NSTX Supported by U.S. DEPARTMENT OF ENERGY Office of Science

PP8.00077: Numerical Modeling of HHFW Heating on NSTX

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U Wisconsin

C.K. Phillips, R.E. Bell, J.C. Hosea, B.P. LeBlanc, G. Taylor, E.J. Valeo, J.R. Wilson
Princeton Plasma Physics Laboratory

L.A. Berry, E.F. Jaeger, P.M. Ryan
Oak Ridge National Laboratory

P.T. Bonoli, J.C. Wright
MIT Plasma Science and Fusion Center

R.W. Harvey
CompX

T. Brecht
UMN

and the NSTX Team

Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
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Ioffe Inst
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U Quebec

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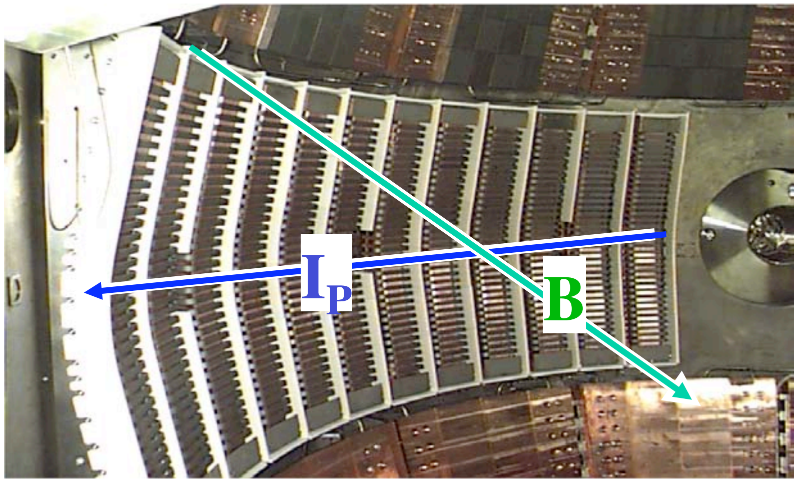
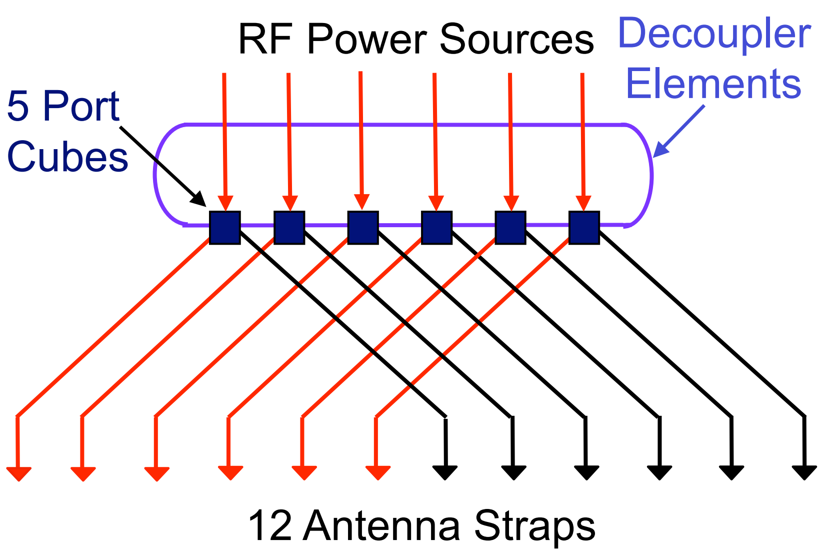
Overview

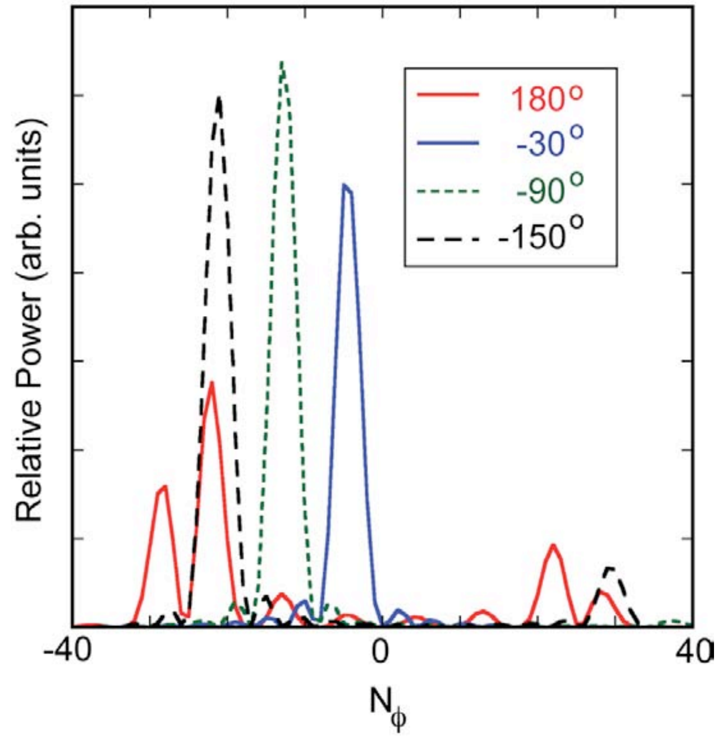
- ***Motivation:***
  - Efficient rf heating and current drive required in ST devices and ITER
- ***Approach:***
  - Utilize full wave and ray tracing codes to analyze NSTX HHFW heating and current drive experiments
- ***Conclusions:***
  - Power absorption by ions depends on ion temperature and concentration, as well as $k_{//}$
  - Power deposition profiles from the AORSA and GENRAY codes are comparable, but TORIC appears to predict somewhat stronger ion damping.
  - Possible mode conversion to “slow wave” evident in some NSTX parameter regimes

NSTX HHFW antenna spectrum ideal for studying dependence of heating on antenna phase



HHFW antenna extends toroidally 90°

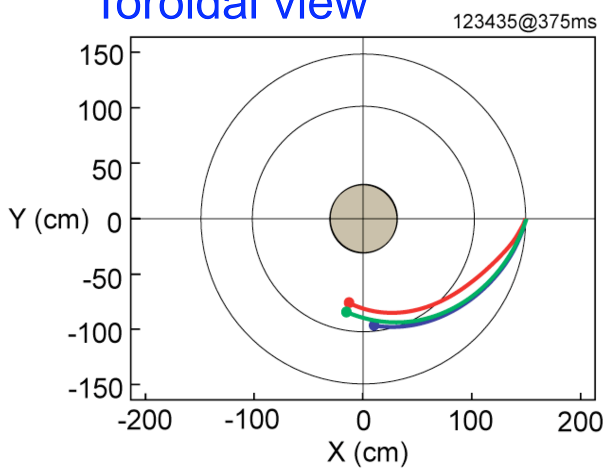




- Phase between adjacent straps easily adjusted between 0° to 180°
- Well-defined spectrum is launched

Strong "single pass" absorption ideal for studying competition between core heating and edge power loss

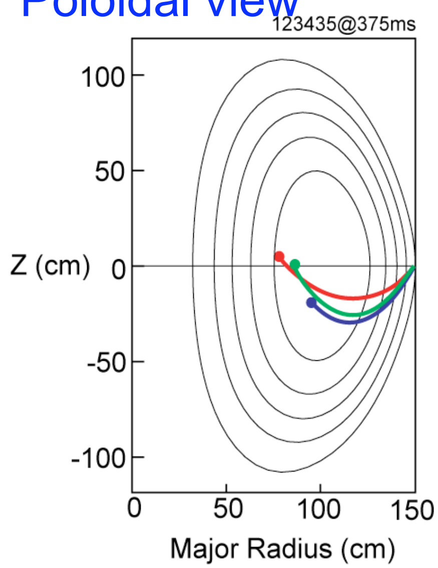
GENRAY: Toroidal view



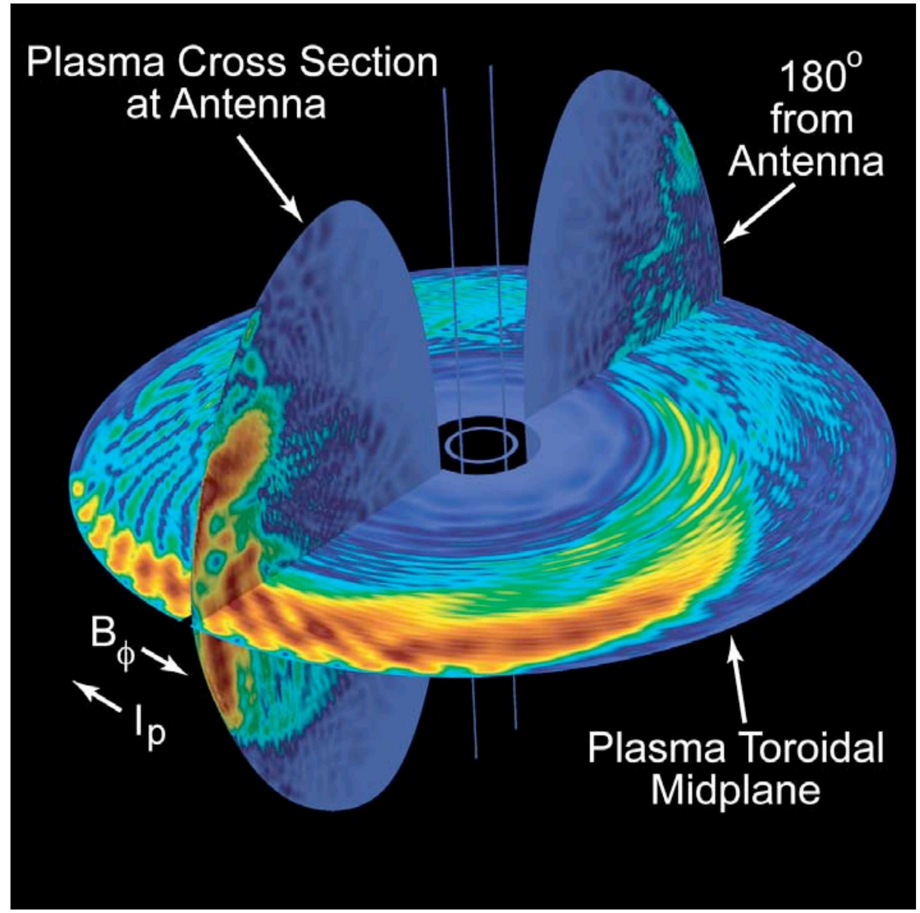
——	-30°
——	180°
——	-90°

rays stopped at 80% deposition

Poloidal view



AORSA: $|E_{RF}|$ field amplitude for -90° antenna phase case with 101 n_ϕ



Edge power loss occurs in the vicinity of the antenna -- there is no multi-pass damping (except in low density start-up conditions)

NSTX experiments show heating efficiency depends on launched $k_{||}$, edge density and magnetic field

- Heating efficiency for $k_{//} = 8\ m^{-1}$ increased substantially as B_T increased from 0.45 T to 0.55T
- Core heating efficiency degrades with decreasing $k_{//}$ in L-Mode & H-Mode Plasmas
- Edge power loss increases when density level required for perpendicular propagation is near antenna/wall

Ref: Hosea et al 2008 Phys. Plasmas 15 056104

- At this meeting, see also:

  G. Taylor TI3.00002; B. LeBlanc JO4.00011;

  J.C. Hosea PP8.00075;T. Brecht JP8.00067

Full Wave and Ray Tracing codes are compared for NSTX HHFW experiments

The AORSA and TORIC full wave codes solve the kinetic wave equation:

$$\nabla \times \nabla \times \mathbf{E} - \frac{\omega^2}{c^2}\left(\mathbf{E} + \frac{i}{\omega\epsilon_0}\mathbf{J}_p\right) = i\omega\mu_0\mathbf{J}_s \quad \textbf{\textit{where}} \quad \mathbf{J}_p(\mathbf{r}) = \int d\mathbf{r}'\overline{\overline{\boldsymbol{\sigma}}}(\mathbf{r},\mathbf{r}')\cdot\mathbf{E}(r')$$

• AORSA uses a non-local, integral operator correct to "all orders" in ($k_\perp\rho_s > 1$)

See E.F. Jaeger et al, Phys. Plasmas 9 (2002) 1873.

• TORIC uses a quasi-local model valid to "all orders" with the Bessel functions evaluated with the local HHFW root of the hot plasma dispersion relation

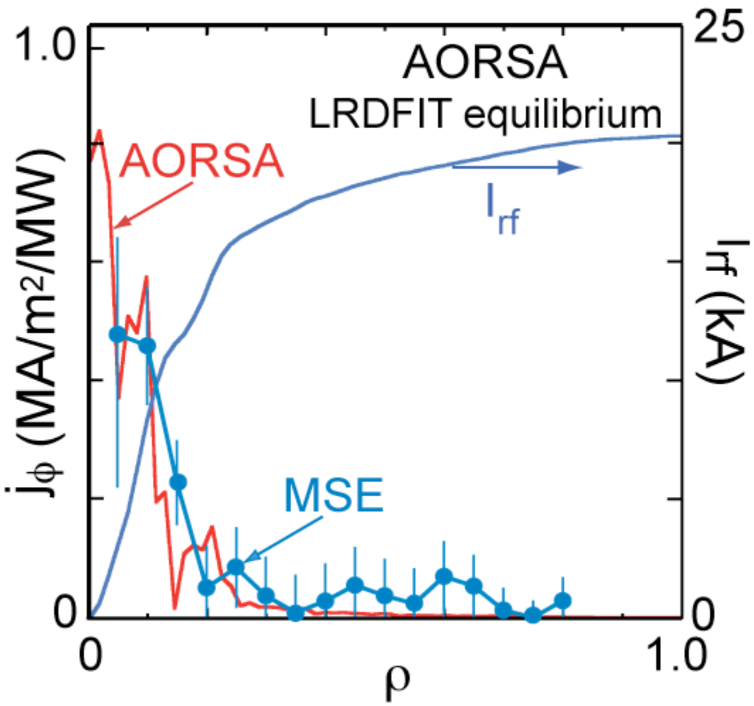
See M. Brambilla, Plasma Phys. and Controlled Fus. Res. 44(2002)242

GENRAY Ray Tracing Model uses the full hot plasma dielectric tensor to evaluate the power deposition profiles

See Smirnov A P, and Harvey R W 2003 The GENRAY Ray Tracing Code, Report CompX-2000-01, Ver. 2 March 17, 2003

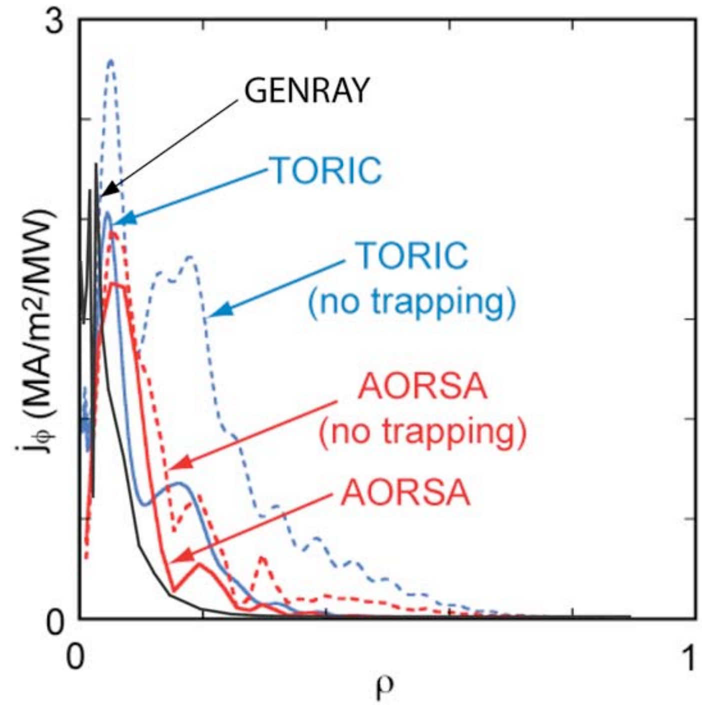
Previous comparisons found good agreement for electron-absorption-dominated HHFW CD plasmas

Measured CD at k_ϕ=-8 m^{-1} in shot #123435 consistent with modeling



AORSA used full antenna spectrum and Ehst-Karney approximation, including trapping effects

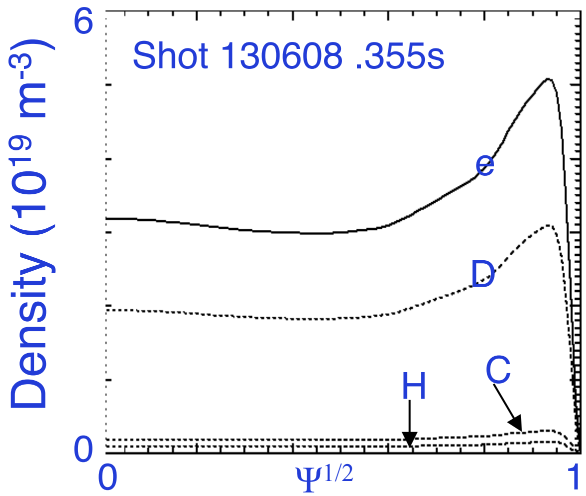
MSE normalized assuming 1.2 MW of HHFW power absorbed in plasma



AORSA, GENRAY and TORIC results similar for single Nphi=12 at peak of launched spectrum

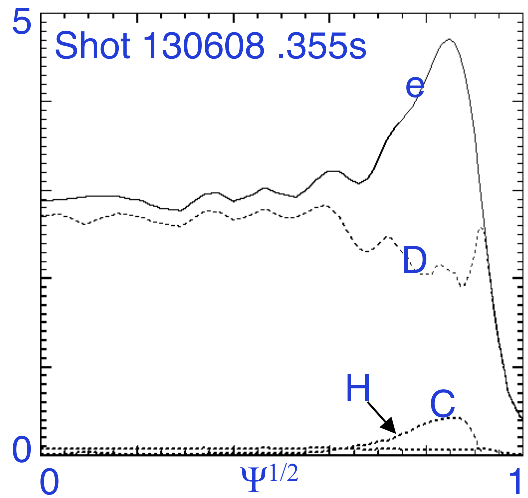
Power deposition found to depend on fits to the measured electron density profile and z_{eff} profile

Three possible fits to the density profiles from Thomson Scattering in H-mod



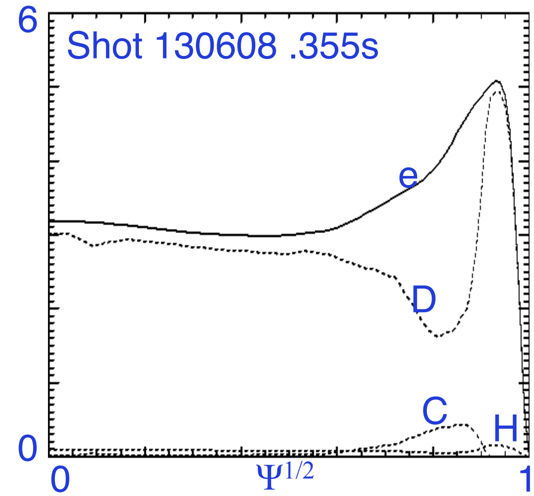
FIT A

- Smoothed fit to ne
- Flat z_{eff} profile from VB
- H/D ratio from Hα/Dα spectroscopy data
- Carbon density from z_{eff} and quasineutrality



FIT B

- Higher order spline fit to ne
- Carbon profile from CHERS
- Deuterium calculated using quasineutrality
- H/D ratio from Hα/Dα spectroscopy data



FIT C

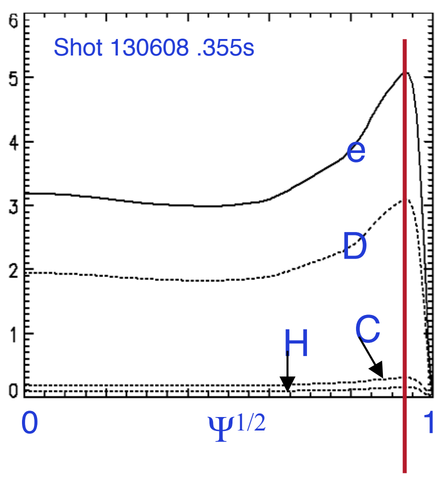
- Smoothed fit to ne
- Carbon profile from CHERS
- Deuterium calculated using quasineutrality
- H/D ratio from Hα/Dα spectroscopy data

Note that the location of the peak of the density “wing” depends on the fit

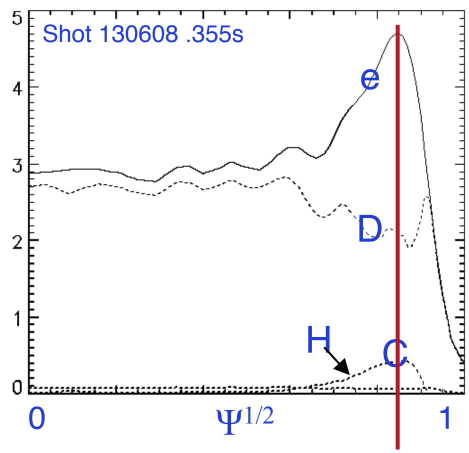
Profile shape, especially near the edge, affects power split between ions and electrons

TORIC Code Results (shot #130608 with $k_{//} \sim 7\ m^{-1}$)

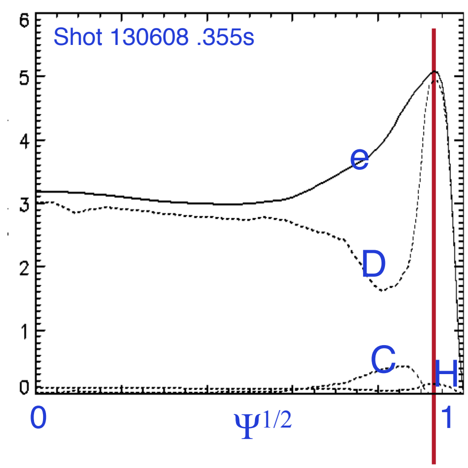
FIT A	FIT B	FIT C
$P_e = 86\%$	$P_e = 89\%$	$P_e = 82\%$
$P_D \sim 0$	$P_D \sim 0$	$P_D \sim 0$
$P_H = 14\%$	$P_H = 11\%$	$P_H = 18\%$



FIT A



FIT B

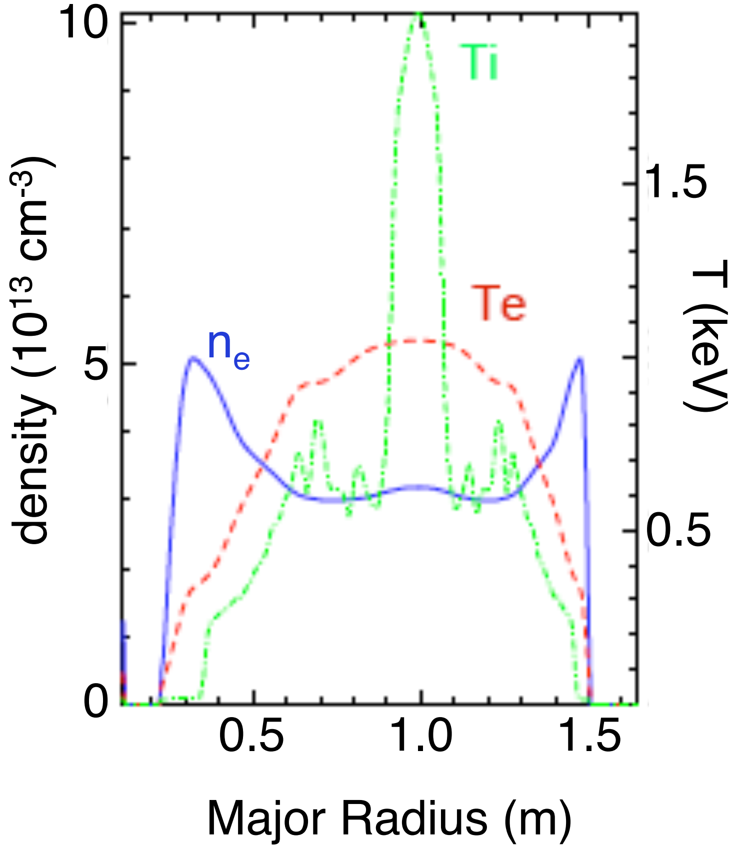


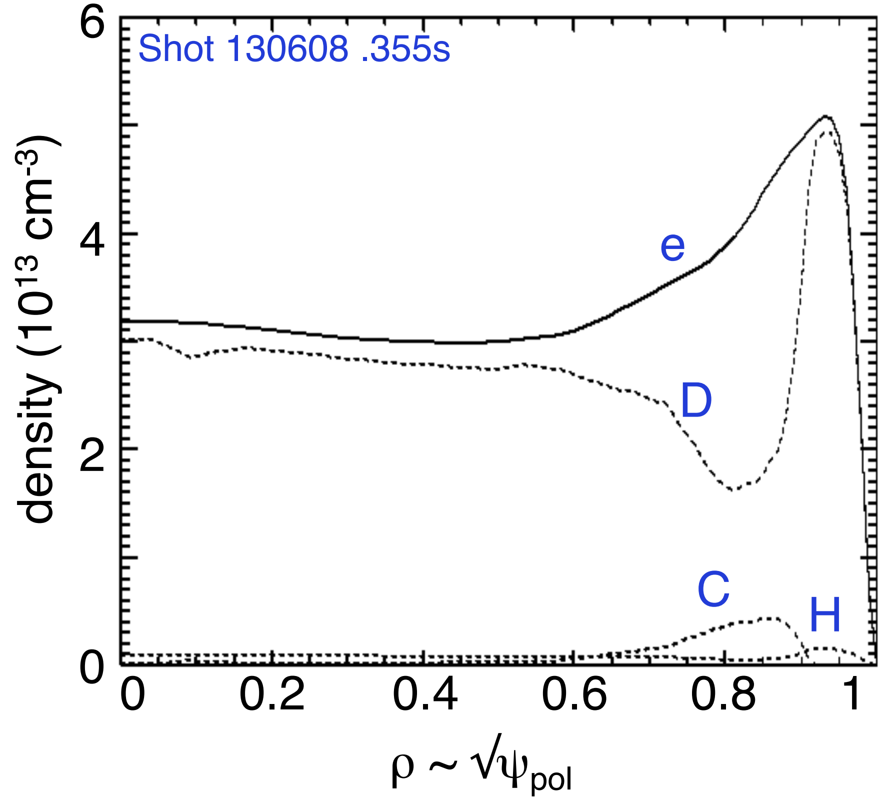
FIT C

The fit to the electron density, as well as the use of a radially varying z_{eff}, has a weak but noticeable effect on the power partitioning among the various plasma species.

Effects of ion temperature on power deposition examined using profiles from D_2 H-mode shot

$B_T \sim 0.54T$ $I_p \sim 975$ kA





Electron density and temperature from Thomson scattering

Ion temperature and Carbon profiles from CHERS

H / D ratio from $H_\alpha D_\alpha$ spectroscopy

Magnetic equilibrium from EFIT2

Ion absorption increases as Ti increases for lower launched $k_{//}$

Code	Power to:	CHERS $T_i(0)$~2 keV	4 X CHERS $T_i(0)$~2 keV
AORSA	e	94	41.2
	D	.21	22.9
	H	5.8	35.9
GENRAY	e	96	39.2
	D	0.2	30.3
	H	3.3	28.5
	C	0.5	2.0
TORIC	e	88.9	26
	D	0.4	41.6
	H	10.7	32.4

Profiles from #130608

f_{rf} = 30 MHz

$k_{//}$ ~ -7 m^{-1} at antenna

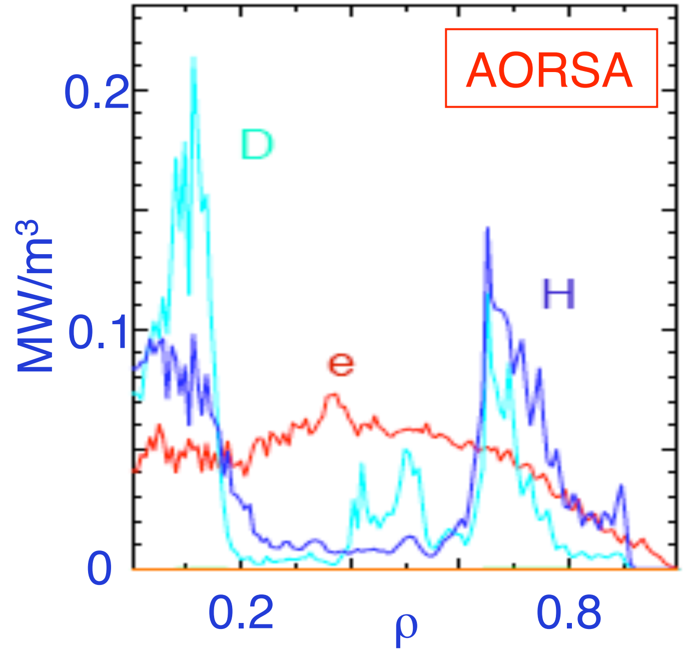
(N_ϕ = 12)

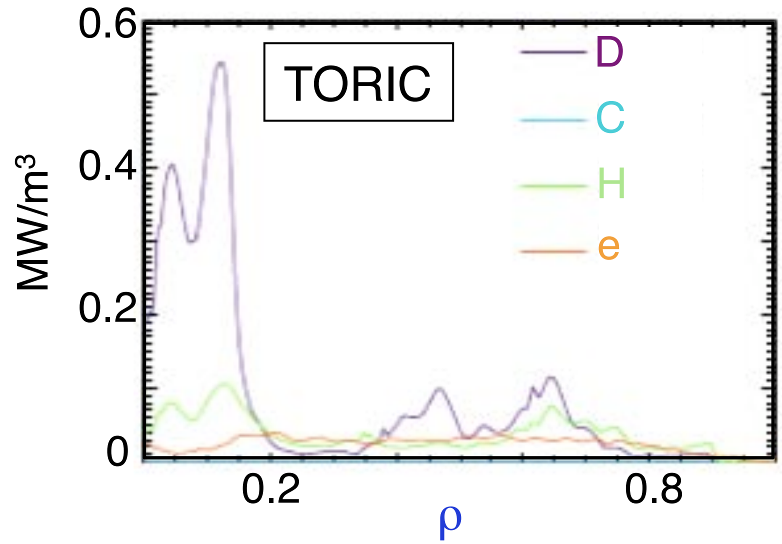
AORSA and GENRAY electron – ion power partitioning are comparable

GENRAY predicts more damping on D than does AORSA

TORIC predicts more ion absorption than either AORSA or GENRAY

Radial power deposition profiles from codes differ in some details



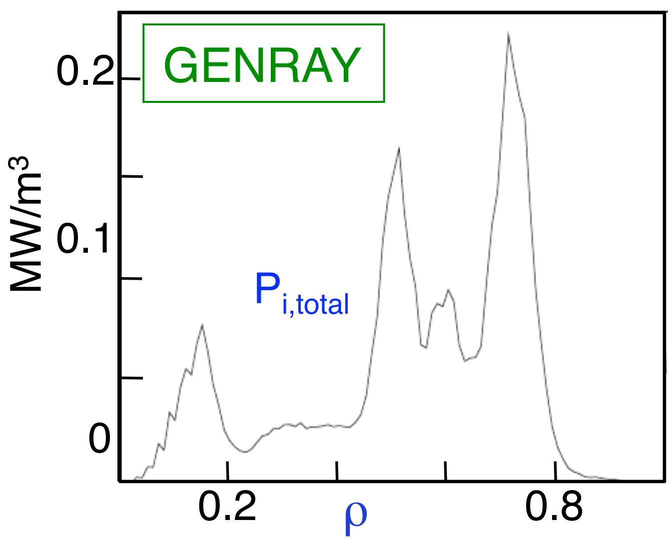


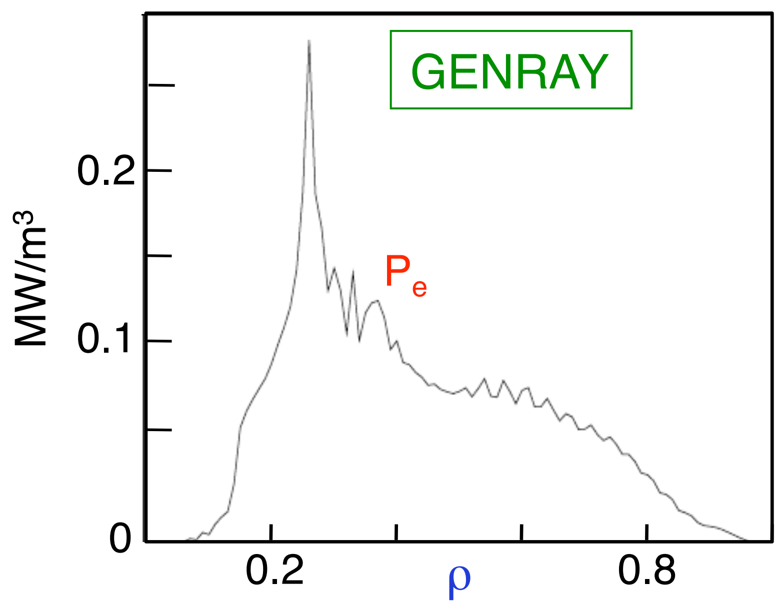
TORIC predicts more central D absorption

Shot #130608

$k_{//} = 7\ m^{-1}$

4 X Ti case





GENRAY predicts less on-axis absorption

Ion absorption increases as Ti increases at higher launched $k_{//}$ ~ 13 m^{-1}

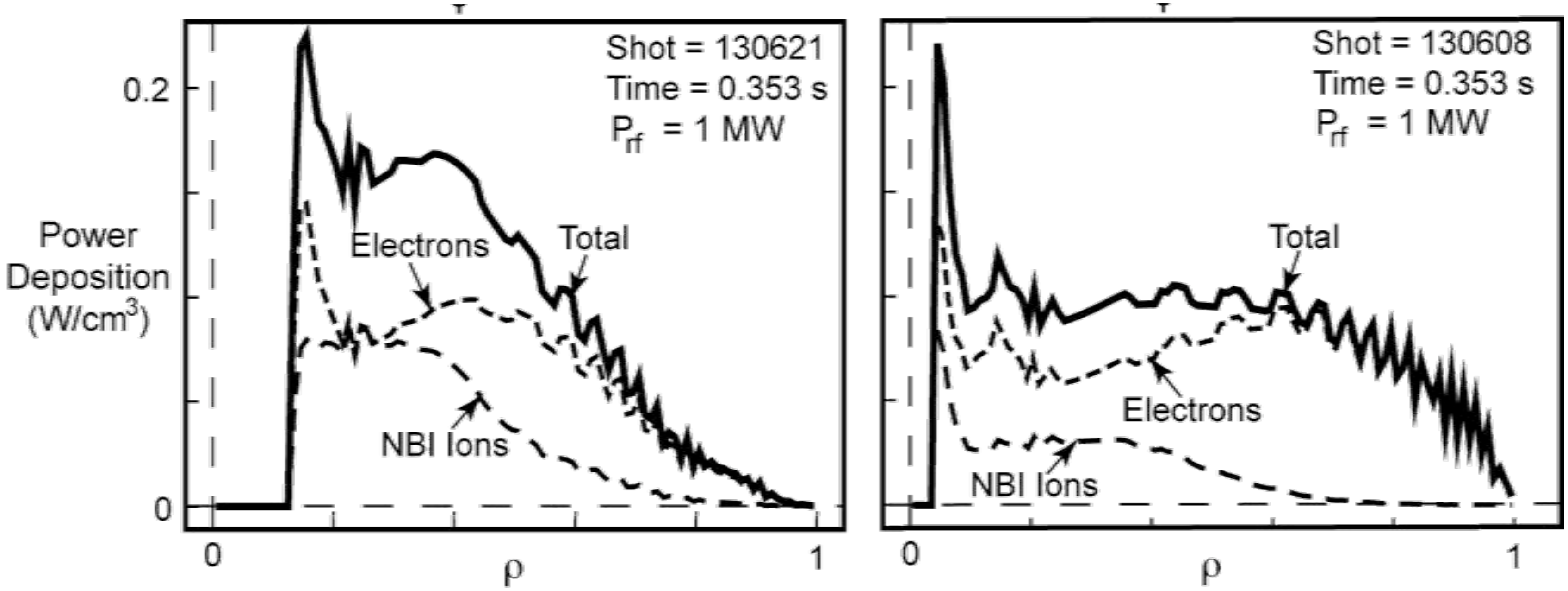
Code	Power to:	CHERS $T_i(0)$~2 keV	4 X CHERS $T_i(0)$~8 keV
AORSA	e	99.2	80
	D	0.1	4.8
	H	0.7	15.2
GENRAY	e	99.9	89.2
	D	~ 0	2.6
	H	0.2	7.8
	C	~ 0	0.3
TORIC	e	99.0	69.5
	D	~ 0	11.6
	H	~ 1	18.9

Profiles from #130608
$k_{//}$ ~ 13 m^{-1} at antenna
(N_{ϕ} = 22)

All three codes predict dominant electron absorption with measured Ti(0) ~ 2 keV
At higher Ti, the codes predict more ion absorption,
but the power splits are different between the three models

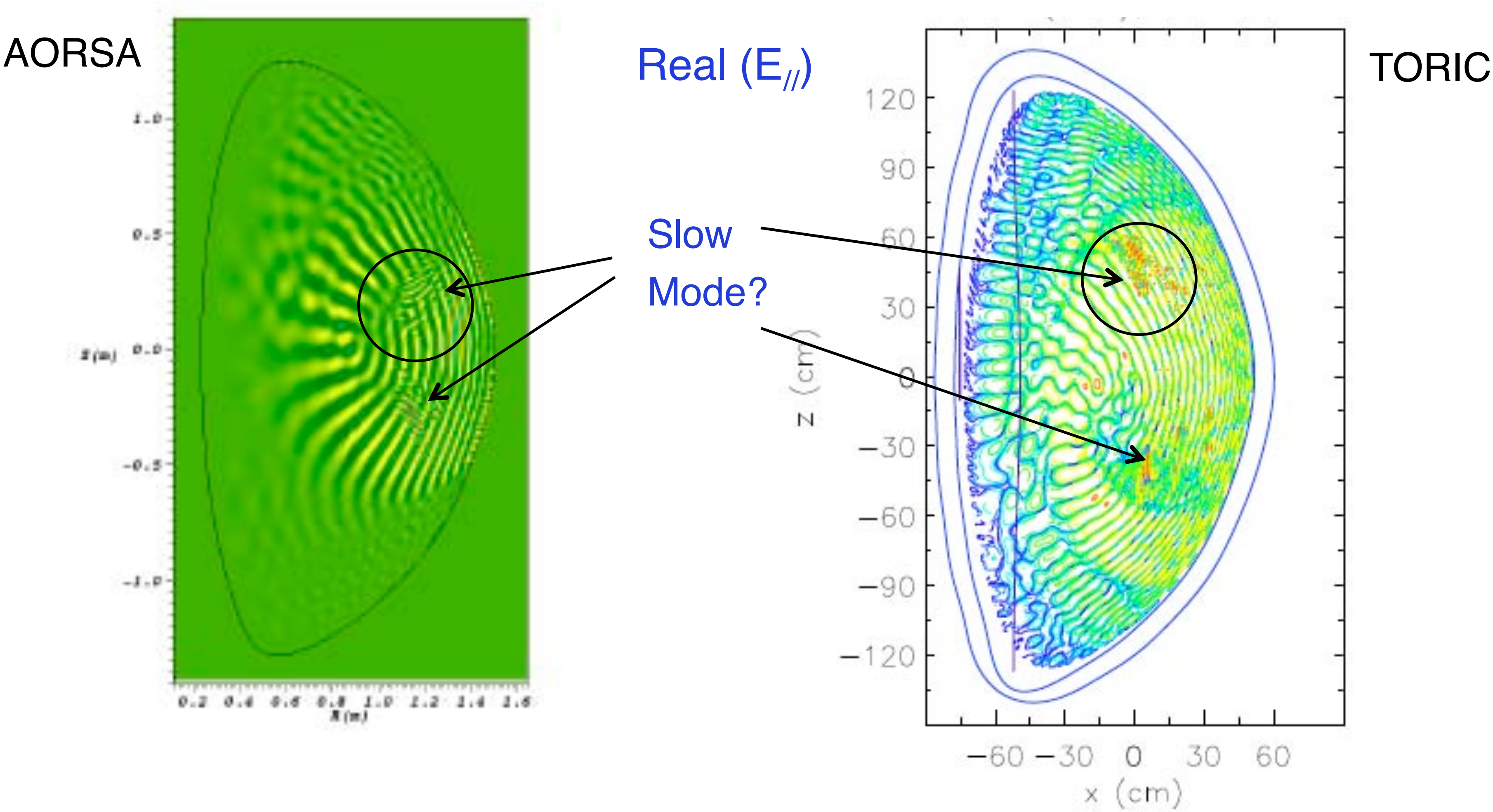
Significant RF power deposition on slowing NBI ions predicted in H-Mode plasmas, particularly at lower k_ϕ

$k_\phi = -8\ m^{-1}$	$k_\phi = -13\ m^{-1}$
$P_e = 73\%$	$P_e = 84\%$
$P_{fi} = 27\%$	$P_{fi} = 16\%$



- Modeling does not include RF acceleration of fast ions that can enhance fast-ion population and drive ions out of plasma
- Power is deposited on electrons and fast ions, not thermal ions
- Detailed comparisons with TORIC and AORSA are underway

Short wavelength mode seen in $E_{//}$ in AORSA and TORIC simulations

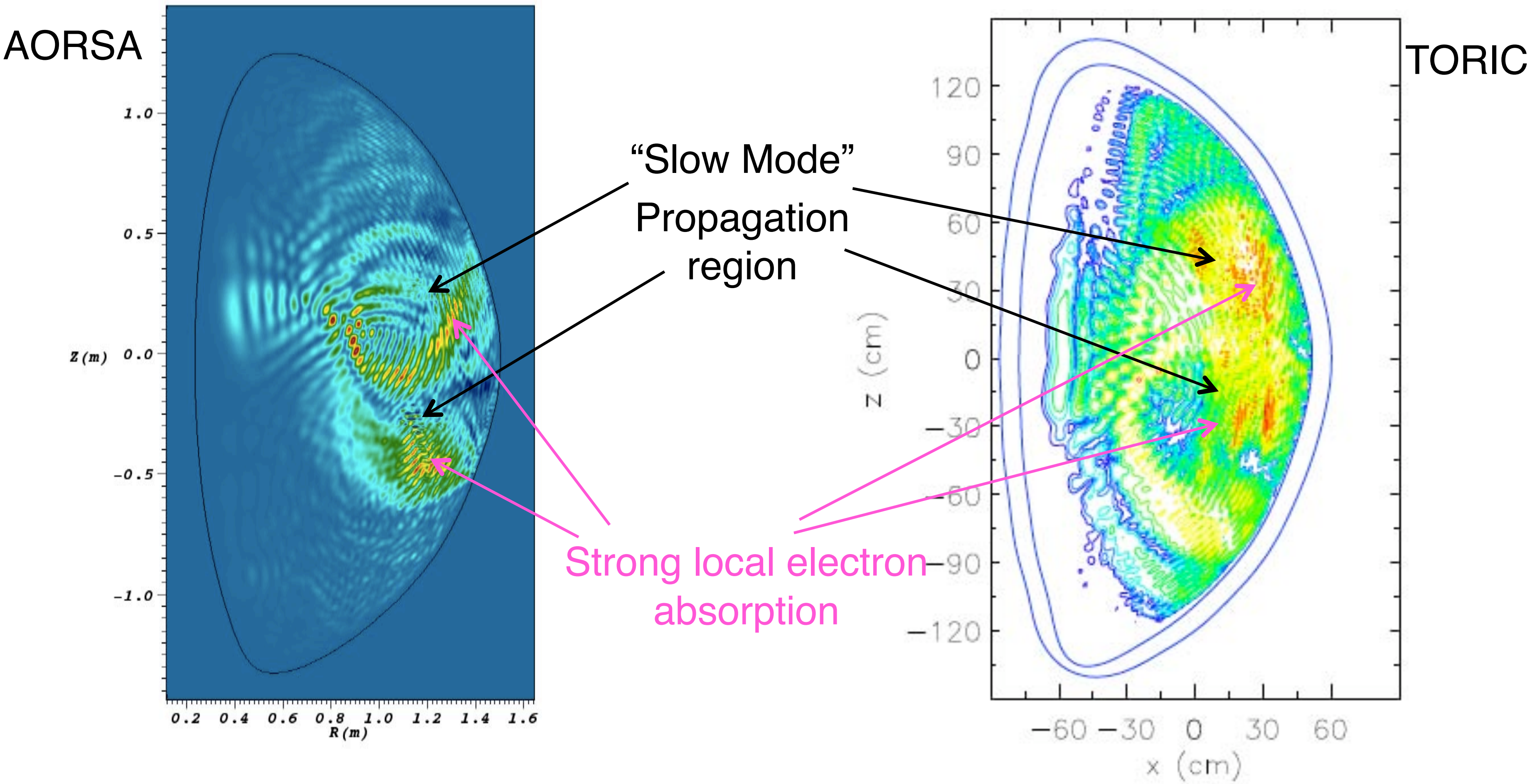


"Slow mode" seen mainly in $E_{//}$, not E_{+} or E_{-}

Mode is localized mainly off-midplane

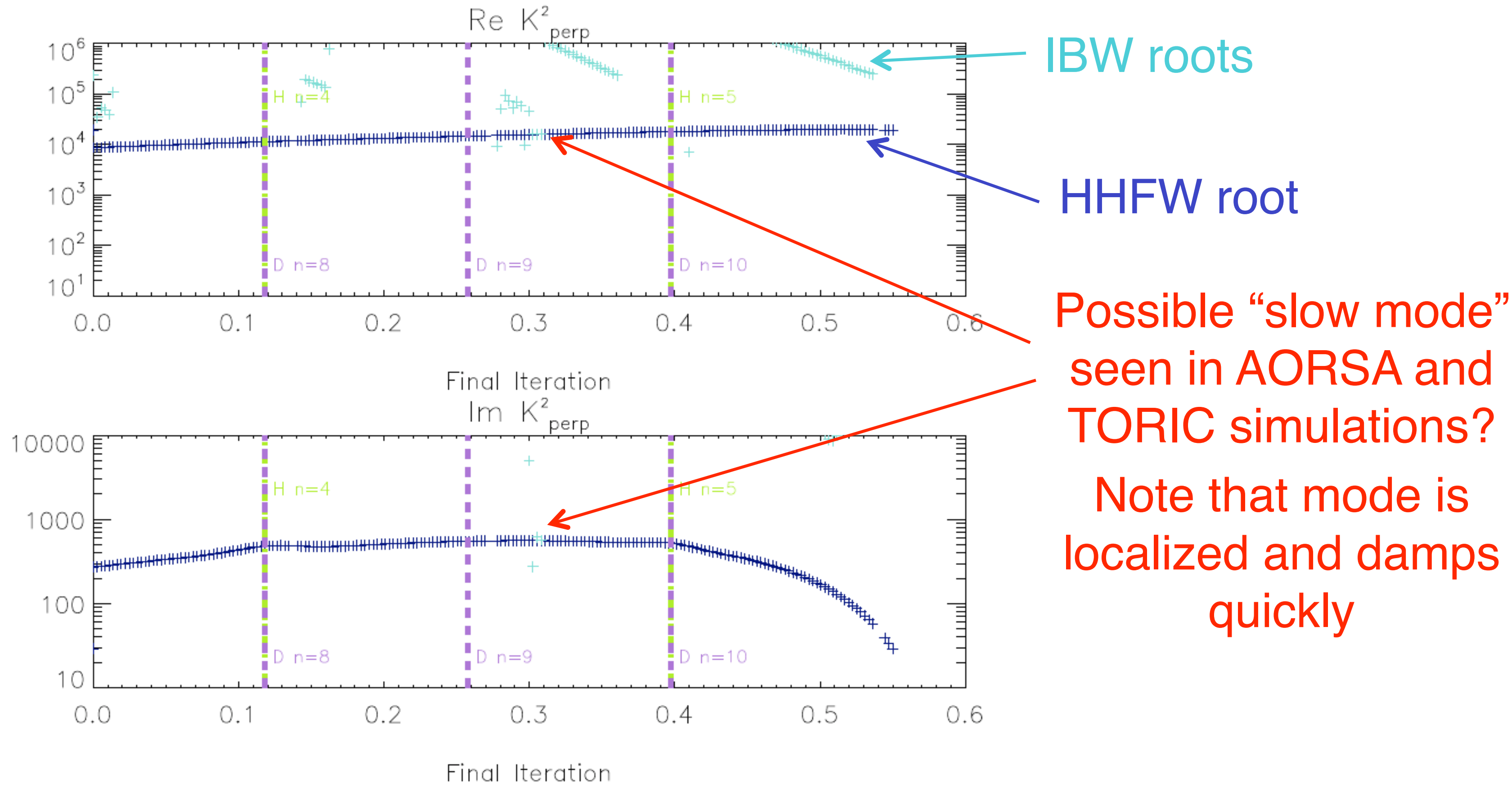
Mode is present in simulations with high spatial resolution

The electron power absorption is higher in regions near but not on slow mode excitation



Two-dimensional electron power deposition contours for shot #130608 with 4 X CHERS for Ti profile and $k_{//} \sim -7\ m^{-1}$

Initial dispersion relation calculations indicate "slow mode" may be present in some HHFW regimes



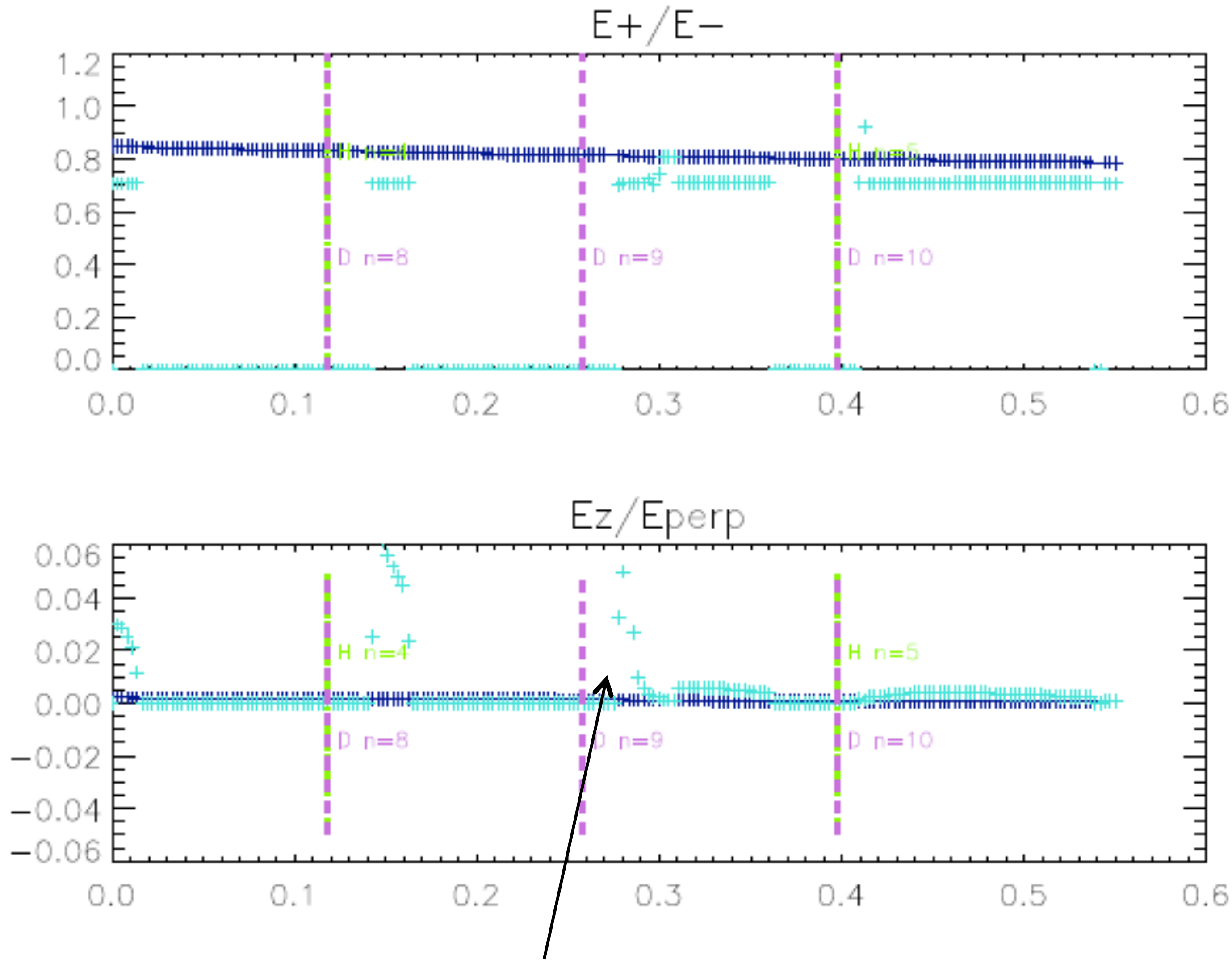
Roots obtained with the CRF full hot plasma dispersion relation code

See Ignat and Ono Phys. Plasmas 2 (1995) 1899

Used typical NSTX parameters and $k_{//} \sim 7\ m^{-1}$ at antenna

Future work: redo with better fits to NSTX data and include effects of Bp on $k_{//}$

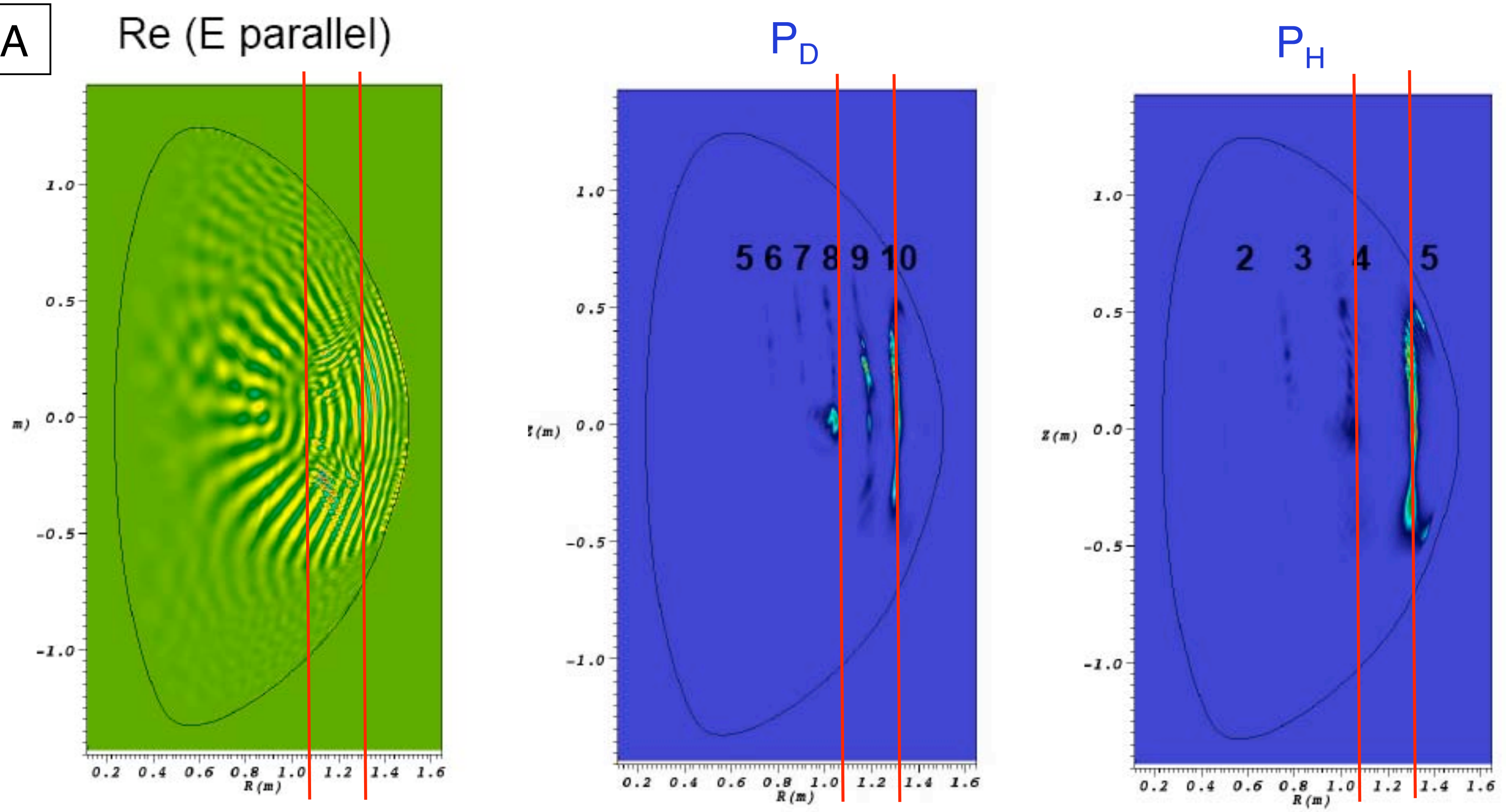
The “slow mode” has mainly $E_{//}$ polarization



Possible “slow mode” seen in AORSA and TORIC simulations?

"Slow mode" appears to propagate between cyclotron harmonics

AORSA



In dispersion relation studies, the "slow mode" root is found between cyclotron harmonics, in D-only as well in D-H plasmas

The mode has a short wavelength perpendicular to B_0.

Summary and Conclusions

- Full wave and ray tracing codes provide qualitatively similar predictions for NSTX HHFW heating and current drive profiles
  - Power absorption by ions becomes significant, even with Ti(0) ~2 keV, at lower launched $k_{//}$
    - Consistent with earlier studies in L-mode plasmas by Rosenberg et al; Mau et al; Jaeger et al; Phillips et al; Harvey et al.
    - Also depends on relative concentrations of ion species
  - Power deposition profiles from the AORSA and GENRAY codes are comparable, but TORIC predicts somewhat stronger ion damping.
    - HHFW root finder in TORIC may need improvement
  - Possible mode conversion to “slow wave” evident in some NSTX parameter regimes
    - “Slow Mode” may be related to two short wave length, hot plasma modes that propagate between cyclotron harmonics, which were identified by Ignat and Ono [Phys. Plasmas 2 (1995)1899].