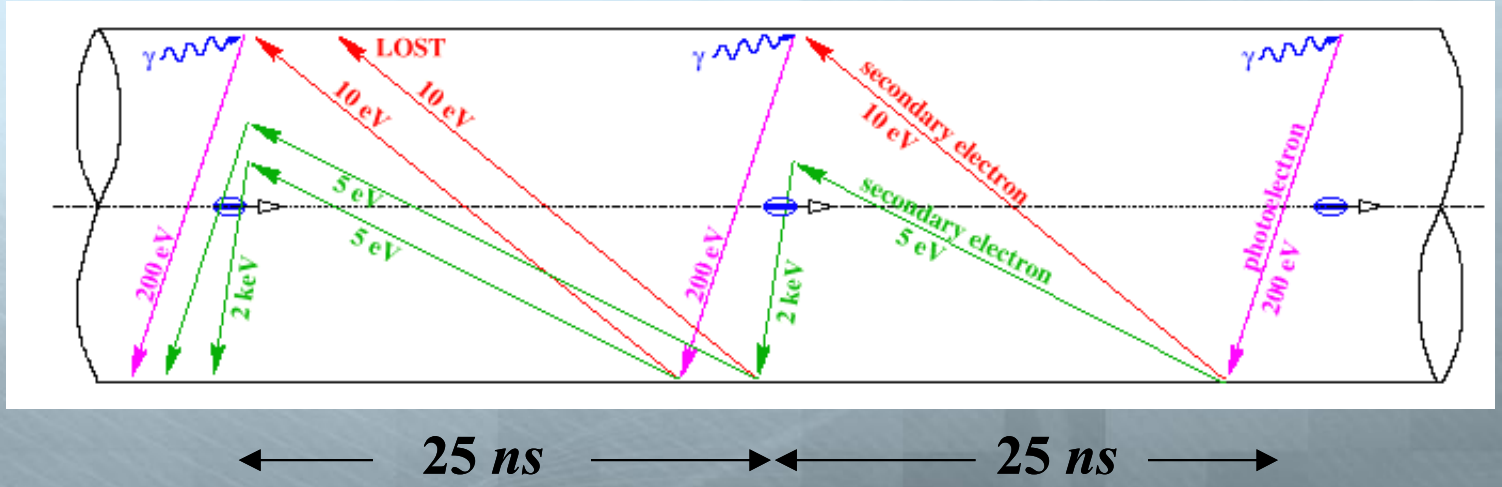


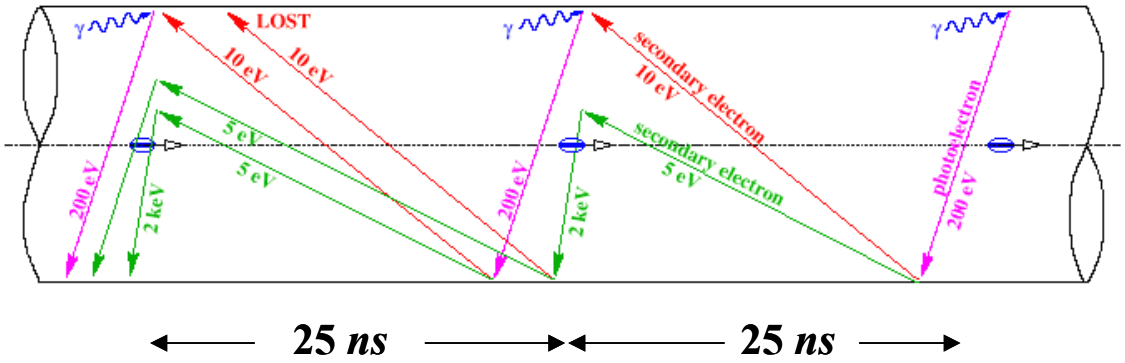
Visualization of the Electron Cloud in the Main Injector

Saksham Malhotra and Paul L. G. Lebrun

Purpose

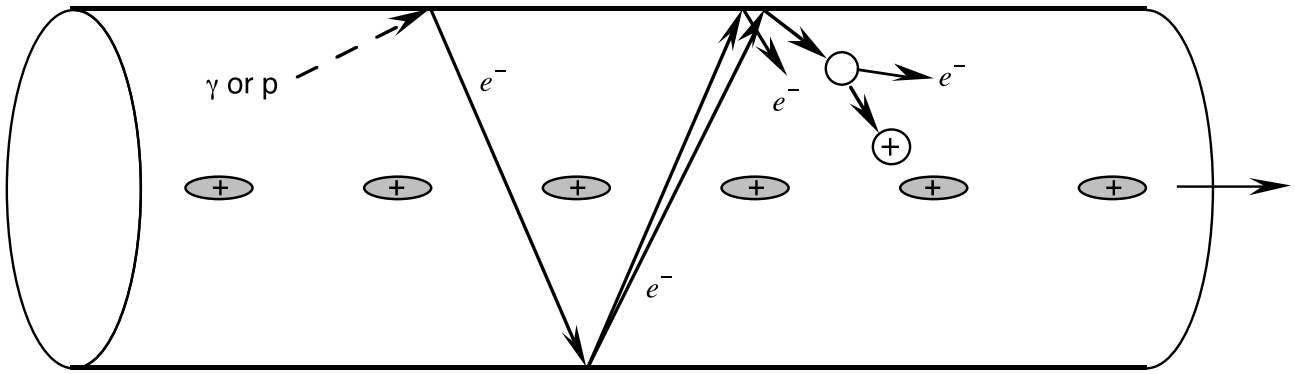
- The electron cloud effect is a phenomenon that occurs in a particle accelerator. The cloud could disrupt the beam via electro-dynamic interactions.
- Through the use of R scripting language, I am going to build a small visualization package to create compelling animations describing the dynamics of the electron cloud in the Main Injector.
- The R statistical package has been chosen because (1) it has extensive statistical capabilities and (2) has a wide range of graphical capabilities.

What is the Electron Cloud Effect?



- Beam emits photoelectrons through synchrotron radiation.
  - Beam-Gas Ionization/Stray Protons
- The photoelectrons propagate through the beam pipe.
- Upon striking the wall of the chamber, they create more electrons through Secondary Emission Yield (SEY).
- This yield is characterized by the function ^{TM}.

Formation of the Electron Cloud

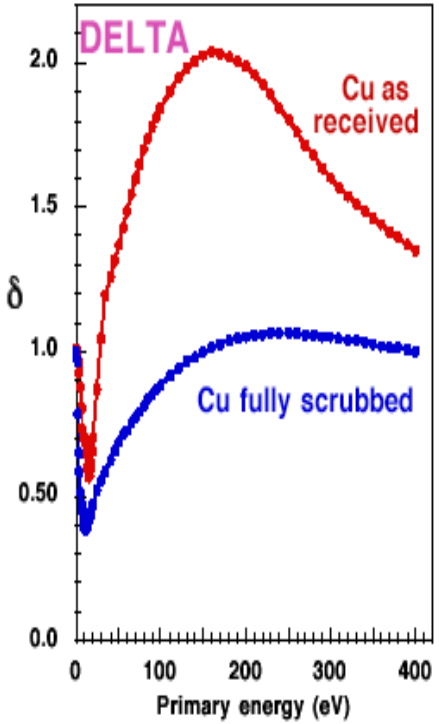


- The beam travels in a succession of short bunches.
  - With charge $Q_b = N_b Ze$
- Factors that cause the ECE:
  - Bunch intensity, bunch shape, beam loss rate, photon reflectivity, SEY, vacuum pressure, chamber size

Why does it matter?

- Many consequences for the accuracy and efficiency of the beam.
  - Multi-bunch instability
  - Emittance Growth
  - Gas desorption from walls/energy deposition on walls
  - Particle loss/interference
- How Can We Control?
  - Scrubbing
    - Reduces exponentially
  - Low-SEY Coatings

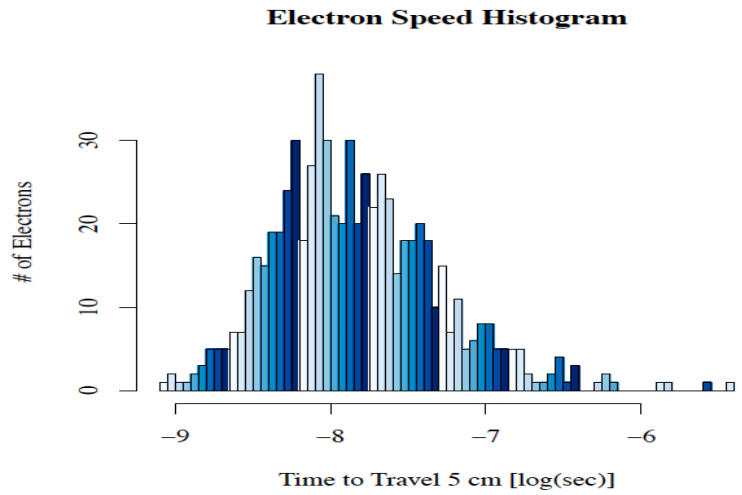
(R. Cimino and I. Collins, proc. ASTEC2003, Daresbury Jan. 03)

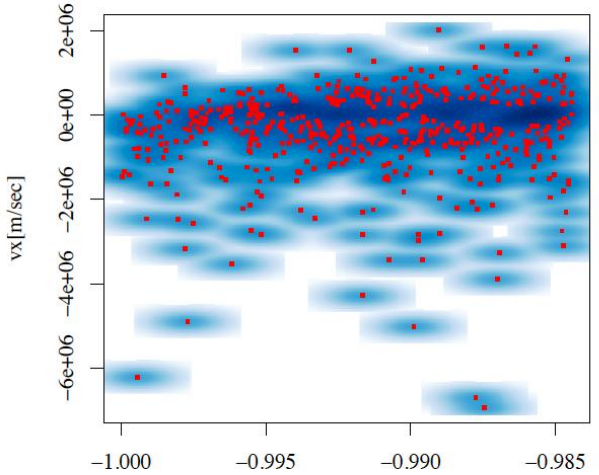


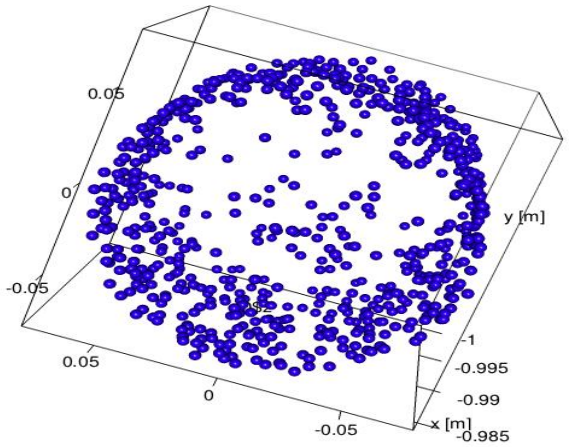
Why animate the electron cloud?

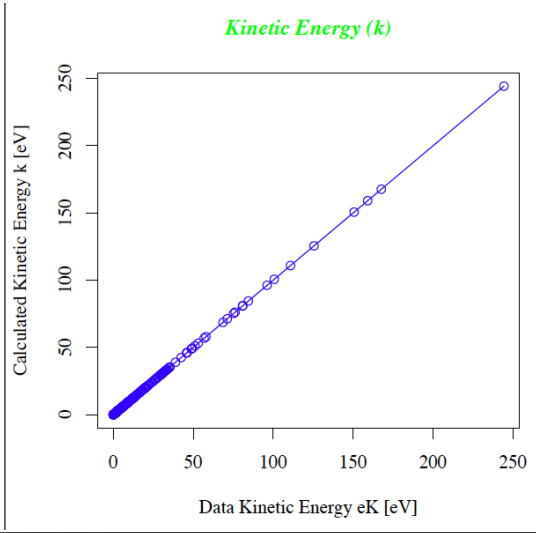
- To create a visualization of the electron cloud effect
  - Illustrate to public
  - Create an animation of the dynamics within
  - To illustrate a variety of factors, such as velocity and density, besides simply position
- Discover something new in the 3D model that cannot be seen in 2D or through the data.
  - Can be used to limit the negative effects of the electron cloud effect

Early Visualizations







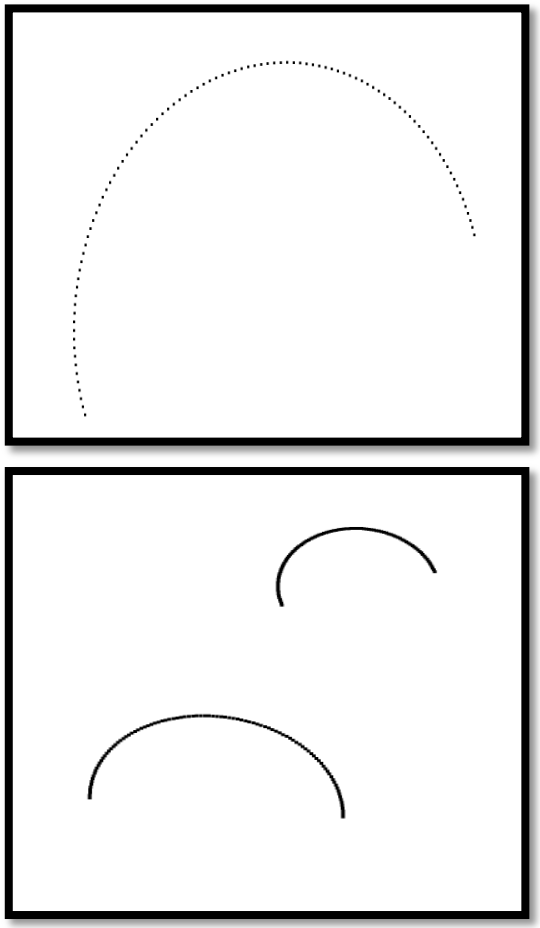


How Do We Animate?

- 2 Basic Things are needed
  - An half open cylinder that represents the chamber that the beam is traveling in
  - The electrons themselves, plotted in 3D
- Other Requirements
  - Some way to demonstrate the velocity of the electrons to gain a better understanding of the dynamics of the electron cloud
  - This some plot at multiple time-steps to be able to create an animation

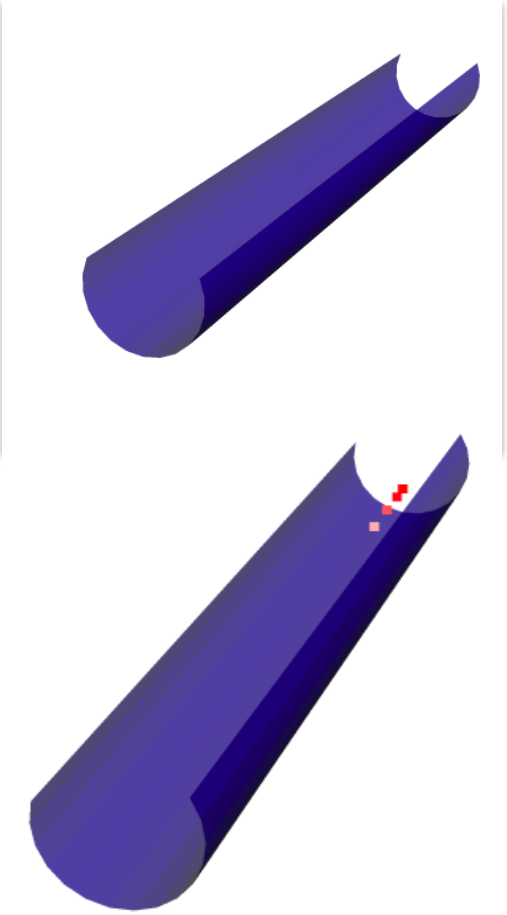
Building the Cylinder

- The next step was to "build" the cylinder in which I could create the animation of the electron cloud effect.
- Since there is no direct function in RGL (the Open GL interface for R) for creating a half open cylinder, I had to create numerous thin rectangles looping around to create my cylinder.
- This would be accomplished by first creating an initial rectangle, multiplying it by a rotation matrix to move it onto the next point in the circular motion (in a loop).
- To start off, I decided to use a single point instead of a rectangle to get a grasp of coding a loop to create my cylinder

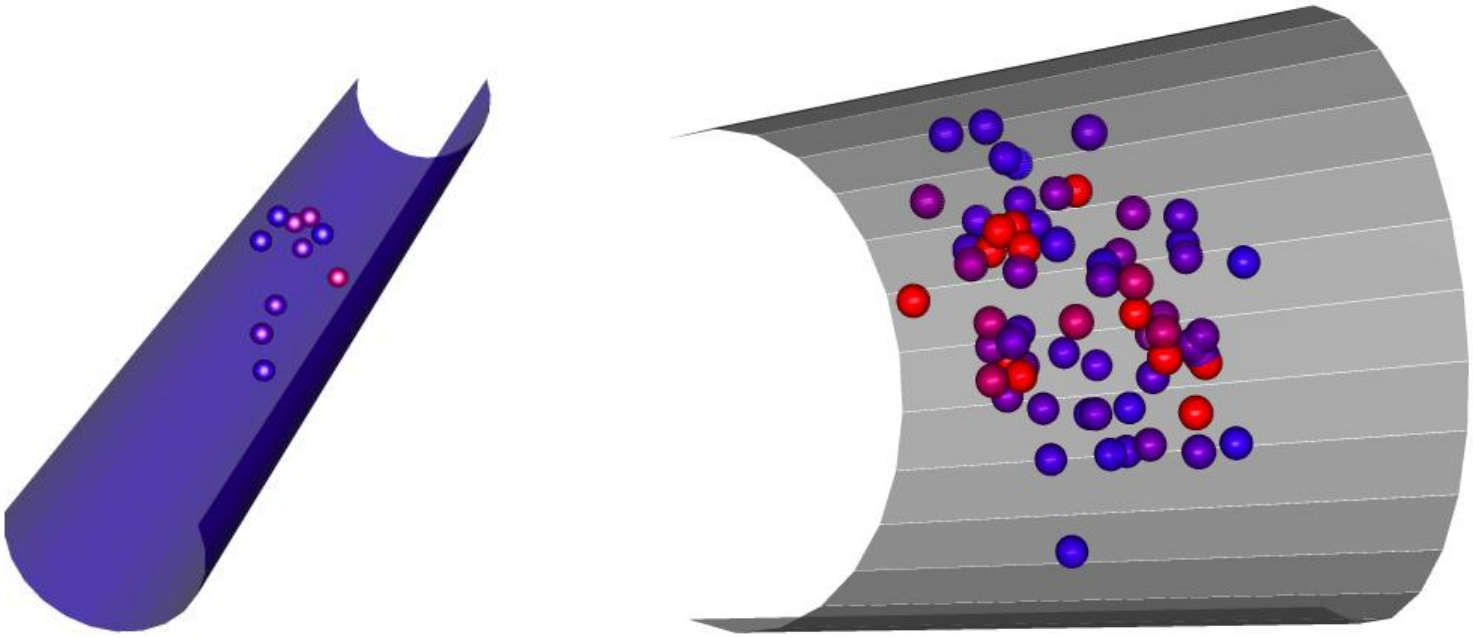


The Cylinder

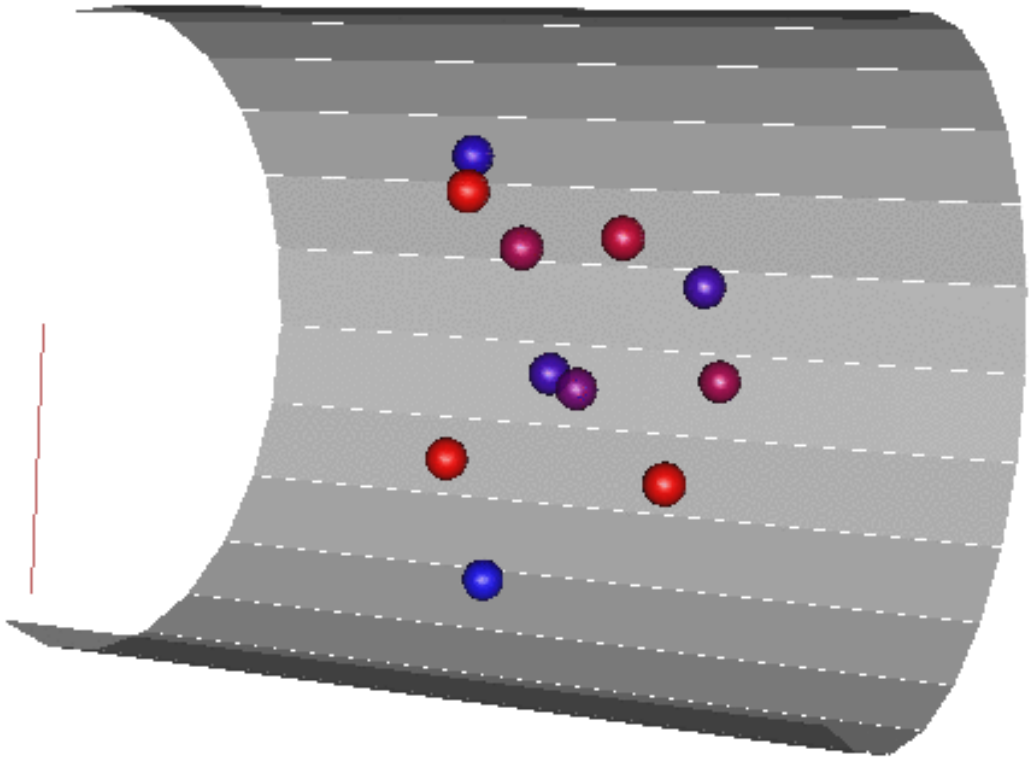
- Substituted rectangles for points and then built the cylinder.
- Adjusted the material and texture of the cylinder to add transparency, color, reflectivity, and a light source to illuminate the cylinder.
- Add a few arbitrary points within the cylinder and demonstrate velocity.



Electron Cloud Visualizations



Animation



Conclusion

- The Electron Cloud effect is a detrimental effect in the Main Injector by having consequences for the efficiency and accuracy of the beam.
- A 3D animation is valuable because it creates an easily viewable visualization and maybe reveal more than the data or a 2D drawing.
- The visualization reveals how the electrons disrupt by “clouding” around the beam.
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Acknowledgements

- Paul LeBrun
- Everyone Else