Correlating Pedestal Density Structure with Divertor Target Temperature in DIII-D

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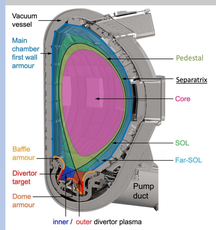
MOTIVATION & FRAMEWORK

Background



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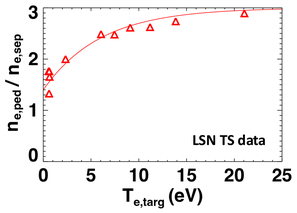
Project Goal: Investigate if there exists an empirical correlation between pedestal structure and particle Temperature at the divertor

Pedestal: narrow transport barrier that sets boundary conditions which influence core performance
- $n_{e,ped}$ → upstream density profile

Separatrix: boundary surface separating the core from the edge plasma & guides field lines to the divertor
- $n_{e,sep}$ → downstream density profile

Divertor: location on the reactor wall where all the heat and particle flux is 'dumped'
- Goal of detachment → plasma cools sufficiently before reaching the wall
- $T_{e,targ}$ → electron Temperature at the target (divertor)

Edge-core coupling: pedestal structure and divertor electron Temperature



Correlating pedestal density profiles with divertor electron Temperature may inform edge transport modeling & conditions for reaching detachment

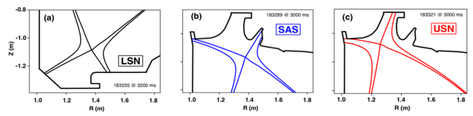
$$\frac{n_{e,ped}}{n_{e,sep}} = 3.0 - 1.6e^{-T_{e,targ}/6}$$

Key Questions:
- Does this hold across other experiments?
- Under what conditions does it change or break down?

Experimental setup and divertor configurations

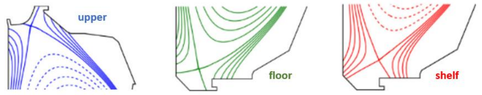
Experiment 1 – Canik Database

Towards a self-consistent EPED-SOLPS Coupled Integrated Model



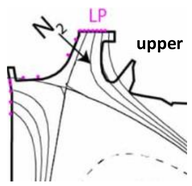
Experiment 2 – Moser Database

Divertor closure impact on detachment and pedestal shape

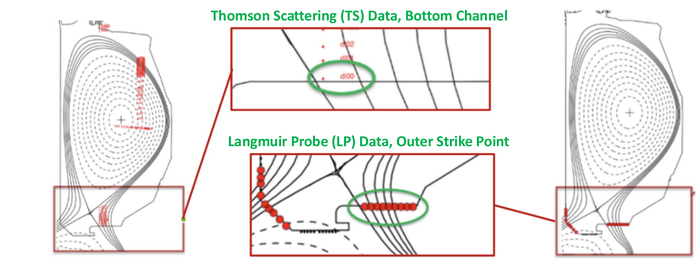


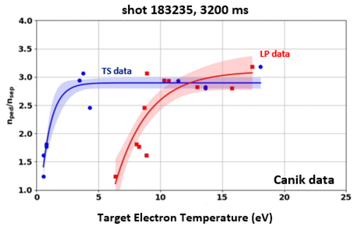
Experiment 3 – Wang Database

Divertor detachment and pedestal structure in a closed Upper divertor



Diagnostics for determining target electron Temperature



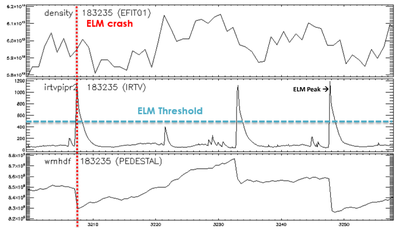


- **LP data overestimates $T_{e,targ}$ at low temperatures (<5-10 eV)**
- **Curve fit → Saturating Offset Exponential**
  - $f(T_e) = a\left(1 - e^{-bT_e}\right) + c$

METHODOLOGY

ELM filtering

Peaks included by threshold identifies ELM crashes



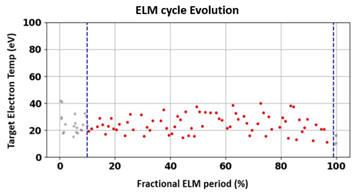
Core Plasma Density
shows pedestal buildup, impacted by ELM crashes

Heat Flux
sharp, periodic spikes correspond to ELM events

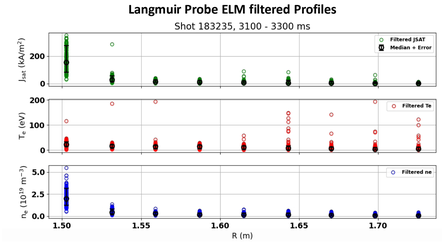
Stored Energy
recovers between ELMs, drops during each crash

Evolution of median temp measurements over ELM cycles informs % of data to accept

- Optimal fractional period only accepts steady-state data
  - Consistent range of **10-99%** used for this analysis
- Exclude evolving temp trends → correspond to ELM come-down/build-up



Data averaging methods



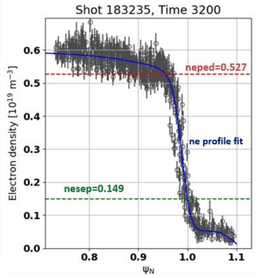
- LP data
  - Median *time* average
  - Weighted *spatial* average:

$$T_{e,targ} = \frac{\int_{targ} n_e T_e dV}{\int_{targ} n_e dV}$$

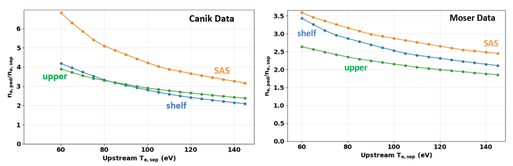
- TS data
  - Weighted *time* average
  - No spatial averaging necessary

Shifting the separatrix position in density profiles

Adjusted the flux coordinate mapping φ_N to align with upstream TS measurements



Sensitivity scans show density ratio dependence on $T_{e,sep}$



- Select $n_{e,sep}$ based on the electron temperature at the separatrix ($T_{e,sep}$)
- Sweeping from 60-140 eV in $T_{e,sep}$ shifted the density ratio by a factor of ~2-3, depending on the divertor configuration

Future data processing refinements

- Power balance refinement: improved methodology for picking correct $T_{e,sep}$ values
- Broaden the datasets used (shots/experiments) and separate regimes (attached vs near-detached)
- Account for plasma shape and impurity seeding
- Limit data to only include probes within 1-2 heat flux from the divertor

Acknowledgments & References

References: R.S. Wilcox et al., Nuclear Fusion (submitted)

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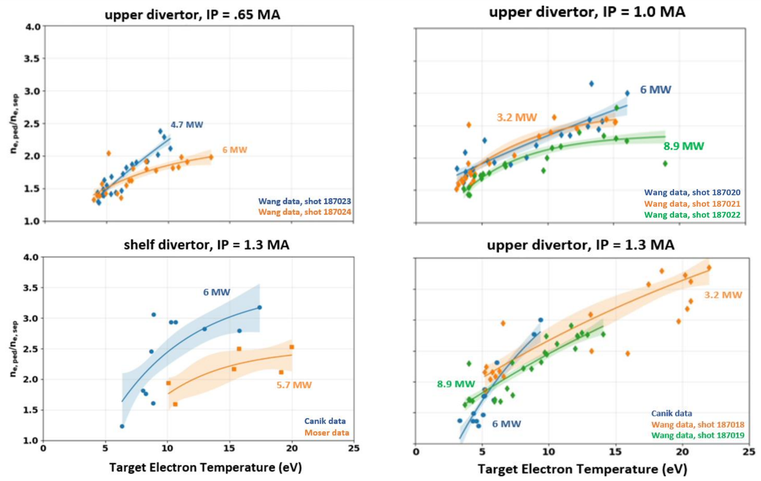
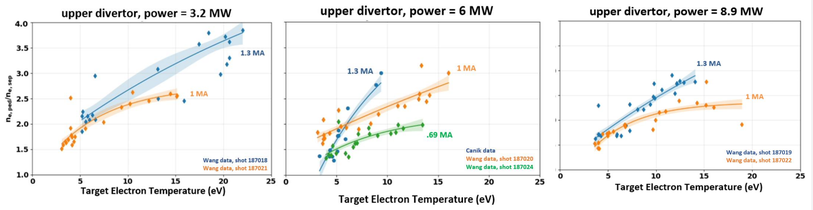
CORRELATION ANALYSIS & RESULTS

Power variation using consistent current (I_p) and divertor configuration



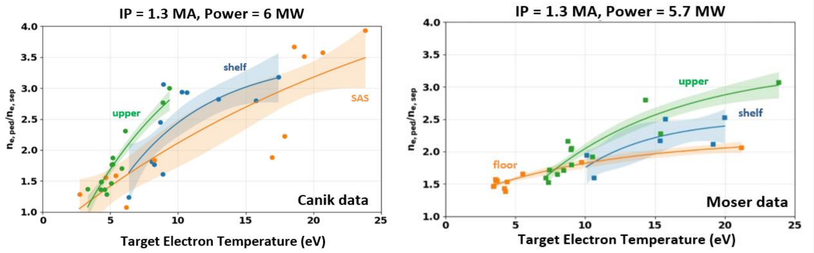
- **Shots @ various input powers (~3-9 MW) fall along similar curves**
- **Some datasets show consistent curves between variables, others diverge significantly**

I_p variation using consistent power and divertor configuration



- **$n_{e,ped}/n_{e,sep}$ increases with current during attachment**

Consistent I_p and power across different divertors



- **Divertor geometry and plasma shape affect correlation curve**
- **Upper divertor shows steepest ratio rise @ low $T_{e,targ}$**
- **Level differs by geometry**
  - **Closed divertors → ratio >15 eV reaches ~2.5-3.5 range**
  - **Open divertors → ratio >15 eV reaches ~1.8-2.2 with a broader scatter**

Conclusion

- Divertor target diagnostics disagree @ low temperatures
- ELM Filtering plays a minor role in data processing
- Determination of the $T_{e,sep}$ plays a significant role in the pedestal density ratio

A **single, unified function does not appear to be representative of all data,** or even a subset of data where individual variables are held fixed, that could be used to extrapolate a causal relationship in a predictive simulation framework.