

# 3-D Source, Neutron Wall Loading & Radiative Heating for ARIES-CS


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# Overview

- Motivation
- Methodology
- Source Map
- Results
  - Neutron Wall Loading
  - Radiative Heating

# Motivation

- 1-D modeling
  - Uniform source acceptable approximation

- 3-D modeling enabled by new neutronics tool, MCNPX-CGM
  - Source distribution becomes limiting approximation in model analysis

# Neutron Source Methodology

- Generate hex mesh in real space from uniform mesh in flux coordinate space
- Generate cumulative distribution function for source density in hex mesh
- Sample hex mesh and mesh cells for source position

# Generate Hex Mesh

- Uniform spacing in
  - 1 field period in ***toroidal*** direction
  - $2\pi$ in ***poloidal*** direction
  - Flux plasma surfaces in ***radial*** direction
- Use Fourier expansion to convert
  - First to $(r,z,\phi)$
  - Then to $(x,y,z)$
- *Note: Degenerate hexes along magnetic axis*

# Mesh Indexing

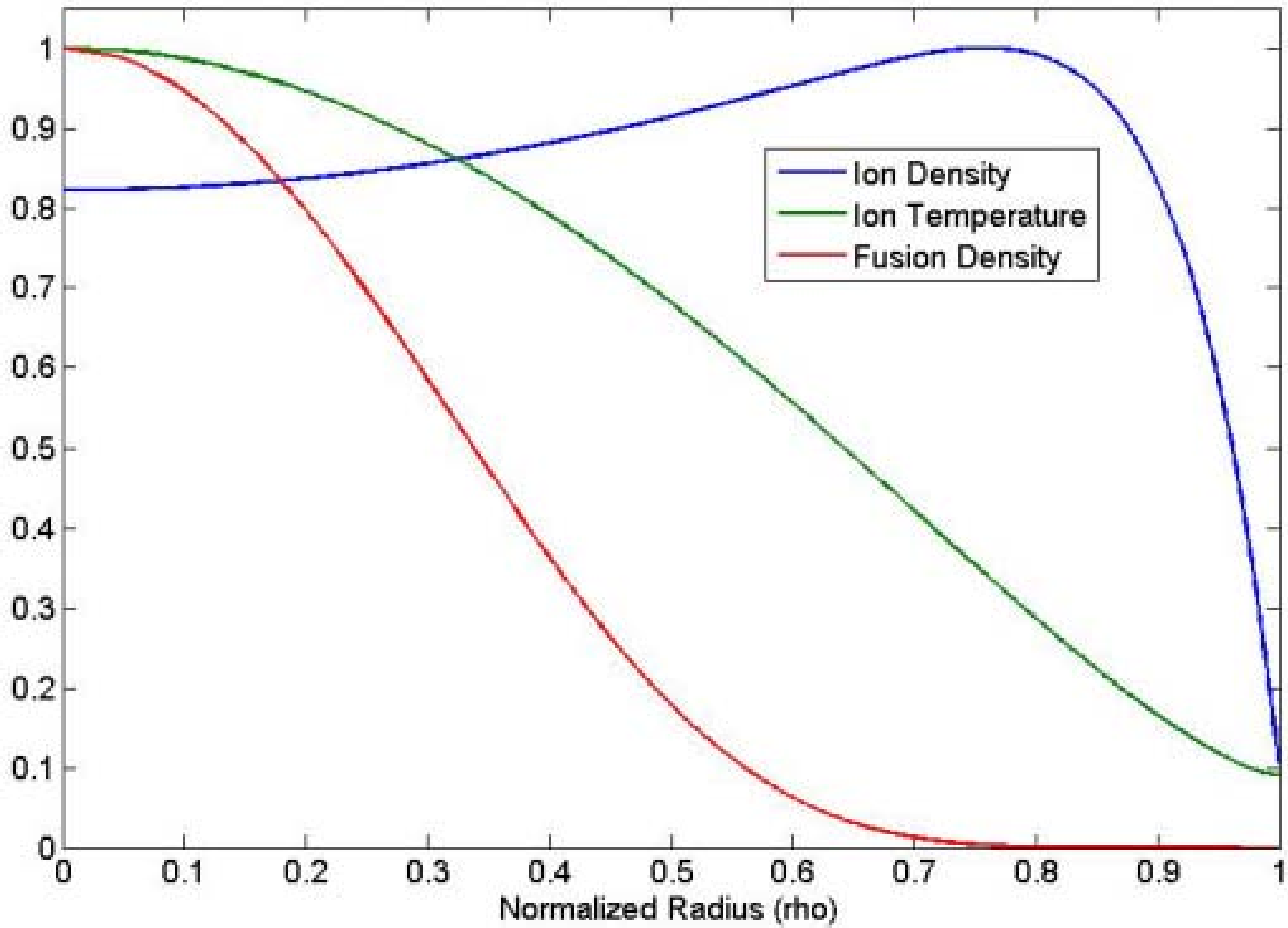
- Mesh vertices are indexed to increase most rapidly in the poloidal direction, then the radial direction and finally in the toroidal direction
- Mesh hexes are numbered to correspond to the lowest numbered vertex that forms that hex

# Mesh Conveniences

- Use extra storage to simplify calculations
  - Extra vertices are stored for $\theta=2\pi$ even though these points are redundant with $\theta=0$
  - Extra hexes are indexed at the maximum in each dimension even though there is no space there
    - Since they are defined to have 0 volume these hexes won't interfere with the probabilities

# Fundamental Source Density

Note: based on Data from J. Lyon (ORNL)



# Source Strength on Mesh

- Evaluate source density at each mesh vertex, $s_{vi}$
- Define mesh cell source strength as simple mean of associated mesh vertex source densities

$$S_{hi} = \frac{1}{8}\sum_{vj} S_{vj}$$

- Define mesh cell probability as normalized source strength

$$p_{hi} = \frac{V_{hi}S_{hi}}{\sum_{hj} V_{hj}S_{hj}}$$

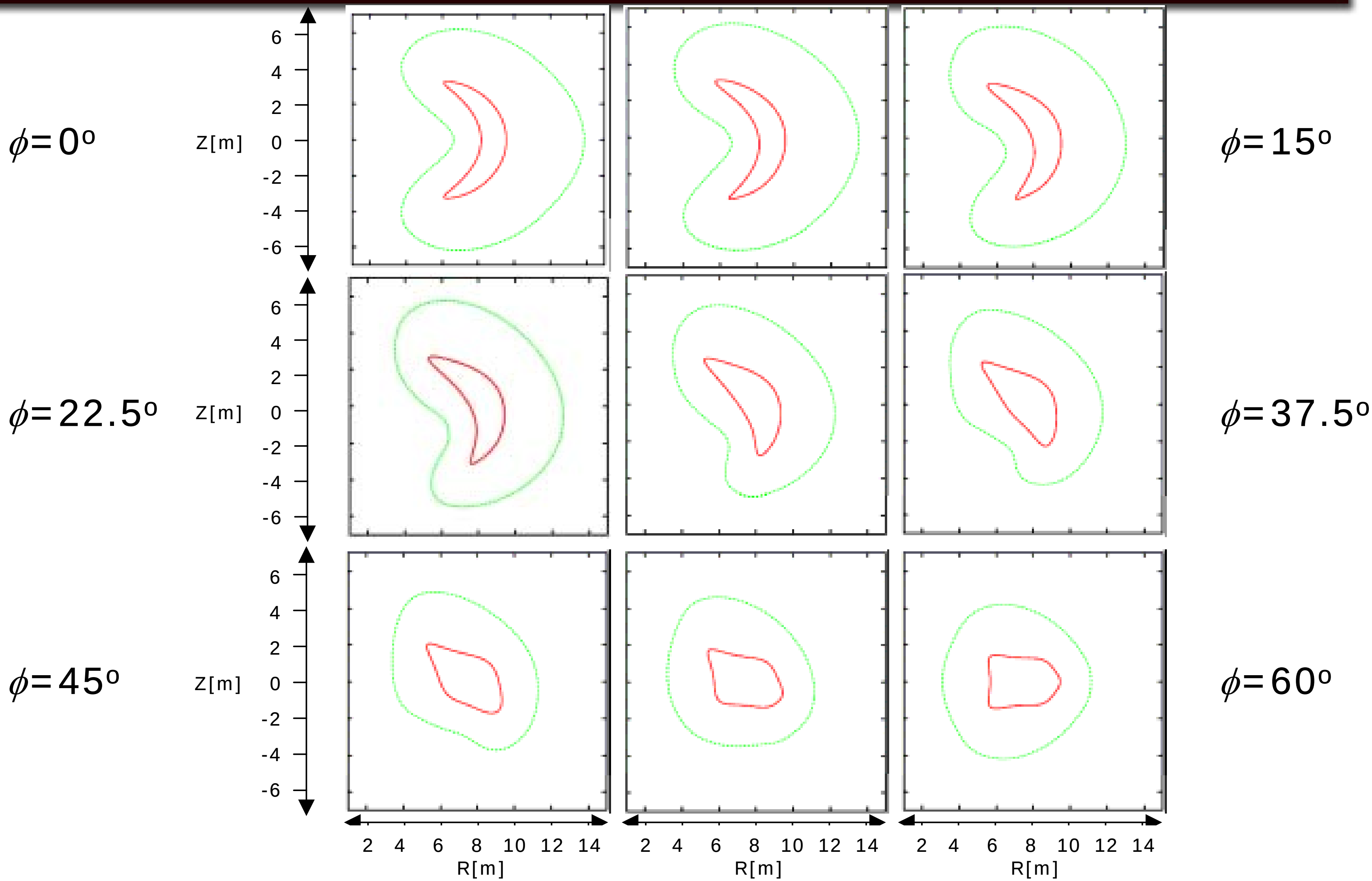
- Evaluate CDF for this discrete PDF

$$P_{hi} = \sum_{hj=1}^{hi} p_{hj}$$

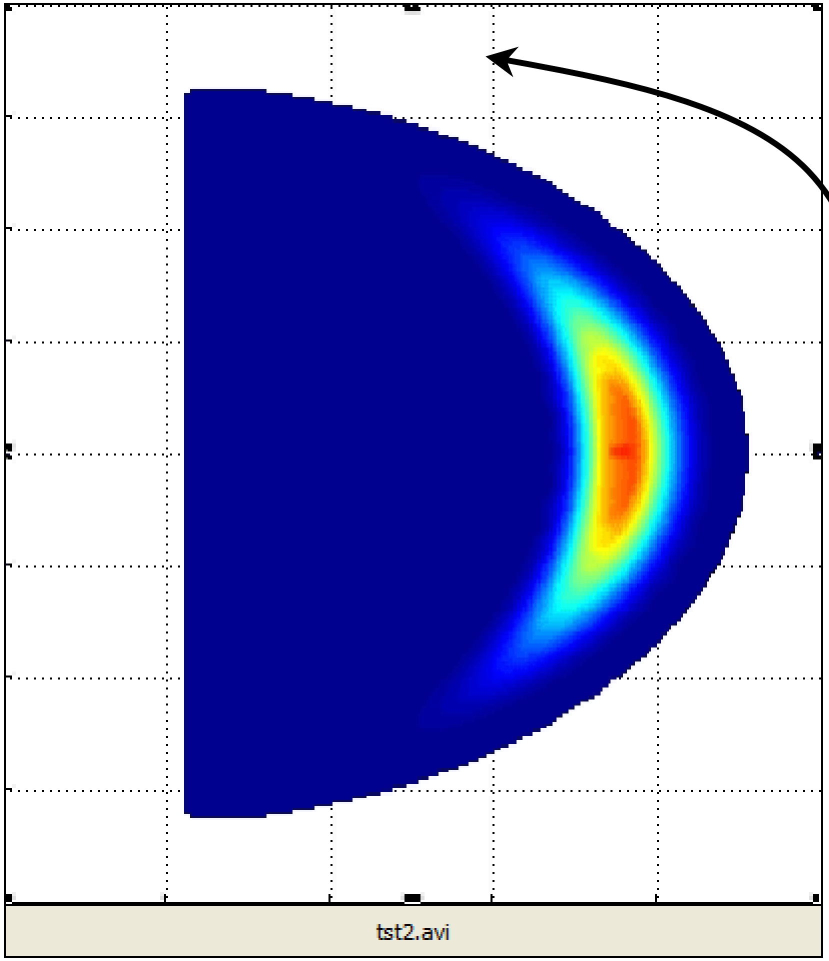
# ARIES-CS Parameters

- Major radius, R = 7.75 m
- Fusion power, P = 2355 MW
  - Radiative power, $P_h$ = 354 MW
- 5cm SOL everywhere
- 727 $m^2$ FW area

# Plasma & Mid-Coil Profiles



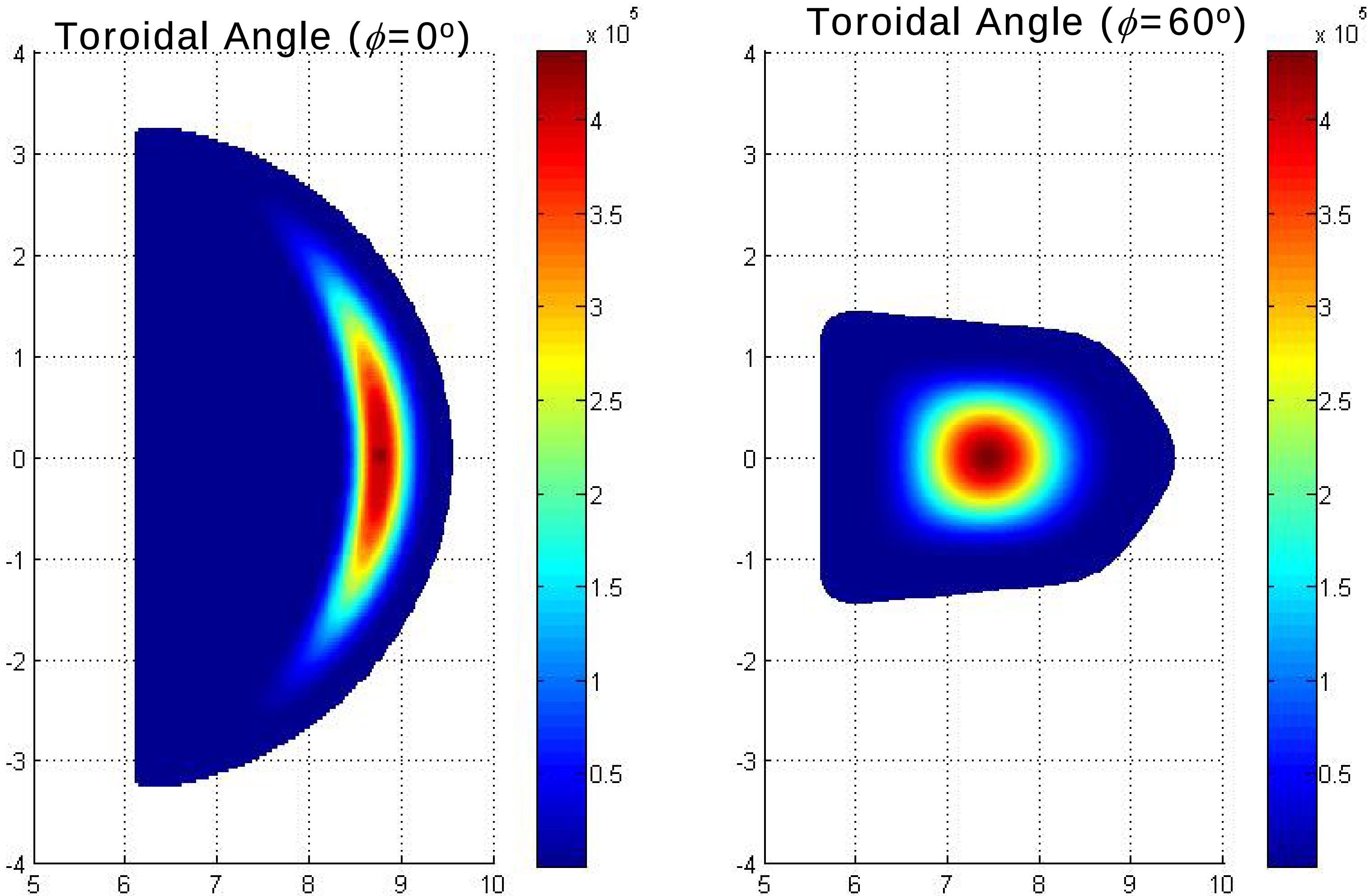
# Source Probability Map




Increasing
Poloidal Angle
(0° at O/B midplane)

# Peak source probability lower at 60º

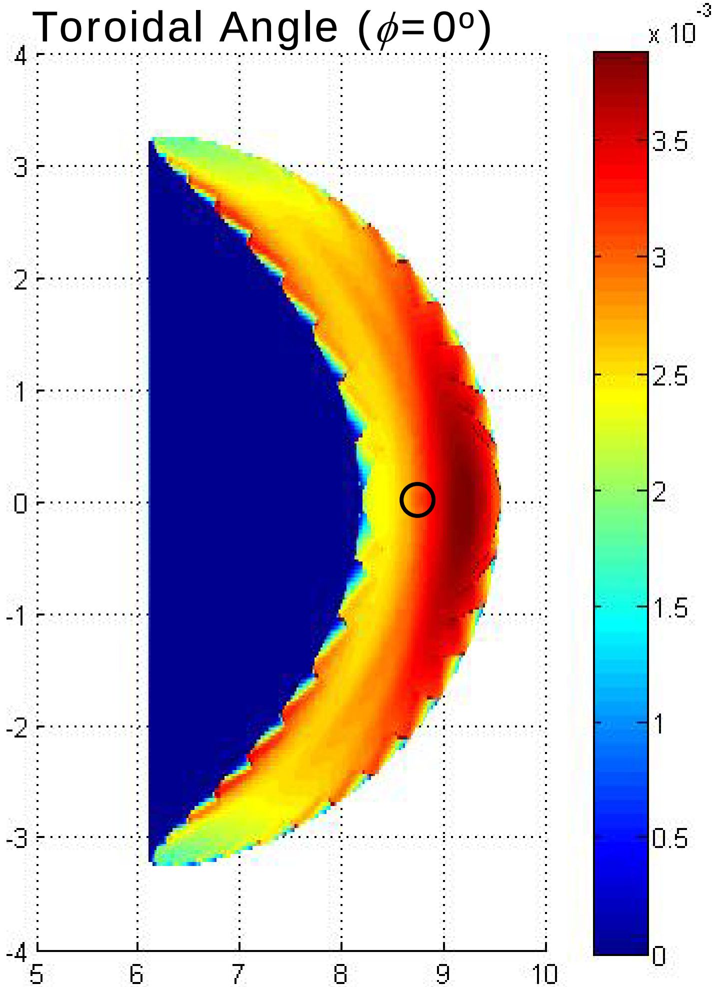
**Peak source density is identical, as expected!**

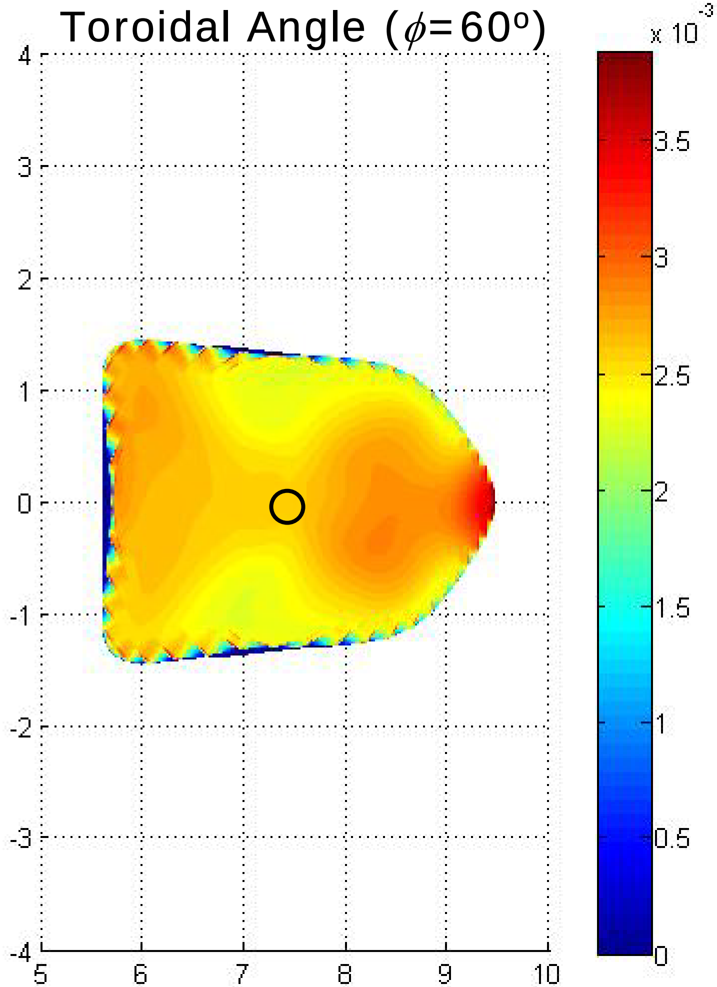


# Peak source probability lower at 60º

**Source volume is smaller because of lower major radius.**

***(ignore artifacts of interpolation at domain boundary)***

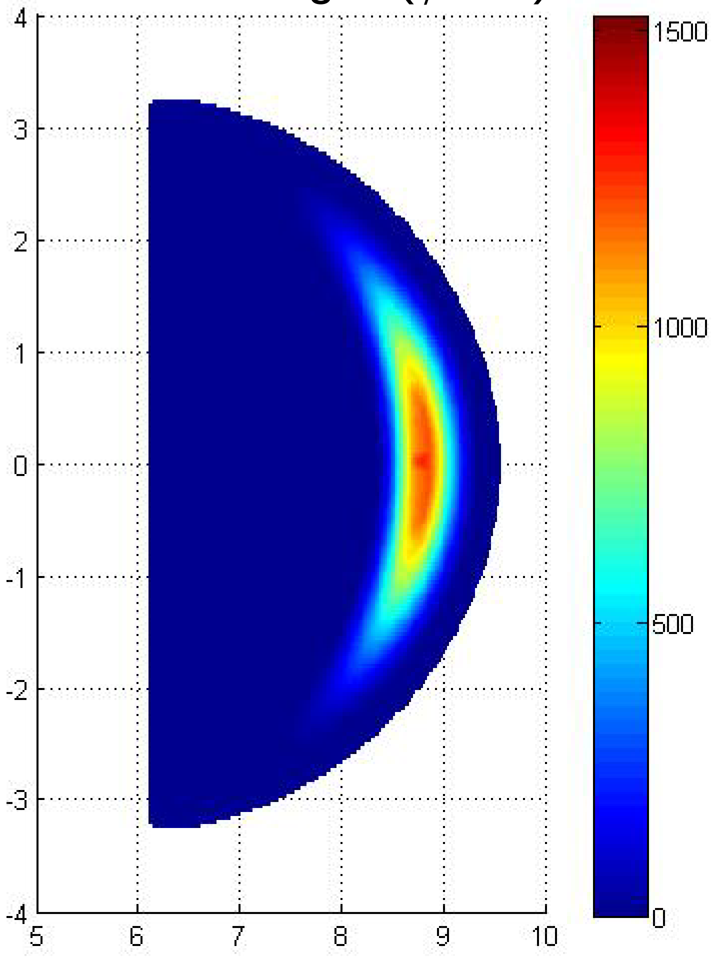


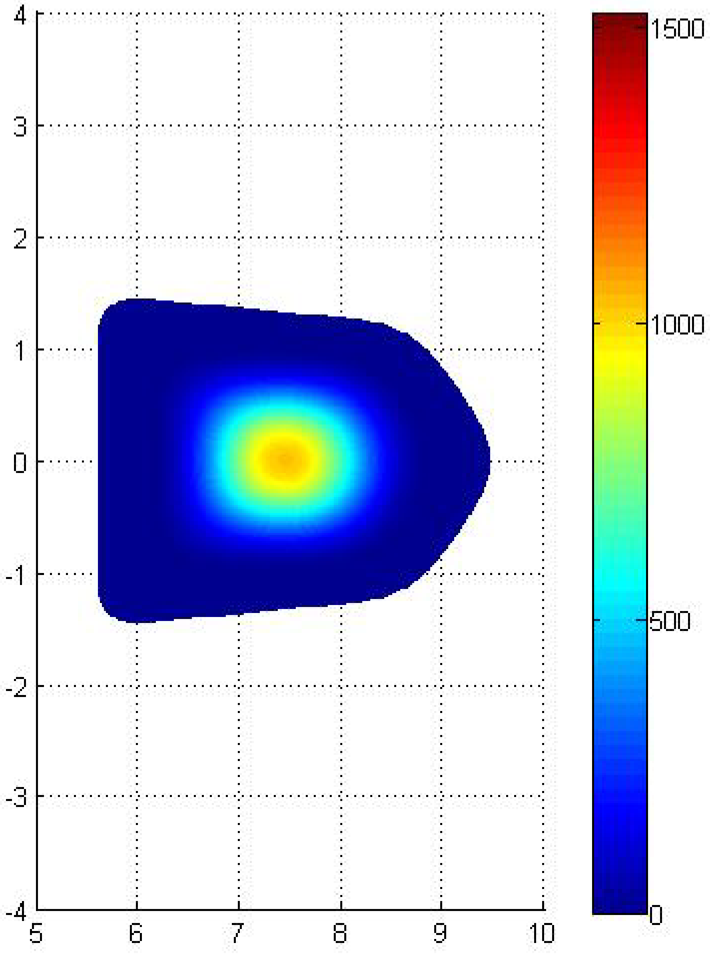
# Peak source probability lower at 60°

**Peak source probability is lower because of volume.**

Toroidal Angle ($\phi$=0°)




Toroidal Angle ($\phi$=60°)

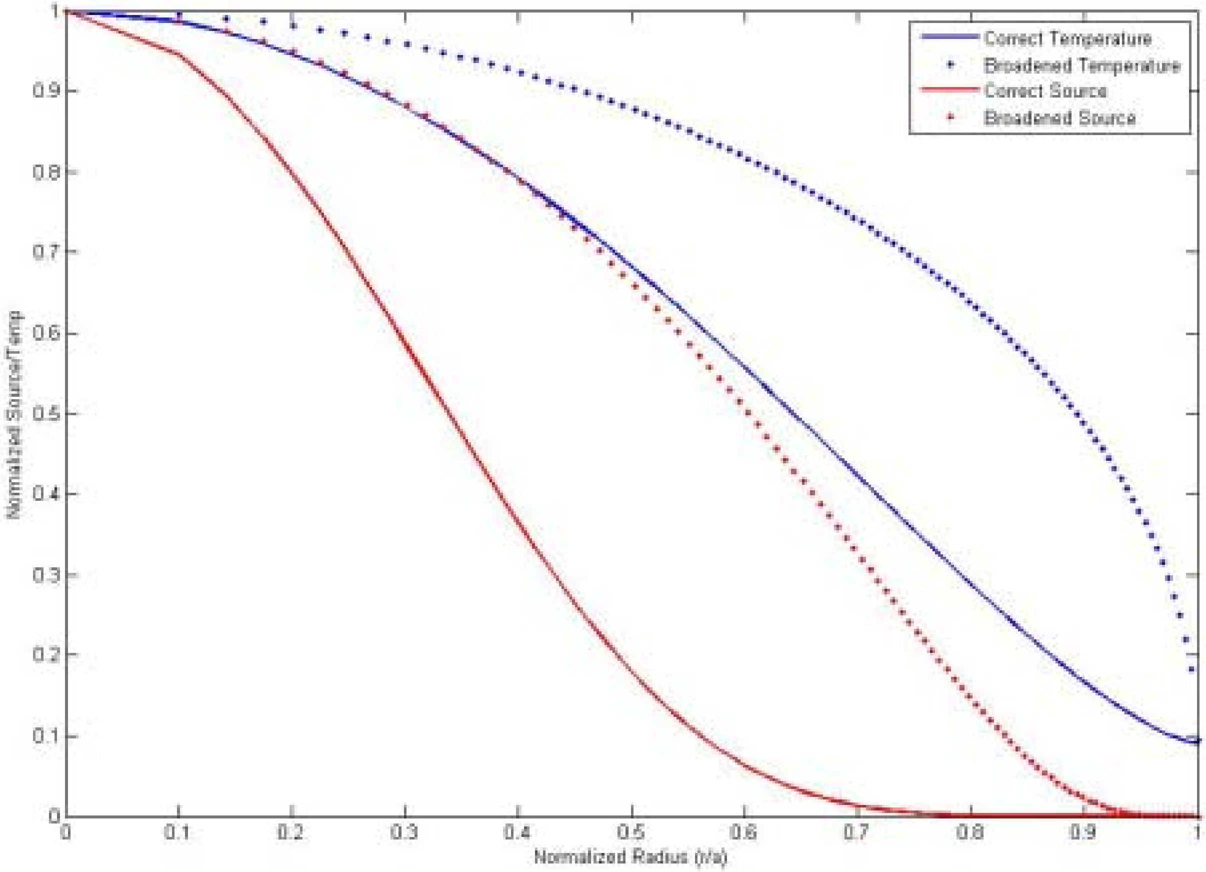


# Sampling Source CDF

- Know vertex coordinates and CDF of source strength
- Find $hi$ such that for random variable $\xi$
$$P_{hi-1} < \xi < P_{hi}$$
- Sample trilinear coordinate system of mesh cell $hi$ uniformly
- Map trilinear coordinates to real coordinates for origin

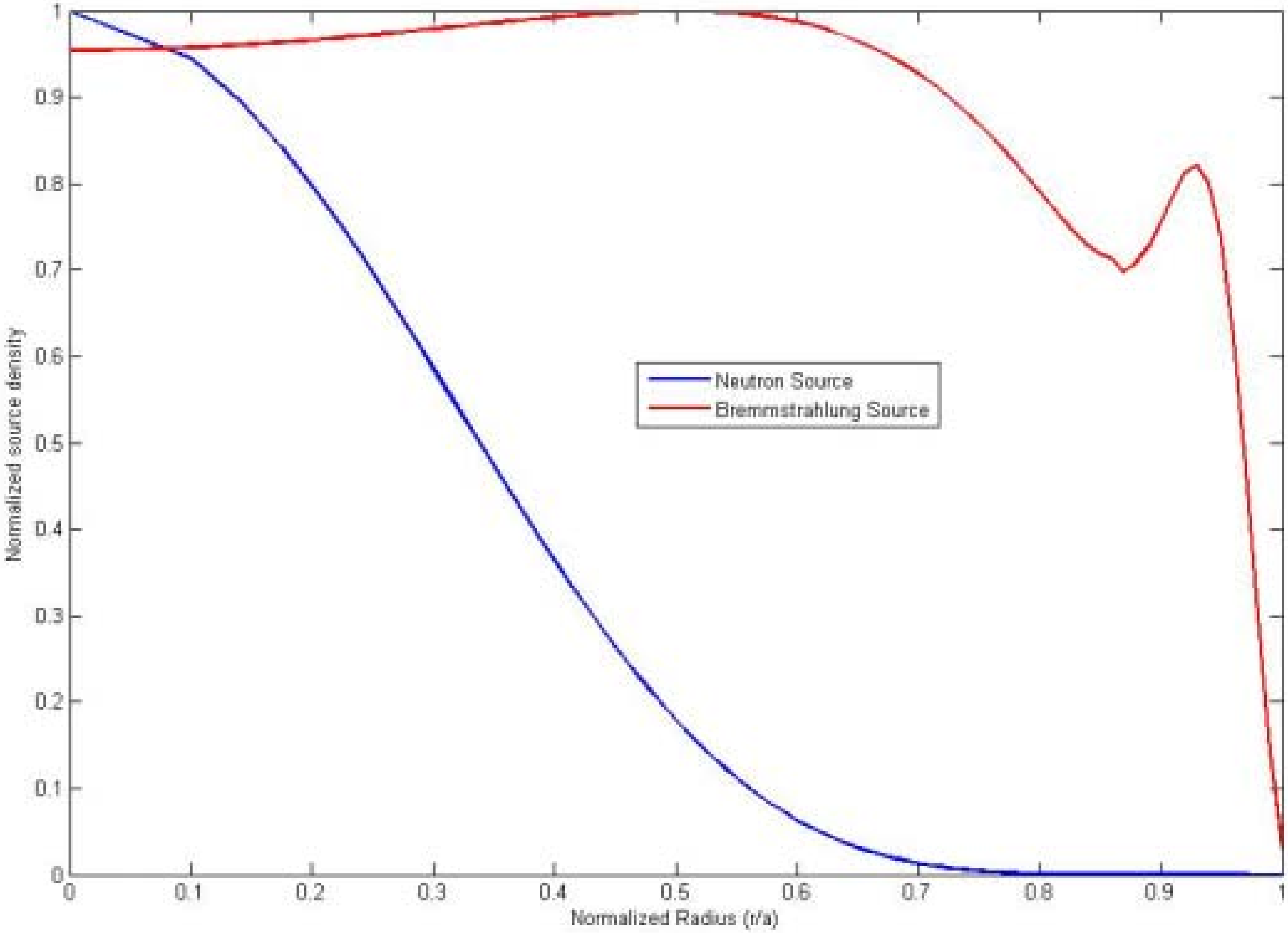
# Artificial Broadening of Source

- For comparison, an artificial ***unphysical*** source was contrived



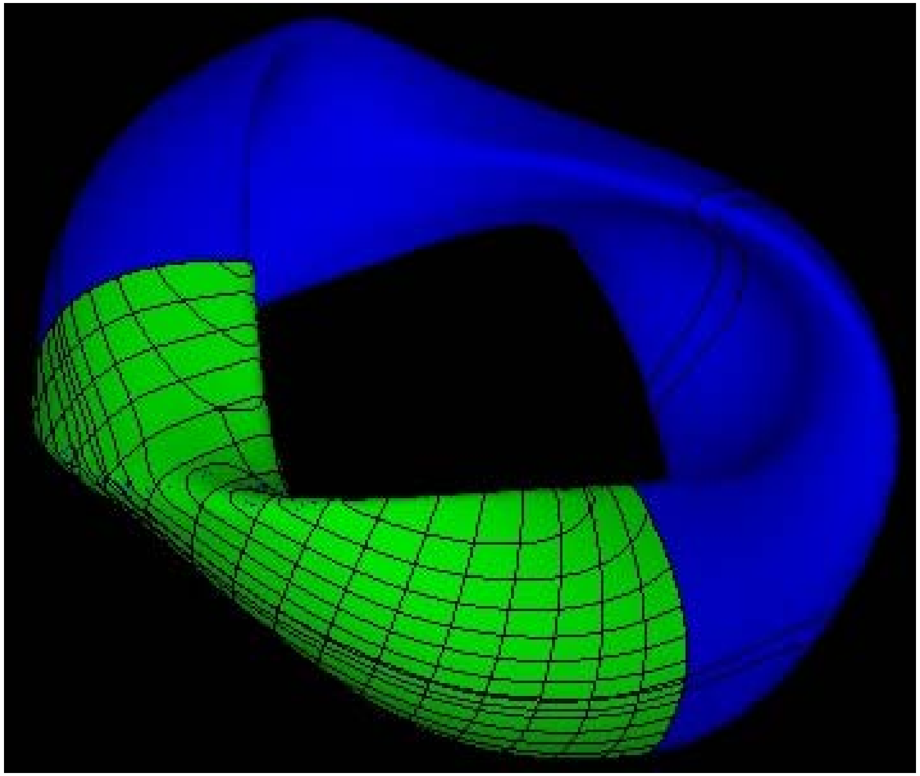
# Radiation Heating Source

Note: based on Data from J. Lyon (ORNL)



# Results and Analysis

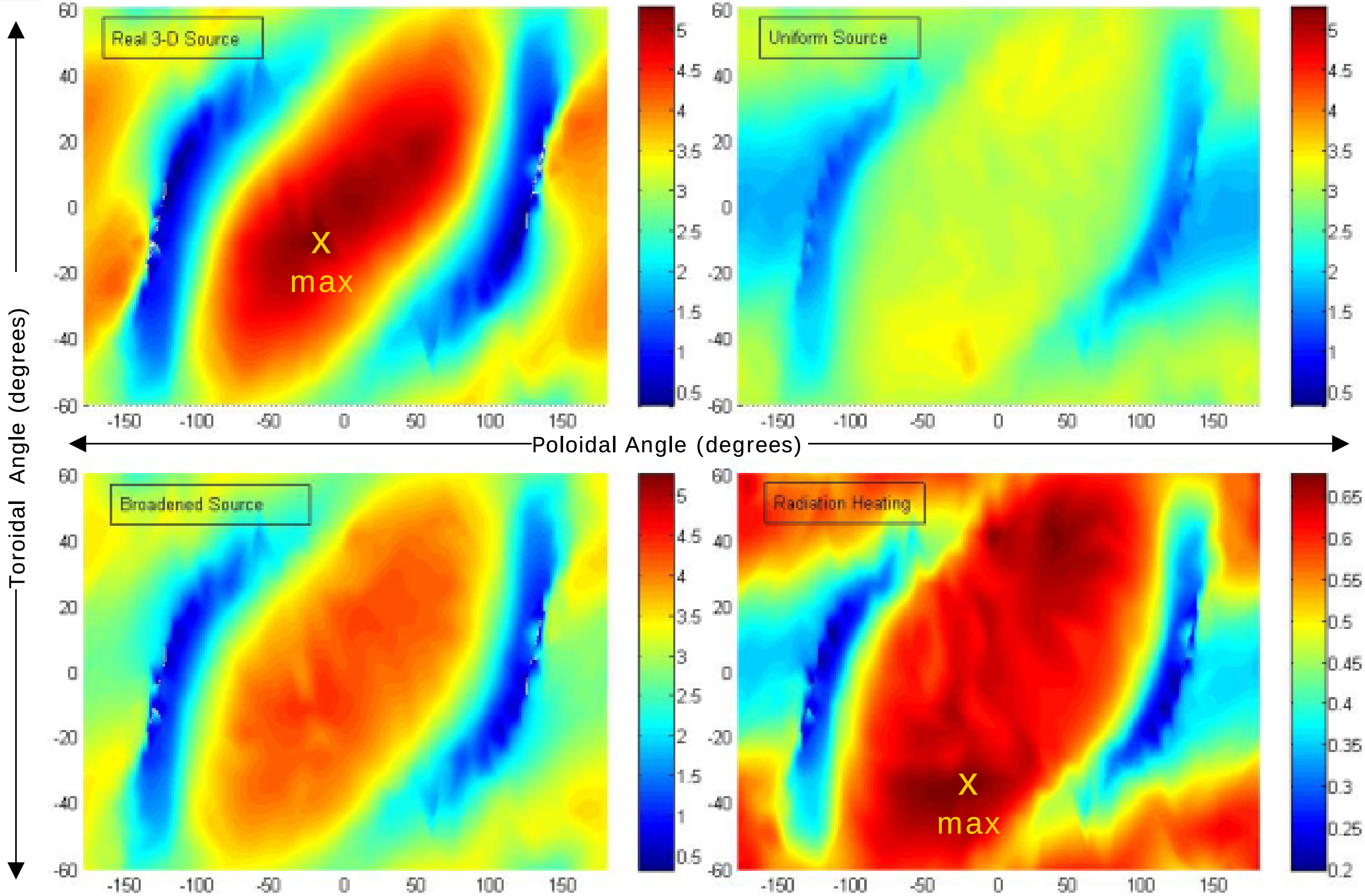
- Calculate NWL on surface grid
  - Some statistical variation
- Transform (x,y,z) coordinates of each patch to $(\theta_P, \phi_T)$
- Interpolate results on 200 x 200 uniform grid in $(\theta_P, \phi_T)$



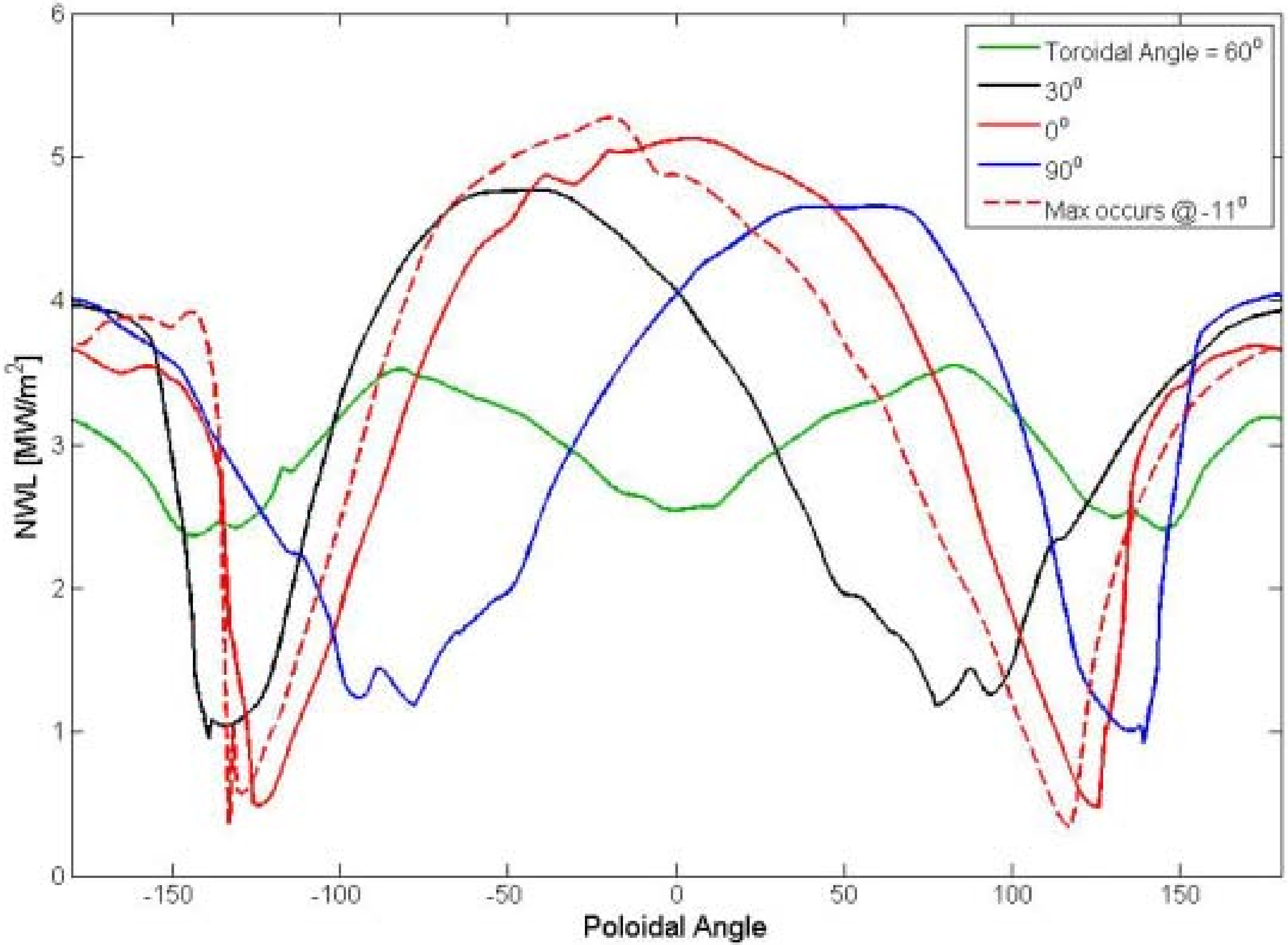
# NWL Summary

| | Peak (Min) [MW/m$^2$] | Toroidal Angle (degrees) | Poloidal Angle (degrees) |
|---|---|---|---|
| Real 3-D Source | 5.26 (0.32) | -11 (-4) | -18 (-116) |
| Broadened Source | 4.38 | -33 | -11 |
| Uniform Source | 3.56 | -49 | -21 |
| Rad. Heating | 0.68 (0.2) | -34 (11) | -17 (-117) |

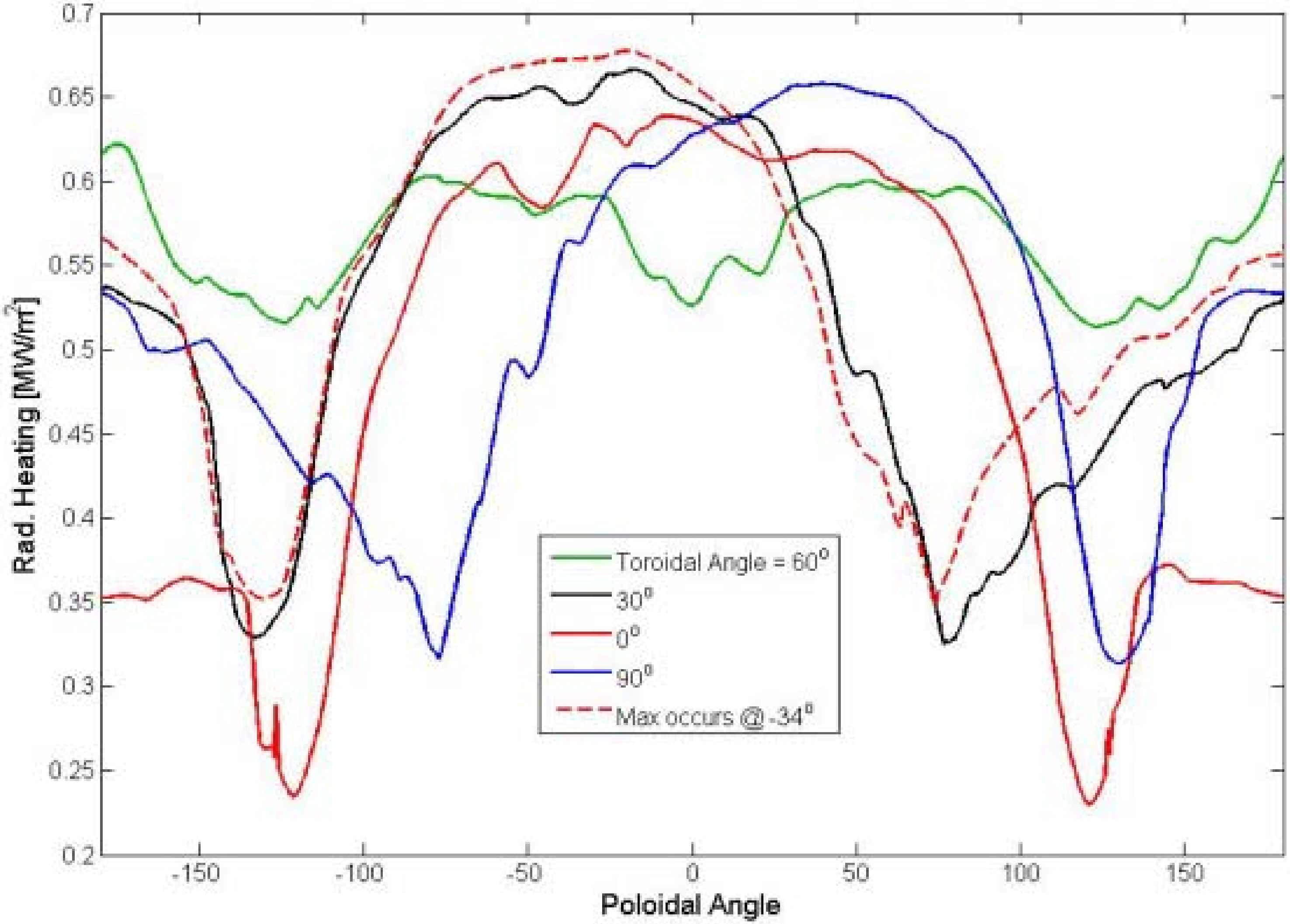
# NWL Maps (colormaps in $MW/m^2$)



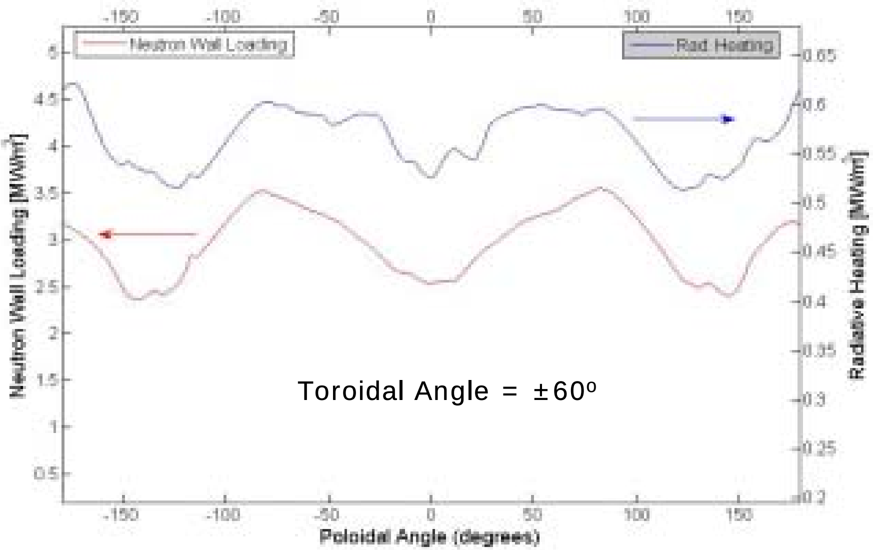
# Neutron Wall Loading Profiles

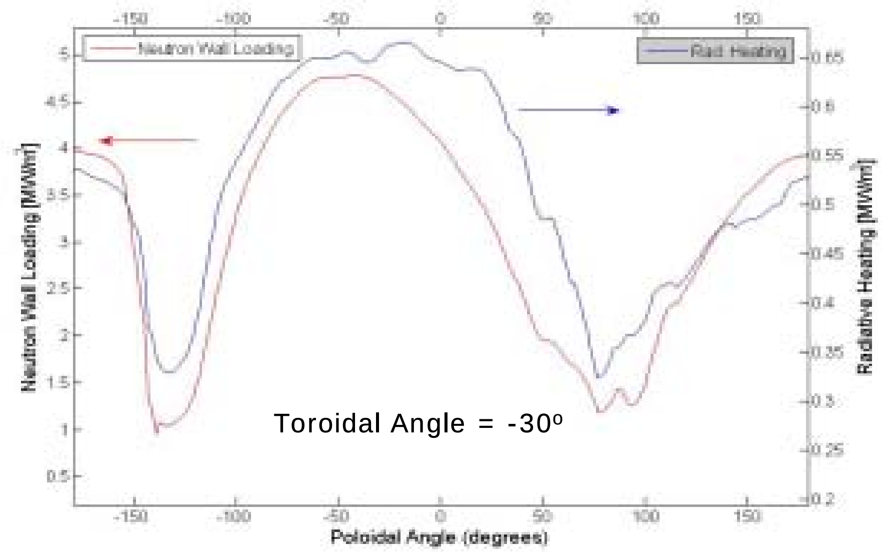


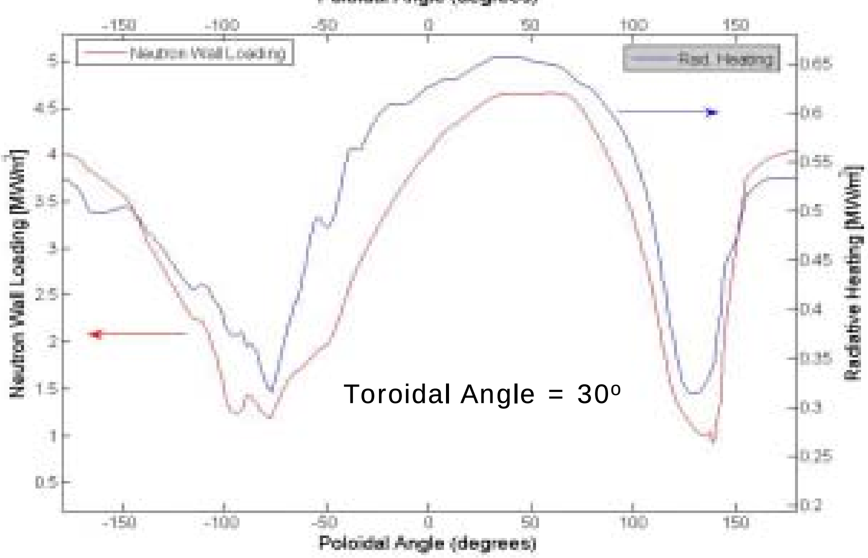
# Radiation Heating Profiles

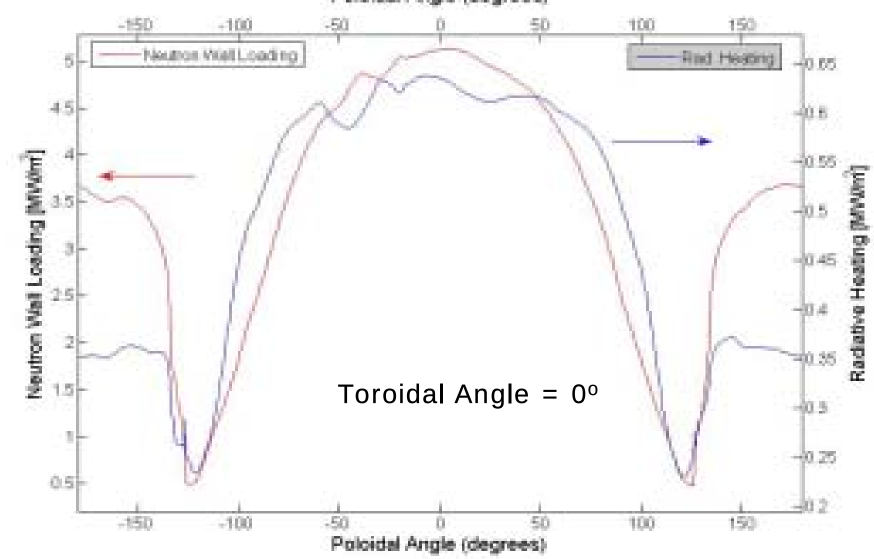


# Note: all figures use consistent scale for NWL (on left) and for Rad. Heating (on right)



# Generalized Plasma Neutron Source

- 3-D Source methodology provides generic mechanism for neutronics source term
- Areas of improvement/research
  - Mesh spacing in minor radius dimension
  - Calculation of hex-averaged source density
  - Sampling of hex

# Conclusion

3-D modeling of plasma source is important for accurate determination of NWL

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