Collective Effects in NSLS-II

S. Krinsky

NSLS-II Accelerator Advisory Committee Meeting

October 10-11, 2006

Overview

- Intrabeam Scattering
- Touschek Lifetime
- Landau Cavity
- Impedance Model and Instability Thresholds
- Impedance Calculations

NSLS-II Current

N=number of electrons in single bunch (7.8x10^9)
Ne =Bunch Charge (1.25 nC)
M=number of bunches (1040)

Single Bunch Current $I_0 = \frac{N e}{T_0}$ (.5 mA)

Peak Bunch Current $I_p = \frac{N e}{\sqrt{2\pi}\,\sigma_t}$ (33 A for σ_t=15 ps) ignoring bunch lengthening

Average Current $I_{av} = \frac{M\ N e}{T_0}$ (500mA)

Comparison Between NSLS-II, ESRF, APS

	NSLS-II	ESRF*	APS*
Energy (GeV)	3	6	7
Circumference (m)	780	844.4	1100
RF Frequency (MHz)	499.46	352.2	351.9
RF Voltage (MV)	3.9	9.0	9.5
Mom. Compaction ($x10^{-4}$)	3.7	1.86	2.9
Synchrotron Tune	.0096	.006	.007
Horiz. Emittance (nm)	0.5	3	3
Coupling (%)	1	0.5	1
Chromaticity x/y	5/5	5.5/5.8	5/7
Rad. Damp. Time x/s (ms)	12/6	7/3.5	9.5/4.7
RMS Energy Spread (%)	0.1	0.1	0.1
RMS Bunch Duration (ps)	15	14	24

*K. Harkay et al, Proc. EPAC2002, “A preliminary comparison of beam Instabilities among ESRF, APS and SPRING-8”

Damping Wigglers

$$\frac{\varepsilon_w}{\varepsilon_0} = \frac{1+f}{1+\frac{L_w}{4\pi\rho_0}\left(\frac{\rho_0}{\rho_w}\right)^2}$$

$$f \cong \frac{2C_q\gamma^2}{3\pi^2\varepsilon_0}\frac{L_w\rho_0\beta_{x0}}{\rho_w^3}\left[\frac{K_w^2}{5\gamma^2}\left(1+\frac{L_w^2}{12\beta_{x0}^2}\right)+\frac{\eta_0^2}{\beta_{x0}^2}+\eta_1^2\right]$$

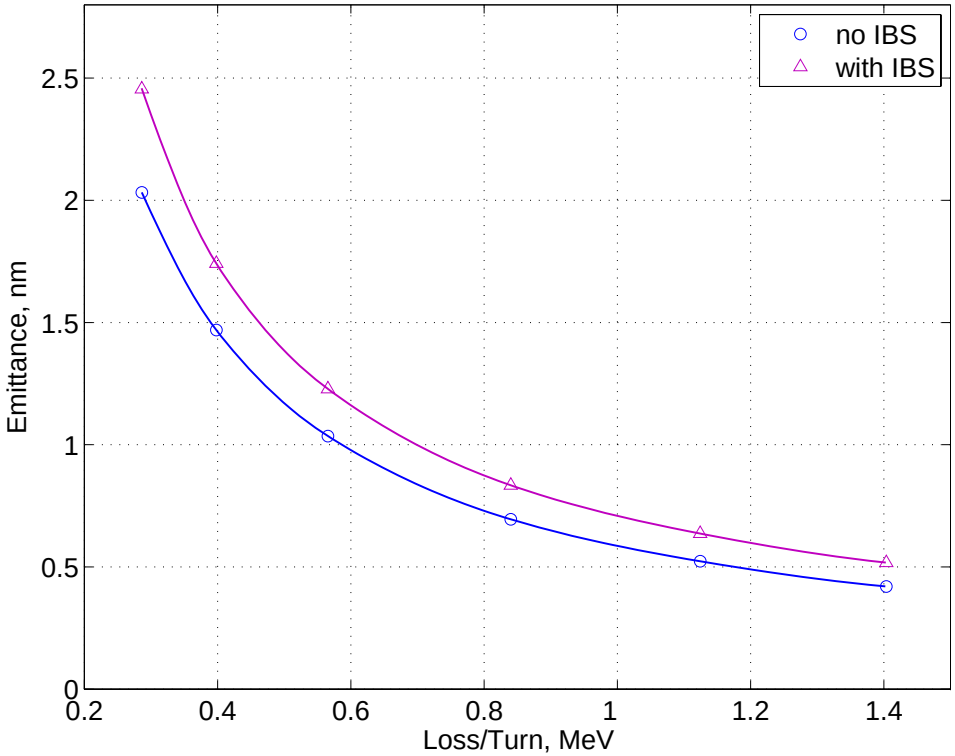
$$\beta_x(s) = \beta_{x0} + \frac{s^2}{\beta_{x0}} \qquad \eta(s) = \eta_w(s) + \eta_0 + \eta_1 s \qquad \eta_w(s) = \frac{1}{\rho_w}\left(\frac{\lambda_w}{2\pi}\right)^2\left(1-\cos\frac{2\pi s}{\lambda_w}\right)$$

$$\frac{K_w}{\gamma} = \frac{\lambda_w}{2\pi\rho_w} \qquad C_q = 3.84\times10^{-13}\,m$$

$$\frac{\delta_w}{\delta_0} = \sqrt{\frac{1+\frac{L_w}{2\pi\rho_0}\frac{4}{3\pi}\left(\frac{\rho_0}{\rho_w}\right)^3}{1+\frac{L_w}{4\pi\rho_0}\left(\frac{\rho_0}{\rho_w}\right)^2}}$$

Intrabeam Scattering

Horizontal emittance vs. total SR loss.



B. Podobedov

Touschek Lifetime

$$\frac{1}{\tau_{tous_1/2}} = \frac{\sqrt{\pi}\, r_e^2 c\, N_b}{\gamma \varepsilon_{acc}^4} \frac{\sigma'_x}{V} D\left(\frac{\varepsilon_{acc}^2}{\gamma^2}\frac{\beta_x}{\varepsilon_x}\right)$$

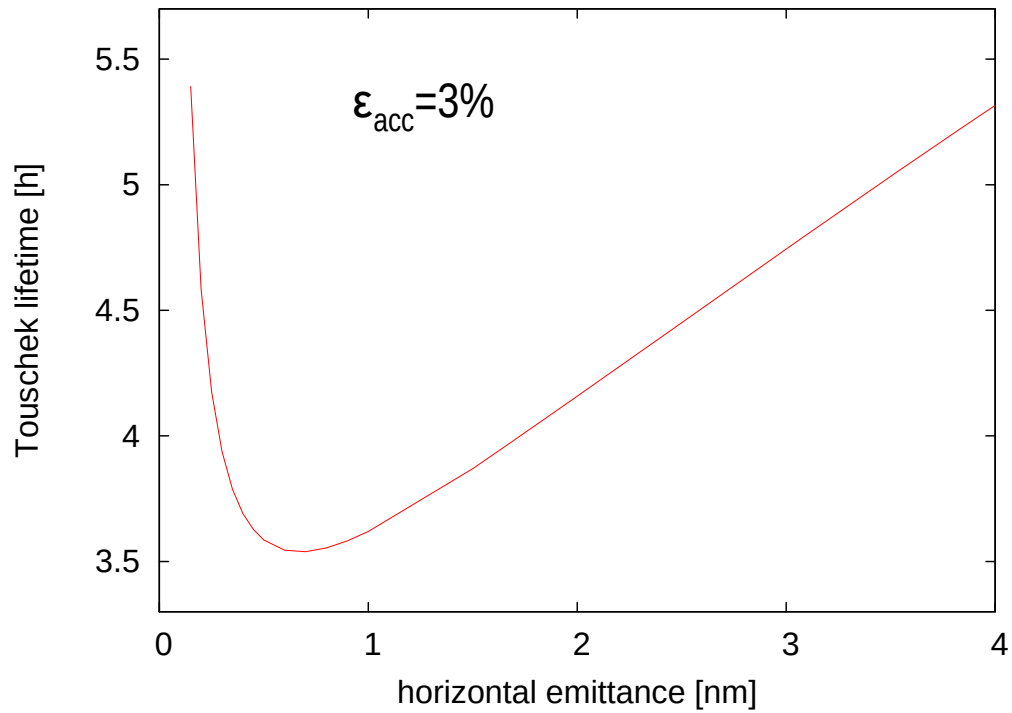
$$\zeta = \left[\varepsilon_{acc} / \gamma\sigma'_x\right]^2 \approx \frac{\varepsilon_{acc}^2}{\gamma^2}\frac{\beta_x}{\varepsilon_x}$$

Ignores dispersion

Lifetime remains roughly constant

as we reduce emittance!

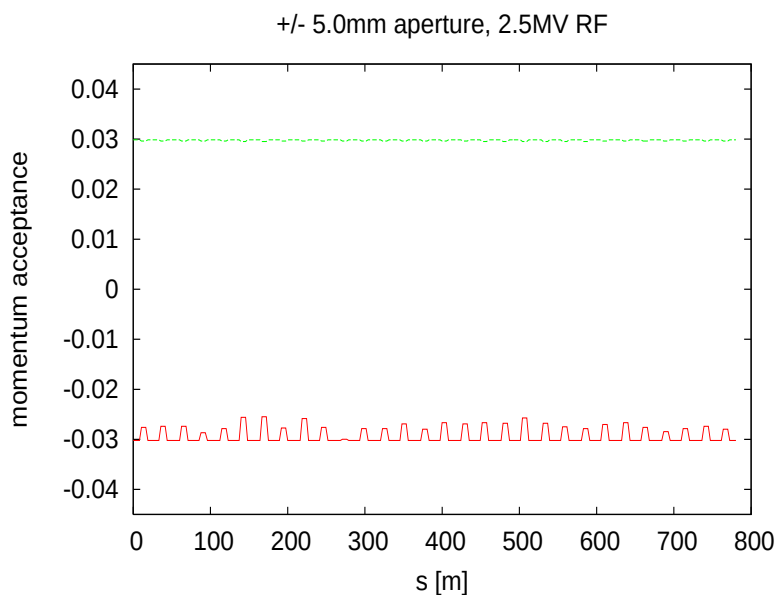
Lifetime very sensitive to energy acceptance!

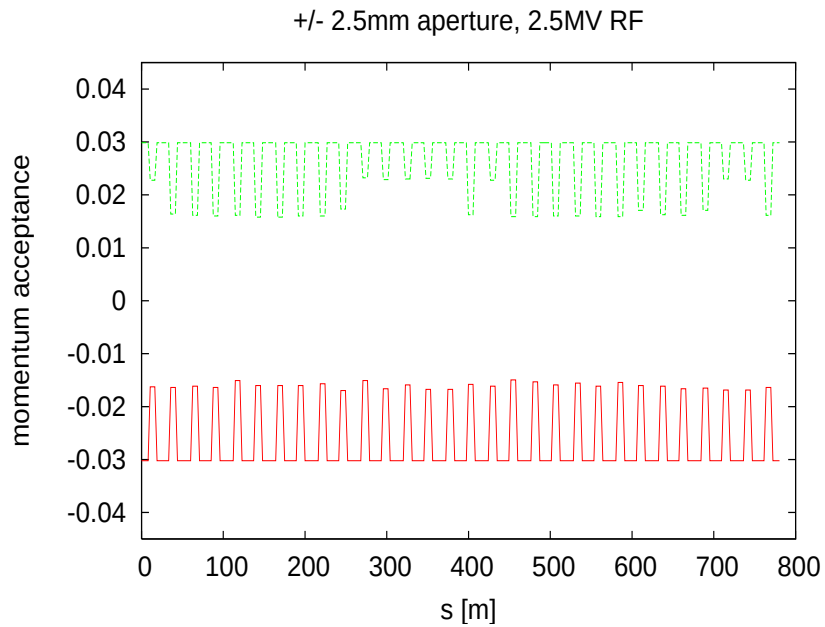


B. Podobedov

C. Montag

Dependence of Touschek Lifetime on Undulator Gap





Energy acceptance is limited by vertical gap in undulator

Touschek lifetime with fundamental cavity ~2Hrs

Touschek lifetime with Landau cavity > 3Hrs

Passive Third-harmonic Landau Cavity (1.5 GHz)

Use of a bunch lengthening Landau cavity can increase Touschek lifetime, raise microwave instability threshold and decrease intrabeam scattering.

Initial estimates indicate we can increase bunch length by factor of ~2

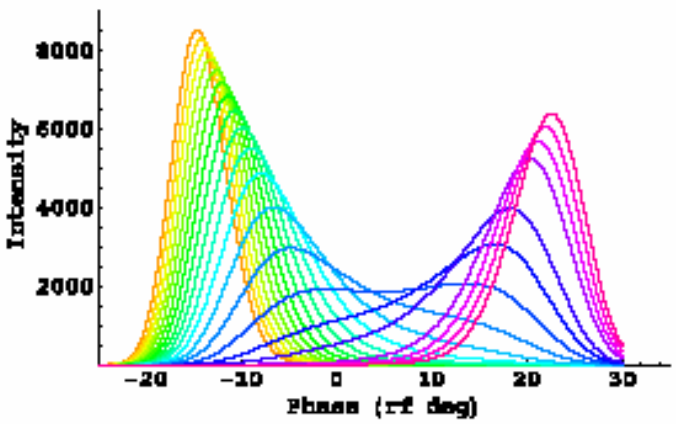


Figure 1: Line densities of bunches uniformly sampled along the length of an 80%-fill bunch train. The leading edge of each bunch is on the right and the progression of leading bunches to trailing bunches is from left to right. Each bunch is normalized to unity with respect to ring azimuthal angle.

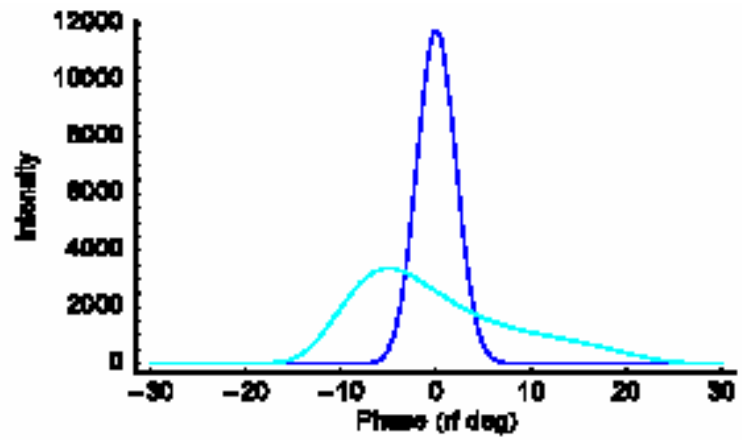


Figure 3: Line densities of unstretched (blue) and stretched (aqua) bunches in a uniform fill.

N. Towne

Instabilities

Limitations on Single Bunch Current

Short-Range Wakefield (Broad-Band Impedance)

- Longitudinal Microwave Instability
  - ---Inductive and Resistive Elements
- Transverse Mode Coupling Instability
  - ---Resisitive Wall
  - ---Geometric Impedance: Changes in Chamber Cross-Section

Limitations on Average Current

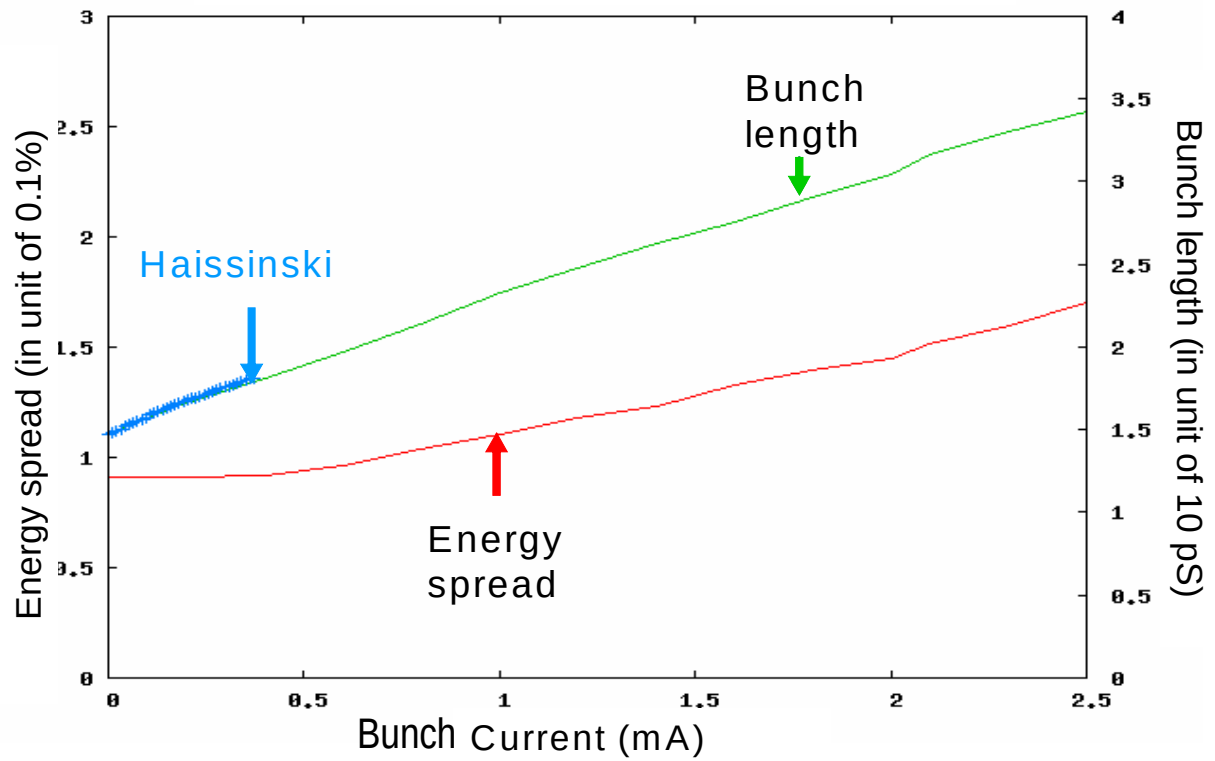
Long-Range Wakefield

- Longitudinal Coupled Bunch Instability
  - —RF Cavity HOM
- Transverse Coupled Bunch Instability
  - ---Resistive Wall
  - ---RF Cavity HOM

Impedance Model

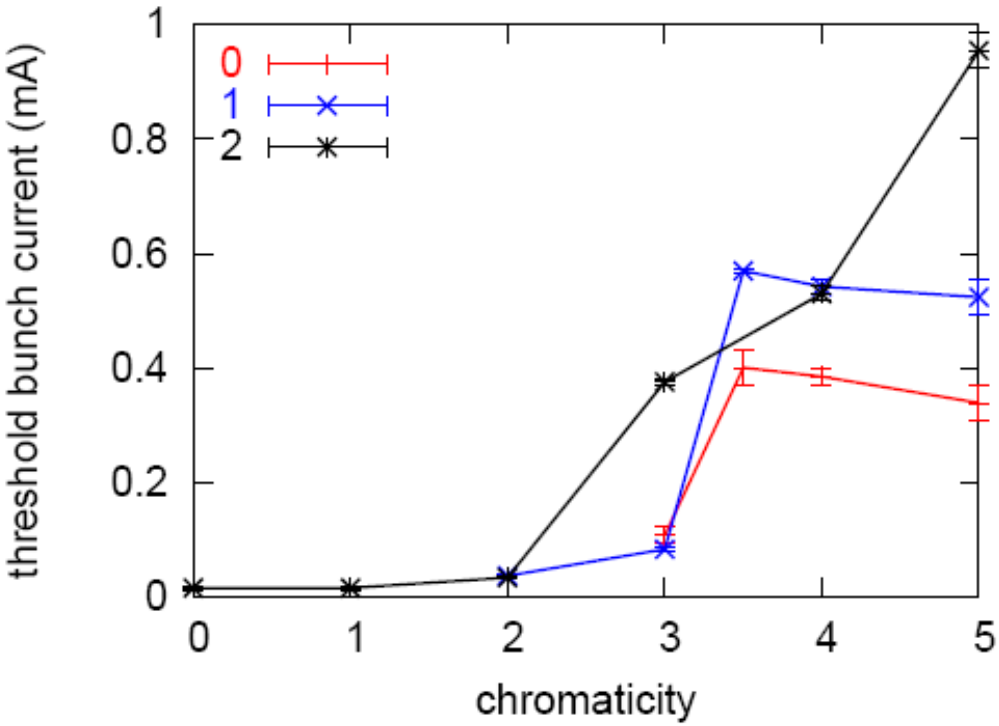
CESR-B cavity higher-order modes β_x=18m
720m of aluminum with half-gap of 12.5mm and $\beta_{y,av}$=7.6m $\kappa_{\parallel} = 4.0 V/pC \quad \kappa_y = 0.68 KV/pC/m$
60m of copper with half-gap of 2.5m and $\beta_{y,av}$=2m $\kappa_{\parallel} = 1.3 V/pC \quad \kappa_y = 5.6 KV/pC/m$
Transverse broad-band impedance with $f_r = 30GHz, \quad R_y = 1M\Omega/m, \quad Q_y = 1, \quad \beta_{y,av} = 7.6m$ $\kappa_y = 19 KV/pC/m$
Longitudinal broad-band impedance with $f_r = 30GHz, \quad R_s = 30k\Omega, \quad Q_s = 1$ $(\mathrm{Im}\, Z_{\parallel}/n)_0 = 0.4\Omega \quad \kappa_{\parallel} = 35V/pC$

Longitudinal Microwave Instability



Li-Hua Yu

Transverse Instabilities: Tracking Studies



0: fund RF, no long. wake

1: fund RF, long.+ trans. wake

2: fund + Landau RF, long.+ trans. Wake

(all 1300 bunches filled)

For zero chromaticity:

a) Single bunch TMCI threshold is >0.5mA

b) Coupled bunch transverse instability due to RW wake has threshold ~15mA average current

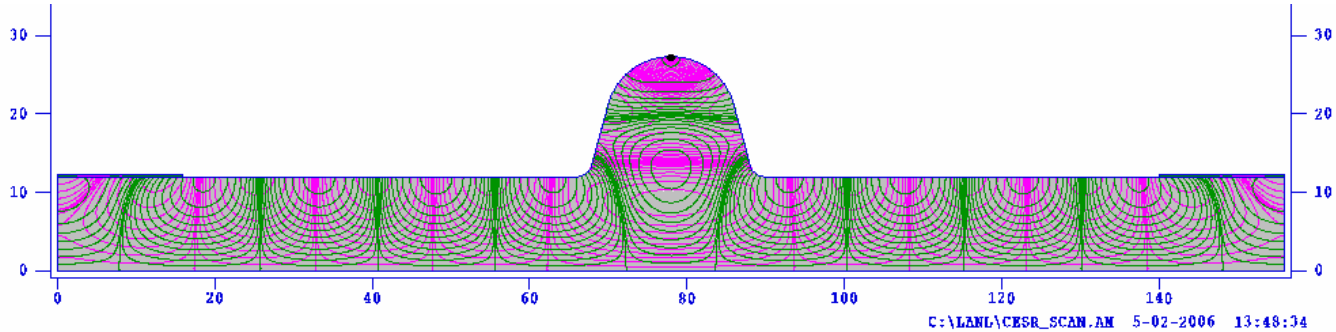
M. Blaskiewicz

Impedance Calculations with GdfidL

Object	Number of times	Loss factor V/pC	$(ImZ_{\|}/n)_0$ ohm	H-Kick Factor V/pC/m	V-Kick Factor V/pC/m
Absorber	180	$3.4x10^{-3}$	$9.2x10^{-6}$	0.5	0.002
Bellows [1]	180	$8.7x10^{-3}$	$124x10^{-6}$	0.8	2
BPM	270	$20x10^{-3}$	$47x10^{-6}$	0.9	1.1
CESR-B cavity	3	3.6	$40x10^{-3}$	58	58
Dipole Chamber	90	$0.24x10^{-3}$	$0.5x10^{-6}$	0.045	0.045
Flange [1]	300	$0.47x10^{-3}$	$16x10^{-6}$	0.141	0.141
Injection Region	1	TBD	TBD	TBD	TBD
SCU chamber geometric	TBD	$7.4x10^{-3}$	$495x10^{-6}$	58	190
SCU chamber ease	TBD	$5.6x\ 10^{-3}$		13	26
CPMU geometric	TBD	$95x10^{-3}$	$1.1x10^{-3}$	136	425
CPMU resistive wall	TBD	$66x10^{-3}$		112	225
Al resistive wall	1	4.0		272	545
Scraper	2	TBD	TBD	TBD	TBD

A. Blednykh

CESR-B cavity longitudinal impedance and coupled bunch growth rates



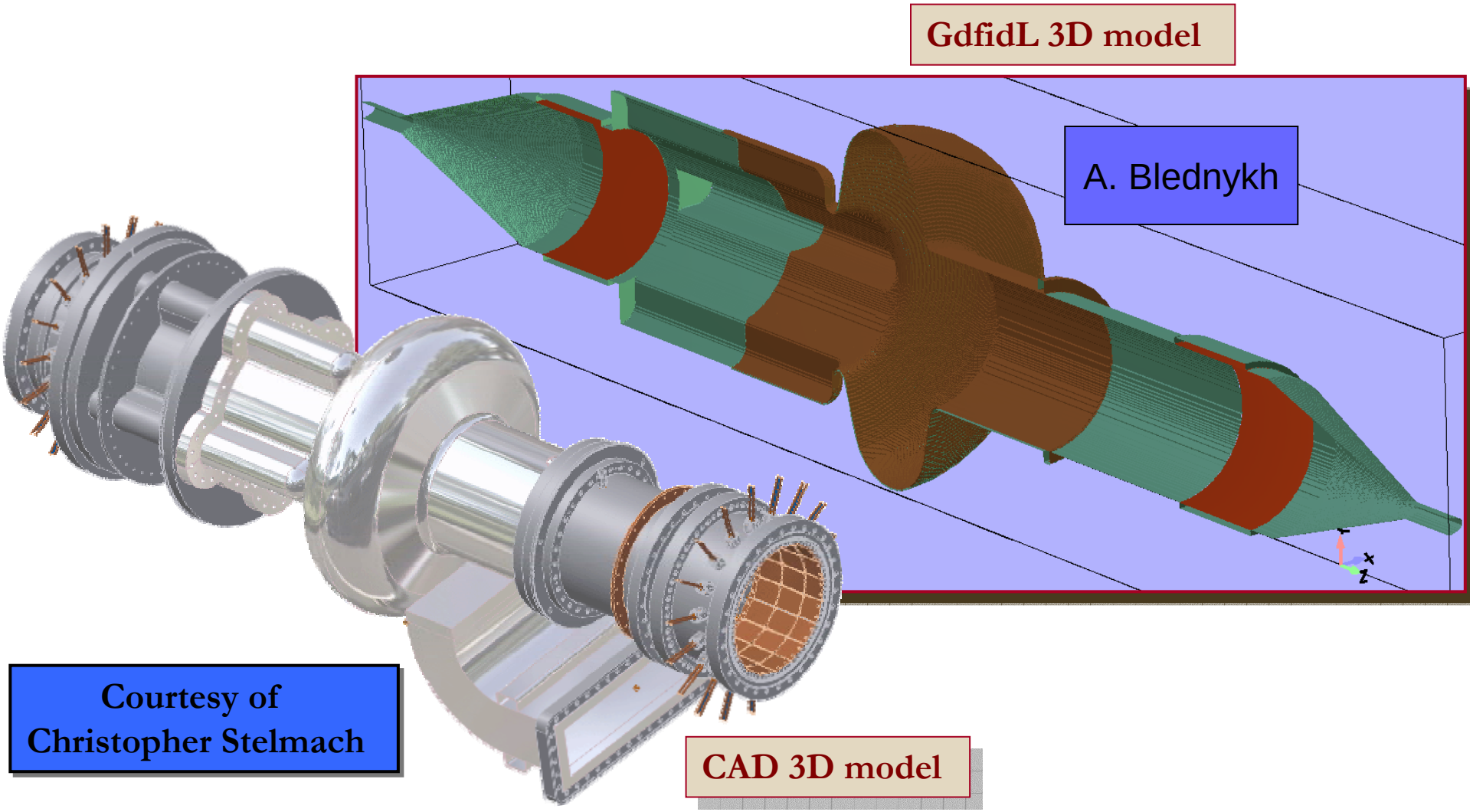
Jim Rose

CESR-B cavity geometry: Superfish Calculation

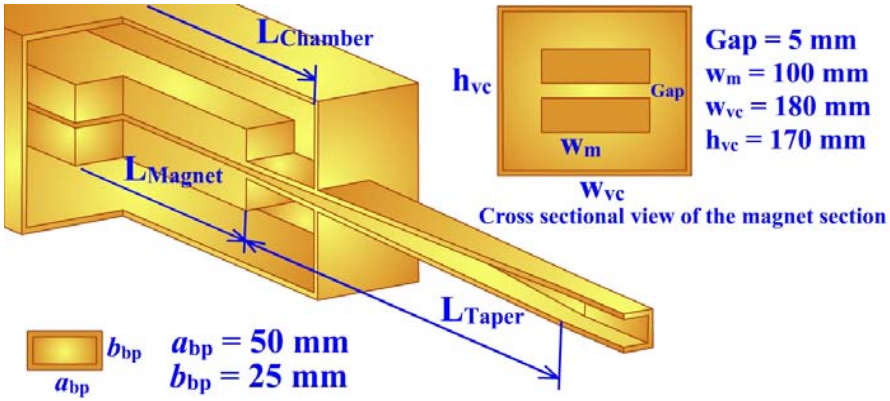
CESR-B Higher Order Longitudinal Modes		
Frequency (MHZ)	Shunt Impedance (Ohms)	Q
976.696	62.4	281
1019.929	118.2	106
1109.5	361	48
1235.0	4.9	37
1387.5	46.9	39
1585.511	143.8	135
2034.228	491.1	154
2085.399	1038.9	95

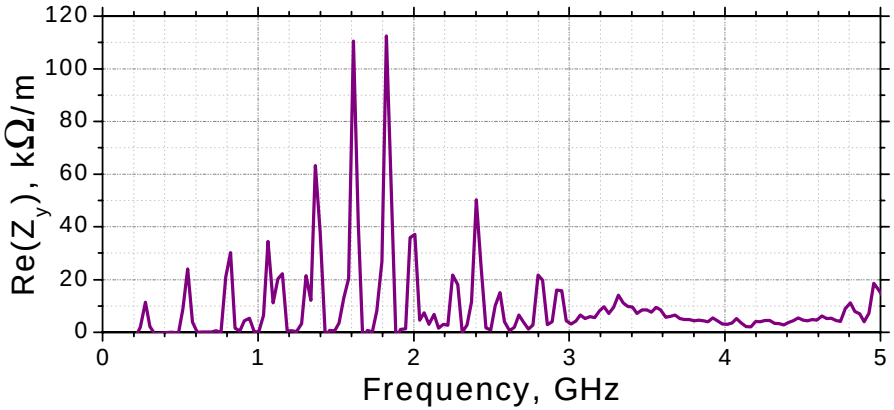
With 4 cavities and I_{av}=0.5 A, ZAP predicts the longitudinal coupled bunch growth time is 37ms, which is larger than radiation damping time of 5.5ms.

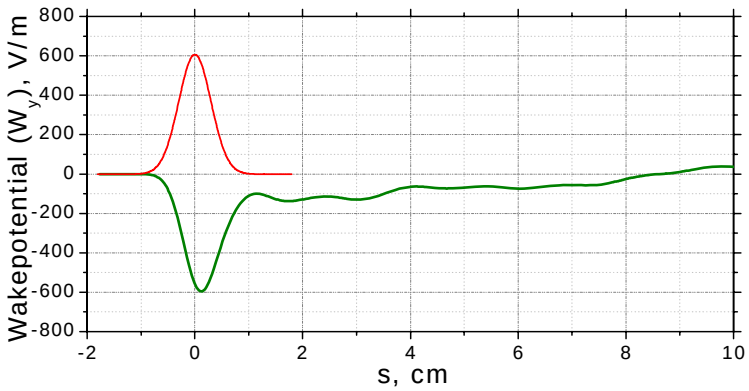
3-D GdFidL Calculations for CESR-B Cavity

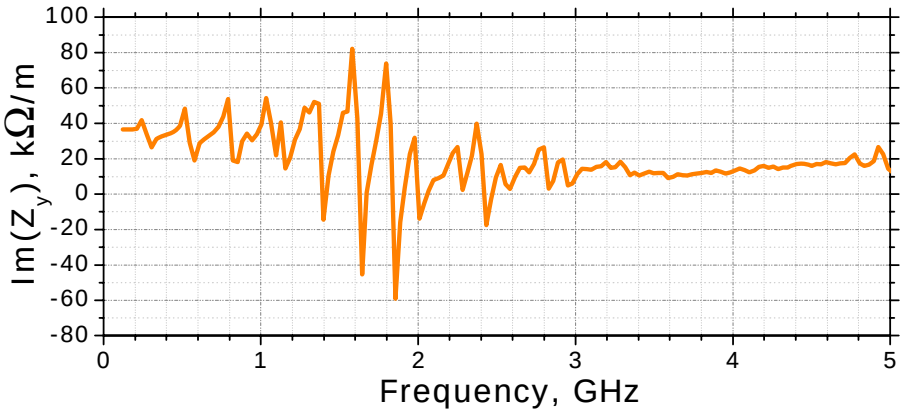


In-vacuum Undulator (CPMU)









A. Blednykh

Concluding Remarks

- Single bunch (0.5mA) and average current (500mA) goals are achievable
- To stabilize transverse coupled bunch instability requires positive chromaticity (~5)—We also plan to use transverse coupled bunch feedback system.
- At the moment we are estimating instability thresholds based on an impedance model suggested by experience at ESRF and APS.
- We are calculating the NSLS-II impedance budget. Once this is done, we will estimate the instability thresholds using the calculated impedance.
- Intrabeam scattering increases emittance by 20% (less with use of Landau cavity).
- Touschek lifetime reduced by use of small gap undulators. However, it is >3hrs with the use of Landau cavity.