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Comments on the CesrTA Experimental Program

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Advanced Photon Source

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LCWS08 and ILC08: Damping Rings

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Outline

- Challenges for ILC DR
- Opportunities at CesrTA
- Discussion

Acknowledgements

R. Rosenberg (ANL), L. Loiacono (UT Austin)

M. Furman, G. Dugan, M. Palmer, R. Macek, M. Pivi, C. Celata, S. Krishnagopal, … Many others!

Challenges for ILC DR design

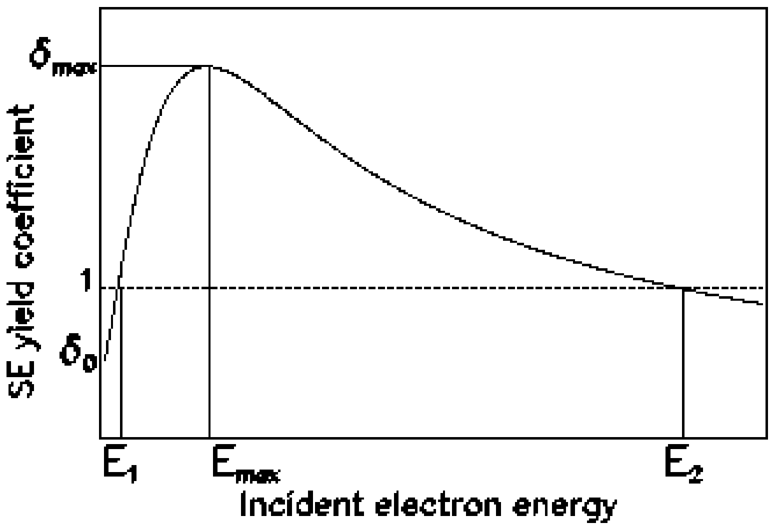
- Can electron cloud effects be predicted sufficiently well to avoid known instabilities?
- Are there new effects not yet observed, e.g., in a wiggler-dominated ring?
- Are well-conditioned surfaces ($\delta_{max} \leq 1$) sufficient to control the electron cloud? How important is $\delta(0)$ and how does it vary? (Contributed by rediffused and/or elastically scattered electrons.)
- How accurately does photoelectron generation need to be modeled?
- Recent results suggest that the local electron cloud can be strongly affected by neighboring elements
  - Trapped-electron ejection mechanism observed in quadrupoles at PSR; does this occur in the DR? Are there other examples?
  - Creates need to model multiple elements rather than one at a time

Secondary electron emission

- Universal δ curve [1], peak values surface dependent

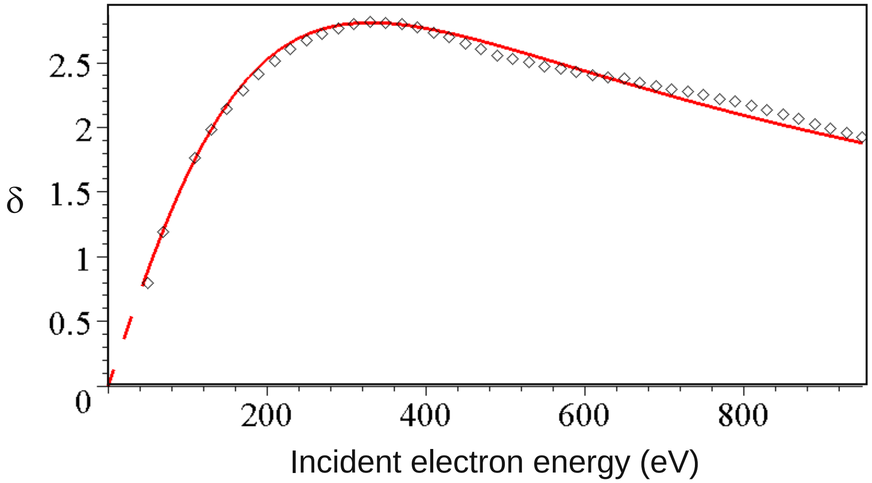
$$D(x) = \frac{sx}{s-1-x^s}$$

  - δ_{max} ~1-3 metals, >10 non-metals
  - E_{max} 250-400 eV
  - E_1 ~20-50 eV
  - E_2 ~1 keV but much higher at grazing incidence



- EC lifetime depends strongly on δ_0 ~0.5 (CERN, PSR)

- APS Al chamber secondary emission measured (R. Rosenberg) and fit to universal curve: δ_{max} 2.8, E_{max} 330 eV, s=1.86 (L. Loiacono) [2]. Dependence below 50 eV must be estimated, e.g., by scaling to the CERN data.

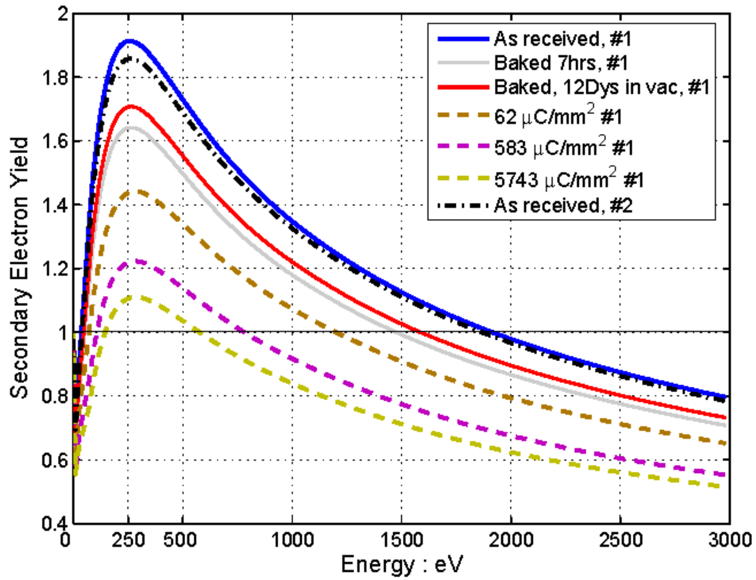


[1] M. Furman, M. Pivi, PRST-AB 5, 124404 (2002).

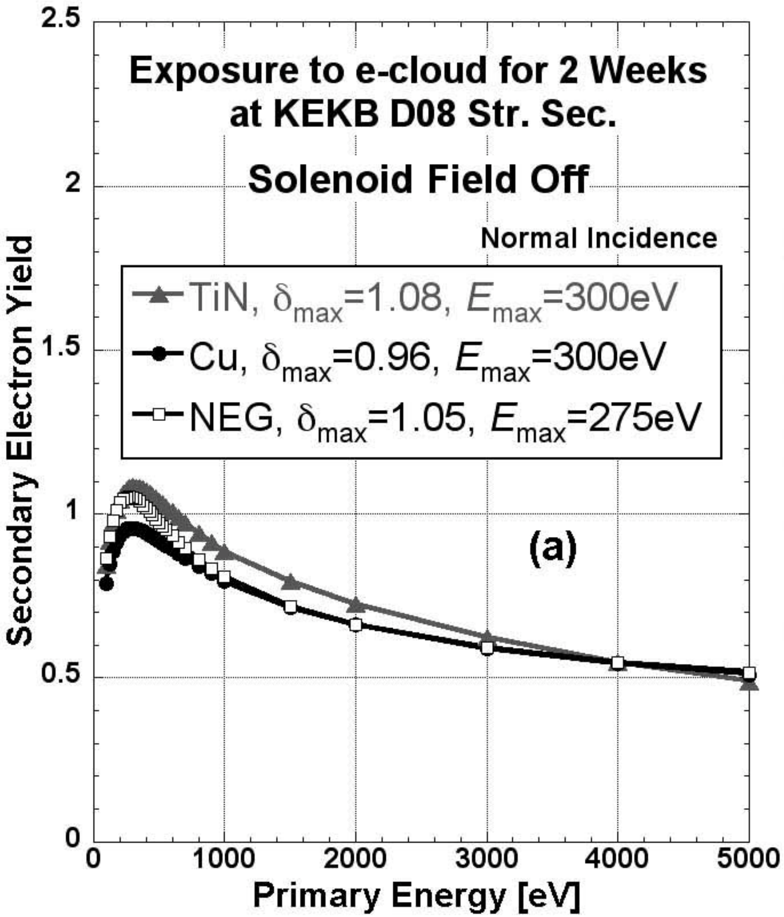
[2] K. Harkay, R. Rosenberg, L. Loiacono, Proc 2003 PAC, 3183 (2003).

Secondary electron yield coefficient

- Recent results show that well-conditioned surfaces tend toward δ_{max} ~1, possibly due to graphite and carbide formation



SEY of TiN/Al under different conditions **[F. Le Pimpec et al., Proc. ECLOUD07, KEK Proc. 2007-10, 68 (2007) http://chep.knu.ac.kr/ecloud07].**



SEY of TiN, Cu, NEG after exposure in the KEKB LER (measured *in situ*). Before exposure, δ_{max} ~1.8 for all. **[S. Kato, M. Nishiwaka, Proc. ECLOUD07, KEK Proc. 2007-10, 72 (2007) http://chep.knu.ac.kr/ecloud07].**

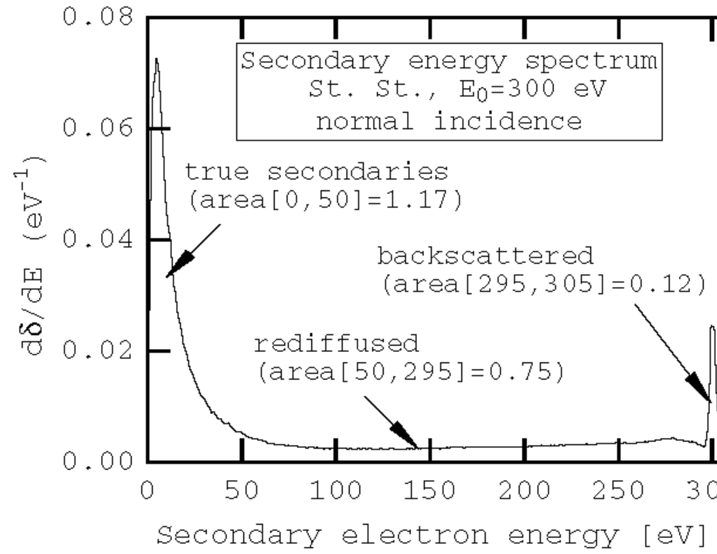
Secondary electron distribution

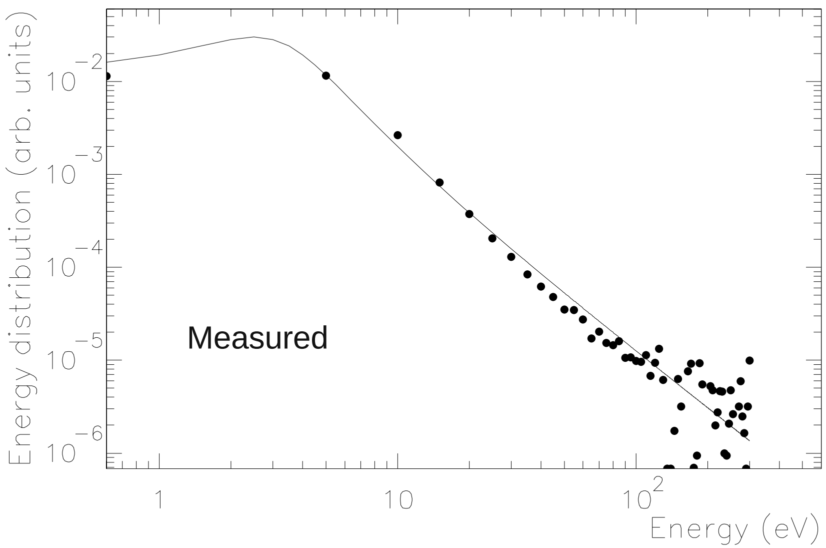
[1] M. Furman, M. Pivi, PRST-AB 5, 124404 (2002)

- Emission has 3 components [1]
  - **True SE** peaks at 1-3 eV, surface independent

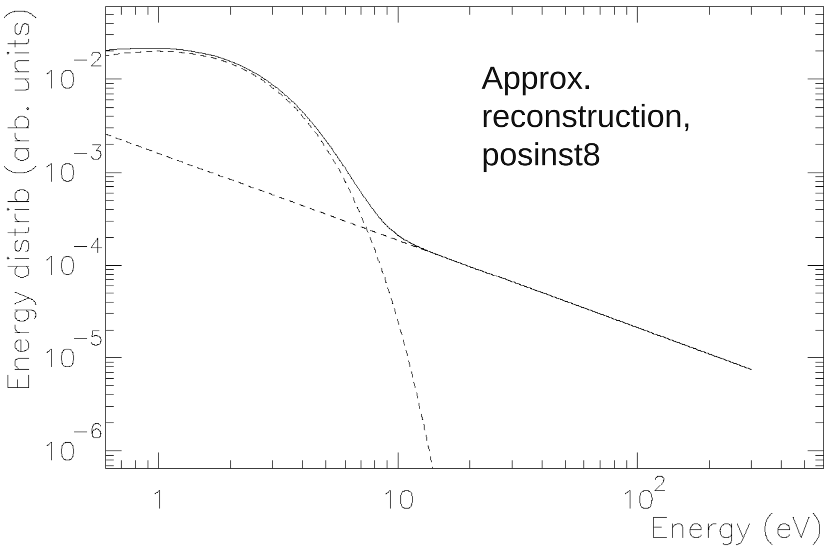
$$f_{ts} \propto E^{p_n - 1} e^{-E/\varepsilon_n}$$

  - **Rediffused** varies/sensitive to surface **(Cu vs. SS)**
  - **Elastic** depends on primary energy





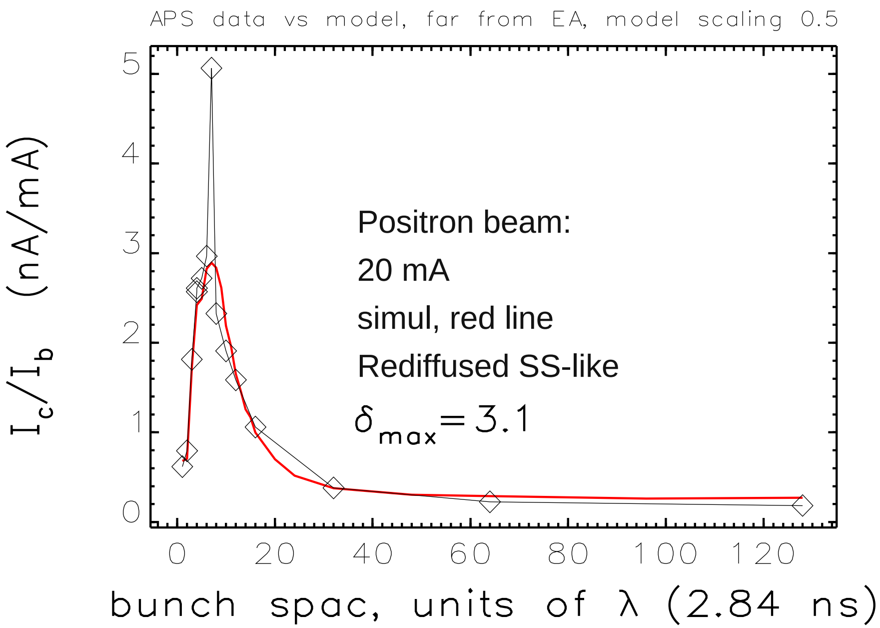
APS RFA distribution fitted to a Lorenztian func: <E> 2.5eV, width 5 eV (10 bunches, 128 λ_{rf} bunch spacing, 2 mA/bunch)
[For more info., see: K. Harkay et al., Proc. 2003 PAC, 3183].

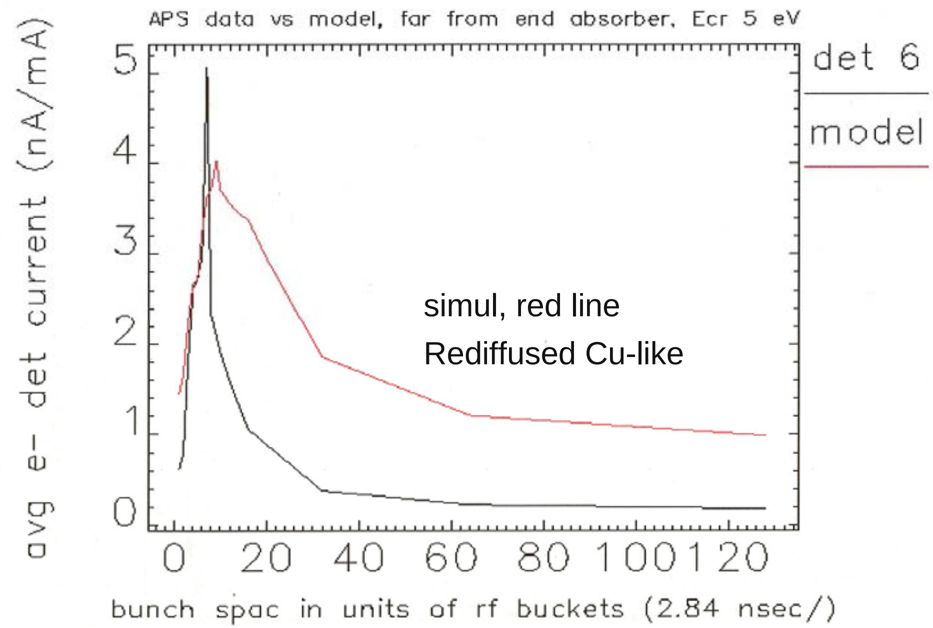


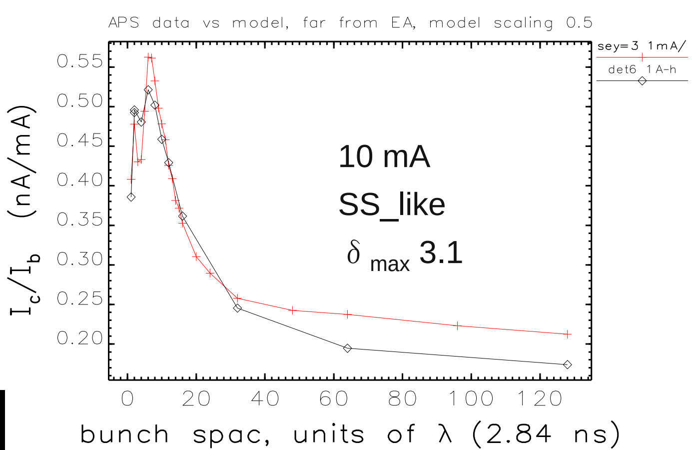
True secondary and rediffused components [1] using APS parameters (p_n=2, ε_n=1)

Sensitivity of secondary parameters on multipacting resonance

Comparison of APS RFA with simulated normalized electron wall current as a function of bunch spacing (10 bunches).







RFA vs. POSINST: $f_{ts} \propto E^{p_n - 1} e^{-E/\varepsilon_n}$

- **Peak at 20 ns bunch spac. (7 λ) sensitive to true secondary electron spectrum**
- **Amplitude (max current) sensitive to δ_{max}**
- **Peak width sensitive to rediffused component**
- **Unfortunately, electron beam poorly modeled with the same parameters**

Photoemission

- Even when δ important, EC buildup can be sensitive to the photoelectrons
- Measured photon reflectivity and PE yield for 10-1000 eV photons on Al alloy (at Elletra)
- Applied to DAΦNE photon spectrum
- Total eff. photoelectron yield: 0.2

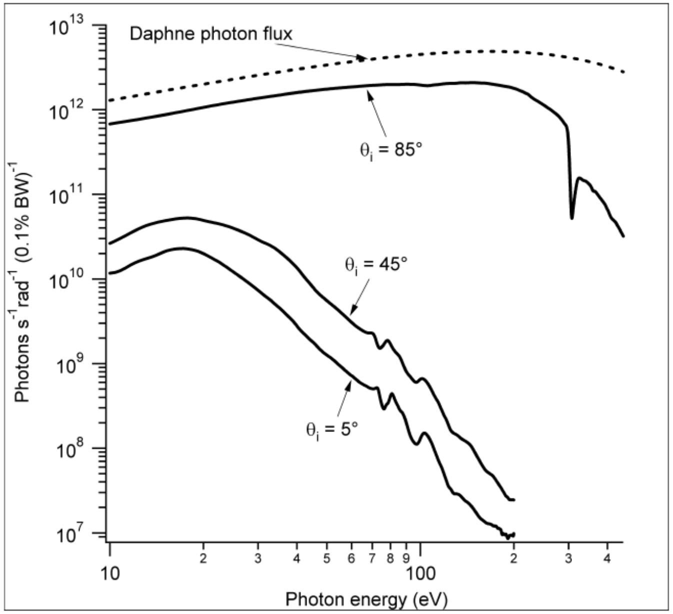


Fig 5: Number of reflected photons obtained by the reflectivity curves at incidence angle θ_I = 85°, 45°, 5°.

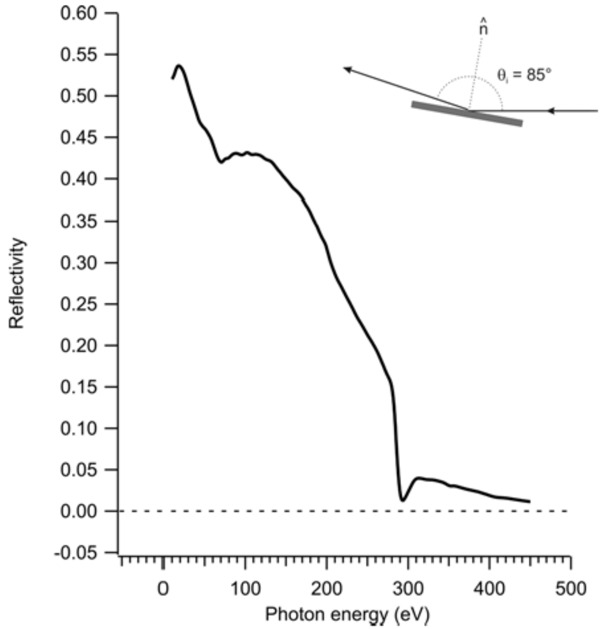


Fig 3: Reflectivity measurement with an incidence angle of 85°.

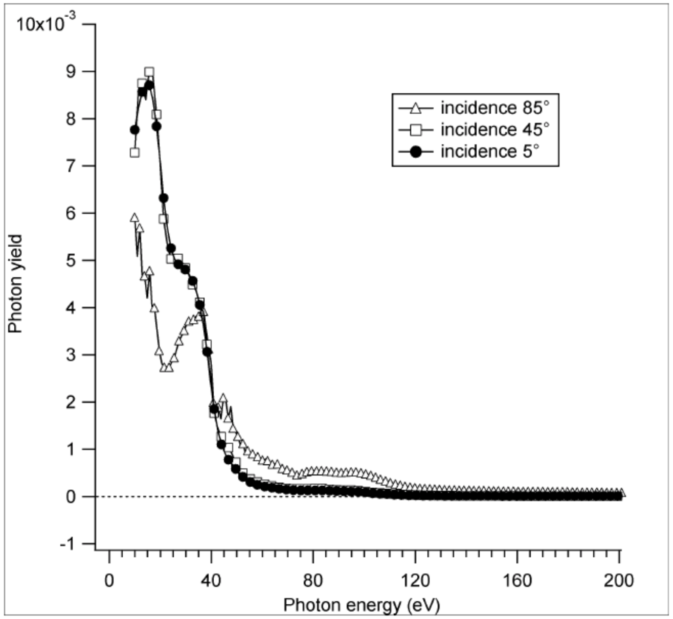


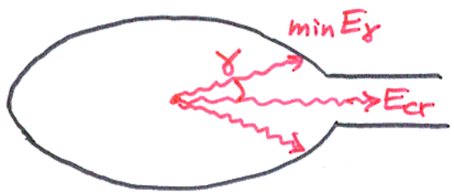
Fig 6: Photoelectron yield of the Al sample measured at incidence angles 85°, 45°, and 5°.

N. Mahne et al., EuroTev-Report-2005-013. http://www.eurotev.org

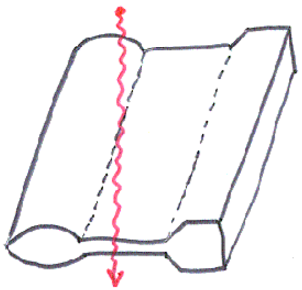
Photoemission vs. vacuum chamber geometry

Photon spectra, incident angle varies widely with local geometry

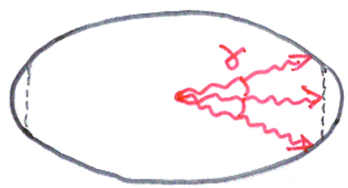
typical antechamber



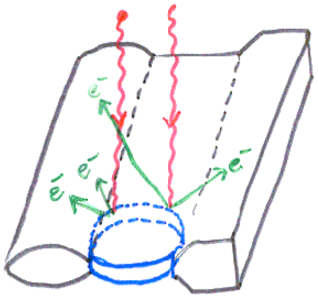
photons emitted from upstream bend



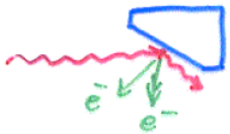
no antechamber



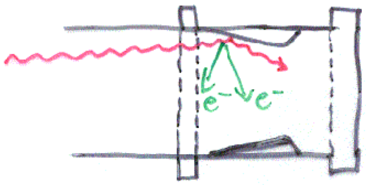
radiation end absorber (EA)



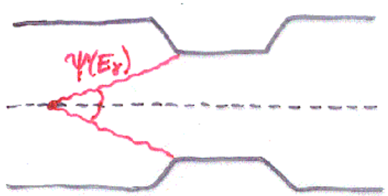
side view, EA



radiation mask



vertical restriction
(e.g. small-gap chamber)



Schematic photoemission spectra vs photon energy

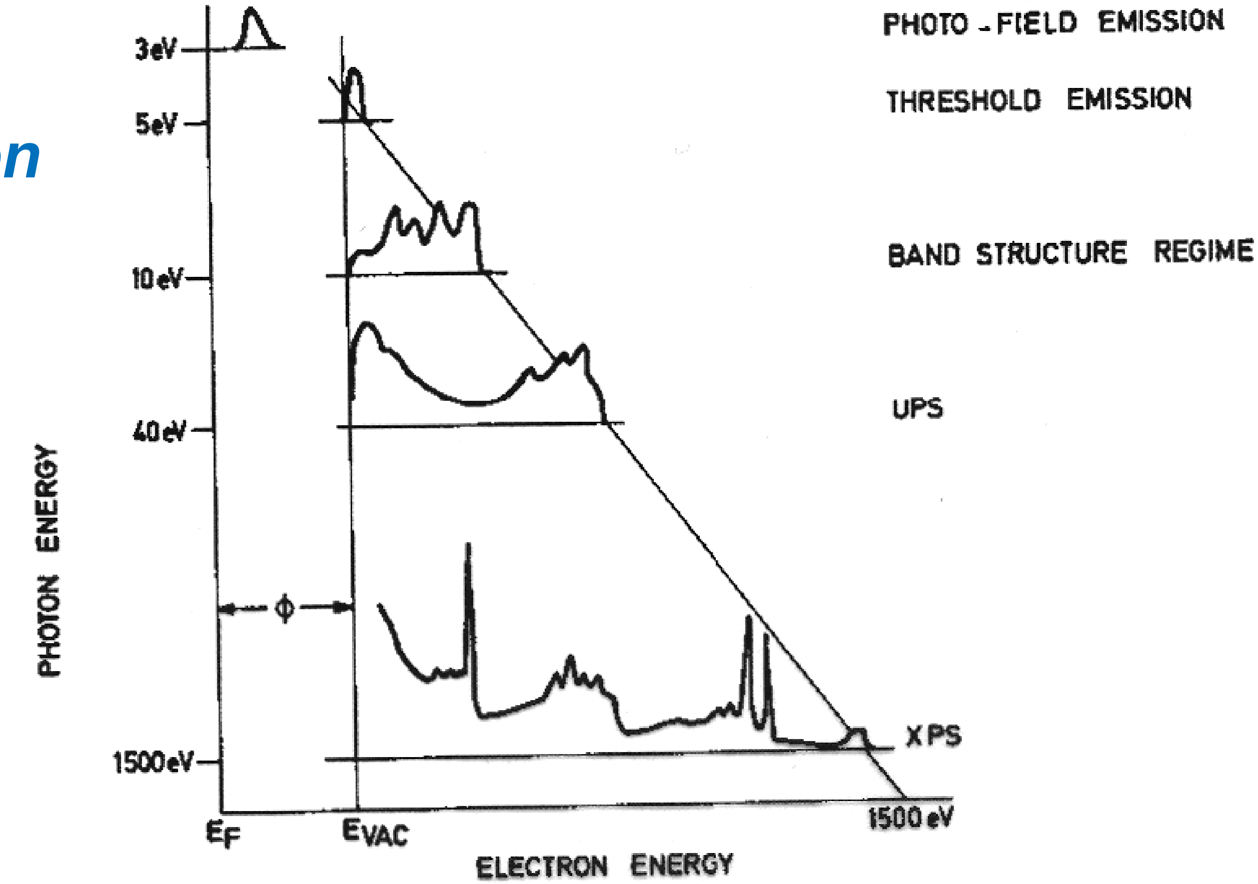


Fig. 5.3 Energy ranges and specialized spectroscopies in photoemission. XPS, excited by soft X-rays, shows spectra of considerable complexity including core level spikes, Auger peaks, valence-band emission and inelastic electrons. UPS has an intrinsically higher resolution and cross section for the valence 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 ϕ, such as, e.g.,a high electric field

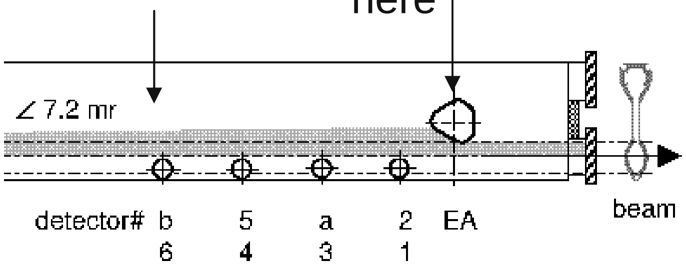
Figure credit: B. Feuerbacher and B. Fitton in "Electron Spectroscopy for Surface Analysis," p. 155 (Springer-Verlag, Berlin, 1977). With kind permission of Springer Science+Business Media.

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

Dramatic z-dependence in drifts (APS, Al δ_{max} 2.2)

~ 1 m upstream

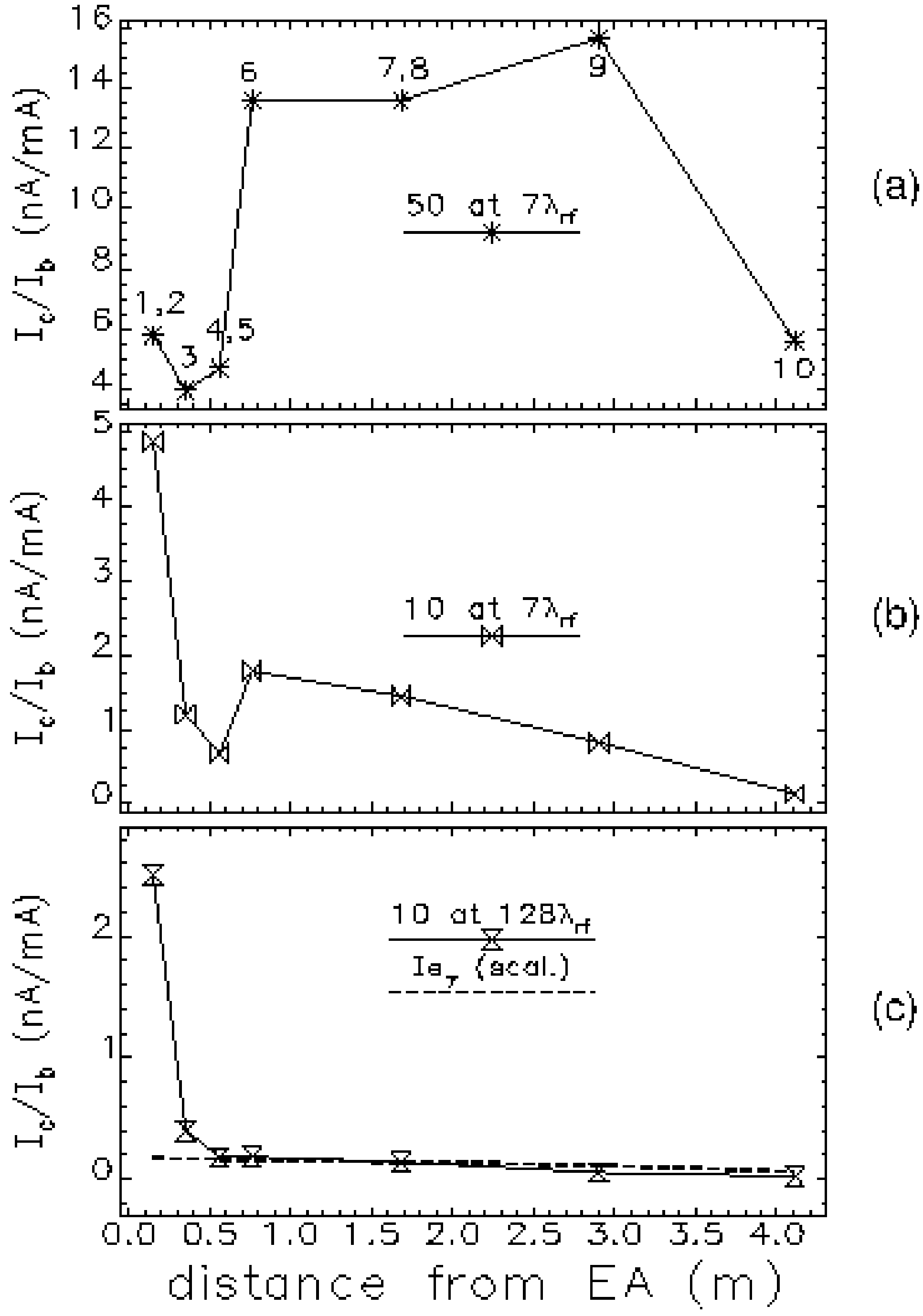
No ante-chamber here



a) For long bunch train at multipacting bunch spacing, amplification strongly suppressed at det 1,2.

b) At multipacting bunch spacing, short bunch train (center), det 6-9 strongly amplified; det 1,2 increase but only a factor of 2.

c) Det 1,2 dominate for large bunch spacing, consistent with photoelectrons (bottom) (all 2 mA/bunch)



Opportunities at CesrTA

- Suite of dedicated diagnostics and study time
- Correlate local cloud properties (RFAs) with global beam phenomena (bunch tune, bunch emittance)
- Quantify mitigation techniques (low-δ coatings, grooves)
- Existence of both positron and electron beam in same chamber provides more data to determine surface emission parameters
  - Parameters must be consistent in drifts, bends, particle species
  - Separate secondary-dominated from photoelectron-dominated conditions
- Traditionally more attention paid to positron data
  - Electron cloud effects clearly more important in this case
  - However, electron beams also exhibit weak multipacting, vacuum effects (e.g., APS); poorly modeled so far
  - Photoelectron component may be more important for electrons

Thoughts on CesrTA experiments (1)

Study both positron and electron beams

- Track down horizontal tune shift vs. lattice; vary current (below/above multipacting threshold)
- Define canonical set of data that is repeated over time
- Decide later what is minimum set of overlap of interest
- Use electron beam data to help determine photoemission parameters

Instrumentation

- Investigate low-energy enhancement in wiggler RFAs (~20 eV) (else zero-bias suppression (?))
  - Vary collector bias
  - Identify threshold dependence (bunch current? spacing?)

Thoughts on experiments (2)

Surface conditioning: $\delta(E)(t)$

- Record RFAs also during CHESS operation to quantify wall bombardment rate (C/cm^2 per A-h) over time
- EC mitigation: compare data for different chamber preparation over time

EC lifetime: $\delta(0)(t)$

- Bunch train with witness bunch, over time; compare wigglers on/off
- If schedule allows, vent chamber; repeat

Interaction between elements

- Study behavior of cloud adjacent to wiggler as a function of wiggler field; both for non- and for multipacting conditions
- Tune arc dipole (Pivi)

Thoughts on experiments (3)

- Non-multipacting regime
  - Measure EC energy distributions (RFAs), fit to three components of secondary distribution; compare with Cu, SS, Al measured elsewhere
  - Compare drifts, dipoles, wigglers (on/off) (RFAs). Compare positrons and electrons.
  - Record bunch tune shifts, bunch size

- Multipacting regime
  - Vary bunch spacing, bunch current, bunch train length
  - Look for nonlinear pressure rise above multipacting threshold
  - Measure EC energy distribution
  - Compare drifts, dipoles, wigglers (on/off) (RFAs). Compare positrons and electrons.
  - Record bunch tune shifts, bunch size

Other possible diagnostics

- Quadrupole sweeper (or more simply, as at KEKB)
  - Quantify electron trapping in quads

- Heat load
  - Uncertainty of contribution of electron cloud a big issue for LHC
  - Measured heat load twice as big as expected for cryocooled undulator at ESRF

Quadrupole diagnostic at PSR

- EC suspected trapped in quadrupole fields at PSR (Macek) and KEKB (Fukuma)
- Studies at PSR indicate EC lifetime in quads is orders of magnitude longer (~100 μs) than in drifts (~100 ns)
- Evidence that trapped electrons are ejected into neighboring drifts via **E**×**B**
- Preliminary KEKB data shows this happens in e+ rings also

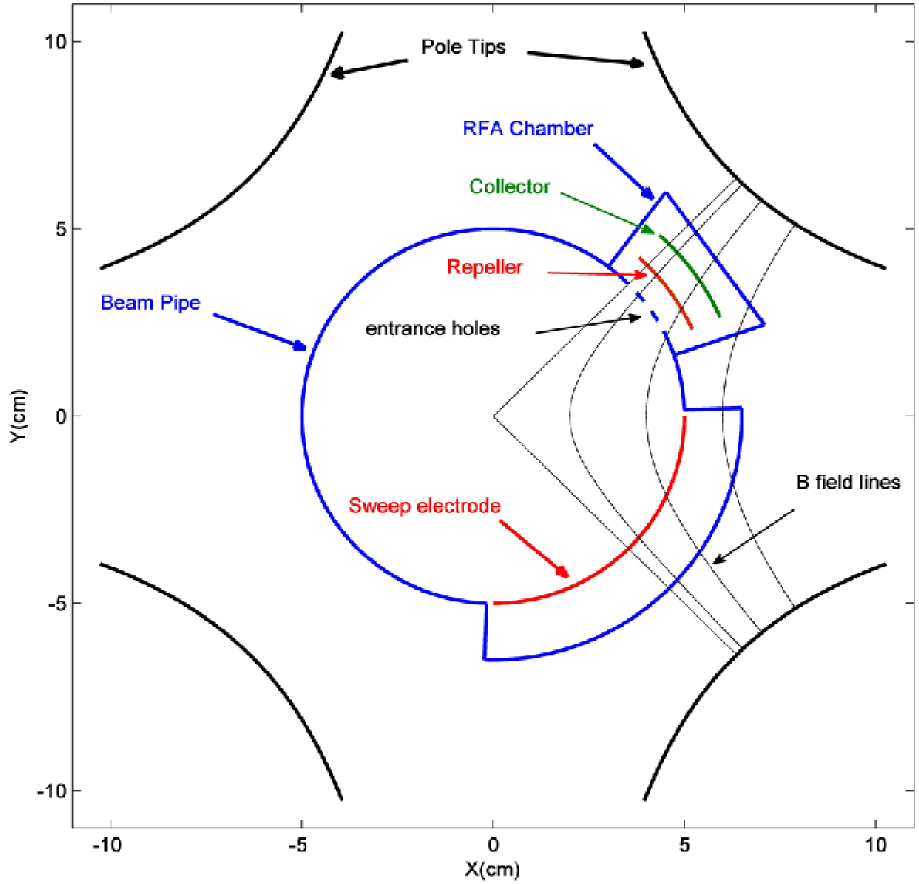
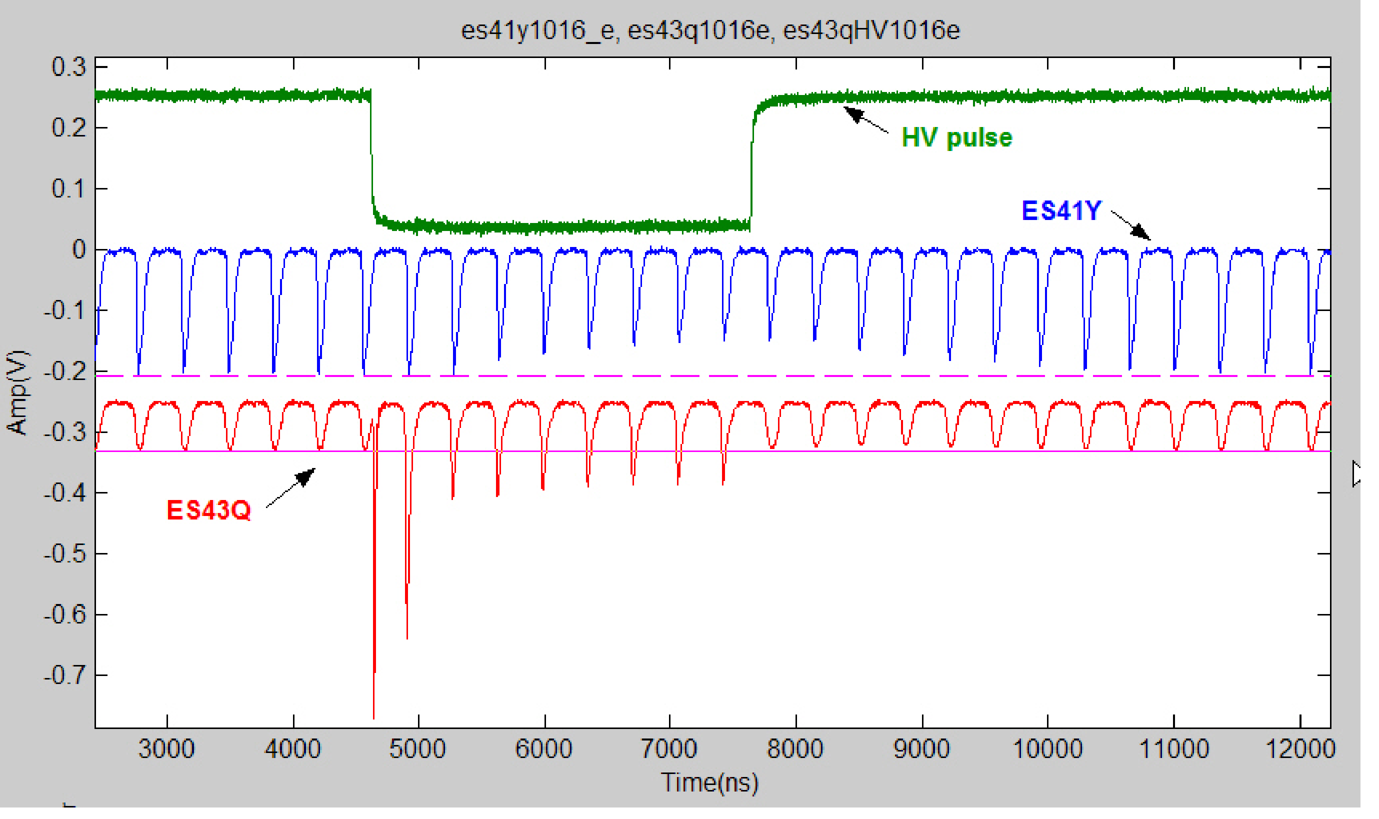


Figure 1. Schematic cross section of the electron sweeping diagnostic in a quadrupole magnet. Its principal components are an RFA chamber containing a repeller grid and collector plate, holes in the beam pipe at the entrance to the RFA chamber, and a high voltage sweeping electrode.

Fig. courtesy R. Macek (see also Proc. ECLOUD07, 52 (2007)).

ES43Q sweeping near end of accumulation

95 μA production beam



- **Sweeping ES43Q will remove a fraction of the electrons available to be ejected into the drift space**
- **At ES41Y see significant suppression of electrons during the sweeping pulse**

Slide courtesy R. Macek (see also Proc. ECLOUD07, 52 (2007)).

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Discussion

- In the past decade, much progress has been made in understanding electron cloud generation and beam interaction, but the surface emission phenomenon remains complex and questions remain
- Experimental data typically leads modeling efforts (exception was prediction of density stripes in dipoles (Furman, Zimmermann))
- Flexibility and diagnostics suite at CesrTA offers excellent opportunity for systematic benchmarking of EC generation models, in particular for consistency between positron and electron beams
- Suggestions for experiments focus on quantifying surface emission parameters, including both secondary and primary components of the cloud
- CesrTA offers opportunity to understand greater success in modeling positron data compared with electron data (e.g., CesrTA, APS)
- Focus on more accurate modeling of the photoelectron component based on measurements (DAΦNE, SLAC/SSRL)