Confinement and Pedestal Characteristics in H-mode with ECH Heating

by
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with
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GENERAL ATOMICS
133-09/RP/rs

Electron Cyclotron Heating simulates plasma heating in ITER

- **The physics of all projected plasma heating in ITER is similar to heating by ECH**

  – MeV neutral beams, ECH, ICRF minority heating, LHCD, and fusion product heating all deposit **most of their power thermally in the electron fluid**

  – These heating systems introduce **little or no toroidal angular momentum**

- **Most of world database is for positive-ion NBI, but positive-ion NBI heats mostly the ions and introduces toroidal rotation**

- **ECH H-mode experiments in present-day tokamaks provide a good simulation of heating effects in ITER**

Experiment considerations:

- **Experiments comparing ECH and NBI must be done with same density, torque, ion species, plasma shape**

  – Experiments with NBI show strong sensitivity to these parameters; not contradicted in ECH experiments

  – Very few shots satisfying these conditions are available

- **Experiment caveats:**

  – ECH power in DIII-D is not high above the threshold P_{L-H}

    - Representative confinement requires $P_{aux} > 1.5 - 2 \times P_{L-H}$

  – ECH is sometimes related to density pumpout

    - Can be counteracted by gas injection, but this affects pedestal, which affects confinement

  – H-mode density rise can limit ECH accessibility due to cutoff

 – ECH heating profile can be quite different than for NBI

H-mode questions for electron heating:

- **Threshold power**: Is P_{L-H} different for electron heating than for positive-ion NBI?

  – Do the dependences on plasma parameters differ?

- **Confinement**: Is confinement in electron-heated H-mode the same as in NBI H-mode?

- **Pedestal**: Is the H-mode pedestal different for electron heating than for NBI?

- **ELMs**: Are ELMs similar in frequency and character at the same power?

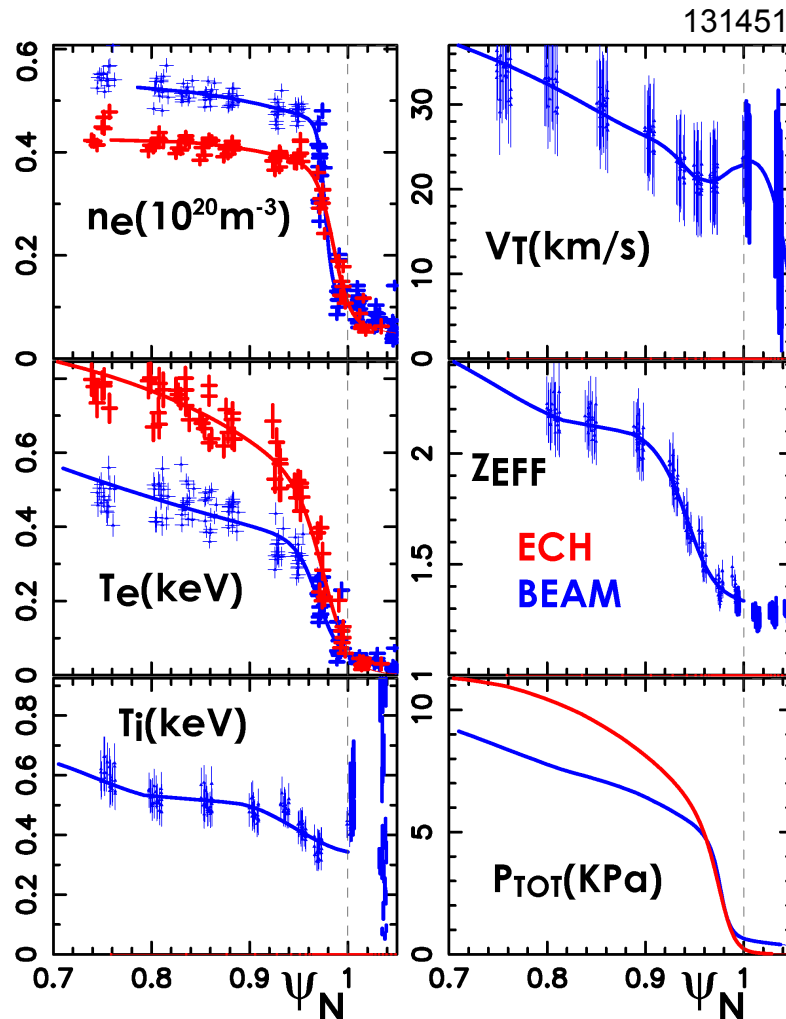# P_{L-H} for ECH in <u>Deuterium</u> is significantly smaller than that in NBI H-mode
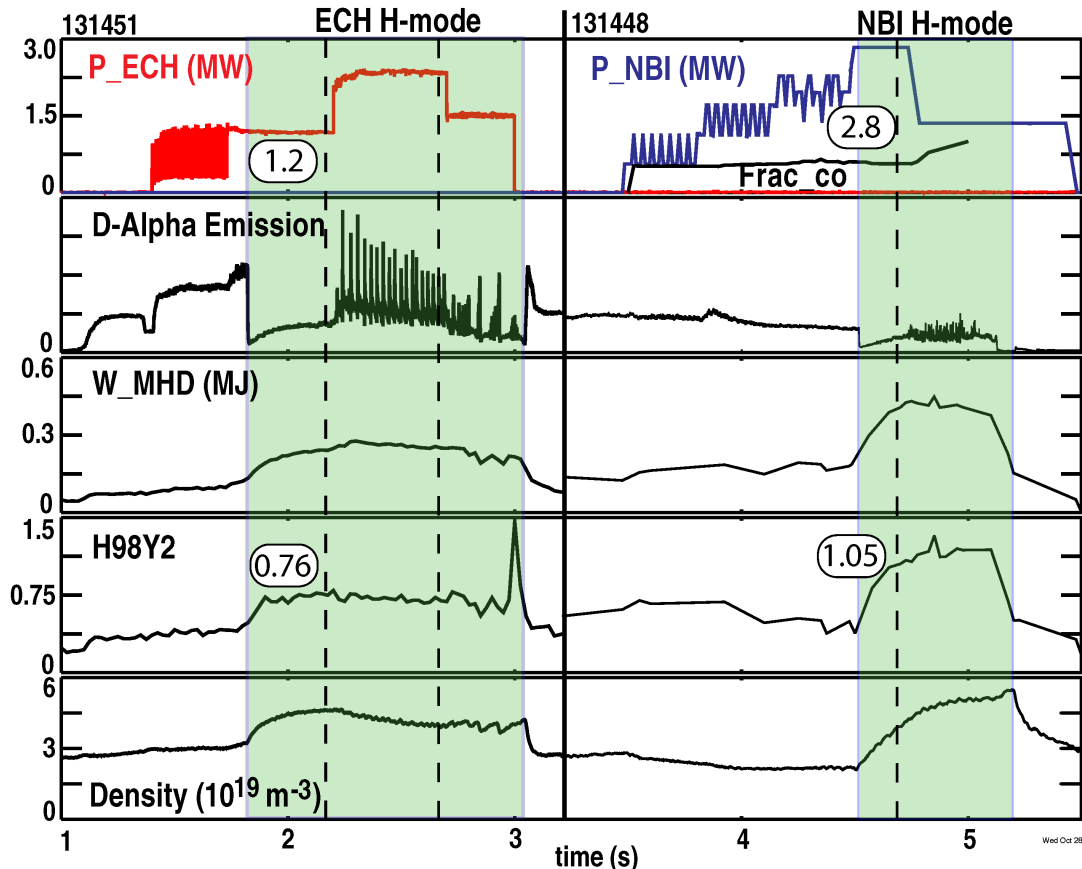
- **Large Type 1 ELMs in ECH phase, quite different than in NBI phase**
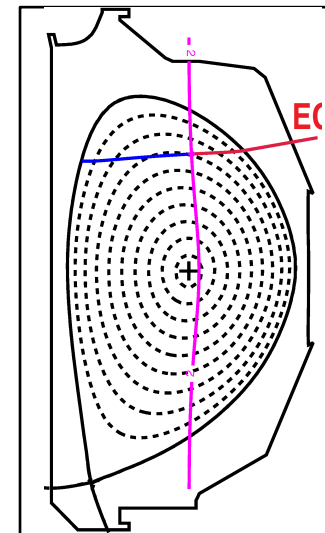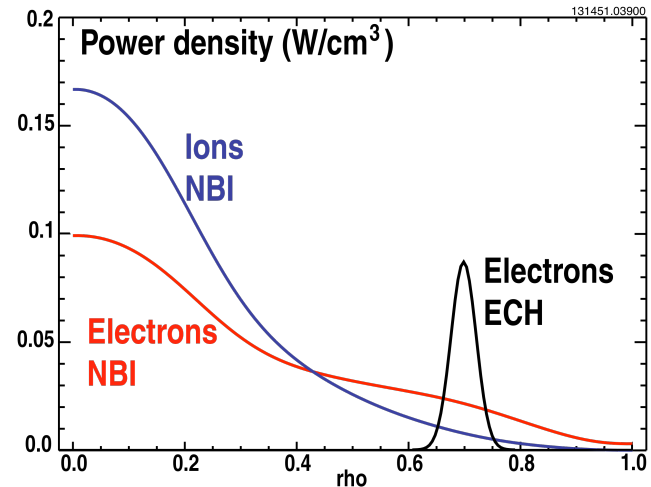
- **ECH heating profile far out-board of NBI in this experiment**

- **Difference in P_{L-H} is MUCH smaller in H and He**

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# ECH pedestal has higher T_e, lower density than NBI

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- **Pedestal widths for density and T_e are about the same, but T_e pedestal is higher and density pedestal is lower for ECH case**

- **ECH phase has large regular Type 1 ELMs, while NBI phase has small irregular ELMs**

- **No T_i, V_T, or Z_{eff} measurements are possible during ECH-only phase; P_{TOT} assumes $T_i = T_e$**

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Magnitude and density dependence of P_{L-H} for ECH is similar to that for NBI in <u>Helium</u> Plasmas
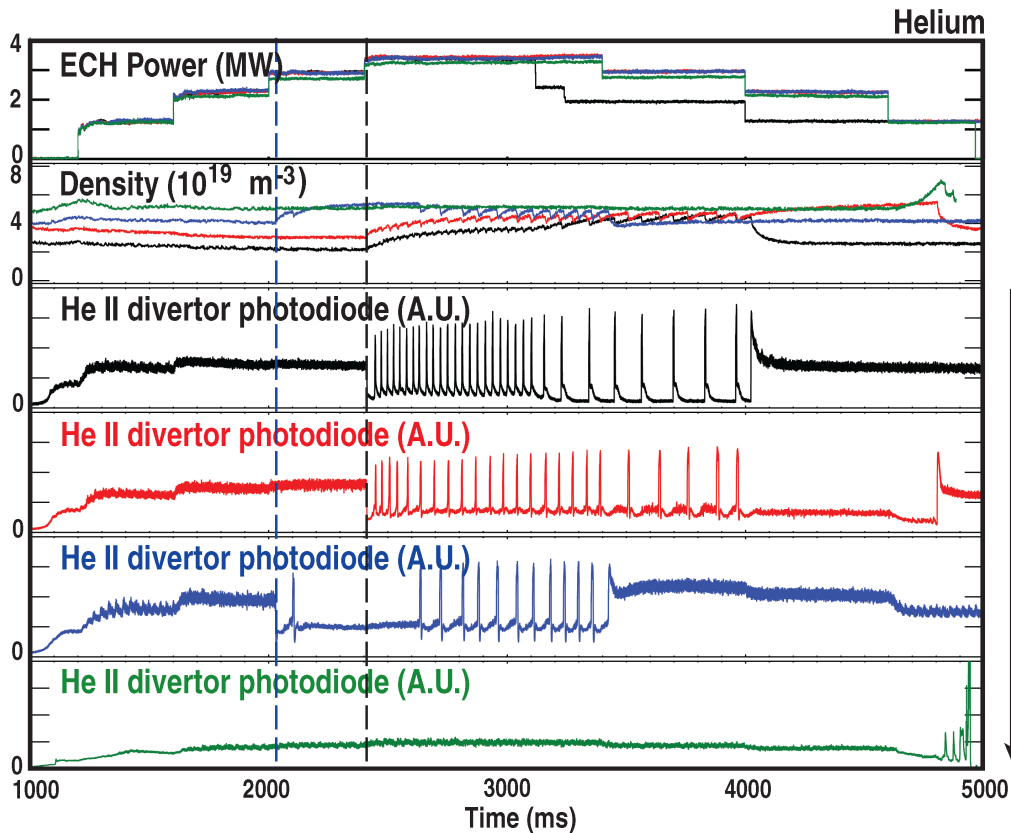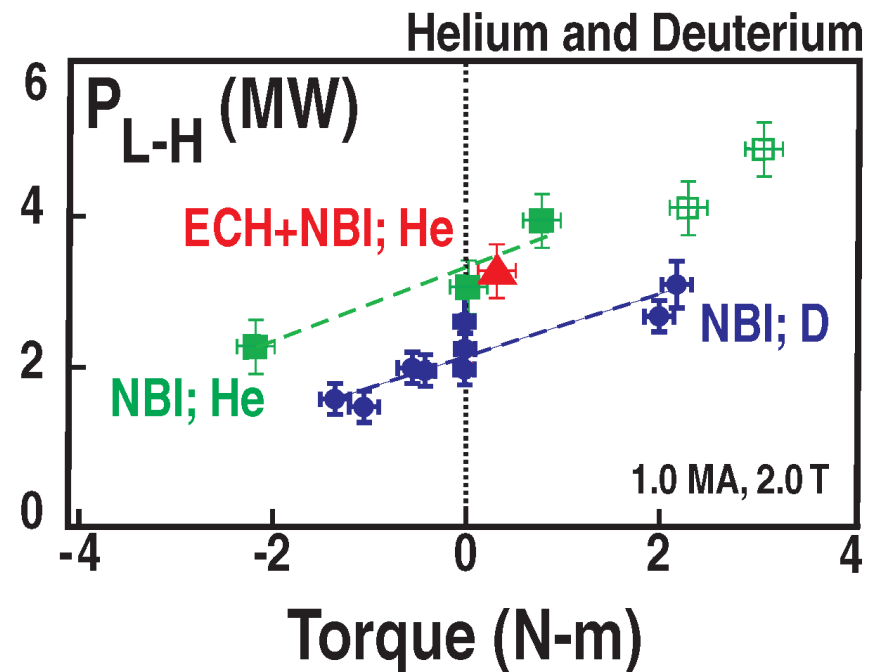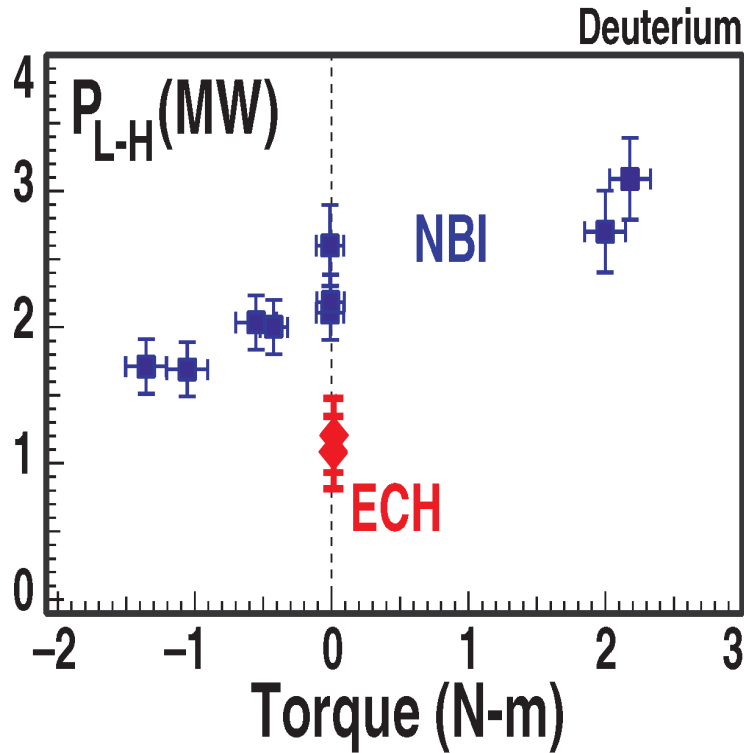

- **General discharge character similar to D NBI H-mode**
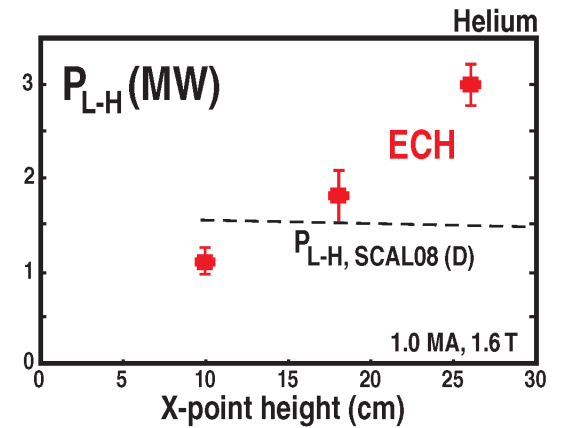- **Threshold power has similar density dependence**
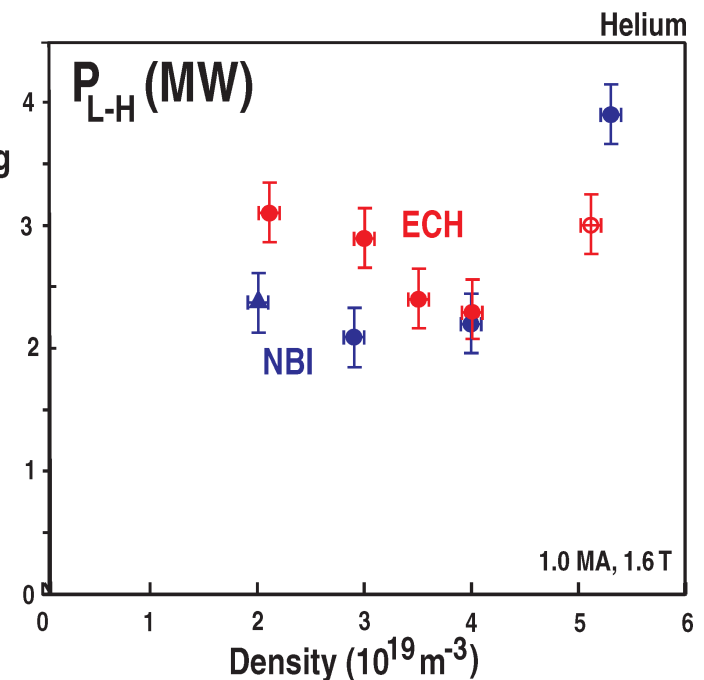
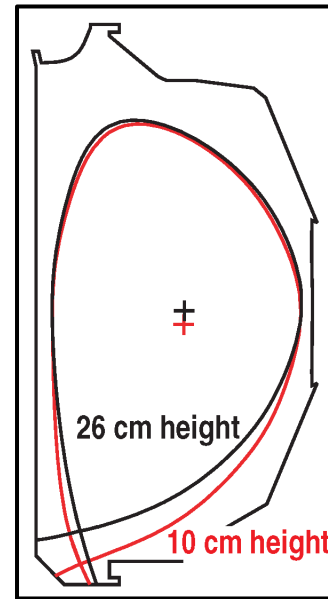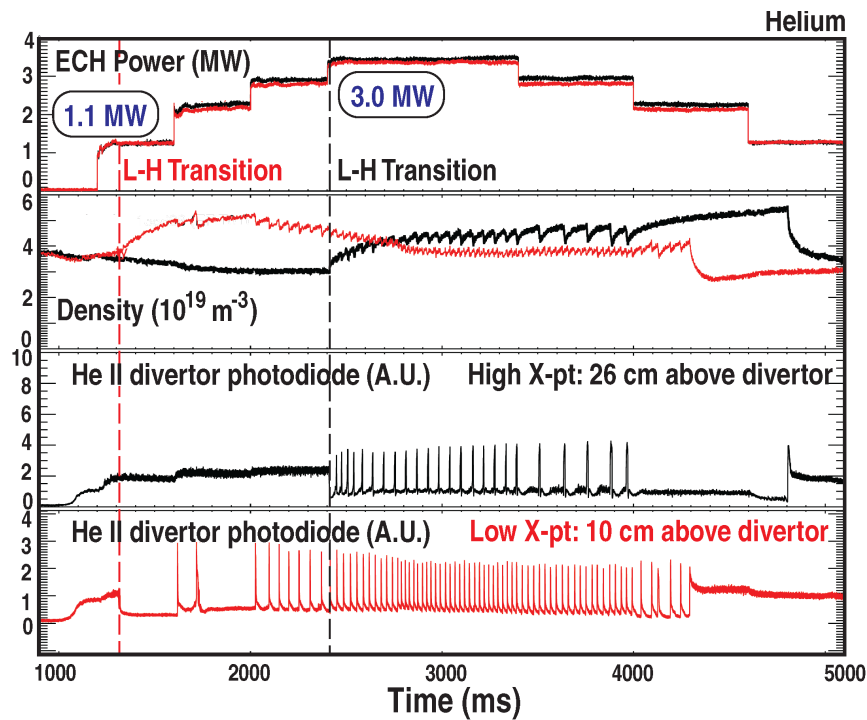TP8.00004 – P. Gohil

Magnitude of P_{L-H} with ECH is similar to that with balanced (torque-free) NBI for <u>Helium</u>


P. Gohil, 2009 H-mode Workshop

P_{L-H} shows strong dependence on X-point height for ECH in Helium (same as for NBI in Deuterium)

Helium

ECH Power (MW)

1.1 MW   3.0 MW

L-H Transition   L-H Transition

Density (10^{19} m^{-3})

He II divertor photodiode (A.U.)   High X-pt: 26 cm above divertor

He II divertor photodiode (A.U.)   Low X-pt: 10 cm above divertor

Time (ms)

26 cm height

10 cm height

Helium

P_{L-H} (MW)

ECH

$P_{L-H, SCAL08}$ (D)

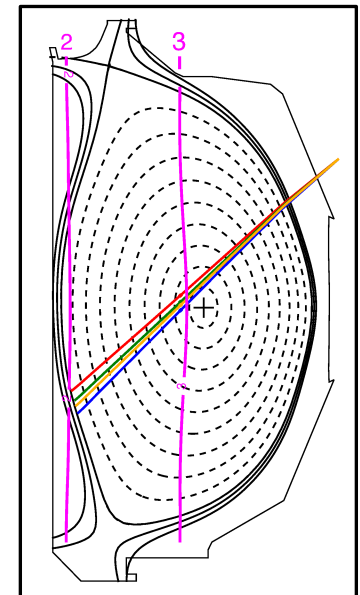1.0 MA, 1.6 T

X-point height (cm)

• **X-point height dependence unaccounted for in the scaling**

Assessing confinement with power well above P_{L-H} can be done by combining ECH and NBI
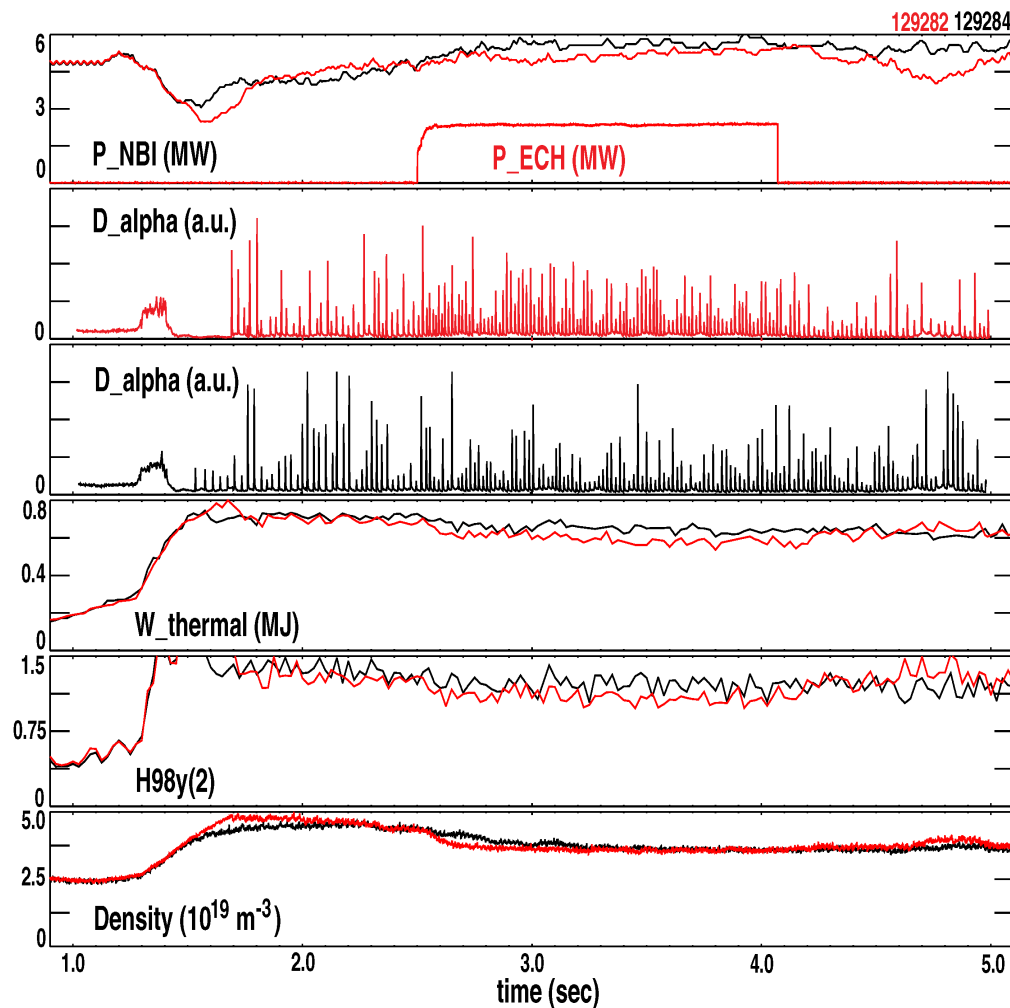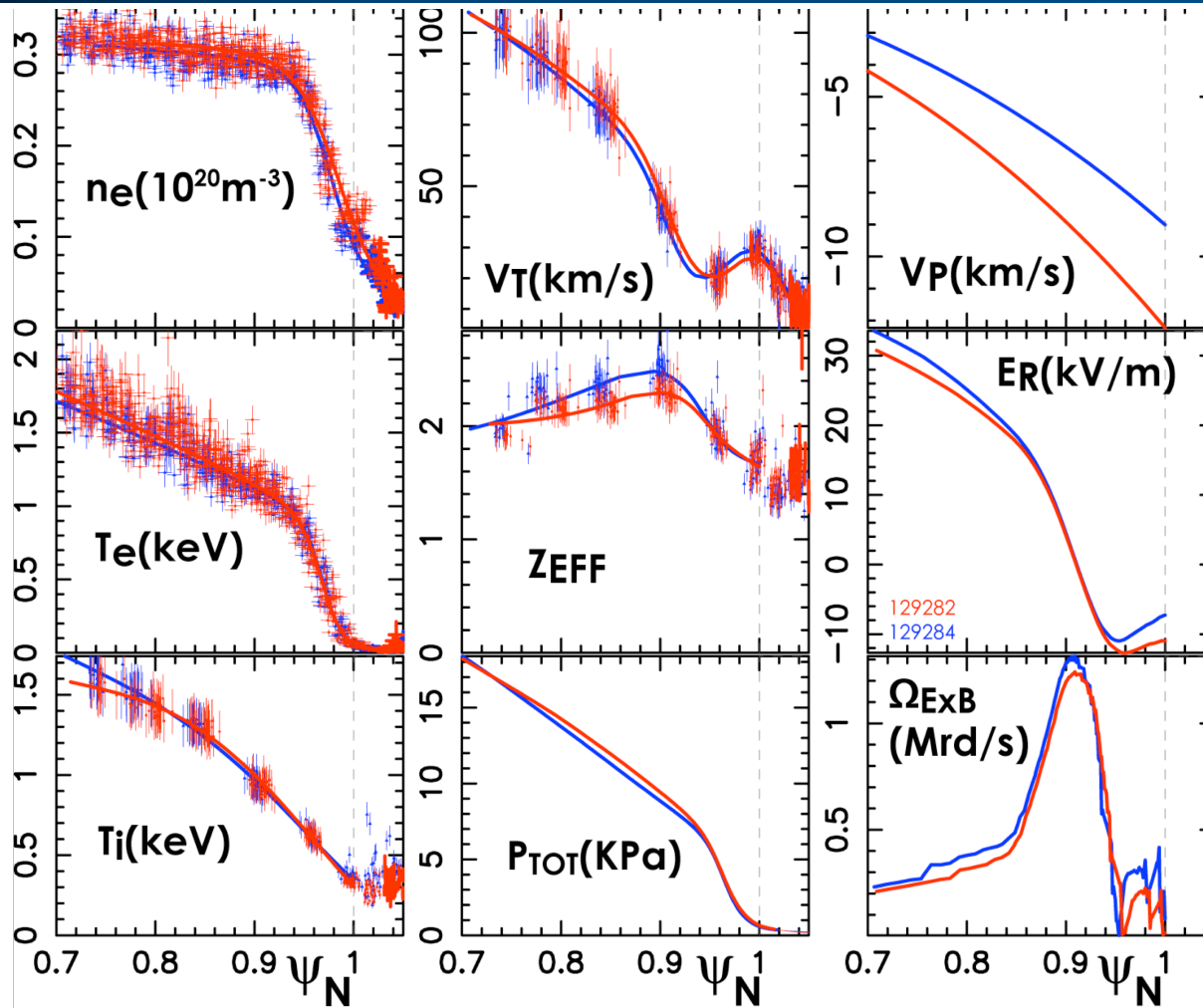
- **3rd harmonic ECH near plasma center**
- **ELM frequency increases from 40 Hz to 60 Hz**
- **Decrease of H98y2 from 1.22 to 1.06 during ECH**

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P_NBI (MW)

P_ECH (MW)

D_alpha (a.u.)

D_alpha (a.u.)

W_thermal (MJ)

H98y(2)

Density (10^{19} m^{-3})

time (sec)

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Pedestal is very similar for NBI and NBI+ECH H-mode discharges

- **6 MW NBI+ECH case has 40% power in ECH**

T. Osborne

Provisional Conclusions

- **P_{L-H} appears to be significantly lower for ECH than for NBI in D, but similar in He**

    - Same plasma shape dependence, some differences in density dependence

- **Confinement (H98y2) with pure ECH near the threshold power or with ECH+NBI well above the threshold power is smaller by 20-25% in the few shots available with identical parameters**

- **Pedestal widths are nearly the same for ECH and NBI H-modes, but T_e pedestal height is higher and density is lower for ECH**

- **Distinct differences seen in ELM behavior are seen, with ECH more likely to have large regular Type 1 ELMs**