Electrode Biasing Experiment for Local SOL Control In NSTX

L. Roquemore[1], S.J. Zweben[1], C.E. Bush[2]
R.J. Maqueda[3], R.J. Marsala[1], Y. Raitses[1]
R.H. Cohen[4], D.D. Ryutov[4], M. Umansky[4]

1- PPPL ; 2-ORNL ; 3-Nova Photonics ; 4-LLNL

TP8.00091

Poster APS DPP Meeting Nov. 2007

Summary

A set of small electrodes was installed in NSTX to test a proposal by LLNL to control the width of the scrape-off layer (SOL) by biasing the electrodes to create a strong local poloidal electric field. The effect of this local biasing was measured with Langmuir probes between the electrodes, and by the NSTX gas puff imaging (GPI) diagnostic located ~1 m away along the magnetic fields lines intersecting the electrodes. Changes in the local density and potential were seen by the probes in some cases, but not much change was seen in the D_α profile or the turbulent motions as seen by the GPI diagnostic.

Theory of Active SOL Broadening

- Apply toroidally asymmetric perturbations in SOL near divertor plate to create ExB flows to induce turbulent broadening [R.H. Cohen et al, Nucl. Fusion (1997); D.D. Ryutov et al, PPCF (2001), R.H. Cohen et al, PPCF (2007)]

  - perturbation can be biasing, 'wavy' plates, gas puffing
  - effects confined to divertor region by X-point shear
  - potential distribution along B-field line calculated

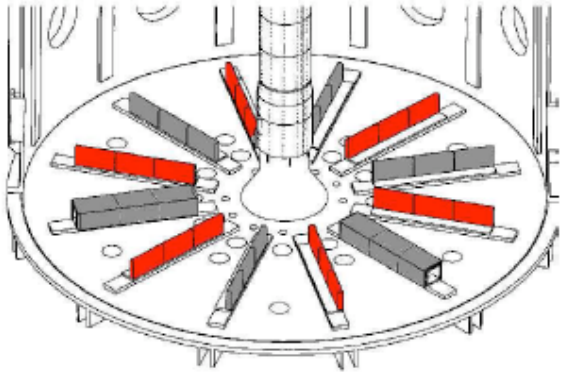
- Open questions:
  - how far do perturbations extend along and across B ?
  - do these perturbations locally induce turbulence ?
  - can the effects be simulated with BOUT (or XGC) ?

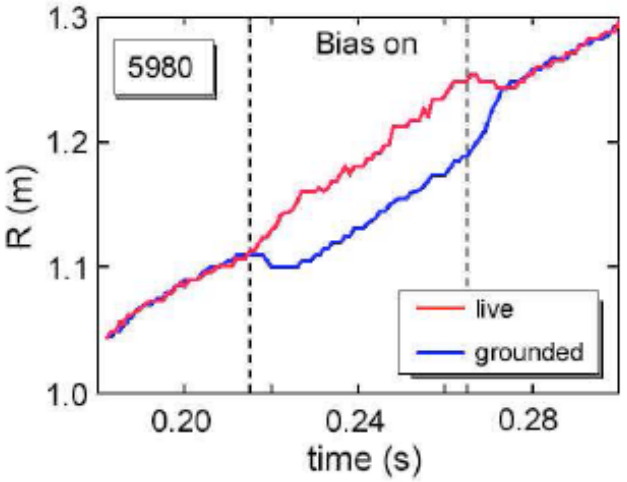
Previous Experiments

- Most tokamak biasing experiments aimed to modify E_r and poloidal flow [e.g. PBX-M, DIII-D, TdeV, TEXTOR…]

- MAST experiment done to test idea of Cohen and Ryutov, resulting in partial confirmation of theory

biased (and grounded) "ribs" in divertor (~80 V, 3 kA total)



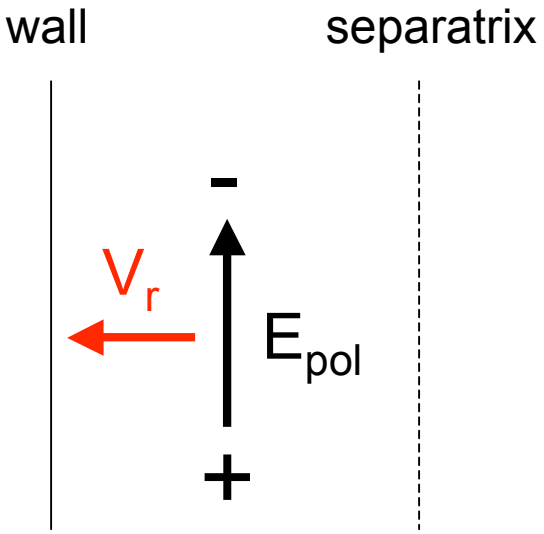


peak of D_α

G.F. Counsell, EPS Conference (2003)

SOL Control by Edge Biasing

- Create localized poloidal electric fields in SOL to make local radial $V_r = E_{pol} \times B$ drift to drive plasma outward
- If V_r is larger than the outward turbulent transport speed, local SOL width will be increased (particles and heat)



- $V_r(\text{cm/sec}) = 10^8 \, E_{pol}(\text{V/cm})/B(\text{G})$
- for this V_r to dominate SOL width as determined by a typical 'blob' speed of ≤ 1 km/sec, we would need only $E_r \sim 2.5$ *V/cm* in NSTX

NSTX Electrode Biasing Experiment

- Locate electrodes on B field lines of GPI diagnostic to see effect of bias on local turbulence and D_α profile (e.g. see 'blobs' move faster outward, or inward)

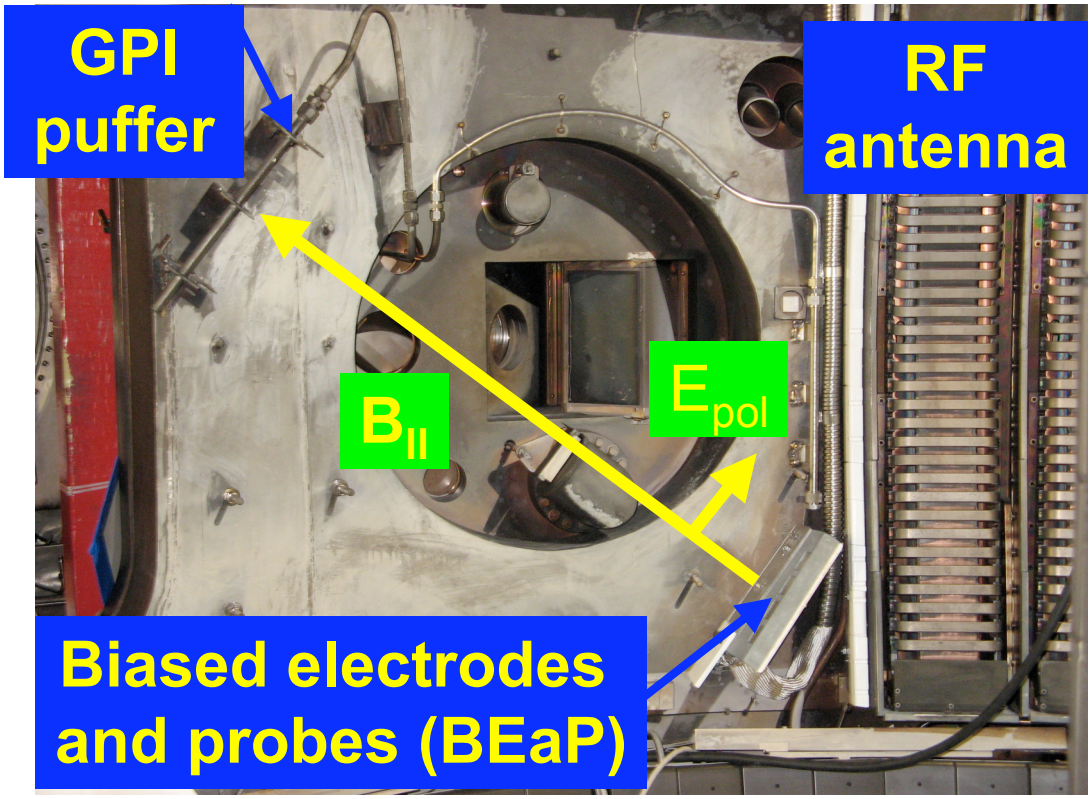
- Installed Langmuir probes between the electrodes to measure local potential, n_e and T_e, and turbulence

- Can correlate fluctuations in probe and GPI to determine location of electrodes in GPI field of view

=> ***Look for effect of electrode bias on GPI and probes***

=> ***Did not expect to make "global" modification of SOL***

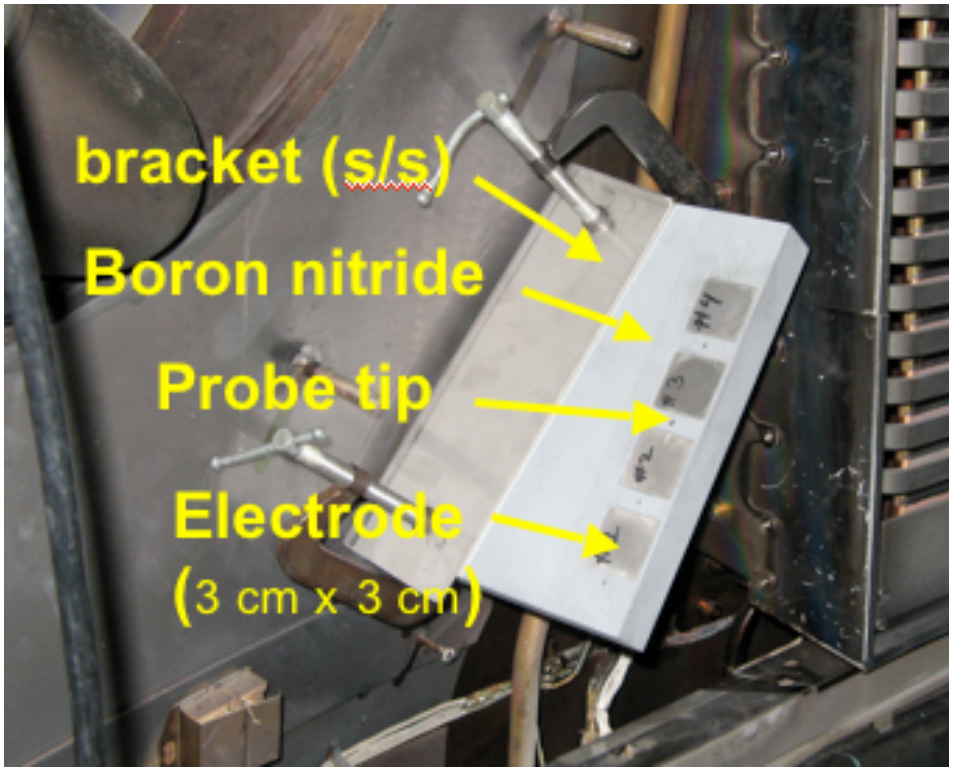
Biased Electrodes and Probes in NSTX

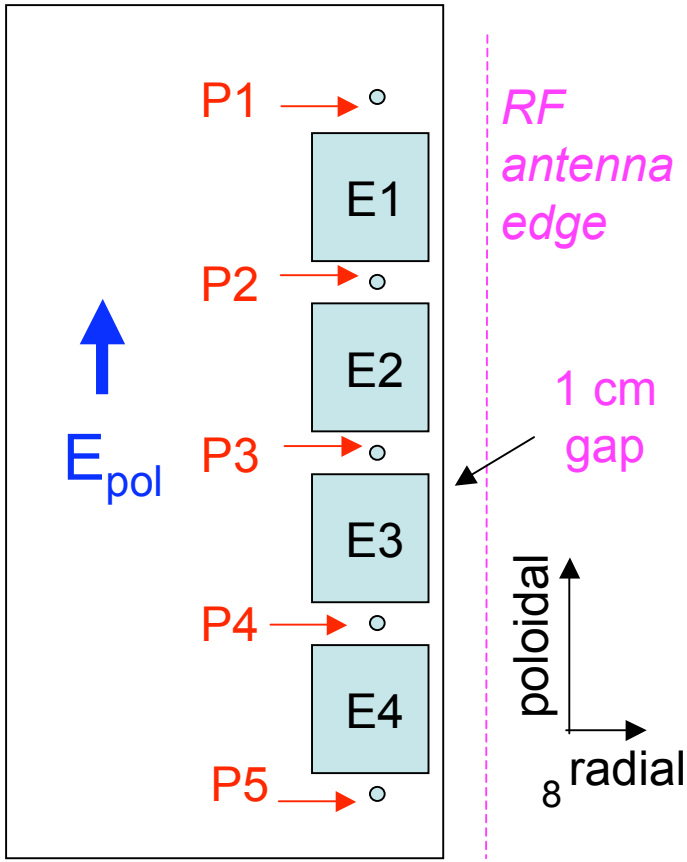


- installed ~ Dec. '06
- leading edge ~ 1 cm behind RF antenna
- 4 electrodes of size ~ 3 cm x 3 cm
- 5 Langmuir probes next to electrodes

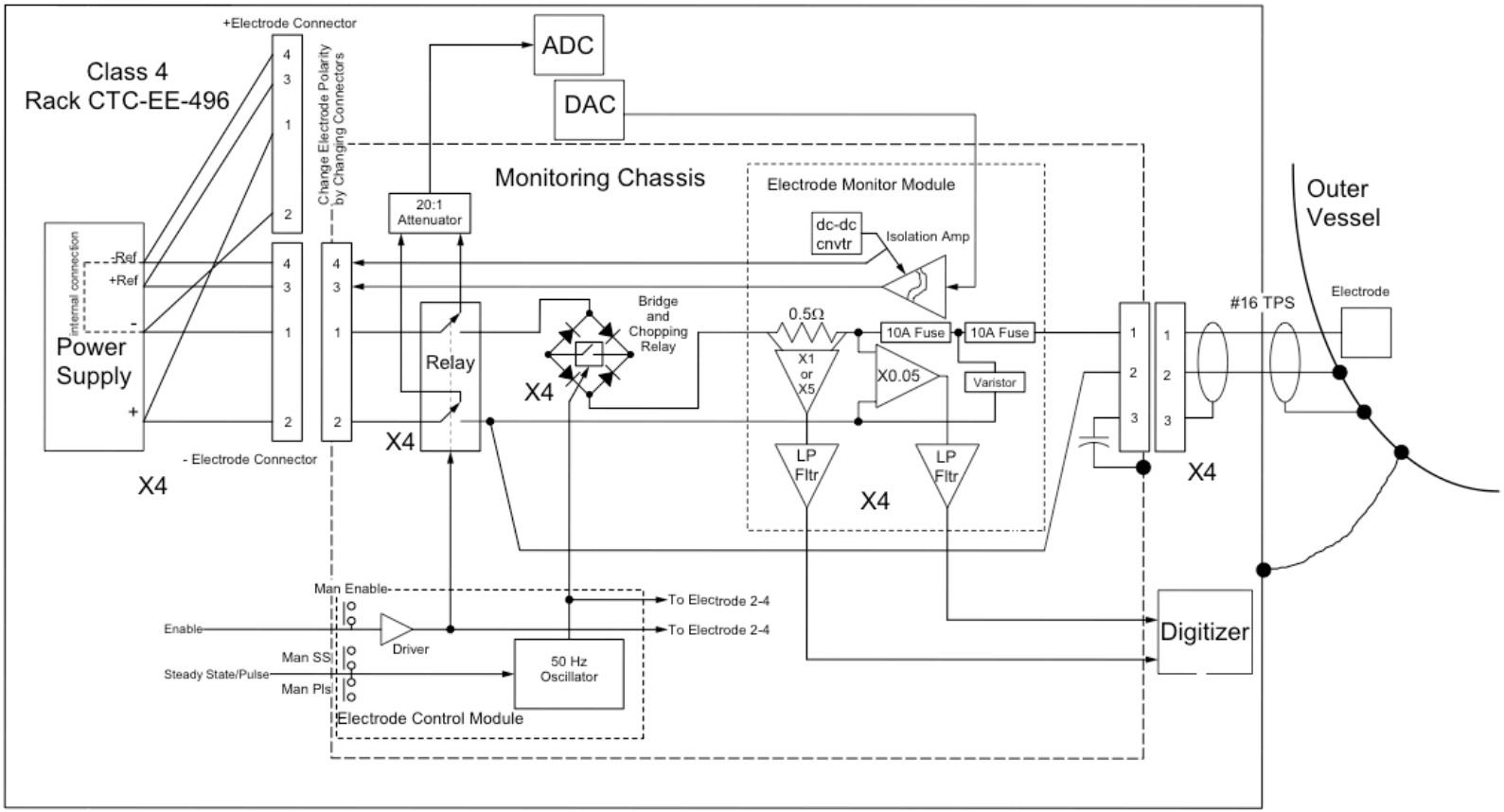
Biased Electrodes and Probes (BEaP)

- up to ± 100 V, 10 A on any 3 electrodes
- electrode voltage modulated @ 50 Hz
- Langmuir probe DC or swept ± 50 volts





Circuit for Modulated Electrode Bias



- Electrode ground at nearby vessel wall

Biased Electrode Data for 2007

- Ohmic LSN plasma, B=4.5 kG I=0.8 MA, ΔB drift down

Shot	Electrode #1	Electrode #2	Electrode #3	probes
123678	0	0	off	swept
123679	-20 volts	-20 volts	off	swept
123680	0	0	off	swept
124059	0	0	off	+50 volts
124060	-70 volts	-70 volts	off	+50 volts
124061	-70 volts	-35 volts	off	+50 volts
124062	-35 volts	-70 volts	off	+50 volts
124676	0	-90 volts	0	swept
124677	0	-95 volts	+10 volts	swept
124678	0	-95 volts	+20 volts	swept
124679	0	-95 volts	+25 volts	floating
124680	0	-95 volts	+30 volts	floating
124681	0	-95 volts	+30 volts	-50 volts
124682	0	-95 volts	+30 volts	+50 volts
124683	0	-95 volts	+40 volts	+50 volts
124684	0	-95 volts	+40 volts	floating
124688	-95 volts	0	+50 volts	floating

electrode #4 hard grounded for all shots (without any current monitor)

Expected Effects of Biasing

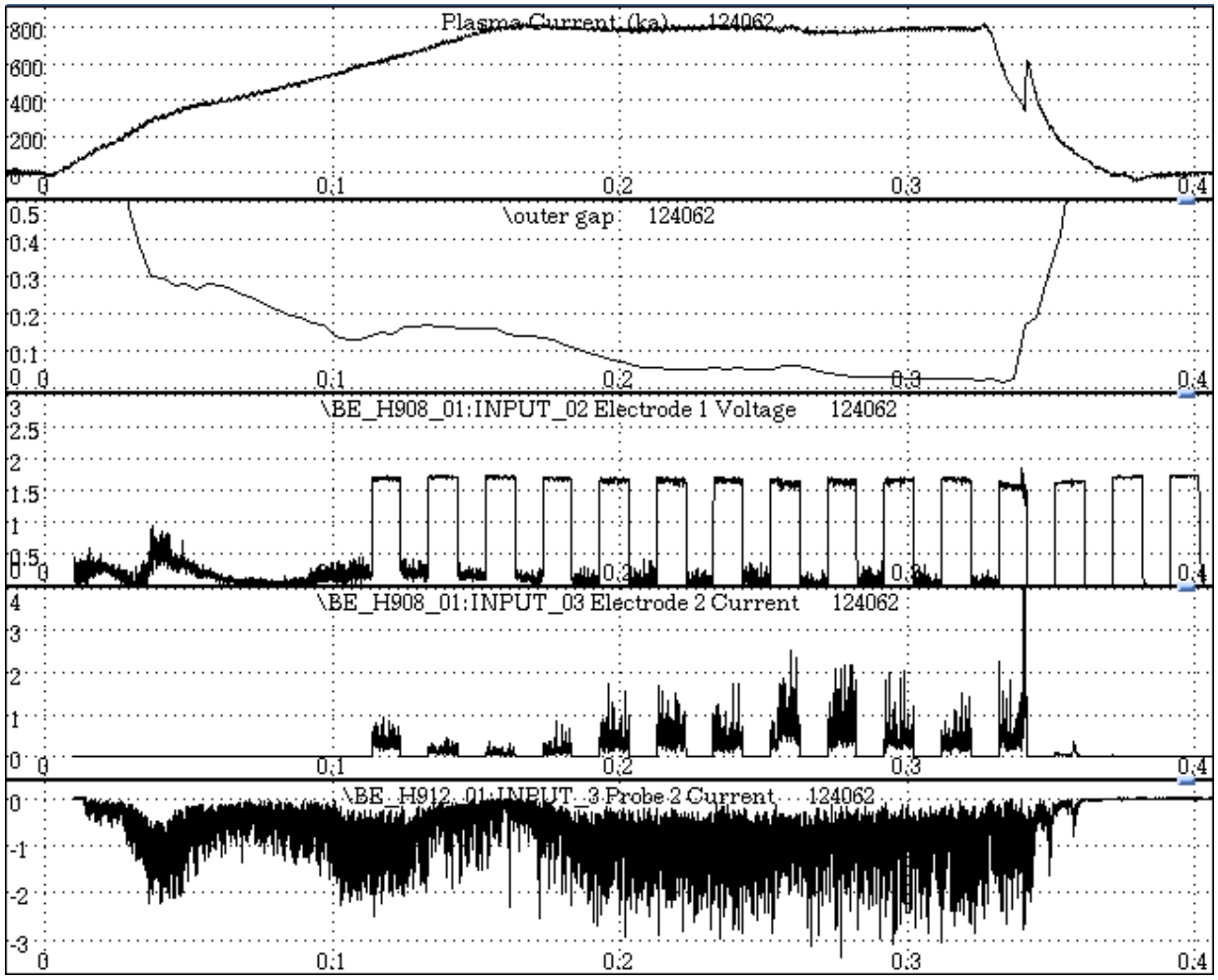
- If the voltage applied to electrodes appears on flux tubes tied to electrodes, the poloidal electric field between electrodes #2 and #3 should be up to E_{pol} ~135 V/cm

- This should create a ExB velocity of $V_r \leq 5 \times 10^6$ cm/sec, which is ~ 50 times larger than a typical blob velocity

- The direction of this velocity should be radially outward between electrodes #2 and #3

=> *this should have a **very strong** effect on SOL locally*

Electrode and Probe Signals vs. Time



I=0.8 MA
B=4.5 kG

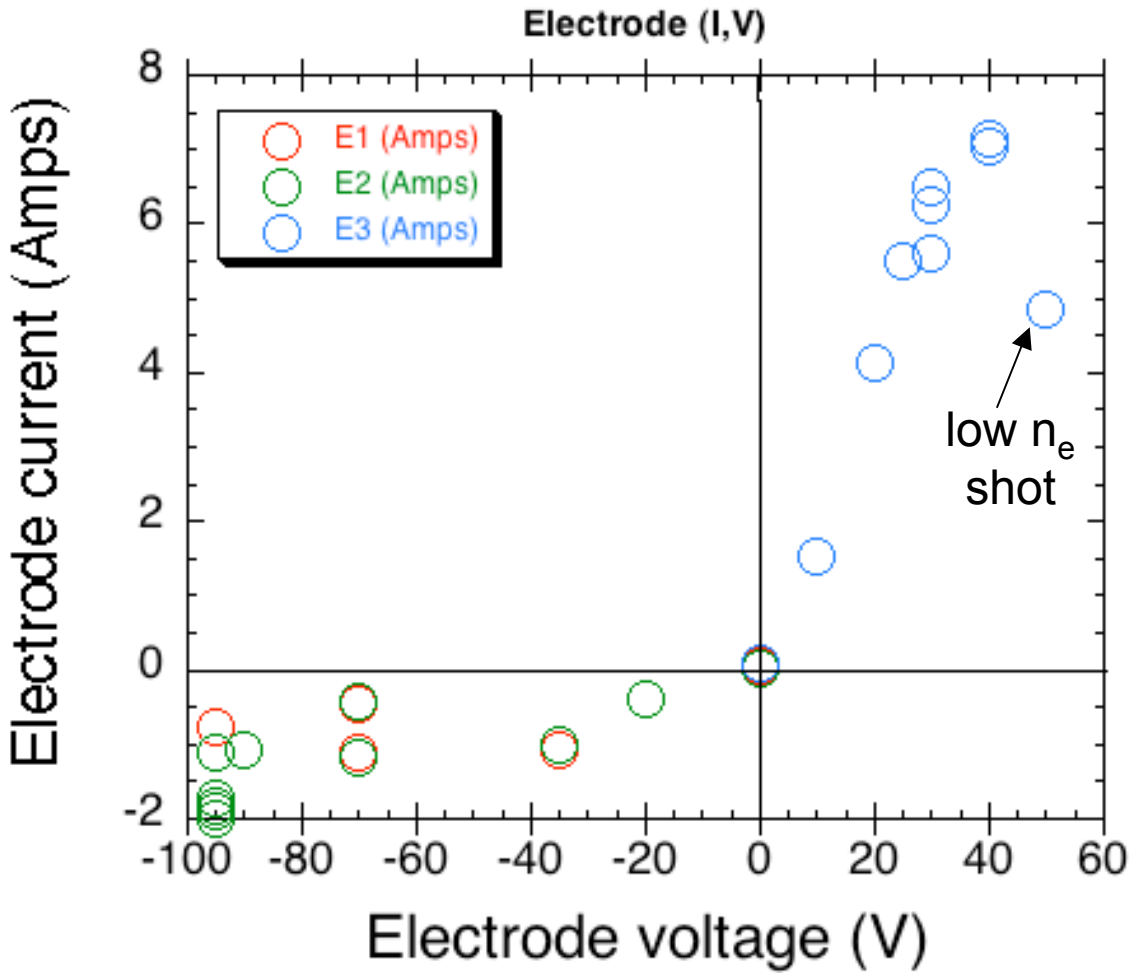
outer gap
15 cm => 1 cm

electrode V
-70 V @ 50Hz

electrode #2
$I_{ion} \leq$ 2 amps

probe #3 $I_{sat,e}$
≤ 0.3 amps

Average Electrode Current vs. Voltage

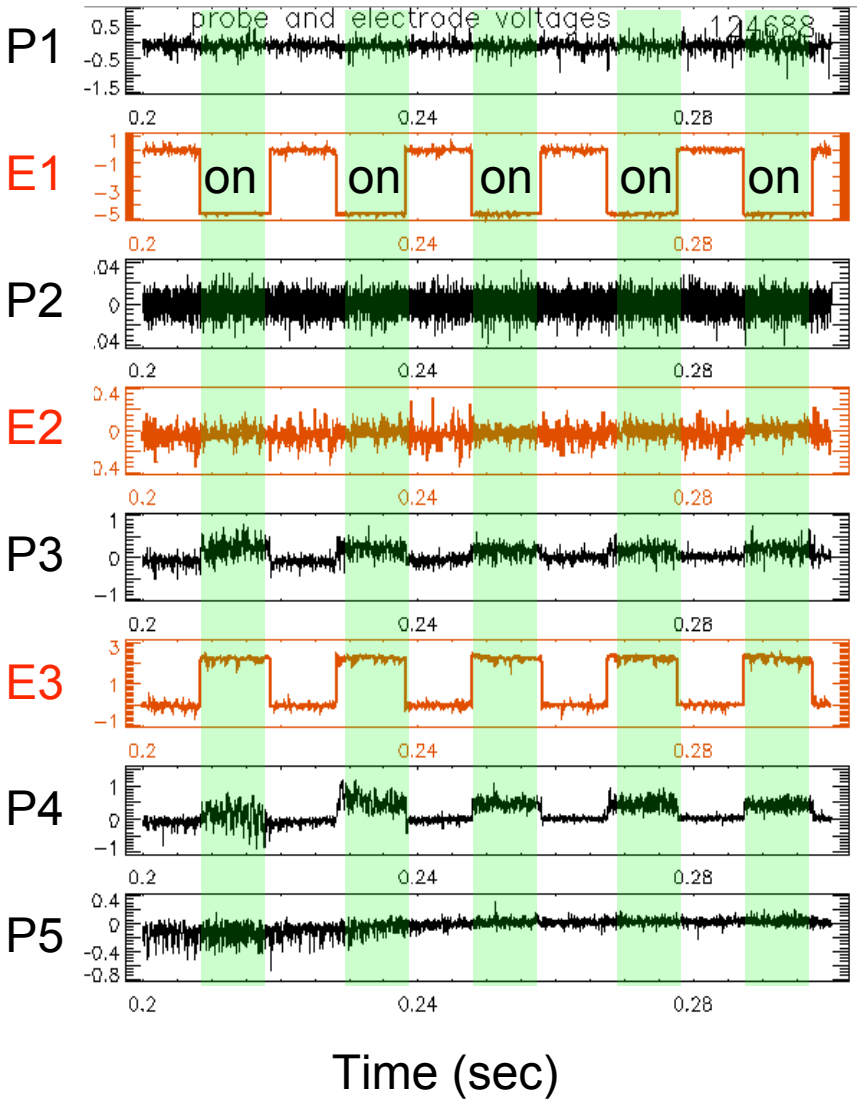


- Looks ~ like typical Langmuir probe
- Electrode current I_e/I_i ~ 7 at ±40 volts
- Probe current I_e/I_i ~ 20 at ±50 volts

electron current may not have reached saturation at the limit of power supply (10 A)

Probe Floating Potential Response

probes = black, electrodes = red

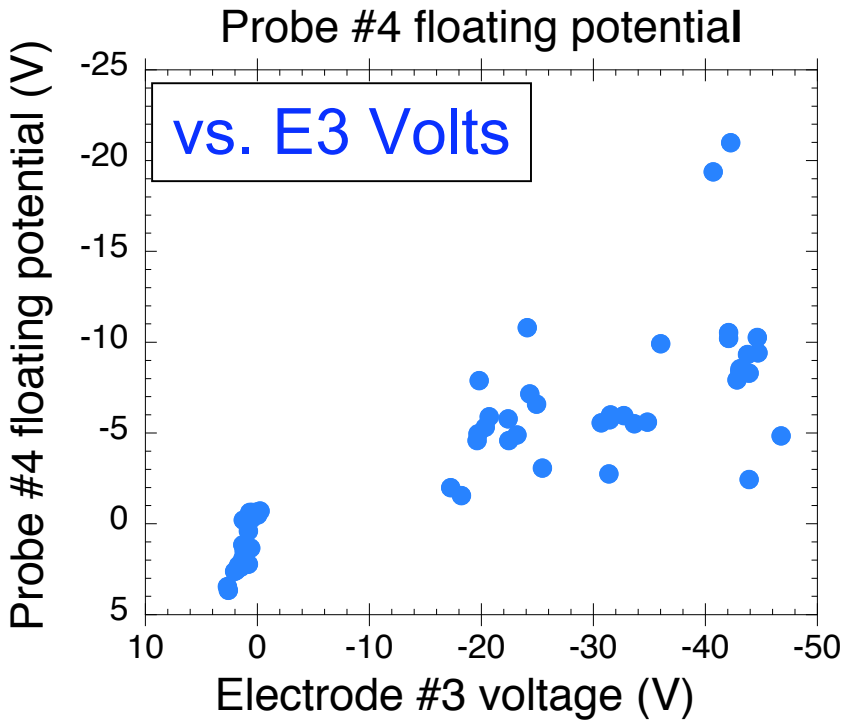


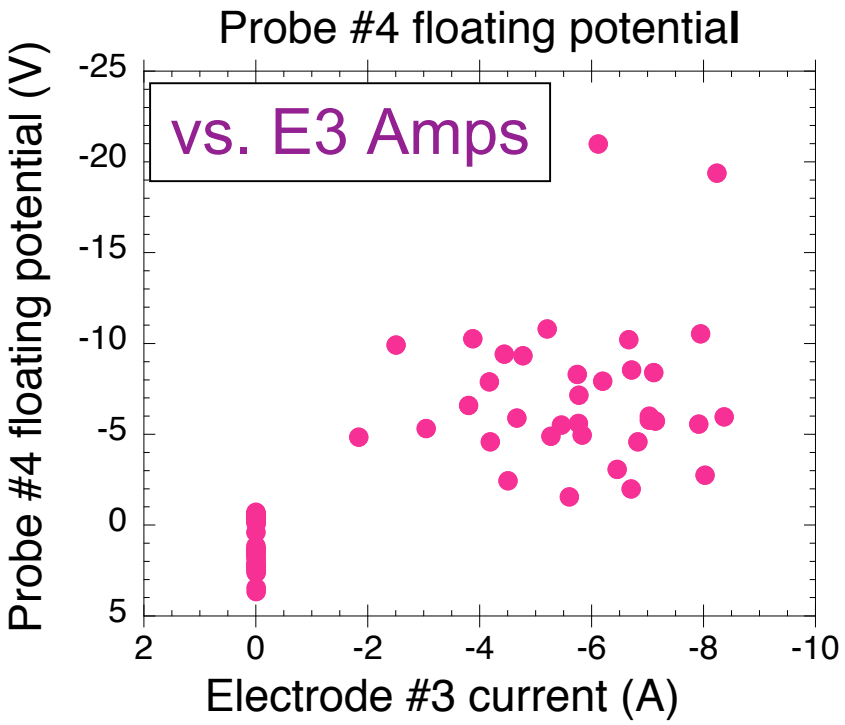
- floating potential of probes near + 50 V electrode up +10 V
- floating potential of probes near - 95 V electrode not change

=> positive electrode affects nearby V_f

negative electrode does not !

Probe Potential vs. Electrode (I,V)

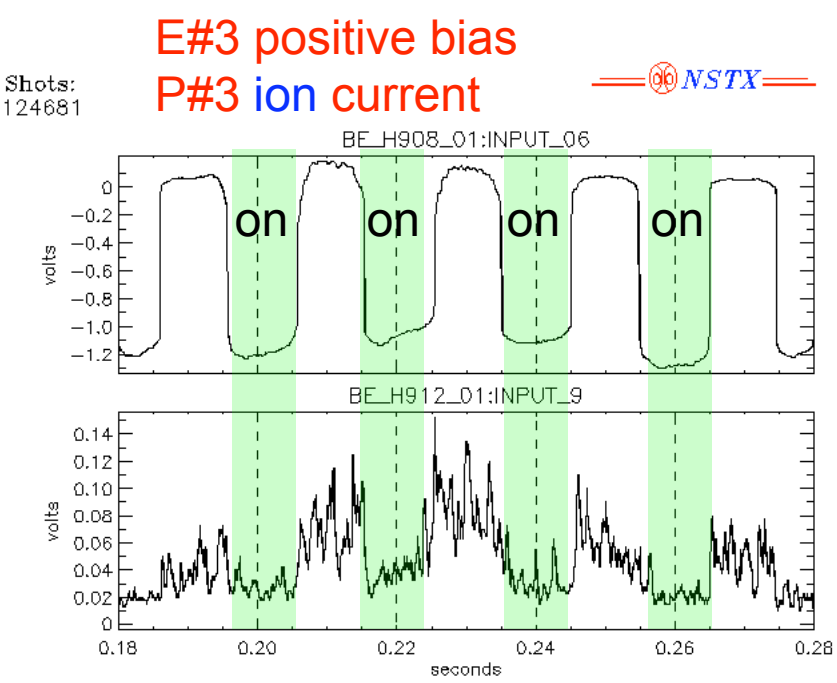


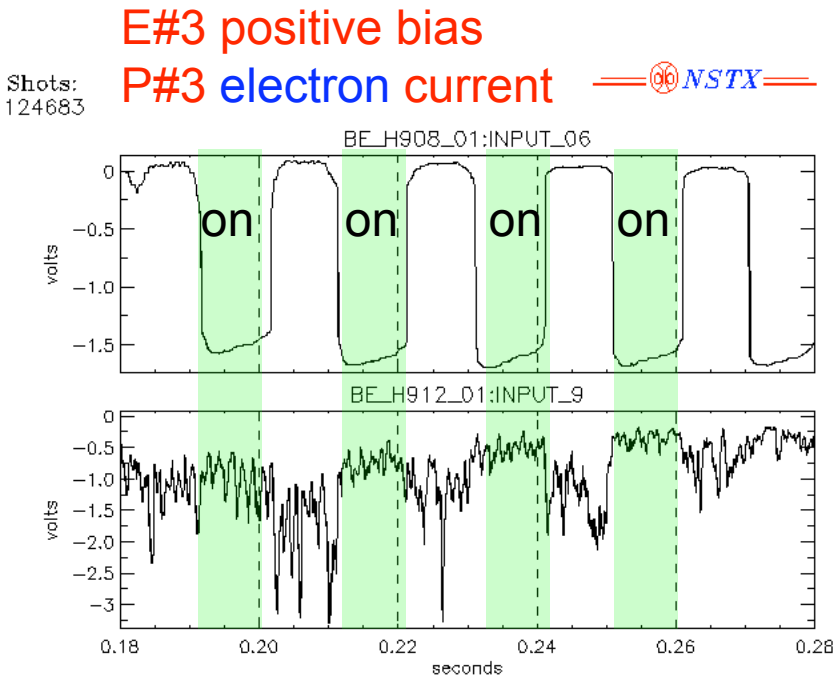


- Probe floating potential change more correlated with the adjacent electrode voltage than the electrode current

- Scatter shows that some other factor(s) affecting potential; for example, the outer gap affects the local density

Density Change Seen by Probes





- I_{sat} (both i+ and e-) decreases with positive electrode bias

$\Rightarrow$ local density *decreases* with positive electrode bias
(may also be some effect due to local V_f change)

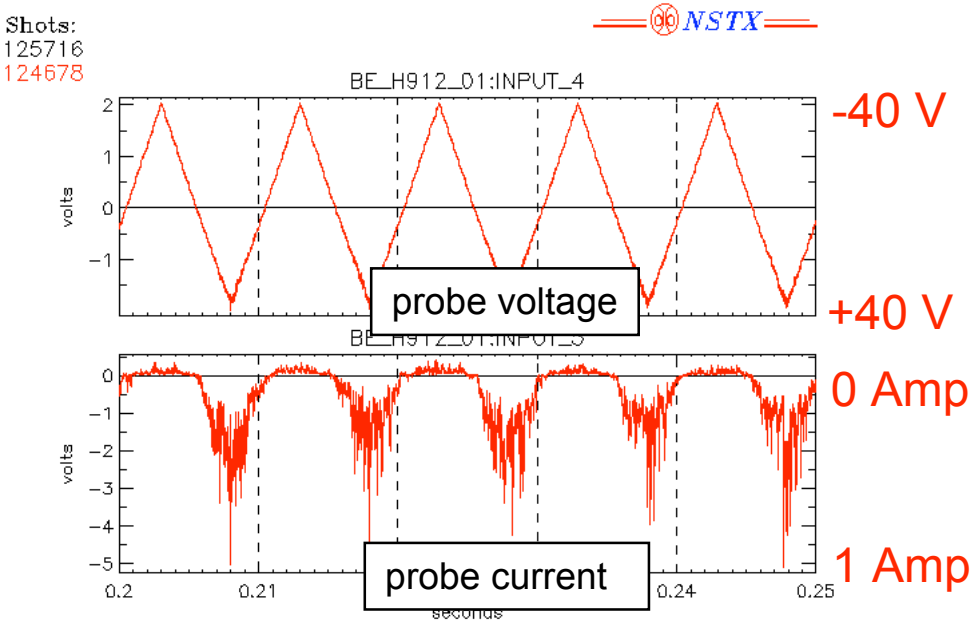
Effects on Probe Fluctuations

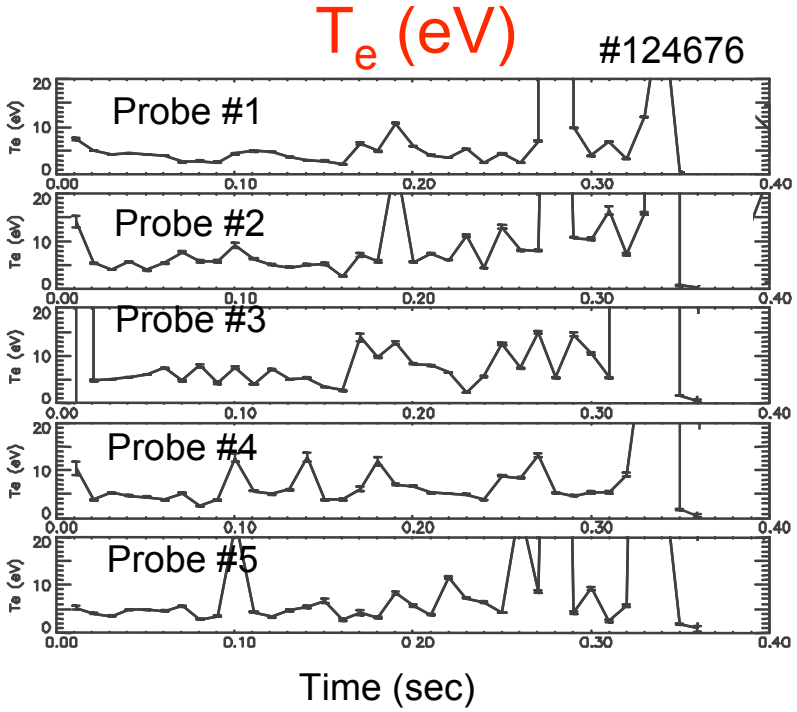
- Positive electrode bias increases nearby probe floating potential fluctuation level and decreases local probe relative density fluctuation level (see plots above)

- Positive electrode bias does not significantly change autocorrelation times or cross-correlation coefficients (i.e. space-time structure of local turbulence)

- Negative electrode bias does not affect nearby probe fluctuations at all

Probe Temperature and Density

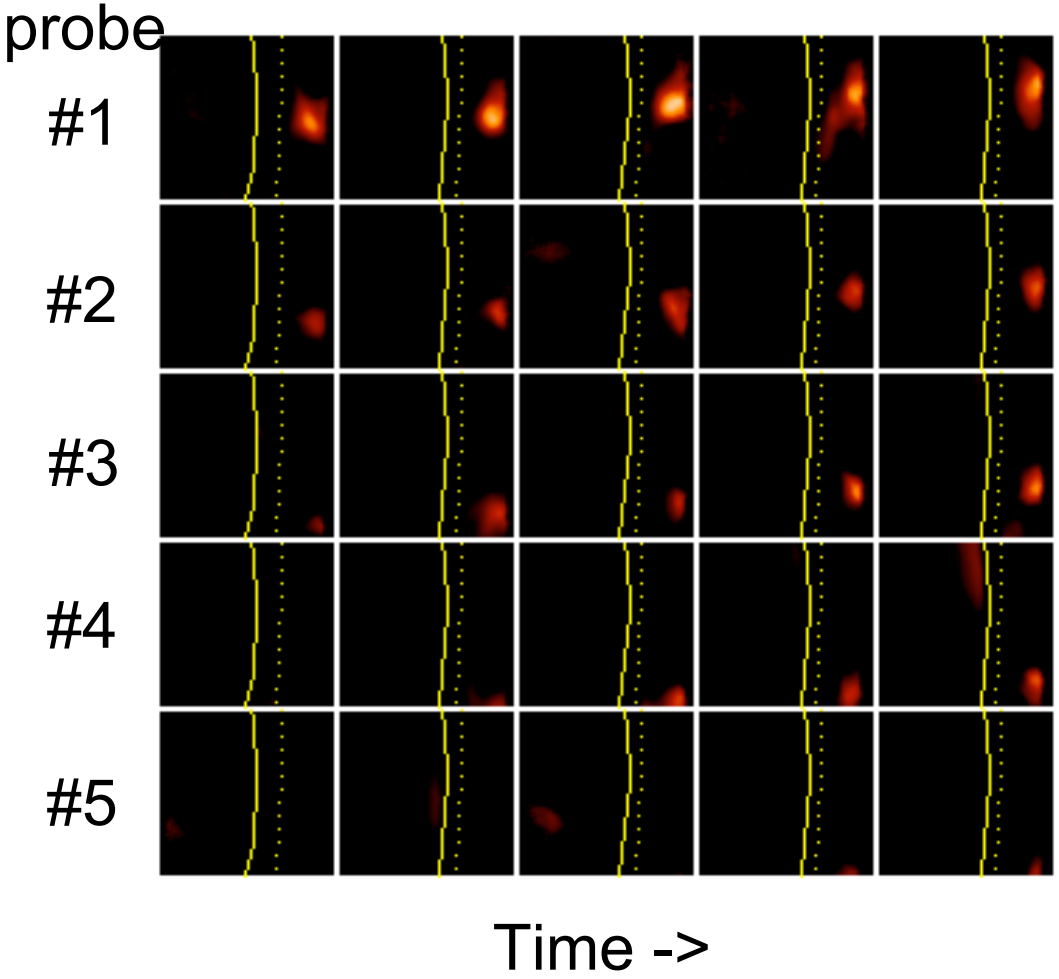




- T_e ~ 5-15 eV (with or without ≤ +20 VDC biasing)
- n_e ~ 10^{12} cm^{-3} from ion saturation current

Correlation of Probe & GPI Fluctuations

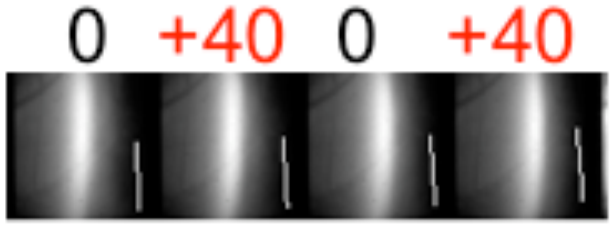
GPI imaging region overlayed with probe correlation strength (red)



- Good correlation of fluctuations along ~ 1 m along B field (C_{12} ~ 50-80%)
- Mapping of probes to GPI agrees with EFIT02 field lines (moves vs. time)
- Size of correlation volume ~ blob size as expected

GPI D_α Profile Response to Bias

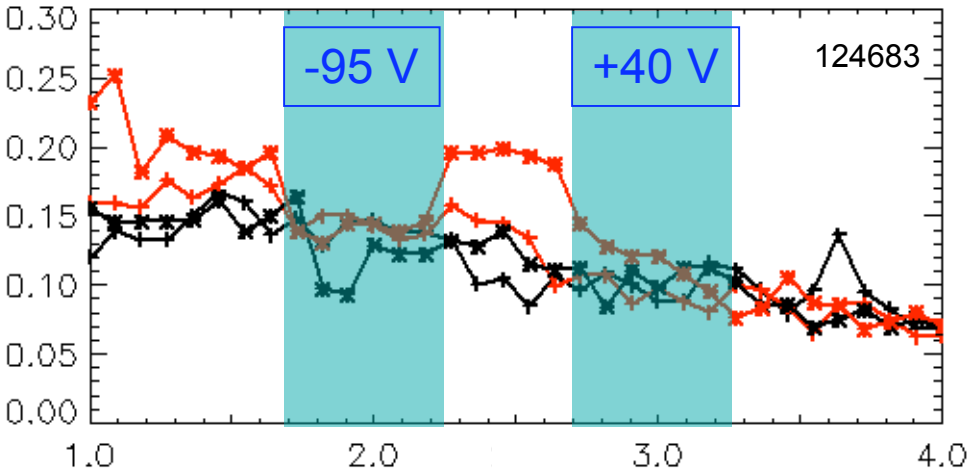
Radial vs. Poloidal Images of D_α



Time ->

Poloidal profile of D_α

red = bias on black = bias off



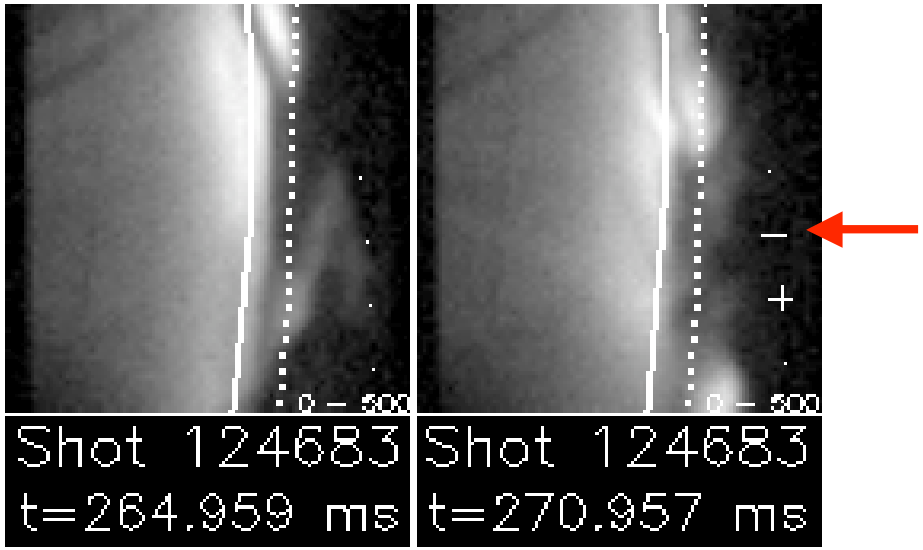
Electrode #

- No change in radial position of D_α profile at GPI location
- Some increase in D_α between electrodes #2 and #3

GPI Turbulence Response to Bias

only visible in movie

Bias Off Bias ±40 V



Electrode location and sign of bias

- Turbulence blobs sometimes look as if they were being 'sucked' between electrodes #2 and #3 ?

Summary of Experimental Results

- Positive bias sometimes had a *significant effect as* measured at an adjacent Langmuir probe:

  - local potential increased by ~ 20% of applied voltage
  - local plasma density decreased by ~ factor of two

- Positive Bias *had a small effect* on the local D_α profile and turbulence seen by the GPI diagnostic

- Negative bias *did not have any effect* on probes or GPI

Comparison with MAST Results

- Electrode voltages similar, but current and power ~ 300 times larger in MAST (3 kA) vs. NSTX (10 A)
- Electrodes at divertor floor in MAST, midplane in NSTX
- Large variation of D_α strike point seen in MAST with bias was not seen in NSTX D_α profile 1 meter upstream
- Negative biasing in MAST showed some effect on heat flux profile on biased rib, but no effect of negative bias seen on probes or GPI in NSTX

Tentative Theoretical Interpretations

- Asymmetric electrode (I,V) characteristic shows that there is significant cross-field current, since I(+) >> I(-)
- Parallel resistive drop along flux tube should be negligible at T_e ~ 10 eV, so full electrode voltage should appear upstream on flux tube (but it apparently does not !)
- Cross-field currents near electrodes may cause reduction in voltage on distant flux tubes, and appearance of voltage on nearby probes in positive bias case
- No clear evidence of increased turbulence due to biasing, as might be driven by K-H instabilities

Open Physics Questions

- Why doesn't full electrode voltage appear as a poloidal electric field at GPI diagnostic 1 meter upstream ?
- What causes increase in floating potential and decrease in density on probes near the positive electrode ?
- How can we make a bigger change in SOL upstream in order to control SOL width

⇒ ***need quantitative modeling of bias voltage penetration parallel and perpendicular to B field***

BEaP After 2007 Run

- coatings by lithium and plasma deposition
- electrodes *not* melted or electrically shorted
- nearby electrical cables and antenna fasteners slightly melted by power flux of unknown origin in far SOL

Improvements Planned for 2008

- Increase positive bias supplies from 10 A to 30 A
- Add a radial array of probes to measure local SOL
- Fast camera view of electrode structure to see D_α
- Look for non-local effects in divertor region along B
- Try biasing with different plasma conditions (RF, NBI)
- Start quantitative modeling of effects of biasing

BEaP Before 2008 Run

new radial
probe array

new cable shield