Super-B:
RF and HOMs.

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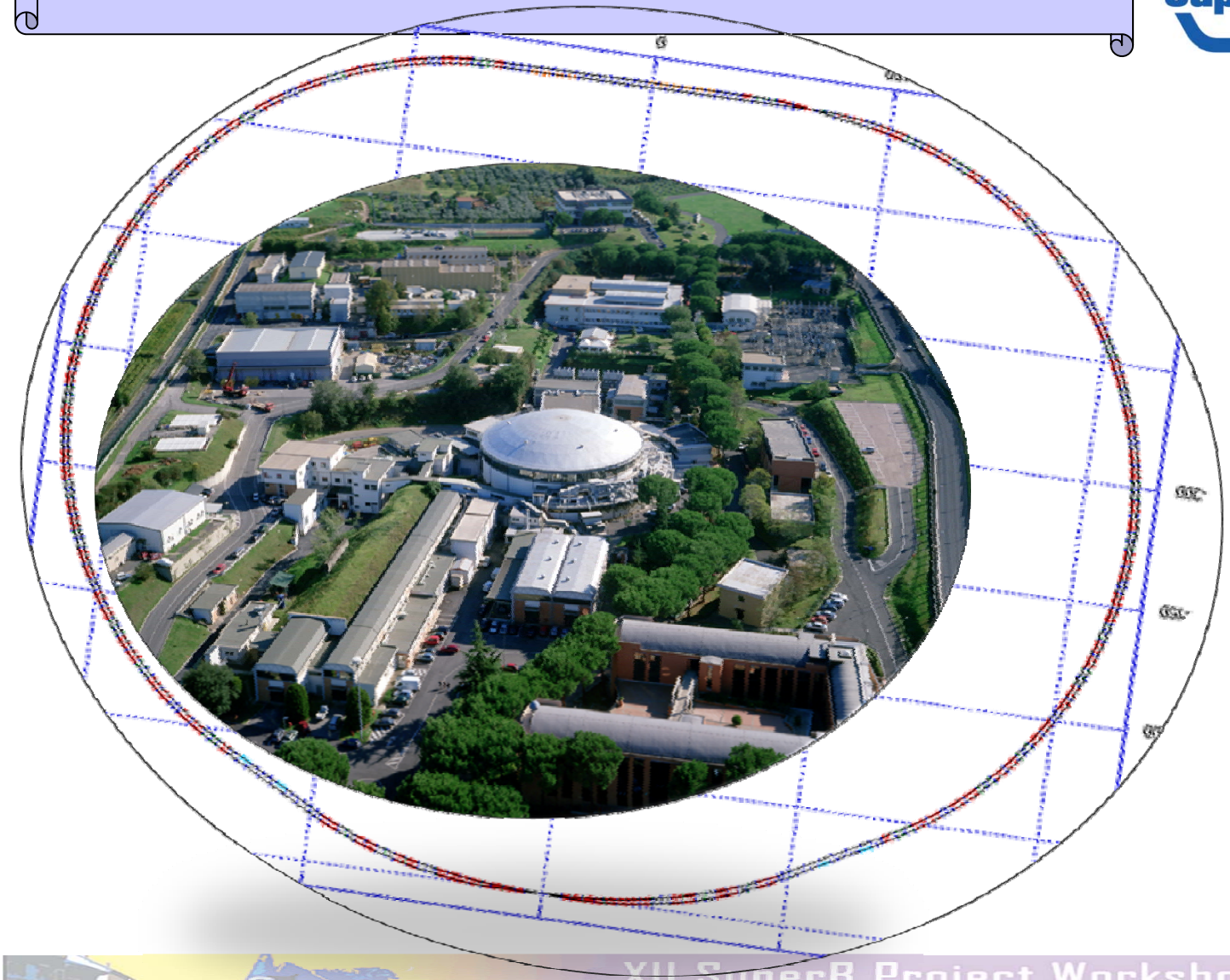
SLAC National Accelerator Laboratory

XII Super B Workshop

March 16-19, 2010

LAPP, Annecy, France

High efficiency, cite independent project.



Super-B parameters. March 3, 2010

Sasha Novokhatski "RF. Impedance"

(Bold: computed values)		Base Line		Low Emittance		High Current		Tau/Charm (prelim.)	
Parameter	Units	HER (e+)	LER (e-)	HER (e+)	LER (e-)	HER (e+)	LER (e-)	HER (e+)	LER (e-)
Energy	GeV	6.7	4.18	6.7	4.18	6.7	4.18	2.58	1.61
Circumference	m	1258.4		1258.4		1258.4		1258.4	
Bunch length (zero current)	mm	4.69	4.29	4.73	4.34	4.03	3.65	4.75	4.36
Bunch length (full current)	mm	5	5	5	5	4.4	4.4	5	5
Beam current	mA	1892	2447	1460	1888	3094	4000	1365	1766
N. Buckets distance		2	2	2	2	1	1	1	1
Ion gap	%	2	2	2	2	2	2	2	2
RF frequency	Hz	4.76E+08	4.76E+08	4.76E+08	4.76E+08	4.76E+08	4.76E+08	4.76E+08	4.76E+08
Revolution frequency	Hz	2.38E+05		2.38E+05		2.38E+05		2.38E+05	
Harmonic number	#	1998		1998		1998		1998	
Number of bunches	#	978		978		1956		1956	
N. Particle/bunch	#	5.08E+10	6.56E+10	3.92E+10	5.06E+10	4.15E+10	5.36E+10	1.83E+10	2.37E+10
Bunch current	mA	1.935	2.502	1.493	1.930	1.582	2.045	0.698	0.903
Energy Loss/turn	MeV	2.11	0.865	2.11	0.865	2.11	0.865	0.4	0.166
Momentum compaction		4.36E-04	4.05E-04	4.36E-04	4.05E-04	4.36E-04	4.05E-04	*4.36E-04*	*4.05E-04*
Energy spread (zero current)	dE/E	6.31E-04	6.68E-04	6.31E-04	6.68E-04	6.31E-04	6.68E-04	*6.31E-04*	*6.68E-04*
Energy spread (full current)	dE/E	6.43E-04	7.34E-04	6.43E-04	7.34E-04	6.43E-04	7.34E-04	*6.94E-04*	*7.34E-04*
CM energy spread	dE/E	5.00E-04		5.00E-04		5.00E-04		5.26E-04	
Energy acceptance		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Synchrotron frequency	kHz	3.01	2.8	2.97	2.77	3.54	3.26	2.96	2.77
Synchrotron tune		0.0126	0.0118	0.0125	0.0116	0.0148	0.0137	0.0124	0.0116
SR power loss	MW	3.99	2.12	3.08	1.63	6.53	3.46	0.55	0.29
RF Wall Plug Power (SR only)	MW	12.22		9.43		19.98		1.68	
Total RF Wall Plug Power	MW	17.08		12.72		30.48		3.11	
Number of cavities		12	8	12	8	20	12	6	4
Number of Klystrons		6	4	6	4	10	6	3	2
Total Number of klystrons		10		10		16		5	
RF Voltage	MV	7.01	5.25	6.88	5.13	9.3	7.2	2.54	1.94
R_s	MΩ								
Q_0									
β									

Main mode Robinson Damping and optimal coupling factor

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- Matching main mode

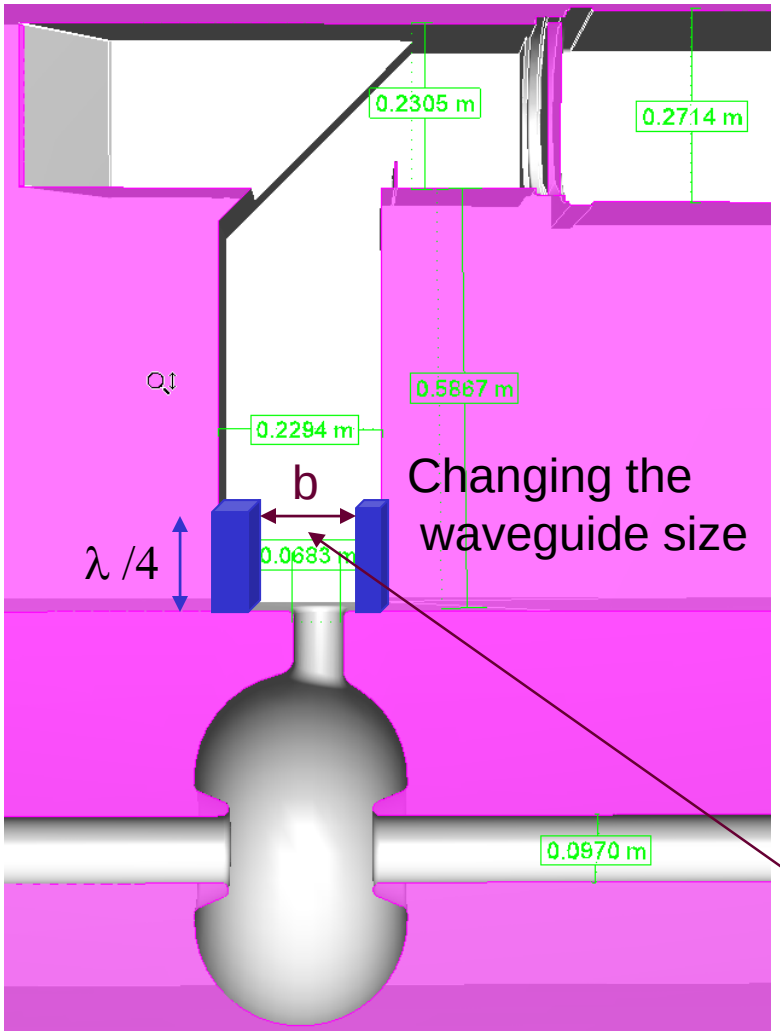
$$\beta = 1 + \frac{2 I_b Z_{sh}}{V_{total}} N_{cav} \frac{U_{S.R}}{V_{total}}$$

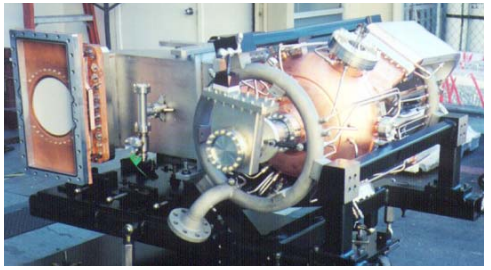
$$\Delta f = - f_{RF} \times \frac{Z_{sh}}{Q} \times \frac{I}{V_{total}} N_{cav}$$

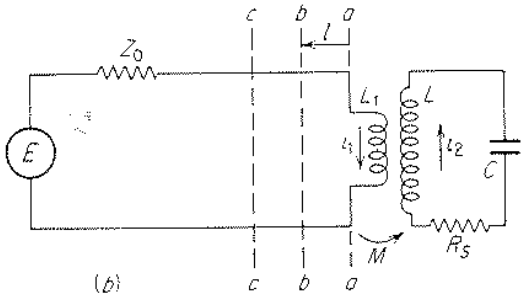
PEP-II	cavity
f [MHz]	476
Z [MOhm]	3.8
Q	32000
Z/Q [Ohm]	118.75

	PEP	-	II	Super	-	B
	LER		HER	LER		HER
Usr [MeV]	0.5		3.55	0.87		2.11
N cav	8		28	8		12
V [MV]	4.05		16.5	5.25		7.01
I [mA]	3000		2000	2447		1892
df [kHz]	-334.96		-191.84	-210.77		-183.07
f rev [kHz]	136.3		136.3	238.2		238.2
betta	6.56		6.55	5.70		8.41

Changing the coupling factor β from 3.6 to 6 of the PEP-II cavity by modifying the coupling box.







$$Q_L = \frac{Q_0}{1+\beta} \qquad Q_0 = \frac{\omega L}{R_s}$$

$$\beta = \frac{(\omega M)^2}{Z_0 R_s} \frac{1}{1+\left(\frac{\omega L_1}{Z_0}\right)^2}$$

$$Z_0 \sim b$$

HOMs

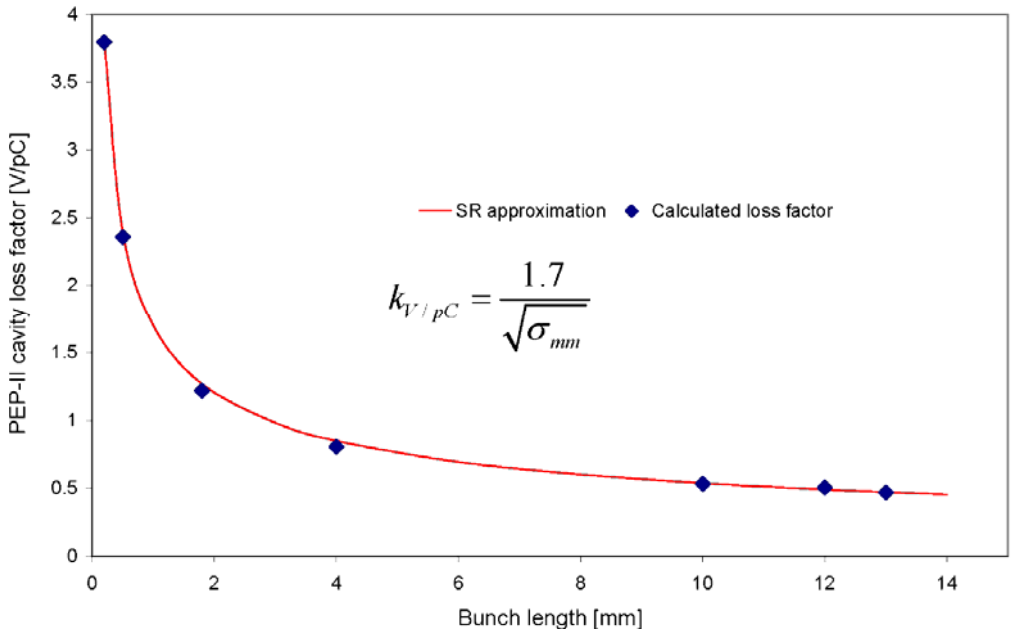
- We need to add HOMs power to synchrotron radiation power.

HOMs in RF cavities

Mode frequency GHz	R/Q Ohm	Qload	Loss factor V/pC	Filling time mks	cos()	exp()	Bunch spacing nsec	Power loss for I= 1 A kW
0.475997	117.3	8000	0.1754	2.675	1.000	0.9969	4.202	0.0000
0.758	44.6	18	0.1062	0.004	0.398	0.1082	4.202	0.4701
1.009	0.43	128	0.0014	0.020	0.066	0.6595	4.202	0.0013
1.283	6.7	259	0.0270	0.032	-0.774	0.7699	4.202	0.0083
1.295	10.3	222	0.0419	0.027	-0.933	0.7349	4.202	0.0140
1.595	2.43	300	0.0122	0.030	-0.299	0.7552	4.202	0.0055
1.71	0.44	320	0.0024	0.030	0.398	0.7542	4.202	0.0023
1.82	0.13	543	0.0007	0.047	-0.602	0.8378	4.202	0.0002
1.898	0.17	2588	0.0010	0.217	0.988	0.962	4.202	0.0065
2.121	1.82	338	0.0121	0.025	0.850	0.718	4.202	0.0519
2.16	0.053	119	0.0004	0.009	0.889	0.3835	4.202	0.0033
2.265	0.064	1975	0.0005	0.139	-0.994	0.9412	4.202	0.0000
	184.4370		0.3811		Total	HOM	power	0.5635

Cavity loss factor and power above cut-off

$$P_{kW} = \left(\frac{1.7}{\sqrt{\sigma_{mm}}} - .3811\right) \times \tau_{spacing} \times I^2$$



HOMs power due to cavities

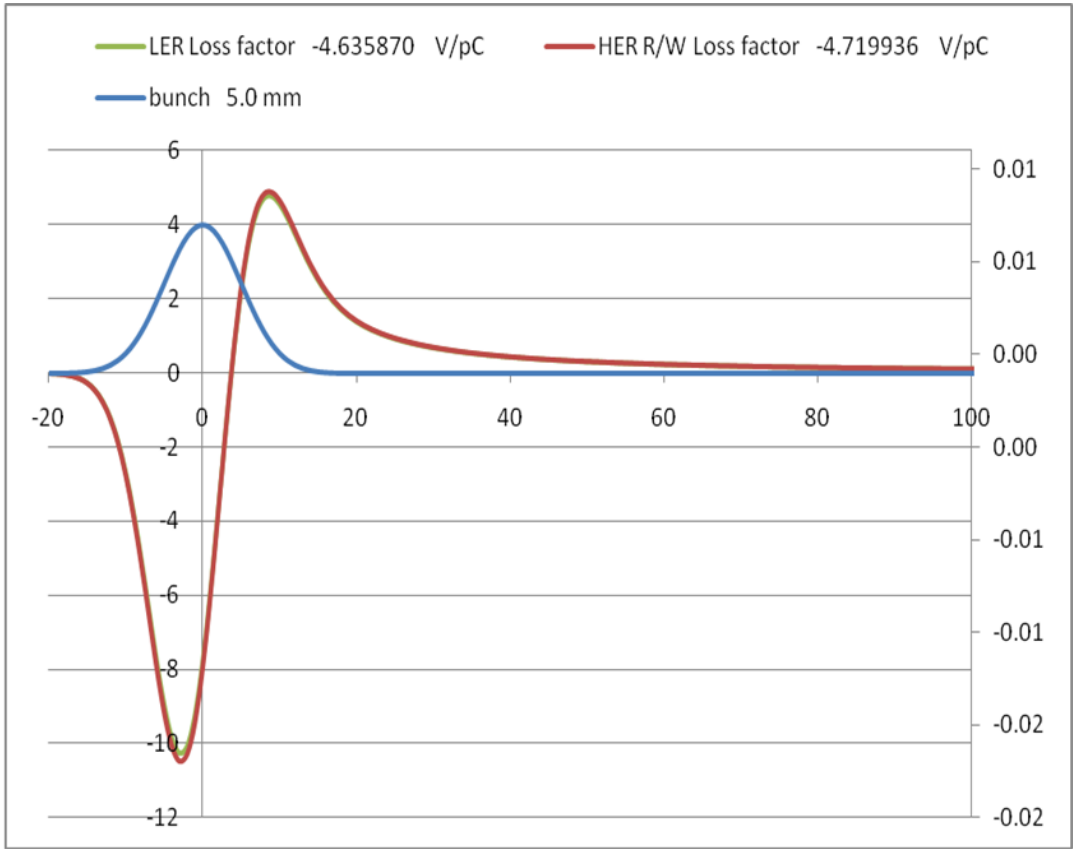
		Beam current A	Bunch length mm	number f cavitie	Power bellow cut-off kW	Power above cut-off kW	Total HOM cavity power kW
LER	Base line	2.447	5	8	26.99	76.28	103.28
	High current	4	4.4	12	54.10	173.11	227.21
HER	Base line	1.892	5	12	24.21	68.41	92.61
	High current	3.094	4.4	20	53.94	172.62	226.56

Beam pipe chamber

	Material	*%*	*pipe radius [m]*	*resistivity [Ohm m]*
LER	Cu	10	0.025	1.69E-08
	Al	50	0.035	2.86E-08
	SS	40	0.045	7.14E-07
HER	Cu	60	0.025	1.69E-08
	SS	40	0.045	7.14E-07

For these beam pipe geometries loss factor is almost the same, because Al part of LER has larger size.

Resistive wake



Resistive wall power

LER

	Base line	*High current*
bunch length [m]	0.005	0.0044
Bunch spacing [ns]	4.2	2.1
beam current [A]	2.447	4
Power (10/50/40) [kW]	122.49	198.24

HER

	Base line	*High current*
bunch length [m]	0.005	0.0044
Bunch spacing [ns]	4.2	2.1
beam current [A]	1.892	3.094
Power (60/0/40) [kW]	74.55	120.76

Longitudinal kicker

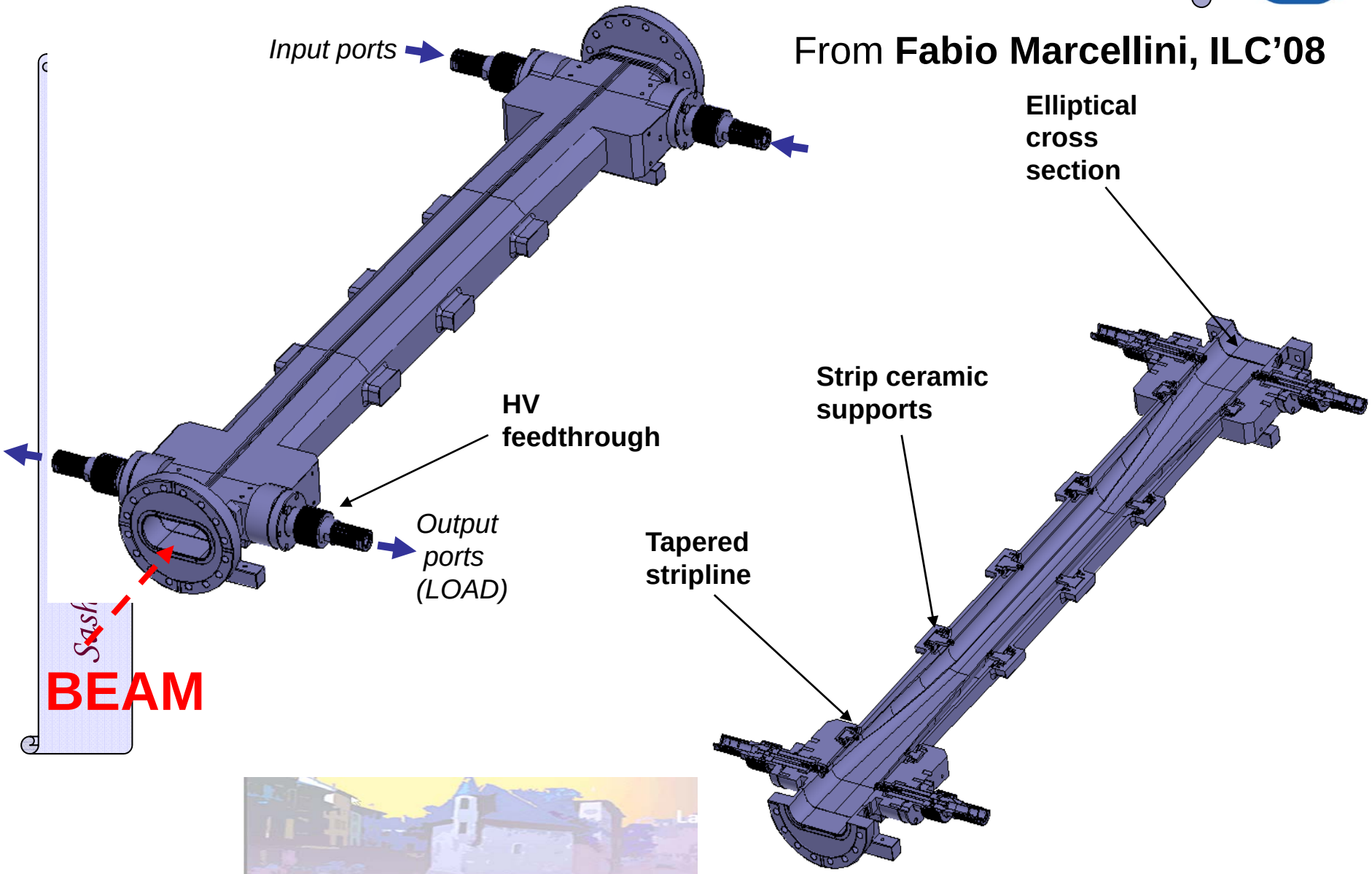
		Beam current	Bunch length	number of long. Kickers	Wake field power
		A	mm		kW
LER	Basic Line	2.447	5	2	10.40
	High currents	4	4.4	2	31.34
HER	Basic Line	1.892	5	2	6.22
	High currents	3.094	4.4	2	18.75

Transverse kicker

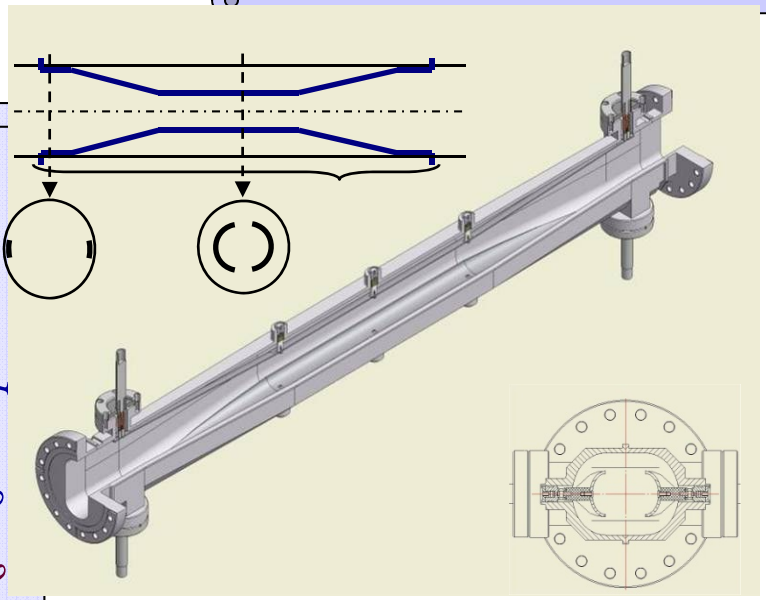
		Beam current	*Bunch length*	*number of kickers*	*Wake field power*
		A	*mm*		*kW*
LER	Basic Line	2.447	5	2	12.57
	High Currents	4	4.4	2	18.27
HER	Basic Line	1.892	5	2	6.22
	High Currents	3.094	4.4	2	9.38

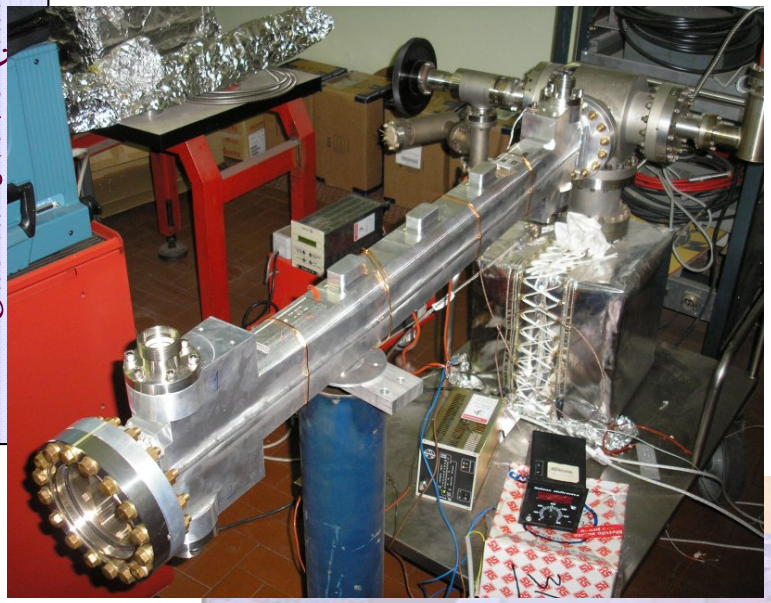
NEW DAFNE INJECTION KICKER

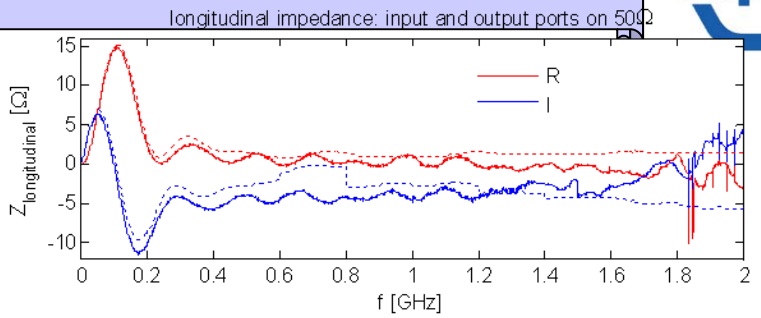
From **Fabio Marcellini, ILC'08**

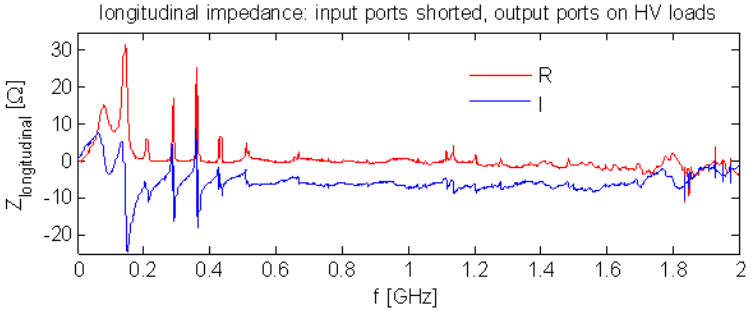


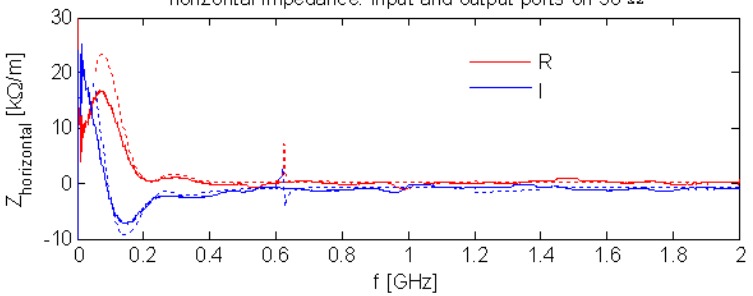
New Injection Kicker Impedance

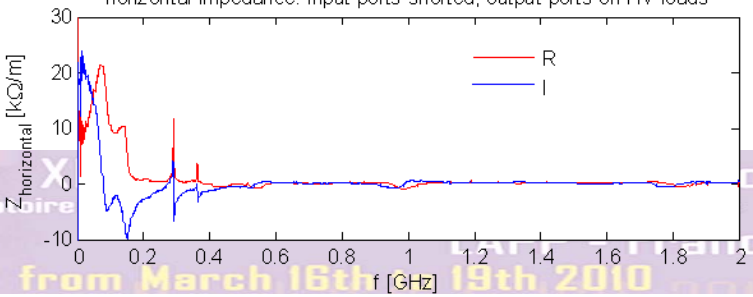












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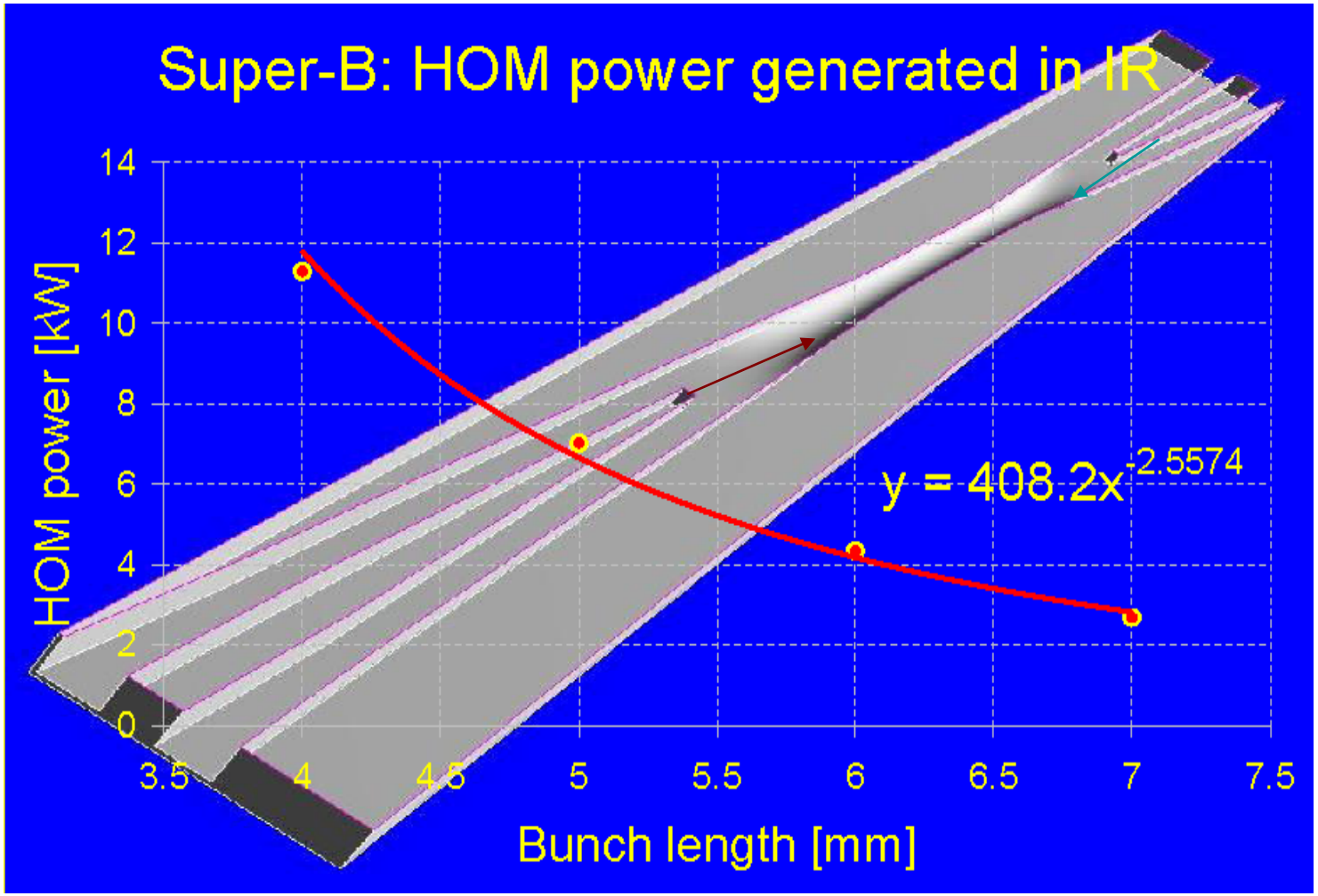
SLAC-type Injector and Abort kickers

		Beam current	*Bunch length*	*number of kickers*	*Wake field power*
		A	*mm*		*kW*
LER	Basic Line	2.447	5	4	9.89
	High Currents	4	4.4	4	16.01
HER	Basic Line	1.892	5	4	5.92
	High Currents	3.094	4.4	4	9.58

Collimators

		LER			HER	
	Base Line		*High Currents*	*Base Line*		*High Currents*
Beam current (A)	2.447		4	1.892		3.094
Bunch length (mm)	5		4.4	5		4.4
Number of collimators	7		7	6		6
Wake field power (kW)	38.73		66.82	19.85		34.27


Super-B: HOM power generated in IR
HOM power [kW]
14
12
10
8
6
4
2
0
3.5
4
4.5
5
5.5
6
6.5
7
7.5
Bunch length [mm]
y = 408.2x^-2.5574

RF cavity limits

- Cavity voltage and forward power
  - Voltage in a cavity is limited by sparks and breakdowns
    - SLAC PEP-II experience: voltage should be less than 0.75 MV per cavity
  - Forward power into a cavity and reflected power are limited by sparks in RF windows
    - SLAC PEP-II experience: transmitted power should be less than 500 KW per cavity and reflected power less than 10%

Super-B RF plug power. Base Line.

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HER	HER	HER	HER	HER	HER	HER	HER	HER	HER	HER	HER	HER+
Total RF voltage MV	Zero I Bunch length mm	Bunch spacing ns	Max voltage per cavity MV	Number of cavities klystrons	S.R. power MW	HOMs power MW	Total cavity loss MW	Total reflected power MW	Total forward power MW	forward to one cavity MW	reflected from one MW	LER Total forward MW
	4.69											
7.01	4.78	4.20	0.58	12.00	3.99	0.27	0.54	0.36	5.16	0.43	0.03	8.19
	5.00			6.00								
												HER+
LER	LER	LER	LER	LER	LER	LER	LER	LER	LER	LER	LER	LER
Total RF voltage MV	Zero I Bunch length mm	Bunch spacing nsec	Max voltage per cavity MV	Number of cavities klystrons	S.R. power MW	HOMs power MW	Total cavity loss MW	Total reflected power MW	Total forward power MW	forward to one cavity MW	reflected from one MW	Plug Power eff.~50% MW
	4.29											
5.25	4.71	4.20	0.66	8.00	2.12	0.41	0.45	0.05	3.03	0.38	0.01	16.38
	5.00			4.00								

Super-B RF plug power. Low emittance.

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HER	HER	HER	HER	HER	HER	HER	HER	HER	HER	HER	HER	HER+
Total RF voltage MV	Zero I Bunch length mm	Bunch spacing ns	Max voltage per cavity MV	Number of cavities klystrons	S.R. power MW	HOMs power MW	Total cavity loss MW	Total reflected power MW	Total forward power MW	forward to one cavity MW	reflected from one MW	LER Total forward MW
	4.73											
6.88	4.82	4.20	0.57	12.00	3.08	0.16	0.52	0.11	3.87	0.32	0.01	6.18
	5.00			6.00								
												HER+
LER	LER	LER	LER	LER	LER	LER	LER	LER	LER	LER	LER	LER
Total RF voltage MV	Zero I Bunch length mm	Bunch spacing nsec	Max voltage per cavity MV	Number of cavities klystrons	S.R. power MW	HOMs power MW	Total cavity loss MW	Total reflected power MW	Total forward power MW	forward to one cavity MW	reflected from one MW	Plug Power eff.~50% MW
	4.34											
5.13	4.77	4.20	0.64	8.00	1.63	0.24	0.43	0.00	2.31	0.29	0.00	12.37
	5.00			4.00								

Super-B RF plug power. High current.

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HER	HER	HER	HER	HER	HER	HER	HER	HER	HER	HER	HER	HER+
Total	Zero I		Max	Number			Total	Total	Total	forward	reflected	LER
RF	Bunch	Bunch	voltage	of	S.R.	HOMs	cavity	reflected	forward	to one	from	Total
voltage	length	spacing	per cavity	cavities	power	power	loss	power	power	cavity	one	forward
MV	mm	ns	MV	klystron	MW	MW	MW	MW	MW	MW	MW	MW
	4.03											
9.30	4.10	2.10	0.47	20.00	6.53	0.52	0.57	1.76	9.38	0.47	0.09	14.41
	4.42			10.00								
												HER+
LER	LER	LER	LER	LER	LER	LER	LER	LER	LER	LER	LER	LER
Total	Zero I		Max	Number			Total	Total	Total	forward	reflected	Plug
RF	Bunch	Bunch	voltage	of	S.R.	HOMs	cavity	reflected	forward	to one	from	Power
voltage	length	spacing	per cavity	cavities	power	power	loss	power	power	cavity	one	eff.~50%
MV	mm	nsec	MV	klystron	MW	MW	MW	MW	MW	MW	MW	MW
	3.65											
7.20	4.01	2.10	0.60	12.00	3.46	0.73	0.57	0.28	5.03	0.42	0.02	28.83
	4.41			6.00								

Super-B RF plug power. Tau/Charm. Beta=6

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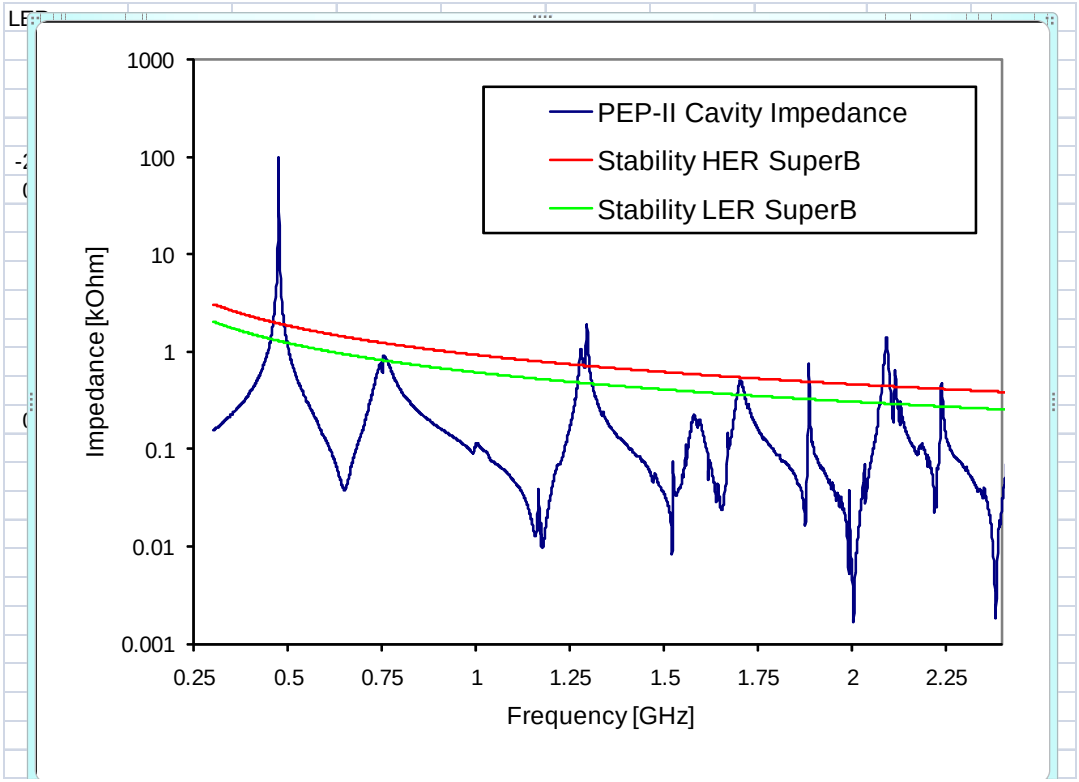
HER	HER	HER	HER	HER	HER	HER	HER	HER	HER	HER	HER	HER+
Total	Zero I		Max	Number			Total	Total	Total	forward	reflected	LER
RF	Bunch	Bunch	voltage	of	S.R.	HOMs	cavity	reflected	forward	to one	from	Total
voltage	length	spacing	per cavity	cavities	power	power	loss	power	power	cavity	one	forward
MV	mm	ns	MV	klystron	MW	MW	MW	MW	MW	MW	MW	MW
	4.75											
2.54	4.84	4.20	0.42	6.00	0.55	0.12	0.14	0.00	0.81	0.13	0.00	1.41
	5.00			3.00								
												HER+
LER	LER	LER	LER	LER	LER	LER	LER	LER	LER	LER	LER	LER
Total	Zero I		Max	Number			Total	Total	Total	forward	reflected	Plug
RF	Bunch	Bunch	voltage	of	S.R.	HOMs	cavity	reflected	forward	to one	from	Power
voltage	length	spacing	per cavity	cavities	power	power	loss	power	power	cavity	one	eff.~50%
MV	mm	nsec	MV	klystron	MW	MW	MW	MW	MW	MW	MW	MW
	4.36											
1.94	4.79	4.20	0.49	4.00	0.29	0.18	0.12	0.00	0.60	0.15	0.00	2.81
	5.00			2.00								

Multi-bunch beam stability

- Threshold for a cavity impedance

$$Z_{th}(\omega) = \frac{4\pi E \nu_s}{\alpha \tau_s N_c I \omega}$$



Summary

- A small modification of a coupler box of the PEP-II RF cavities will considerably improve the RF performance of the Super-B.
- RF and bunch by bunch feed-back may allow to go to higher currents adding more cavities.
- HOM studies are continued.