HHFW Phased Array Operation

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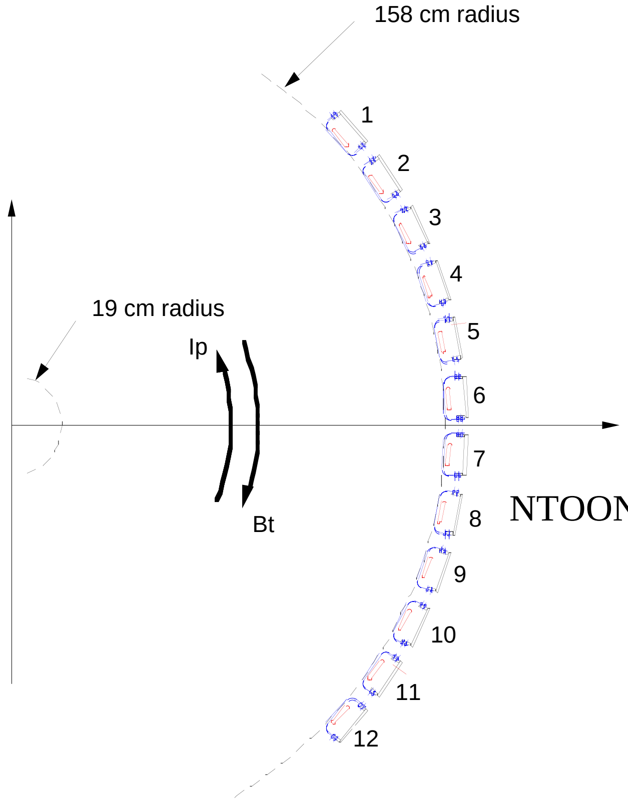
And the NSTX Team

NSTX Results Review
PPPL
September 18, 2001

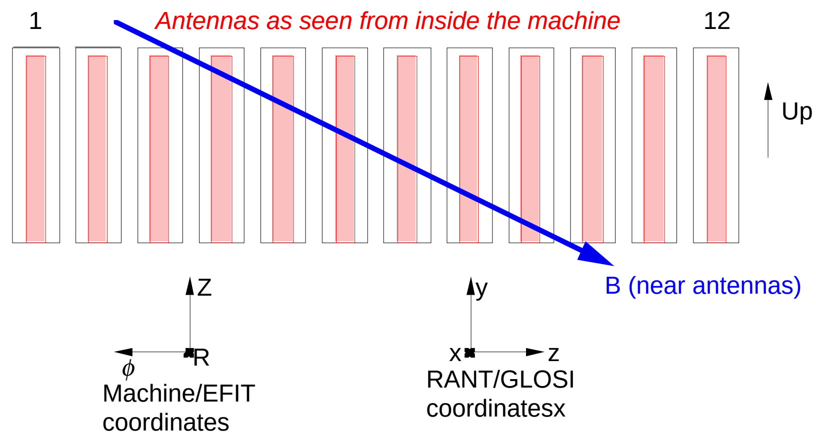
XP-15: HHFW CD/Phasing studies

- He, 0.45 T, single-null divertor, low current (~370 kA), antenna-plasma gap ~ 5 cm.
- July 13 (105860-884, 105892-93)
  - 200 ms, 2.7-3.2 MW rf pulses.
  - Phasing for fast phase velocity ($k_z \sim 8\ m^{-1}$) heating, co-, and counter-CD.
  - Two lower-power (1-1.9 MW), long pulse (400 ms) co-CD shots
- July 25 planned experiments encountered power outages.
- July 30 attempted a few shots (unsuccessful)

Array numbering, phase and coordinate conventions



NSTX HHFW Antennas



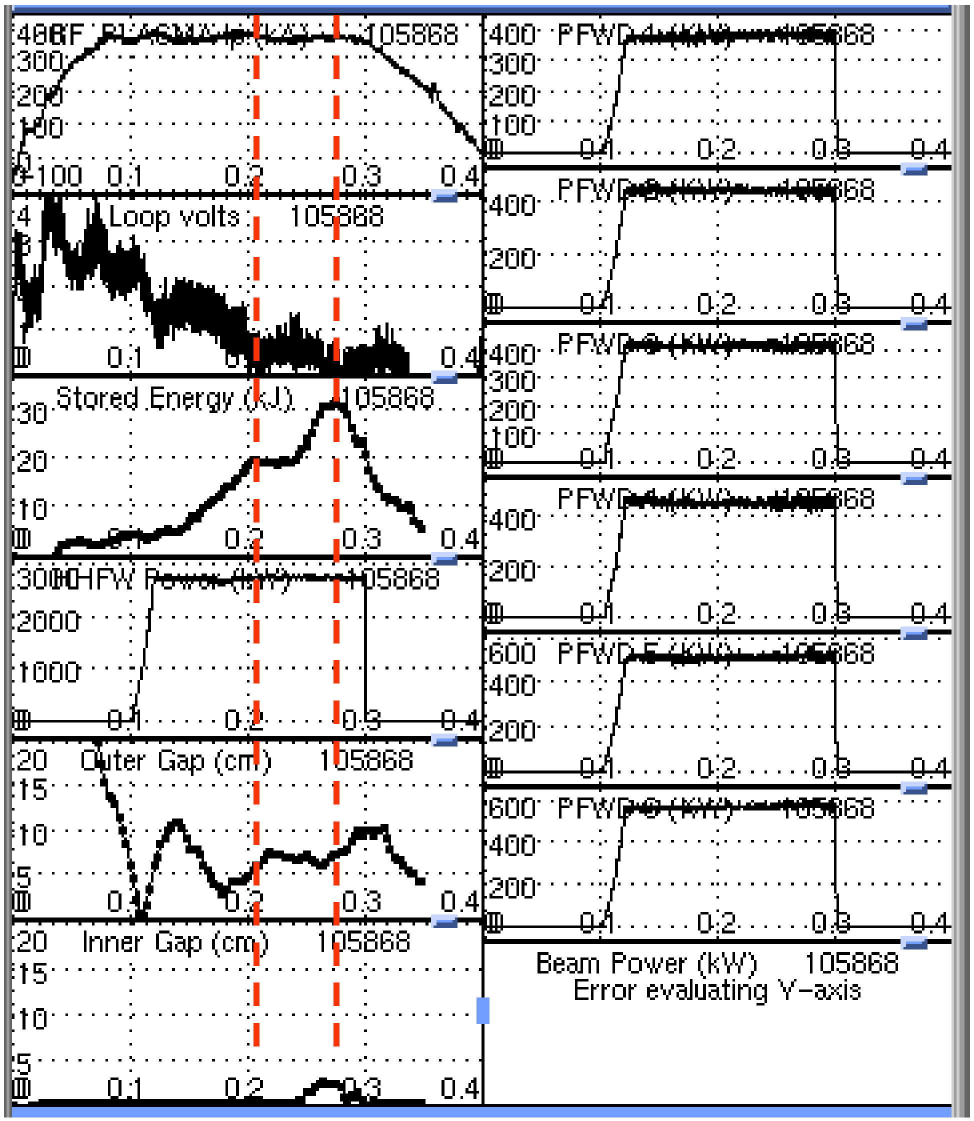
NTOONS phase convention: $V_{i+1} = V_i exp(+j(\omega t-(\theta_{i+1}- \theta_i)) \sim exp(+j(\omega t-k_\phi \phi))$

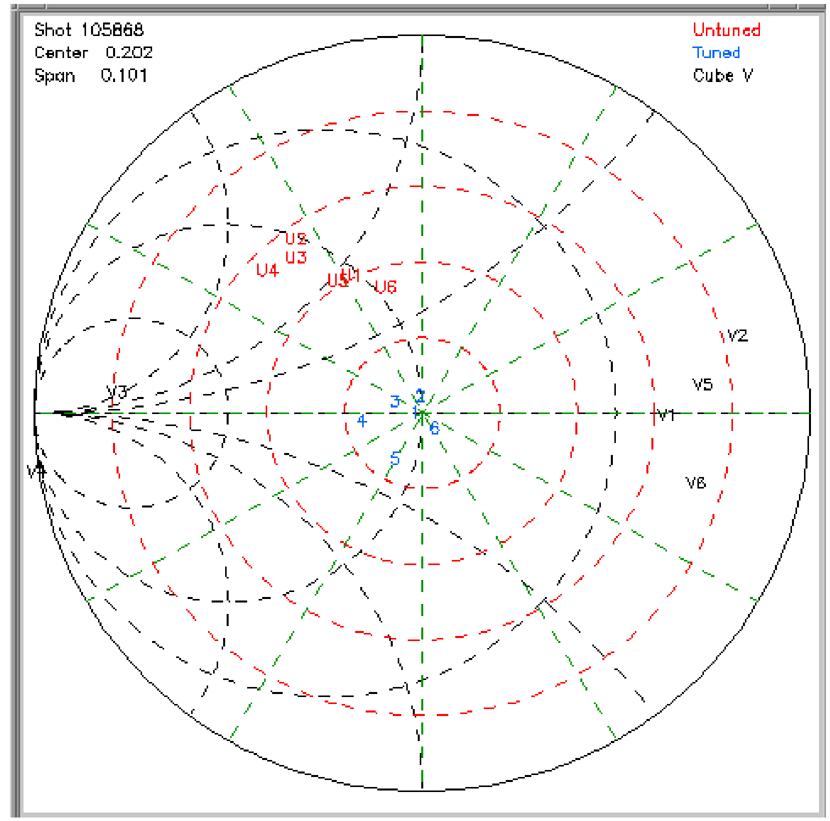
$\Delta\theta = \theta_{i+1}- \theta_i > 0$ → Wave travels in $+\phi$ direction, driving electrons in $+\phi$ direction, hence current in $-\phi$ direction.

$\Delta\theta > 0$ is counter-CD phasing
$\Delta\theta < 0$ is co-CD phasing

Note: RANT/GLOSI uses $exp(-i(\omega t-(\theta_{i+1}- \theta_i)) \sim exp(-i(\omega t-k_z z))$ phase convention, opposite of NTOONS.

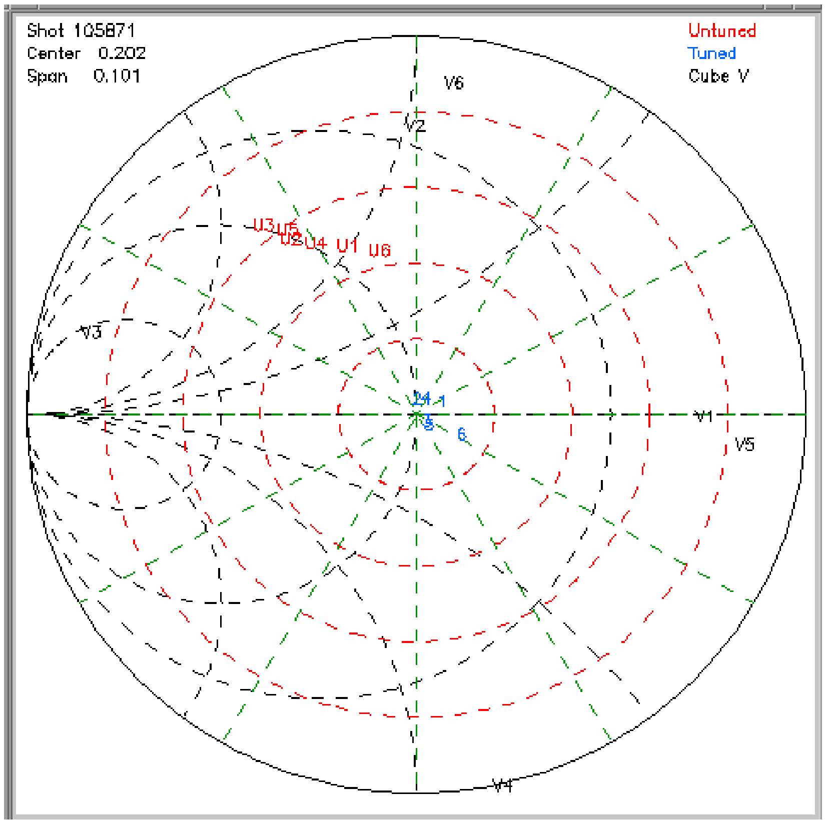
Symmetric Heating (00ππ00) shot 105868
Currently using this shot to analyze ALL phasings



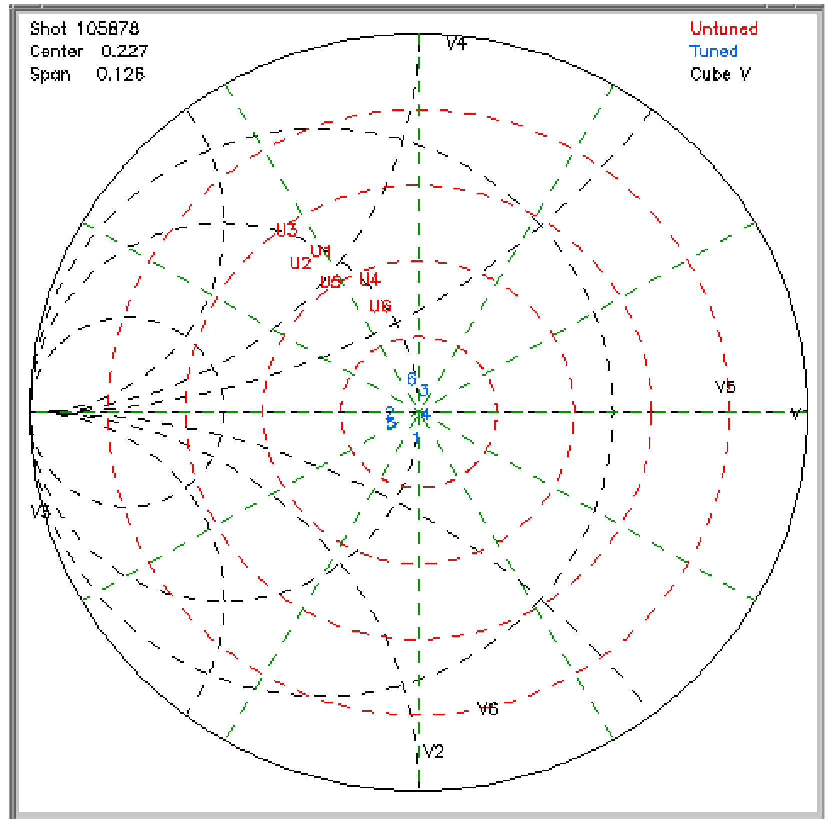


Array phasing for CD shots

105871 +π/2 **phasing (Counter-CD)**



105878 –π/2 **phasing (Co-CD)**



HHFW Phased Operation

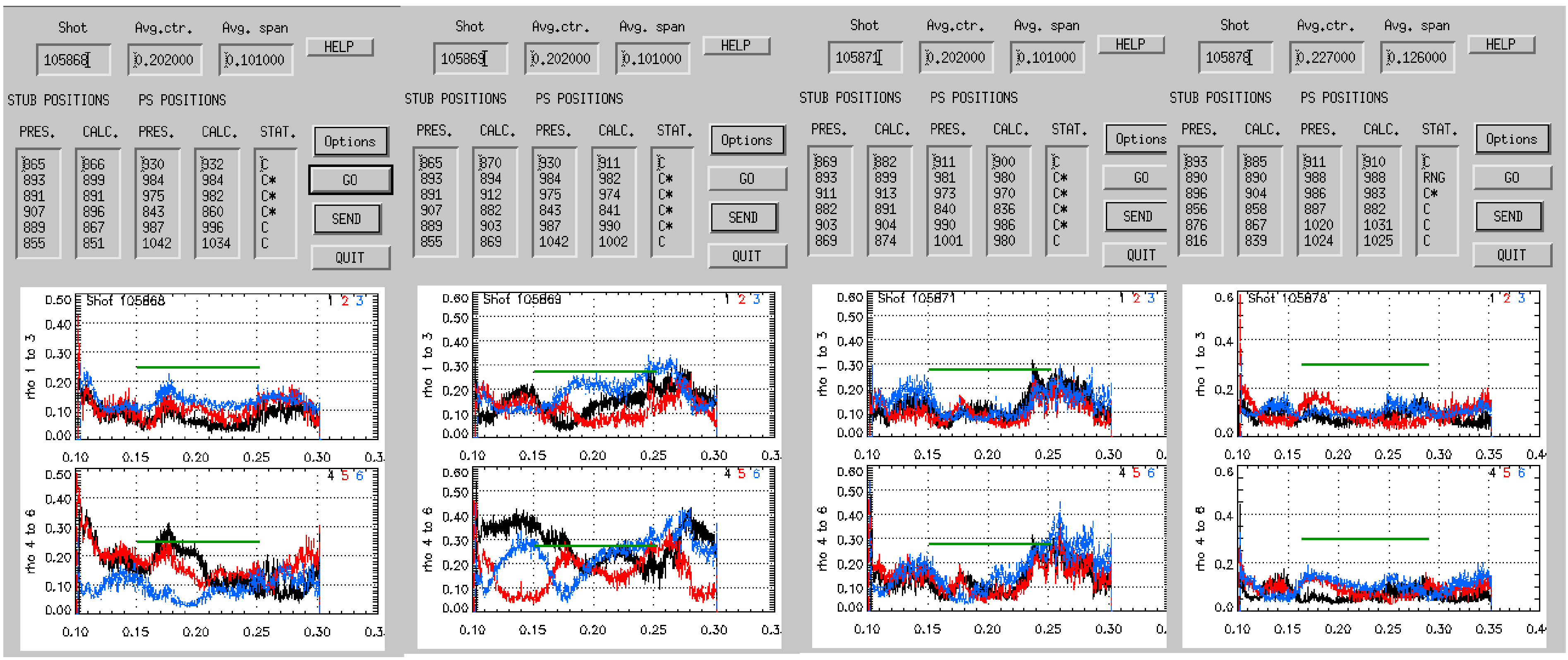
- **Phasings of** $00\pi\pi00$, $+\pi/2$, **and** $-\pi/2$ **have the same spectral peaks and hence similar loading.**

- **Maintaining a match while switching between these three phasings was not a problem.**

- **Maintaining constant plasma conditions for long pulses was more difficult.**

Transmitter load changes somewhat with phase, but adequate match could be maintained for full pulse at 2.7 MW.

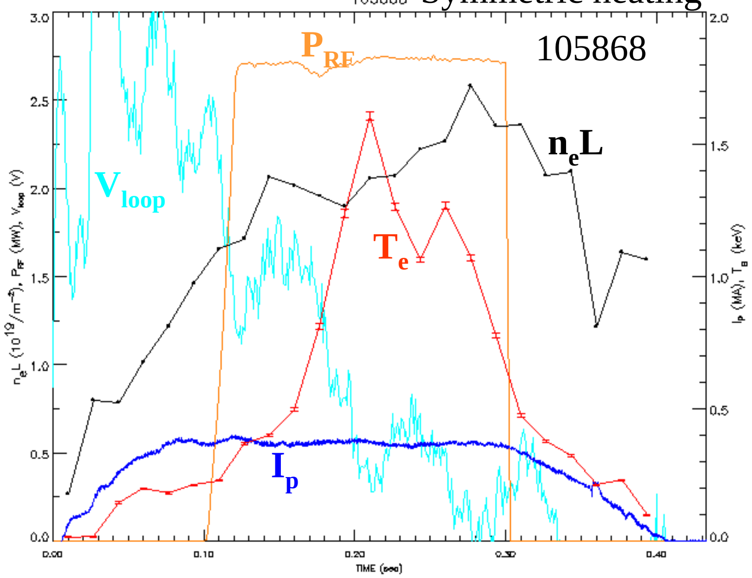
0–0–π–π–0–0 phasing	+π/2 phase shift.	+π/2 phase shift.	−π/2 phase shift.
Good match.	**Match worsens.**	**Match readjusted.**	**Match adjusted slightly.**



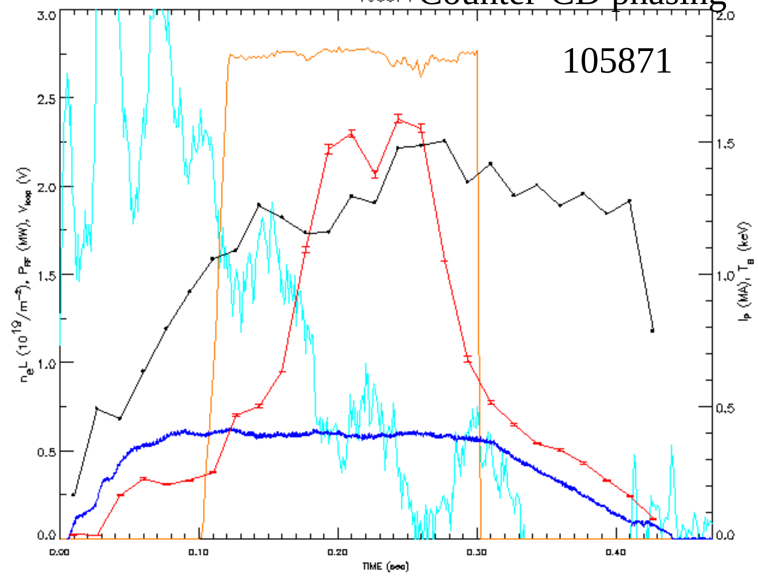
Note that spectral peaks occur at same k_z for all phasings.

Did we see any current drive?

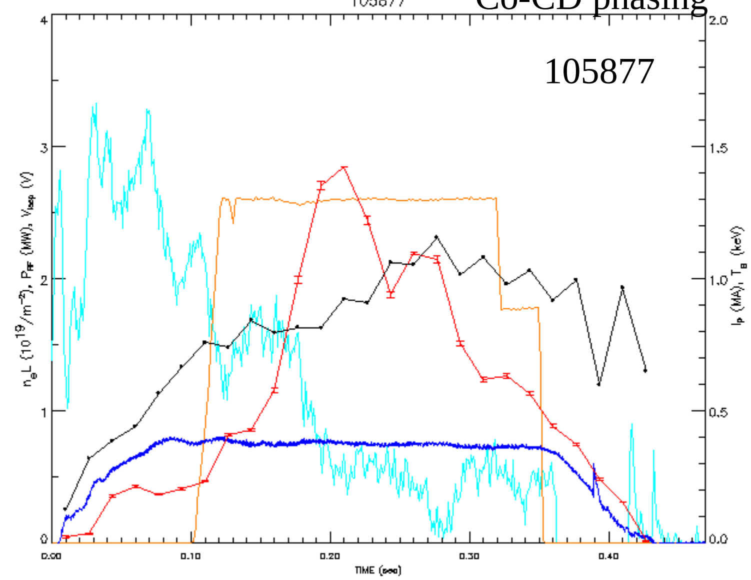
105868 Symmetric heating



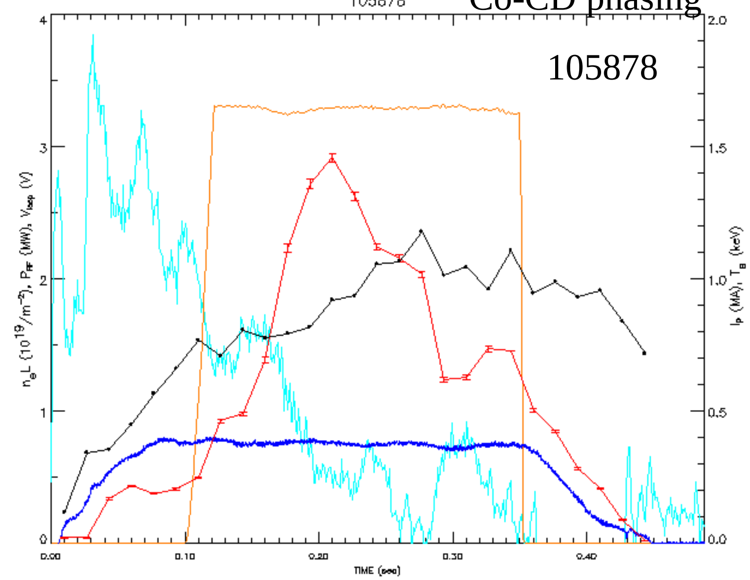
105871 Counter-CD phasing



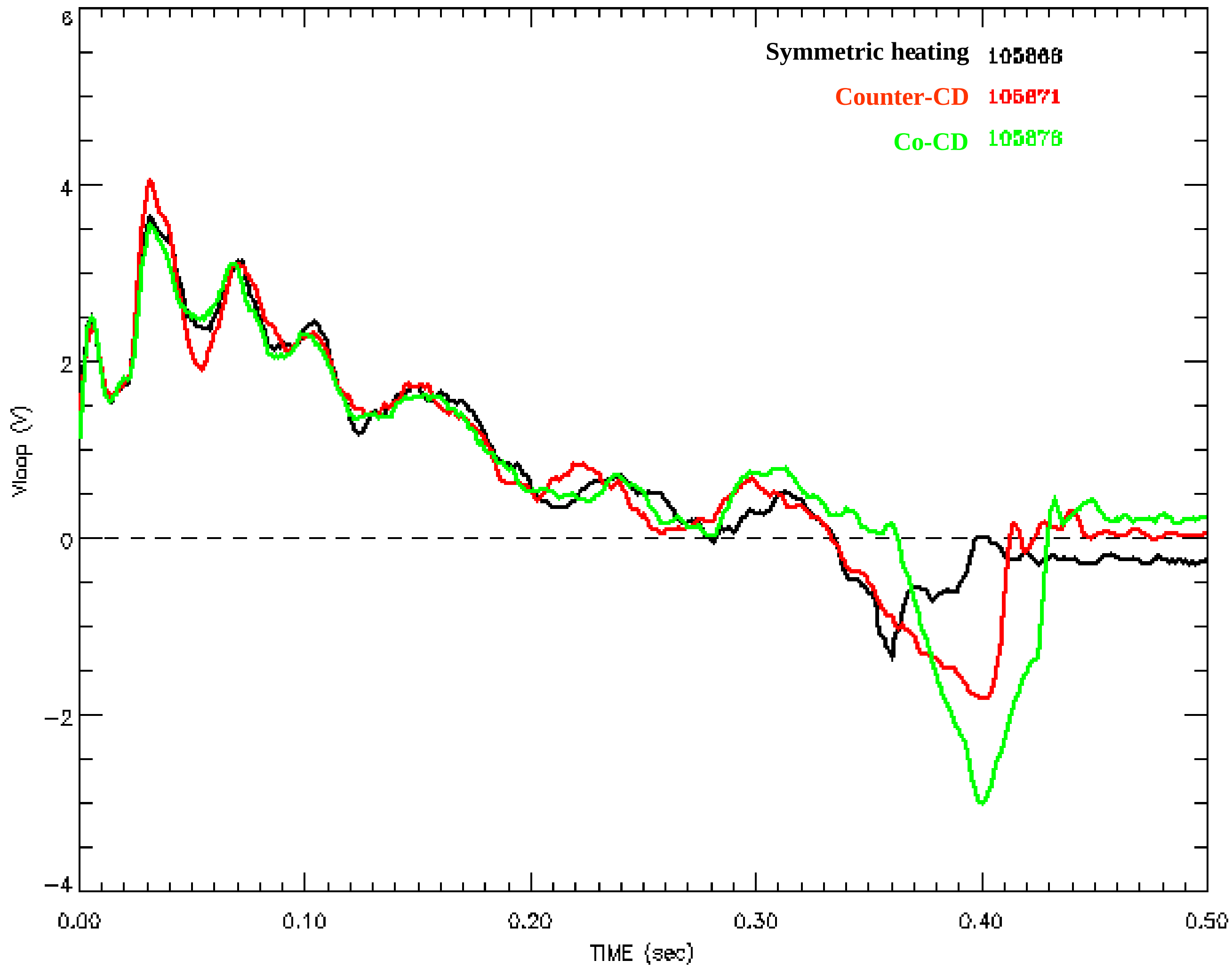
105877 Co-CD phasing



105878 Co-CD phasing



Observe no reponse in the loop voltage when the wave spectrum directional is changed



Results of simple 1-D CD and power balance calculation to compute behavior of profiles, loop volts, temperature with time

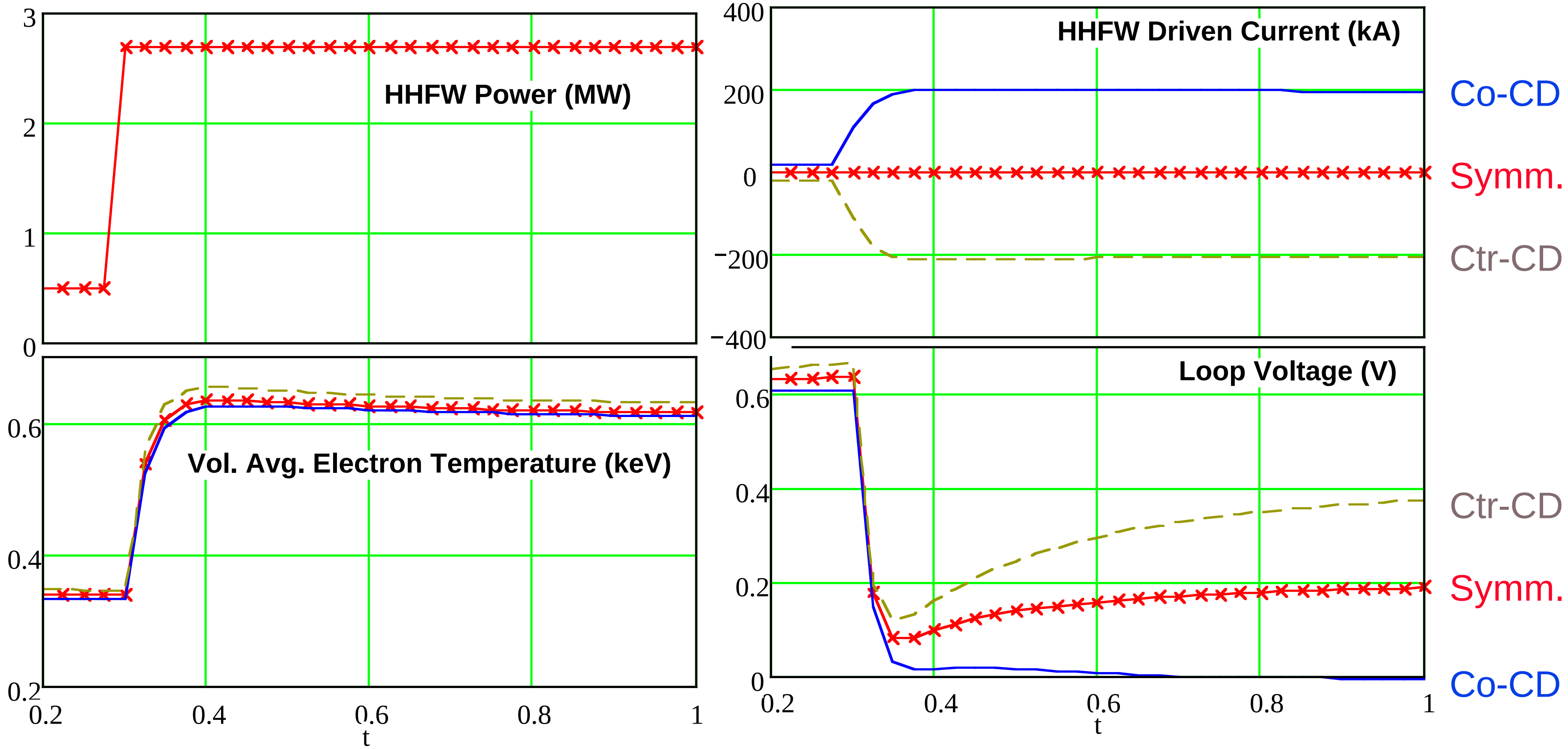
- **Lots of simplifying assumptions:**
  - $Z_{eff} = 2.4$
  - **Fixed density,with profile** $\alpha_n = 0.5$
  - **Fixed temperature *profile*** $\alpha_T = 3$
  - **Temperature *value* determined by power balance**
  - **ITER 89P scaling, H = 2. For 3 MW input, gives** $\tau_E \approx 27$ **ms,** $T_0 \approx 1.9$ **keV**
  - **Lots of large aspect ratio approximations**
  - **Ehst CD approximate formulas, gives** $I_{HHFW} \approx 200$ **kA**

•For $I_p = 400$ **kA, steady-state solutions for co-CD, counter-CD, and symmetric phasing are:**

•	Co	Ctr	Symm.
•I_{cd} =	200 kA	-200 kA	0 kA
•I_{bs} =	160 kA	180 kA	170 kA
•I_{oh} =	40 kA	420 kA	240 kA
•V_{loop} =	0 V	0.7 V	0.2 V

Response of system with time

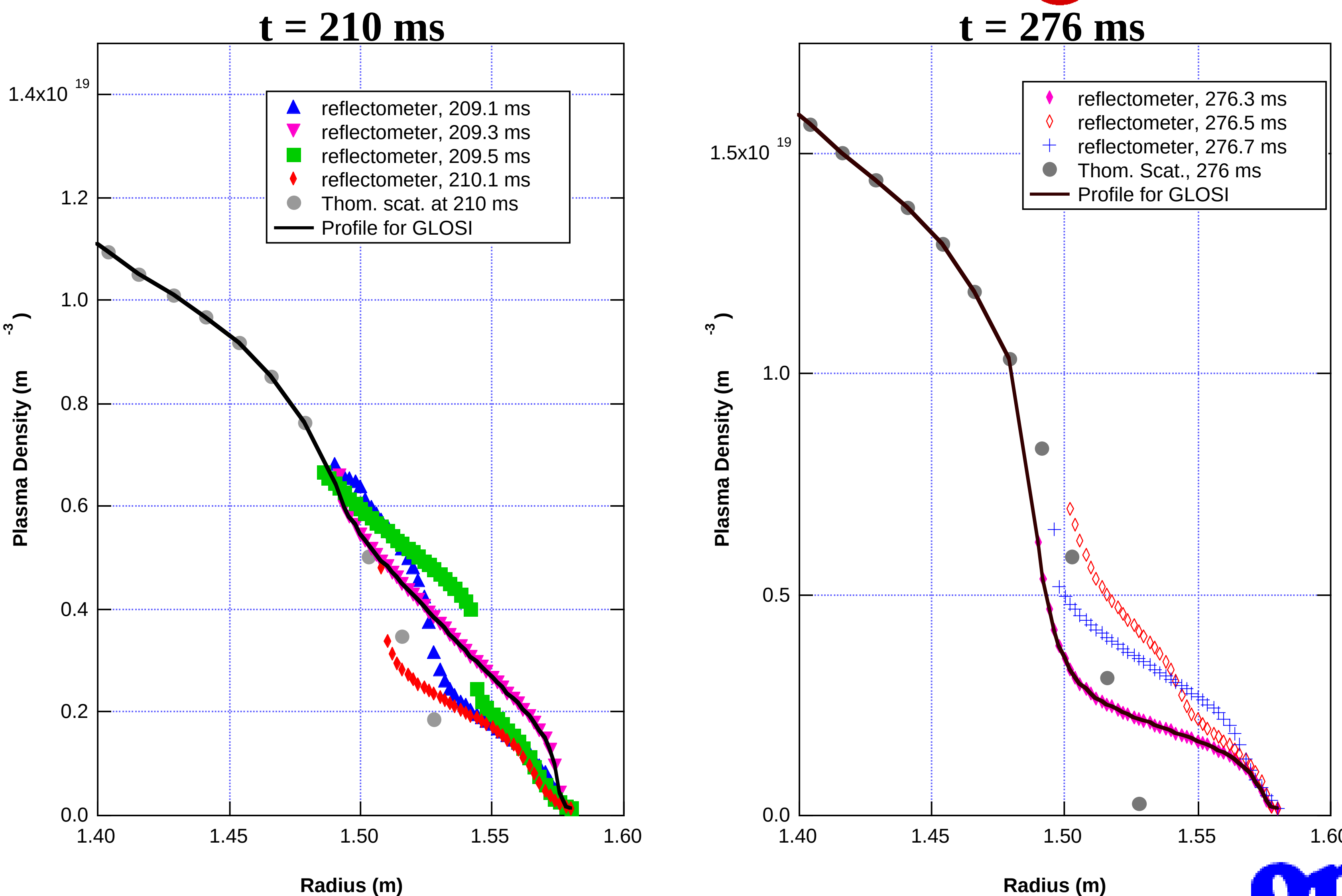
- Application of HHFW power increases temperature in ≈ 60 ms
- Loop volts drop quickly due to decreased plasma resistance
- Loop voltage changes significantly in ≈ 200 ms as current profile equilibrates



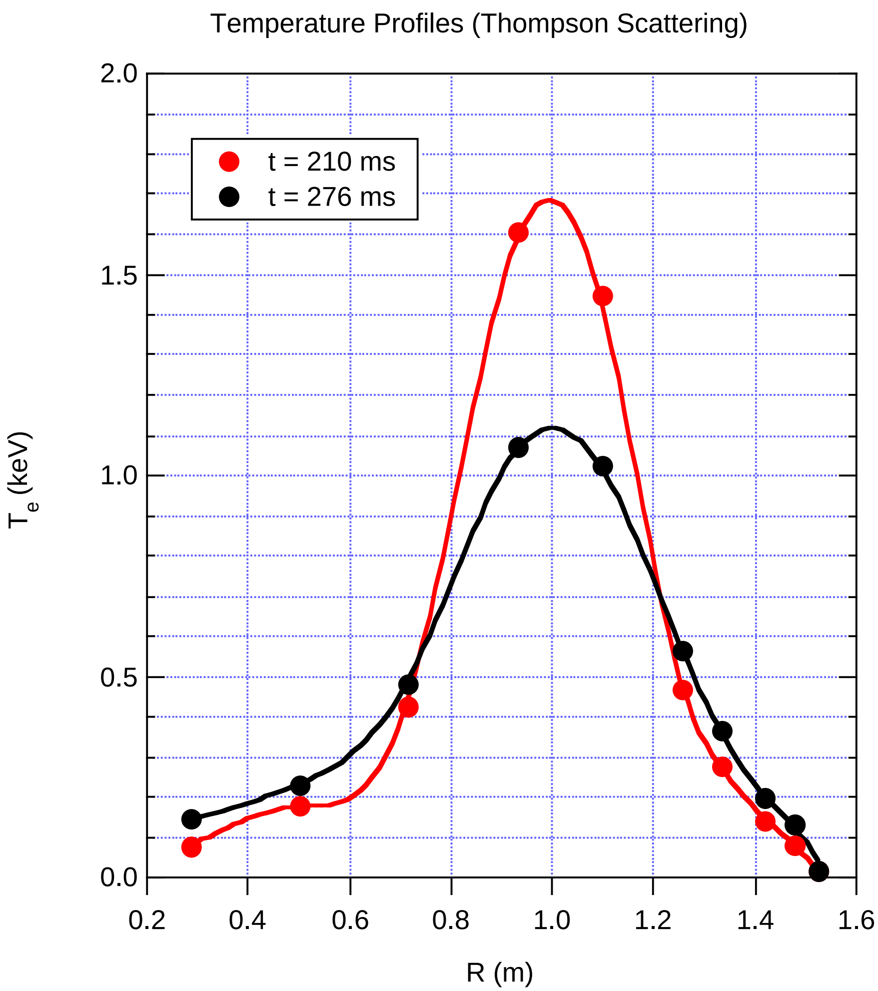
Analysis/Modeling of CD operations

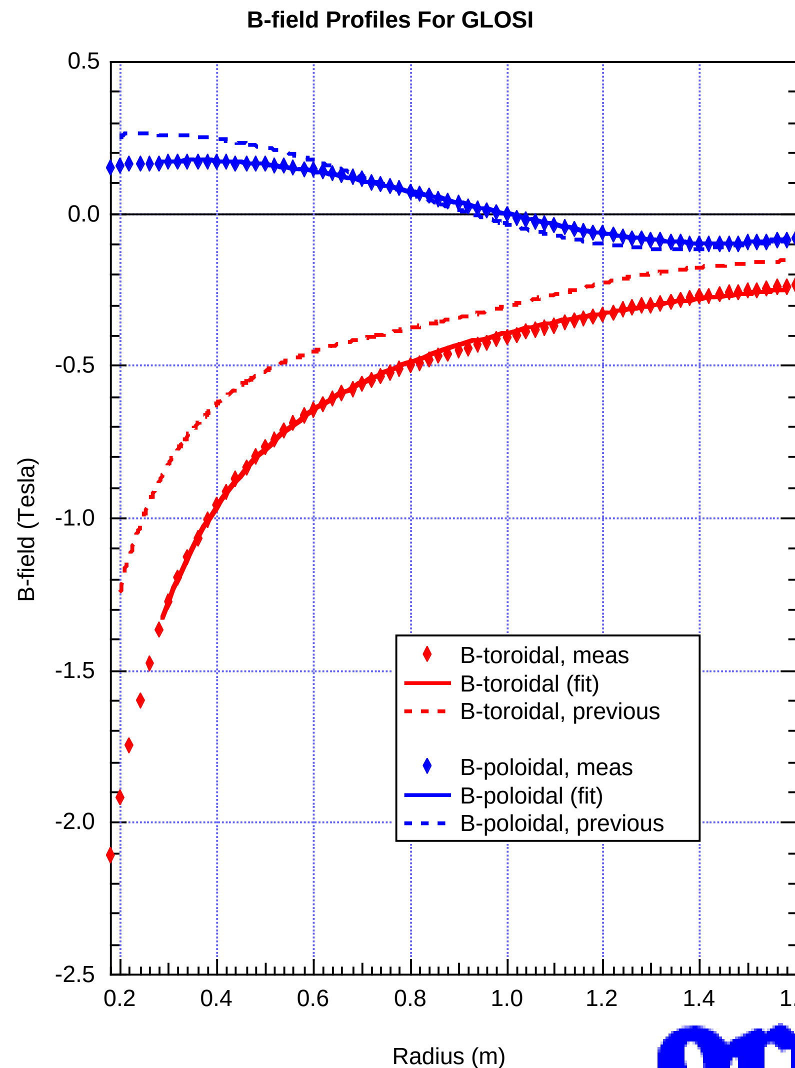
- **Analysis has begun using the edge density profiles of shot 105868 (symmetric heating)**
  - **this was the first shot for which thorough reflectometer analysis was available.**
  - **Subsequent analyses of CD shots indicates that these density profiles are generally applicable to co- and counter-CD phasings as well.**
- **1-D warm plasma slab code (GLOSI) has calculated plasma impedance matrix boundary conditions for two times in the pulse.**
- **RANT3D has calculated the associated power spectra for these BC's for three array phasings.**
- **Ray tracing optics analysis has begun (T. K. Mau).**
- **We will disseminate these parameters to the rest of the modeling community for their consideration.**

Edge density profiles chosen for CD calculations



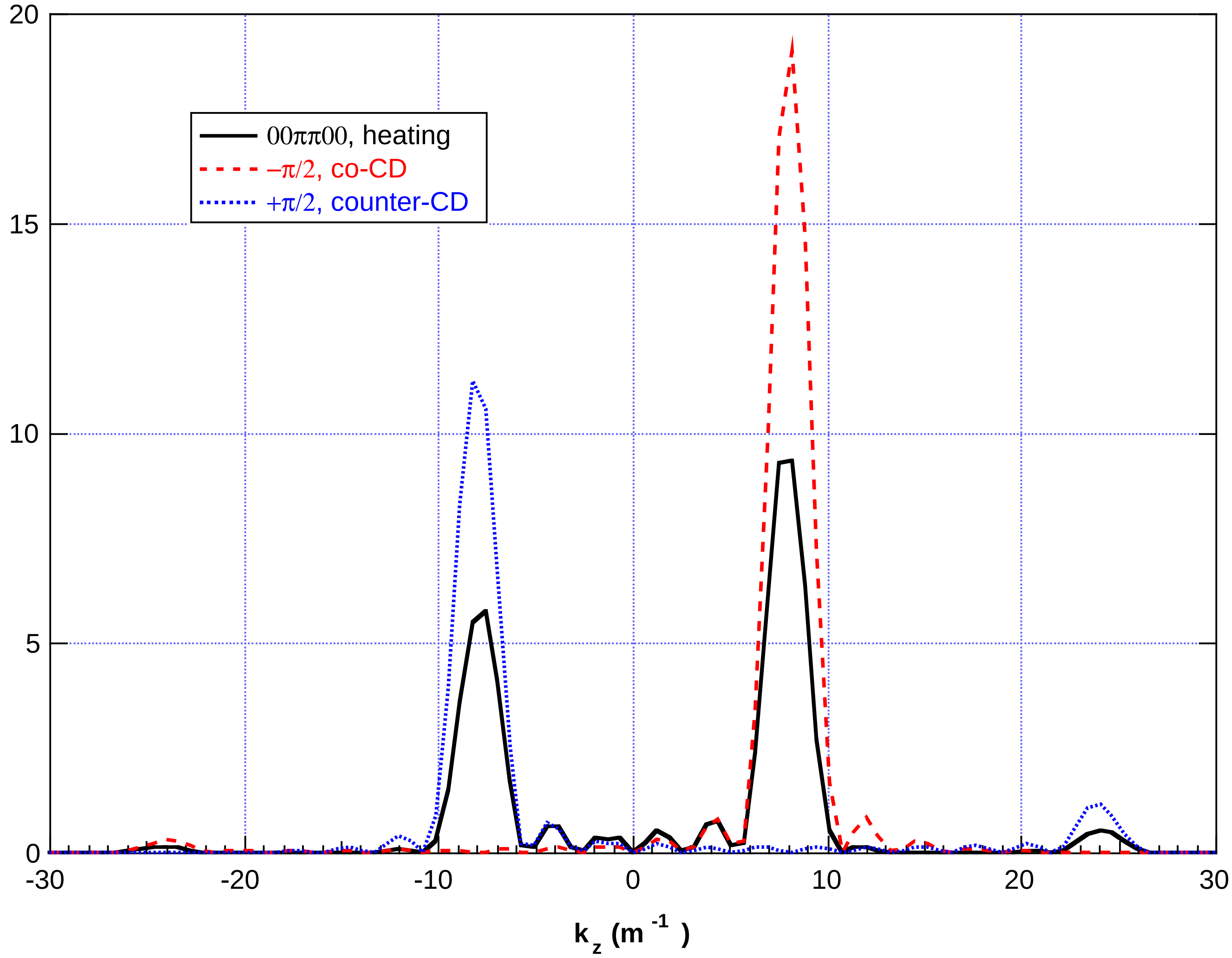
Electron Temperature and B-field profiles for CD calculations



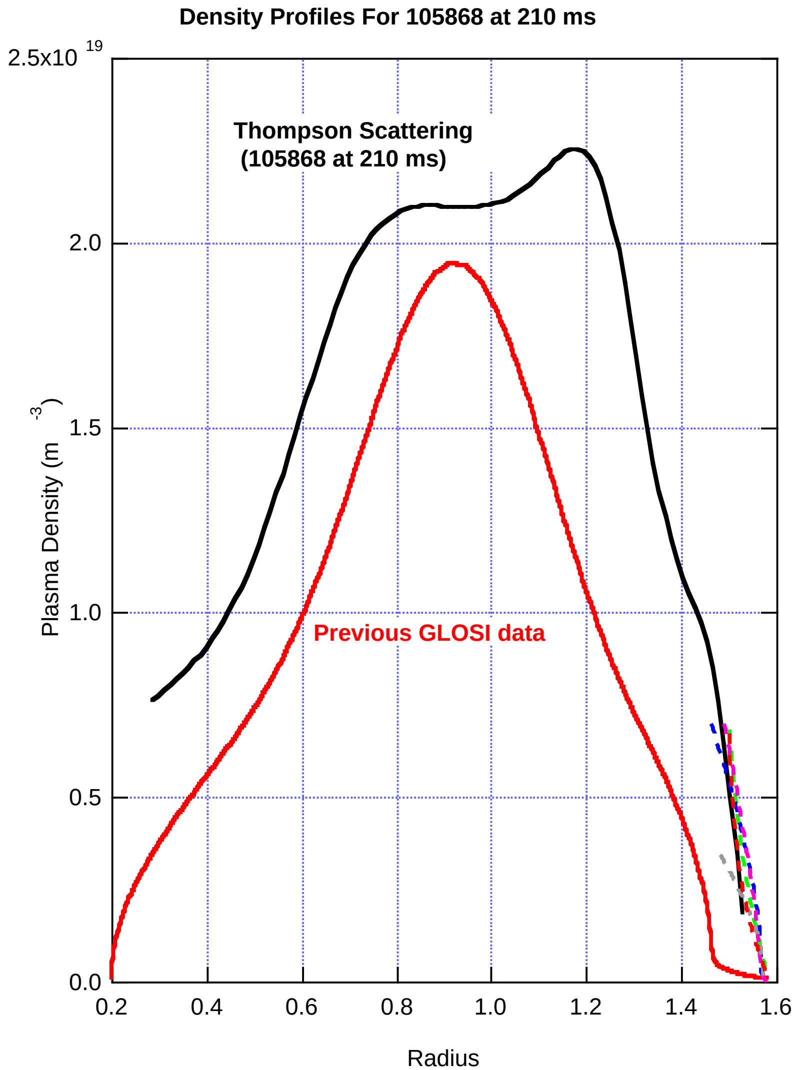


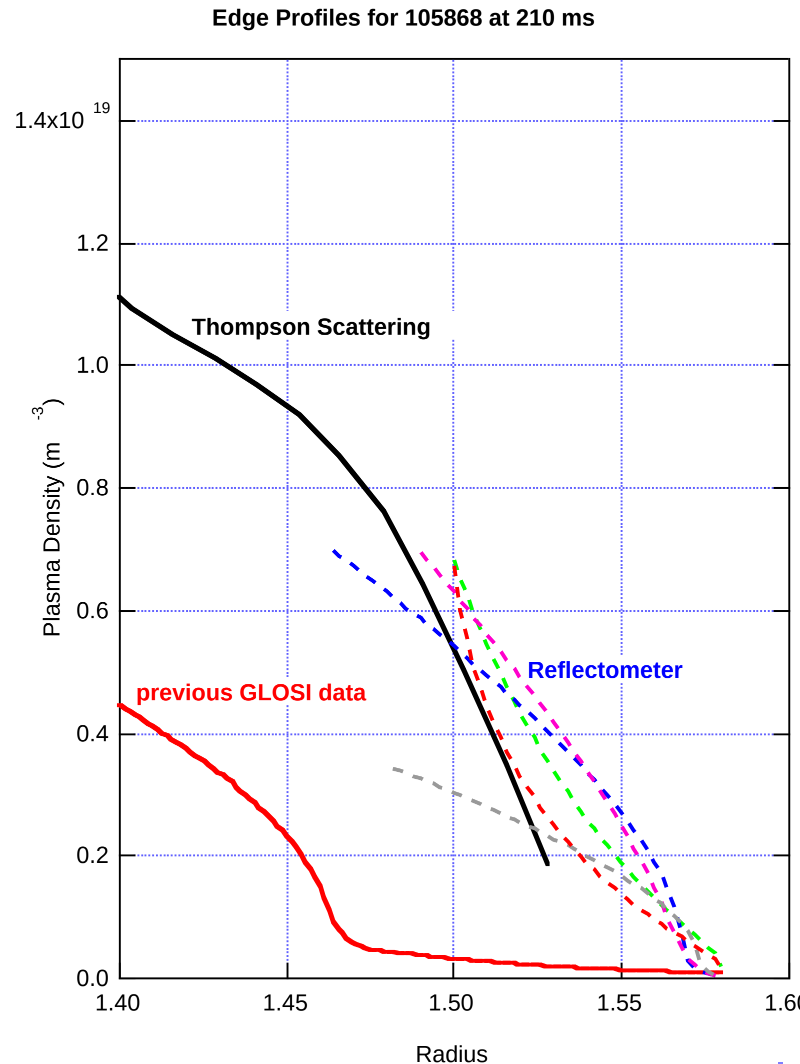
Power spectrum calculated by GLOSI/RANT3D

Plasma response is asymmetrical, driving co-directional current preferentially



Previous current drive calculations assumed edge density profiles that were lower, with longer SOL.





Conclusions and Future Work

- **Initial phased array operation for CD has been performed for relatively short pulses at relatively high power levels.**
  - No operational problems were encountered.
  - Load match at the transmitters was maintained as the array phase was switched.
  - Macroscopic indications of current drive have not been observed.
  - Initial calculations indicate that rf pulses longer than 200 ms may be needed for CD to affect the loop voltage.
- **WORK TO BE DONE FOR APS MEETING:**
  - Ray tracing calculations for current drive.
  - Full-wave calculations for power deposition.
  - Time-dependent CD calculations.
- **FUTURE EXPERIMENTS:**
  - Motional Stark effect measurements will help diagnosis.
  - Phase feedback control will be implemented.
  - May adjust decoupler settings for better isolation in the presence of plasmas (Swain's presentation).