IP feedback based on the triplet of IPBPMs

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19th ATF project meeting, LAL, Orsay, France, 13-15 January 2016

Goal - 2

B. Control of the beam position

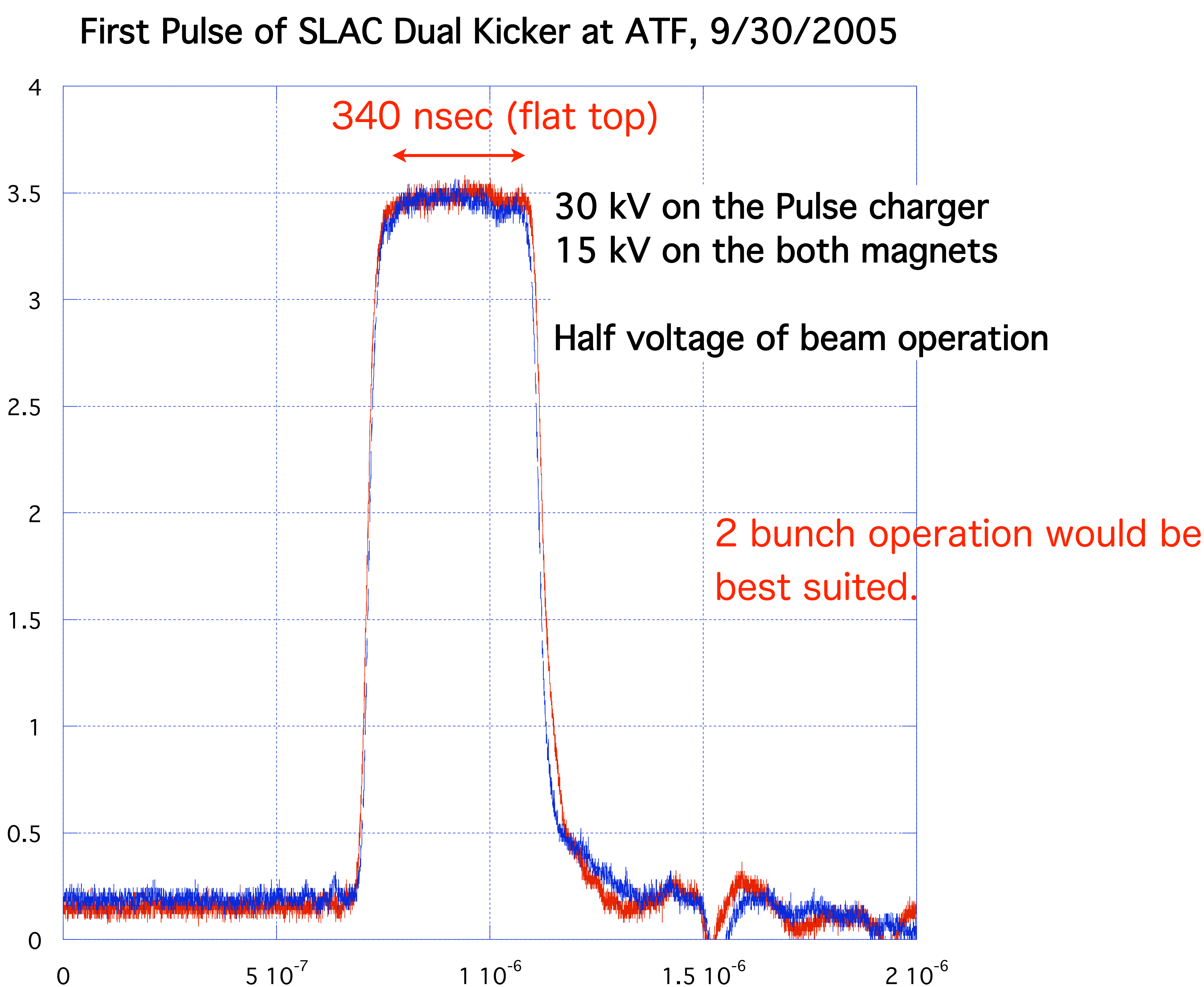
B1) Demonstration of beam orbit stabilization with nano-meter precision at IP.
(The beam jitter at FFTB/SLAC was about 40nm.)

B2) Establishment of beam jitter controlling technique at nano-meter level with ILC-like beam
(2 or 3 bunches)

Requirements

Goal	**ATF-EXT**	**ATF2**
I	Jitter < 30% of σ_y $\gamma \varepsilon_y$=(4.5 → 3)x10^{-8}m	BSM (laser in higher mode) BPMs with 100nm res. at Qs Power supplies of < 10^{-5} Rigid support of Final Q ,BSM
II	Jitter < 5% of σ_y (2nm jitter at FP)	BPM with < 2nm res. at FP Intra-bunch feedback for ILC style beam

Extraction Kicker Pulse

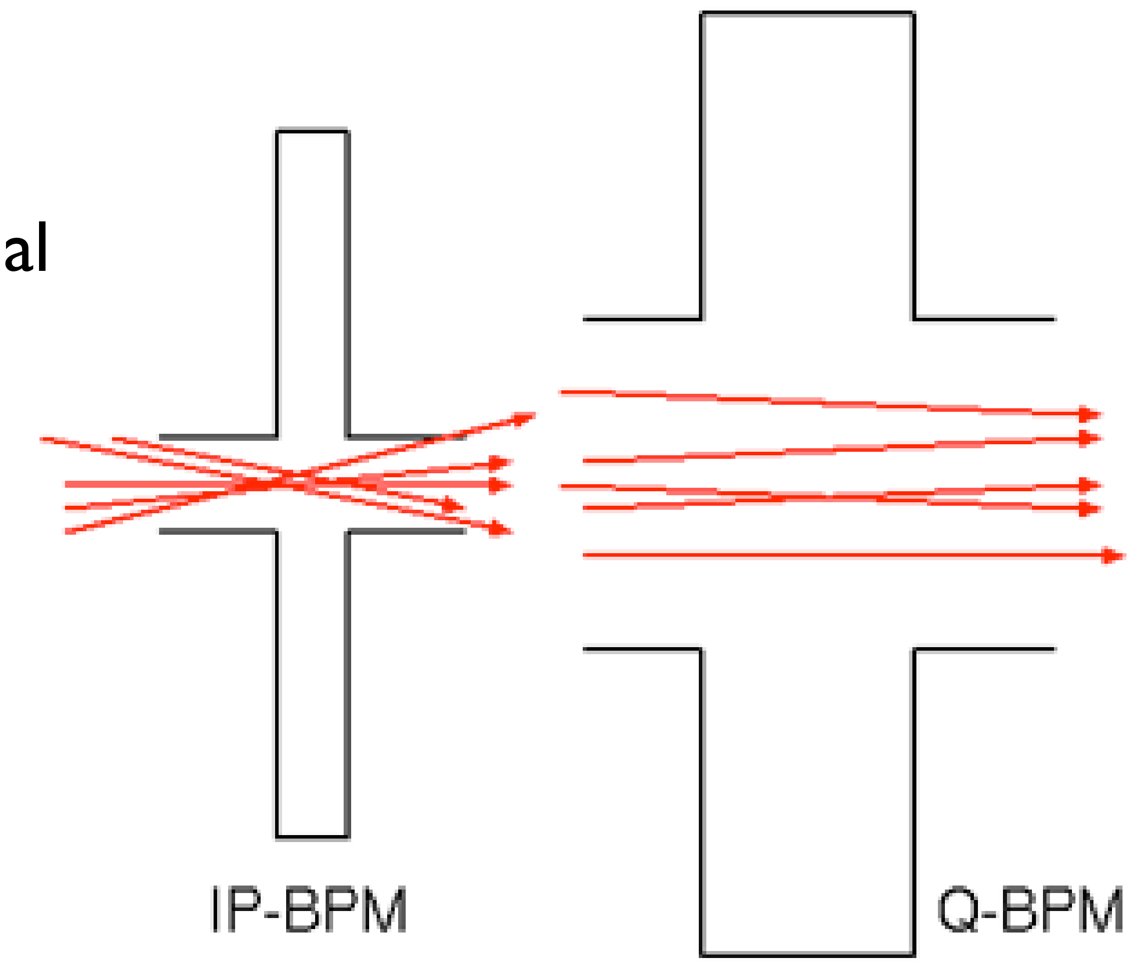


1. Resolution :IPBPM (2nm)

Starting point of the design work

Y.Honda, 1st ATF2 project meeting

- Challenges
  - ultimate y-direction resolution
    - 1 nm signal > thermal/amplifier noise
  - under angle jitter condition
    - 100 urad angle signal < 1 nm position signal
  - under large x jitter
- Basic idea
  - thin gap to be insensitive to the beam angle
  - small aperture to keep the sensitivity
- Additional idea
  - separation of x and y signal
  - higher coupling to have stronger signal



position/angle =f L^2

4 : 1

Position to angle sensitivity

- 0.0032 m/rad in close agreement to Tauchi-san's summary of results:

Estimation (IPBPM)	frequency	$k = \omega / c$	effective cavity length	angle/position		
	Hz		m	ratio: θ / δ	$\theta = 100$urad	if $\theta = \sqrt{\varepsilon / \beta} = \sigma'(IP)$
		effective Length=	0.0165	m/rad	σ'(IP)=	3.464.E-04
Nakamura	6.426.E+09	1.347.E+02	0.0165	3.08.E-03	3.08.E-07	1.07.E-06
Honda	6.426.E+09	1.347.E+02	0.0165	3.08.E-03	3.08.E-07	1.07.E-06
Mafia calculation				2.60.E-03	2.60.E-07	
Alexy	6.426.E+09	1.347.E+02	0.0165	3.34.E-03	3.34.E-07	1.16.E-06
Alexy:numerical int.						
Kubo	6.426.E+09	1.347.E+02	0.0165	3.34.E-03	3.34.E-07	1.16.E-06

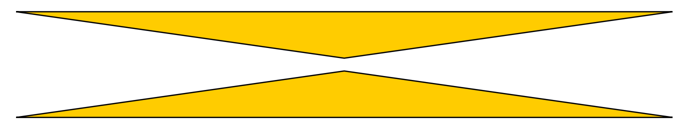
2. Wakefield

Geometric Wakefields: P.Tenenbaum, LCC-0101, August 2002

IPBPM

Depend on gap height, gap width, taper angle, bunch length
θ_T σ_z
Complex theory with 3 regimes

Rectangular collimator



"Shallow Taper":

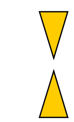
half-width

$$A = \frac{\sqrt{\pi}}{2}\frac{N r_e}{\gamma}\frac{\theta_T h}{\sigma_z r^2}$$

half-gap

$$\sqrt{\frac{\theta_T r}{\sigma_z}} << \frac{r}{h}$$

$$A = 2.7\frac{N r_e}{\gamma}\sqrt{\frac{\theta_T}{\sigma_z r^3}}$$



"Steep Taper:"

$$A = \frac{N r_e}{\gamma}\frac{1}{r^2}$$

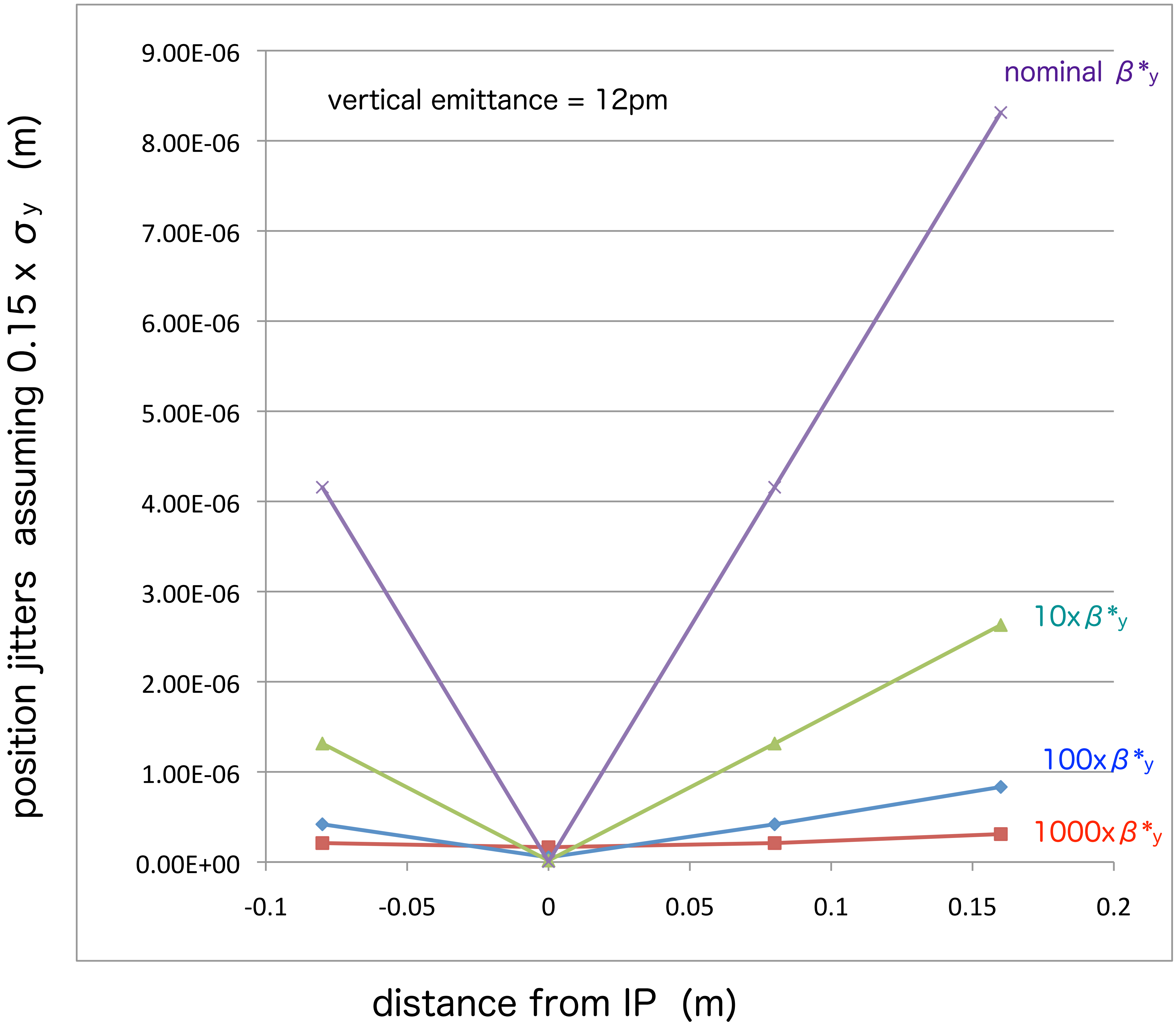
$$\sqrt{\frac{\theta_T r}{\sigma_z}} > 0.37$$

y' = 1.25 ur / mm for I= 1 x 10^{10}/bunch, where y' = A Δy

IPBPM	S_{IPBPM} : distance from IP(C), cm	vertical beam size, um	y' nr for 30% y jitter	y' x S_{IPBPM} at IP (C) nm
B	15.8	54.9	20.5	3.3
A	23.9	82.9	31	7.4

IPBPM	S_{IPBPM} : distance from IP(B), cm	vertical beam size, um	y' nr for 30% y jitter	y' x S_{IPBPM} at IP (B) nm
A	7.92	27.4	10.2	0.8
C	15.8	54.9	20.5	-

y' = 1.13 ur / mm for I= 1 x 10^{10}/bunch by Karl's calculation (Mafia, KNU-IPBPM) in next slide



vertical emittance = 12pm
nominal β^*_y
$10\text{x}\,\beta^*_y$
$100\text{x}\,\beta^*_y$
$1000\text{x}\,\beta^*_y$
position jitters assuming 0.15 x σ_y (m)
distance from IP (m)
9.00E-06
8.00E-06
7.00E-06
6.00E-06
5.00E-06
4.00E-06
3.00E-06
2.00E-06
1.00E-06
0.00E+00
-0.1
-0.05
0
0.05
0.1
0.15
0.2

Dynamic range and resolution of IPBPM-B_Y

Nominal intensity=	1.00.E+10						
no of ports=	2						
sensivity V/nm=	3.10.E-06	Gain	53.3	dB	sensitivity KEKIPBPM V/nm 2.56.E-06		
Input :		hybrid_coupler	3.0	dB			
Noise (dBm)=	-95	SMA cable	7.0	dB			
Noise (V)=	3.976E-06	BNC cable	6.0	dB			
		unknown	6.0	dB			
		Effective Gain	31.3	dB			
Output :		DC-AMP	0	dB			
Max. (V)=	0.60			dBm	V	dBm	V
Max. (dBm)=	8.57			-4.4	0.134	-4	0.1411

beam intensity= 1.00.E+10

			noise level			ADC "resolution"		maximum/dynamic range			"total	ampli-
beam intensity	input attenuator (dB)	Effective Gain	power(dBm)	pulse height	position(nm)	bits/one side	nm/ADC	power(dBm)	pulse height	position(um)	gain"	tude/V
1.00.E+10	0	31.3	-95	3.976E-06	1.3	12	1.29	-22.7	1.634E-02	5.3	31.3	0.6
1.00.E+10	10	31.3	-95	3.976E-06	4.1	12	4.1	-22.7	5.166E-02	16.7	21.3	0.6
1.00.E+10	20	31.3	-95	3.976E-06	12.8	12	12.9	-22.7	1.634E-01	52.7	11.3	0.6
1.00.E+10	30	31.3	-95	3.976E-06	40.6	12	40.7	-22.7	5.166E-01	166.6	1.3	0.6
1.00.E+10	40	31.3	-95	3.976E-06	128.3	12	128.7	-22.7	1.634E+00	527.0	-8.7	0.6

beam intensity= 5.00.E+09

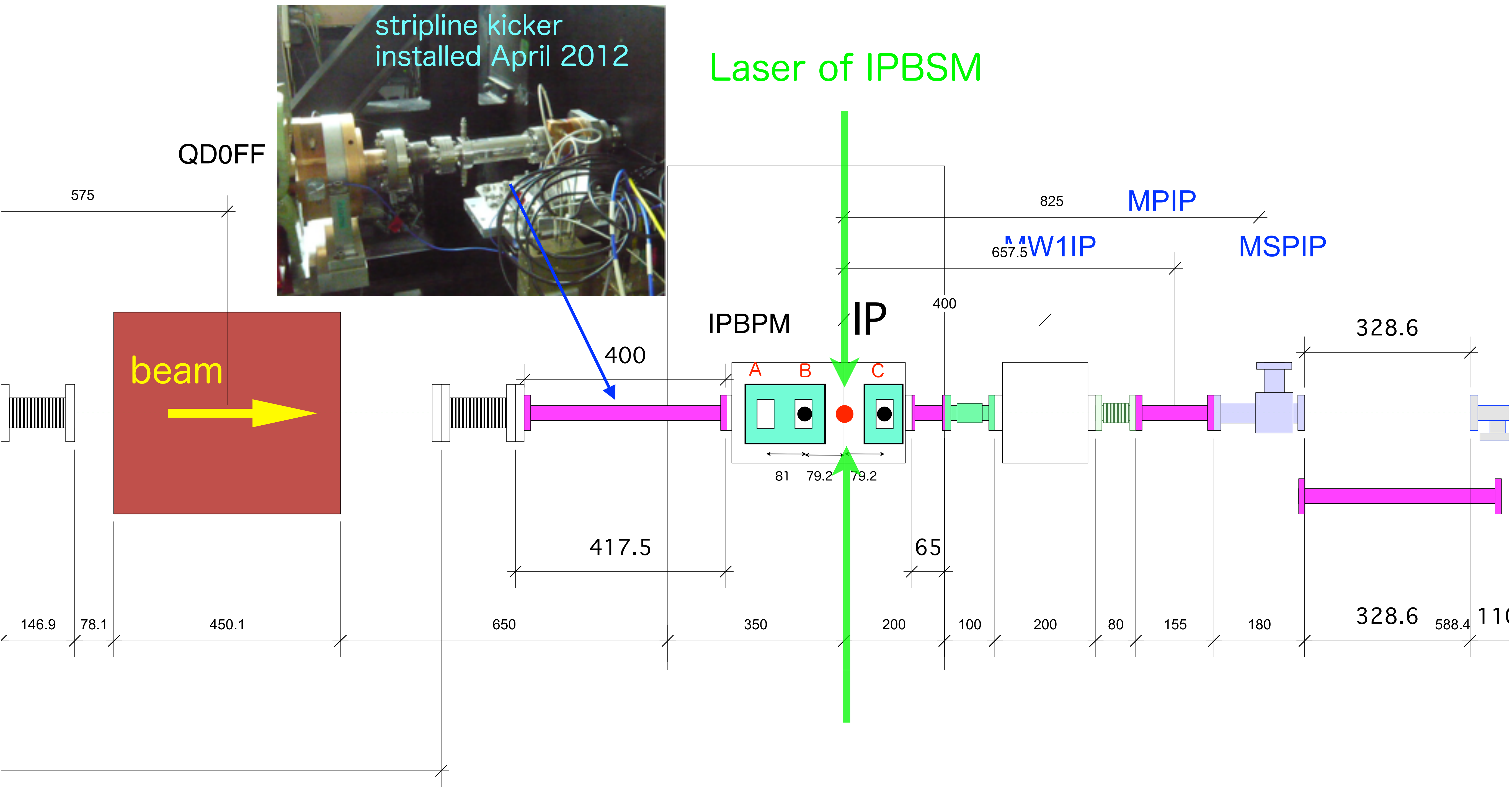
			noise level			ADC "resolution"		maximum/dynamic range			"total	ampli-
beam intensity	input attenuator (dB)	Gain	power(dBm)	pulse height	position(nm)	bits/one side	nm/ADC	power(dBm)	pulse height	position(um)	gain"	tude/V
5.00.E+09	0	31.3	-95	3.976E-06	2.6	12	2.57	-22.7	3.267E-02	10.5	31.3	0.6
5.00.E+09	10	31.3	-95	3.976E-06	8.1	12	8.1	-22.7	1.033E-01	33.3	21.3	0.6
5.00.E+09	20	31.3	-95	3.976E-06	25.7	12	25.7	-22.7	3.267E-01	105.4	11.3	0.6
5.00.E+09	30	31.3	-95	3.976E-06	81.1	12	81.4	-22.7	1.033E+00	333.3	1.3	0.6
5.00.E+09	40	31.3	-95	3.976E-06	256.5	12	257.3	-22.7	3.267E+00	1053.9	-8.7	0.6

beam intensity= 1.00.E+09

			noise level			ADC "resolution"		maximum/dynamic range			"total	ampli-
beam intensity	input attenuator (dB)	Gain	power(dBm)	pulse height	position(nm)	bits/one side	nm/ADC	power(dBm)	pulse height	position(um)	gain"	tude/V
1.00.E+09	0	31.3	-95	3.976E-06	12.8	12	12.9	-22.7	1.634E-01	52.7	31.3	0.6
1.00.E+09	10	31.3	-95	3.976E-06	40.6	12	40.7	-22.7	5.166E-01	166.6	21.3	0.6
1.00.E+09	20	31.3	-95	3.976E-06	128.3	12	128.7	-22.7	1.634E+00	527.0	11.3	0.6
1.00.E+09	30	31.3	-95	3.976E-06	405.6	12	406.8	-22.7	5.166E+00	1666.4	1.3	0.6
1.00.E+09	40	31.3	-95	3.976E-06	1282.7	12	1286.6	-22.7	1.634E+01	5269.7	-8.7	0.6

3. Layout

IPBPM Triplet with movers in the IP chamber



Configuration of IP feedback based on the triplet of IPBPMs

IP at IPBPM-B

σ_y=27.4, 0.037, 54.9 um at IPBPM-A, -B and -C, respectively

(57.4dB, 0dB, 63.4dB)

IPBPM-A / IPBPM-C for the feedback input

IPBPM-B for a witness of jitter at IP (focal point)

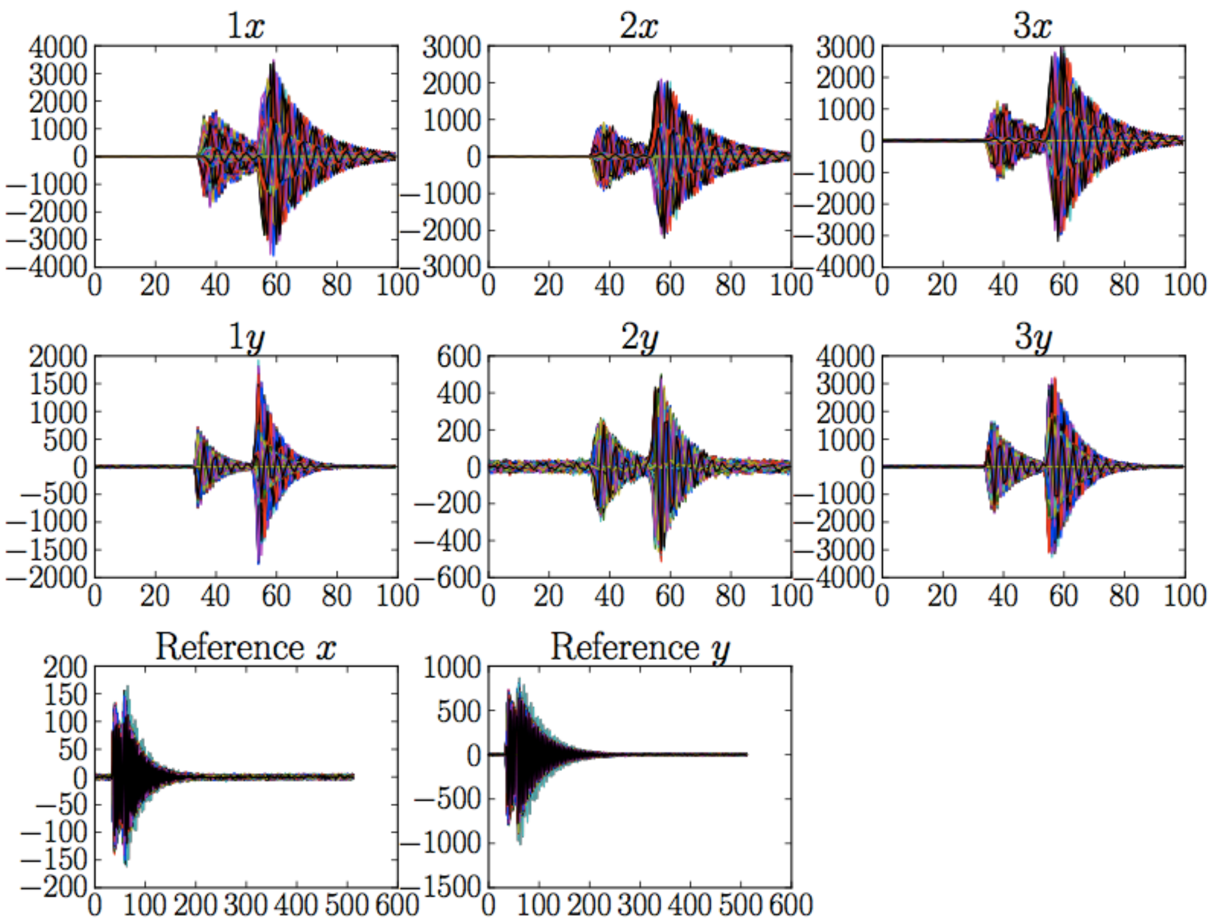
Assuming the jitters scaled with the beam sizes, i.e. 1nm stabilization at IP

Required position resolutions = 0.7, 0.001 and 1.5 um at IPBPM-A, -B and -C, respectively

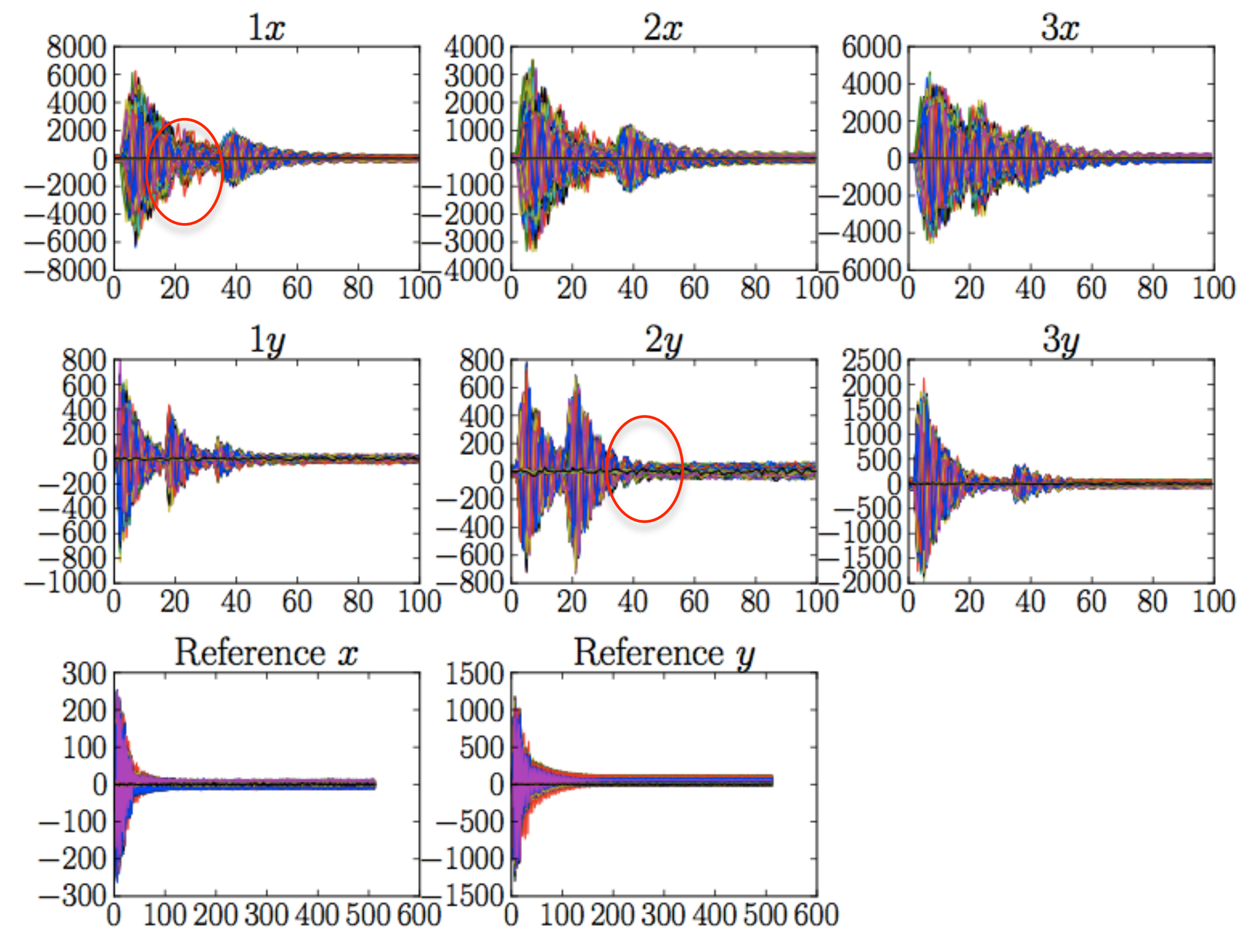
For IPBPM (KEK type)

Waveform – heterodyne (multi bunch)

Two bunch waveform (187.6 ns bunch spacing)



Three bunch waveform (150 ns bunch spacing)



We can see clearly the bunch separation.

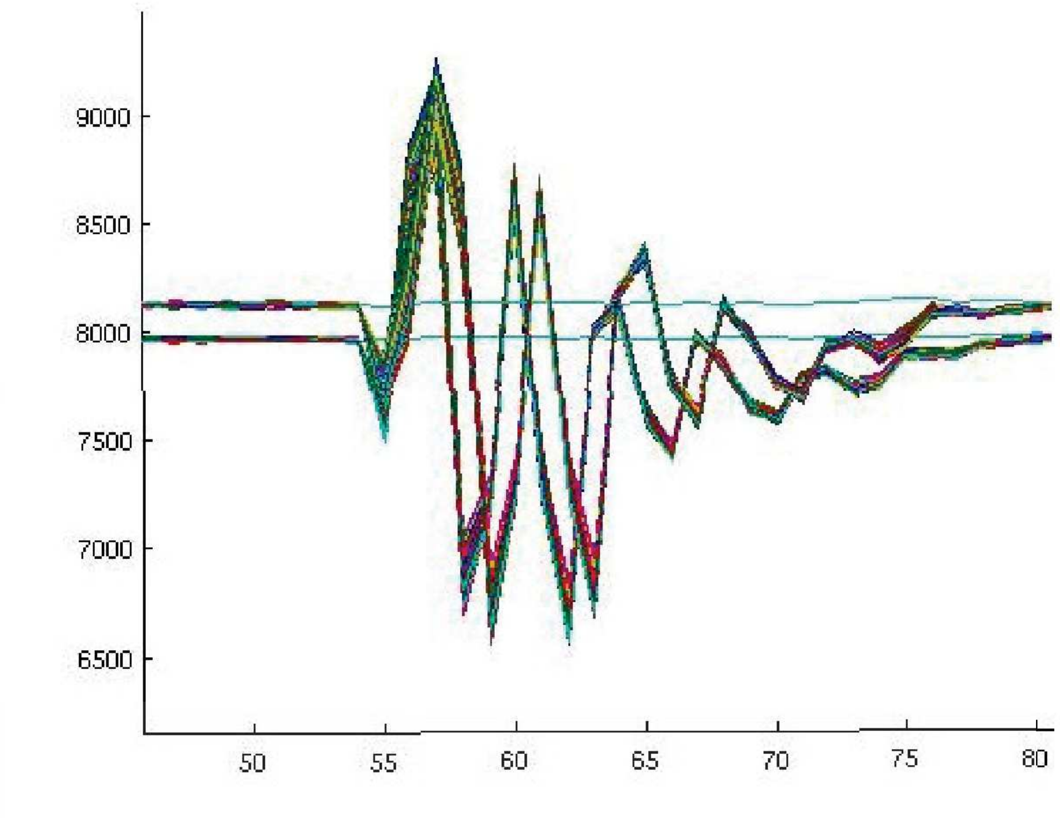
But, how can we use reference information for charge normalization??

YoungIm Kim, 13th ATF2 Project meeting, 11-13 January, 2012

Effect of the 6.4 GHz BPF on baseband output signals

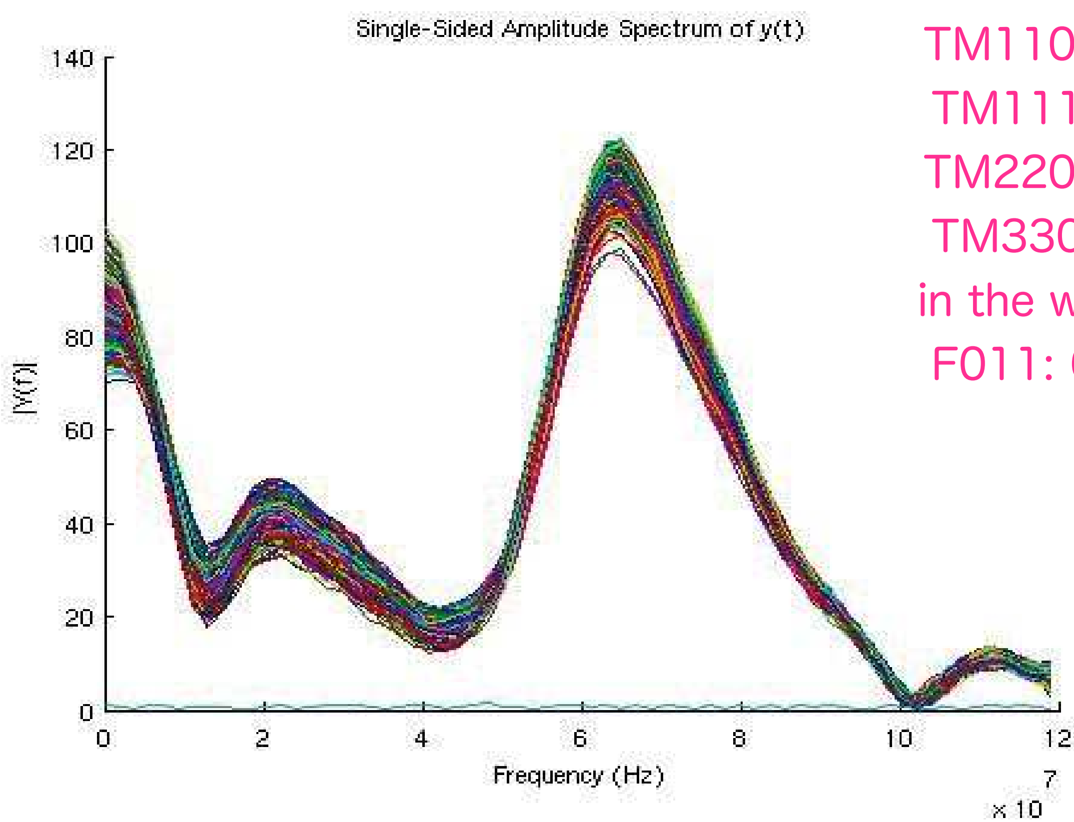
2015.4.15, Glenn, IPBPM_filter_tests2,slide 6

BPF : 6.41 ± 0.1 GHz

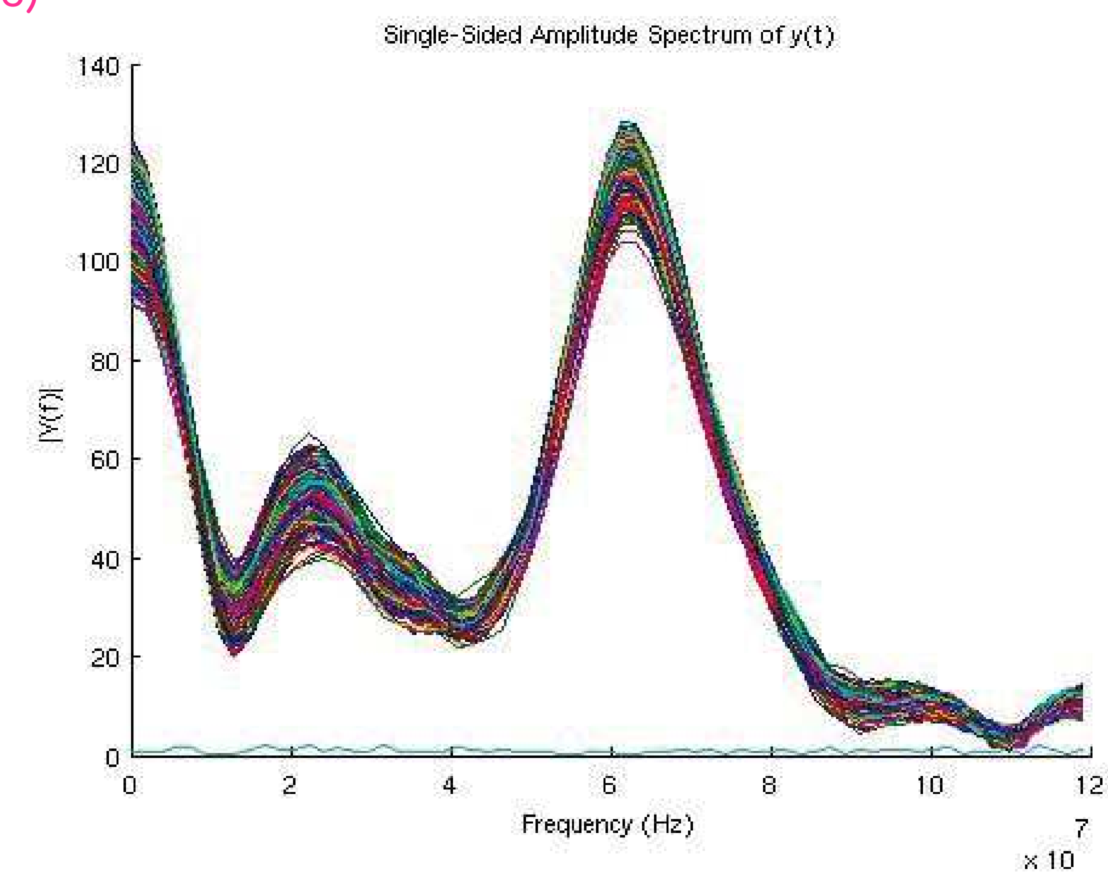


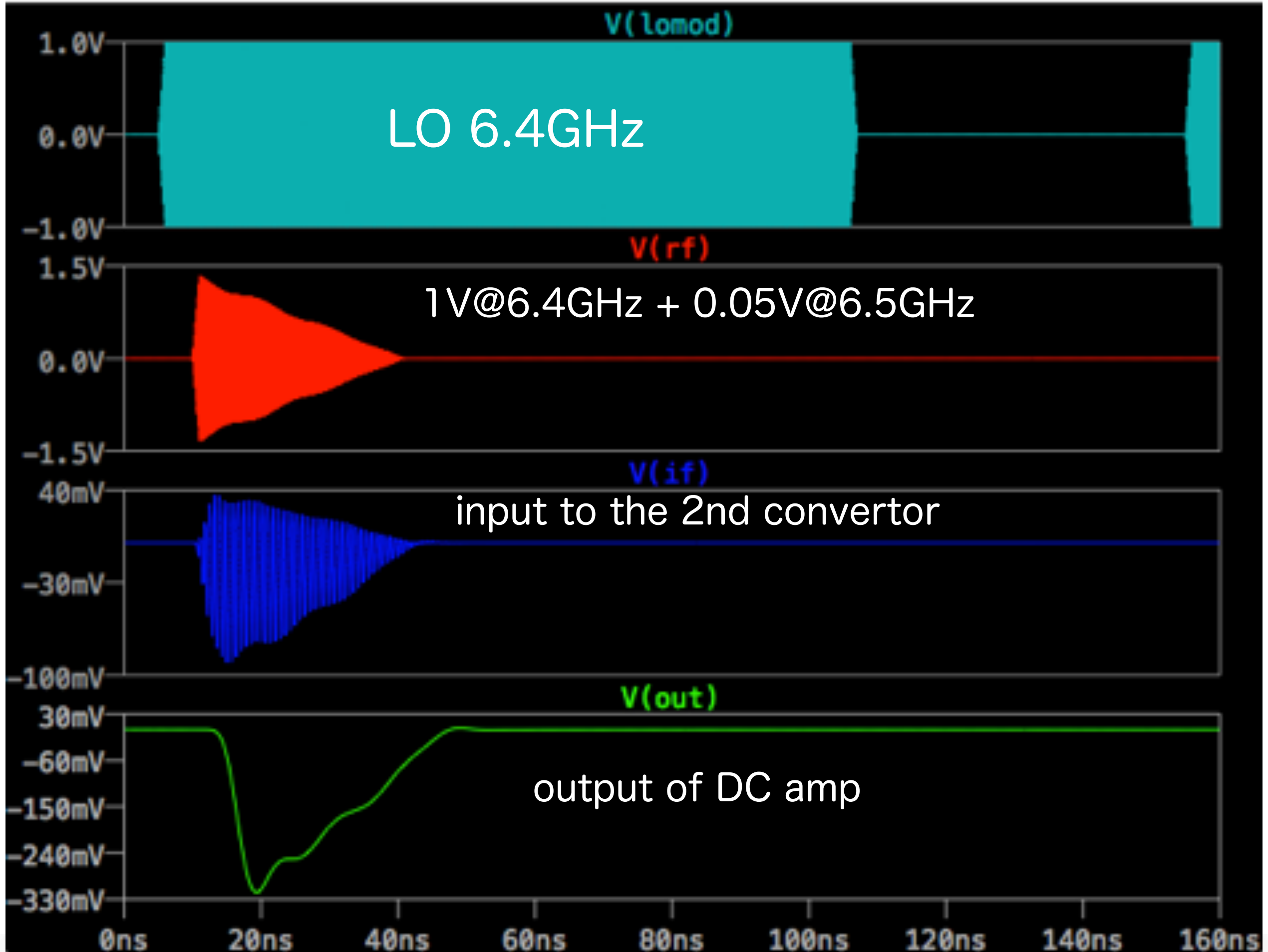
simple calculations
in the cavity
TM120: 6.6GHz(V-dipole)
TM110: 3.9GHz
TM111: 25GHz
TM220: 7.9GHz
TM330: 12GHz
in the waveguide
F011: 6.15GHz

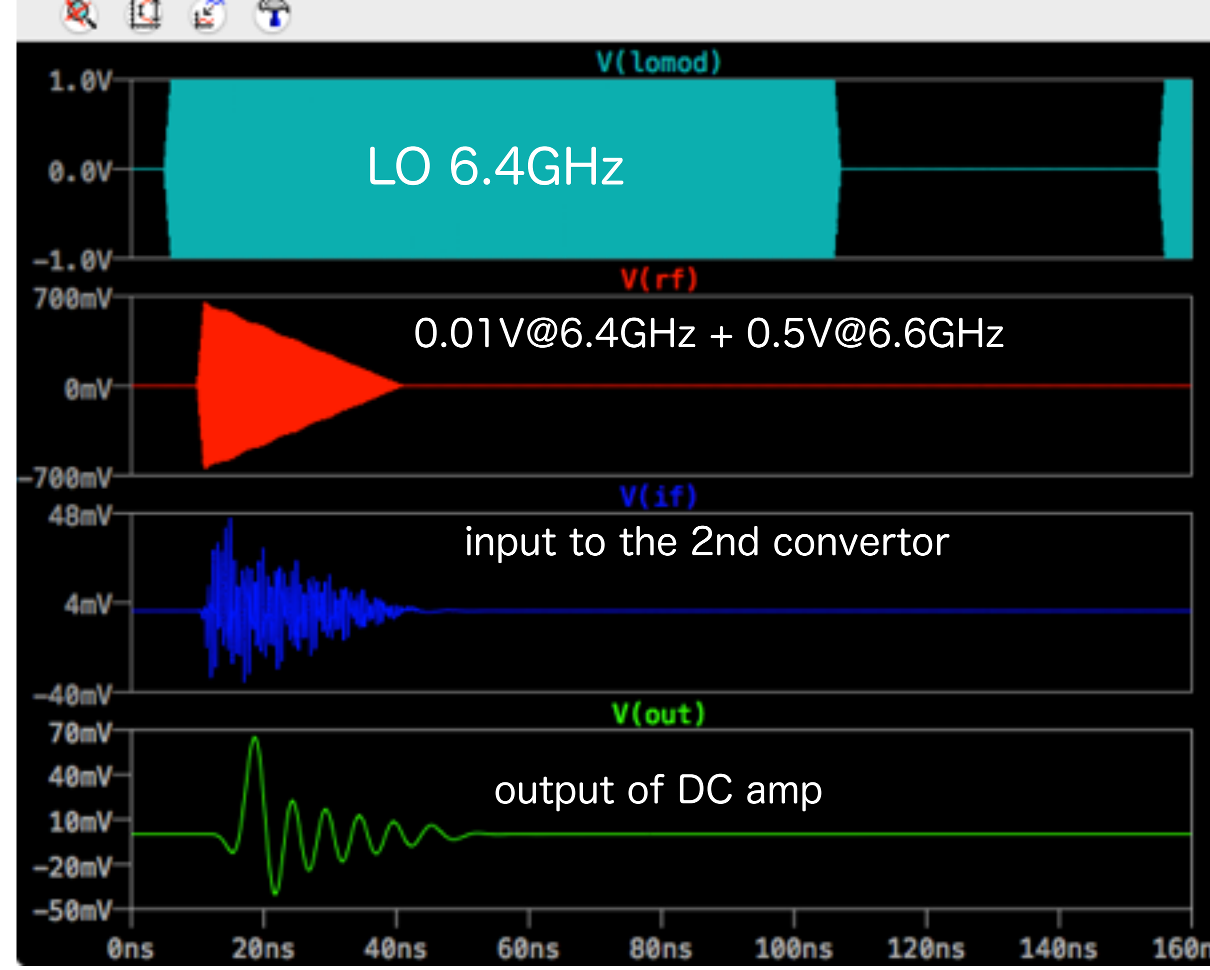
Unfiltered



Filtered




V(lomod)
LO 6.4GHz
V(rf)
1V@6.4GHz + 0.05V@6.5GHz
V(if)
input to the 2nd convertor
V(out)
output of DC amp
0ns 20ns 40ns 60ns 80ns 100ns 120ns 140ns 160ns


V(lomod)
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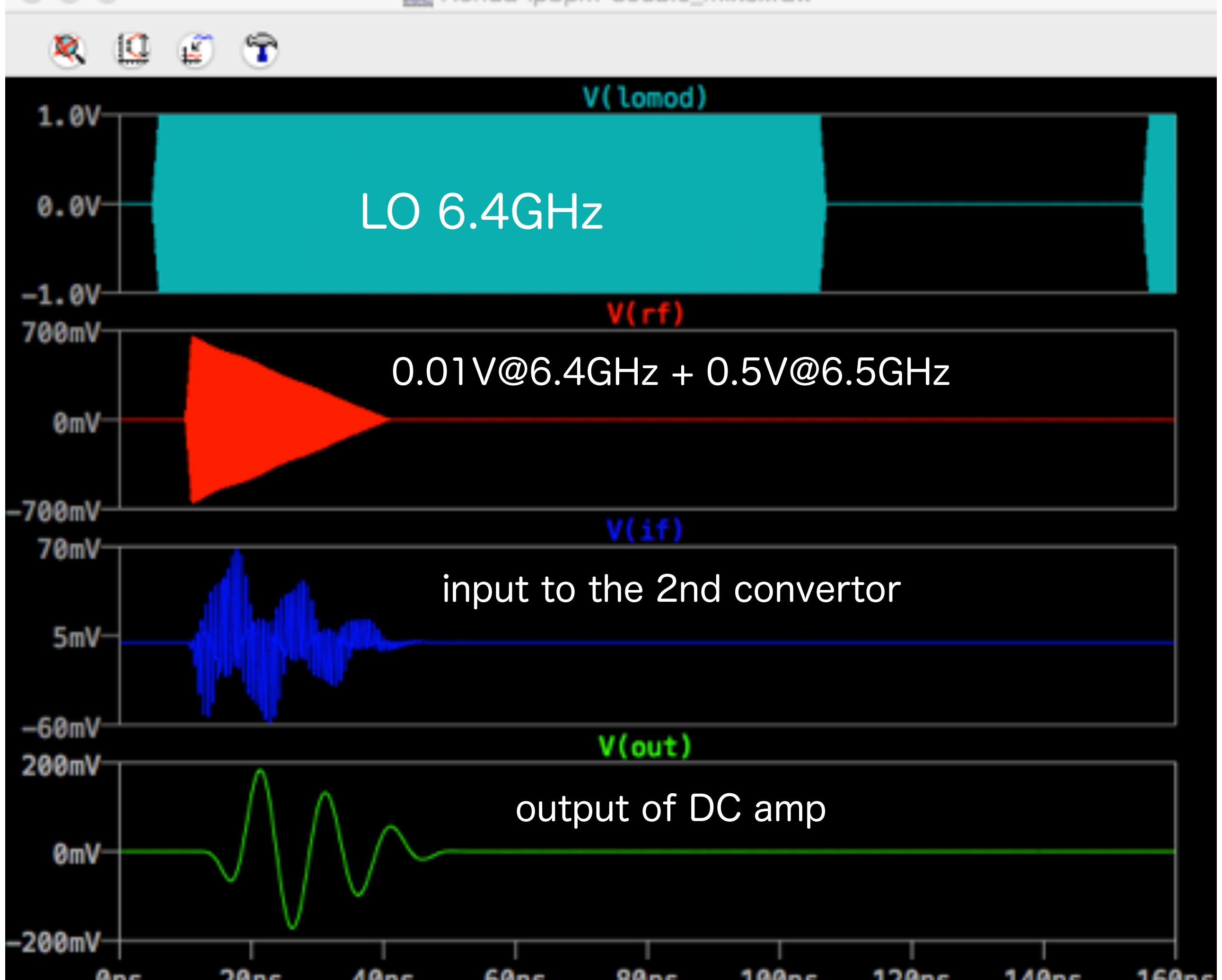
V(lomod)
LO 6.4GHz
V(rf)
0.01V@6.4GHz + 0.5V@6.5GHz
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output of DC amp
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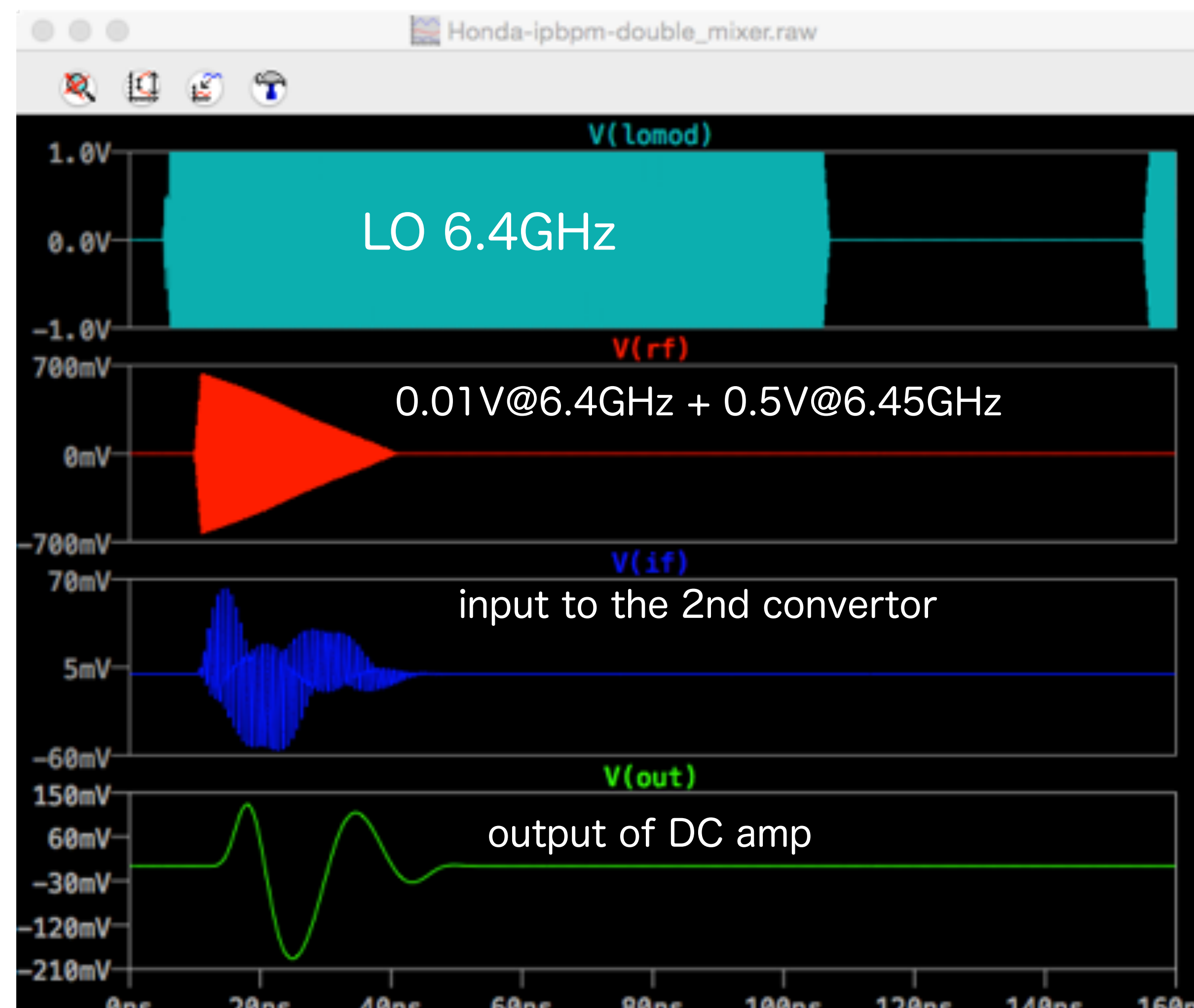
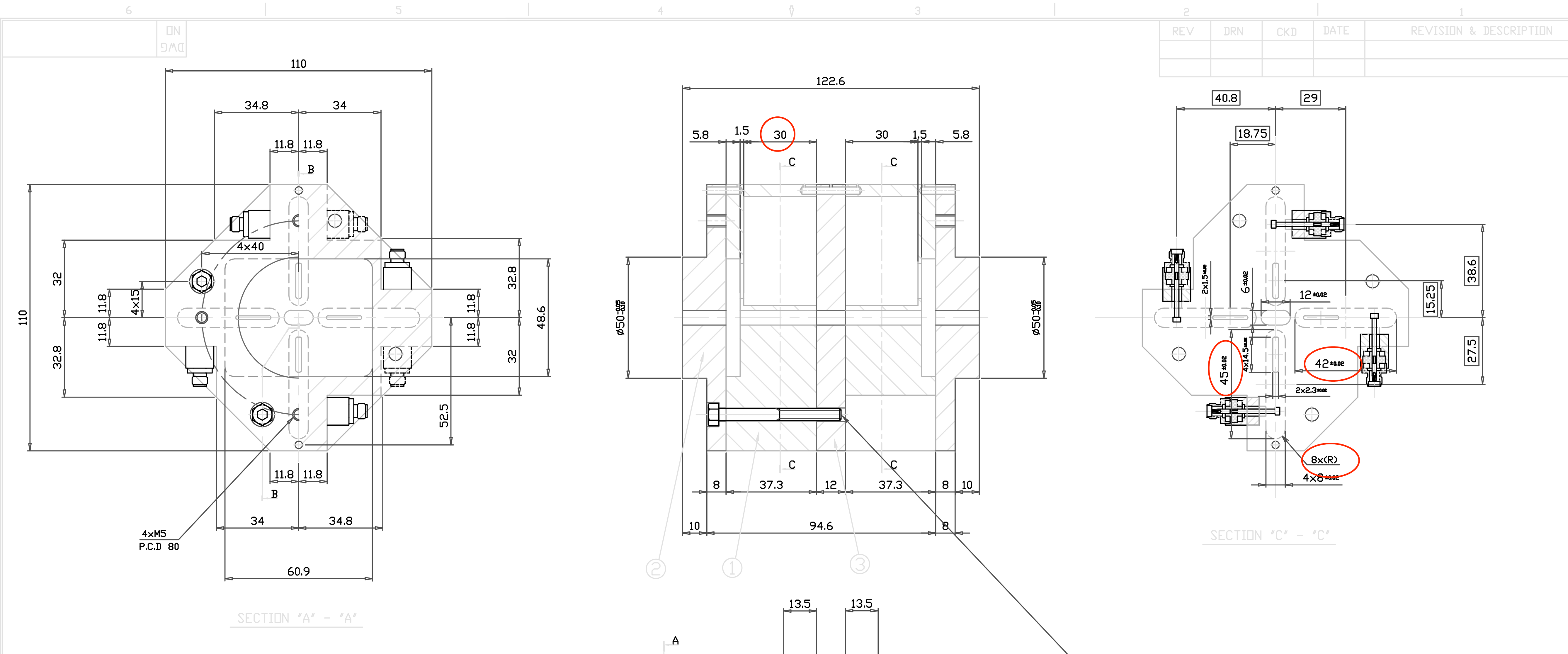
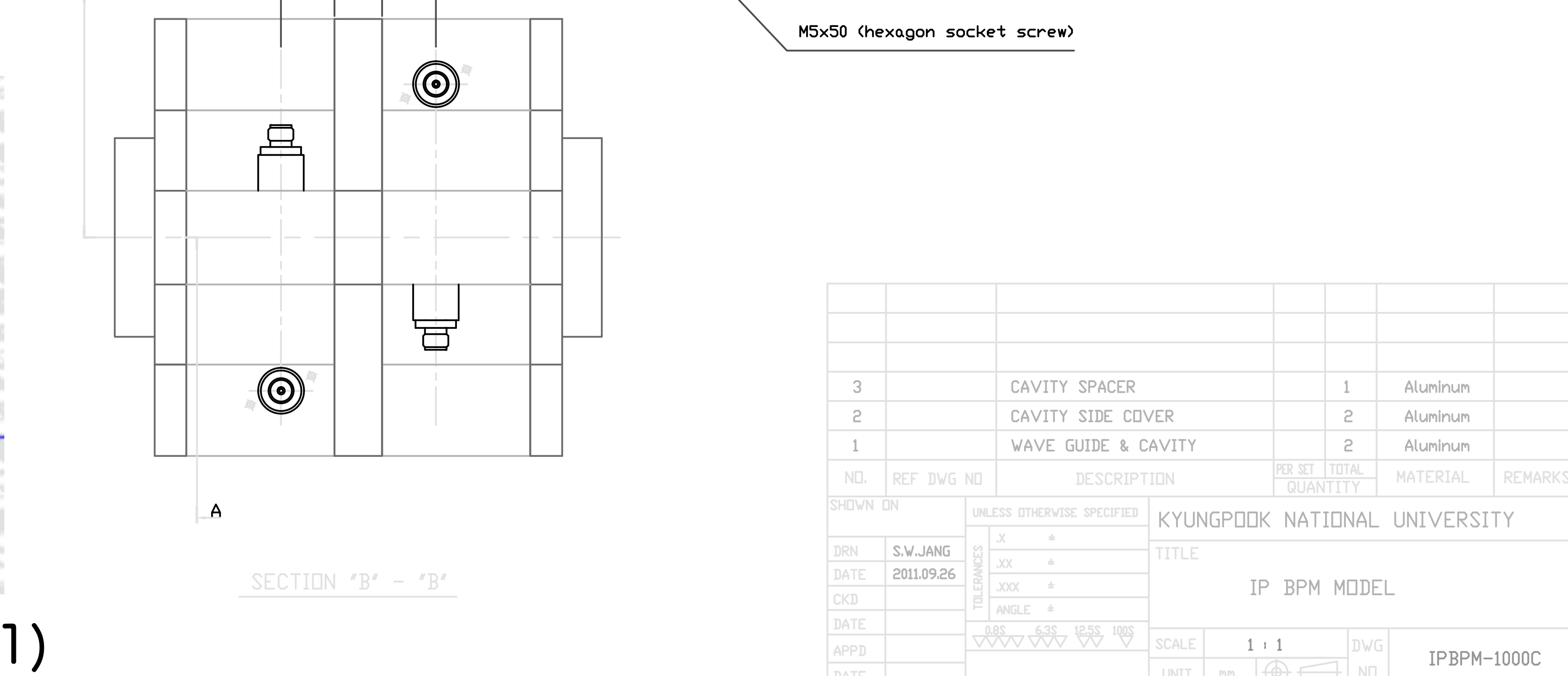
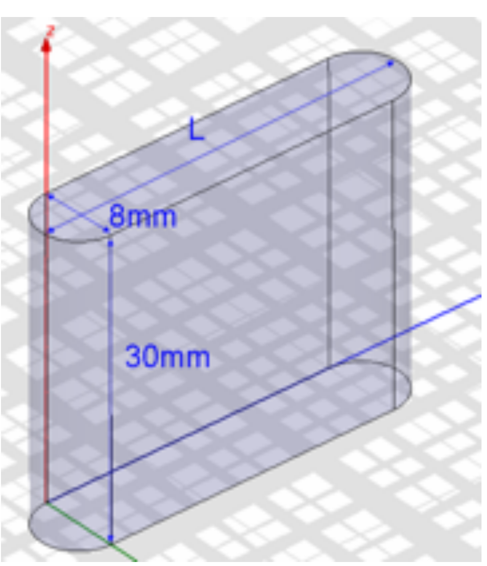

Honda-ipbpm-double_mixer.raw
V(lomod)
LO 6.4GHz
V(rf)
0.01V@6.4GHz + 0.5V@6.45GHz
V(if)
input to the 2nd convertor
V(out)
output of DC amp
0ns 20ns 40ns 60ns 80ns 100ns 120ns 140ns 160ns

RF properties of the wave guide in the IPBPMs

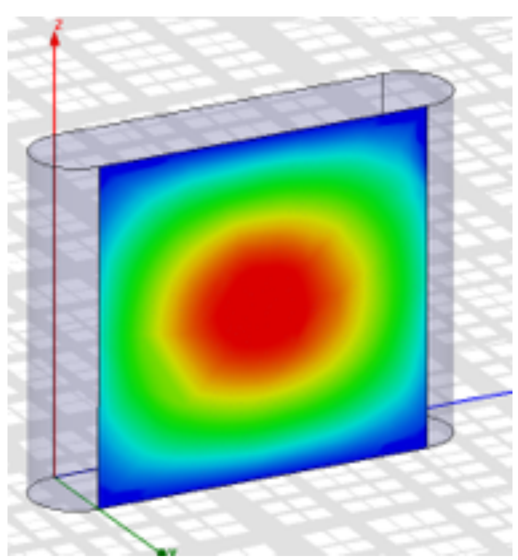
c	m/sec	300000000									
π		3.141592654									
wave guide		present (compact) low Q design		wrong design		high Q cold model		high Q hot model		compact high Q cold model	
a	m	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
b	m	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
L	m	0.042	0.045	0.038	0.041	0.05	0.05	0.057	0.06	0.042	0.045
m		0	0	0	0	0	0	0	0	0	0
n		1	1	1	1	1	1	1	1	1	1
l		1	1	1	1	1	1	1	1	1	1
		Y	X	Y	X	Y	X	Y	X	Y	X
cavity dipole freq.		6.426.E+09	5.712.E+09	6.426.E+09	5.712.E+09	6.426.E+09	5.712.E+09	6.426.E+09	5.712.E+09	6.426.E+09	5.712.E+09
Δf(typical)		1.300.E+07	1.890.E+07	5.800.E+06	2.700.E+06	6.000.E+06	6.400.E+06	5.800.E+06	2.700.E+06	4.000.E+06	4.860.E+06
Q_L(typical)		494	302	1108	2116	1071	893	1108	2116	1607	1175
β(typical)		0.73	1.50			0.64	1.33	2.20	1.28	1.50	2.35
Q_ext(typical)		1171	504			2744	1564	1612	3768	2678	1675
Q_ext(design)		856	841			2442	3901	1590	3382	1669	3394
monopole frequency	f_011	6.145.E+09	6.009.E+09	6.370.E+09	6.196.E+09	5.831.E+09	5.831.E+09	5.650.E+09	5.590.E+09	6.145.E+09	6.009.E+09
diff.freq.		2.815.E+08	-2.973.E+08	5.562.E+07	-4.836.E+08	5.950.E+08	-1.190.E+08	7.758.E+08	1.218.E+08	2.815.E+08	-2.973.E+08
diff.feq./Δf		21.7	-15.7	9.6	-179.1	99.2	-18.6	133.8	45.1	70.4	-61.2
				deformed Q			ringing seen	8.7nm published			
test condition		in the IP chamber		simulation only		tested at LINAC-end		tested at the EXT		tested in the IP chamber	







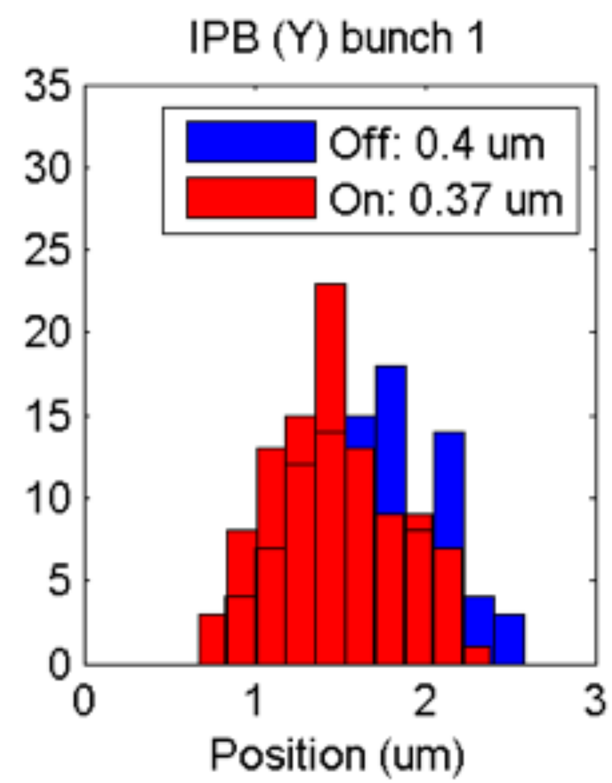
wave guide



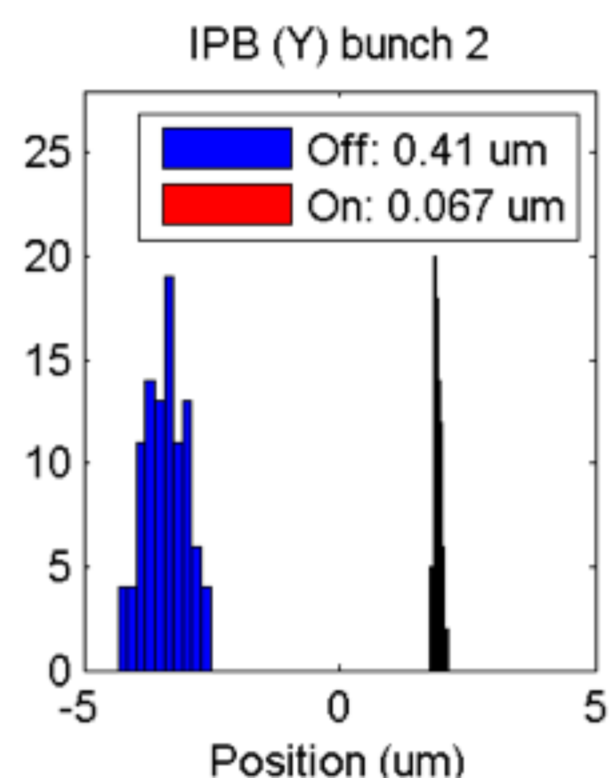
monopole mode (f011)

IPFB results

Bunch 1:
not corrected,
jitter ~ 400nm



Bunch 2:
corrected,
jitter ~ 67nm



Corrected jitter 67nm

→ resolution 47nm

The RF test results

by Siwon

The measured RF test data shown in Table. The Q factor was lower than design values. Maybe, the reason comes from IPBPM assemble method by volt make a RF field leakage between two surfaces of aluminum body.

However, the expected external output voltage was not bad compare with HFSS simulation results. The average output voltages are 3.11uV/nm and 5.14uV/nm for Y-port and X-port, respectively.

The average resonant frequency are 6.4208 GHz and 5.7117GHz for Y-port and X-port, respectively. Also these average frequencies will be used for resonant frequencies of reference cavity BPM.

$$Q_L \equiv \frac{\omega U}{P},\ Q_0 \equiv \frac{\omega U}{P_{wall}},\ Q_{ext} \equiv \frac{\omega U}{P_{out}} \qquad P = P_{wall} + P_{out},\ \beta \equiv \frac{P_{out}}{P_{wall}} = \frac{Q_0}{Q_{ext}} \qquad Q_0 = (1+\beta)Q_L$$

	X(mm)	Y(mm)	f0 (GHz)	Δf(MHz)	Q_L	Decay time (ns)	S21(dB)	S21	β	Q_0	Qext	R/Q	V_out (uV/2nm)
Design Y	48.55	60.75	6.4345	9.100	707.1	17.49	-1.656	0.826	4.761	4073.5	855.6	667481	7.145
Design X	48.55	60.75	5.7237	8.200	698.0	19.41	-1.623	0.830	4.867	4094.9	841.4	765973	7.751
IPA-Y	48.55	60.75	6.4225	13.144	488.6	12.11	-7.460	0.424	0.735	847.7	1153.3	668974	6.162
IPB-Y	48.55	60.75	6.420	14.148	453.8	11.25	-7.545	0.420	0.723	781.7	1081.6	669286	6.365
IPC-Y	48.55	60.75	6.420	23.596	272.1	6.745	-12.68	0.232	0.303	354.3	1171.3	669286	6.117
IPA-X	48.55	60.75	5.712	18.248	313.0	8.722	-3.620	0.659	1.934	918.4	474.8	767786	10.328
IPB-X	48.55	60.75	5.712	19.454	293.6	8.181	-5.370	0.539	1.169	636.7	544.8	767786	9.642
IPC-X	48.55	60.75	5.711	32.318	176.7	4.925	-7.680	0.413	0.704	301.0	427.8	767942	10.882

$$Q_L = \frac{f}{\Delta f},\ \beta = \frac{1 - S_{11}}{S_{11}} = \frac{S_{21}}{1 - S_{21}}$$

$\tau = Q_L/\omega = Q_L/2\pi f$ = 10ns with Q=400

Present status

BPM resolution : 27nm at 0.3 x 10^10 beam intensity

or

IP stabilization at 67nm (→ resolution of 47nm)

What are sources of the resolution limit ?

- electronics noise
- low beam intensity, e.g. poor calibration
- calibration , e.g. IQ tuning
- static signals
  - only seen at the low Q IPBPMs ?
  - could be "filtered out" by the narrow band C-band pass filter
  - may be generated in the waveguide

Measures

- recovery of Q at IPBPM-C by re-fabrication and indium shielding
  to see a correlation between the Q and the static signals
- finer adjustment of IQ angle or detailed calibration in the nanometer range

Future studies

(1) IP at IPBPM-B

feedback with IPBPM-B, monitor at the nanometer level by IPBPM-B

(2) IP at IPBPM-B

feedback with IPBPM-A and --C , monitor at the nanometer level by IPBPM-B

(3) Nominal IP

feedback with IPBPM-A, -B and -C, beam size measurements by Shiitake monitor

We need a full usage of I and Q signals

the measured sensitivity =3mm/rad :

1 ns resolution corresponds to 1/3 urad