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Status of the APS Short X-ray Pulse Project

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SPX Project Team Members

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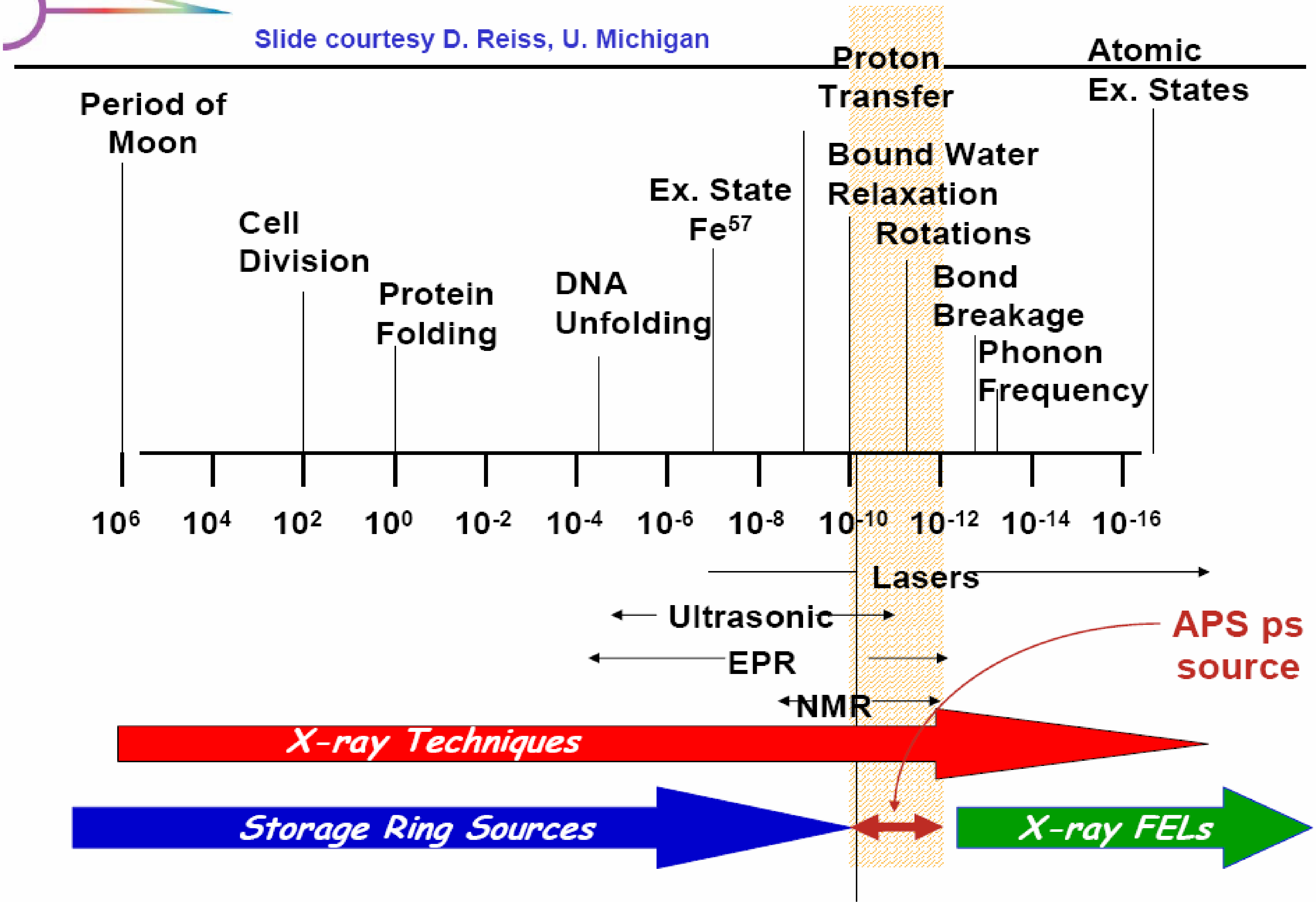
Outline

- Introduction
- Short x-ray pulse generation
- Beam dynamics issues
- Crab cavity design
- Timeline
- Summary

Excerpts from the 2004 Time-Domain Workshop (Aug29 –Sept 1)

- **Summary**
  - "...by far the most exciting element of the workshop was exploring the possibility of shorter timescales at the APS, i.e. the generation of 1ps x-ray pulses whilst retaining high-flux."
  - "... time domain from 1 ps to 100 ps will provide a unique bridge from 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."
- **Recommendations**
  - "The APS should pursue the development of high-flux picosecond beamlines through the use of advanced accelerator techniques. Such beamlines could produce 1 ps x-ray pulses and would be complementary to future LCLS facilities."

Slide courtesy D. Reiss, U. Michigan



Strategic LDRD 2008 submitted†

Ultrafast x-ray tracking of laser-controlled molecular motions

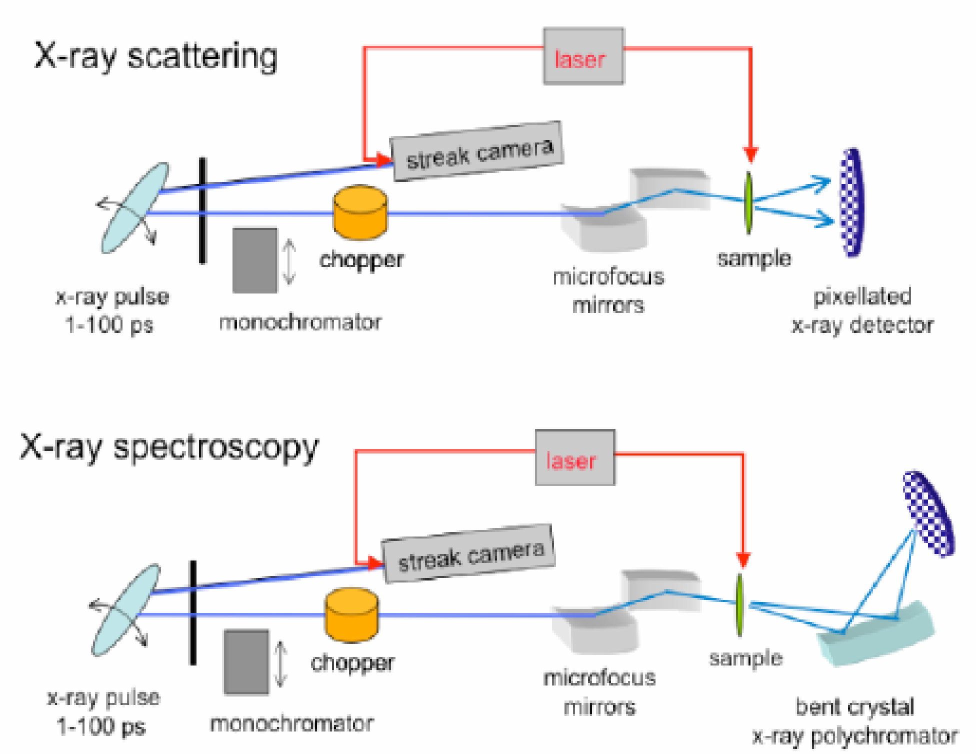
Goal: *Expand science and beamline capabilities to studies of laser-controlled motions in isolated molecule samples (gas or solution phase).*

Science thrust: *Photonic control of molecular motions*
X-ray snapshots of transient molecular species

Beamline thrust: *Enhance flux 100x - pink beam scattering and spectroscopy*

Diverse Team: *Unique SPX capability unites researchers from many parts of Argonne plus significant interest from outside Argonne.*

LDRD team:
Linda Young (CHM)
Lin Chen (CHM)
Robert Dunford (CHM)
Elliot Kanter (CHM)
Bertold Krässig (CHM)
Robin Santra (CHM)
Stephen Southworth (CHM)
David Tiede (CHM)
Stefan Vajda (CHM and CNM)
Bernhard Adams (XSD)
Dohn Arms (XSD)
Klaus Attenkofer (XSD)
Eric Dufresne (XSD)
Eric Landahl (XSD)
Donald Walko (XSD)
Jin Wang (XSD)



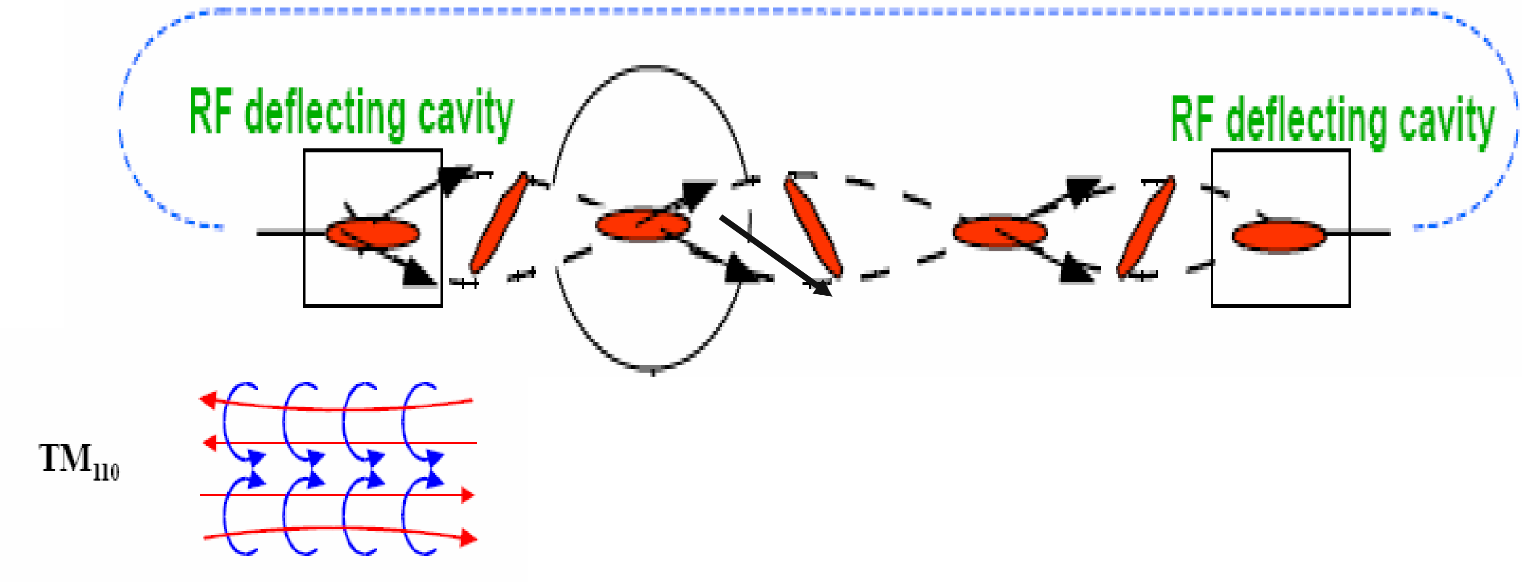
†L. Young (CHM)

Design approaches

- We initially started with superconducting (SRF) deflecting cavity design to provide continuous wave (cw) mode of operation.
- In cw SRF scheme, the short-pulse repetition rate can be as high as the rf frequency of the APS SR, depending on the bunch spacing.
- While femtoslicing gives shorter x-ray pulses, this approach produces significantly higher flux at a much higher repetition rate.

- We concluded “room temperature” copper cavity design can be implemented in a shorter timeframe at much reduced cost.
- Phase I and II of the APS SPX project is based “room temperature” technology.
- CW SRF capabilities will be developed for the Phase III of the APS SPX project.

Crabbing Scheme[†]

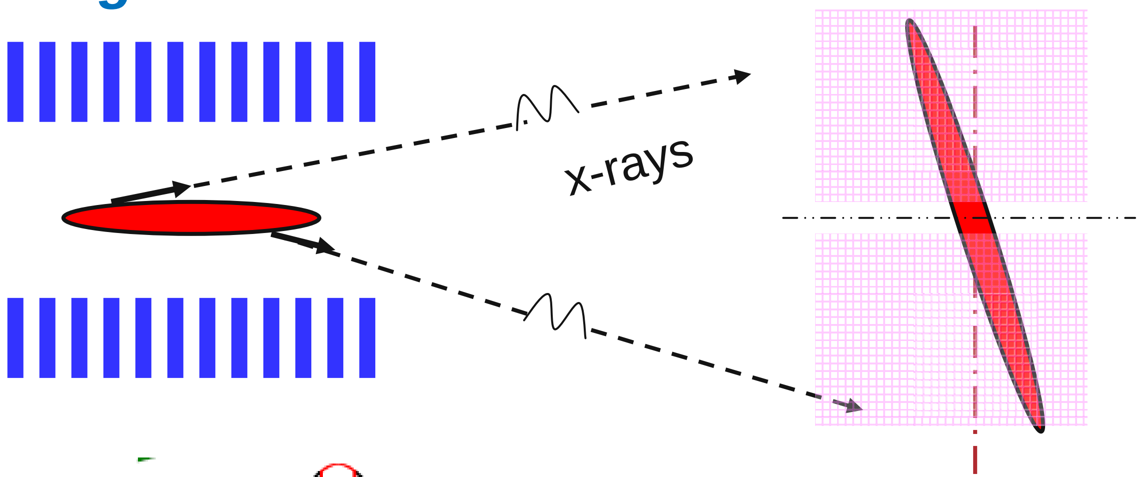


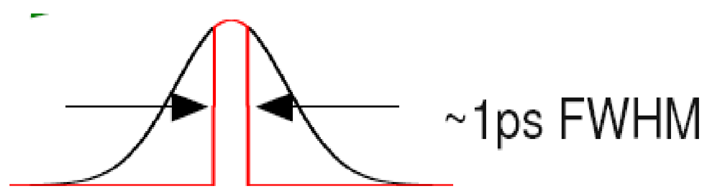
- Deflecting cavity introduces angle-time correlation into the electron bunch
  - "crabbing" the beam
- Electron oscillate along the orbit
- Bunch evolution through the lattice results in electron and photons correlated with vertical momentum along the bunch length
- Second cavity at nπ phase cancels "kick"; rest of the storage ring unaffected

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

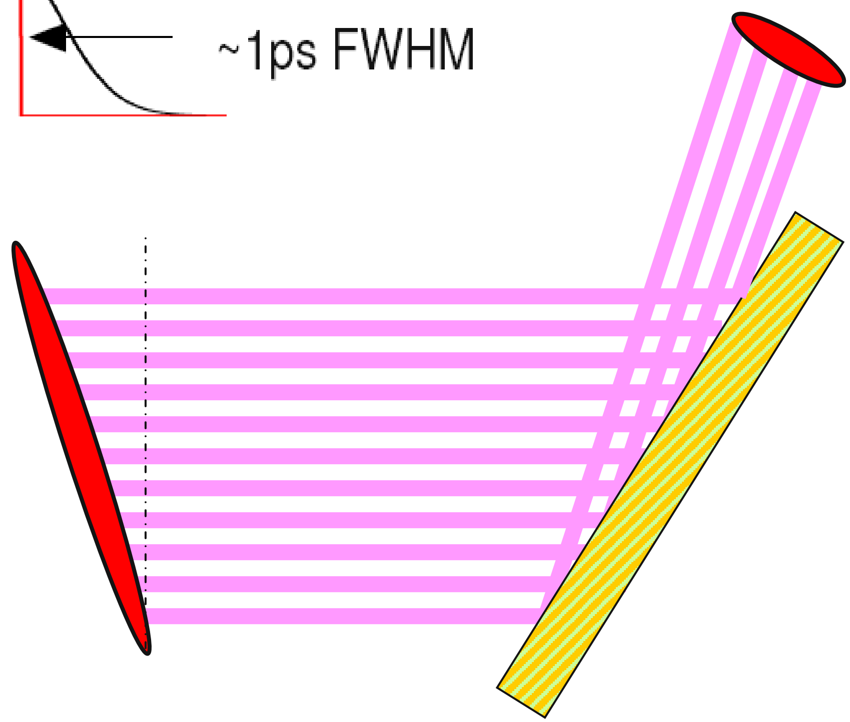
Short x-ray pulse generation

- Slitting, "streak"

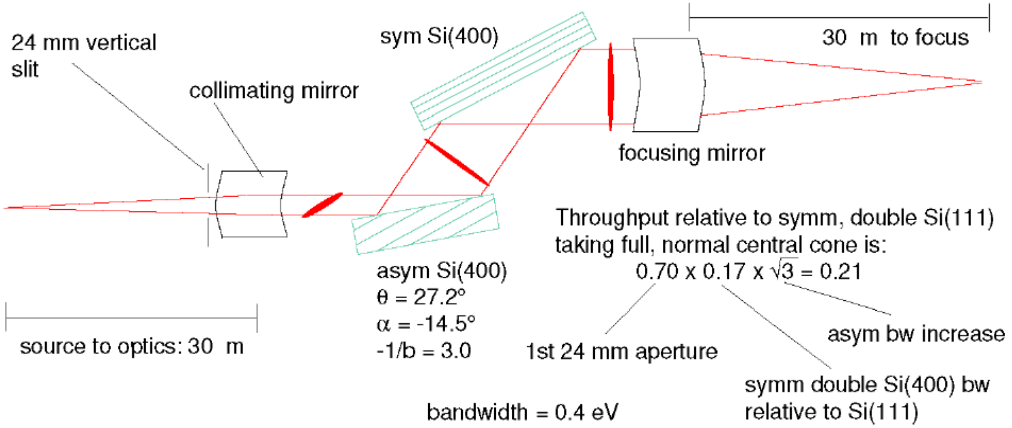


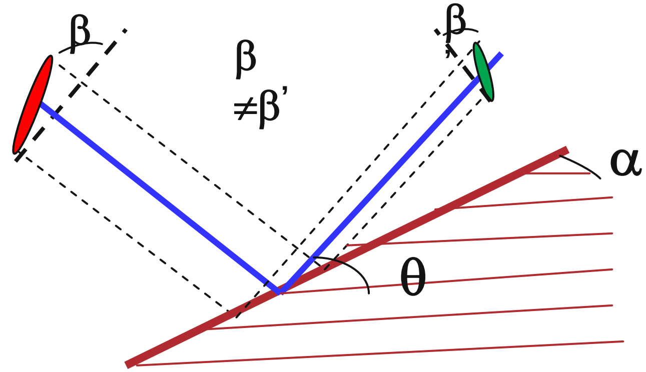


- Compression



X-ray compression optics†





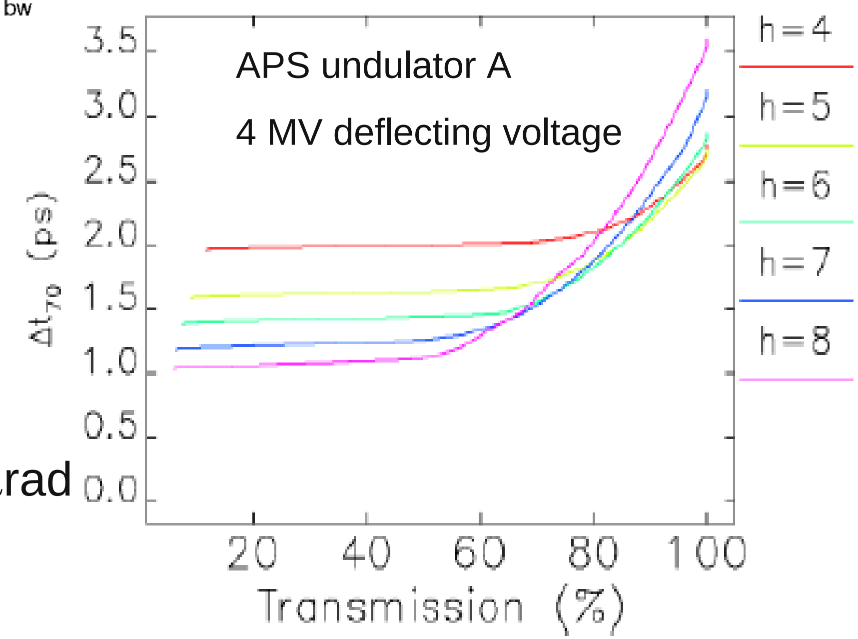
- Compressed pulse length (linear rf):††

$$\sigma_{t,x-ray} = \frac{E}{2\pi h f_0 V}\sqrt{\sigma^2_{y',e} + \sigma^2_{y',rad}}$$

Parameters for APS:

h=8, V=4 MV, $\sigma_{y',e}$=2.0 μrad, $\sigma_{y',rad}$=5 μrad

Calculated compressed x-ray is ~0.5 ps rms.



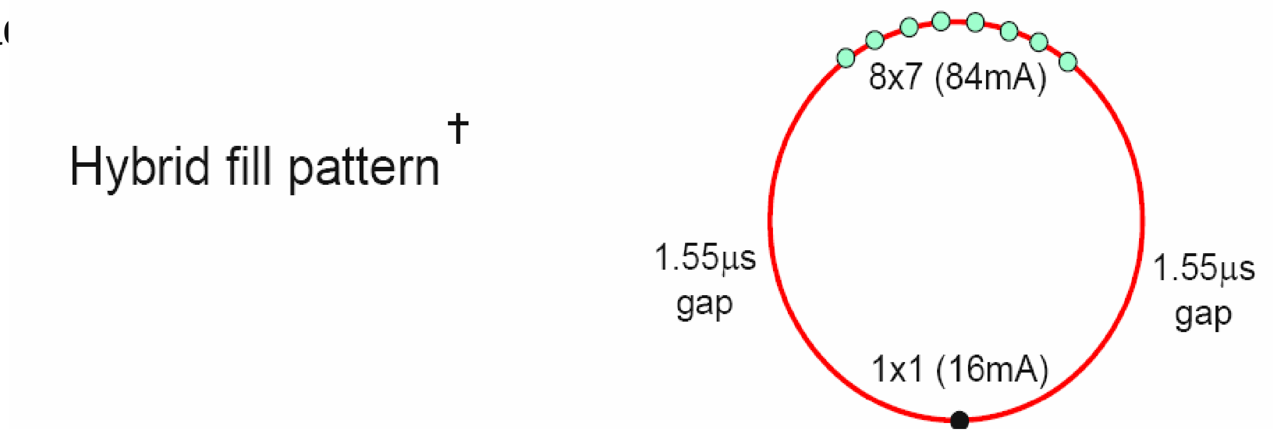
Compression results for 10 keV radiation.††

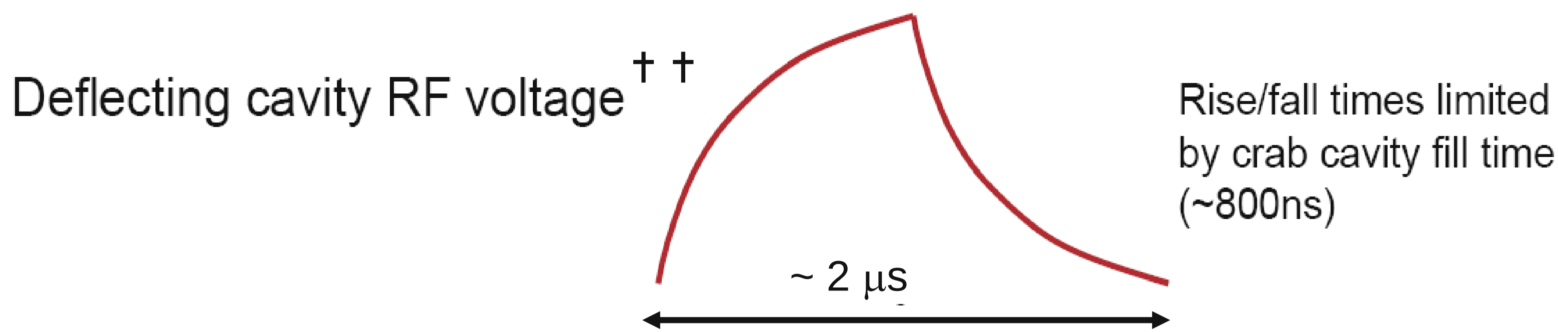
†S. Shastri, R. Dejus, L. Assoufid

†† M. Borland, PRST-AB 8, 074001 (2005)

Technical challenges

- Crab cavities operation must be “transparent” to the APS normal operation outside the “crabbing sector.”
- Under normal operating modes, crab cavity-beam interaction must not induce beam instabilities (transverse and longitudinal) that cannot be controlled by normal a





† J. Carwardine, L. Emery

†† G. Waldschmidt

Beam dynamics issues – collective effects

- The cavity operates in TM_{110} mode (main deflecting mode, vertical polarization)
  - 2815 MHz (8th harmonics of the SR frequency, 351.93 MHz)
- In addition to the main deflecting mode, other frequencies are also present and could be excited by the beam. These are LOM and HOM non-deflecting modes
  - These frequencies are populated in various “passbands”
    - *Monopole*
    - *Dipole*
    - *And higher poles*
- The cavity main design challenge is to reduce the modes growth rate in these passbands for stable SR operation for hybrid fill and 24 singlets.[†]

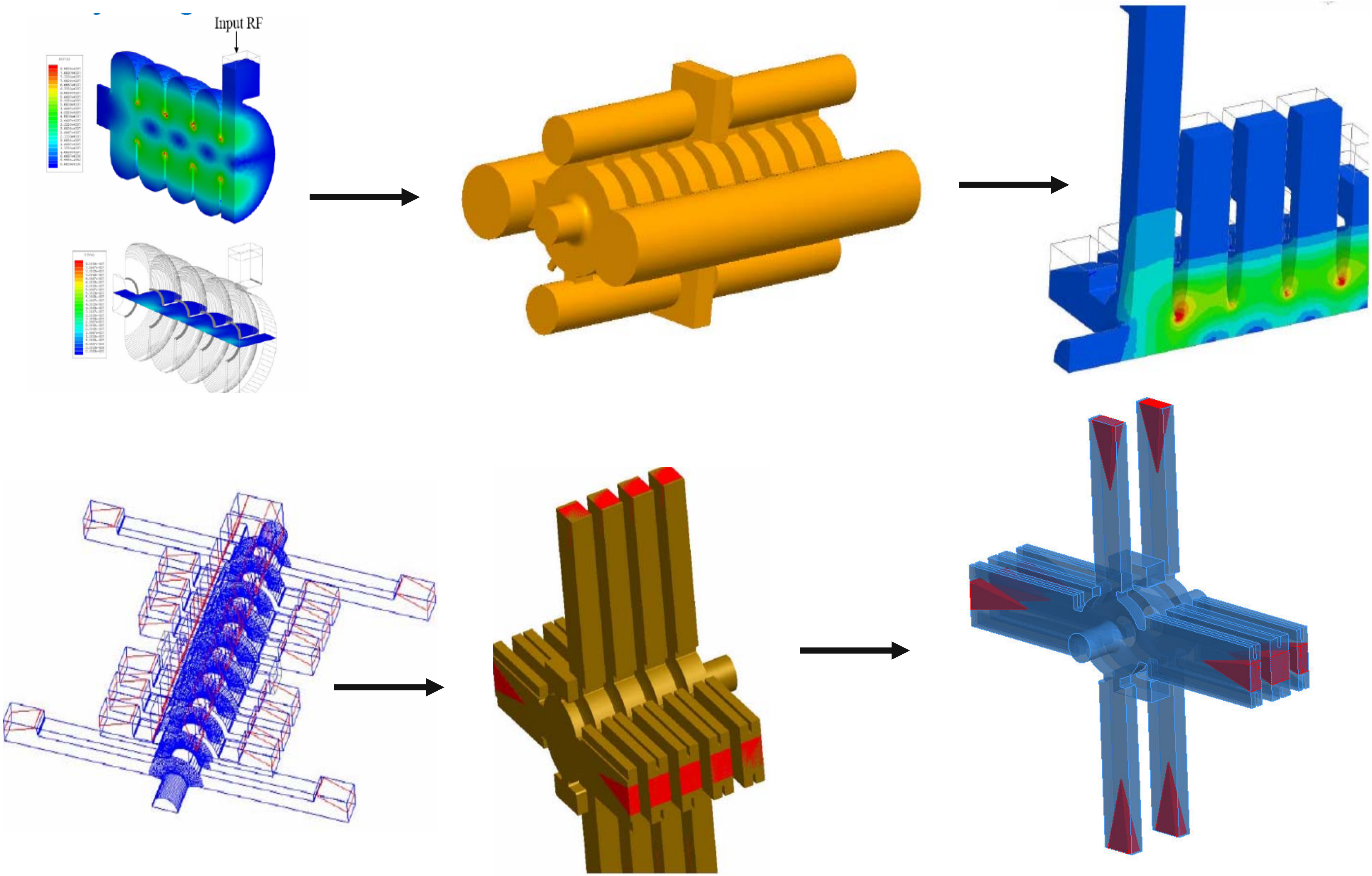
Plane	Growth Rate	Synchrotron radiation Damping Rate	Comment
Longitudinal	60 s^{-1}	208 s^{-1}	Stable
Horizontal	5 s^{-1}	104 s^{-1}	Stable
Vertical	200 s^{-1}	104 s^{-1}	Stable only at 100 mA

- Single bunch: broadband[††]
  - Single bunch limit reduced by 1-2 mA (horiz wake)
  - Present limit 20 mA, deliver 16 mA for hybrid mode is okay

[†]L. Emery, PAC07

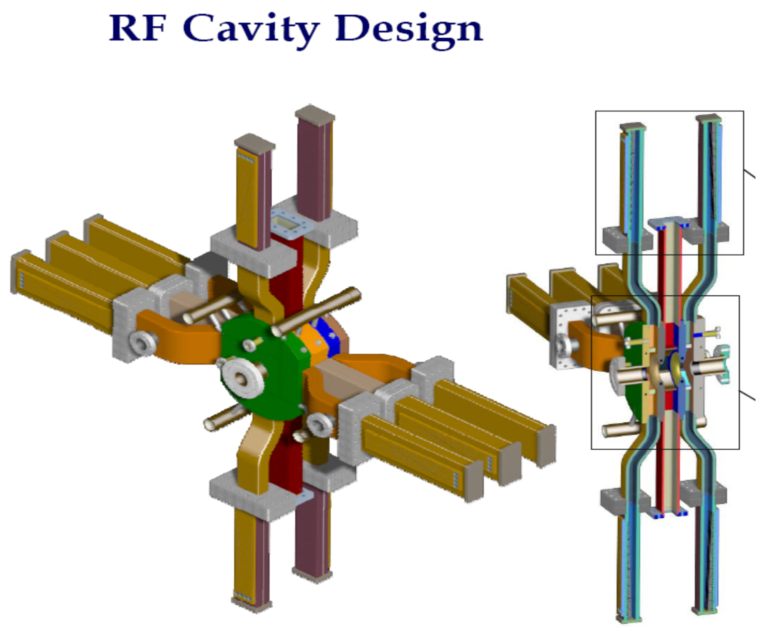
[††] Y.-C. Chae, K. Harkay

“Room temperature” Cavity design evolution†



†V. Dolgashev, SLAC

Crab cavity mechanical design†



Thermal analysis††

- Analysis was performed on the cavity
- A complete analysis of rf heat loss, thermal, stress ands frequency shift was performed for various iris thickness and radii
- The analysis concluded that the frequency shift due to rf heat loss can be controlled with cooling water temperature.

†Courtesy: M. Givens and L. Morrison

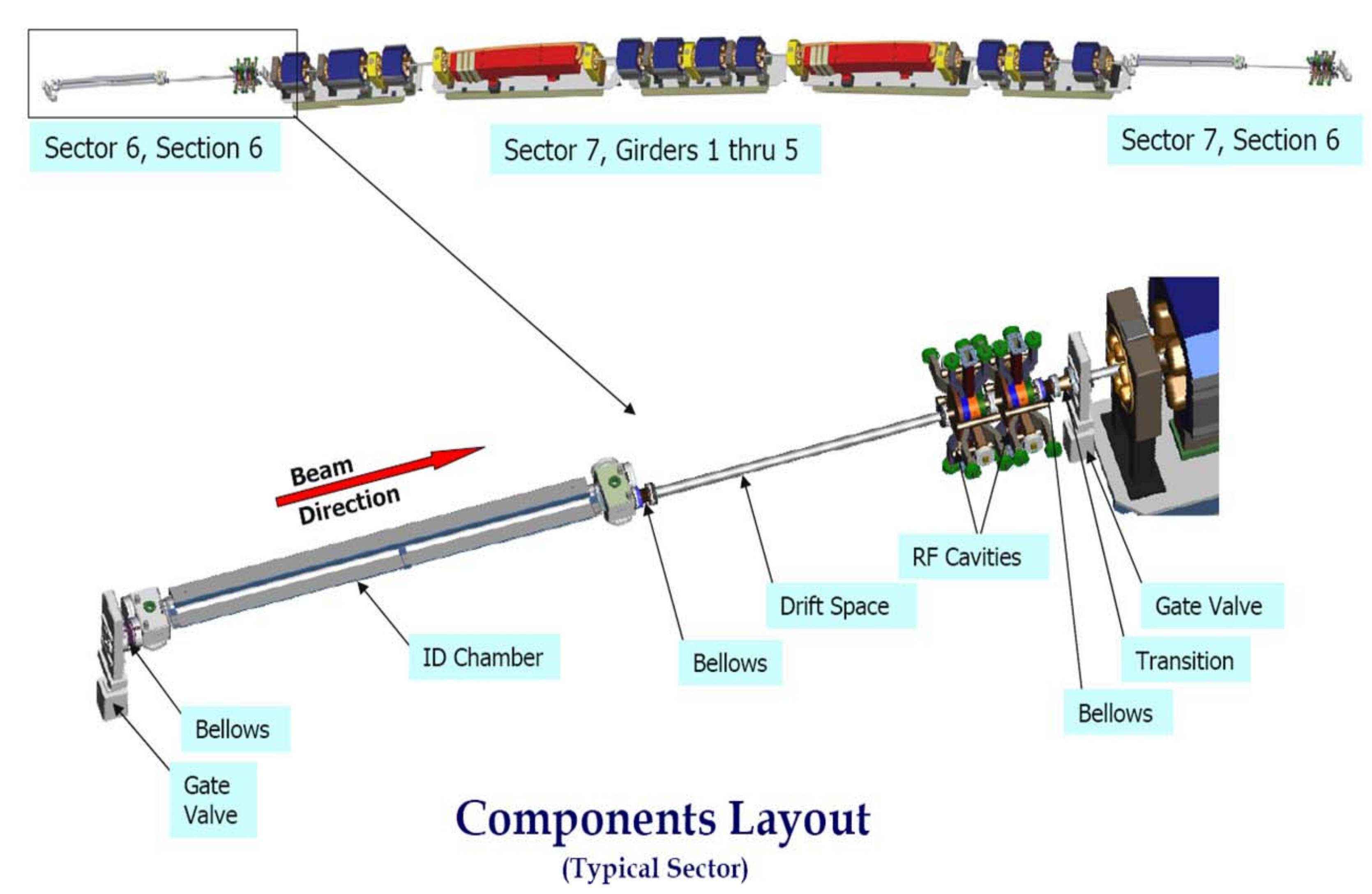
†† P. Den Hartog

Design parameters

Operating frequency	2815 MHz
Nominal RF pulse length	1.3 μs
Number of cell per cavity	3
Cavities layout	2 downstream of S6 ID 2 downstream of S7 ID
Nominal operating deflecting voltage per cavity	2 MV
Nominal operating rep. rate	Phase I ≥ 120 Hz Phase II 1 kHz
Max operating rep. rate for thermal load and mechanical stress analysis	1 kHz
Single bunch threshold	19 mA
Nominal SR beam current	102 mA
Max SR beam current (stability criteria)	202 mA
Longitudinal singe-particle damping rate	208 s^{-1} †
Transverse single-particle damping rate	104 s^{-1} †
RMS bunch length (for 56 singlets in 202 mA hybrid mode)	37 ps †

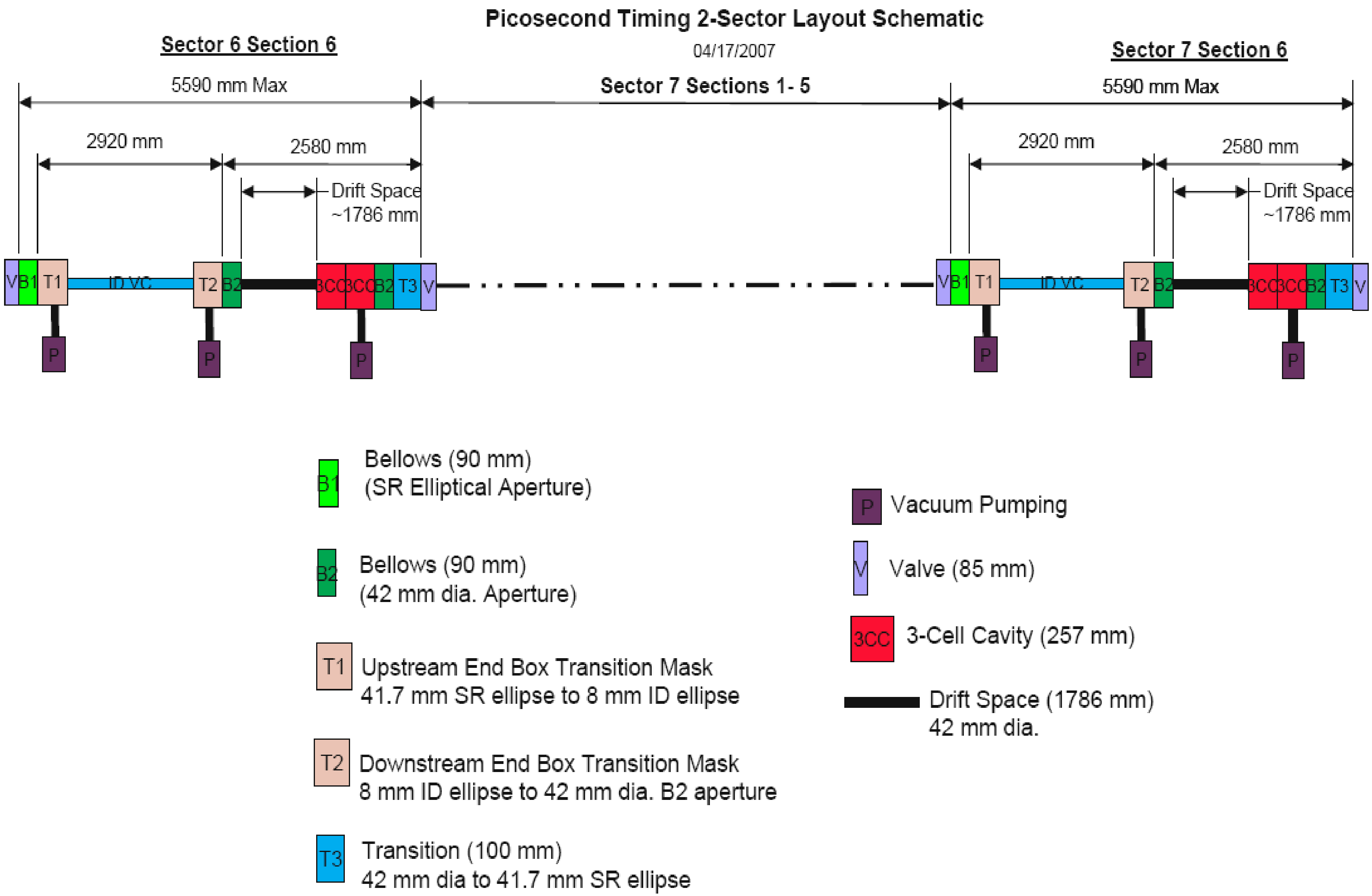
† L. Emery, OAG-TN-2007-023

Two sectors layout†



†Courtesy: L. Morrison

New two-sector layout†



†Courtesy: L. Morrison, P. Den Hartog

Timeline

External crab cavity design review	August 07
Begin SPX infield construction	August 07
Place the order for 2815 MHz klystron	August 07
Final cavity mechanical design	September 07
Order cavities (5)	October 07
SPX infield building Beneficial Occupancy	December 07
Receive prototype cavities (2x 3-cell)	March 08
Install 2x3-cell cavities in S7 (passive)	May 08 SD
Receive remaining cavities (3)	June 08
Receive klystron	July 08
Begin cavity power test and characterization in ITS	July 08
Install cavities and start system commissioning	**September 08 SD**

Summary

- SPX implementation will provide a unique opportunity to conduct experiments using high-flux picoseconds x-rays.
- We started this project fully aware of all the challenges and technical difficulties.
- We have work hard to successfully address many critical accelerator physics, rf, thermal, mechanical, controls issues that have been very challenging and unique in nature. Our baseline design reflects this collective work.
- There are few cavity design issues remain to be addressed in weeks time.
- We are working toward meeting Phase I milestones for September 08.
- We will pursue design and implementation of SRF deflecting cavities system in phase III to provide cw capabilities.