Using VSim to Model Corona Discharge

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Background

- A potential difference is established between two boundaries
  - Boundaries could be conductors or dielectrics
  - In my examples, one boundary is a conductor, the other is a dielectric
- A free electron forms through some process
  - Could be from a stray cosmic ray
  - Could be from UV
- This happens frequently. At normal atmospheric pressure when no potential difference exists, the electron is re-absorbed by a neutral
- If a potential difference exists, then the electron is accelerated, bombards another neutral, creating more free electrons and a cascade effect is launched

What is VSim?

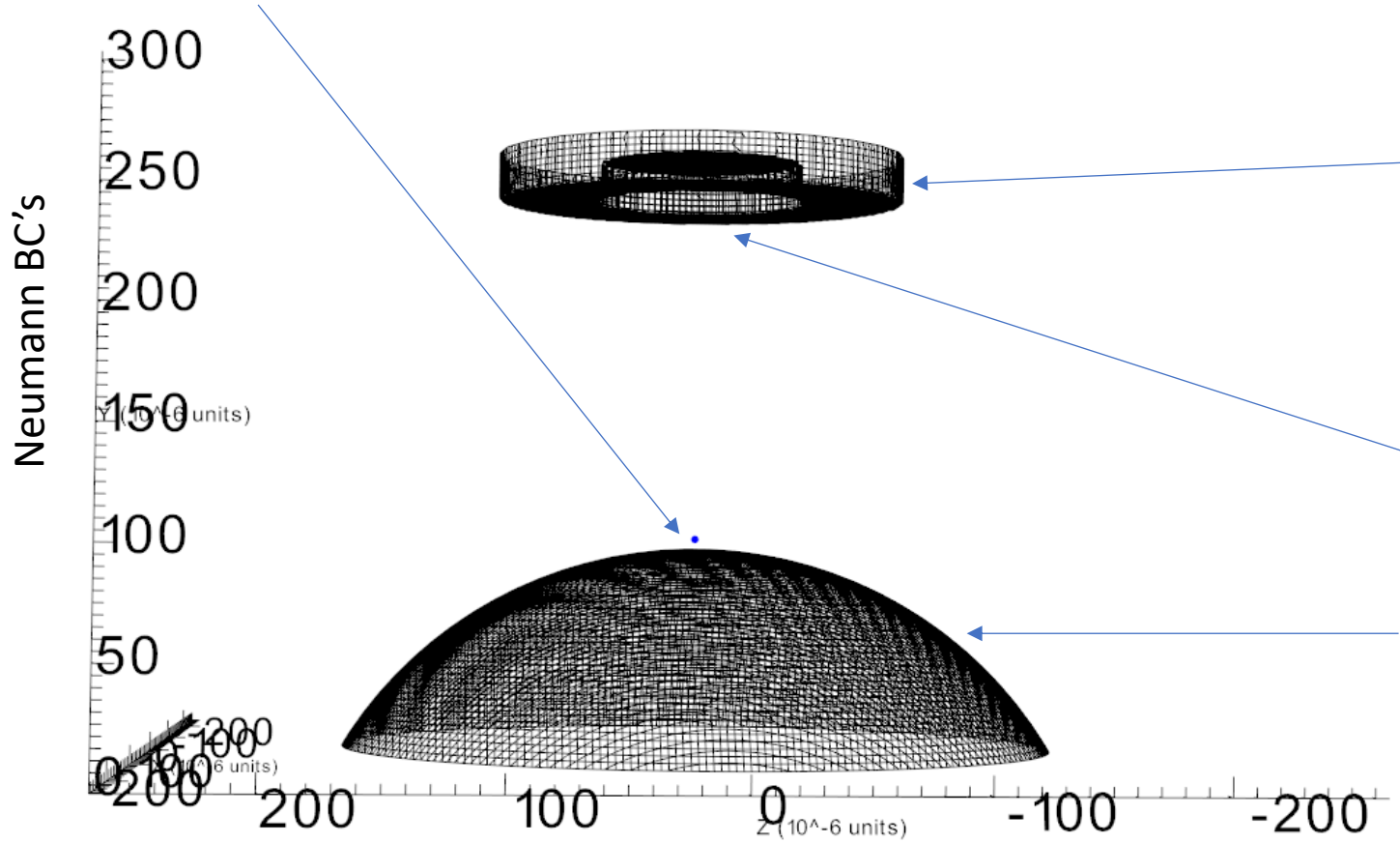
- VSim is the entire computational engine, visualization setup, post-processing and data visualization package
  - Computational engine is called Vorpal
- VSim is a multi-physics, fully kinetic, electromagnetic particle in cell simulation
  - Multi-physics - plasma physics + associated physics (such as reactions with neutrals, secondary emission from boundaries, and many other processes)
  - Fully kinetic : all plasma processes can be captured (in principal)
    - In practice, some time scales are too long to use a PIC code
    - Other conditions also arise that make PIC impractical, e.g. the need for many particles per cell
    - Electrons and ions treated kinetically
  - Electromagnetic – Maxwell's equations are solved at each time step using the plasma current and charge density as source terms (in addition to BC's and external source terms)
    - Electrostatic is a special case in which only the E-field is solved for because self-consistent B-field is very small

Advantages of VSim for Modeling Corona Discharge

- VSim computes the fully self-consistent electric field
  - This electric field is essential to accelerating the electrons
  - VSim can invoke BC's that allow the E-field from the evolving plasma to dominate
- VSim computes the electric field in the dielectrics correctly
  - This E-field is essential to understanding the break down of materials
  - Note that the evolution of electrons is a much shorter time scale than the break down of materials
- VSim includes many collisional processes and secondary emission models
  - Collisions with neutrals is with Direct Simulation Monte Carlo Method
  - There are few assumptions involved in modeling the plasma (e.g. lots of different pressures (from tenuous to dense) can be treated correctly via DSMC method)
- In VSim 11, you will be able to import your own CAD drawings and assign dielectrics to each piece using ES field solve

Overview of Setup

Initial single electron to initialize cascade



Conductor. Potential = 923 V

Dielectric occupies region inside a conductor

Conductor. Potential = 0 V

A few basics to understand correct use of DSMC method

- Easiest way to model collisions is to use cross section tables
- Smallest mean free path (MFP) must be resolved
  - Collisions modeled as a pair-wise process within a cell
  - MFP is energy and collision-type dependent
  - Typically elastic collisions have the largest cross section (smallest MFP)
  - VSim uses No Time Counter method to reduce computational time
- Largest collision frequency must be resolved
- DX ~smallest (MFP/2)
- DT ~ smallest (1/f_coll/2)

Demonstration of How I do this in VSim

- Explain how MFP is determined
- Explain how DX is determined
- Explain how DT1, DT2, DT are determined

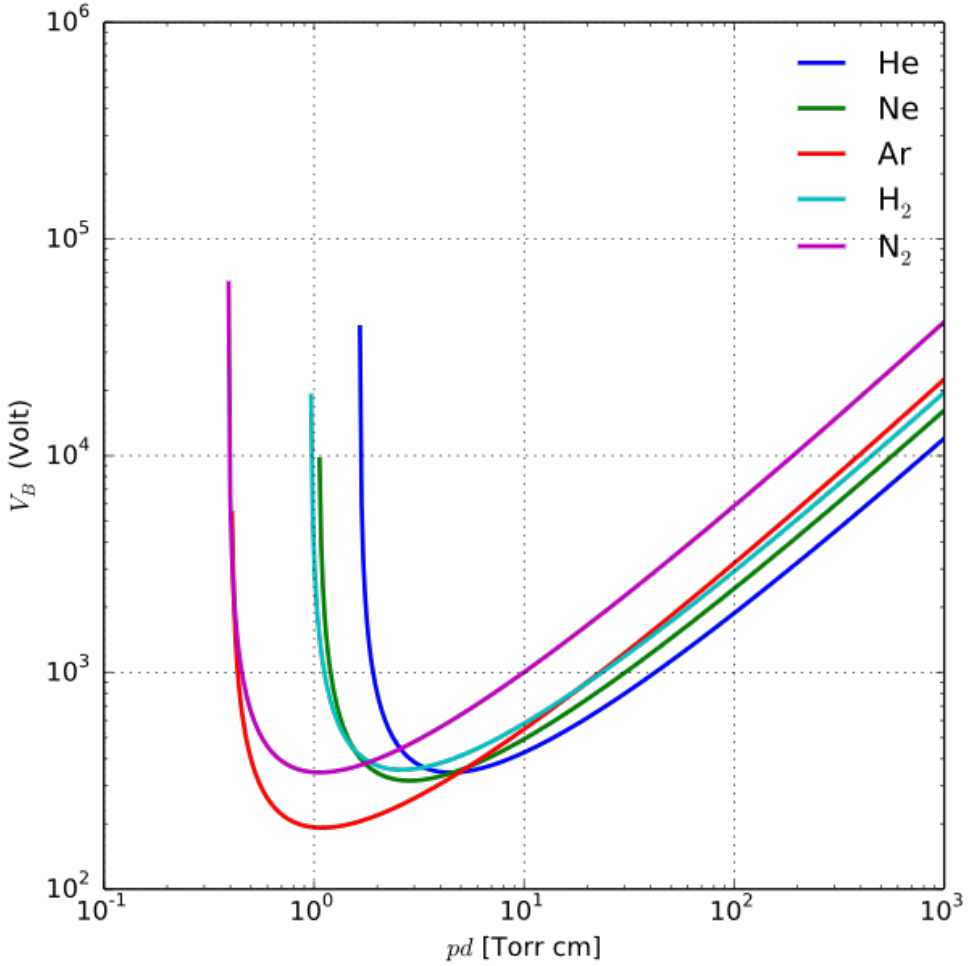
More Boundary Conditions

- YMIN and YMAX are Dirichlet
- ZMIN,ZMAX, XMIN,XMAX are Neumann
  - This allows the potential to float
  - Which allows the potential to be determined by plasma and not BC's
- Particles accumulate on dielectrics which further influences evolution of plasma and dielectric electric field

Explanation of Physics

- Paschen's curve determines the necessary potential difference for discharger to occur
- Paschen's curve assumes the following:
  - Existence of a pre-existing free electron
  - The creation of further free electrons is only achieved by impact ionization.
    - Other types of collisions might impact corona discharge
    - Many collisions can be included in VSim
  - Each ionized atom leads to only one free electron. However, multiple ionizations occur always in practice.
    - You can include multiply ionized ions in VSim to test this effect
  - Free electrons at the cathode surface are created by the impacting ions.
    - You can include secondary emission of electrons off of the cathode from ions in Vsim
    - This would occur on much longer time scales

Paschen's Curve



"Analysis of Paschen Curves for Air, N2, and SF6 Using the Townsend Breakdown Equation", Husain and Nema, Aug 1982

Equations 3 and Table 2:

$$V_b = \frac{Bpd}{\ln pd + k}$$

p= pressure in KPa

d= distance in m

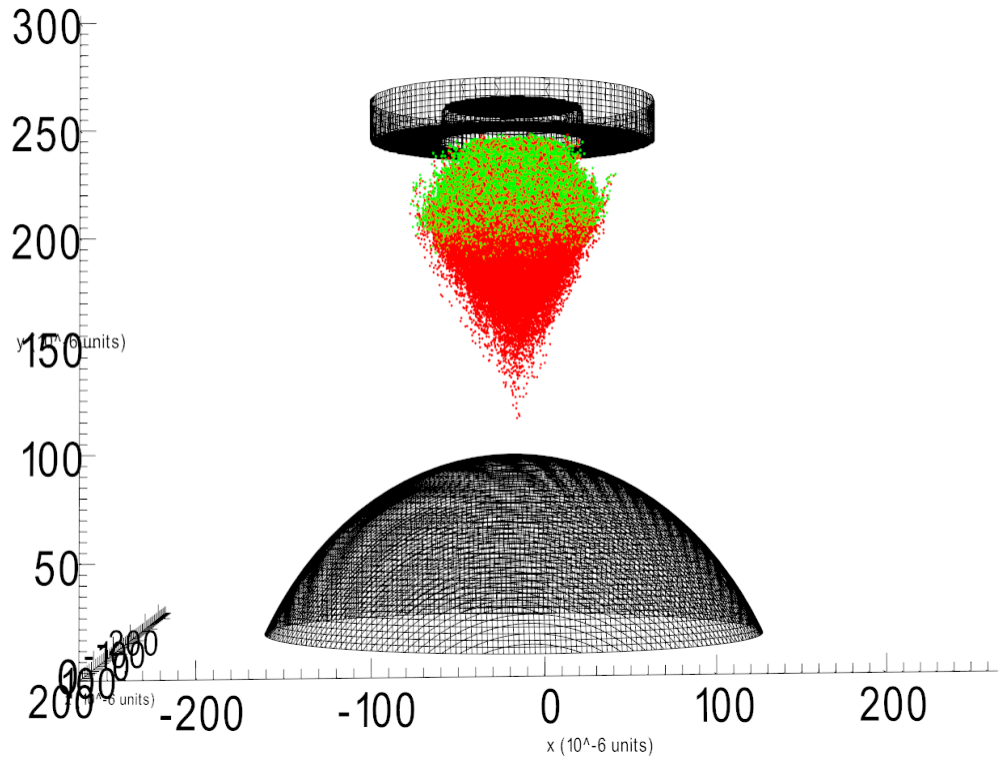
k is "constant which depends on pd

I computed V_b for this simulation to arrive at 923 V

Simulation setup

- N2 is used as background gas
- Neutral pressure = 380 Torr (half an atmosphere)
- Cell Size ~ 3 μm
- Domain size ~ 500 μm
- Included only ionization collisions
- Included a dielectric with relative permittivity = 9
- YMIN and YMAX at fixed potential difference
  - Its possible to put in a time varying potential
- XMIN,XMAX, ZMIN,ZMAX are Neumann BC's (floating potentials)

Results



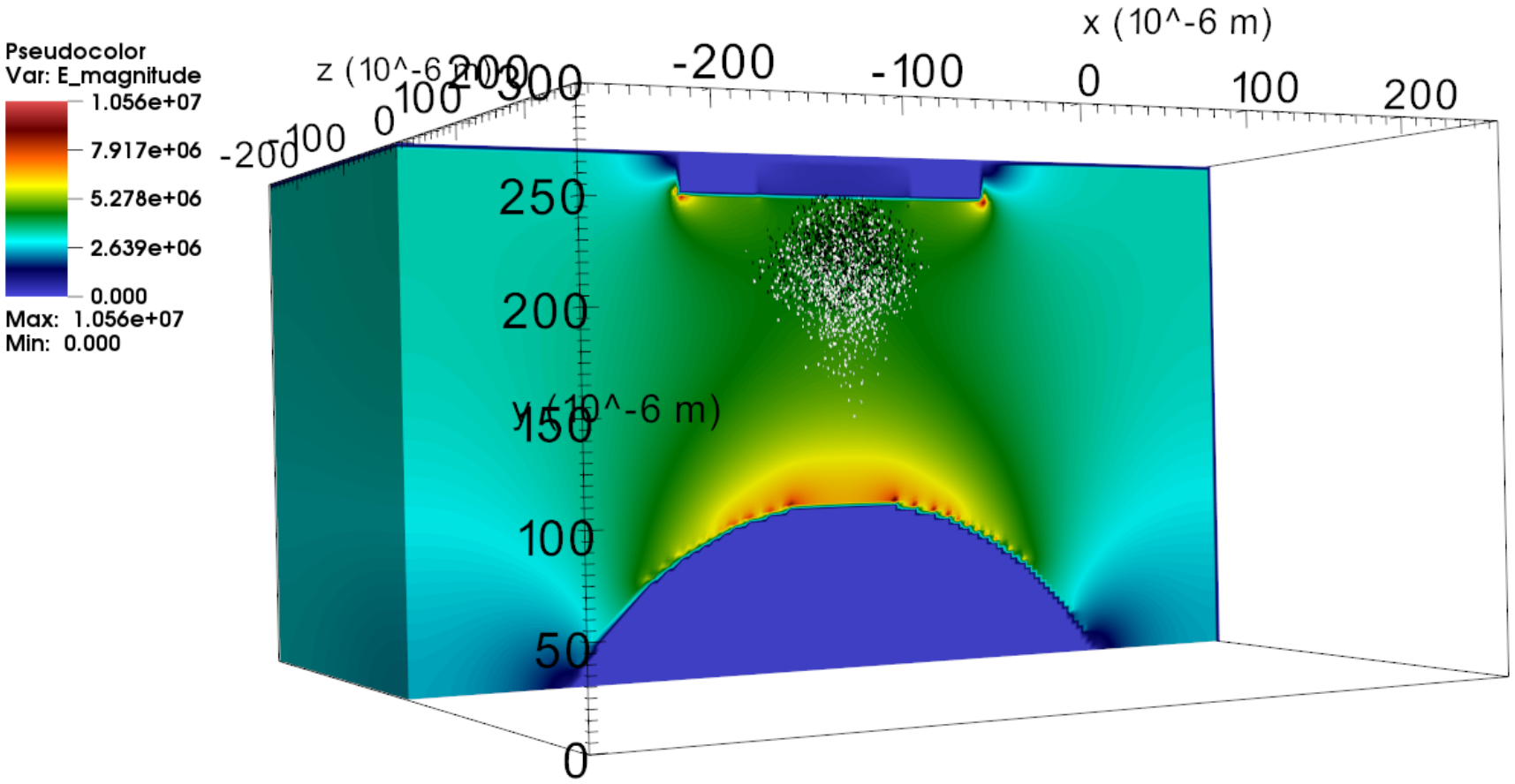
napshot of secondary
lectron and ion
opulations

ellow Dots are electrons

ed Dots are N2+ ions

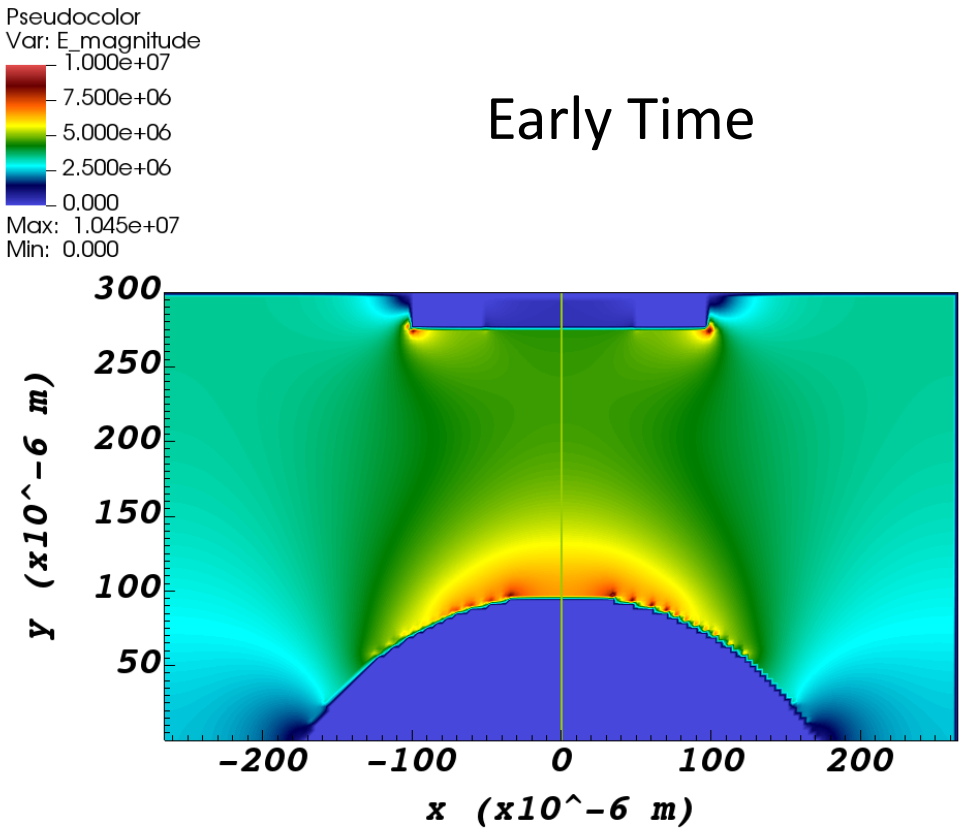
ull up VSim to show movie

Superimposing Particles and Fields

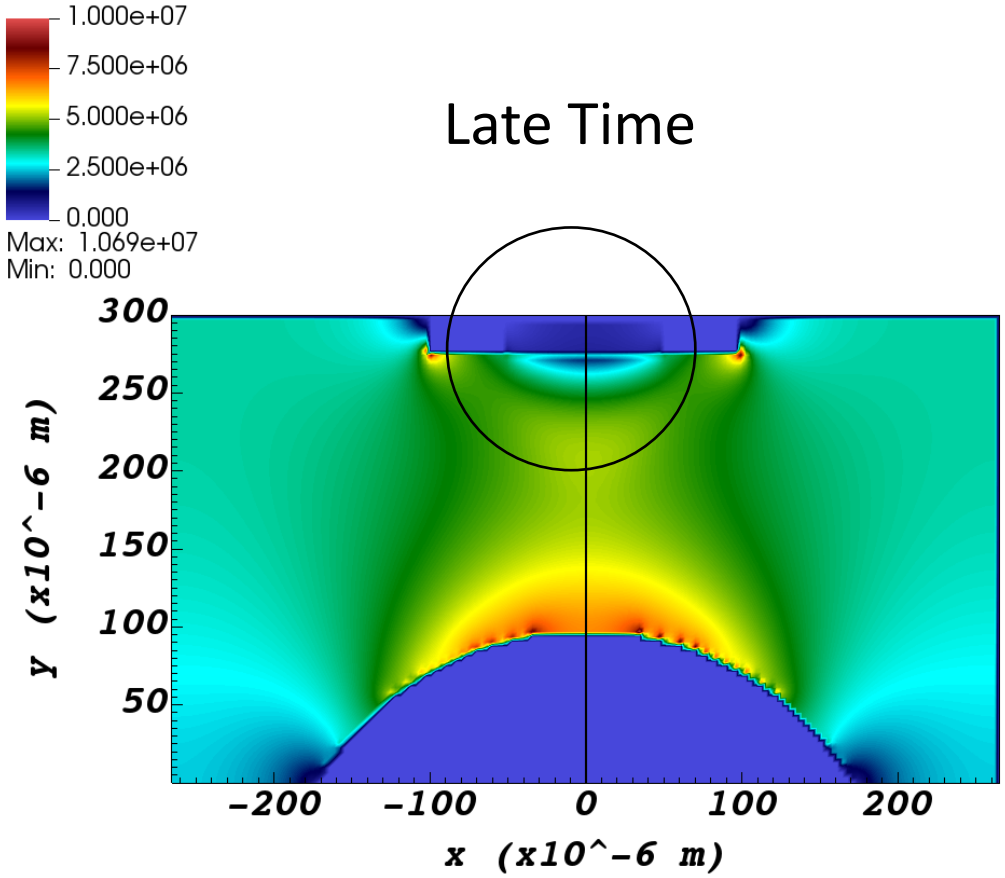


- In Vsim, you can superimpose particles and fields on the same plot
- This plot shows electrons with |E|
- Color scale can be changed to make particles easier to see
- Black dots – electrons
- White dots – N2+ ions

Effect Plasma formation has on Electric Field



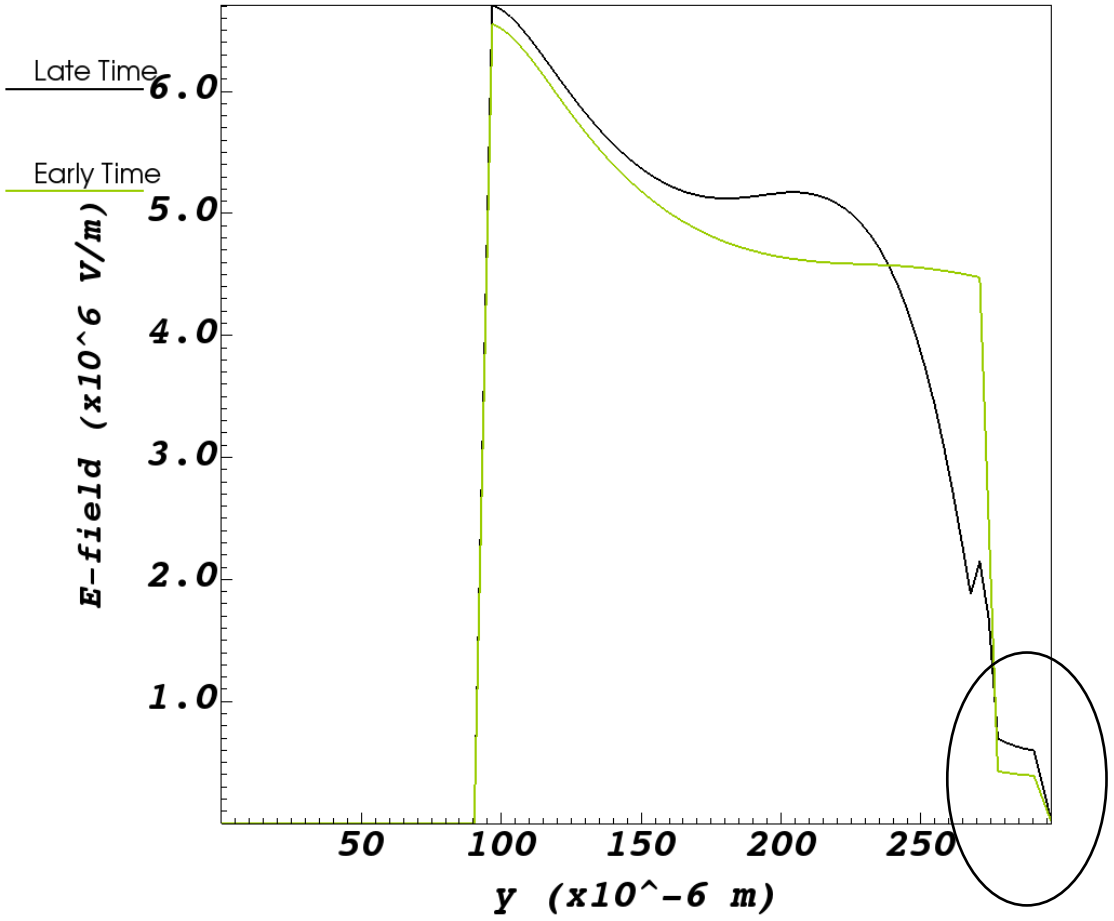
Early Time



Late Time

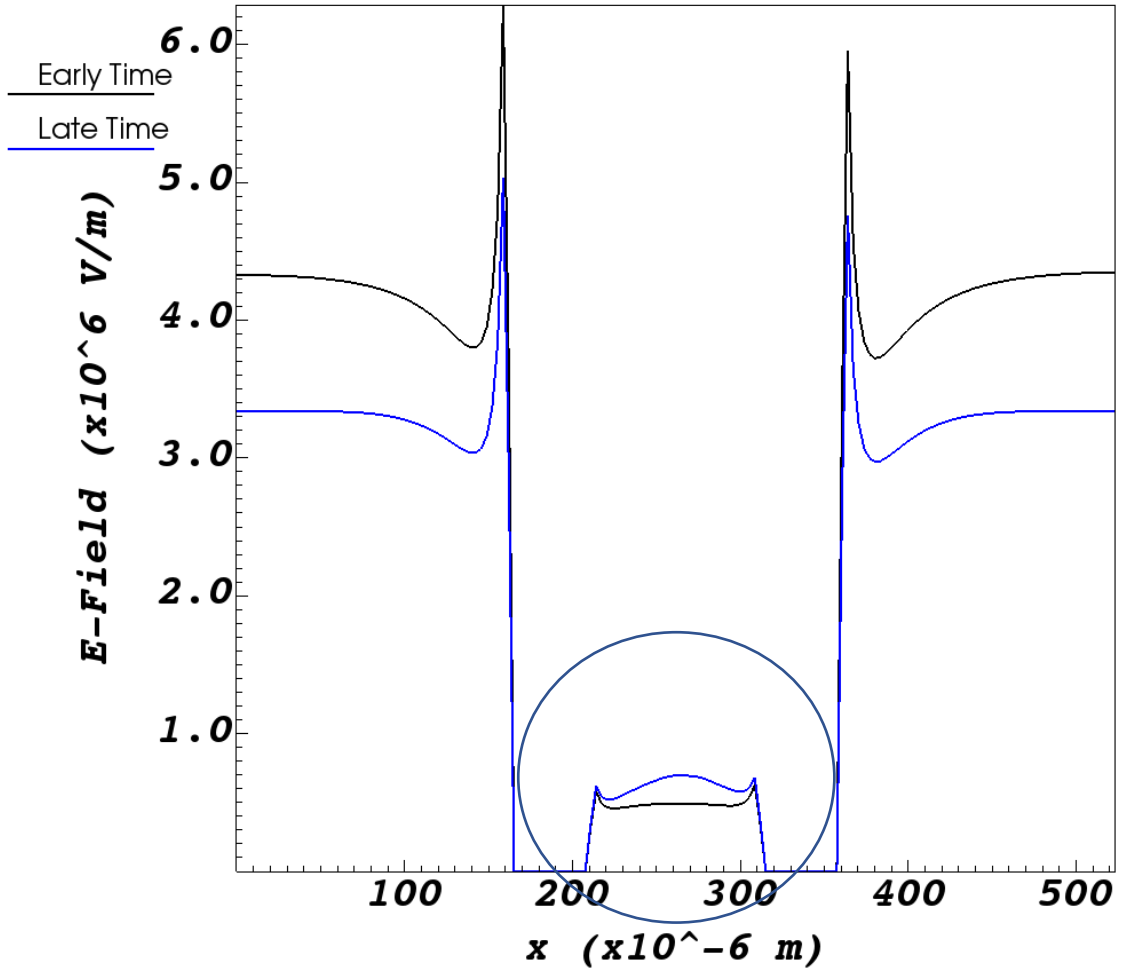
Plasma affects evolution of electric field near and in dielectric

Affect Plasma formation has on Electric Field



Corona Discharge affects electric field in dielectric

Impact of Corona Discharge on Dielectric



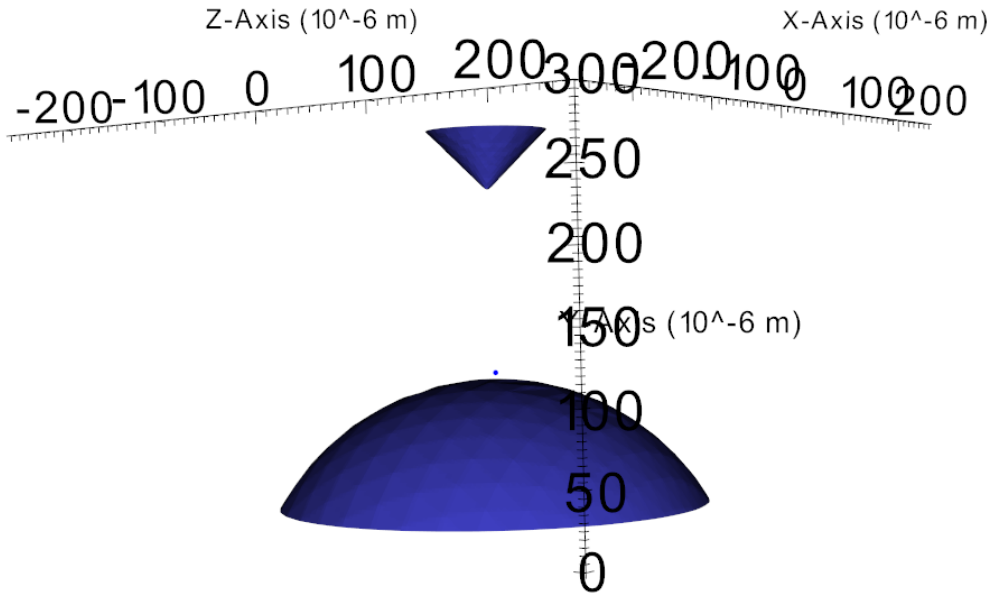
A horizontal slice through the dielectric at two different times

After charged particles are accumulating on the dielectric (blue curve), the electric field within the dielectric has increased.

This could impact dielectric break down

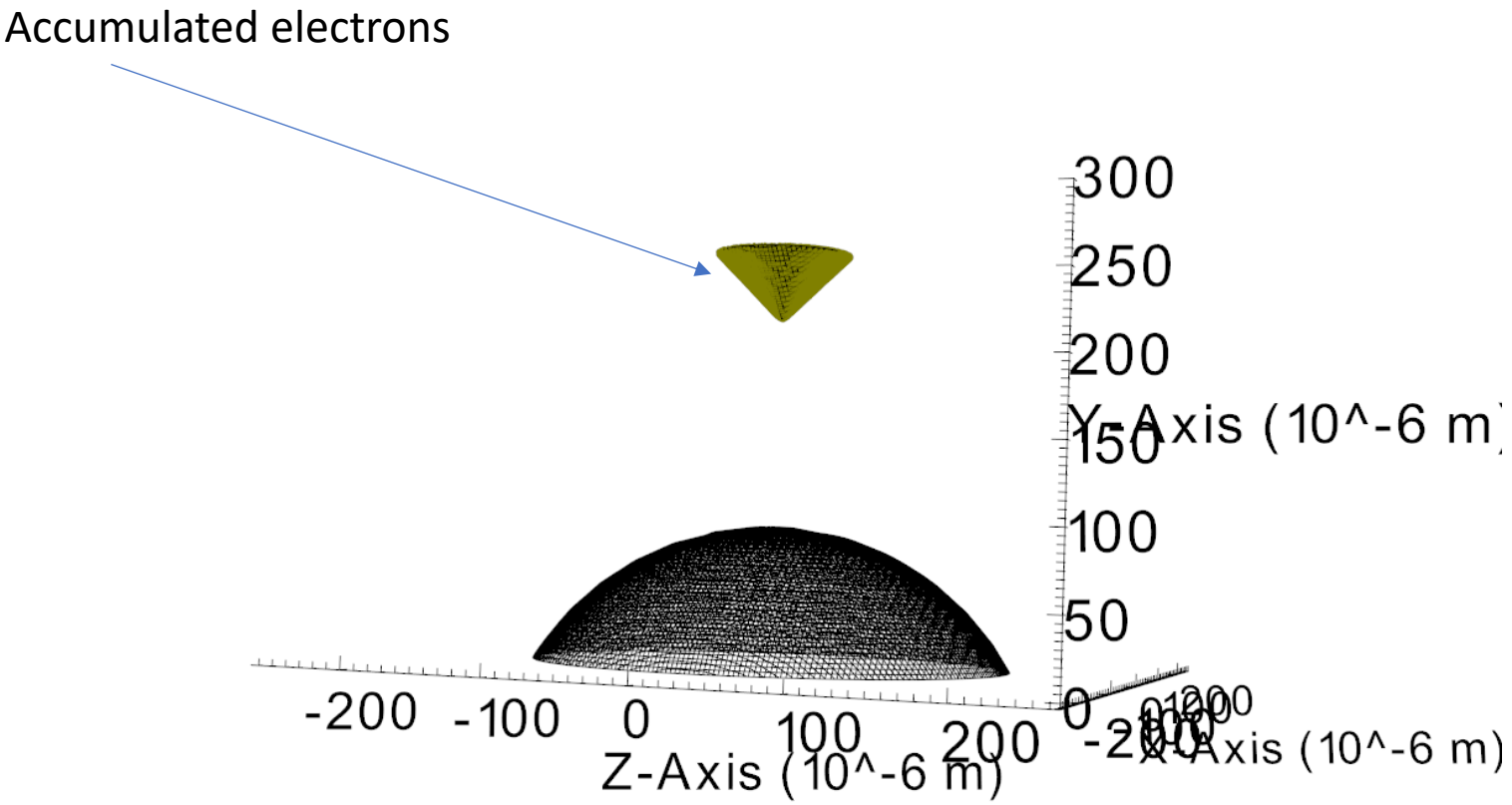
Impact of Shape of Dielectric on Electric Field

- I did a simulation in which the dielectric is cone shaped
- Same set up as before but with a cone
- Show VSim

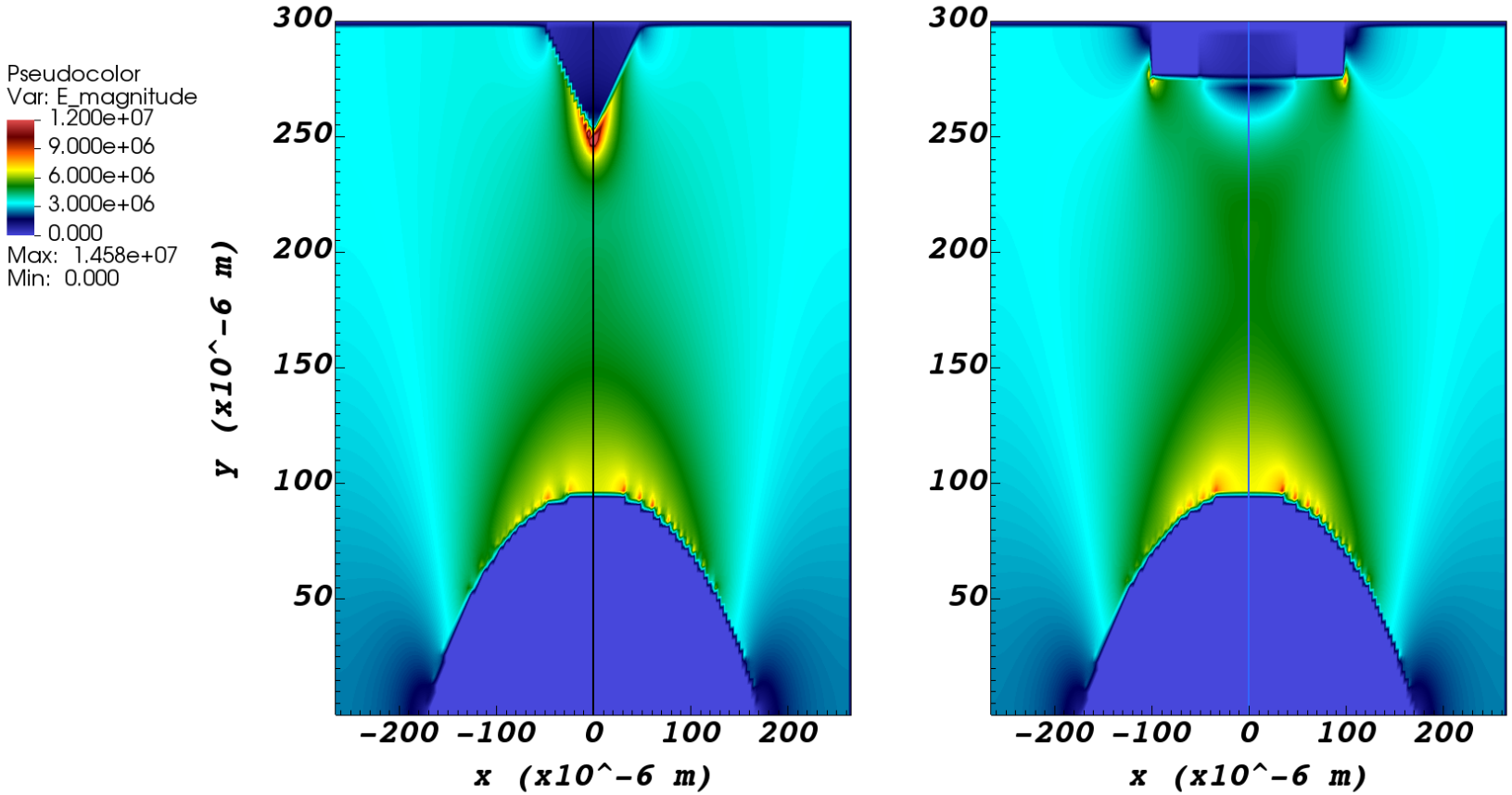


Accumulated particles and secondary emission off of dielectrics

- VSim can model secondary emission due to the impact of ions and electrons
- VSim can also model the accumulation of charged particles on to surfaces



Electric field in Cone vs Disk

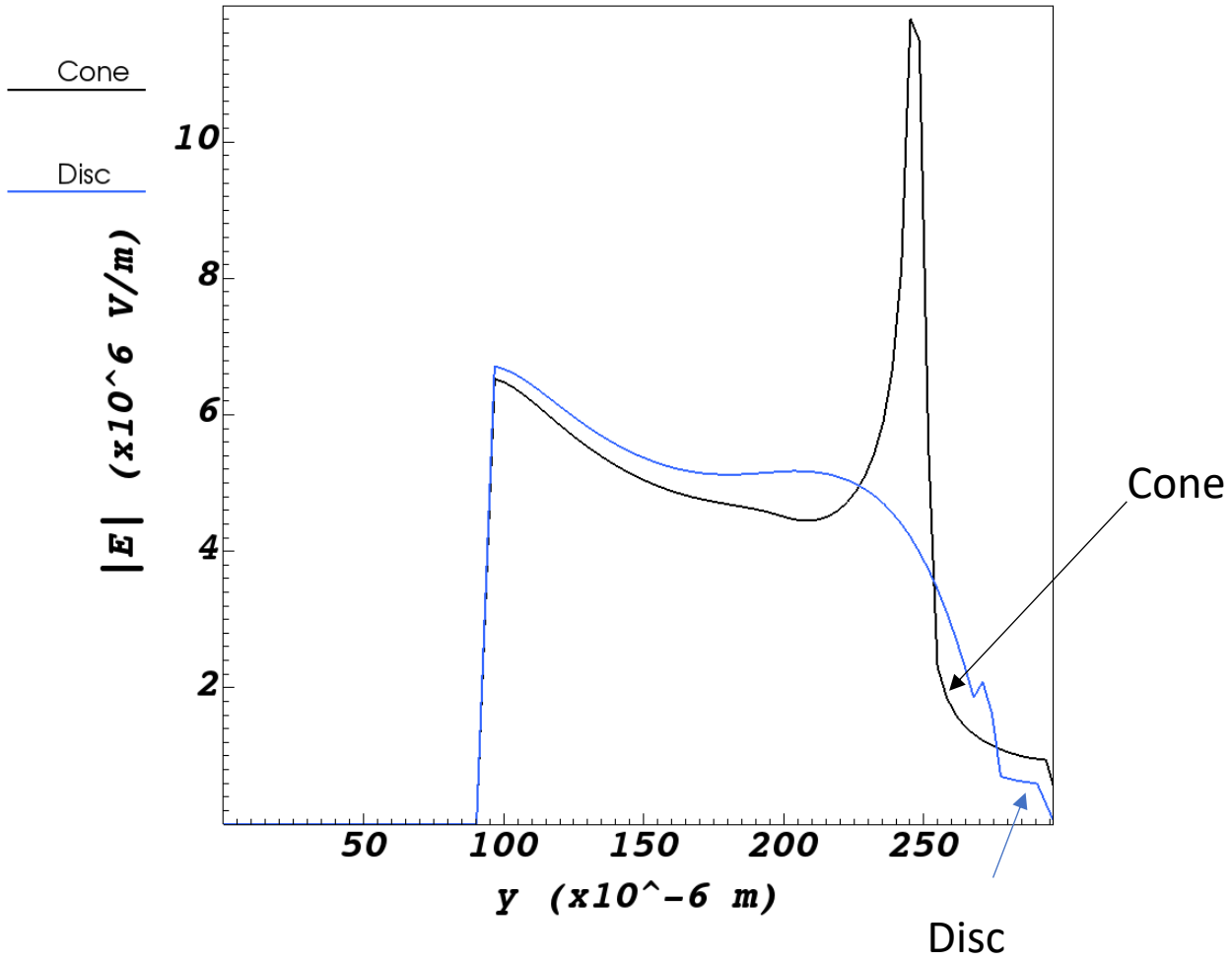


Data are plotted when E-field is maximum

E-field is larger with cone

This is expected. Charge density is greater in “pointy” objects

Lineouts of Both Electric Field Through Dielectric

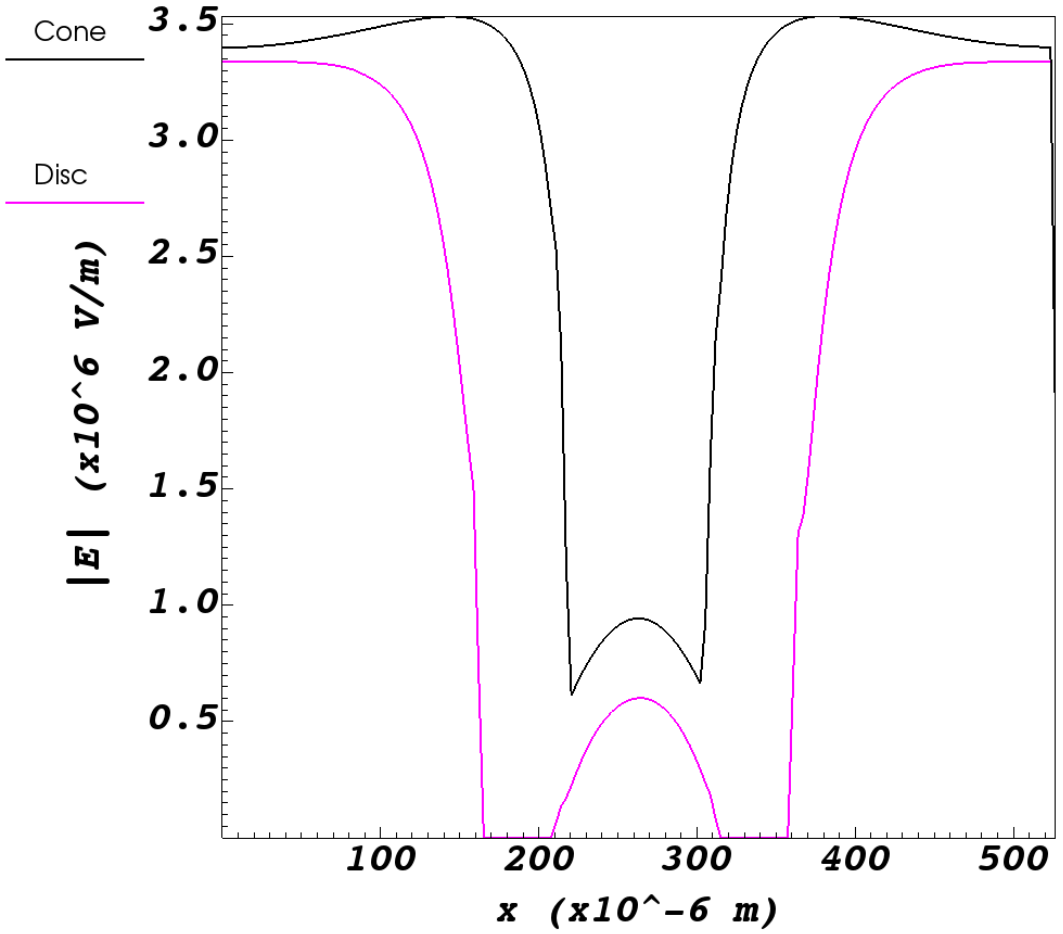


Peak electric field larger in cone

But, how does the electric field compare in the dielectric?

The electric field is larger in the cone

Slice Through Top of Both Dielectrics



- Electric field is larger in cone shaped
- Vsim can be used to model the impact shape has on the electric field in your dielectrics

Conclusion

- VSim can be used to model corona discharge involving complex dielectrics with varied shapes
  - Constant and time-dependent potentials can easily be applied
- Many types of multi-physics processes can be included
  - Collisions
    - Ionization, elastic, charge exchange, excitation and many more
    - Secondary electrons off of surfaces
- New to Vsim 11 – You can import your CAD and assign dielectrics
  - This has been possible with EM field solve for a while
  - Soon you can do it with ES field solve
- Model the electric field in your dielectrics

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