

SIMULATIONS OF ELECTRON CLOUD BUILD-UP and SATURATION IN THE APS

K. C. HARKAY and R. A. ROSENBERG, ANL

M. A. FURMAN and M. PIVI, LBNL

The submitted manuscript has been created by the University of Chicago as Operator of Argonne National Laboratory ("Argonne") under Contract No. W-31-109-ENG-38 with the U.S. Department of Energy. The U.S. Government retains for itself, and others acting on its behalf, a paid-up, nonexclusive, irrevocable worldwide license in said article to reproduce, prepare derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the Government.

ECLLOUD02, CERN, April 15-18, 2002

Work supported by the U.S. Department of Energy under contract DE-AC03-76SF00098 and by the Spallation Neutron Source project (ORNL).

OUTLINE

- INTRODUCTION
- REVIEW APS EXPERIMENTAL RESULTS
- REVIEW SIMULATION OF BIM (PAC01)
- SIMULATION OF EC GROWTH & SATURATION
- CONCLUSIONS, FUTURE WORK

INTRODUCTION

In studies with **positron** beams in the **Advanced Photon Source**, a **dramatic amplification (beam-induced multipacting)** was observed in the electron cloud (EC) for certain bunch current and bunch spacings.

A **horizontal coupled-bunch instability** observed in e+ beam last hours of run, for BIM conditions, above a threshold bunch current; not observed in e- beam.

In previous **modeling** (PAC01), found **qualitative agreement with observed BIM** condition using reasonable values for the secondary electron yield (δ_{SE}) parameters, including the **SE energy distribution**.

Here, we **model and discuss the build-up and saturation process** observed over long bunch trains at the resonance condition.

We search for a **correlation between the EC density and coupled-bunch instability threshold**.

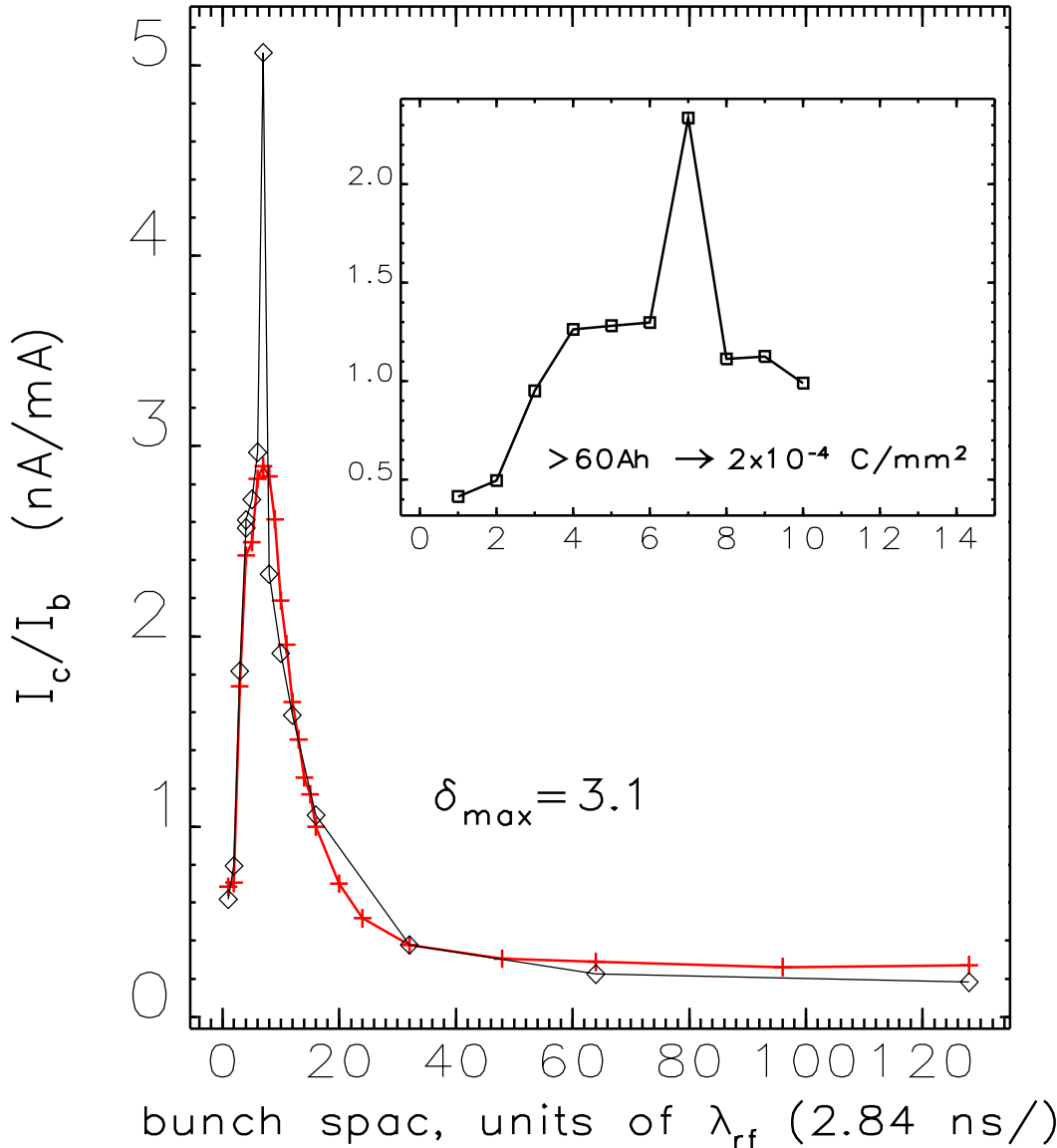
Understanding this saturation mechanism in more detail may have implications for **predicting** electron cloud amplification, instability, and resonance **conditions in future rings**.

SIMULATION PARAMETERS FOR APS (posint8)

	PAC01		ELOUD02	
Circumference	1104	m		
Harmonic no.	1296			
Rf frequency	351.93	MHz		
Bunch population	4.6×10^{10}	(2 mA)		
rms bunch length	5	mm		
Transverse rms sizes	300, 50	μm		
Vacuum chamber semiaxes	4.25, 2.1	cm		
Antechamber slot height	1	cm		
Eff. photoelectron yield	0.1			
No. of photons per e+	0.07			
SE params: δ_{max} ; E_{max}	3.3; 280	eV	3.0 & 2.2; 300	eV
Number of kicks over bunch	5		11	

MEASURED AND SIMULATED ELECTRON DETECTOR CURRENT for BIM in APS

10 e+ bunches; 2 mA/bunch (4.6×10^{10} e+/bunch); vary bunch spacing



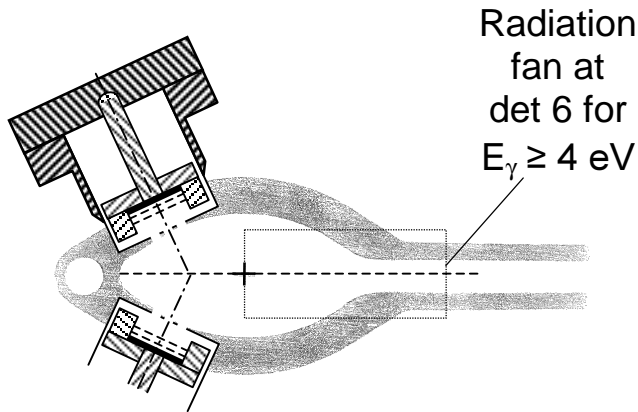
position of peak in modeled I_c/I_b vs bunch spacing (red) **very sensitive** to secondary electron energy spectrum, especially mean energy

Note: User operation with e+ beam typically at $1 \lambda_{rf}$ or $54 \lambda_{rf}$ bunch spacing; never observed BIM until dedicated EC study

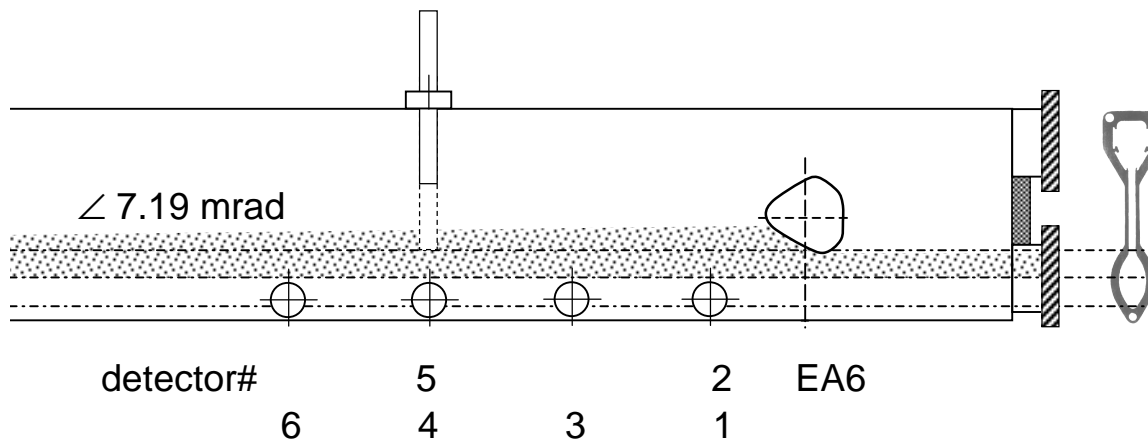
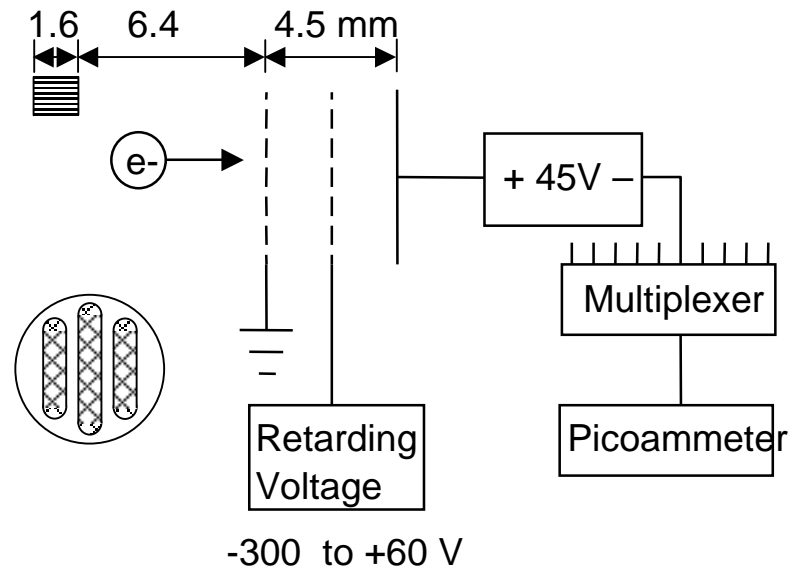
PAC01 results, slightly modified: $\delta_{max} = 3.1$; simulation result **scaled to account for total transmission attenuation of 0.5** (measured RFA grid transmission = 0.8; calculated vacuum penetration transmission = 0.6)

Insert shows normalized EC signal after >60 Ah operation; equivalent surface electron dose shown. **EC build-up data acquired after ~100 Ah.**

ANL RETARDING FIELD ANALYZER (RFA) (Rosenberg)



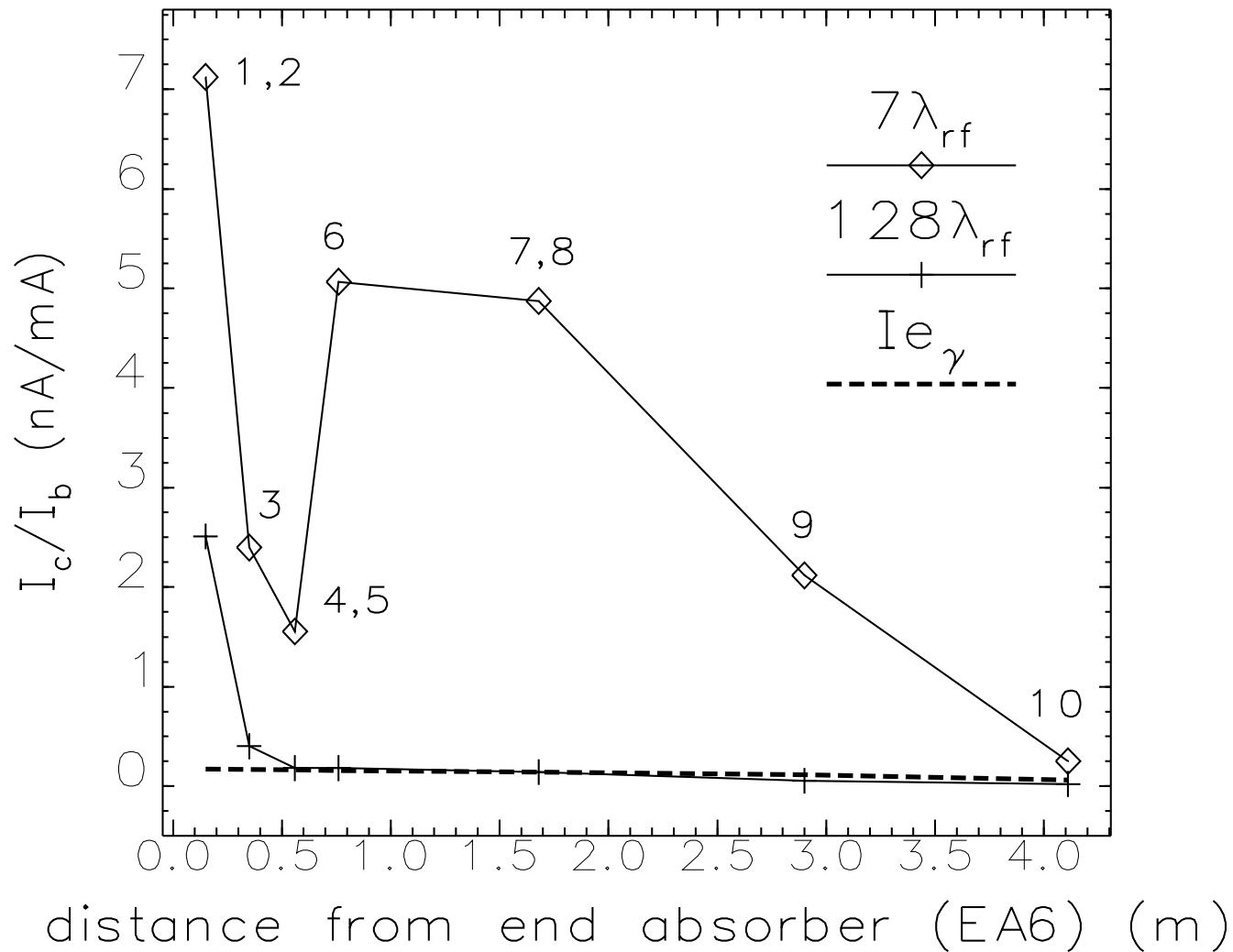
mounting on APS Aluminum chamber, cross-sectional view (42 x 21 mm half-dim)



mounting on 5-m-long chamber, top view, showing radiation fan from downstream bending magnet

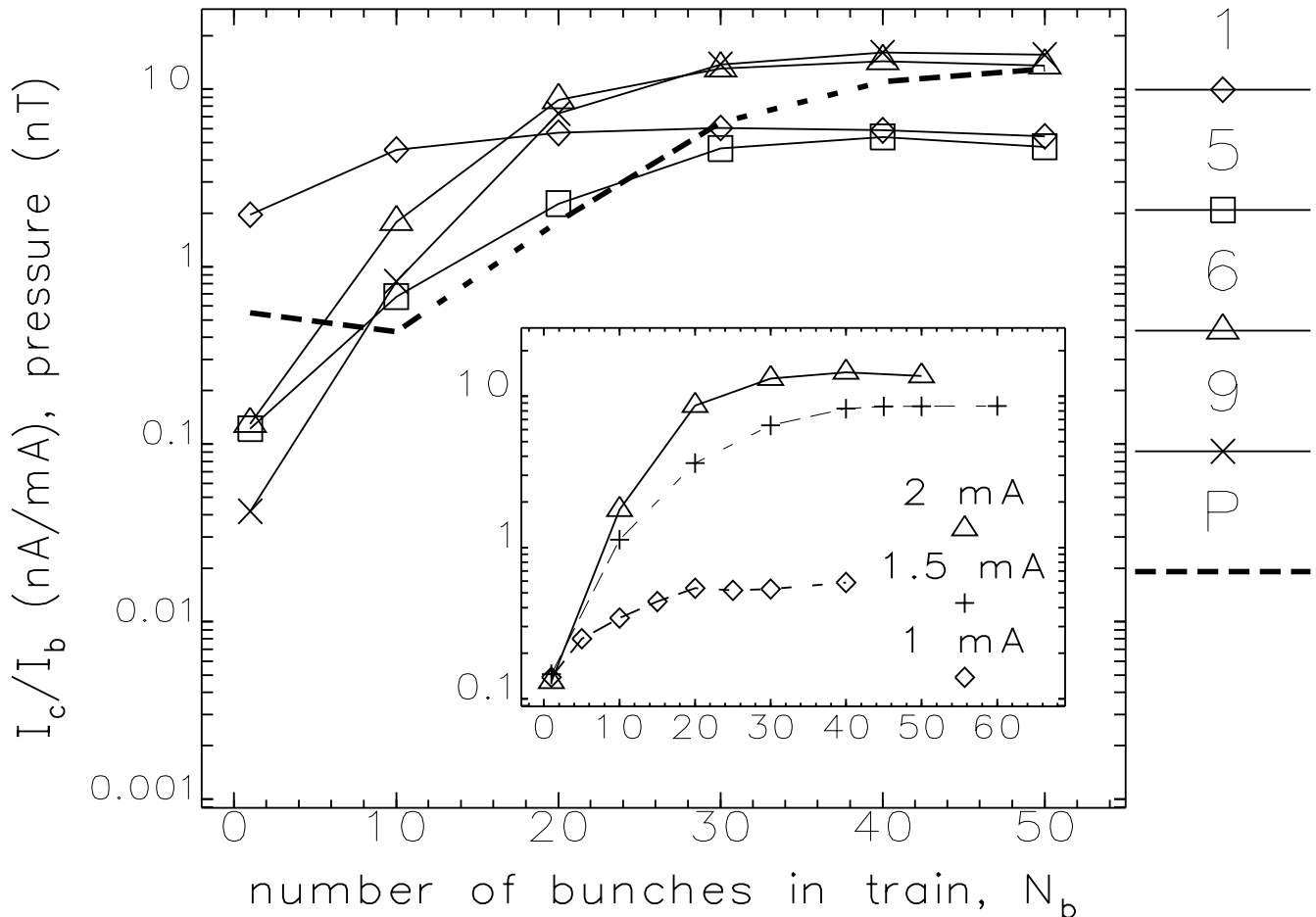
DEPENDENCE OF EC SIGNAL on DETECTOR LOCATION

(photoelectron current, I_{e_γ} , also shown (arbitrary units))



MEASURED EC BUILD-UP and SATURATION OVER BUNCH TRAIN

main plot: 2 mA/bunch; inset: det 6 only



Estimate cloud density given flux at wall and avg electron velocity; compared to avg beam density (e.g., 100 mA, 2 mA/, $\langle E_e \rangle$ 100 eV):

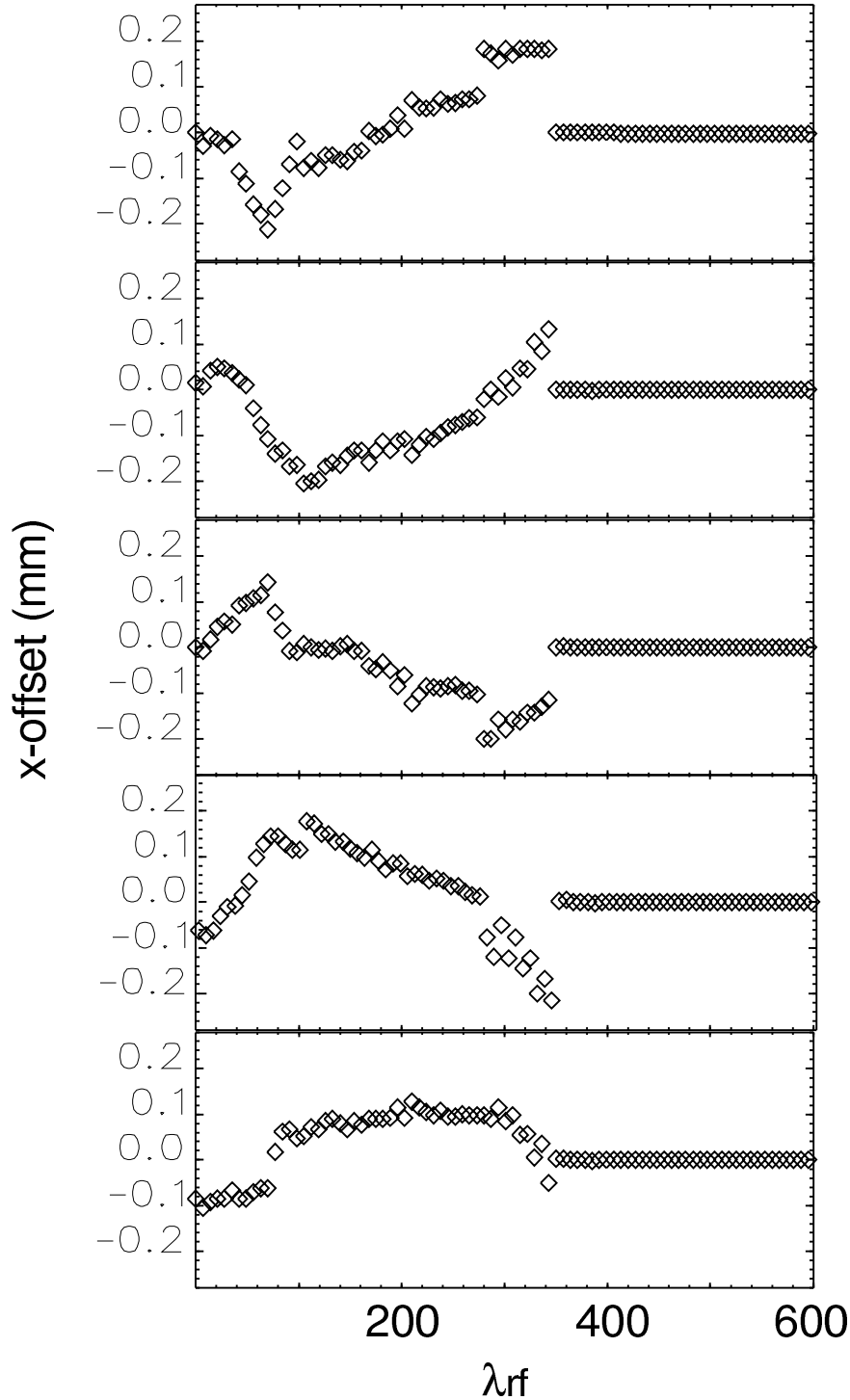
$$n_{EC} = (I_c/I_b) / \text{detArea} * I_b / e \langle v_e \rangle = 10^4 \text{ cm}^{-3}$$

$$n_{beam} = n_b / \text{chambArea} / \text{bunch sep} * \text{fill fraction} = 10^6 \text{ cm}^{-3}$$

~1% of beam density for 1.5–2 mA/; only ~0.1% for 1 mA/

Saturated cloud density varies locally by up to a factor of three

**HORIZONTAL COUPLED-BUNCH INSTABILITY OCCURS AT
EC SATURATION, e+ BEAM
(not seen with e- beam, same conditions)**



machine conditions:

$7 \lambda_{rf}$ (20 ns)
bunch spac;

~ 2 mA/bunch

x-offset data shown:

turn-by-turn BPM
histories;

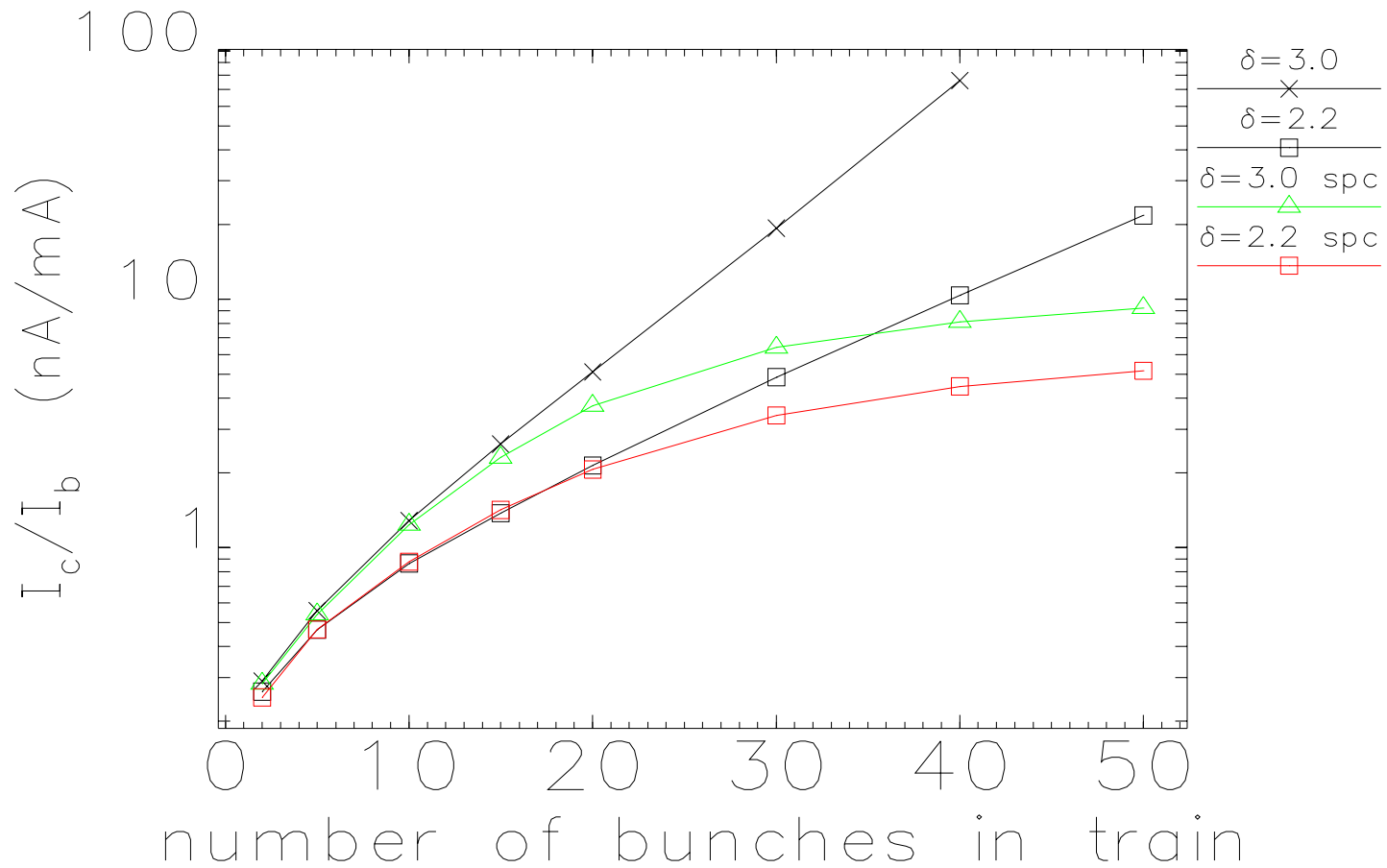
90 mA total;

50 bunches;

5 consecutive turns

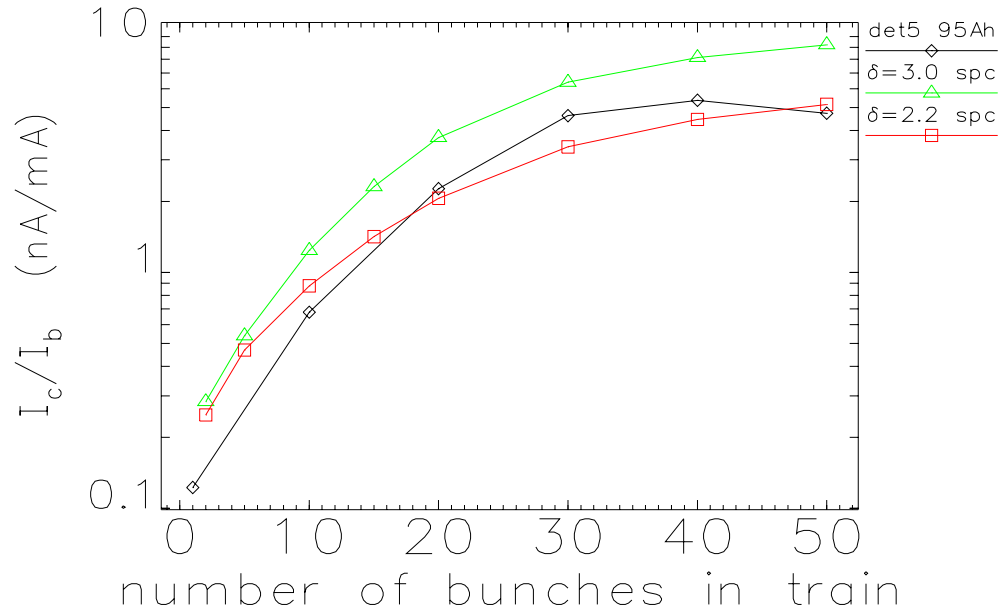
($v_x = 0.2$)

SIMULATION COMPARISON OF δ_{\max} and EFFECT OF SPACE CHARGE

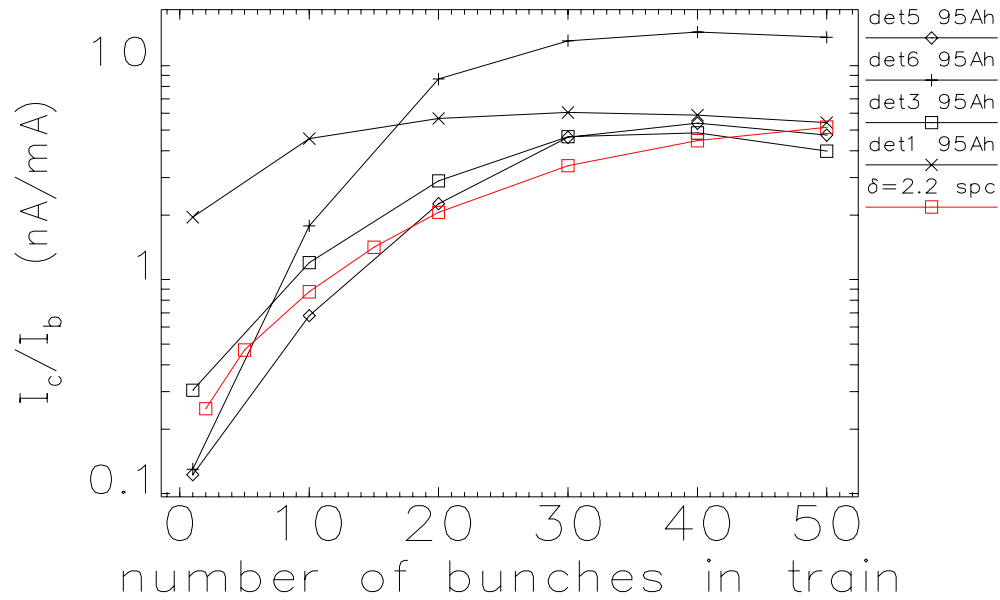


MEASURED AND SIMULATED EC DETECTOR CURRENT for BUNCH TRAIN

fit reasonably good for the best case (det 5):

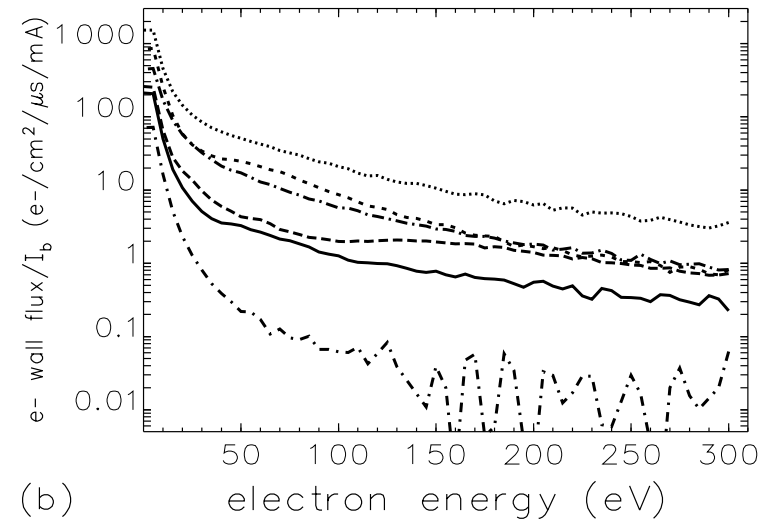
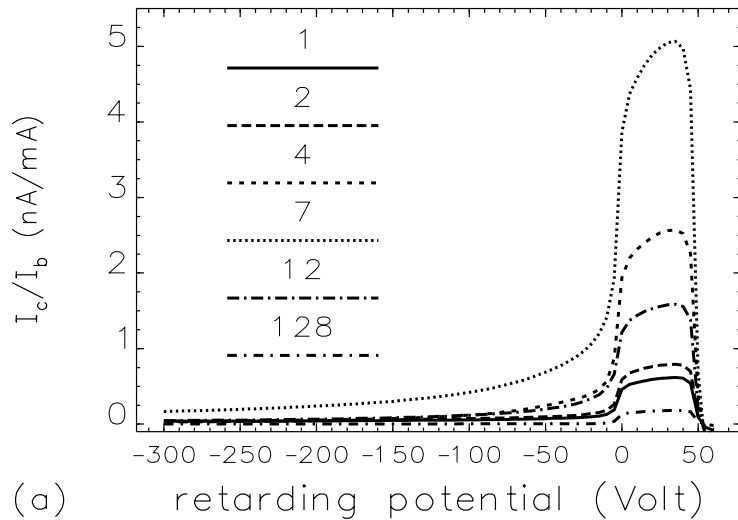


fit at other detectors marginal:



Energy distribution dependence on e+ beam operating conditions

(10 e+ bunches, constant bunch current, vary spacing – units of λ_{rf})



Low energy: good fit with Lorentzian func. (width ~ 4 eV; mean 2.5 eV)

High energy: exponential (secondary electrons through interaction with beam)

Resonant “peaks”: max amplification when “peak” near max $\delta_{SEY}(E)$

SUMMARY

OBSERVATIONS

EC amplification due to BIM observed with e+ beam, 1–3 mA/bunch *and* e- beam, 2 mA/bunch (10x smaller for latter)

Horizontal coupled-bunch instability observed with e+ beam, ~ 2 mA/bunch (4.6×10^{10} e+/bunch) at $7\text{-}\lambda_{\text{rf}}$ bunch spacing (20 ns)

Conditioning effect of chamber observed with beam operation: EC reduced by a factor of two after electron dose of 0.2 mC/mm^2

SIMULATIONS compared with EC MEASUREMENTS

Modeling bunch train where bunch spacing is varied

- matched shape and position of broad peak in collected electron current at wall vs. bunch spacing, BUT
- did not match sharp peak at optimal beam-induced multipacting conditions (positron beam, 20-ns bunch spacing, 2 mA/bunch)
- comparison *very sensitive* to secondary electron parameters, especially *energy spectrum*

Modeling build-up of EC over bunch train of varying length

- kept secondary electron parameters from previous comparison
- good qualitative comparison between measured and simulated EC build-up and saturation, BUT
- EC saturation levels measured at different locations in ring vary by up to a factor of three, while modeled saturation level varies by a factor of two for different values of δ_{max} (corresponding to conditioned and unconditioned, oxidized aluminum surfaces)
- Uncertainty in predicting local EC density approx a factor of three

QUESTIONS & WHAT IS MISSING?

How do we predict EC-induced instability threshold in future e⁺/e⁻ machines? Is average % neutralization the relevant figure-of-merit? At APS, coupled-bunch instability observed for 2 mA/bunch but not 1.5 mA/bunch, although estimated % neutralization the same for both.

Significant variations observed in locally measured EC density (e.g., near photon absorbers in APS, near stripper foil in PSR). How important is including 3-D details of chamber geometry in simulations to model local EC density variation?

Should we try to measure EC in dipoles in e⁺ machines? How does this component of the EC contribute to coupled-bunch instability (thought to be an important contribution in SPS)?

RFA-type detectors can measure EC energy spectrum of electrons striking walls *in situ*: how do we measure low energy electrons that never reach chamber walls?

REFERENCES

M. Furman, M. Pivi, K. Harkay, R. Rosenberg, "Electron-Cloud Measurements and Simulations for the APS," Proc. of 2001 PAC, 679-681 (2001)

R.A. Rosenberg and K.C. Harkay, "Design and Implementation of Simple Electron Detectors for Accelerator Diagnostics," Proc. of 2001 PAC, 2069-2071 (2001)

R.A. Rosenberg and K.C. Harkay, "A rudimentary electron energy analyzer for accelerator diagnostics," Nucl. Instrum. Methods **A453**, 507 (2000)

K.C. Harkay and R.A. Rosenberg, "Measurements of the Electron Cloud in the APS Storage Ring," Proc. of 1999 PAC, 1641-1643 (1999)

International Workshop on Two-Stream Instabilities in Particle Accelerators and Storage Rings, KEK Tsukuba, Japan, Sept 11-14, 2001

<http://conference.kek.jp/two-stream/>

8th ICFA Mini Workshop on Two-Stream Instabilities in Particle Accelerators and Storage Rings, Santa Fe, NM Feb 16-18, 2000

<http://www.aps.anl.gov/conferences/icfa/two-stream.html>