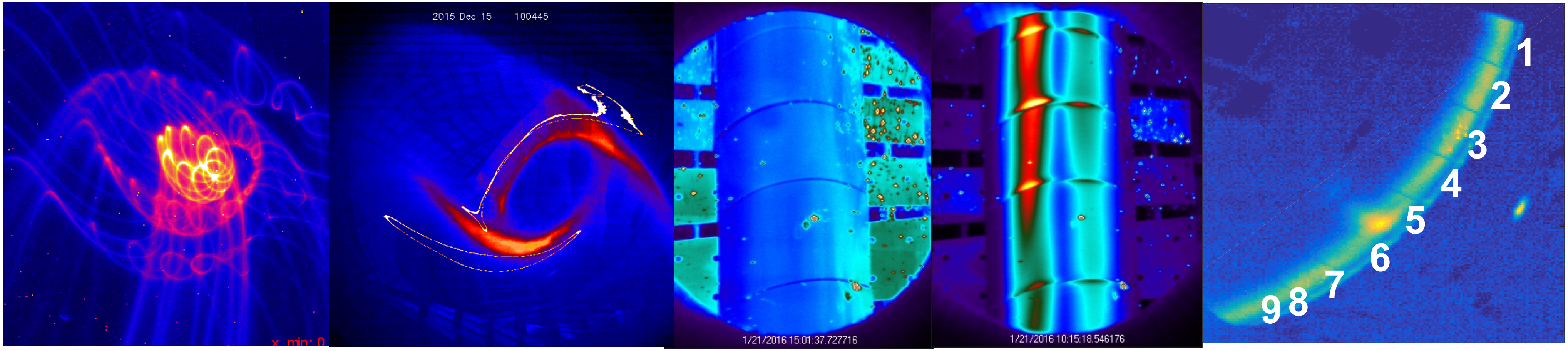
Recent results and near-term plans for Wendelstein 7-X

Thomas Sunn Pedersen
on behalf of the W7-X team

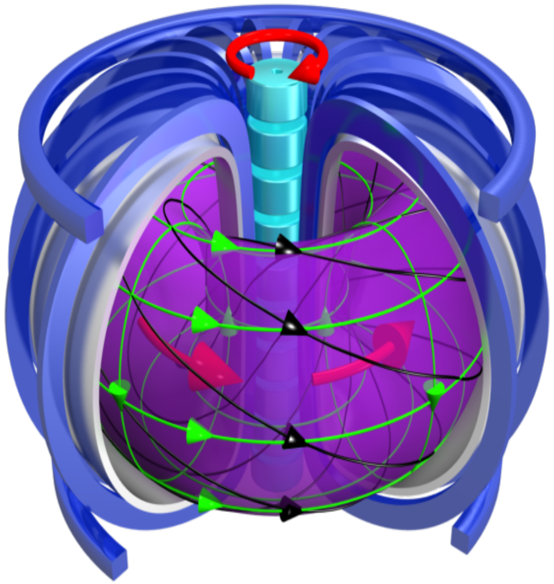


Overview

- The optimized stellarator W7-X
- Planned operation phases
- Plasma-facing components and magnetic topology in OP1.1
- Examples of physics results in OP1.1
- Plans for OP1.2
- Summary

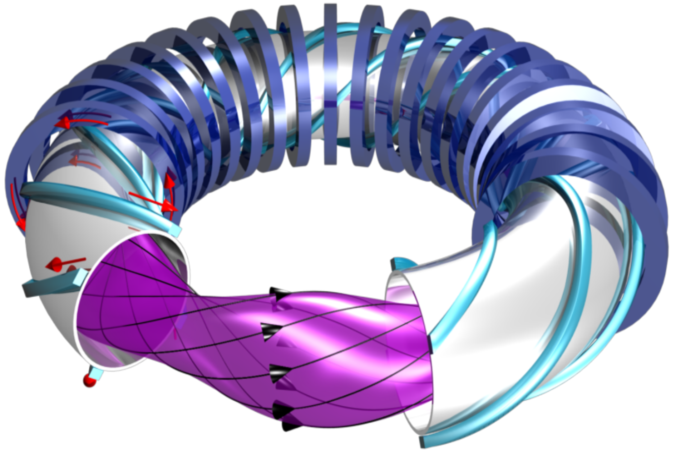
Tokamak and stellarator

- twisted magnetic field
- strong toroidal current in plasma



- excellent plasma confinement
- plasma instabilities require control
- steady-state operation requires strong current drive

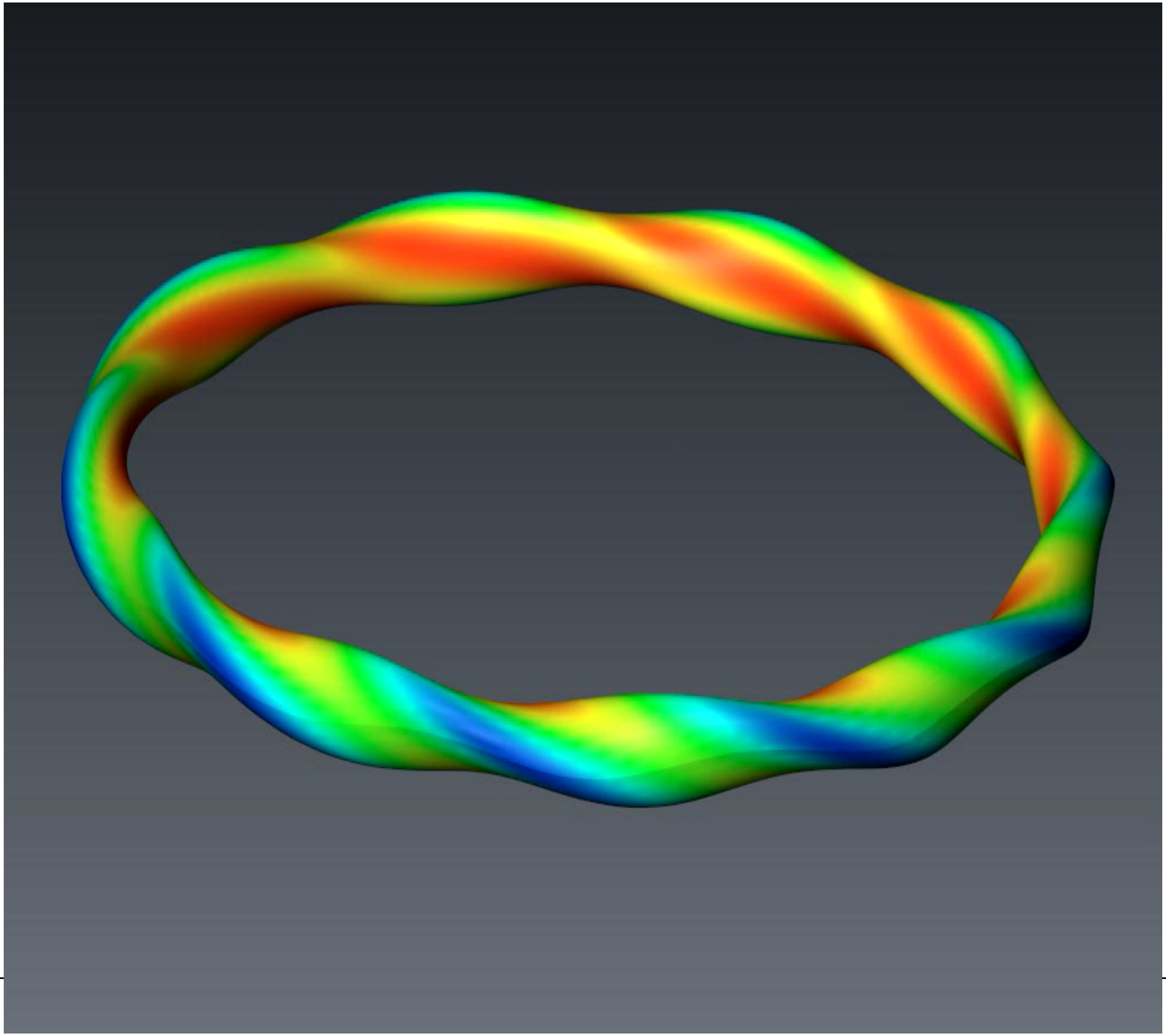
- twisted magnetic field
- weak, self-generated toroidal current



- excellent plasma confinement to be proven: computer optimization needed
- Free of major disruptions
- steady-state

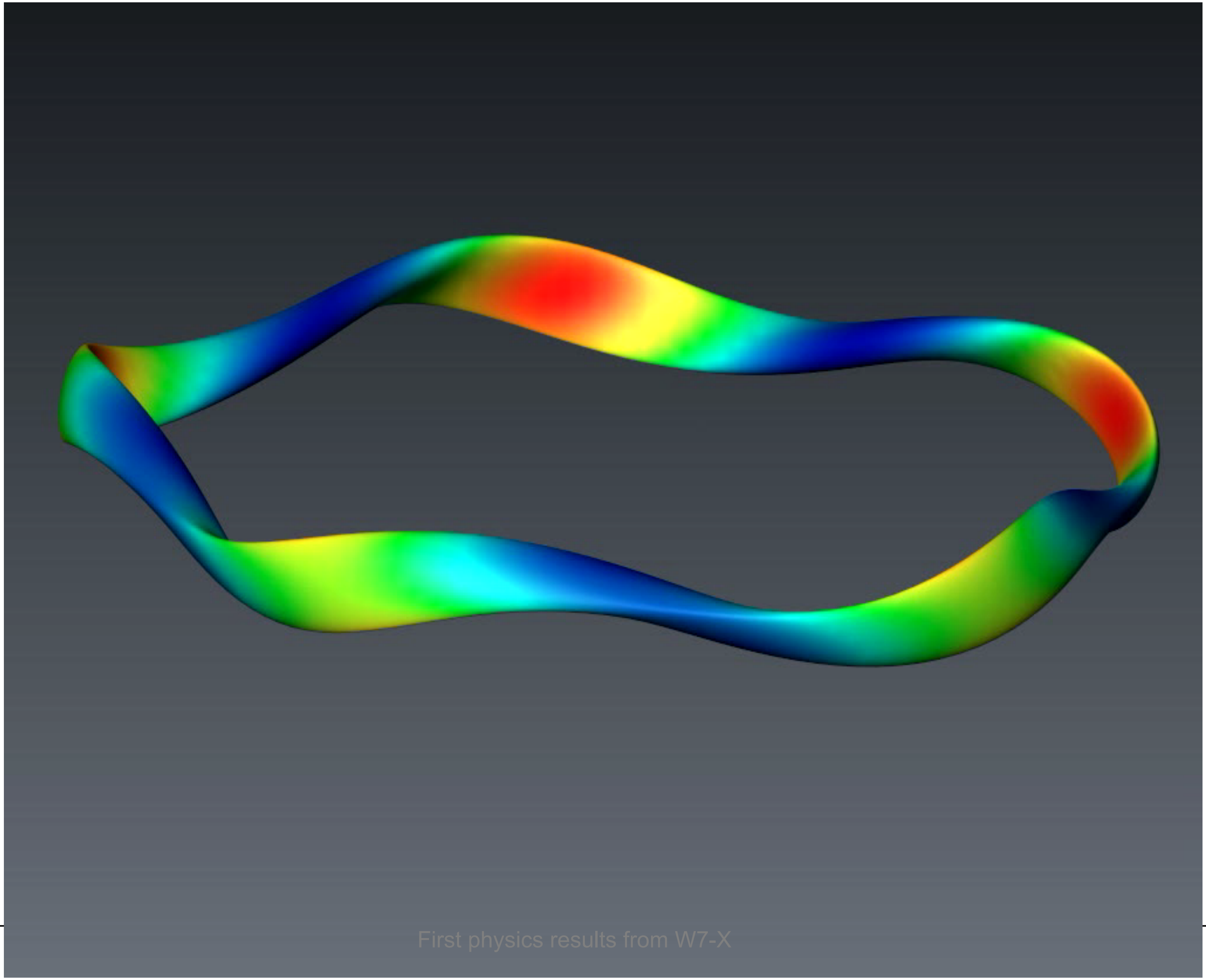
50 keV ion in a classical stellarator

50 keV D-ion in a B=2.5 T R=5 m classical stellarator – scales to α-particle in reactor



W7-X magnetic field optimization

50 keV D-ion in W7-X – scales to α-particle in HELIAS reactor



The optimized stellarator Wendelstein 7-X

Plasma volume **30 m^3**

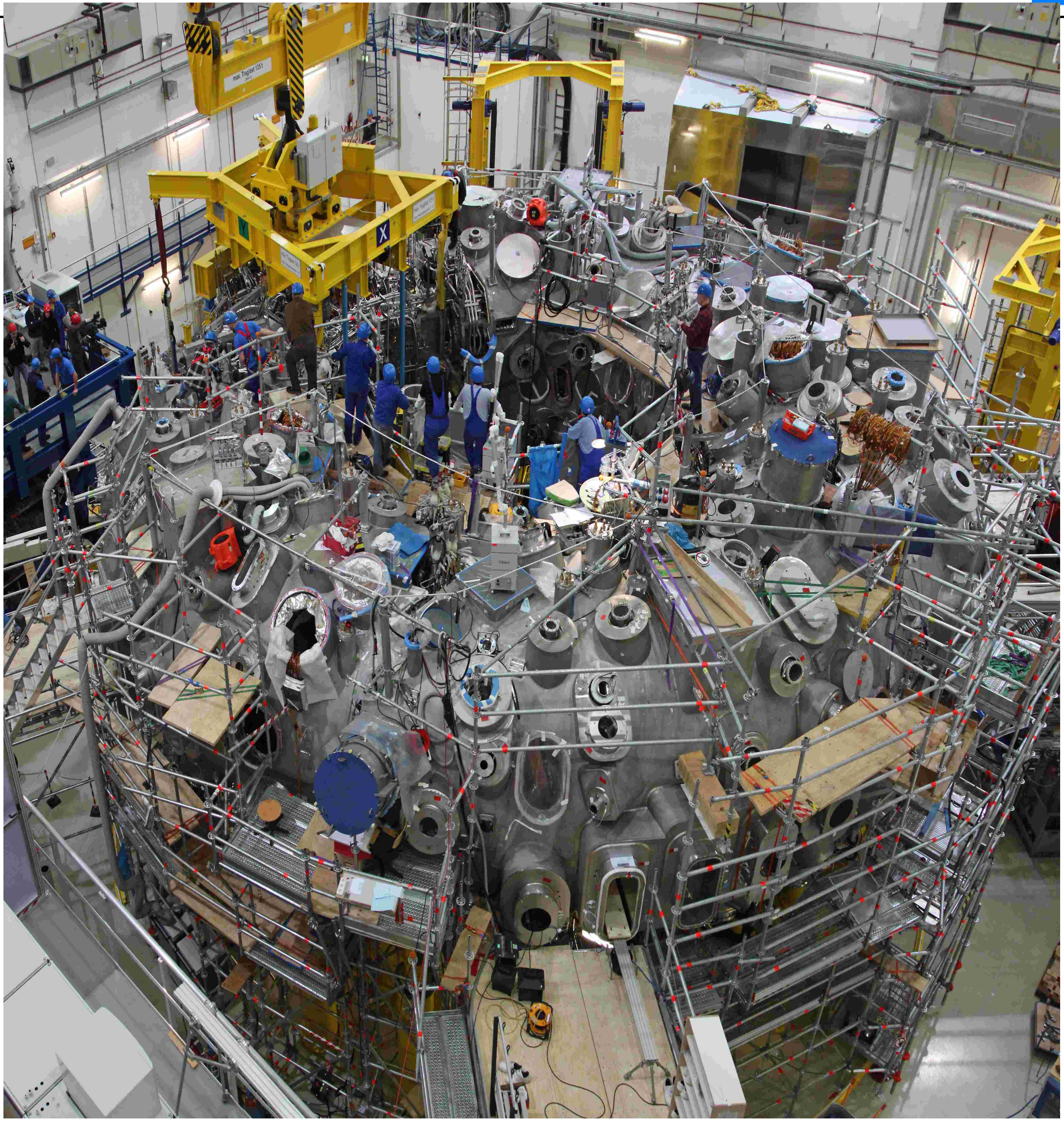
Magnetic field **2.5 T (up to 3 T)**

Superconducting coils **70**

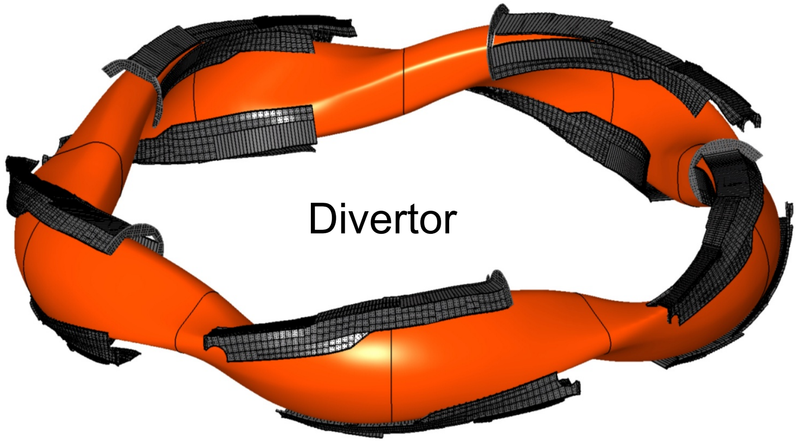
Magnetic field energy **600 MJ**

Cold mass **435 t**

Total mass **735 t**



Wendelstein 7-X operational phases



OP 2: 2020 …

Steady-state operation

Actively cooled divertor configuration

P_{cw} ~ 10 MW

P_{pulse} ~ 20 MW (10 s)

Technical limit **30 minutes** @ 10 MW

OP 1.2: 2017 / 2018

Uncooled divertor configuration

P ~ 10 MW

$\int P\,dt \leq 80$ MJ

τ_{pulse} ~ 10 s at 8 MW

(... 60 s @ reduced power)

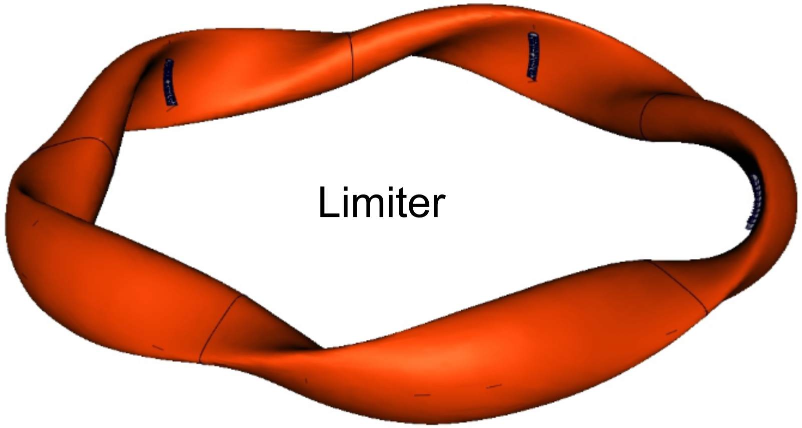
OP 1.1: 2015 / 2016

Limiter configuration

P < 5 MW -> 4.3 MW

$\int P\,dt \leq 2$ MJ -> 4MJ

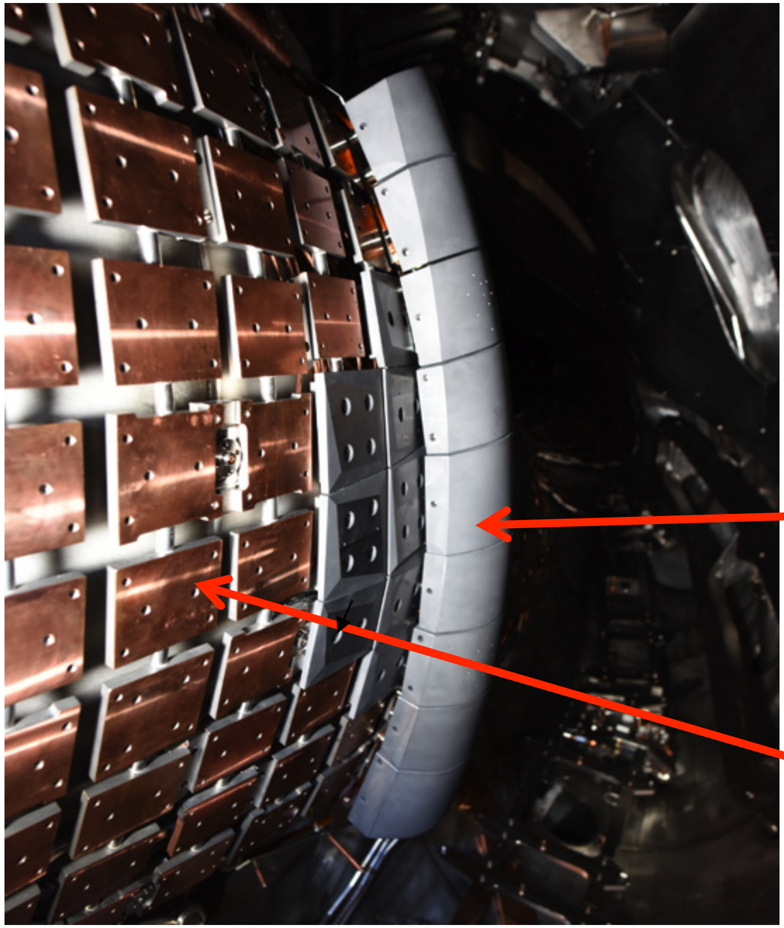
τ_{pulse} ~ 1 s -> 6 s



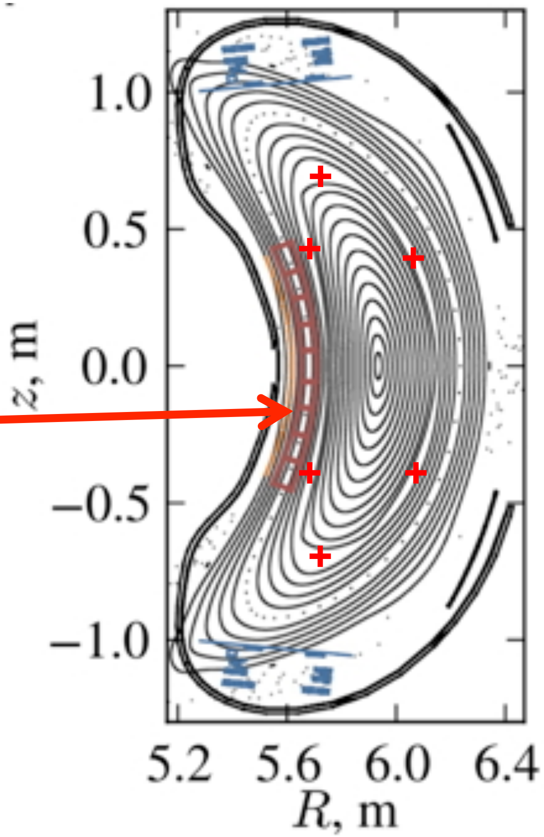
PFCs and topology for OP1.1

- 5 shaped graphite limiters
- Designed to intersect >99% of the convective plasma heat loads
- The rest of the PFCs shielded from direct convective plasma loads

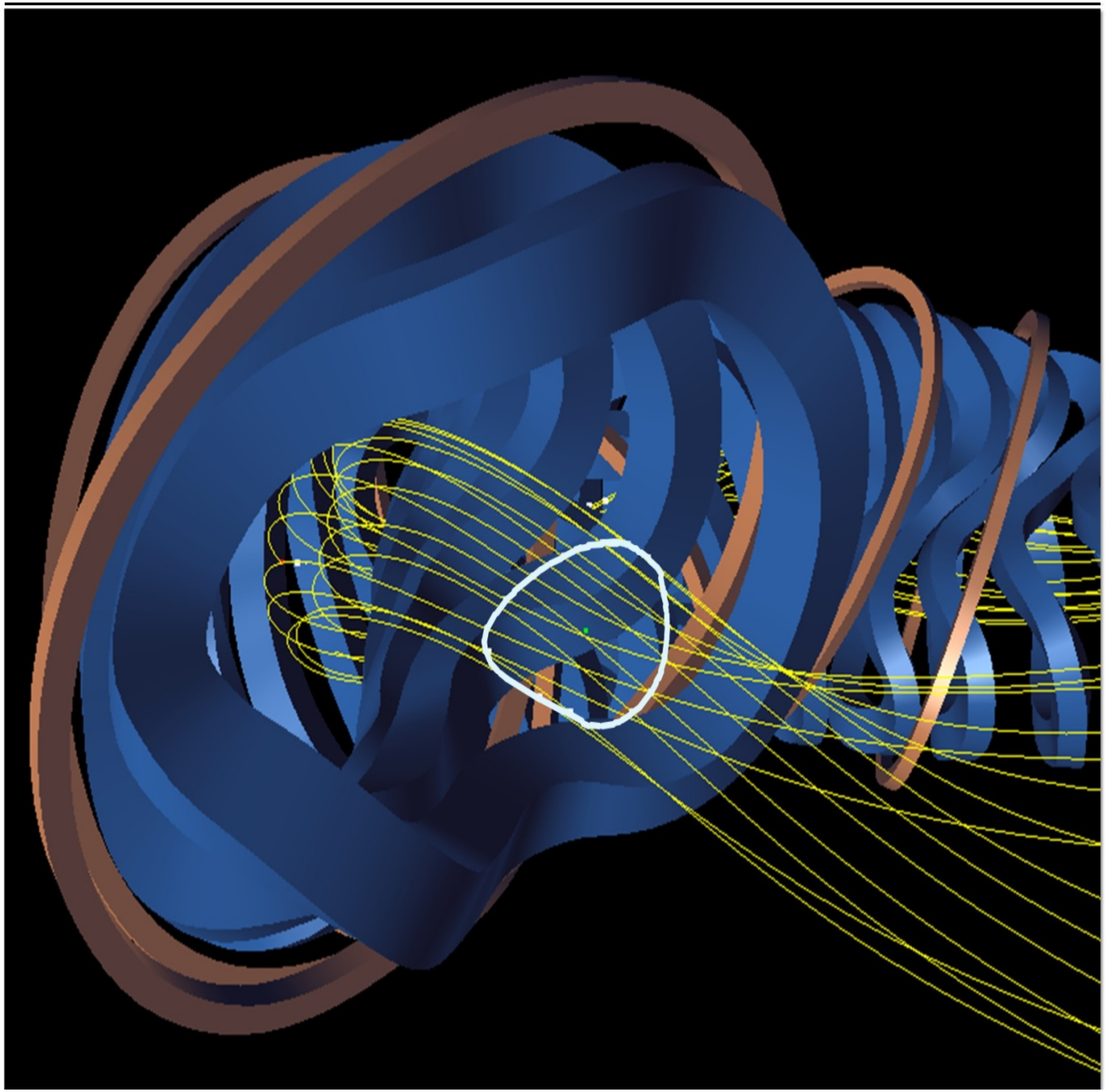
- Magnetic configuration without edge islands ensures “sharp edge”
- Internal 5/6 island chain (+) serves as marker for the topology, indirectly confirming the absence of near-shadow island chains



Bare CuCrZr heat sinks
(all being covered with graphite for OP1.2)

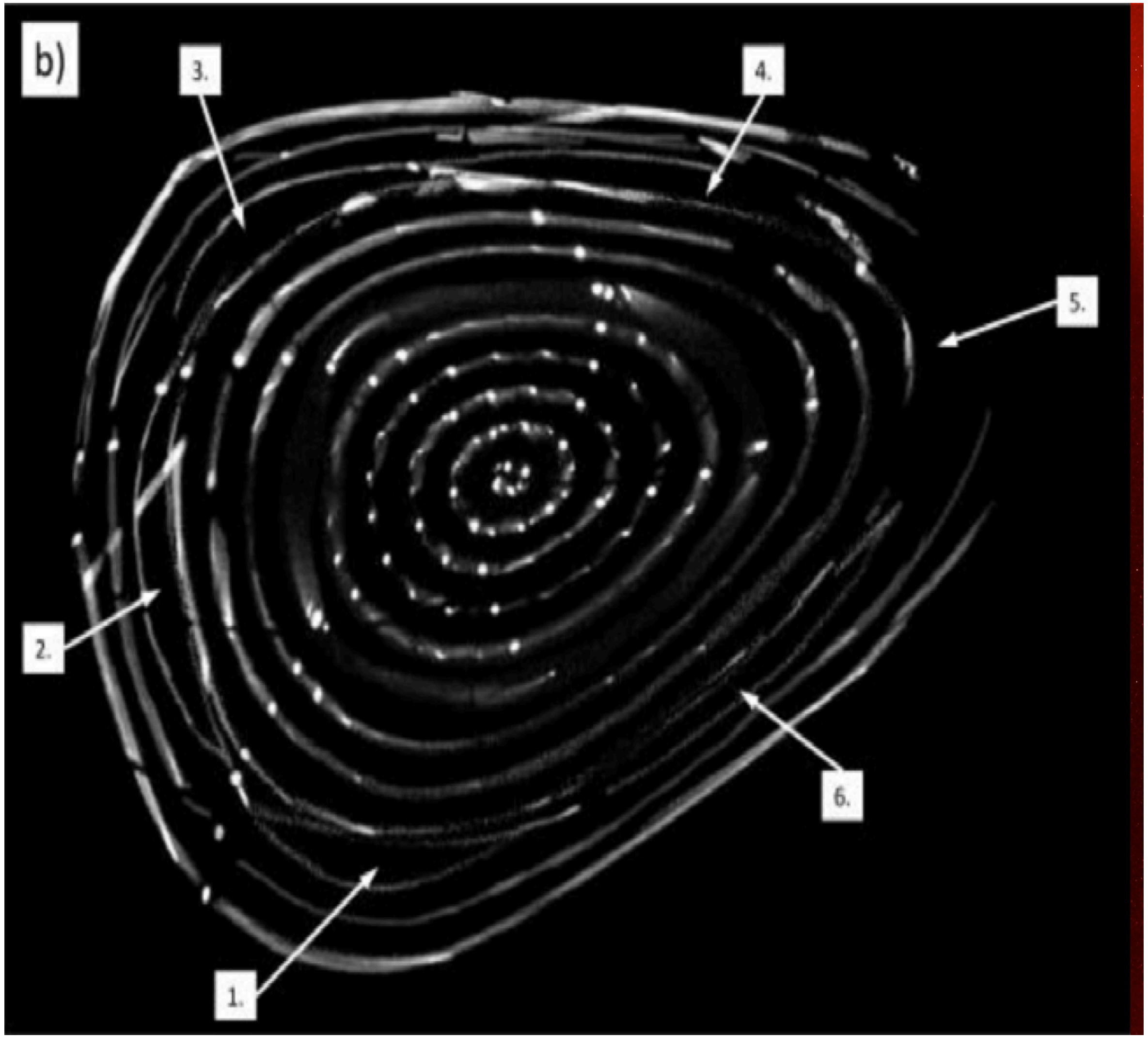


Confirming the topology



Measurements confirmed nested flux surfaces

- As reported earlier[a,b], the expected nested flux surface topology has been verified in great detail, including the intrinsic 5/6 island chain
- There were some deviations but all small
- The configuration chosen for OP1.1 plasma operation was particularly robust against field errors.
- With a different configuration[c,d] we confirmed the topology to an accuracy of better than 1:100000



[a] APS-DPP meeting San Jose, CA (2016)
[b] M. Otte et al., PPCF 58, 064003 (2016)

[c] S. Lazerson et al., Nucl, Fusion (2016)
[d] T. Sunn Pedersen et al., Nature Comm. (2016)

All goals of OP 1.1 were attained …

OP 1.1 priorities: Integral commissioning and first plasma operation

1. Integral commissioning of all systems needed for successful plasma operation ✓
2. Existence of closed flux surfaces all the way to the limiter (at B=2.5 T) ✓
3. Measurement and adequate reduction of B_{11} field errors (✓)
4. Reliable ECRH plasma startup scenario in He ✓
5. Basic ECRH interlocks and safe operation scenarios: $\int P\,dt \leq 2$ MJ ✓
6. Basic impurity content monitoring ✓
7. Central $T_e > 1$ keV at $n_e > 5{\cdot}10^{18}$ m^{-3} in at least 10 discharges in He ✓

$P_{ECRH} \leq$ 4.3 MW

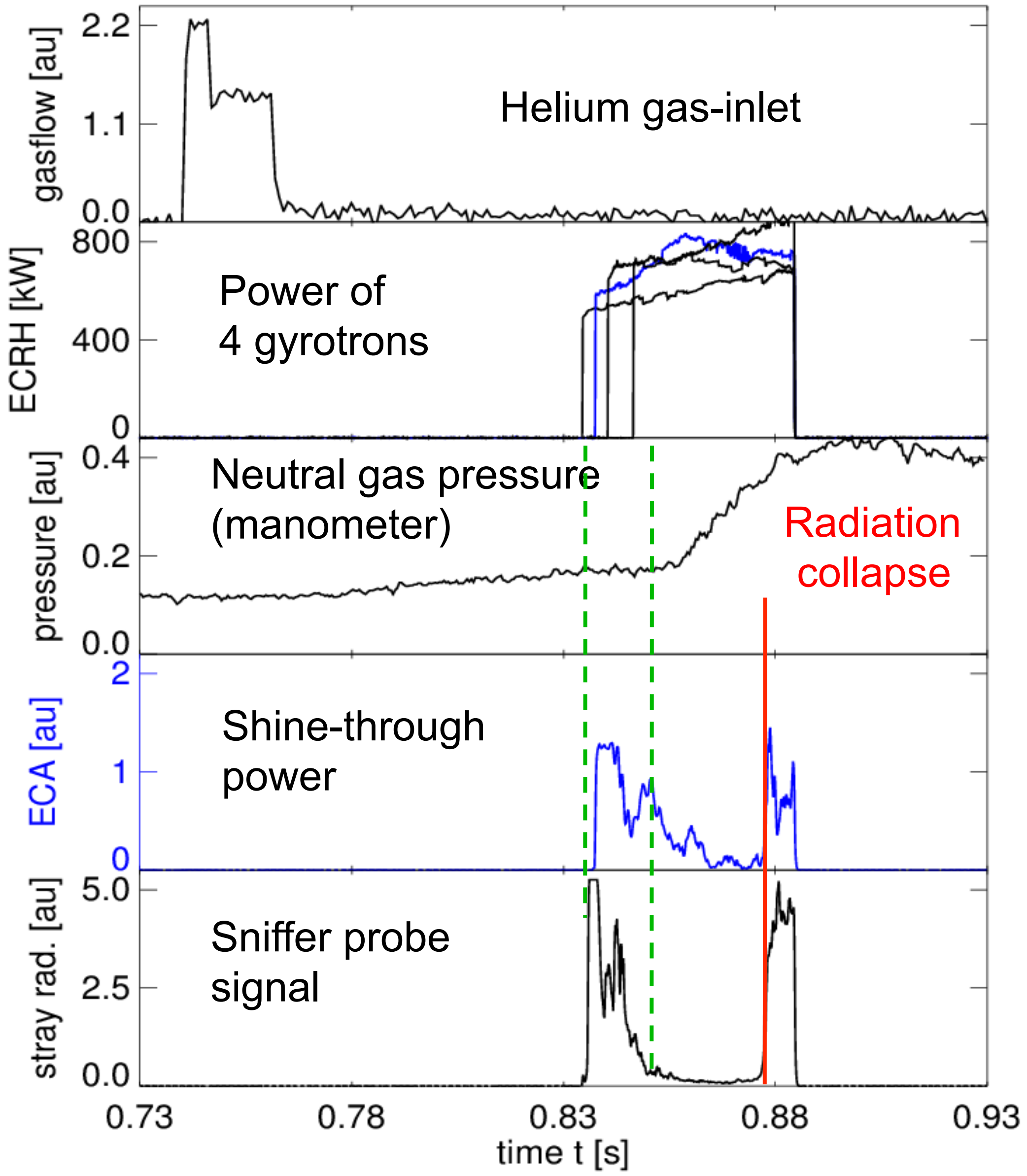
4 MJ / 6 s

$T_e \sim$ 10keV
$T_i \leq$ 2 keV

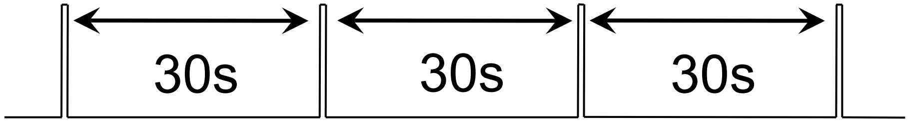
He $\leq 8{\cdot}10^{19}$m^{-3}
H $\leq 2...3{\cdot}10^{19}$m^{-3}

Confirmation of optimization goals of W7-X will be done in later operation phases

Plasma generation (early phase)



- Plasma break-down within 10ms
- Sniffer interlock (radiation collapse) terminates plasma after ~20 ms
- Hundreds of short ECRH cleaning discharges (3 days corresponding to about 4 sec plasma operation)

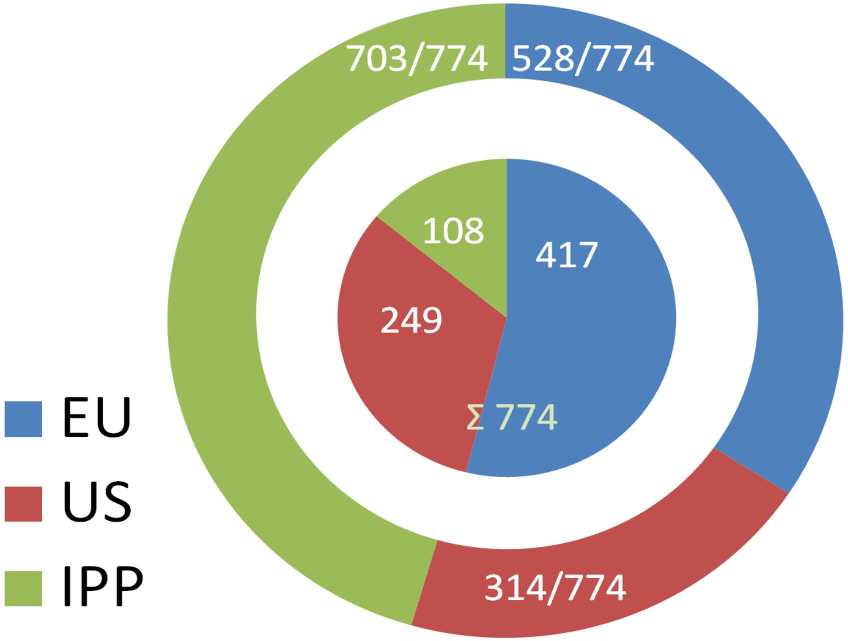


⇒ discharge length extended to ~50ms

⇒ With more pulses and glow discharge cleaning, eventually 6 seconds

Success of OP 1.1: A collaborative effort

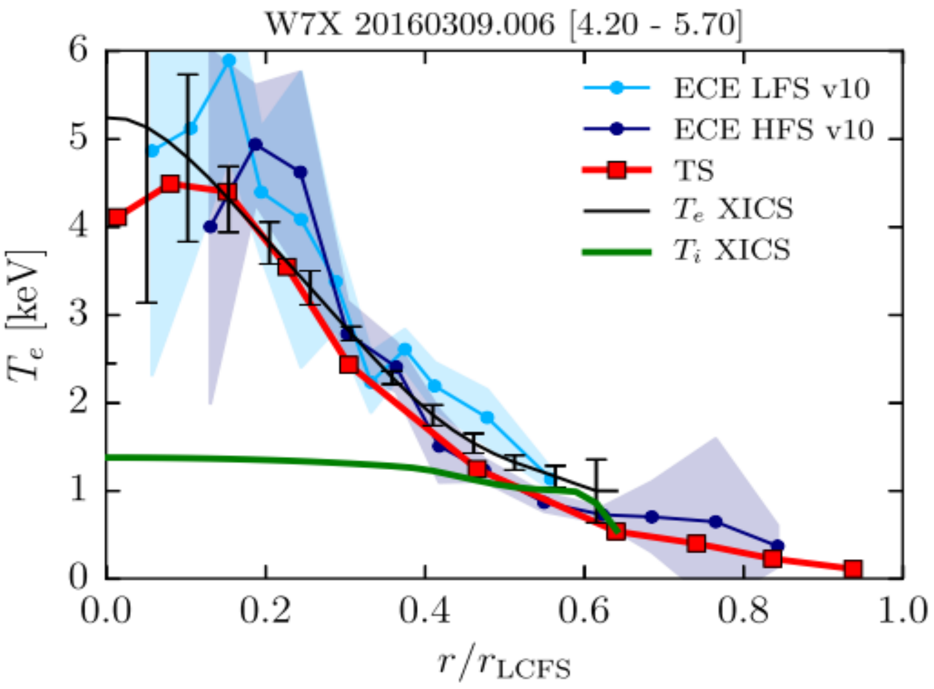
Contributors to conducted proposals



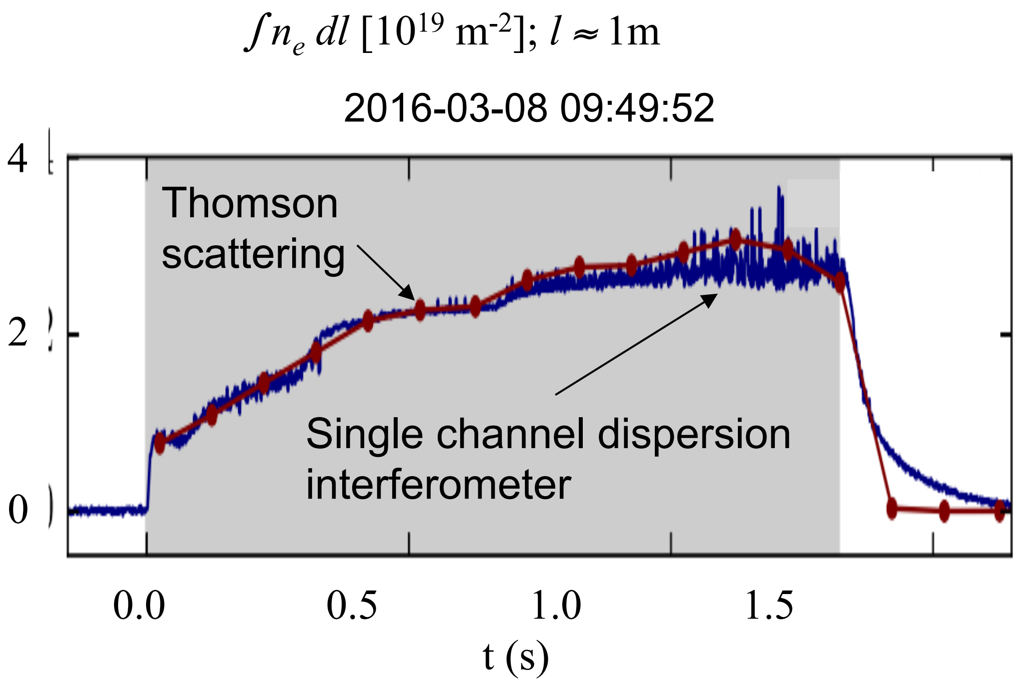
inner circle: ’first proponent‘
outer circle: contributor

- 402 out of 843 plasma experiments (discharges) with physics proposals
- 774 proposals conducted in the 402 physics programs

Measurement of basic plasma parameters



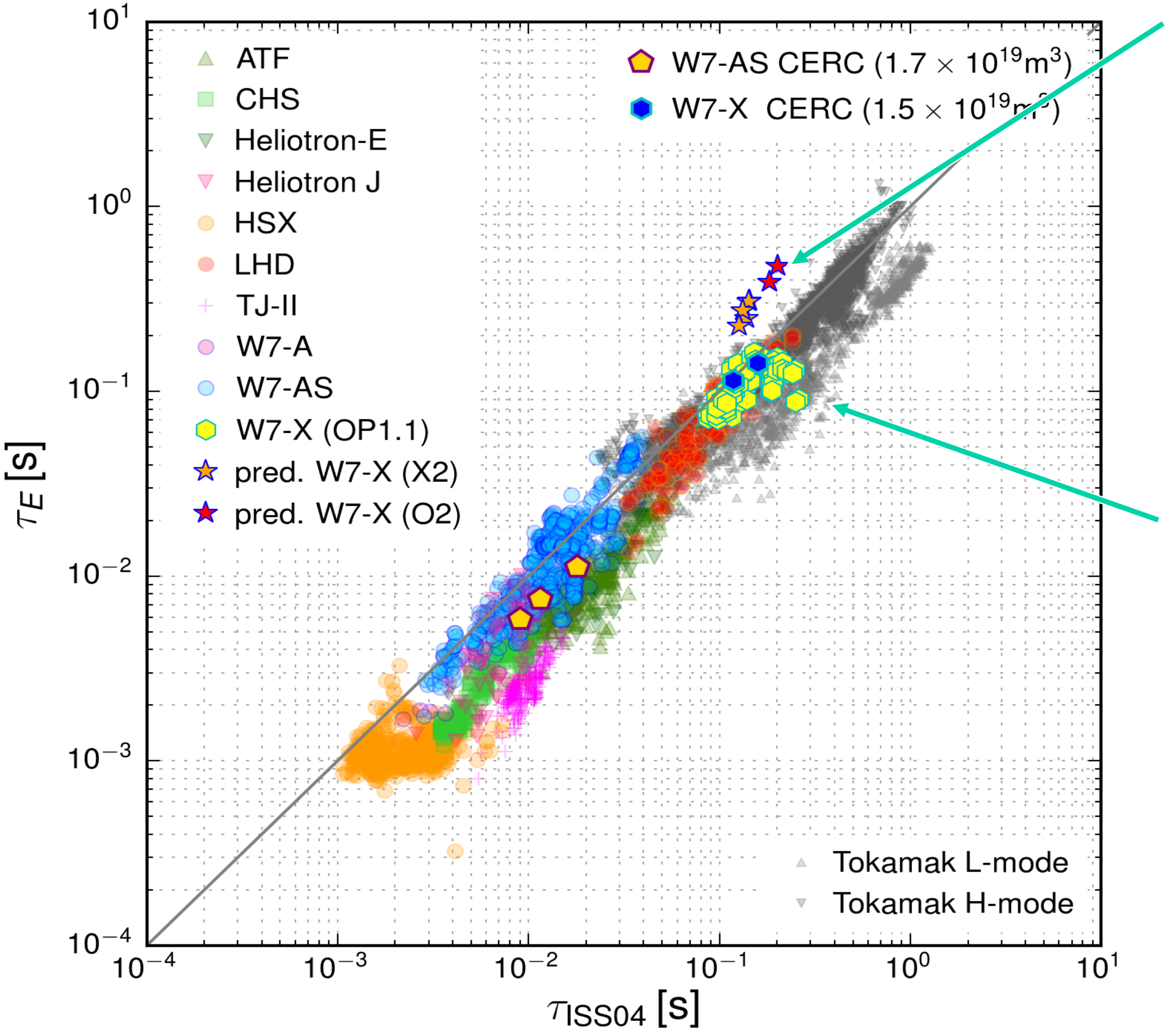
Hydrogen plasma
P_{ECRH} = 0.6 MW, 6 sec



Hydrogen plasma
P_{ECRH} = 4 MW

- Low densities and electron heating by ECRH resulted in $T_e \gg T_i$
- Results in outward pointing electric field in the core giving so-called Core Electron Root Confinement (CERC) – more on that later

Characterization of energy confinement



$$\tau_E^{\mathrm{ISS04}} = 0.134 a^{2.28} R^{0.64} P^{-0.61} \bar{n}_e^{0.54} B^{0.84} \iota_{2/3}^{0.41}$$

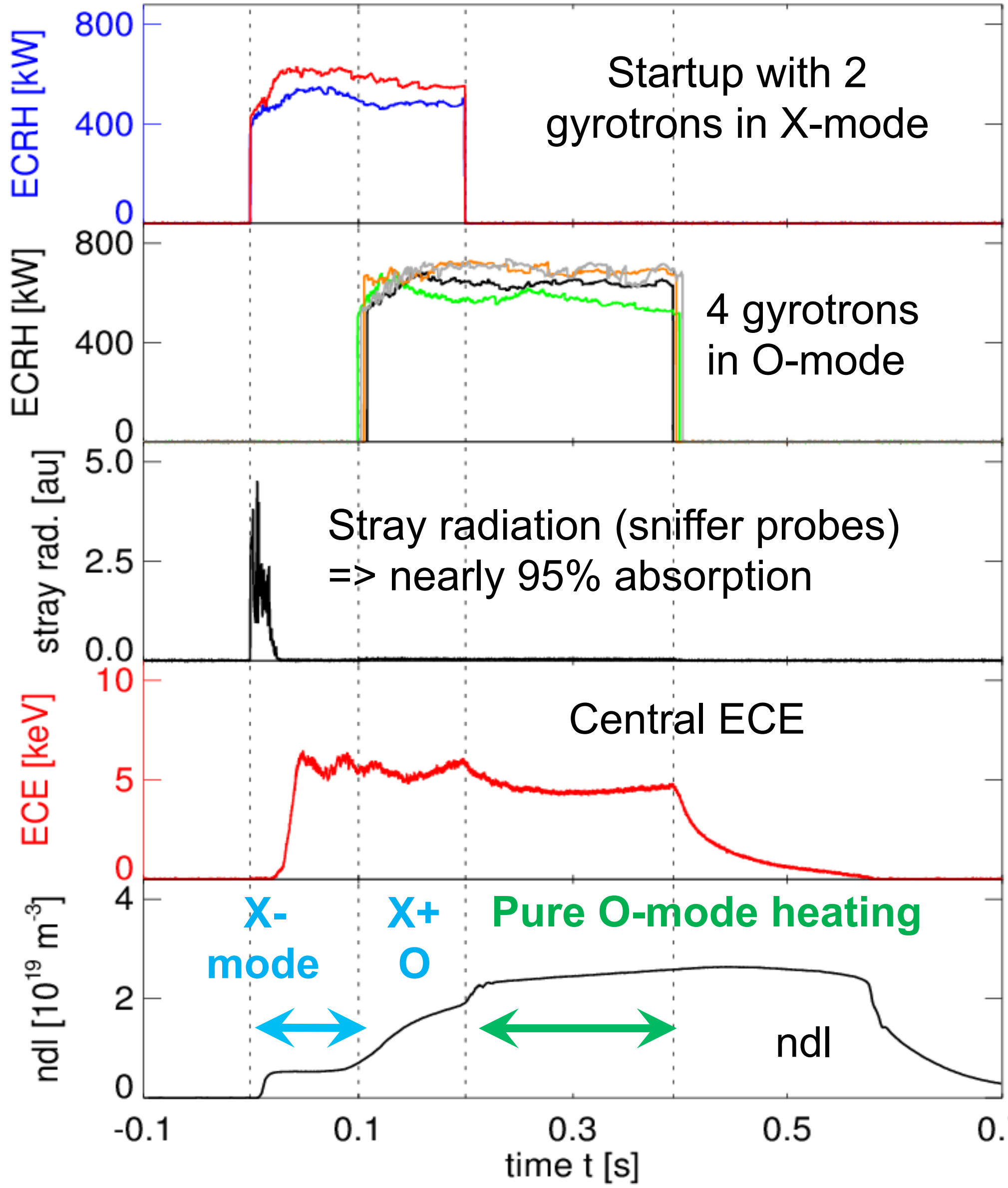
Optimized confinement time as predicted for W7-X ion-regime ($\chi_{e,1/\nu} \sim \varepsilon_{\mathrm{eff}}^{3/2}$)

Confinement times during 1st W7-X campaign

- Best plasmas lie on ISS04-scaling
- Only 16 days of hydrogen operation
- Conditioning of wall was still ongoing; impurity issues

Demonstration of O2-ECRH

- Proof-of-principle for high-density operation with ECRH in future operation phases
- Plasma start-up in X2-mode
  - X2-cutoff at n_e=1.2*10^{20} m^{-3}
- For $T_e \geq$ 5 keV simultaneous X2- and O2-heating
- Finally, sustainment of plasma with only O2-heating
  - O2-cutoff is at 2.4*10^{20} m^{-3}



Startup with 2 gyrotrons in X-mode

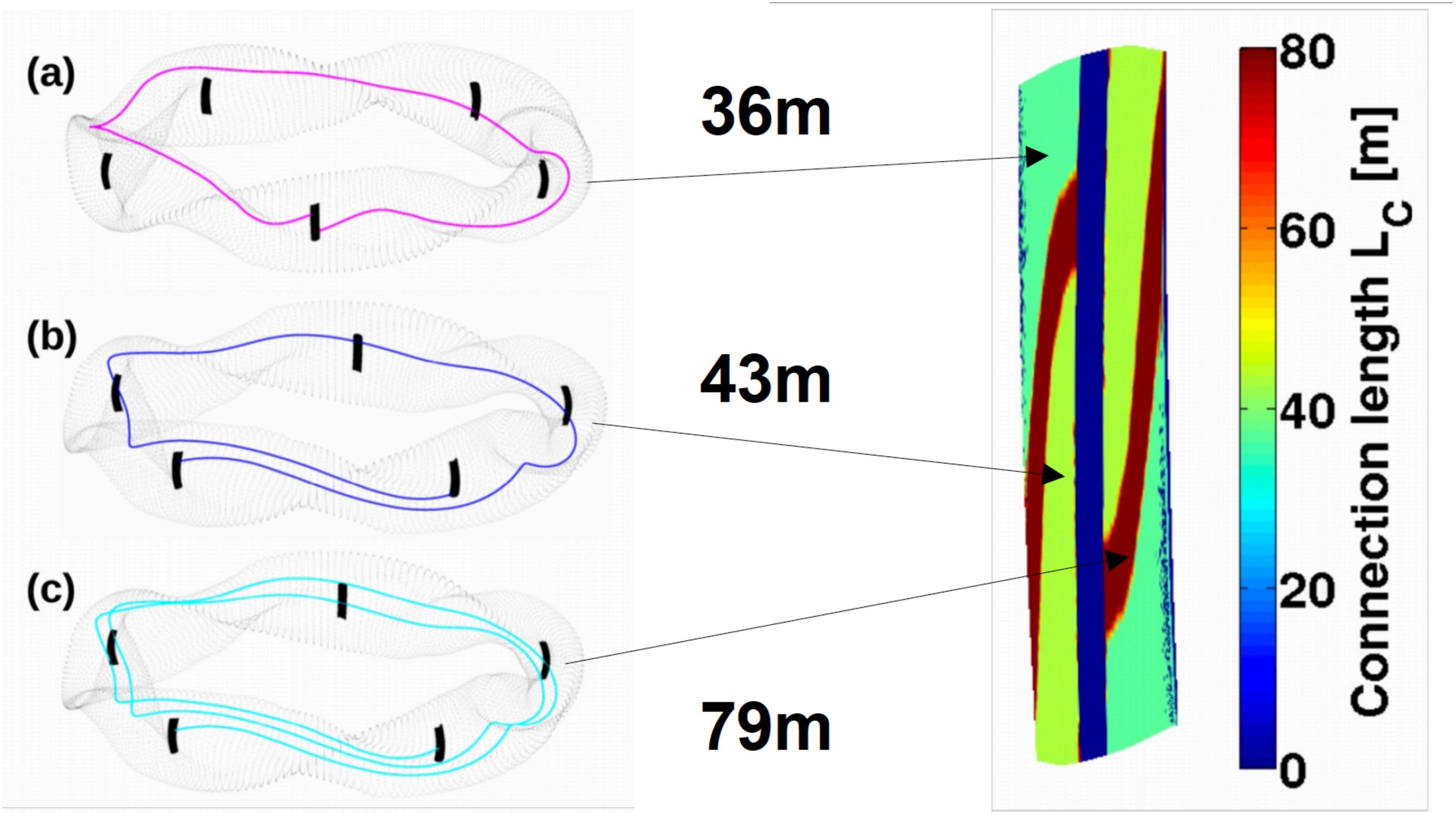
4 gyrotrons in O-mode

Stray radiation (sniffer probes) => nearly 95% absorption

Central ECE

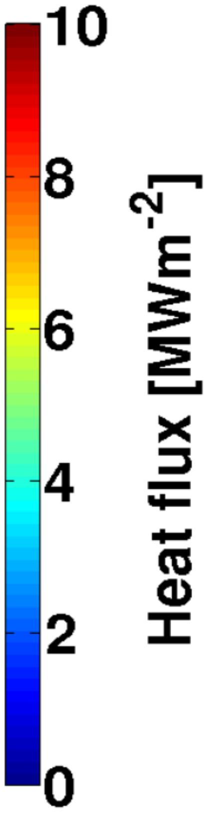
Limiter heat load patterns and a slightly altered configuration

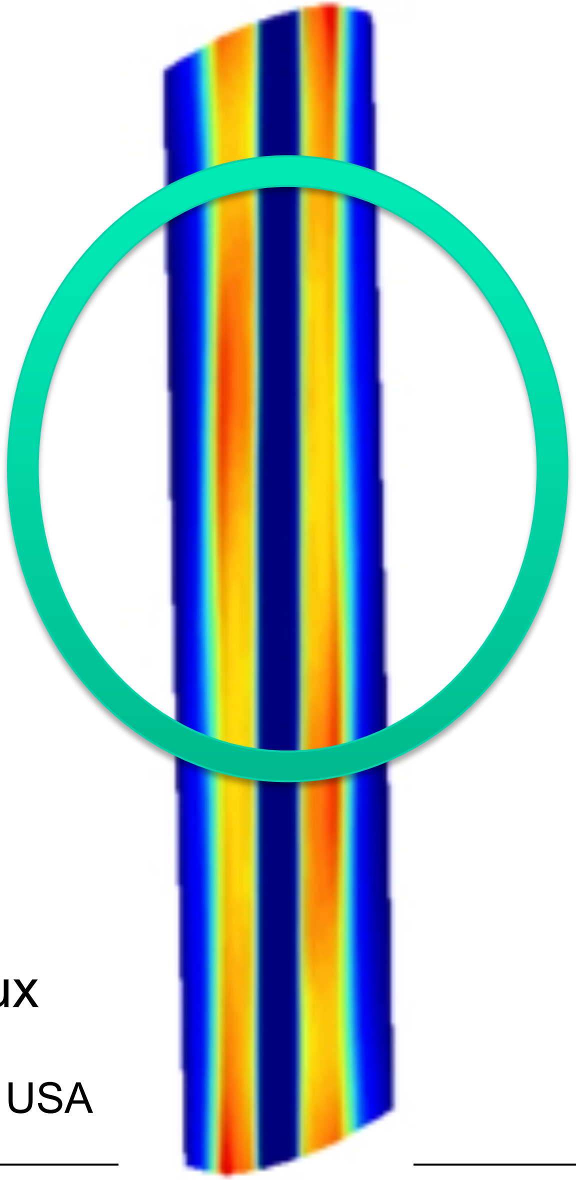
Pattern of connection lengths on limiters



F. Effenberg, O. Schmitz, University of Wisconsin-Madison

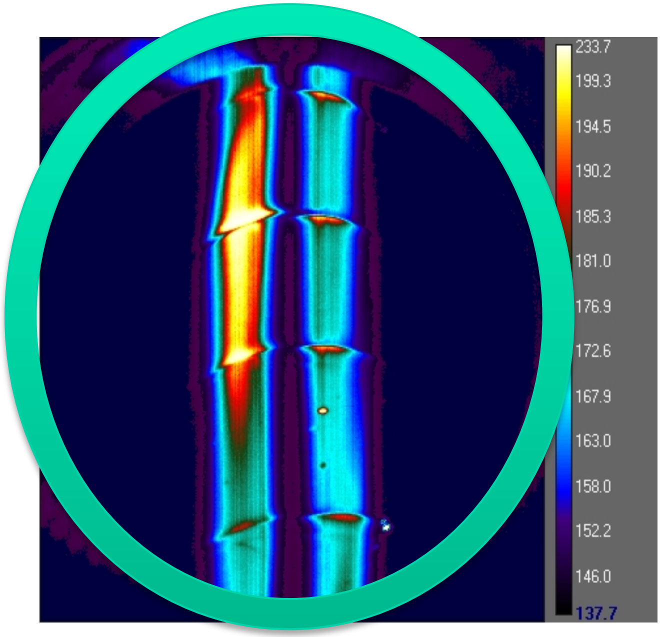
Heat load patterns in OP1.1 agree with predictions





Calculated heat flux

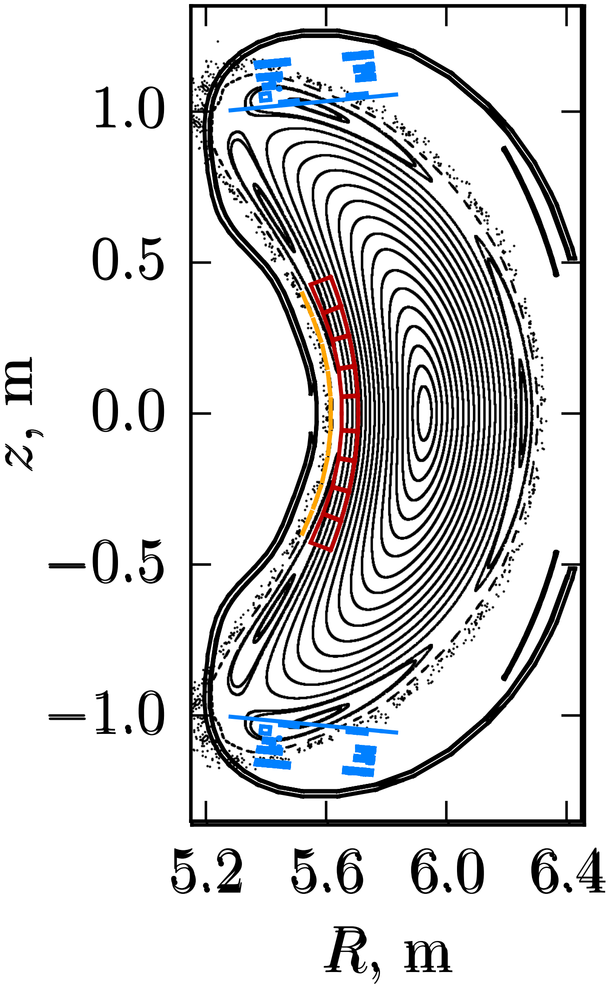
F. Effenberg et al., U. Wisc. USA



IR camera temperature

G. Wurden, LANL, USA

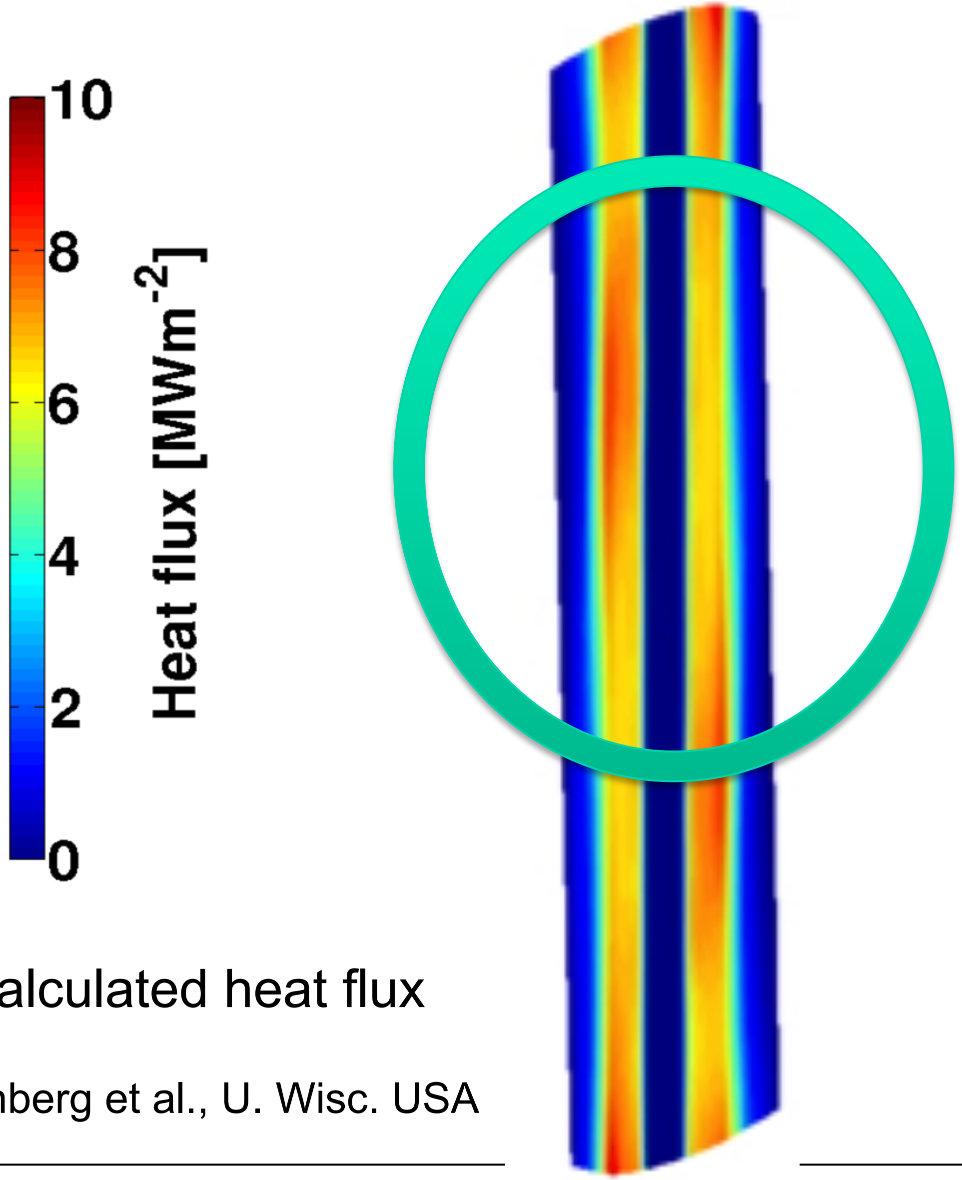
“De-optimized” configuration for OP1.1



This configuration offered:

- Shift of 5/6 island chain inward, away from neutral source region:
  - (It is so small now that it’s not visible on the Poincare plot)
  - Expected particle confinement time increase confirmed [collab, U. Wisconsin]
- Slightly higher iota
  - Shift of heat loads on the limiters
- Neoclassics de-optimized: ε_{eff} factor of 2 higher by increasing mirror term
  - $\varepsilon_{eff}^{3/2}$ is a measure of losses due to bad orbits – almost a factor of 3 naively expected
- More “risky” scrape-off layer topology: 5/5 island chain comes closer [was not a problem]

Heat load patterns in OP1.1 agree with predictions



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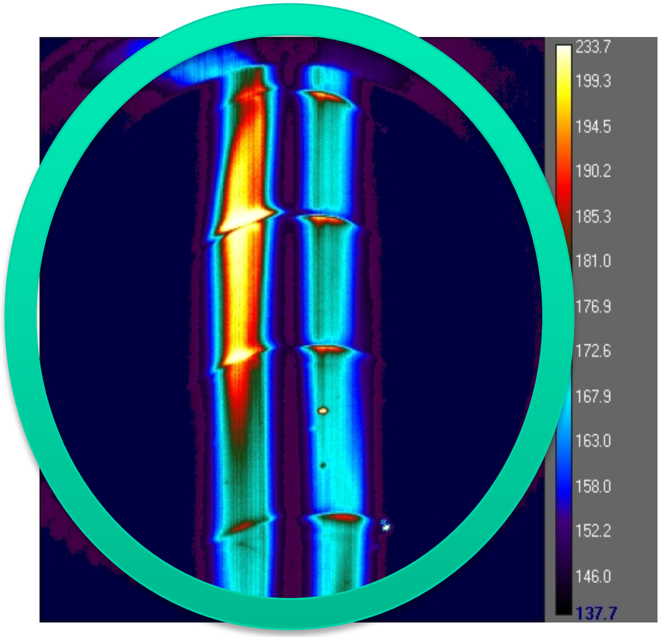

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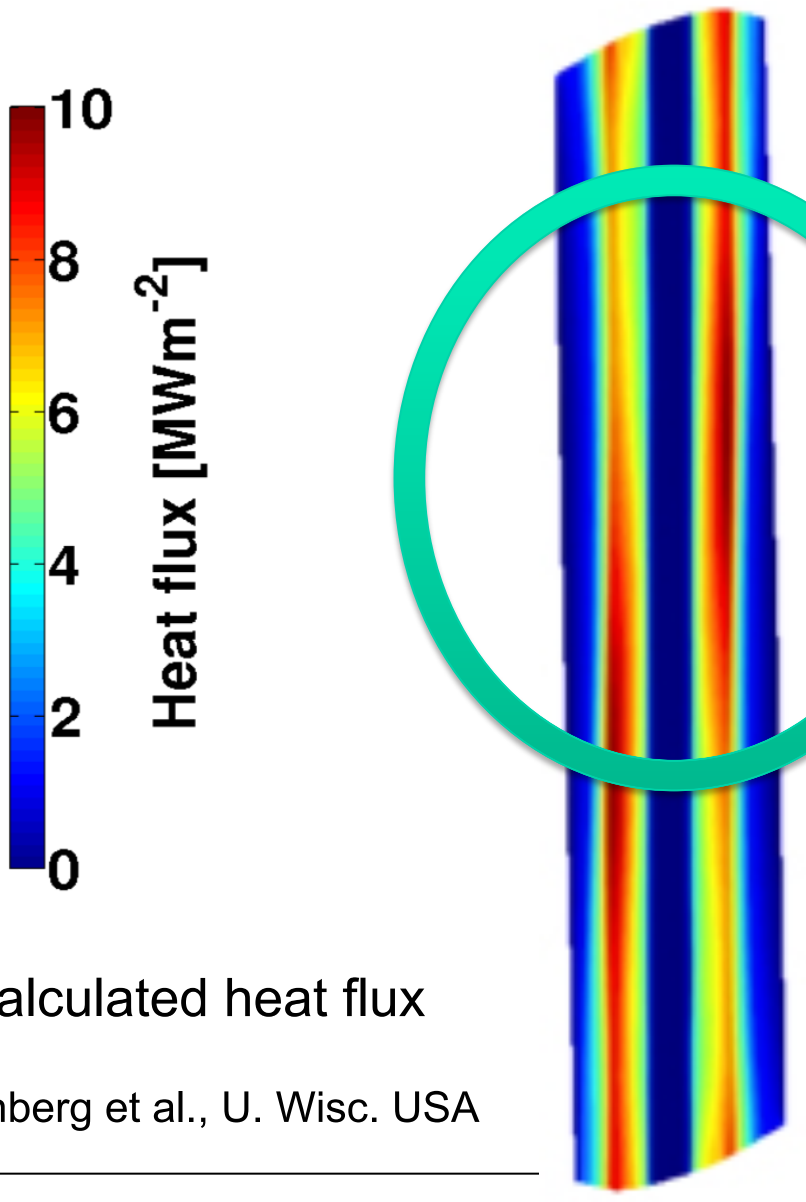
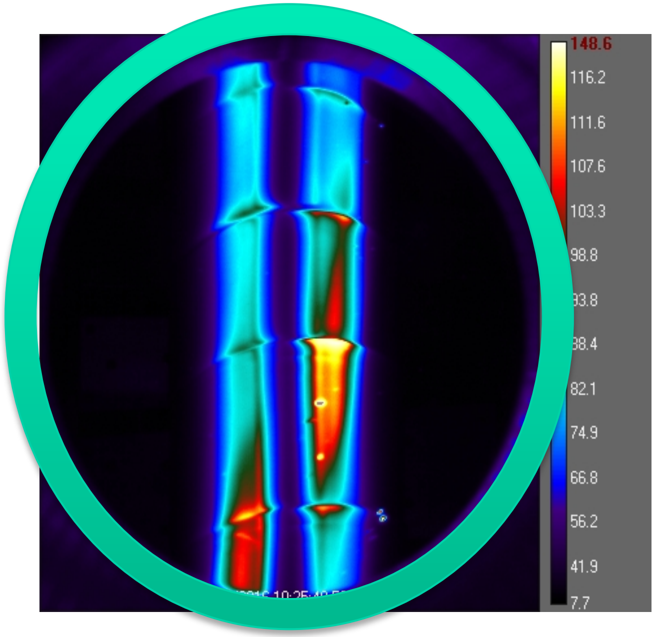


Calculated heat flux

F. Effenberg et al., U. Wisc. USA

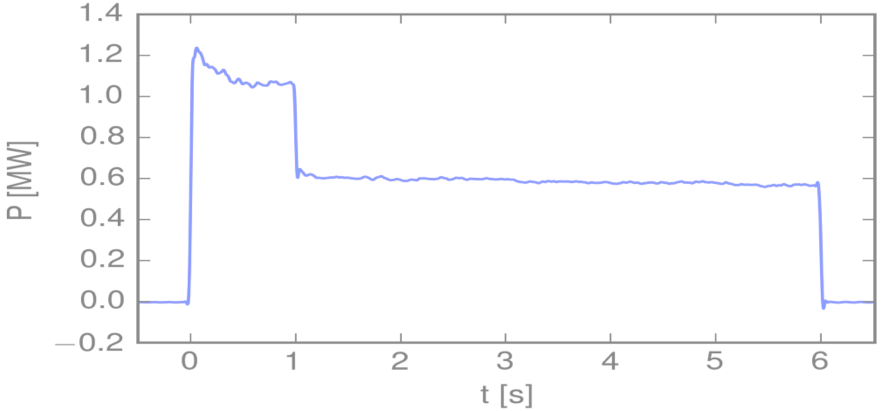


IR camera temperature

G. Wurden, LANL, USA

“De-optimized” configuration

Confinement time with “de-optimized” configuration



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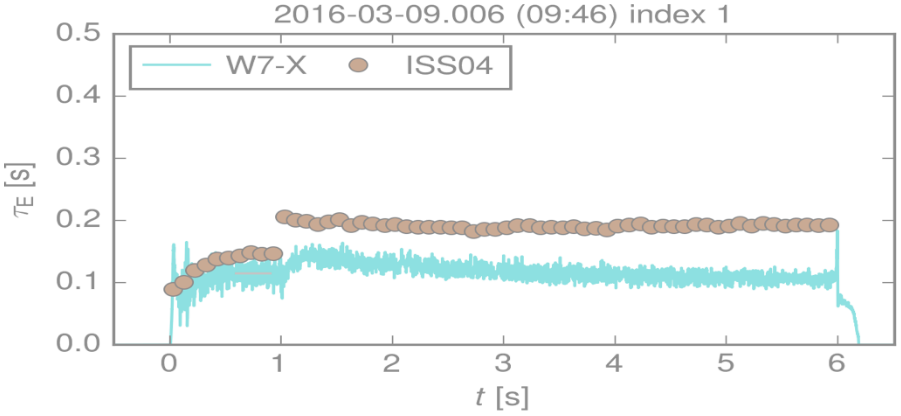

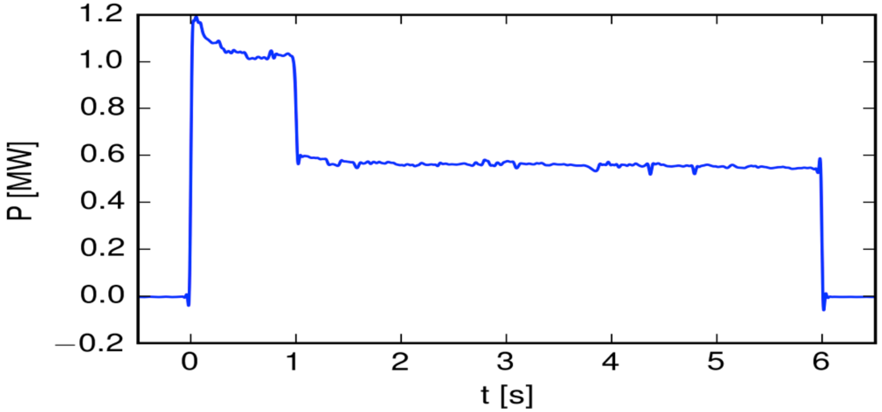

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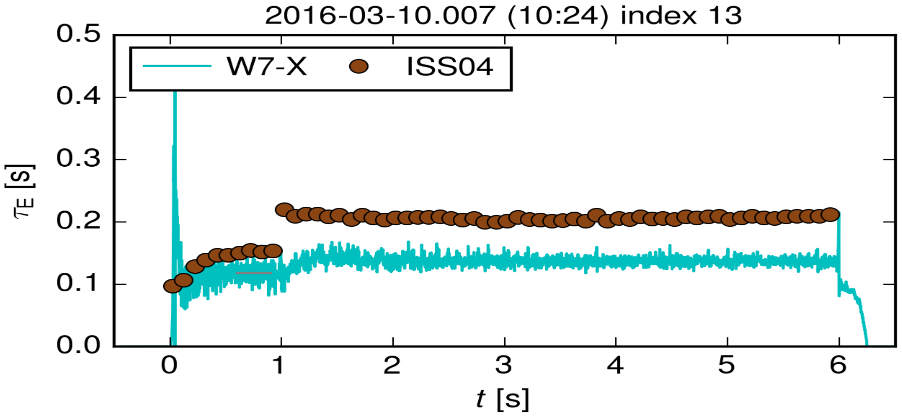
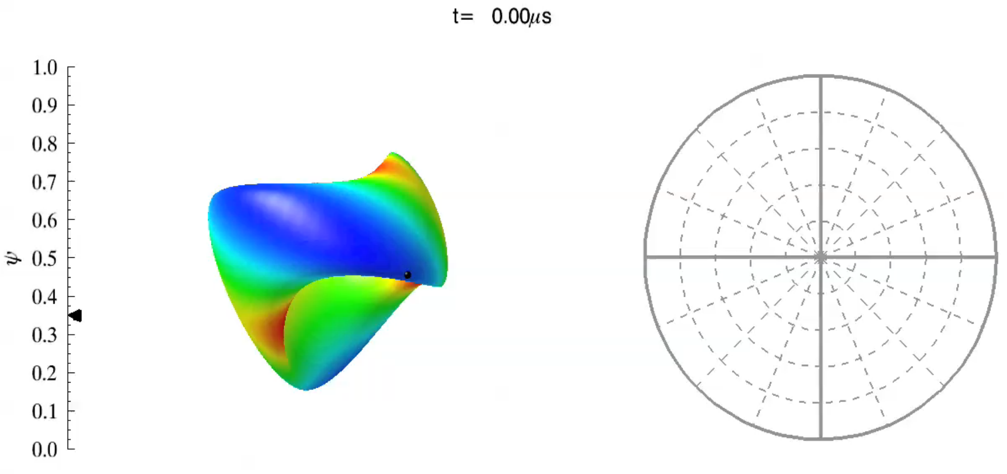


Essentially no change in confinement, as expected

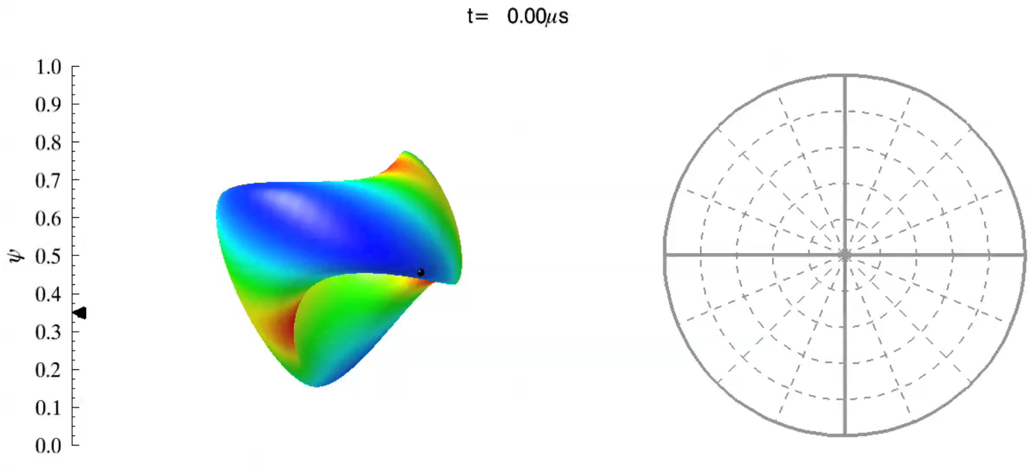
Why expected? Because of electric field effects….

Strong electric fields in stellarators: CNT

This brings me back to the good old CNT days…



Particle drifts out – CNT is not an optimized stellarator



Add a strong radial electric field: Particle stays in

Experimental findings in CNT: 20 ms initially[a], then up to 320 ms[b]

Conclusion: Radial electric fields can significantly heal bad stellarator orbits and therefore effectively mask any ε_{eff} dependences that there would have been otherwise

[a] J. P. Kremer et al. , PRL **97**, p. 095003 (2006),
[b] P. W. Brenner et al., CPP **50** p.678 (2010)

Electric fields in stellarators

How large of a role does the bulk ExB drift play relative to the magnetic drifts?

$$\left|\frac{v_{ExB}}{v_{\nabla B}}\right| \approx \left|\frac{\nabla\phi / B}{(W_k \nabla B / qB^2)}\right| \approx \left|\frac{q\phi}{W_k}\right|$$

Pure-electron plasma: Dominant (factor of 10-1000, CNT: 50)

Thermal particles in a quasineutral plasma: Depends.. (0.2-5)

Set by ambipolarity

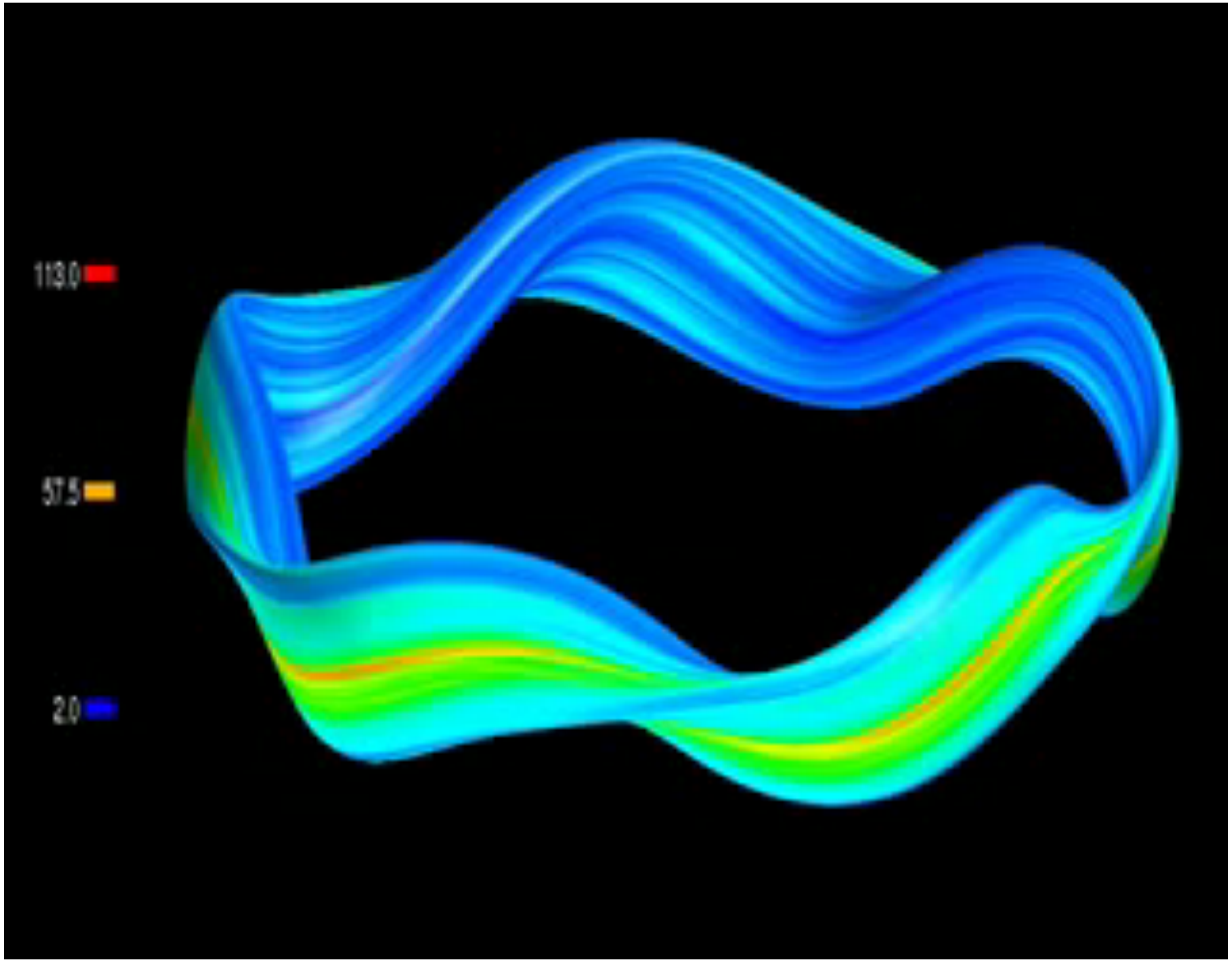
OP1.1 T_e>>T_i leads to relatively strong role in core - CERC

Fusion α's: Negligible (~35 keV/3.5 MeV~0.01)

So, the orbit-healing effects of E_r is going to be smaller in later operation phases, and cannot "fix" α-confinement in a future reactor

Turbulence
Filaments

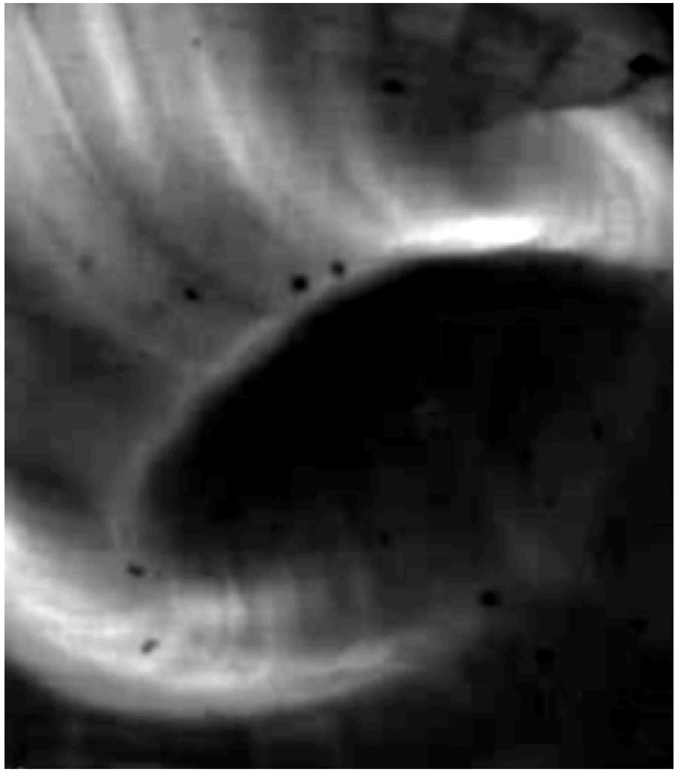
3D turbulence in W7-X

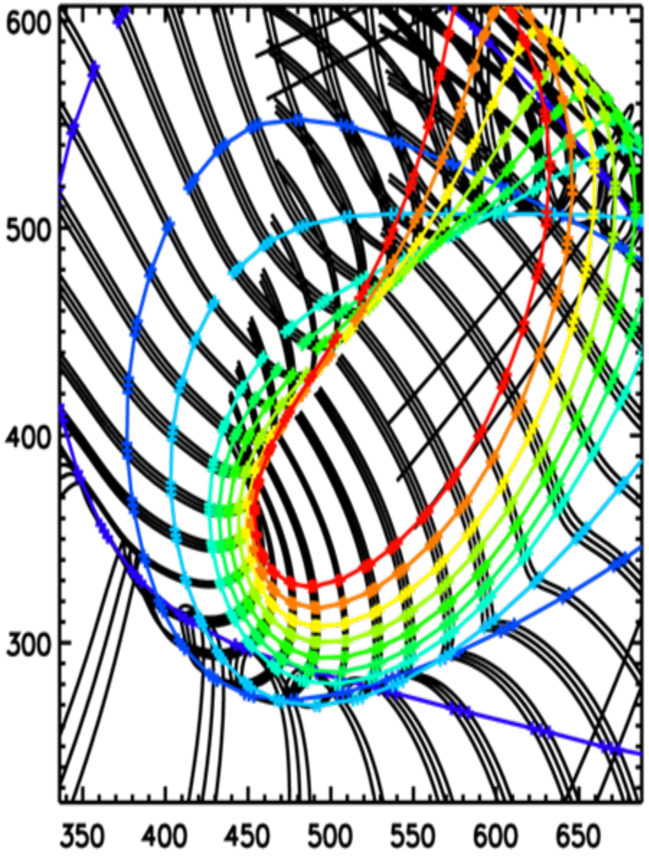


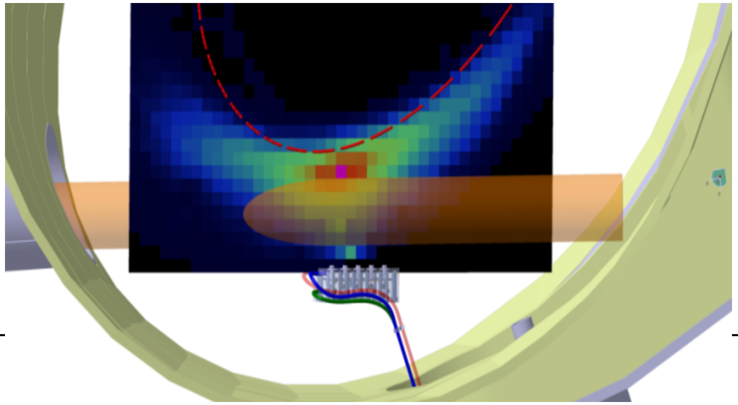
- Structures are highly field-aligned-filamentary
- Rotate and pulsate

Courtesy of Pavlos Xanthopoulos, ST

Filaments are visible when plasma is “cold”



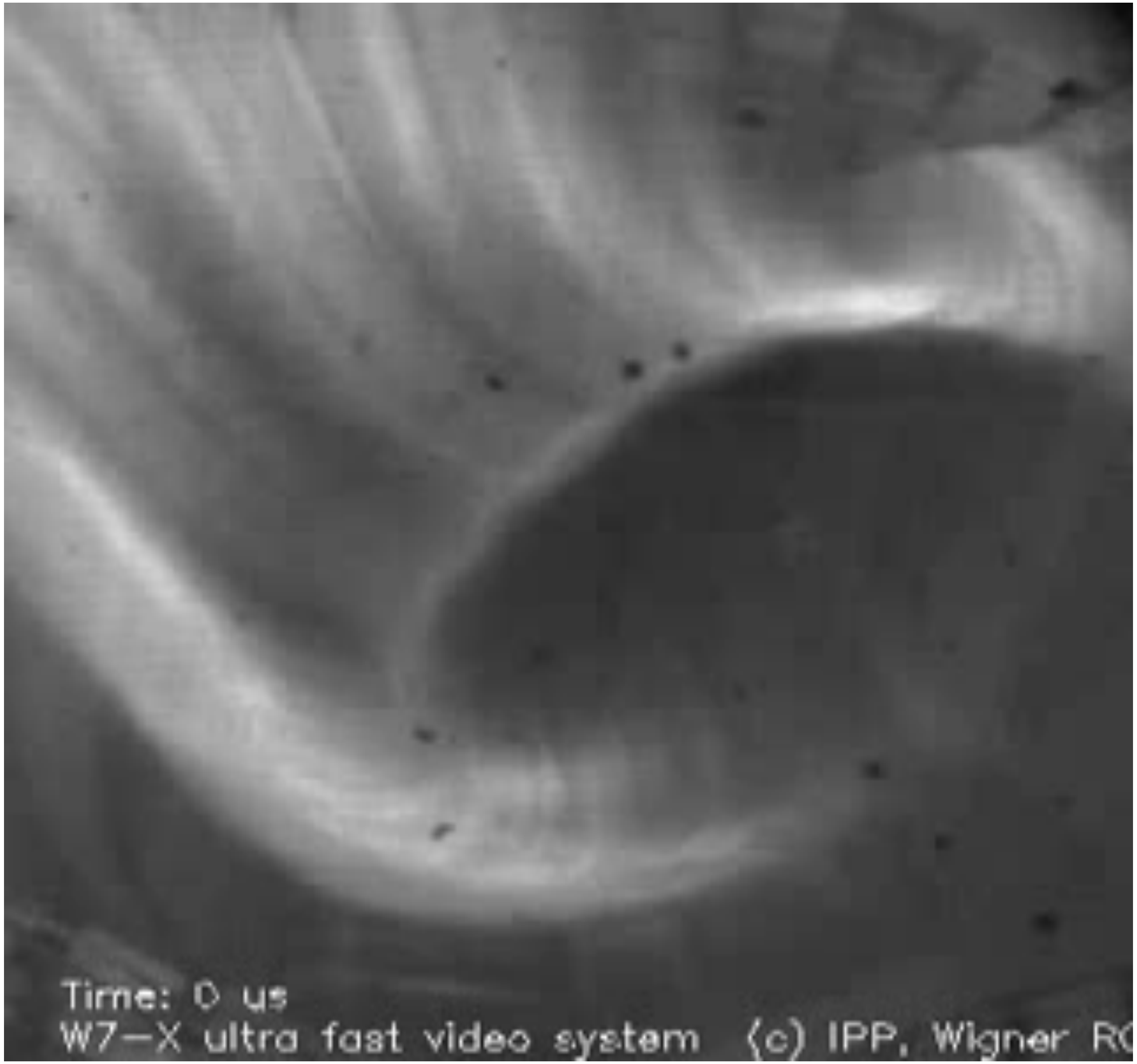




G. Kocsis et al., Wigner RCP, Hungary

- We have a diagnostic for that:
- Photron SA5 camera
    - 46.5kframe/s @ 384x352 pixels
- Field lines in the camera view shown here
- Visualizations can be induced with nitrogen injections from He-beam diagnostic

2.5 ms of dynamics just inside the LCFS



- This is radiation on closed flux surfaces
- Filaments are clearly seen
- They rotate clockwise in this view
- Assuming ExB drift
  - Inward pointing (negative) E-field
  - Expected at $T_e \sim T_i$ at the edge of the plasma

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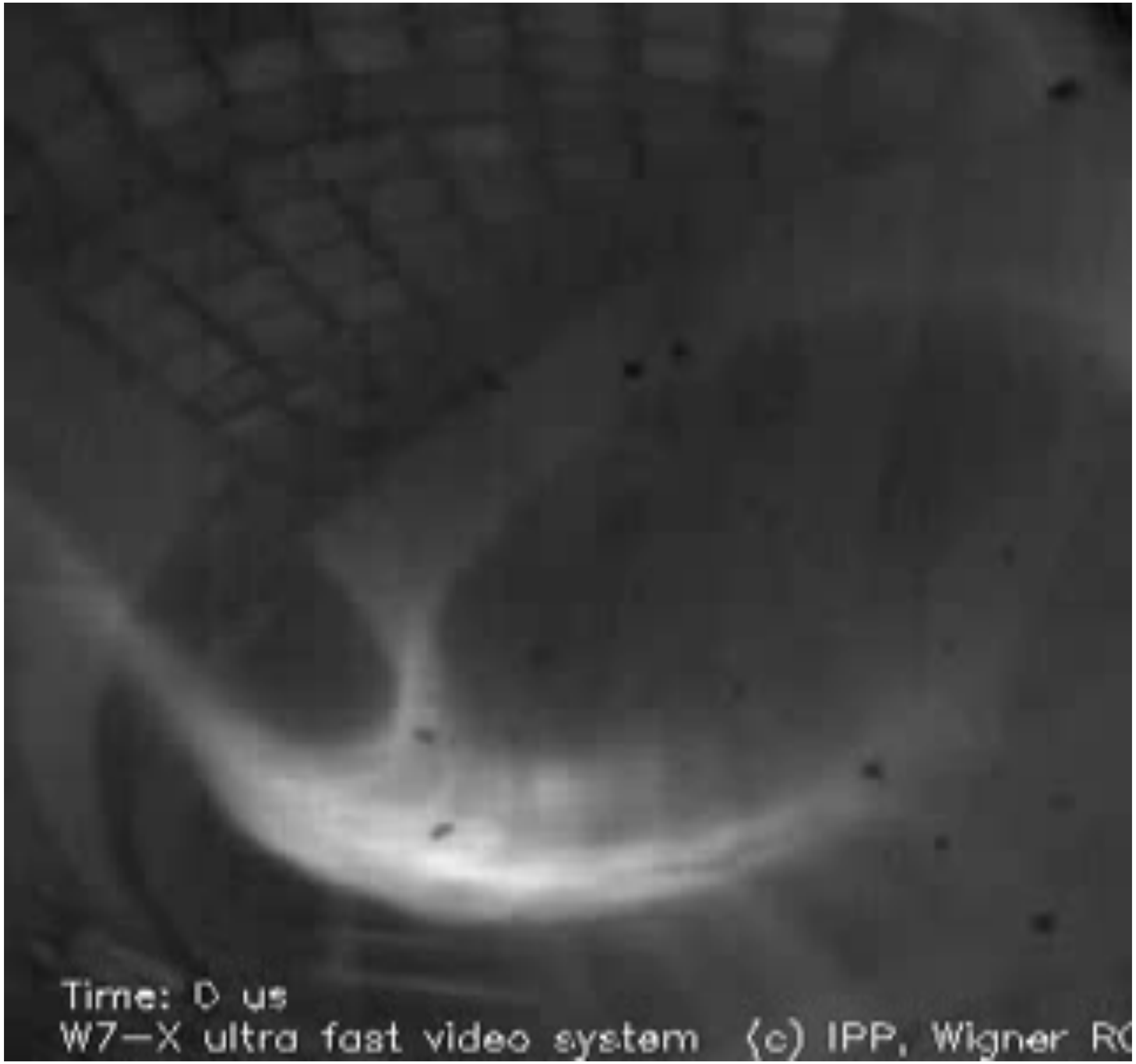
2.5 ms of dynamics just outside the LCFS

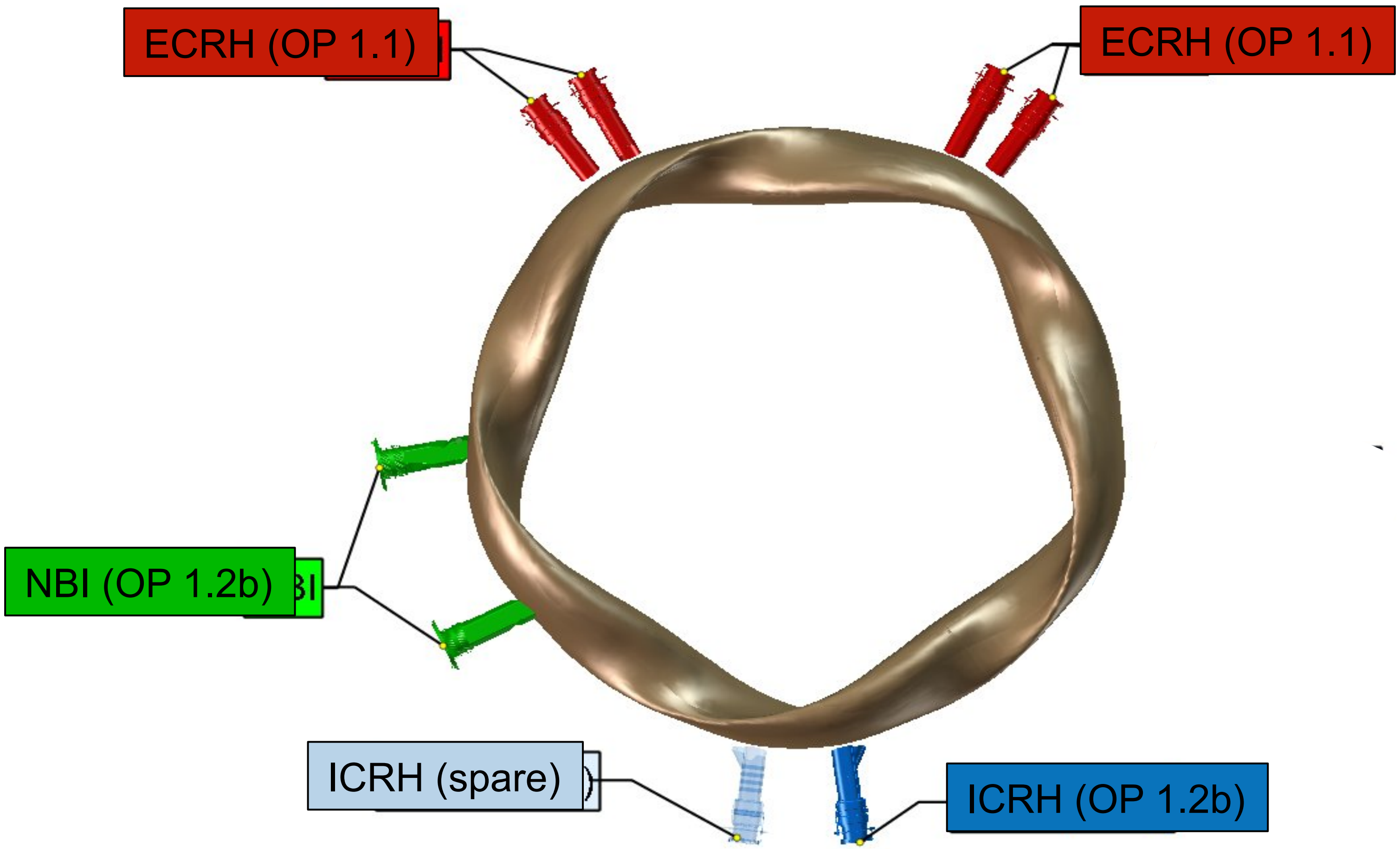


- This is radiation in the SOL induced by a nitrogen puff
- Counter-clockwise rotation initially at least!
- Assuming ExB drift:
  - Outward pointing (positive) E-field
  - Not surprising on open field lines

G. Kocsis et al., Wigner RCP, Hungary

Looking forward to OP1.2

Wendelstein 7-X heating systems



Development of heating systems

Method	OP 1.1	OP 1.2	OP 2
ECRH steady state 140 GHz 2.5 T	**5 MW** X2 LFS launch (front steering)	**9 MW** X2 / O2 LFS & HFS launch (front & remote steering)	**9 MW** X2 / O2 / OXB LFS & HFS launch (front & remote steering)
NBI pulsed 55 keV (H) 60 keV (D)		**7 MW (H)**	**10 MW (D)** **7 MW(H)**
ICRH pulsed 25 – 38 MHz		**2 MW** ^{3}He, H minority	**4 MW** ^{3}He, H minority
		Upgrade of power supplies	**. . .**

Major topics for OP1.2

Optimization of confinement of W7-X ion-regime ($\chi_{e,1/\nu} \sim \varepsilon_{eff}^{3/2}$)

- Requires high heating power and high density
- Strong coupling of ions and electrons
- Involved issues: Fuelling (pellet injection), density limit

Investigation of confinement and core transport

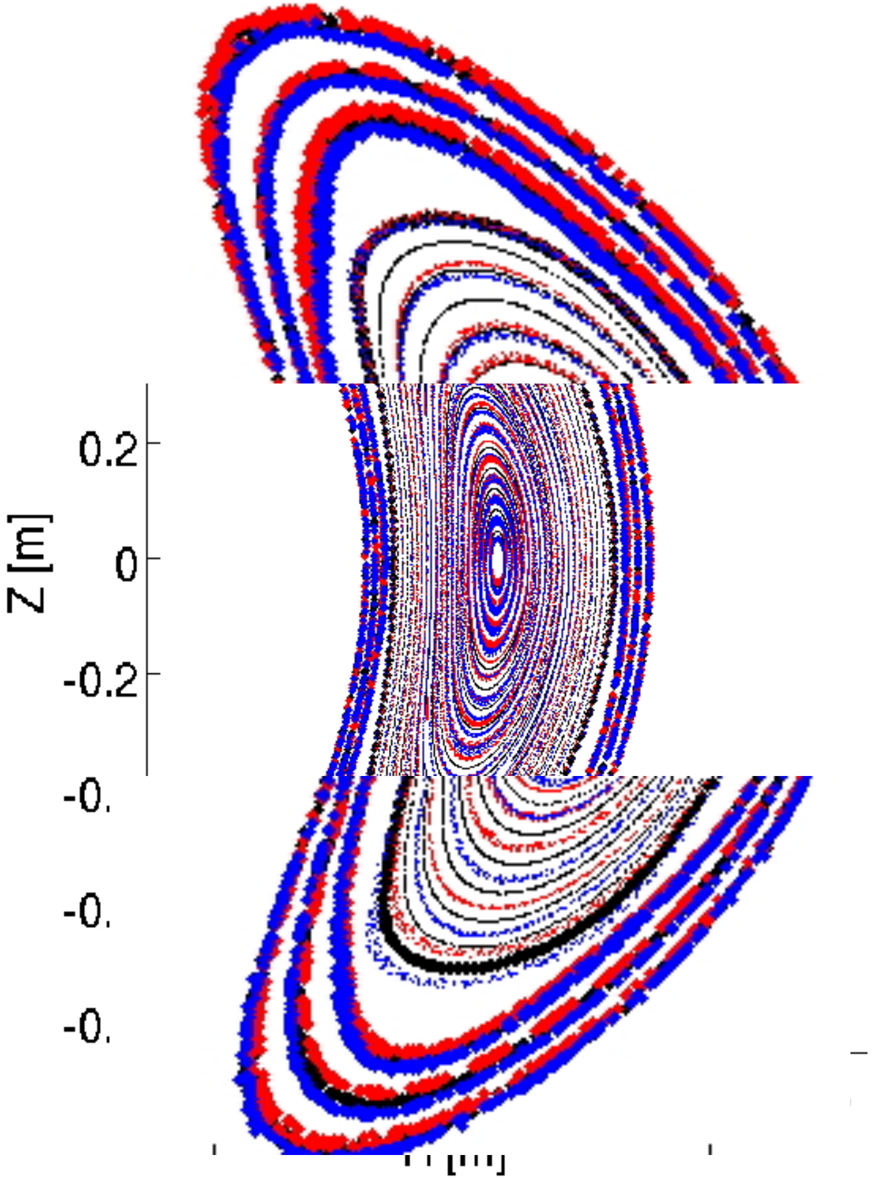
- Anomalous versus neoclassical transport
- Role of neoclassical effects (e.g. thermo-diffusion)
- Role of radial electric field
- Role of heating method and deposition profile
- Tailoring of plasma temperature, density and ι-profiles

Heating scenarios, current drive and fast ion production and confinement

- High density heating and current drive with ECRH (O2-heating beyond X2 cut-
- Ion heating with NBI
- Fast ion production with NBI and ICRH
- Validation of W7-X drift optimization, fast ion driven instabilities (long-term)

Up-down asymmetry in divertor heat loads

- Up-down asymmetries of up to a factor of two in the divertor heat and particle fluxes have been observed in tokamaks and stellarators
- Effect reverses sign when the magnetic field changes sign
  - Guiding-center drift effect (ExB or magnetic drift)
- We will reverse the magnetic field towards the end of OP1.2b
- We have particularly well-diagnosed divertors in HM 30 and 51 (one up, one down)
- By applying an n=0 (ie radial) magnetic field with the trim coils, we can move the flux surfaces (and therefore the plasma) about 1 cm vertically – roughly the SOL width

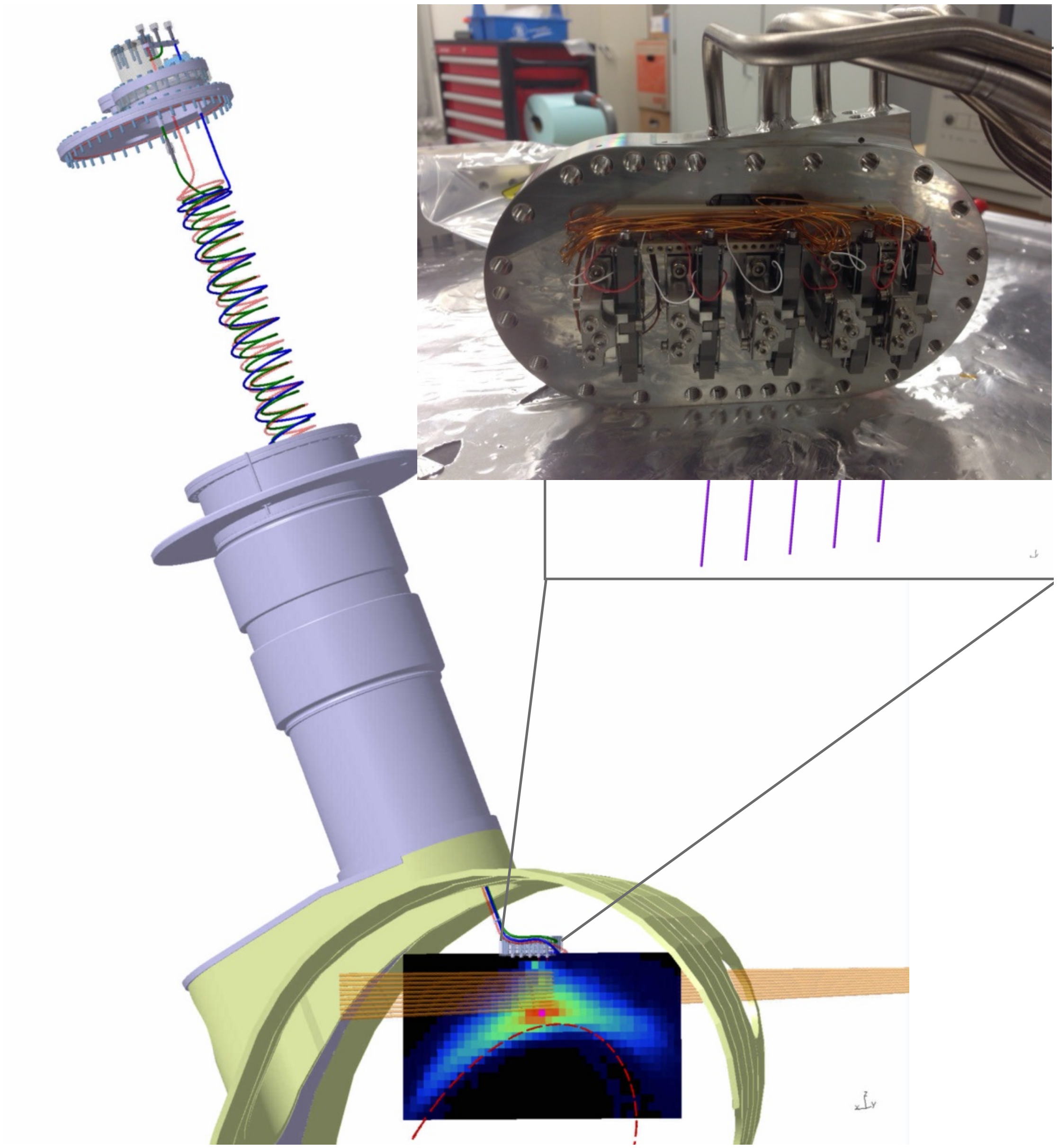


Collaboration with Sam Lazerson, PPPL (USA)

High-pressure fast divertor gas injection system

- Multiple functions
  - Fast fuelling (H_2) in divertor region (msec time scale)
  - He-beam injection as He-beam divertor diagnostic
    - First results in OP1.1 – improved design for OP1.2
  - Ar, Ne, CH_4, N_2 injection for edge radiative cooling in OP1.2

- Multiple locations
  - OP1.2: HM 30 and 51 (installation complete Dec 2016)
    - (Up-down symmetric)
  - OP2: All 10 divertor units

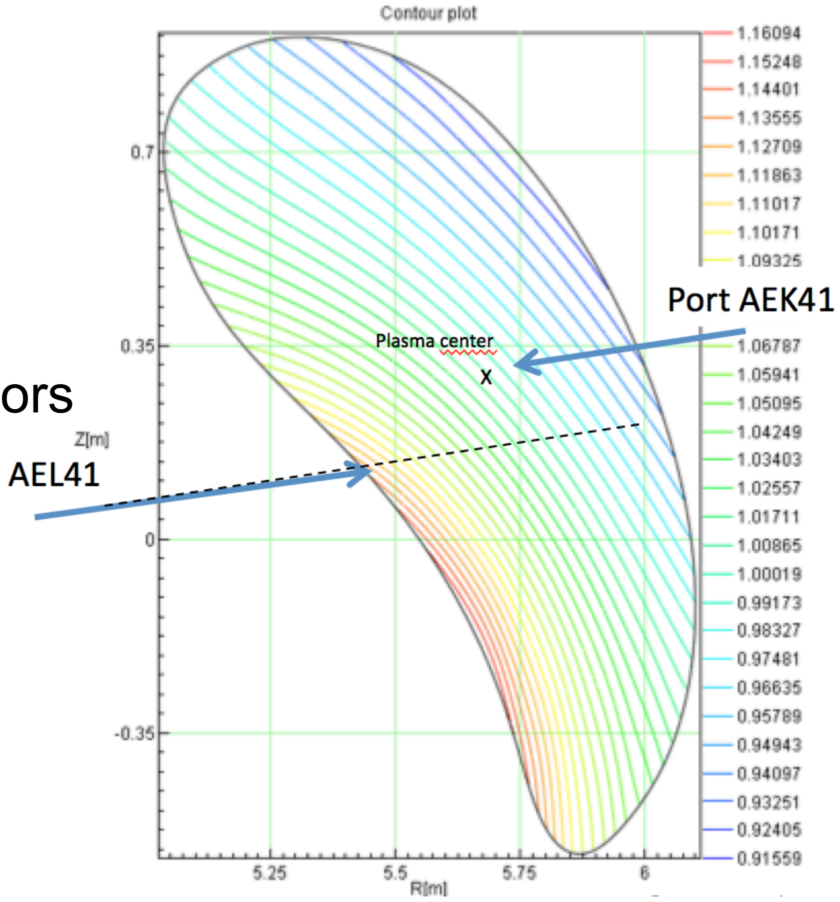


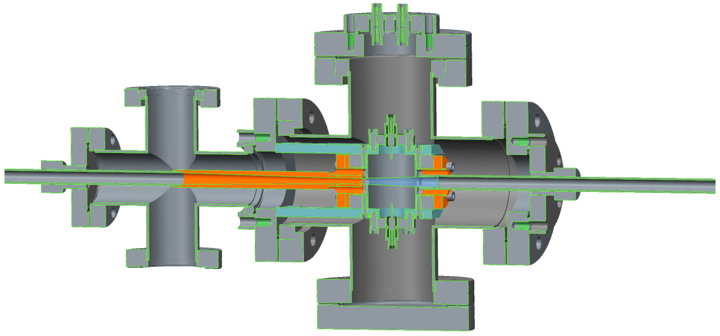
Pellet injection system(s)

Pellet injection system OP1.2

OP 1.2:

- Collaboration IPP Garching: former AUG pellet injection system: operational
- Collaboration ORNL, USA: Microwave cavity in-flight pellet mass detector: operational
- Pellet size: 2 mm
- Pellet speed: 250 m/s
- Repetition rate: 25 Hz
- Comparison LFS vs HFS injection
  - Unclear if HFS injection is better in stellarators





Pellet injection system OP2

OP 2:

- Collaboration NIFS, Japan and ORNL, USA
  - First hardware purchases now in Japan and Germany
  - Exact scope of ORNL part is not yet clear
- Pellet size: 3 mm x 3 mm
- Density increase per pellet ~$3*10^{19}$ m^{-3}
- Pellet speed: 600 m/s
- Repetition rate: 10 Hz for 30 minutes
- Low field side injection
  - Verification in OP1.2 that LFS injection works well
  - If not, a plan B for HFS injection will be challenging given pipe work for water cooling

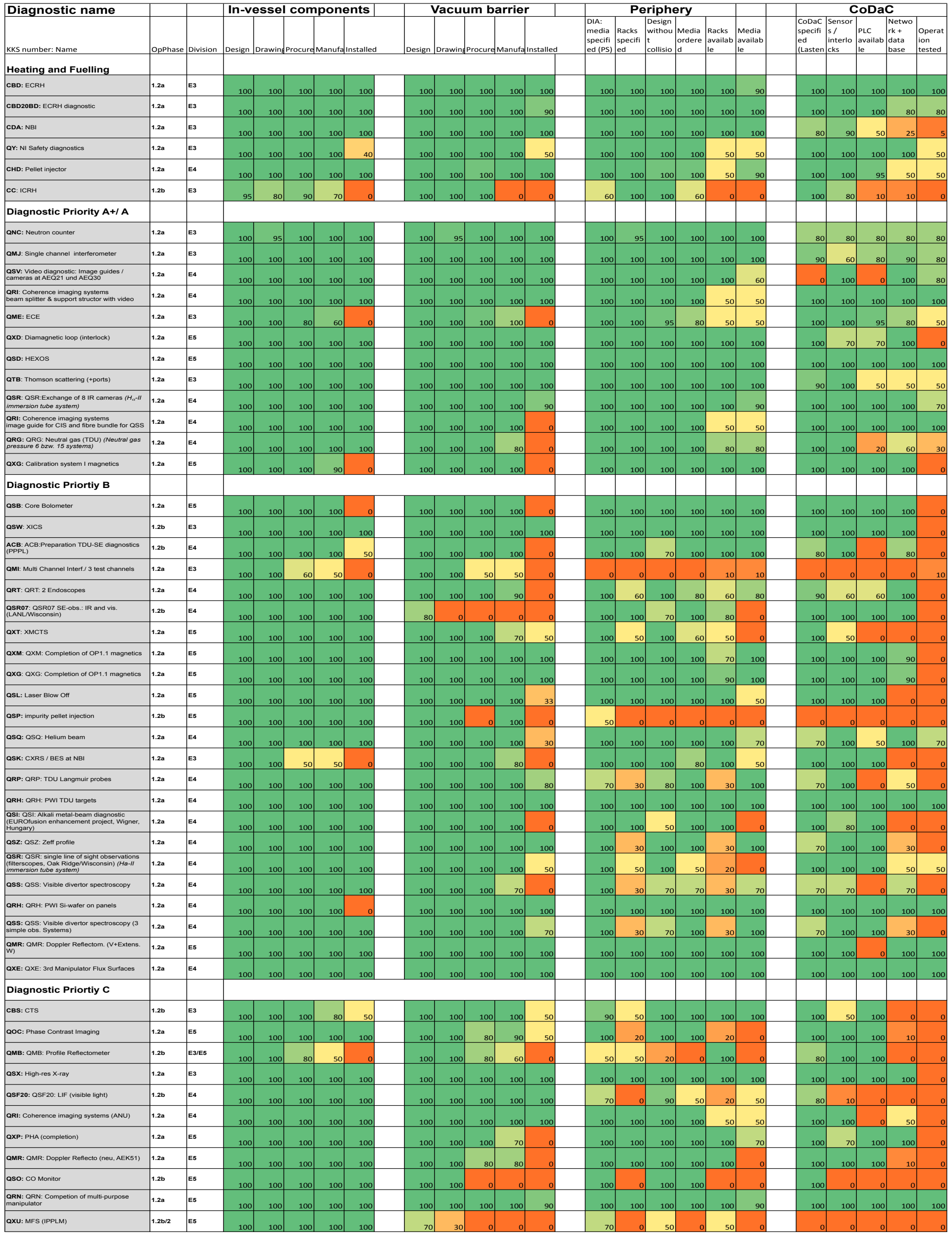
Status January 2017: 46 new or upgraded diagnostics

4 Heating and fueling systems
(1 upgrade, 3 new) plus 2 associated safety diagnostics

12 Must-have diagnostics (A)
(2 new, 10 upgrades/exchanges)

23 Should-have diagnostics (B)
11 new, 12 upgrades/exchanges

11 Might-get diagnostics (C)
5 new, 6 upgrades/exchanges



Diagnostic name			In-vessel components					Vacuum barrier					Periphery						CoDaC				
KKS number: Name	OpPhase	Division	Design	Drawin	Procure	Manufa	Installed	Design	Drawin	Procure	Manufa	Installed	DIA: media specified (PS)	Racks specified	Design without collisio	Media ordered	Racks available	Media available	CoDaC specified (Lasten	Sensors / interlocks	PLC available	Network + data base	Operation tested
Heating and Fuelling																							
CBD: ECRH	1.2a	E3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	90	100	100	100	100	100
CBD20BD: ECRH diagnostic	1.2a	E3	100	100	100	100	100	100	100	100	100	90	100	100	100	100	100	100	100	100	100	80	80
CDA: NBI	1.2a	E3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	80	90	50	25	5
QY: NI Safety diagnostics	1.2a	E3	100	100	100	100	40	100	100	100	100	50	100	100	100	100	50	50	100	100	100	100	50
CHD: Pellet injector	1.2a	E4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	50	90	100	100	95	50	50
CC: ICRH	1.2b	E3	95	80	90	70	0	100	100	100	0	0	60	100	100	60	0	0	100	80	10	10	0
Diagnostic Priority A+/ A																							
QNC: Neutron counter	1.2a	E3	100	95	100	100	100	100	95	100	100	100	100	95	100	100	100	100	80	80	80	80	80
QMJ: Single channel interferometer	1.2a	E3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	90	60	80	90	80
QSV: Video diagnostic: Image guides / cameras at AEQ21 und AEQ30	1.2a	E4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	60	0	100	0	100	80
QRI: Coherence imaging systems beam splitter & support structor with video	1.2a	E4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	50	50	100	100	100	100	100
QME: ECE	1.2a	E3	100	100	80	60	0	100	100	100	100	0	100	100	95	80	50	50	100	100	95	80	50
QXD: Diamagnetic loop (interlock)	1.2a	E5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	70	70	100	0
QSD: HEXOS	1.2a	E5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
QTB: Thomson scattering (+ports)	1.2a	E3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	90	100	50	50	50
QSR: QSR:Exchange of 8 IR cameras *(H_α-II immersion tube system)*	1.2a	E4	100	100	100	100	100	100	100	100	100	90	100	100	100	100	100	90	100	100	100	100	70
QRI: Coherence imaging systems image guide for CIS and fibre bundle for QSS	1.2a	E4	100	100	100	100	100	100	100	100	100	0	100	100	100	100	50	50	100	100	100	100	100
QRG: QRG: Neutral gas (TDU) *(Neutral gas pressure 6 bzw. 15 systems)*	1.2a	E4	100	100	100	100	100	100	100	100	80	0	100	100	100	100	80	80	100	100	20	60	30
QXG: Calibration system I magnetics	1.2a	E5	100	100	100	90	0	100	100	100	100	0	100	100	100	100	100	100	100	100	100	100	0
Diagnostic Priortiy B																							
QSB: Core Bolometer	1.2a	E5	100	100	100	100	0	100	100	100	100	0	100	100	100	100	100	100	100	100	100	100	0
QSW: XICS	1.2b	E3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0
ACB: ACB:Preparation TDU-SE diagnostics (PPPL)	1.2b	E4	100	100	100	100	50	100	100	100	100	0	100	100	70	100	100	100	80	100	0	80	0
QMI: Multi Channel Interf./ 3 test channels	1.2a	E3	100	100	60	50	0	100	100	50	50	0	0	0	0	0	10	10	0	0	0	0	10
QRT: QRT: 2 Endoscopes	1.2a	E4	100	100	100	100	100	100	100	100	90	0	100	60	100	80	60	80	90	60	60	100	0
QSR07: QSR07 SE-obs.: IR and vis. (LANL/Wisconsin)	1.2b	E4	100	100	100	100	100	80	0	0	0	0	100	100	70	100	80	0	100	100	100	100	0
QXT: XMCTS	1.2a	E5	100	100	100	100	100	100	100	100	70	50	100	50	100	60	50	0	100	50	0	0	0
QXM: QXM: Completion of OP1.1 magnetics	1.2a	E5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	70	100	100	100	100	90	0
QXG: QXG: Completion of OP1.1 magnetics	1.2a	E5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	90	100	100	100	100	90	0
QSL: Laser Blow Off	1.2a	E5	100	100	100	100	100	100	100	100	100	33	100	100	100	100	100	50	100	100	100	0	0
QSP: impurity pellet injection	1.2b	E5	100	100	100	100	100	100	100	0	100	0	50	0	0	0	0	0	0	0	0	0	0
QSQ: QSQ: Helium beam	1.2a	E4	100	100	100	100	100	100	100	100	100	30	100	100	100	100	100	70	70	100	50	100	70
QSK: CXRS / BES at NBI	1.2a	E3	100	100	50	50	0	100	100	100	80	0	100	100	100	80	100	50	100	100	100	0	0
QRP: QRP: TDU Langmuir probes	1.2a	E4	100	100	100	100	100	100	100	100	100	80	70	30	80	100	30	100	70	100	0	50	0
QRH: QRH: PWI TDU targets	1.2a	E4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
QSI: QSI: Alkali metal-beam diagnostic (EUROfusion enhancement project, Wigner, Hungary)	1.2a	E4	100	100	100	100	100	100	100	100	100	0	100	100	50	100	100	0	100	80	100	0	0
QSZ: QSZ: Zeff profile	1.2a	E4	100	100	100	100	100	100	100	100	100	100	100	30	100	100	30	100	70	100	100	30	0
QSR: QSR: single line of sight observations (filterscopes, Oak Ridge/Wisconsin) *(Ha-II immersion tube system)*	1.2a	E4	100	100	100	100	100	100	100	100	100	50	100	50	100	50	20	0	100	100	100	50	50
QSS: QSS: Visible divertor spectroscopy	1.2a	E4	100	100	100	100	100	100	100	100	70	0	100	30	70	70	30	70	70	70	0	70	0
QRH: QRH: PWI Si-wafer on panels	1.2a	E4	100	100	100	100	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
QSS: QSS: Visible divertor spectroscopy (3 simple obs. Systems)	1.2a	E4	100	100	100	100	100	100	100	100	100	70	100	30	70	100	30	100	70	100	100	30	0
QMR: QMR: Doppler Reflectom. (V+Extens. W)	1.2a	E5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0	100	100
QXE: QXE: 3rd Manipulator Flux Surfaces	1.2a	E4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Diagnostic Priortiy C																							
CBS: CTS	1.2b	E3	100	100	100	80	50	100	100	100	100	50	90	50	100	100	100	100	100	50	100	0	0
QOC: Phase Contrast Imaging	1.2a	E5	100	100	100	100	100	100	100	80	90	50	100	20	100	100	20	0	100	100	100	10	0
QMB: QMB: Profile Reflectometer	1.2b	E3/E5	100	100	80	50	0	100	100	80	60	0	50	50	20	0	100	0	80	100	100	0	0
QSX: High-res X-ray	1.2a	E3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0
QSF20: QSF20: LIF (visible light)	1.2b	E4	100	100	100	100	100	100	100	100	100	100	70	0	90	50	20	50	80	10	0	0	0
QRI: Coherence imaging systems (ANU)	1.2a	E4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	50	50	100	100	0	50	0
QXP: PHA (completion)	1.2a	E5	100	100	100	100	100	100	100	100	70	0	100	100	100	100	100	70	100	70	100	100	0
QMR: QMR: Doppler Reflecto (neu, AEK51)	1.2a	E5	100	100	100	100	100	100	100	80	80	0	100	100	100	100	100	0	100	100	100	10	0
QSO: CO Monitor	1.2b	E5	100	100	100	100	100	100	100	0	0	0	100	0	100	100	0	0	100	0	0	0	0
QRN: QRN: Competion of multi-purpose manipulator	1.2a	E5	100	100	100	100	100	100	100	100	100	90	100	100	100	100	100	90	100	100	100	100	100
QXU: MFS (IPPLM)	1.2b/2	E5	100	100	100	100	100	70	30	0	0	0	70	0	50	0	50	0	0	0	0	0	0

Summary

- Successful first campaign produced many interesting and encouraging results
- Limiter operation provided a comparison basis for future divertor operation
- In general, good agreement between expected and observed phenomena
  - Data are still being analyzed…
- OP1.2 will be very important for the preparation of OP2, in particular with respect to divertor operation
- New tools are/will be ready for exciting physics program in OP1.2, e.g.:
  - > 15 new diagnostics
  - TDU scraper elements (PPPL/ORNL coll.): now at IPP
  - Two OP1.2 IR endoscopes: now at IPP
  - Pellet injection
  - More power: NBI (7 MW), ICRH (2 MW) , ECRH (now up to 9 MW)