Cornell University
Laboratory for Elementary-Particle Physics

Recent Electron Cloud Studies at CESRTA

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Cornell Laboratory for Accelerator-Based Sciences and Education

LCWS12

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EC Buildup R&D at CESRTA

CESR Configuration
- Damping ring layout
- 4 dedicated EC experimental regions
- Upgraded vacuum/EC instrumentation
- Energy flexibility from 1.8 to 5.3 GeV

EC Diagnostics and Mitigation
- ~30 retarding field analyzers (RFAs) deployed
- TE wave measurement capability in each experimental region
- Time-resolving shielded pickups in two experimental locations
- Four new time-resolving RFAs
- Over 20 individual mitigation studies conducted in Phase I
  - 20 custom chambers
  - In situ SEY measurements
  - Follow-on studies in preparation for Phase II extension of program

Modeling for Extrapolation to ILC Damping Ring Design
- Simulations of photon transport, including scattering (specular and diffuse) in detailed vacuum chamber models including antechambers
- EC growth: establishing physics model parameters for EC growth modeling codes (POSINST, ECLOUD)

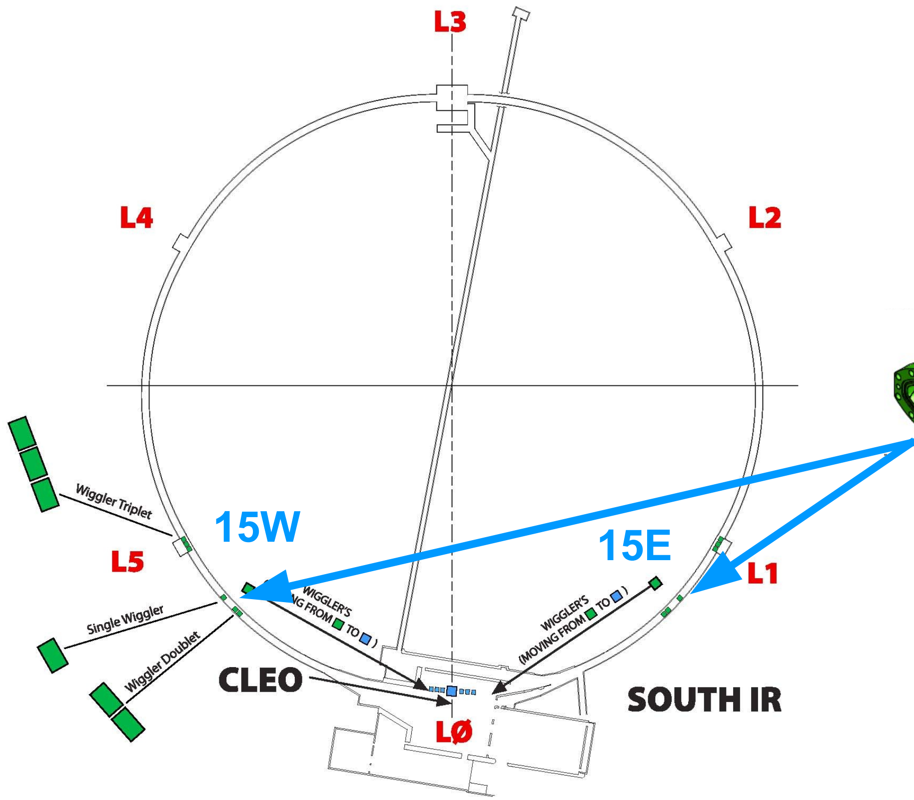
EC Buildup Detectors at CESRTA

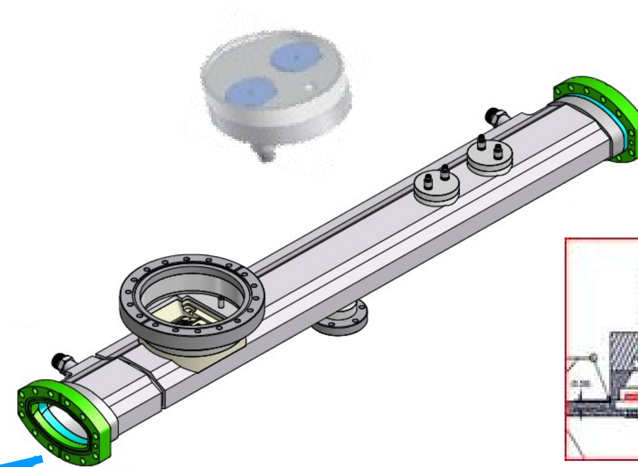
L3 Electron cloud experimental region

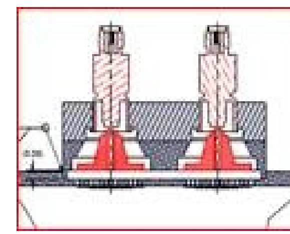
PEP-II EC Hardware: Chicane, in situ SEY station
Four time-resolving RFA's
Field-free and quadrupole diagnostic chambers

New electron cloud experimental regions in arcs (after 6 wigglers moved to L0 straight)

Locations for collaborator experimental vacuum chambers equipped with RFAs and shielded pickup detectors





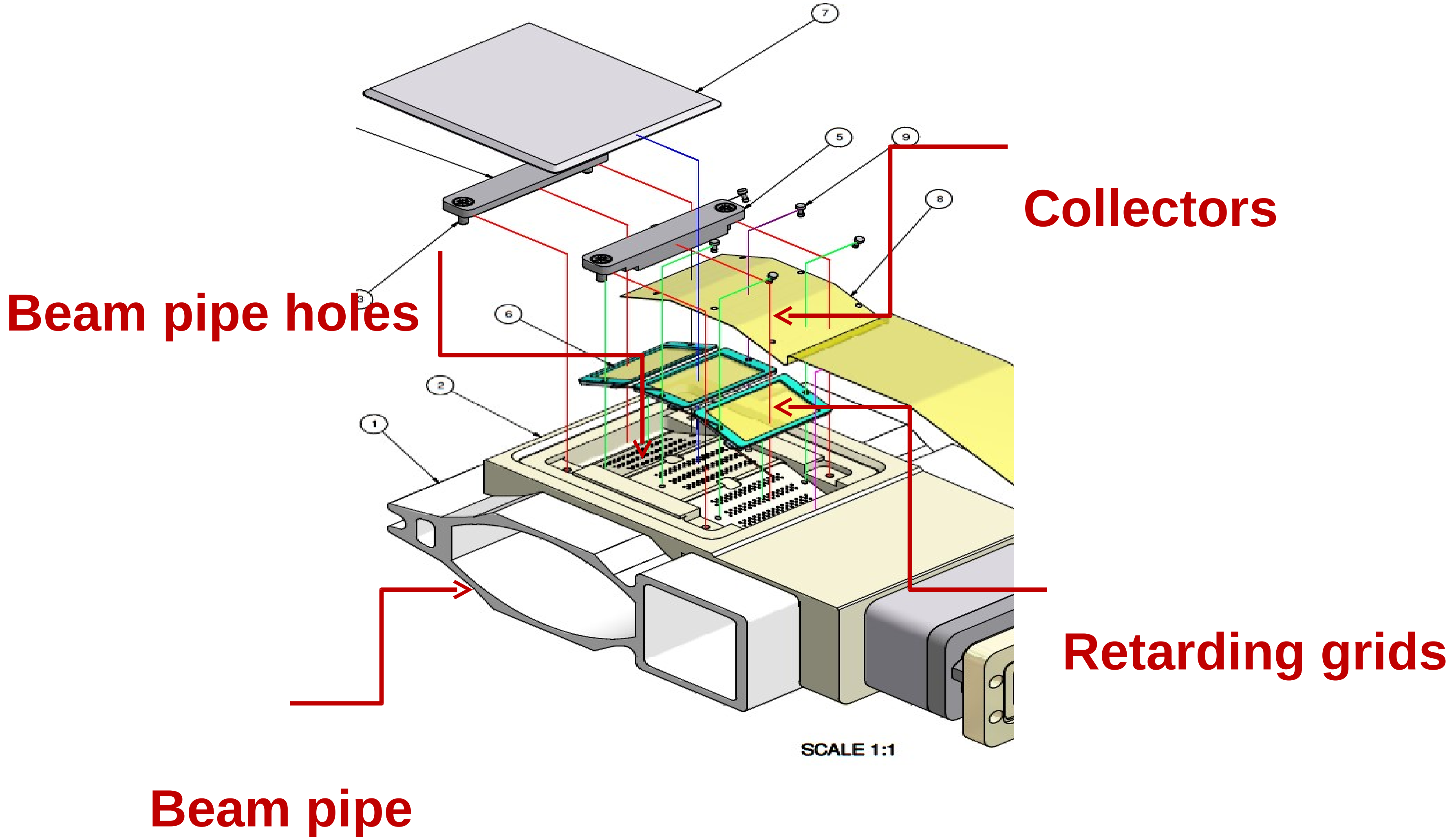


30 RFA's in field-free regions, dipoles, quadrupoles, and wigglers

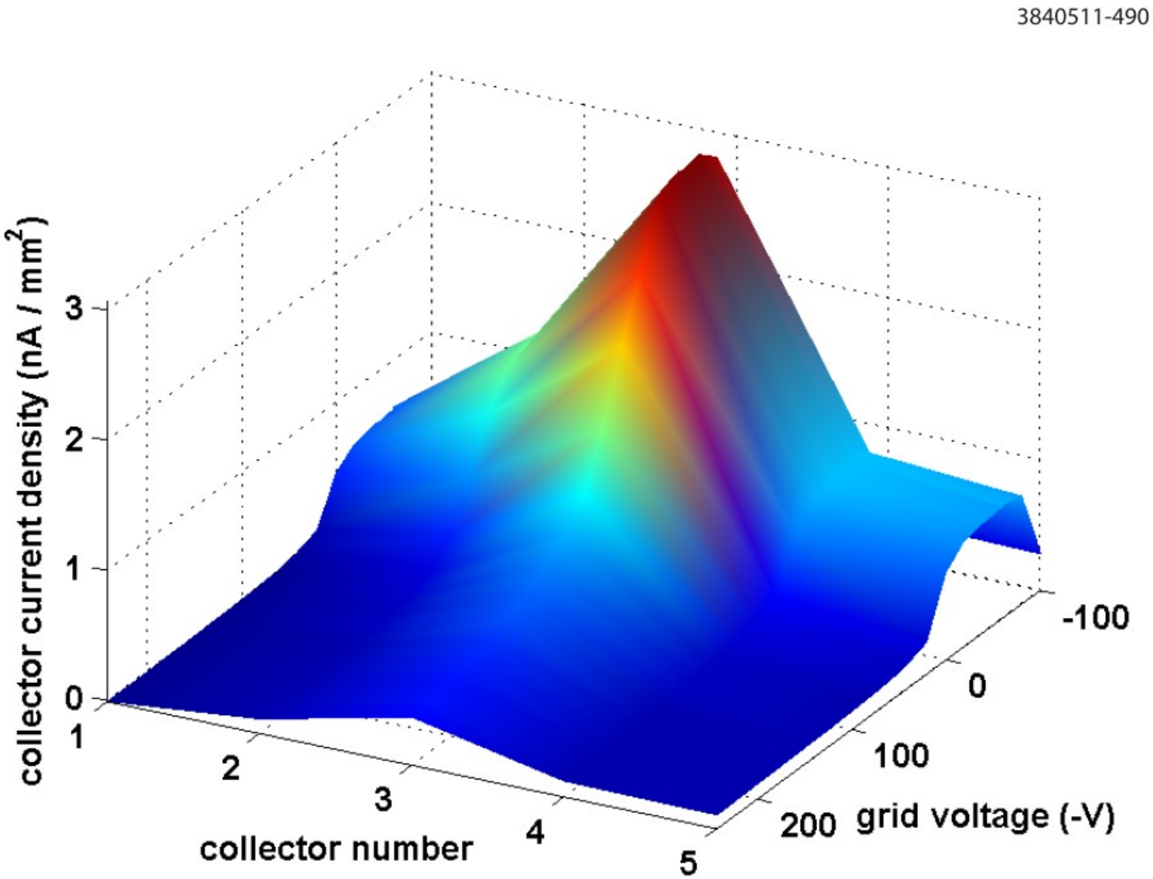
Custom vacuum chambers with RFAs and shielded pickup detectors

Uncoated aluminum, and TiN, amorphous carbon, diamond-like carbon coatings

CESRTA RFA Design



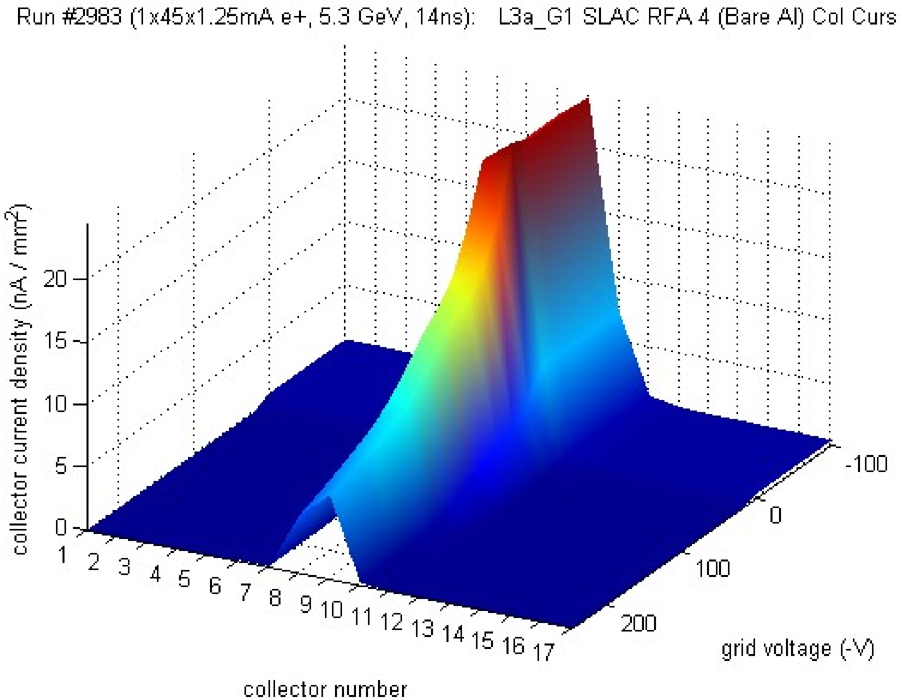
RFA Measurements: Field-free Regions



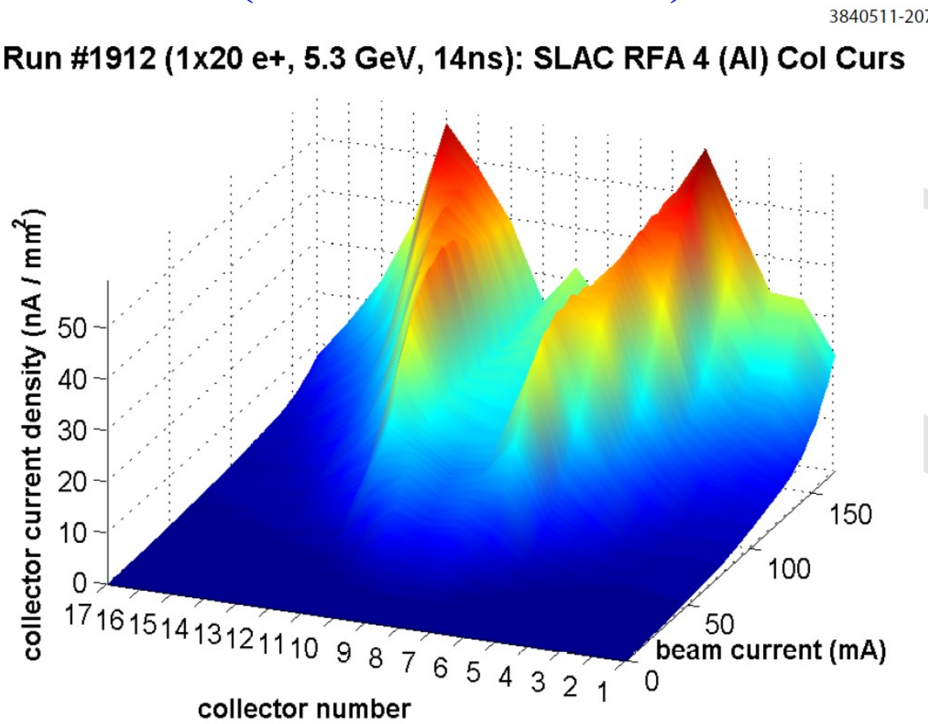
Collector steady-state current density vs retarding voltage
(Cu chamber, I_{beam} = 56 mA)

RFA Measurements: Dipole Field

Collector current density vs retarding voltage (1.25 mA / bunch)

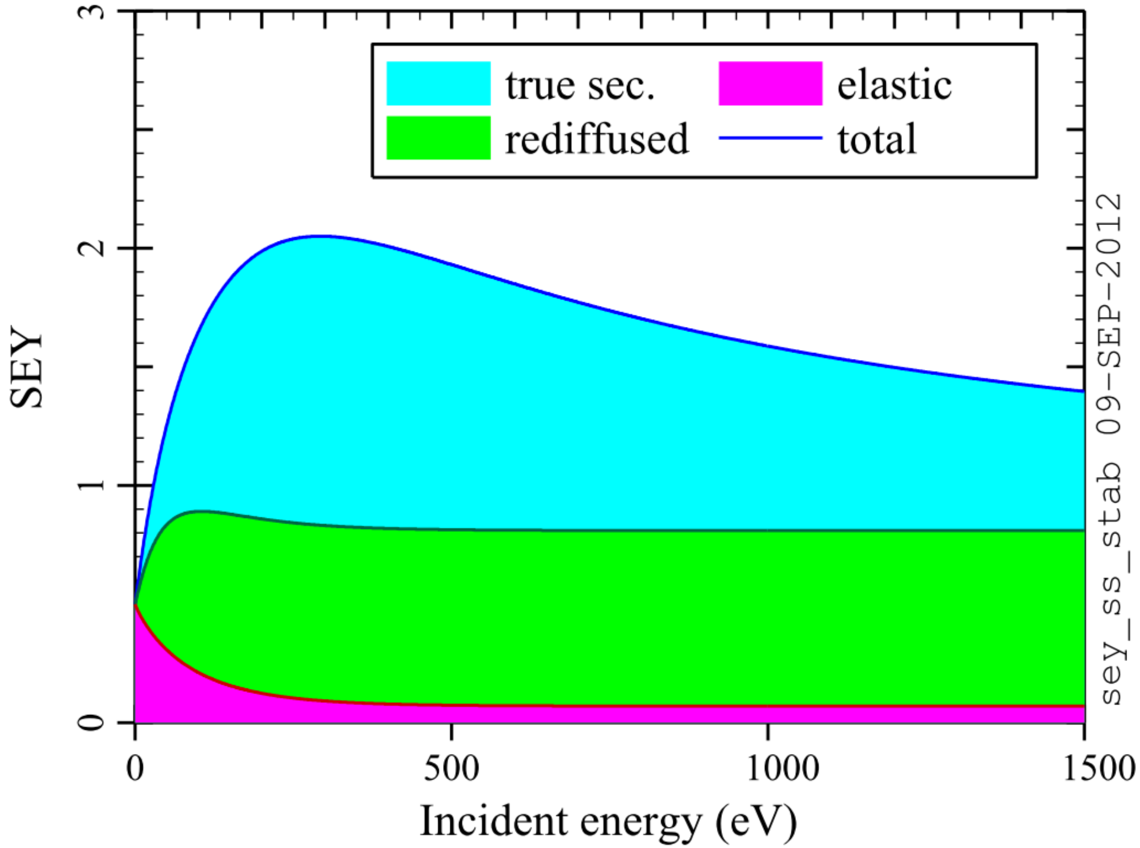


Collector current density vs bunch current (1.25 -- 8 mA / bunch)



The RFA signal is sensitive to cloud photoelectrons and secondary electrons produced on the vacuum chamber wall near the vertical plane containing the beam. At high bunch current the electrons are accelerated to energies greater than the secondary yield curve maximum, resulting in the central depletion zone shown. The cloud splits into two vertical bands.

Secondary Electron Emission Model

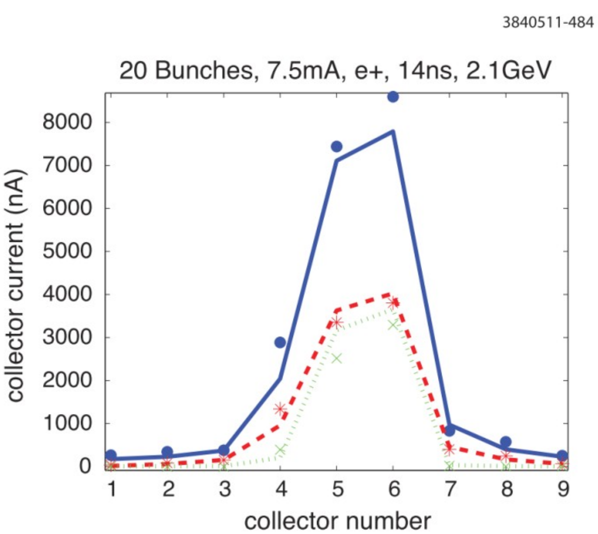


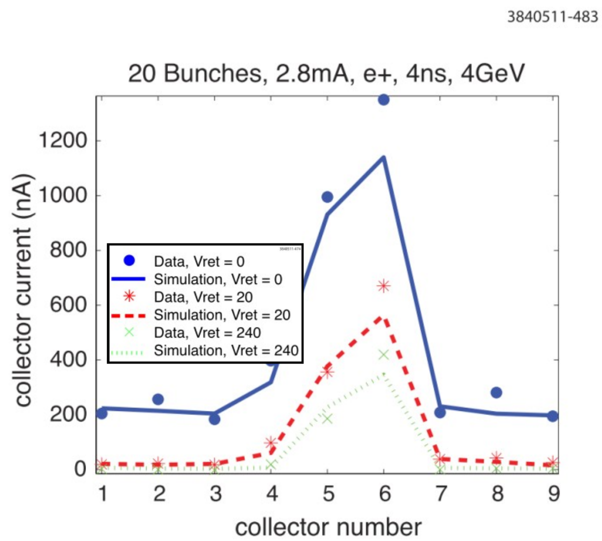
The three secondary electron yield processes differ in their dependence on incident energy and produce electrons of differing kinetic energy distributions. The relative rates of these secondary emission processes depend on the vacuum chamber surface properties such as coating, roughness, grooves, as well as on beam conditioning. Determination of these model parameters is critical for predicting performance limitations for future machines.

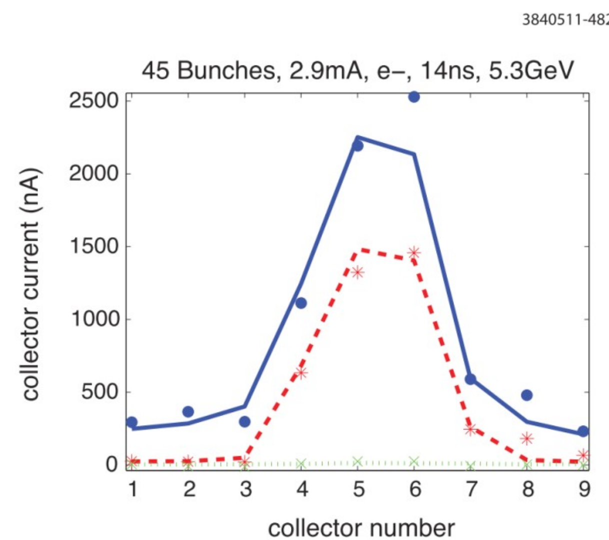
Drift Region RFA Data vs Simulation

J.R. Calvey et al, ECLOUD10, PAC11, IPAC11

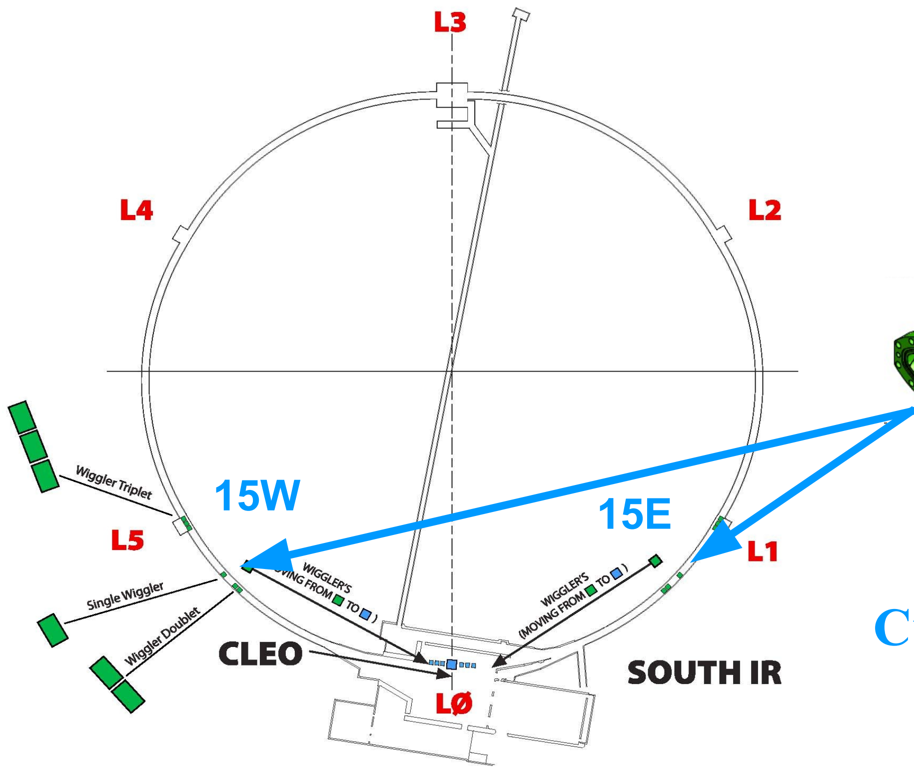
- **RFA measurements provide data for validation of models for electron cloud build-up**
- **Models require parameters describing surface phenomena: photon absorption site distributions (provided by synchrotron photon tracking code Synrad3D), photoelectron production, and secondary electron emission**

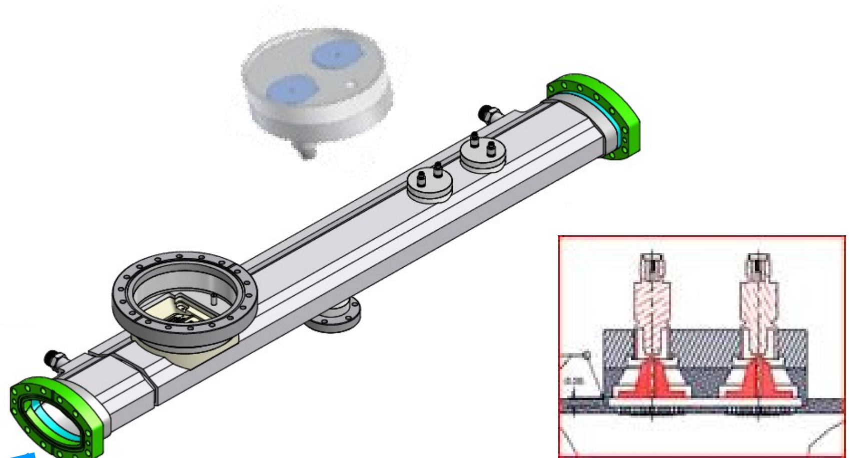






Measurements of the Time Dependence of Cloud Buildup Using Shielded Pickups

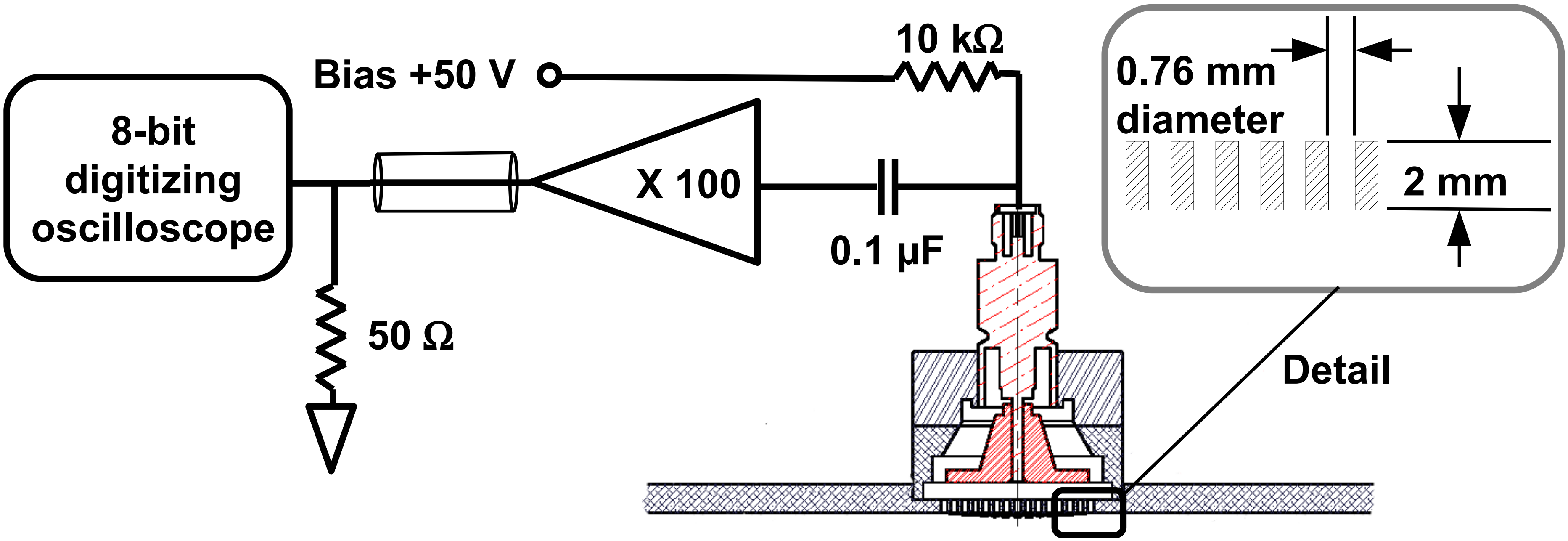




Custom vacuum chambers with RFAs and shielded pickup detectors

Uncoated aluminum, and TiN, amorphous carbon, and diamond-like carbon coatings

Shielded Pickup Design and Readout



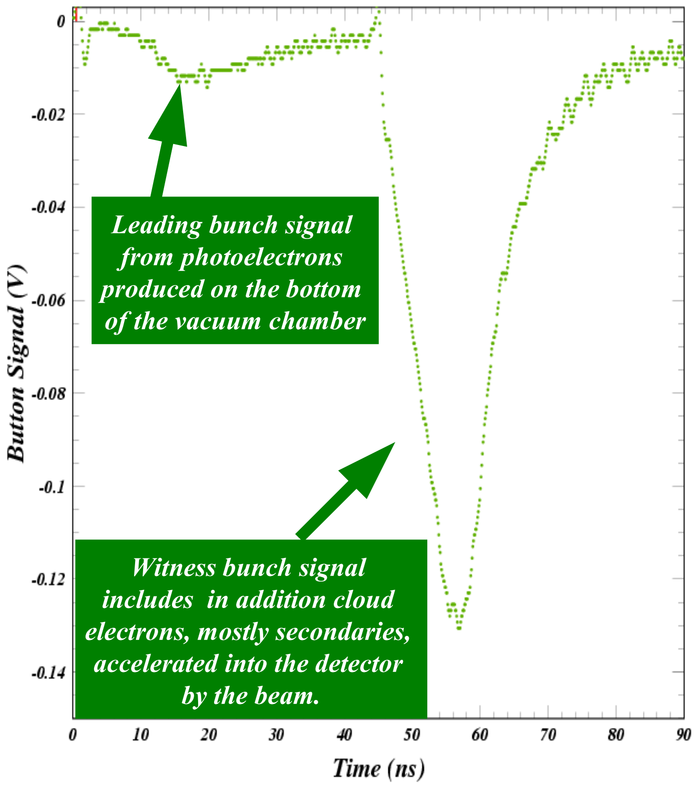
The pickup electrodes are shielded by the vacuum chamber hole pattern against the beam-induced signal.

The +50 V bias ensures that secondaries produced on the electrode do not escape.

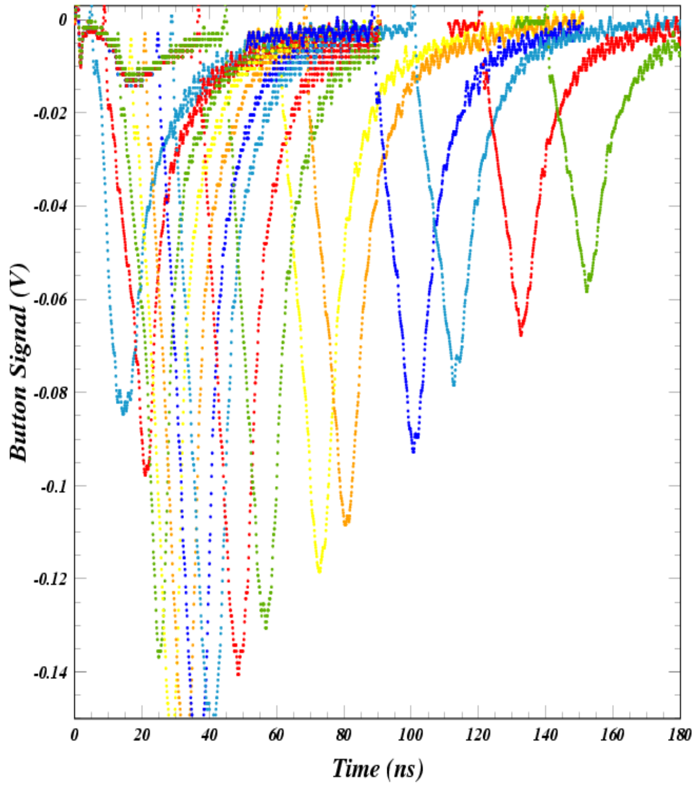
The 8-bit digitized signal is an average over 8k triggers in time intervals of 0.1 ns.

Witness Bunch Method for Constraining Model Parameters
Example : 5/9/2010 2.1 GeV e+ 3 mA/bunch Al v.c. 15W

Shielded pickup scope trace for two bunches 44 ns apart



Superposition of 15 such traces illustrating the sensitivity to cloud lifetime



The single bunch signal arises from photoelectrons produced on the bottom of the vacuum chamber. Its shape is closely related to the photoelectron kinetic energy distribution and the beam kick. The witness bunch signal includes the single-bunch signal as well as the that produced by cloud particles accelerated into the shielded pickup by the kick from the witness bunch. The witness signal is therefore sensitive to SEY.

Electron cloud buildup modeling code ECLOUD

* Originated at CERN in the late 1990's
* Widespread application for PS, SPS, LHC, KEK, RHIC, ILC ...
* Under active development at Cornell since 2008
* Successful modeling of CESRTA tune shift measurements
* Interactive shielded pickup model implemented in 2010
* Full POSINST SEY functions added as option 2010-2012
* Flexible photoelectron energy distributions added 2011
* Synrad3D photon absorption distribution added 2011

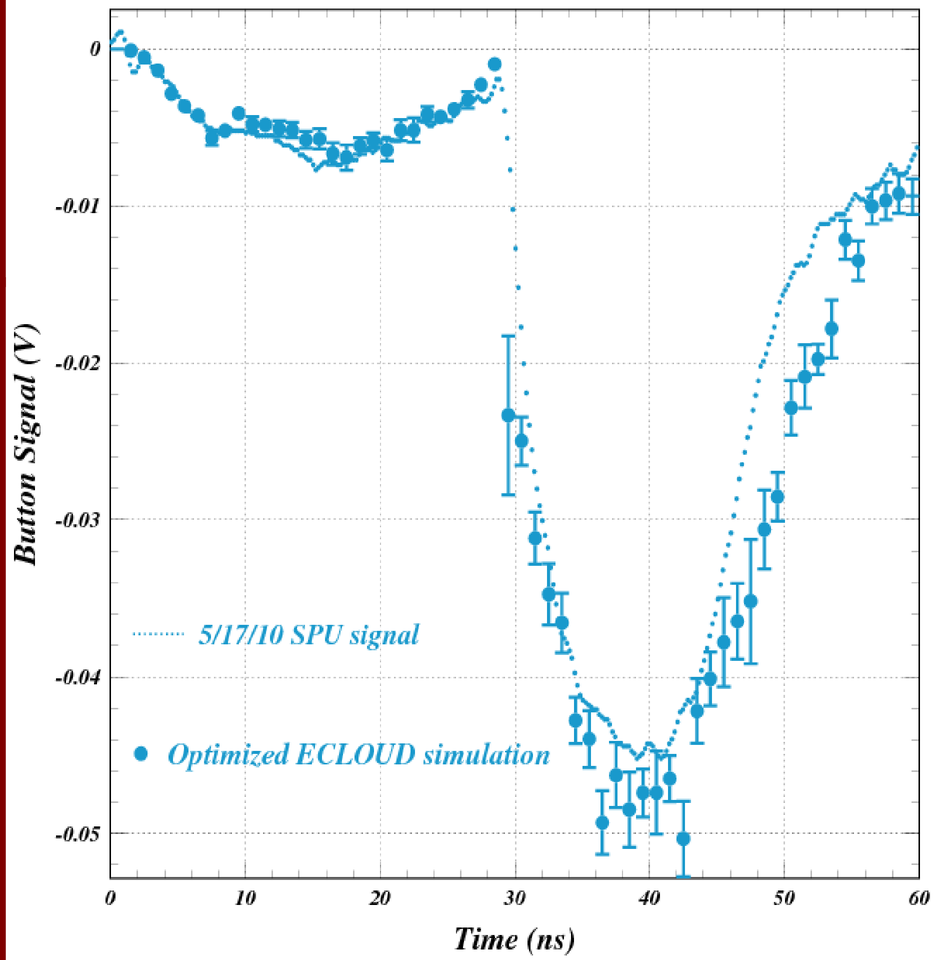
I. Generation of photoelectrons
- A) Production energy, angle
- B) Azimuthal distribution (v.c. reflectivity)

II. Time-sliced cloud dynamics
- A) Cloud space charge force
- B) Beam kick
- C) Magnetic fields

III. Secondary yield model
- A) True secondaries (yields > 1!)
- B) Rediffused secondaries (high energy)
- C) Elastic reflection (dominates at low energy)

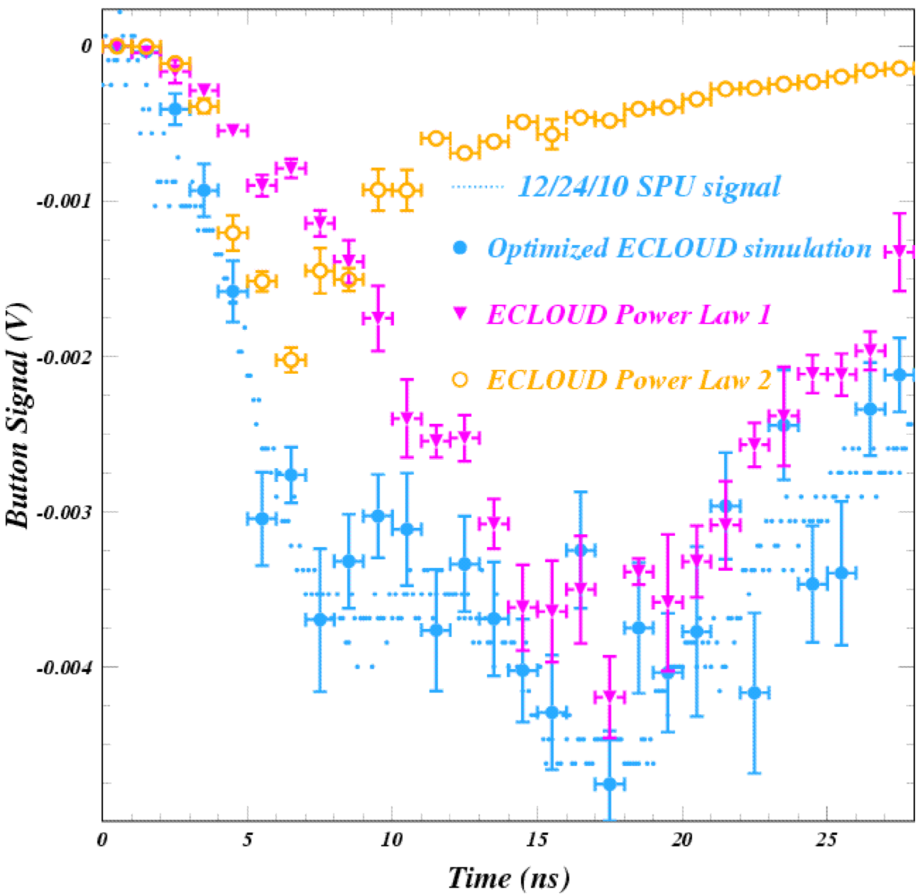
IV. Shielded pickup model
- A) Acceptance vs incident angle, energy
- B) Signal charge removed from cloud
- C) Non-signal charge creates secondaries

Modeled Signal
Counting signal macroparticles in each time slice gives the statistical uncertainty shown



Modeled photoelectron kinetic energy distribution

The shape of the signal from the leading bunch is determined by the photoelectron production energy distribution.



Electron Cloud Buildup Models and Plans at CESRTA
JAC et al, LCWS11
Recent Developments in Modeling Time-resolved Shielded-pickup Measurements of Electron Cloud Buildup at CESRTA
JAC et al, IPAC11

Two Power-Law Contributions

$$F(E) = E^{P1} / (1 + E/E_0)^{P2}$$

$$E_0 = E_{peak} \ (P_2 - P_1)/P_1$$

This level of modeling accuracy was achieved with the photoelectron energy distribution shown below, using a sum of two power law distributions.

$$E_{peak} = 80 \text{ eV} \quad P_1 = 4 \quad P_2 = 8.4$$

The high-energy component (22%) has a peak energy of 80 eV and an asymptotic power of 4.4. Its contribution to the signal is shown as yellow circles in the lower left plot.

$$E_{peak} = 4 \text{ eV} \quad P_1 = 4 \quad P_2 = 6$$

The low-energy component (78%) has a peak energy of 4 eV and an asymptotic power of 2. It's contribution to the signal is shown as pink triangles.

Constraints on the energy distribution of “true” secondary electrons

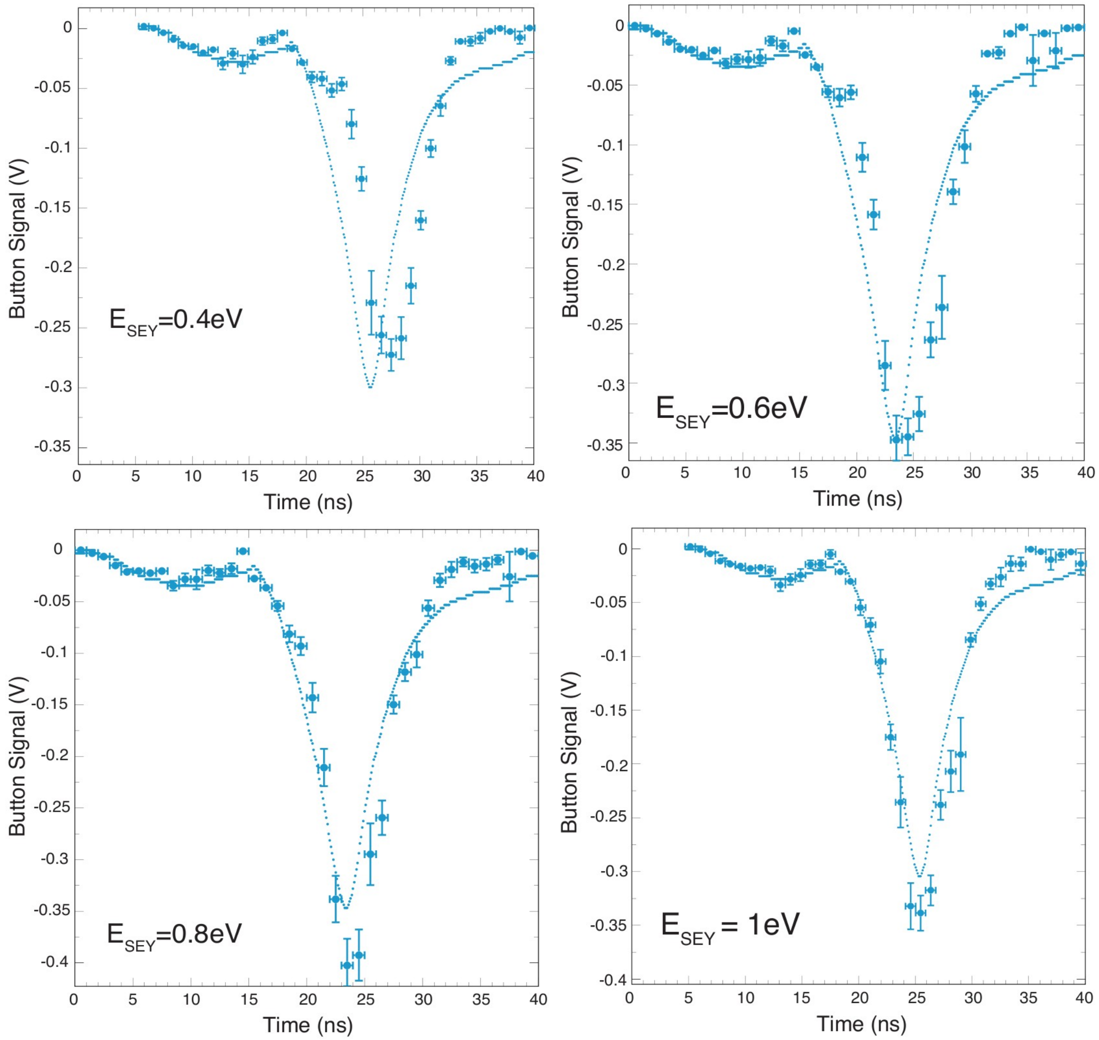
$$f(E_{sec}) \sim E_{sec} \exp(-E_{sec}/E_{SEY})$$

The time development of the cloud is directly dependent on secondary kinetic energies and therefore on the relative probabilities of the three secondary production processes:

1) True secondaries dominate at high incident energy and are produced at low energy

2) Rediffused secondaries are produced at energies ranging up to the incident energy

3) Elastic scattering dominates at low incident energy



The CESRTA Test Accelerator Electron Cloud Research Program Phase 1 Report
M.A.Palmer et al, August, 2012

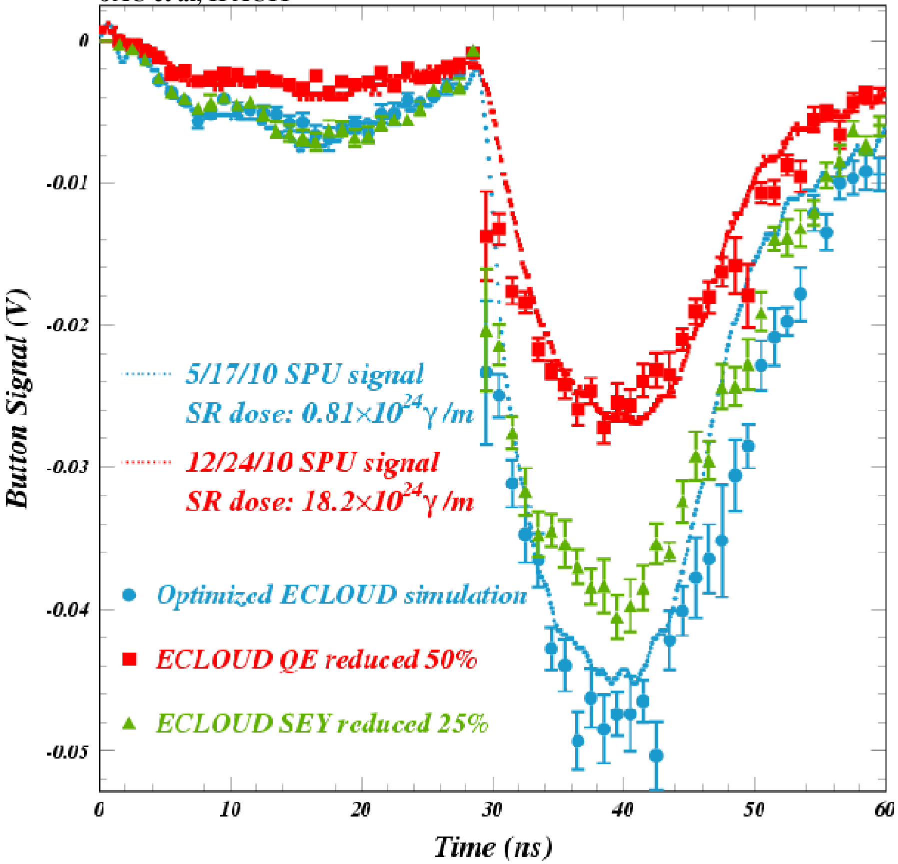
Recent Developments in Modeling Time-resolved Shielded-pickup Measurements of Electron Cloud Buildup at CESRTA
JAC et al, IPAC11

Electron Cloud Buildup Models and Plans at CESRTA
JAC et al, LCWS11

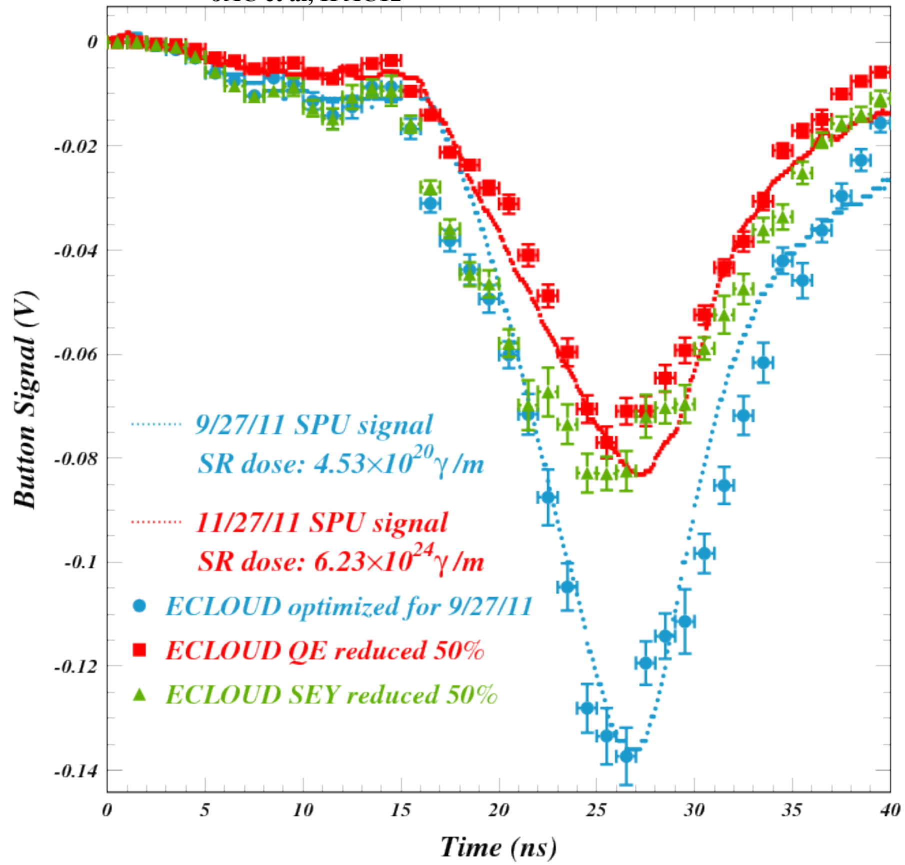
The pulse shape for the 14-ns witness bunch signal sets a lower bound on the model parameter E_{SEY}.

Beam conditioning effects on an amorphous carbon coating

Recent Developments in Modeling Time-resolved Shielded-pickup Measurements of Electron Cloud Buildup at CESRTA
JAC et al, IPAC11

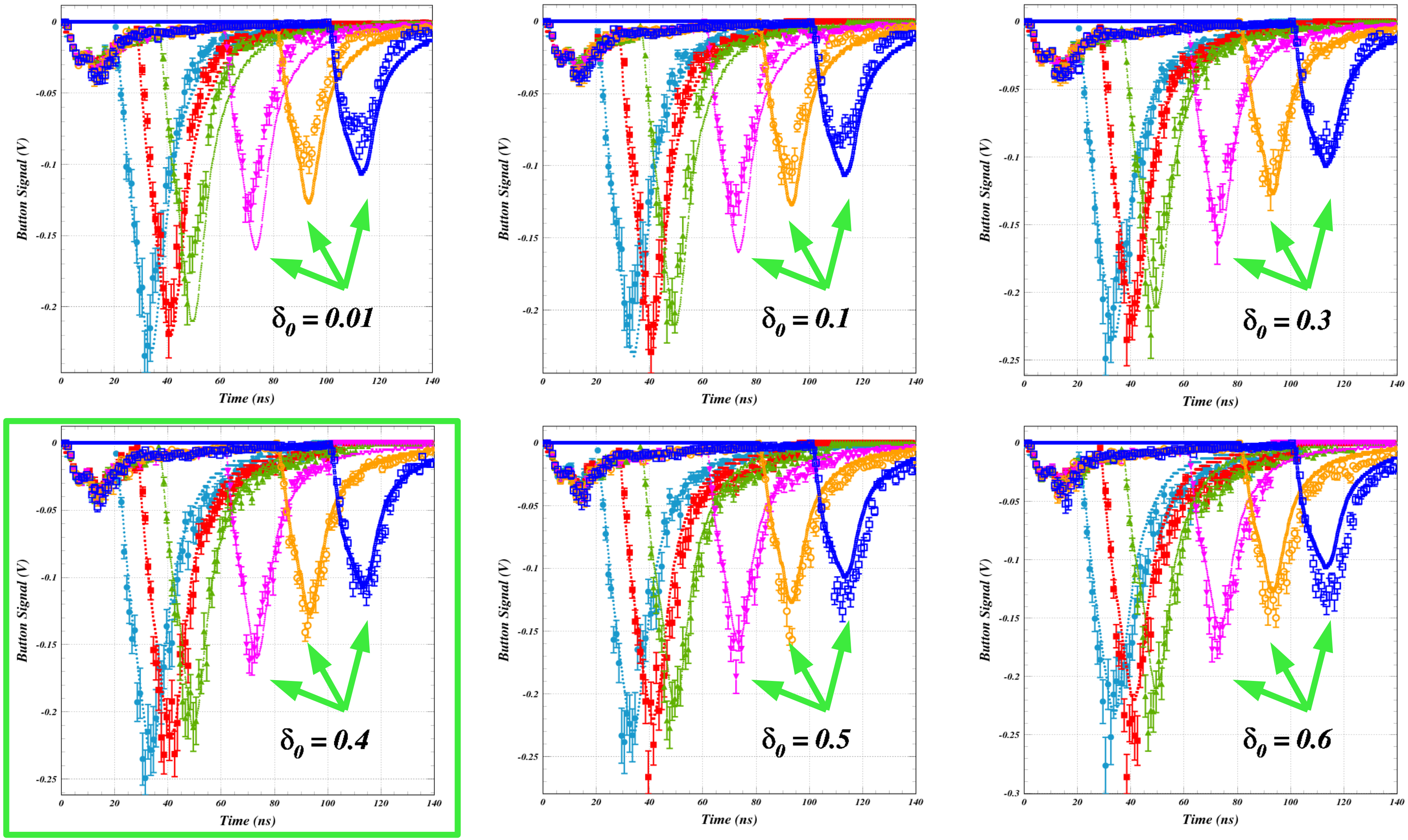


Time-resolved Shielded-pickup Measurements and Modeling of Beam Conditioning Effects on Electron Cloud Buildup at CESRTA
JAC et al, IPAC12



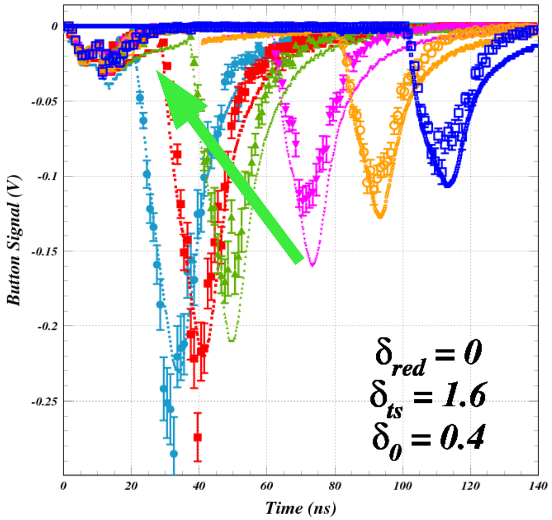
The beam conditioning effect for an amorphous carbon coating is primarily in quantum efficiency in both the early and late conditioning processes.

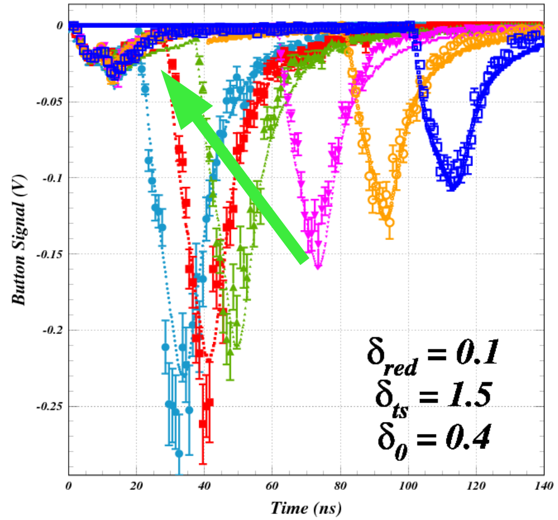
Witness Bunch Study for Uncoated Aluminum 5/17/2010
15W 5.3 GeV 3 mA/bunch e+ 4-ns spacing

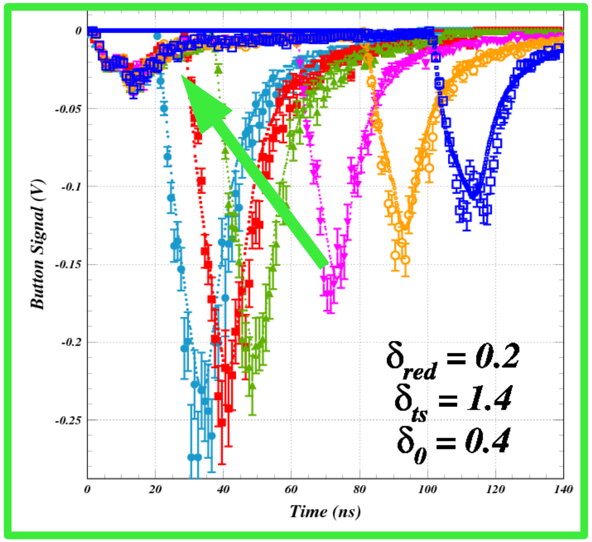


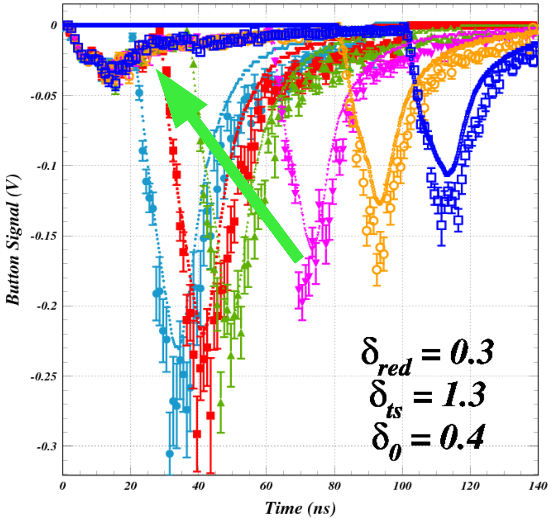
The later witness bunches provide sensitivity to the value for elastic yield.

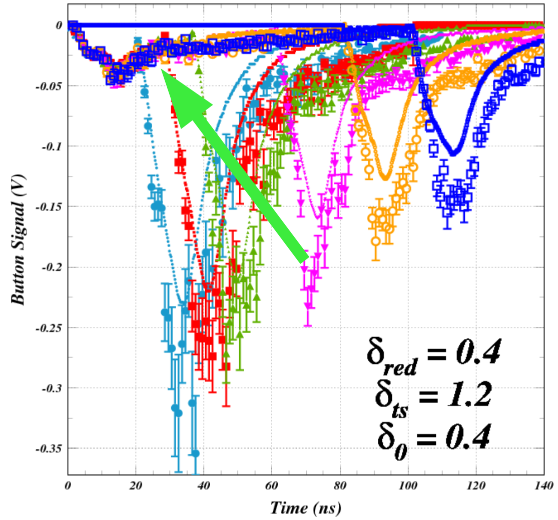
Discriminating between the true and rediffused secondary emission processeses











The rediffused secondary yield process determines the trailing edge of the signal from a single bunch.

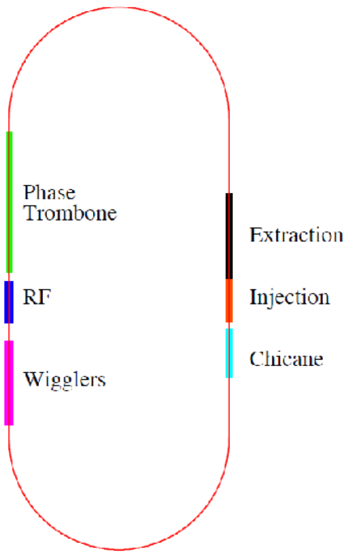
This trailing edge is insensitive to δ_0, as seen on the previous slide.

The late witness bunch signal used to determine δ_0 is also sensitive to the rediffused yield process.

The value for the rediffused yield of 20% for uncoated aluminum is consistent with the value determined using CESRTA coherent tune shift measurements (JAC et al, IPAC10)

ILC Damping Ring Lattice and Vacuum Chamber Design (JAC et al, IPAC12)

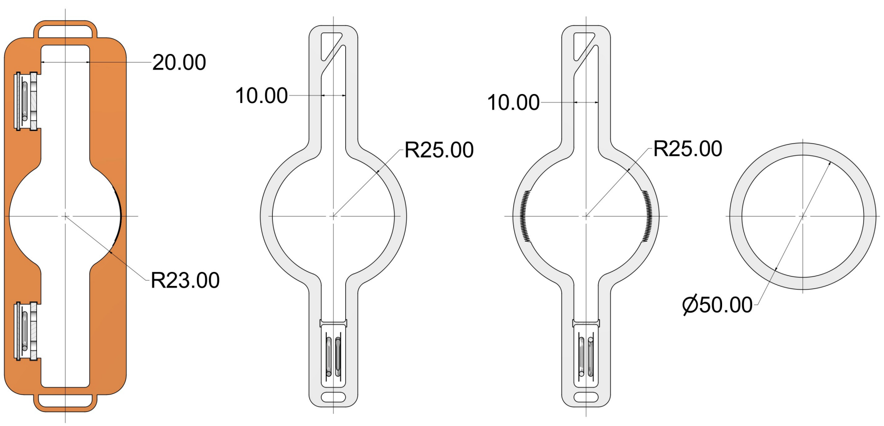
DTC03 layout



1. Circumference = 3238.68m, 710.22m straights
2. ~ 6 phase trombone cells
3. 54 – 2.2 m long wigglers
   wiggler period = 30cm
   14-poles
   B_{max} = 2.16 T
4. Space for 16 RF cavities
   Cryostats for upper and lower positron rings are interleaved

Parameter	10 Hz(Low)	5 Hz (Low)	5 Hz (High)
Circumference	3.238 km	3.238 km	3.238 km
RF frequency	650 MHz	650MHz	650 MHz
τ_x/τ_y [ms]	12.86	23.95	23.95
T_z [ms]	6.4	12.0	12.0
σ_s [mm]	6.02	6.02	6.02
σ_δ	0.137%	0.11%	0.11%
α_p	3.3 X 10^{-4}	3.3 X 10^{-4}	3.3 X 10^{-4}
$\gamma\varepsilon_x$ [μm]	6.3	5.8	5.8
RF [MV] (12 cavities) Total/Per cav	20.4/1.7	13.2 /1.1	13.2/1.1
ξ_x/ξ_y	-50.9/-44.1	-51.3/-43.3	-51.3/-43.3
Wigglers- N_{cells}@B[T]	27@2.16	27@1.51	27@1.51
Energy loss/turn [MeV]	8.4	4.5	4.5
sextupoles	3.34/-4.34	3.34/-4.23	3.34/-4.23
Power/RF coupler @400mA [kW]**	280	150	300

Radiation parameters (damping times, emittance, energy spread, etc. based on map-type wiggler
**(400mA X 8.4 MeV/turn)/12



(a) WIGGLER CHAMBER (b) ARC CHAMBER (c) DIPOLE CHAMBER (d) DRIFT CHAMBER

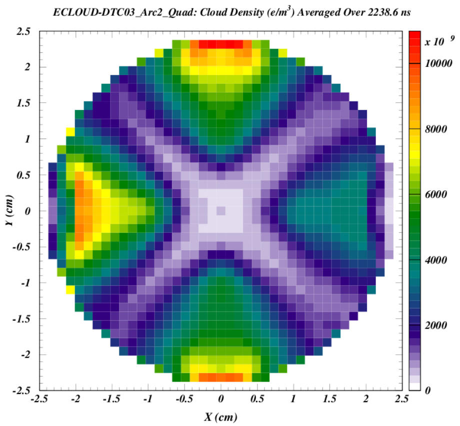
Recommendations for vacuum chamber mitigation techniques in wigglers, dipoles, quadrupoles, sextupoles and field free regions were determined at the ECLOUD'10 workshop.

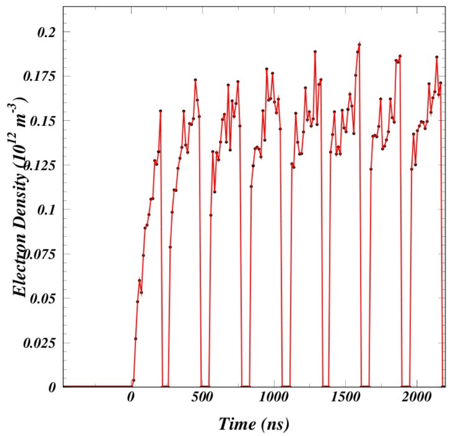
The antechamber design was modified according to Synrad3D photon transport calculations.

Calculated photon absorption site distributions were used as input to cloud buildup models.

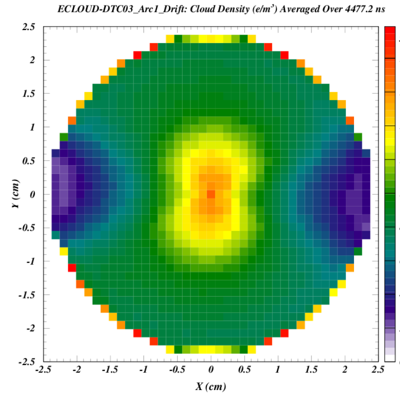
ILC Damping Ring Electron Cloud Buildup Modeling

Quadrupoles

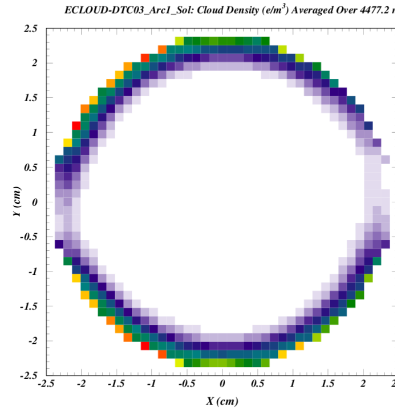




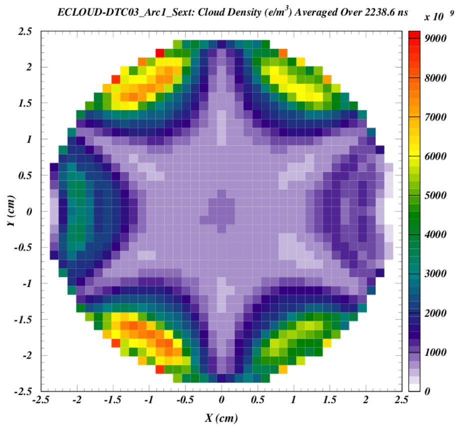
Field-free Regions Solenoids off



Field-free Regions Solenoids on



Sextupoles



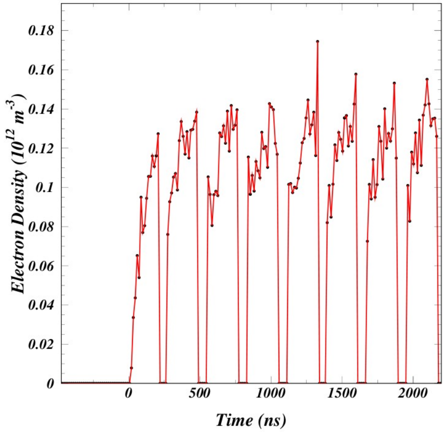


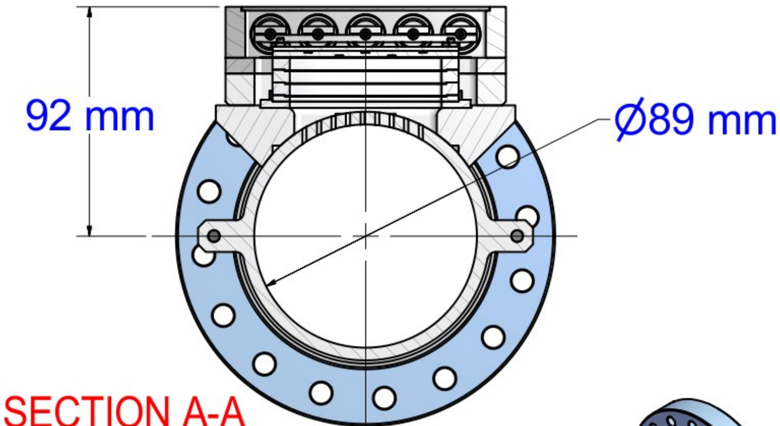
Table 2: POSINST and ECLOUD modeling results for the 20σ density estimates N_e (10^{11} m^{-3}) just prior to each bunch passage in the DTC03 lattice design

	Field-free		Dipole		Quadrupole		Sextupole	
	Length (m)	N_e	Length (m)	N_e	Length (m)	N_e	Length (m)	N_e
Arc region 1	406	2.5	229	0.4	146	1.5	90	1.4
Arc region 2	365	2.5	225	0.4	143	1.7	90	1.3
Wiggler region	91	40	0		18	12	0	

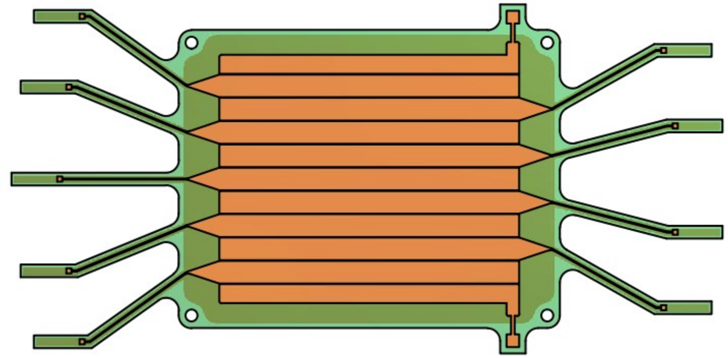
Cloud densities calculated in beam region were used as input to head-tail instability modeling code to provide results for the ILC TDR.

New Time-Resolved RFA's in L3

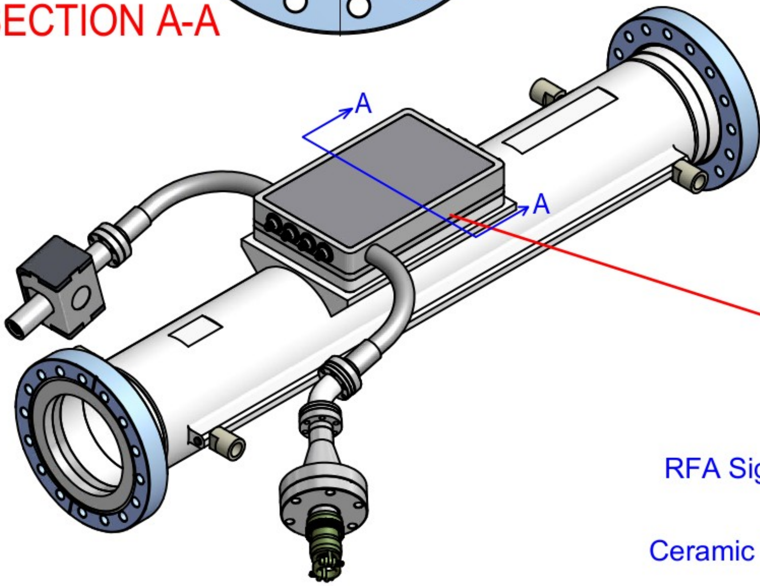
Vacuum chambers bare and TiN-coated, smooth and grooved



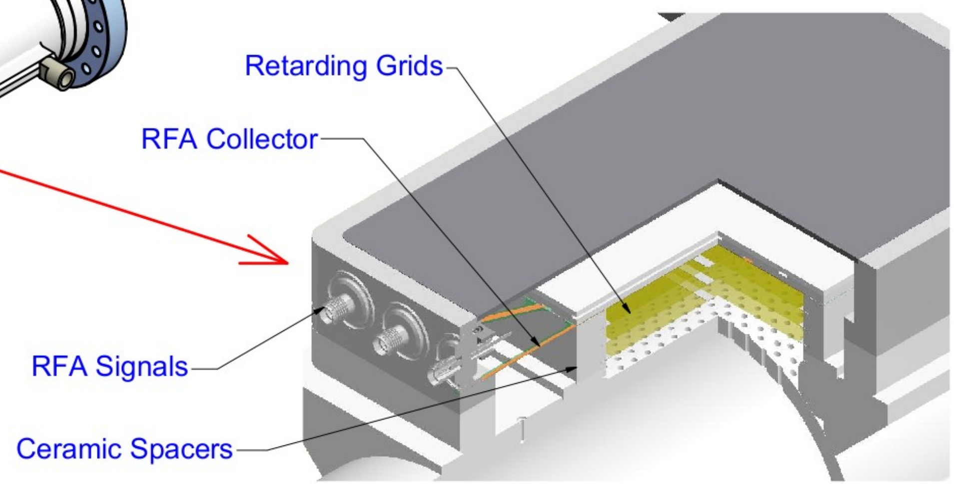
SECTION A-A



RFA Collector with 9 channels

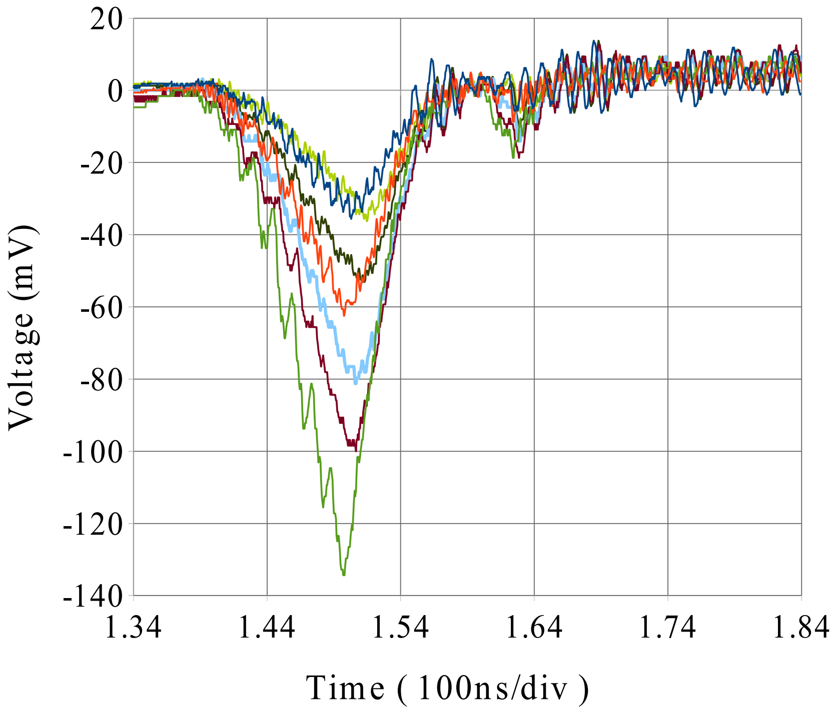


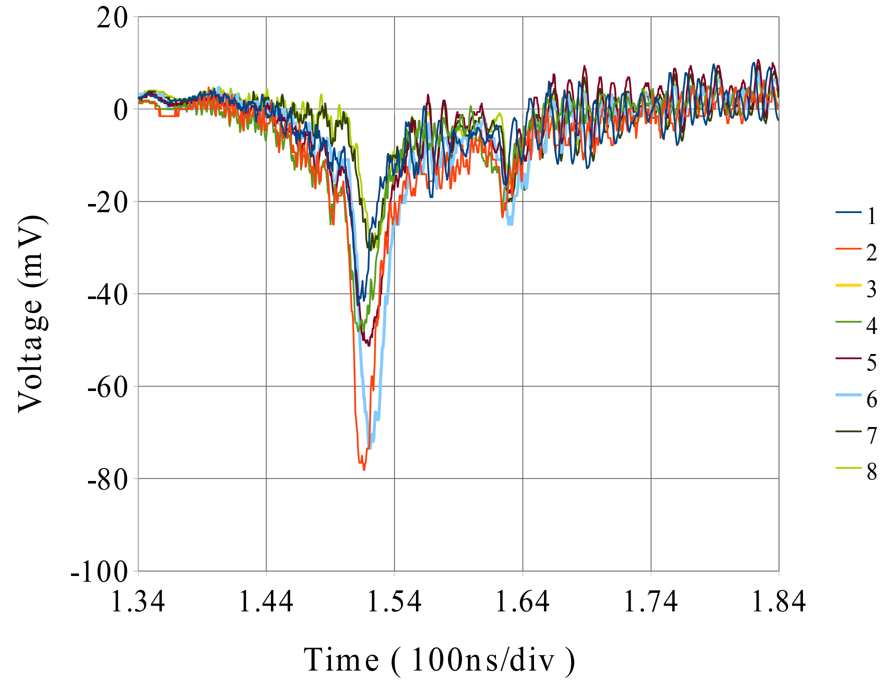
TR-RFA Vacuum Chamber



RFA Structure Detail

New Time-Resolved RFA's in PEP-II Chicane Dipole Field On/Off





Chicane dipole field off

Central collectors dominate.

Chicane dipole field 45 G

Central collectors show a depletion zone. This is known to arise from the peak of the SEY curve and provides information on E_{max}.

Summary and Near-Term Plans

Summary

The time-averaged RFA measurements and the time-resolved measurements shielded pickup of cloud buildup provide remarkable discriminating power between photoelectron and secondary electron production processes. They also provide information distinguishing the various processes contributing to secondary electron production.

The time-resolved information is very sensitive to the production kinematics for both photoelectrons and secondary electrons.

Cloud buildup models including photoelectron production, secondary emission and cloud dynamics have been developed and validated by comparing them to a wide variety of RFA and shielded pickup measurements. These necessitated the development of synchrotron radiation photon tracking modeling to provide the distribution of photon absorption sites for an arbitrary lattice design. These modeling techniques have been used to make quantitative estimates of electron cloud buildup in the ILC positron damping ring.

Near-term Plans

Innovative new detectors combining the time-resolving capability of the shielded pickups with the segmentation and energy sensitivity of the RFAs have been designed, built and installed in four custom aluminum vacuum chambers, bare andTiN-coated, smooth and grooved. Initial data-taking and modeling has begun.