Ray Optics Analysis of
HHFW Heating and Current Drive in NSTX

T.K. Mau
UC-San Diego

NSTX Results Review
September 19-20, 2001

Princeton Plasma Physics Laboratory

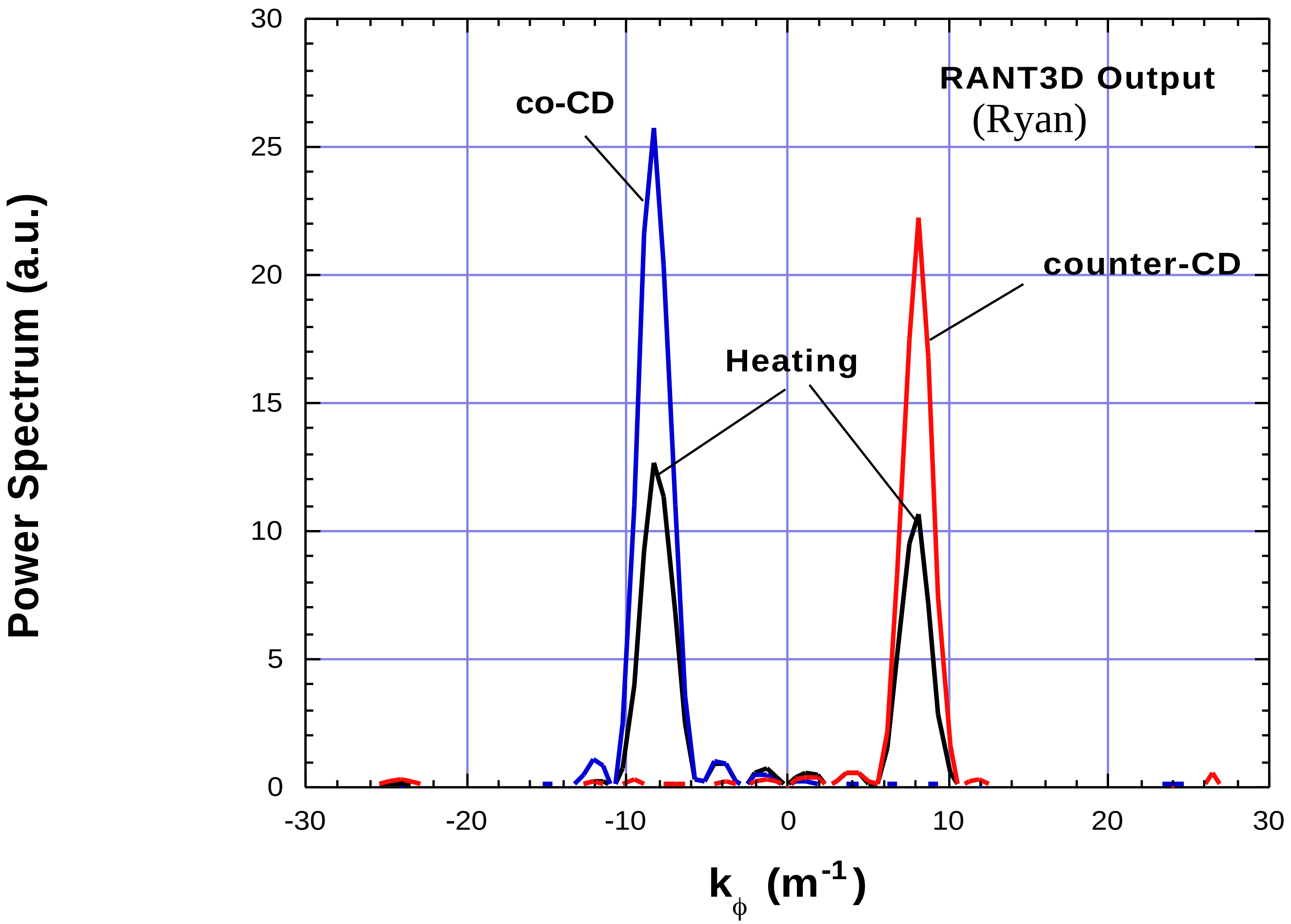
OUTLINE

- Ray optics analysis of most recent HHFW discharges, including heating and current drive
- Status of CURRAY code and project work
- Long term proposed tasks

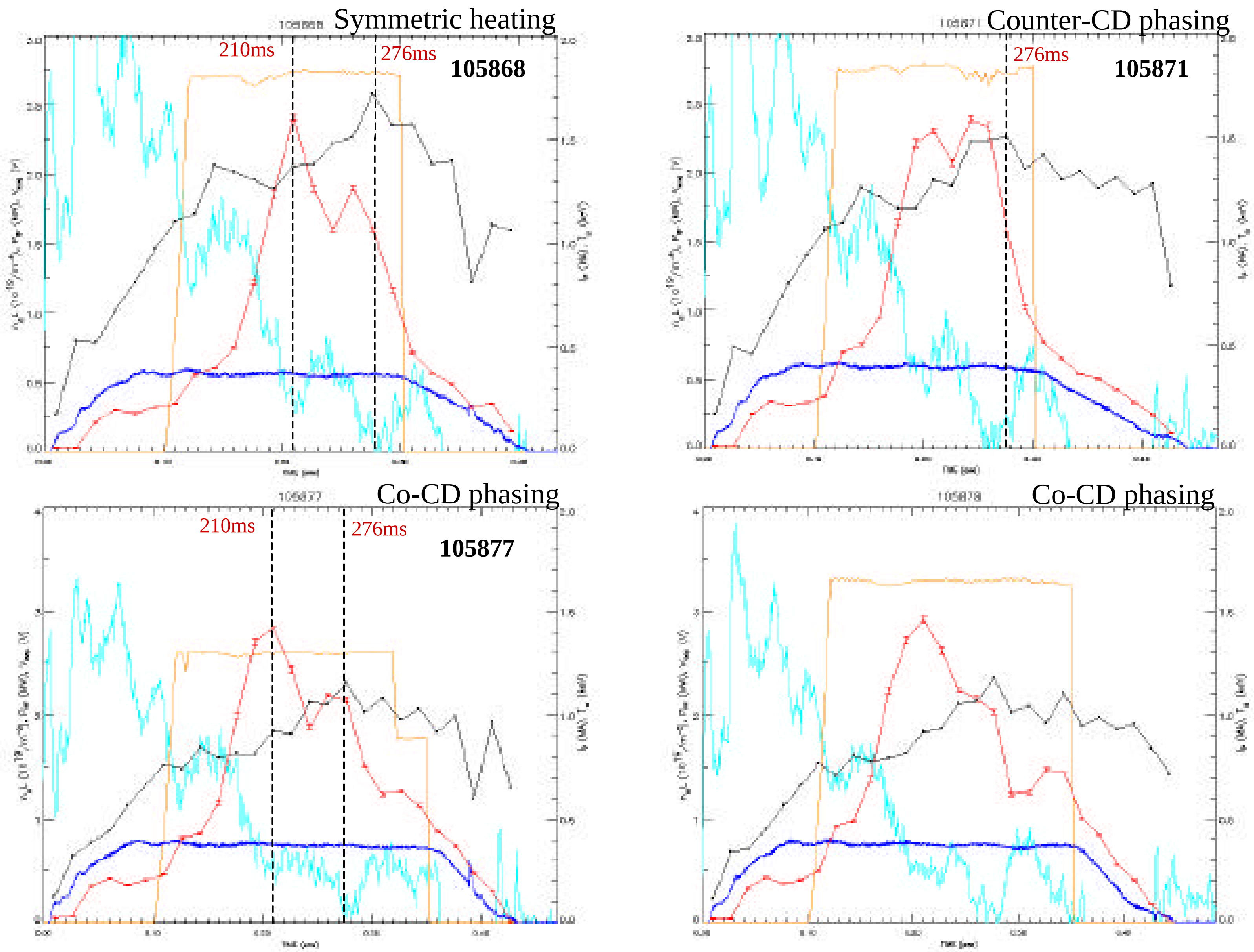
Cases for 3 Antenna Phasings have been Examined

- Heating : 00ππ00 phasing ; Spectrum peaks at $k_\varphi = \pm 8\ m^{-1}$, m = 1
- Co-CD : $\Delta\varphi = -\pi/2$; peaks at $k_\varphi = -8\ m^{-1}$, m = 1
- Counter-CD $\Delta\varphi = +\pi/2$; peaks at $k_\varphi = +8\ m^{-1}$, m = 1

  Dominant $|k_{||}| \sim$ 7-8 m^{-1} launched



Heating and CD Calculations for These Discharges



CURRAY Calculation Model

- EQDSK equilibria reconstructed from EFIT analysis of NSTX discharges.

- For n, T profiles, we use either inferred profiles consistent with the pressure profile, or analytic fits to Thomson scattering measurements. We treat all thermal and energetic ion species to be Maxwellian.

- For now, the launched spectrum is represented by 22-110 rays:

  - Rays star with refractive index (N_φ, N_θ), and P (N_φ, N_θ).
  - Rays initiate along antenna poloidal length inside plasma separatrix.
  - Power distribution : $P(\theta) \sim \cos^2(k_o L)$

- Damping is linear on Maxwellian species, and dispersion relation is still cold ions.

- Current drive is calculated using adjoint technique valid for tight aspect ratios.

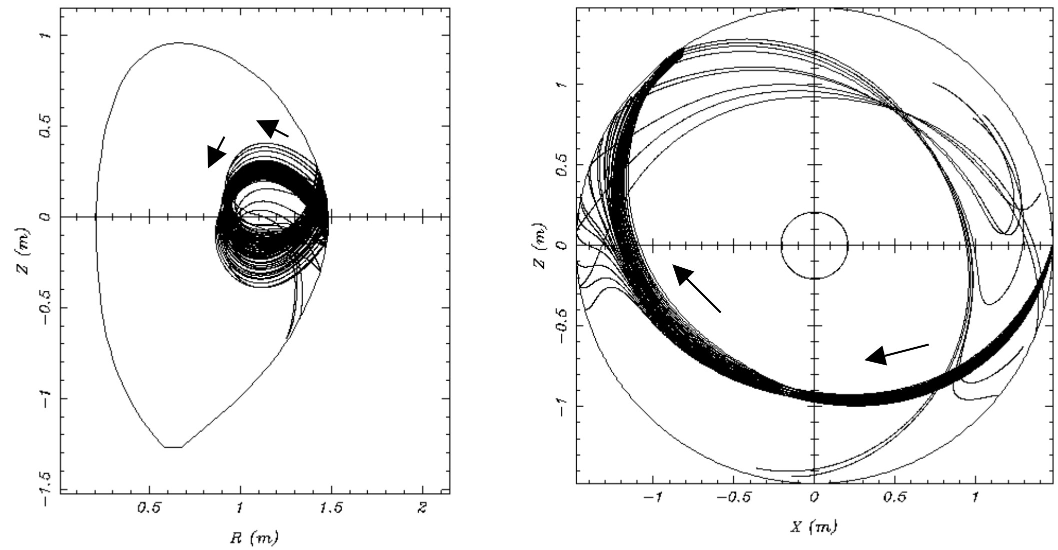
Typical Ray Trajectories

Anti-symmetry in ray directions between Co- and Counter-CD phasing is observed.

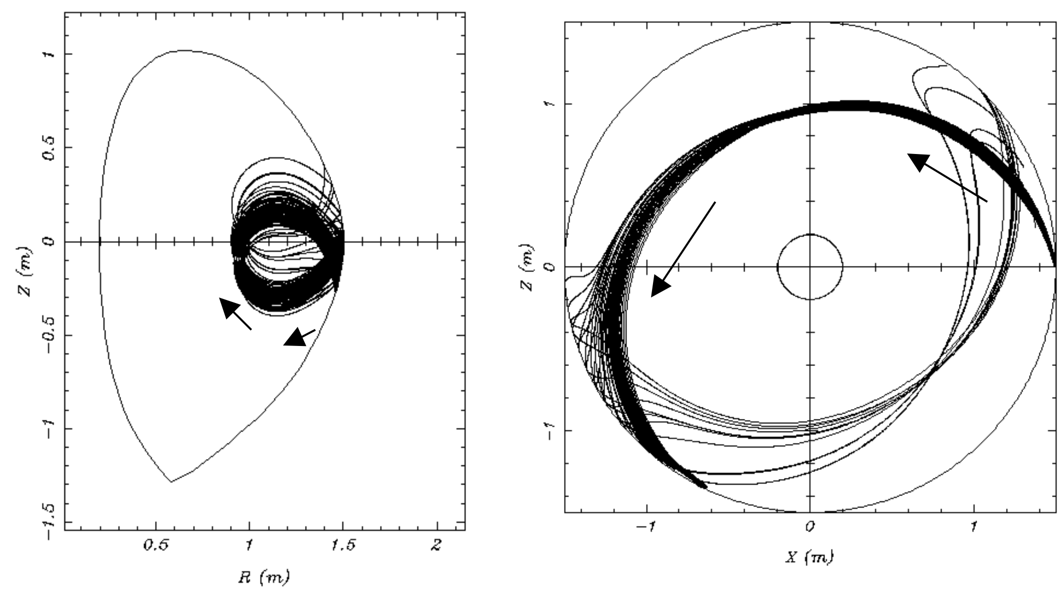
About 90% of power is absorbed in initial poloidally directed loop of the path for the plasma regime:

- β = 1.5 - 2.5 %

Counter-CD

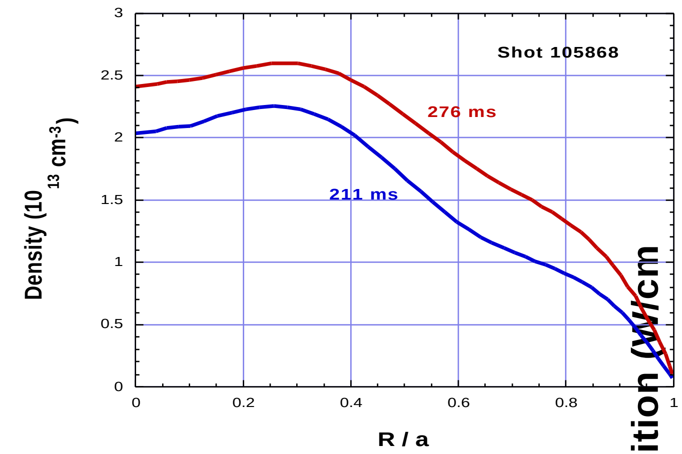


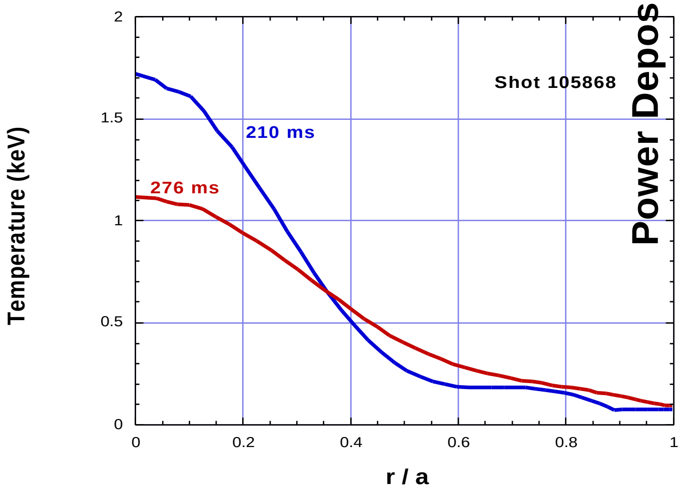
Co-CD

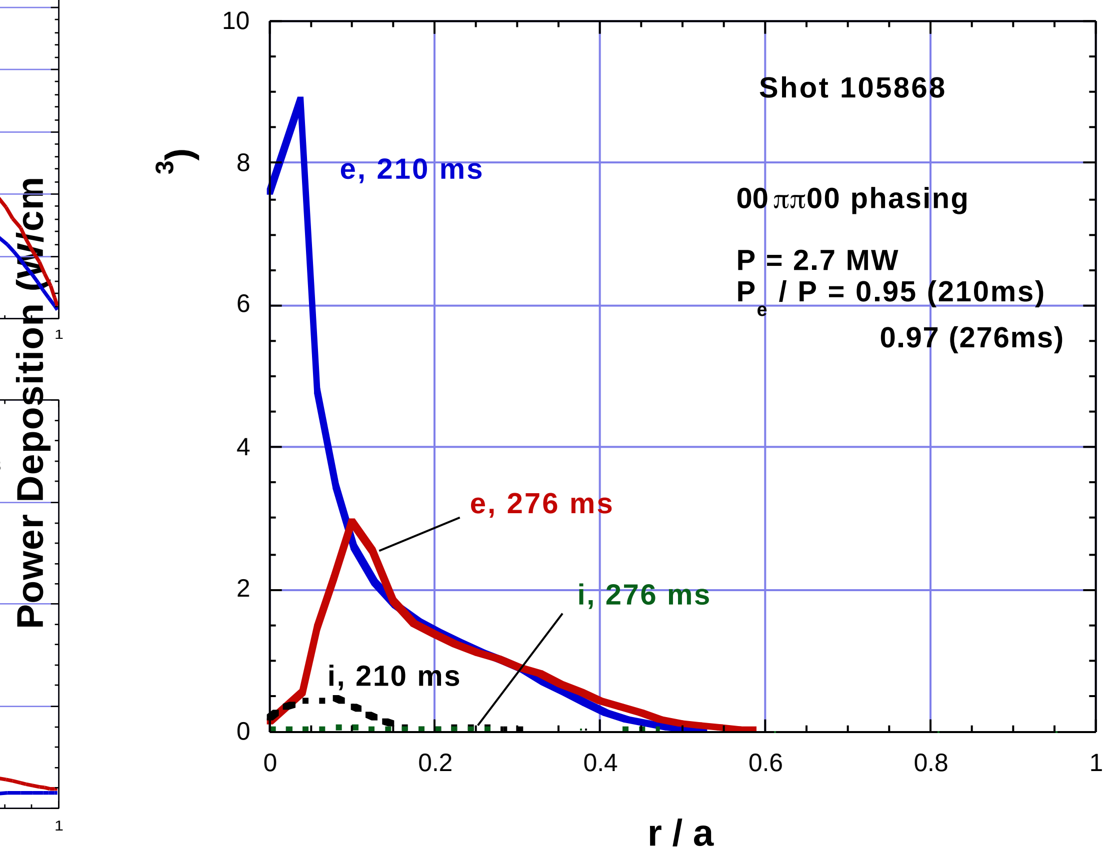


CURRAY Results for Heating Case (105868)

- Power deposition is peaked near magnetic axis, mostly on electrons.
- 5% of H impurity is assumed, which absorbs ~ a few % of power.
- Because the spectrum is asymmetric, we calculate about ~20kA of driven current near axis.

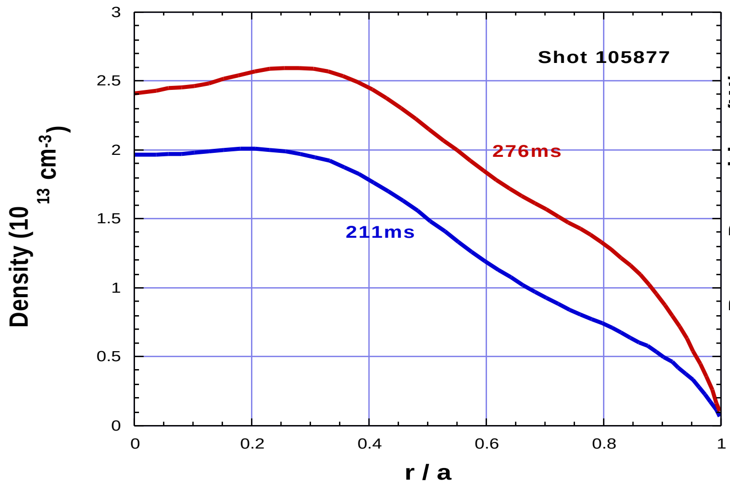


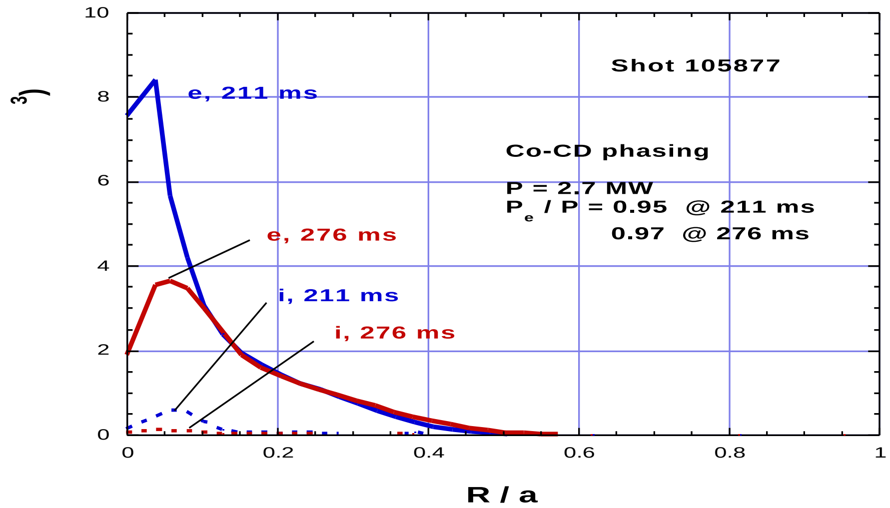


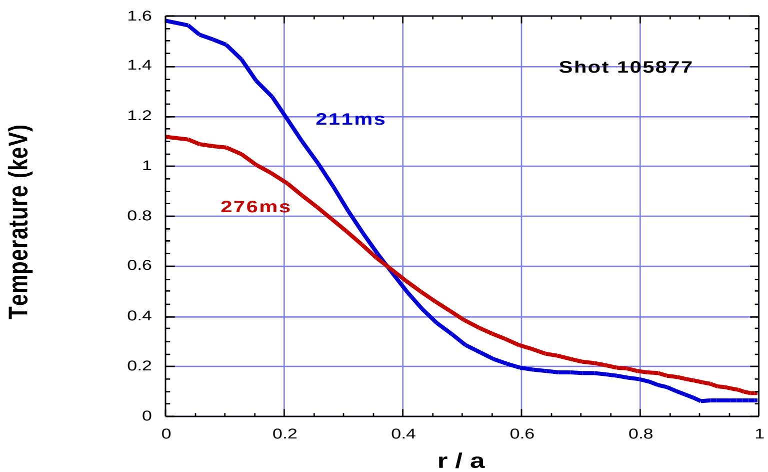


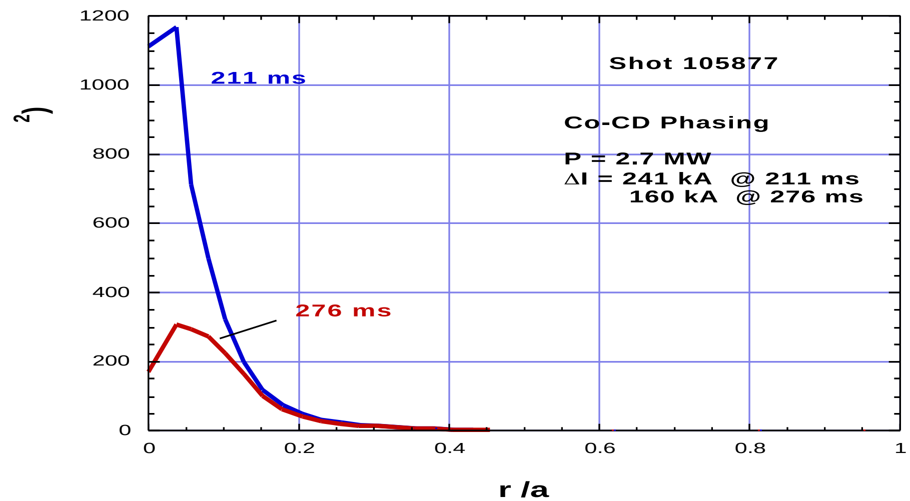
150-250 kA Current Drive for Co-CD Case (105877)

- Current drive profile is narrower than electron deposition profile, because of trapped particle effects.
- Less current is driven at 276ms because of higher n and lower T on axis.



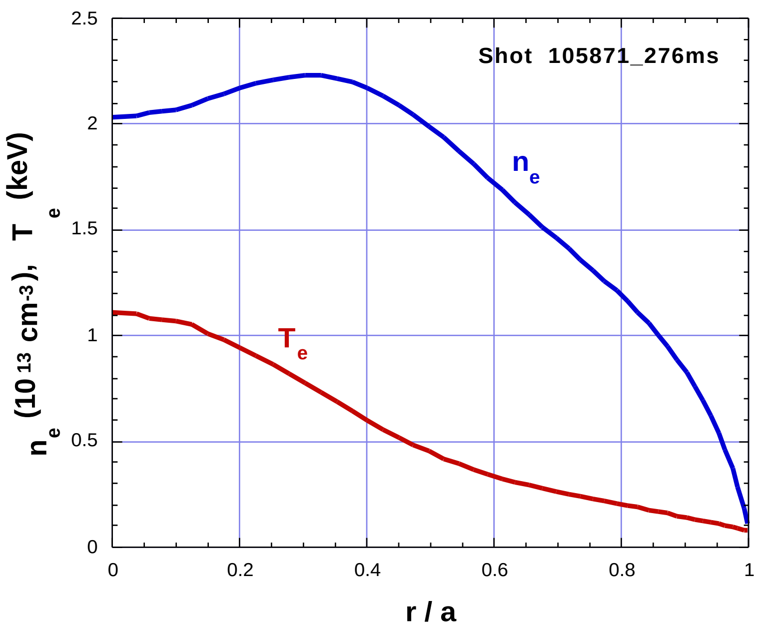


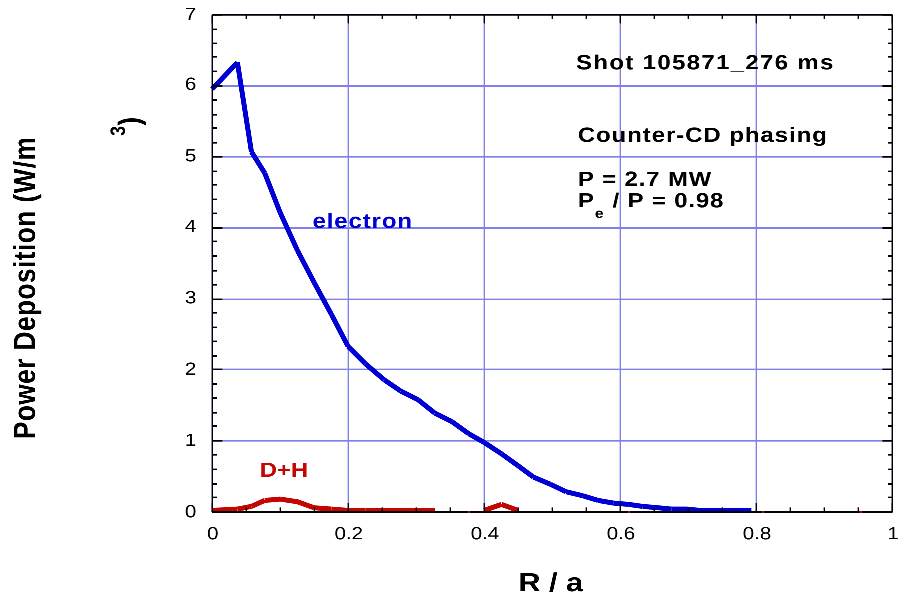


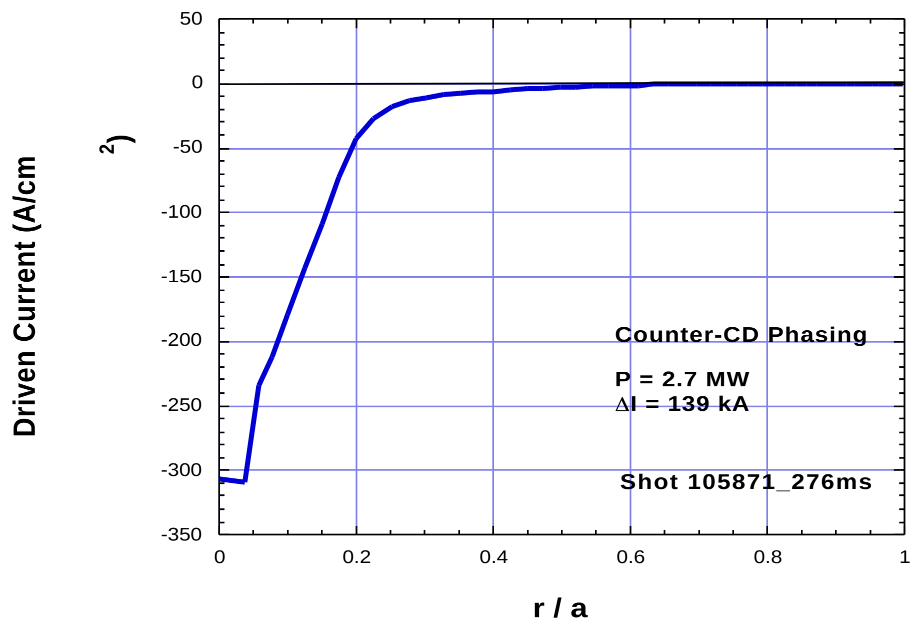


139 KA Current Drive for Counter-CD Case (105871)

- CURRAY predicts 139 kA of CD peaked on axis with 2.7 MW of power.

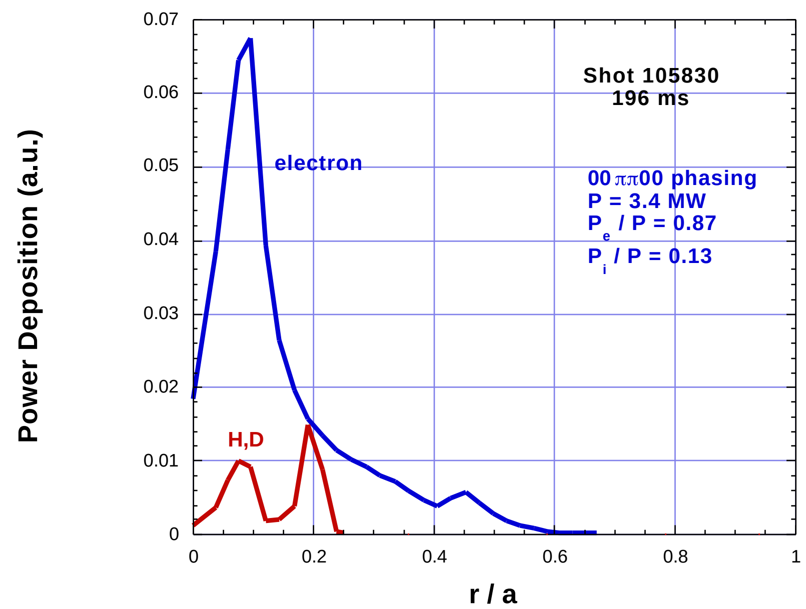


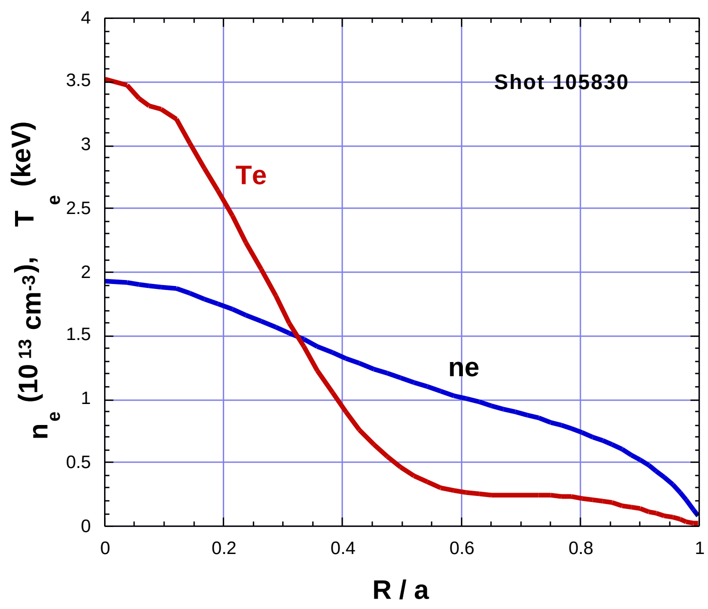


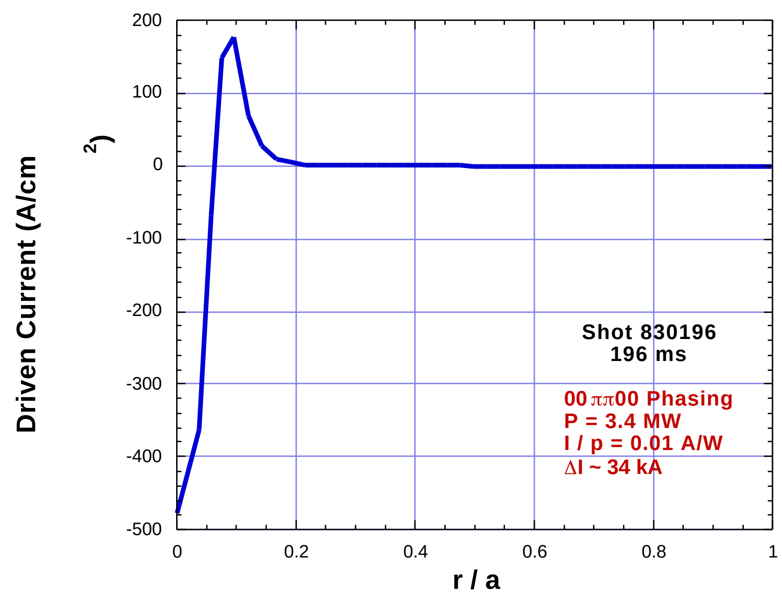


High Power, High Te Case (105830)

- In this case, P = 3.4 MW, T_{e0} = 3.5 keV
- Peaked T_e profile results in strong peaked deposition near axis.
- Ion absorption is not negligible: 9% to H and 4% to D.
- A small amount of net current is driven: 34 kA.







Status of CURRAY Ray Optics Code

- Implementation of CURRAY as an NTCC library module is on-going, in collaboration with Jim Wiley (UT).
  - Fortran90 compilable (done).
  - Replace IMSL routines with free library routines. (done)
  - Code consolidation and simplification -- in process.
  - Interface TRANSP via XPLASMA - near future.
  - APS/DPP poster paper in Long Beach.
- Implement hot plasma dispersion relation
  - On-going, but needs more time than expected.
- Coupling from antenna spectrum to initial rays:
  - Use approximate scheme so far; should benchmark results with full wave code.
- Benchmarking with HPRT and TORIC -- APS paper (Phillips).
- Code needs to be made more efficient !!

ST Theory Topics in HHFW Heating and Current Drive

- **Kinetic Analysis of HHFW Interaction with Ions in High-β ST Plasmas**

  - **Importance:** (1) Wave absorption by thermal ions, beam slowing-down ions and impurity hydrogen can impact power deposition profiles to electrons and ion species, and current drive efficiency in access to high β.
    (2) Insight can be gained in wave-alpha interaction physics.

  - **Why kinetic?** (1) Ion orbits in high-β ST geometry with $\rho_i \sim a$ deviate substantially from same flux surface requiring analysis beyond conventional bounce-averaged quasilinear Fokker Planck solution.

  - **Proposed Approach and Task:**

    (1) Develop analytic tool by coupling Monte-Carlo particle orbit code to wave code.

    (2) Key is to develop RF quasilinear diffusion operator for closely spaced harmonic resonances in the $k^2 \rho_i^2 >> 1$ regime.

    (3) Particle orbit code : ORBIT-RF (GA)
    Wave code : CURRAY (ray tracing) or AORSA/TORIC (full wave).

    (4) Medium to Long-Term Project