Poster P9

NSTX

Local scrape-off layer control using biased electrodes in NSTX

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Transport Task Force Meeting, San Diego 2009

Abstract

An experiment in NSTX was done to test the theory that biased electrodes can control the local SOL width by creating a strong radial ExB drift [Cohen, R.H. and Ryutov, D.D, Nucl. Fusion 37, 621 (1997)]. These electrodes were located in the outer midplane the scrape-off layer and were biased up to ±100 Volts. The radial profile of the plasma between them was measured by an array of Langmuir probes, and the downstream effects were measure by the GPI diagnostic. The biasing caused large changes in the local SOL profiles at least qualitatively with this theory.

<u>Goals</u>

- Eventual goal is to control (i.e. broaden) the heat/particle SOL width at divertor plate by creating convective cells using biased electrodes (or other means)

This could help solve the divertor heat flux problem

- The present experiment is to test this idea in NSTX using biased electrodes in the SOL at the outer midplane

- The next experiment on NSTX will use biased electrodes in the liquid lithium divertor plate diagnostic tiles

Previous Experiments

- Most tokamak biasing experiments aimed to create E_r and not E_{pol} [e.g. PBX-M, DIII-D, TdeV, TEXTOR…]

- Some experiments have shown creation of local E_{pol} in SOL

JFT-2M [Hara et al, J. Nucl. Mat. 241-243, 338 (1997)]
MAST [Counsell et al, J. Nucl. Mat. 313-316, 804 (2003)]
CASTOR [Stockel et al, PPCF 47, 635 (2005)]

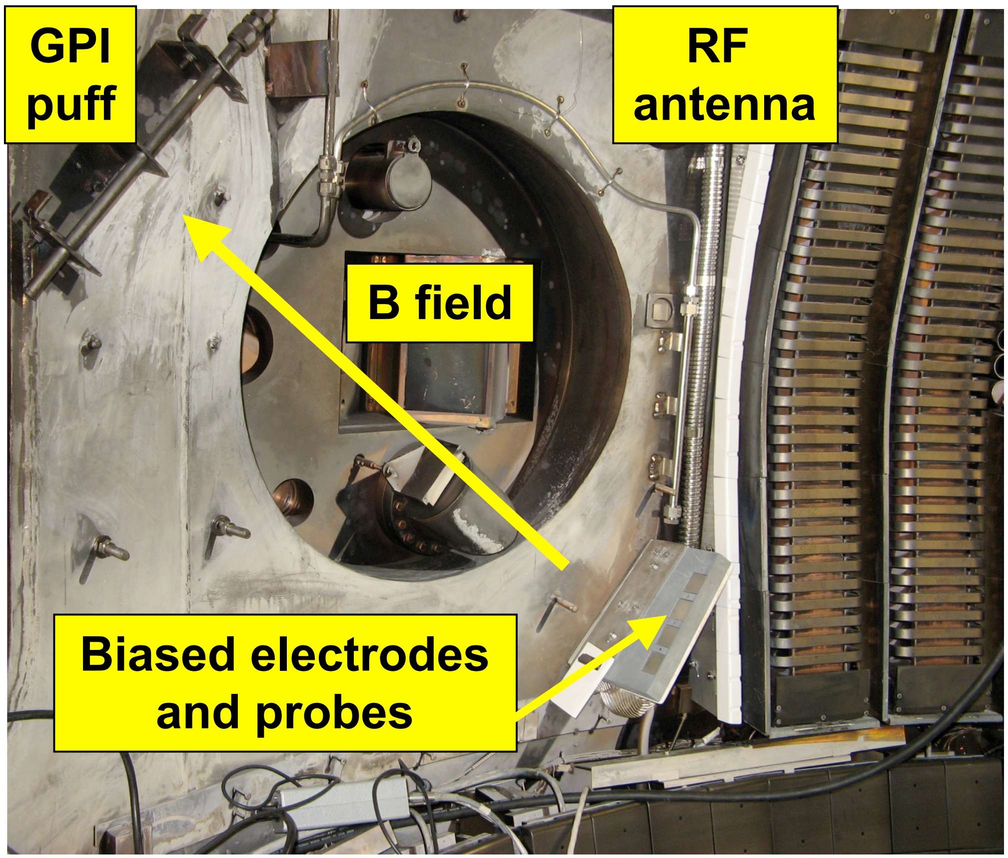
- MAST experiment was done to test idea of Cohen/Ryutov, resulting in partial confirmation of theory, e.g. movement of D_α strike point at biased divertor "ribs"

- Other experiments have seen potential propagate along B

DITE [Pitts and Stangeby, Plasma Phys. Cont. Fusion 32, 1237 (1990)]
TEXT [Winslow et al, Phys. Plasmas 5, 752 (1998)]
W7-AS [Thomsen et al, Plasma Phys. Cont. Fusion 47, 1401 (2005)]

Location of Biased Electrodes

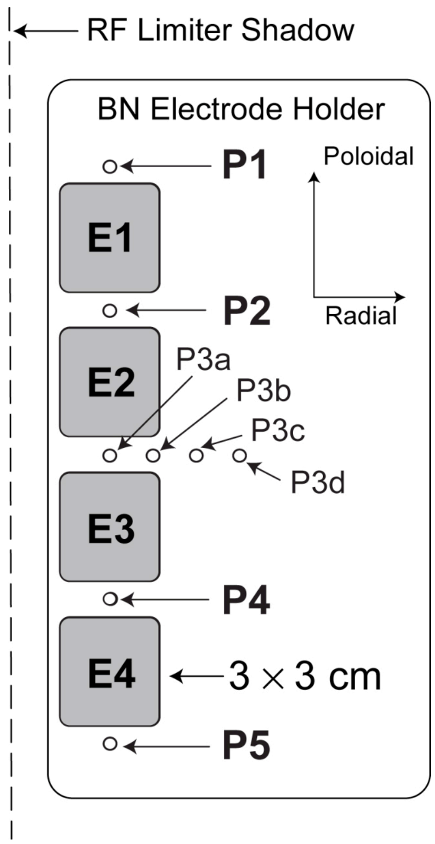
- Electrodes at outer midplane in shadow of RF antenna
- Gas puff imaging diagnostic located ~1 meter along B field

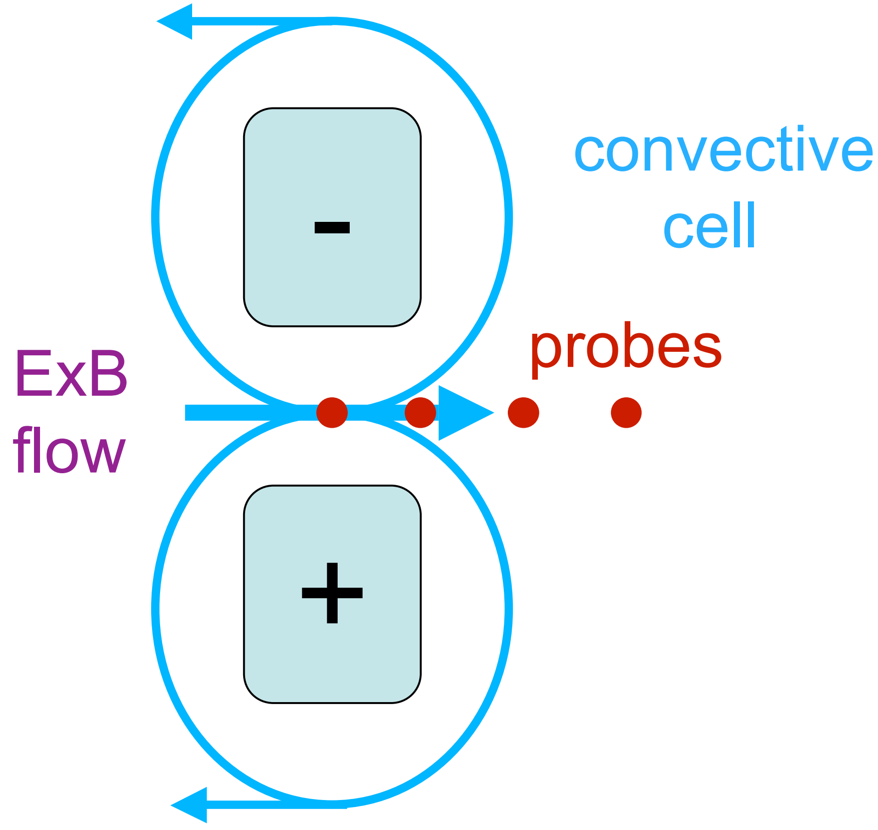


Outer midplane

Probe Measurements of Local SOL

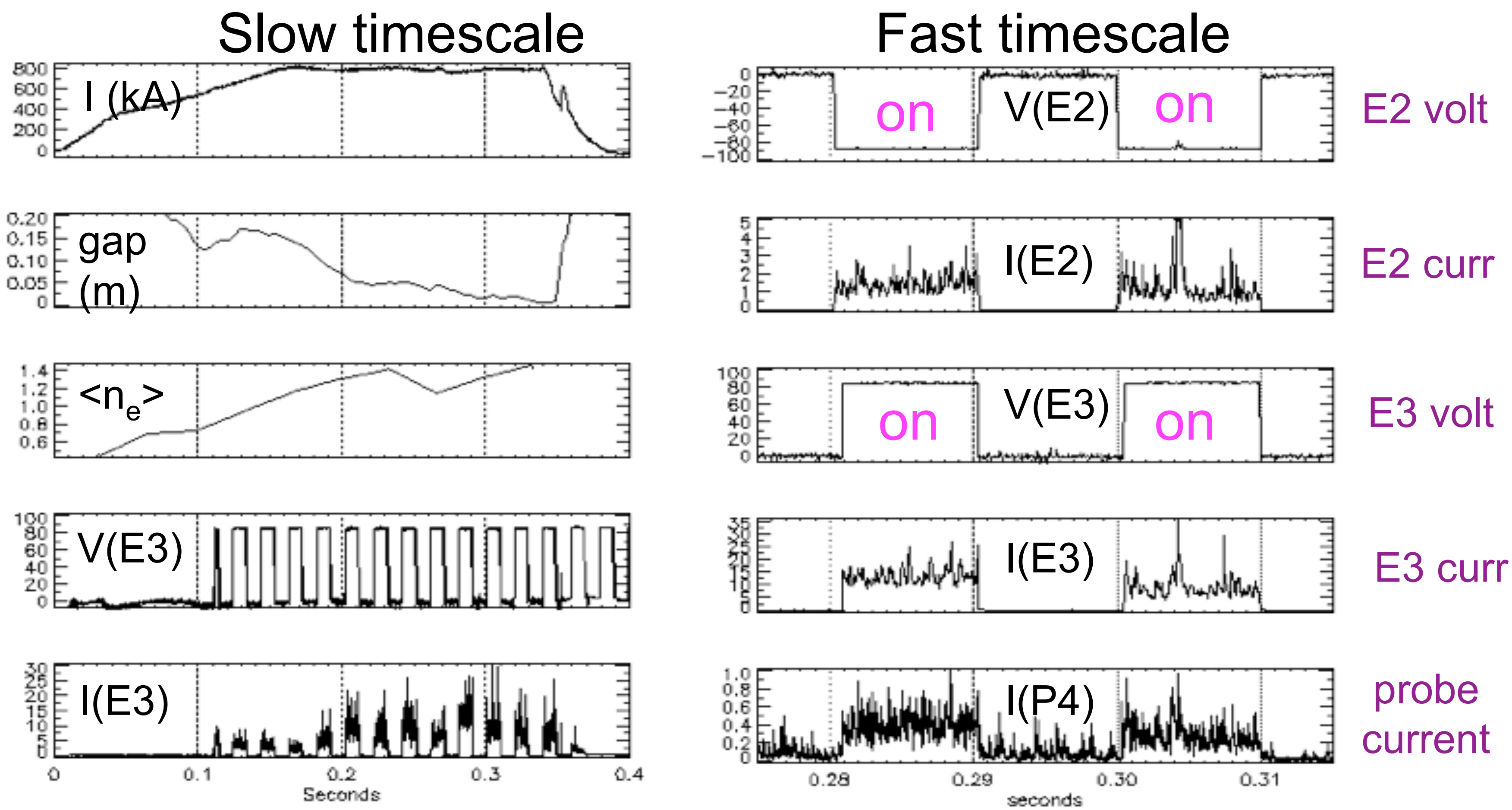
- Radial probe array located below two electrode E2 & E3
- Look for local SOL profile changes in array due to biasing





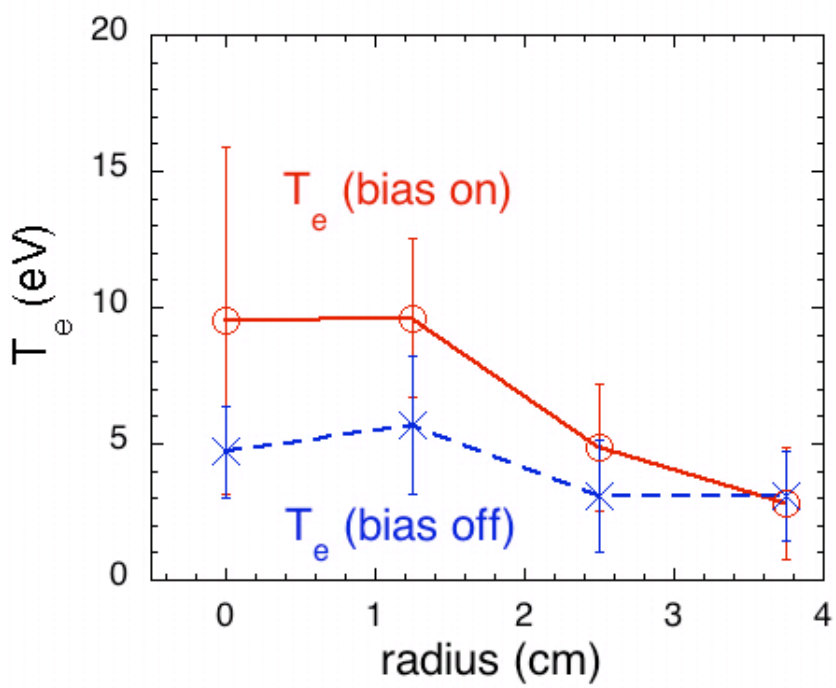
Typical Signals vs. Time

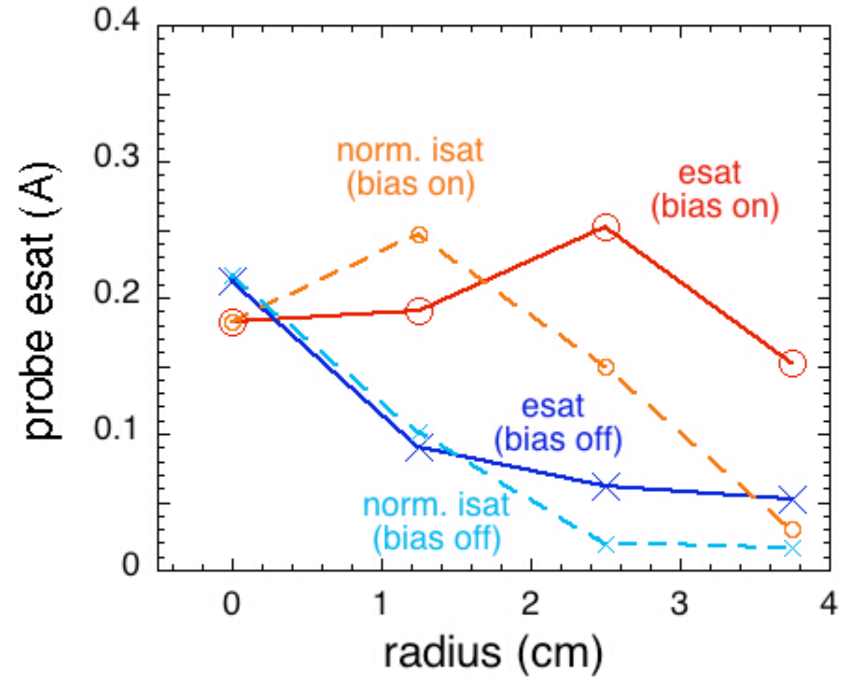
- Electrode voltages modulated at 50 Hz, probe bias +50 V
- See clear increase in probe current with electrode bias



Typical SOL Profiles

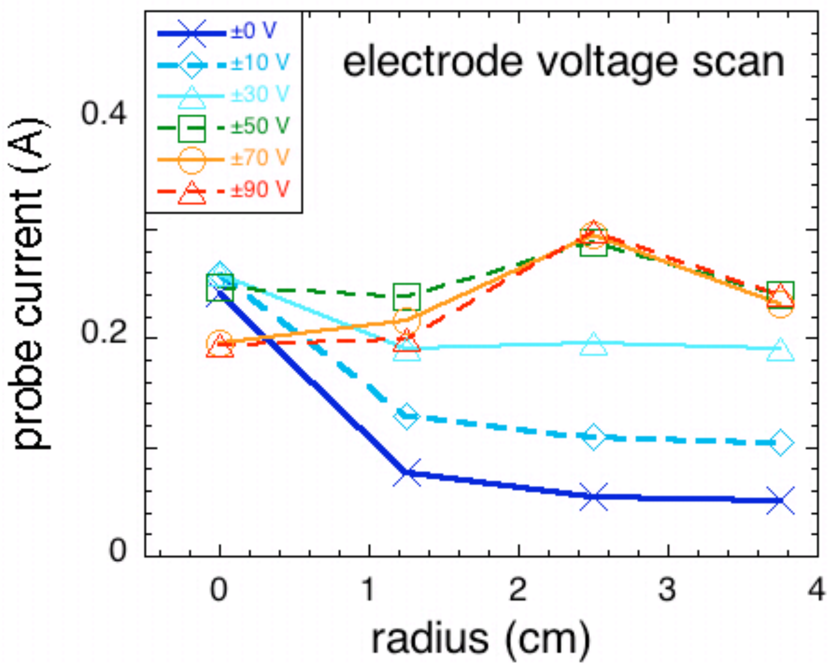
- Electron temperature ~ 10 eV to ~ 3 eV in SOL locally
- Density ~ 1012 cm-3 to 1011 cm-3 in SOL locally
- Electron saturation profiles ~ ion saturation profile

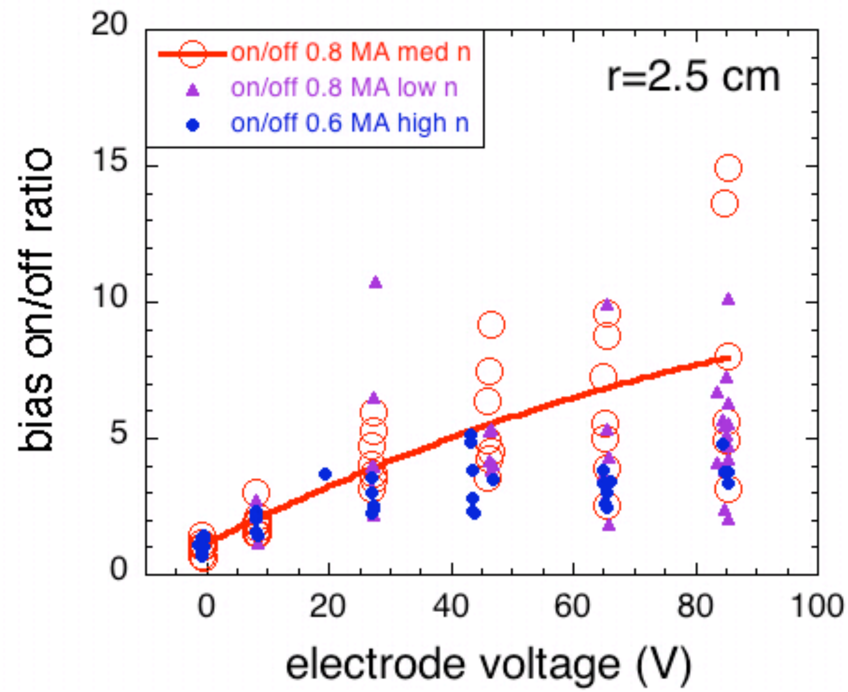




Effect of Bias Voltage on SOL Profiles

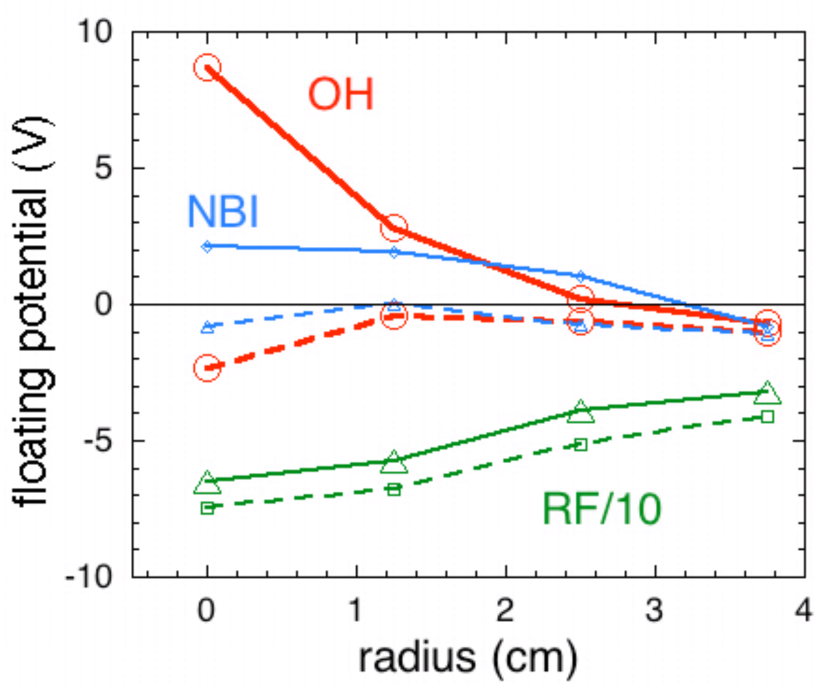
- Electrodes E3 positive, E2 negative, ExB locally outward
- Profiles broaden significantly at or above ±30 V biasing
- Same behavior seen at varying current and density





Floating Potential Changes with Bias

- Floating potential on radial probe array increase with biasing
- Increases normally ~5-20% of applied voltage to electrodes
- Qualitatively similar effect seen in OH, NBI, and RF plasmas



solid lines - with bias

dashed lines - no bias

E3 +90 V for OH,NBI

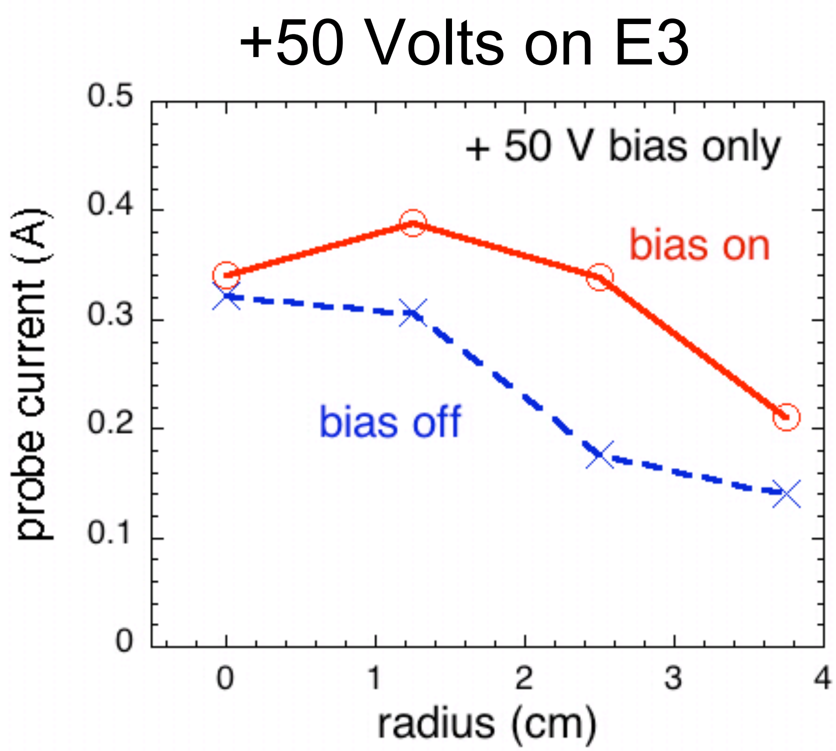
E2 -90 V for OH, NBI

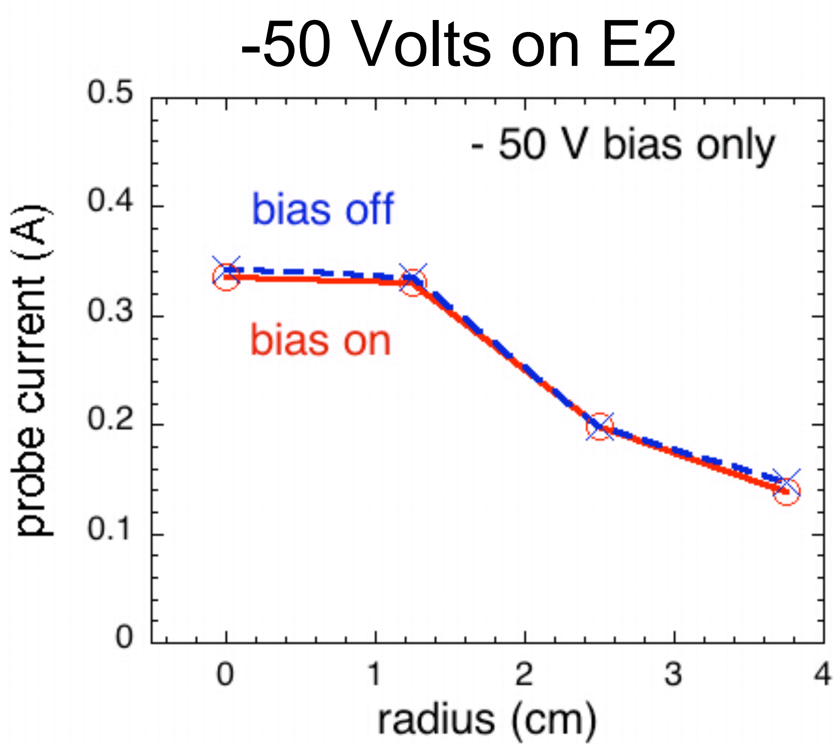
E3 +50 V for RF

E2 -50 V for RF

Single Electrode Biasing

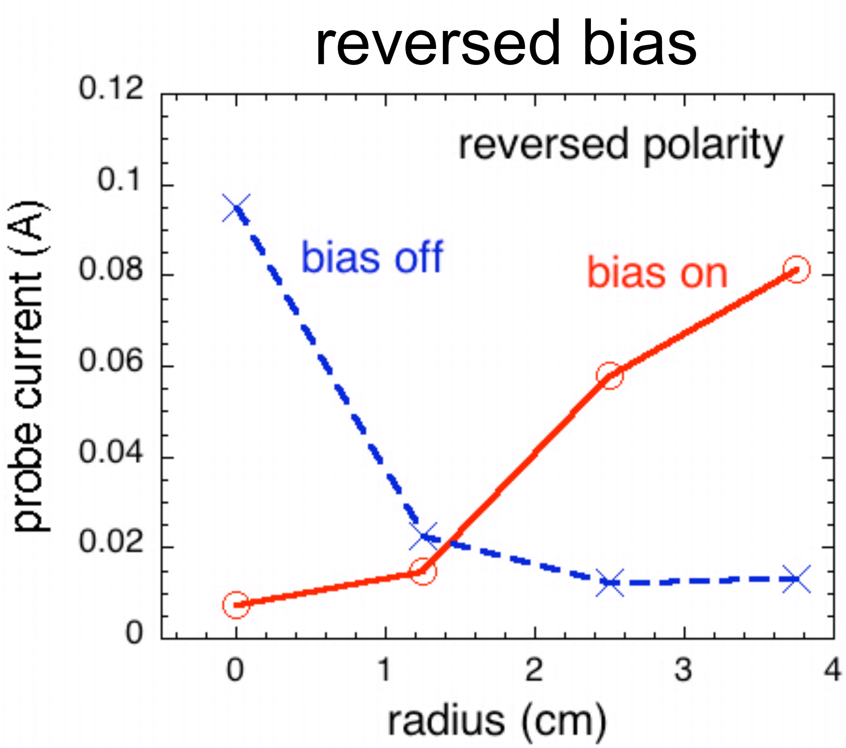
- Significant SOL broadening for +50 V electrode only
- No change in SOL profiles for -50 V electrode only
- Positive electrode controls SOL profile changes

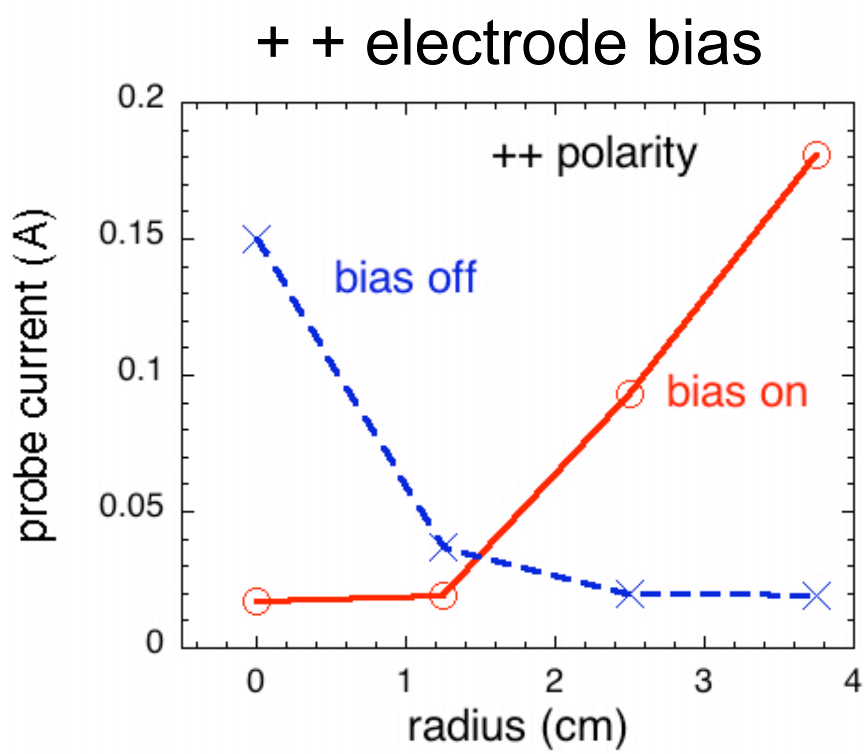




Effect of Varying Signs of Biasing

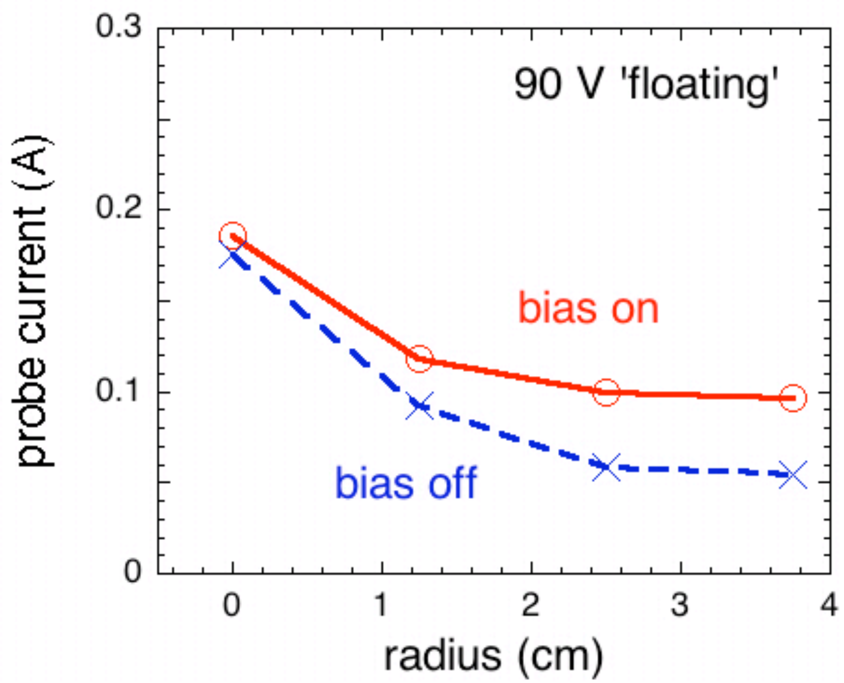
- Reversed bias (E3 negative, E2 positive) reverses profiles
- Both electrodes positive produces almost same result !?





Floating Electrodes

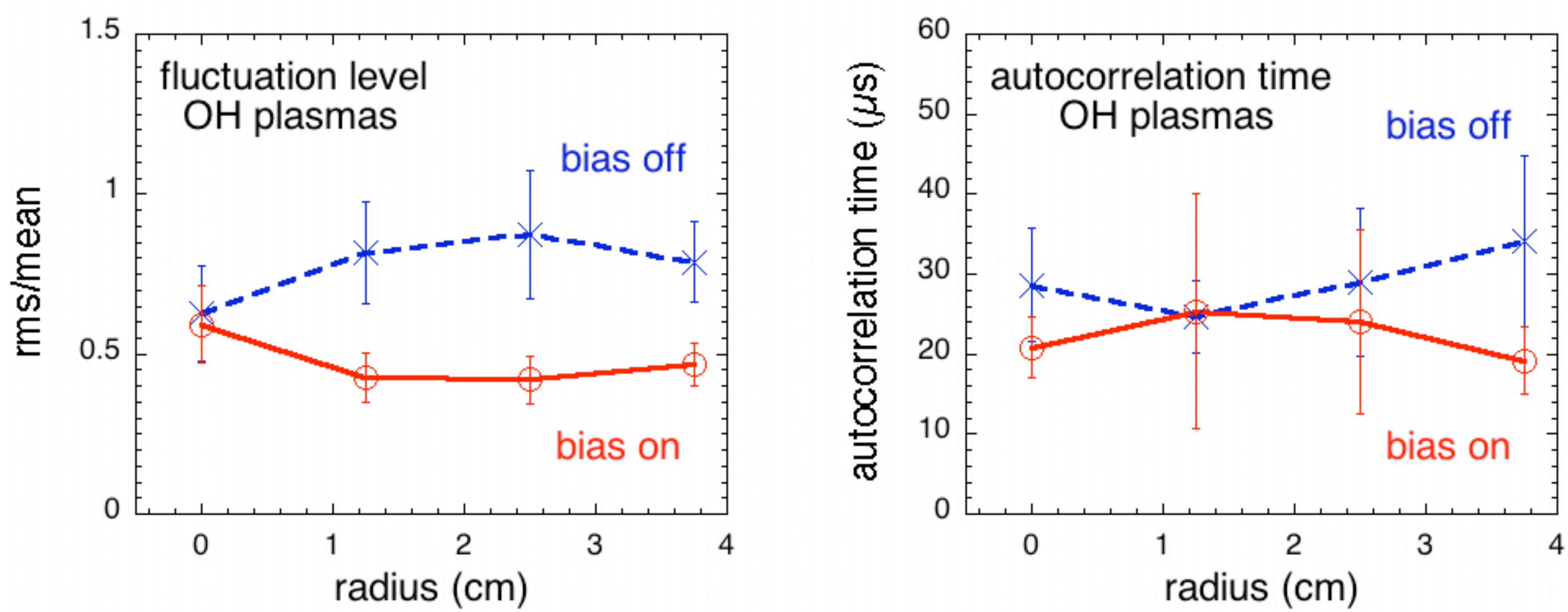
- Biasing E3 + 90 V positive with respect to E2 causes some SOL profile broadening, but not as much as with E3, E2 biased with respect to vacuum vessel



current drawn by floating electrodes ~ 1 Amp, compared with ~8 Amp for + bias with respect to vessel => uses less power

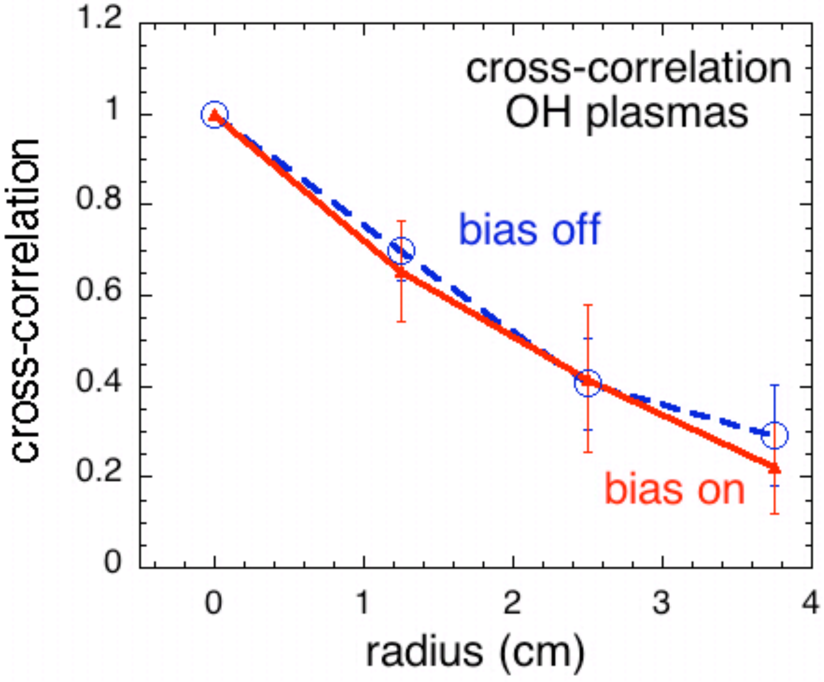
Effect of Bias on Local Turbulence

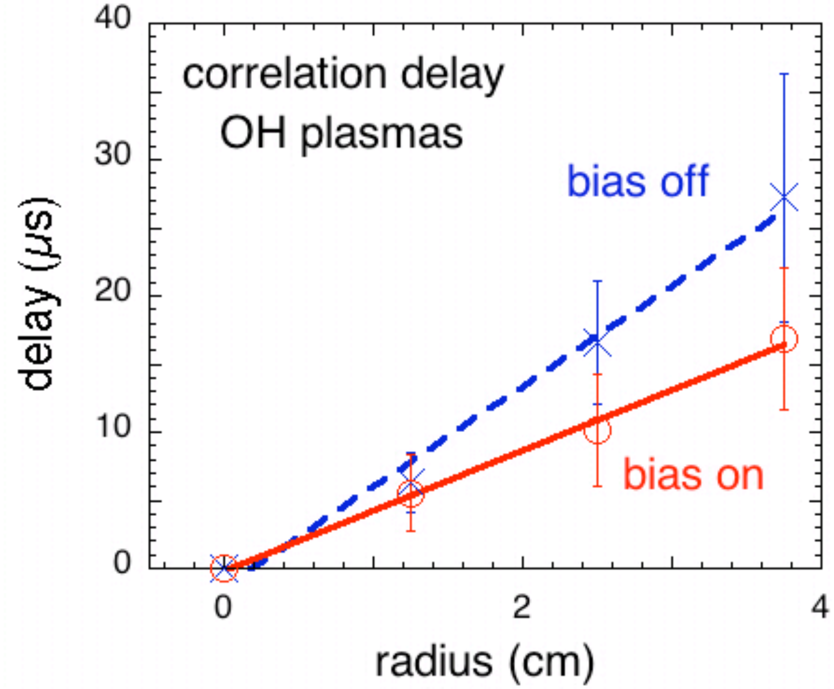
- Biasing (ExB outward) decreases local fluctuation level
- Biasing (ExB outward) doesn't change autocorrelation time



Effect of Bias on Local Turbulence

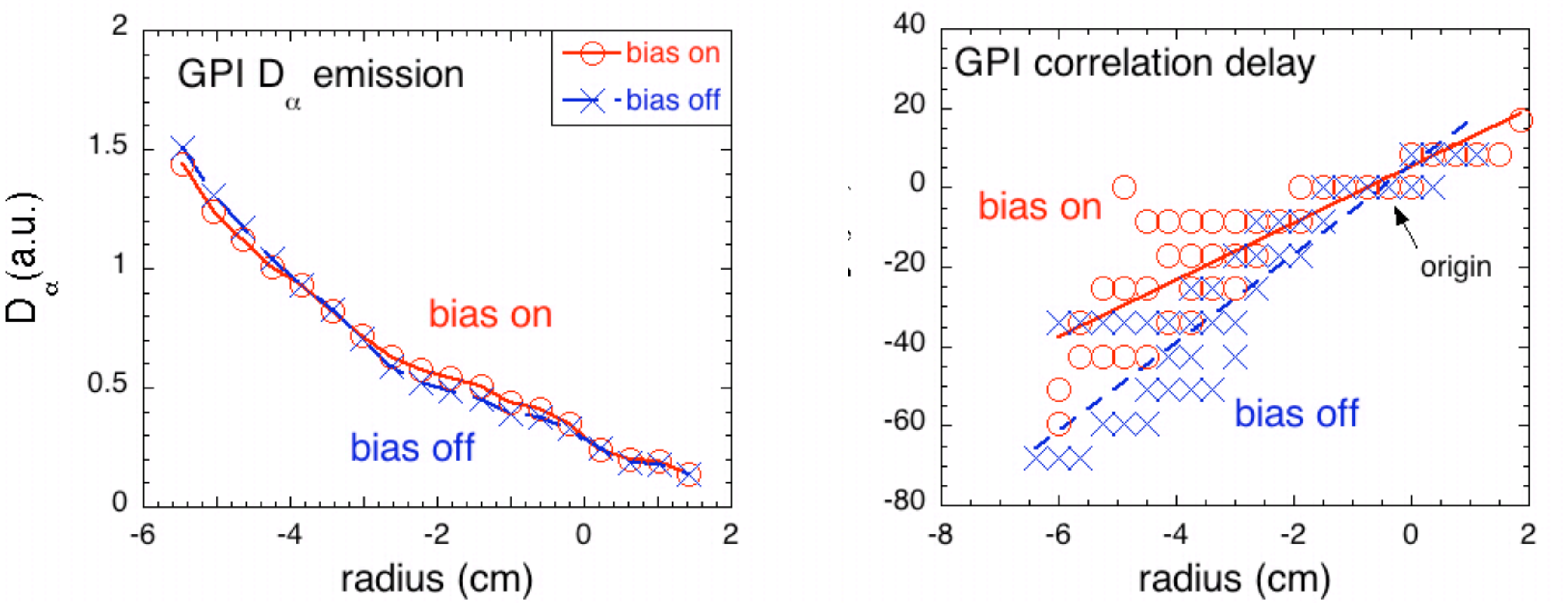
- Biasing (ExB outward) doesn't change radial correlations
- Biasing (ExB outward) increases outward turbulence velocity





Effects of Bias in GPI Diagnostic

- No change in D_α profiles seen by GPI ~ 1 meter along B
- Slight increase in outward turbulence speed seen in GPI



Summary of Experimental Results

1) the particle flux and floating potential between the biased electrodes were strongly modified by the biasing

2) the radial SOL profile broadens for an outward ExB drift, and inverts for an inward ExB drift

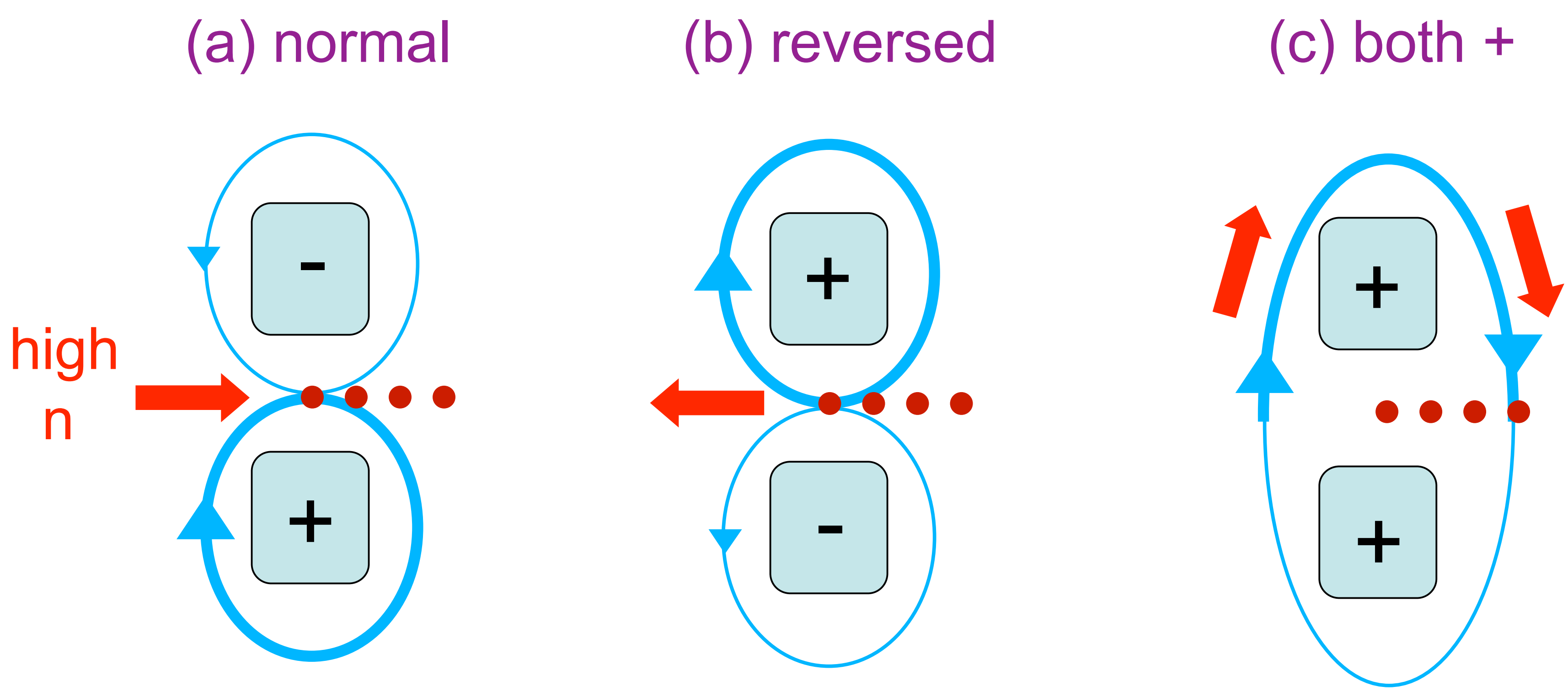
3) these changes are predominantly caused by the positively biased electrode not by the negatively biased electrode

4) the local turbulence measured between these electrodes was only slightly perturbed by this biasing

5) the radial D_α profiles and turbulence measured ~100 cm along B were not significantly changed by the biasing

Qualitative Interpretation of Results

- Outward ExB drift increases density at radial probe array
- Reversed ExB or (++) decreases density at probe array



Model for SOL Profile Modification

- Assume the positive electrode creates a convective cell of radius $L_\perp$ ($\perp$ to B) and length $L_{||}$ (II to B)

- Assume plasma flows with $E_\perp$xB velocity $v_\perp$ ($\perp$ to B) and parallel velocity $v_{||}$ (II to B)

- Number of rotations of convective cell around B at electrode:

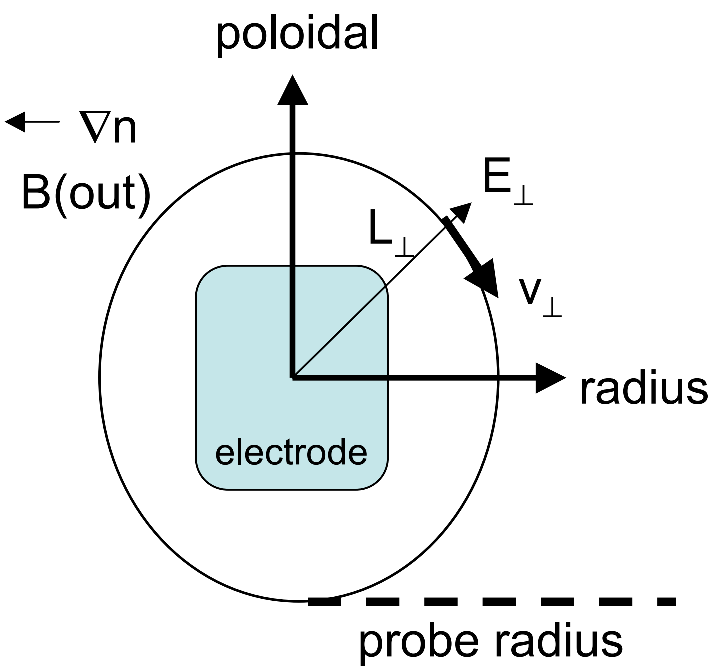
$$N = v_\perp (L_{||}/v_{||})/(2\pi L_\perp)$$

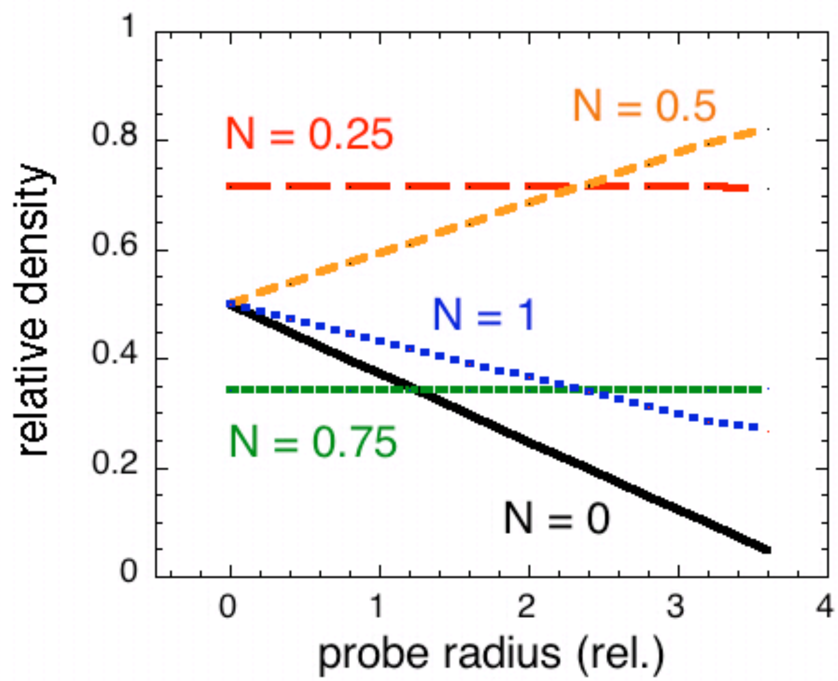
- For example, for $L_{||} \sim 50$ cm (half the distance to the GPI), $L_\perp \sim 3$ cm, $v_{||} \sim 10^6$ cm/sec ($M_{||} \sim 0.5$ at 8 eV), and $v_\perp \sim 4\text{x}10^5$ cm/s ($E_\perp$= 10 V/cm at B=2.5 kG), => N ~ 1

Illustrative Results from Model

- Assume unbiased density profile linear vs. radius (N=0) and constant vs. poloidal direction

N=0.25 rotates poloidal profile into radial profile => flattens
N=0.50 rotates radial profile 180º => inverts profile



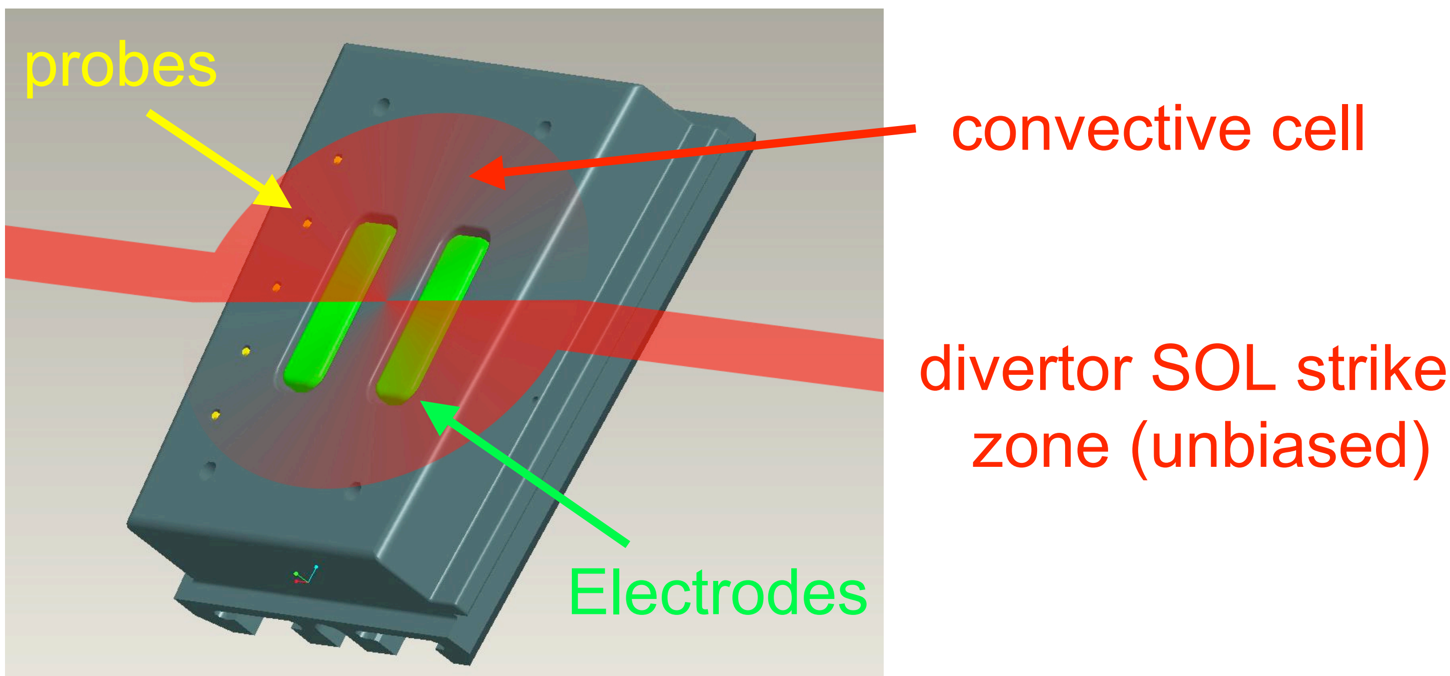


Conclusions from Model

- Best fit to data for outward ExB cases is N~0.25 - 0.5
- This is roughly consistent with expected rotation for the parameters given above (“Model for SOL...”)
- Explains how profile can invert for reversed biasing
- Quantitative model will need to include knowledge of:
  - radial density profile just inside biased electrodes
  - parallel and perpendicular potential scale lengths
  - parallel and perpendicular plasma flow speeds
  - dispersion in parallel flow due to ion distribution

Next Step Experiment in NSTX

- Electrodes in tiles between liquid lithium divertor segments
  - measure effects II and ⊥ B with camera + probes
  - learn to minimize power needed for SOL control



R. Ellis

SOL Control in Future Experiments ?

- In order to consider this (or similar) methods of SOL control for future experiments, we should show in NSTX:

  - ability to control SOL strike zone on divertor plate
  - significant SOL motion with ≤100 V (≥ 5 cm radially)
  - biasing power << SOL power flow (i.e. << 1 MW/m)
  - resistance of electrodes to arcing, coating, neutrons

- Alternative methods of convective cell generation are:

  - ICRH sheaths or LH waves (launched from midplane)
  - wavy or variably coated plates (Cohen/Ryutov ‘99)
  - variably grounded plates (passive voltage generation)

Sign up for copy of paper (submitted to PPCF)