JET Results and Upgrades

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With material provided by:
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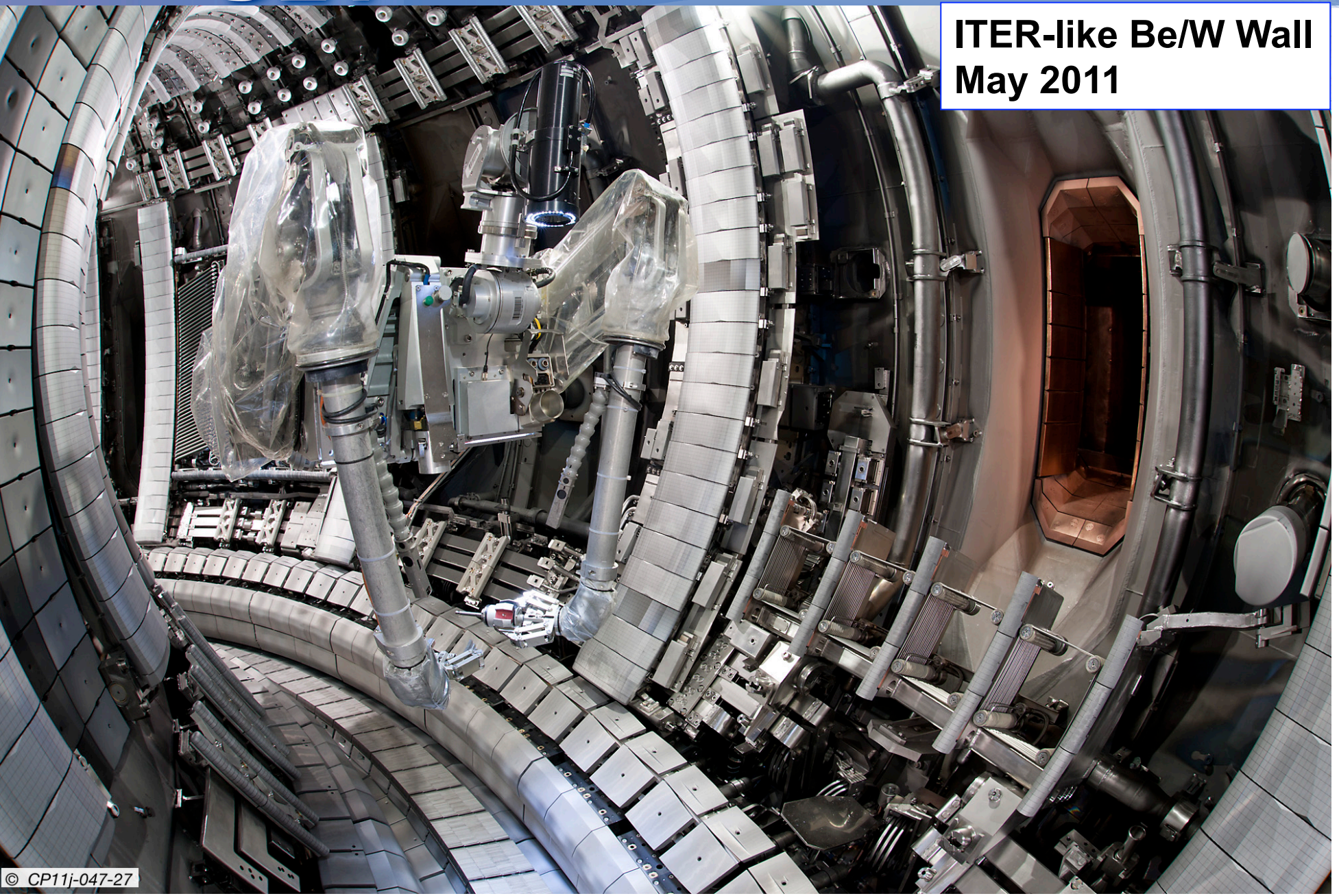
JET is now focused on ITER design consolidation and preparation for operation



OUTLINE

- JET contribution to key ITER issues: a selection of ***recent results*** and ***new upgrades*** to extend capabilities in the critical areas
  - Development of operational scenarios for ITER
  - Neutral Beam Enhancement
  - Enhanced Radial Field Amplifier
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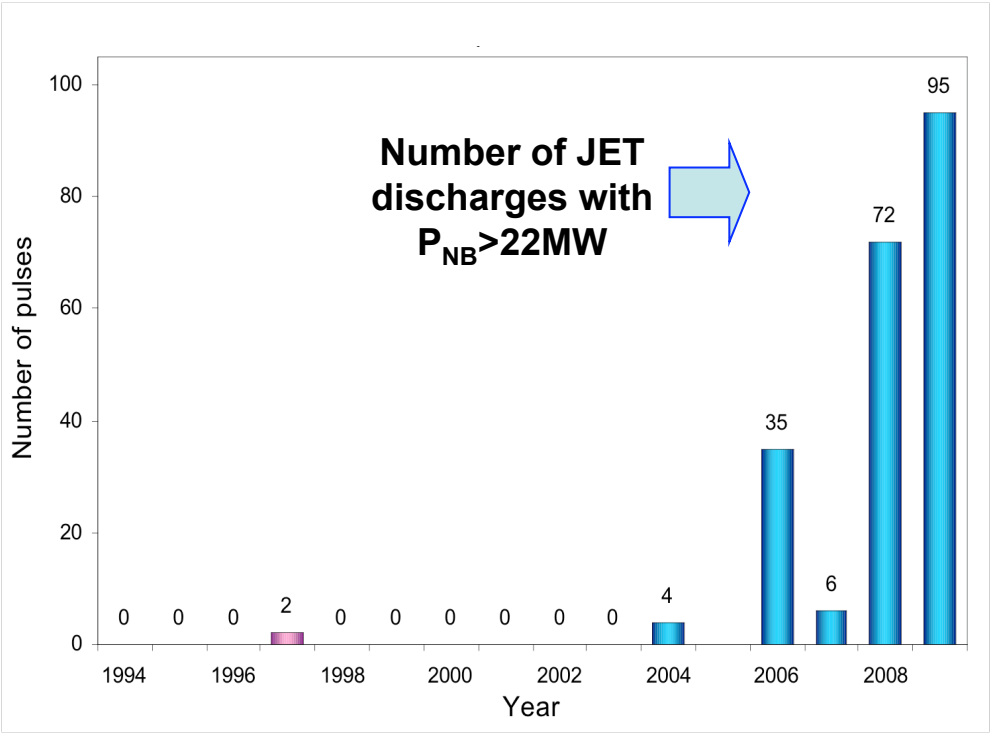
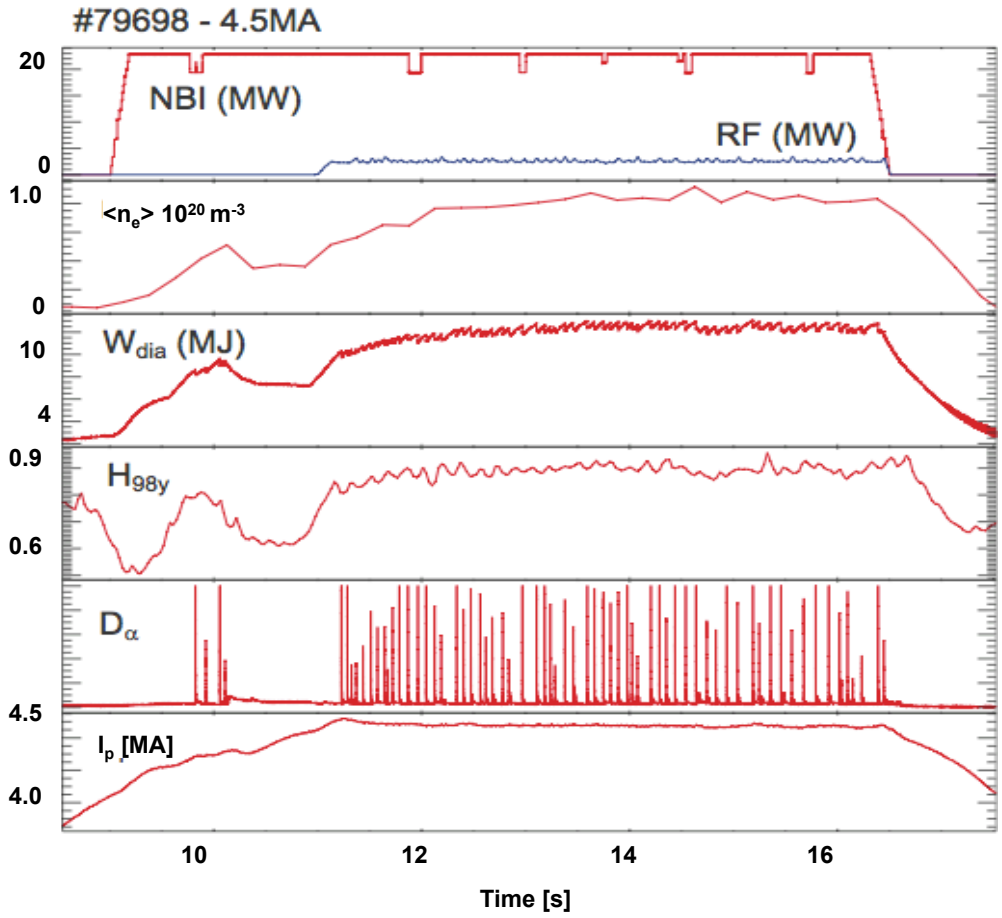
  - Understanding and avoidance of disruptions
  - Test of the ITER plasma facing materials
  - ITER-like Wall
- Conclusion and outlook

High power, high current H-mode
JET Operation 1994-2009



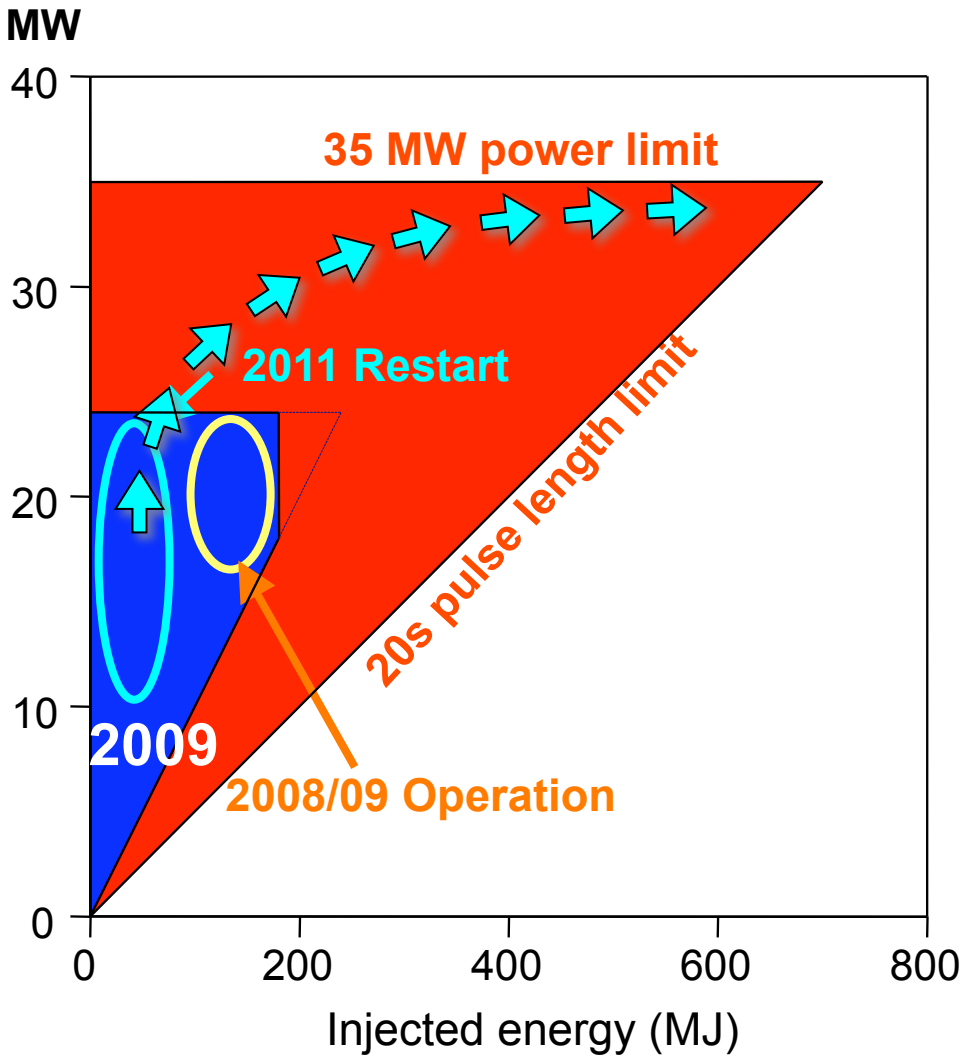


- Trend to high system performance
- Upgraded to 34MW Available 2011onwards
- Higher power will allow full exploitation of high I_p capability

- 4.5MA operation in ELMy H-mode
- P_{in}/P_{L-H}~1.7 required for stationary H-mode

Neutral Beam Upgrade
⇨ Greatly Expanded Operating Space

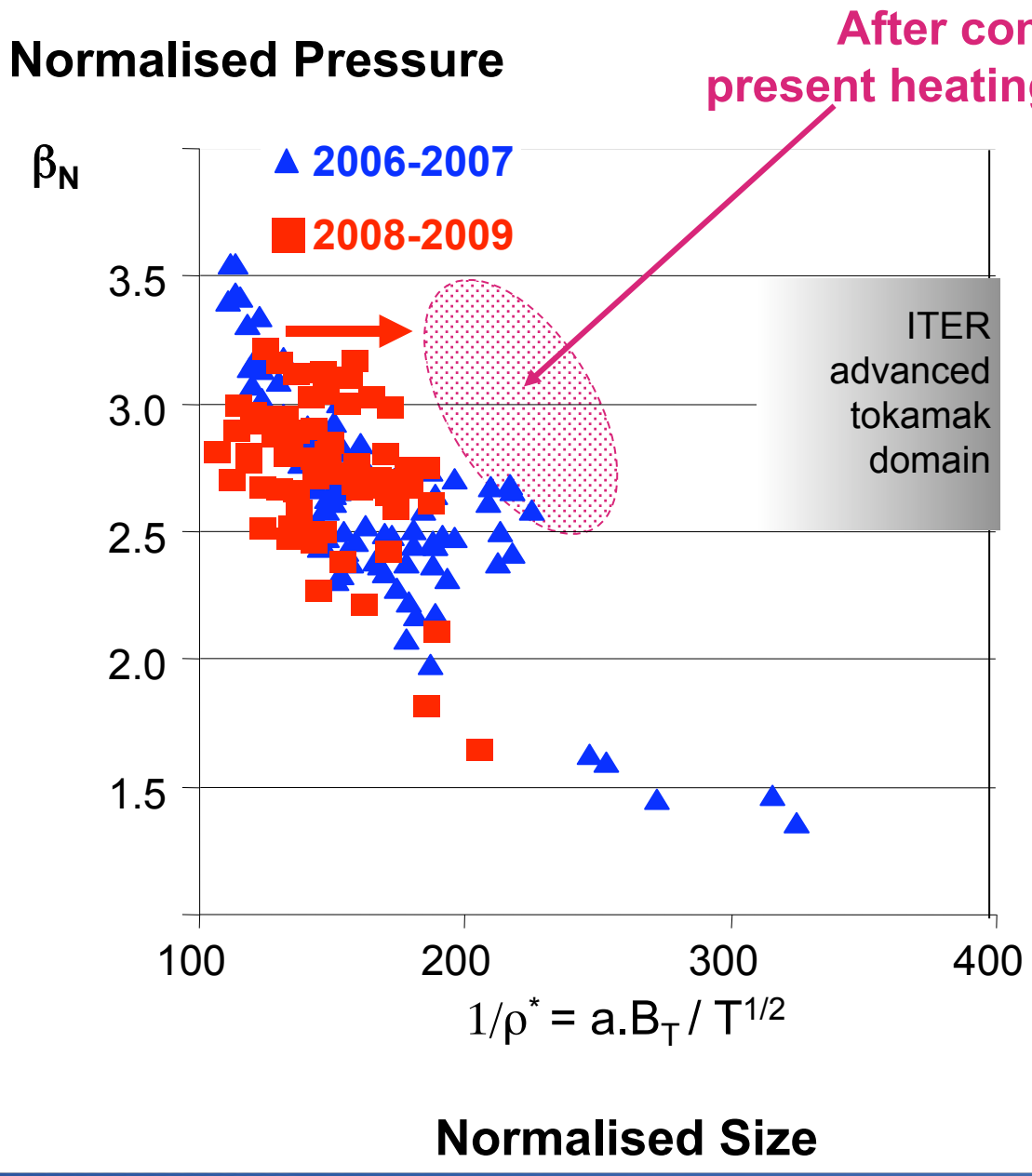
Increased power/pulse-length



Power increase obtained by:

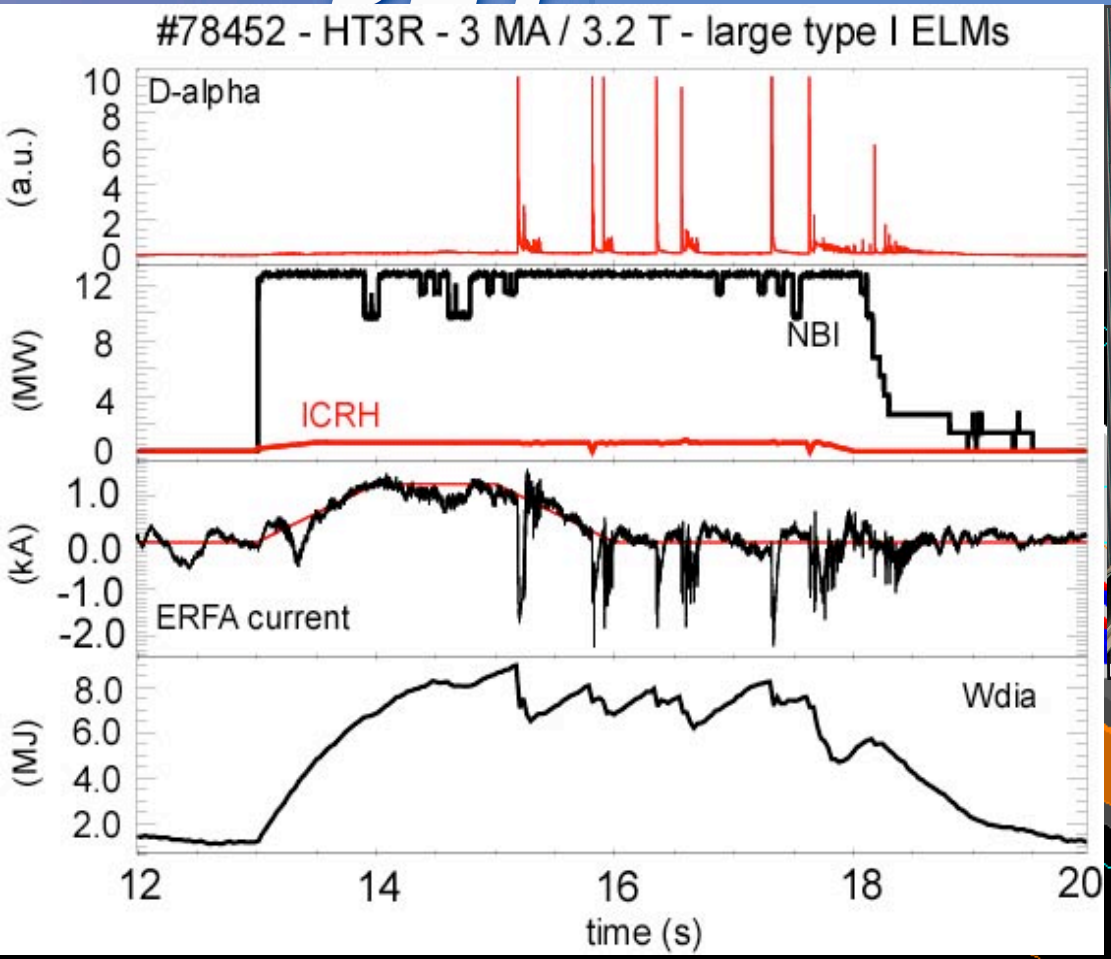
- Increasing the current and voltage of eight beam sources to 125kV/65A
- Installing four new 130kV/ 130A HV power supplies
- Modifying the ion source to produce more molecular ions

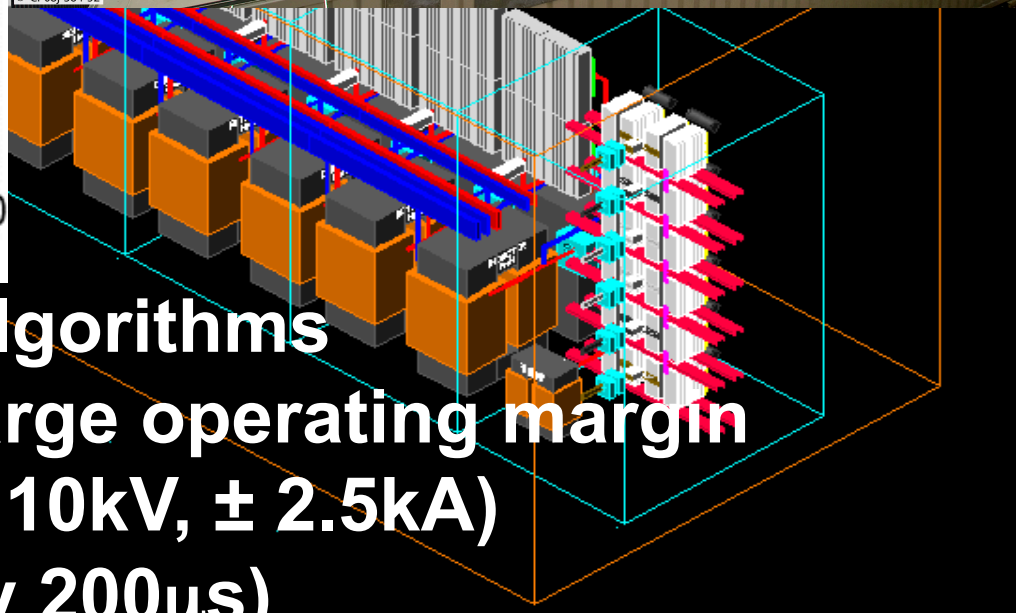
Advanced scenarios



In 2008-2009, JET has made significant progress towards integrated advanced scenario (β_N~3 and H~1.4) at higher toroidal field

Enhanced Radial Field Amplifier





Improved vertical control algorithms

4 new units, IGBT based, large operating margin

± 12kV, ± 5kA (previously ± 10kV, ± 2.5kA)

100μs response (previously 200μs)

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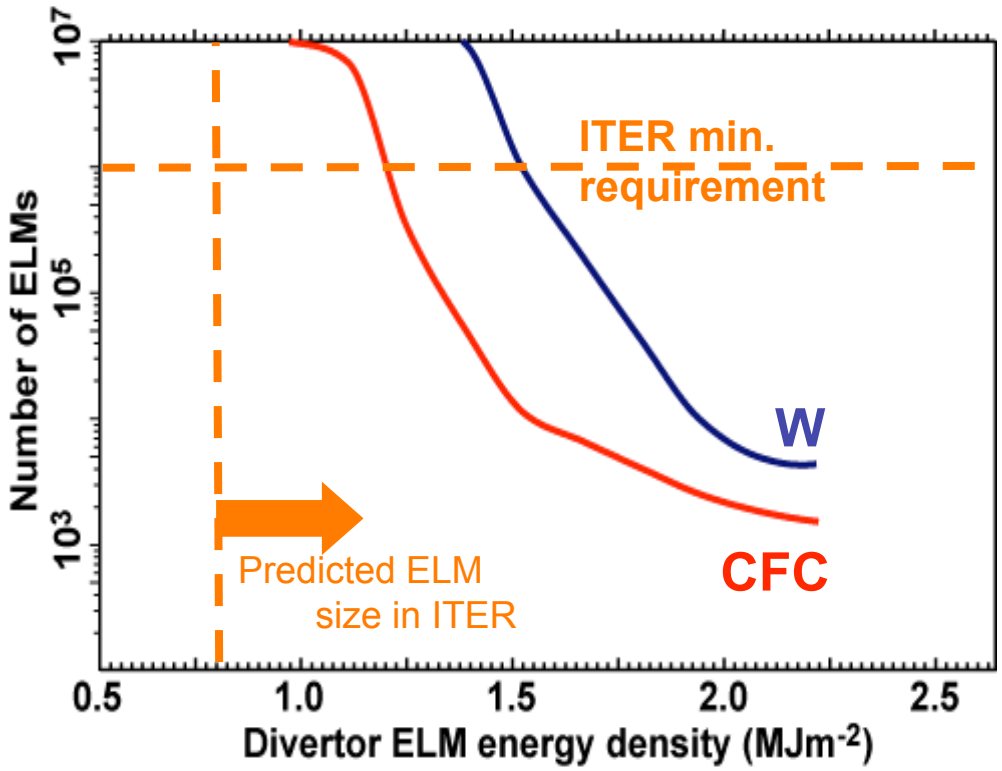
ELM characterization and control

Edge pressure gradient lead to *Edge Localised Modes* (ELMs) that expel particles and produce large transient thermal loads

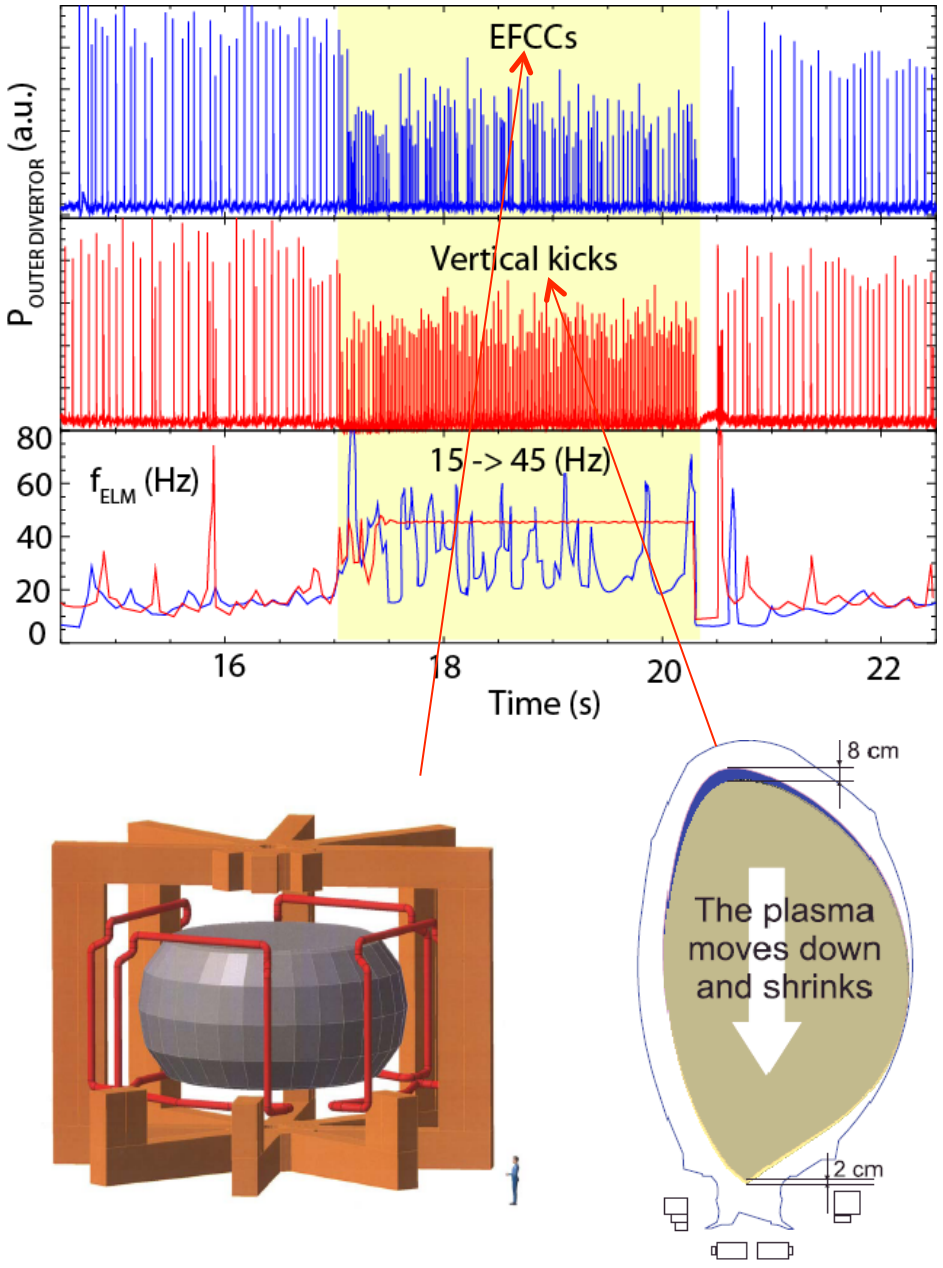
Plasma facing component degradation sets a limit to the amplitude of the Edge Localised Modes (ELMs)

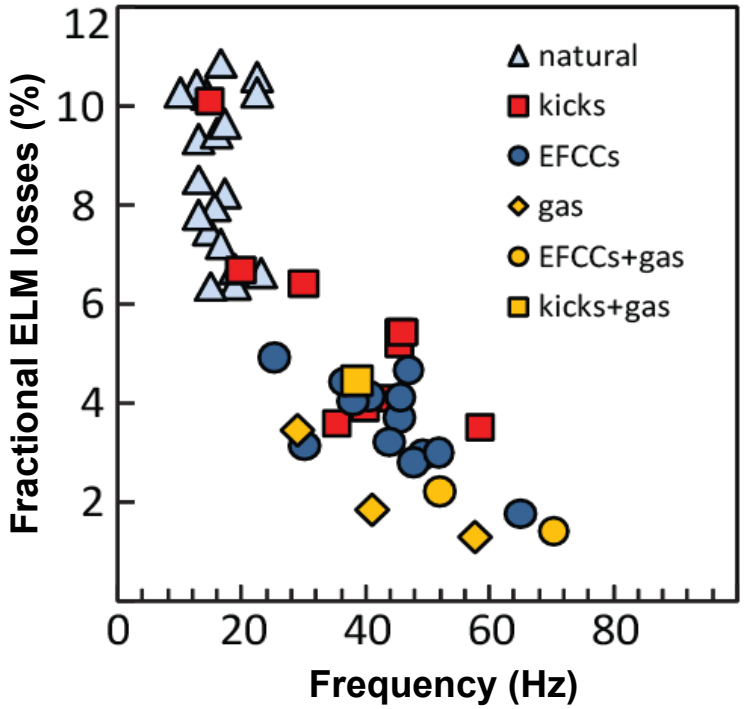
In ITER ELM loads of 1MJm^{-2} correspond to ELM losses <1% of energy stored in the plasma pedestal



Large JET ELMs can exceed 0.5 MJm^{-2}

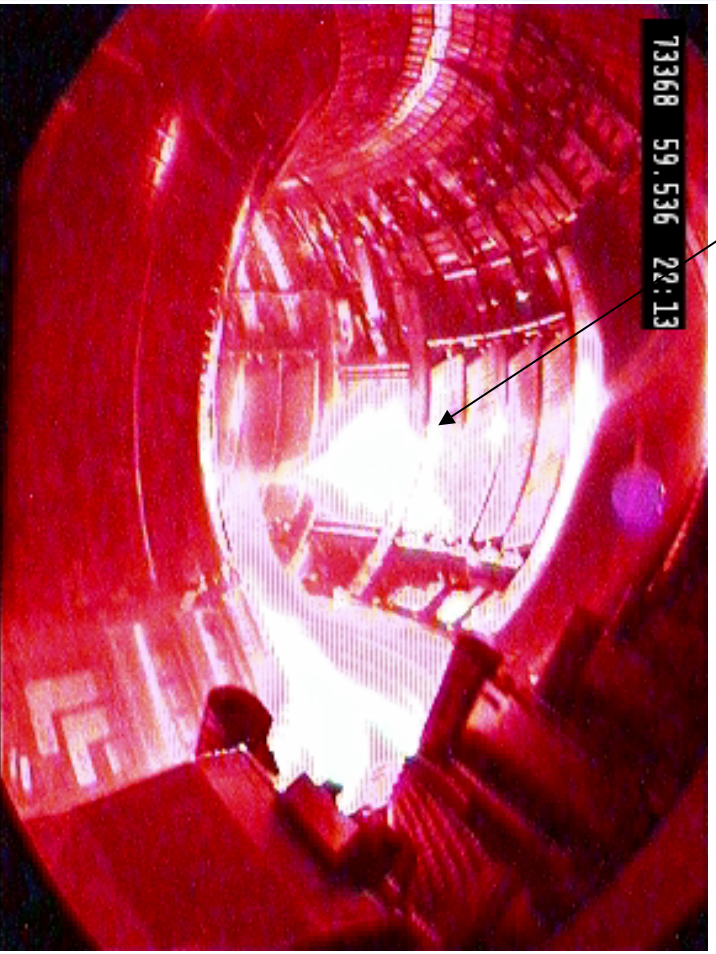
ELM characterization and control

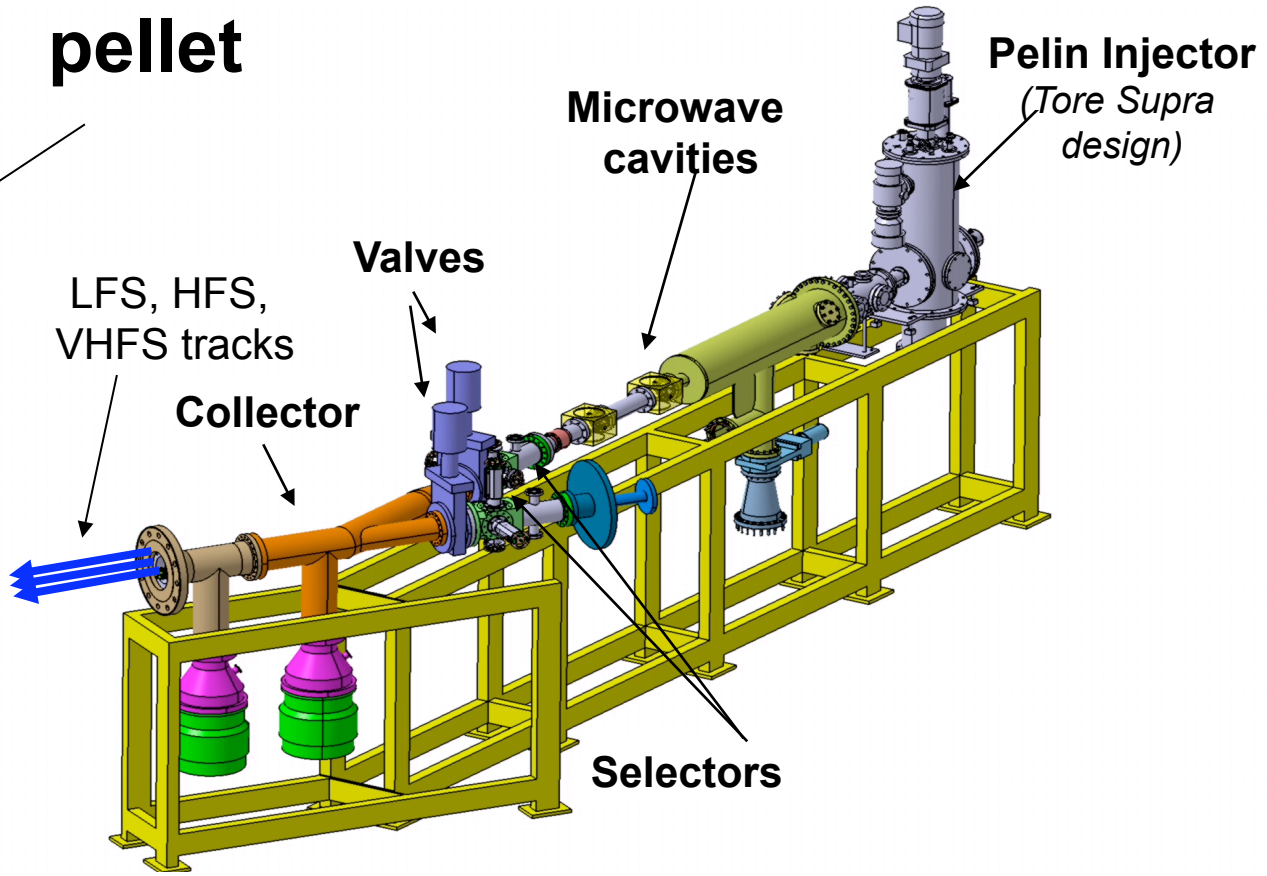




Effective ELM mitigation remains an essential aim for ITER – more research needed.

Upgraded pellet injection for ELM control and deep fuelling





Provide deep fuelling capability

Control edge instabilities

	Size	Velocity	Frequency
	40-63mm^3	100-300m/s	< 15Hz
	2.5-3.5 mm^3	80-200m/s	< 50Hz

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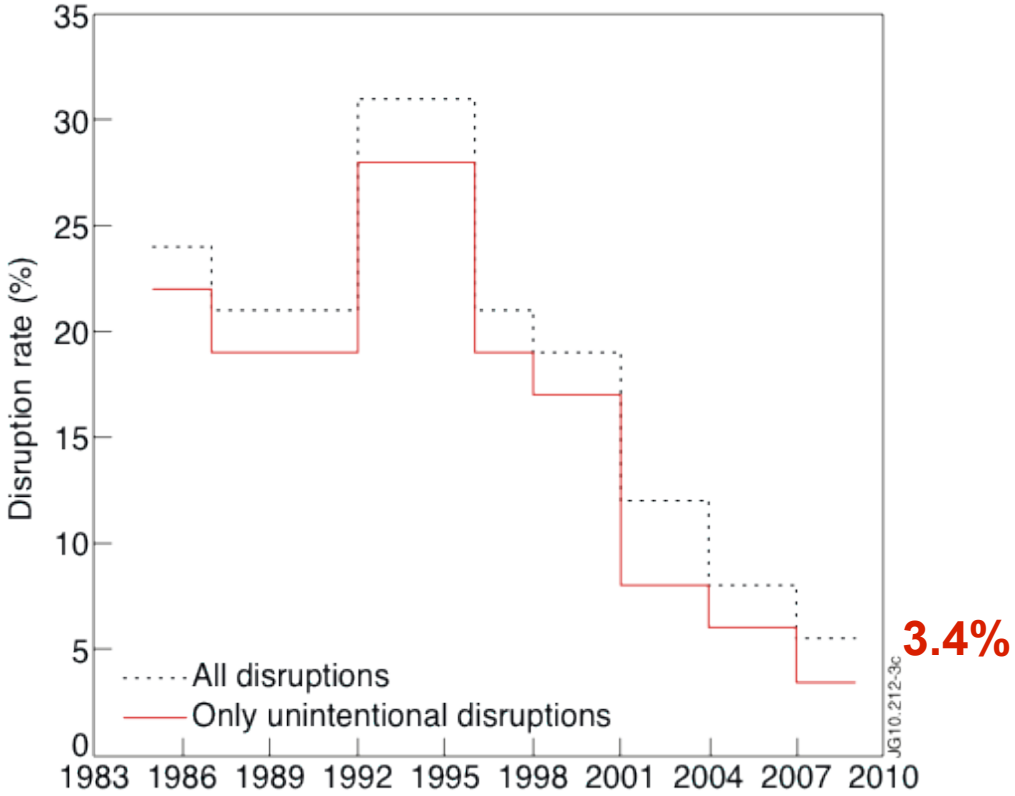
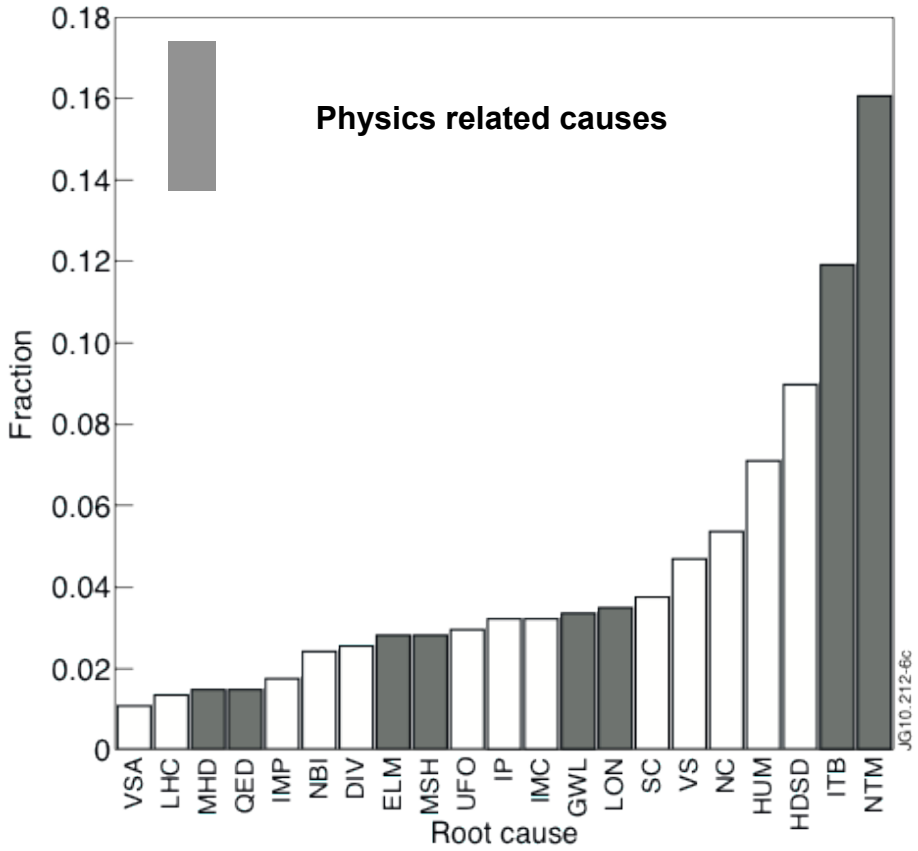
  - ITER-like Wall and supporting diagnostics
- Outlook and outlook

Understanding and avoidance of disruptions

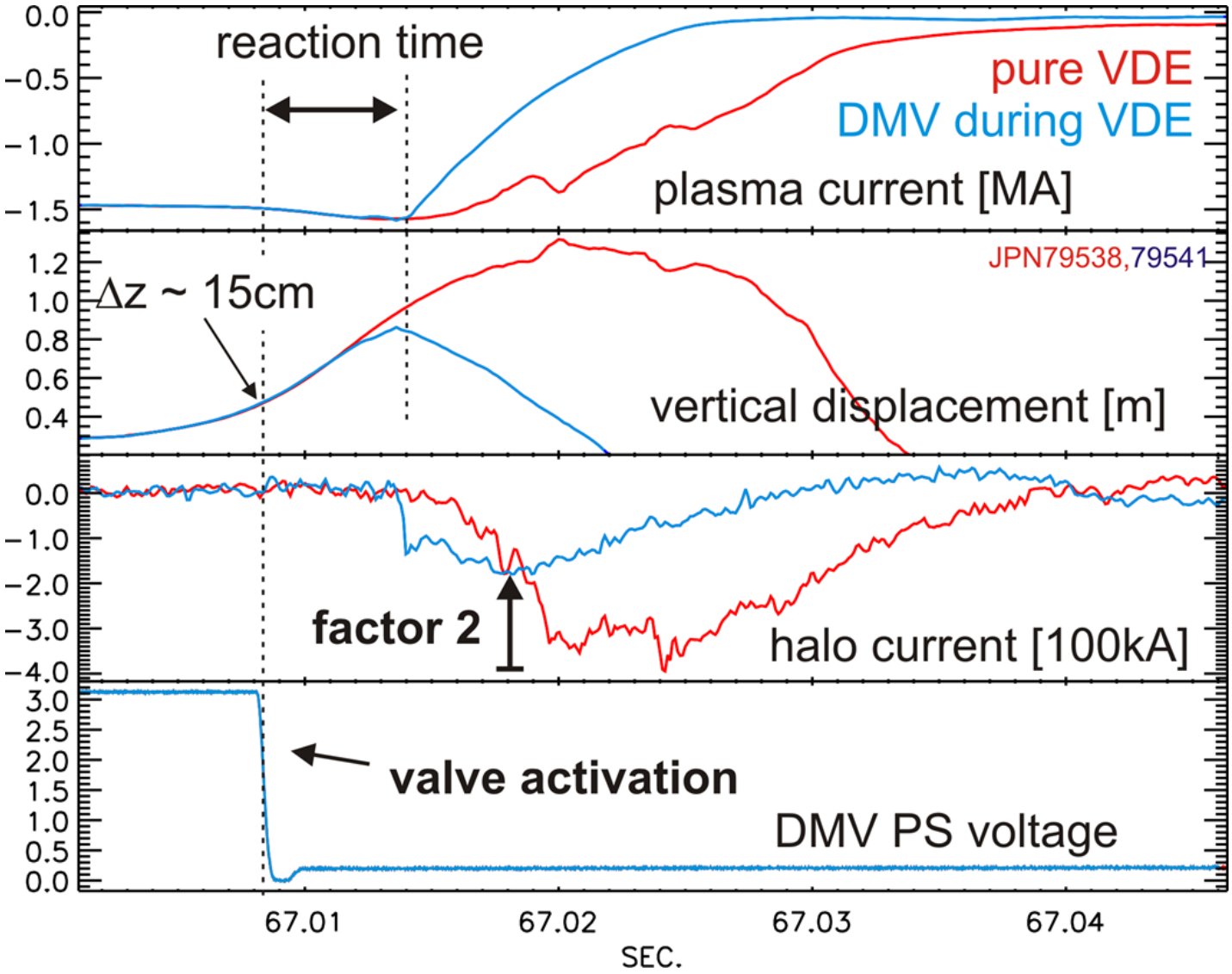
- Plasma disruptions are a major concern for ITER due to **large mechanical vessel forces** and **thermal loads**
- The JET disruption rate decreased significantly over the years[1]
- More than 50% caused by technical issues rather than plasma stability





[1] P.C. de Vries, Nucl. Fusion 49 (2009) 055011

Disruption Mitigation by Massive Gas Injection
⇨ Ne/D_2 and Ar/D_2 mixtures



- Halo currents reduced up to 60% and ~50% of W_{th} radiated
- Peak heat load on upper dump plate reduced from 3.3 to 1.8MW/m^2.
- Runaway generation avoided

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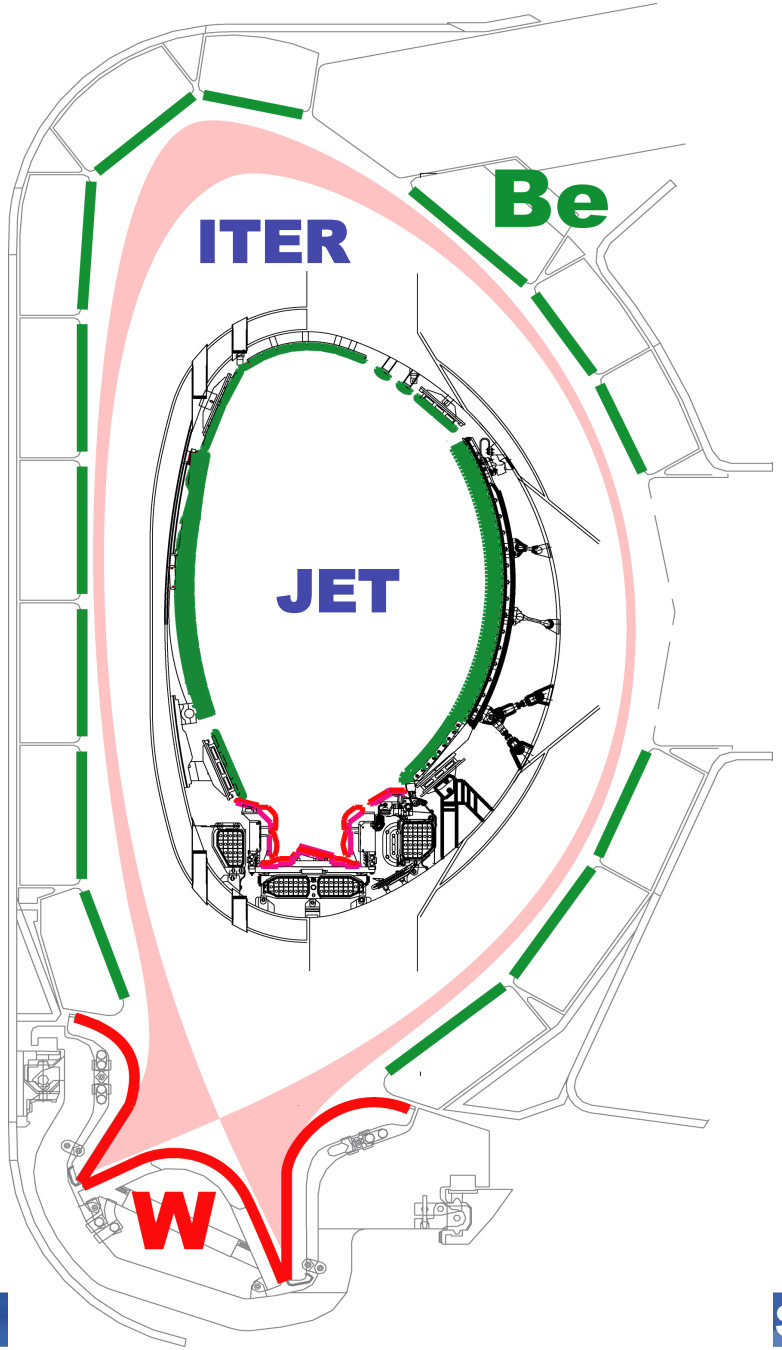
Why the ITER-like Wall is high priority for ITER

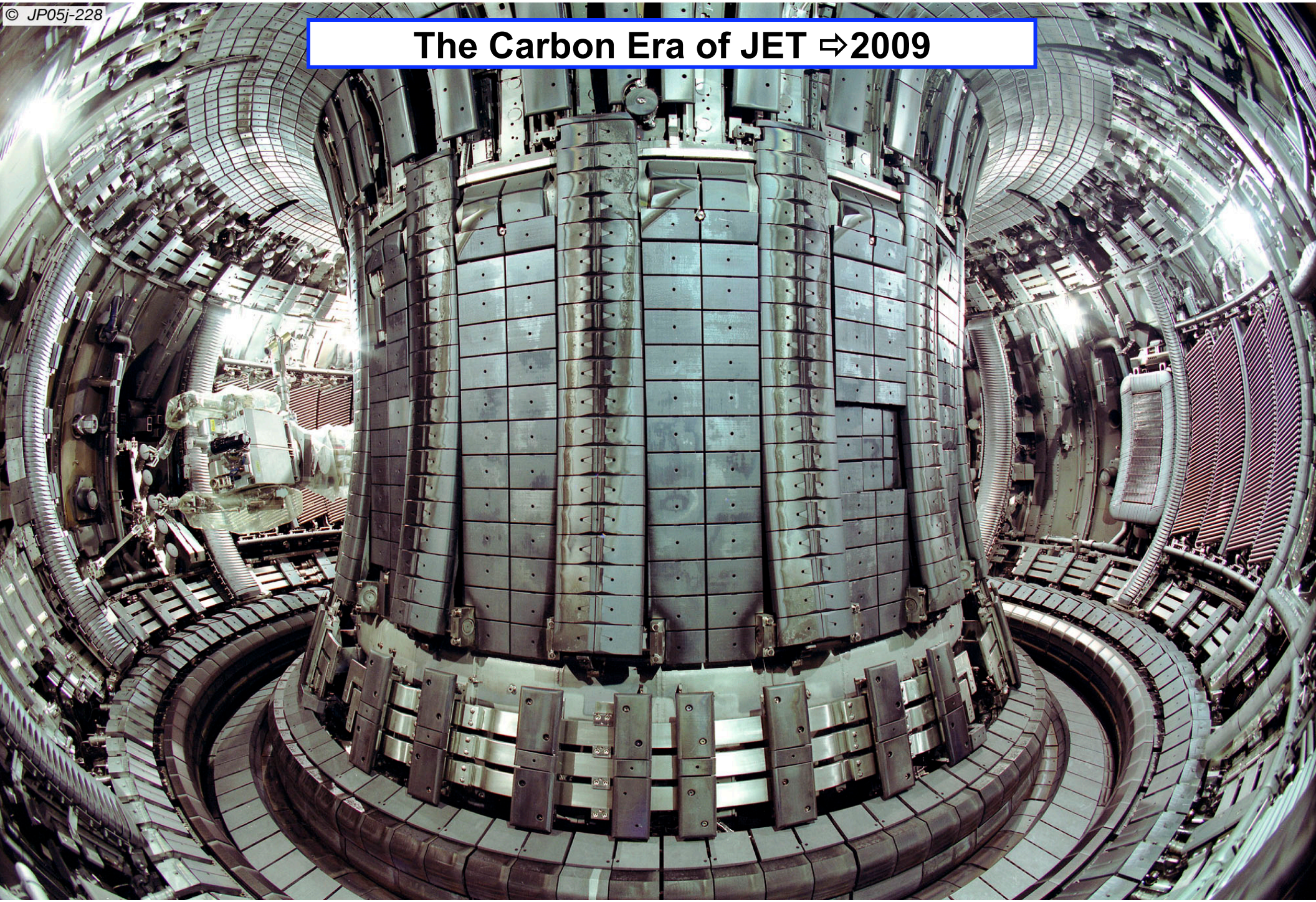


The combination of a beryllium (**Be**) wall and tungsten (**W**) wall is the reference for the DT phase of ITER

The ITER-like Wall (ILW) provides the first ever test of this material combination in the machine closest to ITER parameters.

The ILW will provide critical data on:

⇨Tritium retention
⇨Dust generation
⇨Material migration and wall lifetime
⇨Plasma compatibility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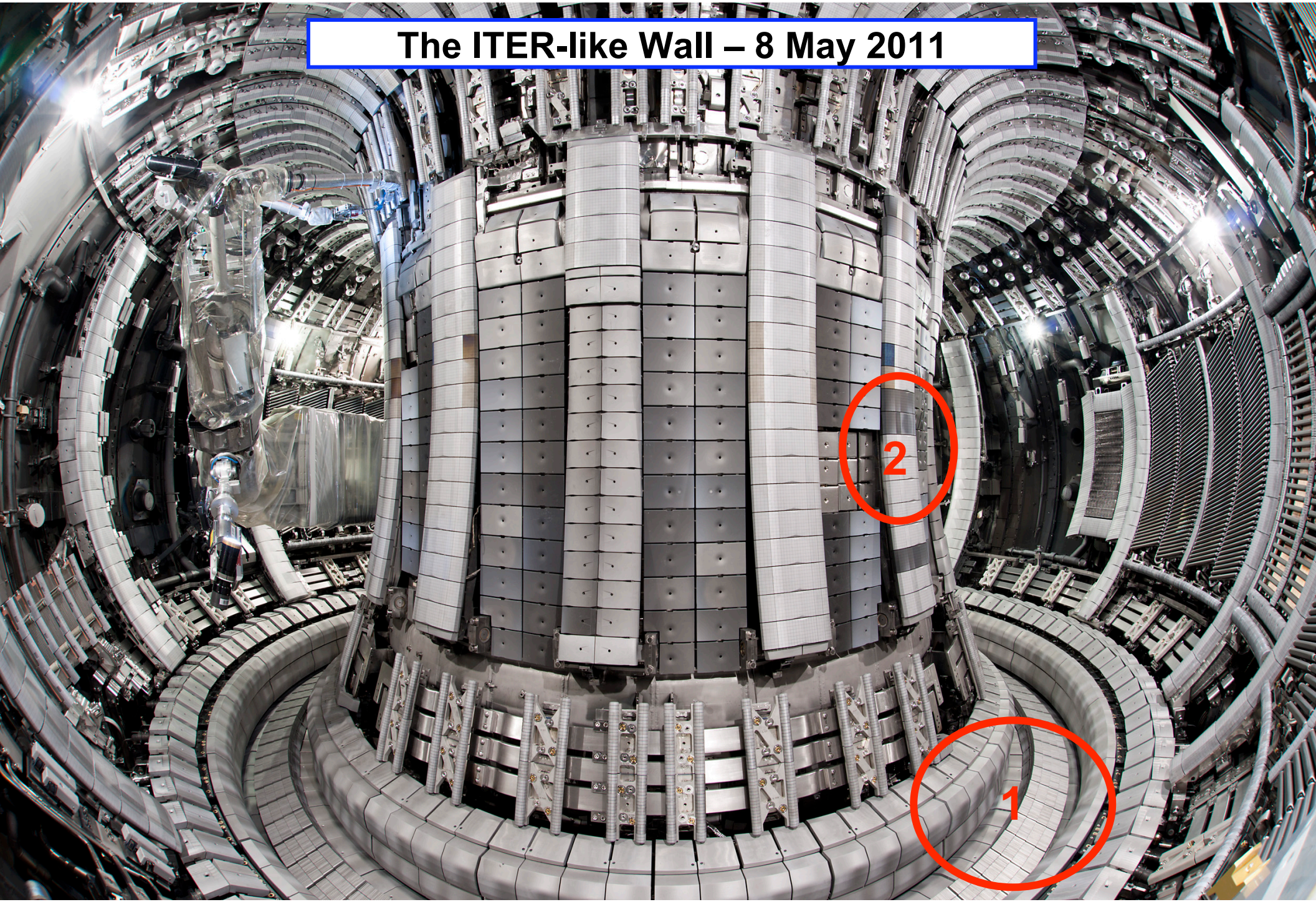
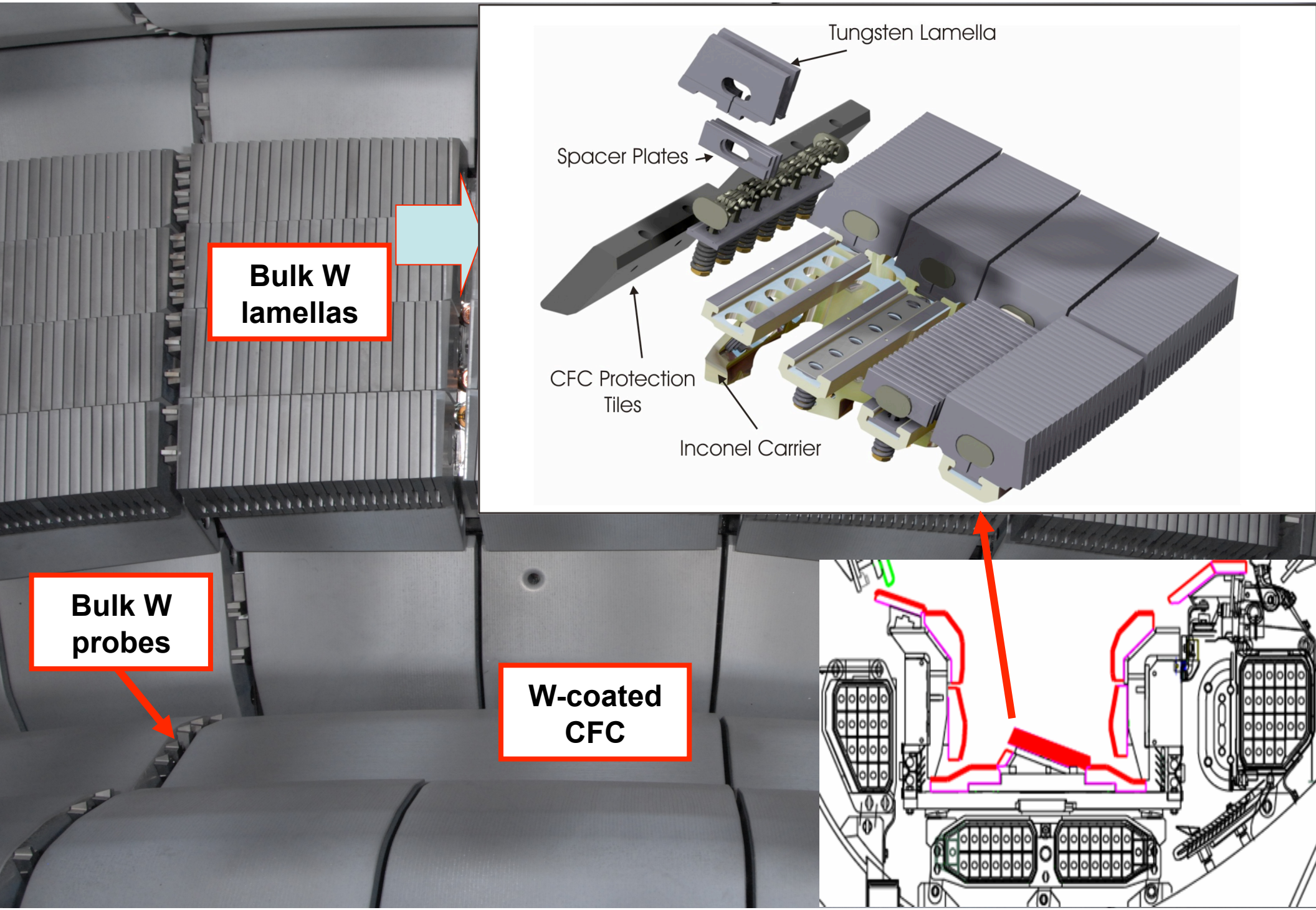
The Carbon Era of JET ⇨2009

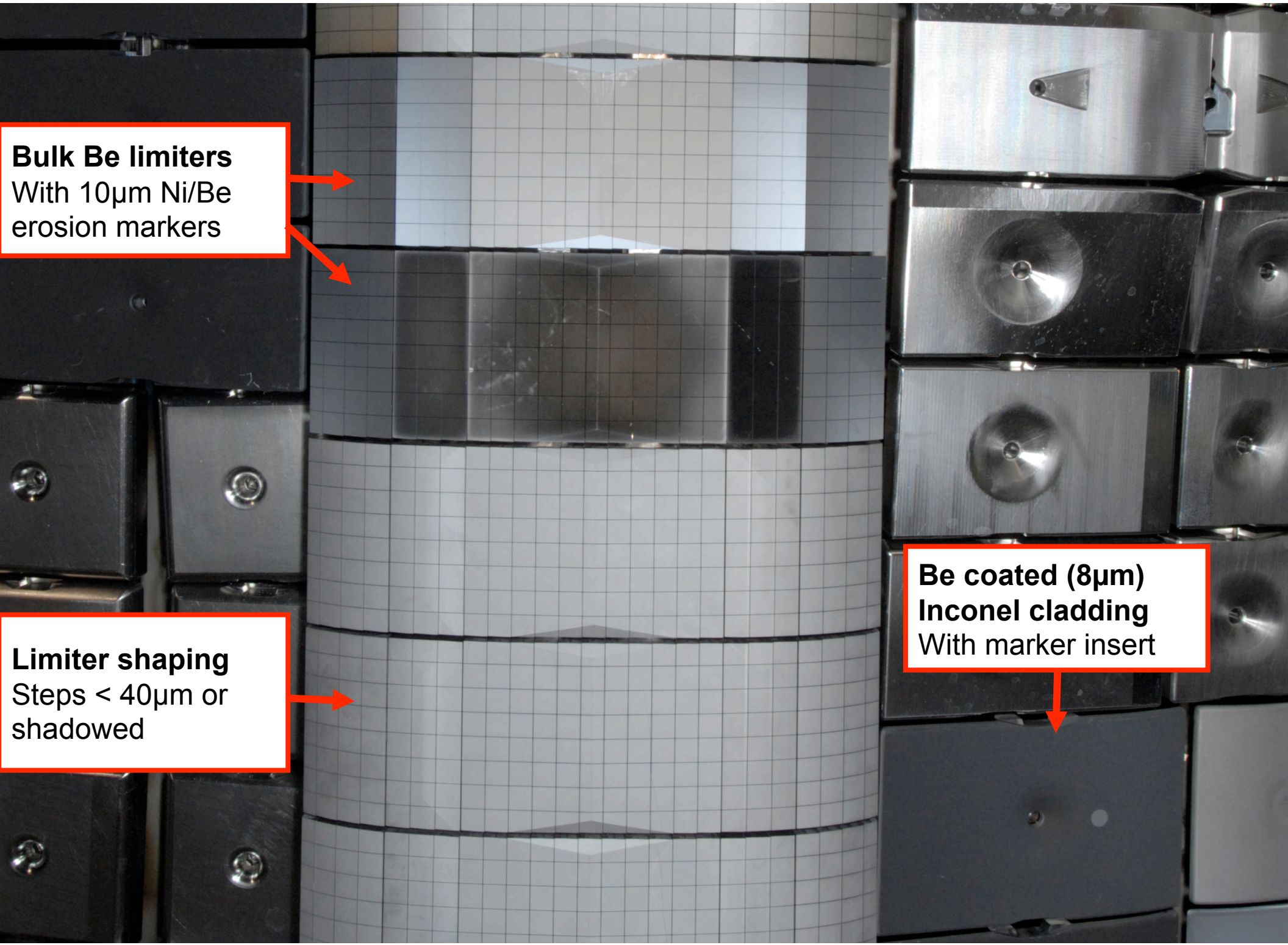
Final documentation of the JET carbon wall in 2009

- JET Active Gas Handling System has excellent capabilities for detailed hydrogenic gas accounting
  - detailed gas-balance measurements completed to give carbon wall benchmark
- Last opportunity to document carbon source strength and migration towards the divertor and to quantify fuel retention
  - 13C injection for post-campaign analysis
- Developed techniques to safeguard the new wall components
  - e.g. development of nitrogen seeding methods to reduce divertor heat loads and physical sputtering

The ITER-like Wall – 8 May 2011

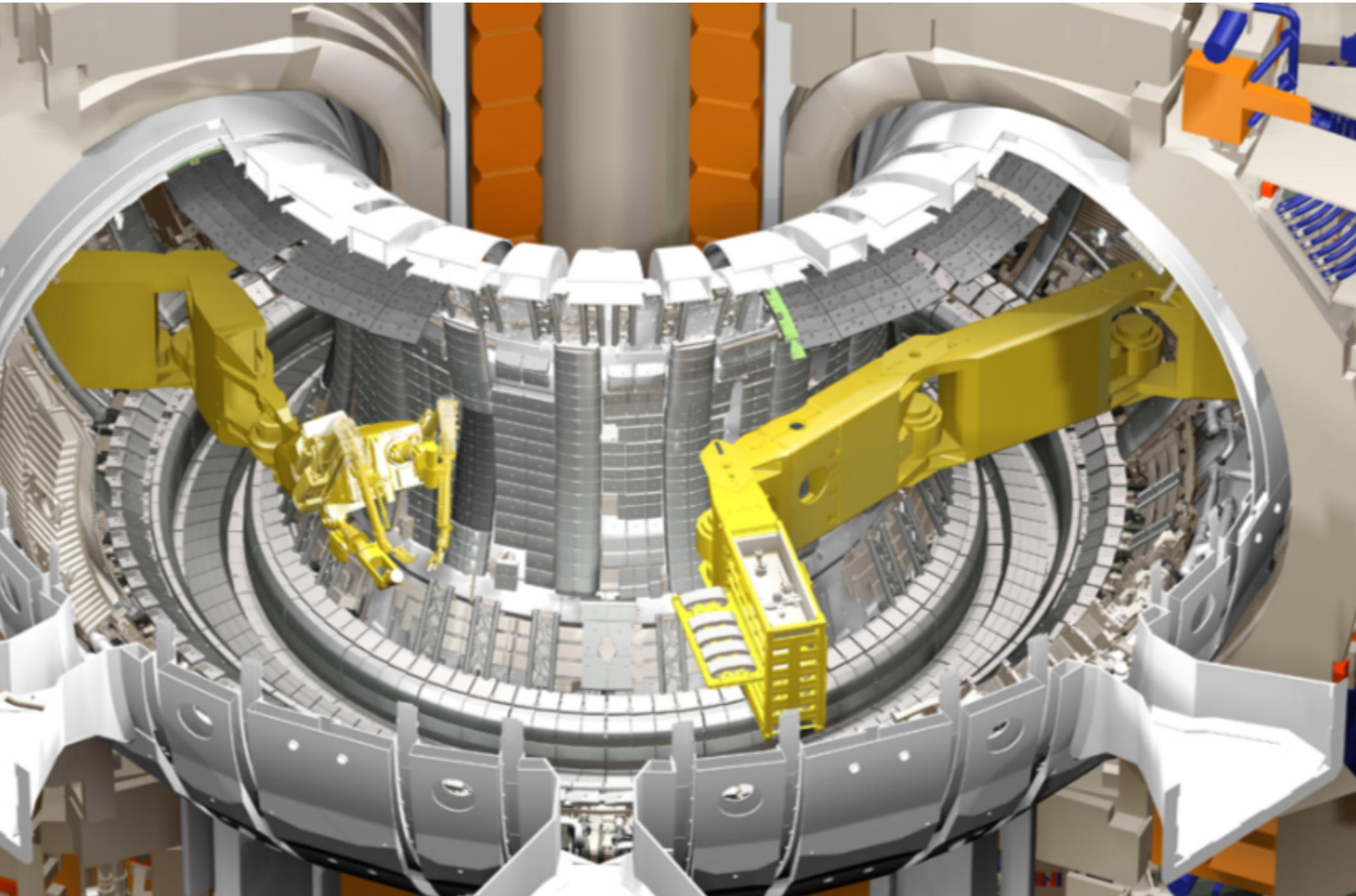



Bulk W lamellas
Tungsten Lamella
Spacer Plates
CFC Protection Tiles
Inconel Carrier
Bulk W probes
W-coated CFC


Bulk Be limiters
With 10μm Ni/Be erosion markers
Limiter shaping
Steps < 40μm or shadowed
Be coated (8μm) Inconel cladding
With marker insert

A new long RH boom delivered tools and components to the place of work

CCFE
CULHAM CENTRE FOR FUSION ENERGY



ITER-like Wall Project Metrics

Number of individual tiles: 5,384 Be tiles (~2 tons Be / ~ 1m^3)
1,288 W-coated CFC tiles
9,216 W-lamellas (~2 tons W / ~ 0.1m^3)
15,828

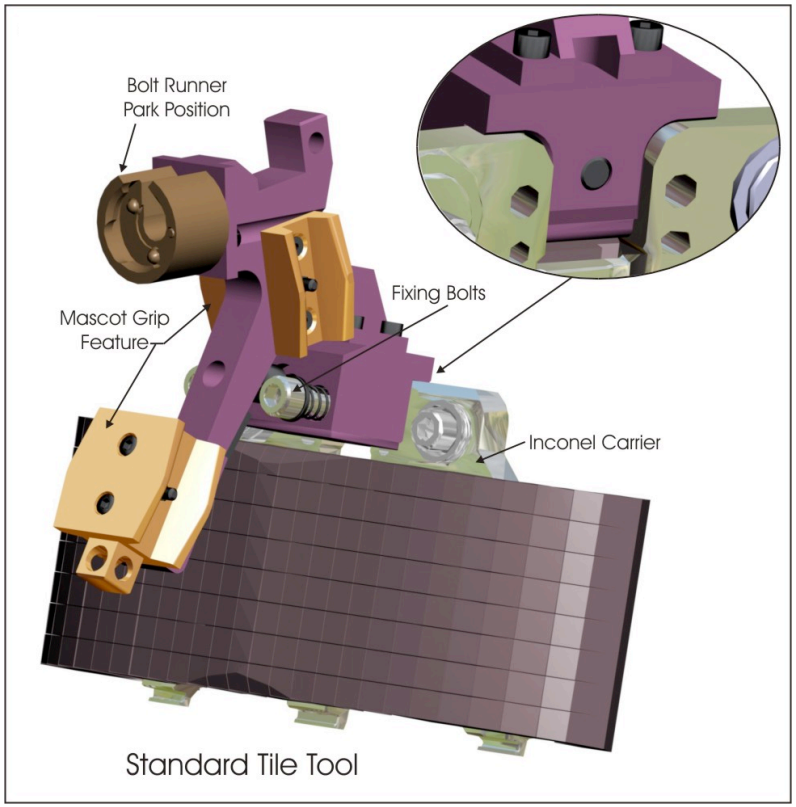
Total number of parts: 82,273 counting bulk W modules as one part

Duration of manned access: < 7% of in-vessel time
(Mostly infrastructure and welding/repairs)

Remote Handling

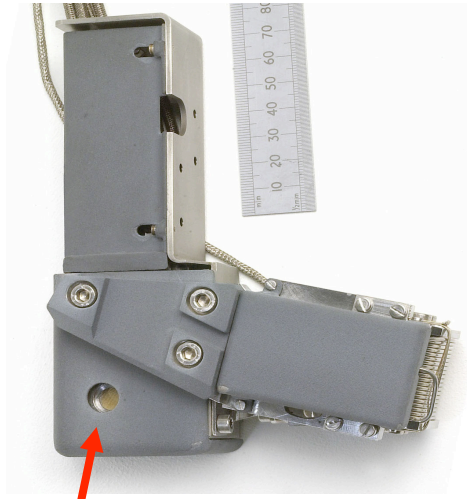
RH preparation for the ITER-like Wall Shutdown required:

- 135 written procedures
  - Sequence Descriptions
  - Detailed Sequences and Task Schedules
  - Multiple VR models and images
- 280 New types of tooling and equipment
- 17 New mock-ups
- 45 Jigs for installation trials

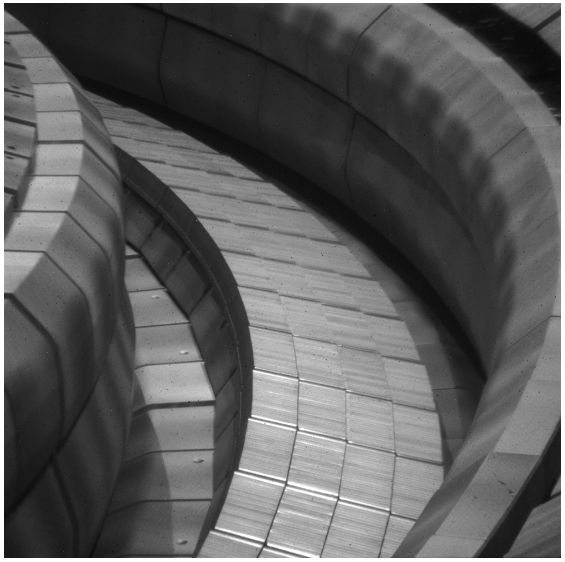


Diagnostic developments for the ILW

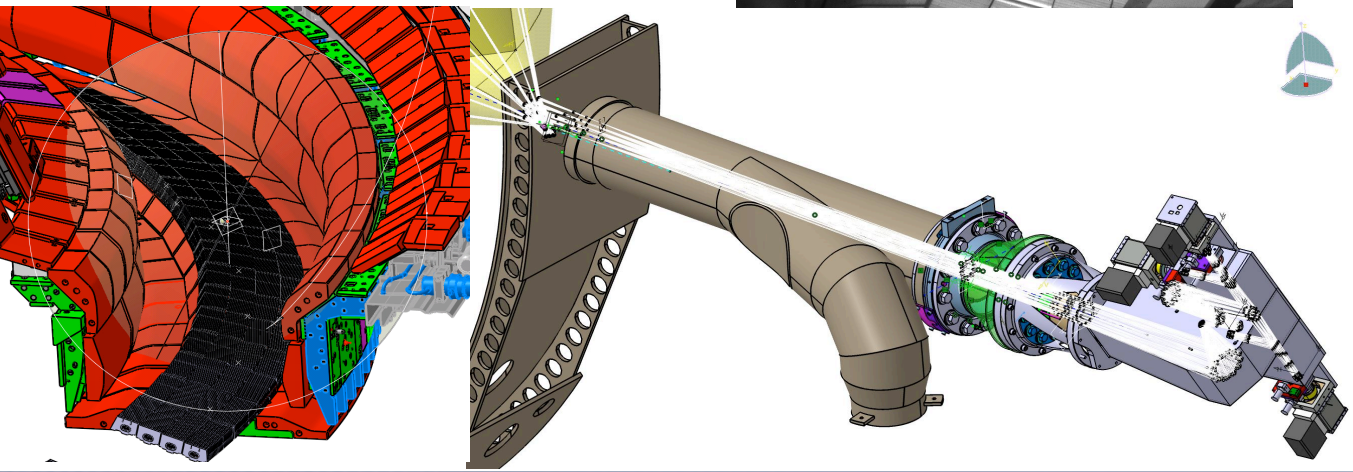
- Spectroscopy systems covering the visible to the X-rays
- Diagnostics embedded in the wall
- IR thermography
- Protection cameras



Quartz Micro-Balances



Divertor endoscope
- Multiple spectroscopic cameras
- Reflective optics



Near IR protection cameras

Conclusion

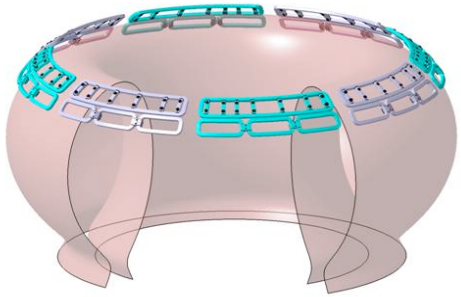
- All enhancements for the JET “EP2” Enhancement Programme are in place
- During the Shutdown Oct 09 – May 11
  - ITER-like Wall completed
  - Neutral Beam Upgrade completed
  - Many new diagnostics installed
- JET Restart commissioning underway
- First plasma due mid August

Outlook

- During the next few years JET will be the only device of its class in the world and well placed to prepare the ITER joint exploitation in the proposed programme
  - ITER-like Wall operating experience
  - High current, high power operation
  - DT campaign

- Further long-term upgrades are under discussion, in collaboration with international partners

In-vessel ELM control coils



ECRH system (10MW, 170 GHz)

[P Spaeh et al, this conference]