Possibilities for Obtaining Subpicosecond X-ray Pulses at the Advanced Photon Source

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Will consider implementation to the APS of the ideas of

a) laser e-beam "slicing"

and

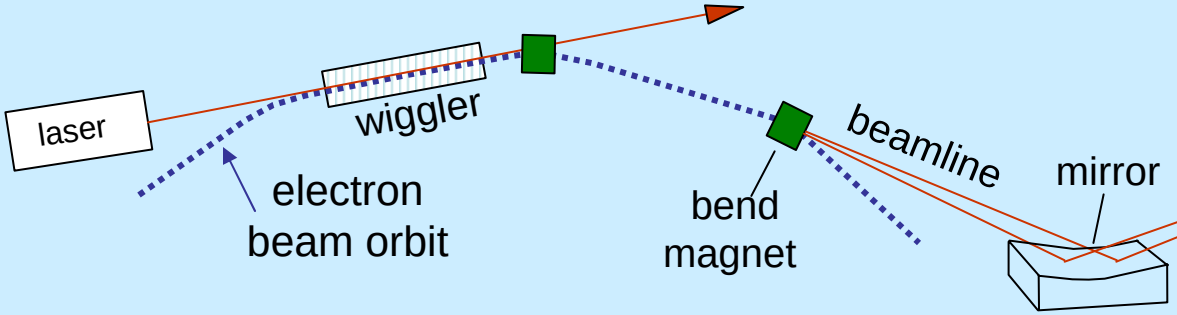
b) rf orbit deflection

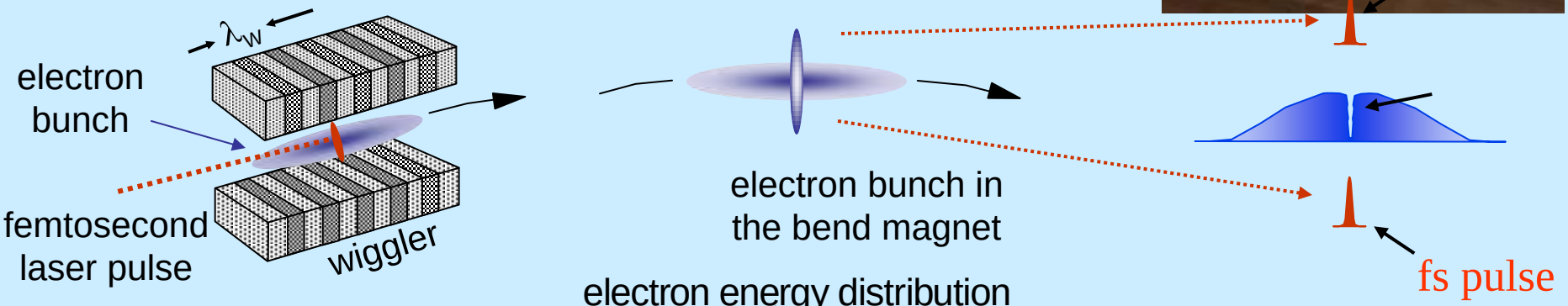
previously published in:

1) A. Zholents, M. Zolotorev, *Femtosecond x-ray pulses of synchrotron radiation*, Phys. Rev. Lett. V76, N6, (1996), pp.912-915.
2) A. Zholents, P. Heimann, M. Zolotorev, J. Byrd, *Generation of subpicosecond X-ray pulses using RF orbit deflection*, Nuclear Instruments & Methods in Physics Research Sect. A (425)1-2 (1999) pp. 385-389.
3) R. W. Schoenlein, S. Chattopadhyay, H. H. W. Chong, T. E. Glover, P. A. Heimann, C. V. Shank, A. A. Zholents, and M. S. Zolotorev, *Generation of Femtosecond Pulses of Synchrotron Radiation,* Science, Mar 24, 2000: 2237-2240.
4) R. W. Schoenlein, S. Chattopadhyay, H. H. W. Chong, T. E. Glover, P. A. Heimann, C. V. Shank, A. A. Zholents, and M. S. Zolotorev, *Generation of Femtosecond X-ray Pulses via Laser-Electron Beam Interaction,* Appl. Phys. B, 1-10, 2000.

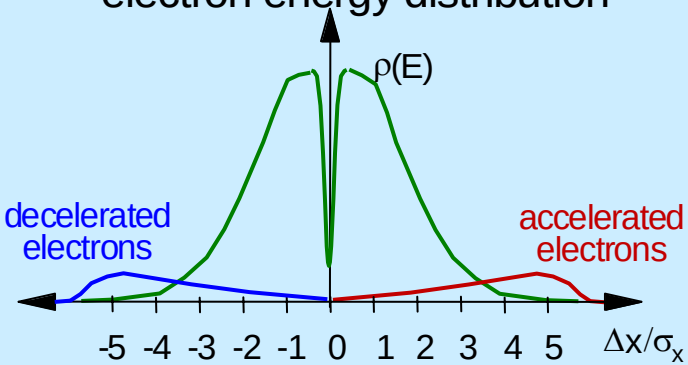
Laser e-beam "slicing"

(specific details in the talk of R. Schoenlein)





electron energy distribution



Energy = 7 GeV
Beam energy spread = 9.4 x10^{-4}

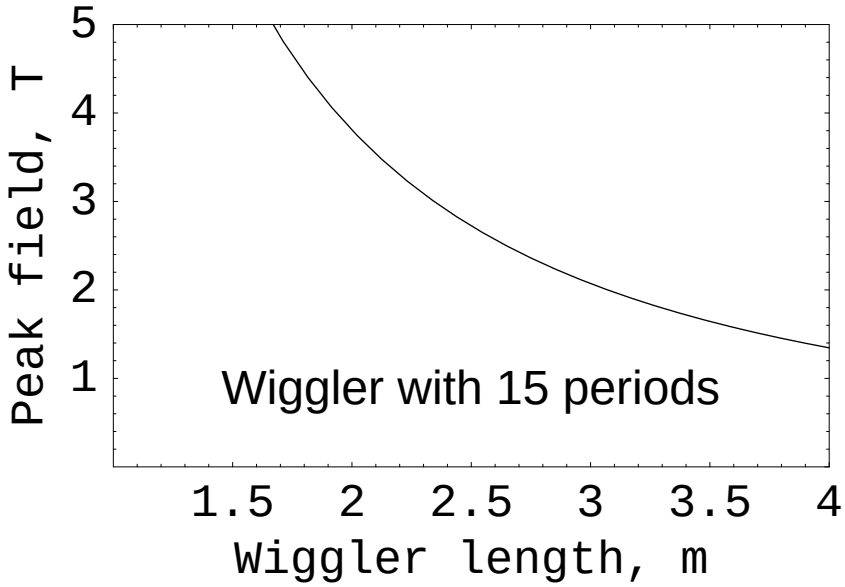
Wiggler period **Laser wavelength**

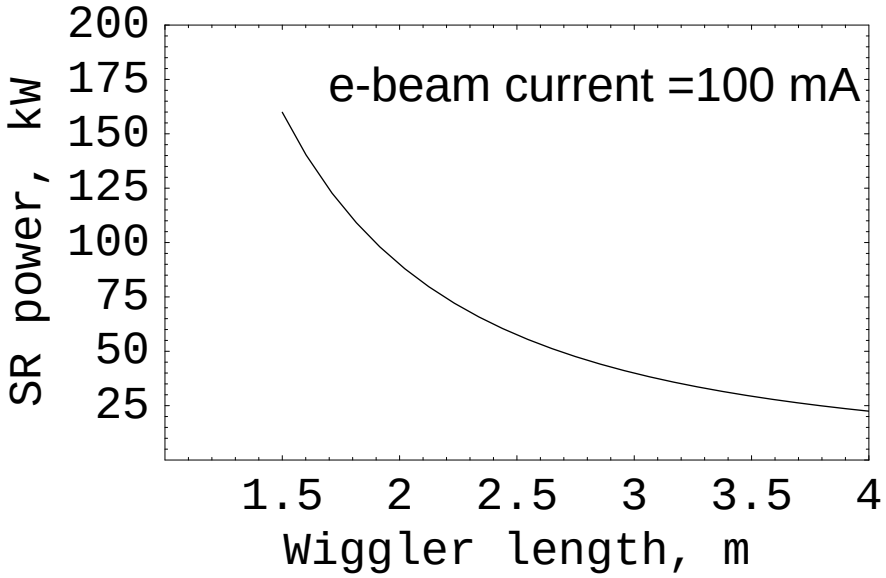
$$\lambda_w = 2\gamma^2 \lambda_L / (1 + K^2/2)$$

Undulator parameter:

$$K = \frac{eB_0 \lambda_w}{mc^2 2\pi}$$

Wiggler matching the FEL resonance at λ_L=400 nm
(2-nd harmonic of Ti:Sapphire laser)





Laser parameters

Energy modulation $\Delta E=7\sigma_e$ requires:

~10 mJ laser pulse at λ_L=400 nm and τ=50 fs

Will provide ~ 100 fs x-ray pulse with ~ 10^5 photons per pulse

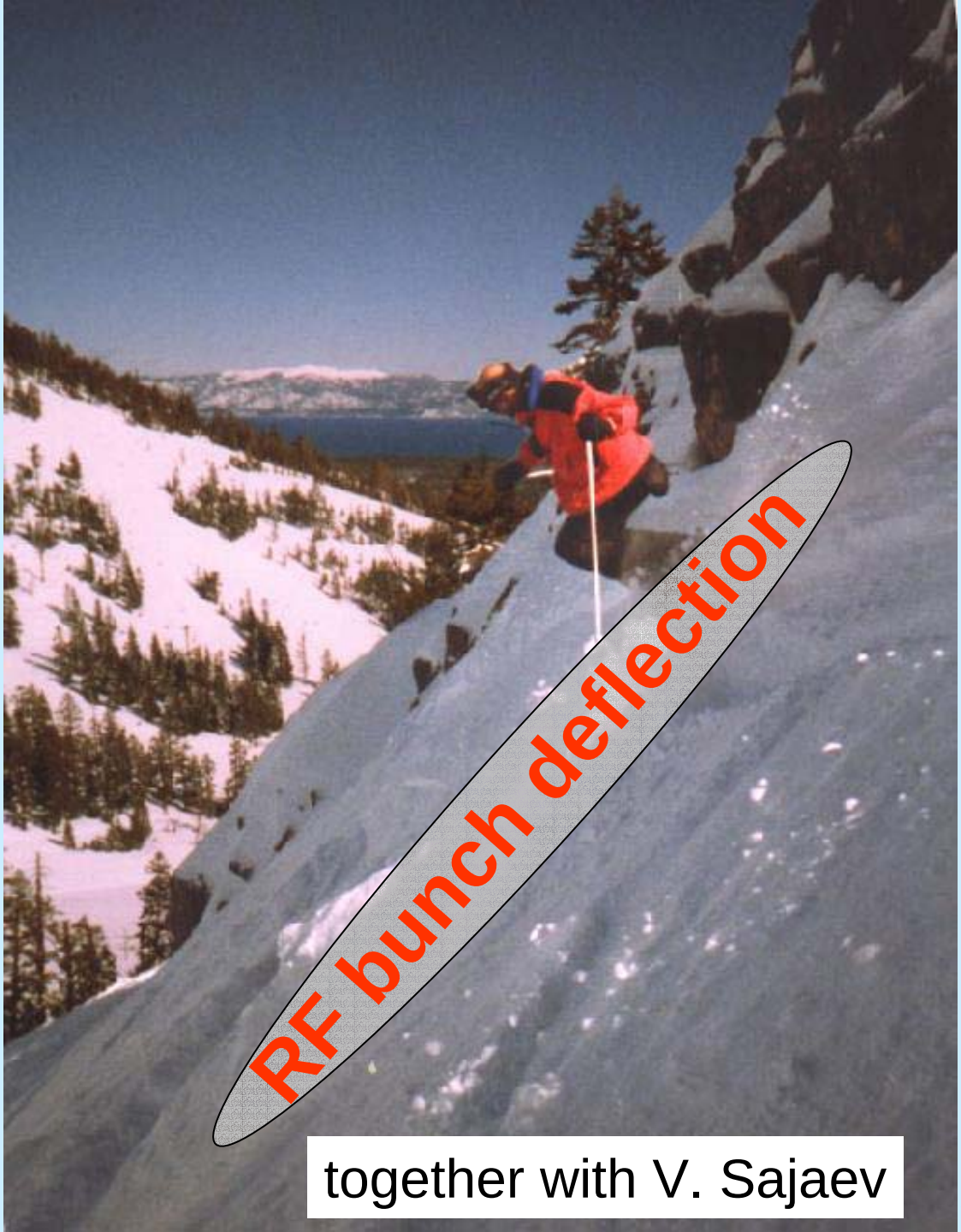
Looks difficult at a high rep.rate

Laser parameters con't

Wiggler W16 can be used at electron beam energy of 4.8 GeV

Then ~1.5 mJ laser pulse is required. → Looks feasible

Wiggler W16 has 19 periods and period of 16 cm and had been recently decommissioning from the ALS

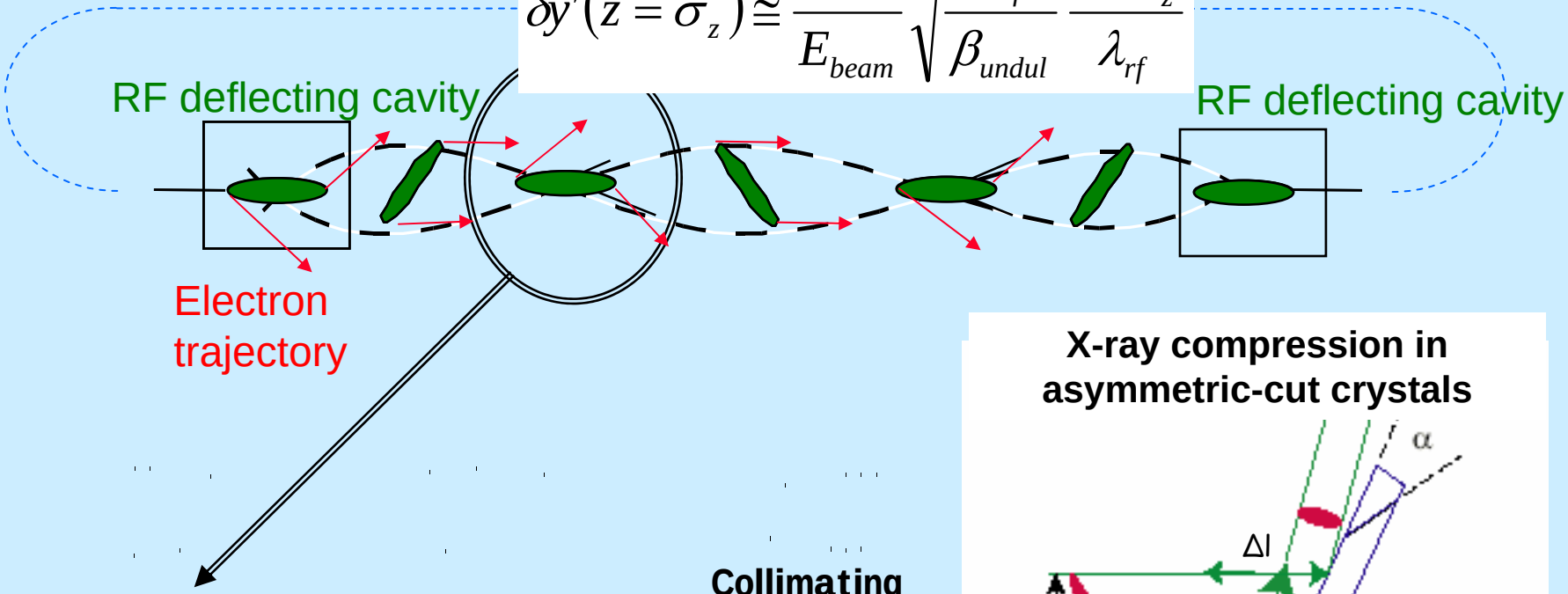


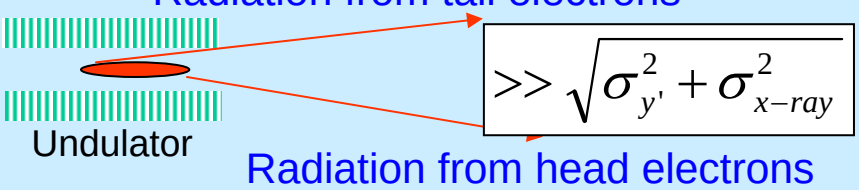
RF bunch deflection

together with V. Sajaev

Obtaining short x-ray pulse from a “long” electron bunch

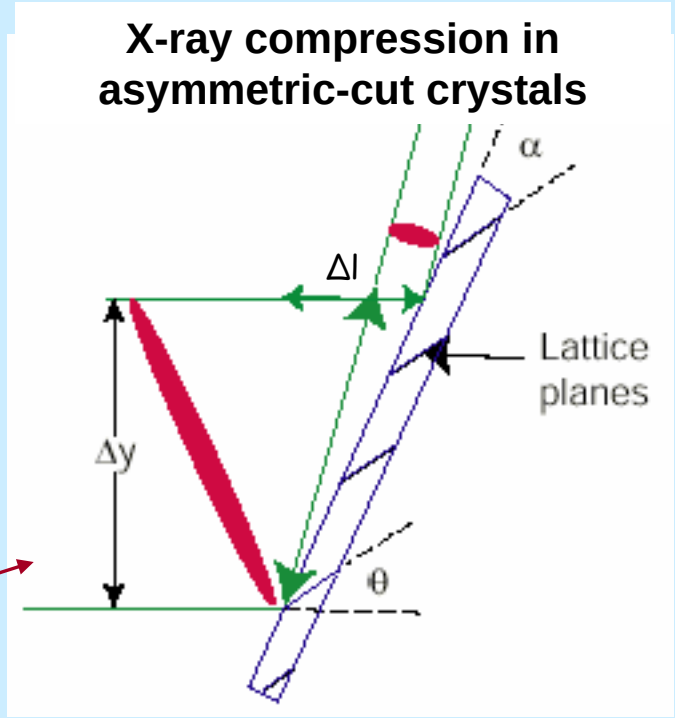
$$\delta y'(z=\sigma_z) \cong \frac{eU}{E_{beam}} \sqrt{\frac{\beta_{rf}}{\beta_{undul}}} \frac{2\pi\sigma_z}{\lambda_{rf}}$$





$$>> \sqrt{\sigma_{y'}^2 + \sigma_{x-ray}^2}$$

Collimating mirror



Input x-ray pulse >> diffraction limited size and natural beamsize

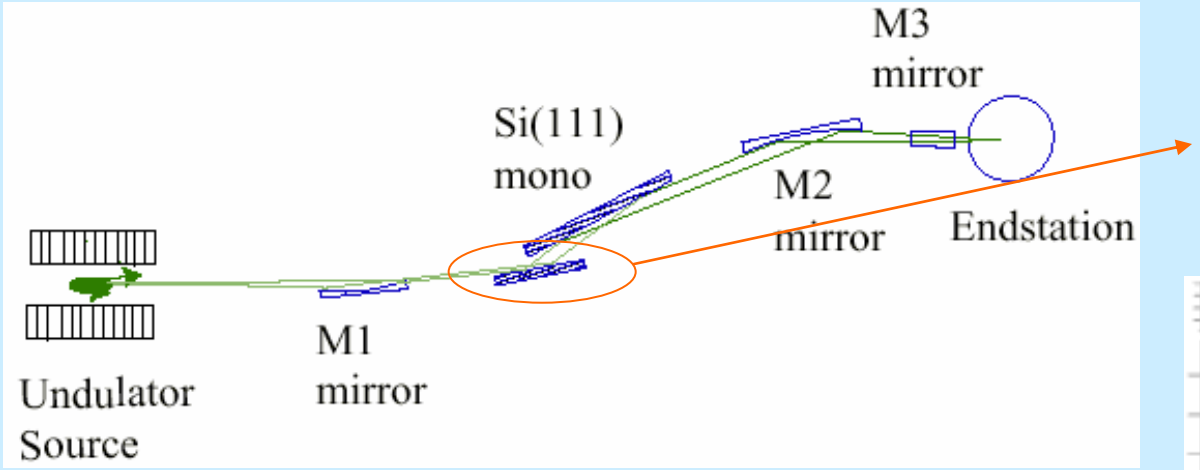
X-ray pulse compression (P. Heimann)

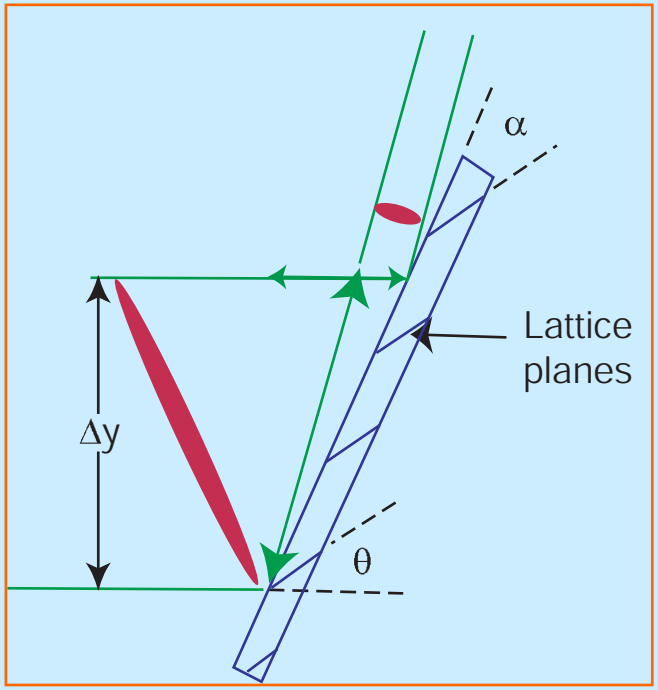
- Optical path length Δl varies linearly with position Δy on crystal

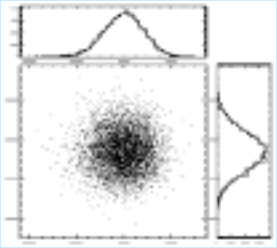
$$\Delta l = 2\,\Delta y \frac{\sin\theta\ \sin\alpha}{\sin(\theta+\alpha)}$$

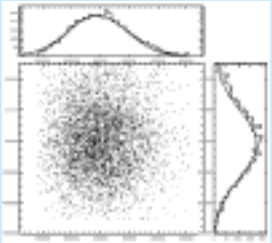
Crystals	λ	Δy	θ	α	Δ*l*
Si(111)	1.5 A	3.8 mm	14.309°	-3.5°	0.6 mm (2 ps)

- We propose to use a pair of asymmetrically cut silicon crystals following collection optics









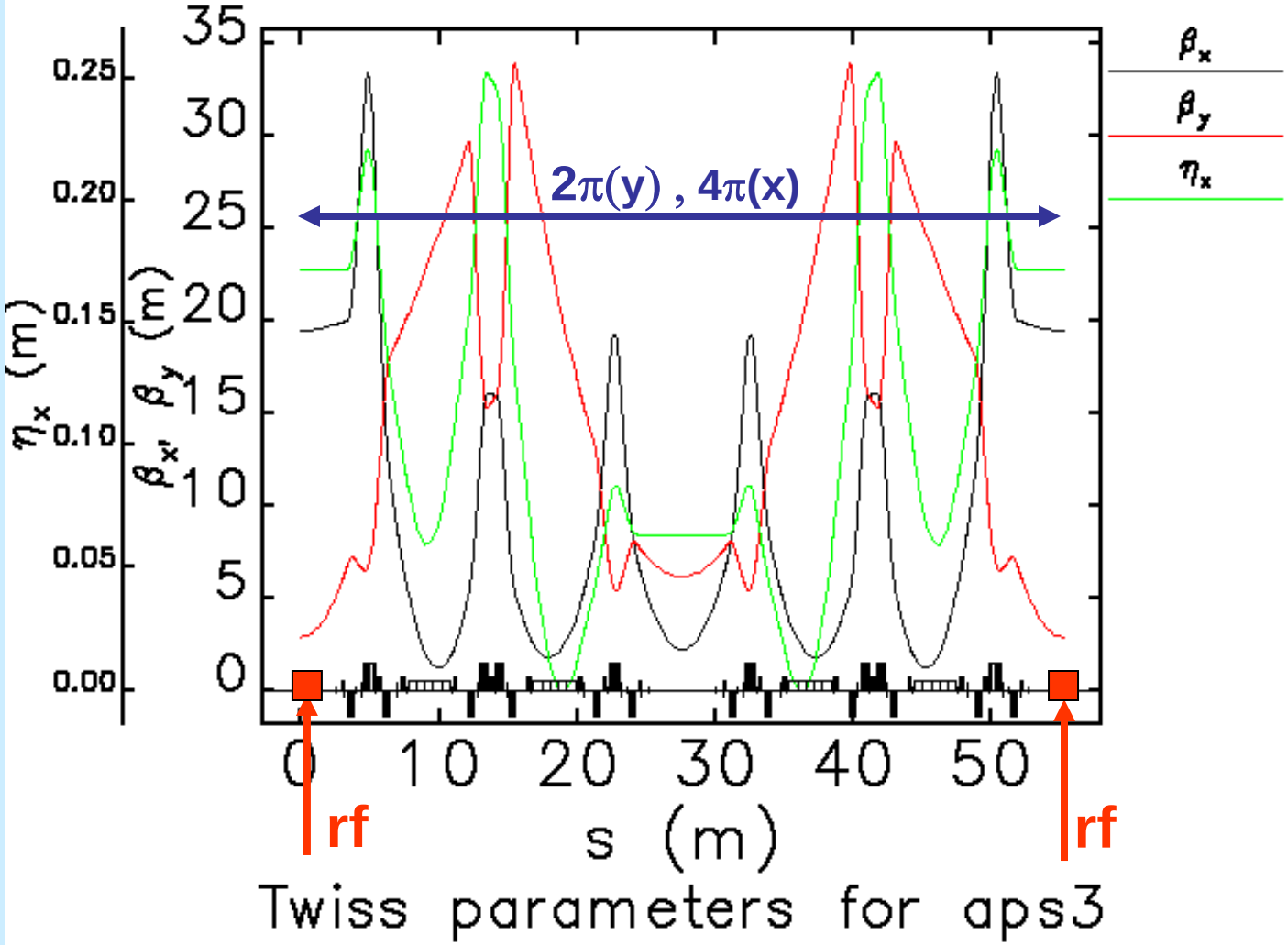
Focus dimensions

20μm (h) x 12 μm (v)

Focus divergence

1.2 mrad (h) x 500 μrad (v)

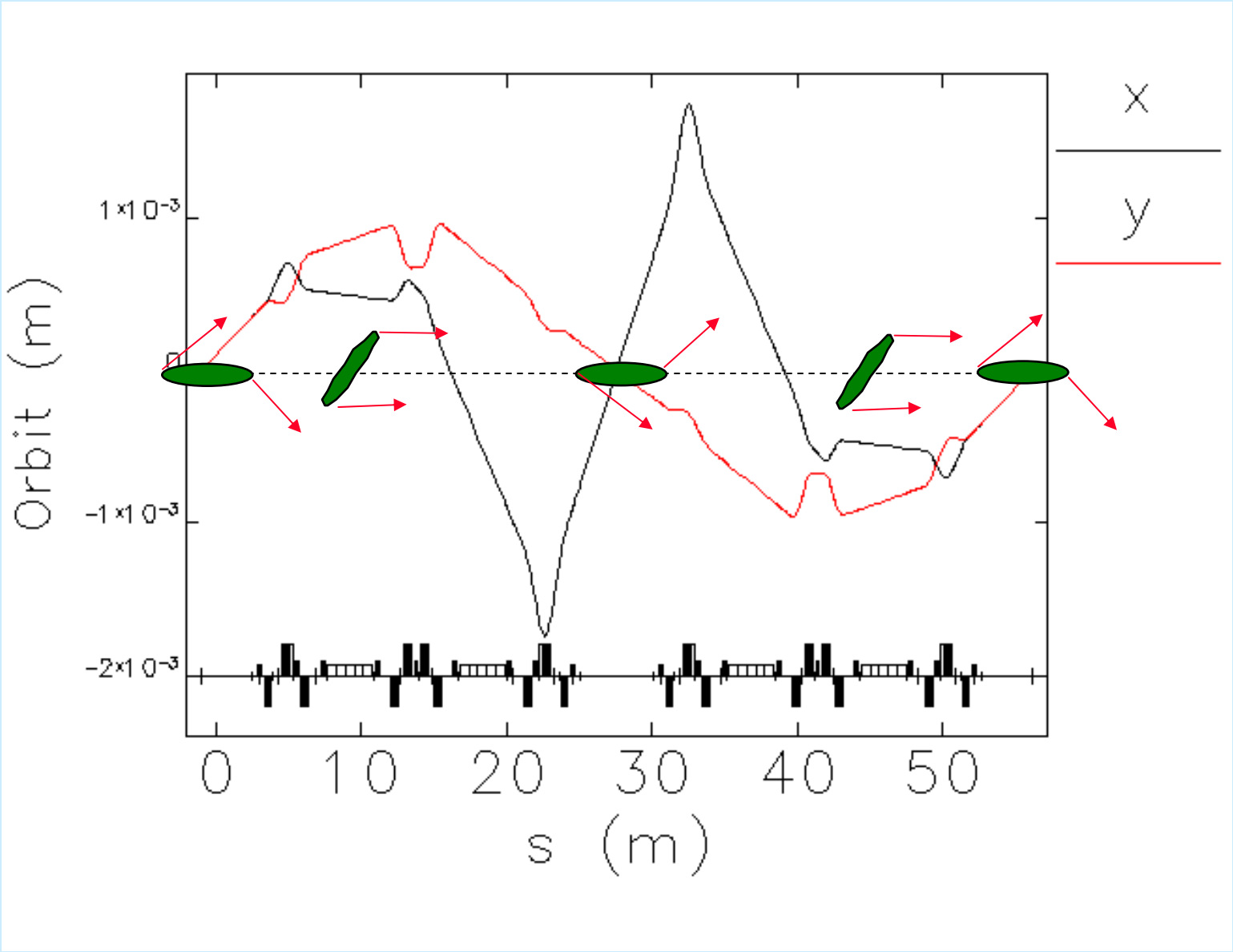
An example for the APS



Two APS sectors are used.

Potentially: three undulator and four bend magnet beamlines.

Trajectory for an electron with $z=\sigma_z$ and 200 μrad kick



Parameters used:

Beam energy = 7 GeV

Vertical beam emittance = 2.5×10^{-11} m

Bunch length, σ = 40 ps

Undulator: 3.3 cm period, 73 periods

Bend magnet field = 0.6 T

Main RF frequency = 352 MHz

Deflection RF frequency= 4x352=1.408 GHz

Results obtained for undulator beamline:

Beam divergence, $\sigma_{y'}$= 2 μrad

X-ray divergence at 1Å, $\sigma_{r'}$= 3.7 μrad

Total divergence = 4.2 μrad

Total transverse rf voltage = 2 MV

X-ray pulse duration (FWHM) = 2 ps

(compression factor ~ 50)

Results obtained for bend magnet beamline:

Beam size, σ_y= 19 μm

X-ray diffraction size at ω_{cr}=19keV, σ_r= 0.1 μm

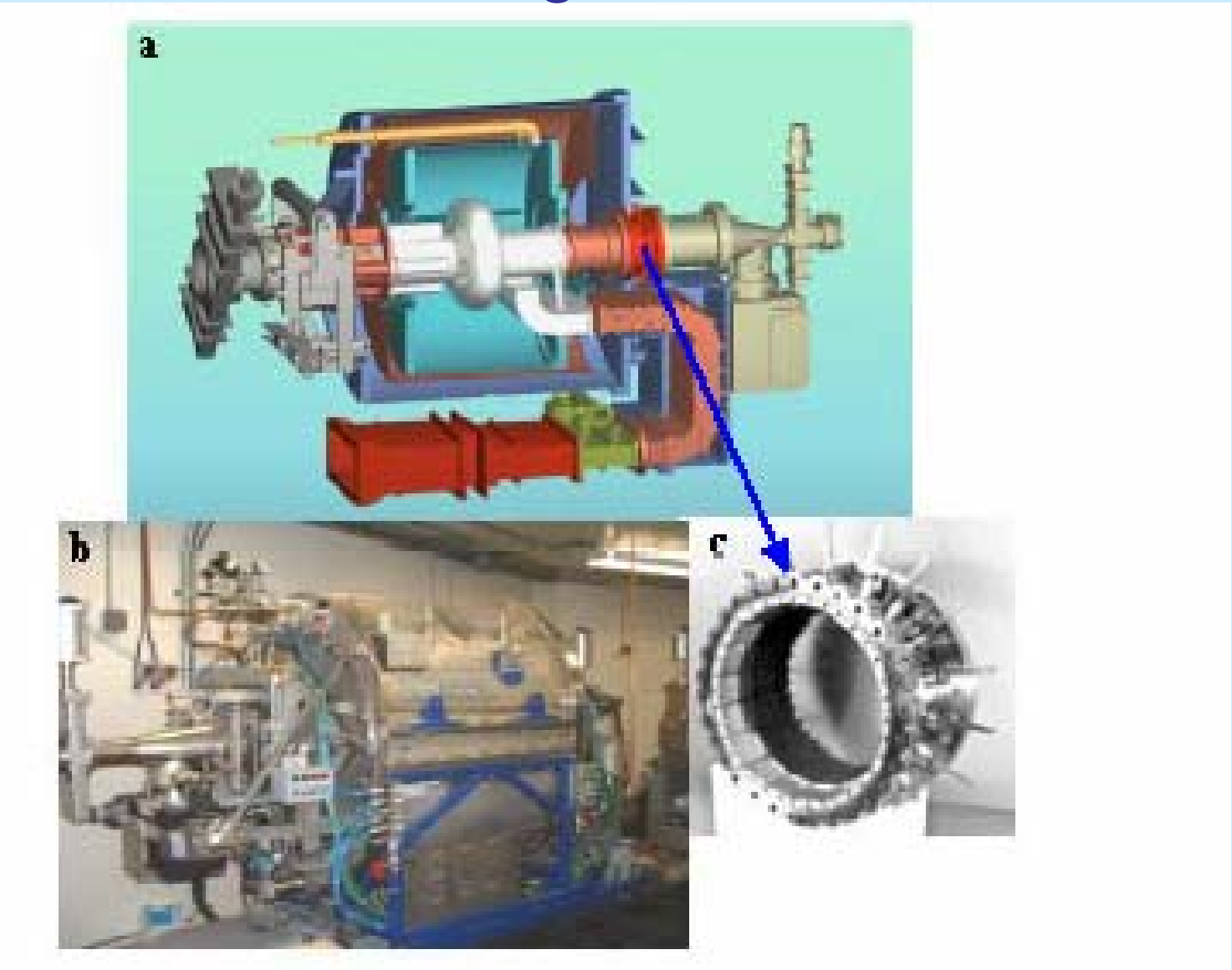
Total size = 19 μm

Total transverse rf voltage = 2 MV

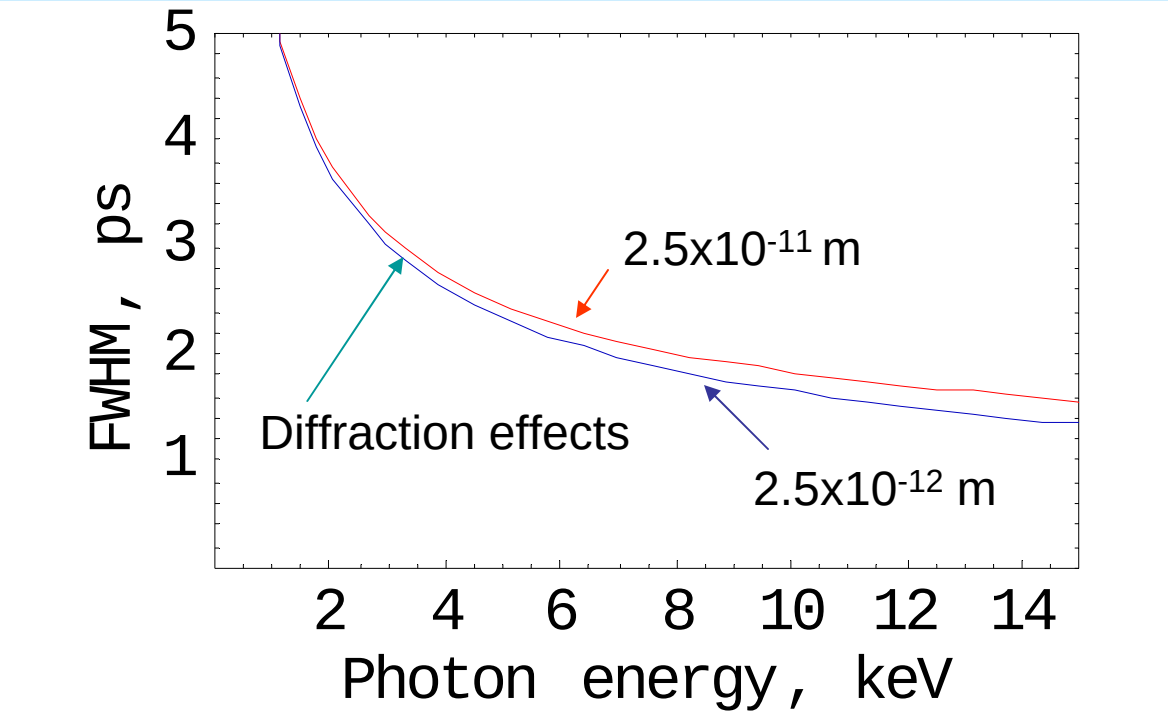
X-ray pulse duration (FWHM) = 1 ps

(compression factor ~ 100)

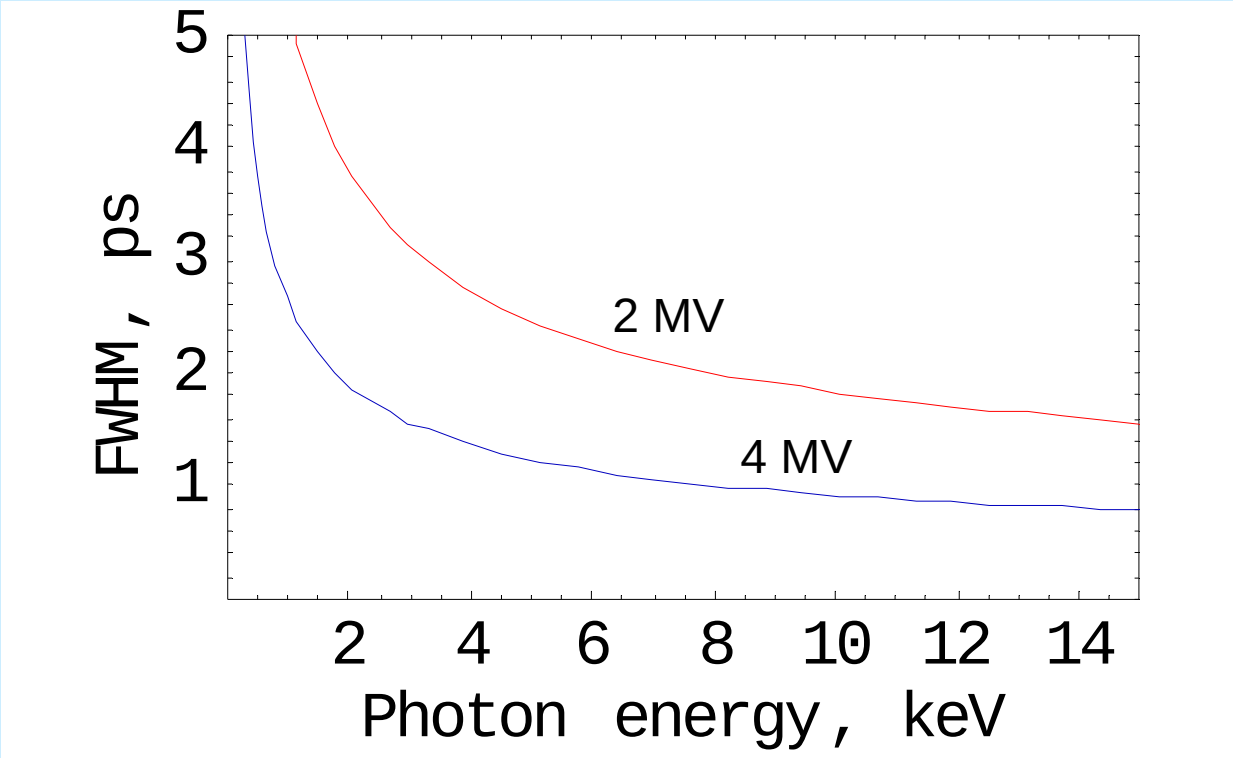
KEK supeconducting deflecting cavity at 500 MHz reaching 1.5 MV/m



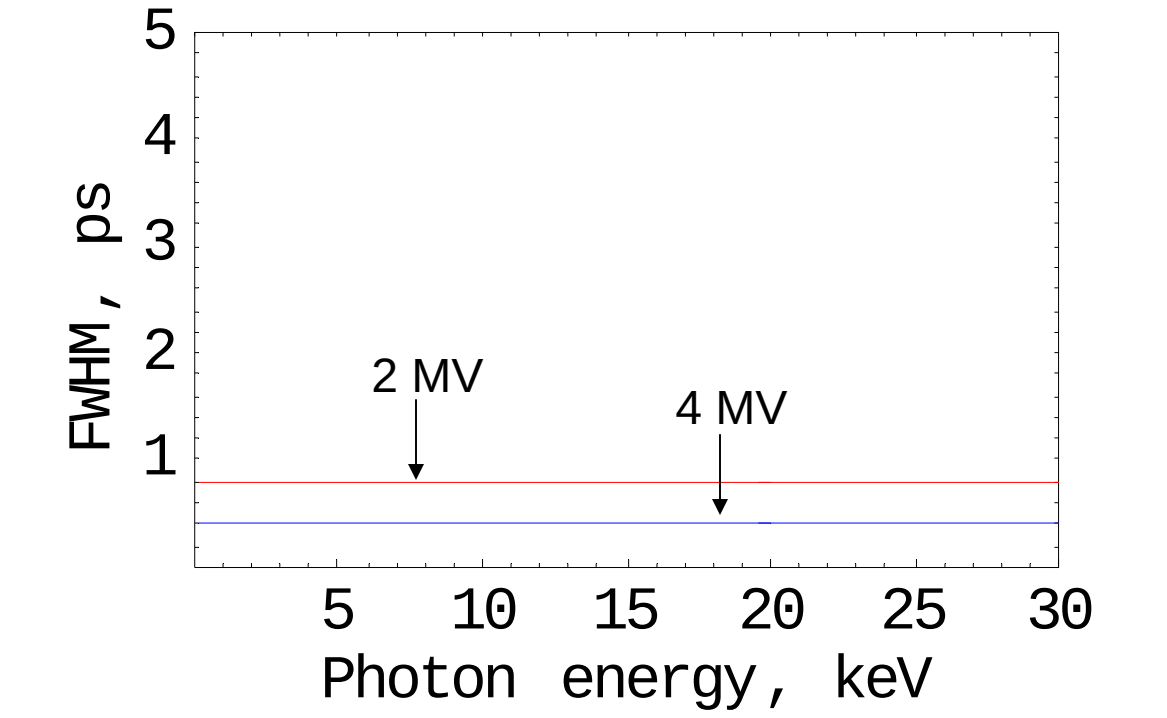
X-ray pulse duration at various photon energies and beam emittance for undulator beamline



Increasing rf deflection voltage



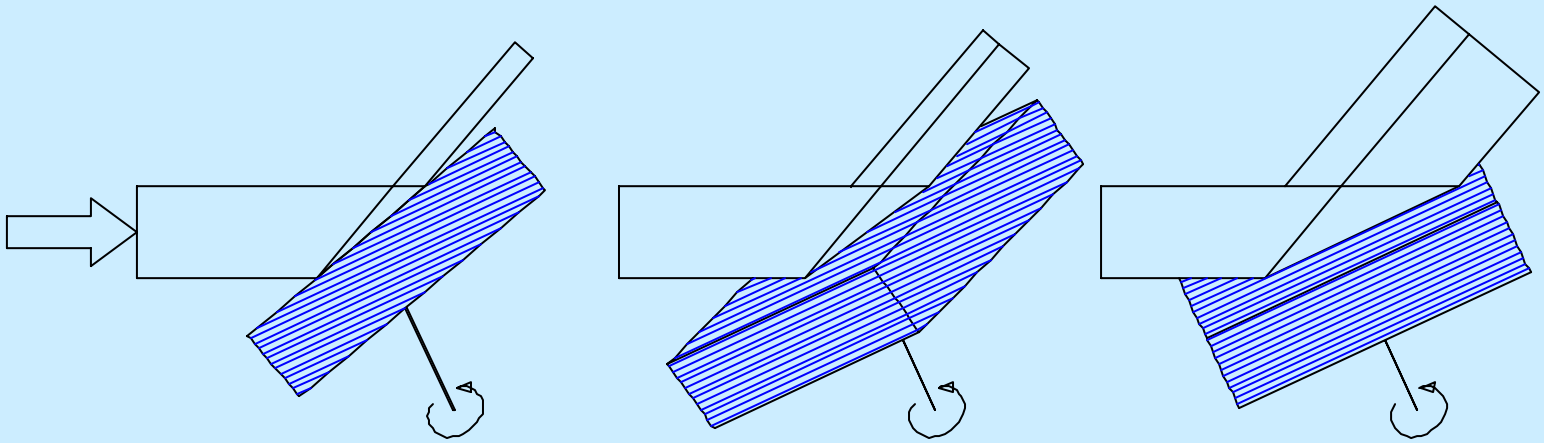
X-ray pulse duration at various photon energies and beam emittance for bend magnet beamline



Tunability of x-ray pulse compression with photon energy (P. Heimann and H. Padmore)

- **Add rotation about axis normal to Bragg planes φ to rotation of Bragg angle θ**

  $\Rightarrow$ **Variation of crystal asymmetry α keeping pulse compression fixed**

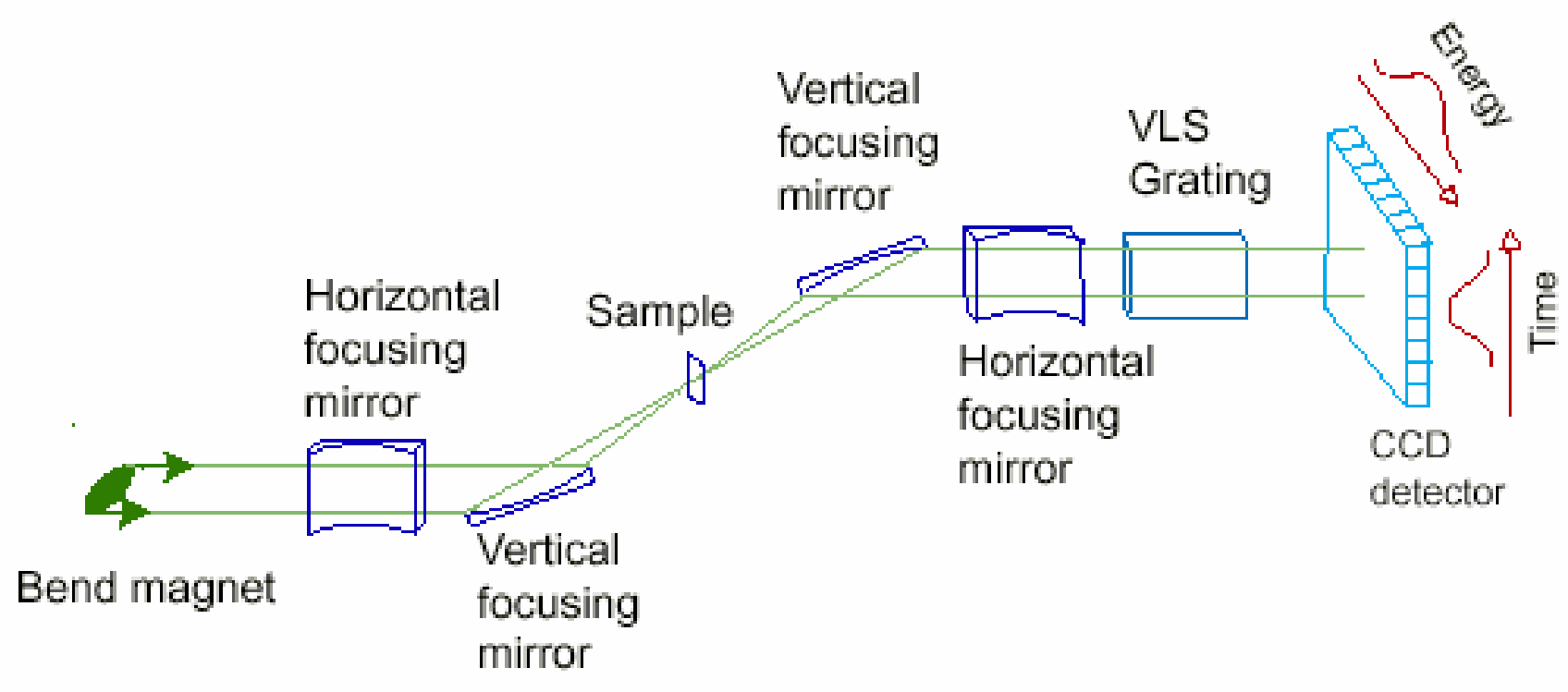


$\varphi = 0°$
$\alpha = 15°$

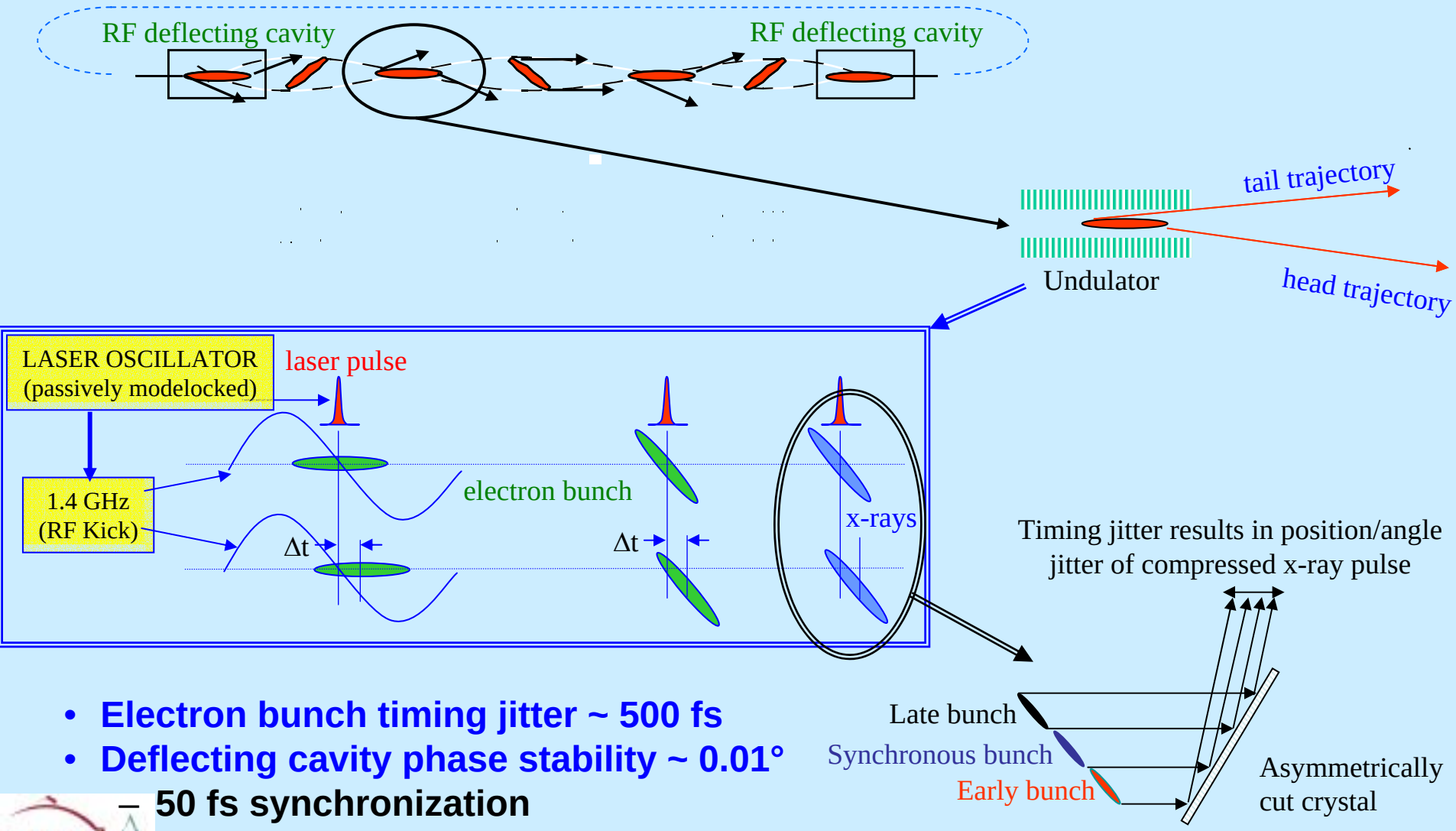
$\varphi = 45°$
$\alpha = 11°$

$\varphi = 90°$
$\alpha = 0°$

Simultaneous collection of different times and photon energies (appropriate for x-ray absorption, not photoemission)



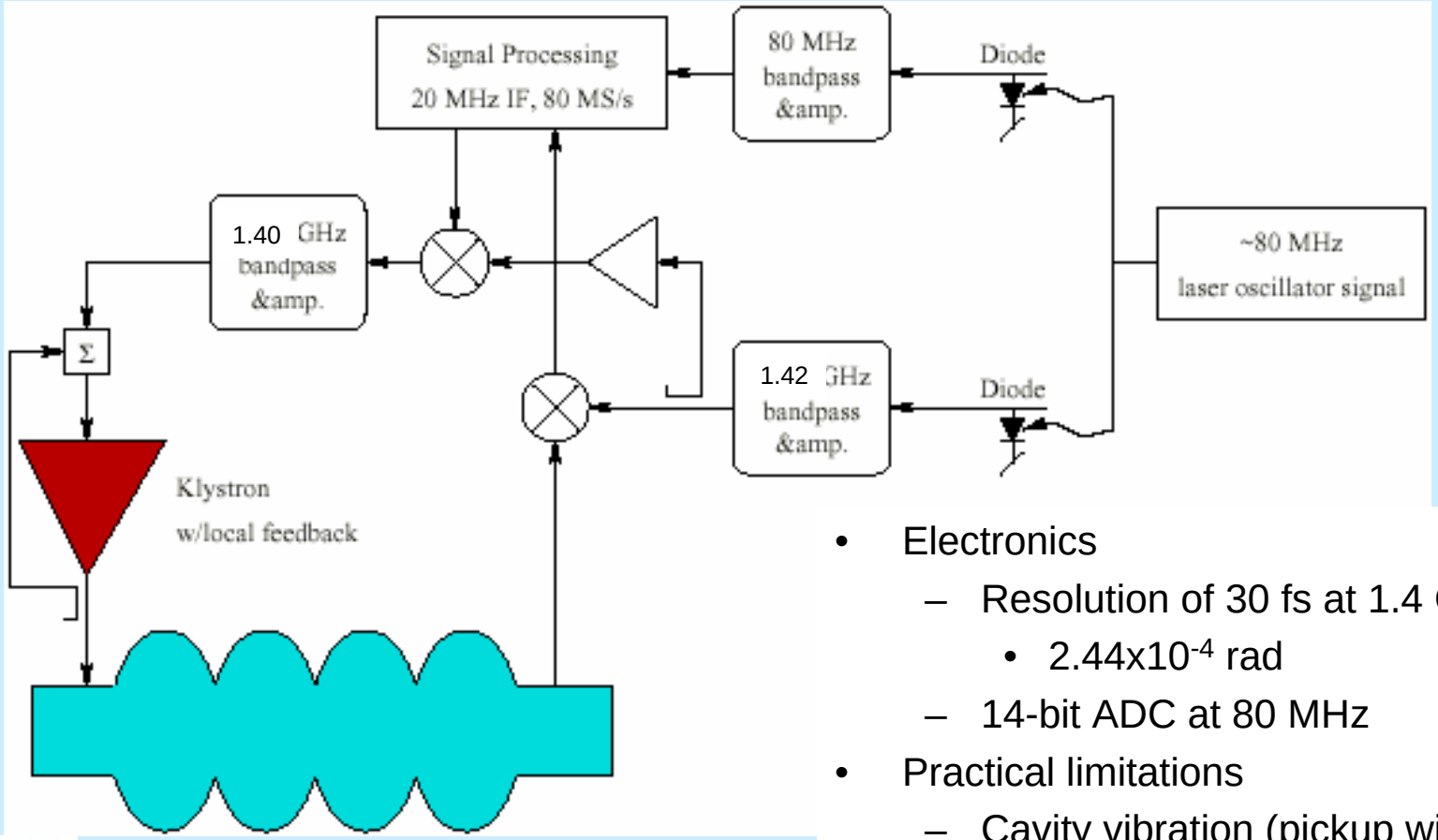
Synchronization to the pump laser pulse



- **Electron bunch timing jitter ~ 500 fs**
- **Deflecting cavity phase stability ~ 0.01°**
  - **50 fs synchronization**

Deflecting cavity RF control (L. Doolittle)

- Control cavity phase and amplitude to minimize timing jitter
  - "Fast" feedback



- Electronics
  - Resolution of 30 fs at 1.4 GHz
    - 2.44×10^{-4} rad
  - 14-bit ADC at 80 MHz
- Practical limitations
  - Cavity vibration (pickup with respect to cavity body)

Flux

- The rf orbit deflection does not affect the x-ray flux.
- Brightness is reduced by a compression factor.
- Laser repetition rate or sample “relaxation time” define the “useful” x-ray flux in the pump-probe experiments.

Summary

- Slicing technique is very challenging at the top energy.
- It might be possible at a lower energy (< 5 GeV)
- X-ray pulses less than 1 ps can be produce using RF orbit deflection technique
- Minimal modification to the APS lattice is required.
- Necessary to build a pair of SR RF deflection cavities.