ERD Observations in RF Heated Helium Plasmas

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Princeton Plasma Physics Laboratory

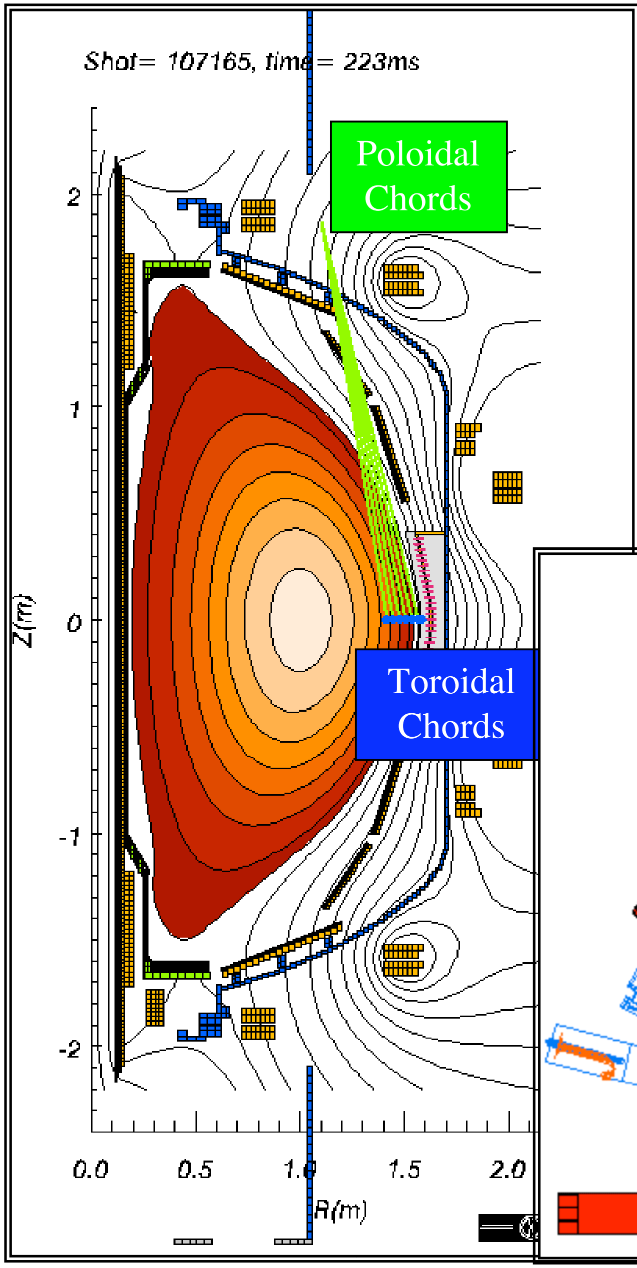
I got married.

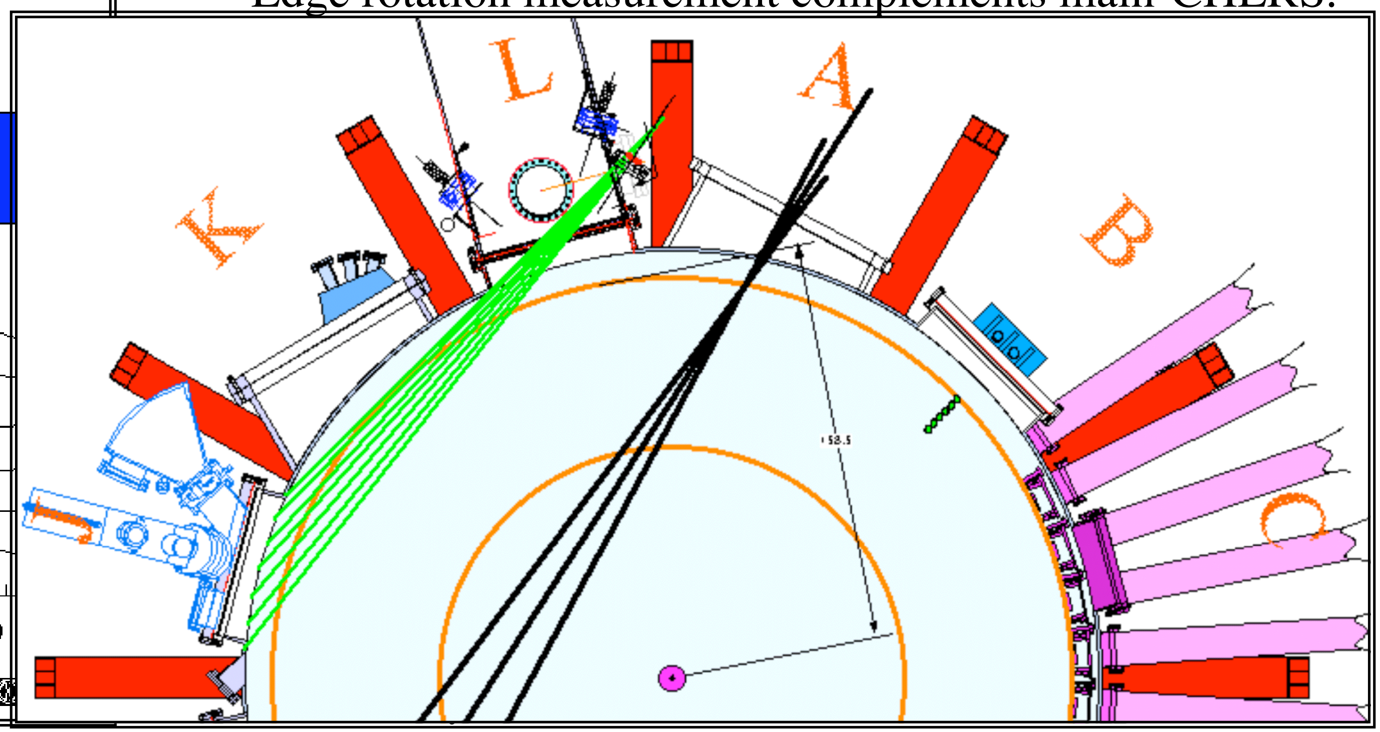
Outline

- The Edge Rotation Diagnostic
- Ohmic, Helium Plasma
  - He (majority ion) and C (impurity ion) dynamics
  - Calculation of E_r from force balance
- RF Heated Helium plasma
  - Cold component comparison to Ohmic plasma
    - RF antenna is a BIG source of C at the edge
  - Hot component dynamics and implications
- Summary

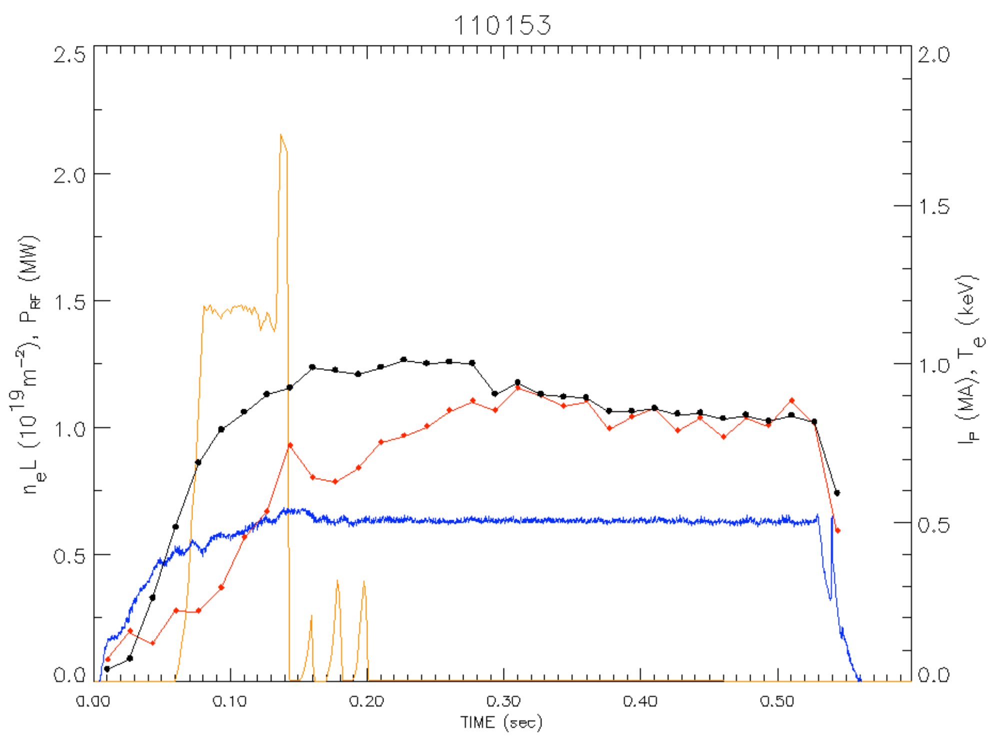
The Edge Rotation Diagnostic

- 10 ms time resolution.
- 6 toroidal and 7 poloidal rotation chords covering 140 to 155 cm.
- Local $E_r = v \times B - \nabla p/eZn$
- Does not require neutral beam.
- Sensitive to C III, C IV (impurity ions), and He II.
- Cold plasma broadens C III emission shell, resulting in possible ∇E_r measurement.
- Edge rotation measurement complements main-CHERS.



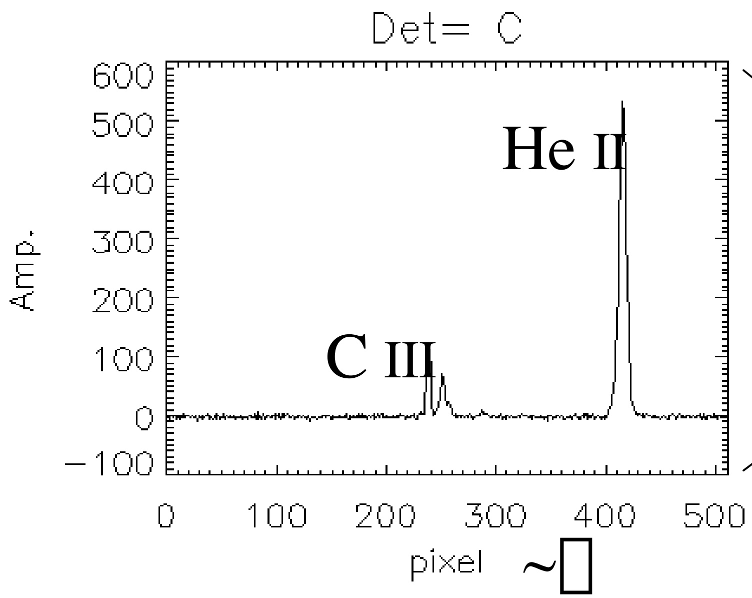


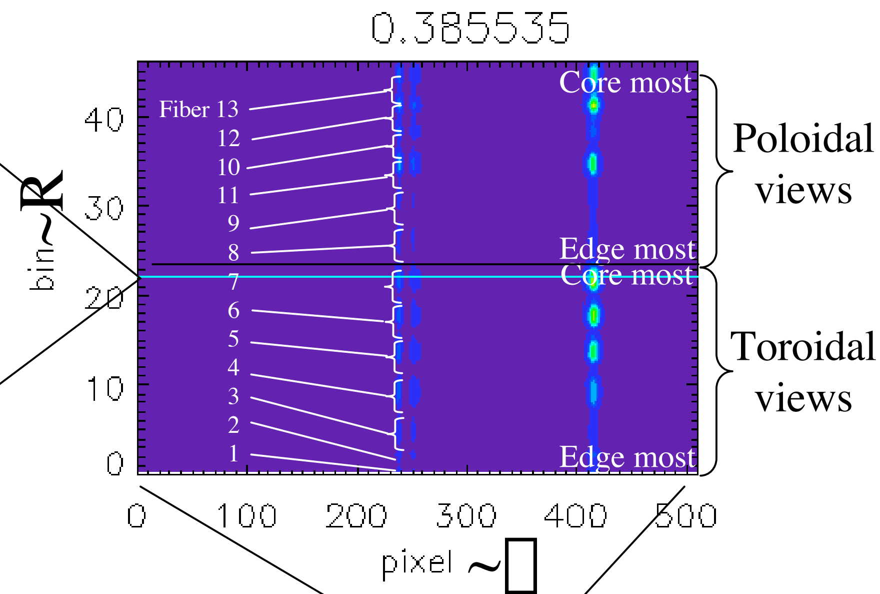
Ohmic He Dischage 110153



- Phil Ryan, et. al RF heating XP
- RF system shut down resulting in an Ohmic, He plasma
- I_p~500 kA, n_e~1.2x10^{19} m^{-3}, T_e~800 eV, B_T~0.44 T

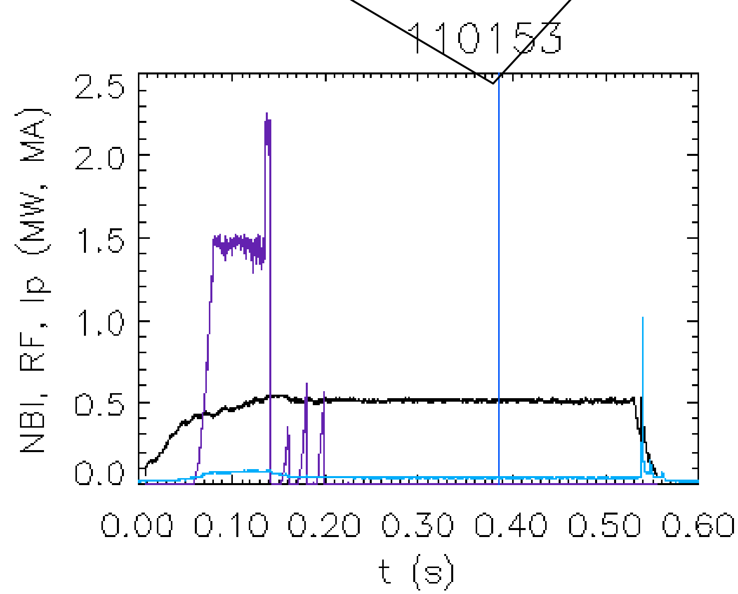
Raw ERD data shows strong He, C light



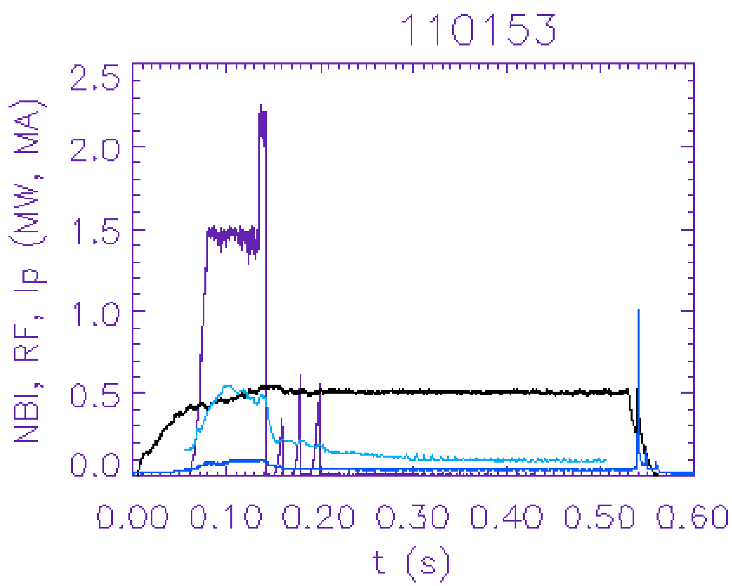


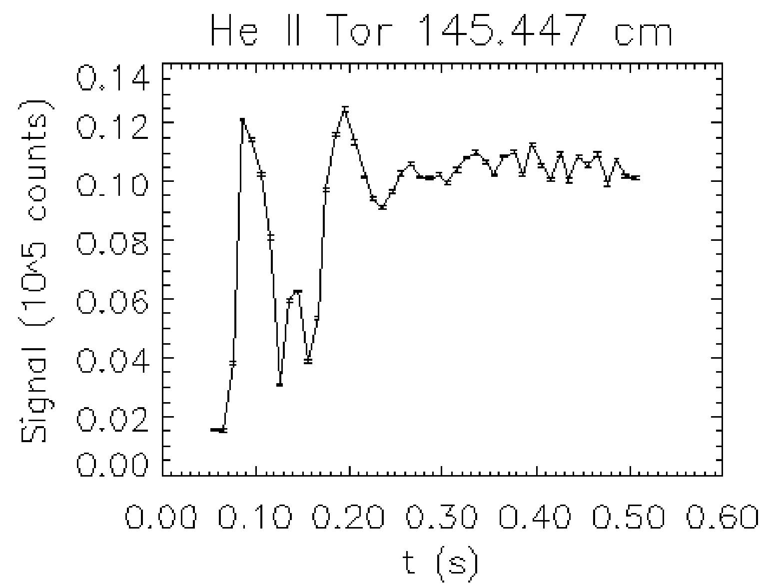
Fit the spectra (He or C)

- Amp.*Width
  - Line brightness
    - Emissivity (inversion)
      - n_z (with ADAS modeling)
- Width
  - Apparent T_i
- Center shift
  - Apparent velocity
    - Local velocity (inversion)

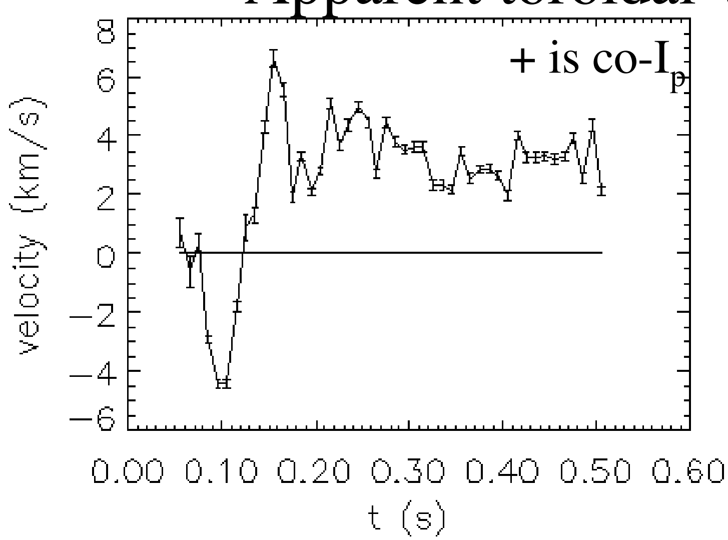


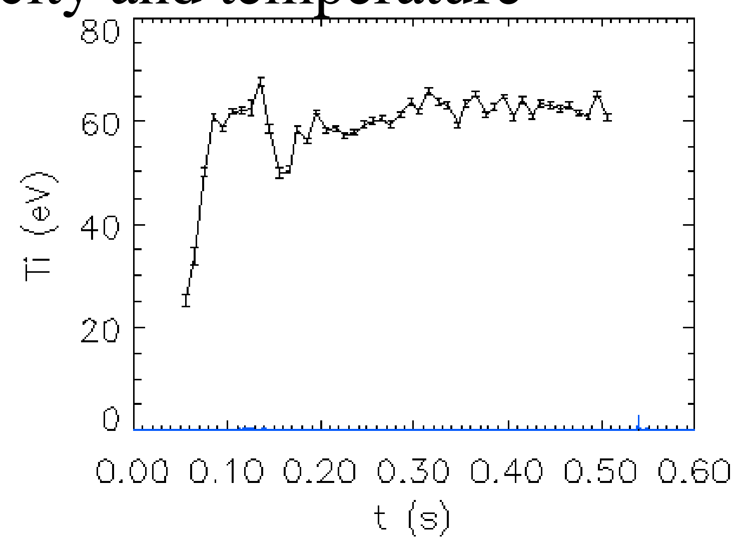
He II evolution at R=145 cm





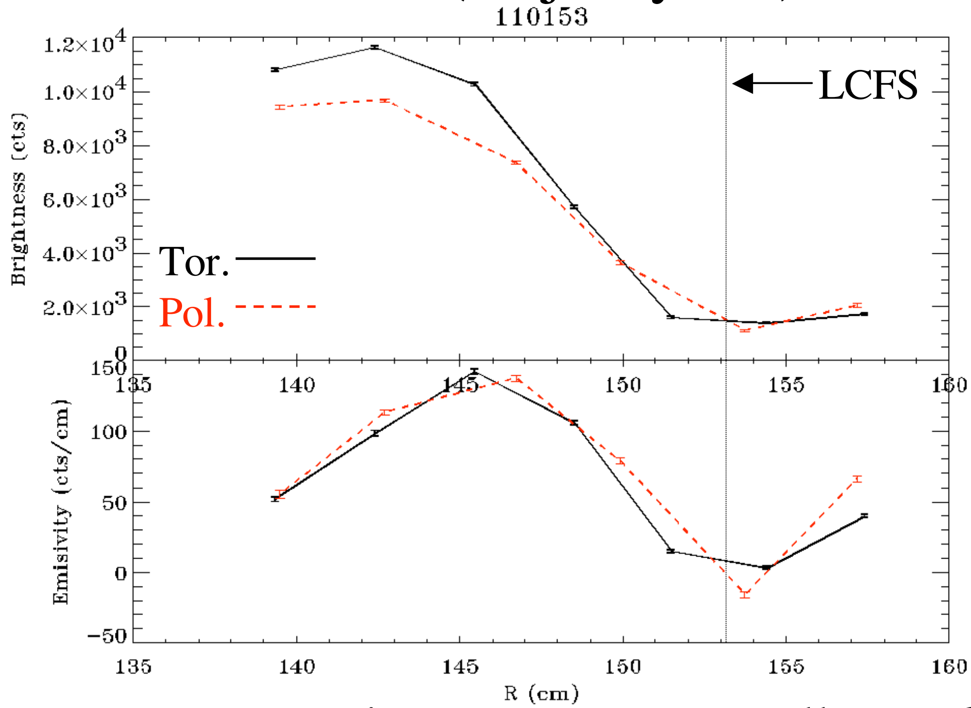
Apparent toroidal velocity and temperature



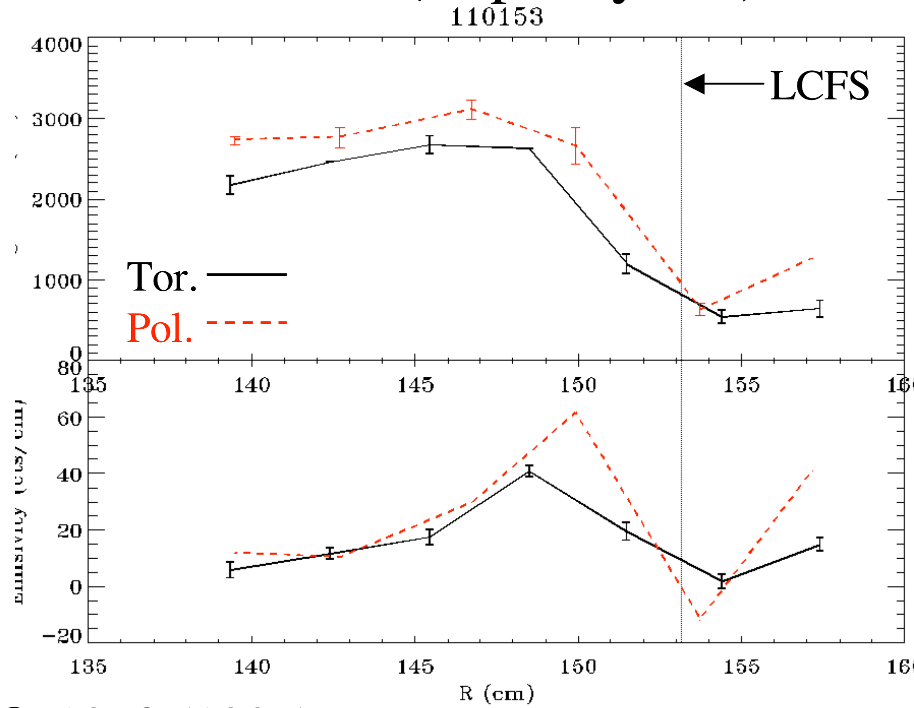


Modified Abel Inversion

He II (majority ion)

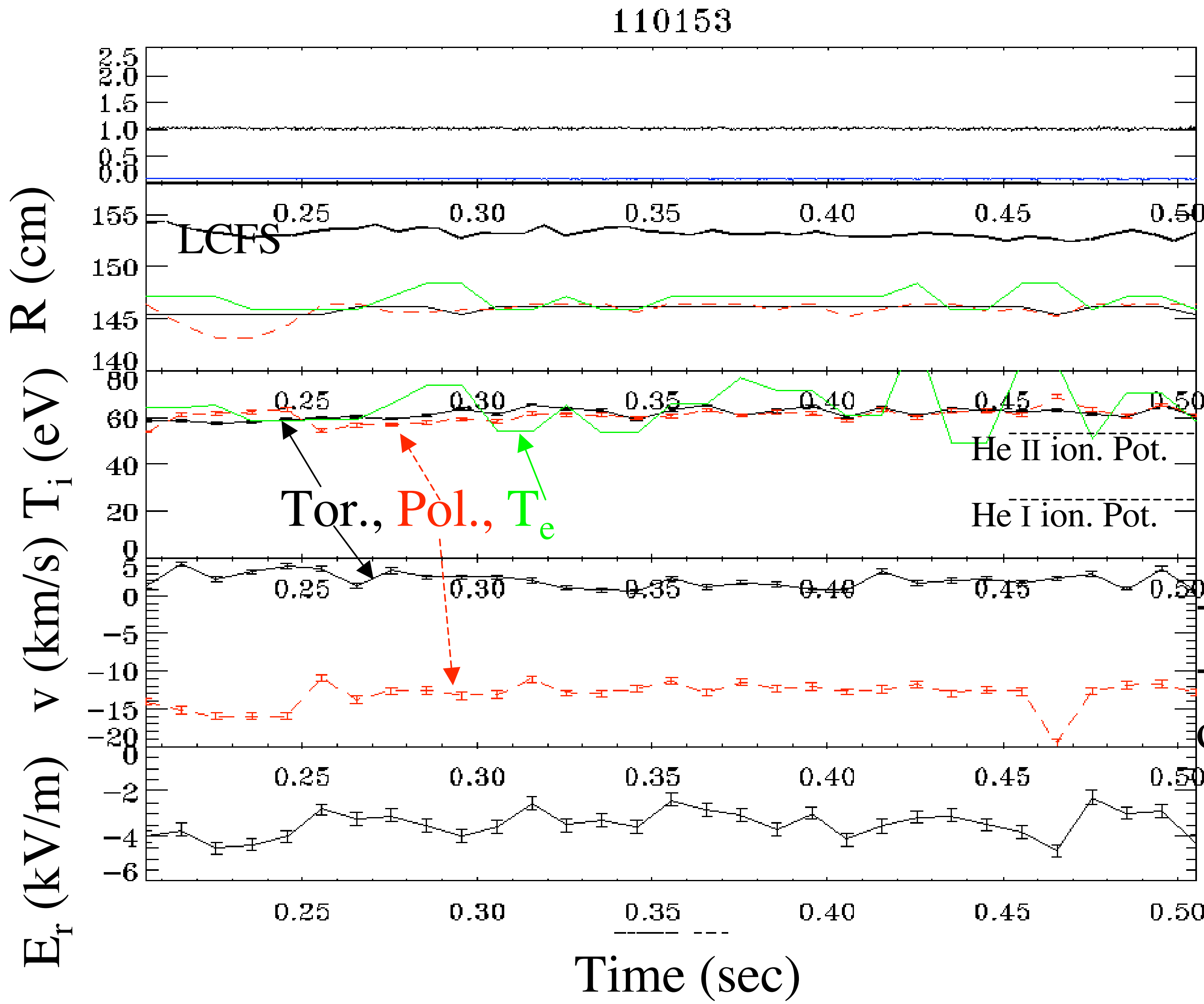


C III (impurity ion)



- Inversion process: R.E. Bell, *RSI* **68**, 1273 (1997).
- Poloidal radii from sightlines w/ EFIT due to strong plasma shaping
- He II peaks further in than C III consistent with its higher ionization potential (54.4 eV compared to 47.9 eV)
- Approximately equal Emissivities suggests that emission is essentially isotropic on the flux surface (during Ohmic He plasmas).

He II dynamics



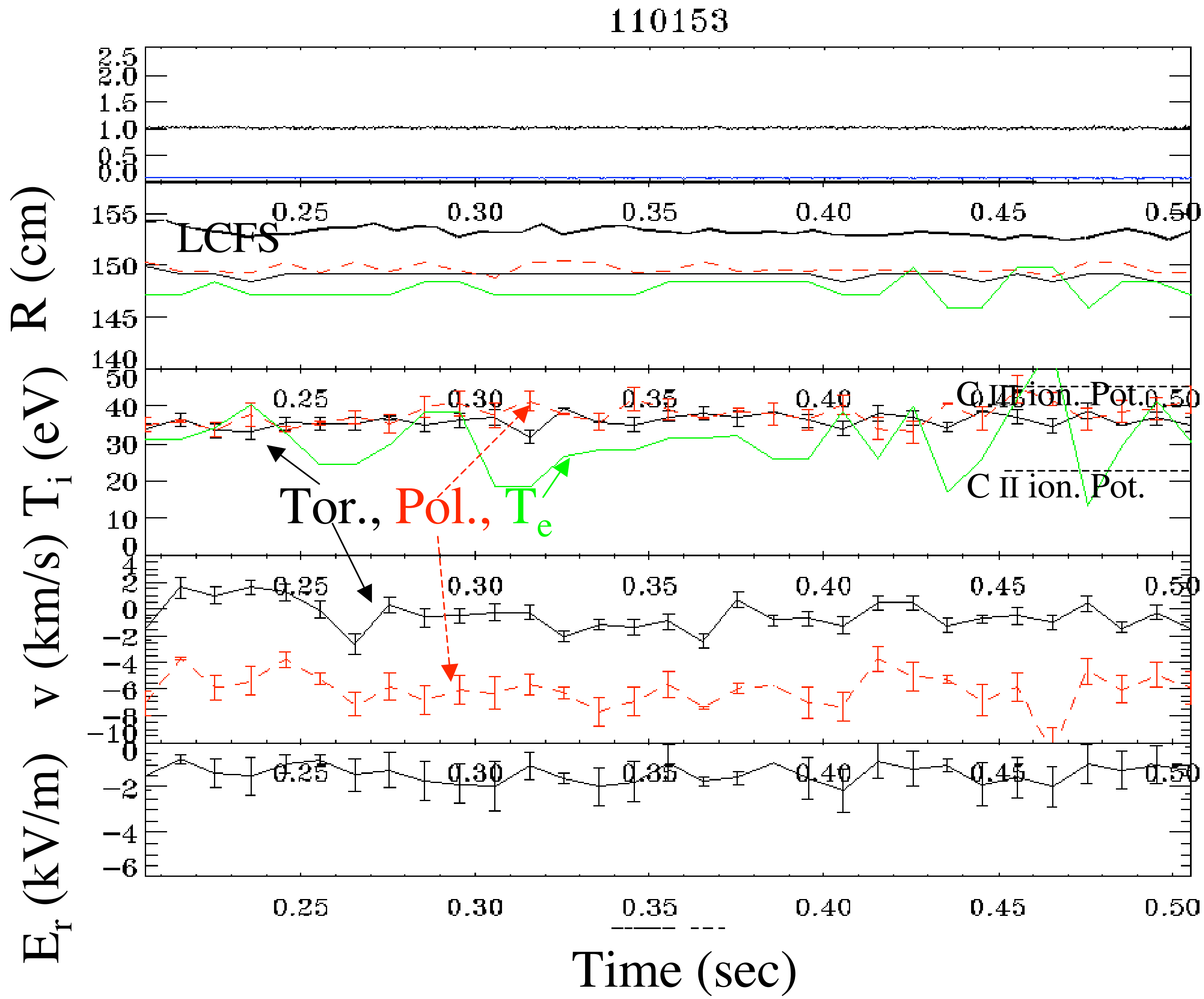
Good pol. & tor. agreement and w/ ionz. potential

T_i isotropic

+ tor. co-I_p
+ pol. down @ outboard mp.

E_r=vxB-∇p/Zn

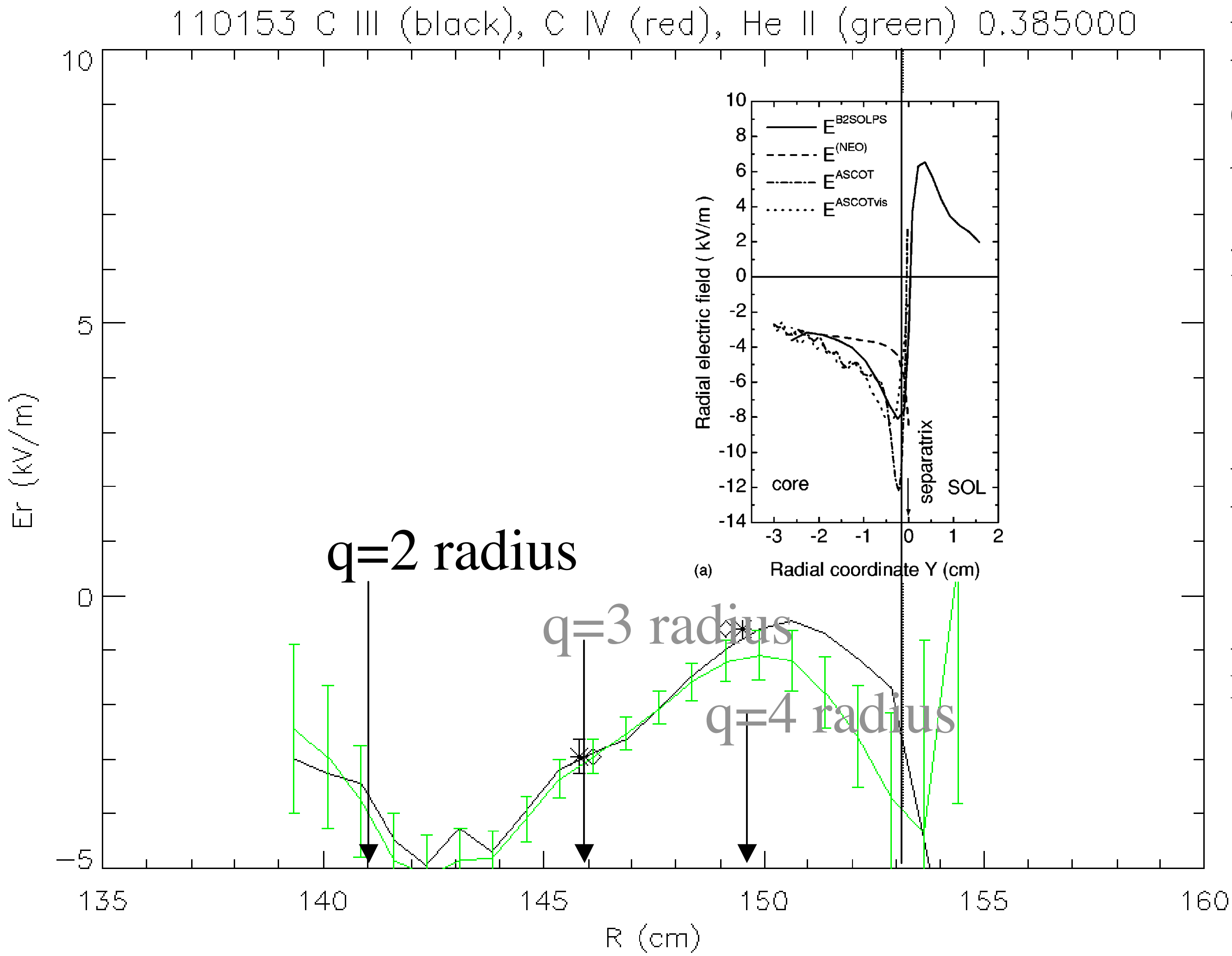
C III dynamics



$R_C > R_{He} \sim 145$ cm not surprising

$T_C < T_{He} \sim 60$ eV not surprising

E_r profile from He II and C III



$E_r = vxB - \nabla p/Zn$

Good agreement between the E_r found from He II and that from C III

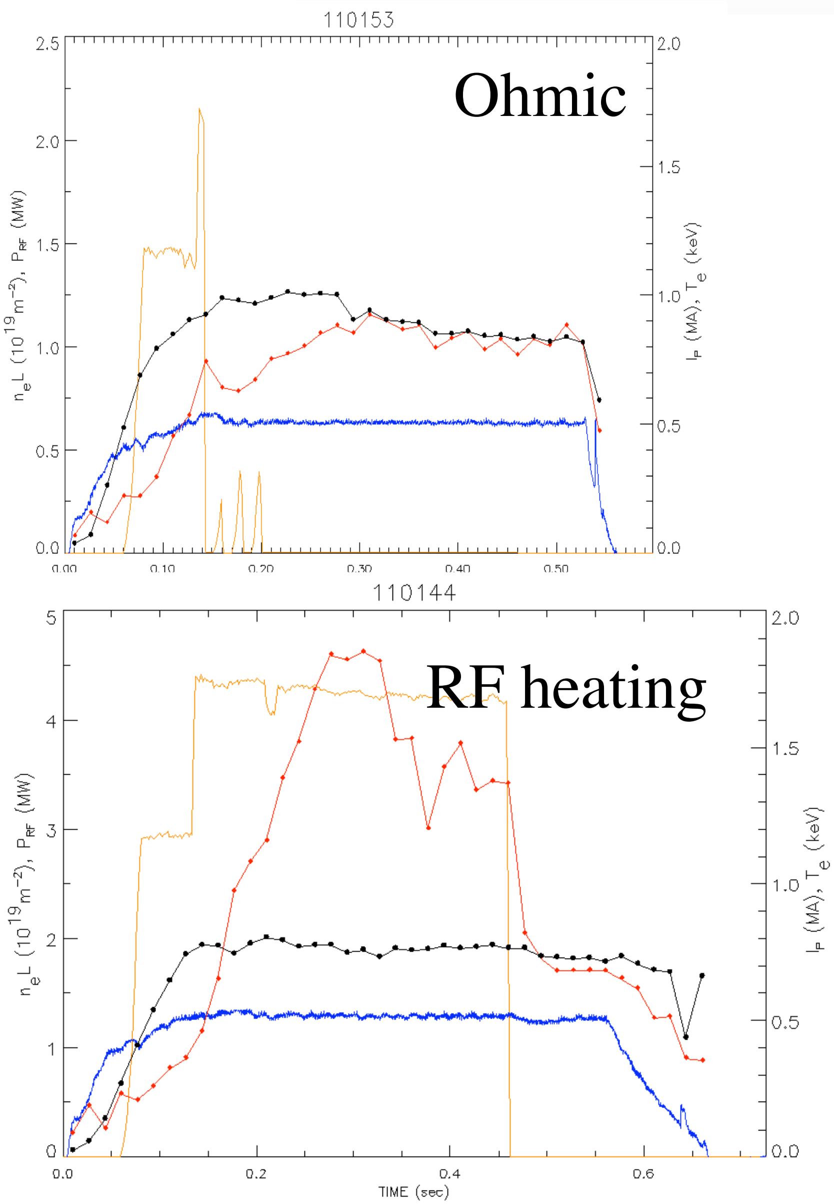
Shape around LCFS similar to simulations for ASDEX-U.

Kiviniemi *PoP* **10** 2604 (2003)

Other structure from TM islands?

Probably not; no MHD activity.

Application of RF power



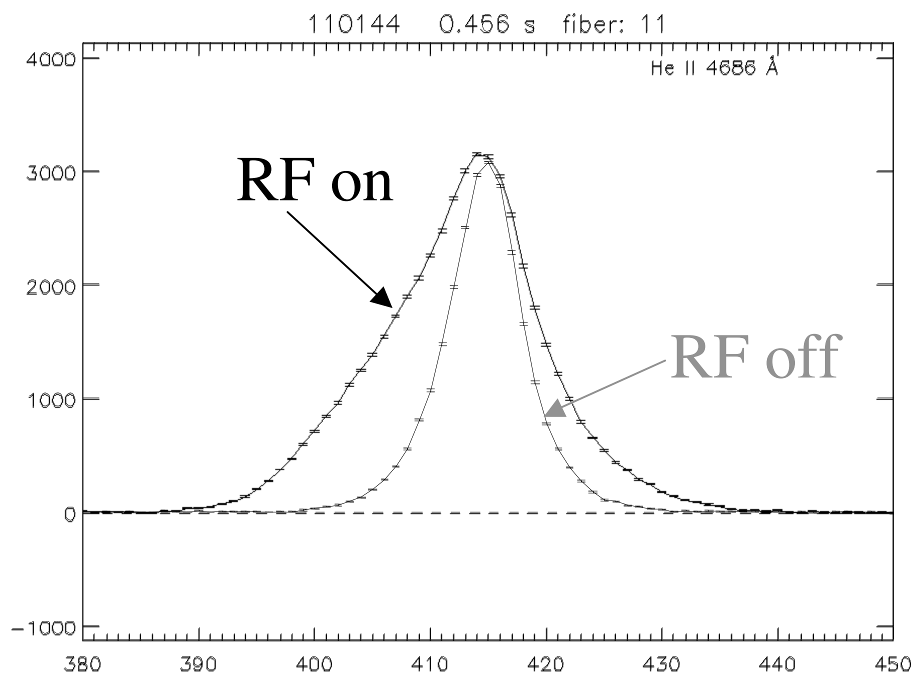
- Two shots from the same day of Phil Ryan's RF heating XP
- Shot 110144 v. 110153
- I_p 500 kA, 500 kA
- B_T 0.41 T, 0.44 T
- P_{RF} 4.3 MW, 0
- T_e 1.7 keV, 0.8 keV
- n_e 2.0×10^{19}, 1.2×10^{19}

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.

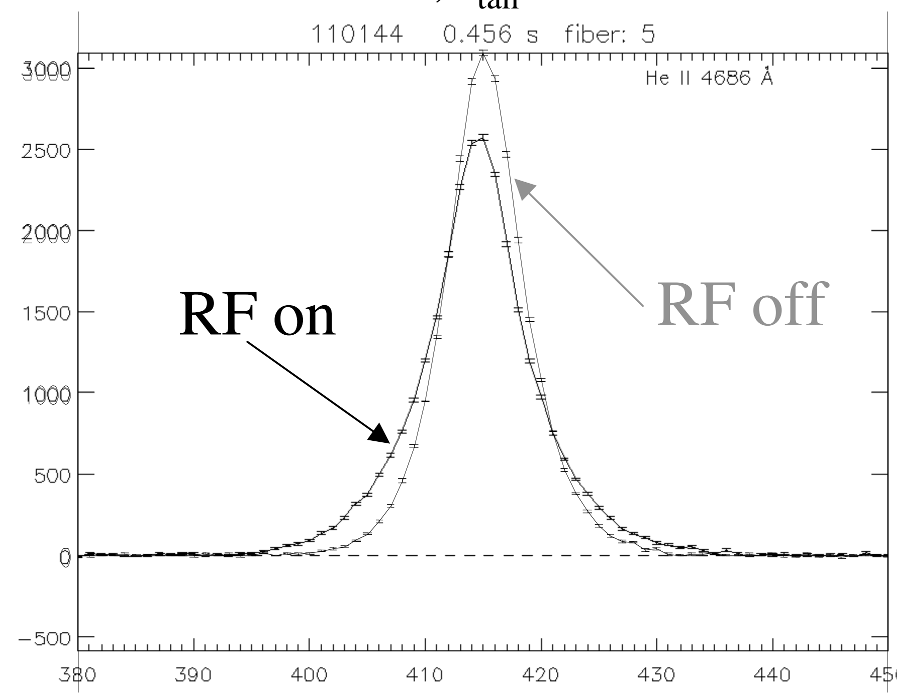
This effect is apparent in edge C (impurity) ions and He (bulk) ions.

Poloidal, r_{tan}~146 cm



Pixel # (~□)

Toroidal, r_{tan}~146 cm

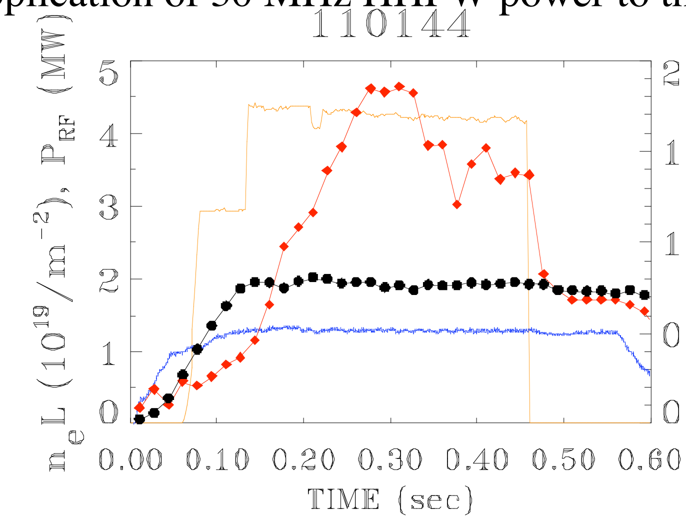


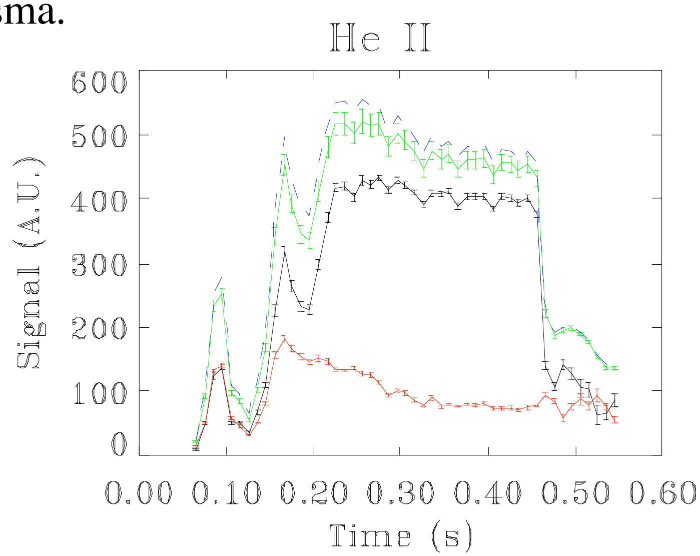
Pixel # (~□)

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

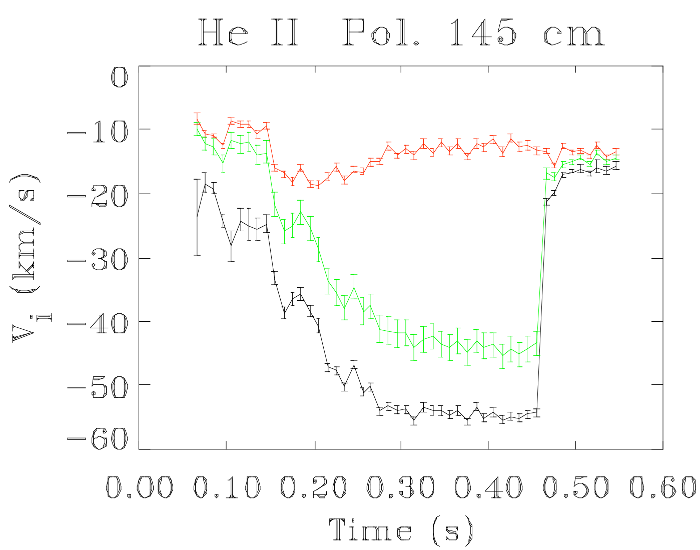
HHFW RF Power heats edge ions

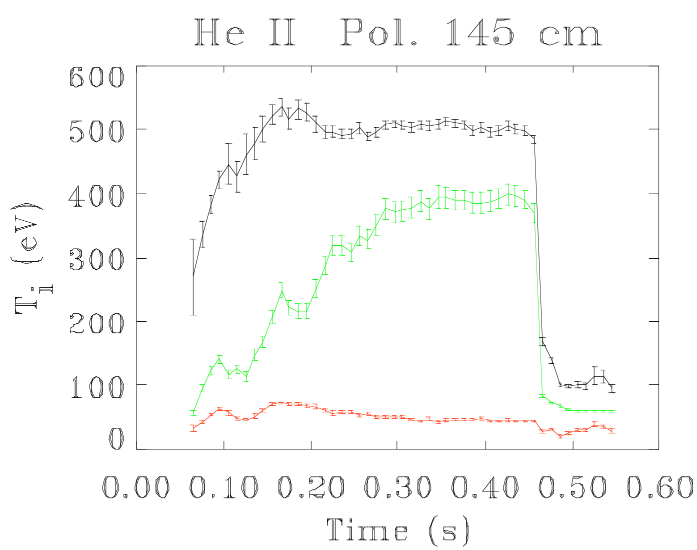
Time evolution of NSTX Shot 110144 shows that edge ion heating is well correlated with the application of 30 MHz HHFW power to the plasma.



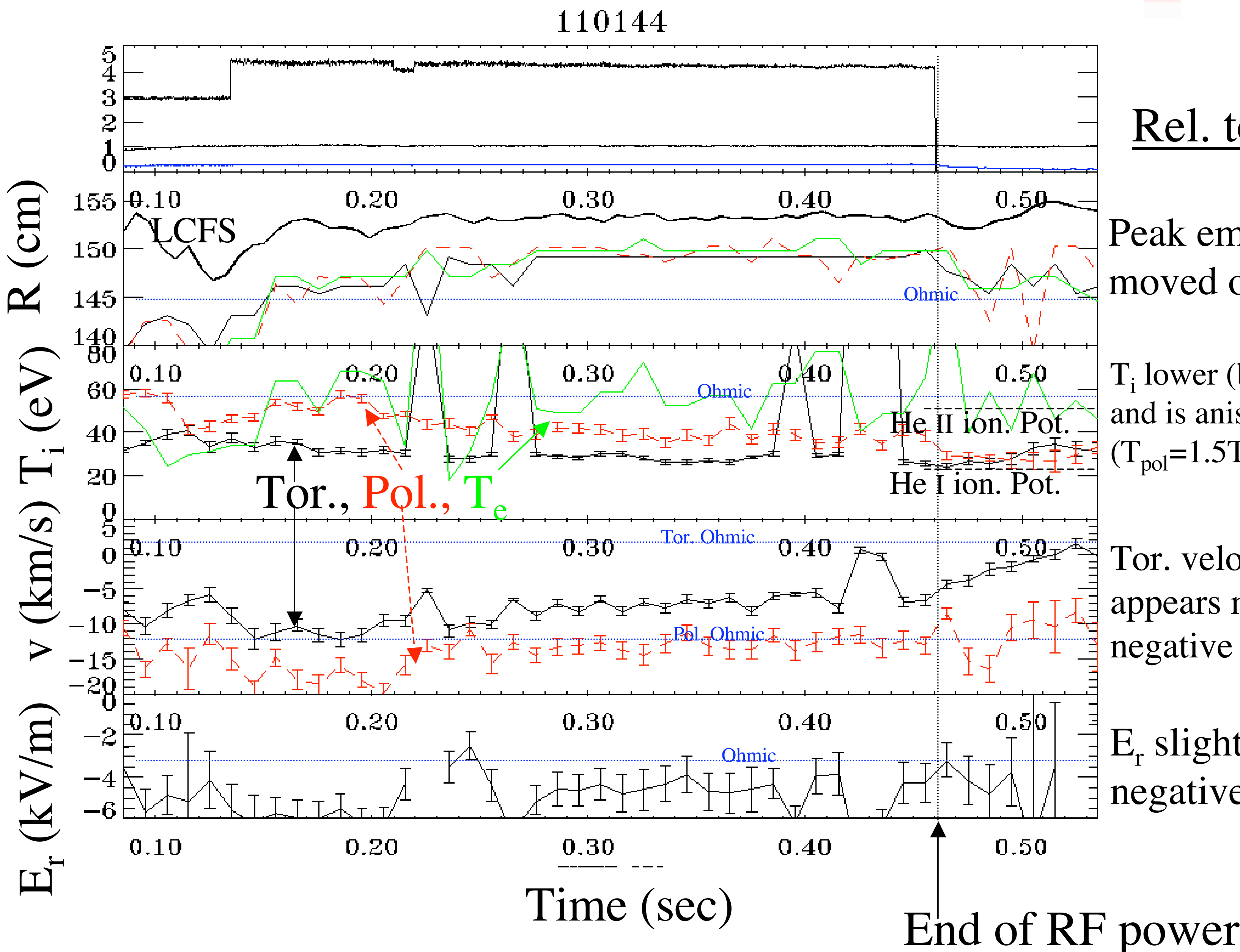


1G fit
2G high
2G low





He II cold component



Rel. to Ohmic

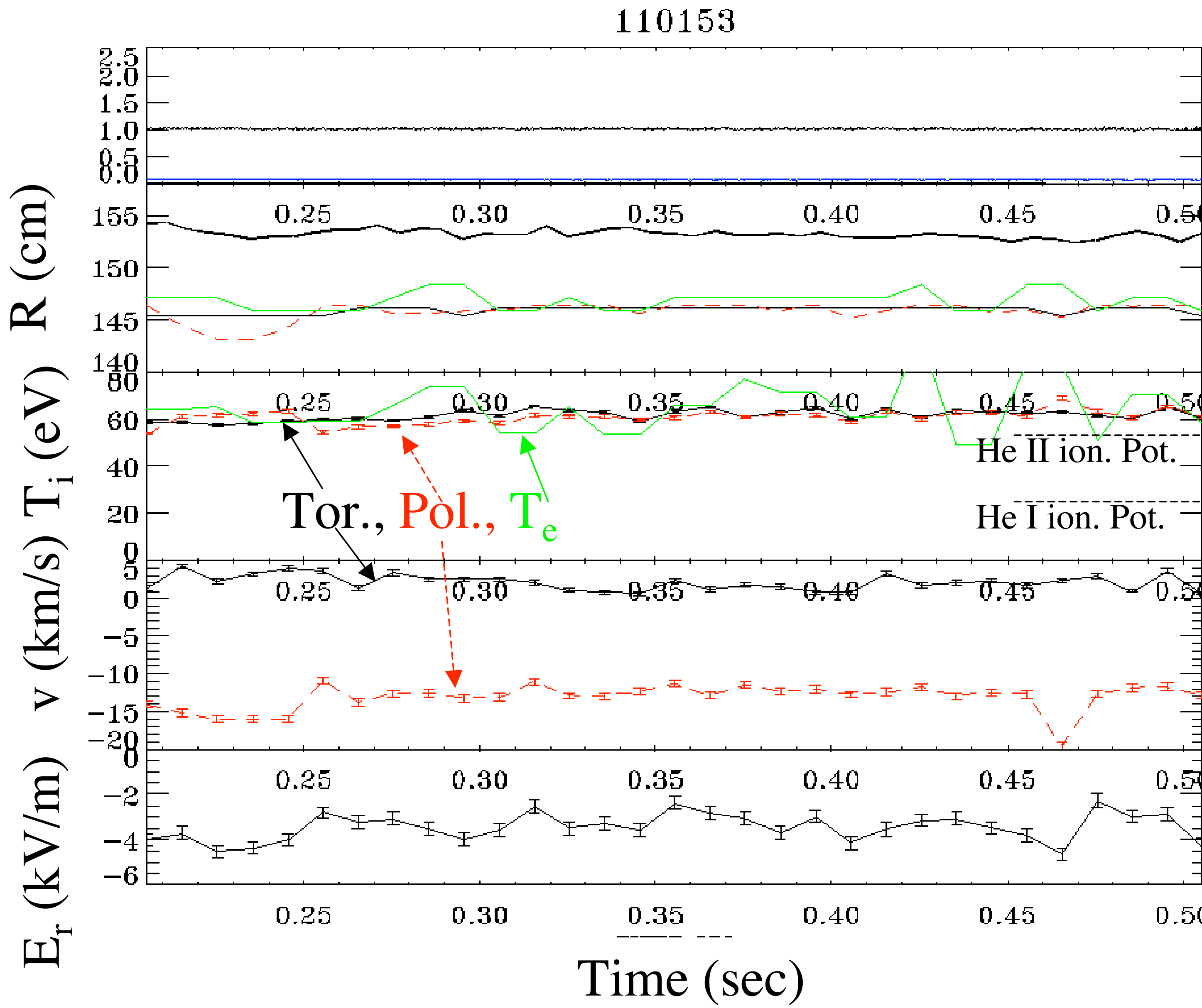
Peak emission has moved outward.

T_i lower (but $n_e = 2n_e$), and is anisotropic ($T_{pol} = 1.5T_{tor}$)

Tor. velocity appears more negative (anti-I_p)

E_r slightly more negative

He II dynamics



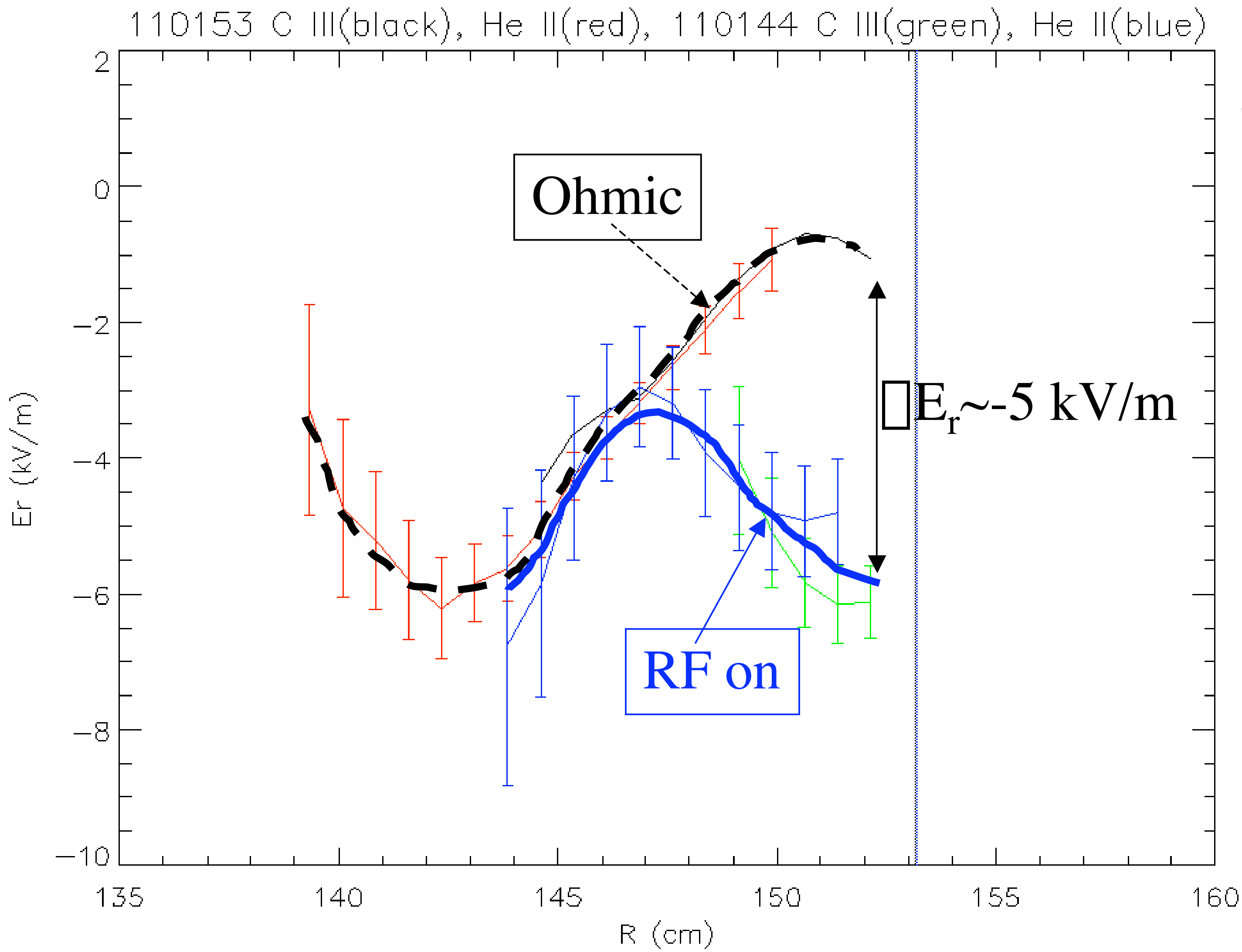
Good pol. & tor. agreement and w/ ionz. potential

T_i isotropic

+ tor. co-Ip
+ pol. up @ outboard mp.

E_r=vxB-∇p/Zn

E_r from He II and C III (cold)



<u>Ohmic v. RF heated</u>

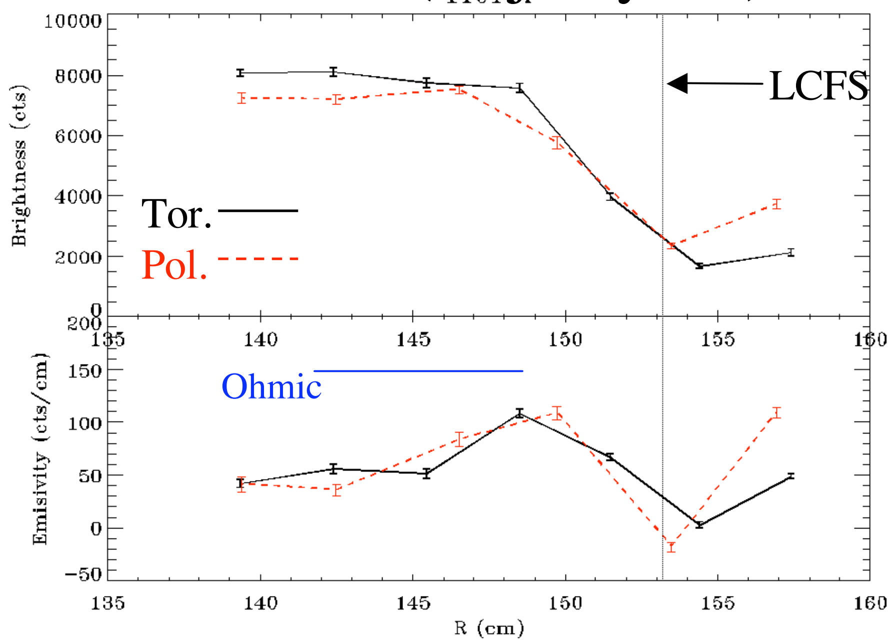
The E_r at the edge most region of the plasma (R>146 cm) is more negative during RF heated plasmas than during Ohmic.

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

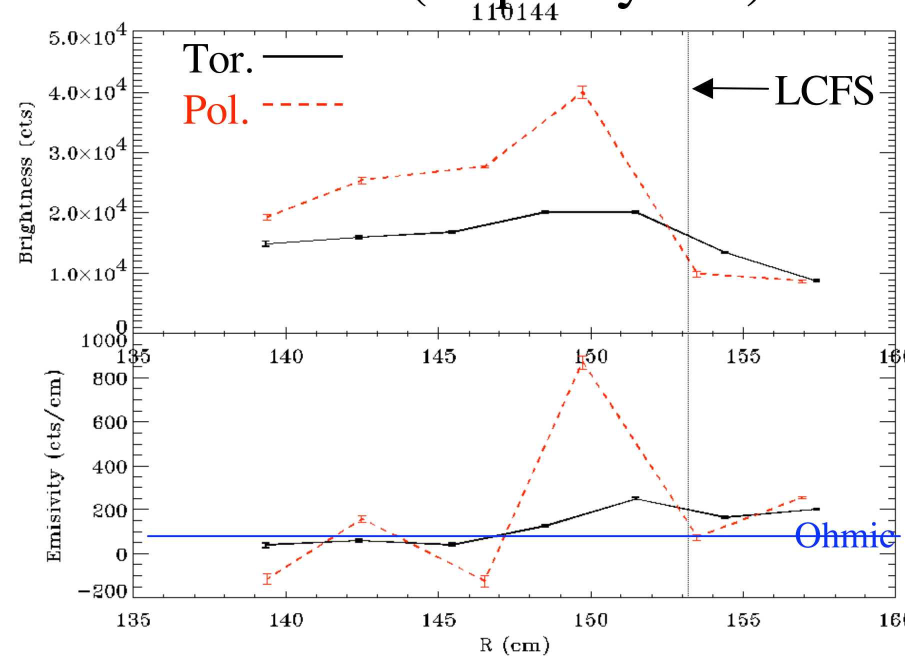
Implies that RF leads to ion loss at the edge of the plasma.

RF antenna sources C?

He II (majority ion)



C III (impurity ion)

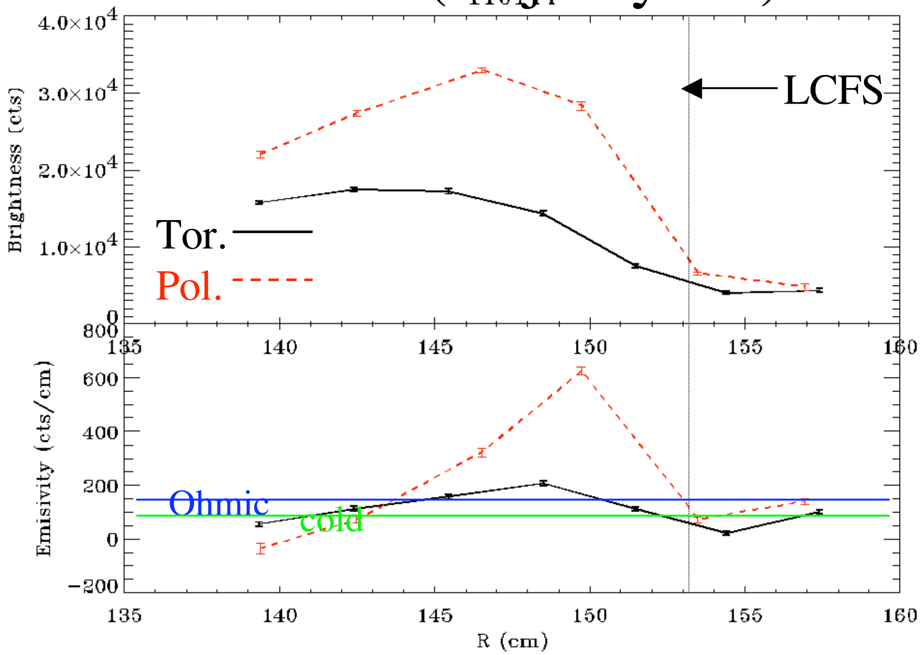


- E_{He} for cold comp. of RF plasma ≈ E_{He} of Ohmic
- E_{He} for c.c. is balanced (tor~pol), as for E_{He} of Ohmic
- E_C of cold comp. of RF plasma >> E_C of Ohmic
- Tor. E_C >> Pol. E_C for c.c. of RF plasma
- Collisions with edge C neutrals responsible for ion loss?

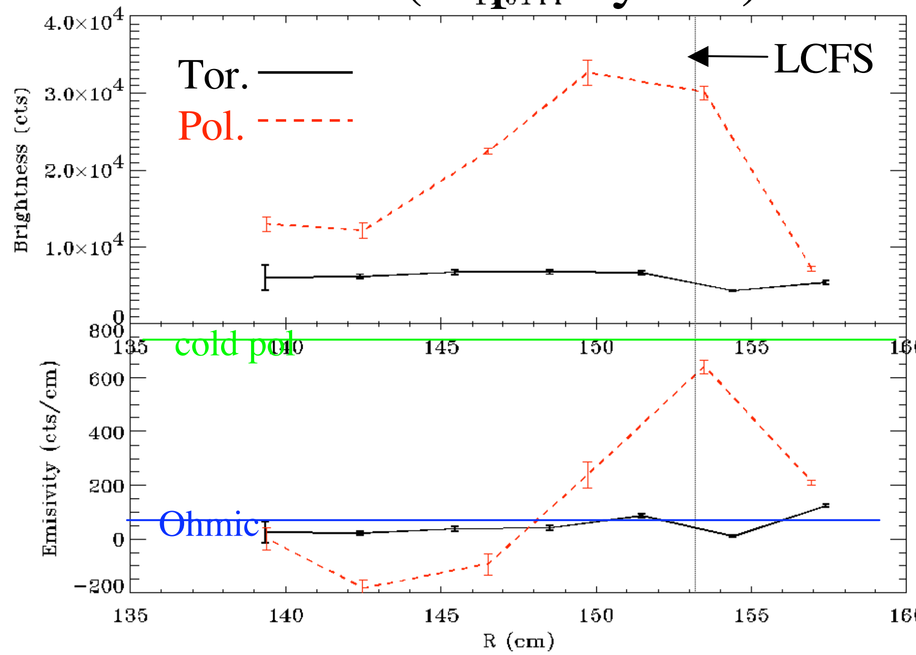
- What about the Hot component?

Hot component of 110144

He II (majority ion)



C III (impurity ion)



- Hot component has an unequal distribution for both He and C, i. e. $E_{pol} >> E_{tor}$
- E_{pol}: He h.c. >> c.c. ~ Ohmic, C h.c. ~ c.c. >> Ohmic
- E_{tor}: He h.c. ~ c.c. ~ Ohmic, C h.c. ~ c.c. > Ohmic

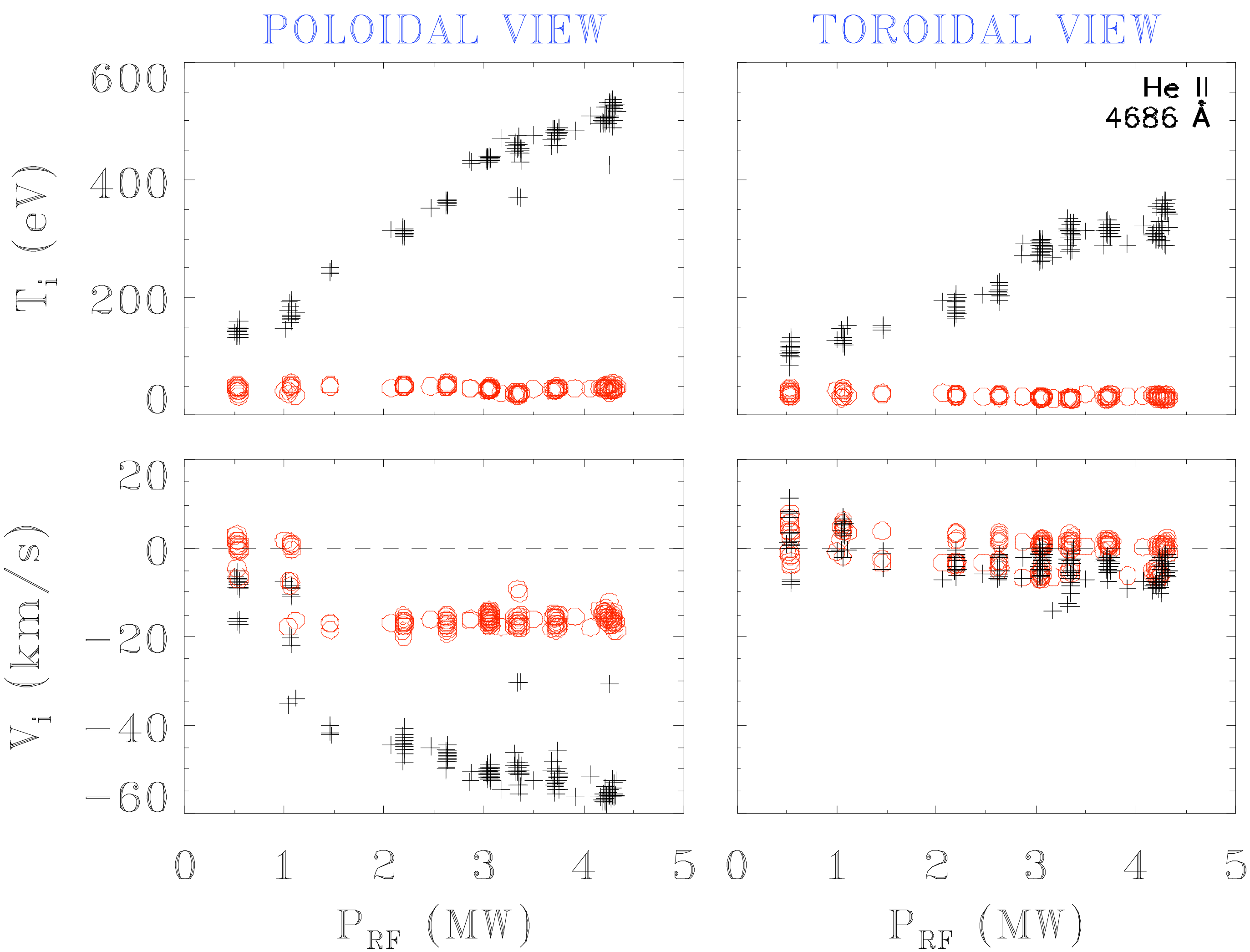
A plasma dissected by Charge Exchange

	He II			C III			C VI CHERS bkgnd	
	He^{+} ~54 eV	He^{2+} ~max T_i	C^{+} ~24 eV	C^{2+} ~48 eV	C^{3+} ~65 eV	C^{4+} ~392 eV	C^{5+} ~490 eV	C^{6+} ~max T_i
C^{0} ~11 eV →	He^{0} ~54 eV	He^{+} ~max T_i	C^{0} ~24 eV	C^{+} ~48 eV	C^{2+} ~65 eV	C^{3+} ~392 eV	C^{4+} ~490 eV	C^{5+} ~max T_i CHERS signl
	C^{+} ~11 eV	C^{+} ~11 eV	C^{+} ~11 eV	C^{+} ~11 eV	C^{+} ~11 eV	C^{+} ~11 eV	C^{+} ~11 eV	C^{+} ~11 eV
		He^{0} ~max T_i		C^{0} ~48 eV	C^{+} ~65 eV	C^{2+} ~392 eV	C^{3+} ~490 eV	C^{4+} ~max T_i
		C^{2+} ~11 eV		C^{2+} ~11 eV	C^{2+} ~11 eV	C^{2+} ~11 eV	C^{2+} ~11 eV	C^{2+} ~11 eV
					C^{0}	C^{+}	C^{2+} ~490 eV	C^{3+} ~max T_i
							C^{3+} ~11 eV	C^{3+} ~11 eV

- E_{pol}: He h.c. >> c.c. ~ Ohmic, C h.c. ~ c.c. >> Ohmic
- E_{tor}: He h.c. ~ c.c. ~ Ohmic, C h.c. ~ c.c. > Ohmic

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.

Summary

- Applying power to the RF antenna coincides with large amounts of Carbon in NSTX
  - Antenna direct source?
    - Effect greater near antenna (poloidal view).
  - Surface waves scouring the walls?
    - Or why do we see anything in the toroidal view?
- This Carbon is useful as a Charge Exchange Diagnostic
  - There are hot ions in the edge.
  - Parametric decay of HHFW on He^{2+} majority as heating mech.
    - How does Carbon get hot? Collisions?
- Does running the antenna clean itself up?
- Need experiments with CHERS and antenna camera.
- Need modeling of edge plasma (CRM, MIST?).

Er from He II and CIII hot