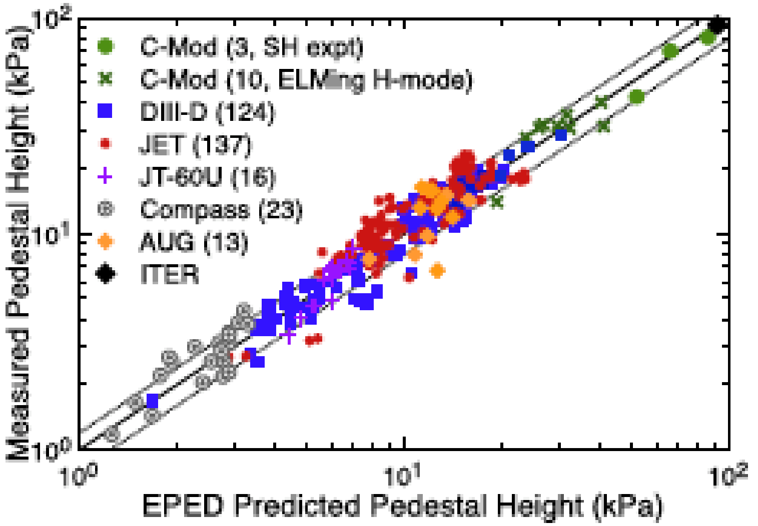
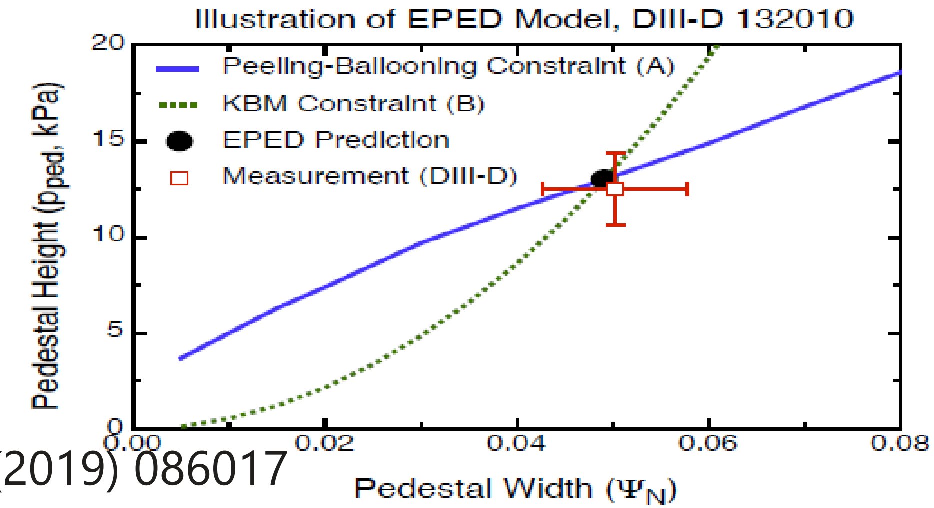
Overview on Density Pedestal Structure: Role of Fueling versus Transport

Saskia Mordijck (W&M)

Motivation

- Models based on pressure profile constraints from KBM and peeling-ballooning modes capture global pedestal pressure structure well





P.B. Snyder et al NF 51 103016 (2011) P.B. Snyder et al. NF 59 (2019) 086017

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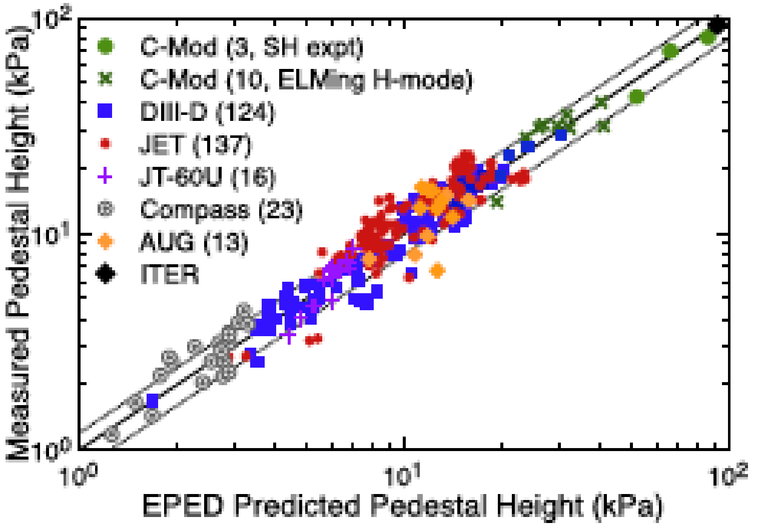

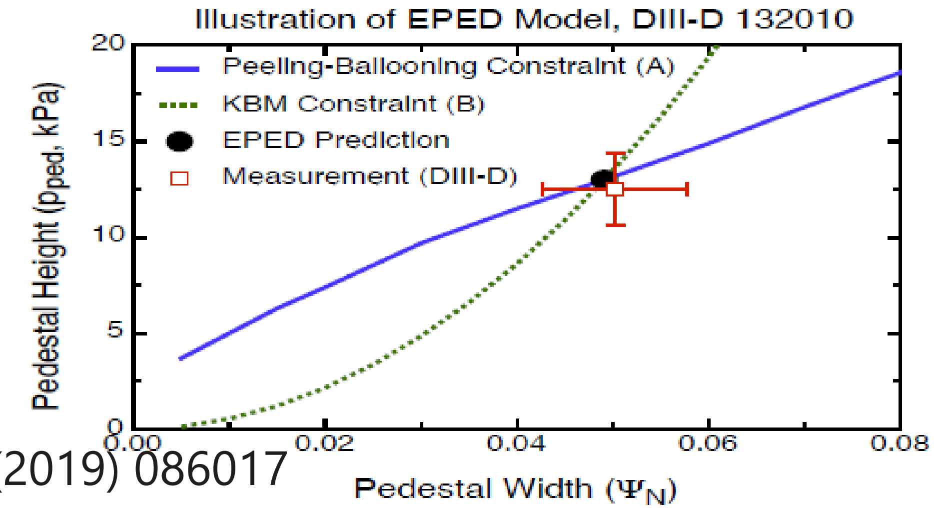

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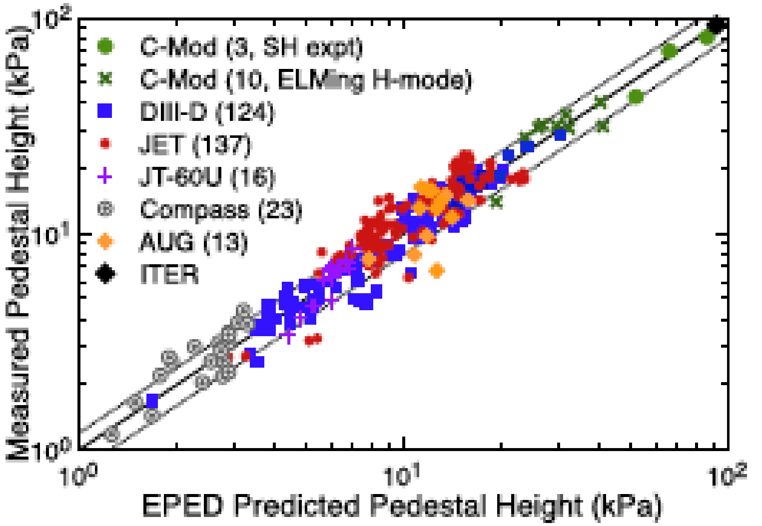
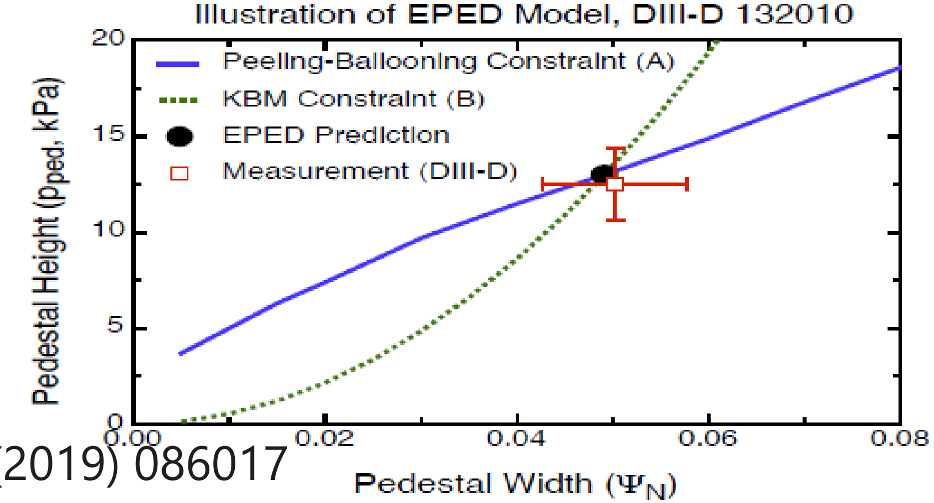
Motivation

- Models based on pressure profile constraints from KBM and peeling-ballooning modes capture global pedestal pressure structure well
- Currently these models require input:
  - Separatrix density
  - Ratio of ne_{ped}/ne_{sep}
- What is the role of ‘fueling’ versus transport?
  - Future machines will have ‘opaque’ SOL and limit fueling





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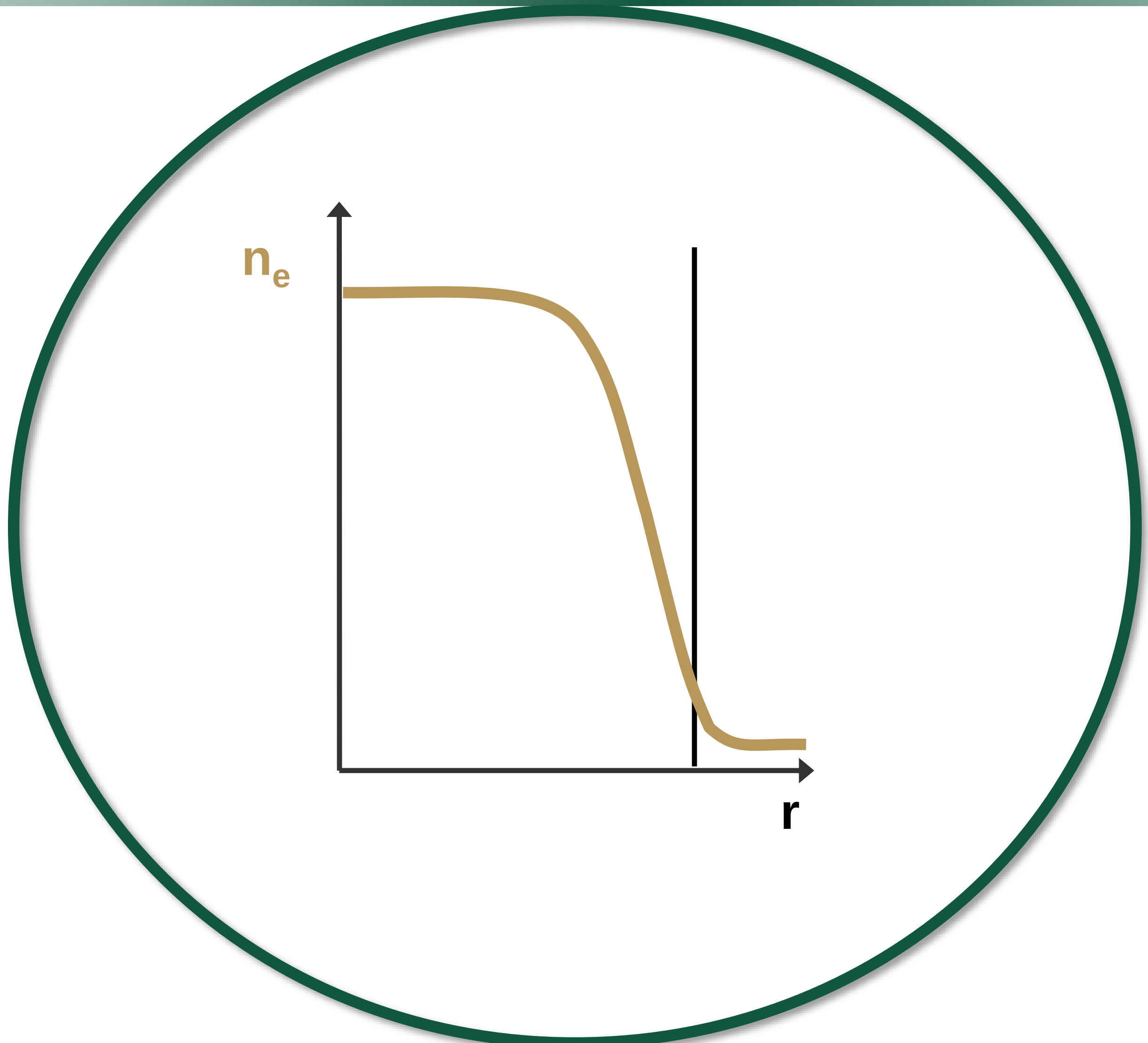
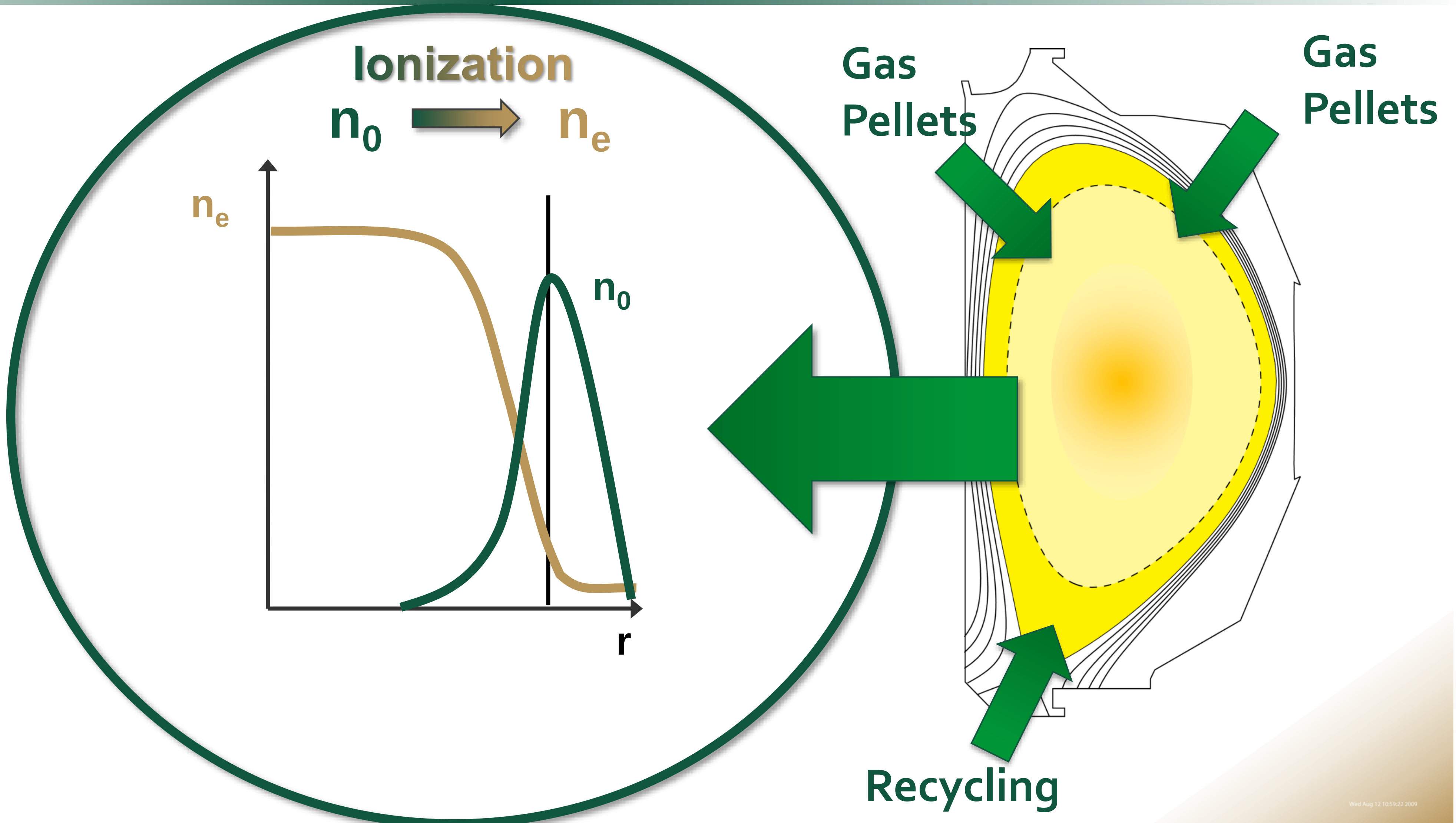
What sets the pedestal density profile?



What sets the pedestal density profile? Role of neutral density and ionization



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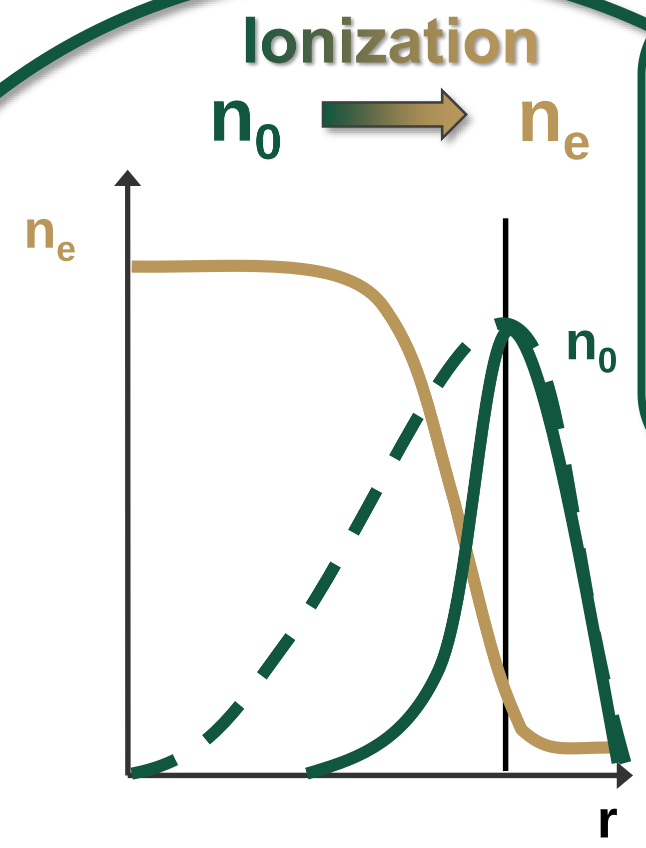

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$\nabla n_e \sim \nabla n_0$

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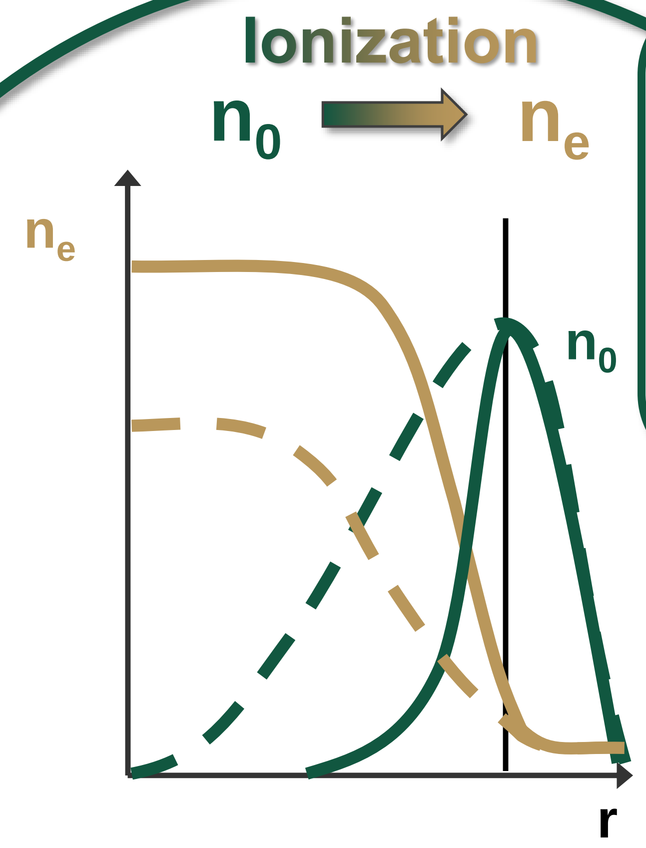

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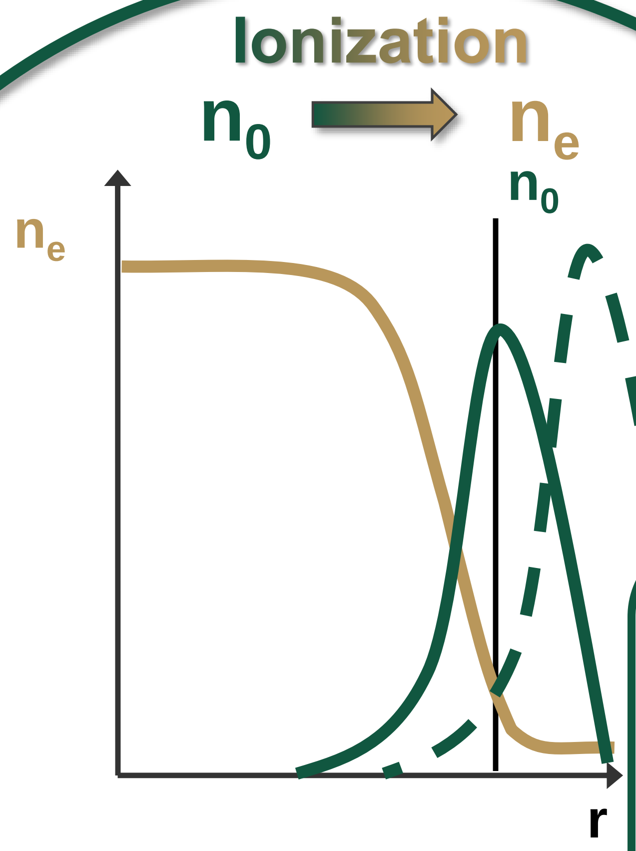

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$n_0 \uparrow \Longrightarrow$ shift out in SOL

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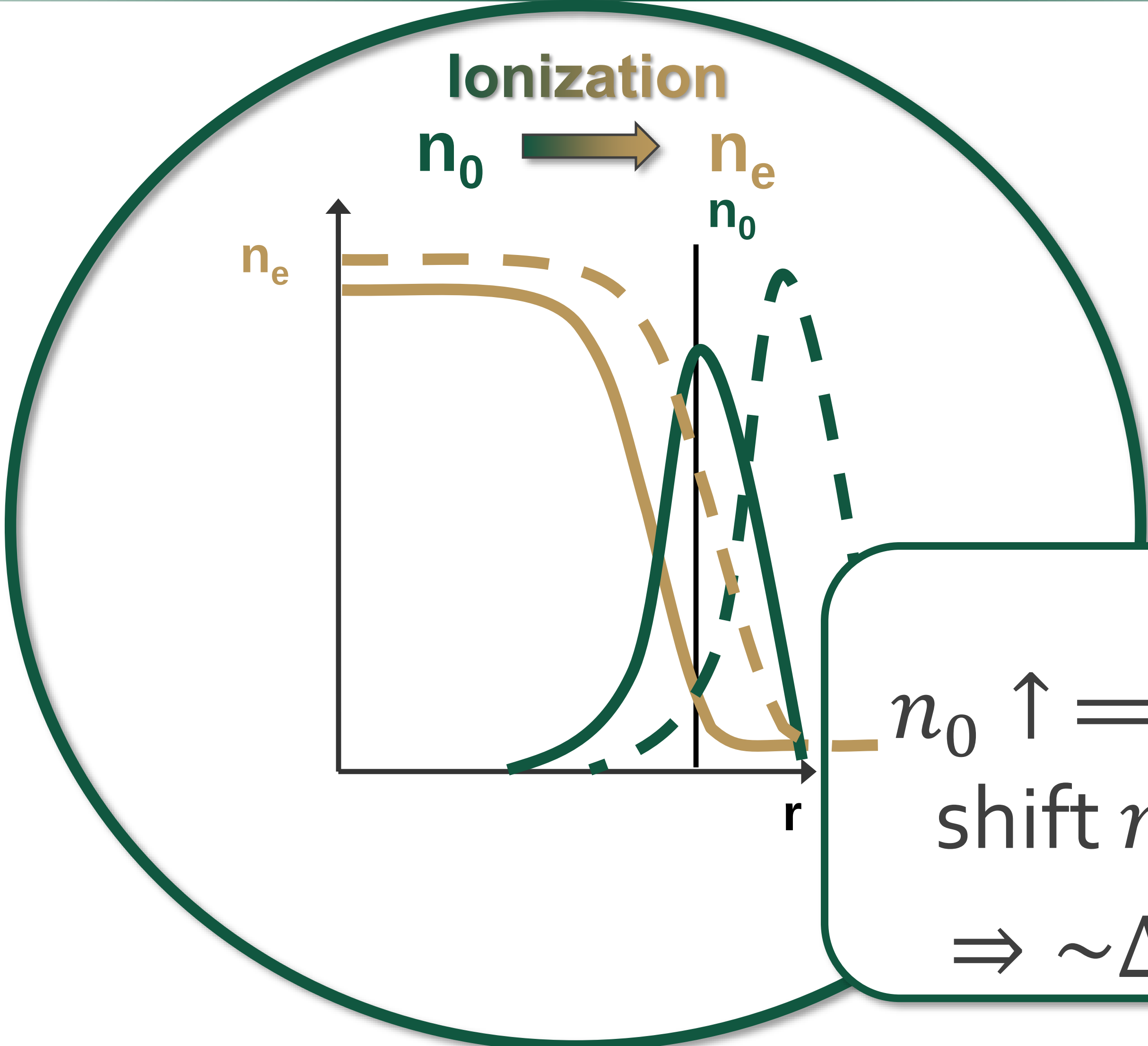

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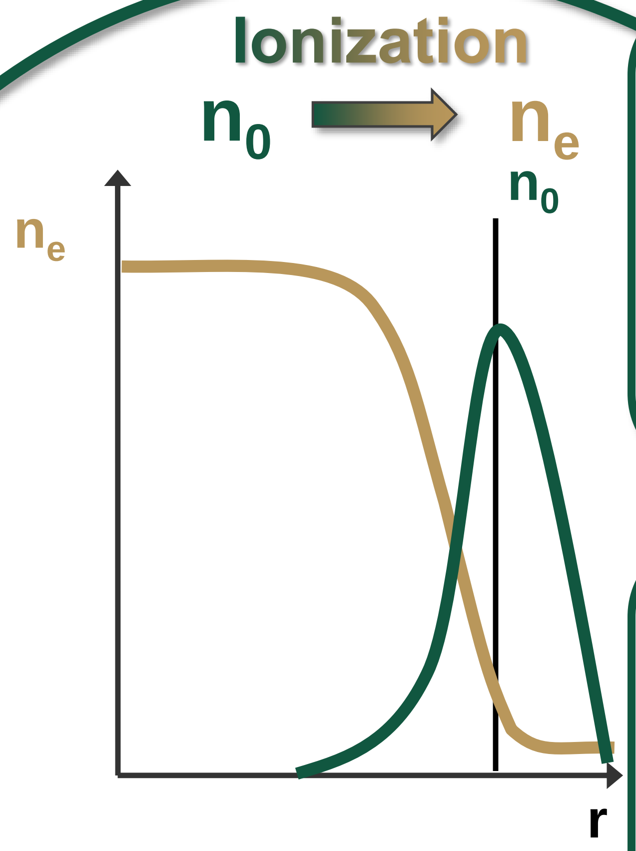

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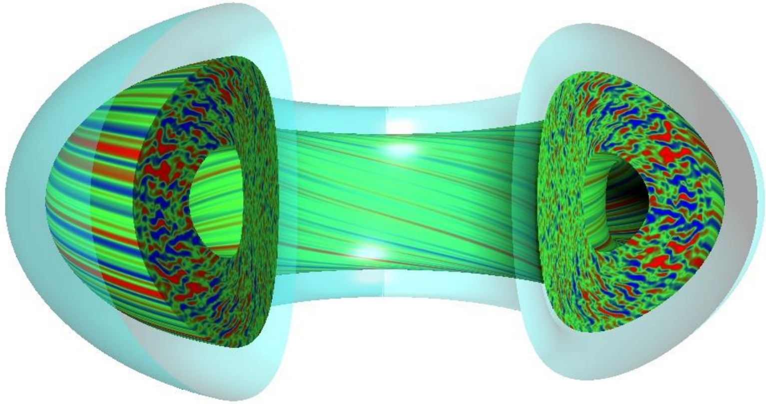
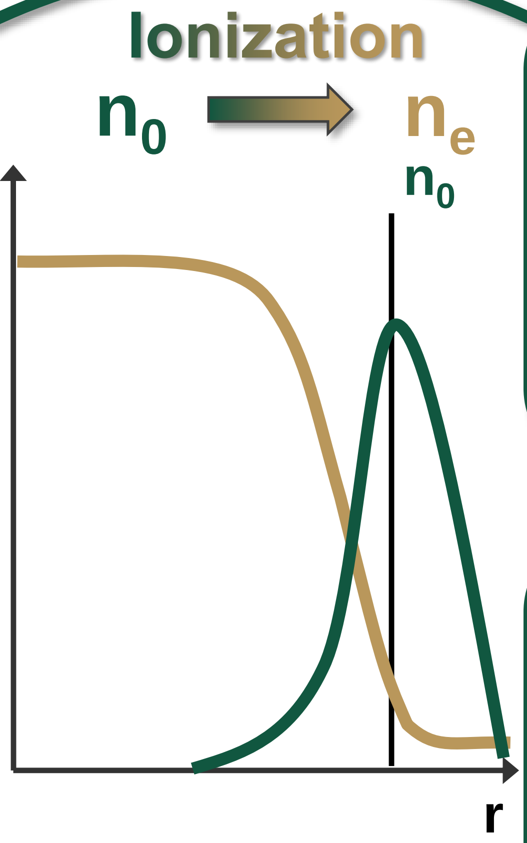


Courtesy GA theory group
General Atomics



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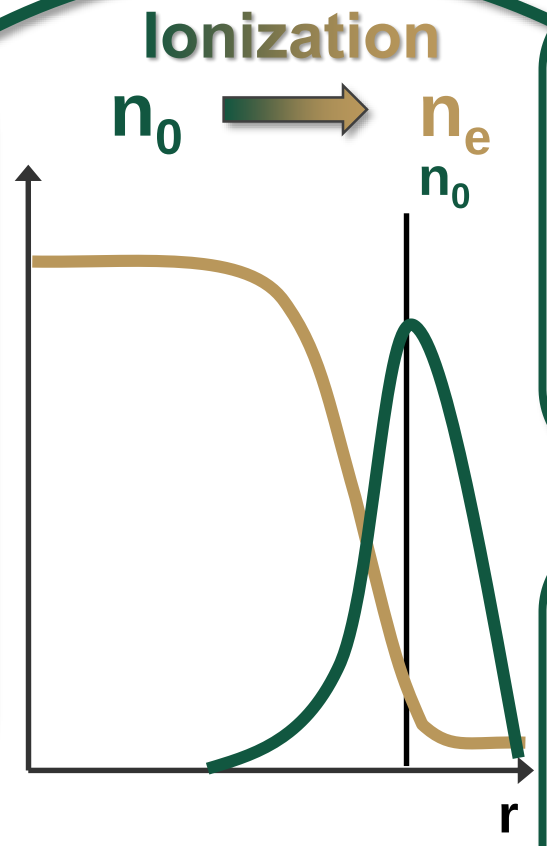

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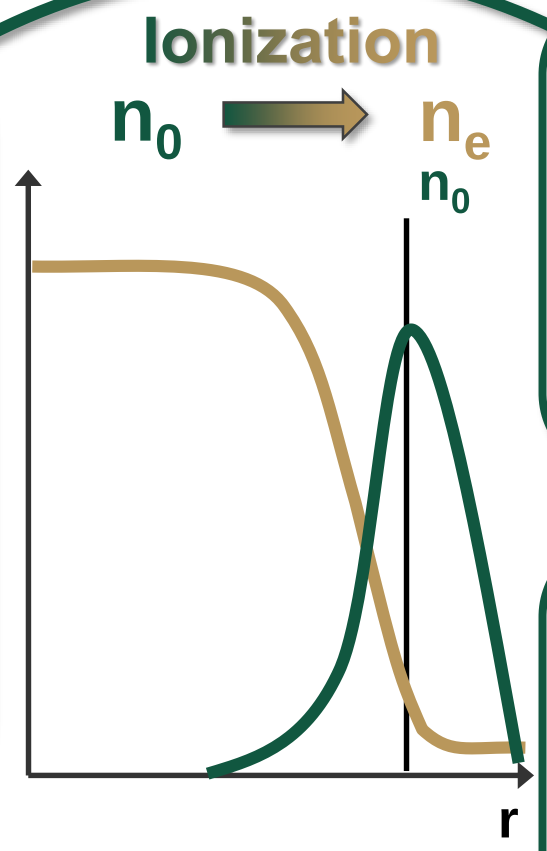

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In future reactor role of transport becomes dominant

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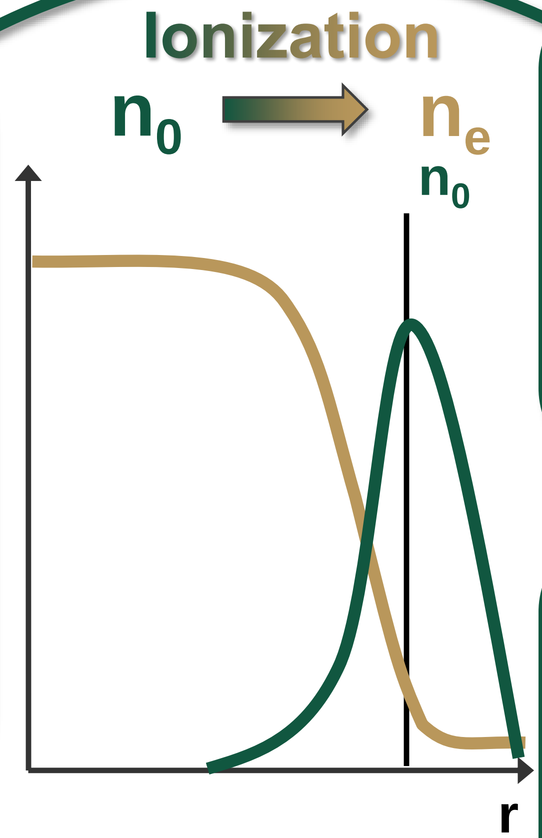

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… Δn_e

n_0 … ift … SOL

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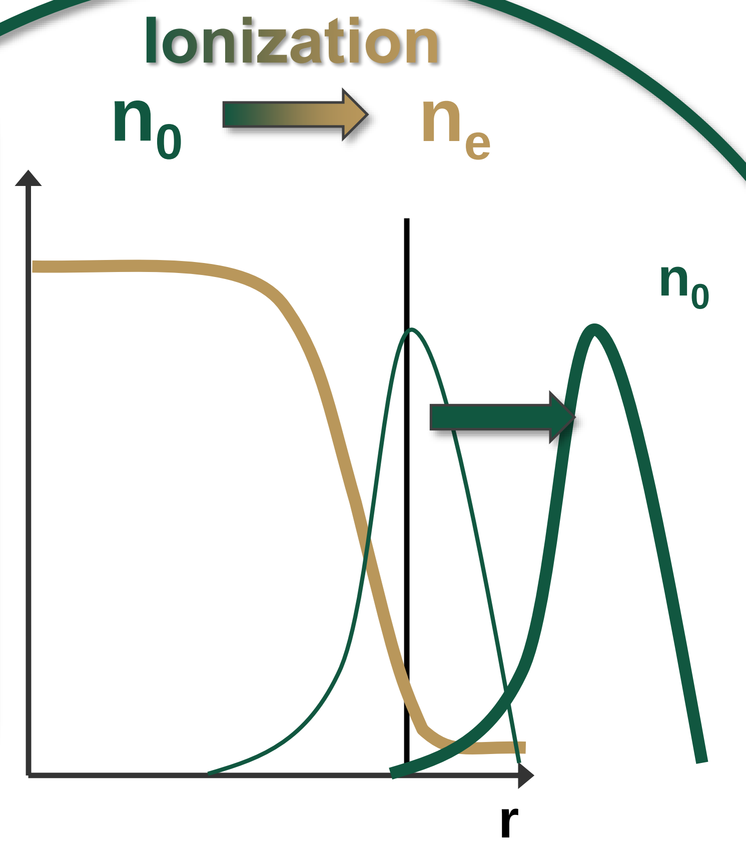

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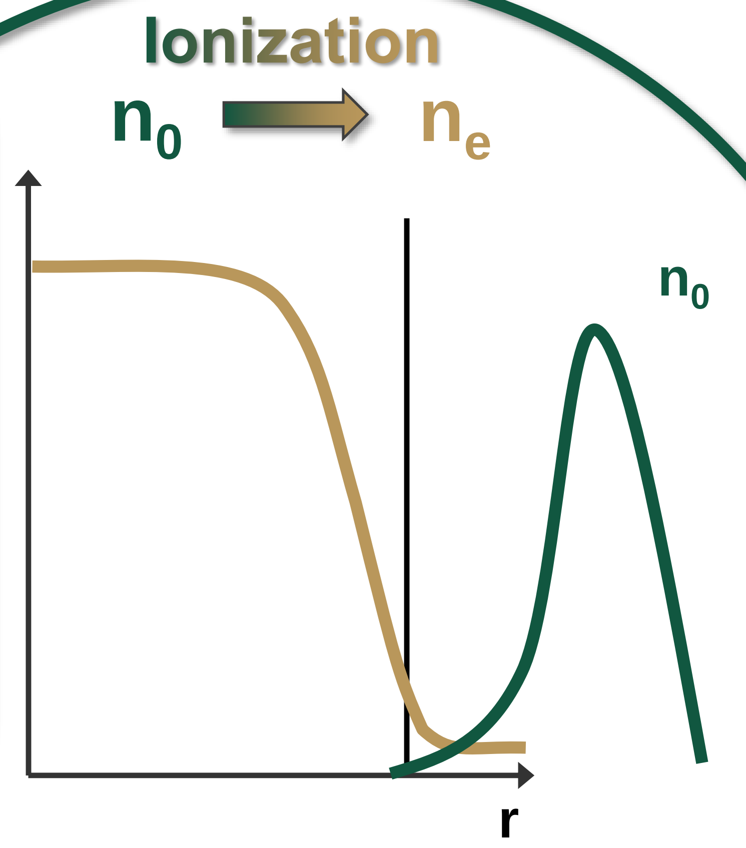

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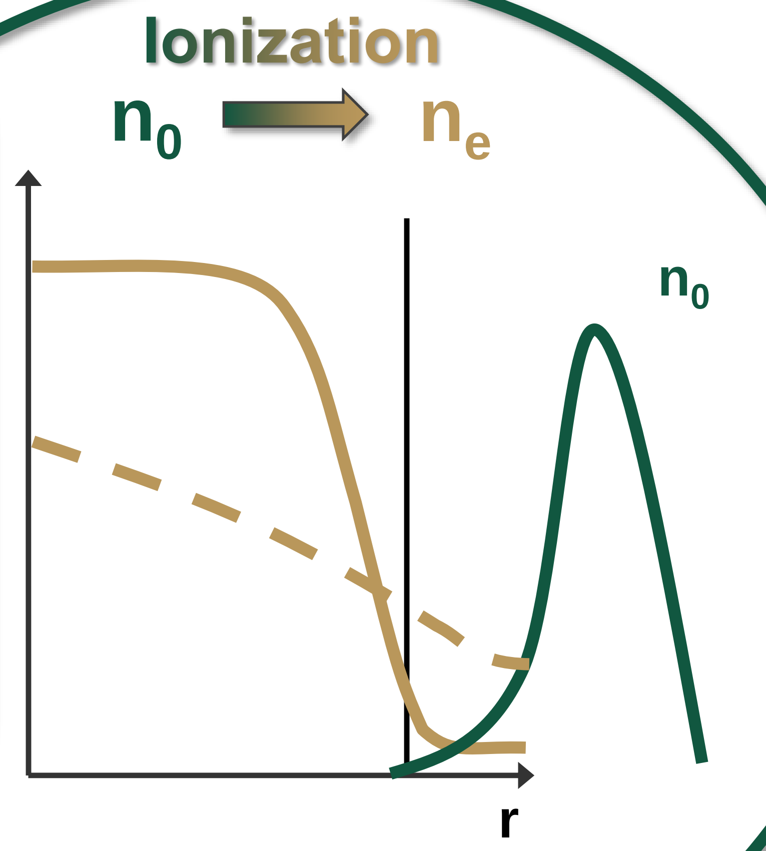

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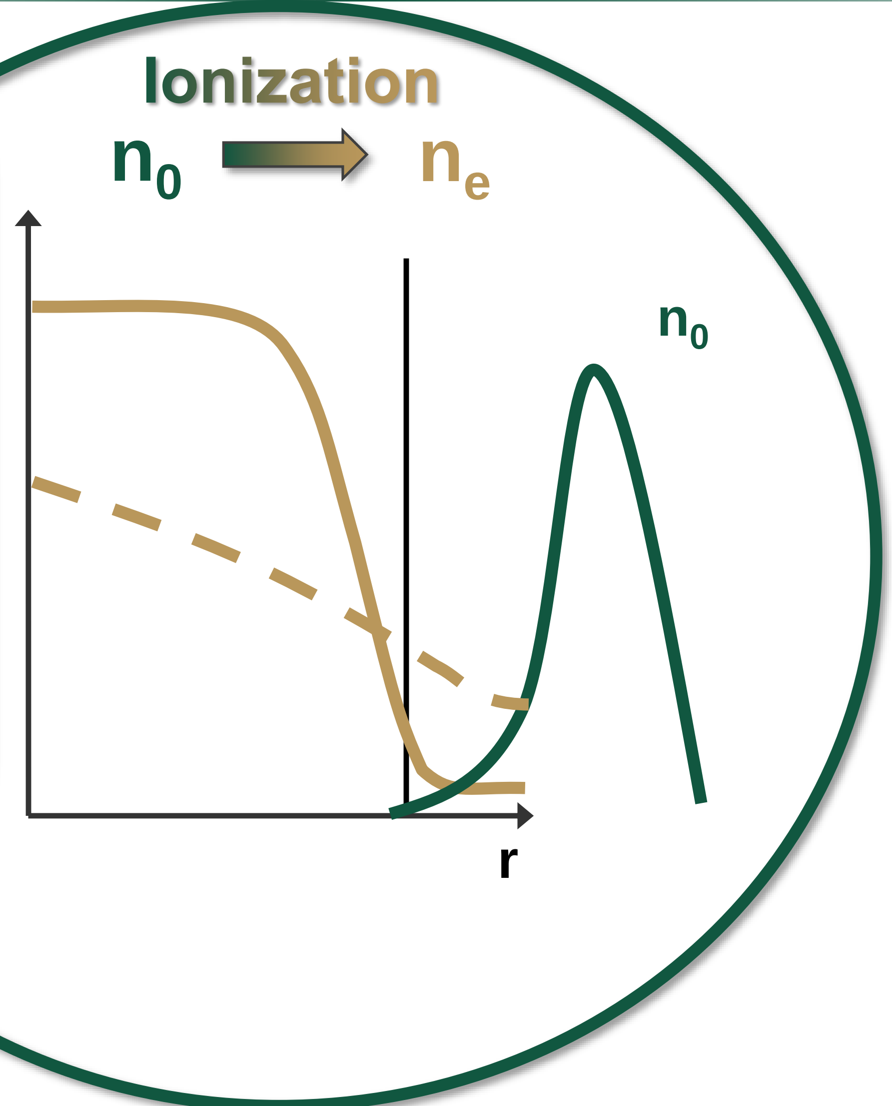

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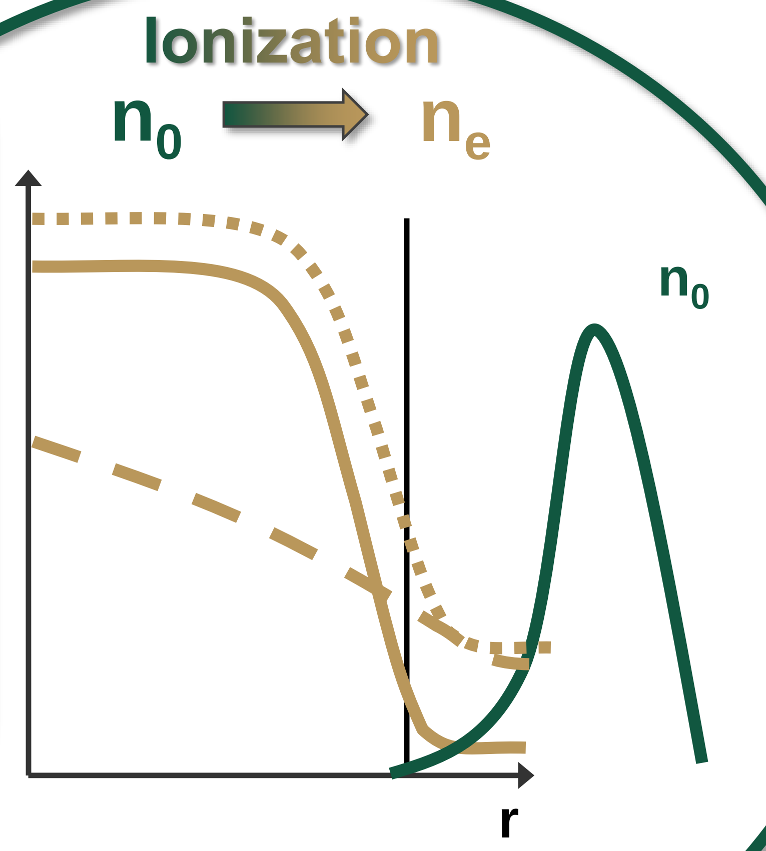
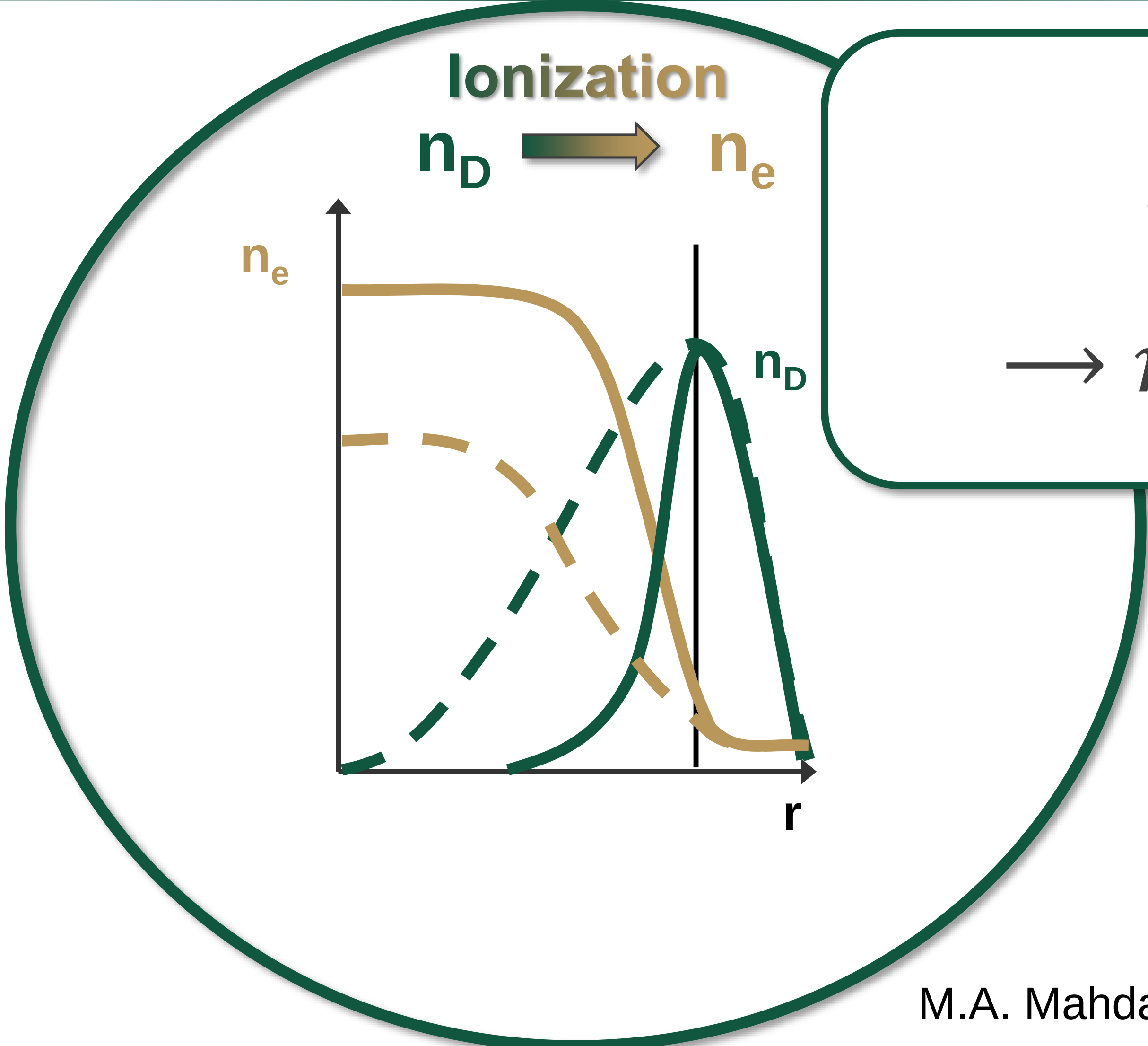


Does the penetration depth of the neutrals determine the electron density pedestal width?



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$$\Delta n_e = \frac{2V_n}{\sigma V_e n_{e_{ped}} E}$$

M.A. Mahdavi *et al* 2002 *Nucl. Fusion* **42** 52

Does the penetration depth of the neutrals determine the electron density pedestal width?

- Model assumes particle balance
  - Constant D and no v for electron transport
  - Exponential decay ne in SOL
  - Flux expansion parameter for neutral: $\boldsymbol{E}$
  - Energy of neutrals ~ energy of the ions: $\boldsymbol{V_n}$
- **Free parameters to 'fit' model to the data**

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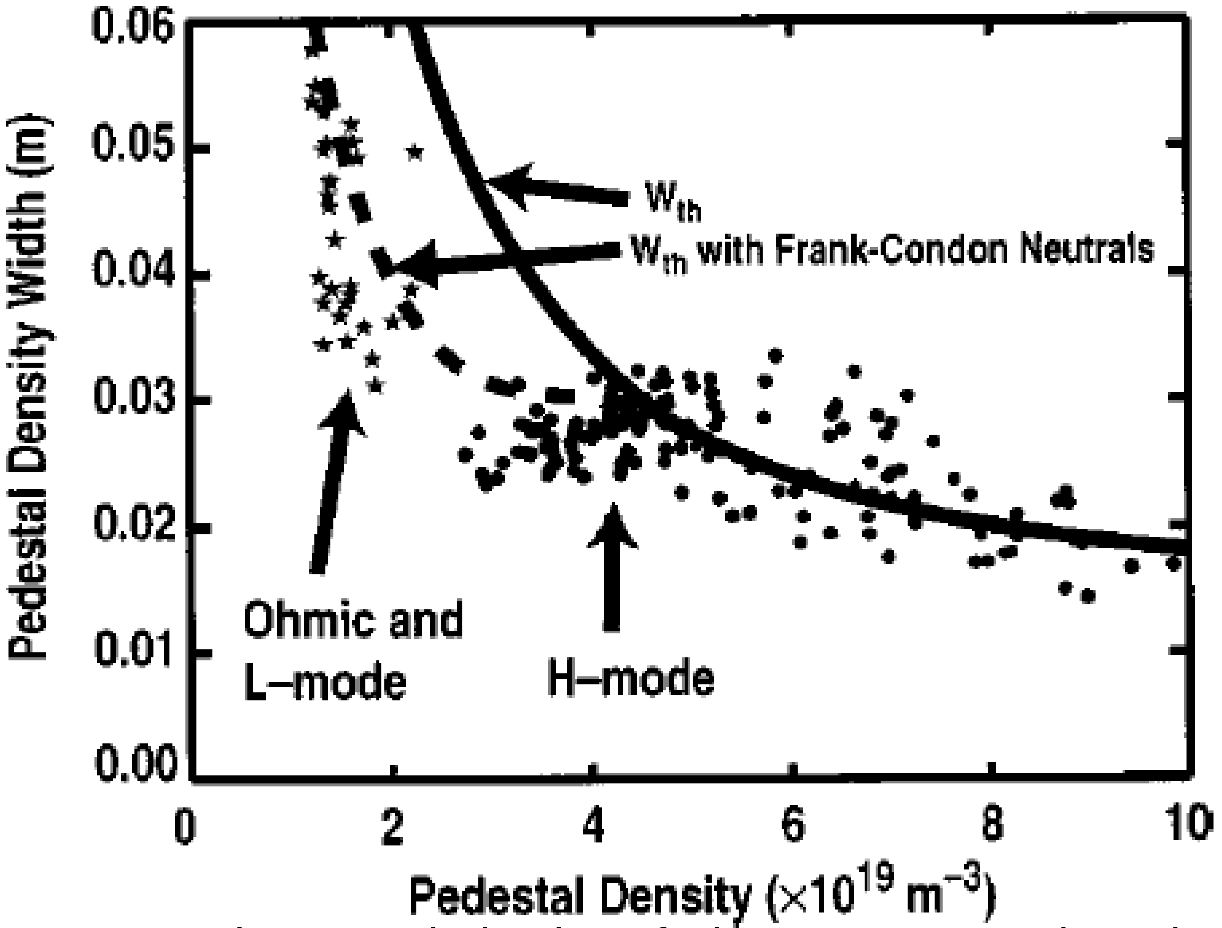
M.A. Mahdavi *et al* 2002 *Nucl. Fusion* **42** 52

Simplistic 1D model finds good agreement for wide range of DIII-D discharges



R.J. Groebner *et al* Physics of Plasmas **9**, 2134 (2002)

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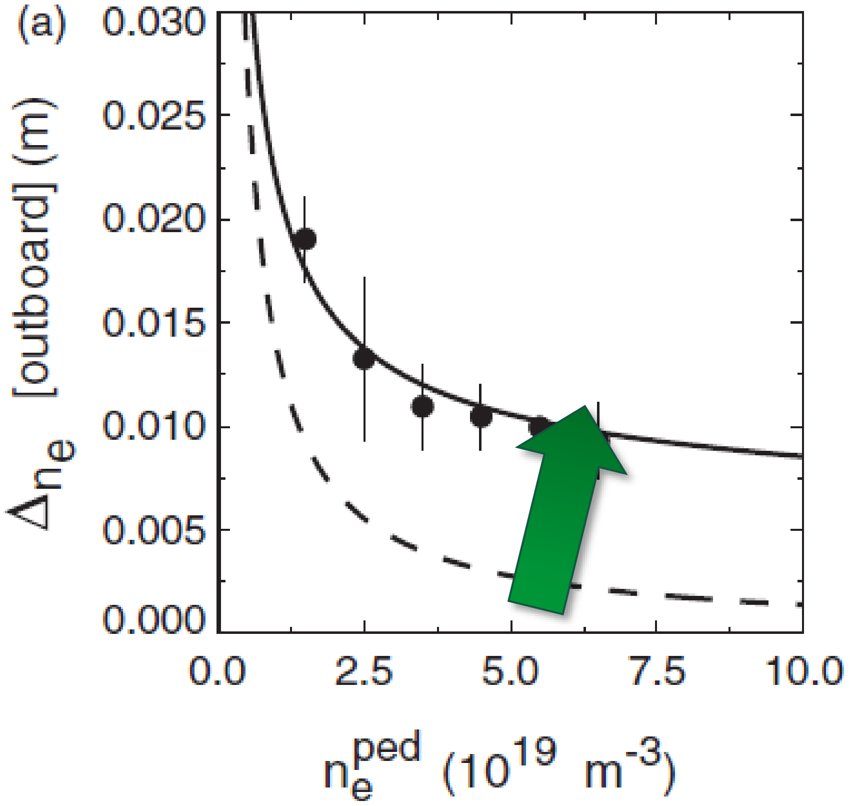
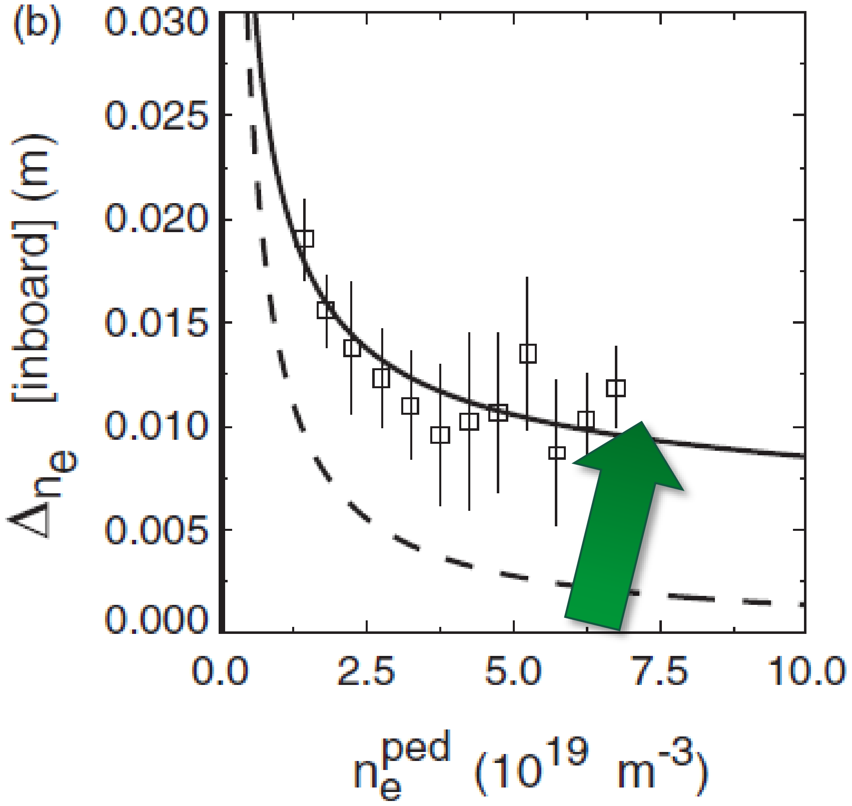
M.A. Mahdavi *et al* 2002 *Nucl. Fusion* **42** 52

Similar as on DIII-D, if the 'drift' speed of the neutrals is reduced good agreement is found on MAST

A Kirk *et al* 2004 *Plasma Phys. Control. Fusion* **46** A187





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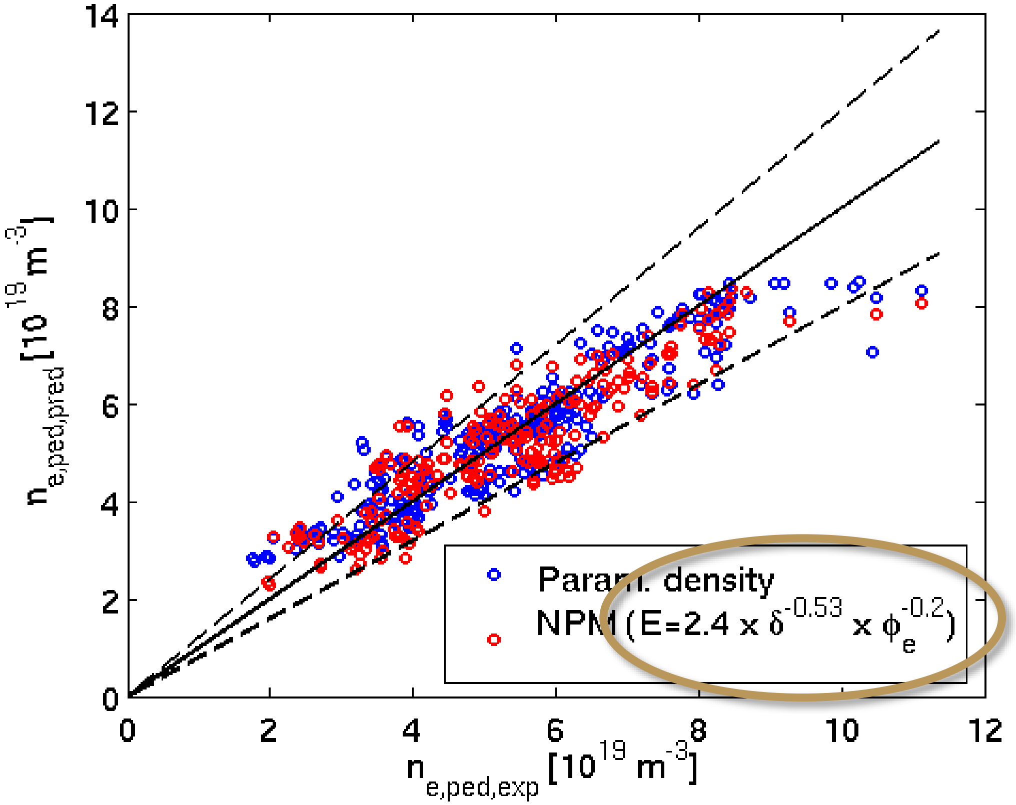
M.A. Mahdavi *et al* 2002 *Nucl. Fusion* **42** 52

However to match fueling experiments on JET, the 'poloidal localization' factor needs to be adapted

- E depends on
  - Plasma shape
  - Fueling levels
- Model could not reproduce different isotope experiments

S. Saarelma 60th APS-DPP conference, 2018



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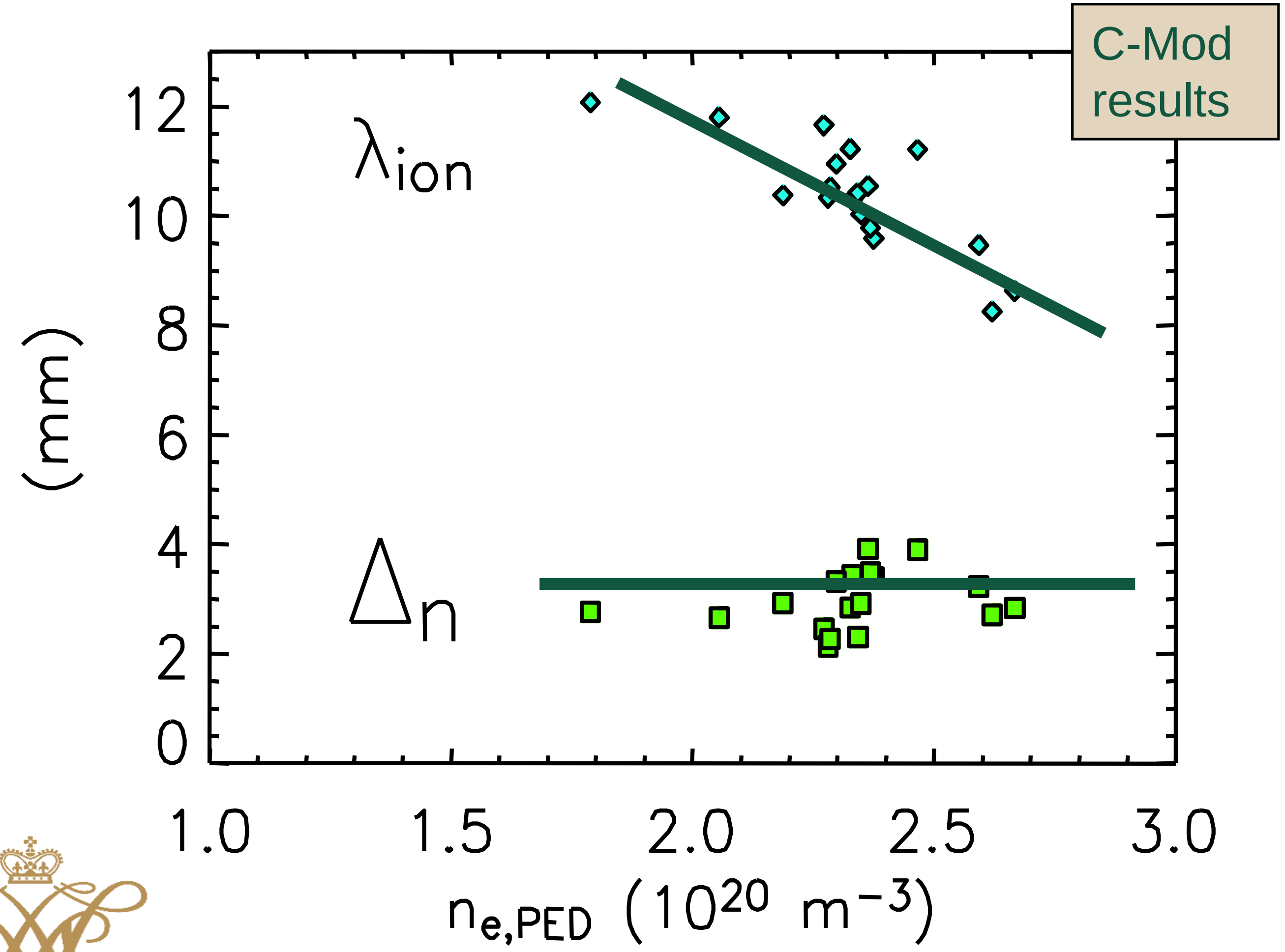
M.A. Mahdavi *et al* 2002 *Nucl. Fusion* **42** 52

C-Mod measurements show reduced neutral penetration depth does not result in reduced pedestal width



J.W. Hughes, et al. *PoP* **13** (2006) 056103

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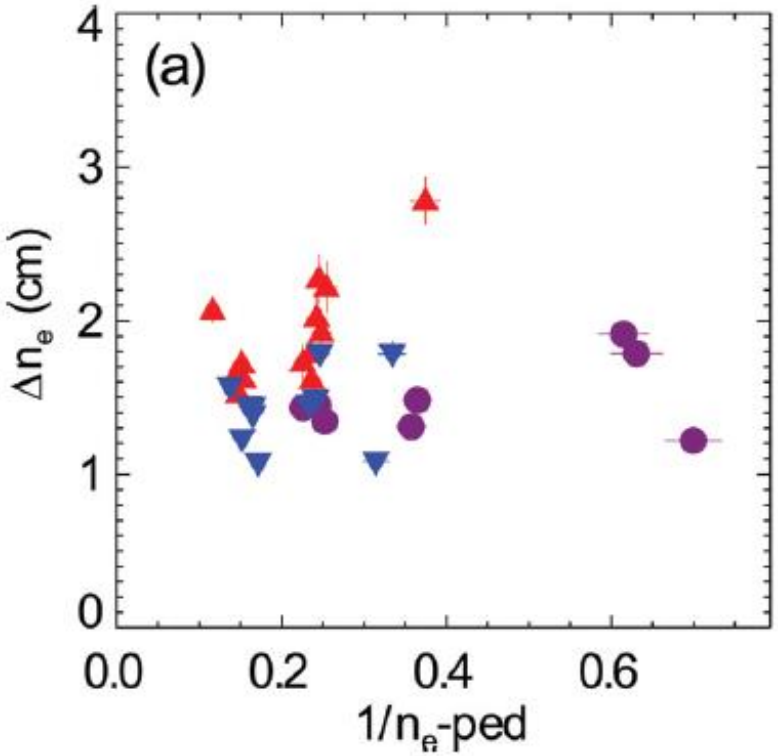
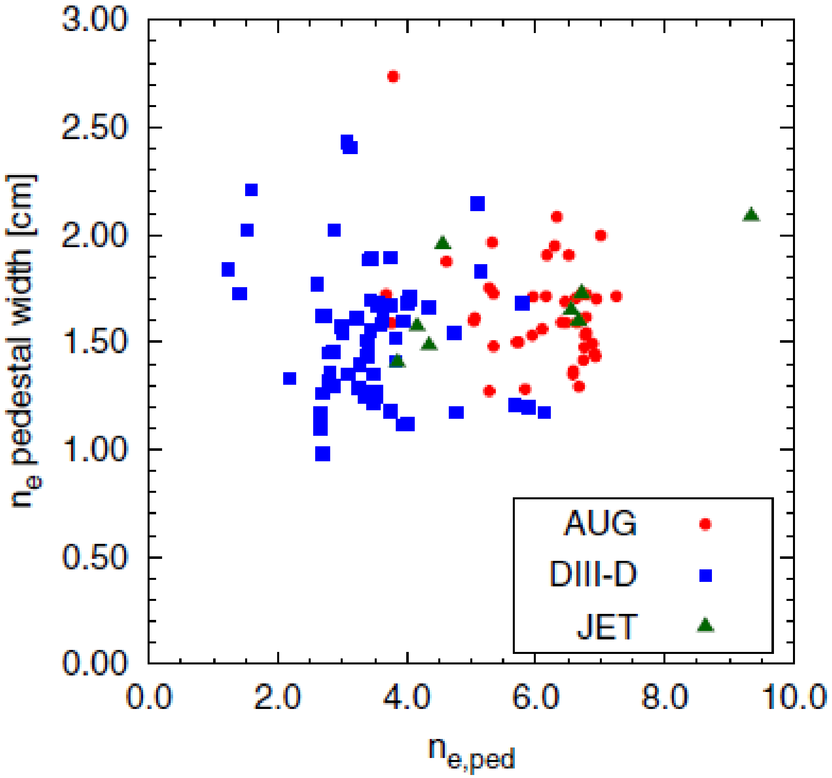
M.A. Mahdavi *et al* 2002 *Nucl. Fusion* **42** 52

Multi-machine database shows no linear trend of $\Delta n_e \sim 1/n_{e_{ped}}$ and indicates a shift in pedestal structure





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M.N.A. Beurskens et al Phys. Plasmas 18, 056120 (2011)

P A Schneider *et al* 2012 *Plasma Phys. Control. Fusion* 54 105009

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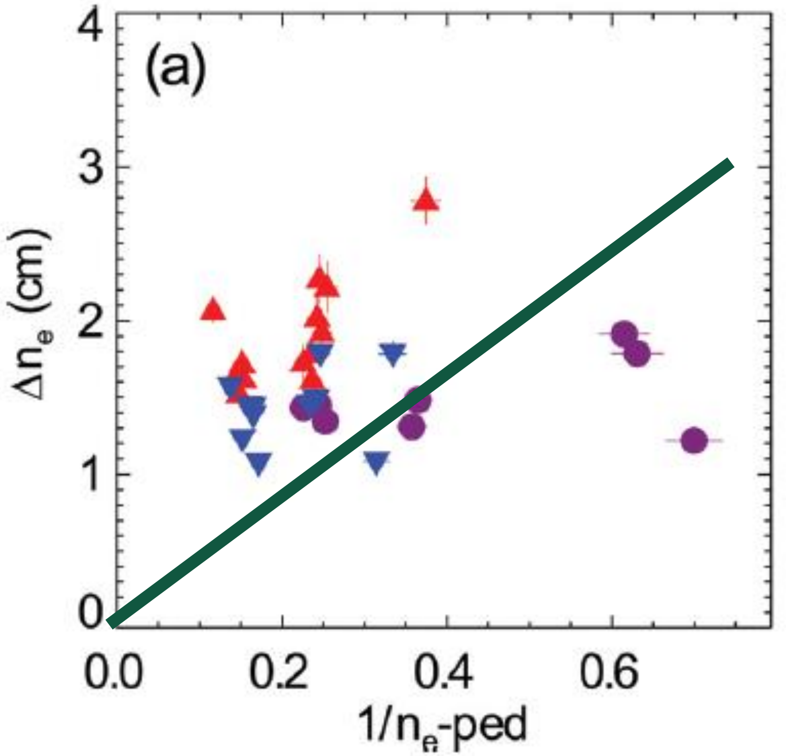

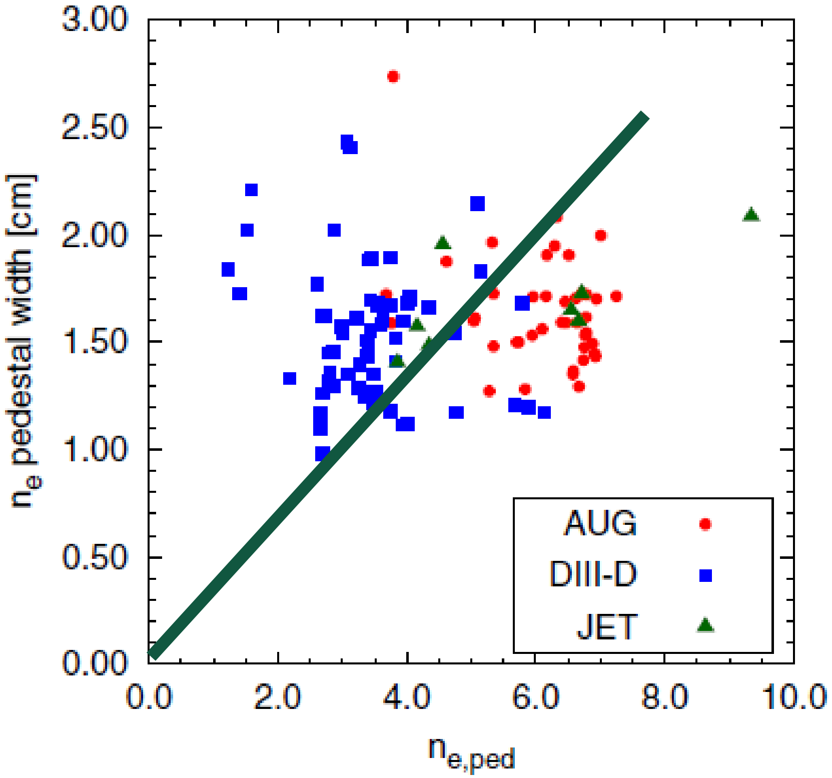

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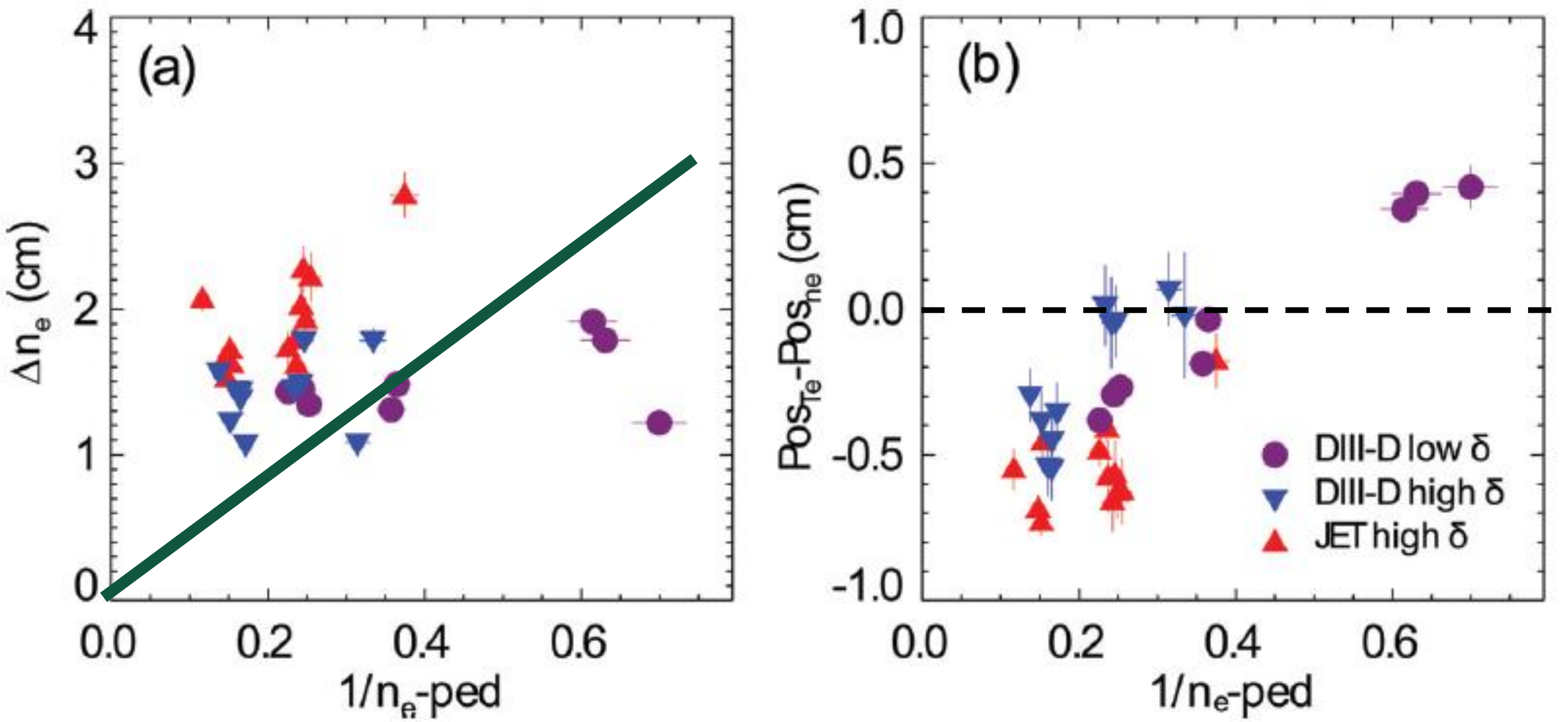

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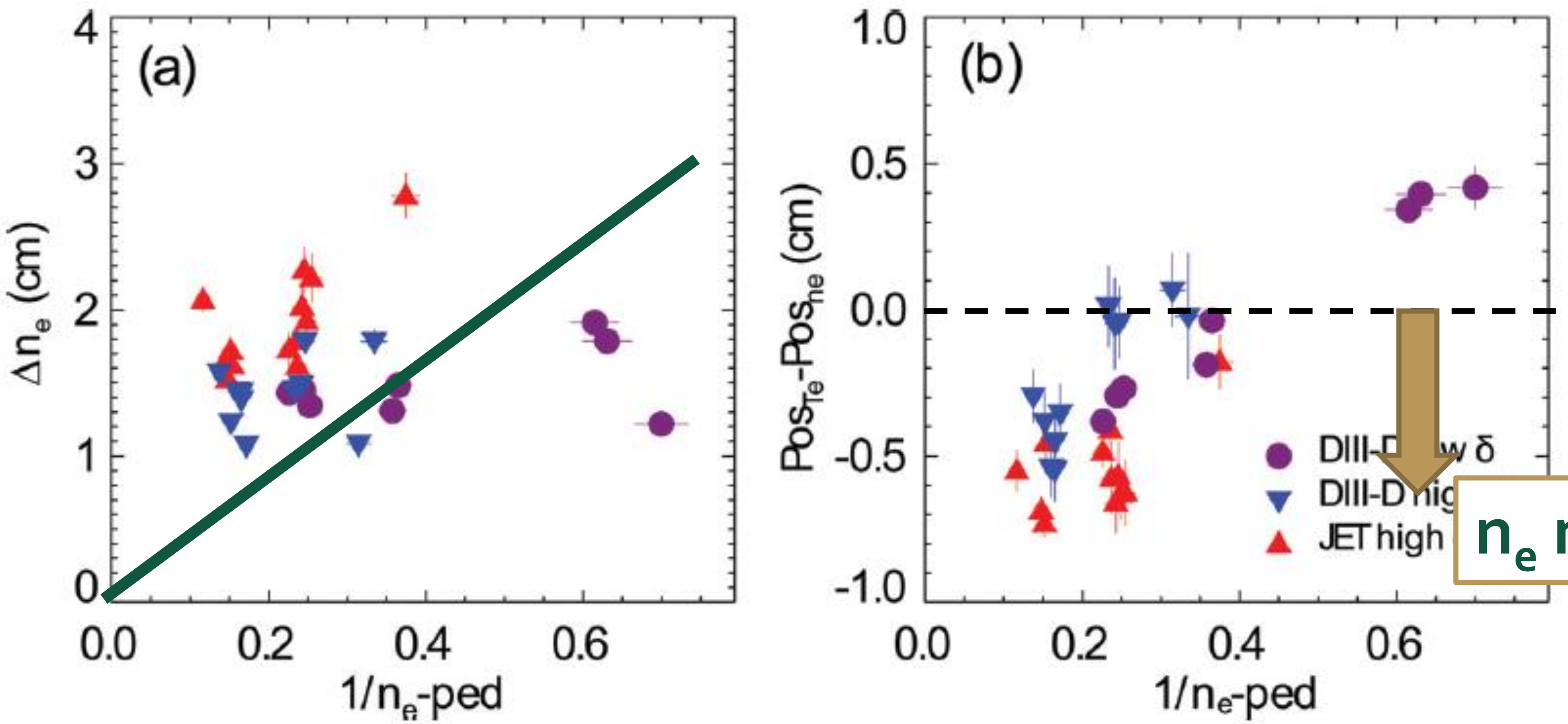

n$_e$ moves out

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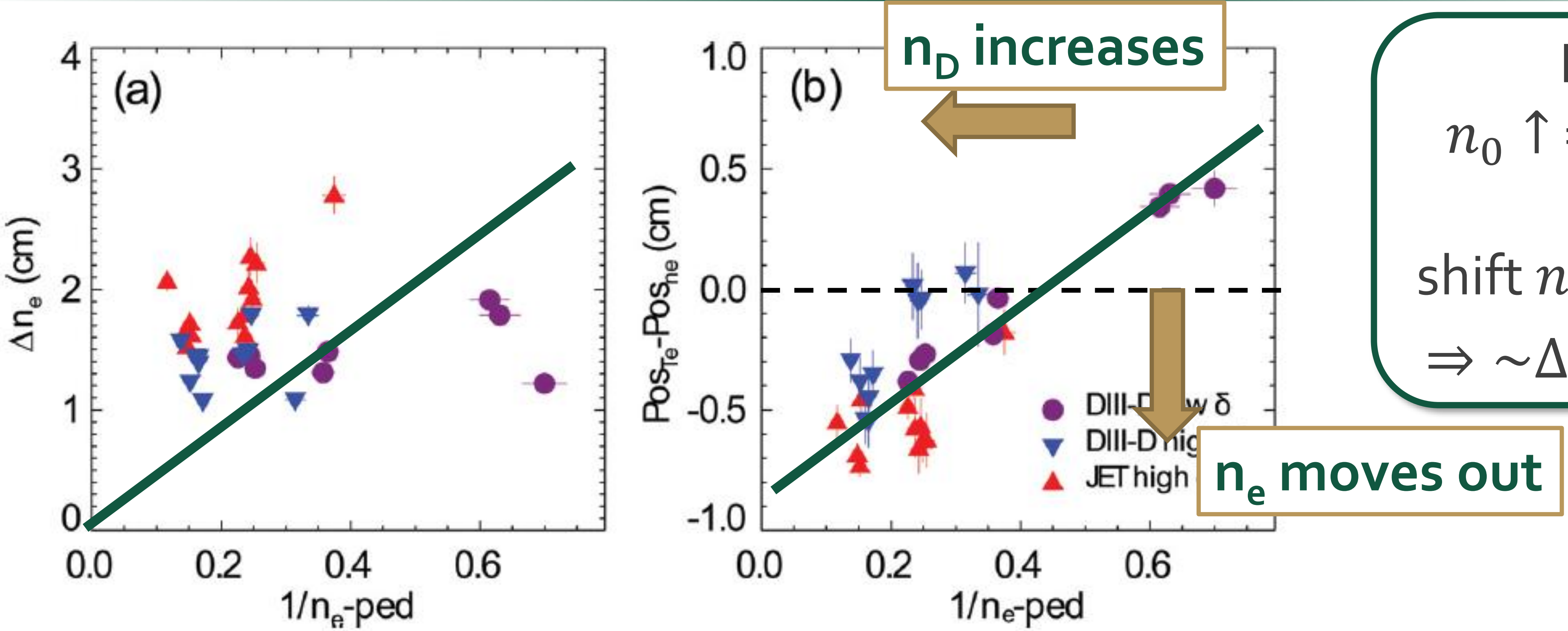

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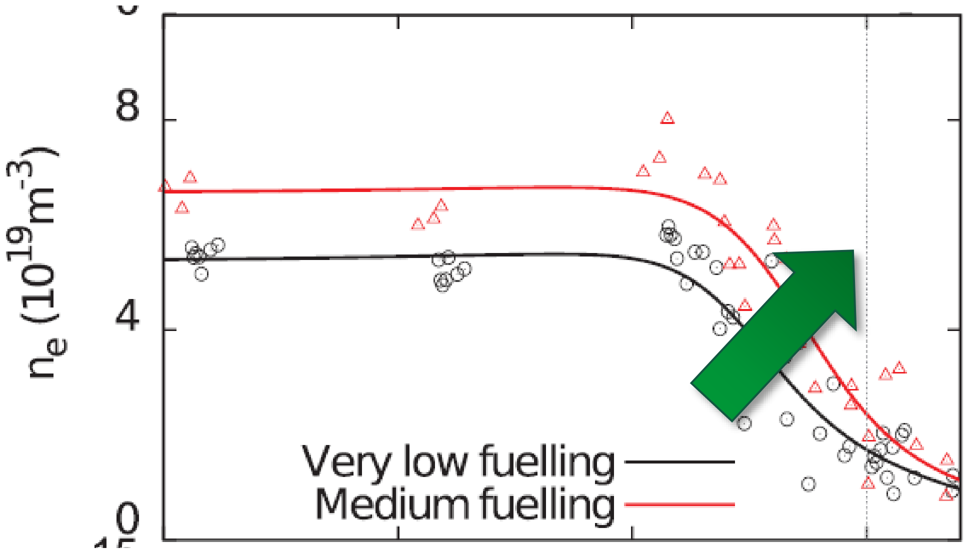
Dedicated fueling studies on AUG and JET show a shift outward of the density pedestal



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M G Dunne *et al* 2017 *PPCF* **59** 014017

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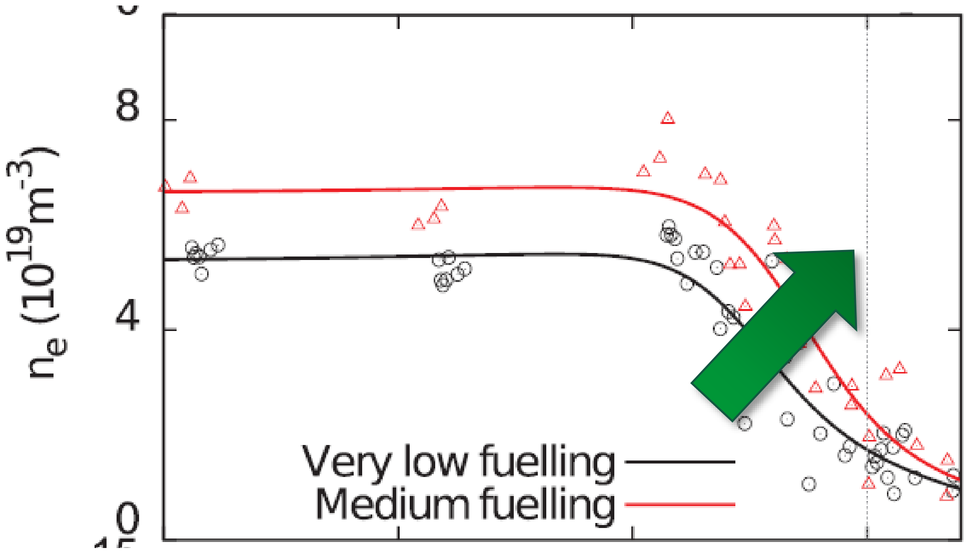

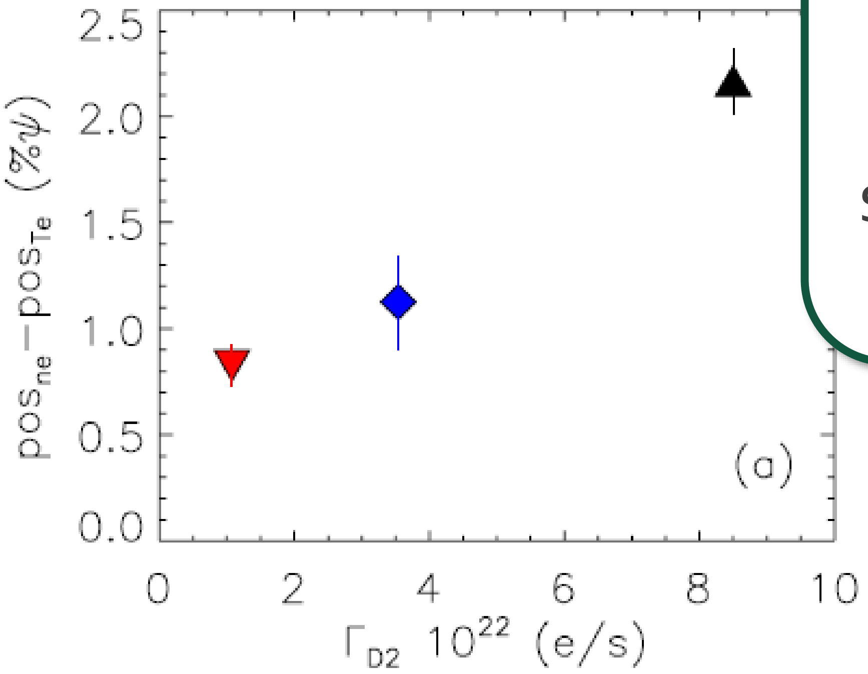

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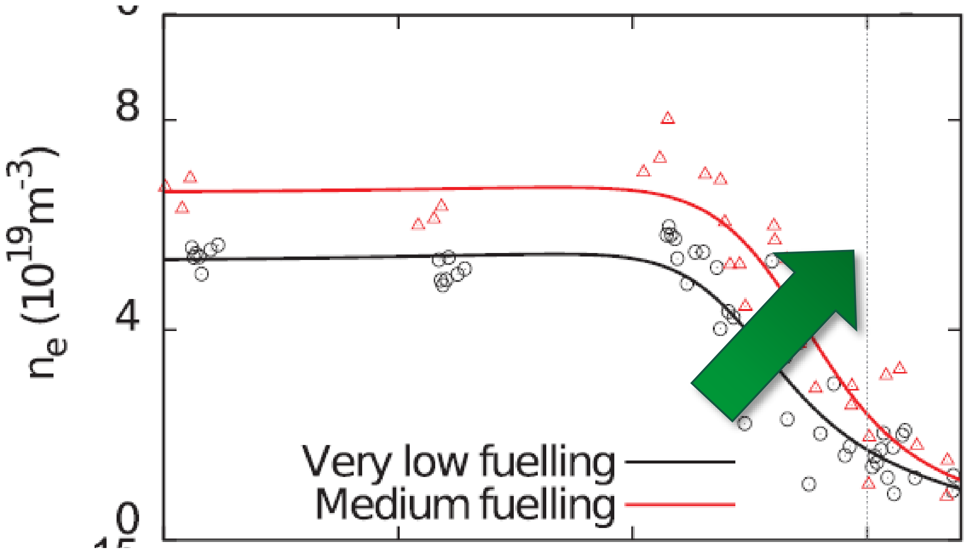

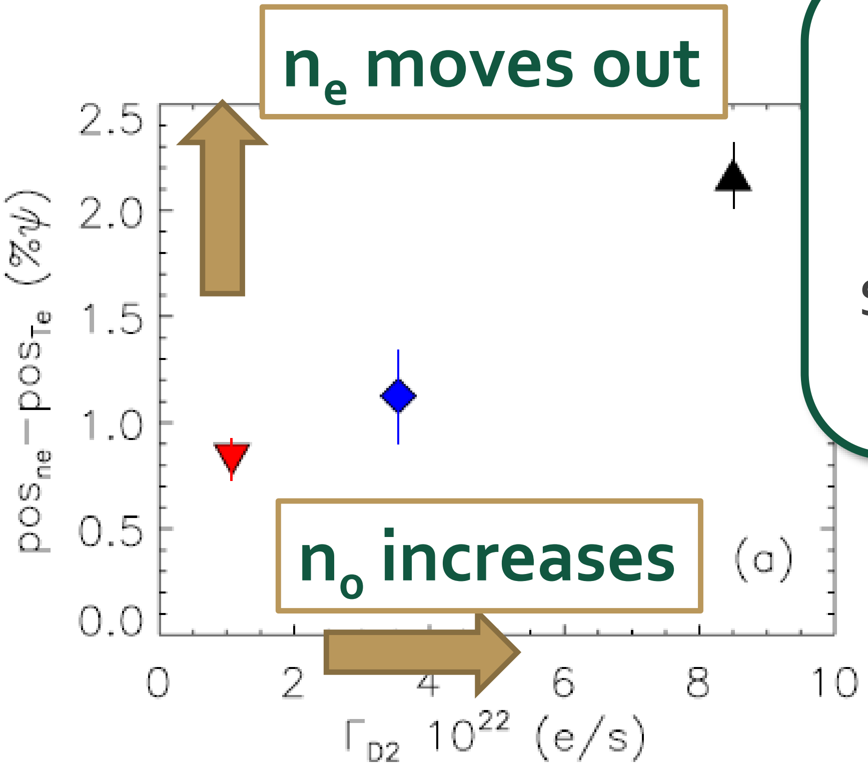

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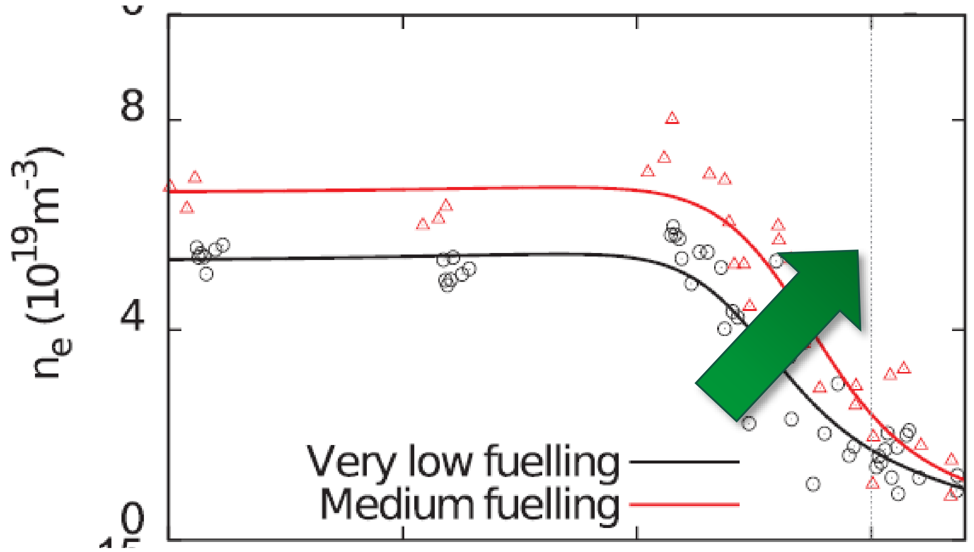
The shift in the pedestal outward was also observed in DIII-D for an open divertor configuration



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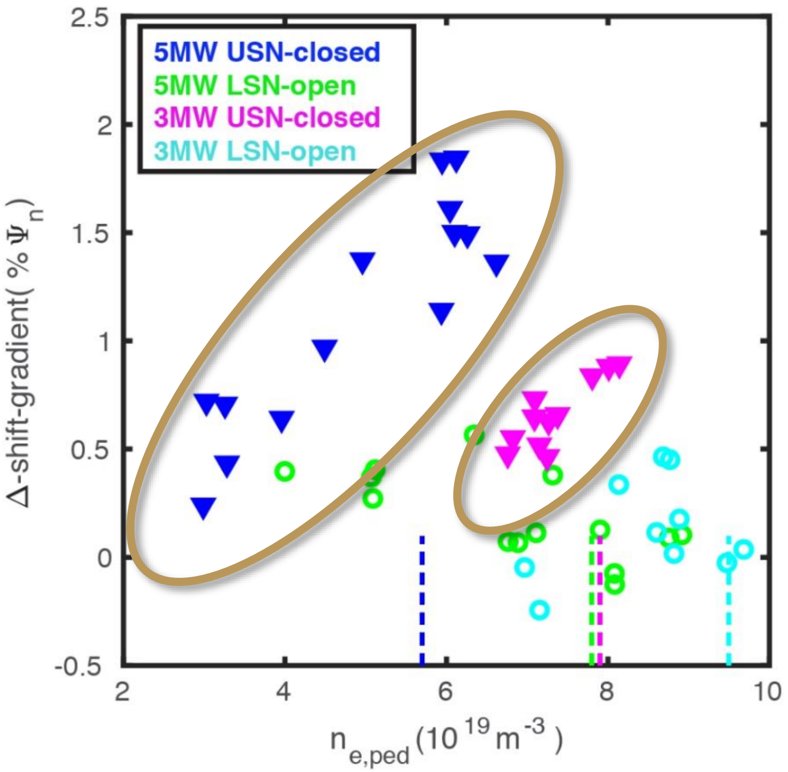

H.Q. Wang *et al* 2018 *Nucl. Fusion* **58** 096014

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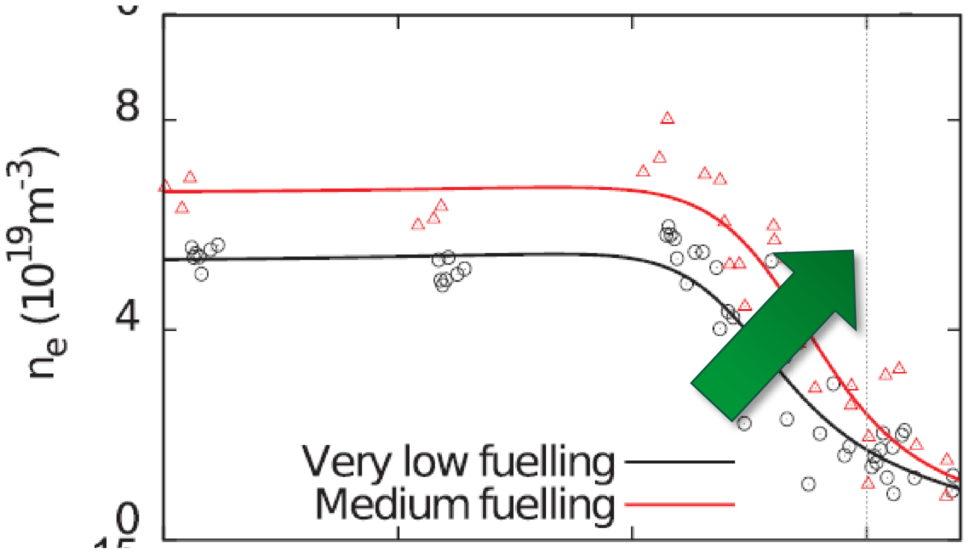
A trend in outward shift cannot be observed if divertor geometry is altered in DIII-D plasmas



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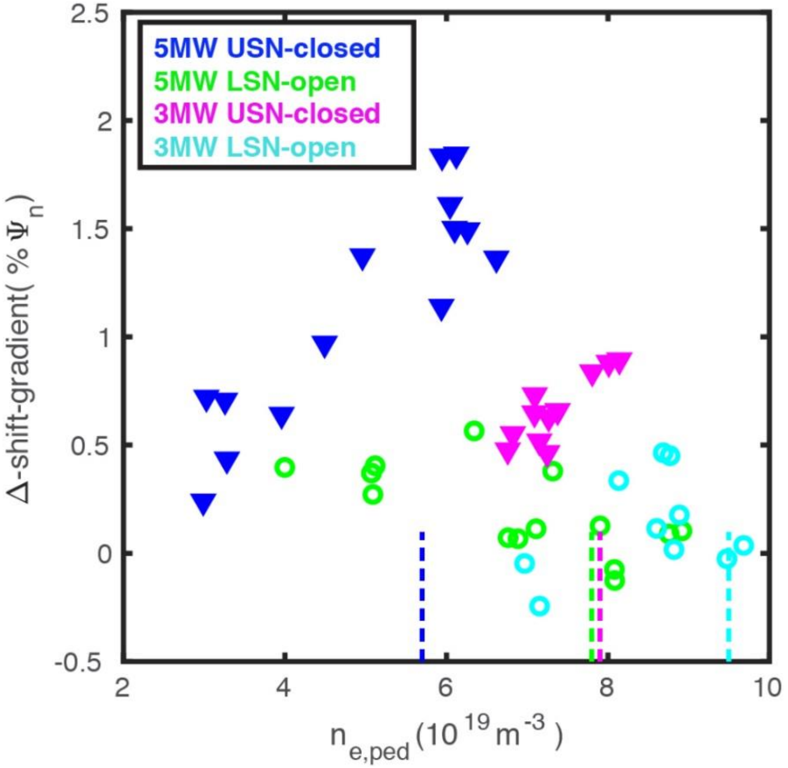


H.Q. Wang *et al* 2018 *Nucl. Fusion* **58** 096014

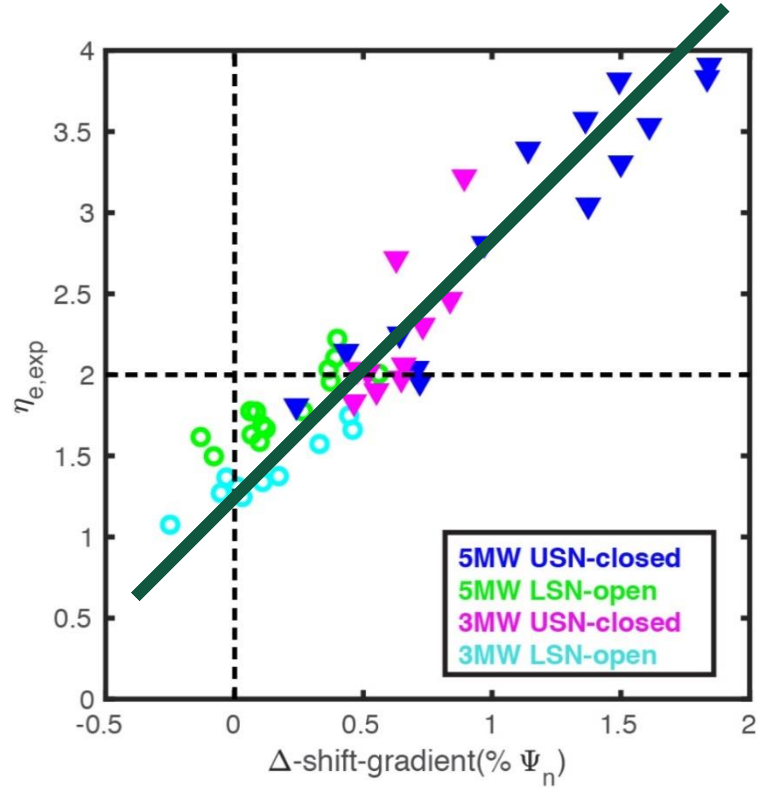
Model 2:

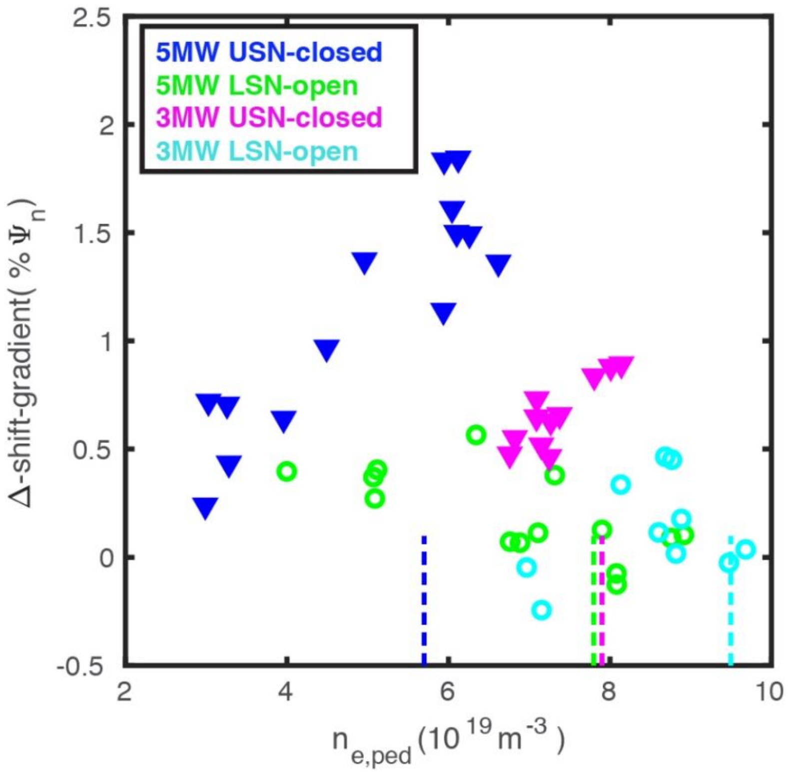
$n_0 \uparrow \Longrightarrow$ shift out in SOL

shift $n_{e_{ped}}$ out in SOL

$\Rightarrow \sim\Delta(n_e - T_e) \neq 0$

Outward shift closely correlated to increasing $\eta_e = L_n/L_{Te}$ for multiple divertor geometries, power and fueling levels in DIII-D





H.Q. Wang *et al* 2018 *Nucl. Fusion* **58** 096014

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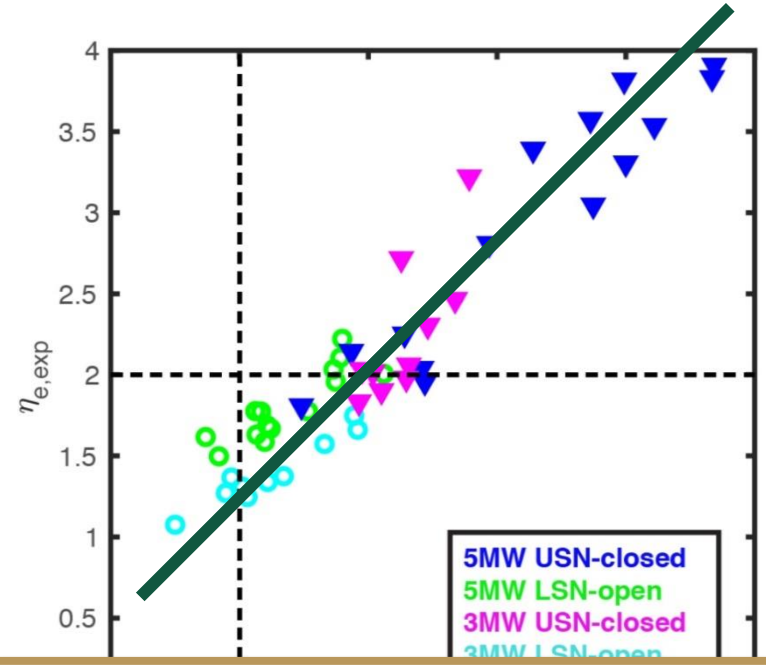
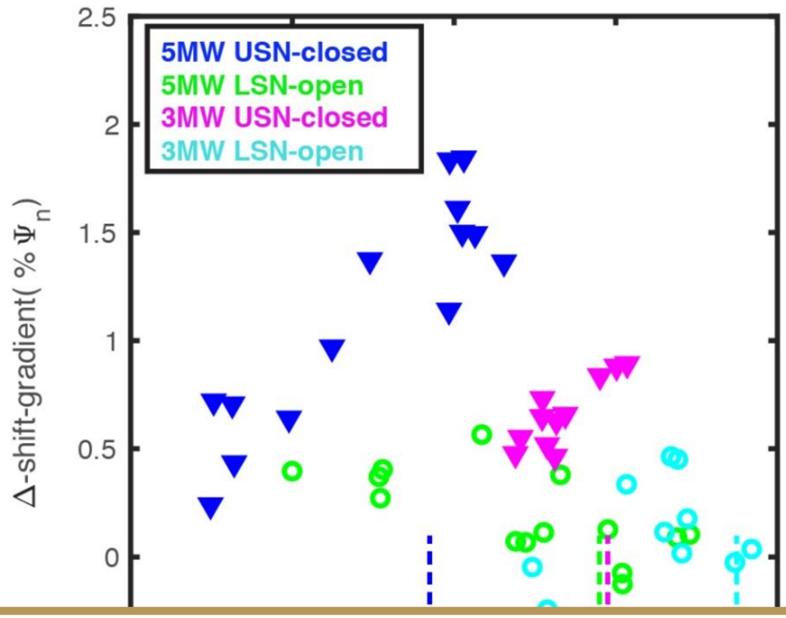
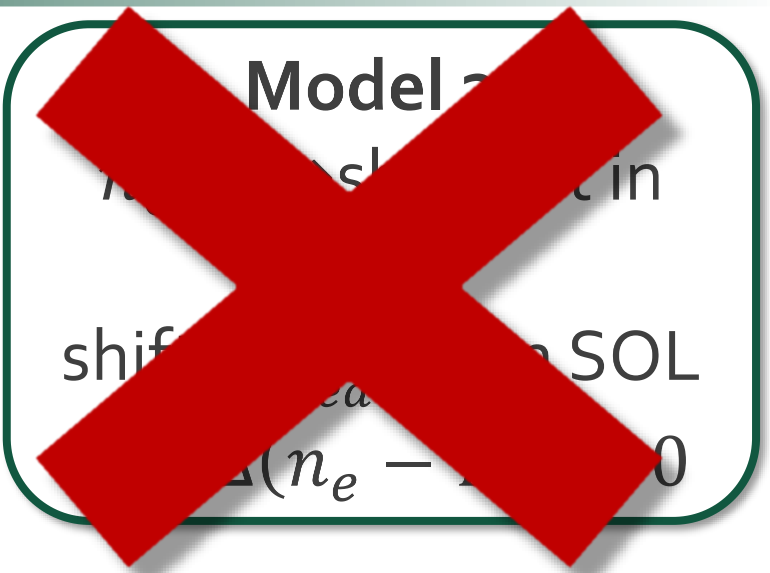






Suggestive that underlying changes in transport cannot be neglected

What sets the pedestal density profile?
In future reactor role of transport becomes dominant

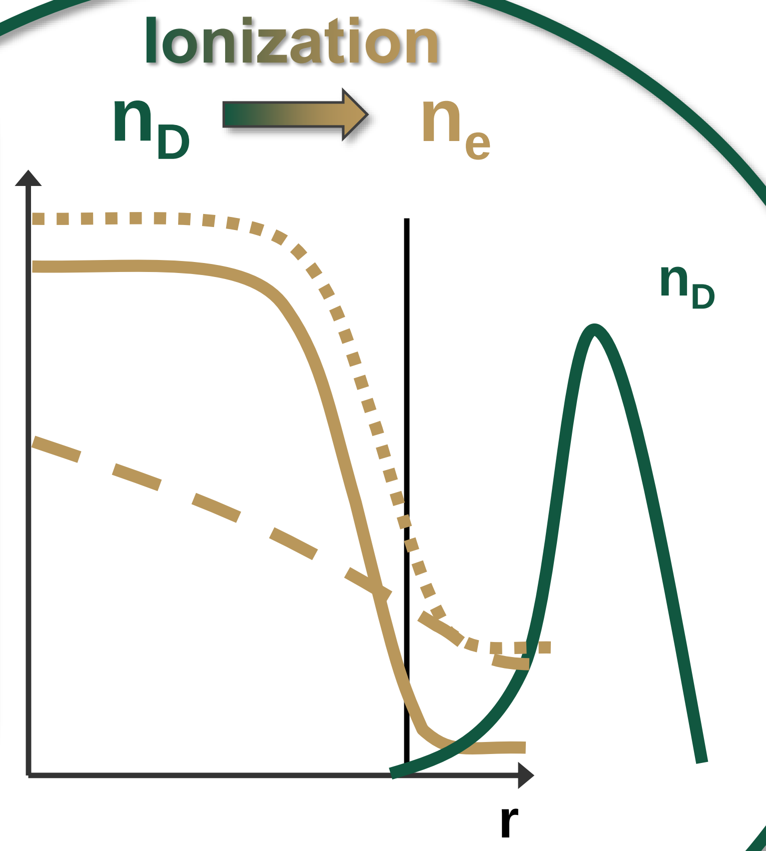
Transport:

$$\Gamma = -D\nabla n + vn$$

if $v \sim 0$

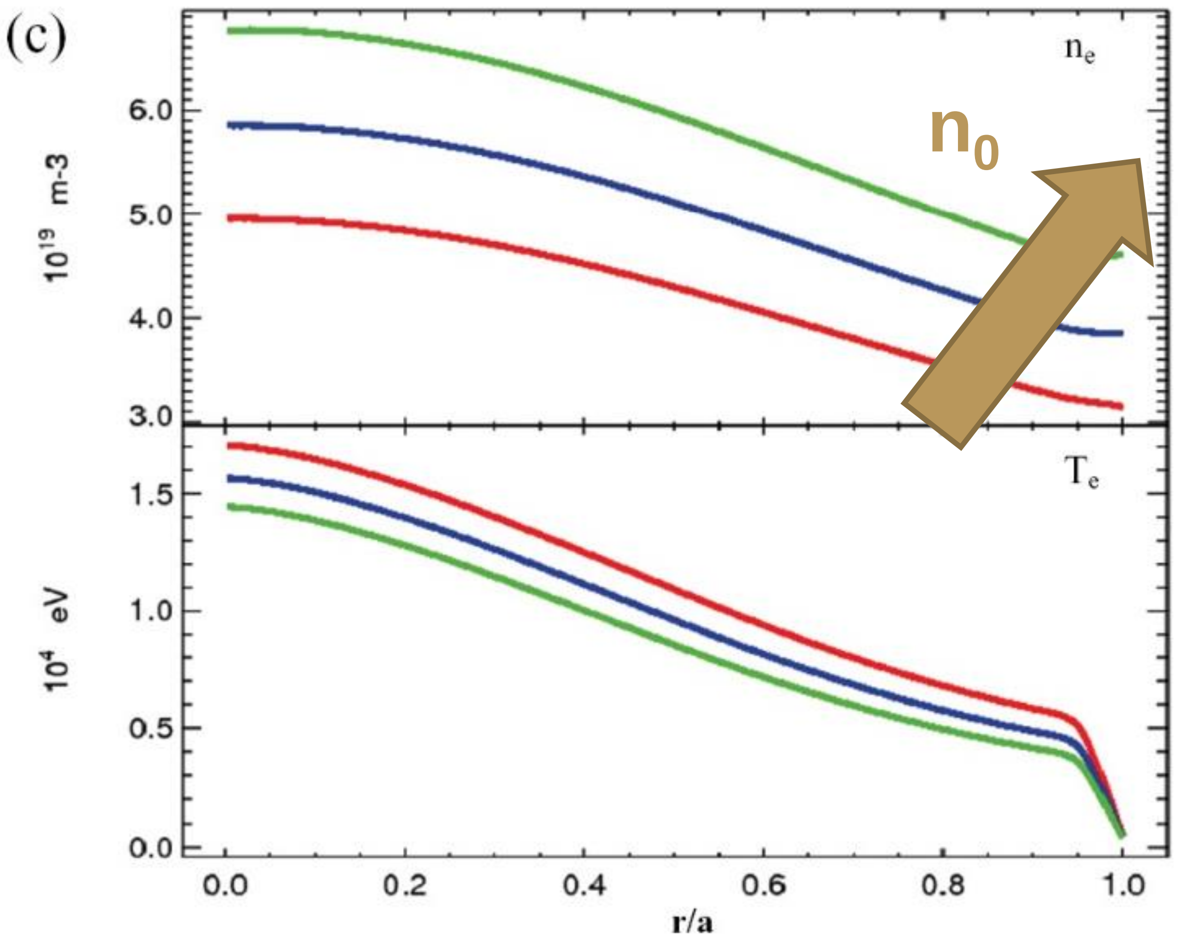
?

if $v < 0$



Integrated predictive modeling for ITER based on understanding of current devices result in disappearance of density pedestal structure

- Integrated modeling using JINTRAC & SOLPS to predict ITER profiles
- The model relies for transport on a diffusion coefficient
- Increases in fueling does not result in a shift, nor an increase of the density gradient
- Need to perform experiments to investigate the role of opacity



M. Romanelli *et al* 2015 *Nucl. Fusion* **55** 093008

Experiments on DIII-D and C-Mod were performed to scan a variety of level of opacity using changes in Ip and gas fueling

Low opacity → **High opacity**

Opacity ~ n_e x a ~ $1/2(n_{e,sep}+n_{e,ped})a$

Experiments on DIII-D and C-Mod were performed to scan a variety of level of opacity using changes in Ip and gas fueling

Low opacity **High opacity**

Opacity ~ n_e x a ~ $1/2(n_{e,sep}+n_{e,ped})a$

DIII-D NATIONAL FUSION FACILITY

a = 0.67m

$1.5x10^{19}$

$4.0x10^{19}$

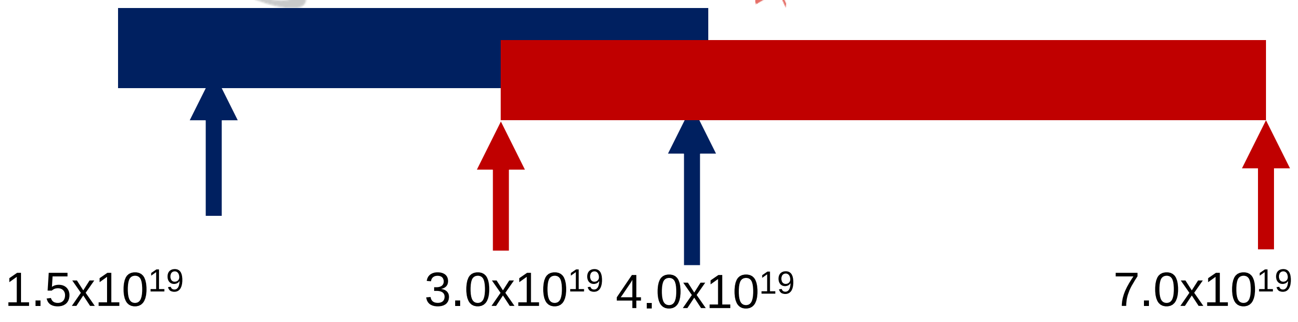
Experiments on DIII-D and C-Mod were performed to scan a variety of level of opacity using changes in Ip and gas fueling

Low opacity **High opacity**

$$\text{Opacity} \sim n_e \times a \sim 1/2(n_{e,sep}+n_{e,ped})a$$

DIII-D NATIONAL FUSION FACILITY a = 0.67m

Alcator C-Mod a = 0.22m



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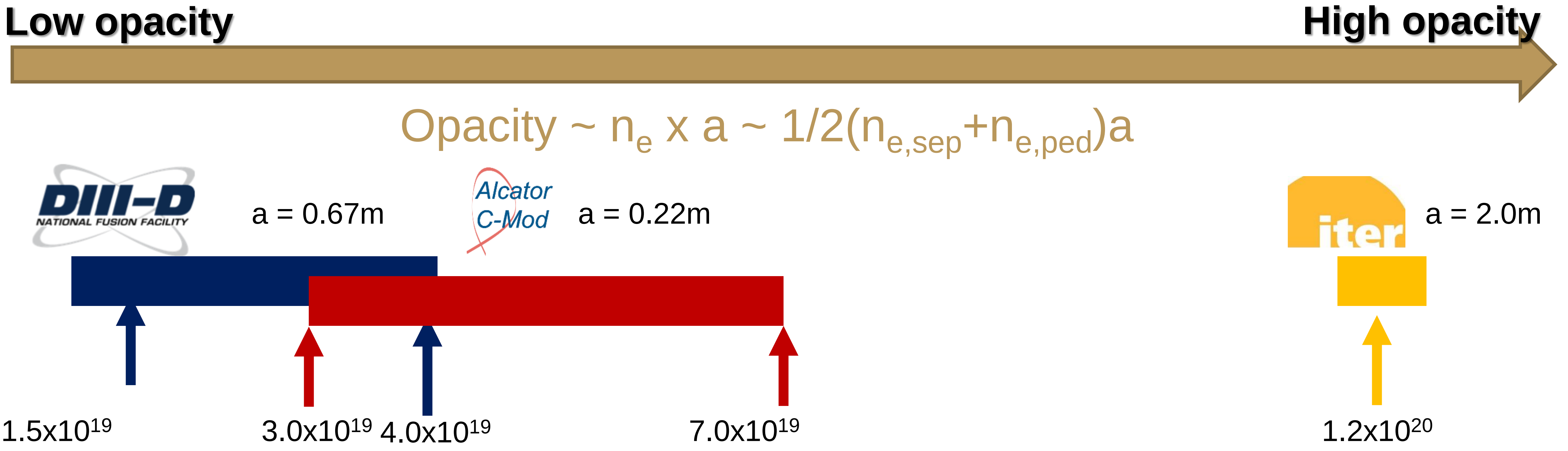

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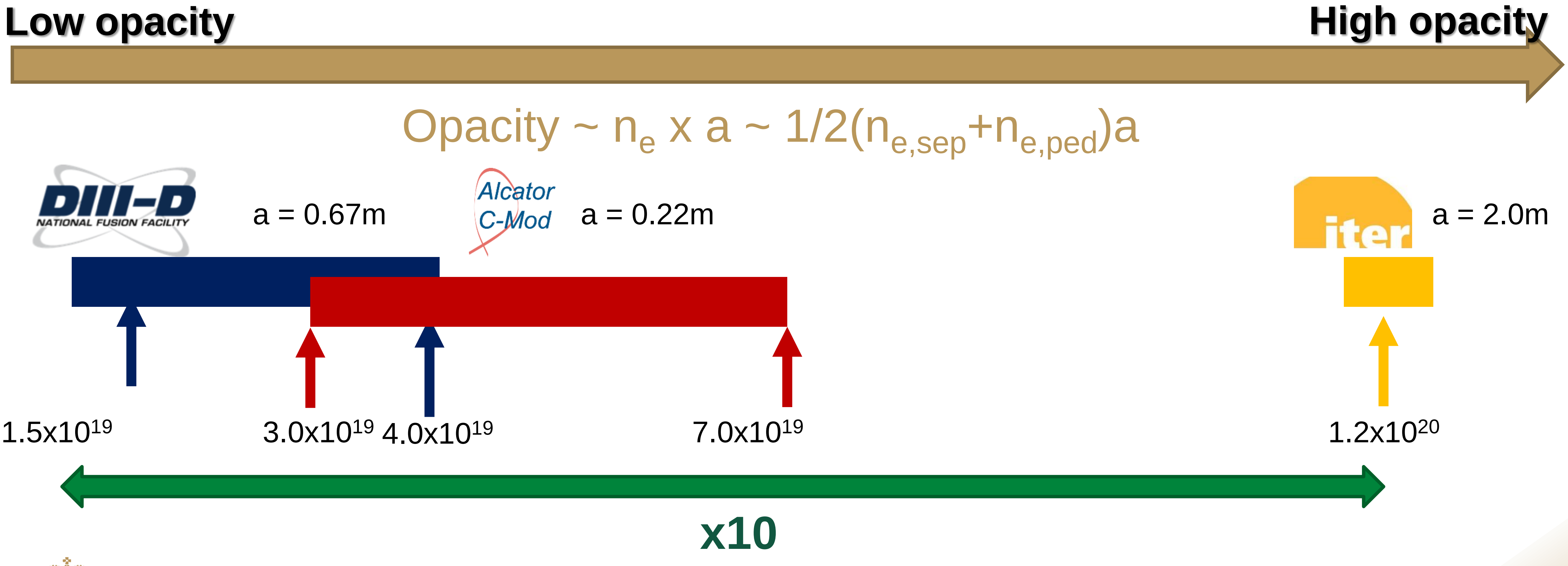

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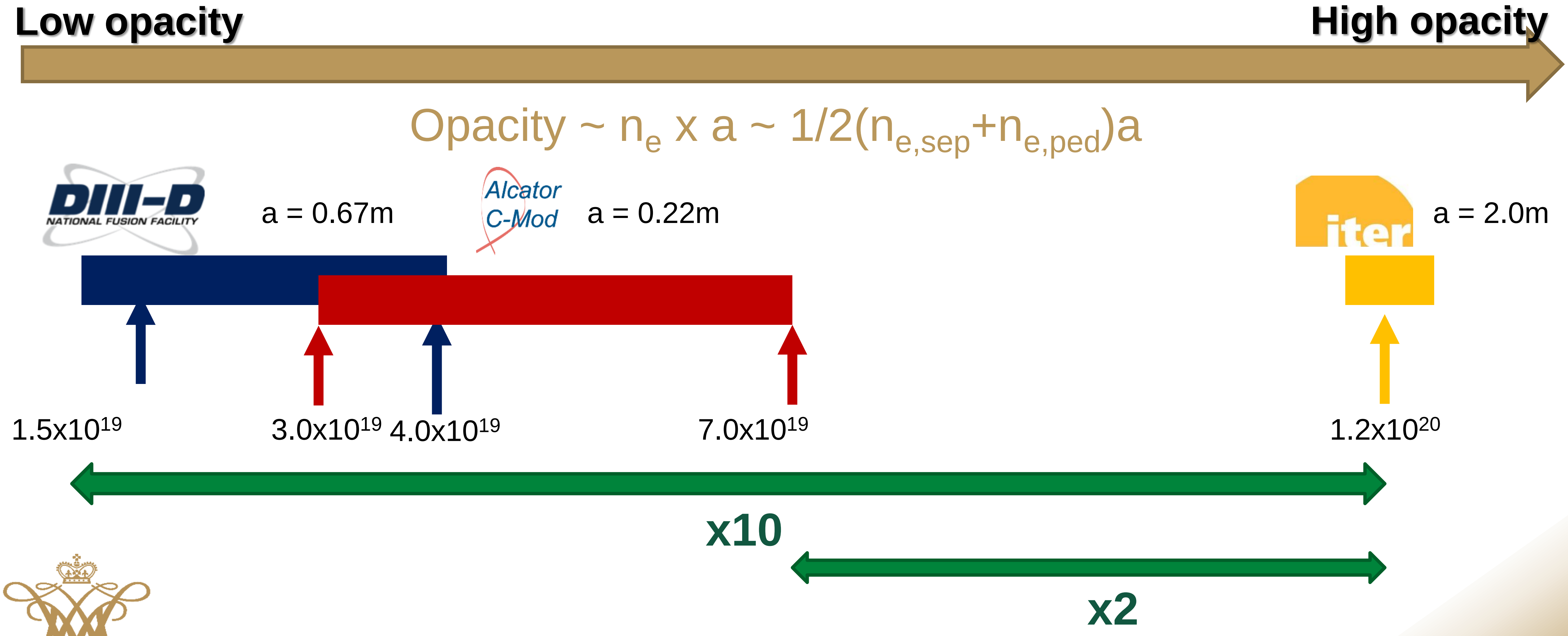
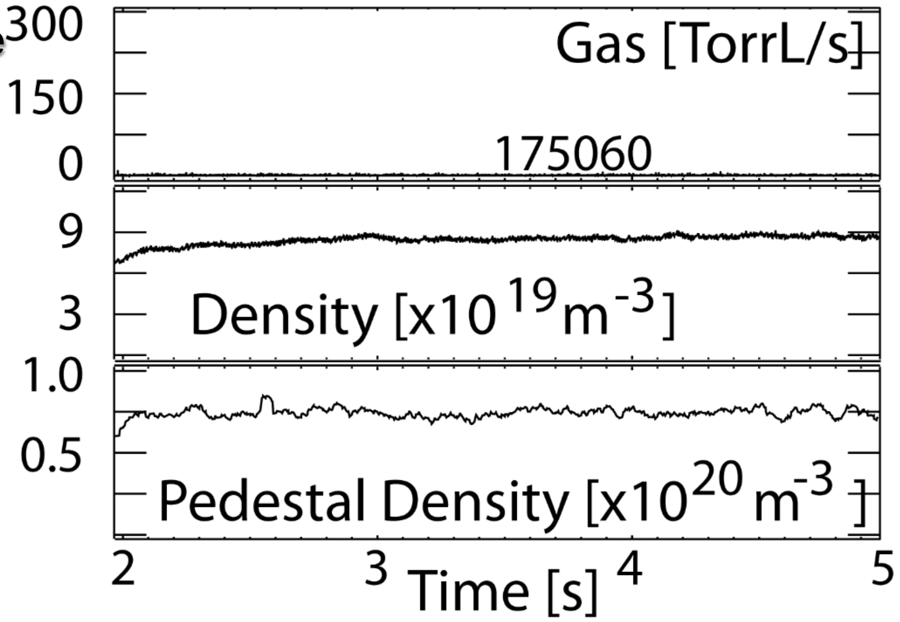


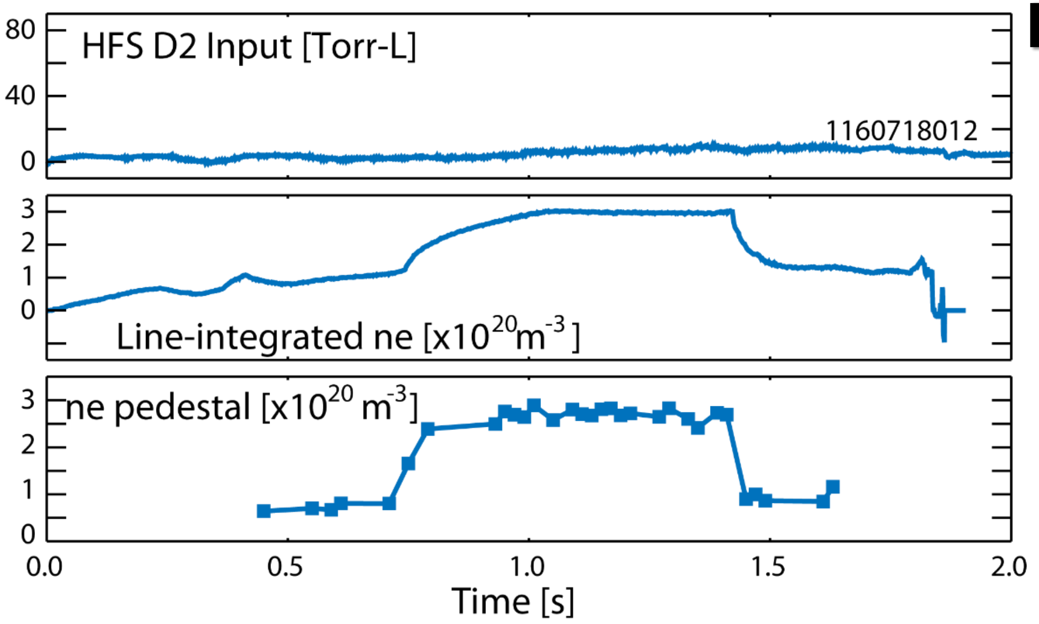
Experiments on DIII-D and C-Mod were performed to scan a variety of level of opacity using changes in Ip and gas fueling

Low opacity — **High opacity**

Lower n_e

DIII-D NATIONAL FUSION FACILITY





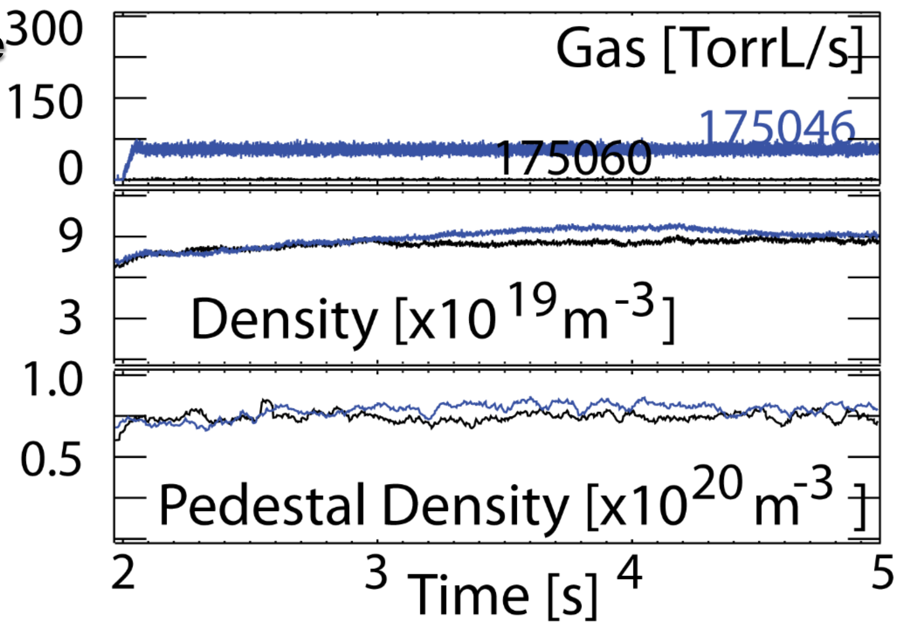
Higher n_e

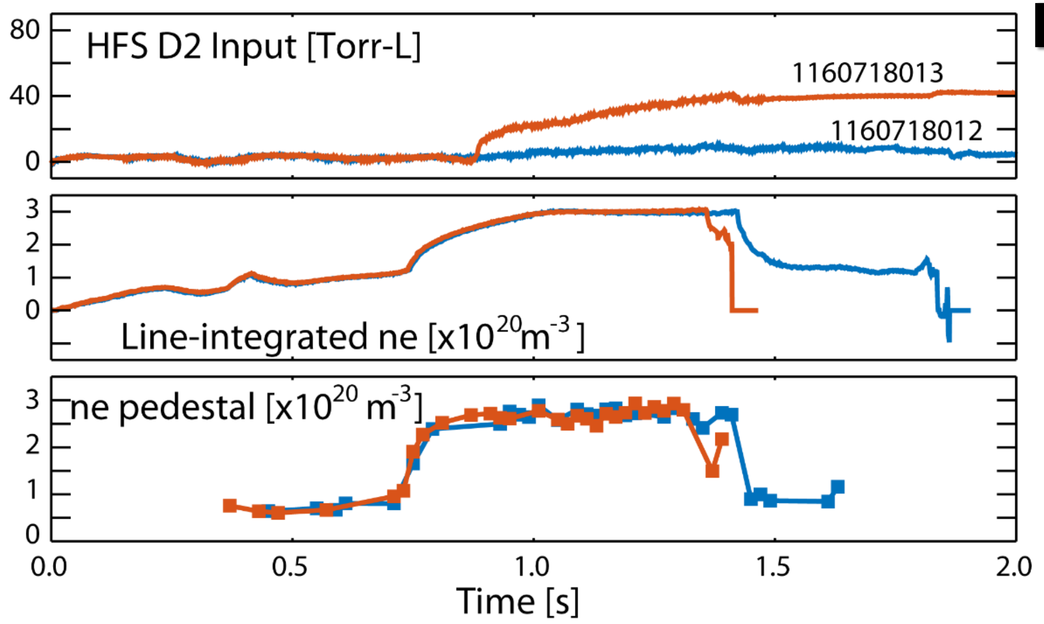
Alcator C-Mod

Experiments on DIII-D and C-Mod were performed to scan a variety of level of opacity using changes in Ip and gas fueling

Low opacity **High opacity**

Lower n_e



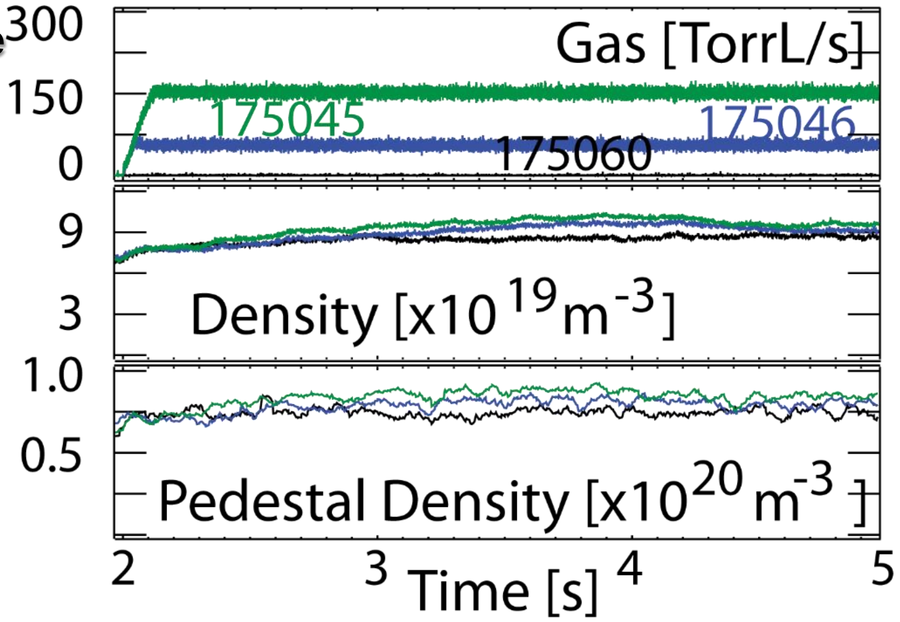


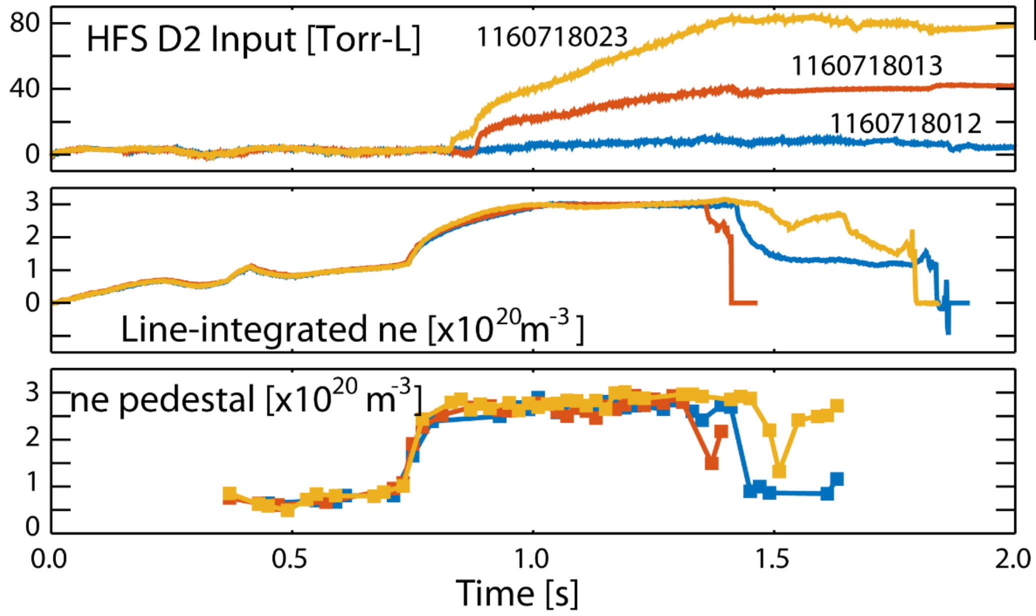
Higher n_e

Experiments on DIII-D and C-Mod were performed to scan a variety of level of opacity using changes in Ip and gas fueling

Low opacity → **High opacity**

Lower n_e → **Higher n_e**

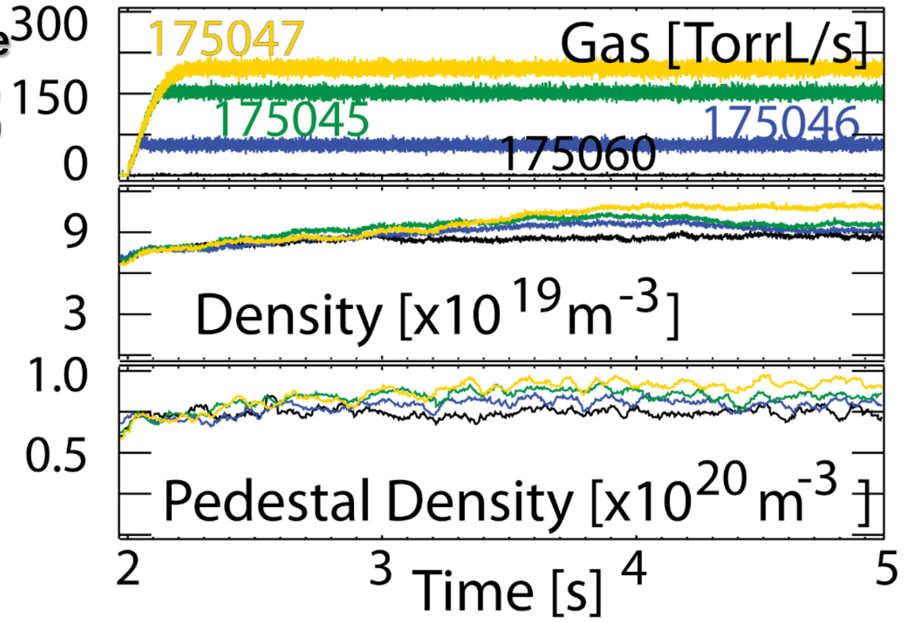


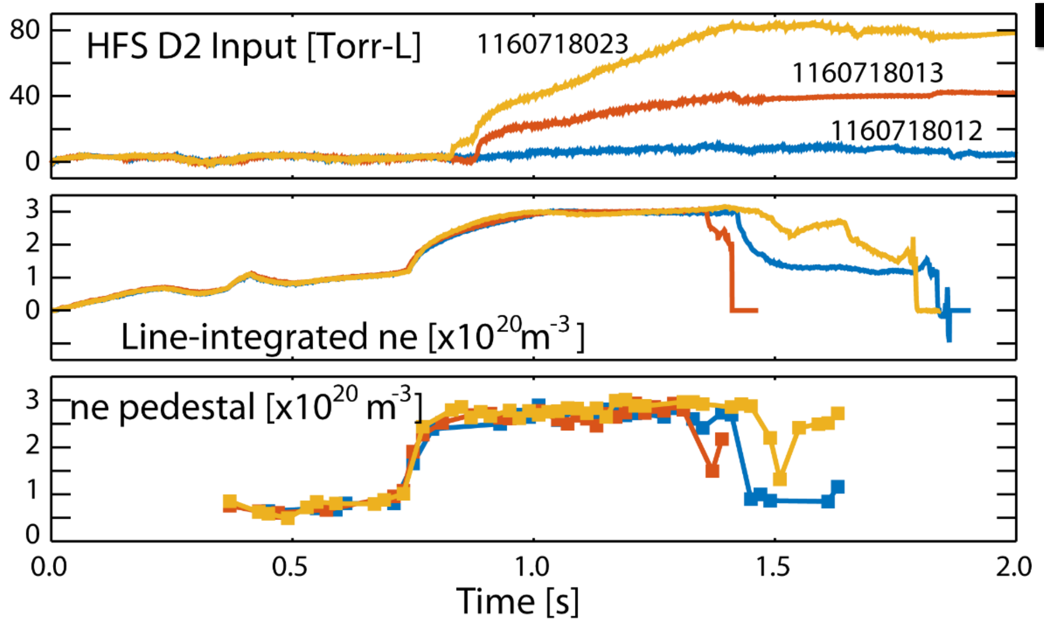


Experiments on DIII-D and C-Mod were performed to scan a variety of level of opacity using changes in Ip and gas fueling

Low opacity **High opacity**

Lower n_e



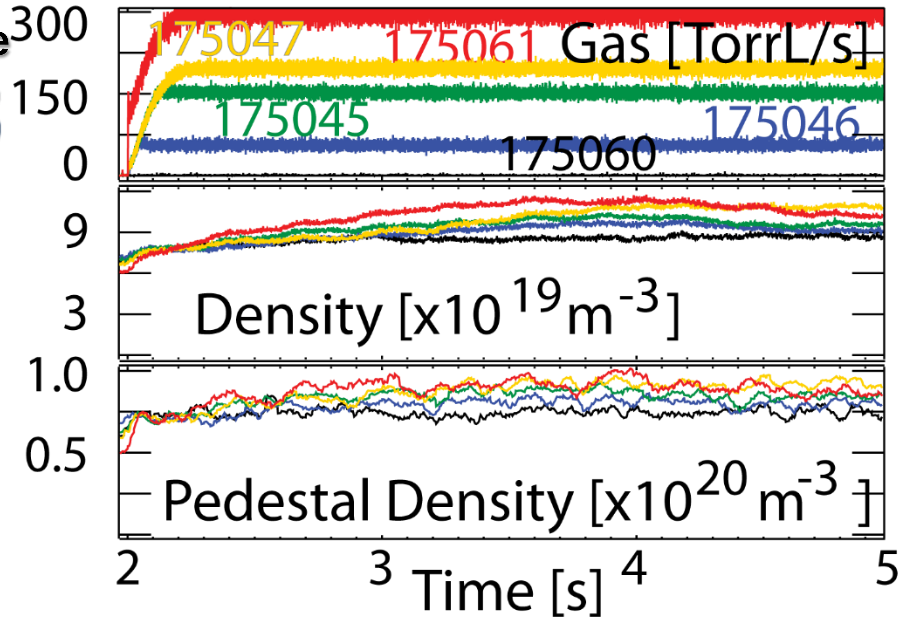


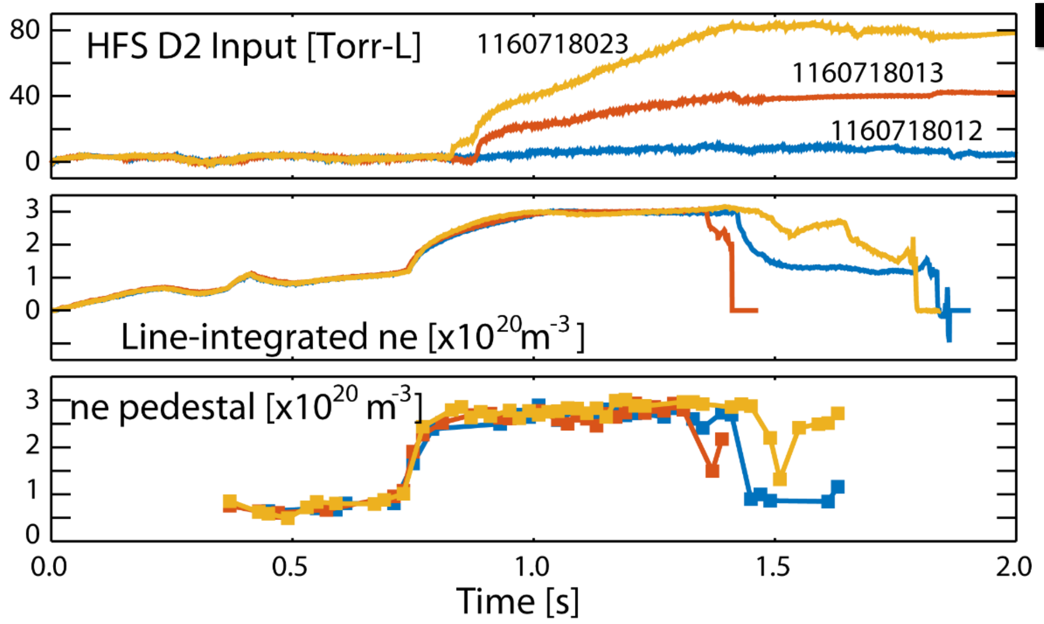
Higher n_e

Experiments on DIII-D and C-Mod were performed to scan a variety of level of opacity using changes in Ip and gas fueling

Low opacity **High opacity**

Lower n_e



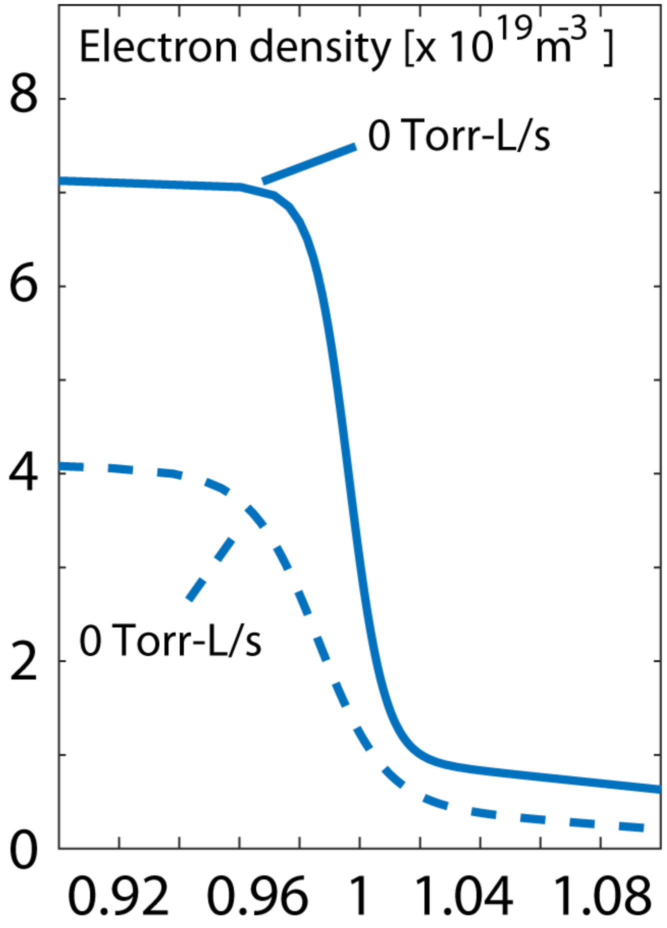


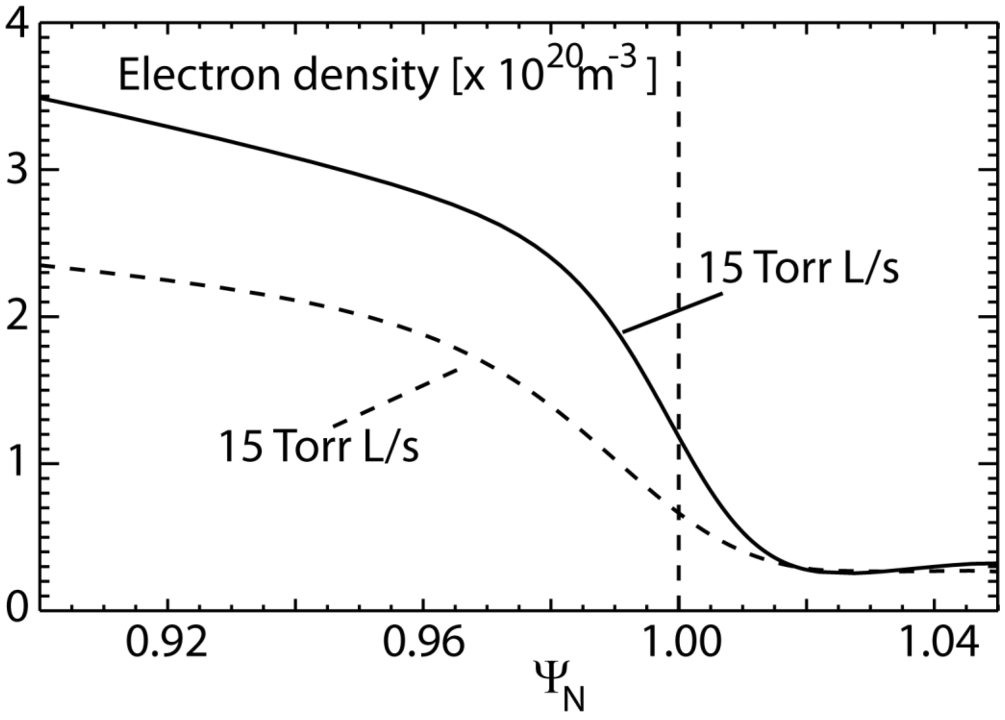
Higher n_e

How does the pedestal structure change with increasing opacity and what is the effect of additional fueling?

Low opacity

Lower n_e





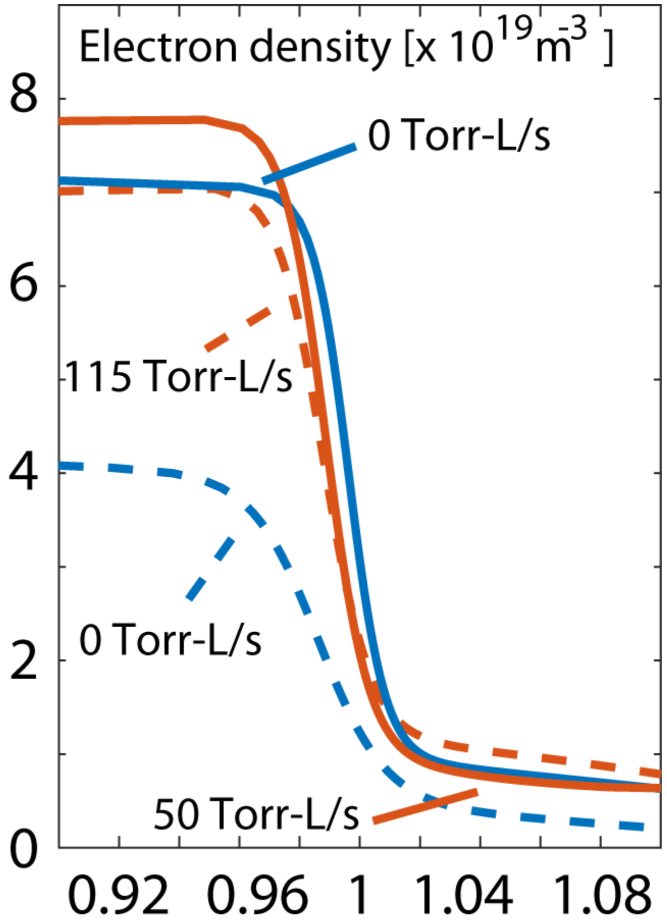
High opacity

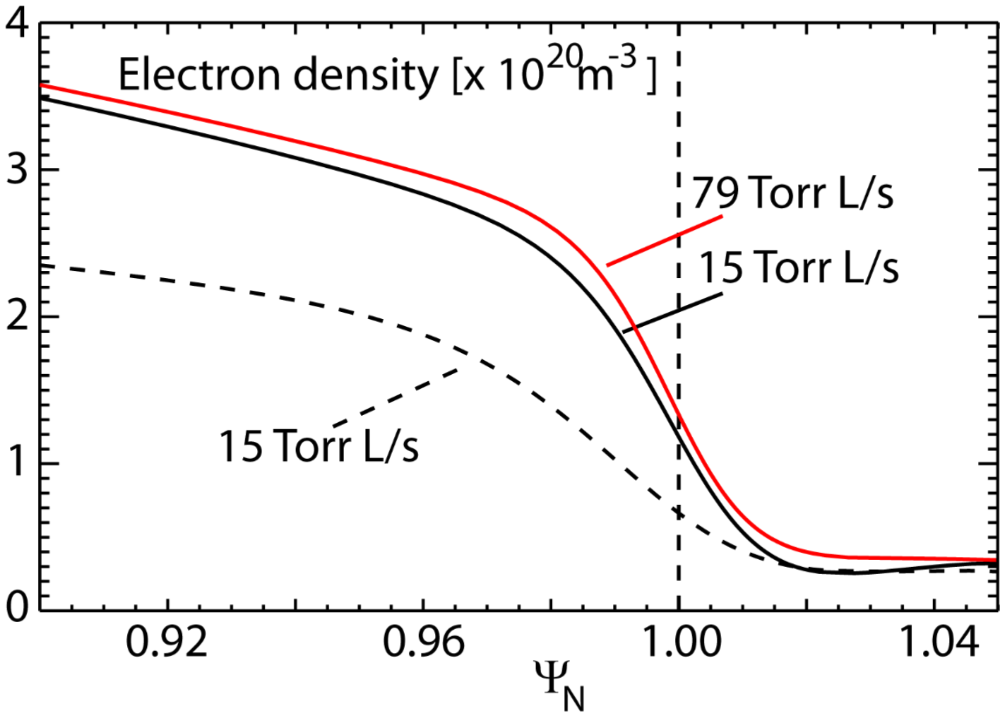
Higher n_e

How does the pedestal structure change with increasing opacity and what is the effect of additional fueling?

Low opacity

Lower n_e





High opacity

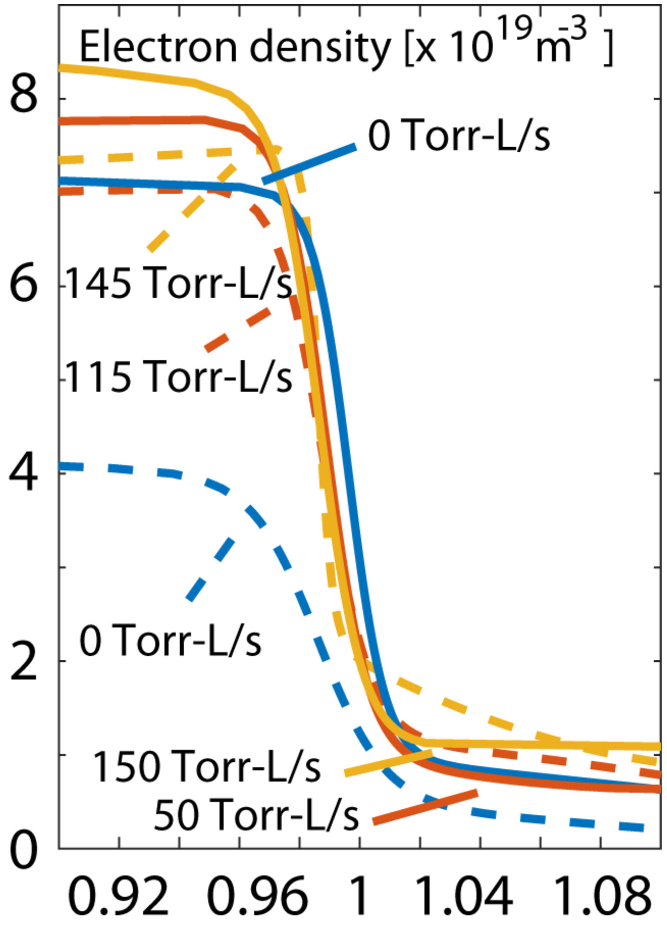
Higher n_e

How does the pedestal structure change with increasing opacity and what is the effect of additional fueling?

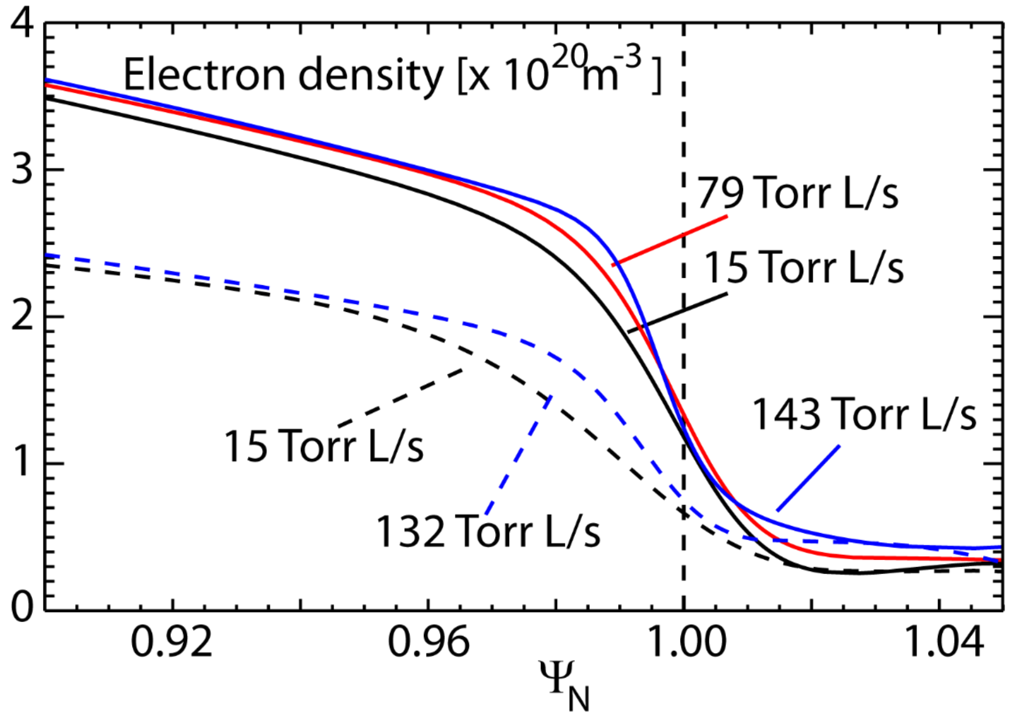
Low opacity → **High opacity**

Lower n_e → **Higher n_e**

DIII-D NATIONAL FUSION FACILITY



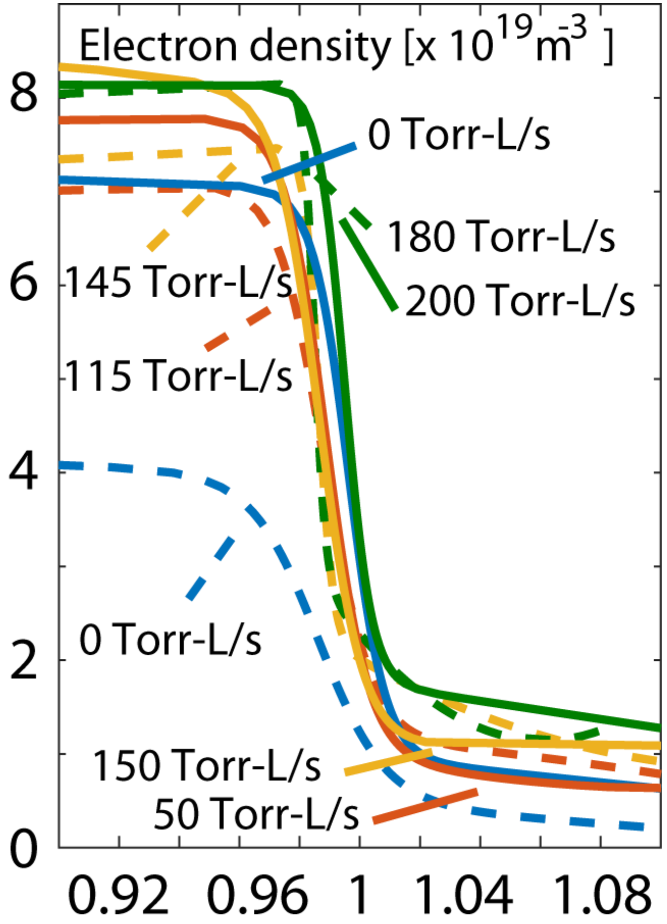
Alcator C-Mod

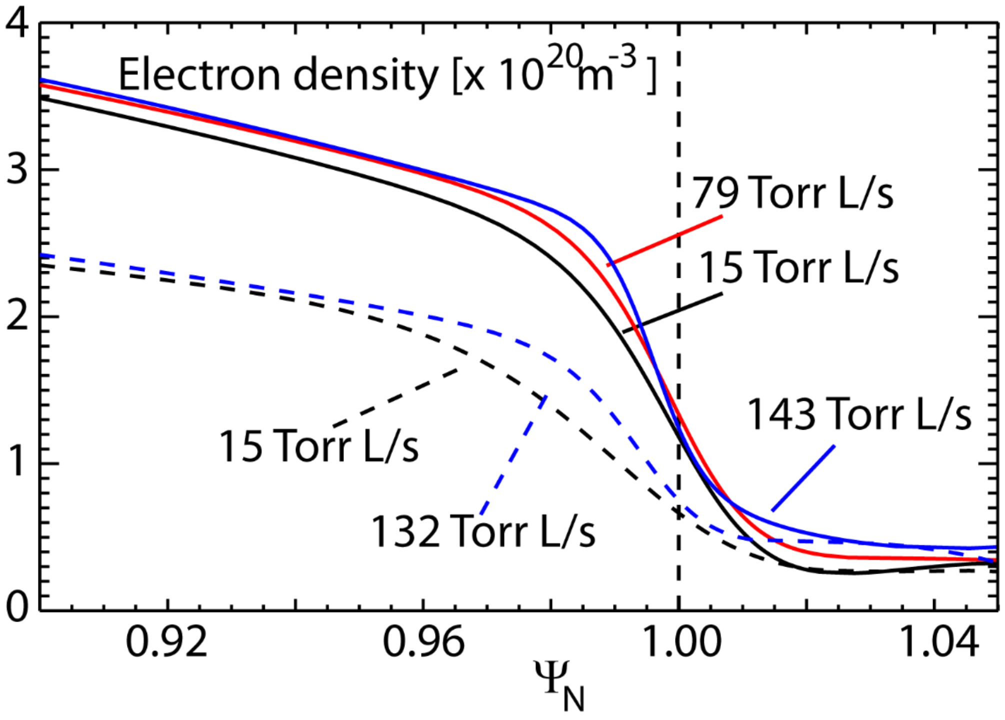


How does the pedestal structure change with increasing opacity and what is the effect of additional fueling?

Low opacity → **High opacity**

Lower n_e → **Higher n_e**



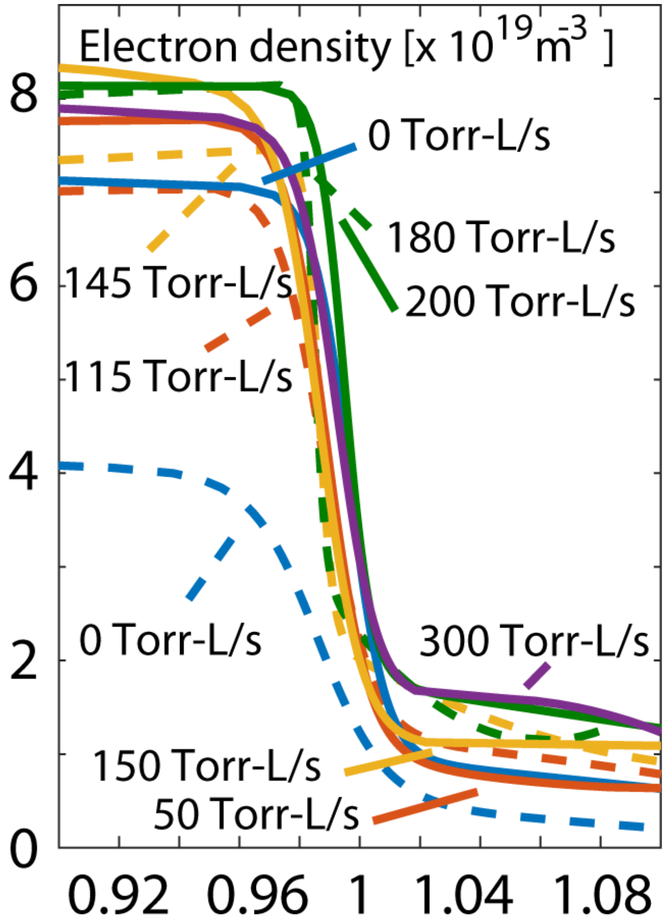


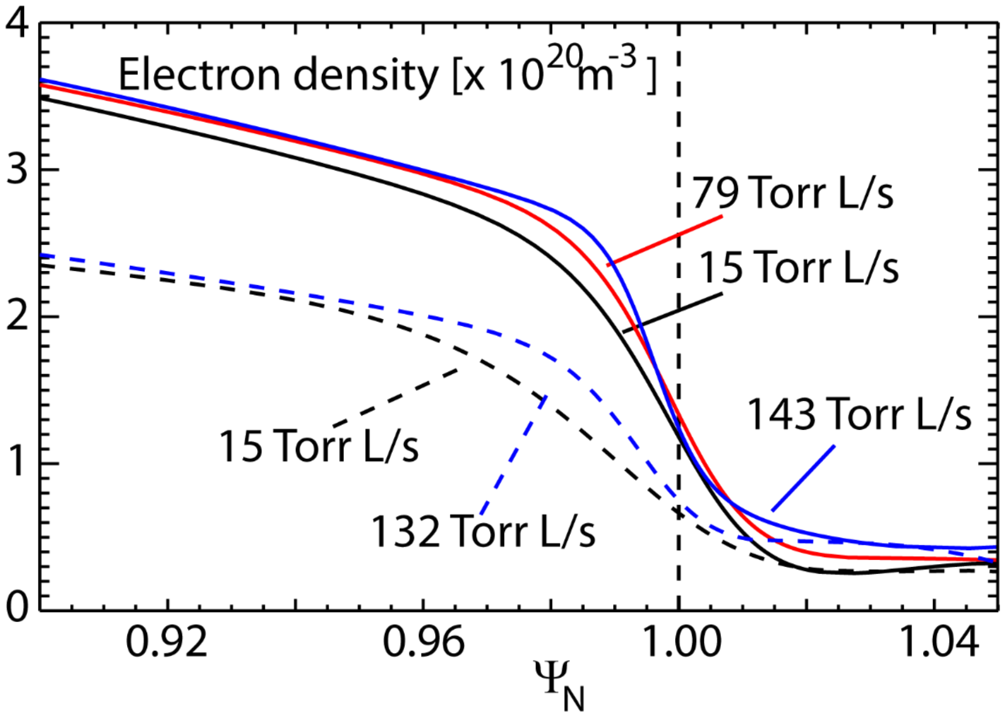
How does the pedestal structure change with increasing opacity and what is the effect of additional fueling?

Low opacity → **High opacity**

Lower n_e → **Higher n_e**

DIII-D NATIONAL FUSION FACILITY



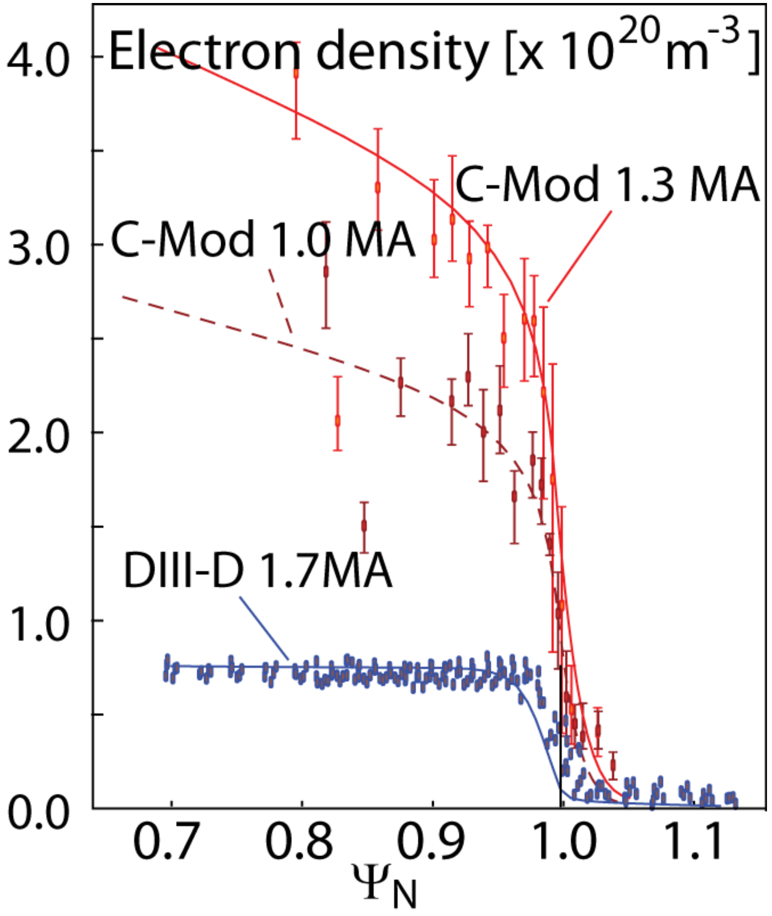


Alcator C-Mod

How does the pedestal structure change with increasing opacity and what is the effect of additional fueling?

Low opacity

Lower n_e



High opacity

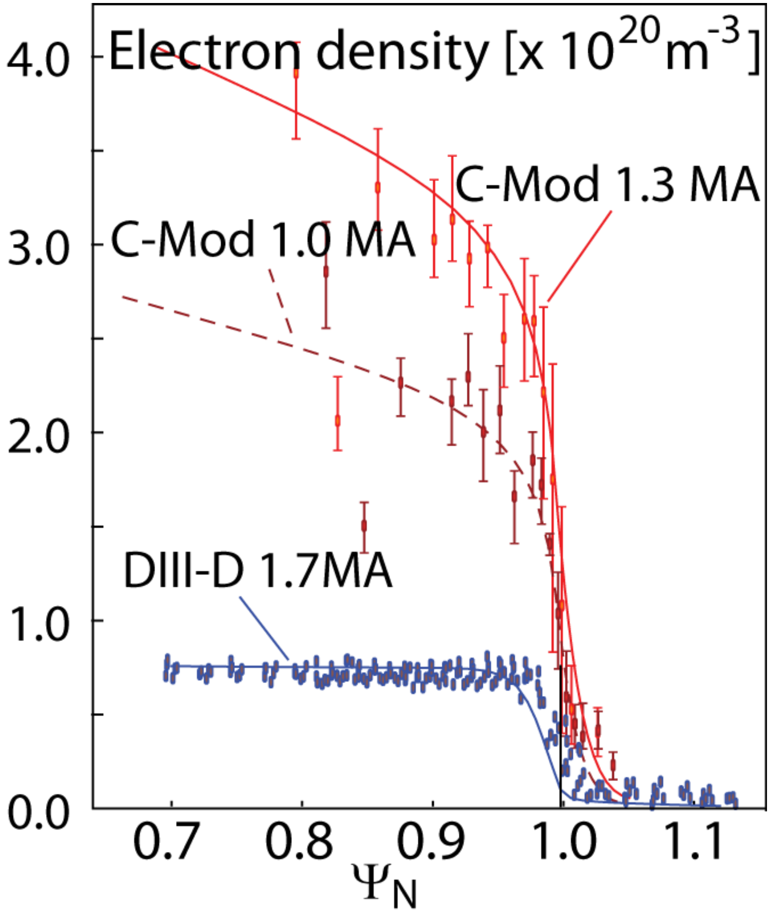
Higher n_e

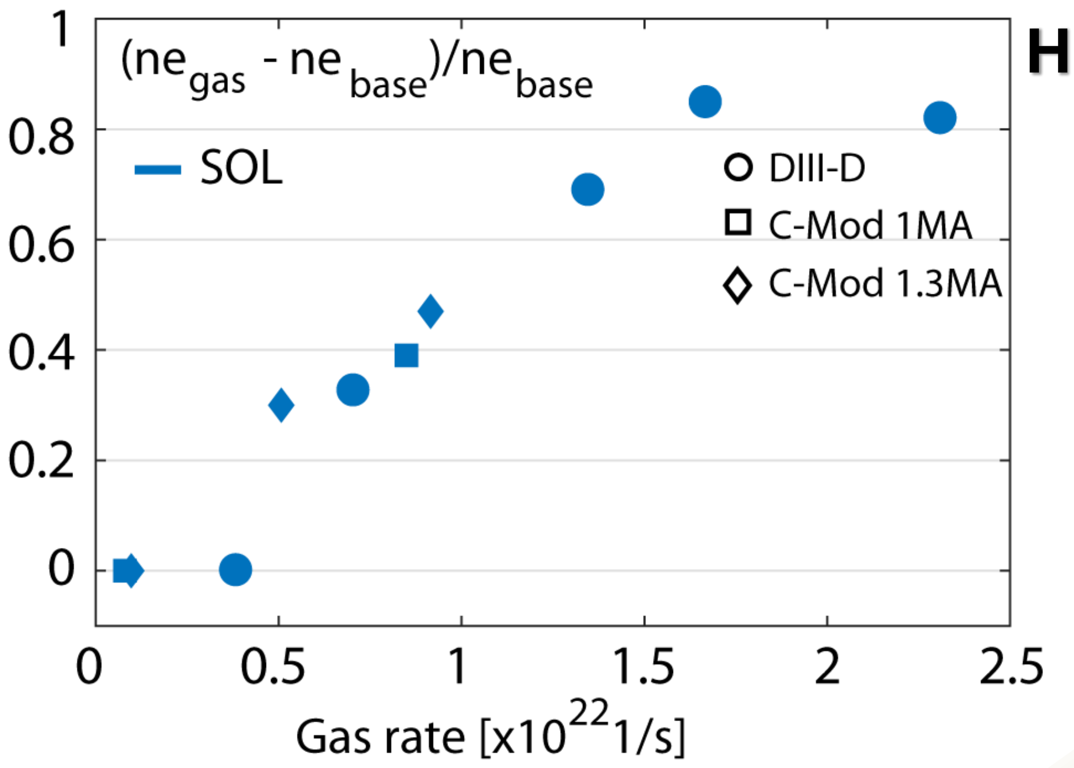
Normalized increases in gas fueling result in an increase in the SOL density independent of opacity levels

Low opacity — **High opacity**

Lower n_e — **Higher n_e**

DIII-D NATIONAL FUSION FACILITY



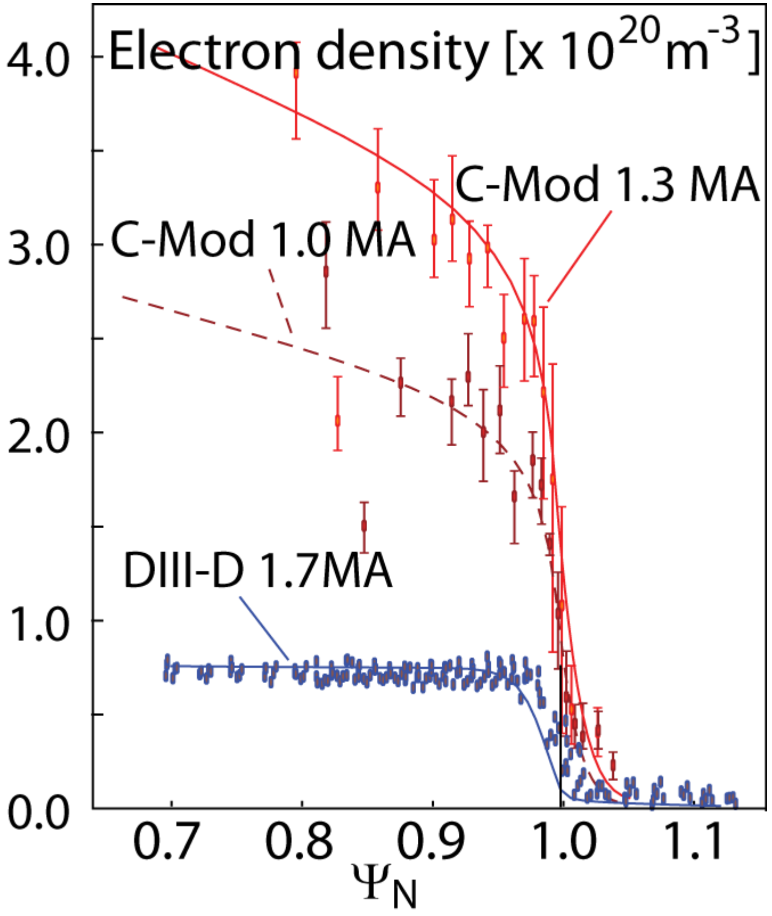


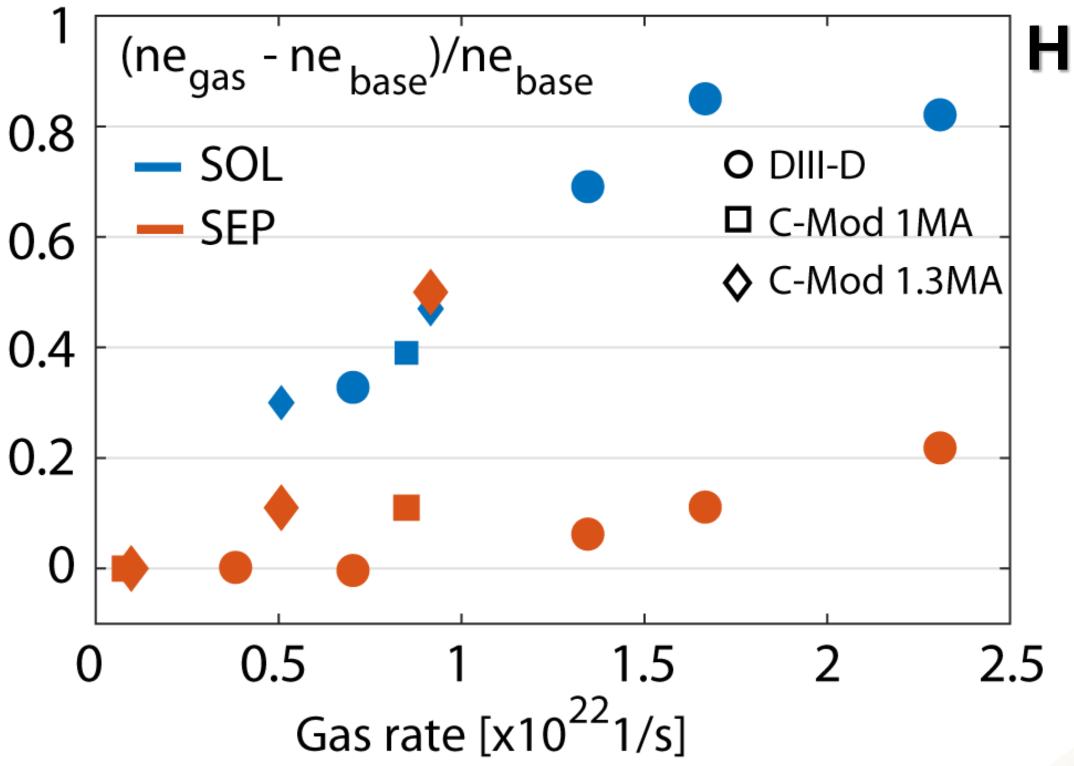
Alcator C-Mod

Normalized increases in gas fueling result in a much more modest increase of the separatrix density

Low opacity

Lower n_e





High opacity

Higher n_e

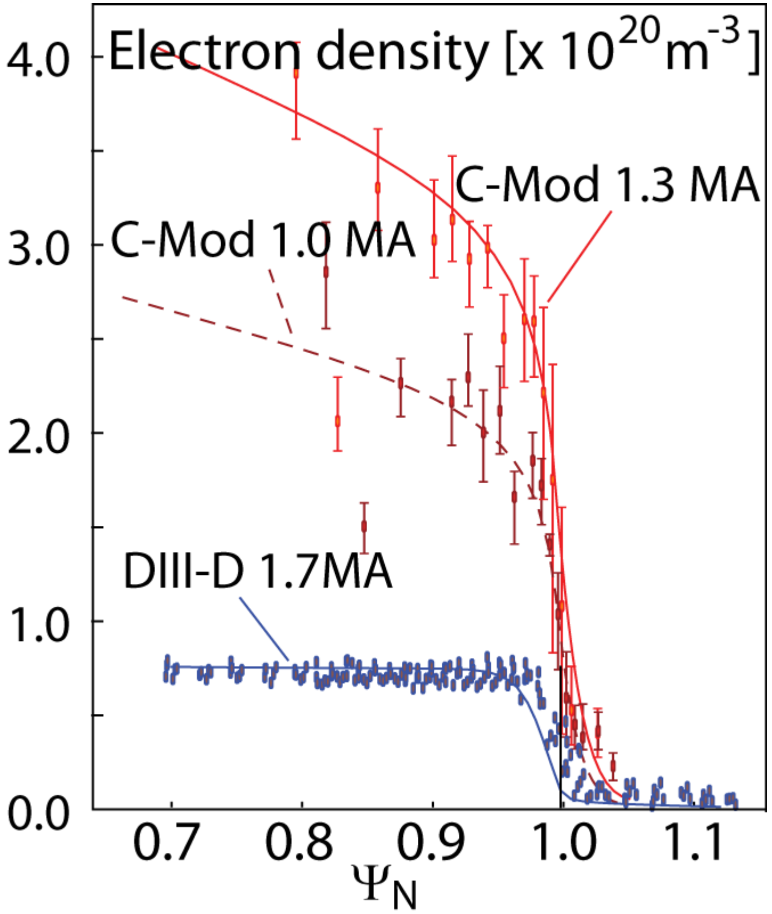
Normalized increases in gas fueling are similar for the pedestal as well as the separatrix

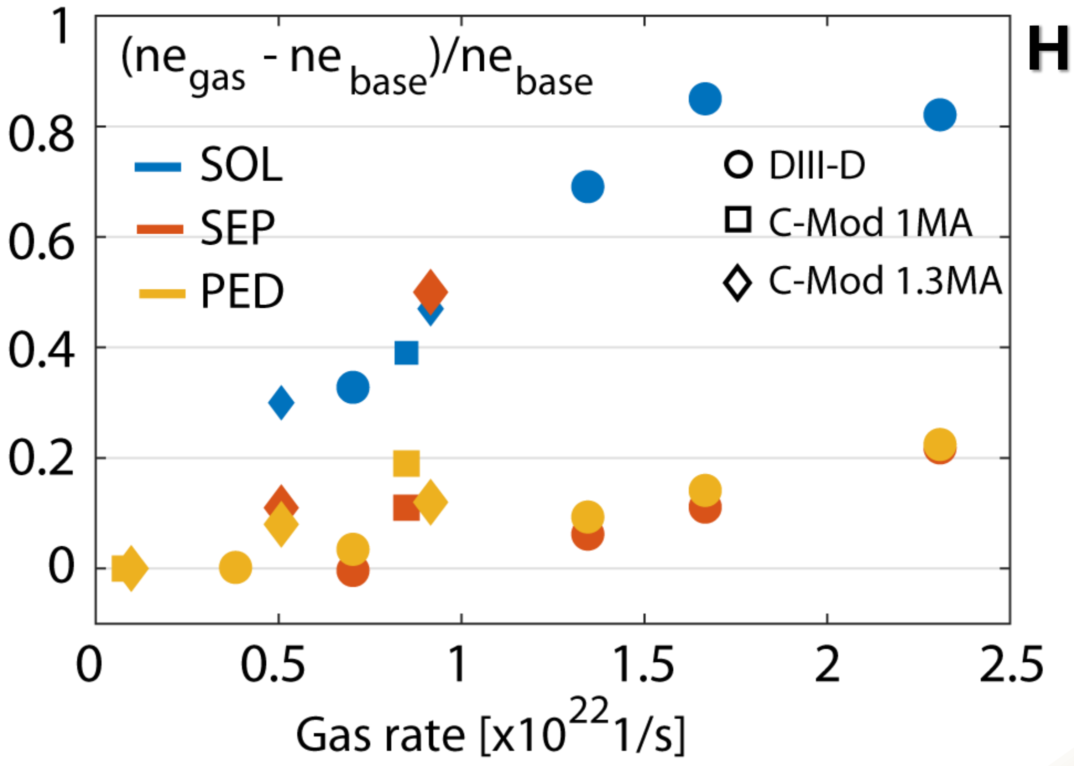
Low opacity

Lower n_e

High opacity

Higher n_e

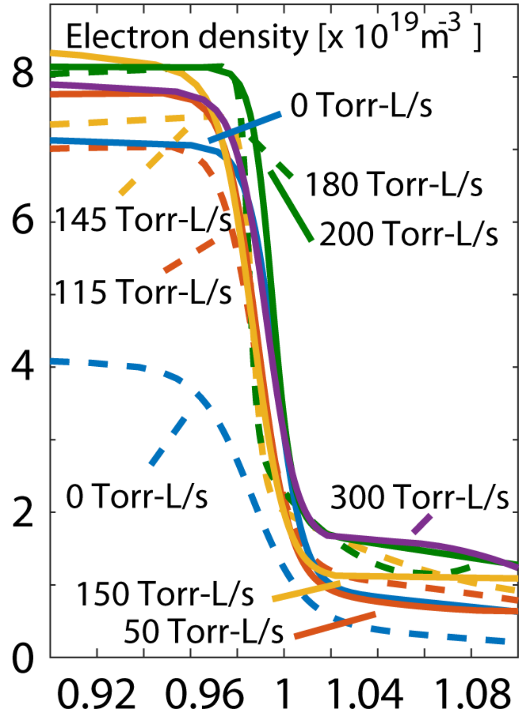




How does the pedestal structure change with increasing opacity and what is the effect of additional fueling?

Low opacity

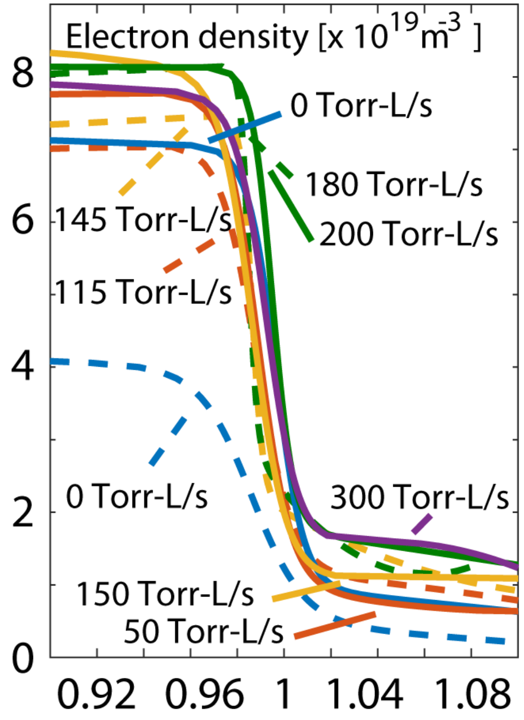
Lower n_e

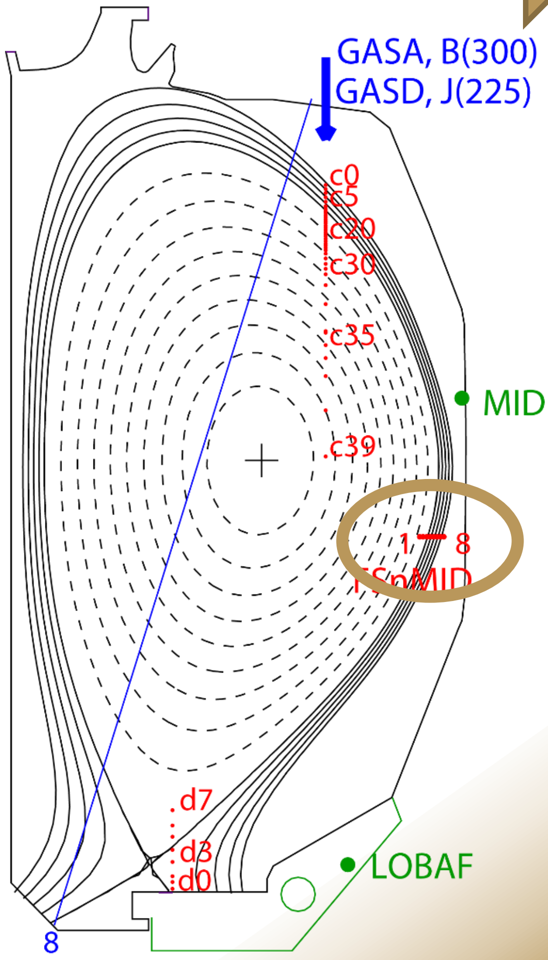


How does the pedestal structure change with increasing opacity and what is the effect of additional fueling?

Low opacity

Lower n_e

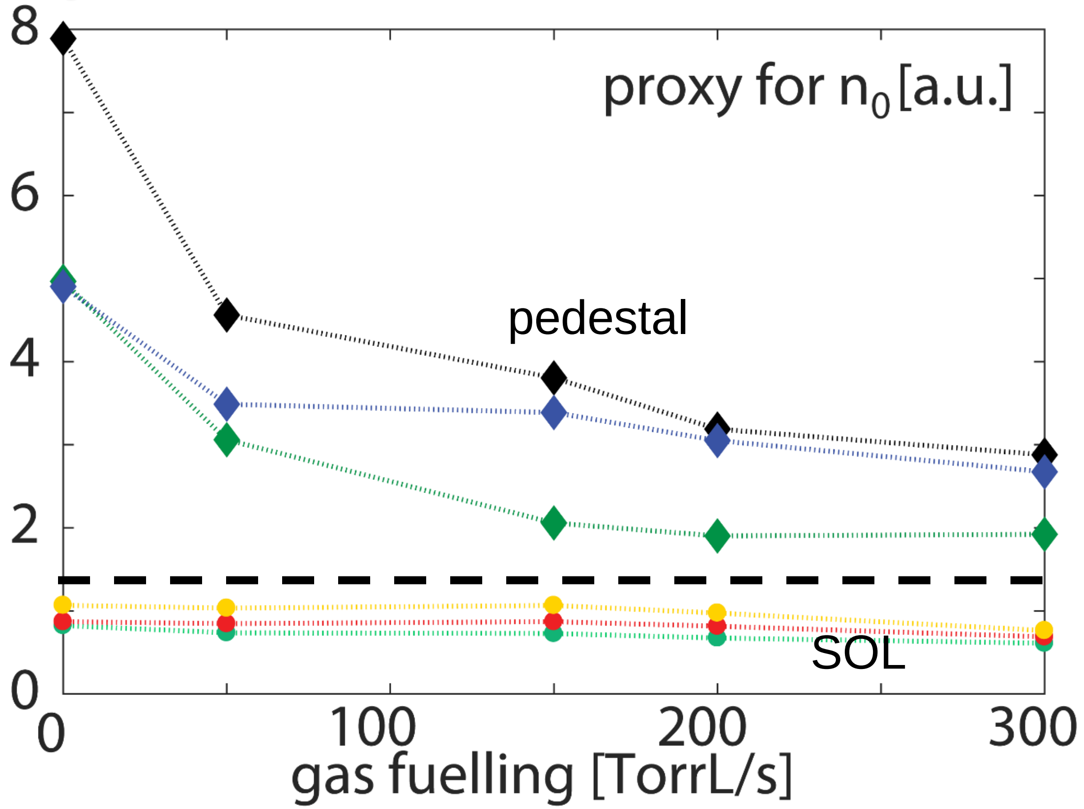


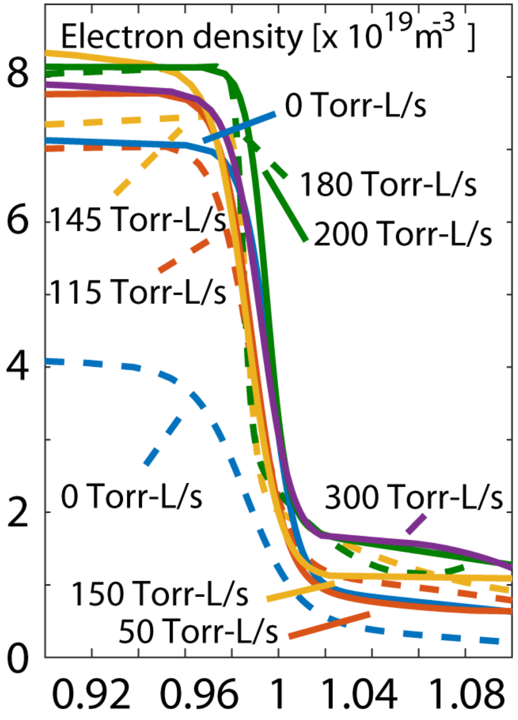


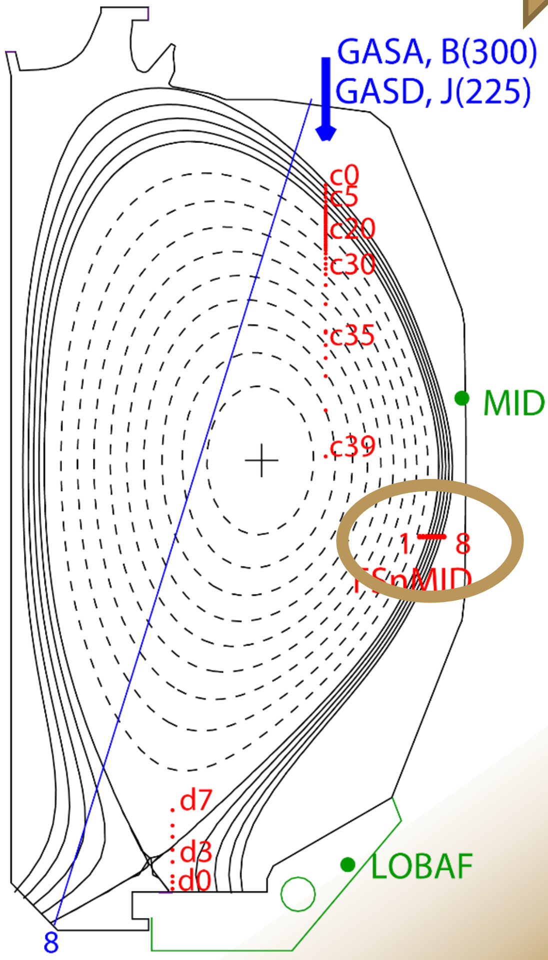
How does the pedestal structure change with increasing opacity and what is the effect of additional fueling?

Low opacity

Lower n_e



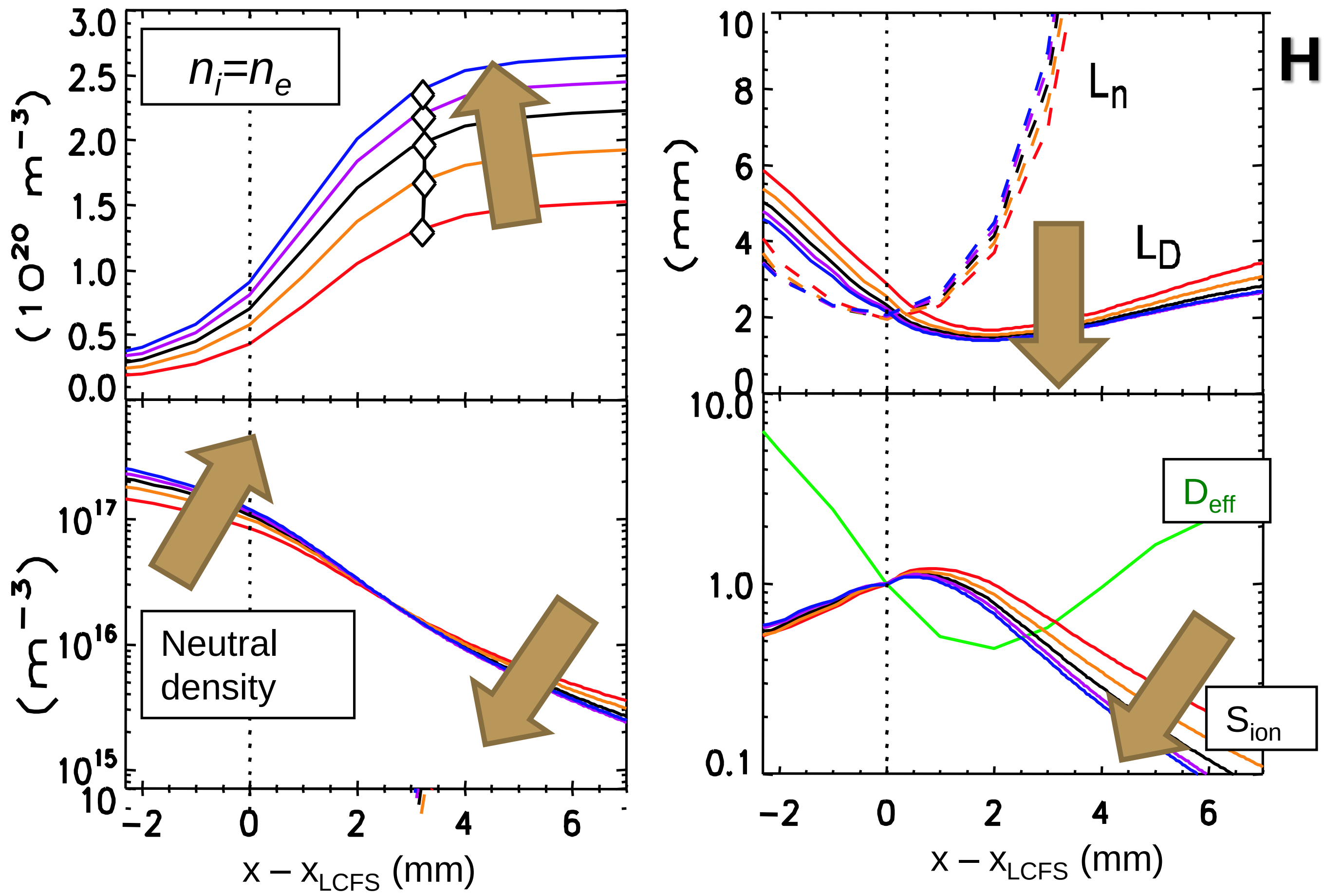




These experiments confirm prior results and modeling from C-Mod: Neutral penetration decreases with increasing $n_{e,PED}$

J.W. Hughes, et al. *PoP* **13** (2006) 056103

- $n_{e,PED}$ scales roughly as $N^{0.5}$
- L_n varies little, indicating stiff n_i profiles



High opacity

Higher n_e

Alcator C-Mod

Changing the modeling for C-Mod like conditions to DIII-D like conditions, we observe similar trends as shown experimentally

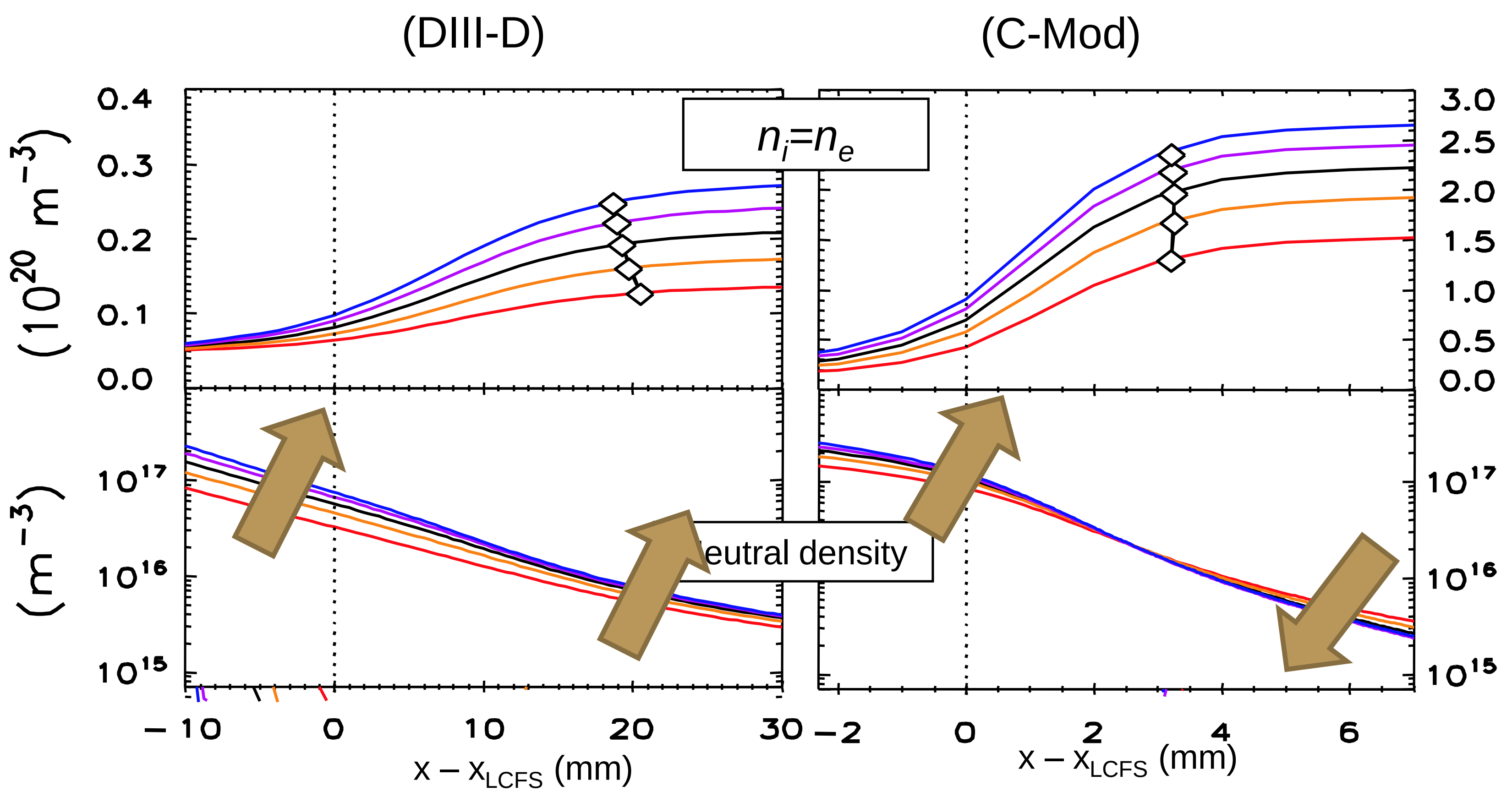
J.W. Hughes, et al. *PoP* **13** (2006) 056103

Low opacity

Lower n_e

High opacity

Higher n_e



These experiments confirm prior results and modeling from C-Mod: Neutral penetration decreases with increasing neped

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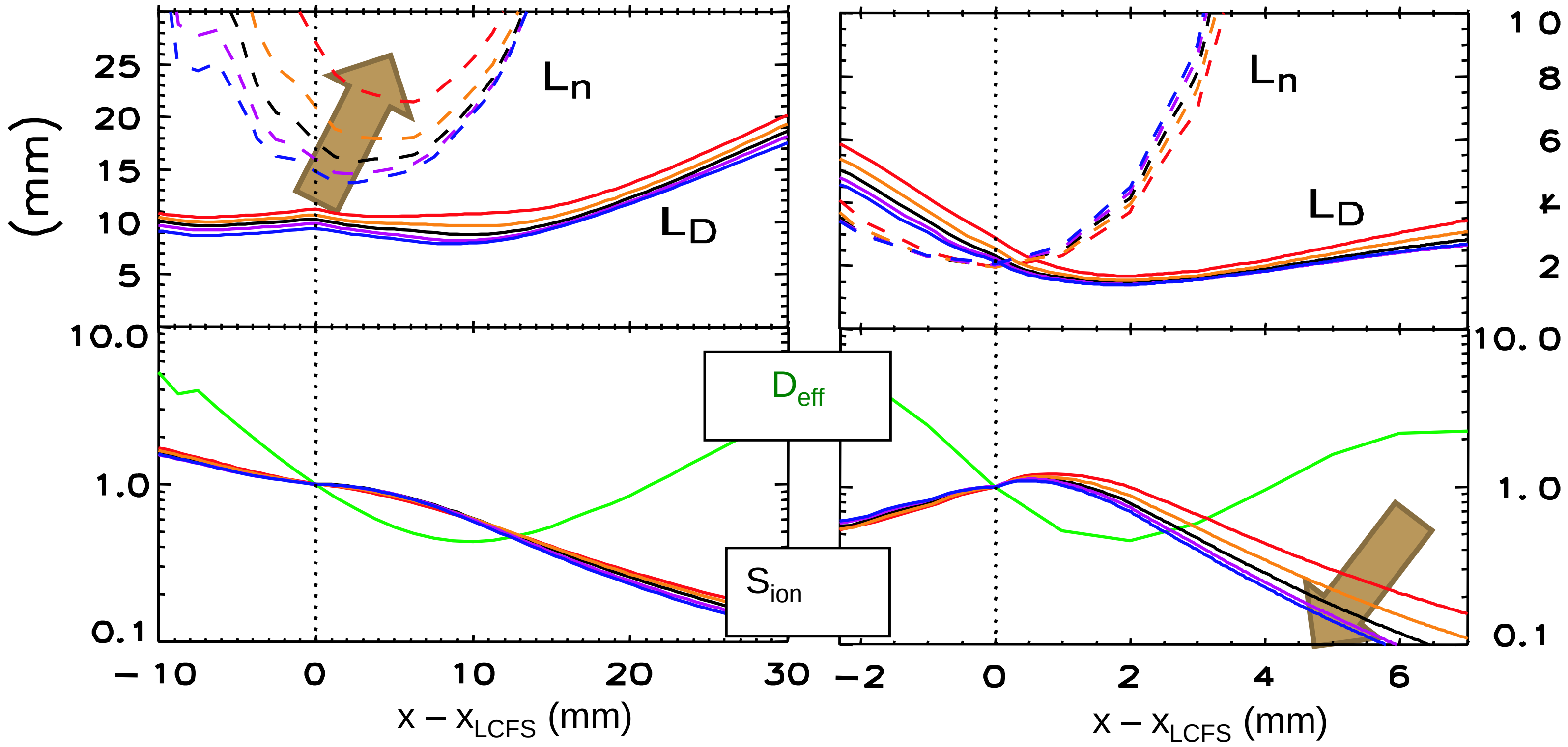
Low opacity

Lower n_e

High opacity

Higher n_e

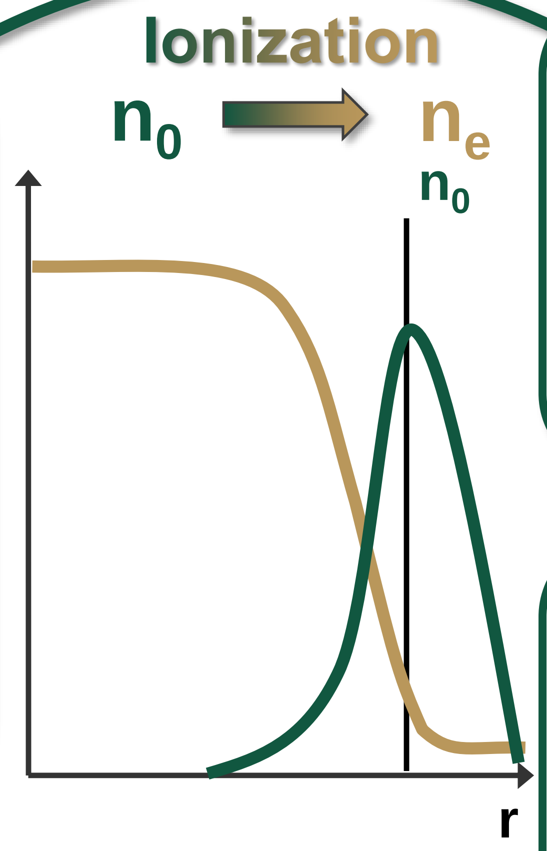


So what will the pedestal profile be like? A need to measure and validate neutral source, to study transport

Transport:

$$\mathrm{T} = -D\nabla n + vn$$

?



Model 1:

$$\nabla n_e \sim \nabla n_0$$

$$\rightarrow n_{e_{ped}} \sim {}^{1}/_{\Delta n_e}$$

Model 2:

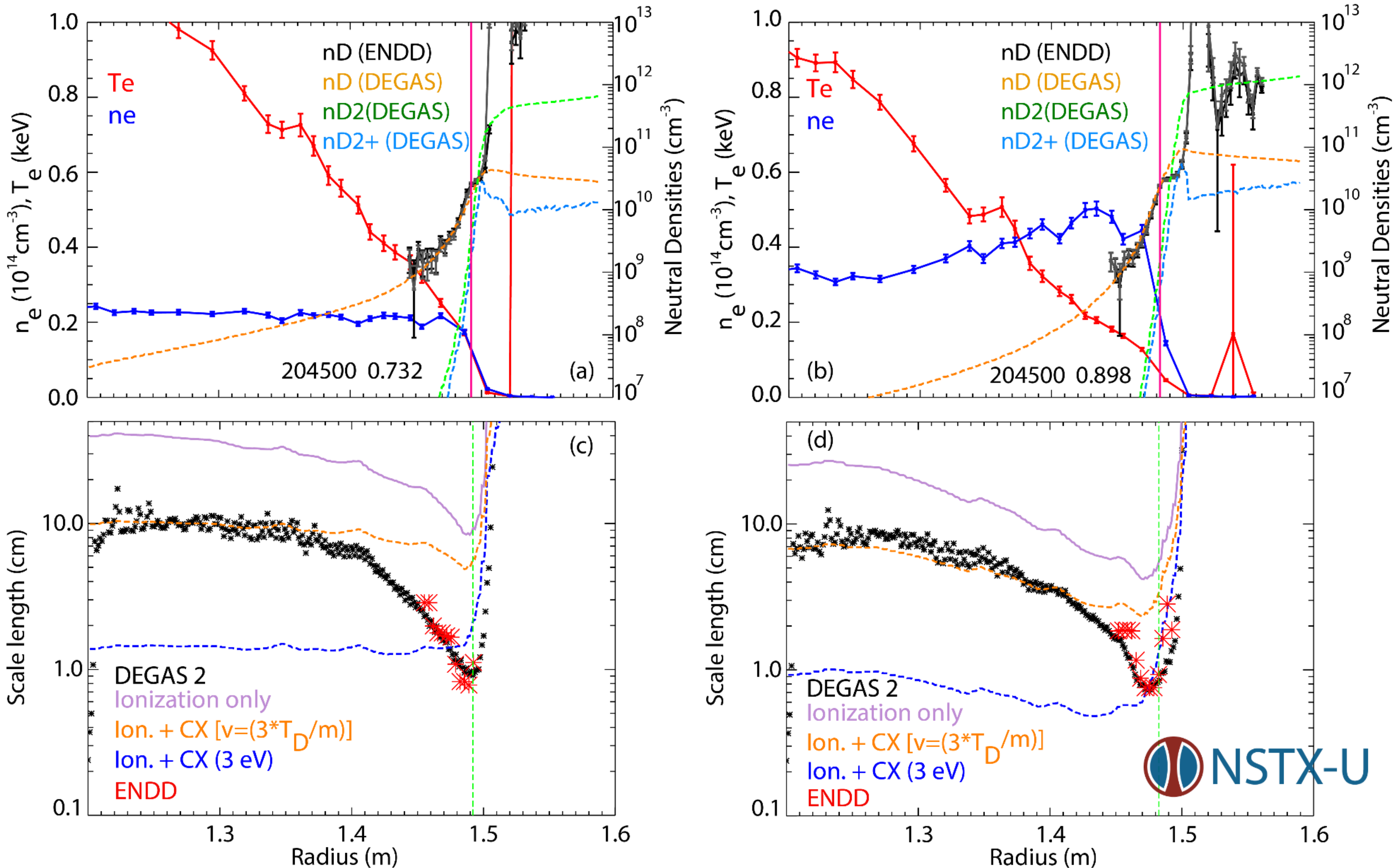
$n_0 \uparrow \Longrightarrow$ shift out in SOL

shift $n_{e_{ped}}$ out in SOL

$$\Rightarrow \sim\Delta(n_e - T_e) \neq 0$$

ENDD diagnostic measurements on NSTX-U have been compared to DEGAS modeling of the neutral sources

- ENDD diagnostic measures D_α
- Direct comparisons of DEGAS to measurements show good agreement
- DEGAS results are very sensitive to electron density and temperature in the far SOL



NSTX-U

Conclusions

- Density pedestal currently influenced by neutral penetration
- However density pedestal structure cannot be solely determined by fueling
- Opaque SOL conditions indicate that 'peaked' pedestal profiles are possible

Good news for ITER/DEMO

- However: we need to identify the role of various transport contribution to the particle flux, which means measure neutrals and validate edge codes