NSTX

Supported by U.S. DEPARTMENT OF ENERGY Office of Science

Modification of the Electron Energy Distribution Function during Lithium Experiments on the National Spherical Torus Experiment

MA Jaworski[a], M. Bell[a], T.K. Gray[b], R. Kaita[a], J. Kallman[a], H. Kugel[a], B. LeBlanc[a], A. McLean[a], S.A. Sabbagh[c], V. Soukhanovskii[d], D. Stotler[a], V. Surla[e]

[a]Princeton Plasma Physics Laboratory

[b]Oak Ridge National Laboratory

[c]Columbia University

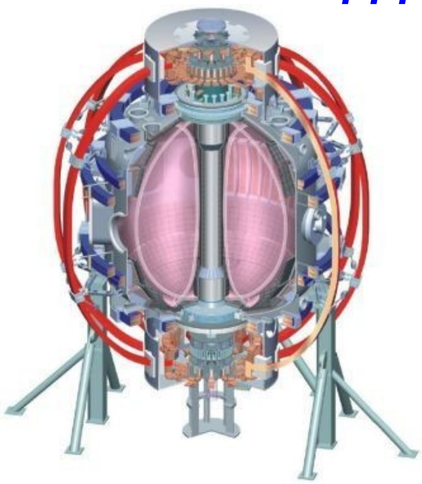
[d]Lawrence Livermore National Laboratory

[e]University of Illinois at Urbana-Champaign

The 2nd International Symposium of Lithium Application for Fusion Devices

PPPL, April 27 -29, 2011

College W&M
Colorado Sch Mines
Columbia U
CompX
General Atomics
INEL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
Old Dominion U
ORNL
PPPL
PSI
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Illinois
U Maryland
U Rochester
U Washington
U Wisconsin



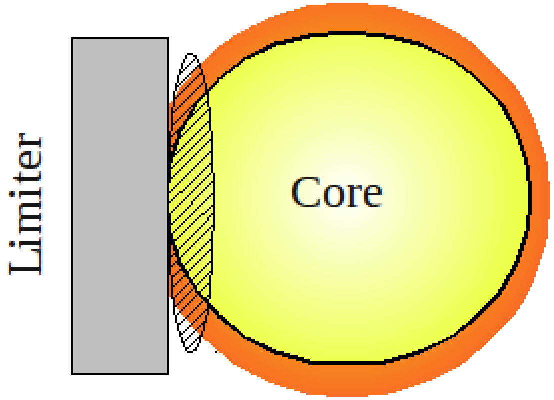
Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
POSTECH
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec

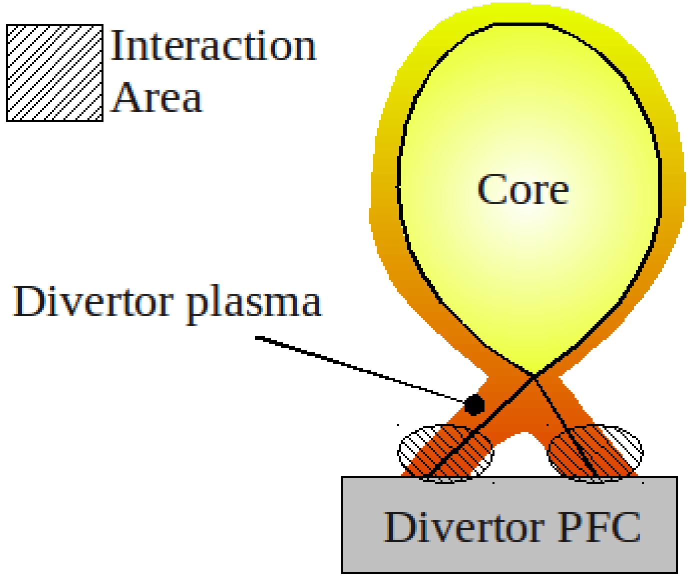
Presentation Overview

- Introduction and review of key issues facing NSTX and other lithiated machines
- Demonstration of the separation between the core plasma and the PFCs in a diverted machine
- Overview of Langmuir probes and interpretation in NSTX
- The results of Electron Energy Distribution Function analysis
- Discussion and implications of results

NSTX was the first divertor machine to use significant quantities of lithium wall conditioning

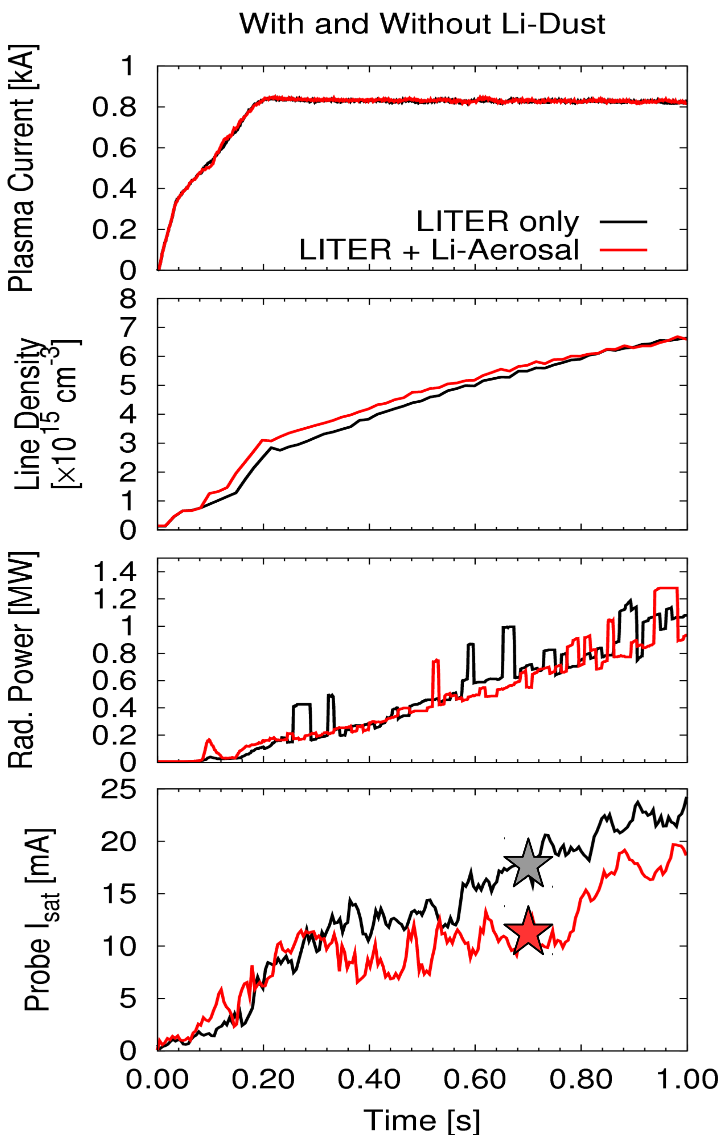
- Lithium utilized on NSTX to condition and alter significant portions of the machine via the LITER evaporator system – especially the divertor floor
- Nearly all other plasma devices using lithium are *limiter* machines and provide a comparison
- Divertors created to *separate* the PFC and associated plasma-material interactions from the core
  - Limiters, by definition, are in direct contact with the core
  - Divertors create a "buffer" plasma between core and the rest of the machine





Protective effect of the divertor demonstrated by Li-Aerosol experiments

- During experiments on NSTX, it is possible to utilize lithium aerosol before and during plasma discharges for additional wall conditioning
- Here, standard LITER application of 30mg/min for ~10min utilized prior to both discharges (300mg total)
- Additional 200mg/s of Li-Aerosol applied in the indicated discharge
- Negligible impact was observed on the core (e.g. line density or radiated power)
- Density in the SOL at the divertor target plate decreased by a factor of two (4.8e19 vs. 2.4e19m^{-3})

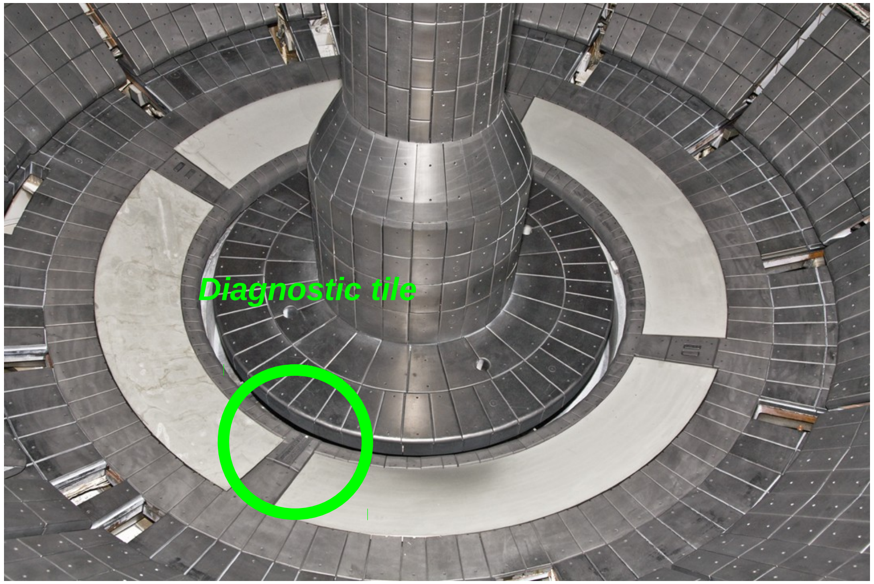


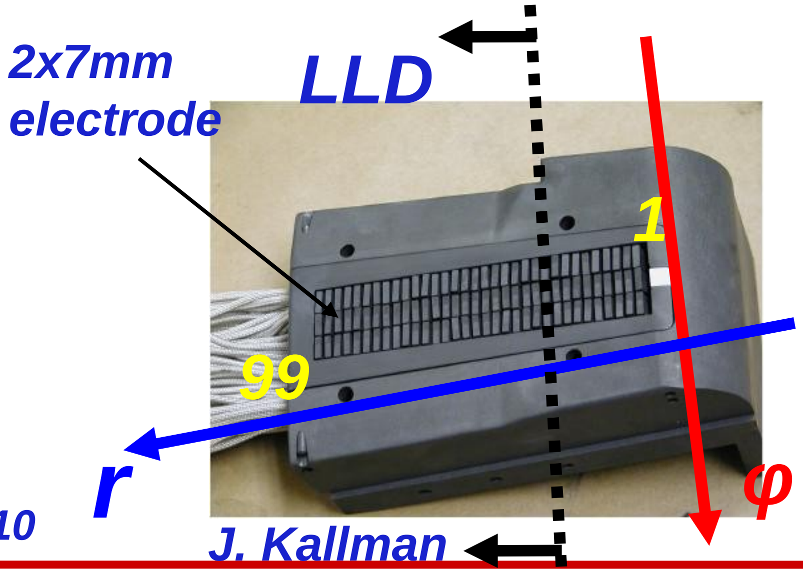
Langmuir probes provide the closest measure of the near surface plasma

- Aerosol experiments demonstrate the utility of the Langmuir probes in diagnosing the plasma in the divertor floor
- Should not be a surprise as Langmuir probes have always been a *local* diagnostic
- Do not suffer from reflections from dynamic surfaces nor complicated views through divertor geometry (See also F. Scotti)
- **However, probe interpretation has been a perennial issue in tokamak plasmas**

Langmuir probe hardware for diagnosing the LLD

- Situated between liquid lithium divertor plate segments
- Provides coverage over graphite and LLD materials
- Electronics developed for flexibility, speed and accuracy (U-Illinois collaboration)
- See also J. Kallman's talk and poster in this session for more information

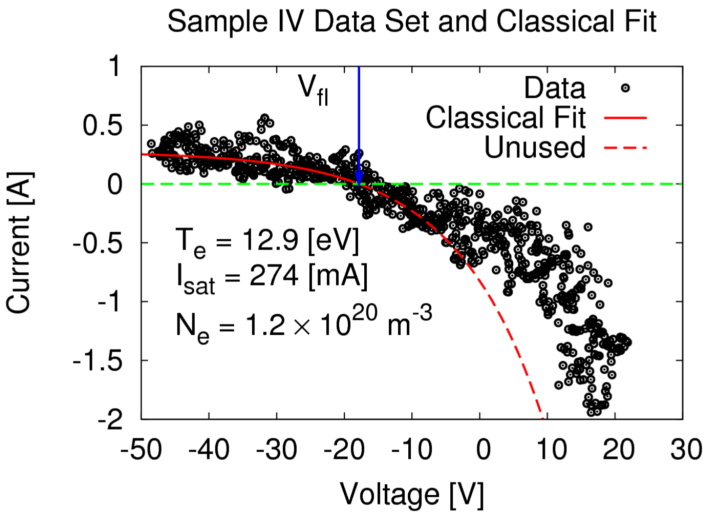


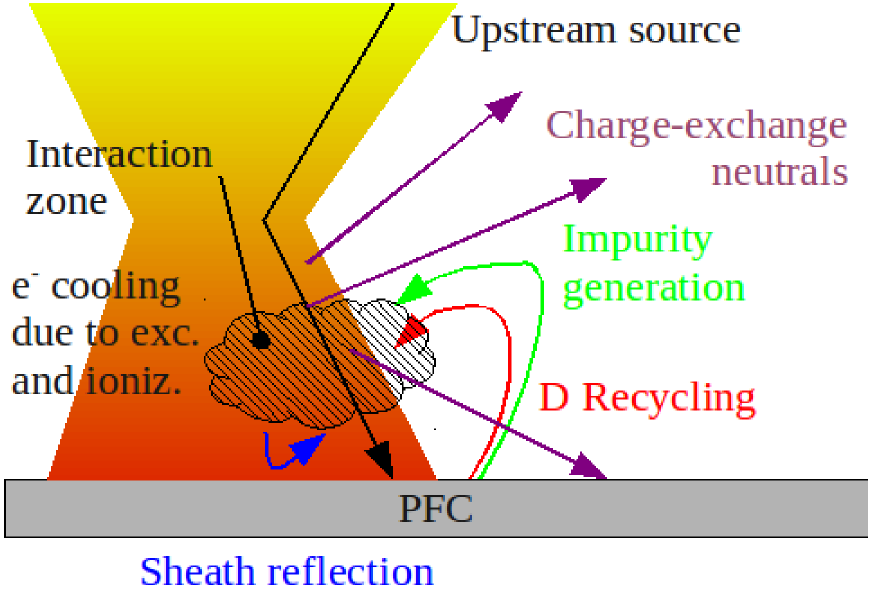


J. Kallman, RSI 2010
M.A. Jaworski, RSI 2010

The classical method of interpreting a probe

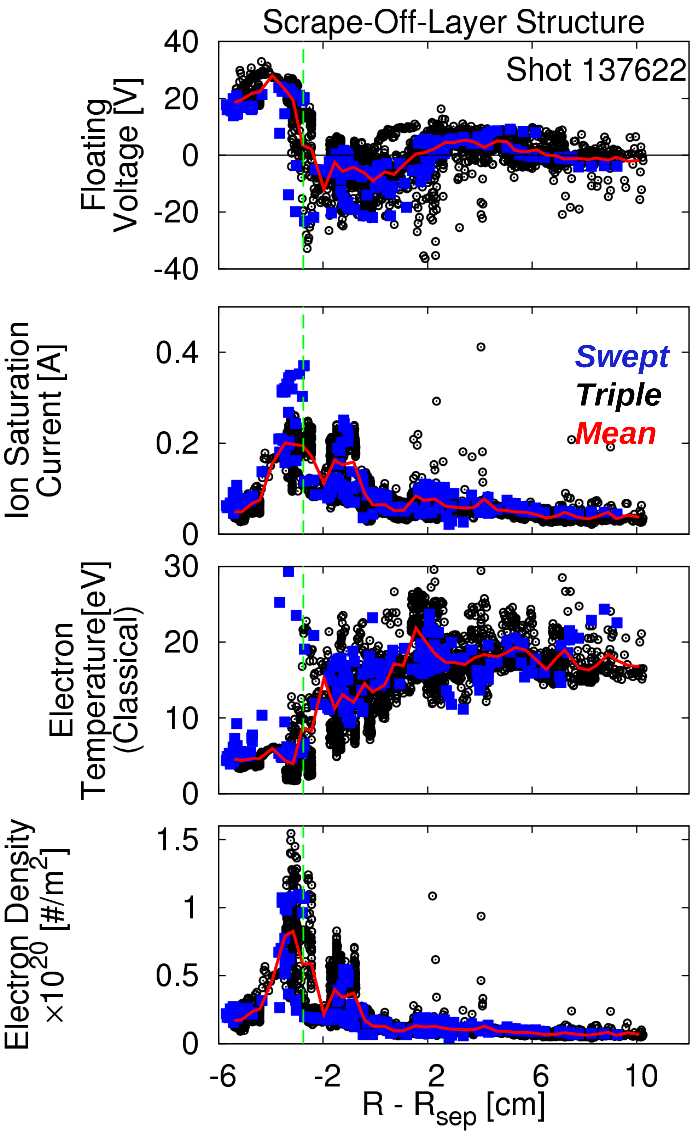
- Classical interpretation makes use of data up floating potential (Tagle, et al., **PPCF**, 1997; Matthews, **PPCF**, 1994)
  - Only samples ~5% of distribution
- Plasma potential cannot be measured
- In principle, electron current contains complete information of distribution function and processes forming it, but requires model to interpret





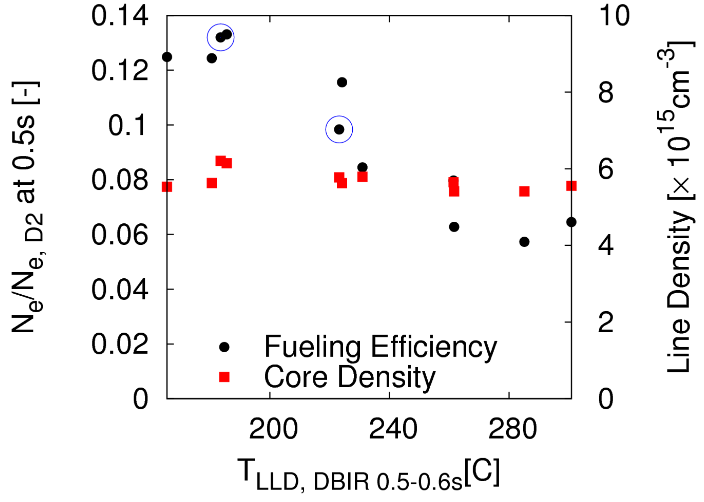
Classical method can be fast and reveals structure

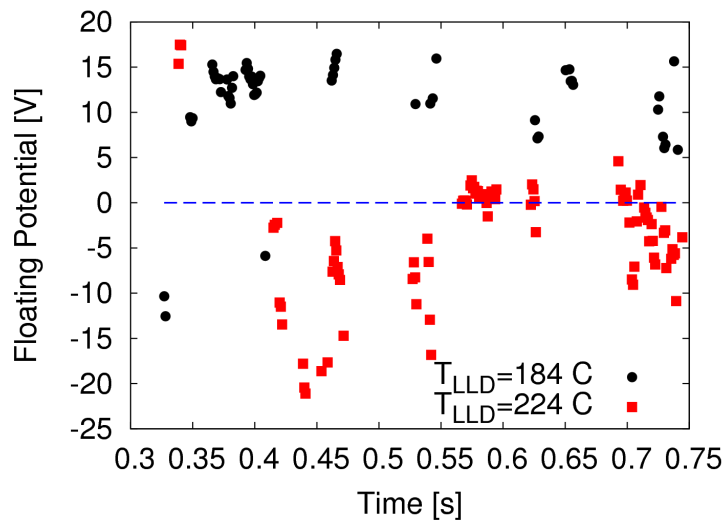
- Simple comparisons from shot to shot often difficult
  - Strong spatial gradients in the SOL result in sensitivity to position
  - Constant plasma motion results in additional temporal variation
- Methods developed to utilize magnetic equilibrium reconstruction as position reference for probe array
- Provides the means of making comparisons between discharges on identical magnetic flux surfaces



Trends in the classical method and machine

- Experiments in mid-run indicated possible changes in LLD performance
  - Fueling increased with negligible impact on the core
  - LLD heated by the plasma during this sequence (see also A. McLean presentation)
- Two shots in sequence used for comparison avoiding discharges with significant ELM activity
- Observe a significant shift in floating potential with the latter (hotter) LLD discharge

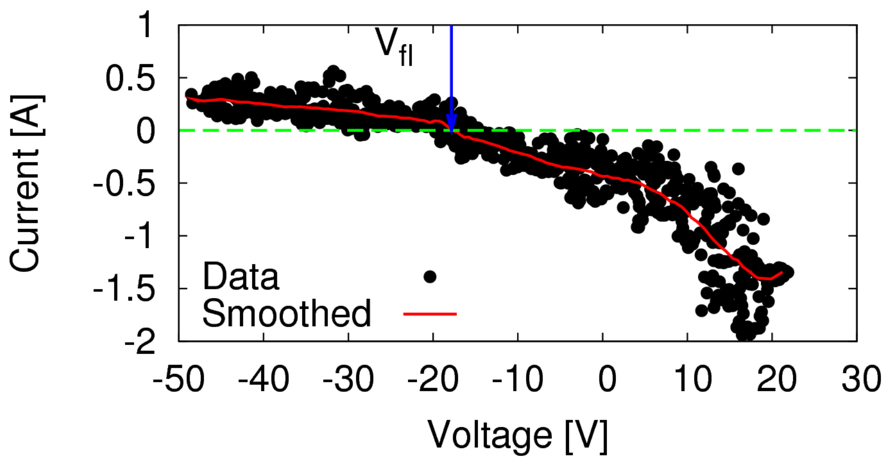


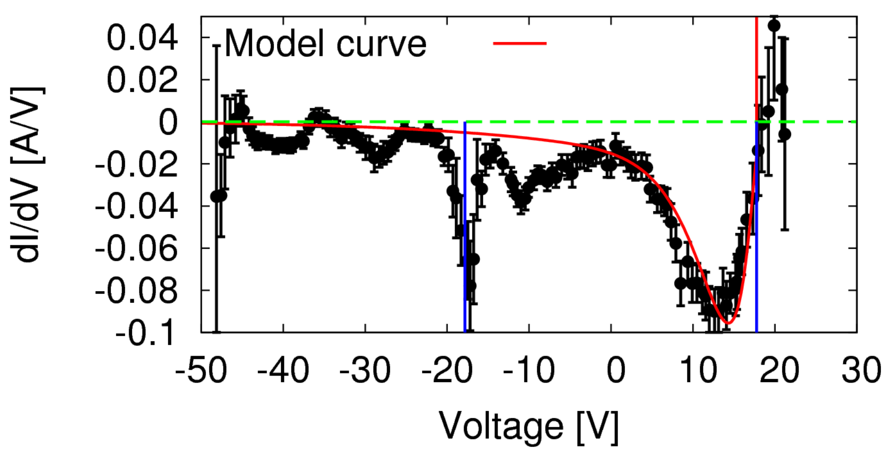


A more complete probe theory

- Recent developments open a means to interpret then entire transition region of electron current
- So-called, first derivative method relies on “non-local” regime of operation
- Approximate form for integral equation developed by Popov and demonstrated on CASTOR (Popov, PPCF, 2009)
- At right illustrates the determination of plasma potential from the IV characteristic and derivative

$$I_e(U) = -\frac{8\pi e S}{3m^2}\int \frac{(W-eU)\, f(W)\, dW}{\gamma(W)\left[1+\frac{(W-eU)}{W}\psi(W)\right]}$$

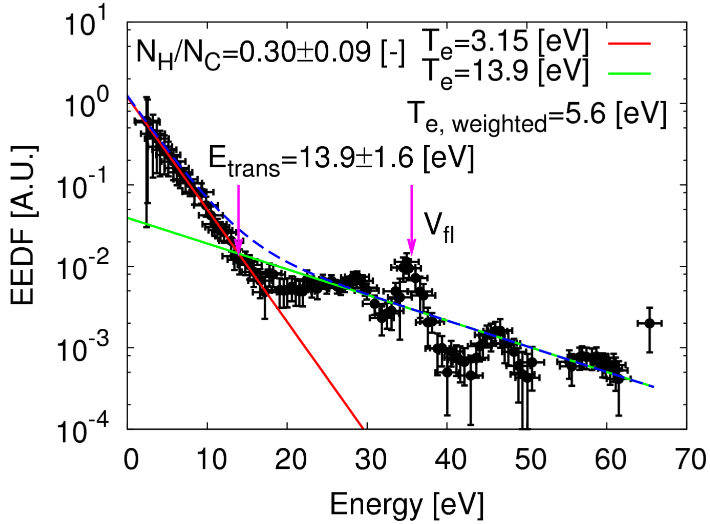




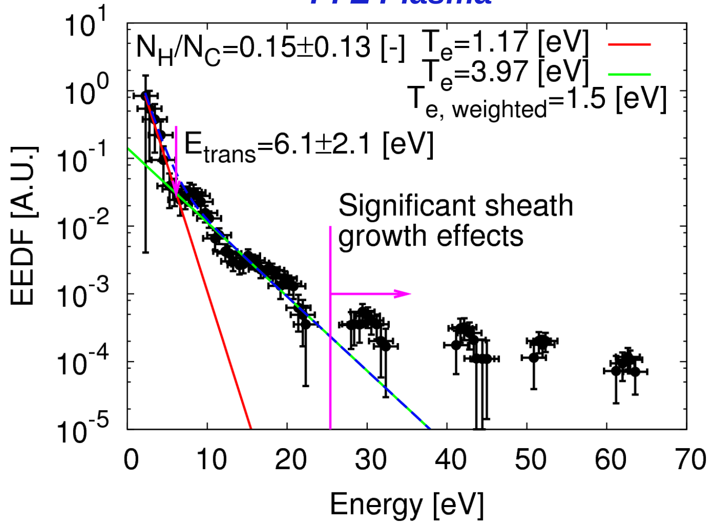
Bi-modal plasmas observed in divertor

- Two cases shown here: SOL and PFZ plasmas
  - Suspected electron beam setting V_{fl} far below expected value (c.f. Demidov, **PRL** 2005)
  - PFZ plasma just inside the separatrix is very dense, but cool and may show evidence of recombination
- Key metrics include the hot population fraction and the density weighted temperature

SOL Plasma

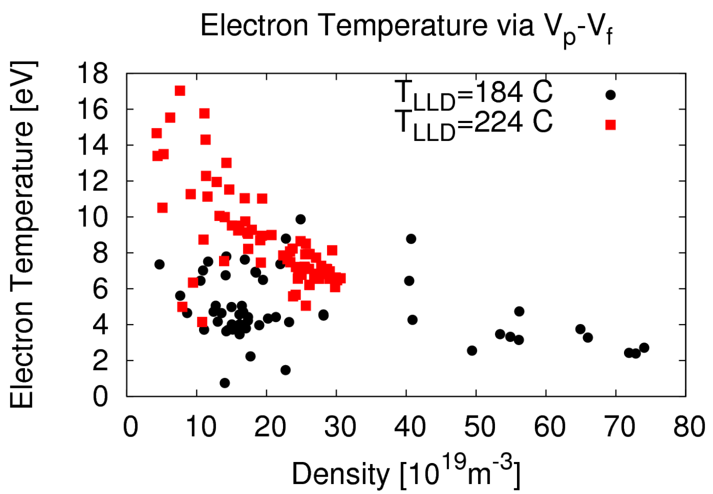


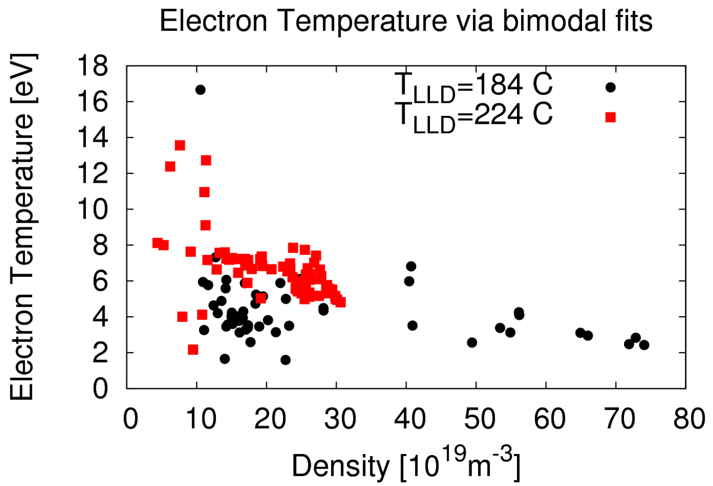
PFZ Plasma



This comparison of LLD discharges shows an increase in temperature at the divertor target

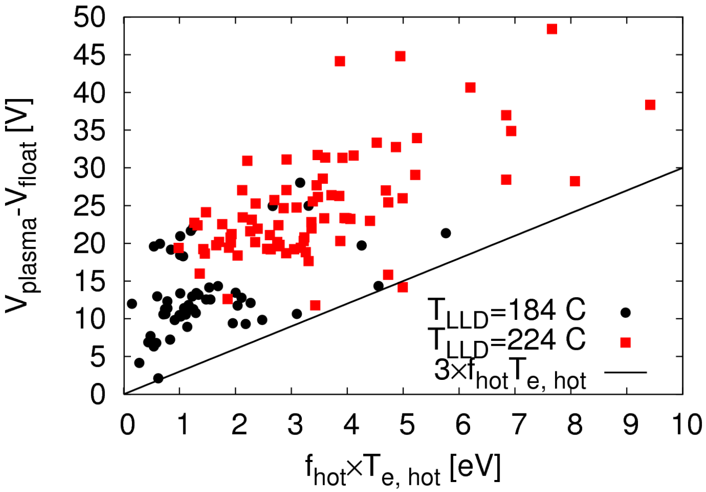
- Separation observed between the two discharges
  - Identical magnetic surfaces compared here (situated in SOL, outboard of I_{sat} peak)
- Most noticeable change is in the electron temperature channel
- Showing electron temperature calculated from V_p-V_f and calculated from density-weighted bimodal temperatures
  - V_p-V_f method may be susceptible to "beams"
  - Both show increased T_e in the latter discharge (hotter LLD)

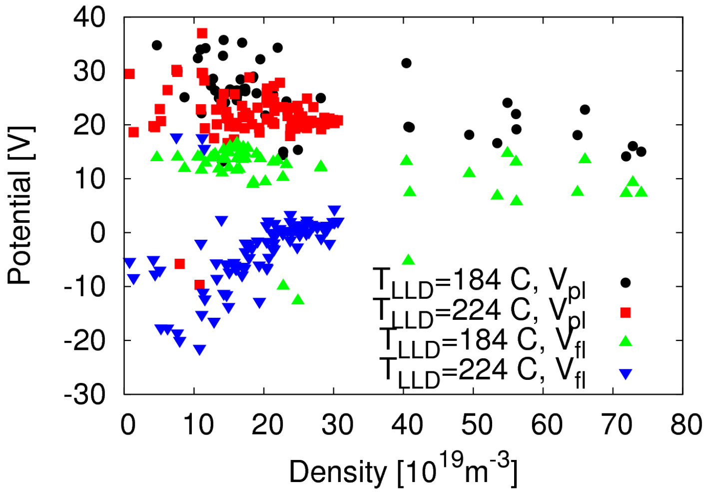




Increase in temperature due to increase in hot population fraction

- Increase in the amount of the hot electron population observed in the hotter LLD discharge
  - Could point to reduction in electron energy sinks (exc. and ioniz.
  - Reduction in gradient effects
  - Both effects suggested in the literature via kinetic codes (Chodura, **CPP**, 1992; Batischev, **PoP**, 1997)
- Plasma potential reduced but not enough to explain the full decrease in floating potential





Discussion

- Divertor operation in NSTX is clearly complex
  - Can demonstrably change the near-PFC plasma while negligibly impacting the core
  - However, improvements are obtained with LITER system over boronized graphite(M. Bell, **PPCF**, 2010)
- EEDF analysis indicates subtle and not-so-subtle changes in the plasma
  - 2-4x increase in divertor plasma temperature in considered discharges, despite increases in fueling
  - Clearest changes observed in floating potential
  - Increase in electron temperature appears commensurate with the increase in hot electron fraction
- Reduced recycling, as might be expected from an absorbing lithium surface, may be the root cause by reducing electron cooling channels and spatial gradients – *under study now*

Summary

- Divertor operation in NSTX is a contrast with operation of a limiter machines
- Divertor plasma provides an effective buffer between PFC and core plasma
  - Insulating effect makes experiments more challenging
- LLD operation produced subtle effects in the core plasma
  - Machine able to withstand 2x increase in amount of fueling gas without appreciable increases in core density
  - Langmuir probes detected significant changes in the target plasma
  - 2-4x increase in plasma temperature – despite increased gas puff
  - Temperature increase occurs alongside increase in hot electron fraction
- Decreased fueling efficiency and increased target plasma temperature consistent with an actively absorbing surface

Thank you!