APS RFA studies and modeling:

Findings vs. open issues

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Advanced Photon Source

2009 Nov 13

Cesr-TA electron cloud simulation WebEx meeting

APS EC study origins: circa 1997

Transverse multibunch instabilities at CESR discovered to be due to trapped electrons in DIP leakage field [T. Holmquist, J.T. Rogers, PRL 79, 3186 (1997)]

SLAC PEP-II and KEKB B-factories both under development; became concerned about ECEs:

Separate, first-generation codes developed to model EC generation and instabilities (M. Furman, K. Ohmi, F. Zimmermann, and colleagues)

LHC: Calculated predictions of a BIM resonance resulted in a crash program at CERN to study ECEs.

We were asked: why don't we observe EC effects at the APS with Aluminum chambers (high δ) and positron beams? Started experimental program in 1997-98 first with e+ beam, then 1998-2004 with e- beam. Collaborator: R. Rosenberg.

Retarding field analyzer (RFA) distribution

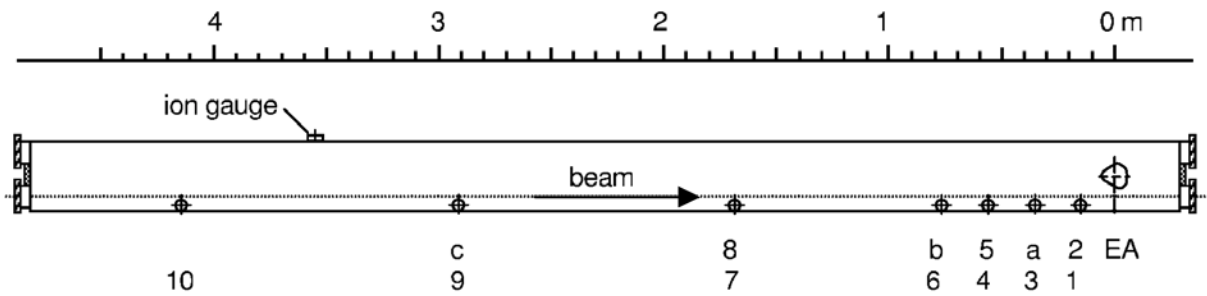
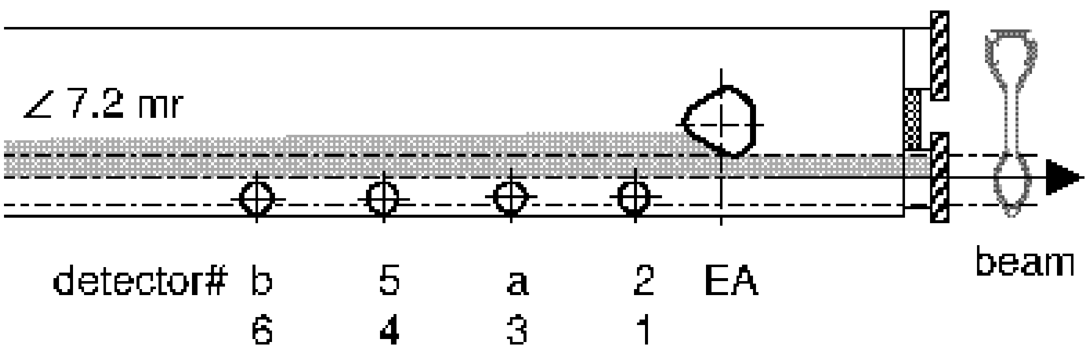


FIG. 1. Modified vacuum chamber (top view) showing locations of RFA detectors 1–10 and BPMs *a*, *b*, and *c*. The top numbers and letters indicate those detectors or BPMs mounted above the chamber midplane; the bottom numbers indicate those mounted below. The end absorber EA intercepts high-energy photons.

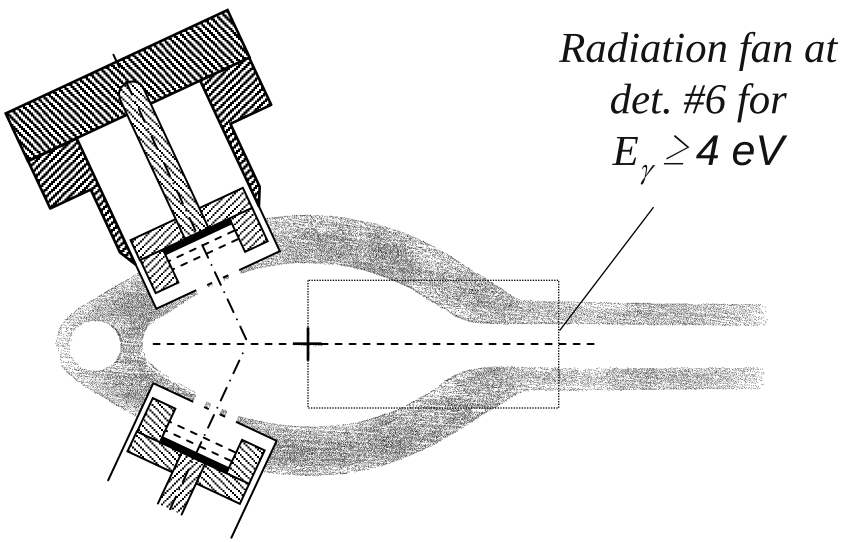
K. Harkay, R. Rosenberg, PRSTAB 6, 034402 (2003)

Mounting on 5-m-long APS chamber, top view, showing radiation fan from downstream bending magnet. Pressure measured locally (3.5 m upstream of EA).



Retarding field analyzer (RFA) †

RFA measures distribution of EC colliding with walls, transmission efficiency ~50%



Mounting on APS Al chamber ***behind vacuum penetration*** *(42* x *21 mm half-dim.)*

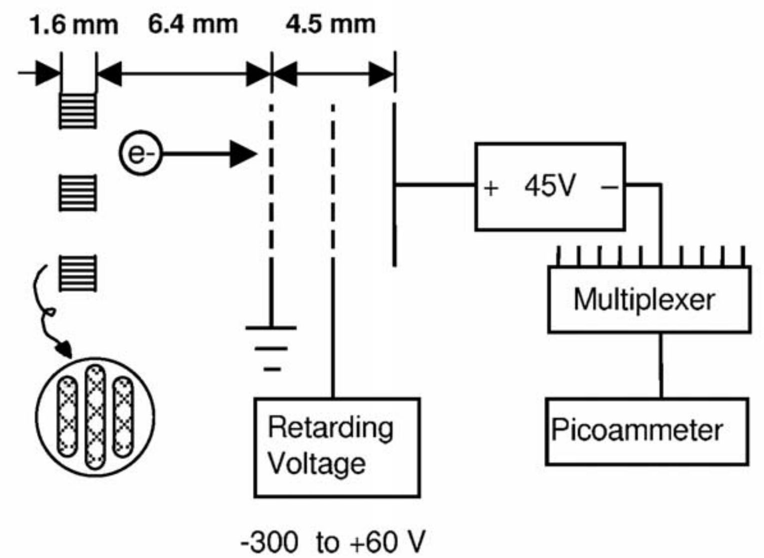


FIG. 3. Schematic of APS planar retarding field analyzer (RFA). The collector is graphite coated to lower δ and biased at +45 V to enhance the collection efficiency. The grounded, outer grid is mounted behind a slotted vacuum penetration to shield the RFA from beam-induced rf noise. The penetration slot area is approximately 1.25 cm^2, and approximate distances between the chamber wall (1.6 mm thick), grids, and collector are indicated.

† ***Designed by Richard Rosenberg***

Machine parameters for APS

Beam energy	GeV	7
Circumference	m	1104
RF frequency	MHz	351.9
Minimum bunch spacing	ns	2.84
Harmonic number	–	1296
Chamber semi-axes (*a*, *b*)	mm	42.5, 21
Antechamber height	mm	10
Chamber material	–	Al
Distance from dipole magnet end to RFA (#6)	m	9.25 (e+/e-)
Dipole bend angle	rad	0.07854
Dipole length (80) (fill fraction ~0.2)	m	3.06
Bunch length (rms)	cm	1

Posinst modeling, SE input params (v8)

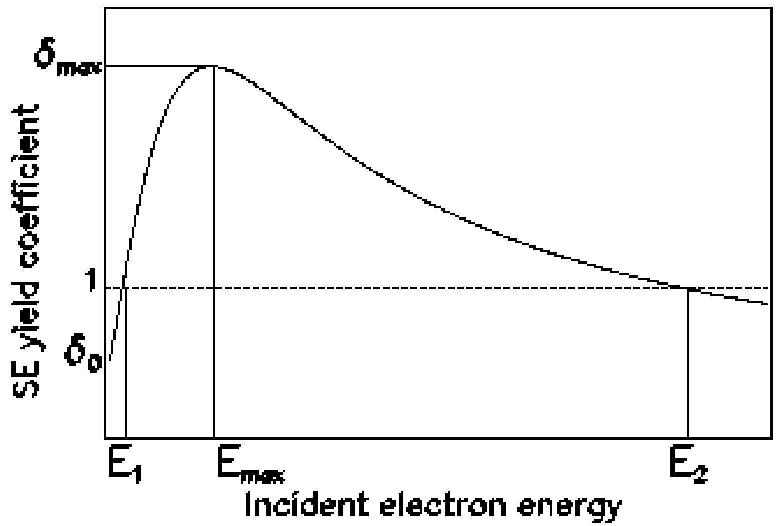
			Copper (CERN)	Stainless steel (LBNL)	Aluminum (APS msrd/fit)	Aluminum (APS model)
Total SEY	E_tot_pk	eV	271	292	330	300
	δ_tot_pk		2.1	2.05	2.8 ±10%	2.2-3.1
True secondary	δ_ts_pk		1.88	1.22		1.26-2.16
	E0_ts_pk	eV	276.8	310		300
	s		1.54	1.813	1.86	1.44
	t1,t2,t3,t4		0.66,0.8,0.1,1	0.66,0.8,0.1,1		0.26,2,0.7,1
Rediffused	P1r	∞	0.2	0.74		0.9
	Er	eV	0.041	40		35
	r		0.104	1		2
	q		0.5	0.4		0.1
	r1,r2		0.26,2	0.26,2		0.26,2
Elastic	P1e	∞	0.02	0.07		0.04
	P1e_pk	δ(0)	0.496	0.5		0.1
	E0e_pk	eV	0	0		5
	W	eV	60.86	100		5
	p		1	0.9		2
	σ_e		2	1.9		2
	e1, e2		0.26,2	0.26,2		0.26,2

Secondary electron emission

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

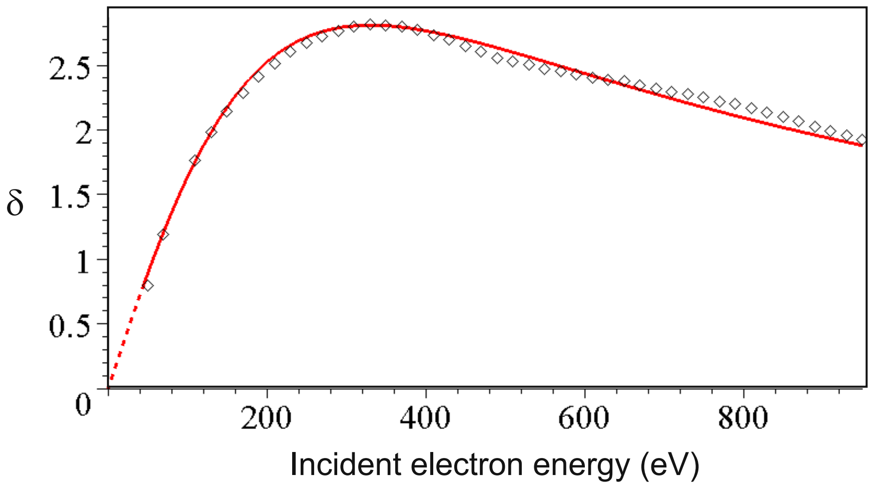
$$D(x) = \frac{sx}{s - 1 - x^s}$$

  - 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 can be estimated in posinst and/or scaled to CERN data.

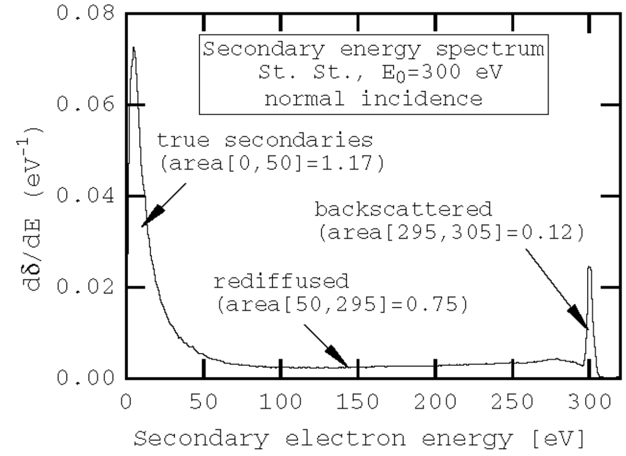


[1] M. Furman, M. Pivi, PRSTAB 5, 124404 (2002).

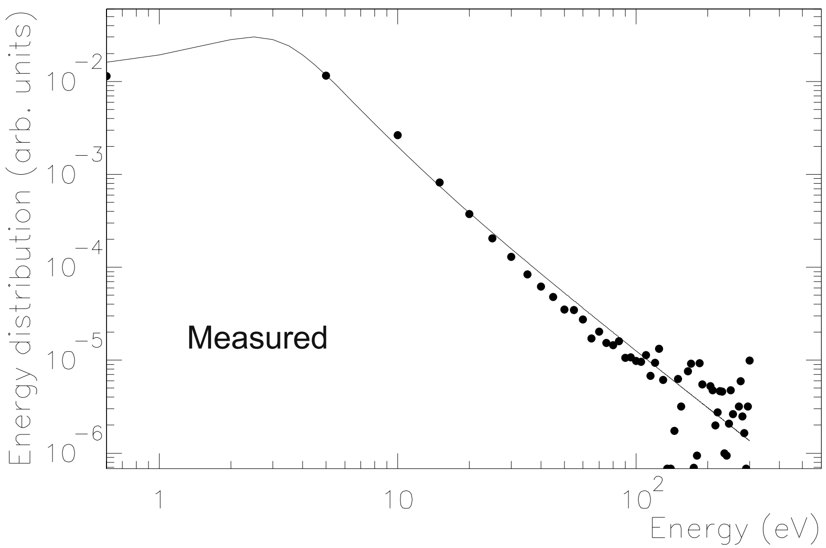
[2] K. Harkay, R. Rosenberg, L. Loiacono, Proc 2003 PAC, 3183 (2003).

Secondary electron distribution function

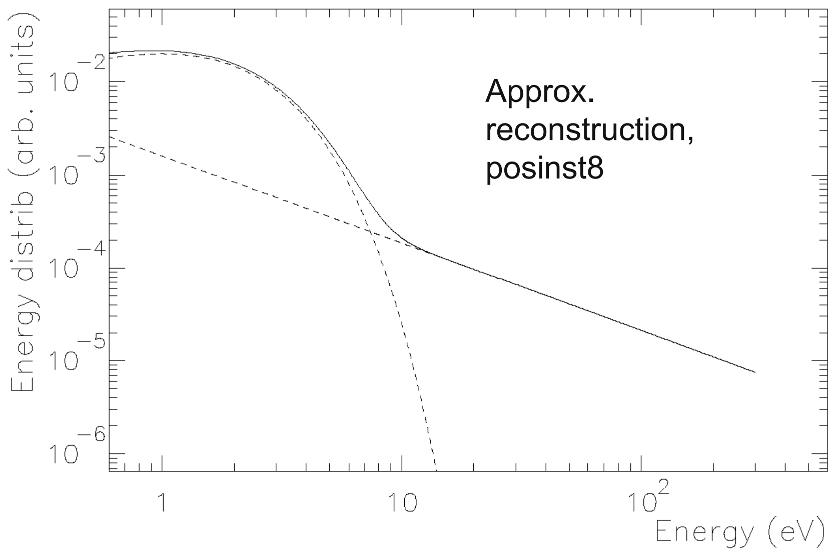
- Emission has 3 components [1]
  - True SE peaks at 1-3 eV, surface independent $$f_{ts} \propto E^{p_n - 1} e^{-E/\varepsilon_n}$$ **p_n=2, ε_n=1**
  - Rediffused varies/sensitive to surface
  - Elastic depends on prim. energy



[1] M. Furman, M. Pivi, PRSTAB 5, 124404 (2002)



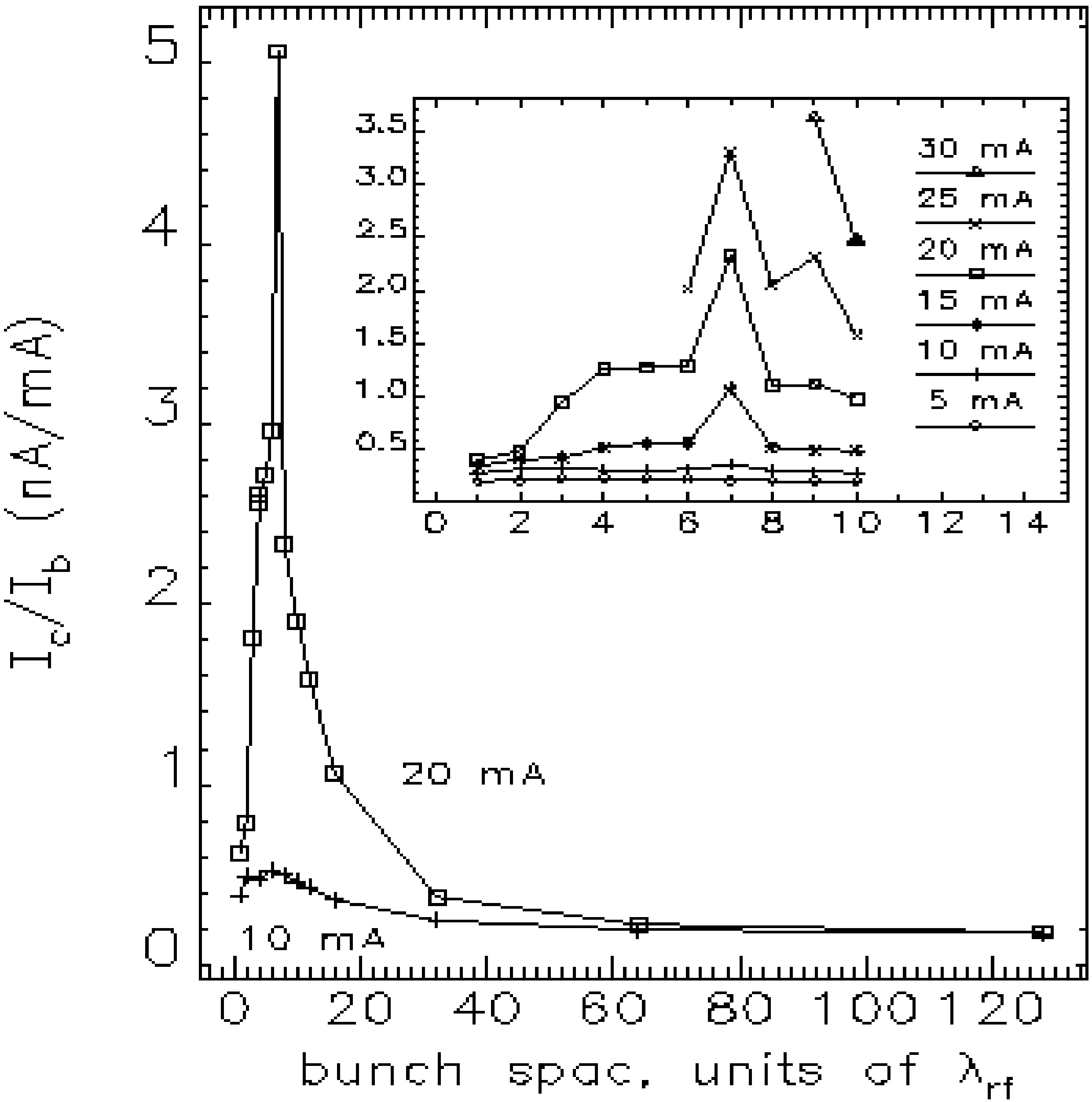
RFA distribution fitted to a Lorenztian func: <E> 2.5eV, width 5 eV (10 bunches, 128 λ rf bunch spacing, 2 mA/bunch) [K. Harkay et al, Proc. 2003 PAC, 3183].



True secondary and rediffused components [1] using APS parameters (p. 6)

Photoemission params

- Effective photoelectron yield: 0.1
- Number photons per e+: 0.07
- Photoelectron σ_y: 5 mm (for det 6)
- Reflectivity ≠ 0
- Dilution: 1 (reflectivity % ?)



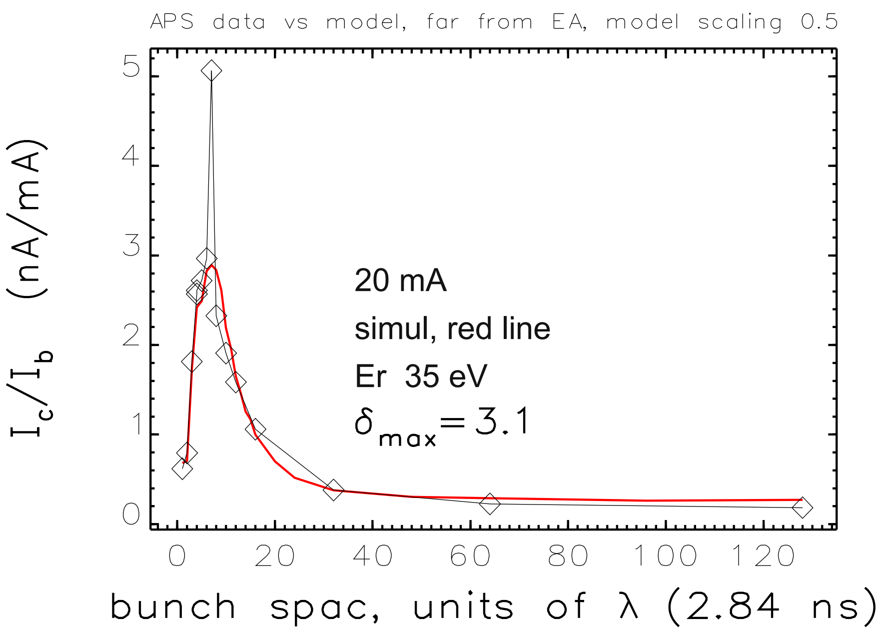
Positron beam: dependence on bunch spacing

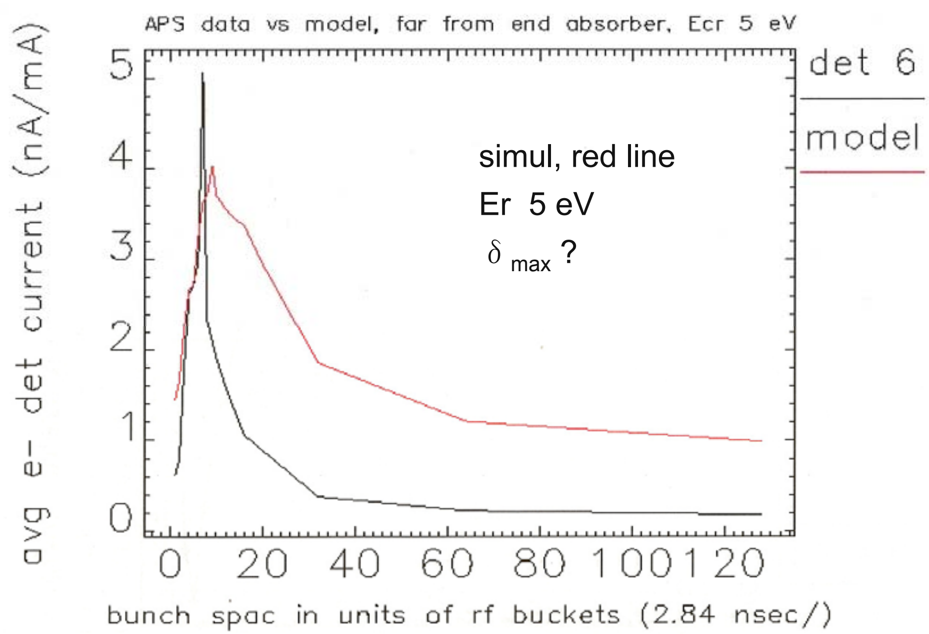
Measured (RFA 6) electron wall current (Ic) as a function of bunch spacing, normalized to the total beam current (Ib) (10 bunches; total current shown).

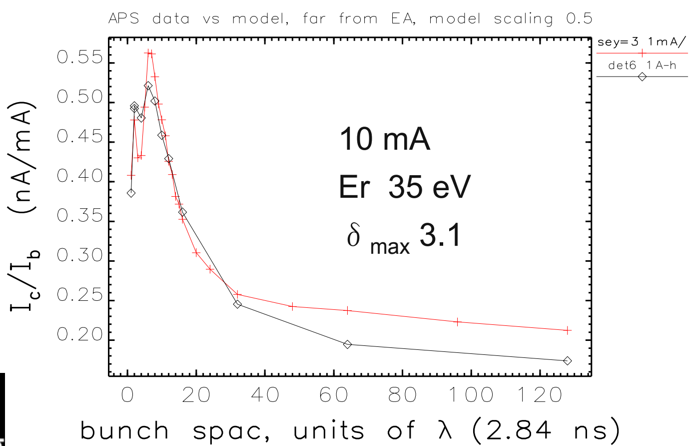
The inset shows a conditioning effect of more than a factor of two reduction after 60 Ah of beam operation.

Multipacting resonance (RFA vs. bunch spacing)

Comparison (RFA det 6) with simulated normalized electron wall current as a function of bunch spacing (10 bunches).



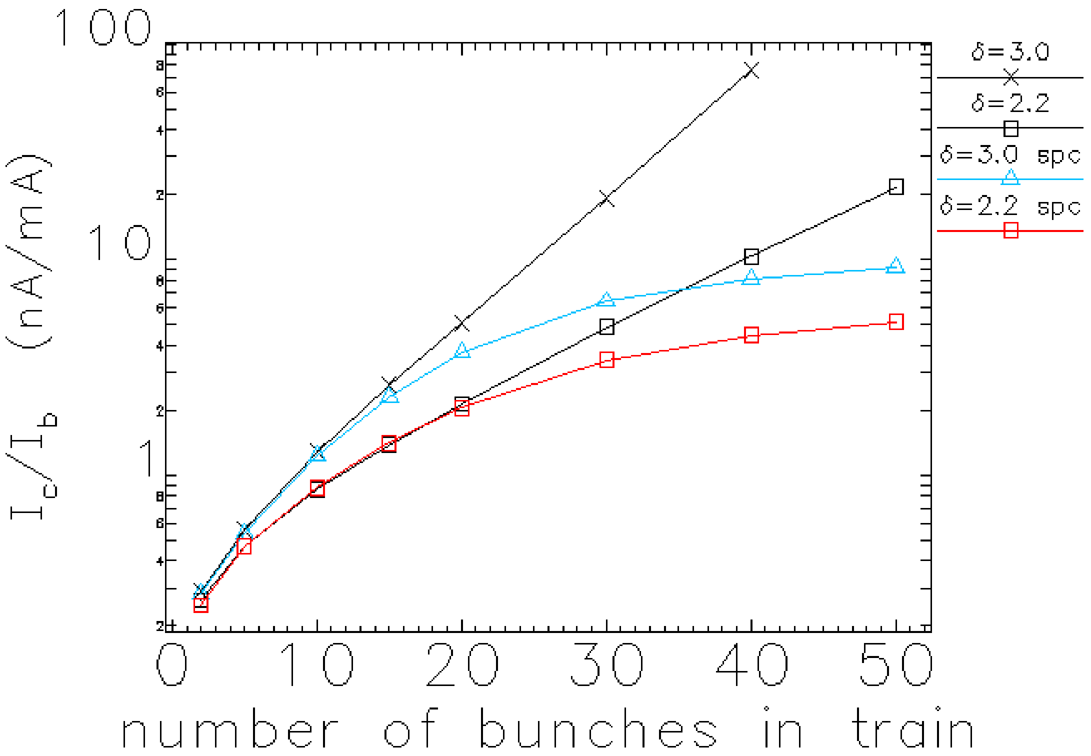


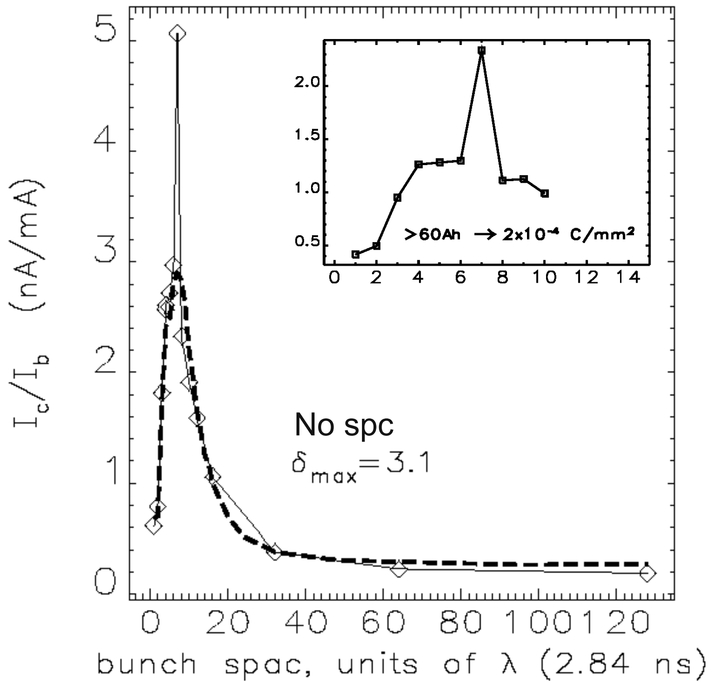


RFA vs. POSINST: $f_{ts} \propto E^{p_n - 1} e^{-E/\varepsilon_n}$

- **Peak at 20 ns bunch spac. (7 bkt) sensitive to true secondary electron spectrum**
- **Amplitude (max current) sensitive to δ_{max}**
- **Peak width sensitive to rediffused component**

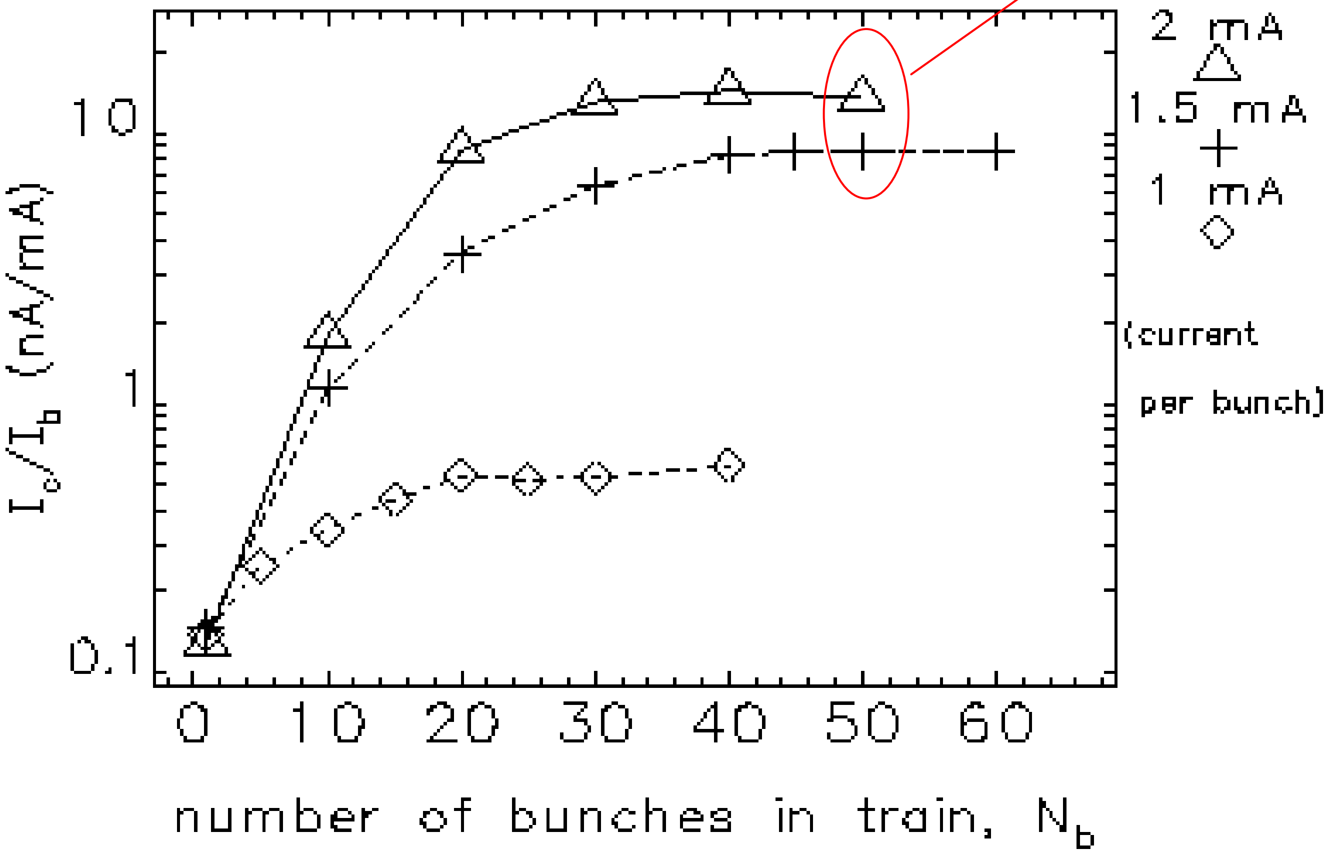
Modeled effect of space charge, 20 ns bunch spacing





Surface conditioning: Wall flux at APS reduced 2x after 60 Ah of surface conditioning (inset, left), equivalent to 10^{-3} C/mm^2 dose, consistent with CERN data (Cu). Conditioned Aluminum chamber RFA data consistent with δ_{max} 2.2.

Cloud build-up and saturation



EC saturates after 20-30 bunches (middle of straight)

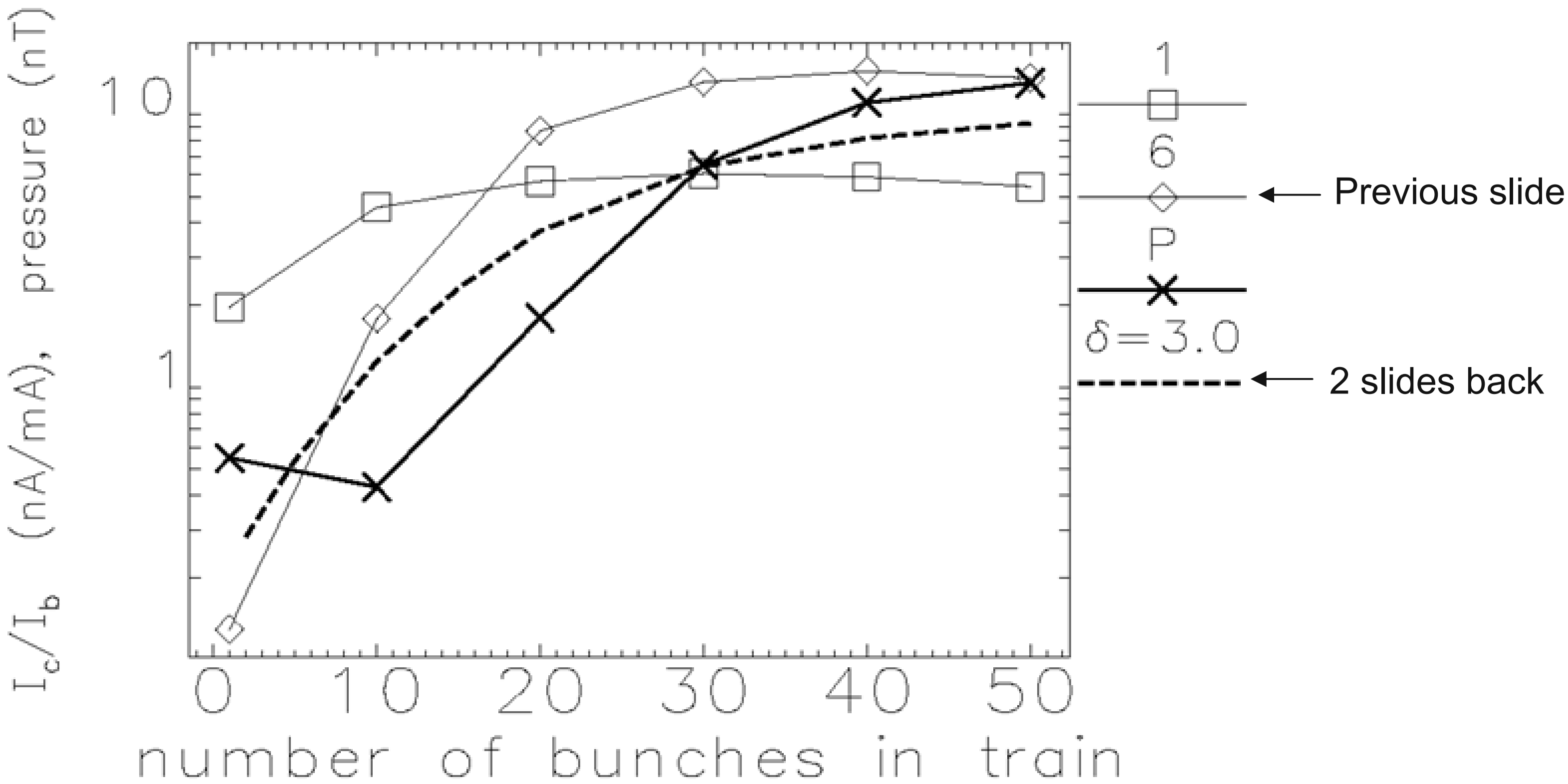
Level varies nonlinearly with bunch current ($7\lambda_{rf}$ bunch spacing)

Associated pressure rise (shown later)

Calculated EC density at saturation (e+ beam)

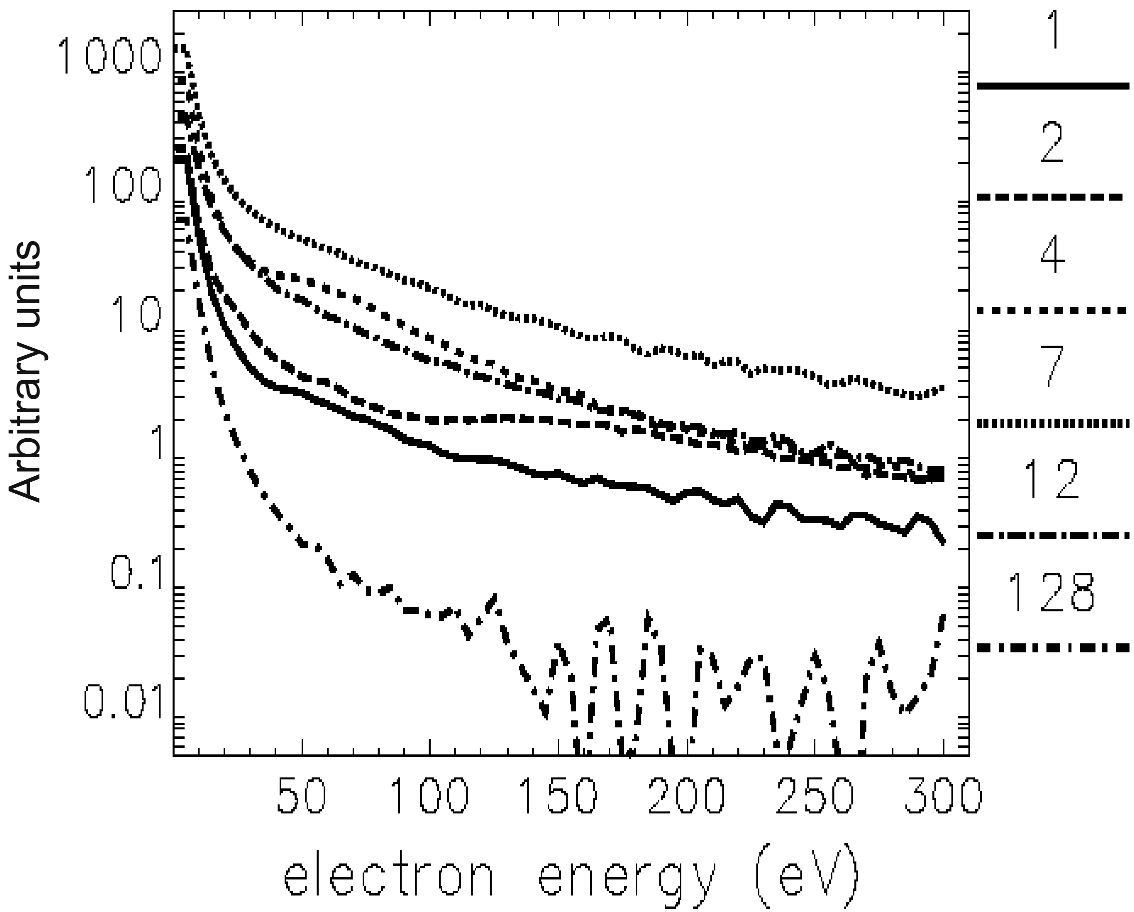
- **KEKB 6e11 m^{-3} (no solenoid) (H. Fukuma, ECLOUD02)**
- **APS 10e10 m^{-3} (")**
- **PEPII 10e10 m^{-3} (between solenoids) (A. Kulikov)**

Buildup over bunch train



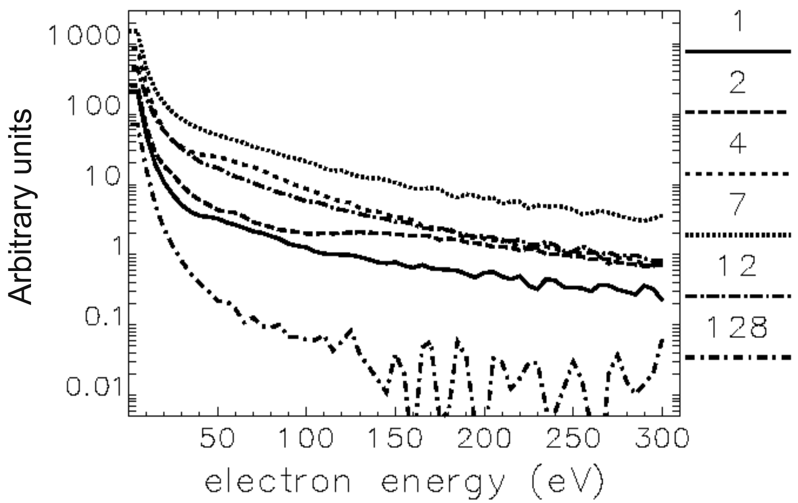
Measured (RFA det 1,6) and simulated (dashed line, δ_{max}=3.0) electron wall current as a function of bunch train length, 20 ns bunch spacing, comparing RFAs 65 cm apart. Anomalous pressure rise P is also shown.

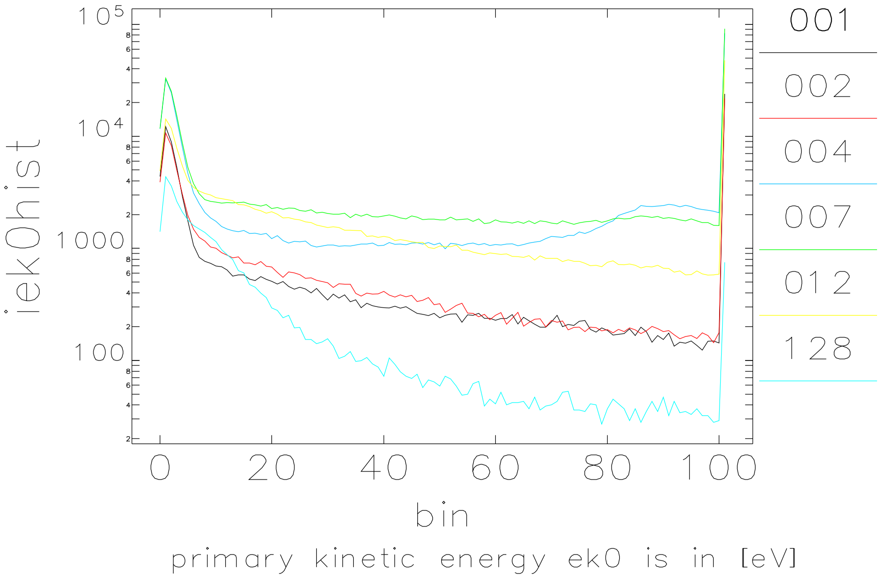
Energy distribution

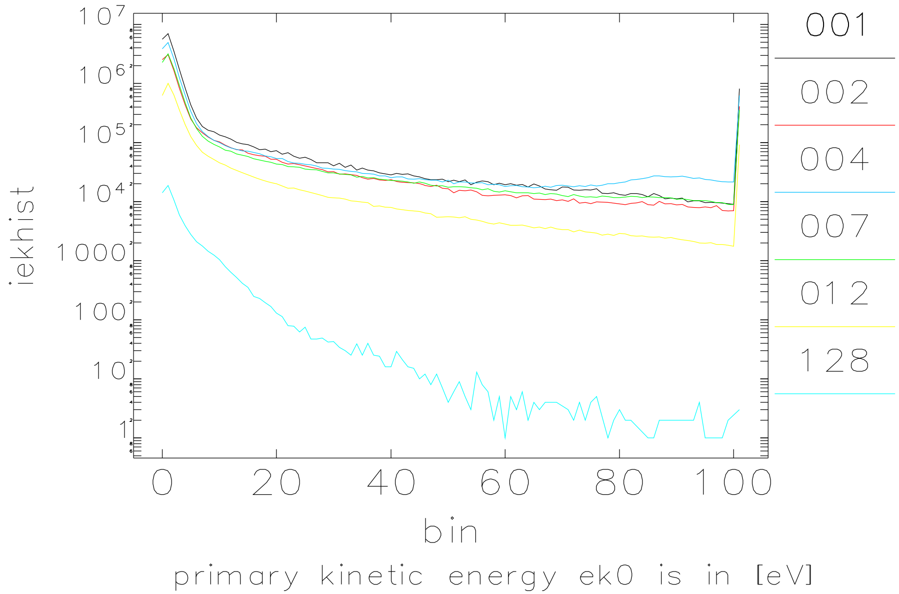


- Energy distributions from differentiated RFA (det6) signals as a function of bunch spacing (units of λ) (10 bunches, 2 mA/bunch)
- Low-energy part is well fit by a Lorentzian with <E> 2.5 eV and width 4 eV
- Long exponential tail on all but 128 λ
- Energy bumps observed for 2 λ and 4 λ, but not on longest tail for 7 λ
- Avg energy ~100 eV for e+ beam at 20 ns spacing; ~10 eV for e- beam at 30 ns spacing

Energy distributions





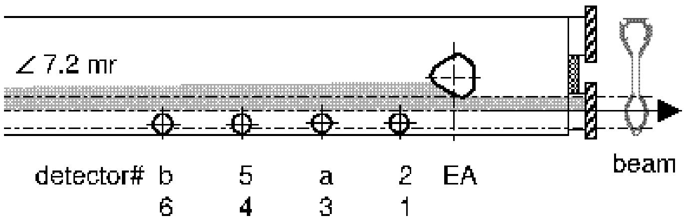


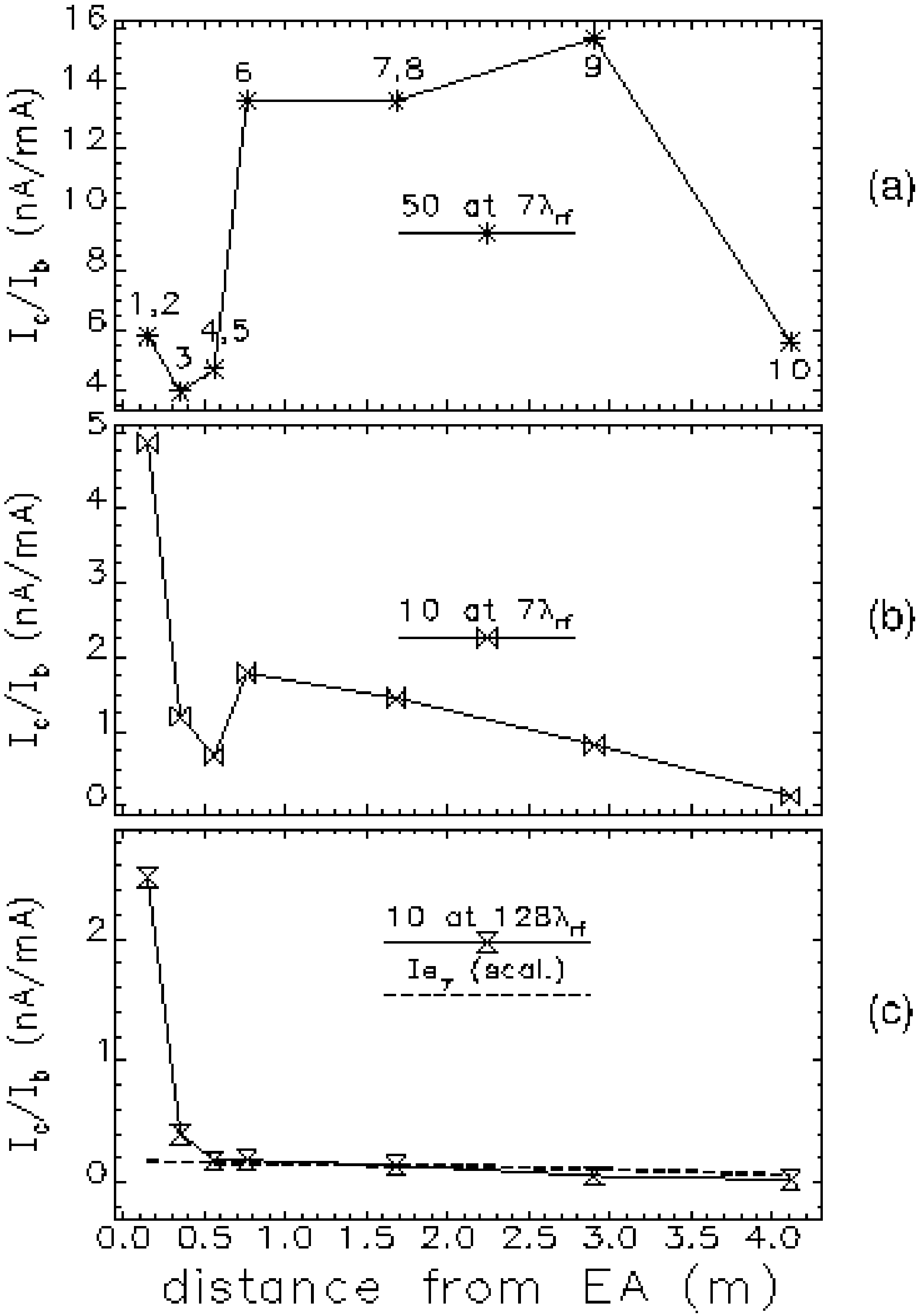
- Simulated energy distributions similar to RFA data
- Simulation results may show similar energy bumps but not explored in detail
- Computed histograms up to 300 eV also

Open issues

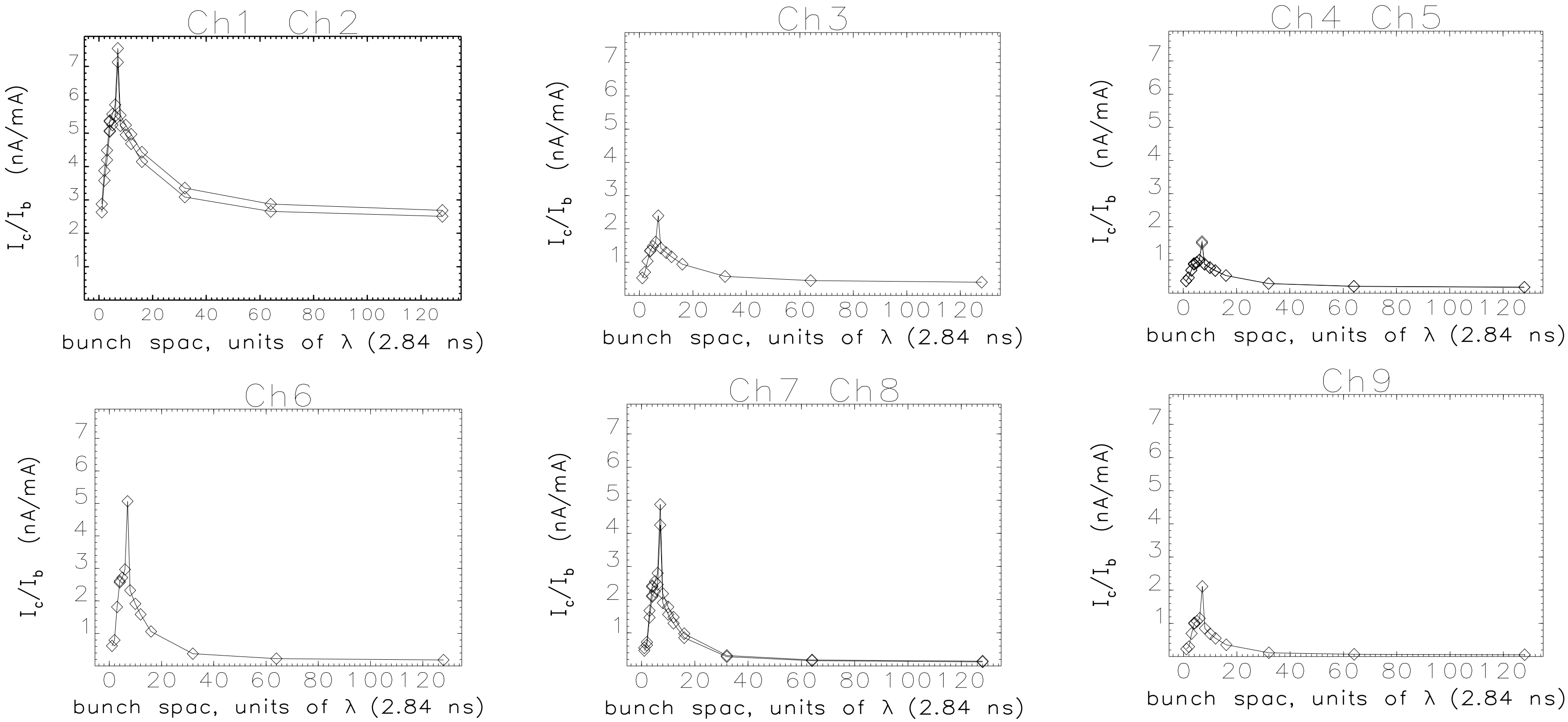
Dramatic Z-dependence

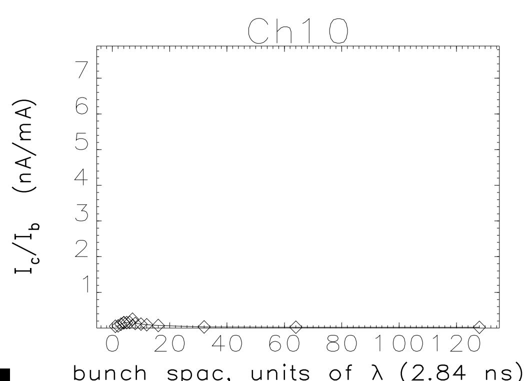
Measured peak RFA current as function of bunch number, spacing, and distance from photon absorber (2 mA/bunch) (after conditioning).





Dependence on RFA position and bunch spacing

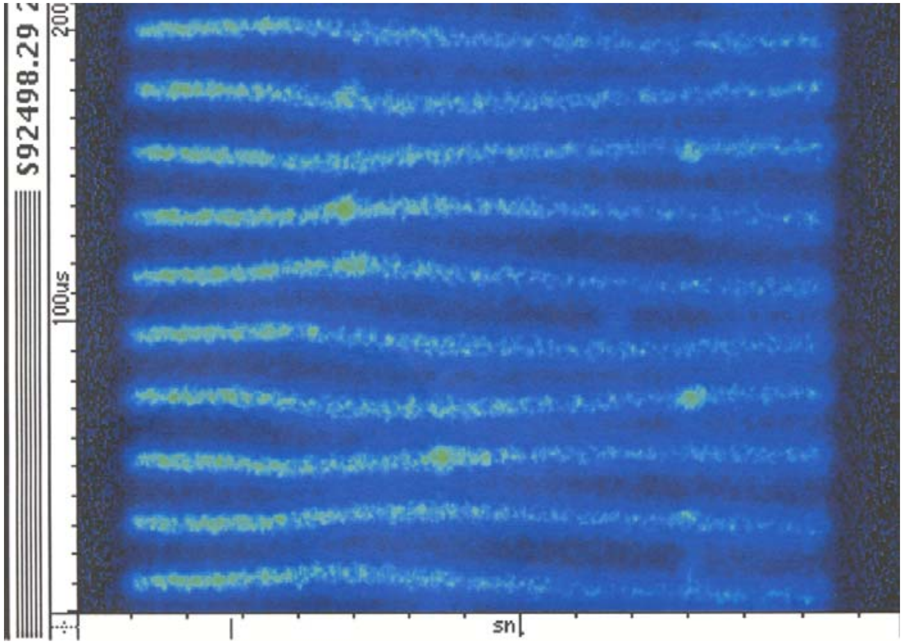




- 10 bunches, 20 mA
- Det 1,2 likely dominated by photoelectrons
- Det 6-8 similar multipacting response
- Det 3-5 current much smaller (multipacting supressed?)
- Det 9-10 current small (smaller radiation fan)

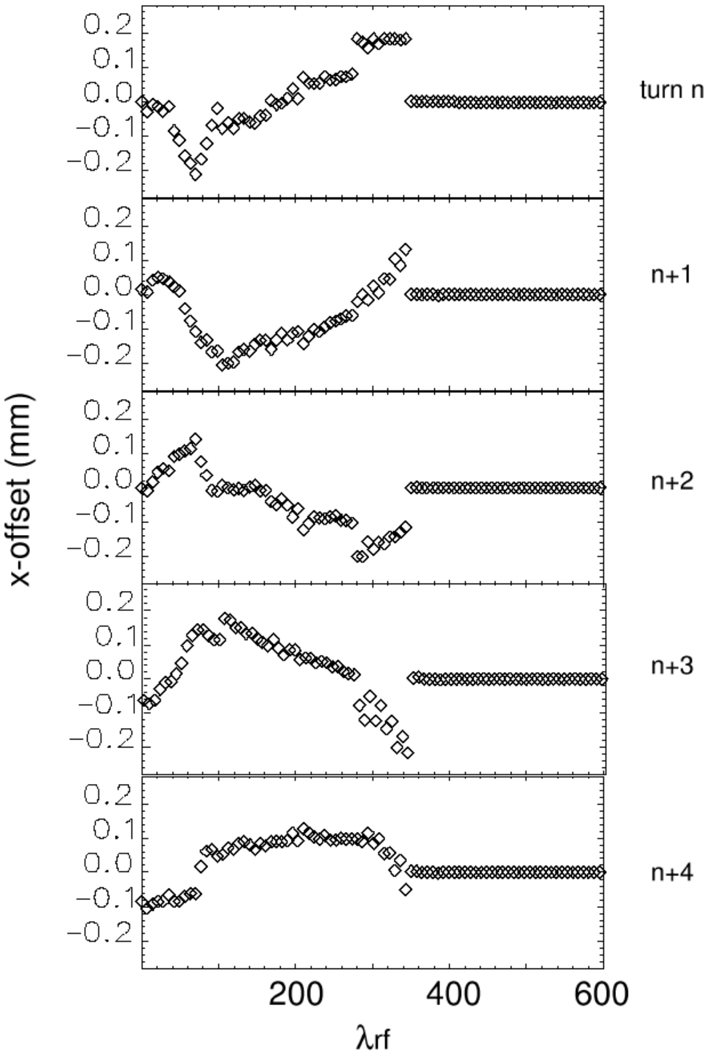
APS electron-cloud driven instability, e+

Acquired near end (9/28/1998) of positron beam operation: max e-cloud amplification with 7 λ_{rf} bunch spacing (head of bunch trains at left)



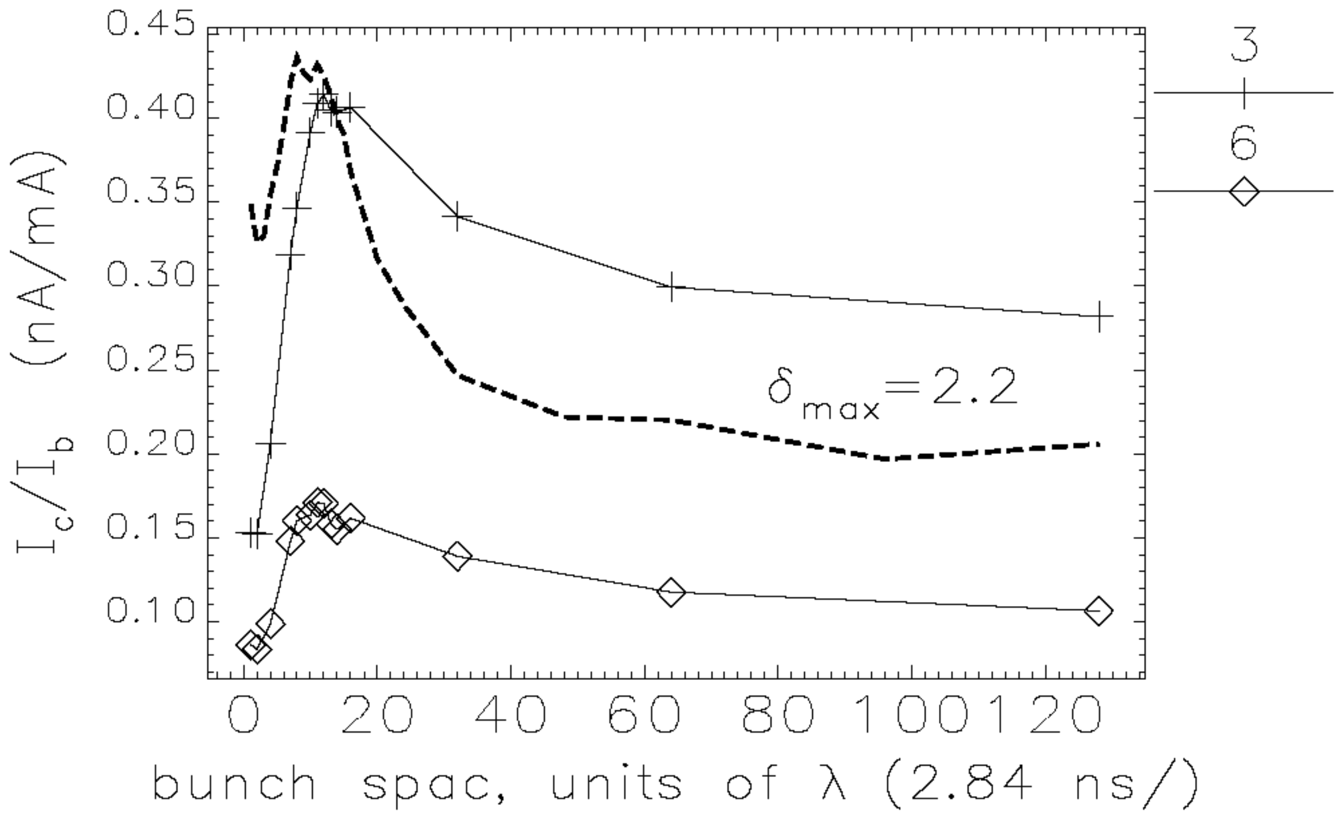
60 bunches, 96 mA, streak camera, x-t

50 bunches, 90 mA, stripline Δx



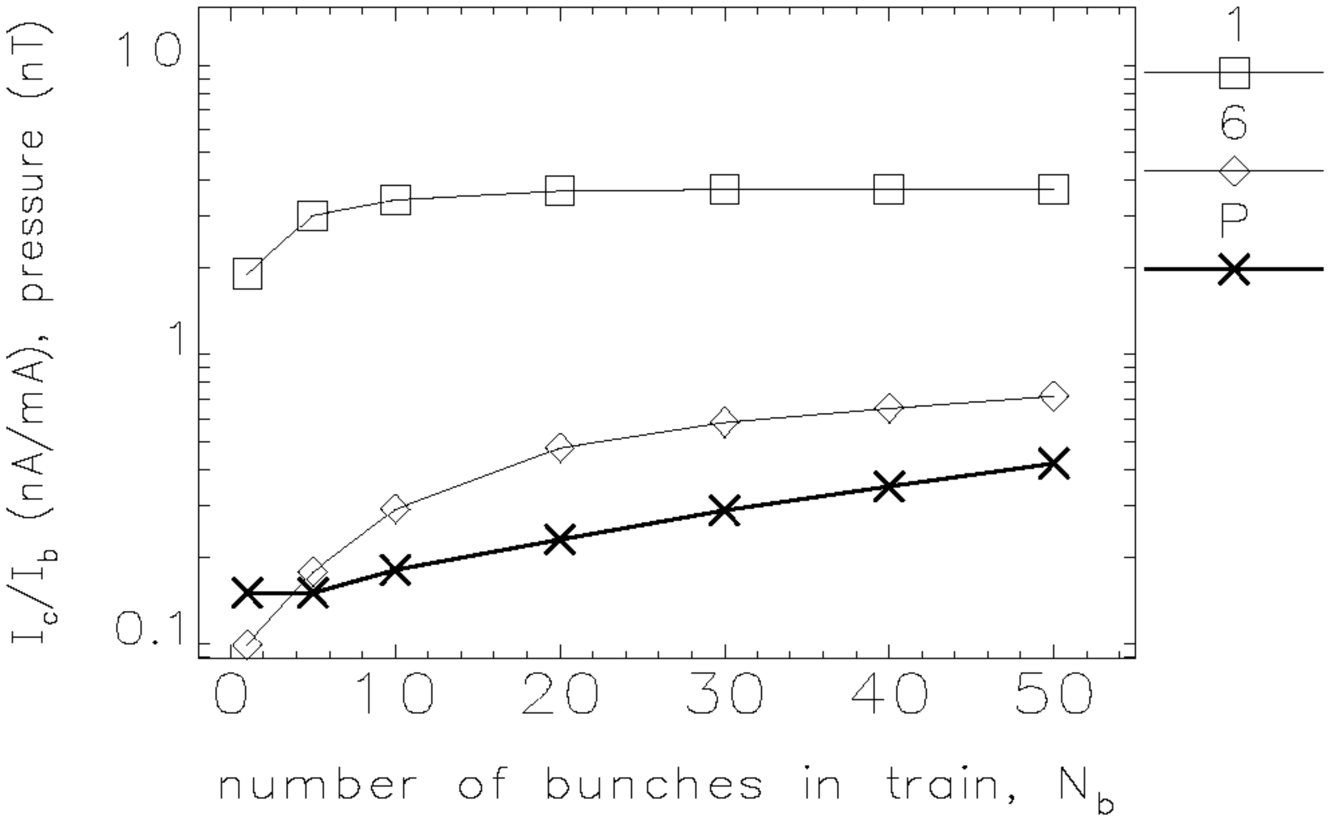
K.C. Harkay, R.A. Rosenberg, PRST-AB 6, 034402 (2003)

Electron beam: weak multipacting effect



Measured (RFA 3,6) and simulated (dashed line) wall current vs. bunch spacing. The peak appears at 30-ns bunch spacing (11 λ). There is additional conditioning of 100 Ah for these data compared to positron data, main plot.

Electron beam: weak cloud buildup



- Measured wall current as a function of bunch train length, 30 ns spacing. The signal near EA (RFA 1) is always higher than RFA 6.
- No anomalous pressure rise is observed for these uniformly-spaced bunch trains.
- **Pressure rise and beam lifetime degradation was observed for certain 100-mA fill patterns, but quickly conditioned away**

Electron beam: energy distributions

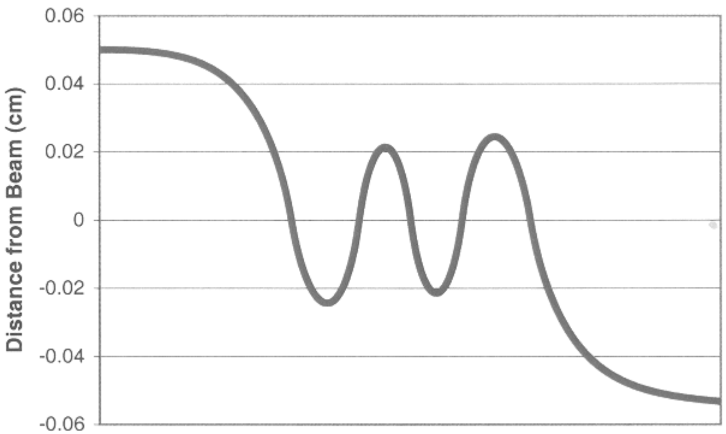
To be plotted…

Summary: RFA data vs. simulations

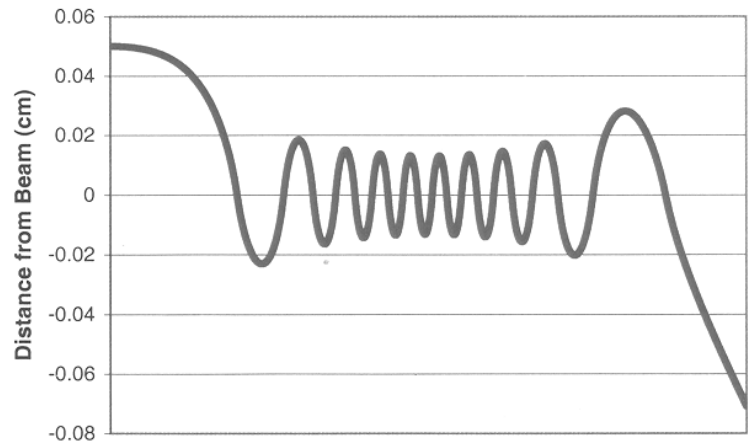
		Positrons RFA (det6)	Positrons posinst8	Electrons RFA	Electrons posinst8
Bunch spacing at max current	λ_{rf}	7	7	11-12	9
Max normalized collector current	nA/mA	3.0 (broad) 5.1 (sharp)	2.9 (broad) (no sharp)	0.17 (det6) 0.4 (det3)	0.44
Width broad peak (vs. bunch spacing)	λ_{rf}	10	10	100	30
Ave. collision energy	eV	88	111	8	151

Used posinst params for conditioned chamber (matched to positrons) to model electron beam. Electron beam operation 4-6 wks after shutdown to switch modes (no chambers vented).

Impulse kick not valid near beam; but nkick =1 vs. 21 similar ave wall collision rate



bunch current 2 mA



10 mA

For 40-ps-long (12-mm) positron APS bunches, cloud electrons that are within about 500 μm of the beam center oscillate several times in the bunch potential (calculations are for vertical plane). The transverse rms beam size is 350 μm (horizontal) and 50 μm (vertical).

[Courtesy L. Loiacono, from K. Harkay, R. Rosenberg, L. Loiacono, ICFA BD Newsletter 33, Apr 2004]

Summary

- Measured electron cloud distribution in APS for bunch trains vs current; positron and electron beam
- Modeling benchmark focused on positron data, det6: near center of drift, far from end absorber
- EC generation depends strongly on true secondary distribution $f_{ts}(E)$ and rediffused components
- Wall conditioning effect: δ_{max} started at 3.1, conditioned to 2.2
- Wall current, collision energy distributions, broad multipacting resonance peak match model well at det6, reasonable surface parameters for Aluminum

Open issues

- Never able to explain (model) sharp resonance peak
- Detector position-dependence rich in physics, not yet modeled to satisfaction (tried case w/o antechamber, inconclusive)
- What predicts CB instability threshold? (more than EC density)
- Weak multipacting effect for electron beam reproduced qualitatively, but details not understood
- Energy distribution different for positrons vs electron beams, confirms expected beam-cloud dynamics. Modeling results not yet understood (photoelectron component? nkicks?)