Collective Effects in NSLS-II

S. Krinsky

NSLS-II Review

May 11-12, 2006

Overview

- Analysis of collective effects in NSLS-II is a work in progress
- R. Nagaoka (SOLEIL) , Y.C. Chae and M. Borland (APS) will visit June 5-9
- In this presentation I will give results obtained to-date and compare expected behavior of NSLS-II to observed behavior in ESRF and APS
- Key features of NSLS-II are lower energy, use of damping wigglers and many small-gap (5mm) undulators
- Touschek Lifetime and Intrabeam Scattering are important issues
- We are evaluating the use of a Landau Bunch Lengthening Cavity and the requirements for longitudinal / transverse feedback
- We are implementing ELEGANT on a cluster to allow parallel processing
- We believe having time-resolved synchrotron radiation monitoring as done at Sector 35 of APS is important

NSLS-II Current

N=number of electrons in single bunch (7.5×10^9)
Ne =Bunch Charge (1.2 nC)
M=number of bunches (1200)

Single Bunch Current $I_0 = \frac{N e}{T_0}$ (.4 ma)

Peak Bunch Current $I_p = \frac{N e}{\sqrt{2\pi}\,\sigma_t}$ (32 A for σ_t=15 ps) ignoring bunch lengthening

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

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

Comparison Between NSLS-II, ESRF, APS

	NSLS-II	ESRF*	APS*
E (GeV)	3	6	7
C (m)	~900	844.4	1100
f_{rf} (MHz)	500	352.2	351.9
V_{rf} (MV)	4.2	9.0	9.5
α (x10^{-4})	3.5	1.86	2.9
ν_s	.009	.006	.007
ϵ_x (nm)	0.5	3	3
ϵ_y/ϵ_x (%)	0.5	0.5	1
ξ_x , ξ_y	5/5	5.5/5.8	5/7
τ_x,τ_s (ms)	11,5.5	7,3.5	9.5/4.7
$\sigma_{\delta 0}$ (%)	0.1	0.1	0.1
σ_{t0} (ps)	15	14	24

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

Comparison Continued

	NSLS-II	ESRF*	APS*
# Straights	32	32	40
# In Vac IDs		4 (2m)	0
#Small Gap IDs		28	25
VacCh Material	Al/SS/Cu	SS/AL/Cu	Al
# Flanges		571	480
# Bellows		290	160
# BPMs		224	360
# RF Cav (Cells)	4(1)	6(5)	16(1)

ESRF*

Number	Gap	Material
16	11mm	SS
2	11	Al
4	8	Cu
1	8	SS
5	15	SS

APS*

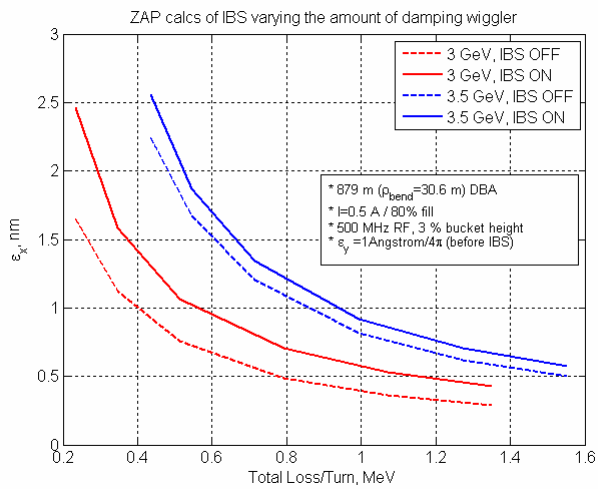
Number	Gap	Material
12	8mm	Al
2	5	Al
1	19.6	Al

Ad Hoc ID Configuration for NSLS-II

	DW	U19	U14	SCW
N_{ID}	8	6	6	2
β_x	15	2	2	2
β_y	3	2	2	2
λ_w (mm)	100	19	14	150
B_w (T)	1.8	1	1.4	3.5
L_w (m)	6	3	2	0.75
b_{gap} (mm)	15	5	5	10
* U_w (KeV)	889	103	134	105
# ϵ_{xw} (nm)	0.49	0.46	0.42	0.42
# $\sigma_{\delta w}$ (%)	0.092	0.090	0.090	0.095

*for N_{ID} IDs #cumulative result from left to right

Intrabeam Scattering



B. Podobedov

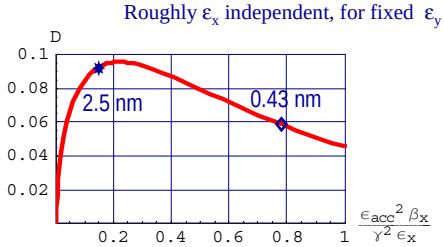
Touschek Scaling with Emittance

$$\frac{1}{\tau_{tous\_1/2}} = \frac{\sqrt{\pi}\, r_e^2 c\, N_b}{\gamma \varepsilon_{acc}^4} \frac{\sigma'_x}{V} D\left(\frac{\varepsilon_{acc}^2}{\gamma^2}\frac{\beta_x}{\varepsilon_x}\right)$$

Roughly ε_x independent, for fixed ε_y

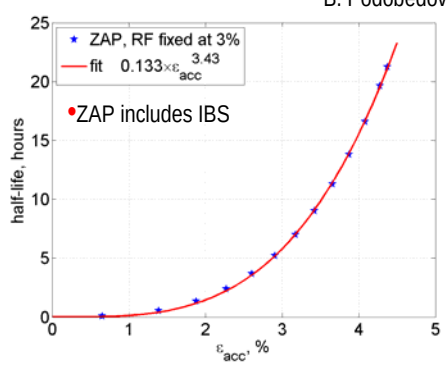
$$\zeta = [\varepsilon_{acc} / \gamma\sigma'_x]^2 \approx \frac{\varepsilon_{acc}^2}{\gamma^2}\frac{\beta_x}{\varepsilon_x}$$

Ignores dispersion



Symbols assume $<\beta_x>$ =13 m, ε_{acc} = 3%

B. Podobedov



Lifetime remains roughly constant

as we reduce emittance!

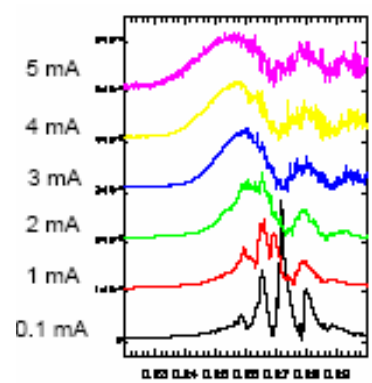
Lifetime very sensitive to energy acceptance!

Transverse Mode Coupling Instability

Vertical Broad-Band Impedance*

ESRF: f_{res}=22GHz βR_s=6.5MΩ/m Q=1
I_{th}=0.8ma (zero chromaticity)
I_{th}=20ma (ξ_x=9, ξ_y=13)

APS: f_{res}=25GHz R_s=1.2MΩ/m Q=1
I_{th}=2ma (zero chromaticity)
I_{th}=9ma (ξ_x=5, ξ_y=6)



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

Transverse Mode Coupling Instability

$$I_{th} \cong \frac{2\sqrt{\pi}\, E \nu_s\, \omega_0\, \sigma_t}{e\, \beta_y\, R_y} \qquad (Broad-Band\ \text{Resonator},\ \omega_r \sigma_t > 1, \xi = 0)$$

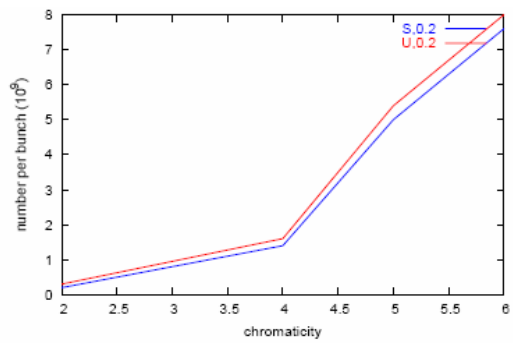
$$ESRF: \quad I_{th} = 0.8\, ma \quad (\beta_y R_y = 6.5 M\Omega / m)$$
$$APS: \quad I_{th} = 2\, ma \quad (R_y = 1.2 M\Omega / m, \beta_y = 4m)$$
$$NSLS2: \quad I_{th} = 1.5 ma \quad (R_y = 1 M\Omega / m, \beta_y = 3m)$$

$$I_{th} \cong \frac{2.4\, E \nu_s\, \omega_0\, \sigma_t}{e\, \beta_y\, R_y^{rw}} \qquad (\text{Re}\,sistive\ Wall)$$

$$R_y^{rw} = \frac{L}{\pi b^3} \sqrt{\frac{Z_0\, c\, \sigma_t}{2\sigma}}$$

$$NSLS2: \quad b = 2.5mm, \sigma = 6\times 10^7 (ohm - m)^{-1}, Cu, \beta_y = 3m, L = 100m, I_{th} = 3ma$$

Transverse Coupled Bunch Instability Threshold



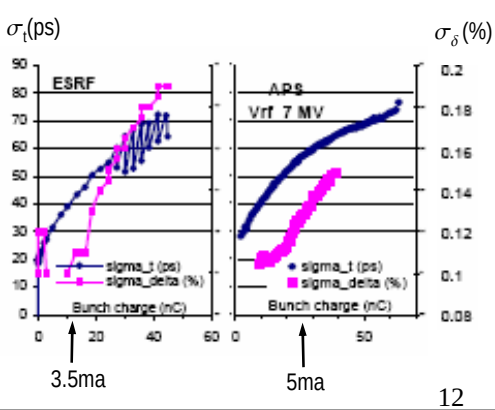
M. Blaskiewicz

- Broad-Band Resonator: R_y=1MΩ/m, f_{res}=30Ghz, Q=1
- Resistive Wall: 100m of Copper with full gap of 5mm
- With Landau Cavity
- β_y=3m

Longitudinal Microwave Instability

Longitudinal Broad-Band (Q=1) Impedance*

ESRF: f_{res}=30 GHz	R_s=42kΩ	(Z/n=0.4Ω)	I_{th}=3.5ma
APS:	Z/n=0.5Ω		I_{th}=5.0ma
NSLS-II: 30 GHz	Z/n~0.25Ω?		



$$Z(\omega) = \frac{R_s}{1 + i\left(\frac{\omega_r}{\omega} - \frac{\omega}{\omega_r}\right)}$$

$$R_s = \left|\frac{Z}{n}\right|_0 \frac{\omega_r}{\omega_0}$$

Longitudinal Microwave Instability

$$I_{th} = \frac{E\,\nu_s\,\sigma_\varepsilon}{e\,R_s\,(\omega_r/\omega_0)}\,S(\omega_r\,\sigma_t)$$

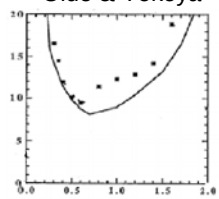
$ESRF:\quad I_{th}(ma) = 8\times10^{-3}\,S(2.6) \;\rightarrow\; 3.5ma$

$APS:\quad I_{th}(ma) = 8\times10^{-3}\,S(4.5) \;\rightarrow\; 5.0ma$

$NSLS2:\quad I_{th}(ma) = 12\times10^{-3}\,S(3.2) \;\rightarrow\; ??$

Oide & Yokoya

S(x)



x

Scaling indicates that behavior should be similar to ESRF.
Oide & Yokoya result yields lower threshold than observed at ESRF&APS.
Li Hua Yu is in process of carrying out tracking calculations using Elegant.
At this time, his results agree with Oide & Yokoya. Predict NSLS-II threshold

$$I_{th} \approx 0.6ma$$

Work continuing to resolve this discrepancy.

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 ~2.5

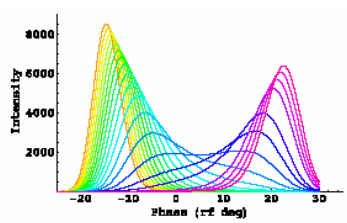


Figure 1: Line densities of bunches uniformly sampled along the length of an 80%-fill bunch train. The leading edge of each bunch is on the right and the progression of leading bunches to trailing bunches is from left to right. Each bunch is normalized to unity with respect to ring azimuthal angle.

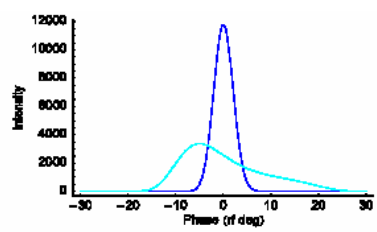
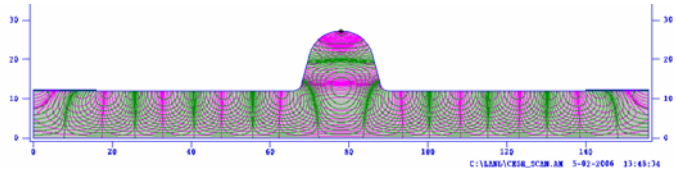


Figure 3: Line densities of unstretched (blue) and stretched (aqua) bunches in a uniform fill.

N. Towne

CESR-B cavity longitudinal impedance and coupled bunch growth rates



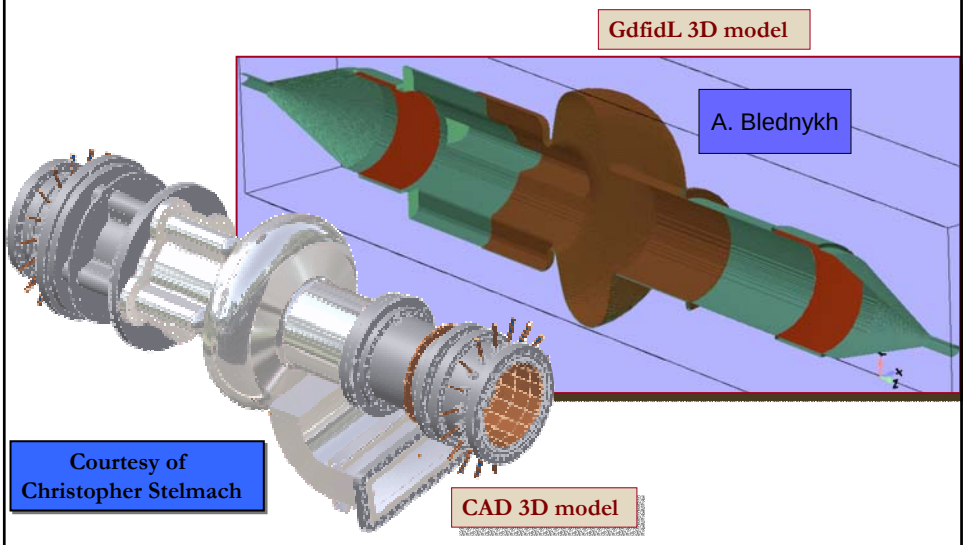
Jim Rose

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

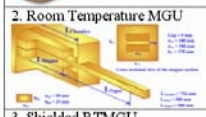
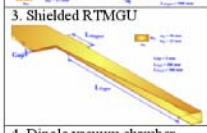
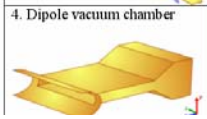
With 4 cavities and I_{av}=0.5 A, ZAP predicts the longitudinal coupled bunch growth time is 37ms, which is larger than radiation damping time of 5.5ms.

3-D GdFidL Calculations for CESR-B Cavity



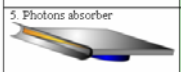
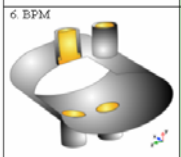
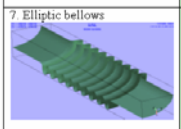
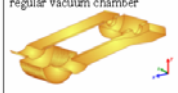
NSLS-II Impedance Budget

Table 1: Budget impedance of the NSLS-II ring components

Components	$\mathrm{Im}Z_y(\omega\to 0)$, Ω/m	$\mathrm{Im}Z_x(\omega\to 0)$, Ω/m	$\frac{\mathrm{Im}Z_\parallel(\omega)}{\omega}\omega_0 Q_{BB}$, Ω	k_{sy}, V/pC/m	k_{sx}, V/pC/m	k_{loss}, V/pC	Estimated number of components
1. Tapered elliptic vacuum chamber	**$3\cdot 10^3$ (75 μm)**	**965 (100 μm)**	$30\cdot 10^{-6}$ (100 μm)	**86 (75 μm)**	**30**	**$0.311\cdot 10^{-3}$**	**10**
2. Room Temperature MGU 	**$58\cdot 10^3$ (500μm)**	**$3.9\cdot 10^3$**	$130\cdot 10^{-6}$ (500 μm)	**505**	**112**		**10**
3. Shielded RTMGU 	$22\cdot 10^3$ (500μm) $14\cdot 10^3$ (120μm)	$3\cdot 10^3$ (500μm) $1.5\cdot 10^3$ (120μm)	$127\cdot 10^{-6}$ (500μm) $49\cdot 10^{-6}$ (120μm)	245	73		
4. Dipole vacuum chamber 	**1.1**	**17.6**	$0.073\cdot 10^{-6}$	**$4.6\cdot 10^{-2}$**	**0.68**	**$0.240\cdot 10^{-3}$**	**72**

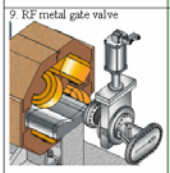
Alexei Blednykh

NSLS-II Impedance Budget (Cont.)

Components	$\mathrm{Im}Z_y(\omega\to 0)$, Ω/m	$\mathrm{Im}Z_x(\omega\to 0)$, Ω/m	$\frac{\mathrm{Im}Z_\parallel(\omega)}{\omega}\omega_0 Q_{BB}$, Ω	k_{sy}, V/pC/m	k_{sx}, V/pC/m	k_{loss}, V/pC	Estimated number of components
5. Photons absorber 	**1.1**	**17.2**	$0.037\cdot 10^{-6}$	**$2.9\cdot 10^{-2}$**	**0.43**	**$0.139\cdot 10^{-3}$**	**120**
6. BPM 	**54**	**42.1**		**1.1**	**0.87**	**$19.971\cdot 10^{-3}$**	**300**
7. Elliptic bellows 	**$8.9\cdot 10^3$**	**$4.6\cdot 10^3$**		**126.2**	**74.64**		
8. Transition from absorber to regular vacuum chamber 	**$9.8\cdot 10^3$**	??	$1140\cdot 10^{-6}$ (bellows)	**55**	**10.4**		**48**

Alexei Blednykh

NSLS-II Impedance Budget (Cont.)

Components	$\mathrm{Im}Z_y(\omega\to 0)$, Ω/m	$\mathrm{Im}Z_x(\omega\to 0)$, Ω/m	$\frac{\mathrm{Im}Z_y(\omega)}{\omega}\omega_0 Q_{BB}$ Ω	k_y, V/pC/m	k_x, V/pC/m	k_{loss}, V/pC	Estimated number of components
9. RF metal gate valve 	$9.8\cdot 10^3$	??	$1140\cdot 10^{-6}$	55	10.4		48
10. Flange							300
11. RF cavity							2
12. Flag							1
13. Resistive wall							

Alexei Blednykh

ESRF Impedance Budget

Table 1: Review of the Vertical Impedance of All Contributing Elements

Element	Number	$\beta_{vertical}$[m]	Im Zt(ω=0)[kΩ/m]	total Im Zt(ω=0)$\beta_{vertical}$[kΩ]
vertical pumping ports	130	19.64	0.014	36
horizontal pumping ports	450		0.000	0
kicker chambers	5	28.7	0.49	70
cavity taper pairs	3	5.27	2.86	45
standard taper pairs	29	4.95	7.52	1079
minigap	1	4.2	13.61	57
invac undulator gap=8mm	2	3.7	33.80	250
RF cavities	6	3.6	11.76	254
scraper cell 6	1	2.85	-46.50	-133
scraper cell 22	1	32	20.09	643
tapered scraper cell 30	1	32	5.67	181
CV7/14 RF-liners	62	35	0.76	1649
the other RF-liners	228	23.4	0.27	1441
flanges	571	20.7	0.10	1182
TOTAL				6756

Gunzel EPAC2002

APS Impedance Budget

Table 1. Impedance Budget of the APS storage ring.

Name	Qty	Z_x (kΩ/m)	Z_y (kΩ/m)	Z/n (Ω)
Absorber	200	4.00E+01	4.00E+00	5.00E-03
Bellow	240	0.00E+00	4.80E+01	4.20E-02
BPM	400	6.40E+01	4.00E+01	2.00E-02
BPM-P05mm	2	8.00E+00	4.00E-01	1.00E-04
BPM-P08mm	22	4.40E+01	1.76E+01	1.10E-03
Flag Chamber	10	1.00E+01	1.50E+02	2.00E-02
ID-5mm	2	1.20E+00	2.20E+02	2.40E-03
ID-8mm	22	4.40E+00	6.16E+02	2.20E-02
RF-sector	4	5.20E+01	6.00E+01	2.00E-01
Scraper-H	2	1.50E+01	1.40E+01	3.20E-02
Scraper-V	2	3.20E+00	4.00E+01	7.50E-02
Strip line	4	8.00E-01	1.20E+00	6.00E-03
Total		**2.43E+02**	**1.21E+03**	**4.20E-01**

Table 2: Broadband Resonator Model.

	R_s (Ω)	Q	f_r (GHz)
Zx	0.6e6	4.0	22
Zy	0.5e6	0.4	20
Z/n	0.22/0.42	2.0	25

Chae PAC2003

SOLEIL Impedance Budget

Table 1: Impedance budget for SOLEIL obtained so far.

Object	Number	Loss factor [V/pC]	$(P)_{500\,mA}$ [kW]	$\Sigma\,\|Z_L/n\|_{eff}$ [mΩ]	$(Z_V)_{eff}$ [kΩ/m]	$\Sigma\,\beta_V\times(Z_V)_{eff}$ [kΩ]	$(Z_H)_{eff}$ [kΩ/m]	$\Sigma\,\beta_H\times(Z_H)_{eff}$ [kΩ]
Shielded bellows	176	8.72×10^{-3}	**1.17**	**48.30**	(0.03, 0.14)	**(52.8, 246.4)**	(0.01, 0.06)	**(15.8, 112.6)**
Flange[1]	332	4.67×10^{-4}	0.12	11.65	(0.00, 0.01)	(0.7, 42.3)	(0.00, 0.01)	(9.1, 46.8)
Dipole chamber	32	1.64×10^{-4}	2.63×10^{-3}	0.48	(0.00, 0.00)	(0.2, 0.7)	(0.00, 0.03)	(0.1, 0.8)
Soleil cavity	1	2.20	**1.55**	9.30	(0.29, 0.44)	(0.8, 1.3)	(0.17, 0.44)	(0.8, 2.0)
BPM	120	6.10×10^{-3}	0.56	**19.20**	(0.03, 0.05)	(28.8, 54.3)	(0.01, 0.05)	**(21.9, 66.6)**
Medium section tapers	10	1.76×10^{-3}	1.24×10^{-2}	9.31	(1.35, 3.41)	**(85.5, 215.9)**	(0.01, 0.56)	(0.4, 33.7)
Long section tapers	3	7.32×10^{-4}	1.55×10^{-3}	1.52	(0.43, 1.13)	(14.9, 39.2)	(0.00, 0.24)	(0.1, 9.2)
In-vacuum ID tapers[2]	4	0.25	0.76	18.92	(0.50, 1.42)	(6.0, 17.0)	(0.13, 0.50)	(9.4, 36.0)
Soleil cavity outer tapers	1	0.17	0.13	6.70	(0.49, 1.56)	(2.6, 8.3)	(0.01, 0.29)	(0.0, 1.6)
Resistive-wall	-	7.31	**5.17**	**85.50**	(21.8, 101.5)	**(135.2, 743.5)**	(7.10, 51.7)	**(34.8, 376.3)**
Injection zone[2]	1	1.86×10^{-3}	1.42×10^{-3}	0.09	(0.00, 0.01)	(0.0, 0.1)	(0.10, 0.72)	(1.2, 8.7)
Pumping holes (@quads)	128	$< 1.0\times10^{-7}$	$< 1.0\times10^{-7}$	0.01	(0.00, 0.00)	(0.0, 0.0)	(0.00, 0.00)	(0.0, 0.5)
Total	-	-	**9.48**	**211.0**	-	**(327.5, 1369.0)**	-	**(93.6, 694.8)**

1 : The shielded flange as described in the main text
2: At nominal positions

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Concluding Remarks

- Single bunch and average current goals appear to be achievable
- Transverse coupled bunch instability may require feedback
- We are facing a theoretical puzzle in regard to microwave instability threshold, which we are working to resolve. However, the threshold is above the 0.4ma required.
- At the moment we are estimating instability thresholds based on the impedances observed 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.
- Realistic calculation of the Touschek lifetime is of critical importance. Work on this problem is underway using both TRACY2 and ELEGANT.