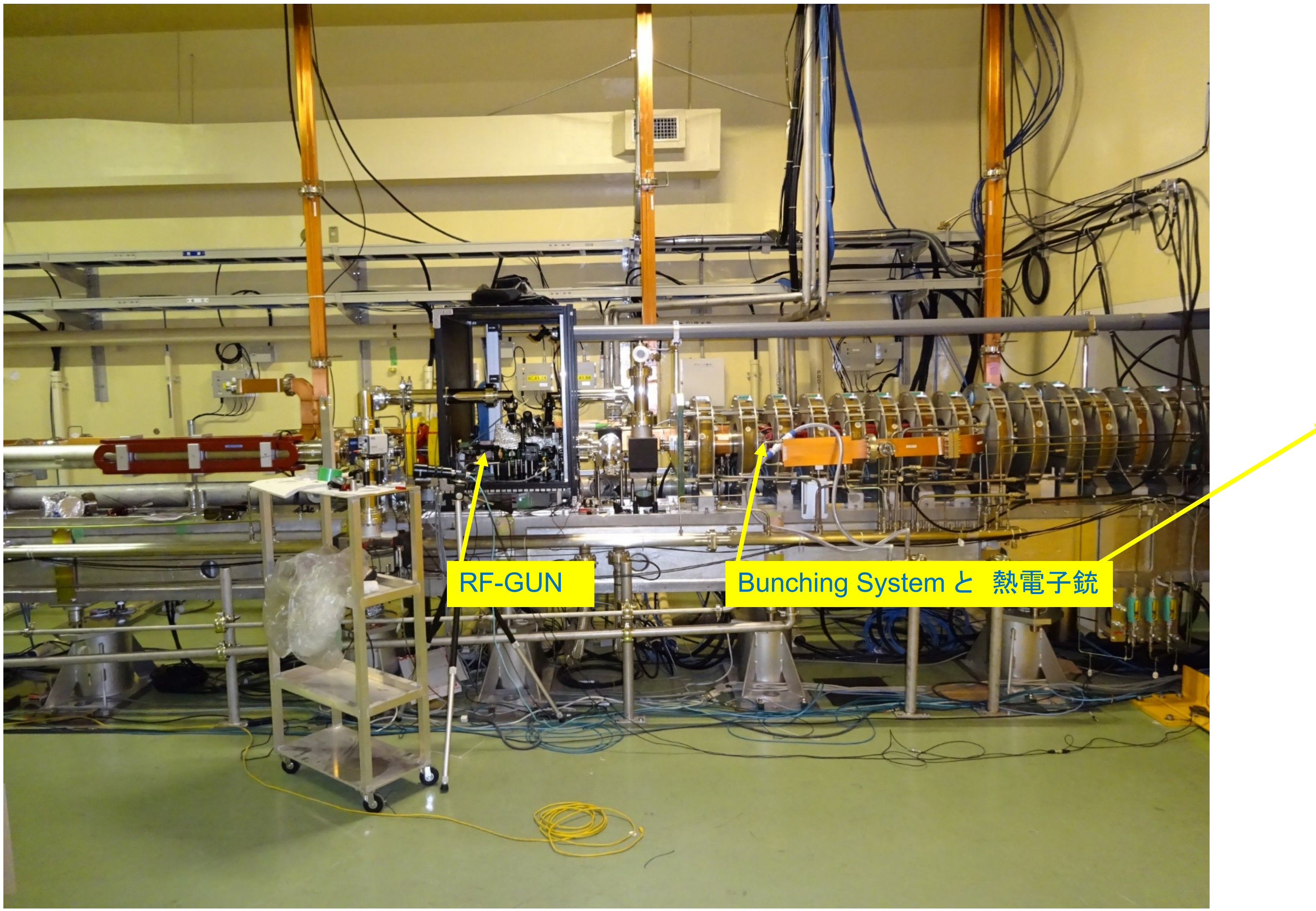
熱電子銃＆高圧ステーション

A1ユニット全景



OTRモニターとエネルギー分析系

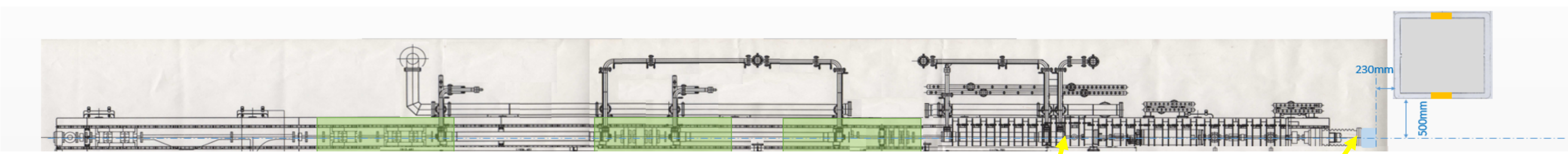
SKBに向けた二階建て改造直前のA1 unit



A1ユニットの再構成 (2015年3月）

開発中のRF Gunのバックアップとして、
熱陰極電子銃の入射部を二階部分に上げ、SKBのフェイズ1に備える。

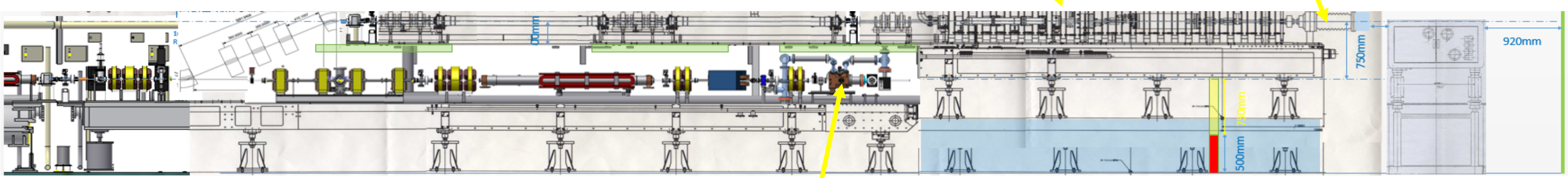
加速管グループと電子銃グループを中心に、目下工事中。(2015年3月）



A1ユニットの再構成のイメージ図（上面図）

Bunching System と 熱電子銃

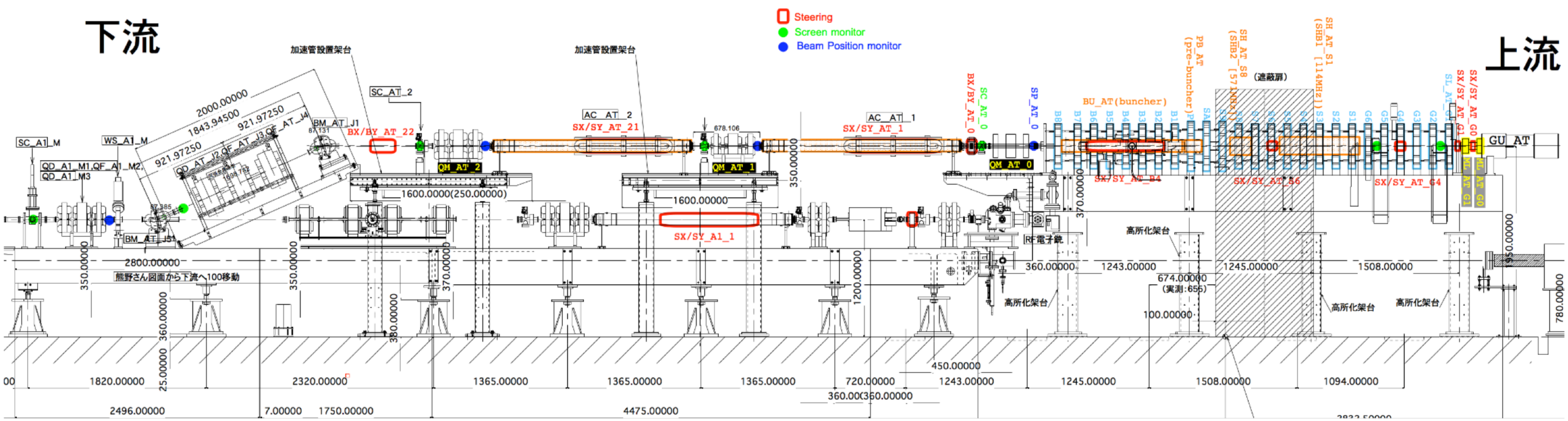
Buncher,Prebuncher,SHB2,SHB1



A1ユニットの再構成のイメージ図（側面図）

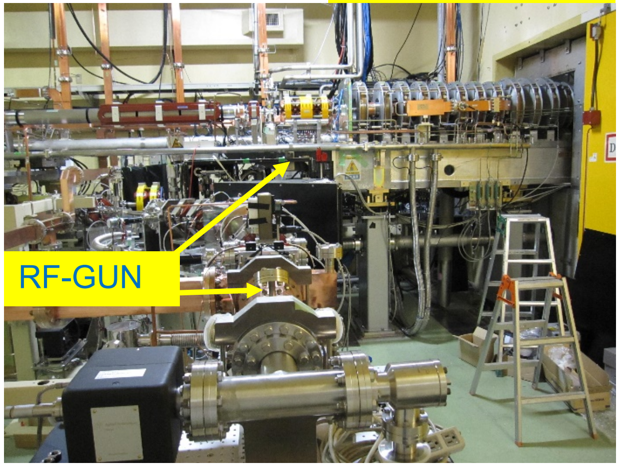
RF-GUN

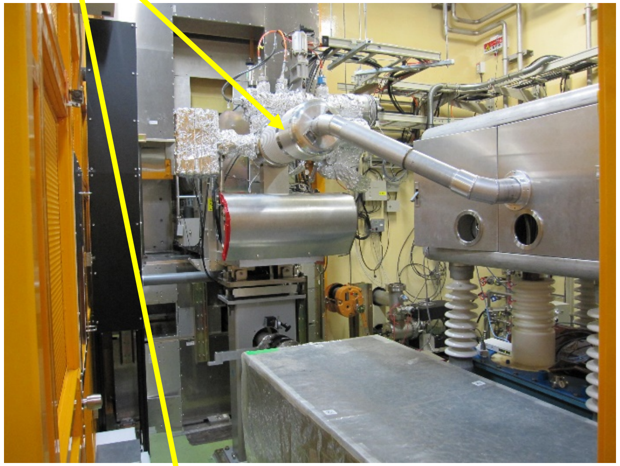
AT unit layout

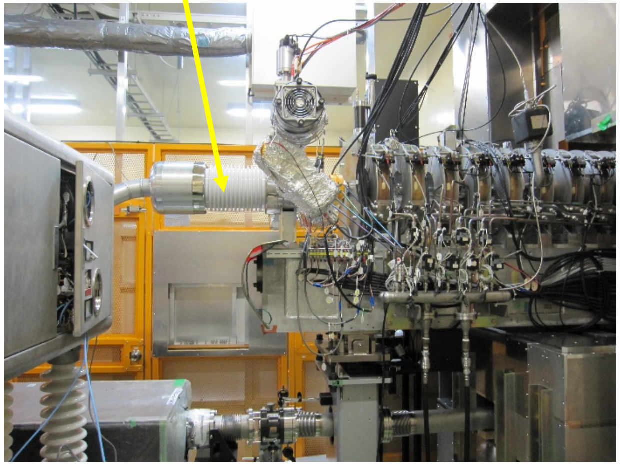


改造直中のA1 unit

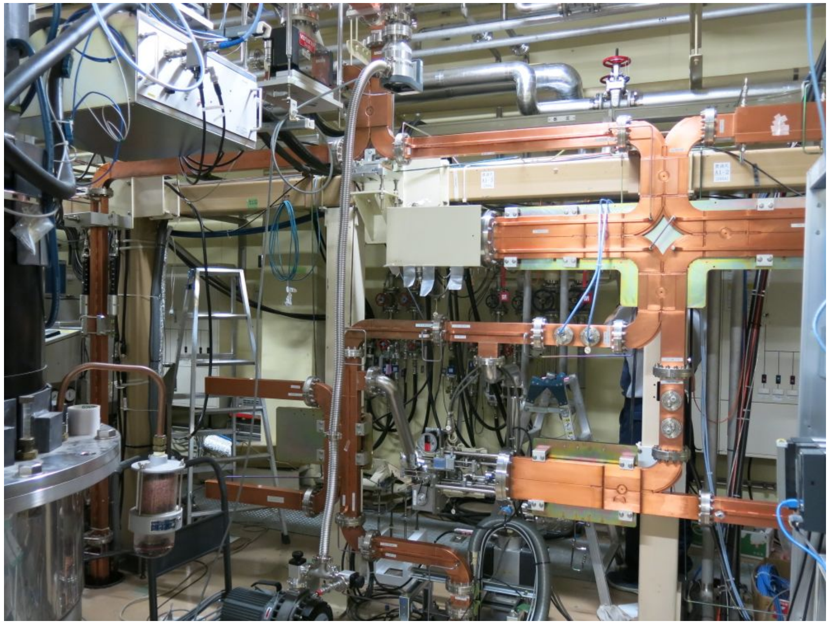
現在のA1 unit

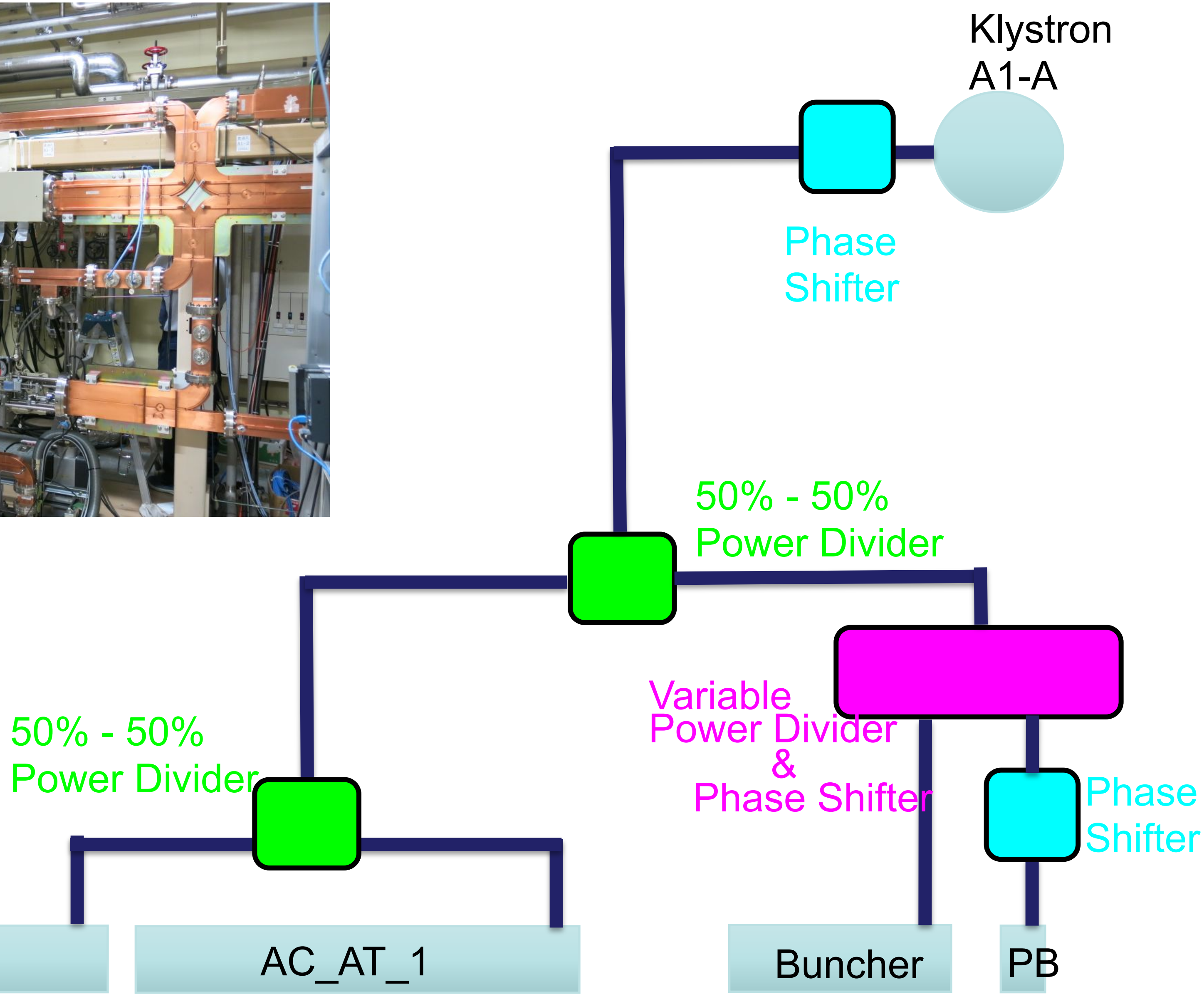






PB+B+Acc1,2 power-phase tuning





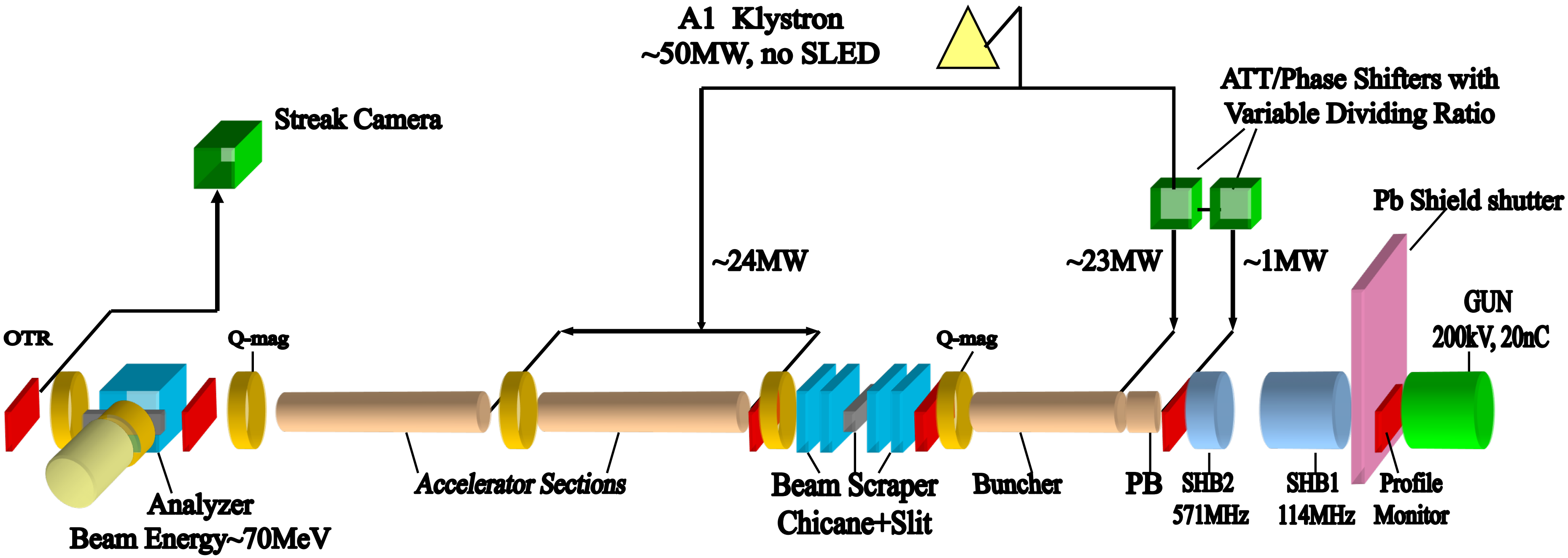
KEK当時の各種装置の許容度と設計値

Tolerance of the Pre-injector Parameter

Instruments	Tolerance range
Gun beam timing	±45 ps
Gun high voltage	±0.38 %
SHB1phase	±1.1 deg
SHB2 phase	±1.3 deg
Buncher phase	±1.7 deg

・The e^+/e^- beam is a single bunch of which width in 10ps (FWHM).

・The each tolerance range is defined so that when each instrument changes the transmission rate of the primary electron beam intensity maintains more than 90% of the maximum value at the positron production target.



Element	Repetition or Frequency	- period	Voltage or Power
Grid pulser	1~50 Hz	-	450~800 V
Gun	50 Hz	-	200 kV
25th SHB1 (standing wave)	114 MHz	8.75 ns	11 kW
5th SHB2 (standing wave)	571 MHz	1.75 ns	7 kW
Prebuncher (travelling wave)	2856 MHz	350 ps	1 MW
Buncher (travelling wave)	2856 MHz	350 ps	23 MW
Accelerating sections (travelling wave)	2856 MHz	350 ps	12 MW x 2
Common frequency of linac/KEKB rings	10.385 MHz	96.289 ns	-

Gun parameters

Beam current	**0 ~ 15 A**	**Heater power**	**40 W**
Grid pulse	**-300 ~ -700 V**	**Cathode temperature**	**950° C**
Bias voltage	**+150 ~ +300 V**	**Acceleration voltage**	**200 kV**
Grid/cathode distance	**180 μm**	**Gun pulse duration**	**4 μs**
Beam duration	**1 ns**	**Residual gas pressure**	**1×10^{-7} Pa**
Beam time jitter	**8 ps**	**ML magnetic field**	**~ 900 G**

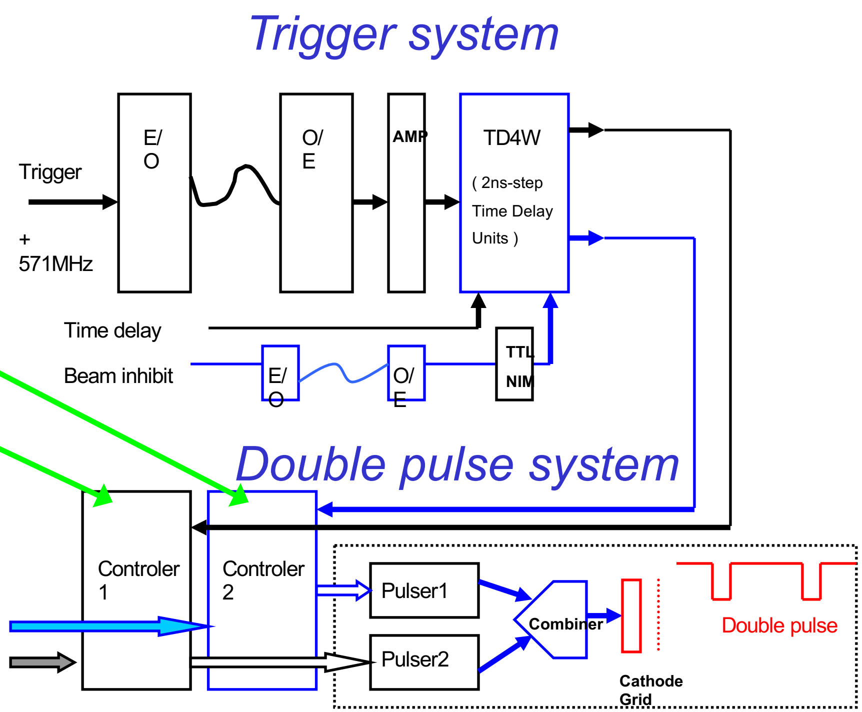
Design values of bunching system A

Prebuncher	Constant impedance	Drift space Buncher	42.27 mm
Max. field	2.0 MV/m	field strength	15 MV/m
shunt impedance	14.97 MM/m	maxi. inpu power	13 Mw
group velocity/c	0.0494	cavity number	
attenuation coefficient	0.0597 Neper/m	buncher section normal section	5 + coupler 28 + coupler
maxi. Input power	2 MW	cavity size D	31.49~34.99 mm
cavity number	3 + couplers	2a	22.44~19.43 mm
cavity size D	24.318 mm	2b	82.53~81.75 mm
2a	36.89 mm		
2b	90.075 mm		

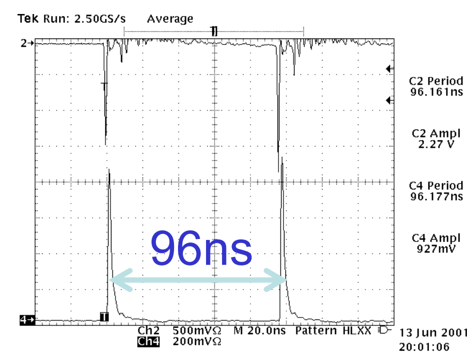
ダブルパルスの生成

Kenteckのパルサーを2台使用

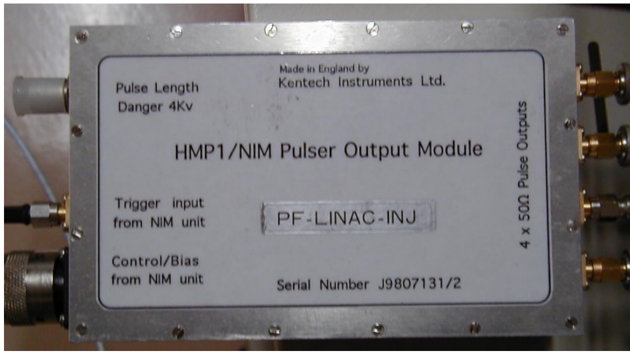
パルサー(制御部)

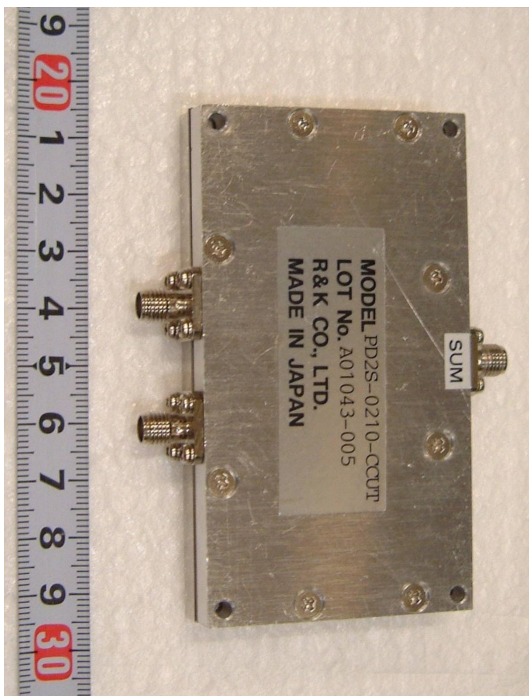


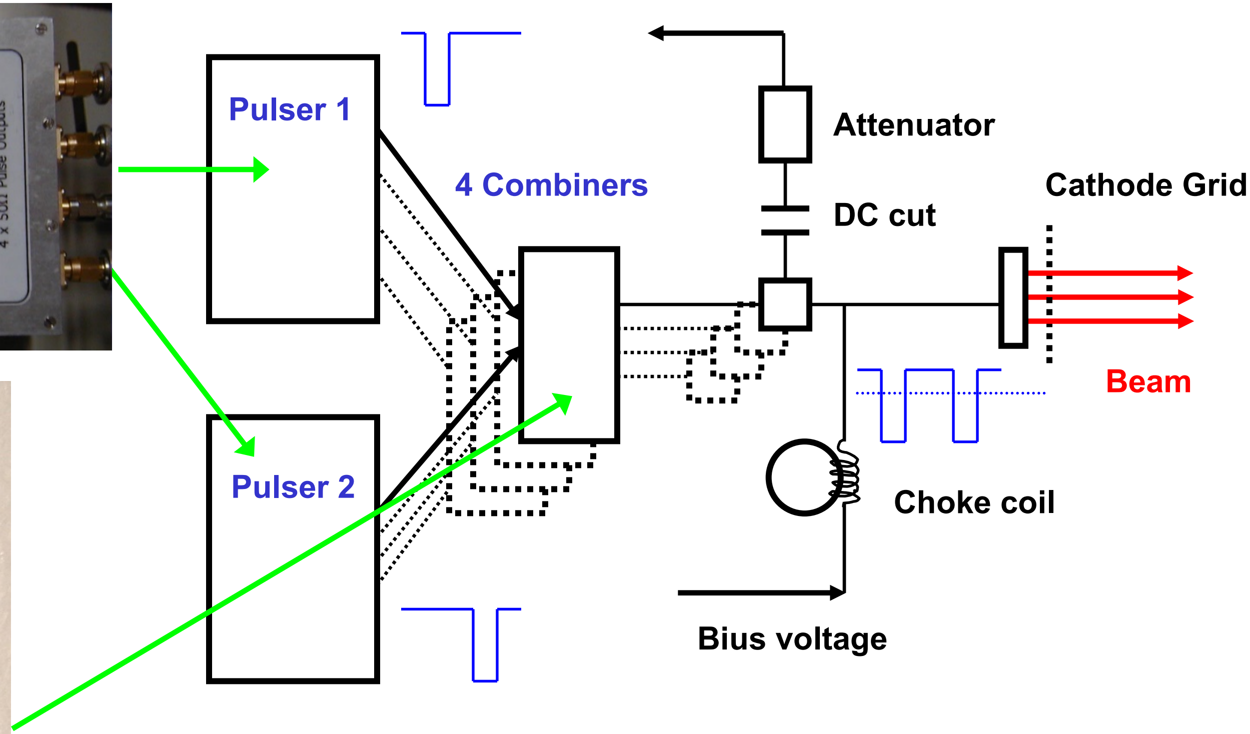
合成後のパルサー出力(上)とビーム波形(下)



Double pulse generation



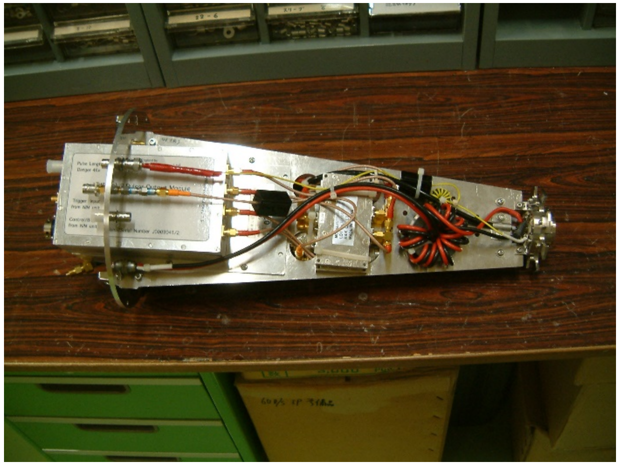


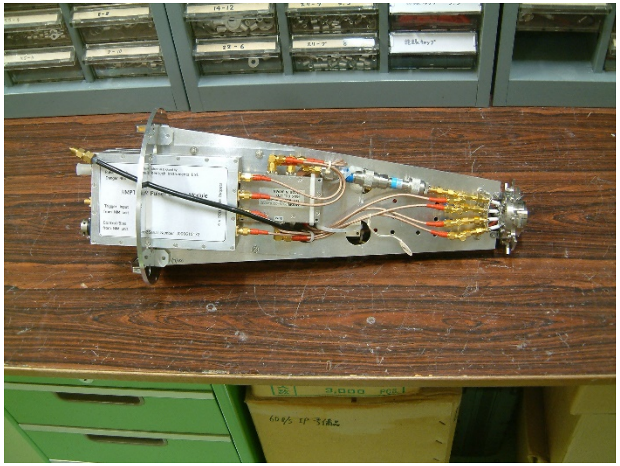


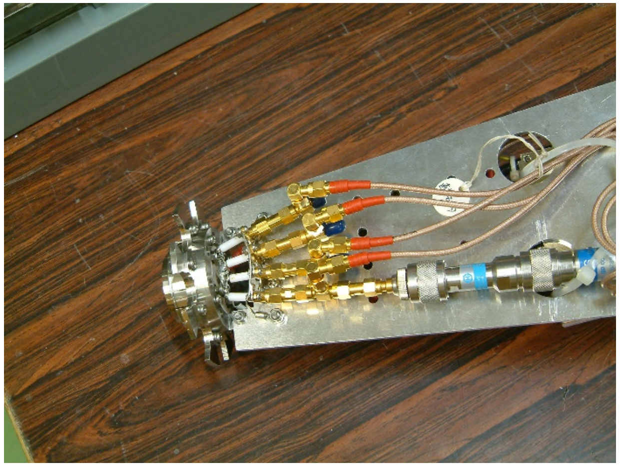
Combine Method of Two Independent Pulses

(1) An individual pulser produces a pulse.
(2) Two independent pulses are combined by rf combiners in order to isolate each other.
(3) 4 combiners are used to reduce source impedance

2 grid pulsers & socket

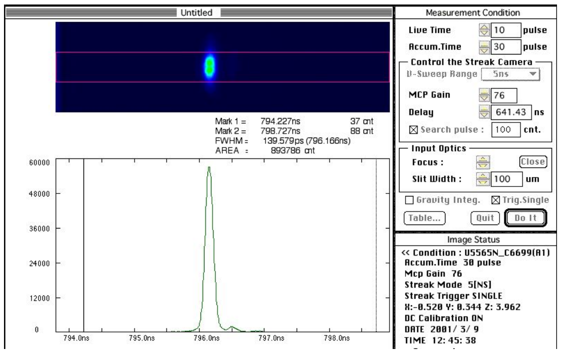


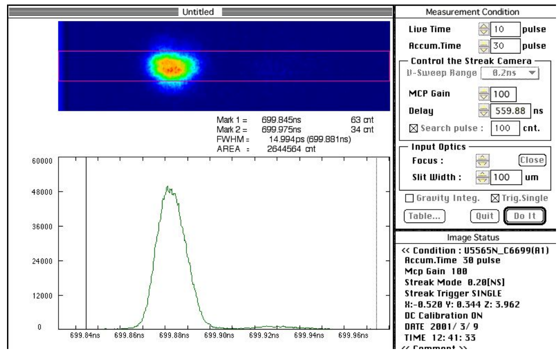




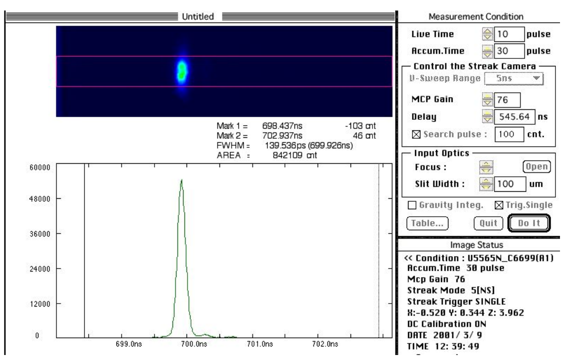
２バンチの形状と電子･陽電子ビーム軌道

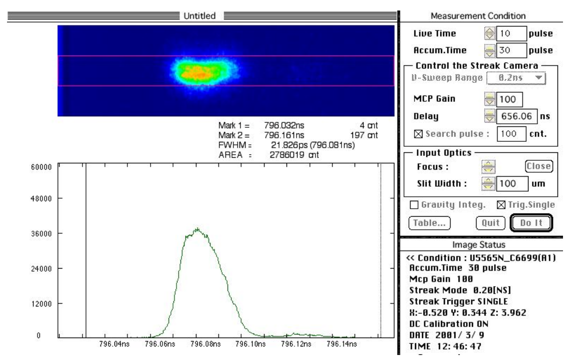
First bunch　　　　　　　　　FWHM　15ps

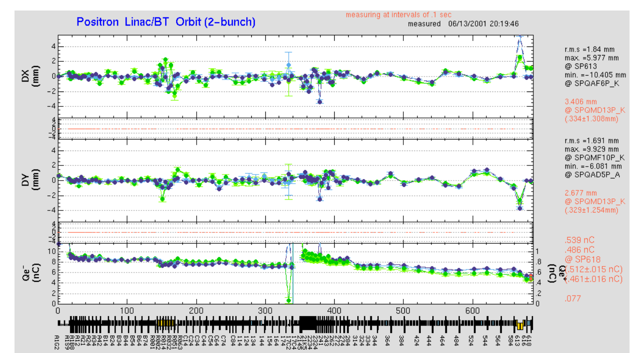




LER入射時の電子と陽電子ビーム軌道
（２バンチ）



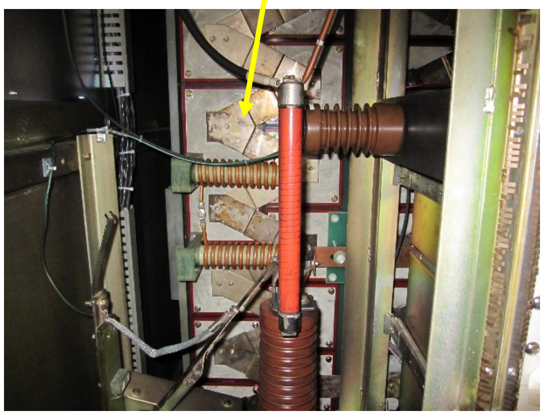




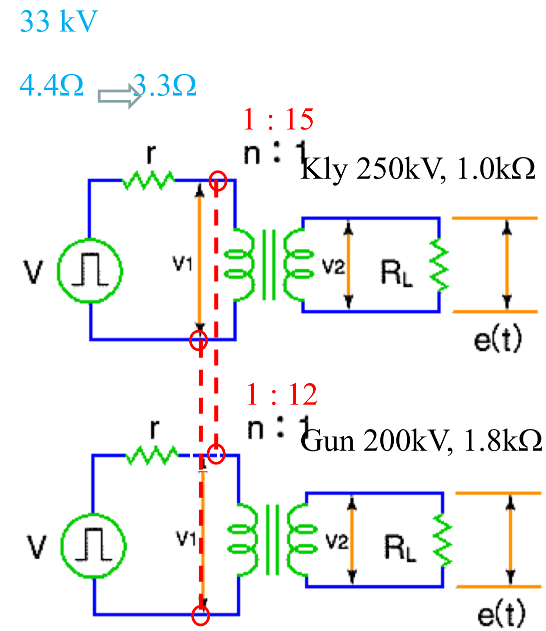
Second bunch

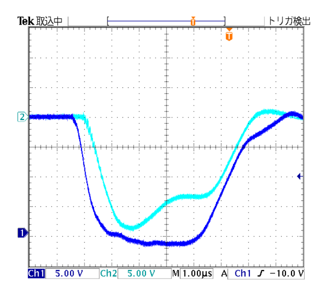
KL-ATと電子銃高圧電源の共用化＋降圧トランス

KL-ATと電子銃高圧電源の共用化＋降圧トランス

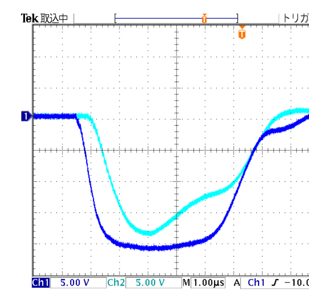


KL_A1 モジュレータ内
PFN 架台裏に設置した





コイル無

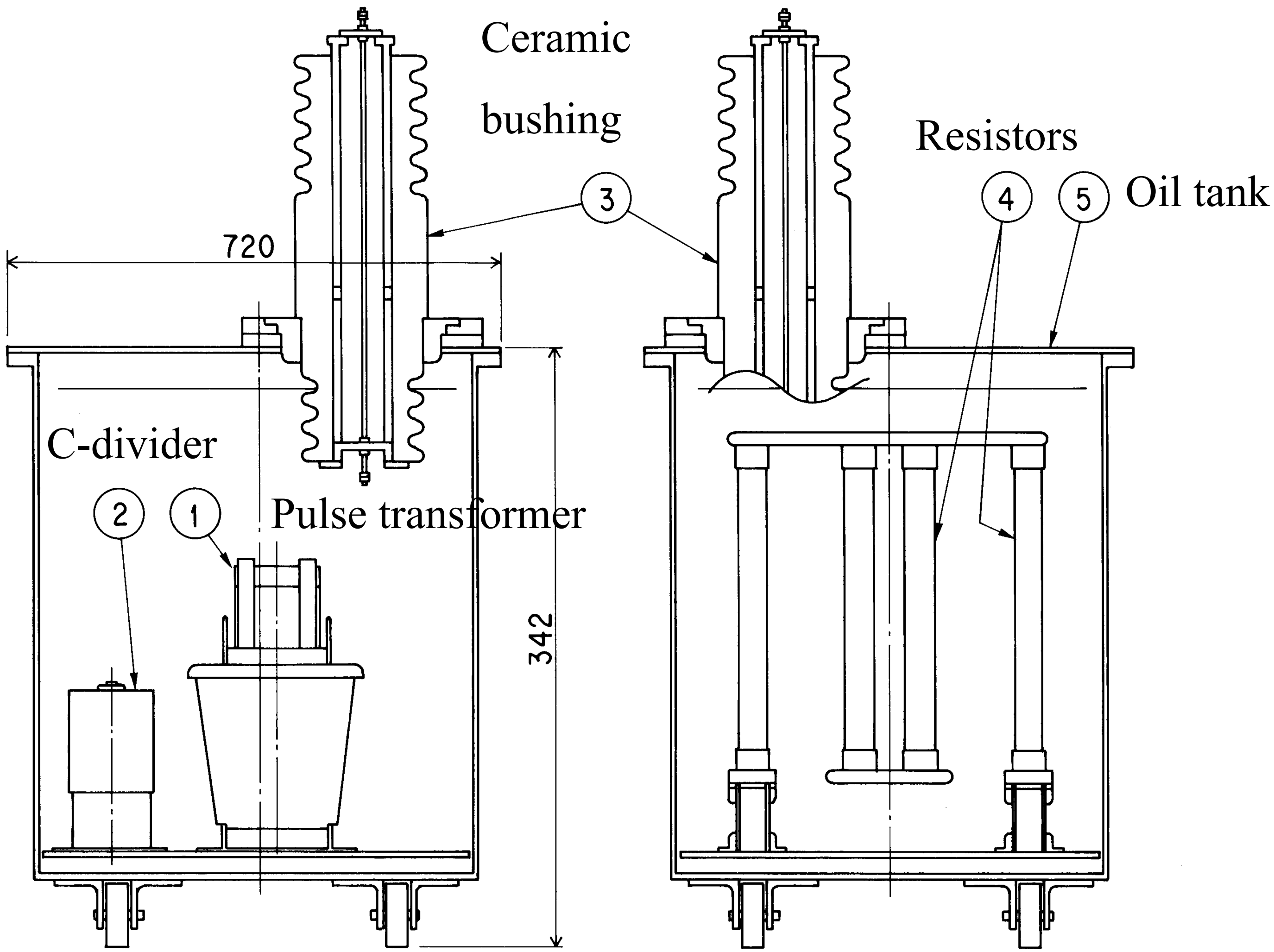


コイル有

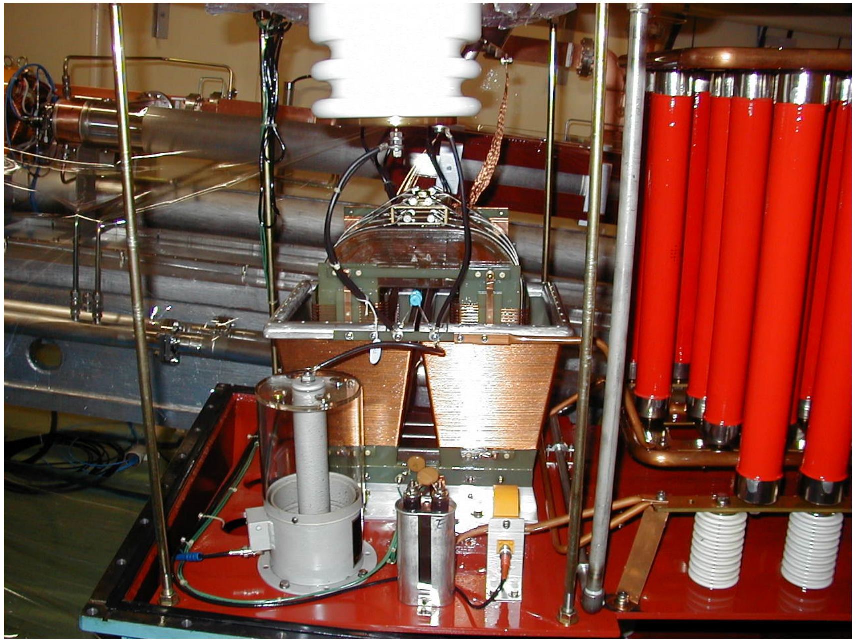
コイルの有無による KLY 高圧波形と GU_A1 高圧波形の比較
(KL_A1 Es：20.0kV)
Ch1(青)：KLY
Ch2(水色)：GU_A1

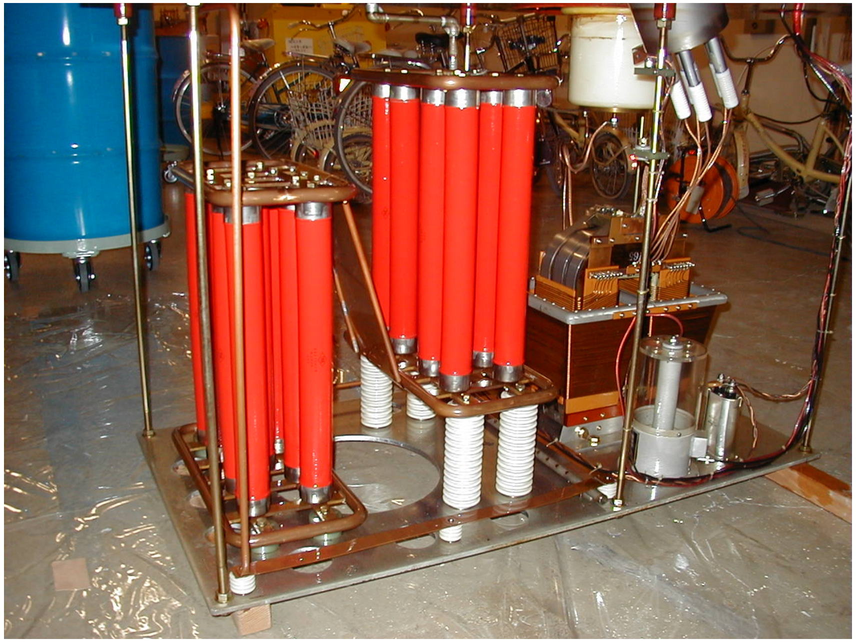
・GU_A1 高電圧波形立下り部をなます為、PFN ～ GU_A1 用ケーブル 間にコイルを取り付けた。
結果、GU_A1 高電圧波形はなまり、KLY 高電圧波形立下り後の歪みが改善された。

Pulse transformer and oil tank of gun A

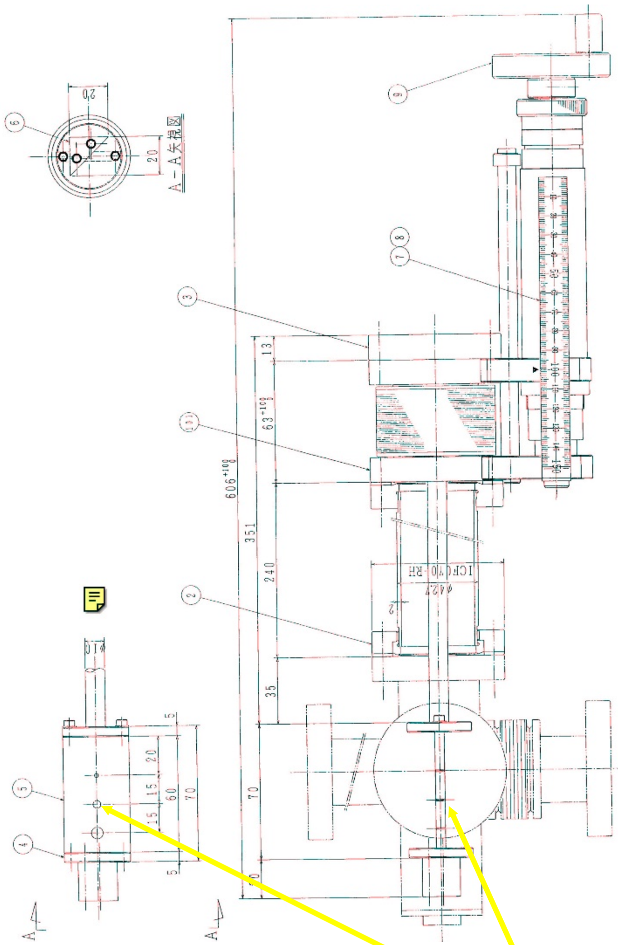


Pulse transeformer & dumy load

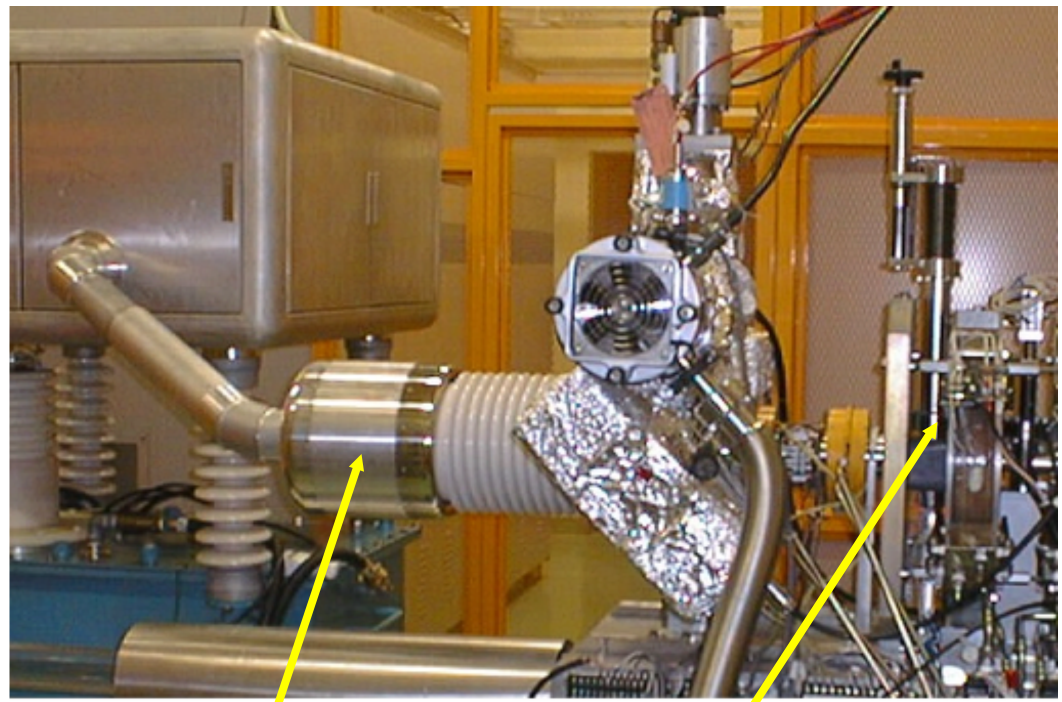




Electron gun and collimator



Collimator holes (2,4,6mmφ)

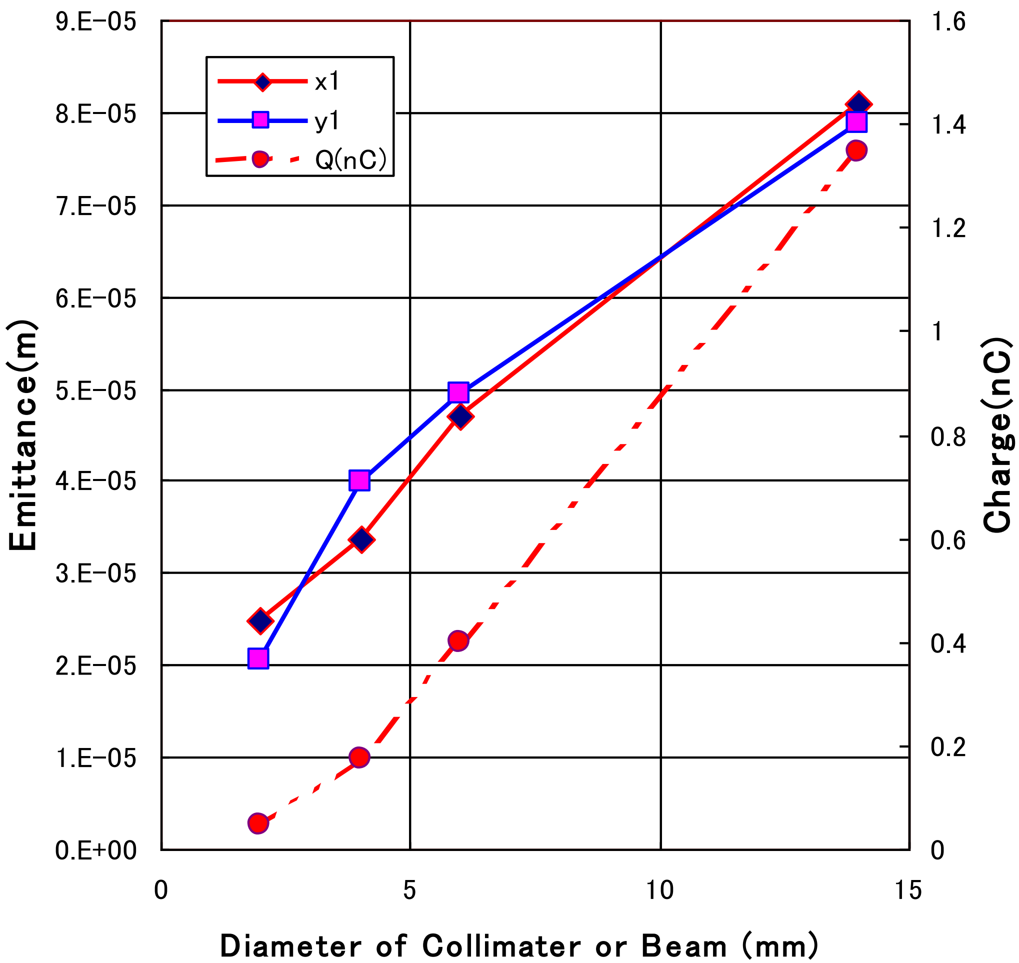


Electron gun

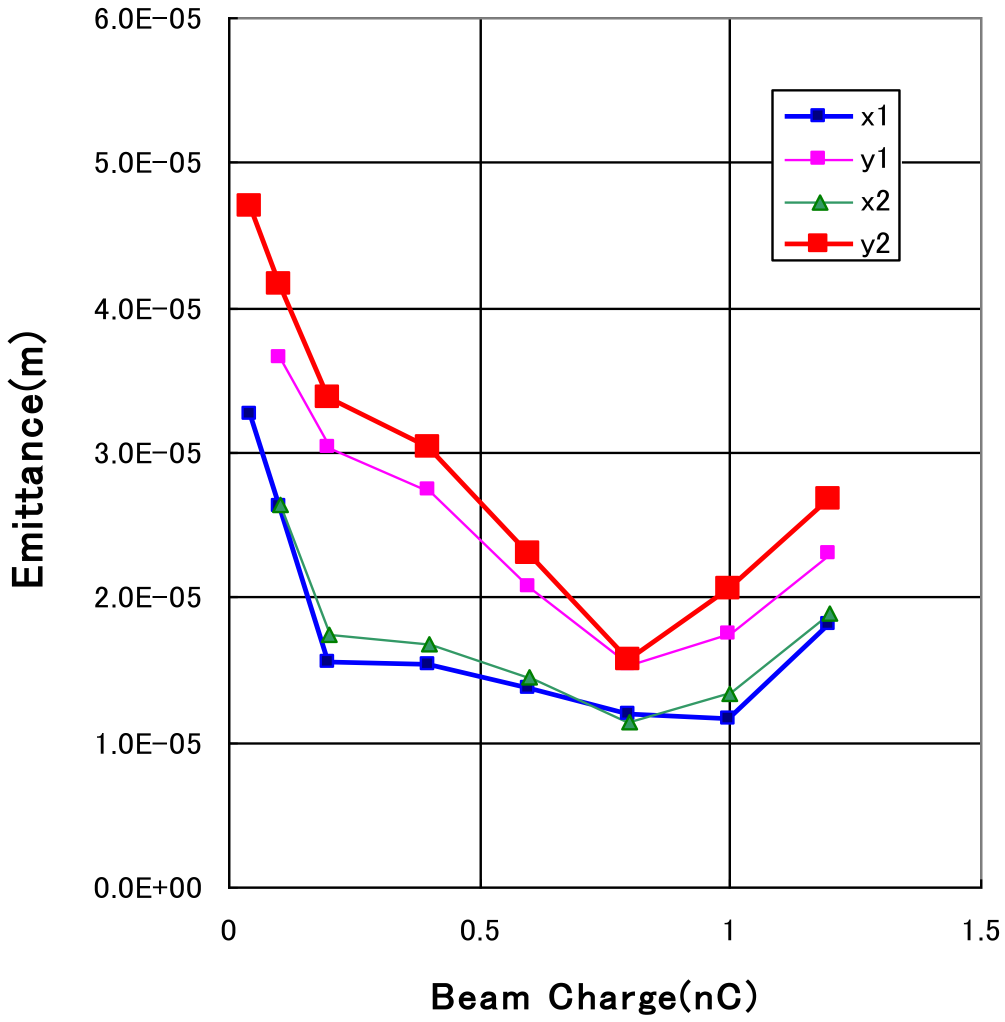
Collimator

電子銃ビームのコリメータとエミッタンス

Relationship between Beam Emittance and Collimator Size

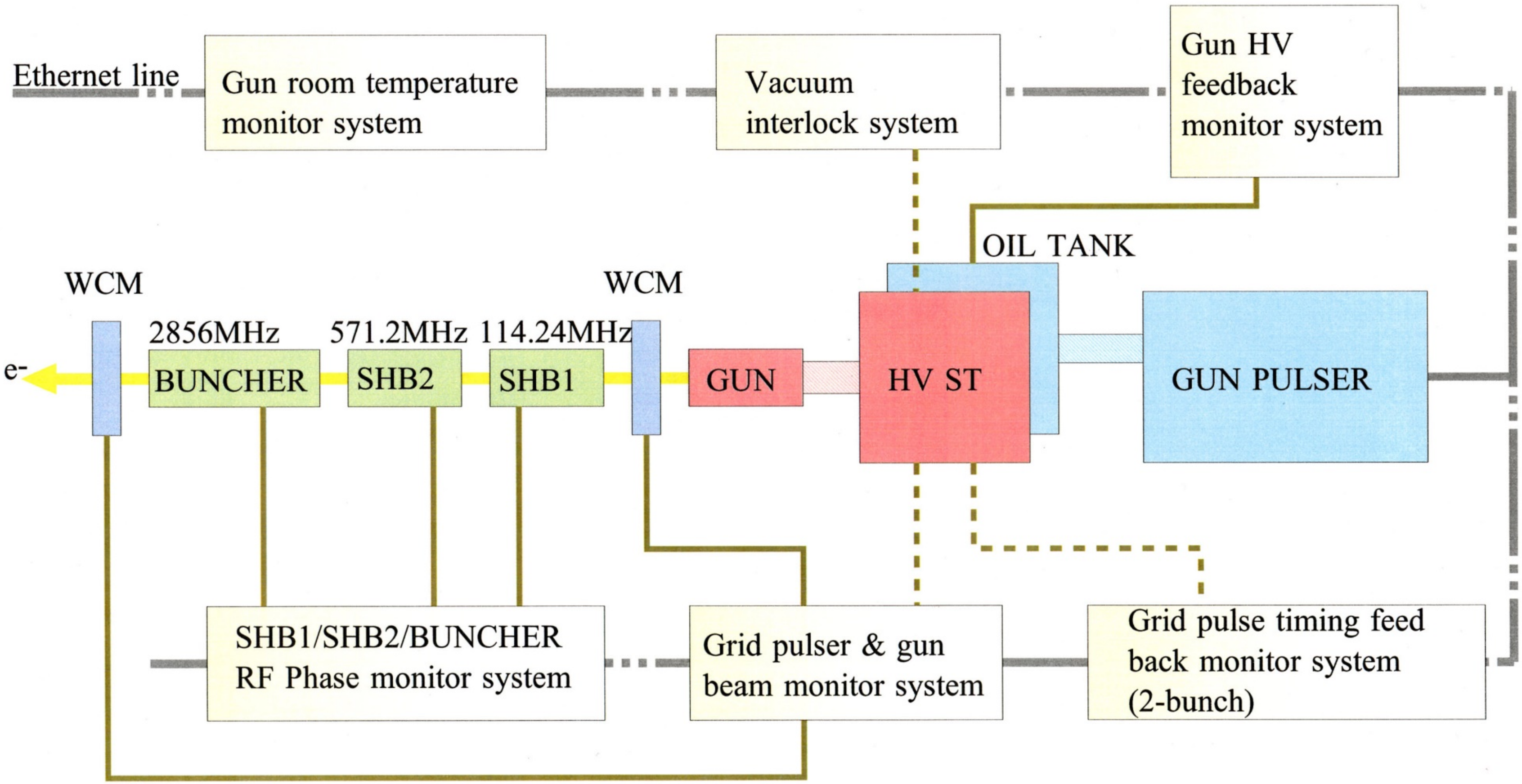


Relationship between Emittance and Beam Charge

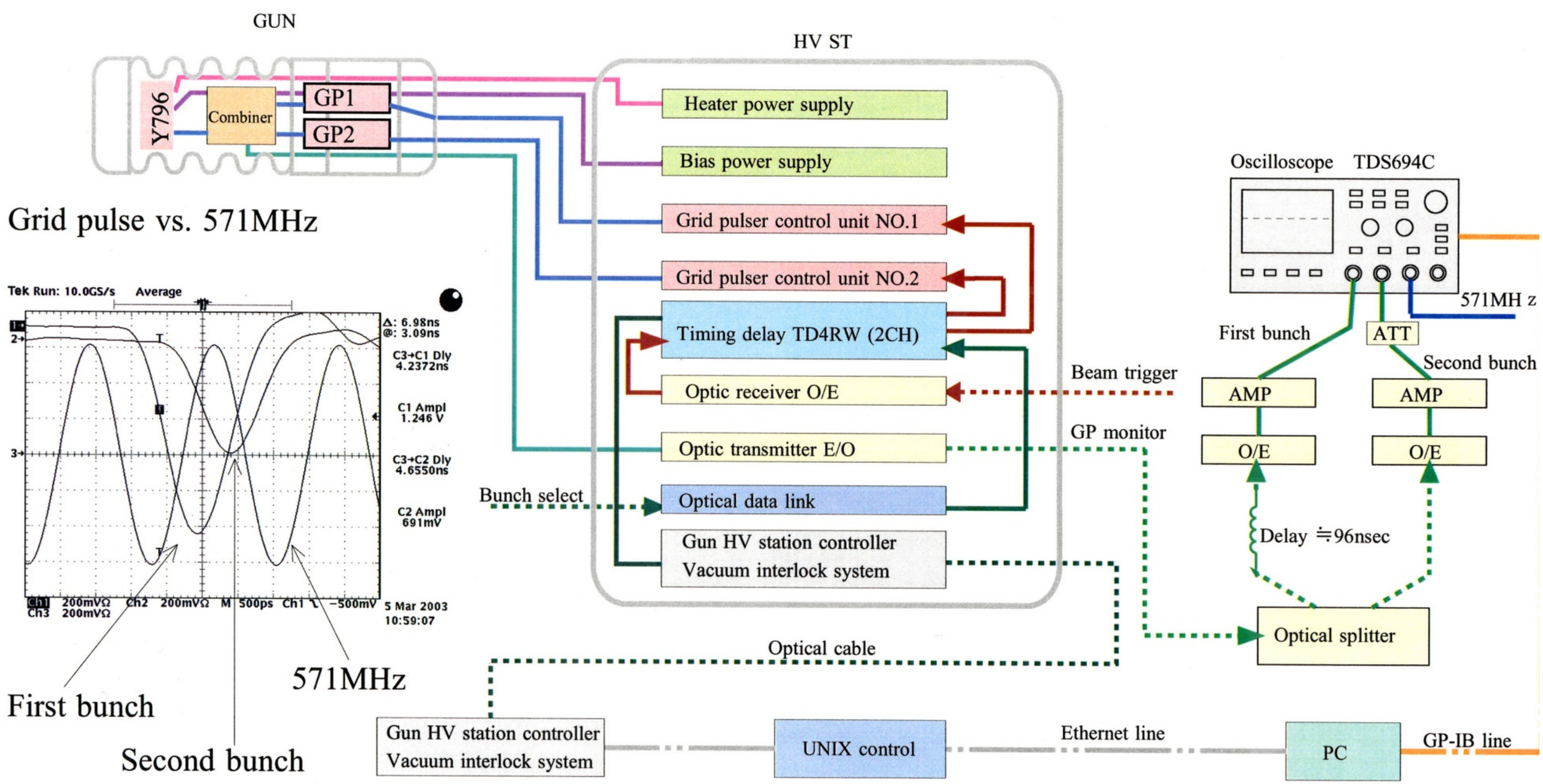


Two-bunch beam generation for KEKB

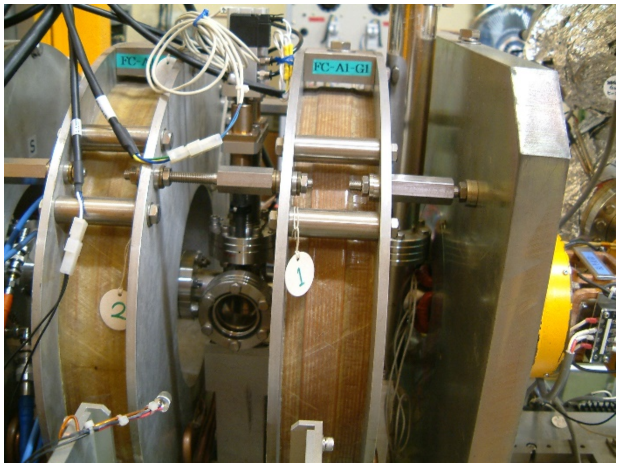
- **Two-bunch beams have been required to reduce injection times into KEKB rings.**
- **Especially for the LER it is being inevitable to increase positron intensity as the stored beam increases. Two-bunch beam acceleration is one of the methods to meet the requirement. In order to accelerate and accumulate the beams successfully, it is at least necessary to satisfy the following conditions: 1) each bunch length should be as short as the present single bunch, that is less than 10 ps, and 2) their time interval should be 97.29 ns that is a period of the common operation frequency between the linac and KEKB rings. Wake field effects are strong for high intensity beams. In normal acceleration sections beam energy of each bunch is thought to be controllable by means of changing acceleration timing with respect to RF pulses. In the bunching section, however, this technique is not useful. To obtain independent operation freedom we developed a system that produces a two-pulse beam from an electron gun each of which intensity and timing are independently changeable. Beam test results are presented as well as the system configuration and performance.**

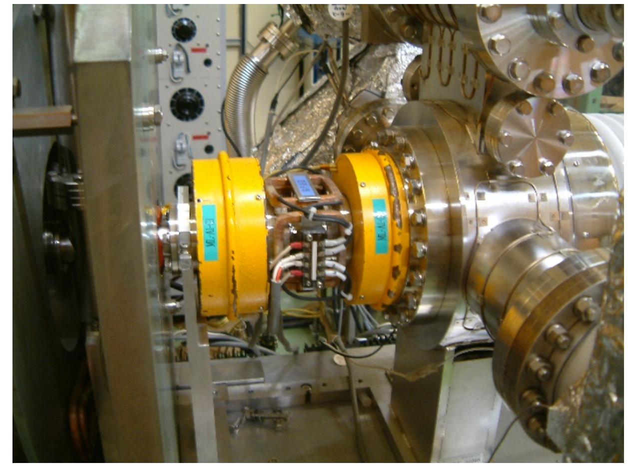

Ethernet line
Gun room temperature monitor system
Vacuum interlock system
Gun HV feedback monitor system
OIL TANK
WCM
WCM
2856MHz
571.2MHz
114.24MHz
e-
BUNCHER
SHB2
SHB1
GUN
HV ST
GUN PULSER
SHB1/SHB2/BUNCHER RF Phase monitor system
Grid pulser & gun beam monitor system
Grid pulse timing feed back monitor system (2-bunch)

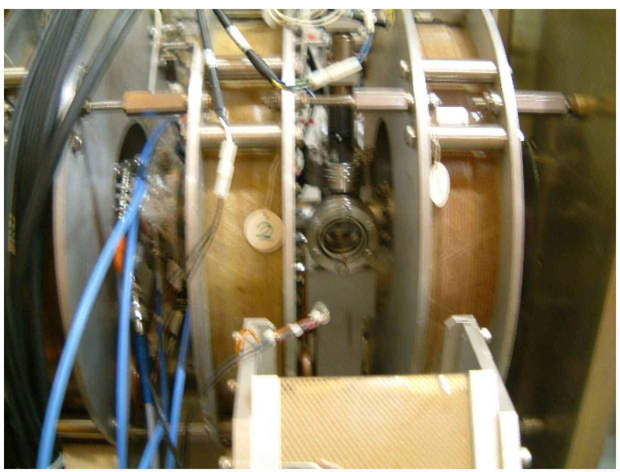
GRID PULSE TIMING FEED BACK MONITOR SYSTEM (2-BUNCH)

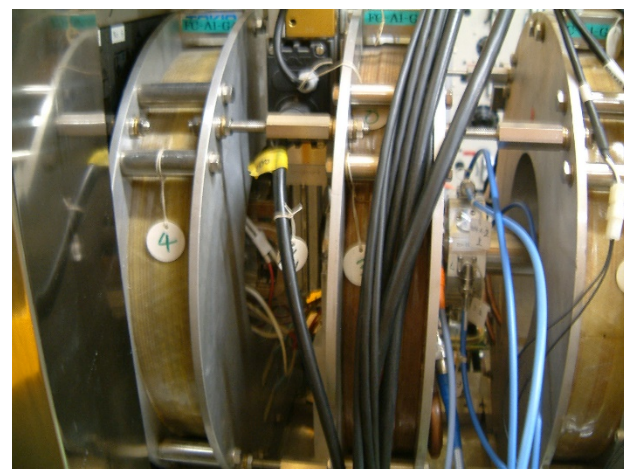


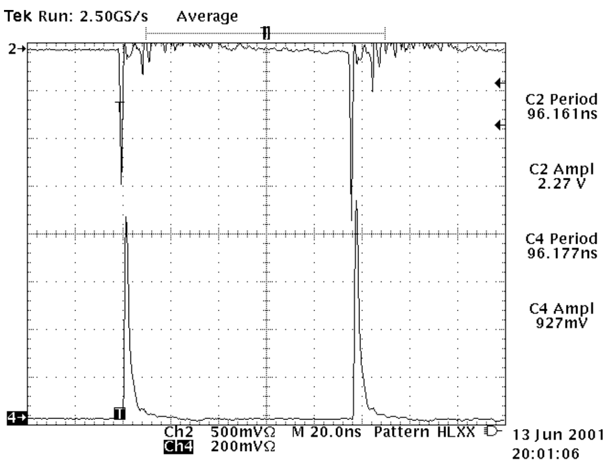
Magnetic lens and focusing coils

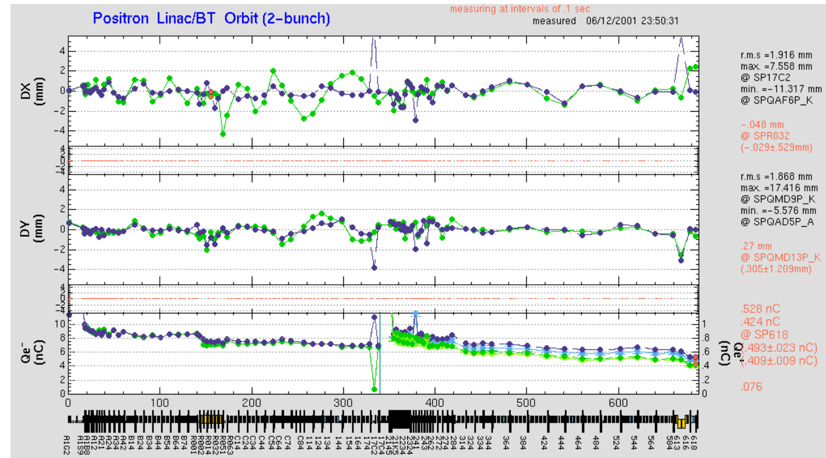


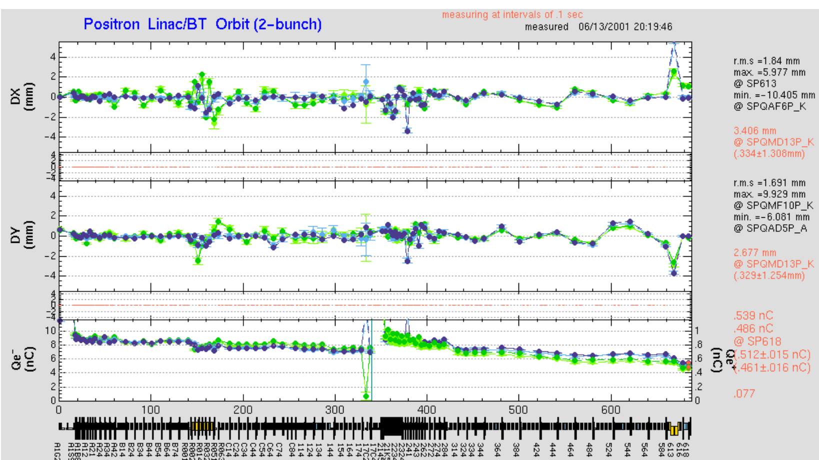


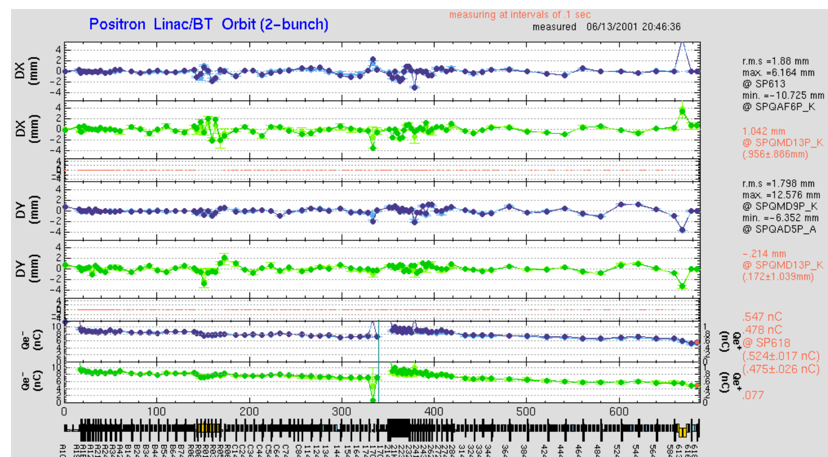




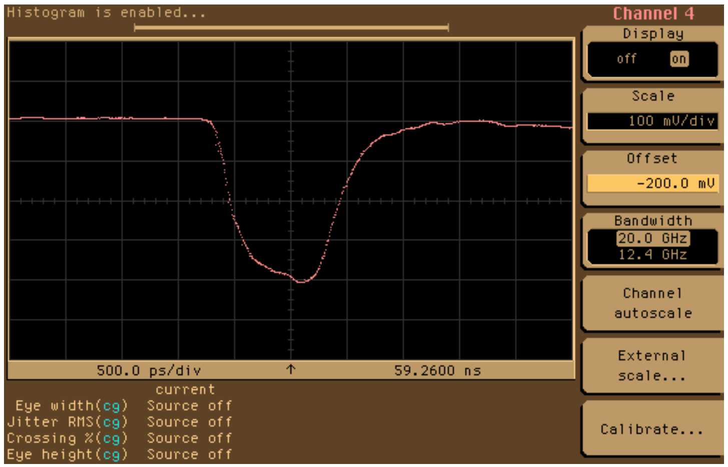

Tek Run: 2.50GS/s Average
C2 Period
96.161ns
C2 Ampl
2.27 V
C4 Period
96.177ns
C4 Ampl
927mV
Ch2 500mVΩ M 20.0ns Pattern HLXX
Ch4 200mVΩ
13 Jun 2001
20:01:06

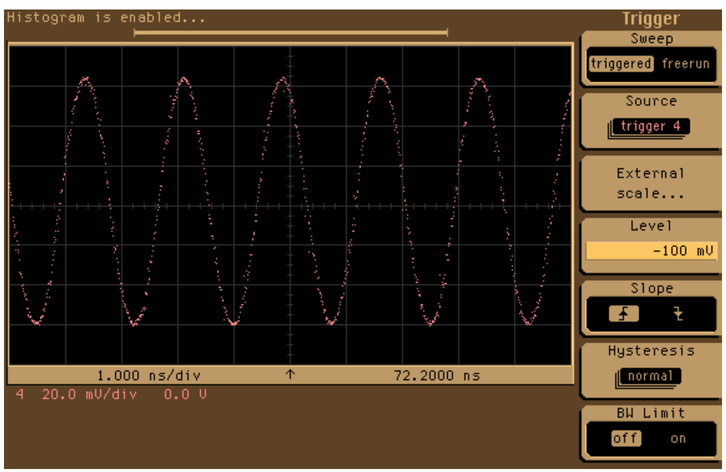

Positron Linac/BT Orbit (2-bunch)
measuring at intervals of .1 sec
measured 06/12/2001 23:50:31
DX (mm)
DY (mm)
Qe⁻ (nC)
Qe⁺ (nC)
r.m.s =1.916 mm
max. =7.558 mm
@ SP17C2
min. =-11.317 mm
@ SPQAF6P_K
-.048 mm
@ SPR032
(-.029±.529mm)
r.m.s =1.868 mm
max. =17.416 mm
@ SPQMD9P_K
min. =-5.576 mm
@ SPQAD5P_A
.27 mm
@ SPQMD13P_K
(.305±1.209mm)
.528 nC
.424 nC
@ SP618
(.493±.023 nC)
(.409±.009 nC)
.076

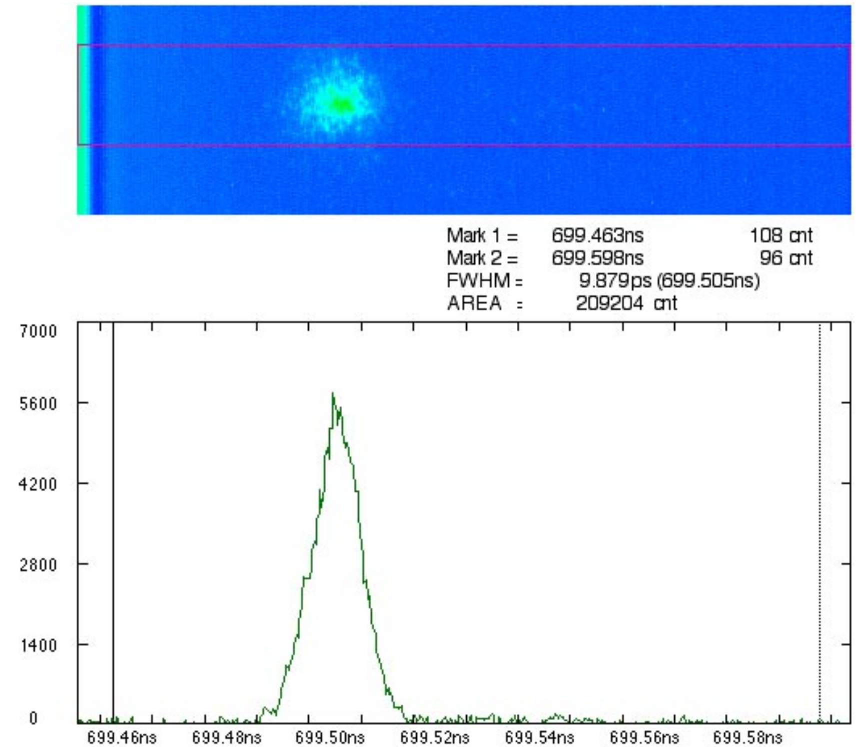

Positron Linac/BT Orbit (2-bunch)
measuring at intervals of .1 sec
measured 06/13/2001 20:19:46
DX (mm)
DY (mm)
Qe⁻ (nC)
Qe⁺ (nC)
r.m.s =1.84 mm
max. =5.977 mm
@ SP613
min. =-10.405 mm
@ SPQAF6P_K
3.406 mm
@ SPQMD13P_K
(.334±1.308mm)
r.m.s =1.691 mm
max. =9.929 mm
@ SPQMF10P_K
min. =-6.081 mm
@ SPQAD5P_A
2.677 mm
@ SPQMD13P_K
(.329±1.254mm)
.539 nC
.486 nC
@ SP618
(.512±.015 nC)
(.461±.016 nC)
.077


Positron Linac/BT Orbit (2-bunch)
measuring at intervals of .1 sec
measured 06/13/2001 20:46:36
DX (mm)
DY (mm)
Qe⁻ (nC)
Qe⁺ (nC)
r.m.s =1.88 mm
max. =6.164 mm
@ SP613
min. =-10.725 mm
@ SPQAF6P_K
1.042 mm
@ SPQMD13P_K
(.956±.886mm)
r.m.s =1.798 mm
max. =12.576 mm
@ SPQMD9P_K
min. =-6.352 mm
@ SPQAD5P_A
-.214 mm
@ SPQMD13P_K
(.172±1.039mm)
.547 nC
.478 nC
@ SP618
(.524±.017 nC)
(.475±.026 nC)
.077

電子銃ビーム波形とバンチ形状

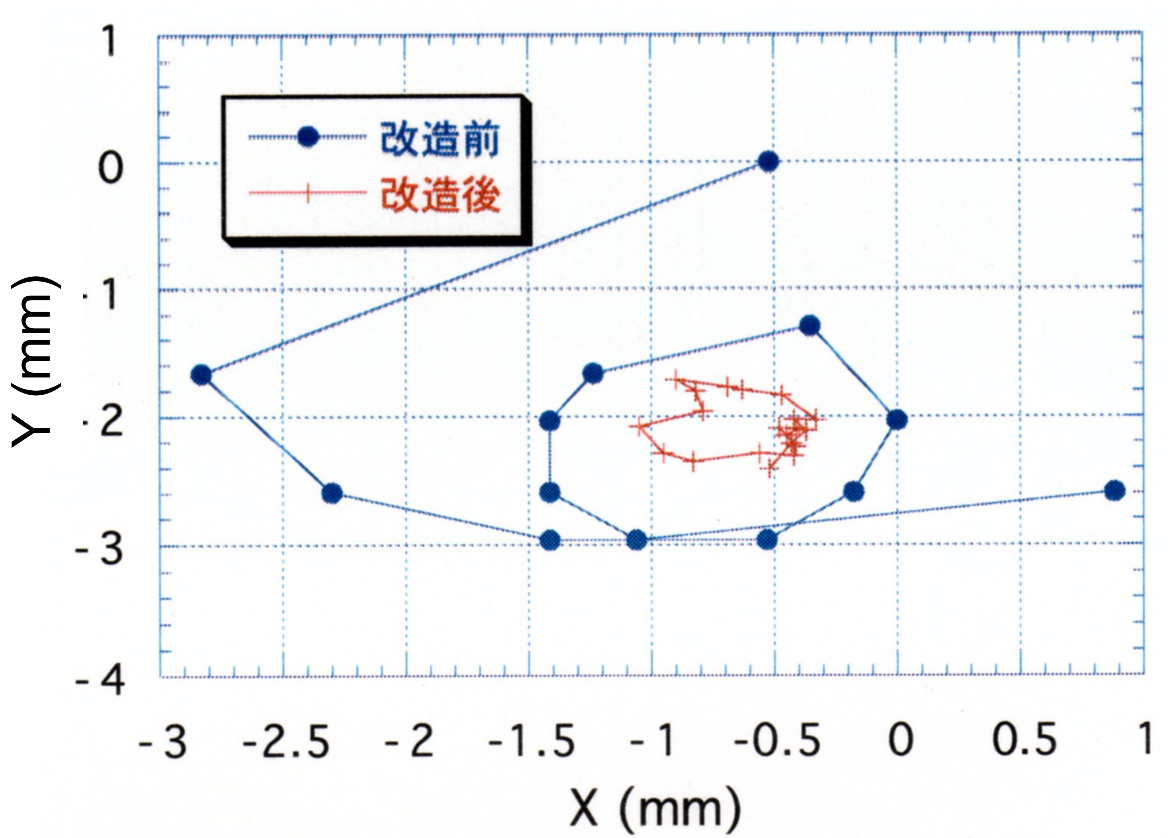




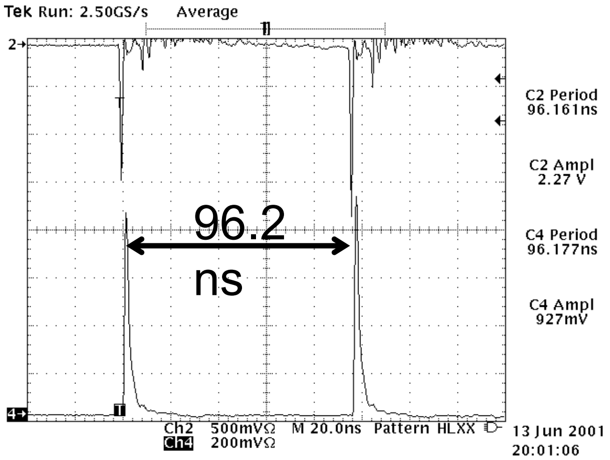


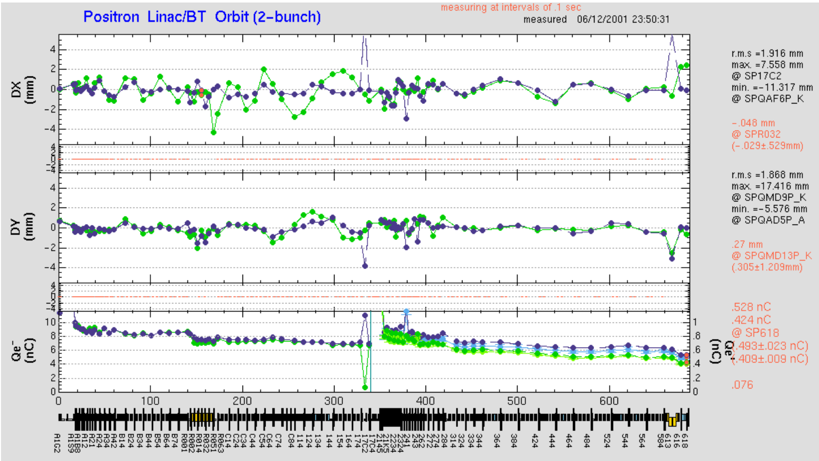
571MHz & induced fields

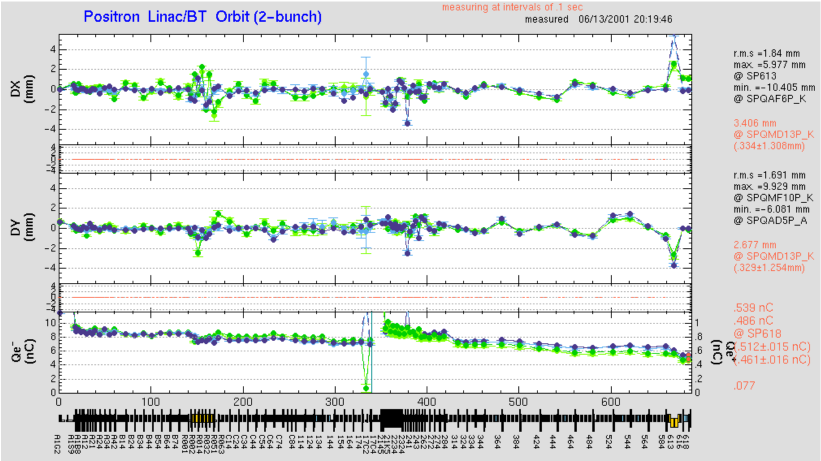
Correlation between beam position and gun-accelerating voltage

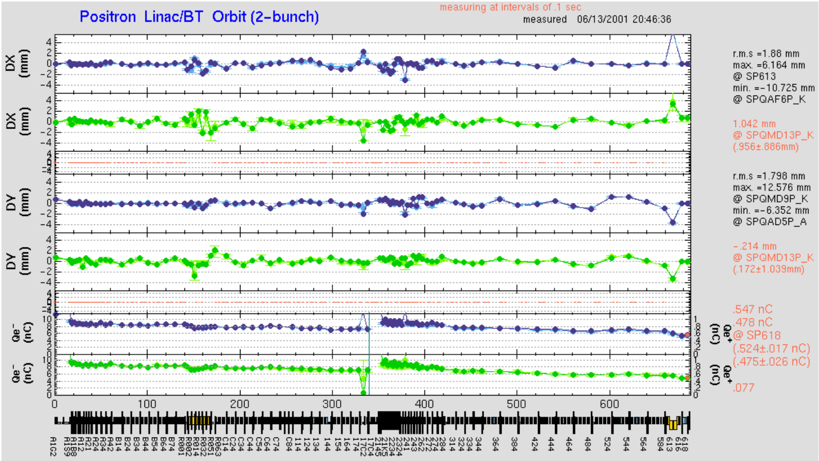


Two bunch beam orbit 1

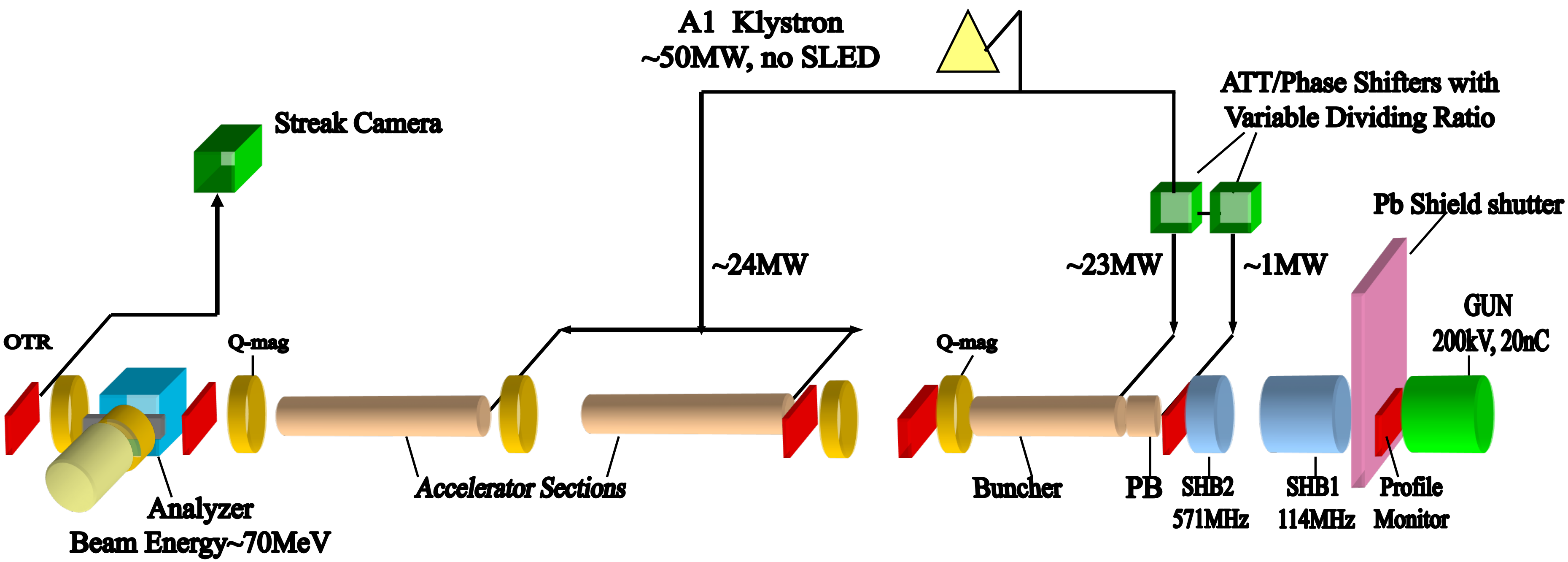








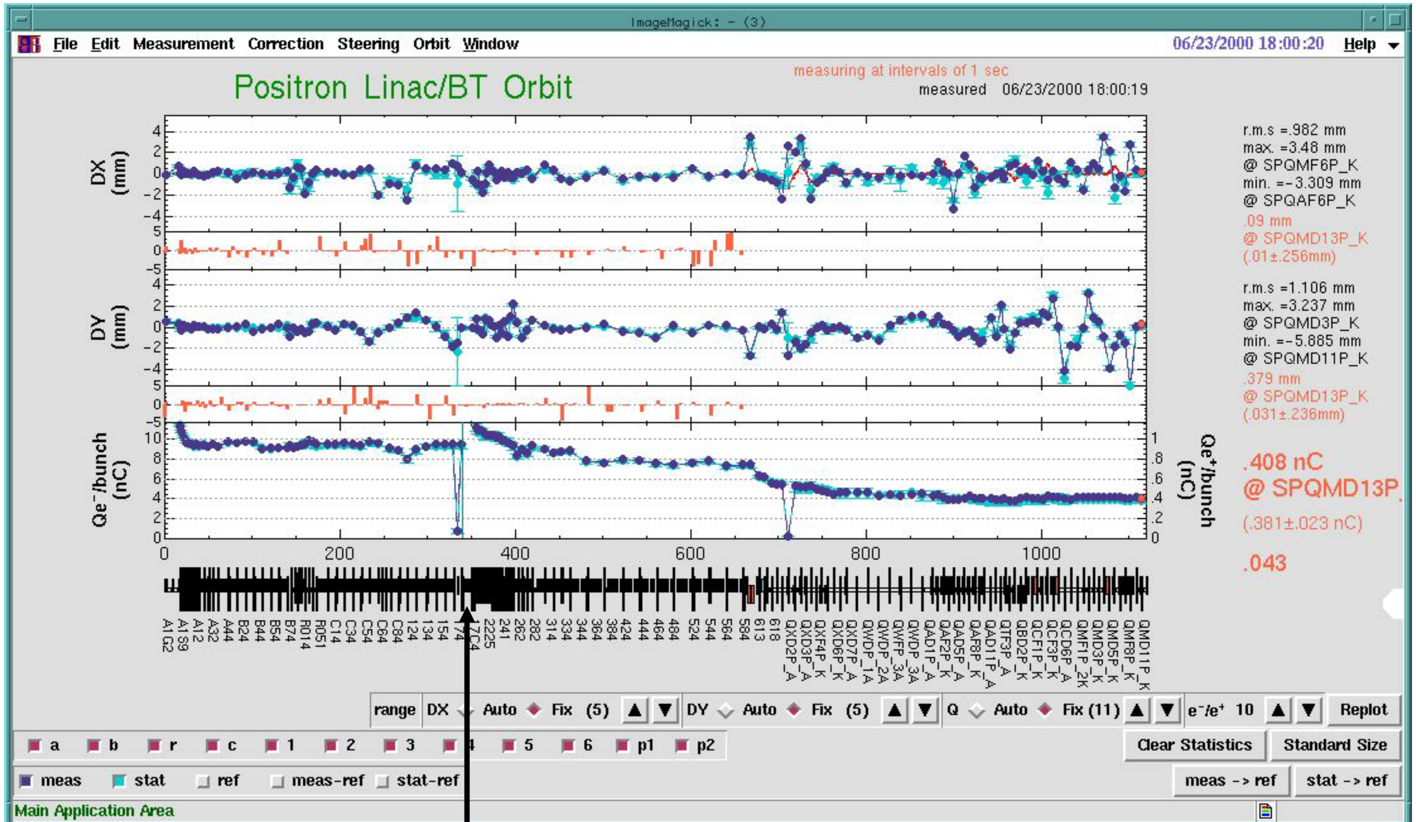
Schematic layout of the pre-injector A



Ｂ８の加速管に誘起されたＲＦの位相を１度以内に押さえるには、各機器は次の許容値以下でなければならない。この値は、対応するグラフの傾きから求めたものである。*のビーム位置はSP-A1-1、他はSP-A4-4で測定した。

ビーム電荷	6nC	8nC	10nC
電子銃			
パルス電圧（°/kV)	―	―	1.29
ビームジッター(°/mm)	-0.17	-0.11	-0.07
ＳＨＢ１位相			
誘起波位相（°/°）	-0.94	-0.93	-0.57
軌道変位 x (mm/°)	(0.12)*	-0.22	0.09
軌道変位 y (mm/°)	(0.30)*	0.14	0.12
ＳＨＢ２位相			
誘起波位相（°/°）	-1.06	-0.64	-0.294
軌道変位 x (mm/°)		-0.11	-0.11
軌道変位 y(mm/°)		0.23	0.23
Ａ１位相			
誘起波位相(°/°)	―	―	1.02
軌道変位 x (mm/°)	―	―	0.033
軌道変位 y (mm/°)	―	―	0.022

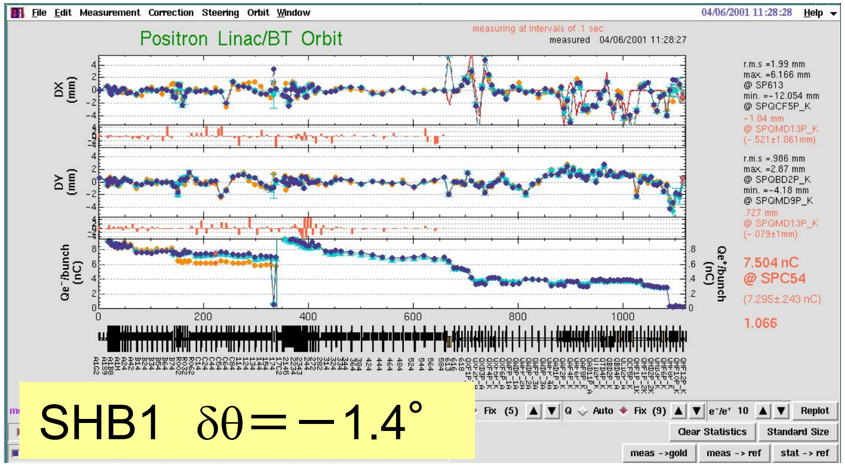
Orbits and Current in KEKB Linac & BT @10nC

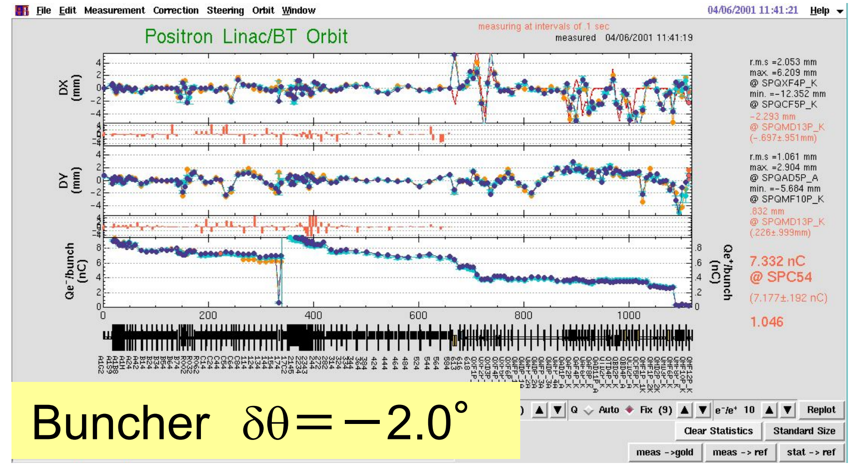


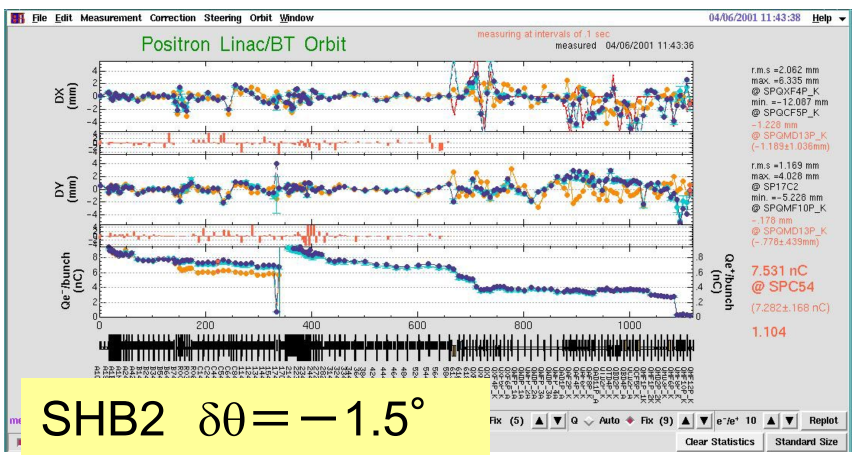
positron production target

The 10-nC electron/positron beams accelerated in the KEKB linac

Tolerance for phases @ 10nC beam







The each tolerance range is defined so that when each instrument changes the transmission rate of the primary electron beam intensity maintains more than 90% of the maximum value at the positron production target.

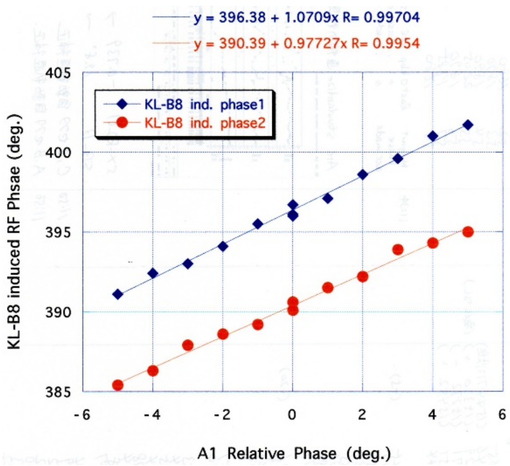
Summary

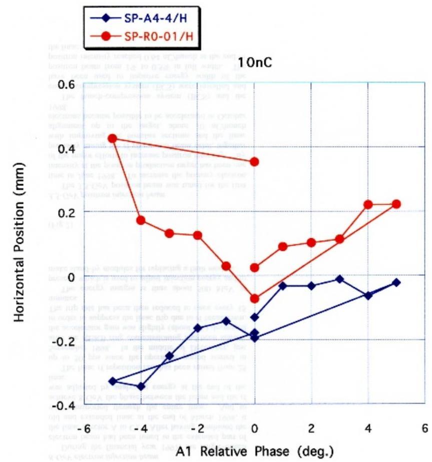
Instruments	Tolerance range	Measurement accuracy	Stability*	Digital feed back
Gun beam timing	±45 ps	5 ps	20 ps	○
Gun high voltage	±0.38 %	0.02 %	< 0.1 %	○
SHB1 phase	±1.1 deg	0.05 deg	0.5 deg	-
SHB2 phase	±1.3 deg	0.2 deg	1.0 deg	-
Buncher phase	±1.7 deg	-	± 1.0 deg	-

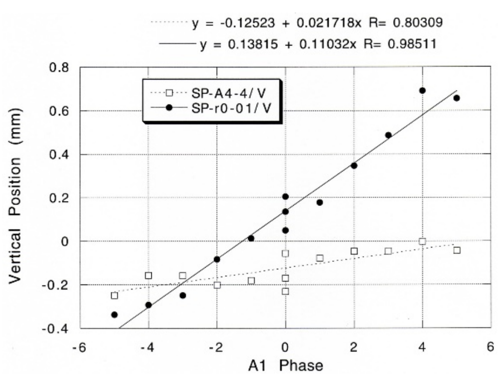
* Long term stability of normal status.

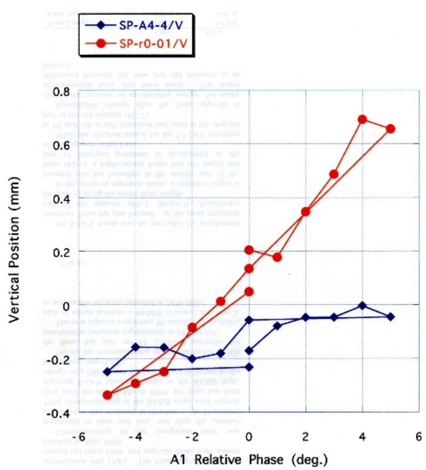
- This system is doing on the reference of a Buncher entrance RF phase.
- Three kinds of RF phases that were directly associated to the electron beam are being measured directly with high accuracy.
- We are able to discover it right away if there is abnormality in these measurement data quantity.
- We aim for a more stable beam from now on, and be thinking digital feed back of SHB1/2 by using the measured value of this system.

Tolerance Measurement @1999/06/18









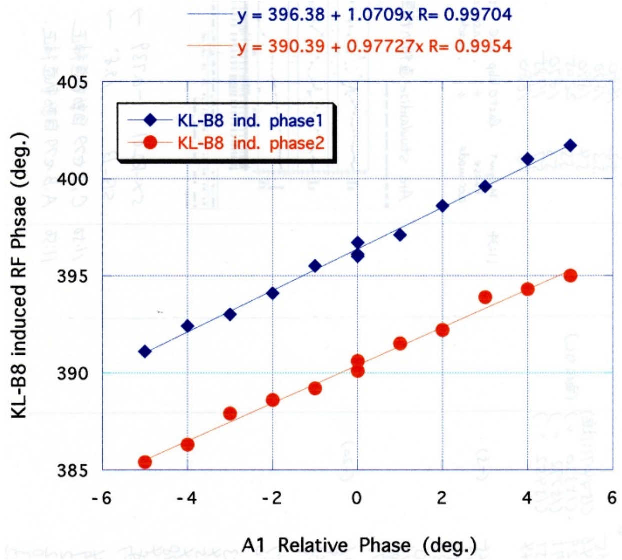
Ｂ８の加速管に誘起されたＲＦの位相を１度以内に押さえるには、各機器は次の許容値以下でなければならない。この値は、対応するグラフの傾きから求めたものである。*のビーム位置はSP-A1-1、他はSP-A4-4で測定した。

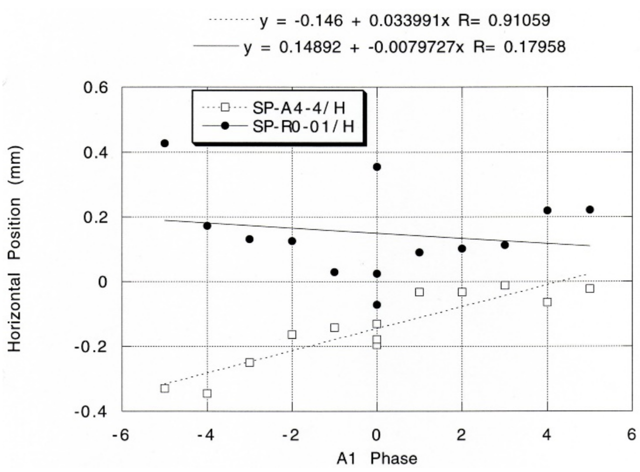
ビーム電荷	6nC	8nC	10nC
電子銃			
パルス電圧（°/kV）	―	―	1.29
ビームジッター(°/mm)	-0.17	-0.11	-0.07
ＳＨＢ１位相			
誘起波位相（°/°）	-0.94	-0.93	-0.57
軌道変位 x (mm/°)	(0.12)*	-0.22	0.09
軌道変位 y (mm/°)	(0.30)*	0.14	0.12
ＳＨＢ２位相			
誘起波位相（°/°）	-1.06	-0.64	-0.294
軌道変位 x (mm/°)		-0.11	-0.11
軌道変位 y(mm/°)		0.23	0.23
Ａ１位相			
誘起波位相(°/°)	―	―	1.02
軌道変位 x (mm/°)	―	―	0.033
軌道変位 y (mm/°)	―	―	0.022

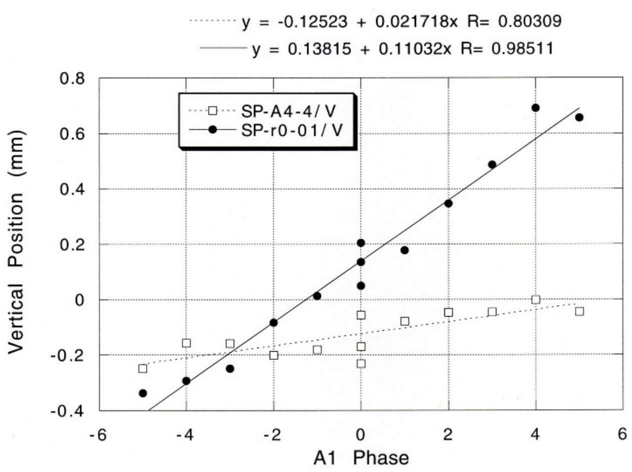
許容値

ビーム電荷	6nC	8nC	10nC
電子銃			
パルス電圧（°/%）	―	―	2.6%
ビームジッター(ps/°)	-39	-48	-95
ＳＨＢ１位相			
誘起波位相（°/°）	-1.06	-1.08	-1.75
軌道変位 x (°/0.2mm)	(1.7)*	-0.91	2.2
軌道変位 y (°/0.2mm)	(0.67)*	1.4	1.7
ＳＨＢ２位相			
誘起波位相（°/°）	-0.94	-1.6	-3.4
軌道変位 x (°/0.2mm)		-1.8	-1.8
軌道変位 y (°/0.2mm)		0.87	0.87
Ａ１位相			
誘起波位相(°/°)	―	―	0.98
軌道変位 x (°/0.2mm)	―	―	6.1
軌道変位 y (°/0.2mm)	―	―	9.1

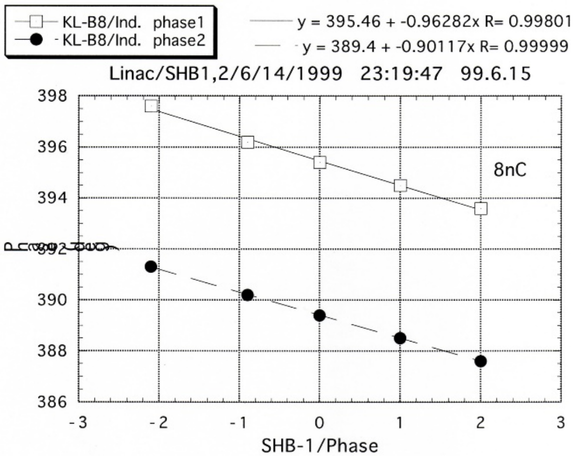
A1 RF-phase dependence @10nC

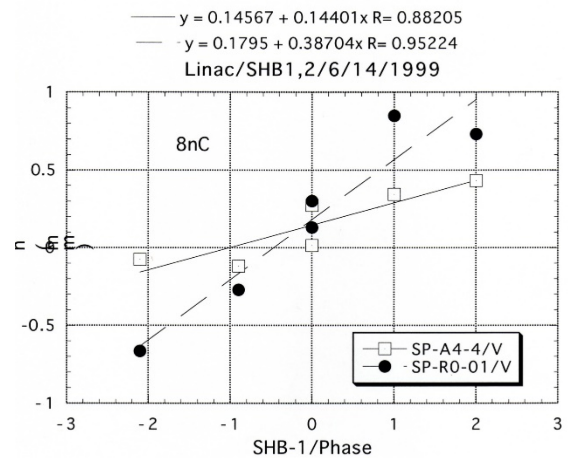


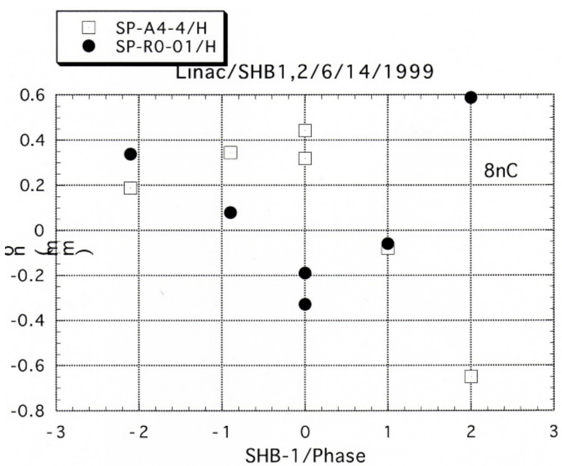




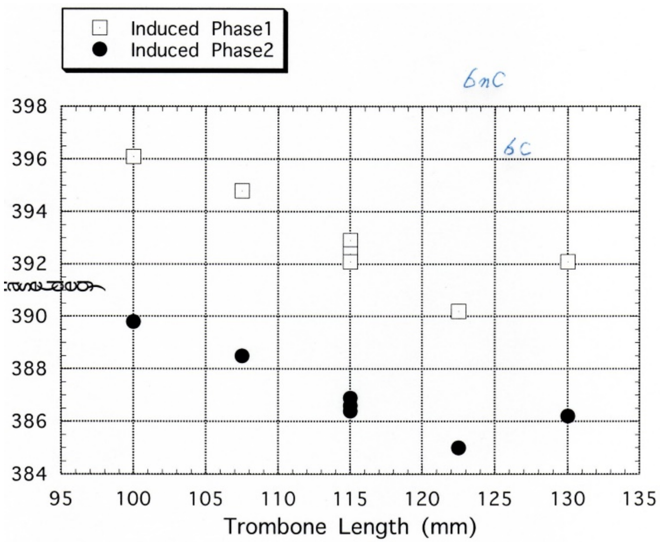
SHB1 RF-phase dependence @8nC, June/14/1999

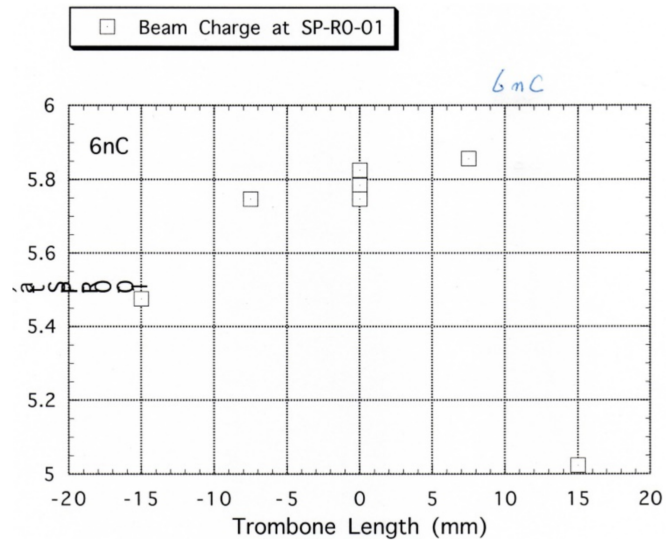


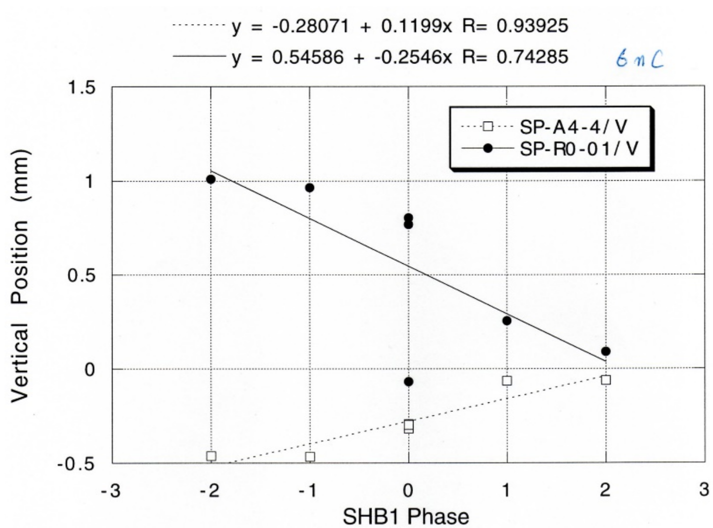




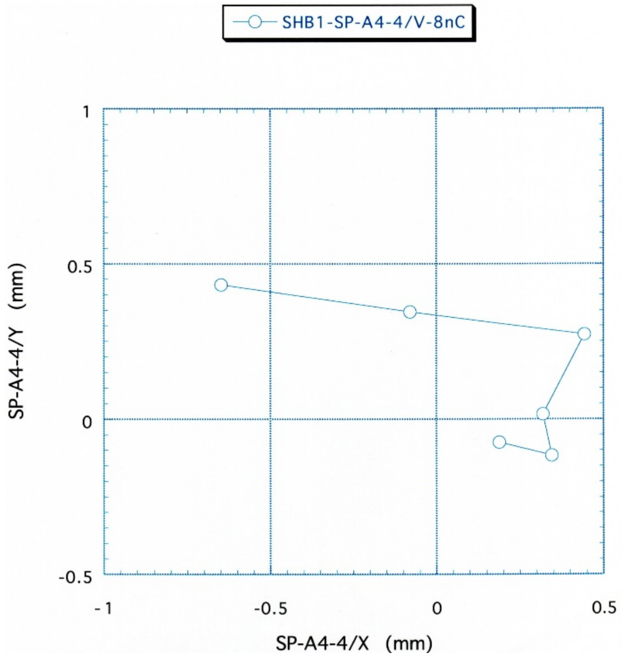
SHB1 RF-phase dependence @6nC

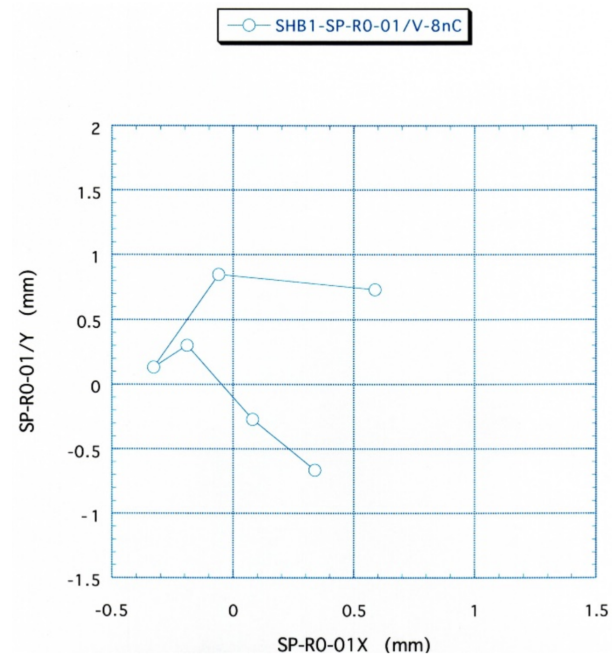


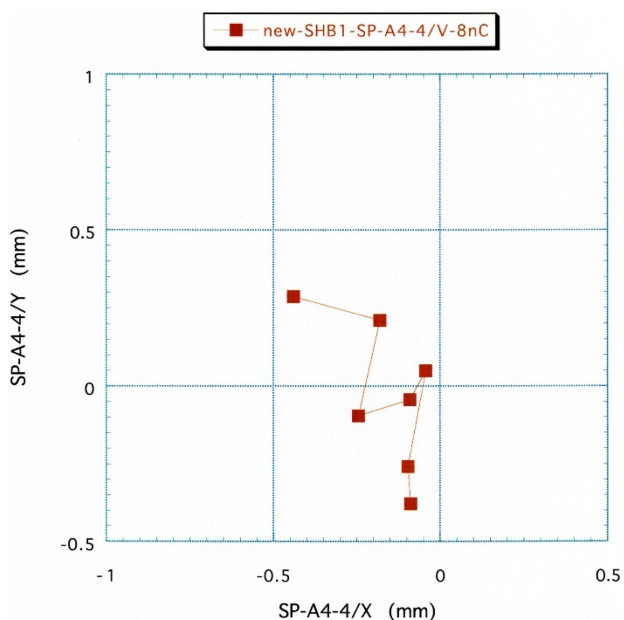


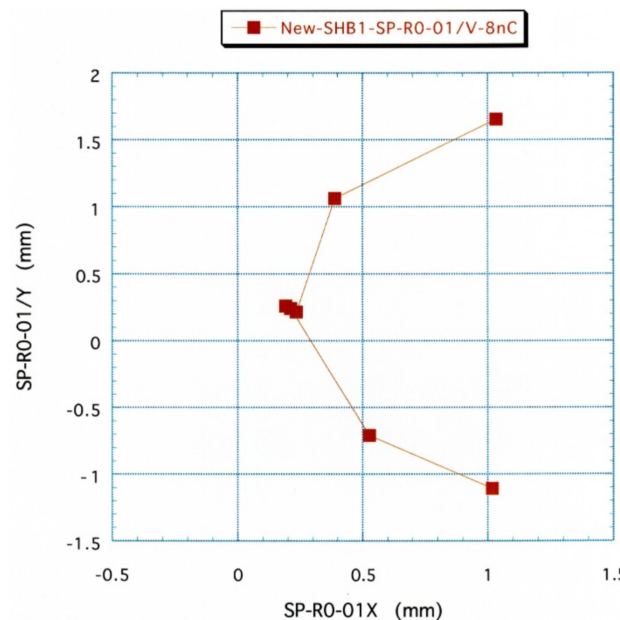


SHB1 RF-phase dependence @8nC

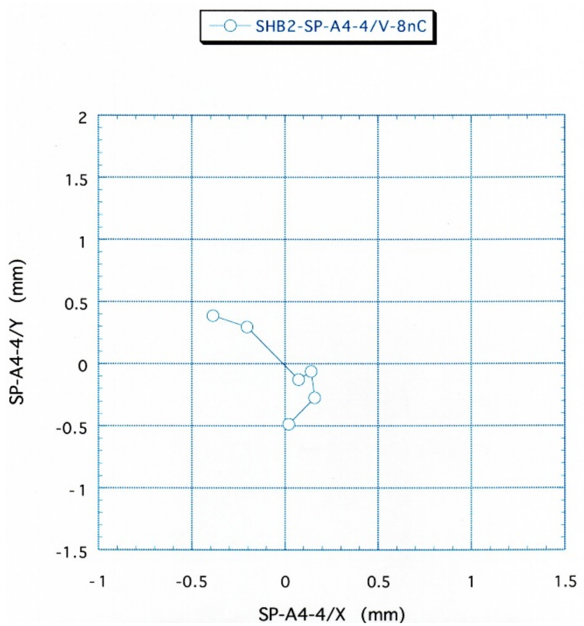


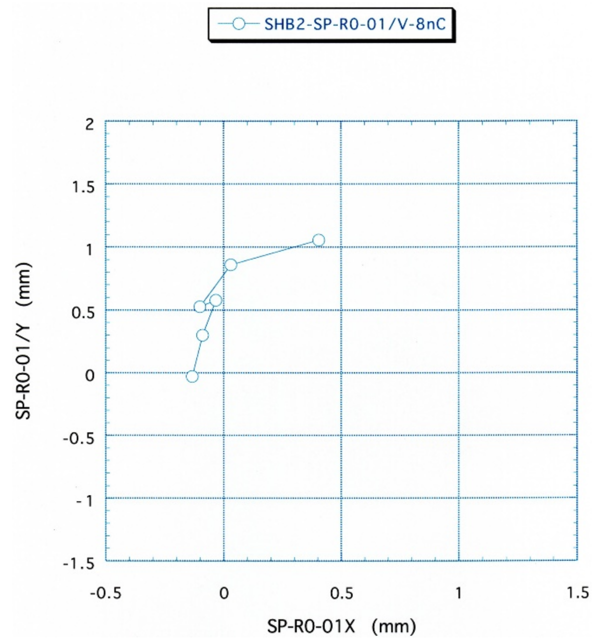


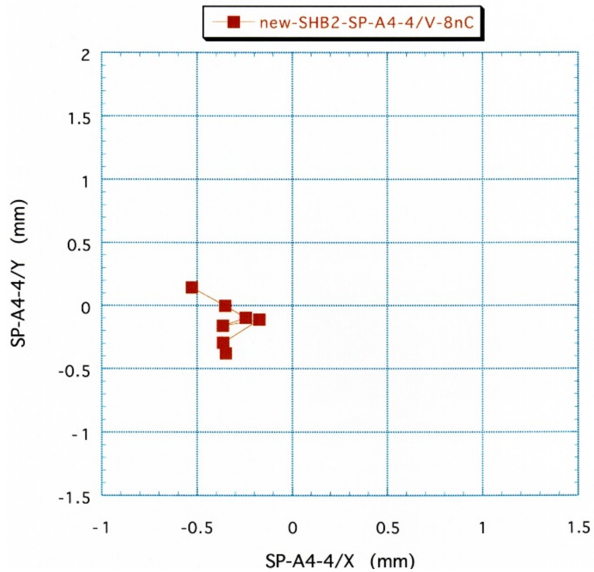


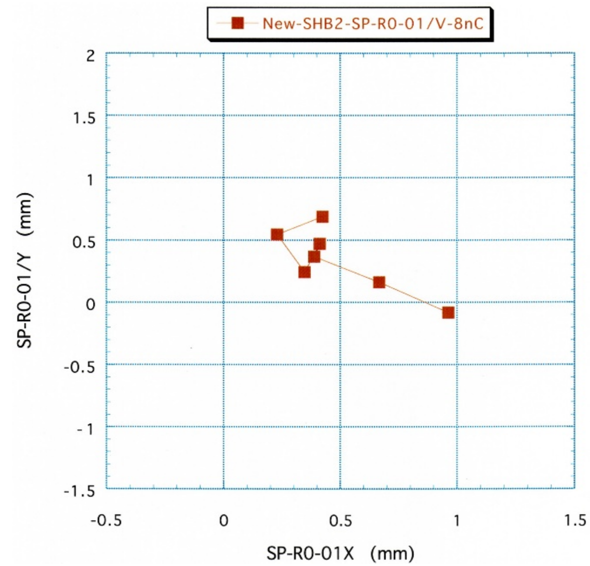


SHB2 RF-phase dependence @8nC

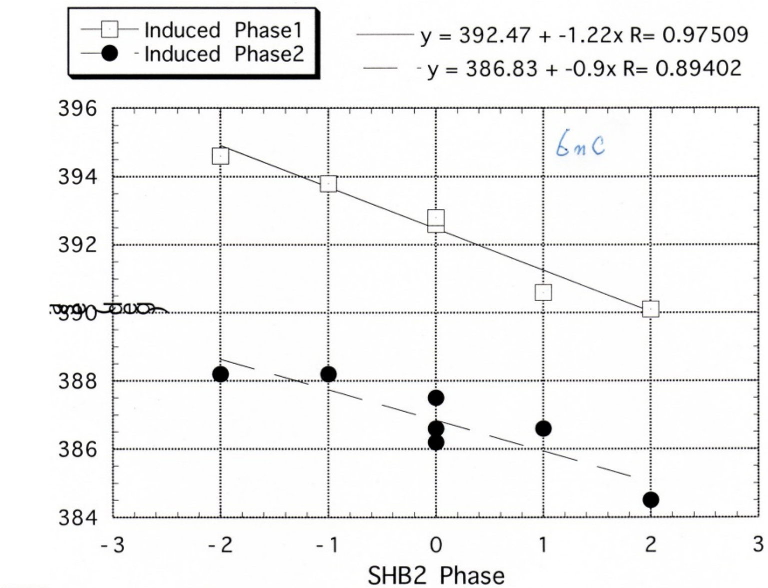


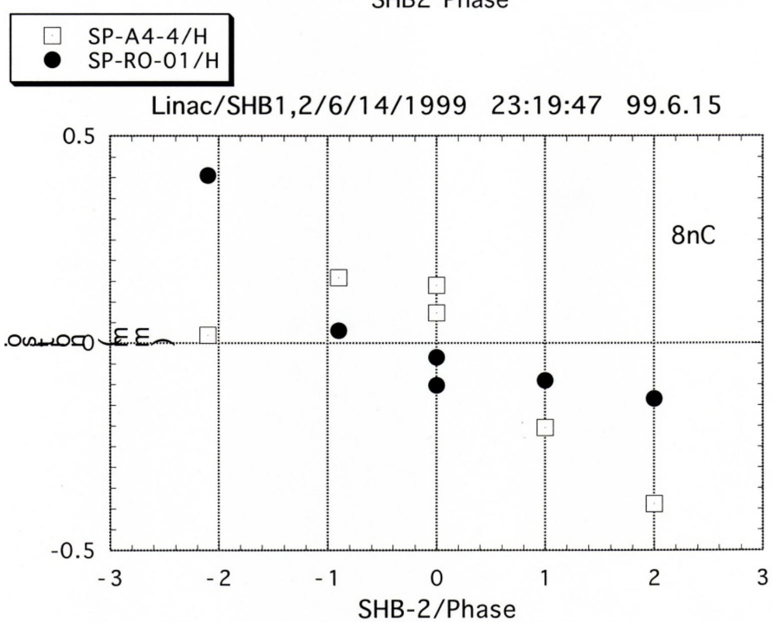




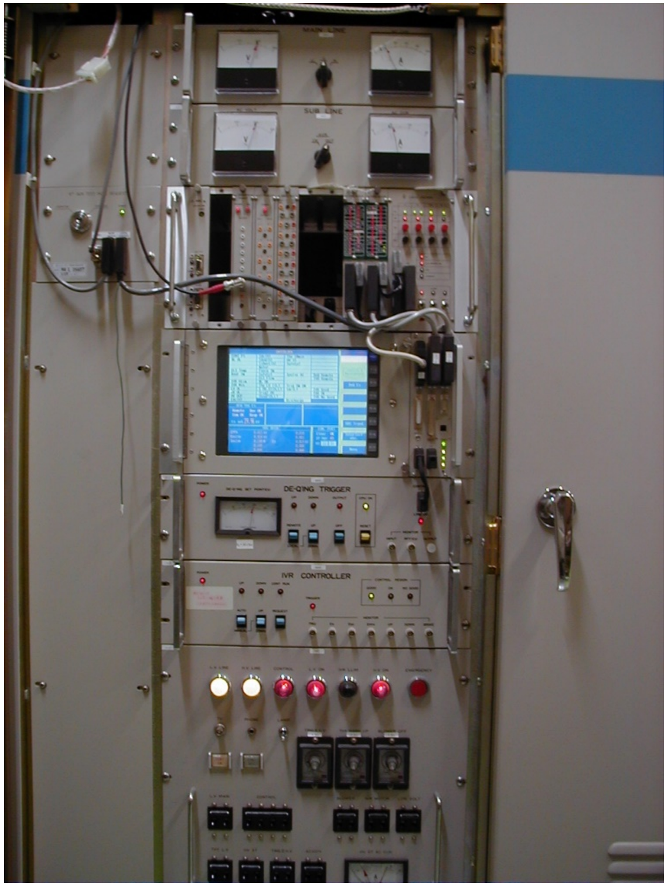


SHB2 RF-phase dependence @6, 8nC



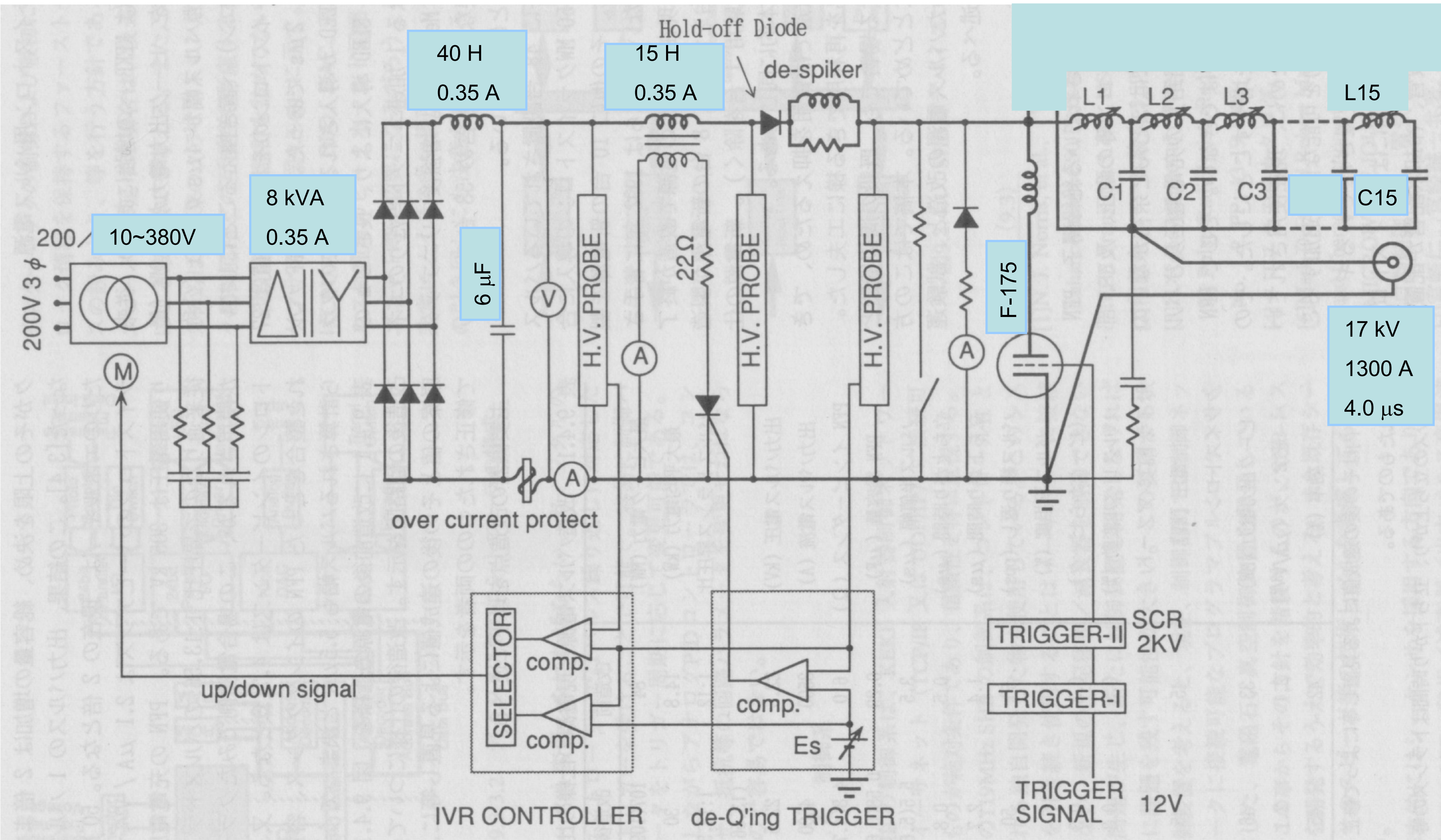


Controller of the gun modulator A

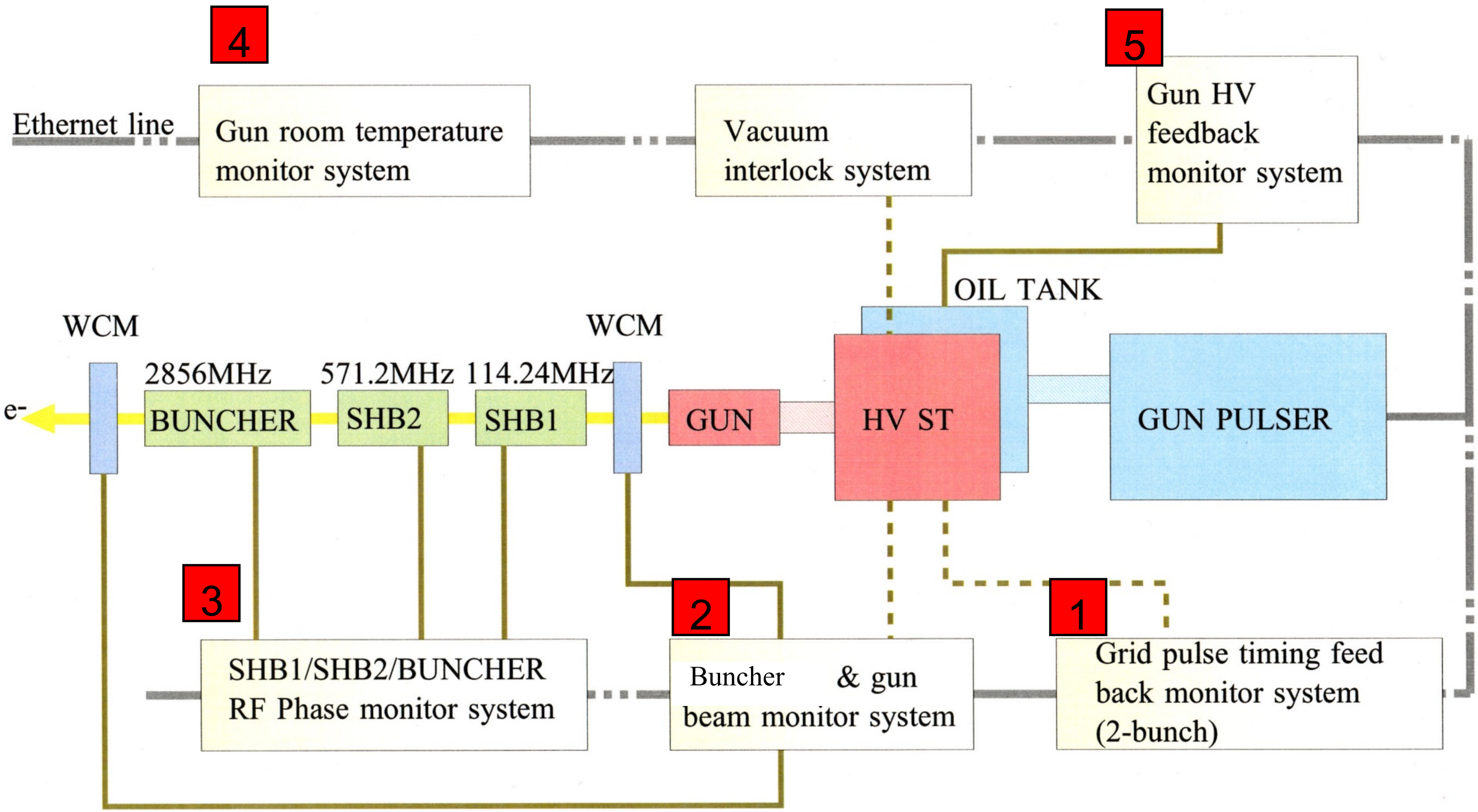


Acceleration voltage	200 kV
Pulse width	4 μs
Pulse repetition rate	50 pps

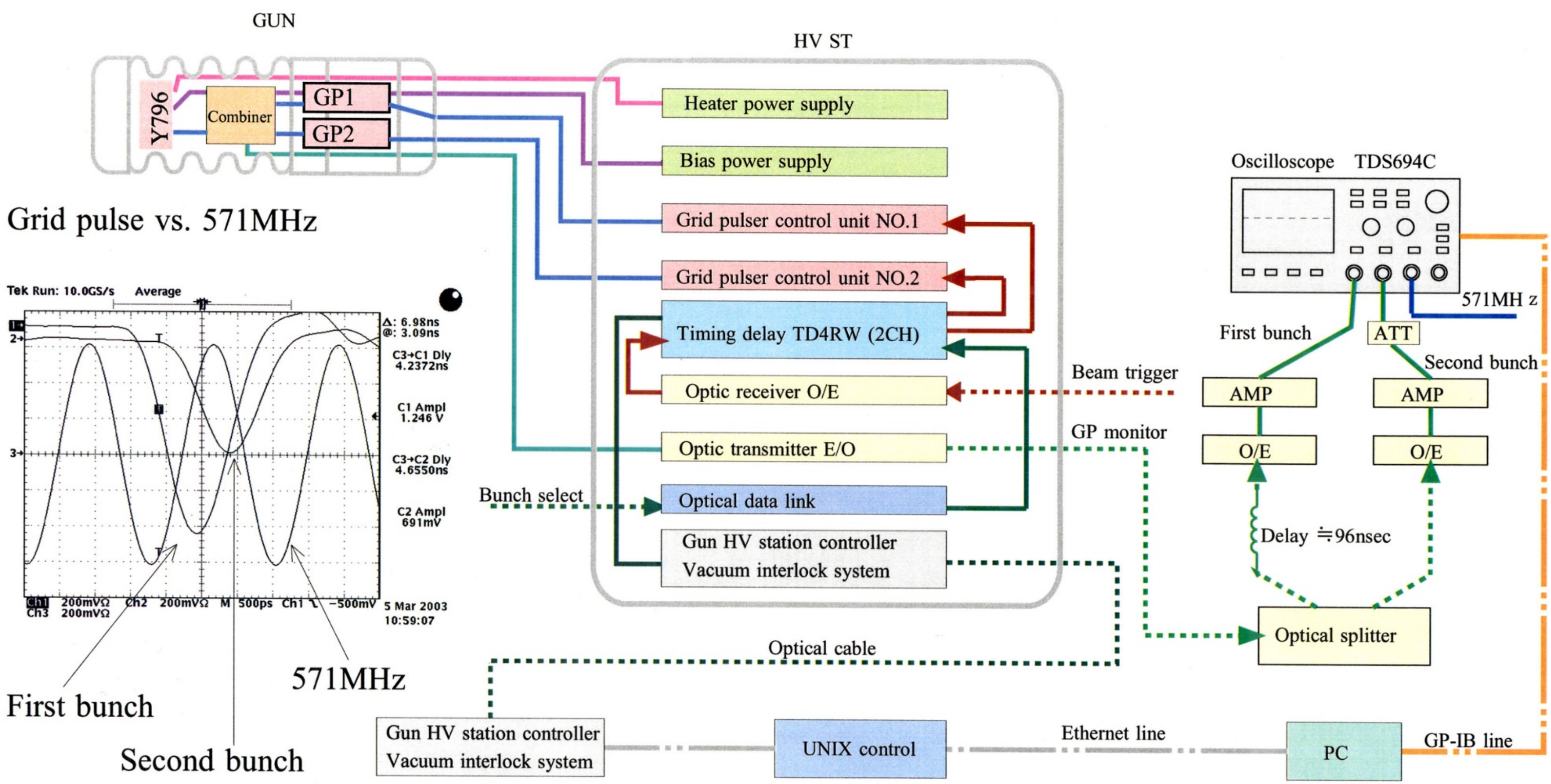
Gun modulator circuit



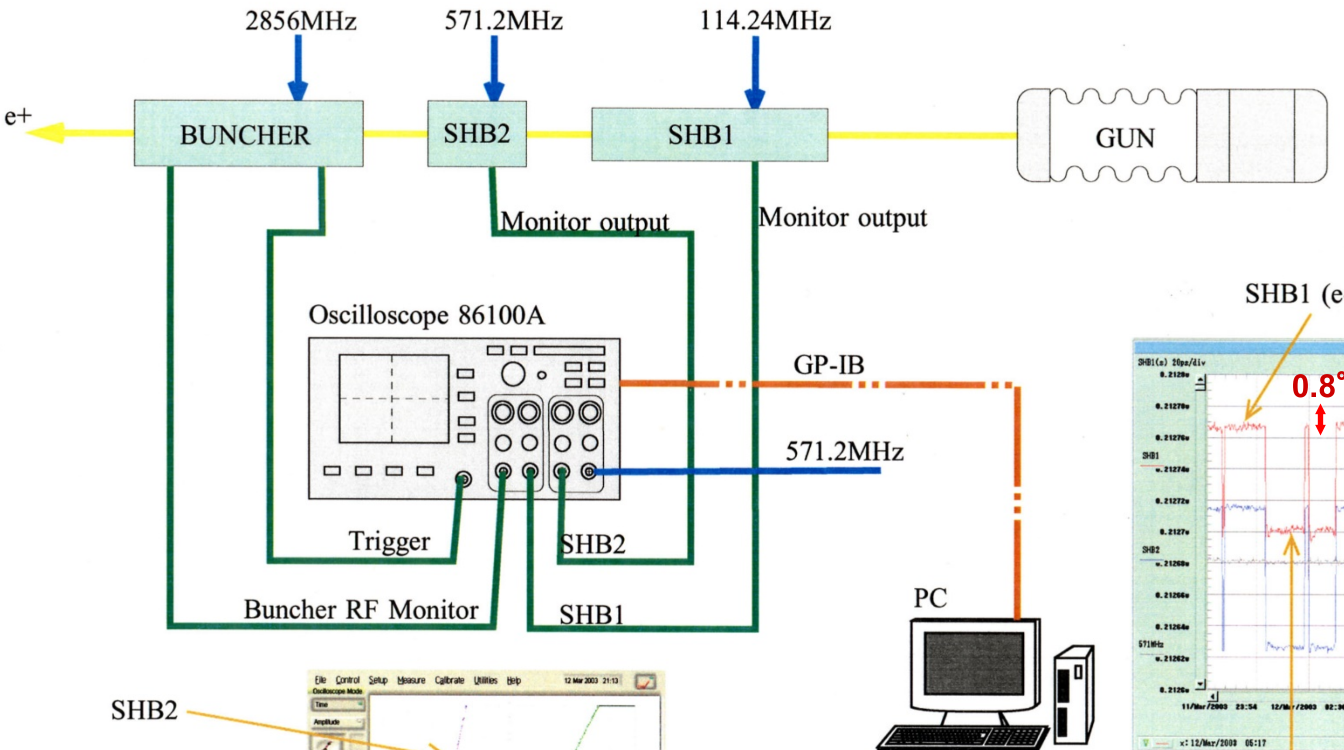
Monitor and feedback systems of gun

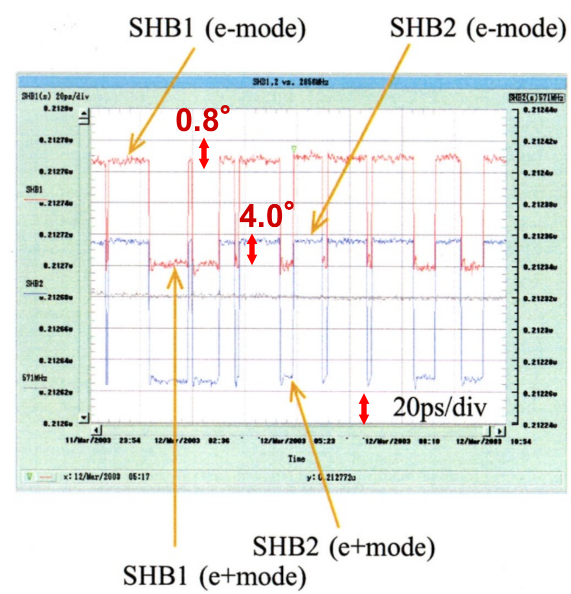


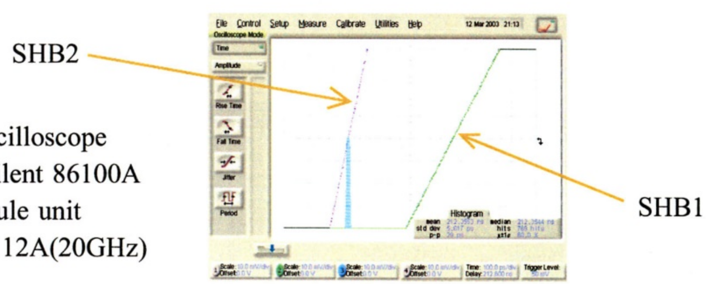
1 GRID PULSE TIMING FEED BACK MONITOR SYSTEM (2-BUNCH)



2 SHB1/SHB2/BUNCHER RF Phase monitor system

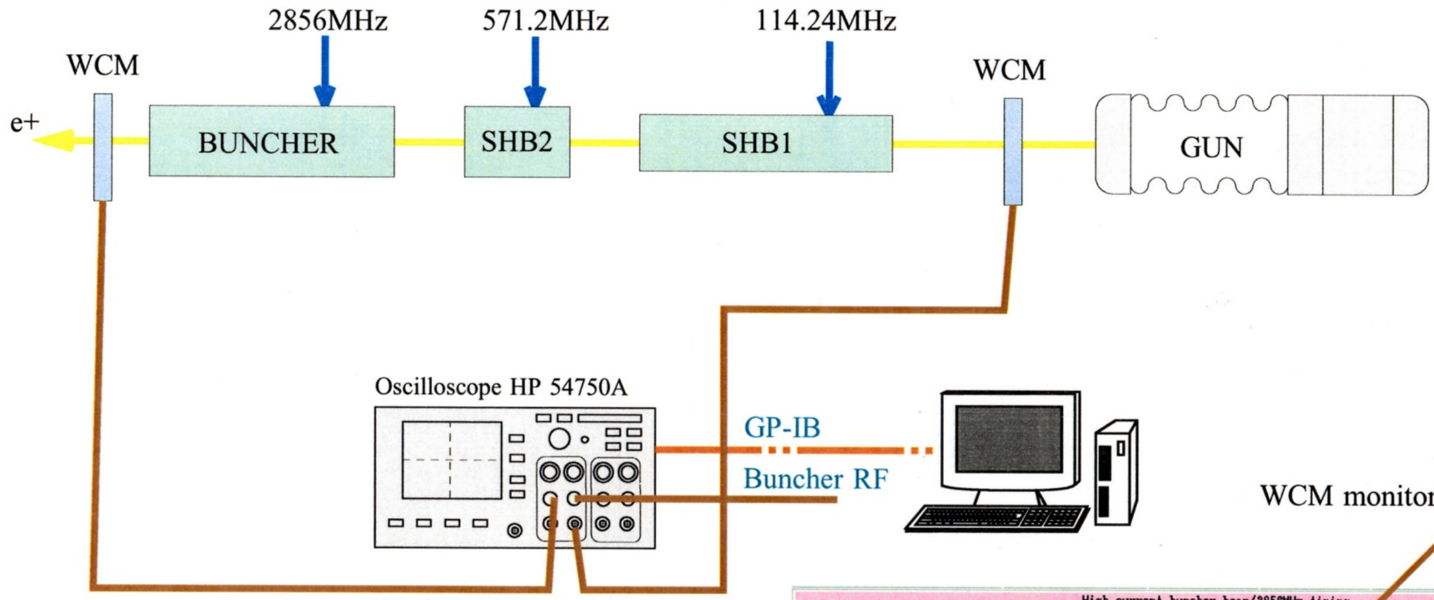






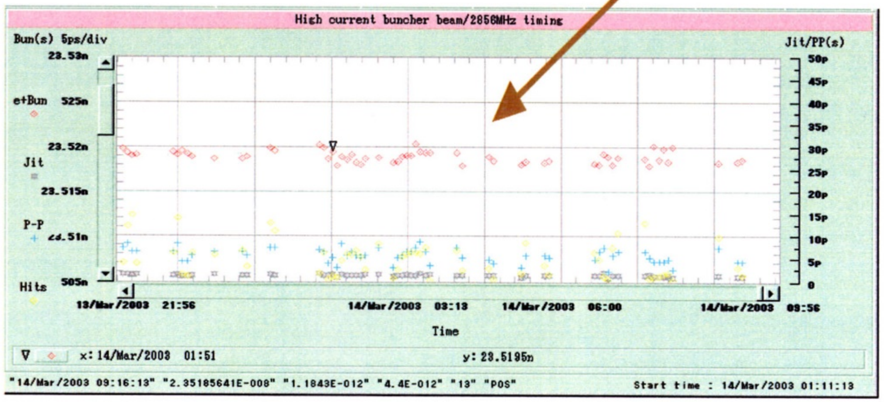
Sampling oscilloscope
:Agilent 86100A
Plug in module unit
:86112A(20GHz)

3 Buncher & gun beam monitor system

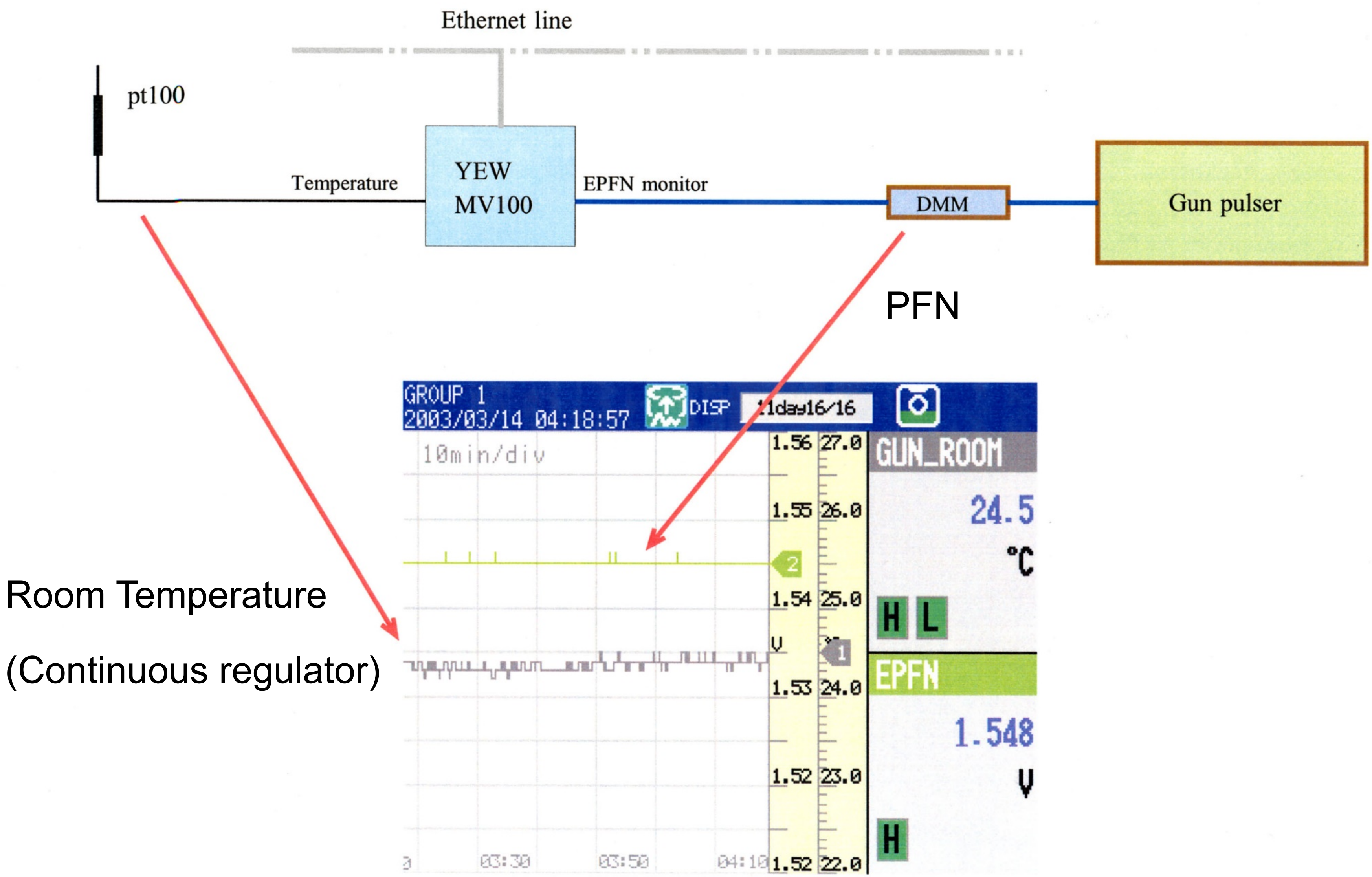


Sampling oscilloscope
:HP 54750A
Plug in module unit
:54753A(20GHz)

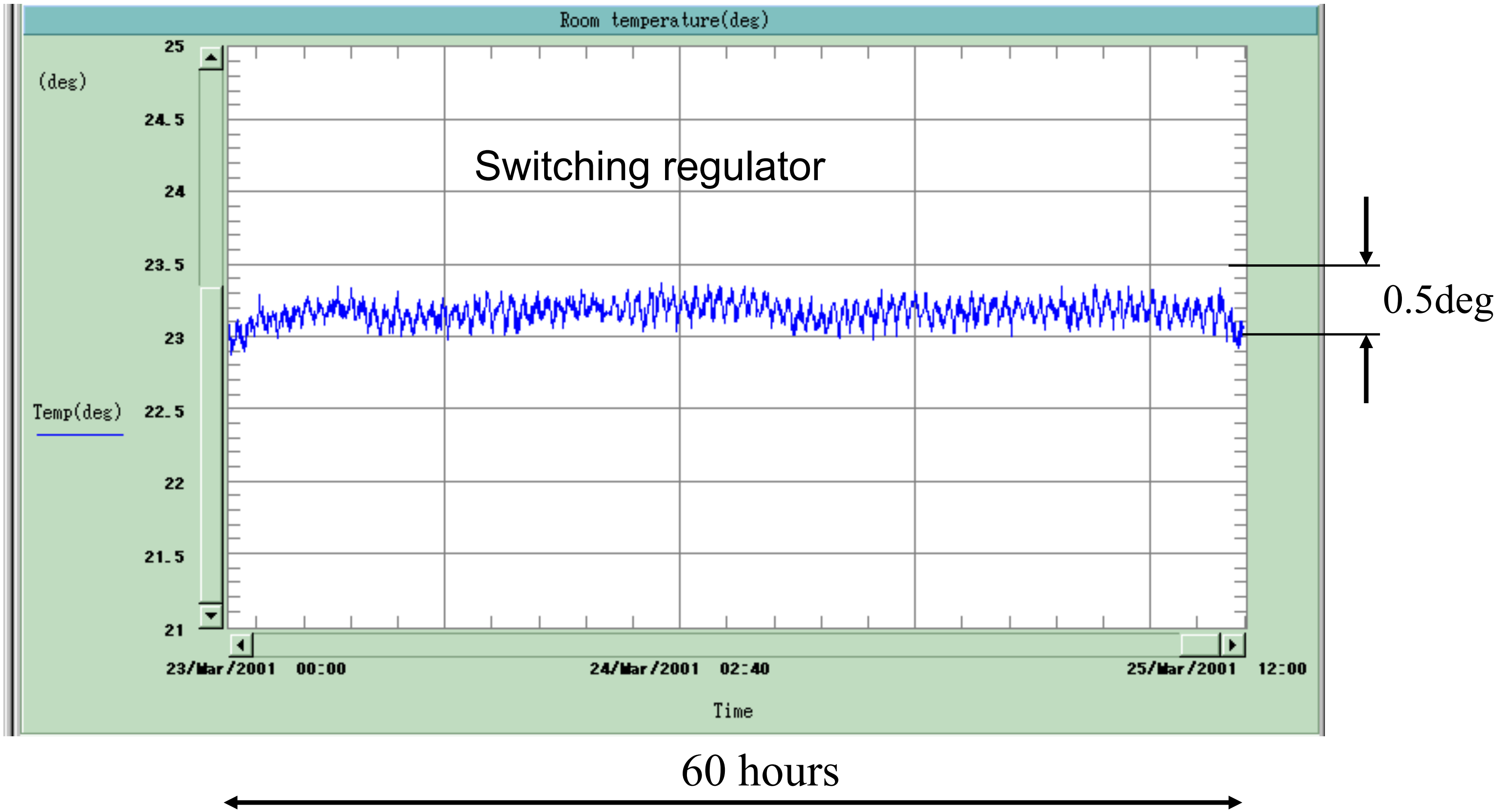
WCM monitor (10nC beam @bucher)



4 Gun room temperature monitor system

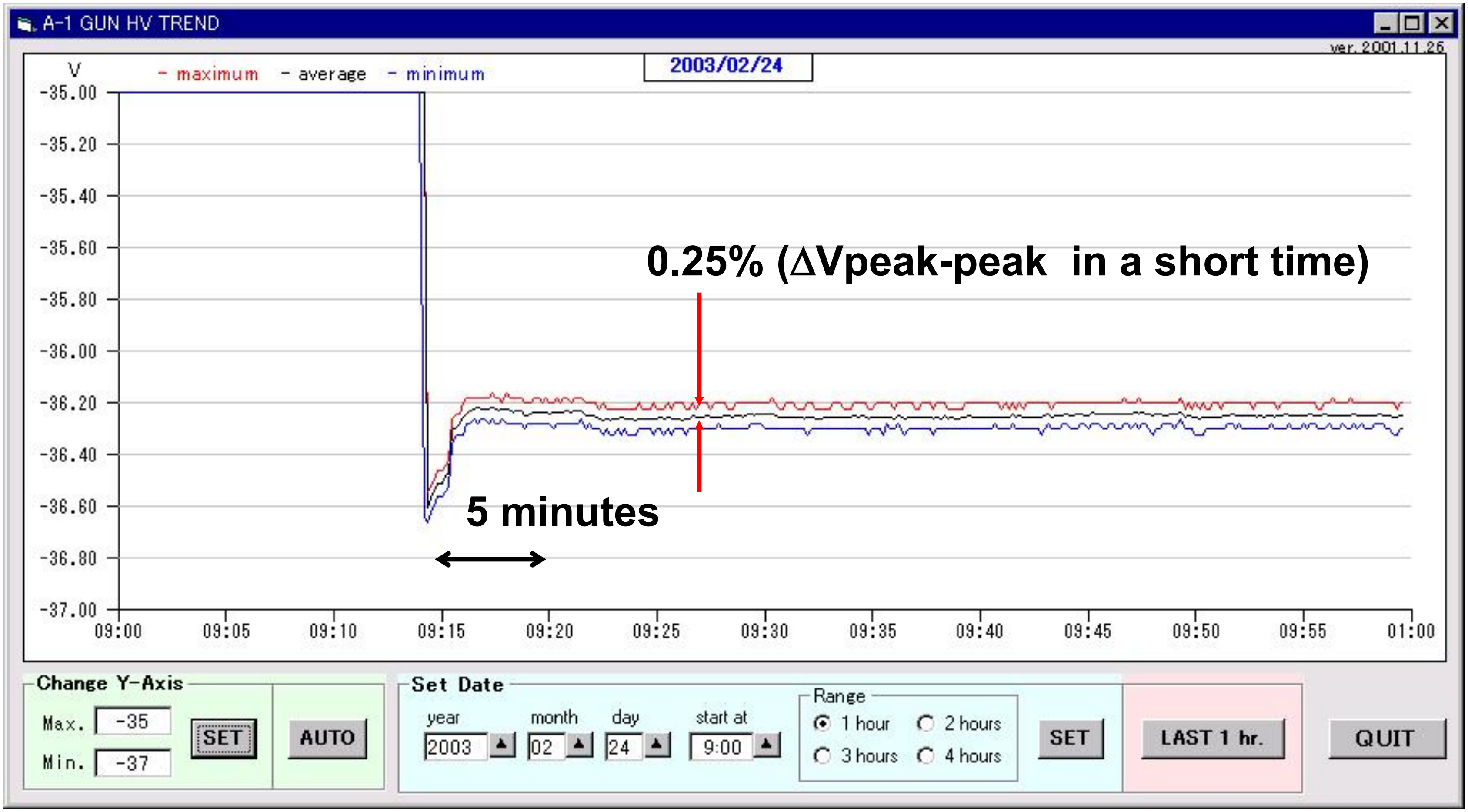


History of Gun Room Temperature

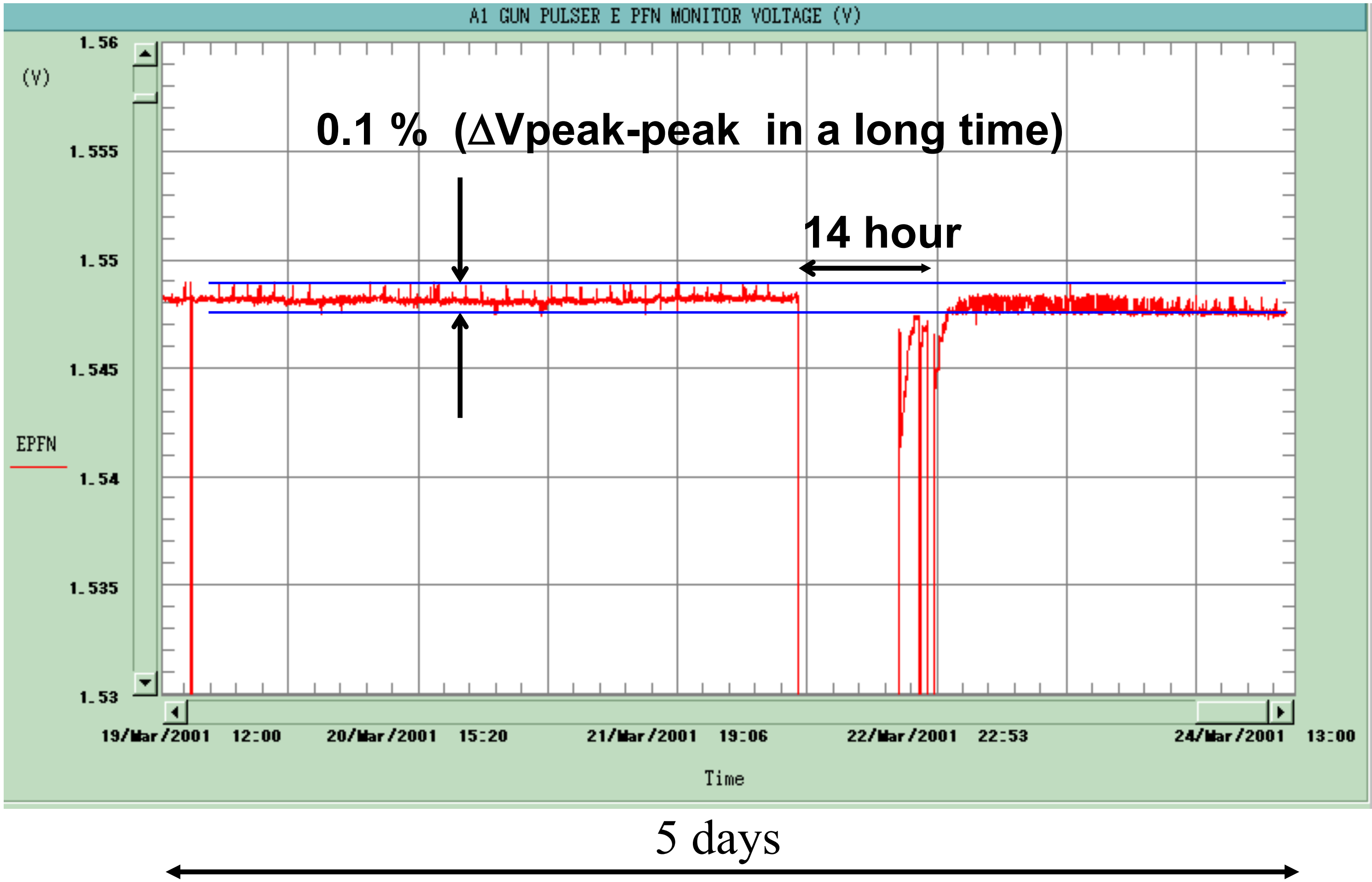


- DMM 3478A
- 2001/03/23 00:00 ～ 2001/03/25 12:00

Gun HV measurement and feedback

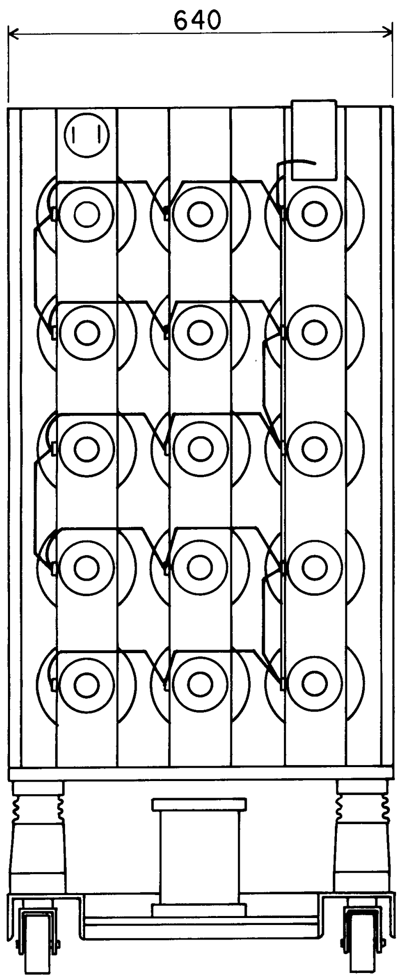


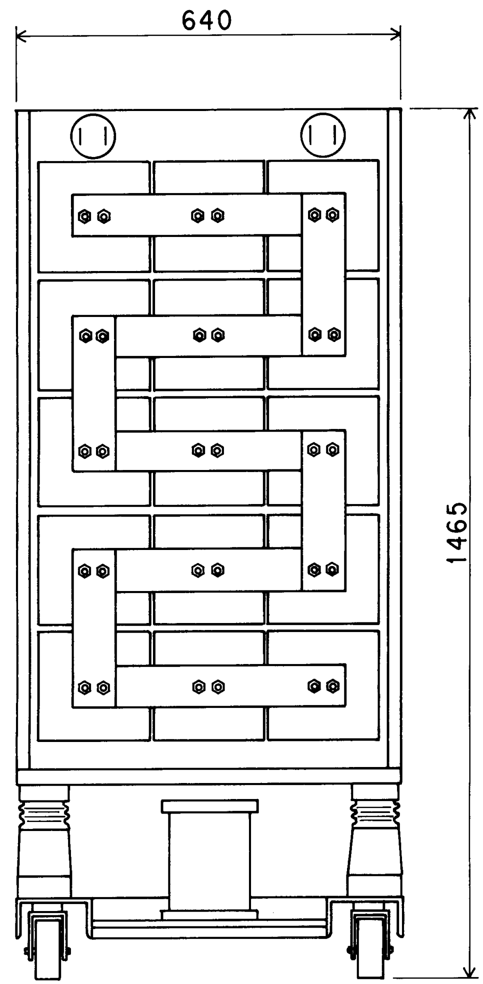
PFN voltage change of the Gun pulser A



- DMM 34401A
- 2001/03/19 12:00 ～ 2001/03/24 13:00

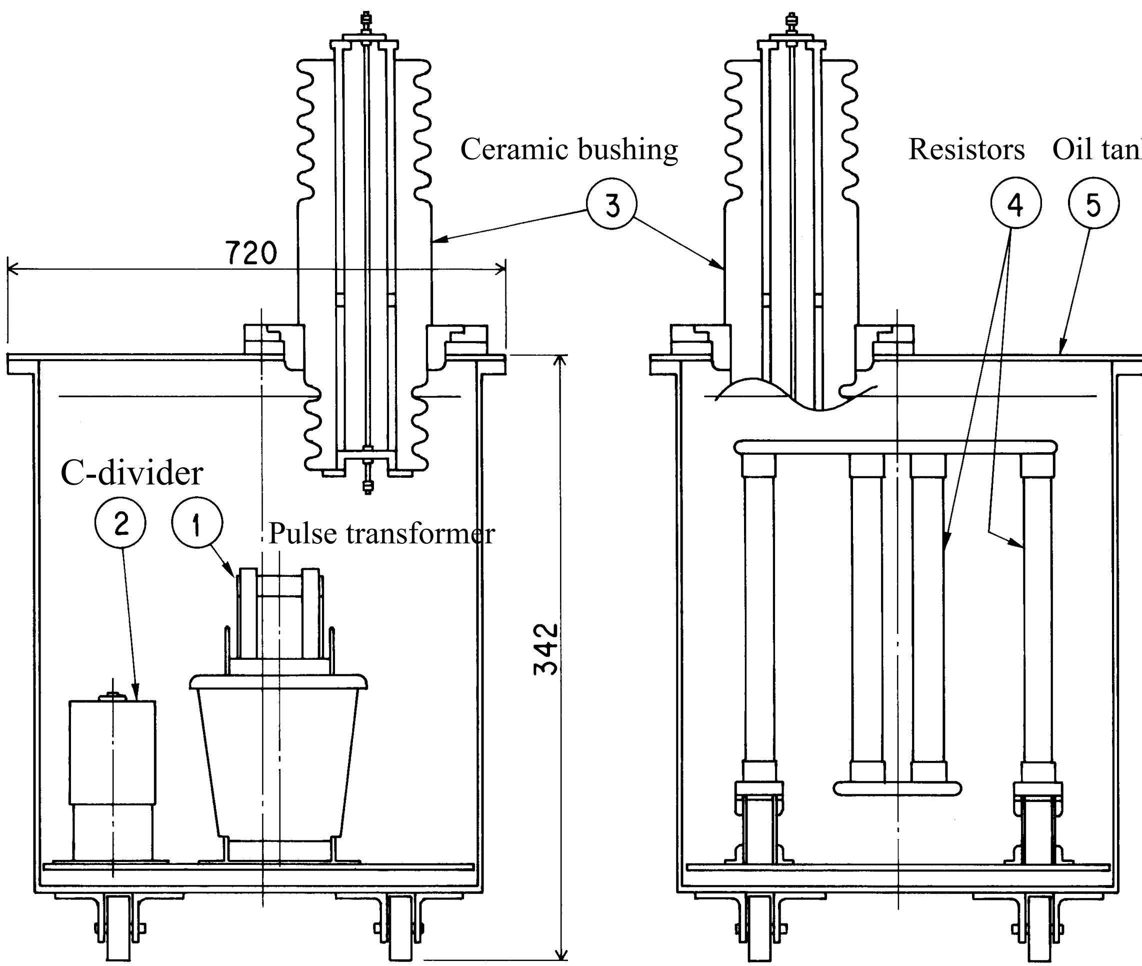
PFN of gun modulators





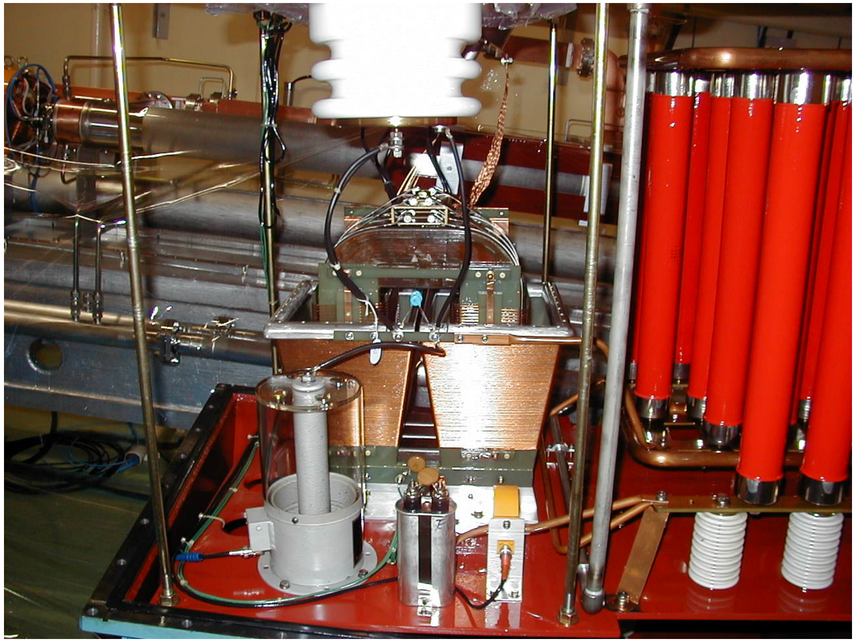
Capacity	**14.6 nF**
Section No.	**3 x 5**
Coil turn No.	**10**

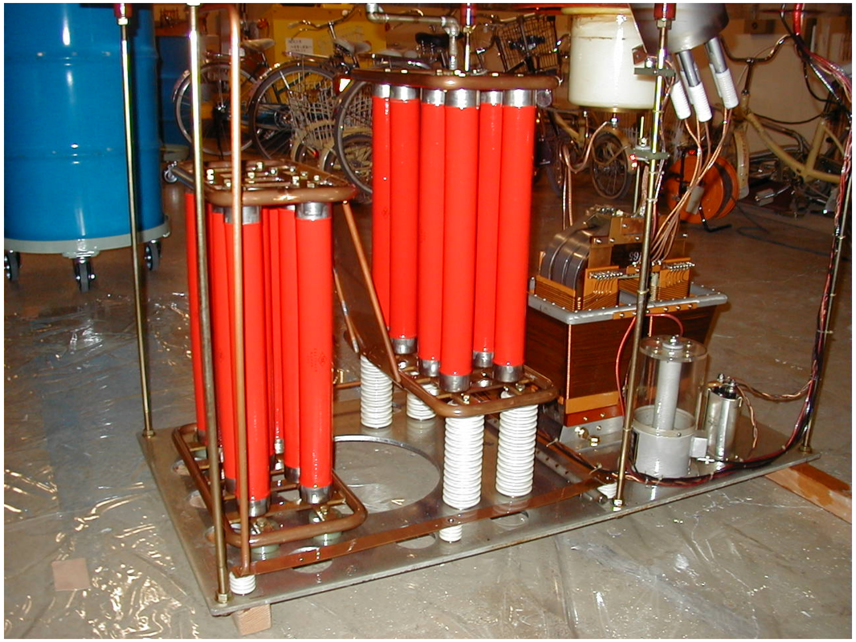
Pulse transformer and oil tank of gun A



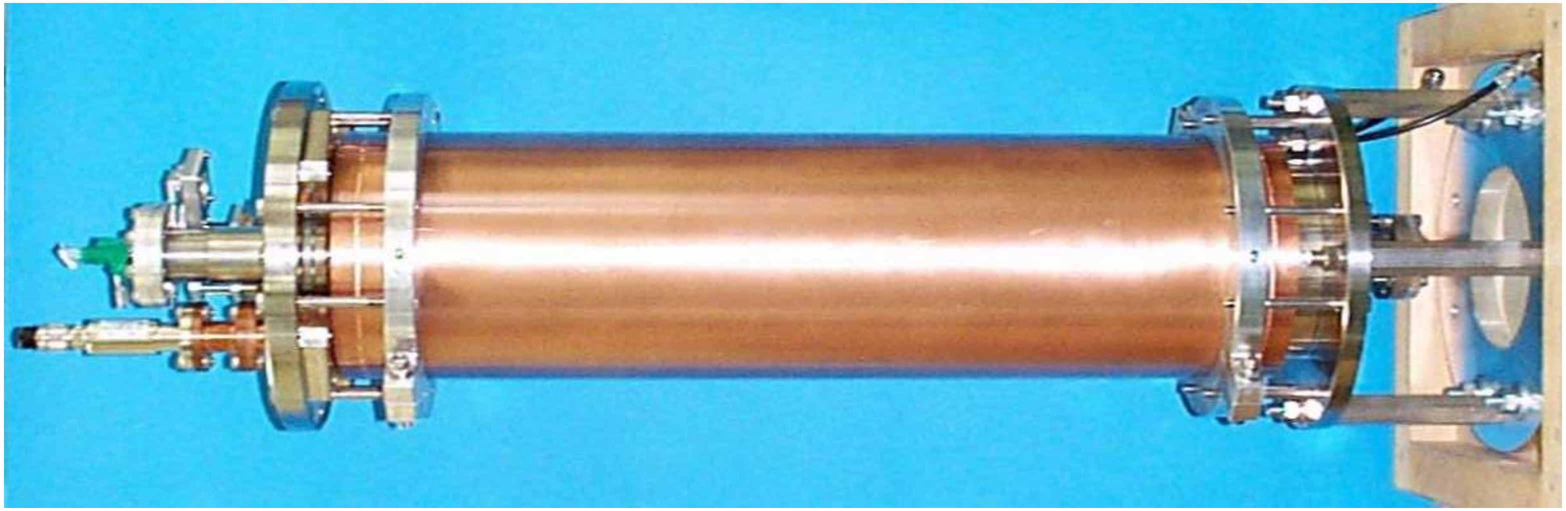
Step up ratio	**1:12**
Secondary impedance	
	1.8 kM
Load resistance	**1.82 kM**
Power consumption	**5 kW**

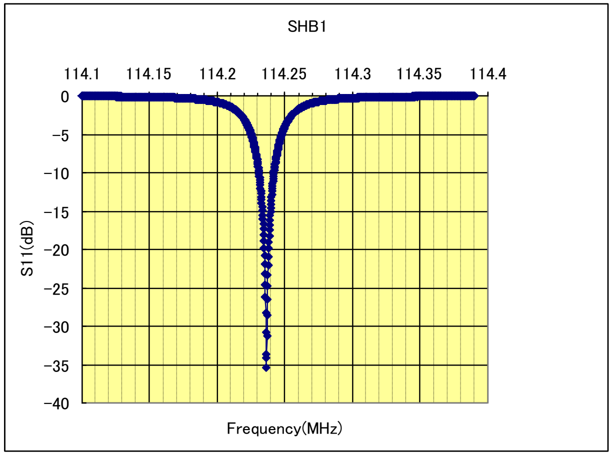
Pulse transeformer & dumy load



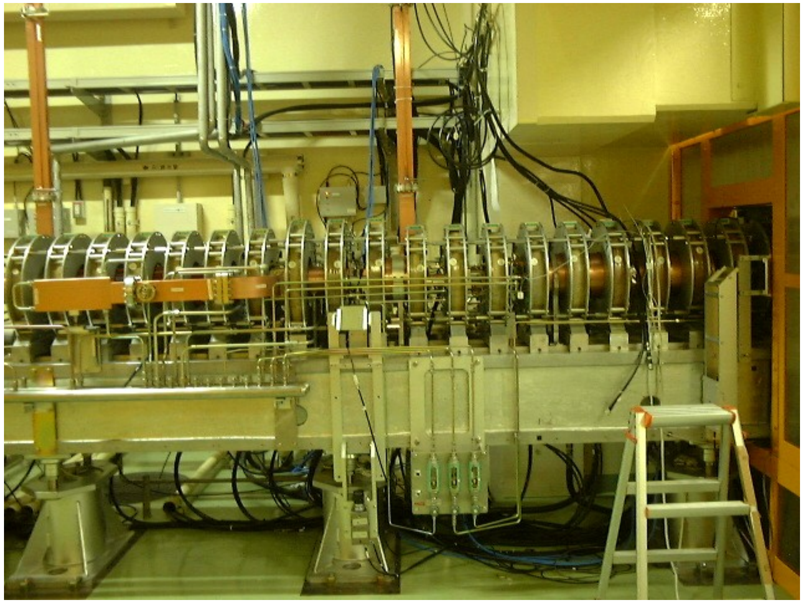


SHB1 of 114MHz





SHB2 of 571MHz



Quantities of Measurement

- Grid pulse amplitude and gun beam amplitude
- Grid pulse timing and gun beam timing
- Buncher beam timing vs. 2856MHz
- SHB1/SHB2/571MHz phase vs. 2856MHz
- Gun pulser E_{PFN} monitor output voltage
- Output signal for e^{+} pulse coil power supply
- Gun room temperature

Summary

Instruments	Tolerance range	Measurement accuracy	Stability*	Digital feed back
Gun beam timing	±45 ps	5 ps	20 ps	○
Gun high voltage	±0.38 %	0.02 %	0.1 %	○
SHB1 phase	±1.1 deg	0.05 deg	0.5 deg	-
SHB2 phase	±1.3 deg	0.2 deg	1.0 deg	-
Buncher phase	±1.7 deg	-	± 1.0 deg	-

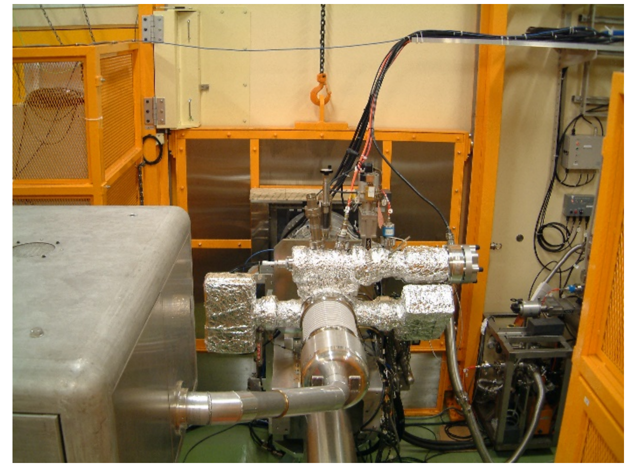
* Long term stability of normal status.

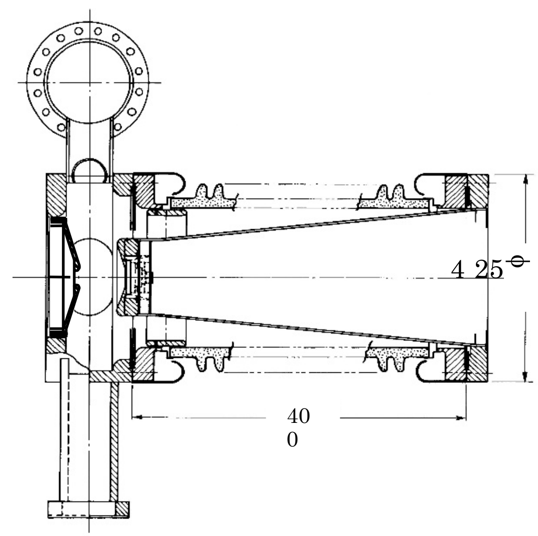
・This system is doing on the reference of a Buncher entrance RF phase.

・Three kinds of RF phases that were directly associated to the electron beam are being measured directly with high accuracy.

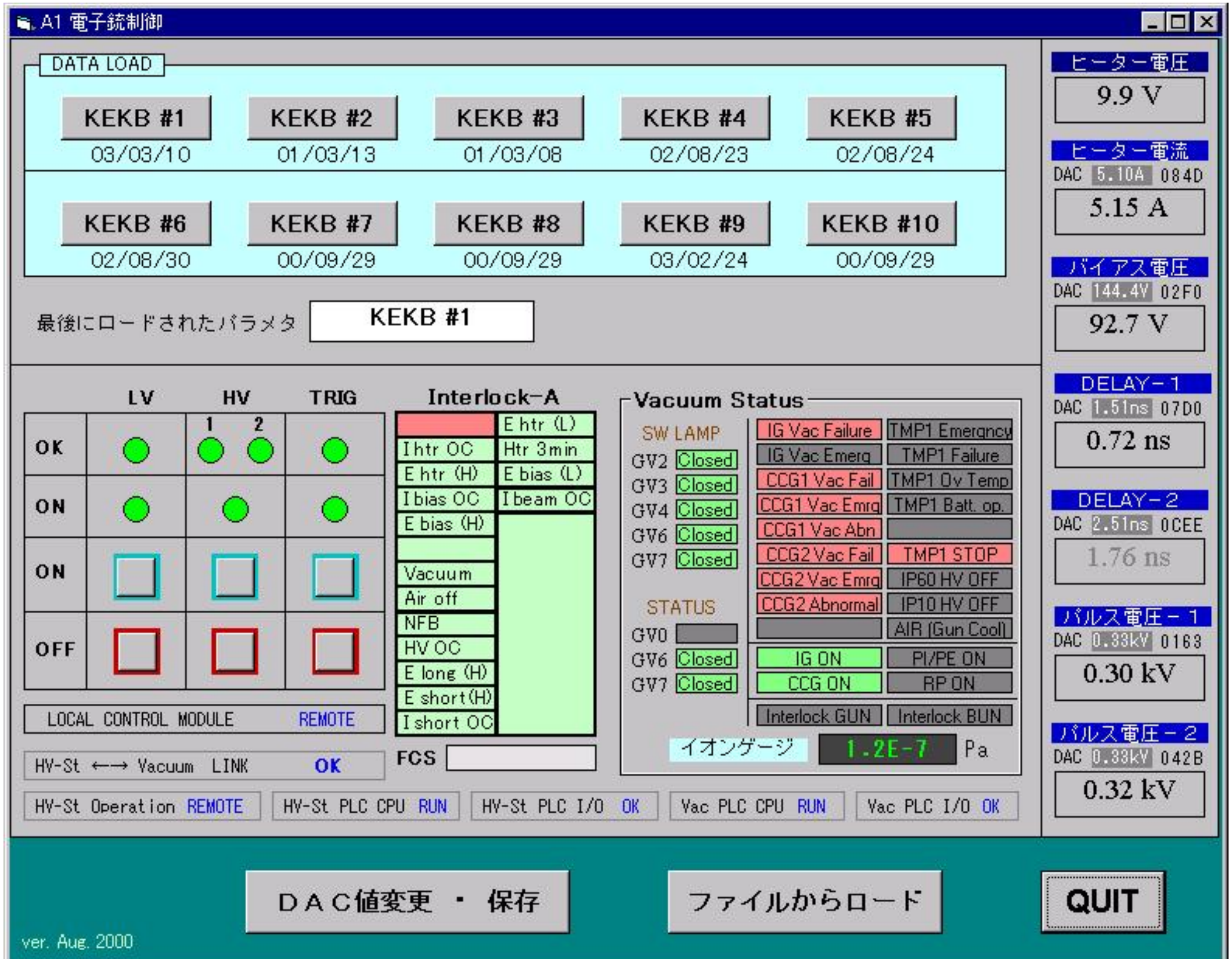
・We are able to discover it right away if there is abnormality in these measurement data quantity.

・We aim for a more stable beam from now on, and be thinking digital feed back of SHB1/2 by using the measured value of this system.

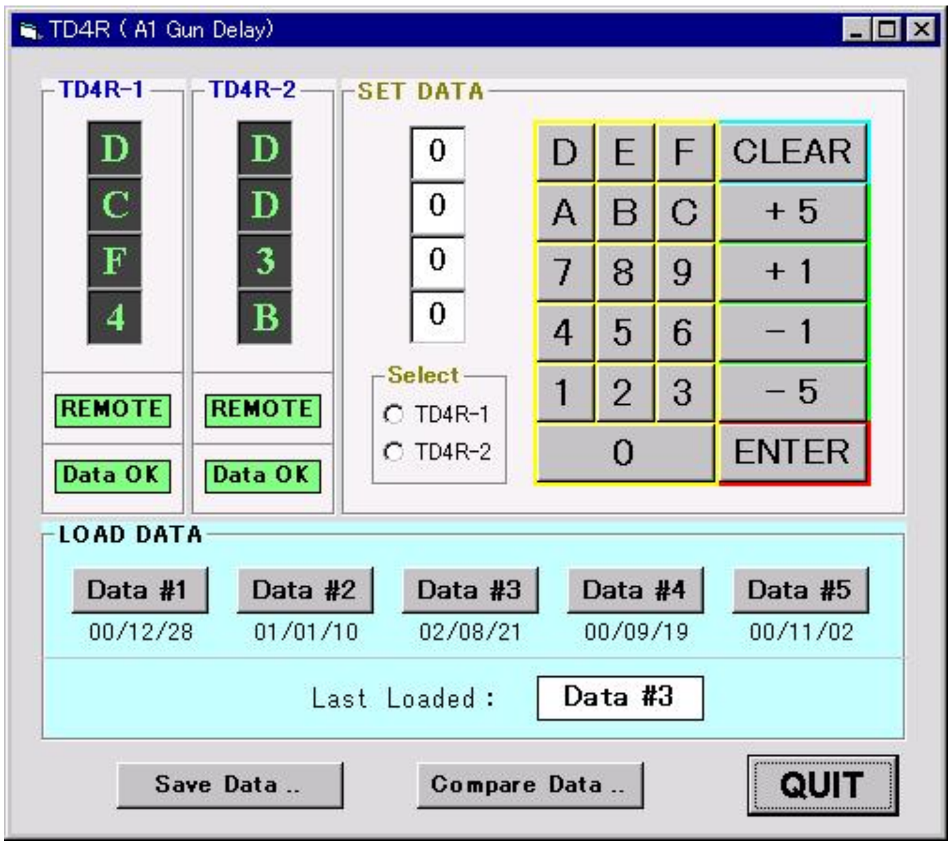


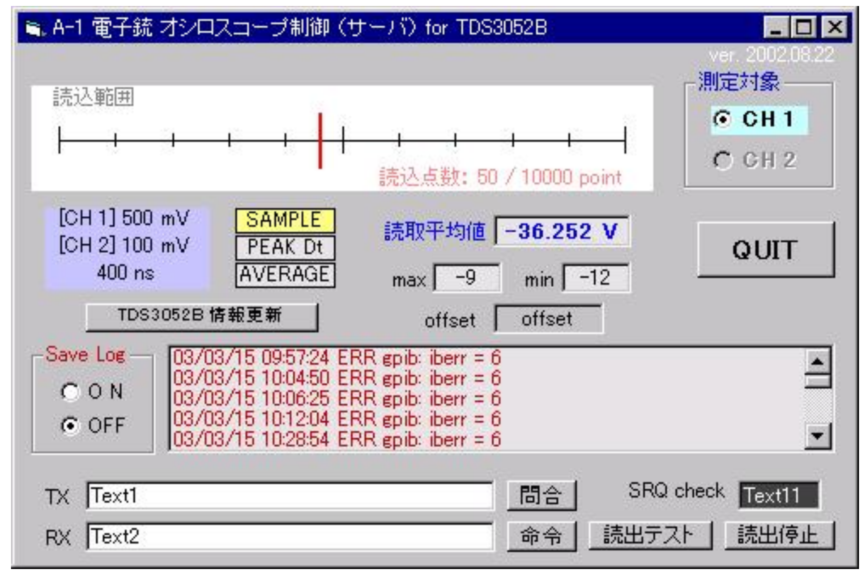

4 25 φ
40
0

Gun control panel 1



Gun control panels 2

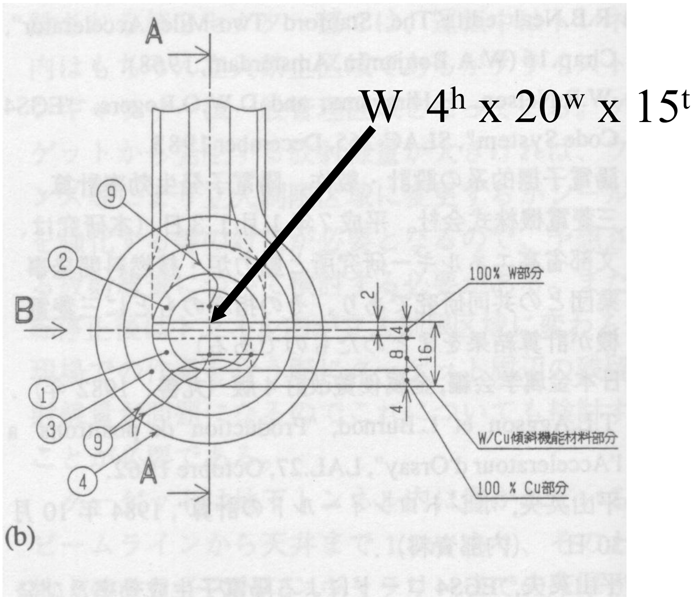


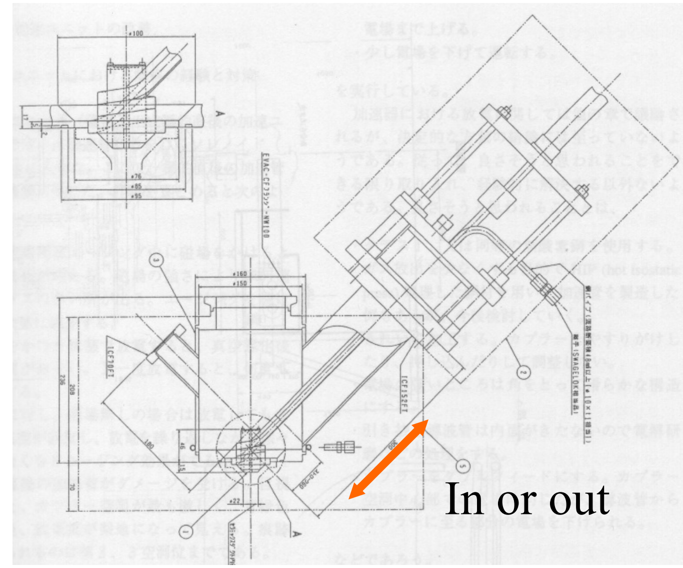


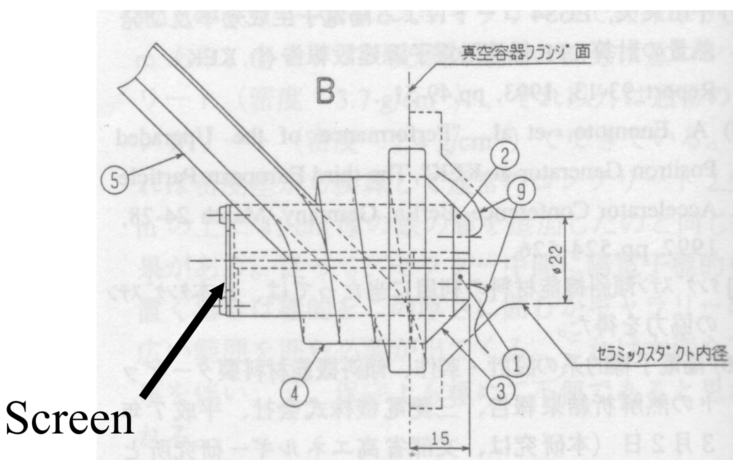
Gun HV measurement

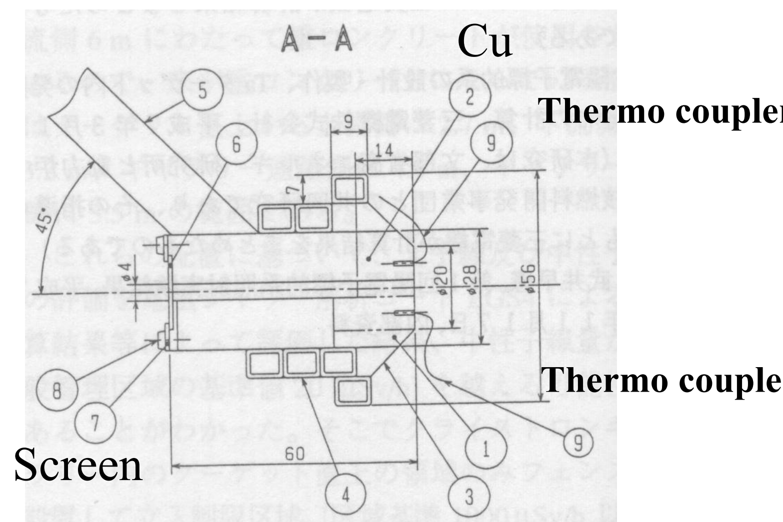
TD4 delay 2-ns step

Structure of the positron production target

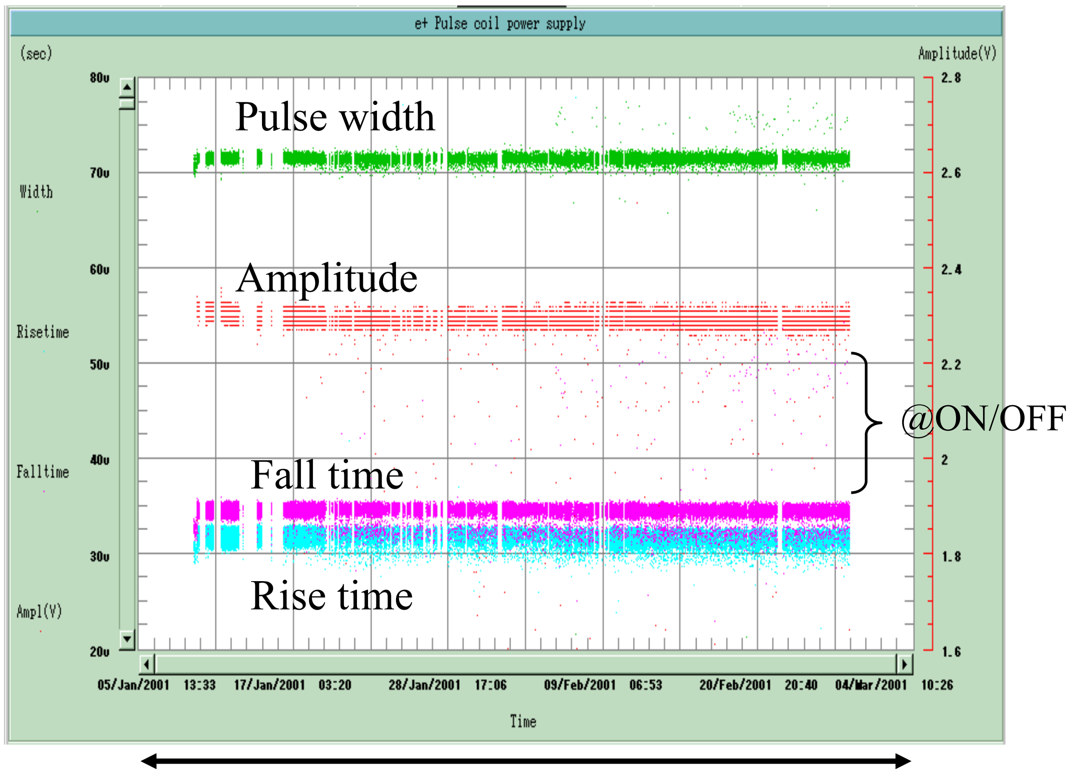






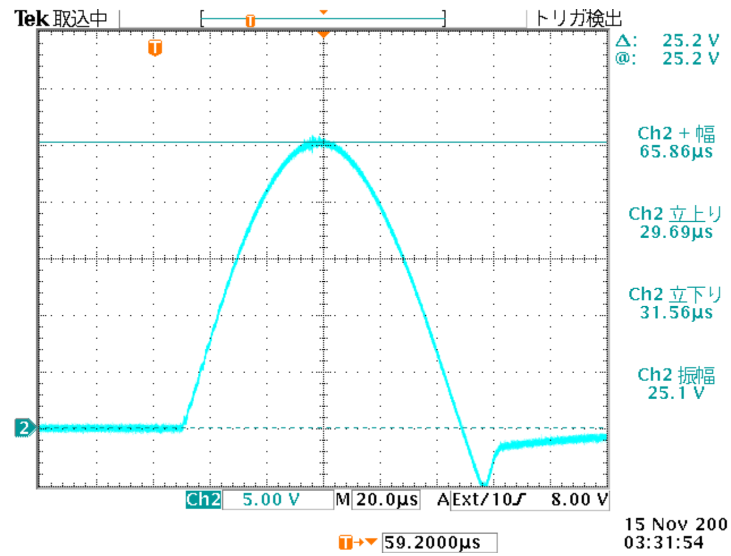


History driving pulse for e+ Focusing Pulse Coil



58days

2001/01/09 11:00 ～ 2001/02/27 21:00



Digital Oscilloscope

TDS3032 (Tektronix)

Two-bunch beam generation for KEKB

- **Two-bunch beams have been required to reduce injection times into KEKB rings.**
- **Especially for the LER it is being inevitable to increase positron intensity as the stored beam increases. Two-bunch beam acceleration is one of the methods to meet the requirement. In order to accelerate and accumulate the beams successfully, it is at least necessary to satisfy the following conditions: 1) each bunch length should be as short as the present single bunch, that is less than 10 ps, and 2) their time interval should be 97.29 ns that is a period of the common operation frequency between the linac and KEKB rings. Wake field effects are strong for high intensity beams. In normal acceleration sections beam energy of each bunch is thought to be controllable by means of changing acceleration timing with respect to RF pulses. In the bunching section, however, this technique is not useful. To obtain independent operation freedom we developed a system that produces a two-pulse beam from an electron gun each of which intensity and timing are independently changeable. Beam test results are presented as well as the system configuration and performance.**