

# **Enhancements To Full-Wave TORIC for HHFW Modeling**

P. Bonoli, PSFC, Cambridge, MA

M. Brambilla, IPP, Garching, Germany

C.K. Phillips, PPPL, Princeton, NJ

NSTX Research Forum

HHFW / EBW Planning Session

September 11-13, 2002

# Applicability of TORIC to HHFW Regime

- TORIC uses SCK wave equation
  - Valid for  $(k_{\perp}\rho_i)^2 < 1$
- But in NSTX we can have  $(k_{\perp}\rho_i)^2 \approx 50$ 
  - $k_{\perp} \approx \omega / V_A$ ,  $T_i = 0.5$  keV,  $n_e = 4 \times 10^{19} \text{ m}^{-3}$ ,  $B_t = 0.25$  T
- Using the ion FLR wave equation in this regime gets wrong wave polarization and subsequently the wrong wave damping
  - ELD  $\propto |E_z|^2$
  - TTMP  $\propto |E_y|^2$
  - Cross - term  $\propto E_y \cdot E_z$

## TORIC Modifications for HHFW Regime

- Reformulated dielectric tensor elements in coefficients of SCK equations using full Bessel function expansion [Brambilla, 2002]:
  - Approach used by Belgian group in the SPRUCE code
  - Can then evaluate cyclotron damping on minority hydrogen, following Ono [Physics of Plasmas **2**, 4075 (1995)]

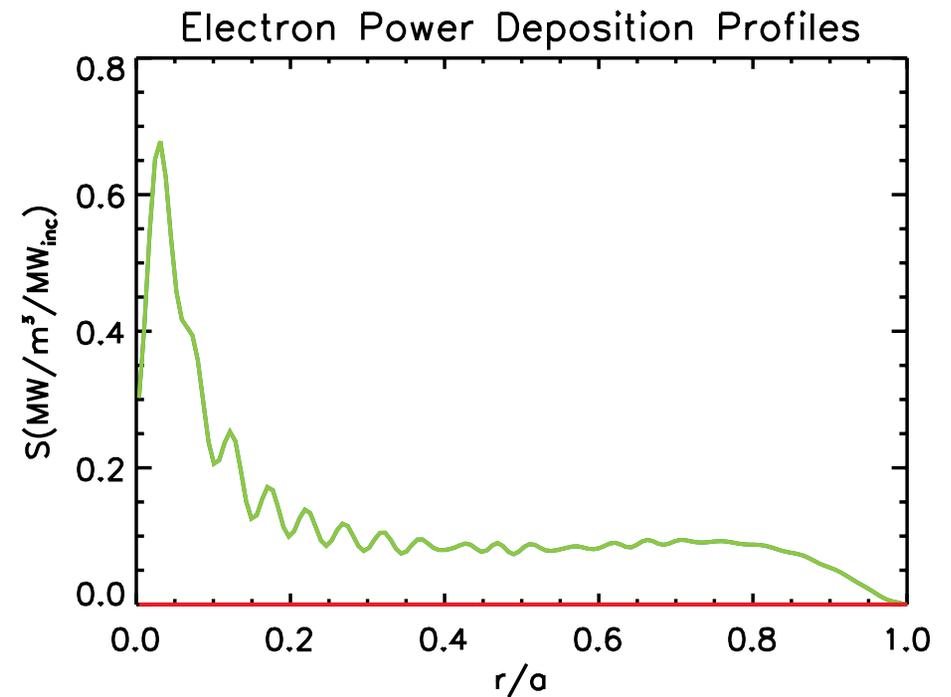
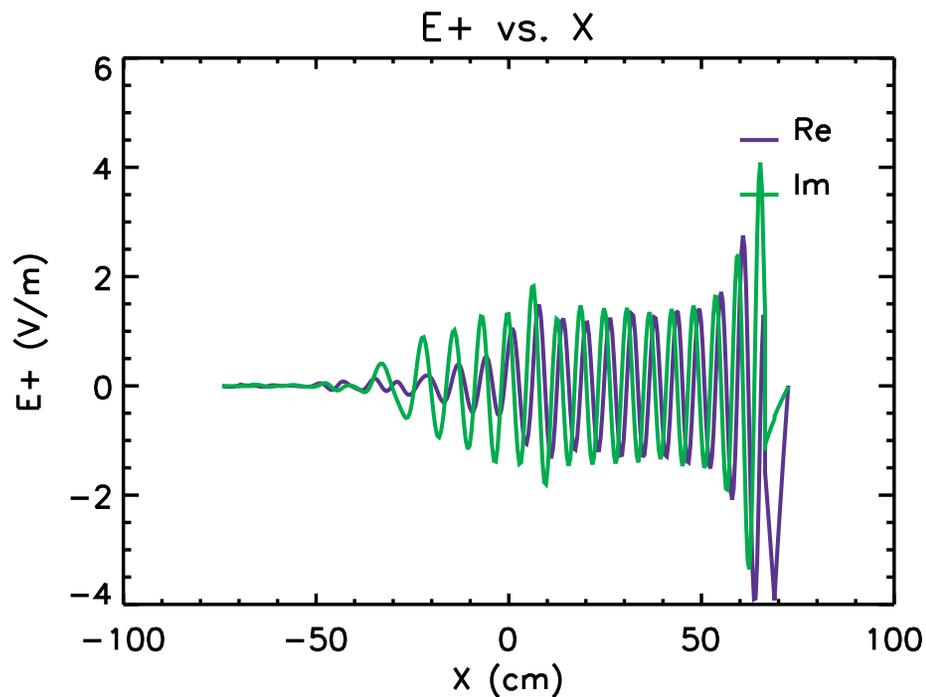
# Applicability of TORIC to HHFW Regime - Tests Performed

- Compare the following:
  - TORIC with ion FLR wave equation
  - METS 1D with full ion Bessel expansion (Phillips)
  - Ray tracing with full ion Bessel expansion (Rosenberg)
  - TORIC with modified full-wave equation

# Parameters for Comparison of Models

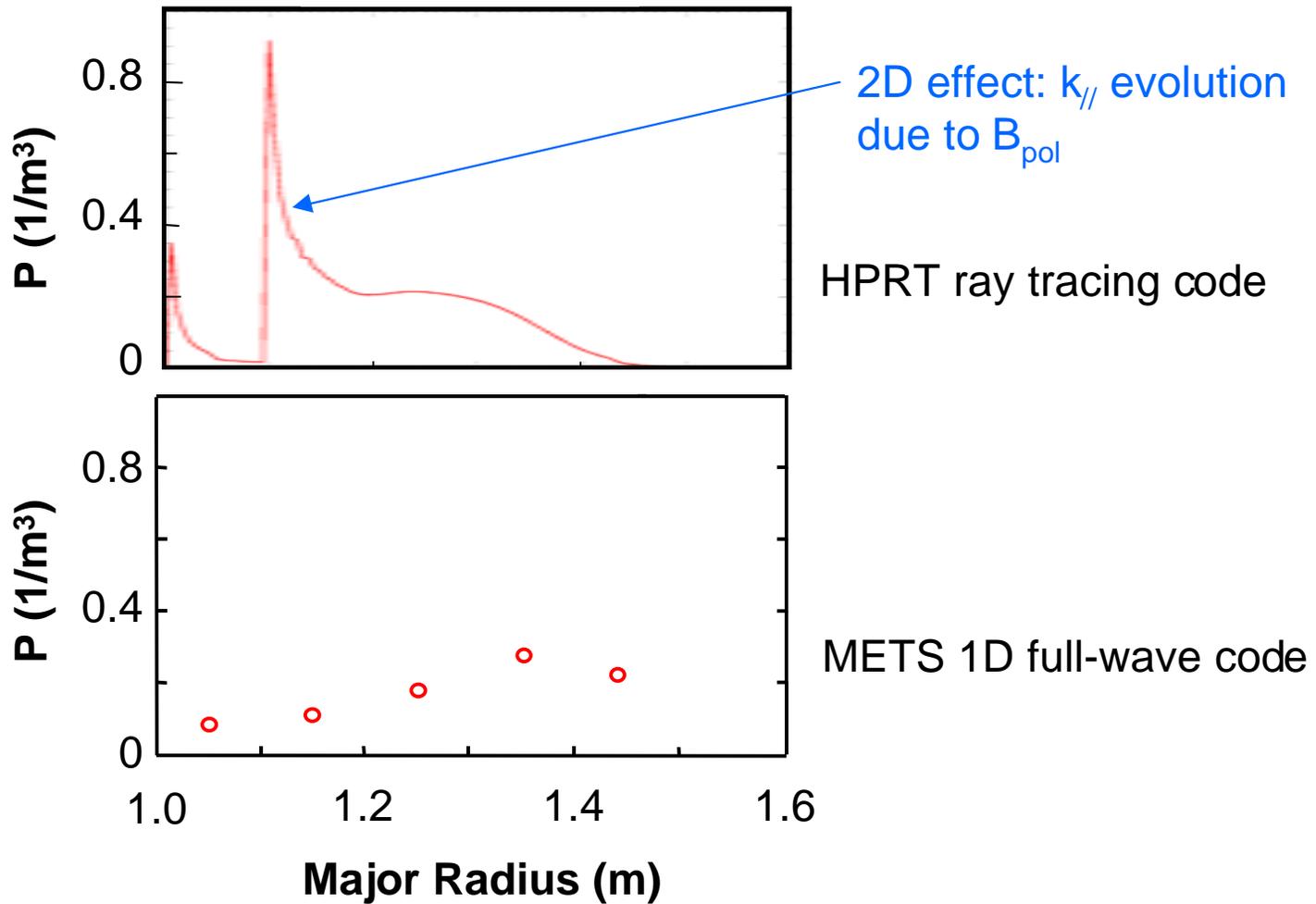
- $T_i(0) = 0.5 \text{ keV}$
- $T_e(0) = 1.5 \text{ keV}$
- $n_e(0) = 4.1 \times 10^{19} \text{ m}^{-3}$
- $B_t = 0.32 \text{ T}$
- $I_p = 800 \text{ kA}$
- Profiles:
  - $n_e \propto [1 - (r/a)^4]$
  - $T_e \propto [1 - (r/a)^4]$
  - $T_i \propto [1 - (r/a)^2]$
- $f_0 = 30 \text{ MHz}$
- $n_\phi = 22$
- $k_{||(\text{ANT})} \approx 14 \text{ m}^{-1}$
- Plasma Composition
  - 90% Deuterium
  - 10% Hydrogen

# TORIC Results with ion FLR Wave Equation

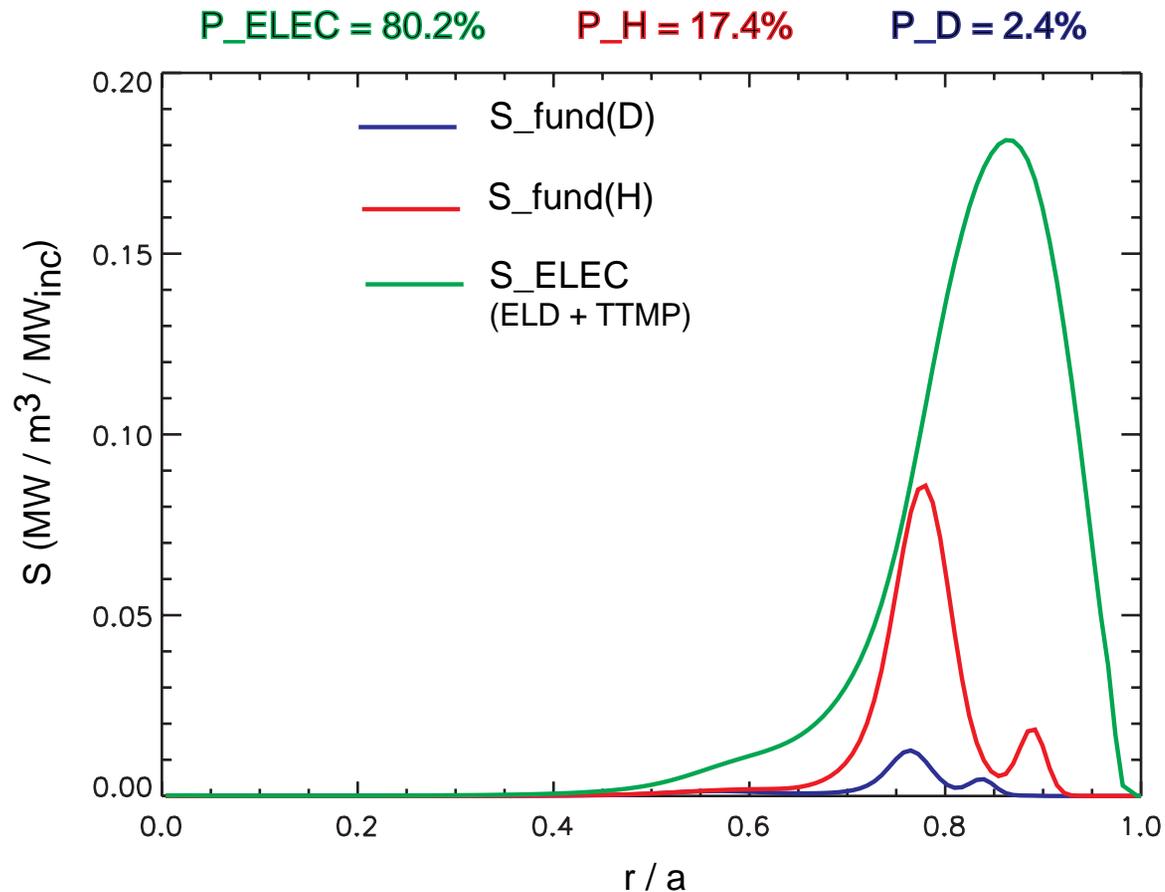


**Results in substantial disagreement with 1-D integral wave code METS and toroidal ray tracing (HPRT)**

Models predict off-axis wave absorption on electrons



# TORIC Results with Modified Wave Equation



**Similar results for electron damping obtained with ORA  
in TORIC , but algorithm uses  $B_{\theta} = 0$**

## Planned Work for FY2003

- Implement TORIC with modified wave equation within the TRANSP - FPPRF module [collaboration with D. McCune, M. Brambilla, and F. Meo]:
  - Can then perform routine transport analysis of NSTX discharges using HHFW heating.
- Immediately begin HHFW current drive studies using the modified full-wave module:
  - Code already coupled to Ehst - Karney efficiency parameterization.