Integrated Approach to Modeling Impact of Plasma Instabilities on Liquid Lithium Surface in NSTX Device

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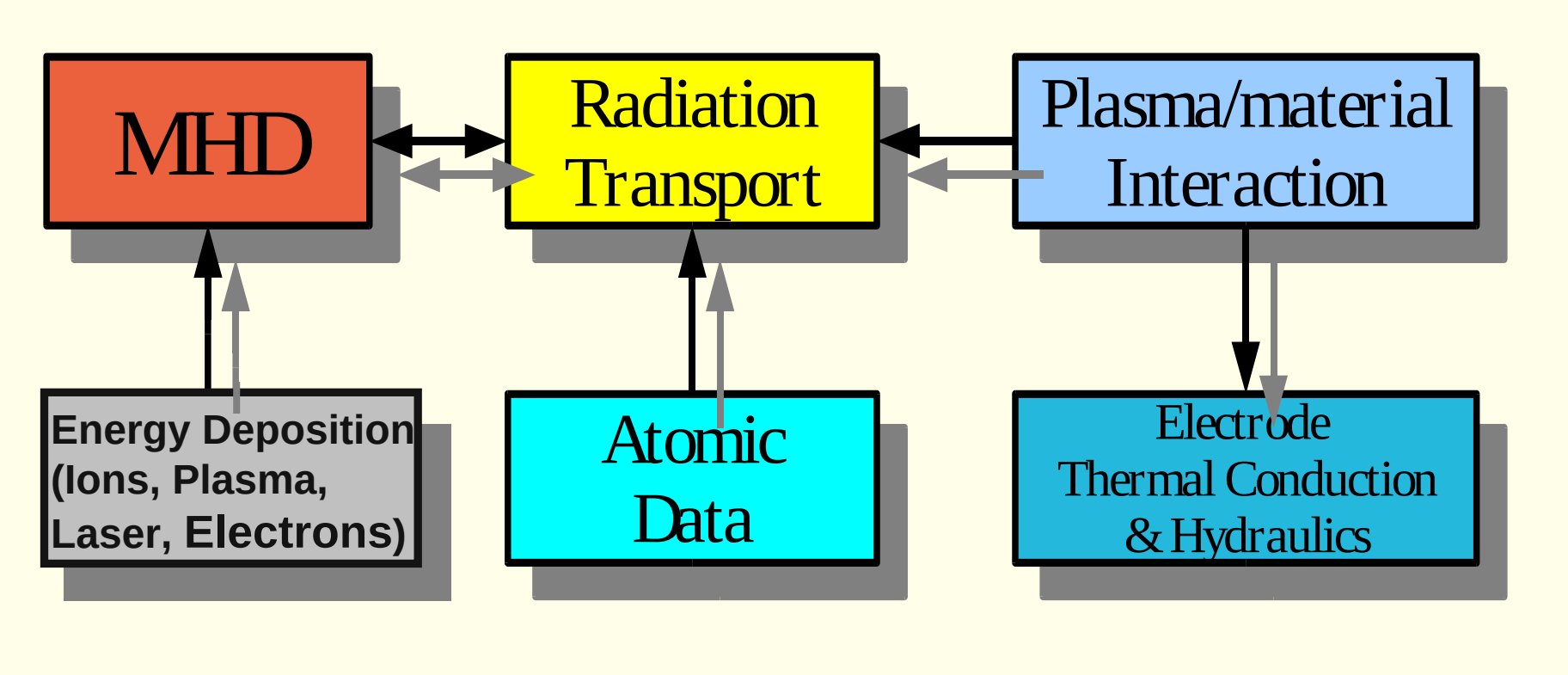
Outline

- **HEIGHTS Upgrade**
- **Liquid Divertor in NSTX Device**
- **Magnetic Field Reconstruction**
- **Integrated Approach**
- **Modeling Results**
- **Summary**

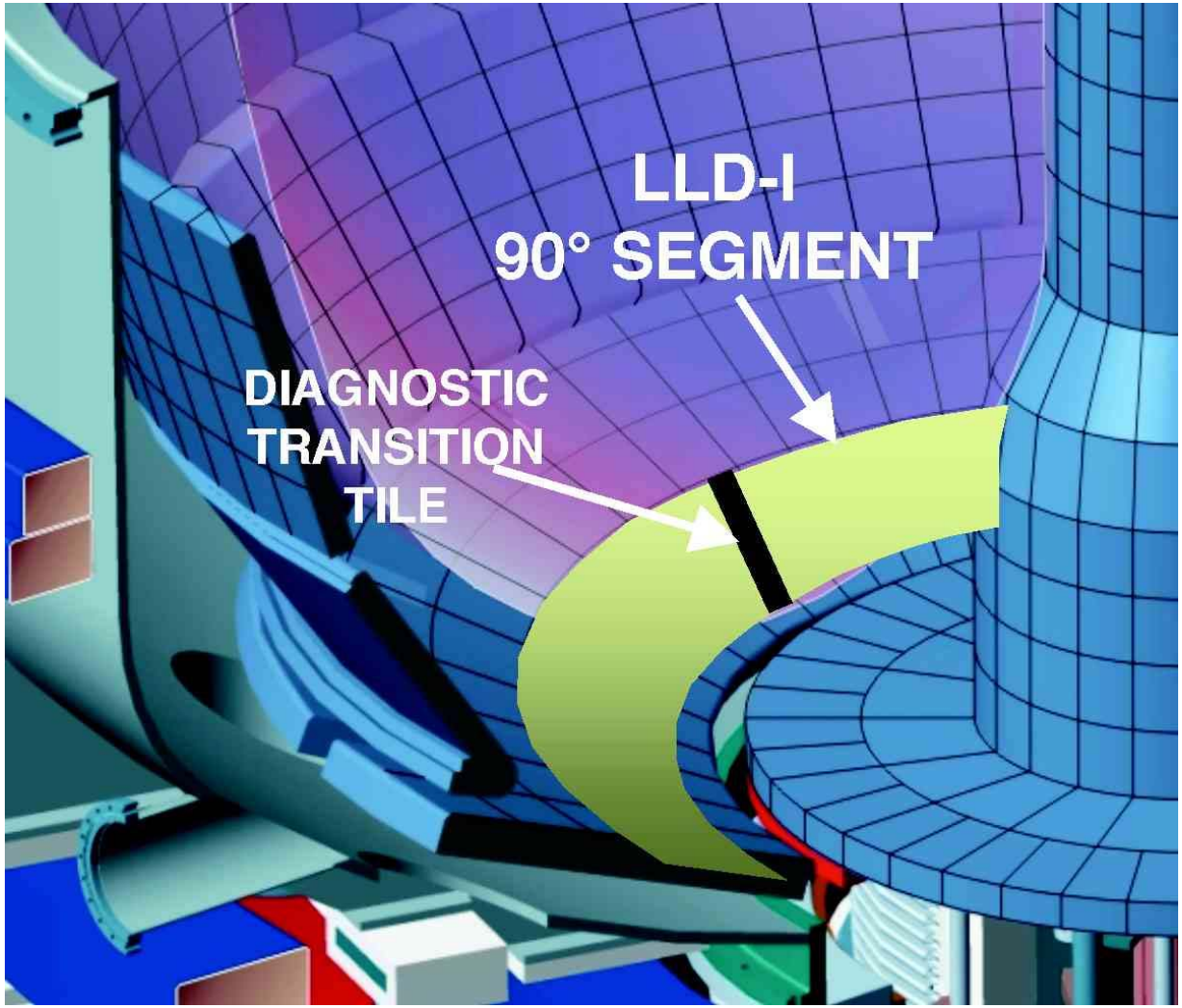
HEIGHTS Simulation Package



Plasma Transient / Instabilities: Plasma Material Interaction Key Concerns

- **HEIGHTS major modeling events for surface and structural response to plasma transients:**
  - *Edge Localized Modes (ELM's)*
  - *Disruptions*
  - *Vertical Displacement Events (VDE's)*
  - *Runaway electrons*
- **Key concerns:**
  - *PFC erosion lifetime*
  - *PFC structural integrity*
  - *Plasma contamination*

National Spherical Torus eXperiment



$B = 0.5$ T

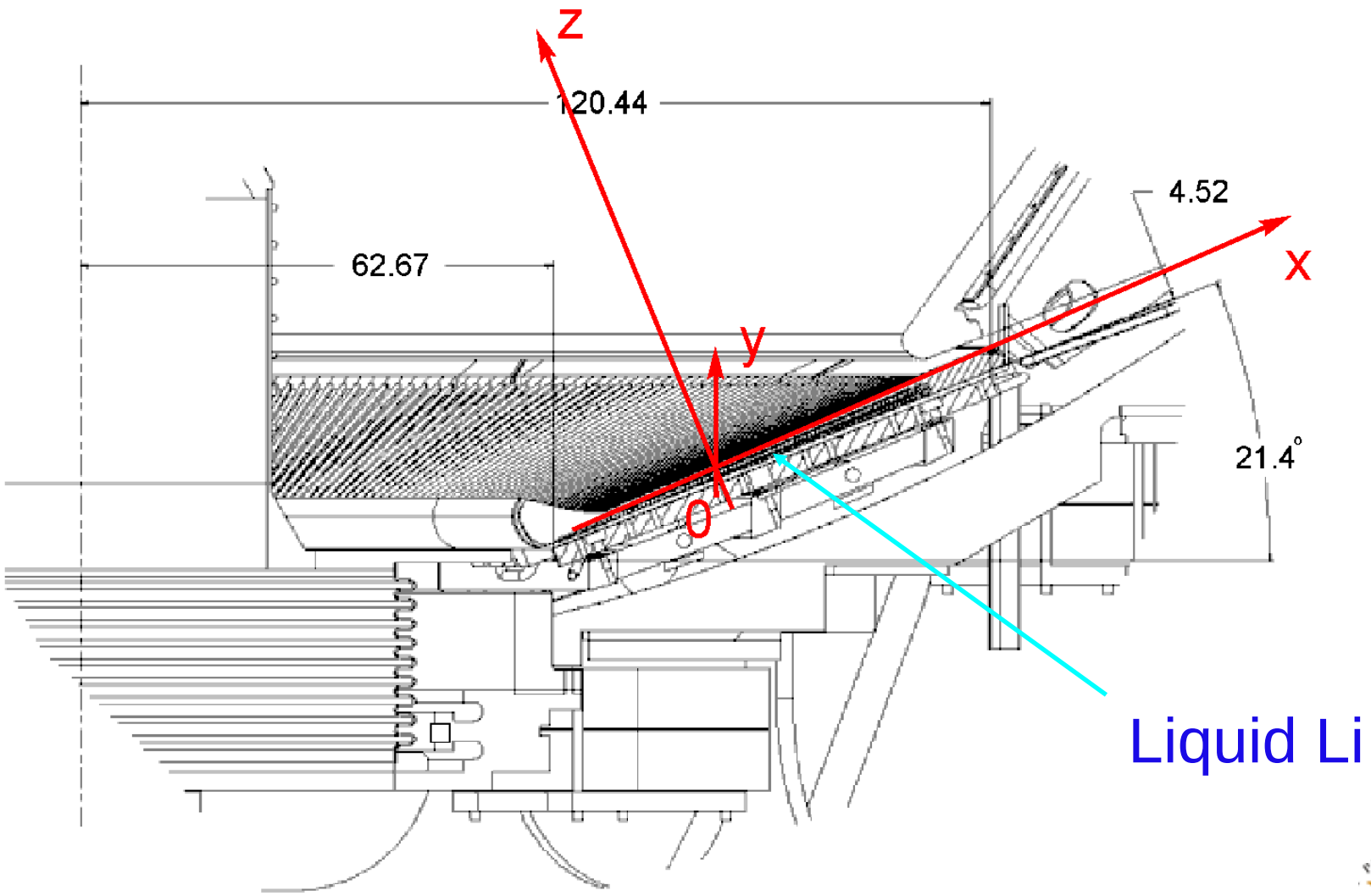
$R_{div} = 81.5$ cm

$\alpha = 5.0$ deg

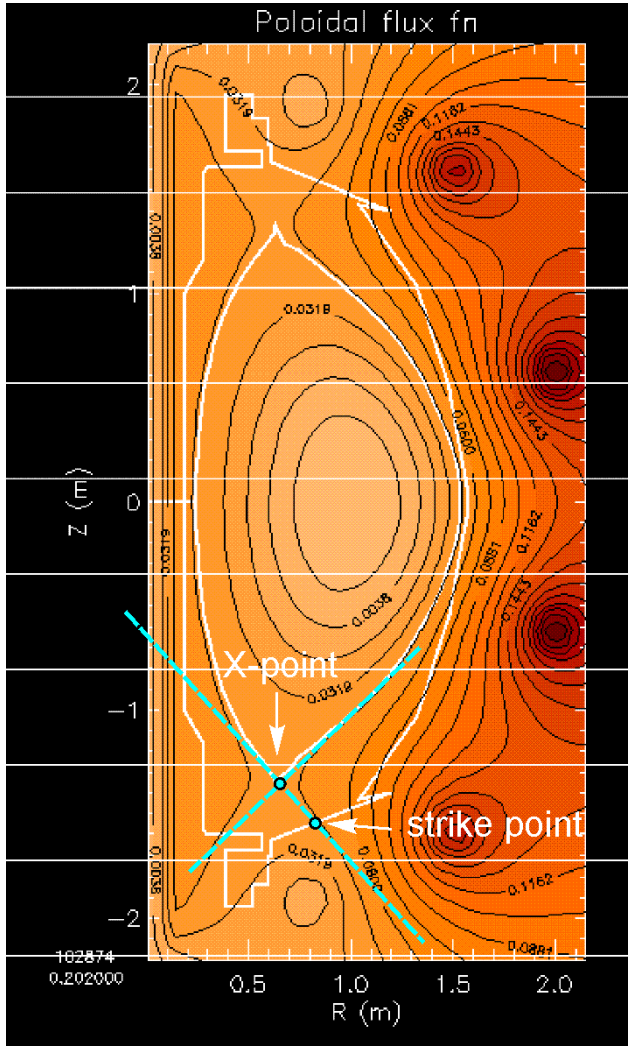
$t_{ELM} < 1.0$ ms

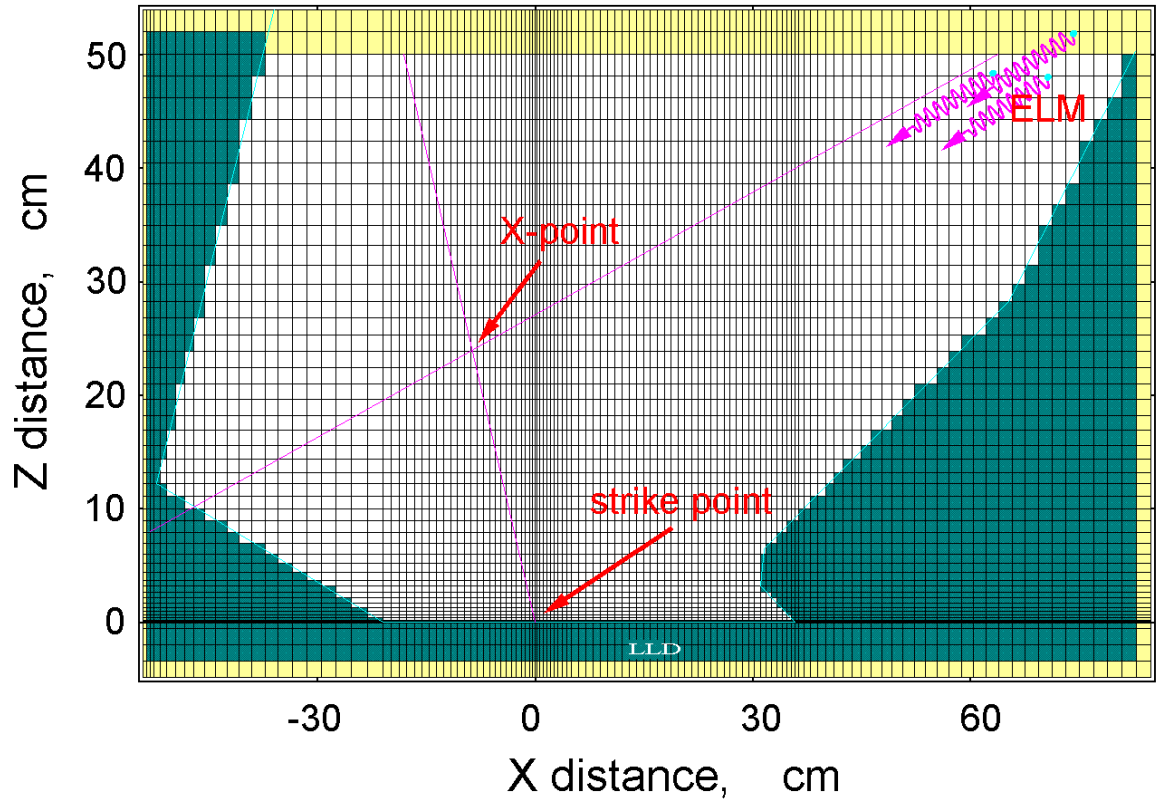
$T_{ELM} = 250$ eV

NTSX Divertor Local Coordinate System



Nearby Divertor Magnetic Field

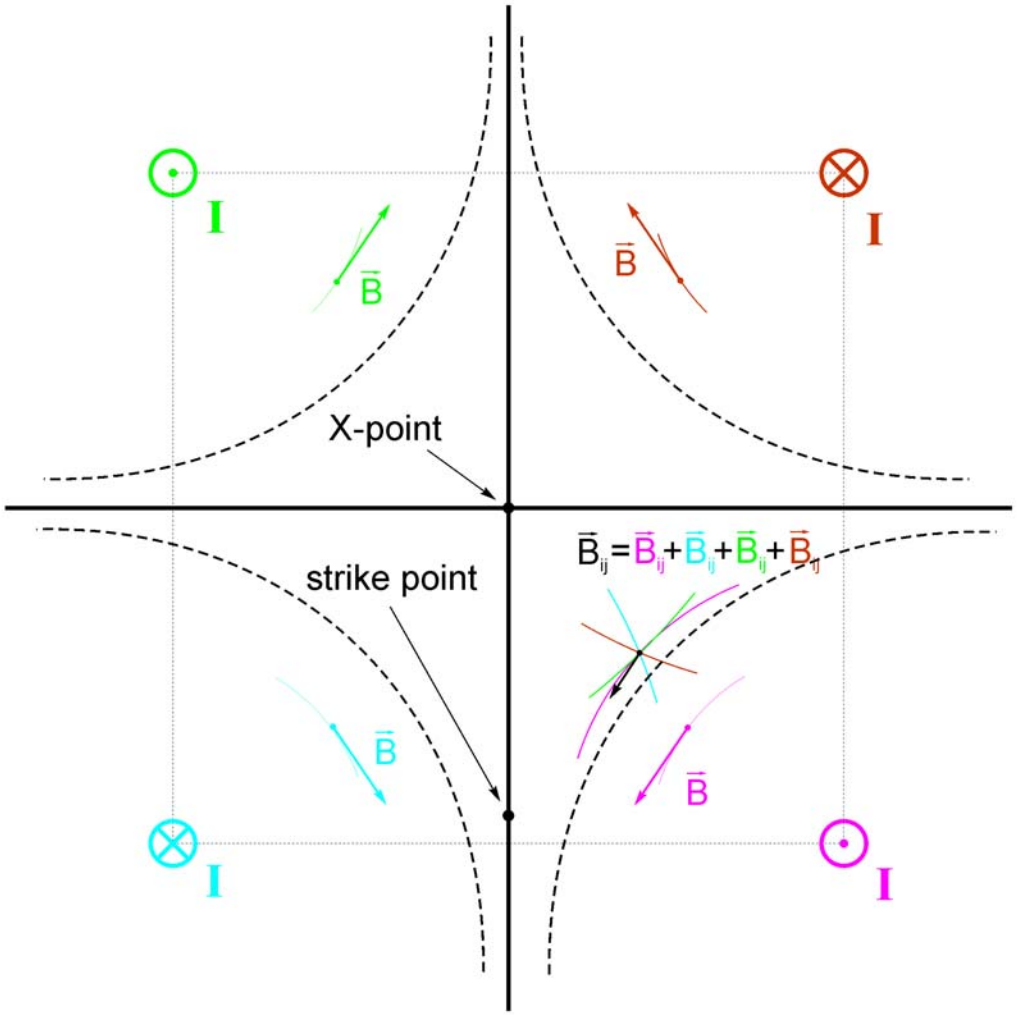




HEIGHTS construction of magnetic field for MHD analysis

$$\nabla \cdot B = 0$$

Construction of Magnetic Field with Four Modeling Currents

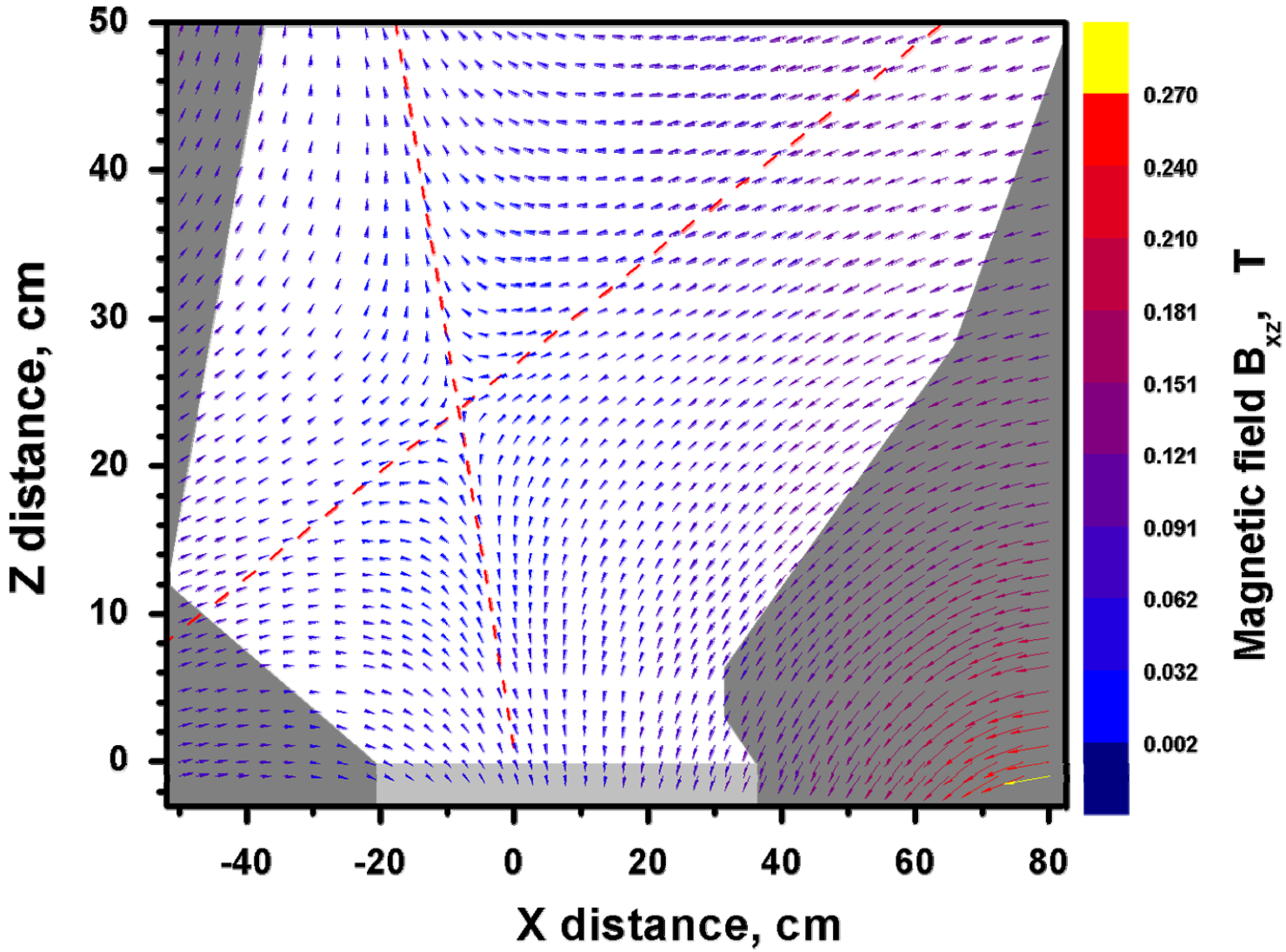


Magnetic field in strike point initialize the whole system:

$$\left|\vec{\mathbf{B}}\right|=0.5T$$

$$\alpha=5.0\,\mathrm{deg}$$

HEIGHTS Reconstructed Magnetic Field



MHD Equations for NSTX

$$\frac{\partial \mathbf{U}}{\partial t} + \frac{\partial \mathbf{F}(\mathbf{U})}{\partial x} + \frac{\partial \mathbf{H}(\mathbf{U})}{\partial z} = \mathbf{\Omega}$$

$$\mathbf{U}\left(/\ \rho, \rho v_x, \rho v_y, \rho v_z, e_t, B_x, B_y, B_z\ /\right)$$

$$\mathbf{F}(\mathbf{U}) = \begin{bmatrix} \rho v_x \\ \rho v_x^2 + p_t - B_x^2/4\pi \\ \rho v_y v_x - B_y B_x/4\pi \\ \rho v_z v_x - B_z B_x/4\pi \\ v_x(e_t + p_h) \\ 0 \\ v_x B_y - B_x v_y \\ v_x B_z - B_x v_z \end{bmatrix} \qquad \mathbf{H}(\mathbf{U}) = \begin{bmatrix} \rho v_z \\ \rho v_x v_z - B_x B_z/4\pi \\ \rho v_y v_z - B_y B_z/4\pi \\ \rho v_z^2 + p_t - B_z^2/4\pi \\ v_z(e_t + p_h) \\ v_z B_x - B_z v_x \\ v_z B_y - B_z v_y \\ 0 \end{bmatrix}$$

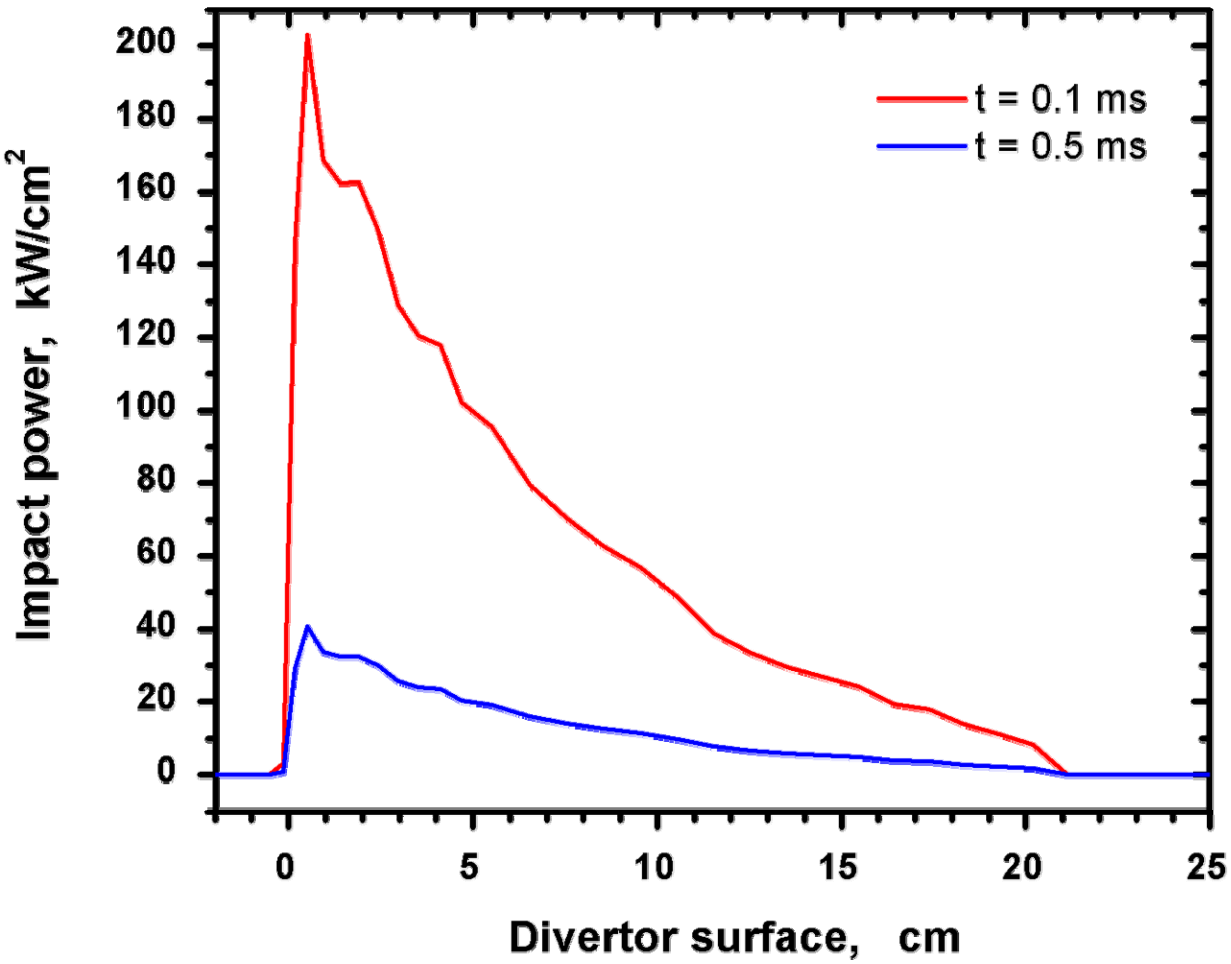
$$\mathbf{\Omega} = \begin{bmatrix} Q_{m,vap} \\ -\frac{B_x}{4\pi}\left(\frac{\partial B_x}{\partial x} + \frac{\partial B_z}{\partial z}\right) \\ -\frac{B_y}{4\pi}\left(\frac{\partial B_x}{\partial x} + \frac{\partial B_z}{\partial z}\right) \\ -\frac{B_z}{4\pi}\left(\frac{\partial B_x}{\partial x} + \frac{\partial B_z}{\partial z}\right) \\ Q_{th} + Q_{rad} + Q_J + Q_{e,vap} + Q_{imp} \\ -v_x\left(\frac{\partial B_x}{\partial x} + \frac{\partial B_z}{\partial z}\right) \\ -v_y\left(\frac{\partial B_x}{\partial x} + \frac{\partial B_z}{\partial z}\right) \\ -v_z\left(\frac{\partial B_x}{\partial x} + \frac{\partial B_z}{\partial z}\right) \end{bmatrix}$$

ρ - density; v – velocity; B – magnetic field; p – pressure
Q_{th} - thermal conduction; Q_{rad} - radiation transport;
Q_J - Joule heat term; $Q_{m,vap}$, $Q_{e,vap}$ - target vaporization;
Q_{imp} - ELM plasma impact.

Physical Processes, an Integrated Approach

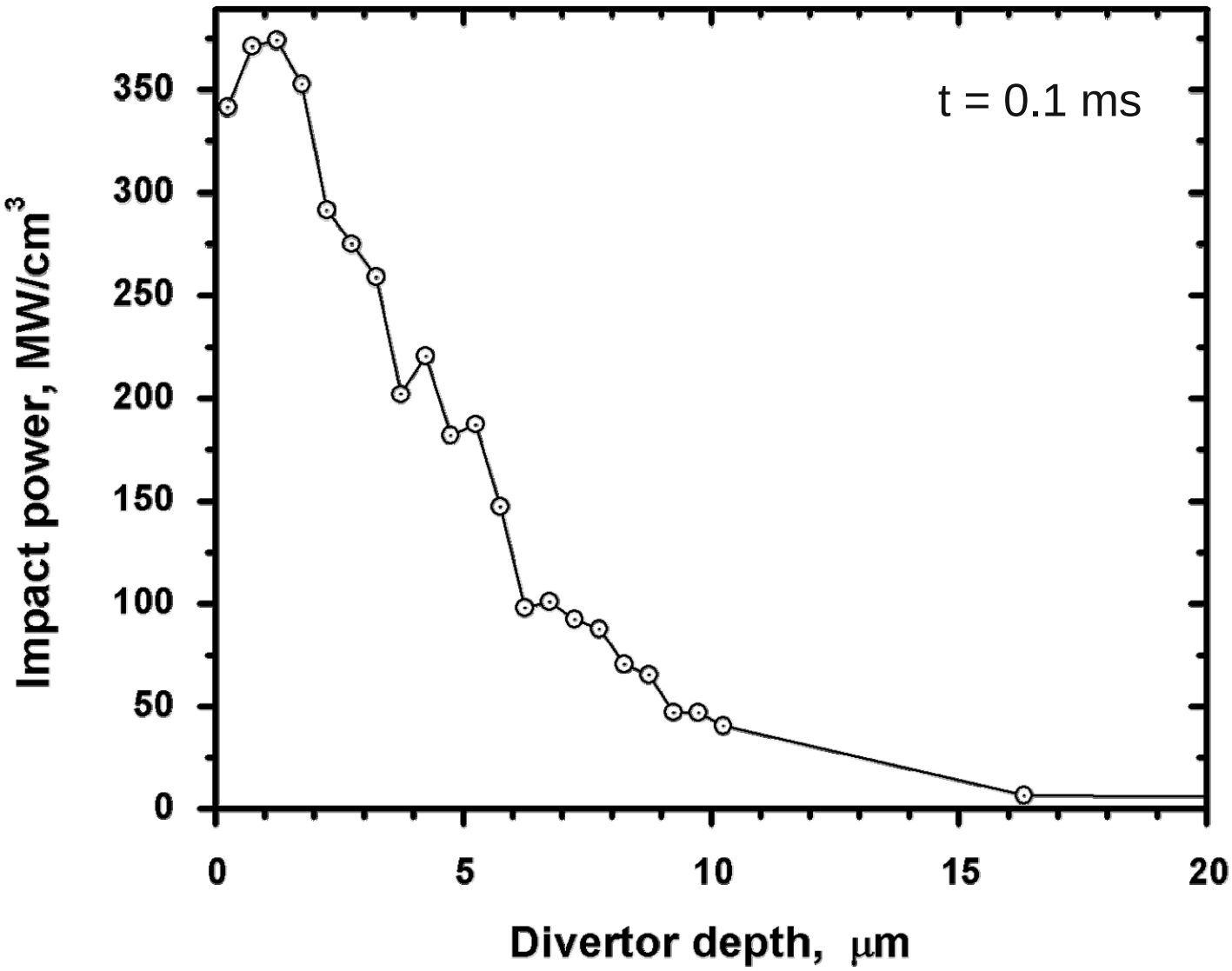
- Monte Carlo algorithm for the ELM plasma impact:
  - *Ions, electrons (initial and secondary), photons (secondary);*
  - *3D Energy deposition into solid and plasma in magnetic field;*
  - *All scattering processes including Bremsstrahlung, Compton Absorption, Photoabsorption, and Auger Relaxation*
- Thermal conduction:
  - *Implicit scheme on sparse matrix technology for heat conduction in plasma;*
  - *Explicit scheme for the heat conduction in liquid target;*
  - *Vaporization model for the liquid target*
- MHD:
  - *Total variation diminishing scheme in Lax-Friedrich formulation;*
  - *Magnetic field divergence correction;*
  - *Implicit scheme on sparse matrix technology for magnetic diffusion*
- Radiation transport:
  - *Weight Monte Carlo algorithm;*
  - *More than 2500 spectral groups for the lithium plasma;*
  - *Full 3D simulation*

NTSX ELM Parameters

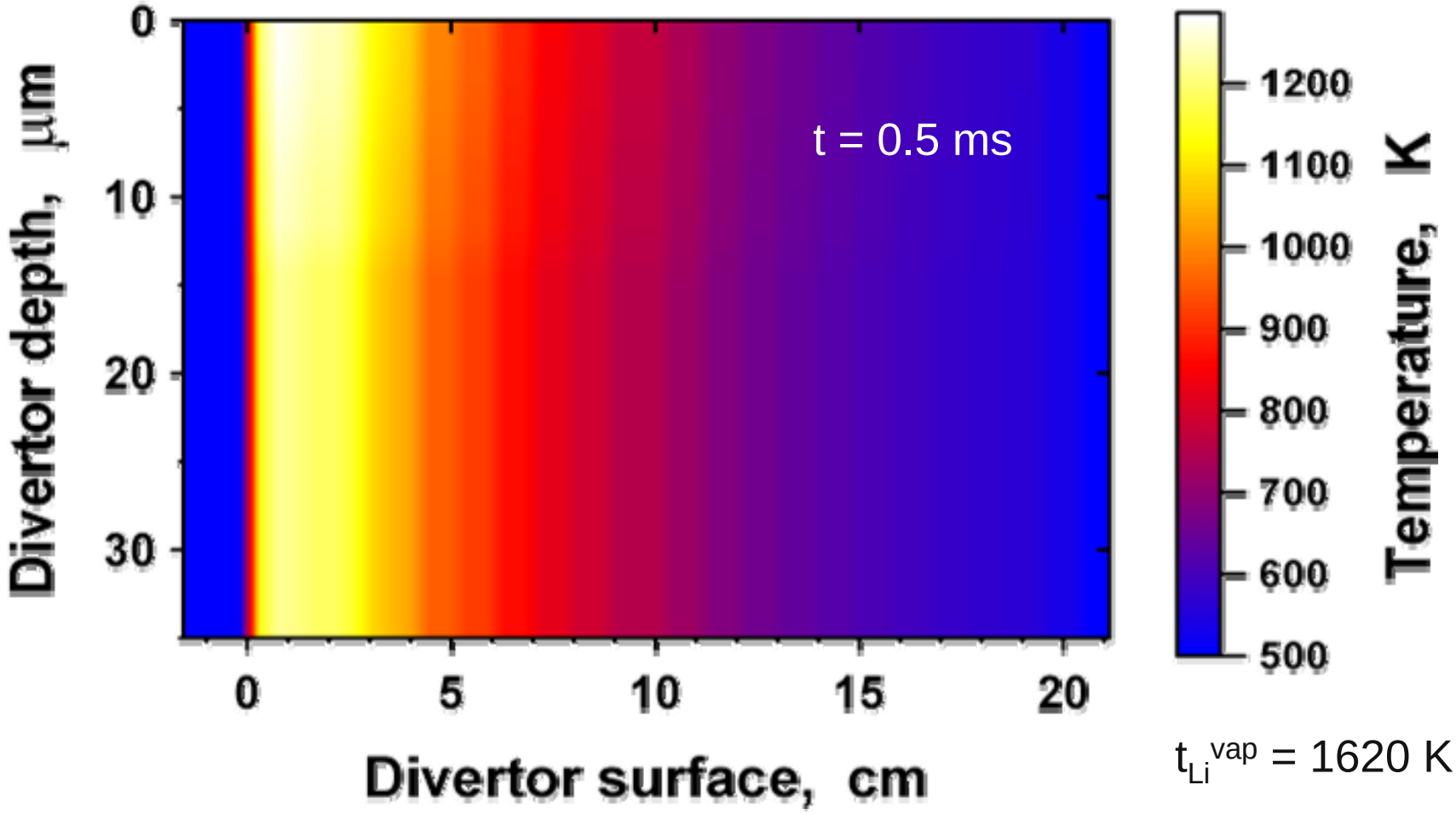


E_{ELM} = 74.0 kJ
t_{ELM} = 0.1-1.0 ms
T_{ELM} = 250 eV
B = 0.5 T
R_{div} = 81.5 cm
α = 5.0 deg
Exponential distribution in SOL

Impact Energy Deposition in Depth



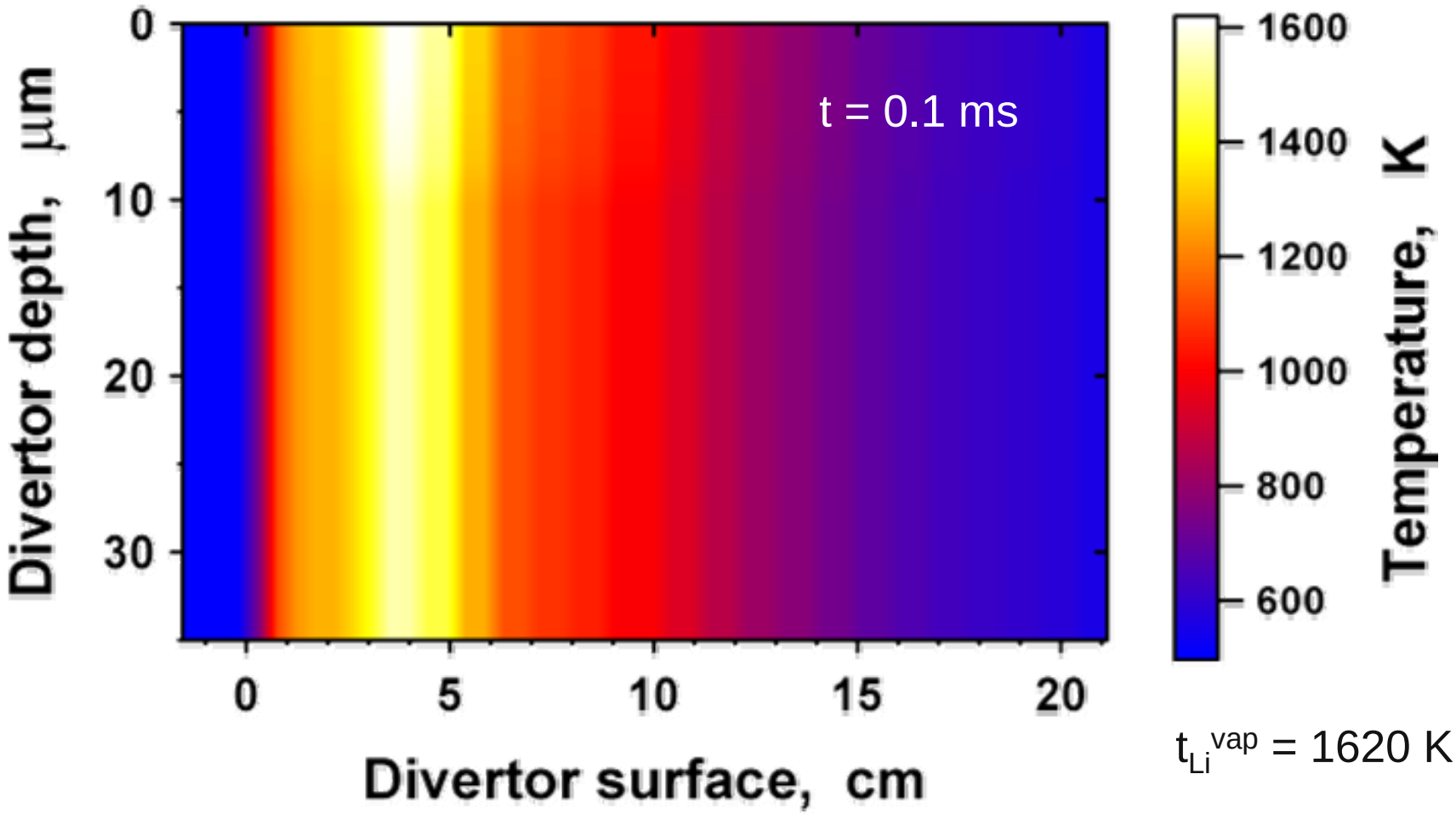
Divertor Temperature Field



t_{Li}^{vap} = 1620 K

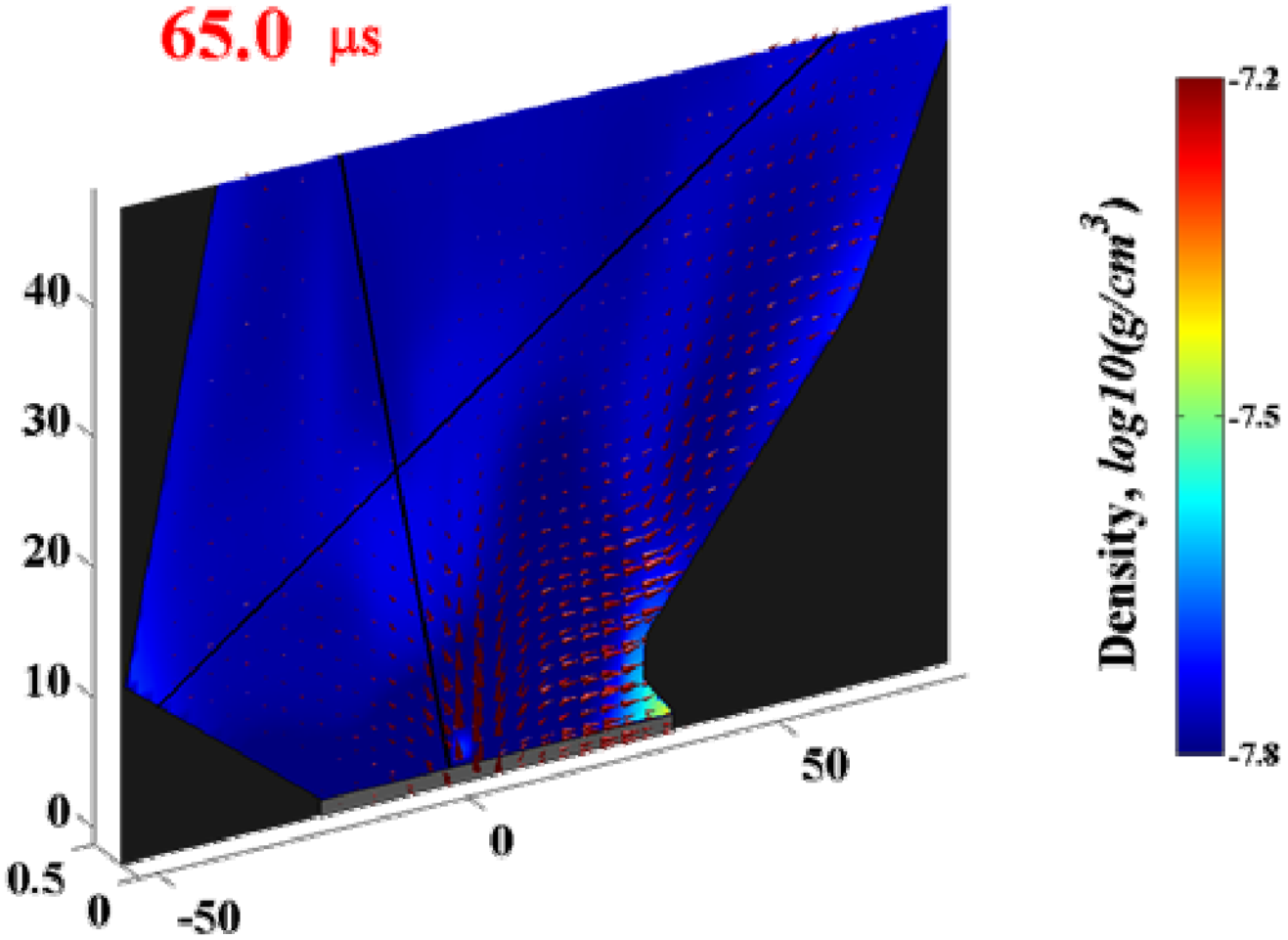
Long pulse did not heat lithium surface to the boiling point

Divertor Temperature Field

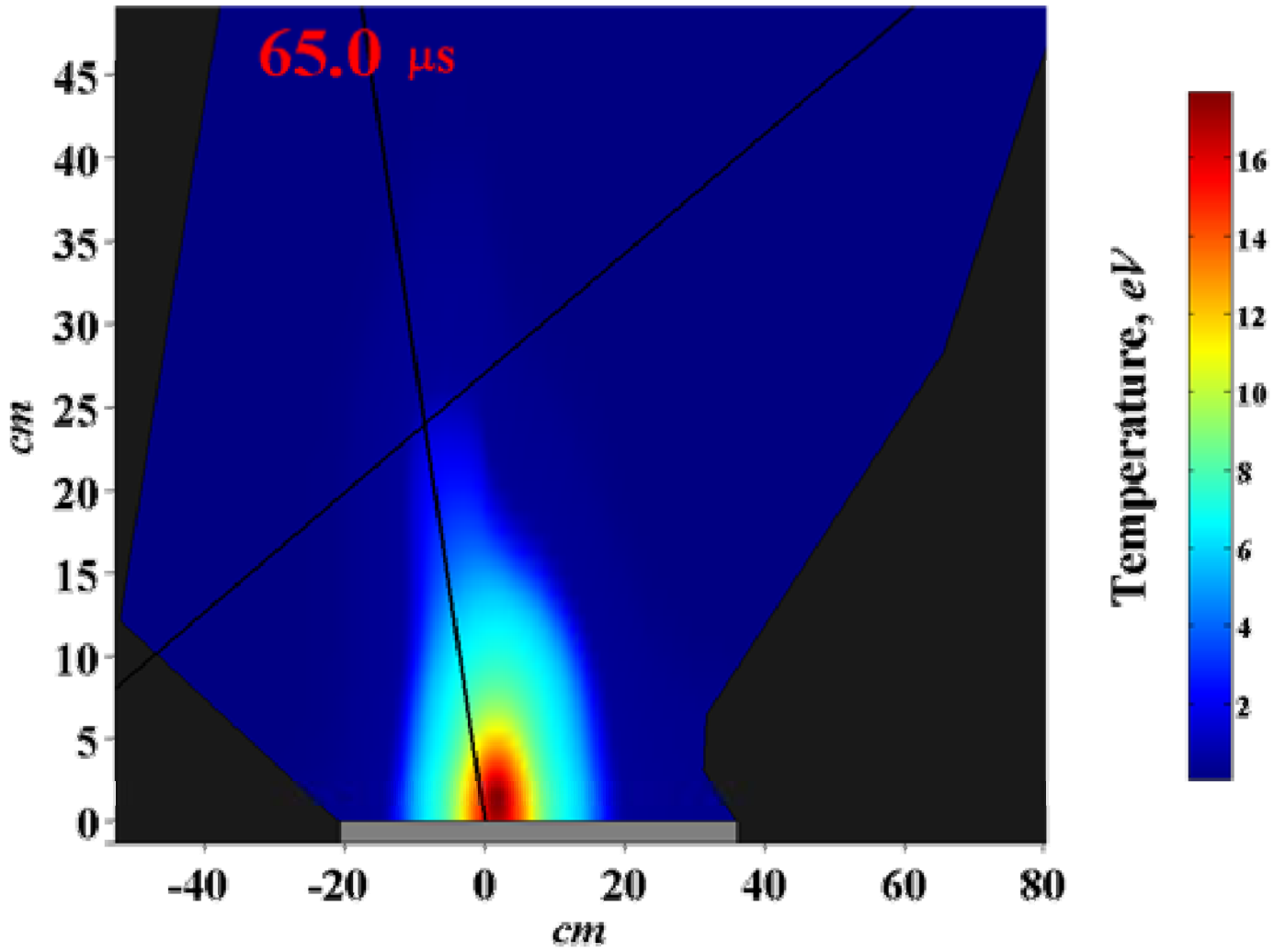


t_{Li}^{vap} = 1620 K

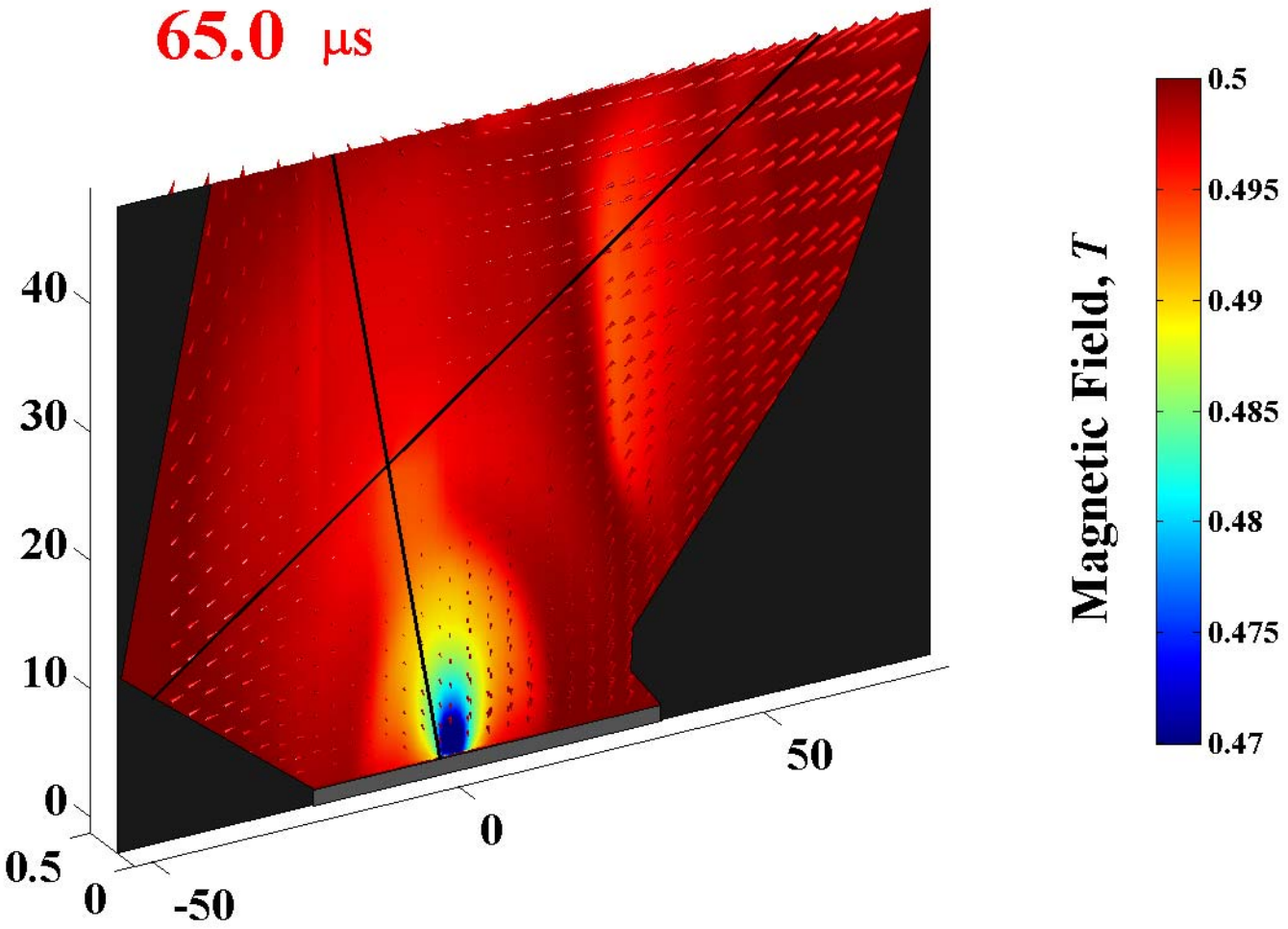
NSTX Divertor Plasma Motion



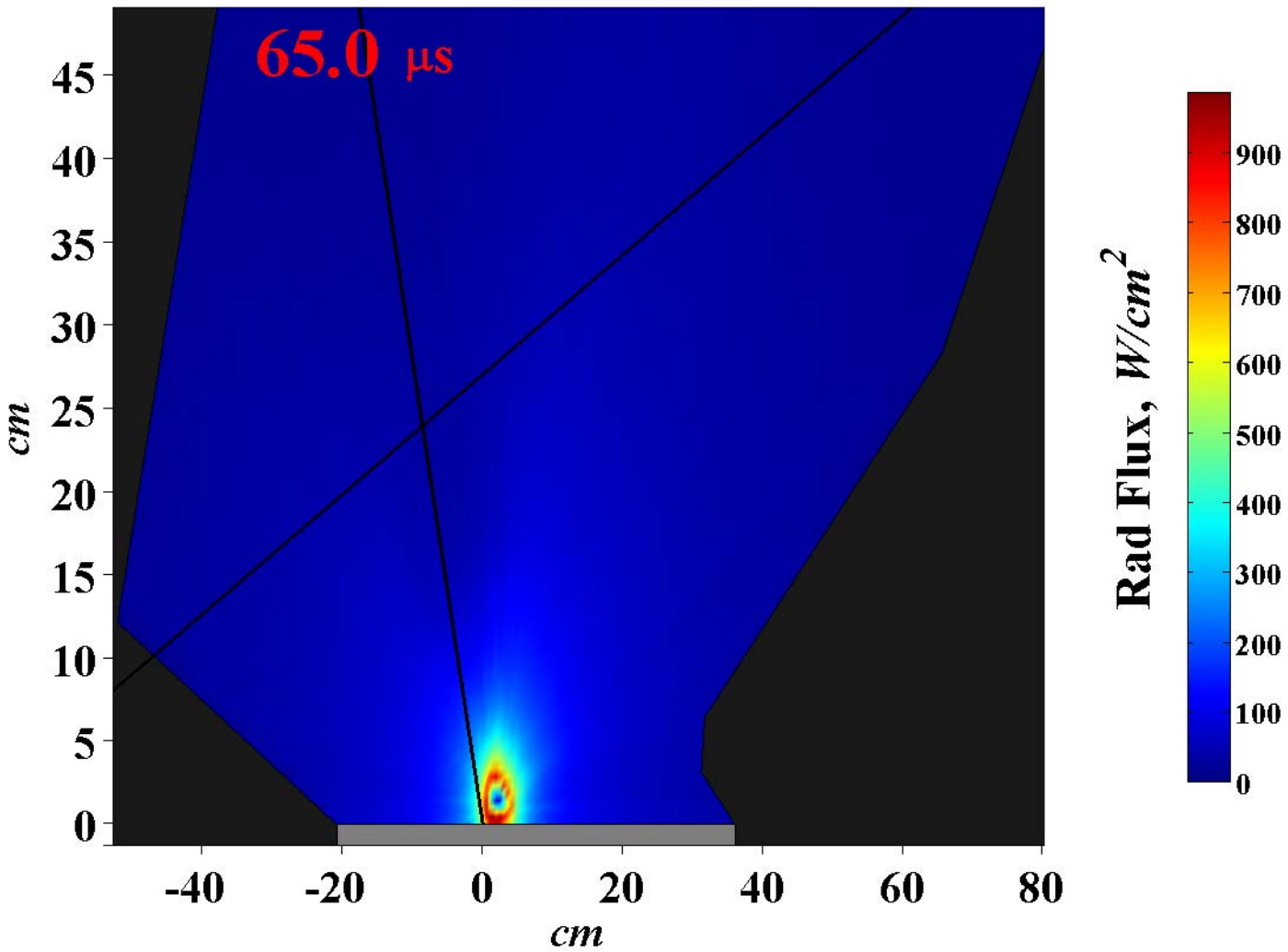
NSTX ELM Temperature Evolution



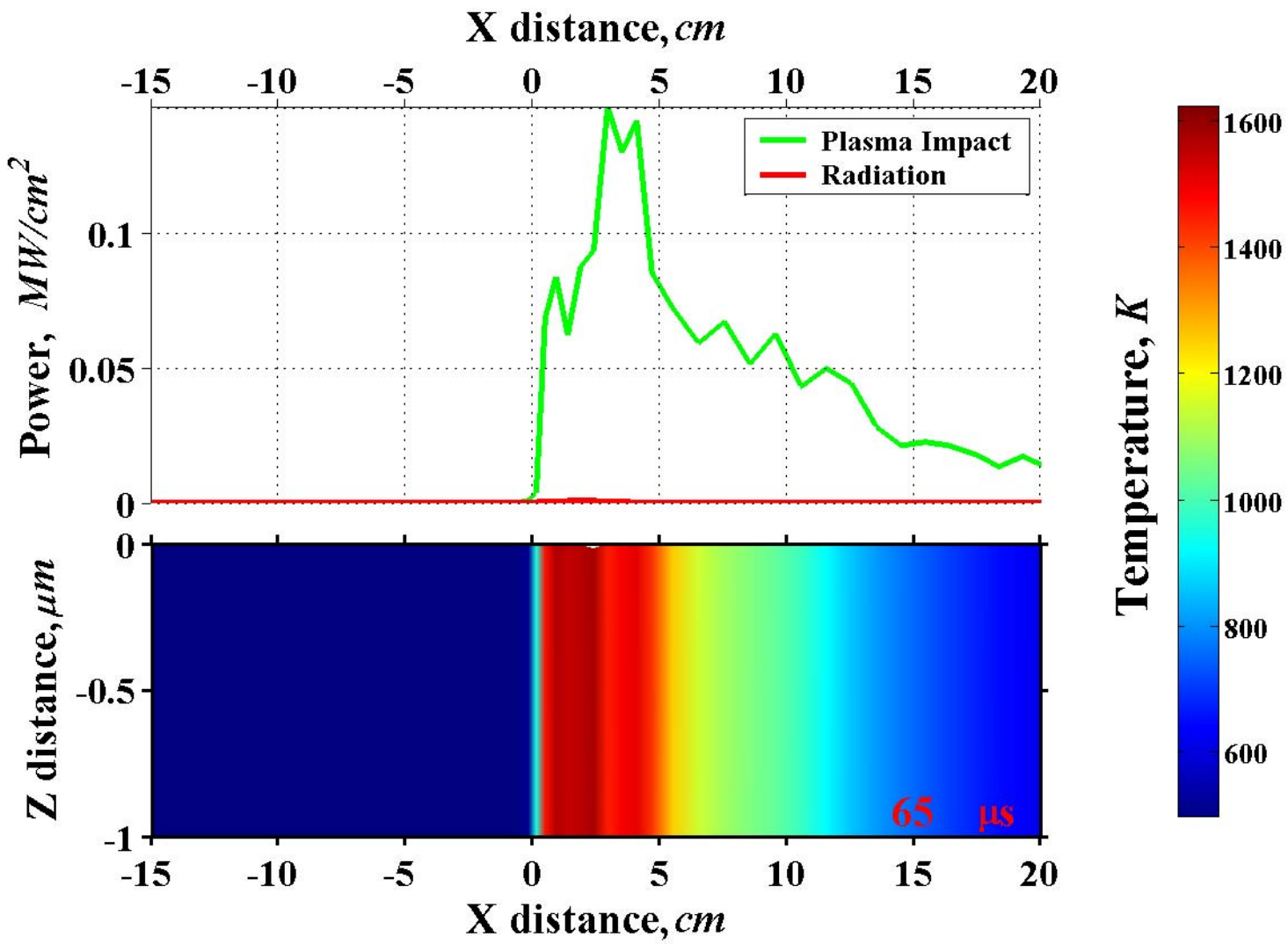
Magnetic Field Evolution during ELM



Radiation Fluxes



Divertor Heat Load



Summary

- NSTX device - major model development and HEIGHTS package effort completed
- Complex nearby divertor magnetic field reconstructed
- Test variant of the ELM is simulated in NSTX geometry with liquid lithium divertor
- Density, Temperature, Velocity, Radiation fluxes, Energy deposition fields are obtained
- Geometry and magnetic field design optimization for contamination migration may be possible