Collective Instabilities

Work done by Nathan Towne, guided by Ilan and me

The following are Nathan's slides with a few comments

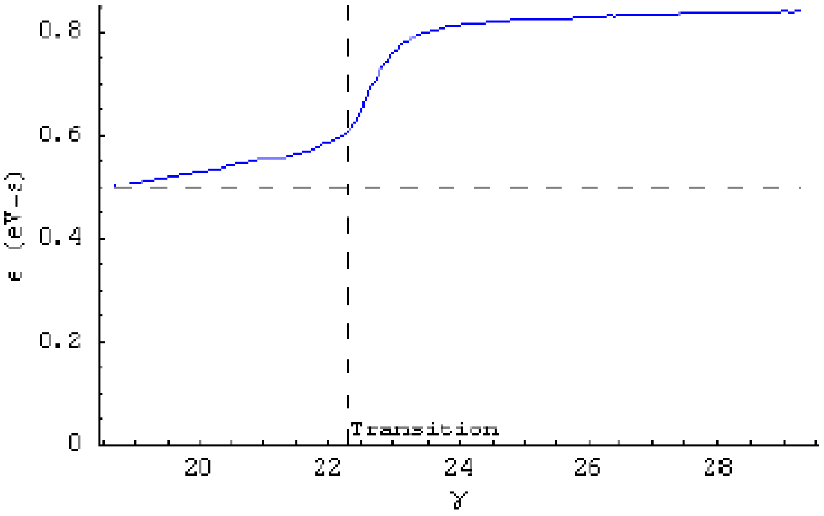
Machine parameters (gold)

Parameter	symbol	value	unit
Circumference	cT_0	$= 3833.845$	m
Gold ions per bunch		$= 10^9$	
Transition	γ_t	$= 22.3$	
RF buckets	h	$= 360$	
Buckets potentially filled	B	$= h/3$	
Bunches in fill		$= 105$	every third bucket
Average beam current	I_{av}	$= 104$	mA
Broad-band impedance	$\lvert Z_n \rvert / n$	$= 3$	Ω
	ω_{BBI}	$= 2\pi \times 1.7$	GHz
Main cavity voltage	V_1	$= 100$	kV (transition)
		$= 300$	kV (storage)
SC HHC voltage	V_2	$= 0$	(transition)
		$= 2.5$	MV (storage)
Momentum compaction	η	$= 0.9 \times 10^{-4}$	(transition)
		$= 2.0 \times 10^{-3}$	(storage)
Nonlinear α	α_1	$= -1.15$	(Blaskiewicz et al. (2001))
Bunch length	σ_t	$= 1.6$	ns (transition)
		$= 1.0$	ns (storage)
Longitudinal emittance		$= 0.5$	eV-s (95%) (transition)
		$= \sim 0.7$	eV-s (95%) (storage)

Parameter	symbol	value	unit
Main cavity			
impedance	R_0/Q_0	$= 63.64$	Ω
count	n_{cav}	$= 2$	per ring
frequency	f_{rf}	$= 28$	MHz
harmonic	h	$= 360$	
Normal-conducting HHC			
impedance per cell	R_0/Q_0	$= 162$	Ω
count	n_{cav}	$= 3$	per ring
		$+ 4$	in common
frequency	f_{rf}	$= 197$	MHz
harmonic	nh	$= 2520$	
Super-conducting HHC			
impedance per cell	R_0/Q_0	$= 46.1$	Ω
count	n_{cav}	$= 1$	per ring
frequency	f_{rf}	$= 56$	MHz
harmonic	nh	$= 720$	

Emittance growth across transition due to the NC HHC

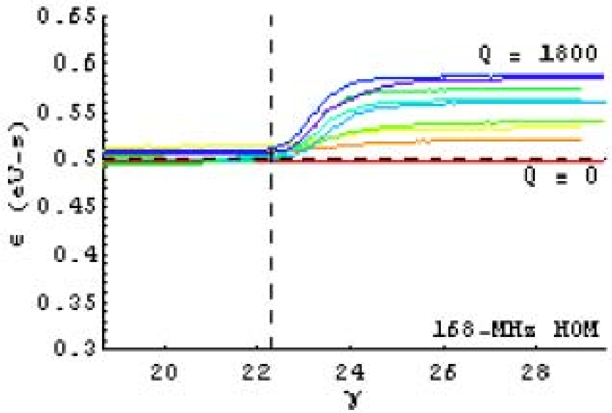
- Simulation across transition shows substantial emittance growth.
- Are the NC HHCs responsible for some of the emittance growth before rebucketing? With SC HHCs and no rebucketing, would removal of some cavities reduce emittance at the top of the ramp?

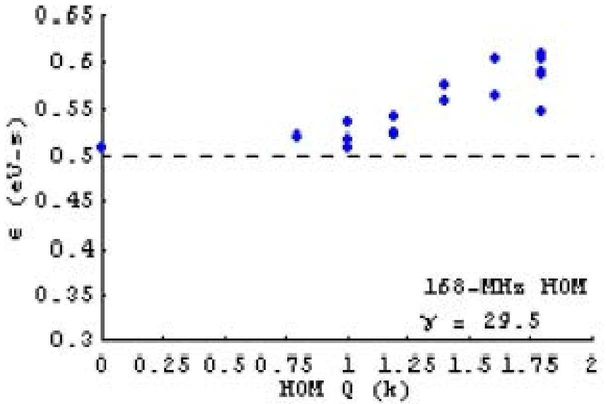


Several Simulations done

168-MHz HOM

- Longitudinal simulations of the ring with the 168-MHz HOM at different Qs show the continuum of variation of emittance growth. The growth of emittance starts at transition and persists for a time after.
- Emittance growth due to the 168-MHz HOM is modest at Q = 1000 and two cavities, even though well above threshold.
- With one cavity, Q between 2000 and 2500 has modest emittance growth.





Two SC HHCs

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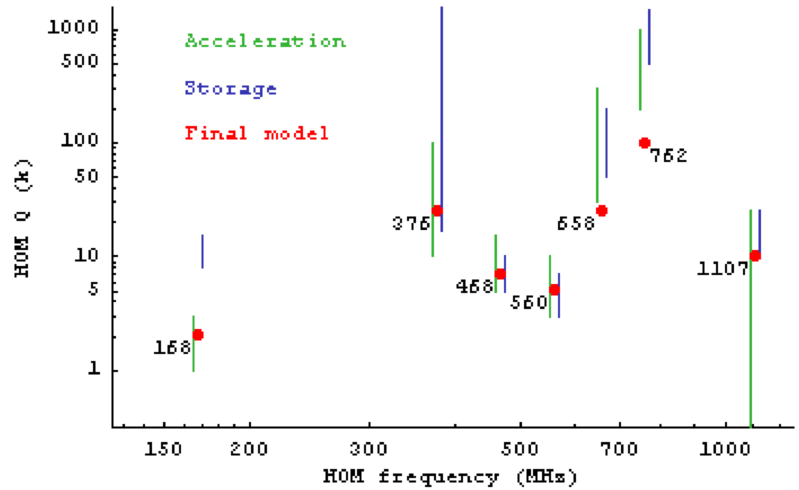
HOM damping derived from CB modes

- Previous work considered Ill effect of one resonator mode at a time
- Green bars bracket tolerance for about 10% emittance growth based on single-HOM tracking runs through transition.
- Blue bars bracket CB thresholds during storage. 1st pass
- Red dots mark HOMs and their damping used in the construction of a composite impedance model of the SC HHC cavity used to assess CB stability and emittance growth.



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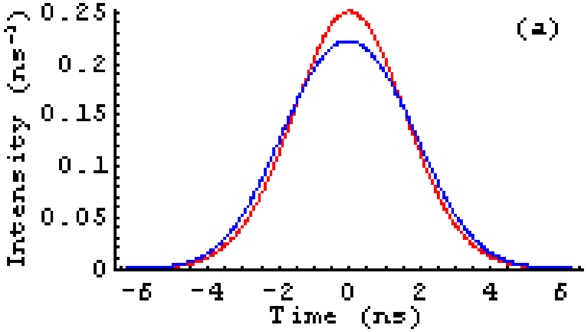
Broad-band impedance

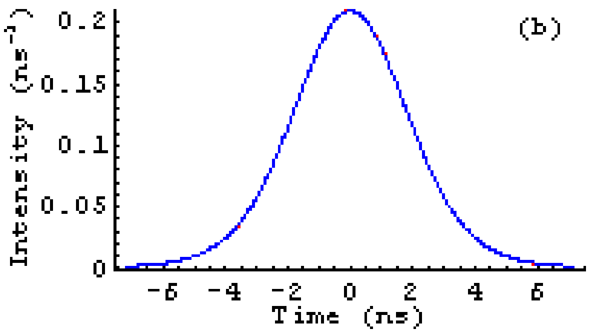
- Bunch profiles are altered by the broad-band impedance with inductive part Zn/n=3.0 Ω (provided by G. Wang). The effect is rather small in storage (b) where the potential well is very deep due to the field in the SC HHCs (2.5 MV). At transition (a), the potential well comes from the main cavities at 100-kV field intensity only.
- Vlasov and tracking simulations in this study do account for this effect.

Transition



$\varepsilon = 0.5$ eV-s

Storage



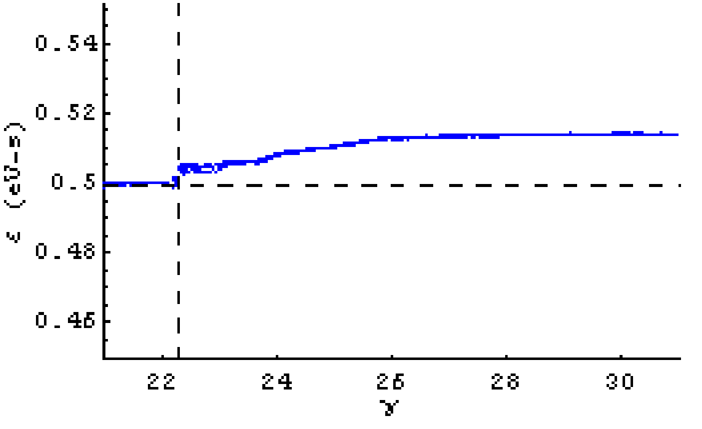
Bunch length 2.0 ns

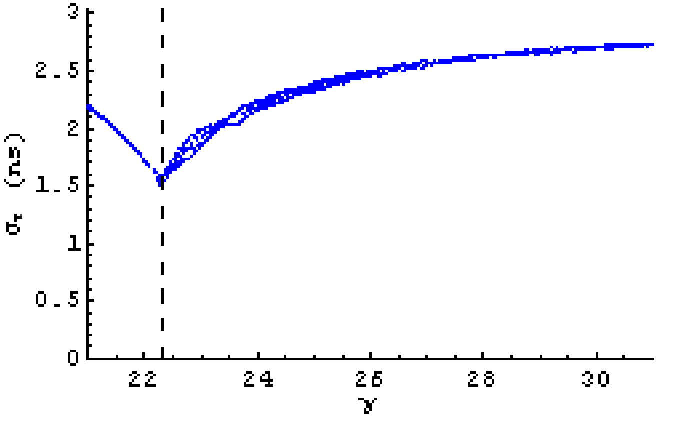
without BBI

with BBI

Acceleration across transition

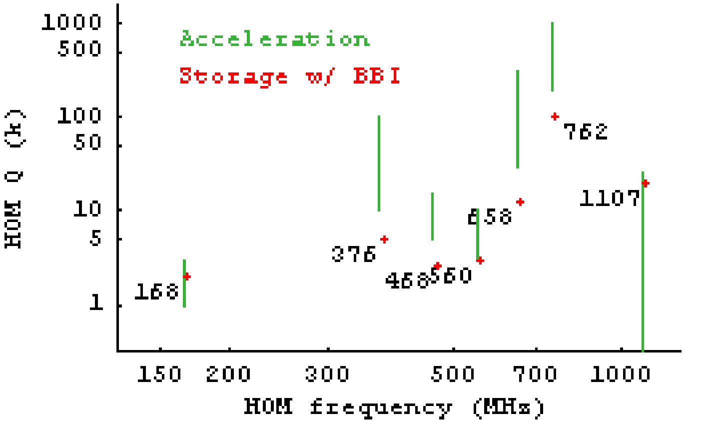
- Longitudinal emittance (top) and bunch length (bottom) during acceleration with composite impedance model (seven HOMs) and BBI.
- Two runs are spliced together in the plots.
- Less than 5% emittance growth for 1.0e9 ions/bunch

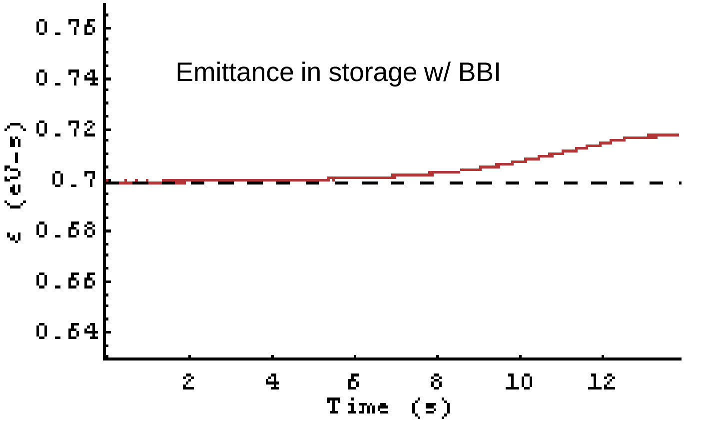




Stability in storage

- Simulation is with nine bunches in nine symmetrically placed buckets, with broad-band impedance. Long range impedance scaled by 120/9
- The seven HOMs are each tuned to be resonant with a non-rf revolution lines at storage energy, and excite distinct coupled-bunch modes.
- HOM Qs are 2k, 5k, 2.5k, 3k, 12k, 100k, and 20k.
- There are still signs of instability, but saturation seems to occur at lower emittance than seen earlier with higher Qs.





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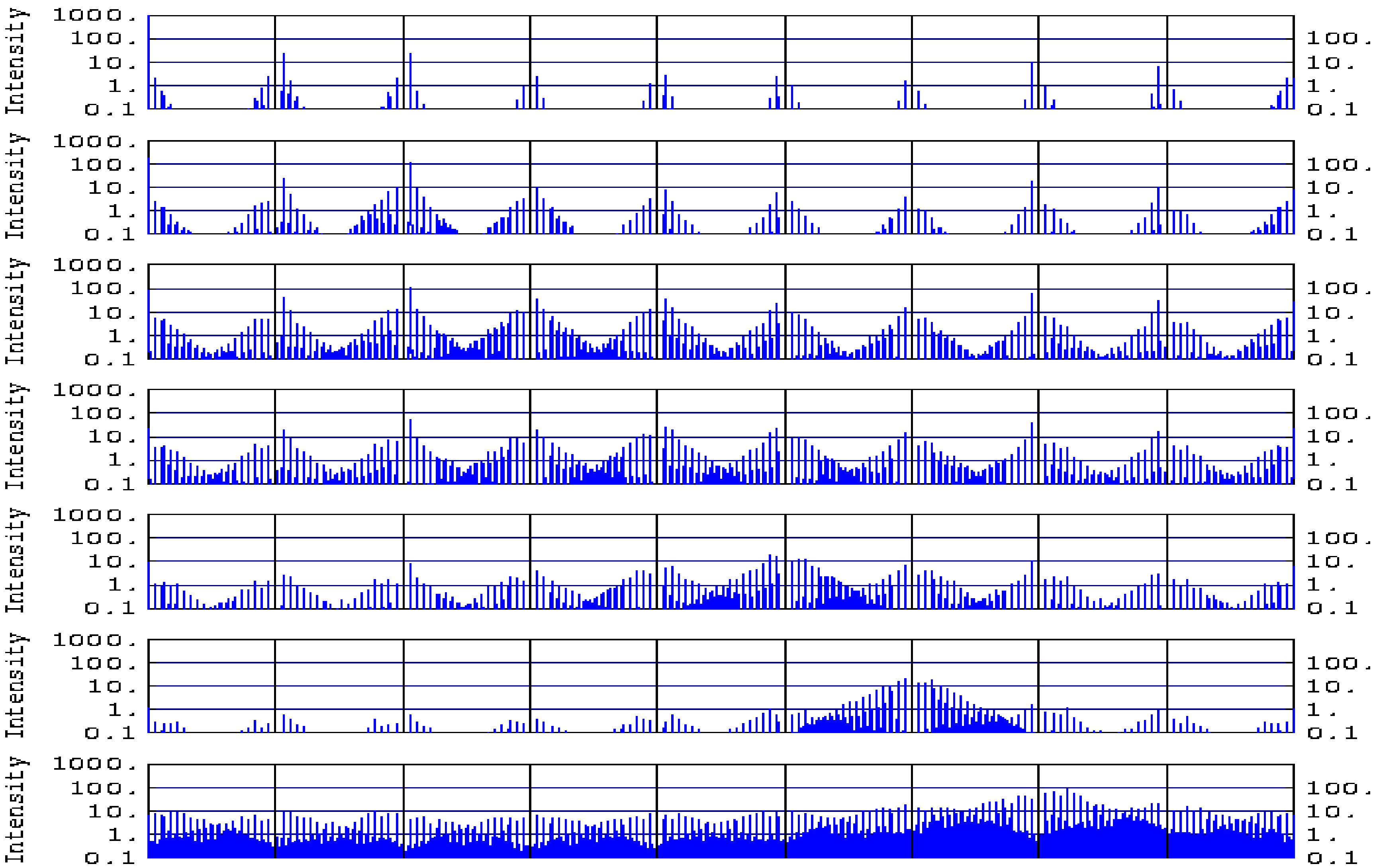
Spectra of the individual modes at flat top



Conclusions

- Stability of CB modes at transition energy is probably not attainable. Instead, it is necessary to manage emittance growth crossing transition with sufficient damping of the SC HHC fundamental and HOMs.
- HOM damping is realizable.
- The number of cavities has an impact on the minimum damping of rf modes - fewer is better.
- Tracking using a model of the NC-HHC impedance based on bench measurement shows strong instability and emittance growth across transition. This may indicate an inaccurate impedance model, or additional damping in the ring not accounted for.
- Ramping the SC HHC to field poses no particular challenge.