INITIAL MODELING OF ELECTRON CLOUD BUILDUP IN THE FINAL-FOCUS QUADRUPOLE MAGNETS IN THE SUPERKEKB POSITRON RING

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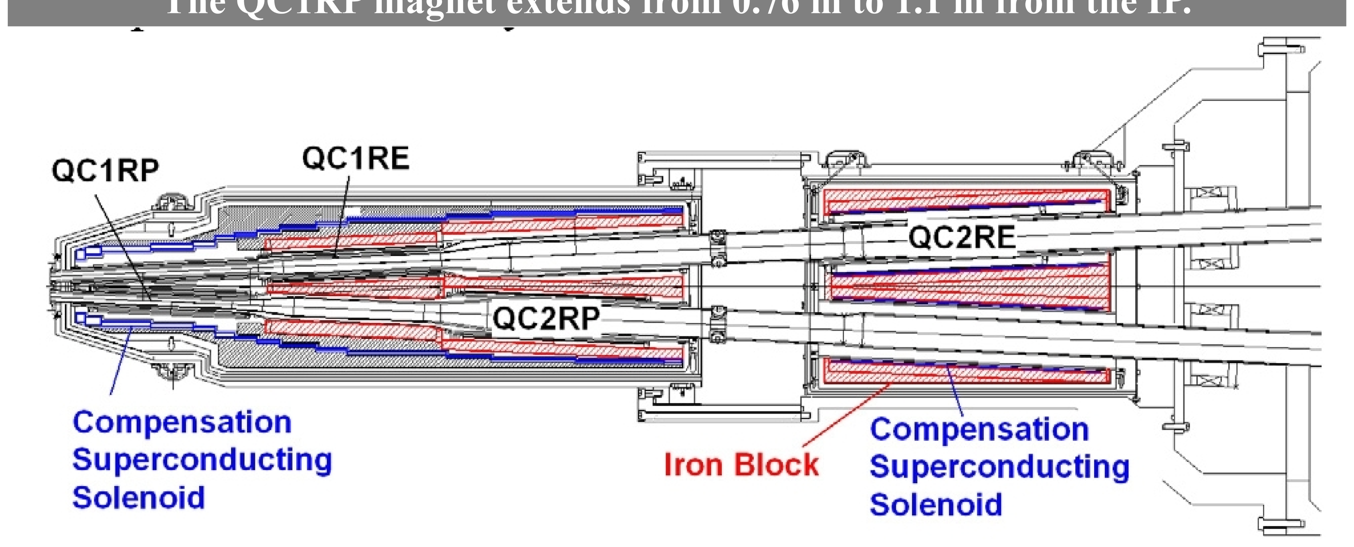
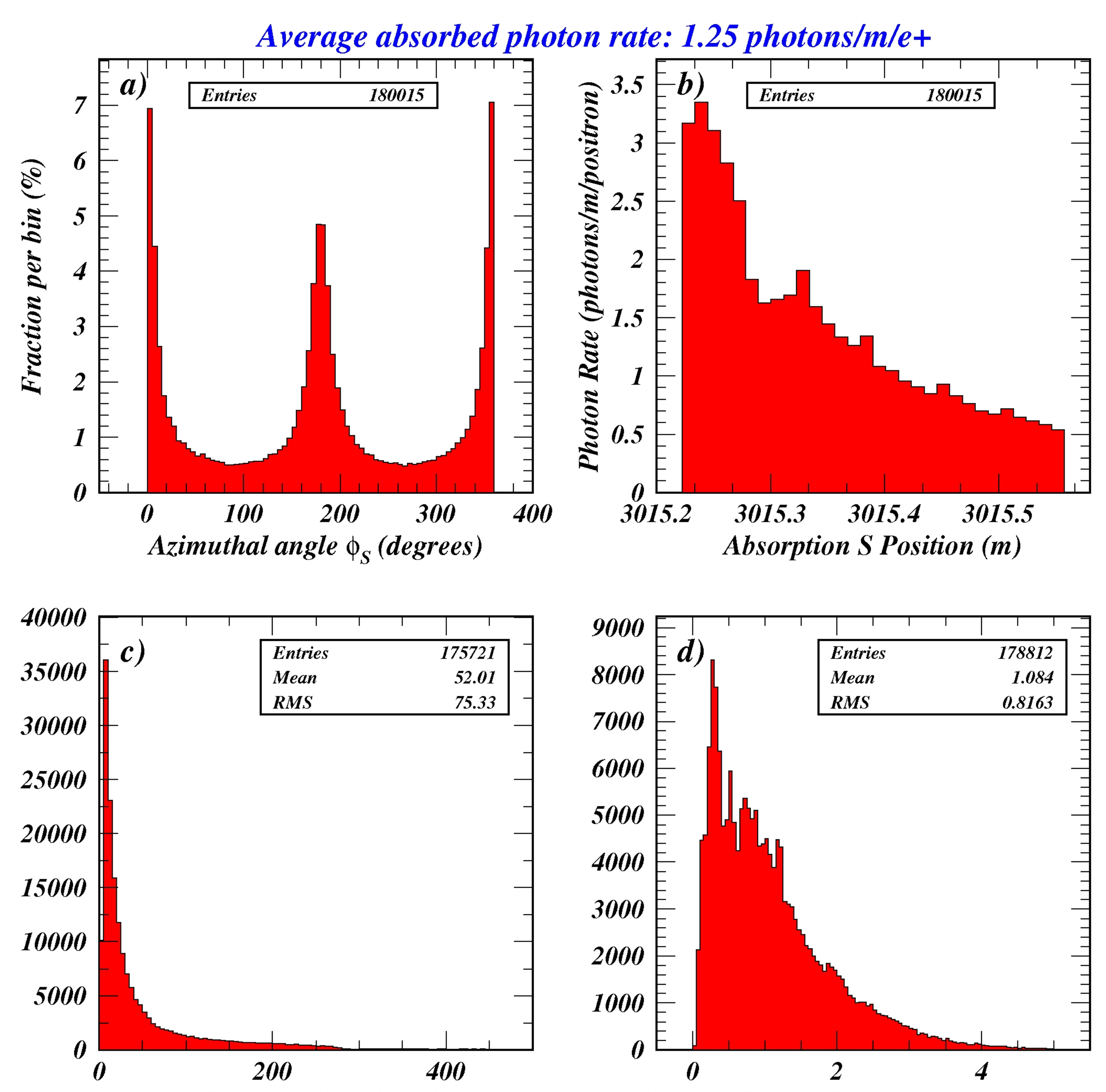
Abstract

We present modeling results for electron cloud buildup in the final-focus quadrupole magnet nearest the interaction point in the SuperKEKB positron storage ring. The calculations employ as input recently obtained estimates of synchrotron radiation absorption rates on the vacuum chamber wall including the effect of photon scattering. While the effect both adds to and subtracts from photoelectron production at the points in the ring where unscattered photons strike the wall, it also produces cloud in the other regions. Results for beam-pipe-averaged and beam-averaged cloud densities are presented, as are estimates for the contribution to the fractional vertical coherent tune shift. The effect of the strong magnetic fields is studied and the dependence on the vacuum chamber surface secondary yield characteristics is considered. Cloud buildup is modeled with a 2D particle-in-cell macroparticle tracking code validated using recent measurements of electron trapping in a quadrupole magnet at the Cornell Electron Storage Ring Test Accelerator.

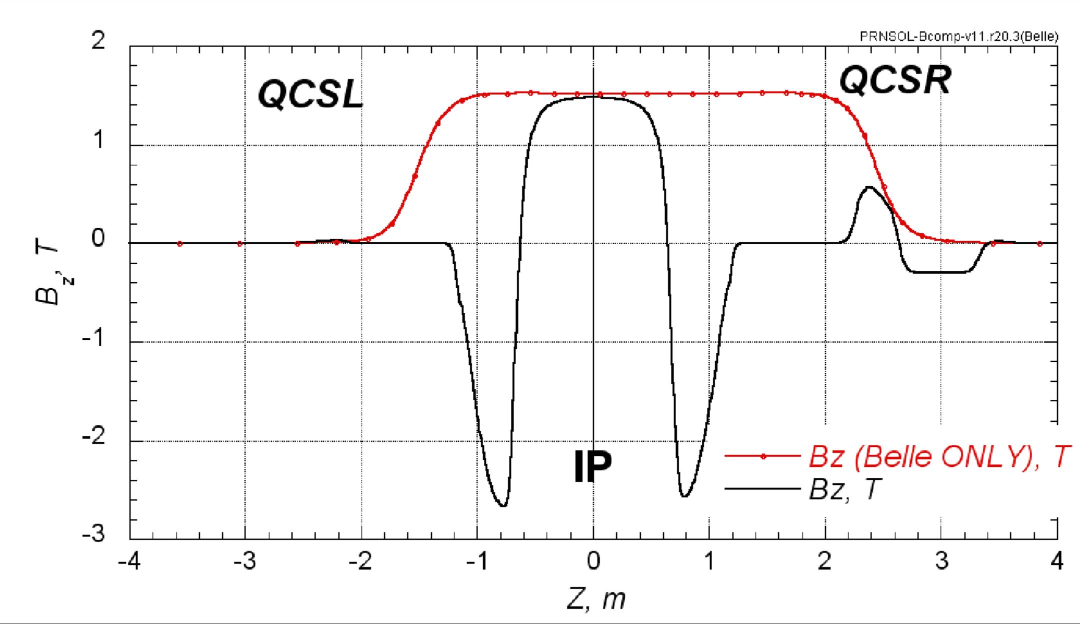
Final-focus quadrupoles in the positron ring upstream of the interaction point. The QC1RP magnet extends from 0.76 m to 1.1 m from the IP.



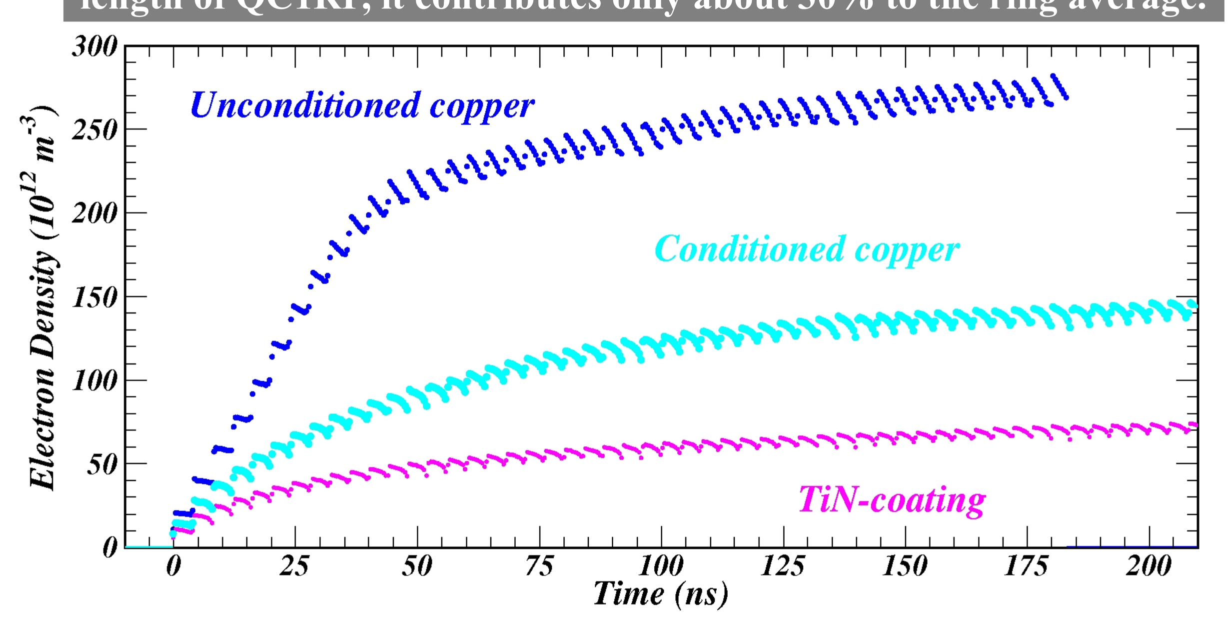
Results from the photon tracking and scattering code Synrad3D (TUPTY080) for the photon absorption rate and distribution in the QC1RP superconduction final-focus magnet. Along with the overall rate, the azimuthal distribution is important because cloud electrons spiral around field lines. The absorbed photon energy distribution informs the choice of photoelectron production energies. The difference between photon track lengths and positron orbit is such that the beam kick is de-synchronized from the photoelectron production.



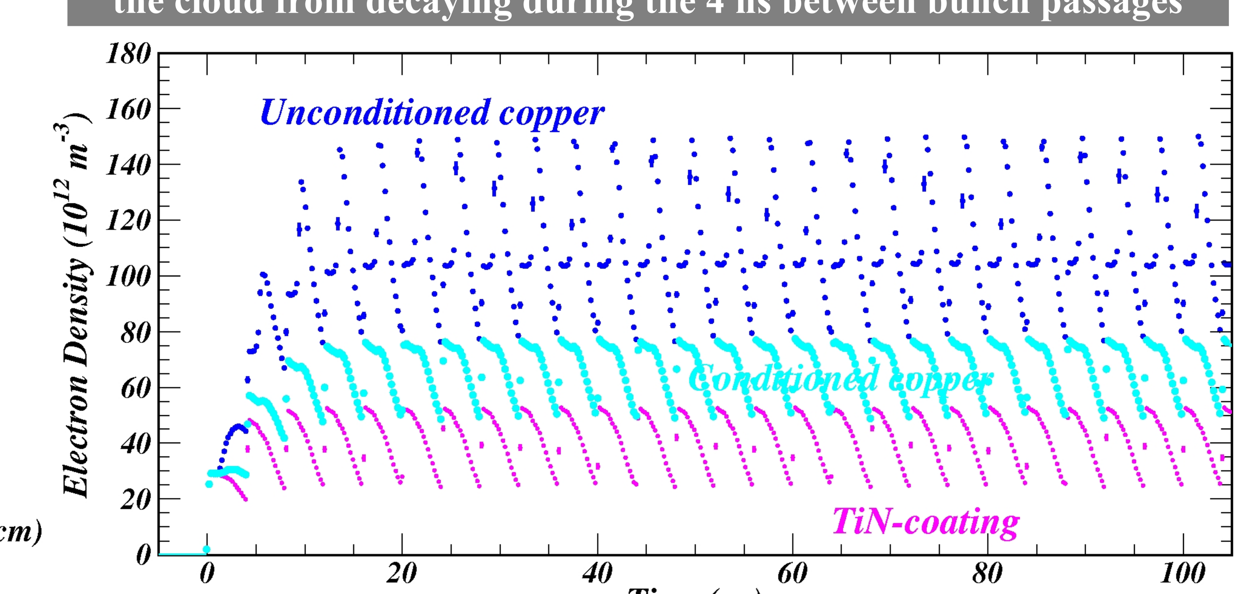
Superposed on the high-gradient (68.7 T/m !) quadrupole magnetic field is the longitudinal field of the detector-solenoid-compensating magnet system. This field varies from about 1 T/m to 2.5 T/m along the length of QC1RP and is rotated by half the crossing angle (83 mrad) around the vertical axis



The local electron cloud density is 2-3 orders of magnitude greater than elsewhere in the ring, but since it is limited to the 334-mm length of QC1RP, it contributes only about 30% to the ring average.



Turning off the magnetic field in the model shows that it prevents the cloud from decaying during the 4 ns between bunch passages



Electron cloud simulation package ECLOUD

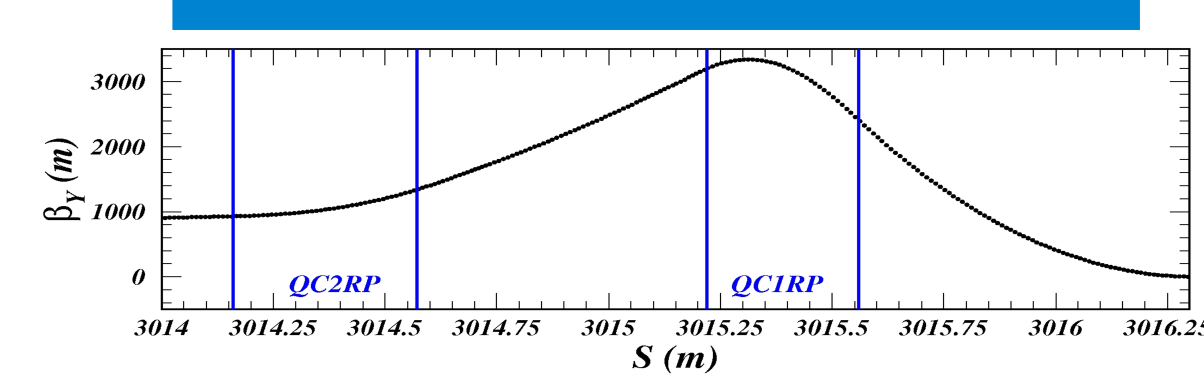
- * Originated at CERN in the late 1990's
- * Widespread application for LHC, KEK, RHIC, ILC …
- * Under active development at Cornell since 2008
- * Successful modeling of CESRTA tune shift measurements
- * Validated with CESRTA measurements of electron trapping in a quadrupole magnet (PRSTAB 18, 041001 2015)

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

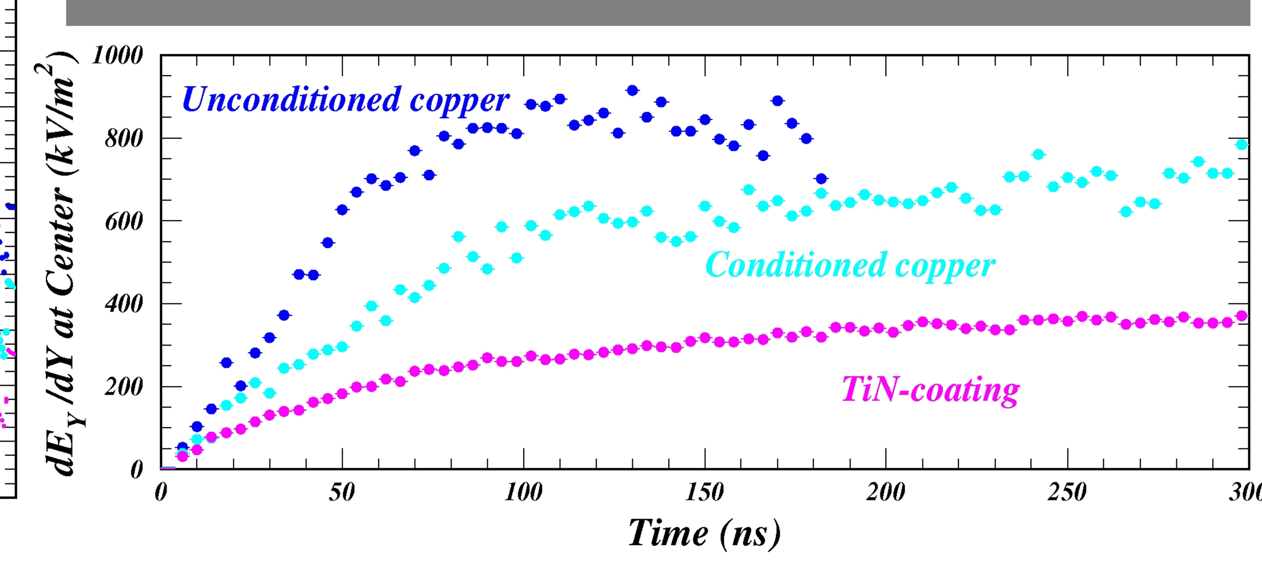
II. Time-sliced cloud dynamics
  - A) Cloud space charge force
  - B) Beam kick
  - C) Magnetic fields

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

IV. Model for a stripline detector in a quadrupole field
  - A) Acceptance vs incident angle, energy, B-field
  - B) Charge entering holes removed from cloud
  - C) Charge hitting wall creates secondaries



The cloud causes vertical focusing via the space charge field gradient. Owing to the very high beta function, the fractional tune shift value of 0.16 is about a factor of 15 higher than caused by the cloud in the entire rest of the ring.



Summary and Outlook

The first estimates of electron cloud buildup in the superconducting final-focus quadrupole magnet nearest the SuperKEKB IP in the 4 GeV positron ring indicate cloud densities 2-3 orders of magnitude higher than previous estimates, reaching 2.5 x 10^{14} m^{-3} . Beam conditioning of the as-received interior copper surface of the vacuum chamber can be expected to reduce the beam-pipe-averaged density by a factor of 2. The density resulting from a TiN coating is lower by an additional factor of 2. Most of the cloud is not near the beam, so the modeled cloud densities averaged over the transverse beam cross section at bunch arrival time are a factor of 4 lower than the beam pipe averages. Since this density is limited to a length of 0.334 m, it increases present estimates of the ring-averaged density by about 30% in the worst case. If the combined high-gradient quadrupole and off-axis solenoidal magnetic fields are absent, the cloud decays substantially during the 4-ns interval between bunch passages and the beam-averaged densities are about 1-2 x 10^{13} m^{-3} .

The contribution of this cloud to the fractional vertical coherent tune shift based on space charge calculations of the electric field gradient on the beam axis is projected to be a factor of 15 larger than previous estimates of the contribution from the rest of the ring, owing to the large beta function value of about 3000~m and the large field gradient values of 400-800 kV/m^2

Several underlying assumptions in these initial modeling results require further study. The effect on cloud buildup of the variation of the solenoidal field along the length of the QC1RP magnet must be estimated. Non-linear effects can also be expected when the factor of 6 longitudinal variation of the absorbed photon rate is taken into account. Also, systematic uncertainties resulting from the ad hoc treatment of the quantum efficiency for photoelectron production, the assumed production kinetic energy distribution, and the fraction which experiences a kick from the positron bunch, must be calculated. In addition, calculations of electron buildup in the other final-focus quadrupole magnets are needed, including those in the electron ring.

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