TORIC Modeling of HHFW in NSTX

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Outline

- TORIC code development:
  - Elimination of numerical instability in code at high mode resolution.
  - “Radial” parallelization of block tri-diagonal matrix solver.
- Sensitivity analysis of ion/electron absorption partition in HHFW.
- Progress in implementing realistic SOL models in full-wave solvers (AORSA)
- Future work

Numerical instability at high poloidal mode number eliminated

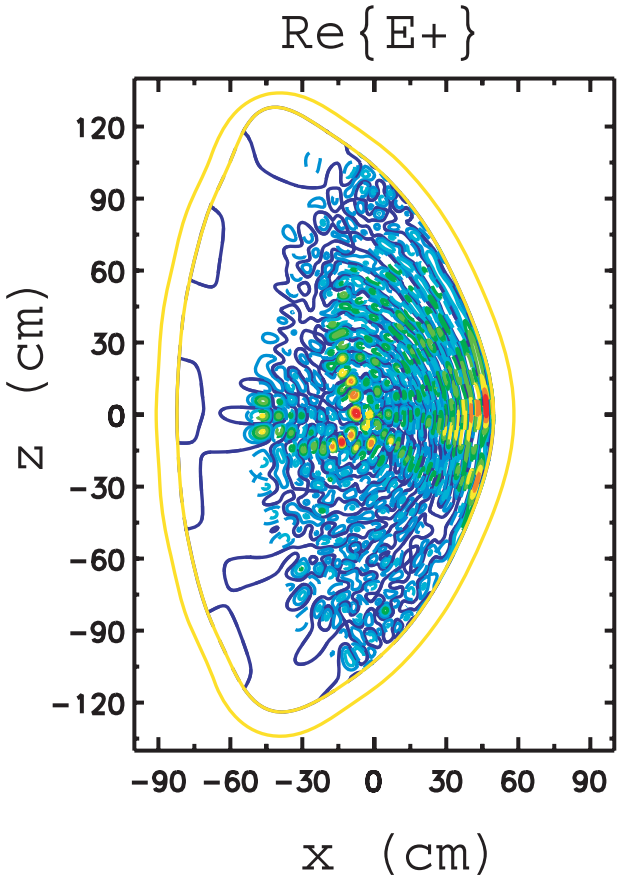
$$\frac{4\pi i}{\omega}\vec{J}_e^{(2)} = -\frac{c^2}{\omega^2}\nabla_\perp \times [\lambda_0(\nabla_\perp \times \vec{E}_\perp)] + i\frac{c^2}{\omega^2}\{\nabla_\perp \times [\xi_0(\vec{b}\bullet\nabla)E_\parallel \vec{b} + \vec{b}(\vec{b}\bullet\nabla)[\xi_0 \vec{b}\bullet(\nabla_\perp \times \vec{E}_\perp)]\},$$

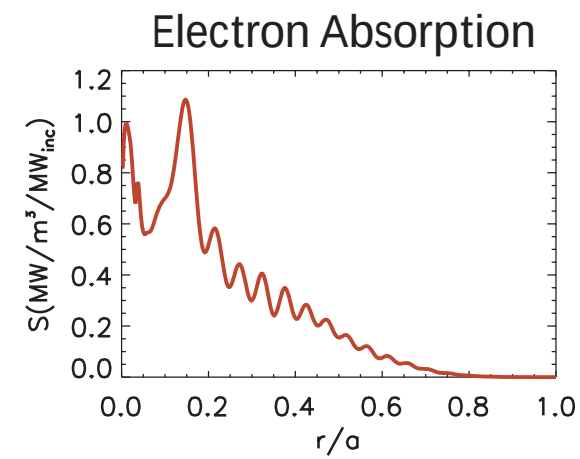
$$\lambda_0 = \frac{1}{2}\frac{\omega_{pe}^2}{\Omega_{ce}^2}\frac{v_{te}^2}{c^2}[-x_e Z(x_e)], \qquad \xi_0 = \frac{1}{2}\frac{\omega_{pe}^2}{\omega\Omega_{ce}}\frac{v_{te}^2}{c^2}[x_e^2 Z'(x_e)].$$

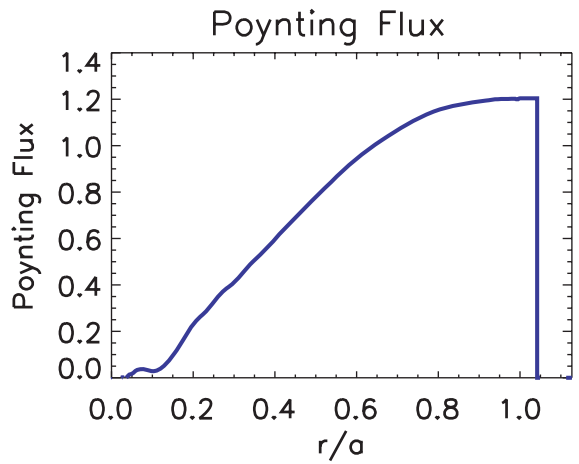
- Secord order electron FLR current:
  - First term (above) corresponds to TTMP
  - Second term is cross-term between TTMP and ELD
- Found instability was caused by error in the cross-term.
- Also resolves instability seen in the LHRF TORIC solver.

High resolution simulations of HHFW heating in NSTX can now be carried out using TORIC

[N_r=480, N_m=511]







- **Prior to correction, Poynting flux and power absorption behaved poorly as N_m was increased beyond 63-127.**

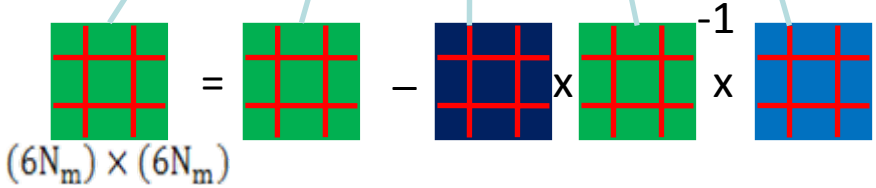
New TORIC parallel solver is 2-4 times faster

Uses a 3-D parallelization of block-tridiagonal matrix system

Current Solver

$$\underline{L_i} \cdot \vec{x}_{i-1} + \underline{D_i} \cdot \vec{x}_i + \underline{R_i} \cdot \vec{x}_{i+1} = \vec{y}_i$$

$$\underline{D_{i+1}} = \underline{D_{i+1}} - \underline{L_{i+1}} \times \underline{D_i^{-1}} \times \underline{R_i}$$



- Serial (Radial direction [i=1.. N_ψ]: Thomas Algorithm)

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  2-D Parallel (Poloidal m modes : Scalapack matrix calculation -> $6N_m \times 6N_m$)

New Solver

$$Ax \equiv \begin{bmatrix} a_1 & b_1 & & & & \\ c_2 & a_2 & b_2 & & & \\ & c_3 & a_3 & b_3 & & \\ & & \ddots & \ddots & \ddots & \\ & & & & b_{n-1} & \\ & & & c_n & a_n & \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} r_1 \\ r_2 \\ r_3 \\ \vdots \\ r_n \end{bmatrix} \equiv r.$$

- 1-D Parallel (Radial direction: combination of Divide-and-Conquer and Odd-even cyclic reduction Algorithms)→# P1 groups

  P.Garaud, Mon.Not.R.Astron.Soc,391(2008)1239-1258

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  2-D Parallel (Poloidal m modes : Scalapack matrix calculation $6N_m \times 6N_m$)

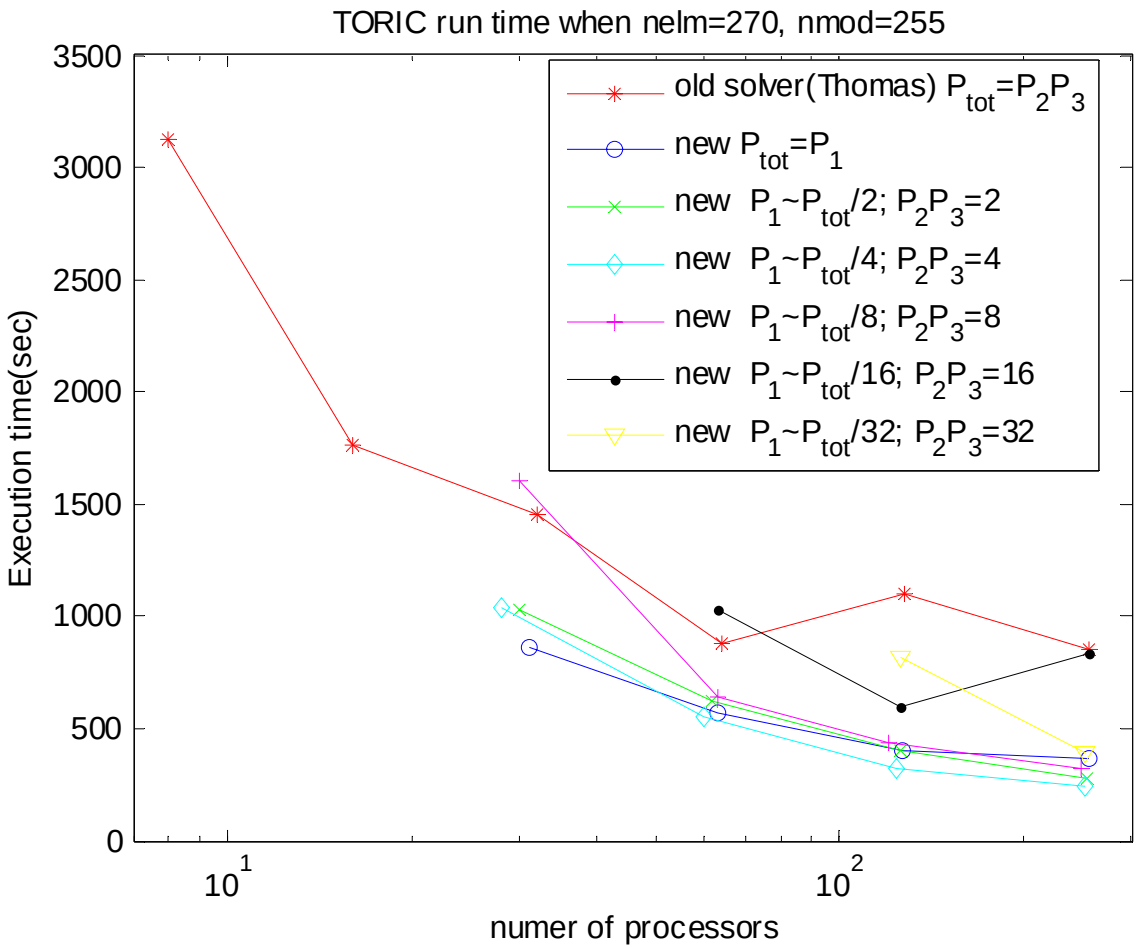
  → #P2*P3 processors

  = **3-D grid (P_tot=P1*P2*P3)**

J. Lee, MIT

New solver is crucial for efficient parallel performance of TORIC in TRANSP

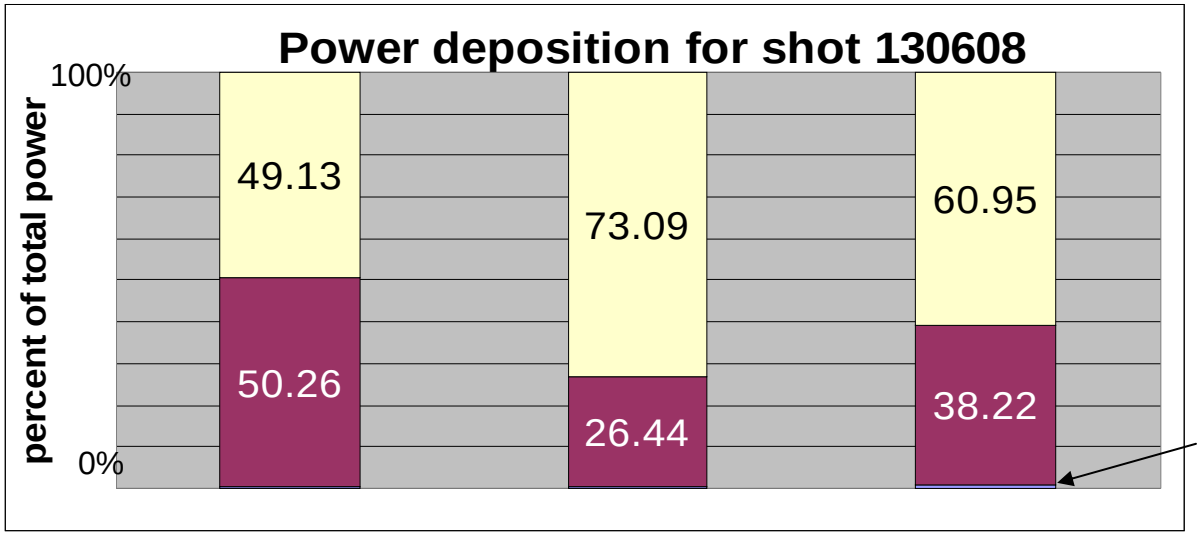
- Optimized grid→ P1=Ptot/4 and P2P3=4

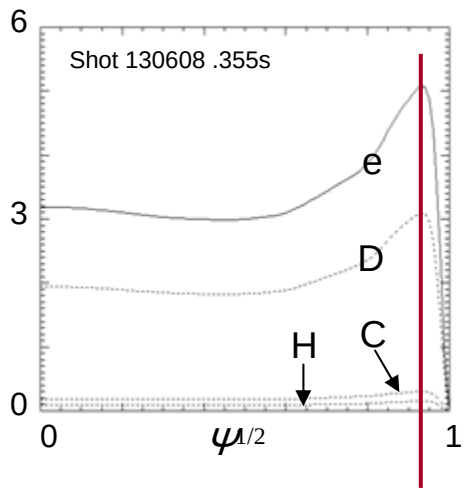


J. Lee, MIT

Will provide sufficient mode resolution in parallel implementation in TRANSP

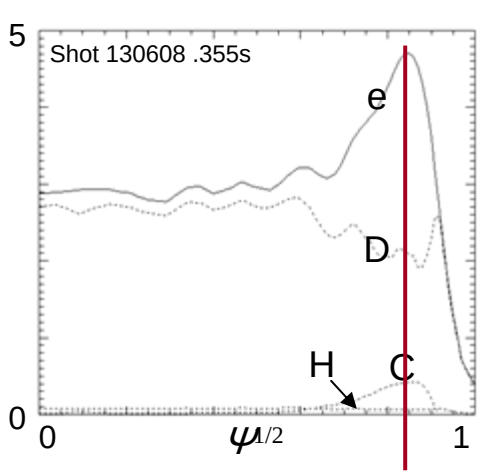
Profile shape, especially near the edge, affects power split between ions and electrons



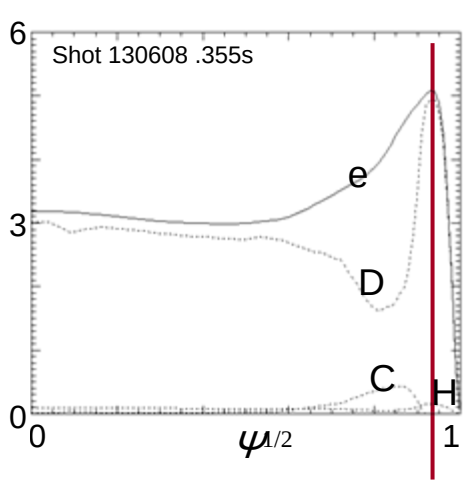


Menard smoothing

$n_i \propto n_e$ and n_c from $\overline{z_{eff}}$



R. Bell spline fit



R. Bell smoothing

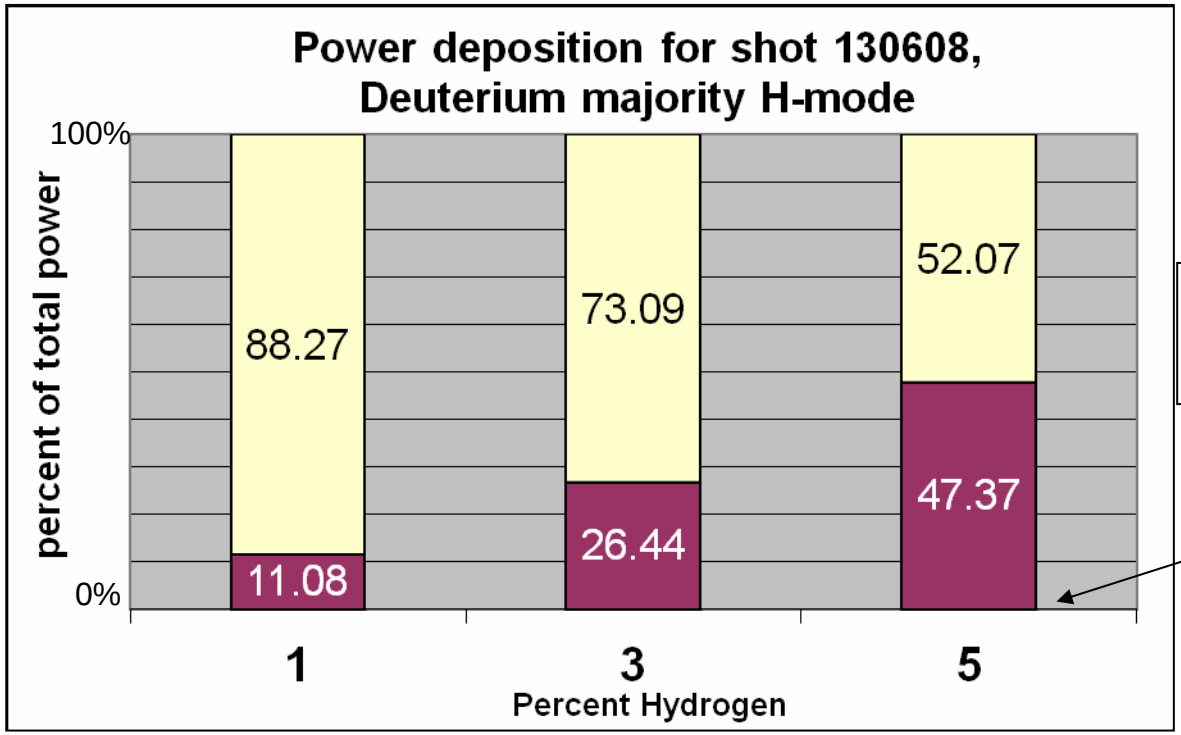
n_C from CHERS

n_H/n_D from Hα/Dα

n_D from z_{eff} & quasineutrality

T. Brecht (NUF 2009)

Hydrogen absorption increases as H concentration increases in H-mode plasmas



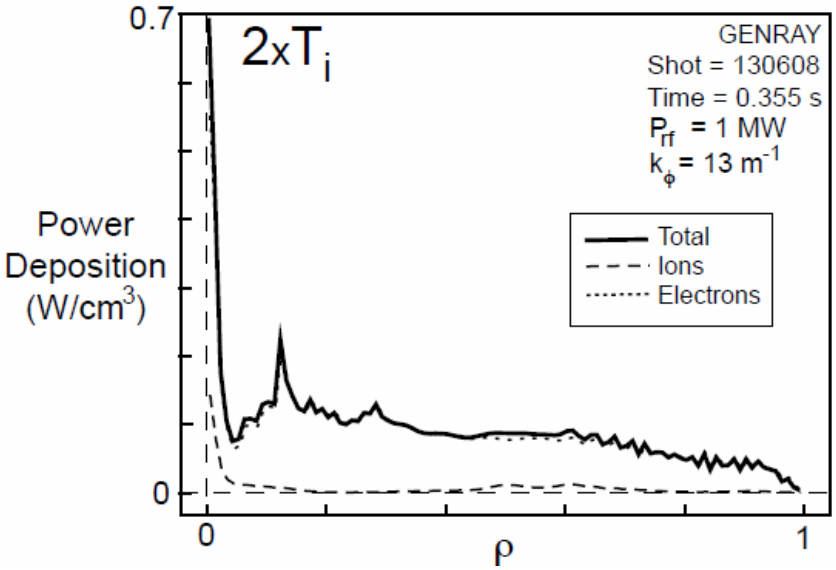
This level of sensitivity necessitates careful measurement and control of H concentration in experimental plasmas

Comparable trend found in L-mode simulations

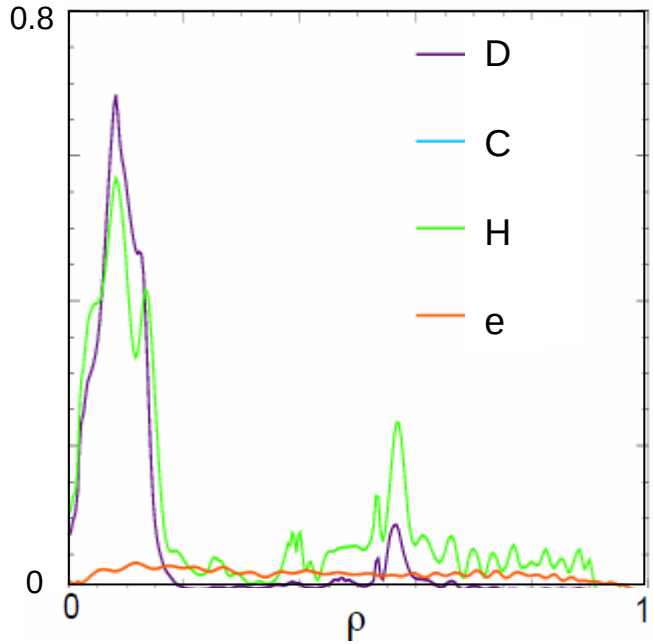
T. Brecht (NUF 2009)

GENRAY and TORIC predict electron absorption decreases as T_i increases

GENRAY



TORIC



Code:	Power to:	CHERS	CHERSx2	CHERSx4
TORIC	e	71.77	39.4	7.91
	H	26.85	27.36	4.43
	D	1.38	33.23	87.66
GENRAY	e	99.3	84.7	45.3
	H	0.7	9.1	20.2
	D	0	6.1	31.4

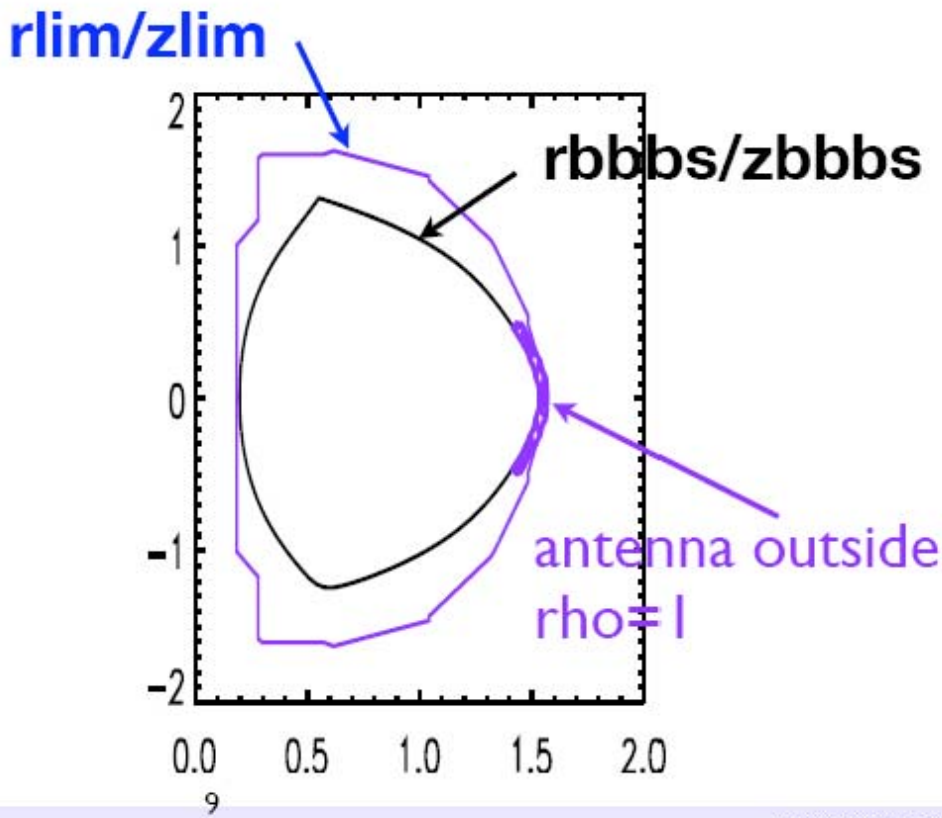
TORIC predicts stronger dependence on T_i than GENRAY

>> recent TORIC code fix may resolve the discrepancy

T. Brecht (NUF 2009)

AORSA boundary has been extended to the limiter

- combining Thompson scattering, charge exchange and reflectometer data with **SOLPS** results gives an estimate of the 2D profiles
- edge gradients are large



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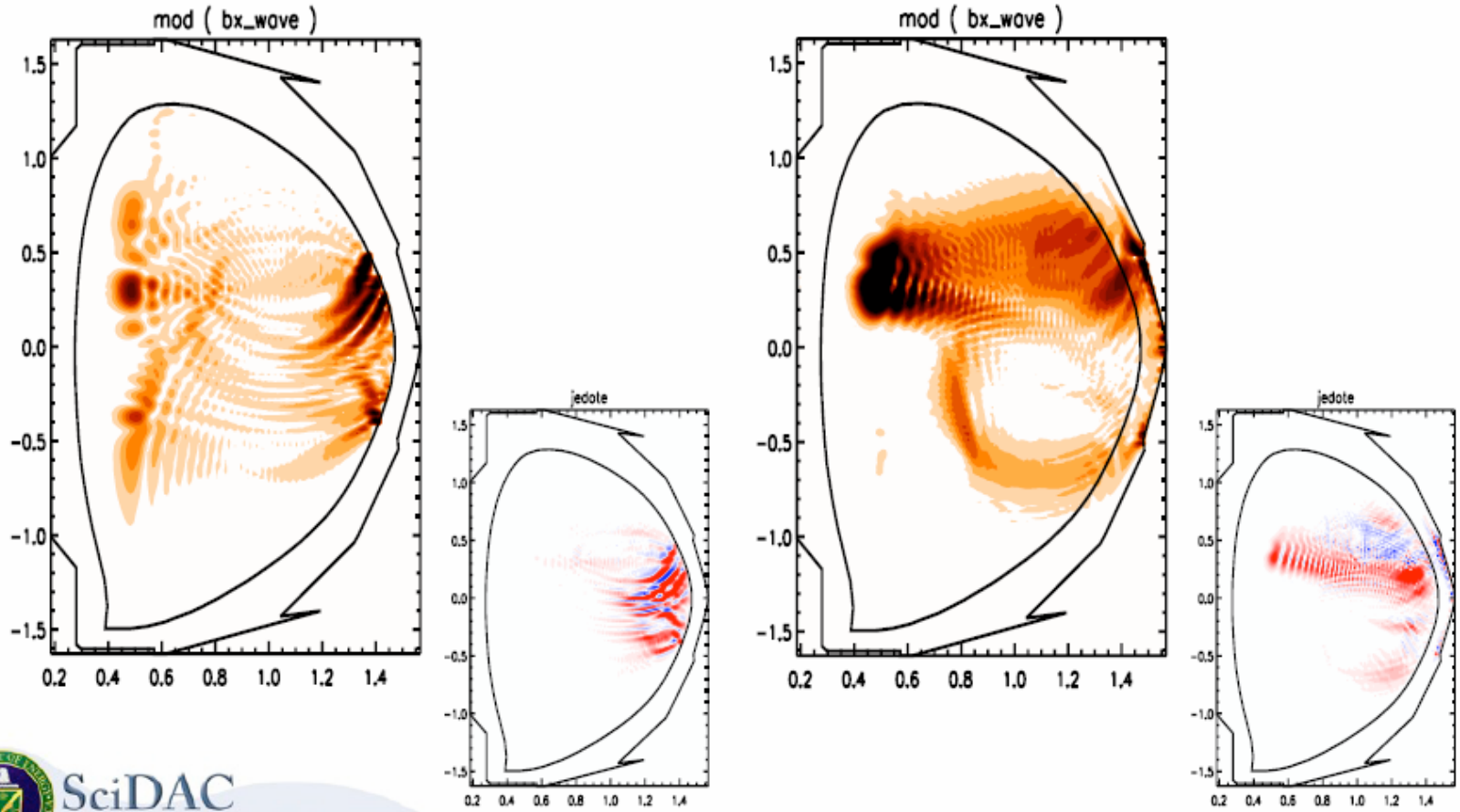
Wave fields depends on location of the launcher and SOL profiles

- NSTX HHFW, shot 128797@400ms, D ~1keV, maxwellian, 1MW@30MHz, nPhi = -18, 128x256 using smooth profiles



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Conclusions

- **RF power deposition on ions and electrons is sensitive to:**
  - Edge density profiles
    High density nearest the edge of the plasma causes more ion absorption than when density rises away from the edge.
  - Hydrogen concentration
    Hydrogen absorbs more RF power as its concentration increases in both H- and L- mode plasmas.
  - Ion temperature
    Ion absorption increases significantly with rising ion temperatures. (even modest temperatures of 3 keV)

- Future work:
  - Revisit dependence of power partitioning on T_i
  - Explore effect of limiter boundary on wave propagation
  - Carry out 3D field reconstructions for wave propagation in SOL
  - Improve algorithms in TRANSP for more accurate, faster simulations