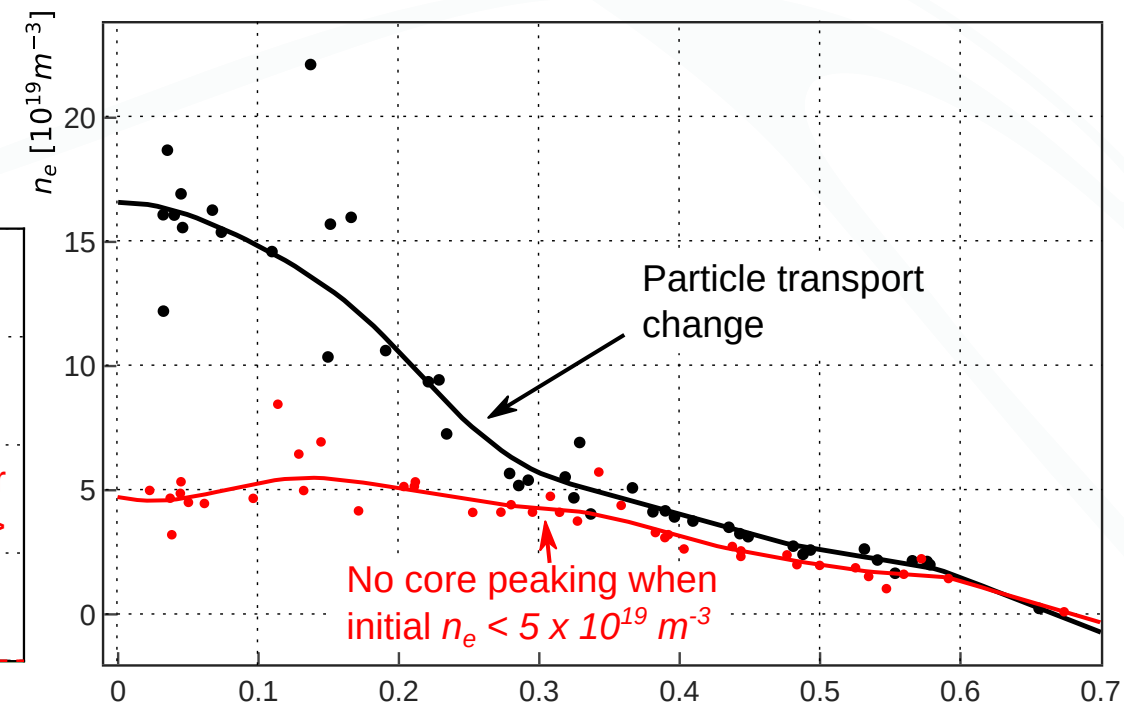
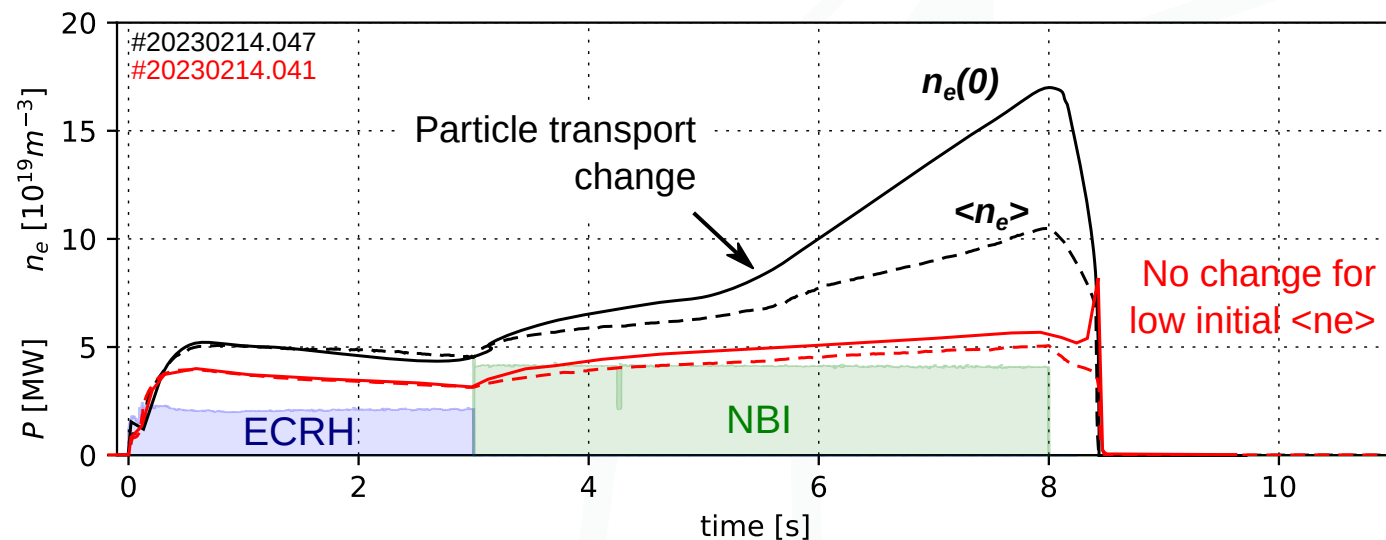


NBI core density peaking

Core density peaking with NBI (observed in OP2.1b) examined in detail.

- On-set dependence on initial density confirmed
- Abrupt change of particle transport within fixed radius when passing some threshold.
- Radial location appears to change with configuration
- Co/counter source selection has no significant effect.
- Scaling of peaking with source rate not clear (varied number of NBI sources).



ECRH pump-out

- Re-introducing ECRH pumps-out density and impurities.
- Investigated effects on pump-out rate:

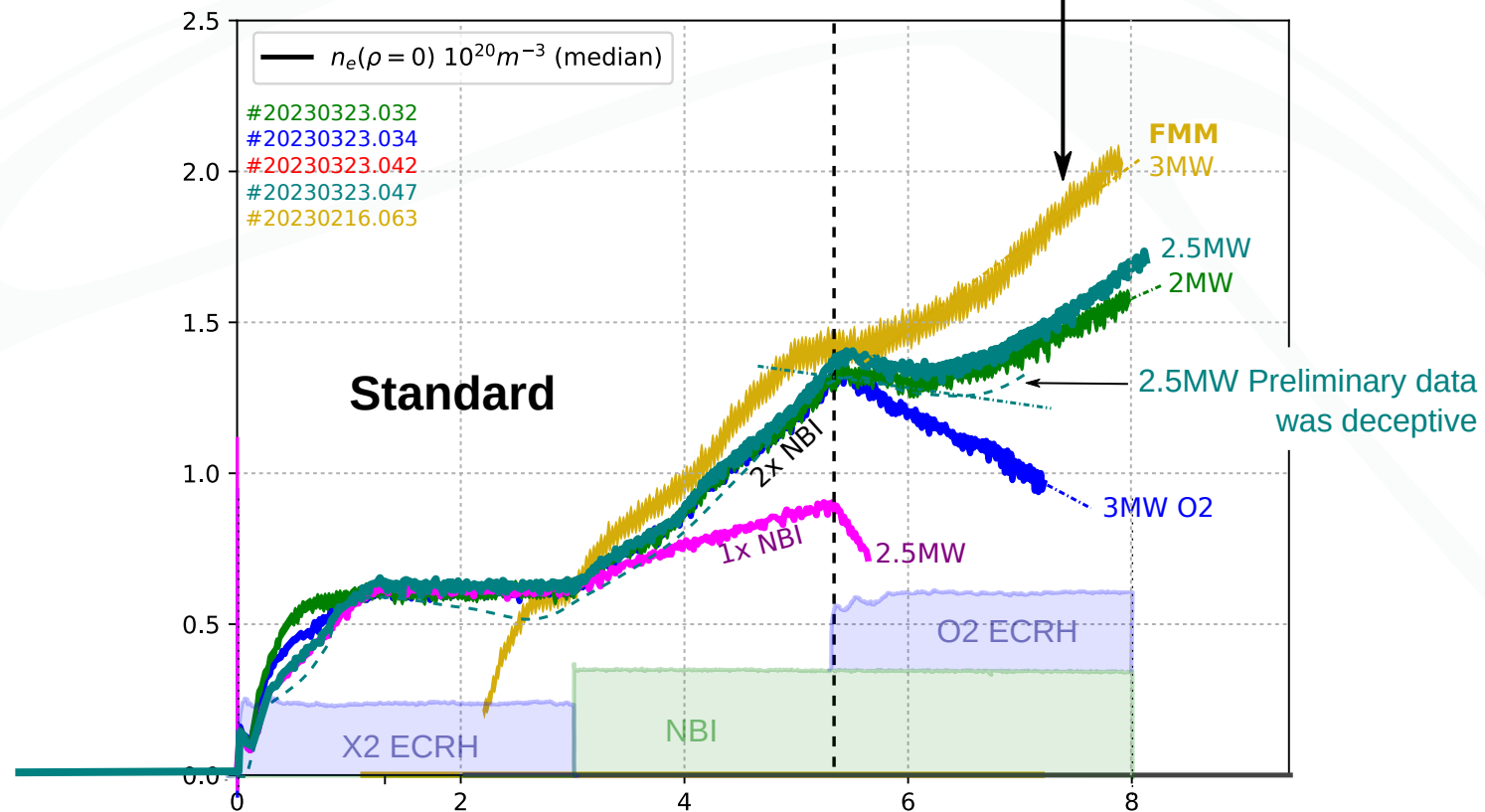
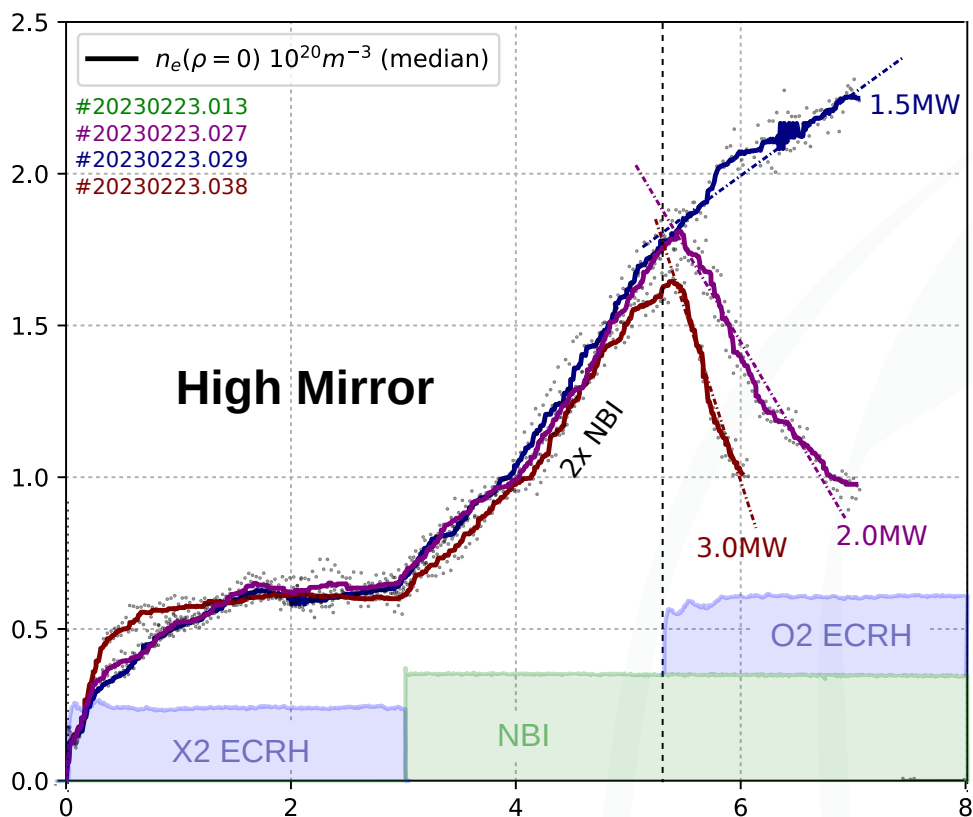
Significant:

- ECRH power.
- Initial density
- NBI source rate
- Magnetic configuration

Not significant:

- O2 vs X2 absorption
- O2 off-axis (gyrotron choice)

FMM configuration: Limited pump-out even at 3MW ECRH
 --> **High-performance candidate.**
 ... really config or initial n_e condition?

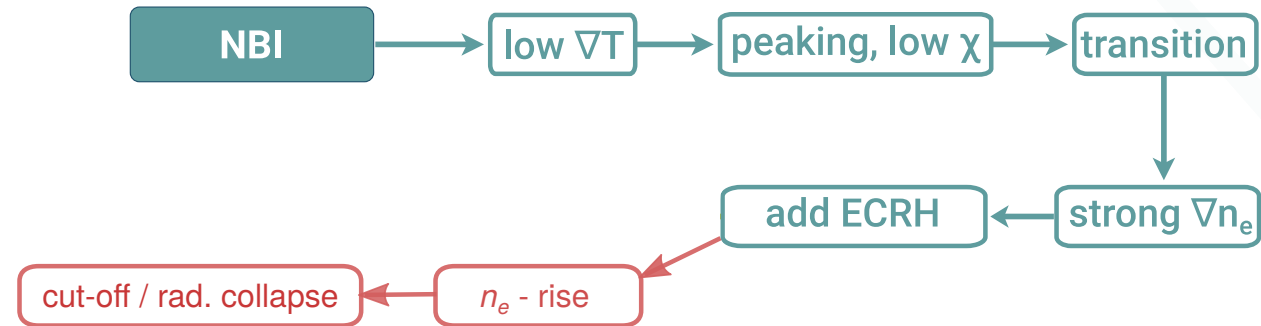
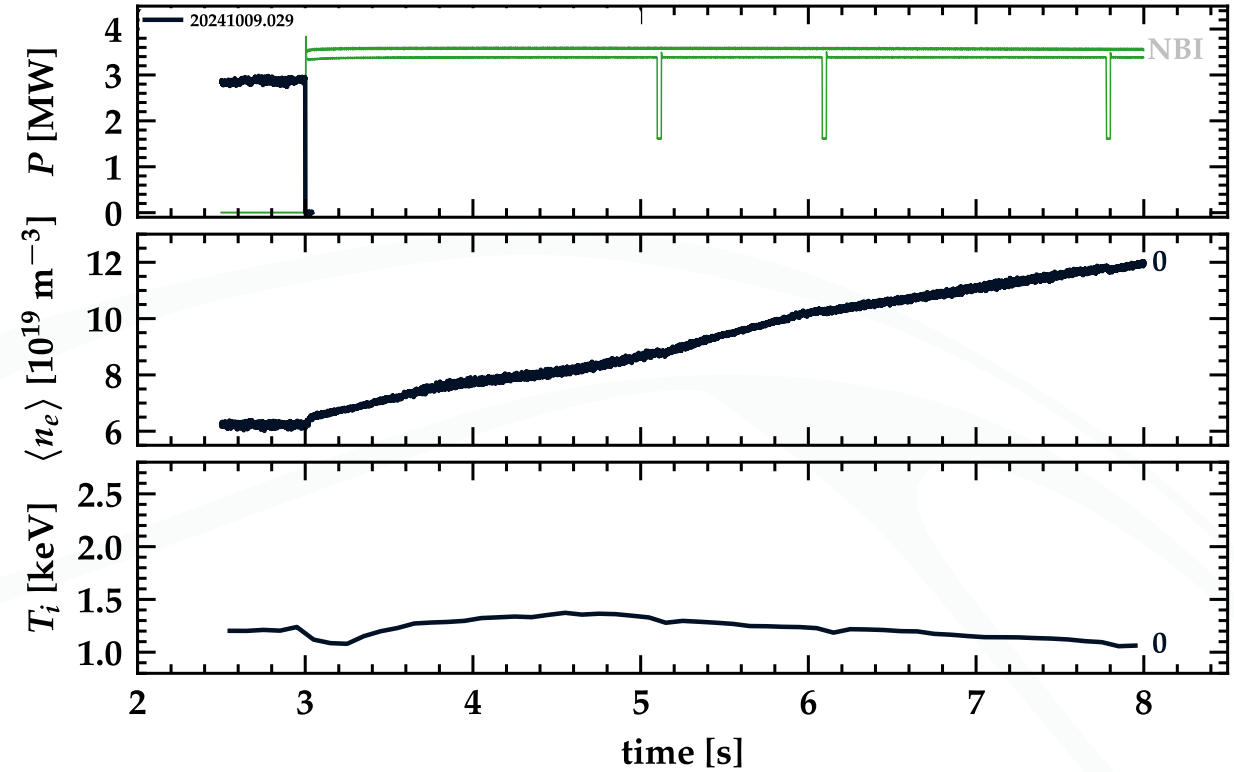


Scenario 4: NBI + ECRH reintroduction - 'pump-out'



Heating with reduced χ_i to raise plasma temperature.

- Similar to post-pellets, but with particle source.
- Density evolution depends on ECRH power.

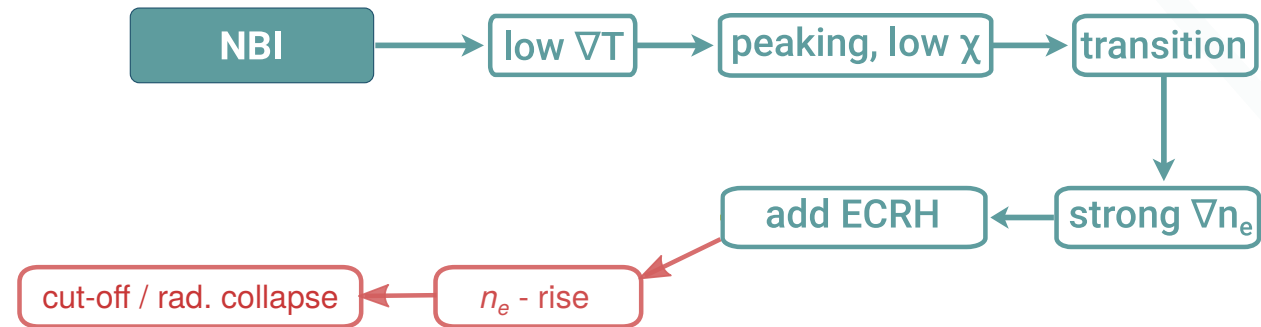
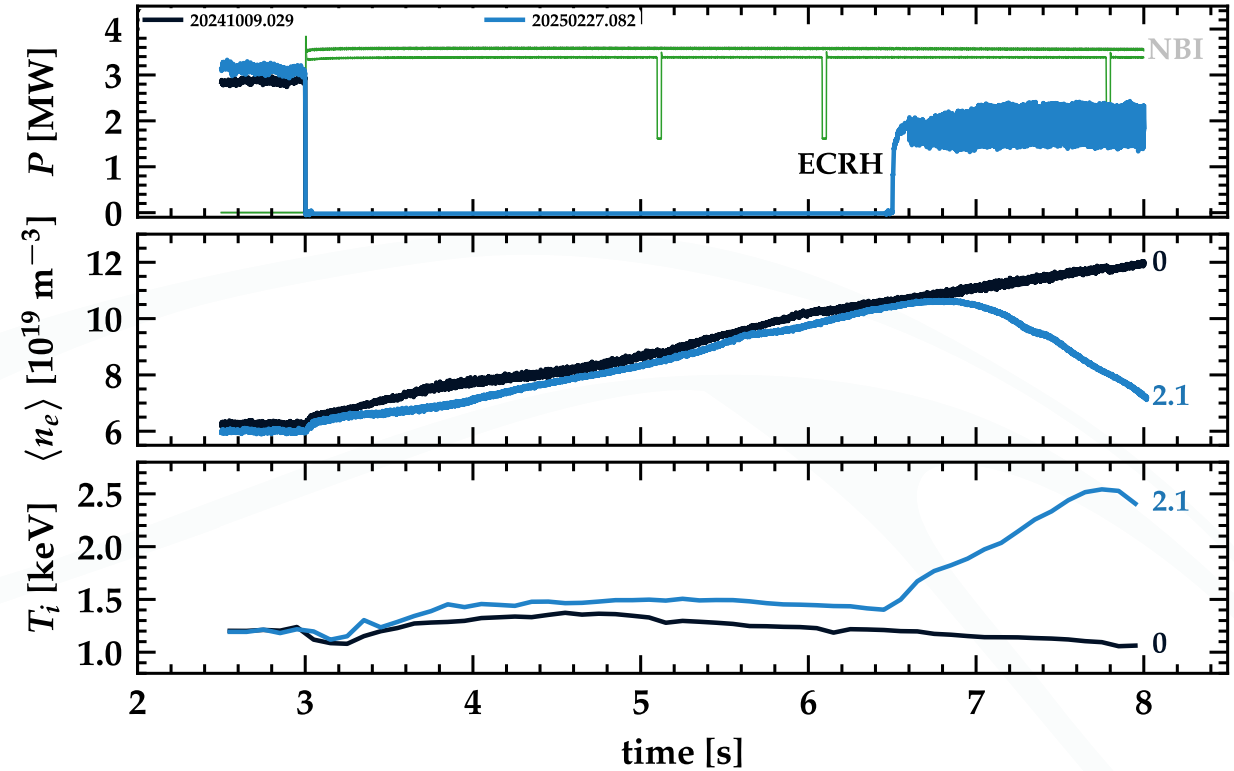


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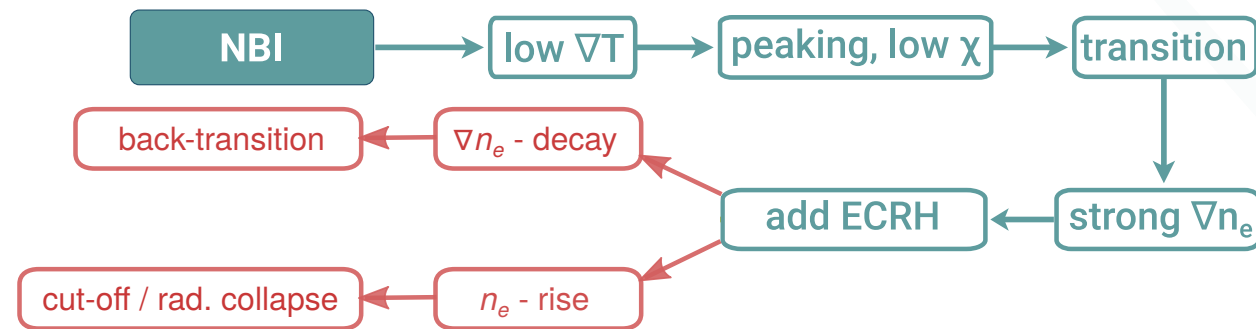
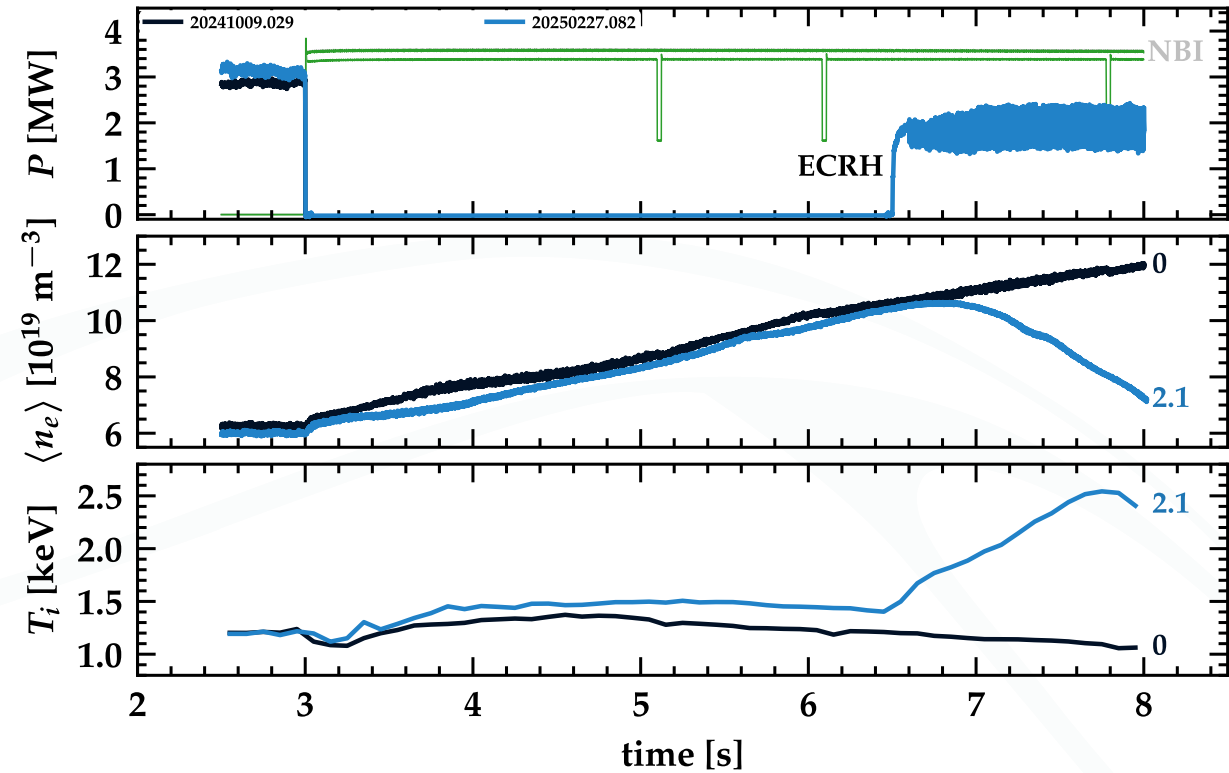
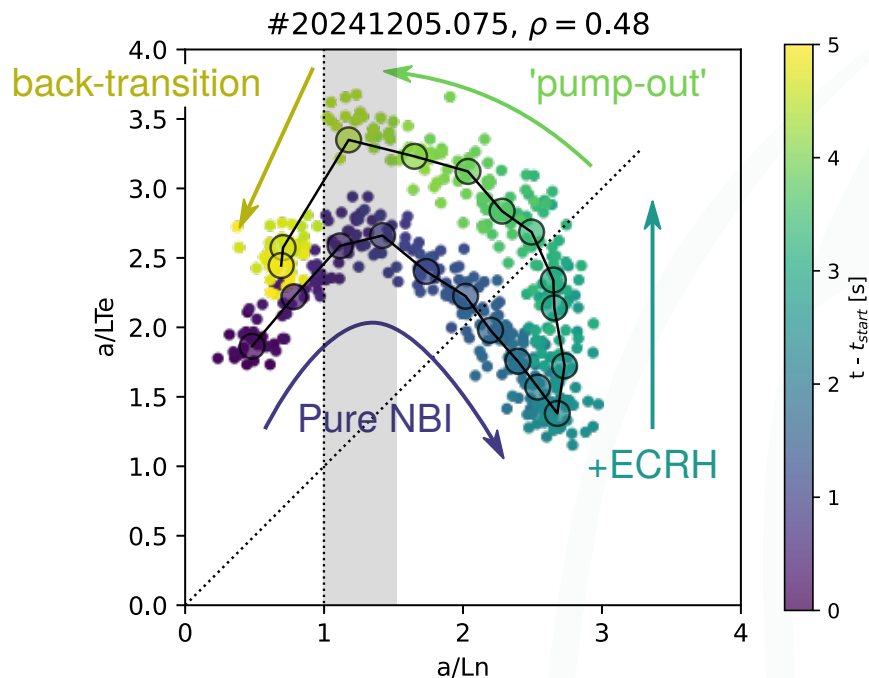
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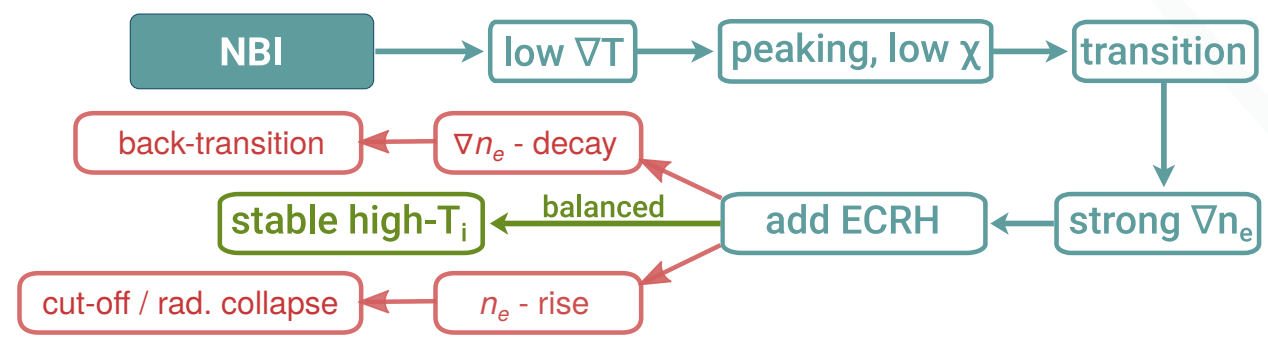
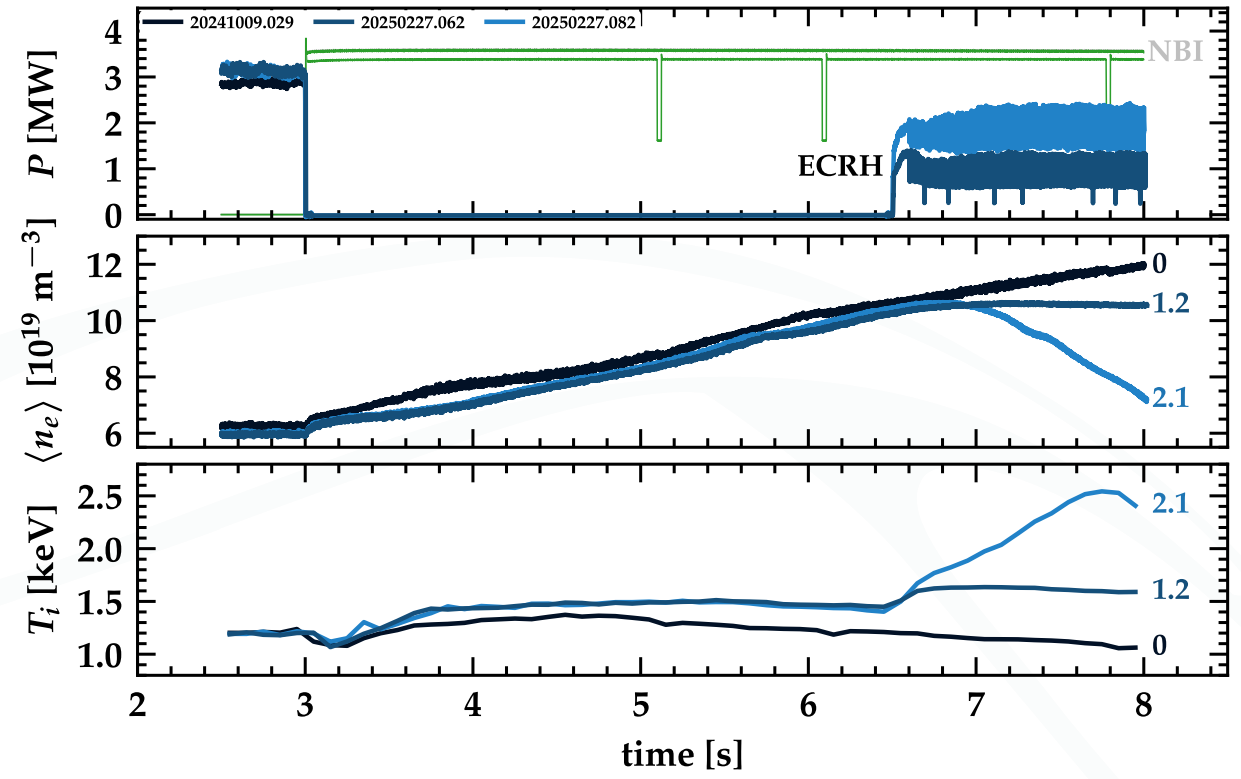
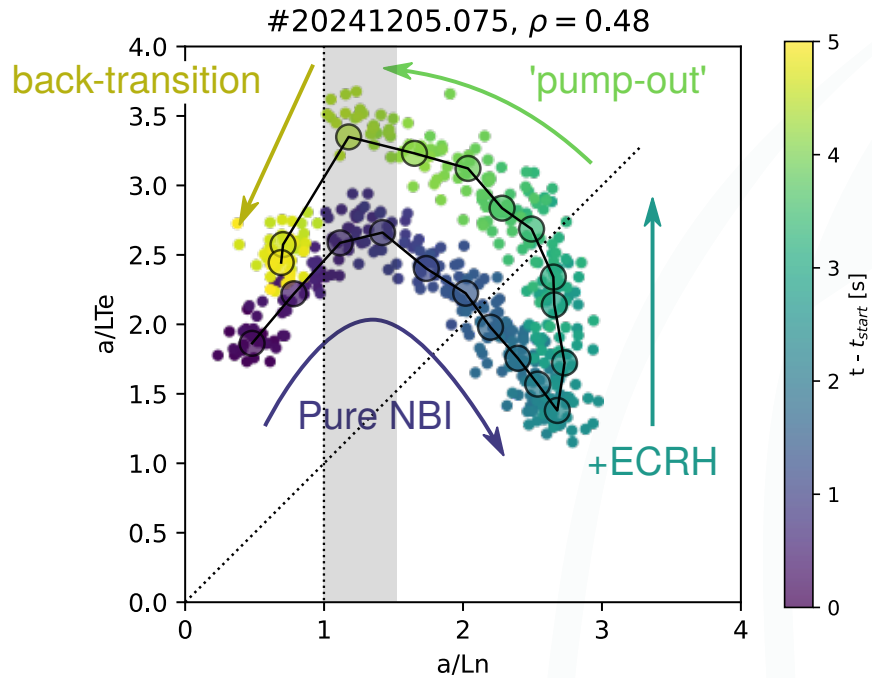


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- Compensate particle source \Rightarrow balance for steady state

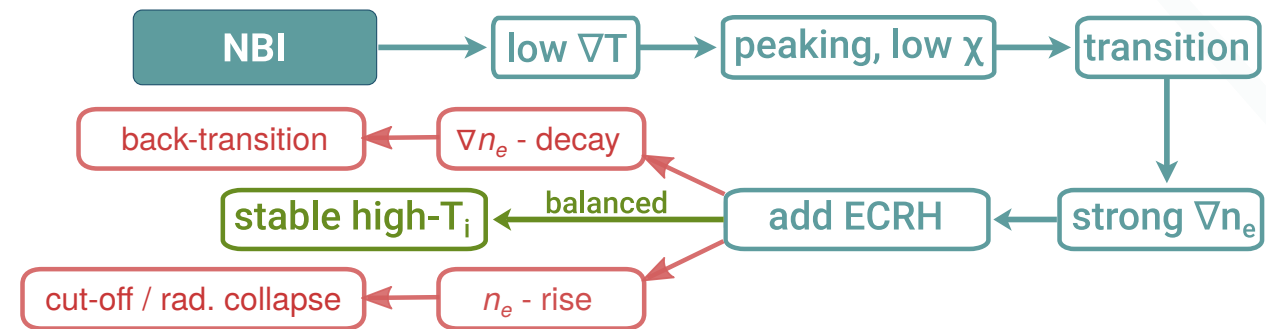


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- Balance strongly configuration dependent



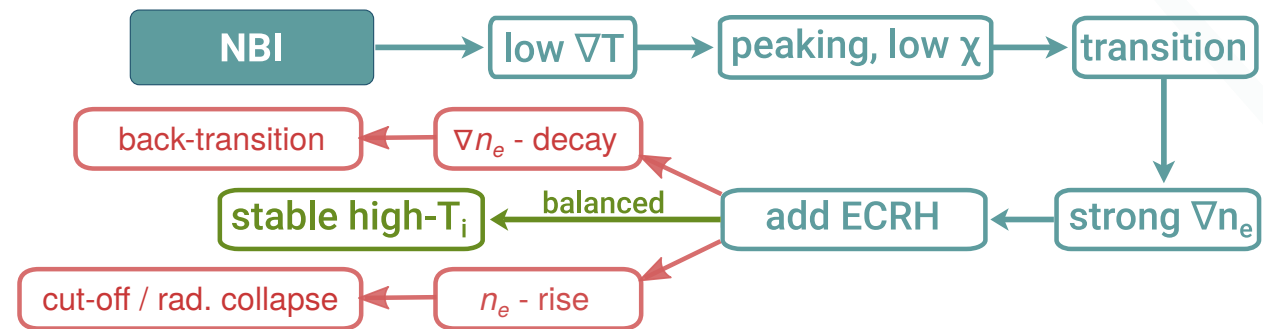
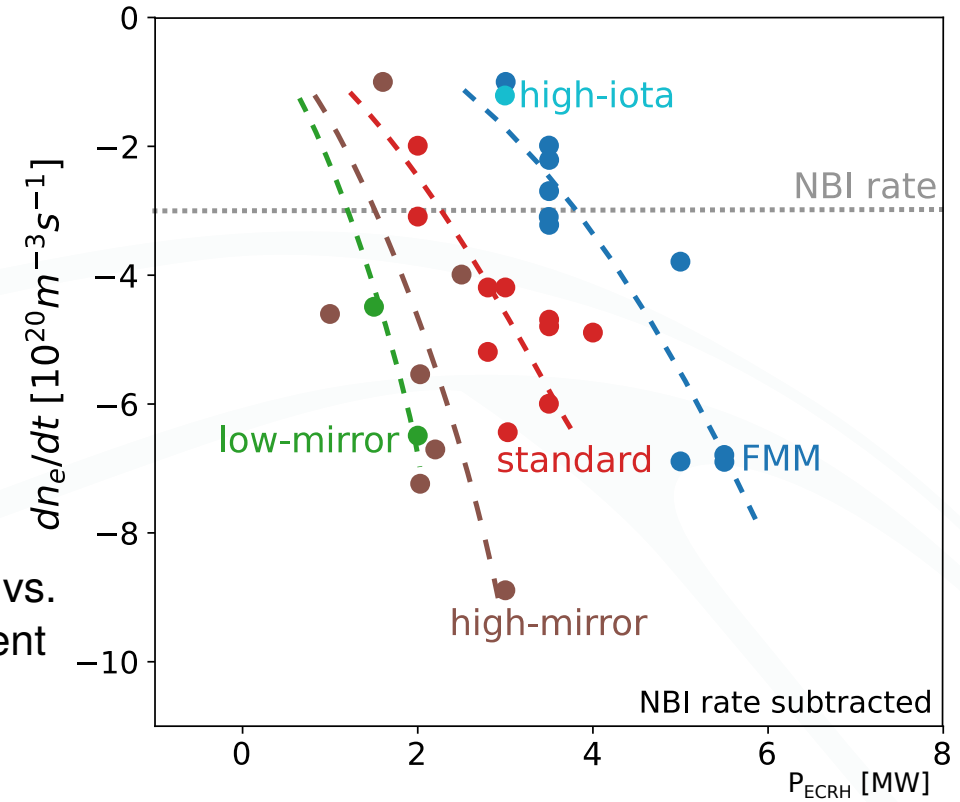
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'Pump-out' rate vs. power for different configurations.

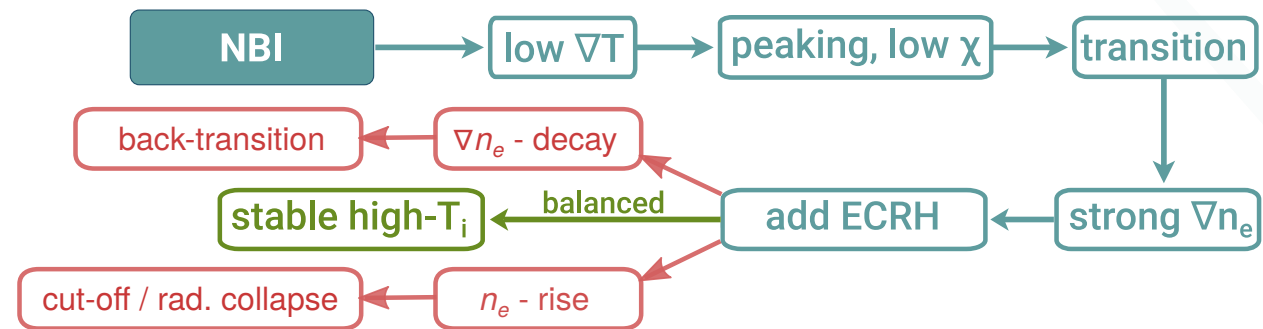
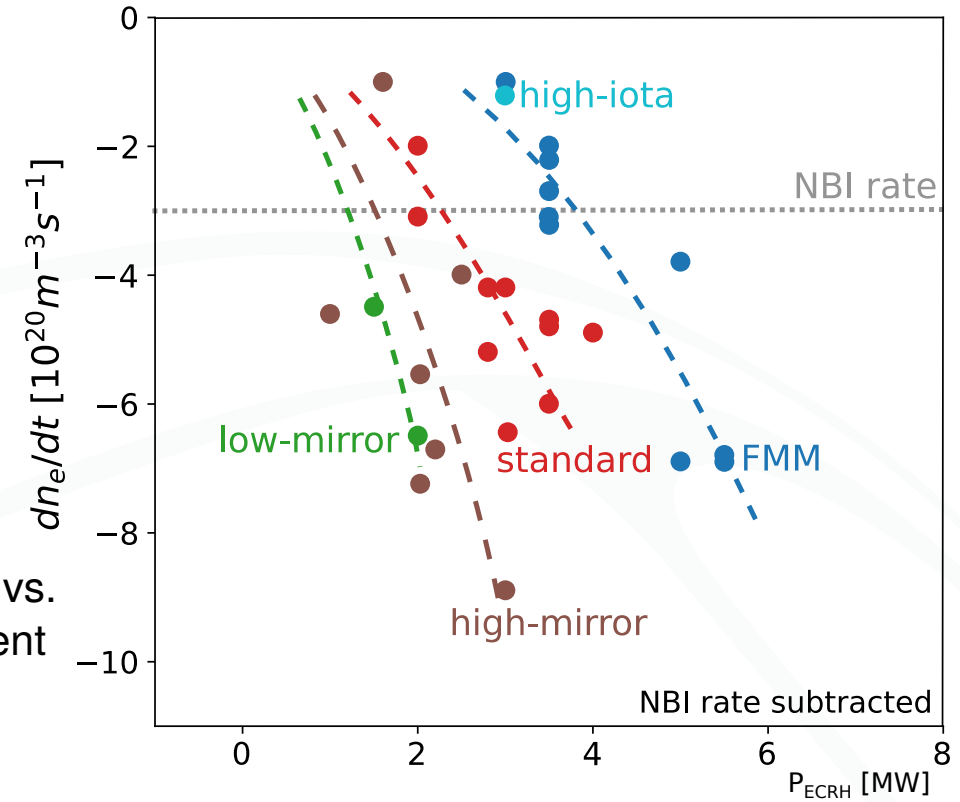


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Heating with reduced χ_i to raise plasma temperature.

- Similar to post-pellets, but with particle source.
 - Density evolution depends on ECRH power.
 - Compensate particle source
⇒ balance for steady state
 - Balance strongly configuration dependent
 - Many significant contributions:
 - Beam deposition change.
 - Recycling flux change.
 - Neoclassical flux.
 - Turbulence flux.
 - *Other anomalous effects??*
- ⇒ Need systematic scans with good data.

'Pump-out' rate vs. power for different configurations.

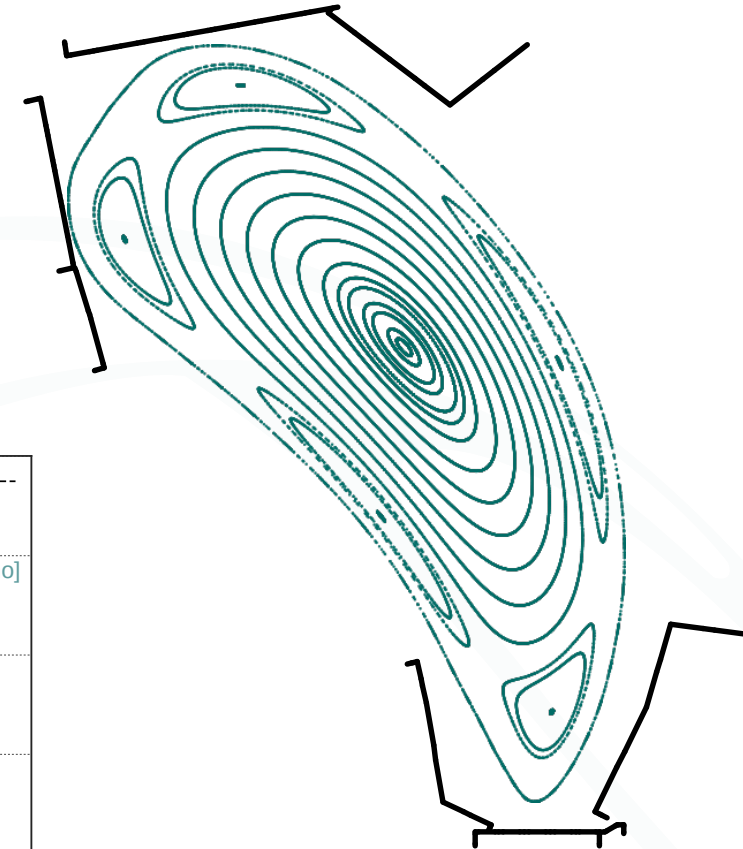
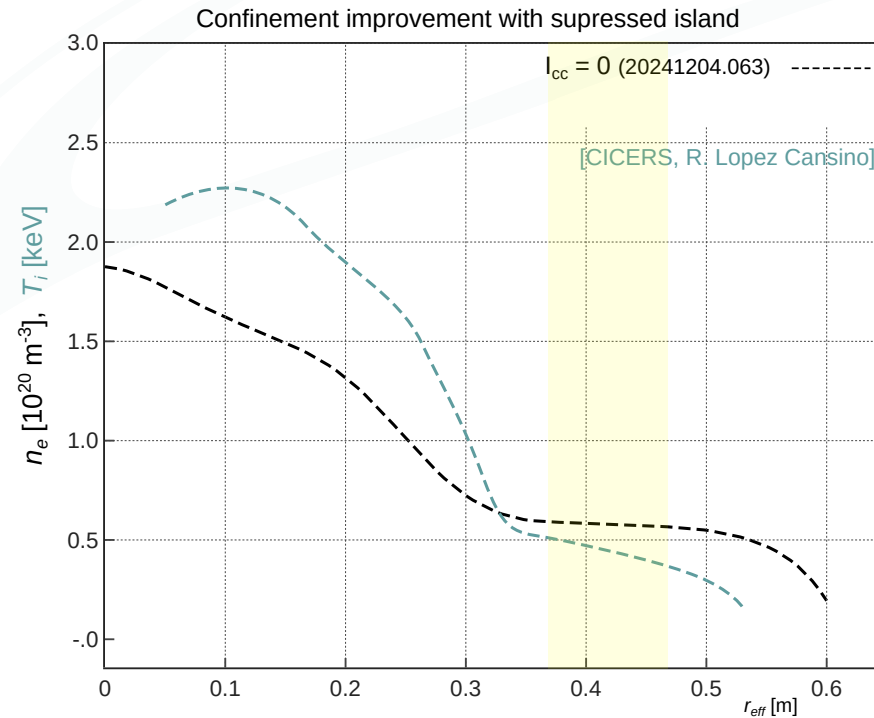


Scenario 4: NBI + ECRH reintroduction - FMM002



The balance depends on configuration

- Best in high(er)-iota: FTM/FMM002
- FMM002 has higher volume, but T_i flattened due to internal island [Lopez Cansino]

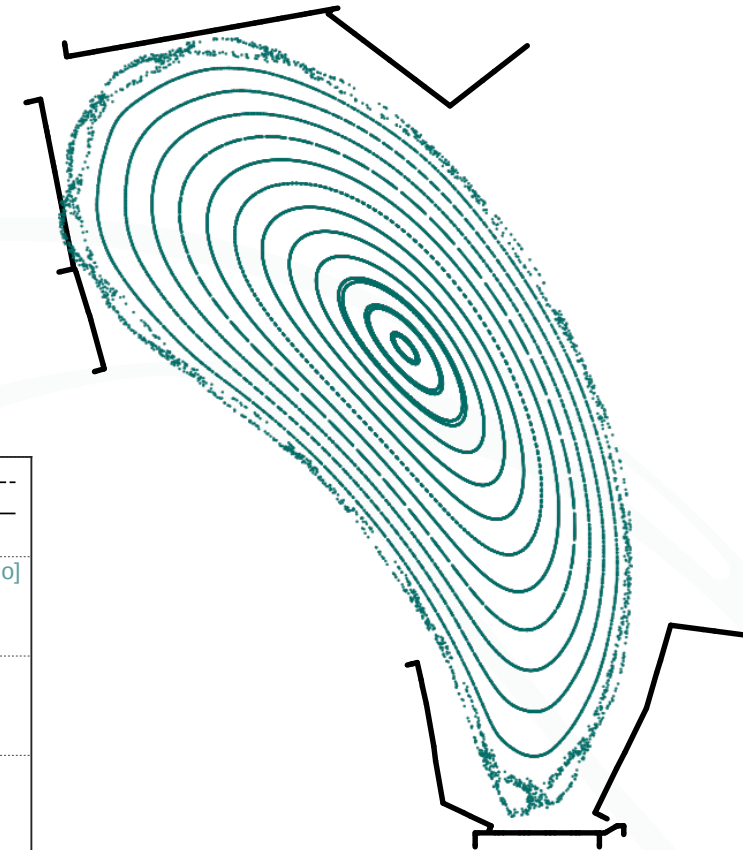
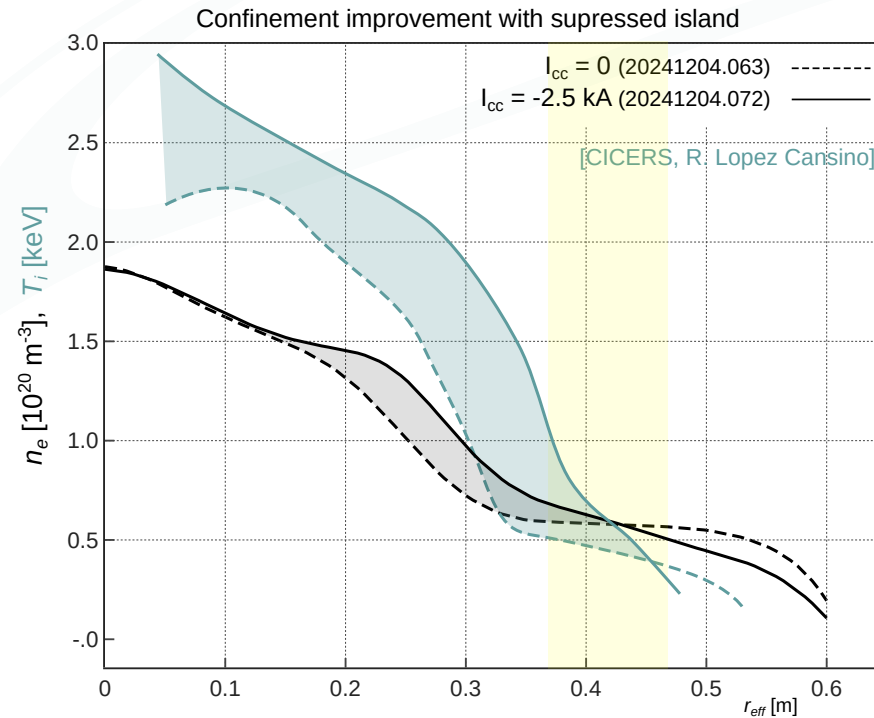


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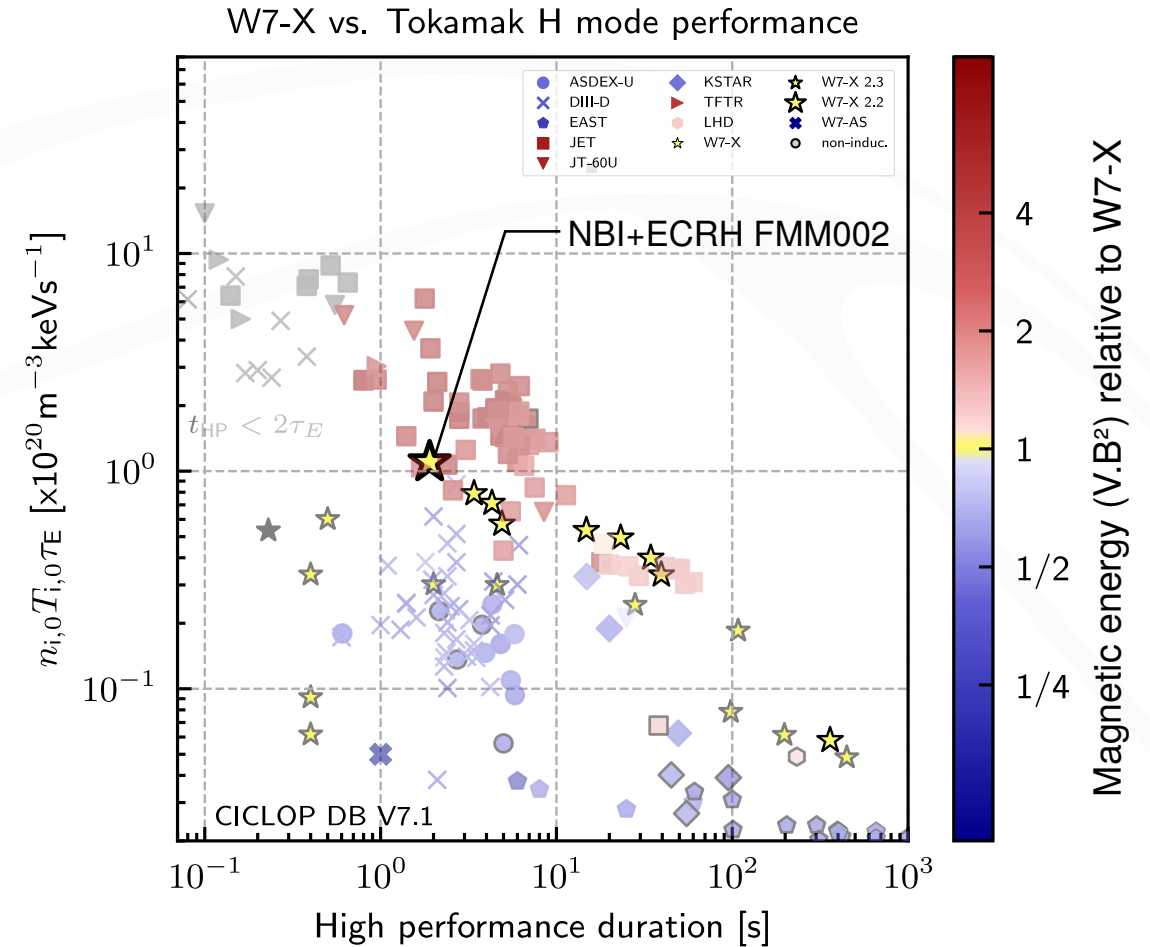
- Best in high(er)-iota: FTM/FMM002
- FMM002 has higher volume, but T_i flattened due to internal island [Lopez Cansino]
- Island suppressed with control coils
 - > Larger radius of gradients.
 - > Higher core T_i + higher stored energy



Scenario 4: NBI + ECRH reintroduction - duration



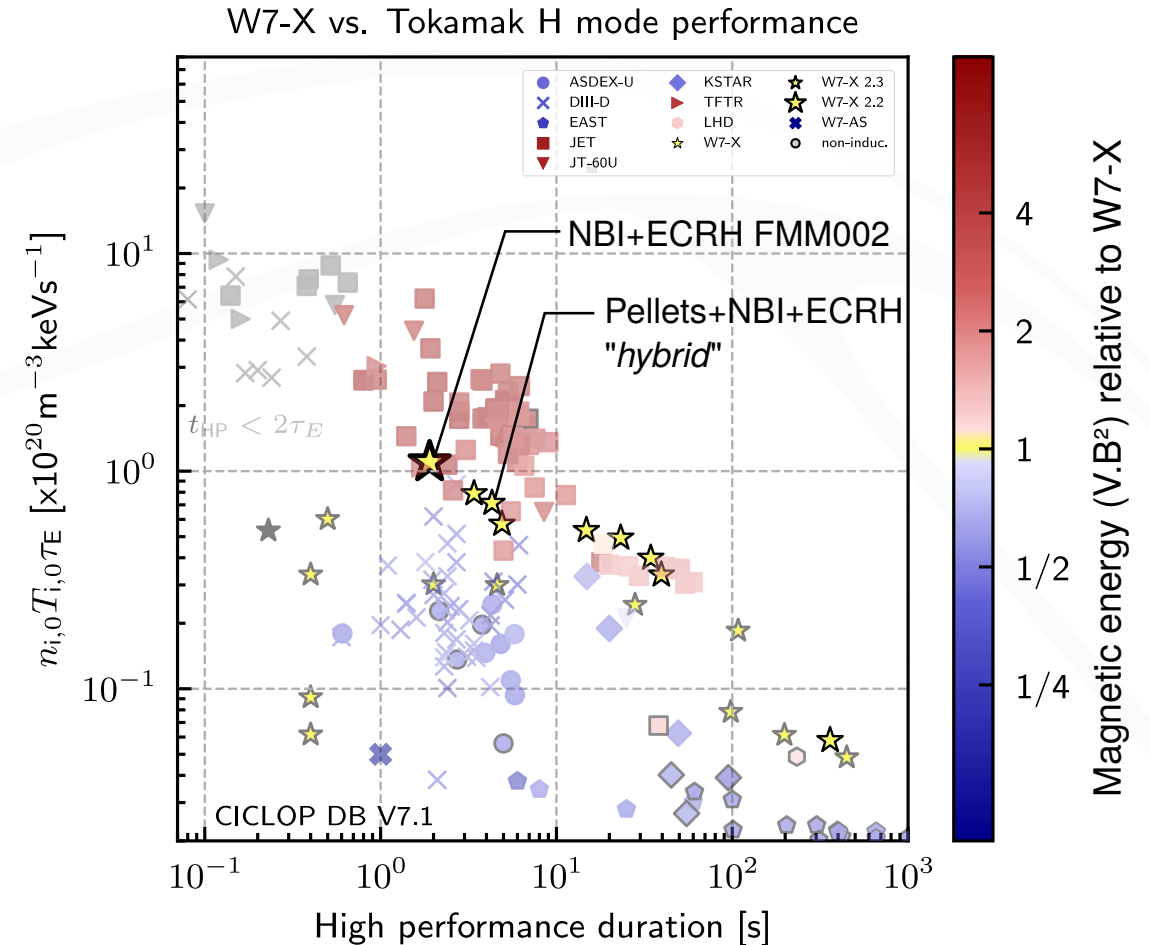
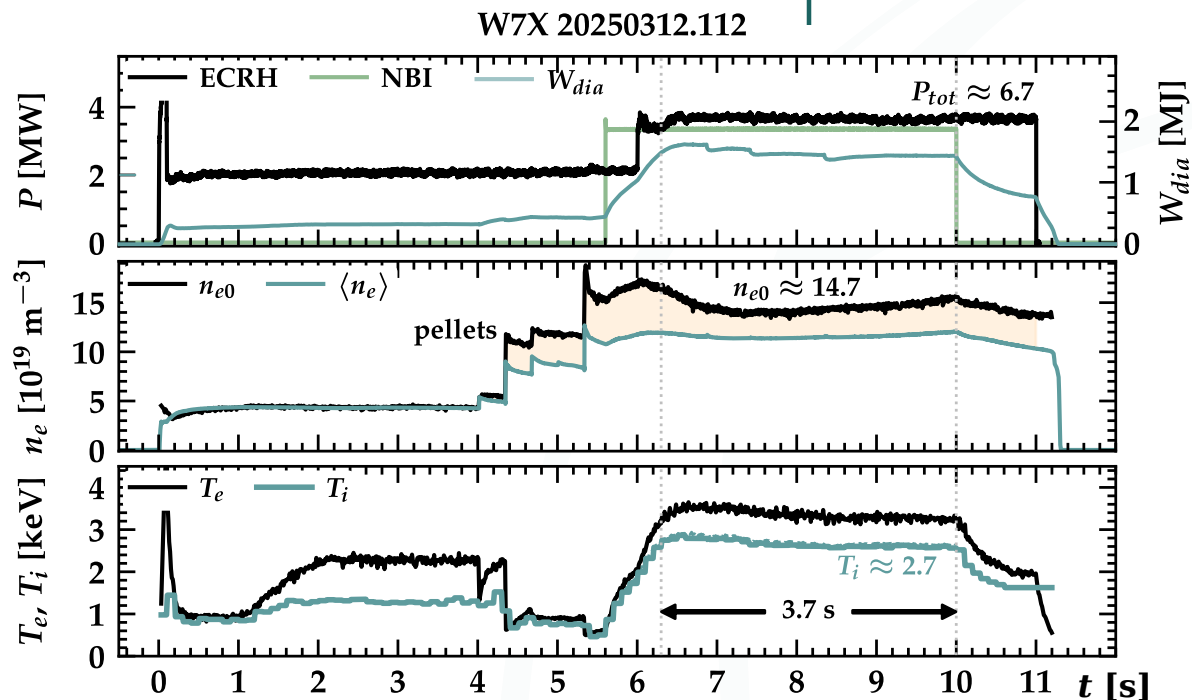
The FMM002 gives record $n T \tau_E$ equivalent to Tokamak H-modes of same size+field for 1.9 seconds.
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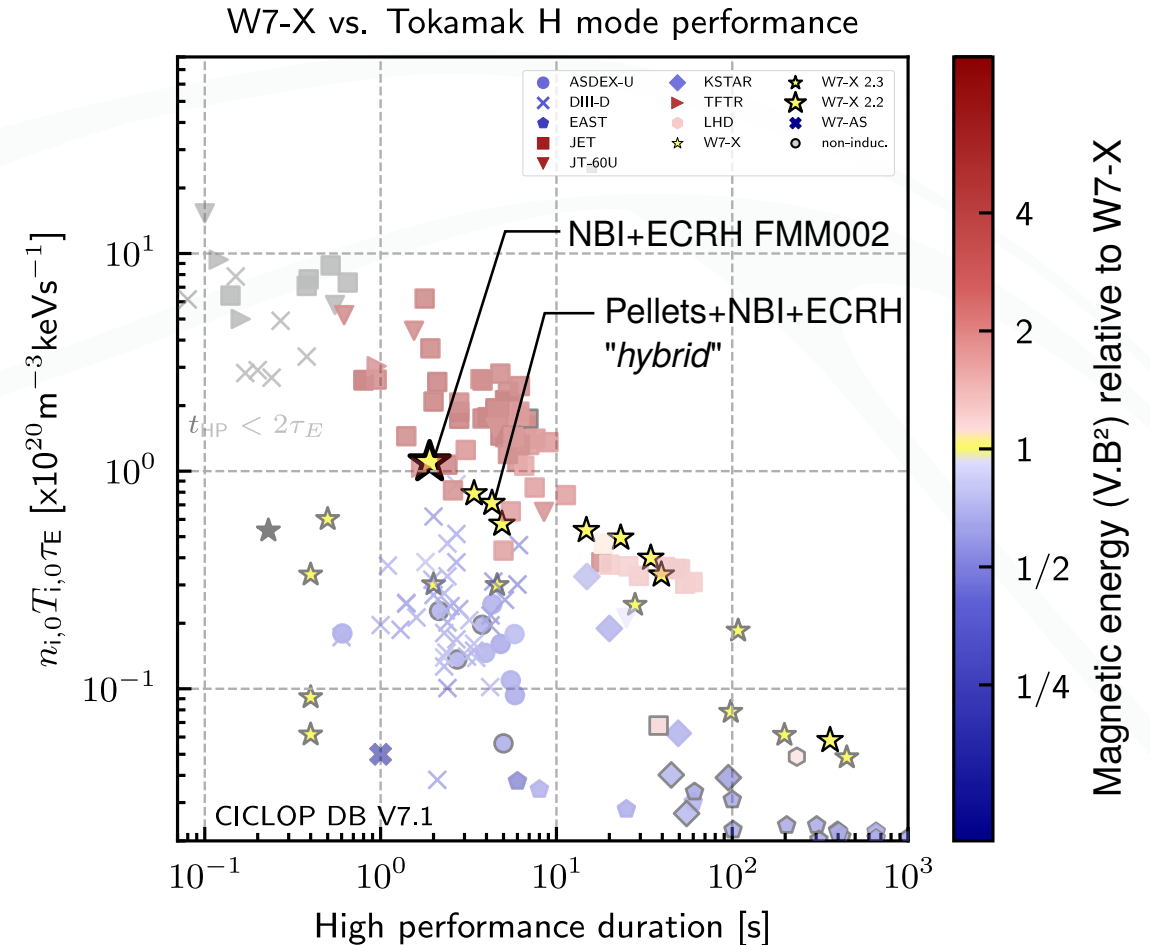
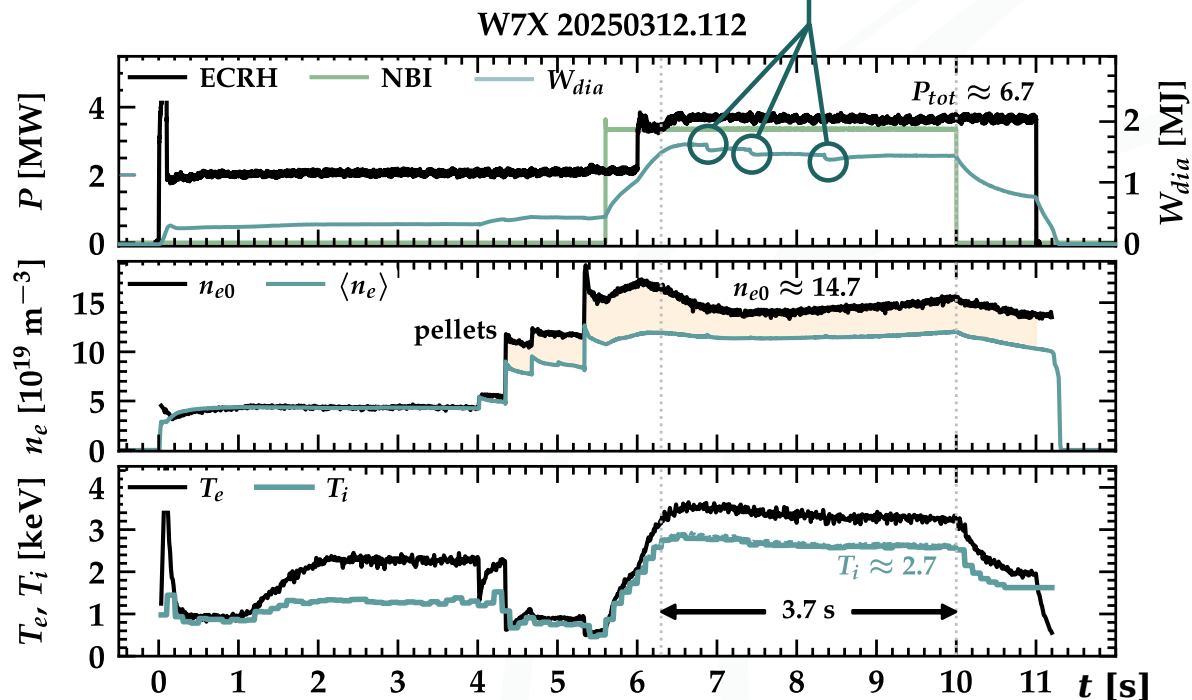
- Hybrid scenario with short pellet chain to create initial density gradient --> Slightly longer (more time for HP)
- Fast crashes --> MHD?



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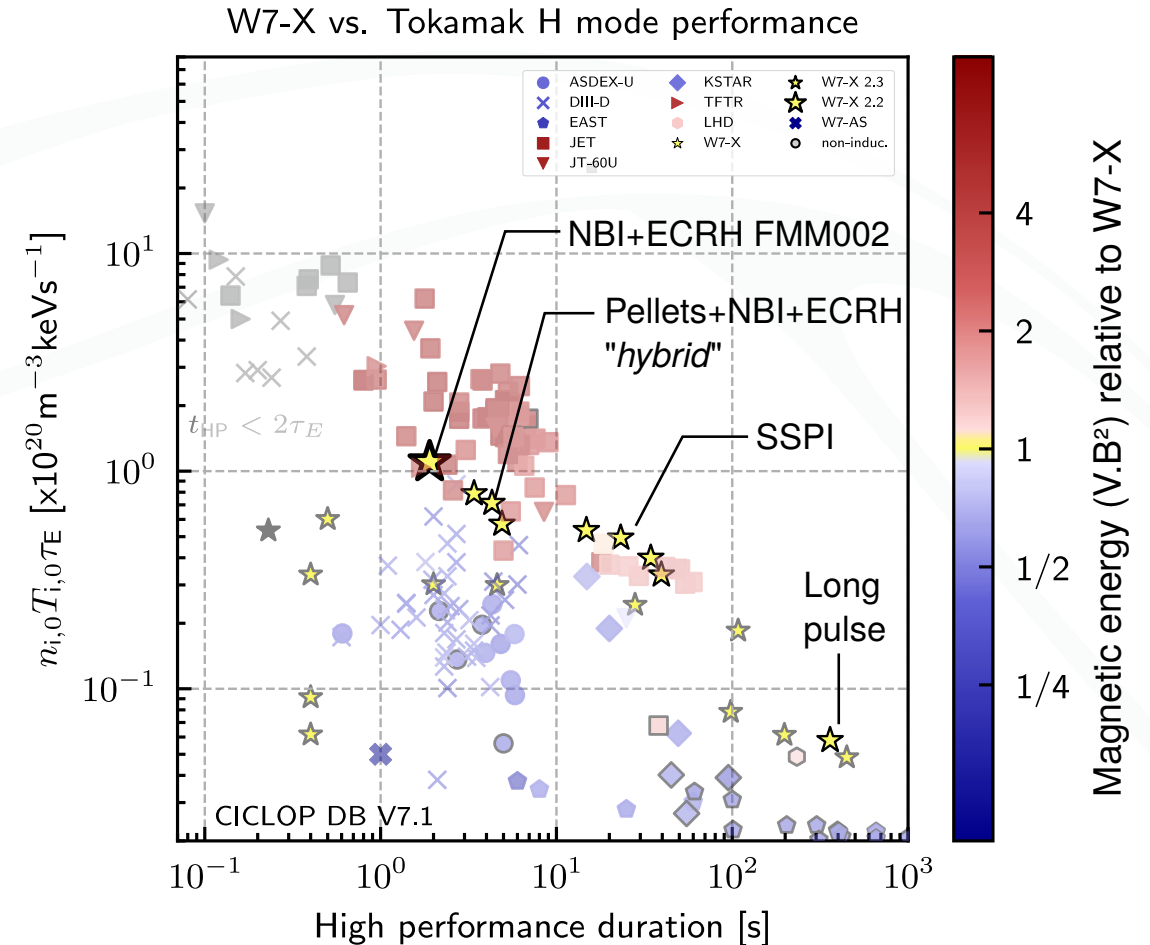
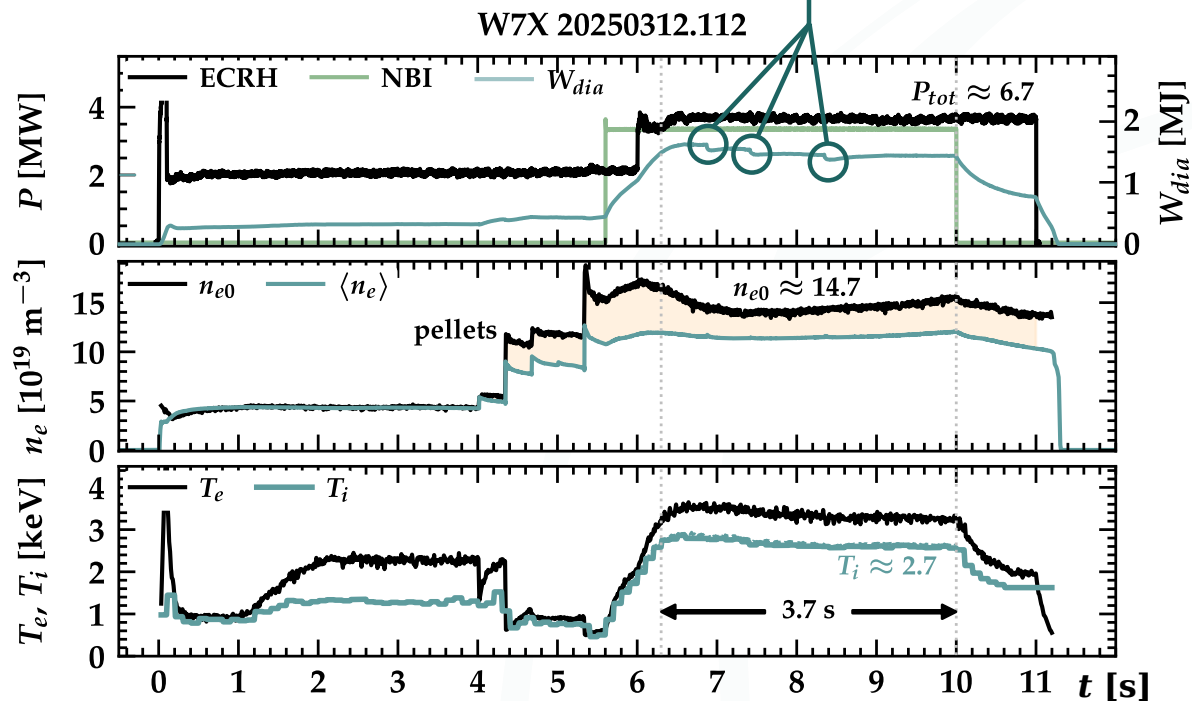
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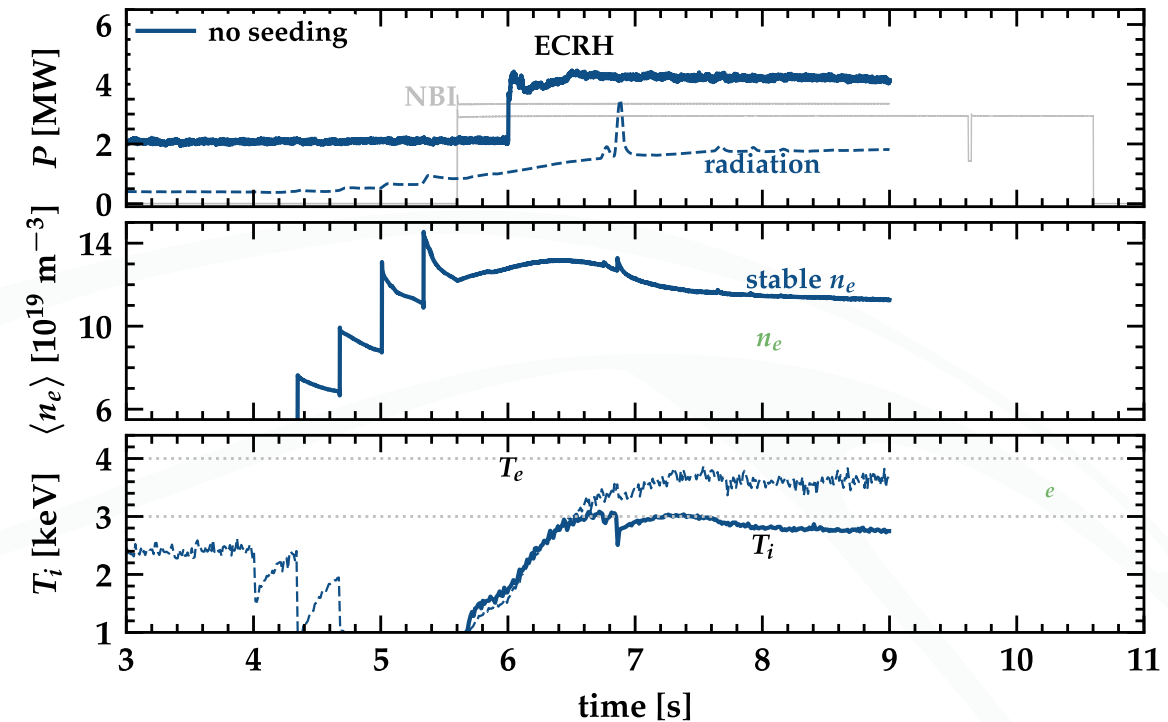


Scenario 4: NBI + ECRH reintroduction - seeding



Unable to extend/repeat:

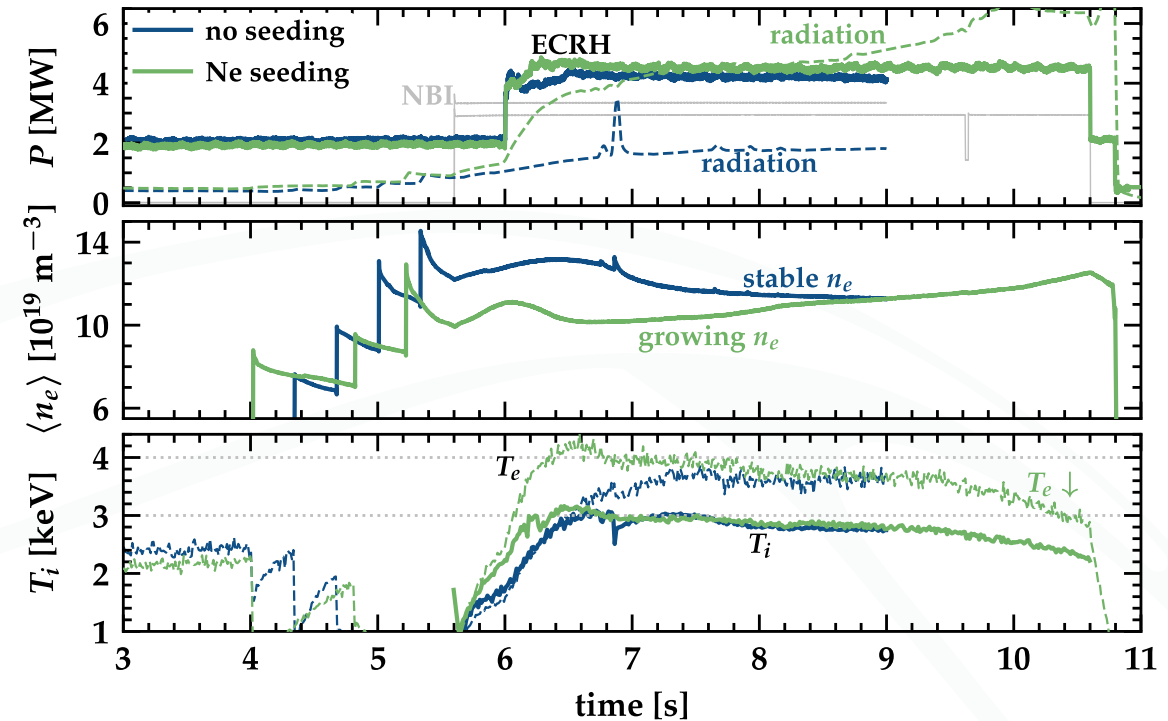
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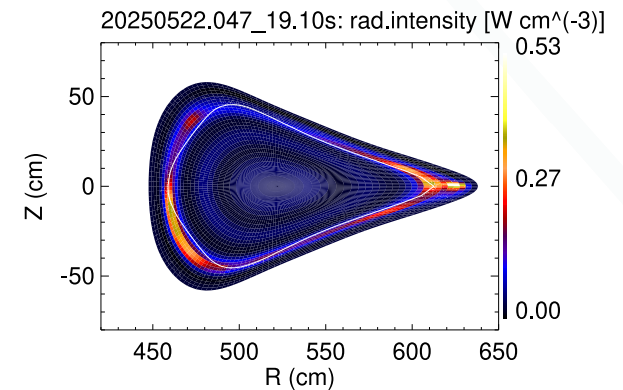
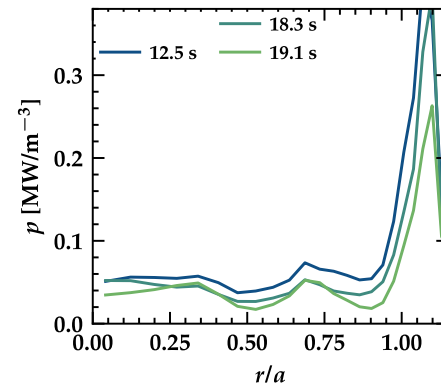
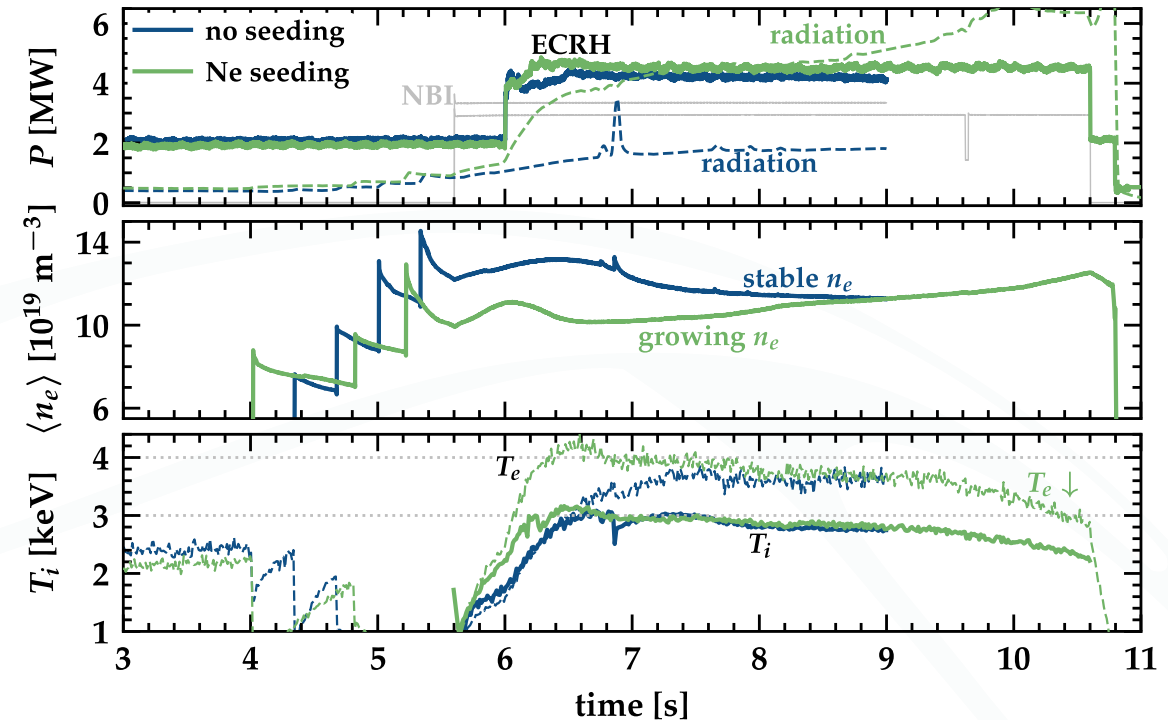


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Impurity accumulation (see T. Romba's talk)

- +0.5MW core radiation
less power flux at gradient region.
⇒ Too low pump-out ⇒ rising density



20250522_047_19.10s: rad.intensity [W cm⁻³] Thu Jun 5 09:15:09 2025

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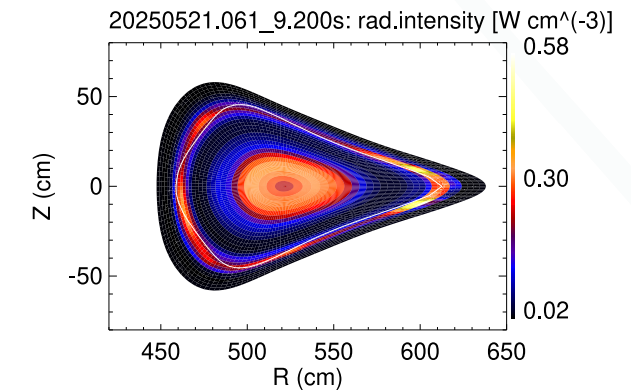
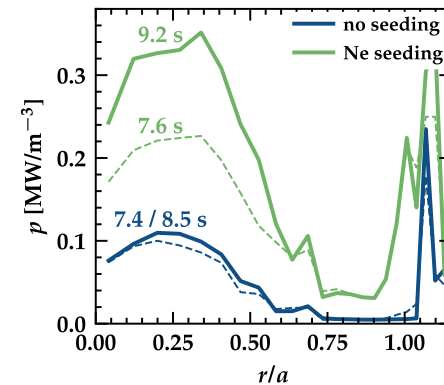
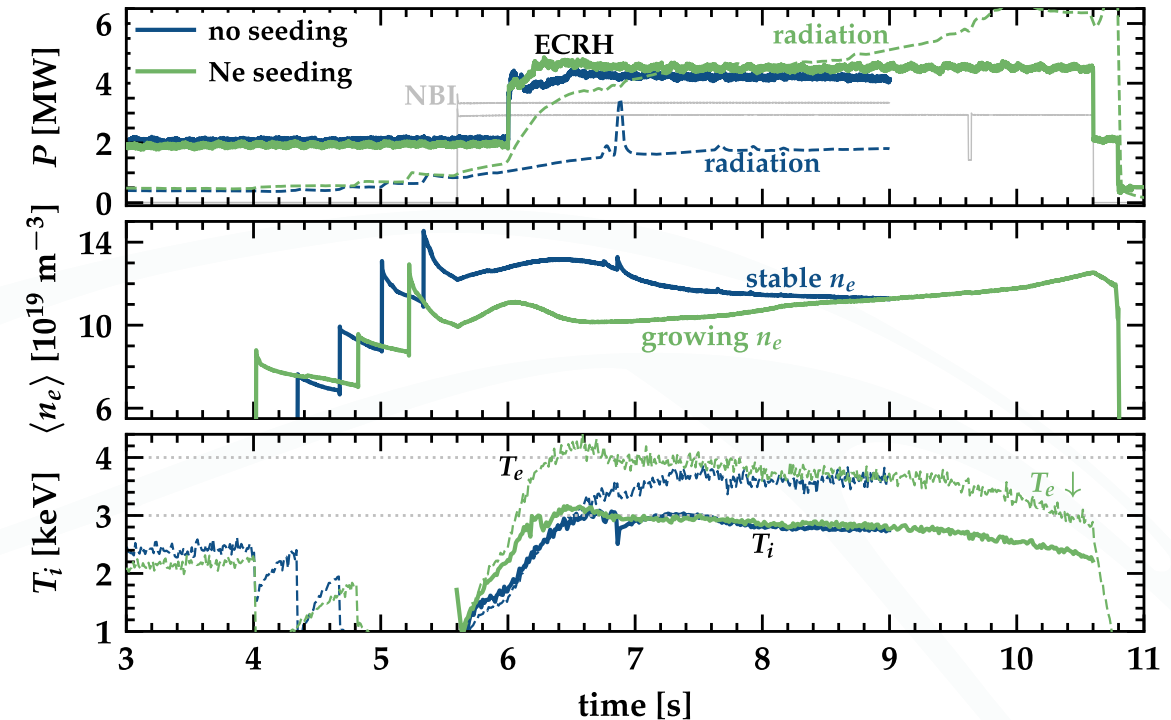


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Impurity accumulation (see T. Romba's talk)

- +0.5MW core radiation
less power flux at gradient region.
⇒ Too low pump-out ⇒ rising density
- Raising power by 0.5MW works, but now
pump-out varies also with impurity content.
⇒ feedback control required.



20250521_061_9,200s: rad.intensity [W cm⁻²] Fri Jun 6 10:42:51 2025

Density profile control



Maintaining density gradients is now too difficult.

ECRH pump-out effect depends on:

- Initial conditions (n_e , a/L_n , a/LT_e , a/LT_i , Z_{eff} )
- Pellet size variation + NBI breakdowns (20ms) change initial conditions.

Density profile control

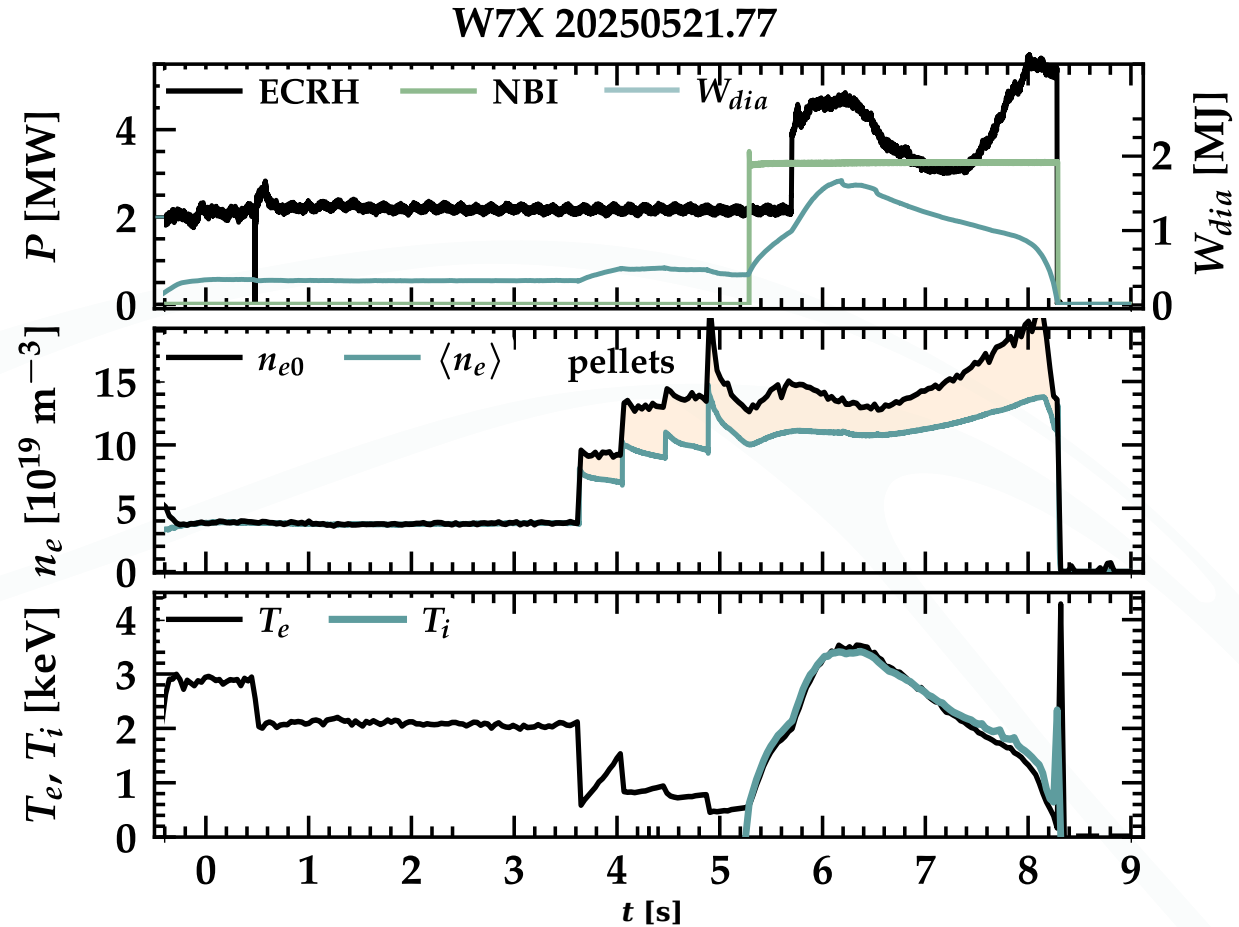
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Tested feedback of ECRH vs density [L. Krier].

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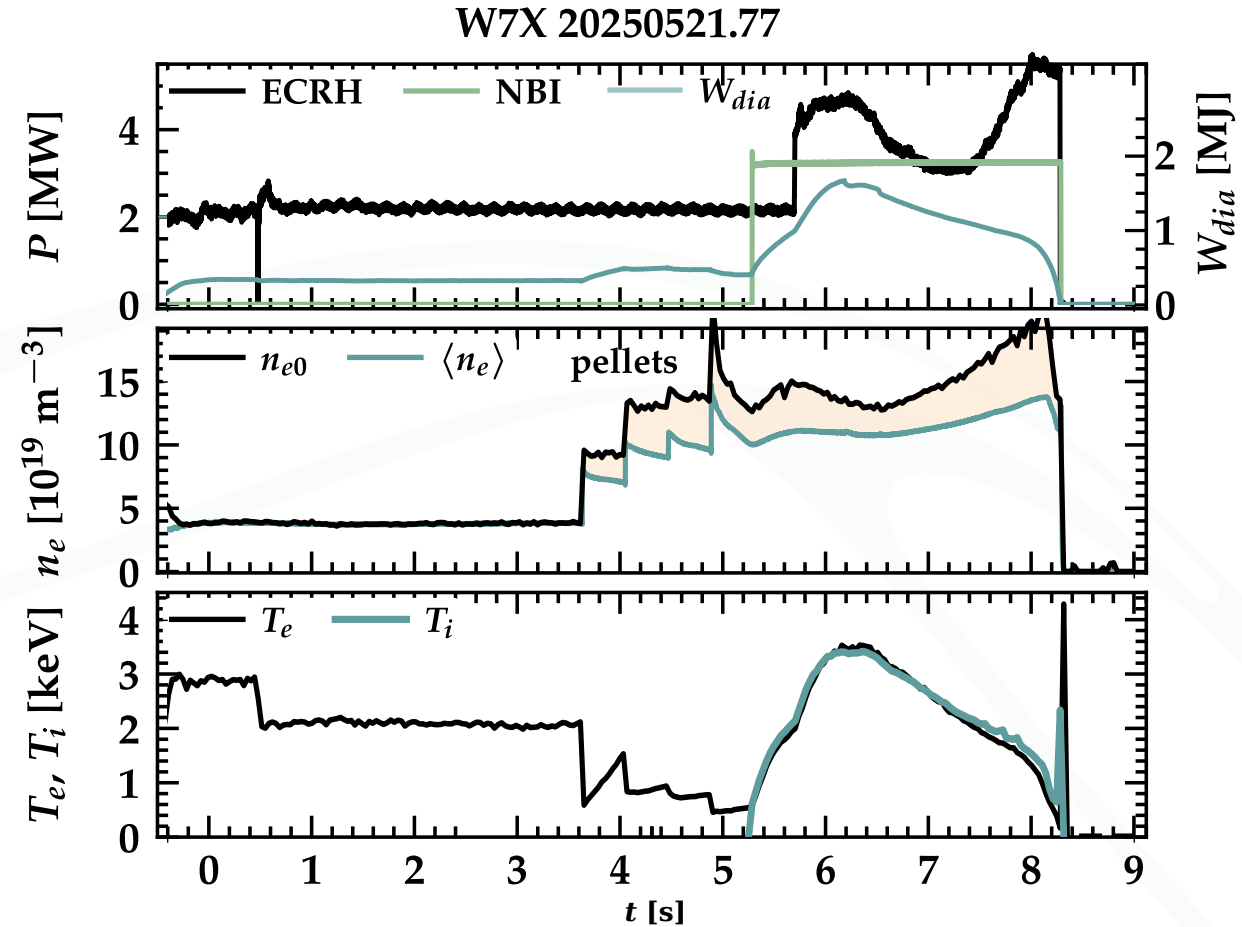
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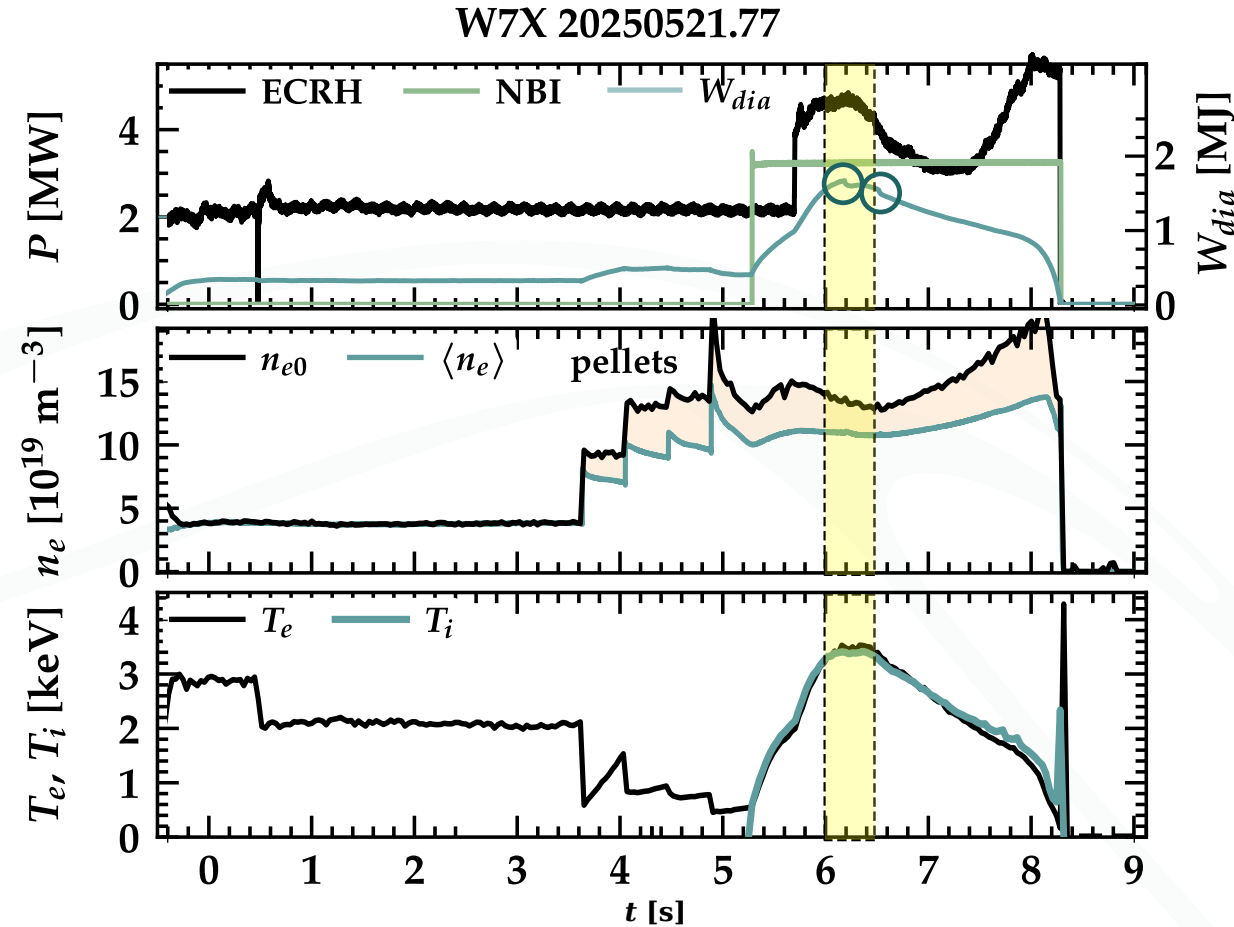
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- Requires live feed of P_{ECRH} to controller of radiation power fraction [V. Perseo].
- This was briefly $T_i = 3.5$ keV, $W_{dia} = 1.5$ MJ with **small crashes**.
Deliberate overshoot and then recovery for pulsed high beta studies?



- 1) NBI peaking rate:
 - EIM + FTM: finer scan of pure NBI sources including modulations - 0.5, 1.0, 1.5, 2.0, 2.5.
 - Other configs: Main steps to compare: 1,2,3,4 sources. Not expecting anything.

 - 2) ECRH pump-out:
 - EIM + FTM: full scan. Finer around balance point but including min/max P_{ECRH} .
 - Other configs: Big steps to find balance and document way too much and way too little P_{ECRH} .

 - 3) Initial conditions - systematic look at pump-out of same P_{ECRH} but different start conditions:
 - Reintroduction time - Full scan of t_{ECRH} for same P_{ECRH} . EIM
 - Drop NBI power $\sim 0.2\text{s}$ before reintro (yes, I know this is fariyl doomed to failure)
- Re-try the 'early start' (low-field-like) NBI peaking to get over the a/Ln threshold with low edge density.

Others looking at this:

- Sebastian Bannmann, Emil Overduin

- generally other people always try this in new configurations.

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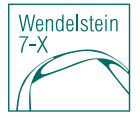
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Particle transport proposals



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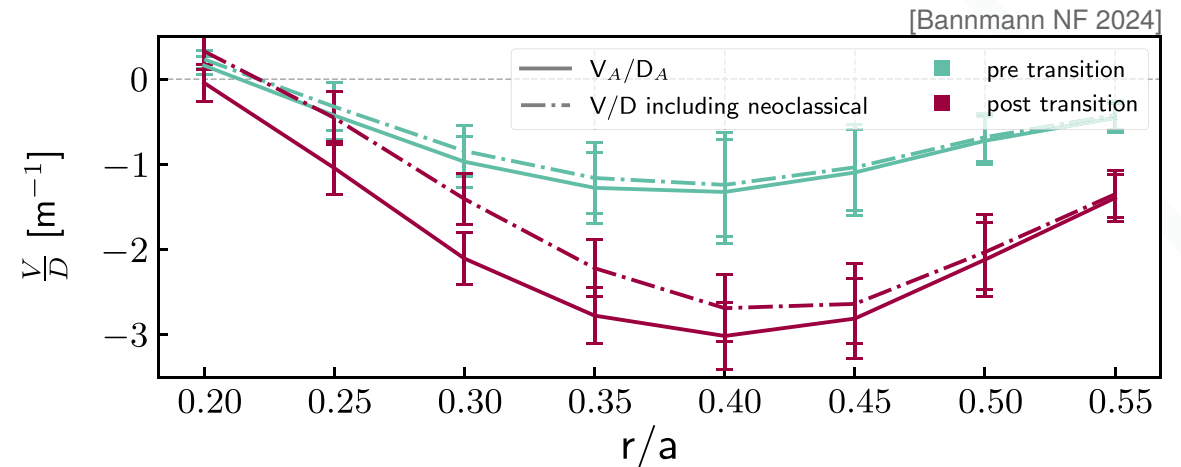
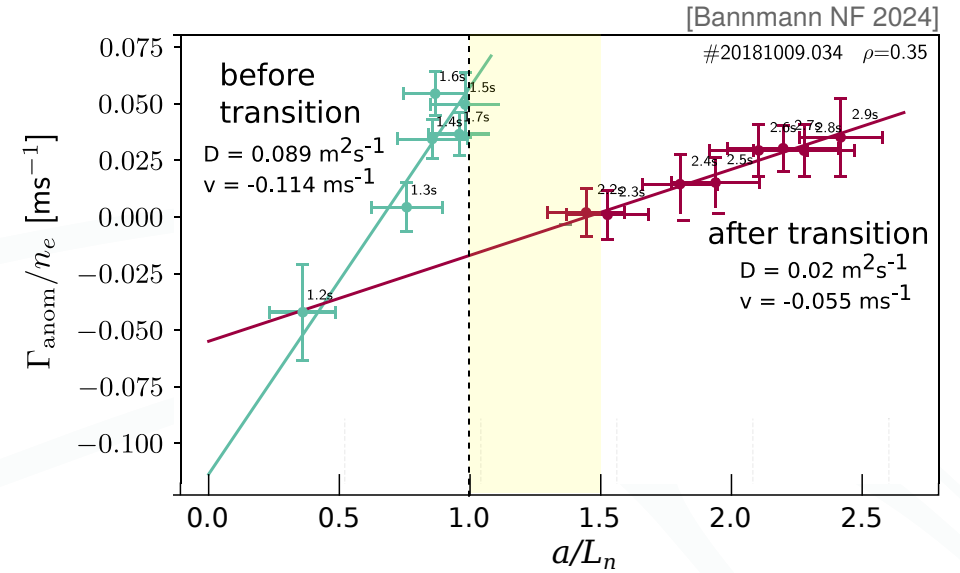
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NBI - particle transport

Particle transport easier to study in NBI

[Ford NF 2024; Bannmann NF 2024]

- Sudden drop of particle diffusion past $a/L_n \sim 1.0$
- v/D reduced by $\sim x3 \Rightarrow$ stronger peaking



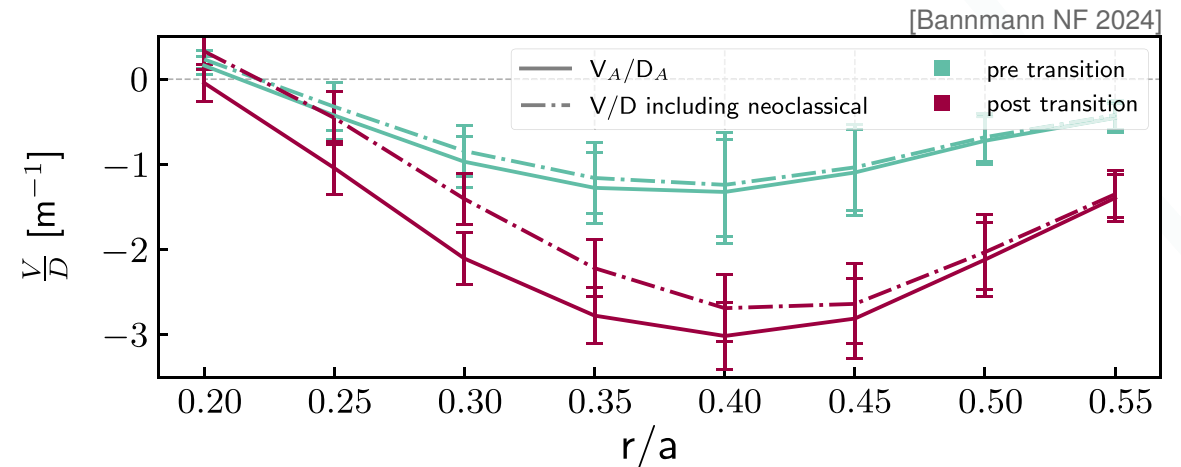
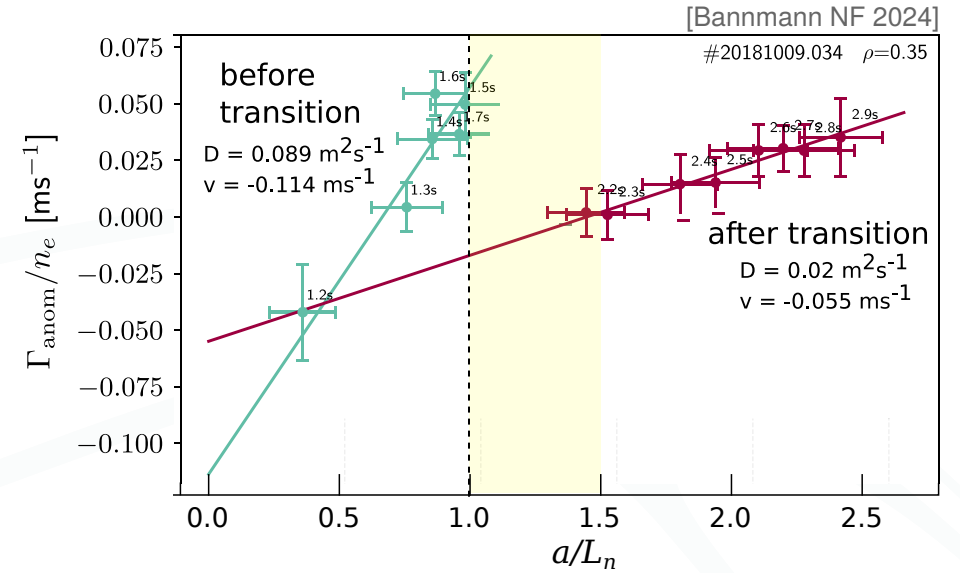
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- Final gradient would be given by balance:

$$-\frac{\nabla n}{n} = -\frac{v}{D} + \frac{\int sdV}{V'Dn},$$



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$$-\frac{\nabla n}{n} = \underbrace{\frac{v}{D}}_{\text{Due to pinch}} + \underbrace{\frac{\int s dV}{V' D n}}_{\text{Due to source}}$$

Here $\sim 50\%$ from NBI source and pinch.

[Bozhenkov PPCF 2025 (submitted)]

