Short X-ray Pulses Project at the APS

Argonne NATIONAL LABORATORY

K. Harkay

APS upgrade MAC Review

Nov. 15, 2006

Outline

- Background
- Short x-ray pulse generation feasibility study
- Project plan: fast track implementation
- Status
- Far term
- Summary

Science drivers for ps x-rays

APS Strategic Planning Workshop: Time Domain Science Using X-Ray Techniques (Aug 2004)

*"…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."*

APS User's Meeting: Workshop on Generation and Use of Short X-ray Pulses at APS (May 2005)

APS Upgrade Planning: Workshop on Picosecond Science (June 2006)

Goal:

- ~1 ps pulses
- Energy tunability
- Flux comparable to 100 ps
- High repetition rate
- No impact on emittance, stability, current

Atomic and molecular dynamics, coherent/collective processes:

- Atomic and molecular physics
- Condensed matter physics
- Biophysics/macromolecular crystallography
- Chemistry

Feasibility study & project team

Beam dynamics, RF, ME

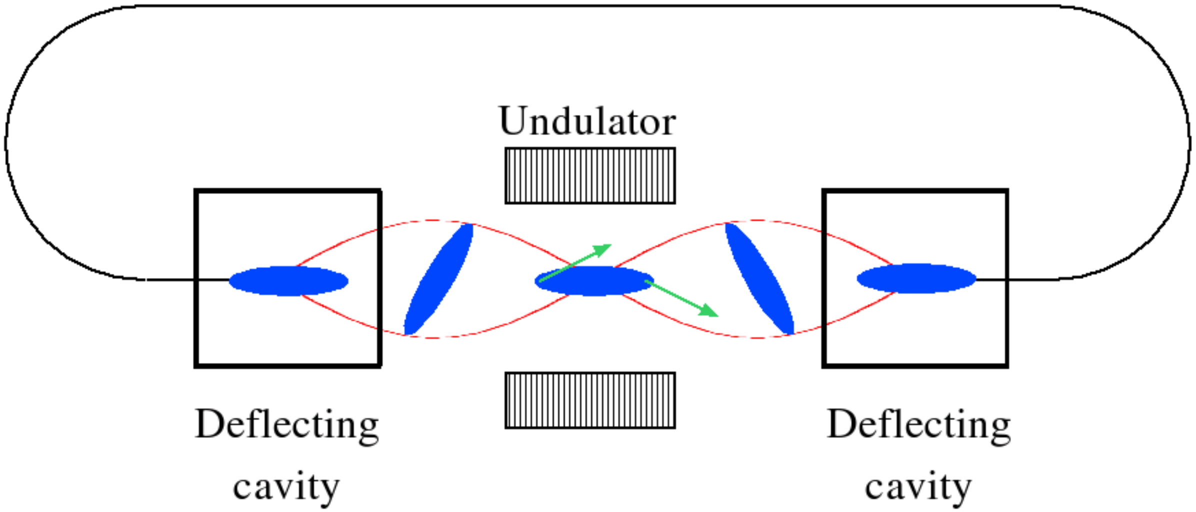
M. Borland
J. Carwardine
Y.-C. Chae
P. DenHartog
L. Emery
K. Harkay
A. Nassiri
V. Sajaev
G. Waldschmidt
A. Zholents, LBNL *
V. Dolgashev , SLAC *

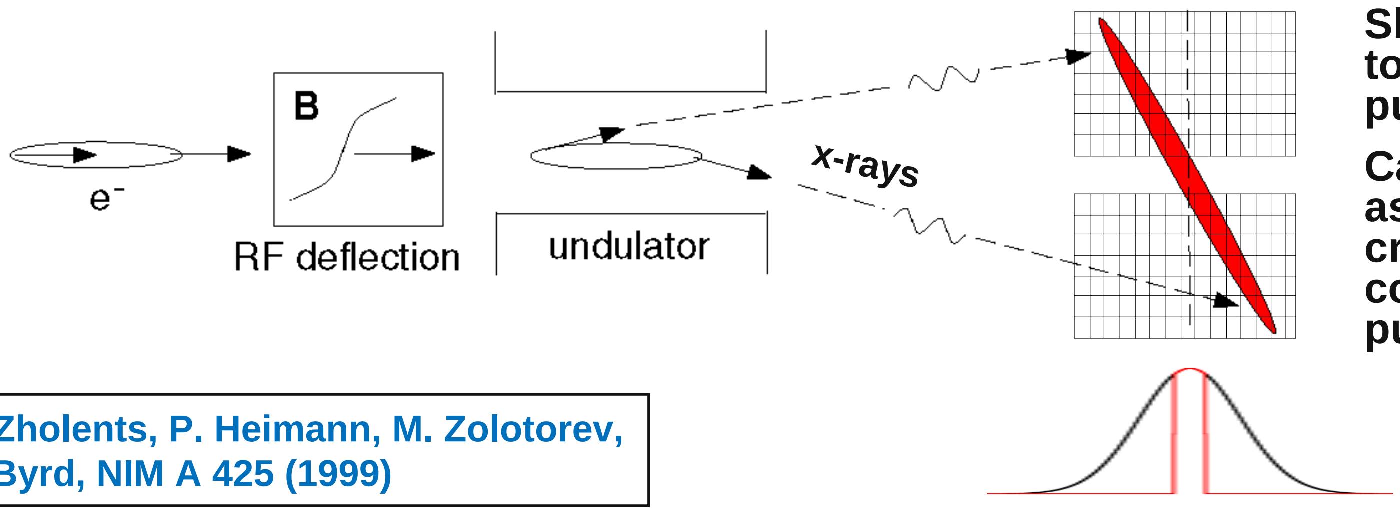
Undulator radiation, x-ray optics, synchronization, diagnostics

B. Adams
L. Assoufid
R. Dejus
E. Landahl
F. Lenkszus
A. Lumpkin
S. Shastri
G. Srajer
J. Wang
B. Yang

*** All affiliated with APS except where noted**

Short-pulse generation with rf deflection†



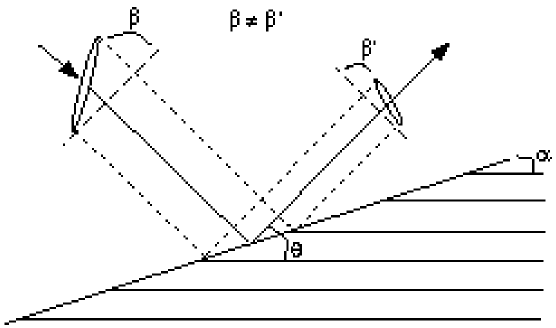


Slits can be used to clip out a short pulse.

Can also use asymmetric cut crystal to compress the pulse.

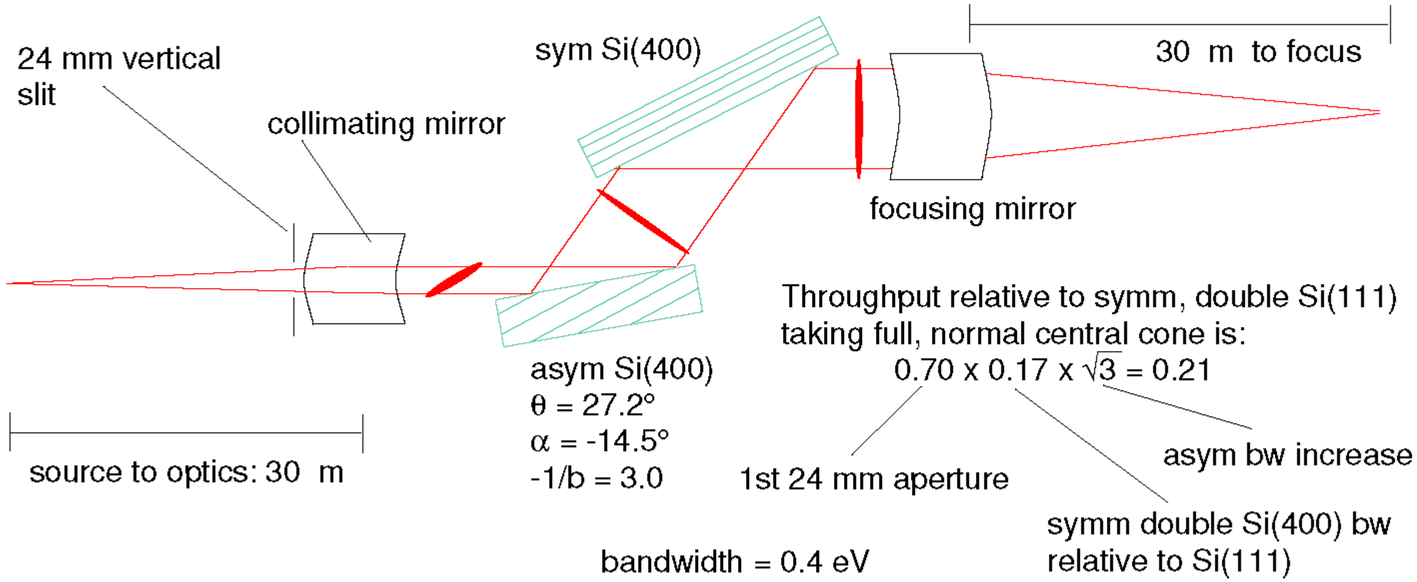
† **A. Zholents, P. Heimann, M. Zolotorev, J. Byrd, NIM A 425 (1999)**

X-ray compression optics



Asym. cut crystal: throughput ~ 2-15x better than slit

S. Shastri, R. Dejus, L. Assoufid



Compressed pulse length (linear rf):

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

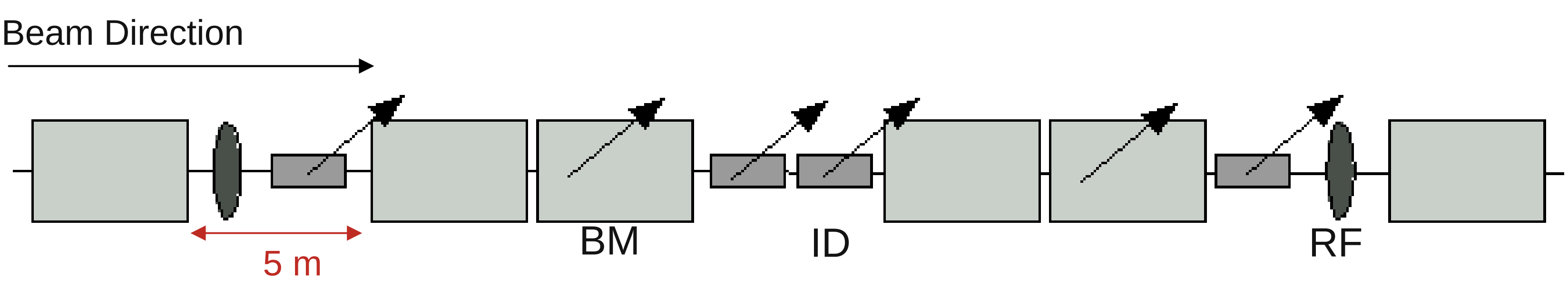
M. Borland, PRST-AB 8, 074001 (2005)

For APS: h=8, 6 MV deflect. voltage, $\sigma_{y',e}$ = 2.2 μrad, and $\sigma_{y',rad}$ = 5 μrad; the calc'd compressed x-ray pulse length is ~0.36 ps rms.

Feasibility study conclusions

1. M. Borland, PRST-AB 8, 074001 (2005)
2. M. Borland, V. Sajaev, PAC 2005, 3886
3. Y.-C. Chae, ASD/APG/2005-07

- X-ray pulses of order ~1 ps achievable in APS
- Critical issues:
  - Vertical emittance growth due to nonlinearities and/or uncompen-sated chromaticity; corrected with sextupole optimization [1,2]
  - Tight tolerances for cavity-to-cavity errors [1]
    - *Phase error < 0.04° for $<y'>/\sigma_{y'} < 10\%$*
    - *Voltage difference < 0.5%*
  - LOM/HOM damping to avoid multibunch instabilities [3]
    - $R_s * f_p < 0.8\ M\Omega - GHz$
    - $R_T < 2.5\ M\Omega/m$
- Initial implementation was to have been a N-sector insertion



Choice of Cavities: Pulsed versus CW

Pulsed

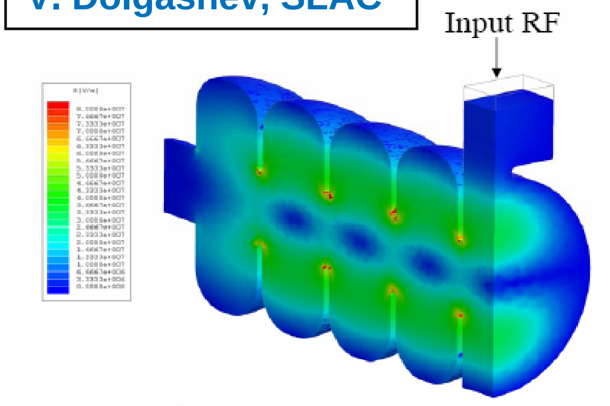
- Variable pulse length
- Room temperature technology
- Cavities are 0.5 m long and water cooled
- Cheaper and faster to implement
- Repetition rate limited to ~1 kHz
- Compatible only with hybrid mode
- 30-year history of pulsed deflection in linear beam transport; **none** in rings

P. Anfinrud, NIH

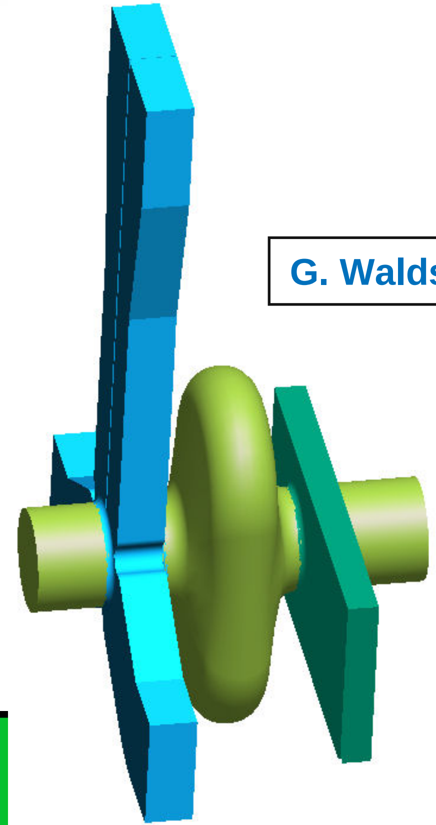
CW

- High repetition rate (CW)
- Compatible with all operating modes
- Opportunity to develop SC RF expertise at APS
- Cavities require ~2.5 m
- Cryocooling technology
- More expensive and longer time to implement

V. Dolgashev, SLAC



G. Waldschmidt



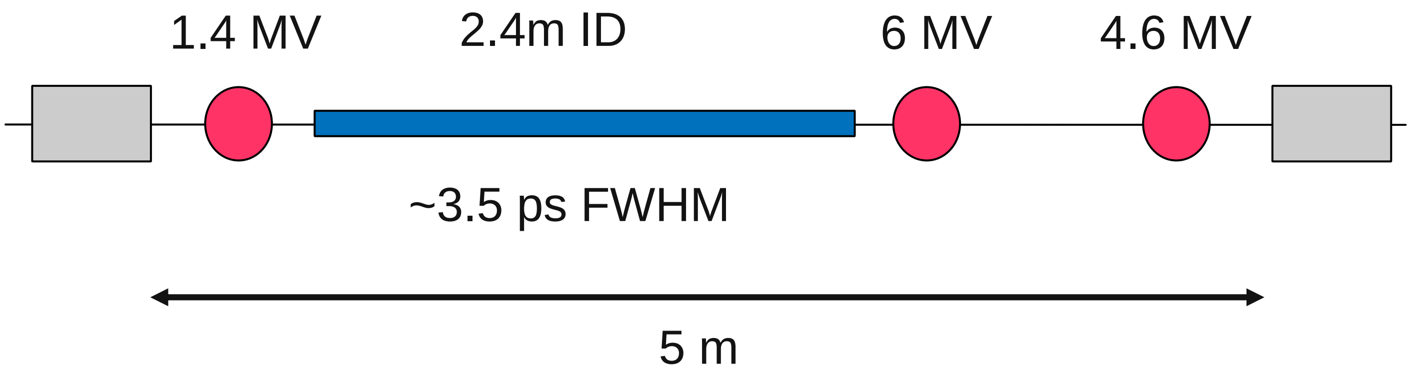
*Fast track implementation**

- While pursuing the CW option, two things happened:
  - Space in adjacent sectors unavailable
  - Compact single-sector idea **A. Nassiri**
- Fast track is feasible and timely
  - Some hardware already in house: Spare linac klystron + modulator (relocate to ring area)
  - Other hardware in advanced design phase: crab cavity structures from SLAC
- Sector 7 identified as first user

*Aggressive schedule not without technical challenges

Phase I: compact option in 7ID

Standard 5 m long straight section

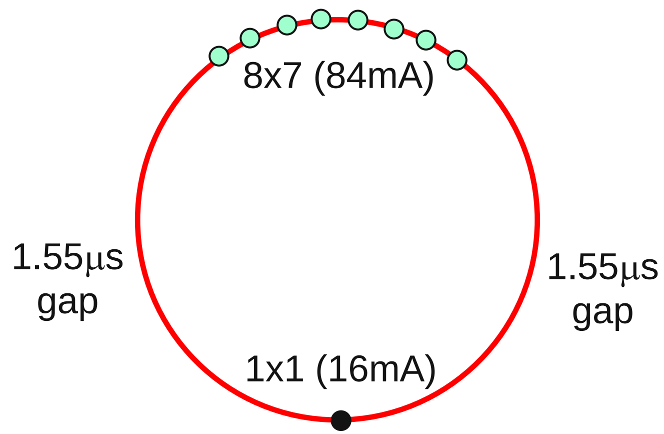


- Limited capability within ~12 mos
- Low rep rate (120 Hz)
- Beamline: commissioning, diagnostics development, thin slit optics, etc

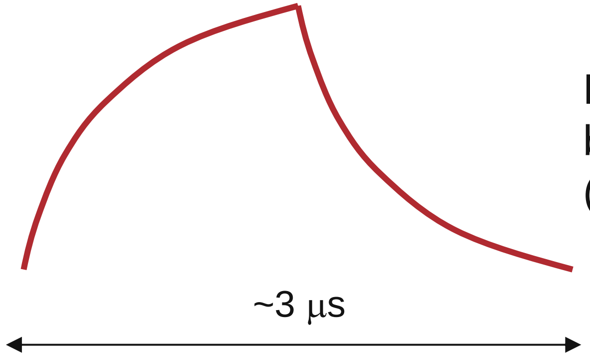
A. Nassiri, V. Sajaev, M. Borland

Hybrid Fill Pattern and Chirp Timing

Hybrid fill pattern



Deflecting cavity RF voltage

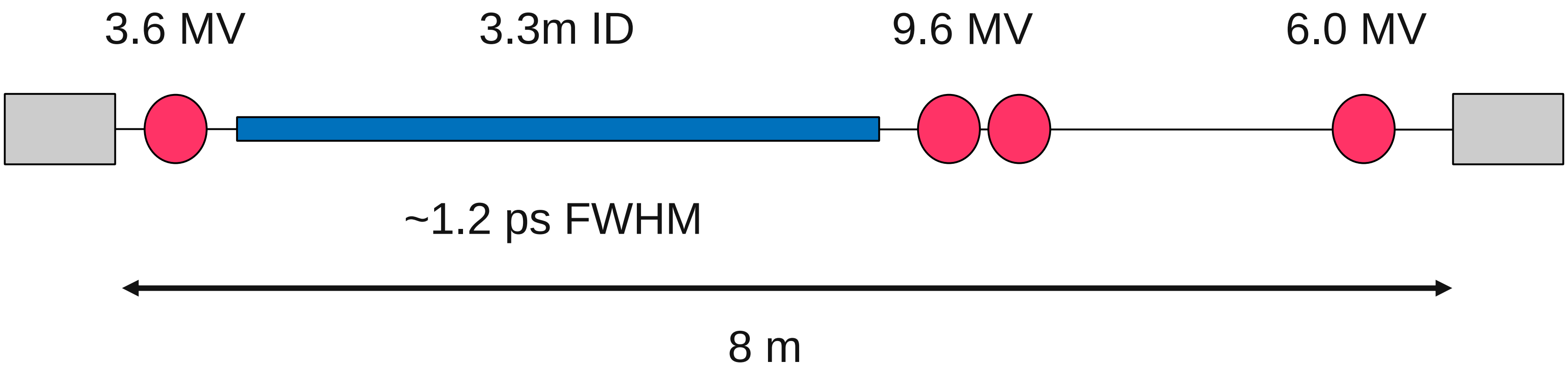


Rise/fall times limited by crab cavity fill time (~800ns)

J. Carwardine, L. Emery

Phase II: Upgrade Path

Extended (8 m) long straight section



- Increased flux
- Rep rate up to 1 kHz
- Phase 1 + ~12 mos
- Beamline: short-pulse experiments

V. Sajaev, M. Borland

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Phase I project status

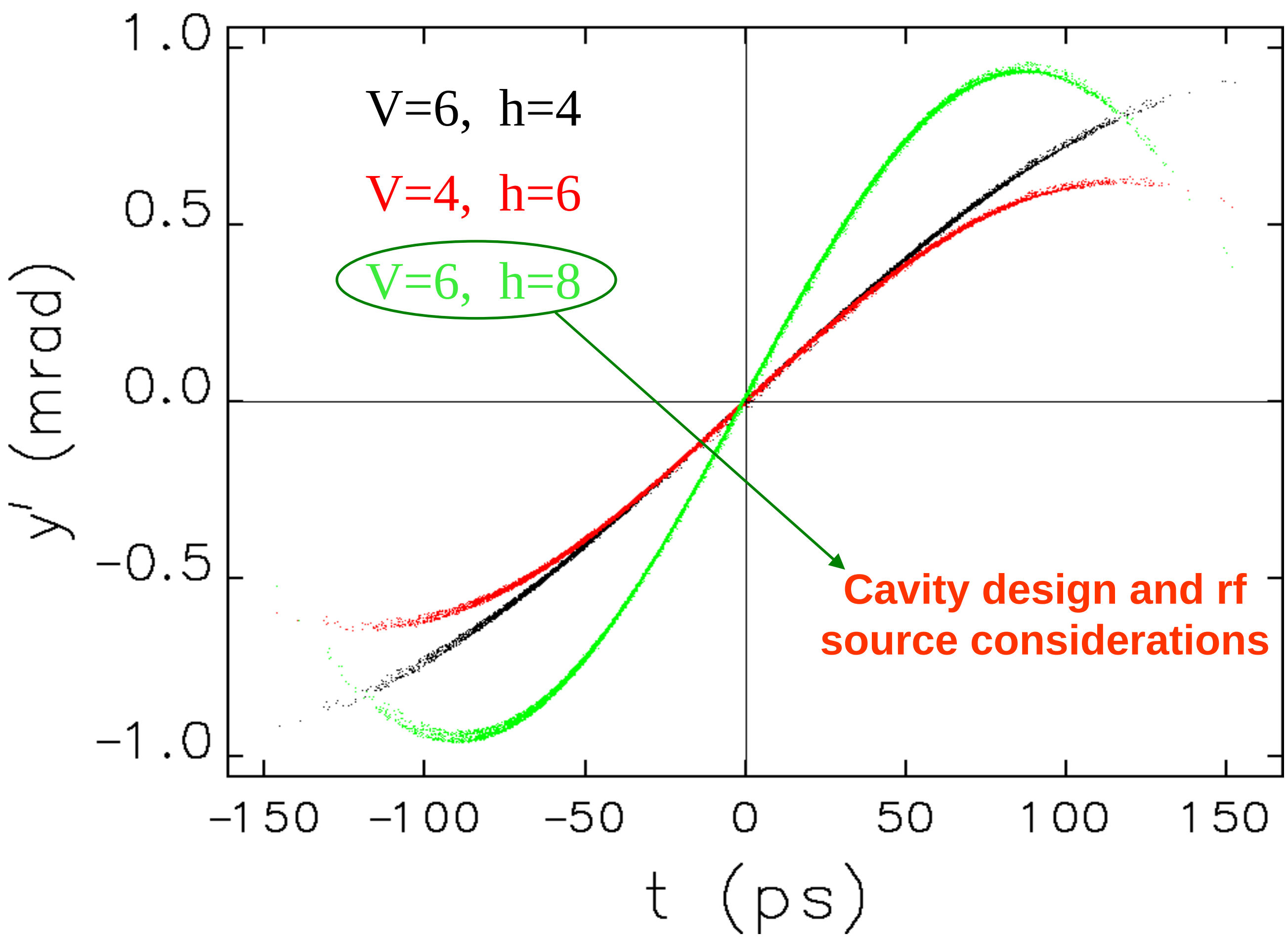
- Physics specifications
- RF system tolerances
  - 1 kHz operation more challenging (vs. 120 Hz)
    - *Phase error < 0.05° (vs. 0.22°)*
    - *Voltage difference < 0.1% (vs. 0.4%)*
- Beam dynamics: collective effects, frequency choice
- RF cavity design: HOM damping, thermal engineering (collaboration with SLAC)
- Sector girder layout, RF layout
- Photon diagnostics, synchronization
- Schedule and commissioning plan

L. Emery at al., OAG-TN-2006-40

M. Borland, OAG-TN-2006-51

B. Yang, F. Lenkszus et al.

Frequency choice: what hV is required?



Can get the same compression as long as h*V is constant

Higher V and lower h: more linear chirp and less need for slits

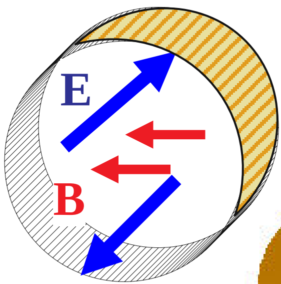
Higher h and lower V: smaller maximum deflection and less lifetime impact

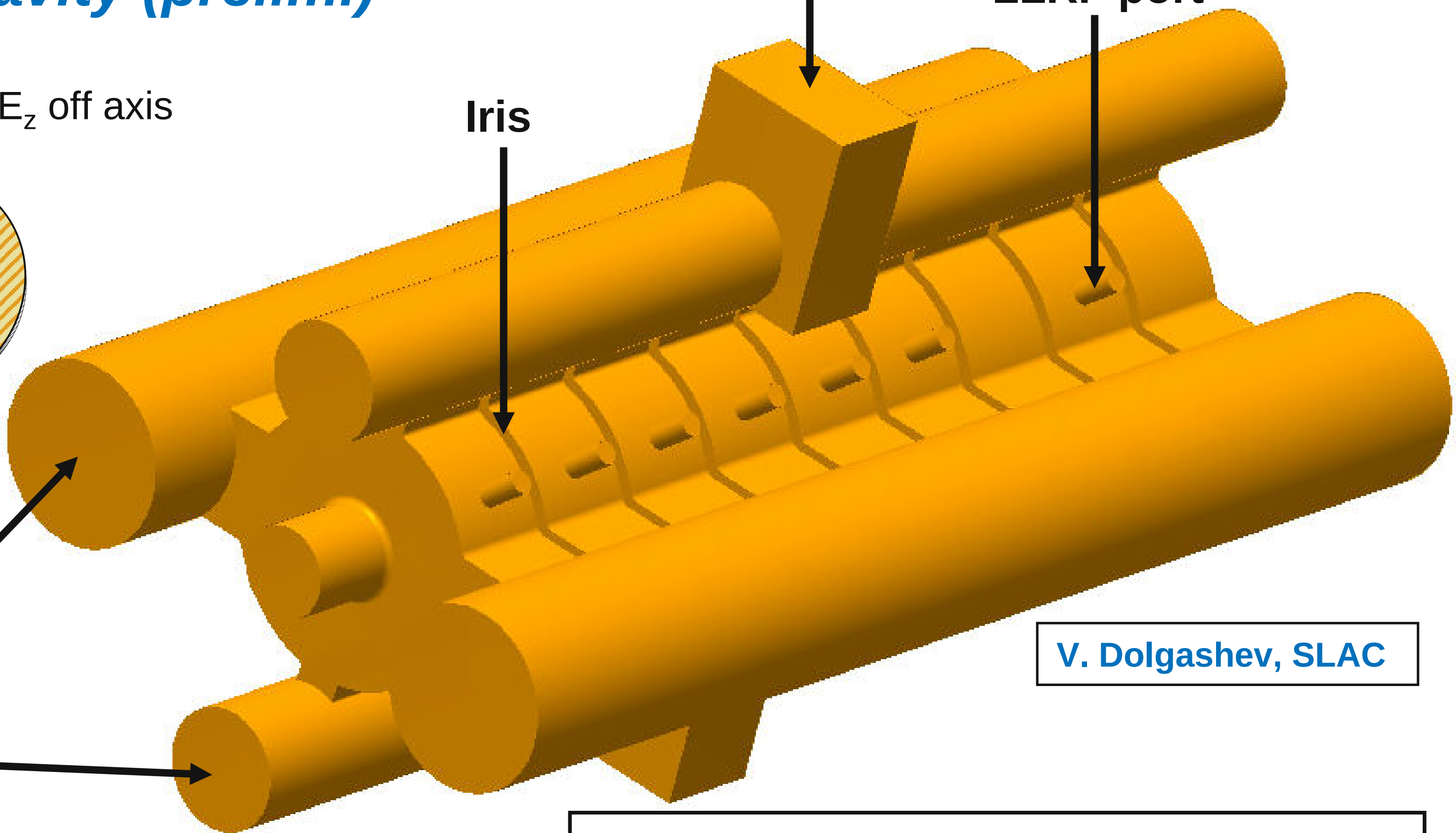
Higher h and maximum V: shortest pulse, acceptable lifetime

M. Borland, APS ps Workshop, May 2005

9-cell Cavity (prelim.)

TM110 B_{ϕ}, E_z off axis





V. Dolgashev, SLAC

Main design considerations:
- 6 MV deflecting voltage
- Preserve single bunch limit
- Avoid multibunch instabilities
- Min thermal loads/mechanical stresses

Beam dynamics issues: collective effects

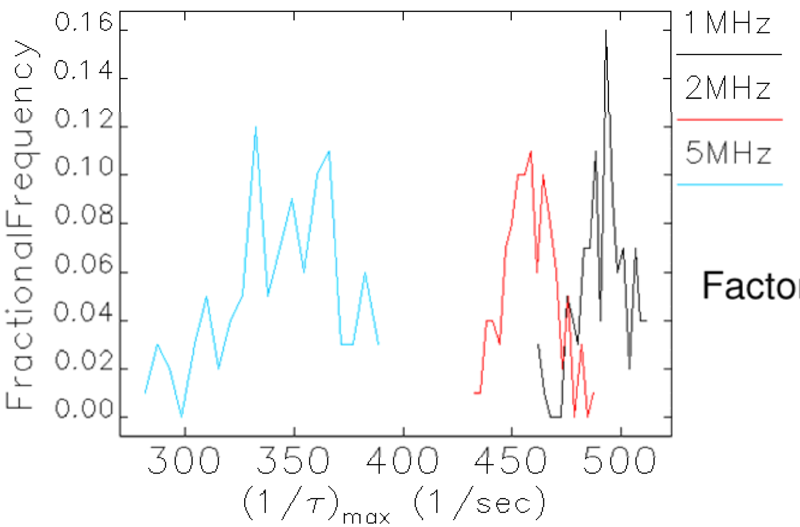
Y.-C. Chae

- Single bunch: broadband
  - Numerical computation of wake from three cavities
  - Horiz: 60% of total ring wake
  - Vert: 10% of total ring wake
  - Single bunch limit reduced by 1-2 mA (horiz wake)
  - Present limit 20 mA, deliver 16 mA for hybrid mode: okay

Beam dynamics issues: collective effects (cont)

Y.-C. Chae, L. Emery, M. Borland

- Multibunch: LOM, HOM non-deflecting modes
  - Analysis of randomized mode frequencies vs. fill pattern
  - Vary uncertainty/spread (typ ±2 MHz)
  - Vary deflecting freq:
    - *Linac s-band (2856 MHz); h=8 (2815 MHz); h=8±0.5*
  - LOM: worst mode 1.9744 MHz
  - HOM: worst mode horizontal deflecting
  - Req'd deQ factor ~50

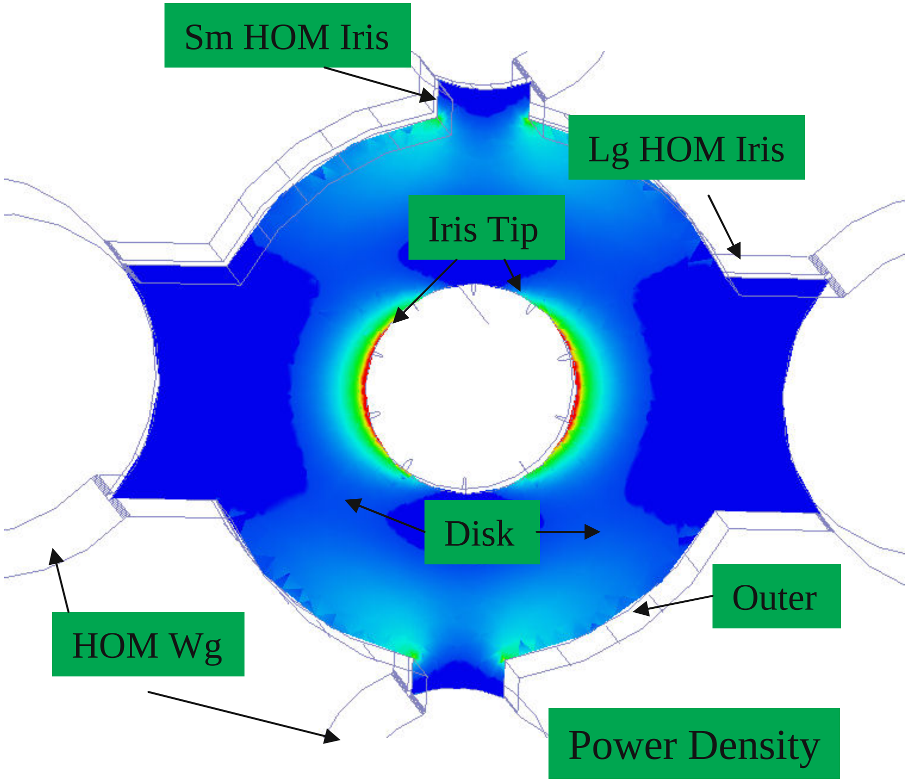


Factor 50

L. Emery

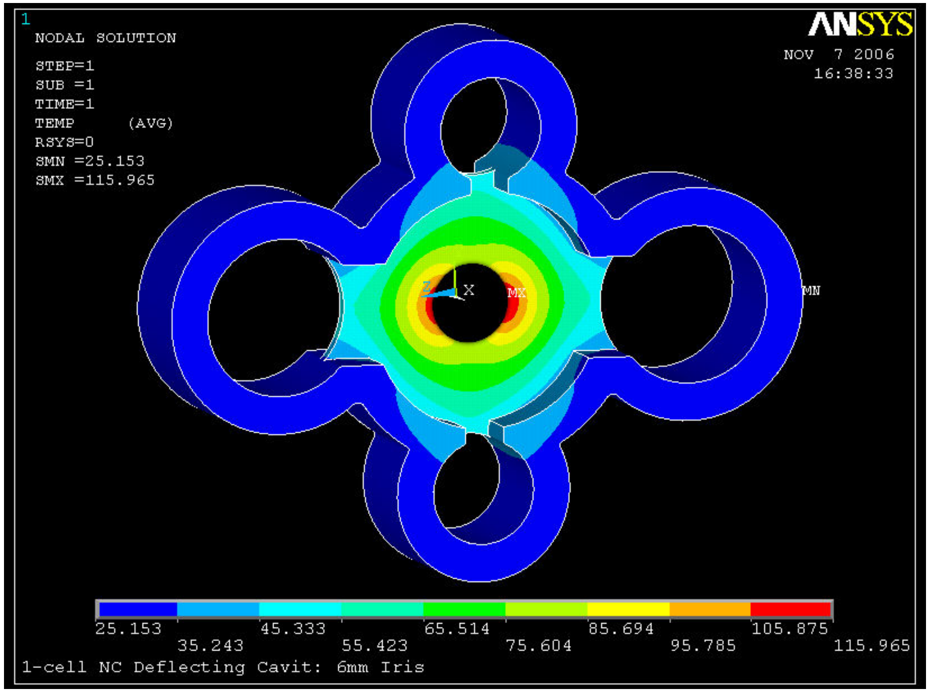
Contoured Iris: Aggregate power loss (prelim.)

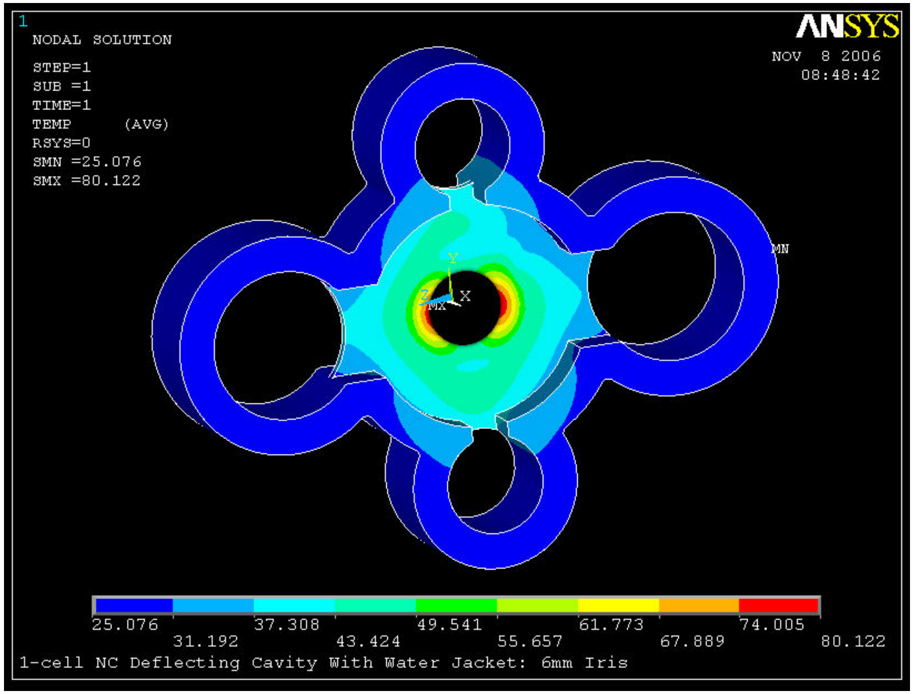
	6 mm
Freq (GHz)	2.815
P_{Total} (W)	1601
$P_{IrisTip}$	510 (32%)
P_{Disk}	609 (38%)
P_{Outer}	414 (26%)
$P_{HOMIrisLg}$	7.5
$P_{HOMIrisSm}$	58.5
P_{HOMWg}	1.5



B. Brajuskovic, G. Waldschmidt

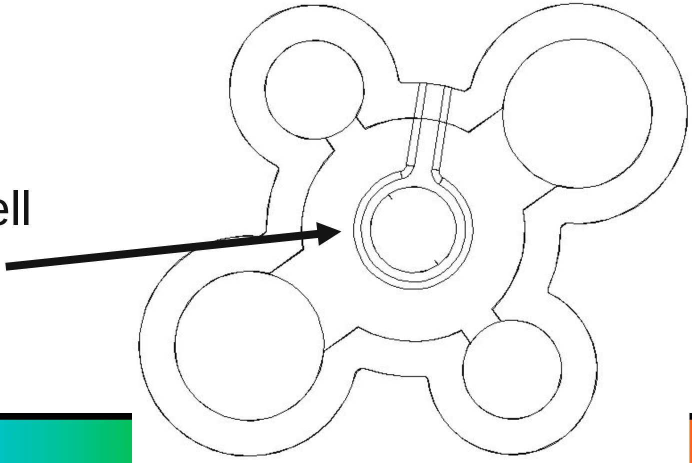
Remote vs Local Cooling of Iris (prelim.)





B. Brajuskovic, G. Waldschmidt

- Rf power loss load calculated by HFSS and imported into Ansys
- Remote cooling with 25°C water on outer shell
- Local iris cooling with 4-mm cooling channel
- Alternative: heat pipe (not shown)



Diagnostics: Minor upgrades

Purpose: To monitor beam stability inside and outside deflection insertion

Upgrade existing diagnostics to single bunch, single turn capability:

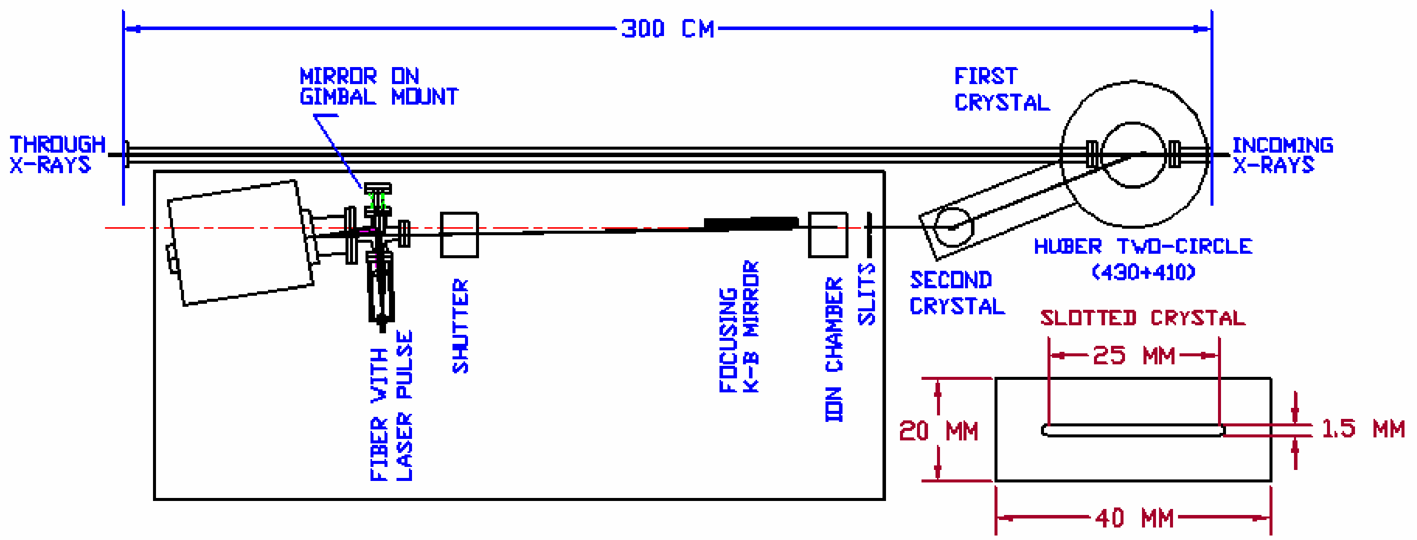
- Electron BPM, 120 – 1000 Hz rate
- Time-resolved photon imaging of beam dynamics (sector 35 BM & ID)

B. Yang, A. Lumpkin,
E. Landahl, E. Dufresne

New diagnostics in 7ID

B. Yang, A. Lumpkin,
E. Landahl, E. Dufresne

- X-ray streak camera in 7-ID-B hutch to measure:
  - Unperturbed bunch length (defl. cavity off)
  - Phase jitter of electron bunch relative to defl. cavity rf
  - Transverse momentum chirp at low defl. cavity voltage
  - y-t correlation with crab cavity at full power
  - Jitter and drift between pump laser timing and defl. cavity rf



- Explore electron bunch tilt diagnostics concept using a stripline in S7 straight
- Explore simple x-ray detectors for beam divergence in S7 straight

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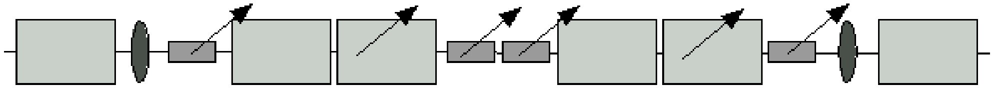
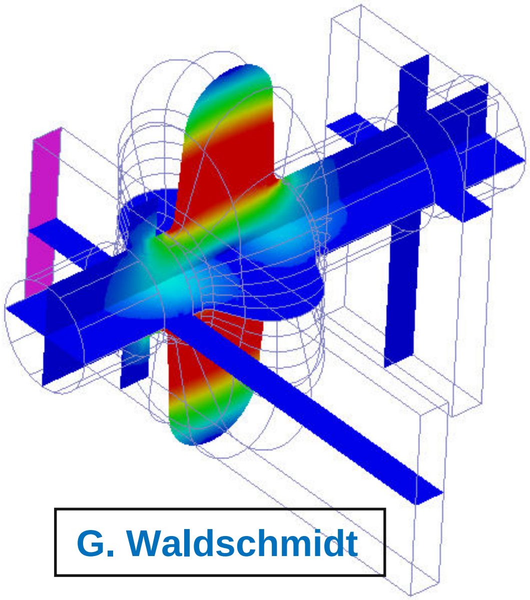
Far-term plans

- **Phase III**
  - N-sectors or N 1-sectors
  - Phase 2 + ~2 yrs
  - 1-ps xray pulses
  - CW (24-bunch operation, ERL) or pulsed
  - Beamline: pulse compression optics



- **Parallel R&D in CW deflecting cavities in rings**
  - KEKB crab crossing
  - ILC, LHC crab crossing (FNAL, CERN)
  - SC RF expertise at JLab, Cornell

→ **APS SC RF deflecting cavity development**

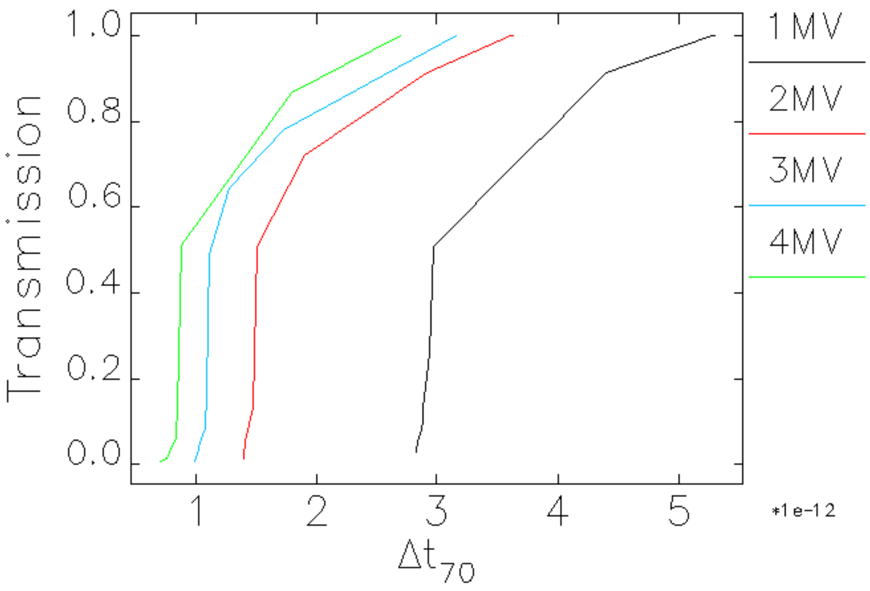


- **Other light sources interested:** Diamond, PETRA3, …

Compatibility with future APS upgrades

- ERL (see M. Borland's talk)

- APS 1 nm option: "crab surprise"
  - Vertical emittance growth compensation easier than present APS due to small coupling and small nonlinear effects
  - 4 MV deflection sufficient for 1 ps due to smaller vertical beam size and longer undulator



V. Sajaev, ASD/APG/2006-14
M. Borland, OAG-TN-2006-26

Summary

- ~1 ps x-ray pulses feasible at APS
- Offers exciting new science possibilities, complementary to XFELs
- Fast-track short x-ray pulse project underway
- Phase I implementation planned in 7 ID within ~12 mos
  - Machine: rf design, beam dynamics, commissioning plan
  - Beamline: diagnostics, synchronization
- Picosecond science expected within first 2 yrs
- Far term R&D being pursued in parallel for CW capability
- Compatible with APS upgrade options