NSLS-II Beam Diagnostics Overview

Om Singh
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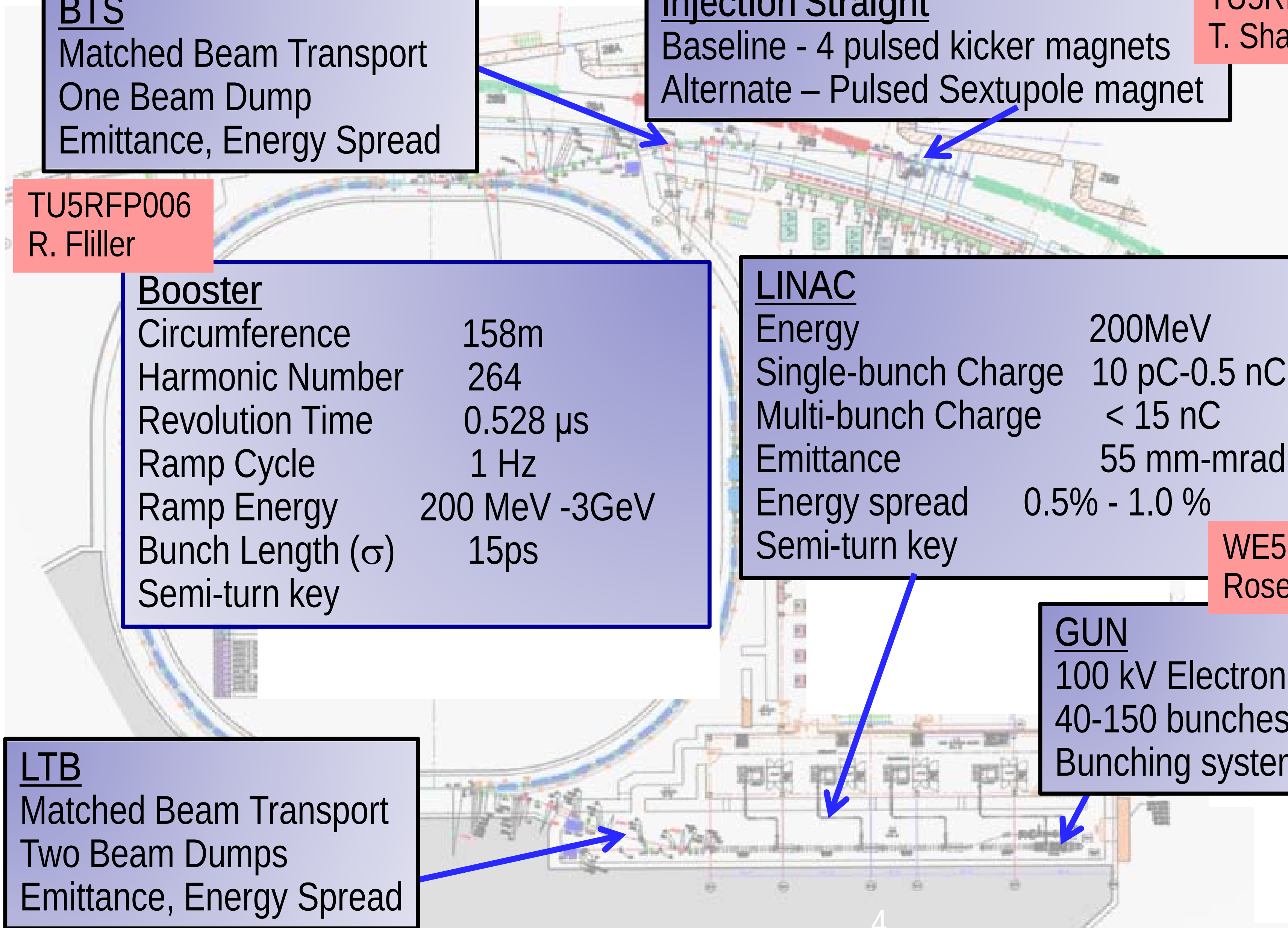
Outline

- Injector Overview
- Storage Ring Overview
- R&D and Design effort
- Fast Orbit Feedback
- Summary

NSLS-II Injector - Overview



BTS
Matched Beam Transport
One Beam Dump
Emittance, Energy Spread

Injection Straight
Baseline - 4 pulsed kicker magnets
Alternate – Pulsed Sextupole magnet

TU5RFP012
T. Shaftan

TU5RFP006
R. Flliller

Booster

Circumference	158m
Harmonic Number	264
Revolution Time	0.528 μs
Ramp Cycle	1 Hz
Ramp Energy	200 MeV -3GeV
Bunch Length (σ)	15ps
Semi-turn key	

LINAC

Energy	200MeV
Single-bunch Charge	10 pC-0.5 nC
Multi-bunch Charge	< 15 nC
Emittance	55 mm-mrad
Energy spread	0.5% - 1.0 %
Semi-turn key	

WE5PFP066
Rose & Ma

GUN
100 kV Electron Gun
40-150 bunches; 2 ns
Bunching systems

LTB
Matched Beam Transport
Two Beam Dumps
Emittance, Energy Spread

Injector Diagnostics

Monitor	Injector			
	Gun/Linac	LTB	Booster	BTS
Wall Current Monitor	5			
Fast CT		2	1	2
Integrating CT		2		2
DC CT			1	
Fluorescent Screen/ OTR	3	9	6	9
Energy Slit		1		1
Beam Dumps		2		1
RF BPM	3	6	24	7
Streak Camera			1	

Key SR Parameters

Parameter	Nominal Value
Energy	3.0 GeV
Stored Beam	500 mA; $\Delta I/I$ = 1%
RF frequency	499.68 MHz
Circumference	792 m
Revolution period, T_0	2.642 μs
Harmonic number	1320
Number of bunches filled	1056 (~80%)
Tunes - Q_x, Q_y	33.36, 16.28
Emittance Bare Lattice ε_0 (H/V)	2.0 /0.01 nm-rad
Emittance with 8-DWs ε (H/V)	0.60/0.008 nm-rad
Bunch length	15-30 ps
9.3 m & 6.6 m straight sections	15/15 (30 cells)
Synchrotron frequency, f_s	3.0-3.6 kHz

Top up > 1 minute

Bunch to bunch variation = 20%

3^{rd} Harmonic bunch length cavity

2 RF & 1 injection in 9.3 m

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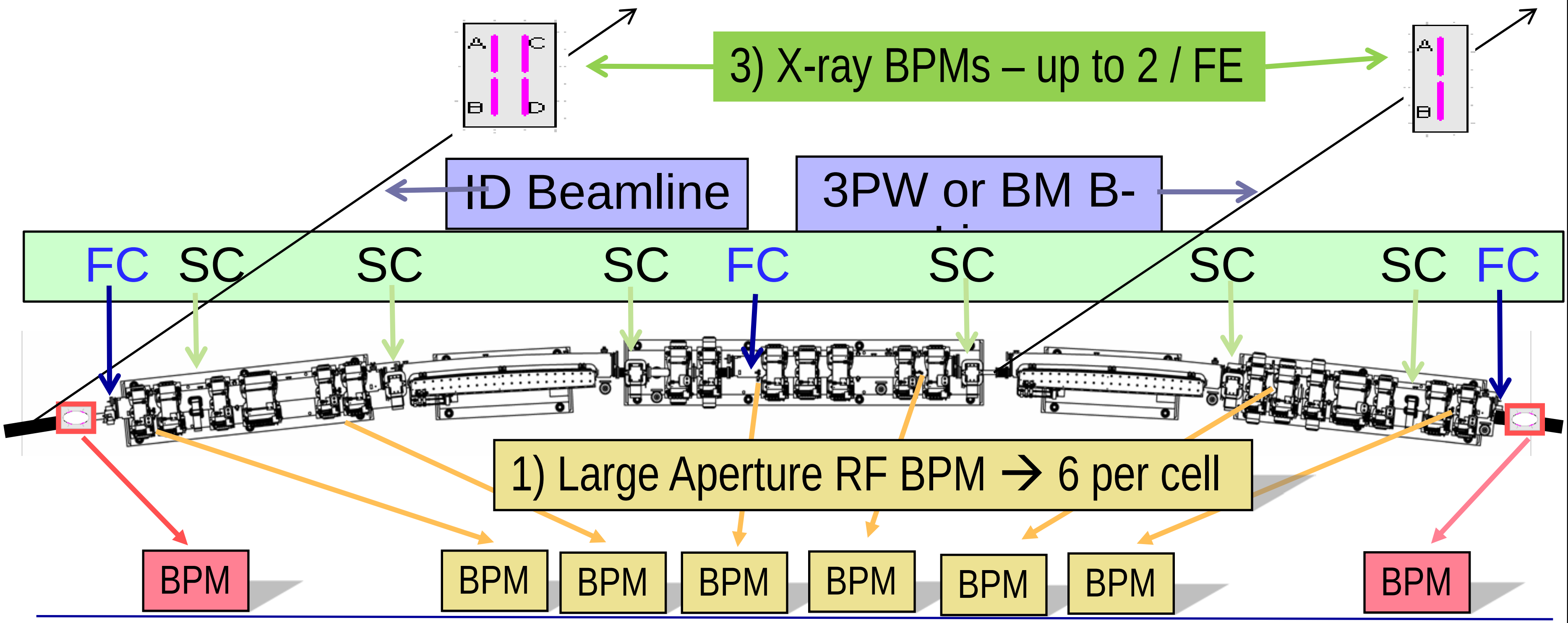
SR Diagnostics

Monitor	Qty	Comment
RF BPM – TBT & Stored Beam	180	Itech – Brilliance
ID RF BPM	2 or 3 per ID	3 in canted BL
Photon BPMs (BM/ ID)	2 per BL	Workshop at NSLS-II
DC Current Transformer	1	Test @ SPEAR3
Tune Monitor	1	
Fill Pattern Monitor	1	WCM or Stripline
Fluorescent Screen	1 (3 position)	Injection straight
X-ray Radiation BL (BM/ 3PW)	2	TH5RFP015 -Pinayev
Visible Radiation BL (BM)	1	
Transverse Feedback Systems	1 H & 1 V	Inst. Tech; Dimtel Inc.
Beam Loss Monitors	60	
Beam Scrapers (X & Y)	2 sets	
Bunch cleaner/bunch purity	1	Not in baseline

SR Cell BPM/Corrector Layout



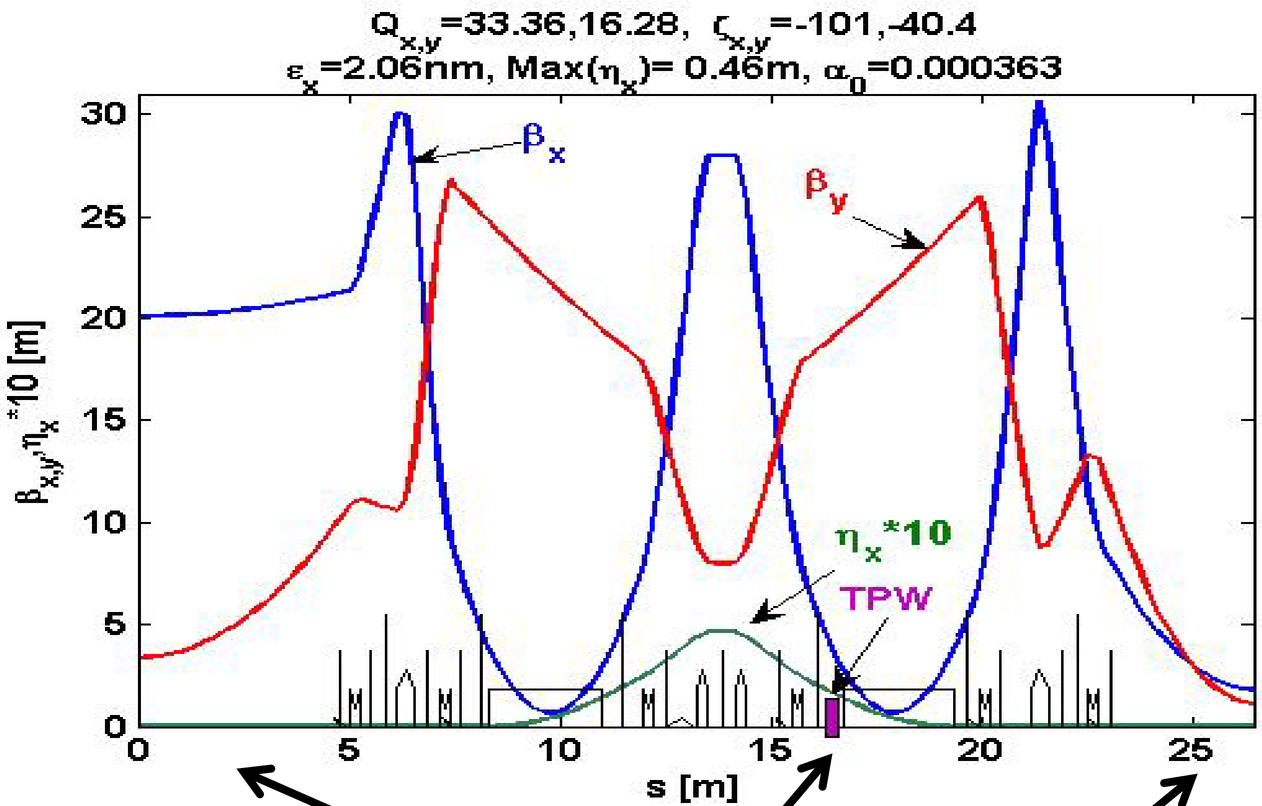
2) Small Aperture RF BPMs → 2 or 3 per Cell; Button Assembly on a Stand or ID Chamber

4) **Six slow correctors (SC)– 0.8 mrad;**

Three Fast correctors (FC)– 0.02 mrad

SR Lattice & Electron Beam sizes/divergences

Lattice Functions



Electron Beam Sizes & Divergences

Types of source	9.3m ID	1-T 3-Pole wiggler	Bend magnet	6.6m ID
σ_x (μm)	108	175	44.2	29.6
$\sigma_{x'}$ (μrad)	4.6	14	63.1	16.9
σ_y (μm)	4.8	12.4	15.7	3.1
$\sigma_{y'}$ (μrad)	1.7	0.62	0.63	2.6

Most challenging Beam stability Requirements = ~ 0.31 μm

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RF BPM – R&D and Design

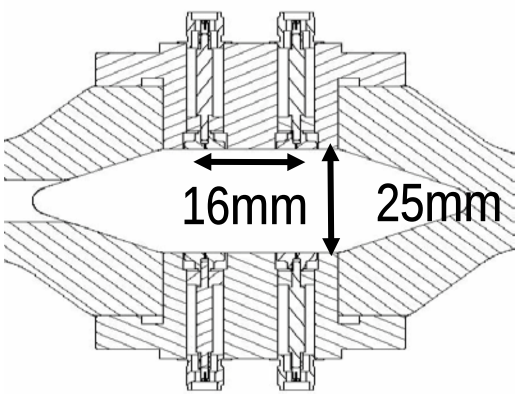
Key areas in RFBPM performance

1. RF Button Geometry
2. RF Button Mechanical Mounting Stability
3. Vacuum Chamber Microwave Modes
4. RF BPM Electronics

1. RF BPM Button-Sensitivity Optimization

- Large Aperture (LA) Button Optimized – 32 mm to 16 mm hor sep
- Resulted in two-in-one LA Button Design – 7mm diameter button
- Thickness = 2mm; Housing spacing = 0.25mm

- Small Aperture Button (SA) (APS Design) are being considered – 4 mm dia
- SA Button hor sep = 9.6 mm; Rotated installation achieves effective 4mm hor sep



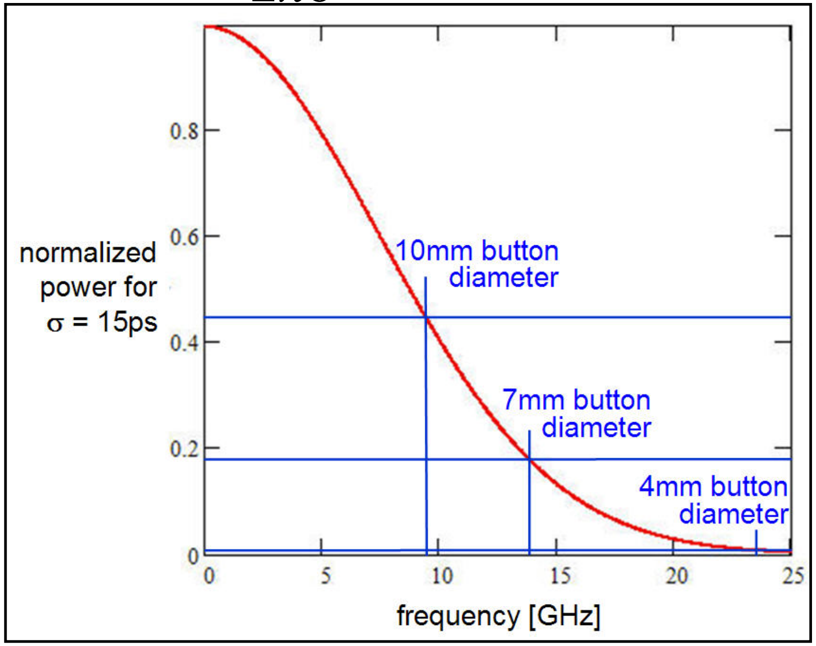
Multipole Chamber

RF Button	Large Aperture	Small Aperture
Button diameter (mm)	7	4
x- Separation (mm)	16	4-9.6
y- Separation (mm)	25	10
x-Sensitivity (/mm)	0.1	0.15-0.27
y-Sensitivity (/mm)	0.1	0.26-0.15

RF BPM Button – Heating Optimization

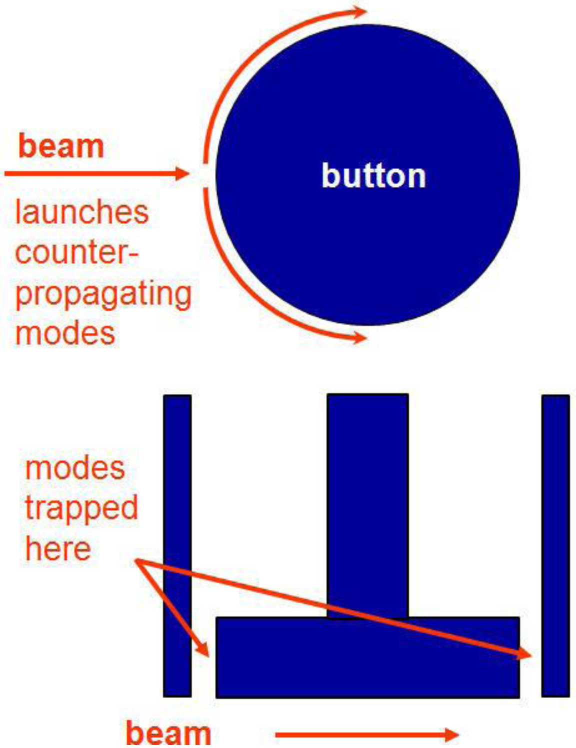
Bunch Gaussian BW (σ=15psec)

$$f_{beam} = \frac{1}{2\pi\sigma} = 10.6\,GHz$$



Freq of trapped mode (r=3.5mm)

$$f_{button} = \frac{c}{2\pi r} = 13.65\,GHz$$



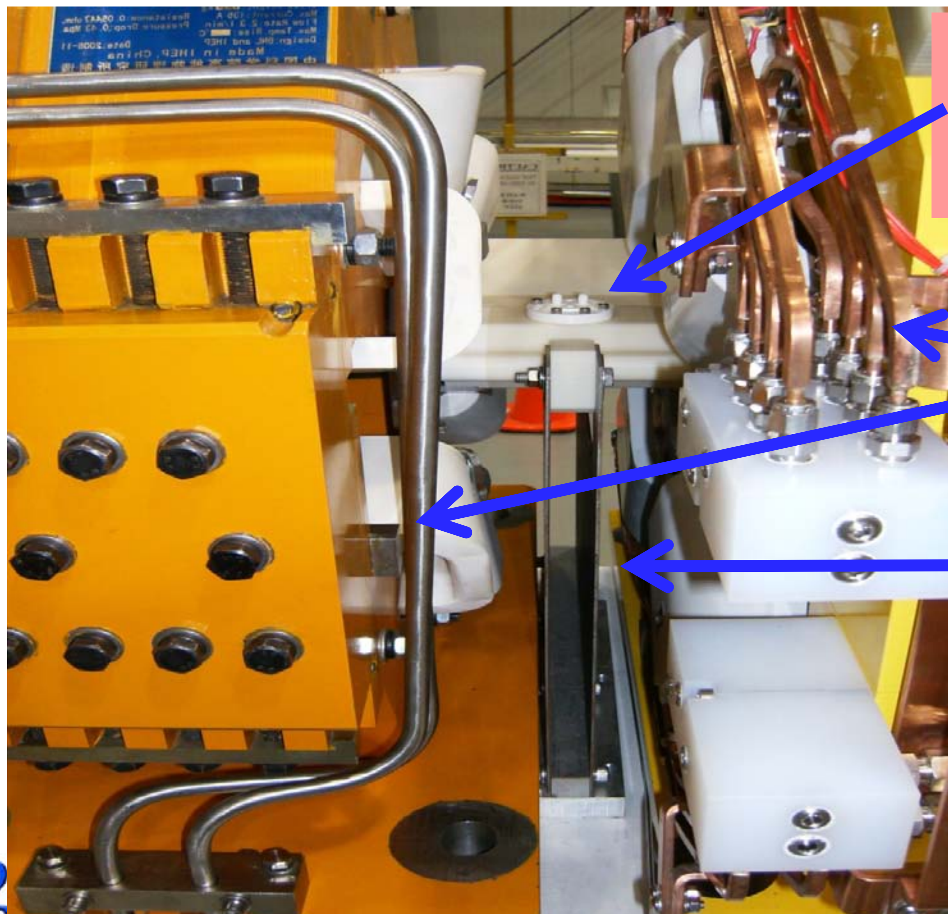
Relative voltage induced $V \propto \frac{Q}{a} e^{-\left(\frac{f_{button}^2}{2f_{beam}^2}\right)}$

TU5RFP014 - I. Pinayev, A. Blednykh

TH5PFP080; TH5PFP081; TH5RFP011 - P. Cameron

2. Large Aperture RF BPM Button Mounting

- A invar plate is fastened to vacuum chamber (LA buttons)
- Restricts x/y thermal motion < 500nm & 200nm respectively
- Provides flexibility in z direction



Small Aperture RF BPM Button Mounting

- High Stability Stand - An array of four 50mm dia invar rods bolted to base
- FEA Transient Thermal Analysis – Temp → 25±0.1 ºC; Air (1 hr); Base (24hr)
- Results in ± 60 nm deformation combined (Spec ± 100 nm)

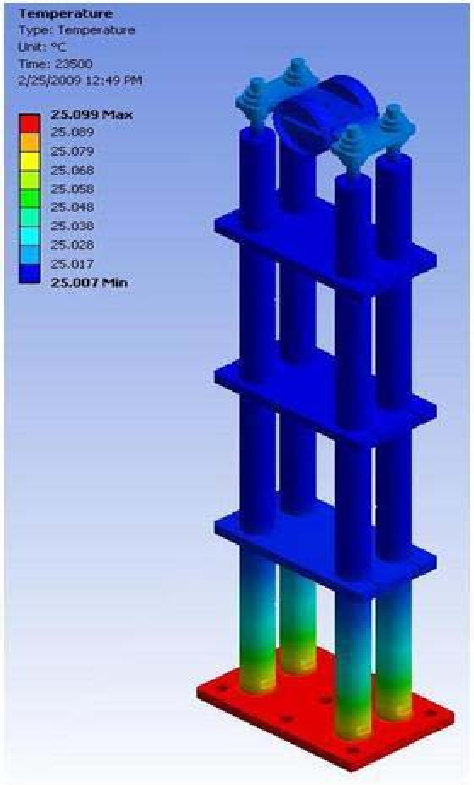
FEA Transient Thermal Simulation Results

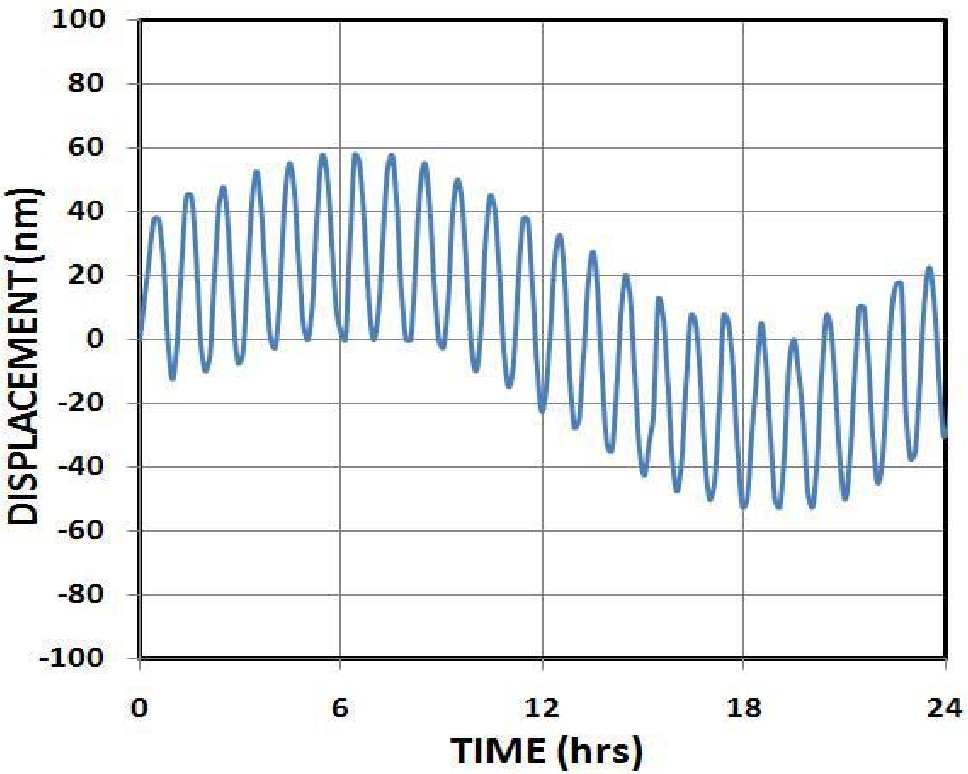
Temp.

Dist.

@ t

= 6.5hrs





3. Chamber Microwave Modes

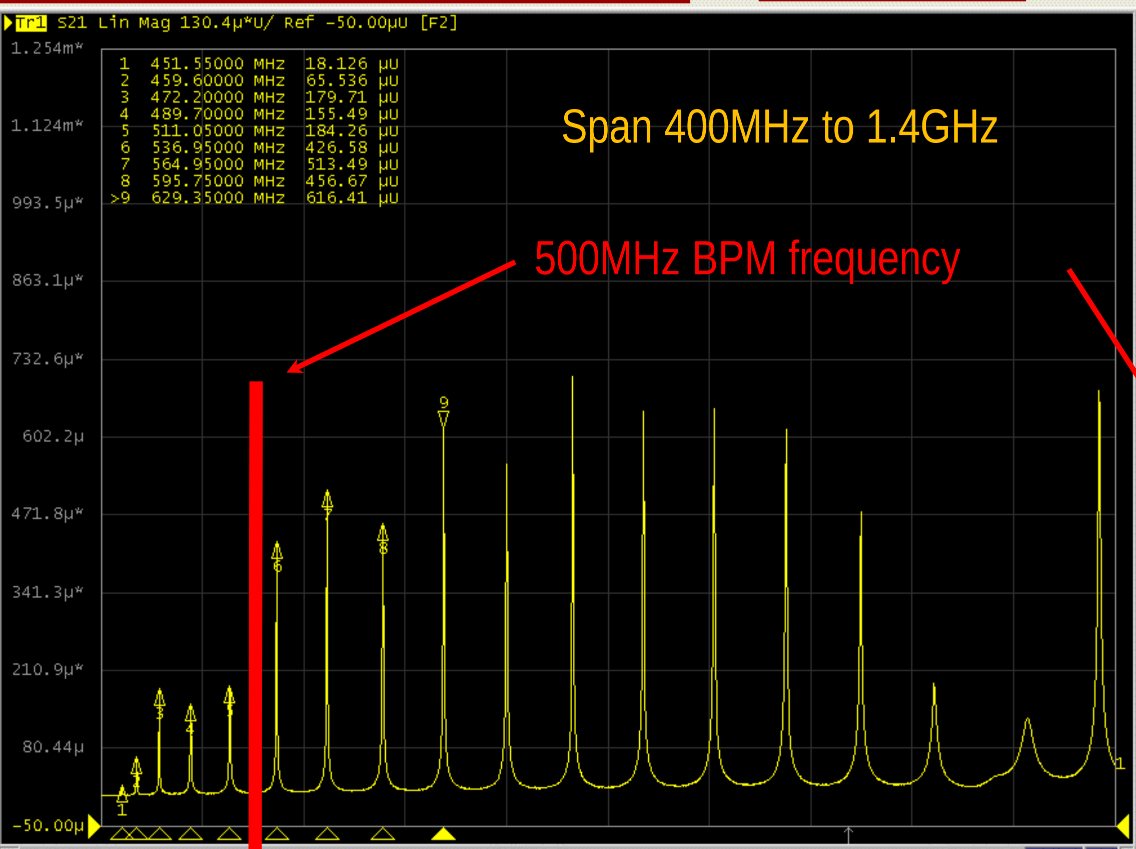
S4 Multipole Chamber

$$\lambda_{mnp} = \frac{2\pi}{\sqrt{\left(\frac{2\pi}{\lambda_c}\right)^2 + \left(\frac{p\pi}{L}\right)^2}}$$

Courtesy Alexei Blednykh

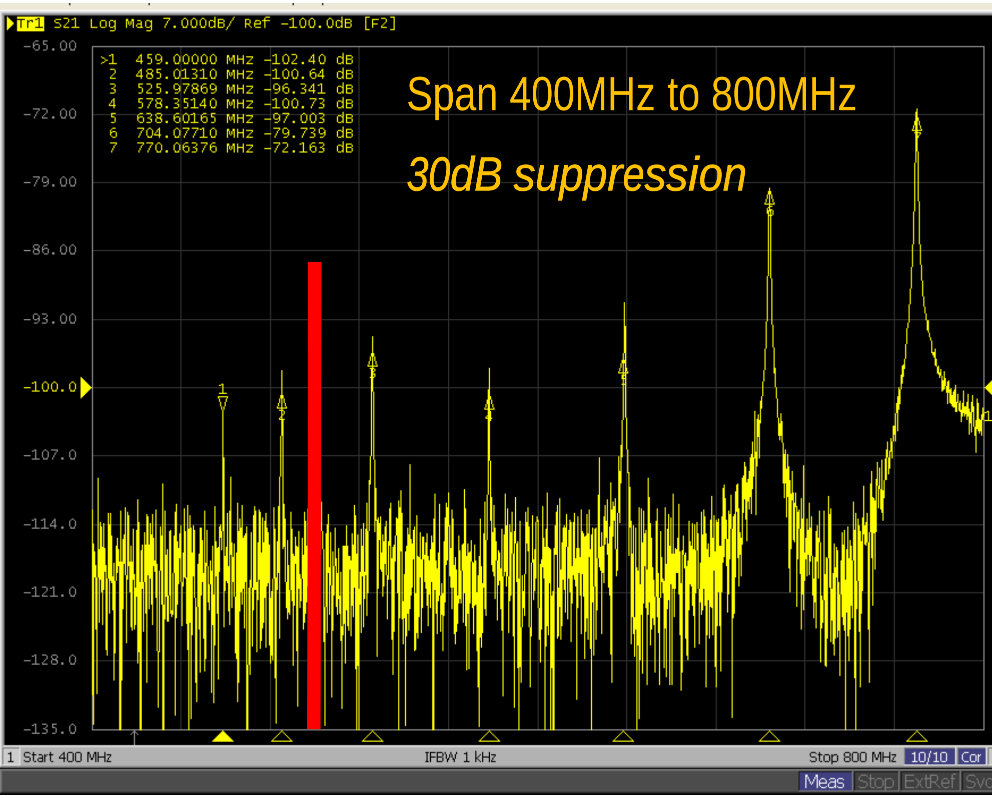
$$\lambda_c = 0.673\text{m}$$

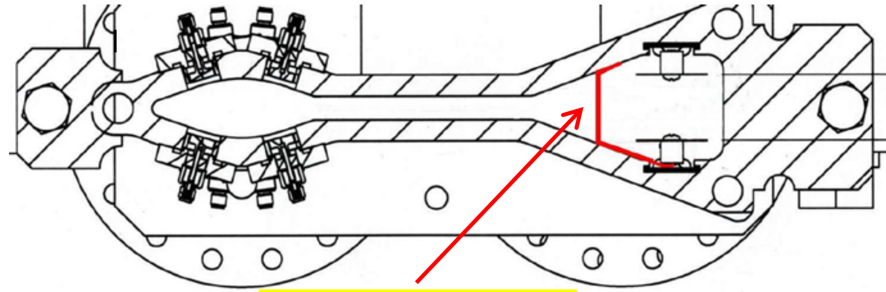
$$f_c = 445.7\,MHz$$



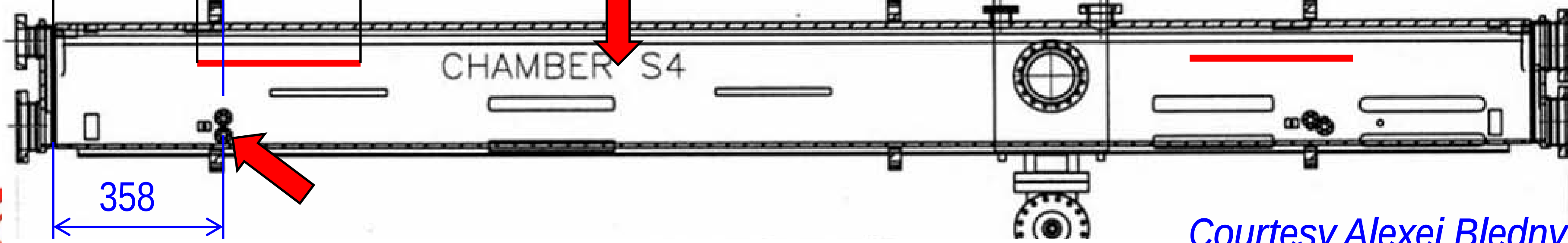
Measurements f, MHz	GdfidL f, MHz	Equation f, MHz
447.96	448.81	448.47
451.63	456.80	456.49
460.04	469.82	469.55
472.05	487.46	487.24
490.06	509.25	509.09
511.67	534.67	534.58
536.89	563.24	563.23
595.72	594.50	594.56
628.97	628.05	628.19
663.79	663.54	663.76

Mode Generation from Loop to Button





200mm		255mm		300mm	
MHz	*dB*	*MHz*	*dB*	*MHz*	*dB*
457.763	-97	458.488	-100	458.669	-98
481.091	-93	483.412	-94	484.573	-98
517.333	-93	521.976	-94	523.137	-102



Courtesy Alexei Blednykh

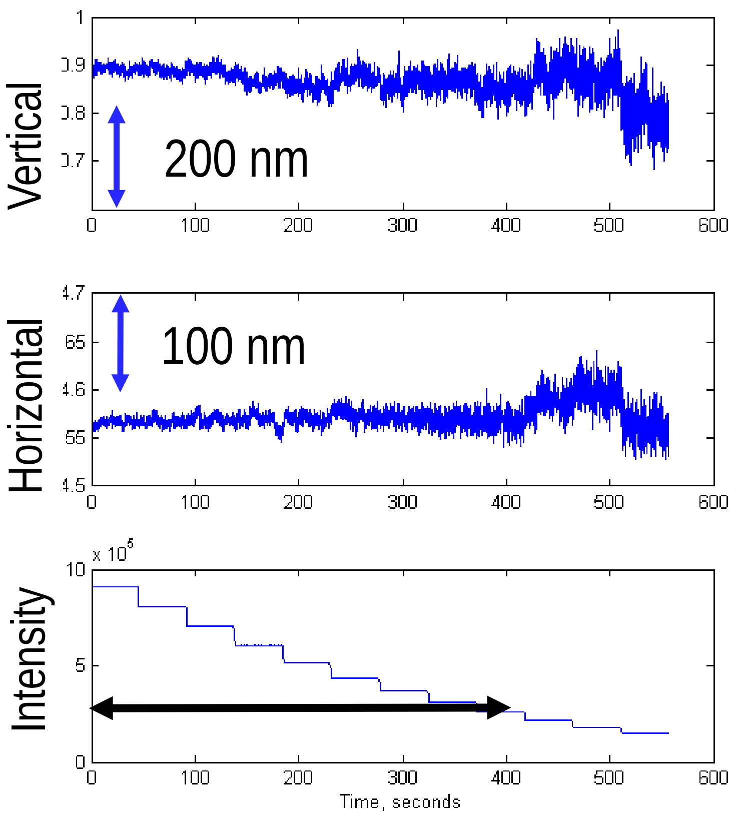
4. RF BPM ELECTRONICS

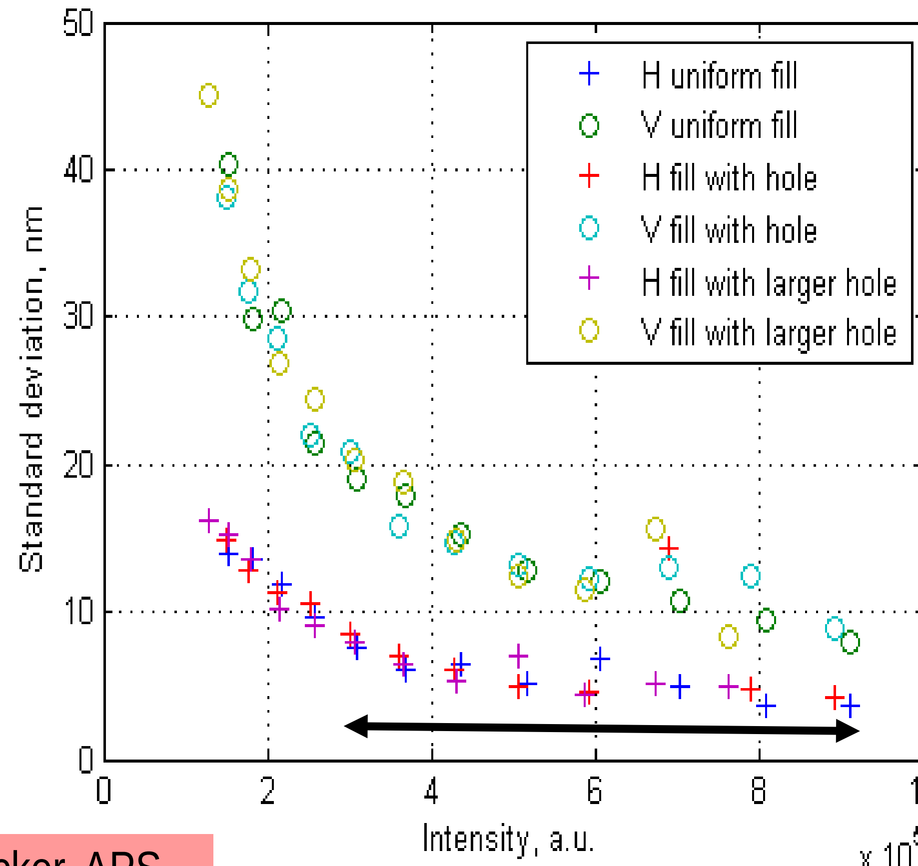
- Libera Brilliance BPM electronics evaluation as a part of R&D
- Performance exceeds NSLS-II baseline requirements
- Brilliance Performance was evaluated based on
  - ✓ Raw data availability
  - ✓ Turn by turn data availability
  - ✓ 10 kHz data for fast orbit feedback
  - ✓ Mis-steering interlock data
  - ✓ 10 Hz data for slow orbit acquisition
  - ✓ Resolution and stability requirements

Measure Intensity Dependent Noise - Brilliance

- Connect small aperture APS SR RF button (1-4 splitter)
- Steer stored beam to create intensity changes BPM at APS SR
- With intensity changes from 9 a.u. to 3 a.u. –

  1) DC Offset < 100 nm; 2) AC Noise 10nm → 20nm (10 Hz BW)

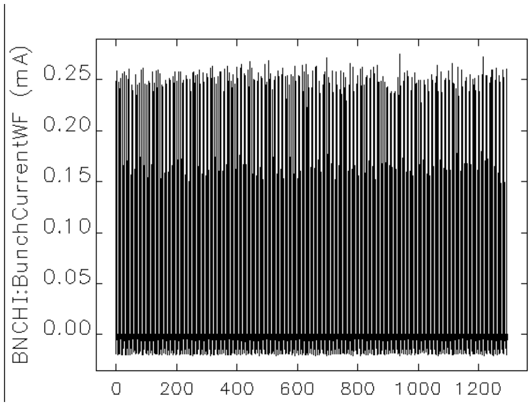




G. Decker, APS

Measure Fill Pattern Dependance – Brilliance

- A) SR fill with 324 uniform bunches (1296 bucket)
- B) Knock out 20 % bunches; C) knock out 30 % bunches
- Results – Fill pattern dependance < 100 nm



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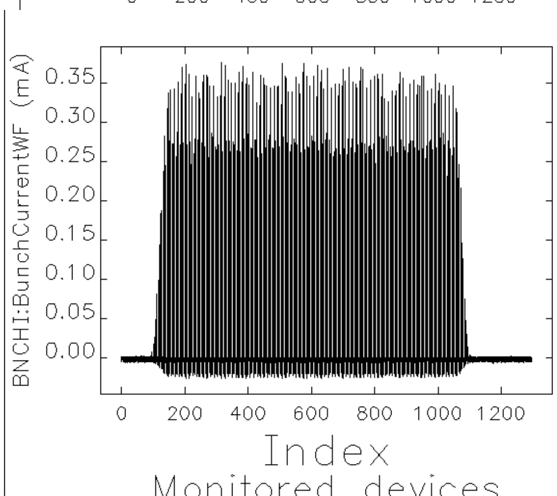
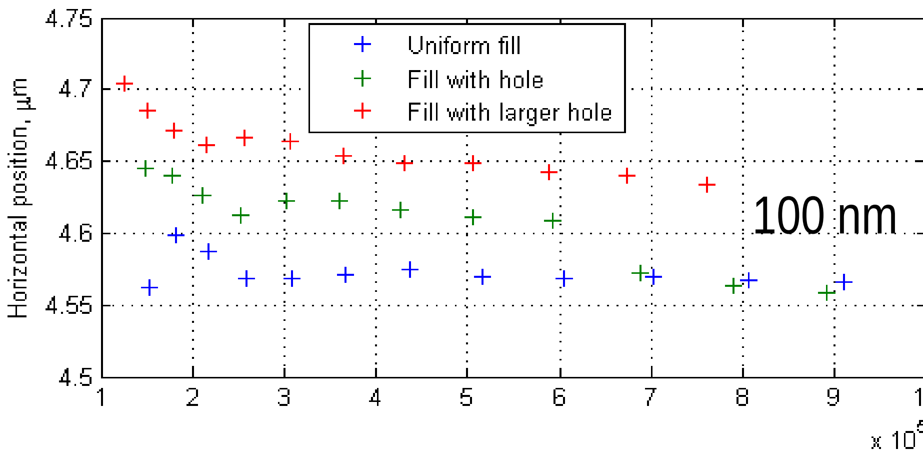
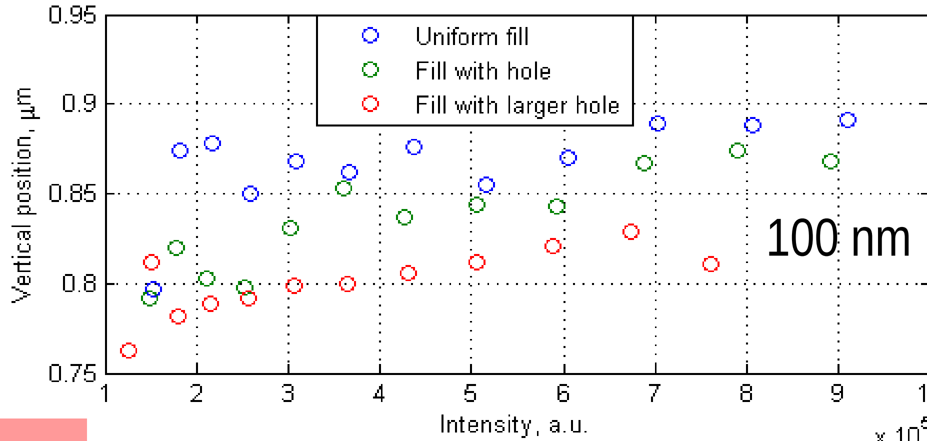


B&C



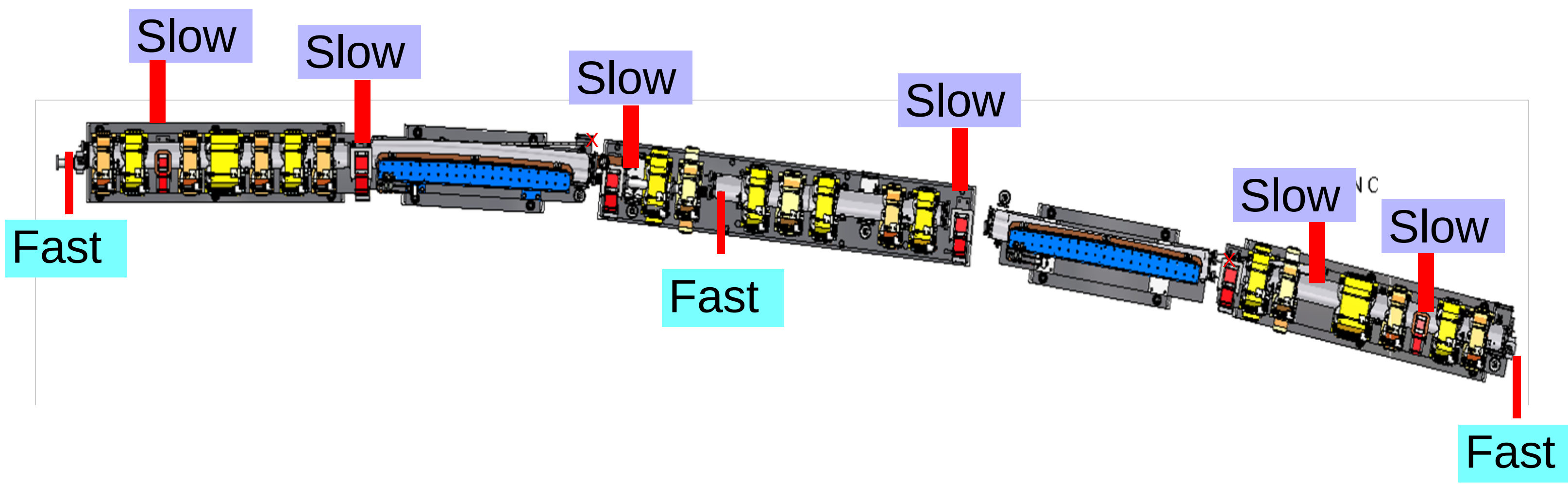


X-ray BPM – workshop summary

- X bpms play key roles for orbit stability and orbit recovery
  - ✓ Lever advantage increases S/N ratio
  - ✓ XBPMs provide 1st look what comes out of ID
  - ✓ Show least dependence with variation in
    - Intensity , individual bunch charge , bunch fill pattern
- Works well for BM and fixed gap ID
- ID XBPM performance enhanced by Decker distortion
- ID gap variation has challenges –
  - ✓ Feedforward techniques helps so some degree
  - ✓ Develop hard X-ray BPM

Orbit Feedback

- Optimized Corrector configuration –
  - ✓ 6 slow correctors, 0.8 mrad full strength; ~10 Hz BW - for alignment
  - ✓ 3 fast corr; 0.02 mrad full strength, ~ 2 kHz BW - for fast orbit feedback
- Upto 8 RF BPMs & 4 XBPMs available for alignment & fast orbit feedback
- Fast orbit feedback system process rate 10 kHz; Orbit corr BW DC-200Hz



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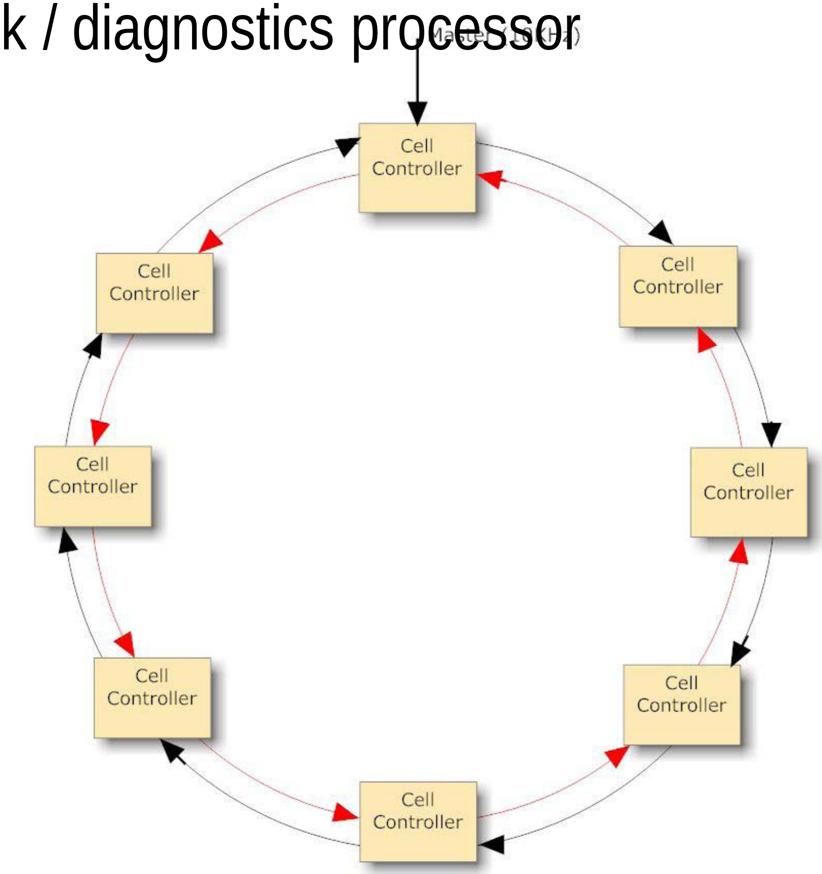
Orbit Feedback

- Need to Circulates > 240 BPM data to all 30 cells at 10 kHz rate
  - ✓ Develop fast synchronous communication (FPGA based)
  - ✓ Architecture - synchronous, deterministic, fault tolerance
  - ✓ Provide BPM data to feedback / diagnostics processor

Collaboration –

LBL; NSLS-II; Others



Orbit Feedback & Diagnostics Processor

- Feedback processor based on FPGA technology
- Explore change of inverse response matrix (IRM) “on-the-fly” with fdbk ON
  - Switch between preloaded IRM synchronously

- Valuable diagnostic tools utilizing FPGA technology
  - ✓ Implement FFT for critical diagnostics signals
  - ✓ Implement spatial as well as temporal displays for diagnostics
    - Visual operator tools to monitor baseline performance
    - Early sign of hardware fatigue/ malfunction - bpm or power supplies
    - Early sign to detect the noise source presence and its location

Summary

- Injector diagnostics is in early stage of design
- Linac and Booster systems – semi-turn key
- Storage ring diagnostics design in progress
- RF BPMs evaluation is at mature stage
- Fast orbit feedback sub-systems design in progress

Acknowledgment

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NSLS-II SR RF BPM System – Performance Requirements

Parameters/ Subsystems			Conditions	Large Aperture RF BPM Resolution Requirement	
				Vertical	Horizontal
Single bunch, Single turn resolution (@ 378 kHz)			0.05 nC charge	500 µm rms	500 µm rms
			5.0 nC charge	20 µm rms	20 µm rms
Single bunch stored beam resolution (0.017-200 Hz BW)			0.02 mA current	10 µm rms	10 µm rms
			2.0 mA current	1 µm rms	1 µm rms
50 mA *** to 500 mA Stored beam resolution – 20% to 100 % duty cycle	BPM Receiver Electronics	Assuming no contribution from bunch/ fill pattern effects	**0.017 Hz to 200 Hz	0.2 µm rms	0.3 µm rms
			200 Hz to 2000 Hz	0.4 µm rms	0.6 µm rms
			**1 min to 8 hr drift	0.2 µm pk-pk	0.5 µm pk-pk
		Bunch charge/ fill pattern effects only	DC to 2000 Hz	0.2 µm rms	0.3 µm rms
	Mechanical motion limit at Pick-up electrodes assembly (ground & support combined)	Vibrations	50 Hz to 2000 Hz	10 nm rms	10 nm rms
			4 Hz to 50 Hz	25 nm rms	25 nm rms
			0.5 Hz to 4 Hz	200 nm rms	200 nm rms
		Thermal	**1 min to 8 hr	200 nm pk-pk	500 nm pk-pk

** ID BPM system (small aperture RF BPM) resolution values will be smaller (factor of ~ 0.5)

*** @ 5 mA – 50 mA stored beam, BPM receiver resolution values will be worse (factor of ~2)

SR Photon Diagnostics Beamlines