Status of Short X-ray Pulse (SPX) Project at the Advanced Photon Source

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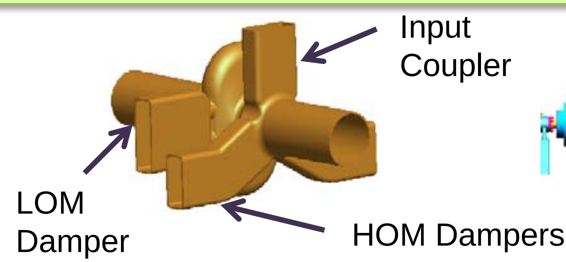
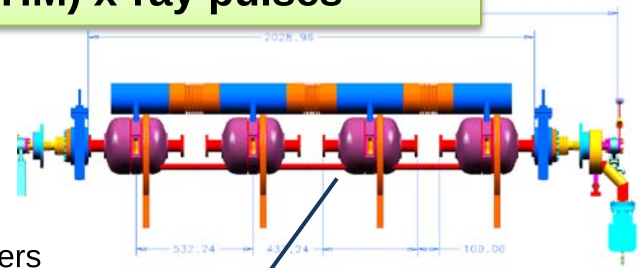
Outline

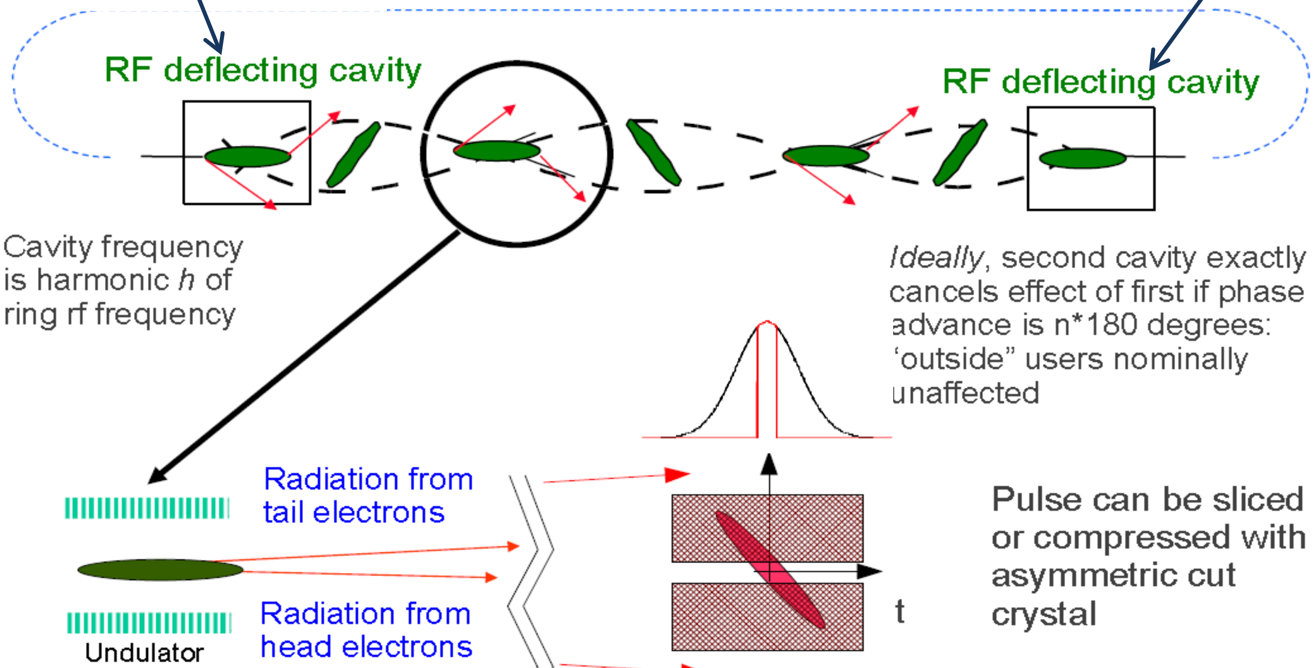
- Transverse RF Chirp Concept
- Ultrafast Science with SPX
- SPX Technical Components
- Performance Parameters
- R&D Plan
- Summary

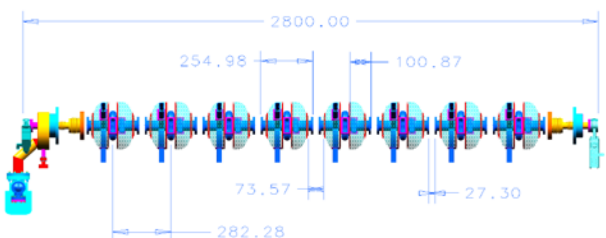
Transverse Rf Chirp Concept[1]

Baseline : 2 MV deflecting voltage, ~2ps (FWHM) x-ray pulses

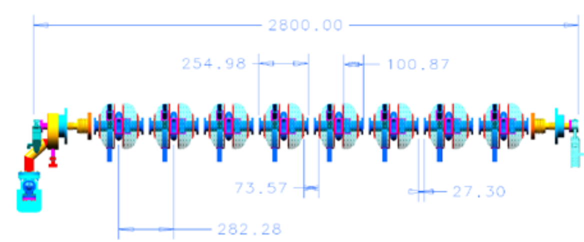








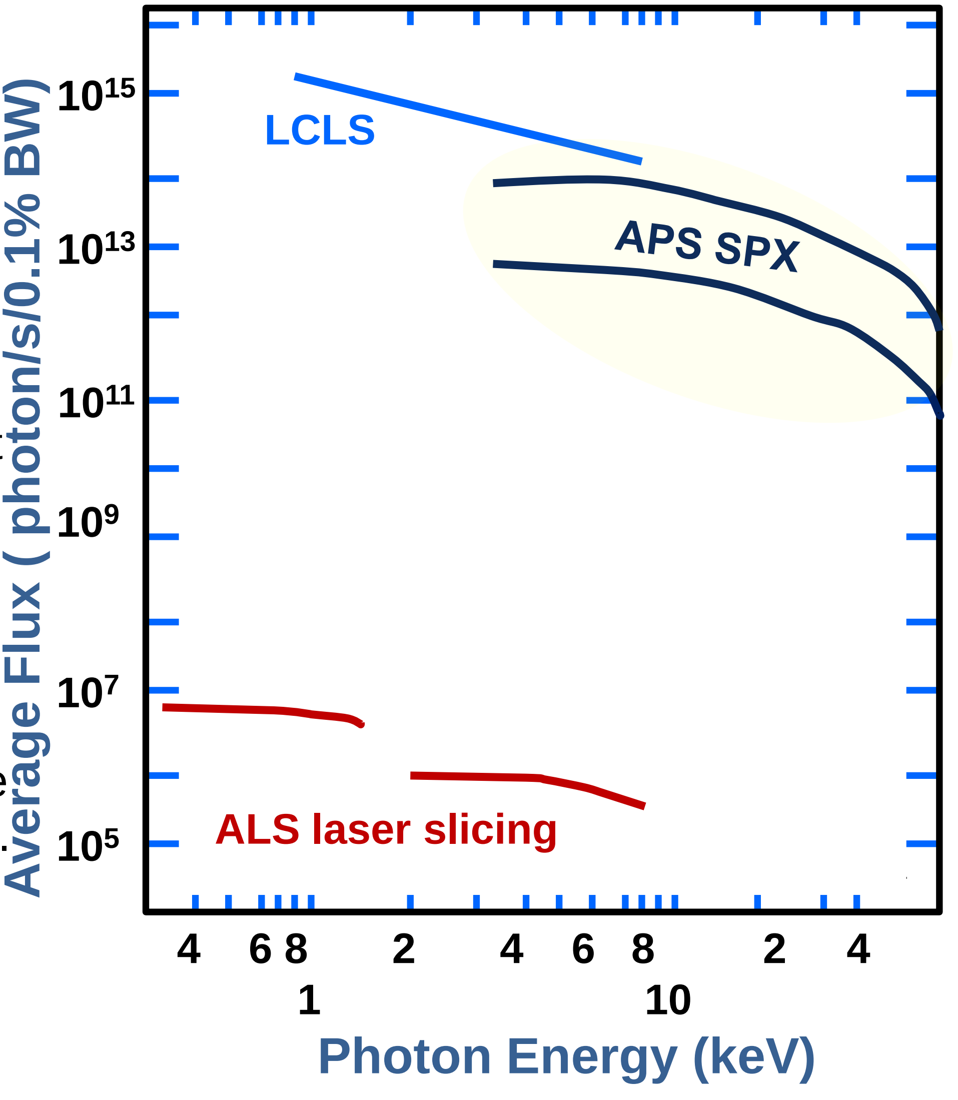
Future Goal : 4 MV deflecting voltage, ~1ps (FWHM) x-ray pulses



[1] A. Zholents et al., NIM A 425, 385 (1999).

Ultrafast Science with SPX

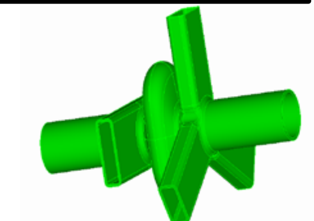
- SPX is a new generation of ultrafast x-ray source that can probe matter with nanometer and picosecond precision. World's first high average, **high repetition rate, tunable, polarized ultrafast x-ray source for a variety of applications in chemistry, materials, atomic & molecular physics and biology**
- It enables time-resolved x-ray scattering at the picosecond timescale while retaining the powerful characteristics of synchrotron radiation.
- Time-resolved diffraction. Understanding and controlling energy and heat transfer in thin films. Understanding carrier and lattice relaxation processes after photo excitation.
- **Picosecond timescale is ideal to probe dynamics in nano-scale systems which evolve at the speed of sound ~1nm/ps.**



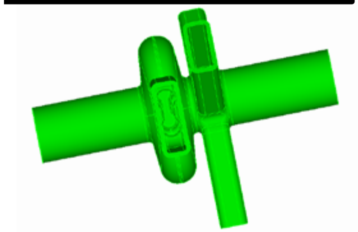
SPX Technical Components

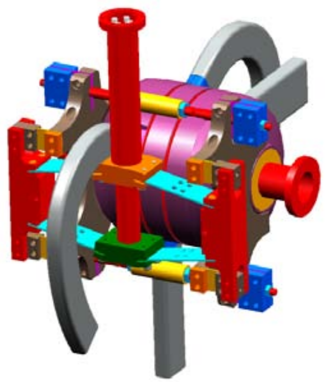
- Two cryomodules, each with 4 SC deflecting cavities equipped with:
  - Tuner with warm motor and piezo
  - LOM/HOM dampers
  - Precision cavity alignment

Mark I ("baseline")

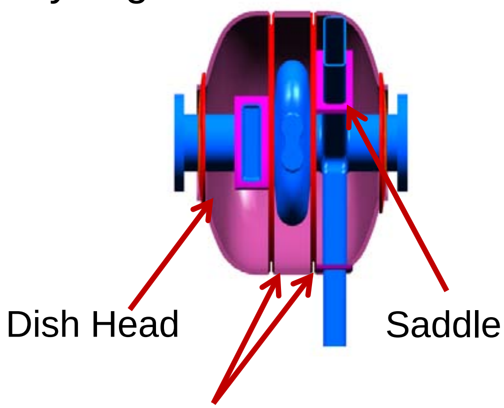


Mark II ("alternate")

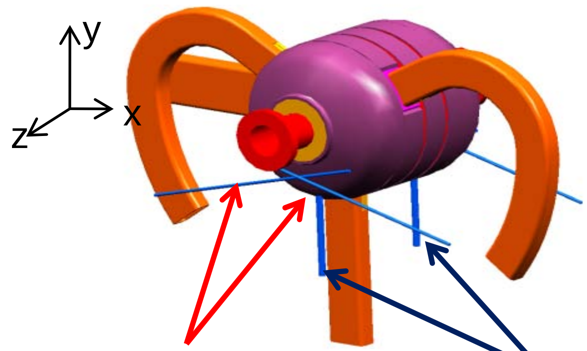




JLab scissor jack style



Precision alignment concept

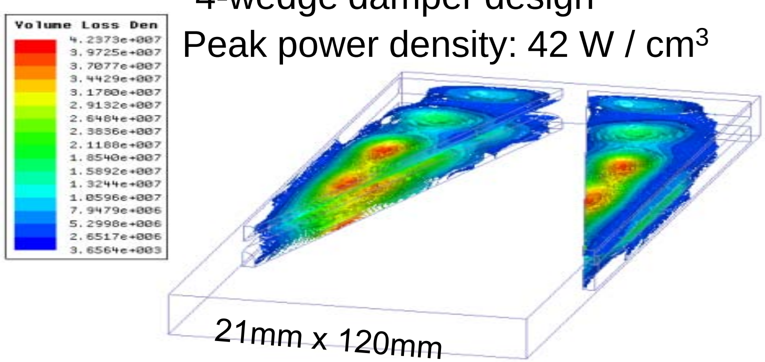


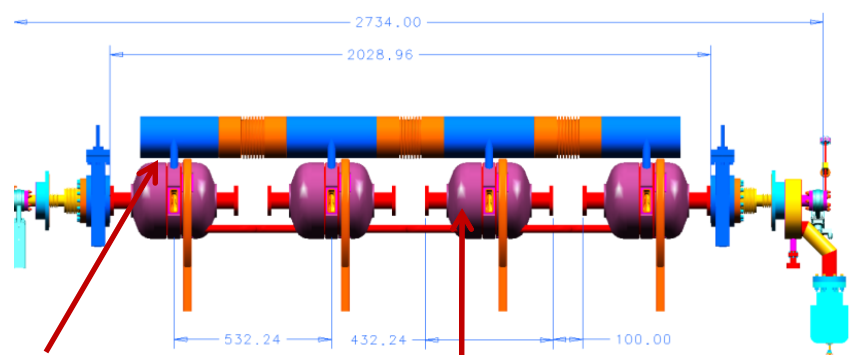
Nitronic rods for fixed "X" direction

High precision actuators each end of cavity for vertical "Y" motion (1mm)

4-wedge damper design

Peak power density: 42 W / cm^3





Helium vessel riser will be sized for heat load

Helium volume 9.4 L

SPX deflecting cavities, **THP212**, G.Waldschmidt

SPX Technical Components (2)

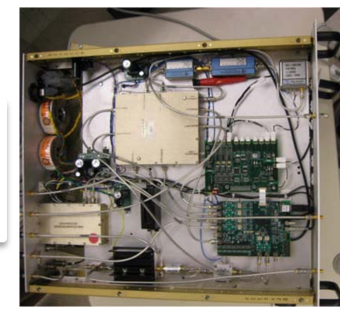
- A cryoplant for 2.0K operation

Quantity	Value
Refrigeration @ 2.0K (4 MV)	320 W with 100% capacity margin
Refrigeration @ 5-8 K for dist.& intercepts	500 W
LN2 is planned for 80K shield cooling	4 kW

Example: ELBE Cryoplant
220 W@ 1.8K + 200 W @80K

- High-power rf system based on 10-kW CW klystrons
  - One klystron per cavity
- Low-level rf system capable of delivering required amplitude and phase stability
  - Primarily regulate the amplitude and phase of the SPX deflecting cavity fields
  - Engineering and production of LLRF system for 8 cavity installation
- Diagnostics
  - Measure beam tilt inside and outside SPX zone
  - Measure beam arrival time with respect to a phase reference and provide this information to low-level rf controls.
  - Cerenkov detectors/loss monitors to protect cavities

LLRF4 based Receiver/Controller Chassis



X-ray detector is the key to Beam Arrival Time array tilt monitor
Need fast (sub-ns rise time, low-intensity dependence – Diamond a good candidate
Initial test with polycrystalline diamond detector
- rise time ~160 ps

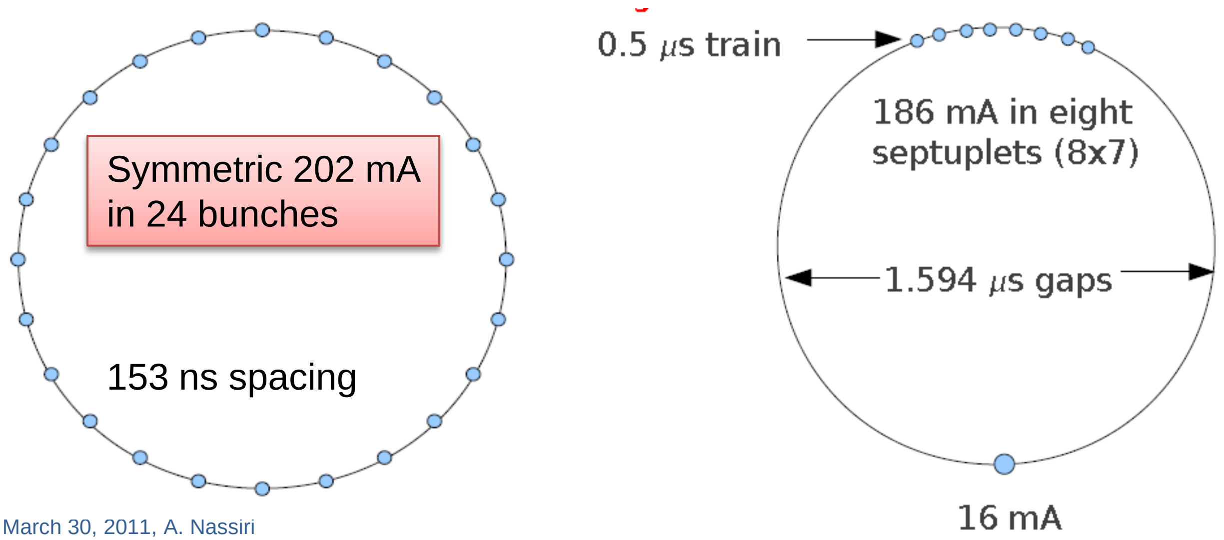
Diamond Detector

X-rays strike copper beam dump

Single-Bunch and Multi-Bunch Stability Result[1]

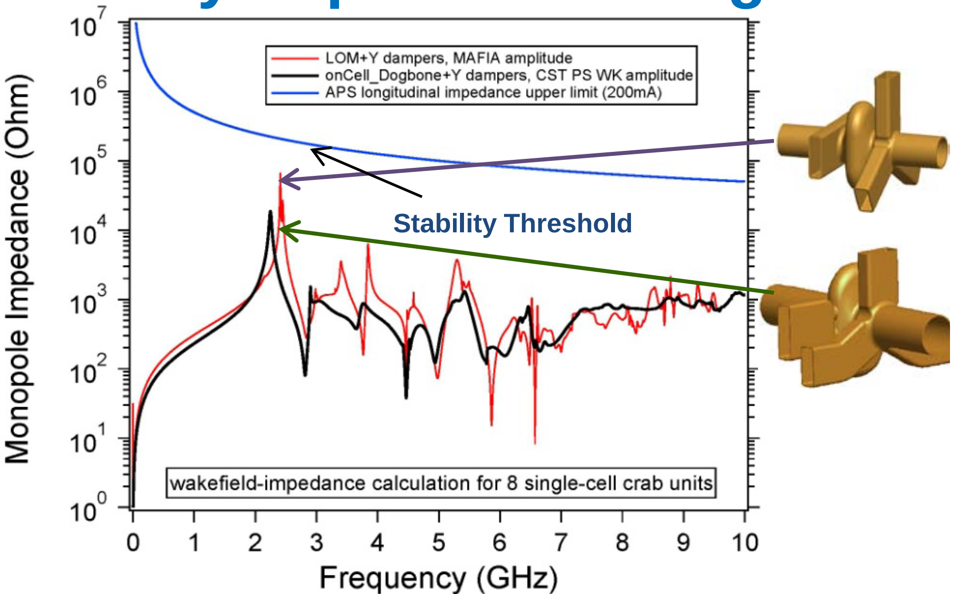
- SPX system in 24-singlets (4 mA per bunch) does not degrade the performance of single particle dynamics.
- Q's of longitudinal and transverse planes are very low (20 -800)
- Based on current operations coherent damping is applicable here
- Transverse plane would be stable in baseline number of cavities (8)
- Recent work demonstrates the possibility of "adjusting" hybrid pattern to reduce the worst-case growth rate

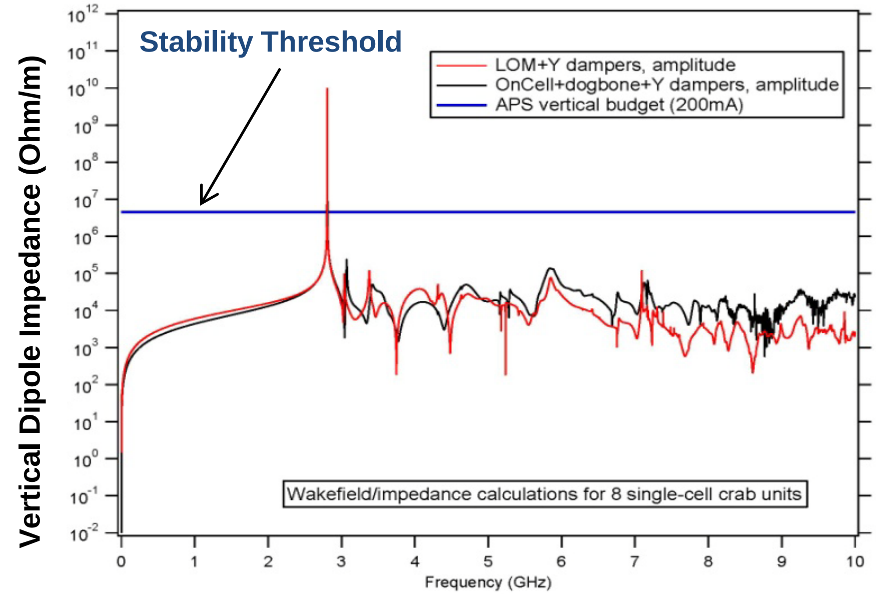
Plane	Growth Rate	Damping Rate		Comment
		Synchrotron Radiation	Coherent	
Longitudinal	30 s^{-1}	208 s^{-1}	Not applicable	Stable
Horizontal	180 s^{-1}	104 s^{-1}	>600 s^{-1}	Stable
Vertical	125 s^{-1}	104 s^{-1}	>600 s^{-1}	Stable



[1] L. Emery, Y-C. Chae

Cavity Impedance Budget





Monopole Stability Threshold:

$$R_s = \frac{V^2}{2P_l}$$

$$R_s * f_p < 0.5M\Omega - GHz$$

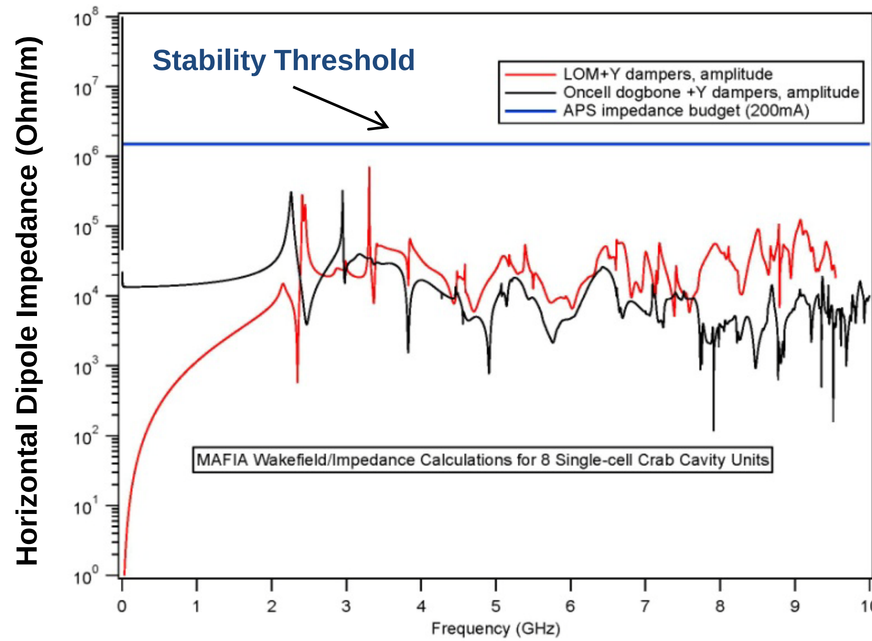
Dipole Stability Threshold:

$$R_t = \frac{V^2\big|_{r=r_0}}{2\,P_l\,k\,r_0^2}$$

$R_t < 1.5M\Omega / m$ Horizontal dipole

$R_t < 4.5M\Omega / m$ Vertical dipole

Cavity to cavity coupling will be tuned to meet stability specification for a single horizontal dipole mode.



Plots courtesy of H. Wang, JLab

Tolerances from Beam Dynamics Simulations[1]

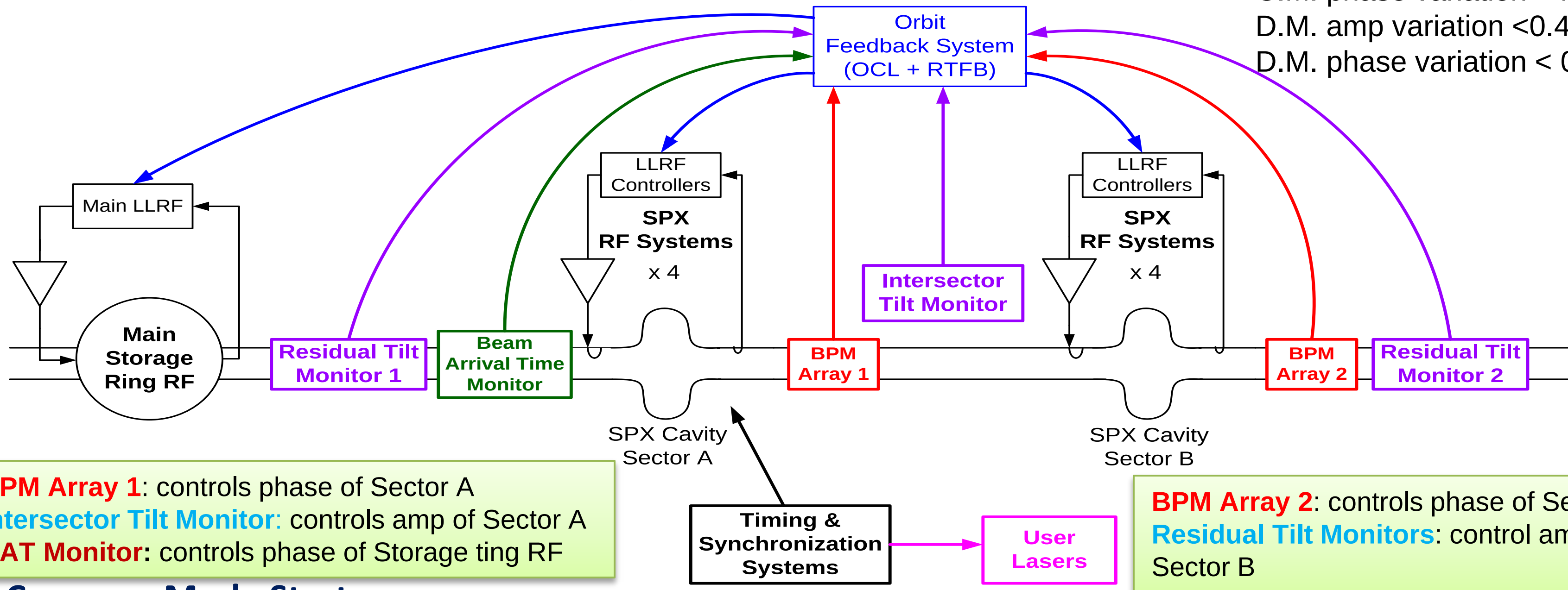
Parameter	Baseline	Future Goal
Common mode amplitude variation[1]	<1%	<1%
Common mode phase variation[2]	<4.8 deg	<4.8 deg
Voltage amplitude mismatch between cavities[3]	<0.8%	<0.4%
Voltage phase mismatch error between cavities[4]	<0.14 deg	<0.07 deg

[1] Keep intensity and pulse length variation under 1% rms.
[2] Keep intensity variation under 1% rms.
[3] Keep rms emittance variation outside SPX region under 10% of nominal 35 pm.
[4] Keep rms beam motion outside of SPX region under 10% of beam size/divergence.

[1] V. Sajaev, M. Borland, L. Emery, A. Nassiri
SPX Physics Requirements Documents

Conceptual System Design Approach

C.M. amp variation <1%
C.M. phase variation <4.8 deg
D.M. amp variation <0.4%
D.M. phase variation < 0.07 deg



BPM Array 1: controls phase of Sector A
Intersector Tilt Monitor: controls amp of Sector A
BAT Monitor: controls phase of Storage ting RF

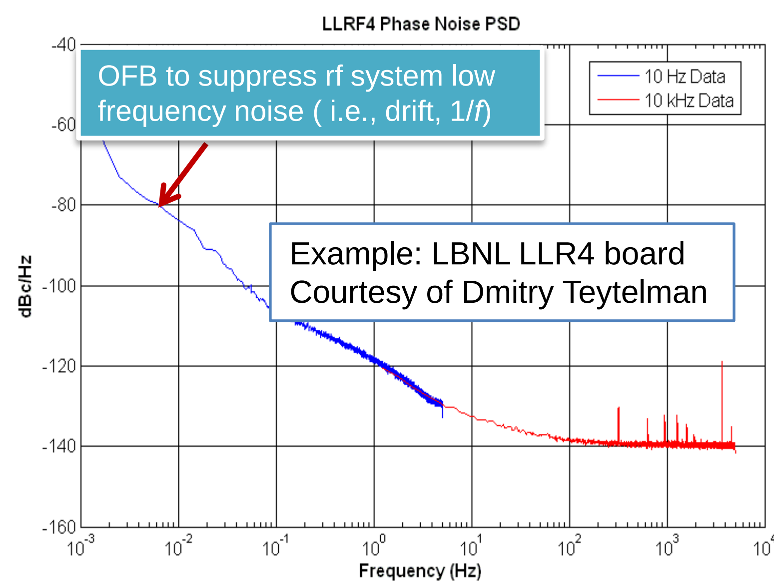
BPM Array 2: controls phase of Sector B
Residual Tilt Monitors: control amp of Sector B

Common Mode Strategy

- Main RF used to lock beam to MO via Beam Arrival Time diagnostic
- **BPM Array 1 corrects for common mode phase error < 100 Hz**
- **Deflected Tilt Monitor corrects for common mode amp error < 100 Hz**
- SPX RF system responsible for noise spectrum > 10Hz

Differential Mode Strategy

- **Orbit Feedback (BPM Array 2) controls differential phase error < 100 Hz**
- **Residual Tilt Monitors control differential amp error < 100 Hz**
- SPX RF system responsible for noise spectrum > 10Hz



Slide courtesy of T. Berenc

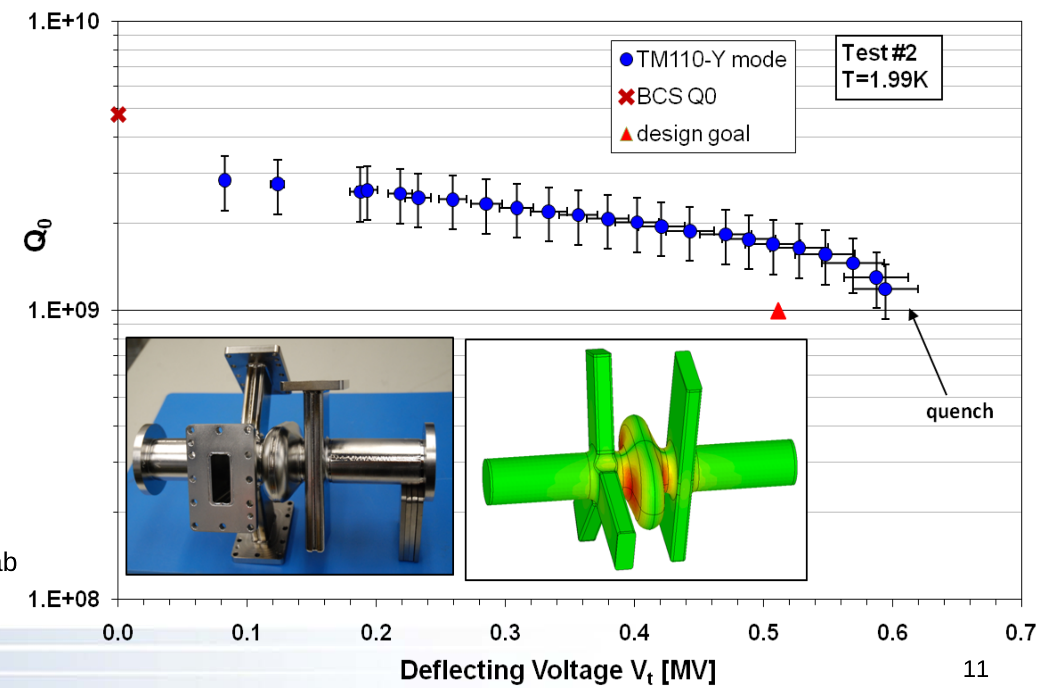
R&D Status

- Baseline cavity tests performed at JLab. It meets rf performance with 10% safety margin on deflecting voltage.

Contributed talk, **WEOBS13**, H. Wang

- Fabrication of the “alternate” cavity is underway at JLab.
- Design of a cryomodule and ancillary components including dampers, tuner, precision alignment system have started.
- Collaborative work with LBNL on the development of low-level rf controllers and precision timing and synchronization system have started.

- On-going effort on lattice development, beam dynamics, collective effects
- Installation in ring of a 2-cavity cryomodule is planned for a single sector test.
  - Address risks that cannot be addressed by off-line experiments
  - Chirp is sufficiently well-defined to allow proof-of- concept for x-ray pulse length reduction.



Plot courtesy of H. Wang, JLab

Summary

- Short x-ray pulse generation using SC rf deflecting cavities gives much higher average flux compared to other schemes:
  - Laser slicing
  - Low-α operation
  - RF phase modulation
  - Harmonic cavity
- SPX should provide ~2 ps FWHM or less x-ray pulses to
  - 3 insertion devices and 2 bending magnets beam lines
- Single-sector test should allow us to have an early look at chirped x-rays and address additional risks.
- R&D tasks are progressing well.
- Collaboration with JLab and LBNL is off to a great start.
- We are very excited and looking forward to proof-of-concept demonstration in 2013.

Acknowledgements

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SLAC: C-K. Ng, Z. Li

ANL: N. Arnold, T. Berec, B. Berg, M. Borland, B. Brajuskovic, D. Bromberek, Y-C. Chae, E. Dufresne, L. Emery, G. Decker, J. Fuerst, A. Grelick, D. Horan, B. Laird, F. Lenkszus, Y. Li, R. Lill, J. Liu, V. Sajaev, T. Smith, G. Waldschmidt, G. Wu, B. Yang, A. Zholents