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# *Time-resolved Research and Short X-ray Pulses at the APS*

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*APS Monthly User Meeting*

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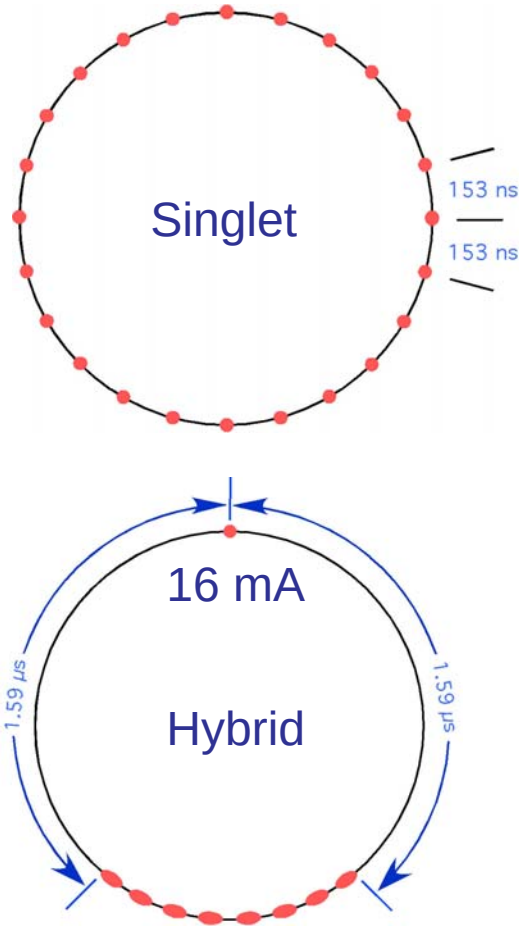
*Acknowledgements* *Michael Borland, ASD*

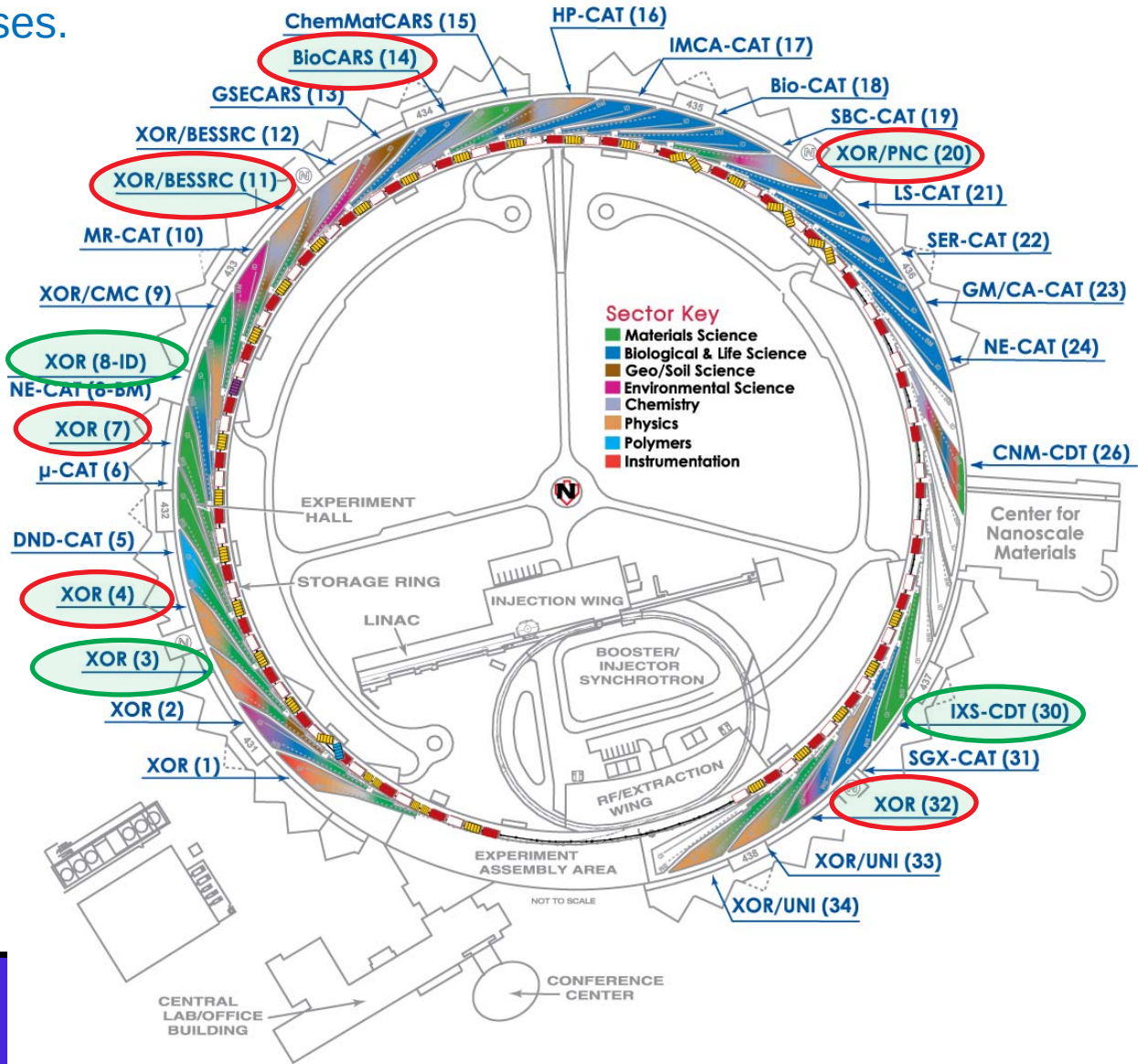
*Katherine Harkay, ASD*

*Patrick Den Hartog, AES*

# *Ultrafast Science in Time-Domain at the APS*

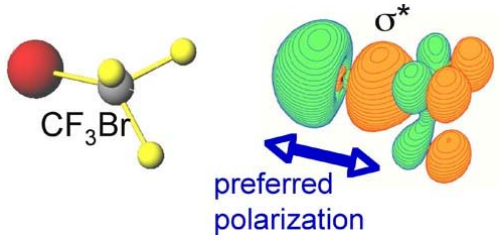
- Many beamlines around the ring have dedicated ultrafast programs taking advantages of time-structure of x-rays pulses.



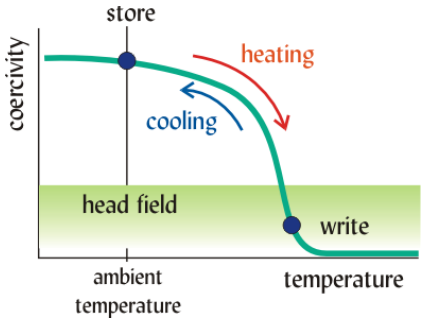



# Current Time-Domain Science and Challenges

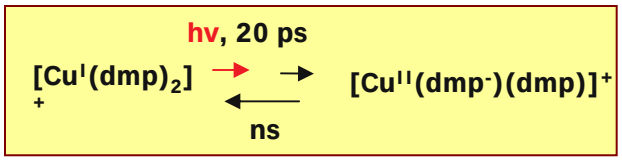
- Atomic, molecular and optical physics: molecular alignment in strong field (Young Group)

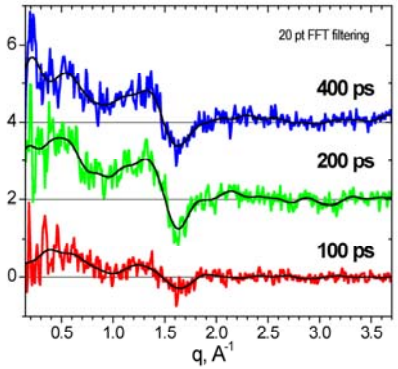



- Ultrafast magnetic and lattice transitions in ultrathin magnetic transitions (Walko et al.)




- 100-ps WAXS probing structure of molecules and their interaction with solvent (Tiede Group)



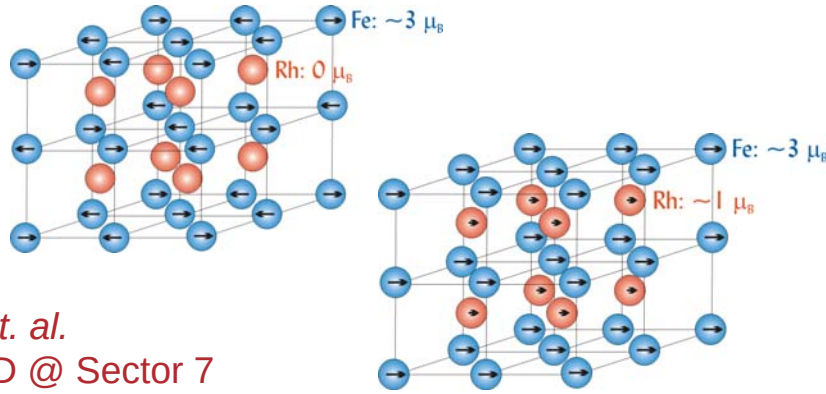

- …

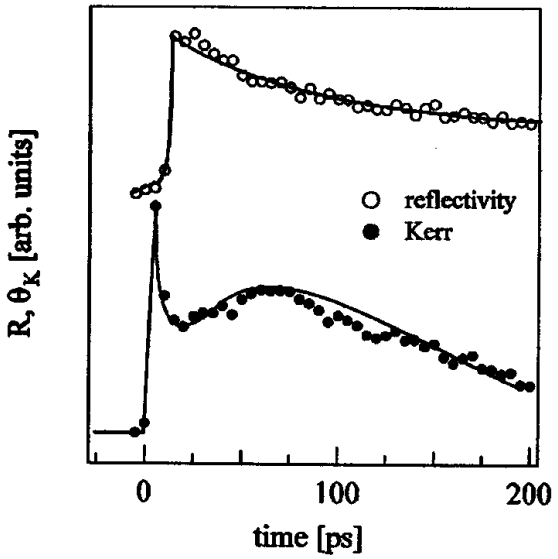
## Challenges

X-ray pulses at the APS are too long!

# Time-Resolved X-ray Diffraction

- Phase transitions in magnetic FeRh thin films
- FeRh undergoes a magnetic and structural phase transition on ultrafast time scales.
- AFM to FM upon heating
- Anomalous volume expansion of ~1%

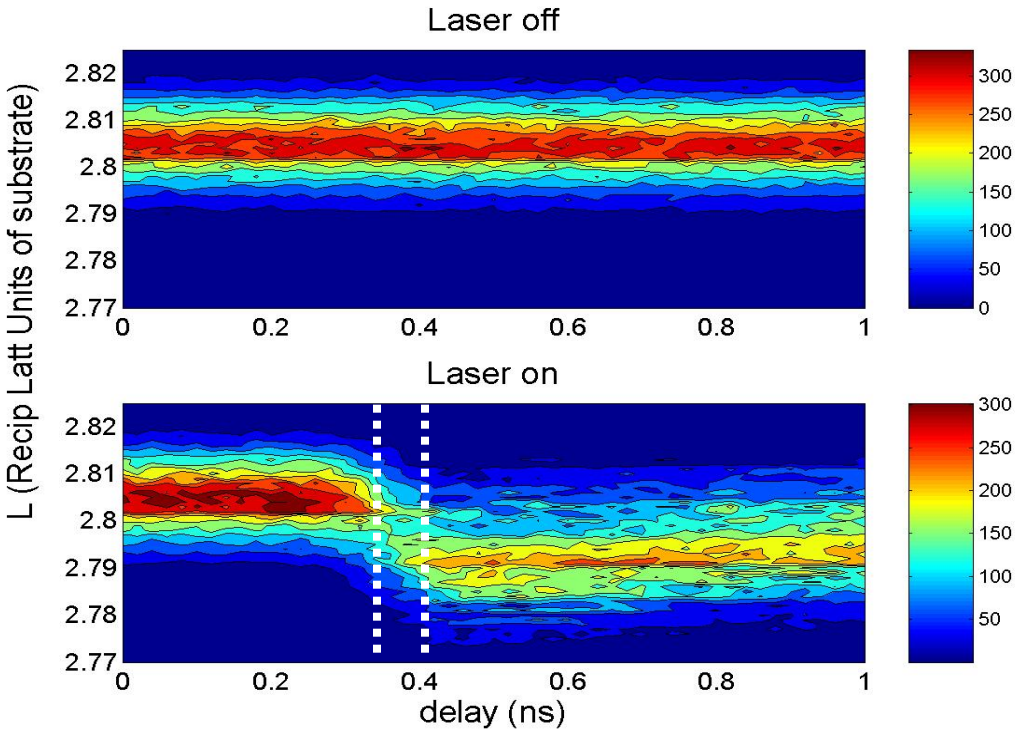



lattices dynamics vs.
magnetic phase transition

*from:* J.-U. Thiele, M. Buess, C. H. Back, Appl. Phys. Lett. **85**, 2857 (2004)

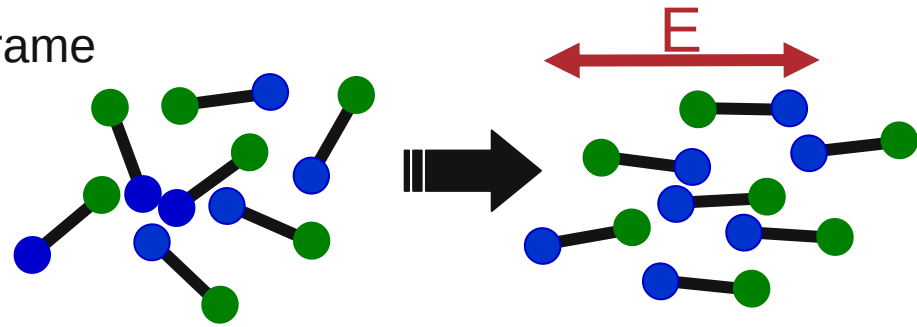
Walko, *et. al.*
TRR/XSD @ Sector 7



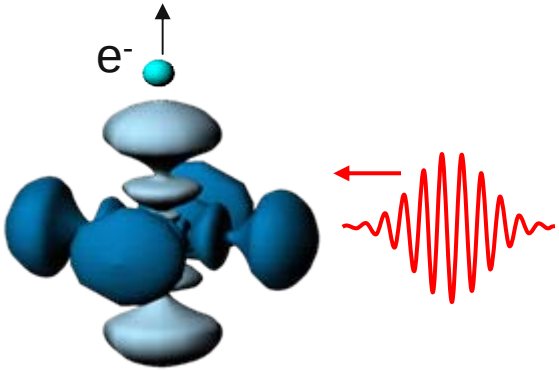
# Strong-field control of x-ray processes

(L. Young group/ANL)

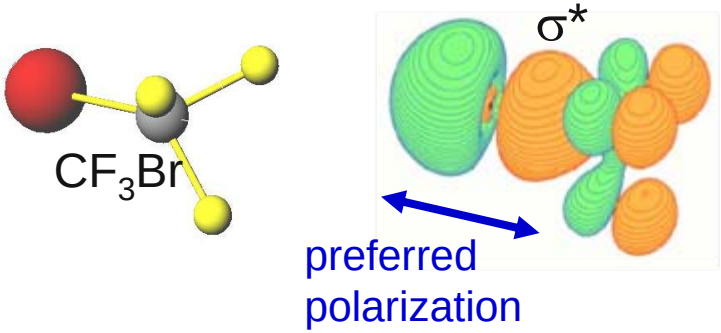
- Serial “crystallography” via molecular alignment: picosecond
- Laser Alignment of Molecules
  - Control of molecular axis angle in lab frame
  - Measurements average over sample
  - Decreased variation in angle for S/N
    - *low temperature, laser/x-ray overlap*




Dipole interaction between molecules and laser electric field
short x-ray pulse (ps) is essential to match the alignment time scale




***Orbital alignment in ultrafast field ionization***
***$10^{14}$-$10^{15}$ W/cm$^2$***




***X-ray absorption by laser-aligned molecules***
***~$10^{12}$ W/cm$^2$***

# *Science Enabled by ps Sources*

- Ultrafast solid state phase transitions: picosecond
- Photochemistry in solution: picosecond
- …

Current and future ps and sub-ps sources

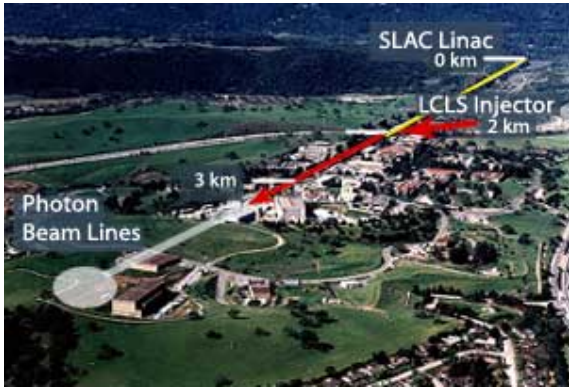



Table-top plasma sources
Short pulse 300 fs - 10 ps
Divergent radiation - low flux
Low rep-rate (10- 1kHz)
Not tunable (target dependent)

Laser slicing sources (ALS, SLS)
Short pulse 100 -300 fs
Rep-rate kHz
Low flux $10^5$ ph/s @ 0.1%bw
Not effective at high-energy sources

LCLS/XFEL
Short pulse 100 fs
Fully coherent
Extremely high brilliance
Low rep-rate (120 Hz)
Limited tunability

# *Short Pulse Capability at the APS*

- Implementation of short x-ray pulse capability at the APS provides an excellent opportunity to address exciting scientific problems on picosecond time scale.
- Two workshops addressed the needs of short-pulse source at the APS
  - The APS strategic planning time domain workshop - September 2004
  - short-pulse workshop - May 2005

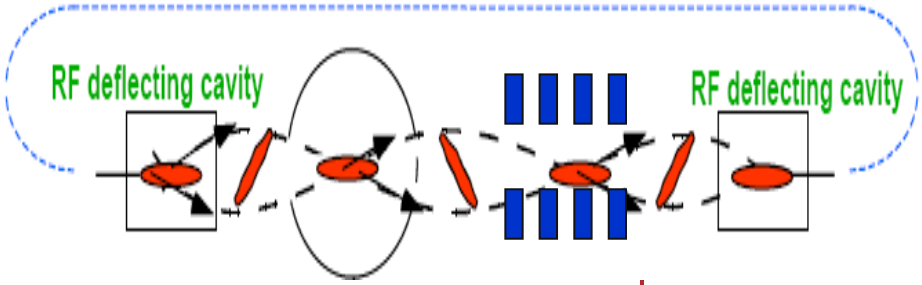
*"Time-domain research has been an important component of the ongoing science at the Advanced Photon Source. Researchers at the APS have contributed greatly to our understanding structural changes on the ~100 picosecond and longer time scale and on the atomic length scale… However, by far the most exciting element of the workshop was exploring the possibility of shorter timescales at the APS, i.e., the generation of 1 ps x-ray pulses whilst retaining high-flux. This important time domain from 1 ps to 100 ps will provide a unique bridge for hard x-ray science between capabilities at current storage rings and future x-ray FELs."*

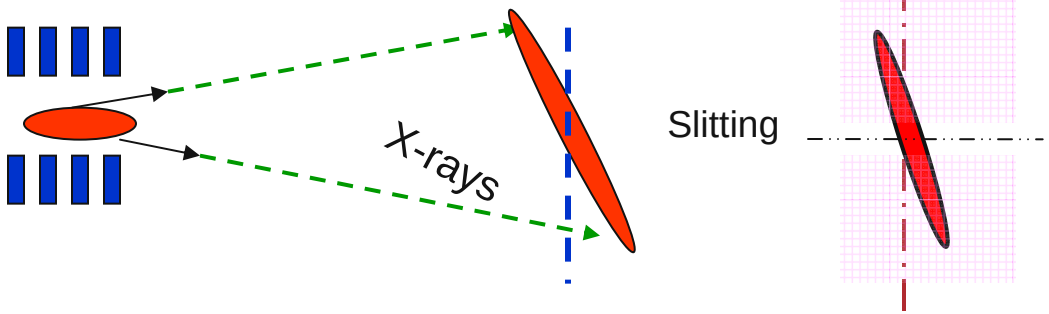
"*This unique potential has generated substantial interest and technical activities both during and subsequent to the workshop and, we believe, is of primary strategic importance for future scientific directions for the Advanced Photon Source. Such a development has the potential to turn the Advanced Photon Source into a Mecca for time-resolved x-ray work!"*

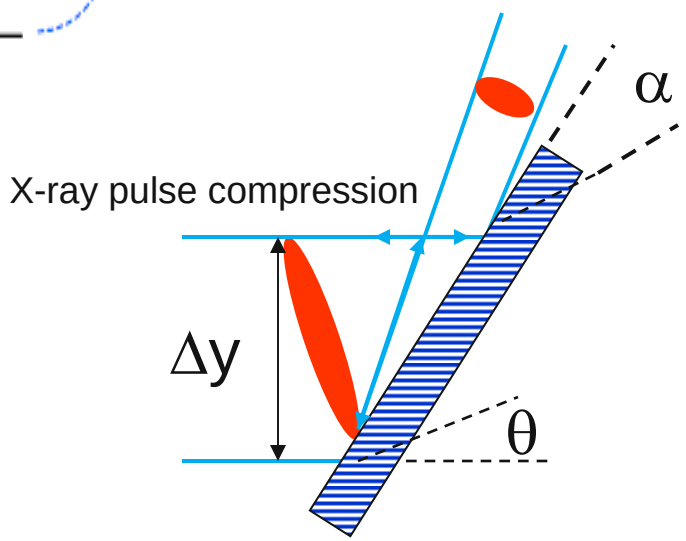
"This important time domain from 1 ps to 100 ps will provide a unique bridge for hard x-ray science between capabilities at current storage rings and future x-ray FELs"

# Concept

- Use transverse-deflecting rf cavities to impose a correlation ("chirp" between the longitudinal position of a particle within the bunch and the vertical momentum.
- The second cavity is placed at a vertical betatron phase advance of $n\pi$ downstream of the first cavity, so as to cancel the chirp.
- With an undulator or bending magnet placed between the cavities, the emitted photons will have a strong correlation among time and vertical slope.
- This can be used for either pulse slicing or pulse compression.



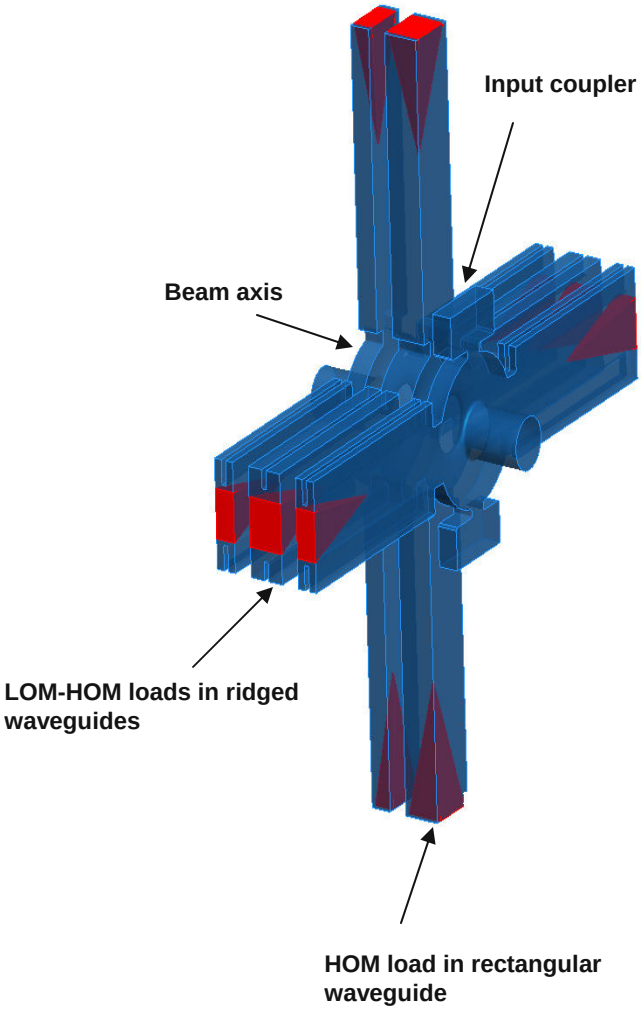




A. Zholents, P. Heimann, M. Zolotorev, J. Byrd, NIM A 425(1999), 385

# Accelerator Implementation - Option 1*

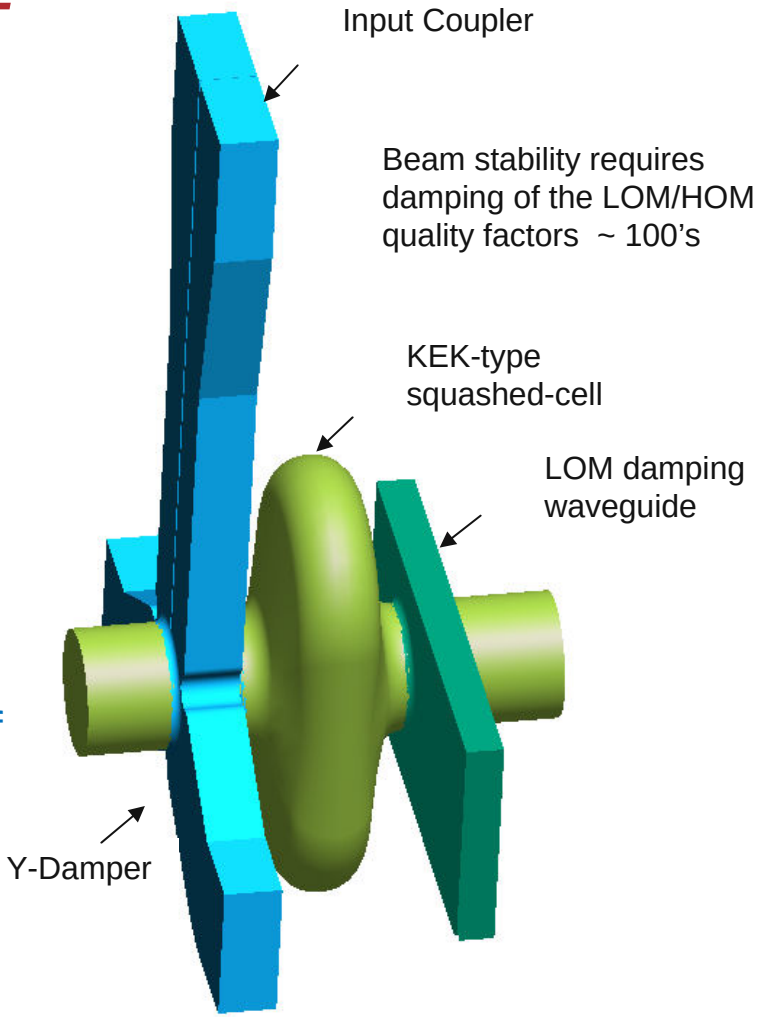
- Feasible to implement in 1 sector.
- Room-temperature copper cavity- “warm” system
  - Extensive feasibility design studies are done.
  - Rf and beam dynamics issues have been addressed.
  - Initial mechanical design of the cavities system is completed.
  - But it has limited performance and operational flexibility
    - *Limited to 100 Hz repetition rate in phase I*
    - *Limited to 1 kHz repetition rate in phase II*
      - Requires new rf power system to support 1KHz operation
    - *Will only work with “hybrid” fill pattern with singlet ( 1 + 8*7)*
    - *Limited x-ray flux*




* Dolgashev, Nassiri, Waldschmidt

# Accelerator Implementation - Option 2*

- It was considered and discussed in 2004-2005 but has not been not fully developed.
- Superconducting RF deflecting cavity "cold" system
  - Preliminary feasibility design is underway.
  - Preliminary rf and beam dynamics analysis is underway.
  - Main advantages of "cold" system:
    - *It allows continuous wave (cw) operation.*
      - Pulse repetition rate @ storage ring rf frequency (352 MHz)
    - *It allows chirping of all bunch fill patterns in the storage ring.*
    - *Higher x-ray flux*




Prototype cavity without dampers to be fabricated in 2008 by JLAB

* Nassiri, Waldschmidt, Li (LBNL)

# *FY08 Action Items*

- Mini-workshop on Feb. 15 with goals of
  - Review and discuss viable accelerator configuration options
    - *Technically sound, feasible and cost effective*
    - *Realistic plans to implement ps-science capabilities at APS*
  - Discuss the options between accelerator and scientific communities
- Workshop in conjunction with the APS User Meeting
  - Science using short x-ray pulses *at the APS*
  - Build consensus on the most time effective and maximum benefit/cost approach.
- Conduct feasibility design studies of superconducting RF deflecting structures and RF systems configuration.
- Perform initial beam dynamics and multibunch instability simulations and analyses.

- Submit a pre-conceptual design proposal to DOE-BES to secure R&D funds.