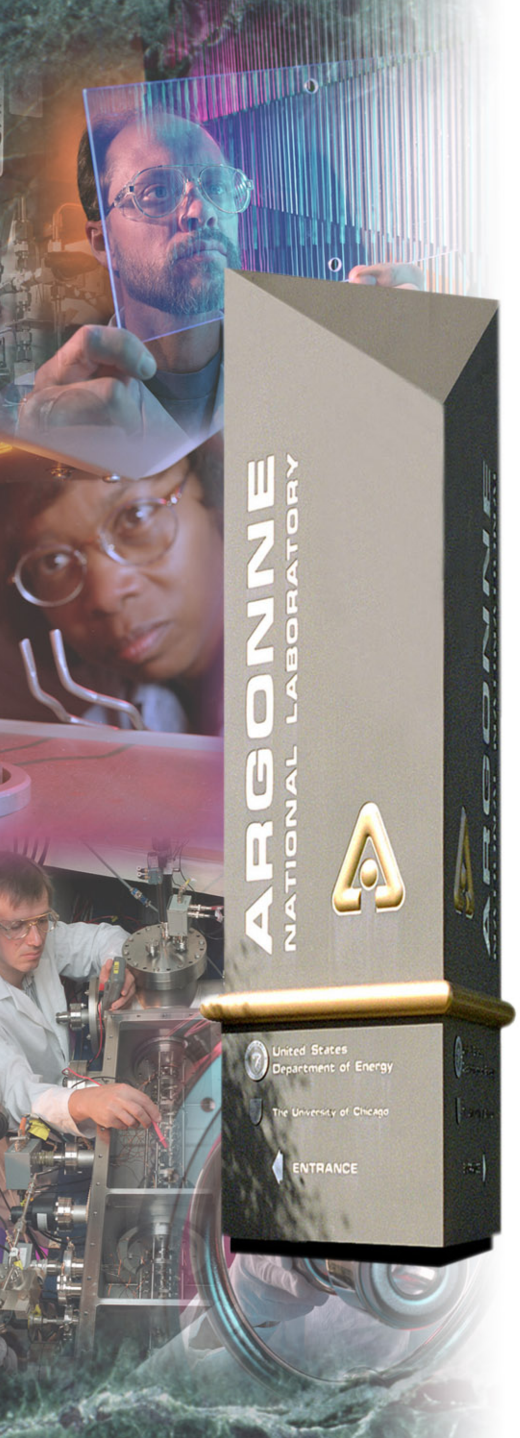

Status of Short X-Ray Pulse Project at APS Using Crab Cavities

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Beam dynamics

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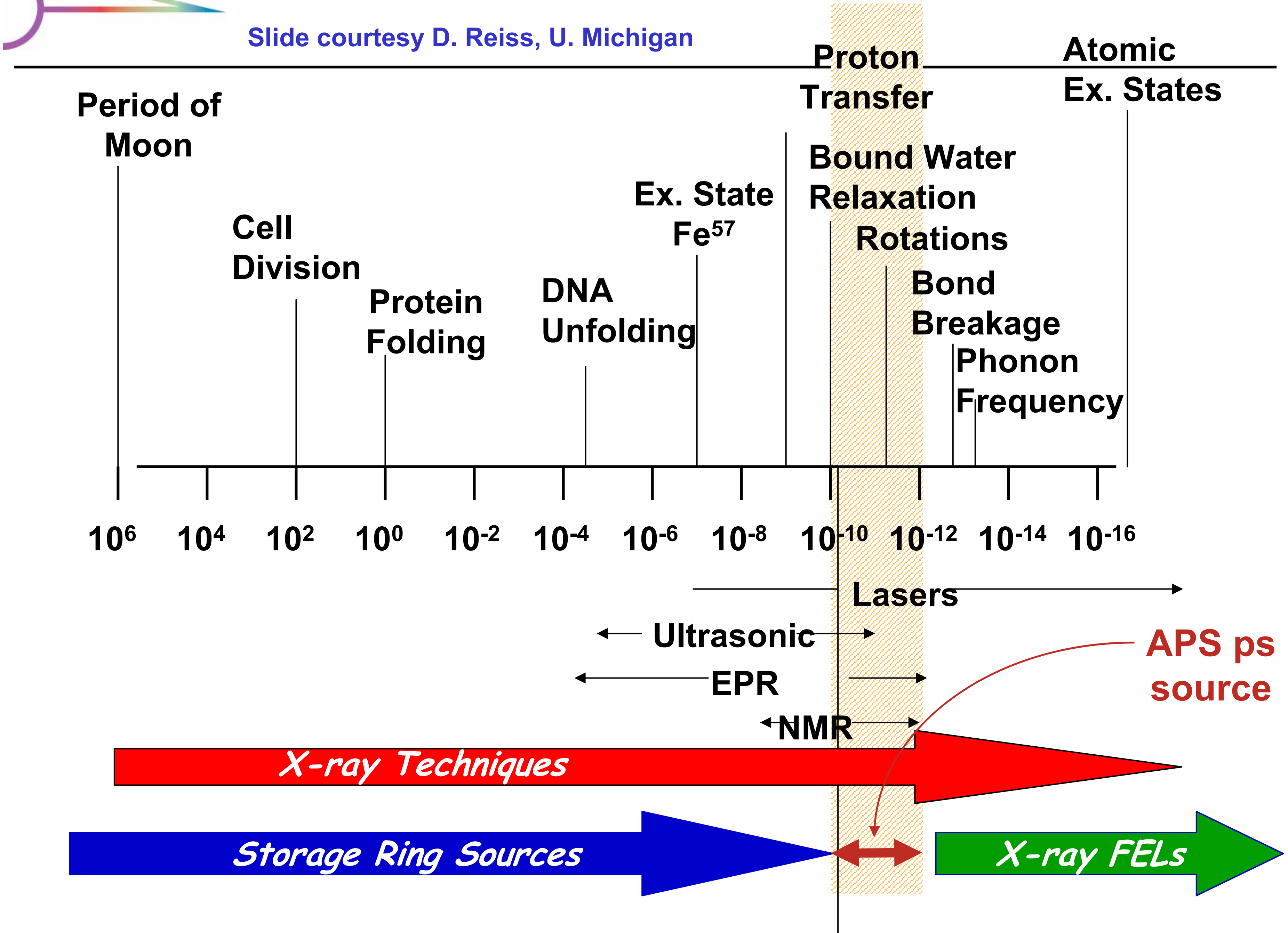
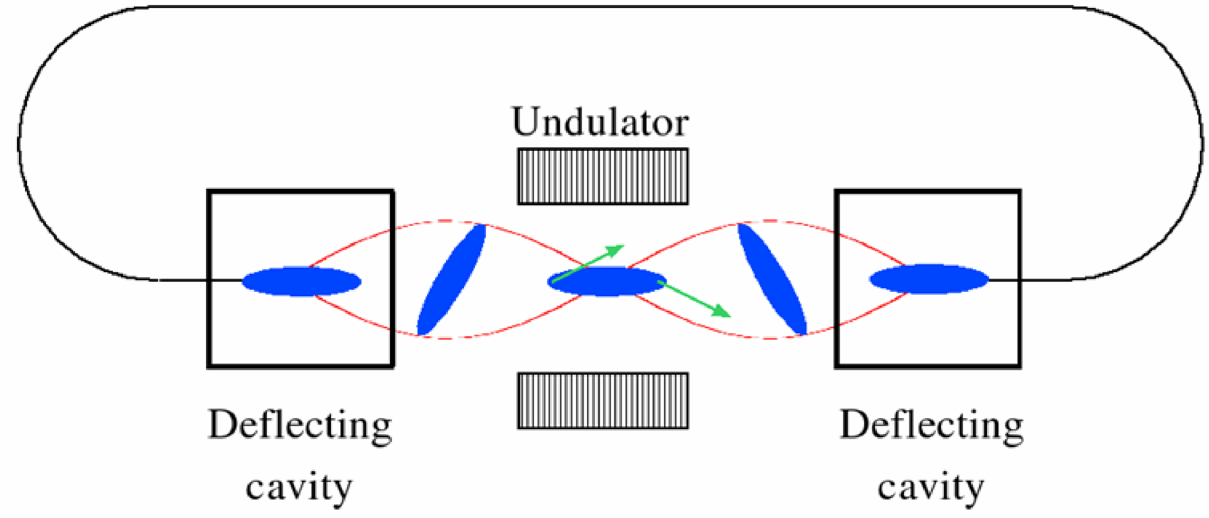
Slide courtesy D. Reiss, U. Michigan



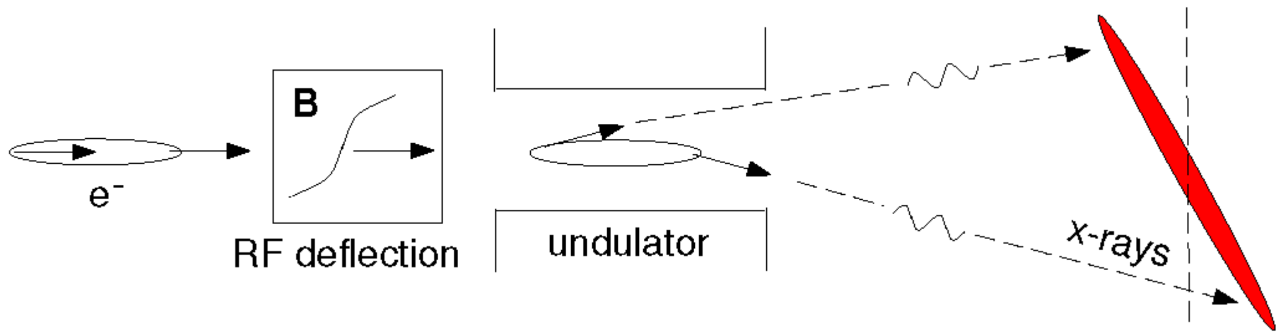
Crabbing scheme†

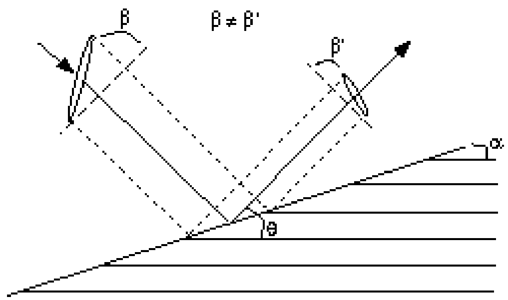


- Deflecting ("crab") cavity operating in TM_{110} mode; B_x kicks head and tail of bunch in opposite directions vertically
- Bunch evolution through lattice results in electrons & photons correlated with vertical momentum along the bunch length
- Second crab cavity at $n\pi$ phase cancels kick; rest of storage ring nominally unaffected

† A. Zholents, P. Heimann, M. Zolotorev, J. Byrd, NIM A425 (1999)

Generation of ps-pulses





Slitting, "streak," or compression

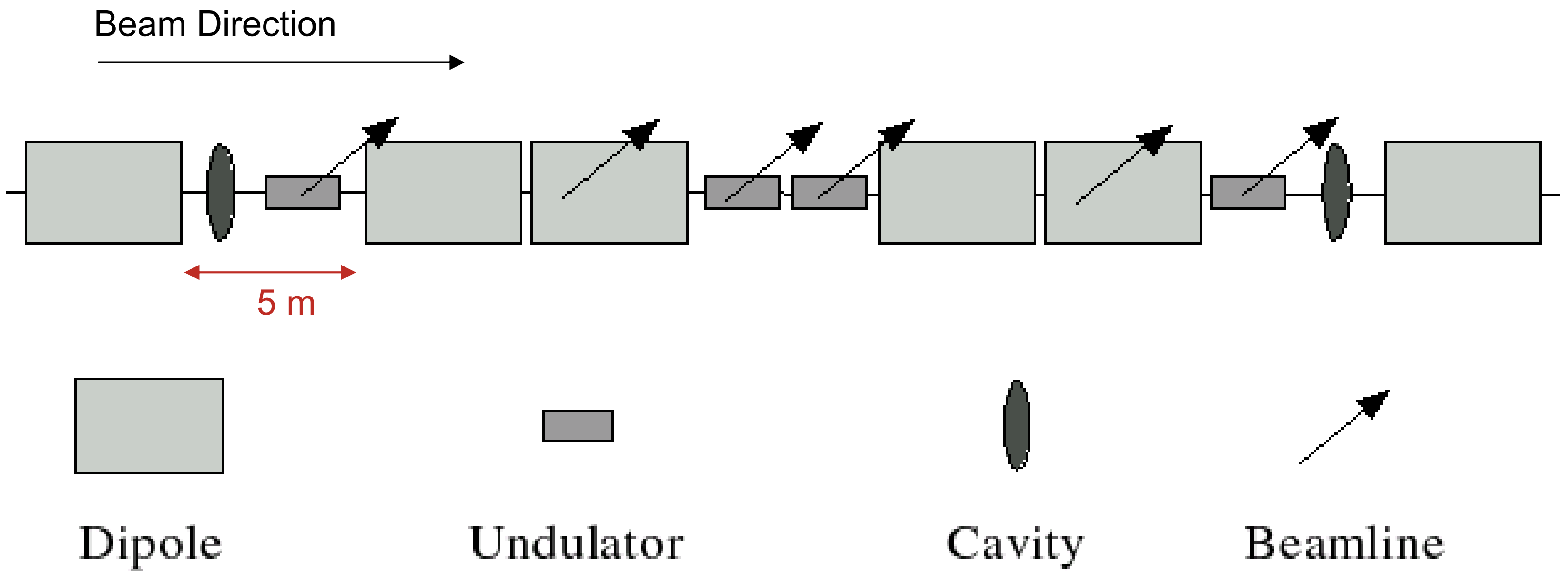
Asymmetric cut crystal; throughput ~ 2-15x better

Compressed pulse length (linear rf):

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

For APS: h=8, 4 MV deflect. voltage, $\sigma_{y',e}$ = 2.0 µrad, and $\sigma_{y',rad}$ = 5 µrad; the calc'd compressed x-ray pulse length is ~0.5 ps rms.

Implementation at APS



- **Space for rf is 2.5 (or 3.1 m if quads removed)**
- **Minimum implementation shown: 4 IDs and 2 BMs**
- **Emittance growth compensation allows more sectors: maximum number between deflecting cavities to be studied**

Parameters & design criteria

Beam dynamics

- **Goal: no impact on performance of crab cavities outside insertion**
- **Beam dynamics parametric study:**
  - **h ≥ 4 (1.4)** (~1 ps (FWHM) pulses)
  - **Deflecting voltage ≤ 6 MV** (lifetime)
- **Typical bunch length 40 ps rms (100 ps FWHM)** (std. 24-bunch mode)

RF

- **Availability of 20-kW class cw rf amplifiers → h = 8 (2.8 GHz)**
- **Available insertion length for cavities nominally 2.5 m (up to 3.1 m)**
- **Starting point Cornell/KEKB crab cavity design**

X-ray optics

- **Throughput**
- **Pulse duration and spot size**
- **Energy tunability**

Beam dynamics issues

(M. Borland, V. Sajaev, A. Zholents)

- **Vertical emittance growth the most serious issue due to nonlinearities and/or uncompensated chromaticity**
- **Sextupole optimization virtually compensates emittance growth – this requires sextupoles in crabbing section**

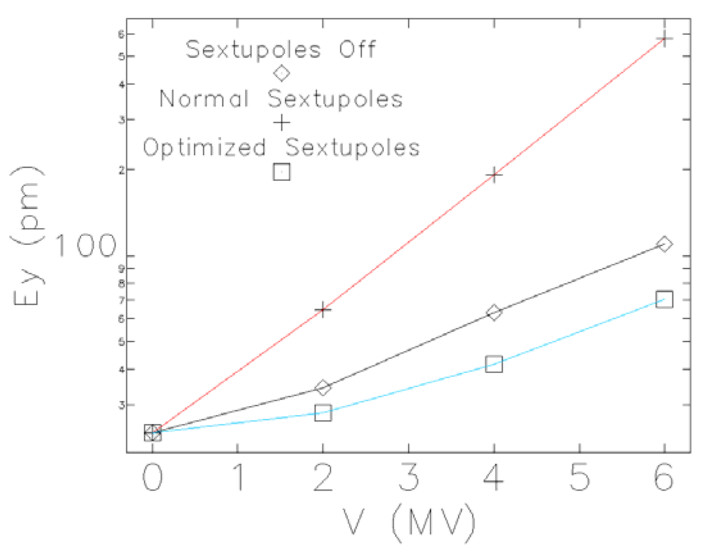


Fig. courtesy V. Sajaev (PAC05)

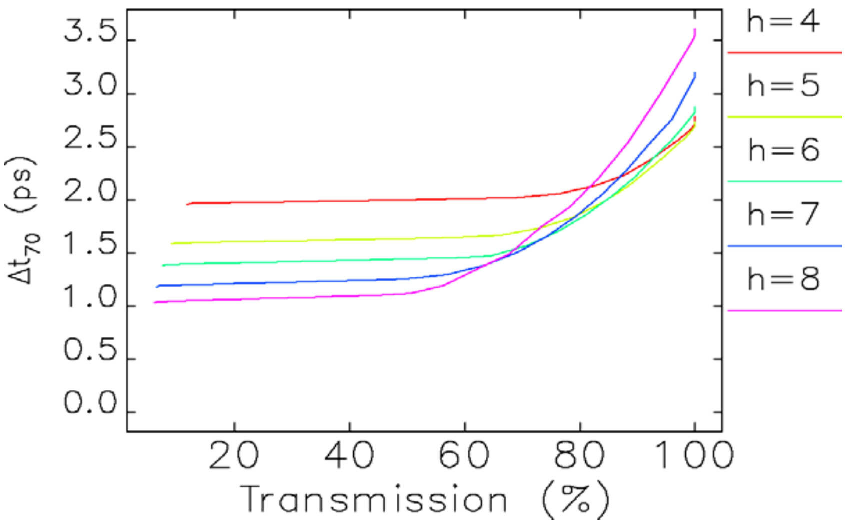


Fig. courtesy M. Borland (PRST-AB)

Beam dynamics issues (cont.)

(M. Borland, Y-C. Chae)

Effects of rf errors: emittance growth or orbit kicks

- Cavity-to-cavity phase error < 0.04 for $\langle y' \rangle / \sigma_{y'} < 10\%$
- Cavity-to-cavity voltage difference < 0.5%

Instability thresholds for LOM/HOMs

	Longitudinal	Transverse
Damping rate (1/s)	212	106
Ring Parameters	I_{total}=100 mA, E = 7 GeV, α=2.8e-4	$\omega_s/2\pi$=2 kHz, ν_s=0.0073, β_x = 20 m
Stability Condition: Growth Rate < Damping Rate	$R_s * f_p$ < 0.8 MΩ – GHz	R_T < 2.5 MΩ/m

SRF crab cavity issues
(G. Waldschmidt, A. Nassiri, D. Horan)

- Deflecting mode TM_{110}: B_x on axis, E_z off axis. Beam couples very strongly to TM_{100} (LOM)
- CW operation requires SRF – pulsed SLAC-type structure for BD study
- Single-cell vs. multiple-cell SC cavity configurations compared. Only single cells allow req'd LOM/HOM damping
- Design considerations: available space, rf power, available rf amplifiers, HOM/LOM damping, tuning, input couplers

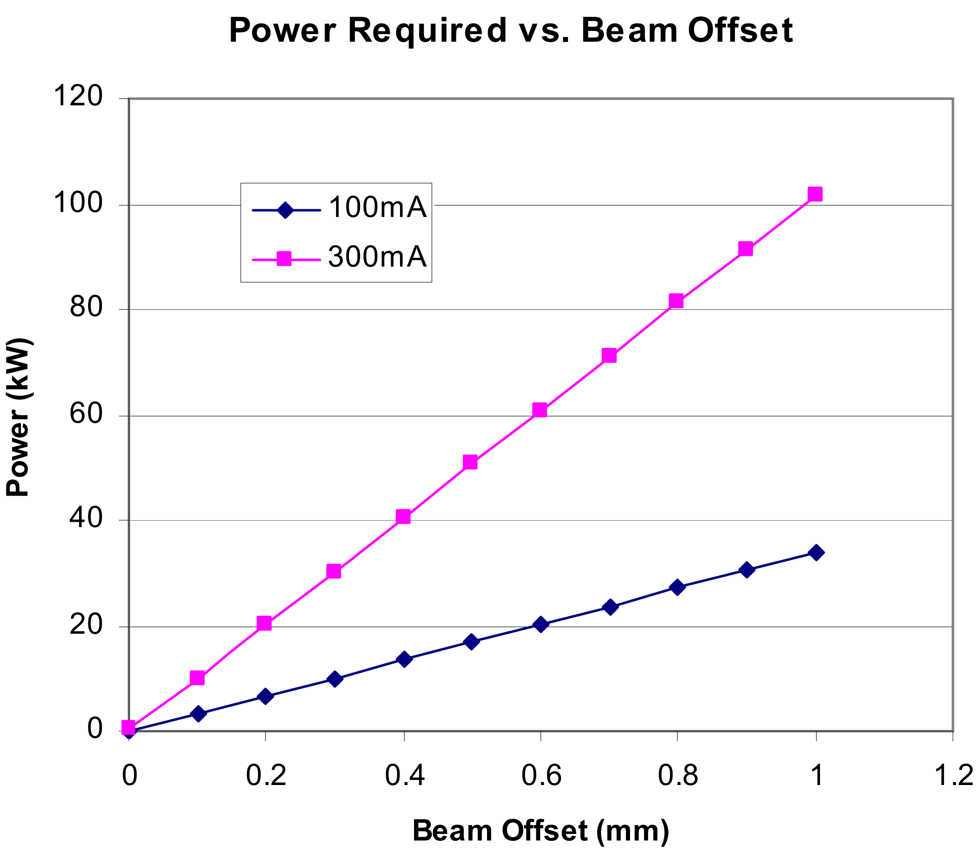
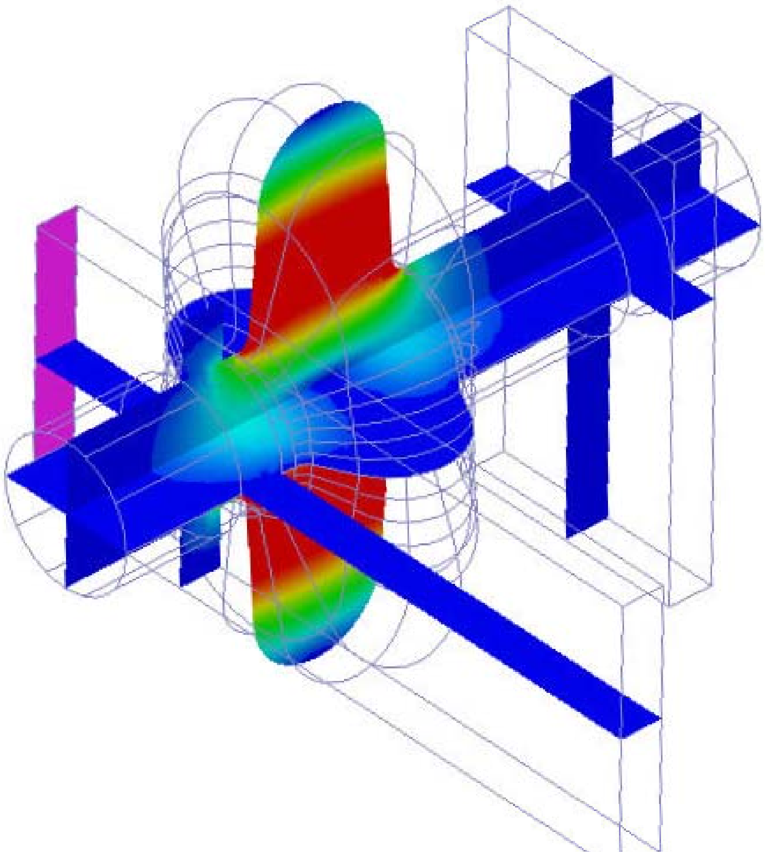


Fig. courtesy G. Waldschmidt

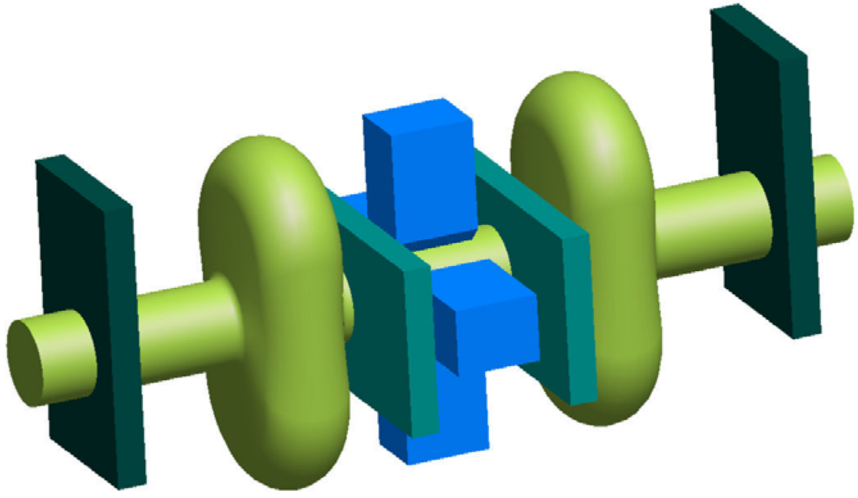
SC rf deflecting cavity design

(G. Waldschmidt, G. Pile, D. Horan, R. Kustom, A. Nassiri)

Figs. courtesy G. Waldschmidt (see EPAC06)



Deflecting mode field calculations with **asymmetric LOM damper** designed to satisfy damping criteria given by APS multibunch stability threshold.

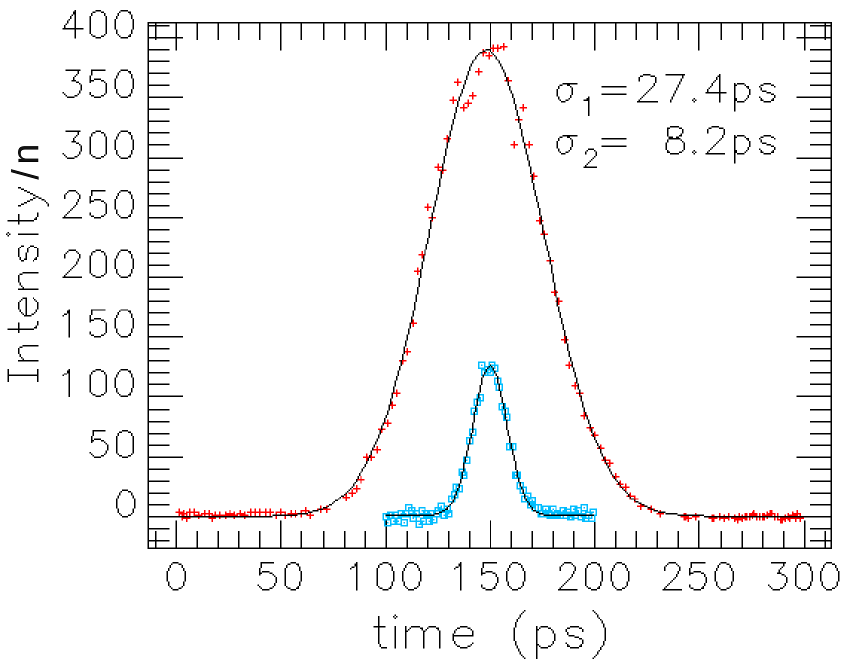


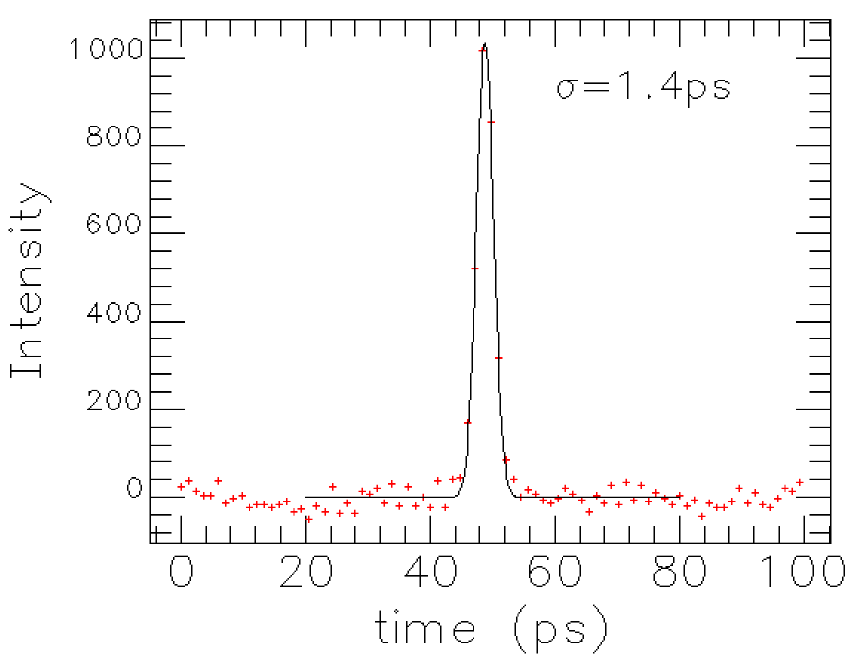
Configuration including LOM/HOM dampers (center) and input couplers (ends) for a pair of single-cell cavities. "Squashed" cavity design allows damping of unwanted dipole mode (with wrong polarity)

- Calculations completed for iris effect (TE modes → horiz deflection) and LOM/HOM power driven by beam
- Ongoing effort:: cryomodule design issues, simulation of TE mode effects

Transient ultrashort pulses using dipole kick (W. Guo, PAC05)

Figs. Courtesy W. Guo





Time-ave. , intensity norm to n=300 pulses. **Ratio of** initial (red) to slitted (blue) **pulse length is 3.3:1; intensity ratio is the same.**

Shortest pulse measured, single shot. Vertical tune jitter causes time ave. pulse length to increase over large n.

- Results to date for a train of low-current electron bunches (« 1mA). Effort ongoing to optimize kick with high current single bunch (~5 mA) to obtain as short a pulse length as possible (wakefield effects).
- Begun effort to synchronize kick with the pump probe laser trigger

Summary

- We believe ~1 ps pulses achievable in APS
- Implementation involves installing SRF crab cavity insertion across 2-4 sectors and upgrading existing ID beamlines
- Capability is complementary to the even shorter pulses expected from x-ray FELs, yet provide all advantages of rings
- Transient pulse generation (synchrobetatron coupling) and imaging now being studied – user experiment planned later this year
- Pulsed NC deflecting rf will allow beam dynamics study (SLAC-type), "cheap" test with low power (resonant kicks)
- DOE is interested!