Max-Planck-Institut für Plasmaphysik

Results from and plans for Wendelstein 7-X and the optimized stellarator path to fusion power

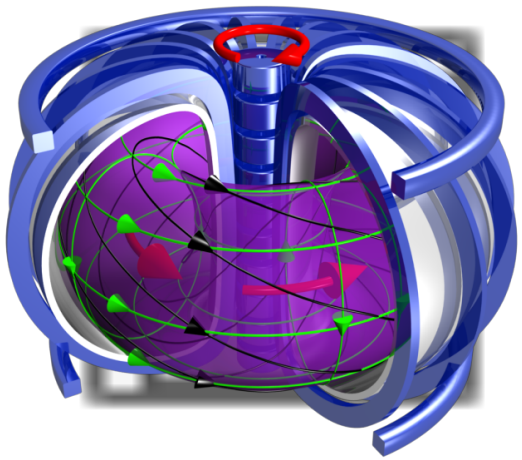
T. Sunn Pedersen, for the W7-X Team

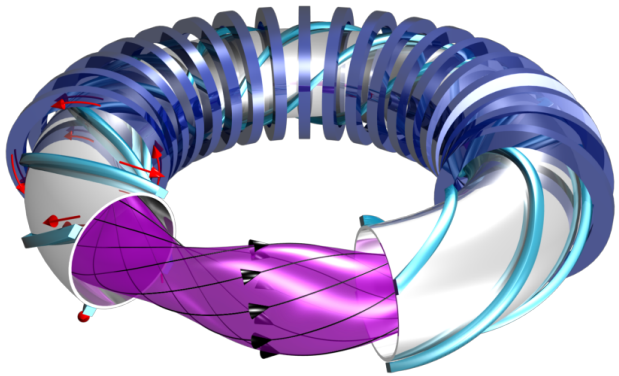
MAX PLANCK GESELLSCHAFT

EUROfusion

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

The stellarator power plant has attractive features



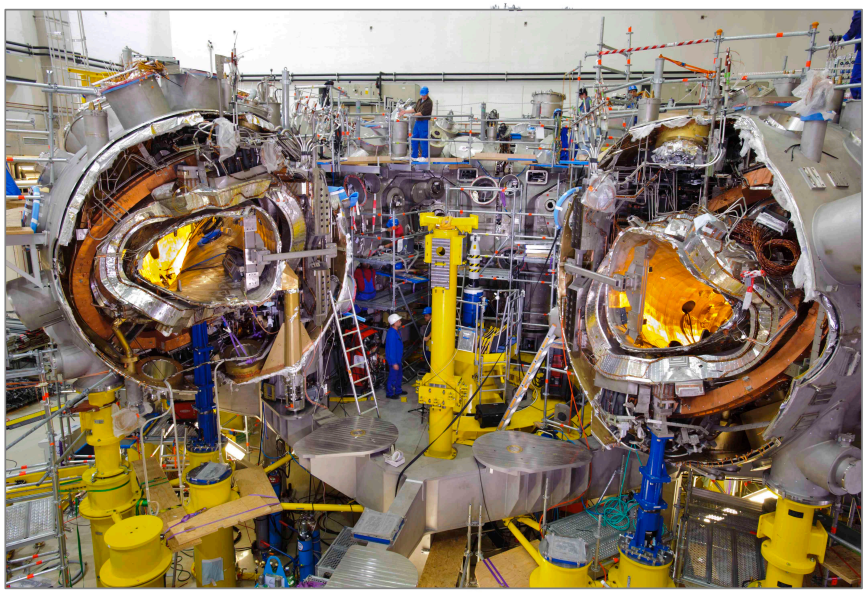


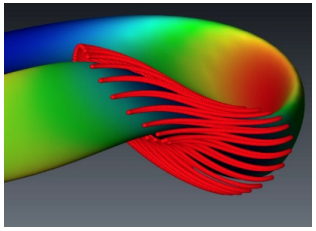
- Good plasma confinement τ_E demonstrated, also at high T and n, ie. high triple products
- Disruptions/runaway currents may damage vessel walls significantly
- Strong current drive is necessary:
  Several 100's of MW recirculating in a reactor

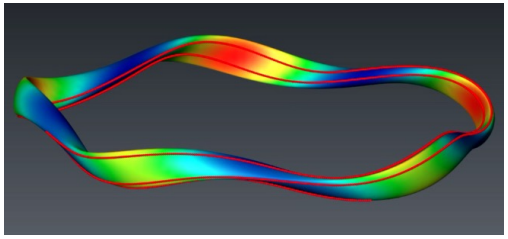
- At high T, good plasma confinement τ_E requires computer optimization
- Plasmas more stable, runaway electrons not a concern
- Intrinsically steady state. No need for current drive – hence, low recirculating power
- Much higher densities possible – allowing lower T

Wendelstein 7-X

Located in Greifswald, Germany.
In preliminary operation three times in the time period 2015-2018
Goal: To experimentally verify the reactor-relevance of optimized stellarators







Major radius: R=5.5 m, minor radius: a=0.5 m

Plasma volume: 30 m^3

Superconducting coils (NbTi), B=2.5 T on axis

Magnetic field topology optimized for

(among other things):

Low neoclassical losses

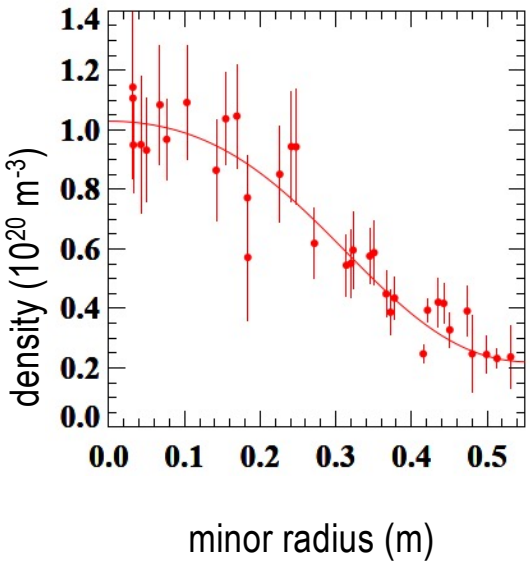
A stable and efficient plasma exhaust solution

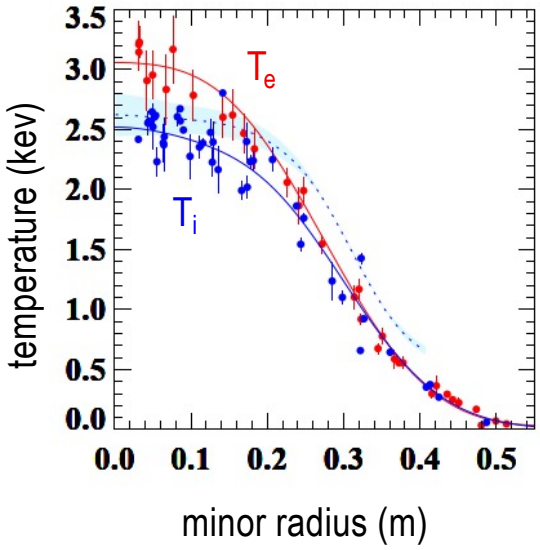
using the island divertor concept

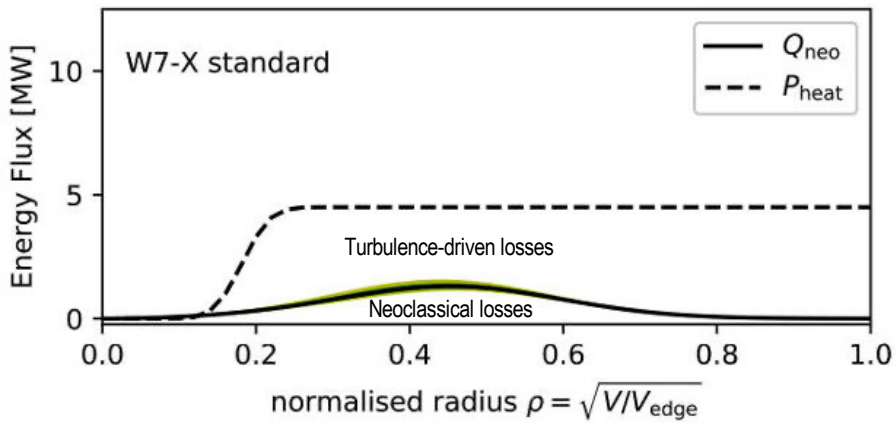
High-performance discharges give proof of NC optimization

Given the measured density and temperature profiles, the neoclassical transport can be calculated with high confidence

- Shown here: Pellet-fueled discharge with central ECRH heating 4.5 MW and τ_E = 0.23 s
- Most of the transport is due to turbulence (about 70% at mid-radius – even more at other radii).





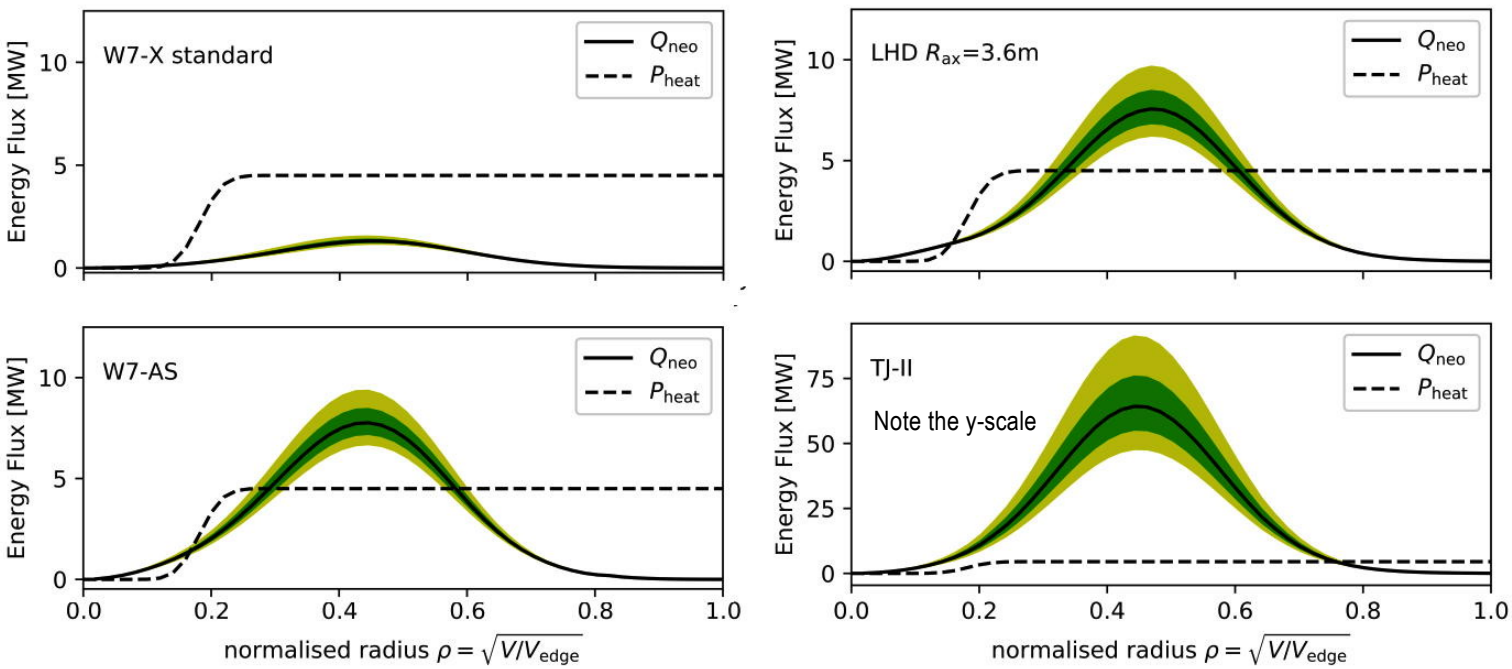


Discharge 20180918.045 at t = 3.35 s. From C. Beidler et al., Nature (2021)

Comparison to other magnetic configurations

- We can calculate the equivalent neoclassical losses in less optimized configurations
  - Assume same density and temperature profiles and, for other devices, similar plasma volume and B-field strength
  - Result: much higher neoclassical losses, often larger than applied heating power

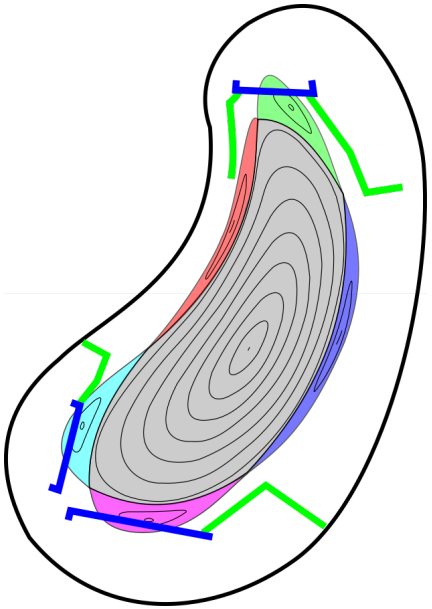
(shown on previous slide)

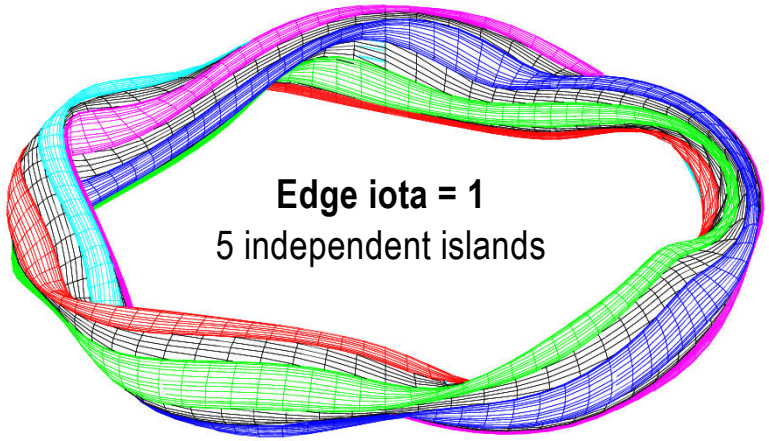


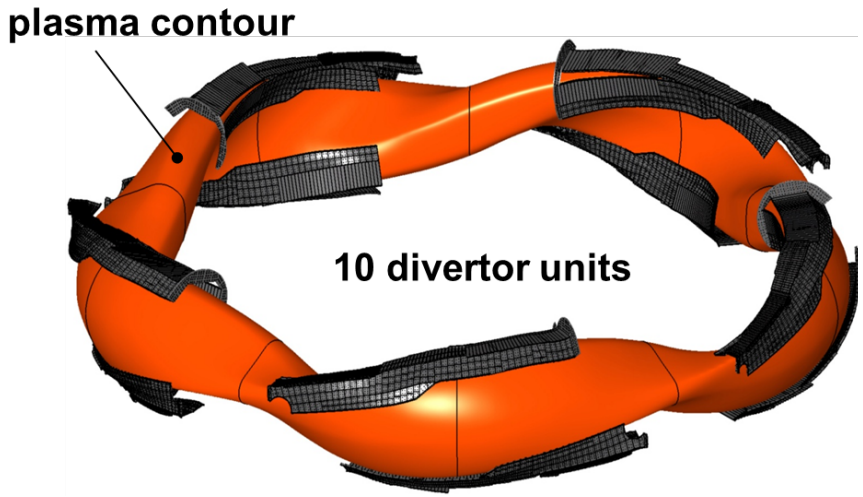
Proves efficacy of neoclassical optimisation of W7-X.

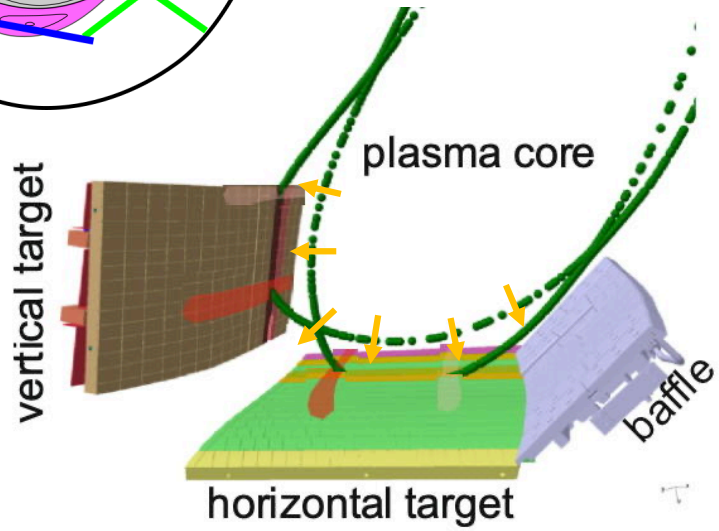
Beidler et al, Nature (2021)

Island Divertor of W7-X



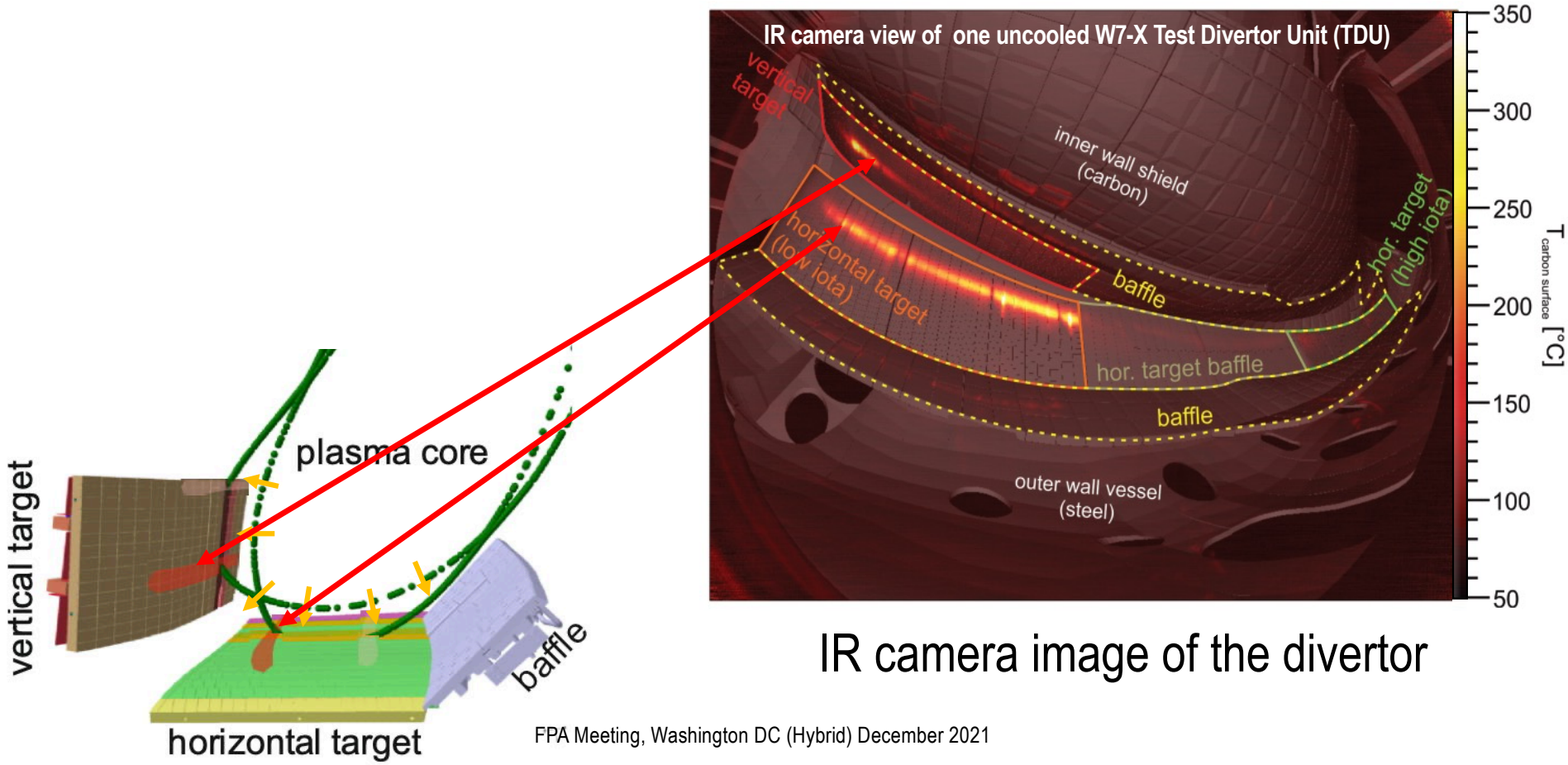






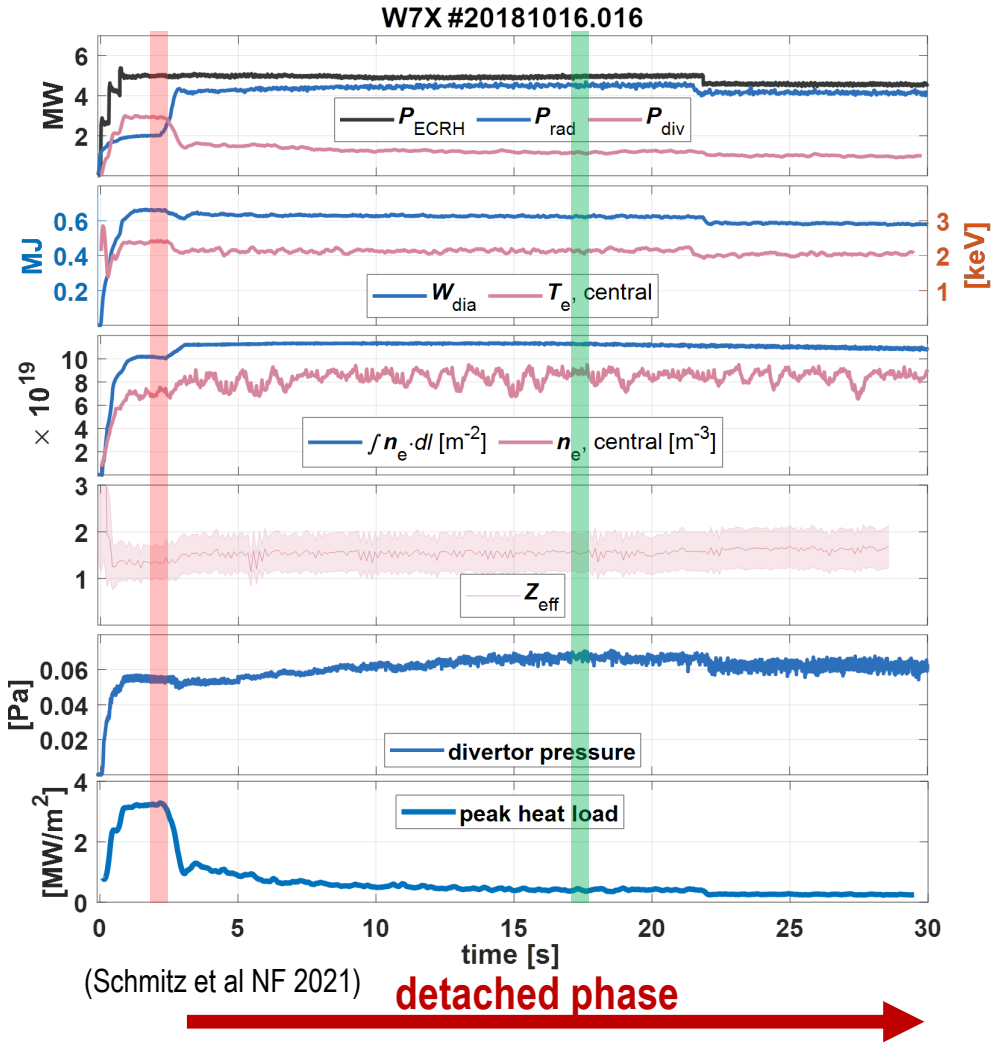
Standard configuration:
iota =1= n/m = 5/5
➔ 5 islands

The island divertor at Wendelstein 7-X

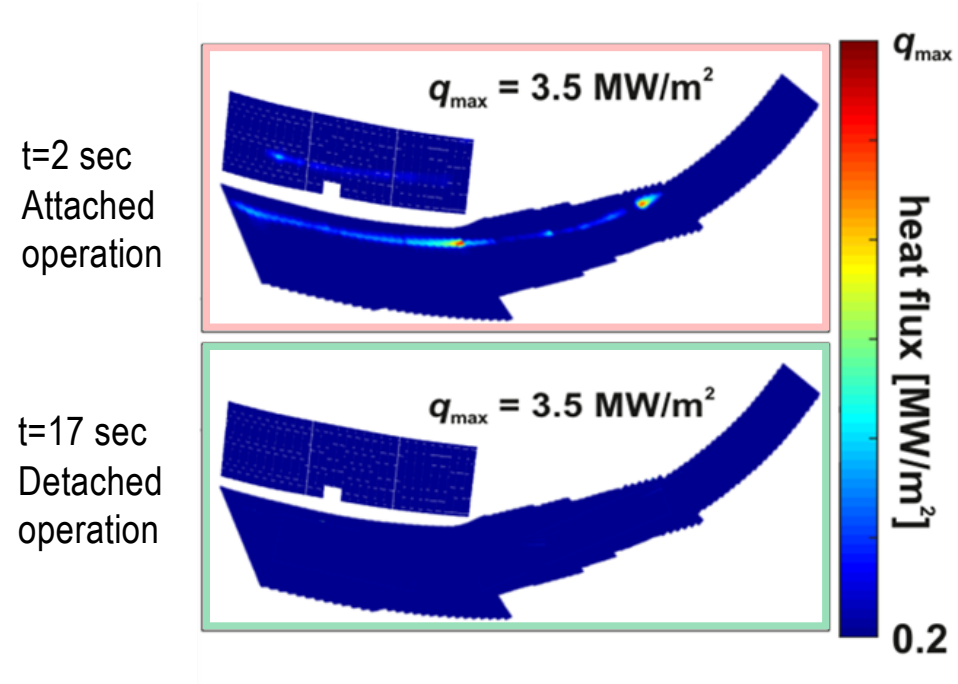


IR camera image of the divertor

Long, Complete Stable Detachment (26 s) at W7-X

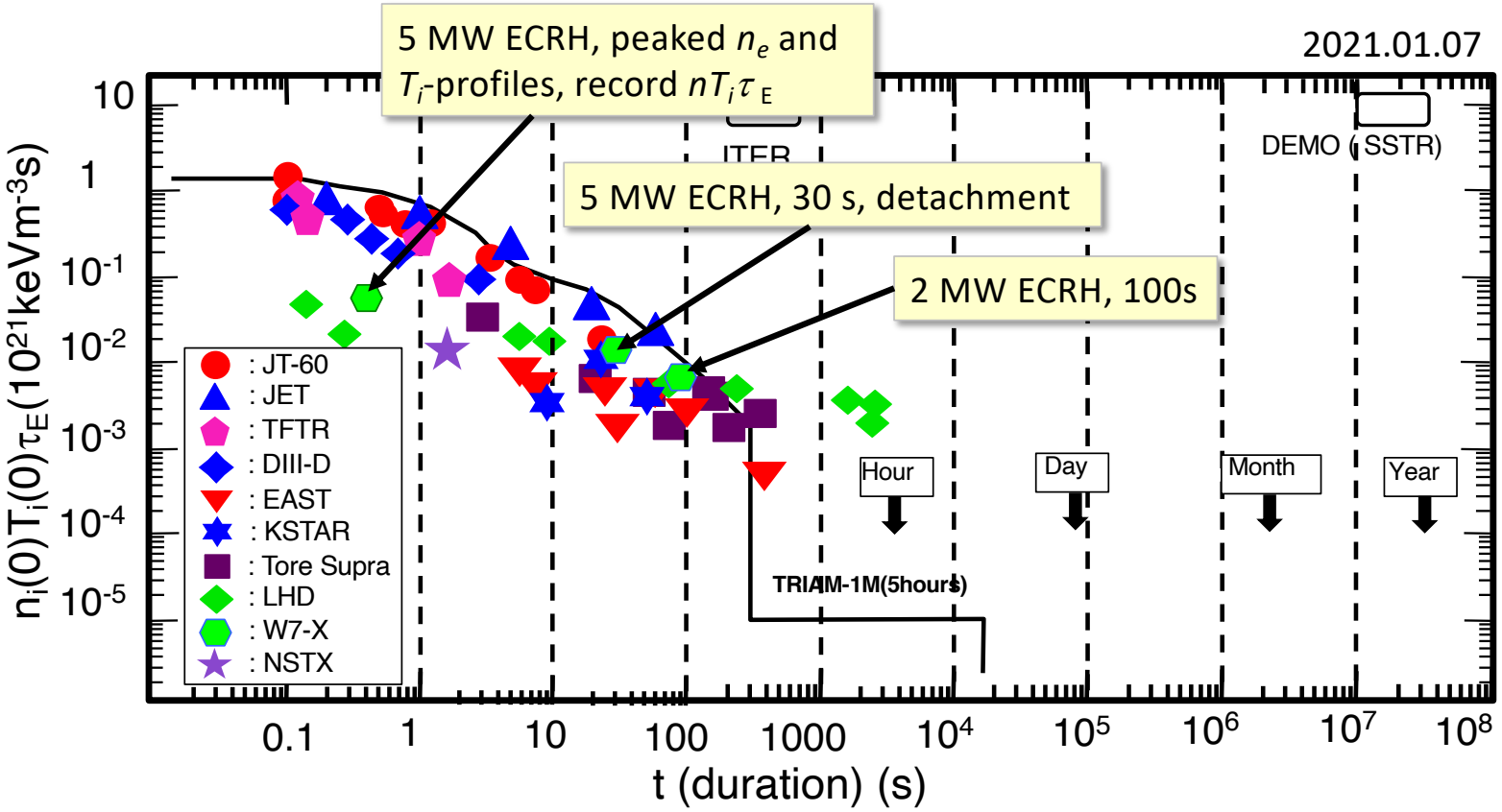


(Schmitz et al NF 2021)



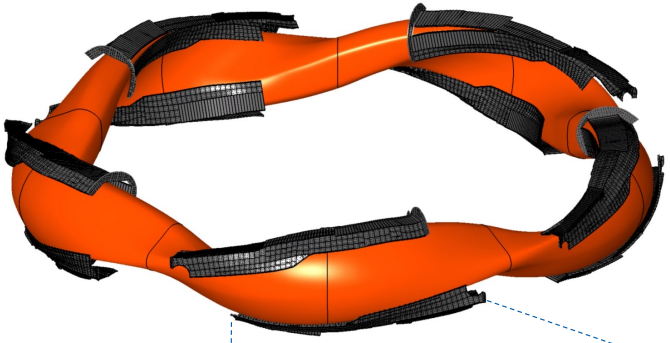
- Virtually no convective loads to the target during detachment.
- Constant $Z_{eff} \approx 1.5$ – low impurity content
- Efficient exhaust: particles compressed into divertor by a factor of >20, particle exhaust balances particle fueling in this discharge

Overall performance achieved so far (with uncooled divertor)



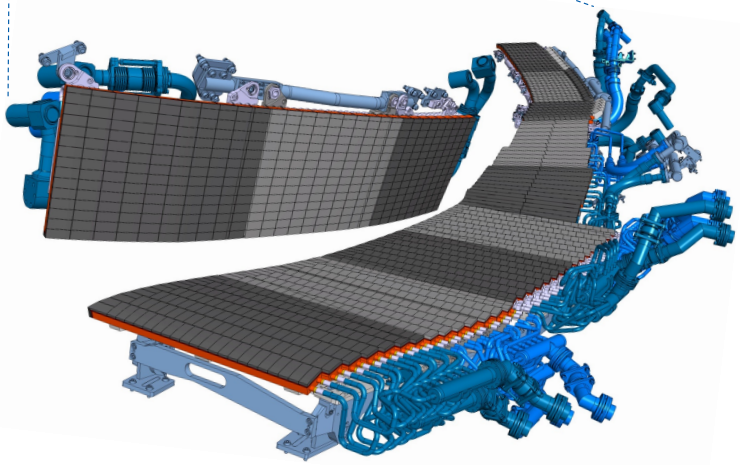
Courtesy of M. Kikuchi

Integration of the actively cooled divertor

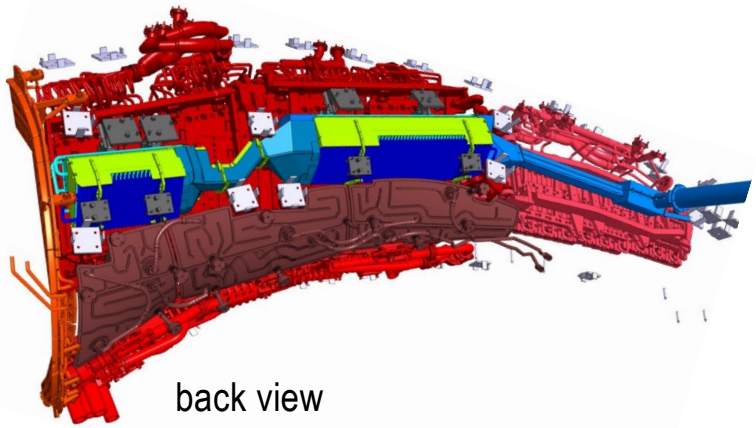


high-heat-flux (HHF) **divertor on Wendelstein 7-X**

- Steady-state heat flux removal up to 10 MW/m^2
- Cryopumps are also being installed – giving >4x higher pumping speed

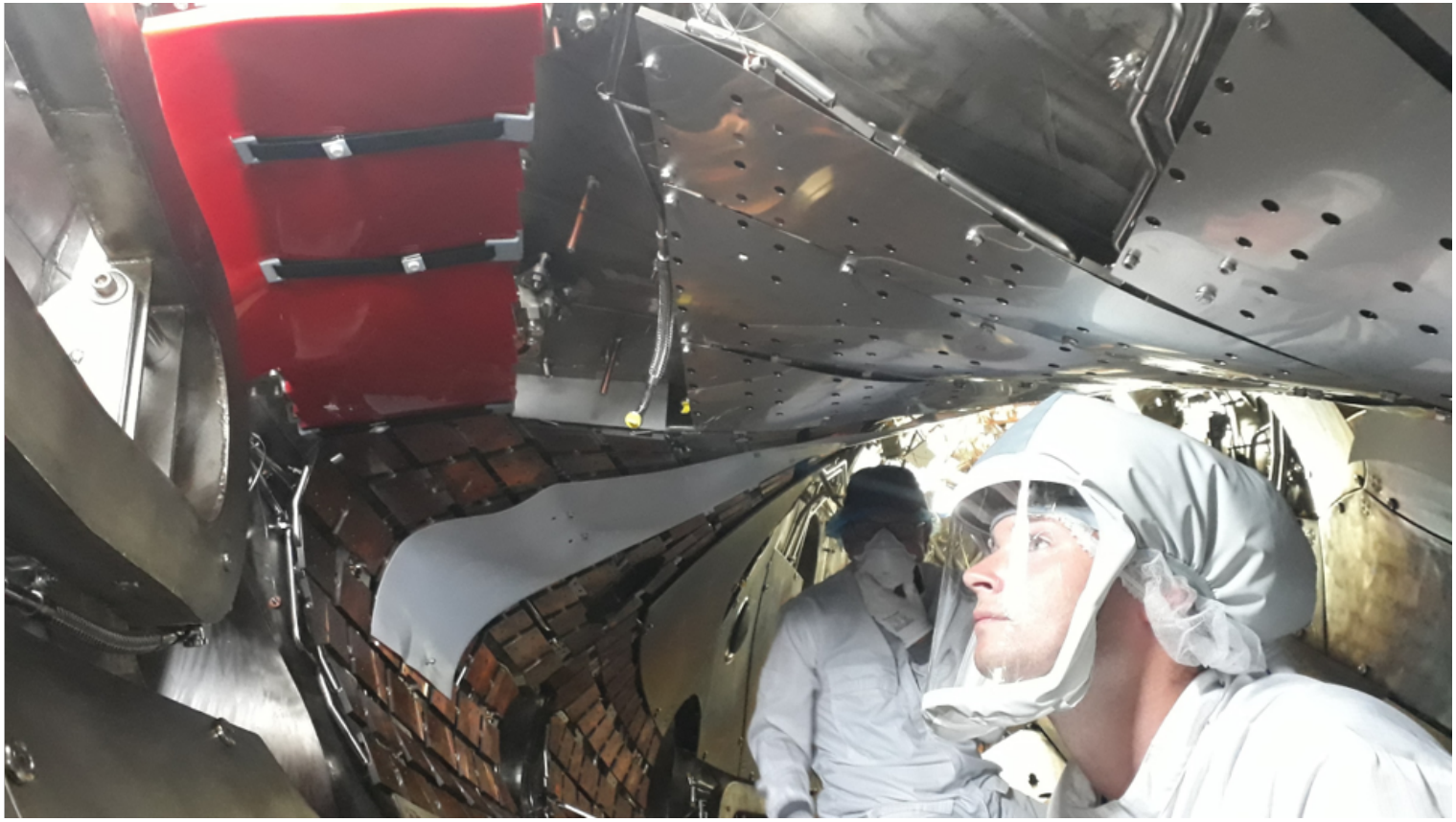


front view
divertor unit



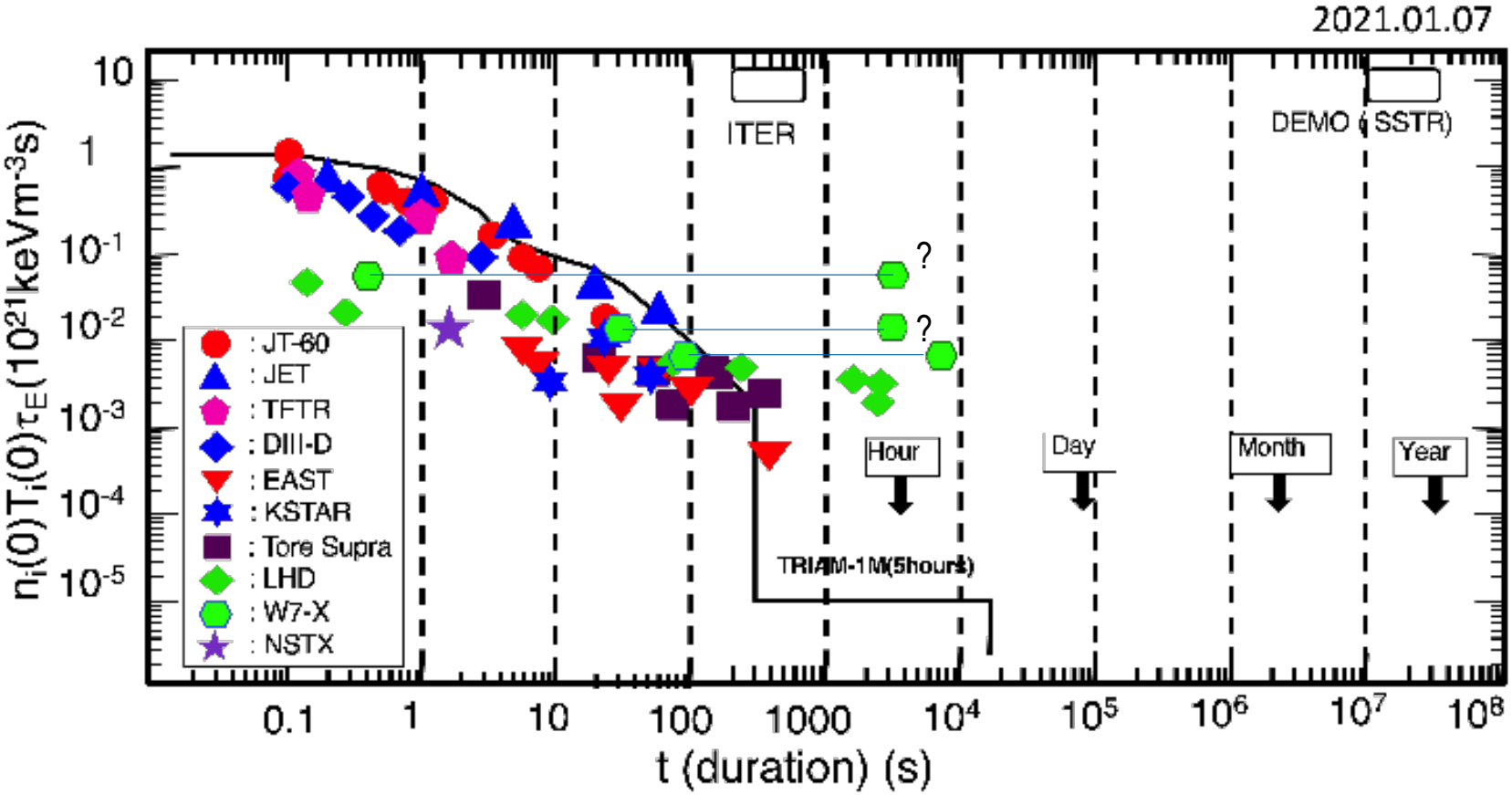
back view
divertor unit with cryo pump

In-vessel assembly continues despite COVID-19

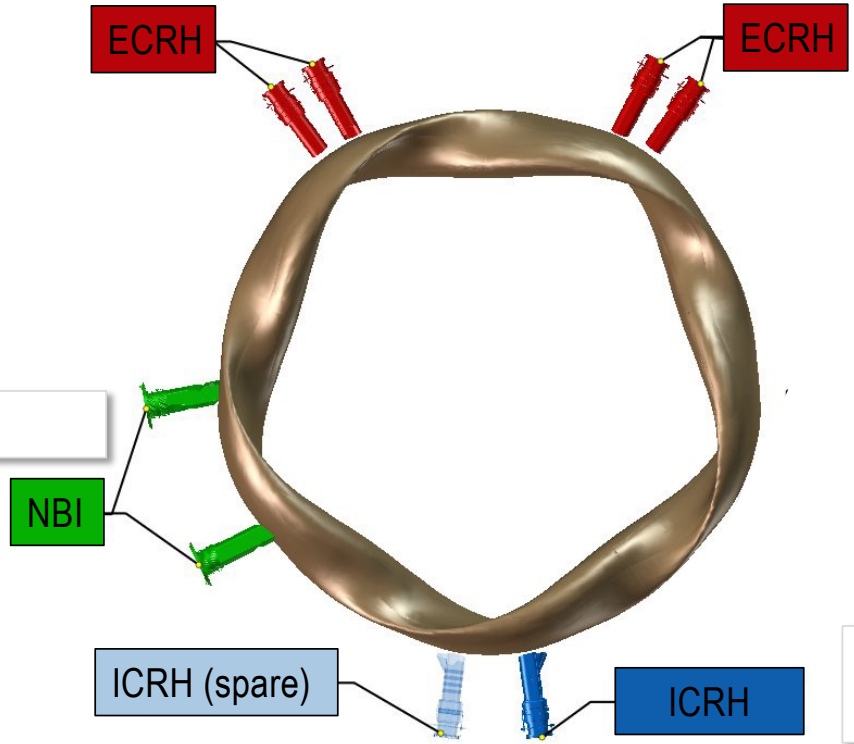


Despite COVID, and related safety measures, the in-vessel installation completed on Dec 2021

Quasi-steady state operation (18 GJ)



W7-X heating systems: Extensions for early phases of OP2



- **Extension of ECRH facility from 10 to 12 gyrotrons**
- **Program to upgrade from 1 MW to 1.5 MW per gyrotron**

2nd harmonic @ 140 GHz
Steady-state (30 minutes)

- **Doubling NBI power**

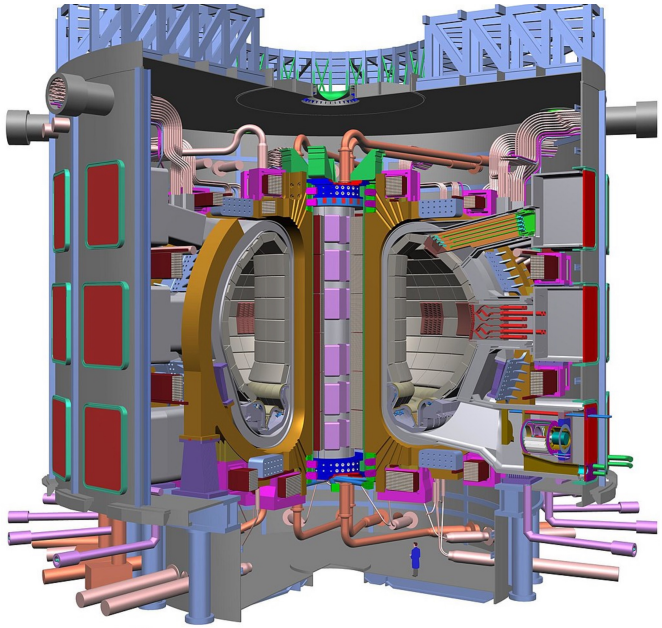
Pulsed (~ 10 sec)

- **Adding ICRH**
- ≤ 1.5 MW (25-38 MHz)

Pulsed (~ 10 sec)

Stellarator power plant visualized and compared

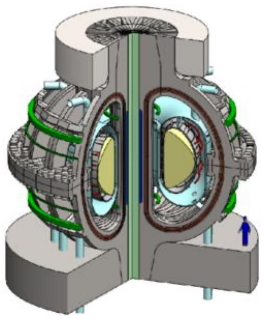
500 MW fusion power
(no net electricity production foreseen)



ITER, Wikimedia Commons

Largest coil dimension (PF)

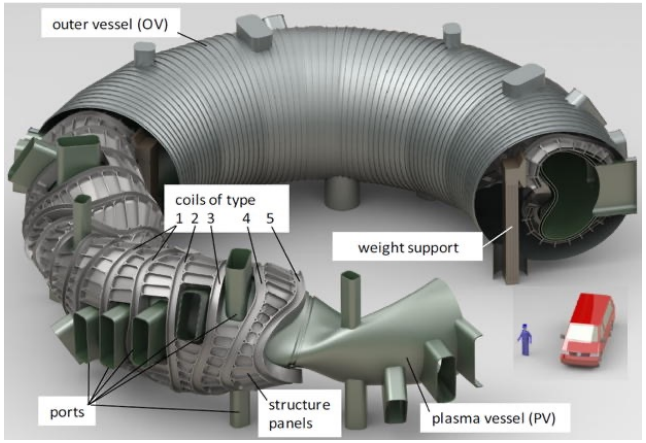
190 MW electricity



ARC, Sorbom et al.

Largest coil dimension (PF)

Up to 2.6 GW fusion power
Up to 1 GW electricity



„WARC“ illustration adapted from F. Schauer et al., Fusion Engineering and Design 88 p. 1619 (2013)

Largest coil dimension (non-planar TF)

Summary

- **A number of milestones and results have been achieved already in early operation of W7-X:**
  - Proof that the optimization to reduce neoclassical transport is successful
  - Stable, complete divertor detachment, with good exhaust efficiency
- **Preparations are well underway for steady-state operation with significantly enhanced fueling, pumping, and heating capabilities**
  - In-vessel installation has ended in December 2021
  - First plasma operation with a water-cooled divertor expected for September 2022
- **Attractive, robust, flexible reactor concept**