Summary Report: Working Group 2
Storage Ring Sources
Future Light Source Workshop
SLAC, March 1-5, 2010

S. Krinsky and R. Hettel

Sessions

1. Low Emittance Ring Design
   --Y. Cai
2. Novel Concepts
   --D. Robin
3. Experience From Existing Rings
   --J. Safranek
4. Advances in Storage Ring Technology
   --G. Decker

Charge to the future ring working group:

A. Evaluate light source concepts and architectures that are beyond state-of-the-art and are presently in the conceptual or R&D stage and that would have transformational radiation characteristics.

Response:

The knowledge gained from the design, construction and operation of recent storage ring sources provides the necessary foundation for a successful R&D program to pursue the design of a diffraction limited x-ray source based on a storage ring with energy ~5 GeV, horizontal & vertical emittances ~10 pm, and brightness ~10^{23} .

- **State-of-the-art new light sources: NSLS-II, MAX-IV, SPring8-2, USR7, PEP-X**
  - Large dynamic & momentum apertures
    - Analytic approach, Lie Algebra, resonances and chromatic effects
    - Numerical optimization-- multi-objective optimization, genetic algorithms
  - Improvement of lattice, cell design
    - Multi-Bend Achromat
    - Compact and combine function magnets
    - Octopole magnets
  - Low frequency RF and Harmonic cavities
  - Into a favorite region of emittance for longer Touschek lifetime

There has been great progress in the optimization of the dynamic aperture and energy acceptance:

- Analytic: Lie Algebra, tune footprint, chromatic effects
- Numerical: Multi-Objective Optimization
- Experimental: characterization of non-linear optics

Some recent insights:

- With sextupoles having independent power supplies, symmetry of the linear optics can be reduced
- Multiple bend achromatic lattices with octupoles as developed for MAX-IV have very good nonlinear optics and may provide important guidance to the design of a diffraction-limited x-ray storage ring
- Hybrid lattices combining DBA periods with other types of structures such as minimum emittance cells show significant promise.

Charge to the future ring working group:

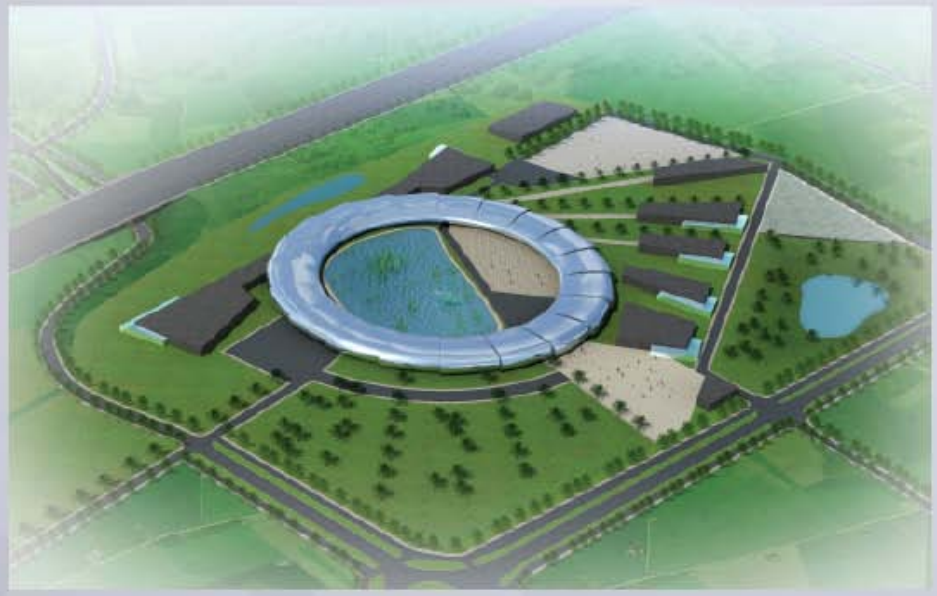
B. Evaluate concepts that could significantly change the economics of construction and operation of advanced light sources. Assess the cost/performance trade-offs in terms of overall construction and operation cost, accessibility to researchers, etc.

Response:

The innovative mechanical design for MAX-IV offers the possibility of significant cost savings. A study should be pursued to evaluate if such a design is applicable for the construction of a diffraction-limited x-ray source.

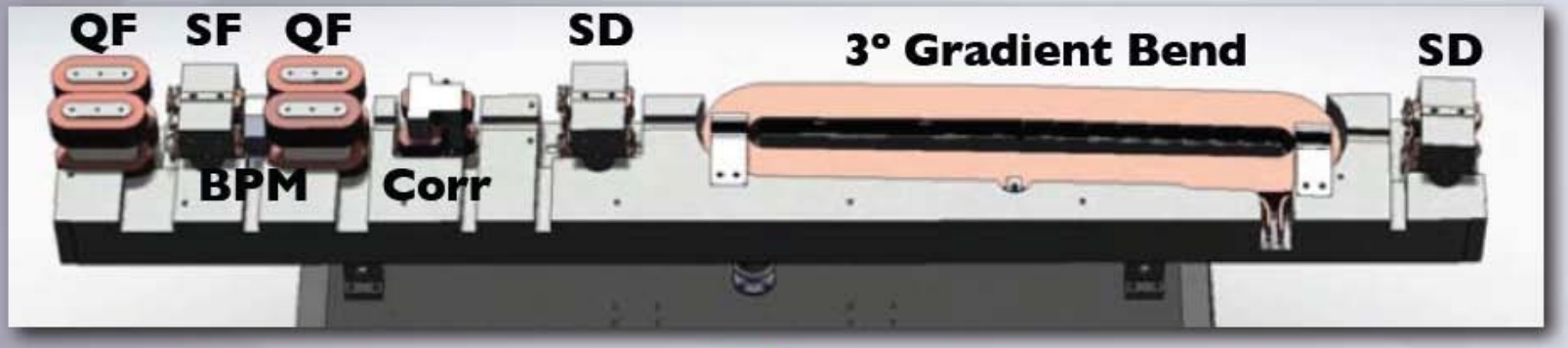
Design and Technology Choices with Budget Constraints

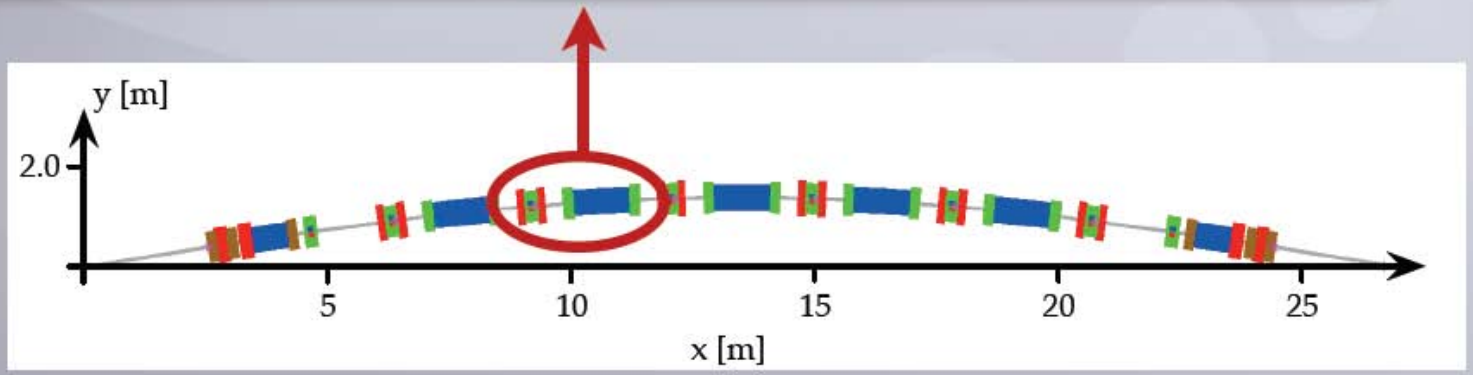
- Lattice & Magnets
  - Multibend achromat lattice
  - Integrated magnet design
  - Girders / Supports
  - Soft-end dipoles
- Vacuum System
  - NEG-coated vacuum chamber
- RF Systems
  - 100 MHz RF
  - Harmonic Landau cavities
- Insertion Devices
  - Damping wigglers



Integrated Magnet Design (3 GeV Storage Ring)

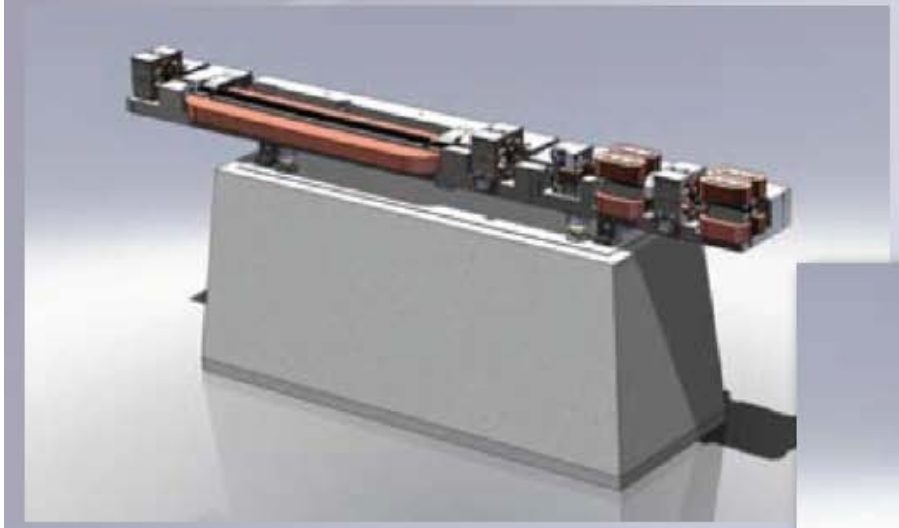
- Each unit cell and matching cell is machined from two solid blocks of iron (demonstrated at MAX III → NIM A **601** (2009) 229)
- Excellent in terms of alignment and comparably inexpensive to manufacture

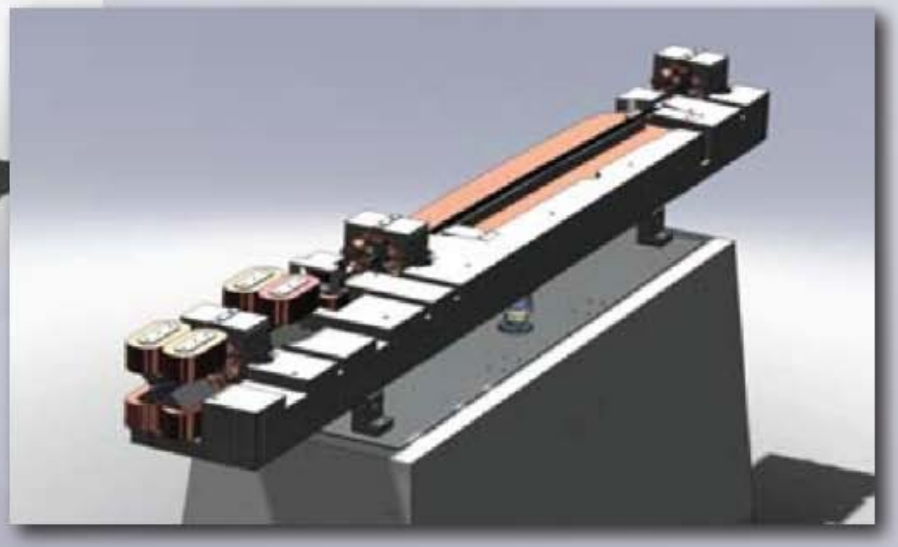




Supports

- Solid iron magnet blocks = "girders"
- Install on simple but massive concrete supports → inexpensive
- Vibrational eigenfrequencies pushed beyond 100 Hz → stability



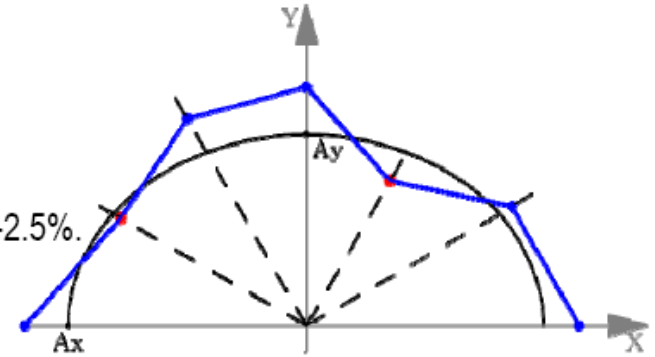


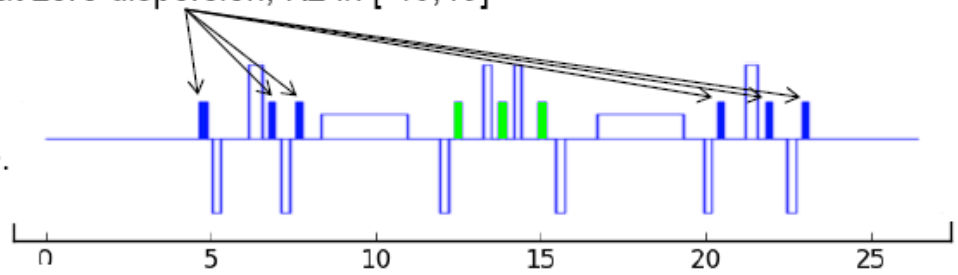
Low Emittance Ring Design--Y. Cai

LER 2010 Workshop Summary	C. Steier
The Near Future Light Source: NSLS-II	W. Guo
The MAX IV 3 GeV Storage Ring	S. Leemann
Lattice Design and Performance for PEP-X	Y. Nosochkov
Parallel Tracking-Based Optimization of Dynamic Aperture and Lifetime with Application to the APS Upgrade	M. Borland
SPring 8 Upgrade Plan	T. Watanabe
Multi-Objective Optimization of Dynamic Aperture	L. Yang
Impedance and Collective Effects in Future Light Sources	K. Bane

Optimization Setup

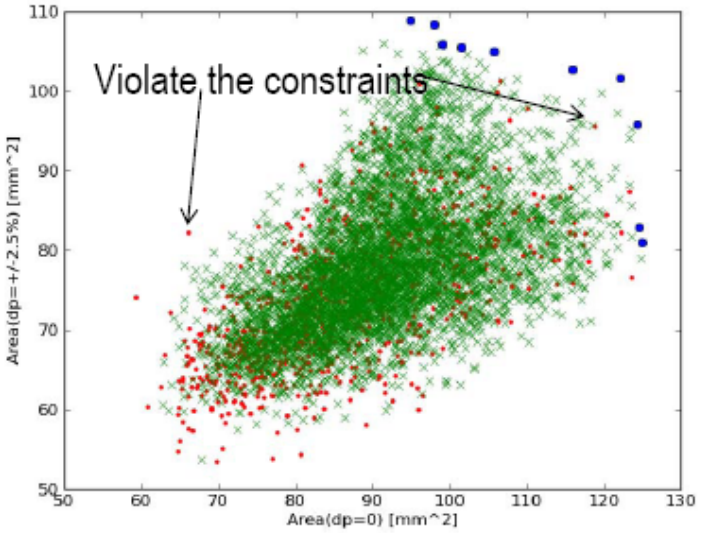
- Optimize:
  - DA of on momentum
  - Average DA of off momentum dp/p0=+2.5% and -2.5%.
- Parameters:
  - Strength of 6 sextupoles at zero dispersion, K2 in [-40,40]
- Constraints:
  - DA fully covers an ellipse.
- Remarks:
  - Tune is fixed (33.43, 16.35), as given by Weiming Guo.
  - Linear chromaticity is fixed (1.44, 0.15), as given. (3 chromatic sextupoles are fixed)

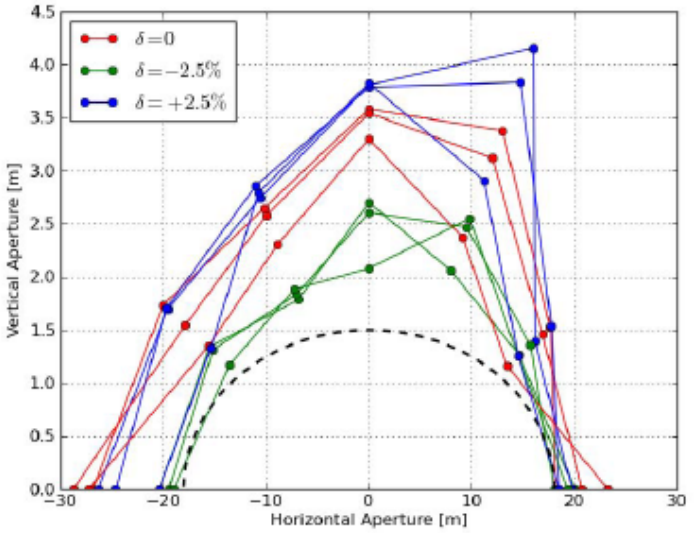




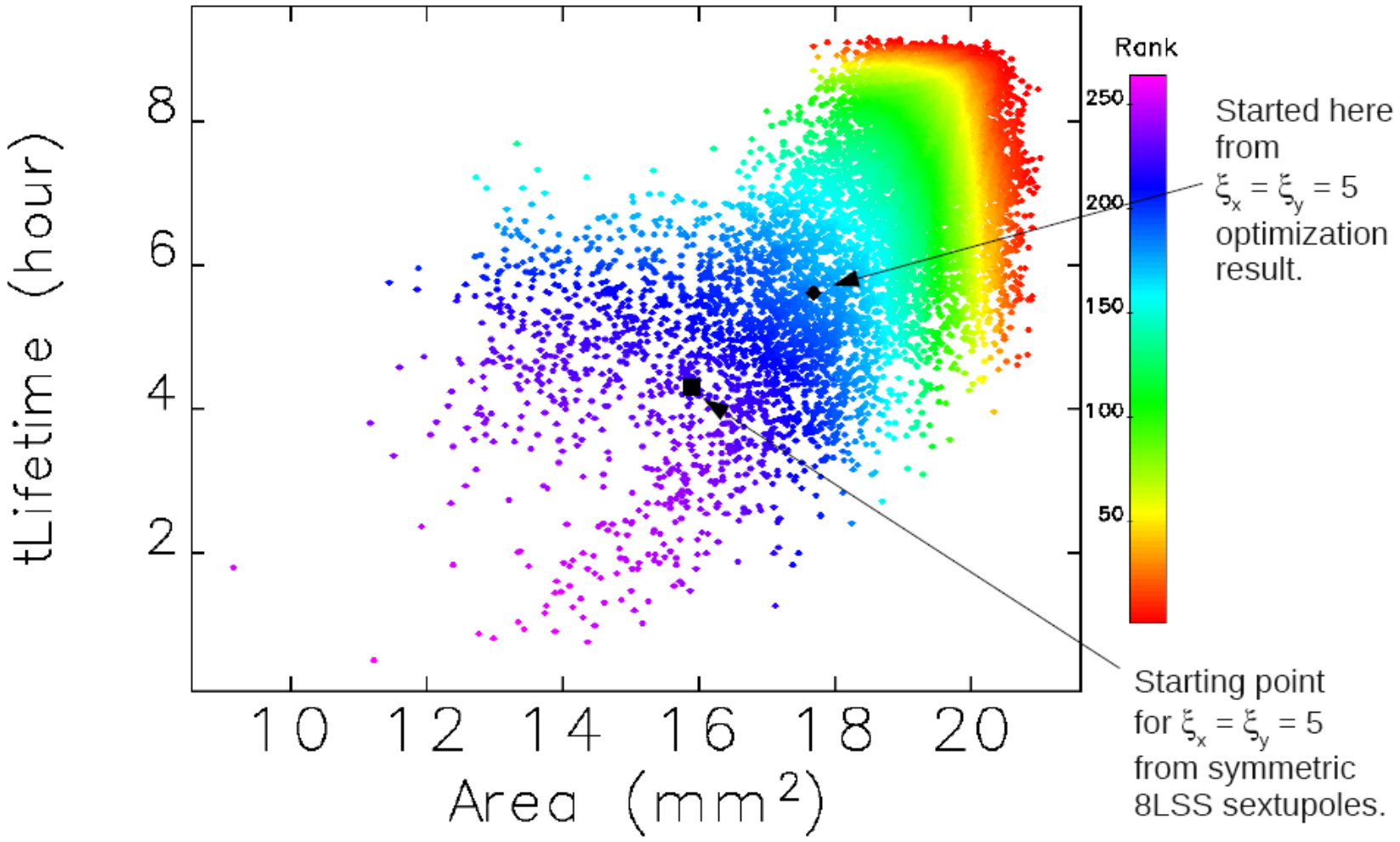
Preliminary Results (3)

- First order chromaticity is adjusted to (+2,+2) by tuning two sextupoles in dispersive region.
- Same tuning knobs as for chromaticity (~0,~0)





Optimization of 8RLSS for $\xi_x = \xi_y = 7$



Experience From Existing Rings--J. Safranek

- Lessons learned from machine studies on existing rings
- Experimental characterization of nonlinear optics
- On-axis injection into small dynamic aperture
- Experience with insertion devices at BESSY-II
- Integrated instability and lattice design for ultimate rings
- Impedance modeling of the APS storage ring: current and APS uprade

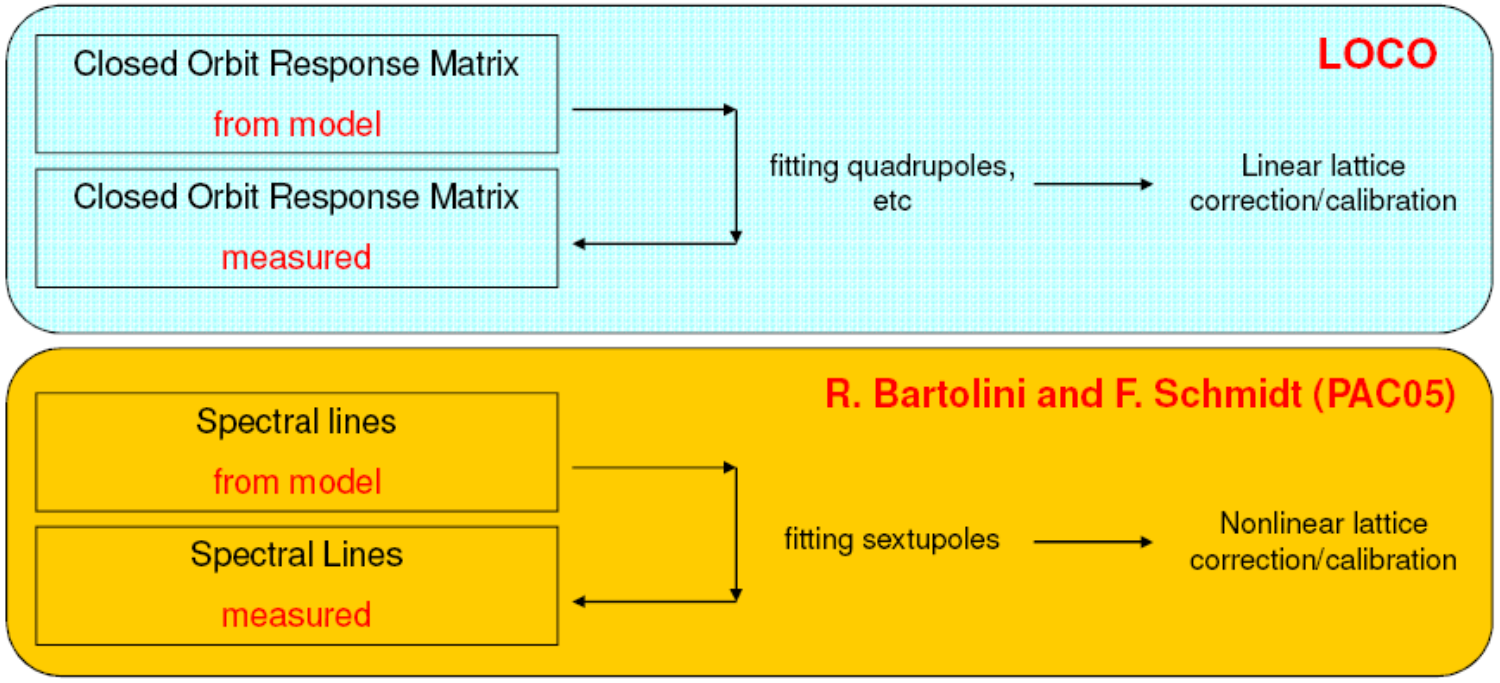
- L. Nadolski
- R. Bartolini
- L. Emery
- J. Bahrdt
- K. Harkay
- Y.C. Chae

Reconstruction of the nonlinear model of a storage ring

Amplitudes and phases of the spectral line of the betatron motion can be used to compare and correct the real accelerator with the model by

fitting the sextupoles' gradients

Comparison with LOCO-type of machine modelling

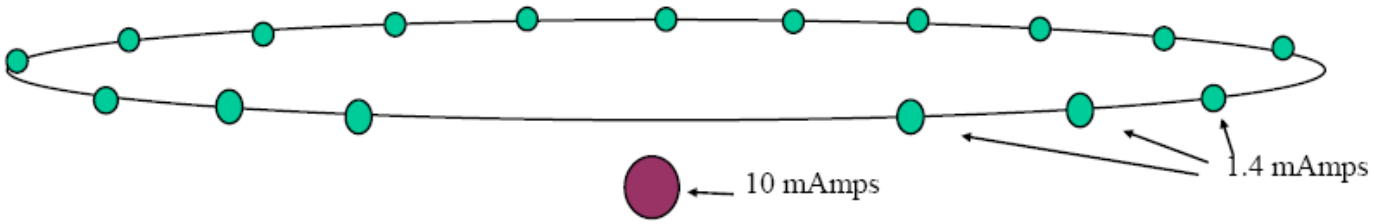


Novel Concepts--D. Robin

Five themes:

- Enhanced lasing (Dao Xiang, SLAC)
- Gamma-rays Compton Scattering (Ying Wu, Duke)
- Compact Light Sources (Ron Ruth, Lyncean)
- Short Pulses (Mike Borland, ANL, Xiaobiao Huang, SLAC)
- Tailored Operation (David Robin, LBNL)

Quasi single bunch Operation



- Change the orbit of one bunch in the storage ring
- Requires short pulse / high repetition rate kickers

Idea originated in early 1980s at NSLS ("VUV Wobbler" by L. Blumberg.in 1980) but has been rediscovered and modified

G. Portmann, S. Kwiatkowski, J. Julian, M. Hertlein, D. Plate, R. Low, K. Baptiste, W. Barry, D. Robin, *Creating a Pseudo Single Bunch at the ALS First Results,*2008 Beam Instrumentation Workshop, Tahoe City, CA USA

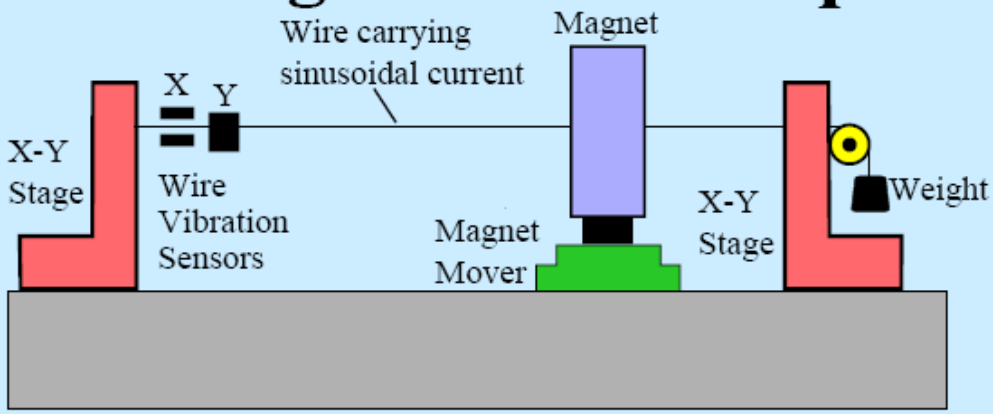
Tailored Bunches

- Tailored bunch operation has the potential to extend the flexibility of storage rings
  - Potential to avoid “special” operational modes with limited beam availability
- Studying the simplest incarnation of this mode – Quasi-single bunch
  - Enabled via fast high repetition rate kickers
- May be possible to do more exotic modes
- Possibly short pulse single turn injection (with possibility of lasing)

Advances in Storage Ring Technology--G. Decker

Limits to achievable stability	G. Decker
Stability and alignment of NSLS-II magnet system	A. Jain
Fast switching IDs and experience with the APS CPU	L. Emery
Cost-saving design choices for MAX-IV	S. Leemann
Status of CANDLE Synchrotron	V. Tsakanov
Photon source and optics considerations	T. Rabedeau
Normal-conducting crab cavity design	V. Dolgashev

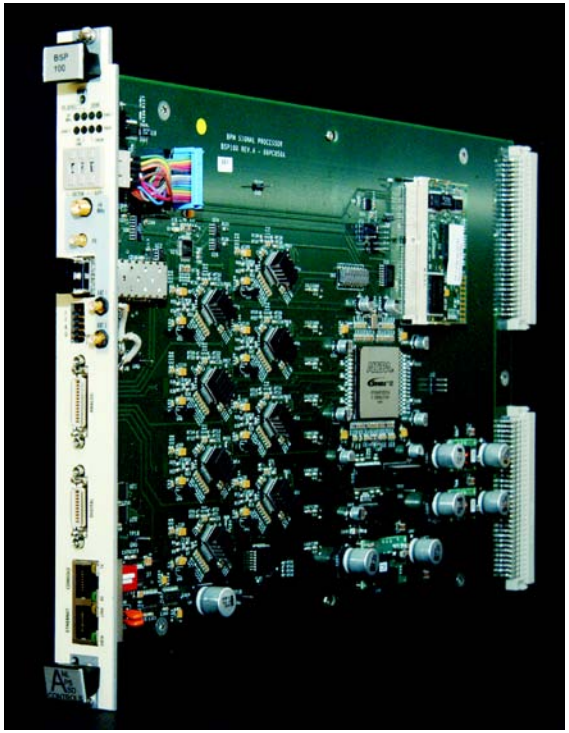
The Vibrating Wire Technique: Basics



- An AC current is passed through a wire stretched axially in the magnet.
- Any transverse field at the wire location exerts a periodic force on the wire, thus exciting vibrations.
- The vibrations are enhanced if the driving frequency is close to one of the resonant frequencies, giving high sensitivity.
- The vibration amplitudes are studied as a function of wire offset to determine the transverse field profile, from which the magnetic axis can be derived.

Limits to achievable stability (cont'd)

- AC electronics state-of-the-art is at the level of 1 nm / √Hz
  - Adequate to support ultimate storage ring beam stabilization

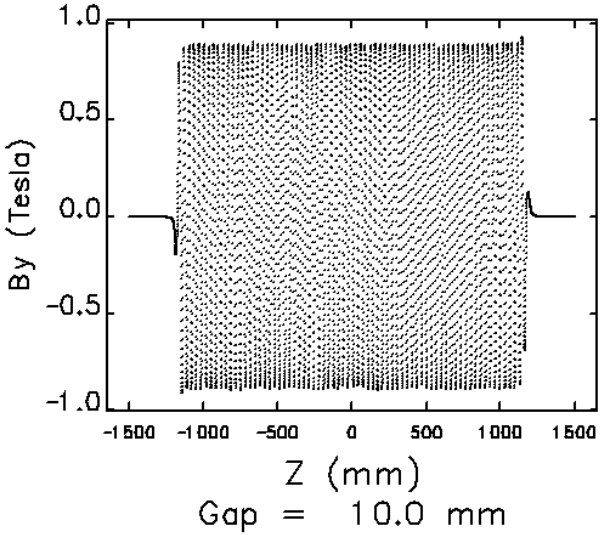


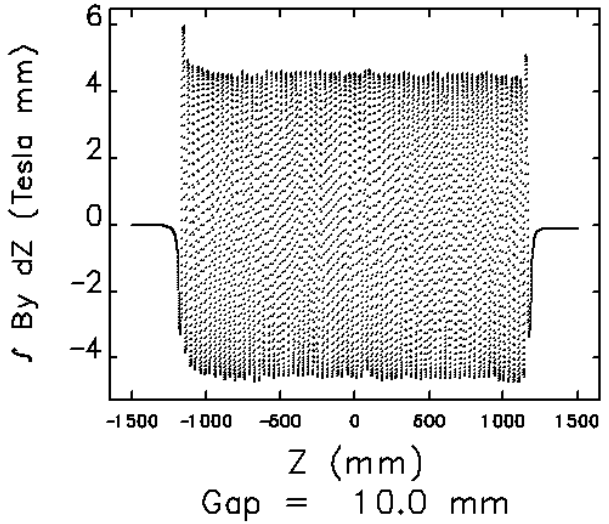
APS BSP-100 FPGA Module

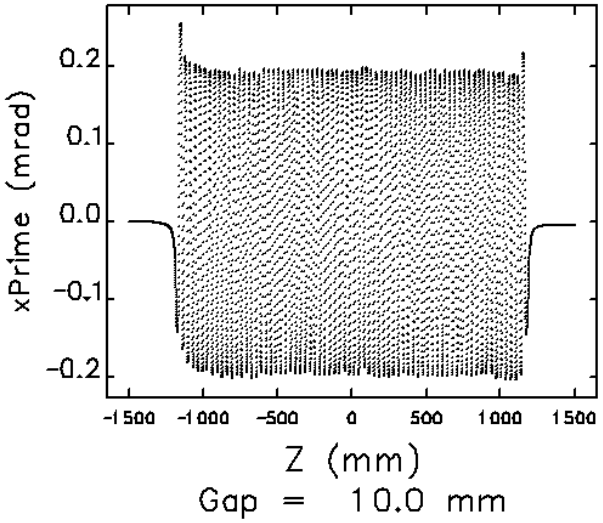
Commercial BPM Electronics
(Instrumentation Technologies)

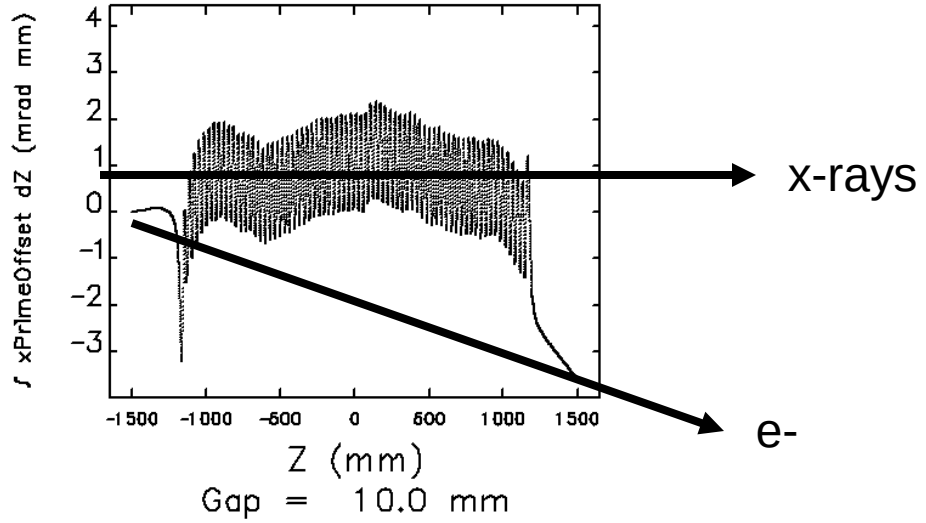
High-performance bunch-bunch BPMs needed for 10-pm rings with tailored bunches

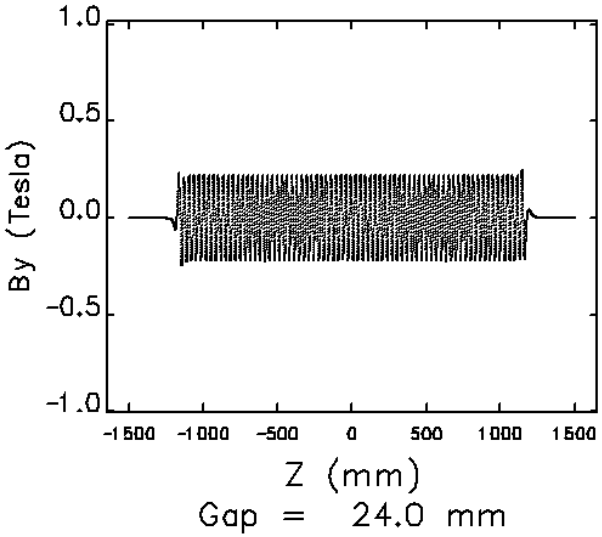
Insertion Device Field Integrals

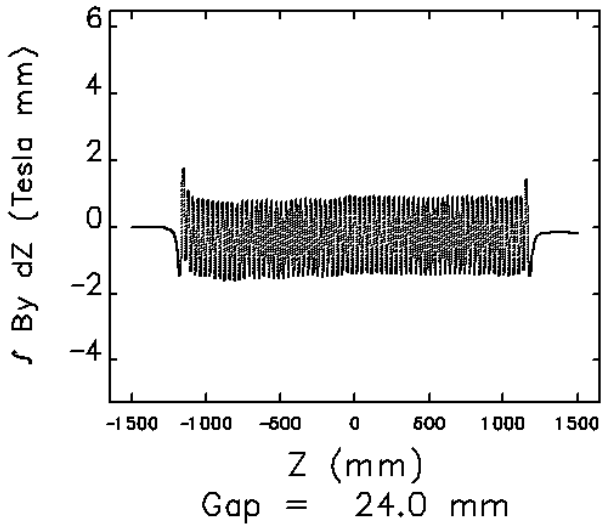


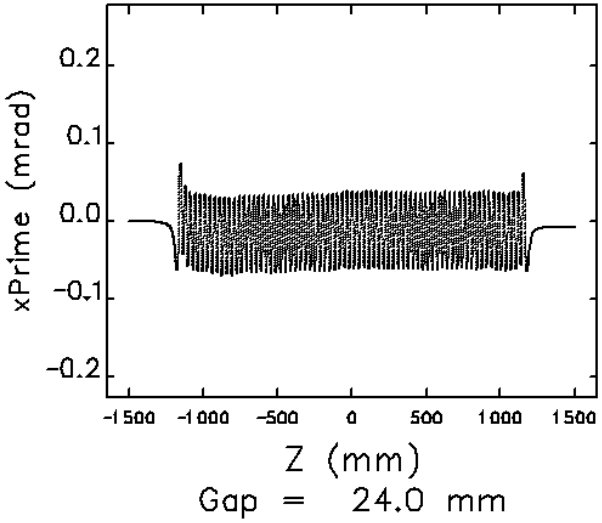


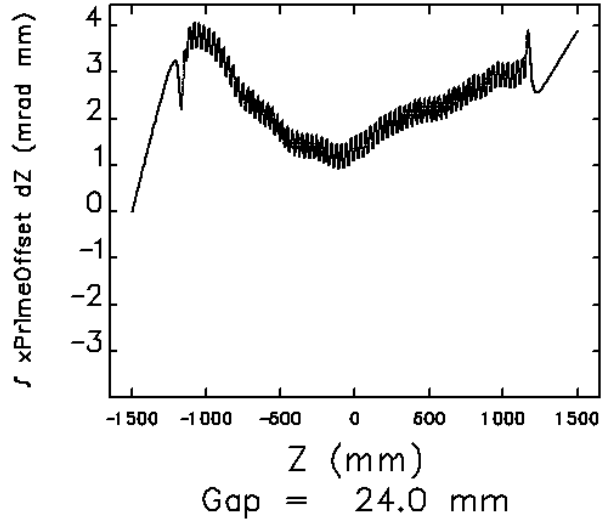




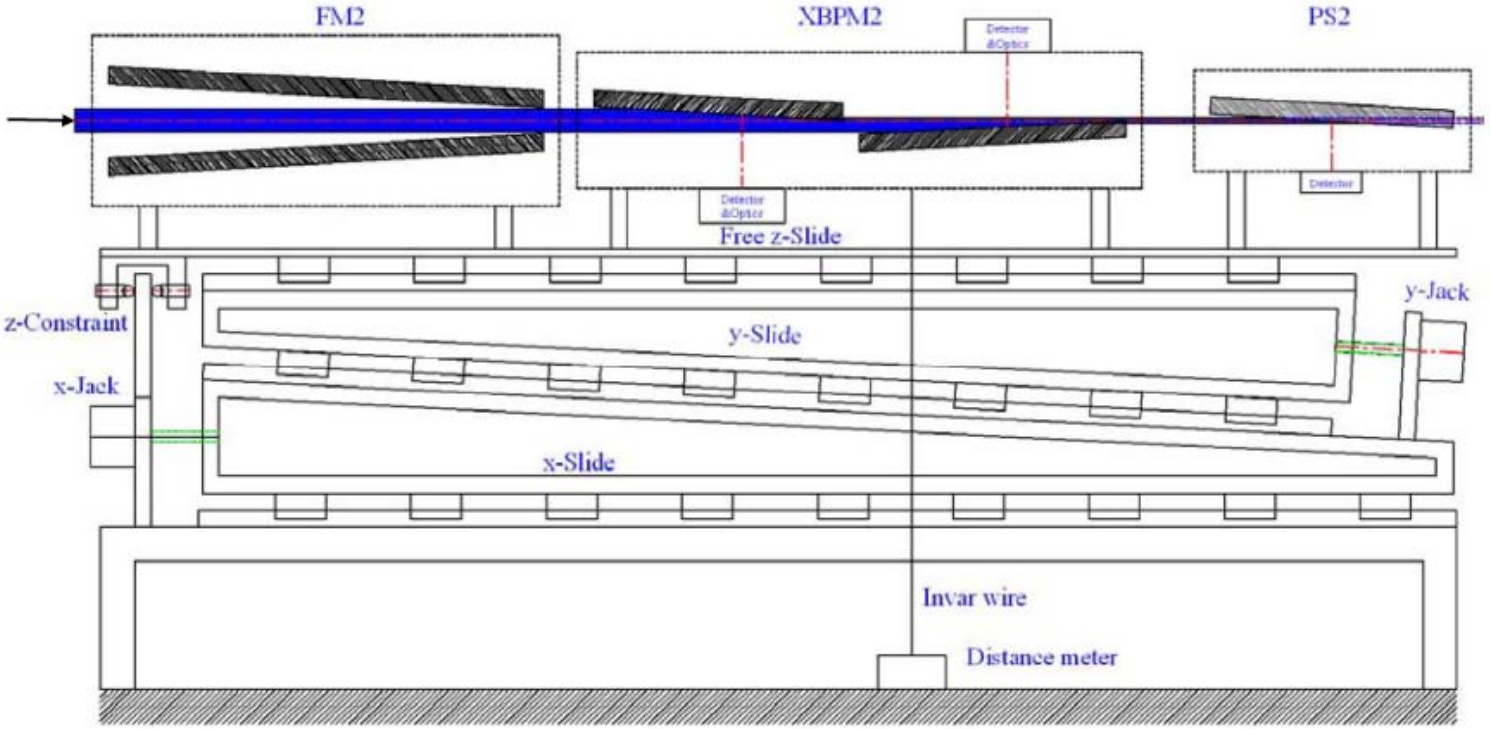

1.0
0.5
0.0
-0.5
-1.0
By (Tesla)
-1500 -1000 -500 0 500 1000 1500
Z (mm)
Gap = 24.0 mm


6
4
2
0
-2
-4
∫ By dZ (Tesla mm)
-1500 -1000 -500 0 500 1000 1500
Z (mm)
Gap = 24.0 mm


0.2
0.1
0.0
-0.1
-0.2
xPrime (mrad)
-1500 -1000 -500 0 500 1000 1500
Z (mm)
Gap = 24.0 mm

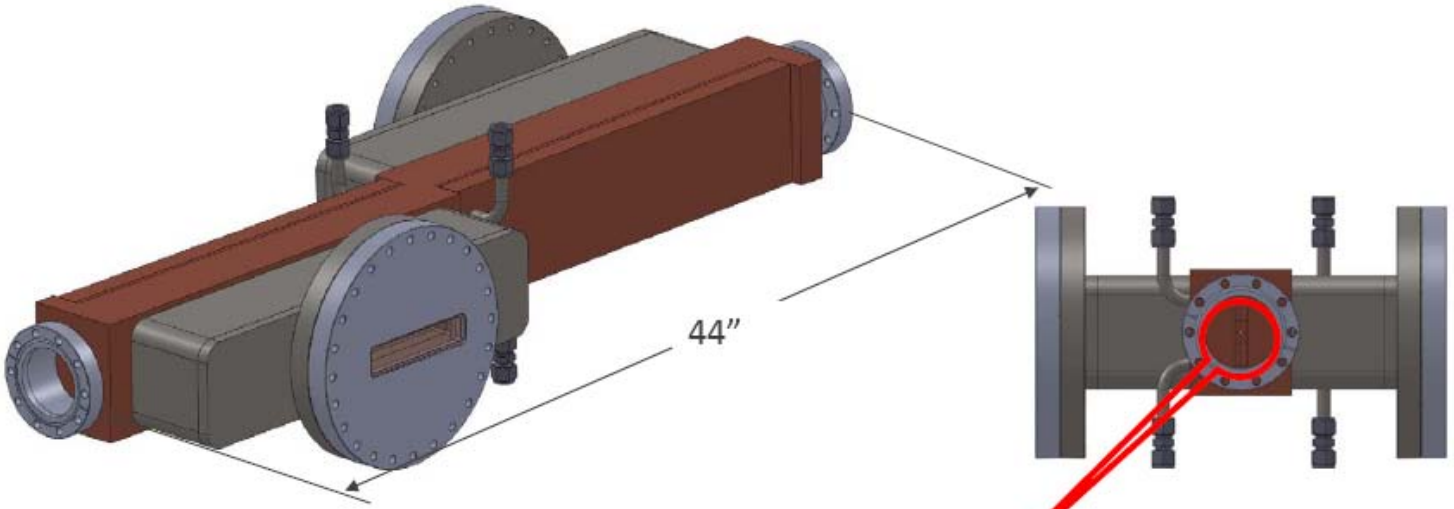

4
3
2
1
0
-1
-2
-3
∫ xPrimeOffset dZ (mrad mm)
-1500 -1000 -500 0 500 1000 1500
Z (mm)
Gap = 24.0 mm

Grazing-incidence Hard X-ray Fluorescence-Based Insertion Device X-ray Beam Position Monitor Conceptual Design (GRIID-XBPM)

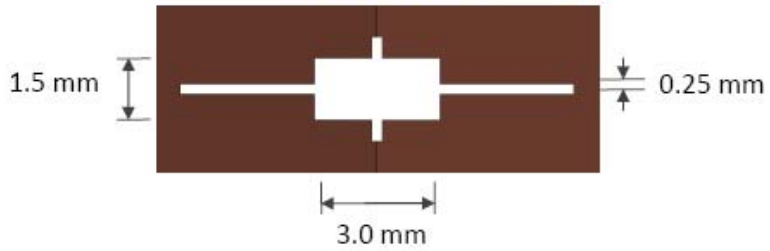


Concept courtesy of Bingxin Yang

Conceptual Design of the first article GRIIDXBPM



Outlet Detail

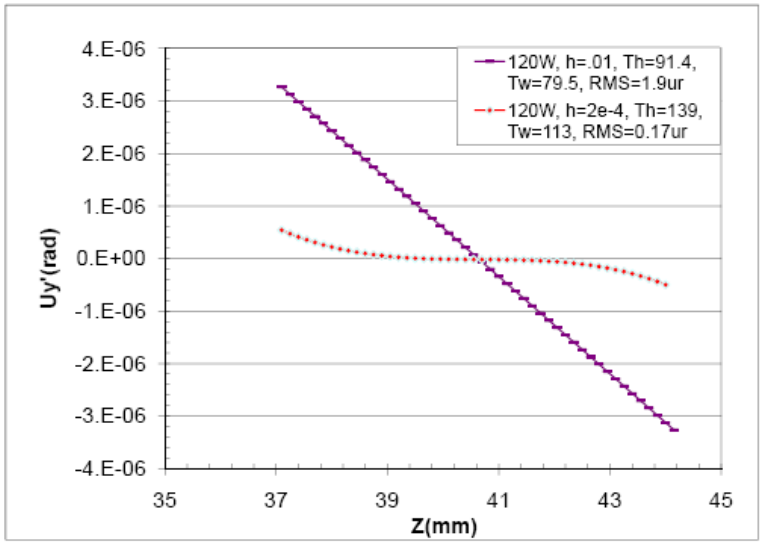


Courtesy of Soon-Hong Lee, AES-MED

X-ray Optics:

- Existing x-ray mirror figure error possibly too large to preserve 10-pm emittance transmission
- Cooling Si monochromators at higher temperature than LN (~150 K instead of 87 K) reduces thermally induced slope error by an order of magnitude to a small fraction of a microradian
- Feedback on x-ray mirror pitch and possibly monochromators needed to maintain point angle at distant experimental stations

Reduce the wet wall heat transfer coefficient to operate the mono crystal at elevated temperature (i.e., reduce LN flow)… 1.9μr → 0.17μr rms!



A. Ringwall

RF Beam Manipulation:

- Fast, stable kickers would benefit tailored bunch operation, bunch replacement for on-axis injection, etc
- Crab cavities for bunch length reduction
- Harmonic cavities for bunch lengthening and compression
- Pulsed rf undulators for tailored bunch lasing(?)