Crab Cavities & Emittance Growth Issues

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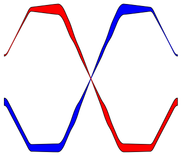
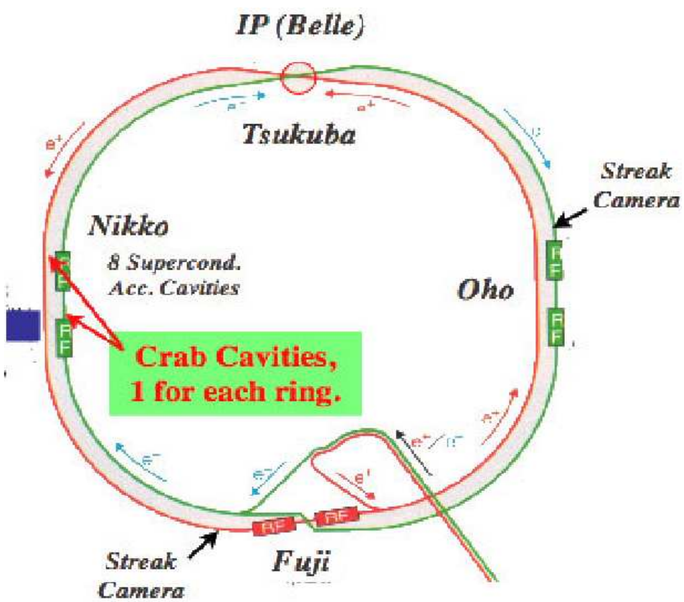
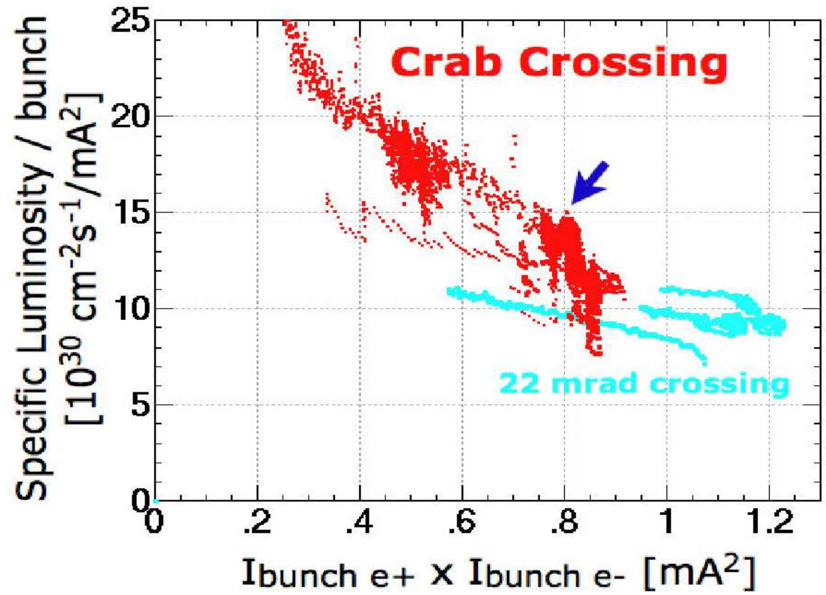


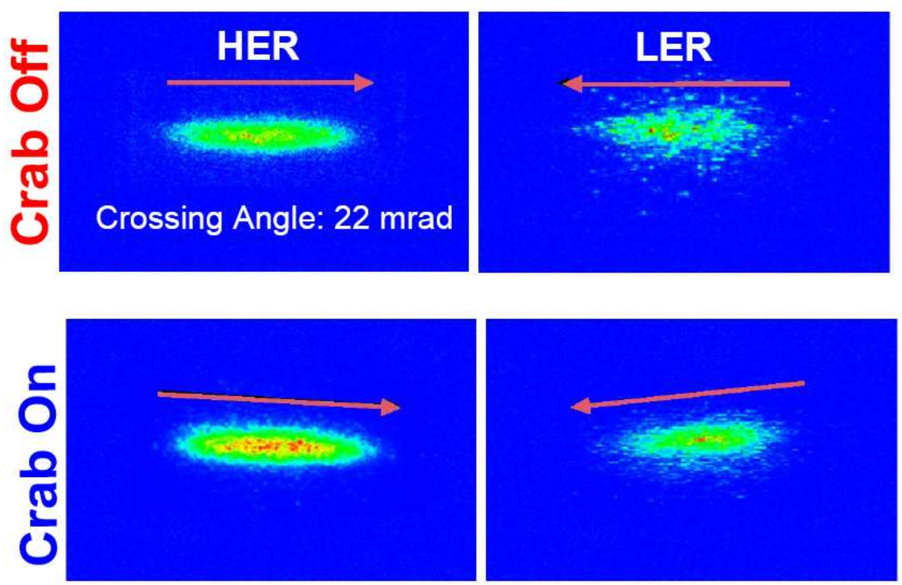
Topics

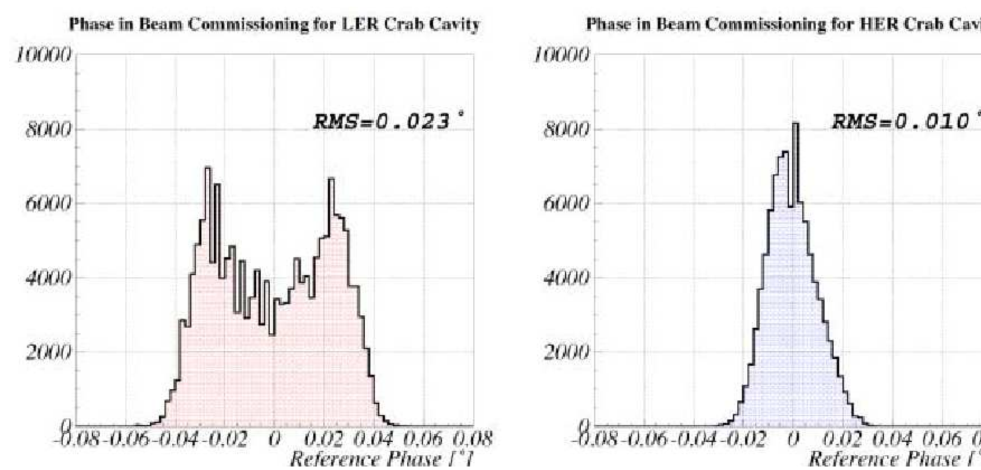
- KEK-B, A Few Words
- LHC IR Upgrade with Crab Cavities
- RF Curvature, Phase Jitter & Emittance Growth Estimates
- Some Optics & Coupling Issues

KEK-B Crab Cavities





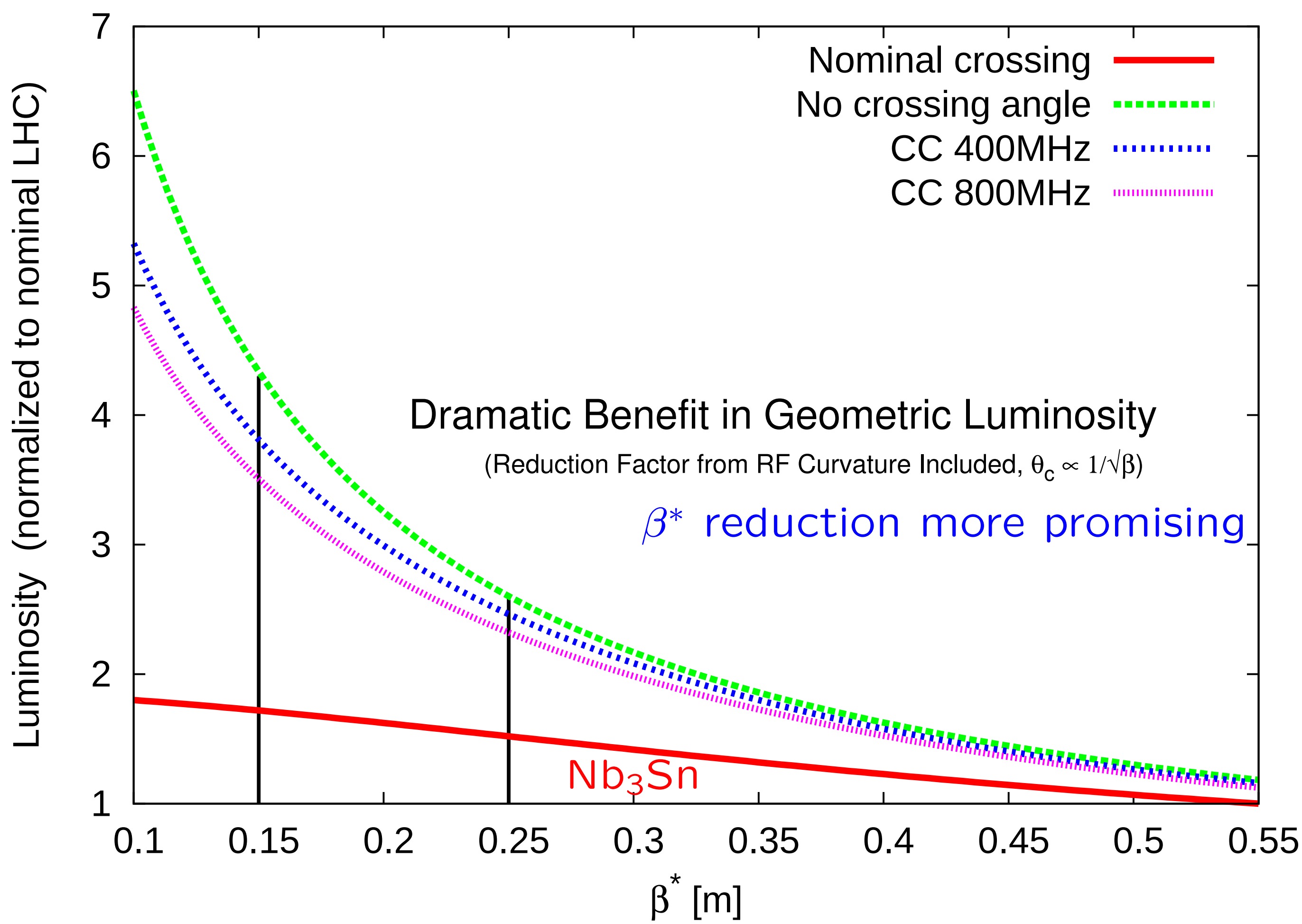




— Courtesy KEK-B

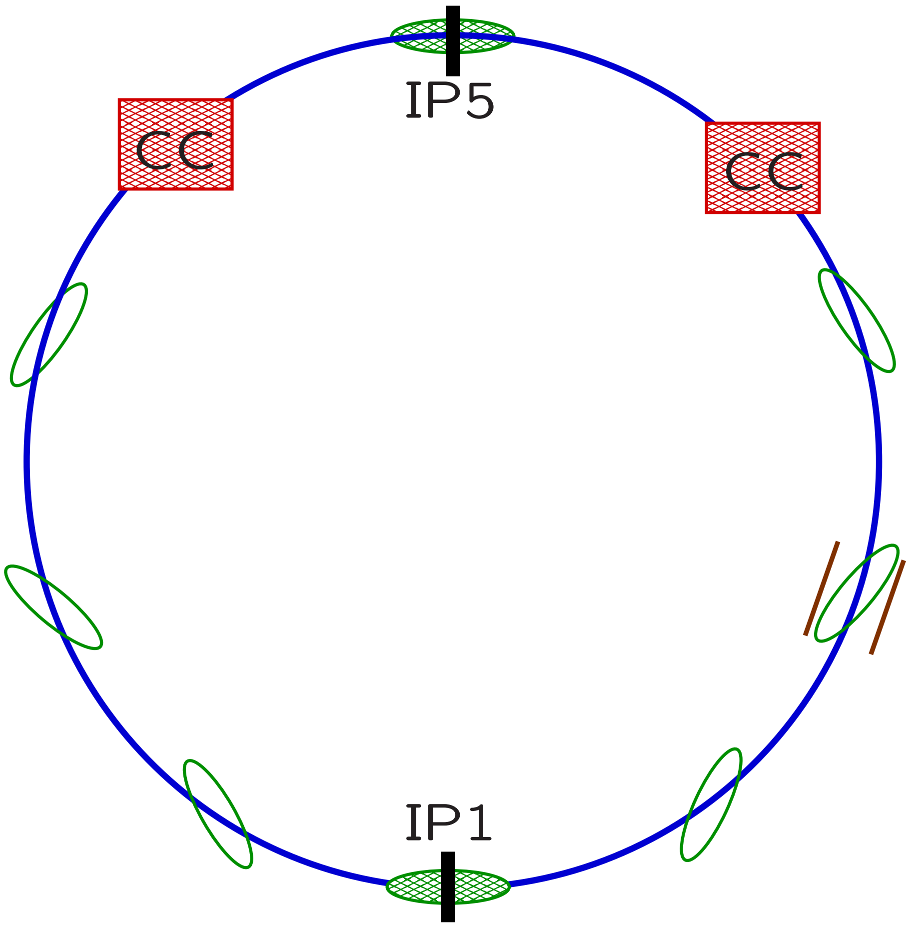
Geometric Luminosity

$$\theta_c \text{ Reduction Factor: } \frac{L}{L_\circ} \approx \left[1 + \left(\frac{\sigma_z}{\sigma_x^*}\tan\left(\theta_c/2\right)\right)^2\right]^{1/2}$$

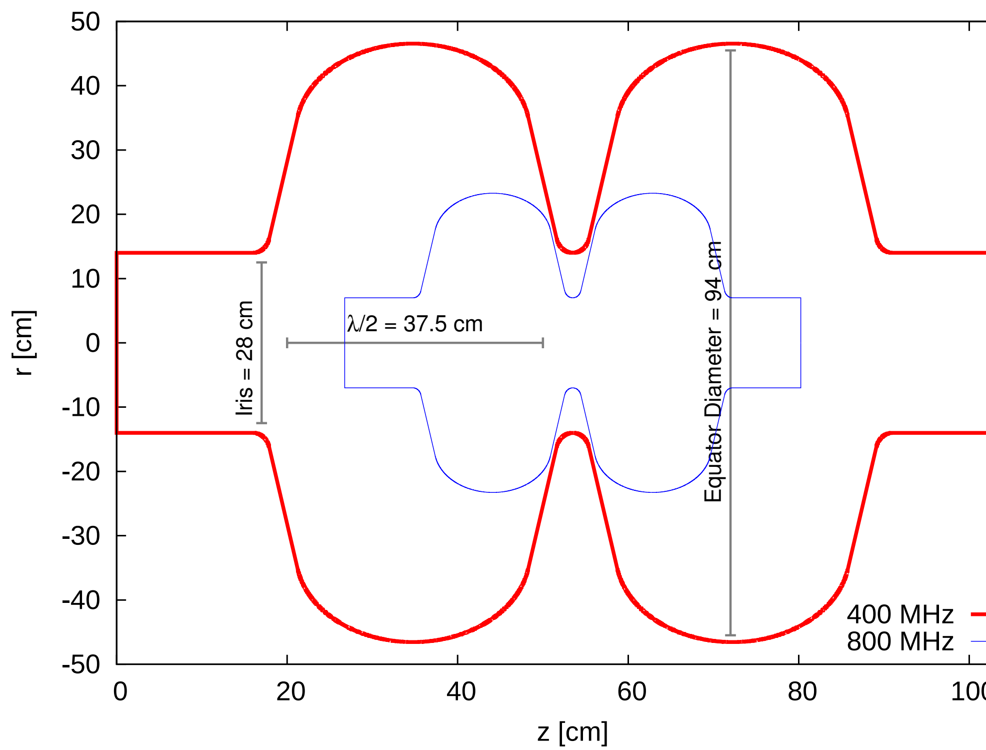


Larger θ_c: Alleviate Long range beam-beam, Simple IR design (Sep. Quads, NbTi) & machine tuning...

Small θ_c (0.3-0.6 mrad)

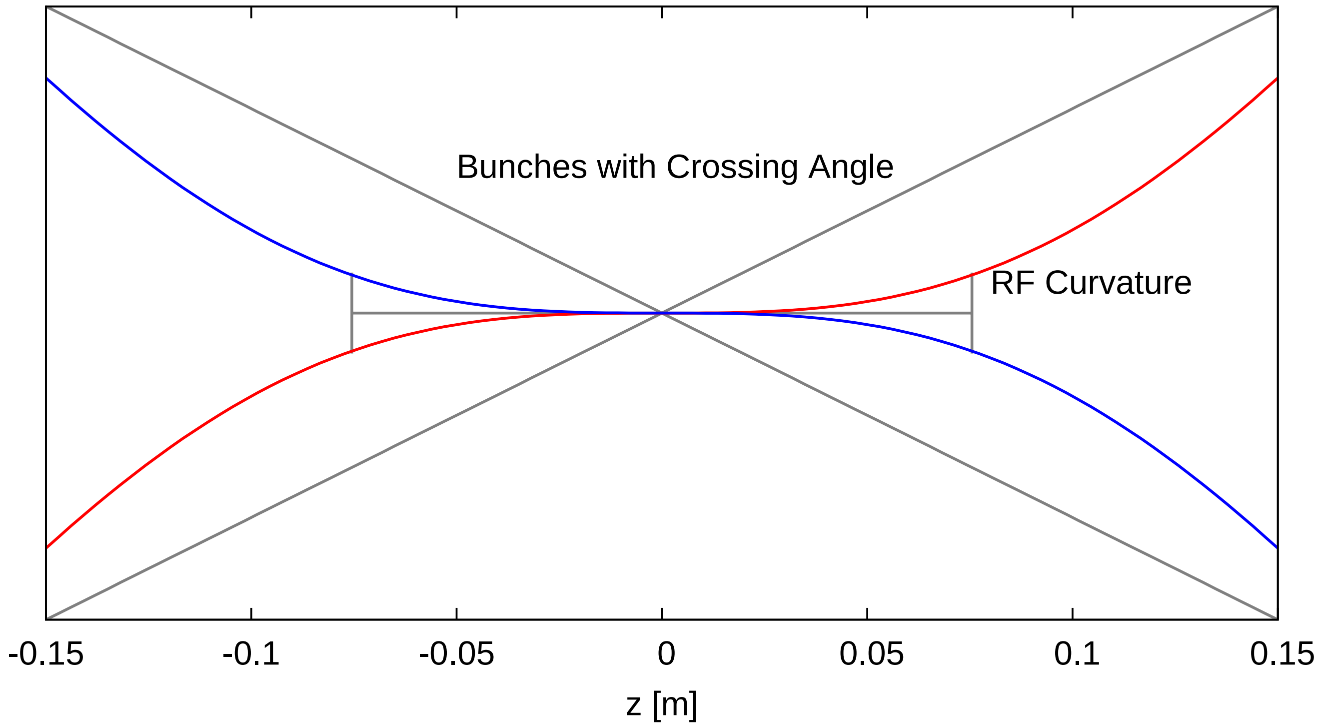


β^*	25 (15) cm
Deflecting Voltage	8.31 (10.73) MV
E_{peak}	~50-60 MV
B_{peak}	~ 300-500 Oe
RMS Orbit	0.35 (0.45)mm
Peak Orbit	2.4 (3.0) mm
Tune Shift $\{Q_x, Q_y\}$	$\{0.5,1.2\}\times 10^{-4}$



$$V_{crab} \propto \frac{1}{\omega_{rf}\beta^*} \quad \{\theta_c \sim \frac{1}{\sqrt{\beta *}}\}$$

RF Curvature & Emittance Growth

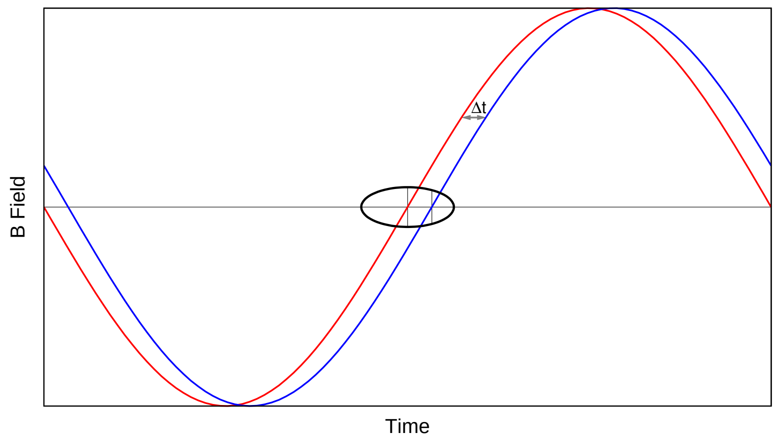


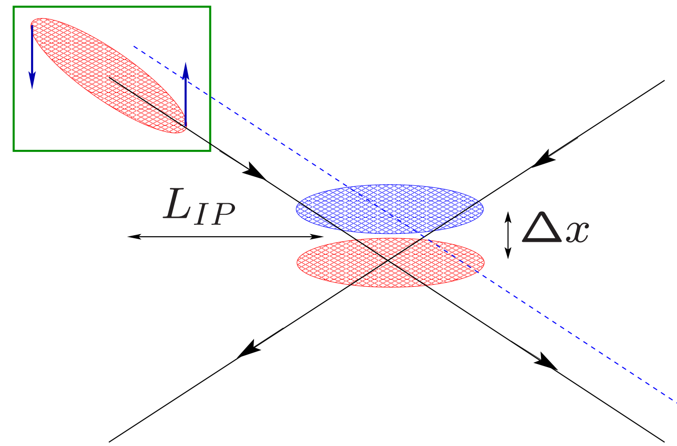
- No significant emittance growth due to finite θ_c from simulations
- No measurable emittance growth observed in RHIC
- Head to tail transverse separation is smaller with CC than finite θ_c ($\lambda > \sigma_z$). Tune shift is different and need to be calculated

Noise Tolerances

Phase jitter introduces random offset:

$$\left(\frac{\Delta\epsilon_x}{\Delta t}\right)_{BB} \approx n_{IP} f_r \frac{8\pi^2\xi^2}{\beta_x^*}(\Delta x)^2 \qquad \left\{\Delta x_{IP} = \frac{c\theta_c}{\omega_{RF}}\delta\phi\right\}$$





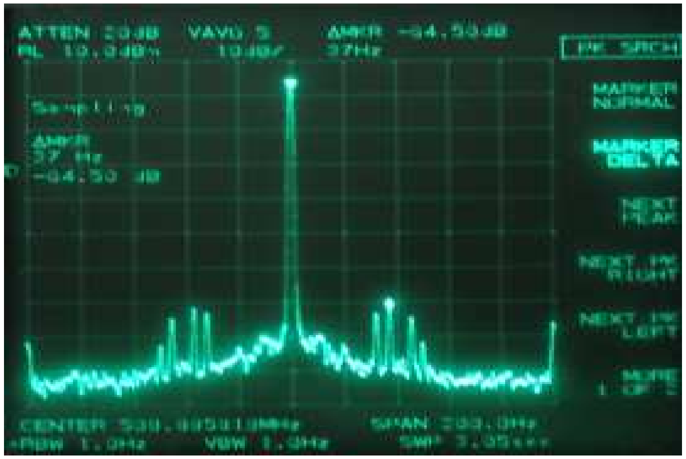
Random Dip Kicks: $$\frac{1}{\epsilon}\frac{\Delta\epsilon_x}{\Delta t} \approx \frac{f_r(1-s_0)}{4\sigma_x^*\left(1+\frac{g}{2\pi|\xi|}\right)^2}(\Delta x)^2$$

For 1% Emittance Growth/Hr

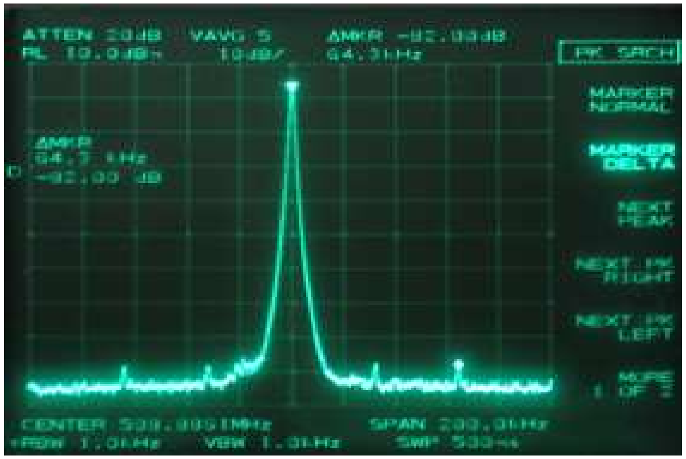
Jitter Estimate	Amp.	Phase	
		Beam-Beam	Dip. Kicks
Analytical	$\sim$ 0.04%	0.01° (0.006°)	0.006° (0.003°)
Simulation (WS)		0.002°	-
Simulation (SS, K. Ohmi)		$<$ 0.001°	
Feasible Today	0.01%	0.003°	

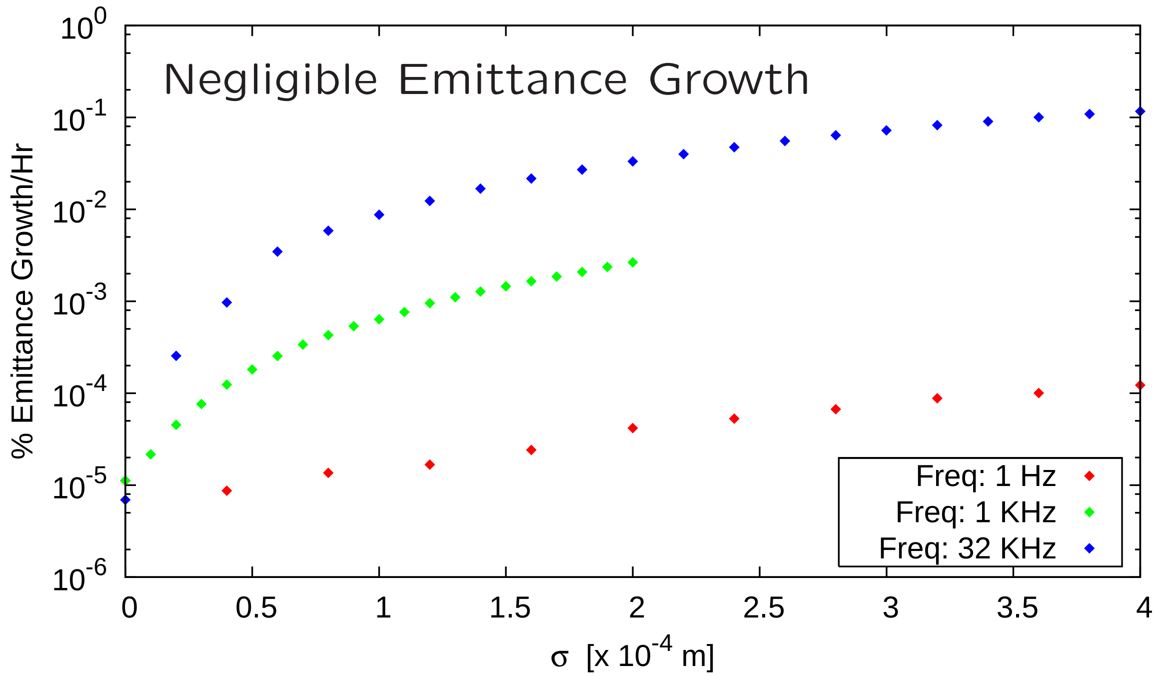
Modulated Jitter

Span 200 Hz



Span 200 kHz





— Measurements courtesy K

Some Optics Issues

- Horizontal orbit $\sim$2 mm for $\beta^* = 0.25$ m. Collimation issues ?
- Error in β_{crab} & $\Delta\phi_{cc\to ip}$ similar to ΔV_{crab} error:

$$\Delta\phi_{err} \sim 0.25^\circ \Rightarrow \quad \theta_{res} < 1\mu\text{rad}$$

- $\Delta\phi_{cc\to ip}$ to be optimized with luminosity & lifetime.
- Local β-function modification at cavity, extra degree of freedom.
- Coupling introduces vertical θ_c & offset (prelim estimate):

$$\text{Tilt Err} \sim 1 \text{ mrad}$$
$$\Delta Q_{min} \sim 1.5 \times 10^{-3} \Rightarrow \quad \theta_{c,y} \sim 6\mu\text{rad}$$

- Impact of Sextupoles: Ph. adv. variation with amplitude (simulations needed)

Conclusions

- Dramatic benefit ($\times 2.5$) on luminosity gain with β^*
- 800 MHz ($\theta_c < 0.6$ mrad) seems best option considering RF, beam dynamics, technical & cost aspects (IR07 for details)
- Noise issues do not appear to be problem but more SS simulations needed
- Longitudinal collimation ? Need to investigate any collimation inefficiency & machine protection issues due to oscillating bunch
- Collaboration: BNL, CERN, DL/CI, KEK-B, LBNL, SLAC, Cornell
- CC workshop early next year (April 08)