The Sector 1 Perspective on Accelerator Upgrades and Somewhat Related Topics

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Sector 1 Coordinator

3/29/02

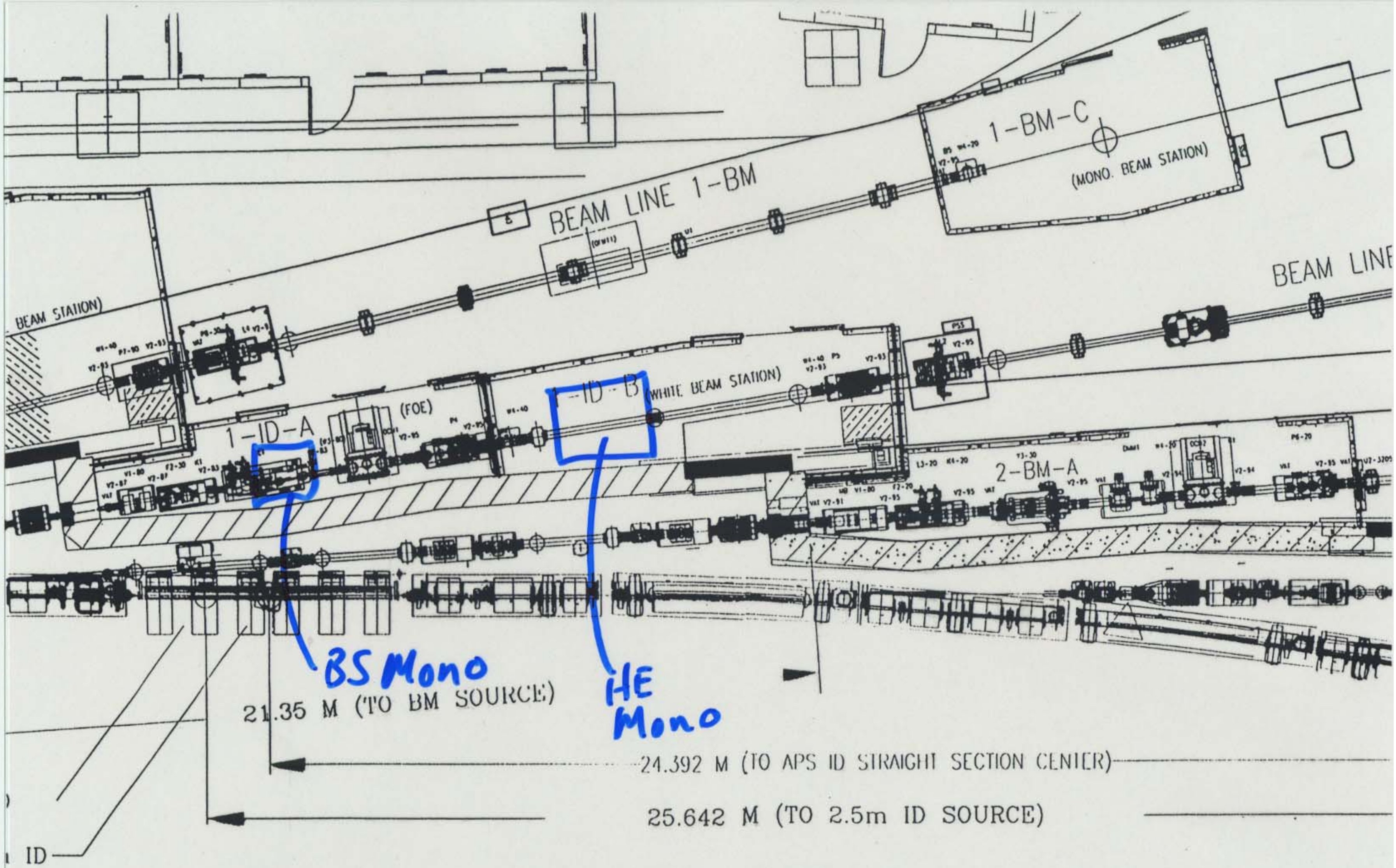
Issues to Address

- Insertion devices/vacuum chambers
- Storage Ring Energy
- Storage Ring Current
- Beam emittance/β functions
- Timing
- Stability
- Top Up

Sector 1 Scientific Programs

- High Energy X-ray Optics and Techniques
- X-ray Optics Development
- Time Resolved X-ray Techniques

- **Other Sector 1 Activities**
  - Support of XFD engineering
  - Test Bed for Novel Experiments
  - Support of Developing CATs
  - Independent Investigators

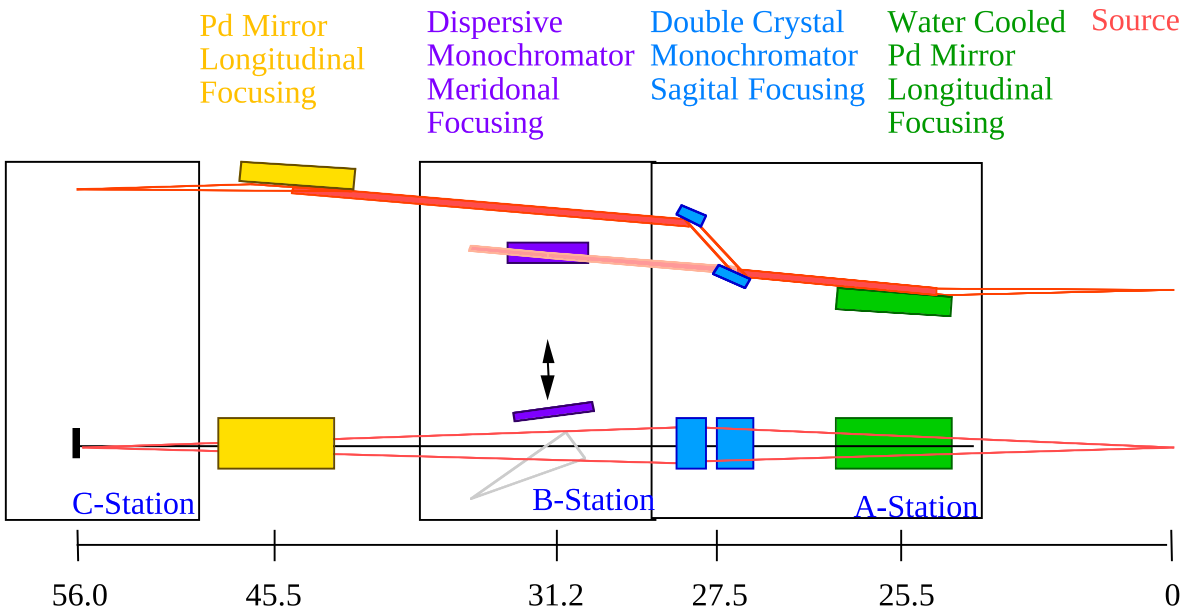


- APS DIFFERENTIAL PUMPING SYSTEM
B1 CF150 100 ID100 BELLOWS
V2-92 - CF250-200 ID150X200 BELLOWS
V2-93 - CF200-200 ID150X200 BELLOWS
W4-40 - ID & BM BL DUAL WINDOWS CF150
OCM1 1-ID DOUBLE CRYSTAL MONOCHROMATOR
OFM3 - 3-BM MIRROR
OFM4 - 2-ID FIRST HD MIRROR

1-ID Optics

- White Beam
- Kohzu DCM (1-ID-A)
  - Si (111) 6 ➔ 19 keV
  - Si (311) 10 ➔ 45 keV
- High Energy Mono (1-ID-B)
  - Si (111) 48 ➔ 300 keV
    - mostly 65 to 85 keV
- No Mirrors
- All LN_2 Cooled
- No focusing
- NID mono coming soon

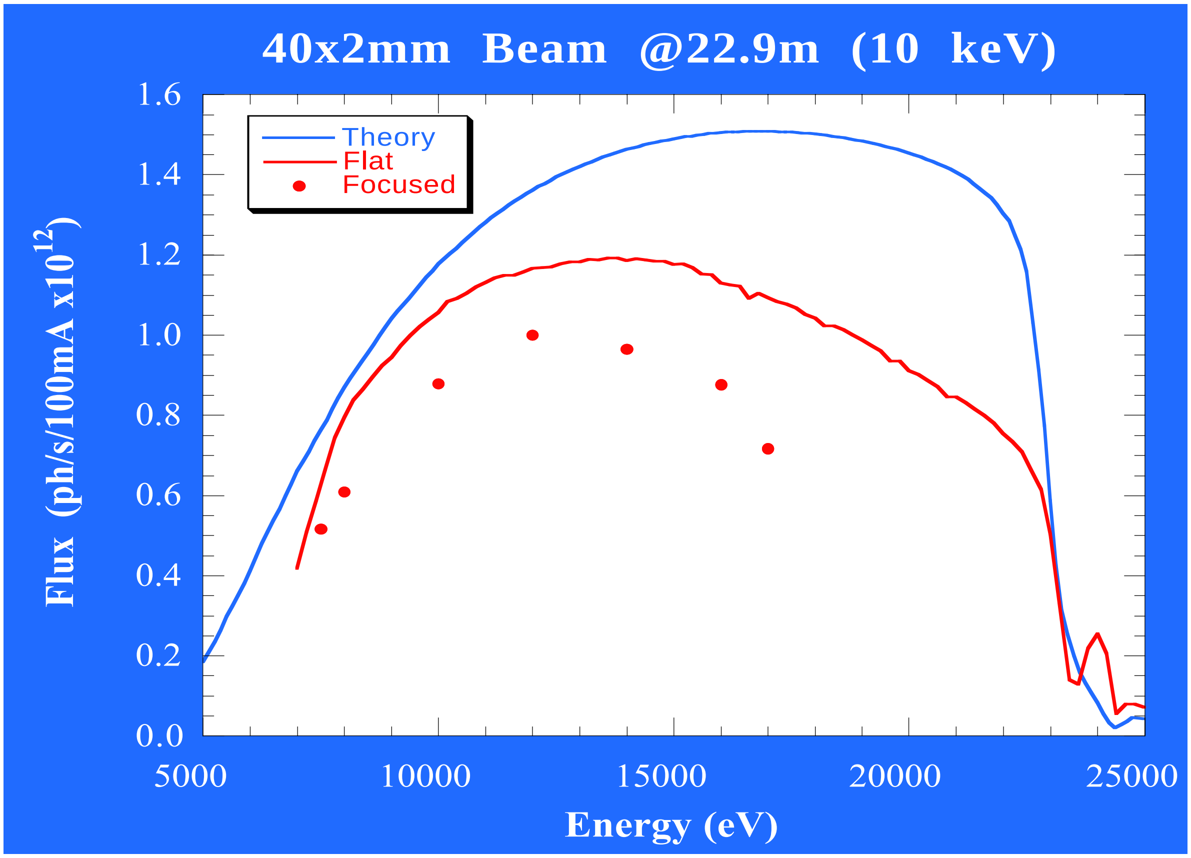
1-BM Optics



B-Station White,Pink, Focused Mono (E = 5 – 500 keV)

C-Station Focused Mono (E = 5 – 24 keV)

Flux in 1-BM-C



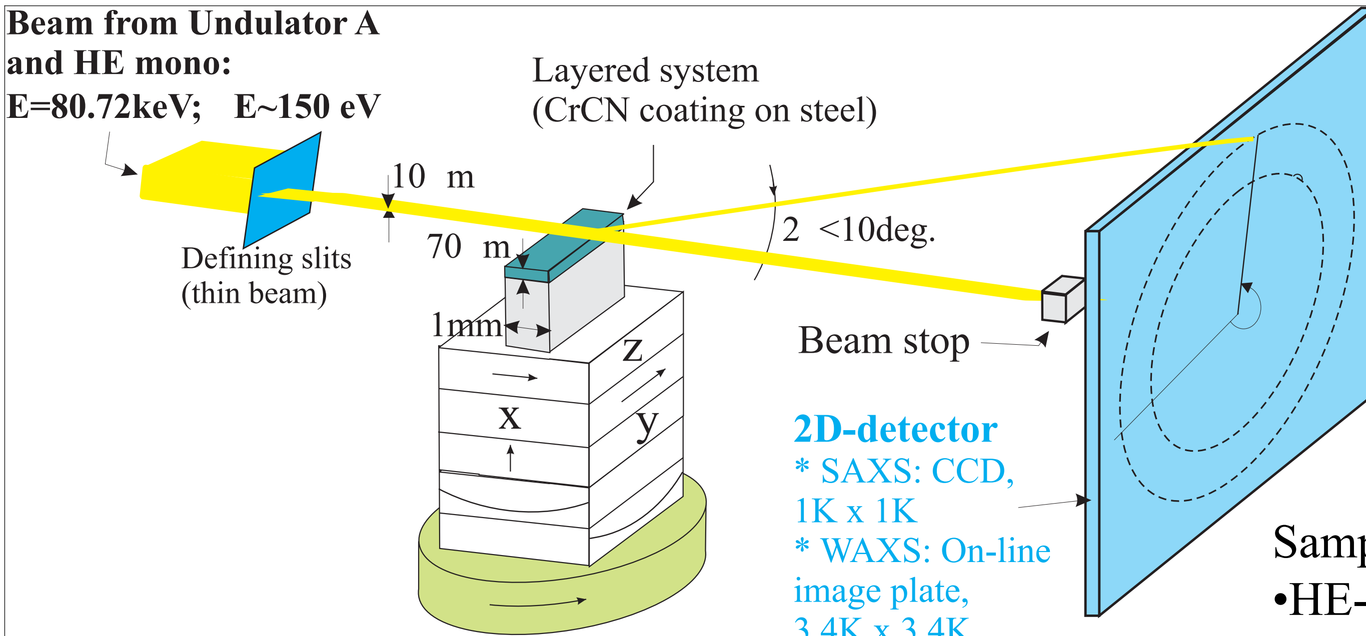
1-ID (1 x 1 mm@65 m) ~1.0 x 10^{13} ph/s

High Energy Program

- Optics Development
- Stress/Strain/Texture
- Powder Diffraction
- Small Angle Scattering
- Diffuse Scattering
- Amorphous Scattering
- Trace Element Analysis
- Imaging
- Miscellaneous
  - Archaelogy

1-ID-C

High-energy x-ray scattering: probing layered systems



Sample-detector:
- HE-SAXS=5m
- HE-WAXS=1m

FEATURES

High-energies:
- Penetration power: bulk probe
- Large q-space -fast- with 2-D detectors ($t_{exposure}$~10 sec)

Measurement Geometry:
- Direct depth resolution to ~10µm
- Perform WAXS,SAXS (and imaging) with little change in setup

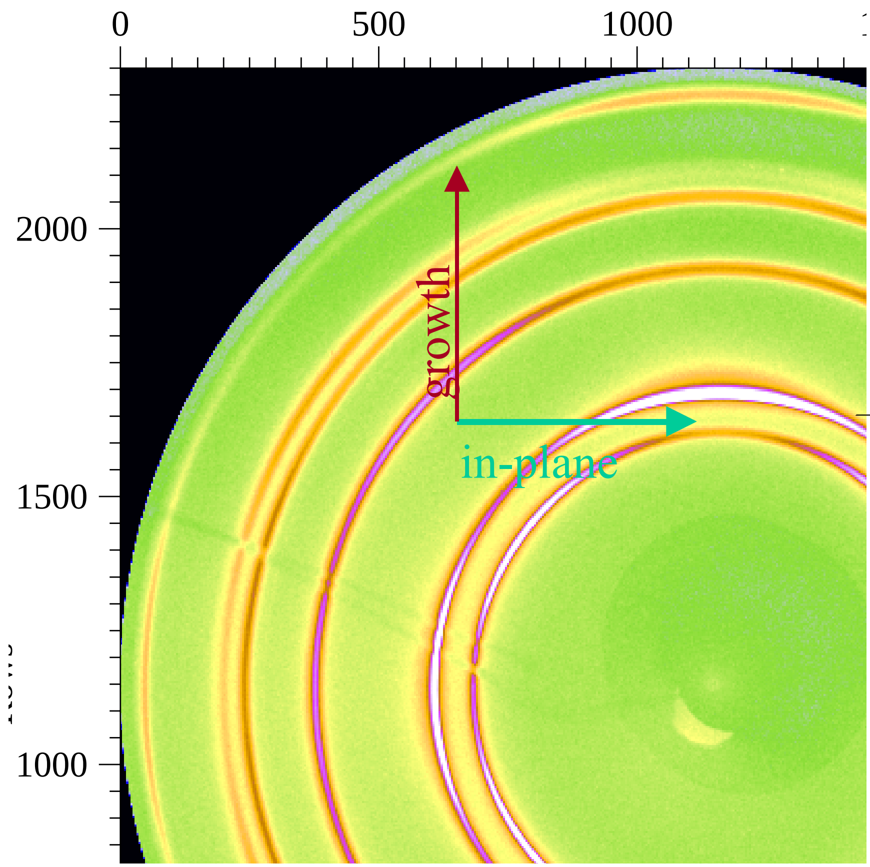
J. Almer, U. Lienert, D. Haeffner, M. Odén

1-ID-C

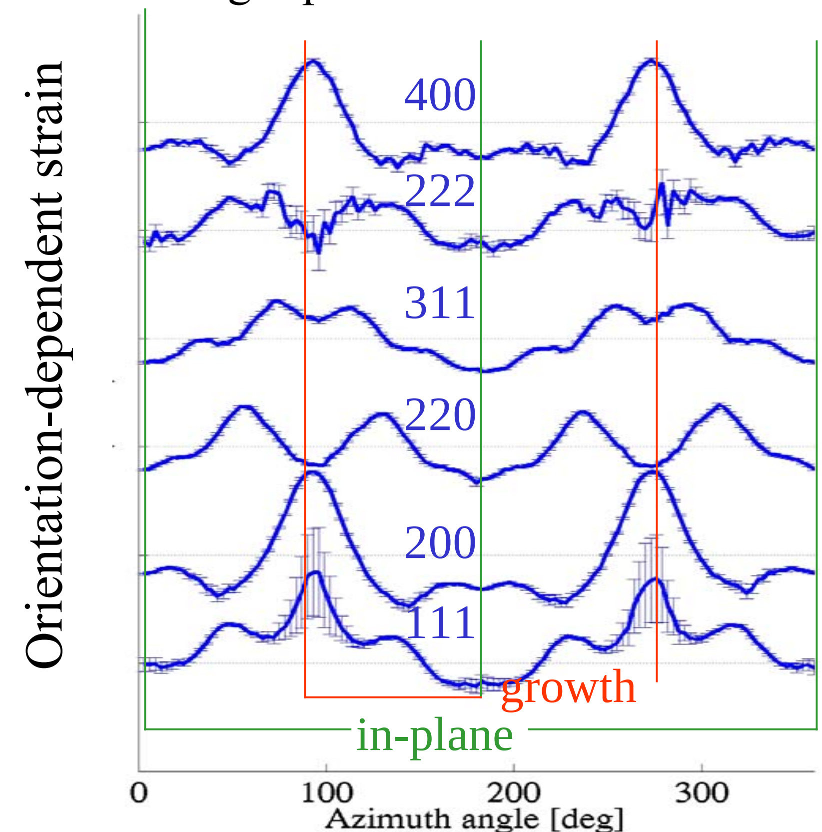
HE-WAXS : strain and microstructure

CrCN coating on steel

MAR 2-D detector: d_{min}~ 1A



[100] growth texture
Single-phase cubic structure



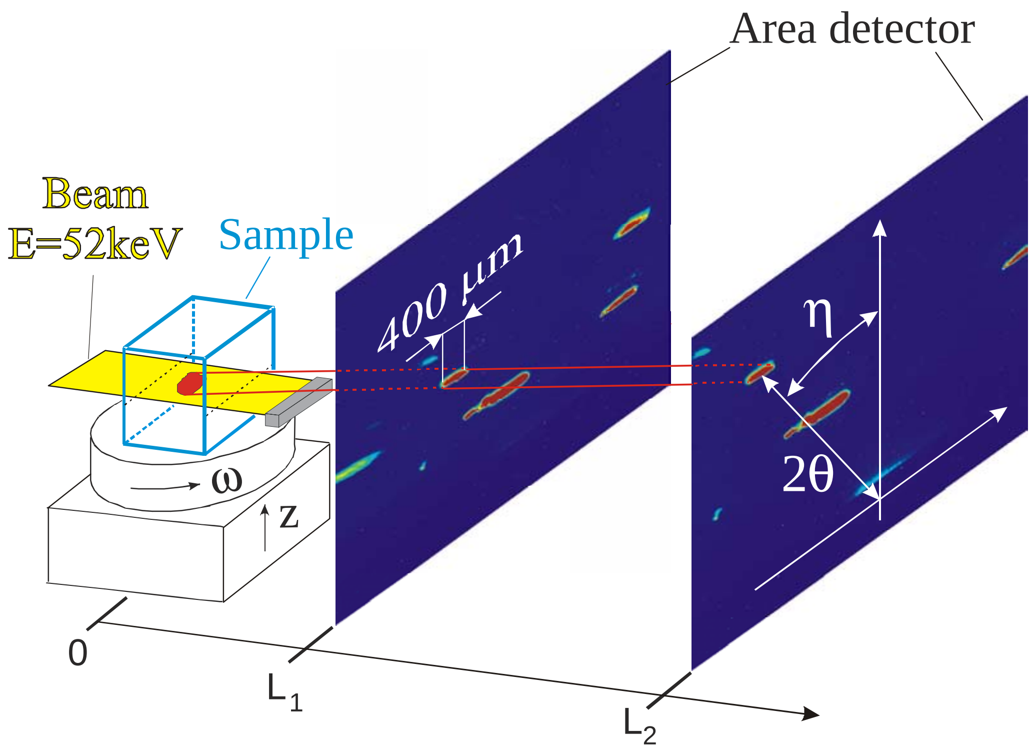
UNIQUE CHARACTERISTICS

Strain Texture Phase ID	simultaneous = fast	→	*in-situ dynamical studies*
	with **direct** depth resolution	→	*probe of buried interfaces*

J. Almer, U. Lienert, D. Haeffner, M. Odén

Grain boundary mapping: Tracking

- Dependence of abnormal grain growth in Al on grain orientation, shape and neighborhood



- Line focus
- Reflections by ω-rotation
- Projects grain cross section onto detector
- Backtracing => grain outline
- Grain orientation
- Some minutes per layer

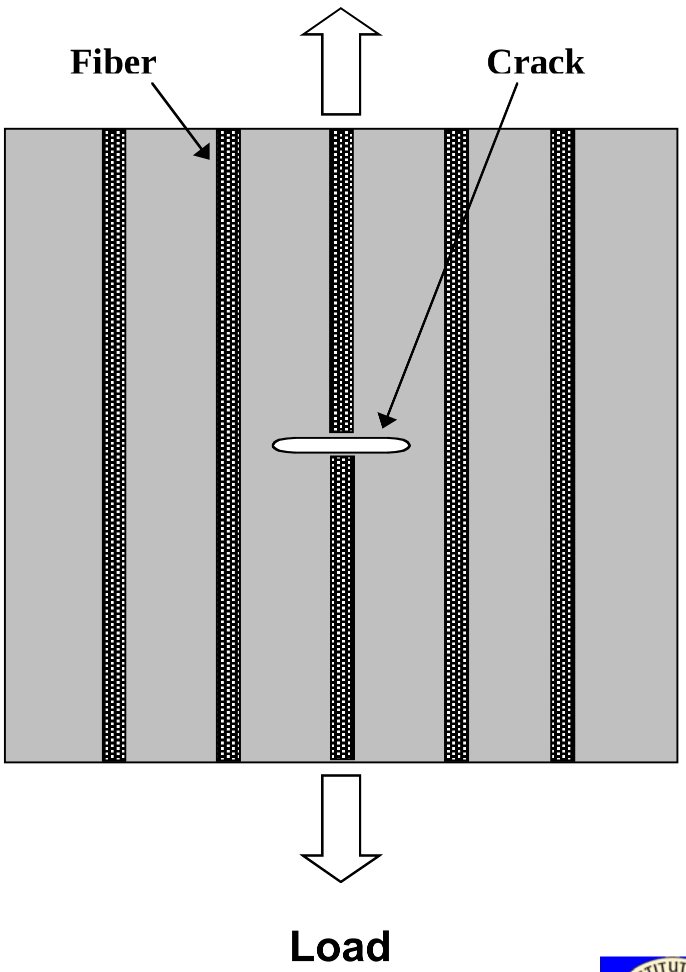
- Limitation: mosaic spread

H.F. Poulsen, J. Applied Cryst., 2001
R.M. Suter, D.C. Hennessy, U. Lienert, 1-ID-C

Damage Evolution in Fiber Composites

E. Ustundag, California Institute of Technology

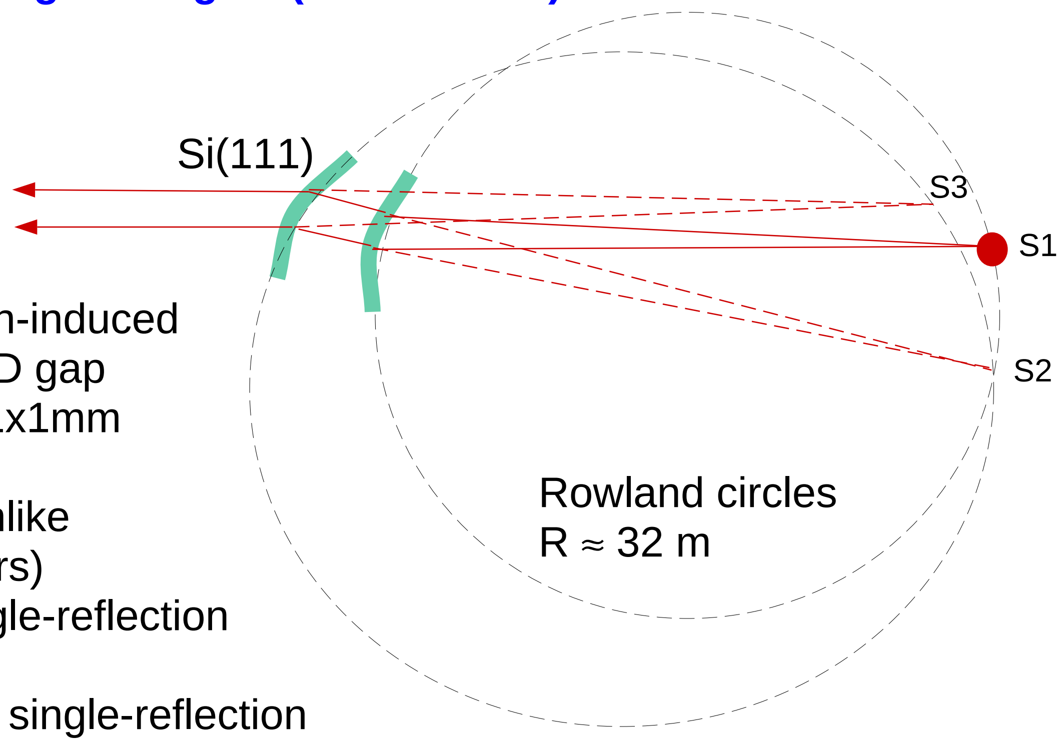
- Internal damage (e.g., fiber breaks) can have a significant effect on the lifetime of a composite.
- Measurement of internal stresses due to this damage is very difficult (only diffraction offers a complete characterization capability).
- Systematic study is underway to combine X-ray and neutron diffraction with micromechanics modeling to determine the evolution of internal damage and stress state in composites.
- Results will be very important in lifetime prediction and design of composites.
- Constitutive laws that govern the *in-situ* mechanical behavior of components in a composite are also expected to be determined.
- Research funded by DOE and NSF.



Sec. 1: High-Energy X-Ray Optics Development

Cryogenically-Cooled Bent Double-Laue Monochromator for High Energies (50 - 200 keV)

S. D. Shastri

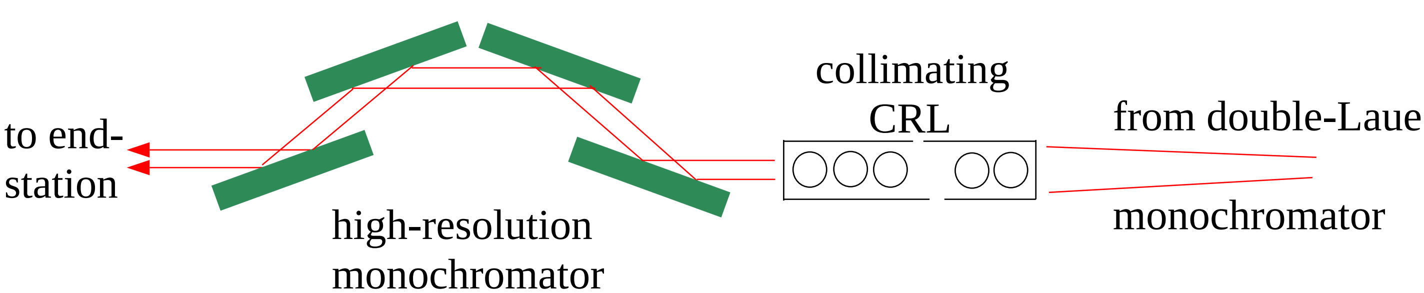


Properties:
- cryo-cooling, no filtration-induced flux sacrifice at closed ID gap
- high flux >10^{12} ph/s in 1x1mm aperture at 60 m
- brilliance preserving (unlike mosaic monochromators)
- fully tunable (unlike single-reflection schemes)
- in-line, fixed exit (unlike single-reflection schemes)
- over 10 times more flux than flat crystals, but **without increased energy spread** ($\Delta E/E=10^{-3}$)

In Development: Higher Energy Resolution

A narrower energy window ($\Delta E/E=10^{-4}$ or better) would benefit:

- high-resolution powder diffraction and stress/strain measurements (i.e., lineshape analysis)
- anomalous scattering
- excitation of nuclear resonances (e.g., nuclear lighthouse effect)
- high-resolution spectroscopy (e.g., Compton scattering, atomic physics)
- improved stability

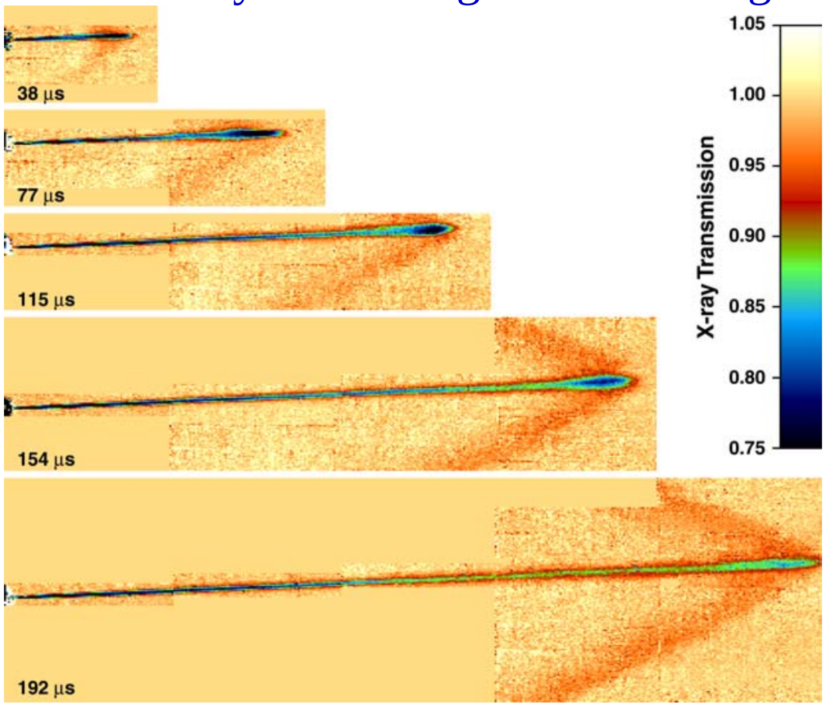


Time Resolved

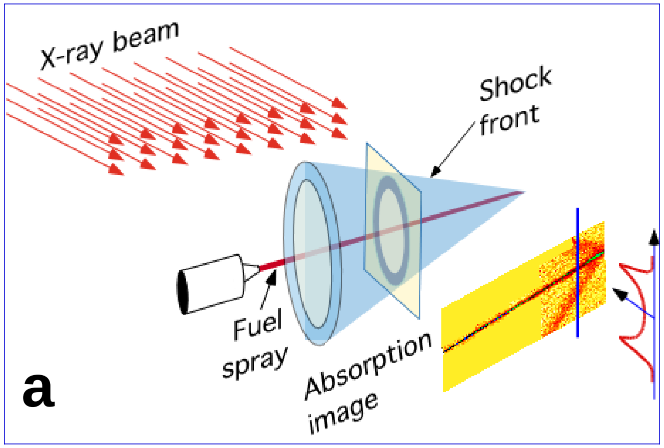
- Fuel Sprays
- Nanoparticle Diffusion in Polymer Films
- Fast XANES
- Powder Diffraction
- Pump-Probe Studies

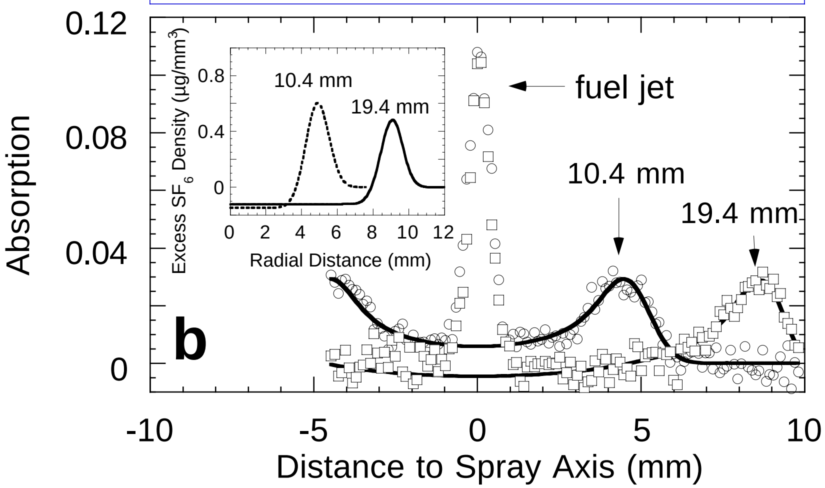
Fuel Sprays Project - Diesel Injections

Directly visualizing shock waves generated by high-pressure diesel sprays



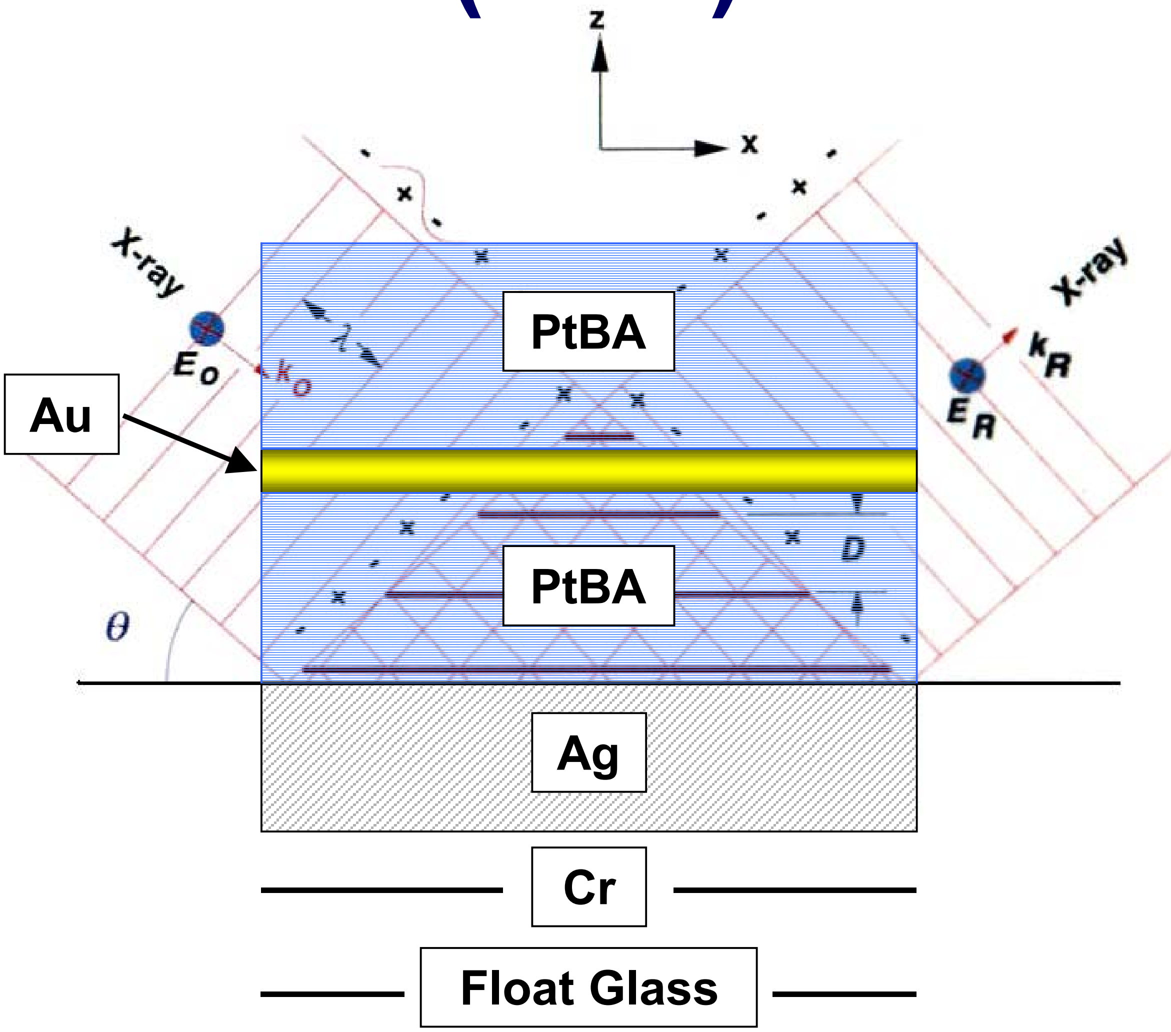
Deconvolution of the Mach Cone - Gas density distribution





- Quantitative evaluation of the shock waves
- Fast 2-D detector proven to be extremely effective
- Fluid dynamics simulation should provide insights on the high-pressure and high-speed liquid jet
- First set of data for validating simulation models

X-Ray Standing Waves Generated By Total External Reflection (TER)



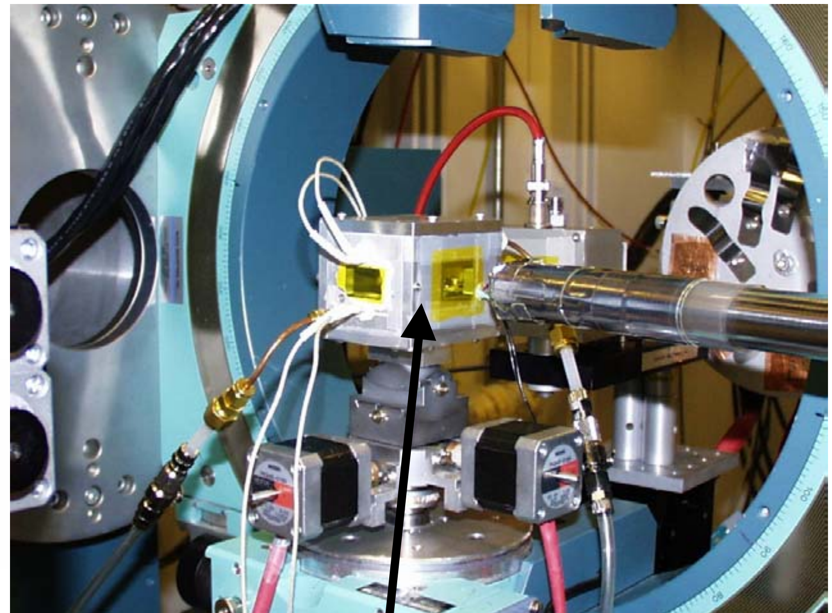
$$D = \frac{\lambda}{2\sin\theta}$$

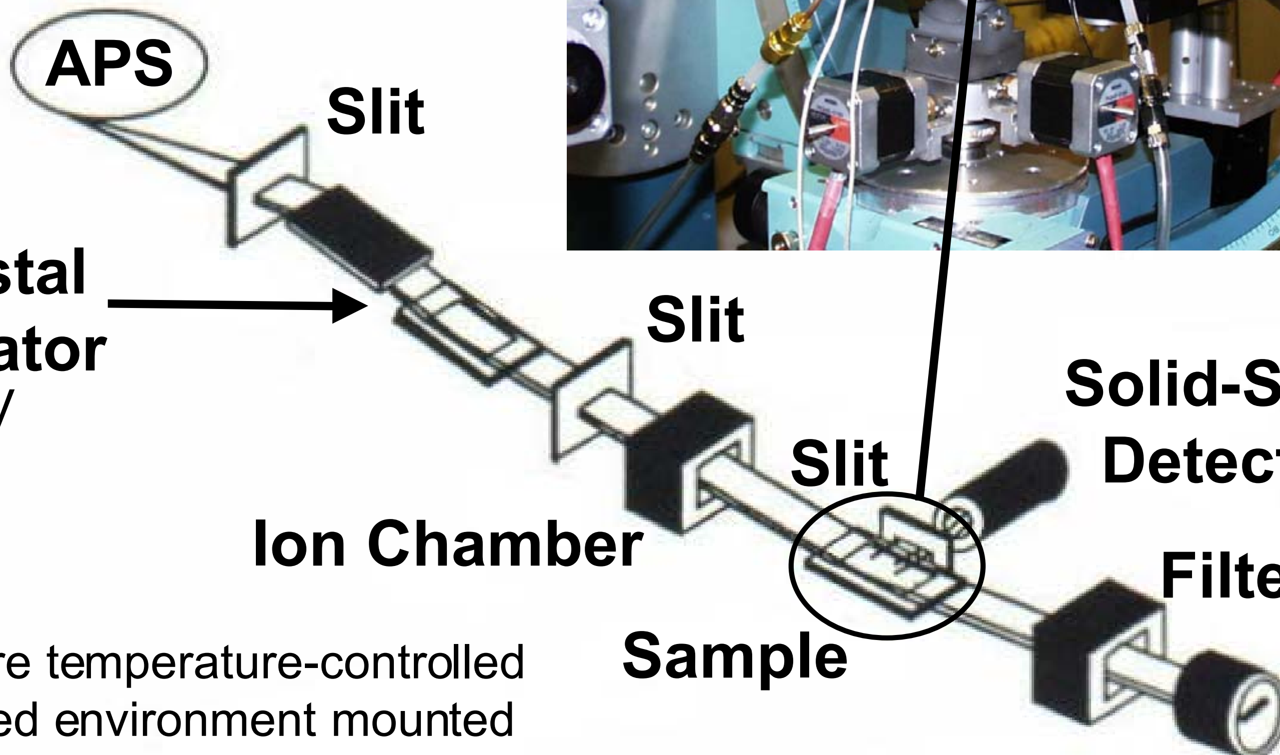
Bedzyk et al., *Physical Review Letters*, **62**, 1989.

Experimental Setup

1-BM-C beamline at APS

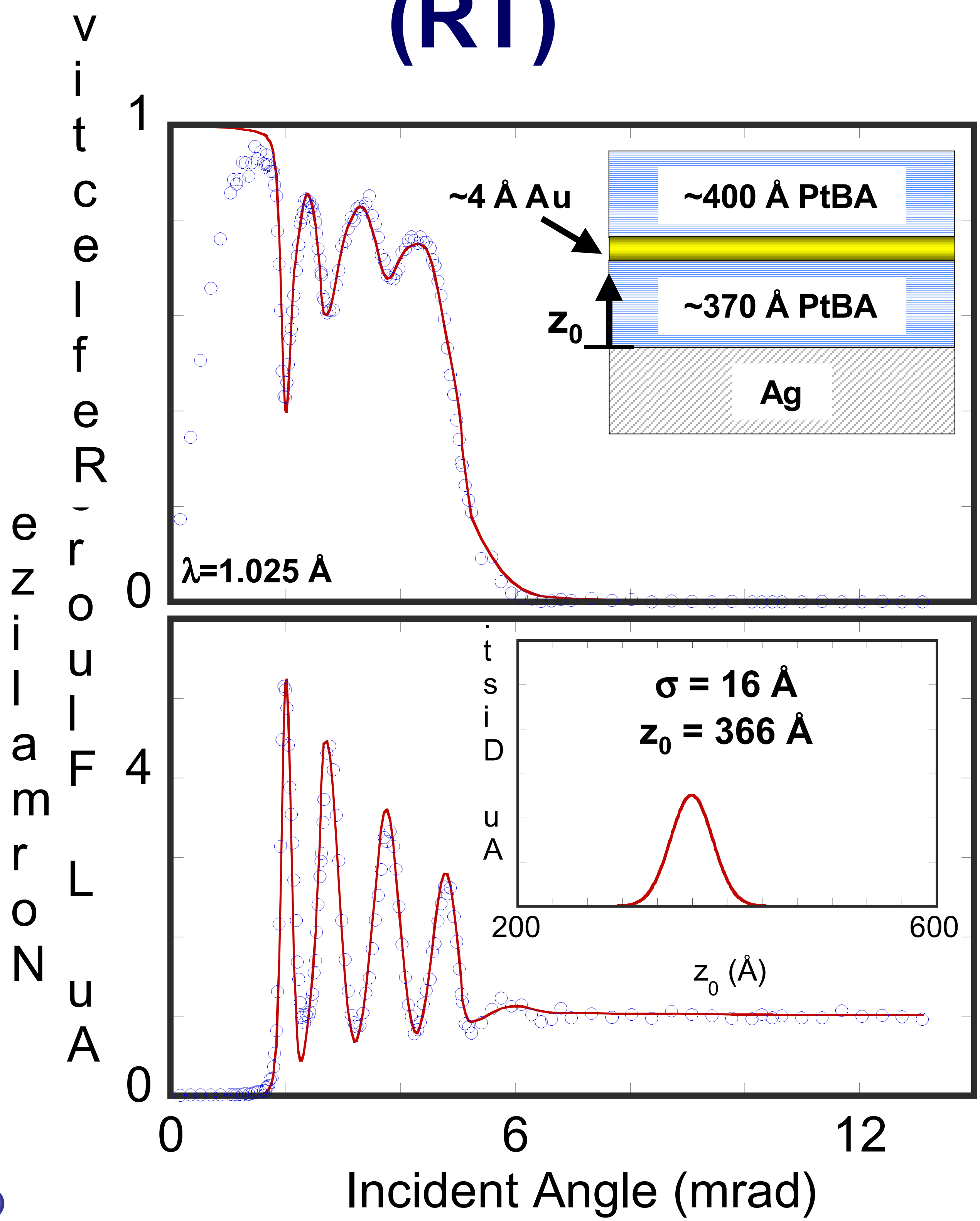
Beam size ~ 2.25 (H) x 0.045 (V) mm^2
Flux ~ 5 x 10^8 photons/s/mm^2





Samples are temperature-controlled in a He-filled environment mounted on a four-circle diffractometer.

Reflectivity & XSW Fit (RT)

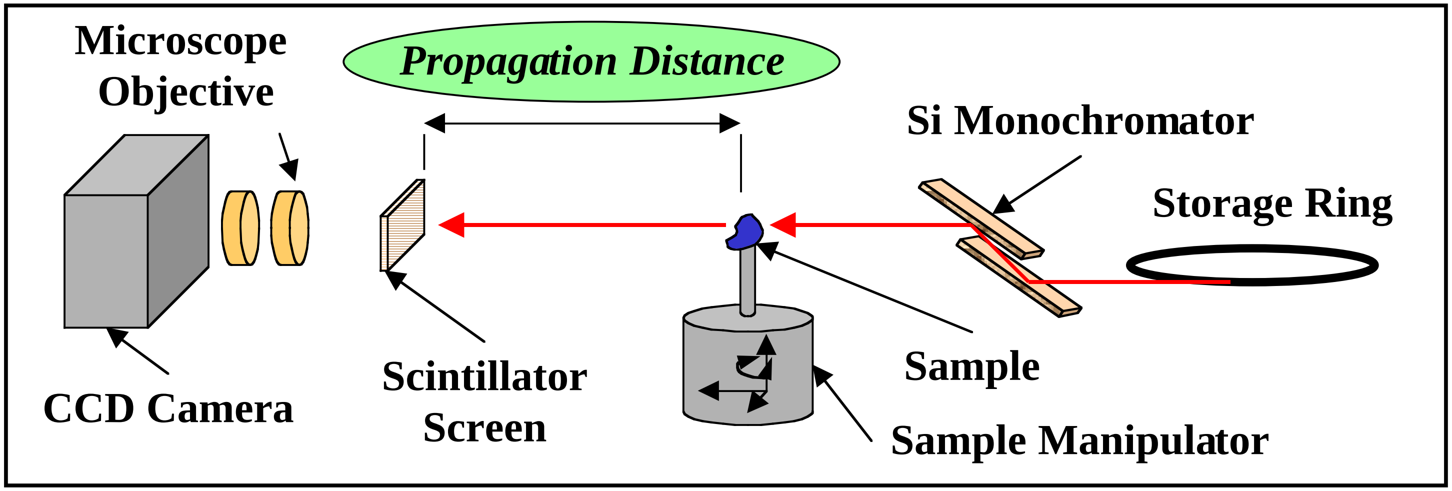


Optics

- Interferometry
- Phase Contrast Imaging
- HHL Optics
- Si-Ge Graded Crystals

Phase Contrast Imaging

Experimental Setup



Principle

Besides absorption, contrast occurs from interference due to Fresnel Diffraction

Advantages

Low dose, simple setup, high resolution, low and high energy, light and heavy materials.

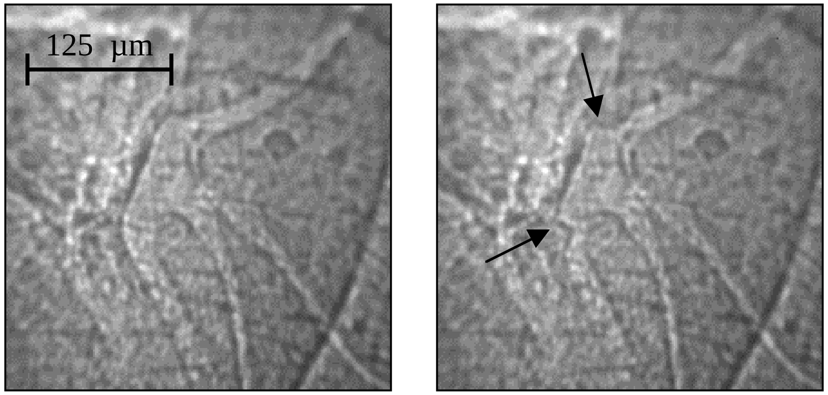
W-K. Lee , K. Fezzaa, J. Wang, SRI-Cat, UPD, Argonne National Laboratory.
S. Stocks, North Western University, Chicago IL.
M. W. Westneat, Dep. Of Zoology, Field Museum of Natural History, Chicago IL.

Phase Contrast Imaging

Some Applications

Biological samples
(10-22 keV)

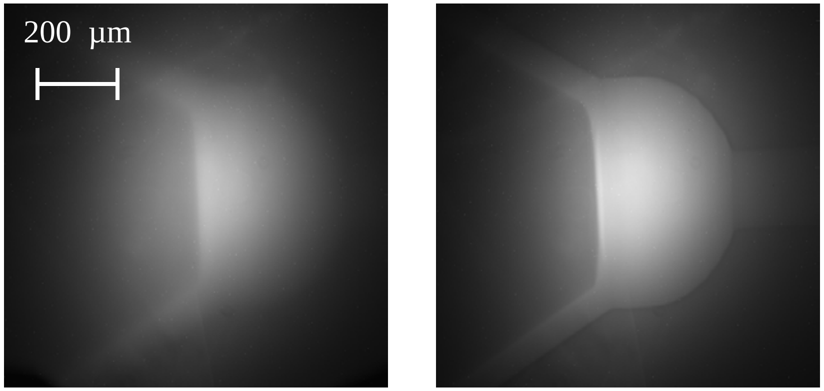
Studies in progress: Insect bio-mechanics Respiration, Locomotion, Feeding.



Observation of heart beating of a spider.

Stainless-Steel Fuel Injectors *(70 keV)*

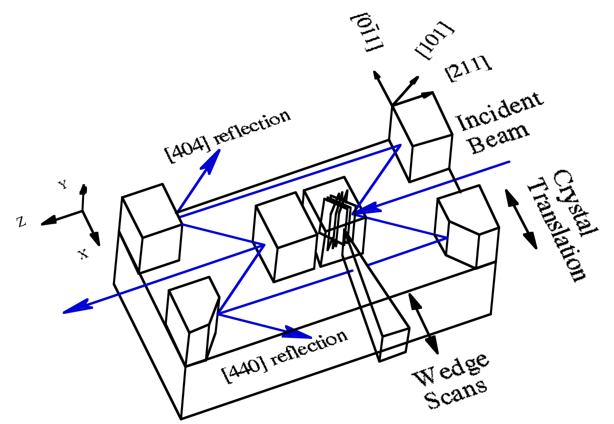
Possibilities: Time resolved studies of injection cycles.



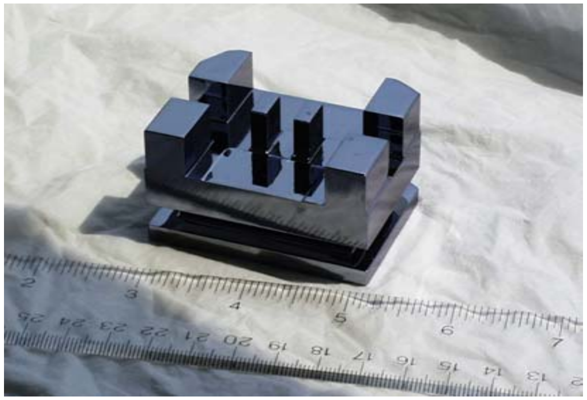
Injector nuzzle seen in different modes
Absorption (left) and Propagation (right)

Interferometry

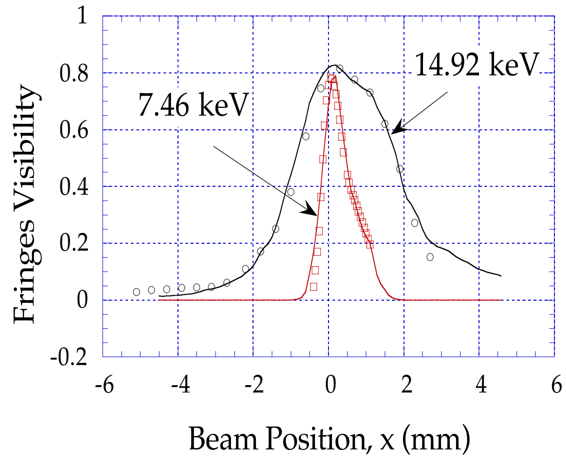
Large and variable Path Length Difference X-rays Interferometer



Schematic of the principle, showing the 1° corners cuts on one arm



Silicon 4-Bragg Interferometer



The fitting values of the longitudinal λ_L and transverse λ_T coherence lengths are :

λ_L= 25 [175] µm
λ_T =30 [200] µm
@ 7.46 [14.92] keV

Could be used as a Fourier Transform Spectrometer at these energies.

Fezzaa, K. and Lee, W-K.
J. Appl. Cryst., 166-171 (2001).

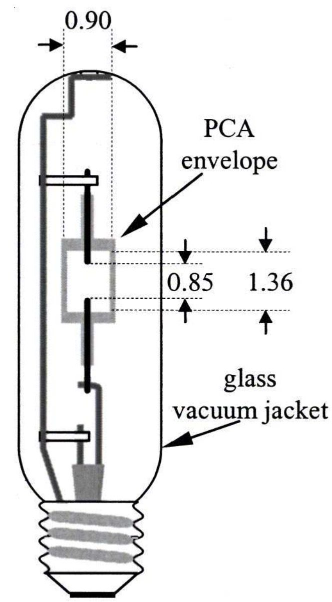
Sec. 1: High-Energy X-Ray Fluorescence

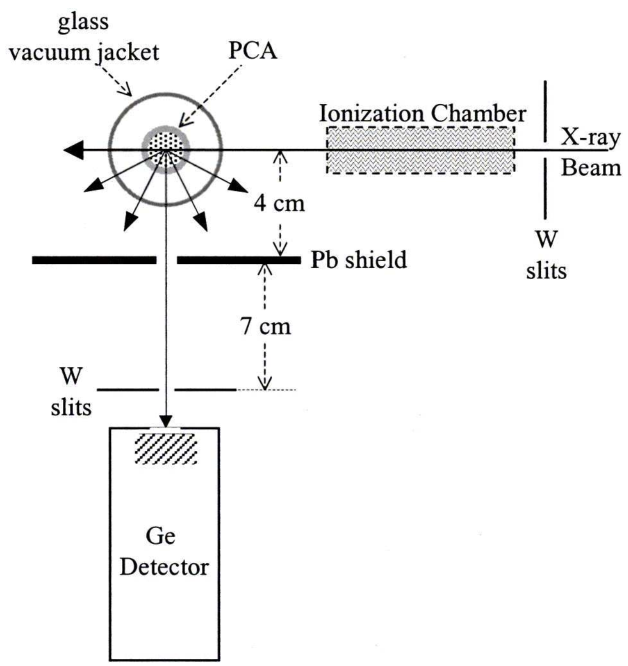
Minority additives distributions in ceramic metal halide arc lamps

Applied Phys. Lett. **79**, 1974-1976 (2001)

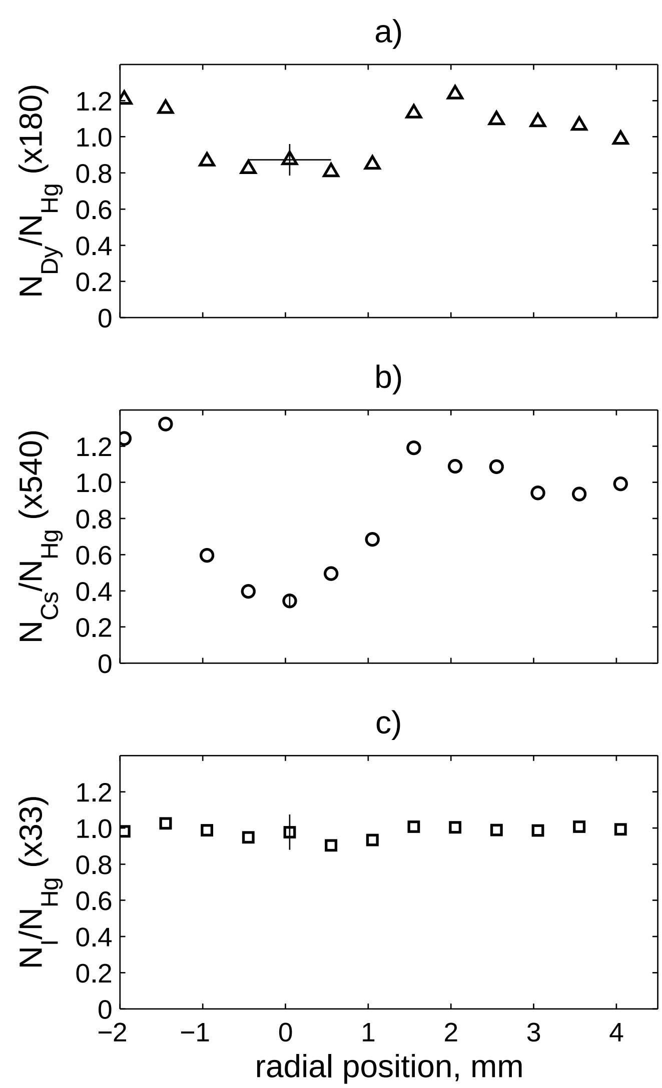
J. J. Curry - Univ. of Wisc., Madison
S. D. Shastri - SRI-CAT
H. G. Adler - Osram Sylvania, MA

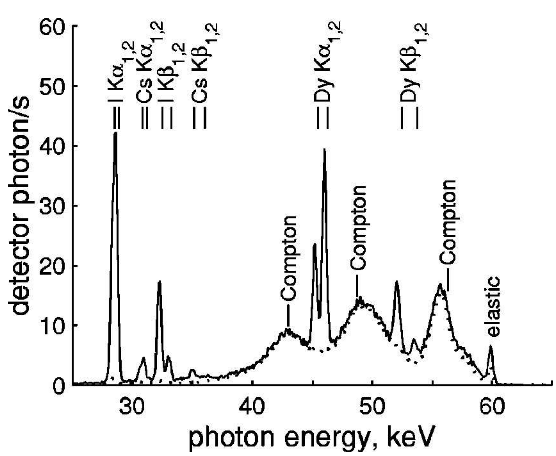
Minority additives (Dy, I, Cs) in Hg significantly influence efficacy and color.





60 - 90 keV

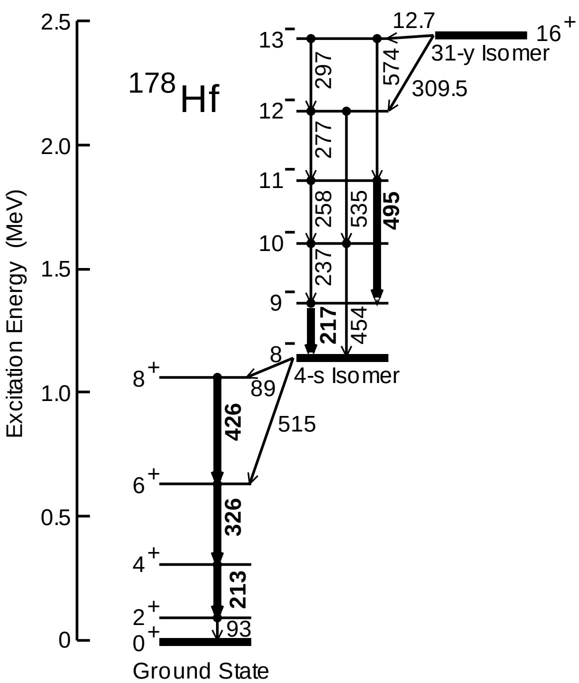




Sec. 1: (Absence of) X-Ray Induced Acceleration of the Decay of the 31-yr Isomer of ^{178}Hf

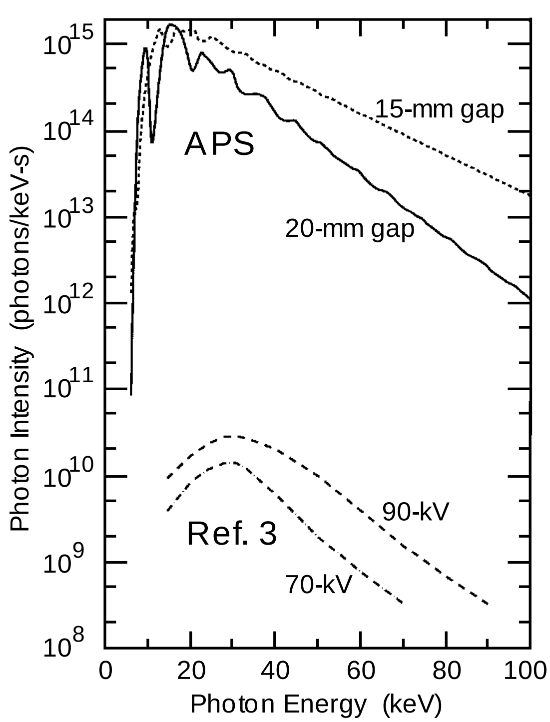
Phys. Rev. Lett. **87**, 072503 (2001)

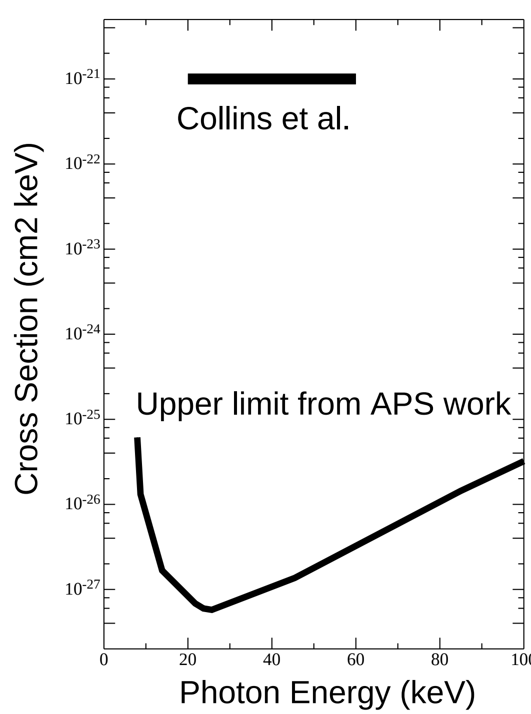
S. D. Shastri, A. Mashayekhi - APS (SRI-CAT)
J. Schiffer, D. Gemmell, I. Ahmad, E. Moore - ANL (Physics)
J. Wilhelmy, R. Rundberg, J. Banar, L. Pangault, G. Miller - LANL
J. Becker, D. McNabb, T. Wang, A. Kraemer - LLNL



Collins *et al.* have repeatedly seen accelerated decay triggered by a dental x-ray machine, with cross-sections violating nuclear physics sum-rules (PRL **82**, 695 (1999)). This has lead to intensified conjectures on energy sources, weapons, γ-lasers, etc (Science **283**, 769 (1999)).

No effect was observed in the APS experiment using white beam from a tapered undulator.





High Energy Program Perspective

- Short period undulators
- Small gap ID chambers
- Horizontal source size
  - At high energy, source size, divergence dominated by storage ring contributions
  - For microfocusing, small β
  - For unfocused beam, large β
- Lower storage ring energy

High Energy Undulators

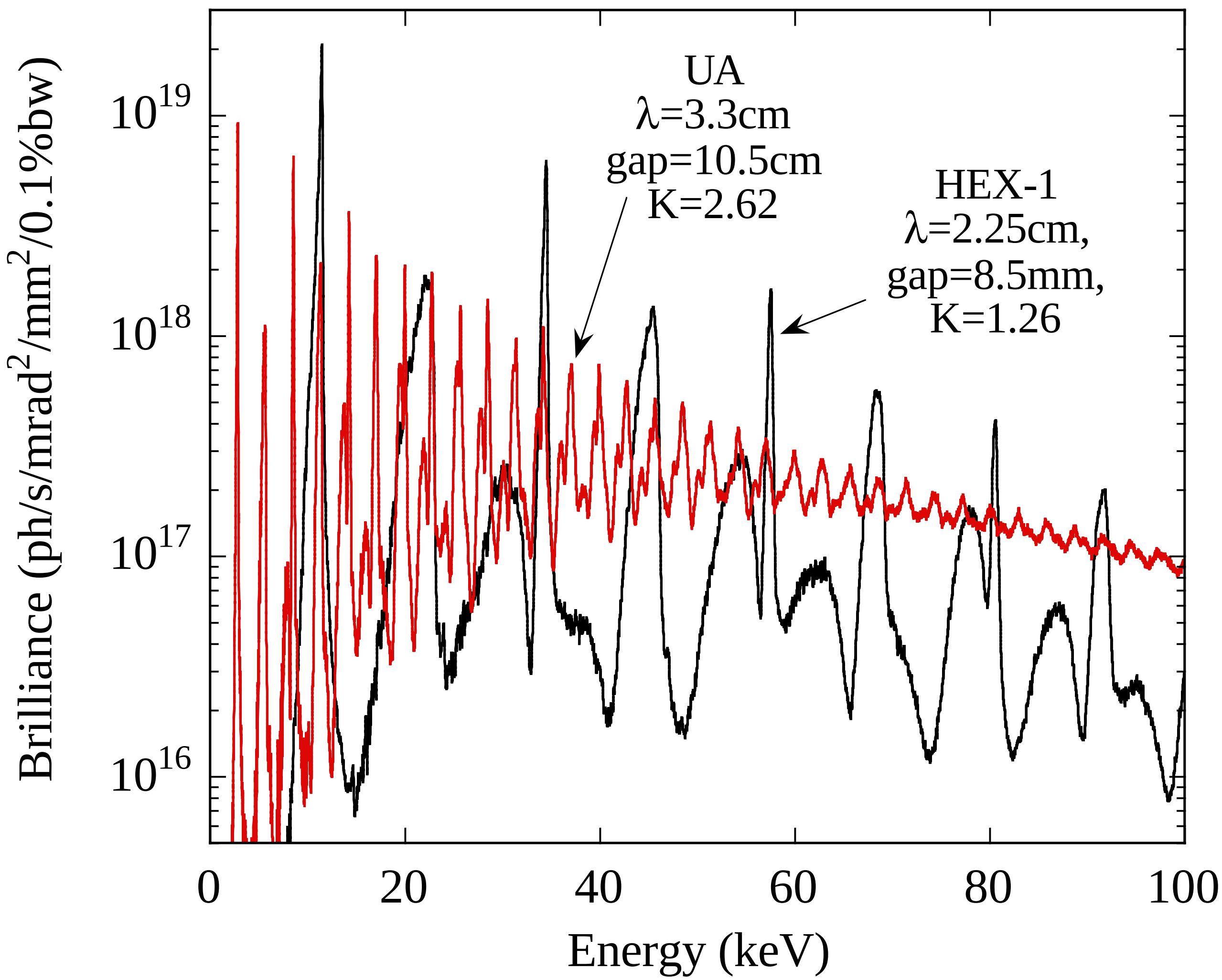
Undulator Design Factors

- Design for maximum brilliance
- Full spectral coverage above 35 keV
- The design will be based upon a minimum gap of 8.5 mm
- Permanent magnet devices
- Two devices may be used for spectral coverage
- All devices will be 2.5 m in length
- Use APS storage ring values from August of 2001

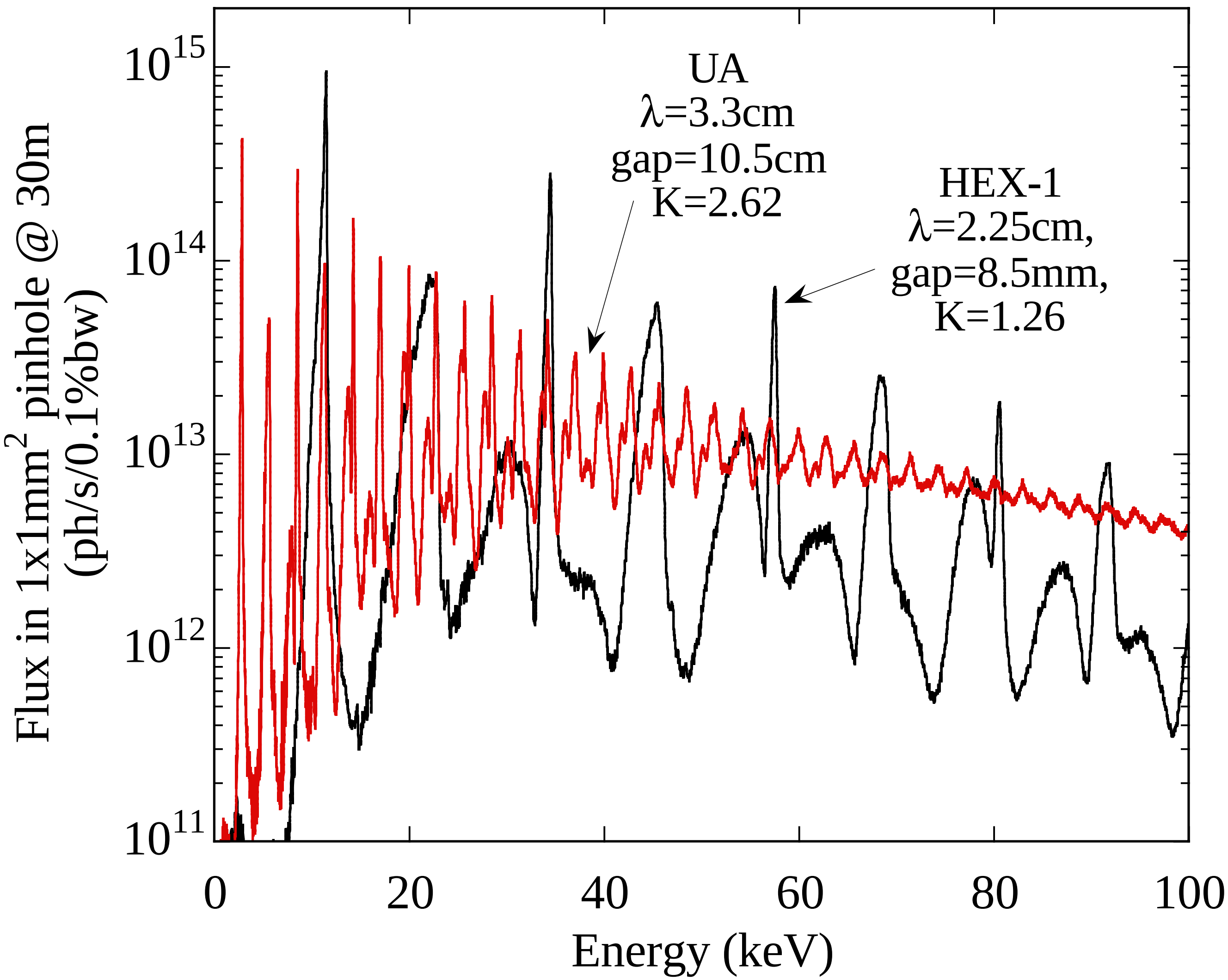
Summary of Undulator Parameters

	UA	HEX-1	HEX-2
Period (cm)	3.3	2.25	2.05
Length (m)	2.5	2.5	2.5
Number of Periods	72	111	122
Minimum gap (mm)	10.5	8.5 (6.5)	8.5
B_{max} (T)	0.85	0.6 (0.85)	0.5
K_{max}	2.62	1.26 (1.8)	1.0
Total Integrated Power (kW)	5.4	2.8 (5.7)	2.1
Integrated Power in 1 x 1 mm^2 @ 30 m (W)	160	168 (234)	155

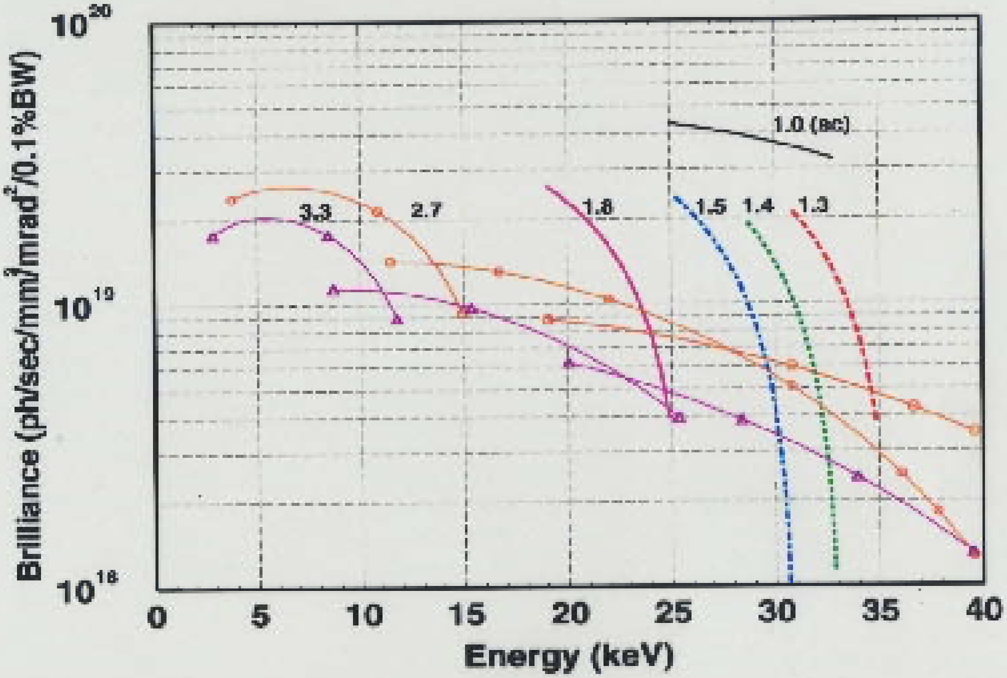
High Energy Undulator Brilliance



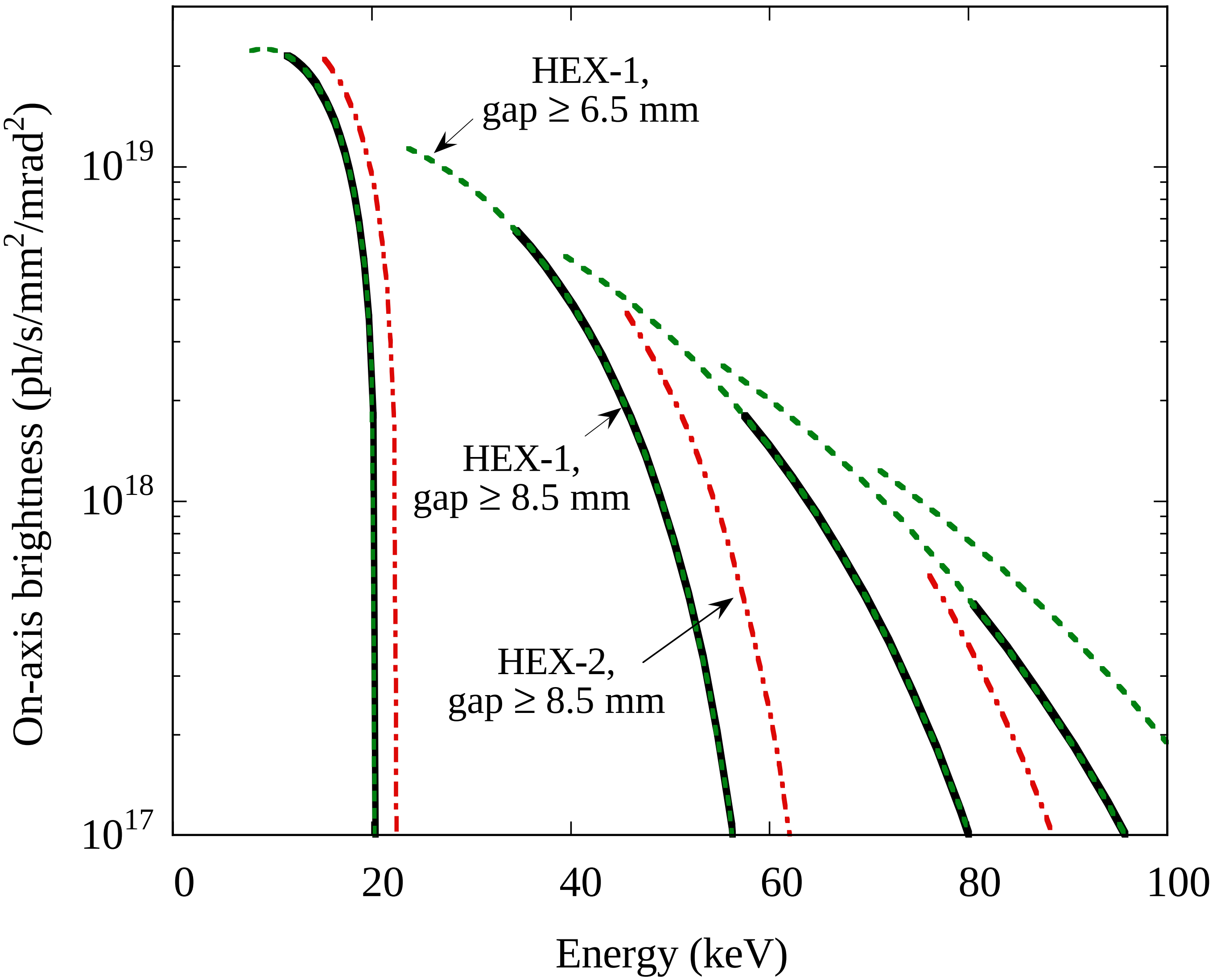
High Energy Undulator Flux



Tunability range of the APS undulators with a minimum gap of 6.5 mm



Undulator Tuning Curves



High Energy Undulators

Conclusions

- Considerable gains in brilliance are available when two devices are used for spectral coverage.
- Power and power density is much less of a problem for short period devices.
- Gains of approximately a factor of 10 are available over Undulator A.
- Flux and brilliance criteria give similar results.
- Substantial gains would be available with a 6.5-mm vacuum chamber and likely APS storage ring upgrades.

Implication of Lower Storage Ring Energy for APS High Energy Programs

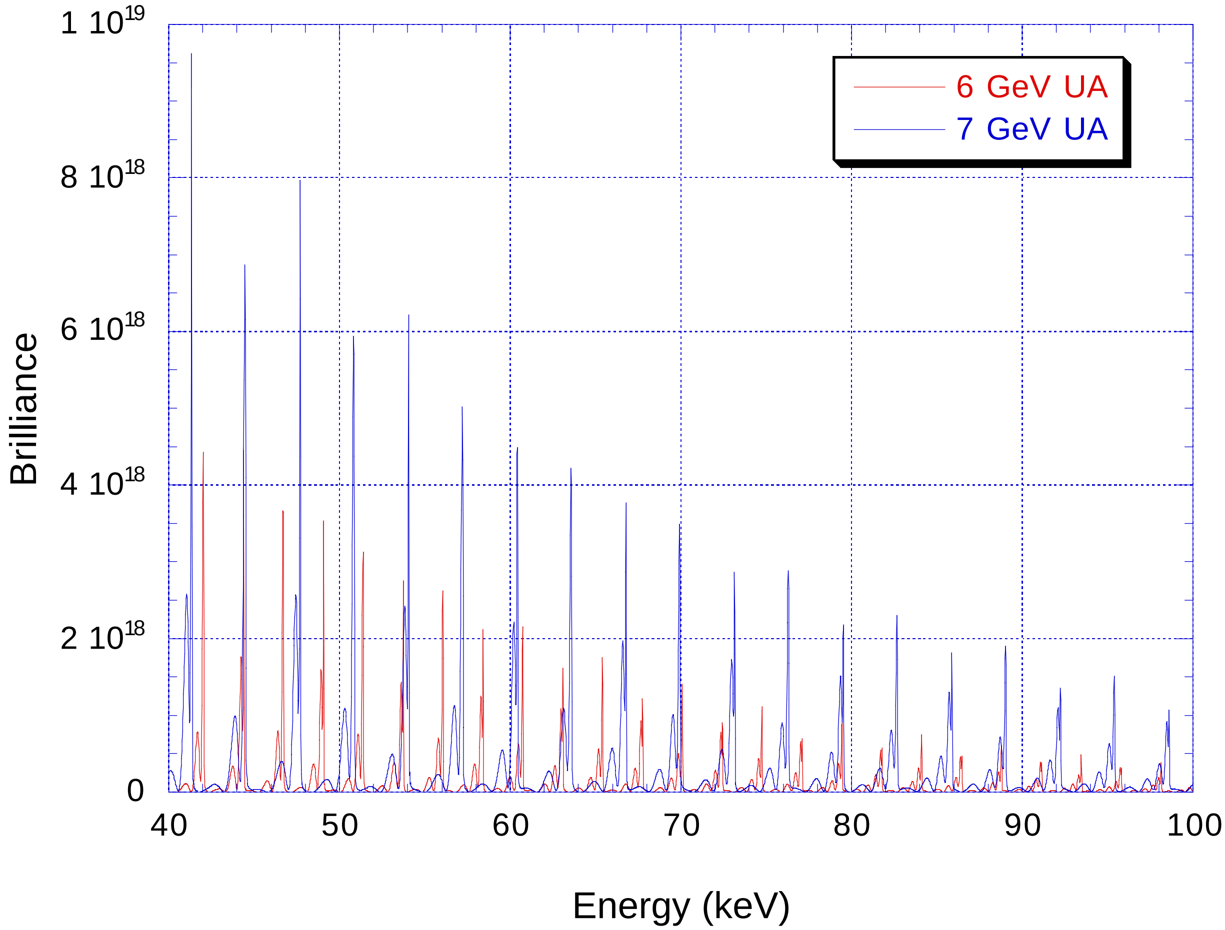
- ~~Not Optimal~~

  ~~Not Good~~

  ~~Bad~~

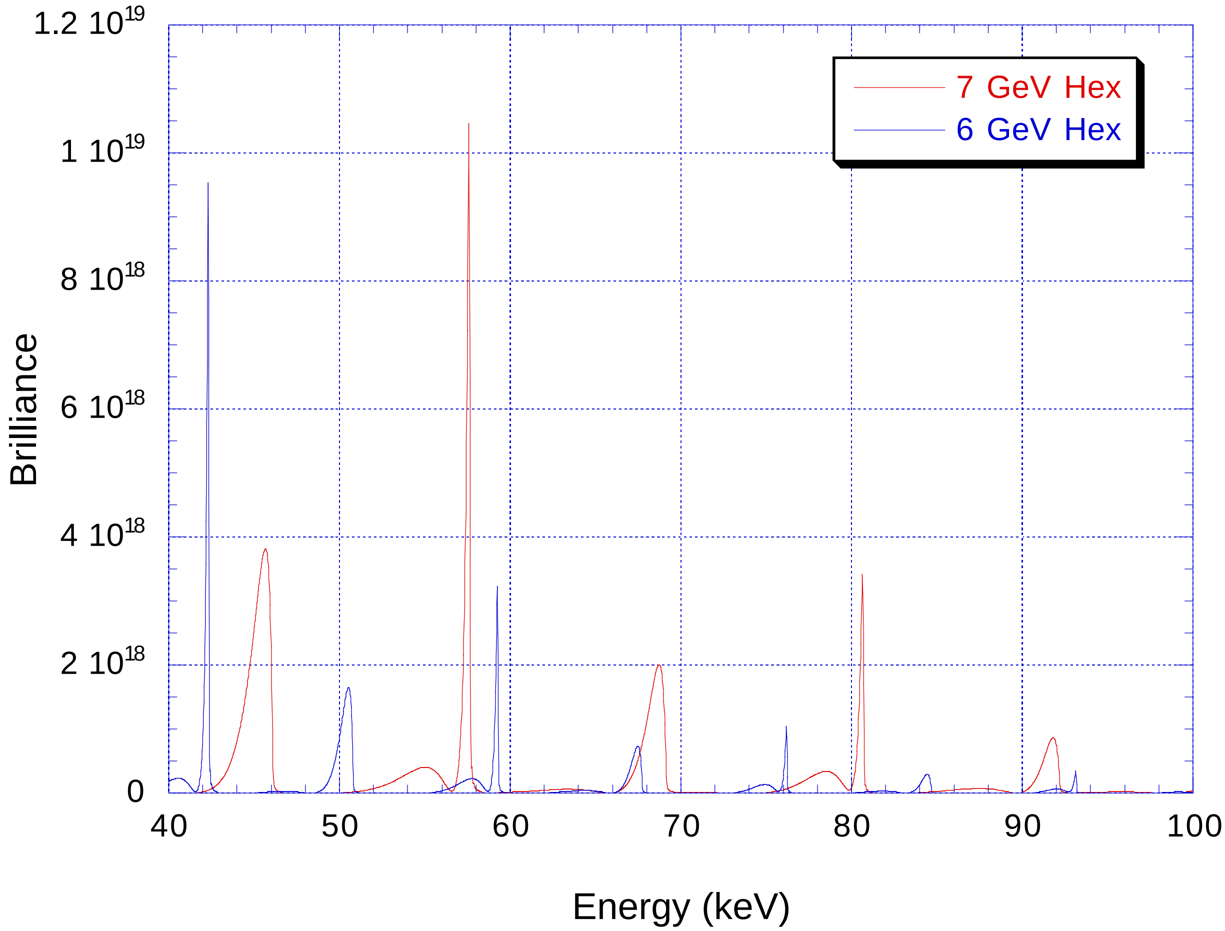
  Sucks a lot

Undulator A



Calculation for a perfect device

HEX-1



Calculation for a perfect device

Implication of Lower Storage Ring Energy for APS High Energy Programs–II

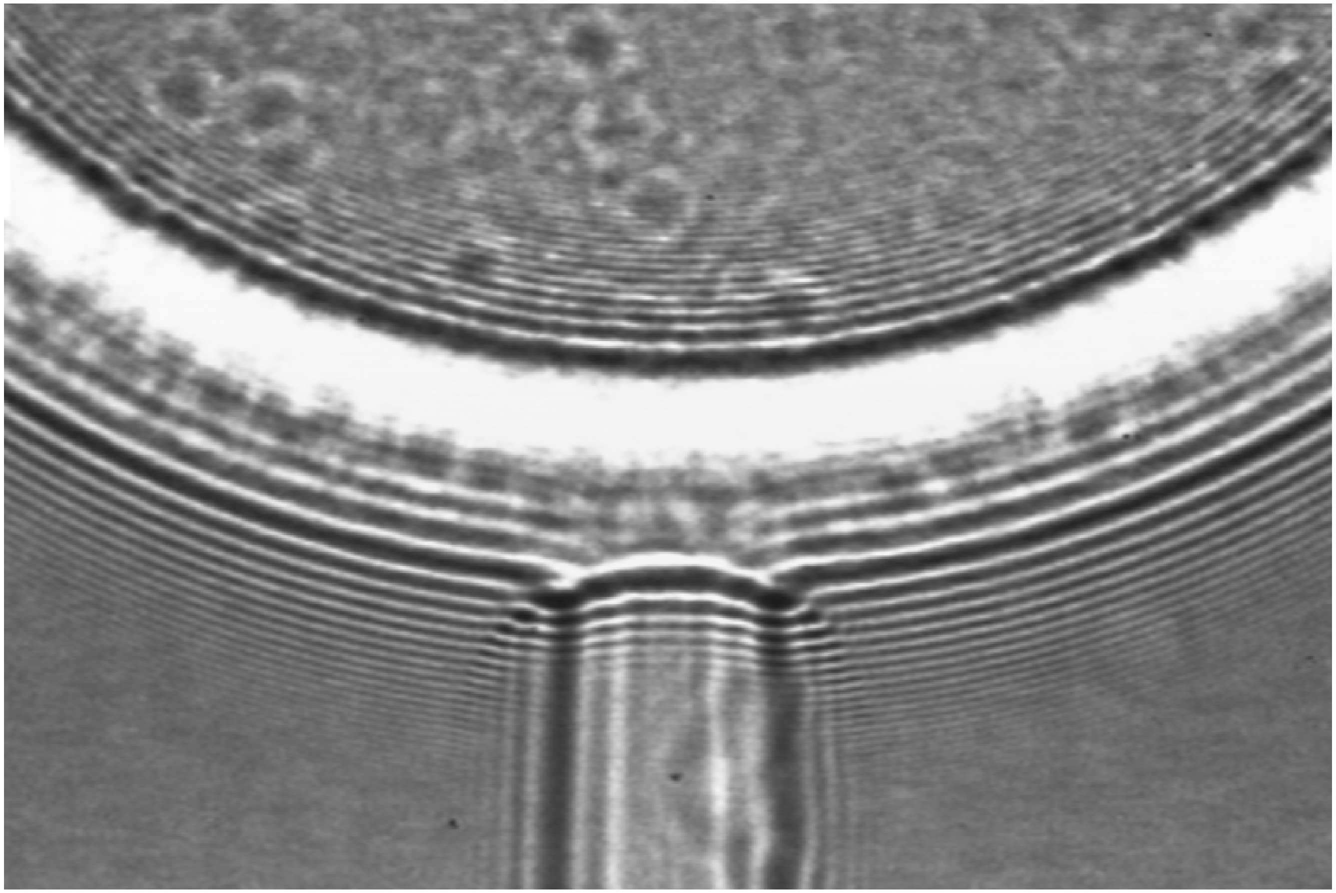
- Even with 300 mA, losses in brilliance
- Real devices with field errors will look worse
- Tunability will be severely compromised

Phase Contrast Imaging Perspective

- Current beamline issues
  - Flow induced vibrations in mono
  - Optical surfaces
  - Be windows
- Stability in the 1 to 100 Hz primary range
- Source size is resolution limiting (in particular horizontal)
- Phase contrast imaging sensitive to angular moves of 1/100 of rocking curve, i.e., ~0.5 μrad

Holography (Fresnel diffraction) of a Polystyrene (plastic) Sphere covered with 15 μm Thick layer of Parylene (plastic).

D = 310 cm



λ = 0.7 Å

50 μm

J. Baruchel et al., *SPIE* 3154, p.51, 1997.

Bending Magnet Perspective

- High current is obvious path for flux gains
- Current optics will most likely fail
- Low energy operations hurts high energy programs

Issues Summary

- Insertion devices/vacuum chambers
  - High energy program wants optimized devices with small-gap chamber
- Storage ring energy
  - Arrrgh!!! Leave it alone
- Higher storage ring current
  - Okay, but a not a high priority

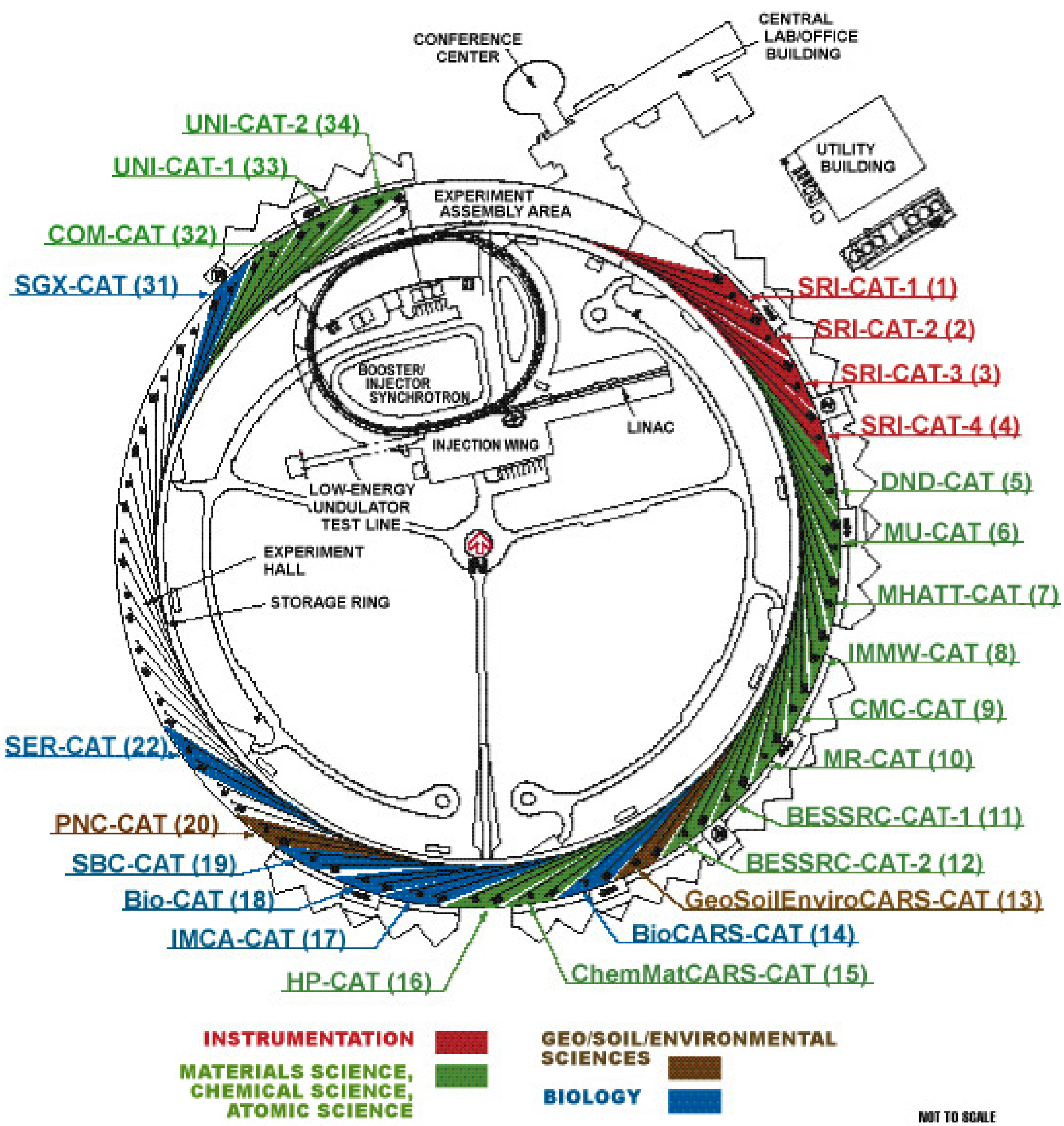
Issues Summary

- Beam emittance/β functions
  - It would be great to vary βs by sector
  - It would also be nice to occaisionally use different βs at different times
- Timing
  - We don’t care
- Stability
  - Long term is good, but improvements are always welcome
  - ~100 Hz we do not know if the storage ring is good enough
- Top Off
  - See below

Dean’s Moderately Informed Digression to Other CATs

- Semi-facts
  - Everyone you ask is very impressed by the storage ring performance
  - The protein crystallography beamlines do not use current capability and will not benefit from upgrades
  - Very few experiments outside of Sector 3 use timing
  - Most people do not care about the bunch pattern, but want it to change infrequently

APS Collaborative Access Teams by Sector & Discipline



Digression Continued

- More semi-facts
  - Generally top-off is well liked, but people would like it 100% of the time
  - Brilliance is over rated as a metric
  - For most beamlines additional brilliance will not be used
  - No users are pushing for higher current

Digression Continued

- My opinion on main factors limiting science at the APS
  - Lack of beamline manpower
  - Burnout of existing personnel
  - Generation-old optics
  - Lack of modern detectors at beamlines and lack of a detector pool
  - A general lack of education in what is capable at the APS by user community
  - Beamlines with too much scope

Sector 1 Recommendations

- An aggressive effort in ID development
- Education of the users
  - IDs
  - Storage ring
- Leave the ring energy at 7 GeV
- Go slow on higher currents
  - 10% a year
- Allow β functions to vary around the ring
- Top-off as much as possible