Electron Cloud Buildup Characterization Using Shielded Pickup Measurements and Custom Modeling Code

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Cornell Laboratory for Accelerator-Based Sciences and Education

ECLOUD'12

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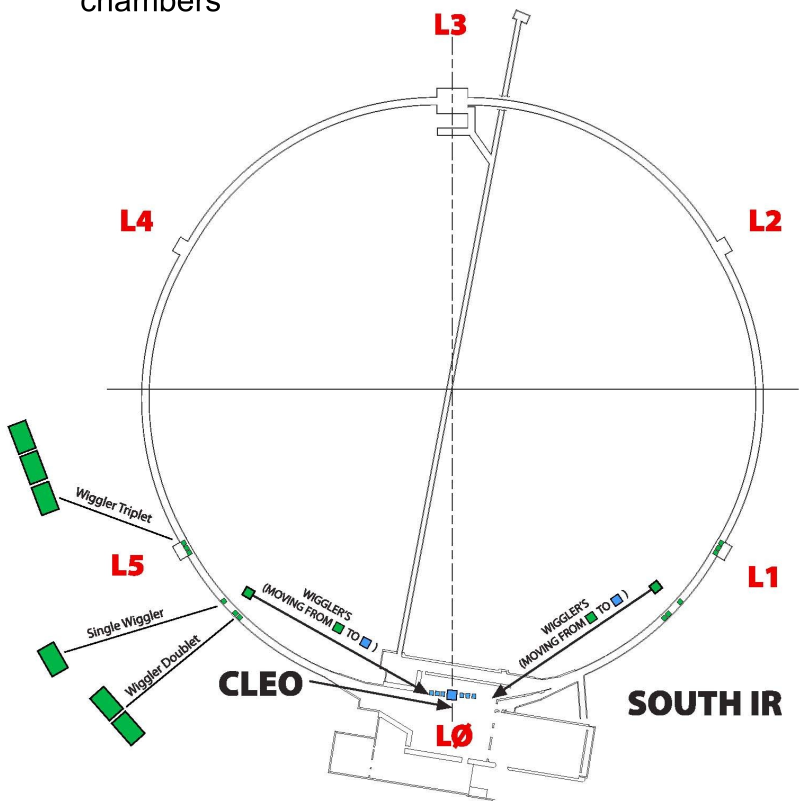
EC Buildup Detectors at CESRTA

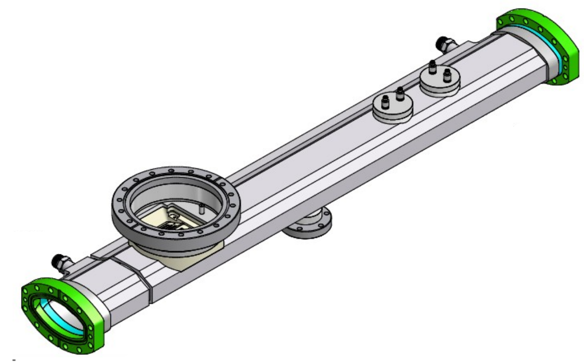
L3 Electron cloud experimental region

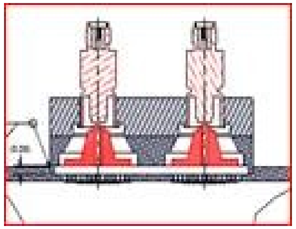
PEP-II EC Hardware:
Chicane, upgraded SEY station
(commissioning in May 2009)
Drift and Quadrupole diagnostic chambers

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

Locations for collaborator experimental vacuum chambers





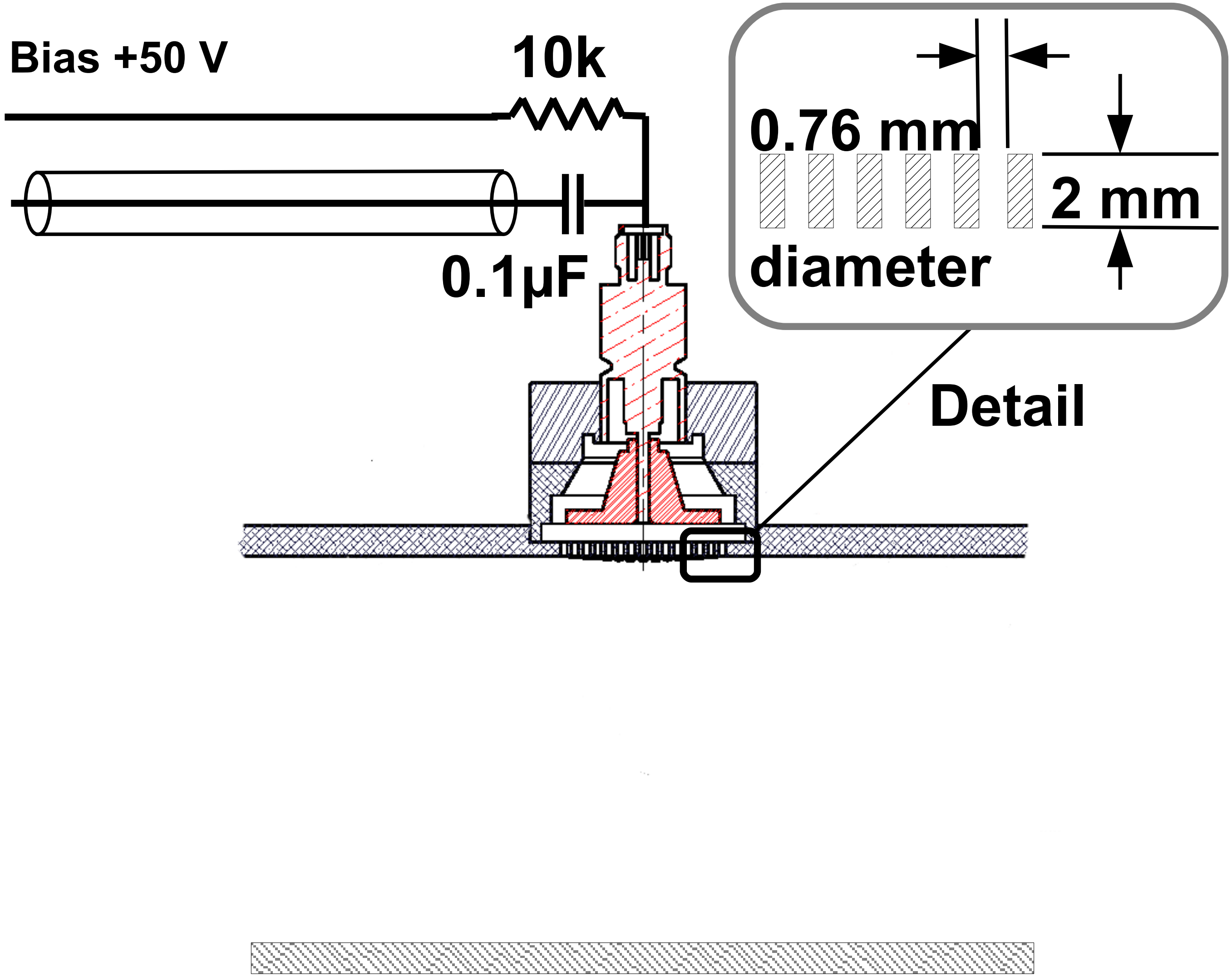


30 RFAs in drift regions, dipoles, quadrupoles, and wigglers

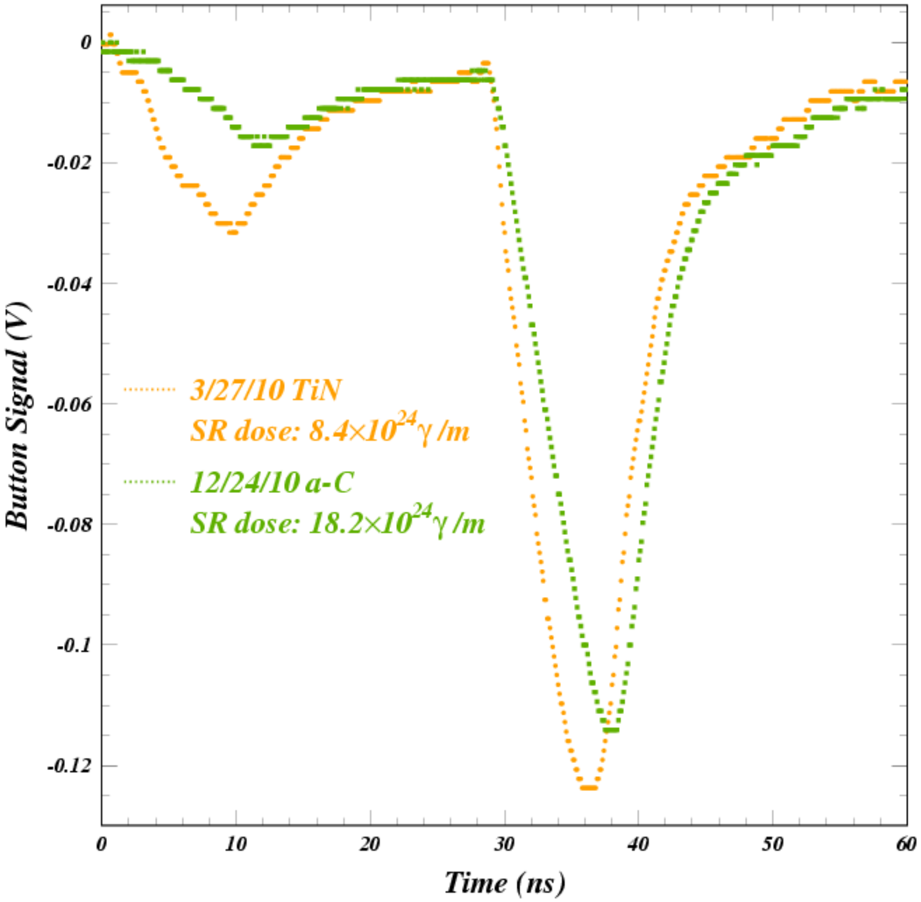
Custom vacuum chambers with shielded pickup detectors

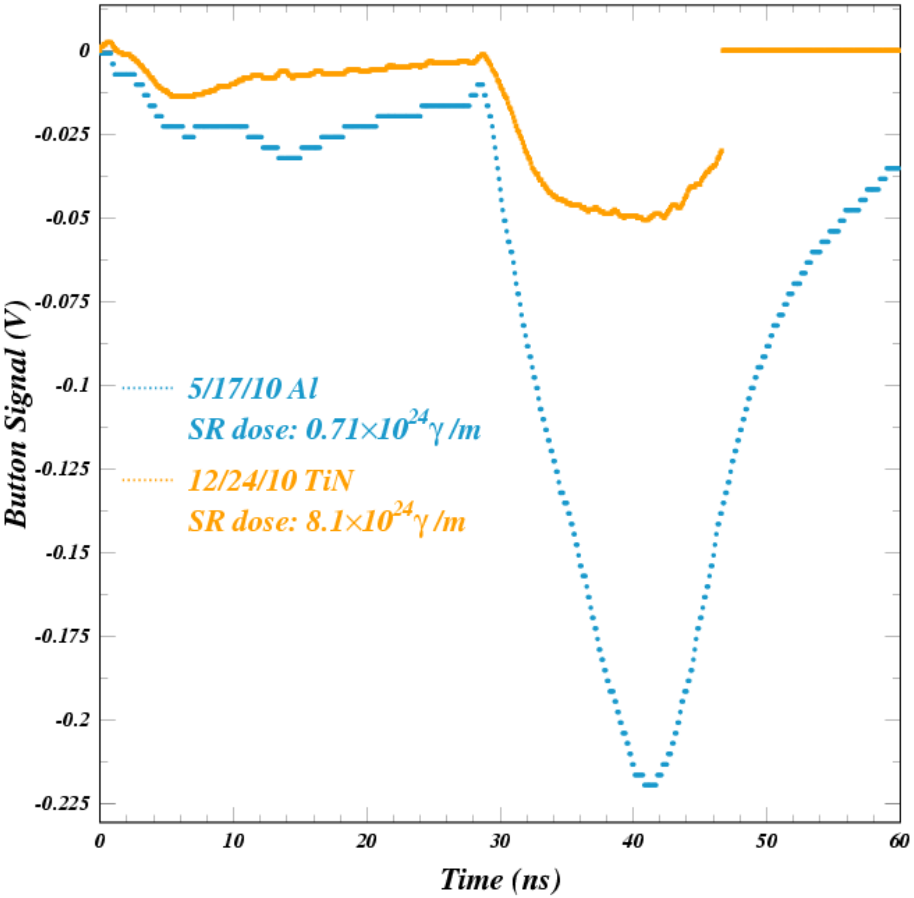
Uncoated aluminum, and TiN, amorphous carbon, diamond-like carbon coatings

Shielded Pickup Design and Readout



In Situ Vacuum Chamber Comparisons – Coating Comparison --





The carbon coating suppresses photoelectron production relative to the TiN coating, especially at high photoelectron energy. However, the secondary yield is somewhat higher.

The quantum efficiency for reflected photons and the secondary yield are both much smaller for conditioned TiN than for uncoated aluminum.

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

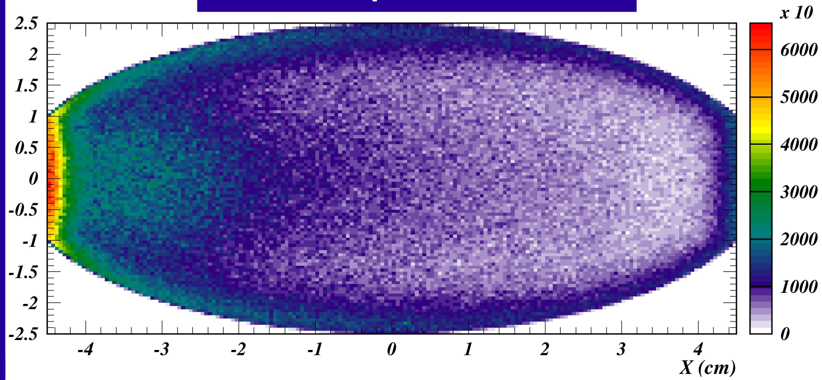
I. Generation of photoelectrons
- A) Production energy, angle
- B) Azimuthal distribution (v.c. reflectivity)

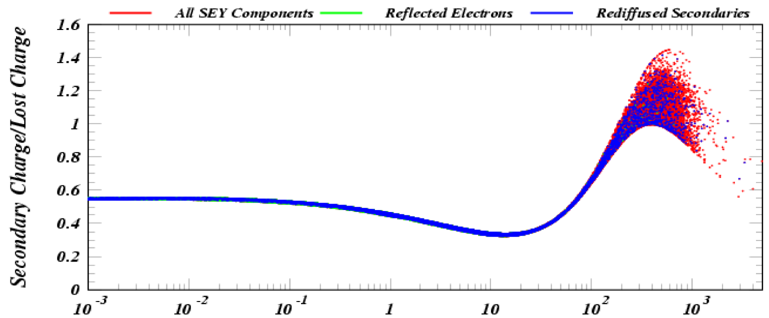
II. Time-sliced cloud dynamics
- A) Cloud space charge force
- B) Beam kick
- C) Magnetic fields

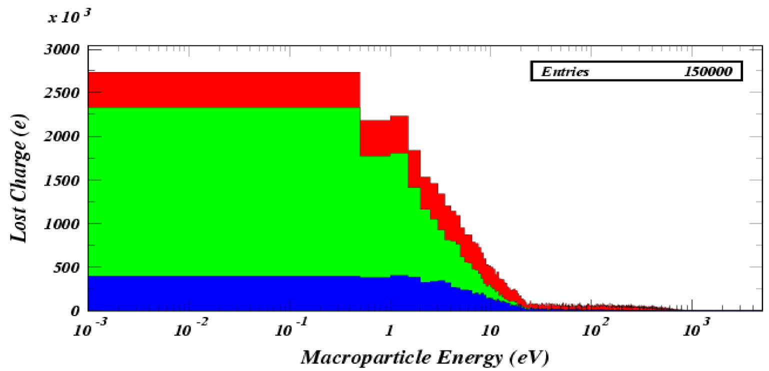
III. Secondary yield model
- A) True secondaries (yields > 1!)
- B) Rediffused secondaries (high energy)
- C) Elastic reflection (dominates at low energy)

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

Cloud snapshot after 14 ns

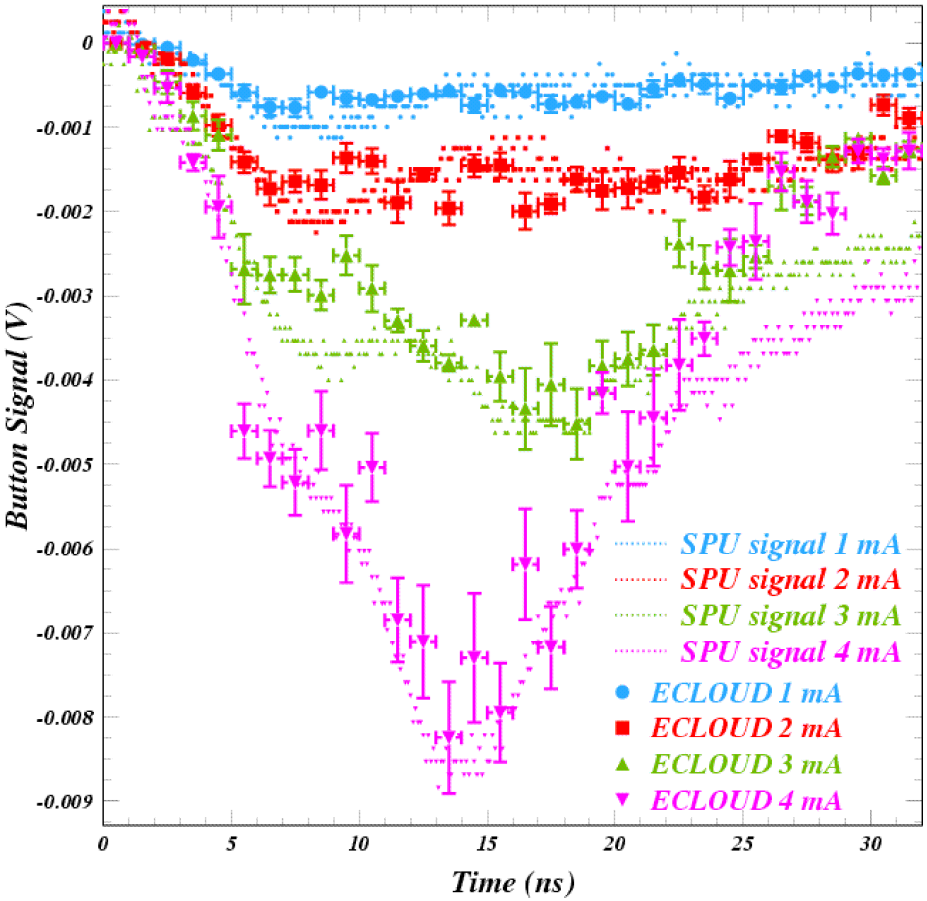






ECLOUD Modeling of CESRTA Shielded Pickup Pulse Shapes: Photoelectrons

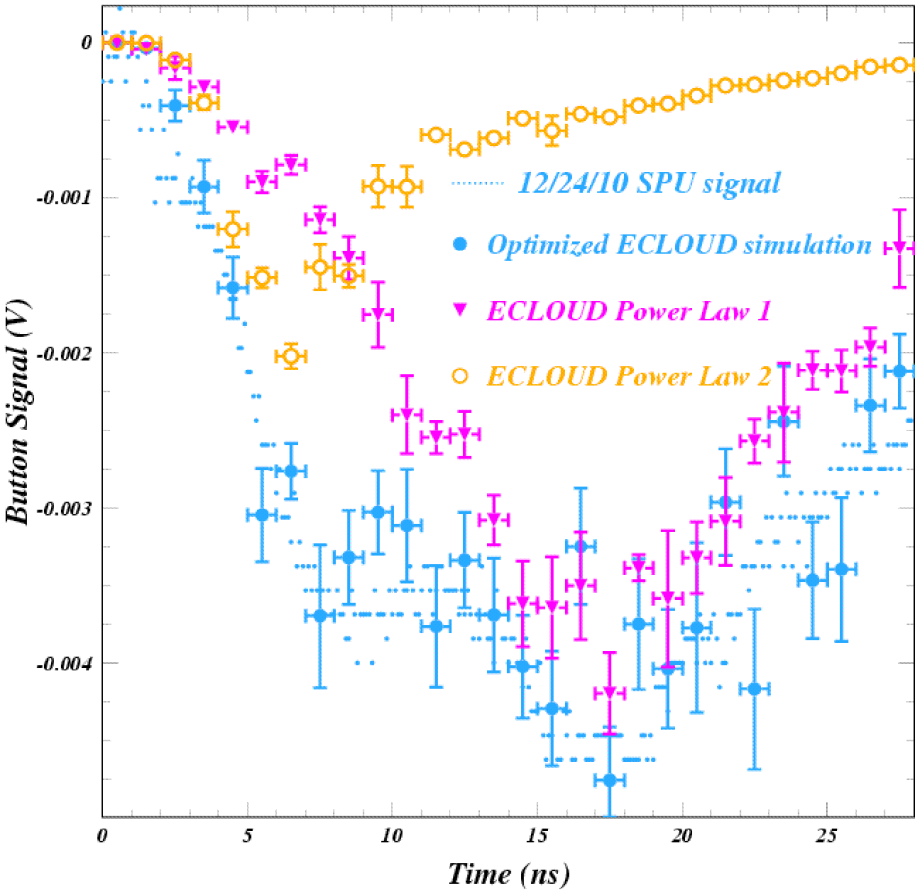
JAC et al, IPAC11, WEPC135, *Recent Developments …*



Disentangling the Photoelectron Production Kinetic Energy Distribution from the Beam Kick Strengths

The early SPU signal from the leading bunch for a positron beam is largely due to photoelectrons produced on the bottom of the vacuum chamber. This is the closest production point where the beam kick attracts the photoelectrons toward the SPU. Thus the size and shape of the leading bunch signal is determined by the reflected photon rate, azimuthal distribution, the quantum efficiency for producing photoelectrons, and the kinetic energy distribution of the photoelectrons. In particular, the arrival time distribution determines the shape. By modeling the shape for different strengths of beam kick, we can determine the photoelectron energy distribution. An example of such an analysis is shown on the left. Note that the signal begins just a few nanoseconds after bunch passage even for weak beam kicks, indicating that high-energy photoelectrons were produced (hundreds of eV).

Example: 3 mA/bunch 5.3 GeV e+ 15E a-Carbon



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.

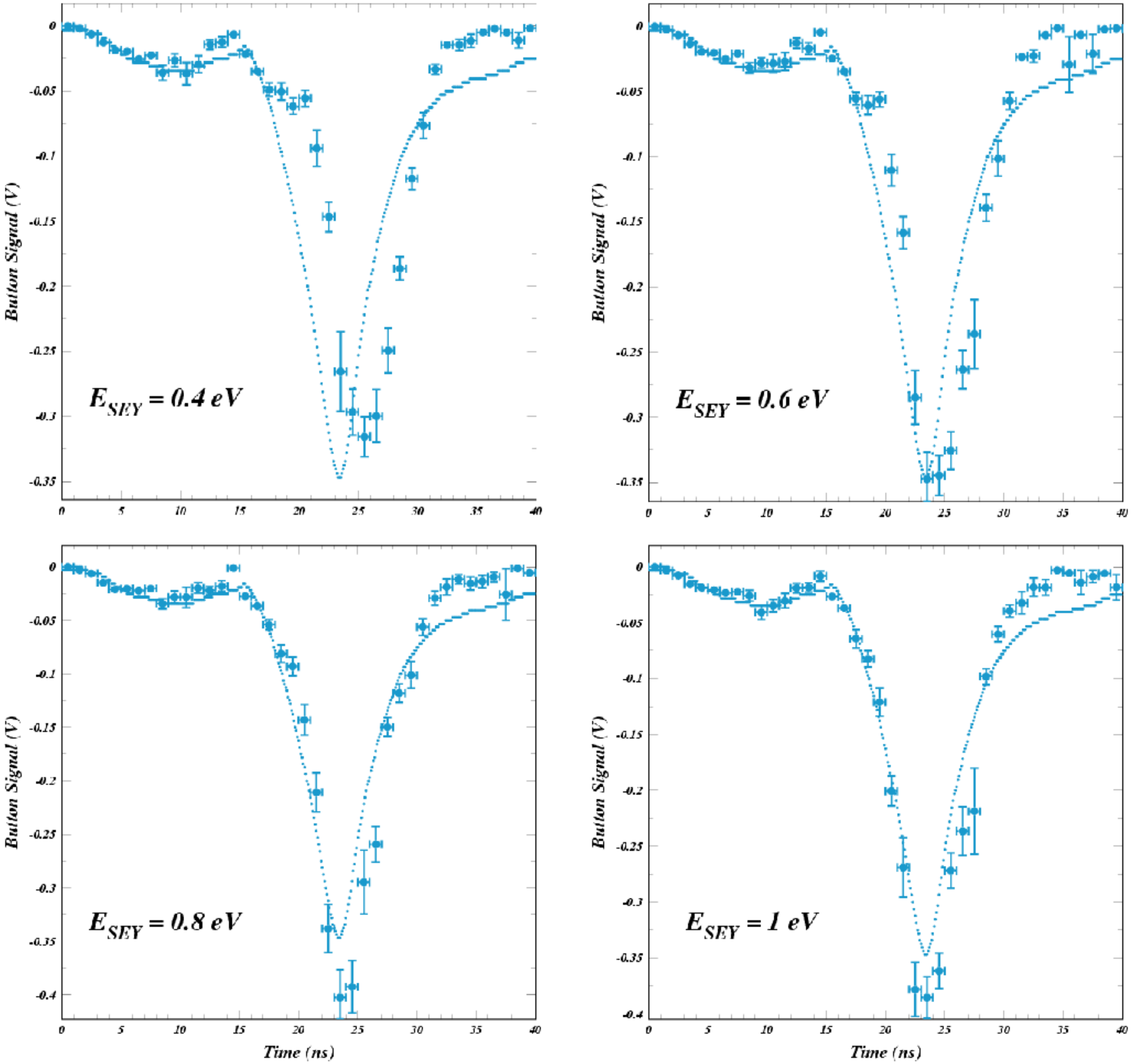
$$E_{peak} = 80 \text{ eV} \quad P_1 = 4 \quad P_2 = 8.4$$

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.

ECLOUD Modeling of CESRTA Shielded Pickup Pulse Shapes: Secondary electrons



Constraints on the kinetic energy distribution for secondary electrons

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

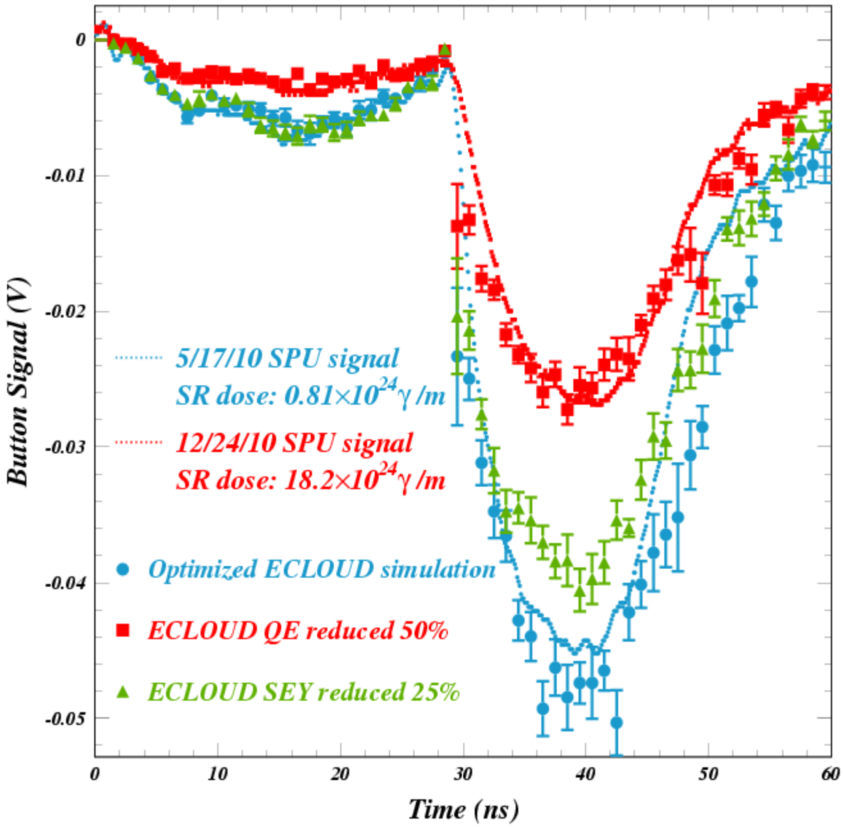
A Lower Bound on the E_{SEY} Parameter

The signal from a witness bunch following 14 ns after the leading bunch includes additionally a much larger contribution from secondary cloud electrons accelerated into the SPU detector by the witness-bunch kick.

The figures on the left show that if the secondary energy distribution does not include sufficiently high energies, the modeled 14-ns witness bunch signal shape is distorted and inconsistent with the measured signal.

In Situ Vacuum Chamber Comparisons – Conditioning Effects --

JAC et al, IPAC11, WEPC135, *Recent Developments* ...



Beam Conditioning in an Amorphous-carbon-coated Al Chamber

Shielded pickup signals measured in an amorphous-carbon-coated chamber in May (blue dotted line) and December (red dotted line) of 2010 for two bunches carrying 4.8×10^{10} 5.3 GeV positrons 28 ns apart. The synchrotron radiation dose increased by a factor of twenty during this time interval. The ECLOUD model optimized for the May data is shown as blue circles, the error bars showing the model statistical uncertainties.

The leading bunch arises from photoelectrons produced on the bottom of the vacuum chamber. Careful tuning of the energy distribution and quantum efficiency for photoelectrons produced by reflected photons is required to reproduce its size and shape. The signal from the witness bunch includes additionally the contribution from secondary cloud electrons accelerated into the SPU detector by the witness bunch kick and is therefore crucially dependent on the secondary yield and production kinematics. Since the conditioning affects both signals similarly, we can conclude that the conditioning change is in the quantum efficiency rather than in the secondary yield.

The December measurement is reproduced by a 50% decrease in the modeled quantum efficiency for photoelectron production. A reduction in the secondary yield of 25% is inconsistent with the observed effect, since the leading bunch signal is unchanged.

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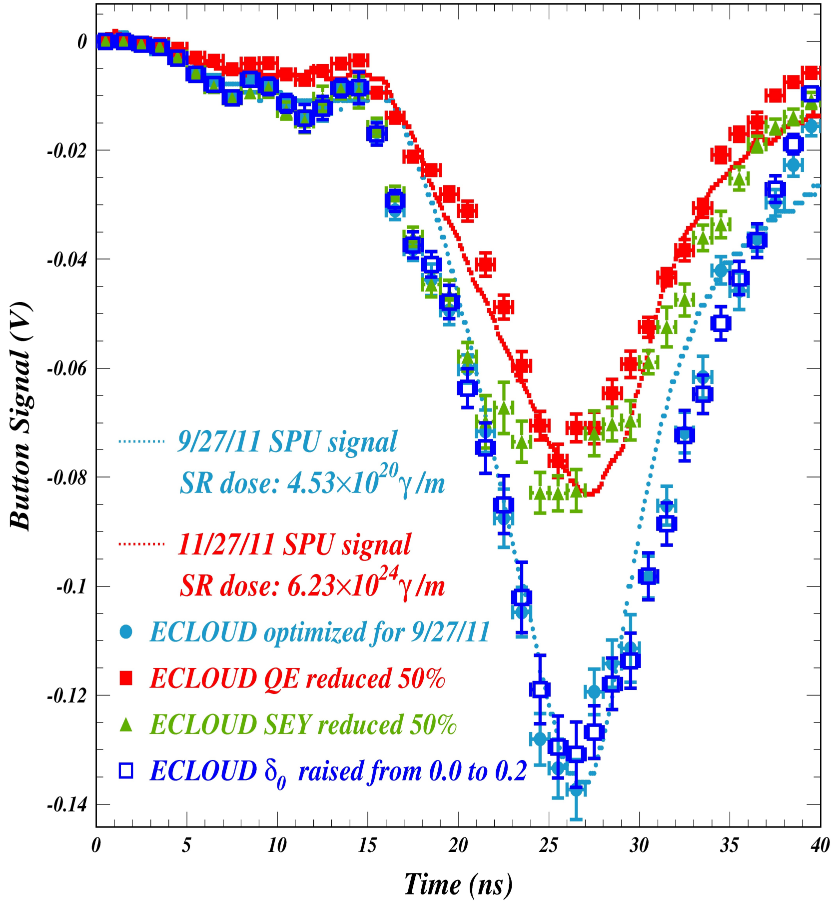
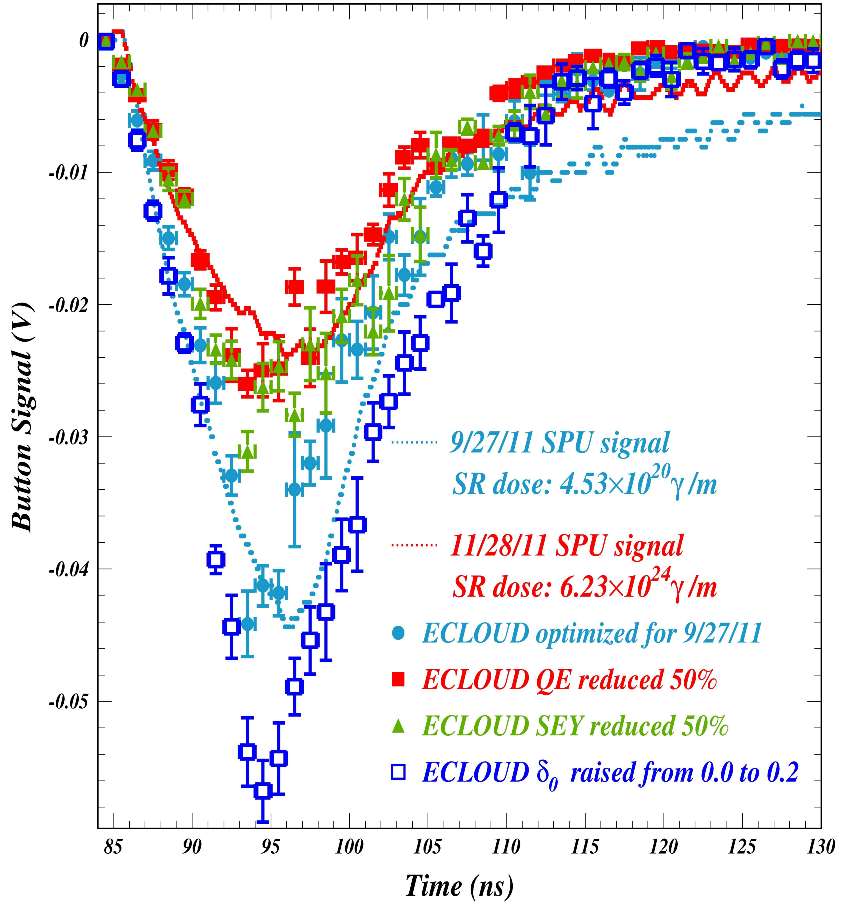
Conditioning of a Previously Unconditioned Amorphous Carbon Coating

JAC et al, IPAC12, TUPPR064, Time-Resolved Shielded-Pickup ....

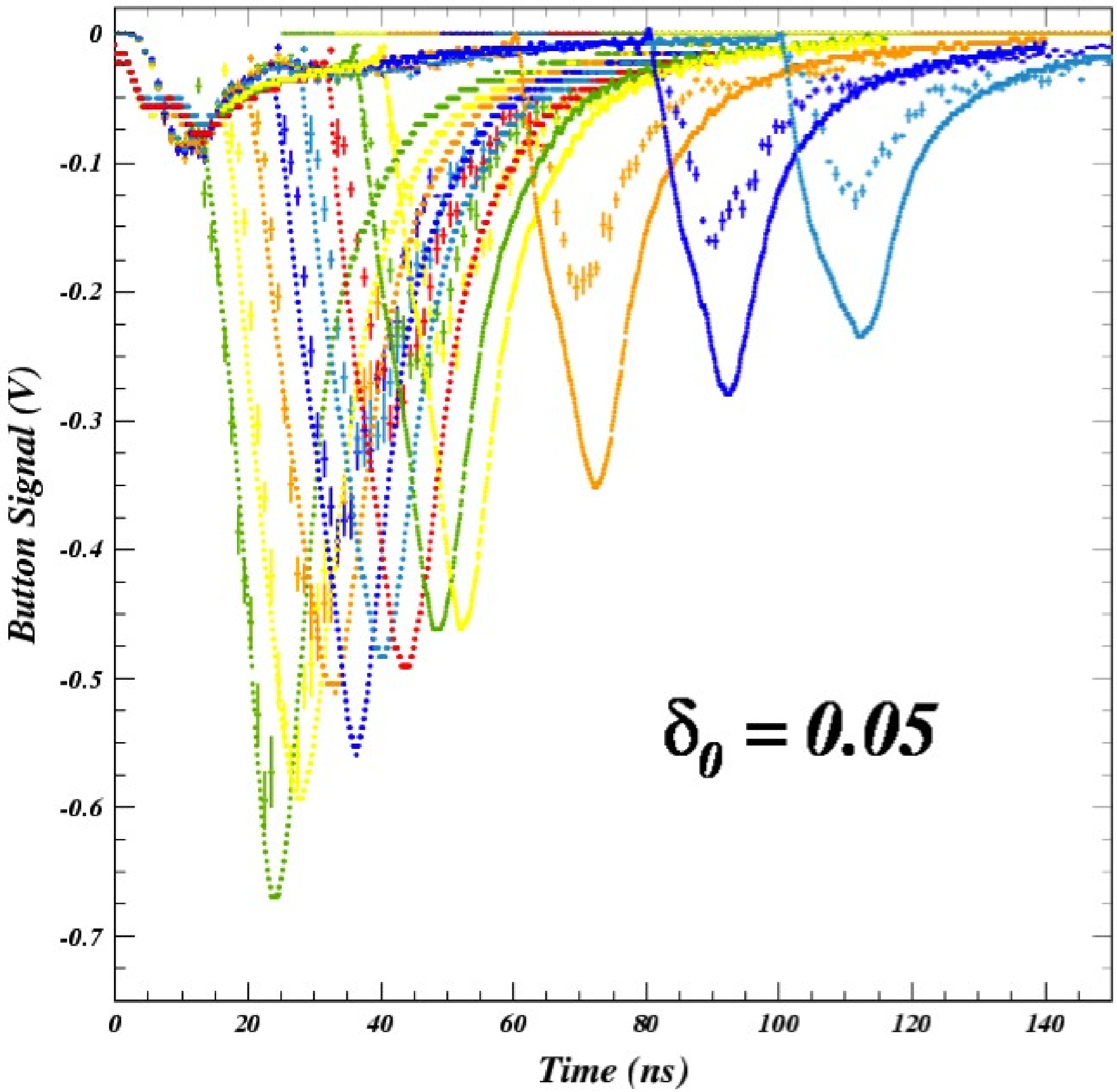




Conditioning effect for a previously unprocessed a-C coating affects the quantum efficiency, not the SEY, as for the late condition4ing process.
The elastic yield value does not affect the 14-ns bunch.

The elastic yield value does influence the signal from the witness bunch delayed by 84 ns.
An unprocessed elastic yield as high as 20% can be excluded.

Shielded Pickup Witness Bunch Studies for Determining Cloud Lifetime



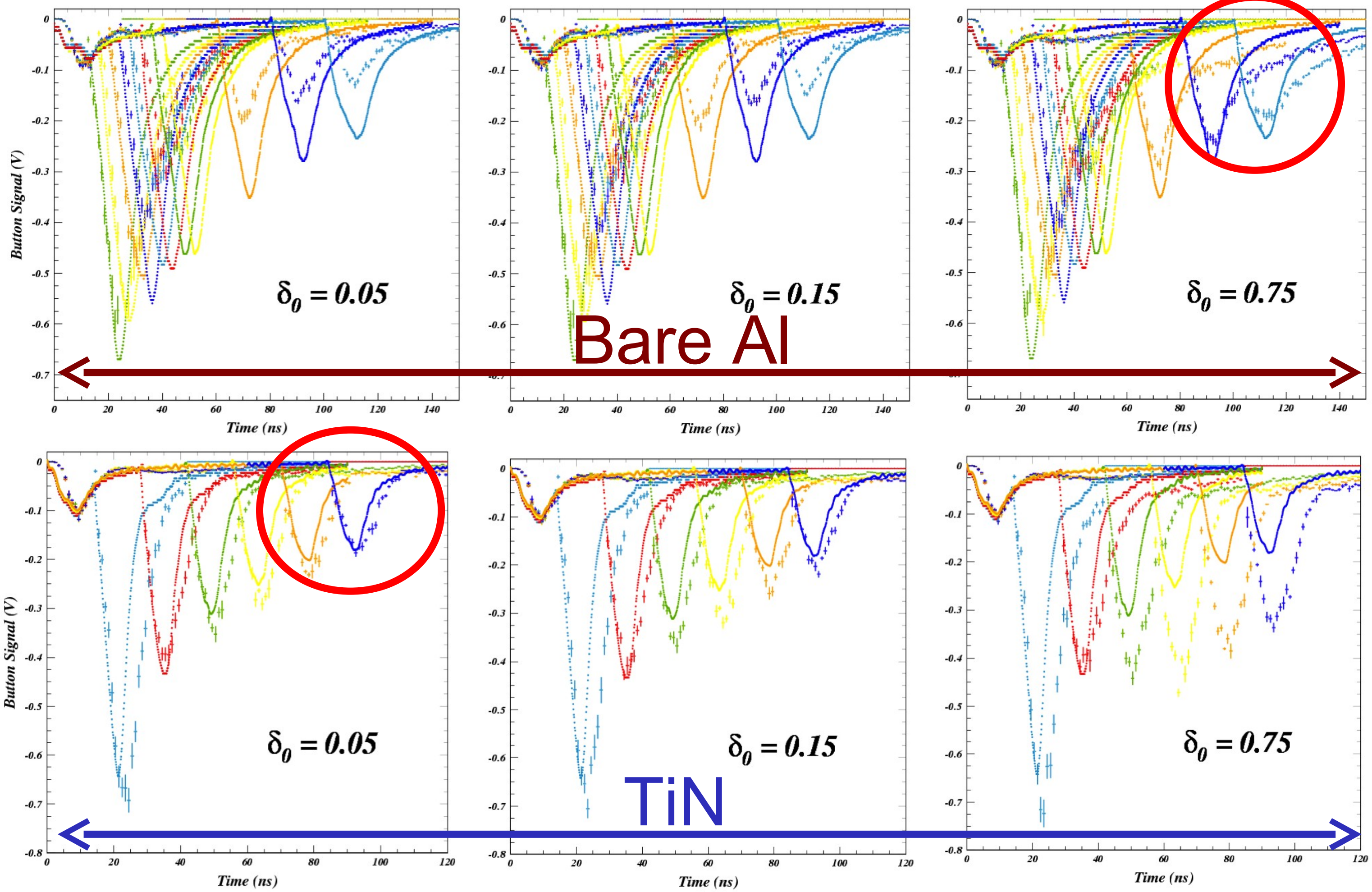
Superposition of eleven two-bunch SPU signals with time delays between 12 and 100 ns, compared to the ECLOUD model result

The cloud lifetime following passage of the final bunch is determined by the elastic secondary process, because it dominates at low incident electron energy, while the true and rediffused secondary processes both produce secondaries with reduced energy.

This was the original motivation for the shielded pickup development and was the analyis of first priority. These analyses have shown cloud lifetimes for the coated chambers (TiN, amorphous carbon, and diamond-like carbon) to be dramatically shorter than for the uncoated aluminum chamber.

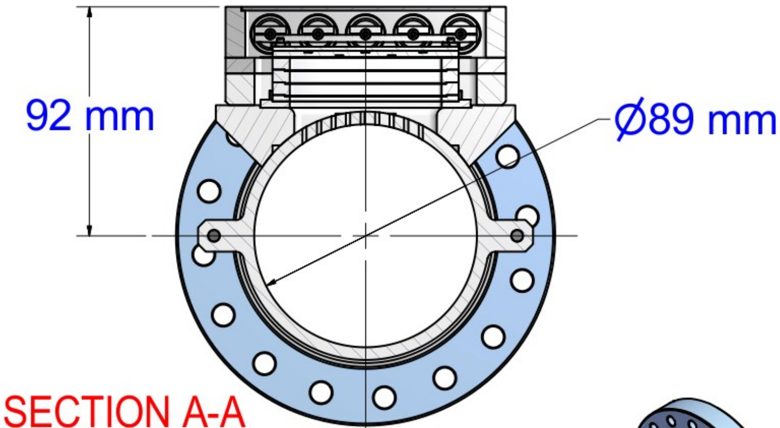
This early study shows discrepancies with the measured signals which were later found to be due to an unrealistic model for photoelectron production. Despite these deficiencies in the model, the conclusion that an elastic yield value of 0.05 is too low for this uncoated aluminum chamber is clear.

Determining the Elastic Yield Parameter δ_0 – Compare uncoated Al with TiN coating--

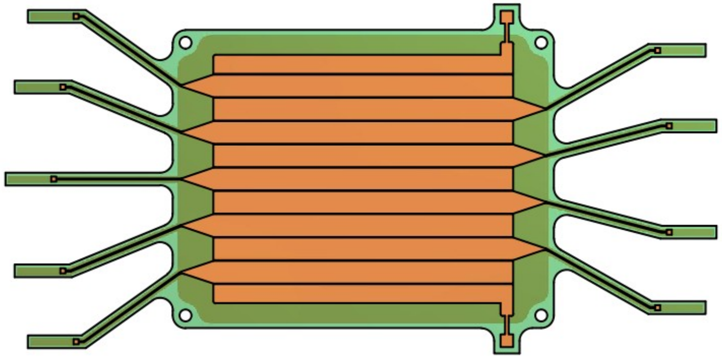


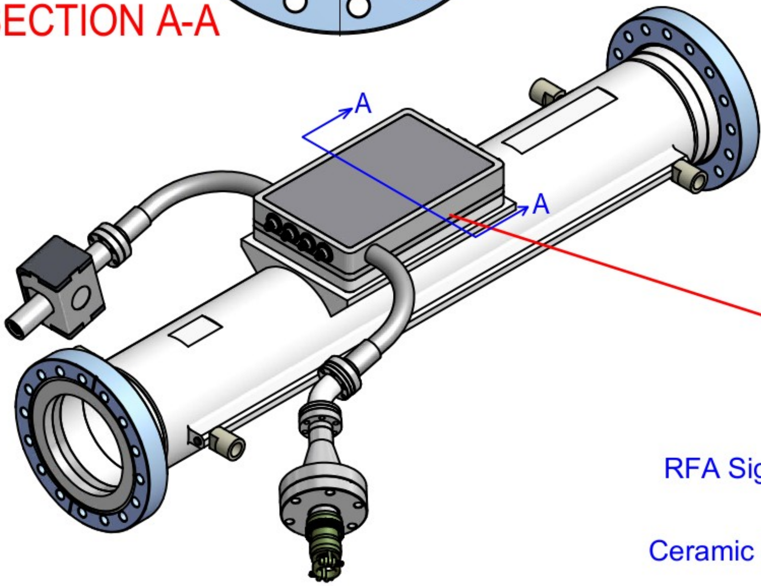
Witness bunch studies with delays up to 100 ns show clear sensitivity to the secondary elastic yield parameter, giving a value of about 0.75 for bare aluminum and about 0.05 for the TiN coating.
The discriminating power is independent of the photoelectron model.

New Time-Resolved RFA's in L3

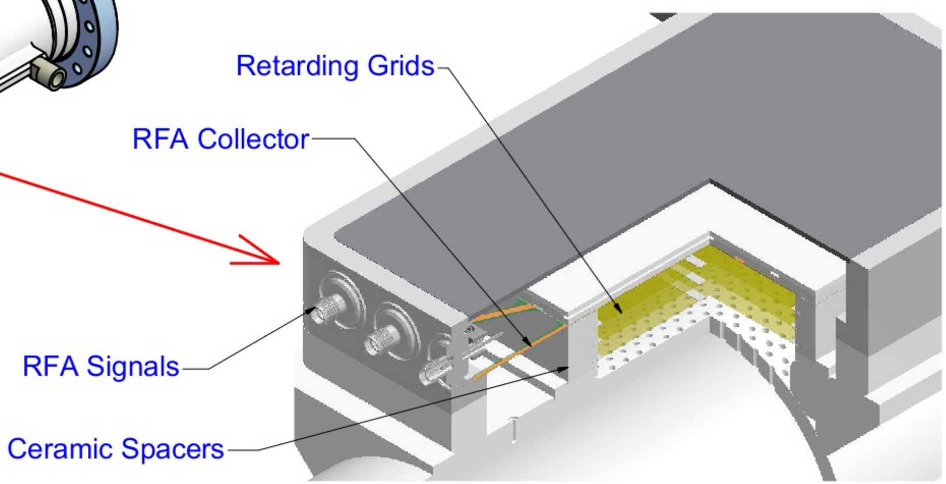


SECTION A-A


RFA Collector with 9 channels

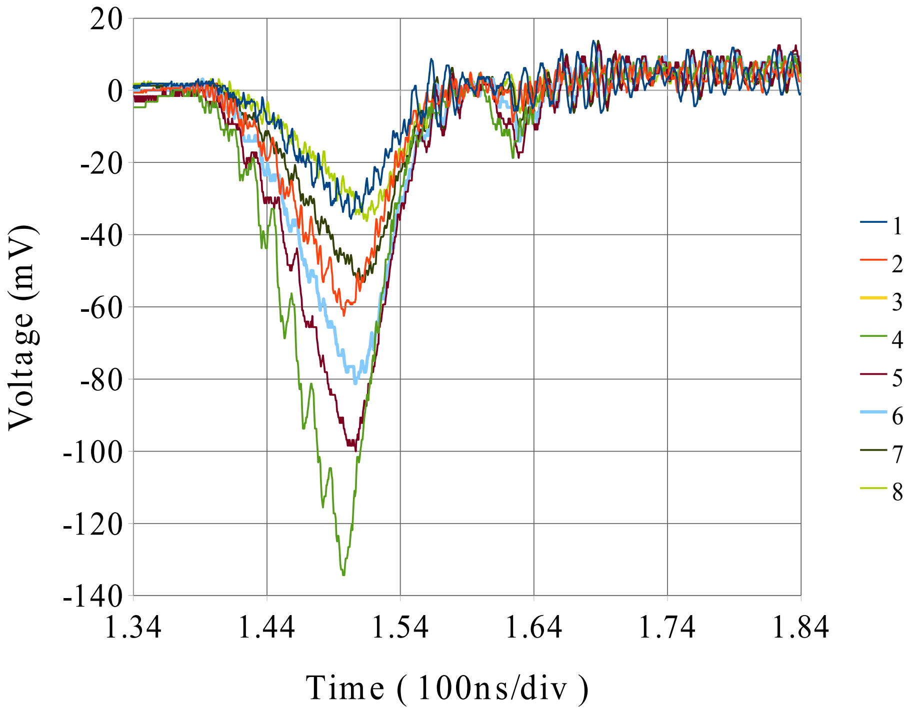


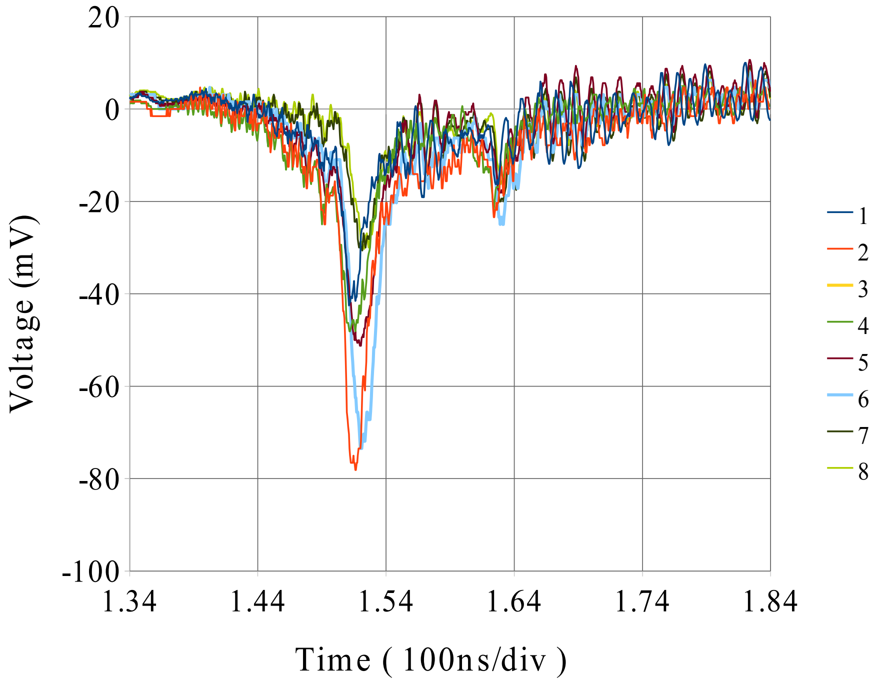
TR-RFA Vacuum Chamber



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}.

Conclusions and Next Steps

Conclusions

Time-resolved measurements of cloud buildup using shielded pickup detectors can provide remarkable discriminating power between photoelectron and secondary electron production processes. They also provide information distinguishing the various processes contributing to secondary electron production.

In particular, such time-resolved information is very sensitive to the production kinematics for both photoelectrons and secondary electrons.

**New information using this method is also coming from the CERN PS.
See G.Rumolo, these proceedings. IPAC'12, WEPPR010, F.Caspers et al, "The impressive resemblance (between simulation and measurement) suggests that our electron cloud model correctly describes the phenomenon and the rationale for the data analysis is promising."**

Next Steps

This summer we will remove the custom amorphous carbon and diamond-like carbon-coated vacuum chambers and replace them with uncoated aluminum and TiN-coated chambers. This will allow us to test the method of studying conditioning for coatings where the SEY is known to change.

Two additional time-resolved RFA's will be installed in grooved chambers, both uncoated and TiN-coated.

Extensive data samples for electron beams and with solenoidal magnetic fields remain to be analyzed.

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