

Development of LIBS for JET

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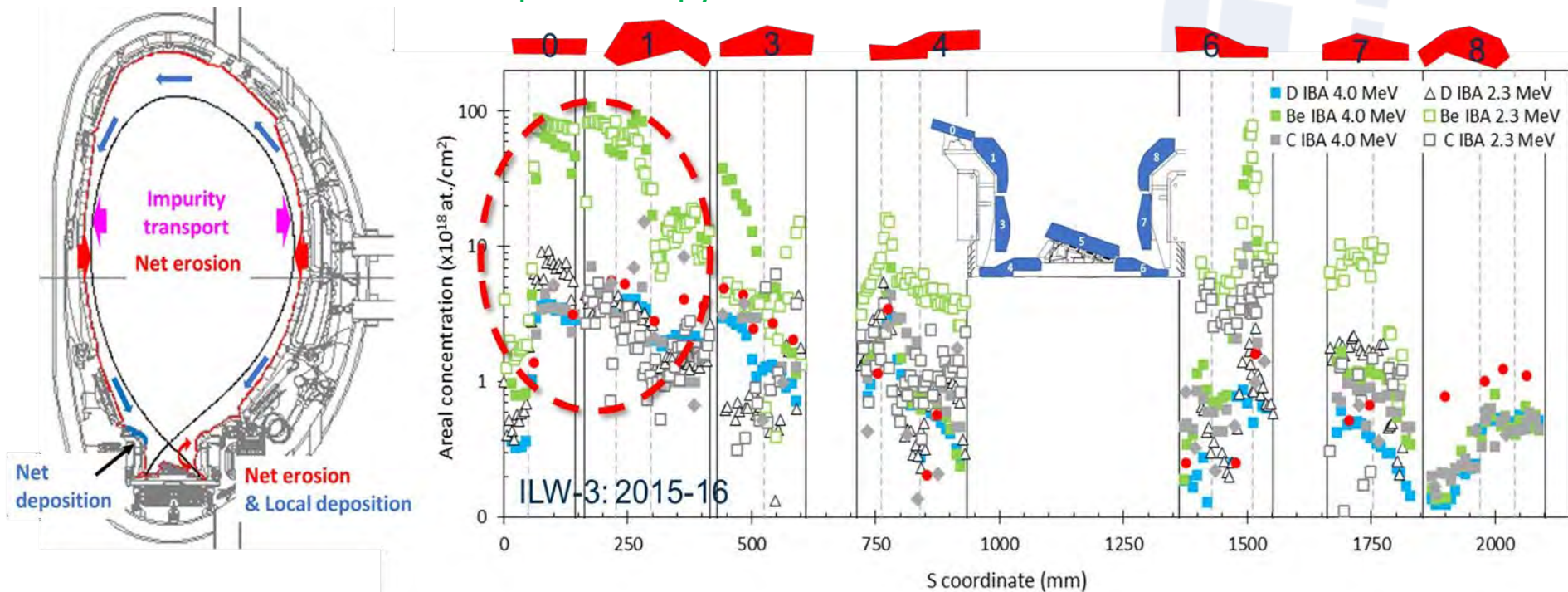
*See the author list of “Overview of T and D-T results in JET with ITER-like wall” by C. F. Maggi et al. to be published in Nuclear Fusion Special Issue





Introduction

- ITER and future power plants such as DEMO must limit in-vessel tritium (T) retention to reduce risks of potential release during normal and off-normal operation including accidents conditions
- T-retention in ITER and DEMO will mainly be driven by co-deposition with tungsten (W) eroded from main wall
- ITER safety limit: 700 g of tritium in the reactor
- Accumulation of dust and tritium in vacuum vessel could significantly impact operation of ITER and DEMO
- Monitoring of vacuum vessel tritium inventory is essential for safety analysis
- Currently laser based techniques (e.g. LIBS and LID-QMS) are most promising
- LIBS = Laser-Induced Breakdown Spectroscopy

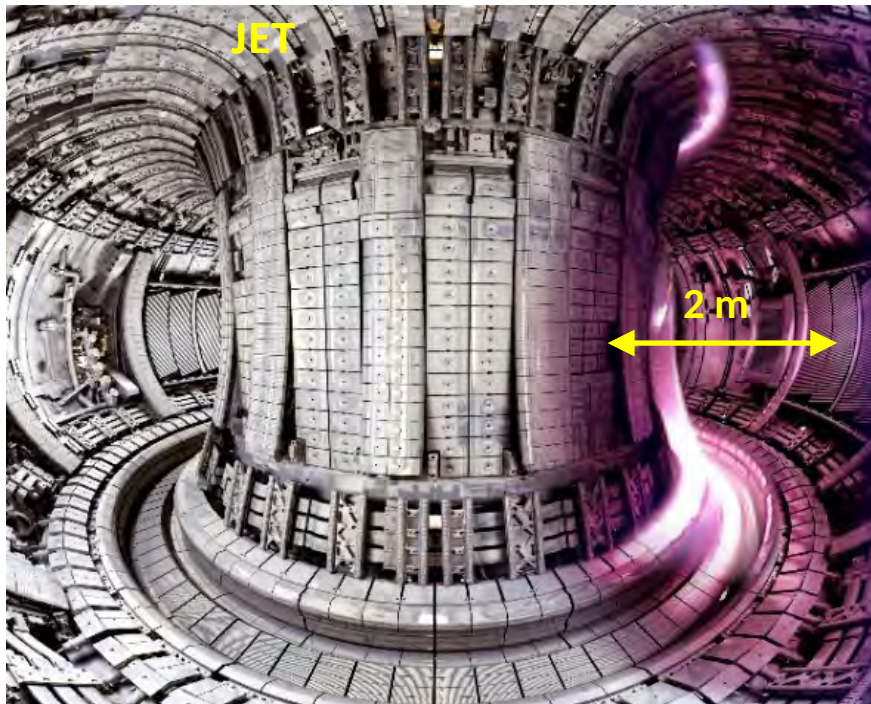




JET tokamak

JET - flagship in worldwide fusion research for 40 years (1983-2023)

- Produced up to 60-s long plasma pulses in a tokamak configuration
- Can use actual DT fusion fuel → record fusion energy output ~69 MJ
- Realistic choice of wall materials (beryllium, tungsten) but ITER will change beryllium wall to tungsten
- **Now in the decommissioning phase**
- LIBS experiment in August 2024
- Sample retrieval starts in August-September 2024
- Post-mortem analysis of JET PFCs in 2025-



Deuterium-tritium operations at JET with ILW-like wall

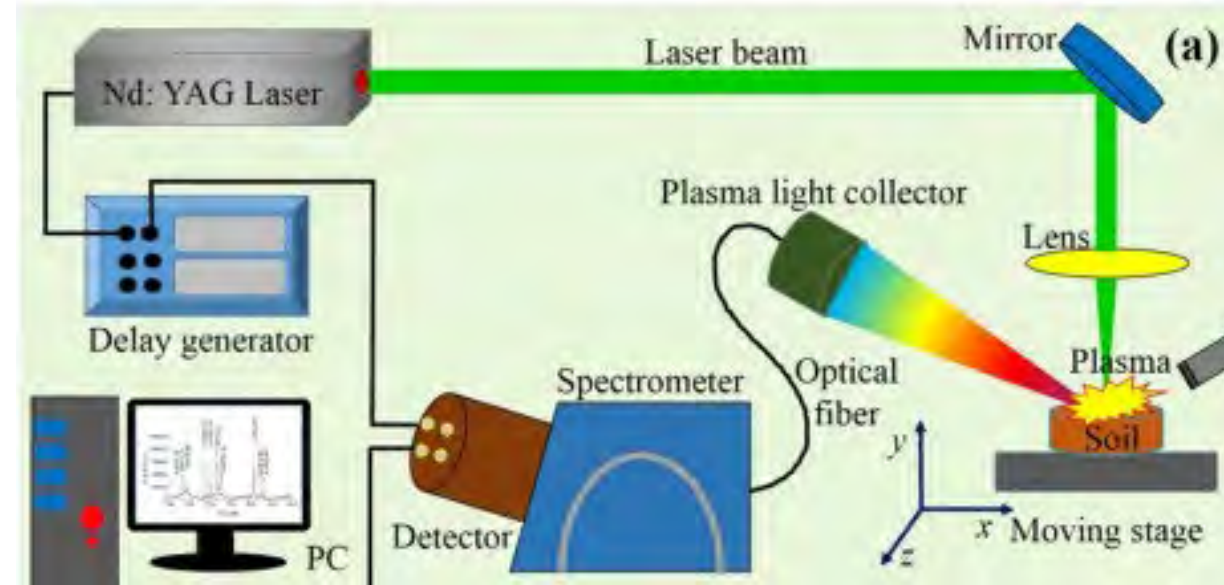
	T100 100% T ₂	DTE2 2 nd Deuterium-Tritium experiment	DTE3 3 rd Deuterium-Tritium experiment
Date	2020-21	2021-22	2023
Tritium through-put (g, T atoms, Bq)	100, 2.0e25, 36PBq	150, 3.0e25, 54PBq	100, 2.0e25, 36PBq
JET configuration	JET-ILW ITER-Like wall	JET-ILW ITER-Like wall	JET-ILW ITER-Like wall



LIBS in fusion reactors

- Laser-induced breakdown spectroscopy (LIBS) is a type of atomic emission spectroscopy which uses a highly energetic laser pulse as the excitation source
- Laser is focused to form a plasma, which atomizes and excites species
- These excited-state species emit light at unique wavelengths
- This light can then be collected with a spectrometer

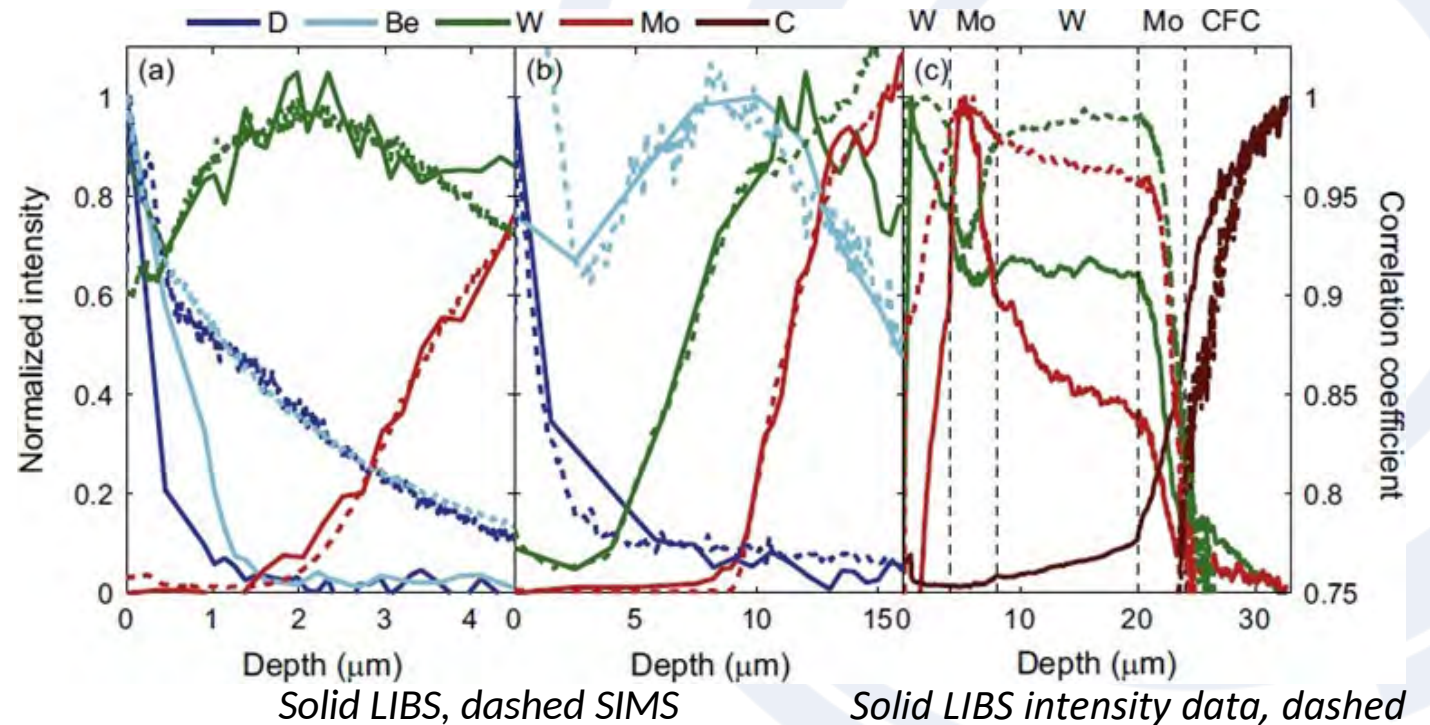
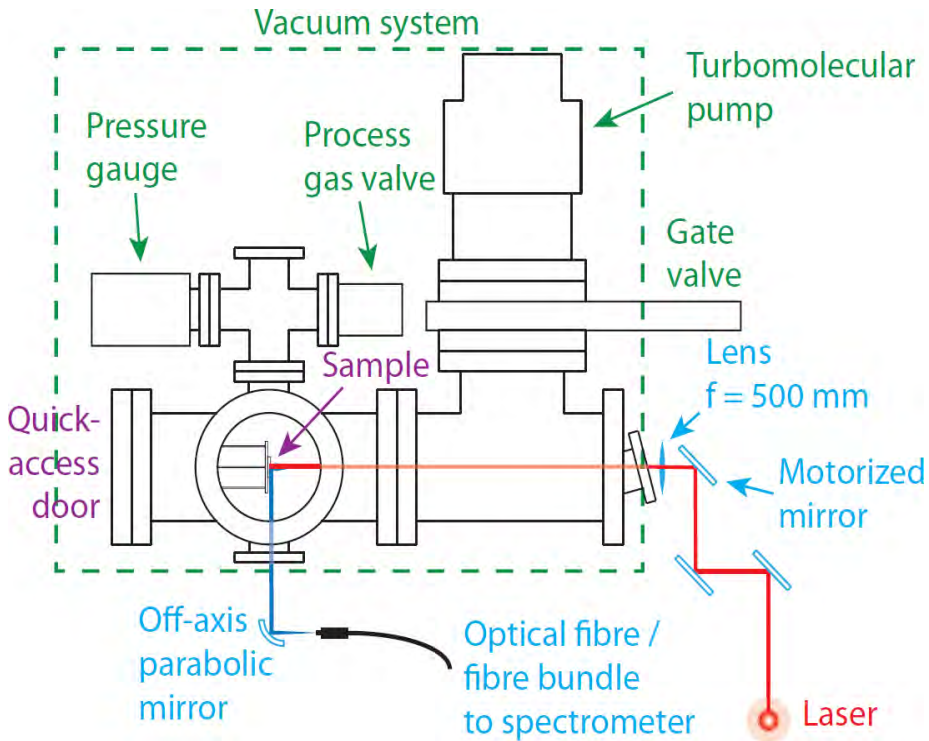
- LIBS allows detailed inspection of vacuum vessel of fusion reactor
 - ✓ Particularly critical is to assess the amount of radioactive tritium retained in the layers
 - ✓ Also possible to determine thickness and elemental composition of the co-deposits
 - ✓ LIBS provides an (almost) unlimited access to different regions of reactor wall – without the need to remove wall components from the reactor
 - ✓ LIBS parameters can be tailored such that impact on wall structures is minimized → no need for replacement after LIBS measurements





Test measurements at VTT- why there?

- VTT has long experience in studying JET and other fusion-relevant samples in laboratory conditions
- LIBS setup located in licensed Be- and T-compatible nuclear laboratories at VTT
- Several JET samples analysed and their depth profiles determined since 2011
- Good correspondence to other profiling techniques, e.g., Secondary Ion Mass Spectrometry (SIMS)
- Prototype LIBS enclosure commissioned and several JET samples analysed in February-March 2024



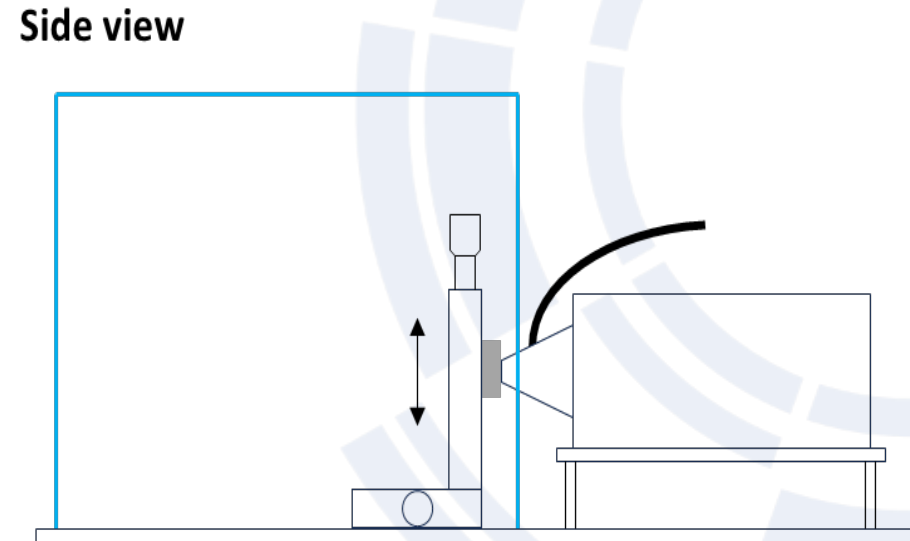
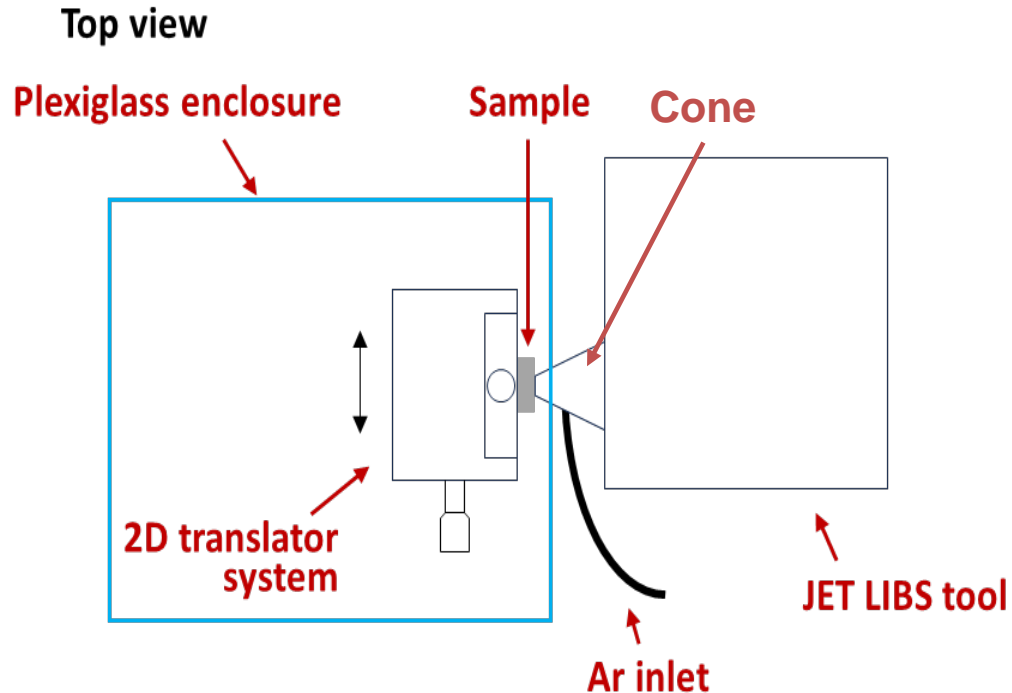
Old setup: vacuum system inside a fume cupboard and a ns laser

J. Karhunen et al, J. Nucl. Mater. 463 (2015) 931-935



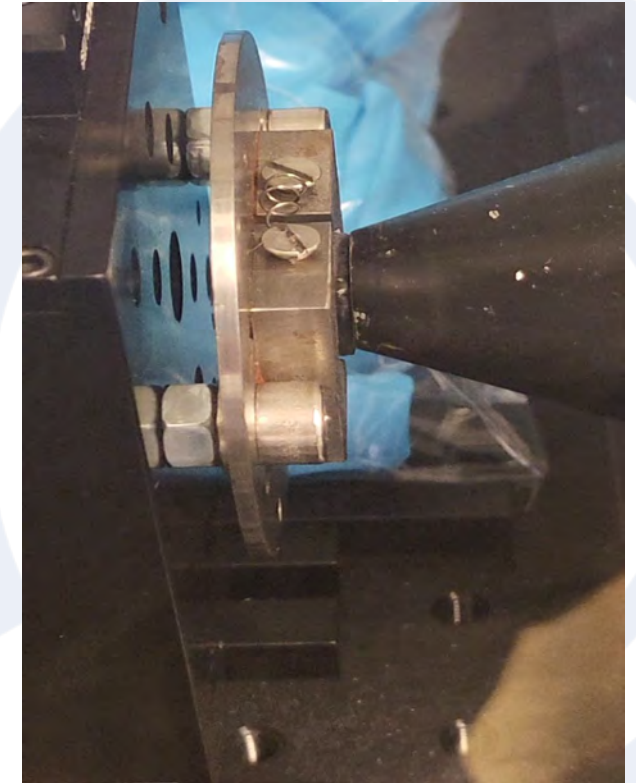
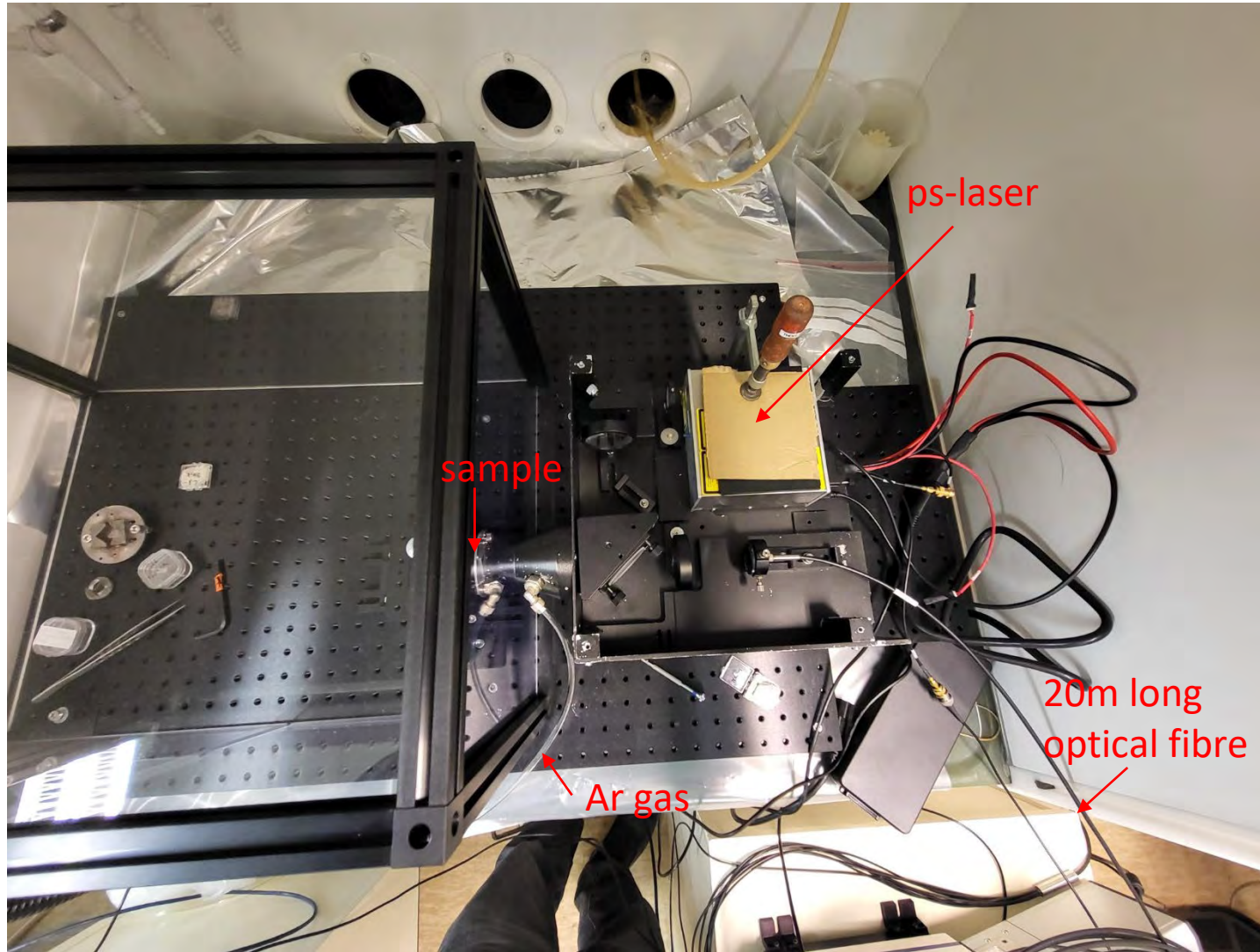
LIBS system at VTT

- LIBS system at VTT recently upgraded to allow investigations in conditions similar to JET
 - ✓ Samples placed in a **plexiglass enclosure inside a fume cupboard** for Be safety
 - ✓ Cone of the JET LIBS tool brought in contact with the sample surface through a hole in the enclosure
 - ✓ Sample mounted on a **2D translator system** allowing accurate positioning of the laser spot in horizontal and vertical directions
 - ✓ Measurements in atmospheric pressure with an **Ar flux fed into the cone**





LIBS system at VTT, new setup





Test measurements at VTT and JET

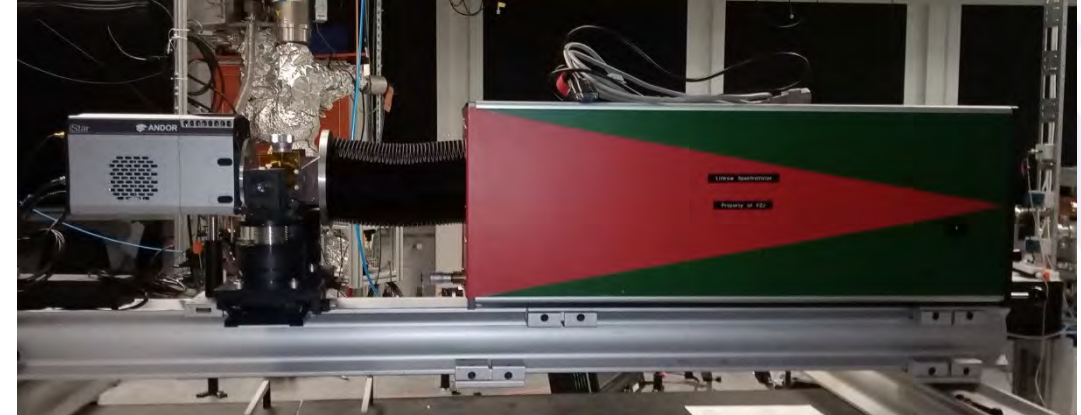
Aryelle 200

-UV-VIS-IR (250-750 nm) spectrometer

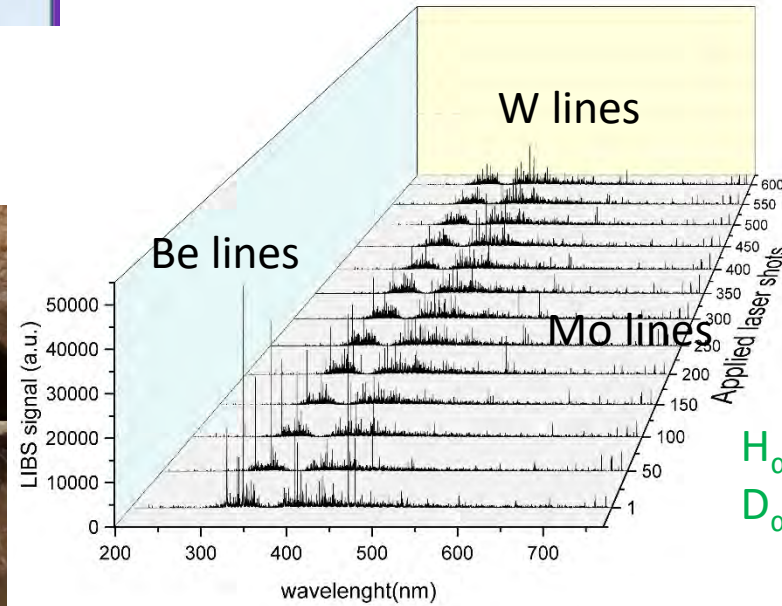
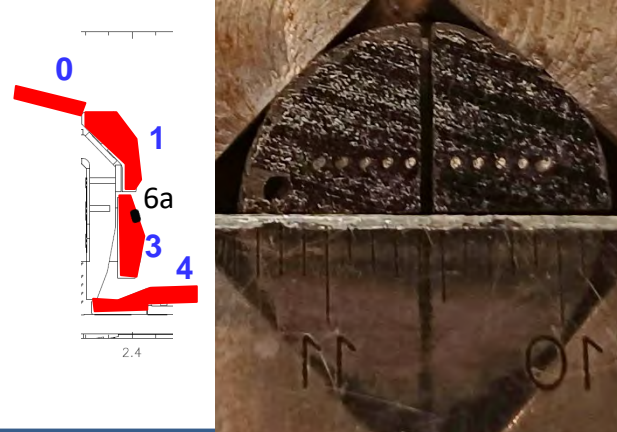


Littrow spectrometer

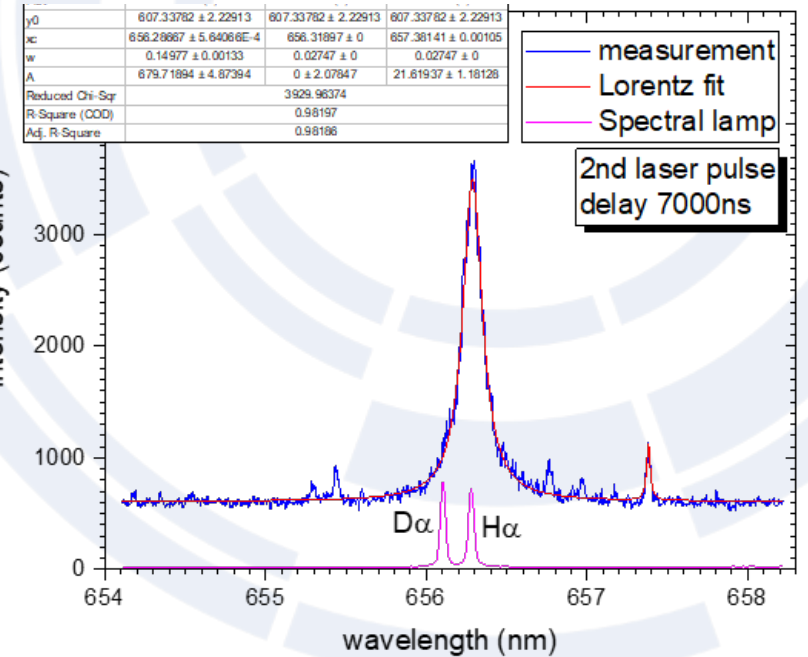
-High resolution (0.03 nm @ 500 nm) spectrometer



JET sample 2IWG3A_6a

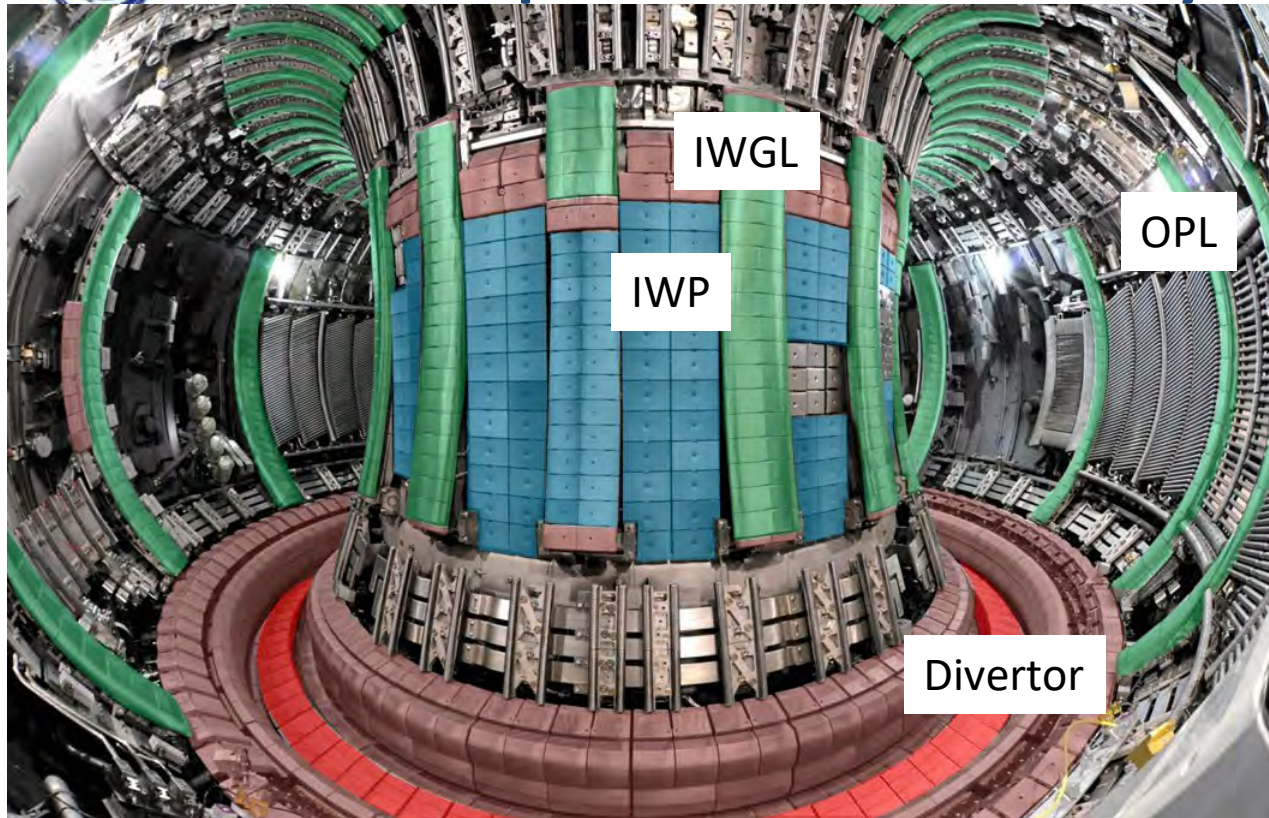


H_{α} - D_{α} : 0.18 nm
 D_{α} - T_{α} : 0.06 nm





Wall components for LIBS analyses selected

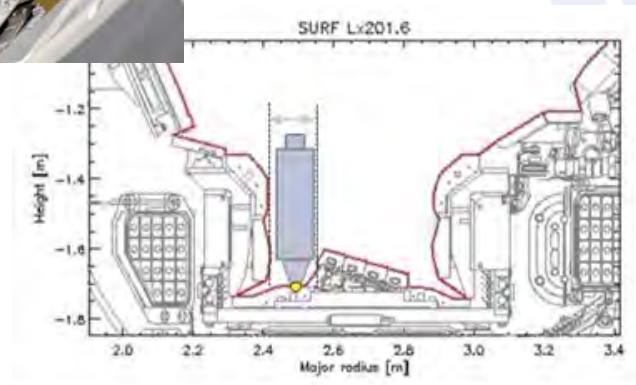


JET has several different wall materials – aim to analyse a representative set of components from each region

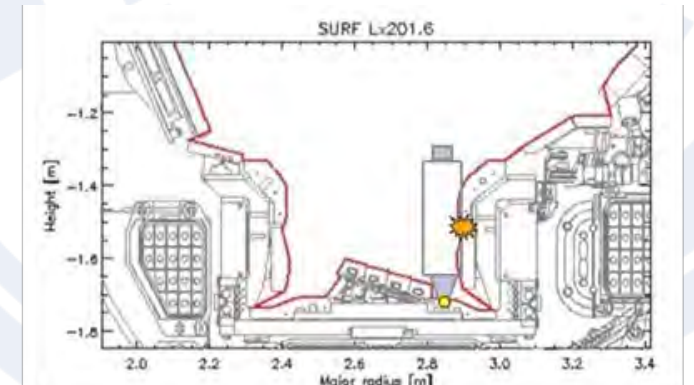
- Almost 50 individual wall and divertor tiles identified for LIBS measurements, corresponding to ~960 LIBS locations
- Not all interesting regions can be measured – restrictions set by dimensions of LIBS enclosure and JET geometry + limited time available
- LIBS measurement campaign ~2 weeks in August 2024 (16h/day in two shifts)
- LIBS experiment coordinated by VTT and UKAEA RACE team

Bulk Be
 Be coated inconel

W - coated CFC
 Bulk W



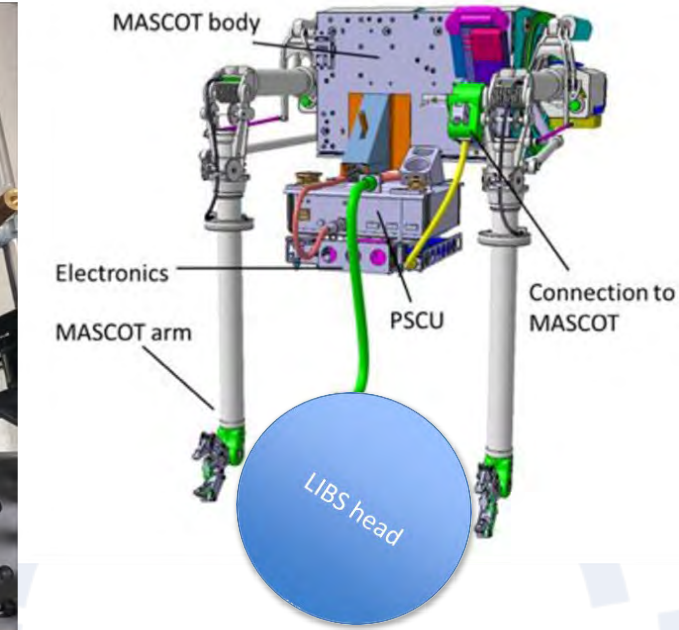
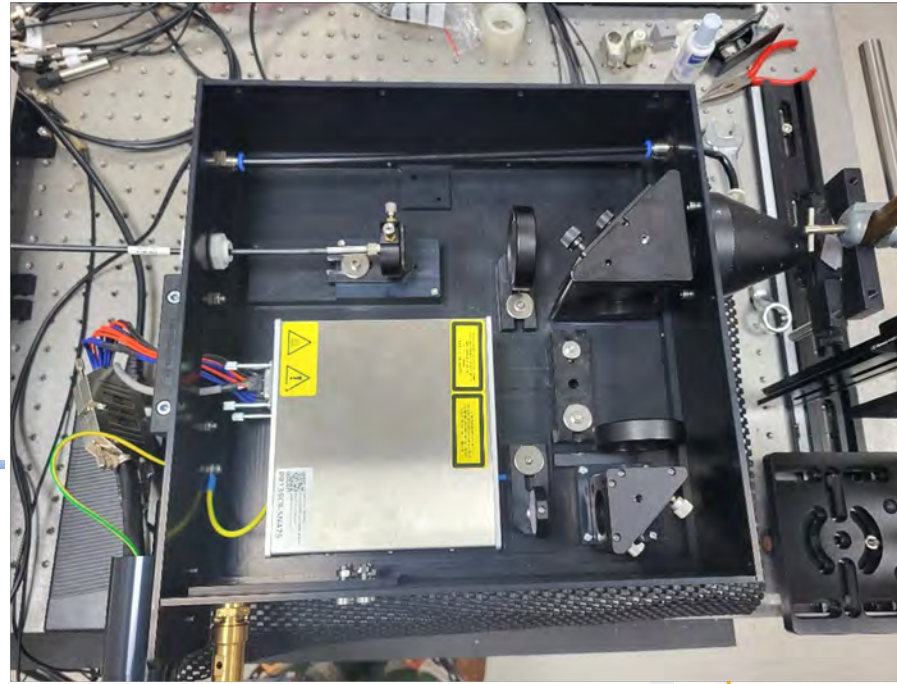
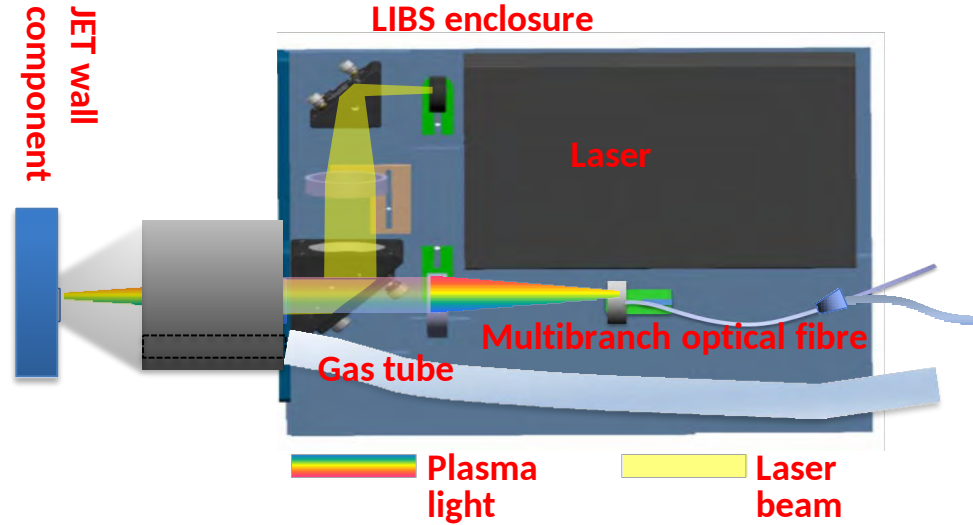
Accessible



Not accessible due to tool dimensions

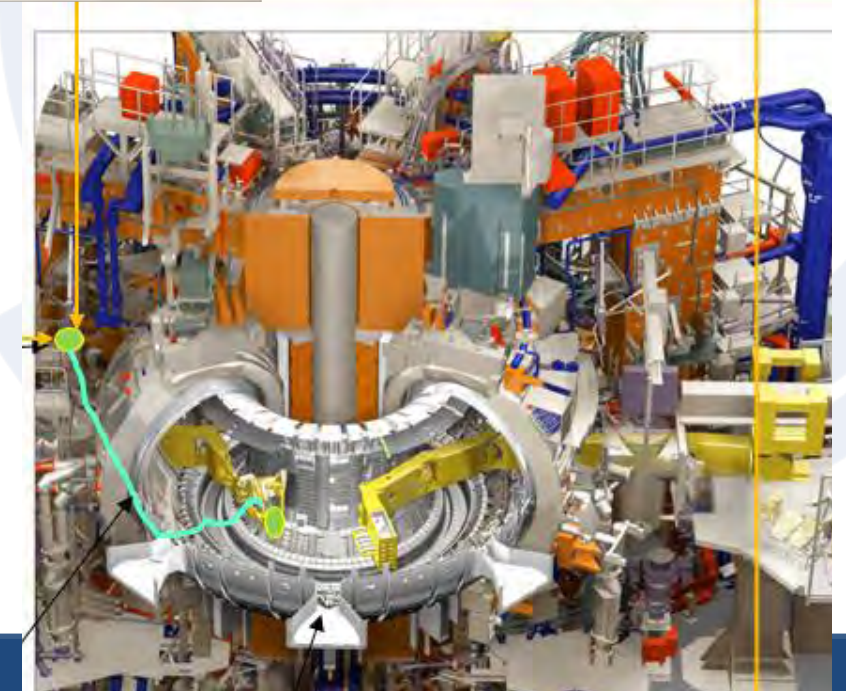


LIBS system at JET



Design made by S. Almaviva at ENEA, Italy

- LIBS enclosure will be mounted on the JET MASCOT arm
- RH boom moves the entire setup close to the wall, the outermost cone is in contact with the sample to be investigated
- Argon gas flux will be applied to increase signal intensities
- Optical fiber guides the emitted light into spectrometers, located outside of the vessel



LIBS

In-Vessel Training Facility

Mock-up Trials

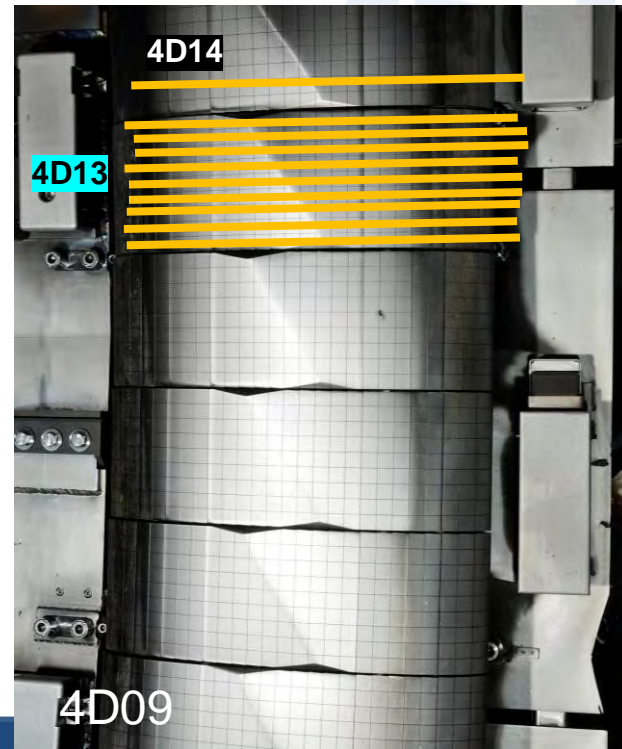
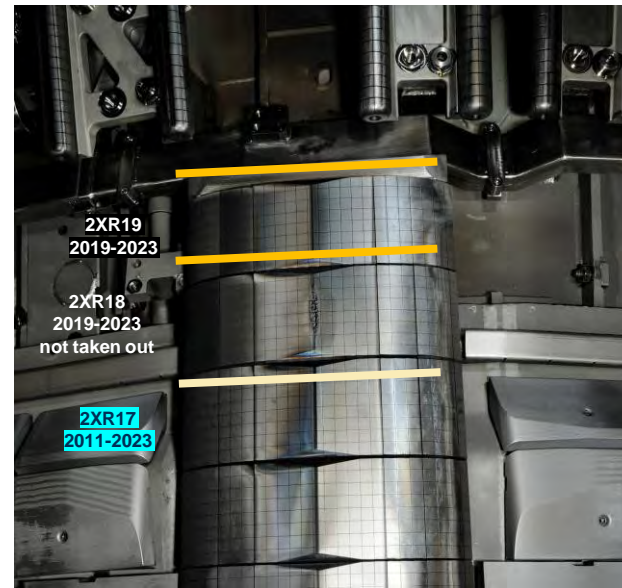
Umbilical = napanuora
(in Finnish)



LIBS locations on limiters

IWGL tile ID	LIBS Detail	Number of Spots
2XR19 W Top Tile	R1 (All columns)	25
2XR19	R2 (All columns)	25
2XR17	R7 (All columns)	25
2XR9	High resolution	200
2XR8	R7 (All columns)	25
2XR4	R2 (All columns)	25
2XR3	R7 (All columns)	25
3X14	C3, RW	31
8Z10	R5 LM2-C3; R5 LW1-C2	2
8Z14	C3	22
7X7	R5 LW1-C3	4
TOTAL		409

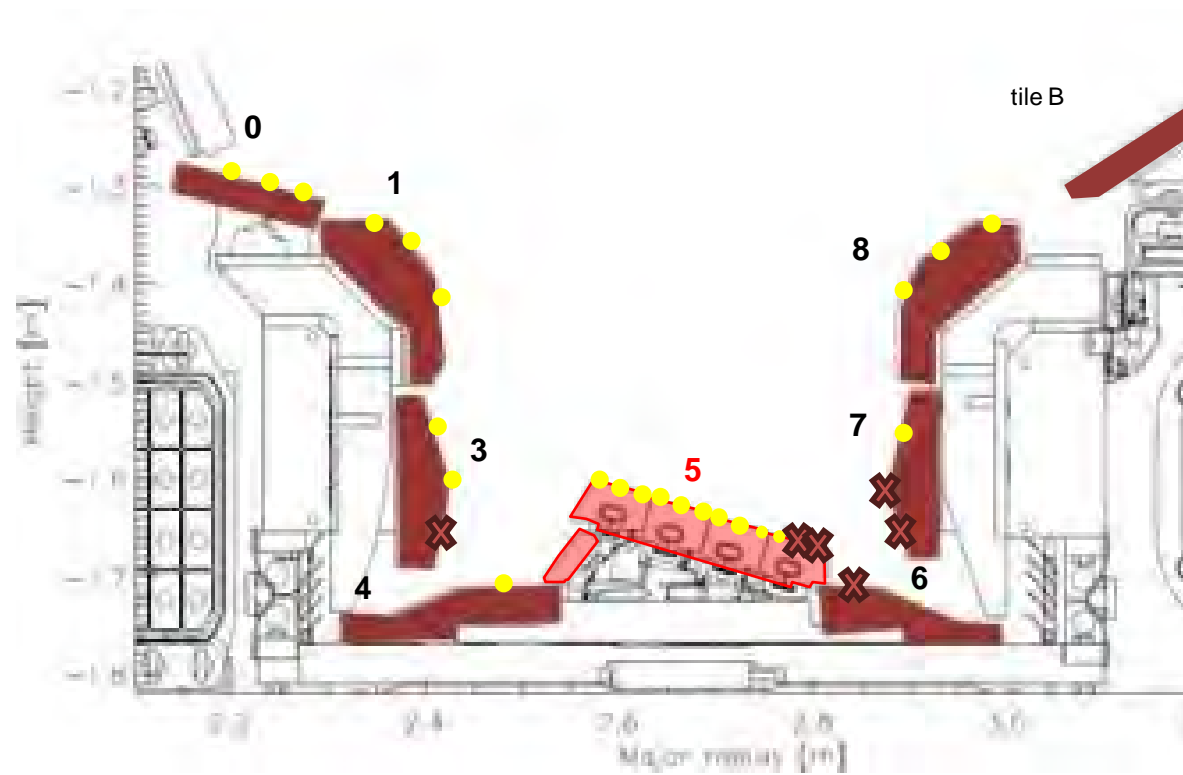
OPL tile ID	LIBS Detail	Number of Spots
4D23	R2 (All columns)	26
4D22	R8 (All columns)	26
4D14	R2 (All columns)	26
4D13	High Resolution	234
4D4	R2 (All columns)	26
4D3	R8 (All columns)	26
TOTAL		364



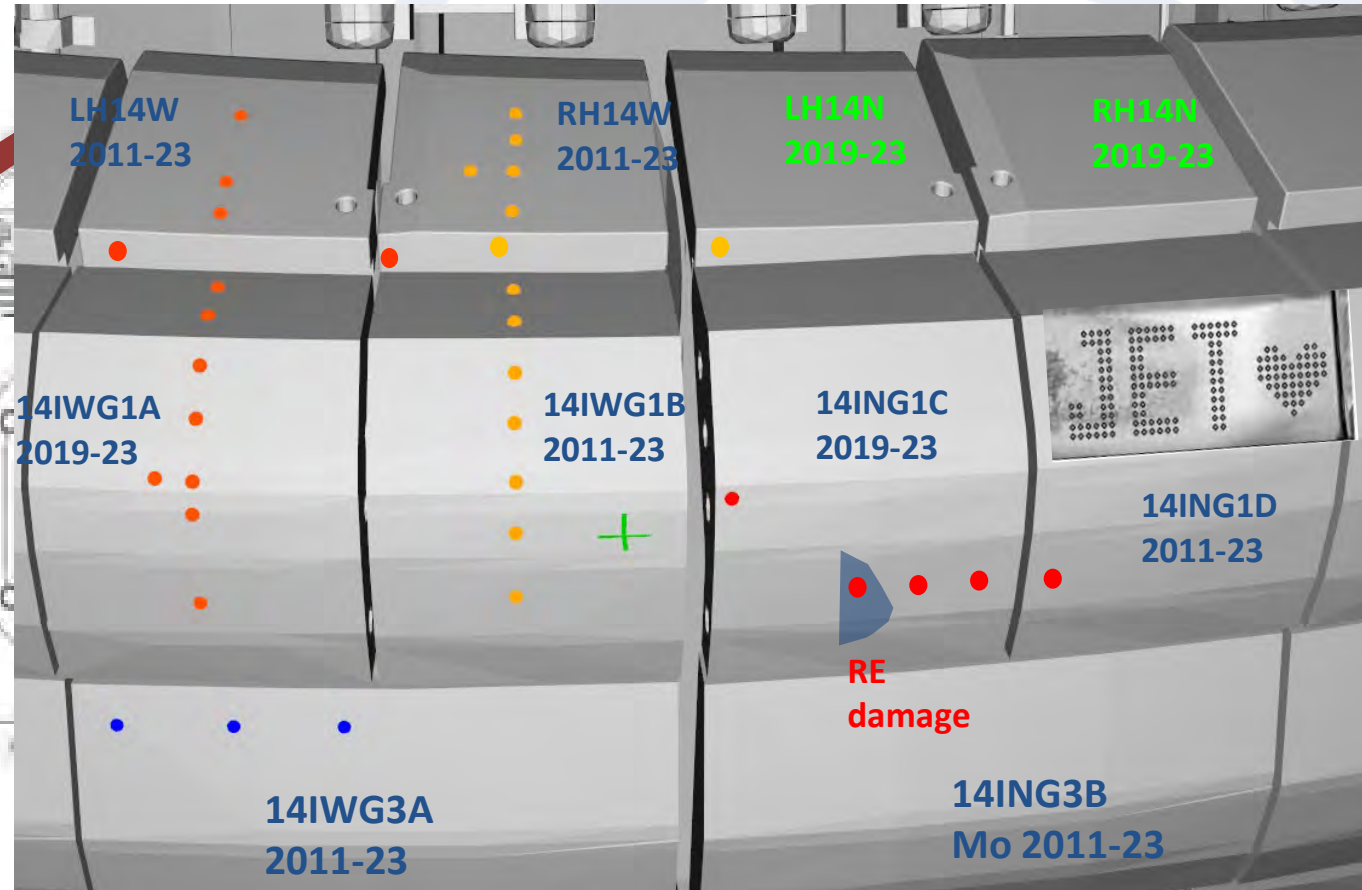


LIBS locations at divertor (module 14)

Poloidal cross section of divertor
LIBS locations indicated with yellow circles



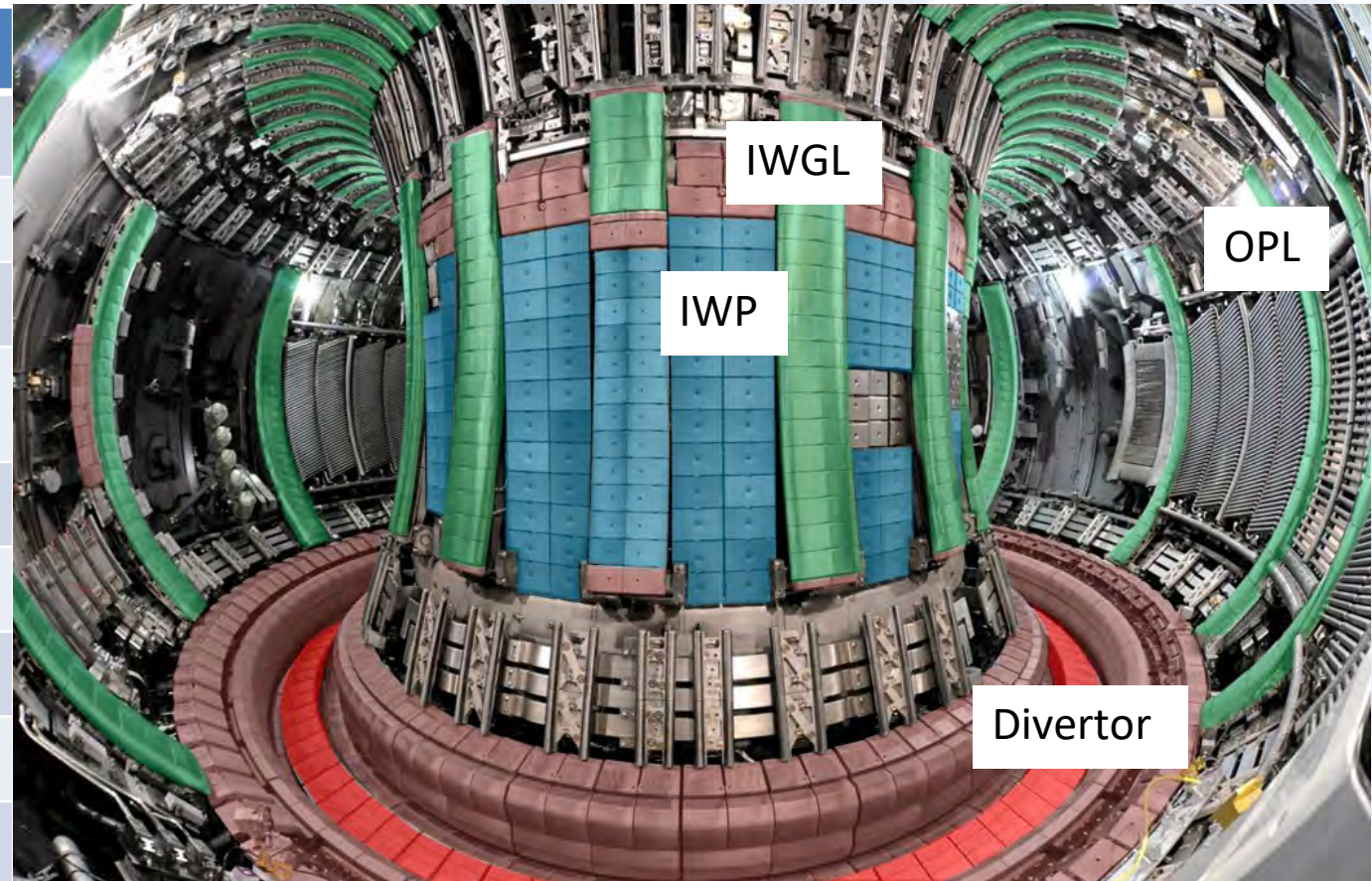
Inner divertor module 14 with
LIBS locations





Summary of LIBS locations at JET

Location ID	Number of spots
Inner wall guard limiters	409
Outer poloidal limiters	364
Inner wall protection	13
Inner +base divertor carriers	52
Tiles 0 (HFGC)	21
Tiles 5 (LBSRP)	72
Outer divertor carriers	30
Vessel wall	6
TOTAL	967





Conclusions

- **LIBS system designed and commissioned** for investigating composition and tritium content of co-deposited layers and plasma facing surfaces at JET
 - ✓ Utilizes **MASCOT manipulation RH system** to access different regions on the JET vessel wall
 - ✓ Consists of **a sub-ns laser, necessary optics, photomultipliers and two spectrometers**
- **Commissioning and testing of the LIBS system** completed both at VTT and at JET
 - ✓ Real JET samples (from divertor and limiters) analyzed at VTT and “clean” samples at JET
 - ✓ Data analysis of VTT and JET results still on-going
- **Final LIBS experiment will be made in August 2024**
- **~960 locations** will be analysed during the measurement campaign (~2 weeks, 16h/day)
- **Potential issues during the LIBS experiment**
 - ✓ Main concern **damage on the 20m long optical fibre** (spare fibre will be available)
 - ✓ **Is there enough tritium - or even deuterium** - available for quantitative analyses?
 - ✓ **Actual number of locations** that can be covered during the measurement campaign?