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

S.A. Veitzer, S. Mahalingam, P. Stoltz

Tech-X Corporation

High Gradient Collaboration Workshop 2008

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

This work is funded under the auspices of DOE through the SBIR program (Phase I)

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

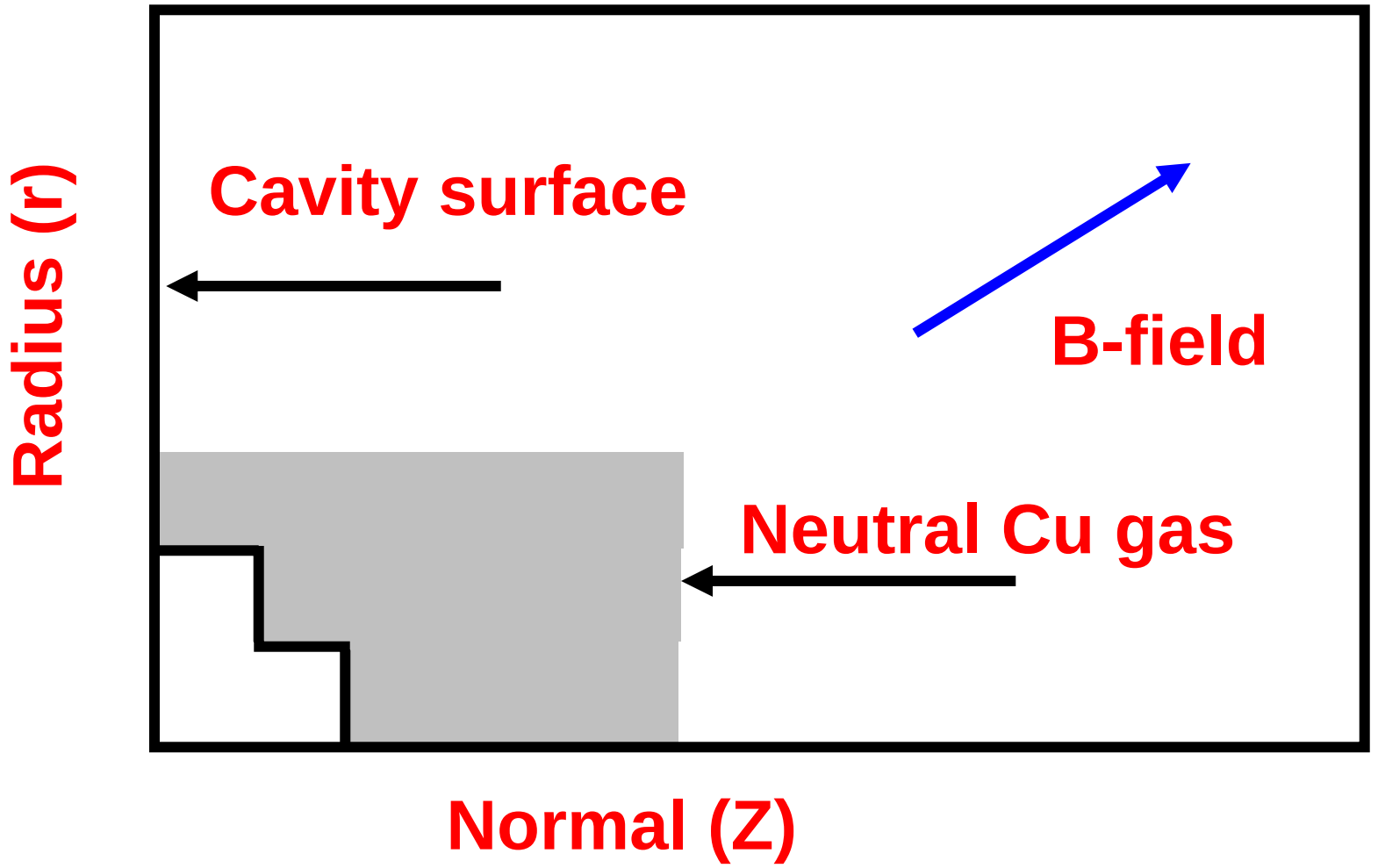
OOPIC Pro (2D Cylindrical) simulation physical parameters

- **Simulation area**
  - 10μm x 10 μm cylinder
- **Conical surface defect**
  - 2 μm high x 2 μm 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} #/m^3 (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**
  - $1x10^{-14}$ seconds
- **Particle weighting**
  - 1 simulation particle = $1x10^{6}$ 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**

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

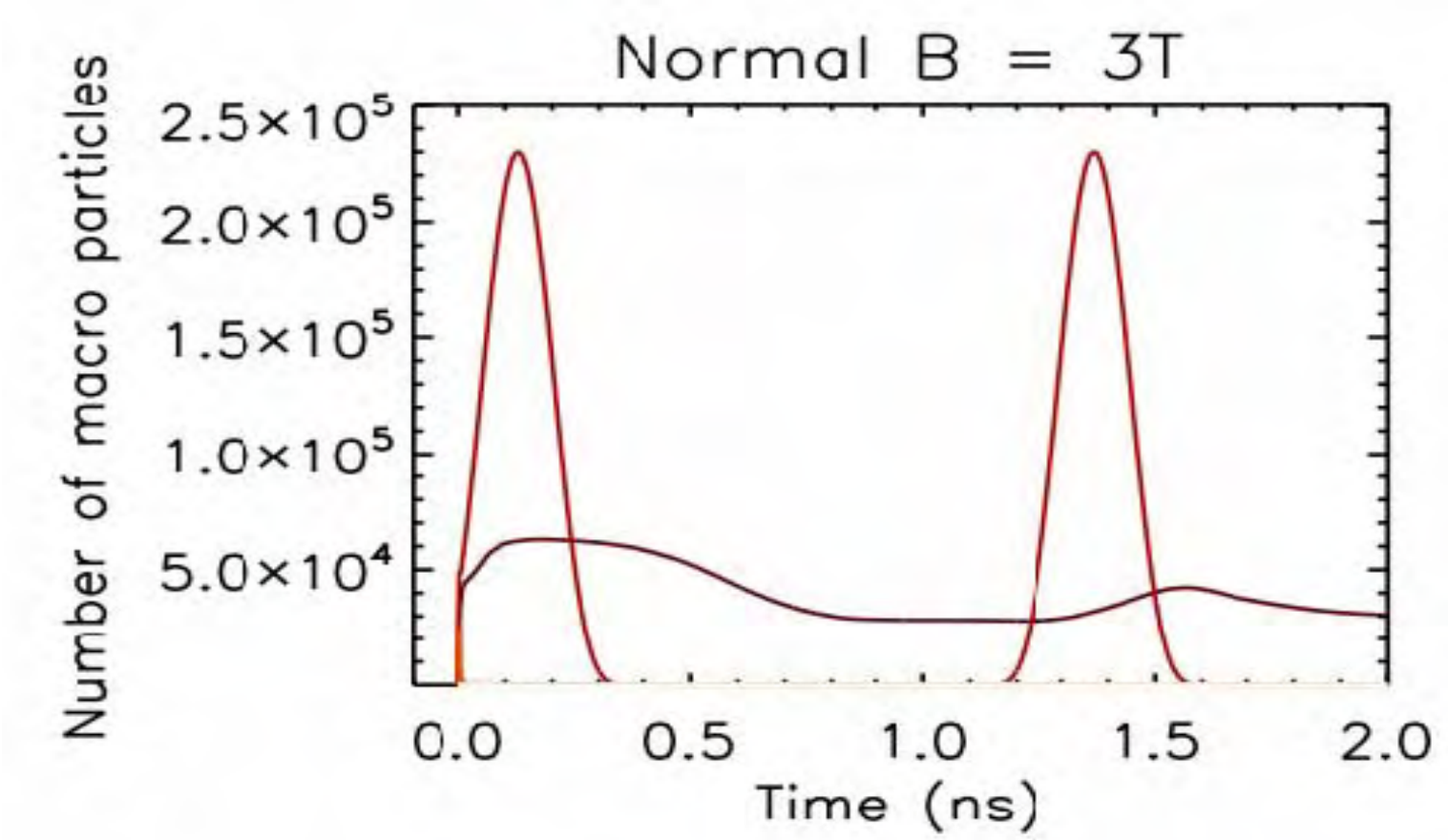
Ionization produces more electrons

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

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

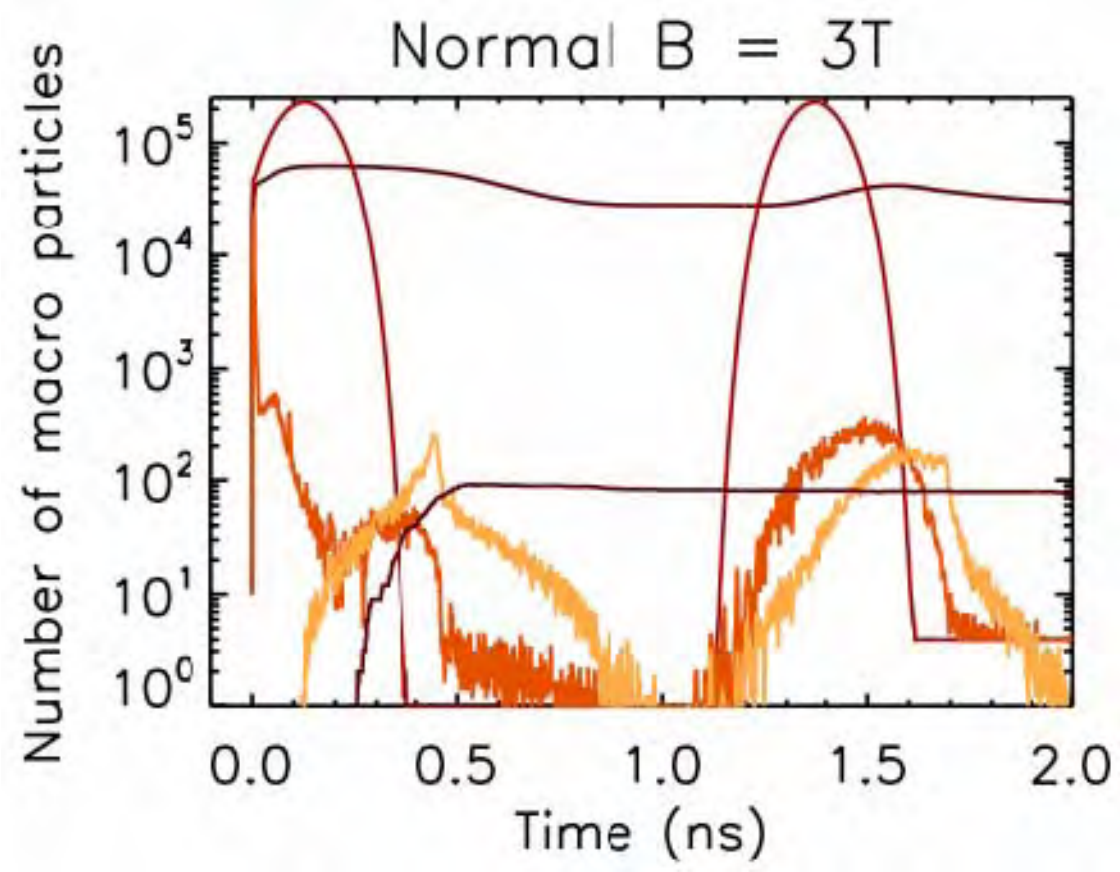
Field emitted electrons and ions are the most abundant particle species

- 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

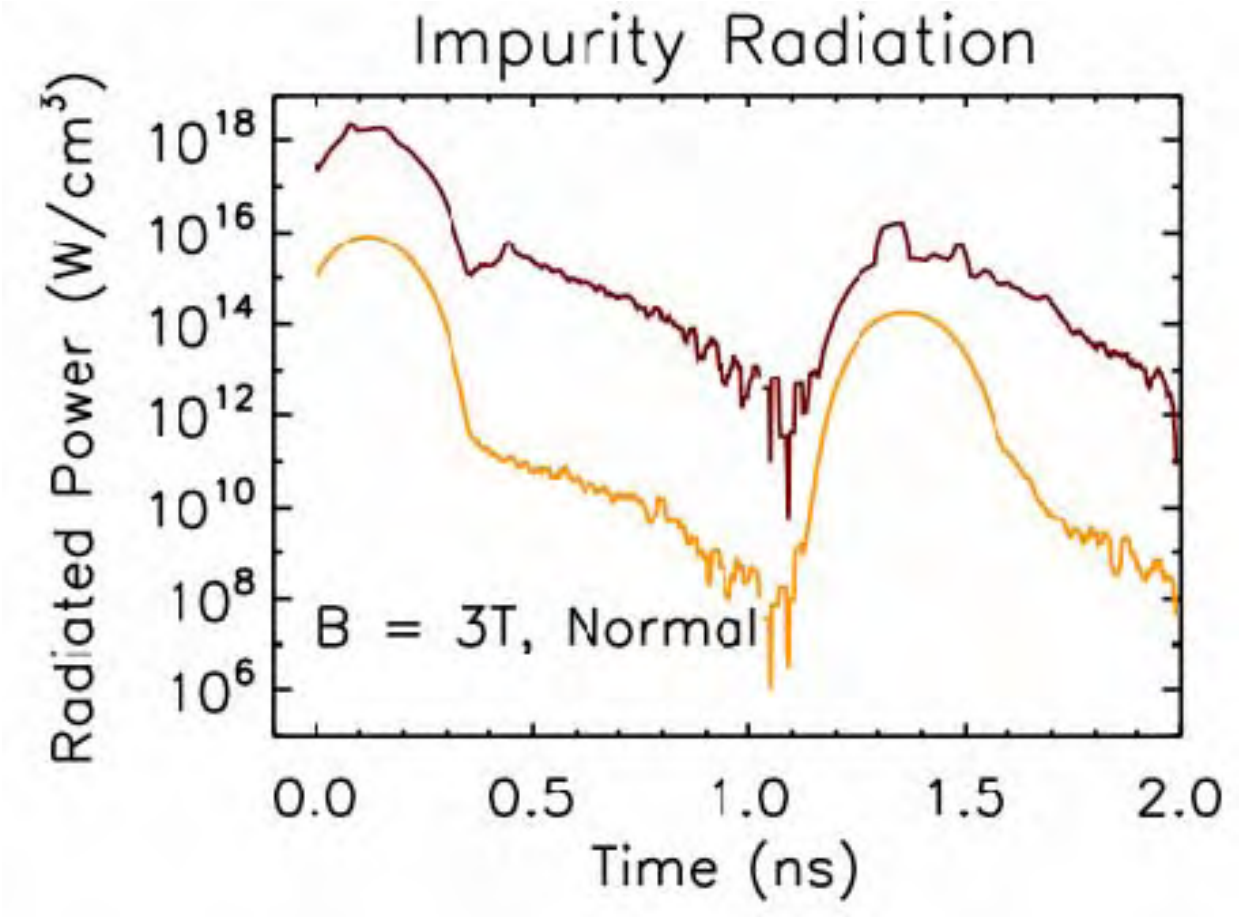
- Ions produce secondary electrons when they impact the walls
- Ions produce neutral Cu atoms through sputtering



Impurity radiation peaks at short time scales

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

- $P_L \sim 3.5 \times 10^{-25} n_i n_e / T_e^{.5}$
- $P_C \sim 1.5 \times 10^{-32} n_i n_e T_e^{.5}$



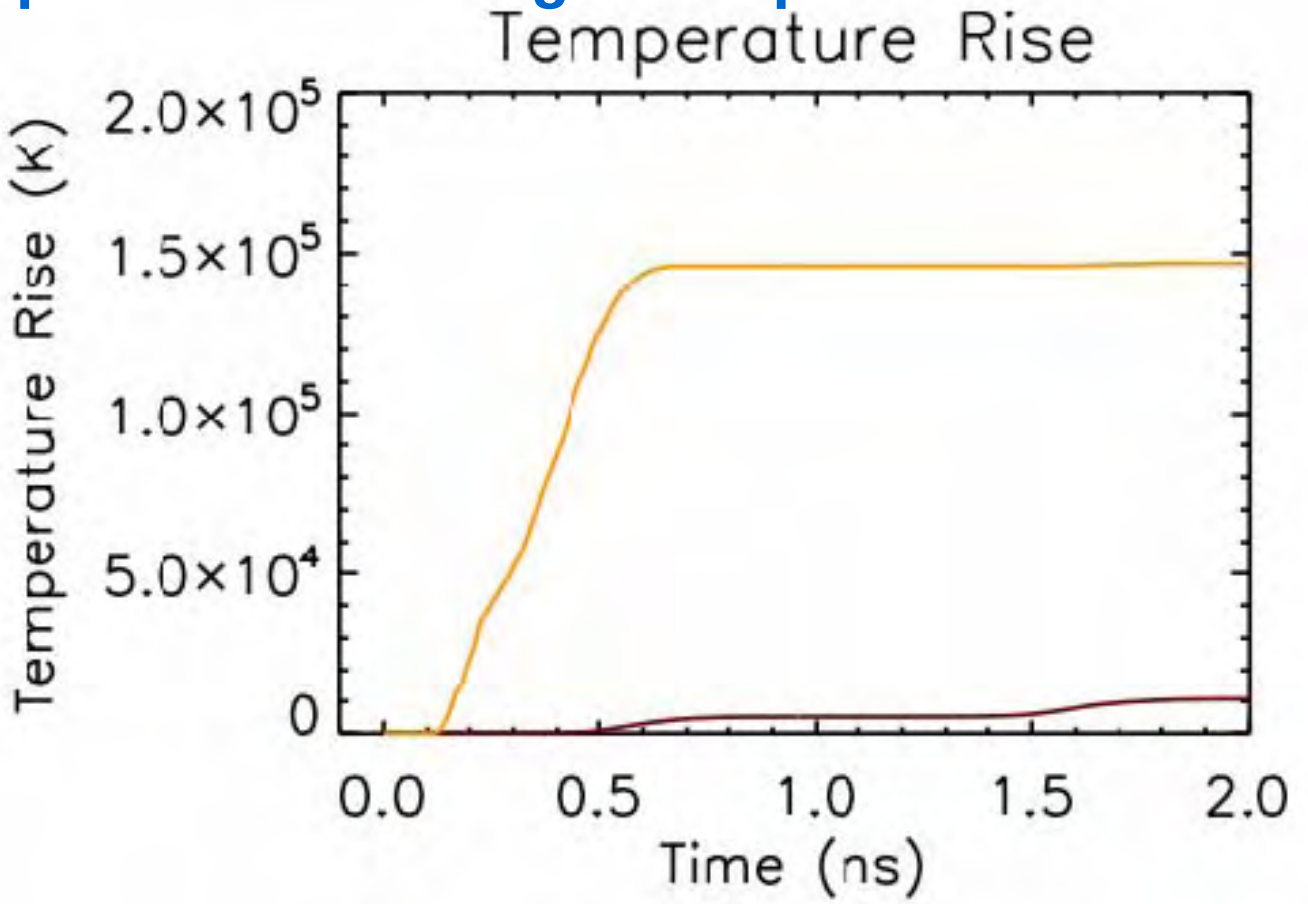
Radiated power is high where electron and ion densities are high

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

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

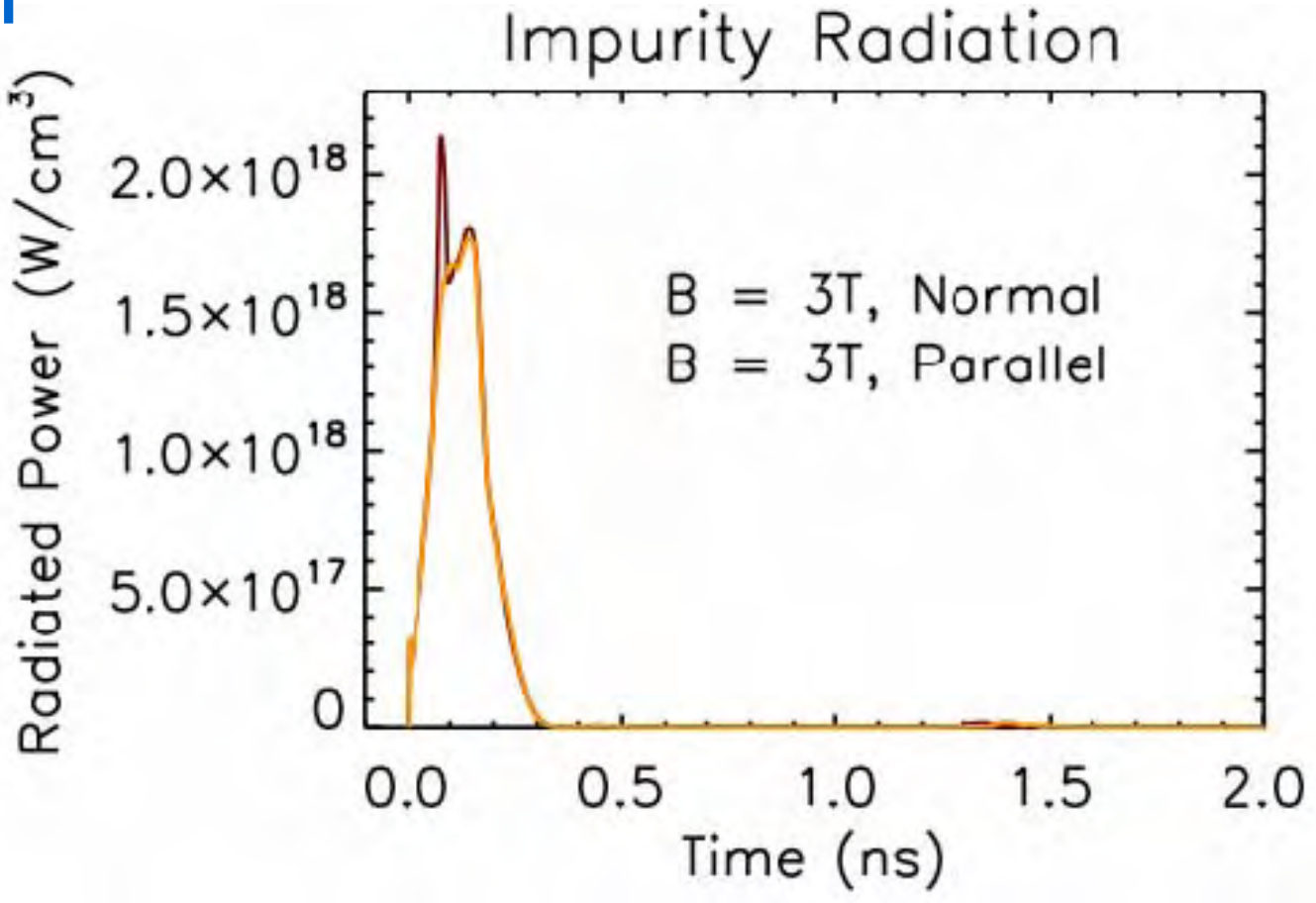
Surface heating is due to particle bombardment

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



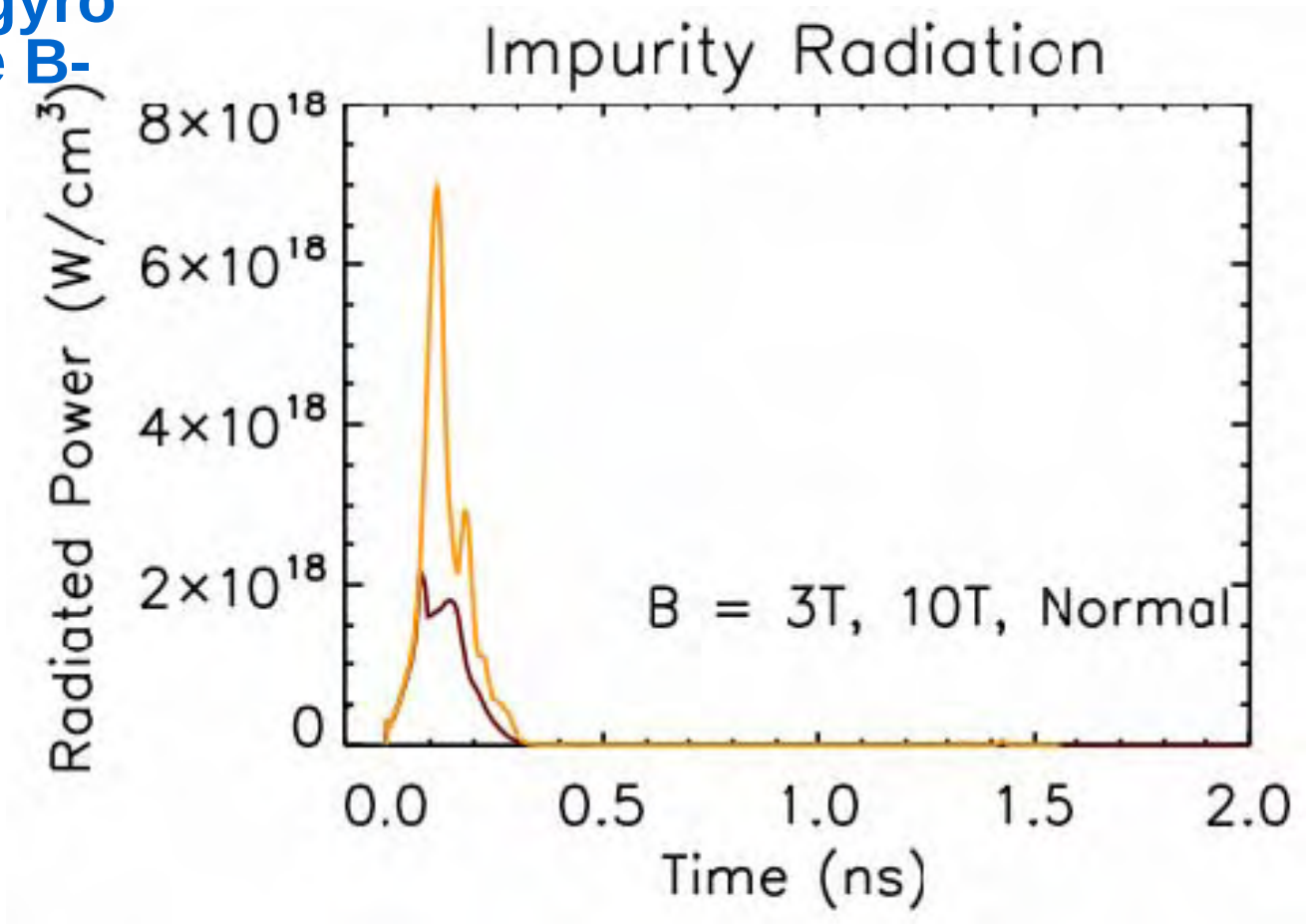
Magnetic field direction affects impurity radiation

- **Total radiated power is greater when the B-field is normal to the surface**
- **Here, B = 3 T**



Magnetic field strength affects impurity radiation as well

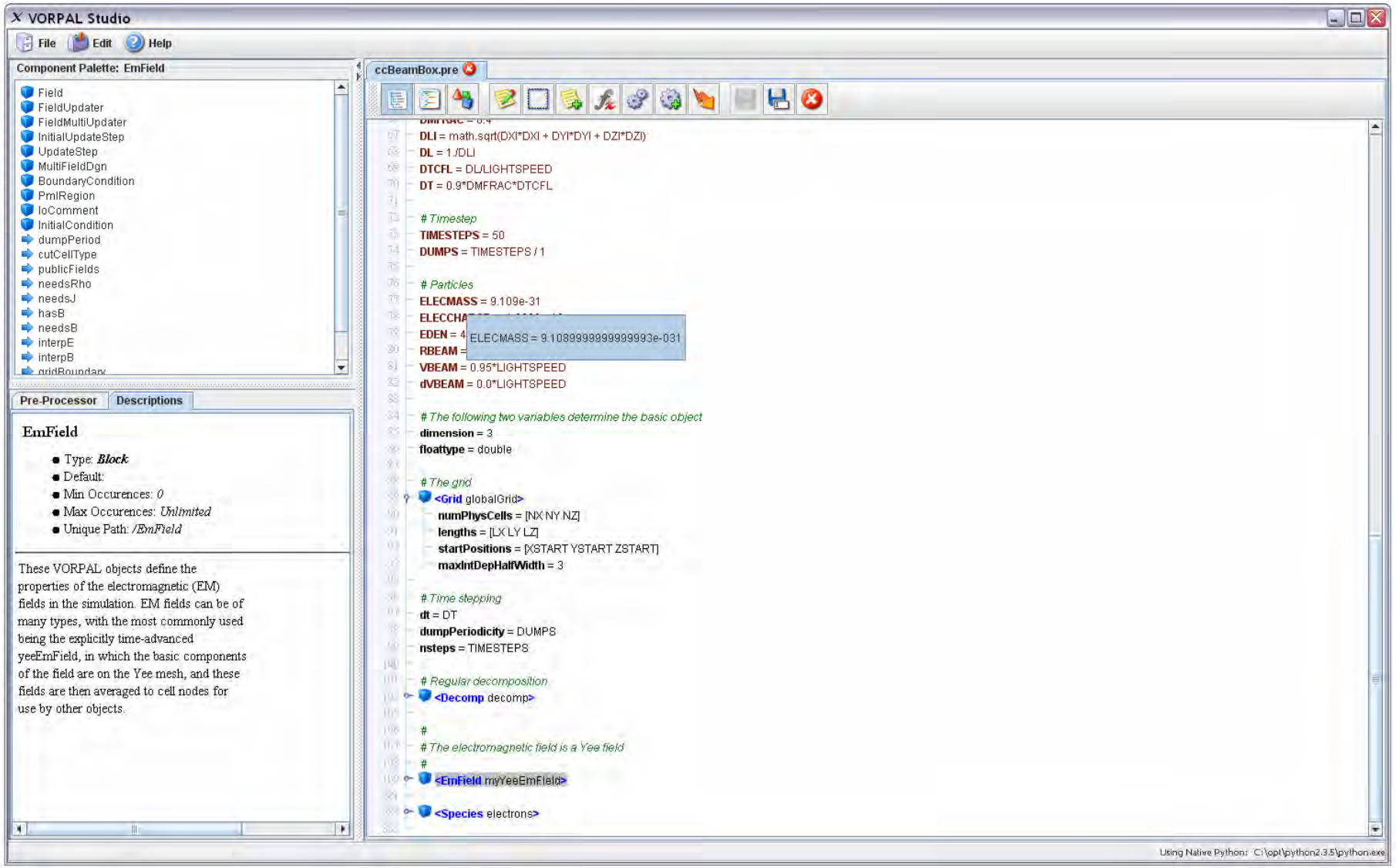
- **Electrons may return to the defect by executing a gyro orbit around the B-field**



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



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

TxPhysics Web UI brings quick visualization to surface processes