Special Studies with Crab Cavities

Background of special studies
Special study 1: Controlled RF noise with crab cavities
Special study 2: Longitudinal kicked beam with crab cavities
Summary

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KEK

Background of the special studies

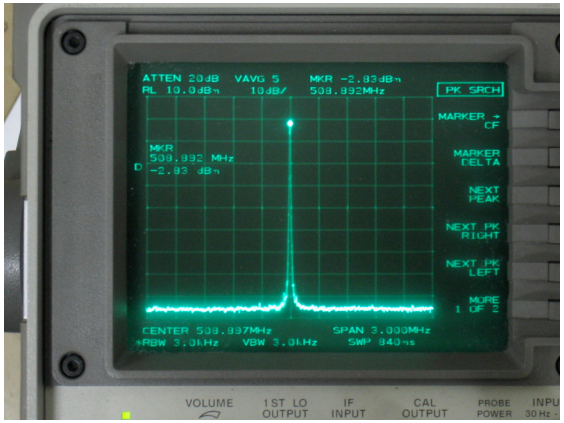
- Crab crossing was proposed for the upgrade of LHC.
- KEKB is the first machine which applied the crab crossing.
- We started collaboration for;
  1) Basic studies for LHC crab crossing using KEKB crab cavity.
  2) Understand and solve luminosity reduction of KEKB at high current.
- As a collaboration meeting between LHC and KEKB, we held a video meeting on Aug. 5, 2008.
- In the meeting CERN LHC people suggested several ideas for the KEKB machine studies.
- We picked up two studies;
  1) Controlled RF noise study with crab cavities.
  2) Longitudinally kicked beam study with crab cavities.

- We conducted above studies on Dec. 12 with Rogelio-san from CERN.
- Funakoshi-san conducted study1 again and obtained different results.

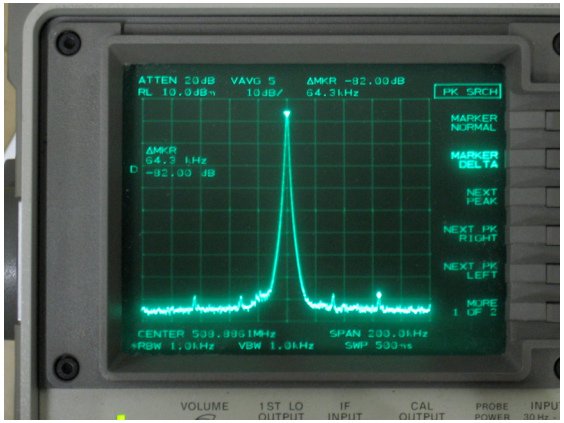
Presented at MRC2007 by Akai-san

Phase stability (cavity pick up signal)

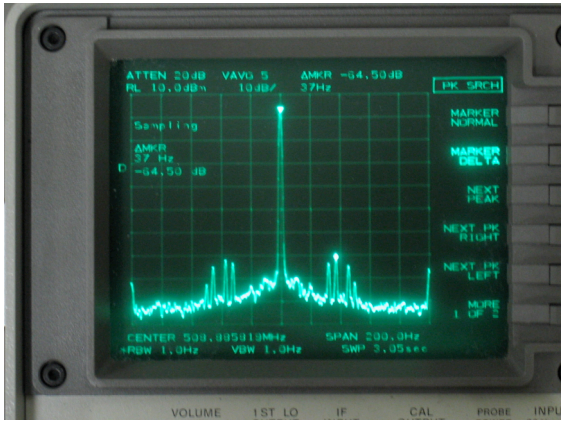
LER



Span 3MHz
No significant sidebands seen.



Span 200 kHz
Sideband peaks at 32kHz, 64kHz.
Phase error < ± 0.01 deg (fast)



Span 200 Hz
Sideband peaks
at 32, 37, 46, 50, 100 Hz.
Phase error < ± 0.07 deg (slow)

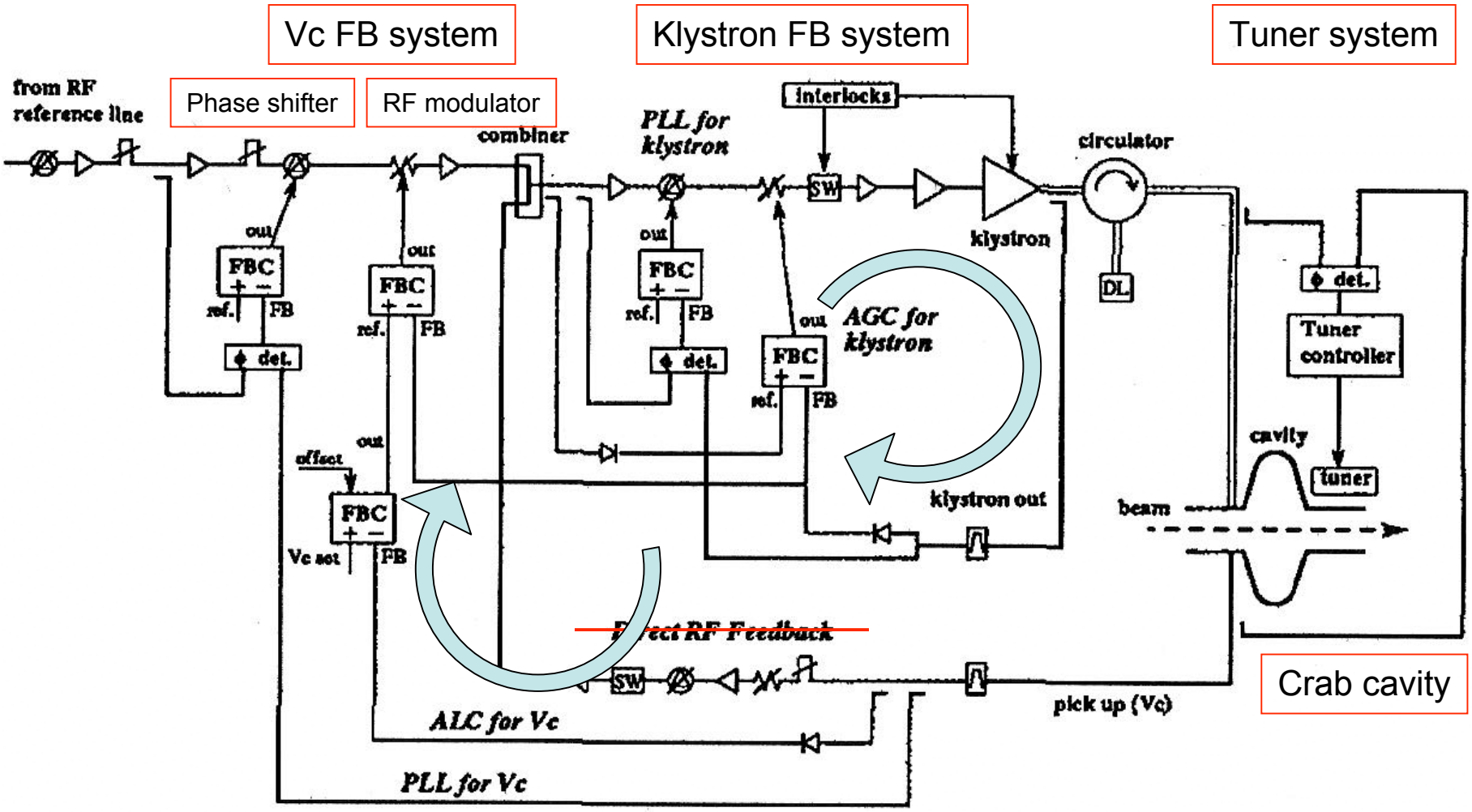
According to b-b simulation by Ohmi-san, allowed phase error for N-turn correlation is $0.1\times\sqrt{N}$ (degree).

- Spectrum of pick up signal is consistent with phase detector data.
- The measured phase error is much smaller than the allowed values given by beam-beam simulation.

Special study 1
Controlled RF noise study with the KEKB crab

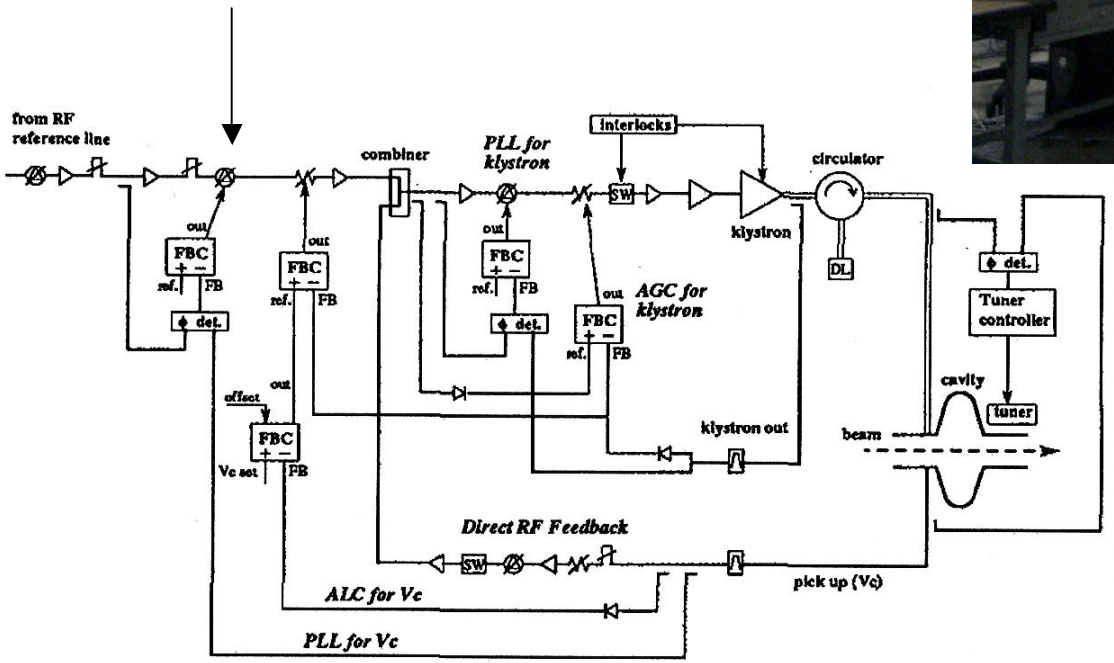
- Add controlled RF noise to the crab cavity
- Measure beam size and luminosity
- Controlled noise
  - Single frequency
  - Close to the horizontal betatron tune: ν_x (~50kHz)
  - Far away from ν_x
- Beam conditions
  - Single LER beam with a beam current of 100 mA
  - Single HER beam (100 mA)
  - Colliding beams (HER/LER: 65/100 mA)

Controlled RF noises study
LLRF of crab cavity



Phase modulation

Added sinusoidal wave from a function generator to a phase shifter of Vc PLL.



Control system at D11 station

Phase modulation and phase error

Phase modulated oscillation

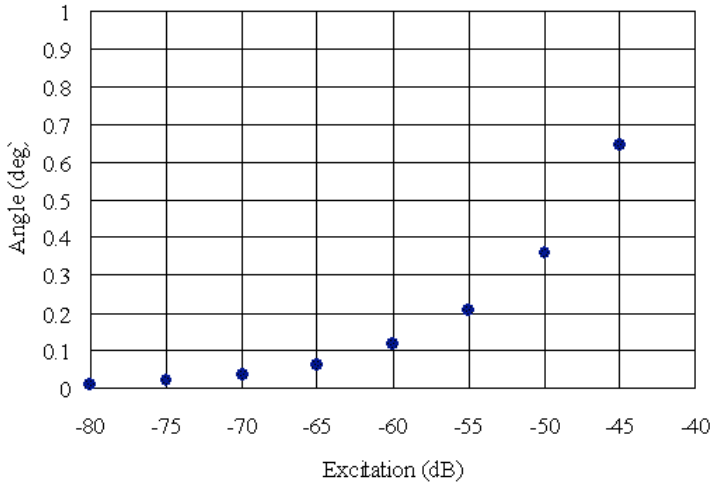
$$Vc \cdot \sin(\omega t + \varphi)$$ Phase modulation: $\varphi = \varphi_0 \sin(\nu t)$

$$= Vc\{\sin(\omega t)\cos(\varphi) + \cos(\omega t)\sin(\varphi)\}$$

$$\approx Vc\{\sin(\omega t) + \varphi_0 \sin(\nu t) \cdot \cos(\omega t)\}$$

$$\approx Vc[\sin(\omega t) + \frac{\varphi_0}{2}\{\sin((\omega+\nu)t) - \sin((\omega-\nu)t)\}]$$

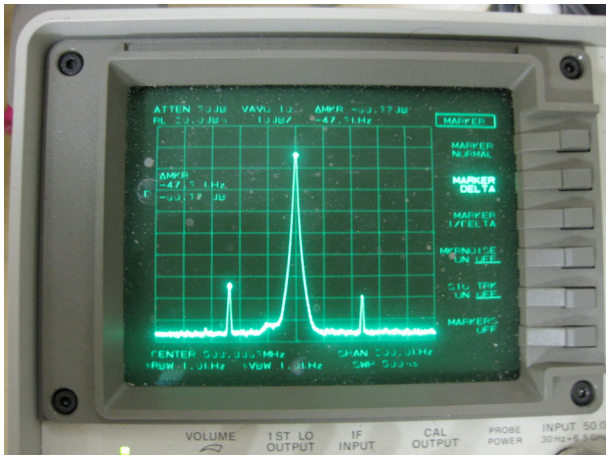
sidebands



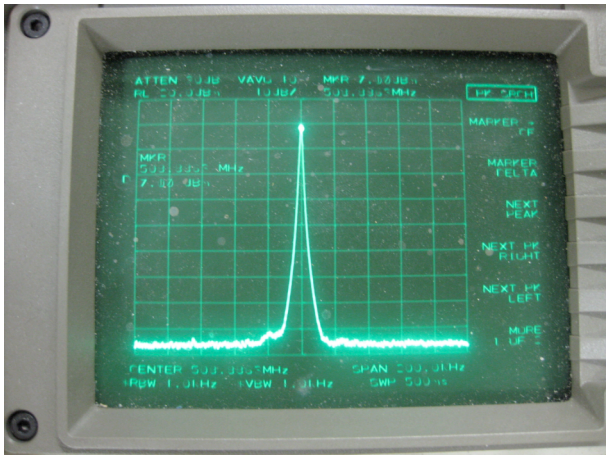
Phase modulation amplitude (phase error) φ_0 is given by;

$$\varphi_0(rad) = 2 \times 10^{X(dB)/20}$$

HER excitation: 47.5 kHz, -61 dB



No HER excitation



Dec. 12, 2008

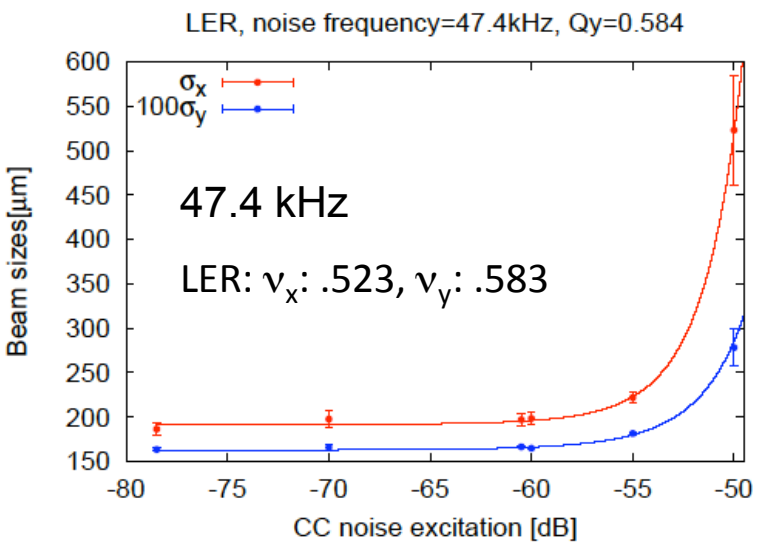
Study 1
Beam study conditions

Tune	Single/Colliding	Current (mA)	Frequency moduration (kHz)	Time
Beam injection				
SR monitor setup for low beam currents				
H: 0.523, V: 0.583	LER single	100	42.0	10:53–11:08
		100	47.4	11:18–11:28
		100	scan at 60dB	11:34–11:40
H: 0.5226, V: 0.6016	HER single	100	39.7	11:57–12:03
		100	47.5	12:10–12:19
		100	scan at 55dB	12:22–12:24
Collision tuning				12:30–14:00
	HER/LER colliding	65/100	HER: 39.8	14:13–14–20
		65/100	HER: 47.5	14:25–14:30
		65/100	LER: 42.0	14:59–15:06
		65/100	LER: 47.4	15:20–15:28
LER–V: 0.5962	LER single	100	LER: 47.4	15:49–15:58

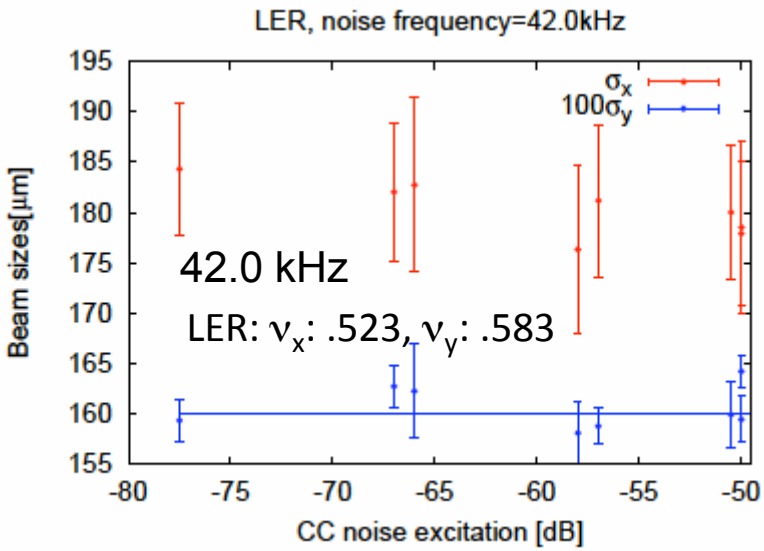
Summarized by Rogelio-san

Single beams

LER

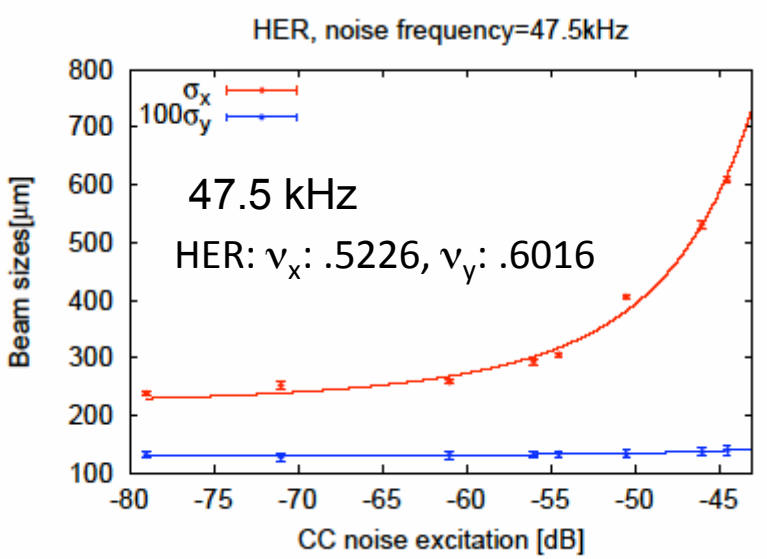


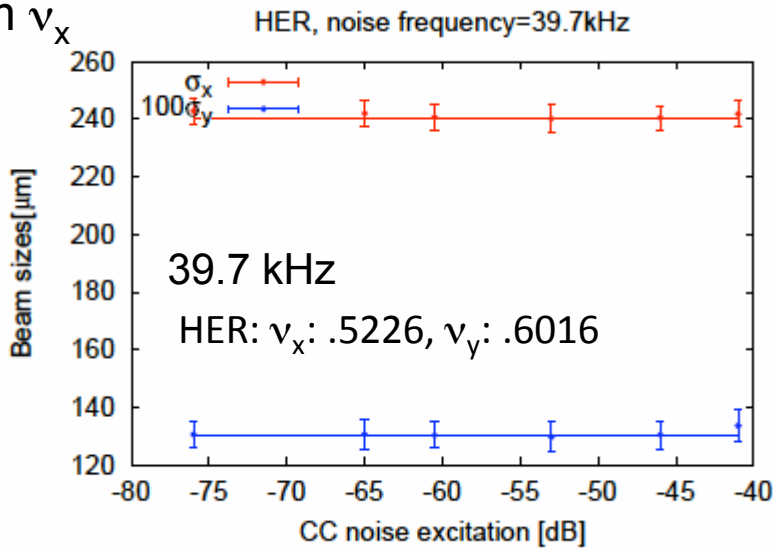
Close to ν_x



Far away from ν_x
Close to ν_y

HER

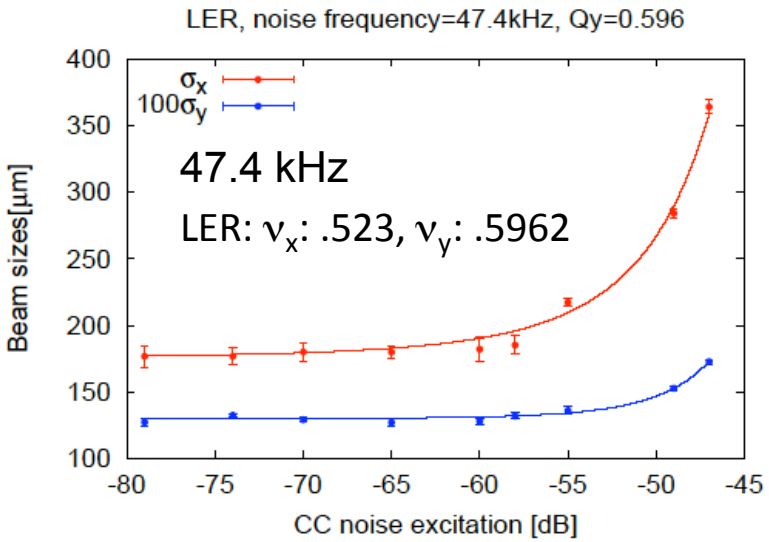




Summarized by Rogelio-san

Single beams

LER



Close to ν_x

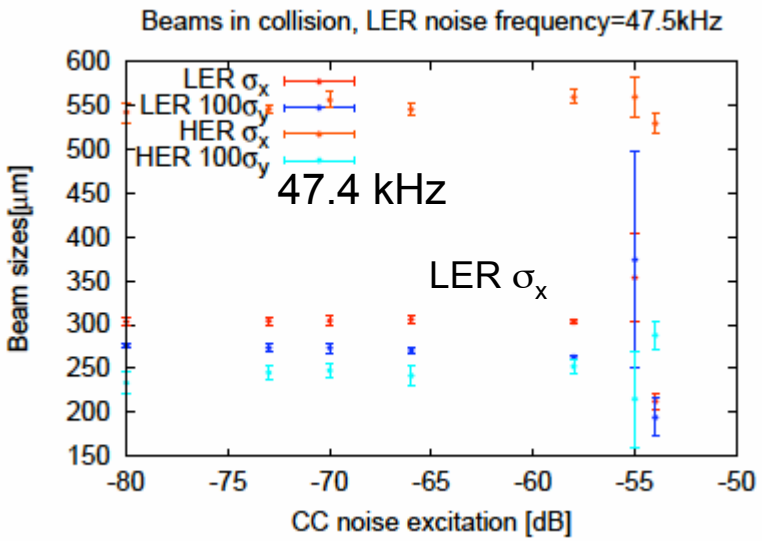
We tested again for LER single beam with a different vertical tune.
ν_y: .589 →.5962

LER: ν_x: .523, ν_y: .583
HER: ν_x: .5226, ν_y: .6016

Summarized by Rogelio-san

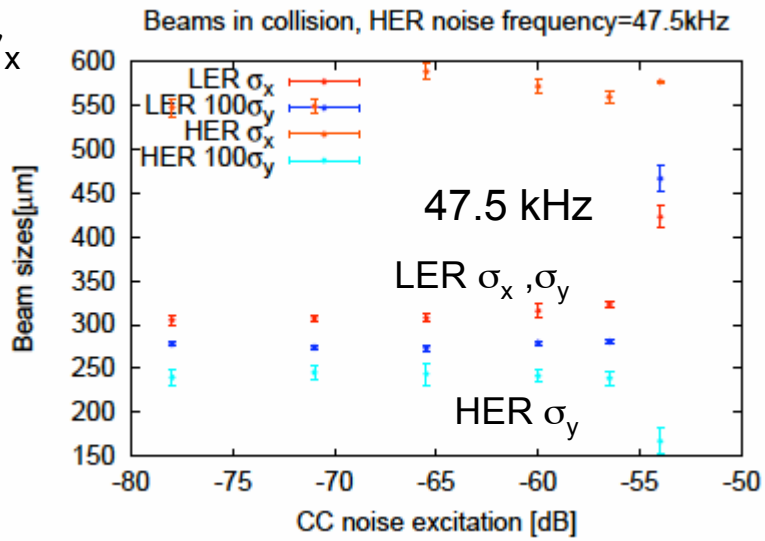
Colliding beams

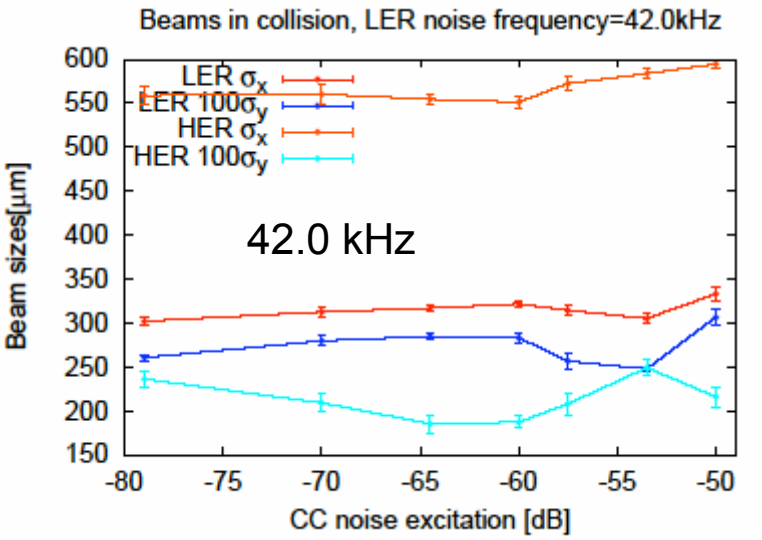
LER CC noise



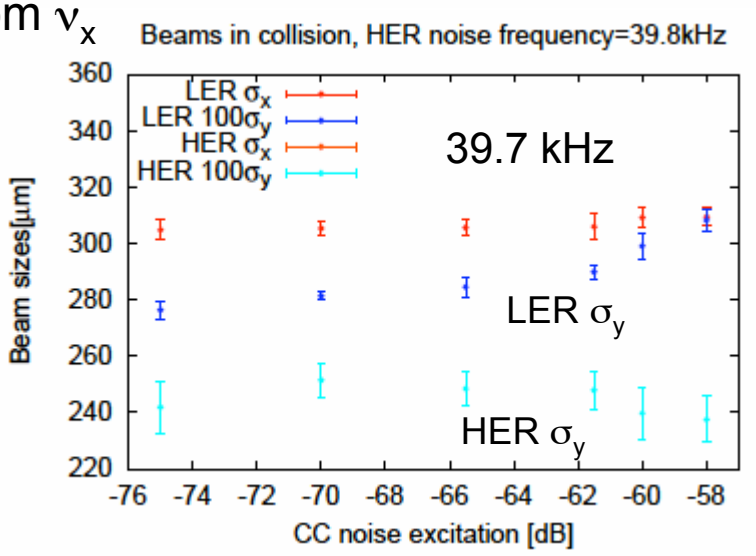
Close to ν_x

HER CC noise





Far away from ν_x
Close to ν_y



Summary of study 1

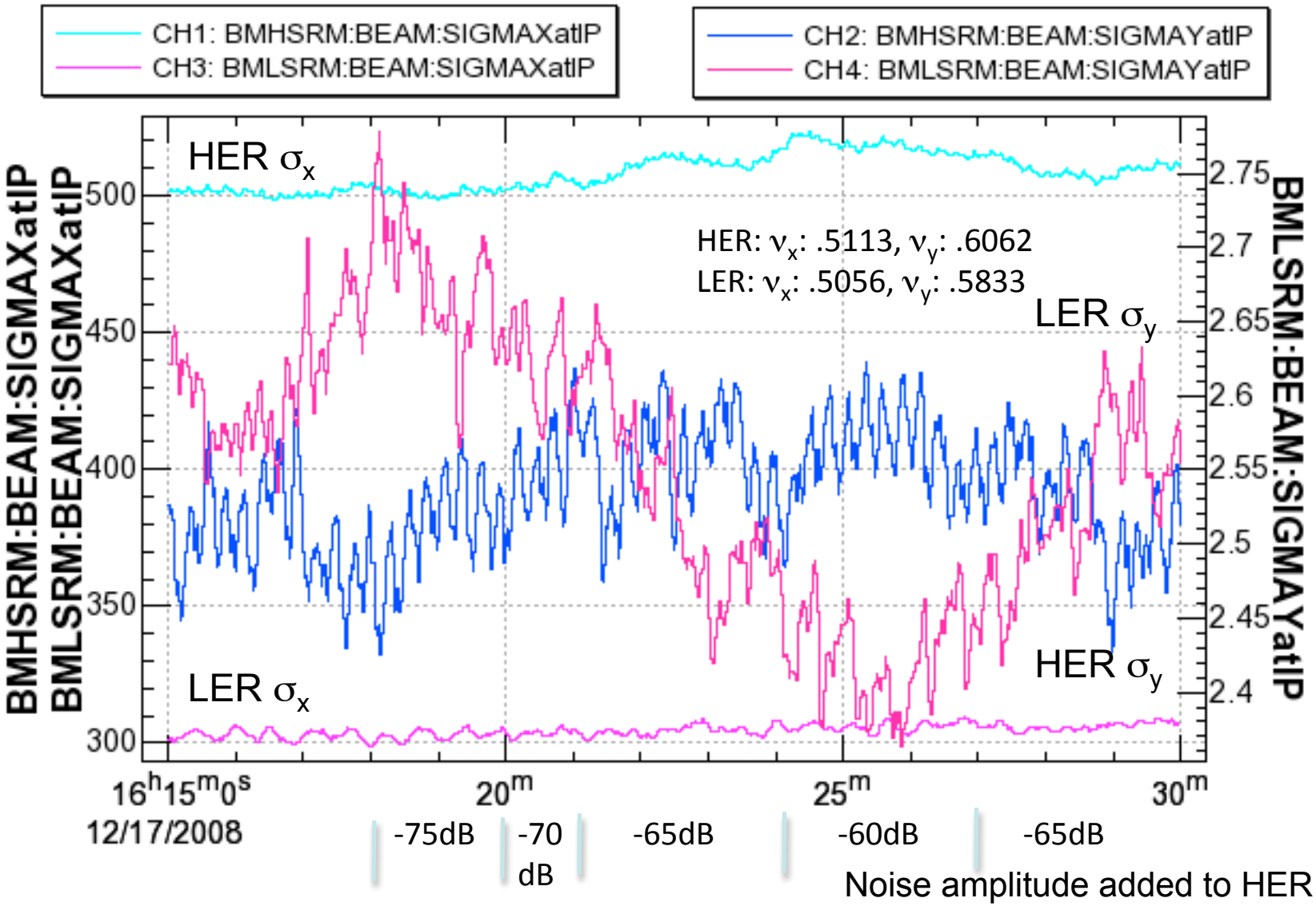
Beam condition	Noise	Beam size	
LER single	LER ν_x	LER σx ↑ LER σy ↑	Threshold: -60dB
	LER ν_y		
HER single	HER ν_x	HER σx ↑	Threshold: -60dB
	HER ν_y		
Colliding	LER ν_x	LER σx ↑ ??	Not significant
	LER ν_y		
	HER ν_x	HER σy ↓ LER σx ↑ LER σy ↑	
	HER ν_y	HER σy ↓ LER σy ↑	

How can we understand these behaviors?

Funakoshi

HER crab controlled phase noise 39.1kHz (HER:ν_y)

2008/12/17
1600/1037mA (L/H)
1585 bunches

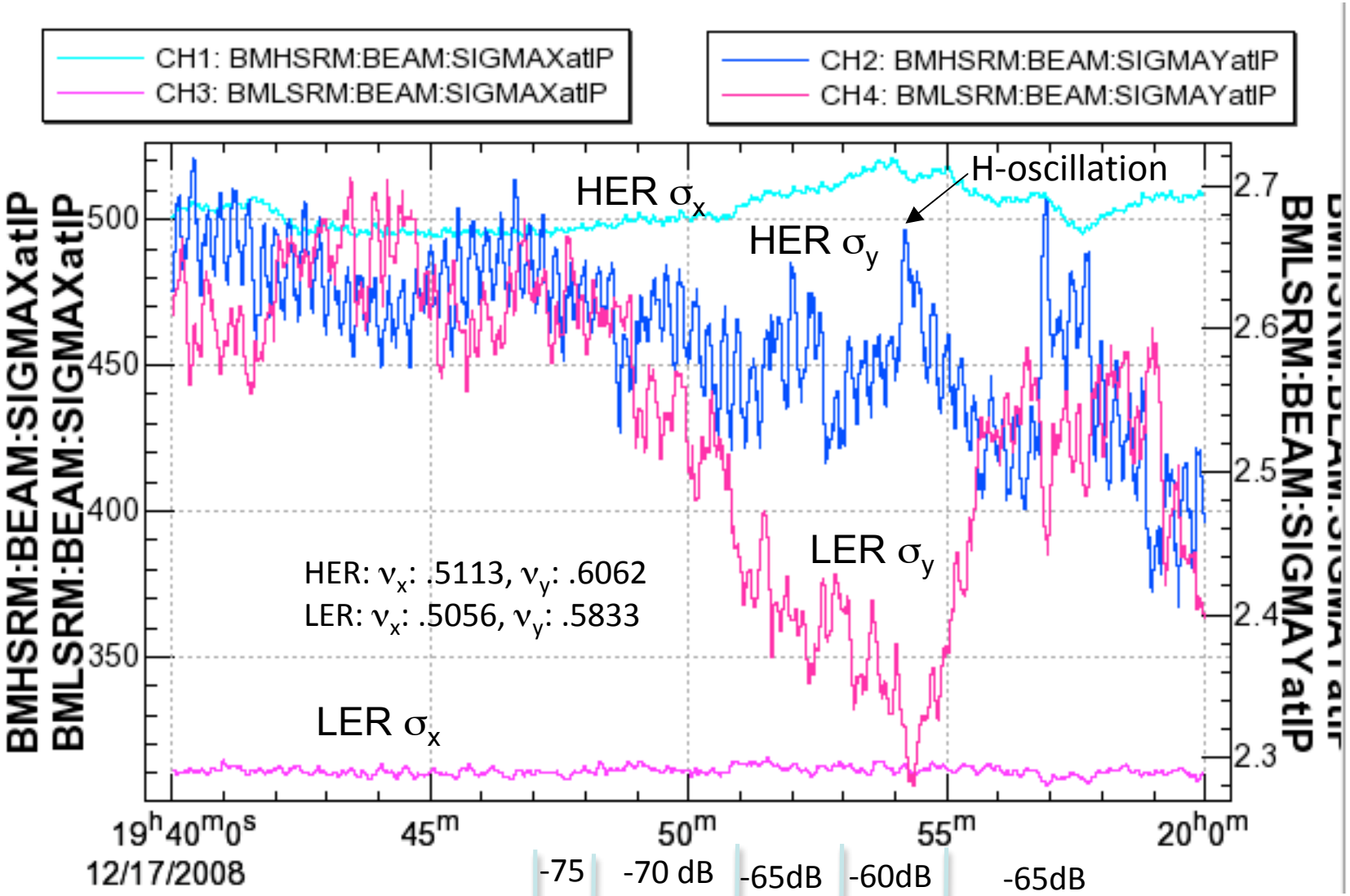


Noise amplitude added to HER crab

Funakoshi

HER crab controlled phase noise 41.1kHz (LER:ν_y)

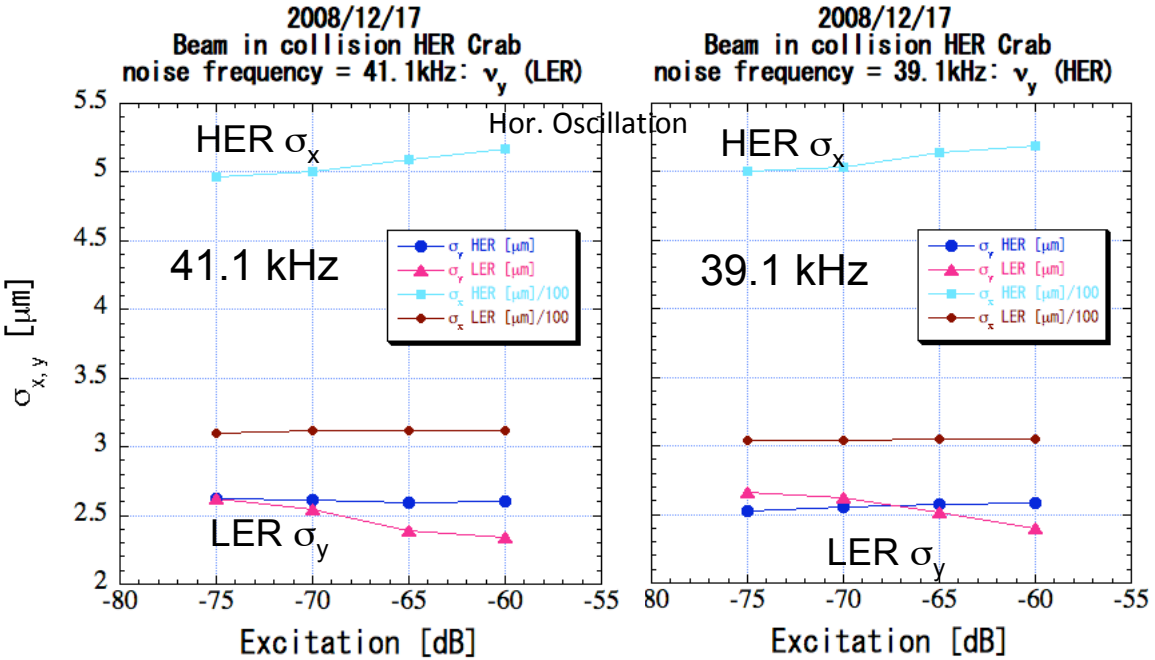
2008/12/17
1600/1037mA (L/H)
1585 bunches



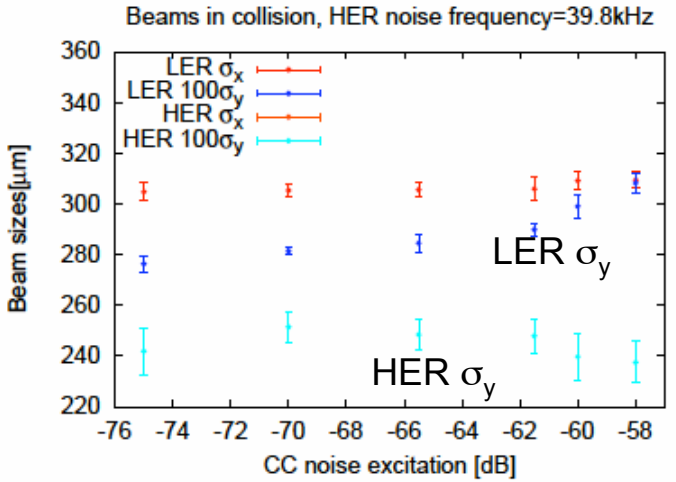
Funakoshi

Study results and comparison with previous data

Present data (Dec. 17) contradict previous data (Dec. 12).
These behaviors depend on tuning conditions.



Previous data
39.8 kHz



Dec. 17
Physics run (LER 1.6A, HER 1.1A)
HER: ν_x: .5113, ν_y: .6062
LER: ν_x: .5056, ν_y: .5833

Dec. 12
Beam study (LER 100mA, HER 65mA)
LER: ν_x: .523, ν_y: .583
HER: ν_x: .5226, ν_y: .6016

x-y coupling parameters scanned
R4

R4, x-y coupling parameter, was scanned as a tuning knob for both rings.
Measured Luminocity, Beam size, Beam life, etc. with and w/o RF noise.
No significant differences were observed.

Definition of R matrix

- Definition in the SAD code

$$\begin{pmatrix} u \\ p_u \\ v \\ p_v \end{pmatrix} = T \begin{pmatrix} x \\ p_x \\ y \\ p_y \end{pmatrix}$$

Normal (uncoupled) coordinate

Usual coordinate

$$T(s) = \begin{pmatrix} \mu I & SR^t S \\ R & \mu I \end{pmatrix} = \begin{pmatrix} \mu & 0 & -R4 & R2 \\ 0 & \mu & R3 & -R1 \\ R1 & R2 & \mu & 0 \\ R3 & R4 & 0 & \mu \end{pmatrix}$$

R matrix

$$S = \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}$$

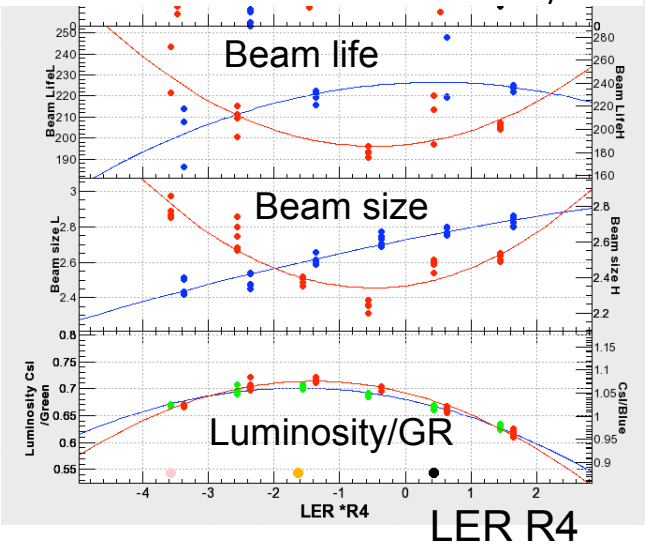
$$\mu^2 + \det R = 1$$

Funakoshi

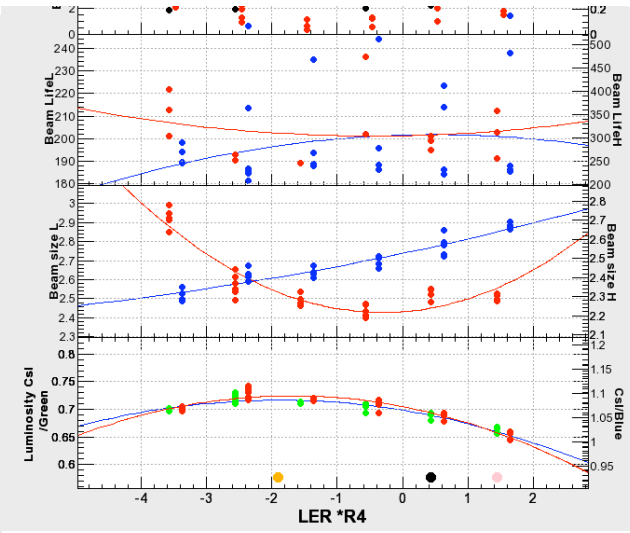
R4 scanning results

No significant variations.
Other parameters, R1,R2,R3 were also scanned, but no variations were found.

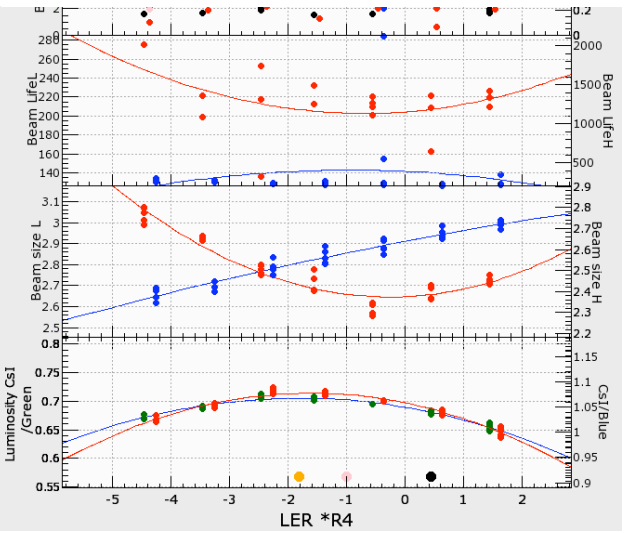
with noise:-65dB (HER:ν_y)



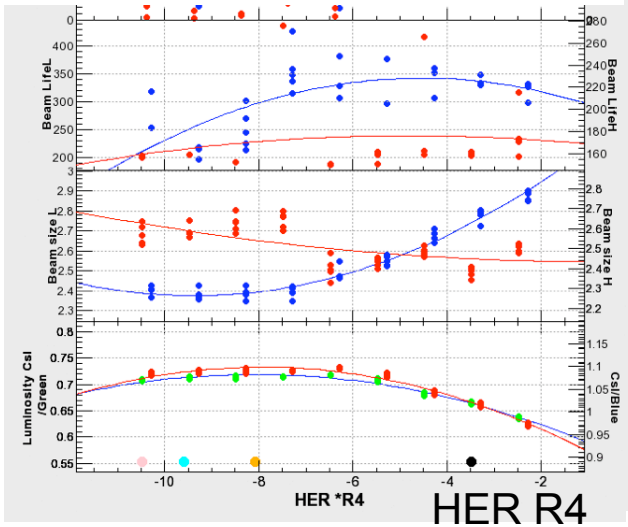
with noise:-65dB (LER:ν_y)

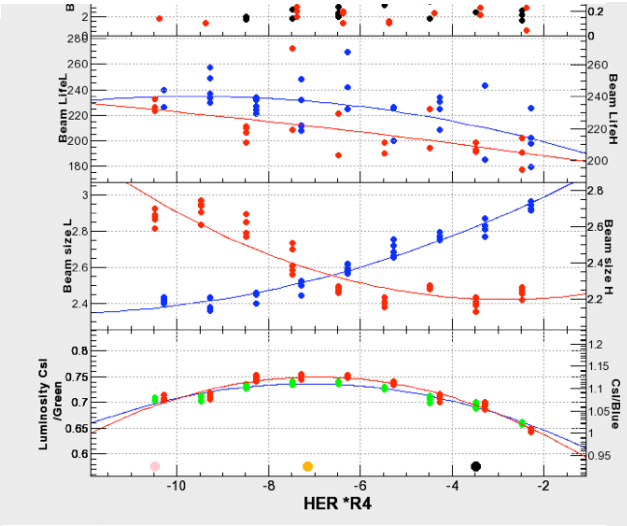


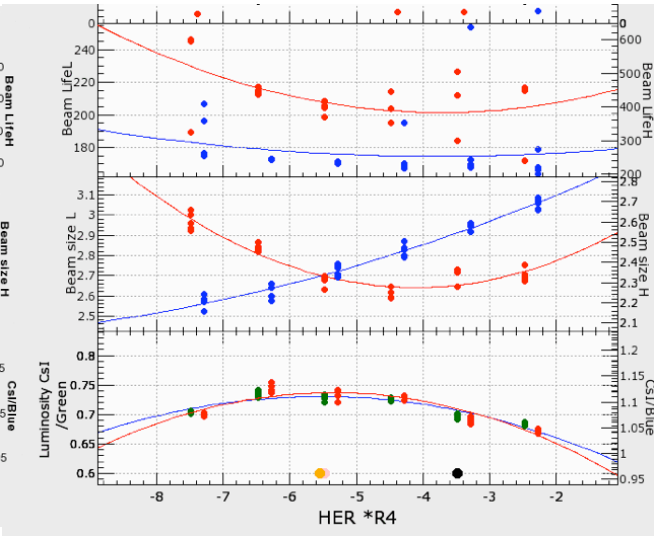
w/o noise



LER R4





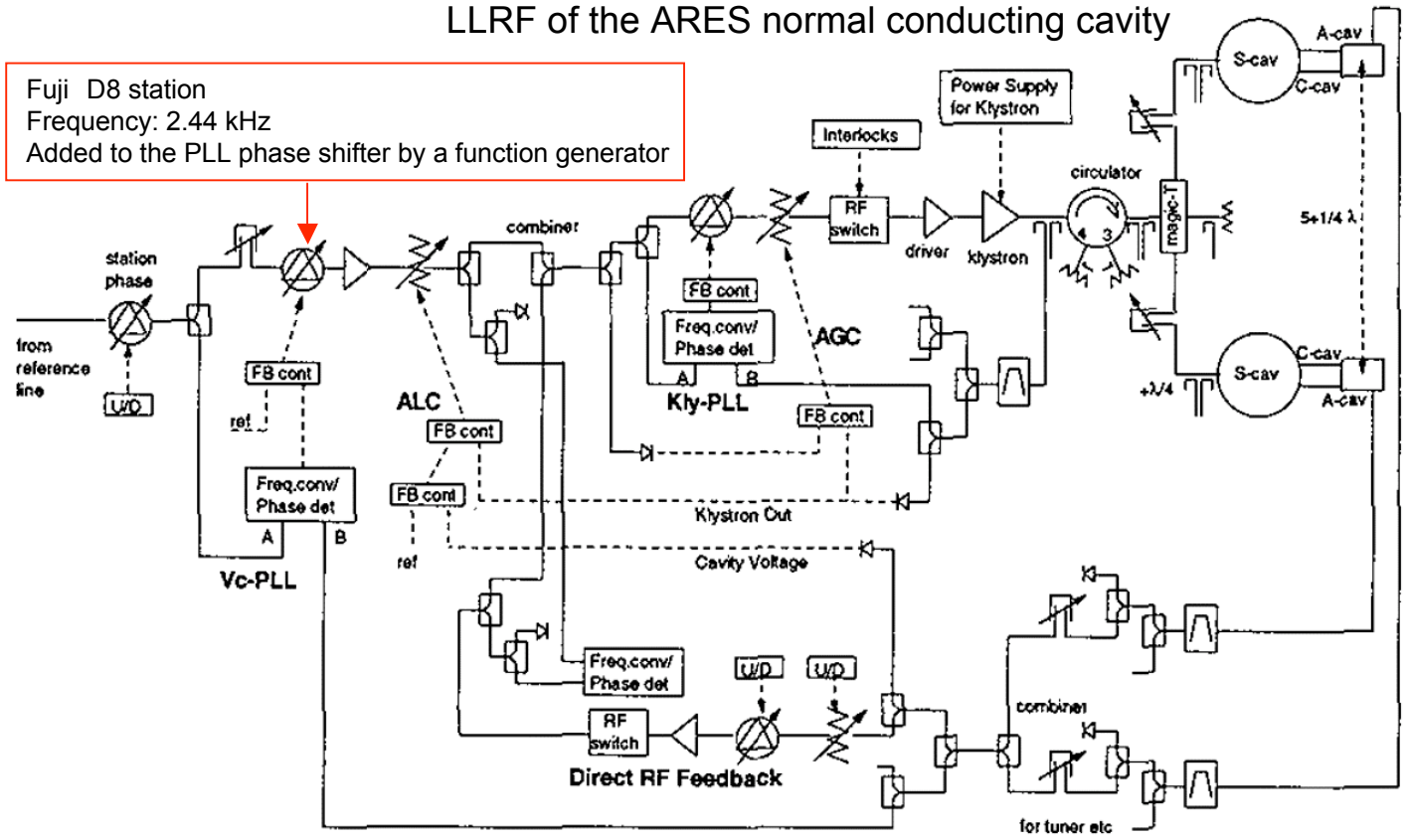


HER R4

Special study 2
Longitudinally kicked beam with crab cavities

- Longitudinal beam kick with ARES cavities
- Monitor beam position by Turn-by turn BPM (by Ohnishi-san)
  - BOR for backup (by Flanagan-san and Fukuma-san)

LLRF of the ARES normal conducting cavity



Beam study conditions

time	Beam	ARES	Freq(kHz)	amp (mV)	amp (-dB)	beam status	crab	Lkick	Hkick	FB	TBT-BPM	BOR
18:04		A-E	2.4449	4.6	55.3		ON	LOW	ON	ON	BPM1 80651	
18:08				12	46.5		ON	ON	ON	OFF	BPM1 80744	BOR1 80830
18:10				4.6			ON	LOW	OFF	OFF		BOR1 81212
18:15	pixD8			12			ON	ON	OFF	ON	BPM1 81807	BOR1 81624
							ON	ON	OFF	OFF		BOR1 81854
	crab OFF											
18:20				4.6			OFF	LOW	OFF	OFF		
18:23				12			OFF	ON	OFF	OFF	BPM1 82338	BOR1 82446
18:26				4.6			OFF	LOW	OFF		BPM1 82653	
18:27				12			OFF	ON	ON	OFF	BPM1 82750	BOR1 82836
							OFF	ON	ON		BPM1 82812	
18:30				4.6								
18:32				12			OFF	ON	OFF		BPM1 83239	
	LER single bunch operation: 1mA									FB-ON	until 18:06:05	
										FB-ON	18:15 to 18:18	

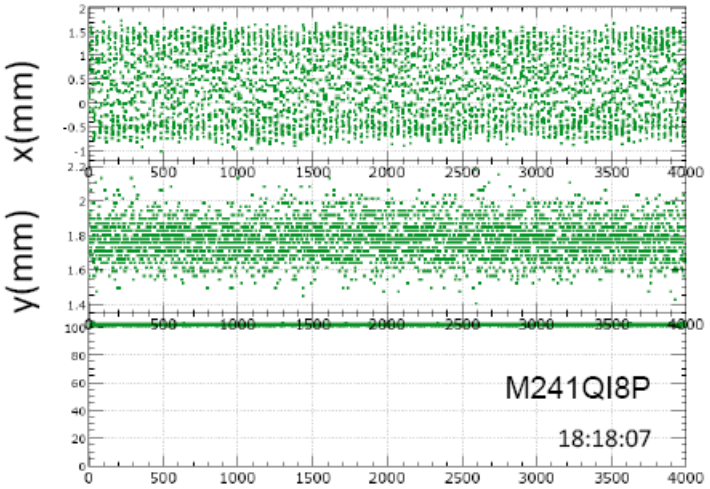
Control system of ARES (D8 station)

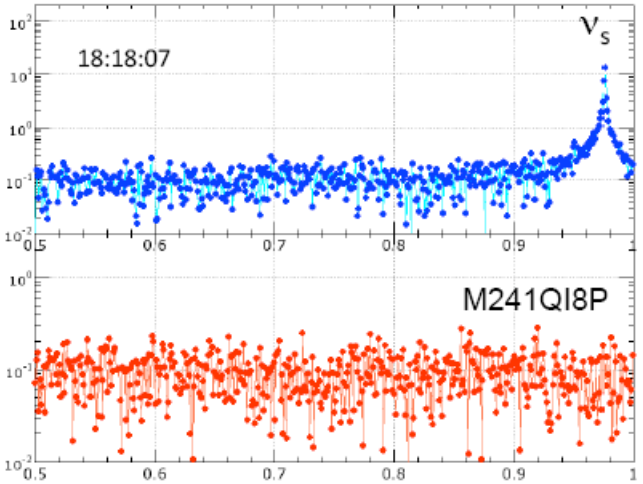
Pickup signal of the ARES D8A

Crab ON/OFF with longitudinal kick (-46.5 dB)

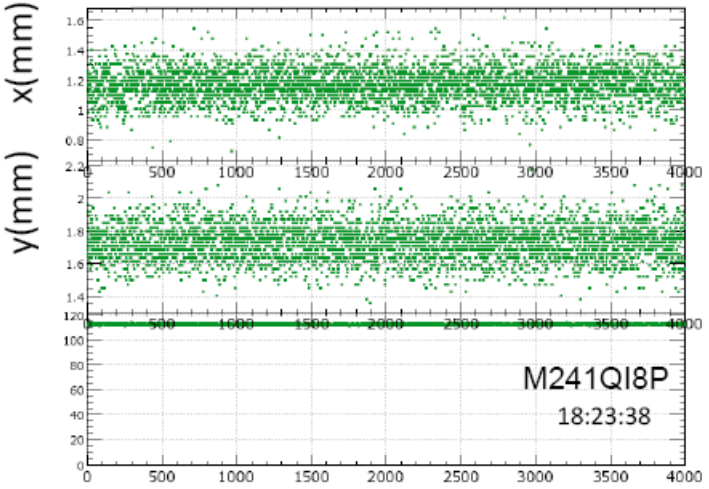
LER single beam: single bunch with 1 mA
Turn-by-turn BPM at no dispersion

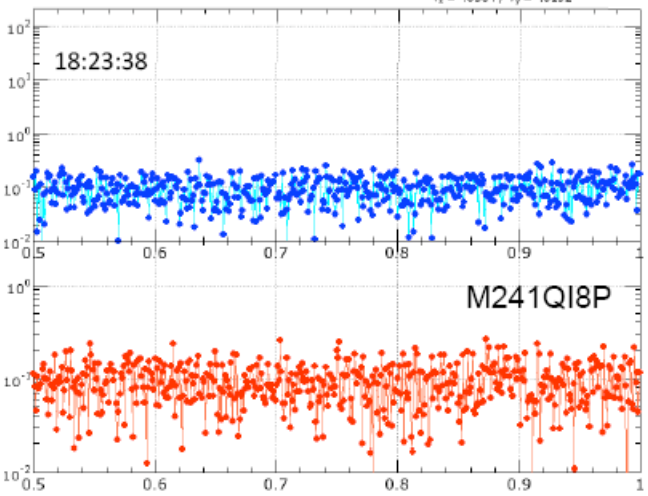
Crab ON





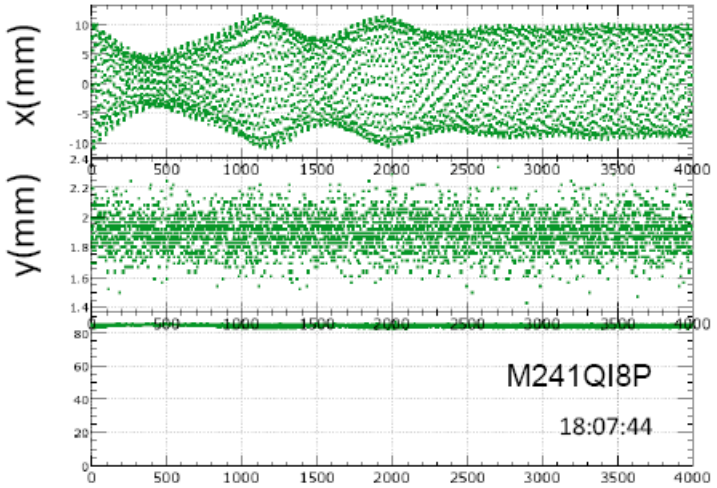
Crab OFF



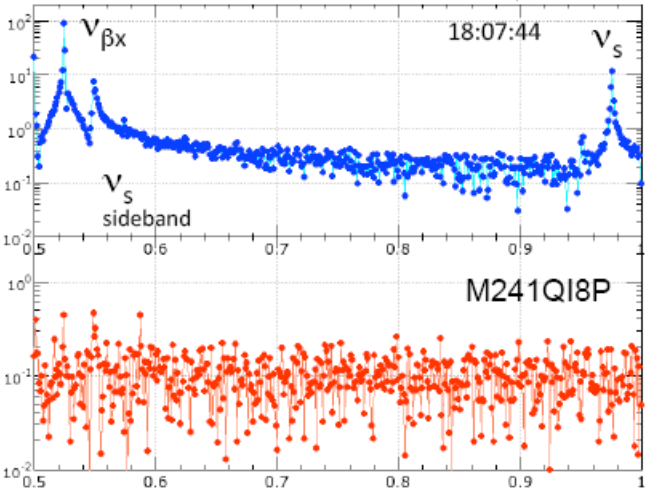


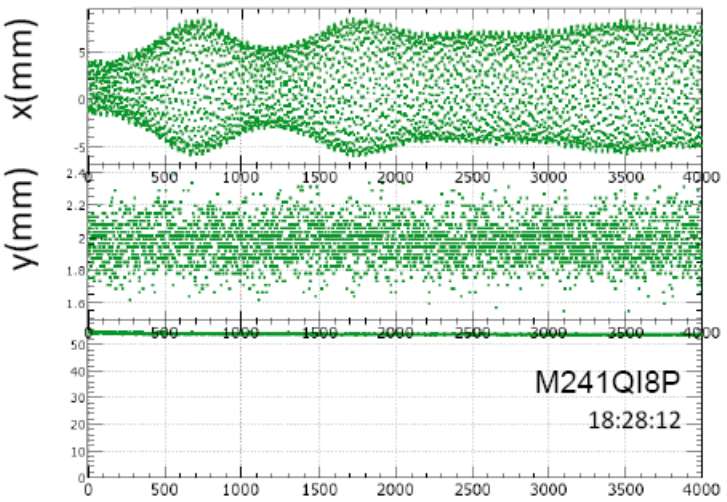
Crab ON/OFF with longitudinal kick and horizontal kick

Horizontal kick: injection kicker

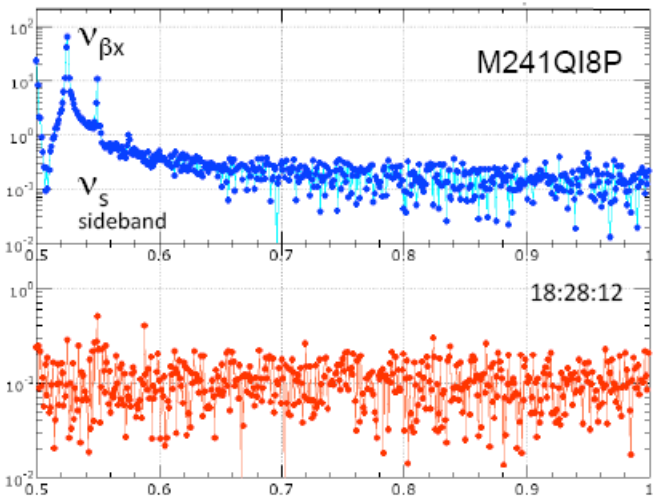


Crab ON

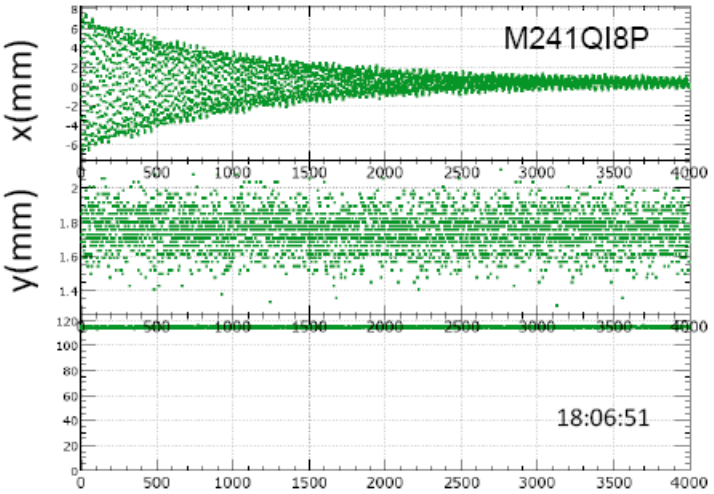




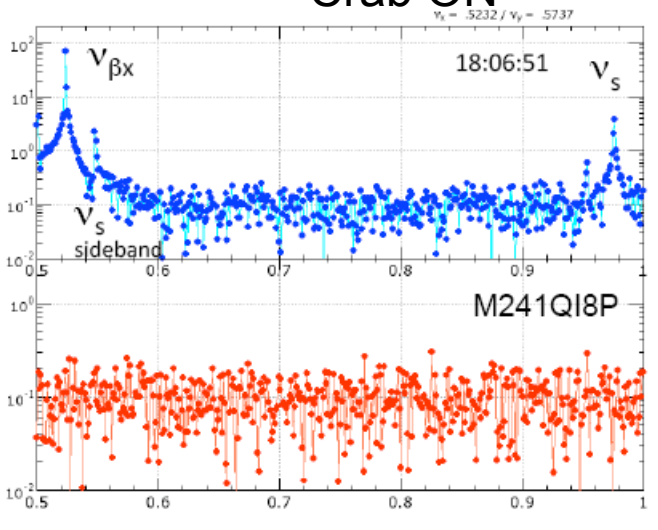
Crab OFF



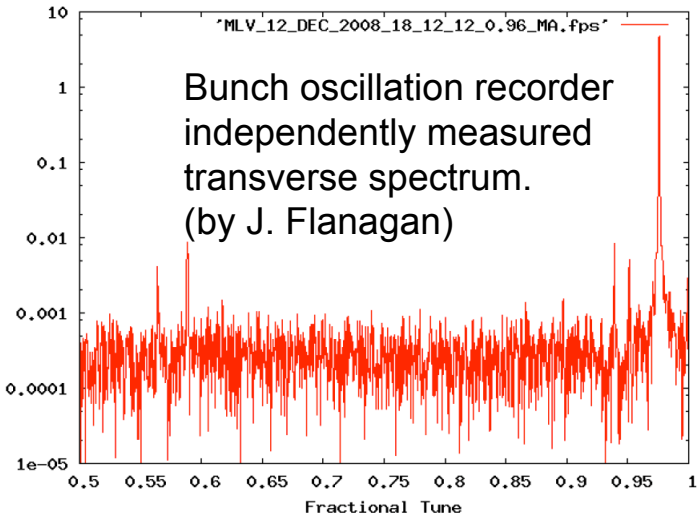
Crab ON with low longitudinal kick (-55.3 dB) and horizontal kick



Crab ON



Crab ON: L. Kick LOW, H. Kick OFF, FB ON



Summary of study 1 and 2

- Study 1
  - Controlled RF noise added to the crab cavity.
  - Single beam σ_x blew up near ν_x (threshold: -60dB)
  - No significant effects near ν_y (far away from ν_x)
  - Colliding beams have much complicated behaviors.
  - Those behaviors are dependent on tuning conditions.
    - Dec. 17 data contradict Dec. 12 data.
  - Need more studies to understand.

- Study 2
  - Longitudinal beam kick by ARES cavities.
  - First observation of x-z coupling at crab cavity.
  - Detailed data analysis in progress.