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Expected Performance for the CW Picosecond Source

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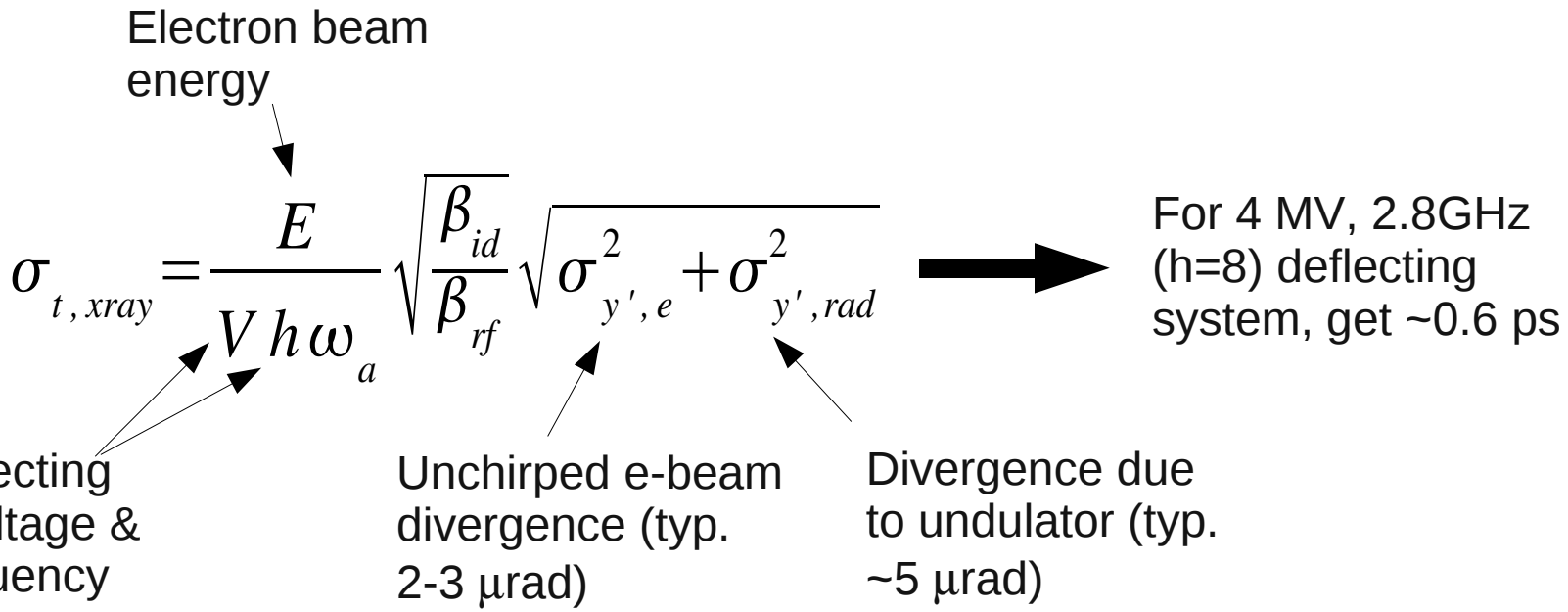
Outline

- Determining potential performance
- Results for 24-bunch and hybrid modes
  - Emittance growth
  - Pulse duration
  - Variation with photon energy
  - Details of time structure
- Phase variation issue for hybrid mode
- Tolerances
- Lattice testing.

Estimating X-ray Pulse Duration

- X-ray pulse duration can be estimated assuming gaussian distributions[1]



- Vertical emittance matters because it affects the electron beam divergence
  - Vertical emittance will grow because second cavity can't exactly compensate first[1]

[1]M. Borland, Phys. Rev. ST Accel Beams 8, 074001 (2005).

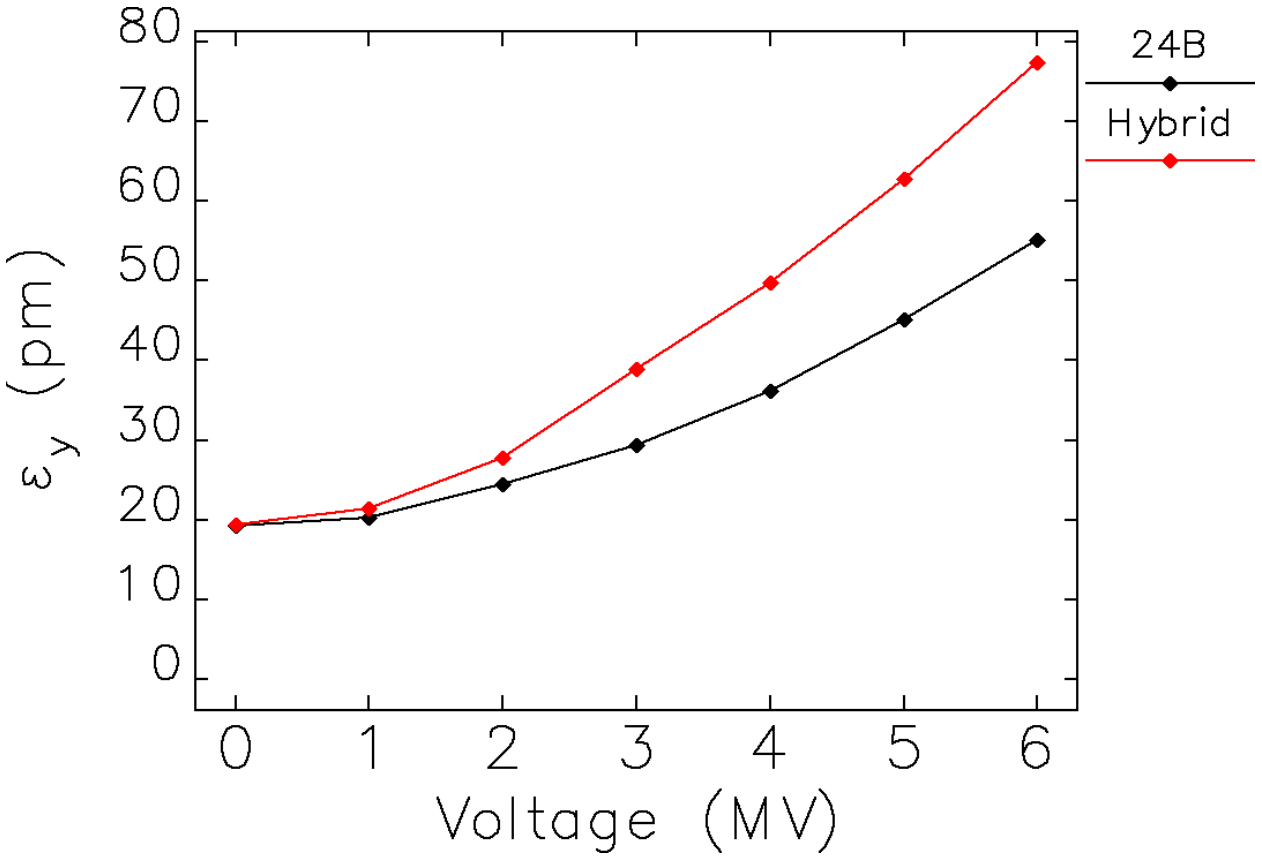
Modeling X-ray Pulse Duration

- Detailed modeling is needed to get reliable results
- Must include[1,2]
  - Emittance growth of the electron beam
  - Effect of electron bunch length
  - Effect of sinusoidal nature of deflecting force
  - Accurate single-electron radiation distribution
  - Length of beamline, slit spacing
- Must perform sextupole optimization to reduce emittance growth[1,3,4]
- We perform all of the above with the APS-developed code **elegant** and related tools[5,6,7]
  - Linux cluster and parallel computing indispensible.

[1]M. Borland, Phys. Rev. ST Accel Beams 8, 074001 (2005)
[2]R. Dejus, "Undulator Calculations," private communication.
[3]V. Sajaev, ASD/APG/2005-06, March 2005.
[4]M. Borland and V. Sajaev, Proc. PAC 2005, 3886-3888.

[5]M. Borland, APS LS287, September 2000.
[6]Y. Wang, M. Borland, Proc. PAC07, 3444-3446.
[7]M. Borland *et al.*, Proc PAC 2003, 3461-3463.

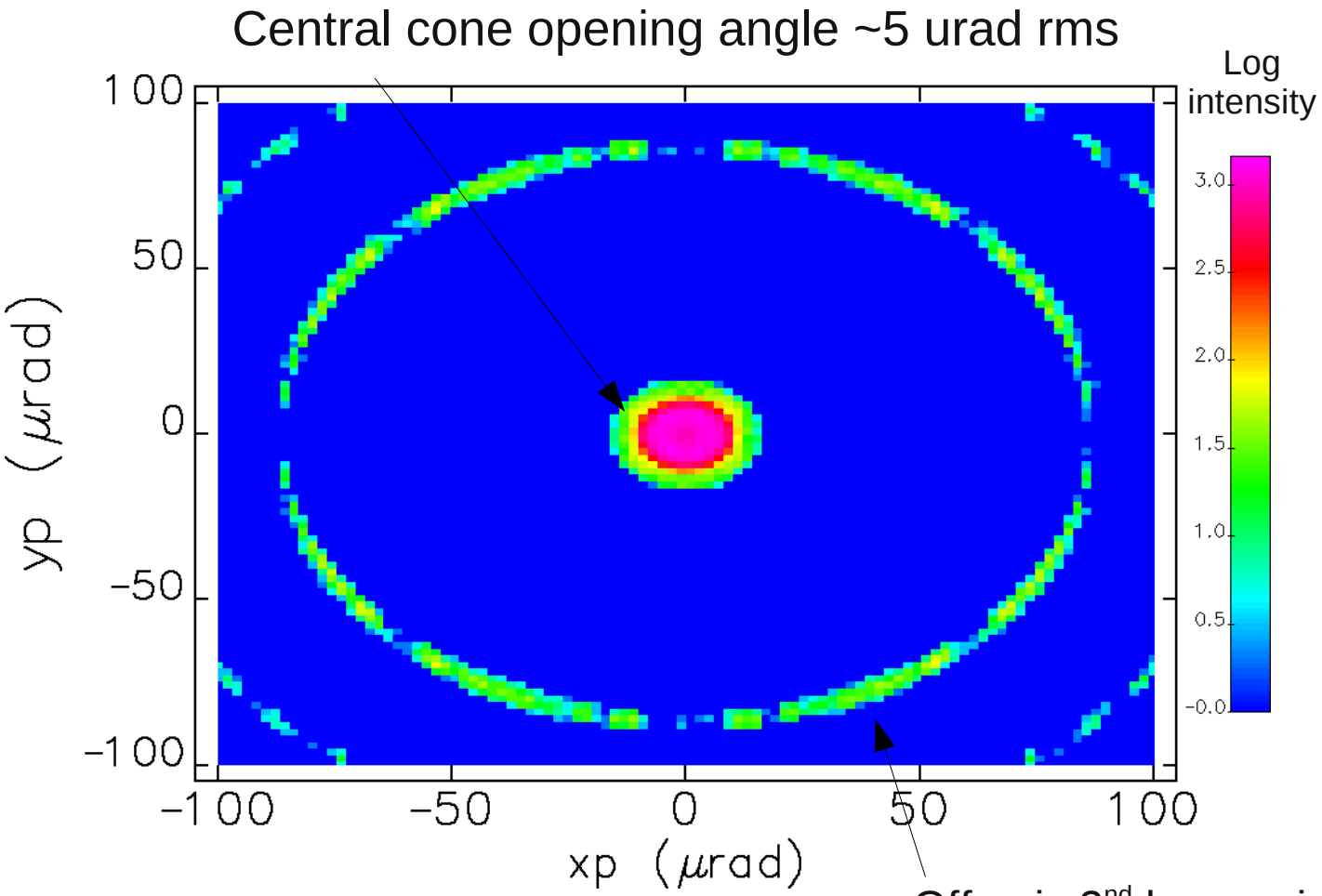
Emittance Growth for Optimized Configurations



- Starting vertical emittance is 20 pm (0.8% coupling)[1]
  - Normal operation is 30~40 pm
- Working points based on present operations[1]
- Hybrid-mode results are for intense bunch only

[1]L. Emery, private communication.

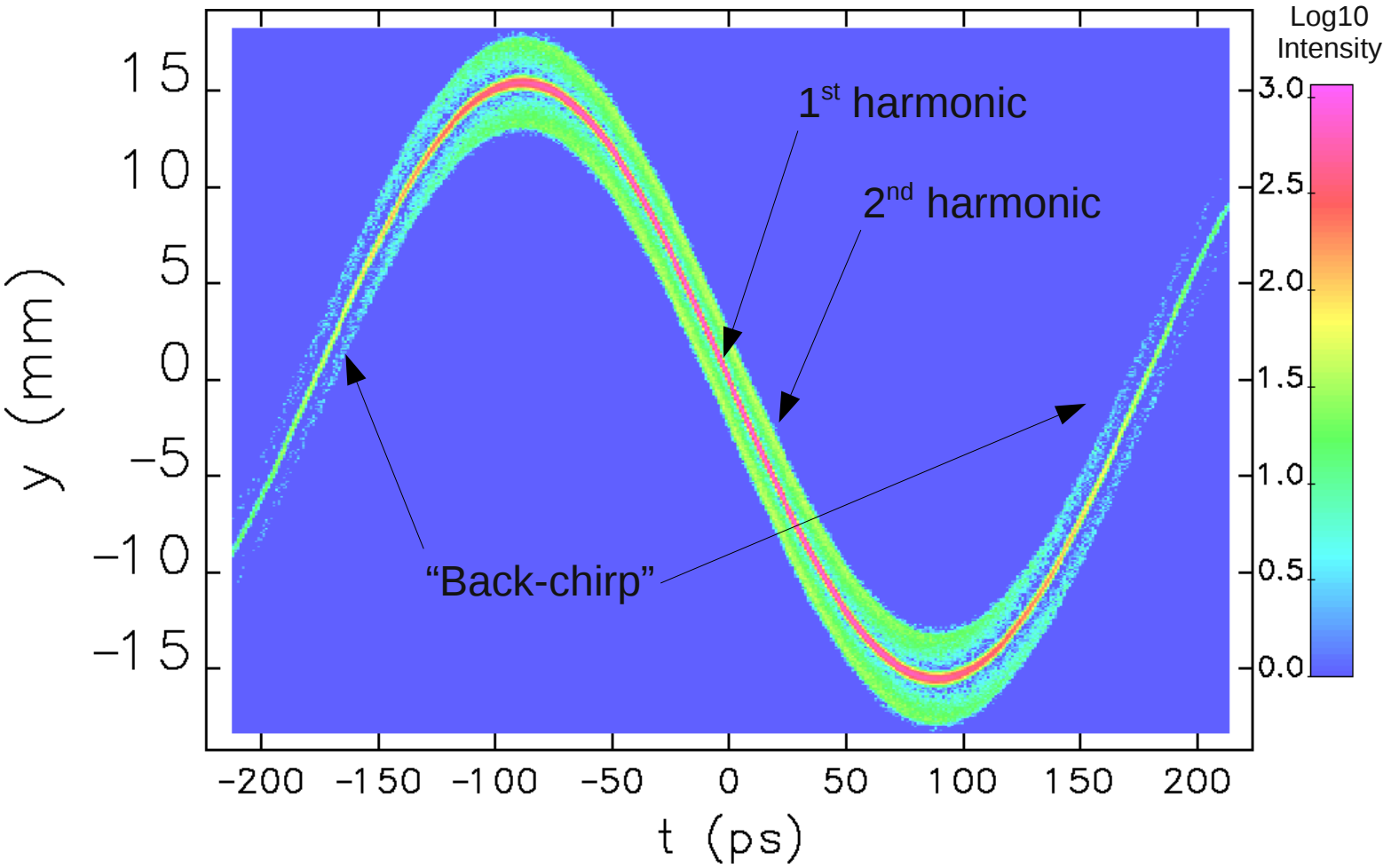
Single-Electron Radiation Pattern (2.4m UA, 10 keV)



Samples from such a distribution are added to the angular coordinates for each electron, giving the photon beam phase space.

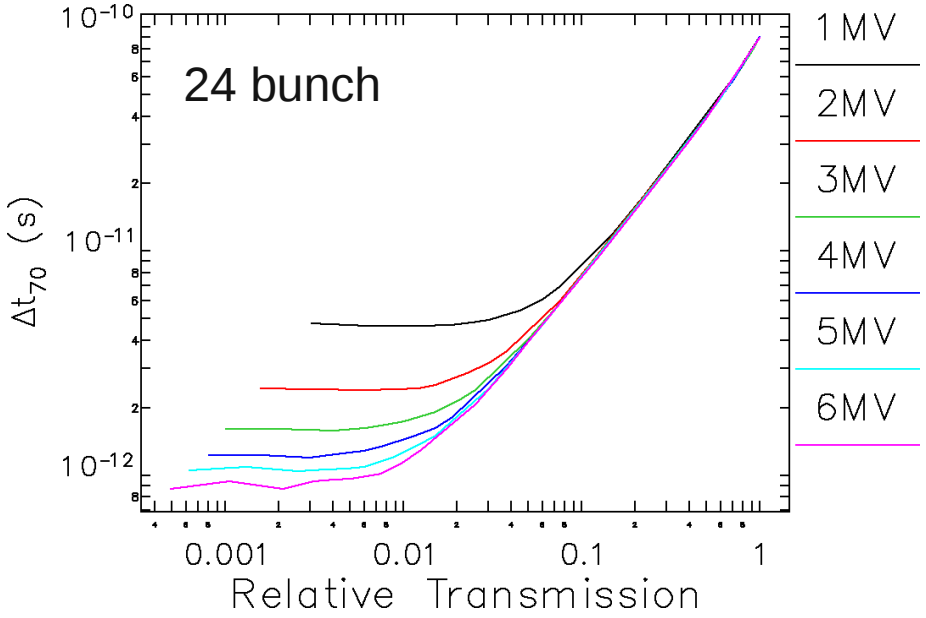
Data courtesy R. Dejus.

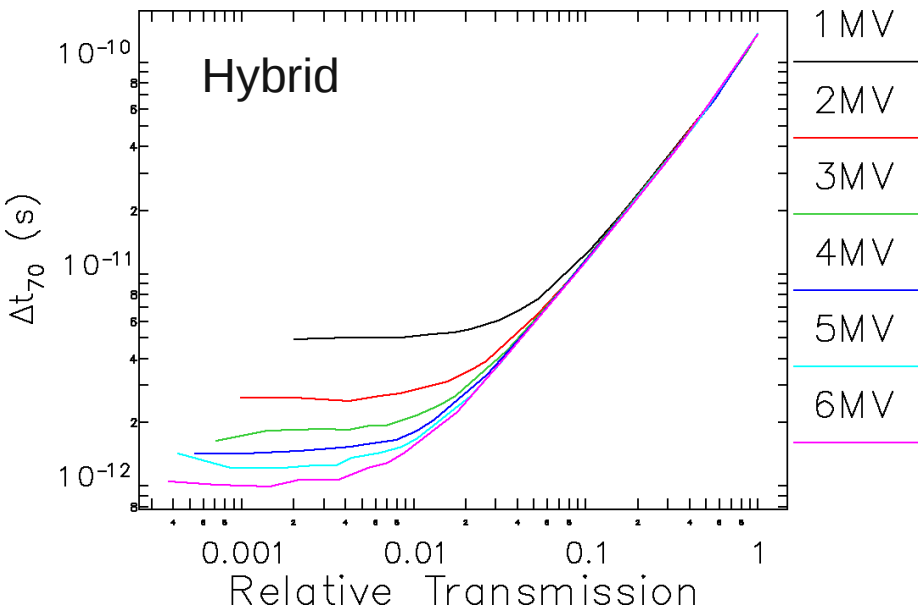
Radiation Distribution 26.5m from Source (Hybrid Mode)



26.5m is the distance to a 2mm x 3mm aperture in the ID7 beamline.
Aperture is typically set at 0.5 mm in both planes. (E. Dufrense.)

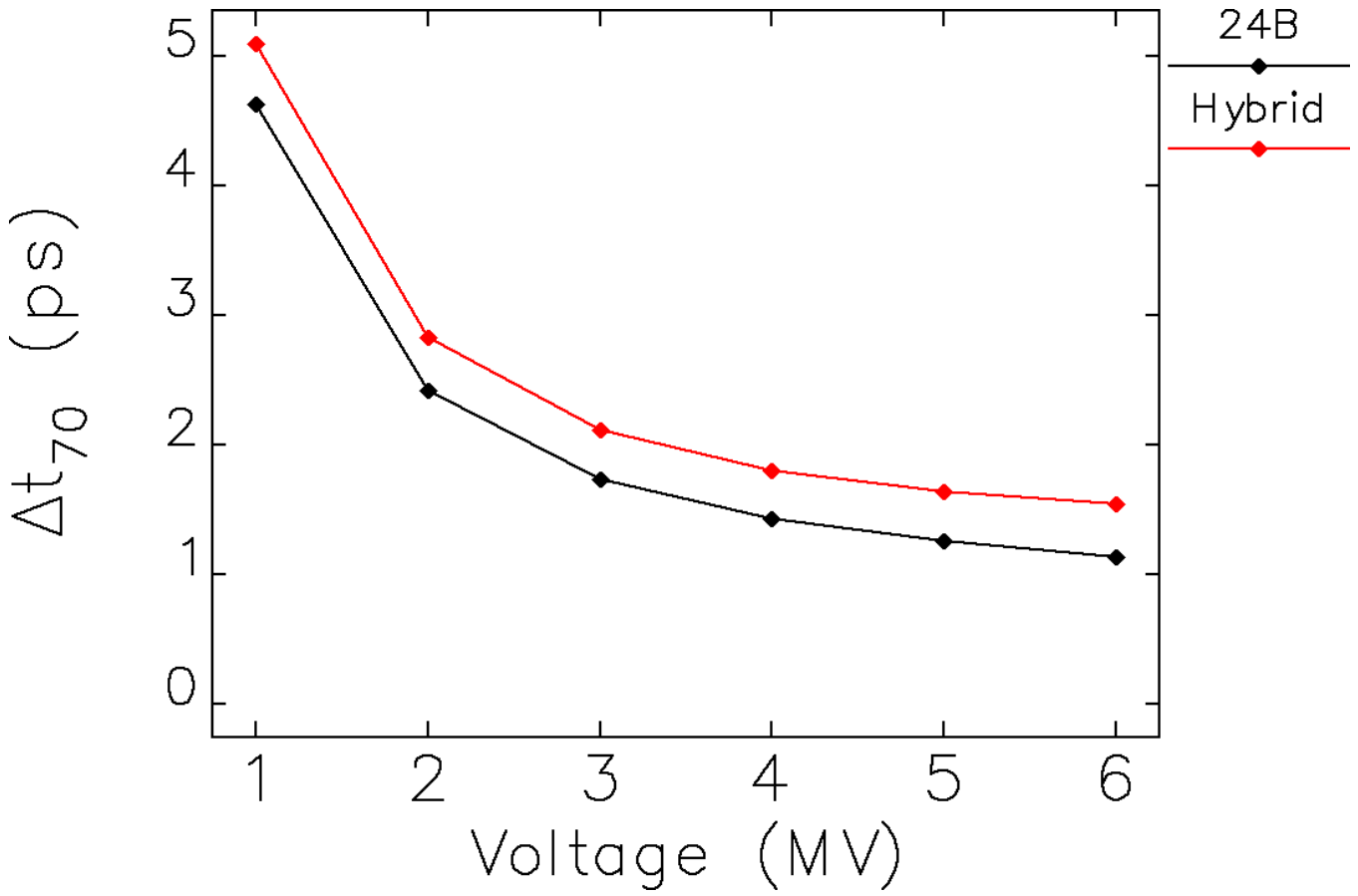
X-ray Slicing Results (2.4-m U33, 10keV)





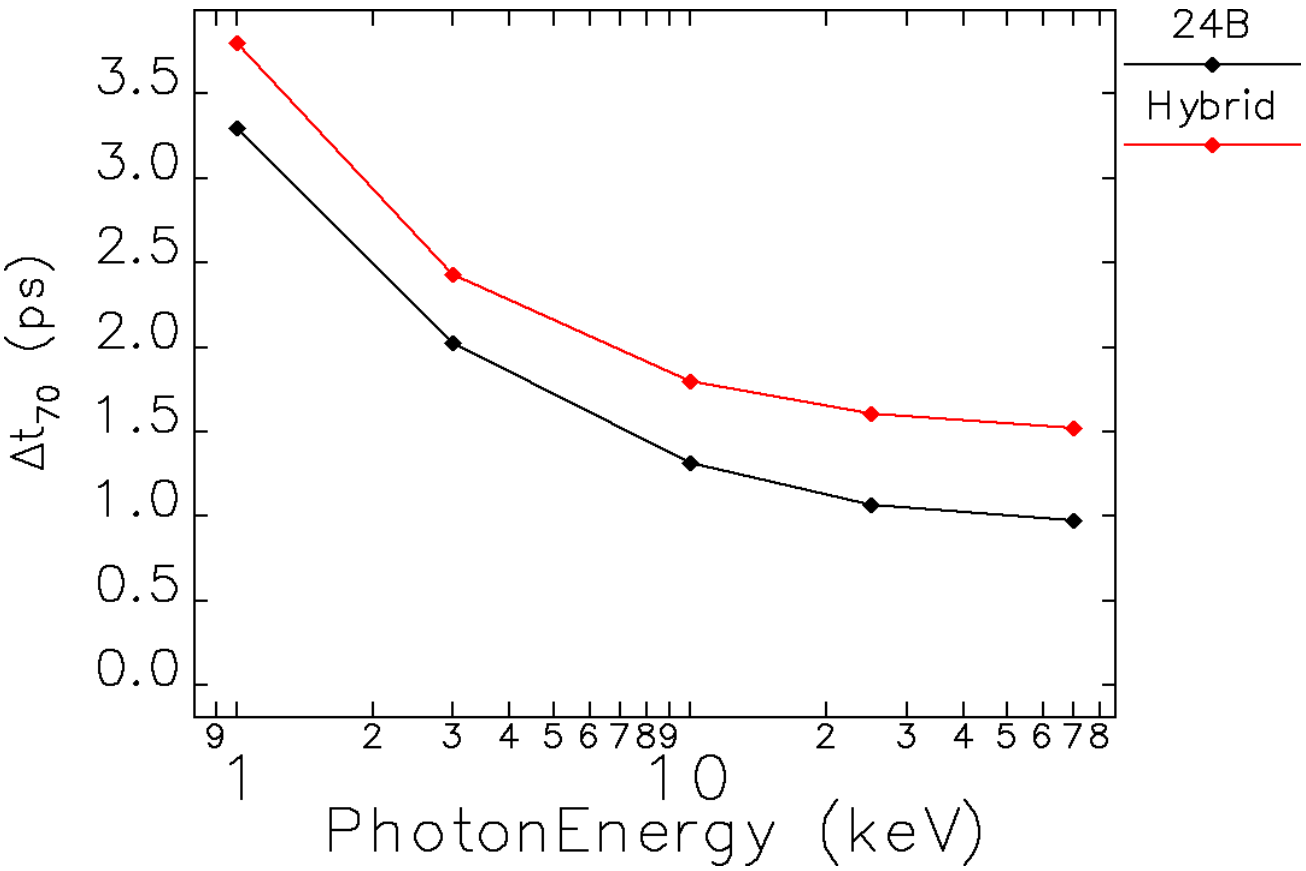
- Two slits at 26.5 m
  - Vertical slit is varied from ±100 mm to ±0.010 mm
  - Fixed horizontal slit of ±0.25 mm (E. Dufrense)
    - *Helps to remove the 2nd-harmonic pollution*

Results for Constant 1% Transmission



- 24-bunch mode better due to smaller emittance
- Diminished returns evident even at 4 MV (compare to 2 MV)
- No compelling reason to go above 4 MV
  - Even 2 MV might be acceptable...

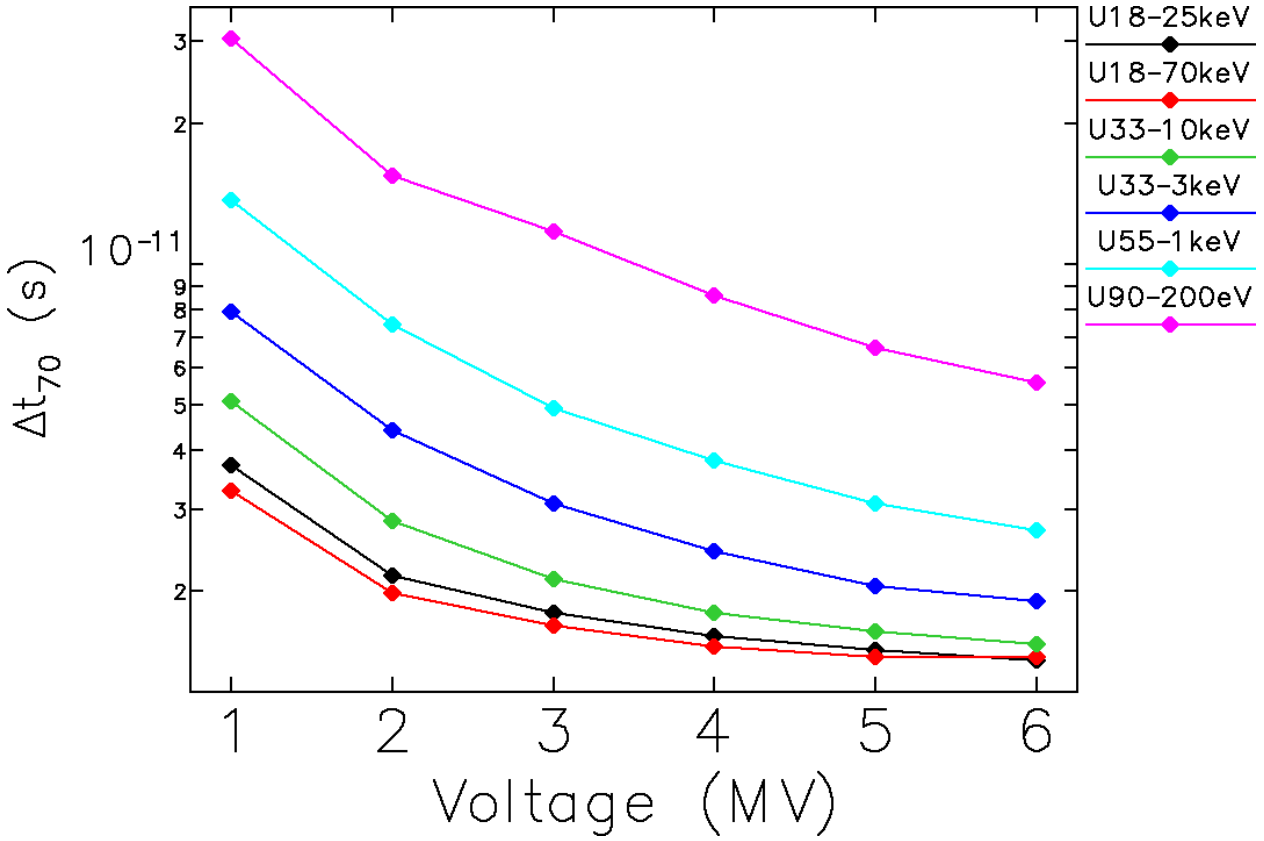
Effect of Photon Energy (4 MV, 1% Trans.)[1]



- Problem: intrinsic divergence of the photon beam increases as photon energy decreases
- Assumed 2.4-m ID: variously used U18, U33, and U55 devices

[1]M. Borland, OAG-TN-2008-016, April 16, 2008.

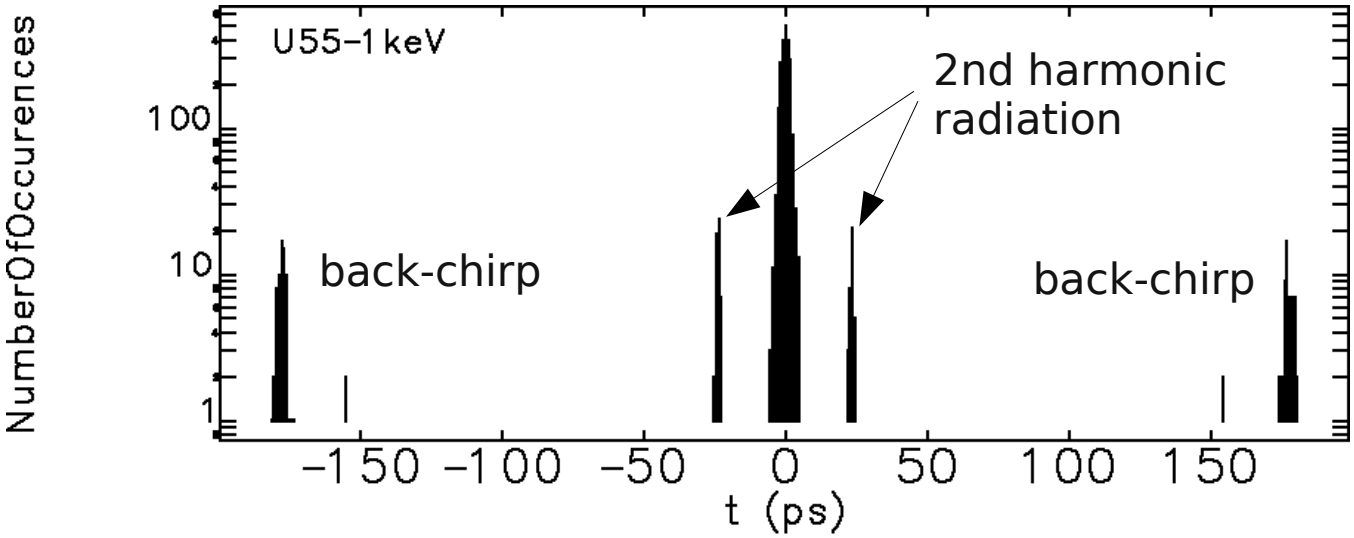
Effect of Photon Energy (1% Trans.)[1]

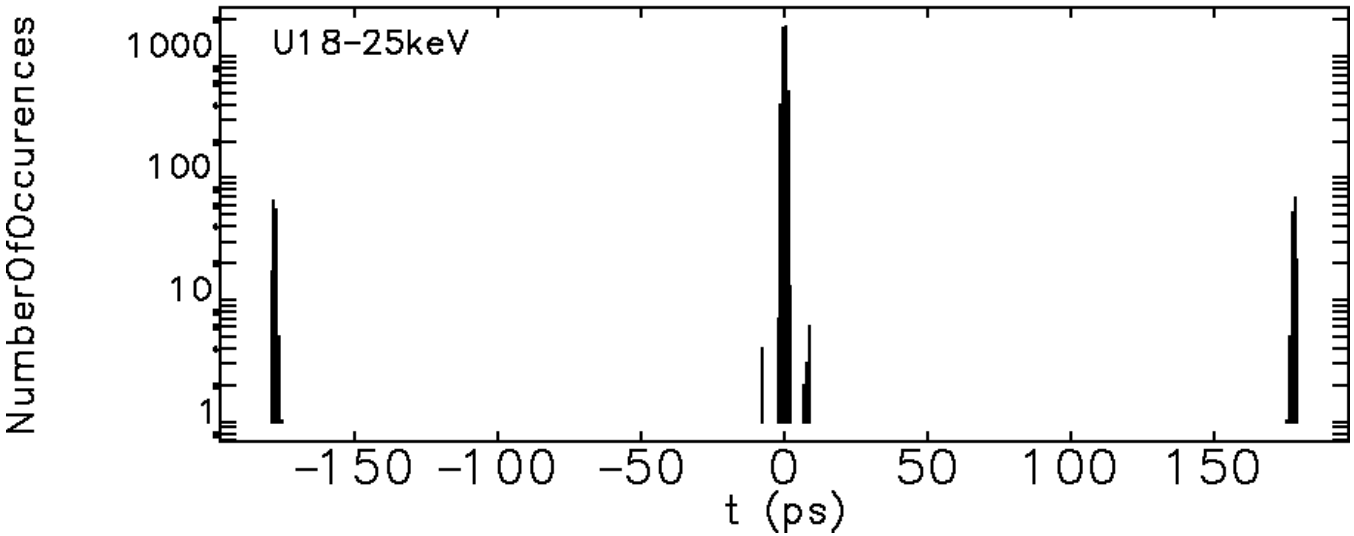


- For softer photons, higher voltage gives a significant advantage
  - Emittance growth doesn't come into play
  - Motivates against relaxing requirement to 2 MV

[1]M. Borland, OAG-TN-2008-016, April 16, 2008.

Details of X-ray Slicing Results for Hybrid Mode[1]





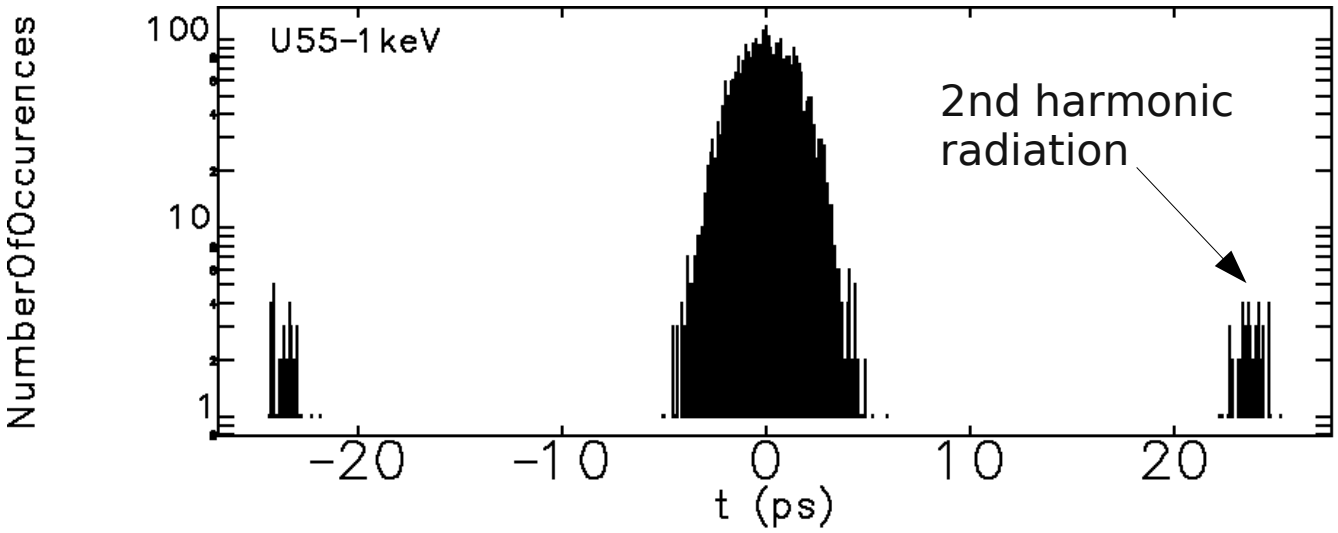
Back-chirp pulses have about 3% of the intensity of the central pulse.

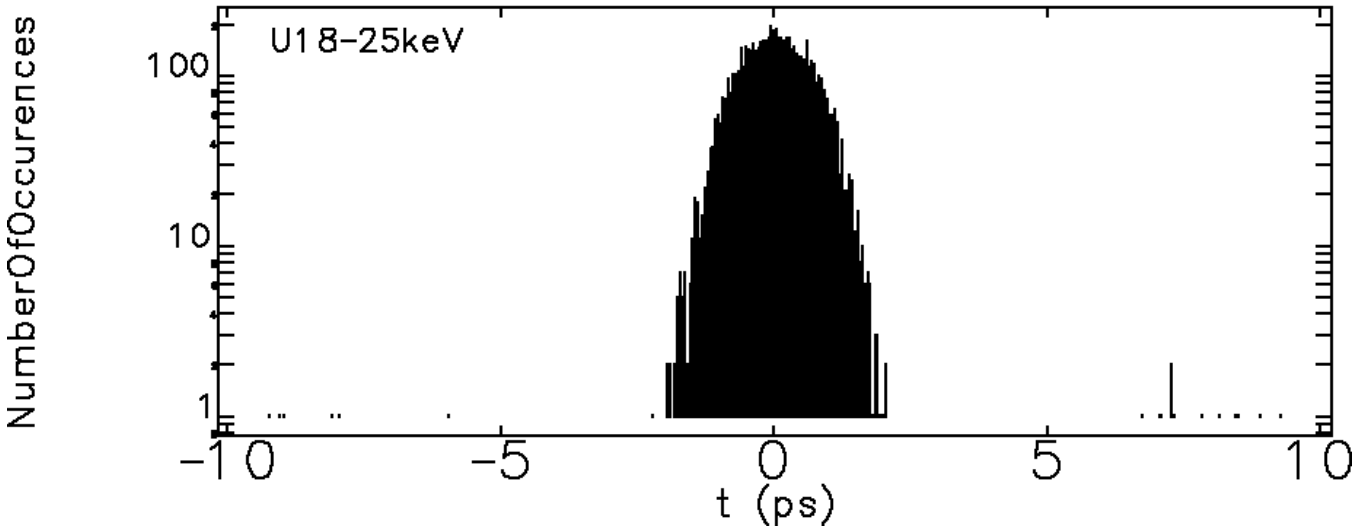
2nd harmonic pulses seen with up to ~2% of central intensity.

[1]M. Borland, OAG-TN-2007-016, 3/16/07.

Slits: H=0.5 mm, V=0.2 mm

Details of X-ray Slicing Results for 24 Bunch Mode



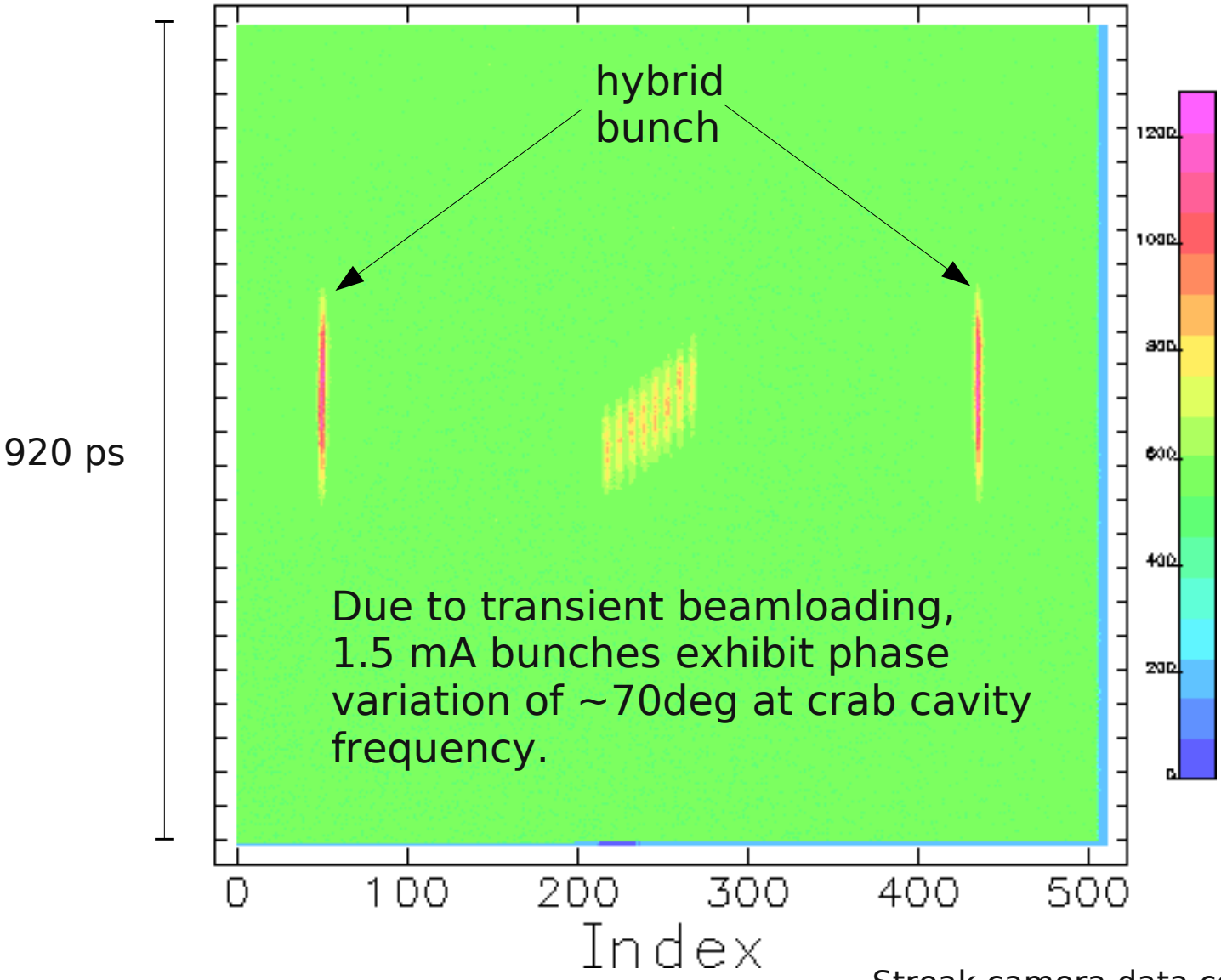


Back-chirp pulses have about 0.02% of the intensity of the central pulse and are not seen here.

2nd harmonic pulses seen with up to ~2% of central intensity.

Slits: H=0.5 mm, V=0.2 mm

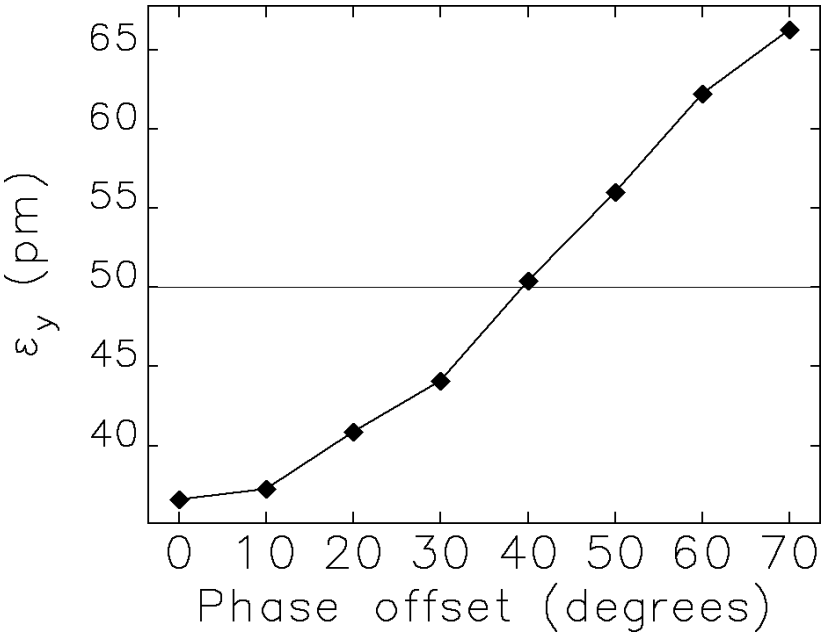
Phase Variation Issue for Hybrid Mode[1]



[1]M. Borland, OAG-TN-2008-12, April 4, 2008.

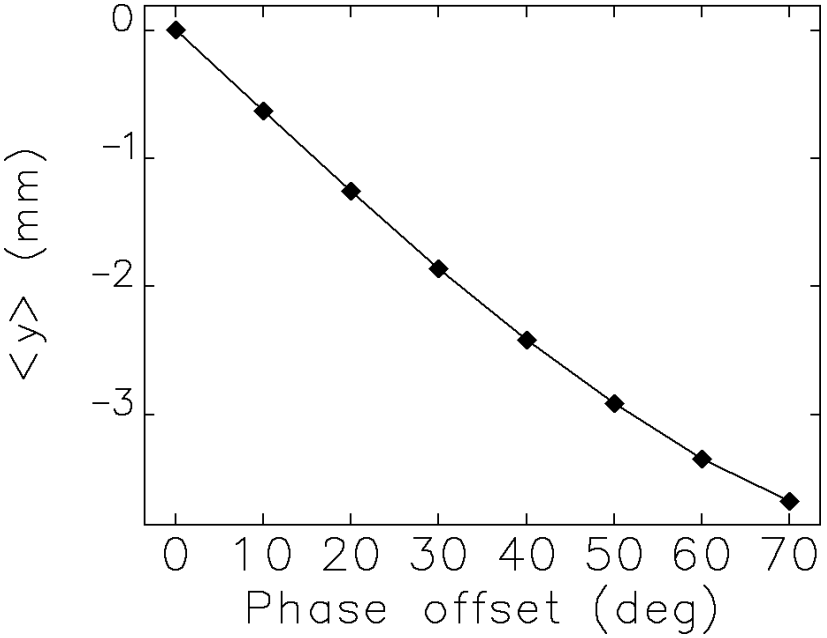
Streak camera data courtesy B. Yang.

Phase Variation Issue for Hybrid Mode[1]



Average emittance of small bunches slightly less than emittance of the hybrid bunch.

Position variation at the BM source between the cavities is large. Total beam height is ~10 mm at this point.



[1]M. Borland, OAG-TN-2008-12, April 4, 2008.

Tolerances

- Original studies[1] of CW cavities with two-sector separation covered most effects
  - Beta function mismatch at cavities
  - Betatron phase advance error between cavities
  - Lattice coupling between cavities
  - Cavity roll about longitudinal axis
  - Cavity phase errors
  - Cavity voltage errors
- The lattice-related issues appear manageable with standard lattice correction[2]
  - We have not revisited these
- Found cavity-related issues were challenging
  - We updated these studies for the latest 24-bunch and hybrid mode parameters.

[1]M. Borland, Phys. Rev. ST Accel Beams 8, 074001 (2005).
[2]V. Sajaev and L. Emery, Proc. EPAC 2002, 742-744.

Criteria and Method for Setting Error Allowances[1,2]

- Criteria
  - Limit emittance variation due to errors to <10%
  - Beam motion relative to size and divergence should be <10%
- Reference levels
  - 24 bunch mode: vertical emittance at 4 MV is 36 pm
  - Hybrid mode: vertical emittance at 4 MV is 50 pm
  - Horizontal emittance should be ~3.1 nm
    - *Variation due to errors is very small*
- We partition the error budget equally between differential phase and differential voltage errors
- We assume identical errors in all the cells of a cavity
  - Effective center of cavity will move if this isn't true
  - This needs to be investigated

[1]M. Borland, Phys. Rev. ST Accel Beams 8, 074001 (2005).

[2]M. Borland, "Long-Term Tracking, X-ray Predictions, and Tolerances," SPX Cavity Review, 8/23/07.

Summary of Important Tolerances[1]

Quantity	Driving Requirement	24-bunch	Hybrid
Common-mode voltage	Keep intensity and pulse length variation under 1%	±1%	±1%
Differential voltage	Keep emittance variation under 10% of nominal	±0.44%	±0.43%
Common-mode phase relative to bunch arrival	Constrain intensity variation to 1%	±10 deg	±10 deg
Differential phase	Keep centroid motion under 10% of beam size	±0.07 deg	±0.09 deg

- Tolerance on timing signal from crab cavity to users: ±1 ps

[1]M. Borland, "Long-Term Tracking, X-ray Predictions, and Tolerances," SPX Cavity Review, 8/23/07.

Lattice modification[1]

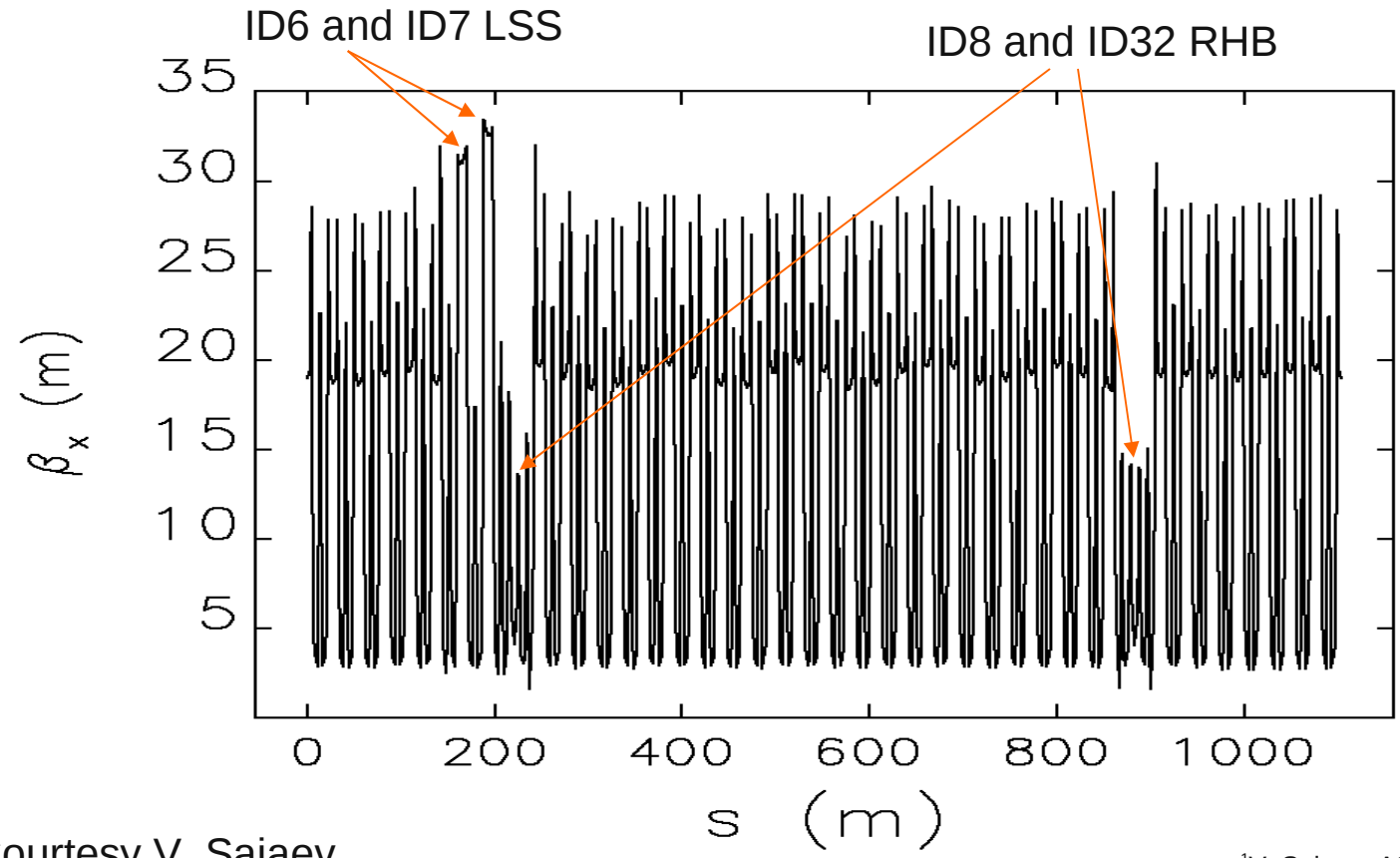
- Undulator A and 4 MV superconducting cavity won't fit in standard straight section (SS)
  - Straight section length has to be increased
  - Can remove one quadrupole on each side of the SS
- Installation of two cavities would require modification of two straight sections (e.g., ID6 and ID7)
- APS sometimes operates in Reduced Horizontal Beamsize (RHB) mode for ID8 and ID32
  - This option needs to be preserved
- Possible lattice will include
  - Longer SS at ID6 and ID7
  - RHB at ID8 and ID32
- Test possible since all magnets independently powered
  - Turn off quadrupoles that would need to be removed
  - Adjust other quadrupoles as needed

Courtesy V. Sajaev.

[1]V. Sajaev, ASD/APG/2008-06, April 18, 2008.

Lattice test[1]

- The lattice was tested during machine studies in “24 singlets” mode
- Lifetime and injection efficiency acceptable for normal 2-minute top-up interval and normal operational coupling
- Below is the plot of measured horizontal beta functions of entire ring



Courtesy V. Sajaev.

[1]V. Sajaev, ASD/APG/2008-06, April 18, 2008.

Conclusions

- Extensive studies have been performed for CW system
  - Presented studies cover only single-particle dynamics
- Emittance growth for 4 MV is acceptable
  - Present results start from base of 20 pm, which seems to be minimum presently achievable
  - We stay under 50 pm (2% coupling)
  - Little benefit from going to higher voltages
- Performance depends on photon energy
  - 10 keV: below 2 ps FWHM with ~1% of nominal intensity
  - 1 keV: below 4 ps FWHM with ~1% of nominal intensity
- Tolerances have been defined
  - Differential voltage tolerances are tight
  - Differential phase tolerances are very tight
  - Determined by desire to limit vertical emittance variation and beam motion
- A potential operational lattice with LSS and RHB has been tested successfully.