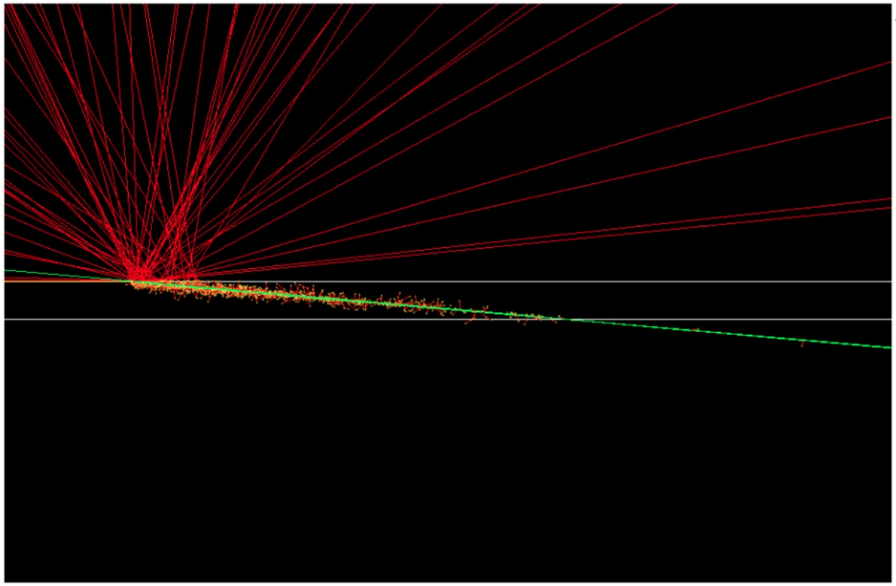
Simulations of synchrotron-radiation-induced electron production in the CESR vacuum chamber wall



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6 June 2018

Motivation

- Observations and Predictions at CESRTA and Outlook for ILC, G.Dugan et al, ECLOUD12
- The CESR Test Accelerator Electron Cloud Research Program: Phase I Report, M.A.Palmer et al, CLNS-12-2084 (2013)
- Investigation into Electron Cloud Effects in the International Linear Collider Positron Damping Ring, J.A.Crittenden et al, Phys. Rev. ST Accel. Beams, Vol 17, 031002 (2014)
- J.A.Crittenden, THPAF26, IPAC18
- S.Poprocki, THPAF25, IPAC18
- Stephen Poprocki, ECLOUD18

I) Extensive CESRTA measurements of tune shifts and beam sizes in 2016 and 2017 at 2.1 and 5.3 GeV with varying bunch populations, together with improved data-taking methods and analysis techniques pointed to the need for more sophisticated modeling.

II) While the necessity of a detailed model of synchrotron radiation photon scattering inside the CESR beam pipe had been recognized and addressed, new information on roughness, material and coating had not been taken into account.

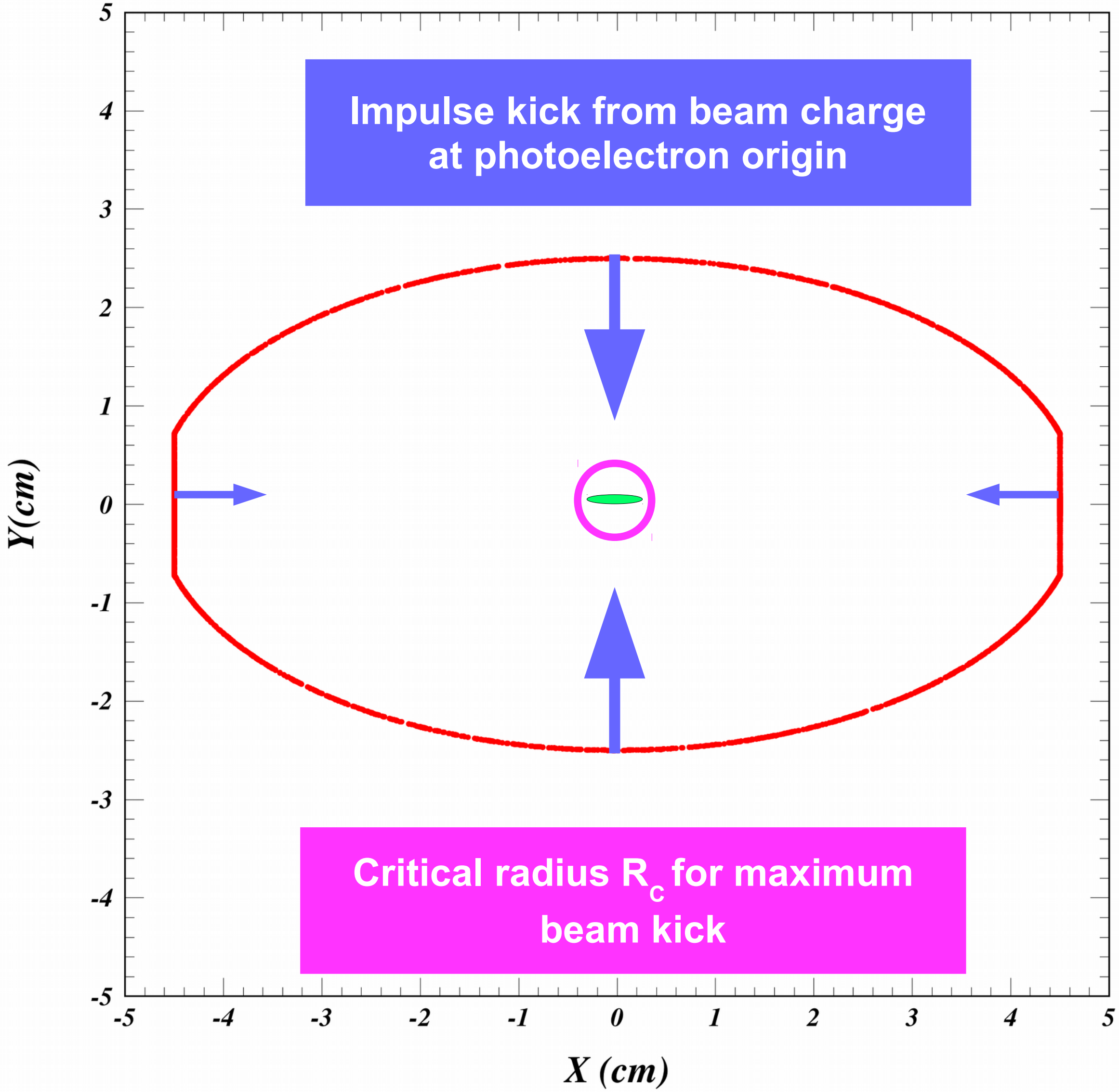
III) The assumptions in the electron cloud buildup model for the dependence of quantum efficiency on azimuthal absorbed photon location remained coarse and ad hoc, as did the photoelectron production energy distributions.

IV) Over the past decade, much progress in modeling low-energy atomic processes has been implemented in Geant4.

We describe here the implementation of a Geant4 postprocessor for the Cornell Synrad3D photon tracking code.

Motivation

Interplay of beam kicks with photoelectron energies



<u>2.1 GeV</u>

<u>0.6e10 e+/bunch (0.4 mA)</u>

X kick: 0.02 eV (-0.14 eV from image)

Y kick:1.10 eV (+0.50 eV from image)

R_C=9.2 mm

Max kick: 1.2 keV

<u>5.3 GeV</u>

<u>9.5e10 e+/bunch (6 mA)</u>

X kick: 4 eV (-32 eV from image)

Y kick: 235 eV (+120 eV from image)

R_C=3.7 mm

Max kick: 14 keV

9 eV: 25 mm/14 ns

36 eV: 50 mm/14 ns

Outline

I) **Photon tracking model extensions**

1) Effect of microgrooves
2) Dependence on pipe material
3) Effect of thin surface layers

II) **Modeling of photoelectron production**

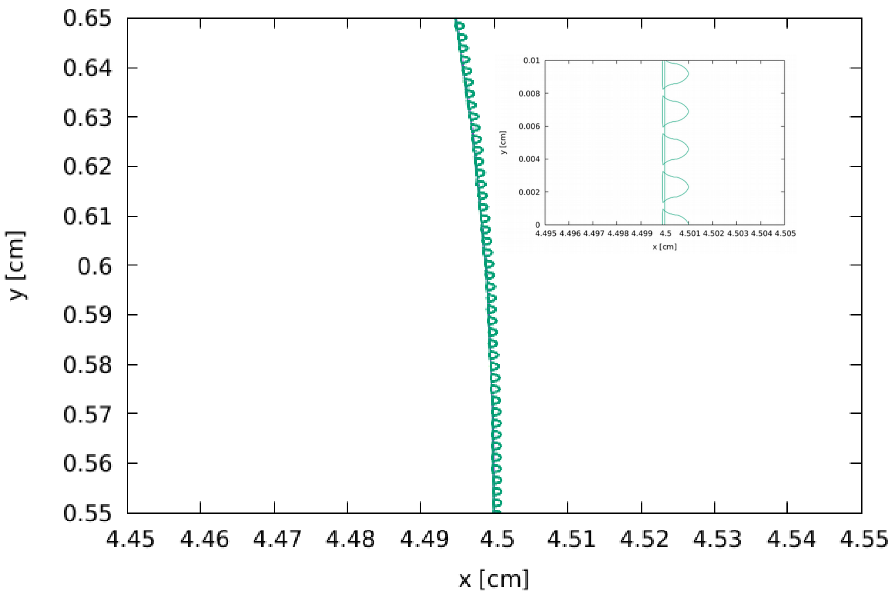
1) Photoelectric and atomic de-excitation processes
2) Dependence on beam-pipe materials

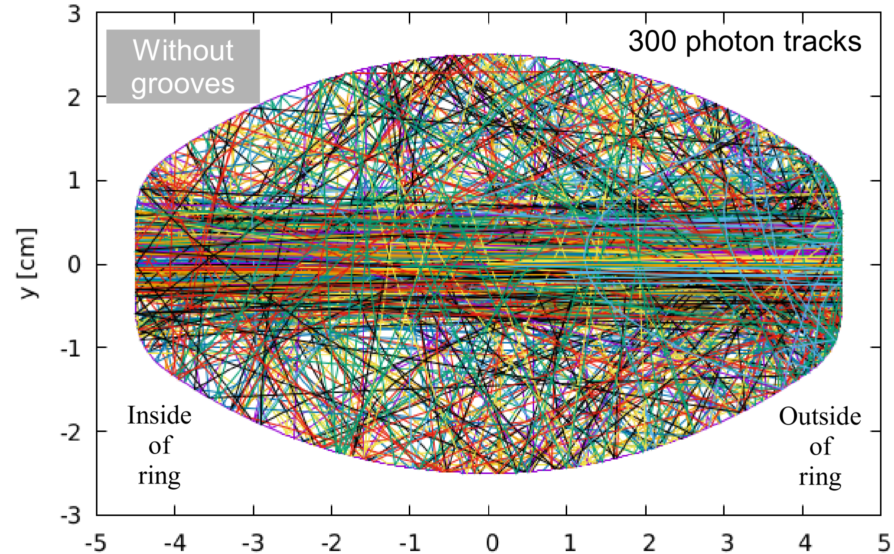
III) **Combined results input to electron cloud buildup model**

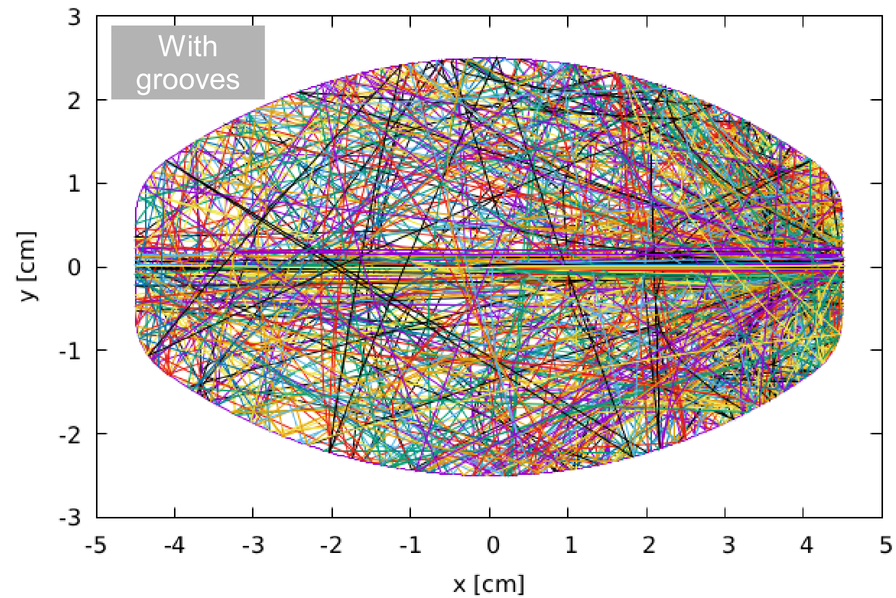
1) Photoelectron production rate distributions
2) Electron production energy distributions

Implementation of 10-μm grooves in the CESR vacuum chamber model

Measurements of x-ray scattering from accelerator vacuum chamber surfaces, and comparison with an analytical model, G. F. Dugan, K. G. Sonnad, R. Cimino, T. Ishibashi, and F. Schäfers, Phys. Rev. ST Accel. Beams 18, 040704 (2015)



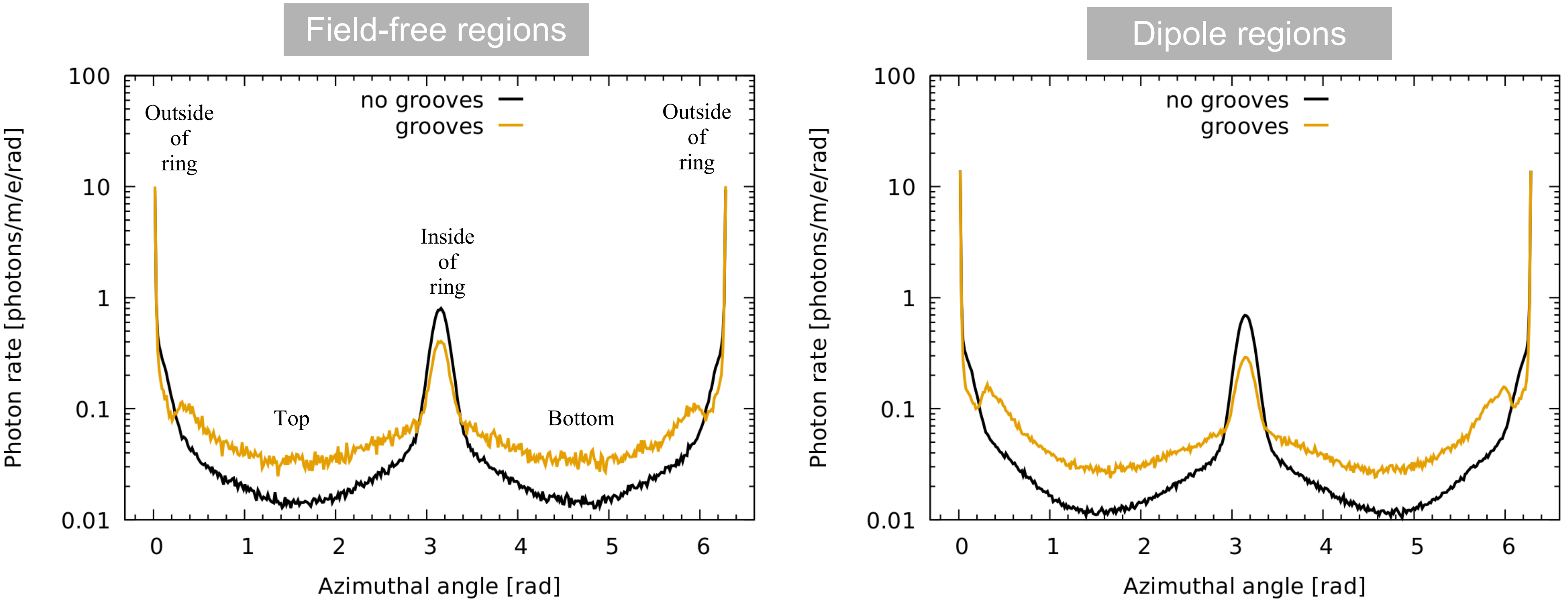




Small grooves observed in AFM measurements result in greatly enhanced out-of-plane photon scattering.

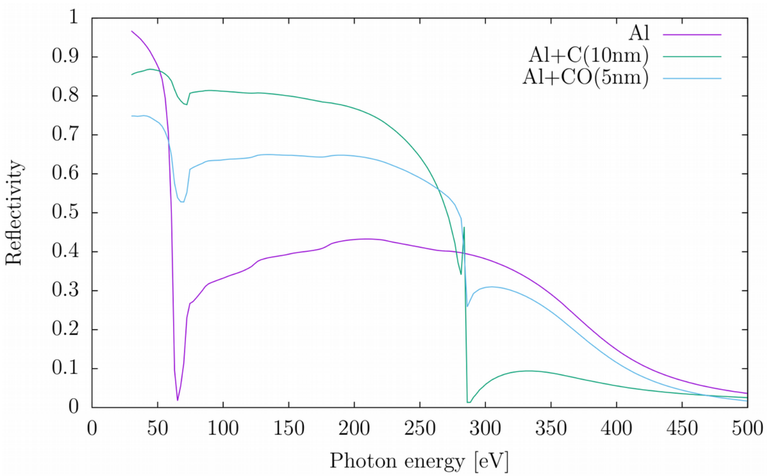
Curved trajectories in XY coordinate system result from the longitudinal pipe bend in the dipole magnet.

Azimuthal distribution of photon absorption sites



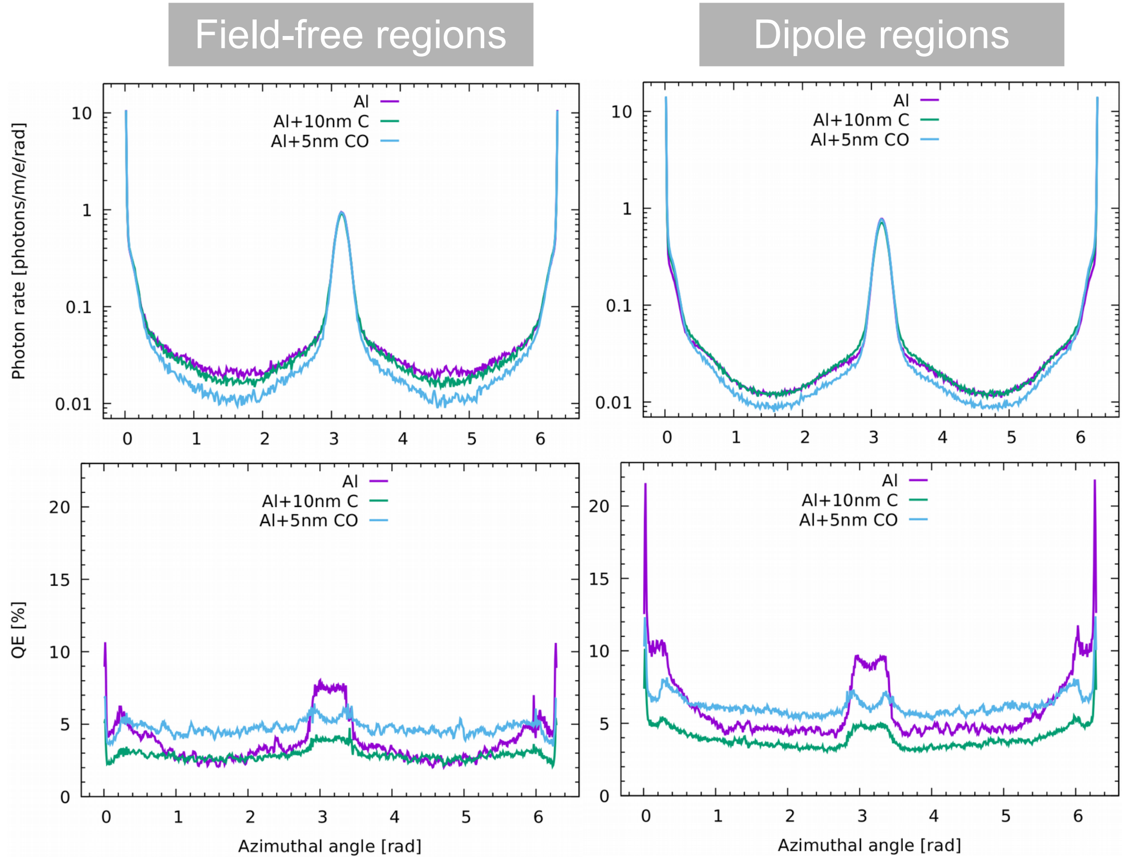
The effect of grooves is to enhance photoelectron production on the top and bottom of the beam-pipe, increasing the contribution of dipole regions to the tune shift and emittance growth calculations owing to cloud pinning on the magnetic field lines.

Reflectivity dependence on material



Reflectivity derived from Henke LBNL tables for various vacuum chamber surface materials

Determines photon absorption site distributions, absorbed photon energies and incident wall angles

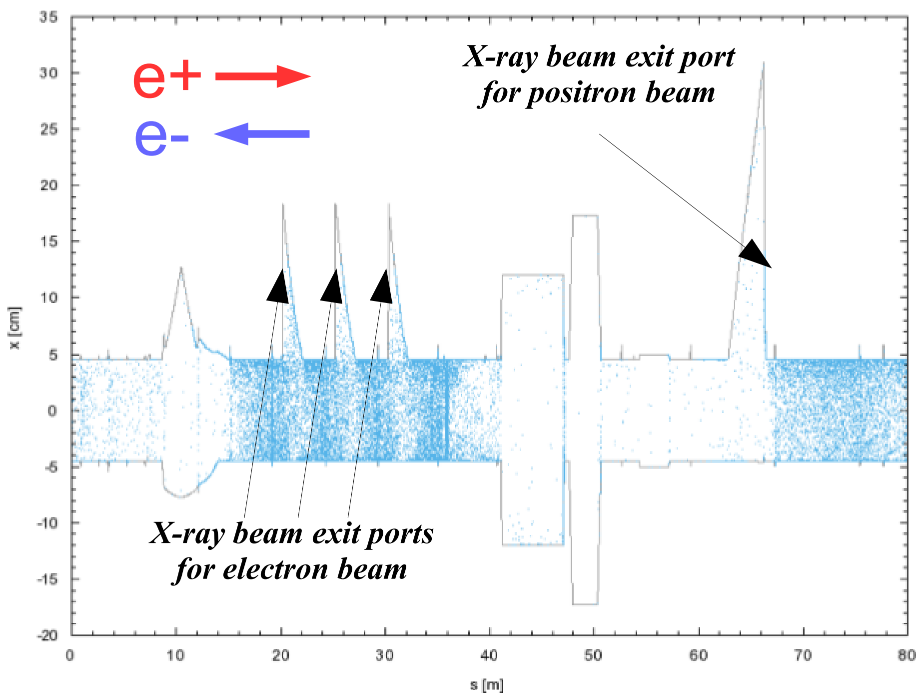


Product of quantum efficiency and photon rate used as input to electron cloud buildup model

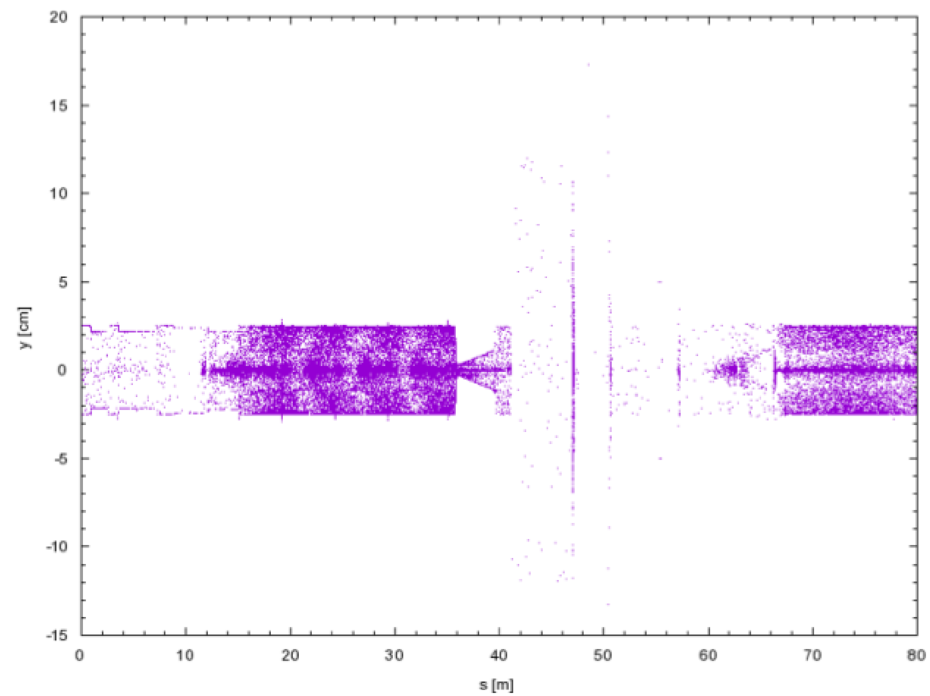
Detailed model of CESR vacuum chamber

Simulating synchrotron radiation in accelerators including diffuse and specular reflections, G. Dugan and D. Sagan, Phys. Rev. Accel. Beams 20, 020708 (2017)

Plan view



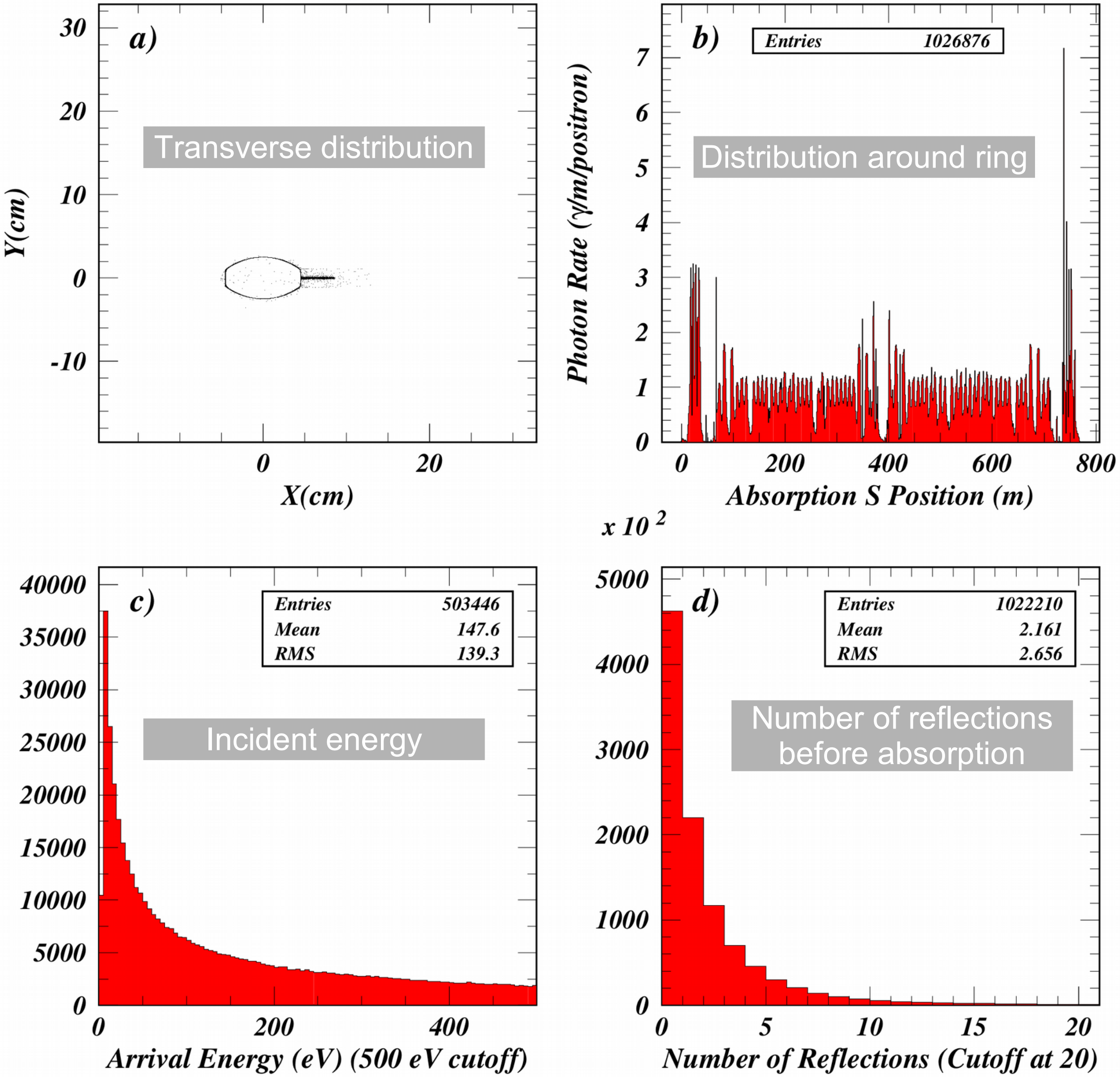
Elevation view



10^6 photons tracked around the 768-m CESR ring
Vacuum chamber model includes gate valves, bellows, etc

Photon tracking results 5.3 GeV e+ beam

Average absorbed photon rate: 0.78 photons/m/e



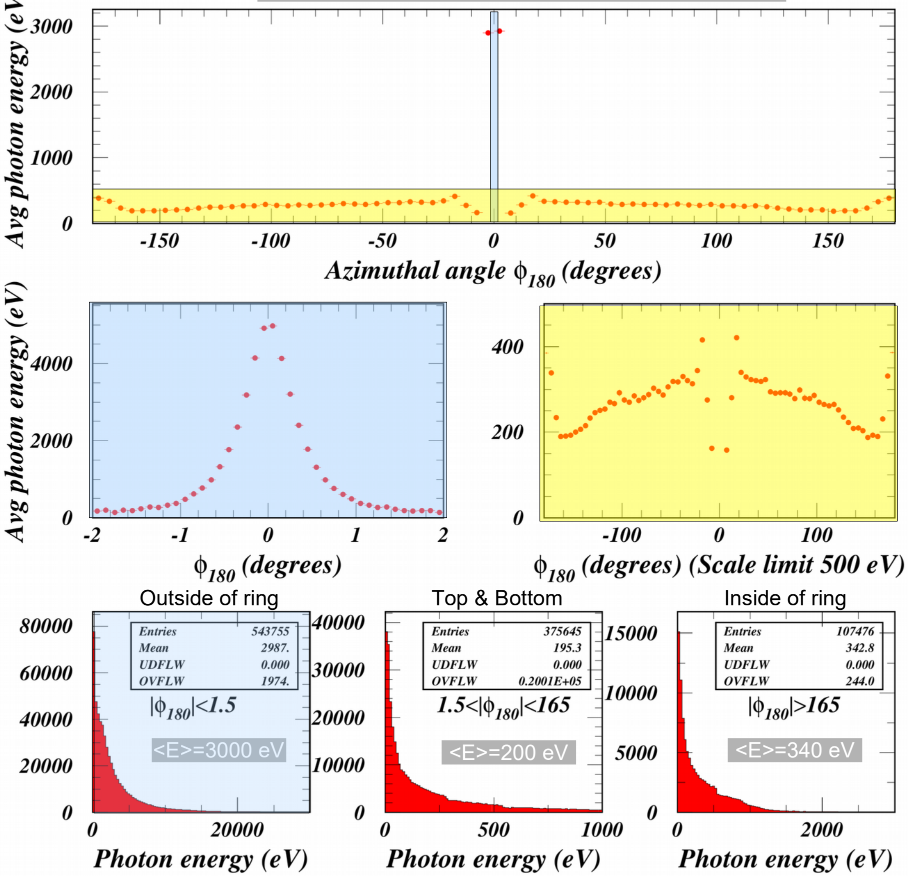
Characteristics of absorbed photons

Hot spots around ring due to vacuum chamber geometry

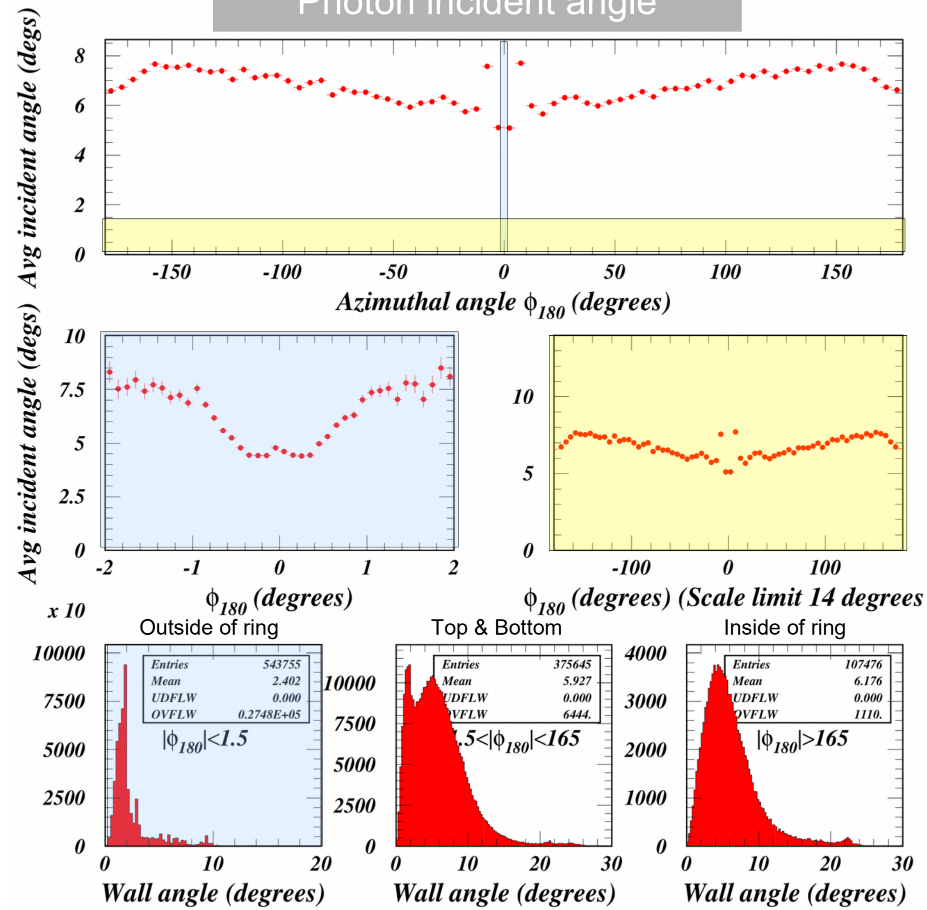
Diffuse scattering and many reflections result in absorption sites on top and bottom of vacuum chamber

Absorbed photon energies and grazing angles
5.3 GeV e+ beam

Photon energies

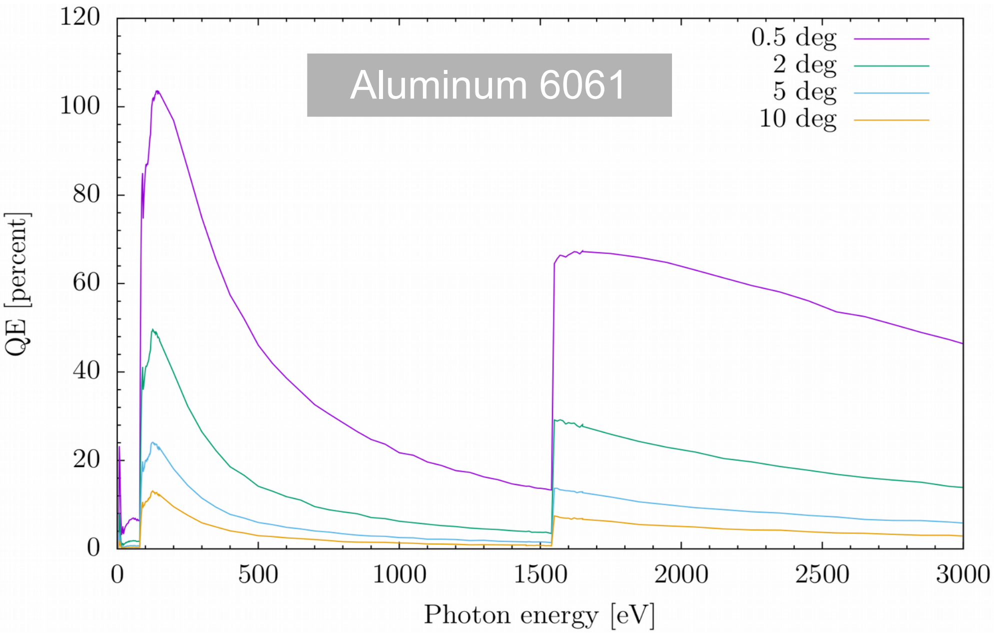


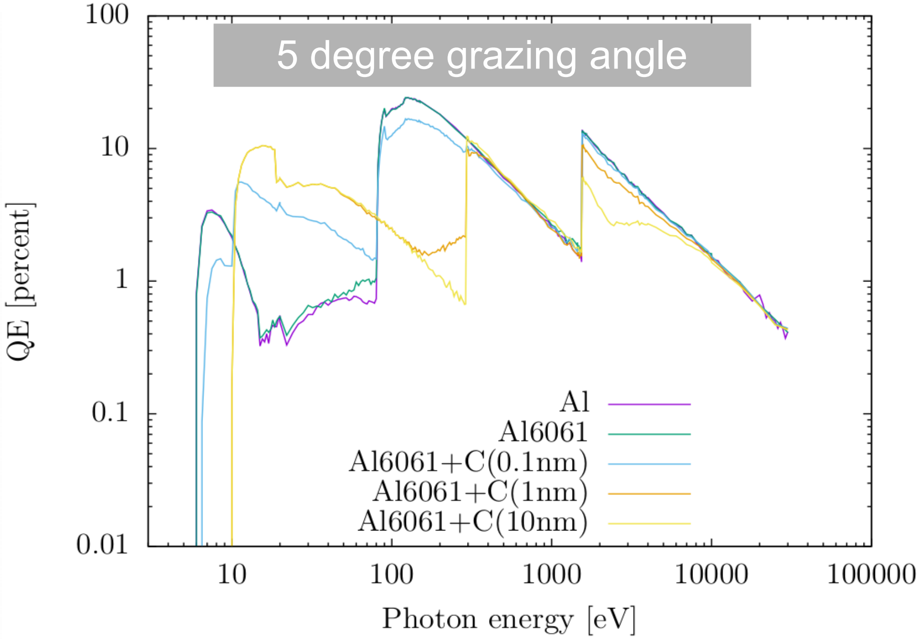
Photon incident angle



Dramatic dependence of photon energies and incident angles on azimuthal absorption location
We distinguish three azimuthal regions for generating photoelectron energies
Absorption site and energy distributions averaged over dipole and field-free regions separately for input to electron cloud buildup modeling

QE dependence on photon energy and incident angle





Geant4 photoabsorption cross sections show important dependence on photon energy and incident wall angle.

The photon tracking code Synrad3D provides this information on a photon-by-photon basis.

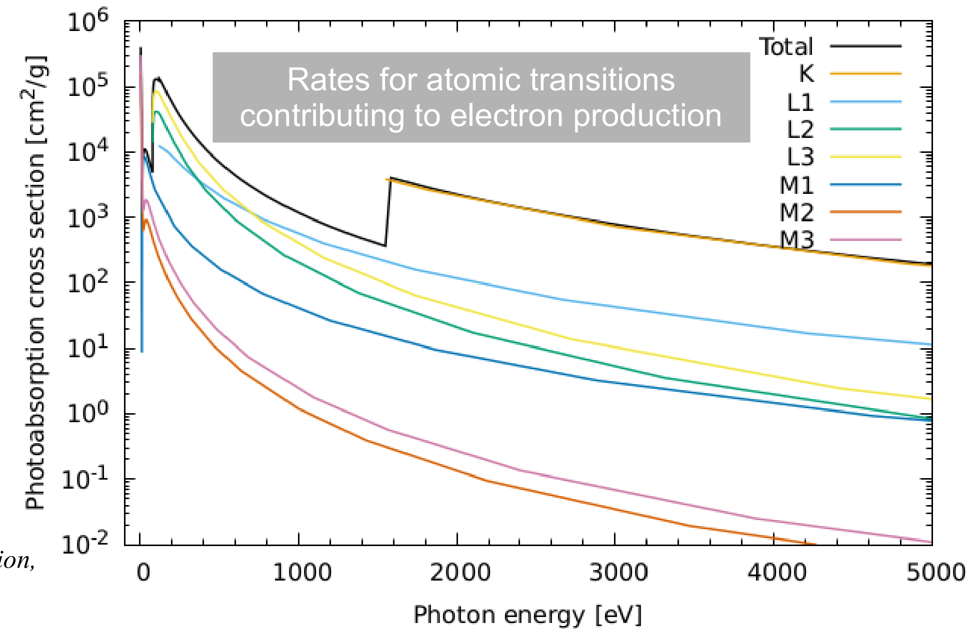
Evaluated Atomic Data Library in Geant4
-- comprehensive, detailed --

non-radiative transitions

Element	Subshells	Transition Probability	Emitted Electron (eV)
13–Al	K L1 L1	7.83944– 2	1311.80
	K L1 L2	8.32180– 2	1349.65
	K L1 L3	1.62725– 1	1350.12
	K L1 M1	1.35884– 2	1420.69
	K L1 M3	1.76485– 3	1425.98
	K L2 L2	1.42920– 2	1387.50
	K L2 L3	3.66942– 1	1387.97
	K L2 M1	6.49294– 3	1458.54
	K L2 M3	3.65883– 3	1463.83
	K L3 L3	2.09226– 1	1388.44
	K L3 M1	1.27063– 2	1459.01
	K L3 M2	3.65189– 3	1464.29
	K L3 M3	4.20421– 3	1464.30
	L1 L2 M1	2.98134– 1	27.6900
	L1 L2 M2	1.67498– 2	32.9700
	L1 L2 M3	1.46673– 2	32.9800
	L1 L3 M1	5.89896– 1	28.1600
	L1 L3 M2	1.45284– 2	33.4400
	L1 L3 M3	4.66786– 2	33.4500
	L1 M1 M1	1.12532– 2	98.7300
	L1 M1 M2	2.61944– 3	104.010
	L1 M1 M3	5.21749– 3	104.020
	L2 M1 M1	1.50408– 1	60.8800
	L2 M1 M2	8.00076– 1	66.1600
	L2 M1 M3	4.94996– 2	66.1700
	L3 M1 M1	1.44757– 1	60.4100
	L3 M1 M2	2.47625– 2	65.6900
	L3 M1 M3	8.30465– 1	65.7000

subshell parameters

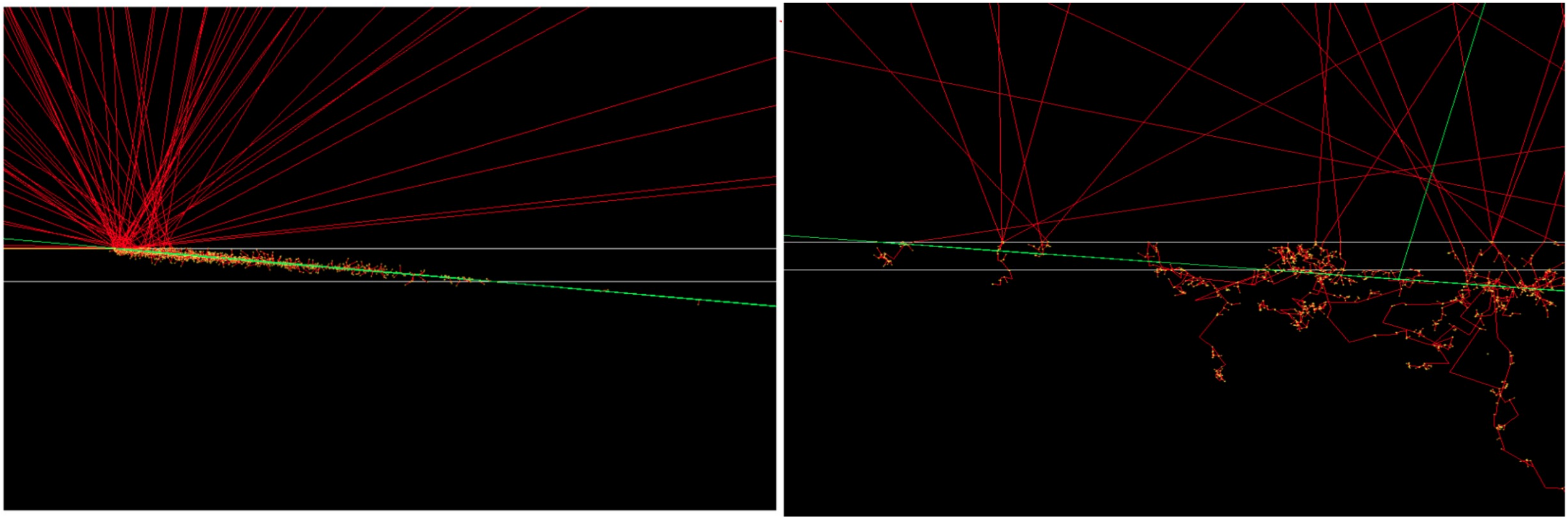
Element	Subshell	Electrons per Subshell	Binding Energy (eV)	Kinetic Energy (eV)	Average Radius (milli-A)	Radiative Width (eV)	Non-Rad. Width (eV)	"Average Total Energies" Photons (eV)	Electrons (eV)	Local (eV)
13–Al	K	2.00	1549.90	2191.00	63.1760	1.38230– 2	3.65180– 1	54.5949	1460.64	34.6619
	L1	2.00	119.050	307.380	324.100	1.48830– 5	1.38950+ 0	0.01128	93.7117	25.3270
	L2	2.00	81.2000	288.300	306.880	2.69150– 6	5.71690– 3	0.00114	65.3653	15.8336
	L3	4.00	80.7300	285.960	307.960	2.70920– 6	5.71420– 3	0.00105	64.9330	15.7959
	M1	2.00	10.1600	33.5300	1292.90					10.1600
	M2	0.33	4.88000	18.3800	1817.70					4.88000
	M3	0.67	4.87000	18.2400	1823.40					4.87000



Progress in Geant4 Electromagnetic Physics Modelling and Validation,
J. Apostolakis et al, Journal of Physics664, Nr 7, 072021 (2015)

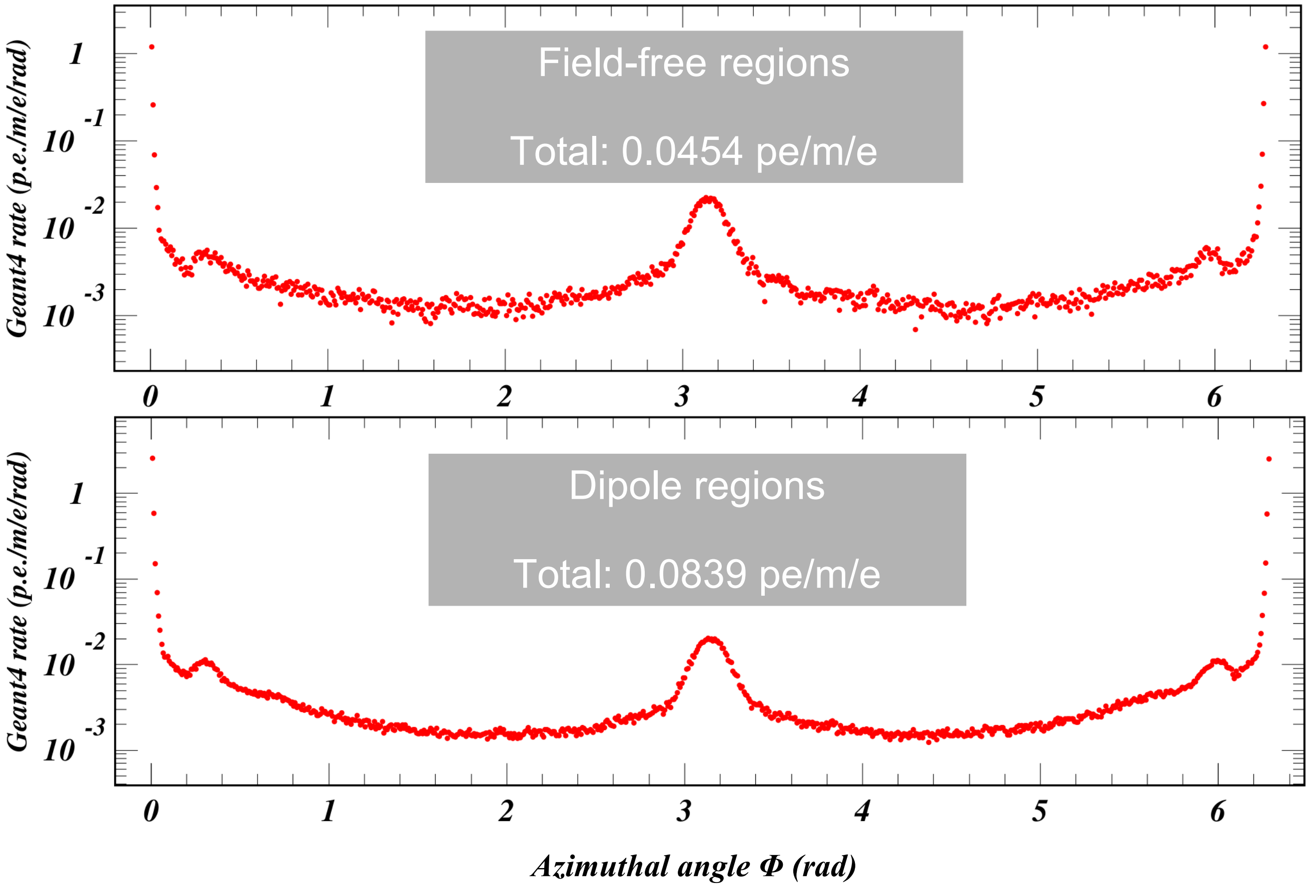
Geant4 includes rates for the photoionization and atomic de-excitation processes fluorescence, Auger and Coster-Kronig electron emission.
Vacuum chamber material composition is defined in Geant44 input file.

Geant4 events



30 eV and 2 keV photons. Zoom in on 5-nm CO layer

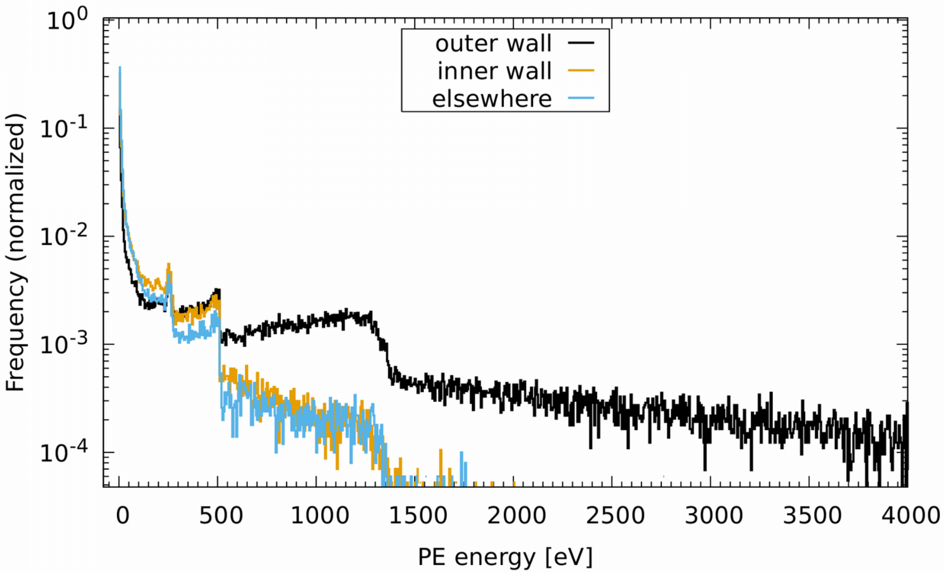
Electron production rates from Geant4
5.3 GeV e+ beam



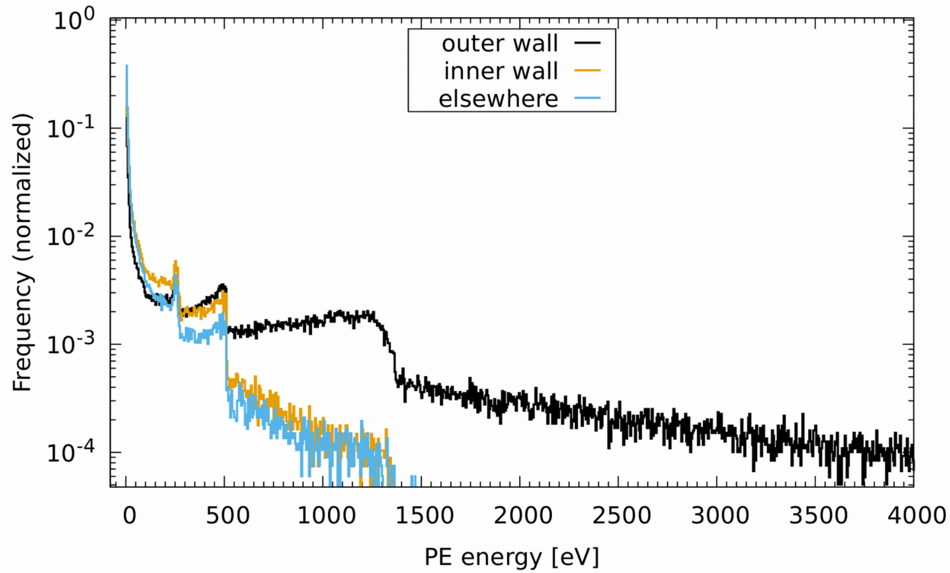
Number of electrons per beam particle per meter provided to electron cloud buildup modeling in 720 azimuthal location bins averaged over dipole and field-free regions separately.
These values replace the overall photon absorption rate and QE values used in the previous electron cloud buildup model.

Photoelectron production energies 5.3 GeV e+ beam

Field-free regions



Dipole regions



Strong dependence on azimuthal production location

Reflection selects low energy photons

Photoelectron energy distributions provided to electron cloud buildup modeling for each of the three azimuthal regions separately for field-free and dipole regions of the ring

Summary

Improved measurements and data analysis for CESRTA beam dynamics motivated detailed modeling development

Photon tracking code updated with sophisticated vacuum chamber model

Electron production model based on Geant4 implemented as post-processor for photon tracking code

Combined model validated using CESRTA tune shift and beam size measurements

Implementation of means of choosing vacuum chamber surface properties and materials enables generalisation to other applications

This work addresses the CESRTA project goal of providing validated modeling tools for present and future accelerator projects