Max-Planck-Institut für Plasmaphysik

Particle and energy transport of the improved confinement NBI scenario at W7-X

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47th EPS Plasma Physics conference, 2020/1, Sitges, Spain

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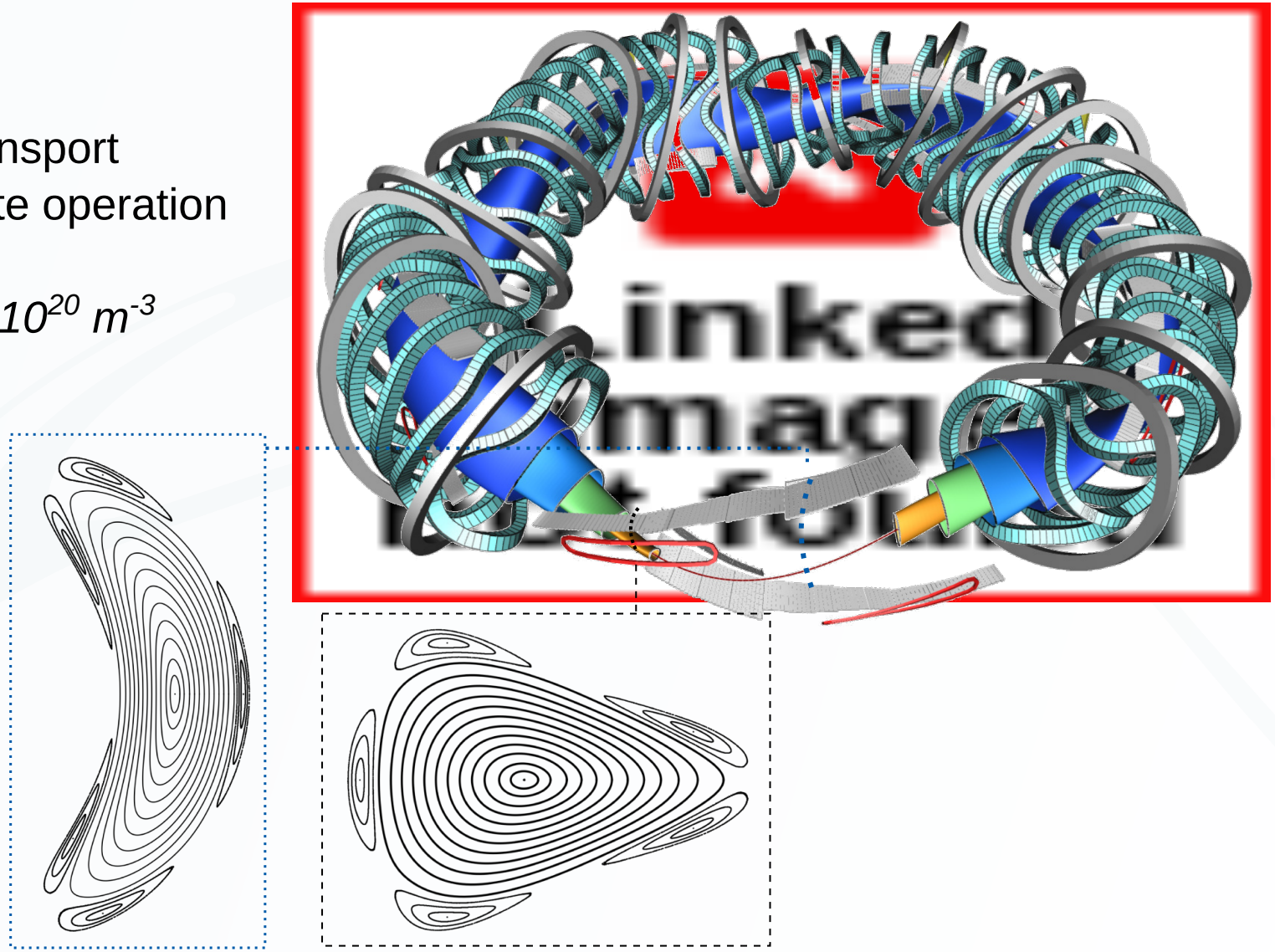
The Wendelstein 7-X Stellarator

Wendelstein 7-X:
- 5 period helixcal axis stellarator
- Optimised to reduce neoclassical transport
- Designed to demonstrate steady-state operation with continuous ECRH heating.
- Operation at high density: $n_e \sim 1.8 \times 10^{20}\ m^{-3}$

R_0	5.5 m
a	0.5 m
V	30 m^3
B_0	⩽ 3 T
ι_a $(\sim q_{95}^{-1})$	5/6 ... 5/4

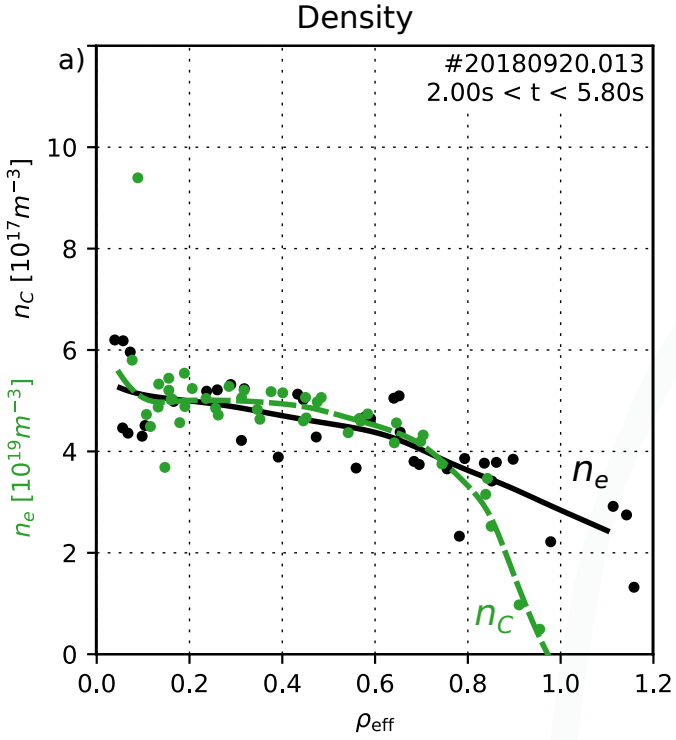
	2024	2026+
pulse	200s	30 min
ECRH	7.5MW	10 MW
NBI	2.6MW	5.2MW
ICRH	-	1.5MW

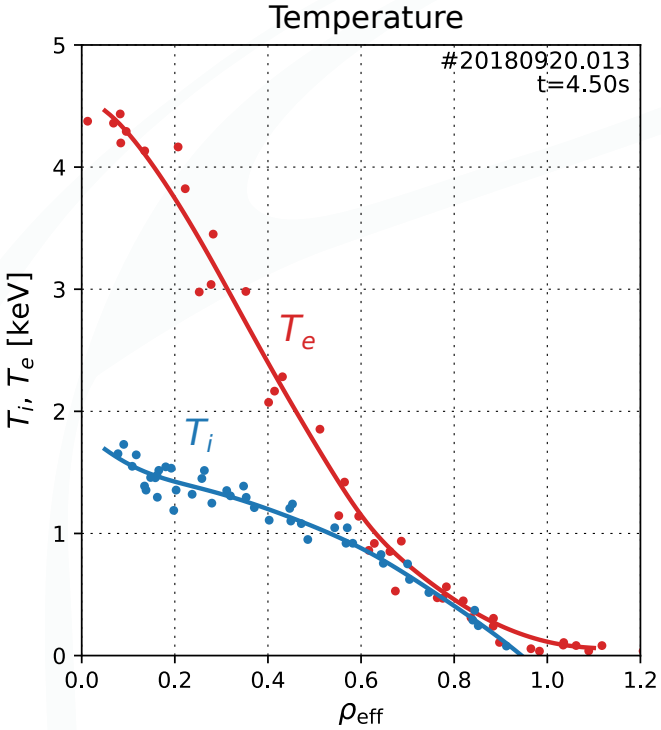


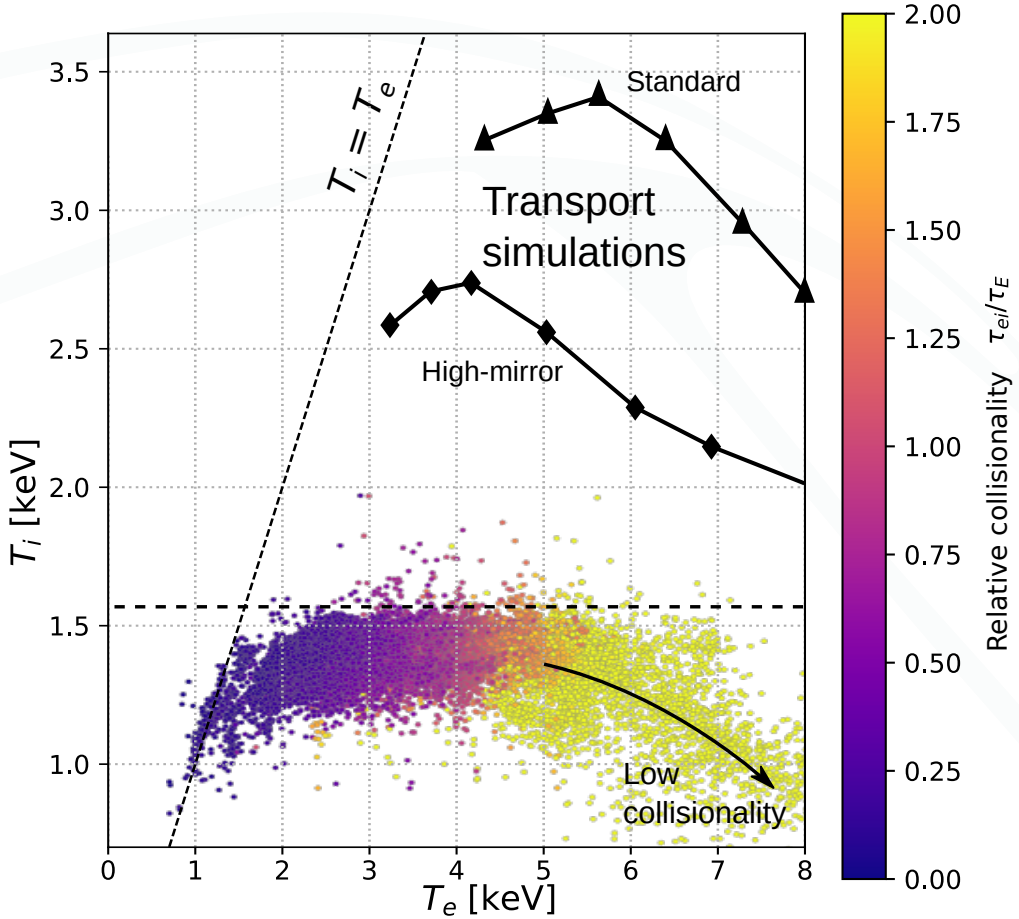
Gas-fuelled ECRH discharges

Typical scenario for long pulse, divertor experiments, parameter scans etc:
- Gas/recycling fuelled.
- Continuous ECRH heated.

Result:
- Steady-state
- Flat ne profiles
- Core $T_i \leq 1.5$keV --> Turbulence dominates e + i heat fluxes.
- Low, flat impurity density profiles







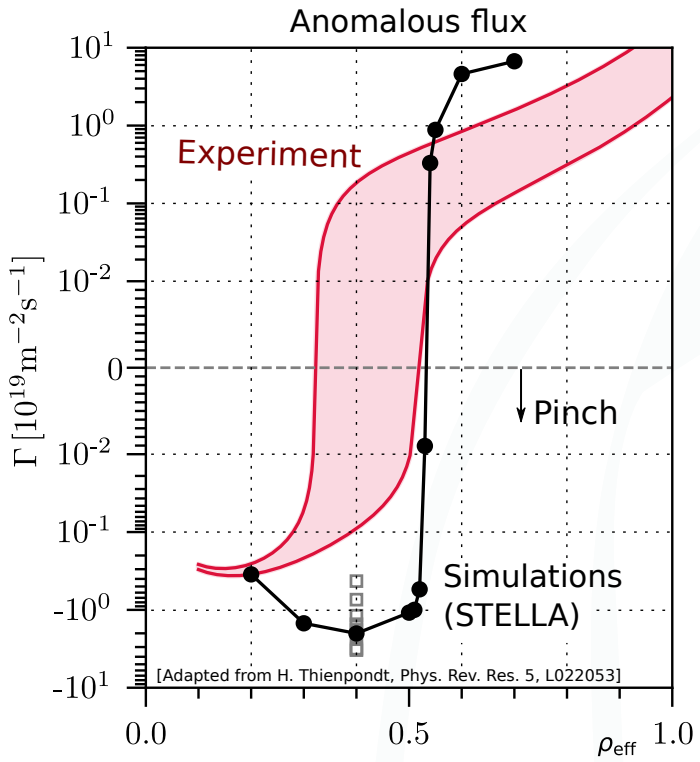
Gas-fuelled ECRH discharges

Main ions:

Neoclassics --> hollow, Experiment = flat

- Requires requires core anomalous pinch.
- Pinch is seen in some new gyrokinetic simulations

  [H. Thienpondt, Phys. Rev. Res. **5**, L022053 (2023)]
- No quantitive understanding.
- Difficult without measured neutral fuelling profile.



Impurities:

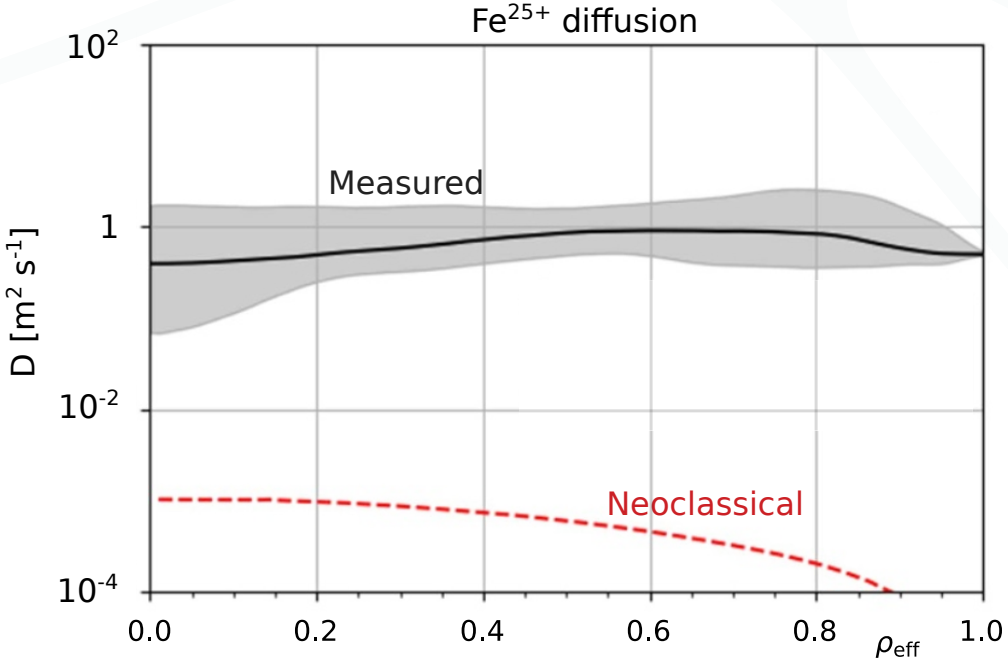
Neoclassics --> peaked, Experiment = flat

Require strong anomalous flux to flatten (D >> $0.1\mathrm{m}^2\mathrm{s}^{-1}$) .

[T. Romba PPCF **65** 075011 (2023)]

Measured *v,D* in LBO injections show strong anomalous diffusion

[Swee Nucl. Fus. **64** 086062 (2024), B. Geiger Nucl. Fus. **59** 046009 (2019)]

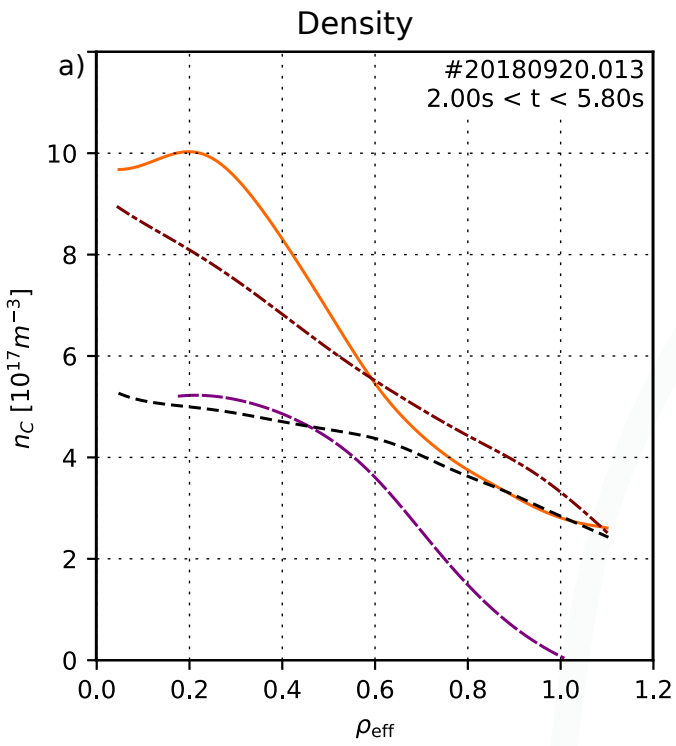


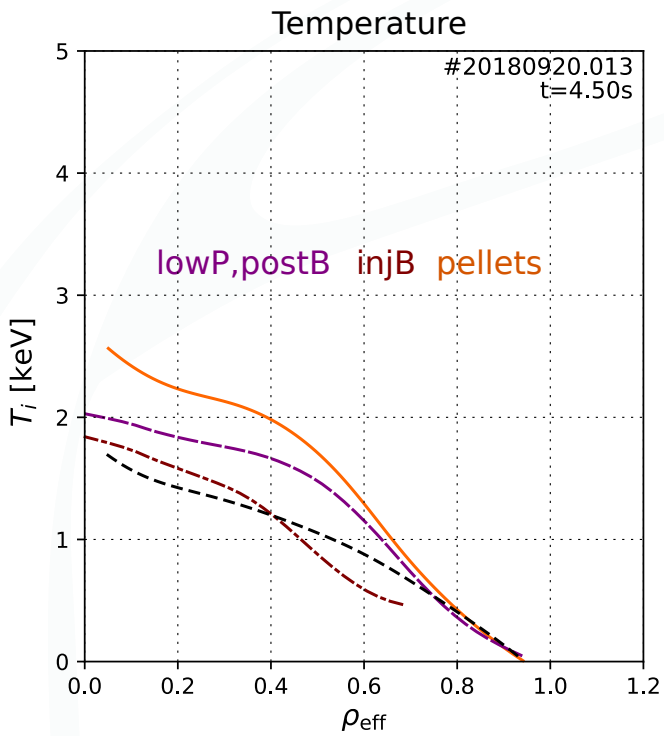
Reduced turbulent transport scenarios

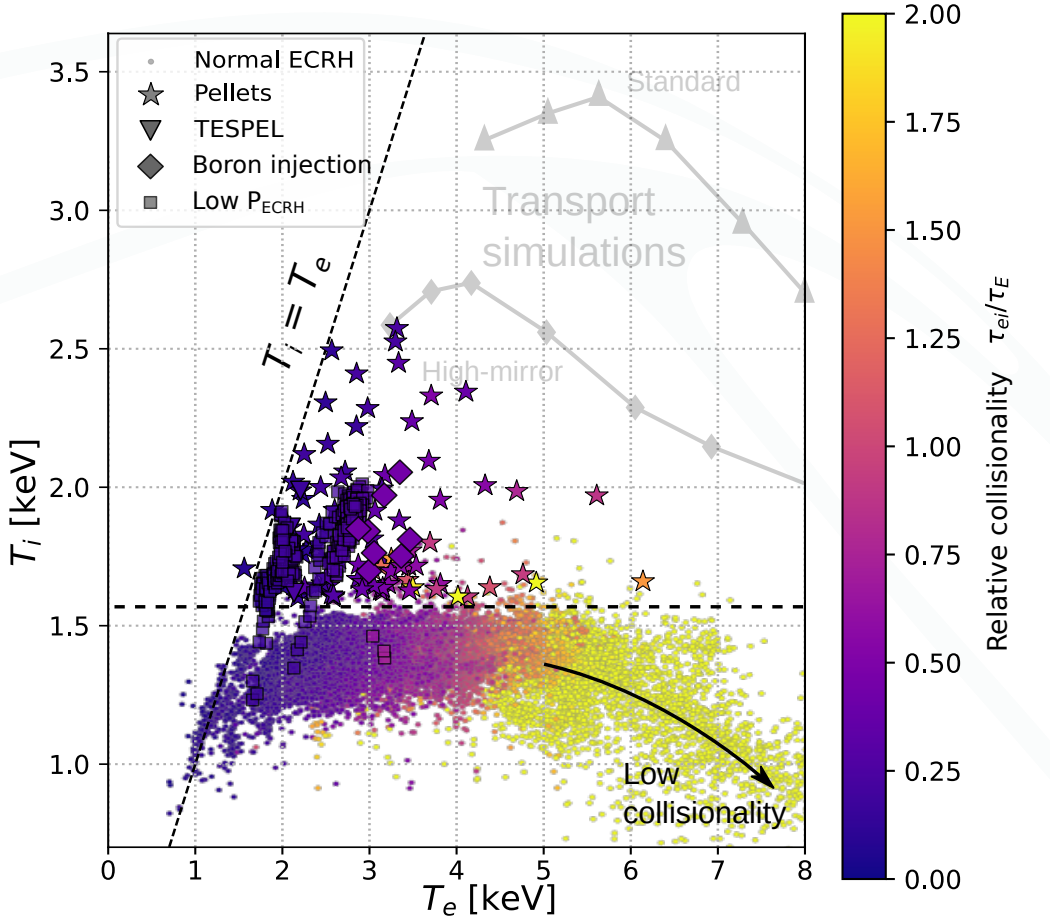
Varous scenarious show effects of reduced turbulence:

- After pellets --> peaked n_e, peaked n_z --> neoclassical Q_i --> T_i > 1.5keV [S. Bozhenkov Nucl. Fusion **60** 066011 (2020)]
- Impurity pellets, boron injection --> peaked n_e --> T_i > 1.5 keV [R. Lunsford Phys. Plas. **28** 082506 (2021)]
- Some low power ECRH --> Spontaneous peaked n_e, n_Z [D. Zhang PPCF **65** 105006 (2023)]

∇n_e --> ITG suppression [P. Xanthopoulos, PRL **125** 075001 (2020)]
--> Reduced χ_i --> Higher ∇T_i *(see Poster M. Wappl)*



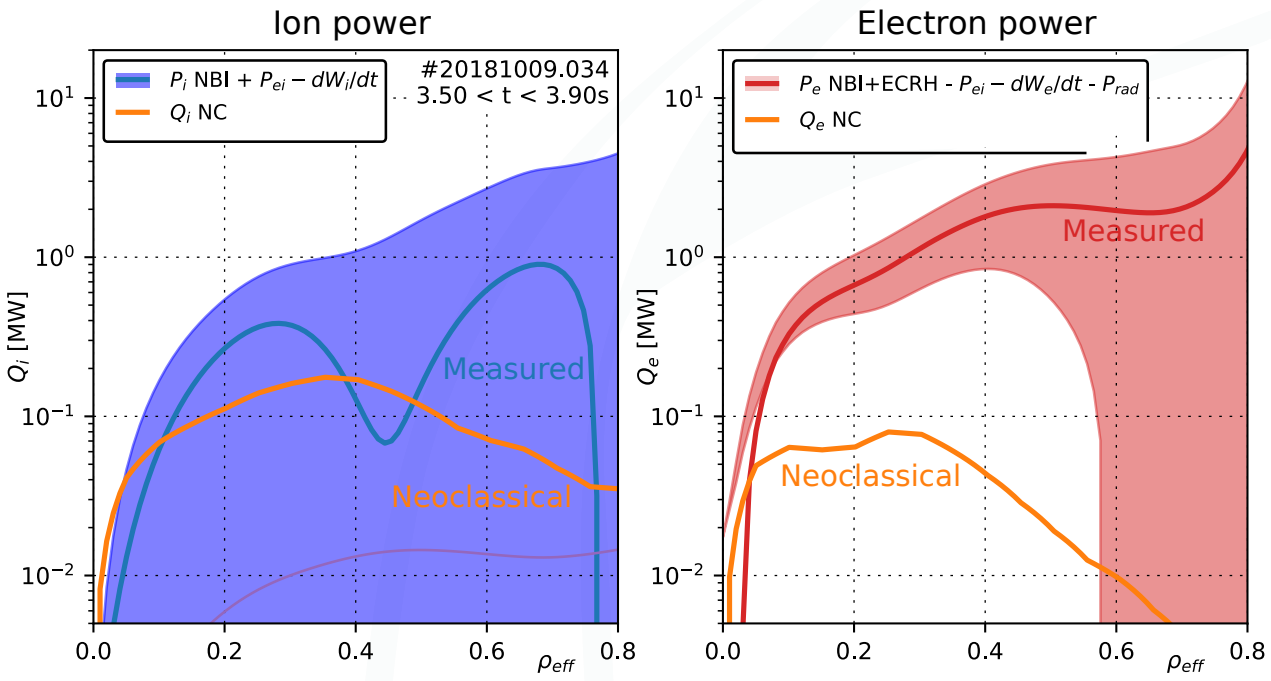


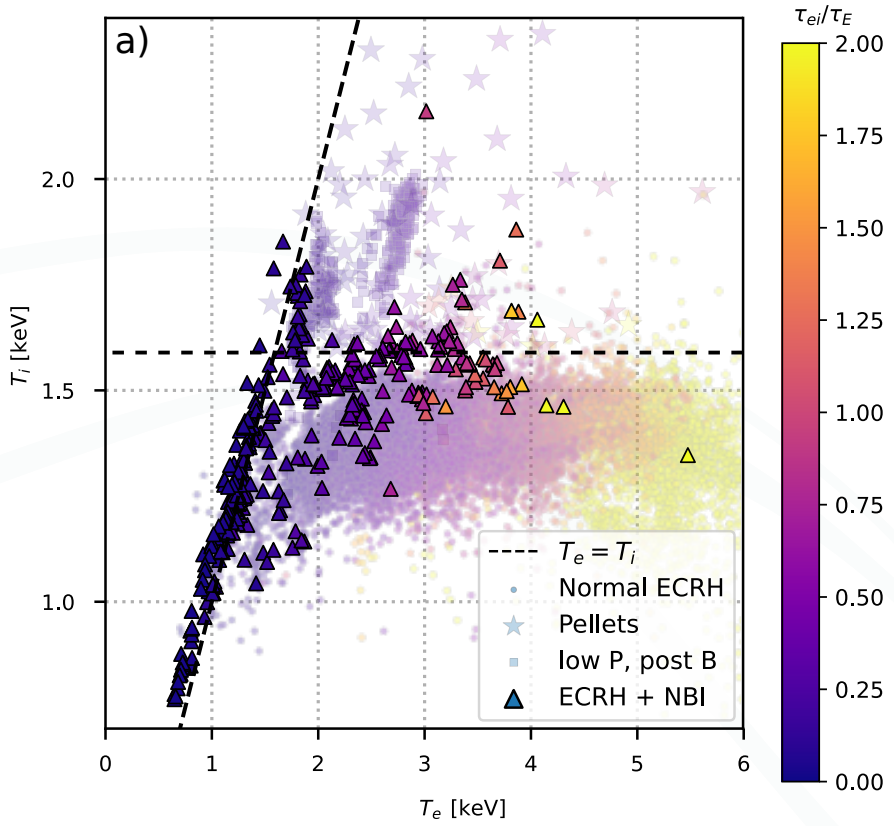


NBI (±ECRH) Scenarios

- NBI also sometimes gives density gradients.
- Is the turbulent transport reduced compared to ECRH?
  - Not immediately clear from Ti - some above Ti > 1.5
    --> need to look at transport coefficients.

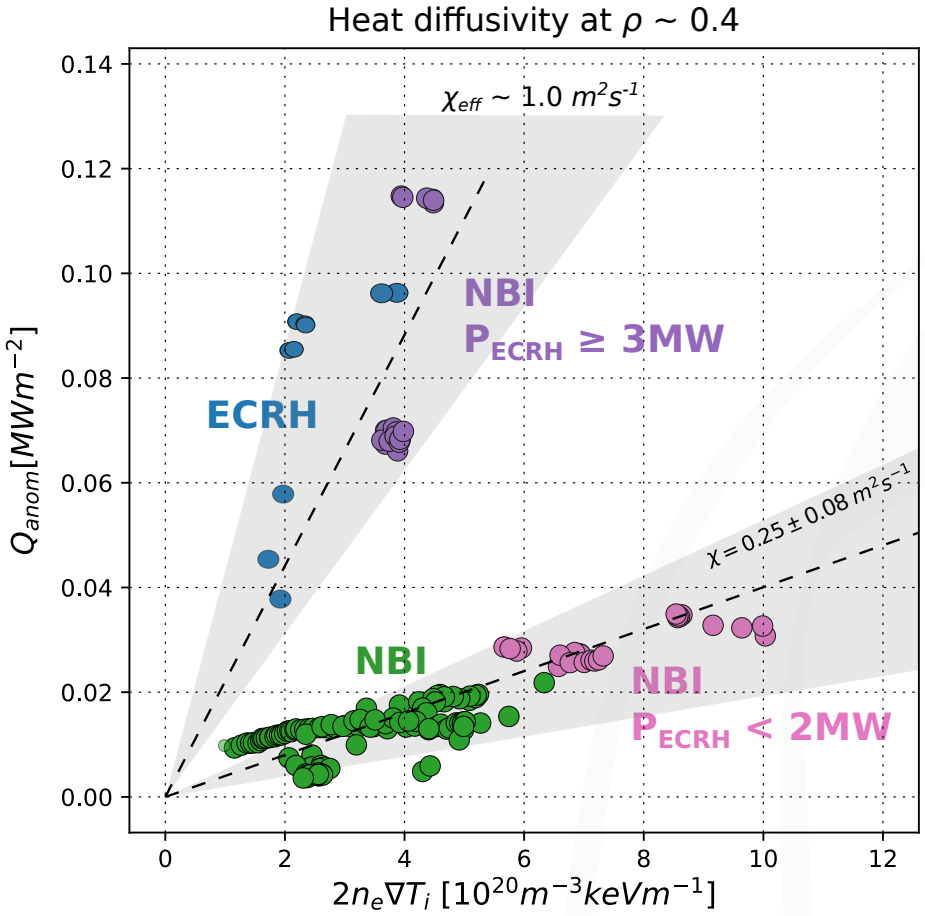
Energy fluxes:
- Pure NBI: Not possible to separate Q_i, Q_e due to high collisionality and similar heating effect of NBI - $P_e \sim P_i$.
- Some NBI+ECRH plasmas hint at **possibility** of Q_i near neoclassical levels:

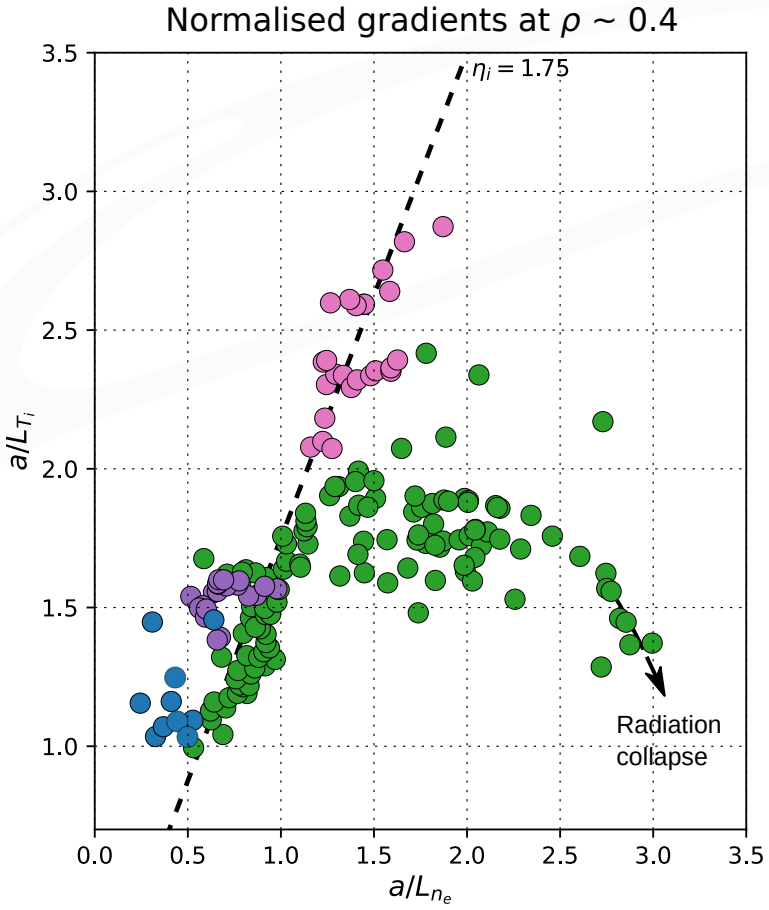




NBI (±ECRH) - Anomalous heat diffusivity

- Not possible to separate Q_i, Q_e due to high collisionality and similar heating effect of NBI - $P_e \sim P_i$.
- Look at combined χ_{eff} in gradient region ($\rho \sim 0.4$) reveals two branches:
  Dominant ECRH: $\chi_{eff} \sim 1\ m^2s^{-1}$ as in pure ECRH scenarios [M. Beurskens, Nucl. Fus. 61 116072 (2021)].
  Dominant NBI: $\chi_{eff} \sim 0.25\ m^2s^{-1}$



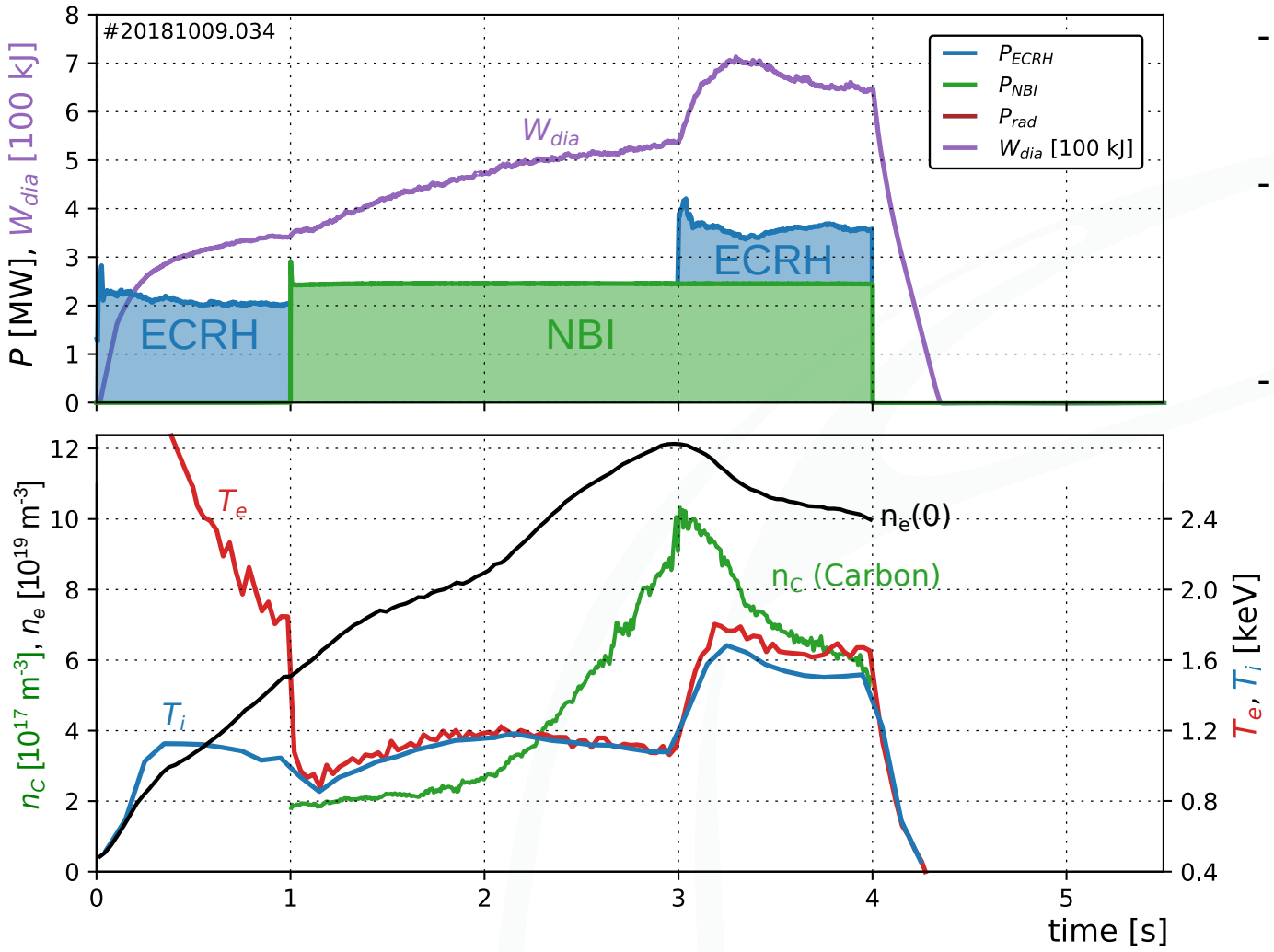


- Pure NBI has reduced χ_{eff}, but much broader power deposition results in similar ∇T_i. (and T_{i0})
- Mixed NBI with low PECRH maintain $\chi_{eff} \sim 0.25$ and exploit it for higher ∇T_i.
- All plasmas with $a/L_{ne} > 1.0$ have lower χ_{eff}.
- Without additional ECRH, NBI plasmas can undergo radiation collapse.

[O. Ford Nucl. Fus. 64 086067 (2024)]

NBI + ECRH reintroduction

- Density gradient builds up in pure NBI phase, which is exploited with reintroduction of O2 ECRH at high ne.



- Density peaking accelerates at a given time after switch to pure NBI --> Particle transport changes.

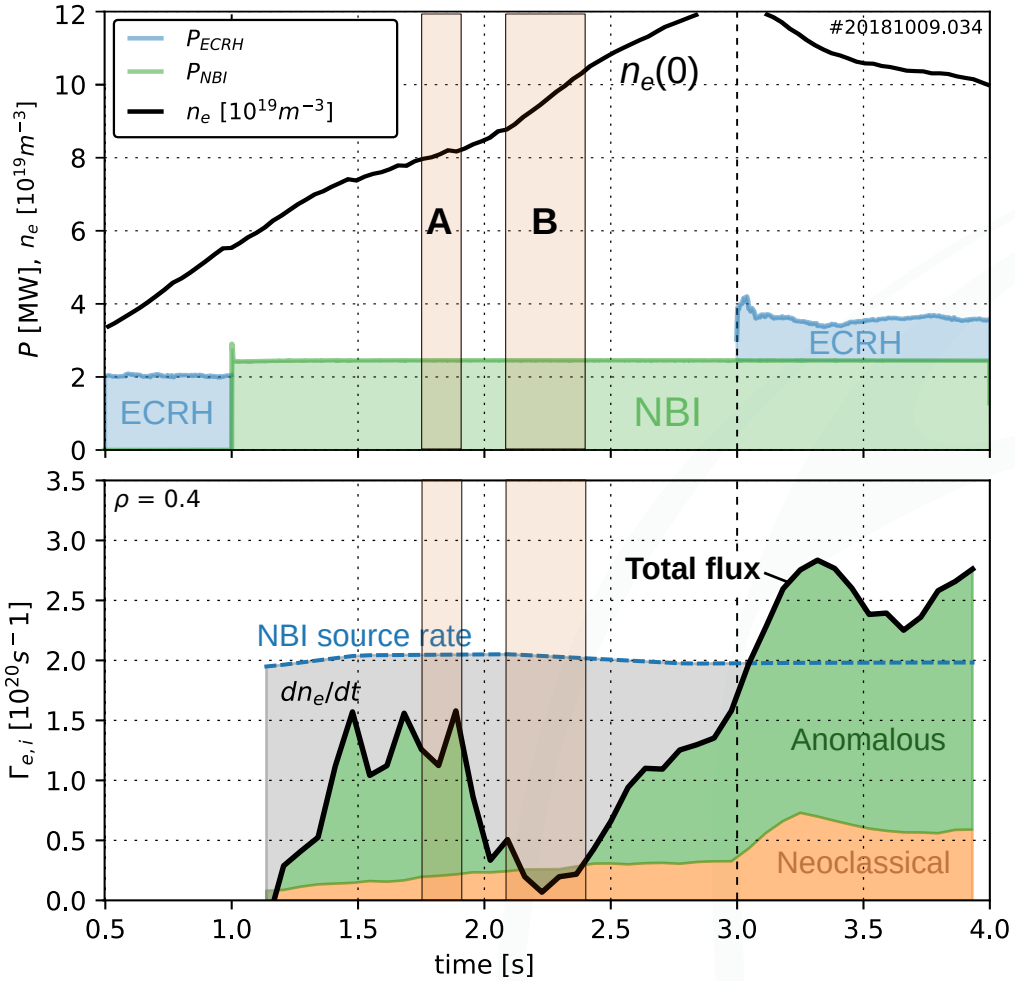
- Impurities accumulate from this time, almost entirely determined by neoclassical transport. [T.Romba Nucl. Fus. **63** 076023 (2023)] (see talk by T. Romba)

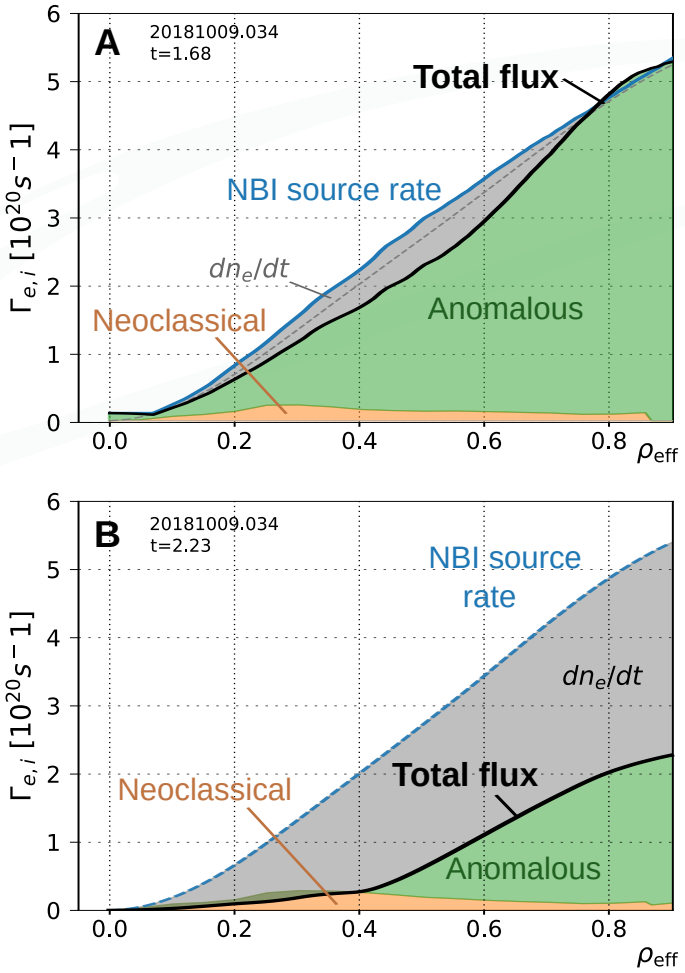
- Reintroduced ECRH stops density peaking or reduces it, and flushes out impurities.

[O. Ford Nucl. Fus. 64 086067 (2024)]

Pure NBI - Particle flux

- Particle balance during pure NBI phase shows:
  - Initially significant **outward** anomalous flux (opposite to ECRH case) --> slow n_e rise.
  - Sudden drop in particle flux with no external changes --> fast n_e rise.





- Drops to apparently neoclassical flux level.

  Really no tubulent flux??

- Increases again shortly afterwards.

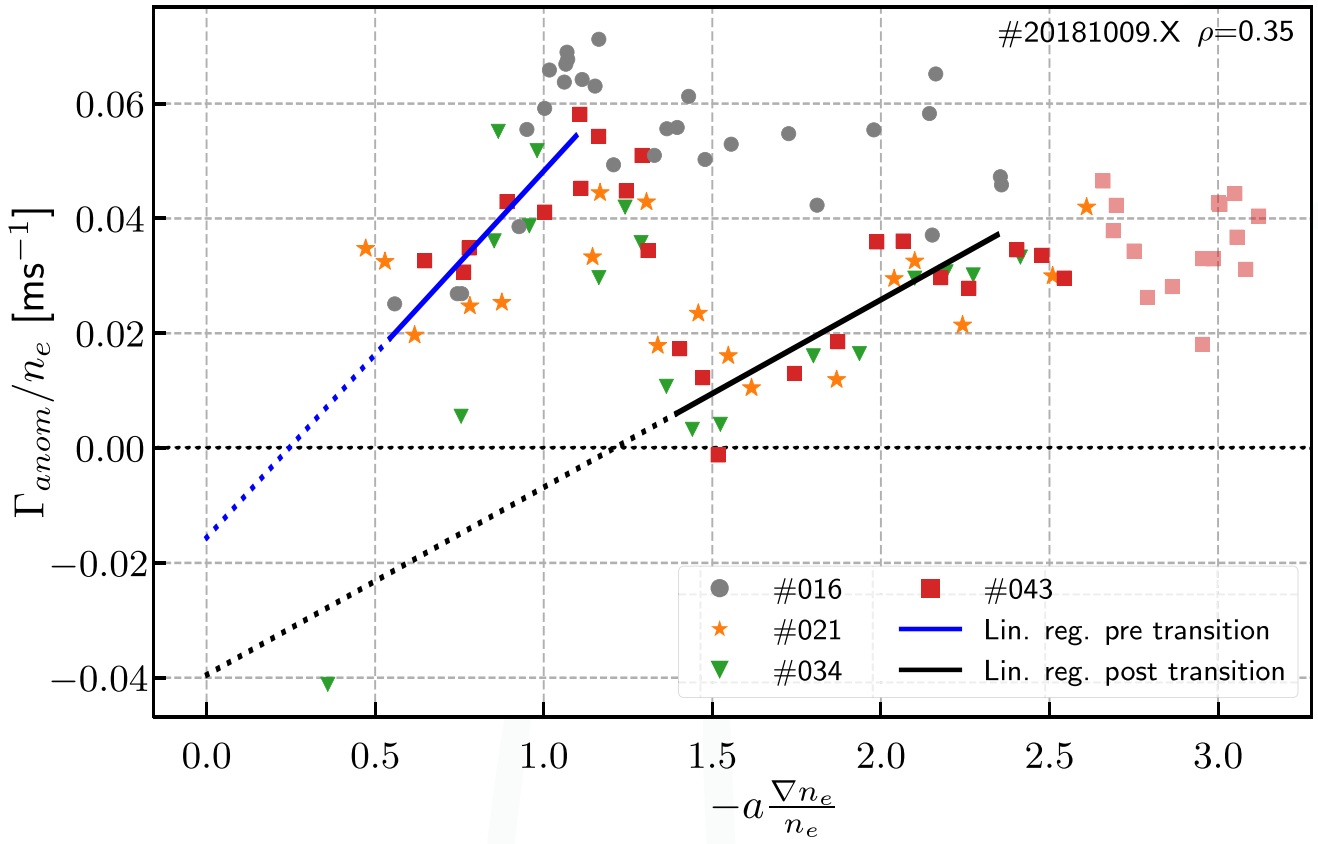
- Increases again at ECRH reinroduction, reducing n_e a little.

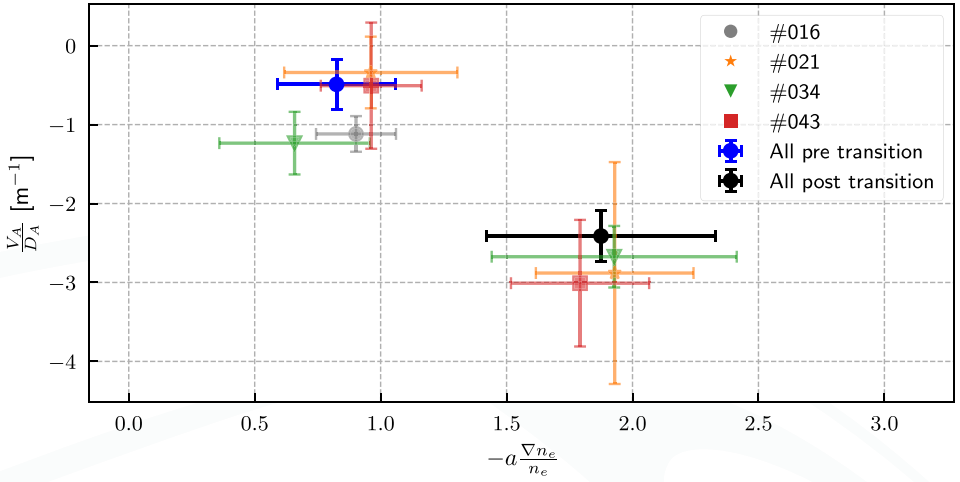
[O. Ford Nucl. Fus. 64 086067 (2024)]

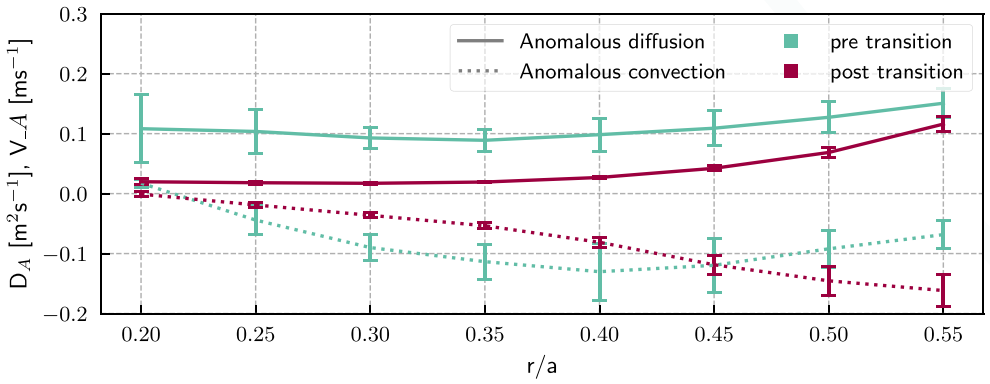
Pure NBI - Particle transport

∇n_e is changing. What is just an 'expected' reponse to this?
--> Decompose into diffusive D and convective v.
- Indicates two phases of ~consistent v, D, with significant drop of D at $a/L_n \sim 1.3$.

$$\frac{\Gamma_{\text{anom}}}{n} = -D_A \frac{\nabla n}{n} + V_A$$







[S. Bannmann Nucl. Fus. 64 106015 (2024)]

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