Finite Orbit Monte-Carlo Simulations of FW Heating Discharges in DIII-D, NSTX and ITER

by

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in collaboration with

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Outline

• Synthetic diagnostic results of finite orbit Monte-Carlo coupled by full wave code in DIII-D and NSTX HHFW heating discharges reasonably reproduce measurements
  – Outward radial shift
  – Fast ion spectra

• Preliminary simulation in ITER suggests that finite orbit effect may also significantly modify fast ion distribution in velocity space
Zero-Orbit Width Simulation Does Not Reproduce Outward Shift of Measured FIDA Signals in DIII-D

DIII-D FW discharge #122993
W.W. Heidbrink PPCF 49 (2007)

- CQL3D to include finite orbit effect is underway
- Similar discrepancy in NSTX HHFW discharges (D. Liu, PPCF 52 (2010))
- This study is aimed at resolving this discrepancy with finite orbit width effect

FIDA Signals vs. \( R_{maj} \) (cm)

- CQL3D/GENRAY
- Measurement

\( 5\Omega_D \) and \( 6\Omega_D \)
For This Purpose, ORBIT-RF is Coupled with AORSA in a Self-Consistent Way (RF SciDAC)

E.F. Jaeger
POP 9 (2002)

AORSA

Linear full wave code

Wave fields

D.L. Green,
18th Topical Conf., in RF Power in Plasma (2009)

P2f

Fast ion distribution

ORBIT-RF

Monte-Carlo code
Increased Neutron Rates During FW Heating Indicate Absorption of FW By Beam Fast Ions

NSTX #128739

DIII-D #122993

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Time (s)

0.1 0.2 0.3 0.4

NB Power (MW)

FW Power (MW)

Density ($10^{19}$ m$^{-3}$)

$T_e$ (keV)

Neutrons ($10^{13}$ s$^{-1}$)

Time (s)

1 2 3 4

NB Power (MW)

FW Power (MW)

Density ($10^{19}$ m$^{-3}$)

$T_e$ (keV)

Neutrons ($10^{13}$ s$^{-1}$)
NSTX: Good Agreements Are Obtained in Spatial Profile and Spectra with No FW Heating

- NSTX NB discharge #128742
  \[ P_{NB} = 2.0 \text{ MW}, \ E_{\text{inj}} = 65 \text{ keV} \]

\[ \int_{30\text{keV}}^{60\text{keV}} E_{\lambda} dE_{\lambda} \]

At \( R = 112 \text{ cm} \)

 measurement

**Diagram:**
- Magnetic axis
- Normalized FIDA Signals
- \( R_{\text{maj}} \) vs. \( E_{\lambda} \)
- FIDA Signals (a.u.)

**Legend:**
- Measurement
- ORBIT simulation
NSTX: FW Heating Simulation Predicts Enhanced Outward Shifts Compared to Measured Signals

- **NSTX NB discharge #128742**
  
  \[ P_{NB} = 2.0 \text{ MW}, \ E_{inj} = 65 \text{ keV} \]

- **NSTX NB+HHFW #128739**
  
  \[ P_{FW} = 1.0 \text{ MW}, 30 \text{ MHz} \]

The graphs show the normalized FIDA signals as a function of major radius \( R_{maj} \) for each discharge condition. The simulations and measurements are compared, with the simulation results showing an enhanced outward shift compared to the measured signals.
DIII-D: Qualitative Agreement is Obtained in Spatial Profile of FIDA Signals for #122993

**DIII-D #122993**

- $P_{ICRF} = 1.0$ MW, 60 MHz
- $\int_{45keV}^{70keV} E_\lambda dE_\lambda$
- Measurement
- ORBIT-RF/AORSA
- $5 \Omega_D$
- $6 \Omega_D$

**DIII-D #141187**

- $P_{FW} = 0.7$ MW, 60 MHz
- ORBIT-RF/AORSA prediction
- $\int_{45keV}^{70keV} E_\lambda dE_\lambda$
- Vertical view
- Comparison with FIDA is underway
- $4 \Omega_D$

**Vertical**

- $\int_{30keV}^{60keV} E_\lambda dE_\lambda$
- Tangential
ITER: Finite Orbit Effect Appears to Average Out Anisotropic Distribution

- D(10%) minority fundamental harmonic heating scenario
- $n_e(0): 7.3 \times 10^{13} \text{ cm}^{-3}$, $T_e(0): 24 \text{ keV}$, $T_T(0): 25 \text{ keV}$, $T_D(0): 25 \text{ keV}$
- $f_{\text{ICRF}}: 40 \text{ MHz}$ $P_{\text{ICRF}}: 20 \text{ MW}$ $n_\varphi: -35$

![Diagram showing zero-orbit width and finite orbit width](image-url)
Summary

• ORBIT-RF/AORSA provides a comprehensive tool to model FW heating scenarios with finite orbit width effects

• Simulations reasonably reproduce spectra and outward radial shifts of measured FIDA signals in DIII-D and NSTX FW heating experiments with NB injection

• Finite orbit width effect may significantly modify fast ion distribution in ITER