Session II, Summary

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Beam dynamics issues (global cc)

		Simulation	KEKB	SPS	LHC w/o cc	Tevatron
	Optics preparation	seems OK	-	-	-	-
▲	b-b limit w/ x-angle	OK	~0.06	OK	-	OK
▲	Ramping w/ beam	OK (w/b-b?)	○	●	-	-
◎	Crab phase noise	Done?	OK	●	-	-
▲	Impedance	tolerance	OK	●	-	-
	Dynamics aperture	OK	OK	●	-	-
	DA w/ long-range BB	OK	-	●	-	-
	S-B resonances	OK	OK	●	-	-
	Physical aperture	+ 0.5σ	-	●	-	-
▲	Beam collimation	Maybe OK	-	●	-	-
	Coherent oscillation	To be done	solved	-	-	-
	Luminosity leveling	promising	○	-	-	-
	AC dipole	OK 800MHz?	-	●	○	?
	Head-tail osci. like crabbing	?		?	○	?

○: can be tested, ●: can be tested if cc is brought

Layout & Design

- Layout, Optics & Operational Scenarios
  by Riccardo de Maria (*BNL)*
- Minimum test scenario: Single Crab Cavity in LHC
  by Yipeng Sun *(CERN)*
- KEK-B Crab-Experiments for the LHC & Super KEK-B
  by Rogelio Tomas (*CERN)*
- Crab Cavity Momentum Cleaning
  by Yipeng Sun *(CERN)*

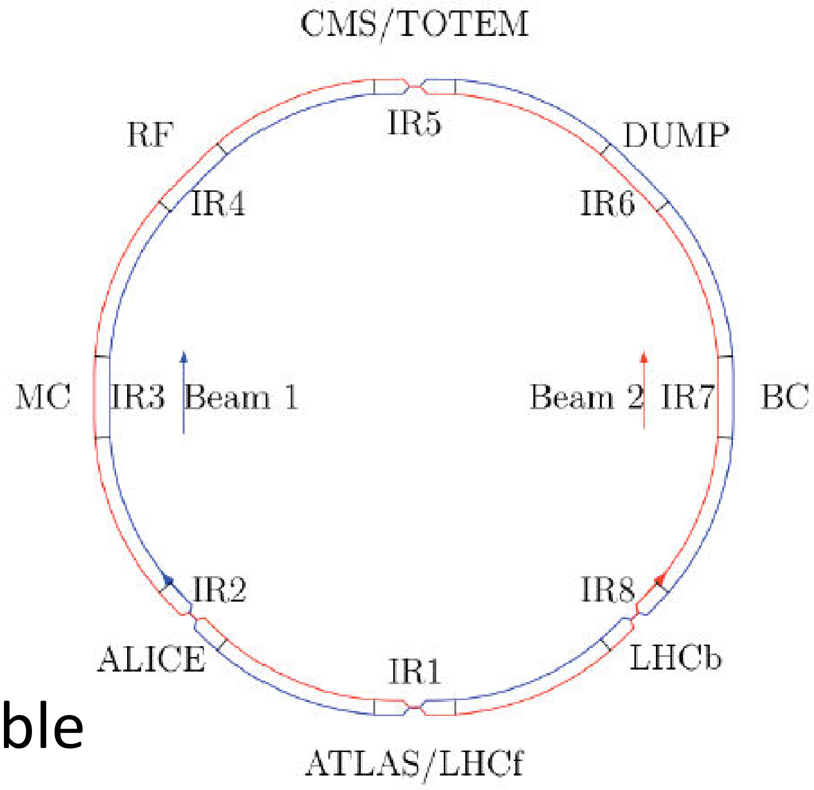
Crab cavity prototype test: operational scenarios and optics

Riccardo de Maria (BNL),
R. Calaga (BNL), Y. Sun(CERN), R. Tomas(CERN
Acknowledgments to O. Bruening, S. Fartoukh, M. Giovannozzi, G. Kotzian, W. Hoefle, J. Tuckmantel, F. Zimmermann.

September 16, 2009

Summary

- In this talk, the operational scenario and optics design of crab cavity test (phase I) were presented.
- Phase I
  - Global cc (cc@ IR4)
  - Luminosity gain 10~25%
- Optics
  - Un-squeeze @ IR4
  - Constraint
    - Beam size (aperture)
    - Phase advance (crab<->IP)
  - Proposed optics seems feasible



Sketch of the operations

The prototype test will use at the beginning few bunches and only after success the nominal intensity beam.

- Injection and ramp: the cavity should be transparent
  - 0-kick: RF loops on to maintain 0 energy in the cavity (possible in case of a cryo failure?)
  - detuned: the beam does not see it (5kHz is enough?)
  - dephased: the cavity act like a dipole kicker (watch out for distortion!)
- Collision: the cavity should show its effect.
  - ramp: few tens of turns fulfill adiabaticity (see Yipeng)
  - measure luminosity improvements
  - test luminosity leveling

More details will be given by Stefano.

During collisions we would like to make an efficient use of the cavity voltage...

Crab Voltage

The effect of the crab cavity depends on RF voltage and phase and the optics parameter of the machine.
We define V_{full} to be the voltage needed by one cavity to rotate each bunch of half crossing angle ($\theta_c/2$), that is:
fully compensate the geometric reduction if there is one crab cavity per beam.
The cavities for the test may or may not reach this voltage.

$$\frac{\theta_c}{2} = \frac{V_{full}\,\omega_{rf}}{2cE_0} \frac{\sqrt{\beta_{crab}\beta^*}\cos(2\pi(\psi^x_{cc\to ip} - \mu_x/2))}{\sin(2\pi\mu_x/2)}$$

From the optics point of view the relevant quantities are:
the β function at the location of the cavity β_{crab} and the collision point β^* and
the phase advance between them $\psi^x_{cc\to ip} = |\psi_x(s_{ip}) - \psi_x(s_{cc})|$.

The other quantities are: E_0, beam energy; $\theta_c = d_{sep}\sqrt{\varepsilon/\beta^*}$, the crossing angle; ω_{rf}, the crab cavity RF frequency;
μ_x is the horiz.tune.
β_{crab} and $\psi^x_{cc\to ip}$ can be optimized.

Move Qx near integer?
(factor 3 lower β_{crab} for Qx =0.1)

IR4 un-squeeze for crab cavity operation

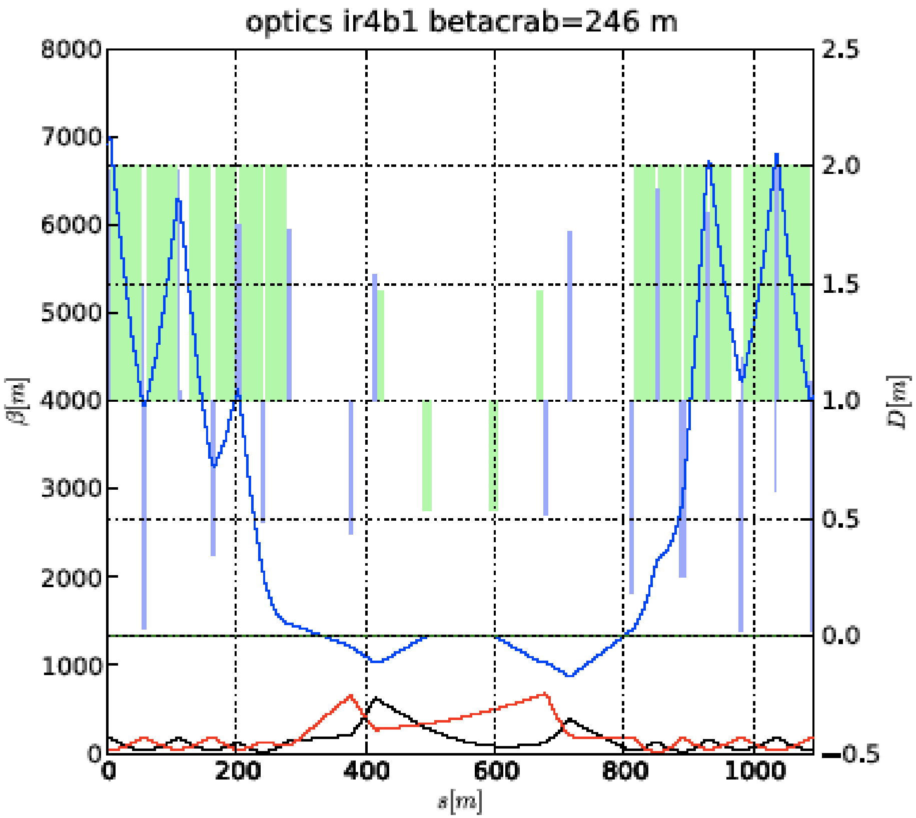
In order to use efficiently the cavity voltage, we need the largest possible beta function and the right phase advance between the IPs.

We propose to perform an un-squeeze similar to the way the beta function is squeezed in the IP1 and IP5 to reduce the beam size.

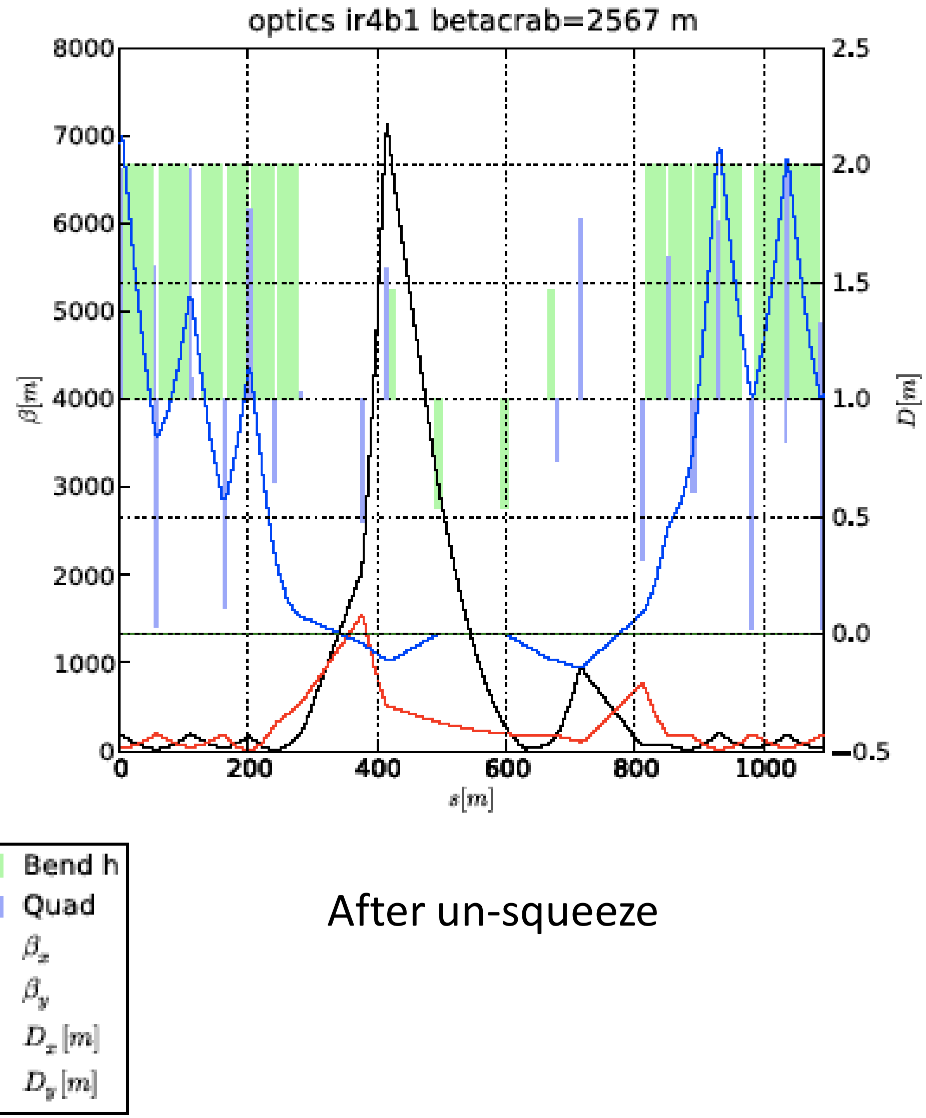
The un-squeeze is designed to start at 7TeV and reach the maximum beta function at the crab cavity location. The total phase advance of the insertion is kept constant.

It is possible to start at lower flat top energy: the peak beta function will be necessarily reduced, but the optics will gain tunability by the gradients reserve not available at 7TeV.

Un-squeeze (IR4) @ 7GeV



Before un-squeeze



After un-squeeze

Single crab cavity test scenario in LHC

Yi-Peng Sun, Ralph Assmann, Javier Barranco, Rama Calaga, Akio Morita, Rogelio Tomás, Thomas Weiler, Frank Zimmermann

ABP Group, BE Department, CERN; BNL, U.S.; KEK, Japan

Thanks to D. Schulte, C. Bracco (MATLAB code), O. Bruning, J.-P. Koutchouk, M. Giovannozzi, F. Schmidt, and U. Dorda

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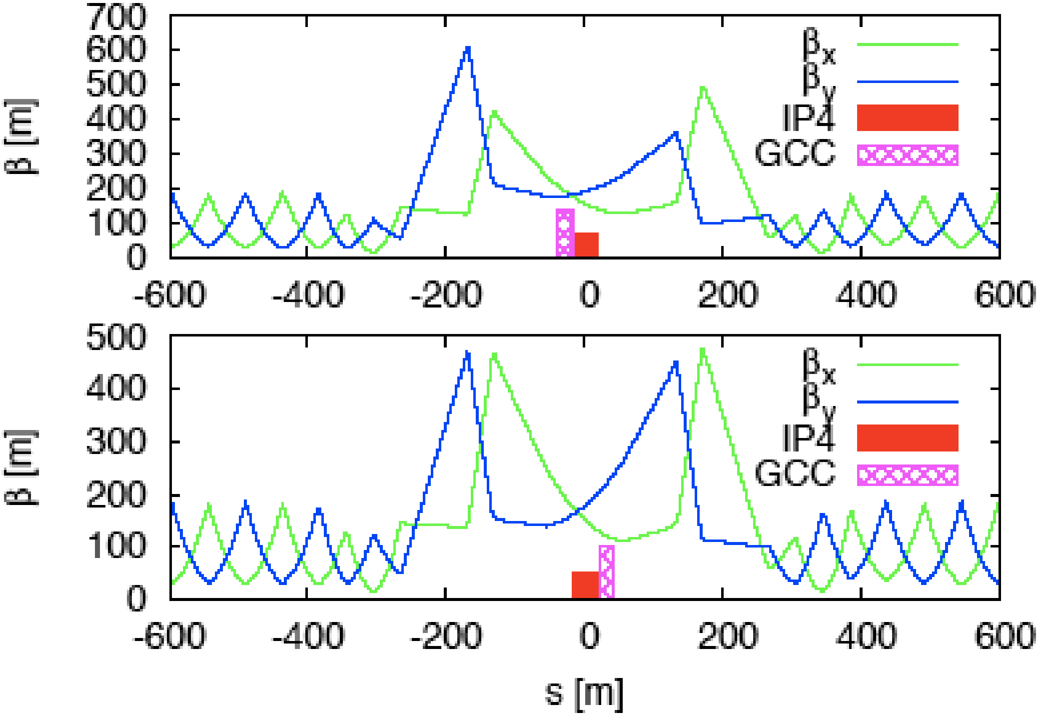
Conclusions (1)

- Various beam dynamics issues have been studied
- LHC optics can fulfill the requirements to install CC
- Minimum dynamic aperture acceptable
- Global crabbing scheme requires an additional 0.5σ aperture
- z-dependent 'beta beating' very small
- With only one 800-MHz global crab cavity, the luminosity gain can be as large as 25% for reduced beam emittance
- Emittance growth study for the CC voltage ramping shows that a ramping period of longer than 10 turns sufficient

Conclusions (2)

- Local cleaning inefficiency of the LHC collimation system not affected by CC presence
- Available phase space for the circulating beam only moderately disturbed by the global crab cavity
- Hierarchy of primary (TCP), secondary (TCSG), tertiary (TCTH), beam dump (TCDQ) horizontal collimators and shower absorbers (TCLA) is maintained
- Crab collision case with both beams crabbed, simulated beam-beam tune shift = head-on collision tune shift
- Second-order synchro-betatron resonances introduced by the crossing collision suppressed by the crab cavities.

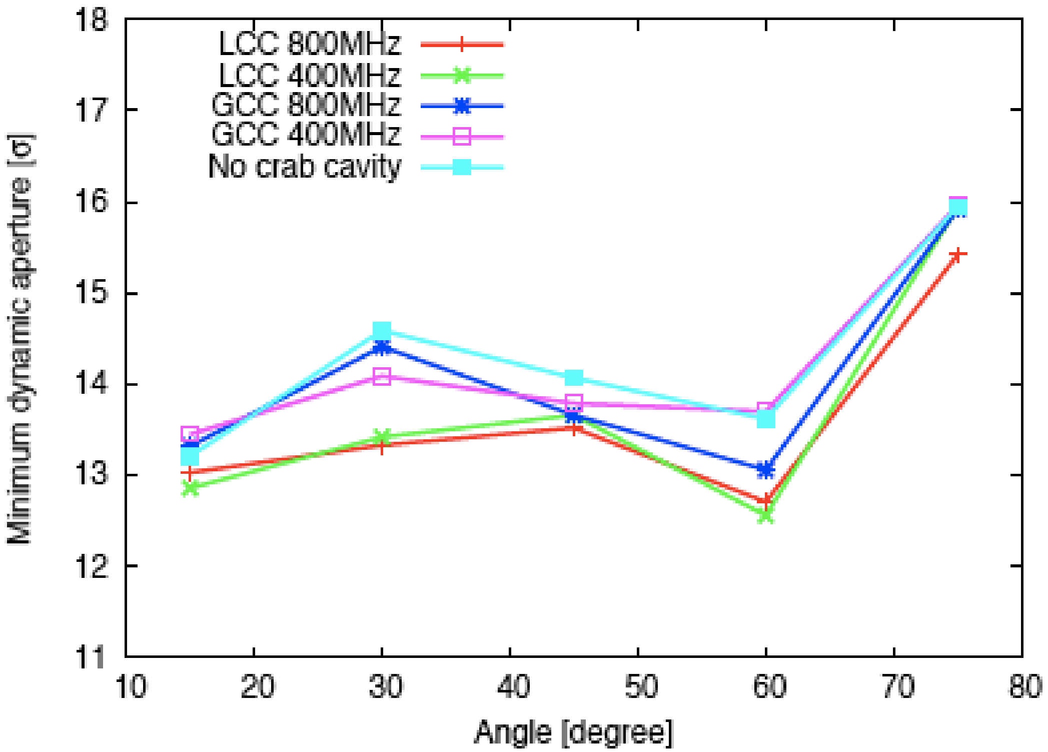
IR4 Optics



1) Increase β_{CC} (up to 3 km) –> 2.3 MV

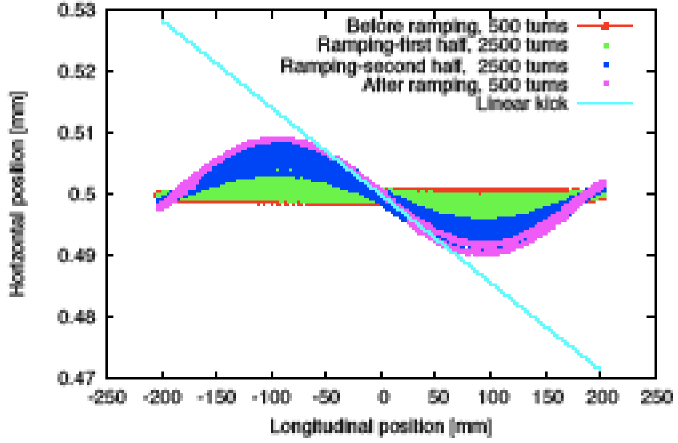
2) Move Q_x near int. (factor 3 reduction for $Q_x = 0.1$)

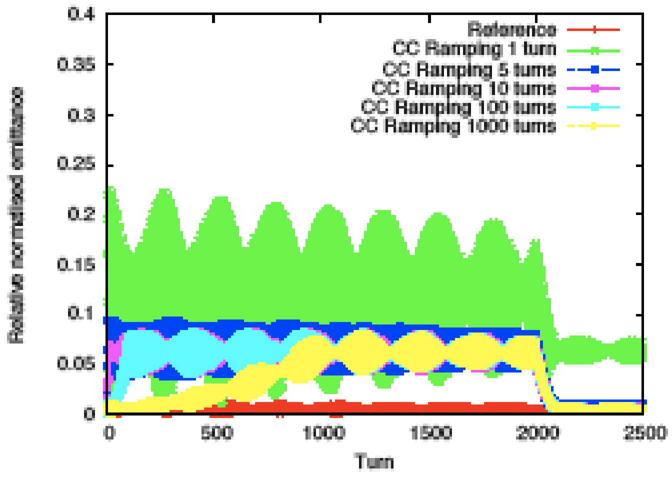
Dynamic aperture



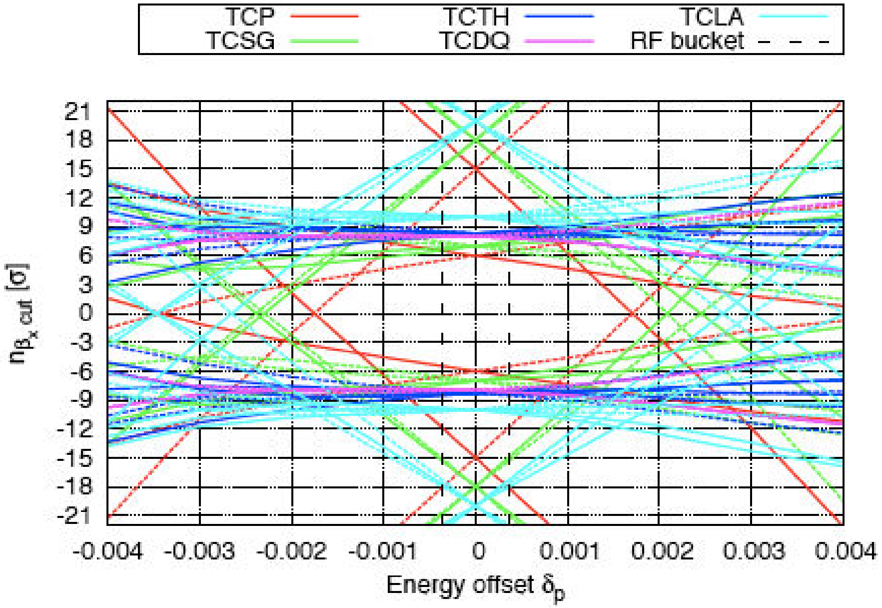
- Min DA over 60 error seeds; 100,000 turns
- Maximum decrease of 1 σ (average)

Emittance growth





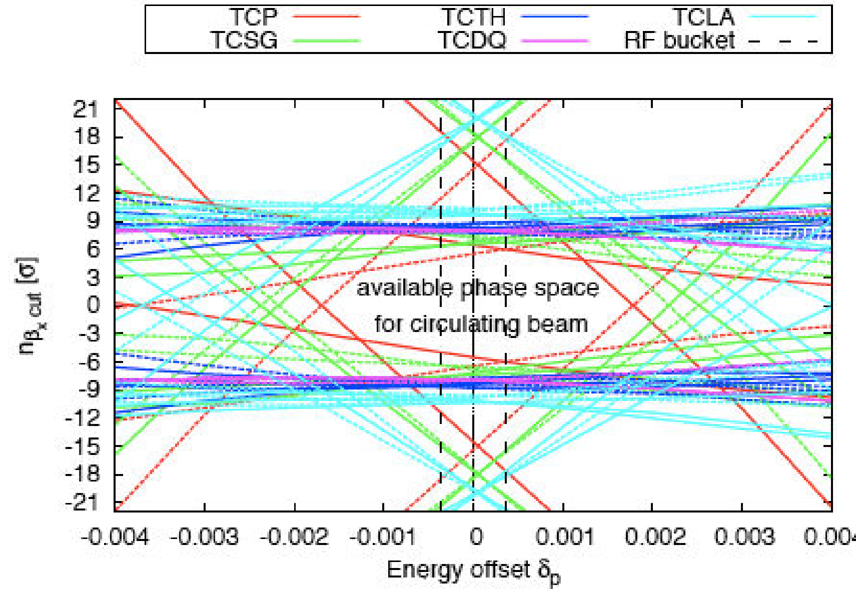
- Left: check of crab cavity ramping
- Right: relative horizontal emittance growth indicateds ramping time > 10 turns



Off-momentum beat (δ_p-dependent D_x and β)

No crab

With crab



Crab beat @$1\sigma_z$ + Off-momentum beat (δ_p)

My summary

- This talk makes several things clear on feasibility of global crab crossing operation at LHC.
  - Emittance growth in case of crab ramping
  - Physical aperture and beam collimation
  - Dynamic aperture
  - Synchro-betatron resonance

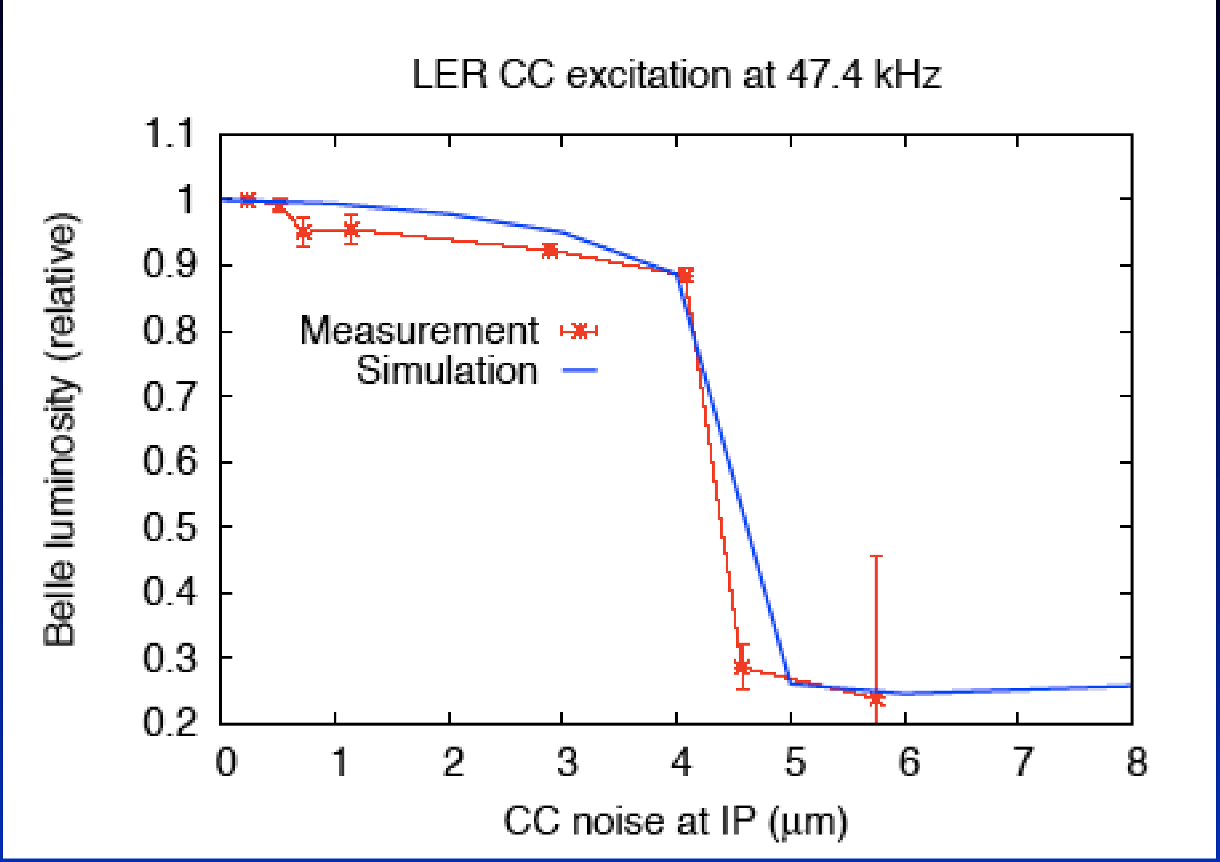
KEK-B Crab Cavity Experiments for the LHC & Super KEK-B

Y. Funakoshi, Y. Morita, K. Nakanishi, K. Ohmi,
K. Oide, Y. Onishi, *KEK*
R. Tomás, Y. Sun and F. Zimmermann, *CERN*
R. Calaga, *BNL*

Conclusions on noise studies

- A beam-beam driven noise-instability has been observed in KEKB
- The instability requires a frequency within the beam-beam continuum spectrum and amplitude of few % of the σ.
- In degrees this corresponds to 0.2°.
- First effects of noise observed at 0.03°
- Extrapolating to LHC:
  - CC RF phase stability $<< 0.03^\circ$ (OK!)
  - 0.3μm IP offset stability??
  - KEKB BB-tuneshift was $0.046 >$ LHC tuneshift

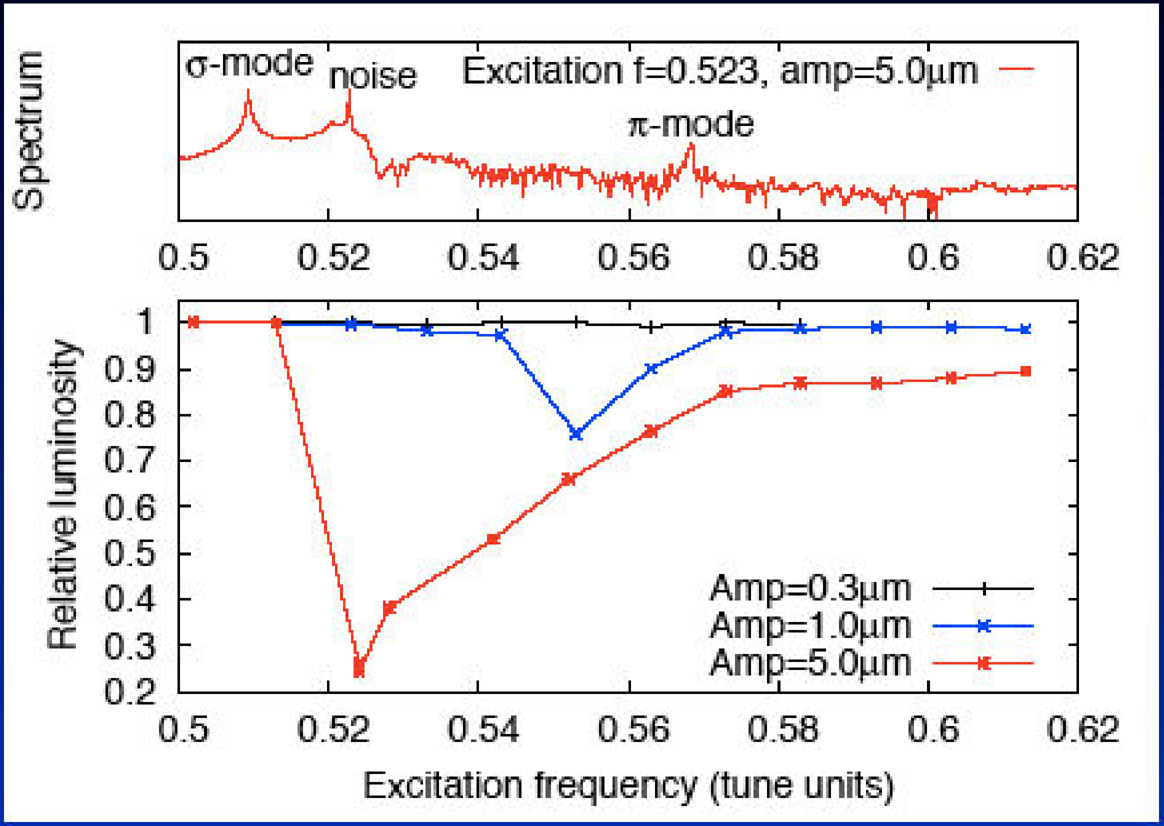
LER CC noise close to Q_x (exp. vs sim.)



→Measurement and simulation in excellent agreement!

→Shocking abrupt luminosity loss at 4.5μm$\approx 0.02\sigma_x^*$

Understanding the phenomena (simulation)



→ Luminosity loss versus frequency

→ Instability is most severe for frequencies within the continuum spectrum (between σ and π modes)

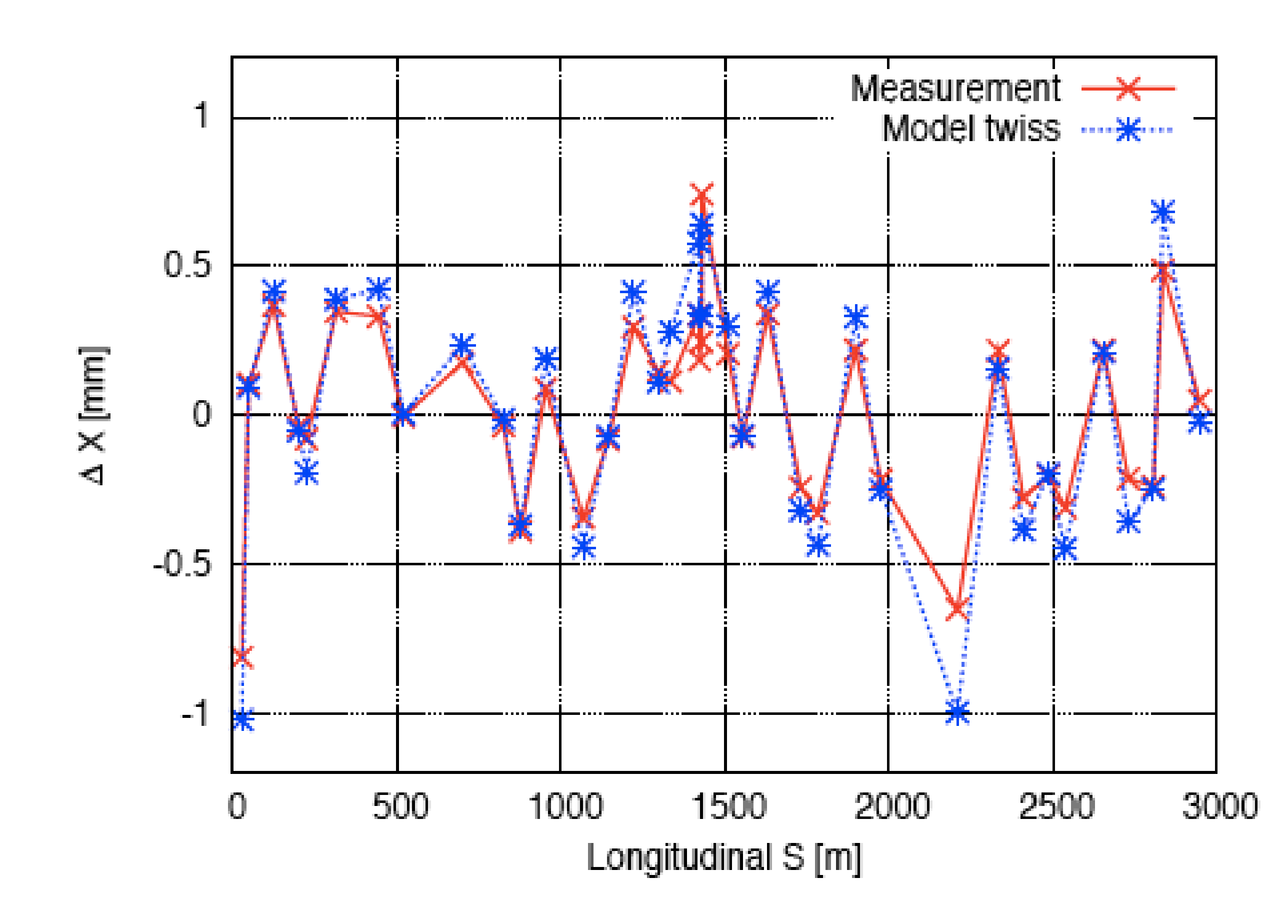
→ No instabilities at the tune (σ-mode).

Crab dispersion measurement

The most precise measurement of crab dispersion turns out to use the closed orbit with CC phase offset:

- KEK regularly operates CC with 10° phase offset
- This offset is like a dipole kick
- $x_{D_{cc}}$ is obtained by subtracting orbits with and without CC

Crab dispersion measurement



Model and measured $x_{D_{cc}}$ are in very good agreement!

Crab momentum cleaning in LHC

Stéphane Fartoukh, Yi-Peng Sun, Rogelio Tomás
and Frank Zimmermann
European Organization for Nuclear Research (CERN)
Thanks to: Ralph Assmann

16 Sep., 2009

S. Fartoukh' proposal

Derivation

$\frac{dt}{T_0} = \frac{dC}{C_0} = \eta \cdot \delta p$ and $\Delta p_{x,CC} = \frac{q \cdot V_{CC}}{E_s} \cdot sin(\omega_{CC} \cdot t)$
$\longrightarrow \Delta p_{x,CC} = \frac{qV_{CC}}{E_s} \cdot sin(\frac{\omega_{CC}}{\omega_0} \cdot \eta \cdot \delta p \cdot n)$

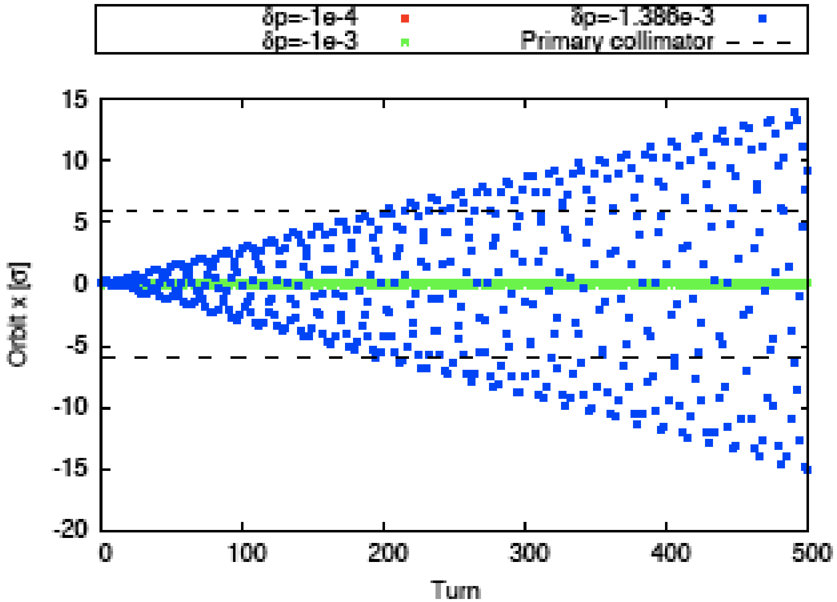
Tune of crab-AC-dipole, formula

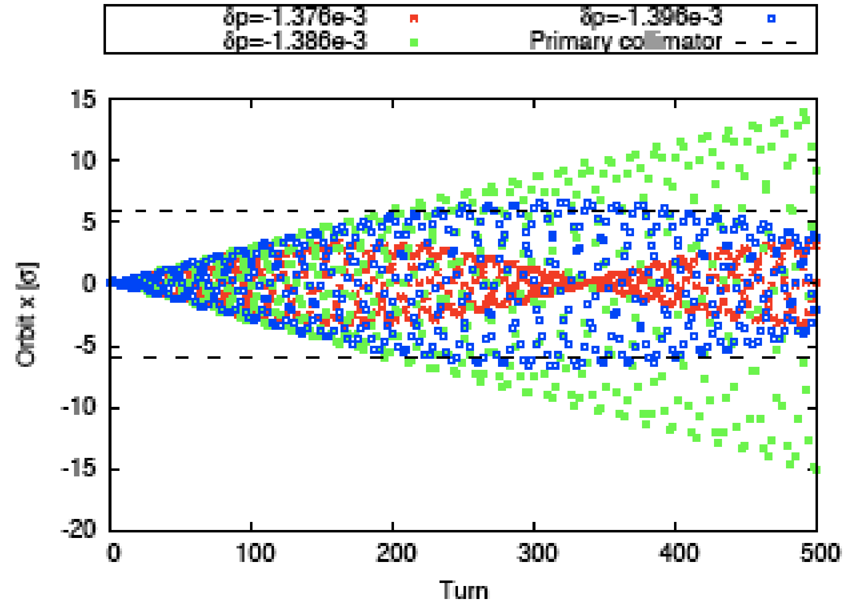
$Q_{ACC} = \frac{\omega_{CC}}{\omega_0} \cdot \eta \cdot \delta p$

Tune of crab-AC-dipole, LHC

For LHC $\eta_0 = 3.4 \times 10^{-4}$, $\omega_0 = 11$KHz
with $\omega_{CC} = 800$MHz, $Q_{ACC} = 0.025$ for $\delta p = 0.001$
with $\omega_{CC} = 8$GHz, $Q_{ACC} = 0.31$ for $\delta p = -0.001386$
——»» $Q_{ACC} = Q_x = 0.31$, coherent oscillations

Coherent oscillation with 8-GHz CC (1)





$\delta p = -0.001386$, $Q_{ACC} = Q_x = 0.31$ works with 3×10^{-6}rad, smaller than LHC AC dipole strength

Conclusion

- Crab-AC-dipole works in LHC for 8-GHz & 2.4-GHz
- Clean very early the off-bucket particles which have not yet reached the abort gap (good for background)
- Alternative to the momentum collimation insertion
- pi/2 IR phasing–> $\beta^* = 15\text{cm}$
- For 800-MHz, Q_x–> 0.04 to use linear resonance; or creat the condition for 4th-order resonance

What To do next

- **2.4-GHz possible in LHC?**
- **Crab-cleaning collimation tracking: on-going**
- **Find resonance condition for 800-MHz CC**