



Modeling of RF Breakdown using Particle In Cell (PIC) Codes

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The overall purpose of this work is to understand the physics responsible for breakdown, the mechanisms for breakdown onset, and diagnostics for detecting breakdown, using numerical modeling and simulation

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Numerical simulation of breakdown requires accurate simulation codes



- **We are employing two Particle in Cell (PIC) FDTD codes**
 - OOPIC Pro: 2-Dimensional, R-Z geometry, serial
 - VORPAL: 3-Dimensional, Cartesian, massively parallel
 - Both are self-consistent (We solve Poisson's Eq with particles and EM fields)
- **Physical processes include**
 - Self-consistent particle-field interactions
 - Field emission from conducting surface
 - Impact ionization of bulk neutral gas
 - Ion-induced secondary electron production
 - Physical sputtering of neutral gas
- **We numerically measure indicators of cavity breakdown**
 - Number of particles as a function of time
 - Evolution of particle densities and particle fluxes
 - Radiated power from impurities (line and continuum)
 - Surface heating from particle bombardment
 - TxPhysics numerical library

OOPIC Pro (2D Cylindrical) simulation physical parameters



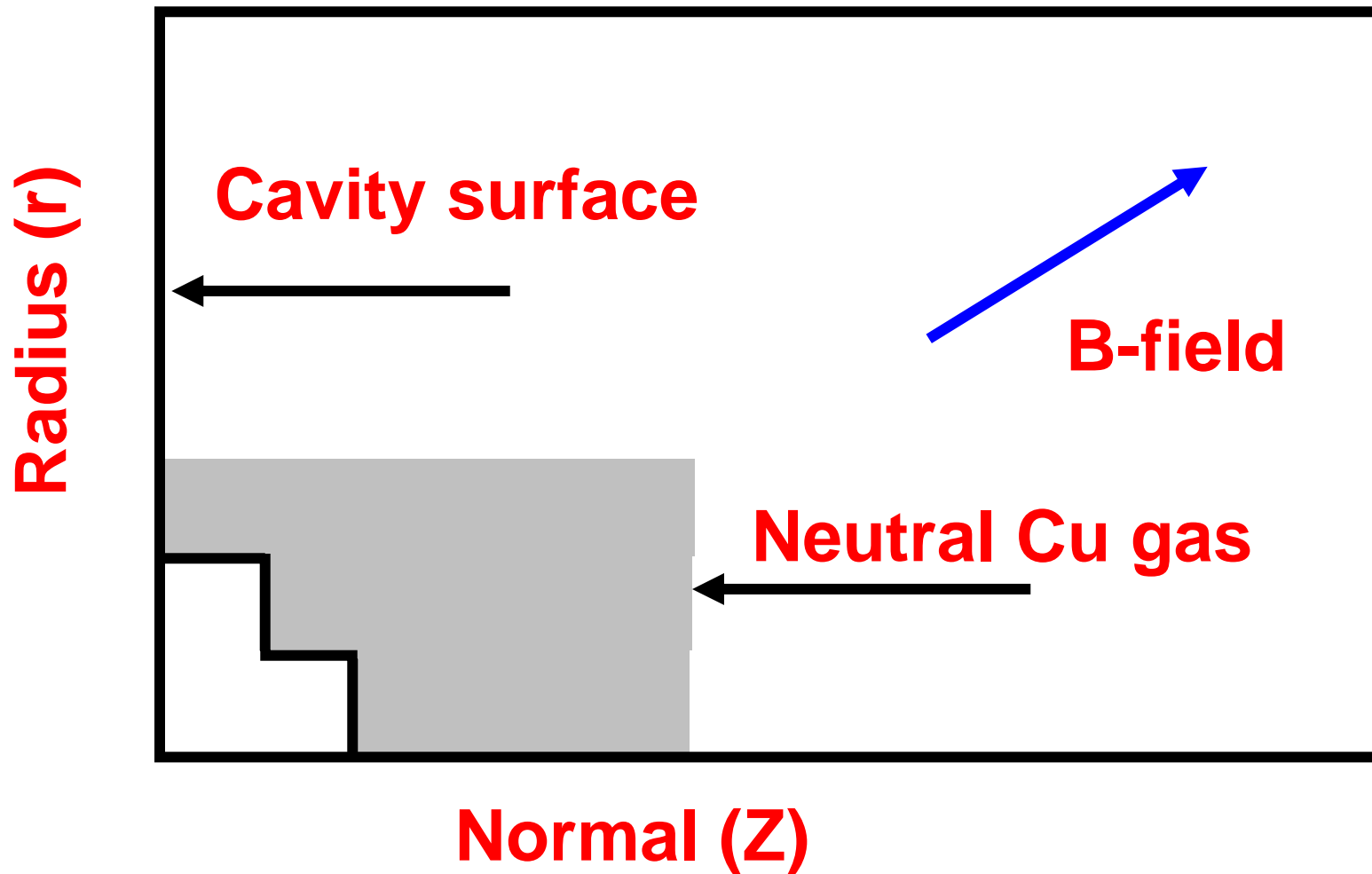
- **Simulation area**
 - 10 μ m x 10 μ m cylinder
- **Conical surface defect**
 - 2 μ m high x 2 μ m wide
- **Electric Field boundary condition**
 - Normal to surface (up to 60 MV/m)
- **Applied Magnetic Field**
 - Normal, Parallel, Oblique to surface (up to 3.0 T)
- **Field emitter**
 - Fowler-Nordheim, $\beta = 184$
- **Background gas pressure**
 - 2.3×10^{26} #/m³ (7000 Torr)
- **Applied RF signal**
 - $f = 805$ MHz

OOPIC Pro (2D Simulation) simulation parameters



- **Number of computational cells**
 - 50 x 50 (RZ)
- **Cell spacing**
 - 0.2 μm
- **Timestep**
 - 1×10^{-14} seconds
- **Particle weighting**
 - 1 simulation particle = 1×10^6 real particles
- **Neutral gas region**
 - 30 x 30 cells
- **Solver**
 - Electrostatic simulation with multigrid Poisson solver
- **Computation time**
 - 6 hours (serial) to simulation 2.6 ns

2D simulation geometry (Cylindrical)



An applied RF field controls the dynamics



- When the RF field is pointing towards the surface field emission occurs from the defect
- When the RF field is pointing away from the surface field emission is suppressed

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

Electrons ionize neutral gas near the surface defect



- Background Cu neutral gas is ionized by electrons which are field emitted from the surface

QuickTime™ and a YUV420 codec decompressor are needed to see this picture.

Electrons ionize neutral gas near the surface defect



- The background gas density is decremented due to impact ionization

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

Ionization produces more electrons



- Ions are accelerated towards the surface
- Ionization electrons are accelerated away from the surface

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YUV420 codec decompressor
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Ionization produces more electrons



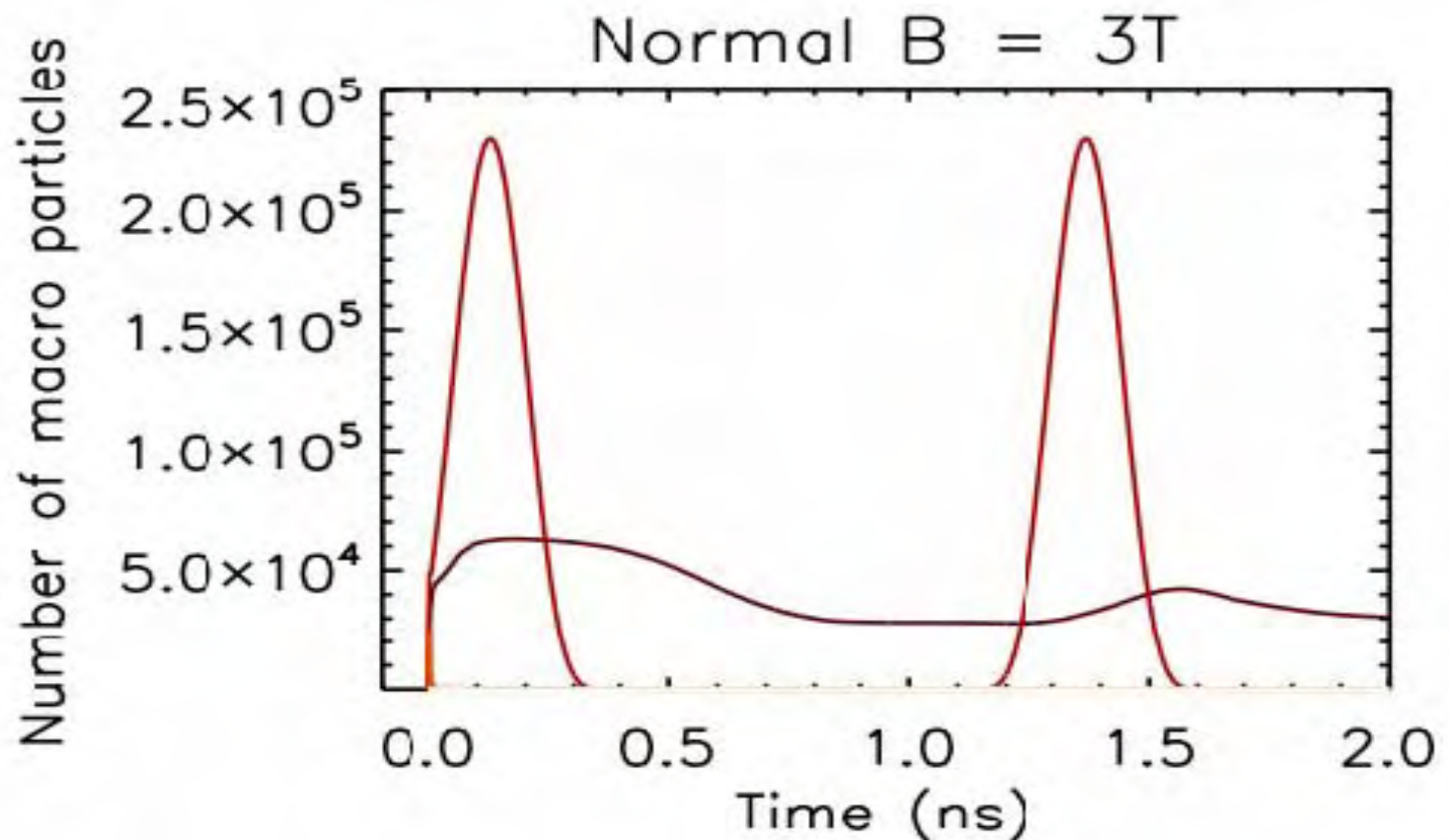
- Ion density evolves away from the defect due to surface-enhanced electric fields

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are needed to see this picture.

Field emitted electrons and ions are the most abundant particle species



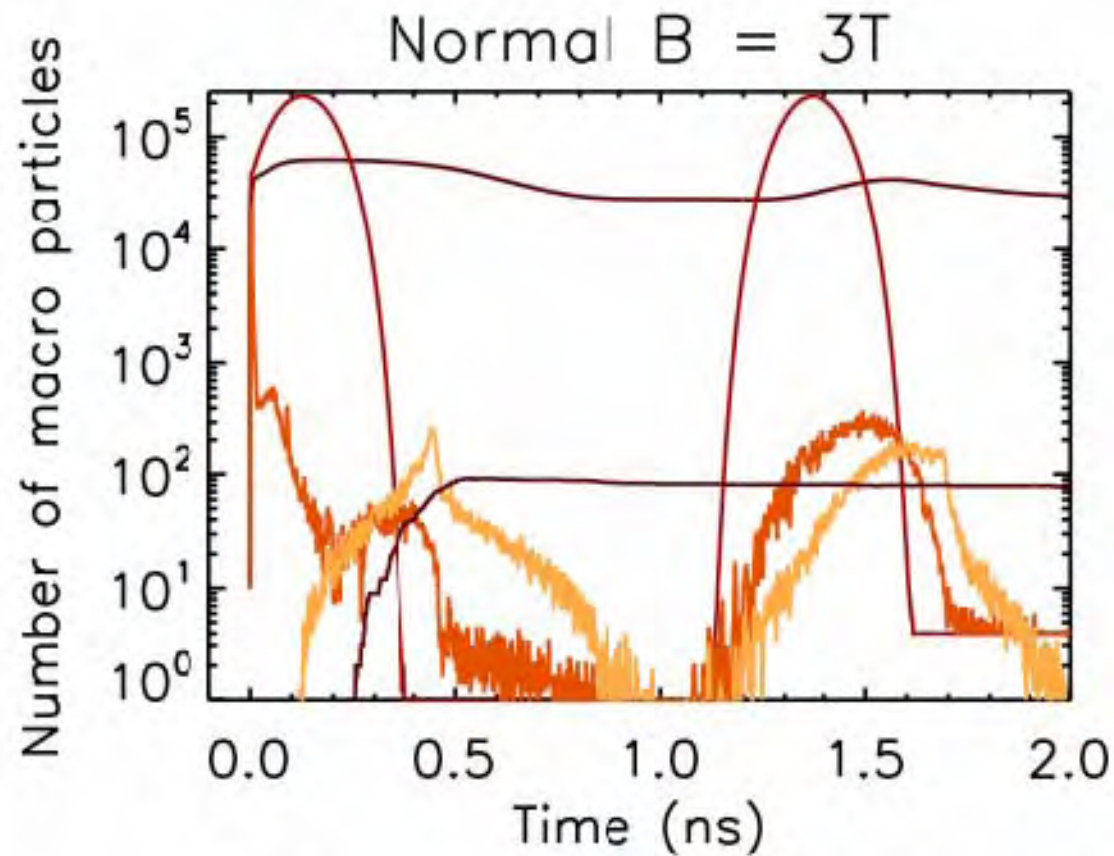
- The phase turns on/off the field emitters
- Particles are lost to the center of the cavity and to the walls



We also model secondary electron production and physical sputtering



- Ions produce secondary electrons when they impact the walls
- Ions produce neutral Cu atoms through sputtering



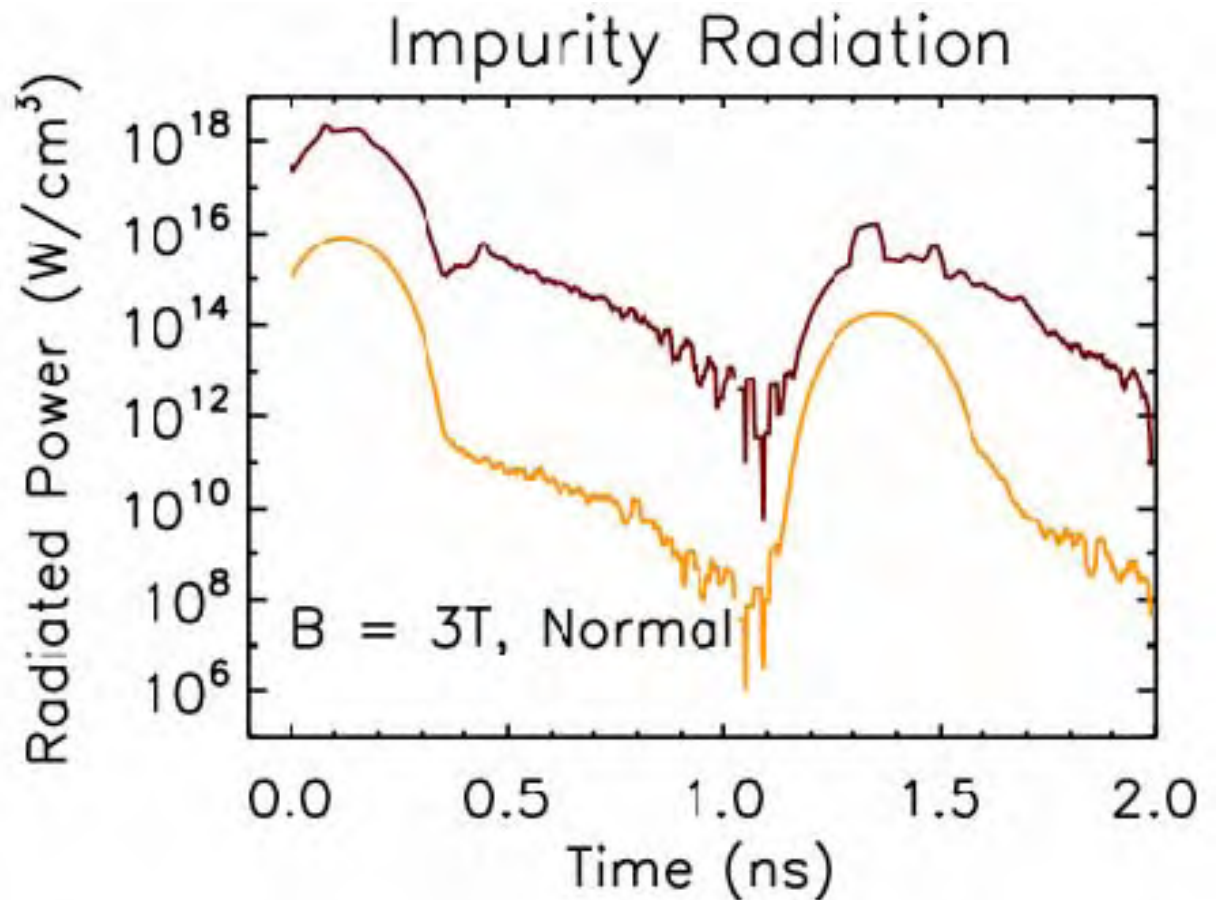
Impurity radiation peaks at short time scales



- Coronal model (Mosher, 1974)
- Line radiation dominates over continuum (Brehmstrahlung plus recombination)

- $P_L \sim 3.5 \times 10^{-25} n_i n_e / T_e^{.5}$

- $P_C \sim 1.5 \times 10^{-32} n_i n_e T_e^{.5}$



Radiated power is high where electron and ion densities are high



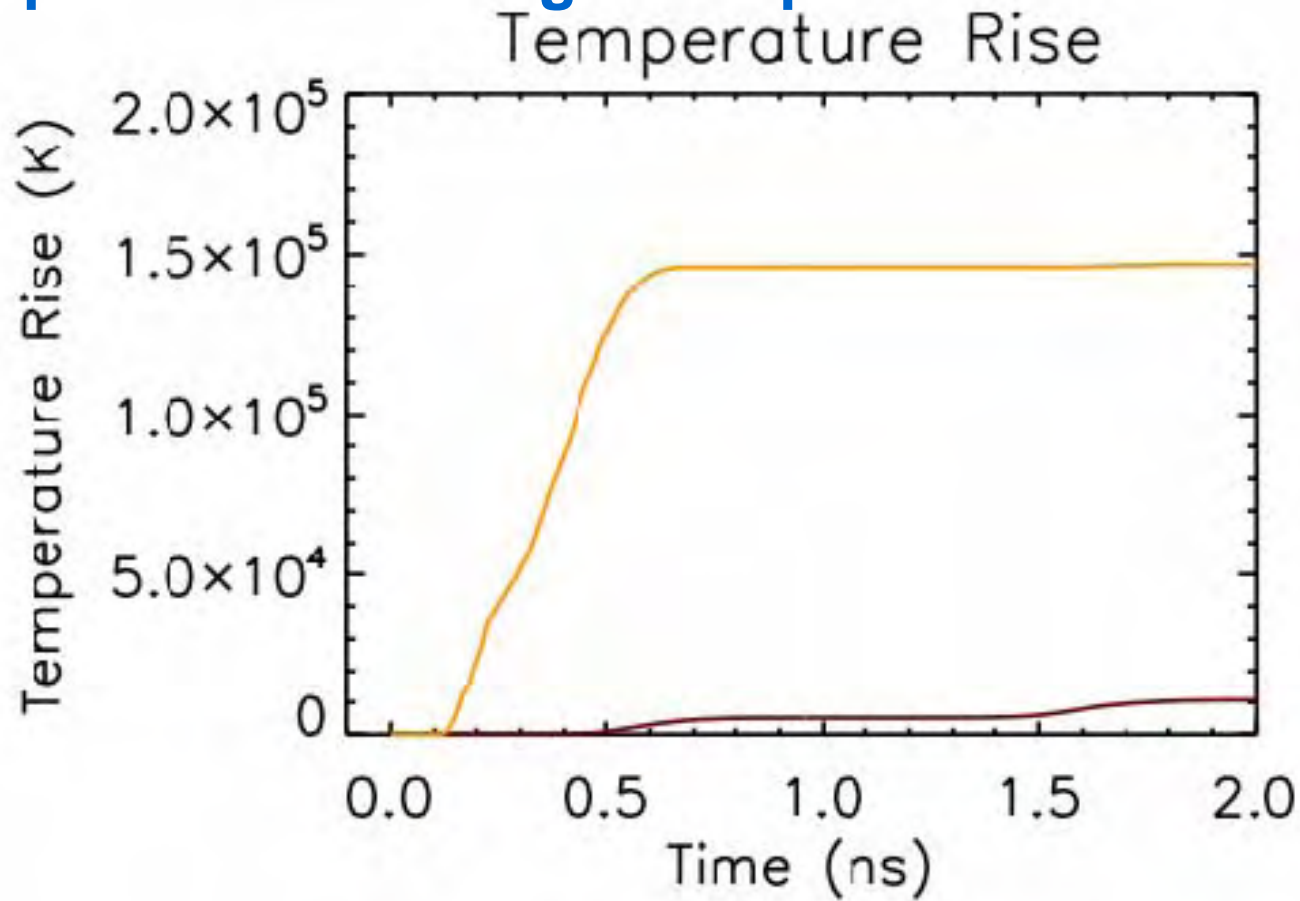
- Peak radiation occurs at short time scales, when the neutral gas ionizes

QuickTime™ and a
YUV420 codec decompressor
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Surface heating is due to particle bombardment



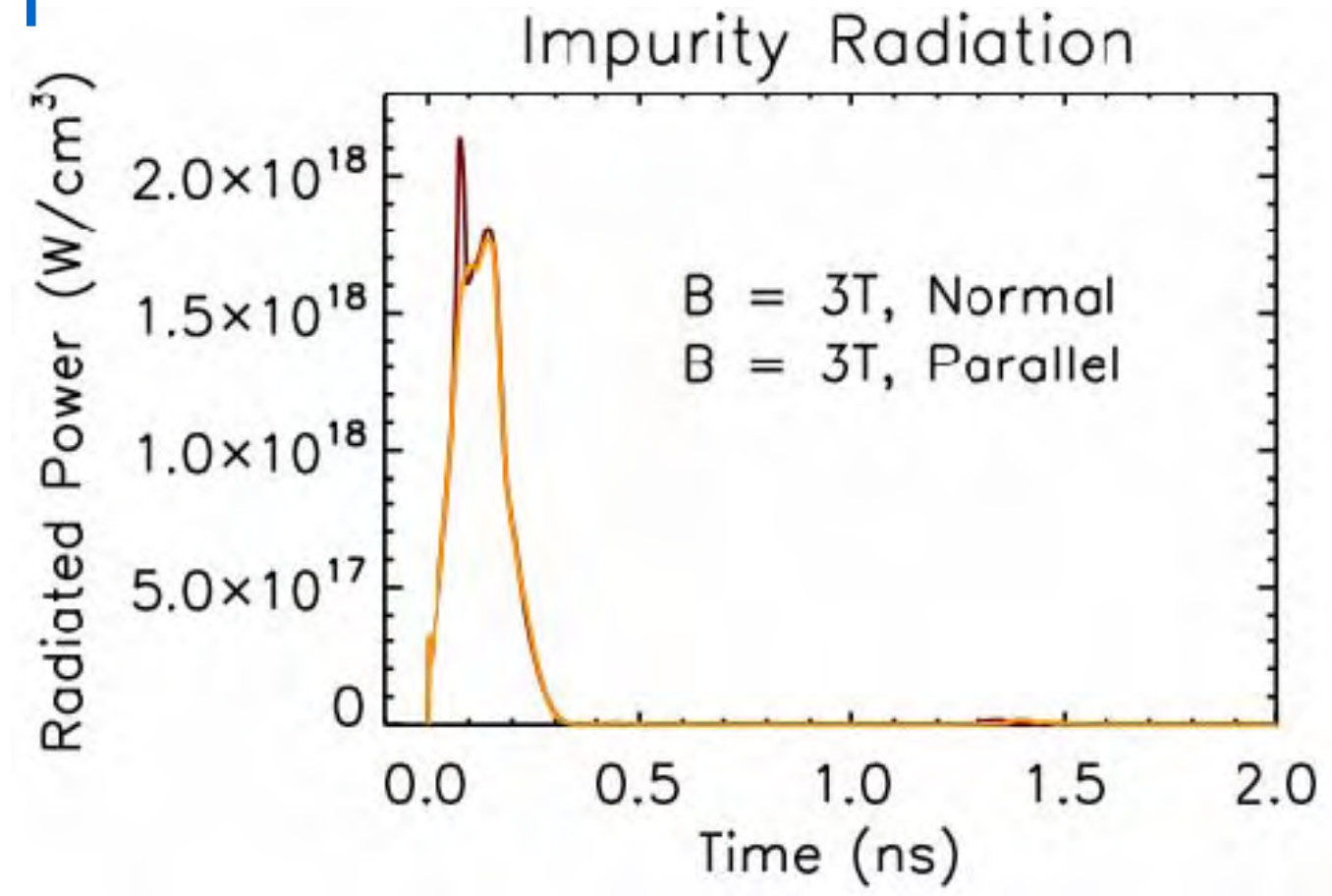
- Ion and electrons impacting surfaces deposit half of their energy as heat
- Approximation using bulk specific heat



Magnetic field direction affects impurity radiation



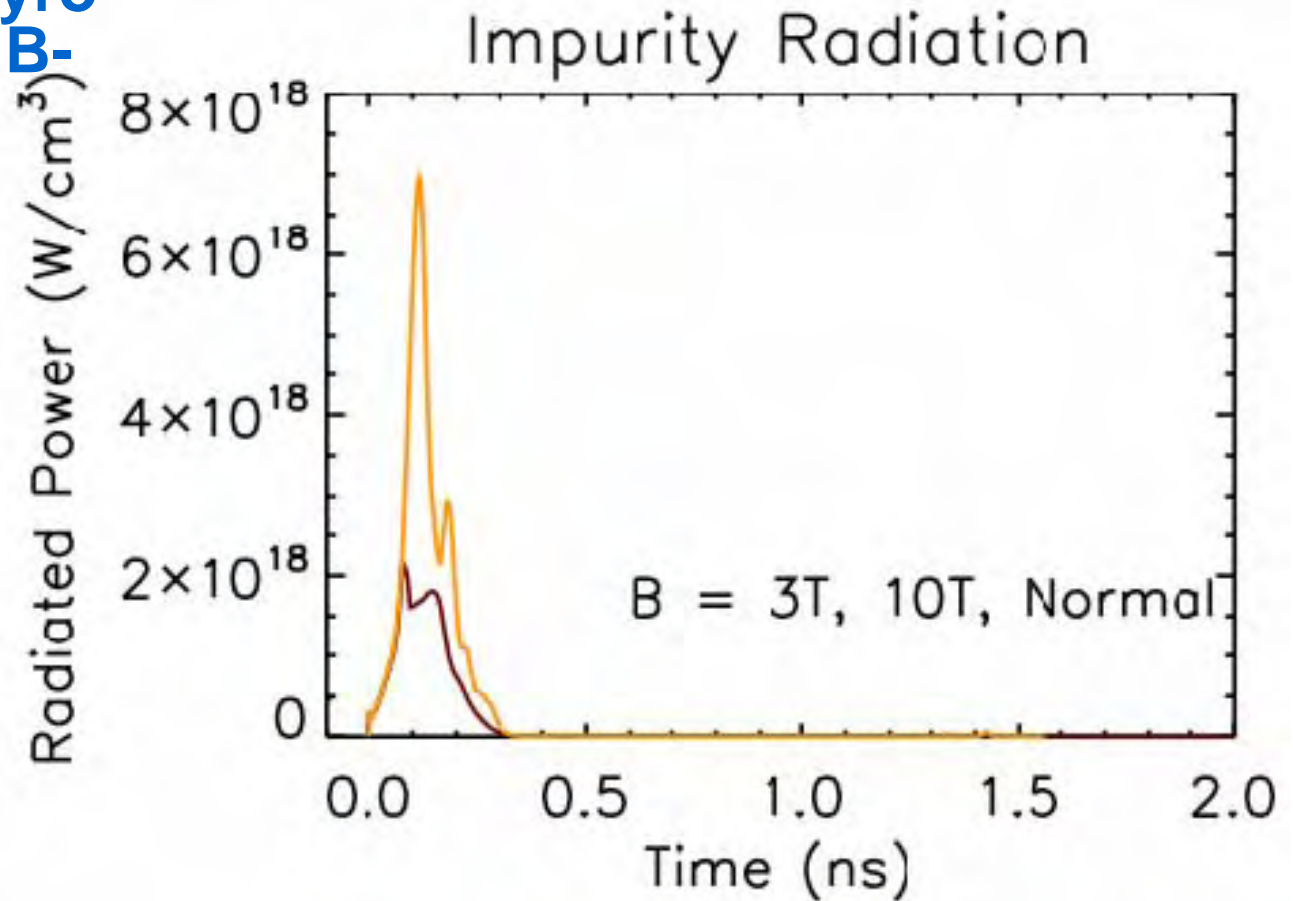
- Total radiated power is greater when the B-field is normal to the surface
- Here, $B = 3\text{ T}$



Magnetic field strength affects impurity radiation as well



- Electrons may return to the defect by executing a gyro orbit around the B_z field



Future directions



- **New Physics**
 - X-rays from electron/surface impacts (like Integrated Tiger Series model)
 - Coupling radiation back to ion temperature
 - Allow outgoing radiation to couple to plasma (opacity modeling)
 - Repopulation of background gas with sputtered atoms
- **New User Interfaces**
 - Translation of OOPIC input files to VORPAL using VpStudio
 - Web UI for visualization of VORPAL simulations (VorpalView or TxView)
- **New Simulations**
 - Better understand effects of magnetic field on breakdown
 - Automated optimization in OOPIC and VORPAL
 - Allow user to specify a quantity to be maximized or minimized as a certain model parameter is varied

VpStudio is a friendly interface for creating VORPAL input files



The screenshot displays the VORPAL Studio application window. The title bar reads "X VORPAL Studio". The interface is divided into several sections:

- Component Palette: EmField**: A list of components on the left side, including Field, FieldUpdater, FieldMultiUpdater, InitialUpdateStep, UpdateStep, MultiFieldDgn, BoundaryCondition, PmlRegion, IoComment, InitialCondition, dumpPeriod, cutCellType, publicFields, needsRho, needsJ, needs, hasB, needsB, interpE, interpB, and gridBoundary.
- Pre-Processor / Descriptions**: A section below the palette showing details for the selected "EmField" component. It lists properties such as Type: *Block*, Default, Min Occurrences: 0, Max Occurrences: *Unlimited*, and Unique Path: */EmField*. Below this, a paragraph explains that these VORPAL objects define the properties of the electromagnetic (EM) fields in the simulation.
- Code Editor**: The main area on the right shows the contents of a file named "ccBeamBox.pre". The code includes mathematical definitions for DLI , DL , $DTCFL$, and DT . It also defines simulation parameters like `TIMESTEPS = 50`, `DUMPS = TIMESTEPS / 1`, and `ELECMASS = 9.109e-31`. Comments describe the grid, time stepping, and decomposition settings.

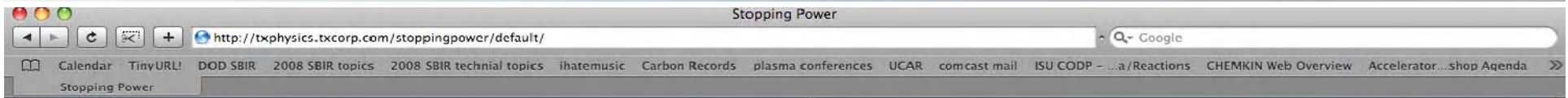
At the bottom right of the window, a status bar indicates "Using Native Python: C:\opt\python2.3.5\python.exe".

Future directions



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TxPhysics Web UI brings quick visualization to surface processes



Stopping Power

Experimental Definition

Beams:

Targets:

Minimum Energy: MeV/Nucleon

Maximum Energy: MeV/Nucleon

Target Temperature: eV

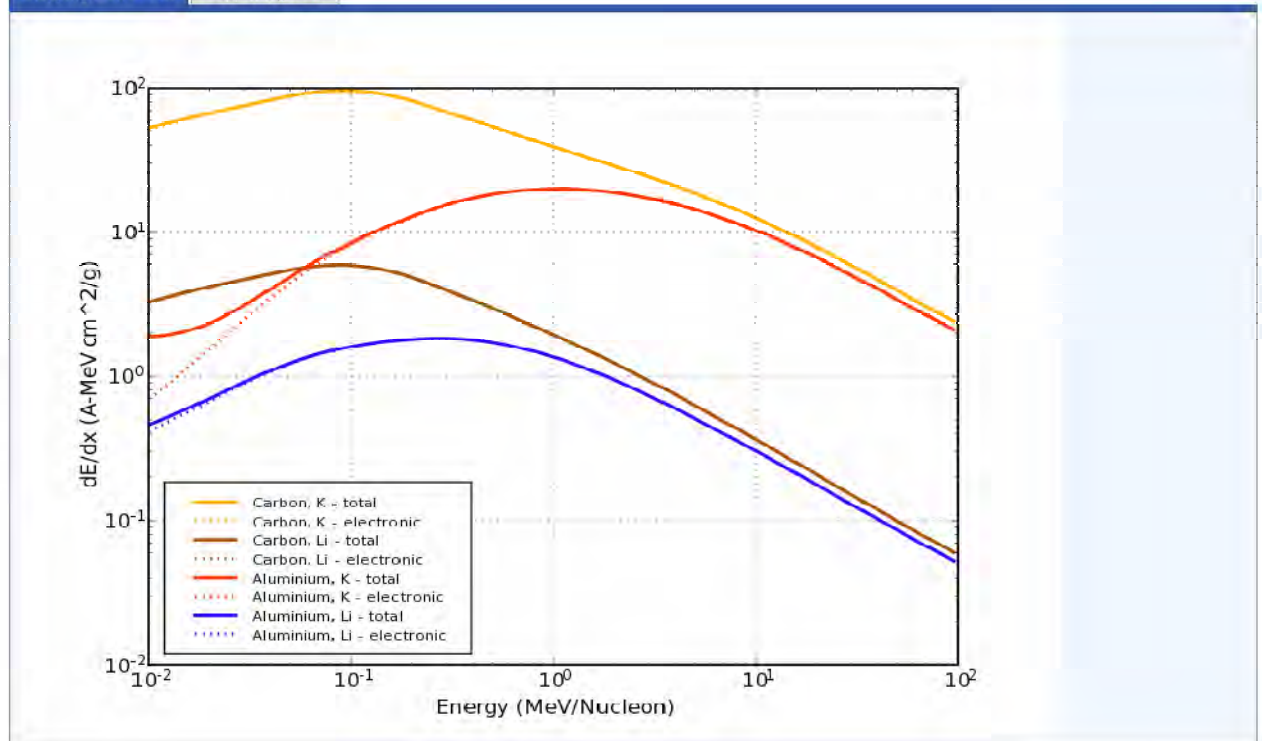
Display Options

Components:

Plot one of:

Units one of:

Stopping Power Plot



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