Max-Planck-Institut für Plasmaphysik

Overview of the results from the divertor experiments at Wendelstein 7-X and their implications for steady-state operation

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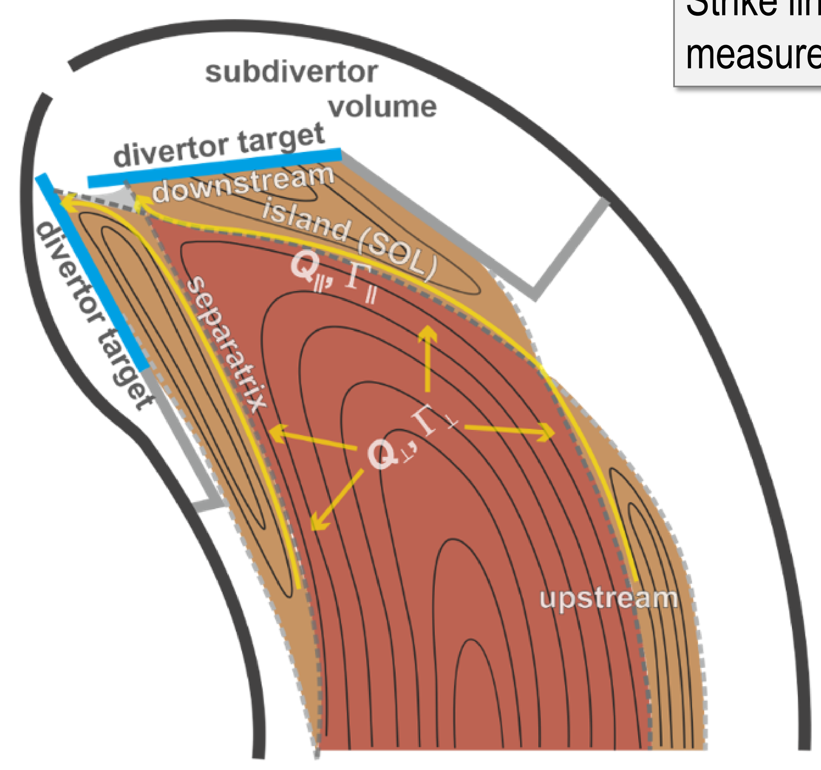
Introduction

W7-X wants to demonstrate high power, high performance at steady-state
10 separate divertor units, adapted to the shape of the flux surfaces

Large magnetic islands (standard: 5/5) form so-called **island divertor**.
Resonant islands require error field correction [1,2]

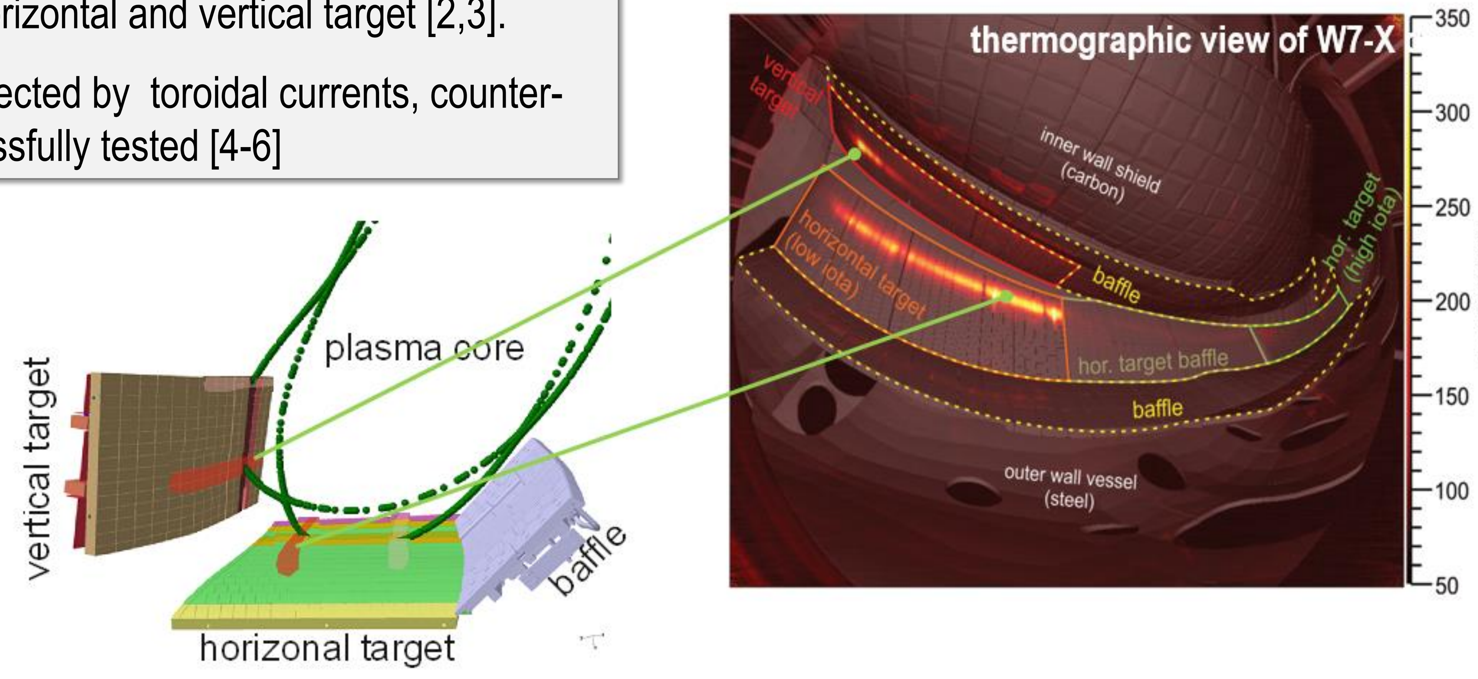
Open field lines guide ions lost from the confined plasma to the divertor target (**scrape-off layer**)
Island divertor features ExB drifts [3]

Neutral compression provided by neutrals **recycling** near the divertor target



Island divertor at W7-X in **standard configuration** forms **two strike-lines** on horizontal and vertical target [2,3].

Strike lines may be affected by toroidal currents, counter-measures were successfully tested [4-6]



How well island divertor can **spread power** on the **divertor surface**? W7-X will operate with up to **30 minutes of plasma duration** with 10 MW of heating with technical limit of the divertor heat flux at 10 MW/m².

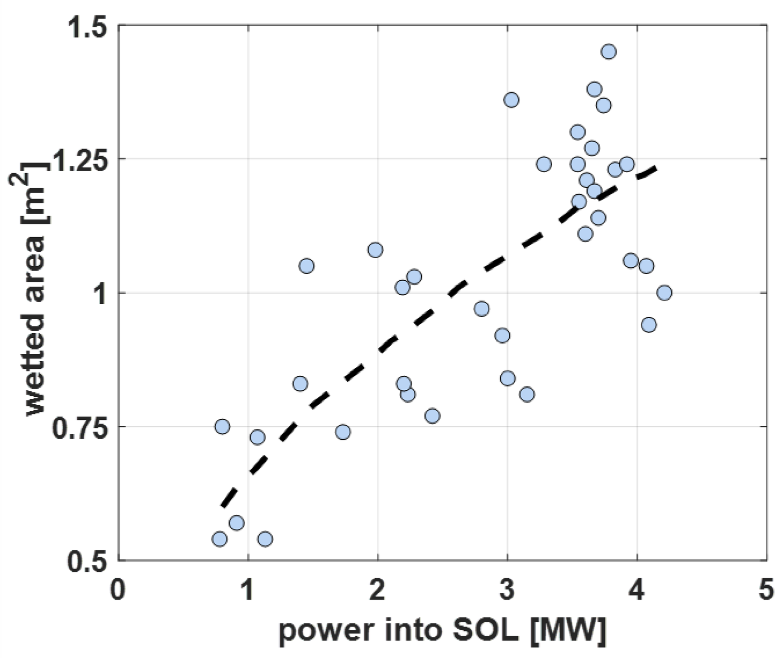
[1] S. A. Bozhenkov *et al.*, Nucl. Fus. **57**,126030 (2017)
[2] S. A. Lazerson *et al.*, Nucl. Fus. **57**, 046026 (2017)
[3] K. C. Hammond *et al.*, PPCF **61**, 125001 (2019)
[4] A. Dinklage, this conference
[5] Y. Gao *et al.*, Nuclear Fusion **59** (2019)
[6] T. S. Pedersen *et al.*, Nuclear Fusion **59**, 096014 (2019)

Attached plasmas

Large wetted areas allow for efficient heat flux spreading

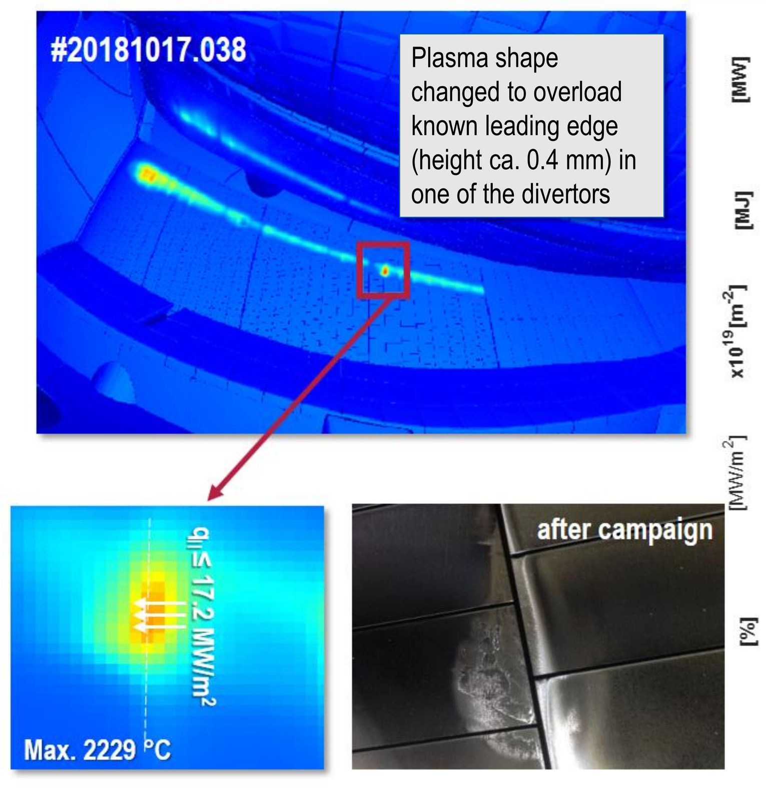
- Wetted area A_{wet} is ratio of heat absorbed by the divertor (in eg. MW) to peak heat flux (in eg. MW/m²)
- The allowed peak heat flux of the HHF divertor is 10 MW/m²
  ➔ If P_{SOL} ~ 8 MW so A_{wet} > 0.8 m²
- **Positive scaling with SOL power observed for attached plasmas**
  $A_{wet} \sim P_{SOL}^{0.44}$

W7-X (standard): < 1.5 m² [1]
JET (L-mode): <1.6 m² [2]
ASDEX Upgrade (L-mode): < 0.8 m² [3]



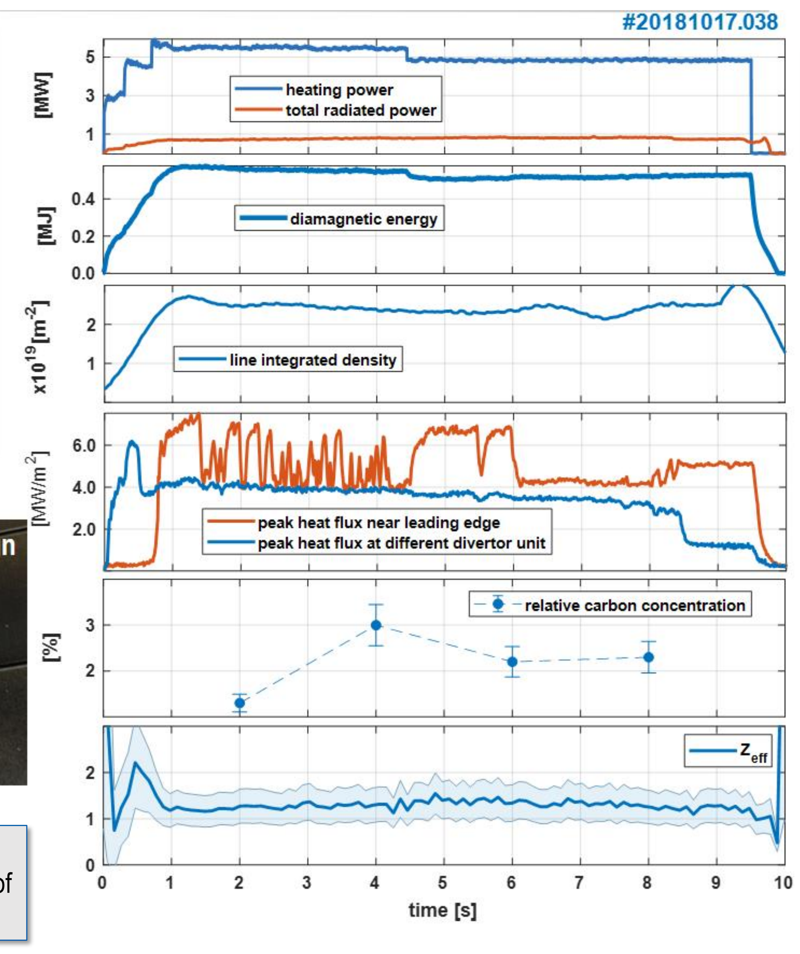
[1] H. Niemann *et al.*, Nucl. Fusion 60 (2020) 084003
[2] T. Eich, et al., JNM 415 (2011) S856, [3] B. Sieglin, et al., PPCF 58

Overloading leading edges showed that W7-X has good impurity screening



Parallel heat flux to the leading edge of 17.2 MW/m2. T_{surf} > 2200°C

Strong material removal from leading edge and re-deposition of carbon



Very low plasma radiation to increase divertor loads

Stable plasma in spite of strong influx of impurities.

Transient modulation of heat flux due to localized increase of plasma radiation.

Low concentration of carbon in the plasma core.
Confirmed by low Z_{eff}

Detached plasmas

Complete, stable detachment for 26 seconds

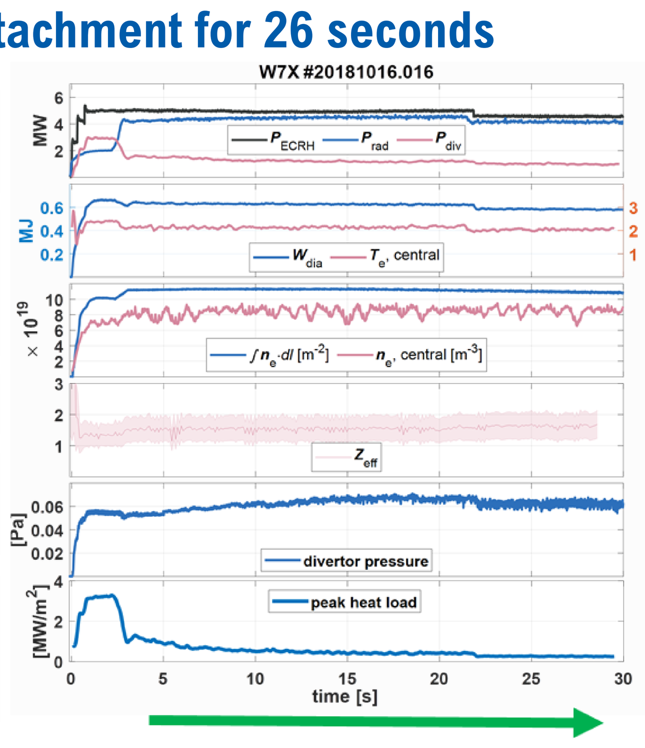
Radiated power fraction of 80-90%

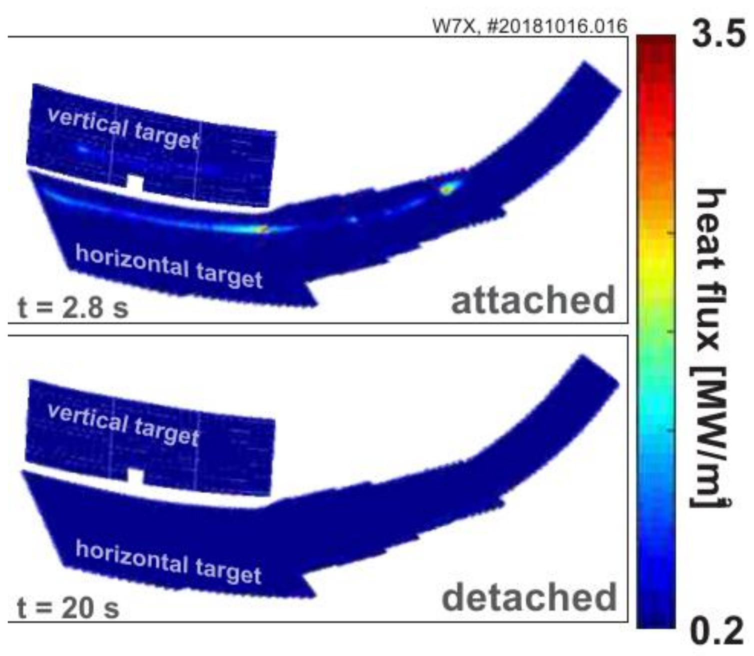
Drop in diamagnetic energy ≲10 %

Constant Z_{eff} ≈ 1.5

Sufficient sub-divertor pressure

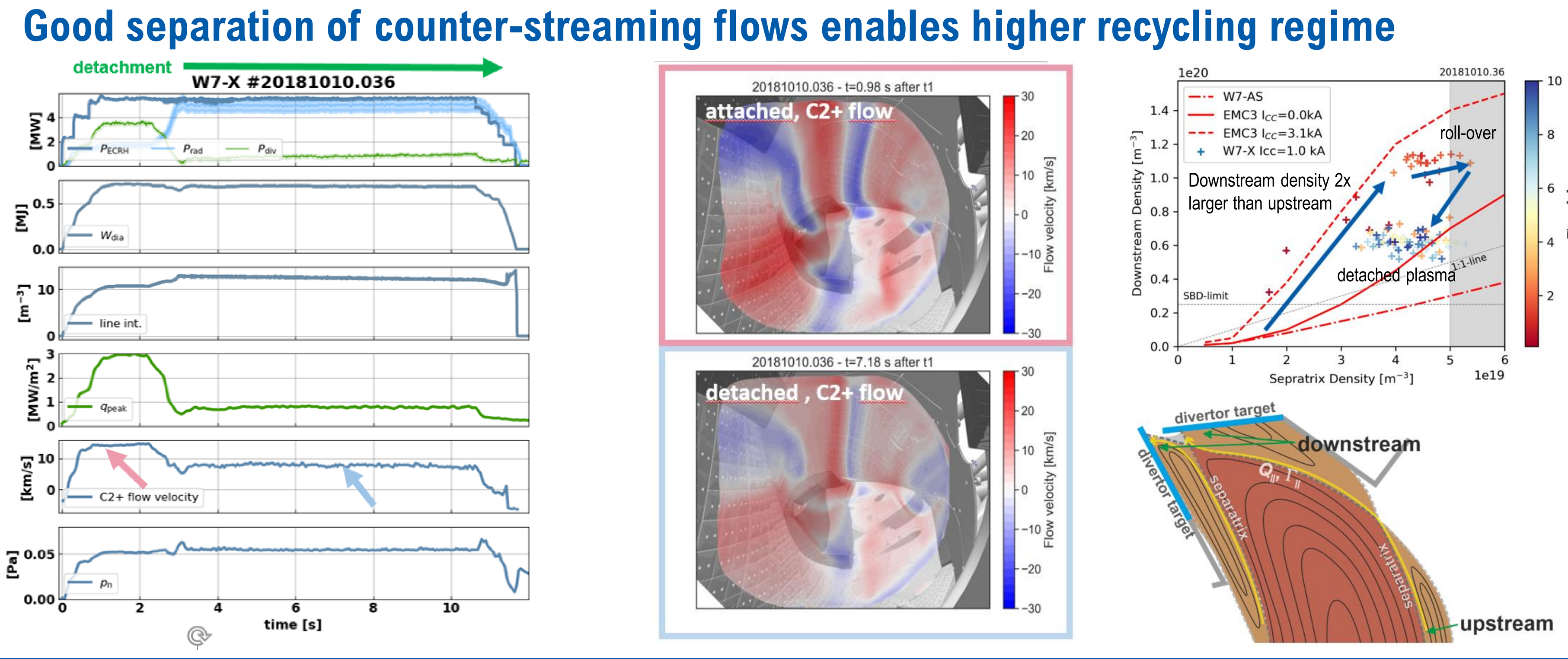
Virtually no convective loads to the target.





[O. Schmitz, et al., Nucl. Fusion 61 (2021) 016026]

Good separation of counter-streaming flows enables higher recycling regime

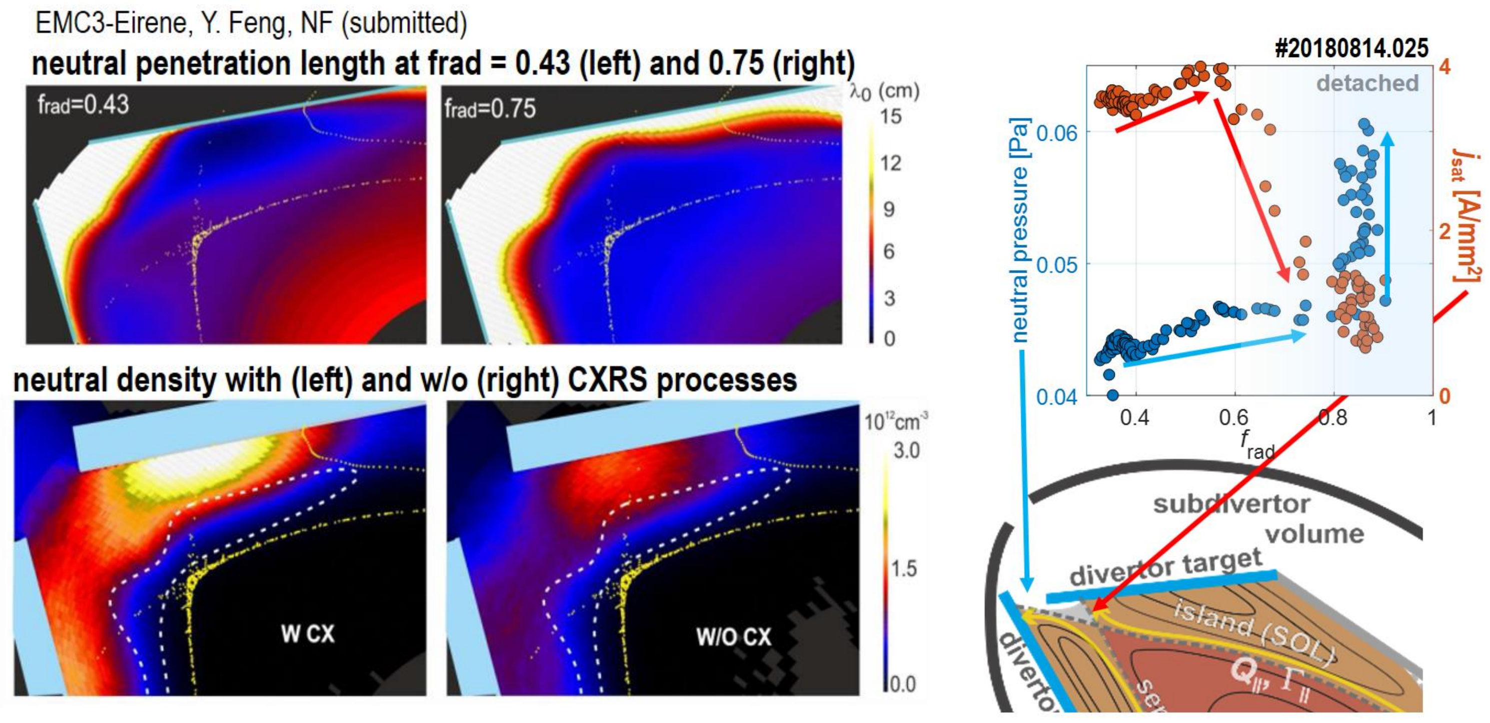


The flow measurement is performed by coherence image spectroscopy [1]. It measures the Doppler shift of carbon ions, which serve as a proxy for the bulk plasma flow. → V. Perseo, this conference. At W-X, the flows are well separated due to sufficient island size. They do not contribute to the momentum dissipation in the scrape-off layer. This enables high-recycling regime, important for particle exhaust. → F. Reimold, this conference

[1] V. Perseo, et al., Nuclear Fusion 59, 124003 (2019)]

Neutral pressure sufficient for steady-state density control at W7-X

EMC3-Eirene, Y. Feng, NF (submitted)



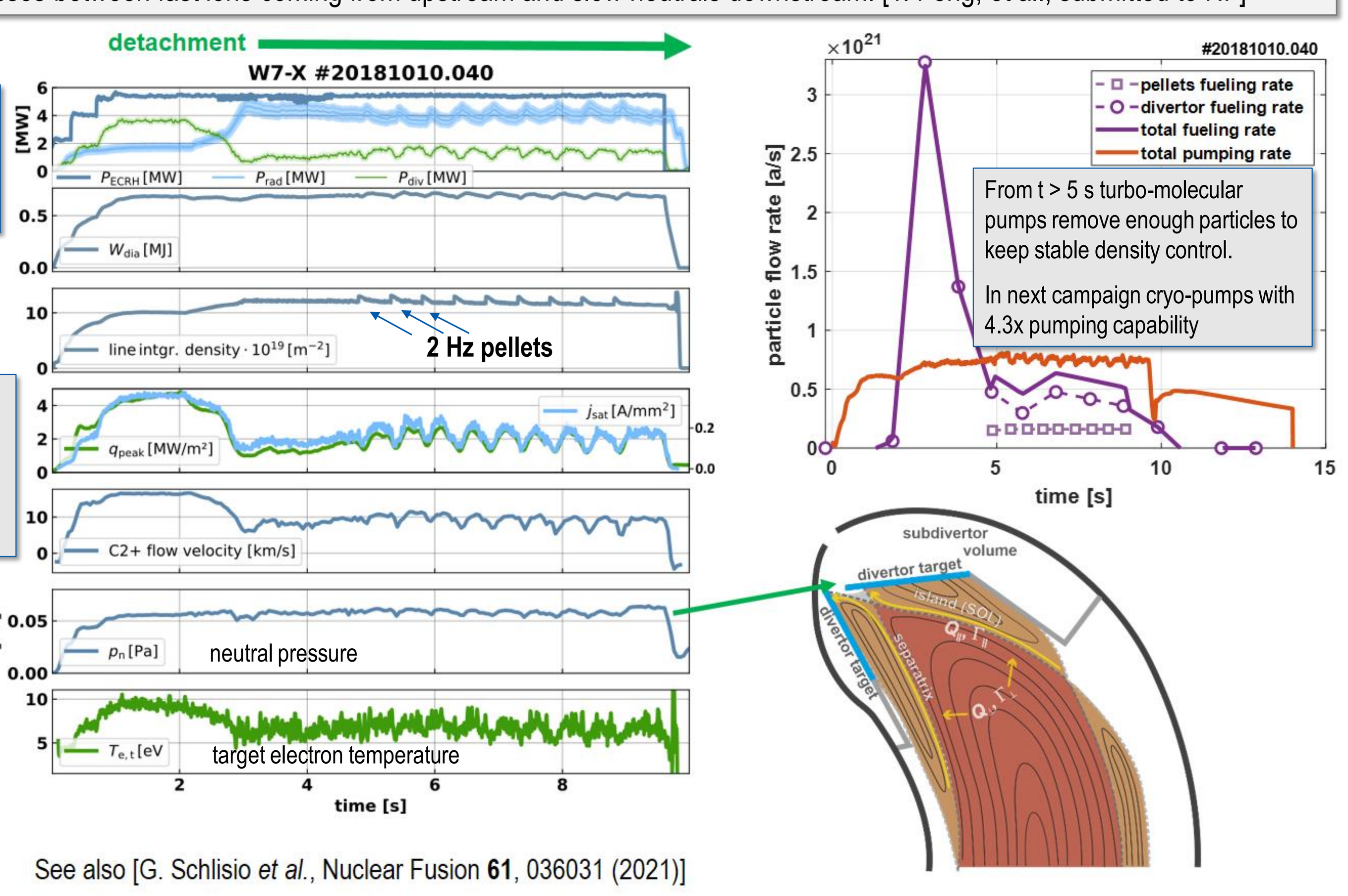
Two effects increase neutral pressure:

1. Longer penetration length mainly due to lower plasma temperature (5 eV) in the islands $\lambda_0 = v_{ith}/n\sqrt{<\sigma v>_{CX} < \sigma v>_i}$
2. CXRS processes between fast ions coming from upstream and slow neutrals downstream. [Y. Feng, et al., submitted to NF]

Plasma radiation increases with each pellet injection

Modulation of heat and recycling fluxes ← response to upstream pressure changes

Also other scrape-off layer parameters are modulated by pellet injections.



See also [G. Schlisio *et al.*, Nucl. Fusion **61**, 036031 (2021)]

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28th IAEA-FEC, Nice, France (2021)

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