# Divertor ion temperature measurements on MAST by retarding field energy analyser


By Sarah Elmore[1,2]

with

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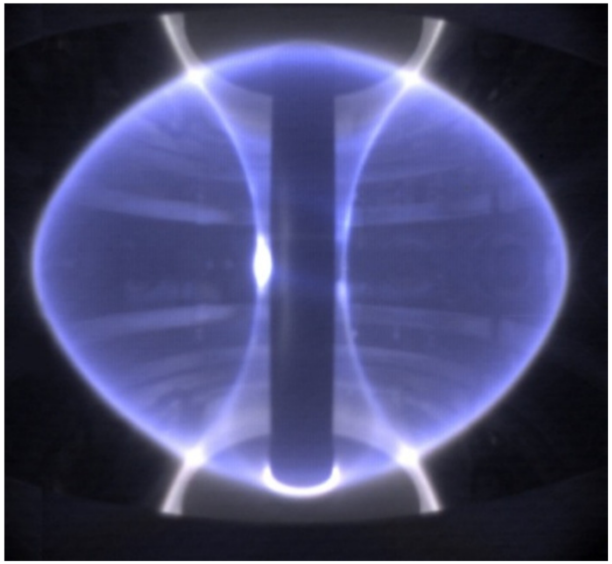
# Overview

- **Motivation for studying scrape-off layer (SOL) ion temperatures ($T_i$)**

- **Design of RFEA probes and analysis techniques**

- **Experimental $T_i$ measurements in MAST**

- **Conclusions**



# Introduction and motivation

- **Measure ion temperatures ($T_i$) in the edge of tokamak plasma**
  - important for determining damage on plasma facing materials from sputtering

- **Few measurements of $T_i$ compared to $T_e$**
  - $T_i = T_e$ assumed for Langmuir probe calculations of electron density ($n_e$) and power to divertor ($P_{div}$)

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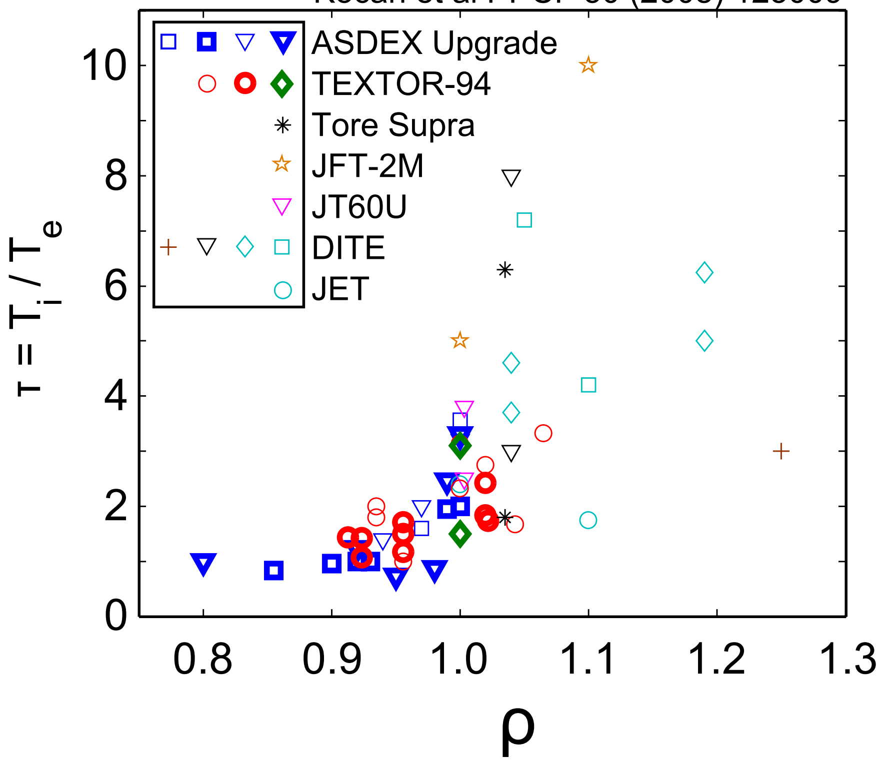
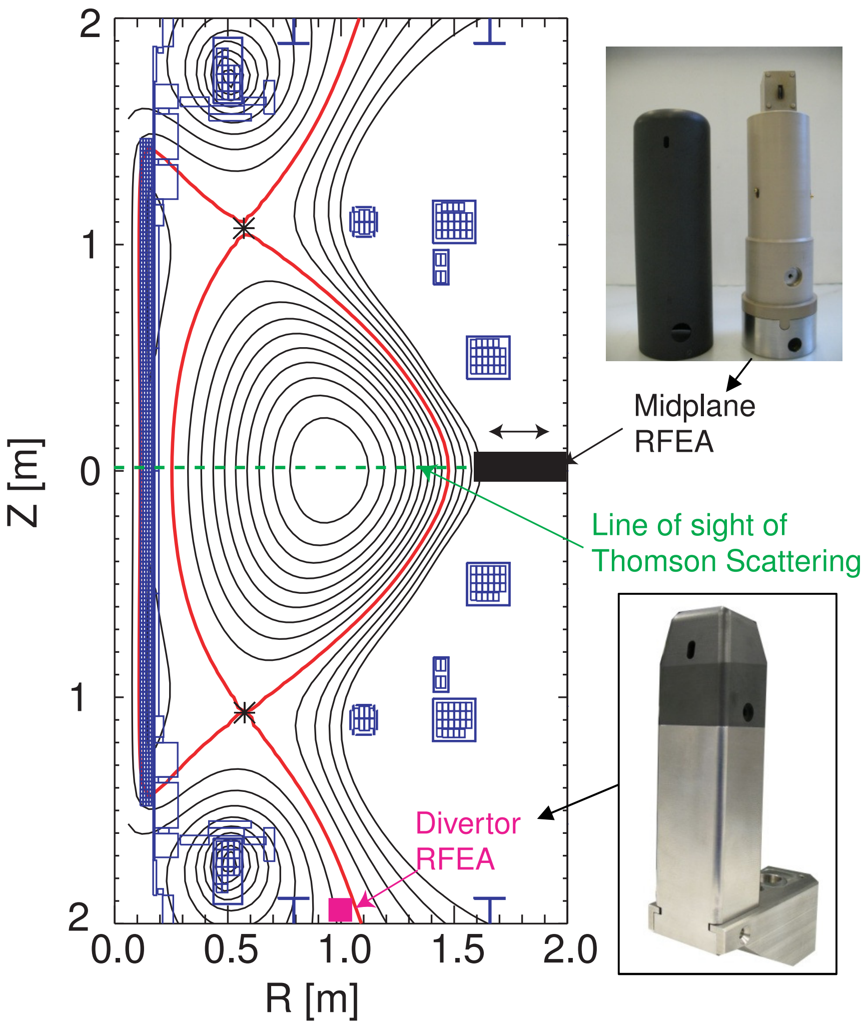
- **Few measurements of $T_i$ compared to $T_e$**
  - $T_i = T_e$ assumed for Langmuir probe calculations of electron density ($n_e$) and power to divertor ($P_{div}$)
  - $T_i \neq T_e$ in the scrape-off layer (SOL)
  - Measurements in a range of tokamaks show $T_i/T_e = 2 \rightarrow 10$ in SOL

Kočan et al PPCF 50 (2008) 125009



# RFEA probes on MAST

**Poloidal cross-section of MAST**




- Two RFEA probes in MAST SOL
  - Midplane – upstream measurements
  - Divertor – target measurements
  - Compare $T_i$ at two points in the SOL

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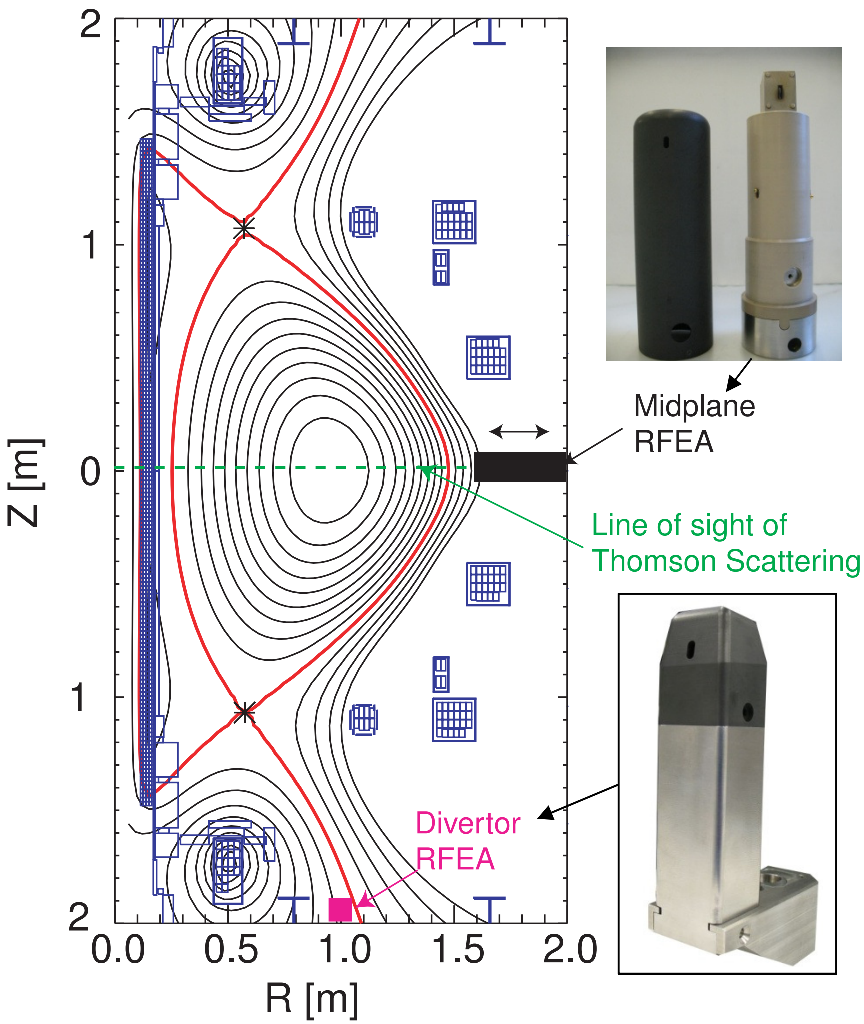


- Two RFEA probes in MAST SOL
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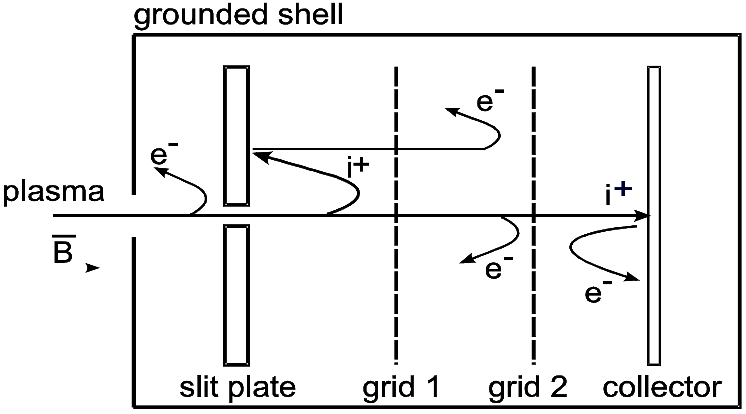
  - Compare $T_i$ at two points in the SOL
- First Divertor RFEA in tokamak
  - low q incident on RFEA
  - sweeping divertor leg

# RFEA probe analysis




**Schematic of RFEA**

- RFEA measures parallel ion distribution aligned along magnetic field
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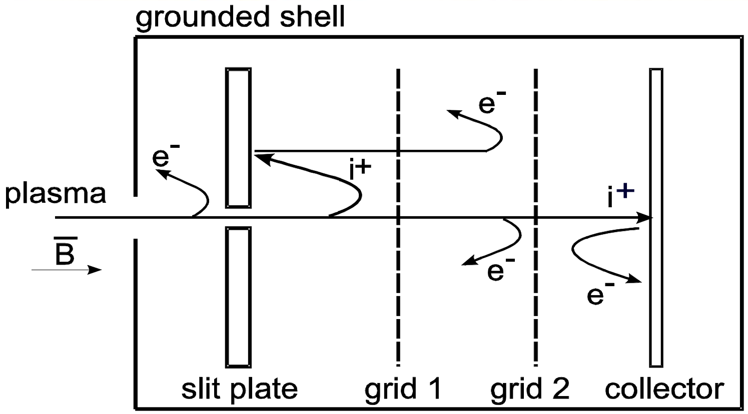


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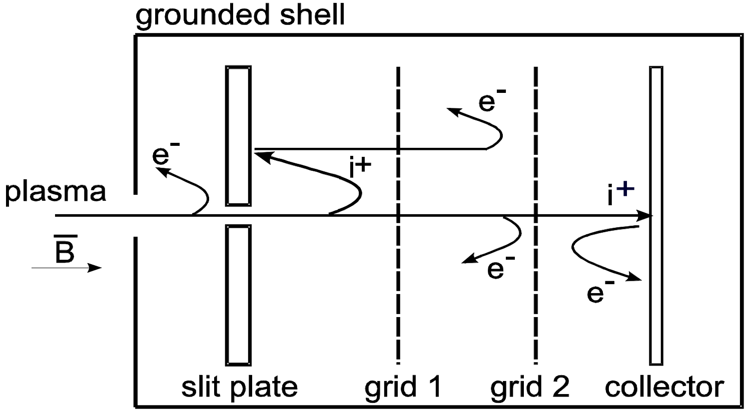


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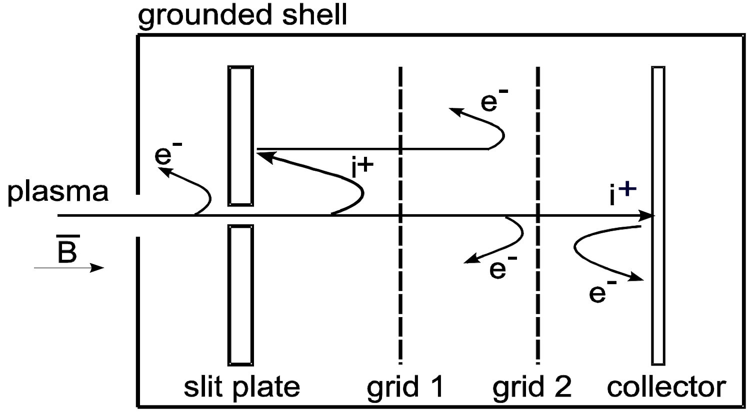


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- Grid 2 biased more negatively than slit plate (-150 V) to repel secondary electrons

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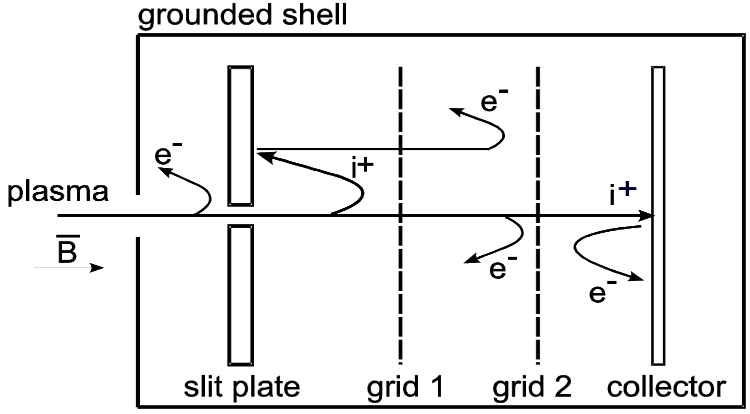


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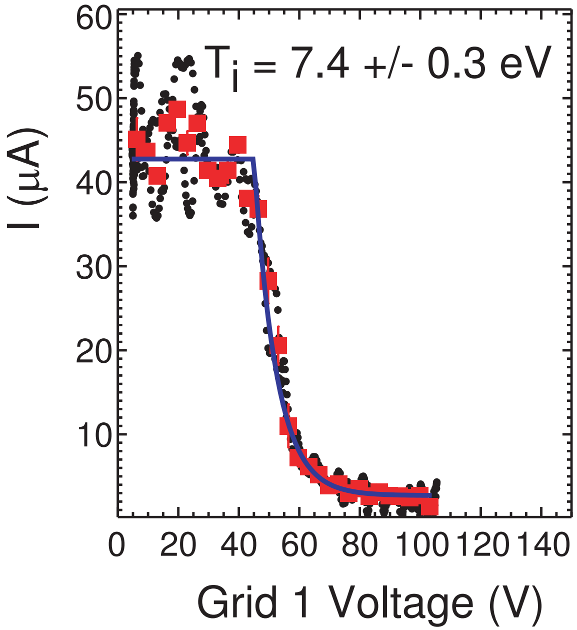
- Ion current measured at collector relates to applied discriminating ion voltage by ion energy distribution
- Extract $T_i$ by fit to decaying part of the I-V characteristic:

$$I_{col} = I_0 \exp\left[\frac{-Z_i}{T_i}\left(V_{grid1} - |V_s|\right)\right]$$

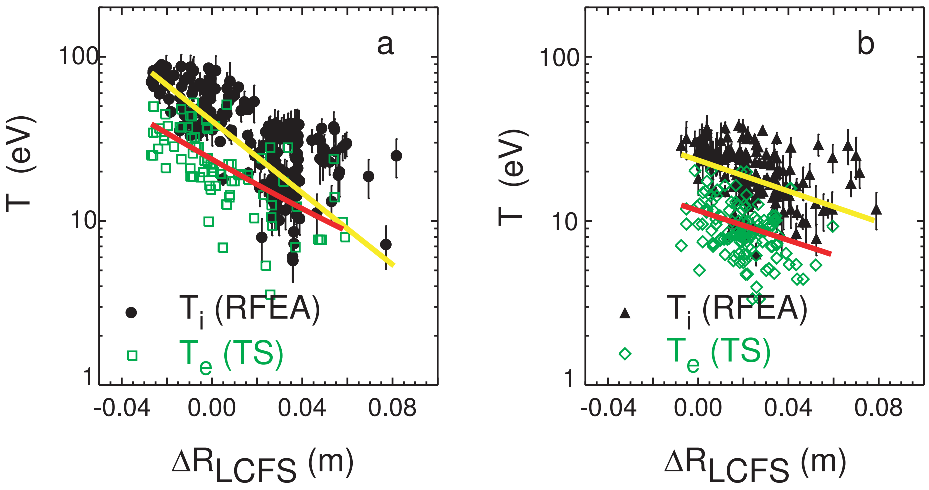
- For $V_{grid1} > V_s$
- where $I_{col}$ is the collector current, $V_{grid1}$ is the discriminating voltage, and $V_s$ is the sheath potential




**Typical divertor I-V characteristic**

# L-mode $T_i$ upstream to target comparison

- Midplane both densities:
  - $T_i/T_e \sim 2$




**(a) Low and (b) high density $T_i$ and $T_e$ (TS) at the midplane**

S. Elmore et al 2012 PPCF 54 065001

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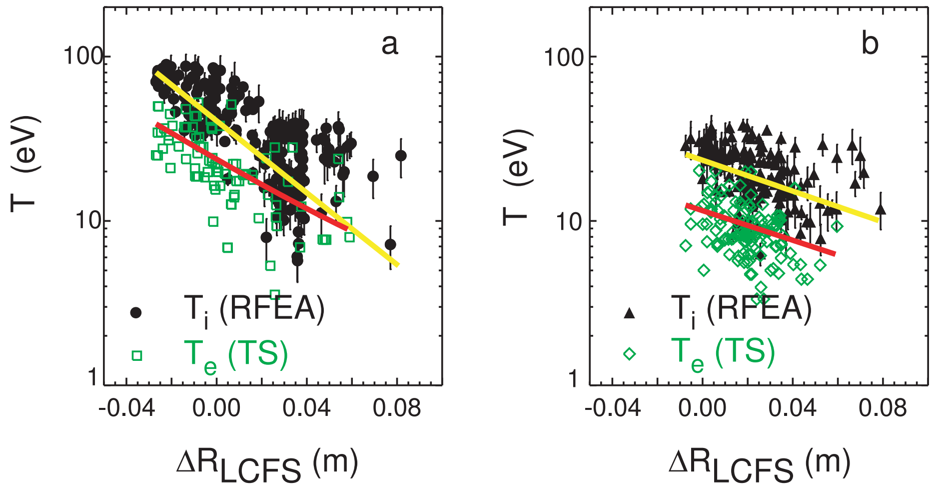


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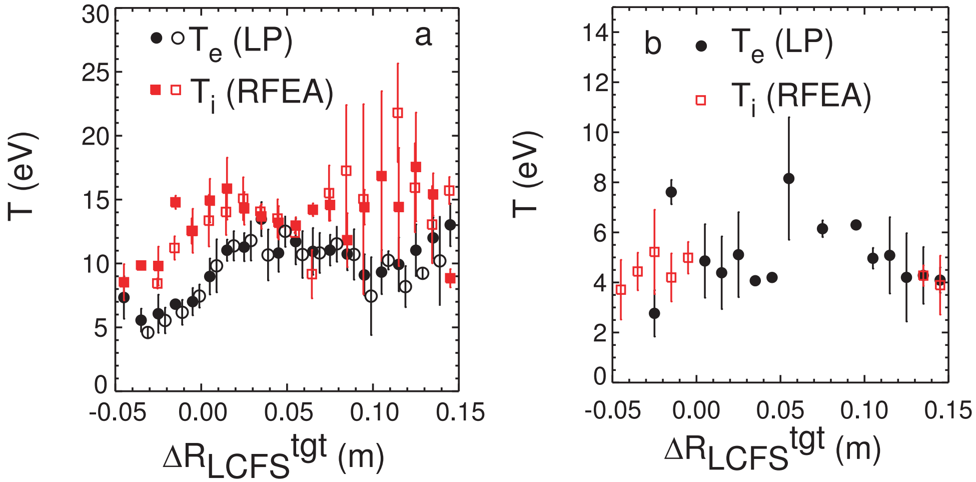


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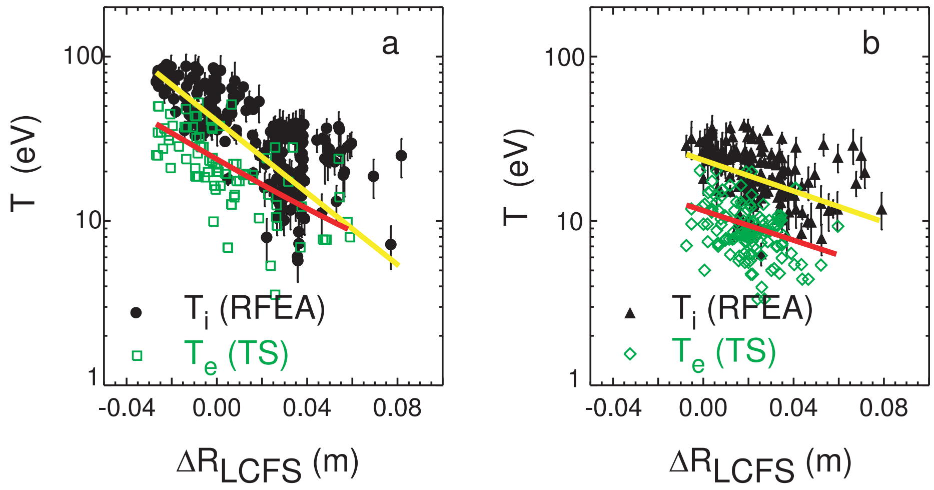
  - low density: $T_i/T_e = 2.4$
  - high density: $T_i/T_e = 1.8$

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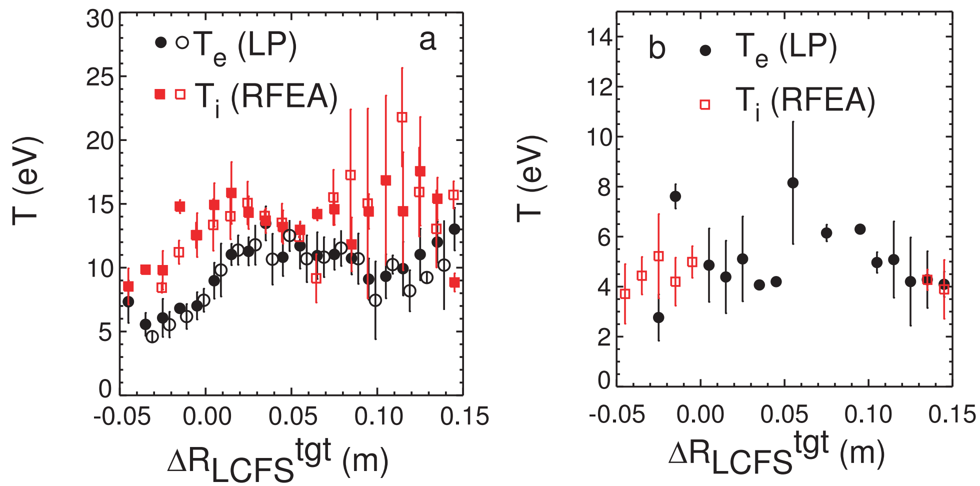


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[1]A Kirk et al 2004 PPCF 46 1591

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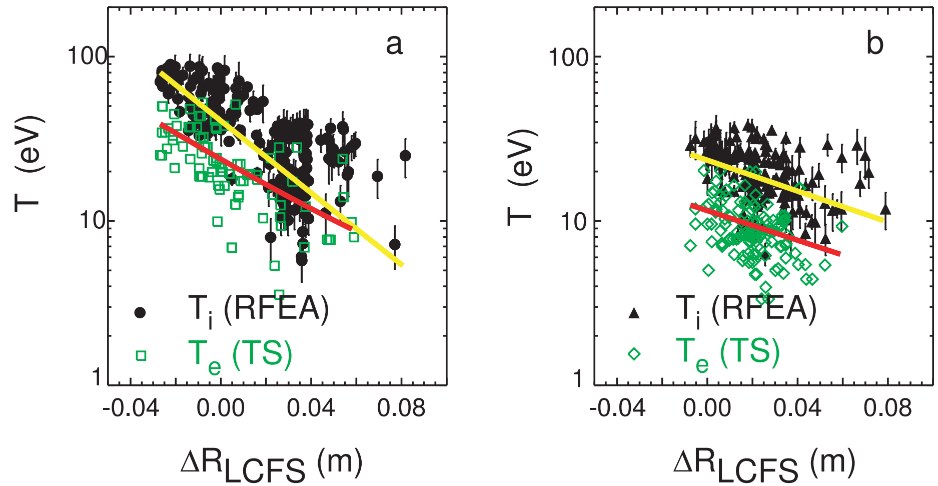
- Knowing both upstream and target $T_i$ can be used to constrain models of the SOL

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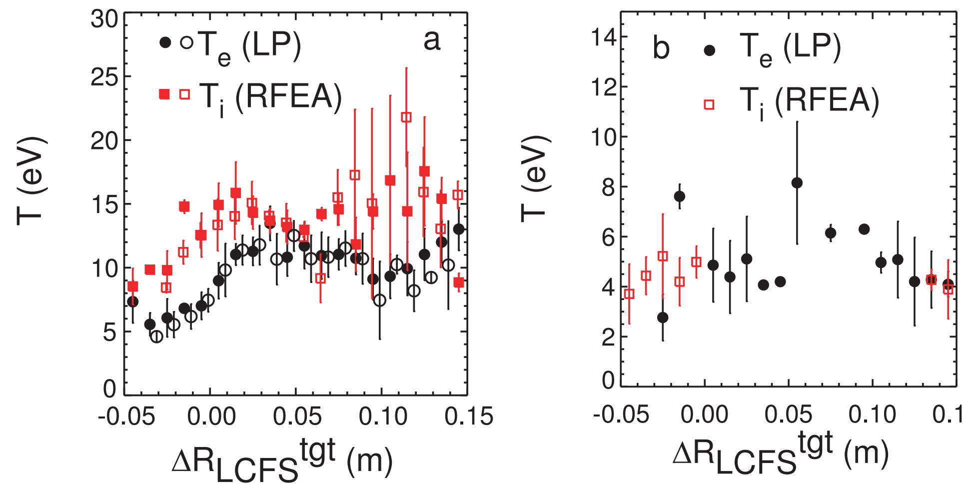


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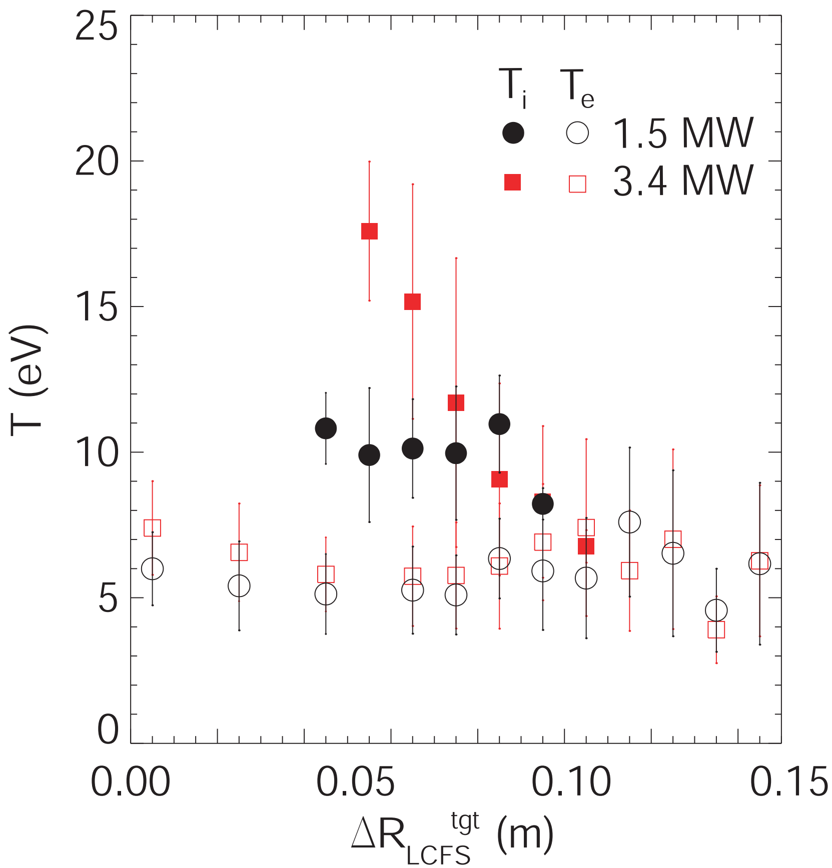


**Profile of $T_i$ and $T_e$ measured at the divertor target in the SOL**

- Double-null plasmas:
  - $I_p$ = 900 kA
- Compare two NBI beam powers
  - 1.5 MW and 3.4 MW

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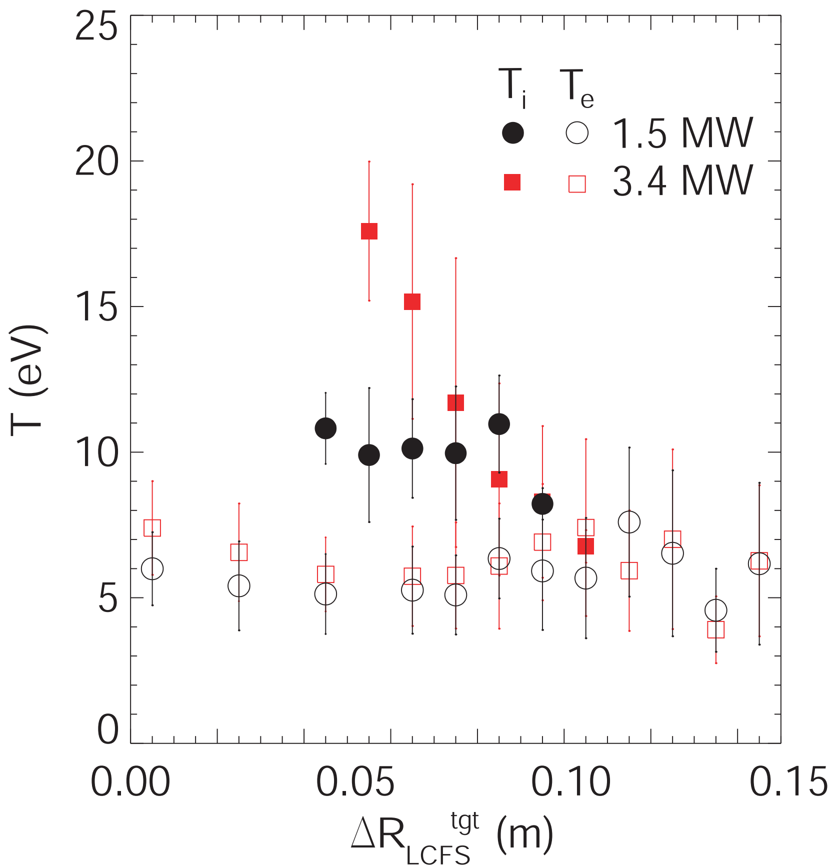


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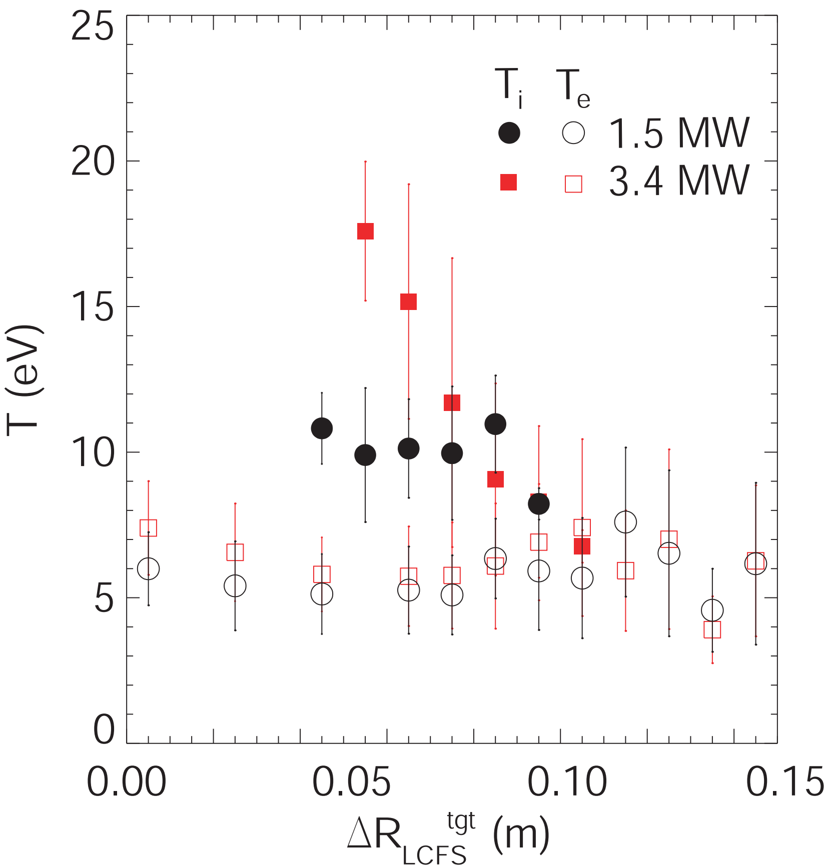


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- Lower beam power: $T_i$ lower and flatter profile
- $T_e$ similar for both beam powers
- $T_i/T_e$ changes with beam power:

1.5 MW: $T_i/T_e \sim 2$
3.4 MW: $T_i/T_e \leq 3$

# H-mode target $T_i/T_e$ scaling with upstream $\nu^*_{LCFS}$

- Investigate target $T_i/T_e$ scaling with upstream LCFS collisionality
  - Measure $T_i/T_e$ 4 cm from the LCFS at target

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- Vary collisionality using 3 double-null H-mode plasmas:
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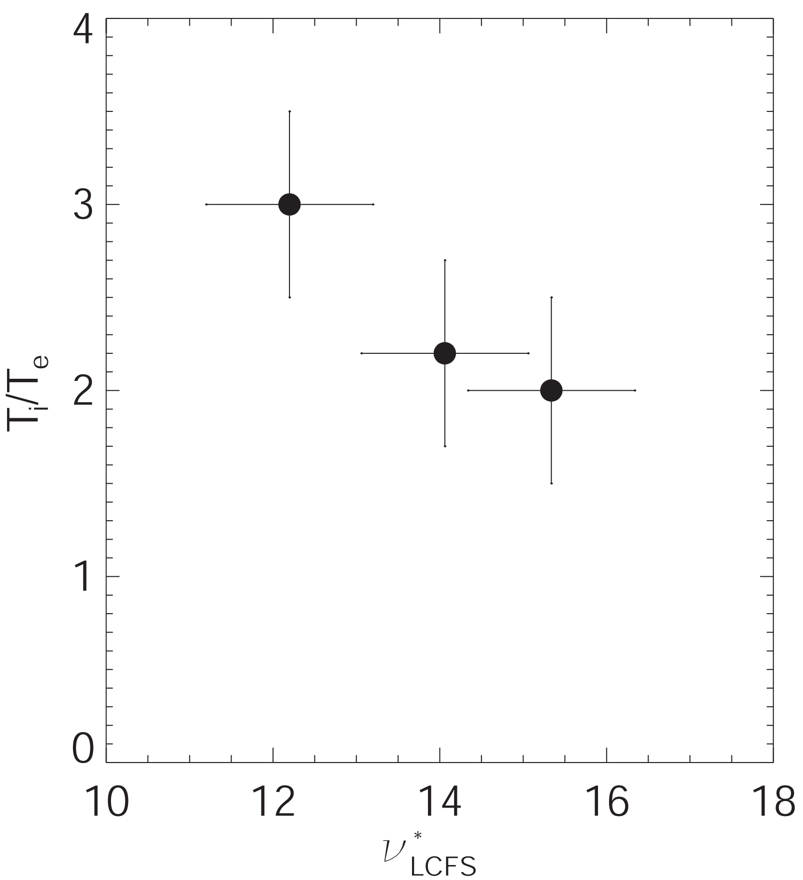


**$T_i/T_e$ at the target as a function of collisionality at the upstream LCFS**

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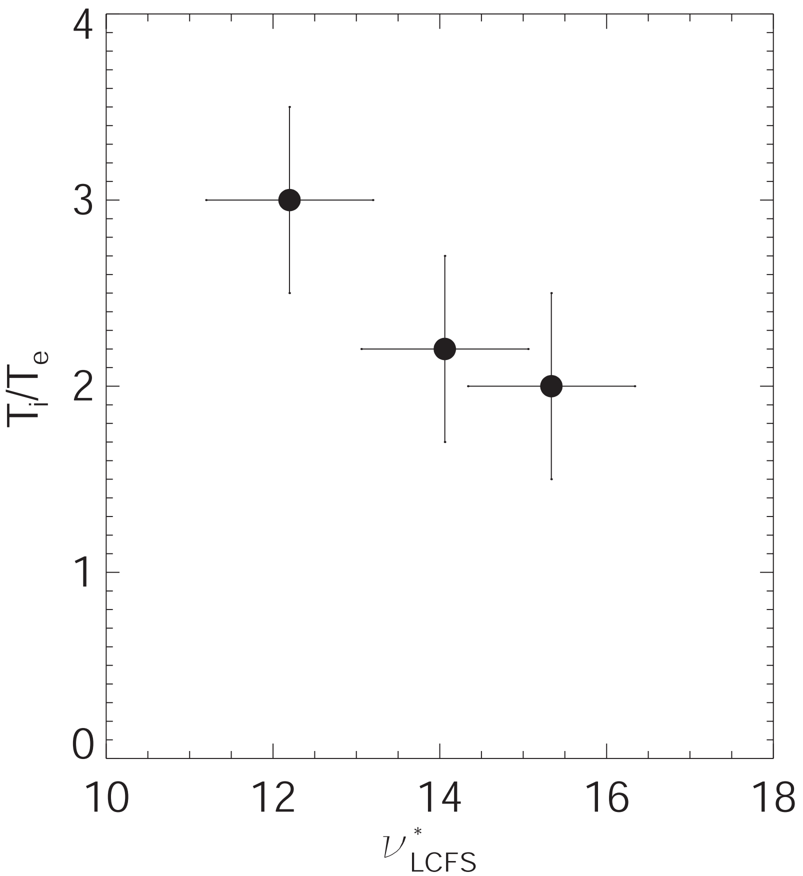
- $T_i$ and $T_e$ measurements at target currently being investigated by B2SOLPS for comparison[1]




**$T_i/T_e$ at the target as a function of collisionality at the upstream LCFS**

[1] E. Havlickova

# Target Average ELM $T_i$ Measurements

- Average ELM $T_i$ measured using slow voltage sweep (40 Hz) during ELMy H-mode
- I-V characteristic is composite of many similar type III ELMs arriving at the target:
  - $I_{ELM}^{peak}$ at divertor RFEA plotted against applied $V_{grid1}$ at $t_{ELM}$

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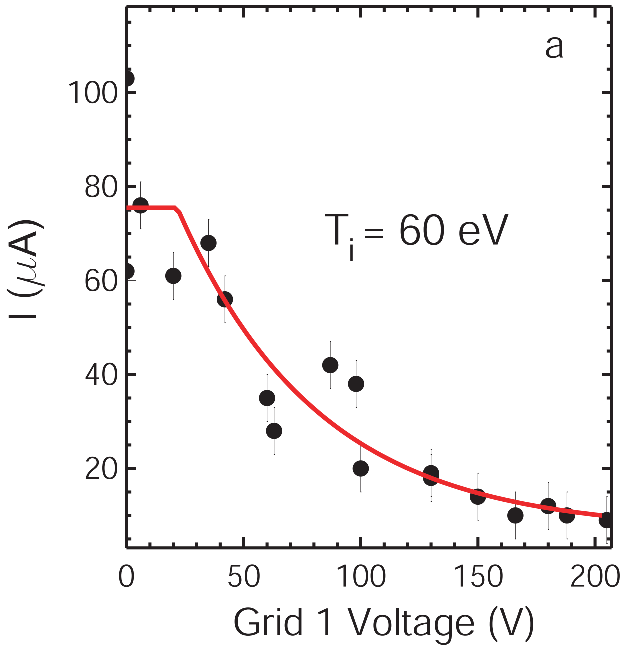


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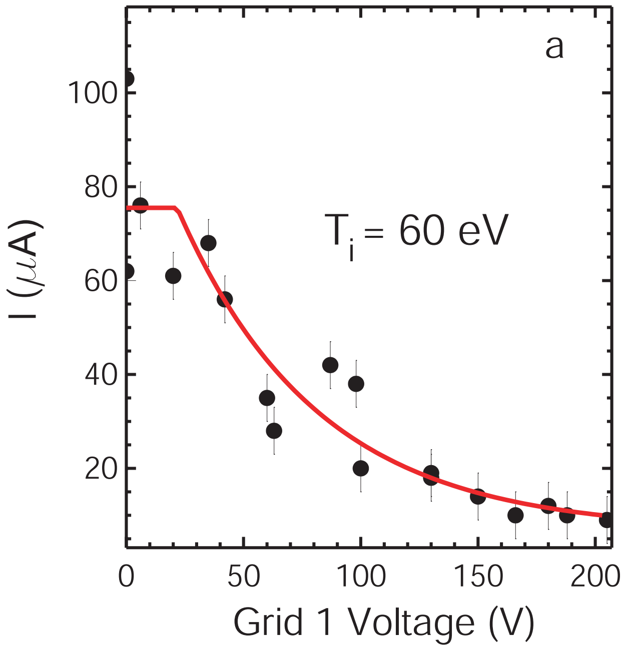


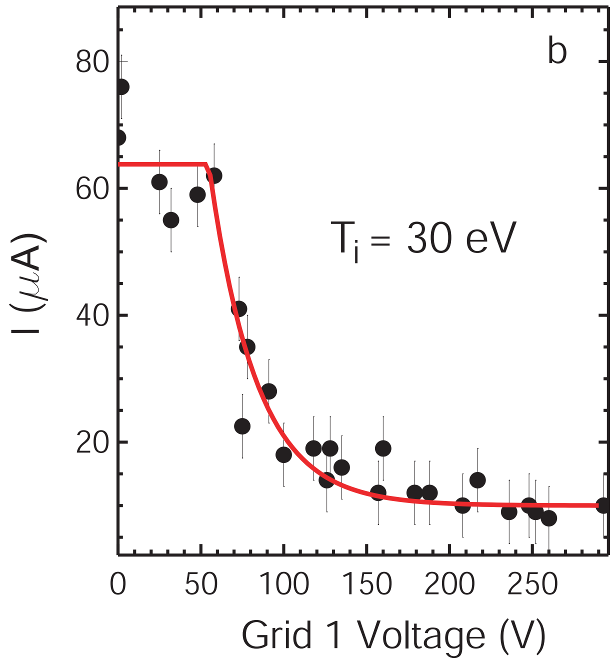


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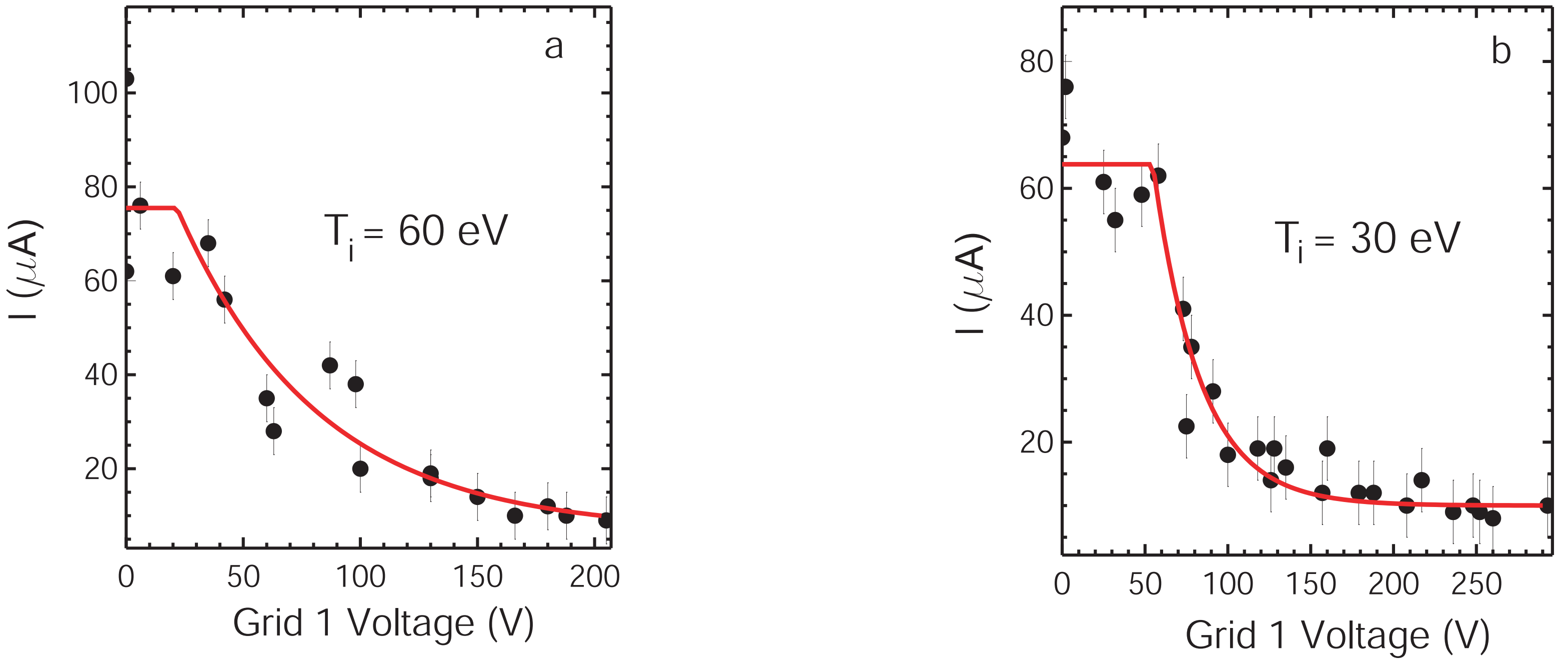


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**See expected cooling with $\Delta R_{LCFS}^{tgt}$**

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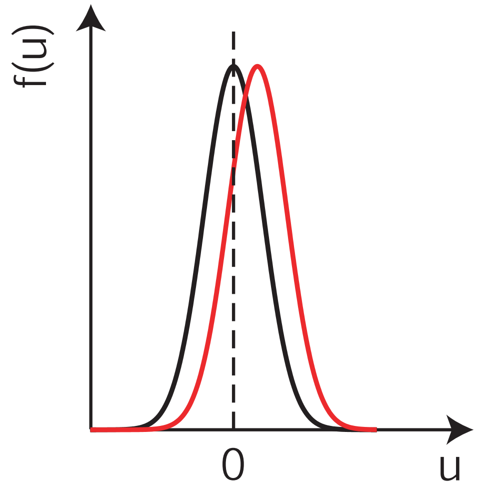
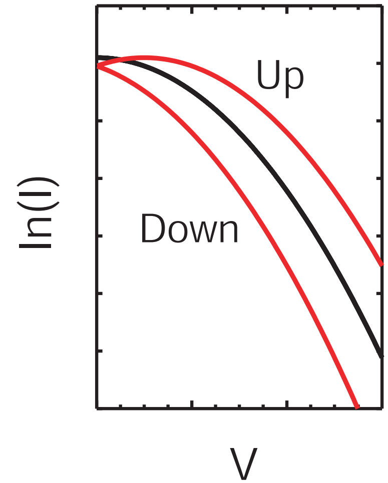
- **Flow effects are being investigated to give valid $T_i$ target measurements**

# Appendix

# Effect of flows




- No flows:
  - RFEA measures the same distribution both sides
  - $T_i$ is the width of the Maxwellian distribution
- SOL flow:
  - shifted Maxwellian distribution
  - RFEA facing flow will see higher end of distribution, u > 0
  - RFEA backing flow sees remaining distribution
- $T_i$ value measured in no flow
  - equal for both sides
  - Slope = $1/T_i$
- With SOL flows
  - ‘up’ side of RFEA measures shallower slope
  - $T_i$ higher on ‘up’ side to ‘down’ side
- Divertor RFEA expected to measure too high since facing flow
- Comparison with modelling[1] of SOL flows will be investigated to compare $T_i$ measured by RFEA to simulated $T_i$

[1] J. Gunn, CEA