Recent Results of HHFW CD Modeling Using CURRAY

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NSTX Results and Theory Review
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OUTLINE

- Modeling results for some recent discharges, with $\Delta\phi$ = -90^o, +90^o, symmetric, and +45^o antenna phase difference..
- The CURRAY ray tracing code
- Validity of empirical j/p formula
- Summary and discussions

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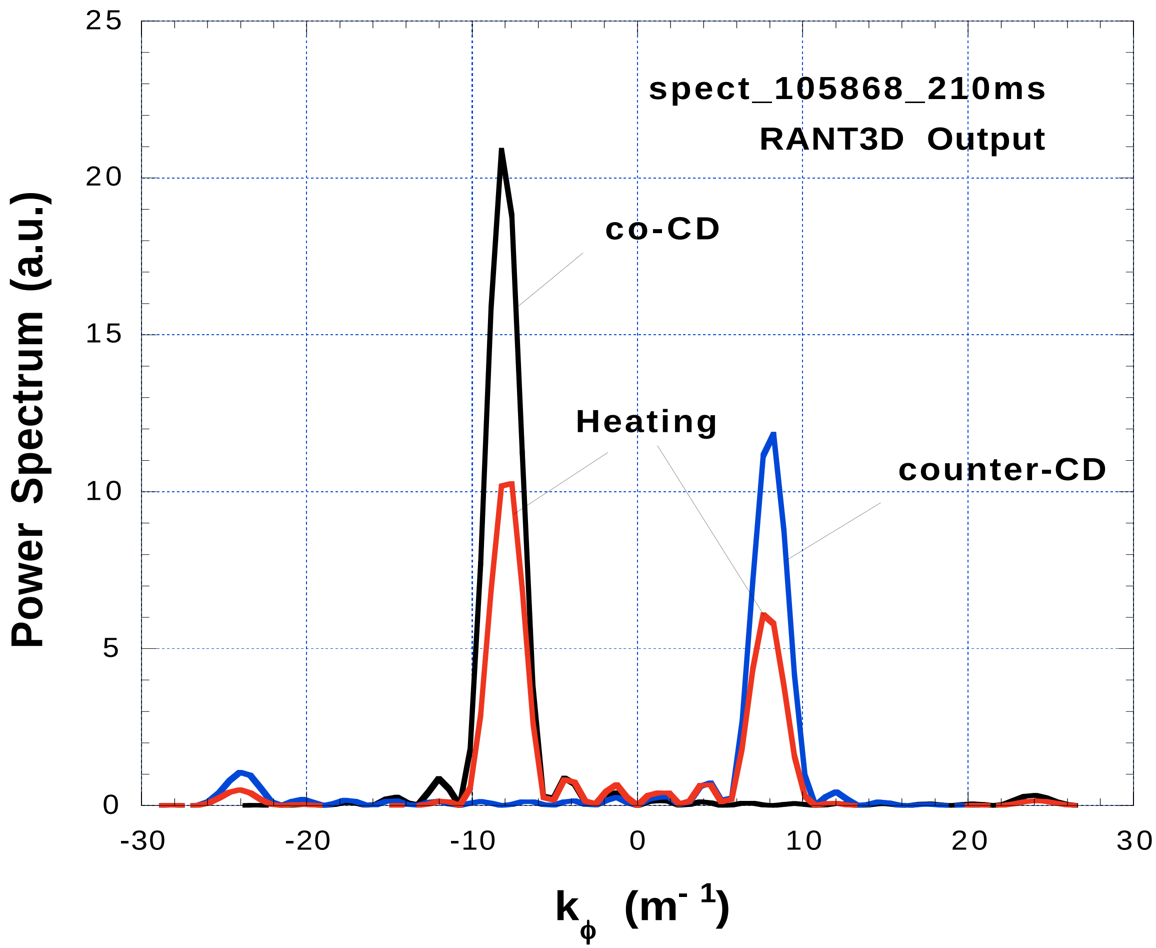
Recent Cases for 3 Antenna Phasing have been Examined

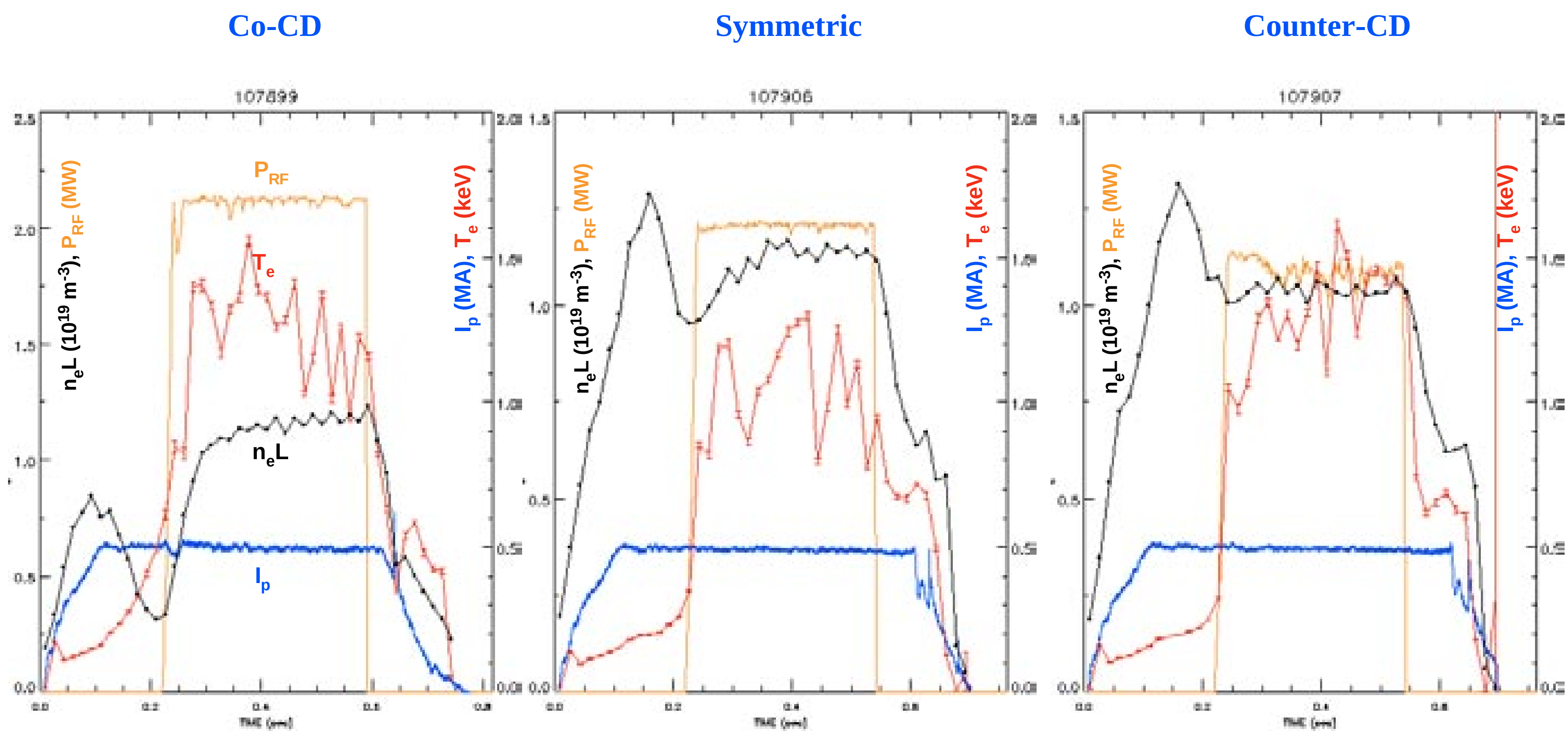
- Heating : 00ππ00 phasing ; Spectrum peaks at $k_\phi = \pm 8\ m^{-1}$, m = 1
- Co-CD : $\Delta\theta = -\pi/2$; peaks at $k_\phi = -8\ m^{-1}$, m = 1
- Counter-CD $\Delta\theta = +\pi/2$; peaks at $k_\phi = +8\ m^{-1}$, m = 1

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



Time History Comparison

(from P. Ryan)



(Note axis scale change for P_{RF} and n_eL for shot 107899)

5 time slices are studied in each discharge.

CURRAY Calculational Model

- The launched spectrum is represented by 11-110 rays:

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

- Dispersion relation is hot electron and cold ion. [Ono, Phys. Plasmas **2** (1995) 4075]

  Damping is linear on Maxwellian species and includes hot plasma effects to all orders in $k_\perp \rho_i$, using $k_\perp$ determined locally via an order reduction scheme.

- Current drive is calculated using the adjoint technique valid for tight aspect ratios.
  [Chiu, et al., *Nucl. Fusion* **37**, 1515 (1997)]

- Density and temperature profiles are from MDS+ tree, assuming $T_i = T_e$. EQDSK equilibrium files from EFIT to experimental data are used.

- For simplicity, Z_{eff} is assumed to be 3.25 based on analysis of Soukhanovskii. Only carbon and Cu impurities are included :
  $f_D = 0.9310$ $f_H = 0.0465$ $f_C = 0.02$ $f_{Cu} = 0.0025$.

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Summary of Analysis Results

Shot	Time(ms)	Ip(kA)	I_{bs}(kA)	P_{rf}(MW)	I_{rf}(kA)	$\gamma_{cd}(10^{18} A/W/m^2)$
107899 (C0-CD)	253	476	24	1.9	154	0.29
	325	500	66	2.1	145	0.39
	391	492	97	2.1	162	0.45
	451	493	71	2.1	151	0.44
	511	494	70	2.1	146	0.41
107907 (counter -CD)	253	498	44	1.1	-81	-0.36
	325	492	61	1.1	-81	-0.51
	391	494	58	1.1	-79	-0.38
	451	490	59	1.1	-73	-0.34
	511	490	59	1.1	-75	-0.36
107906 (heating)	253	492	38	1.2	9	0.038
	325	490	39	1.2	11	0.045
	391	490	67	1.2	14	0.066
	451	490	57	1.2	9	0.042
	511	487	55	1.2	8	0.037

In all shots, electron absorbs almost all wave energy, 96 - 100%

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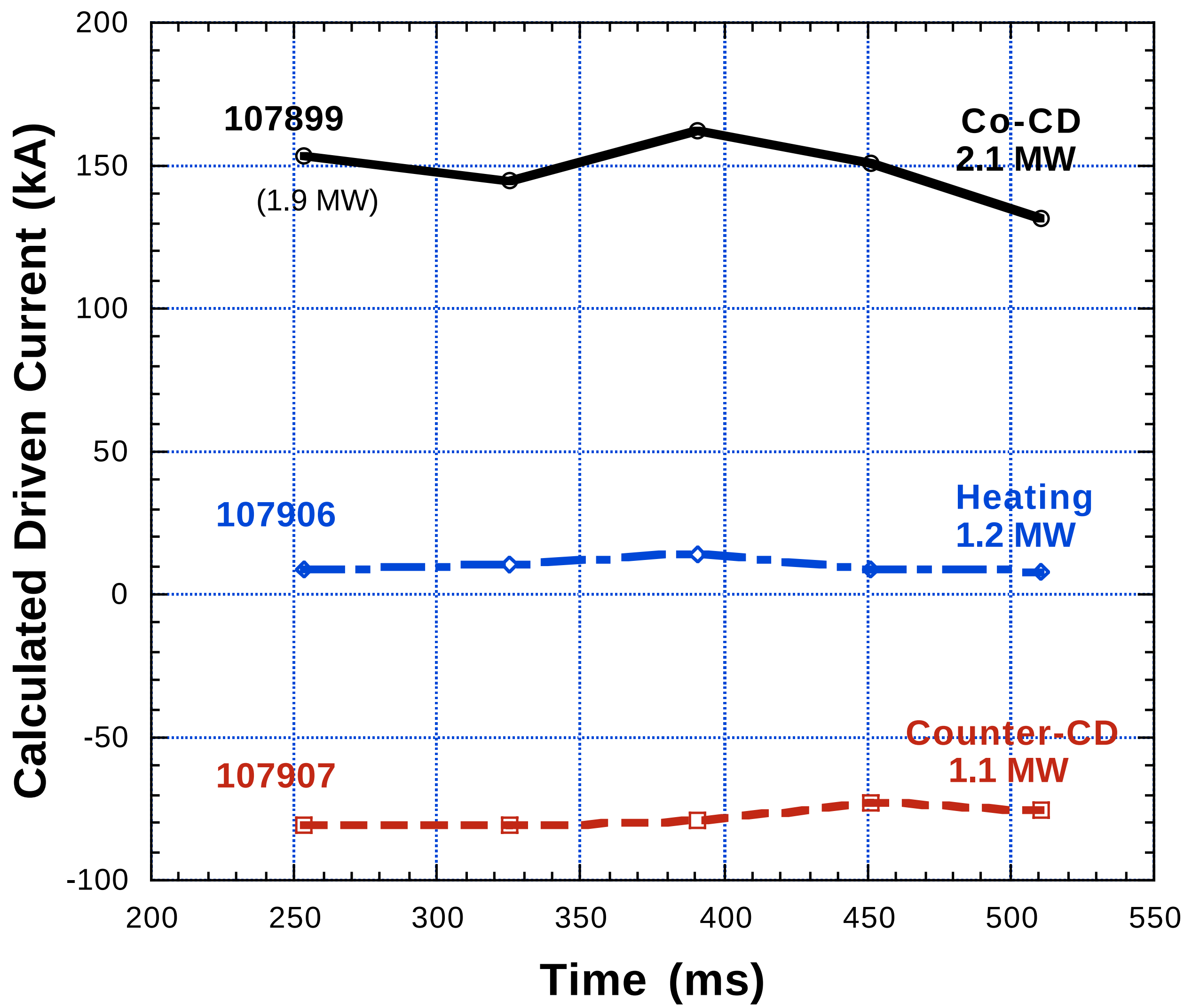
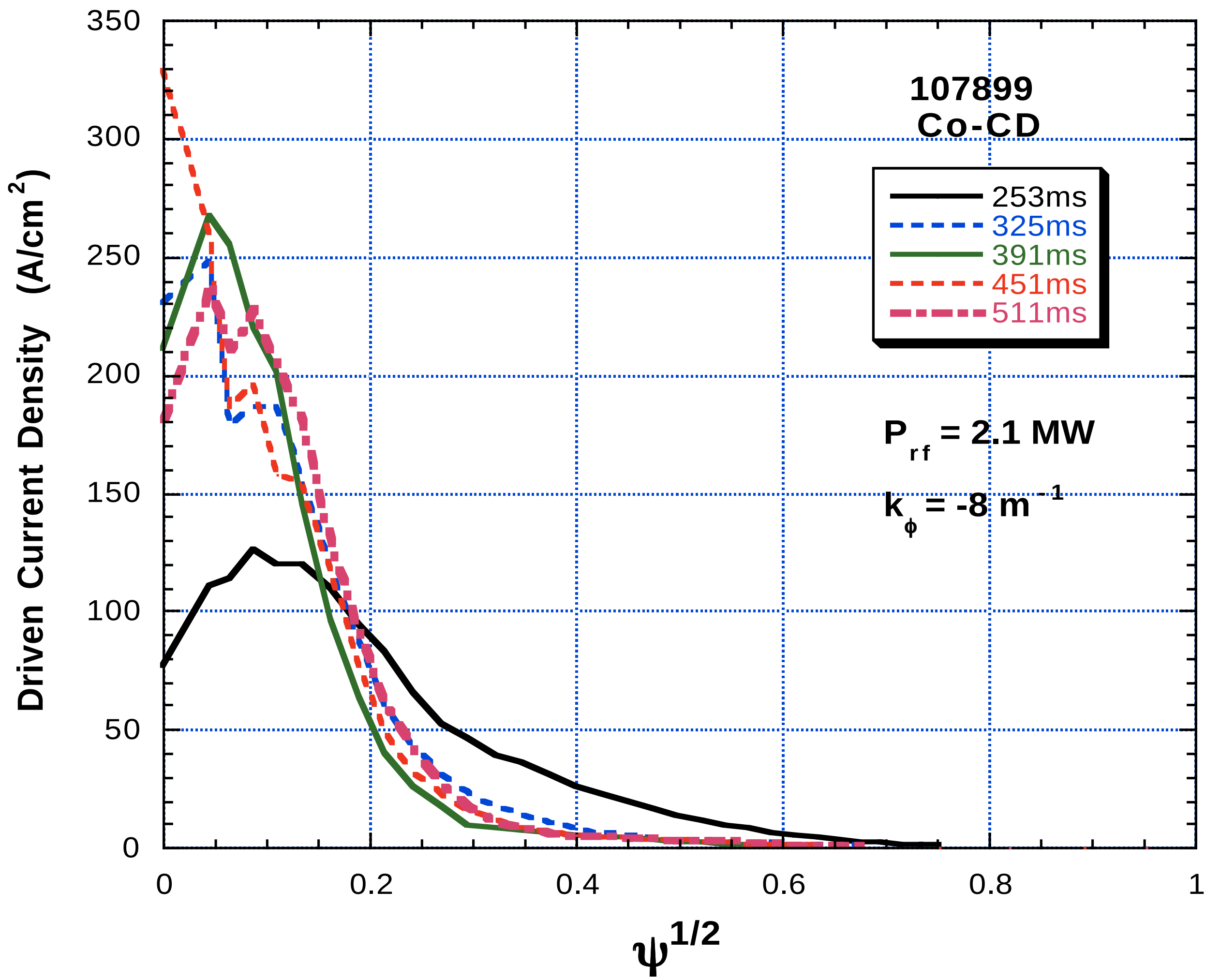
Calculated Time History of Driven Current



Driven Current Density Profiles are Peaked on Axis for Co-CD Case : Shot 107899



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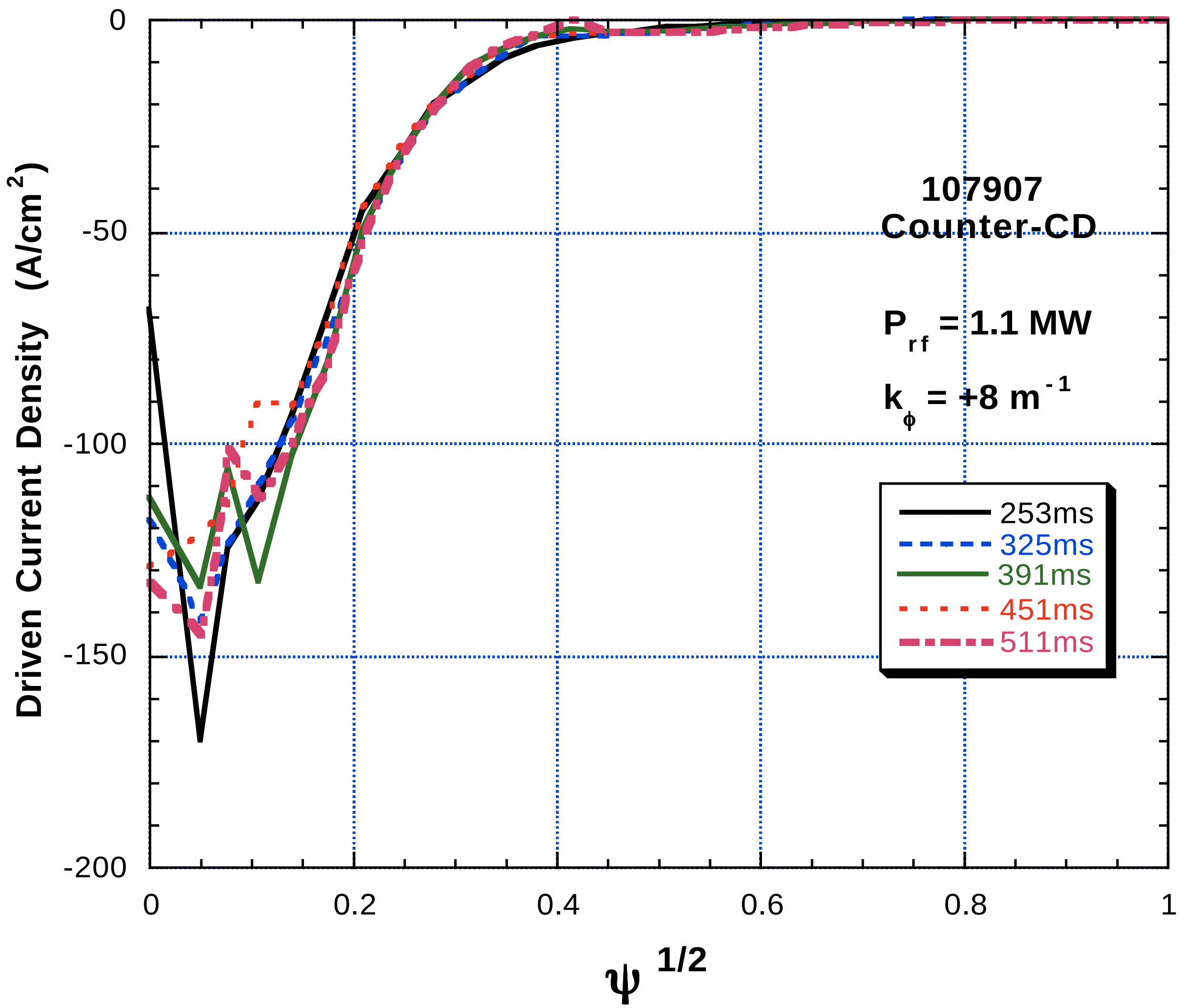
Driven Current Density Profiles Peaked on Axis for Counter-CD Case : Shot 107907



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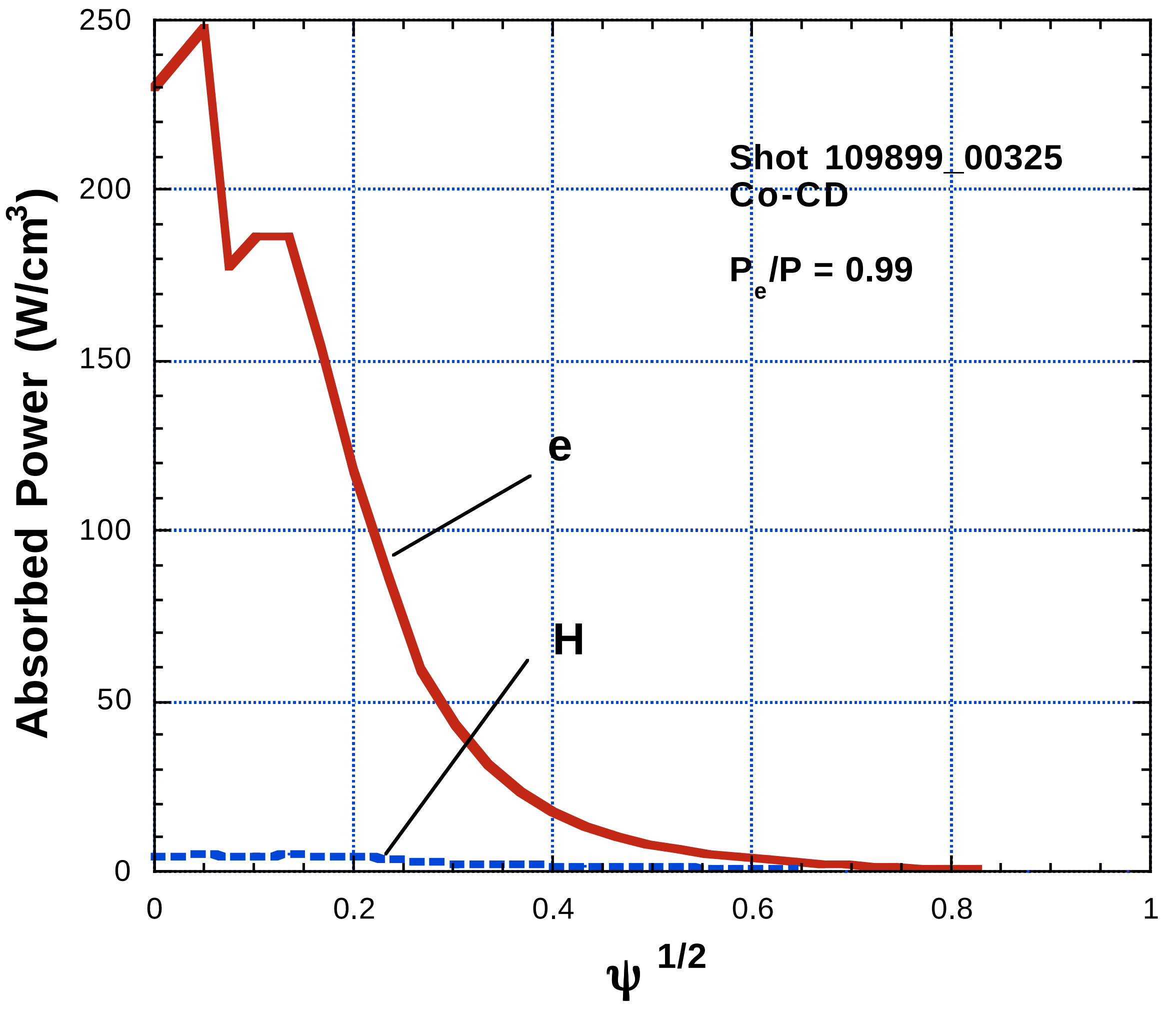
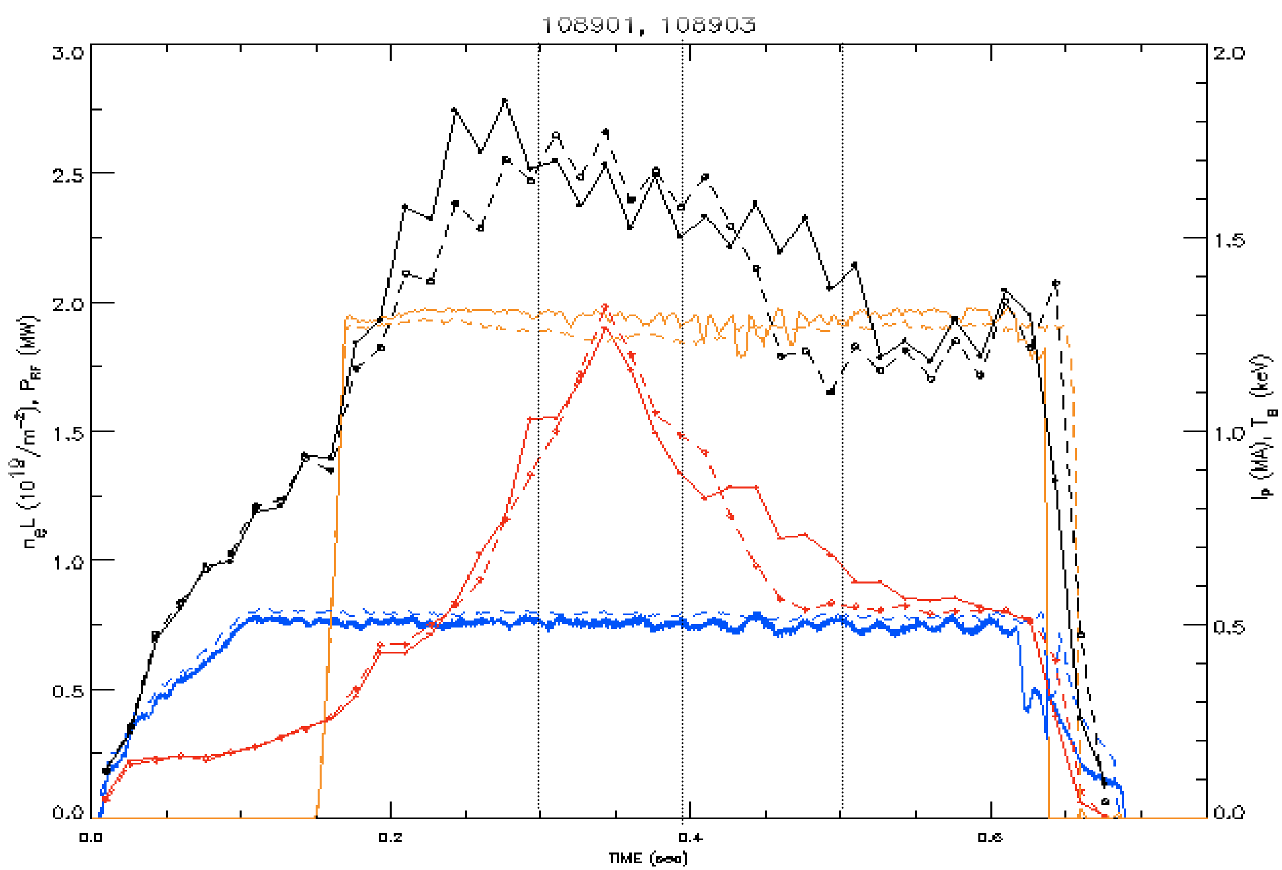
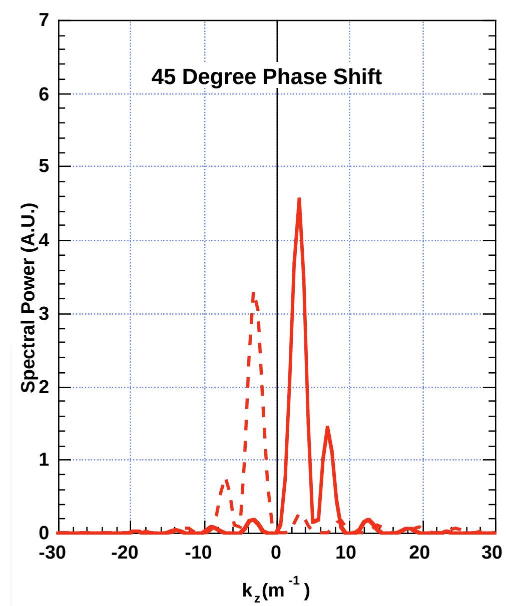
Example of Calculated Wave Absorption Profile



Analysis of Discharge with 45° Phase Shift

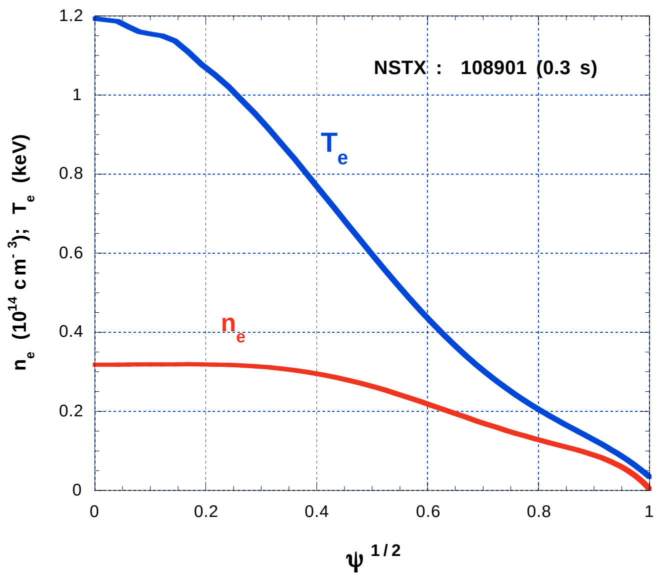
- Shot 108901with counter-CD phasing was analyzed at 0.3 s, 0.4 s, and 0.5 s.
- Assume $T_e = T_i$, and $Z_{eff} = 3.25$ as before

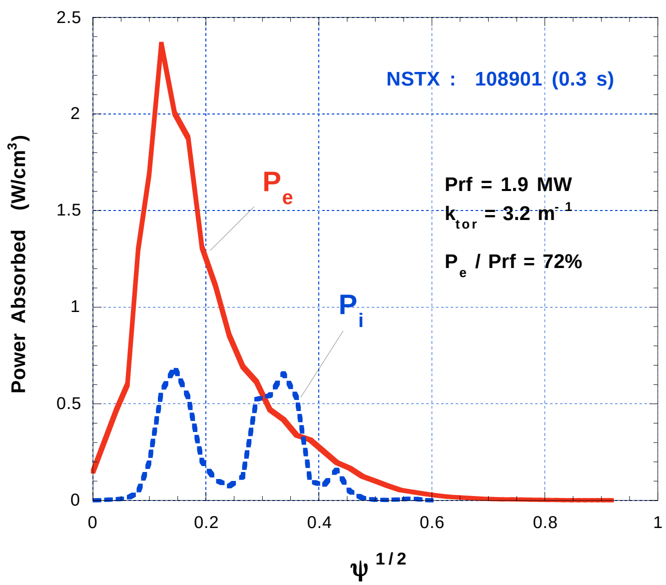




- For Cntr-CD phasing, $k_\phi = 3.2\ m^{-1}$ (m=0) Directivity = 0.76.
- 25 rays are used to model the spectrum.

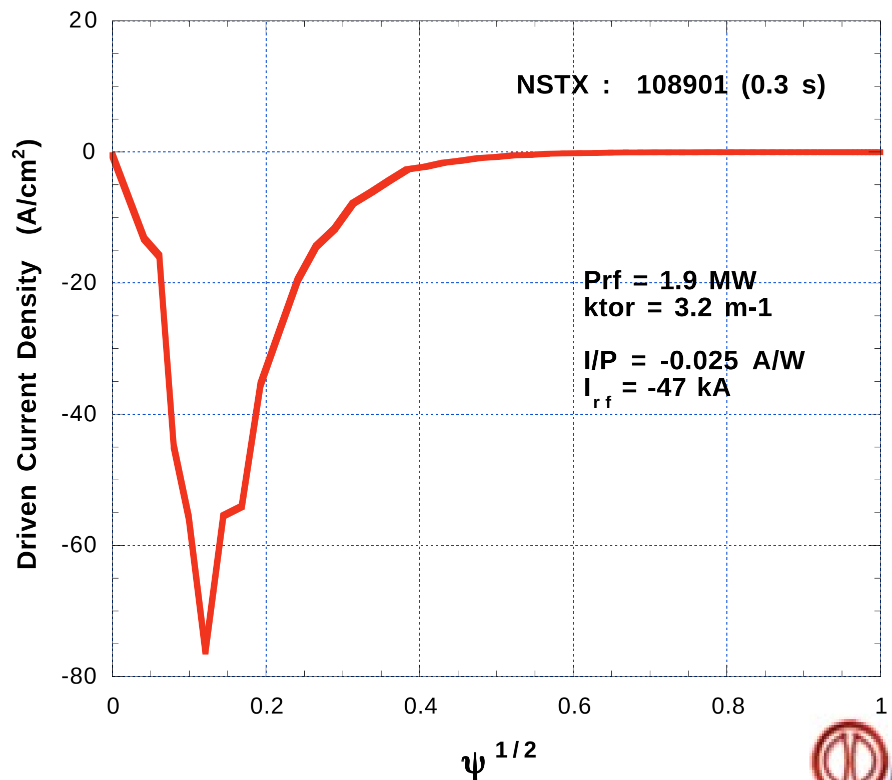
Results of CURRAY Analysis for Shot 108901





- Calculated driven currents are 47, 51, and 47 kA with 1.9 MW at 0.3, 0.4, and 0.5 sec.
- There is significant ion heating due to 4.5% of hydrogen.

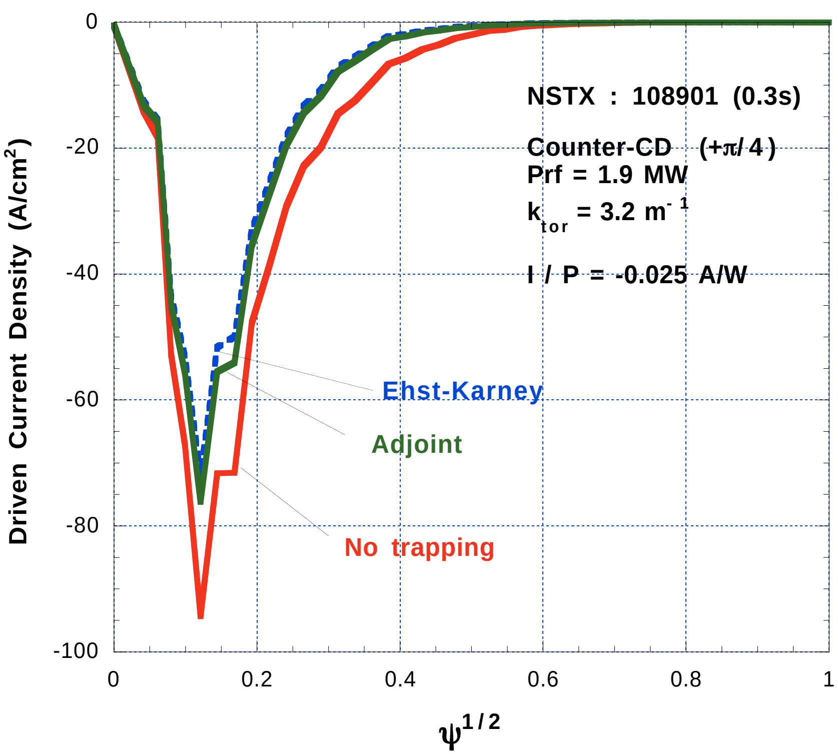
  P_i/P = 0.28, 0.18, 0.19 @ 0.3, 0.4, 0.5 s.

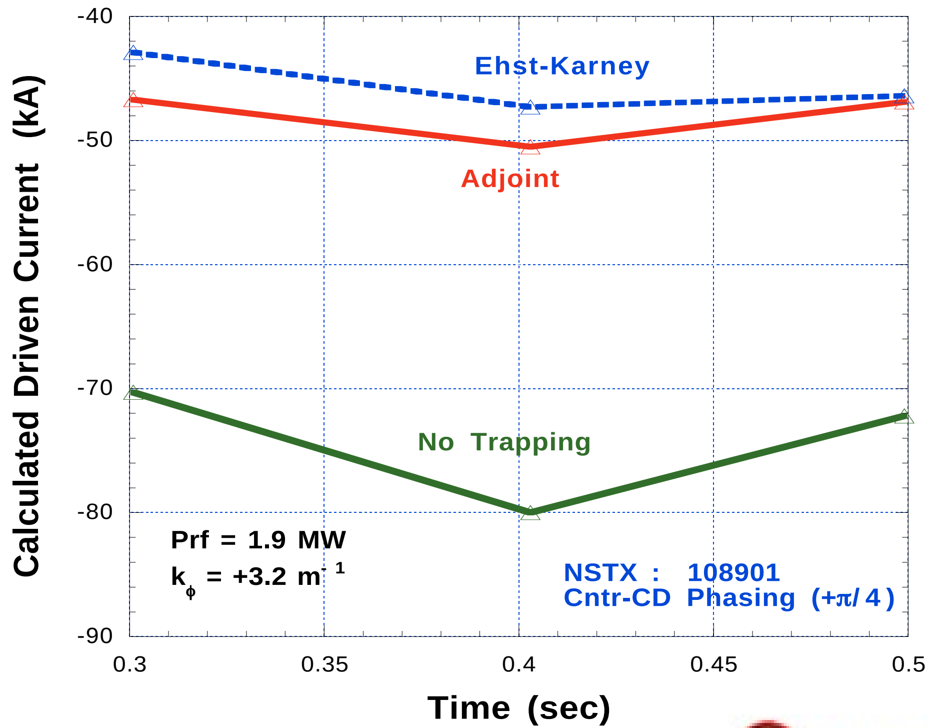


Model Dependence of Calculated Driven Current

- In this range of parameters ($\beta \sim 2\%$), and when current is driven close to the axis, Ehst-Karney formula appears to be a good approximation.

- The trapping effect is quite significant, accounting for 30-40% reduction from the current if no trapping is accounted for.





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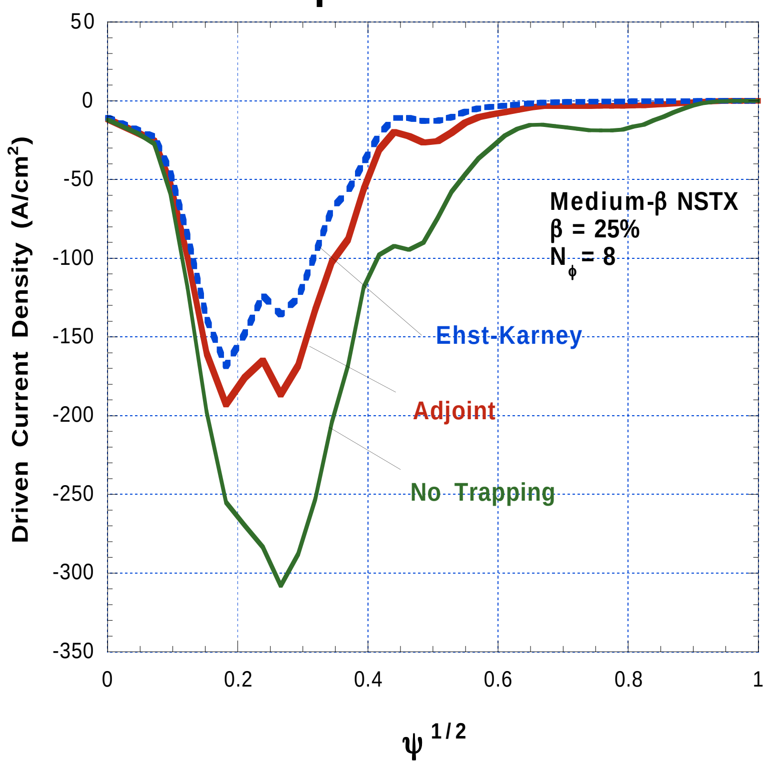
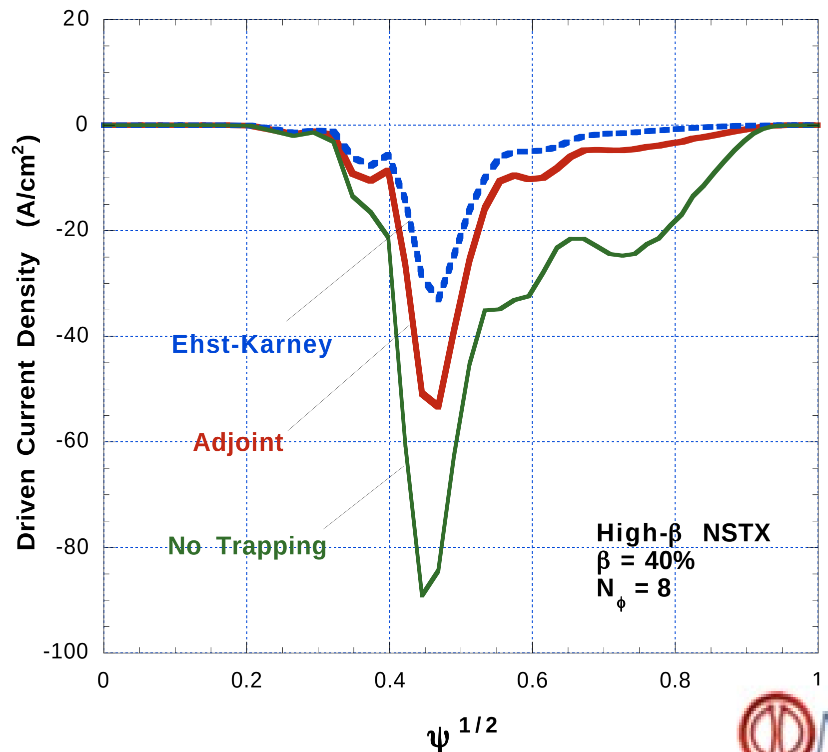
At High β, I/P Must be Evaluated by Adjoint Technique

- At present experiments, β ~ a few %, and the current is driven mostly near the magnetic axis. ⟶ Ehst-Karney j/p formula is adequate.
- As the experiment proceeds to higher β ~ 25-40%, E-K formula under-estimates driven current considerably. ⟶ Adjoint technique is needed.
- Trapping effect becomes stronger at high β as current is driven off axis.

β=25%



β=40%



Summary and Discussions

- HHFW driven current and profiles were evaluated for several recent discharges with co- and counter-CD, and symmetric antenna phasing. A most recent case with $\Delta\phi=+45^o$ has also been examined.

- It was calculated that ~ 150 kA are driven with 2 MW in the co-CD case. while ~40 kA are driven with 1 MW in the cntr-CD case. Practically, no current is driven (~10 kA) in the symmetric phase case. Profiles are all centrally peaked, and only a few % of power is absorbed by ions (H).

- In the $\Delta\phi=+45^o$ case, ~48 kA are driven with ~2 MW. The lower k_ϕ results in ~20% power absorbed by H, and the driven current is slightly off- axis.

- The Ehst-Karney j/p empirical formula is approximately valid in the present low-β regime when compared with the adjoint results. In the 25-40% β-range, the adjoint method must be used.

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Summary and Discussions (cont'd)

- The trapping effect on the CD efficiency is quite strong. Up to 30-40% degradation is calculated for the present operating regime.
- The calculated driven current is high compared to other estimates from experimental data. Effects such as transient reverse DC electric field and other possible causes for this discrepancy will be investigated.
- Progress has been made in coupling CURRAY to TRANSP analysis code last month. A working version of the combined code will be tested in the near future.

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