Storage Ring RF: Superconducting or Room Temperature

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Accelerator Science Advisory Committee Meeting

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NSLS-II RF VOLTAGE, POWER REQUIREMENTS

	Baseline Capability with 2 RF Cavity Systems Required Voltage 3.3 MV		Fully Built-out Capability with 4 RF Cavity Systems Required Voltage 5 MV	
	#	P(kW)	#	P(kW)
Dipole	60	144	60	144
Damping wiggler	21 m	259	56m	517
Cryogenic-PMU	3	76	6	127
EPU	2	33	4	66
Additional devices	~7	120	~10	200
TOTAL		529		1003
Available RF Power		540		1080

Normal conducting vs. SCRF for NSLS-II

Ground Rules:

Systems will be compared at the fully built-up requirements of 5MV, 1000kW beam power.

Both NC and SCRF systems will include a passive, SCRF harmonic cavity for bunch lengthening.

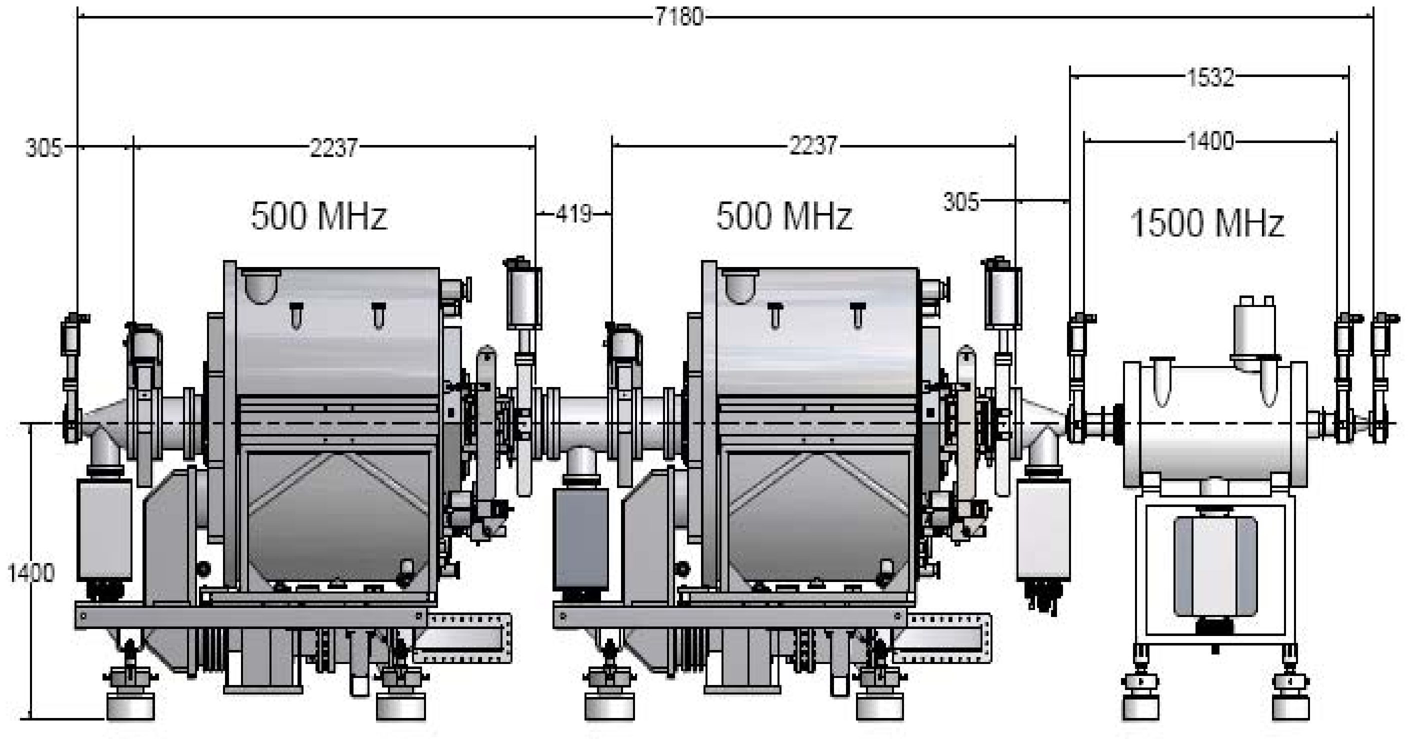
Four approaches were studied: CESR-B, KEK-B, PEP-II and BESSY-II cavities.

The two systems with demonstrated experience in Light Sources (CESR-B and PEP-II) will be compared head to head for the full-up ring configuration.

(Photon Factory cavities are similar in performance to BESSY, used in ASP, but have not yet received Toshiba quote)

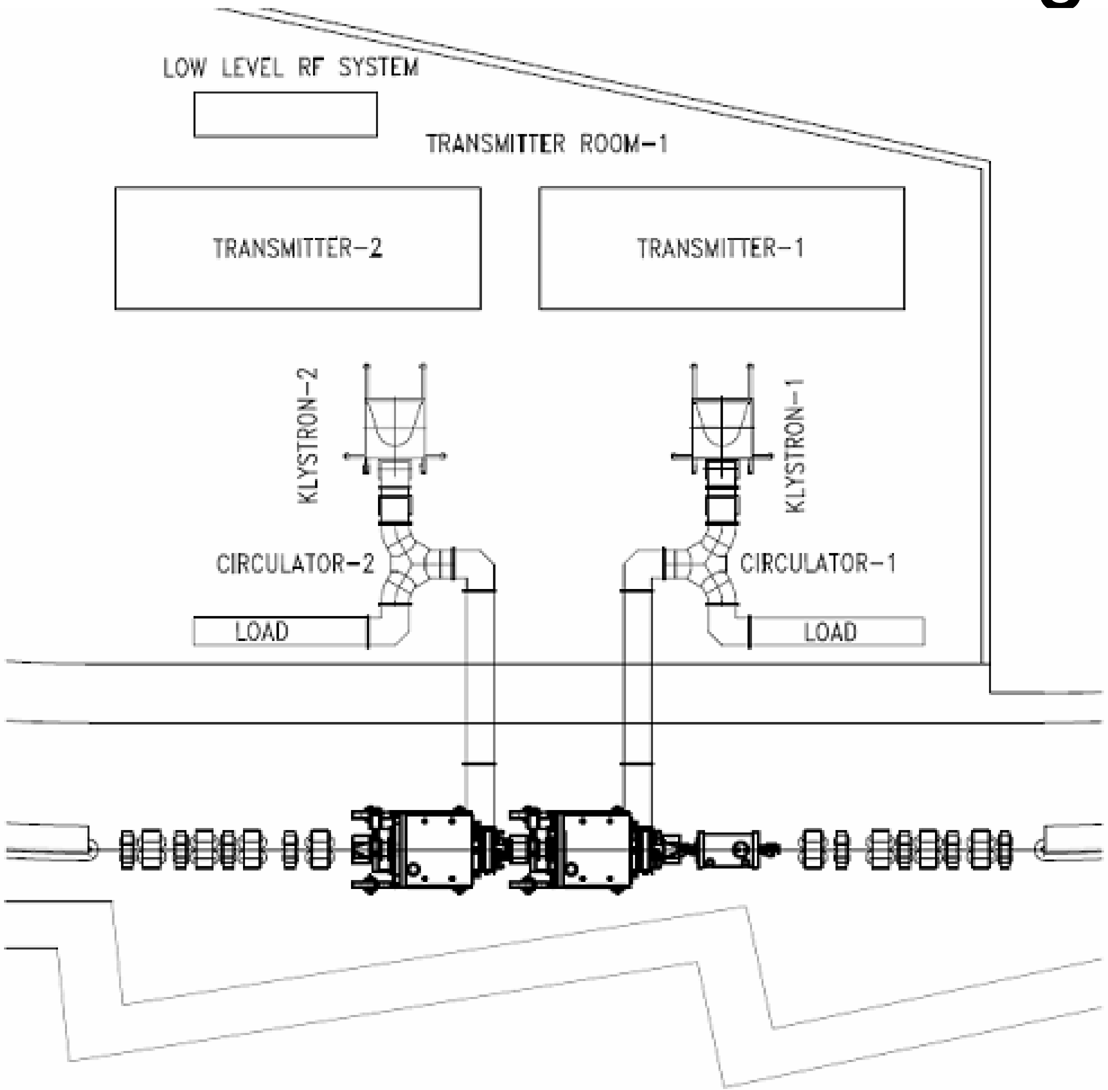
We are confident that both approaches will work, it is a question of technical performance, cost and risk

CESR-B Cavity Layout



Two fundamental plus one harmonic cavities fit in the available 7.2m of long straight

NSLS-II RF Straight layout

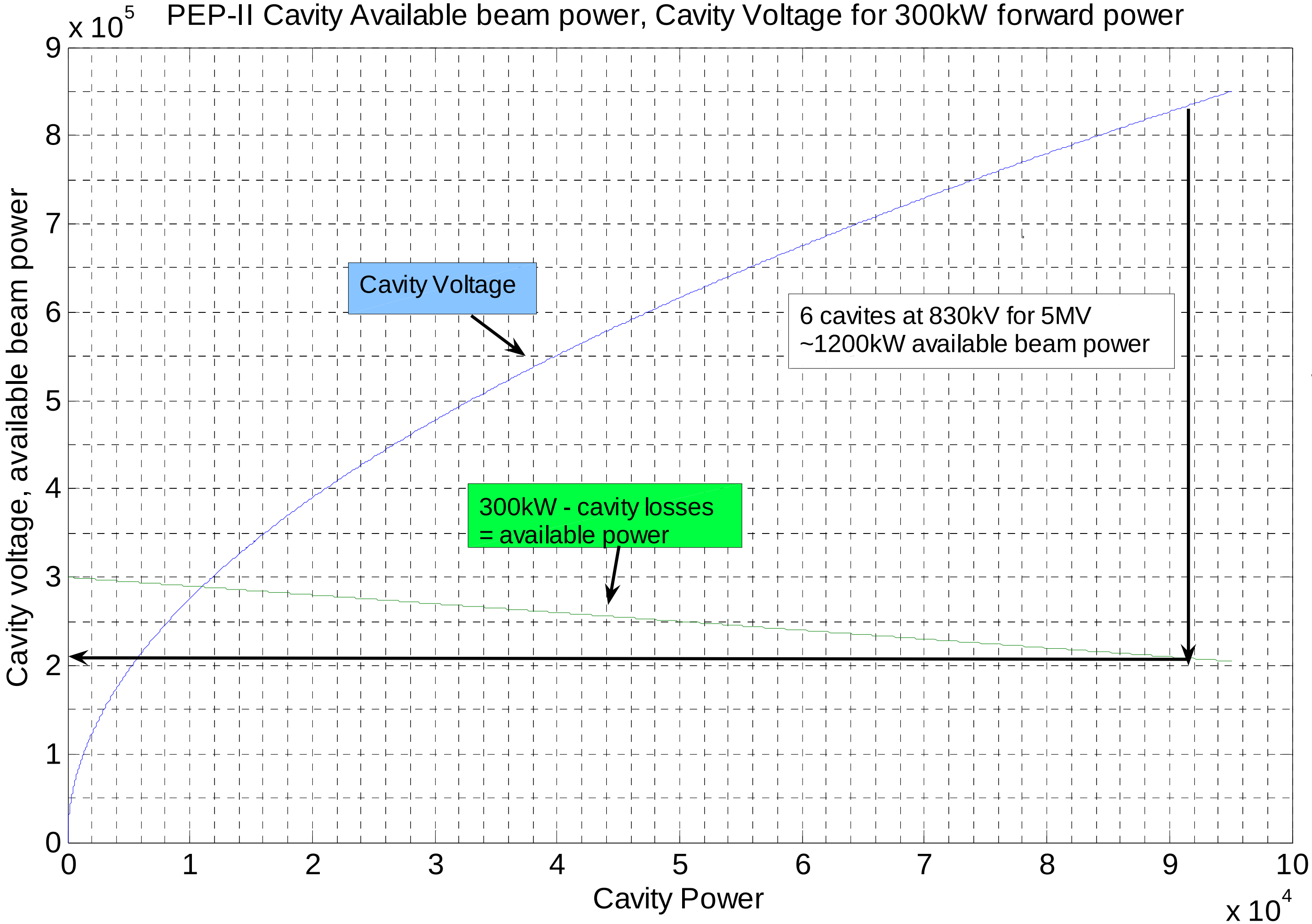


Two 500 MHz cavities
+ one 1500 MHz passive harmonic cavity fit in one 7.2m straight: meets initial power requirements

Second straight reserved for third , possible fourth 500 MHz and
second 1500MHz cavities as additional user insertion devices increase RF power requirement

Klystrons located in adjacent RF building to minimize loop delays in feedback systems

PEP-II Cavity Available Voltage/Power



Freq. = 476MHz→500

Qo = 33000

R_shunt=3.8MΩ

Max wall power=100kW

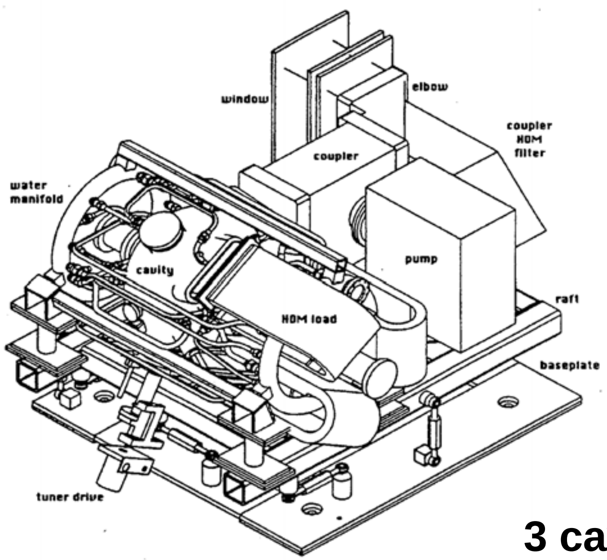
window power=500kW

6 cavities required

PEP-II Cavity Cost

The cost to produce the PEP-II cavity for SPEAR 3 was as follows[2]:

$360k for cavities, produced to SLAC drawings by ACCEL



+$30k for tuner

+$30k for ceramic power window

+$120k for power coupling box

+$100k for three HOM waveguide+loads

Total ~$660k

Length = 1.6 meters, 9.6m for 6 cavities

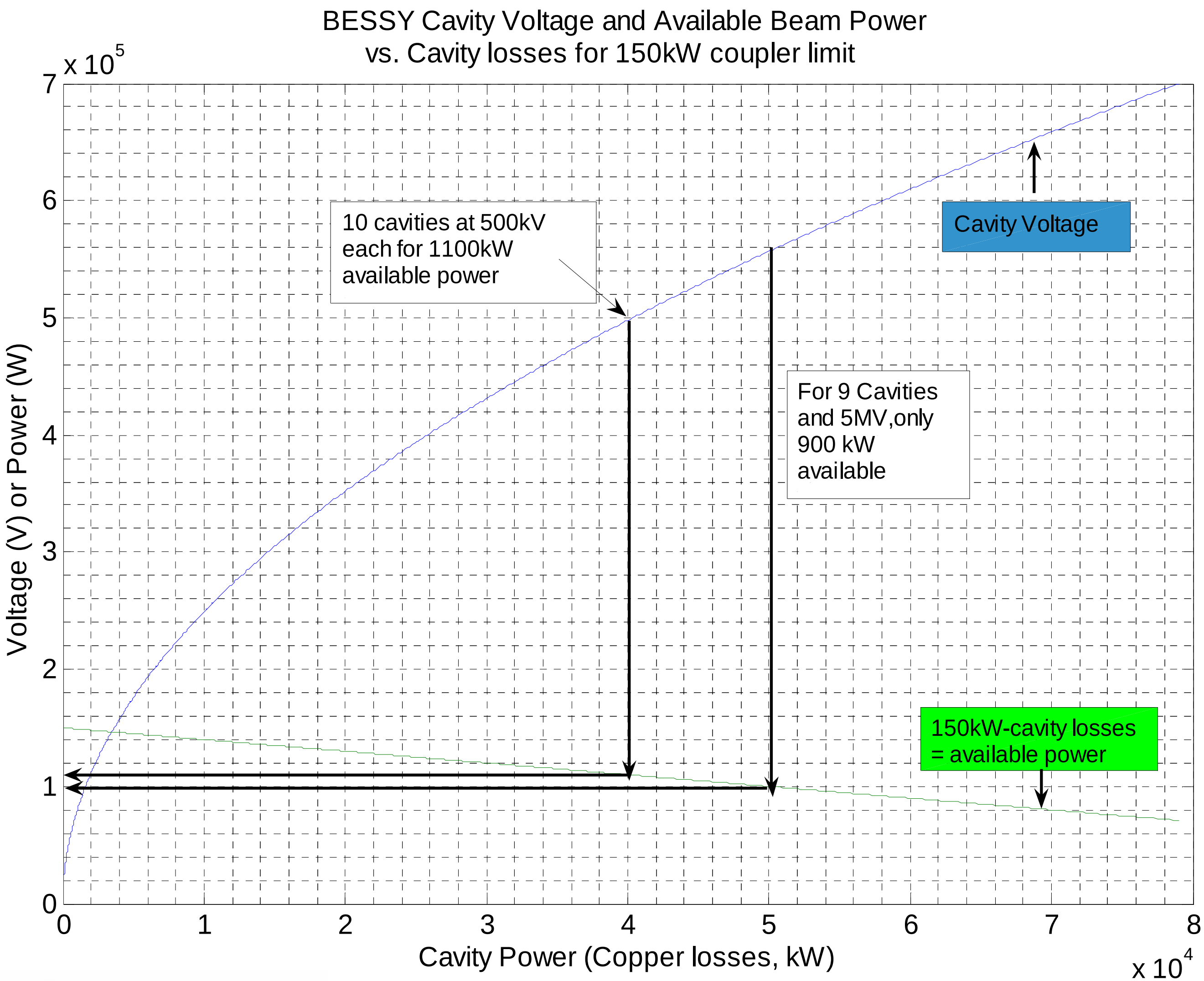
does not fit in single straight

3 cavities (4.8m) plus harmonic requires 6.3m

Compared to 7.2m for 2 CESR-B + harmonic for same performance

The tuner, window, power coupling box and HOM waveguides are challenging to build and were manufactured in the SLAC shops. There is some cost risk associated with these numbers, since the cavities were produced some 4 (?) years ago and copper costs have sky-rocketed. Much of the fabrication had to be done within the SLAC shops due to difficult brazing operations which could not be performed in industry.

BESSY “Willy Wien” Cavity



Freq. = 500MHz

Qo = 26700

R_shunt = 3.1MΩ

Max wall power= 100kW

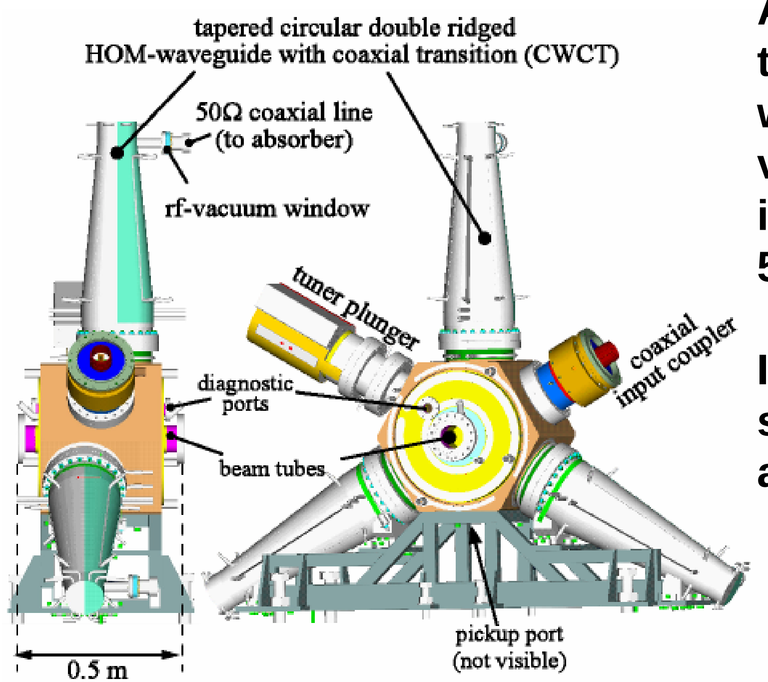
Max coupler power 150kW

10 cavities required

BESSY "Willy Wien" Cavity

A budgetary cost estimate for the BESSY-II cavity has been provided by ACCEL [4] based on 7 complete cavities for the ALBA project of $390k per cavity.

The power coupler limit of 150kW per cavity lends itself to using the same 300kW klystron amplifier baselined in the NSLS-II CDR to power 2 BESSY-II cavities using a waveguide hybrid splitter on the klystron/circulator output



Although the flange to flange length is only 0.5m, this does not include vacuum pumping, which increase the length to ~0.8 m. When you include valves, small tapers and bellows we cannot fit 10 into a 7.2m straight, so a second straight is necessary. 5 BESSY cavities (4m) plus harmonic (1.5) = 5.5m

In principle could put 7 cavities + harmonic in one straight and 3 cavities (2.4m) plus harmonic = 3.8m and have ~3+ meters free for other uses

CESR-B vs. PEP-II Systems Cost comparison

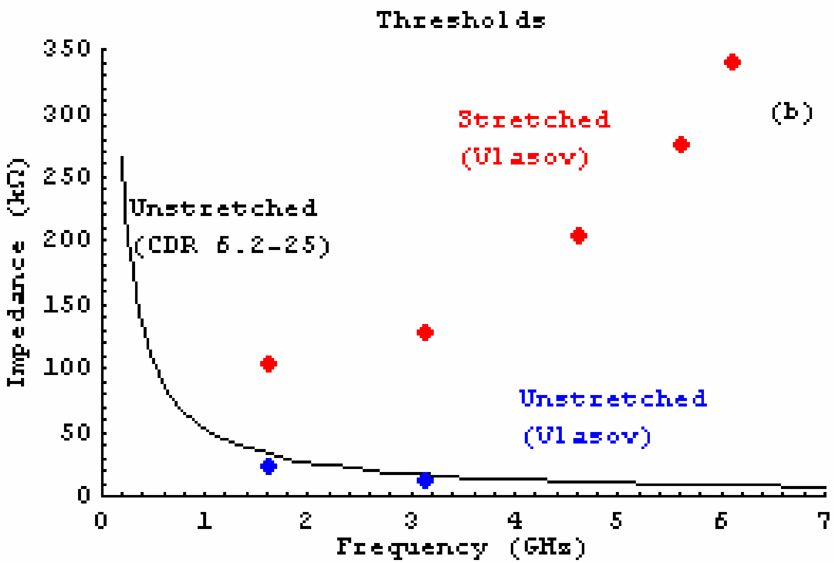
	PEP-II	CESR-B
RF Transmitters	$9.45M (6)	$6.3M (4)
RF Cavities	$3.96M (6)	$7.28M (4)
Cryo-plant cost*	~$2M(150W@4.5k)	$5.3M (700W@4.5k)
Water System**	1626kW rf + 78kW cryo	693kW rf + 364kW cryo
Landau Cavity	$1M	$1M
Longitudinal Damper	$0.5M	N/A
Subtotal Capital cost	$16.91M	$19.88M
RF AC power	$1.793M/year	$1.159M/year
Cryo-plant AC power*	$39k/year	$150k/year
Water plant AC power	$199k/year	$124k/year
RF klystron tubes	$225k/year	$150k/year
Cryogenic gases*	$5k/year	$15k/year
Subtotal Operating	$2.261M/year	$1.618M/year
Total capital +30 year ops	$84.74M	$68.42M
* Includes Harmonic cavity systems ** Cost estimate in progress, advantage SCRF		

Longitudinal Coupled Bunch Instabilities

Longitudinal coupled bunch growth rates for single RF system (unstretched)

Note: damping rate for bare lattice =27ms With 8 Damping Wigglers= 6ms	Growth rate for 500mA
CESR-B (4cavities) bare lattice With 8 Damping wigglers	99ms 121ms
PEP-II (6 cavities) bare lattice With 8 Damping wigglers	13.5ms 16ms
BESSY-II (10 cavities) bare lattice With 8 Damping wigglers	3.4ms 4.6ms

Impedance limits calculated with self-consistent fields using Vlasov equation for stretched bunches

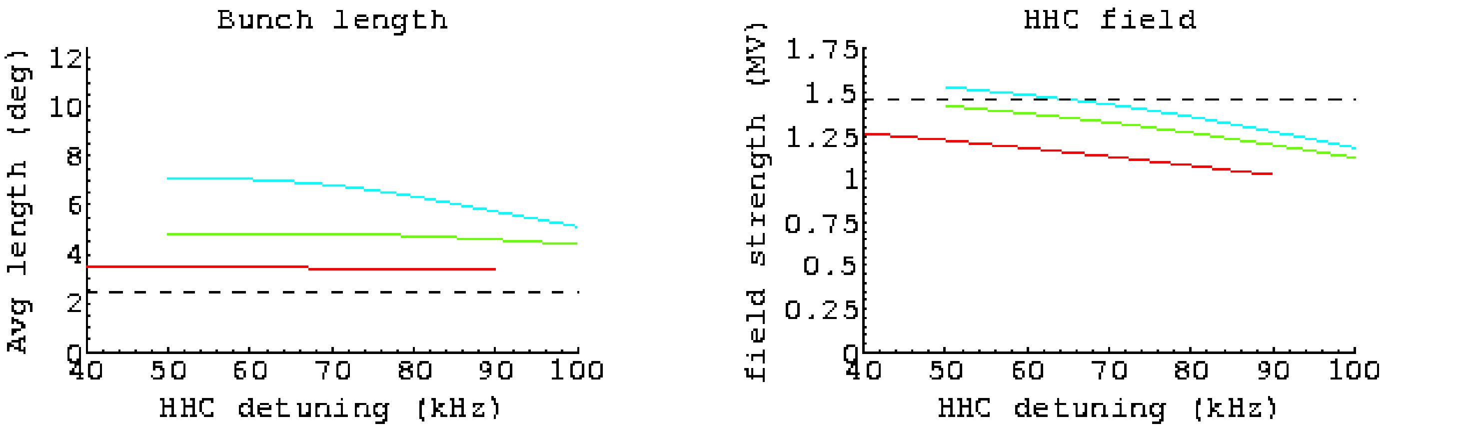


N. Towne

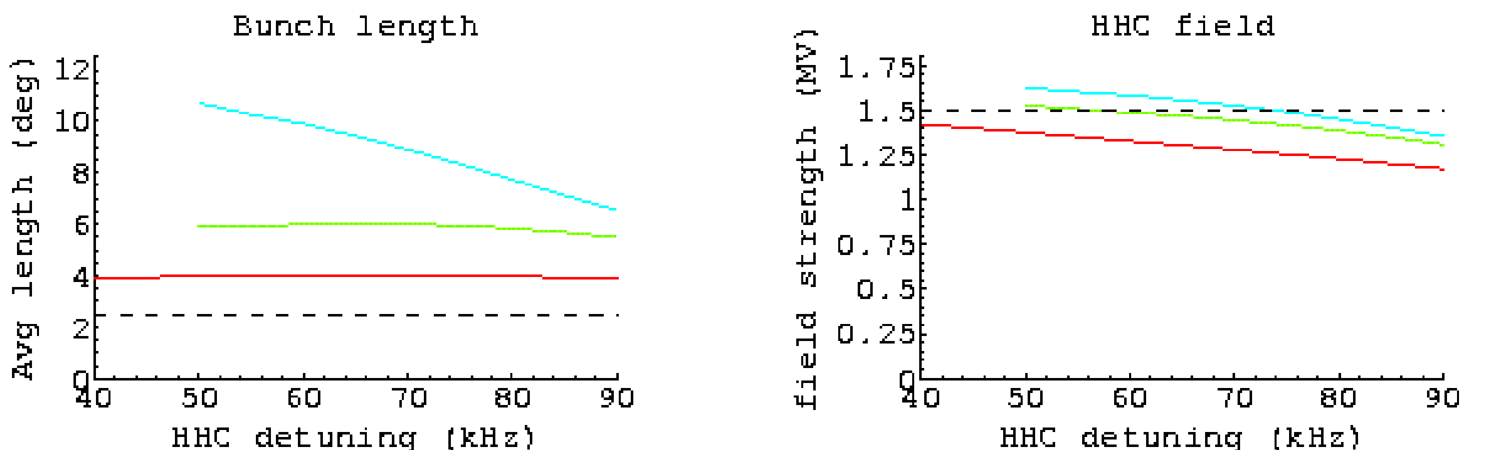
Initial calculations for CBI growth rates for unstretched bunches show damped behavior for both PEP-II and CESR-B cavities. Shortened bunches, if desired, will likely be unstable for NC cavities and possibly SCRF as well. Work continues.

Stretched Bunch length dependence on R/Q

N. Towne



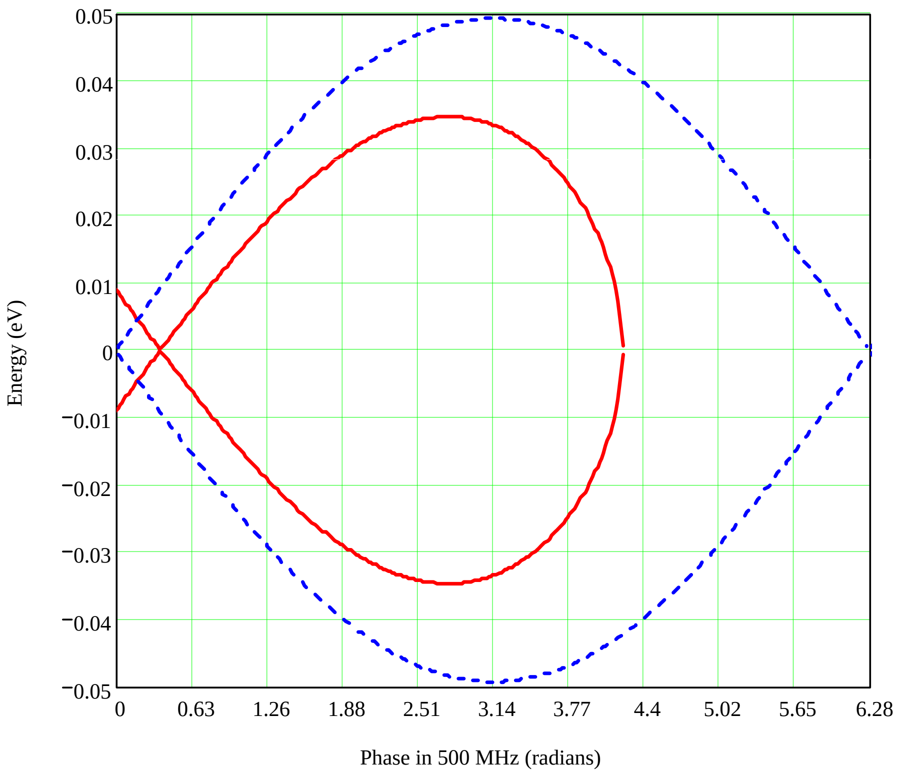
NC bunch lengths (rms) and harmonic cavity (HHC) fields as a function of detuning for one ion gap (red) two gaps (green) and four gaps (blue). Dotted line is unstretched bunch length or optimal HHC field.



SC bunch lengths (rms) and harmonic cavity (HHC) fields as a function of detuning for one ion gap (red) two gaps (green) and four gaps (blue). Dotted line is unstretched bunch length or optimal HHC field.

SCRF has the advantage that voltage is “free”

Plot of 500 MHz stationary bucket and accelerating (radiation losses) buckets E=3 GeV, Loss per turn of 2MeV, RF Cavity Voltage 5.6MV for 3.5% momentum aperture



What if we achieve a 3.5% momentum aperture? Need 5.6MV, need additional   PEP-II cavity
4% requires 6.5MV
Two additional PEP-II cavities !

Or, turn up gradient in 4 CESR-B to 1.65MV each: their limit is ~ 2.4MV!

Summary

- Both systems will work.
- Difference in direct cost in construction ~$3M higher for SCRF
- Difference in total cost over 30 year life ~$16M higher for NCRF
- If the KEK cavity proves acceptable, the direct construction costs are $290k higher for the PEP-II system.
- The PEP-II system has a higher margin in beam power (would have to add installed RF power to take full advantage)
- The CESR-B system has a higher margin in voltage (comes free up to ~factor of 2 higher voltage)

Summary continued

- The lower impedances of the SCRF cavities are attractive for collective effects. Stability margins are increased for CB instabilities. The effects of the ion-gap transients on bunch phase in the presence of the bunch lengthening harmonic cavity are diminished. Lower overall contribution to ring broadband impedance.
- Construction technical, cost and schedule risks are lower for SCRF systems. Available from two sources as completely turn key systems. ACCEL CESR-B system includes electronic racks with tuner drives, Siemens PLC interlocks, etc.
- Larger numbers of systems in the field, with operating experience in light sources.
- For PEP-II cavities BNL would be “prime contractor” with cavity body subcontracted to ACCEL, tuner, HOM, power coupler and window parts machined locally and critical braze and soldering subcontracted to SLAC. Frequency must be changed to 500MHz, this is not considered to be a technical risk.

Summary continued

- Risk of catastrophic vacuum failure in beam-vacuum could lead to significant down-time for SCRF systems. Mitigated by the addition of fast-acting valves bracketing the RF straights.
- CESR-B and KEK-B are first generation SCRF cavities for high current rings. Significant improvements are likely to occur during the life of the machine. The infrastructure will be in place to take advantage of it.

- **The decision is to continue with SCRF CESR-B cavities as the baseline for NSLS-II**