HHFW OVERVIEW

NSTX

J. R. Wilson for the HHFW Team

NSTX RESEARCH RESULTS

September, 19, 2001

Princeton, NJ

PSFC MIT ornl PPPL PRINCETON PLASMA PHYSICS LABORATORY UCSD JOHNS HOPKINS UNIVERSITY

Physics Goals of the 2001 Campaign

- **Further explore Heating physics**
  - Phasing dependence
  - Species dependence
  - Deposition profile
- **Begin ion interaction studies**
  - Thermal ion temperatures
  - Fast ions
  - Interaction with nbi
- **Continue use of HHFW as tool**
  - Early heating to modify discharge evolution
  - Electron heating for transport studies

Technical Goals of 2001 Campaign

- **Increase RF power and pulse width**
  – Meet 6MW milestone
- **Demonstrate phasing capability required for current drive**
- **Continue investigations of launched antenna spectrum**
  – Measure high power s parameters
- **Add dedicated fast camera viewing antennas**

Physics results from 2001 campaign

- **Electron heating observed under a wider variety of conditions (Wilson, LeBlanc)**
  - Heating similar in D and He^4
    - Previous Differences seem related to discharge difference not species
  - Phasing dependence still observed
    - “Faster” phasings still show smaller central T_e
    - Current drive phasings heat the same as balanced
  - Modulated rf power used to measure deposition profile
    - Appears to be complicated by electron energy transport physics

New areas of heating investigation found

- **Very large values of central T_e found**
  - Deuterium plasmas
  - Possible electron energy transport Barrier (LeBlanc)
- **HHFW driven H modes found**
  - Both elm free and elmy H modes observed
  - Lower current and Toroidal Field than NBI H modes
  - Diverted plasmas only

Interaction between HHFW waves and ions observed

- **Interaction between HHFW and NBI observed (Rosenberg)**
  - Ions accelerated to 140 keV
  - Neutron rate increases
  - HPRT code indicates ~50 % of rf power absorbed on beam ions
  - May explain reduction in effective electron heating when NBI combined with early HHFW

High power phasing tests for current drive begun

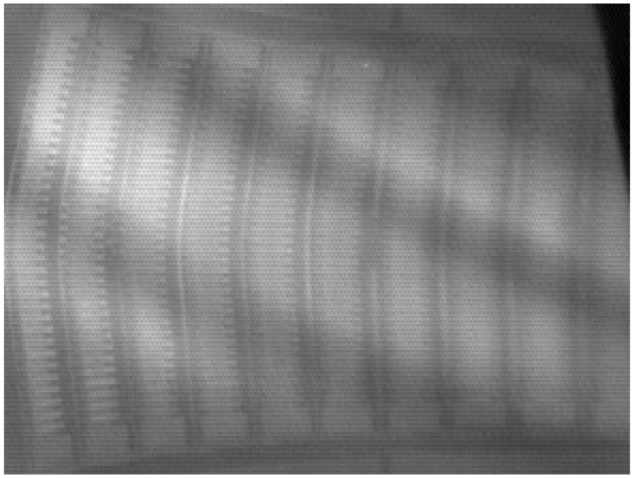
- **Discharges with Co, counter and balanced rf investigated (RYAN)**
  - Similar heating for all phasings
  - Reproducible matching for all phasings
    - Small differences but reproducible so that can vary the phase from shot to shot
  - No obvious differences in loop voltage evolution
    - Difficult to obtain a long steady shot
    - Need MSE

Technical achievements of 2001 run

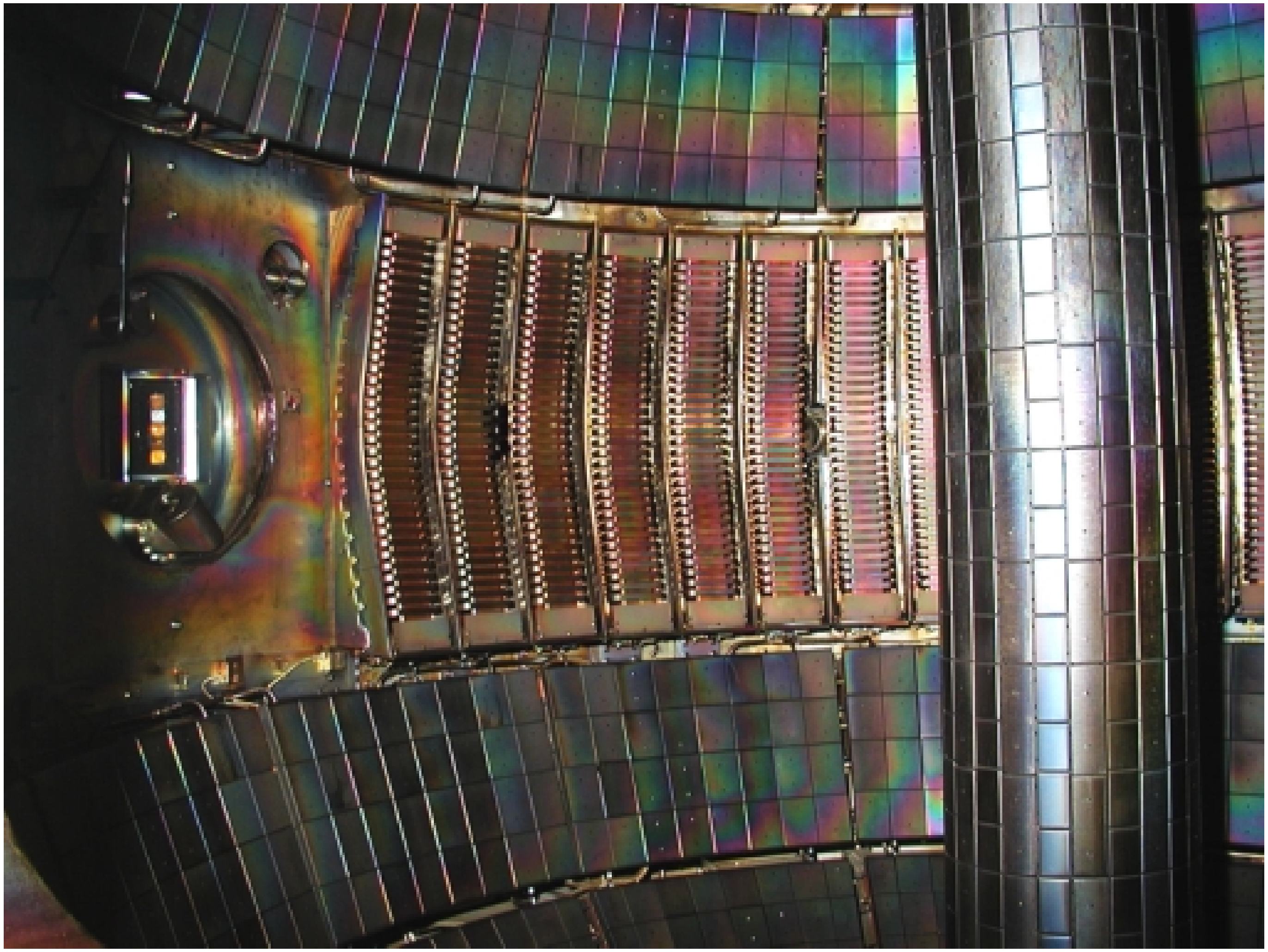
- **Full power milestone met**
  - 6 MW for 30 ms
  - Routine operation at 3-4 MW for 200+ ms
    - Sufficient for physics experiments
- **Four different antenna phasings used**
  - Balanced slow phasing (14 m^{-1})
  - Co, counter, balanced fast phasing (7 m^{-1})
- **Closed loop phase feedback from antenna started**
  - Two transmitters in vacuum

Technical achievements (cont)

- **Detailed measurements of antenna response at high power in the presence of plasma (Swain)**
  - Asymmetry in launched spectrum depends on I_p and outer gap
- **RF camera in routine operation**
  - Thank you Dan Hoffman



Inspection of antenna after run shows no obvious damage



EBW investigations continue to explore application on NSTX

- **The EBW emission source is radially localized (Jones/taylor)**
  - The measured B-X conversion efficiency is consistent with theory

- **Use of a local limiter improves mode conversion efficiency (Jones/Taylor)**
  - An order of magnitude increase in fundamental B-X conversion to T_{rad}/T_e~100%

EBW investigations

- **Waveguide launching of EBW appears feasible (Pinsker)**
  - Poloidal phasing important

HHFW Heating results

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Group

NSTX Run Results 2001

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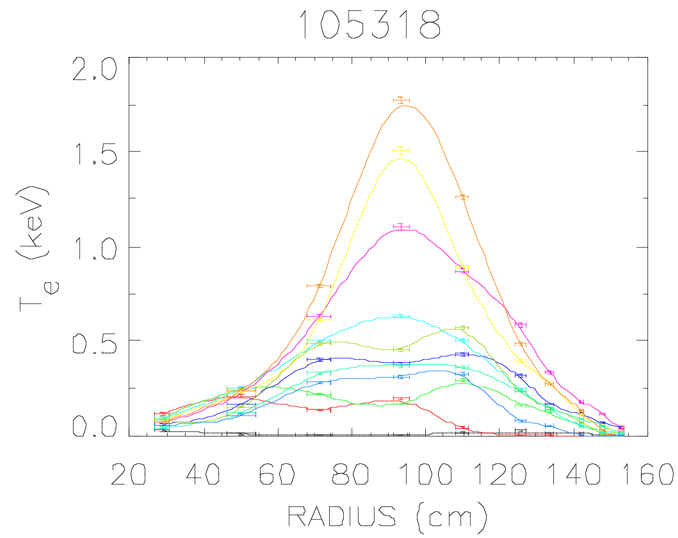
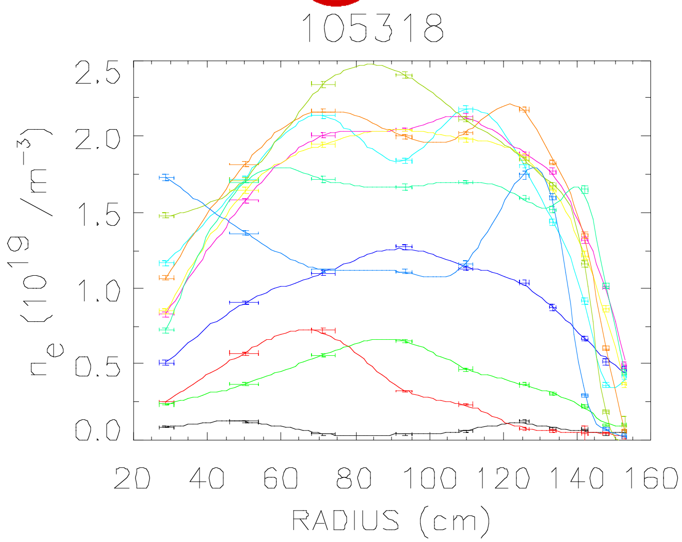
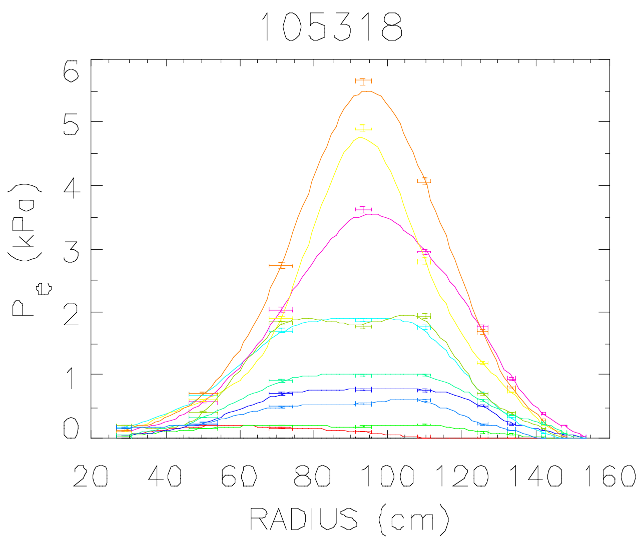
Outline

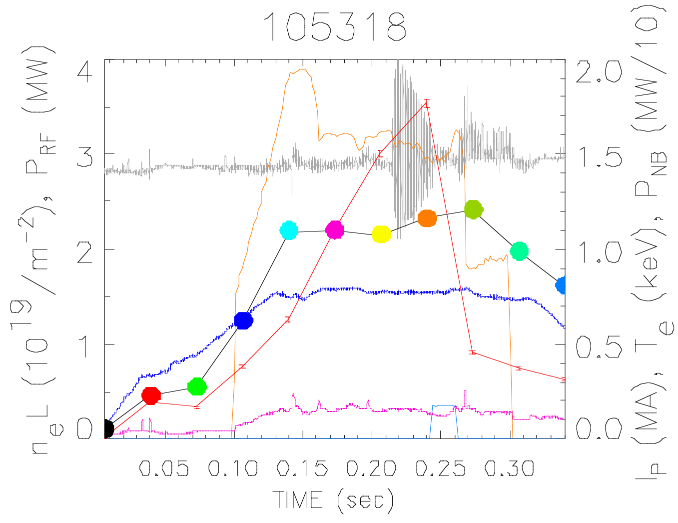
- **Comparison of He and D**
  - – Previously electron heating in deuterium was significantly poorer than in He^4
    - RF theory does not support this
  - – This campaign found similar heating in deuterium at low density
    - Behavior appears to be due to discharge differences between D and He not RF Physics

Electron heating has slow time evolution

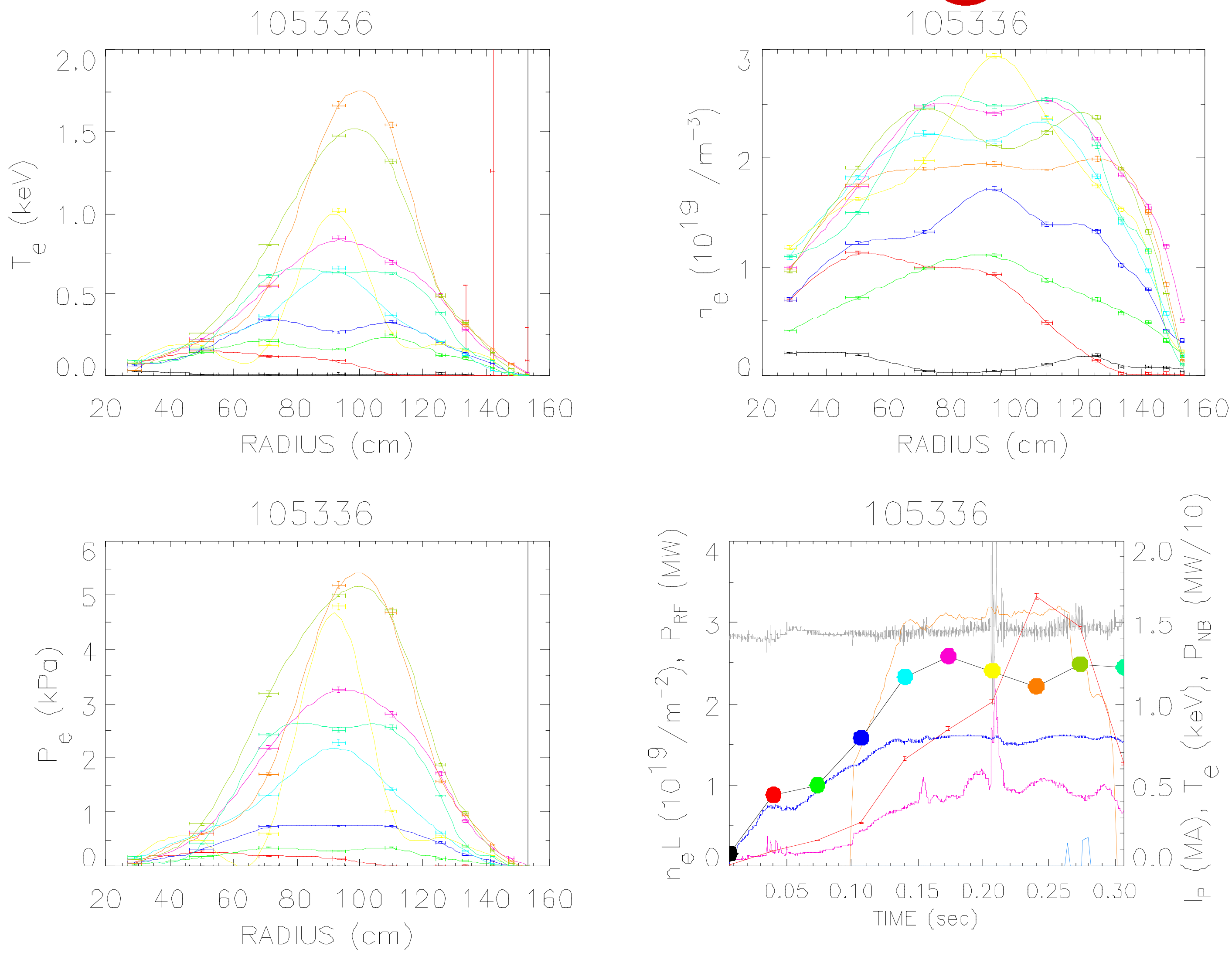








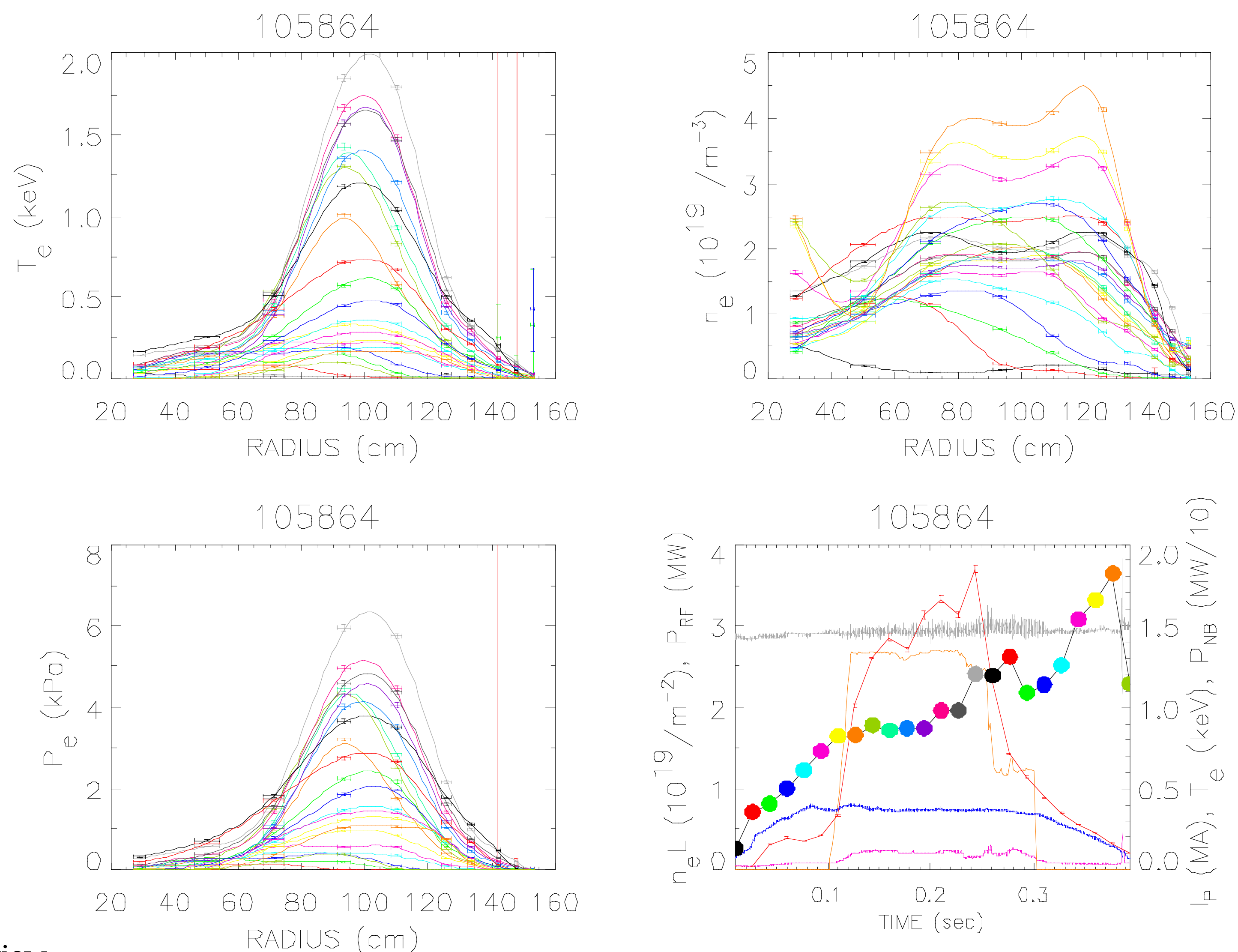
Heating in deuterium similar to helium



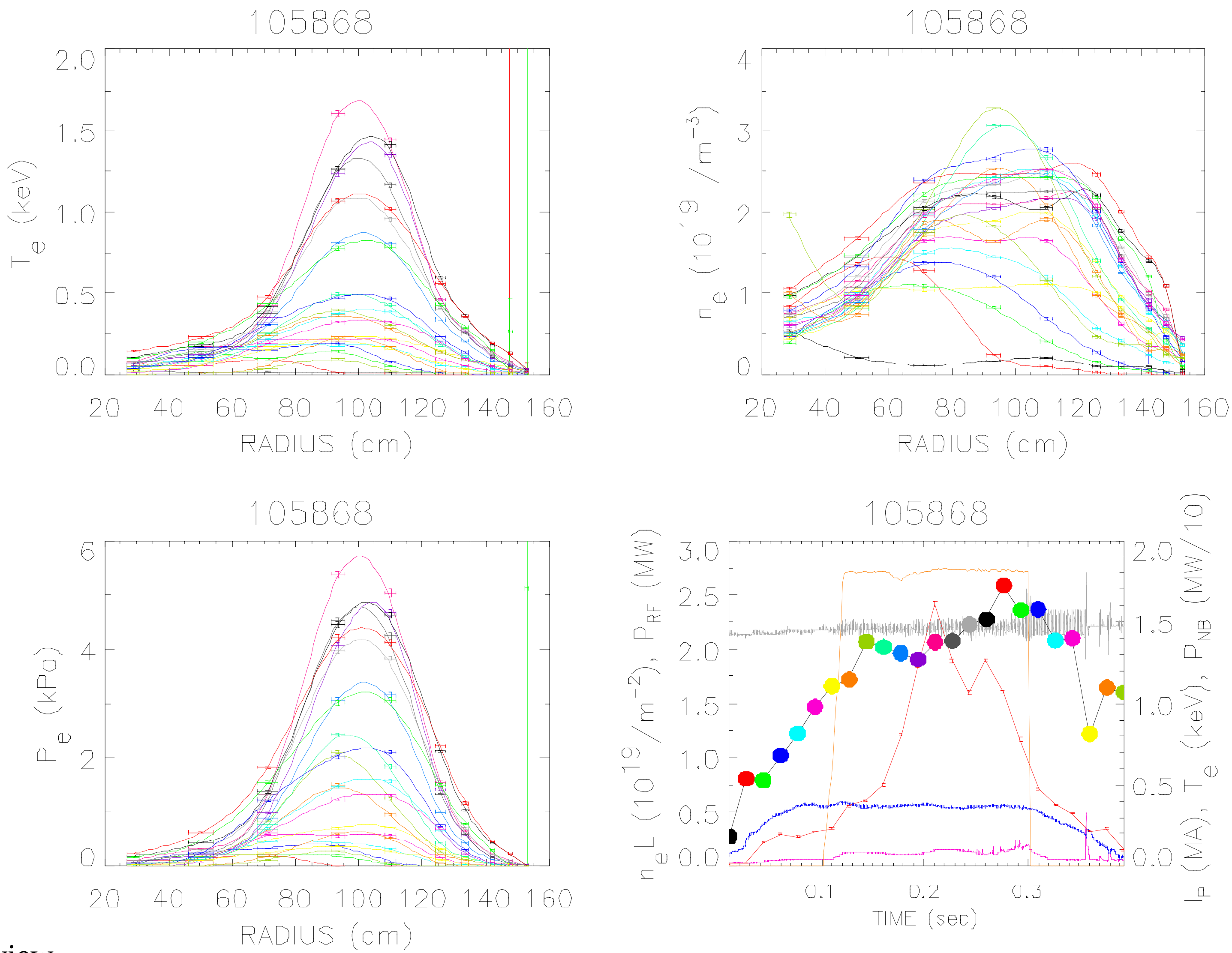
Fast phasing heats plasma

- **Earlier results with limited experience with fast (7 m^{-1}) phasing showed little increase in T_e**
  - Present results show heating, but not as strong

Efficient heating with slow phase velocity



Fast phase velocity nearly as good as slow

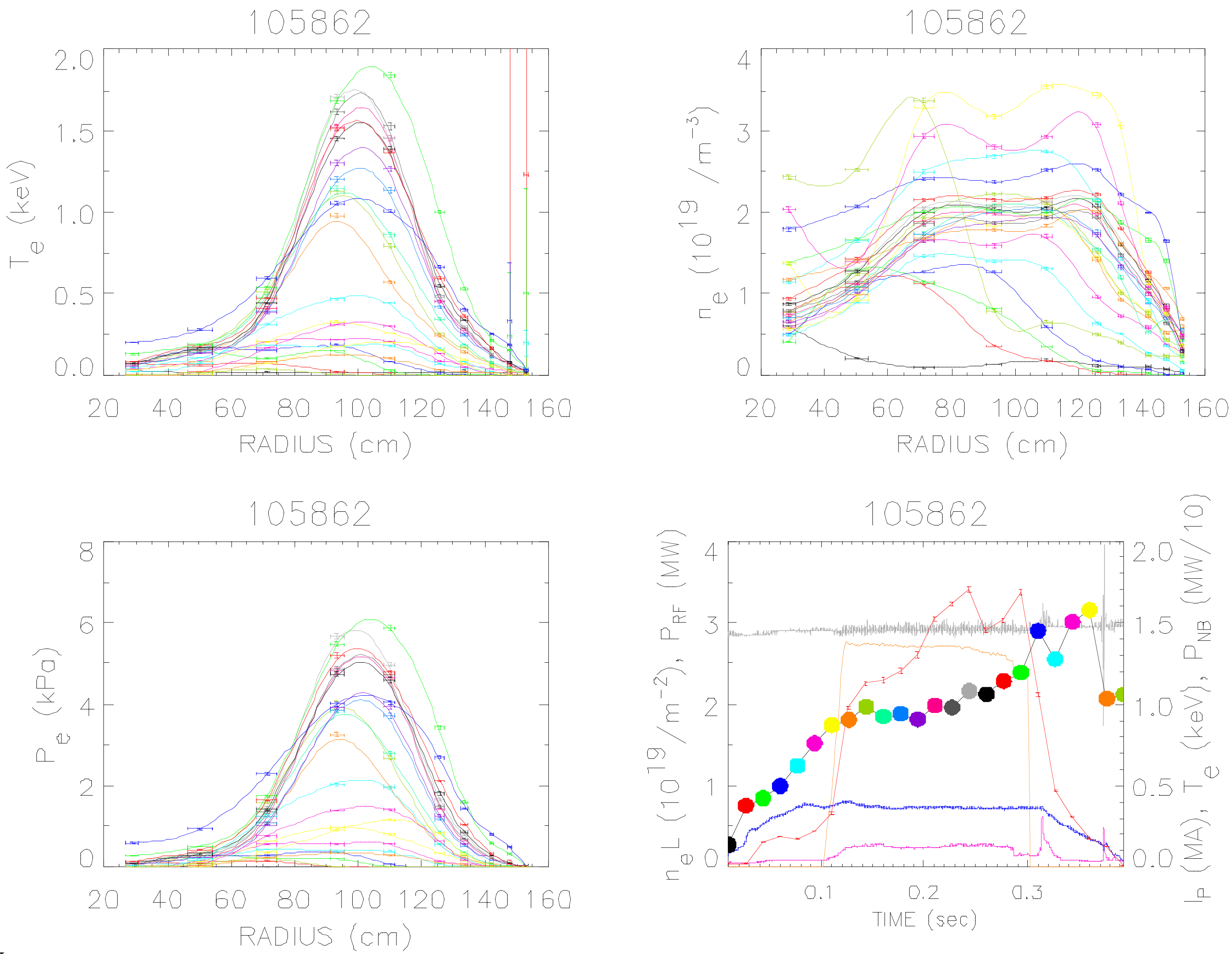


HHFW driven H-modes found

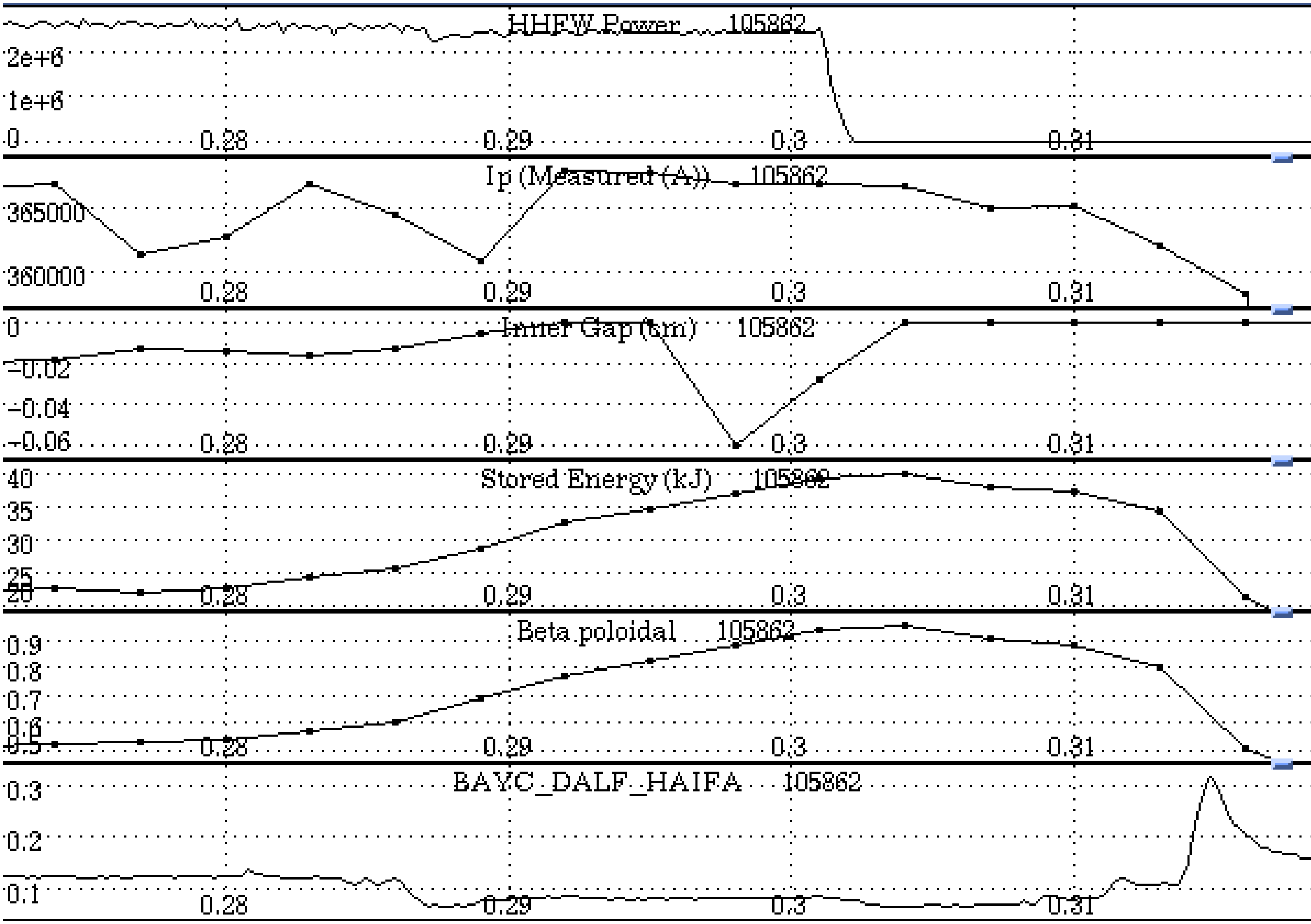
- **As with NBI used LSN plasma**
  - Found at lower current 350-500 kA
  - Found in both He and D
  - Both ELMY and ELM free periods found
  - Large values of β_p produced (0.9)
    - Significant bootstrap current?
    - Surface voltage dips strongly

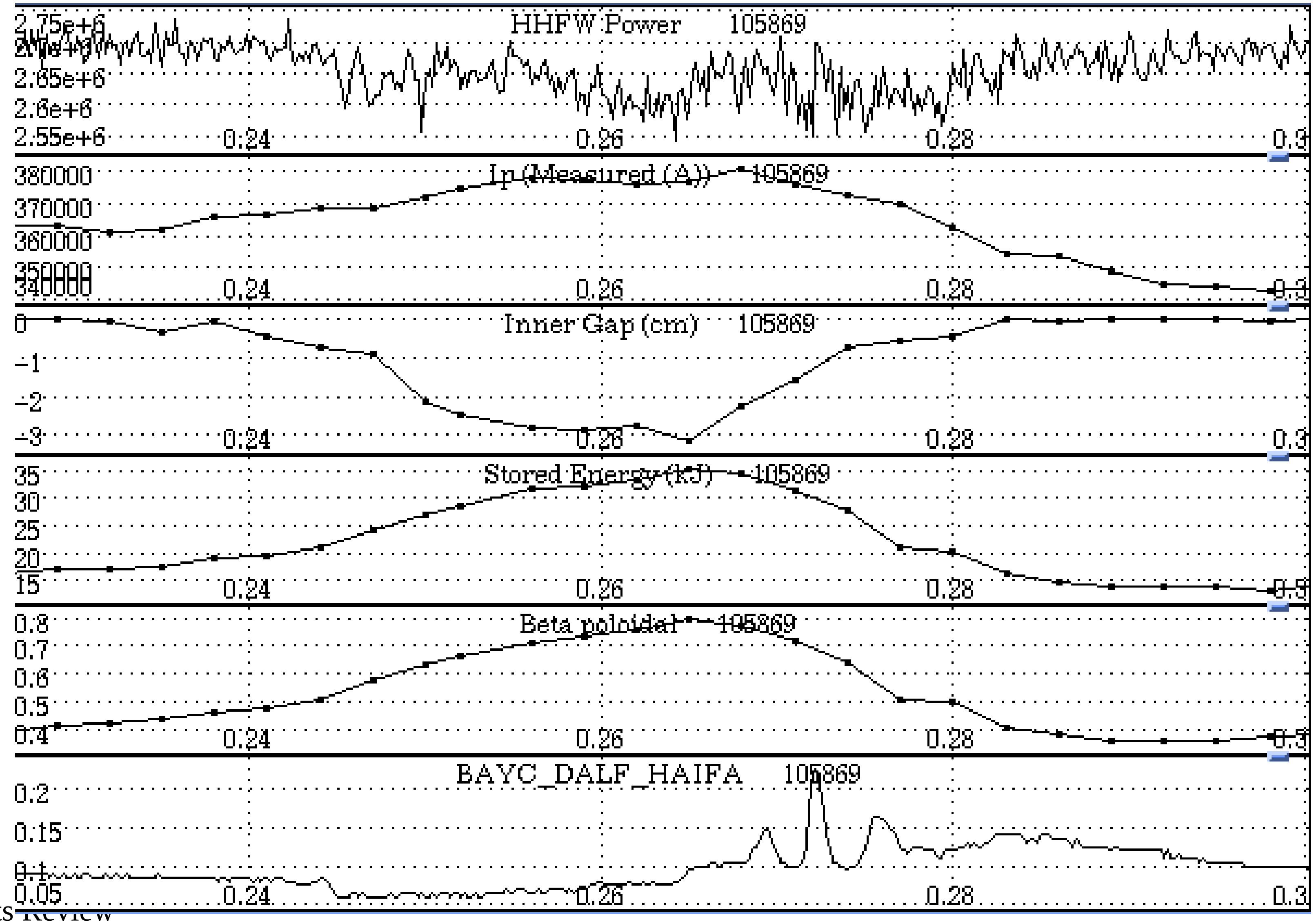
- **Power threshold not determined**

Late H-mode with HHFW alone

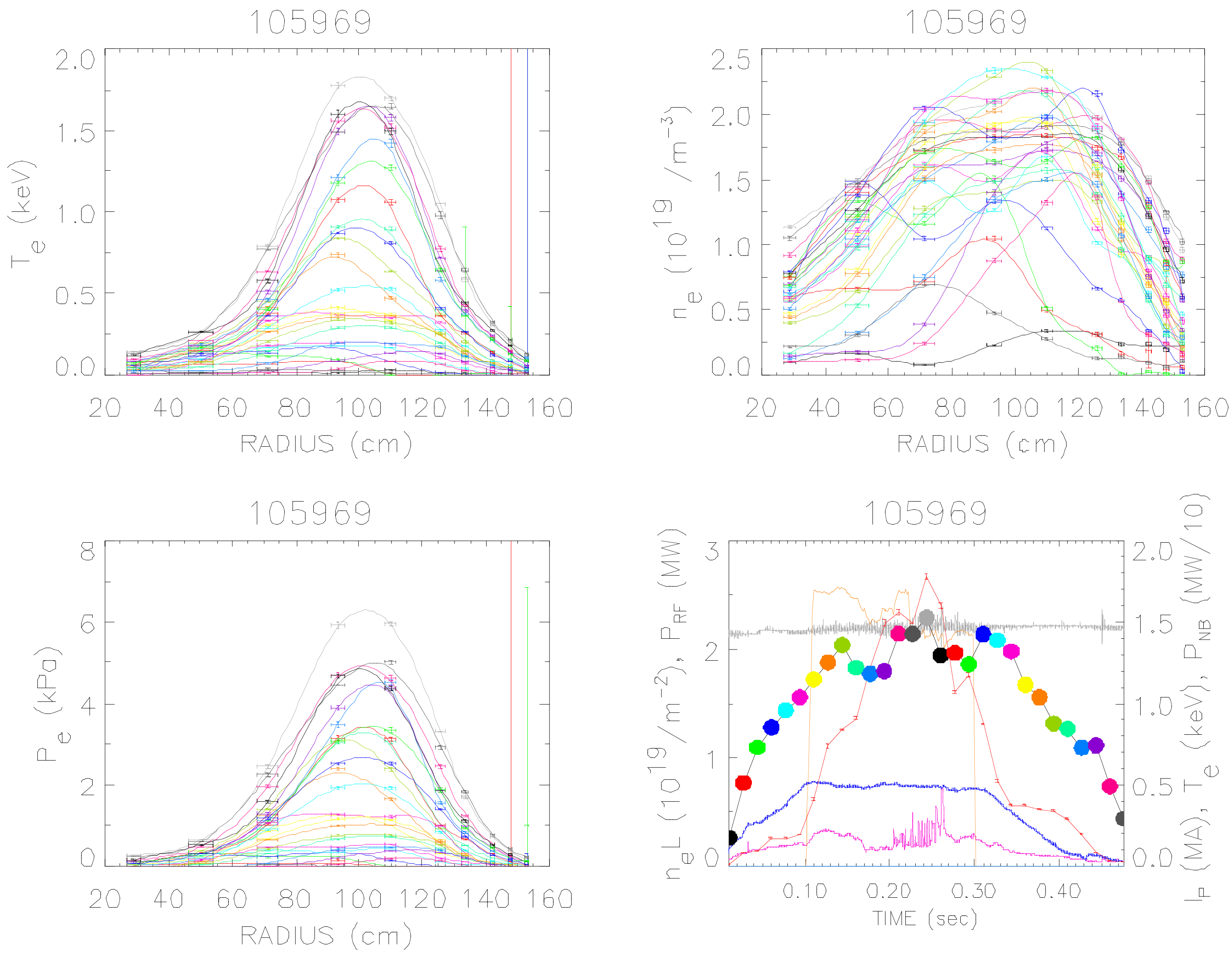


Large increase in β_p

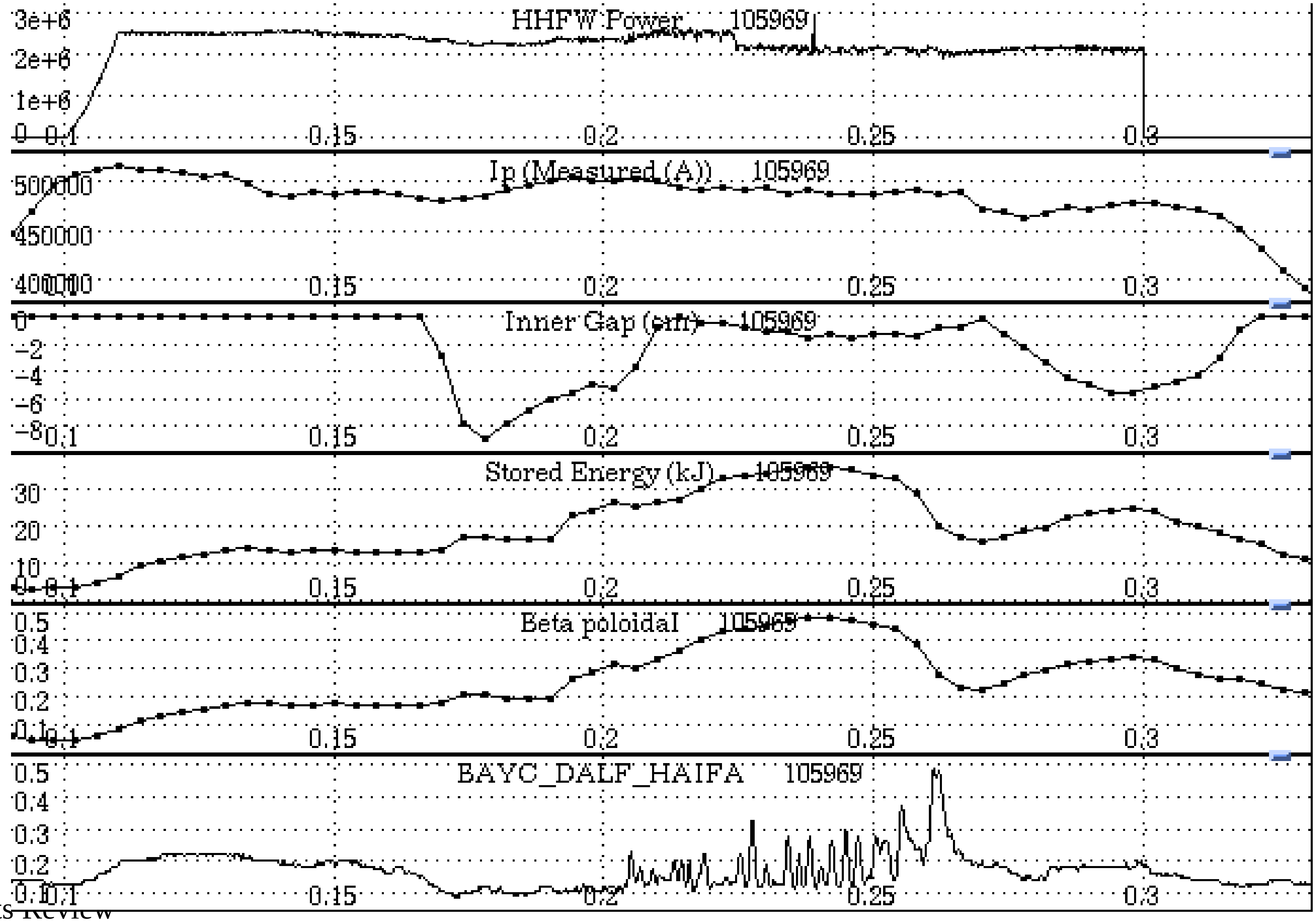



HHFW Power 105869
2.75e+6
2.65e+6
2.6e+6
2.55e+6
Ip (Measured (A)) 105869
380000
370000
360000
350000
340000
Inner Gap (cm) 105869
0
-1
-2
-3
Stored Energy (kJ) 105869
35
30
25
20
15
Beta poloidal 105869
0.8
0.7
0.6
0.5
0.4
BAYC_DALF_HAIFA 105869
0.2
0.15
0.1
0.05
0.24
0.26
0.28
0.3

Long Elmy H-mode



100 ms H-mode at 500 kA



Summary

- **Electron heating more robust during this run**
  - Observed in D and He
  - Observed for four different antenna phases
- **HHFW driven H-modes found**
  - Parameter space of H-modes needs to be established
  - Large β_P low voltage H-modes may allow longer quasi steady state pulses