KEKB Crab Cavity Commissioning

Rama Calaga
BNL/LARP, March 15, 2007

A Great Big Thanks To:

K. Oide, K. Ohmi, H. Koiso, Y. Funakoshi & AP Group
K. Akai, K. Hosoyama, K. Yamamoto & RF Group

Outline

- Crab Cavity Design, RF Controls & Conditioning
- Beam Commissioning
- Optics & Collision tuning

Picture is worth a thousand words...

Getting There

Entrance

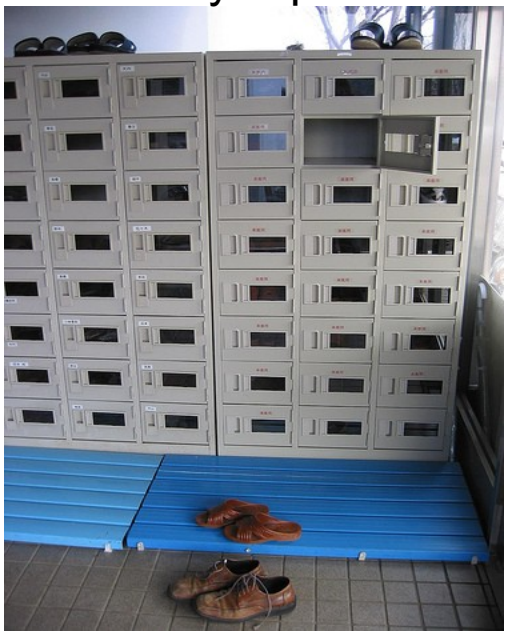
Dorm 2

KEKB Control Room

On my way

No parking problem

Better buy slip-on



KEKB Control Room

Solenoid Winding Samples for e-Cloud

Design Luminosity ~ 10^{34}
circa 1994

Lots of Luminosity

Main Monitors

Main Controls

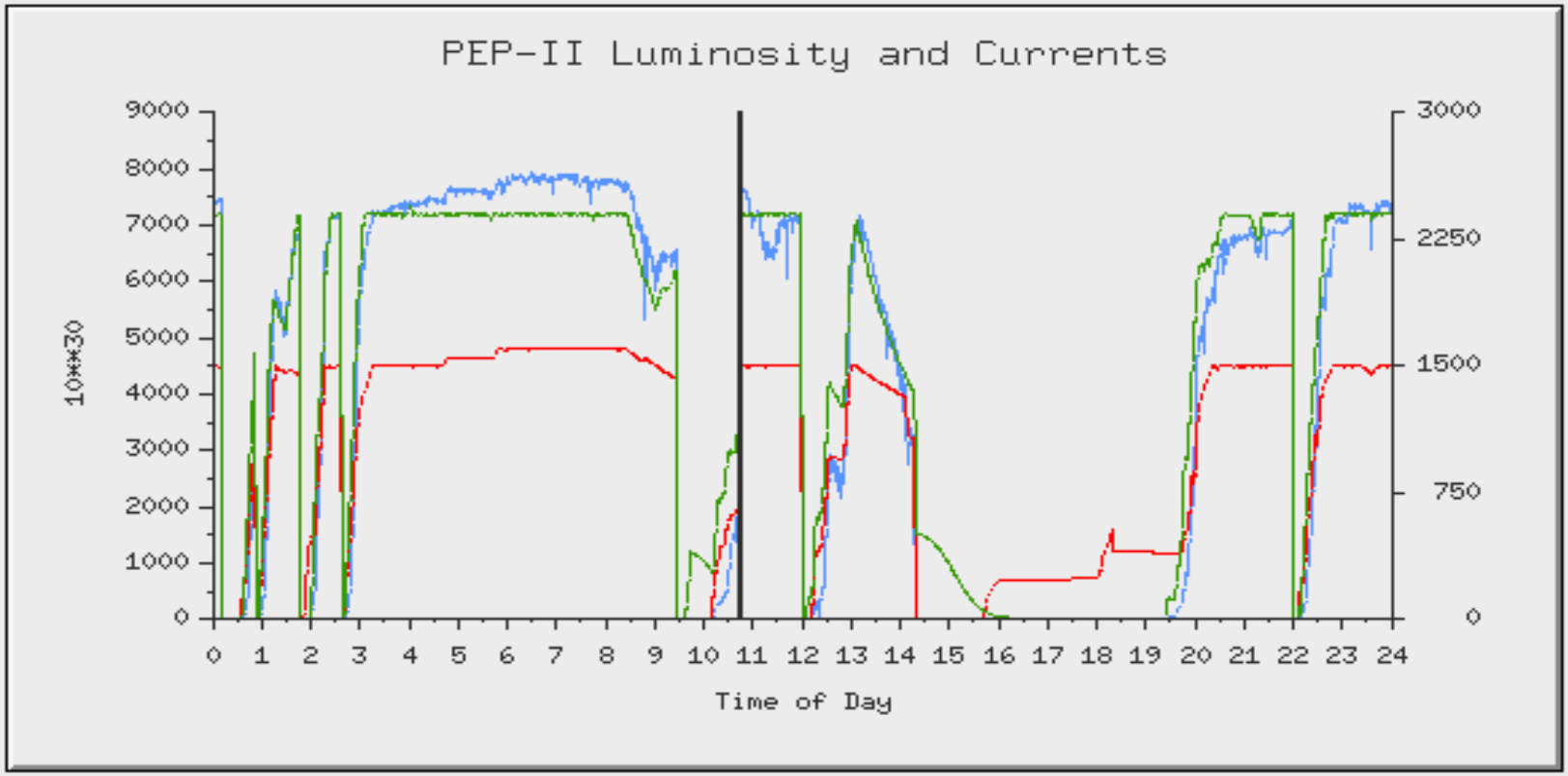
Keep Enemies Closer

I HER	I LER	Luminosity	Spec Lum	E HER	E LER	E CM
741.22	1363.33	2346	4.00	8985	3121	10590
mA	mA	10**30/Sec	N*10**30 / mA**2/Sec	MeV	MeV	MeV

HER N Buckets / Pattern
1722 0:3442:2

LER N Buckets / Pattern
1722 0:3442:2;0=.95

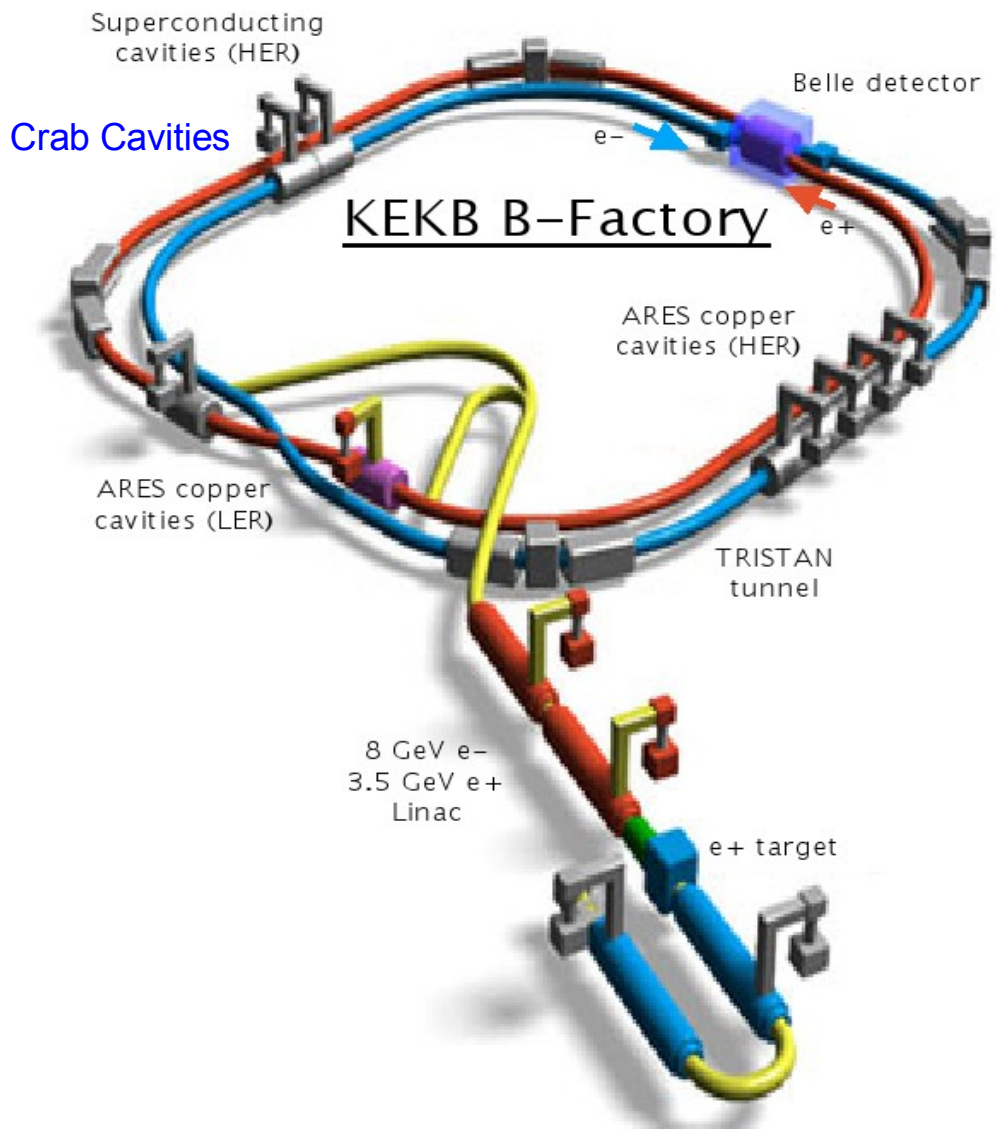
Last Owl/Day/Swing/24hr	159.6	100.6	81.2	341.4	Shift:	36.94 /pb
Peak Luminosities	7970	8092	7455			7865



03/12/2007 10:45:16

PEP II Luminosity & Currents

To More Serious Things



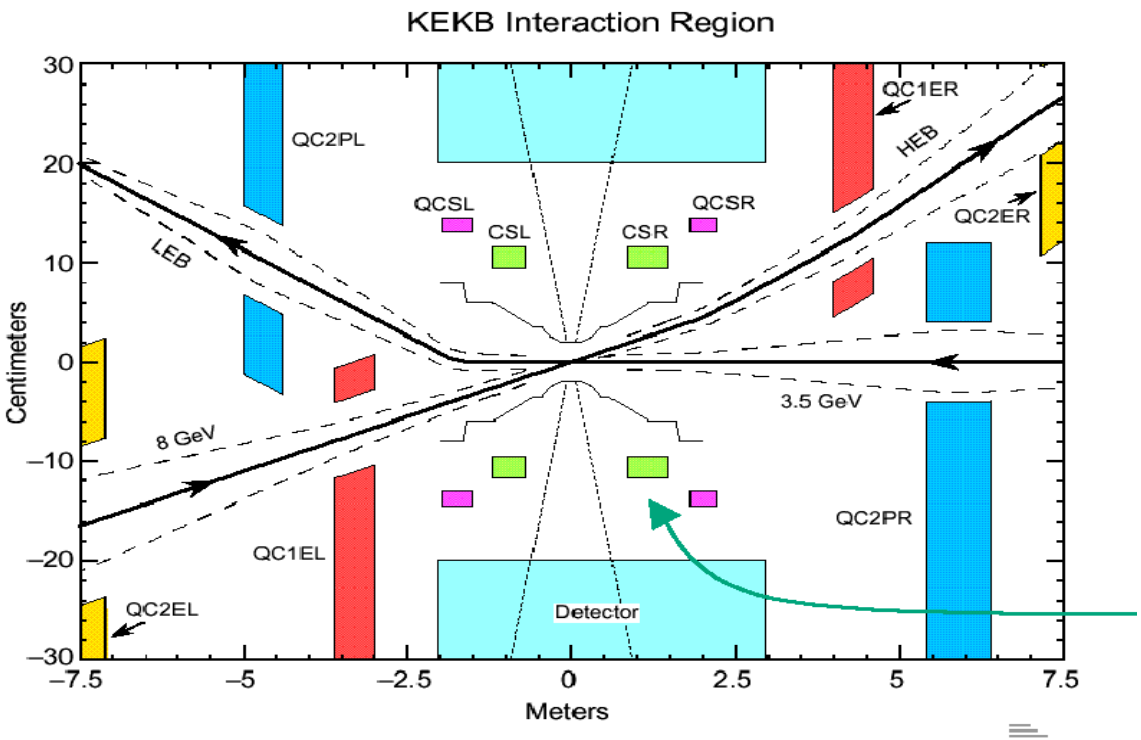
Machine Parameters

	HER	LER
Energy	8 GeV	3.5 GeV
Beam Current	1.662 A	1.34 A
Number of Bunches	1388	1388
Bunch Current	1.2 mA	0.965 mA
Betatron Tune	45.505/43.534	44.509/41.565
Beta Function IP	59/0.65 cm	56/0.59 cm
Bunch Spacing	2.1 m (7 nS)	
Bunch Length	6 mm	
RF & Crab Frequency	508.88 Mhz	

Estimated $\sigma_y^* \sim 2\ \mu m$

Courtesy K. Oide

Crossing Angle (22 mrad)



- Simple IR Design
- No bend for incoming beam
- Solenoid compensation for smaller β
- Smaller bunch spacing (e-cloud)
- Parasitic interactions ??

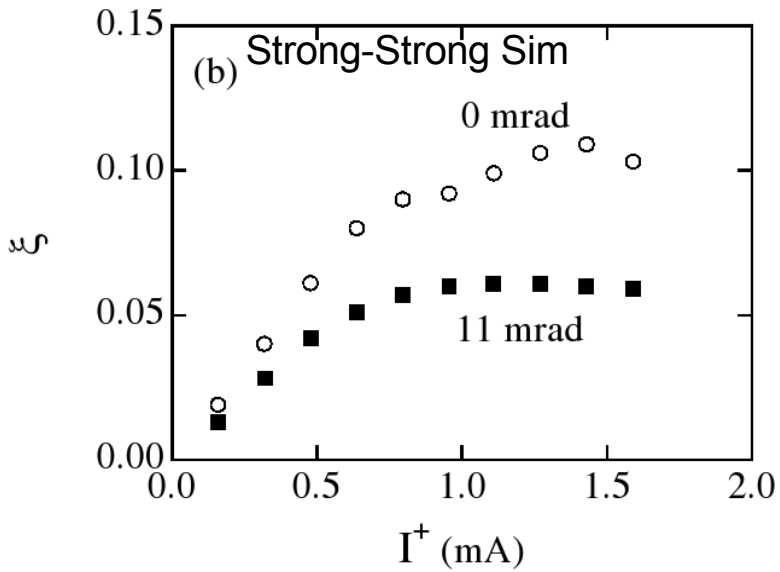
Crossing angle induces z-dependent dispersion at IP

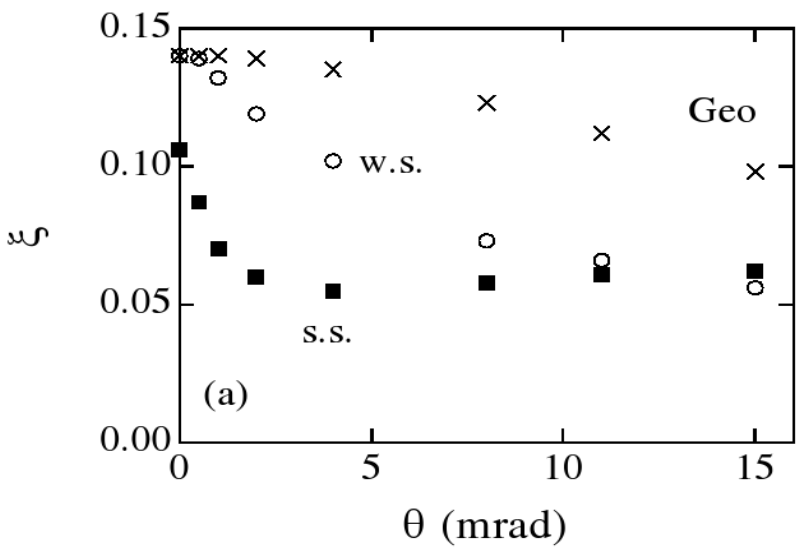
$$\zeta_x = \delta x / z$$

- Geometric luminosity reduction (~ 20%)
- Max achievable BB parameter due x-z coupling (~ factor of 2 smaller)

Courtesy K. Oide

BB Parameter





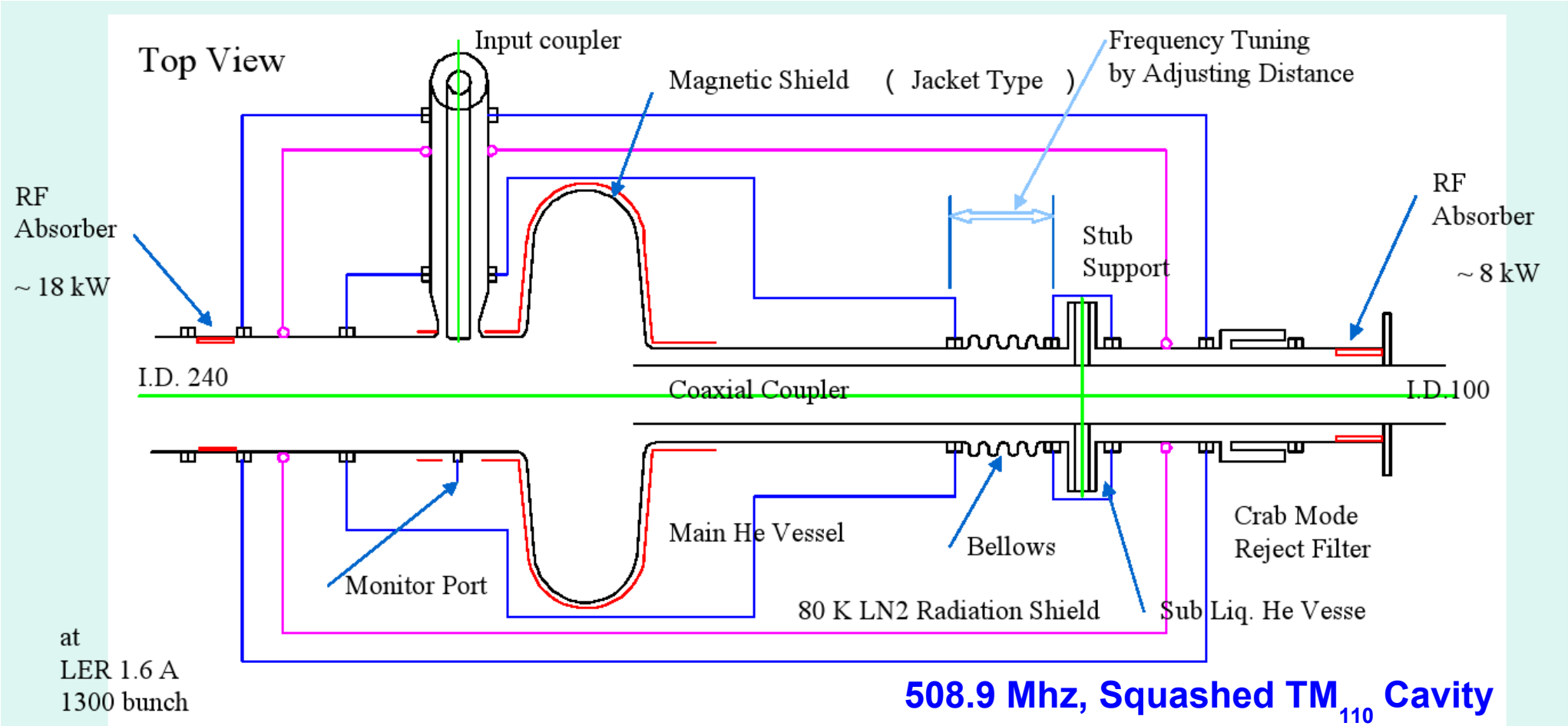
- Max ξ_y with 22mrad crossing angle ~ 0.05
- **$\xi_y \geq 0.1$ with crab cavities** (SS & WS Sim)
- Crab phase tol ~ 0.1 deg (Not Difficult!!)

Luminosity degradation due to vertical diffusion induced by crossing angle

Ohmi et al., Phys. Rev. ST Accel. Beams 7, 104401 (2004)

Crab Cavity & RF

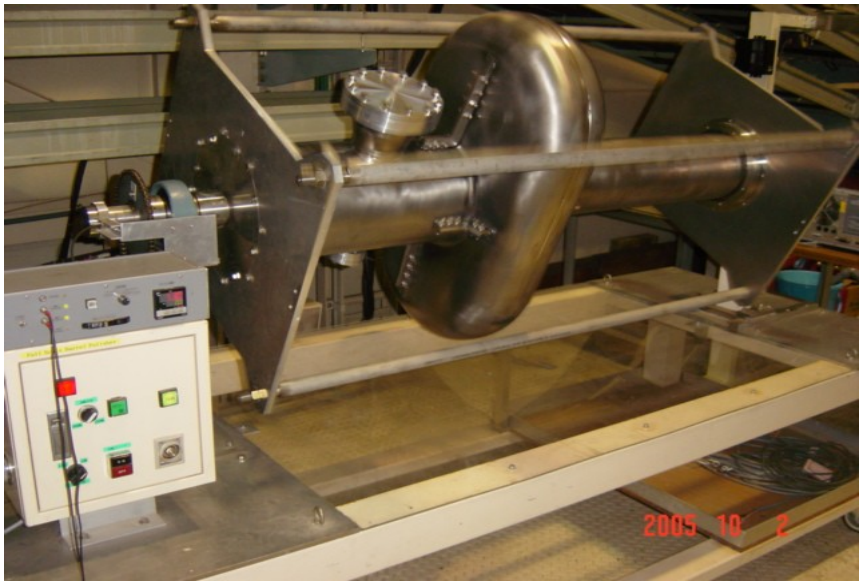
Cavity & Components

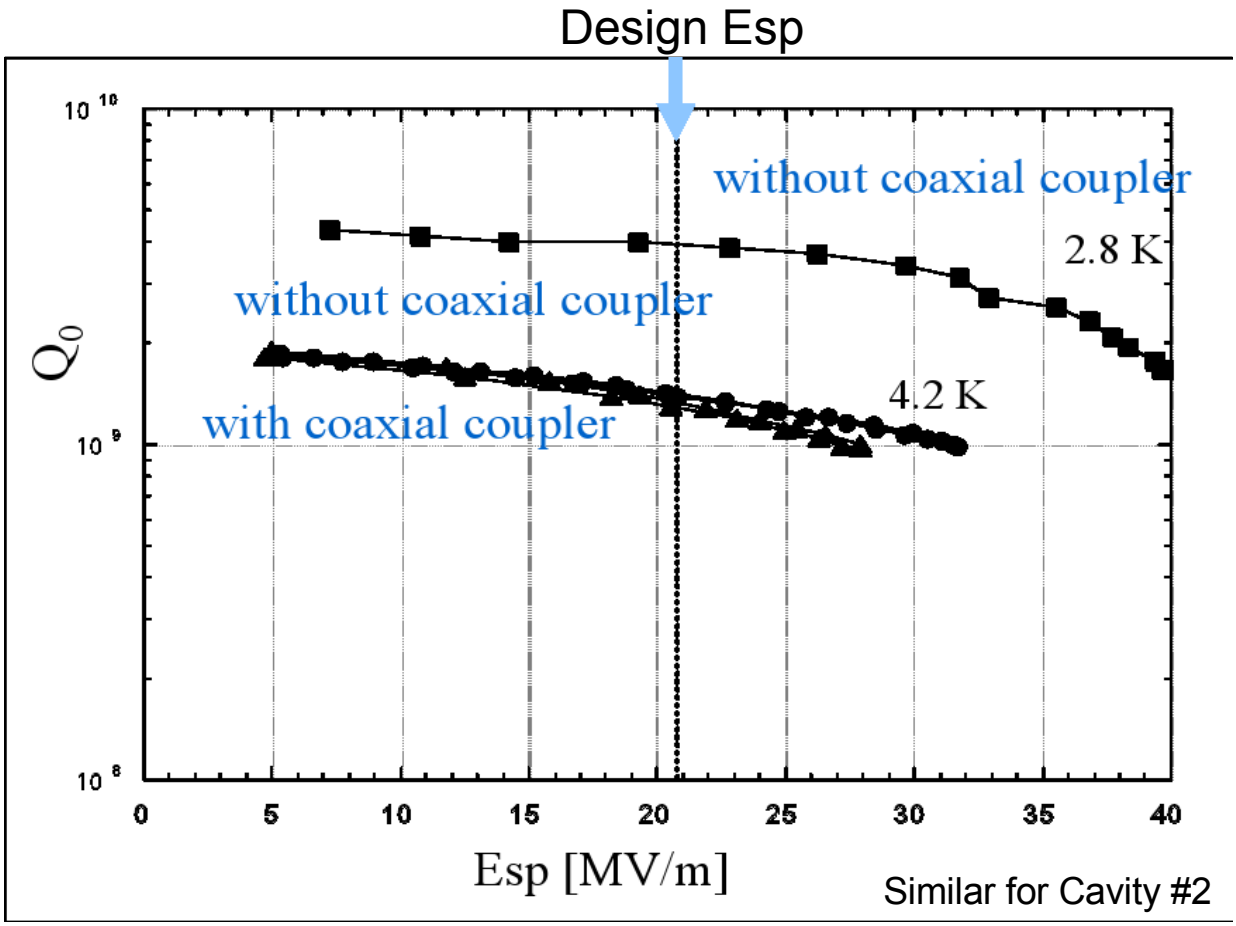


Frequency Tuning: Coax-Coupler (adjust Long. & Hor)

Courtesy K. Akai, K. Hosayama et al.

Cavity #1 Performance

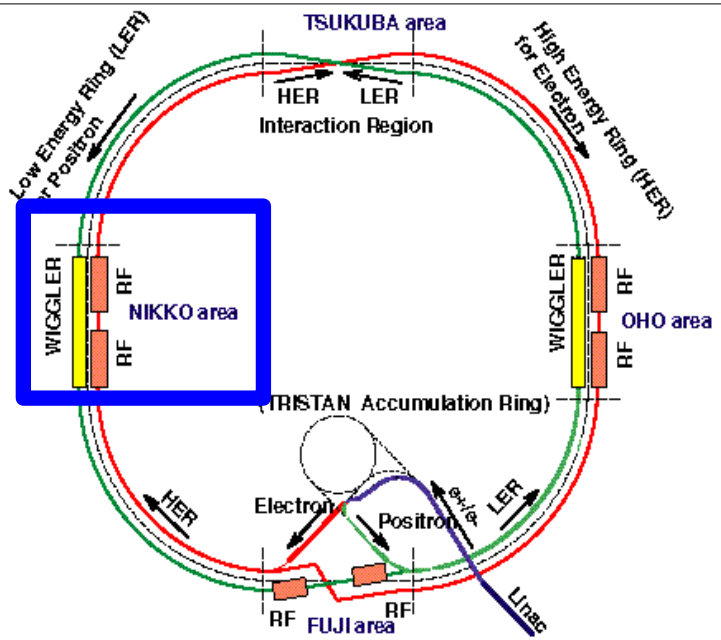




Similar for Cavity #2

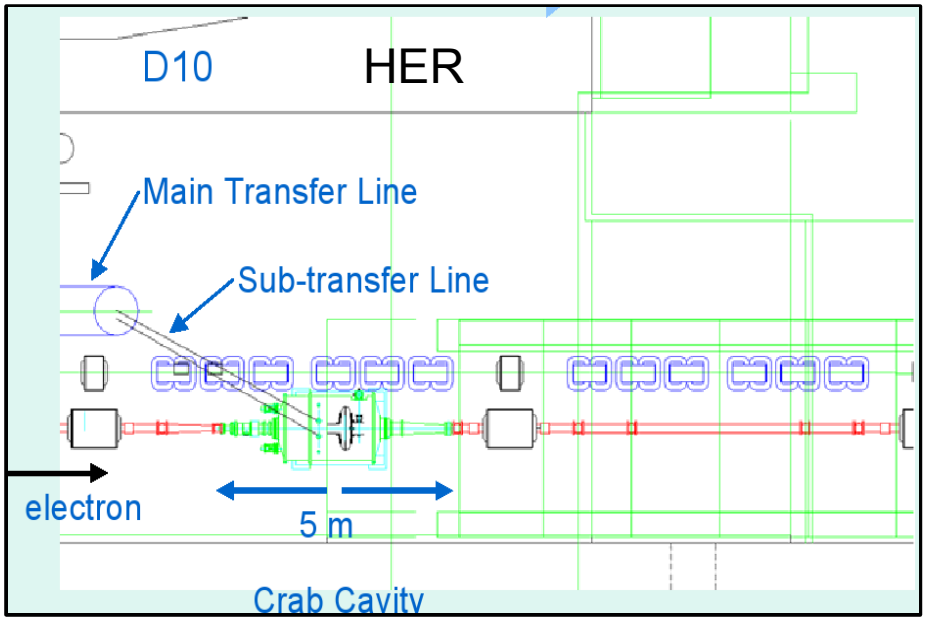
Courtesy K. Hosayama et al.

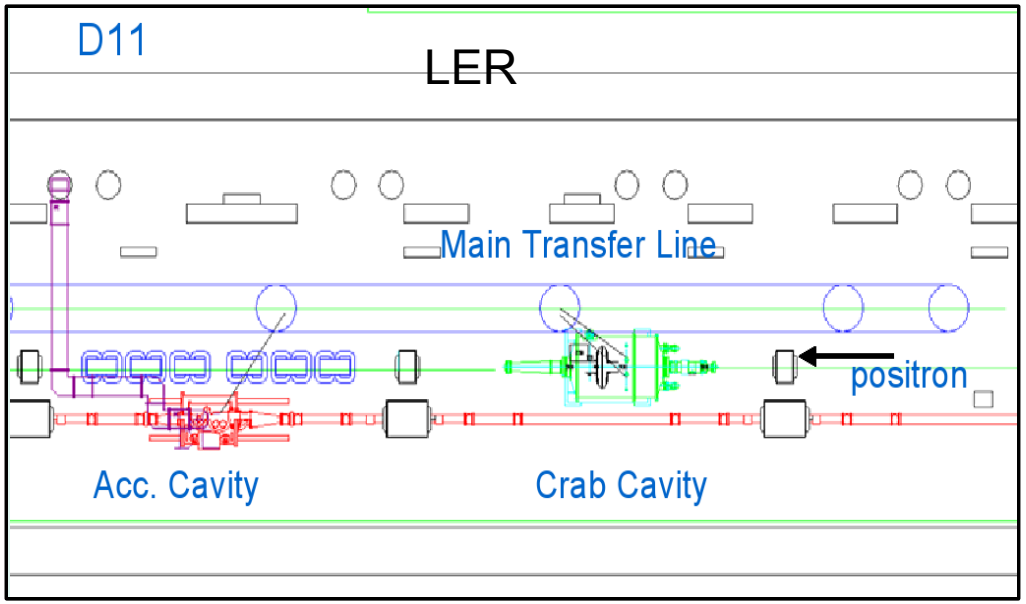
Cavity Installation



Global Crab Cavities 1/ring @NIKKO Area

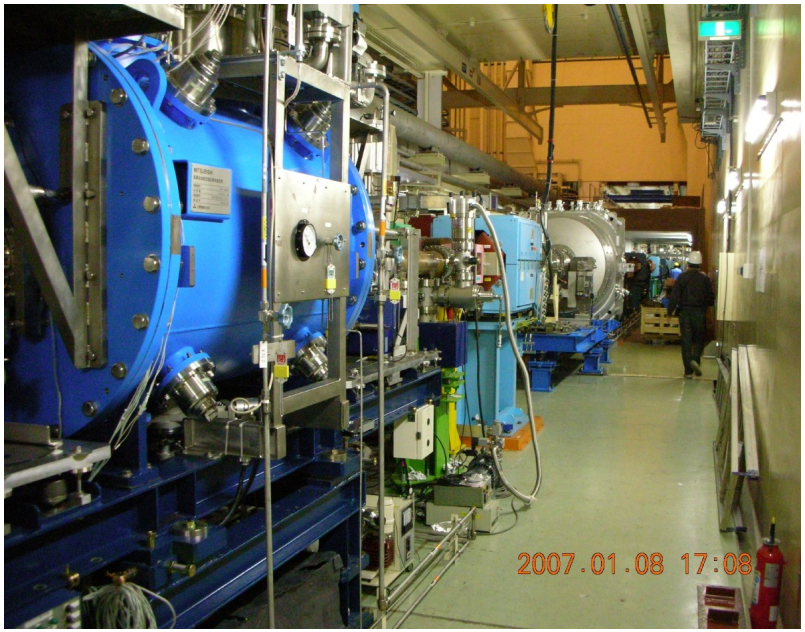
Use existing cooling for Acc. SRF Cavities





Courtesy K. Hosayama et al.

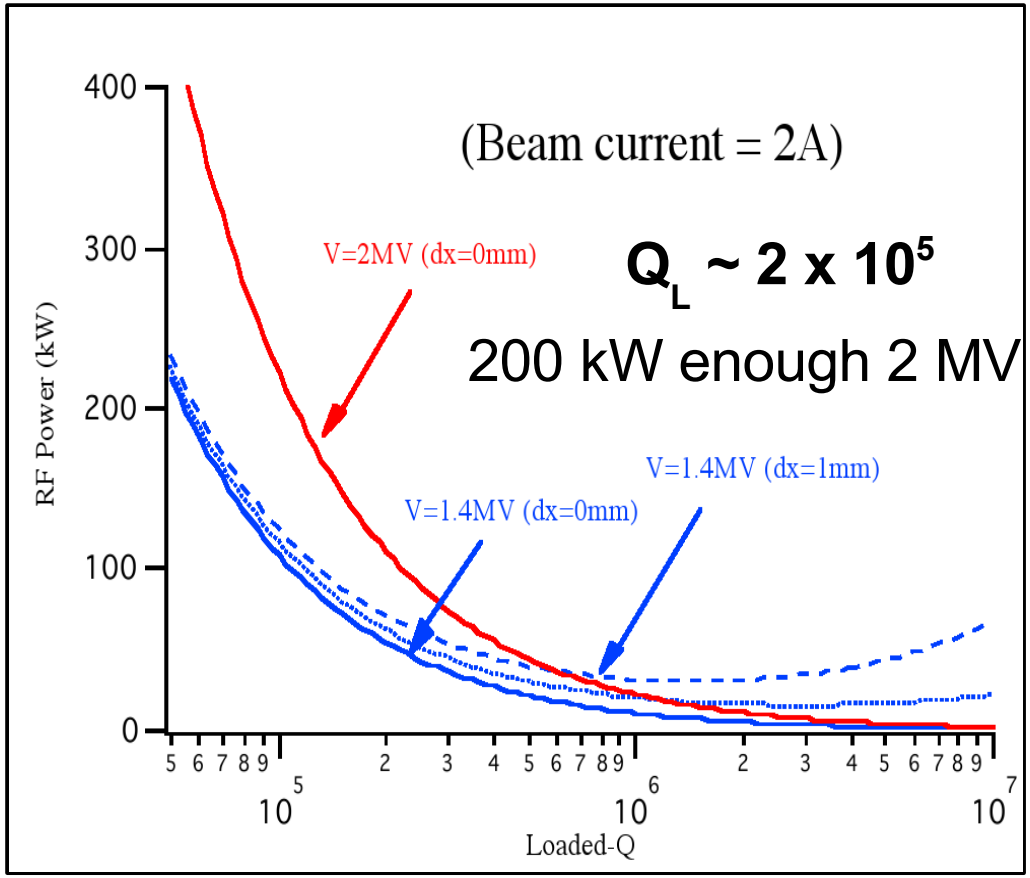
In the Tunnel

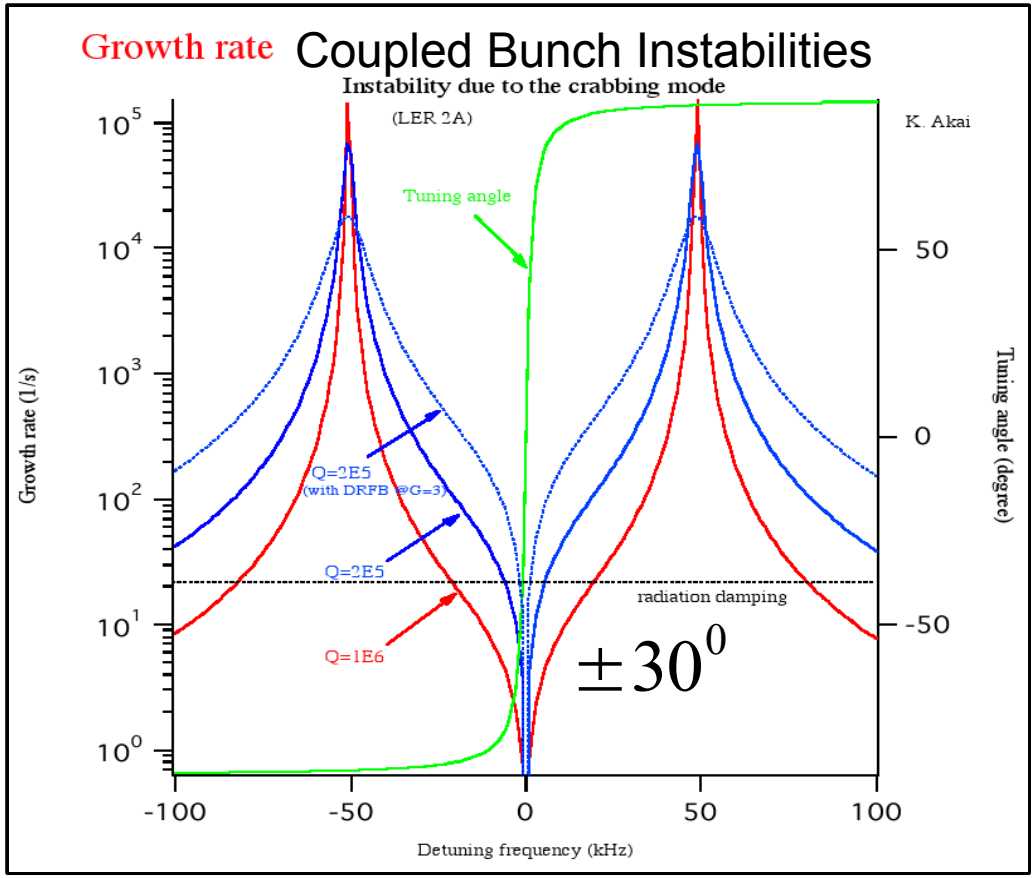


ME

They are doing the work, I am just posing for the camera

RF Power & Detuning

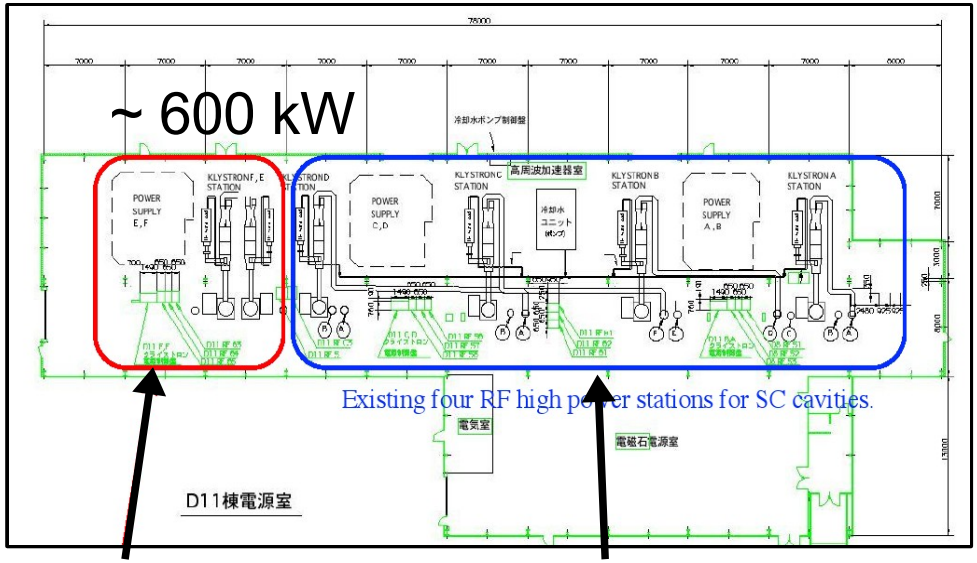




- Frequency is parked far away from ½F_{rev}
- Bunch by bunch feedback to cure CBI

Courtesy K. Akai

RF Control & Feedback

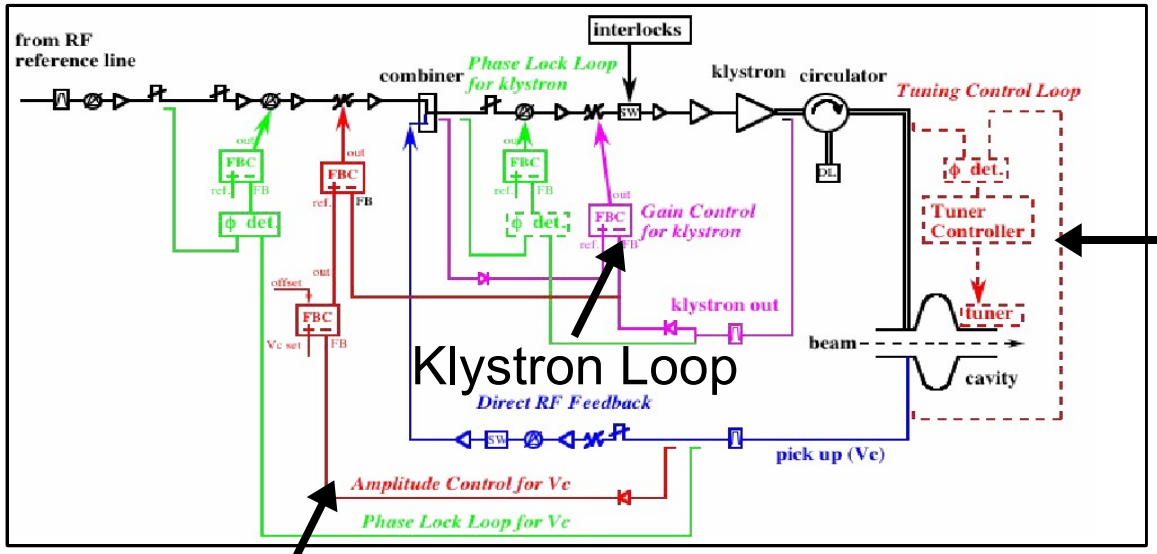


Crab Station

Acc Cavity Station

HER Low Level RF Control

Reference Signal

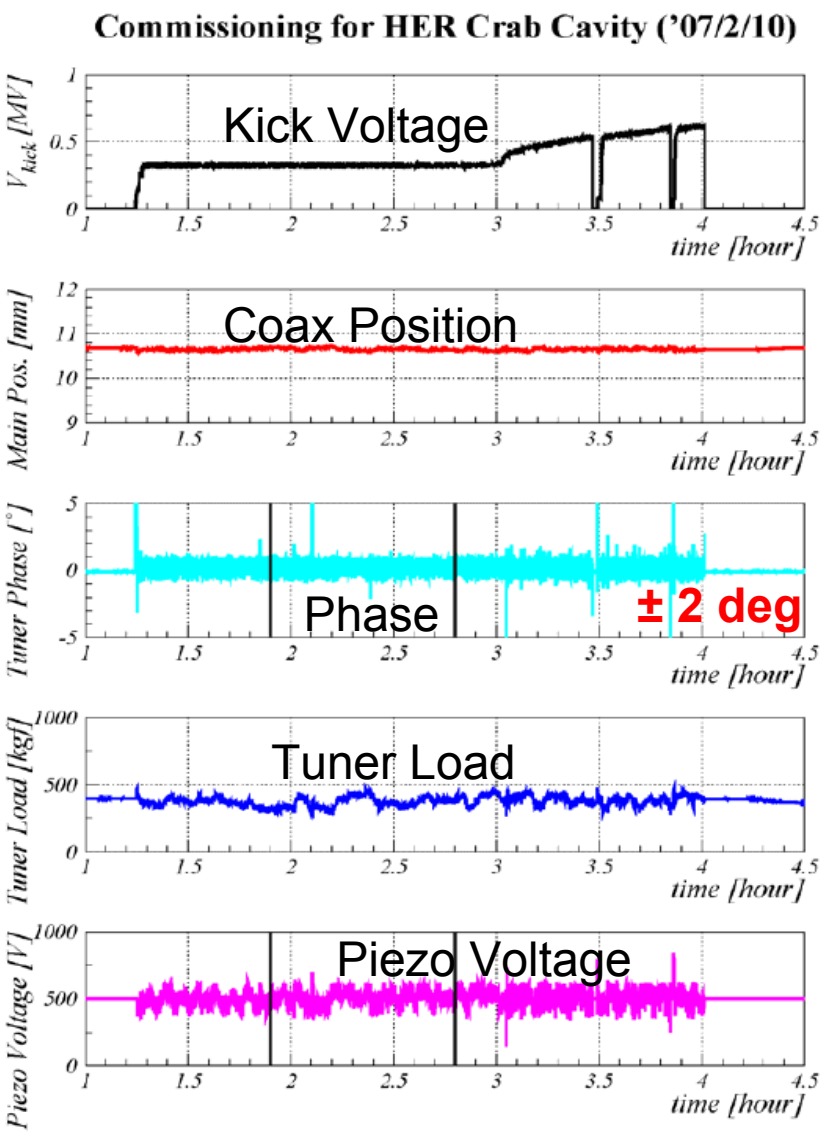


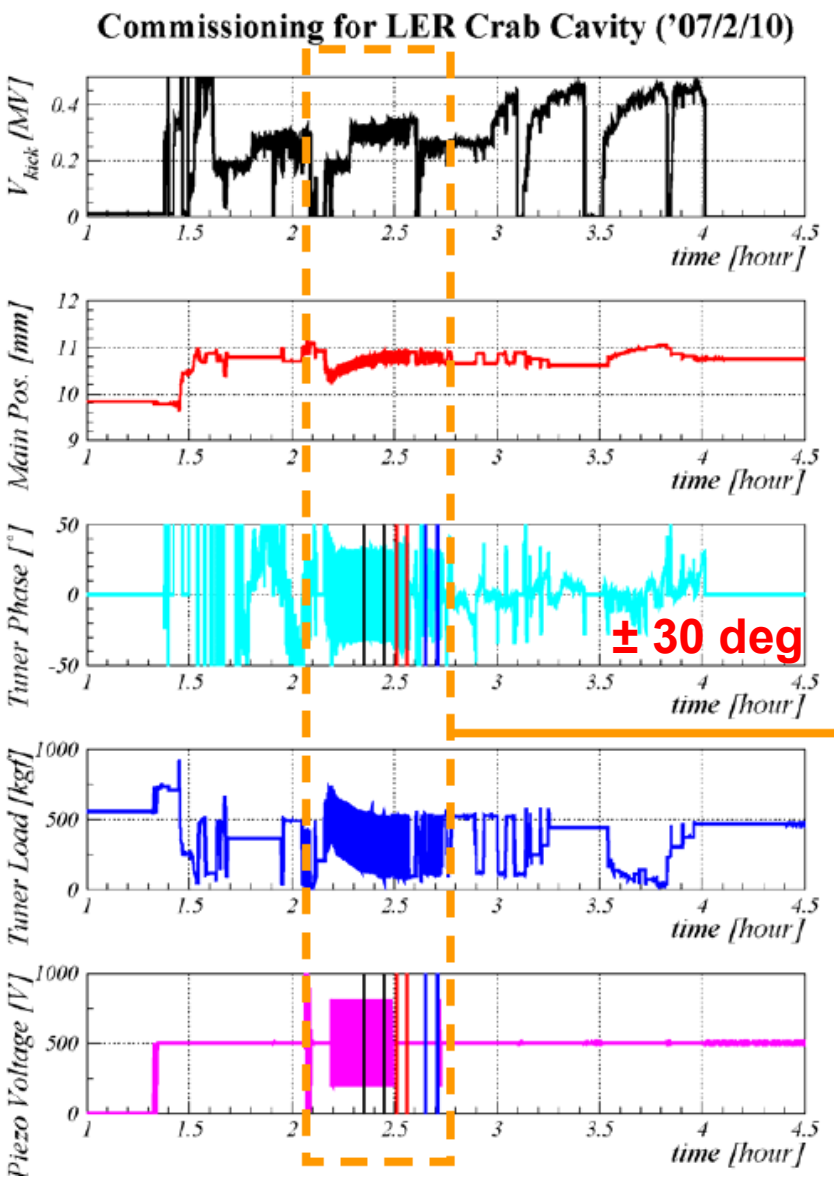
Tuning Loop (slow loop)

Amplitude & Phase Loop (fast loop)

Courtesy K. Akai

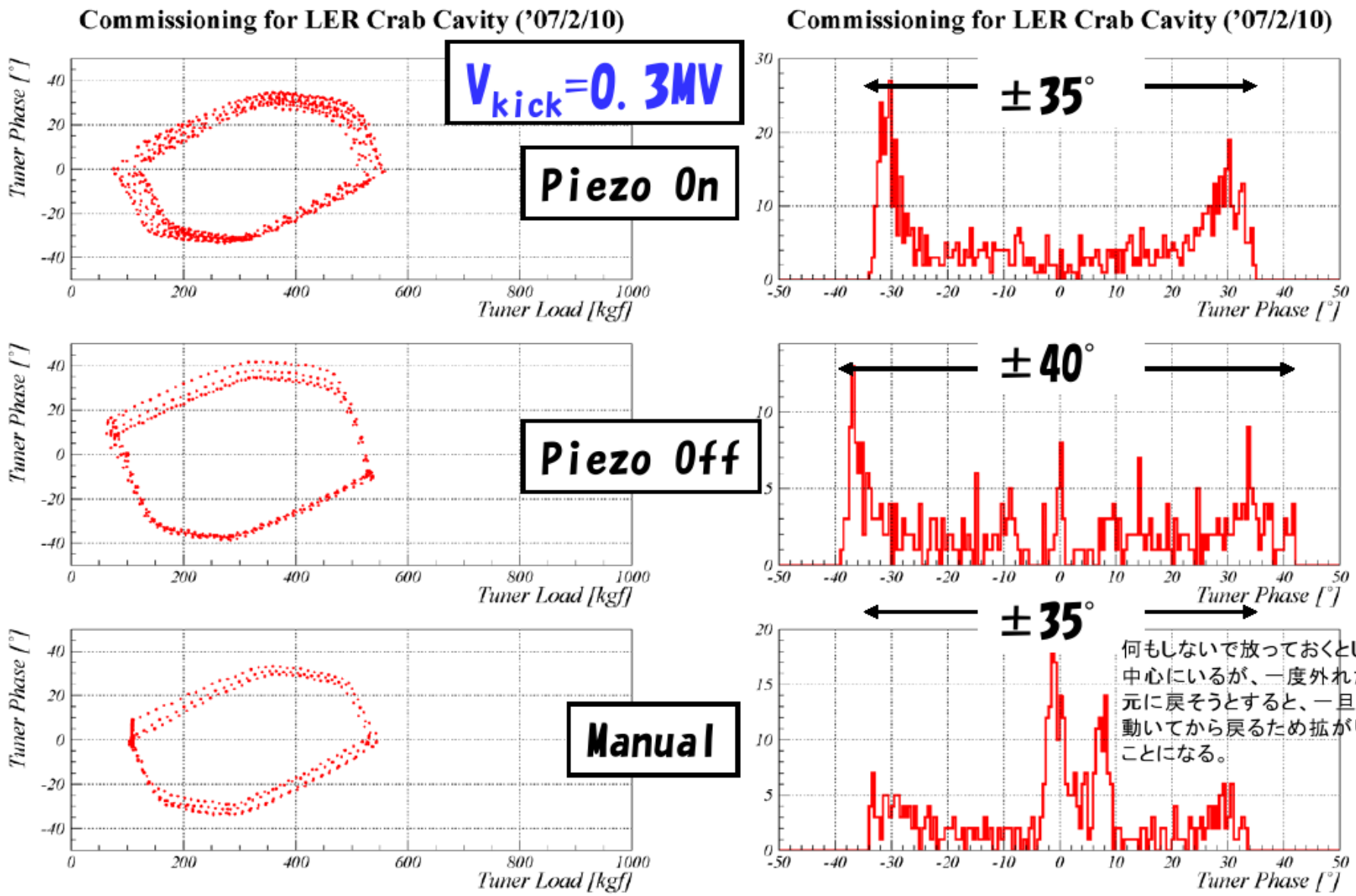
Tuner Response





Courtesy N. Yamamoto

LER号機のTuner Response②

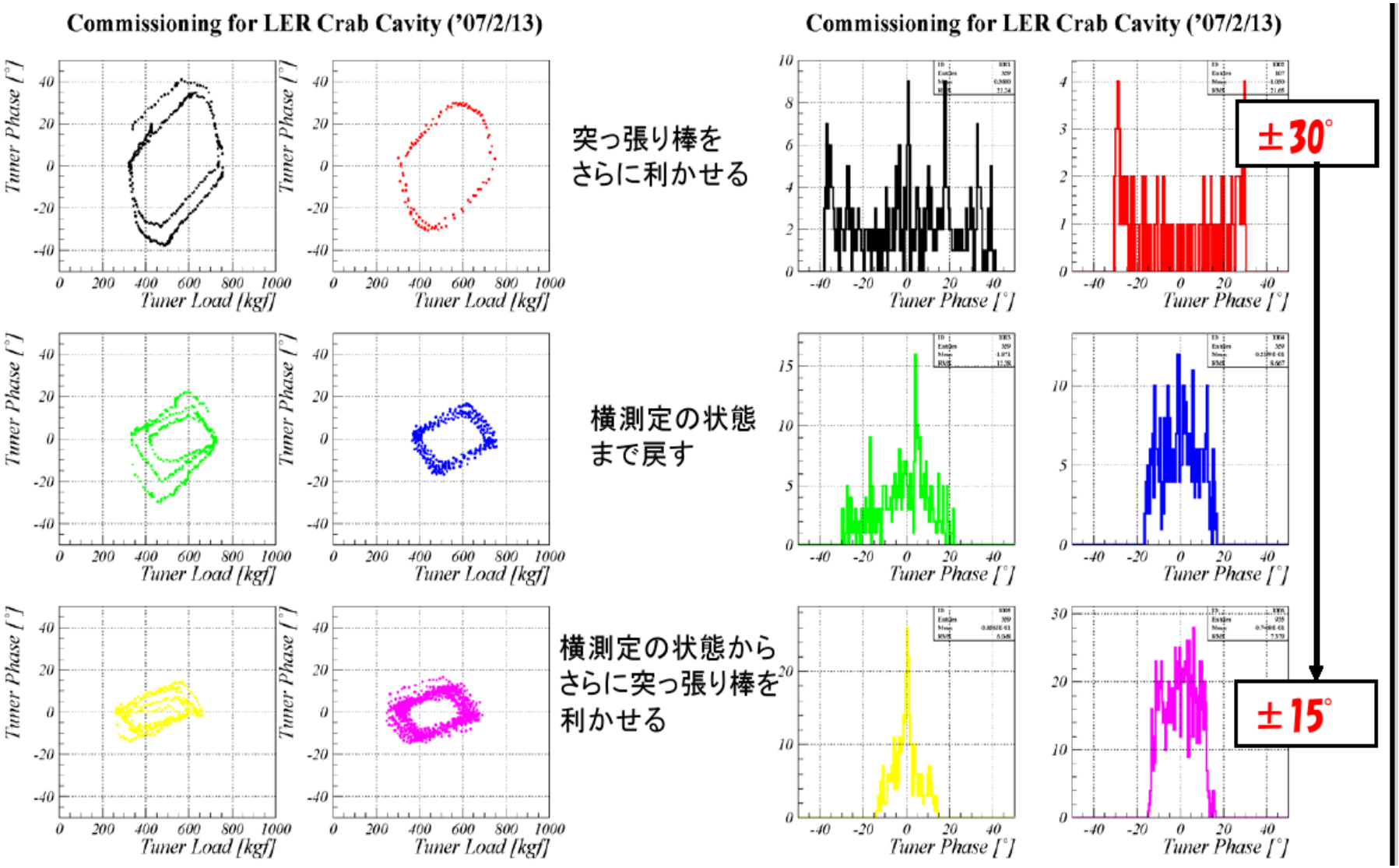


何もしないで放っておくとしばらくは中心にいるが、一度外れた後で元に戻そうとすると、一旦逆方向に動いてから戻るため拡がりは変わらないことになる。

ヒステリシスの傾向は3つのモードの間で違いは無いように見える。
位相の振れ幅は、ピエゾが働いている時の方が若干狭いことがわかる。

Courtesy N. Yamamoto

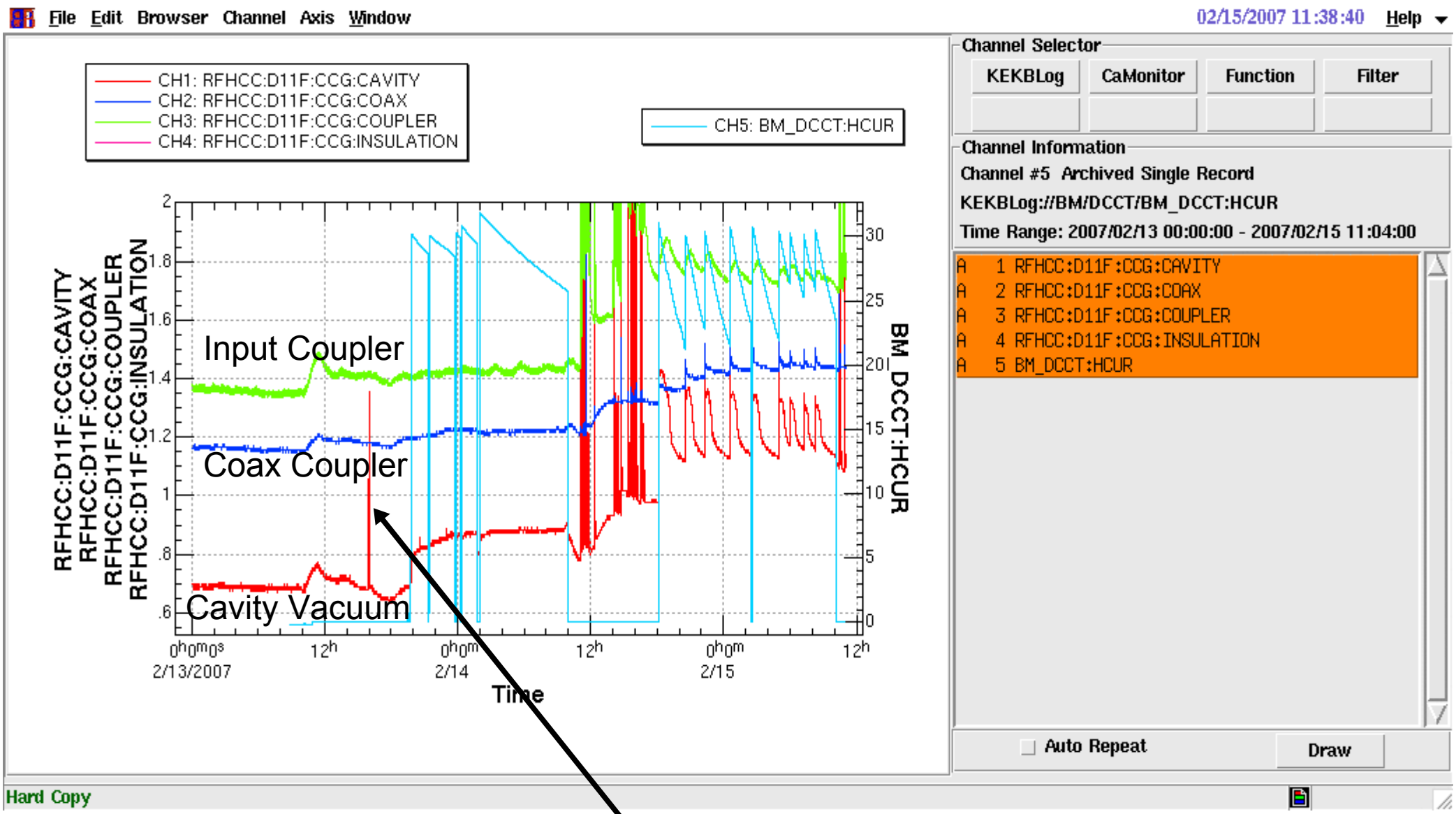
Improvement



- Bulging of screw holding the tuner plate was observed.
- Extra support to the tuning plate with special clamps improved phase stability

Courtesy N. Yamamoto

RF Conditioning



Trip

Courtesy RF Group

Crab Cavity with Beam

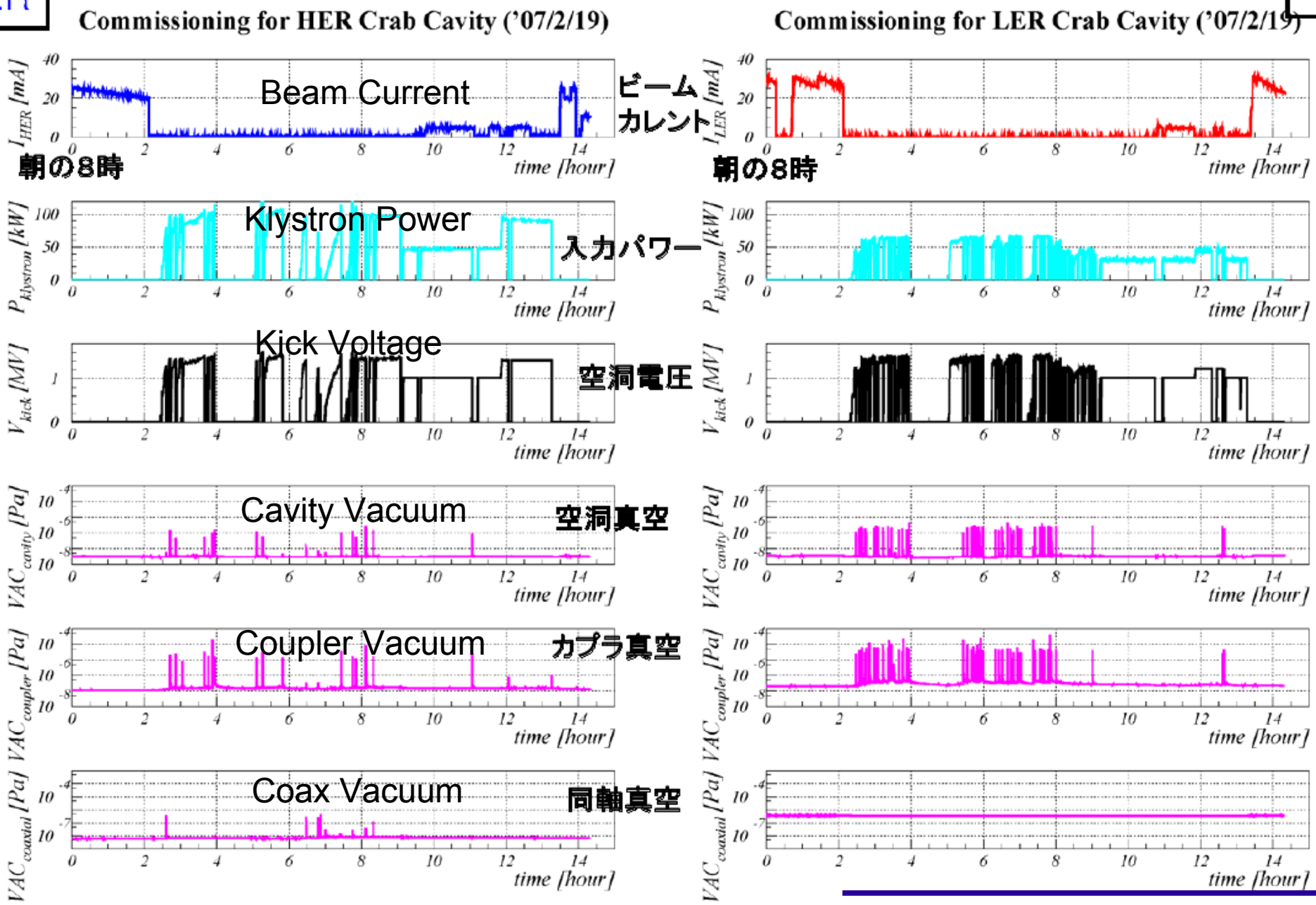
Approx Chronology

- Feb 13 – 18:
  - Mornings: High power RF conditioning (1.6MV/1.4MV CW)
  - Evenings: Beam with Detuned Cavity
    - 2 Modes – 30mA, 30 bunches/Multi-bunch
    - BPM Calibration, Orbit, Optics, Coupling & Dispersion
    - Cavity Field Center, RF Phase..
- Feb 19 – Present: Beam with Crab On
  - Some gradient degradation observed (1.4MV/1.1MV CW)
  - Optics (β_x increased), Dispersion & Coupling Correction, Crab Orbit Feedback
  - Collision Tuning
    - Low Currents (~30 mA with 30 Bunches)
    - IR Scan (BB Kick, σ_y, Coupling, η_y, Waist...)

First Beam Test with Crab "ON"① (2/19)

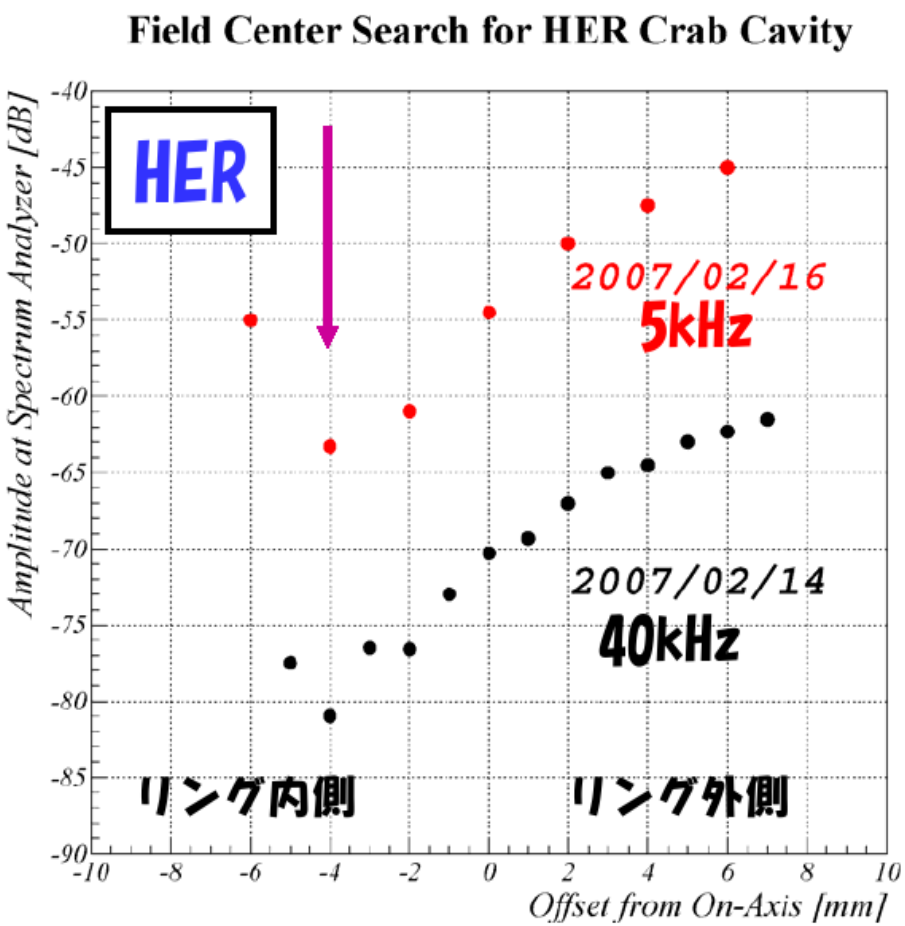
HER

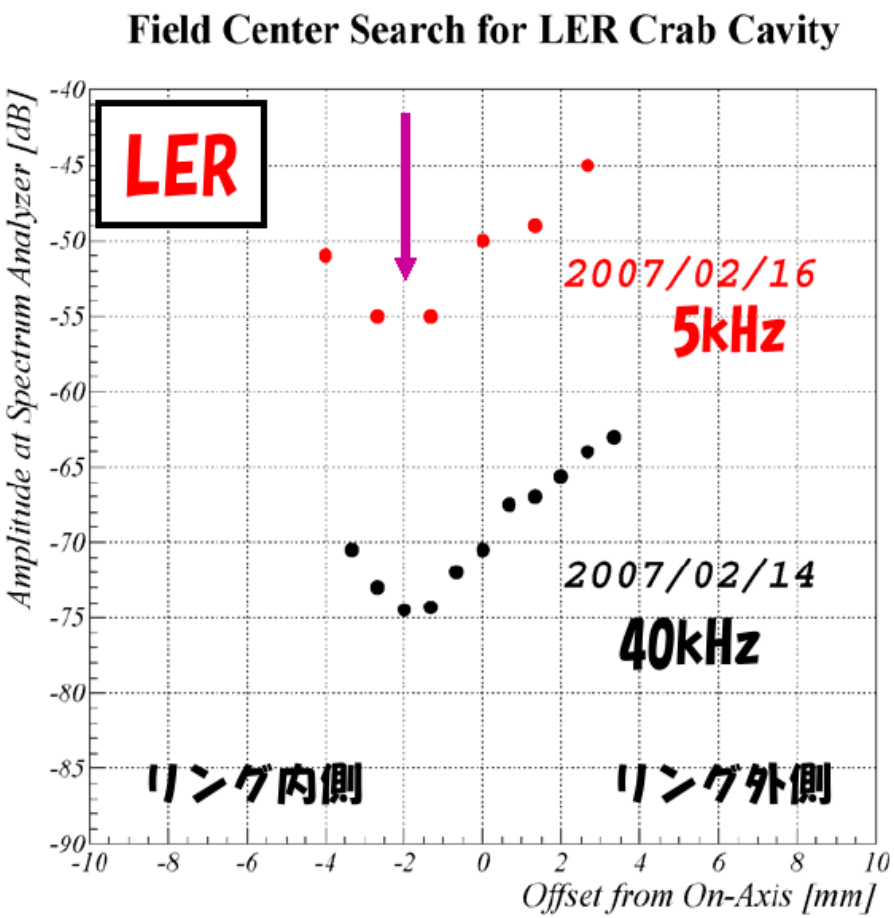
LER



Courtesy N. Yamamoto

Cavity Field Center

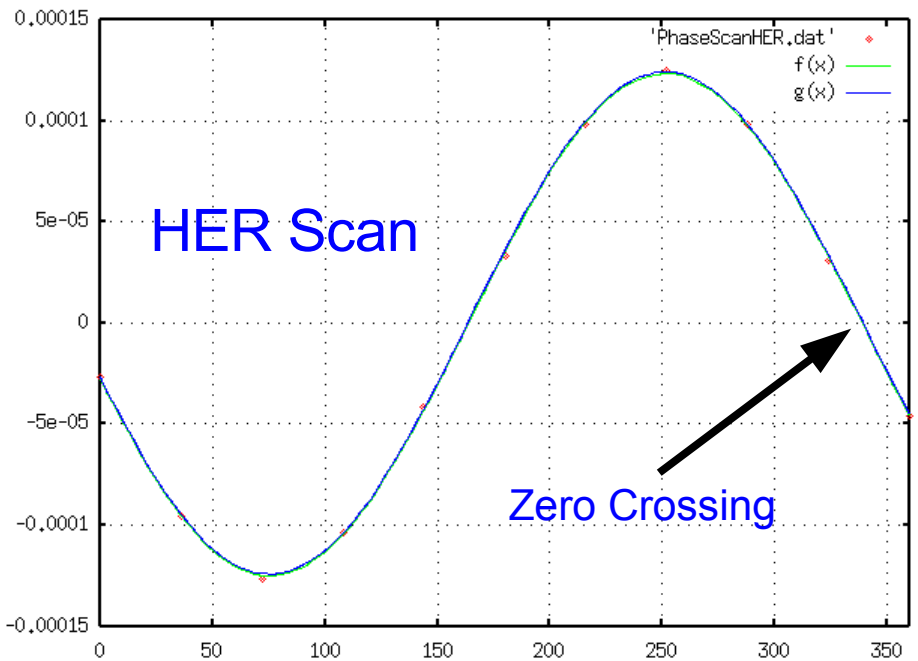


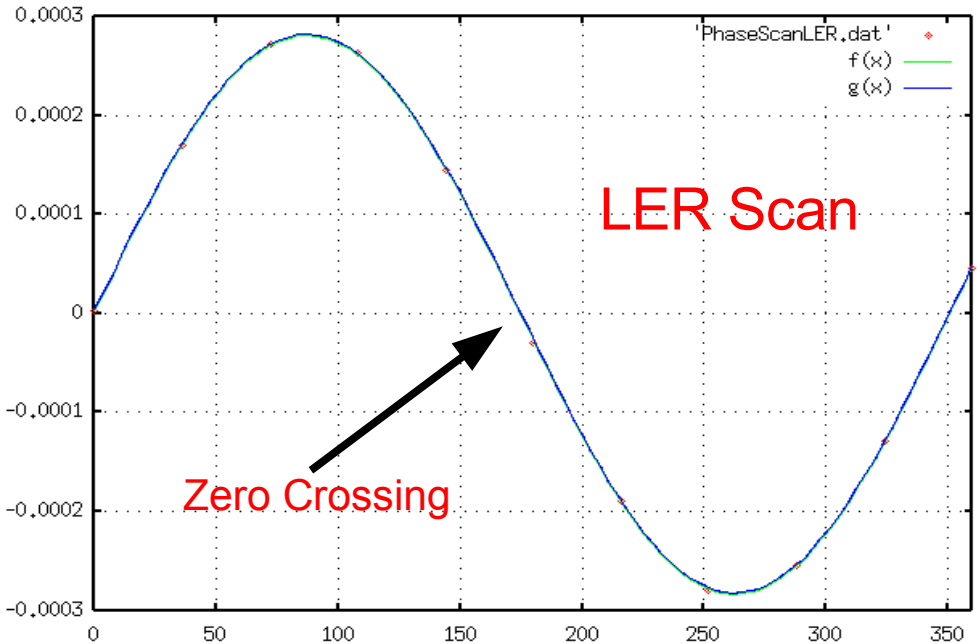


Record output power as a function of horizontal orbit (dipole mode)

Courtesy N. Yamamoto et al.

Crab Cavity Phase Scan

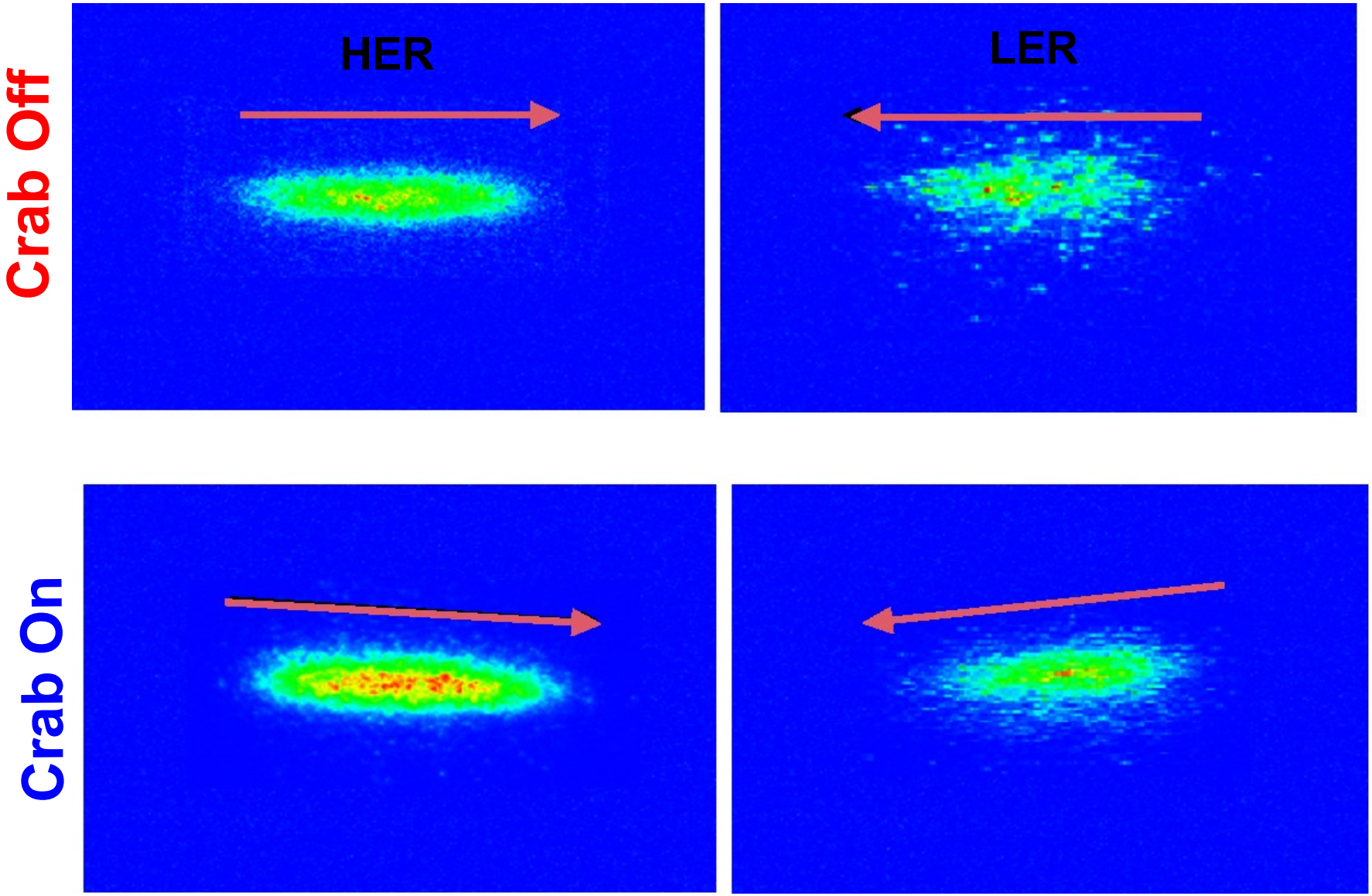




- Zero crossing & sign of the slope not known
- **2π** phase scan vs. relative orbit deviation

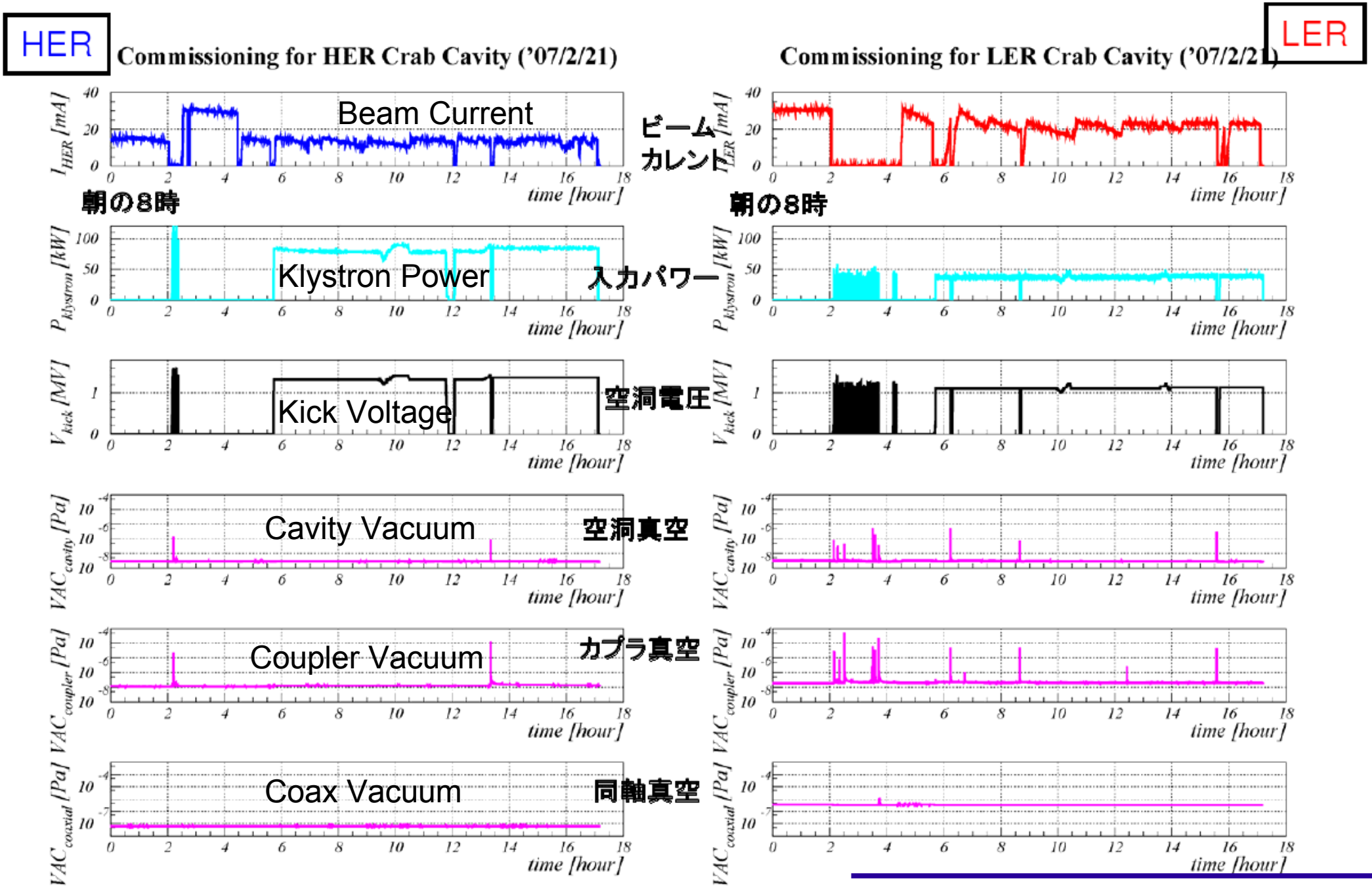
Courtesy Commissioning Group

Streak Camera



Courtesy H. Ikeda, H. Koiso

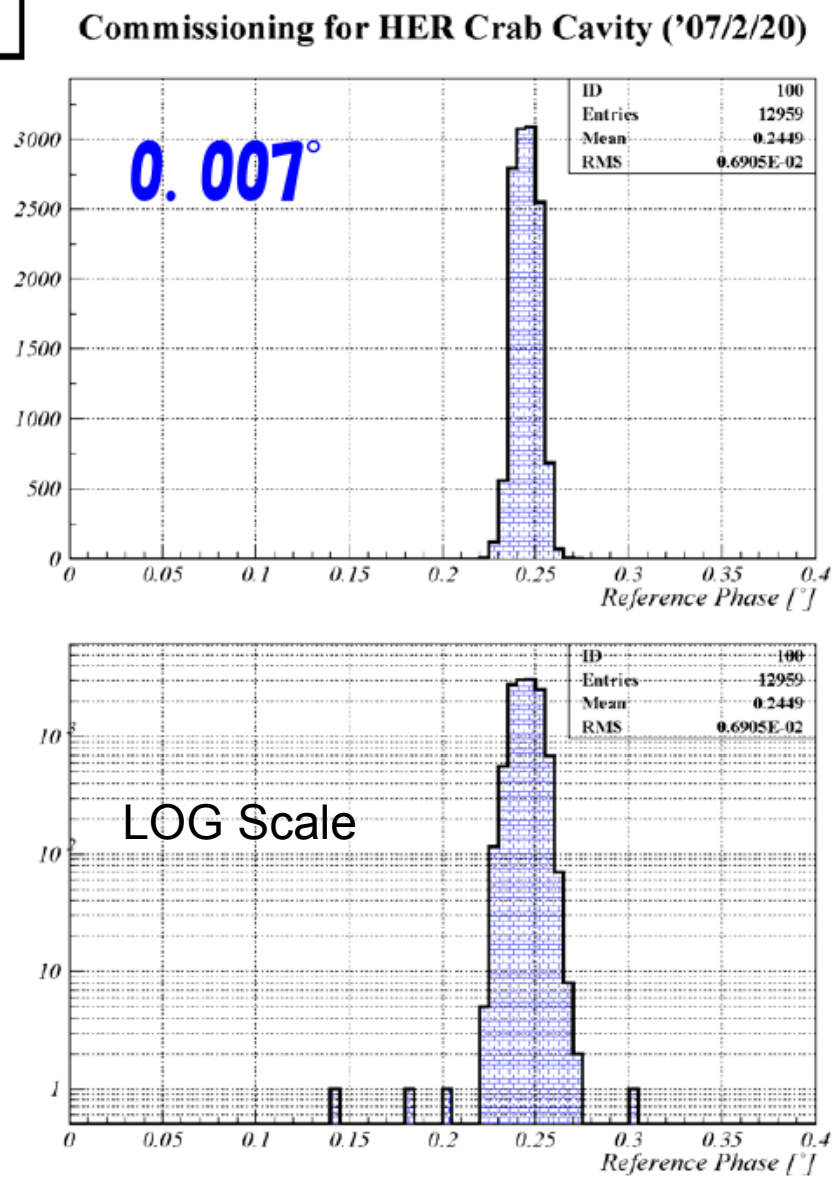
First Beam Test with Crab Crossing① (2/21)



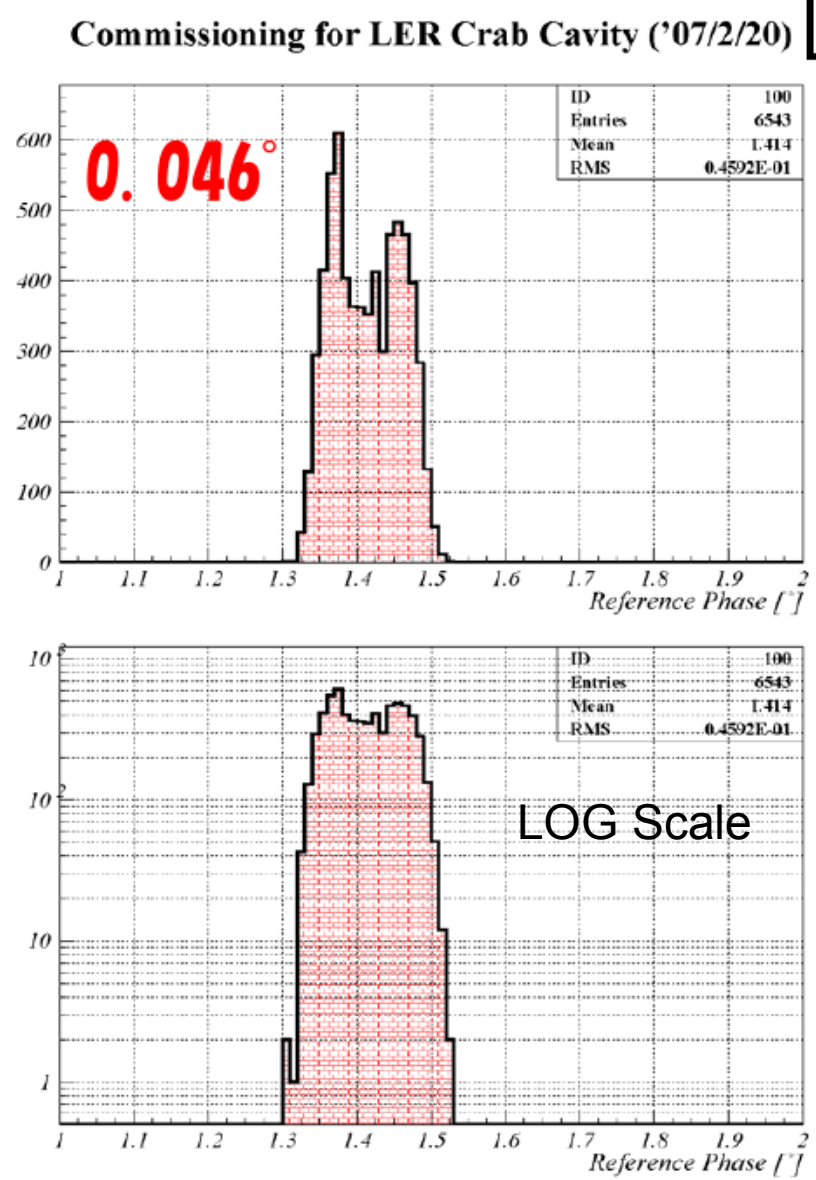
Courtesy N. Yamamoto

Phase Stability during Beam Test

HER



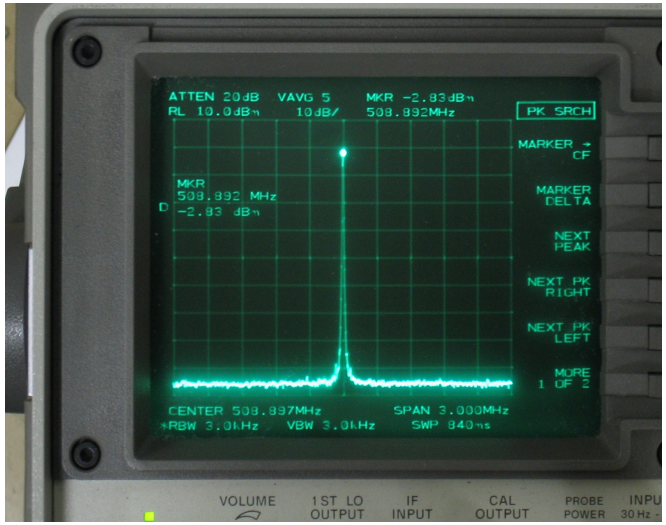
LER



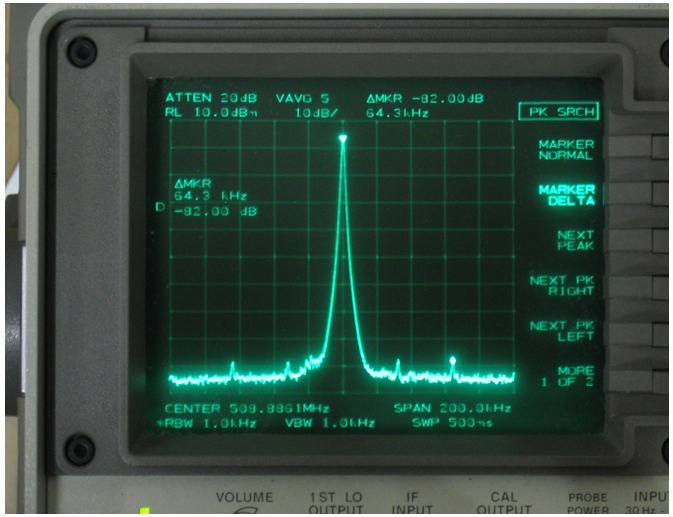
空洞電圧一定モード時の位相の分布（上はlinearで、下はlogである）

Courtesy N. Yamamoto

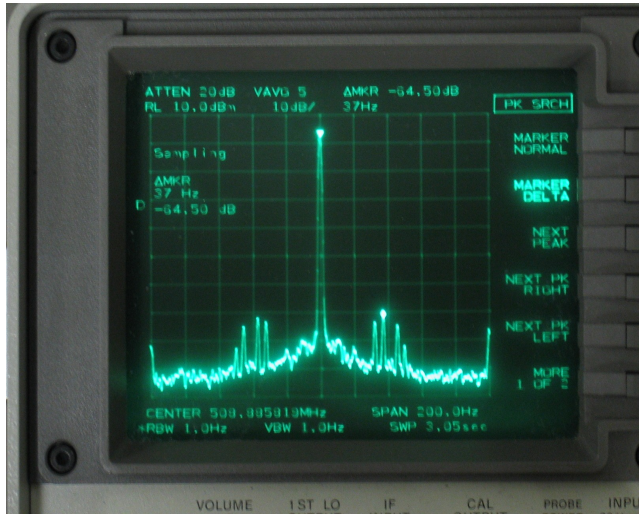
Phase Noise Spectrum



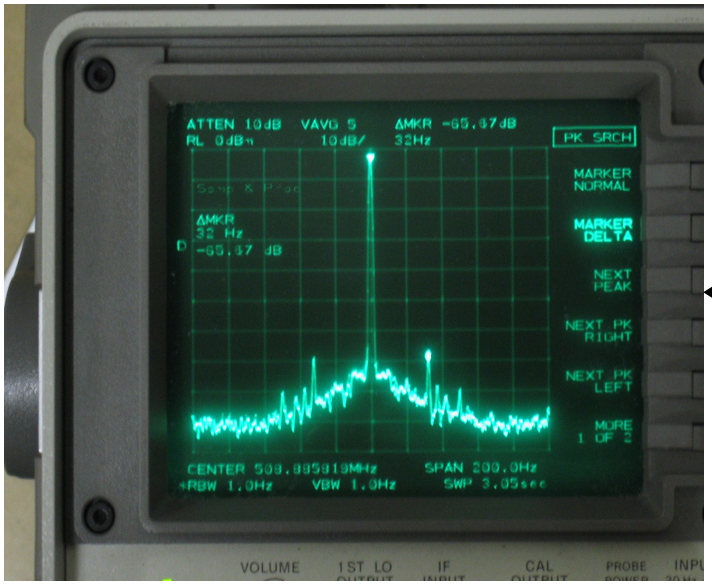
Span 3MHz
No significant sidebands seen.



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)



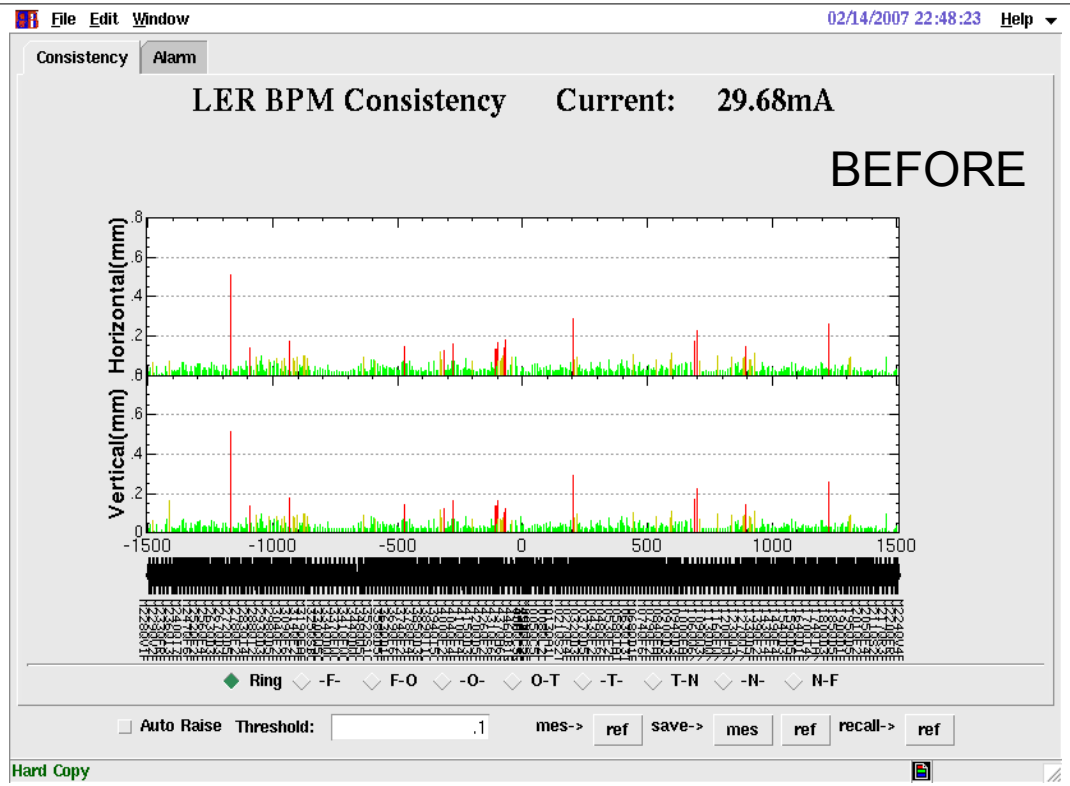
Some of the peaks are also found
in the reference line.
(upstream of the crab station)

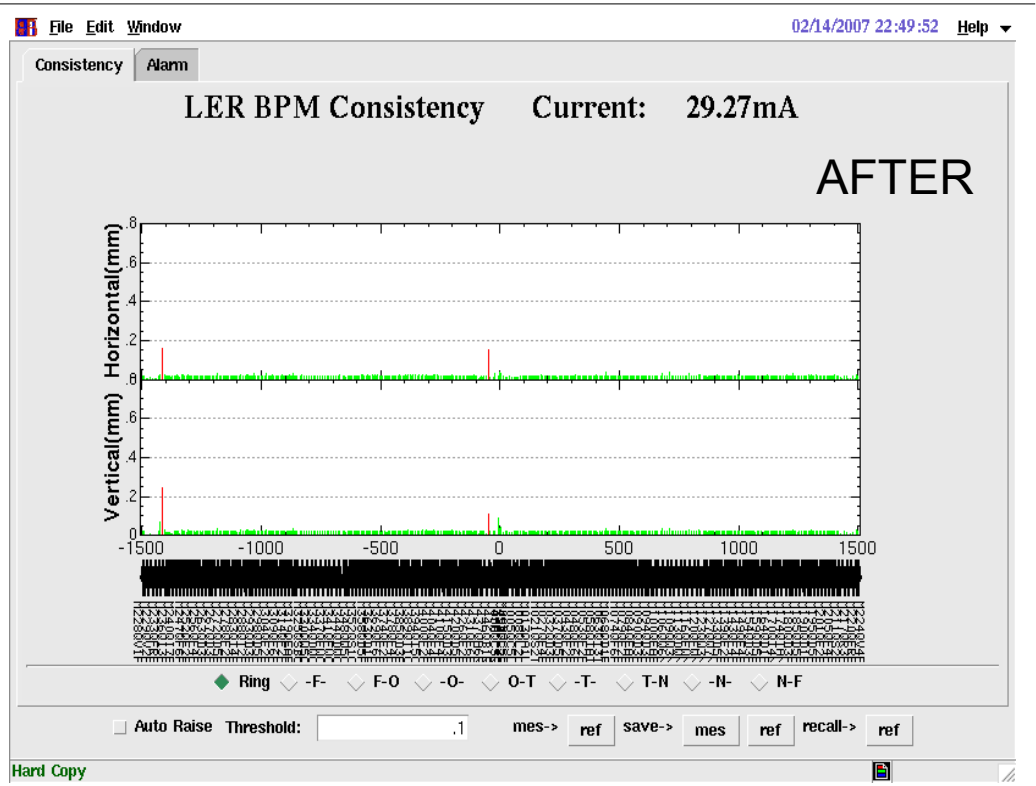
Use this spectrum for LHC simulations ?

Courtesy K. Akai

Machine & Collision Tuning

BPM Gain (450 Dual Plane BPM)



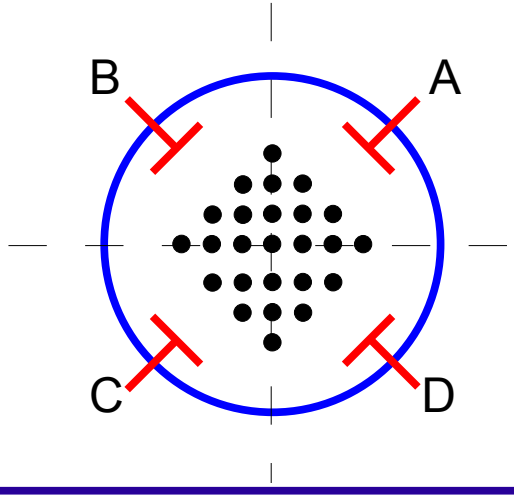


- Use combinations of 3 electrodes to determine position
- ABC, BCD, CDA, DAB should coincide
- Consistency: STDEV(4 Combinations) < 0.1mm

$$V_i = g_i q F(x, y), [i = 1 \ldots 4]$$

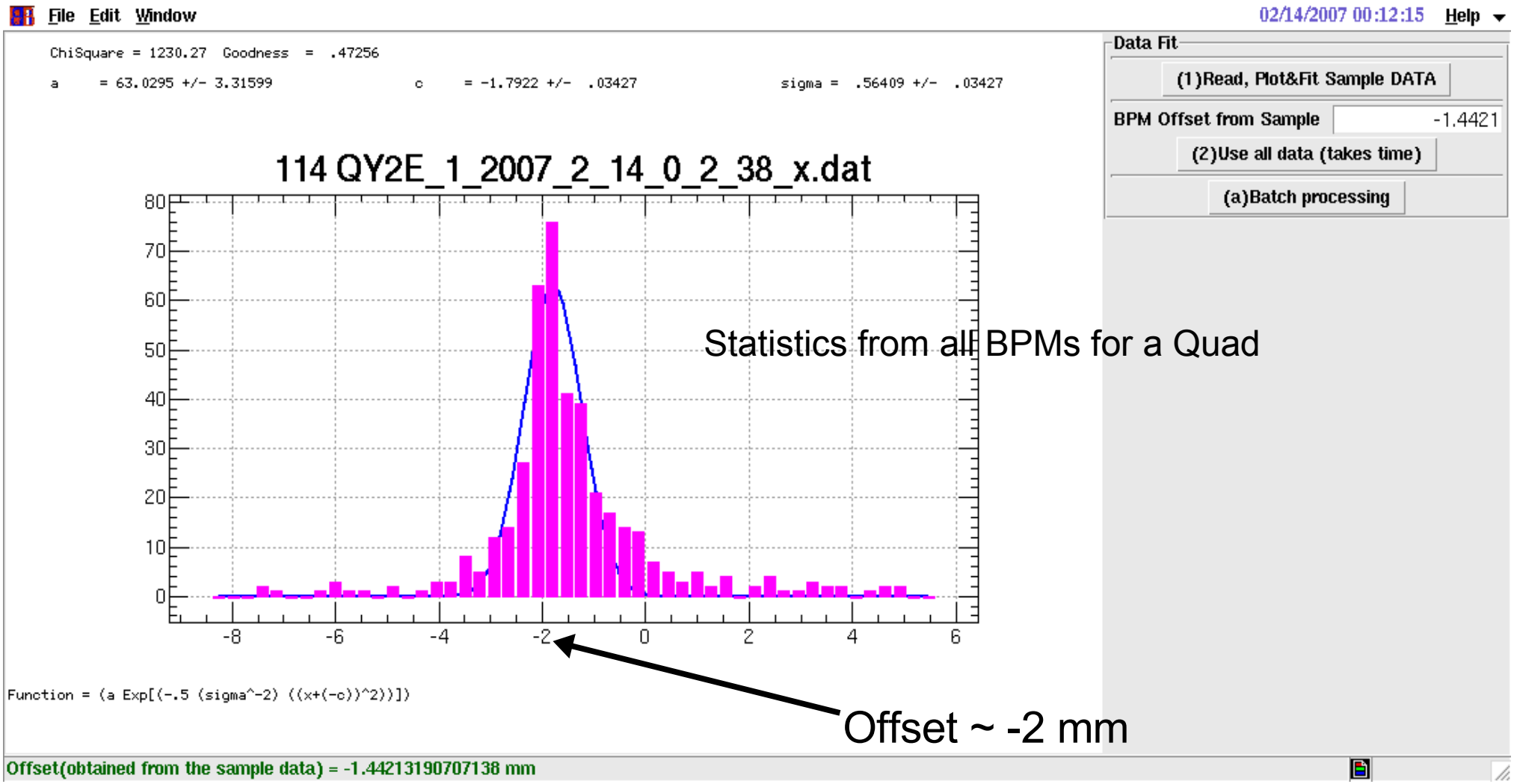
F(x,y): 4th Order Polynomial Fit & Non-Linear Least Squares

4 electrodes & m orbits (m > 4)



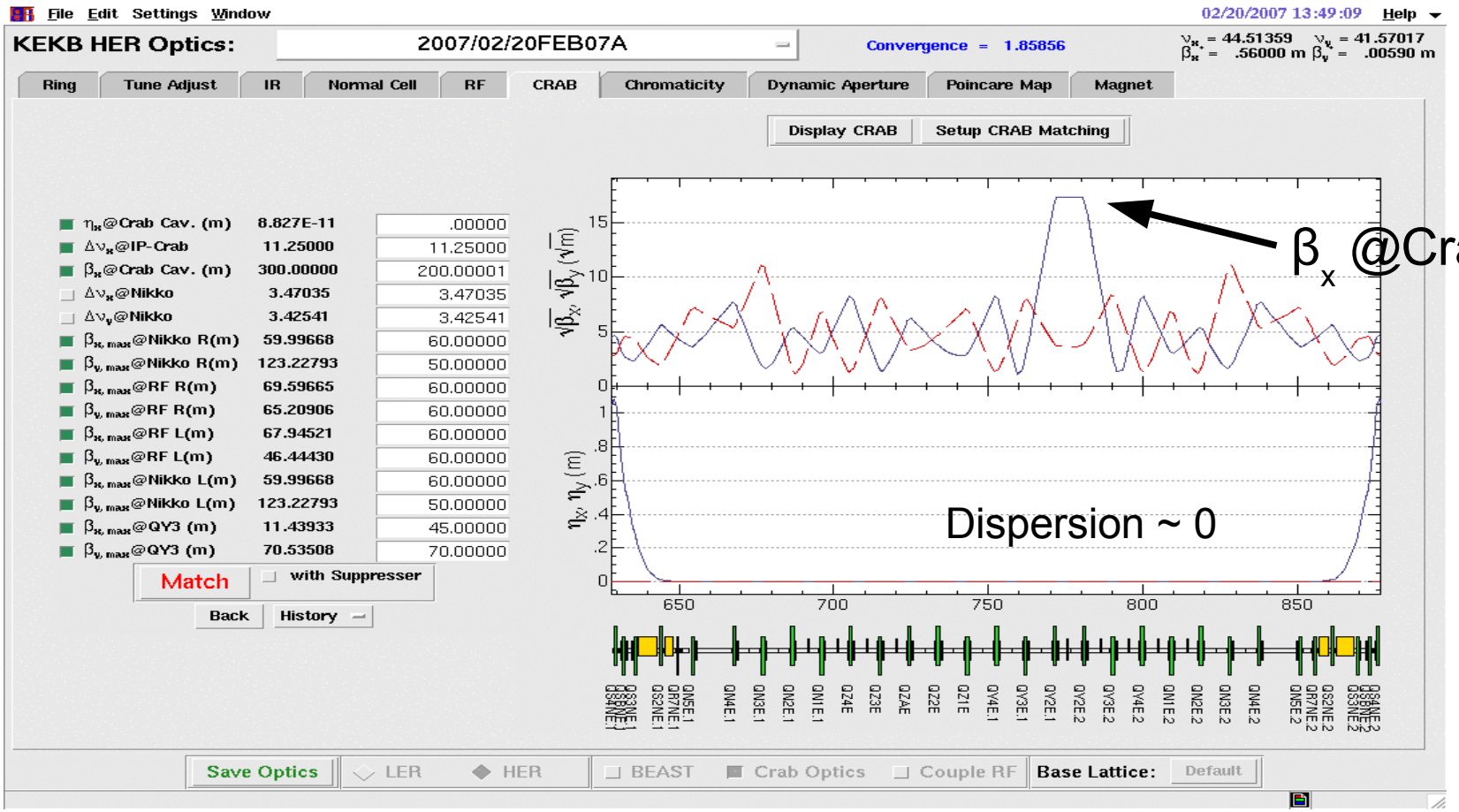
Courtesy M. Tejima

BPM Offset: Quad Modulation



Courtesy H. Koiso et al.

Online Optics Model

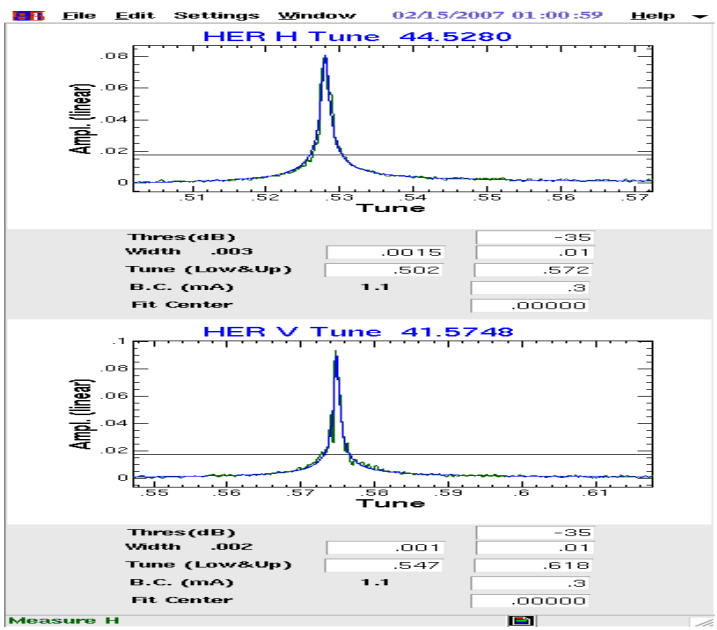


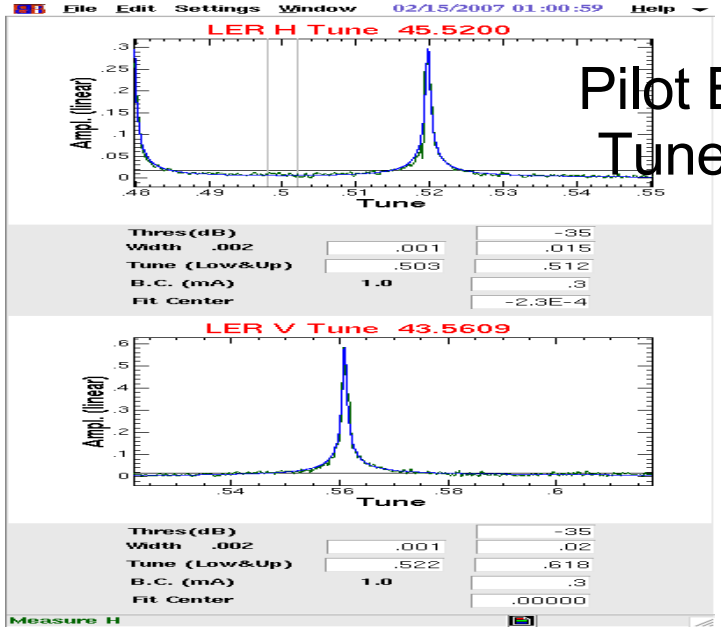
β_x @Crab 200m

- SAD based online optics (Tk interface)
- Easily change $Q_{\{x,y\}}$, $\beta_{\{x,y\}}$, $\xi_{\{x,y\}}$
- Re-Match and send to power supplies

Courtesy K. Oide, H. Koiso

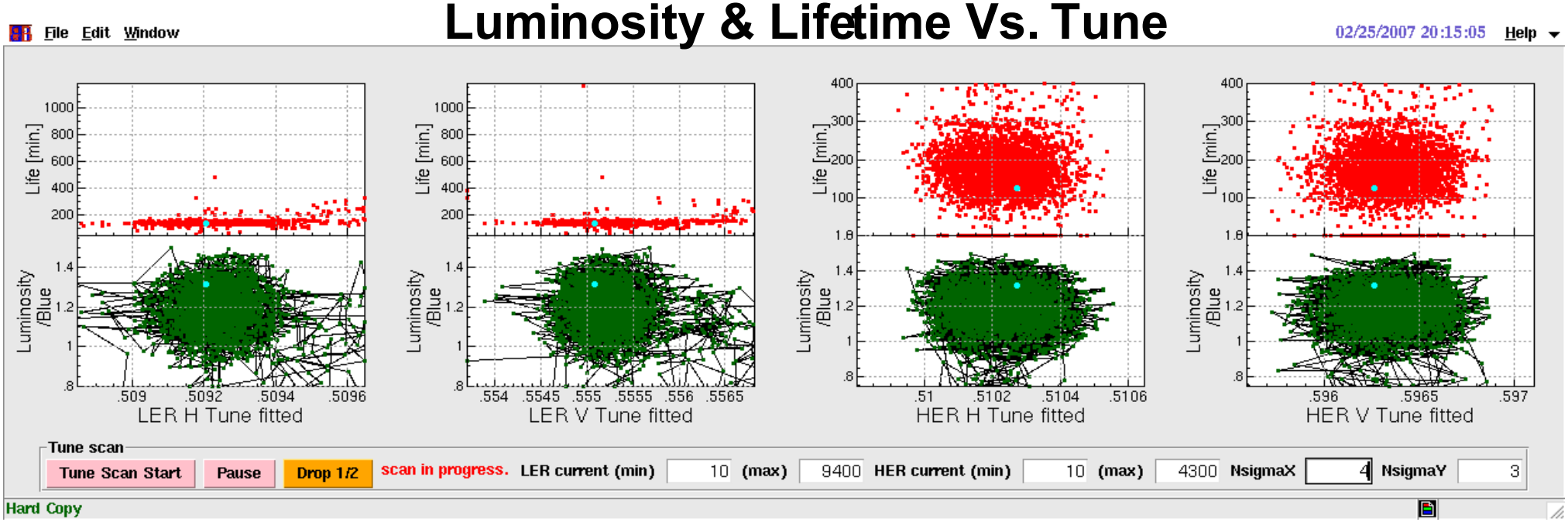
Tune Measurement





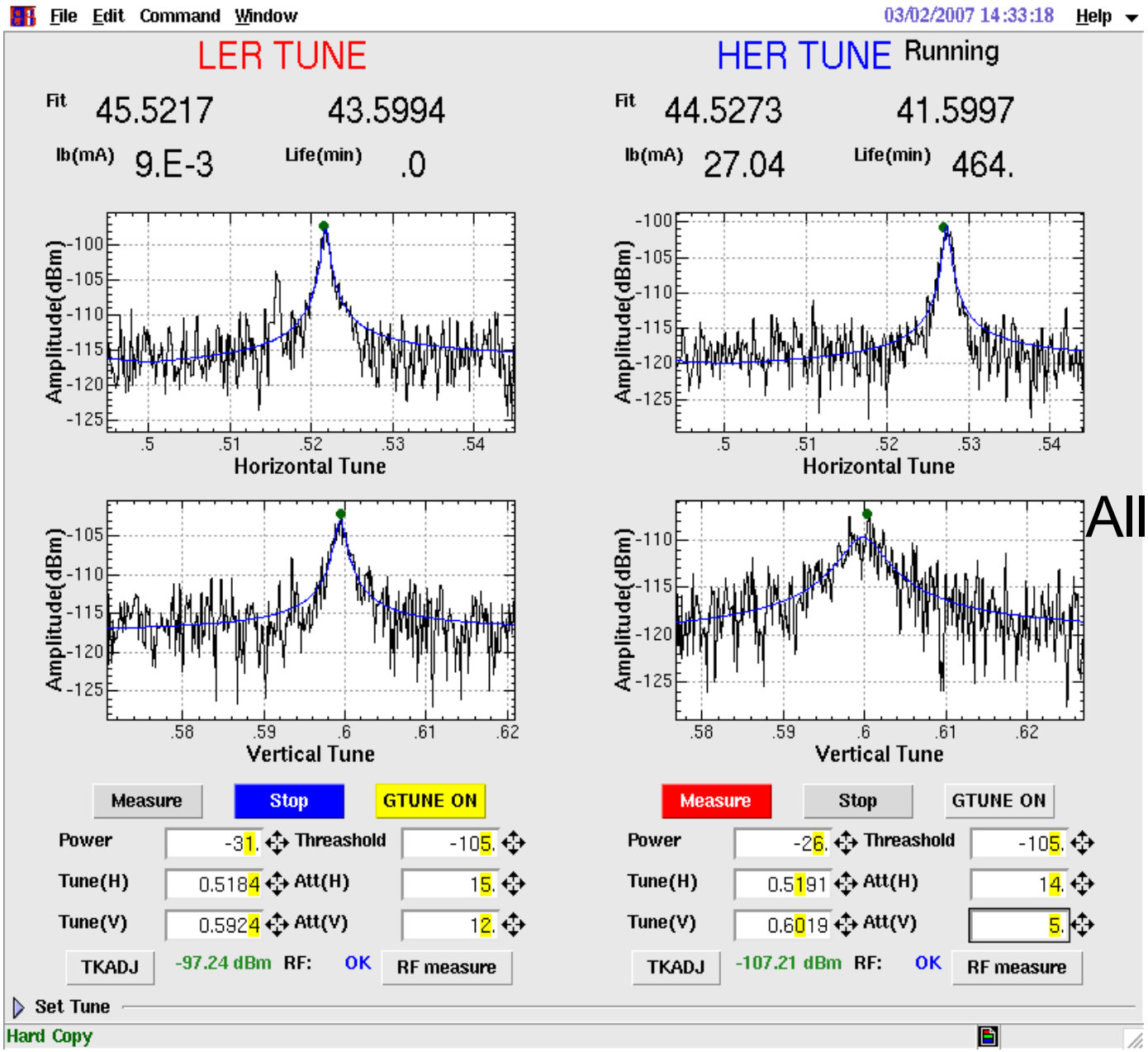
Pilot Bunch Tune
Tune Feedback

Luminosity & Lifetime Vs. Tune



Courtesy KEKB AP Group

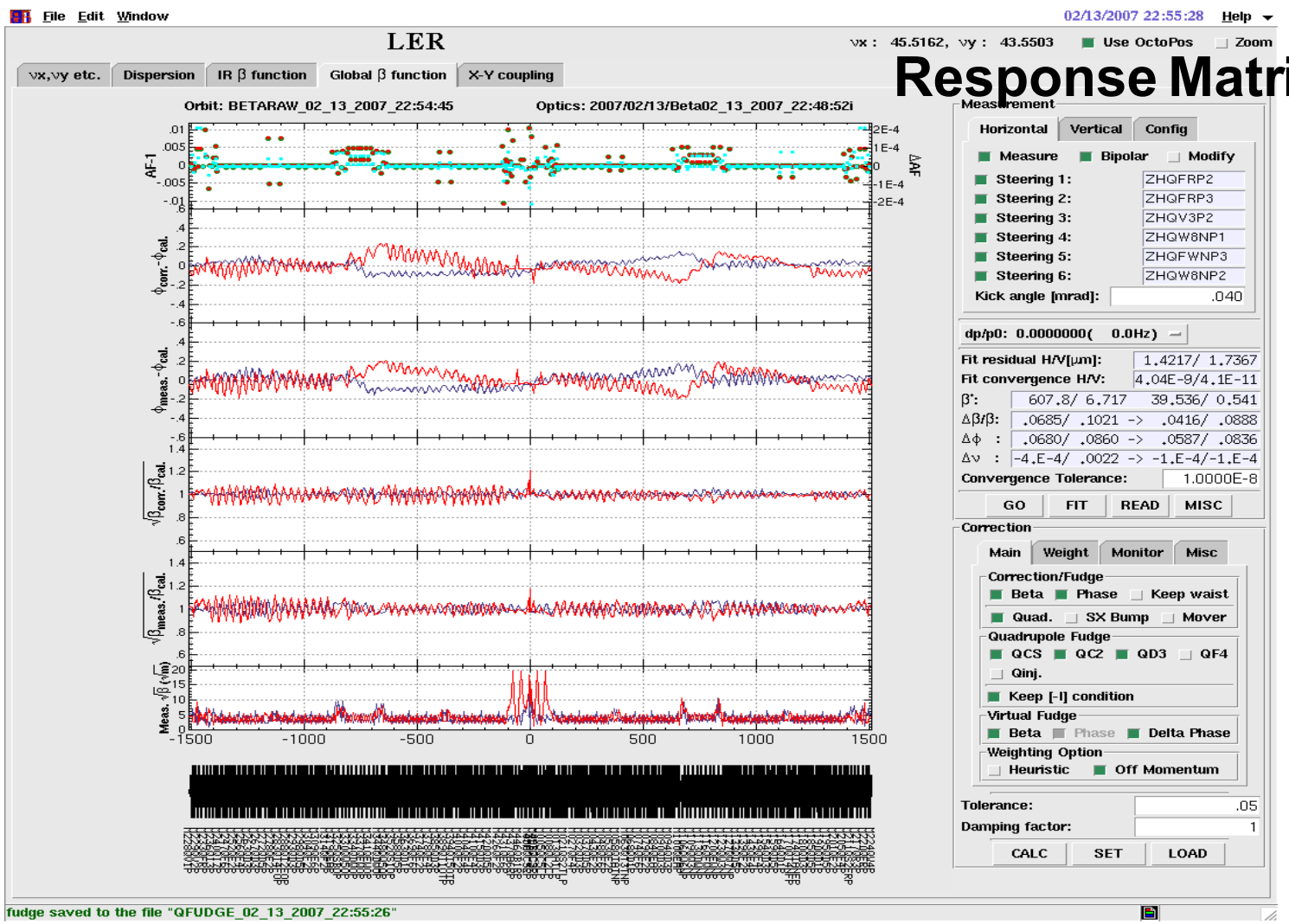
Tune (Freq Sweep)



All Bunches

Courtesy KEKB AP Group

Optics Correction



Response Matrix + QUAD Circuits

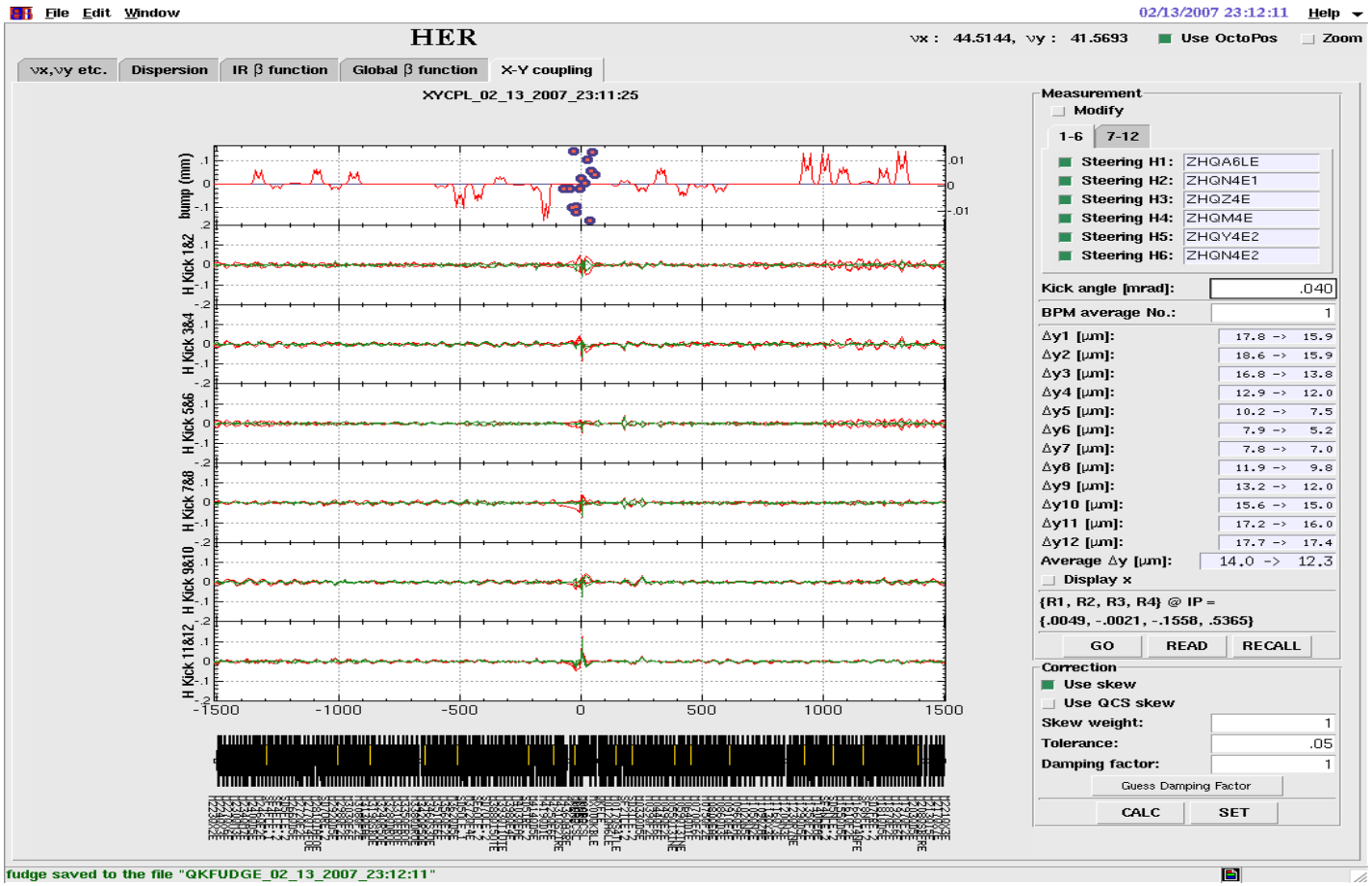
~ 3-4% Beta-Beta
~ 0.04 deg Phase-Beat

6 Correctors: $x_{ik} = f_k \cos(\pi\nu - |\mu_i - \mu_j|) \equiv F(i, \beta_i, \mu_i, f_k, \mu_k)$

Least Squares Minimize: $\sum_{ik} (x_{ik} - F_{kick})^2$

Courtesy A. Morita

X-Y Coupling



$$\Delta y_{rms} < 20\,\mu m$$

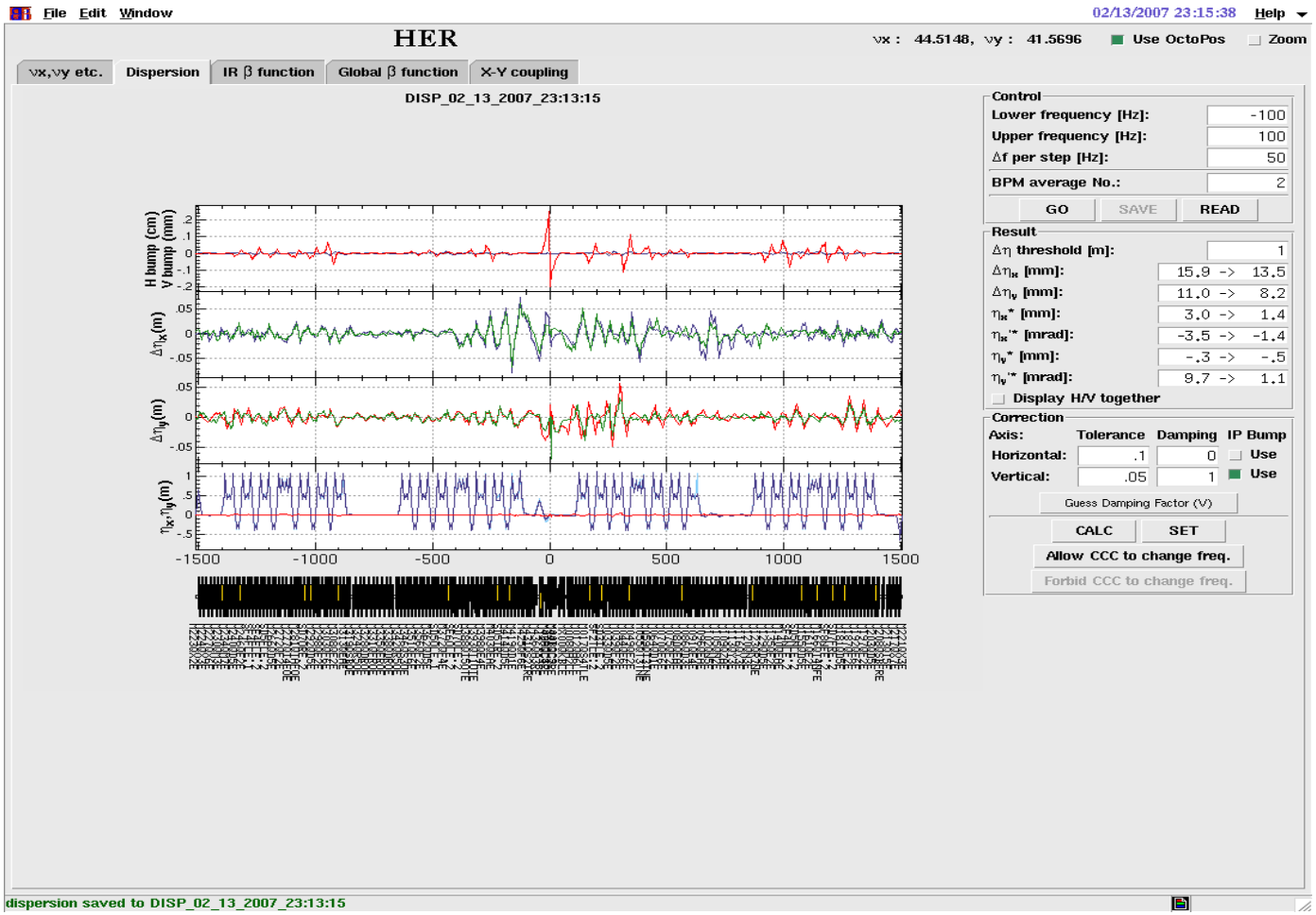
Observe vertical leakage from horizontal steering magnets (reduce ε_y)

Correct:

- IR skew quads LER (8), HER (12) (local IR correction)
- Symmetric vertical bumps @SD sextupoles

Courtesy A. Morita

Dispersion Correction



Typically:

$$\Delta \eta_{(x,y)} < 2\,cm$$

$$\Delta \eta_{(ip,y)} < 1\mathrm{mm}$$

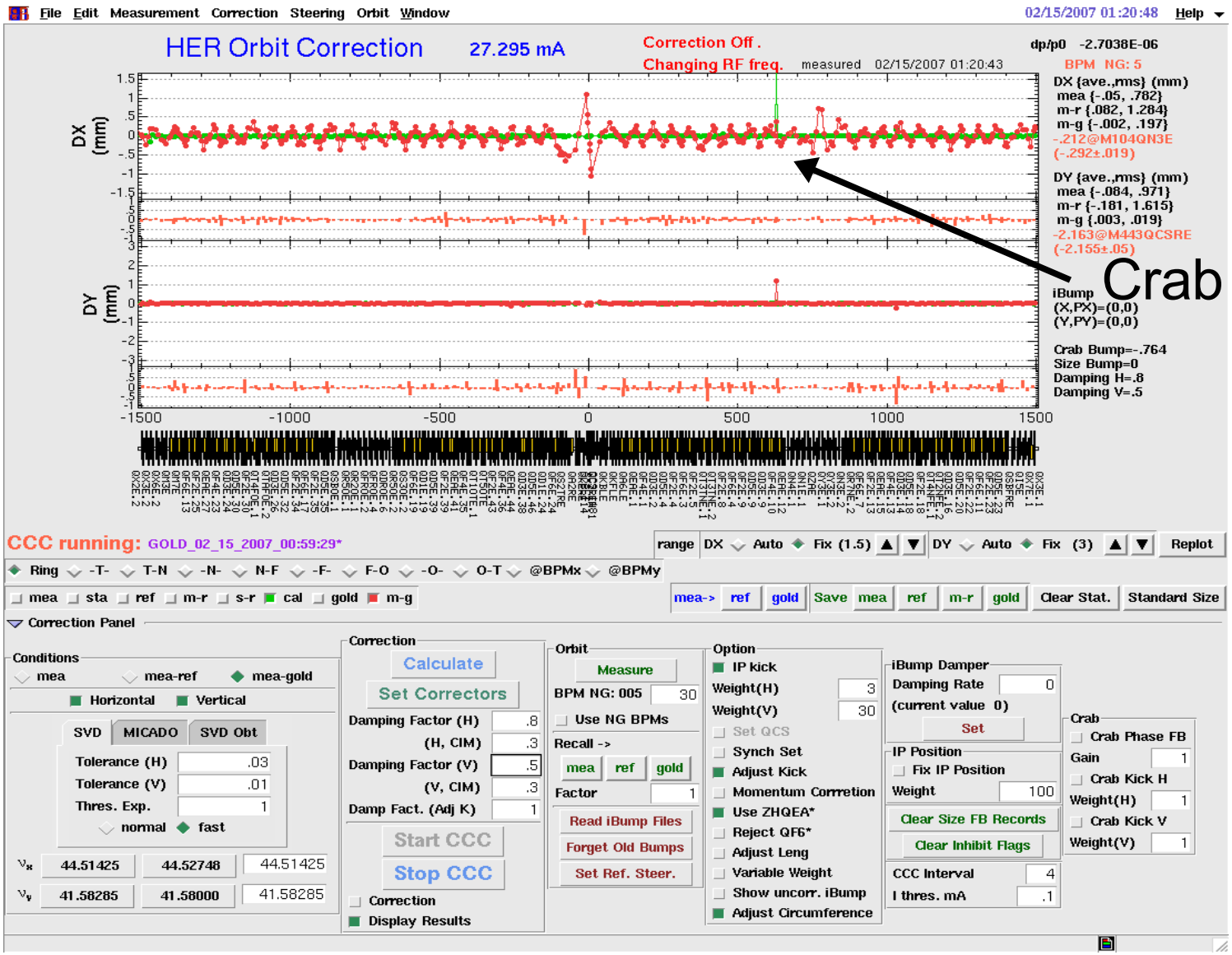
Measure using RF radial loop method

Correct:

- Asymmetric X&Y bumps @SF & SD sextupoles

Courtesy A. Morita

Closed Orbit Correction

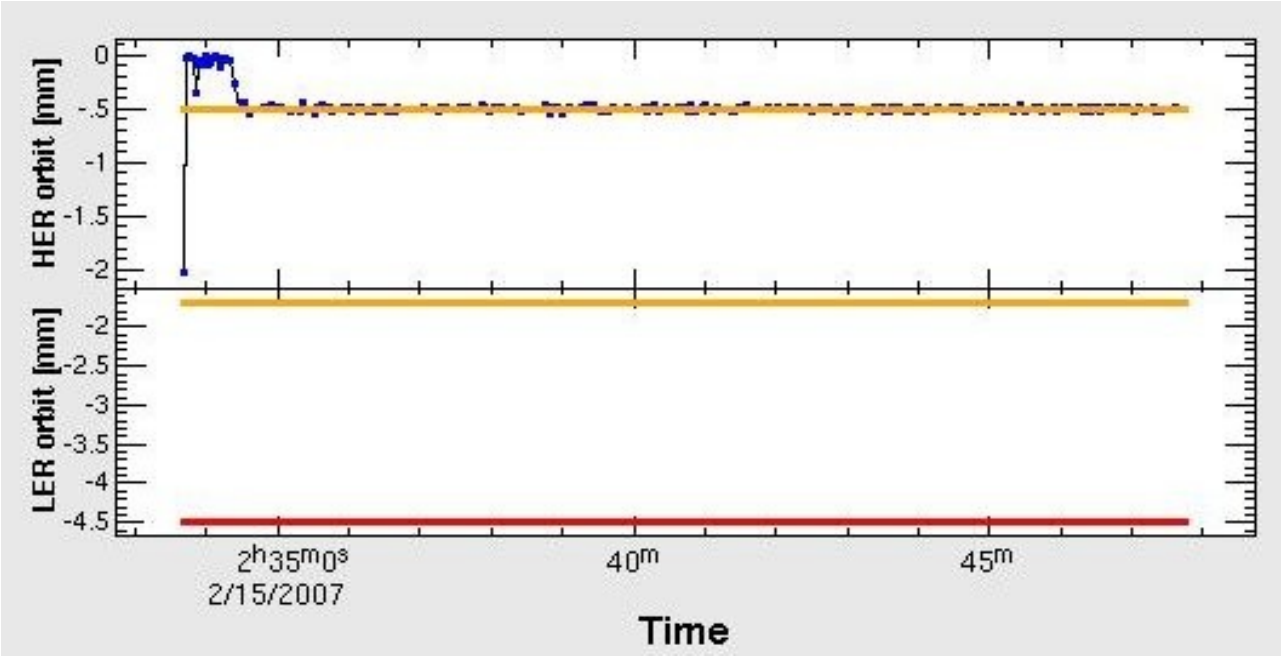


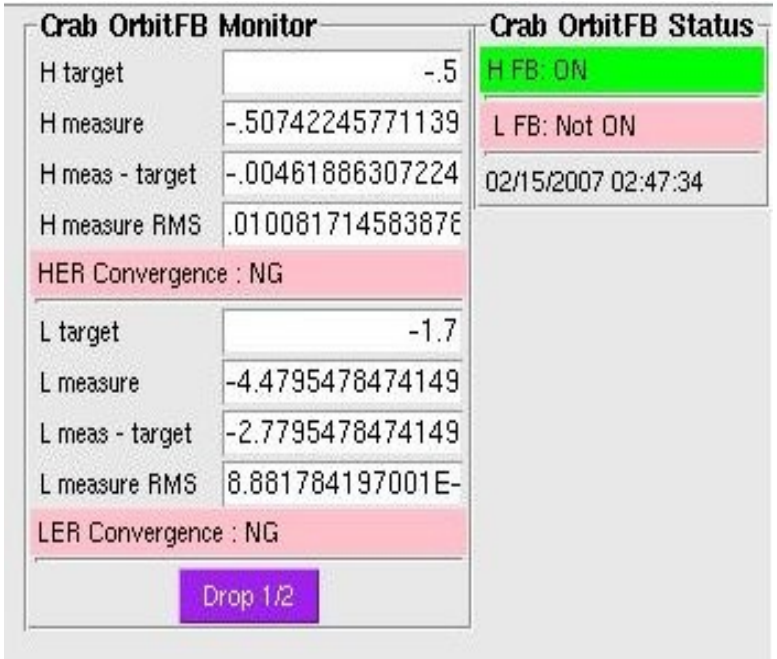
Crab Phase Scan

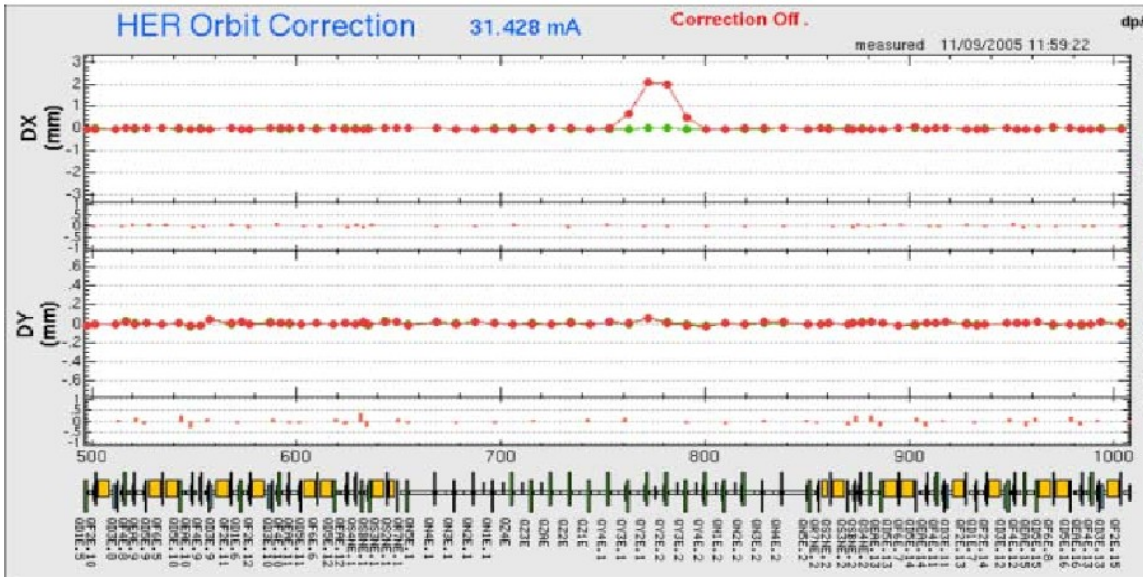
Correction ~ every 10 sec

Courtesy H. Koiso

Crab Orbit Feedback





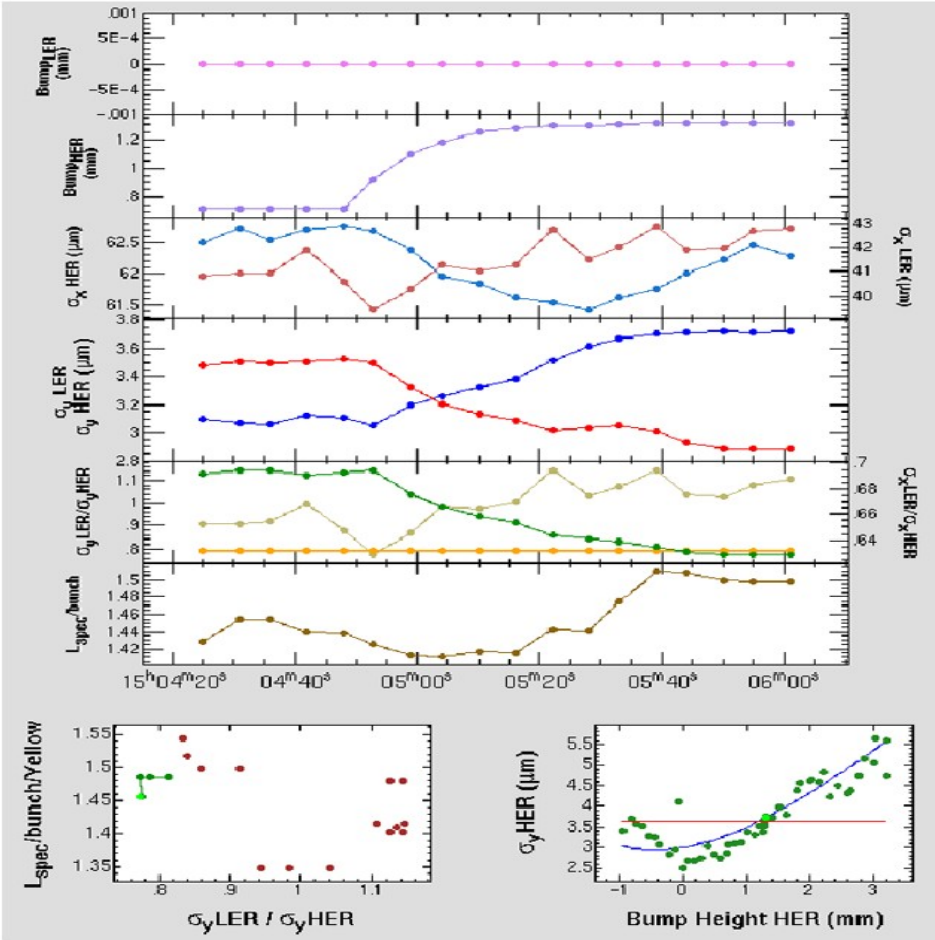


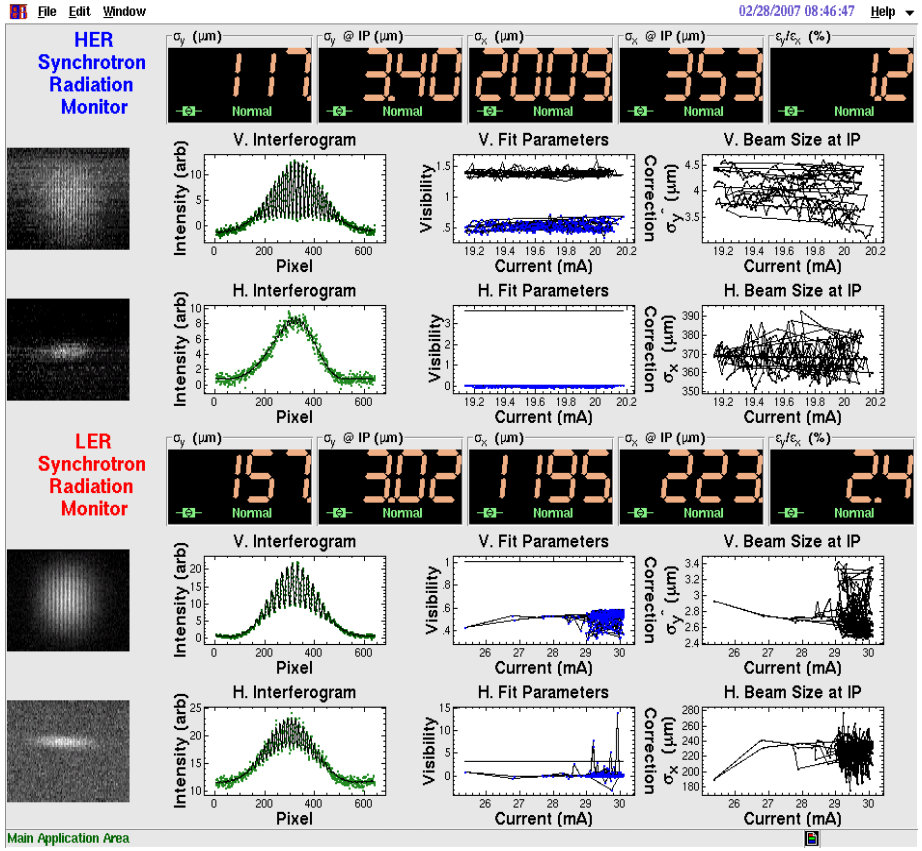
- 4 correctors for each ring
- 1 Hz correction feedback
- Much faster than CCC

Courtesy M. Mazuzawa, Y. Funakoshi

Beam Size Optimization & SR Monitor

- Optimum empirical Ratio of $\sigma_y^{LER} / \sigma_y^{HER}$
- η_y of HER beam controlled by local Horizontal bump in IR
- X-Y local coupling is compensated by skew quads or vertical bumps
- Beam size measured by SR monitors

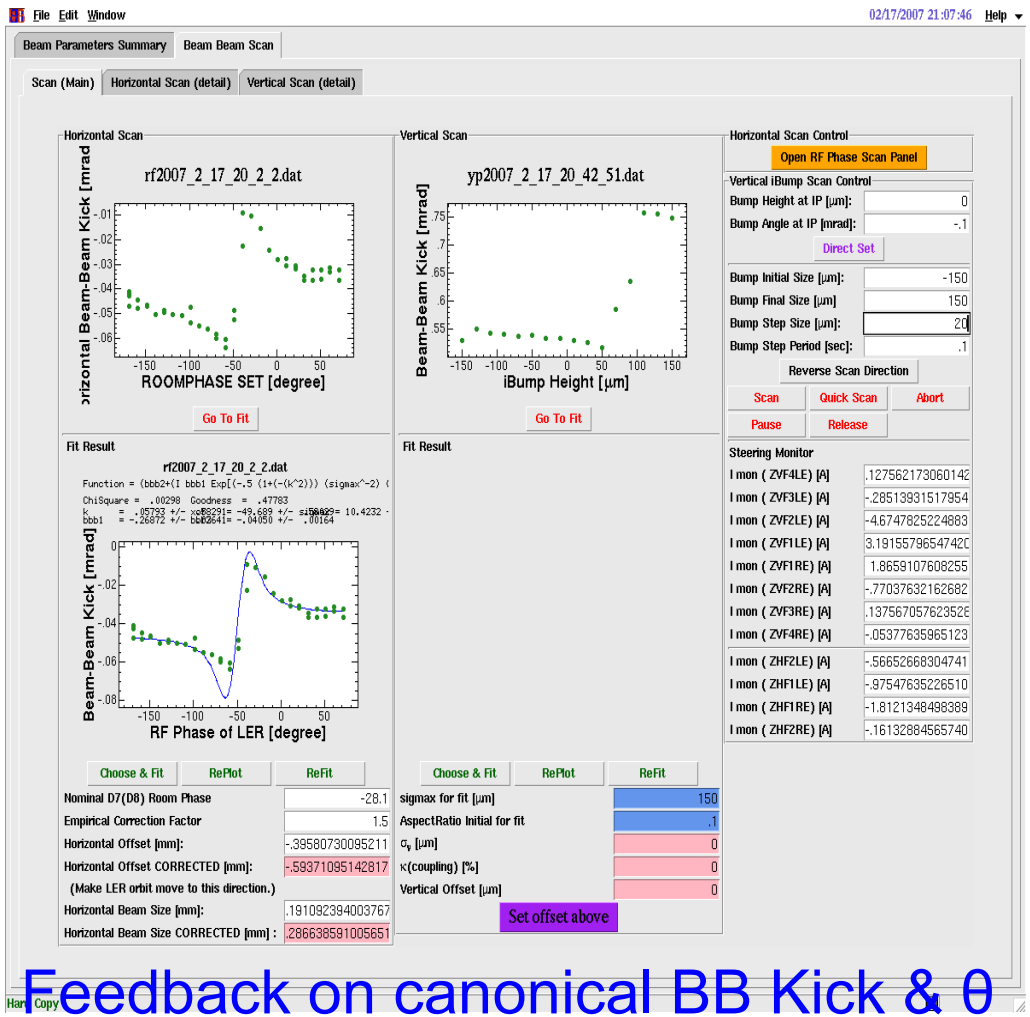


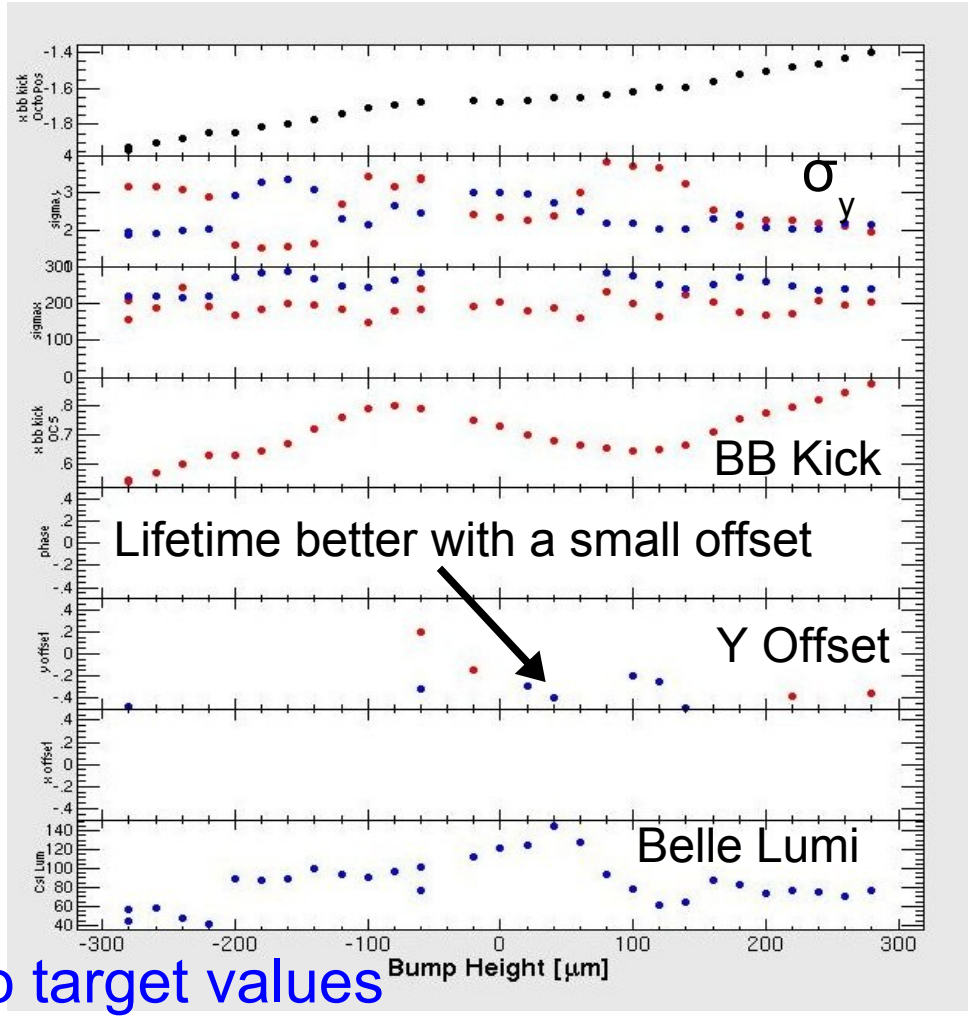


Courtesy KEKB AP Group

IR Orbit Scan

- 12 Local dipole correctors: 4-Hor & 8-Ver
- 4 dedicated BPMs for HER & LER
- Scan orbit to find optimum position with beam-beam



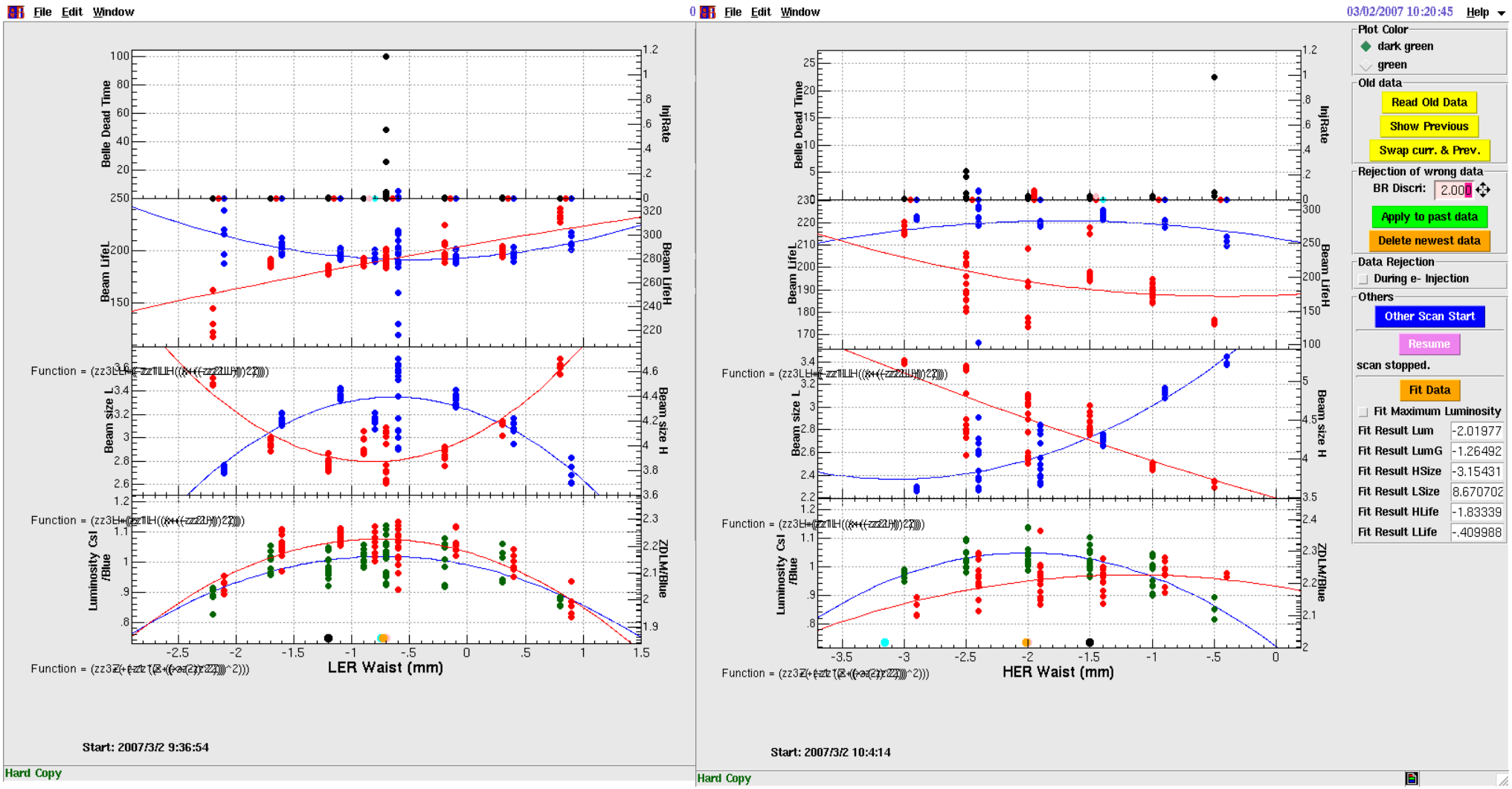


Feedback on canonical BB Kick & θ_c to target values

Courtesy Y. Funakoshi, H. Koiso

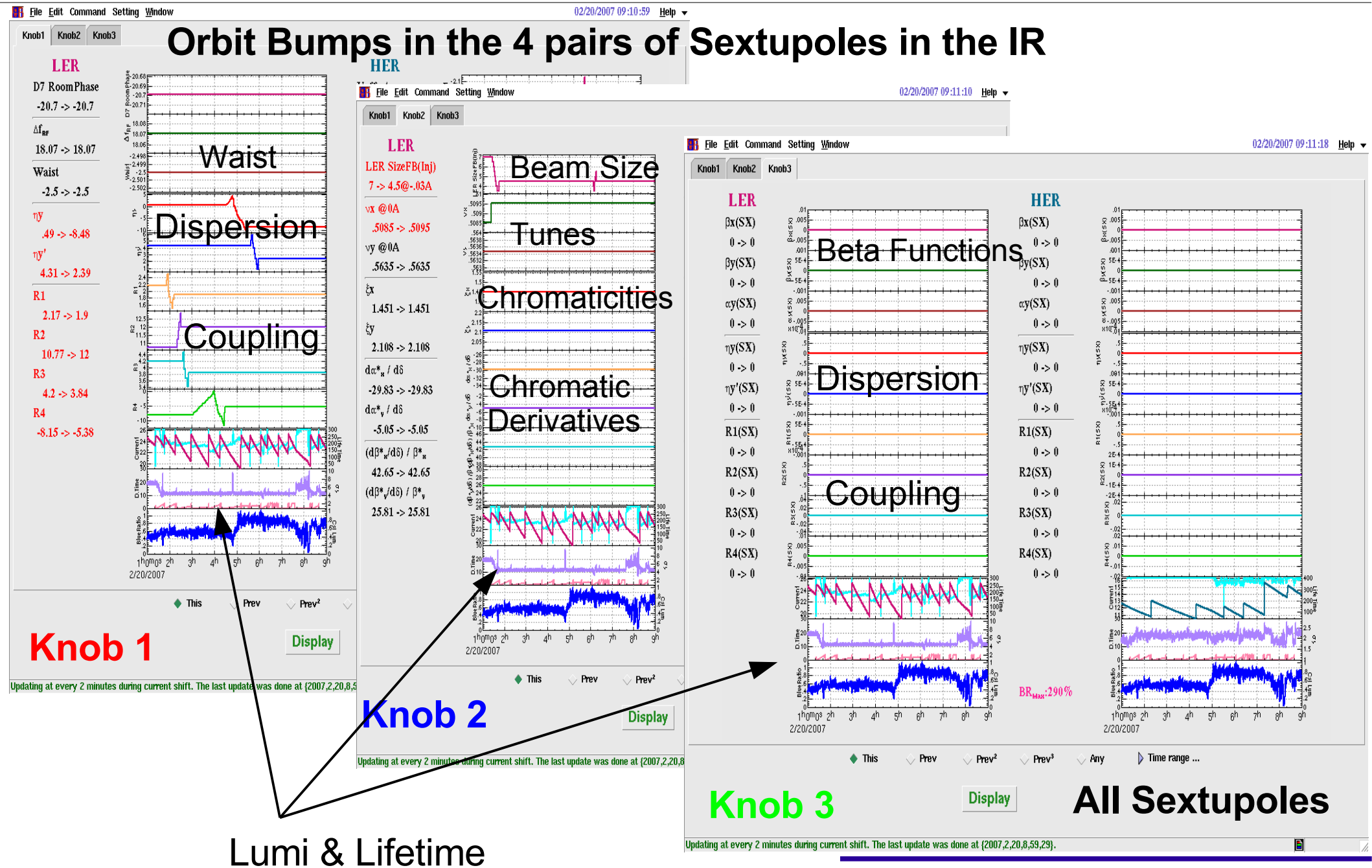
IR Waist Scan

- Vary IR quadrupole ($\Delta\varphi \sim \pi/2$, localized β modulation)
- Measure luminosities, lifetime, and beam size



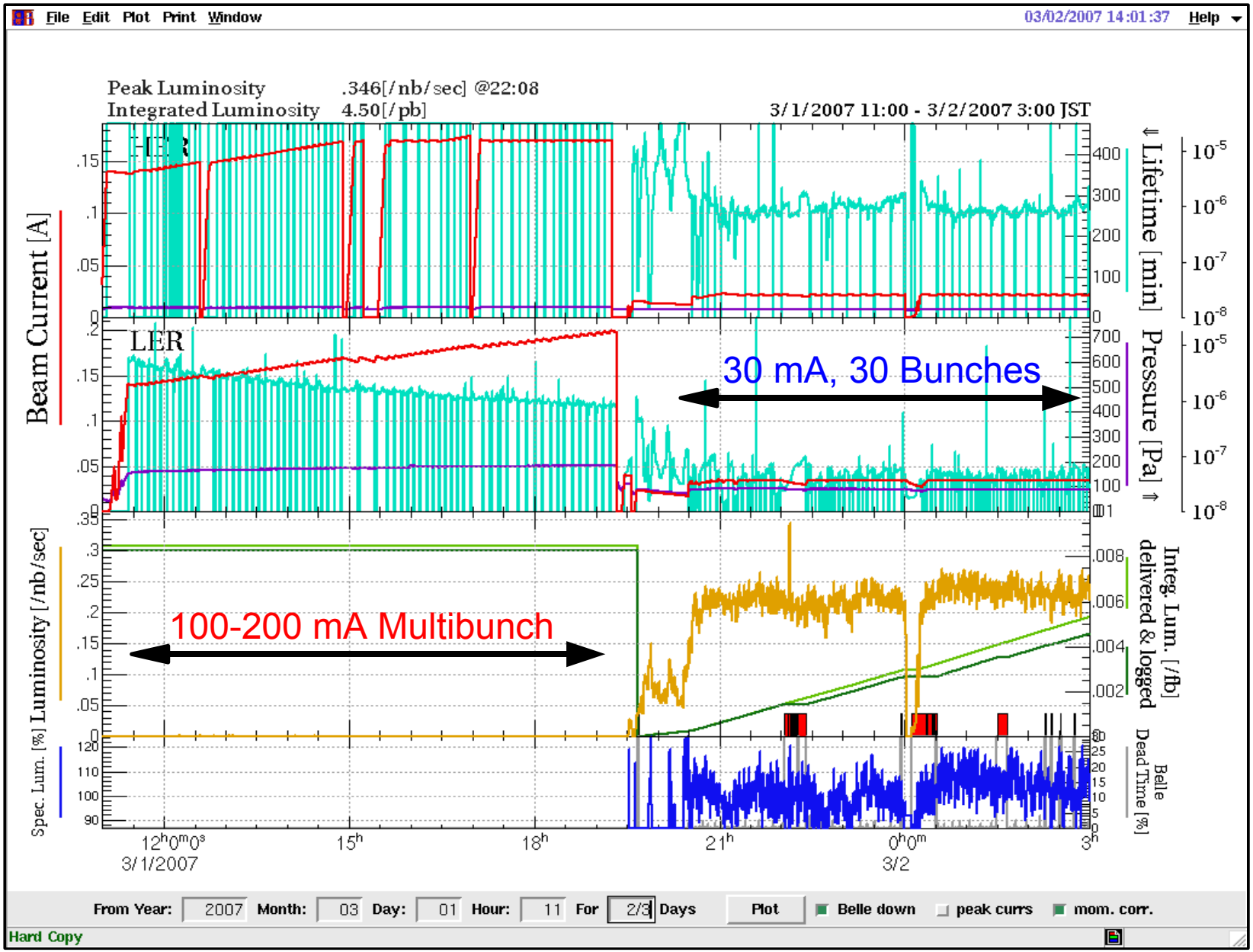
Courtesy Y. Funakoshi, H. Koiso et al.

IP Knob Scan Data



Courtesy Y. Funakoshi, H. Koiso et al.

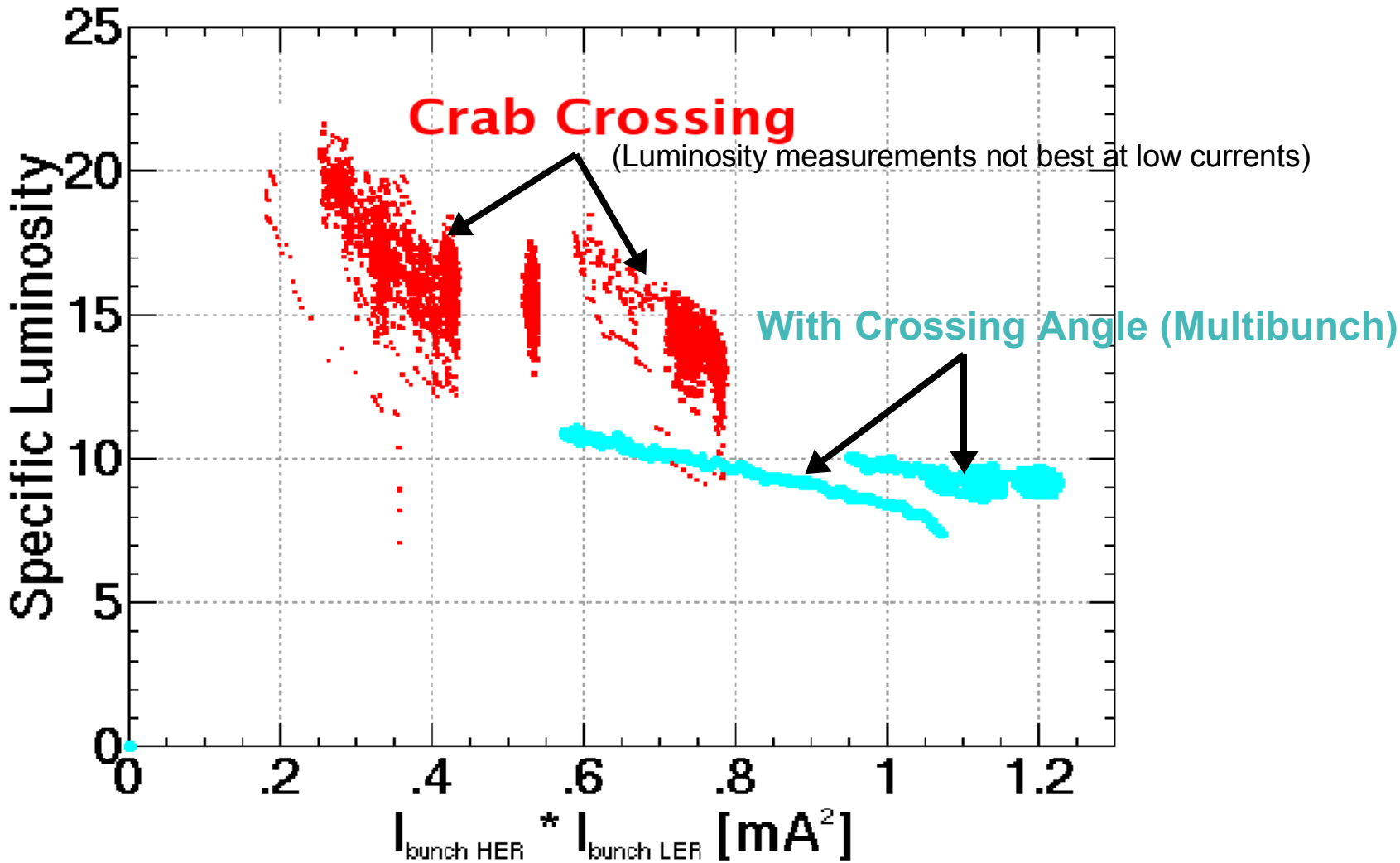
Beam & Crab On



KEKB Control Room

Specific Luminosity

L_{sp} = Lumi/bunch/$q_{ele}q_{pos}$



Courtesy H. Koiso

Conclusions

- Almost 15 yrs of R&D on the idea of crab cavities
- Two cavities installed Jan 2007 and successfully crabbed the beam
- More tuning needed for luminosity optimization, also increase LER V_{crab}~1.4 MV
- Stability and vacuum issues at high currents ??
- Next milestone ~ 200 mA to observe benefits from head-on collision

Need to benchmark Ohmi's Beam-Beam code with HEADTAIL (or others) including LHC sector map + crab cavity for phase tolerances and such for LHC

KEK-B group enthusiastic about LHC crab proposal, future collaboration foreseen

Many Thanks to K. Oide, K.Ohmi & KEKB Team !!

And Good Bye Japan...