Plenary talk for ET3 HHFW

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January 15, 2001

NSTX Research Forum

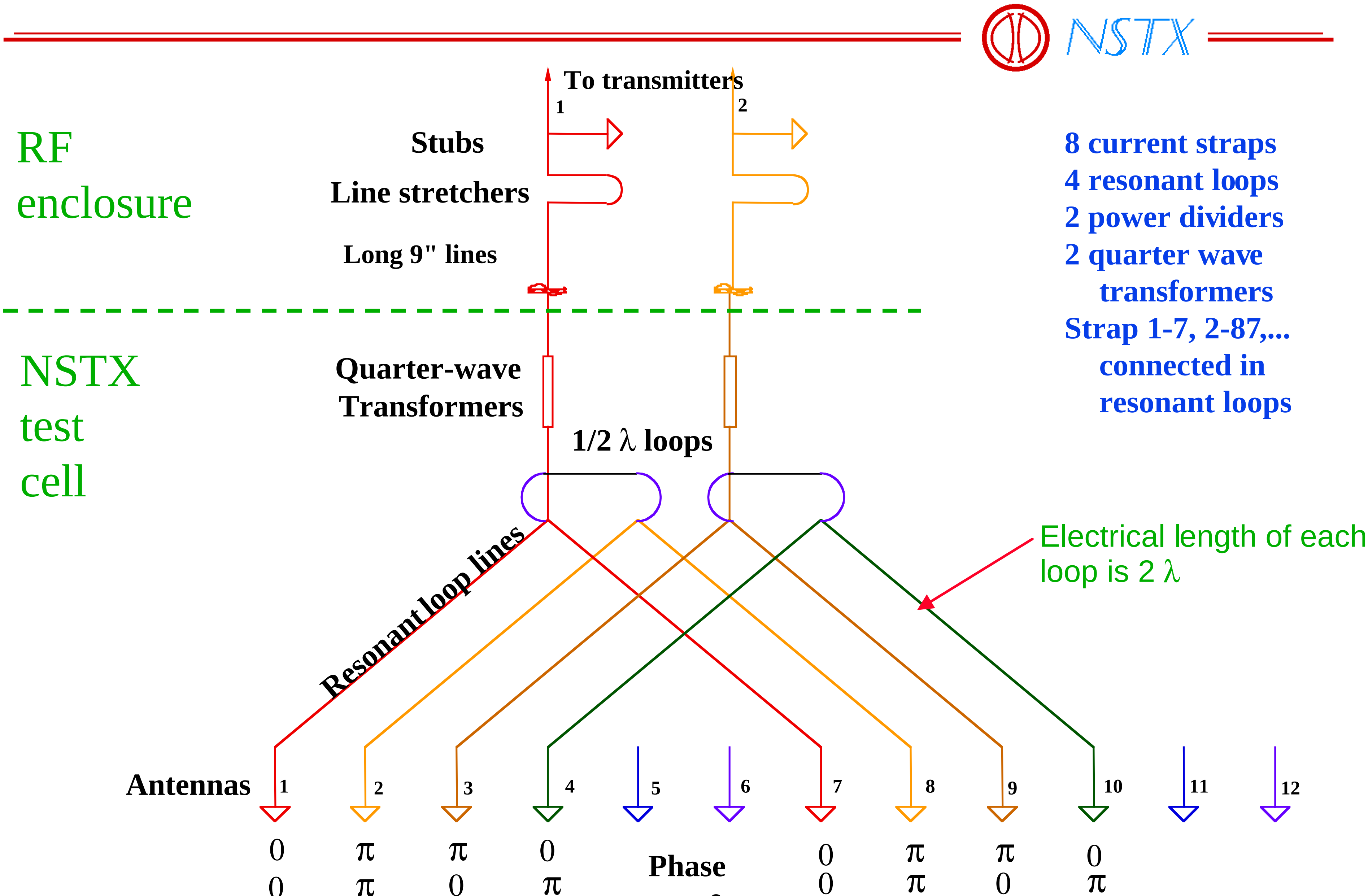
Princeton, NJ

ET3 INTRODUCTION

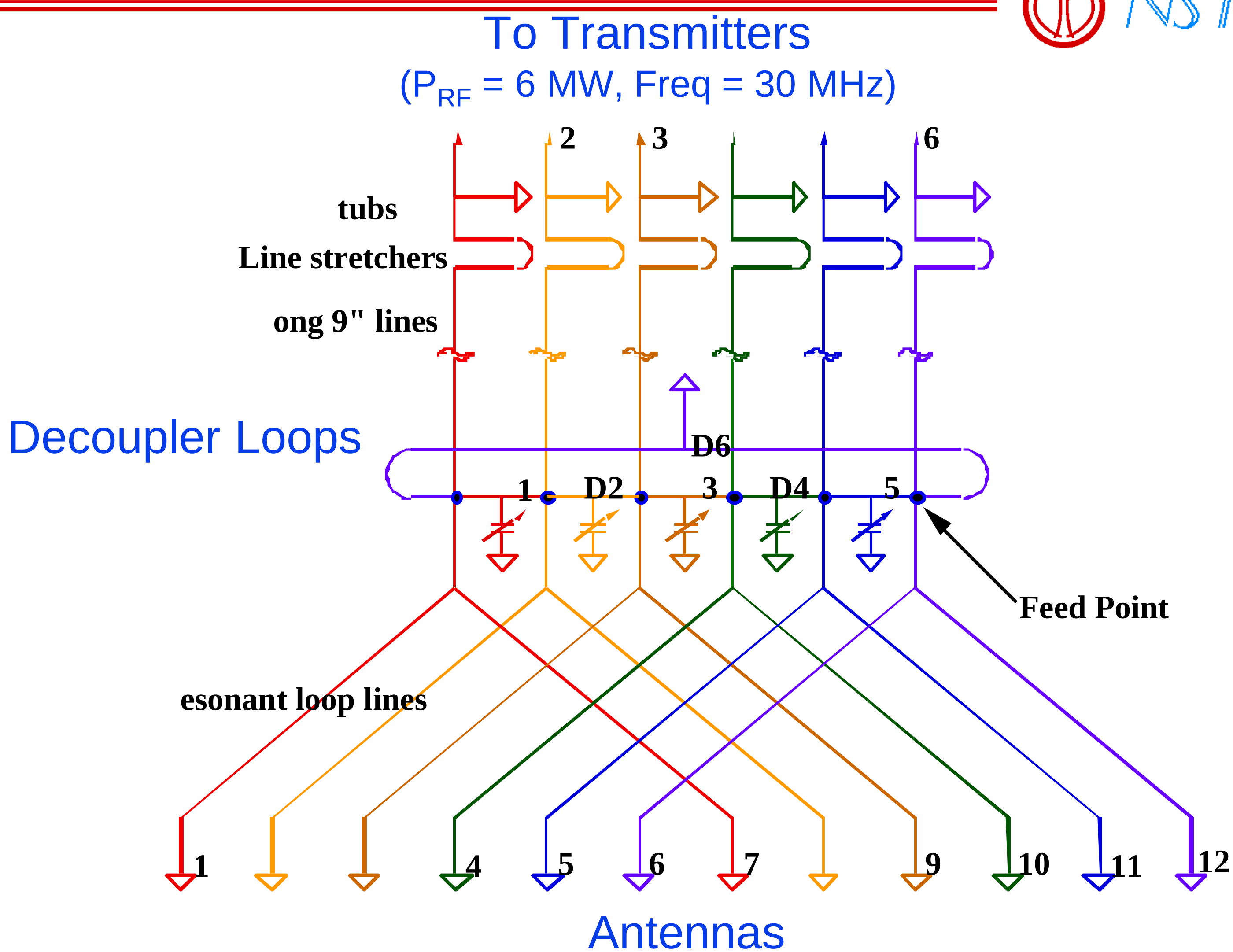
HHFW Campaign has continued since last years Research Forum

- System completed and operated
- Power coupled to plasma increased from 2 to 4 MW
- Confirmation that the increase in soft x-ray emission reported last year was electron heating
  - Detailed study of heating physics begun
  - Study of the role of ions on absorption is beginning
- Phasing capability demonstrated
- Use of of HHFW as discharge control tool
  - Early heating to clamp li and q(0)

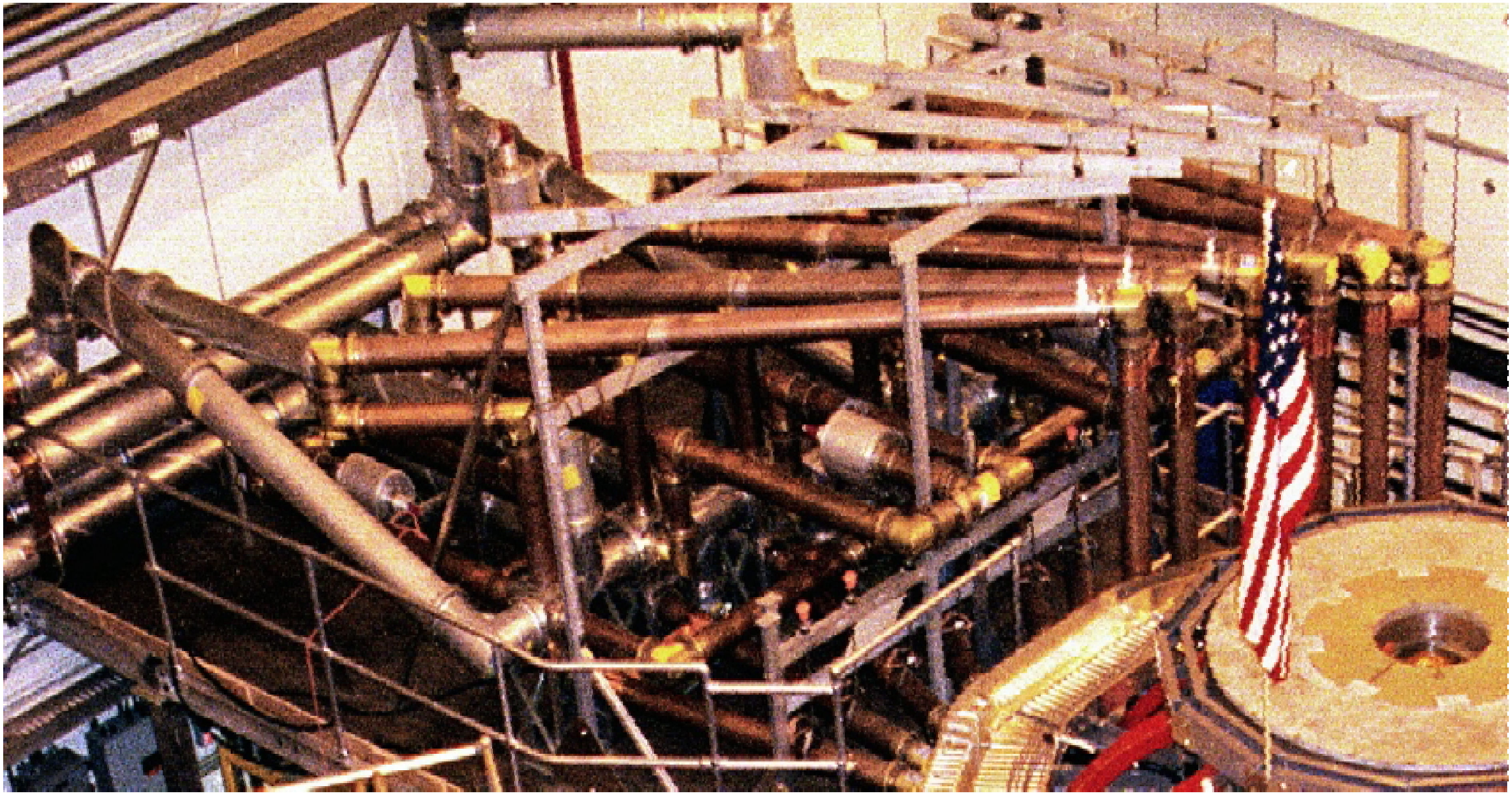
PRELIMINARY TWO TRANSMITTER CONFIGURATION



HHFW SYSTEM DESIGN:
12 STRAPS, 6 TRANSMITTERS, 6 DECOUPLERS



DECOUPLING AND FEED NETWORK



POWER SPECTRUM OF ANTENNA IS PROGRAMMABLE OVER A WIDE RANGE OF $k_{||}$ (~ 2 to ~ 14 m^{-1})

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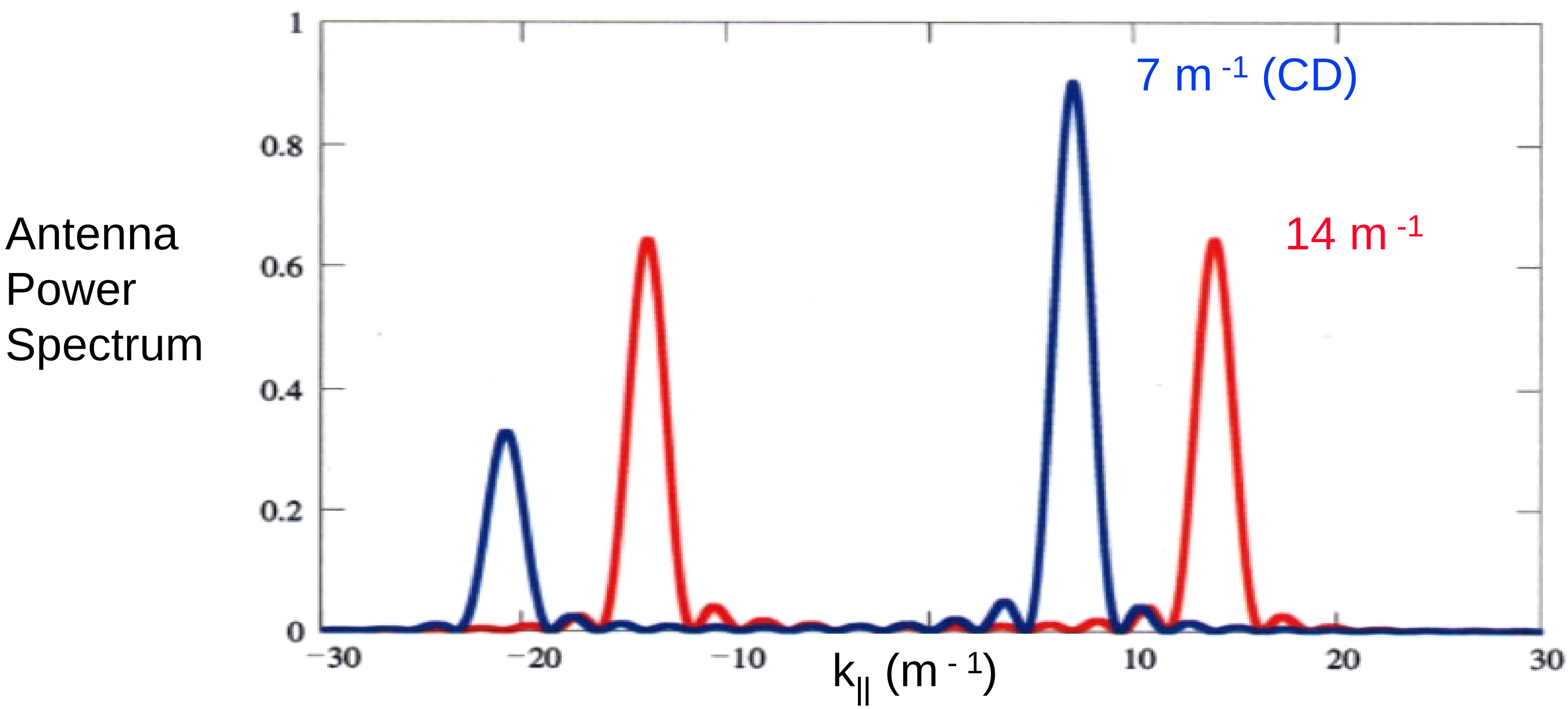

- Programming $k_{||}$ facilitates heating to higher T_e and change to CD phasing
- Decoupling between adjacent straps provided with decoupling loops
  - minimizes mutual effects in vacuum
  - mutual to plasma has small effect on decoupling
- Experiments which follow were conducted with $k_{||}$ ~ 14 m^{-1}

ISSUES FROM LAST FORUM

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Did observed antenna require a change in the tuning and matching configuration?

- Removed quarter wave transformers (6:1) but left remaining design alone
- System performed well
- May reinstall smaller value transformers (2:1) to allow more confidence at high power

Was observed soft x-ray signal increase really electron heating?

- Thomson scattering confirms electron heating

Why did apparent heating disappear during the pulse?

- MHD explains loss of strong central temperature increase during pulse

Why was apparent heating only observed for slowest waves

- Still seen, still not understood

INCREASED HIGH ENERGY SOFT X-RAYS DURING HHFW

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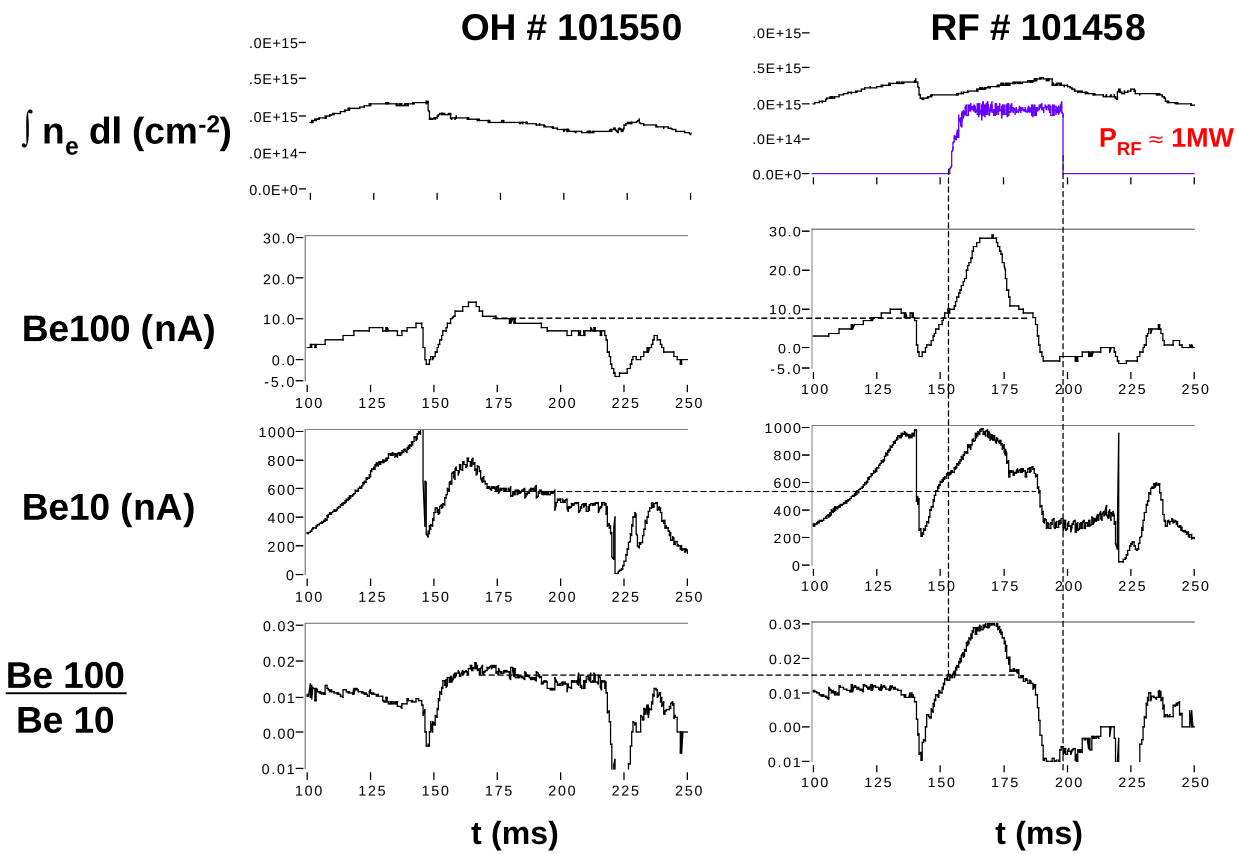
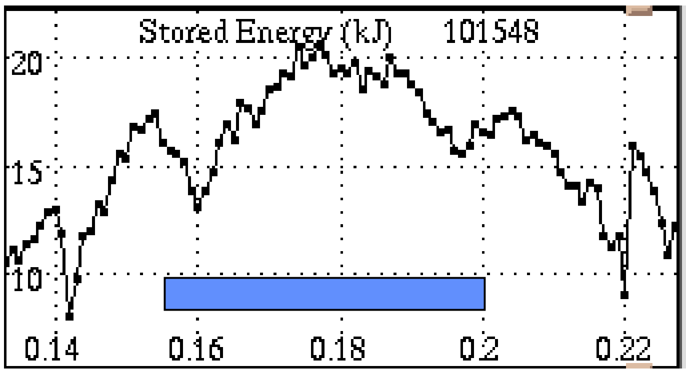


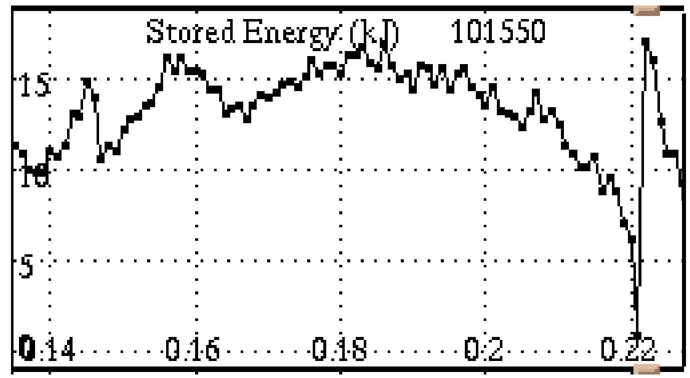
- 60 % increase in Be 100 / Be 10 during first half of RF pulse
- Minor density increase
- Sudden emission drop before the pulse end

First signs of heating observed for $0-\pi-0-\pi$ phasing

900 kW rf



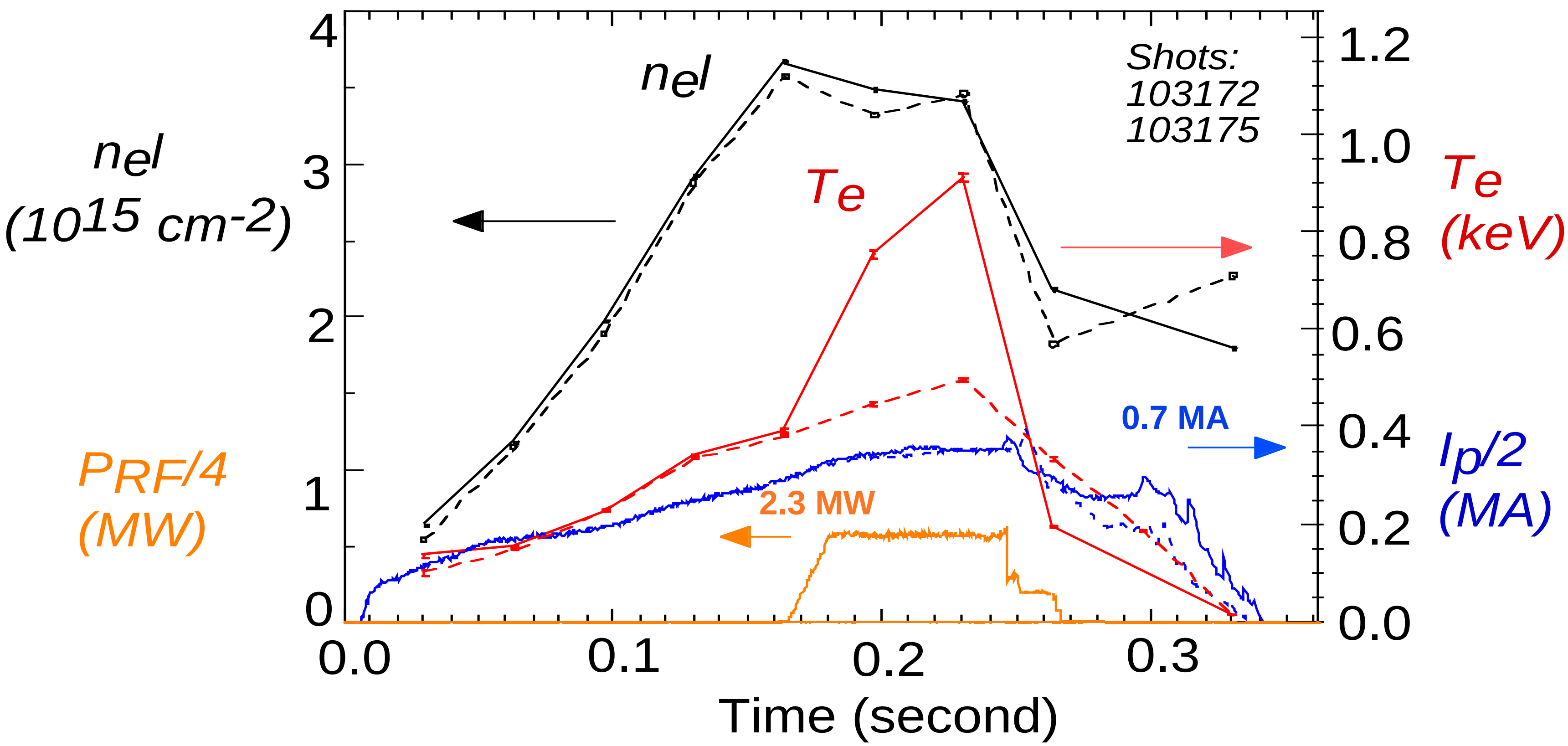
No rf



Columbia University

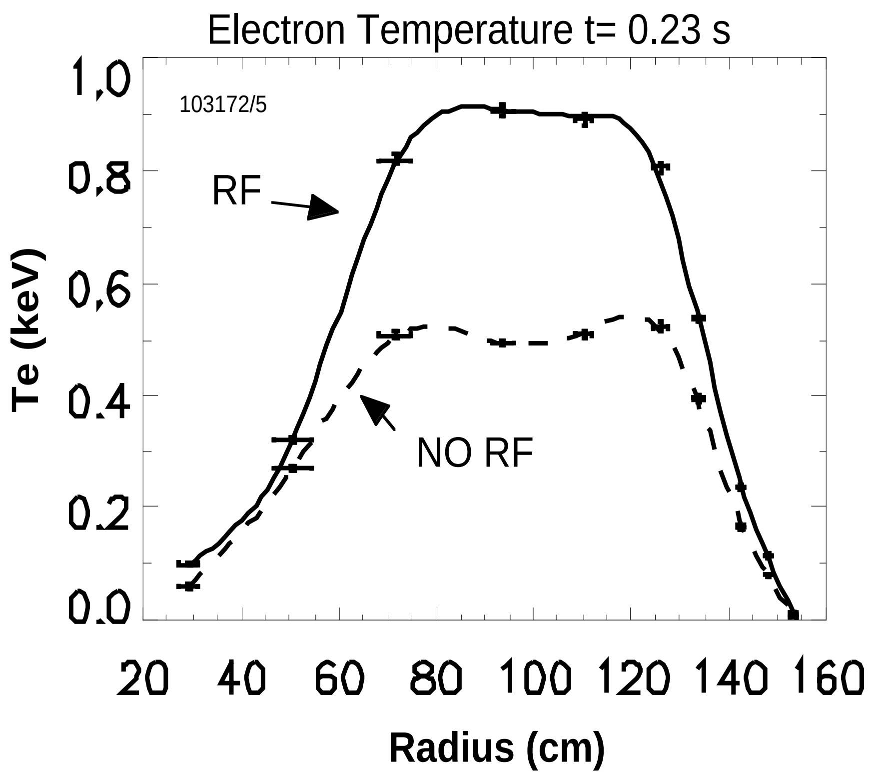
STRONG ELECTRON HEATING HAS BEEN OBSERVED IN HELIUM PLASMAS WITH THOMSON SCATTERING

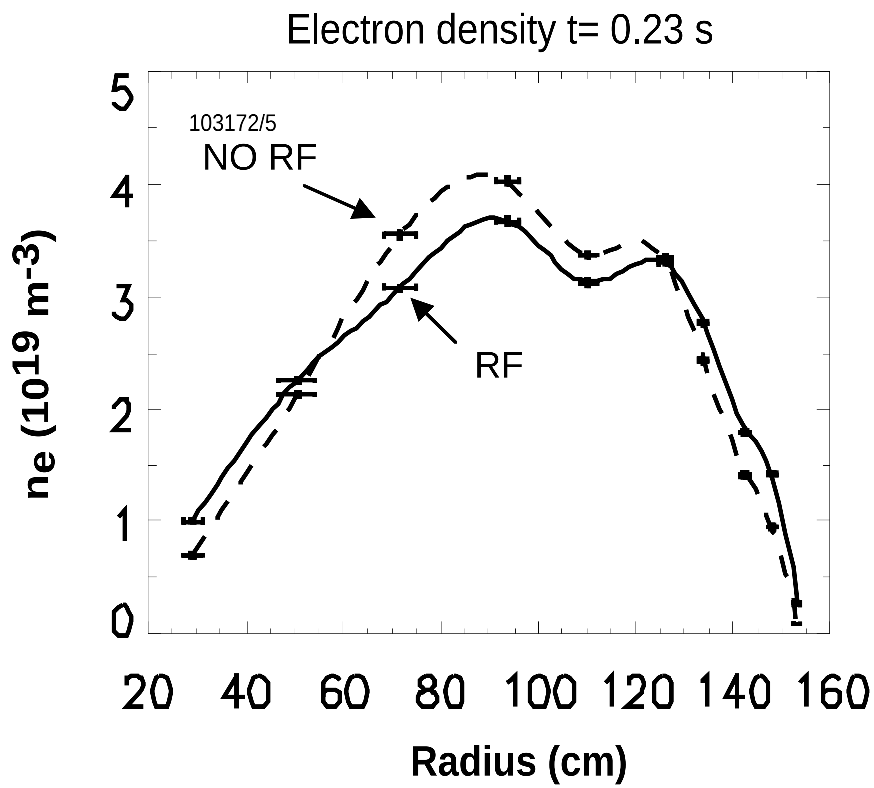
P_{RF} = 2.3 MW, Helium, $k_{||}$ = 14 m^{-1}, B_T = 0.3 T



- T_e(0) increases to ~ 900 eV in helium plasma at P_{RF} = 2.3 MW
- No density increase with RF and V_{loop} decreases by ~ 30 %
- Stored energy increases to 58 kJ: β_T = 10%, β_N = 2.7

BROAD ELECTR ON TEMPERATURE PROFILE OBSERVED IN PRESENCE OF M=1 MHD





- Flattening of the T_e and n_e profiles occurs with the onset of the m = 1 MHD instability prior to the application of the RF

PEAKED HEATING IN THE ABSENCE OF MHD

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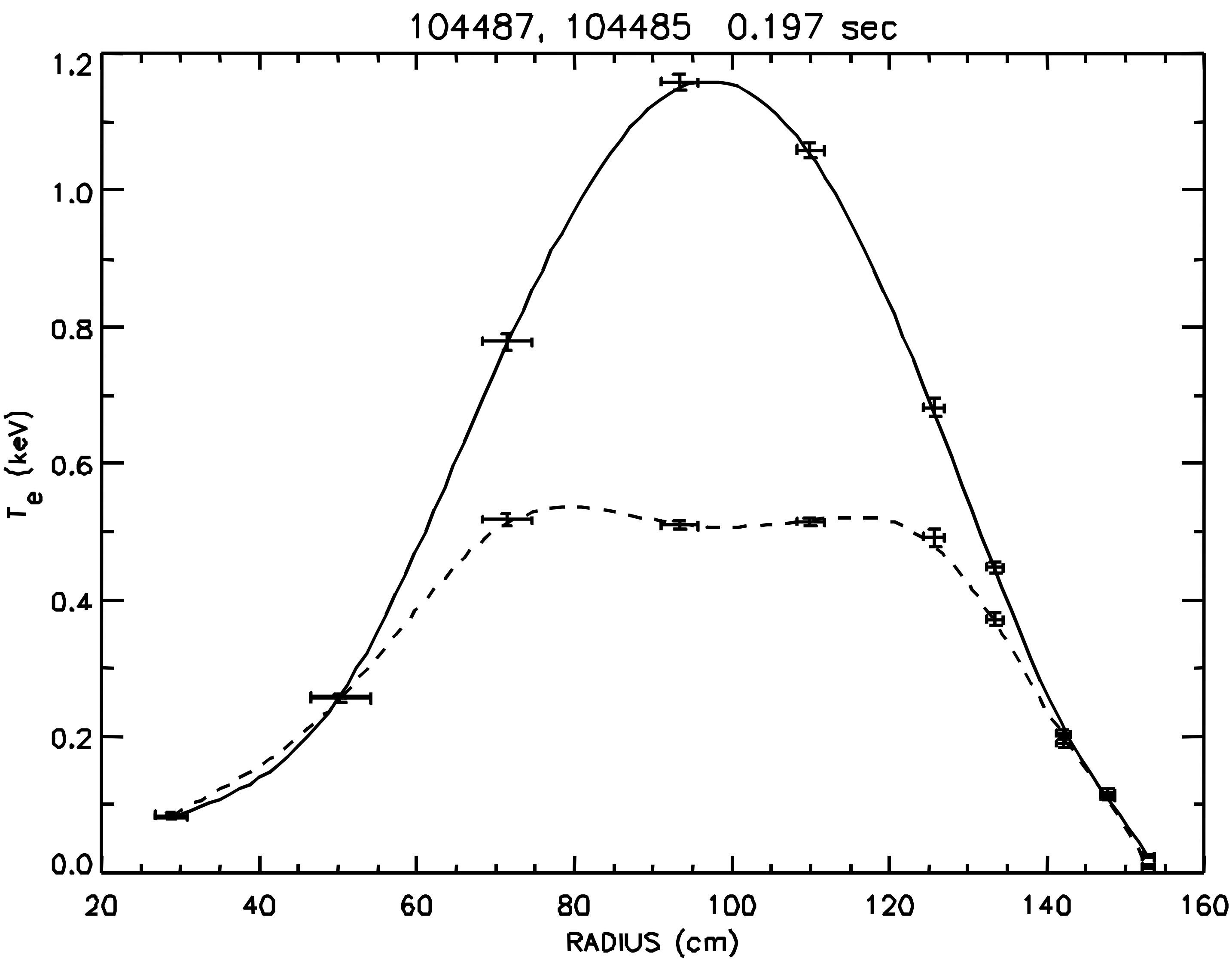
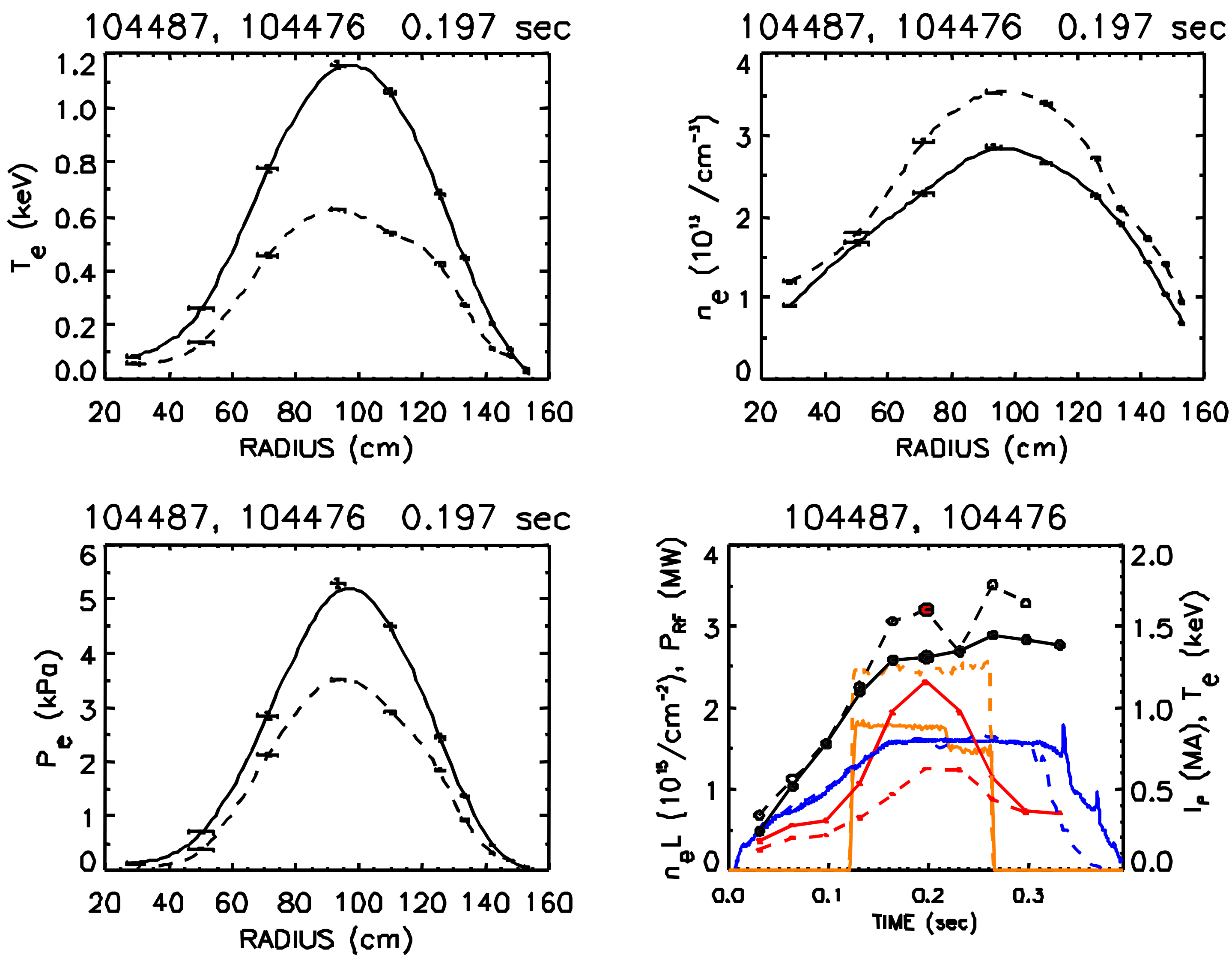


STRONGER HEATING OBSERVED IN HELIUM PLASMAS



PHYSICS ISSUES ARISING FROM THIS YEARS EXPERIMENTS

Phase dependence of heating

Comparison of deposition profiles to modeling

- Several modeling packages in substantial agreement on electron damping
  - CURRAY, METS, TORIC
- TORIC package (Bonoli, Spaleta, Phillips) has been coupled to EFIT
- Difficult to experimentally determine deposition profile

Calculated Electron Absorption Profiles are Consistent With Measured T_e Profiles at OH Target and RF Phases

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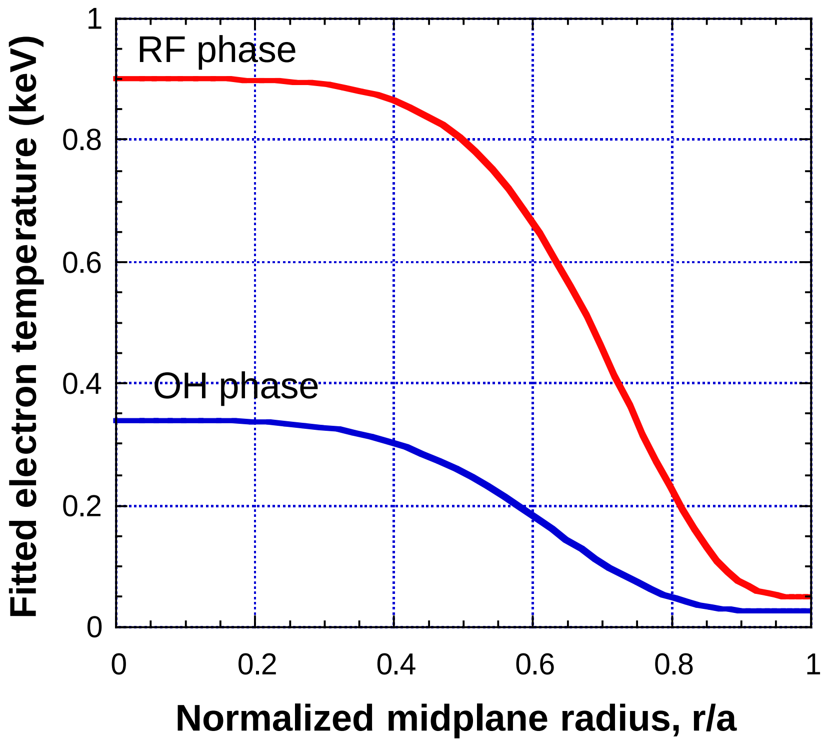
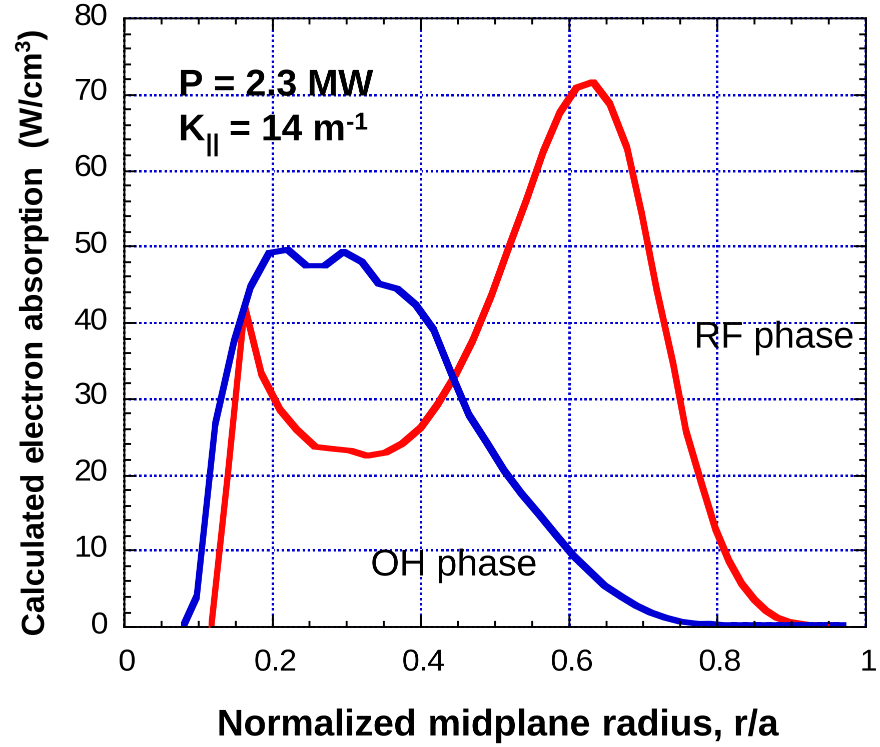
- **Two points on HHFW Shot 103172 have been analyzed in some detail using the 3-D CURRAY ray tracing code.**
  (1) OH Target : @ t = 0.163 s, before RF turn-on
  (2) RF Phase : @ t = 0.230 s, with RF power on.
- **Initial broad near-axis P_e profile at OH phase broadens T_e profile, which moves P_e peak outward resulting in still broader T_e profile in RF phase.**





POWER DEPOSITION SHIFTS FURTHER OFF-AXIS WITH TEMPERATURE INCREASE

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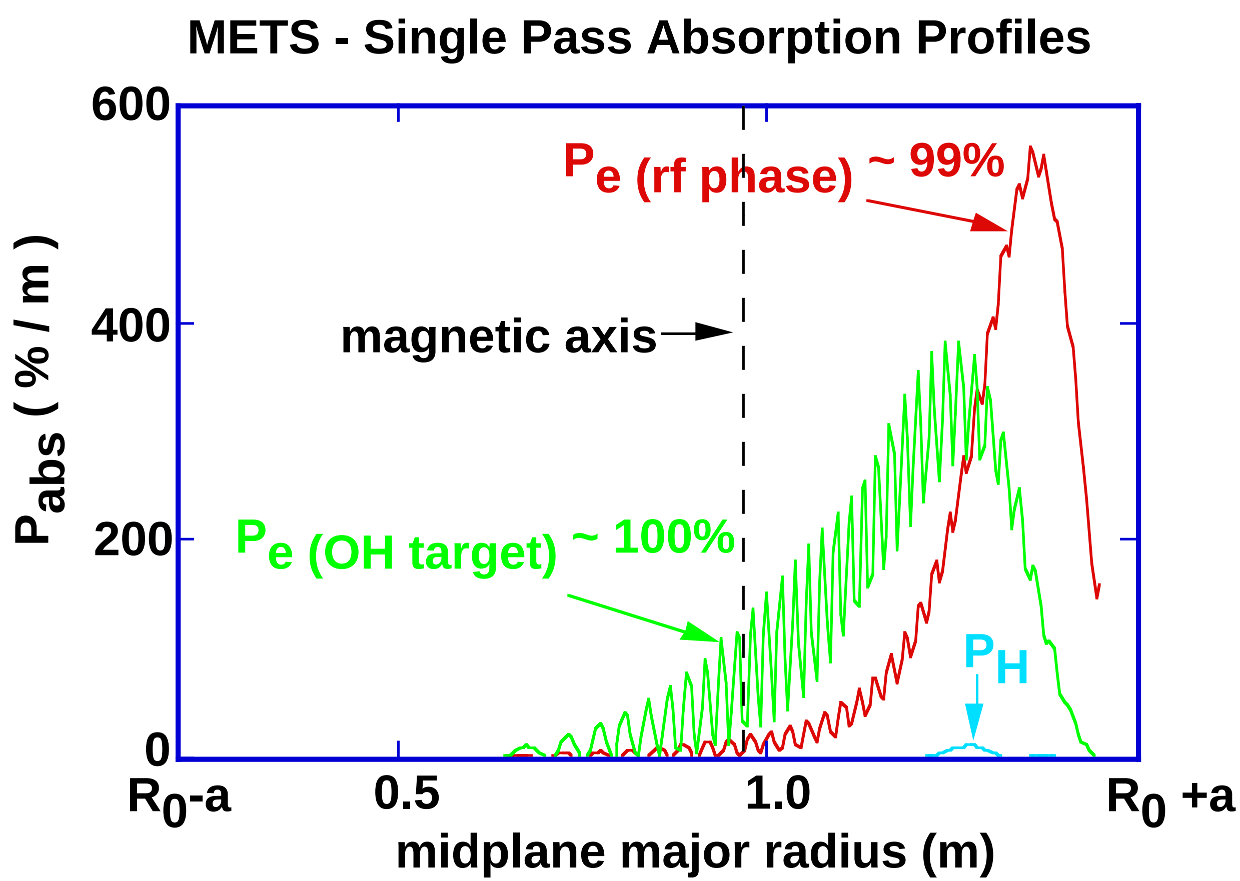

Helium plasma composition: η_{4He} ~ 39% η_H ~ 2% η_D ~ 8% η_C ~ 2%

PHYSICS ISSUES ARISING FROM THIS YEARS EXPERIMENTS

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Ion interaction

- Have made progress on theoretical predictions (Mau, Phillips)
- Preliminary CHERS results do not show strong ion heating during good electron heating
- Diagnostics coming on line

Where does power go when strong electron heating is not observed?

- Adding dedicated rf camera to view antenna
- Adding additional divertor diagnostics
- Adding reciprocating probe (UCSD)?
- Exploring passive plate tile diagnostic

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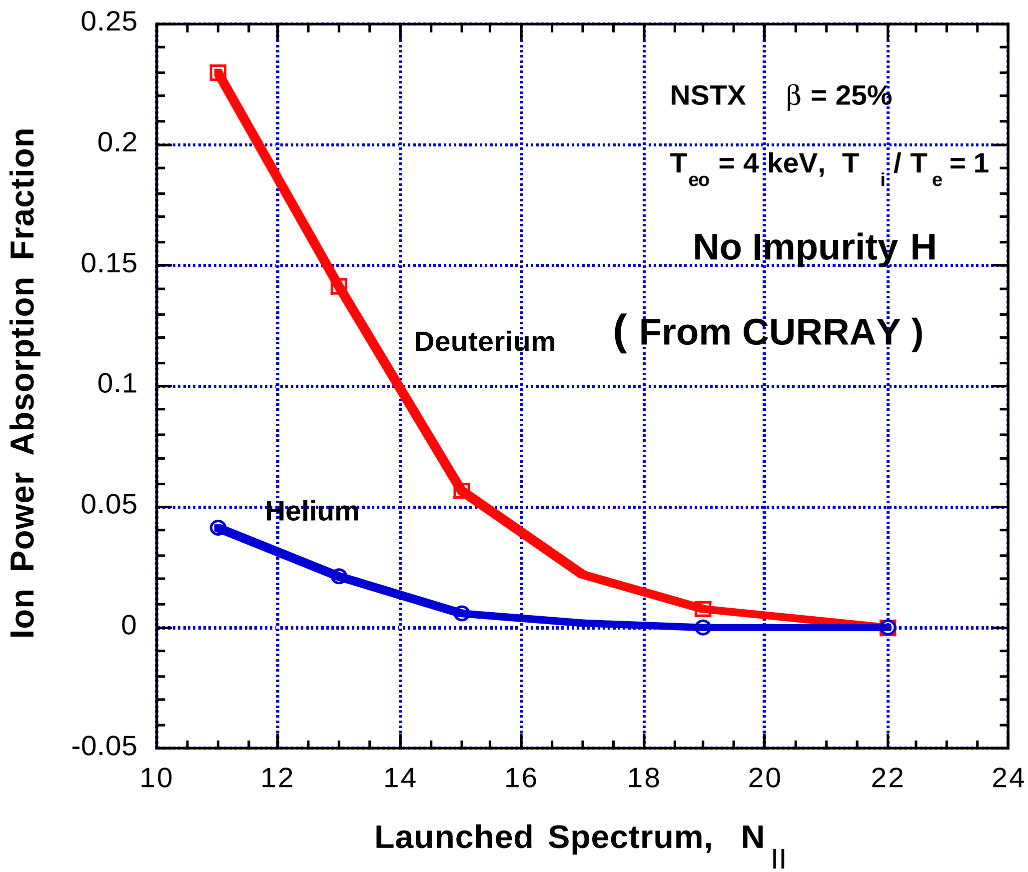
Helium Absorption is Weaker Than Deuterium at Same Plasma β

- Bulk ion absorption becomes weaker as launched $N_{||}$ increases.
- At higher β, operating at higher $N_{||}$ can alleviate concern for bulk deuterium absorption, provided impurity H can be suppressed.
    - Most wave energy is absorbed by electrons near edge before reaching high-β core where ion damping is strong.



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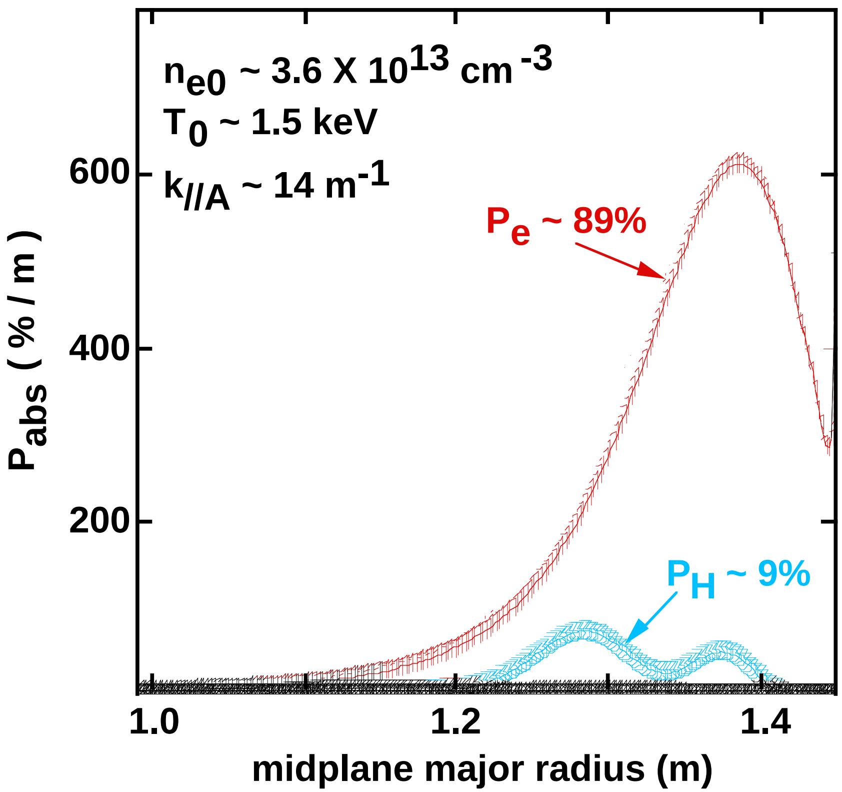
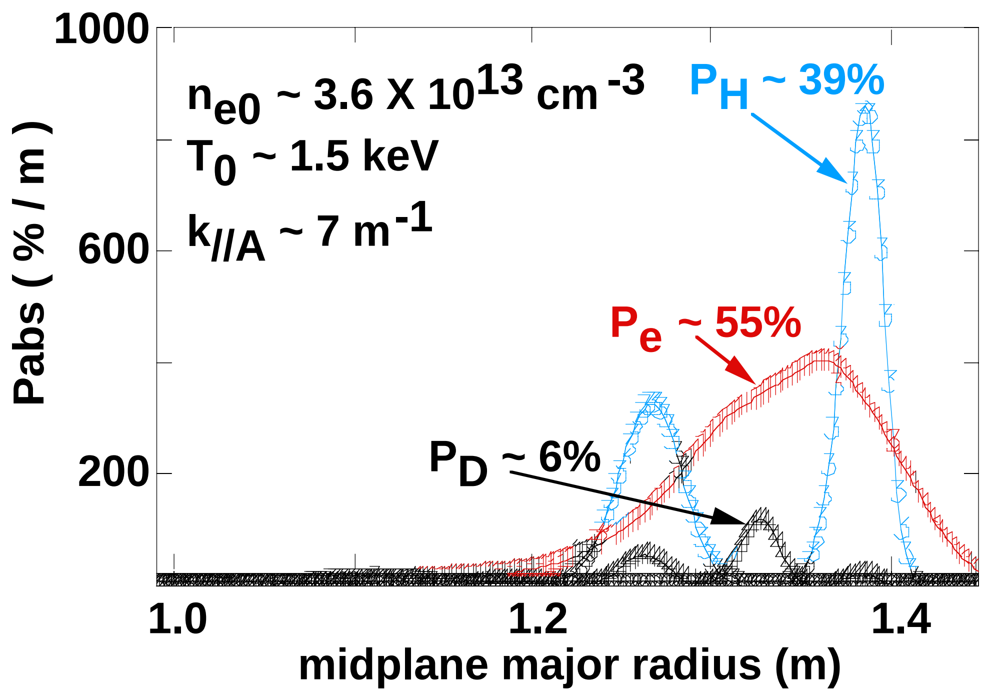
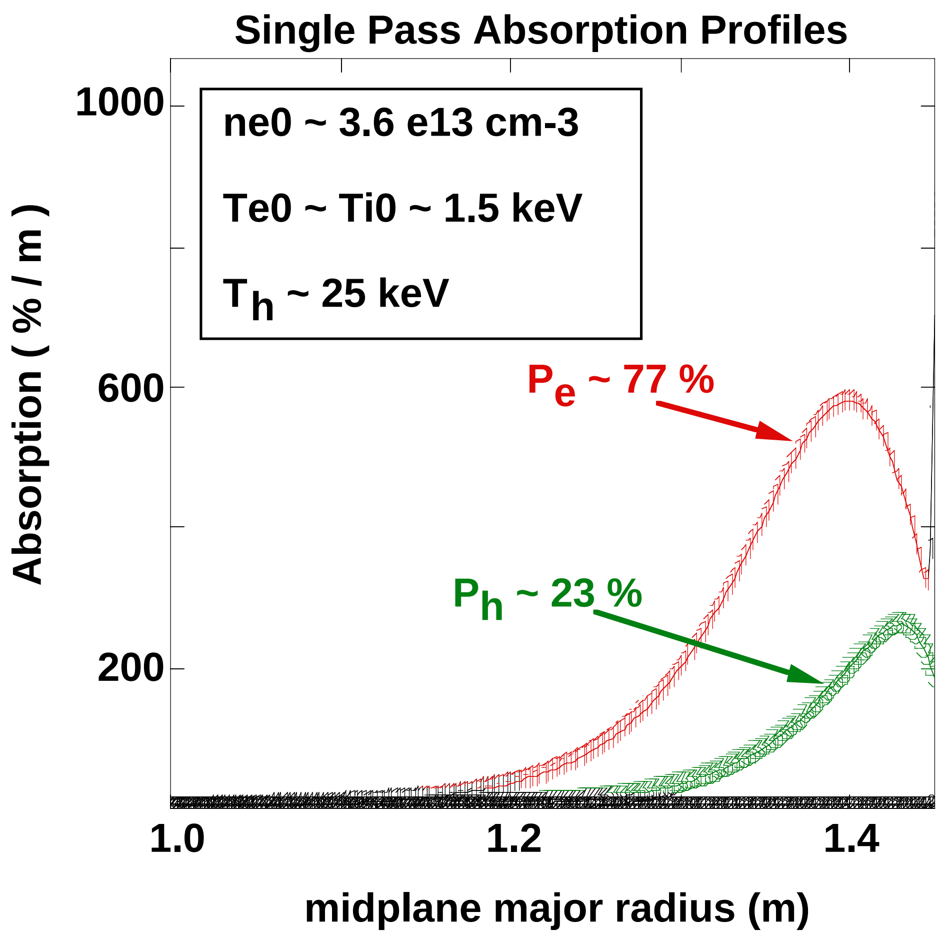
SUBSTANTIAL ION DAMPING POSSIBLE IN DEUTERIUM PLASMAS





deuterium plasma composition: η_D ~ 76% η_H ~ 10% η_C ~ 2% η_{4He} ~ 2%

HYDROGEN MINORITY DAMPING INCREASES IF TAIL FORMS



PHYSICS ISSUES ARISING FROM THIS YEARS EXPERIMENTS

Structure of antenna loading with phasing
- Asymmetry observed in parallel spectrum
- Does this affect ability to do asymmetric phasings

What is happening in early heating experiments that causes the large density increase?

Initial results from XP-025

HHFW heating during I_P ramp-up

- B_T=3kG, Deuterium, $\kappa \approx$ 1.8-2

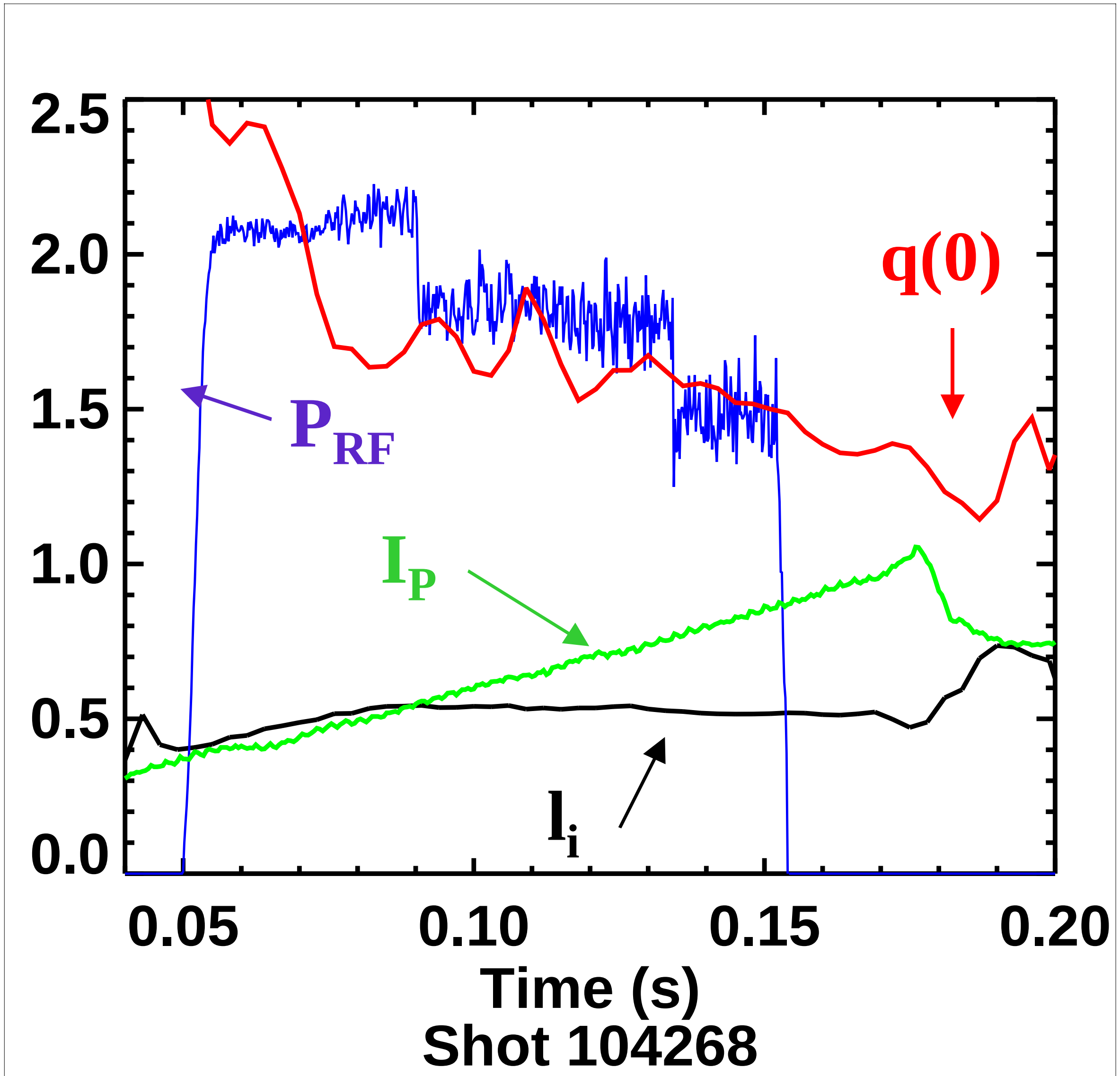
- Important operational results:
  - l_i kept $\leq$ 0.5 up to 1MA and into flat-top
  - q(0) elevated during ramp-up and after
  - Flux consumption reduced
  - 1MA plasma current more reliably achieved

- Central T_e increase generally modest
  - Higher $T_e(0)$ with smaller outboard gap

- Rapid density increase w/ broad n_e profile
  - Smaller density rise when $\Delta T_e(0)$ is larger

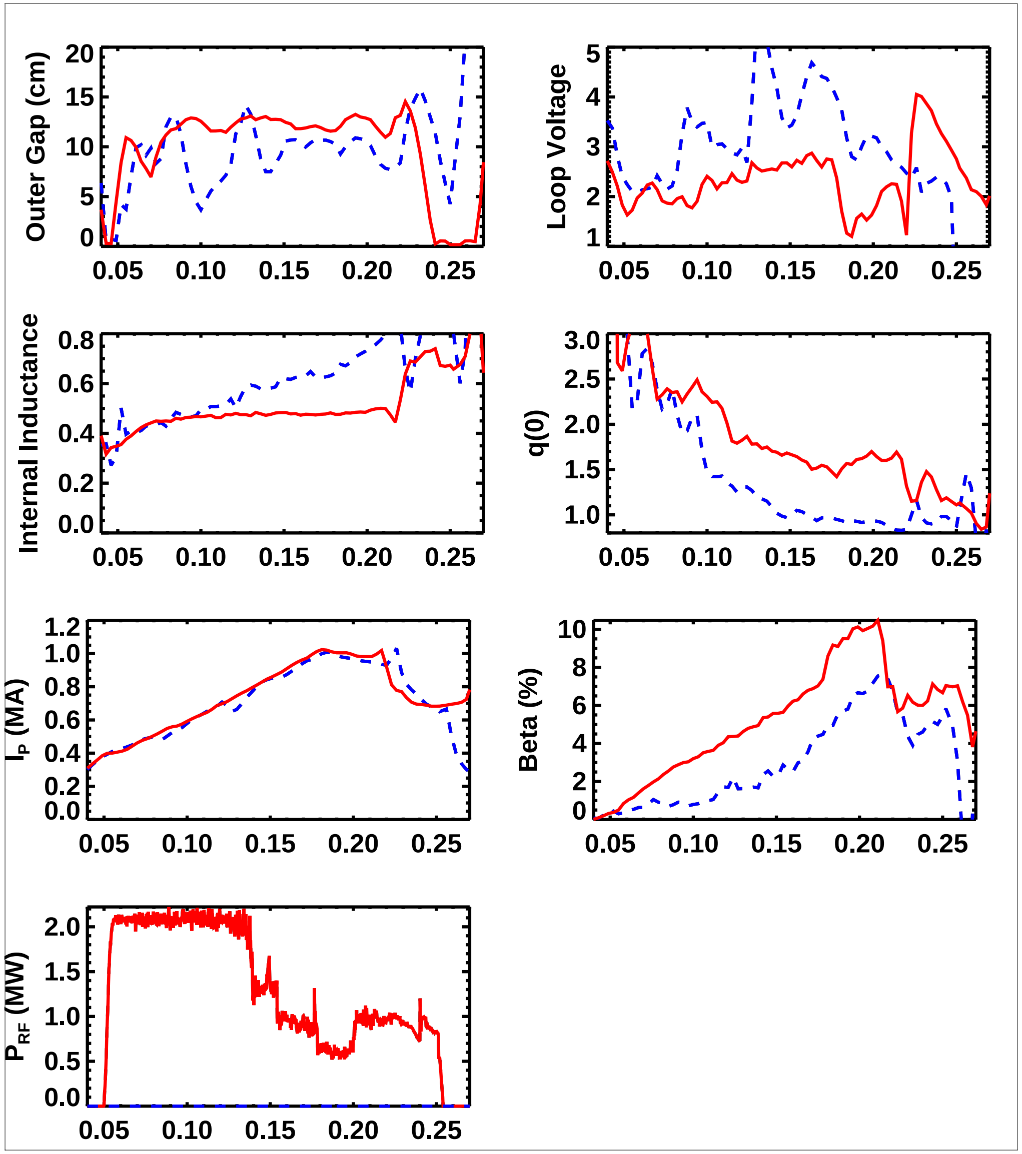
- Results depend on gap and having all 6 XMTRs
  - Transmitter drop-outs modify spectrum and Power

Typical shot with HHFW-elevated q(0)



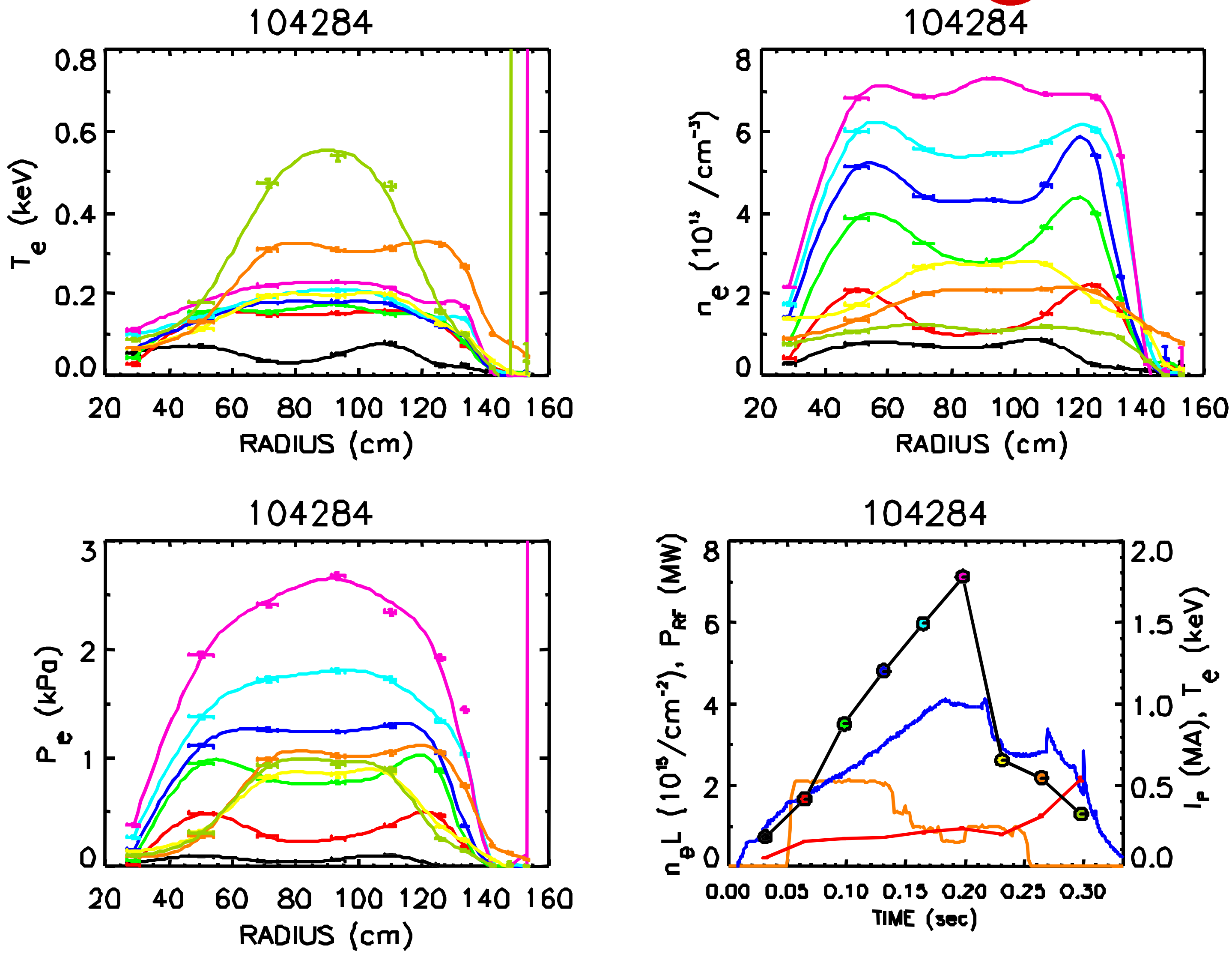
- 7 shots with significant change in q(0), l_i
- These shots have P_{RF} (t=50ms) = 2MW
- Lower powers did not have gap scan
- Higher power (3MW) not tried at all

Early HHFW lowers V_{LOOP} & raises q(0)

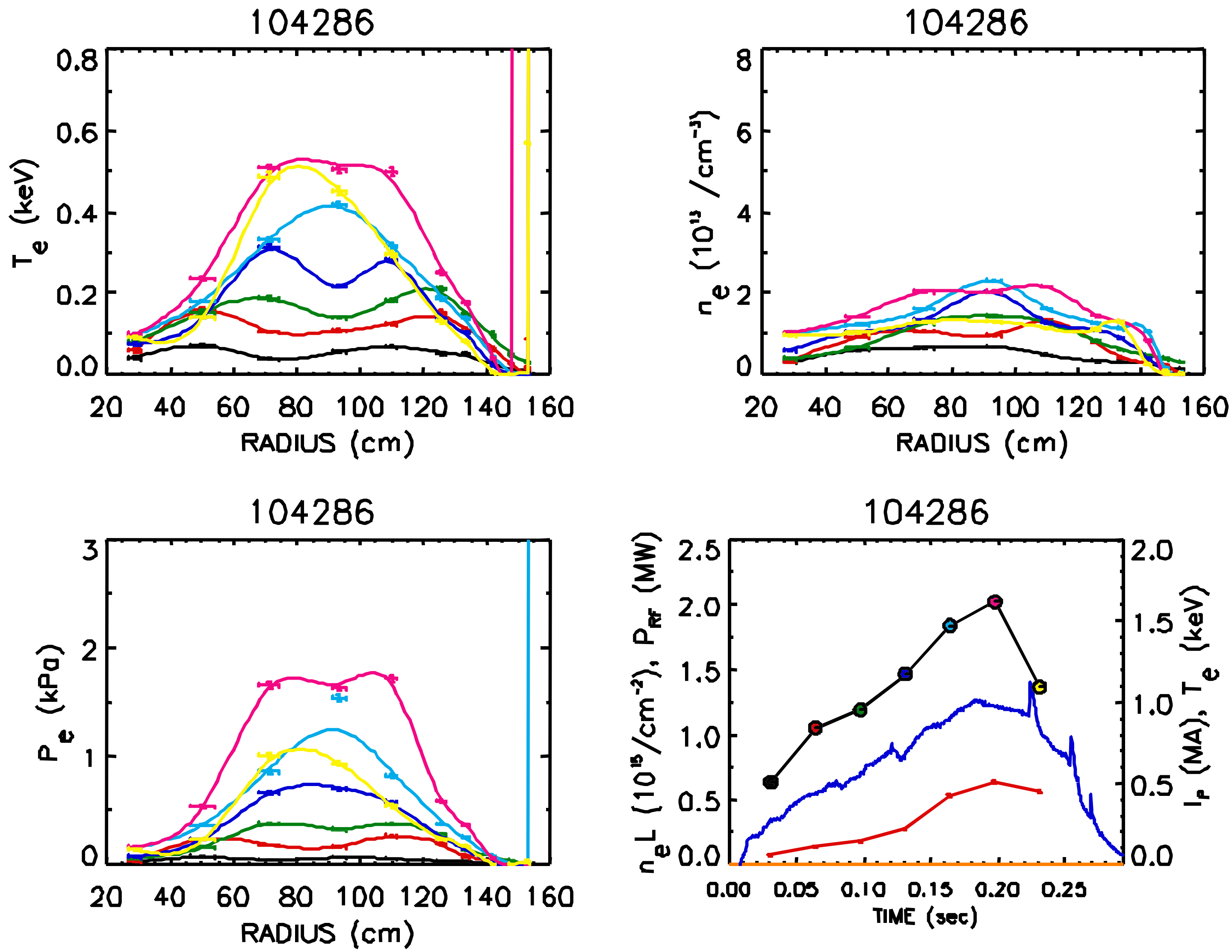


Result requires outer gap of 10 cm - smaller gap leads to larger temperature and smaller density increase with less effect on q(0)

STRONG DENSITY INCREASE OBSERVED WITH EARLY HEATING



OHMIC COMPARISON



ET3 SUMMARY

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HHFW Campaign has made significant strides in the past year

- System brought into full operation
  - Power to 4 MW
  - Complete tuning and matching system utilized
  - Phasing capabilty demonstrated
  - Operation compatabile with wide gap range

- Electron heating demonstrated
  - Central electron temperatures of up to 1.2 keV observed

- Use of HHFW as discharge control tool begun
  - Modification of li and q(0) observed

POINTS FOR BREAKOUT DISCUSION

Understand heating as function of antenna phasing and species

Understand behavior during early heating

Ion absorption

Utilization with NBI

Current Drive

EBW