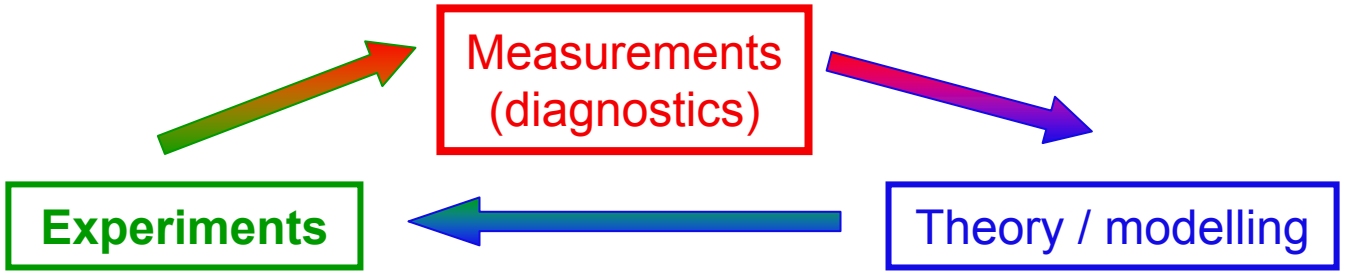
EFDA EUROPEAN FUSION DEVELOPMENT AGREEMENT JET

Overview of the JET New Diagnostic Capability for Edge Pedestal Measurements

Presented by **E. de la Luna**
on *behalf of all contributors to JET EP1 and EP2 Enhancement Programme and Task Force D*

Edge/pedestal measurements



The quality of JET scientific output is strongly linked to the quality of our measurements → **JET ENHANCEMENT PROGRAMME**

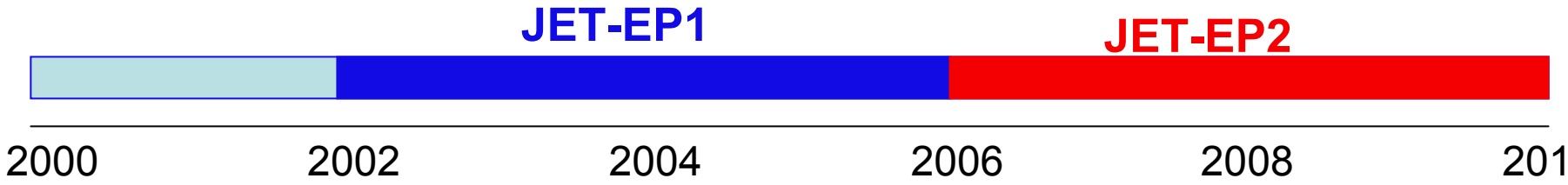
- **Main topics:**
  - Pedestal parameters and their relation with the main plasma confinement
  - Energy/particle flux to the divertor and the main wall

- **Edge/pedestal diagnostics in JET :**
  - T_e : LIDAR, Edge LIDAR, ECE
  - n_e : LIDAR, Edge LIDAR, Lithium beam, reflectometry
  - Ti, v_{tor}, v_{pol} and impurity ion density: Edge CXRS
  - Energy flux to the divertor: IR cameras
  - Fast acquisition system: CATS

- **Diagnostic requirements:** Characterise pedestal parameters (height, width, position) → T_e, T_i, n_e
  - over a large parameter range: n_{ped} = 0.1 – 2 10^{20} m^{-3} , T_{ped} = 0.3 – 3 keV
  - and with good time resolution (ELM characteristics times)

JET Enhancement Programme

Approved by STAC in Jan/2005.



19 projects which are currently being executed

In support of the JET long term programme

- JET-EP2: (2006-2010)

Several working groups to assess the proposals (Feb/March 2005)

- Diagnostics for ITER scenario development
  - Burning plasma diagnostics
  - **Improve profile measurements**
- Diagnostics in support of JET new projects
  - Improve diagnostics (spectroscopy and IR) for safety and scientific exploitation of new wall (and pellets)
- Diagnostics for ITER
  - Test techniques and technologies for ITER, particularly in the field of neutron spectroscopy and radiation hard detectors

Status diagnostics in 2000

Diagnostic (JET name)	Parameter	Performance (2000)
LIDAR (KE3)	Electron density and temperature profiles	Low spatial (12 cm) and temporal resolution (4 Hz)
Edge LIDAR (KE9)	Edge electron density and temperature profiles	6 profiles/pulse (1 Hz), 2-4 cm spatial resolution (flux expansion) Access to pedestal top depends on plasma configuration
Reflectometry (KG8a & KG8b)	Edge density fluctuations Edge density profile (no operative)	Low S/N due to high losses in the waveguides
Lithium beam (KY6)	Edge density profile Edge poloidal current	Low signal. 50-100 ms time resolution for $n_e(r)$ Marginal for current measurements
Edge CXRS (KS7)	Ion temperature, poloidal & toroidal rotation and density impurity	Many fibers were damaged or broken. Upper system particularly badly affected.
ECE (KK3)	Electron temperature profile (limited access to the edge/low optical thickness)	High spatial and temporal resolution (96 channels in 2002). O-mode for B > 2.4 T. Problems at high n_{ped} → cut-off
IR camera (KL3)	Spatial and temporal distribution of divertor tile temperature	Divertor camera: limited spatial and temporal resolution
CATS (fast acquis. system)	Consistent data collection of magnetic and non-magnetic signals. Fast events	10 time windows. Max. length restricted to 1 sec.

JET edge/pedestal diagnostics

2000	JET-EP1 (2002-2006)	JET-EP2 (2006-2010)
LIDAR: low spatial (12 cm) & temporal resolution (4 Hz)	**HRTS:** improve spatial and temporal resolution	
Edge LIDAR: low temporal (1Hz) & medium spatial resolution (2-4 cm)		**Edge LIDAR:** New detectors + digitizer (improved spatial resolution)
Reflectometry: Low S/N (poor performance)	**New MWA:** Improve S/N New **edge density profile reflectometer**	
Lithium beam: medium time resolution (25 ms)		**Lithium beam upgrade**
Edge CXRS: medium time resolution, fibers damaged	**New edge CXRS:** improve spatial and time resolution	
ECE: 48 channels. O-mode for B > 2.5 T: problems at high density→ cut-off	**ECE upgrade**: 96 channels	**ECE upgrade**: extend operational range in X-mode → increase cut-off density
IR camera: limited spatial and temporal resolution	**Wide angle view infrared camera**	**Divertor camera**: improve spatial and temporal resolution
Fast events: CATS (short time windows)	**New fast acquisition system** (KC1M & KC1N)	**Fast cameras**

High Resolution Thomson Scattering

R. Pasqualotto (RFX), M. Beurskens(UKAEA)

Main LIDAR (KE3):

12 cm / 4 Hz

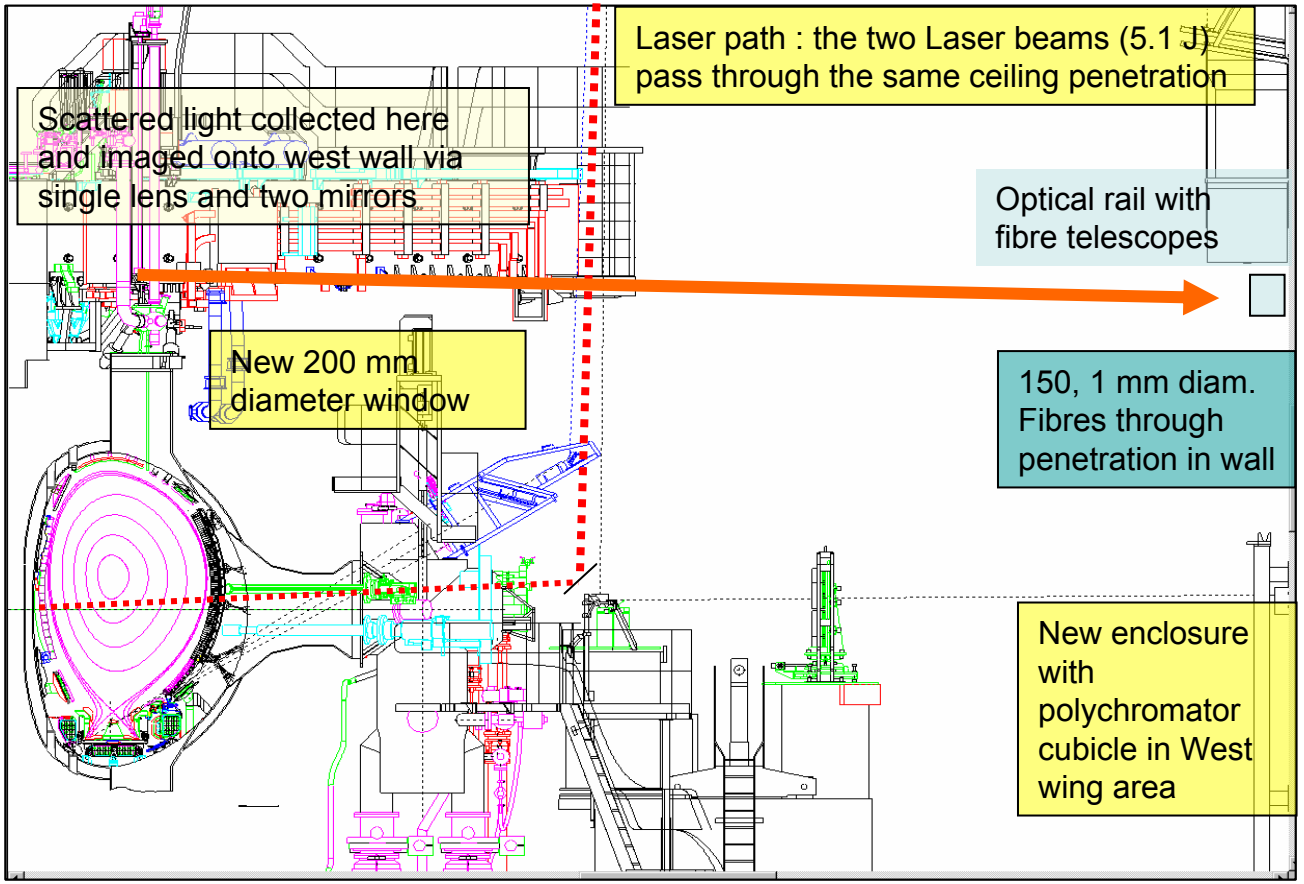
Divertor LIDAR (KE9):

2-4 cm / 1Hz

HRTS:

Expected performance:

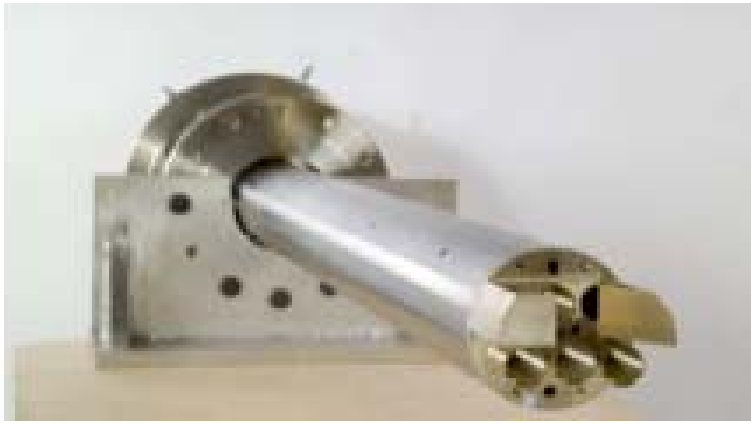
- 5 cm in the core
  2.5 cm at the edge
- repetition rate up to 20 Hz



Status: **A couple of failures in the beam optics → change the design of the beam path. Waiting for the delivery of new optics. Final performance need to be assessed**

Reflectometry

(L. Cupido, IST)



New MicroWave Access (MWA):
4 new corrugated waveguides for reflectometry

Corrugated waveguides = Very low losses = Enhanced S/N

Status: System fully commissioned and giving satisfactory results: S/N of about 20 dB gained with the new system

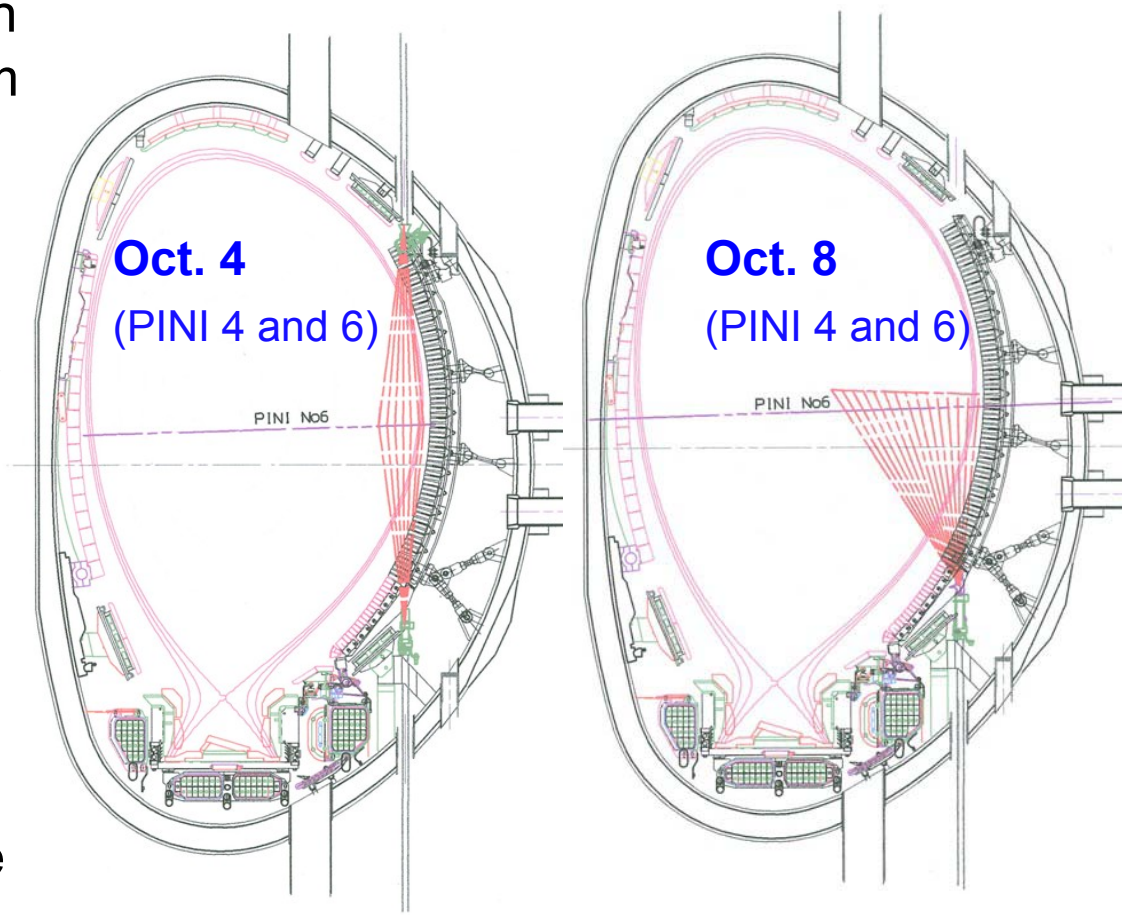
Improved performance of reflectometry measurements in JET

Name	Physics output	Main characteristics	Range of applicability
KG8b	Turbulence measurements	X-mode 4 channels (76-106 GHz)	1.8 T ≤ B ≤ 3.2 T 2.4 T optimum value: both core and edge measurements 3.2 T: only edge meas.
KG8a	Fast edge density profile meas. (ready during 2006)	X-mode (50-70 GHz) Temporal resolution < 1 ms Spatial resolution ≤ 1cm	**1.8 T ≤ B ≤ 2.4 T** 1.8 T: Optimum value ($n_e < 3\times10^{19}$ m^{-3}) 2.2 T: $n_e < 1.5\times10^{19}$ m^{-3}

Edge CXRS

N. Hawkes, Y. Andrew (UKAEA)

- Edge view (Oct. 4) with strict up-down symmetry to discriminate poloidal from toroidal motion
  - ✓ Replace the 'old' system in Oct. 4: 1 new spectrometer, 2 new CCD detectors with faster readout capabilities (better temporal resolution,limited by photon statistics), new fibers (more points/profile)
  - ✓ Increased sensitivity and spatial coverage/resolution for T_i, v_{tor}, v_{pol} and impurity ion density at the edge (13 channels, ~2.5 cm resolution, 3.62 - 3.84 m radial coverage)
- New core view (Oct. 8) for edge/core poloidal rotation
  - 6 channels, ~10 cm resolution
  - for core poloidal rotation, need to know toroidal rotation from core CXS



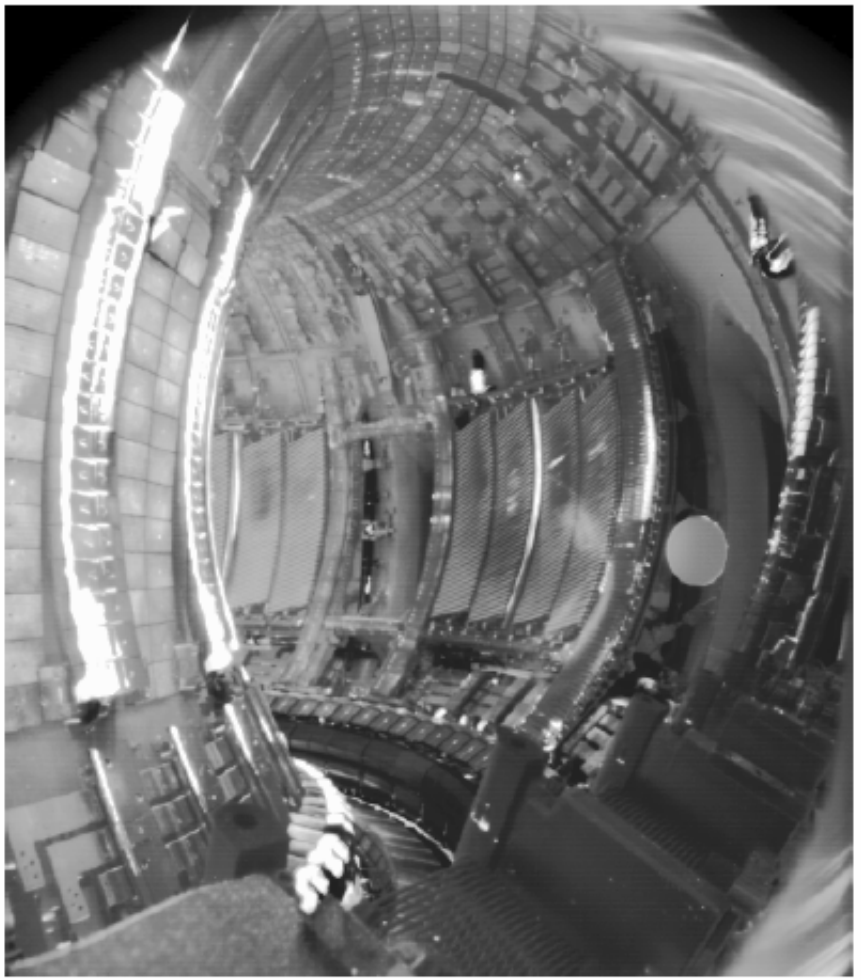
Status: System operational but final performances need reliable beams to be assessed

IR camera: Wide angle view

E. Gautier (CEA) / P. Andrew (UKAEA)

- View of the main chamber and the divertor.
- Large dynamic range from 150°C to about 2000°C. Spatial Resolution 18 mm at three meters.
- Up to 3 integration windows (~20μs to 1500 μs)
- Creates one pulse file per integration window(up to 3 files per pulse).
  Up to ~1 GB per file
- IDL software available (public in the JACs) to read data, display/playback frames, convert to temperature, etc…

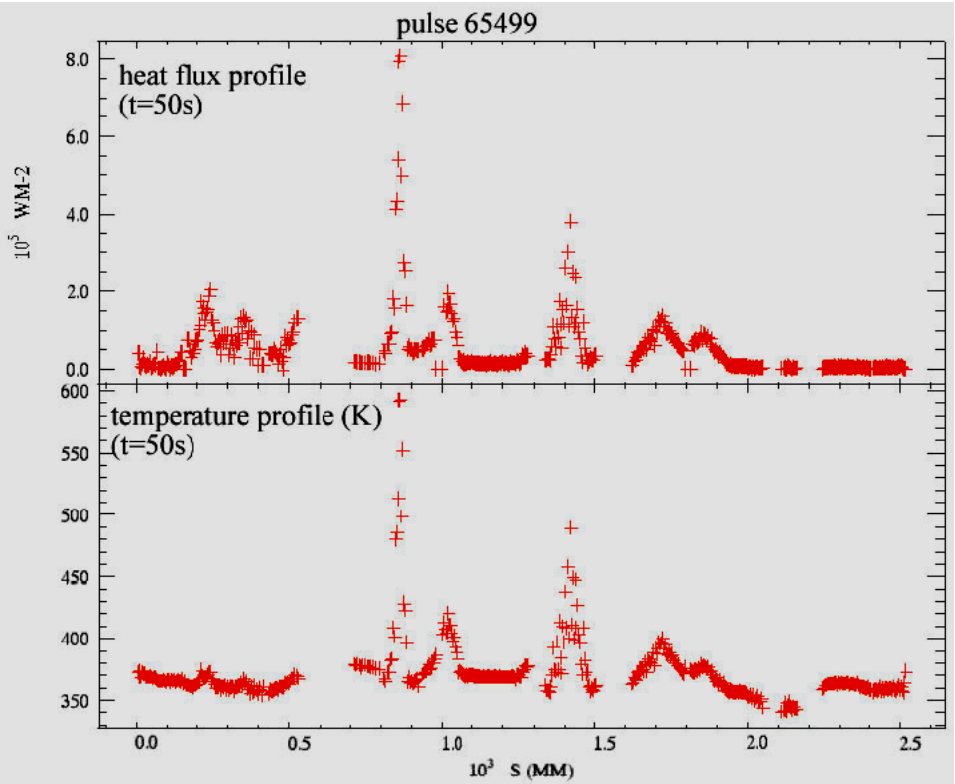
Status: Diagnostic working. First calibration already implemented and first ppf available

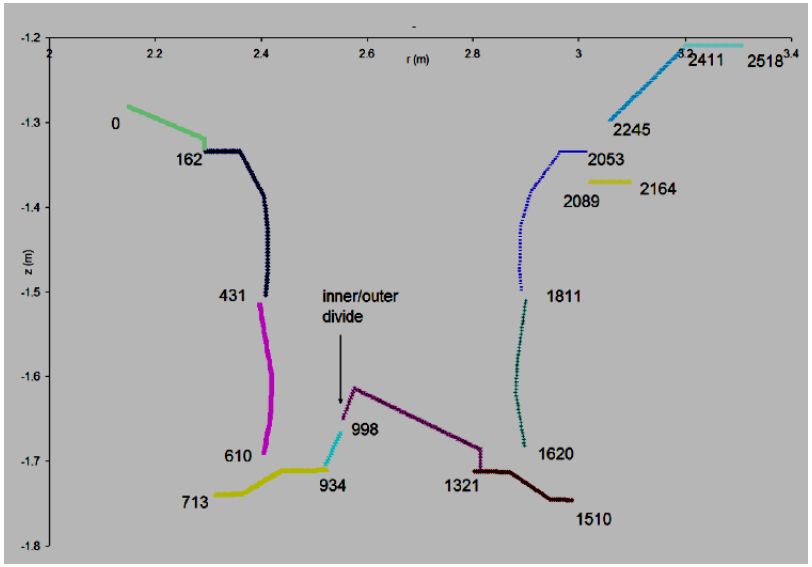


64853 (disruption)

IR camera: First data

- Image is transformed from image space to ‘real’ object space
- Data is reduced to 1D problem by averaging over the s-coordinate -> data analysed with THEODOR heat flux code
- Temperature and heat flux profile, strike point position





s-coordinate: distance along the surface of the divertor from the innermost point on the divertor to the outermost

J. Paley, Data Validation and Coordination Meeting, JET, 21 March 2006

Fast ADCs

B. Alper (UKAEA)

- **Fast ADCs:**
  - capable of recording longer time windows (>10 sec) than CATs
  - at sampling rates up to 2 MHz
  - the role of CATS vis-a-vis the KC1M/N & KK3F systems is under review

✓ **KC1M:** 32 magnetic channels (fixed allocation)
  - typical window = 8 sec at 2 MHz

✓ **KC1N:** 32 non-magnetic channels (selectable)
  - a selection of ECE and reflectometry signals (turbulence) +TAE & interferometer
  - the configuration must be agreed with the DCO

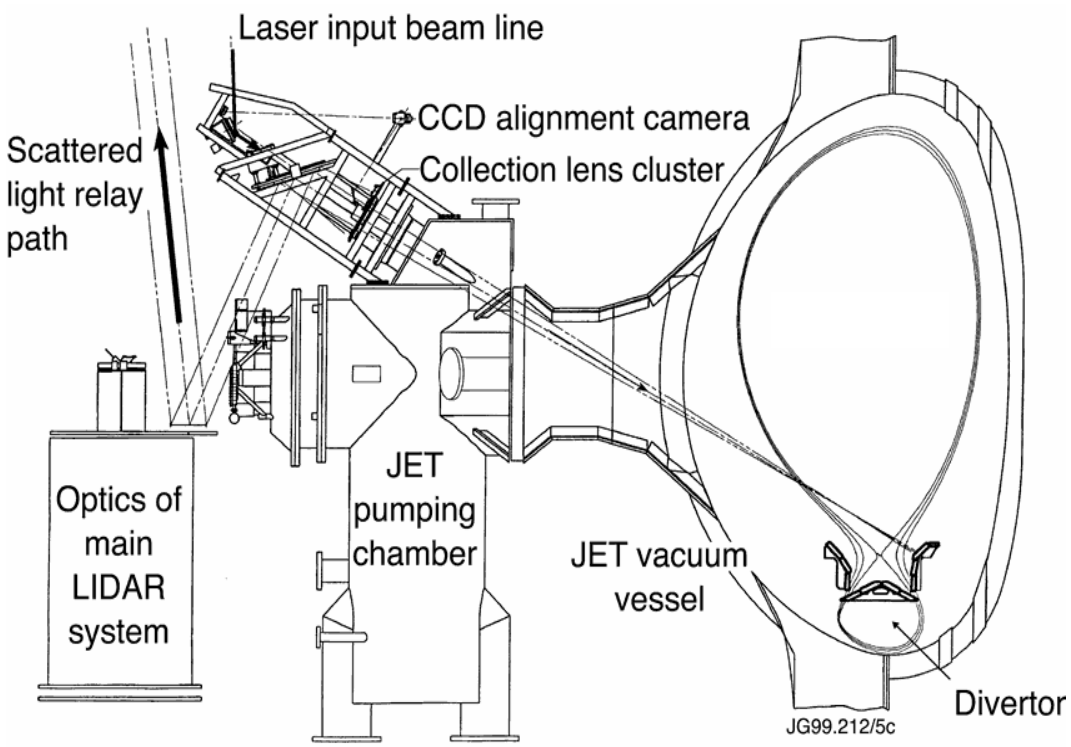
✓ **KK3F:**
  - 48 ECE channels already recorded in CATs (1 MHz bandwidth, data after the first amplifier)
  - additional 48 channels in 2003. New ADCs to provide extended fast data acquisition window (6 Msamples/channel, giving 6 sec storage up to 1 MHz)

JET EP2 (2006-2010)

2000	JET-EP1 (2002-2006)	JET-EP2 (2006-2010)
LIDAR: low spatial (12 cm) & temporal resolution (4 Hz)	**HRTS:** improve spatial and temporal resolution	
Edge LIDAR: low temporal (1Hz) & medium spatial resolution (2-4 cm)		**Edge LIDAR:** New detectors + digitizer (improve spatial resolution)
Reflectometry: Low S/N (poor performance)	**New MWA:** improve S/N (20 dB) New **edge density profile reflectometer**	
Lithium beam: medium time resolution (25 ms)		**Lithium beam upgrade**
Edge CXRS: medium time resolution, fibers damaged	**New edge CXRS:** improve spatial and time resolution	
ECE: 48 channels. O-mode for B > 2.5 T: problems at high density→ cut-off	**ECE upgrade**: 96 channels	**ECE upgrade**: extend operational range in X-mode → increase cut-off density
IR camera: limited spatial and temporal resolution	**Wide angle view infrared camera**	**Divertor camera**: improve spatial and temporal resolution
Fast events: CATS (short time windows)	**New fast acquisition system** (KC1M & KC1N)	**Fast cameras**

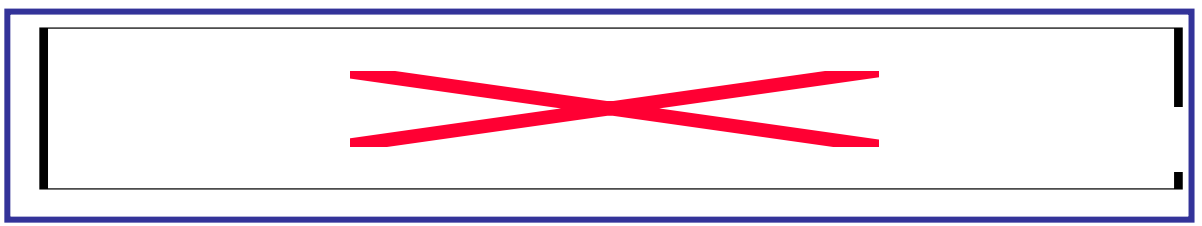
Edge LIDAR: spatial resolution

(M. Walsh, UKAEA)



For Edge LIDAR because of flux surface mapping the spatial resolution is ~ 4 -2 cm, depending on plasma configuration (DOC-U)

Inherent to the system is the fact that its spatial resolution is the convolution product of the response times of the components:



τ_l: laser pulse length

τ_{det}: the detector response time

τ_{dig}: the digitiser speed

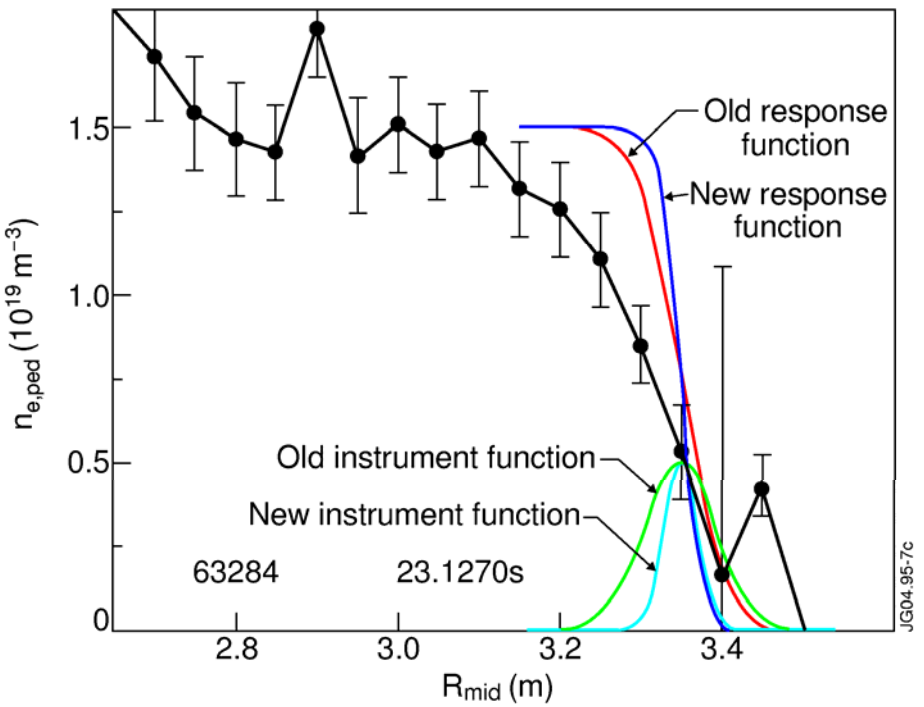
Edge LIDAR: New detectors

Goal: Improve spatial resolution

Proposal:

- Faster digitiser: 4 channels, 20 Gsamples/s (instead of 1 Gsamples/s), 8 GHz bandwidth, 8 bits
- Fast detectors: order of 200 ps rise time instead of 650 ps
- Laser (100ps) to test the chain and determine the spatial resolution

Edge LIDAR Measurements at JET with 6 Gsample/s digitiser.



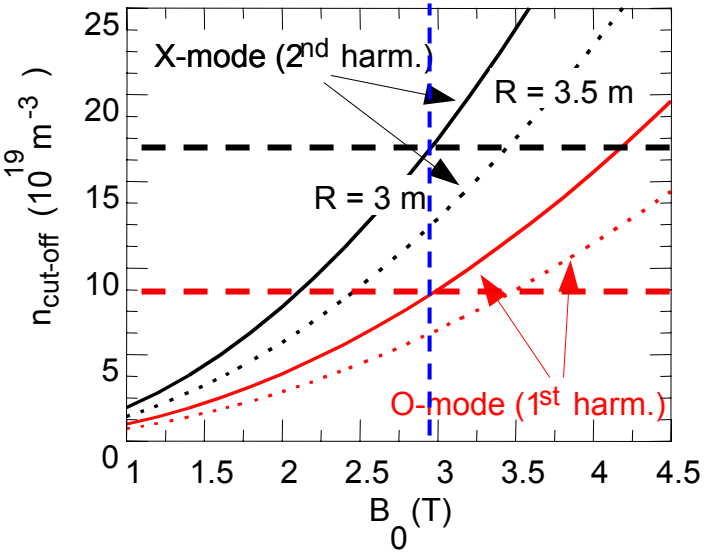
ECE upgrade

(E. de la Luna, CIEMAT)

Goal: Increase the operational parameter range of the radiometer, allowing reliable T_e meas. at high density/high magnetic field.

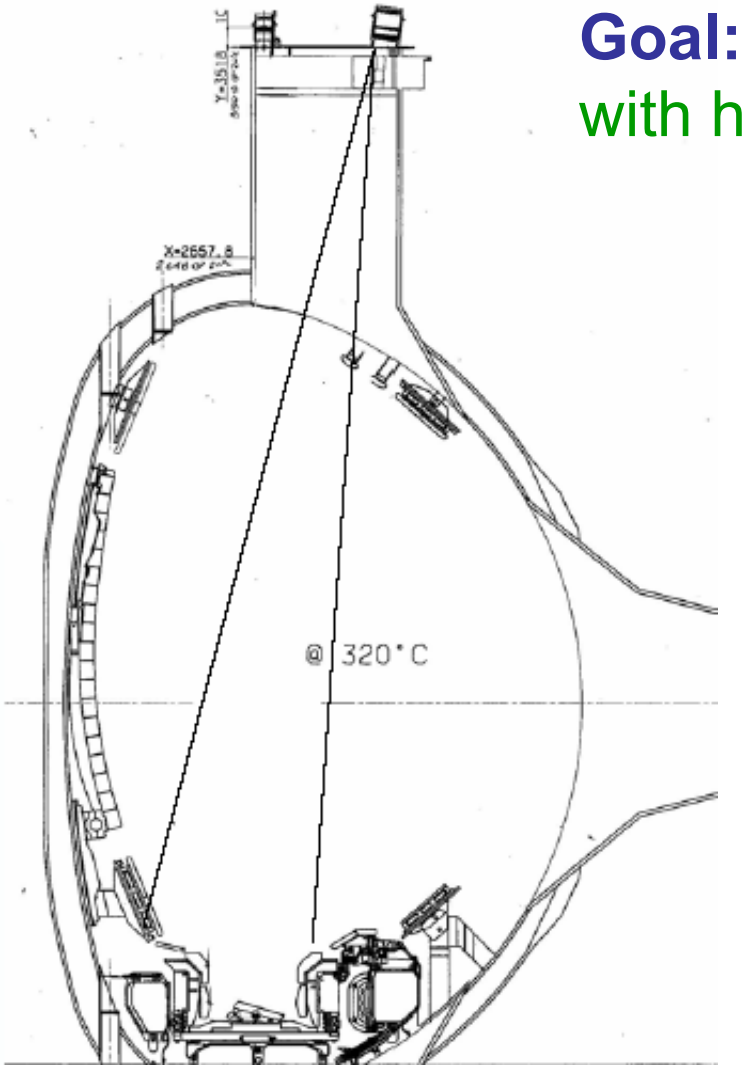
Proposal: Increase the frequency coverage (6 new mixers) to extend the use of 2nd harmonic X-mode polarization (higher $n_{cut-off}$)

- maximum radial coverage using X-mode up to B=3.2 T (2.4 T with the existing system)
- edge/pedestal data (R=3.5-4 m) in X-mode for all magnetic fields used in JET (3 T with the existing system)
- 96 channels: No change in the IF filter banks/ADCs
- Optional: Small separation between channels at higher magnetic field (slight improve in spatial resolution)



The cut-off density for the 2nd harmonic X-mode is twice that of the 1st harmonic O-mode

Divertor IR camera *(T. Eich, IPP)*



Goal: Characterize power deposition in divertor with higher time and spatial resolution (ELMs)

Proposal: Replace the exiting top view camera (before installing the new first wall and divertor materials) by an state of the art system:

NEW camera (possible option):

- 320X256 pixels
- 3 mm spatial resolution
- 4-20 μs exposure time
- Frame rate: 50-100 μs

OLD camera:

- 128X128 pixels
- 5 mm spatial resolution
- 24 μs exposure time
- Frame rate 1.5 ms (mixing spatial and temporal information)

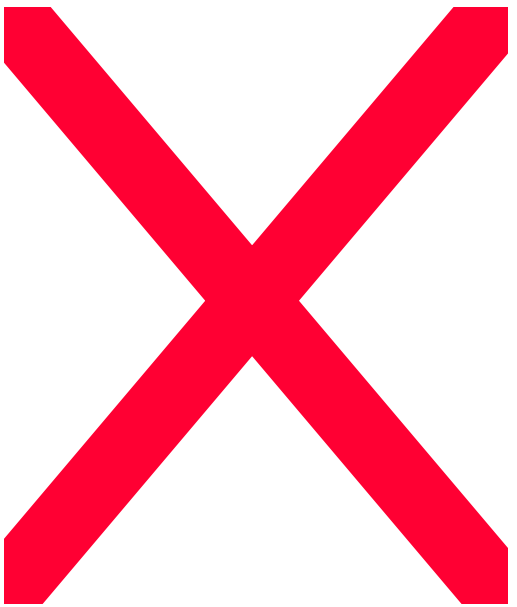
Lithium Beam upgrade

(S.Zoletnik, KFKI)

Goal: Improve accuracy (S/N) and time resolution (and operational space). Beneficial for the measurements of n_e (and edge current)

Proposal: Upgrade of the present system

- ✓ Increase light intensity:
  - Increase the beam current up to 5 mA (from about 1.5 mA). Mainly new emitter.
  - Refurbishment of the periscope (mirror reflectivity)
- ✓ Increase temporal resolution (photon statistics & camera readout speed) (5-10 ms, instead of 25 ms):
  - Fast CCD cameras
  - Test single detectors (solid state detector with high quantum efficiency) to see if ELMs can be resolved
- ✓ Improve spectral resolution for current meas.
  - Higher throughput spectrometers
- ✓ Increase penetration (up to the top of the pedestal) (under study)
  - Increase in beam energy to 100-150 keV (now 60 keV)



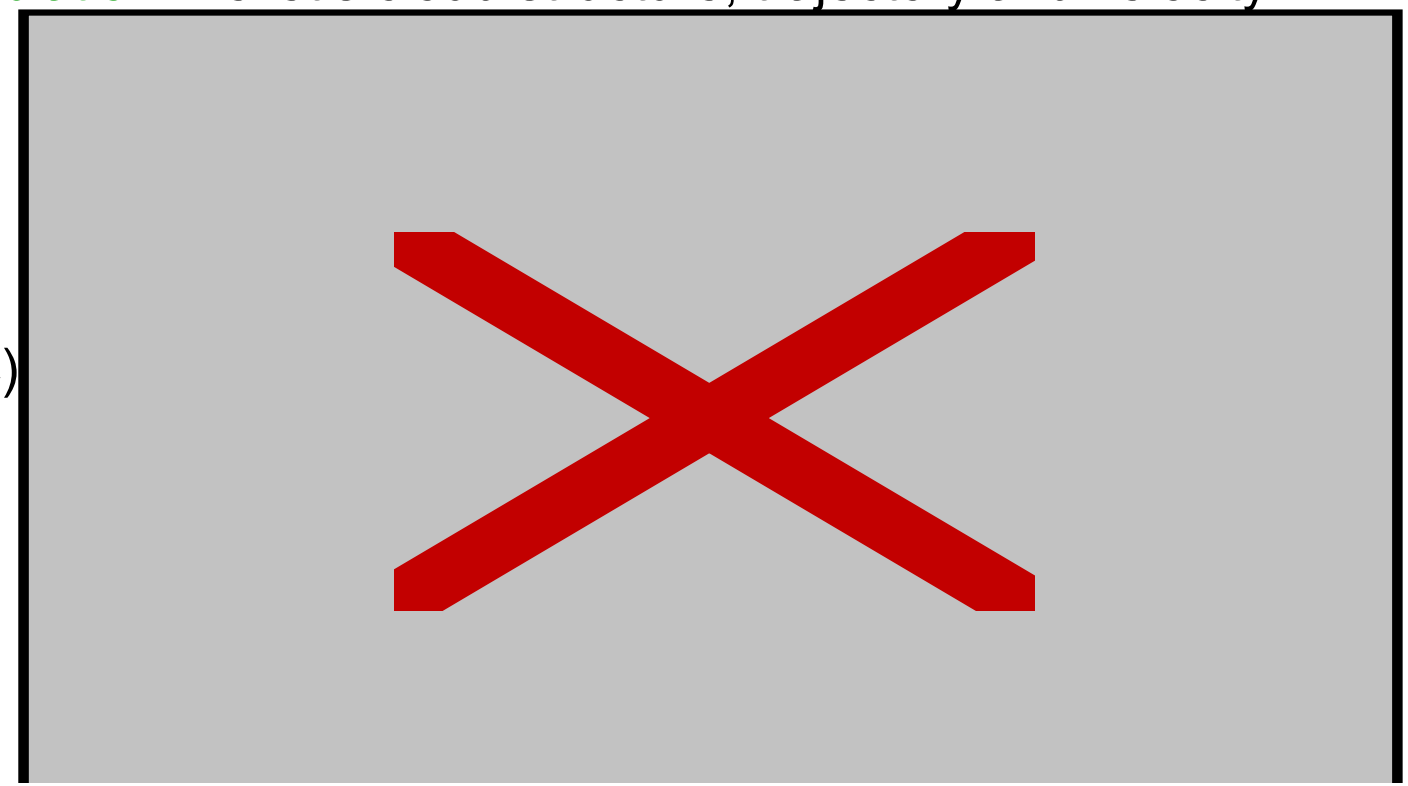
Fast camera

(C. Hidalgo, CIEMAT)

- **Goal:**
  - –2-D imaging of ELMs dynamics: Identify ELMs instabilities in the low field side and proximity to the X-point
  - –Plasma-wall recycling: Particle transport events in divertor and main chamber during ELMs and disruptions
  - –Physics of pellet ablation: Pellet's cloud structure, trajectory and velocity

- **Proposal:**

  Install a fast camera (150-250 kframes/sec) in the visible part of the JET-EP IR endoscope



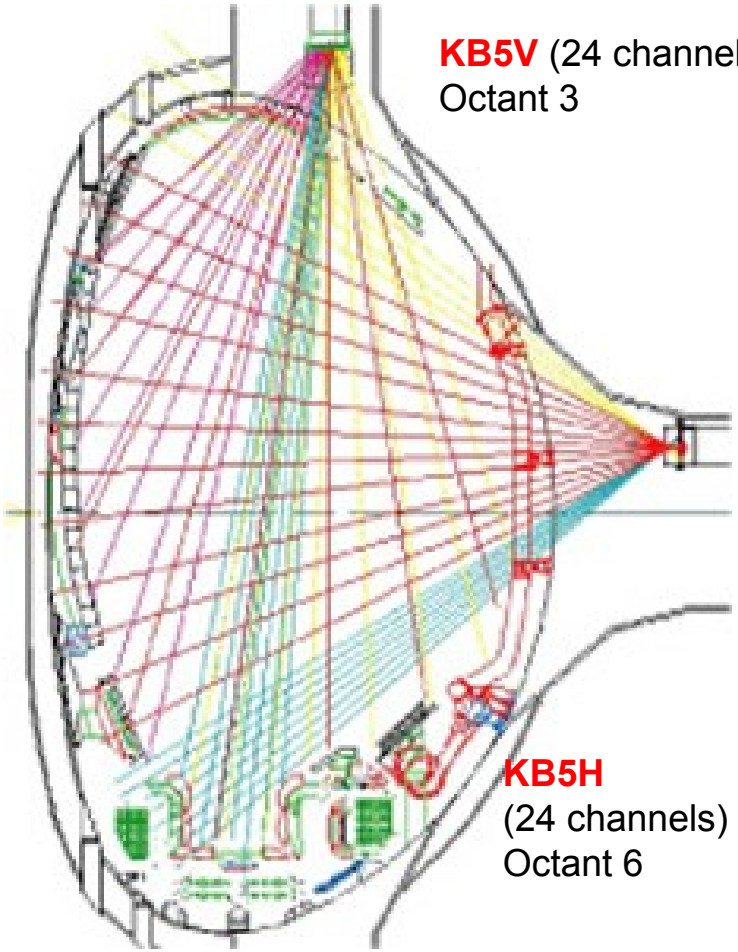
Conclusions

- New diagnostics (edge/pedestal) available in JET:
  - ✓ To improve the accuracy and resolution of profile measurements particularly at the edge (ELMs) and in the ITBs
  - ✓ To extend the operational space of certain techniques
  - ✓ Fast MHD and macroscopic edge instabilities
- More diagnostics than the JET-EP2 package were explicitly supported by an independent body (Expert Working Group chaired by T.Donne)
  - ✓ The set of diagnostics already endorsed by STAC in 2005 is considered the minimum to support JET scientific long term programme
- TF-D: Establish stronger links between the diagnostic community and the theory/modeling groups.
  - ✓ Recommendations & priorities

Bolometer

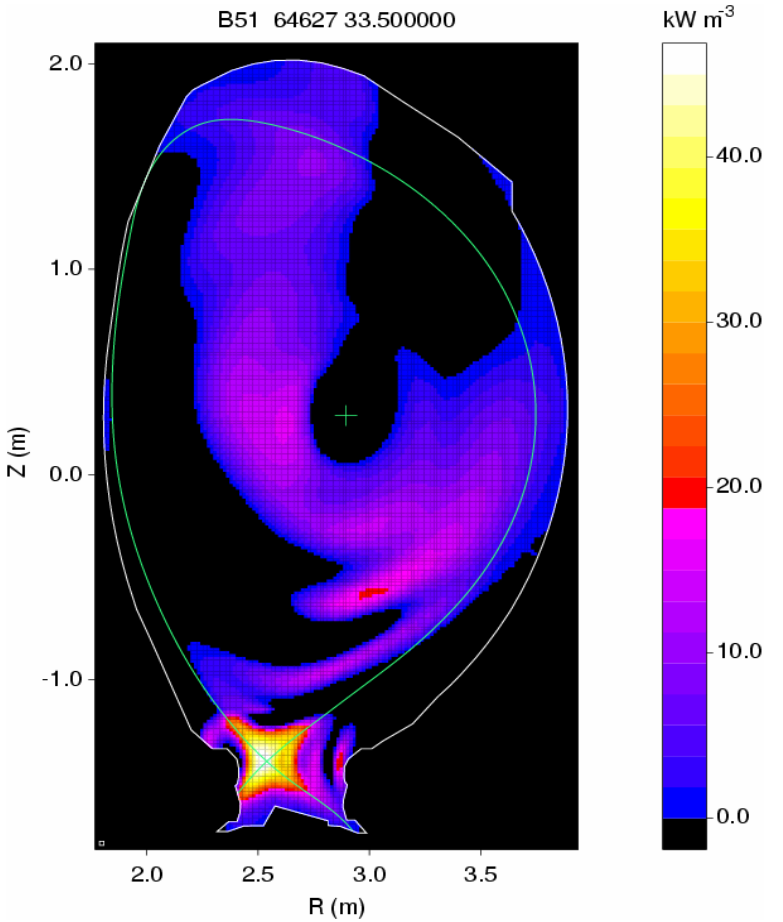
(K. McCormick, IPP)

Total radiation power, radiation profiles through tomographic reconstruction (2 ms temporal resolution)



KB5V (24 channels)
Octant 3

KB5H
(24 channels)
Octant 6



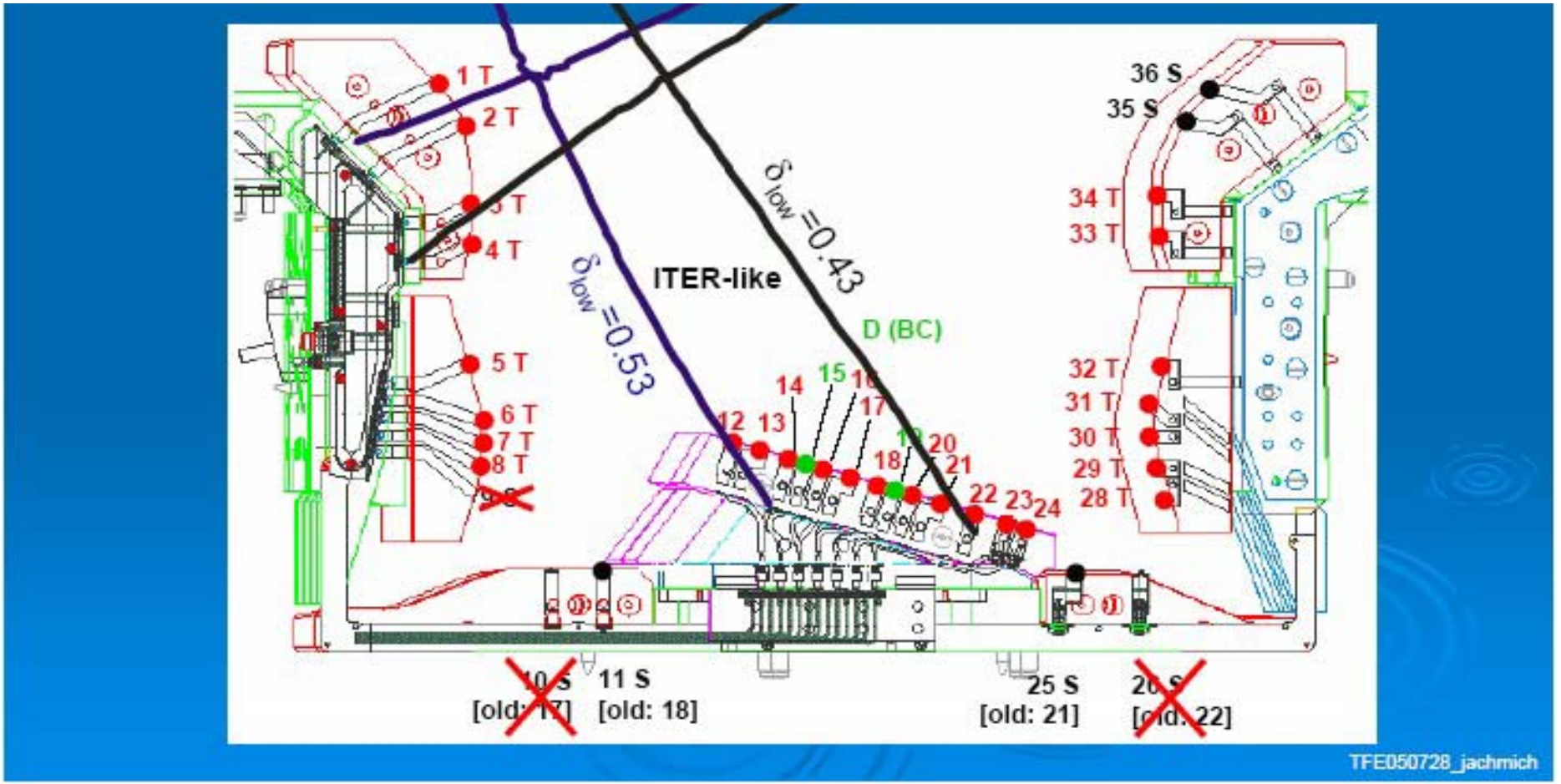
Status: All channels installed and working properly. Fully commissioned.

Divertor Langmuir probes

(W. Fundamenski. UKAEA)

86 new probes have been installed
and old ones have been refurbished

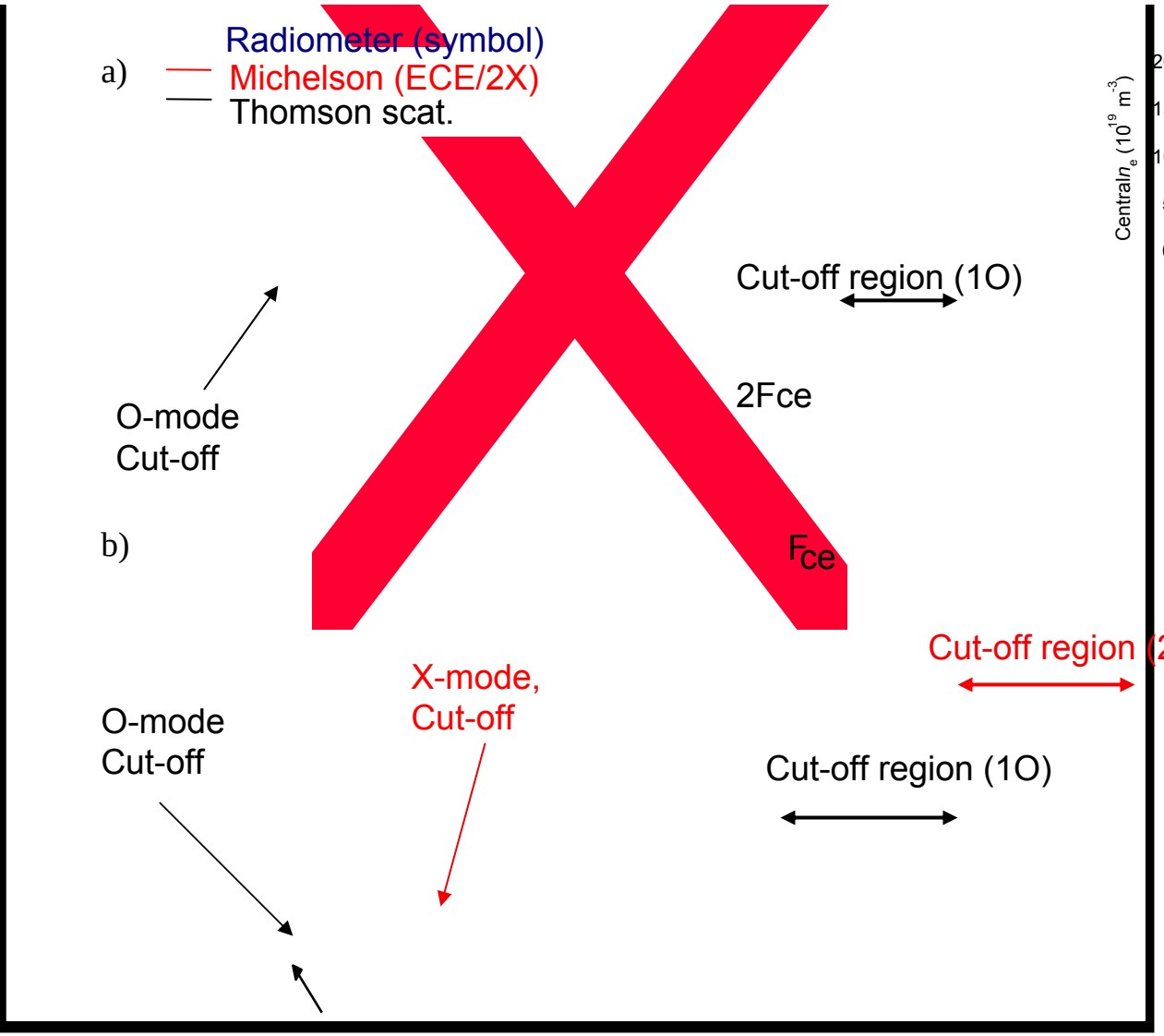
Status:
66 probes working and commissioned

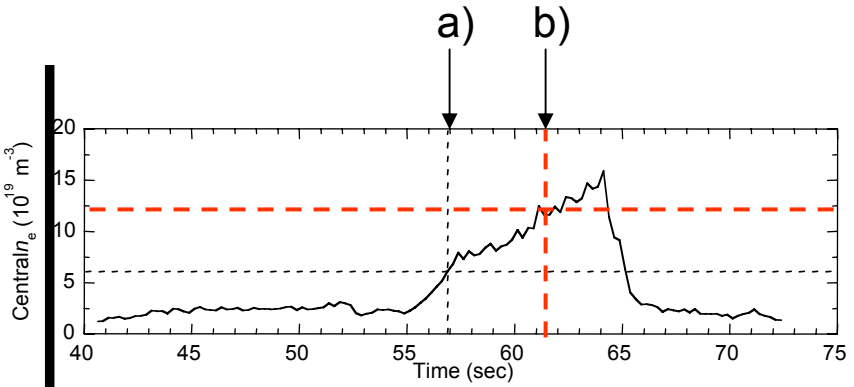


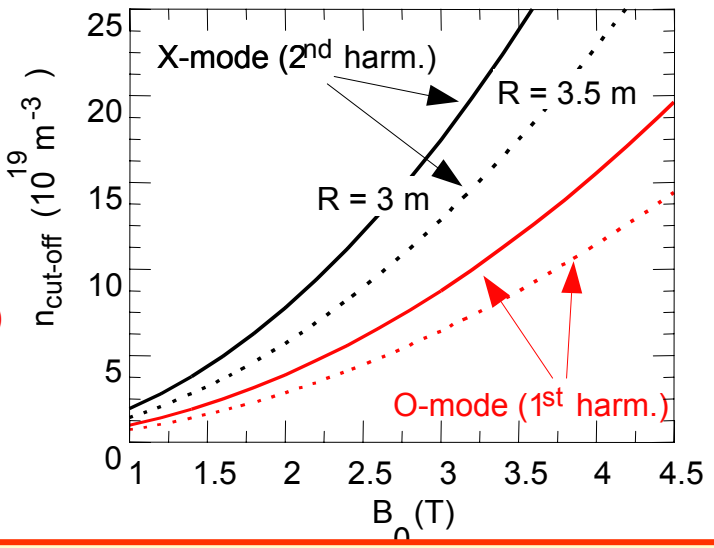
ECE: Cut-off at high density

Temperature profiles

ECE cut-off frequencies







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JET Enhancement Programs

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