L-H transition at low density in ASDEX Upgrade

P. Sauter, F. Ryter, T. Pütterich, E. Viezzer, E. Wolfrum,
D. Coster, R. Fischer and ASDEX Upgrade Team

Max-Planck-Institut für Plasmaphysik
EURATOM Association, Garching, Germany

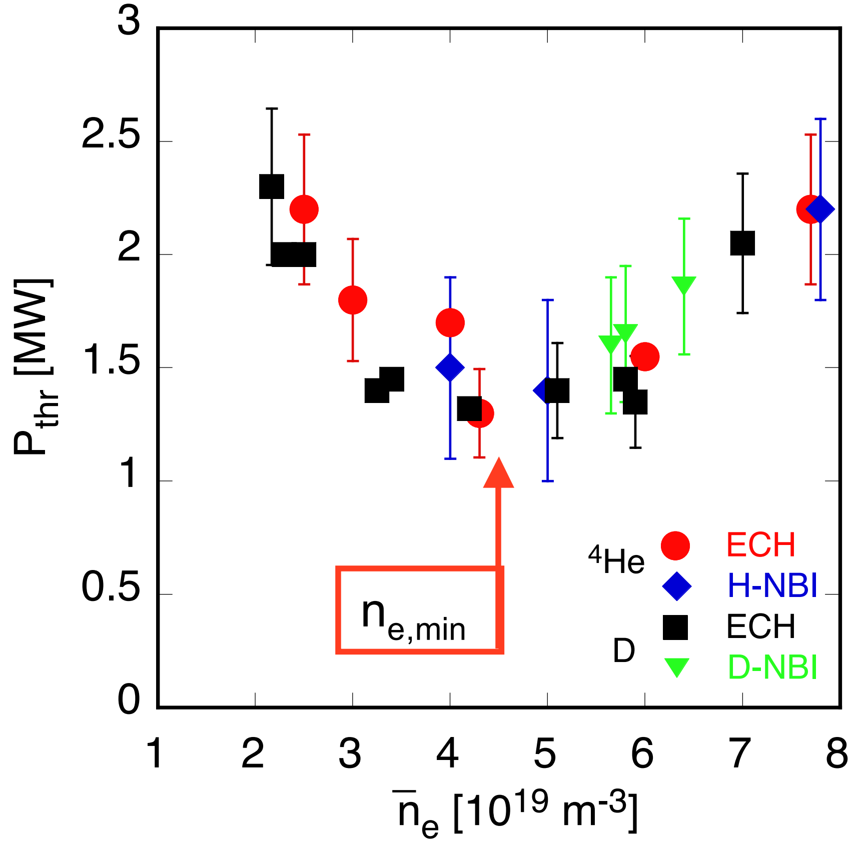
- Motivation
- Experimental approach
- Results

Motivation

- **Aim**: investigate respective role of electron and ion channels in L-H transition mechanism

- Requires decoupling:
  - low density
  - dominant electron heating (or ion heating)

- Corresponds to low density branch of L-H threshold



[F. Ryter NF 2009]

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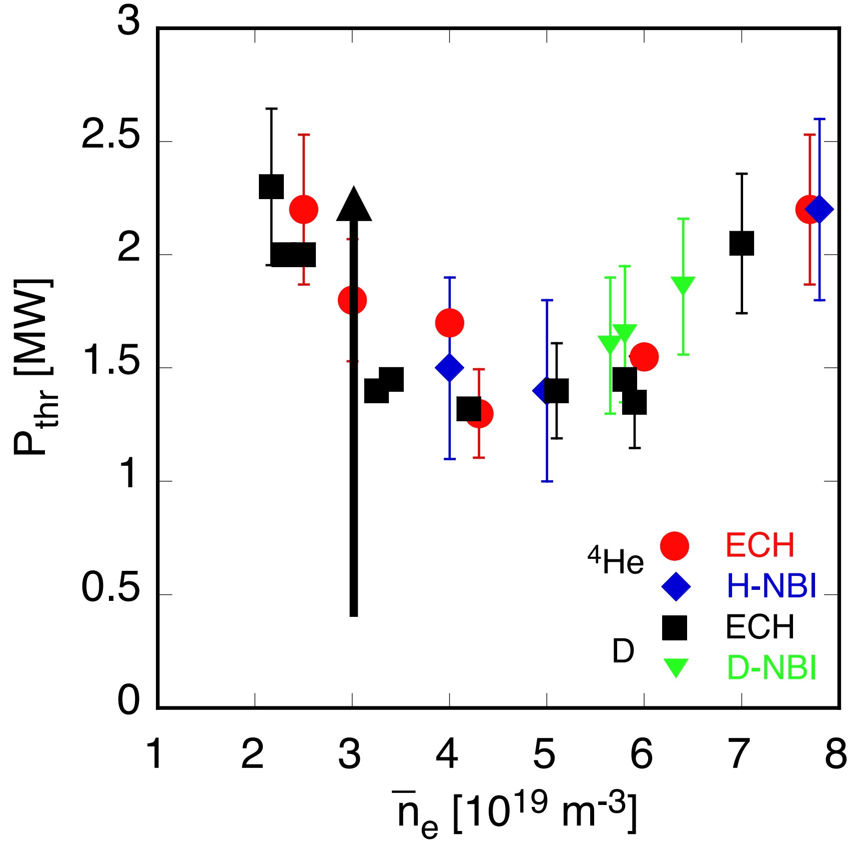

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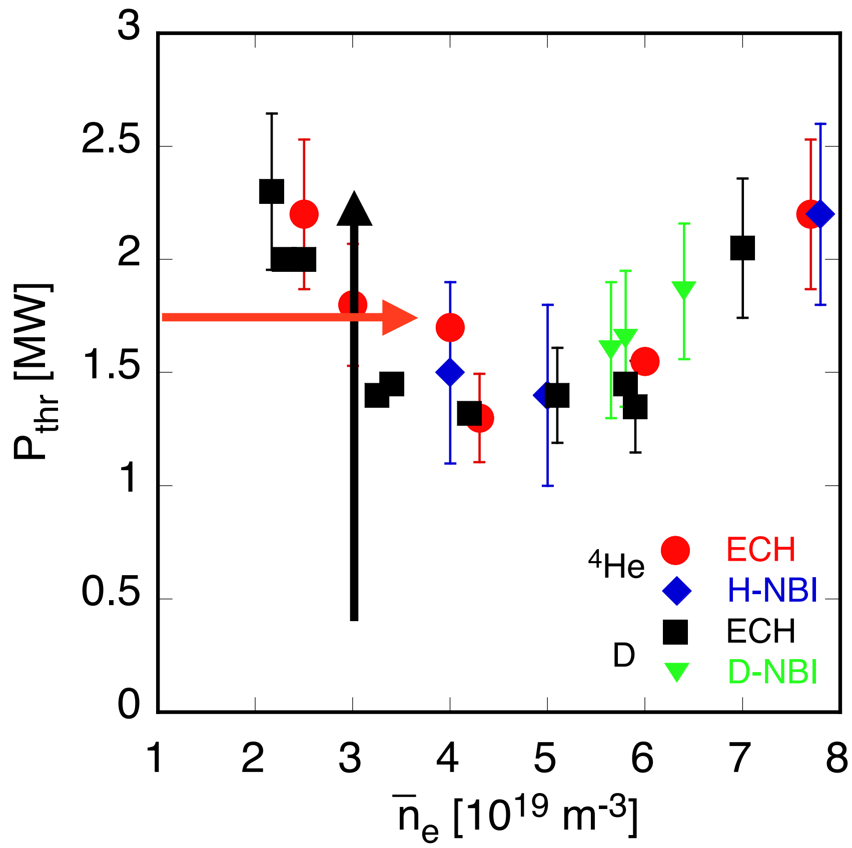


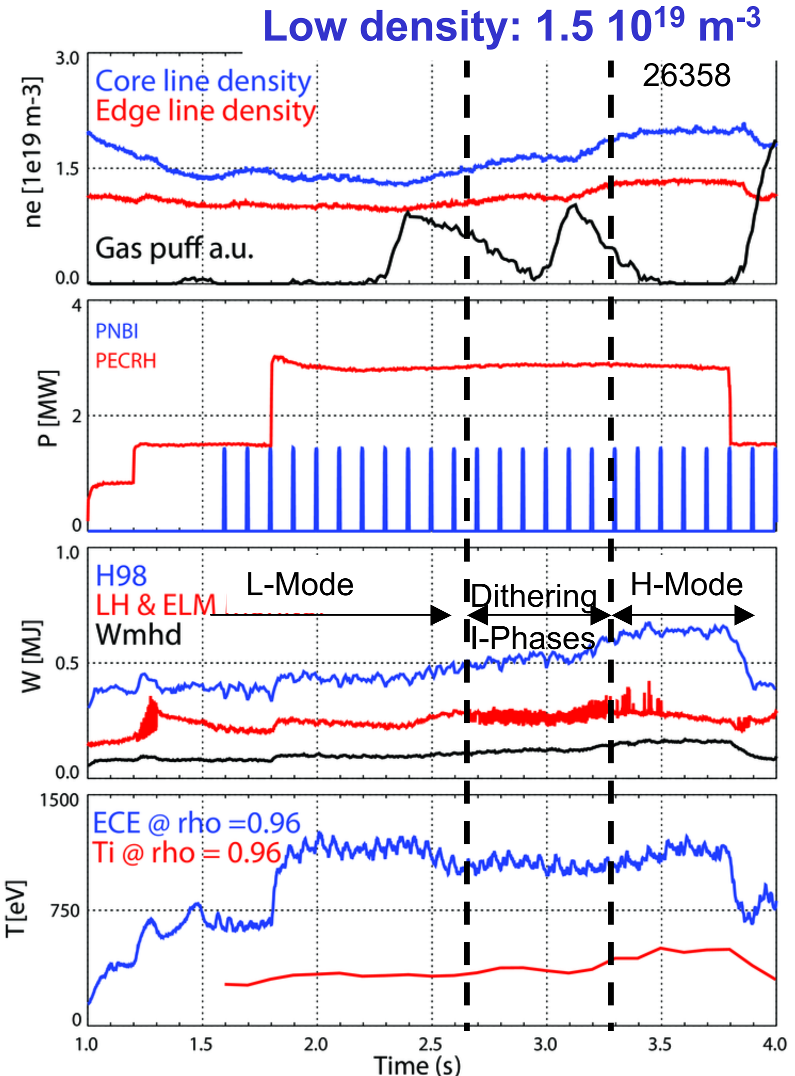
Experimental approach

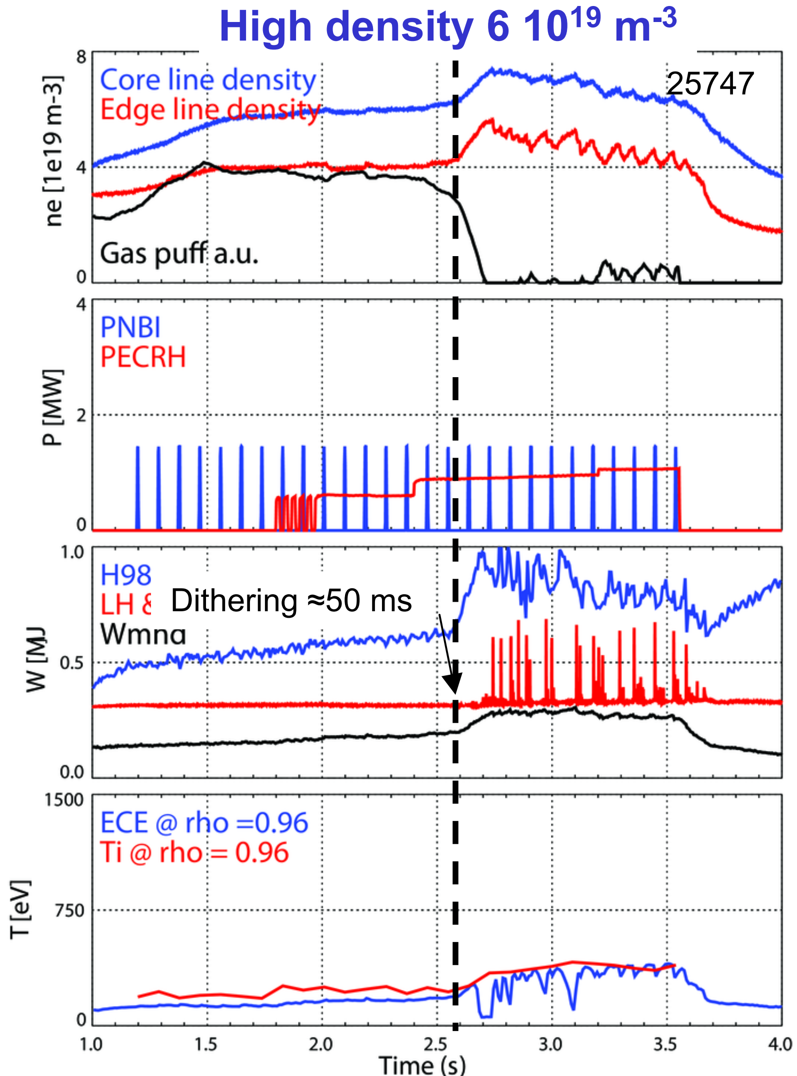
- Electron heating: ECRH up to 3 MW

- L-H transition reached by:
  - P_{ECRH} steps at fixed density
  - Density steps at fixed PECRH

- Edge measurements:
  - T_e from ECE and TS
  - T_i and rotation from CXRS with NBI blips (10ms), boron line
    - edge toroidal and poloidal systems (1.8 ms)
    - core (4 ms)
  - n_e: Li beam, TS, interferometer

Two examples: high T_e/T_i at low density

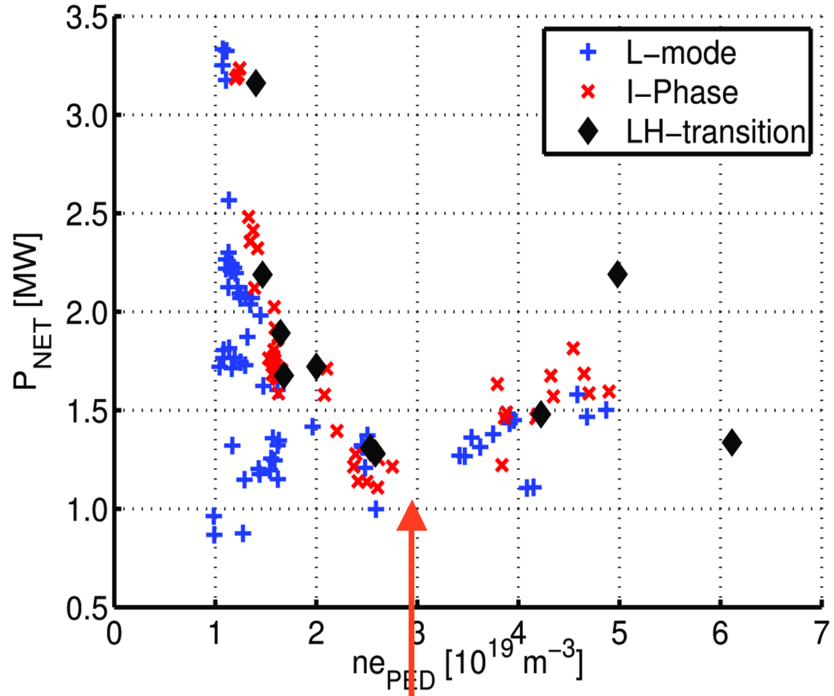




I-Phase: "Intermediate Phase", see G. Conway this workshop, PRL 2011

Operation diagram: explored n_e and P_{heat} ranges

- Range of explored density varies by factor of ≈ 6
- Low density: large variation of P_{heat} because P_{thres} high
- Higher density: limited PECRH range because P_{thres} lower
- I-Phases (dithering) somewhat below P_{thres} *(see also G. Conway this workshop and PRL 2011)*

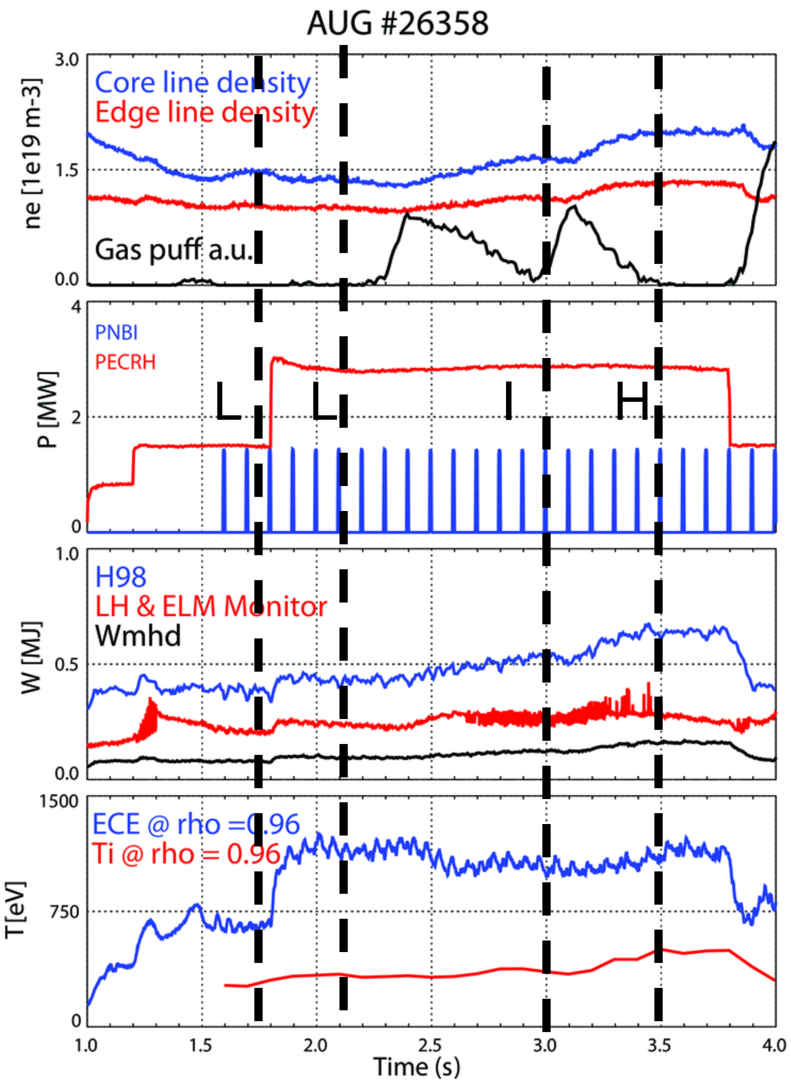


$n_{e,ped,min} \approx 3\ 10^{19}\ m^{-3}$

Edge profiles at different times

Profiles have been analyzed in:

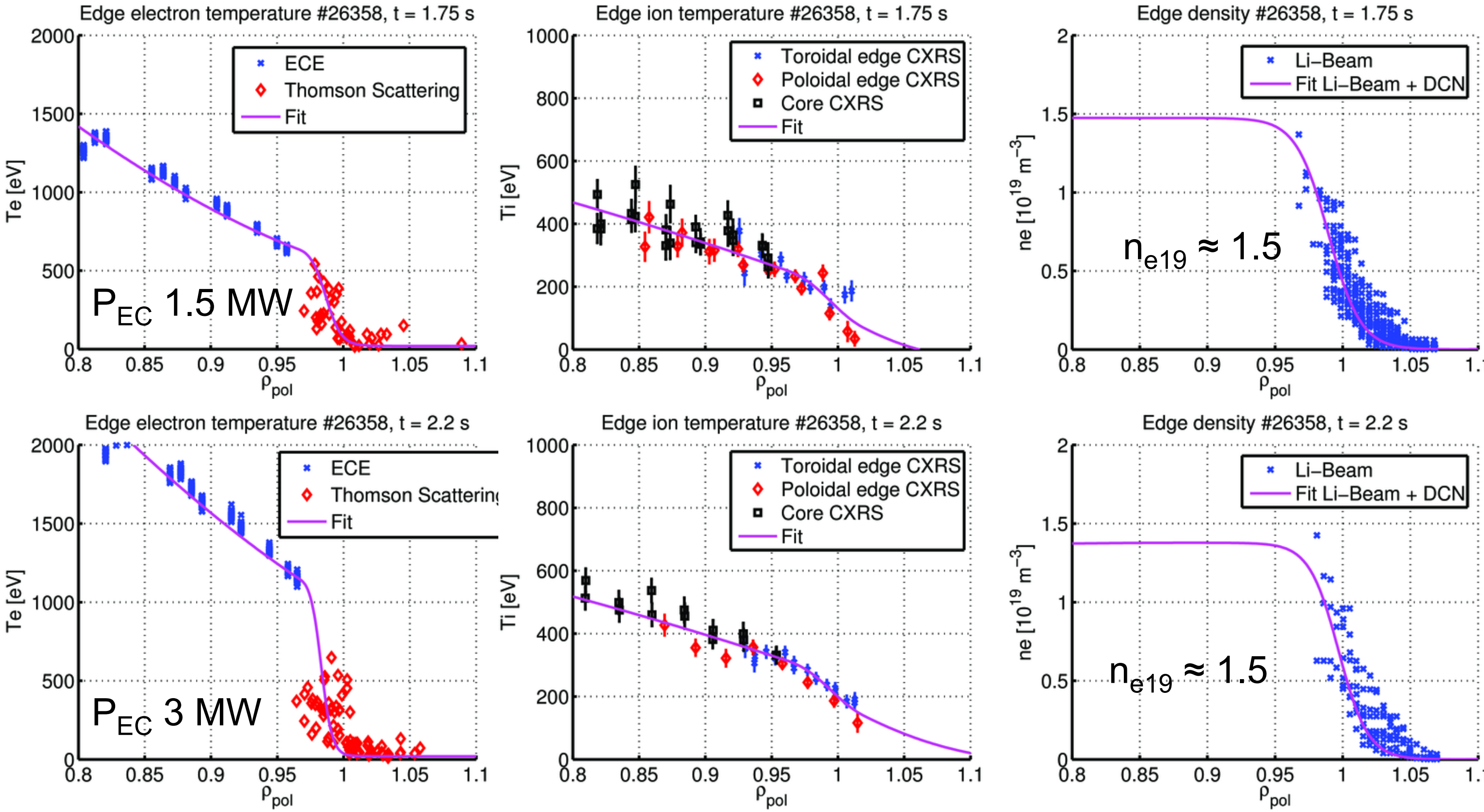
- L-Mode low and high power
- I-Phase
- H-Mode



Edge profiles in L-Mode low and high PECH

Strong increase of edge T_e with P_{ECRH} : clear T_e pedestal in L-Mode

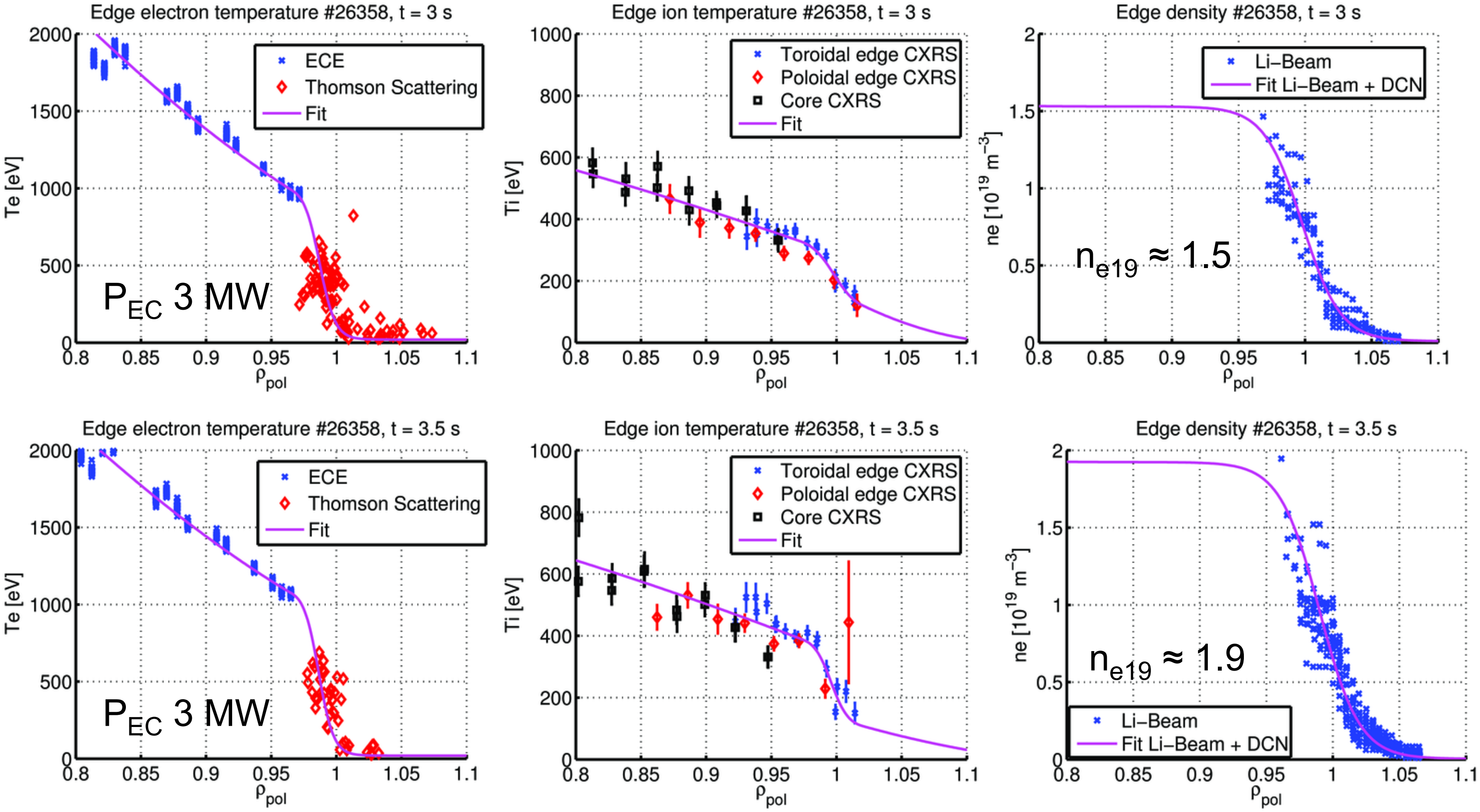
T_i weakly affected



I-Phase and H-mode: T_i pedestal forms

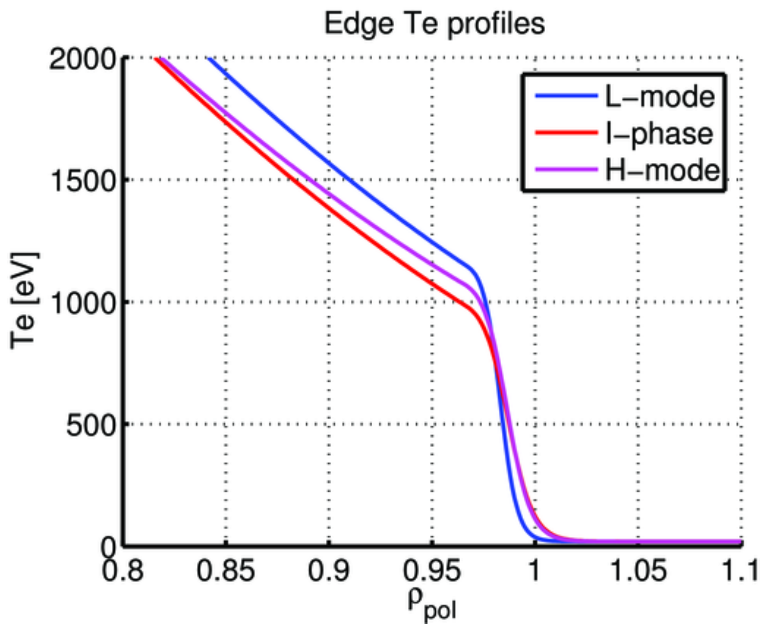
Constant P_{ECRH} ≈ 3 MW : T_e pedestal almost unchanged

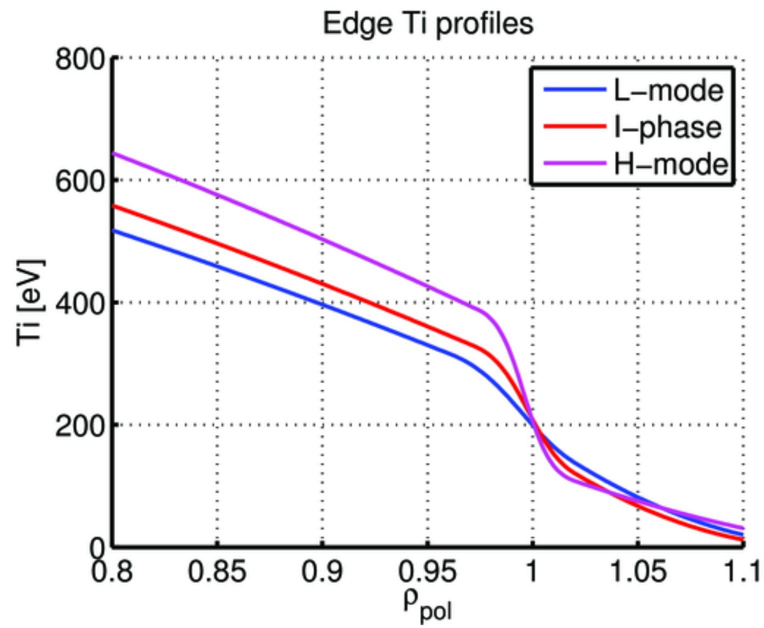
T_i pedestal develops: steeper edge ∇T_i



Edge profiles at constant $P_{ECRH} \approx 3$ MW

T_e pedestal unchanged within experimental uncertainties
T_i pedestal develops from L to H-Mode

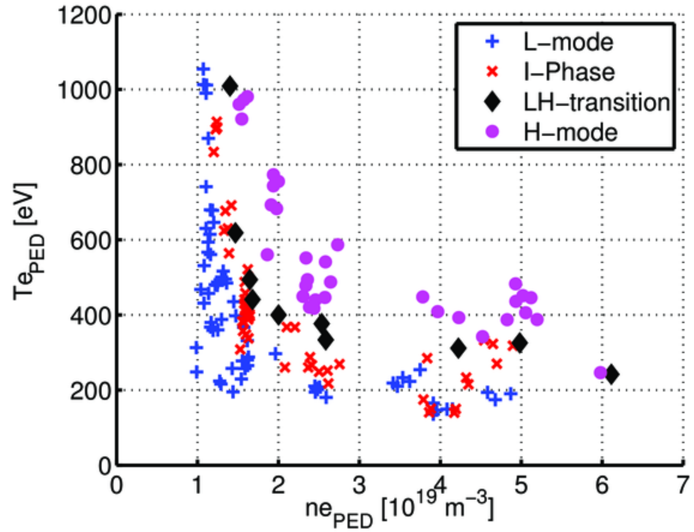




Pedestal data: temperatures versus density

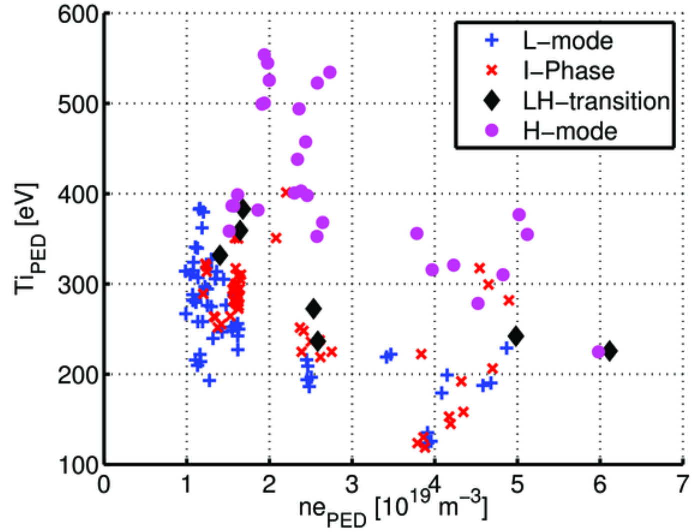
- $T_{e,ped}$ at L-H transition increases towards low density: factor of 3

- $T_{e,ped}$ in H-mode only somewhat higher than at L-H



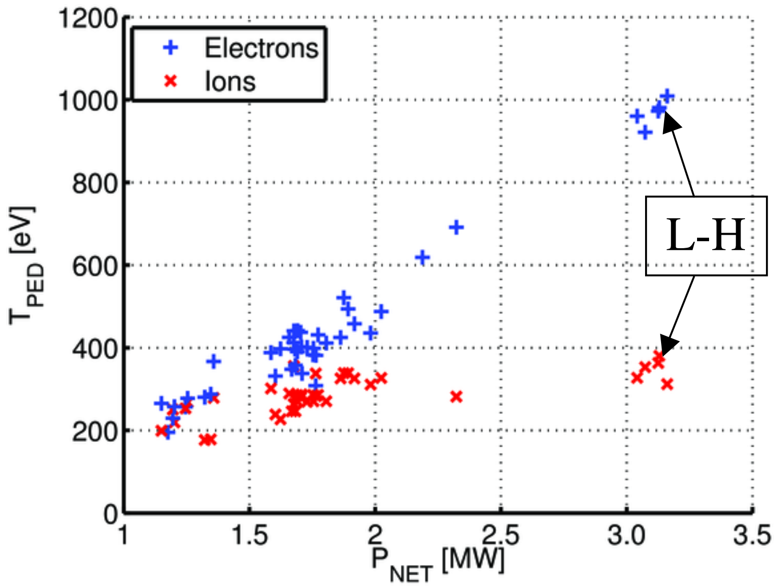
- $T_{i,ped}$ at L-H transition increases only by ≈1.6 towards low density

- $T_{i,ped}$ in H-mode clearly higher than at L-H



Pedestal T_e and T_i can be decoupled

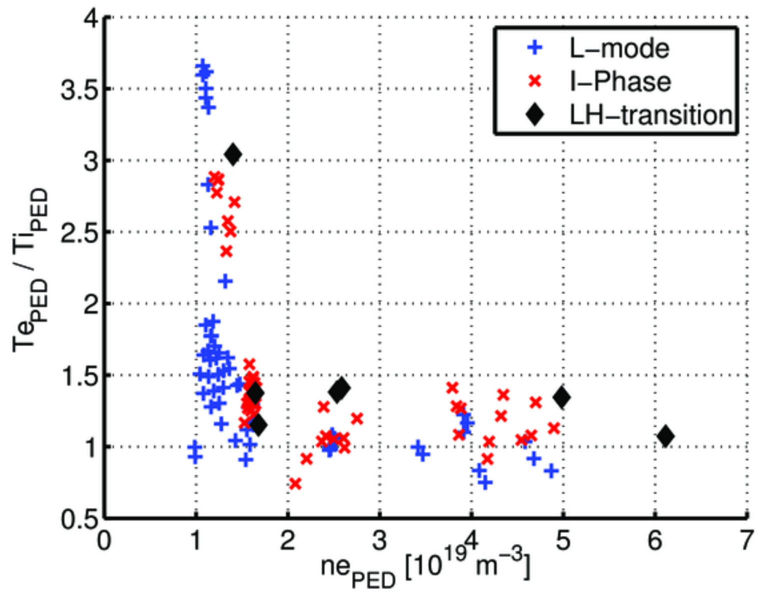
Fixed $n_{e,ped} \approx 1.5\ 10^{19}\ m^{-3}$
Increase of P_{ECRH} up to L-H



Linear increase of $T_{e,ped}$ with P_{heat} in L-mode up to L-H

$T_{i,ped}$ seems to saturate

Density dependence
for $P_{OH} < P_{heat} \leq P_{thres}$

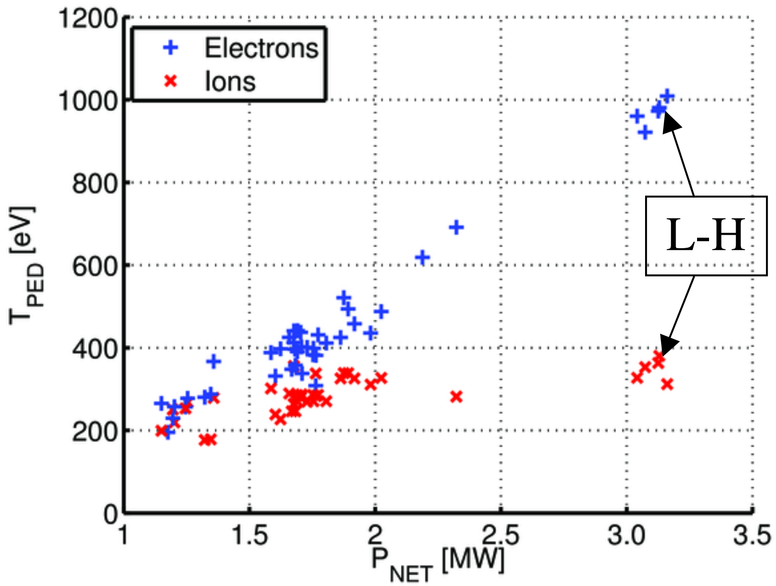


Low density:
T_e/T_i up to 3 at L-H ($P_{ECRH} \approx 3$ MW)

Higher density:
$T_e/T_i \approx 1.5$ at L-H ($P_{ECRH} \approx 1$ MW)

Edge T_e T_i decoupling

Fixed $n_{e,ped} \approx 1.5\ 10^{19}\ m^{-3}$
Increase of P_{ECRH} up to L-H



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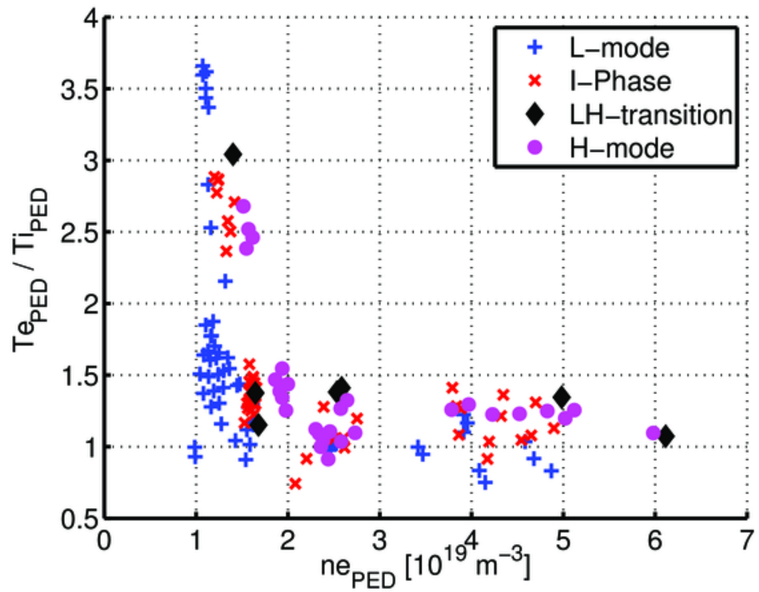

Linear increase of $T_{e,ped}$ with P_{heat} in L-mode up to L-H

$T_{i,ped}$ seems to saturate

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T_e/T_i up to 3 at L-H ($P_{ECRH} \approx 3$ MW)

Higher density:
$T_e/T_i \approx 1.5$ at L-H ($P_{ECRH} \approx 1$ MW)

T_e/T_i decrease in H-Mode

Edge p_e and p_i at L-H versus $n_{e,ped}$ different

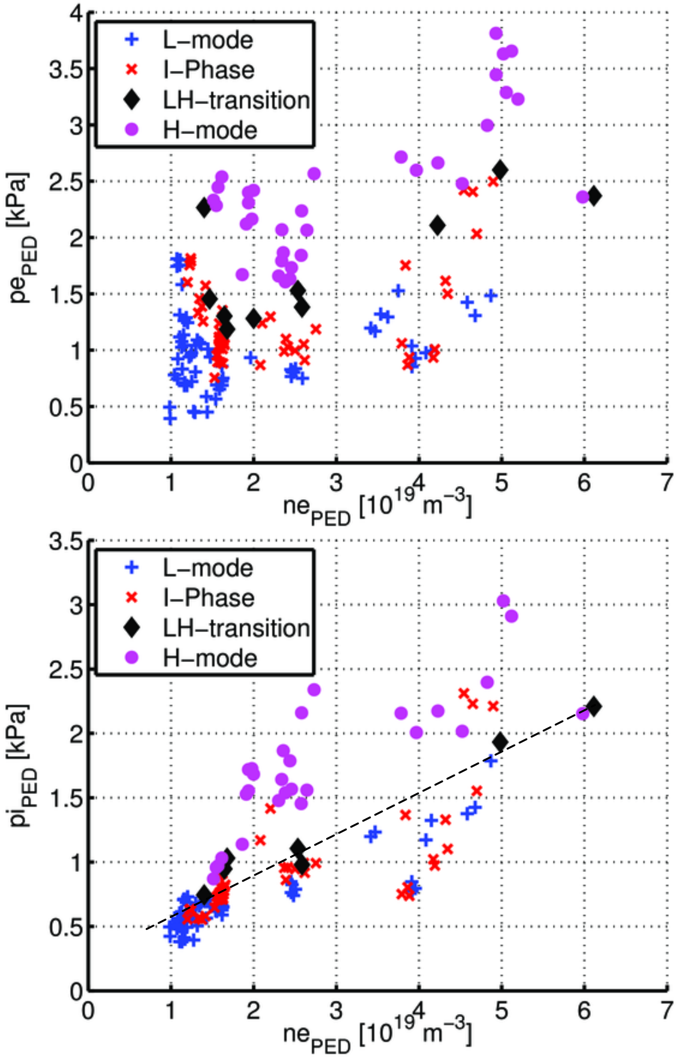
- Edge electron pressure at L-H:
  - 30 % variation at most
  - no clear trend
  - increase toward high density?

- Edge ion pressure at LH:
  - linear increase with edge density

  => factor of 4 variation

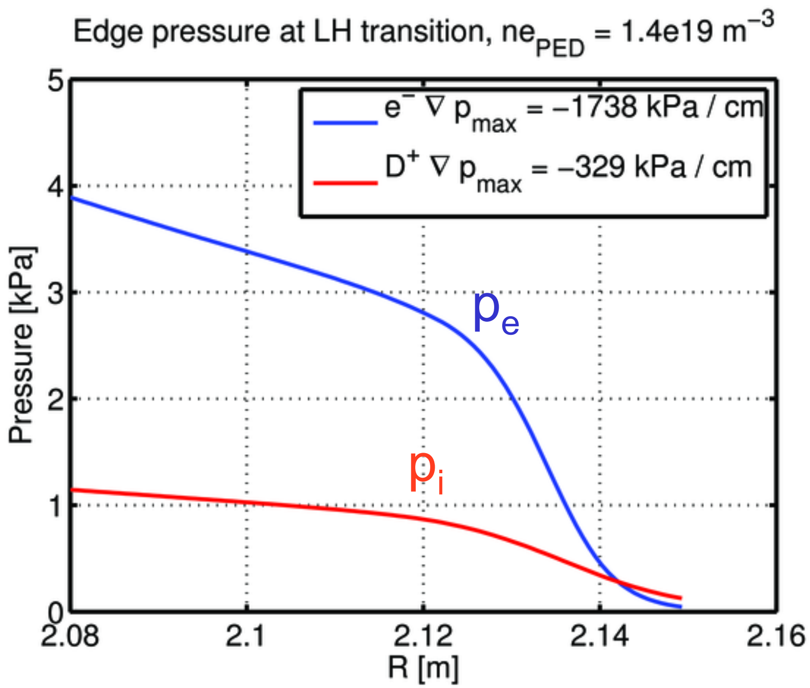
$p_{e,ped} \approx p_{i,ped}$ at L-H at high density

Both $p_{e,ped}$ and $p_{i,ped}$ higher in H-Mode

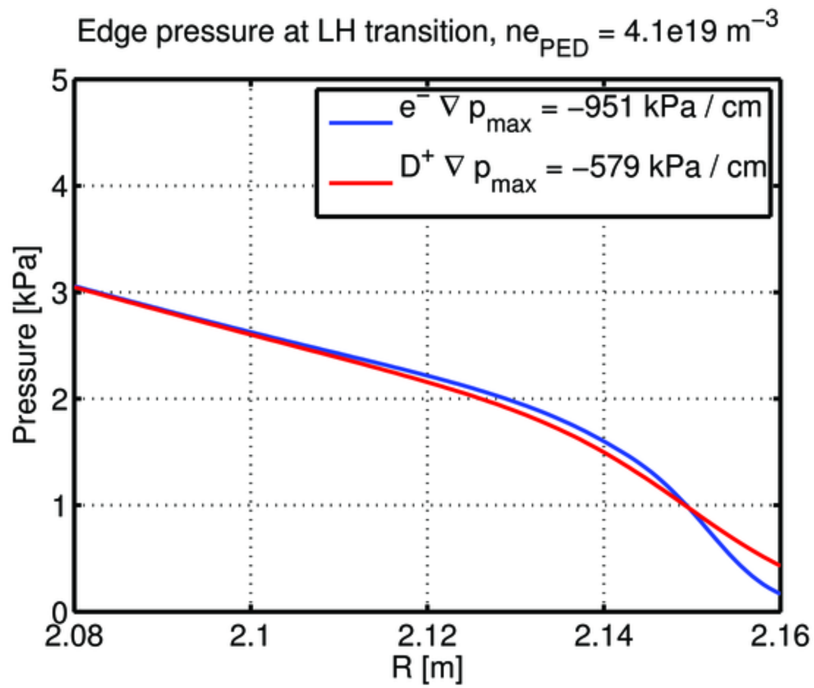


Edge pressure profiles at low and high density

Low density at L-H
$p_e > p_i$ and $\nabla p_e > \nabla p_i$



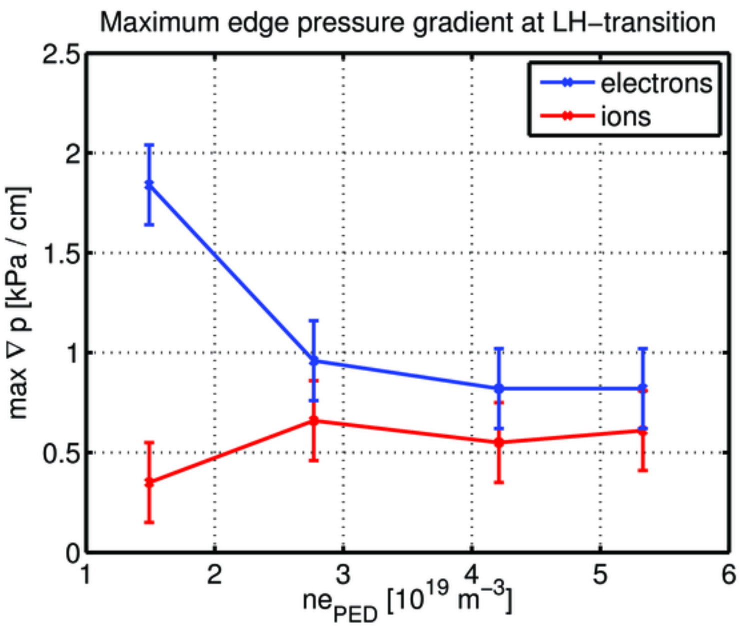
High density at L-H
$p_e \approx p_i$ and $\nabla p_e \geq \nabla p_i$

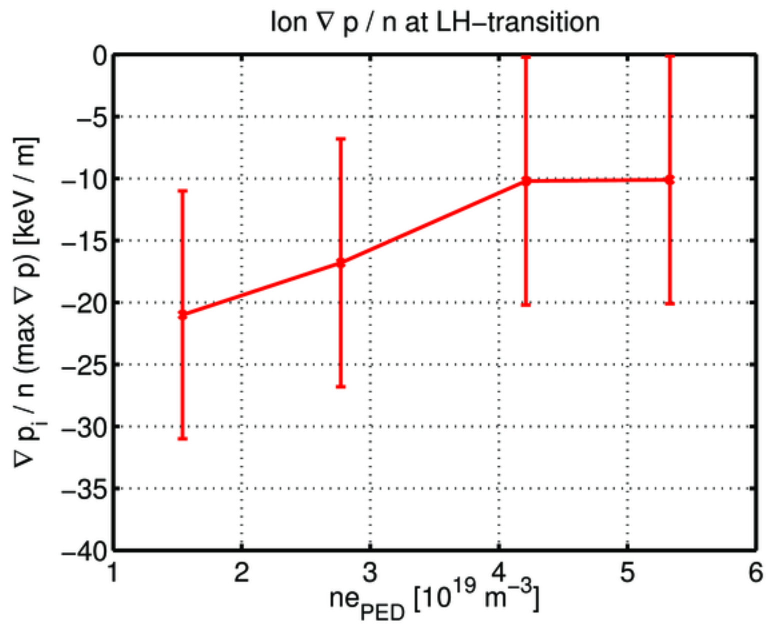


$\nabla p_{e,ped}$ and $\nabla p_{i,ped}$ at L-H versus density

$\nabla p_{e,ped}$ and $\nabla p_{i,ped}$ at L-H taken at their maximum converge with increasing density, as expected

Diamagnetic contribution to E_r from $\nabla p_i/n$ at L-H transition in same range as yielded by Doppler reflectometry in similar discharges (see G. Conway)





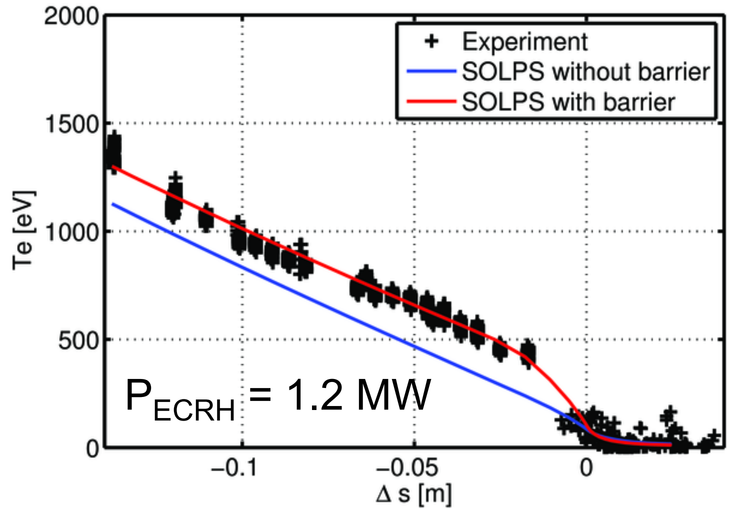
Analysis of L-mode T_e pedestal with SOLPS

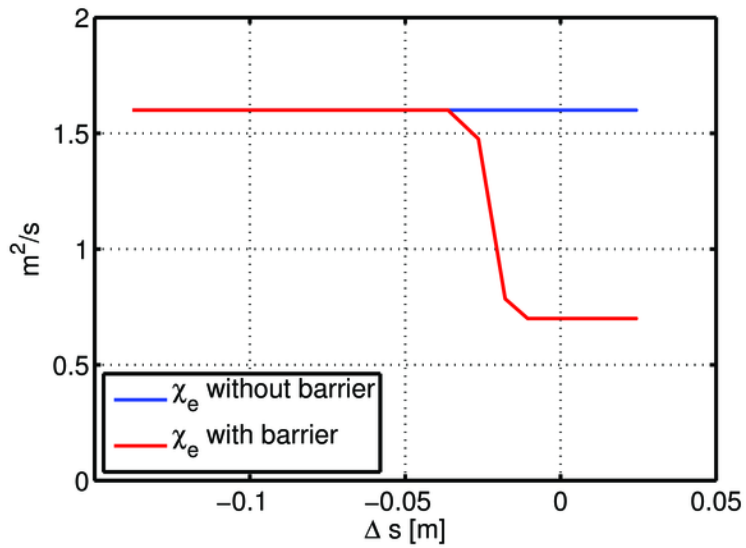
Why using SOLPS ?

- Transport calculated in edge and SOL
- Profiles for radial transport (χ_e) adjusted to match experiment
- Transport along field lines in SOL calculated
  - determines T_e at separatrix
  - no explicit boundary conditions on T_e
- Density and T_i also calculated

Edge ∇Te in L-Mode requires transport barrier in χ_e

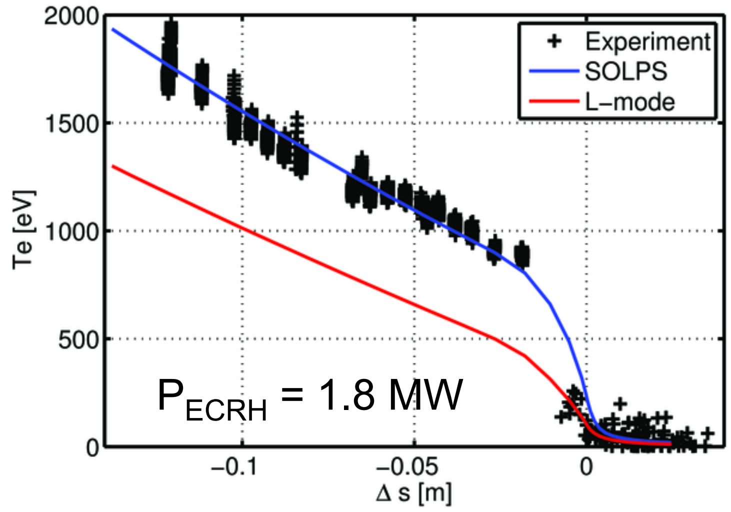
Can only be clear at low density and if P_{thres} high

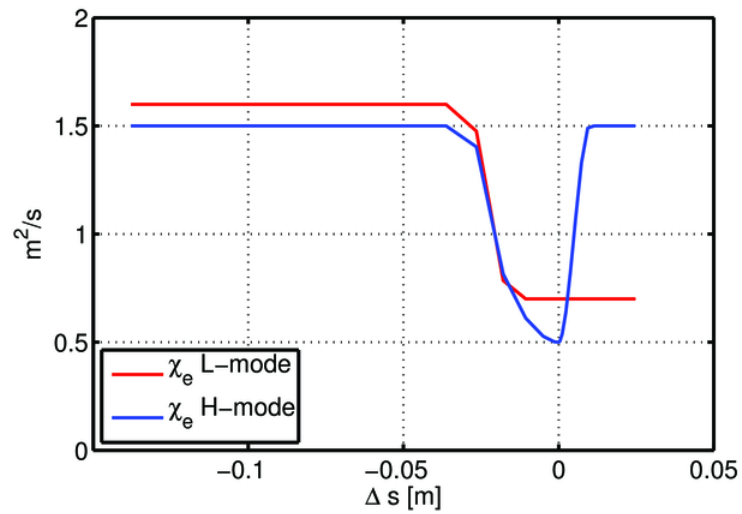




Edge transport barrier in H and L modes

Transport barrier in H-Mode only somewhat deeper than in L-Mode at same power





Summary

- Dependence of edge parameters investigated in low density with dominant electron heating in L-mode up to L-H and in H-mode
- Strong decoupling of T_e and T_i achieved at L-H: edge T_e/T_i up to 3
- T_e in L-mode exhibits clear pedestal at low density and high P_{ECRH} edge transport barrier
- T_i pedestal develops clearly in I-Phase and H-Modes
- Overview of parameters variations at L-H transition in density scan:

	T_e	T_i	p_e	p_i	∇p_e	∇p_i	$\nabla p_i/n$
	x3	x1.5	30%	x4	x2	x2(±1)	x2(±1)
for n_e ↗	↘	↘	↗	↗	↘	↗	↘