Impedance calculations

NSLS-II
Accelerator Systems Advisory Committee
October 8-9, 2007

Alexei Blednykh

Office of Science
U.S. DEPARTMENT OF ENERGY

BROOKHAVEN
NATIONAL LABORATORY

Outline

- Introduction
- Impedance Model and Instability Thresholds
- Impedance Calculations with GdfidL
- Infrared (IR) extraction chamber
- In-Vacuum Undulator
- CESR-B RF straight section
- Concluding Remarks

Introduction

- NSLS-II cluster (24nodes, 2CPU's and 8GB RAM each) was created for impedance and beam dynamic analysis.

- 3D GdfidL code for electromagnetic field computation
  - The conventional algorithm requires a lot of computer resources to compute complex geometries for short bunch length.
  - A new window wake algorithm implemented in GdfidL allows computations of the short-range wakepotential for $\sigma \leq 0.3$ mm for most of the components with present computer resources

- We use simplified geometries to verify computed data with analytical results before computing complex geometries (far-IR chamber, RF assembly, In-Vacuum Undulator)

- Preliminary impedance budget contains loss factors and kick factors for a σ_s=3mm Gaussian bunch.

- In the future we plan to calculate pseudo Greens function using 0.3 mm bunch. Results will be used with particle tracking codes to analyze instability thresholds.

NSLS-II Current

N=number of electrons in single bunch ($7.8x10^9$)
Ne =Bunch Charge (1.25 nC)
M=number of bunches (1056)

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)	792	844.4	1100
RF Frequency (MHz)	499.7	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"

Initial Impedance Model

CESR-B cavity higher-order modes β_x=18m, β_y=3m, η=0
720m of aluminum chamber 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 surface with half-gap of 2.5mm 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 $f_r = 30GHz, \quad R_s = 30k\Omega, \quad Q_s = 1$ $(\mathrm{Im} Z_{\parallel}/n)_0 = 0.4\Omega \quad \kappa_{\parallel} = 35V/pC$

- Based on this approximate model our estimates indicate that NSLS-II goals of 0.5mA per bunch and 500mA average current are achievable.
- Base line design includes transverse feedback system

Detailed Calculated Impedance

$\omega_0 = 2\pi \times 384.6$ kHz

Object	Number of occurrences	κ_{loss} V/pC	$(ImZ_{\|\|}/n)_0$ Ω	κ_x V/pC/m	κ_y V/pC/m
Absorber	180	3.4×10^{-3}	9.2×10^{-6}	0.5	0.002
Bellows [1]	180	8.7×10^{-3}	124×10^{-6}	0.8	2
BPM	200	20×10^{-3} ($\Sigma\kappa$=4)	47×10^{-6}	0.9	1.1
Cavity transitions/straight	2	3.5 ($\Sigma\kappa$=7)	14×10^{-3}	25.4	57
500MHz CESR-B cavity	4	0.31	40×10^{-3}	0.17	0.17
1500 MHz CESR-B cavity	4	0.52	13.4×10^{-3}	2.6	2.6
Dipole Chamber	60	3.3×10^{-5}	0.7×10^{-7}	4.5×10^{-3}	0
Multipole Chamber	90	0.5×10^{-5}	0.1×10^{-7}	0.7×10^{-3}	0
Flange [1]	300	0.47×10^{-3}	16×10^{-6}	0.141	0.141
Injection Region	1	TBD	TBD	TBD	TBD
SCU chamber geometric	TBD	22.6×10^{-3}	0.6×10^{-3}	61	257
SCU chamber ease* (2.5m)	TBD	5.6×10^{-3}		13	26
IR chamber [SM]	4	0.84	2.1×10^{-3}	11.4	22.6
IVU geometric	TBD	95×10^{-3}	1.1×10^{-3}	136	425
IVU resistive wall (3.5m)	TBD	66×10^{-3}		112	225
720m Al resistive wall	1	4.0		272	545
Scraper (Horizontal)	2	0.22	1.4×10^{-3}	22	2
Scraper (Vertical)	2	TBD	TBD	TBD	TBD

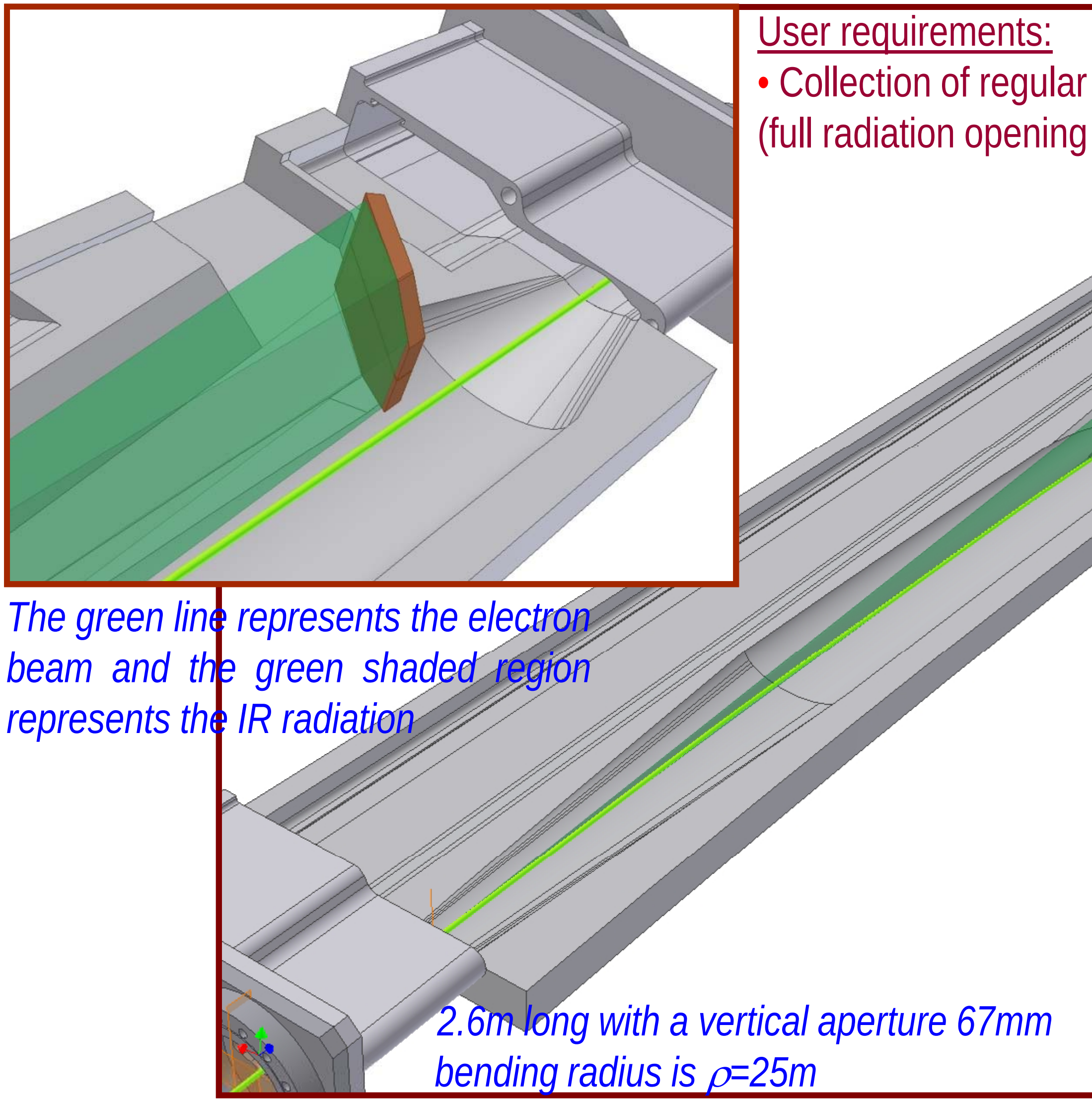
[1] – Values were calculated by R. Nagaoka for SOLEIL with σ_s = 6 mm

[SM] – simplified model

Infrared (IR) extraction chamber

User requirements:

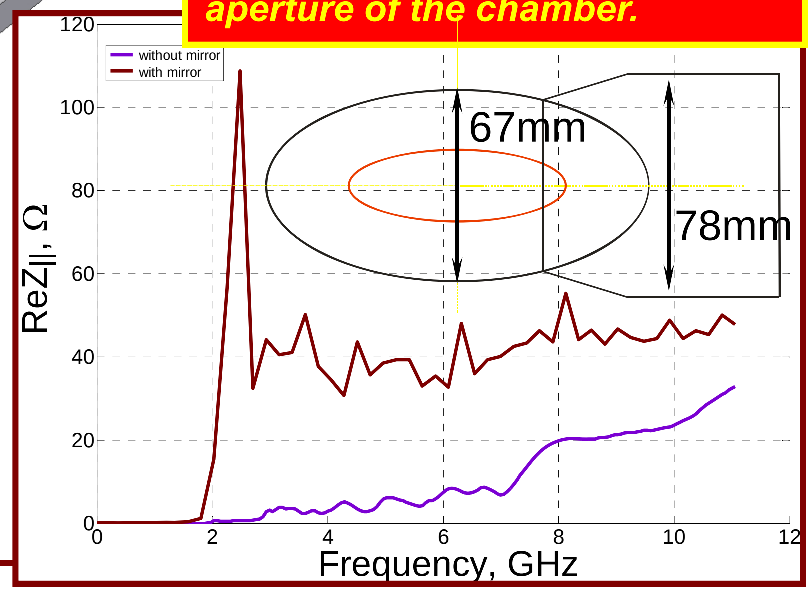
• Collection of regular SR ~ 50mrad (H) and ~ 25mrad (V) (full radiation opening angles of the collected emission)



The green line represents the electron beam and the green shaded region represents the IR radiation

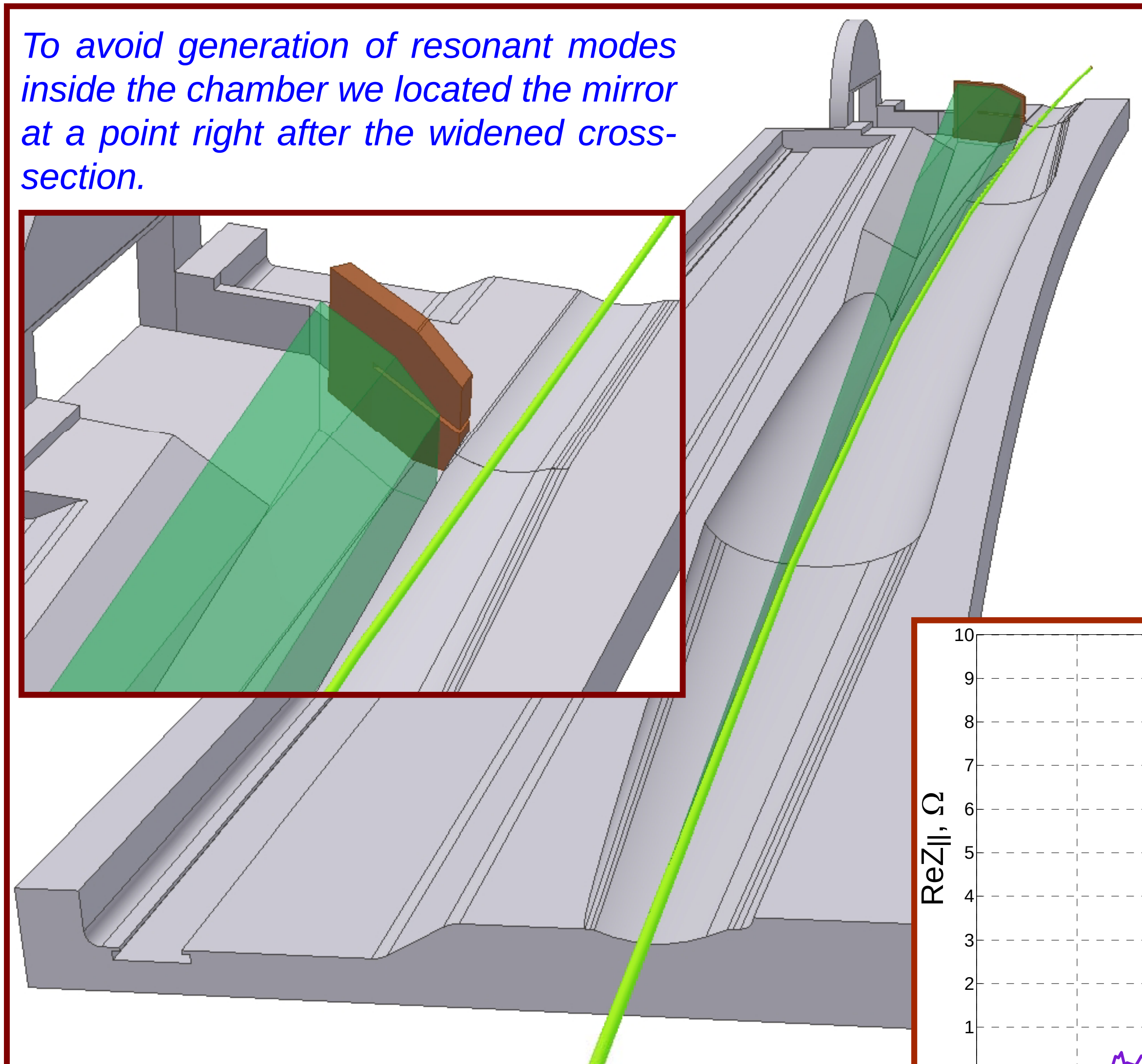
2.6m long with a vertical aperture 67mm bending radius is ρ=25m

Resonance modes (narrow-band impedance) are generated due to the mirror inside the large aperture of the chamber.



A possible variant of IR chamber for NSLS-II

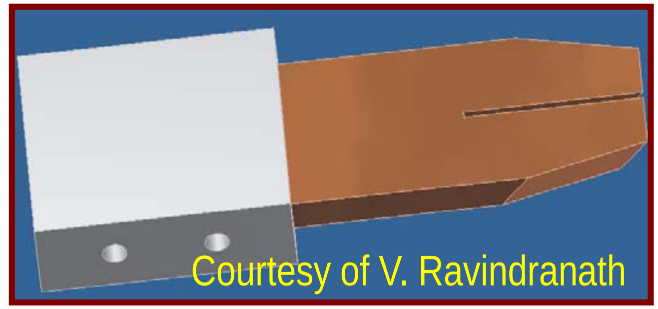
To avoid generation of resonant modes inside the chamber we located the mirror at a point right after the widened cross-section.

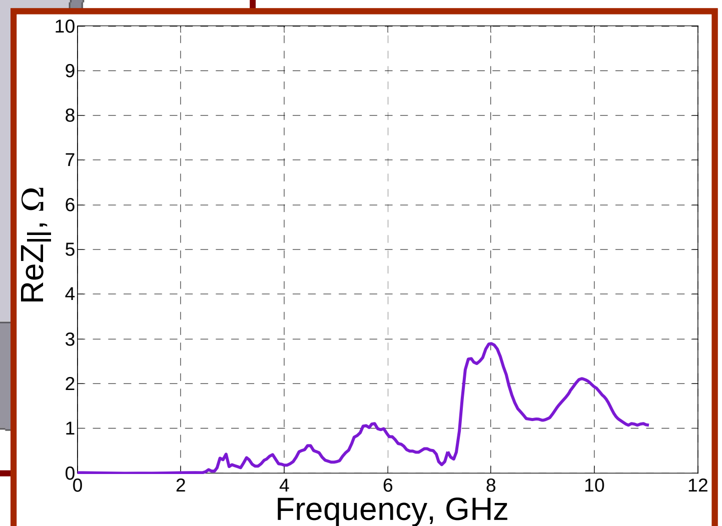


The design of the infrared beam extraction chamber for the NSLS-II storage ring is continuing.

The extraction mirror has a slot and cooling water channels to avoid thermal deformation

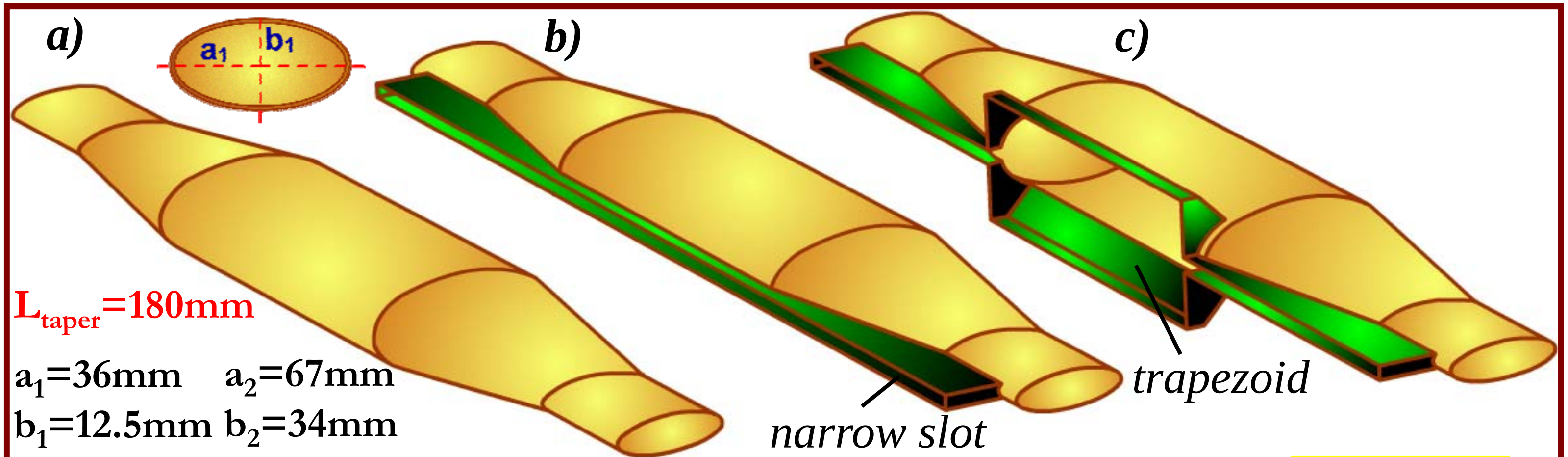
Preliminary design





Simplified model of IR-extraction chamber

Estimate of short-range wakepotential



$\omega_0 = 2\pi \times 384.6$ kHz

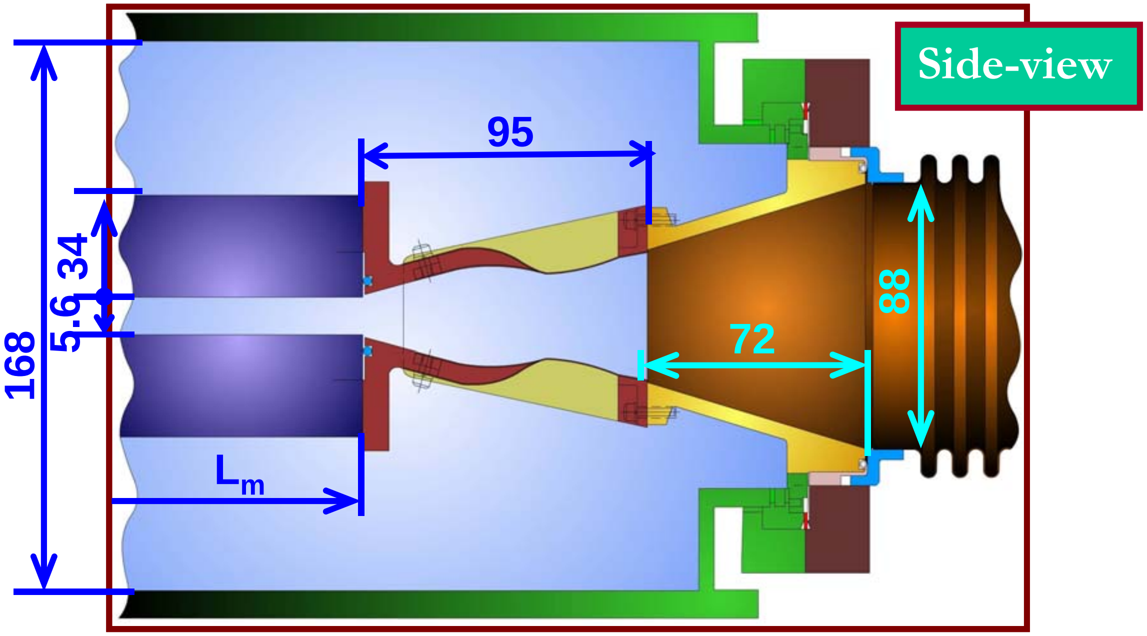
σ_s=3mm

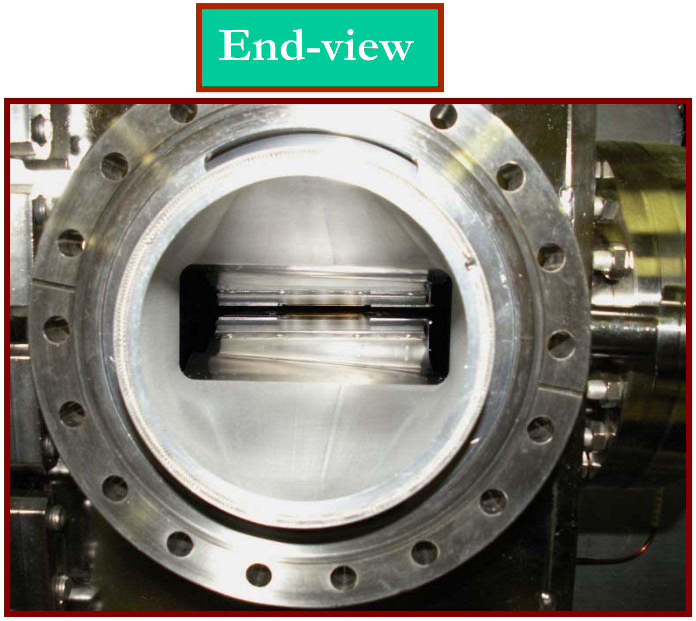
	$(\mathrm{Im}Z_{\parallel}/n)_0$, Ω	κ_{loss}, V/pC	κ_x, V/pC/m	κ_y, V/pC/m
Tapered structure	1.8×10^{-3}	0.83	11.1	22.6
Tapered str. + 10mm narrow slot	1.8×10^{-3}	0.83	11.1	22.3
Tapered str. + 10mm narrow slot + trapezoid	2.1×10^{-3}	0.84	11.4	22.6

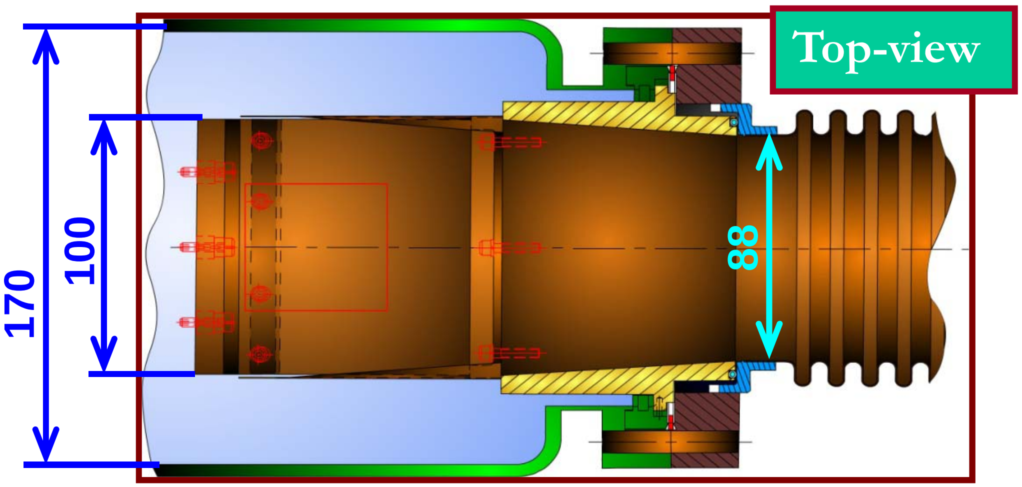
*We thank D. Robin and F. Sannibale for discussion of the results of impedance studies for the IR-extraction chambers for CIRCE**

*J.M Byrd at el., “CIRCE: a dedicated storage ring for coherent THz synchrotron radiation”, Infrared Physics & Technology, 45, 2004.

In-vacuum undulator (NSLS X-Ray ring)



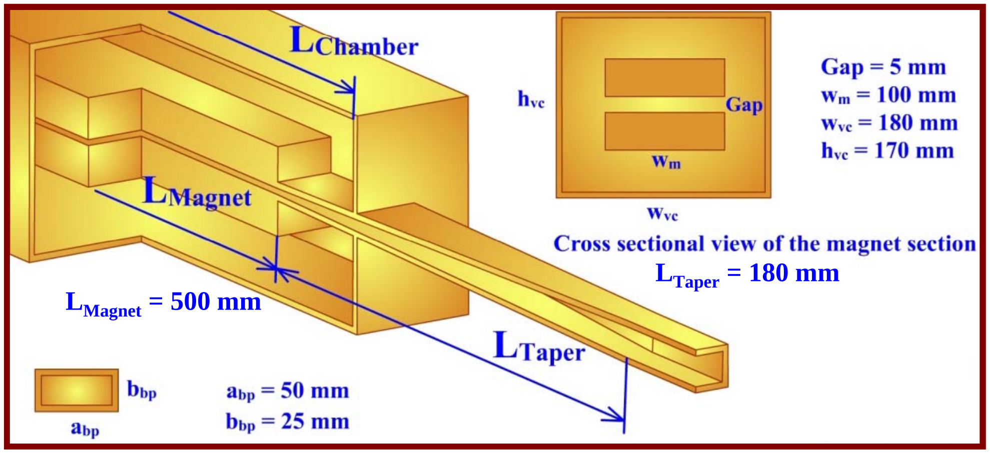




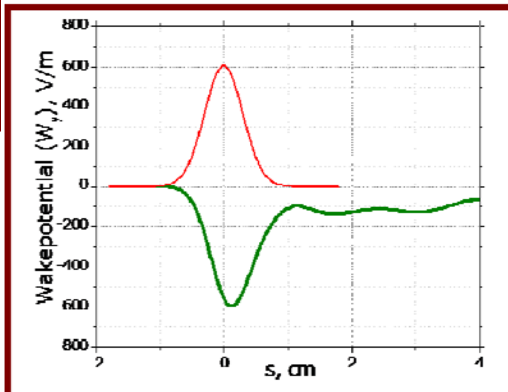
- X-25 currently operating at the NSLS X-Ray ring and has been tailored to meet the NSLS-II requirements

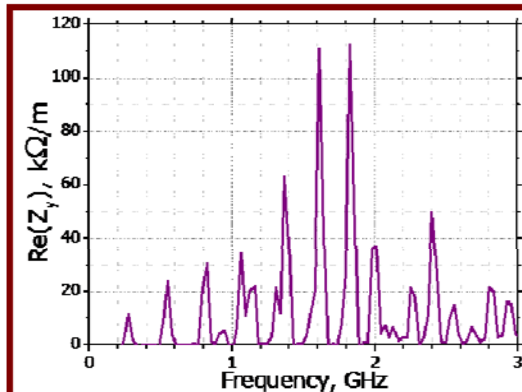
GdfidL model of the in-vacuum undulator

- Short-range wakepotential is predominantly determined by the tapers
- Field strength of modes depends on taper angle
- Long-range wakepotential depends on the cross-sectional geometry of the vacuum enclosure and the length of the magnet
- Resonant modes have been observed experimentally (microwave measurements) in the Prototype Small-Gap Undulator in 1995 by Peter Stefan using pick-up electrodes. It is a similar geometry to current IVU
- X-25 IVU in NSLS X-Ray (1 m long) can be used for experimental studies (with beam, microwave measurements)



Object	κ_{loss}, V/pC	κ_x, V/pC/m	κ_y, V/pC/m
SCU chamber geometric	22.6x10^{-3}	61	257
IVU geometric	95x10^{-3}	136	425
IVU resistive wall (3.5m)	66x10^{-3}	112	225
720m Al resistive wall	4.0	272	545





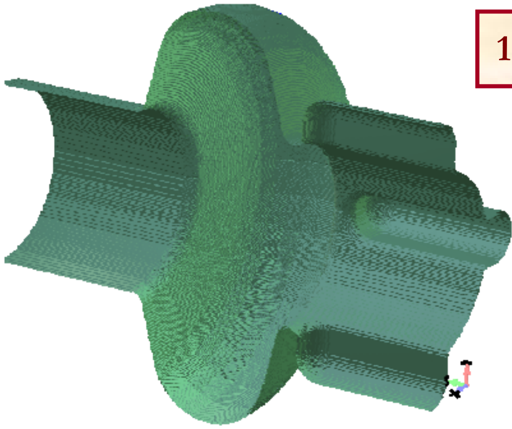
Office of Science
U.S. DEPARTMENT OF ENERGY

Alexei Blednykh

Impedance of RF Straight

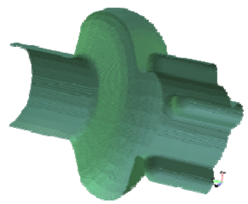
500 MHz CESR-B cavity

2 x

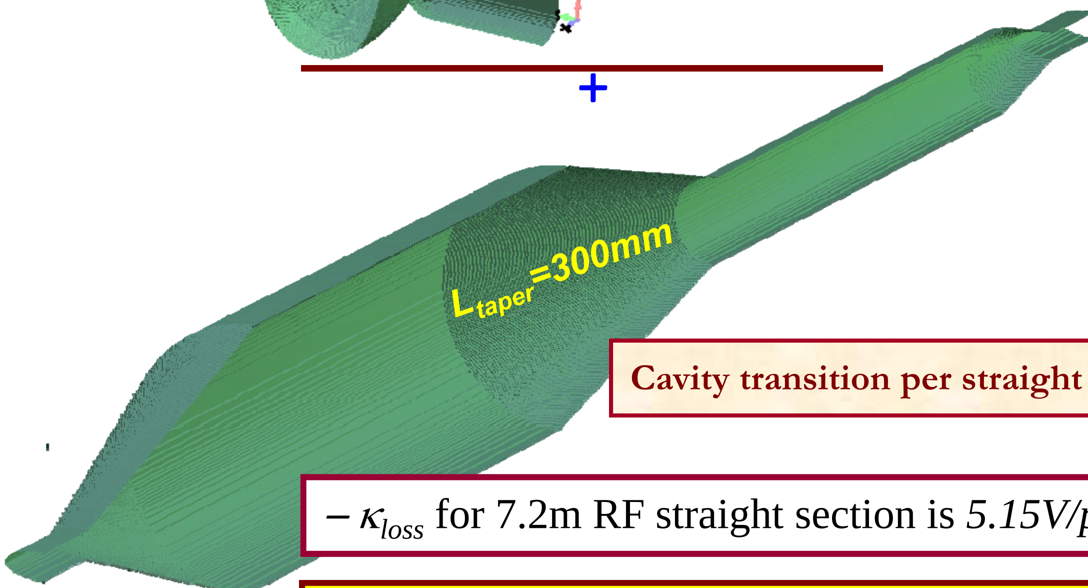


1500 MHz CESR-B cavity

2 x



+



Cavity transition per straight

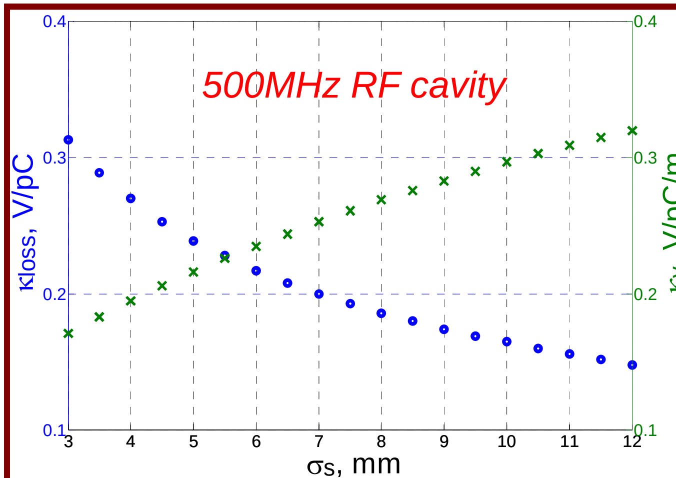
– κ_{loss} for 7.2m RF straight section is *5.15V/pC*

RF straight is now 9.3 m, allowing long taper

	κ_{loss} V/pC	κ_x V/pC/m	κ_y V/pC/m
Main cavity	0.31	0.17	0.17
Harmonic cavity	0.52	2.6	2.6
Cavity transition	3.5	25.4	57

$$-\kappa_{loss}^{Main\ cavity} << \kappa_{loss}^{Cavity\ transition}\ (for\ \sigma_s = 3mm)$$

- κ_{loss} of the HR cavity is increased by a factor of 1.7 ($\kappa_{loss} \propto g^{1/2}/a$) due to scaling of the cavity dimensions by a factor of *3*.



Concluding Remarks

- A detailed calculated impedance including the most important components has been generated using GdfidL code. It will be evaluated and renewed with ongoing changes in components.

- Based on an initial impedance model and the detailed calculated impedance data the NSLS-II goal of 0.5mA per bunch and 500mA average current are achievable.

- The presented design of the far-IR extraction chamber eliminated the problem of resonant modes due to the mirror. Additional short-range wakepotential computations are required.

- In-vacuum undulator geometry needs to be further investigated. Impedance analysis has been performed for a magnet length of 500mm (the real length of the IVU is 3m)

- In the future we plan to calculate effective Green's functions to use in tracking codes to study single-bunch as well as coupled bunch instabilities.

Acknowledgements

S. Krinsky, B. Nash, V. Ravindranath, W. Bruns,
L. Carr, S. Coburn, J. Rose