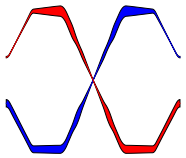
Small Angle Crab Crossing

(Some Requirements & Plans)

Rama Calaga

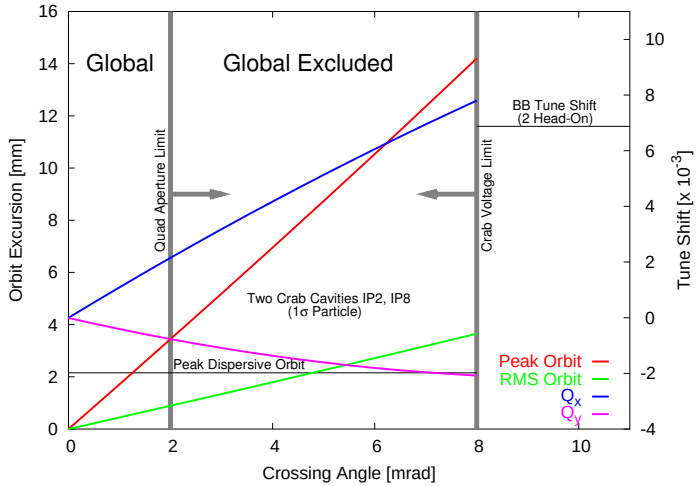
Ack: U. Dorda, R. Tomás, F. Zimmermann



IR07 - Nov 9, 2007

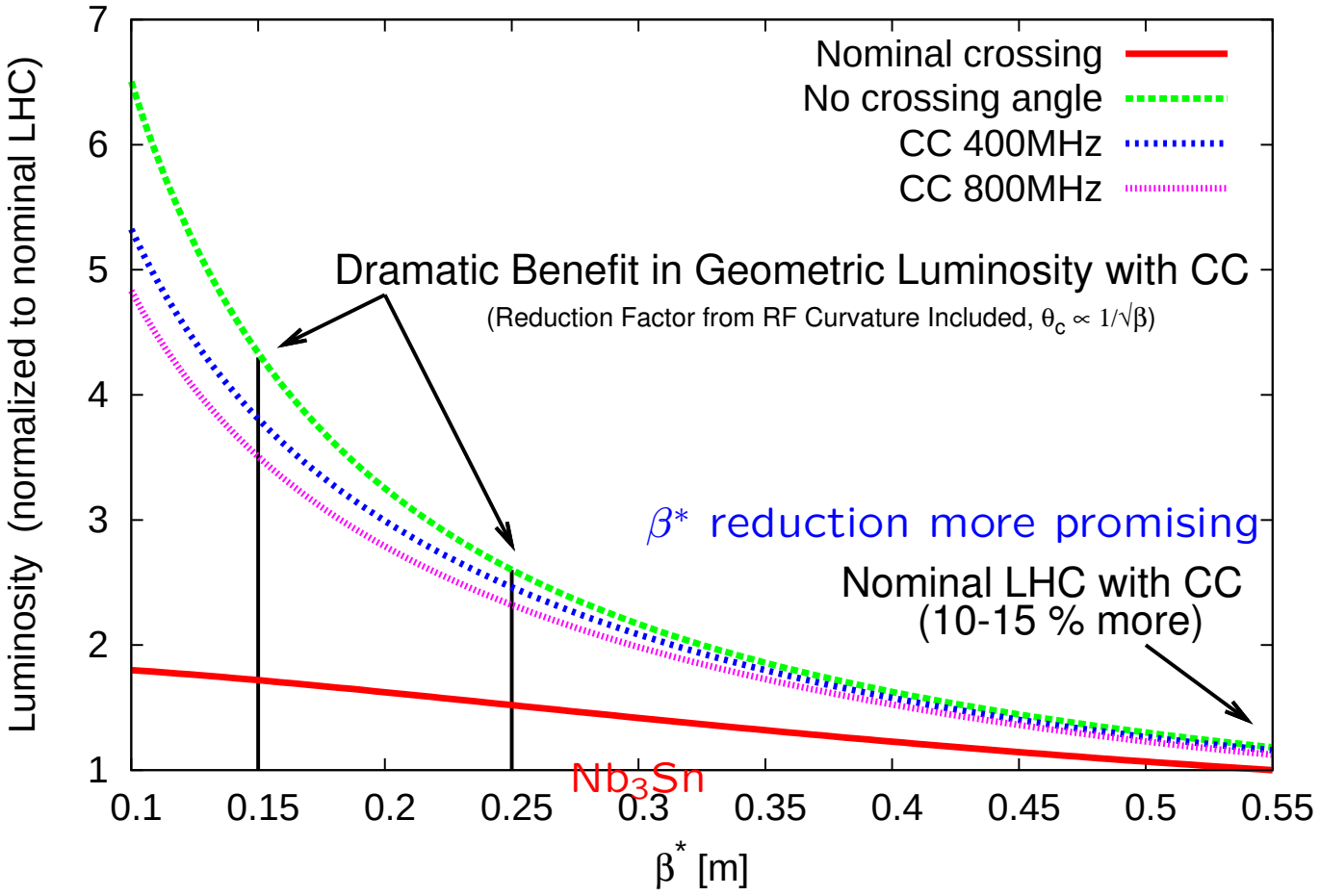
Topics

- Phase I: LHC IR Upgrade with Crab Cavities ($\theta_c < 1$ mrad)
- Requirements
  - Phase Jitter & Emittance Growth Estimates
  - Some Optics & Coupling Issues
  - Some RF requirements
- Plans
  - R&D chart
  - 800 MHz prototype & collaborative efforts



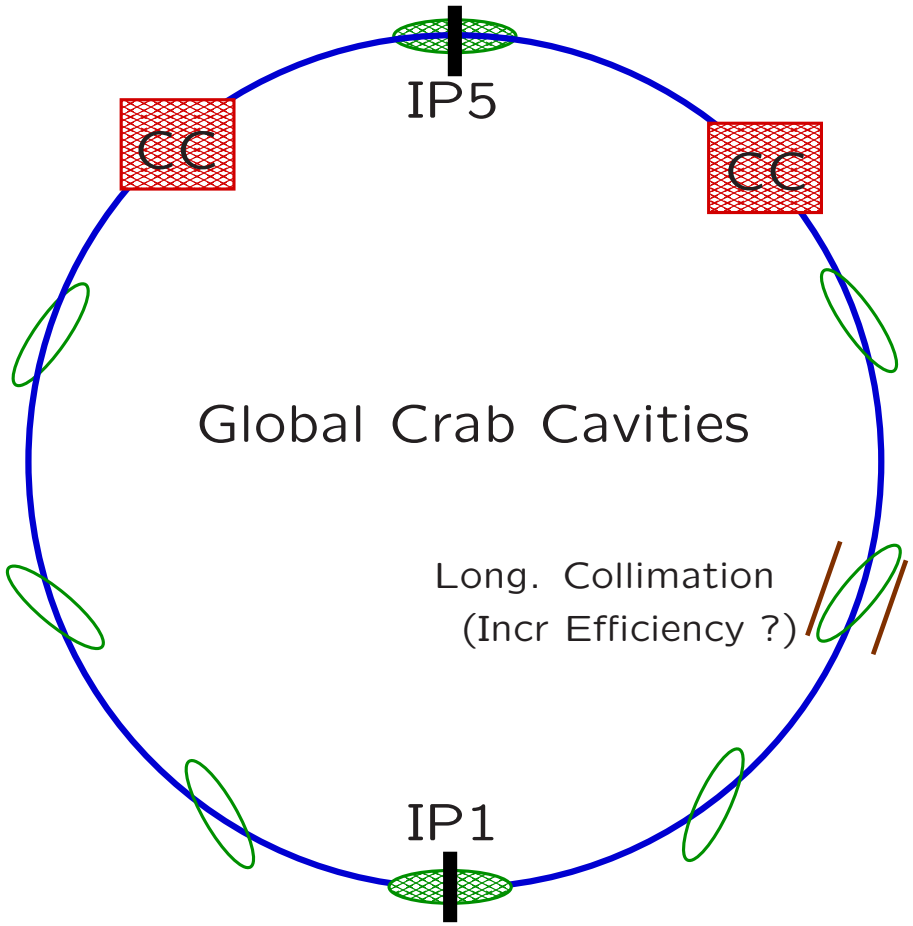
Geometric Luminosity

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



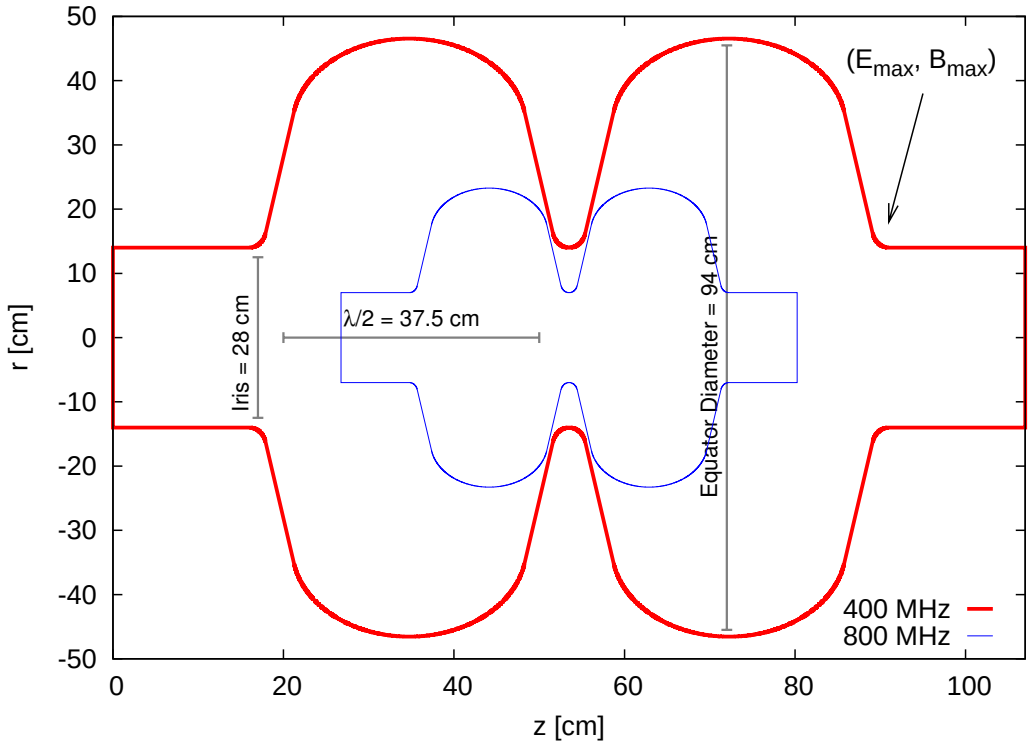
Larger θ_c: Alleviate Long range beam-beam, Simple IR design (Sep. Quads, NbTi) & machine tuning...

Small θ_c (0.3-0.6 mrad)



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

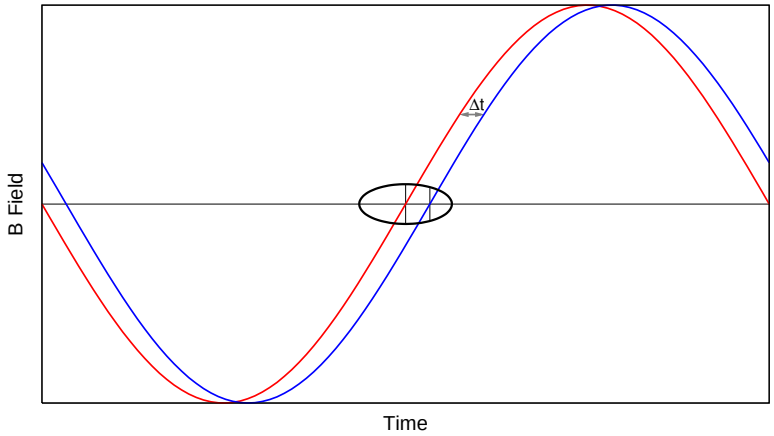
β^*	25 (15) cm
Deflecting Voltage	8.31 (10.73) MV
E_{peak}	$<$ 60 MV
B_{peak}	$<$ 150 mT
RMS Orbit	0.35 (0.45)mm
Peak Orbit	2.4 (3.0) mm
Tune Shift $\{Q_x, Q_y\}$	$\{0.5,1.2\}\times10^{-4}$

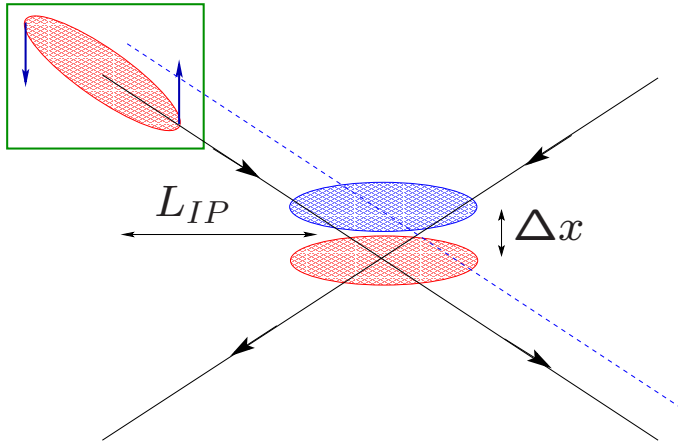


Noise Tolerances

Phase jitter introduces random offset:

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





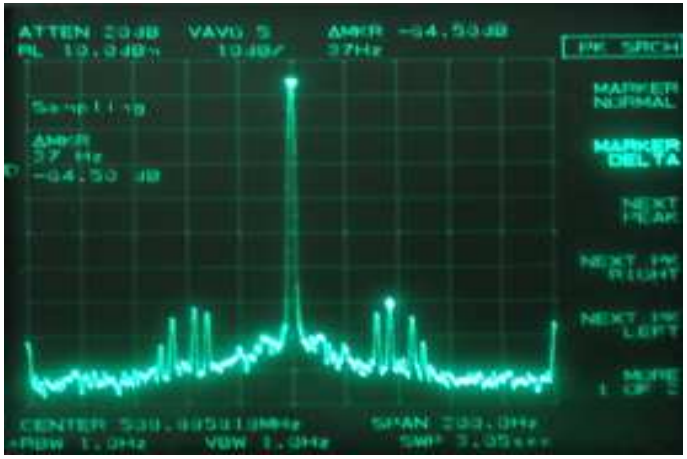
Random Dip Kicks: $\frac{1}{\epsilon}\frac{\Delta\epsilon_x}{\Delta t} \approx \frac{f_r(1-s_0)}{4\sigma_x^*\left(1+\frac{g}{2\pi|\xi|}\right)^2}(\Delta x)^2$

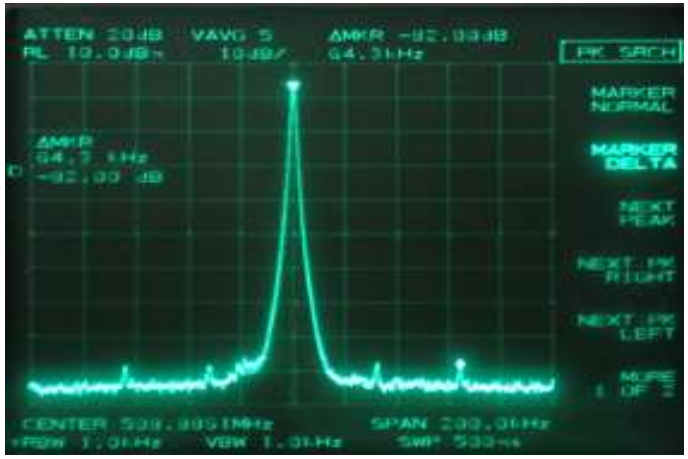
For 1% Emittance Growth/Hr, gain=0.2 (Random turn-to-turn)

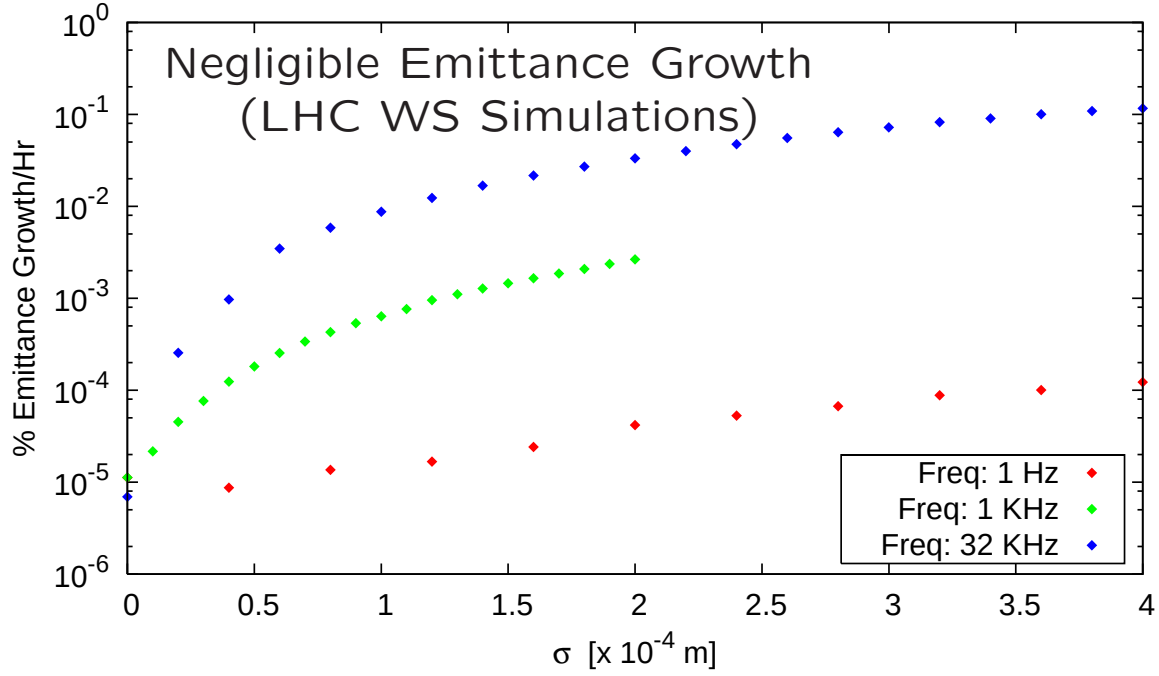
Jitter Estimate	Amp.	Phase	
		Beam-Beam	Dip. Kicks
Analytical	$\sim$ 0.04%	0.01° (0.006°)	0.006° (0.003°)
Simulation (WS)		0.002°	-
Simulation (SS, K. Ohmi)		$<$ 0.001°	
Feasible Today	0.01%	0.003°	

Modulated Jitter

Span 200 Hz KEK-B Span 200 kHz







—— Measurements courtesy KEK-B

Some Optics Issues

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

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

- $\Delta\phi_{cc\rightarrow ip}$ 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)

Some RF Requirements

- Shunt Imp:

$$\frac{R_\perp}{Q_0} = \frac{1}{(kr)^2 \omega U} \int_0^L E_{z(r=r_0)} e^{ikz} dz$$

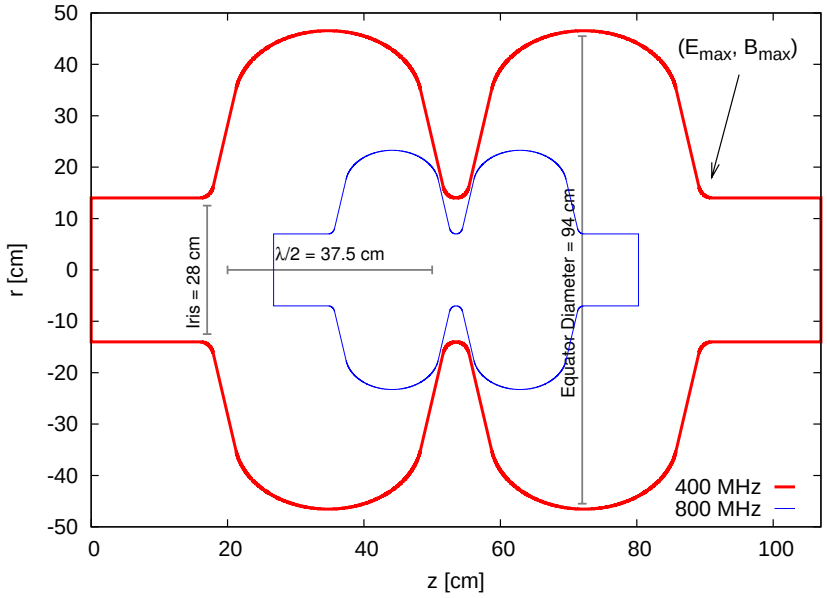
$$\approx 120\Omega \ \{800 \text{ MHz, 2 Cells}\}$$

- Orbit Offset in CC:

$$V_b \approx Q_L I_b \frac{R_\perp}{Q} (\delta x)$$

$$\approx 0.1 \text{ MV/mm}$$

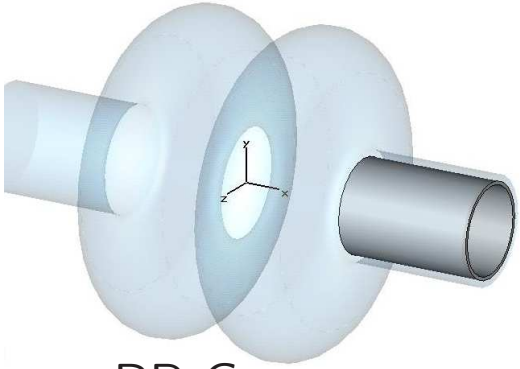
$$\{Q_L{=}10^6, \ I_b = 0.85A\}$$



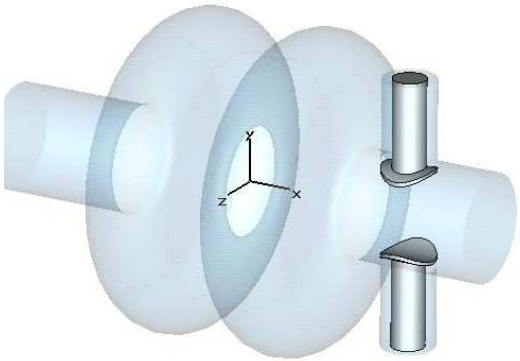
- Peak Fields (B_{kick}: 5 MV, 400-800 MHz):
  - E_{peak} ~ 35-60 MV (TESLA: 70-90 MV/m, limit→ field emission)
  - B_{peak} ~ 185-250 mT (TESLA: 150-190 mT, theory limit ~ 220mT)
  - Reduce peak B-Field (using Aperture, E_{peak}, R/Q)
- Power Requirements (2 - 20 kW, $Q_L = [10^5 - 10^6]$):
  - Beam loading, conditioning ~ 50 kW (commercially available)
  - Microphonics, Lorentz force detuning...

Couplers & Tuners

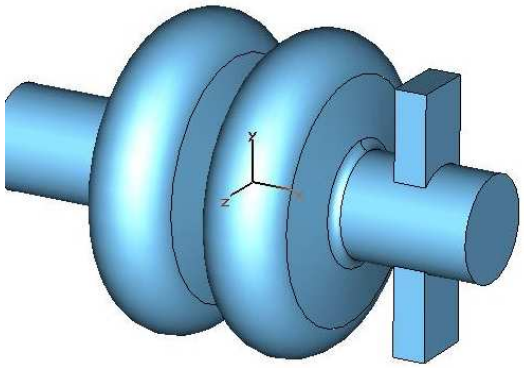
- Couplers:
  - Kick Mode: Co-axial Coupler
  - LOM: Beam Pipe Coax (KEK, $Q_{ext} \sim 10^2$), Fragile
    Waveguide coupler (LBNL, $Q_ext \sim 10^3$), Damping Sufficient ?
    New concepts (Radial BP Coax)
  - HOM: Beam pipe coax (KEK), Additional couplers (CW Power Capability)



BP Coax



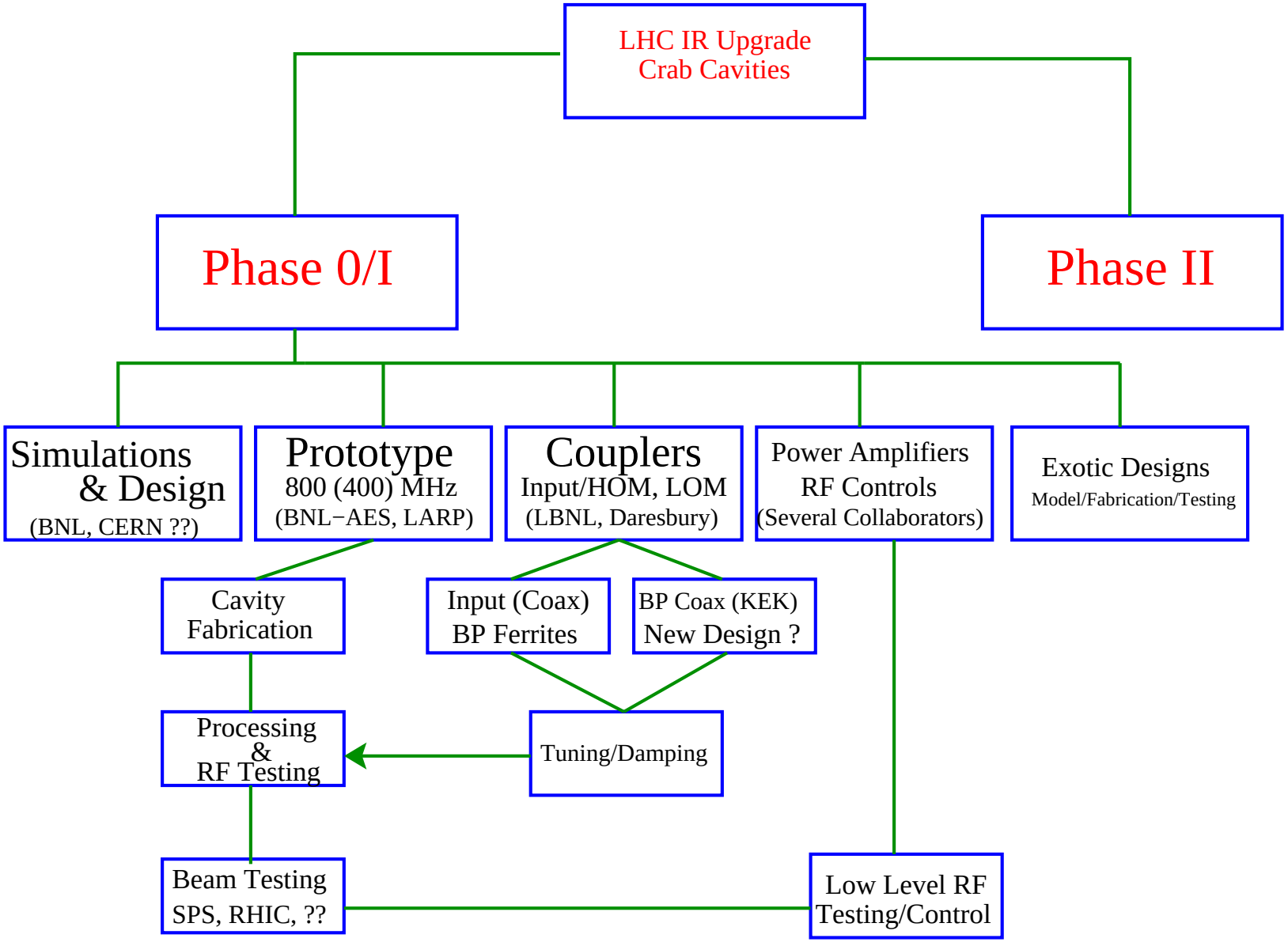
Power Coupler: Coax



Waveguide Coupler

- Tuners:
  - BP coax tuning (Effective & Simple)
  - Conventional tuners (Iris based tuner, Peak Fields→Iris)

A Preliminary R&D Proposal



R&D Notes

- Cavity and coupler design
  - Finish 800 MHz design (peak fields, impedance spectra, HOM damping)
  - Robust design for LOM damping (LBNL, DI/CL)
  - BNL-AES SBIR (I. Ben-Zvi et al., Nov 08)

- RF power, RF controls, & related issues (need effort here)
  - DI/CL, LBNL, KEK-B ?

- Prototype testing:
  - Q_0 slope, Max Gradient (B_{kick}), Multipacting
  - RF stability, Phase noise, Tuning, etc...
  - LOM/HOMs & damping, beam testing

Conclusions

- Dramatic benefit ($\times 2.5$) on luminosity gain with β^* & luminosity leveling is trivial and transparent
- Next step: 800 MHz prototype ($\theta_c < 0.6$ mrad)
- Noise issues do not appear to be problem, more SS simulations needed for benchmarking
- Longitudinal collimation ? Need to investigate any collimation efficiency & impedance benefit (or issues) due to oscillating bunch
- Collaboration: BNL, CERN, DL/CI, KEK-B, LBNL, SLAC, Cornell...
- Deflecting cavity Shanghai workshop (April 08), mini LHC-CC workshop next year (Feb 25-26, 2008: BNL ?)