Current Drive with HHFW – Round 2 suggestions

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Due to lack of CD diagnostics (MSE), need to concentrate on the development of CD operation and macroscopically observable CD demonstrations.

CD Operational Development

- Increase reliable power levels (5-6 MW)
- Increase pulse length (> 1 sec)
- Improve phase control techniques

Current Drive Experiments

- Demonstrate non-inductive CD by increasing flattop pulse length in the absence of ohmic current (i.e., operate with V = 0?)
- Modulate between co-CD/counter-CD on the order of L/R time constants (~200-300 ms)

High Power, Long Pulse CD operation: Development Issues and Questions

High Power Operation

- Antenna/system conditioning
- Anomalous surface heating/impurity production with power?

Long Pulse Operation

- Maintaining suitable match over long time periods
- Anomalous surface heating/impurity production with time?

CD Phasing

- Feedback control of phase.
- Phase change during pulse (both modulated and continuous)
- Anomalous surface heating/impurity production with smaller phase shift between array elements?

A couple of possible CD experiments

All require control of the plasma (no IRE's or whatever) so that confinement remains good (i.e. NOT like initial CD experiments in July).

Scenario 1 –

- Switch from co to counter CD during pulse, look at loop voltage

Scenario 2 –

- Implement feedback control on loop voltage. <– Needs discussion!
- Set V_{loop} at some pre-determined value (maybe 0?) after initial current ramp-up and after HHFW is turned on.
- Look at effect of co vs. counter vs. symmetric phasing of HHFW.

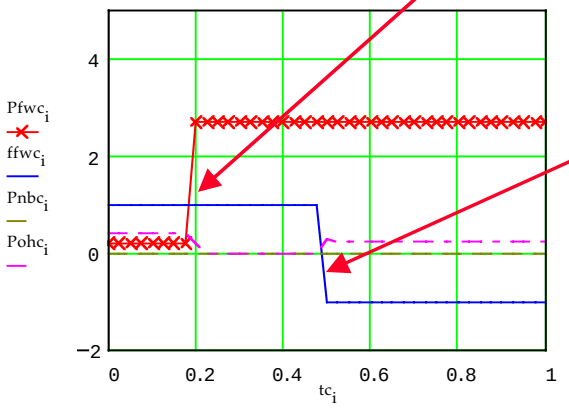
Scenario 1 – Change from co- to counter-CD during pulse

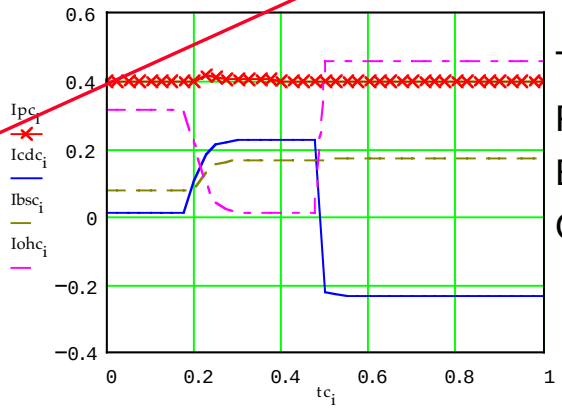
Plots show start of 2.7 MW HHFW co-CD at 200 ms, switches to counter-CD at 500 ms. Loop voltage controlled to maintain I_p = 400 kA

HHFW pwr (red)

Directionality of CD (blue)

OH pwr (mag.)





Total current (red)

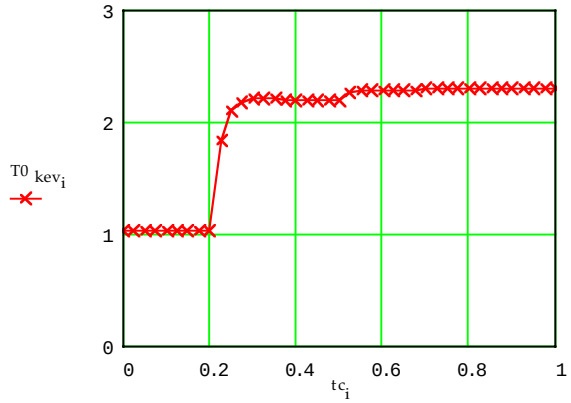
FWCD (blue)

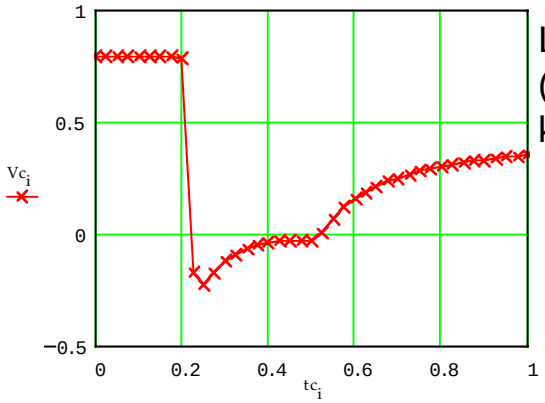
Bootstrap (brown)

Ohmic cur. (mag.)

T on axis (keV)

(assumes α_T = 4)





Loop voltage (maintains I_p= 400 kA)

Note:

$\tau_E \approx$ 25 ms with $P \approx$ 2.7 MW;

maybe optimistic

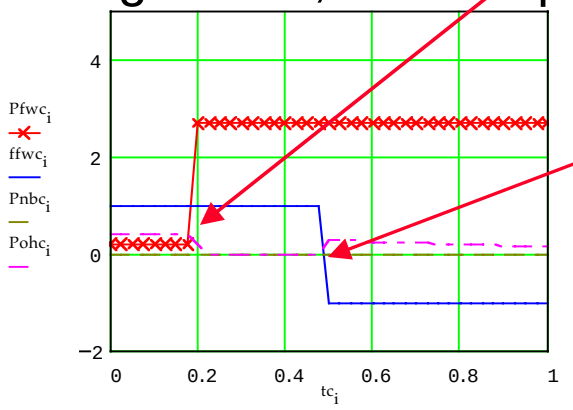
Scenario 2 – Clamp loop voltage to zero

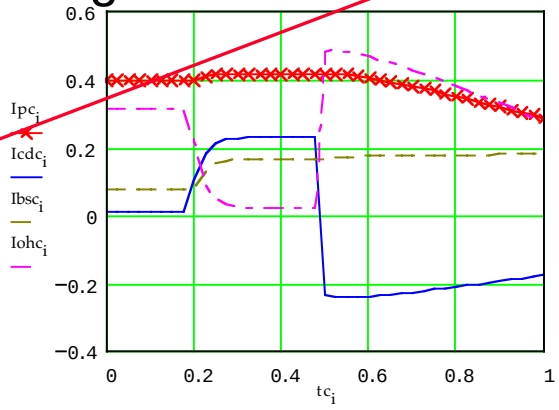
Plots show start of 2.7 MW HHFW co-CD at 200 ms, switches to counter-CD at 500 ms. Current sustained by current drive (≈220 kA) and bootstrap (≈180 kA) during co-CD, then drops during counter-CD

HHFW pwr (red)

Directionality of CD (blue)

OH pwr (mag.)





Total current (red)

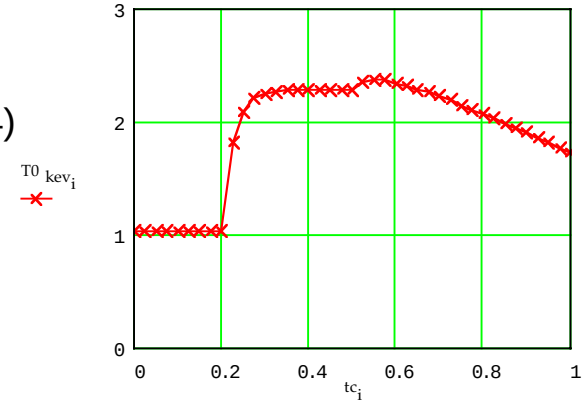
FWCD (blue)

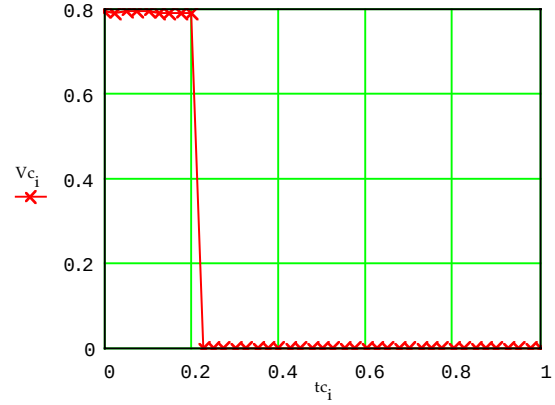
Bootstrap (brown)

Ohmic cur. (mag.)

T on axis (keV)

(assumes $\alpha_T = 4$)

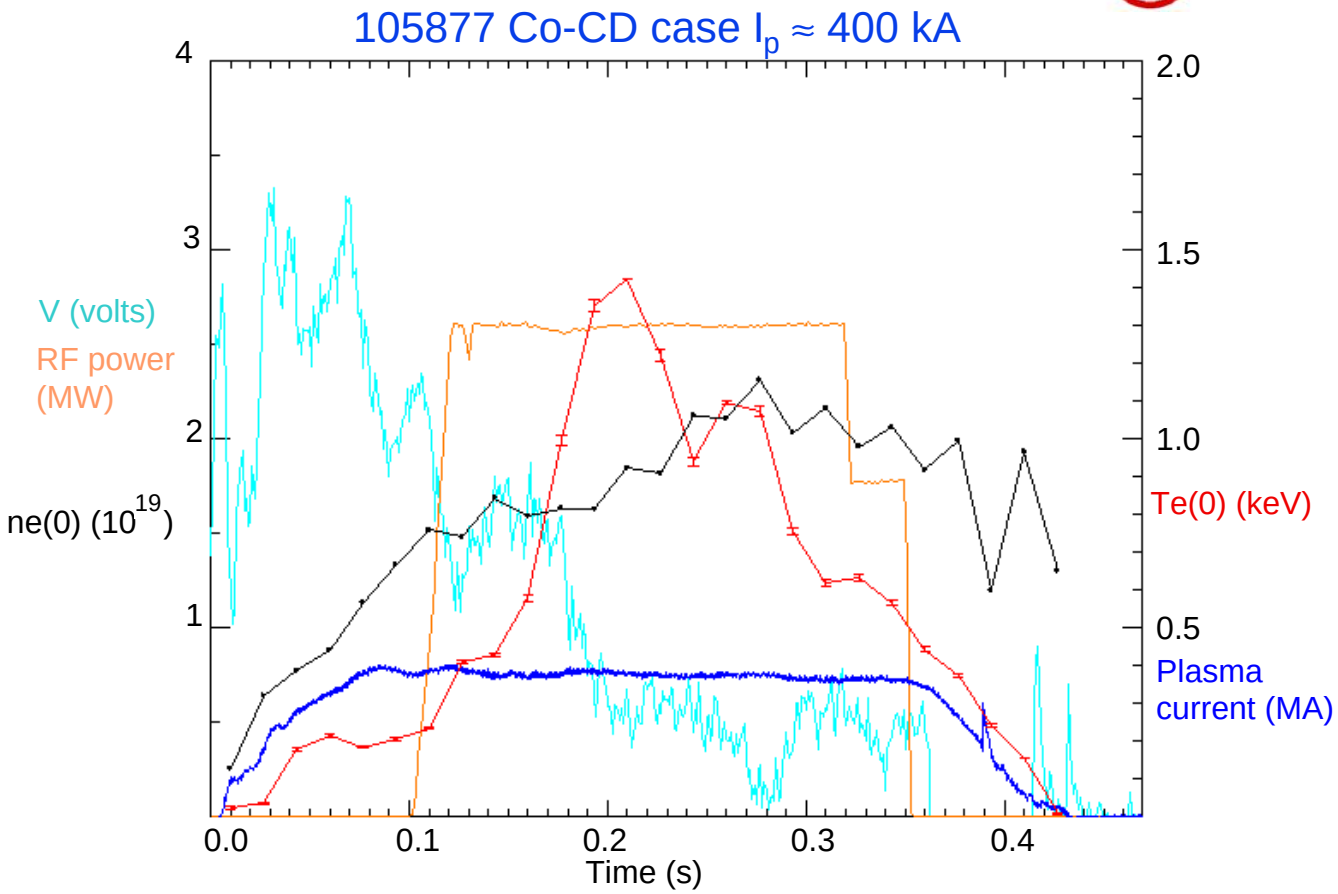




Loop voltage (set to give I_p = 400 kA for t < 0.2 s then set to zero)

For both these cases, times of ~ 200 ms are needed to see external effects, either on loop voltage or on plasma current

For all these cases, the BIG challenge will be maintaining good plasma confinement for long periods

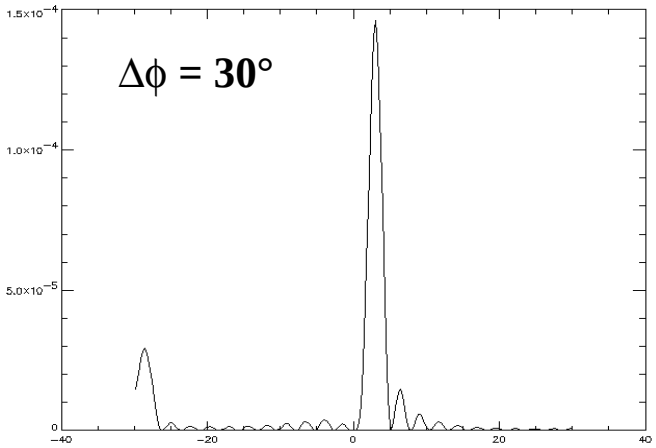


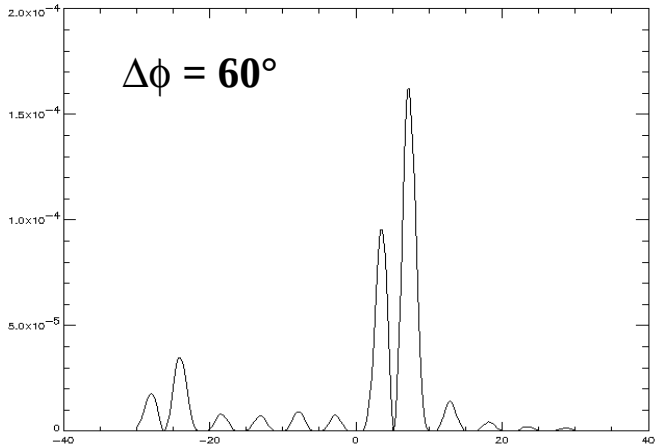
During July CD experiments $T_e(0)$ went to ≥ 2.5 keV for a short time, but then started back down again.

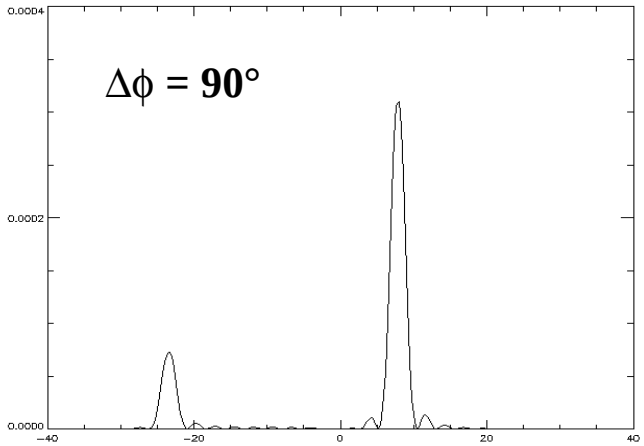
Must work with machine operators and/or theorists to avoid and/or explain.

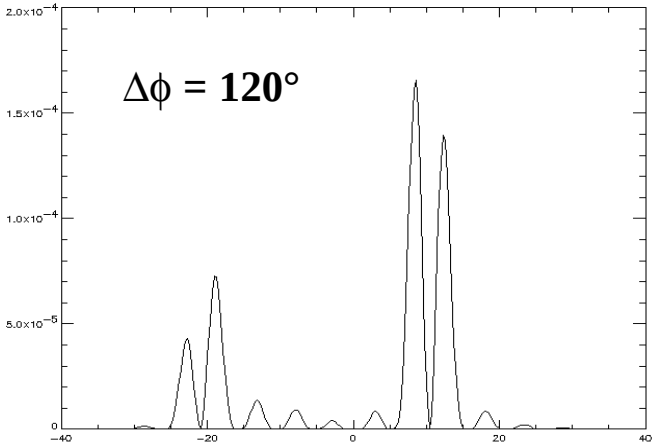
Inter-strap phasing changes give only coarse control of CD efficiency

Due to fixed spacing and 180° phase shift between loop pairs, the locations of spectral peaks are not continuously adjustable.
The optimal directionality occurs at 30° and 90°.



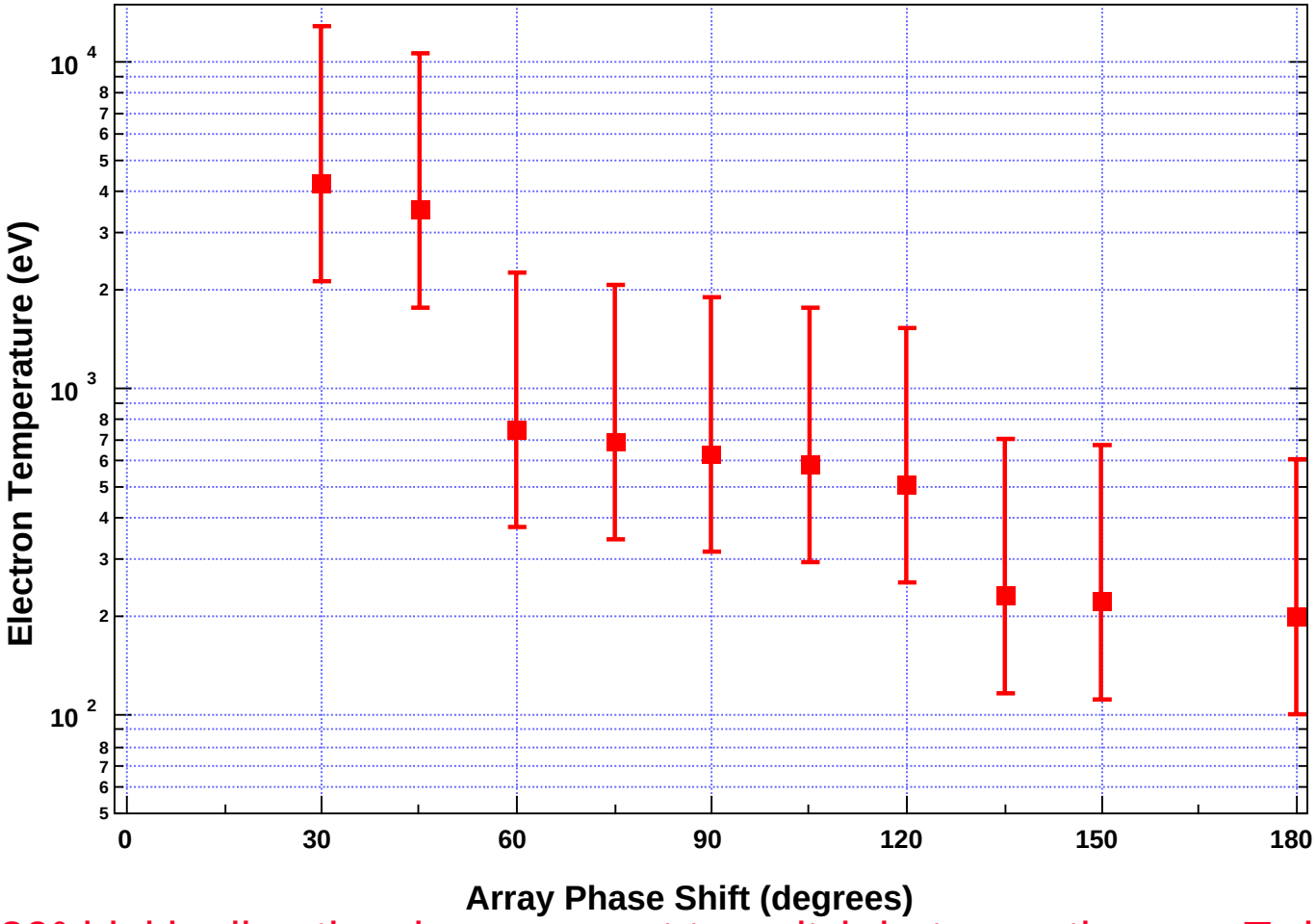






Fine control of phase isn't needed to track T_e during a shot

Electron temperature range where wave phase velocity is 0.5 – 2.0 times electron thermal velocity.



90° and 30° highly directional – may want to switch between them as T_e increases

What's needed

Operations –

- Need capability to operate with stable, long-pulse plasma at $I_p \approx 400$ kA
- Would *like* feedback control on V_{loop} instead of I_p , switching during a shot
- Need fairly good position control

RF system –

- Need increased power and longer-pulse operation
  - Question about heating of antennas or other elements in machine
- May need active control of antenna phasing

Diagnostics –

- MSE! (we wish!)
- *May* want IR camera looking at antenna area to detect heating

Program –

- Dedicated machine time to
  - increase HHFW system power
  - obtain long-pulse plasma capability