ELECTRON CLOUD EFFECTS AT e+/e- MACHINES

and ELECTRON CLOUD DIAGNOSTICS

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

R. MACEK, A. BROWMAN, T.-S WANG, LANL

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INTRODUCTION

Cold, background electrons **ubiquitous** in high-intensity particle accelerators.

Amplification of electron cloud (EC) can occur under certain operating conditions, potentially giving rise to numerous effects that can **seriously degrade accelerator performance**.

Although electron cloud effects **(ECEs)** were **first observed 20 yrs ago** (CERN ISR), **in recent years**, they have been **widely observed and intensely studied** in e+/e- rings and high-energy p+ rings.

Talk will **focus on describing EC diagnostics**, which have led to an **enhanced understanding of ECEs**, in particular, details of beam-induced multipacting and cloud saturation effects.

Such **experimental results** can be used to **provide realistic limits on key input parameters for modeling efforts** and analytical calculations.

Combine EC diagnostics with standard diagnostics to separate geometric wakefield effects from electron cloud effects.

Strong potential for synergy of lessons learned at high-energy, short-bunch e+ machines for understanding ECE in p+ machines.

ELECTRON CLOUD EFFECTS

- Vacuum degradation (electron-stimulated gas desorption)
- Beam-induced multipacting
- e-p instability (coupled oscillations)
- Transverse coupled-bunch instability (electron cloud “wake”)
- Single bunch instability (“head-tail” instability); emittance blow-up (luminosity degradation)
- Electrons trapped in distributed ion pump leakage field (CESR)
- Cloud-induced noise in beam diagnostics (e.g., wire scanners)

ELECTRON CLOUD DIAGNOSTICS

Diagnostics in use

- Electrons colliding with wall (RFA – planar retarding field analyzer)
  - o DC (APS, et al.)
  - o time-resolved (PSR, et al.)
- Electrons in chamber volume
  - o electron sweeper (PSR)
- Electrons colliding with wall in dipole magnet (RFA-type, SPS)
- Infer EC from space-charge tune shift with vs. without EC

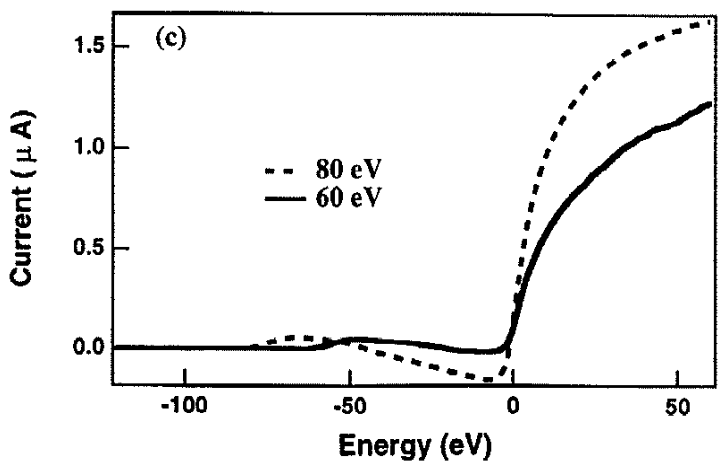
Concepts under development (incomplete list)

- Bessel Box (APS)
- Signal amplitude and phase analysis of stripline pickup pair: electron coherent transverse motion (Lambertson; plans at PSR)
- rf transmission: absorption at electron cyclotron resonance in dipole (Heifets)
- More tune/phase shifts: e.g., phase shift due to EC dielectric constant; expected shifts very small (low EC density): interferometric techniques?

ELECTRON CLOUD DIAGNOSTICS (cont.)

Benefit of shielded collector vs. readily-available striplines or BPMs

- Integrating device; differentiated signal gives EC energy distribution
- Minimum perturbation of electrons in chamber (bias on BPM changes collection length)
- Secondary e- emission (SE) from BPM surface affects measure of true flux



Signal produced from a BPM irradiated by 60-eV and 80-eV electrons as a function of bias voltage applied to the BPM (Rosenberg).

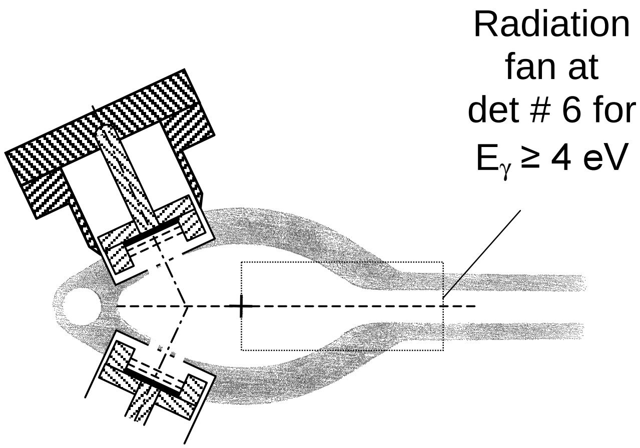
ANL-type RFA devices widely implemented or planned:

APS (ANL), PSR (LANL), BEPC (IHEP), KEKB (KEK), SPS (CERN), IPNS (ANL), AGS booster (BNL), PEP-II (SLAC)

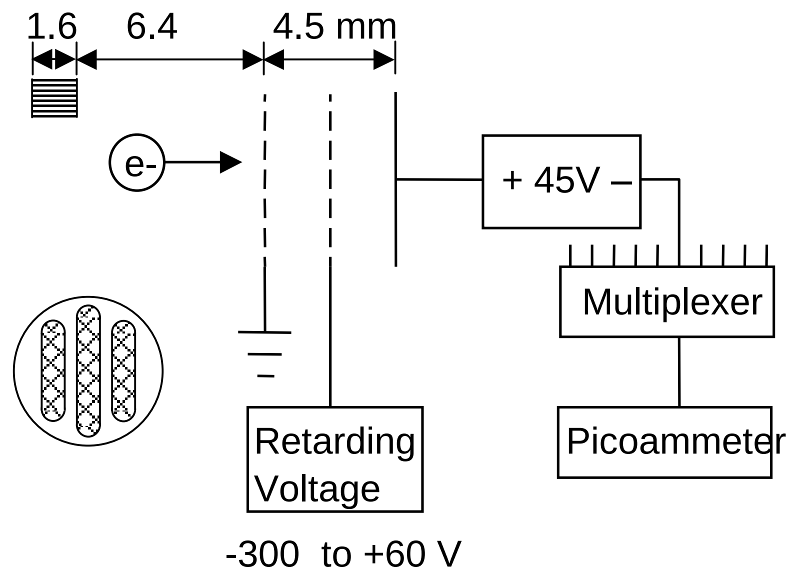
Electron cloud properties vs. cloud-beam interaction vs. electron cloud production processes

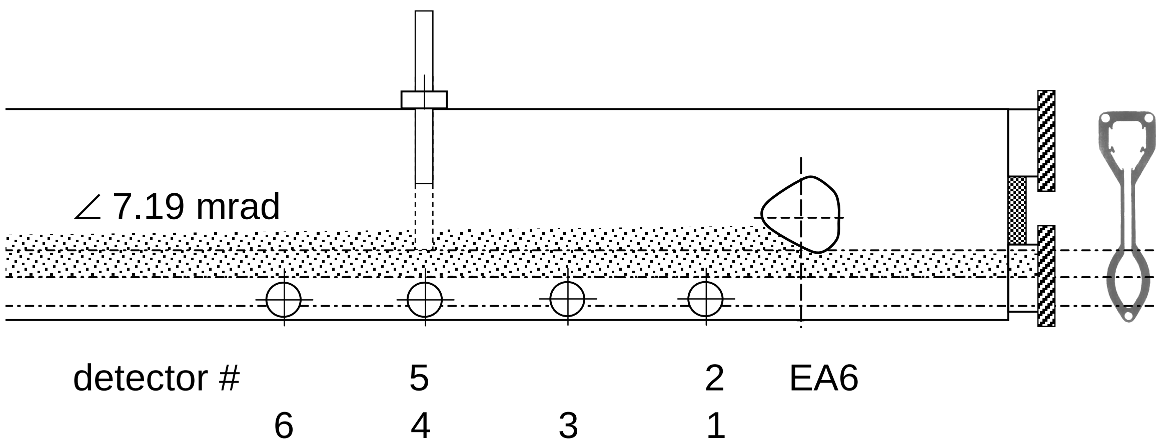
- electron flux vs. beam operating parameters
- integrated energy distributions
- separation of primary vs. secondary components of cloud production
- indirect evidence of cloud distribution near beam (avg. of energy tail)
- time structure
- electrons in gap
- locally measure (*in situ*) effect of chamber surface coatings to lower secondary yield coefficient

ANL Retarding Field Analyzer (RFA), planar geometry (Rosenberg)



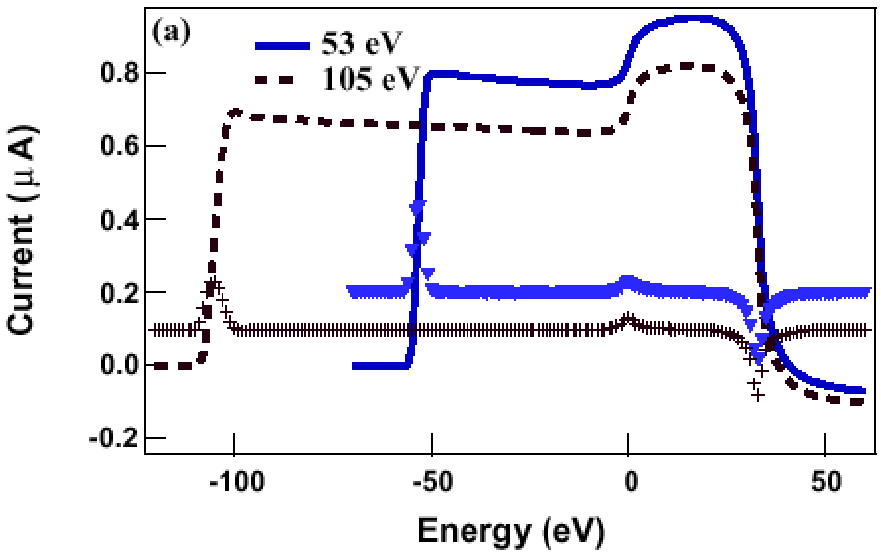
mounting on APS Aluminum chamber, cross-sectional view (42 x 21 mm half-dim)

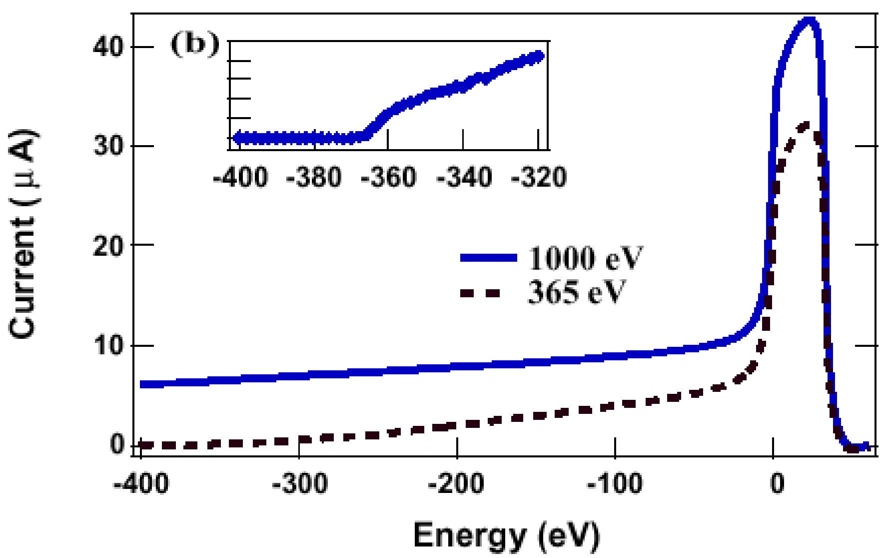




mounting on 5-m-long chamber, top view, showing radiation fan from downstream bending magnet

MEASURED RFA TRANSMISSION CURVES



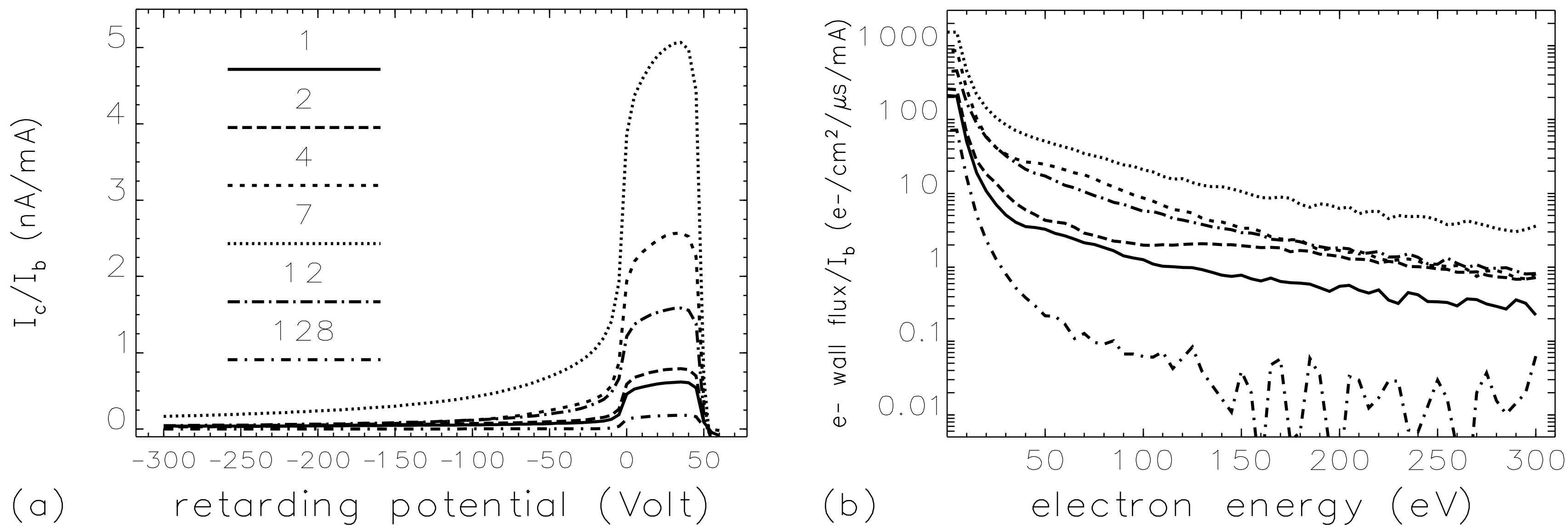


(a) Idealized case of monoenergetic electrons (from electron gun) with perpendicular incidence angle. The differentiated signals are also shown.

(b) More realistic case of monoenergetic electrons scattered from an Al target. The inset shows the differentiated signal for the 365-eV beam near the transmission threshold.

Energy distribution dependence on positron beam operating conditions

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

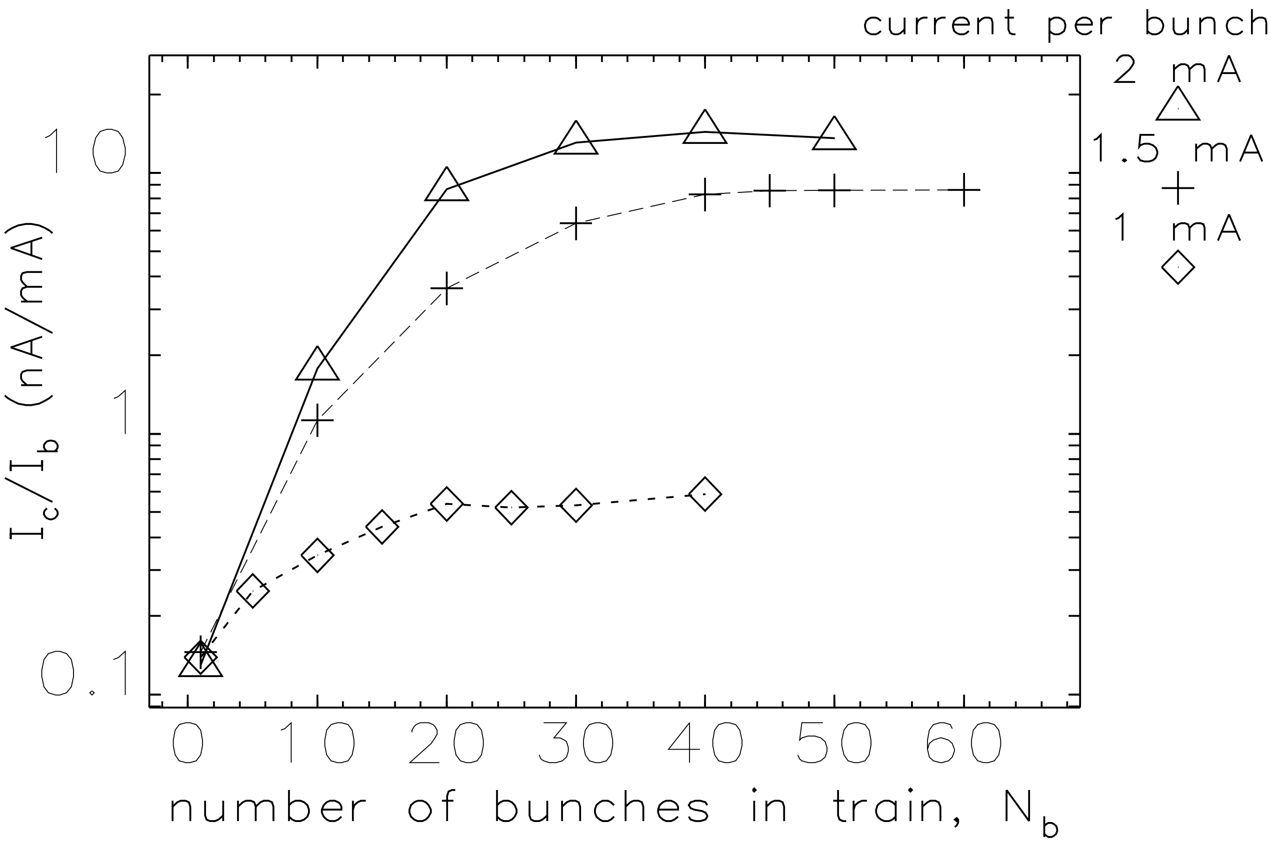


Low energy: good fit with Lorentzian func. (width ~4 eV; mean 2.5 eV)

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

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

Measured electron cloud build-up rate and saturation in APS as function of e+ bunch charge



Estimate cloud density given flux at wall and avg. electron velocity; compare to avg. beam density (e.g., at 100 mA, 2 mA/bunch):

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

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

Saturated EC density varies locally by up to a factor of three;

nonlinear with total beam current;

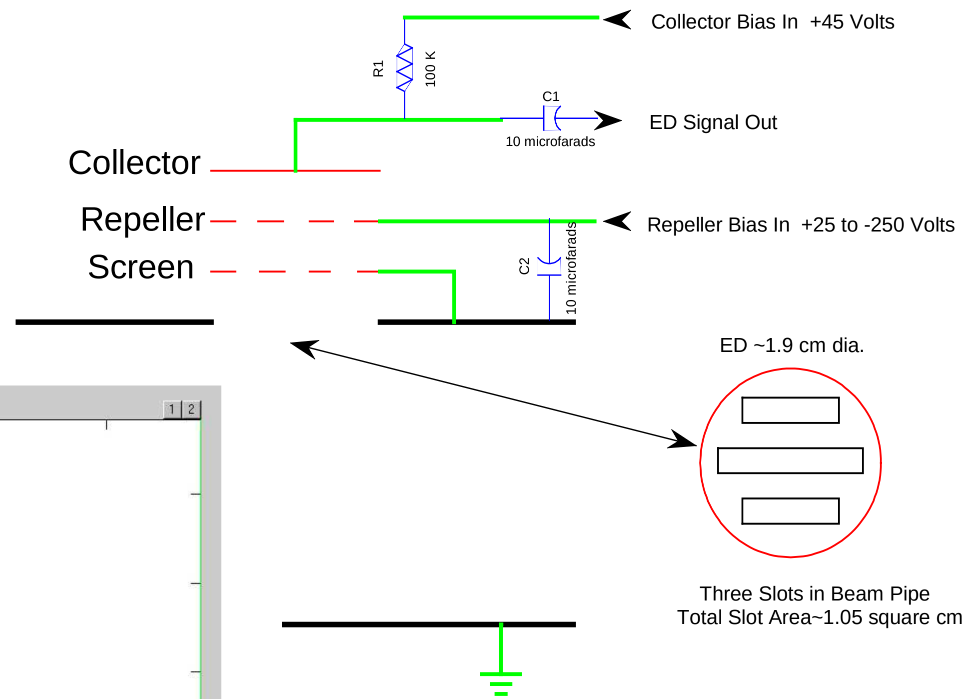
horizontal EC-induced coupled-bunch instability observed for ~2 mA/bunch

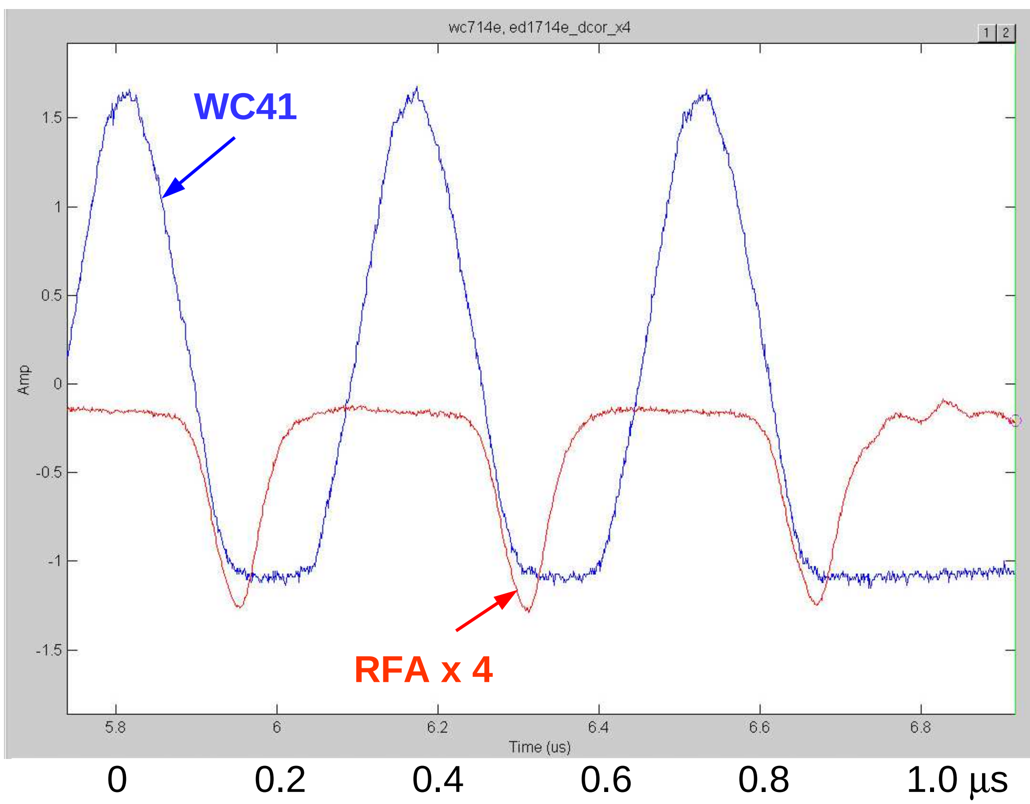
LANL fast RFA (Browman, Macek)

LANL augmentation is fast electronics

(~80 MHz) on the collector output;

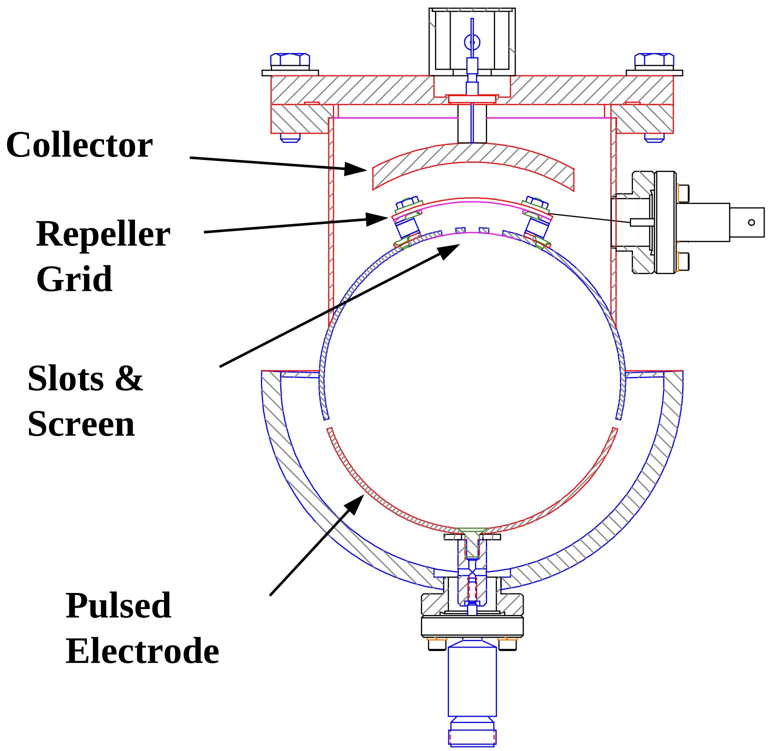
minor mods for improved AC response.

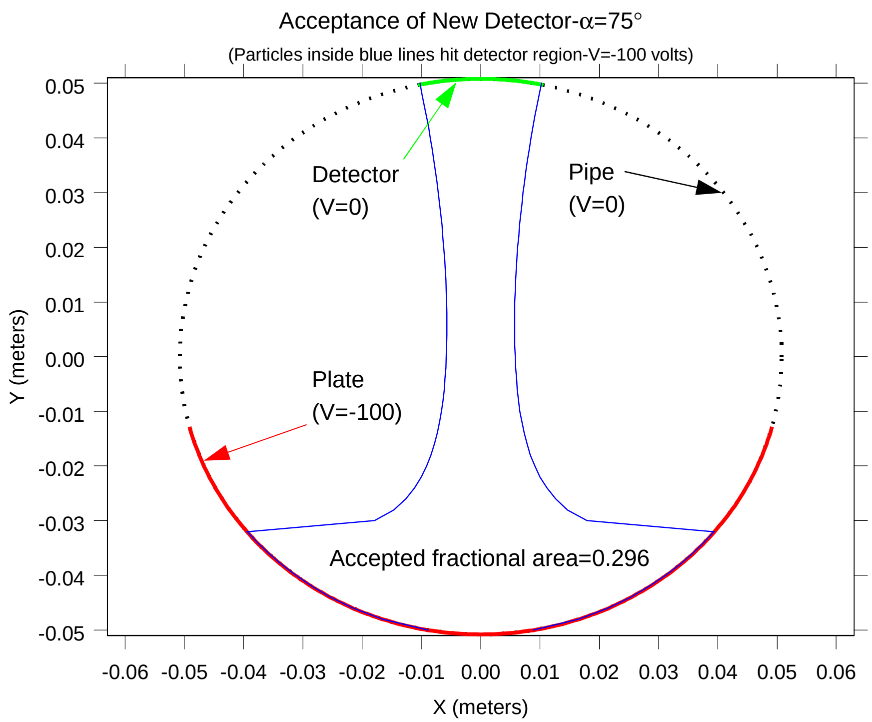




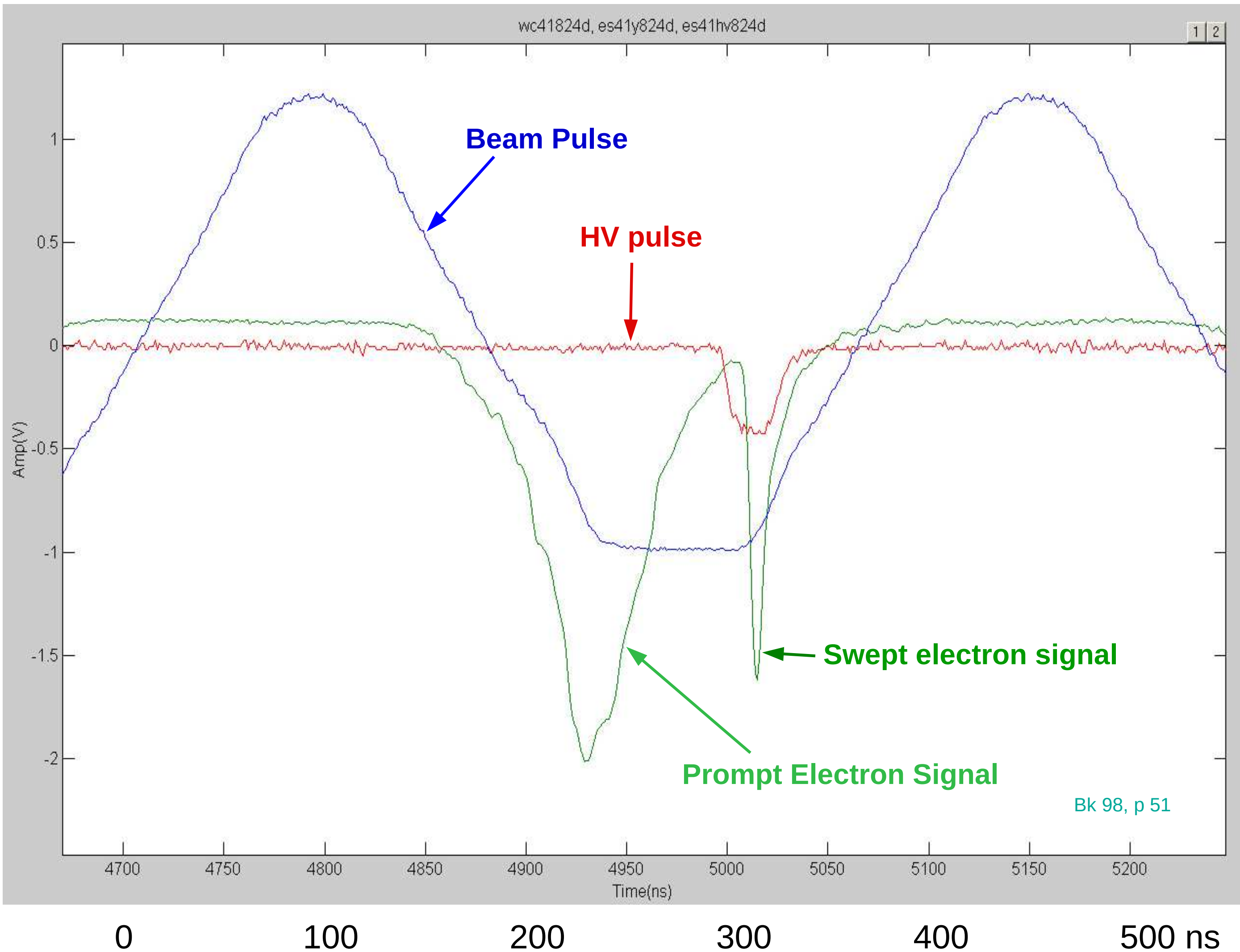
LANL Electron Sweeper (Macek, Browman, Wang)

Curved electrode (α = 75º, ~40 cm long) opposite a larger-aperture RFA (collector has ~8x higher sensitivity.) Timing of short (~20 ns) pulse on electrode selects sampling time in gap. Typical pulse height 500 V.





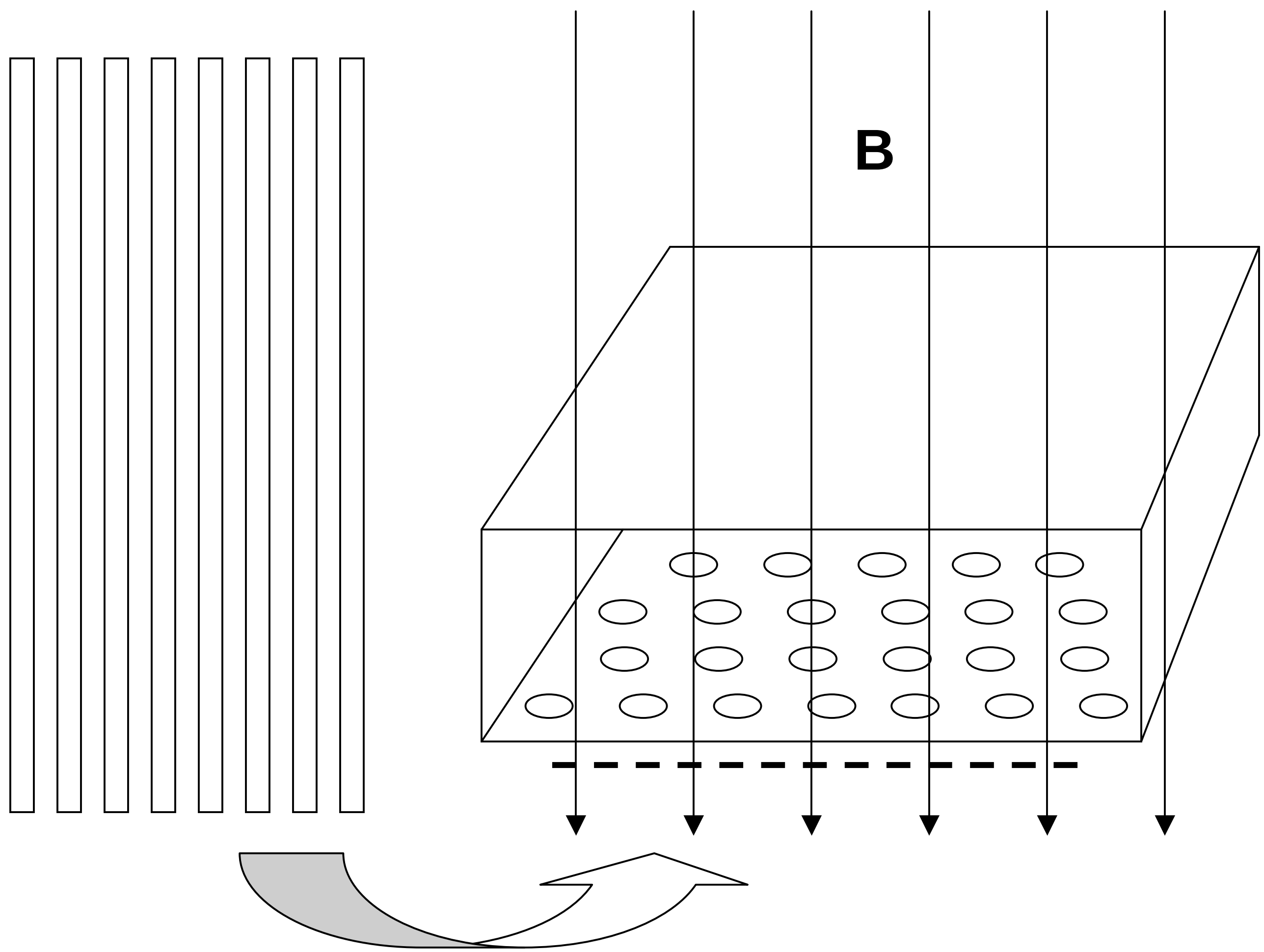
Sample electron data using electron sweeper at PSR



7.7 μC/pulse, bunch length = 280 ns, 30 ns injection notch,
signals averaged for 32 macropulses, repeller = - 25V, HV pulse = 500V

CERN SPS: Special dipole magnet and vacuum chamber installed to measure EC in dipole field
(G. Arduini, M. Jimenez et al., KEK Two-Stream Workshop, Sept 2001)

Strip collector electrodes to measure transverse EC spatial density



SUMMARY

- Electron cloud diagnostics based on planar retarding field analyzer (RFA) have been successful and broadly applicable (short-bunch e+/e- ring, long-bunch p+ ring) in studying the electron cloud properties and dynamics *in situ.*
- EC energy distribution (hitting wall) and estimate of density can be extracted from RFA – not possible with biased BPMs or collecting plates.
- Measurements show significant variation of electron cloud density around the ring; 3-D effects likely to be important in modeling.
- EC diagnostics to date limited to electrons collected at wall, or swept to wall.
- Concepts have been proposed to measure the cloud nondestructively within the vacuum chamber; some ideas under development but mostly not yet implemented.
- There is likely to be synergy between p+ rings and e+ rings in understanding the mechanisms of saturation of the electron cloud and correlation with instability threshold (space charge? % neutralization?)

REFERENCES

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http://www.aps.anl.gov/asd/physics/ecloud/PSR_top.html

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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/