Edge Ion Heating by Launched HHFW in NSTX

T.M. Biewer, R.E. Bell, S. Diem, P.M. Ryan, J.R. Wilson

In 2003 run campaign, during the application of HHFW power, edge ions were observed to heat to high temperatures; 500 eV at 2 cm in from the LCFS.

The 2004 run campaign: greatly expanded number of ERD measurements, with many successful RF experiments, and with new diagnostics (swept Langmuir probe, CHERS, visible camera).

Edge ion heating is observed whenever significant HHFW power is applied; for 3.5, 7, 14 m^{-1} phasing, D_2 & He plasmas, in He II and C III edge ions.

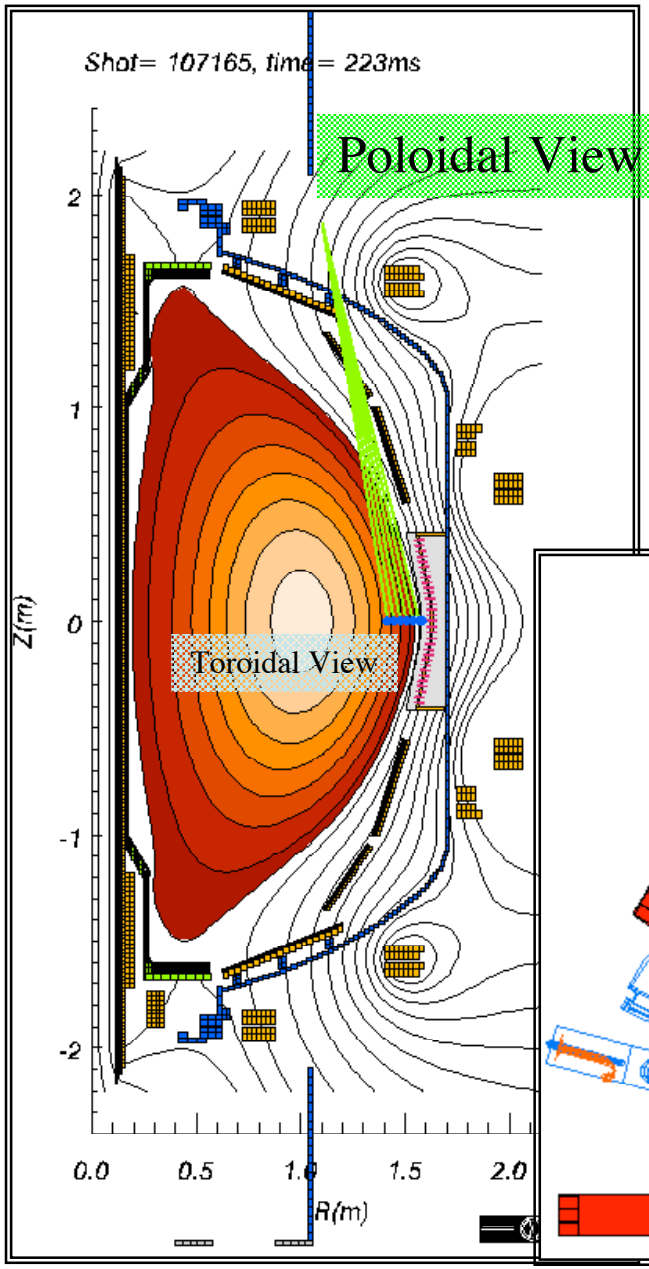
IBW heating identified as a plausible explanation for edge ion heating.

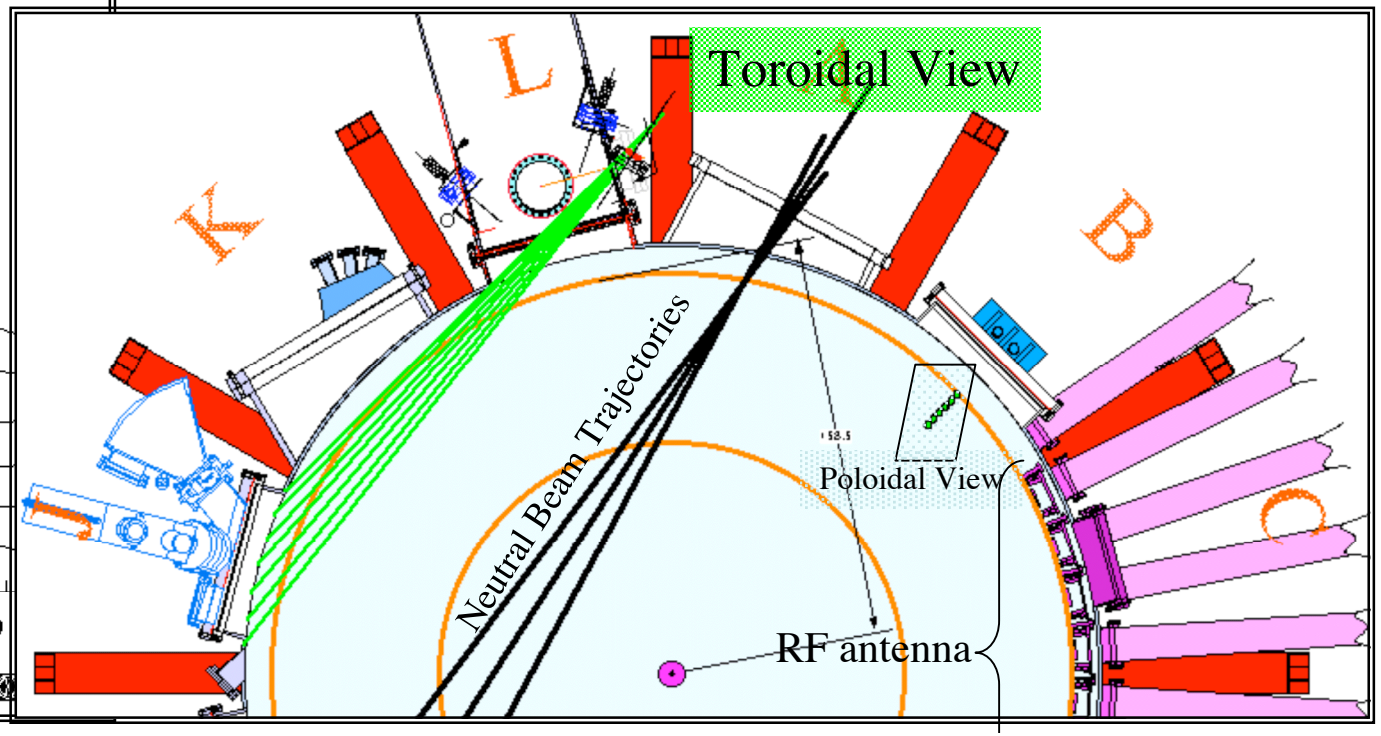
Introduction/Outline

- More extensive ERD data set from 2004 run.
- Distortion to the edge He II and C III spectra.
- Distortion correlates with application of HHFW.
- Edge C III emission increase x10.
  - Visible camera images show enhancement of emission in front of RF antenna.
- Edge T_i and v scale with applied RF power.
- Heating observed in many cases.
- IBW heating is plausible explanation.

Edge Rotation Diagnostic

- 10 ms time resolution
- 7 toroidal and 6 poloidal sightlines cover 140 to 155 cm at the outboard midplane.
- Sensitive to intrinsic emission light of C III, C IV, and He II.
- Measures velocity, temperature, and brightness of edge ions.
- Spectral resolution of 0.22 Å/pixel with 75 μm slits.
- http://w3.pppl.gov/~tbiewer/ERD_RSI.pdf



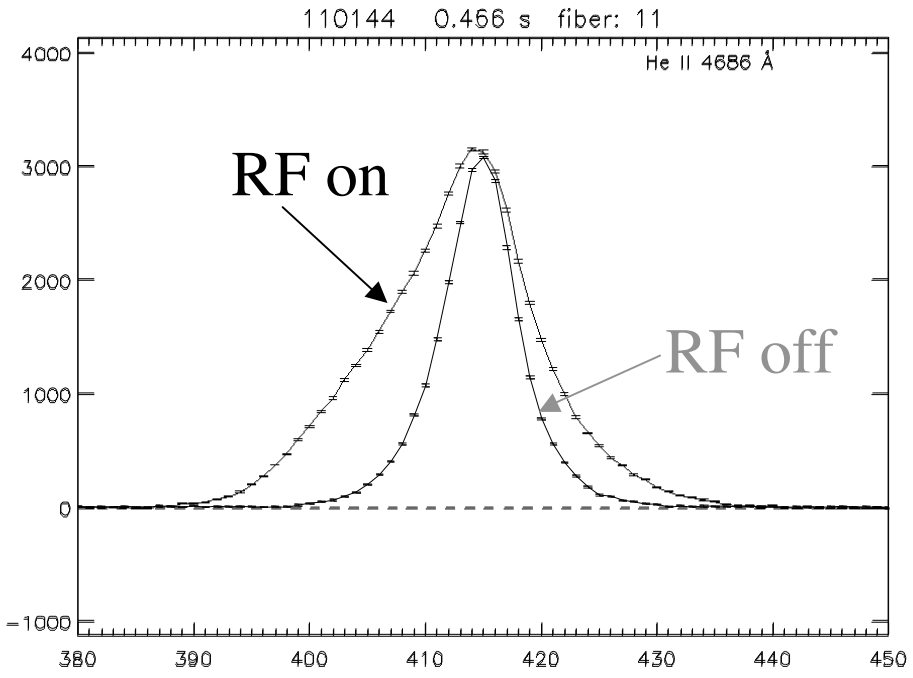


RF Power heats edge ions.

Two successive time frames clearly show the spectral consequences of 30 MHz HHFW heating (4.3 MW input) on the edge plasma.

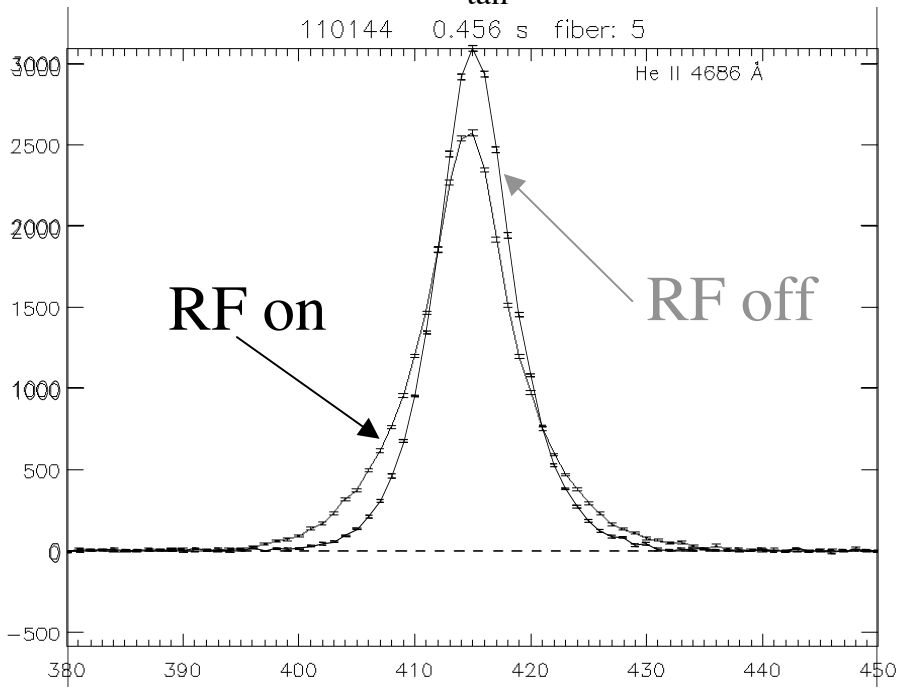
This effect is apparent in edge C (impurity) ions and He (bulk) ions.

Poloidal, r_{tan}~146 cm



Pixel # (~λ)

Toroidal, r_{tan}~146 cm

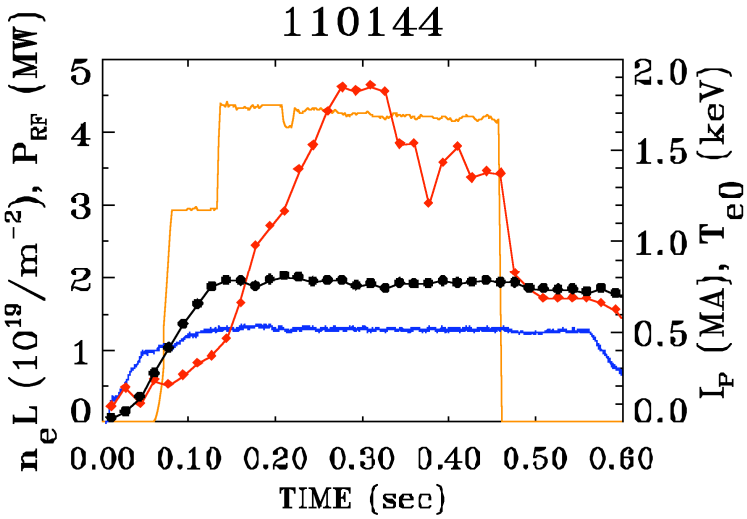


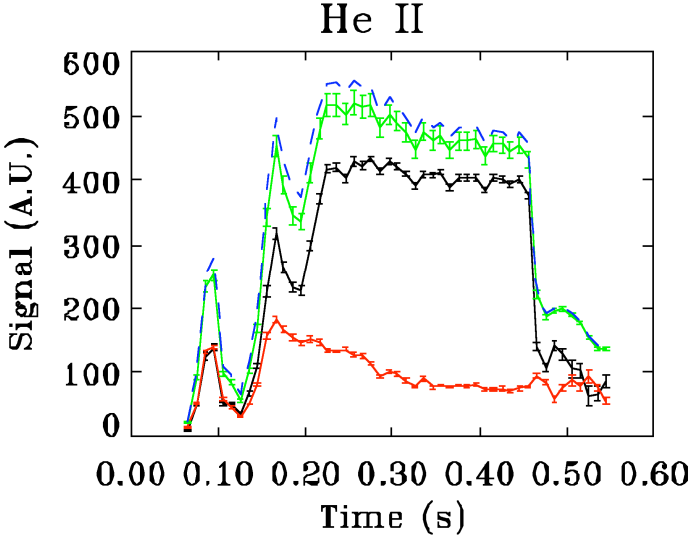
Pixel # (~λ)

Data is best fit with 2 Gaussian distribution function (hot and cold components).

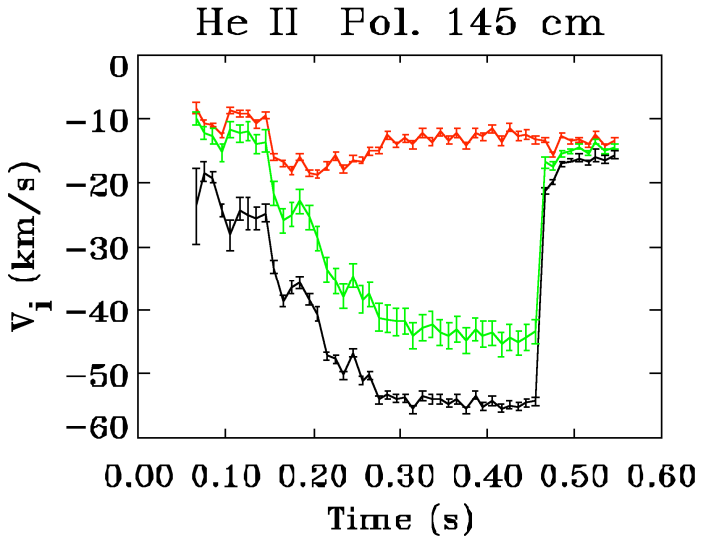
Core e⁻ and edge ion heating is observed.

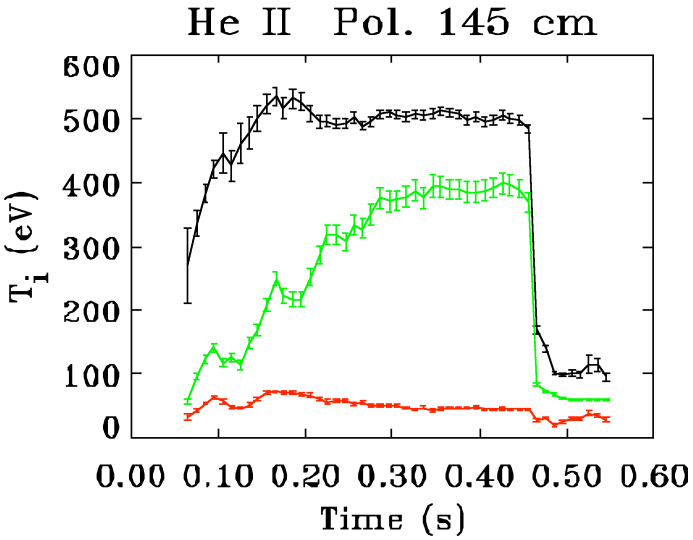
The launched HHFW is expected and observed to heat edge electrons, but hot edge ions are also observed.





1G fit
2G high
2G low

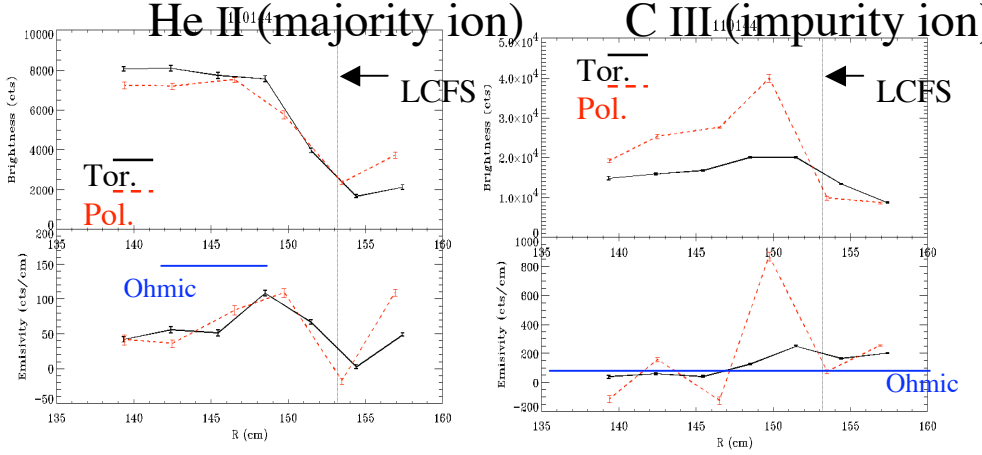




Edge light emission increases.

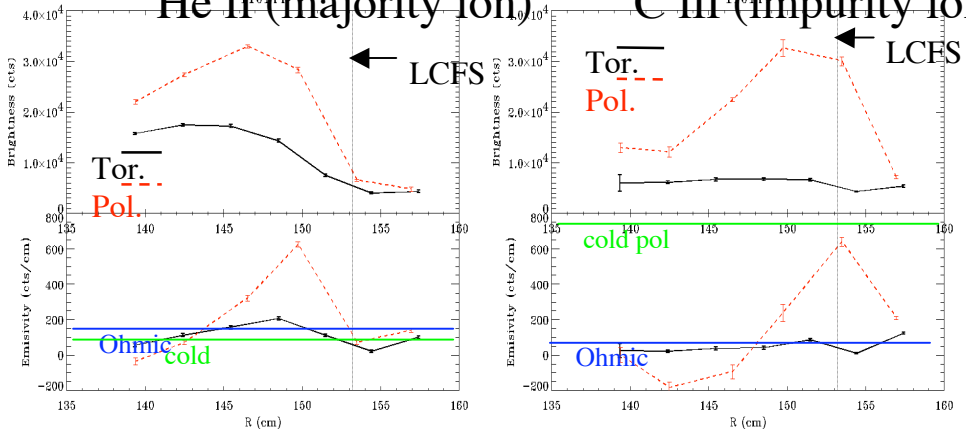
RF (cold) Brightness

He II (majority ion) C III (impurity ion)



RF (hot) Brightness

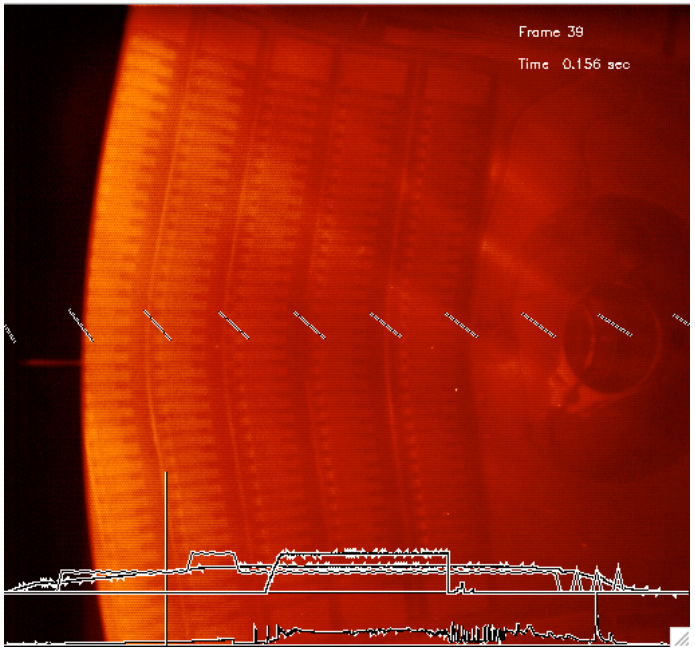
He II (majority ion) C III (impurity ion)



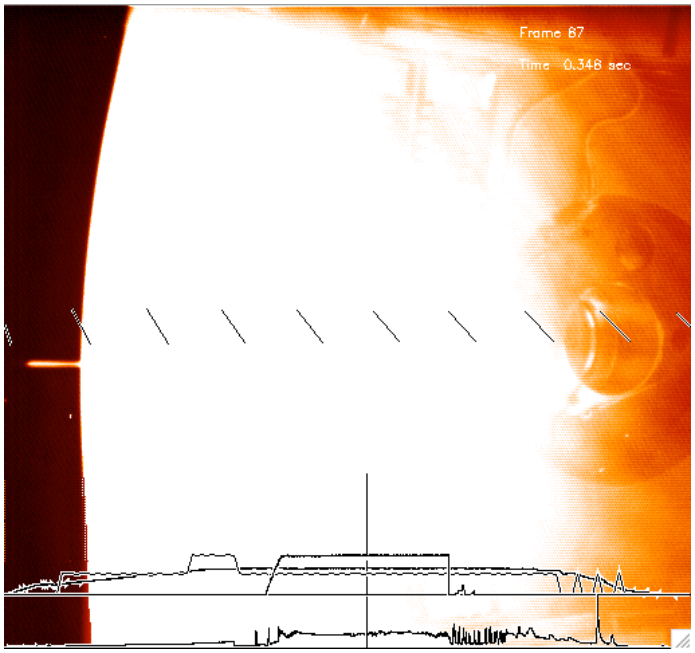
- The powered RF antenna acts as a source of neutral particles at the edge of the plasma.
  - In the poloidal view (~20 cm from the RF antenna toroidally) the brightness of C III increases by a factor of 10.
  - In the toroidal view (~2 m from RF antenna toroidally) the brightness of C III increases by a factor of 3.
- Charge exchange with these antenna sourced neutrals allows the formerly fully-stripped, hot helium ions to be seen by the ERD.
  - "Hot" component represent He^{2+} dynamics.
  - "Cold" component represent He^{+} dynamics.
- Time scales allow two populations to exist simultaneously in non-equilibrium:
  - Emission: ~1 ns.
  - Ionization of hot He^{+}: ~100 μs.
  - Thermalization between hot and cold helium: ~10 ms.

Visible camera confirms antenna emission.

RF off



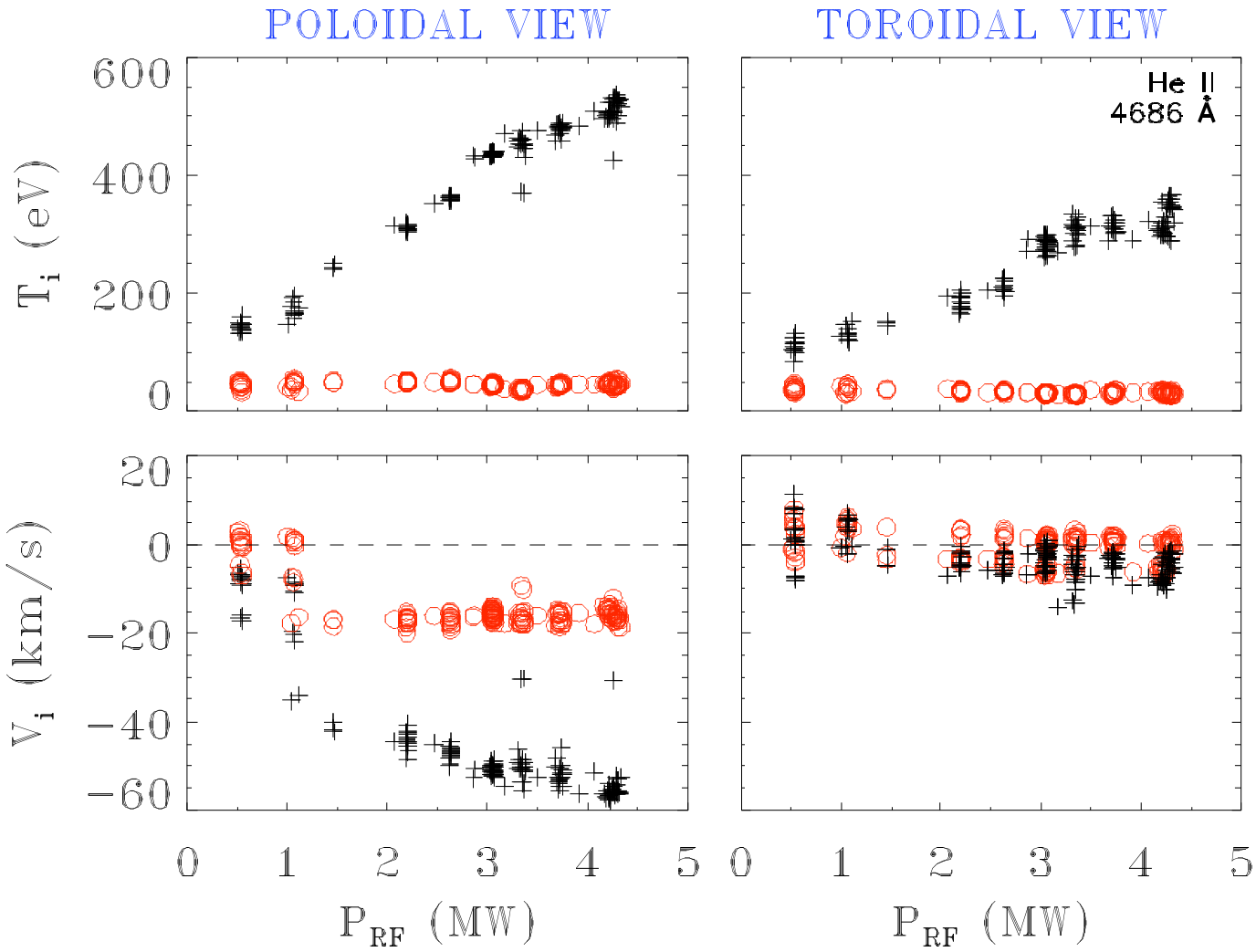
RF on



- Visible camera images show enhanced light emission near the RF antenna when power is applied.
- Diagnostic capability added for 2004 run campaign.

More power leads to more heating.

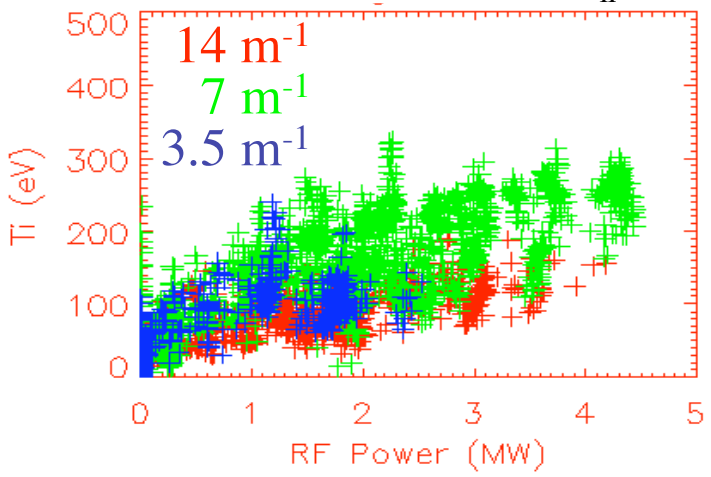
From NSTX Shot 110133 to 110145 the applied RF power was increased.
Empirically, T_i increases as $P_{RF}^{0.47}$.



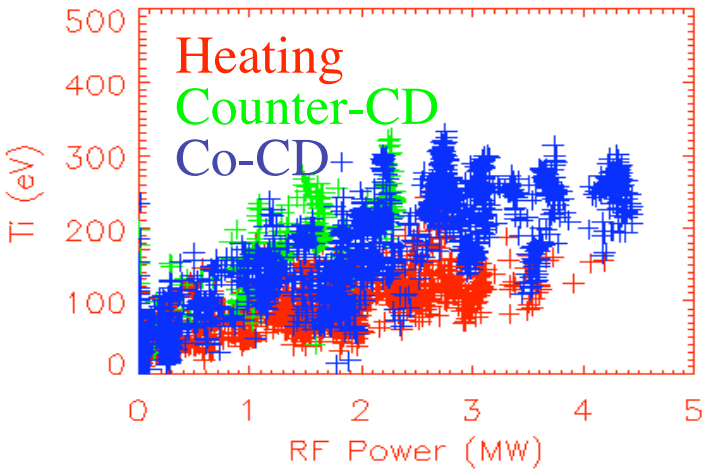
Negative poloidal velocity is upwards on the outboard midplane.
Negative toroidal velocity is opposite to the direction of I_p.

Edge heating observed in many plasmas.

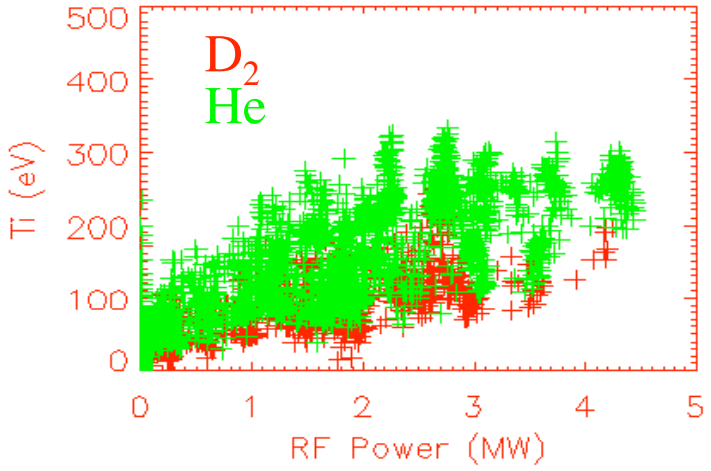
Antenna Phasing ($k_{||}$)



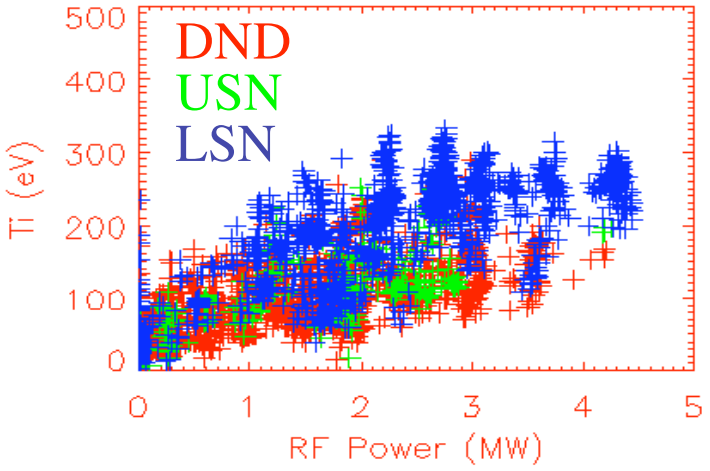
Antenna Phasing



Bulk Gas Species



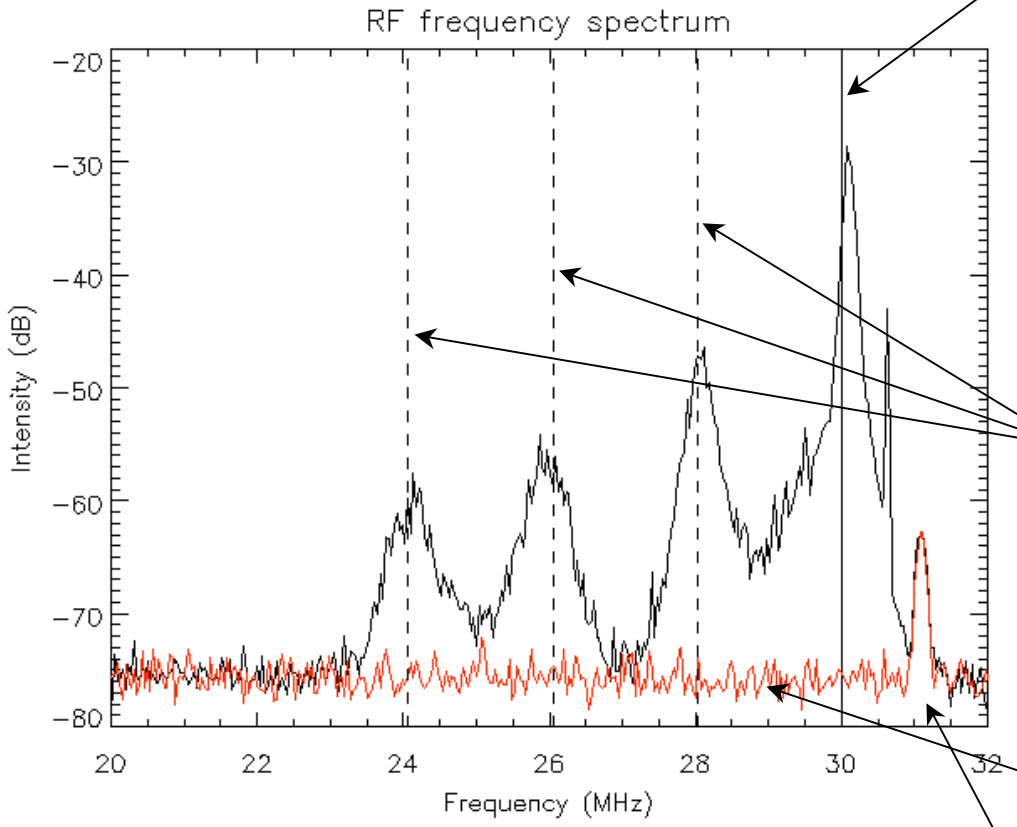
Magnetic Configuration



- 2004 run data spans a wide range of plasma conditions.

IBW heating of edge ions plausible.

See following talk by S. Diem.



The 30 MHz launched HHFW is attenuated in this spectrum with a 40 dB notch filter.

A portion of the HHFW undergoes nonlinear parametric decay into a daughter IBW and an ICQM, which both damp in the outer 10 cm of plasma.

IBW's are observed as lower sidebands of the launched HHFW at the expected frequencies (dashed vertical lines) for the first 3 harmonics of the ion cyclotron quasi-mode.

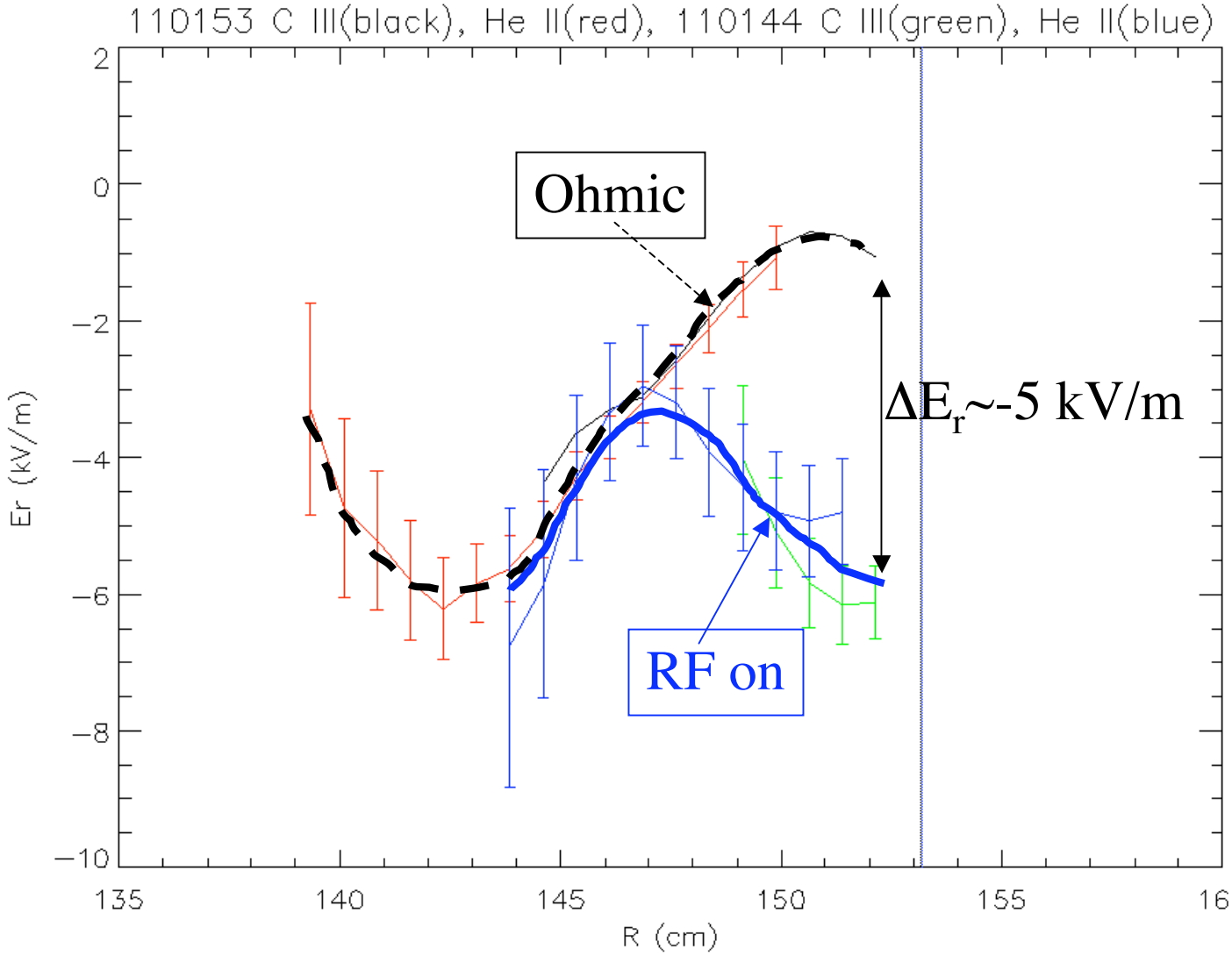
An Ohmic shot (no RF) is shown (in red), indicating the noise-floor of the measurement.

Pick-up from a heterodyne network is present at 31 MHz in both spectra.

Summary

- Distortion to the edge He II and C III spectra, correlated with application of HHFW.
- Edge T_i and v increase with applied RF power.
- More extensive ERD data set from 2004 run always shows edge ion heating when HHFW applied:
  - 3.5, 7, 14 m^{-1}, co-CD, ctr-CD, heating antenna phases
  - Various I_p, B_T, n_e
  - D_2, He plasmas
  - USN, LSN, DND
- IBW edge ion heating is plausible explanation.
  - Parasitic to HHFW heating of core electrons.
  - Consistent with poloidal/toroidal anisotropy

E_r from He II and C III (cold)



Ohmic v. RF heated

The E_r at the edge most region of the plasma (R>146 cm) is more negative during RF heated plasmas than during Ohmic.

For R<146 cm the E_r is similar (for the region measured)

Implies that RF leads to ion loss at the edge of the plasma.