# Electron Cloud Issues for the Advanced Photon Source Superconducting Undulator

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Acknowledgements:

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# Introduction

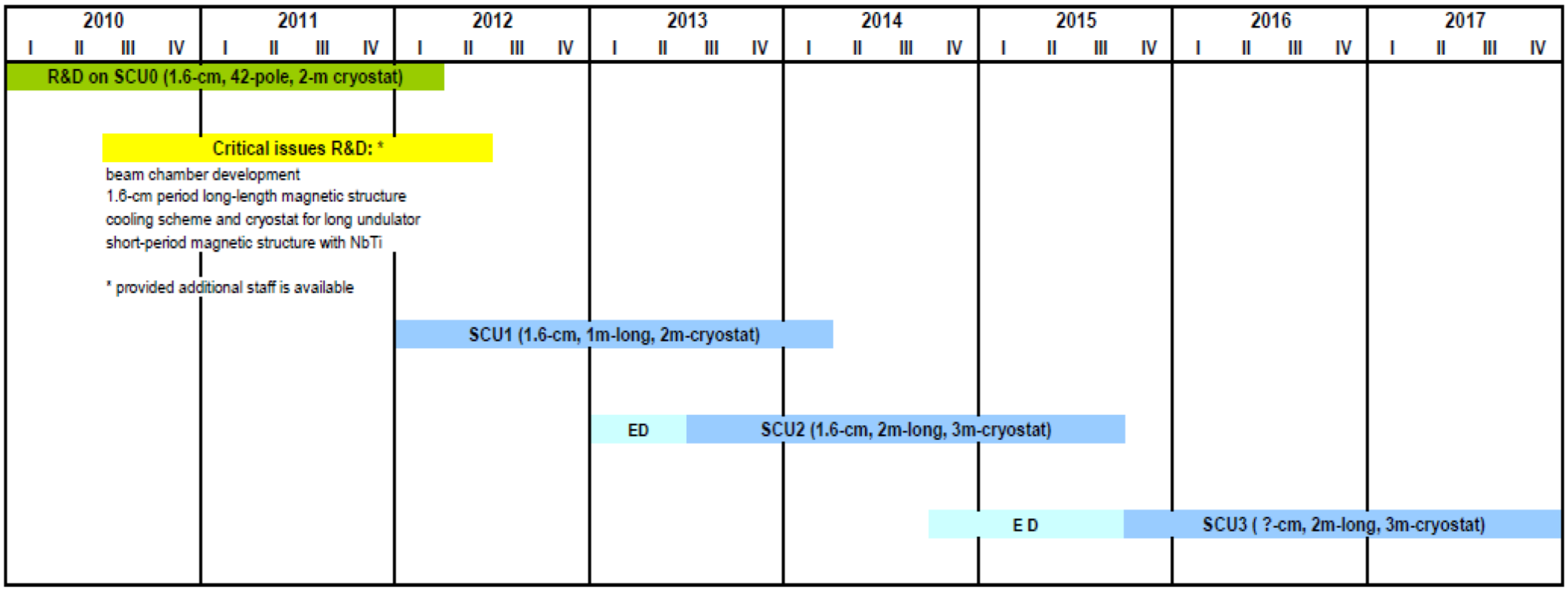
- Advanced Photon Source (APS) a 7-GeV electron synchrotron light source
- APS Upgrade CD0 approved summer 2010
- Development of a superconducting undulator (SCU) part of the upgrade
- Possible electron cloud effects for electron beams
  - Studies at APS and CesrTA
  - ANKA experience with high heat loads in SC insertion device
  - Electron cloud models appear incomplete for electron beams
- Detailed heat load analysis undertaken, conservative assumptions for beam-induced heat load
- Preliminary thoughts on electron cloud mitigation strategies for APS SCU

# Outline

- APS superconducting undulator
- Case for improved photoelectron model
- Strategies for EC mitigation
- Summary

# Superconducting undulators in the APS upgrade program

SCU Road Map

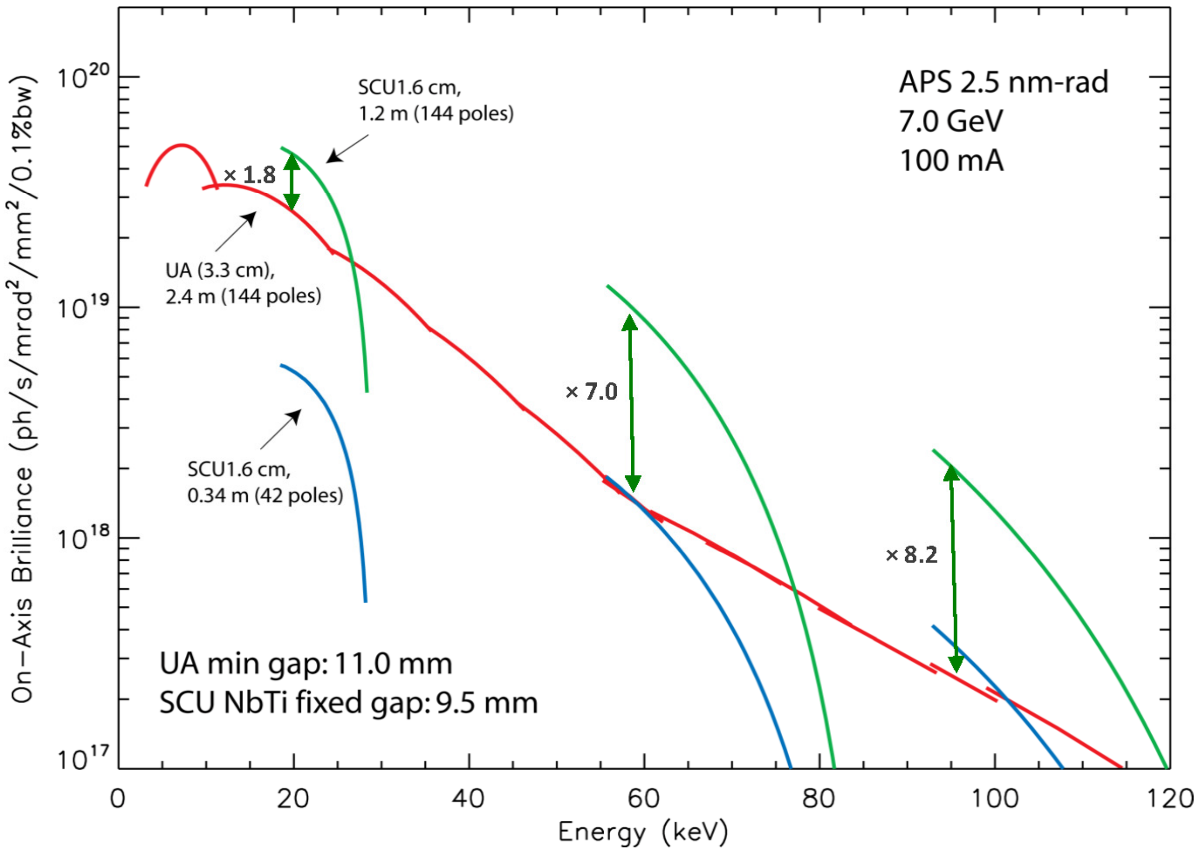


# First two superconducting undulators for the APS

- APS superconducting undulator specifications

| | SCU0 | SCU1 |
|---|---|---|
| **Photon energy at 1st harmonic** | **20-25 keV** | **20-25 keV** |
| **Undulator period** | **16 mm** | **16 mm** |
| **Magnetic length** | **0.33 m** | **1.15 m** |
| **Cryostat length** | **≈ 2.0 m** | **≈ 2.0 m** |
| **Beam stay-clear dimensions** | **7.0 mm vertical × 36 mm horizontal** | **7.0 mm vertical × 36 mm horizontal** |
| **Magnetic gap** | **9.5 mm** | **9.5 mm** |

# Expected performance of SCU0 and SCU1

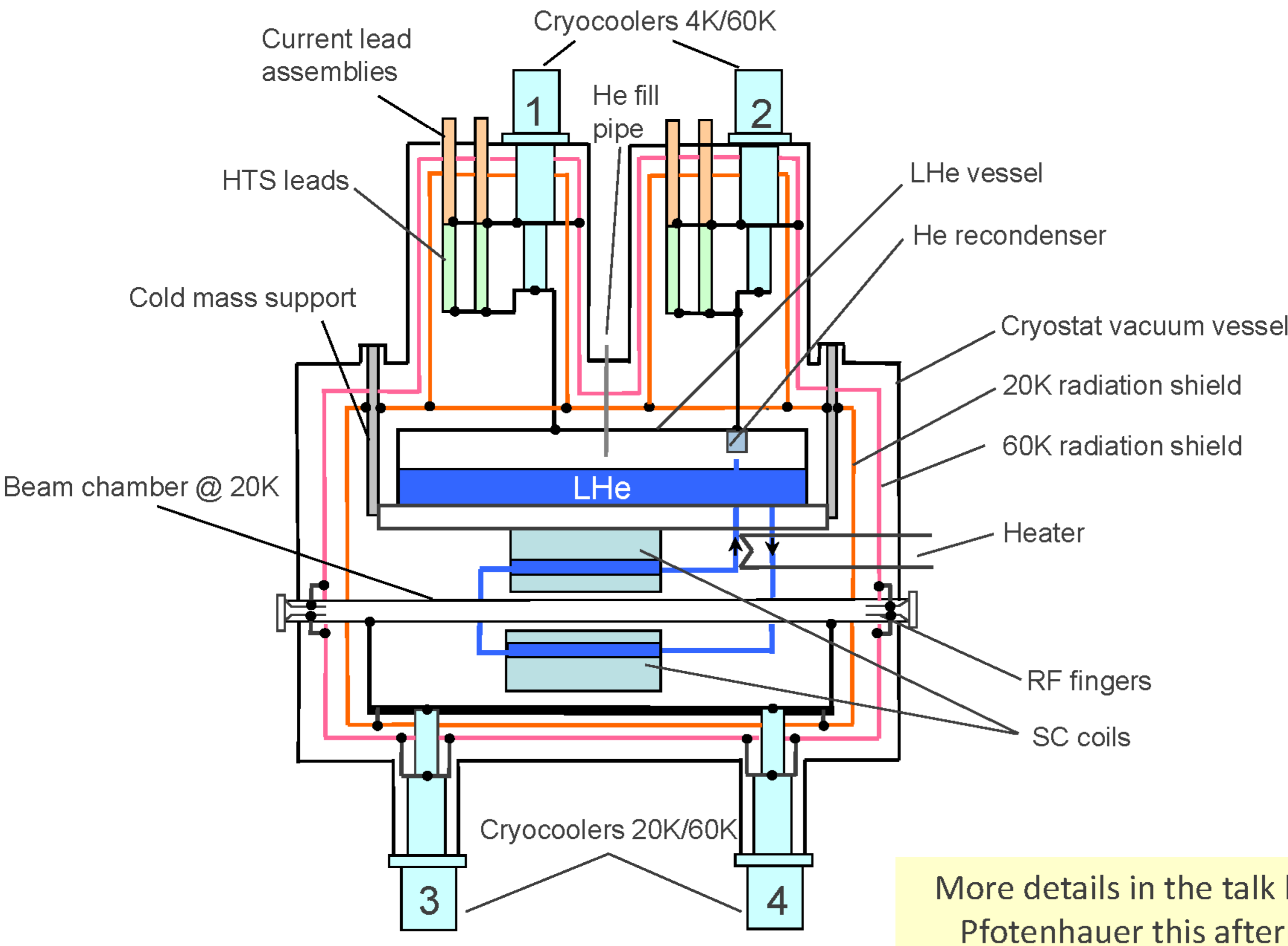



- Tuning curves for odd harmonics for two planar 1.6-cm-period NbTi superconducting undulators (42 poles, 0.34 m long and 144 poles, 1.2 m long) versus the planar NdFeB permanent magnet hybrid undulator A (144 poles, 3.3 cm period and 2.4 m long). Reductions due to magnetic field error were applied the same to all undulators (estimated from one measured undulator A at the APS). The tuning curve ranges were conservatively estimated for the SCUs.
- The minimum energies are 3.2 keV for the UA and 18.6 keV for the SCUs.
- The short 42-pole 1.6-cm-period SCU surpasses undulator A at ~ 60 keV and ~ 95 keV. The 144-pole SCU brilliance exceeds that of undulator A by factors of 1.8 at 20 keV, 7.0 at 60 keV, and 8.2 at 95 keV.

# SCU0 project status and schedule

| Task | Status and schedule |
| --- | --- |
| Initial R&D phase | Complete |
| Conceptual design | Complete |
| Conceptual design review | Passed in February, 2010 |
| Detail design | In progress |
| Cryostat pressure safety review | Passed in July, 2010 |
| Cryostat production review | September 2010 |
| Cryostat manufacture | November 2010 – Spring 2011 |
| Undulator assembly | Summer 2011 |
| Measurement system design and manufacture | Summer 2010- Summer 2011 |
| Undulator tests | Fall 2011 |
| SCU installation into the ring | Winter 2011-12 |
| SCU beam test | Spring 2012 |

# SCU cooling scheme

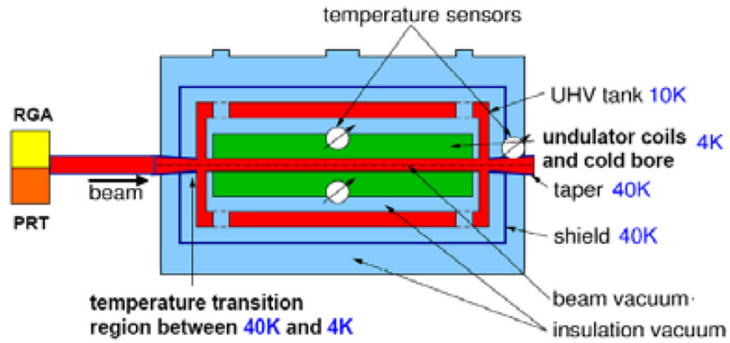



More details in the talk by John Pfotenhauer this afternoon.

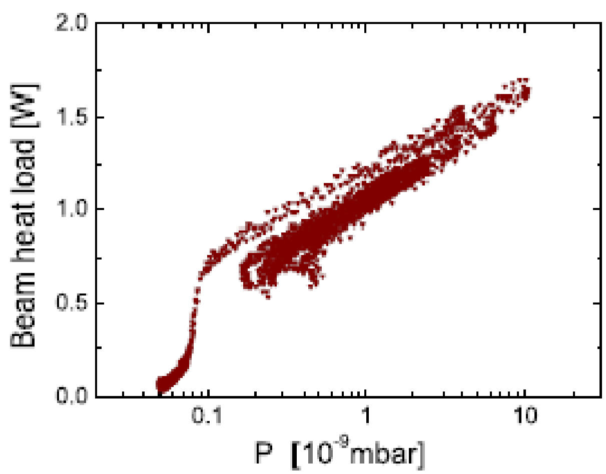
# Experience at ANKA: SCU14 demonstrator

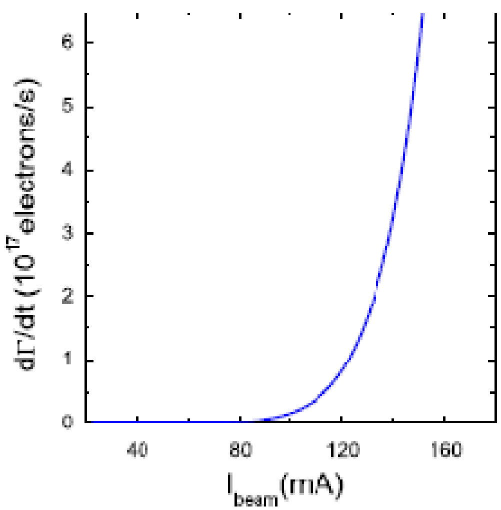
## Beam heat load studies

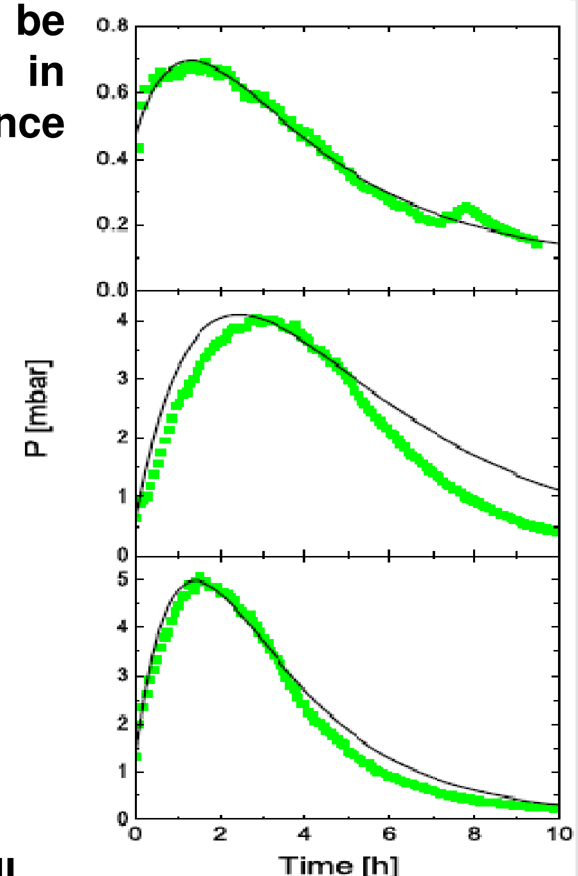
**Performance limited by too high beam heat load: beam heat load observed cannot be explained by synchrotron radiation from upstream bending and resistive wall heating.** S. C. et al., PRSTAB2007




**Pressure rise can be explained by including in eq. of gas dynamic balance electron multipacting.**
S. C. et al., PRSTAB2010




**Possible beam heat load source: electron bombardment of the wall, beam dynamics under study**

# Heat loads and cooling system concept

| Heat source | Heat load @ 4K, W | Heat load @ 20K, W | Heat Load @ 60 K, W |
|---|---|---|---|
| Beam | | 6.6 ( nominal)<br>45 (injection accident) | |
| Radiation | 0.0116 | 1.21 | 4.2 |
| Conduction through: | | | |
| beam chamber bellows | | | 1.4 |
| beam chamber supports | 0.08 | | |
| He vent bellows | 0.006 | 0.07 | 0.9 |
| He fill pipe | 0.012 | | |
| cold mass support | 0.005 | | |
| radiation shields supports | | 1.2 | 5.6 |
| Current leads at: | | | |
| I = 0 A | 0 | | 44 |
| I = 100 A | 0.12 | | 22 |
| I = 500 A | 0.45 | | 52 |
| Total at I = 500 A: | 0.685 | up to 45 | 86.1 |

Conceptual points:

- Thermally insulate beam chamber from the rest of the system.
- Cool the beam chamber separately from the superconducting coils.

In this approach beam heats the beam chamber but not the SC coils !

# Cooling system – SCU dynamic heat load

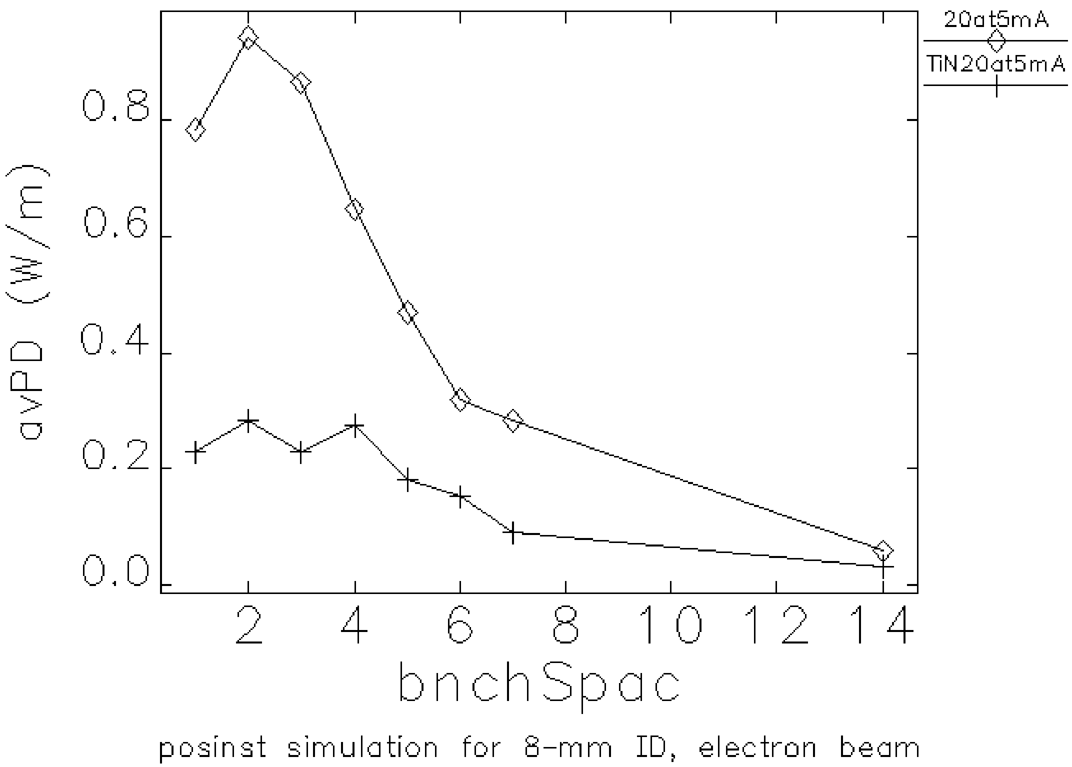
- Task for cooling system is to keep the temperature of superconductor in the range 4.2-6K by intercepting both static and dynamic heat loads in the undulator system.
- Dynamic heat load

| **Heat source** | **Heat load on 2-m long beam chamber** |
|---|---|
| Image current | 2.44 W @ 100 mA [1]<br>(4.88 W @ 200 mA) [1] |
| Synchrotron radiation from upstream magnets | ≈ 0.1 W ( for wide chamber) [1]<br>( 40 W for narrow chamber) |
| Electron cloud | 2 W [1]**[3]** |
| Wakefield heating in the beam chamber transition | 0.093 W [1] |
| Injection losses | 40 W ( accident) [2]<br>2 W (non top up mode) [2]<br>0.1 W ( normal top up mode) [2] |
| Max heat load: | ≈ 45 W ( injection accident)<br>≈ 6.6 W ( non top up mode) |

[1] Maria Petra and Bob Kustom, APS Internal Note, 2004.
[2] Vadim Sajaev, private communication.
**[3] Prelim calcs by K. Harkay**

Slide courtesy Y. Ivanyushenkov

# Preliminary calculations: electron cloud heat load vs. bunch spacing




Assumptions (*posinst*):

- 8 mm vacuum chamber, field-free
- 20 bunches, 5 mA/bunch
- Al: $\delta_{max}$ = 3.0; TiN: $\delta_{max}$ = 1.1
- Simple photon reflectivity model

Uncertainty for electron beam:

- APS positron modeling results agreed well with RFA data
- APS electron beam modeling did not agree well
- Data also from CesrTA suggest that photoemission model needs improvement.

*Posinst* physics: M.A. Furman and M.T. Pivi, Phys Rev ST Accel Beams 5, 124404 (2002).

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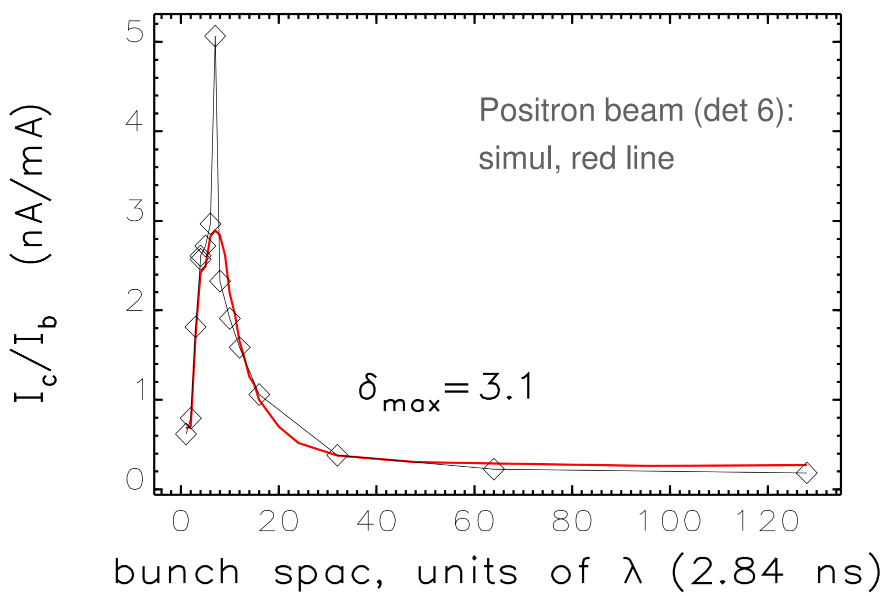
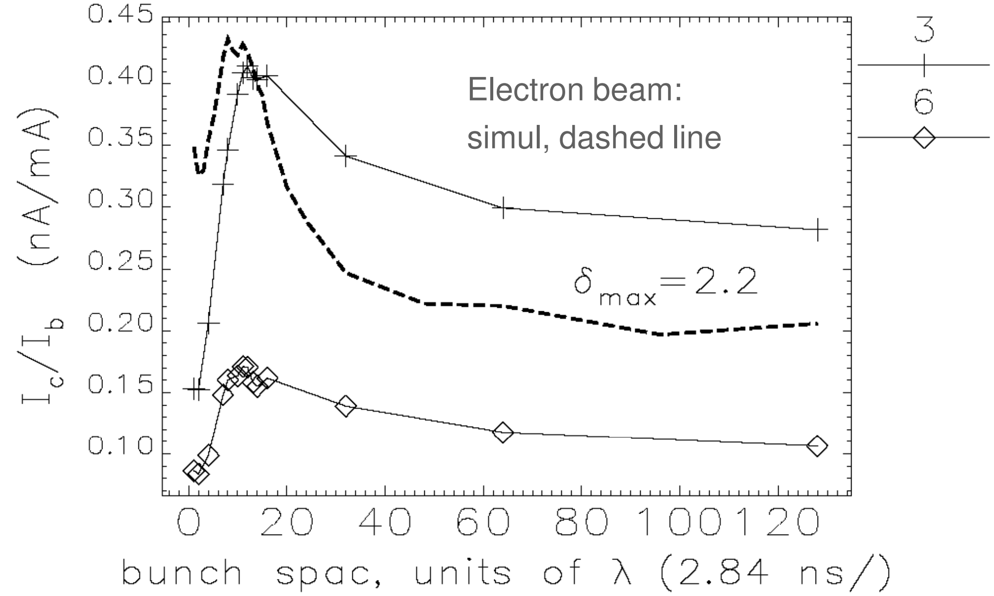
# Multpacting resonance, e+ and e- beams at APS

Comparison of APS RFA data with *posinst* simulated electron cloud wall current as a function of bunch spacing (20 mA, 10 bunches).

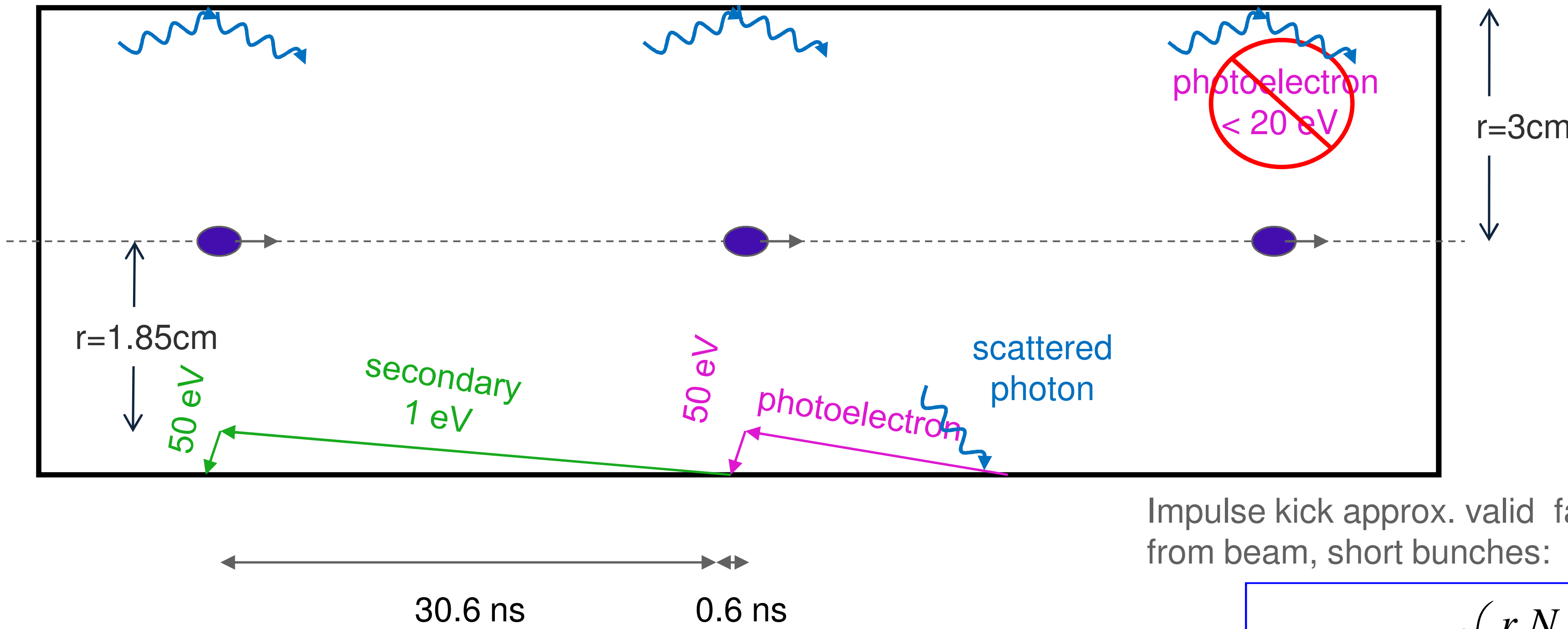



- Multipacting resonance peak position, amplitude, and peak width well modeled, sensitive in detail to secondary electron params (drift region)
- Avg. wall-impact energy well predicted (100 eV)
- Weak dependence on photoelectron params

- Electron beam poorly modeled with same parameters (100 Ah additional conditioning, reducing $\delta_{max}$)
- Avg. impact energy overestimated by factor 10 (150 eV vs. 10 eV msrd)
- Photoelectron model overly simplified – could not improve comparison

# Negative beams can have a weaker BIM effect: APS electron beam, 2 mA/bunch




Impulse kick approx. valid far from beam, short bunches:

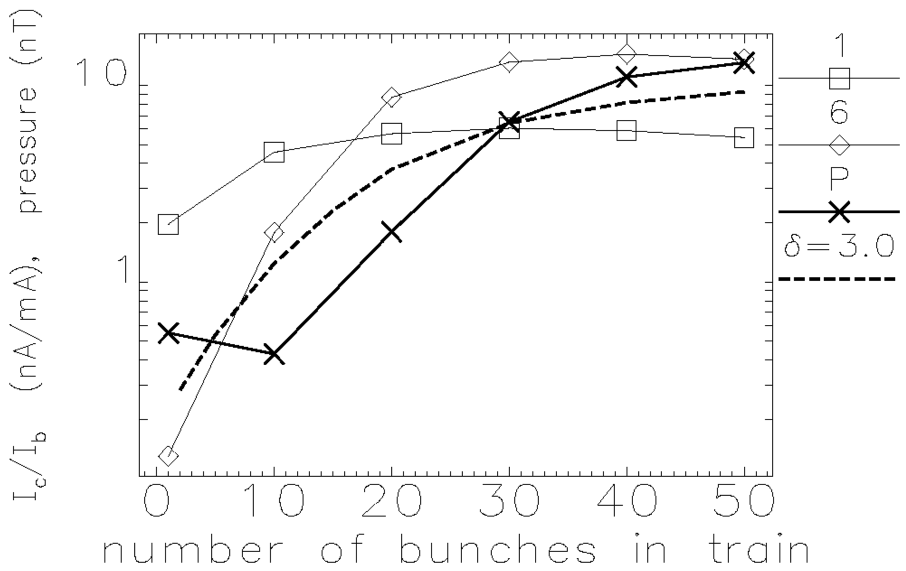
$$\Delta K_e = 2m_e c^2 \left( \frac{r_e N_b}{r} \right)^2$$

$$t_e = \frac{r}{v} = \frac{r}{c} \left( \frac{m_e c^2}{2K_e} \right)$$

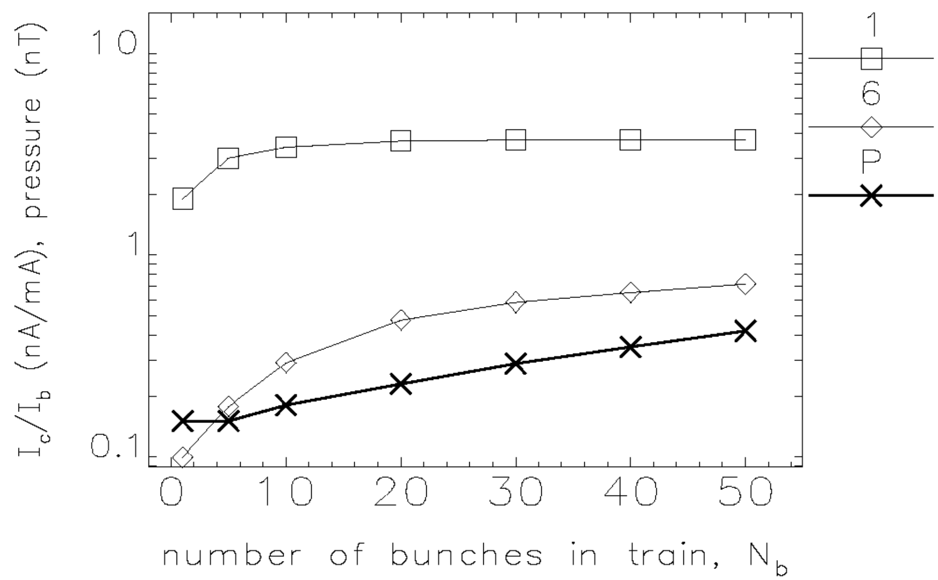
- Assume standard chamber, 11-bucket spacing, field-free
- Reflected photons absorbed between bunches (+ photoelectron)
- Amplification can still occur, but effect is weaker
- Product of electron cloud impact energy and flux on wall results in a power load

# Electron beam: weak cloud buildup, highest near EA

Positron beam, 20-ns spacing




Electron beam, 30-ns spacing




Electron beam:

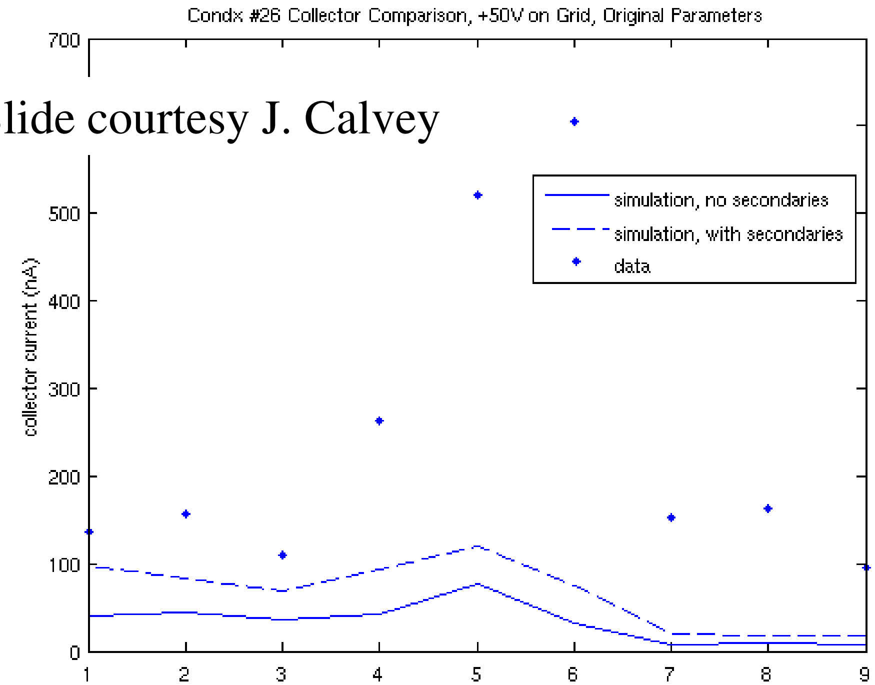
- The signal near EA (RFA 1) is always higher than RFA 6. Suggests that photoelectrons contribute most here.
- **Pressure rise and beam lifetime degradation was observed for certain 100-mA fill patterns, but quickly conditioned away**

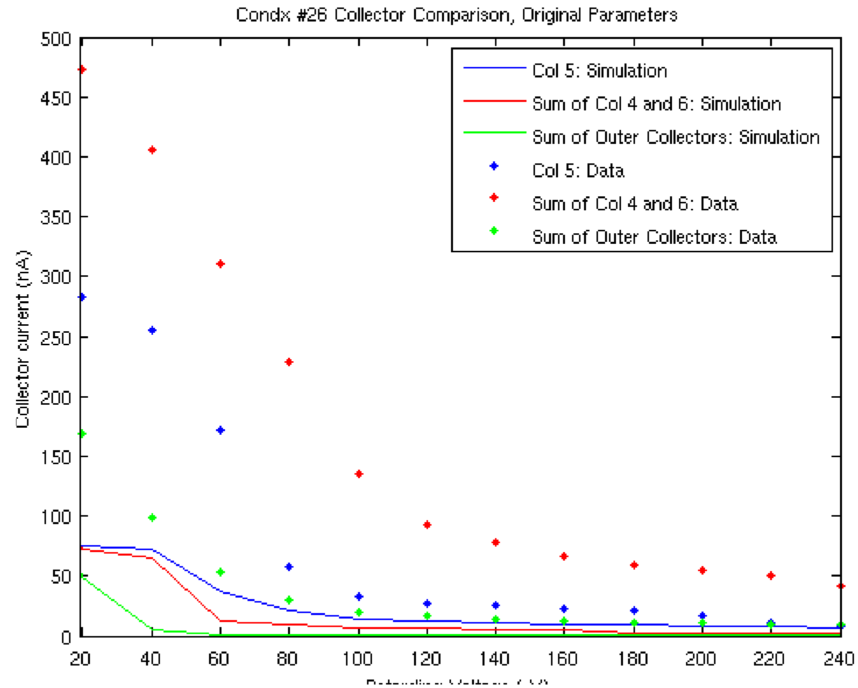
# Primary Energy Distribution

- A lorentzian primary energy distribution has been added to POSINST
- To fit data at high beam energy (especially electron beam data), a high value for the “scale parameter” (HWHM) of the distribution is needed
- Next few slides show several examples of this
  - Left hand plots show RFA data at +50V, compared to simulation with and without secondaries
  - Right hand plots show data/simulation comparison from -20 to -240V, for central, intermediate, and outer collectors
  - Upper plots have HWHM 5eV
  - Lower plots have HWHM 150eV
  - All plots are of the recently installed Al drift chamber at 15W
    - All data was taken on the same day
    - Beam conditions: 5.3 GeV, 14ns spacing

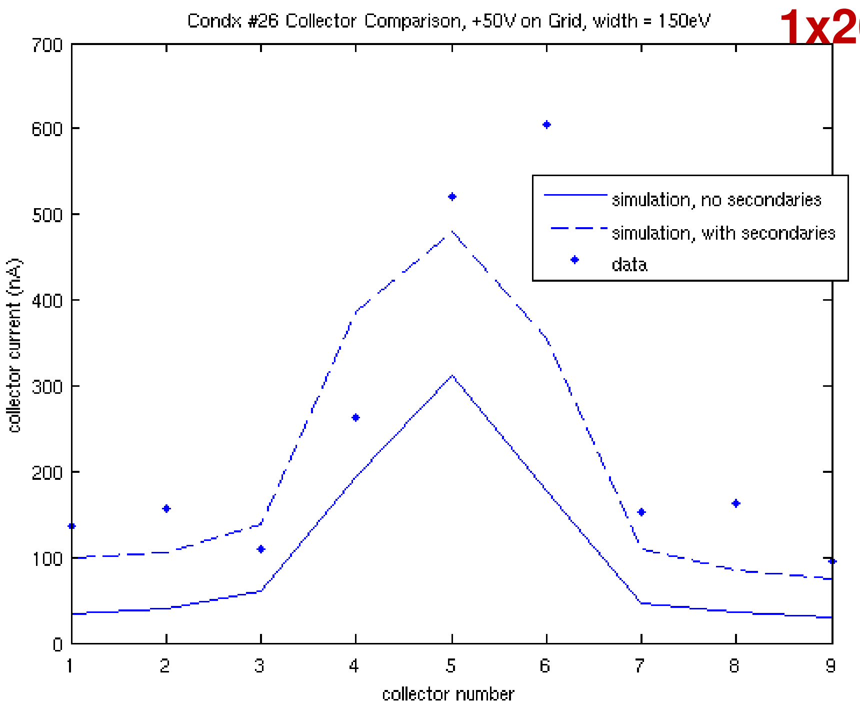
Slide courtesy J. Calvey

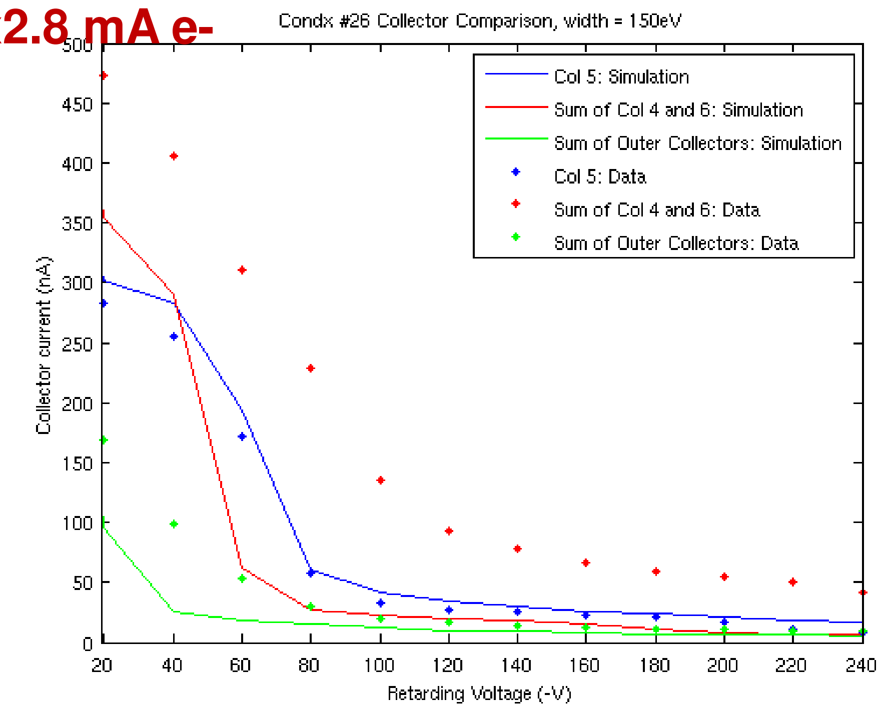
Slide courtesy J. Calvey




1x20x2.8 mA e-



# Effects for electron beams: summary

- Weaker multipacting effect in drifts compared with positron beams.
- Electron-stimulated gas desorption can cause pressure bump, lifetime effect
  - Observed in APS when studying multiplet fill patterns
  - Certain bunch patterns had half the beam lifetime, correlated with larger RFA signals. Effect no longer observed months later due to surface conditioning.
- Electron-beam data at APS and CesrTA suggest that photoelectron distribution should have a longer energy tail. Preliminary simulations show improved agreement:
  - Photoelectron energy modeled as narrow low-energy Gaussian distribution reasonably matched 2 GeV data, but broader energy width of 150 eV matched 5 GeV data better in POSINST (J. Calvey)
  - Studies with shielded buttons and photoelectron model in ECLOUD (J. Crittendon – see  poster)
- RFA data in wigglers at CesrTA relevant, but dynamics will be different since chamber is room temperature.

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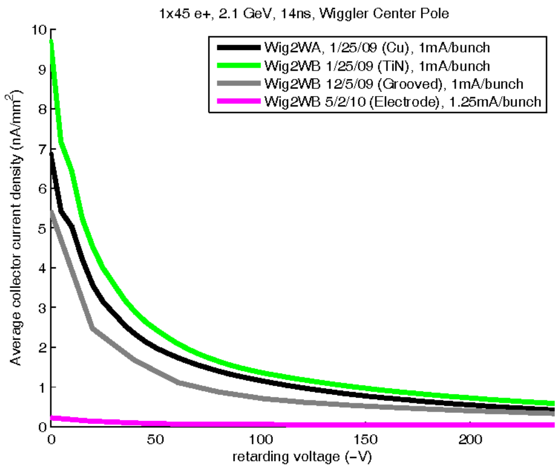
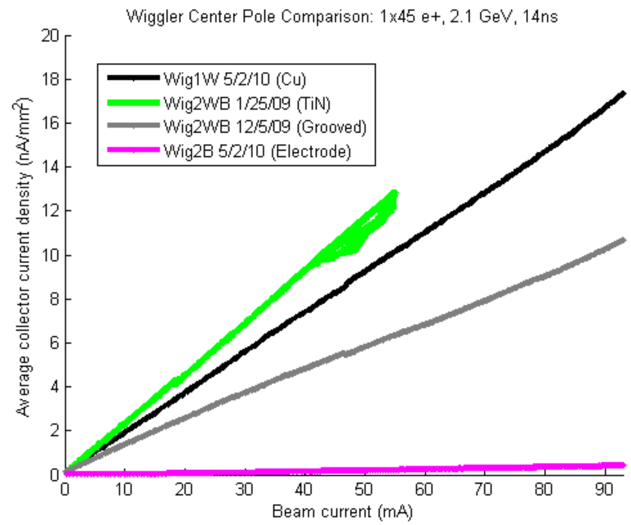
# Clearing electrodes most effective EC mitigation in CesrTA wigglers




J.R. Calvey et al., Proc. 2010 IPAC, 1973 (2010).

Figure 8: Wiggler comparison, 1x45 e+, 2.1 GeV, 14ns

J.R. Calvey et al., Proc. ECLOUD10.




- TiN coating most effective in drifts
- Grooves most effective in dipoles
- Biased electrodes most effective in wiggler RT chamber) TiN coating ***does not*** significantly reduce cloud.
- All comparisons for positron beam

# Shield SCU chamber

- SCU chamber tapers down in two steps from standard arc chamber (85 x 42) mm to SCU chamber (53 x 7.2) mm (full width x height)
- Usual ray-tracing has been done for shielding high-energy x-rays from outer chamber wall
- Lower-energy photons (> 4 eV) intercept SCU chamber top and bottom
- Preliminary thoughts on taper designs to
  - shield photons and minimize photelectron generation in SCU field
  - minimize photon reflections *a la* LHC beam shield
- Modeling of APS SCU chamber with *synrad3d* to be done
  - Also study diffuse scattering, fluorescence
- Need data for photoelectron model (RFA, XPS, dedicated measurements)

# Schematic photoemission spectra vs photon energy

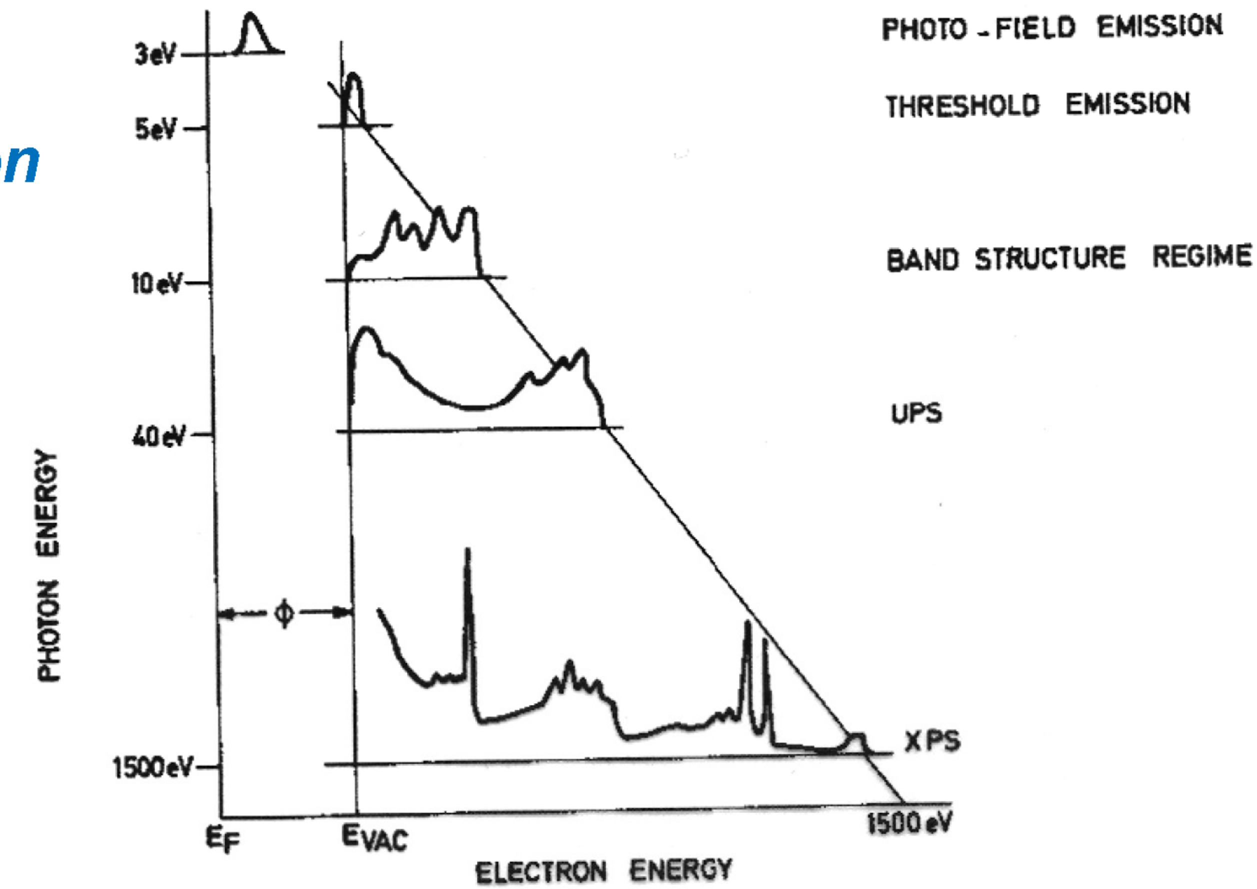



Fig. 5.3 Energy ranges and specialized spectroscopies in photoemission. XPS, excited by soft X-rays, shows spectra of considerable complexity including core level spikes, Auger peaks, valence-band emission and inelastic electrons. UPS has an intrinsically higher resolution and cross section for the valence band. The bandstructure regime, $\hbar\omega \approx 10$ eV, shows sharp structure arising from bulk selection rules. Threshold emission is generally observed without energy analysis. Subthreshold spectroscopy requires additional means to emit photoexcited electrons over the work function barrier $\phi$, such as, e.g.,a high electric field

**Figure credit: B. Feuerbacher and B. Fitton in "Electron Spectroscopy for Surface Analysis," p. 155 (Springer-Verlag, Berlin, 1977). With kind permission of Springer Science+Business Media.**

See also: R. Cimino et al., "VUV photoemission studies of candidate LHC vacuum chamber materials," PRST-AB 2, 063201 (1999).

# References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- R.A. Rosenberg et al., "X-ray photoelectron spectroscopy analysis of aluminum and copper cleaning procedures for the Advanced Photon Source," J. Vac. Sci. Technol. A 12, 1755 (1994).
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  - R. Cimino et al., "Vacuum chamber surface electronic properties influencing electron cloud phenomena," LHC Project Report 669 (2003).
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  - J.M. Jiminez, Proc. ECLOUD04, Napa, CA (2004).

# Summary

- Possible risk of an electron-cloud-induced heat load and vacuum effects for SCU (e.g. ANKA)
- Electron cloud generation and buildup widely-studied for positron and proton rings; far less data for electron rings
- Photoemission can be important for positron beams, but most attention has been paid to mitigating secondary electron emission
- Secondary emission parameters cannot explain observations in electron rings; photoemission model incomplete
- EC mitigation strategies focused on shielding SCU chamber from photons > 4 eV and minimizing photon reflections
- Longer-term strategy may include clearing electrodes
- Photon reflection study with synrad3d to be applied to APS SCU
- Need data for photoelectron model (RFA, XPS, dedicated measurements)
- See Laura's talk