EUROfusion

WP PWIE 2022 Review Meeting SP X2

Salvatore Almaviva, ENEA, Frascati Research Center, via Enrico Fermi 45, 00044 (Italy)

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.

Deliverables

1. **Comparison SP vs. DP LIBS, or alternative LIBS signal enhancement methods: absolute fuel content in W samples and composition**

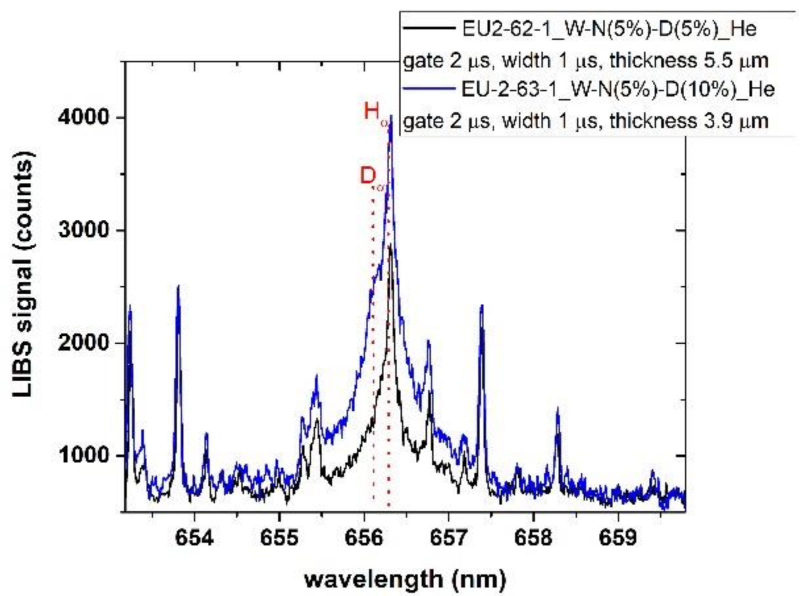
2. **(CF)-LIBS (ps/ns or SP/DP) on samples from different toroidal devices: absolute content and composition (in depth)**

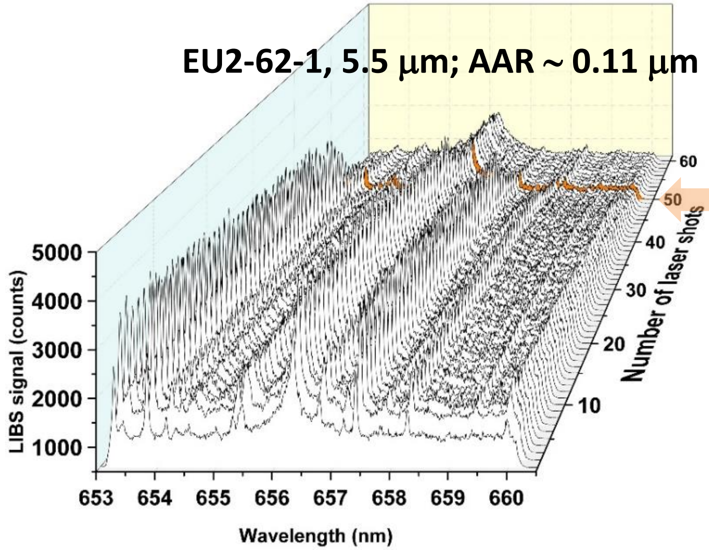
3. **(CF)-LIBS results He loaded samples and surface modifications**

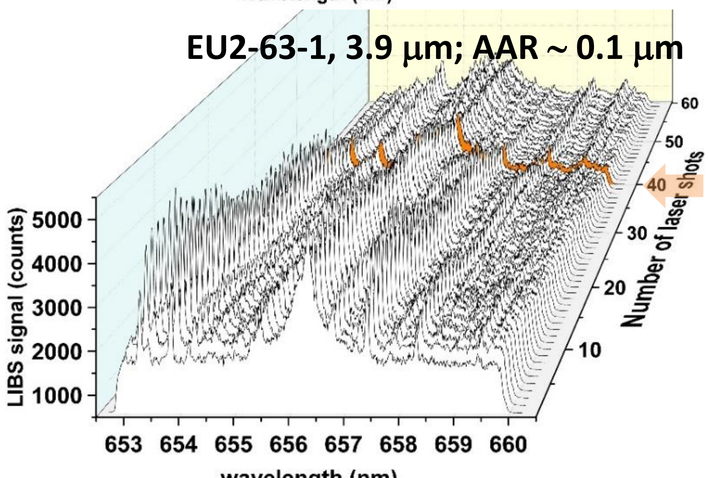
Deliverable 1

➢ **Comparison SP vs. DP LIBS, or alternative LIBS signal enhancement methods: absolute fuel content in W samples and composition: EU2-62-1_W-N(5%)+D(5%) - EU2-63-1_W-N(5%)+D(10%)**

Sample ID	Coating thickness	Type of coating
EU2-62-1	~ 5.5 μm	W-N(5%)+D(5%) on Mo substrate
EU2-63-1	~ 3.9 μm	W-N(5%)+D(10%) on Mo substrate







Deliverable 1

- **Comparison SP vs. DP LIBS, or alternative LIBS signal enhancement methods: absolute fuel content in W samples and composition:**

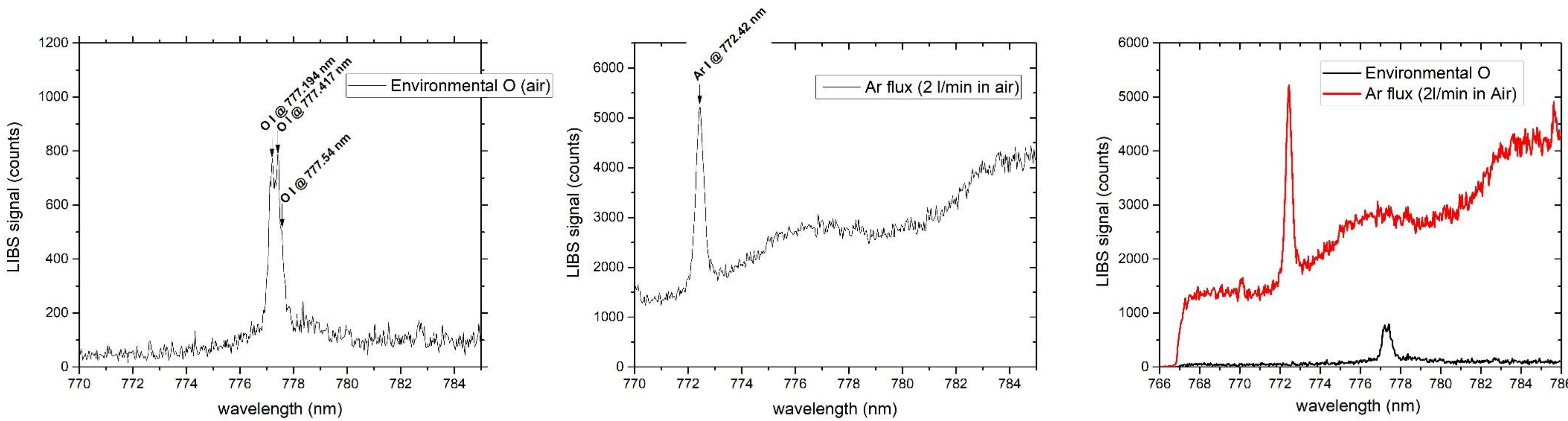
Samples: WFW928 3-4

Morfology: amorphous W with around 15% of oxygen

Thickness: > 1 μm

Research Unit	Specifications	Size (mm3)	Thickness (um)	Gas	Temperature (deg C)	Substrate	# of samples	To whom?	Comments	WP and SP	Produced by
ENEA-POLIMI	W+O	12 x 15 x 1	>1,0		Nominal	Mo	2	ENEA	LIBS	SP X.2	12/2021

The detection of oxygen by LIBS can be observed through the three O I emissions lines at 777.194 nm, 777.417 nm, 777.539 nm. The interfering environmental O signal can be reduced by applying Ar flux



Deliverable 1

- **Comparison SP vs. DP LIBS, or alternative LIBS signal enhancement methods: absolute fuel content in W samples and composition:**

Samples: WFW928 3-4

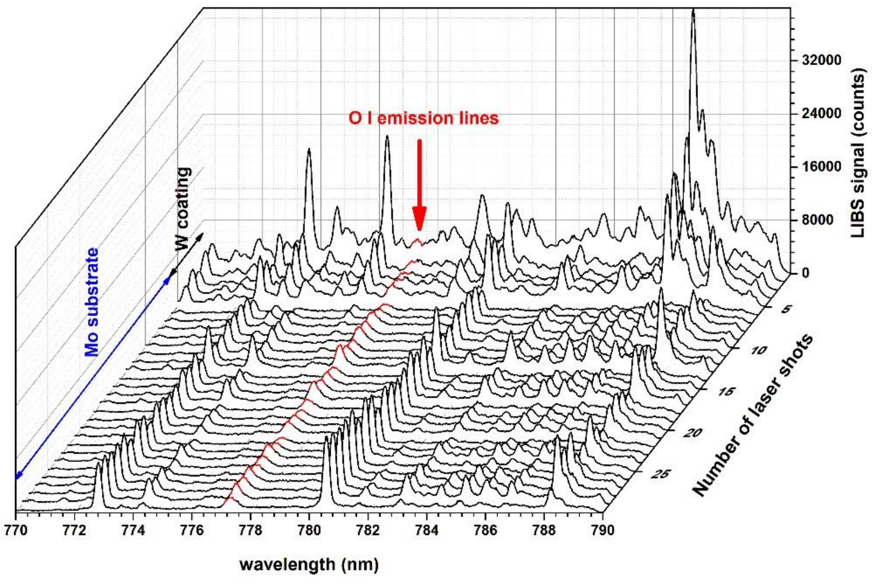
Morfology: amorphous W with around 15% of oxygen

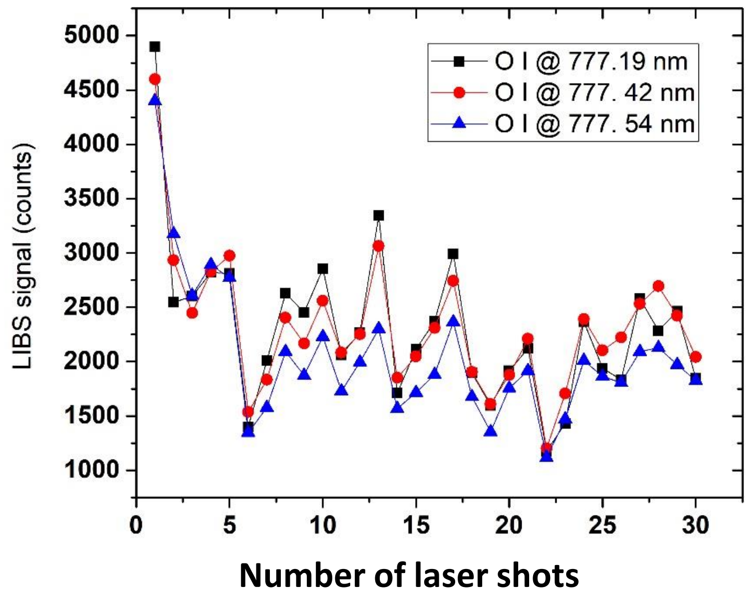
Thickness: > 1 μm → 4 – 5 shots to completely ablate the coating →AAR > 200 – 250 nm

The detection of oxygen by LIBS can be observed through the three strong O I emissions lines at 777.194 nm, 777.417 nm,

The residual O on the Mo substrate is comparable with the W O-enriched coating

The presence of many interfering W emission lines between 777 and 778 nm make it difficult to clearly resolve the three components

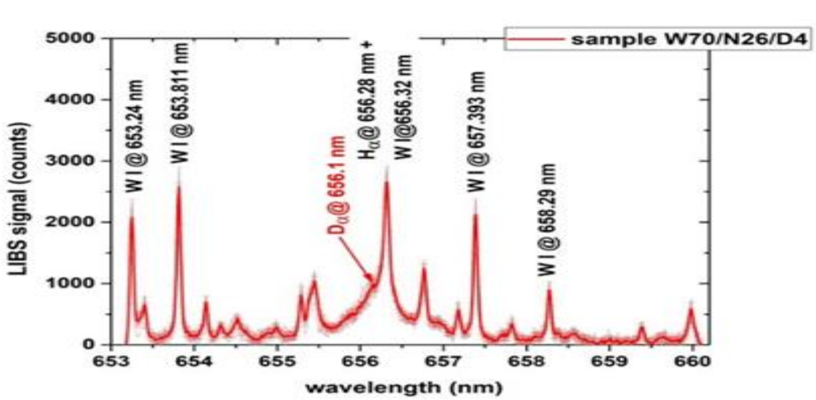


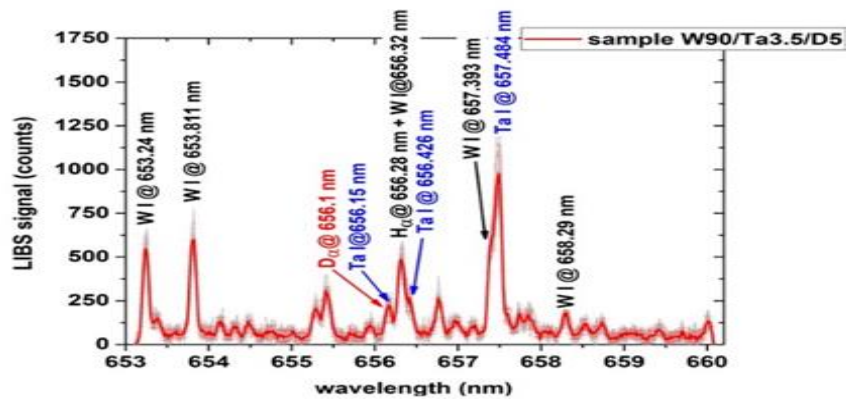


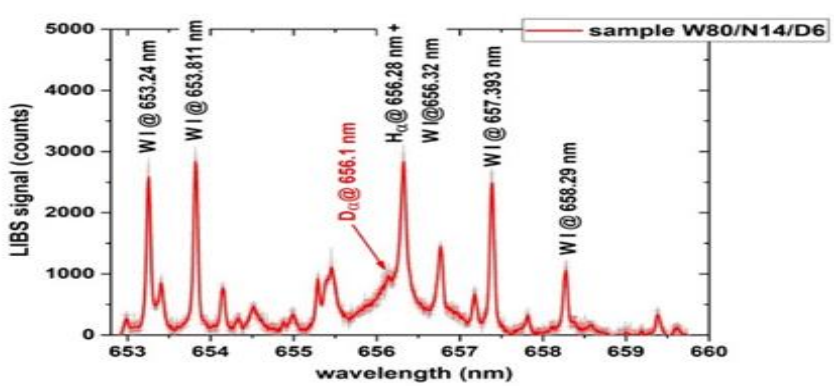
Deliverable 1

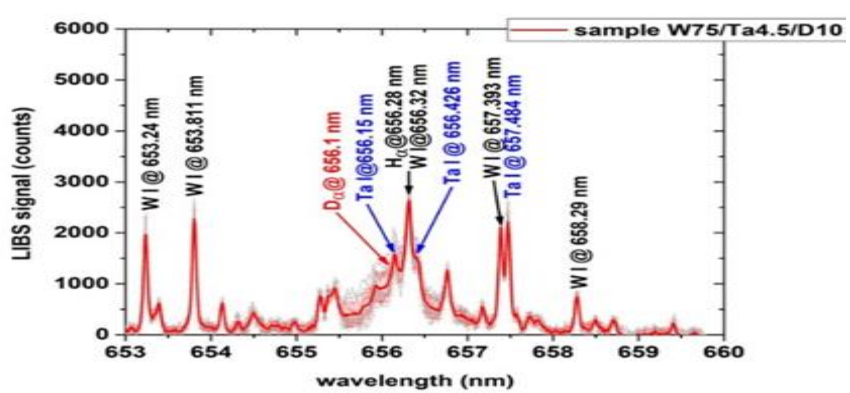
Sample	Element	Wavelength in air (nm)
All	W I	653.29
All	W I	653.81
All	D	656.1
W75/Ta4.5/D10	Ta I	656.16
W75/Ta4.5/D10	Ta I	656.42
All	W I	657.39
W75/Ta4.5/D10	Ta I	657.48

Emission lines detected in the Balmer-alpha region of the spectrum

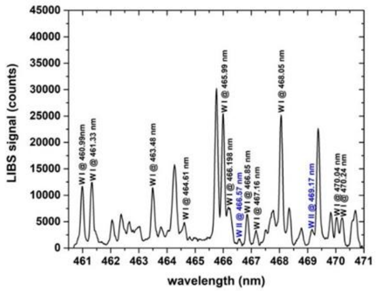


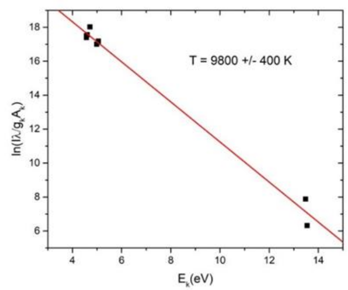






Deliverable 1





Electron temperature: 9800 ± 400 K

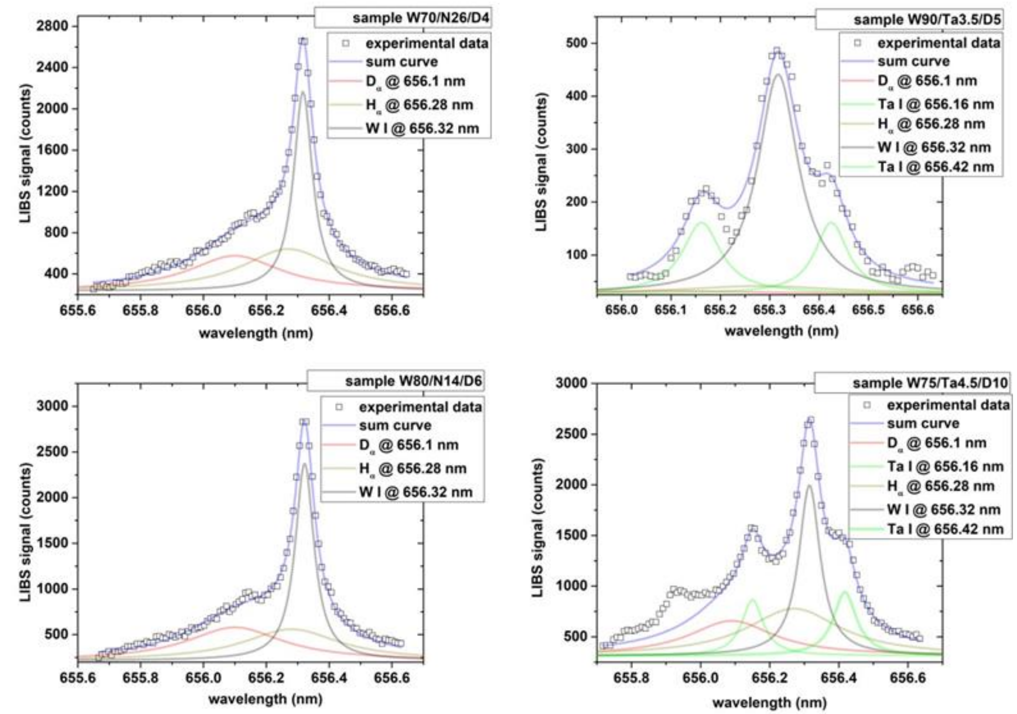
Sample	Electron density (cm^3)
W70/N26/D4	$5.16 \cdot 10^{16}$
W80/N14/D6	$5.27 \cdot 10^{16}$
W90/Ta3.5/D5	$5.27 \cdot 10^{16}$
W75/Ta4.5/D10	$4.52 \cdot 10^{16}$

Electron density: $4.52 – 5.27 \cdot 10^{16}$

Sample	Theor. [D] (%)	Exp. [D] (%)
W70/N26/D4	4	3.35 - 4.18
W80/N14/D6	6	8 - 8.38
W90/Ta3.5/D5	5.6	0.4 - 0.37
W75/Ta4.5/D10	13	10.26 - 10.6

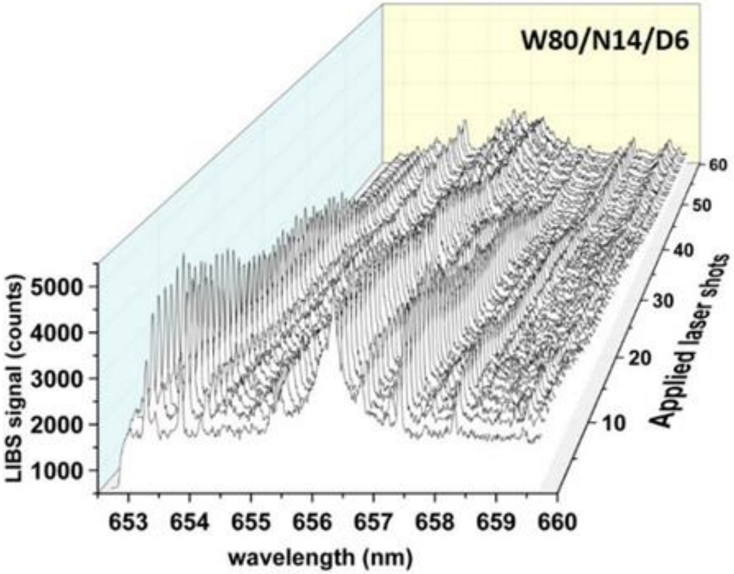
[D]: 0.4 – 10.6 %

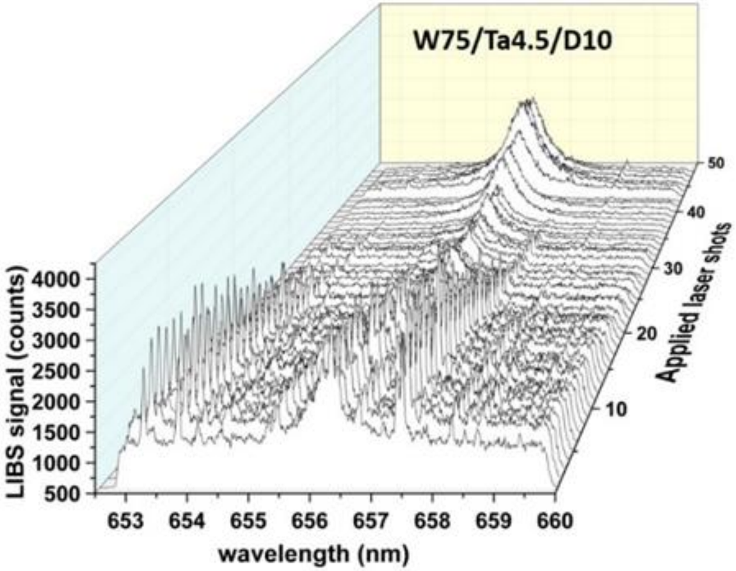
Fit of the experimental line-shapes in the D_α / H_α spectral region of the four samples. Each spectral component of W, Ta, D, H is shown in different colors in each legend, so as so their sum curve (light blue)



Deliverable 1

- **Comparison SP vs. DP LIBS, or alternative LIBS signal enhancement methods: absolute fuel content in W samples and composition The analysed samples in the framework of this deliverable were:**
- **EU2-58-2, Mo substrate / W(90%)-Ta (3.5%) +D(5%) coating thickness ~ 4.8 μm**
- **EU2-59-3, Mo substrate / W(75%)-Ta (4.5%) +D(10%) coating thickness ~ 3 μm**
- **EU-774-11, Mo substrate / W(70%)-N(26%) +D(4%) coating thickness ~ 1 μm**
- **EU-772-1, Mo substrate / W(80%)-N(14%) +D(6%) coating thickness ~ 4.5 μm**



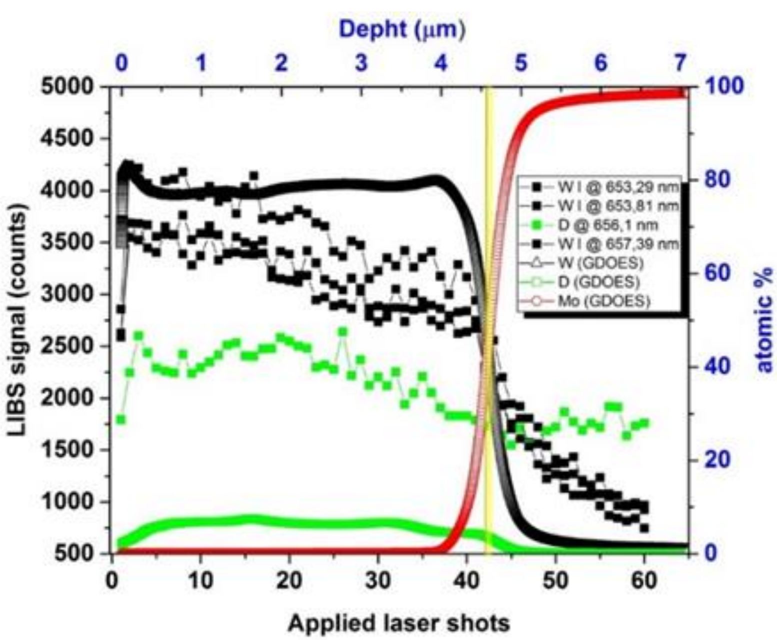


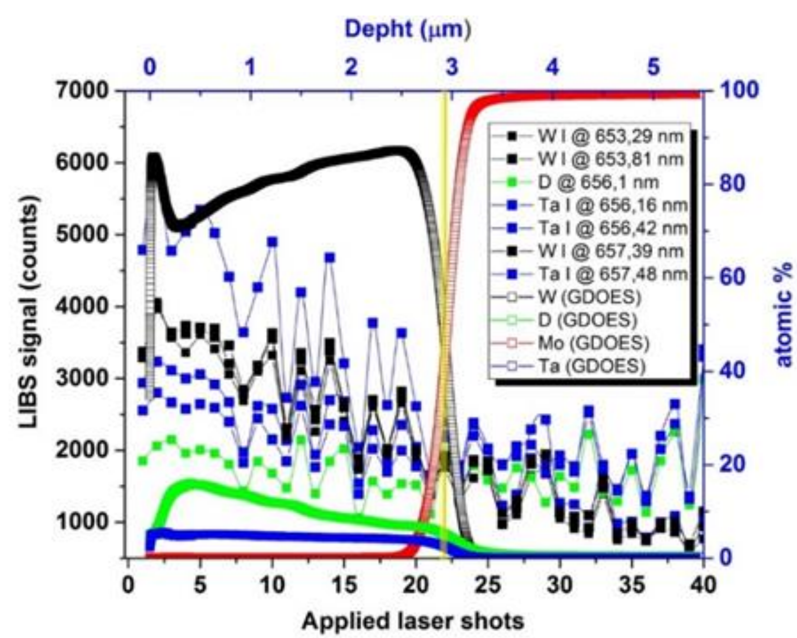
interpulse delay: 65 ns, Energy 58+58 mJ (116 mJ total)

Deliverable 1

- **Comparison SP vs. DP LIBS, or alternative LIBS signal enhancement methods: absolute fuel content in W samples and composition.**

  The Average Ablation rate was 0.11 – 0.12 μm/shot
- **EU2-58-2, Mo substrate / W(90%)-Ta (3.5%) +D(5%) coating thickness ~ 4.8 μm**
- **EU2-59-3, Mo substrate / W(75%)-Ta (4.5%) +D(10%) coating thickness ~ 3 μm**
- **EU-774-11, Mo substrate / W(70%)-N(26%) +D(4%) coating thickness ~ 1 μm**
- **EU-772-1, Mo substrate / W(80%)-N(14%) +D(6%) coating thickness ~ 4.5 μm**

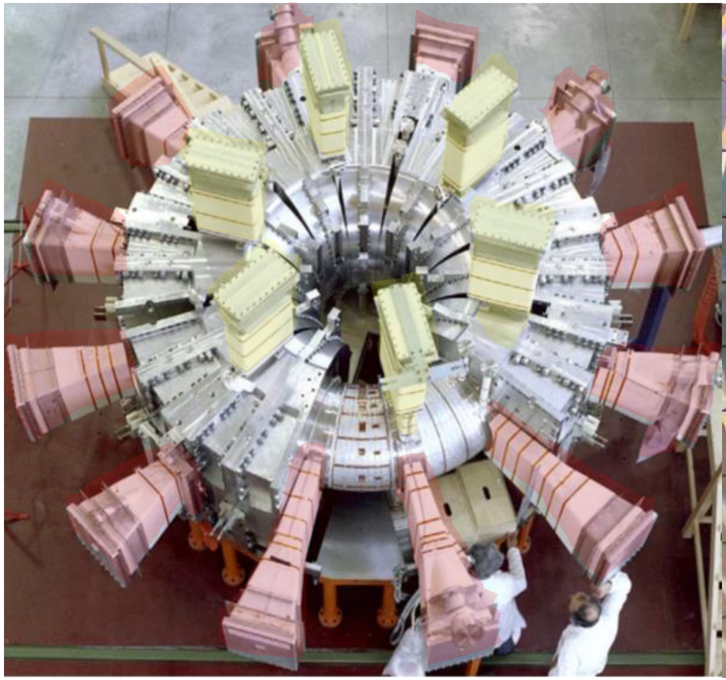


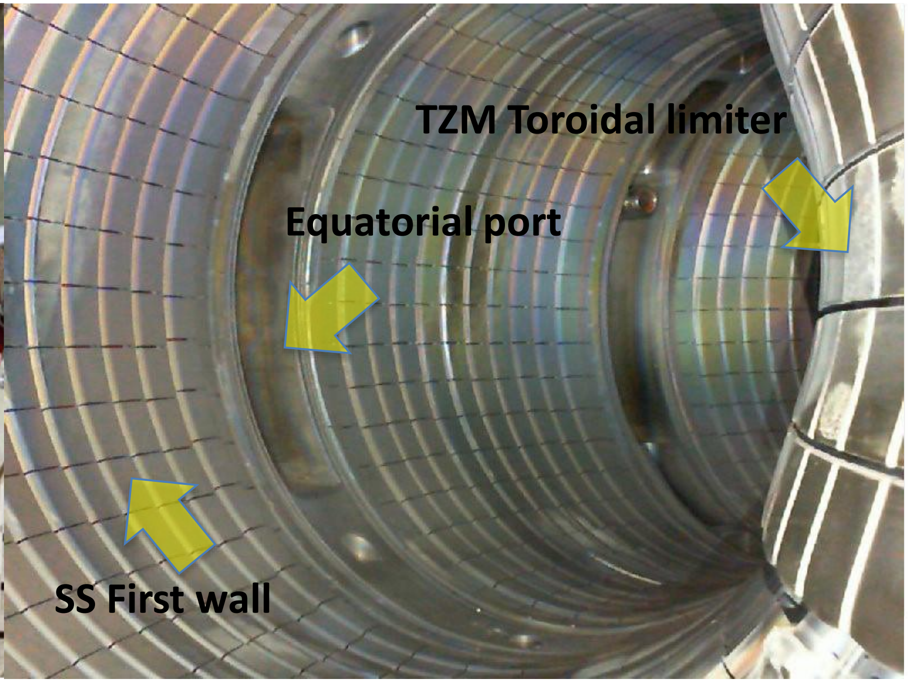


Deliverable 2

FTU was a compact, high-magnetic-field tokamak constructed along the line of the ALCATOR experiments at MIT and of the FT (Frascati Tokamak) experiment in Frascati.

It was designed with a **TZM toroidal limiter (Ti 0.40–0.55 wt%, Zr 0.06–0.12 wt%, Mo balance)** and ended its activity in 2019, to be replaced by the new DTT (Divertor Test Tokamak) device.

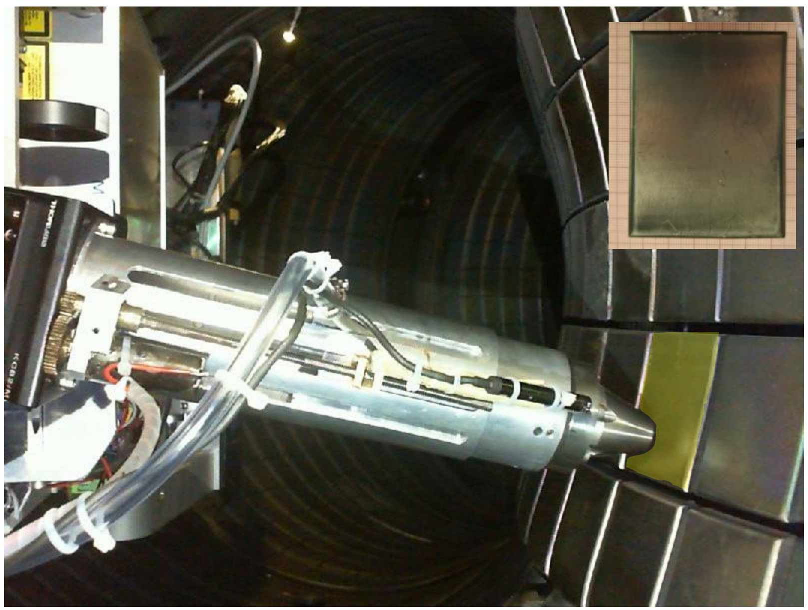


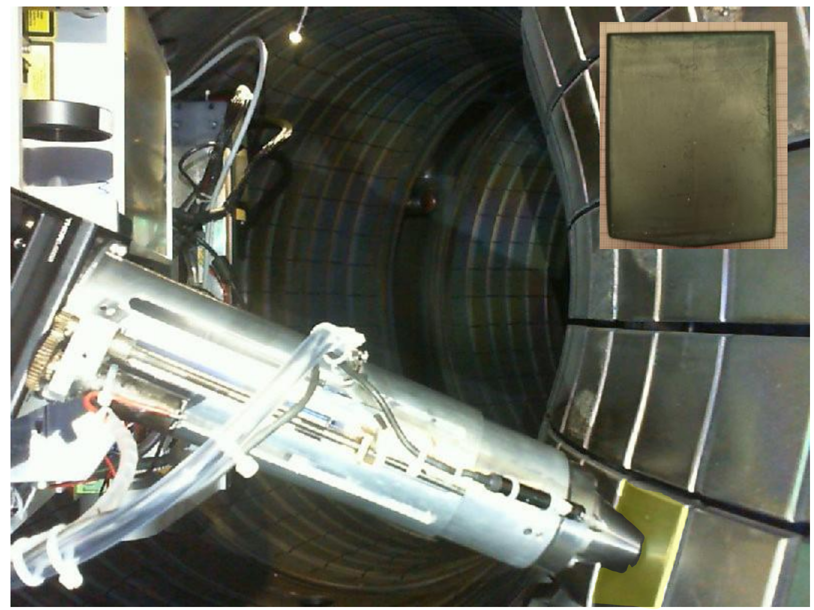


Deliverable 2

- **(CF)-LIBS (ps/ns or SP/DP) on samples from different toroidal devices: absolute content and composition (in depth)**

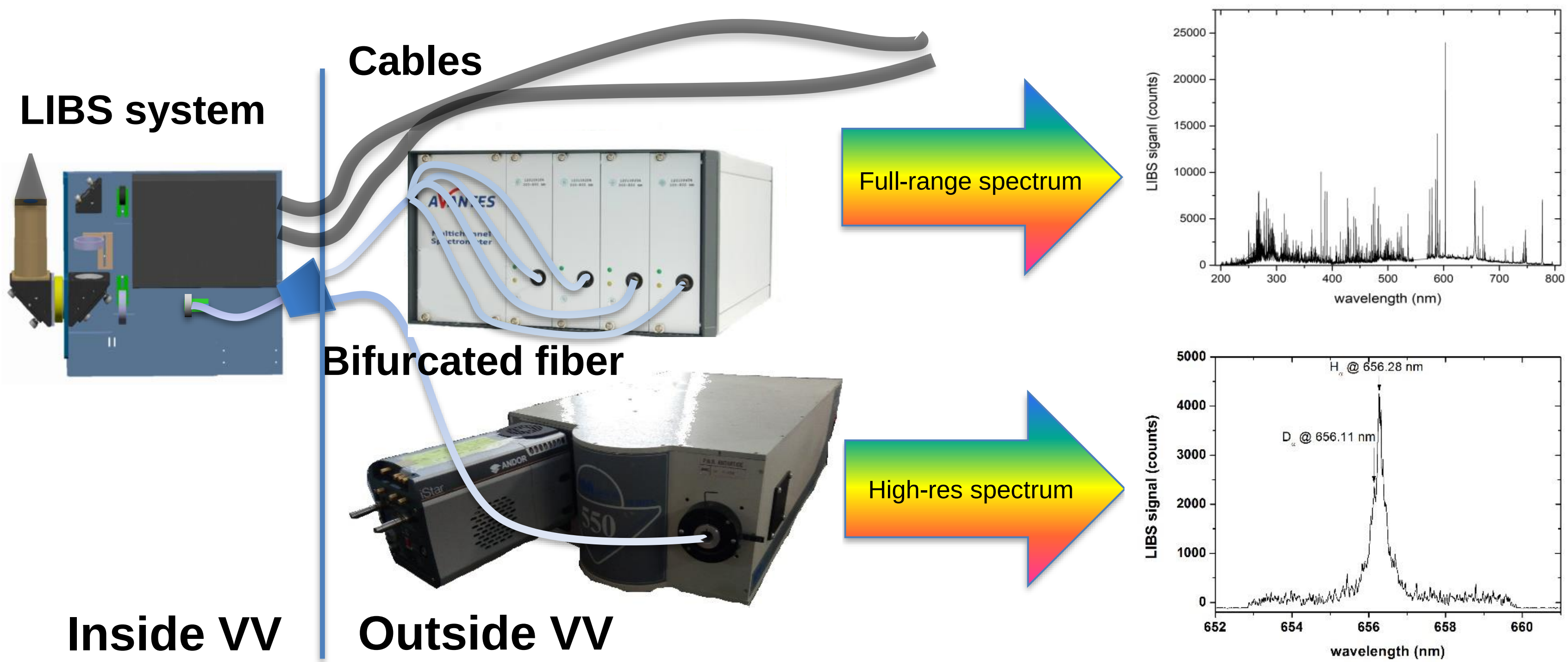
The work included the LIBS analysis of two FTU toroidal limiters tiles.





Deliverable 2

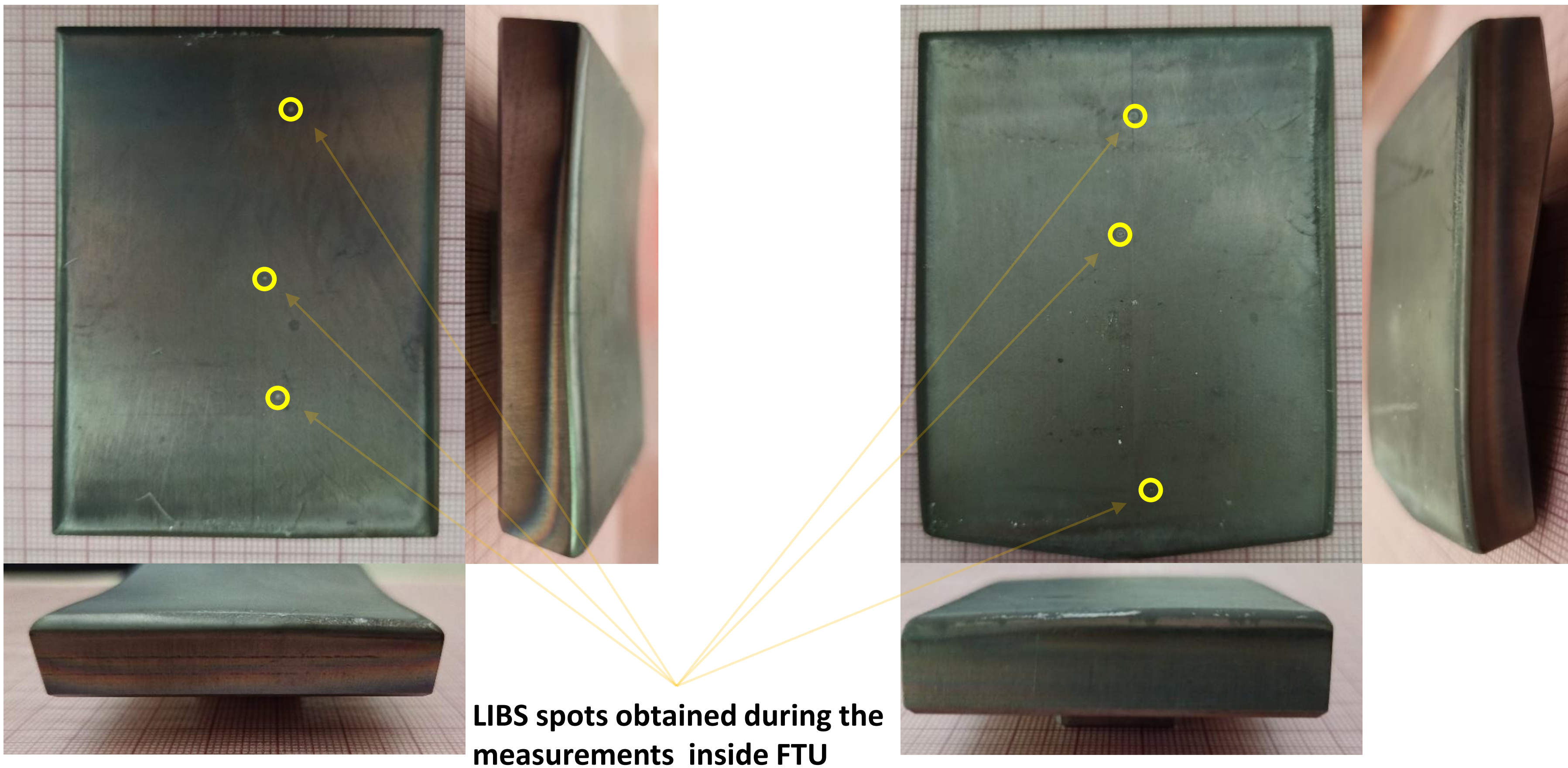
- **Full range spectra acquired <u>with an Avantes multichannel spectrometer system now available in ENEA</u>**



Deliverable 2

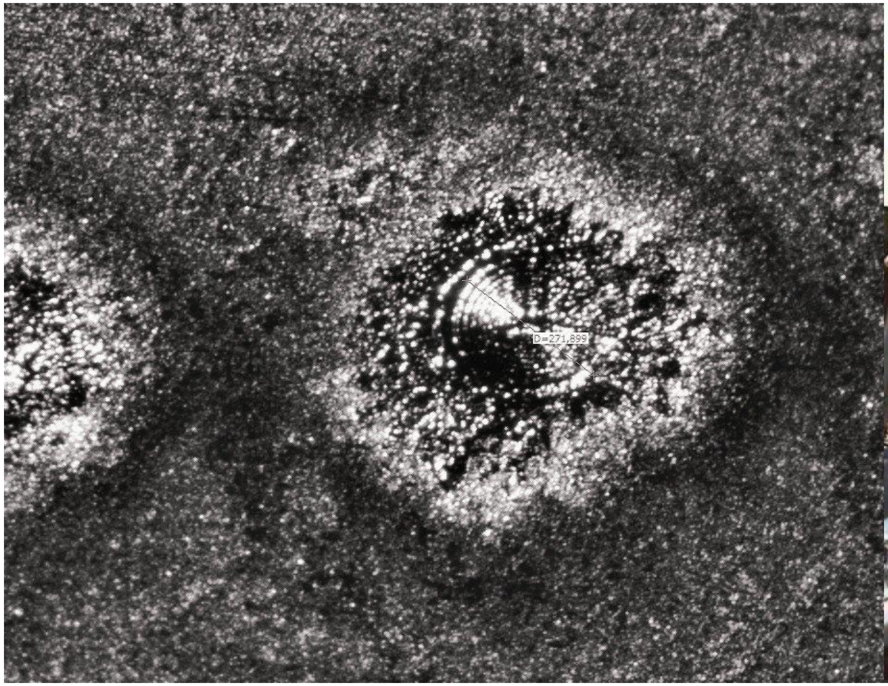
- **(CF)-LIBS (ps/ns or SP/DP) on samples from different toroidal devices: absolute content and composition (in depth)**

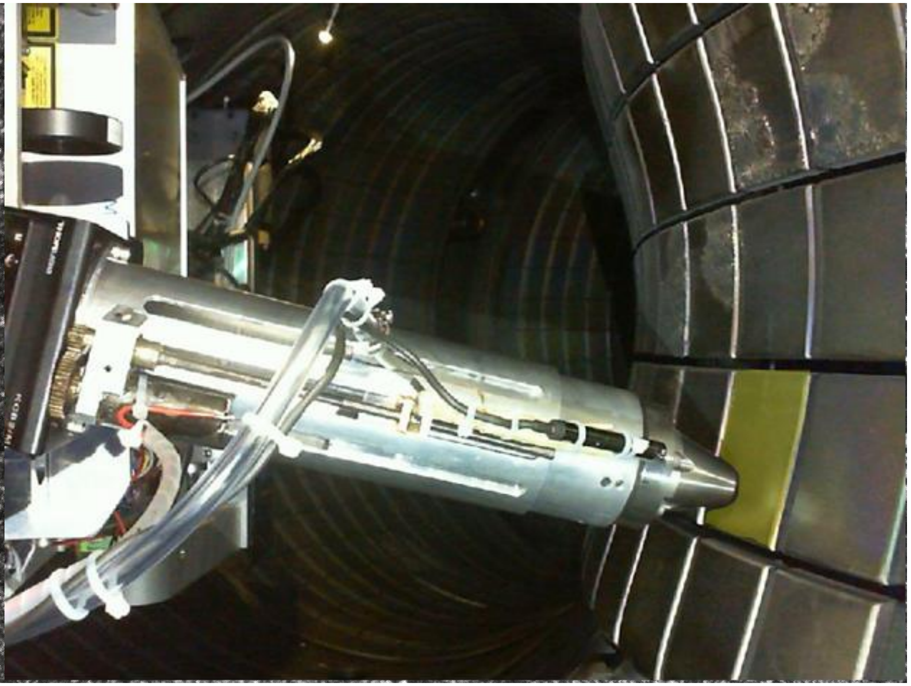
FTU toroidal limiters tiles now available for analysis: 60x80 mm tiles made of TZM (Titanium Zirconium Molybdenum alloy)



Deliverable 2

- (CF)-LIBS (ps/ns or SP/DP) on samples from different toroidal devices: absolute content and composition (in depth)
- The in-depth ns-DP-LIBS analysis was performed with DP-ns-LIBS in air or under He or Ar flux at atmospheric pressure.
- The energy released on the tiles varied between 50 – 100 mJ per pulse
- The laser spot diameter was about 270 μm (energy density 4.8 – 9.6 GJ/cm^2, fluence 48 GW/m^2)



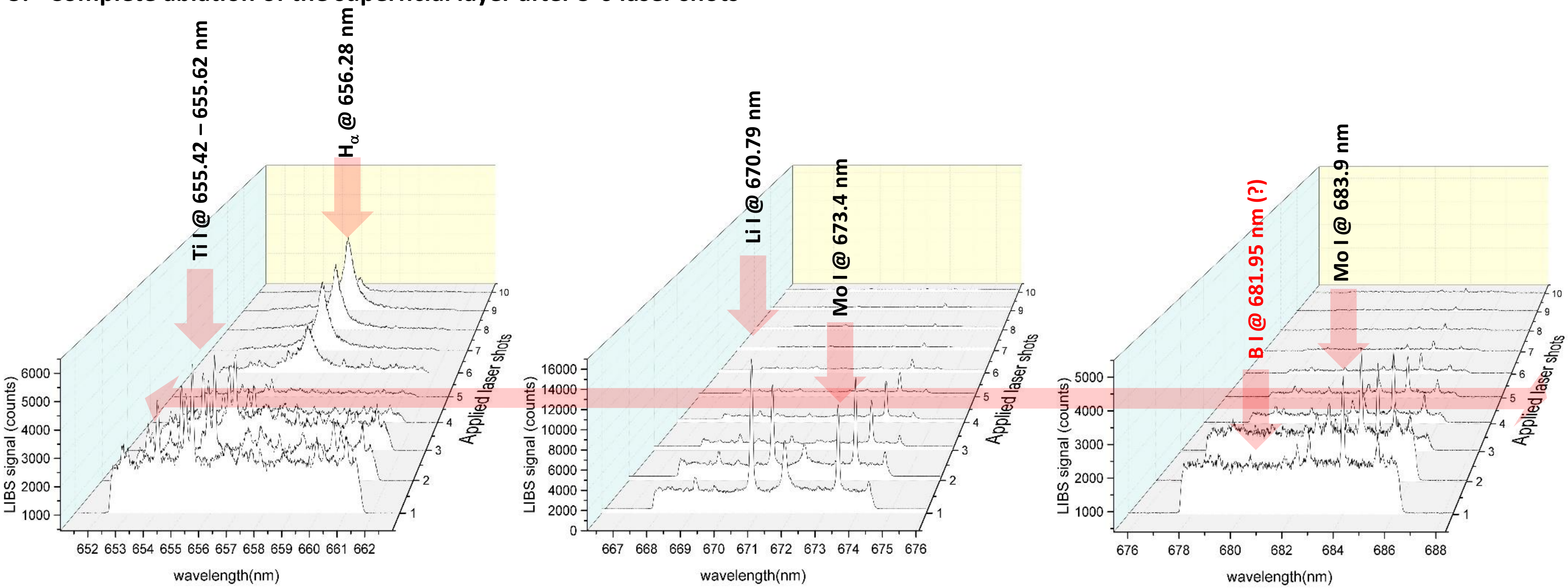


Deliverable 2

➢ **(CF)-LIBS (ps/ns or SP/DP) on samples from different toroidal devices: absolute content and composition (in depth)**

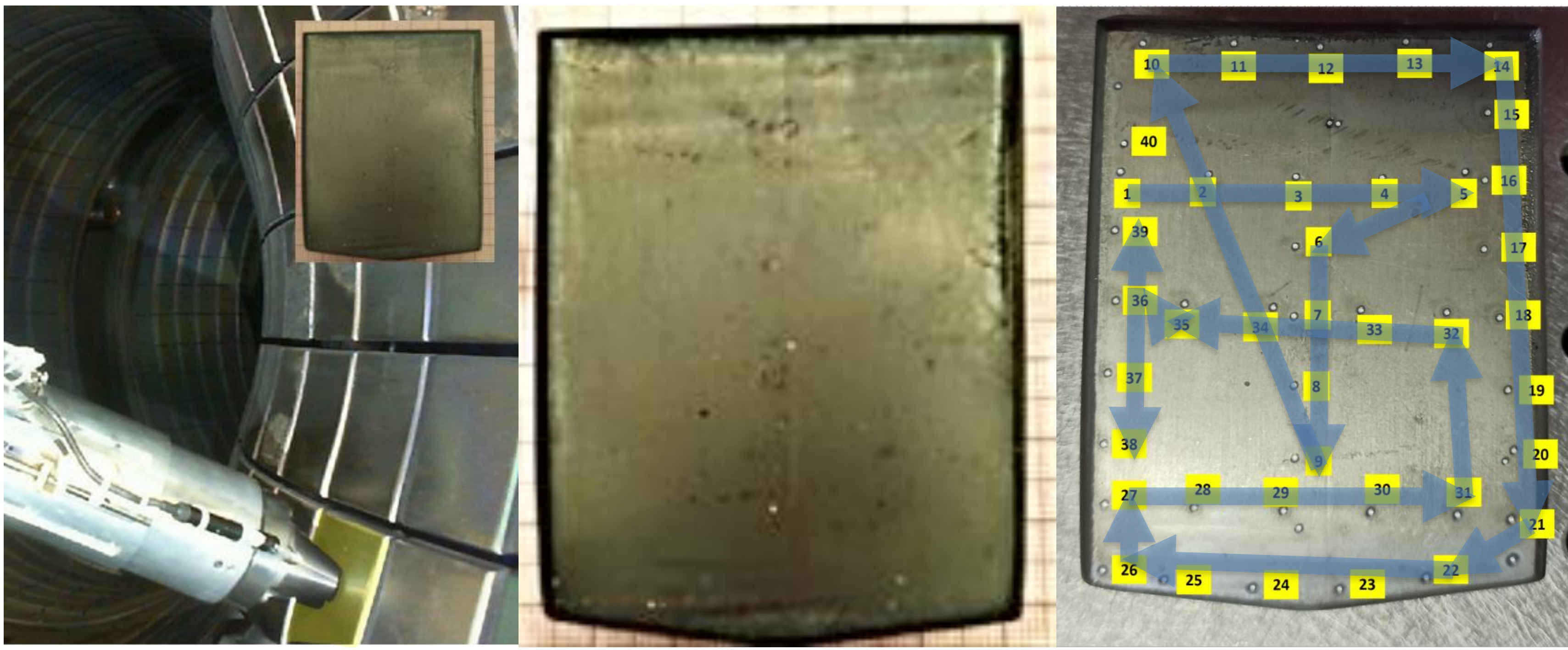
The in-depth ns-DP-LIBS analysis can be summarized as follows:

1. **Presence of Li in the superficial layers**
2. **Presence of Ti and Mo in the superficial layer, probably as material eroded from the tiles surfaces**
3. **Absence of D and H in the superficial layers (although the samples have been exposed in air) but presence of H in deeper layers, when the superficial layer of Li is ablated**
4. **Absence of B in the superficial layers, despite the boronization procedure performed after the experimental campaign.**
5. **Complete ablation of the superficial layer after 5-6 laser shots**



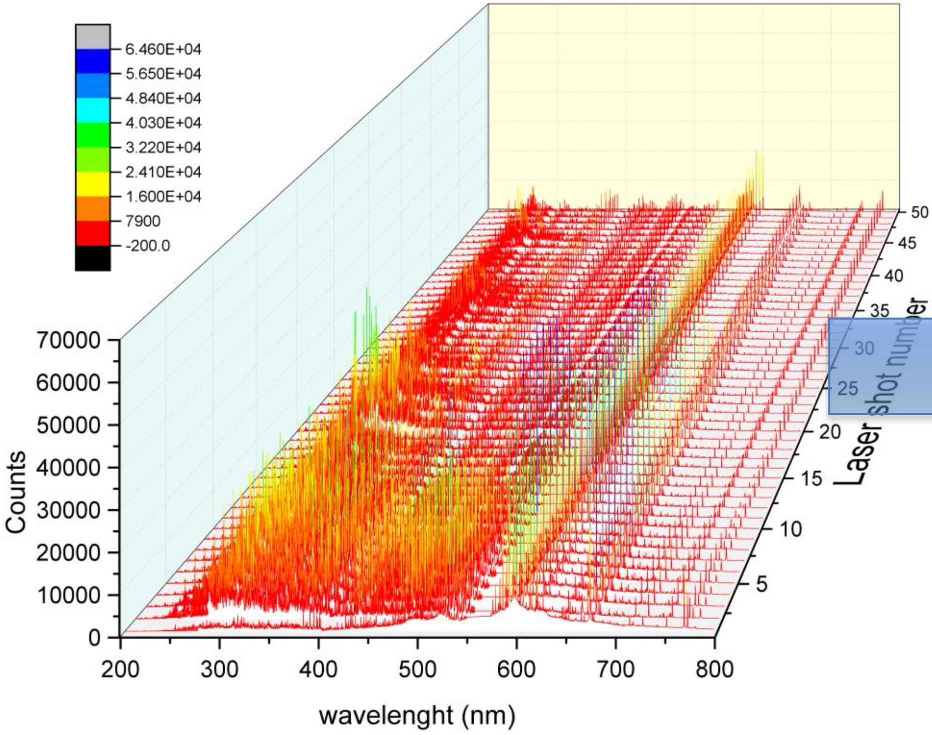
Deliverable 2

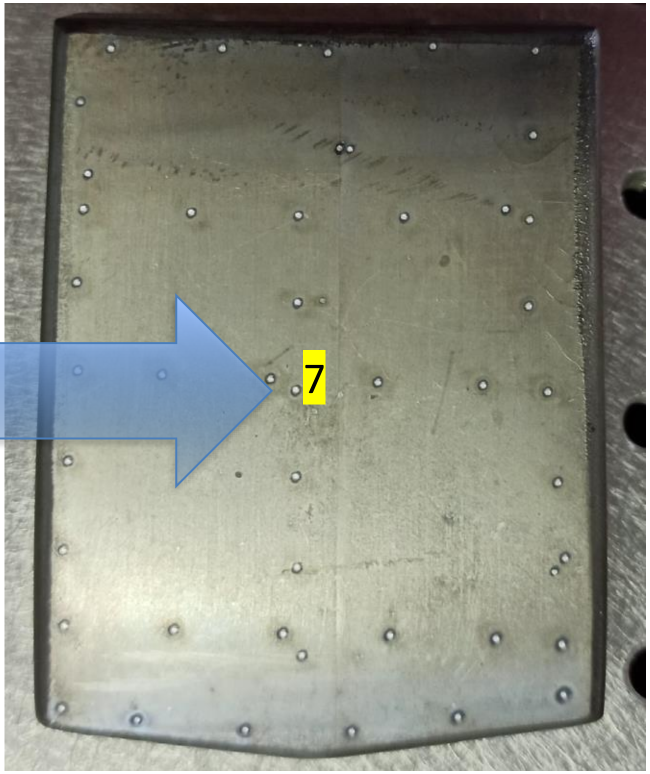
The full range LIBS analysis aimed to map the surface of the lower limiter tile and check for the superficial distribution of the detected elements.



Deliverable 2

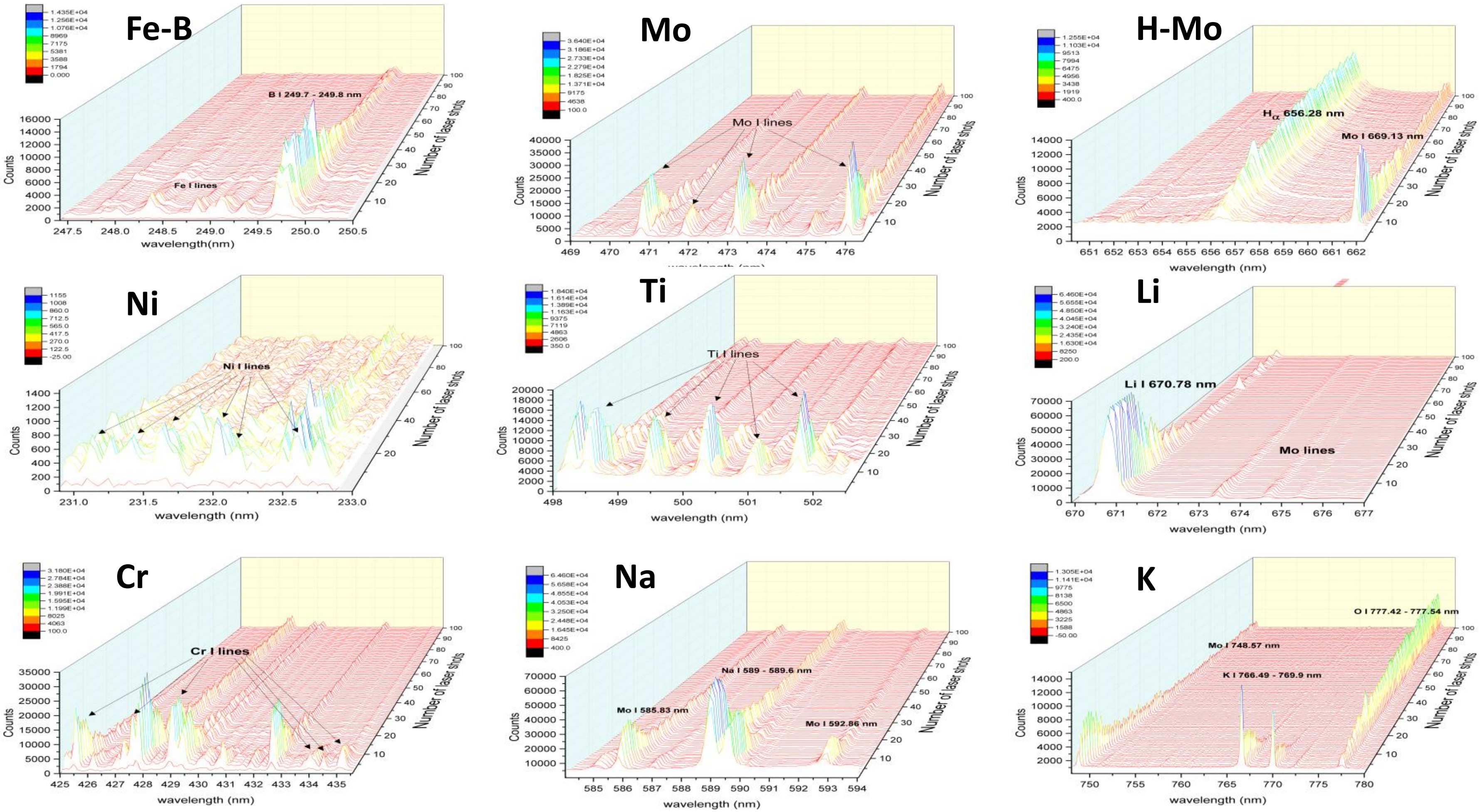
The full range LIBS analysis aimed to map the surface of the lower limiter tile and check for the superficial distribution of the detected elements (Mo, Ti, as constituent of the TZM tile, Fe, Ni, Cr as impurities from the FW constituents, H, Li, B as impurities from previous experimental campaigns, H, N, O from atmosphere, others from post-mortem manipulation).





Example: Depht profiling of the central point (#7)

Deliverable 2



Deliverable 3

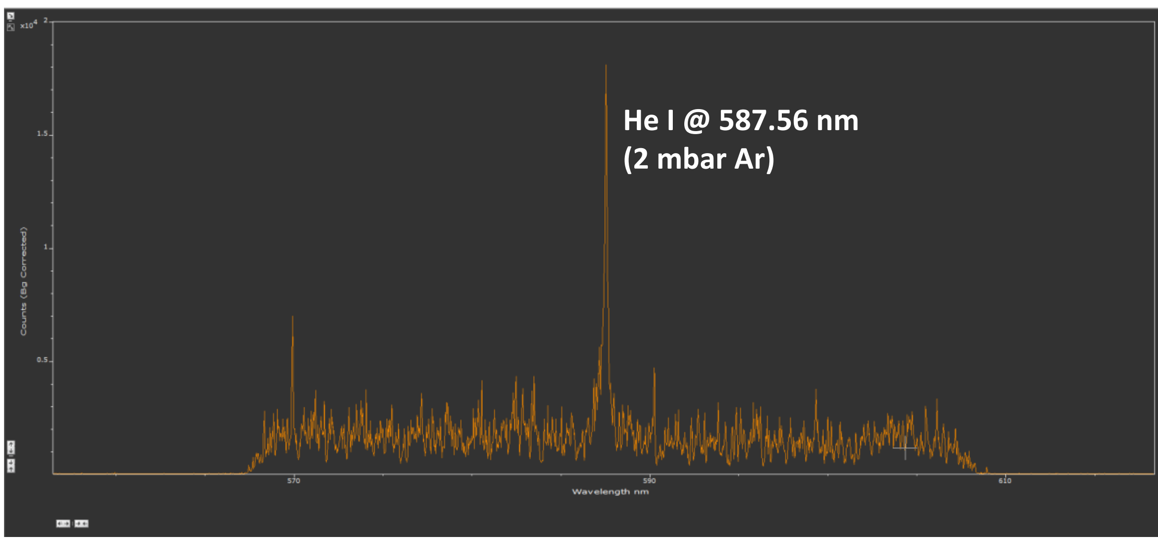
➢ Some results on He loaded samples

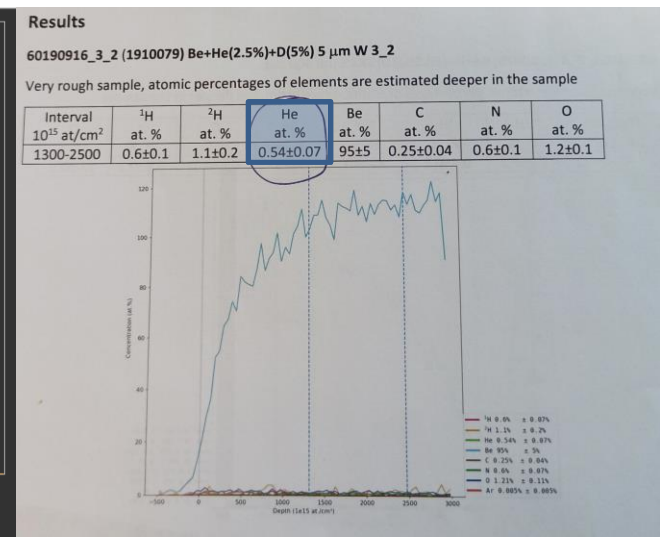
The activity included the LIBS analysis of reference <u>Be coatings under Ar atmosphere (2 – 100 mbar) at VTT</u>, to identify the best spectral region to detect both He and other elements of interest of the coating.

The analyses have been performed on sample 60190916 (nominal atomic percentages Be-He(2.5%)-D(5%)+ others)

The 587.56 nm He I line I was detected free of interference at laser energy E = 51 mJ, gate width = 200 ns, gate delay = 200 ns, Ar atmosphere 2 mbar

TOF-ERDA results for He: 0.54± 0.07 % atomic (realistic concentration)





Results

60190916_3_2 (1910079) Be+He(2.5%)+D(5%) 5 μm W 3_2

Very rough sample, atomic percentages of elements are estimated deeper in the sample

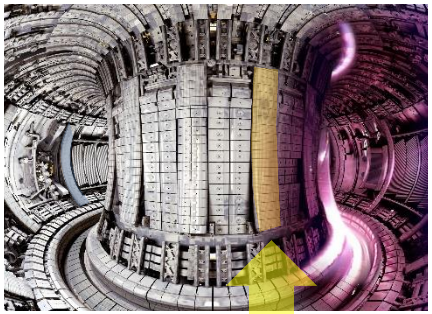
Interval 10^{15} at/cm^2	^1H at. %	^2H at. %	He at. %	Be at. %	C at. %	N at. %	O at. %
1300-2500	0.6±0.1	1.1±0.2	0.54±0.07	95±5	0.25±0.04	0.6±0.1	1.2±0.1

Be campaign at VTT

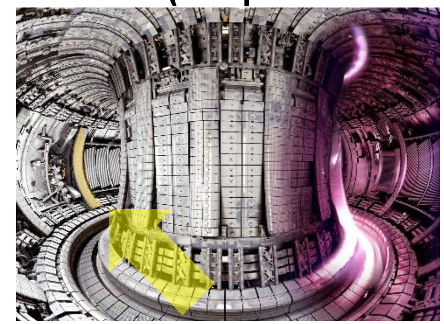
- **LIBS on real samples from the Joint European Torus (JET)**

The activity included the LIBS analysis of real JET tiles <u>under Ar atmosphere (2 – 100 mbar) at VTT</u>, to characterize them by LIBS in comparison with previous SIMS and TDS analyses.

The analyses have been performed on samples from the JET tiles 2XR11 (sample 641) and 4D15 (samples 686 and 755)



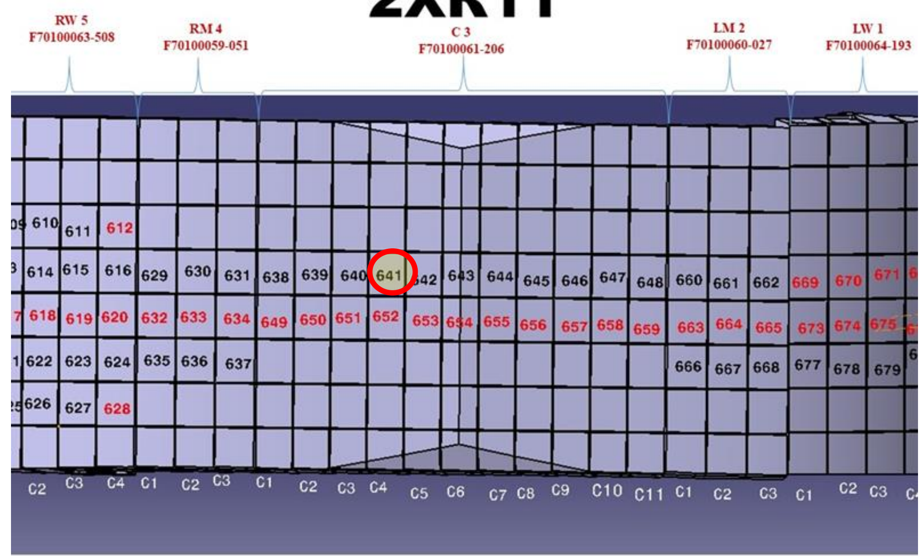
A picture of the sample 2XR11-641 before LIBS analysis



4D15

(from the inner wall guard limiter)

2XR11



(from the wide outer poloidal limiter)

Results- WPPWIE

- **D 1. (Comparison SP vs. DP LIBS, or alternative LIBS signal enhancement methods: absolute fuel content in W samples and composition)**
  1. **Detection of hydrogen isotopes optimized in air when short interpulse delays between the laser pulses (few tenth of ns) are applied.**
  2. **Optimized gate delay and width to resolve D_α–H_α in air. Delay: 4-4.5 µs, width: 1-5 µs**
  3. **LIBS under He flux (2L/min) gives similar results to LIBS in air with shorter gate delays: 2-2.5 µs**
  4. **LIBS under Ar flux (2L/min) gives similar results to LIBS in air with longer gate delays: ≥ 15 µs**
  5. **Ar enhances the LIBS signal compared to air for all the elements, but this will be hard to exploit to resolve D_α–H_α because of an increased electron density and Stark broadening. Instead it can be exploited to search for other elements in traces (e.g. Be)**
  6. **Average Ablation Rates down to 100 nm/shot could be obtained with ns-DP-LIBS by reducing the laser pulse energies (≈ 50+50 mJ), still preserving a good SNR.**

- **D 2. (CF)-LIBS (ps/ns or SP/DP) on samples from different toroidal devices: absolute content and composition (in depth)**

  Main results of post mortem analysis of the TZM limiter tiles of FTU:
  1. **Fe, Cr, Ni have been detected in the superficial layer of the tiles as eroded and redeposited material of the SS first wall exposed to fusion plasma**
  2. **Li was detected on the surface. It comes from previous experiments in FTU with liquid lithium limiters. Similar behavior has been observed for Sn**
  3. **Na and K detected. Probably from manipulation of the tiles after FTU decommissioning**
  4. **B detected as superficial trace element from the preliminary boronization procedure of the first wall with gaseous B_2D_6, performed before each experimental campaign in FTU**
  5. **H, O are not detected in the superficial layers, but they are in deeper layers. It is supposed that the strong Li superficial contamination reduces their concentration in that layer through chemical reactions in air**
  6. **Ti and Mo exhibit similar behavior as main constituents of the substrate.**
  7. **CF-LIBS is ongoing on these samples**

- **D 3. (CF)-LIBS results He loaded samples and surface modifications**

  1. **He was clearly detected at low Ar pressure through its He I emission line at 587.56 nm. To improve He detection at atmospheric conditions ENEA suggests to study the samples under Ar flux.**

WPPWIE ENEA proposal for 2023

- **ENEA is available to analyze and characterize samples from different fusion machines, with its DP, full range, Hi-RES LIBS system, provided that they don't contain Tritium or Beryllium**

- **ENEA is available to collaborate in the analysis of the LIBS spectral data obtained from sample containing Be (e.g. Be samples analysed at VTT and JET PFCs)**

- **ENEA proposes to analyze the effect of Ar as background gas for detecting He and other gases in W based coatings at atmospheric pressure**

- **CF quantification for the superficial Ti, Li, etc on the FTU TZM tiles (already ongoing)**

Compact ps laser

Messaggio (Mio dominio)

Da: Sales <sales@qslasers.com>
Oggetto: RE: inquiry on high Energy DPSS Picosecond MPL300-YLF series
Data: Thu, 9 Jun 2022 13:07:50 +0000
A: salvatore.almaviva@enea.it <salvatore.almaviva@enea.it>
Cc: Gintas Jakubėnas <gintas@qslasers.com>, Saulius Frankinas <saulius@qslasers.com>, Algis Stalnionis <algis@qslasers.com>

Dear Slavatore,

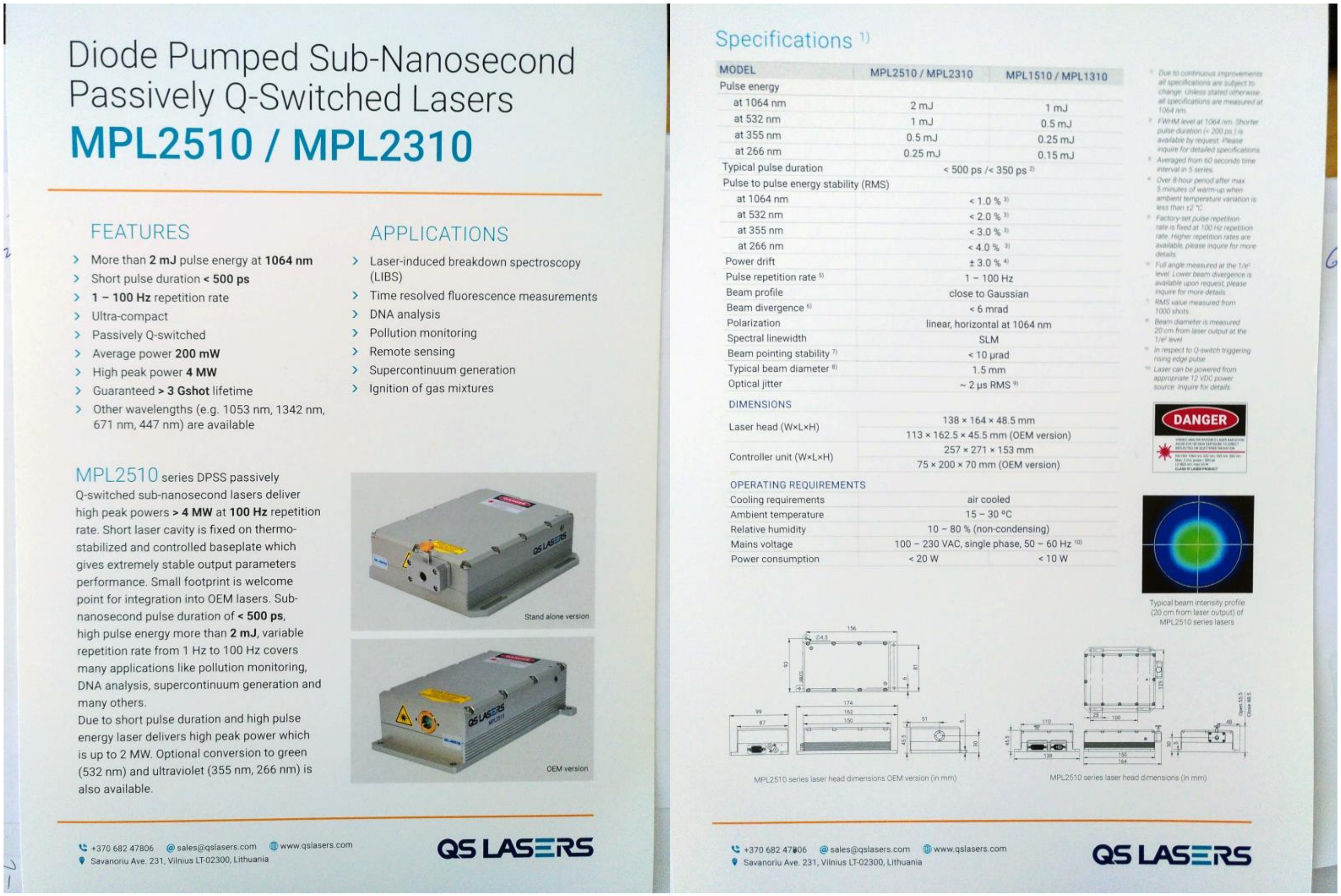
Thank you for your questions and I would like to apologize for the time we took to answer your questions.

As for your questions, my answers are:

1) MPL300-YLF, MPL330-YLF and MPL350 wouldn't fit in 10 kg range.
2) the energy of a single laser pulse if the pulse duration is set at the minimum possible (that should be about 300 ps, as reported in the brochure)
3) The laser is externally triggerable down to single shot.
4) We do not use optical fibers. We use LD current wires and 15 pin connectors (15 wires) for laser head control.

We would like to know would 1064 nm wavelength suit you? We can offer MPL2210 laser (it is currently not in our website). Its energy is 2 mJ (but it can be increased up to (10-20 mJ) and pulse duration is 250 ps -+/- 10 ps and it would fit your weigh requirements: driver with 1-meter-long cables (1 kg) plus laser head (2,3 kg for standard energy but it still would fit in 10 kg range if we increase its energy). MPL2210 is externally triggerable down to a single shot as well. Water tubes are not used in this laser.

Compact ps laser



Diode Pumped Sub-Nanosecond Passively Q-Switched Lasers

MPL2510 / MPL2310

FEATURES

- More than **2 mJ** pulse energy at **1064 nm**
- Short pulse duration **< 500 ps**
- **1 – 100 Hz** repetition rate
- Ultra-compact
- Passively Q-switched
- Average power **200 mW**
- High peak power **4 MW**
- Guaranteed **> 3 Gshot** lifetime
- Other wavelengths (e.g. 1053 nm, 1342 nm, 671 nm, 447 nm) are available

APPLICATIONS

- Laser-induced breakdown spectroscopy (LIBS)
- Time resolved fluorescence measurements
- DNA analysis
- Pollution monitoring
- Remote sensing
- Supercontinuum generation
- Ignition of gas mixtures

MPL2510 series DPSS passively Q-switched sub-nanosecond lasers deliver high peak powers **> 4 MW** at **100 Hz** repetition rate. Short laser cavity is fixed on thermo-stabilized and controlled baseplate which gives extremely stable output parameters performance. Small footprint is welcome point for integration into OEM lasers. Sub-nanosecond pulse duration of **< 500 ps**, high pulse energy more than **2 mJ**, variable repetition rate from 1 Hz to 100 Hz covers many applications like pollution monitoring, DNA analysis, supercontinuum generation and many others.
Due to short pulse duration and high pulse energy laser delivers high peak power which is up to 2 MW. Optional conversion to green (532 nm) and ultraviolet (355 nm, 266 nm) is also available.

Stand alone version

OEM version

+370 682 47806 sales@qslasers.com www.qslasers.com
Savanoriu Ave. 231, Vilnius LT-02300, Lithuania

QS LASERS

Specifications 1)

MODEL	MPL2510 / MPL2310	MPL1510 / MPL1310
Pulse energy		
at 1064 nm	2 mJ	1 mJ
at 532 nm	1 mJ	0.5 mJ
at 355 nm	0.5 mJ	0.25 mJ
at 266 nm	0.25 mJ	0.15 mJ
Typical pulse duration	< 500 ps /< 350 ps 2)	
Pulse to pulse energy stability (RMS)		
at 1064 nm	< 1.0 % 3)	
at 532 nm	< 2.0 % 3)	
at 355 nm	< 3.0 % 3)	
at 266 nm	< 4.0 % 3)	
Power drift	± 3.0 % 4)	
Pulse repetition rate 5)	1 – 100 Hz	
Beam profile	close to Gaussian	
Beam divergence 6)	< 6 mrad	
Polarization	linear, horizontal at 1064 nm	
Spectral linewidth	SLM	
Beam pointing stability 7)	< 10 µrad	
Typical beam diameter 8)	1.5 mm	
Optical jitter	~ 2 µs RMS 9)	
DIMENSIONS		
Laser head (W×L×H)	138 × 164 × 48.5 mm 113 × 162.5 × 45.5 mm (OEM version)	
Controller unit (W×L×H)	257 × 271 × 153 mm 75 × 200 × 70 mm (OEM version)	
OPERATING REQUIREMENTS		
Cooling requirements	air cooled	
Ambient temperature	15 – 30 °C	
Relative humidity	10 – 80 % (non-condensing)	
Mains voltage	100 – 230 VAC, single phase, 50 – 60 Hz 10)	
Power consumption	< 20 W	< 10 W

1) Due to continuous improvements all specifications are subject to change. Unless stated otherwise all specifications are measured at 1064 nm.
2) FWHM level at 1064 nm. Shorter pulse duration (< 200 ps) is available by request. Please inquire for detailed specifications.
3) Averaged from 60 seconds time interval in 5 series.
4) Over 8-hour period after max 5 minutes of warm-up when ambient temperature variation is less than ±2 °C.
5) Factory-set pulse repetition rate is fixed at 100 Hz repetition rate. Higher repetition rates are available, please inquire for more details.
6) Full angle measured at the 1/e² level. Lower beam divergence is available upon request, please inquire for more details.
7) RMS value measured from 1000 shots.
8) Beam diameter is measured 20 cm from laser output at the 1/e² level.
9) In respect to Q-switch triggering rising edge pulse.
10) Laser can be powered from appropriate 12 VDC power source. Inquire for details.

DANGER

Typical beam intensity profile (20 cm from laser output) of MPL2510 series lasers

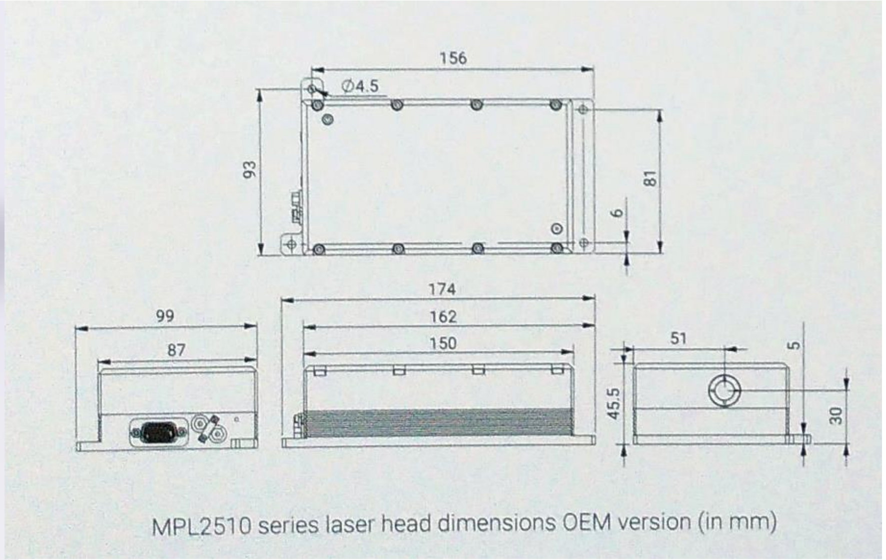
MPL2510 series laser head dimensions OEM version (in mm)

MPL2510 series laser head dimensions (in mm)

+370 682 47806 sales@qslasers.com www.qslasers.com
Savanoriu Ave. 231, Vilnius LT-02300, Lithuania

QS LASERS

Compact ps laser

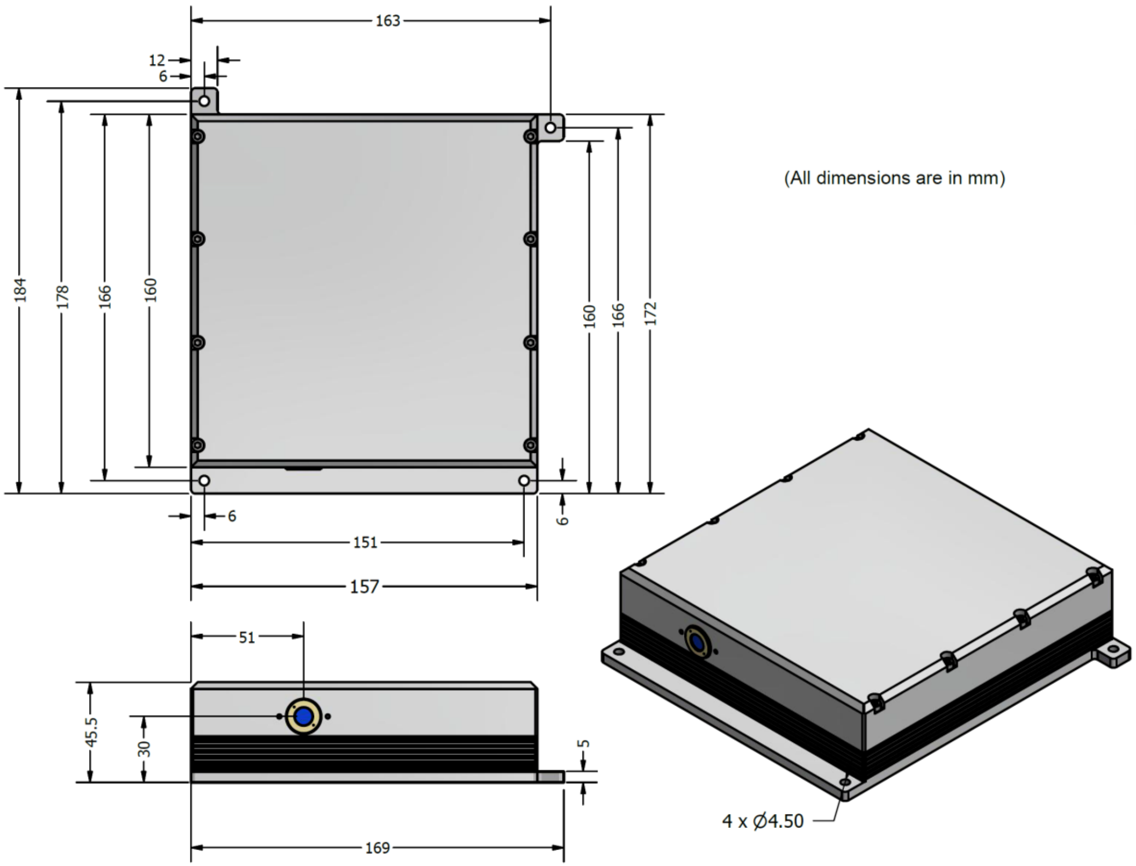


Picture of Laser MPL2510. MPL2210 (10-20Uj) will be about 7 cm wider and the exit will be more left.

2.3 kg in standard configuration (2 mJ per pulse) **≈ 5 kg, 70 mm wider, 10 mm longer** with pulse energy increased up to 10 - 20 mJ

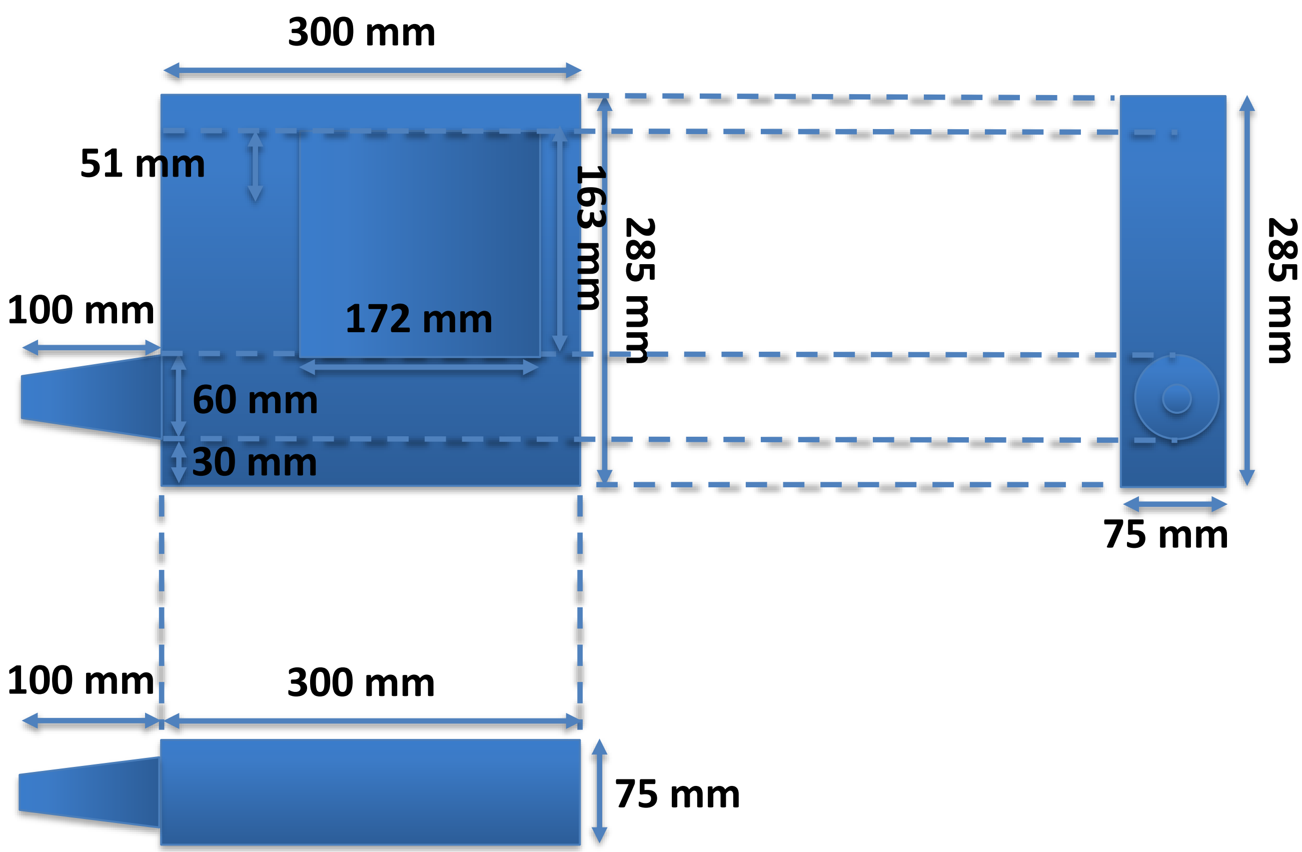
Compact ps laser

Supposed shape of the MPL2210 laser head 70 mm wider, 10 mm longer, with pulse energy increased up to 10 - 20 mJ. **Declared weight ≈ 5 kg**



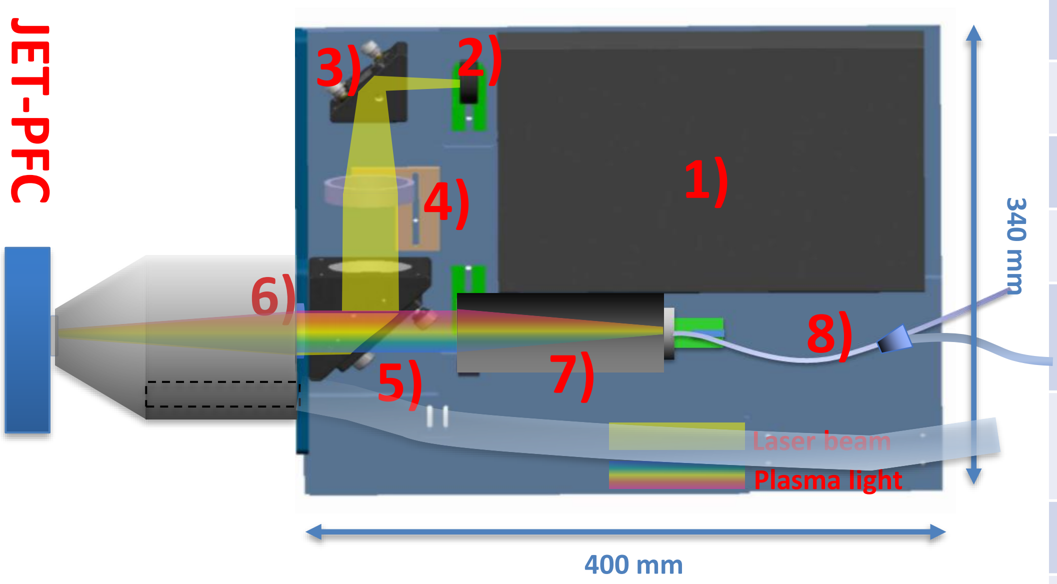
	Description
1)	Ps – laser (λ = 1064 nm)
2)	1'' dia. lens (f = -75 mm)
3)	1'' dia. HR-IR 45° mirror (45°)
4)	2'' dia. lens (f = 200 mm)
5)	2'' dia. HR-IR HT-VIS dielectric mirror (45°)
6)	2-3'' dia. lens (f = 50-200 mm ?) + vacuum cone ?
7)	2-3'' dia doublet
8)	Bifurcated (≥ 20 m) optical fiber

First dimensional sketch of the LIBS head



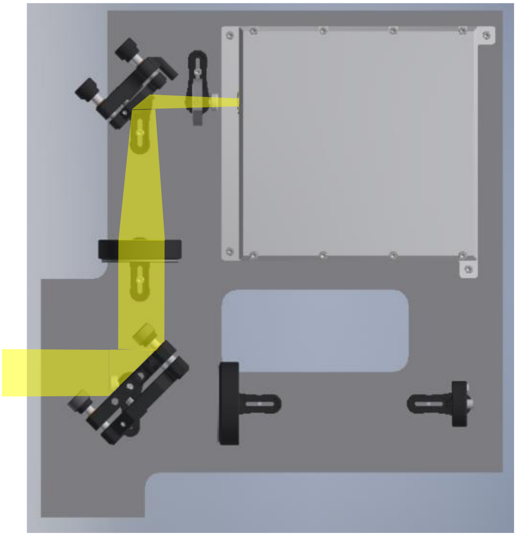
LIBS module for the JET-RHS

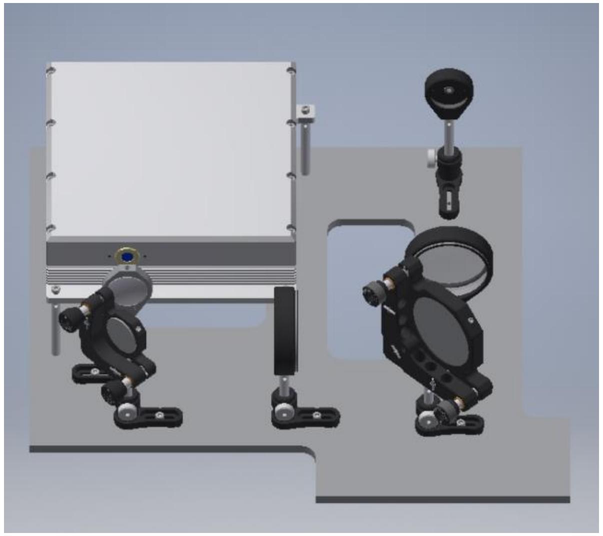
- Given the impossibility to effectively carry a picosecond laser pulse via optical fiber 20 m length and more, the LIBS scheme includes a compact ps laser head fixed on the LIBS head and carried inside the VV.
- A vacuum cone or a physical spacer to put in contact with the JET PFC could be considered in order to ensure the correct focusing distance between the focusing lens and the JET-PFC.
- Background gases like Ar or He could be fluxed on the JET surface to reduce the Stark broadening of the Balmer alpha emission lines of T, D, H

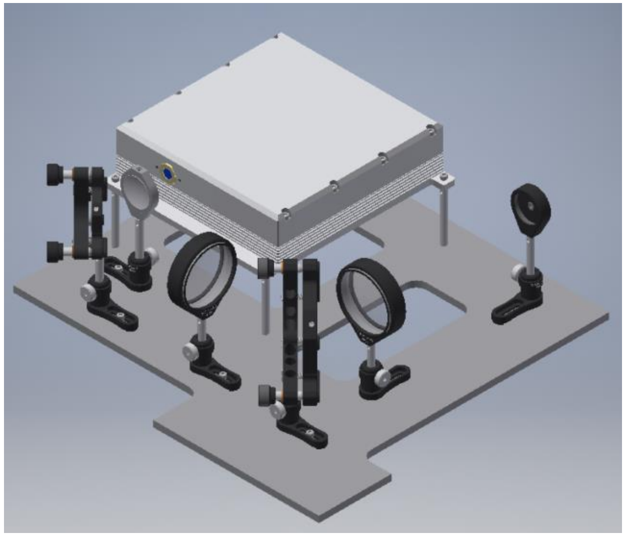


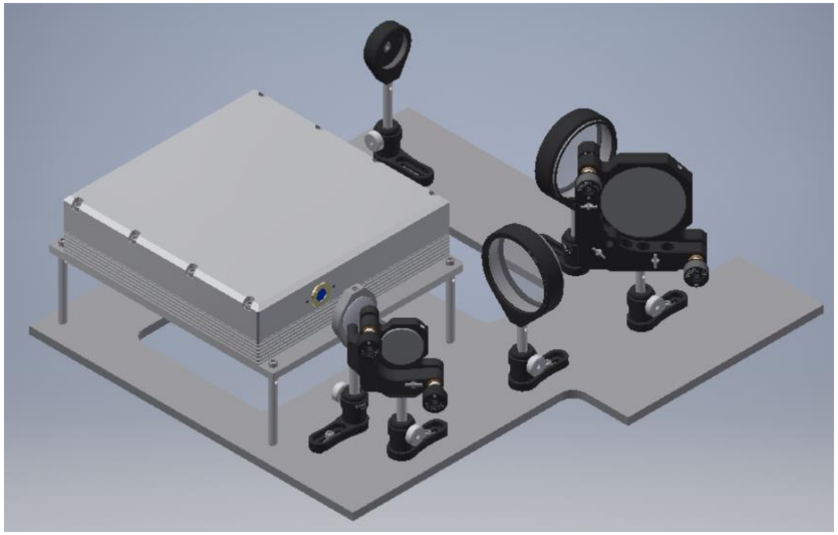
	Description
1)	Ps – laser (λ = 1064 nm)
2)	1’’ dia. lens (f = -75 mm)
3)	1’’ dia. HR-IR 45° mirror (45°)
4)	2’’ dia. lens (f = 200 mm)
5)	2’’ dia. HR-IR HT-VIS dielectric mirror (45°)
6)	2-3’’ dia. lens (f = 50-200 mm) + vacuum cone
7)	2’’ focusing lens (f = 150 mm)
8)	Bifurcated (≥ 20 m) optical fiber

Technical drawings





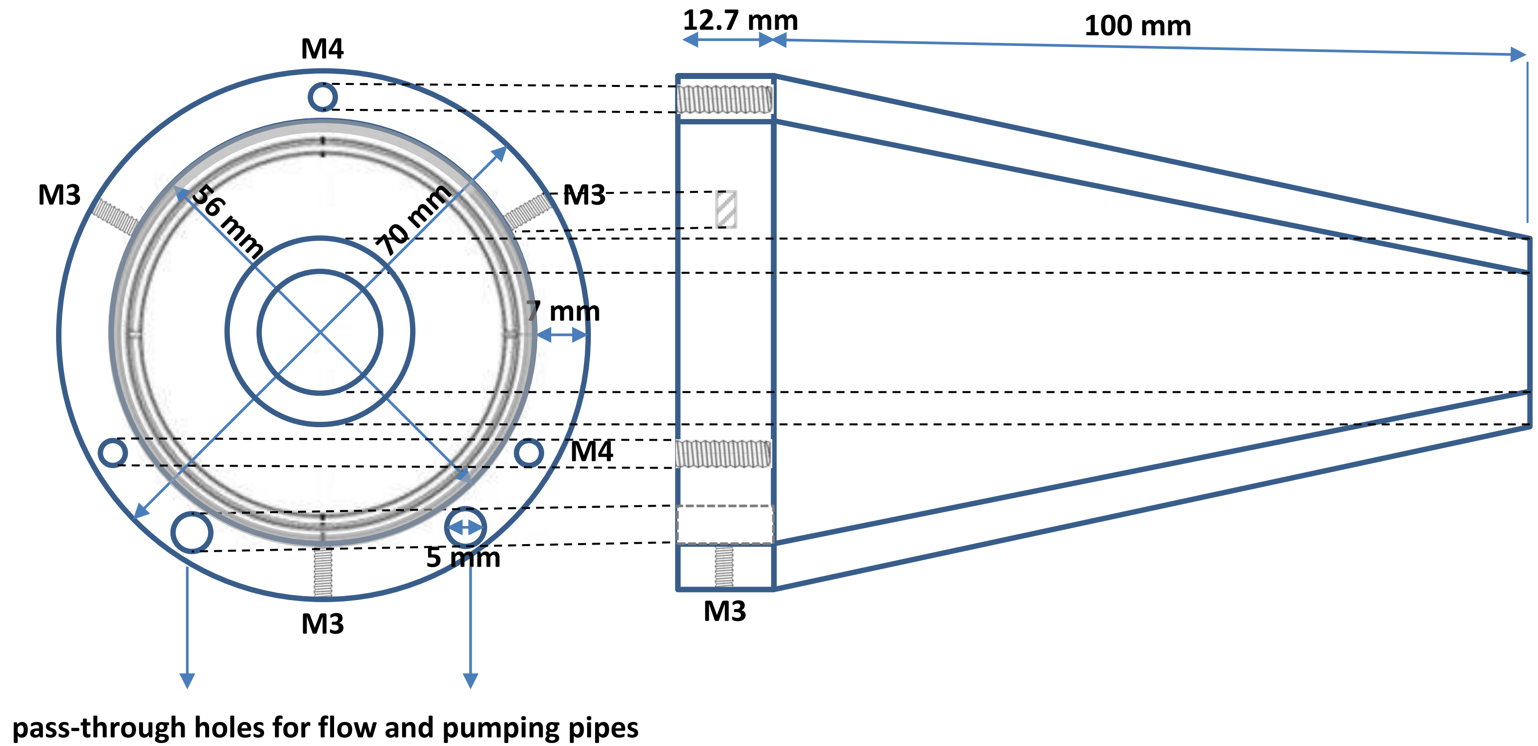




Aluminum platform: 6 mm thick
Laser exit: 8 mm from the platform

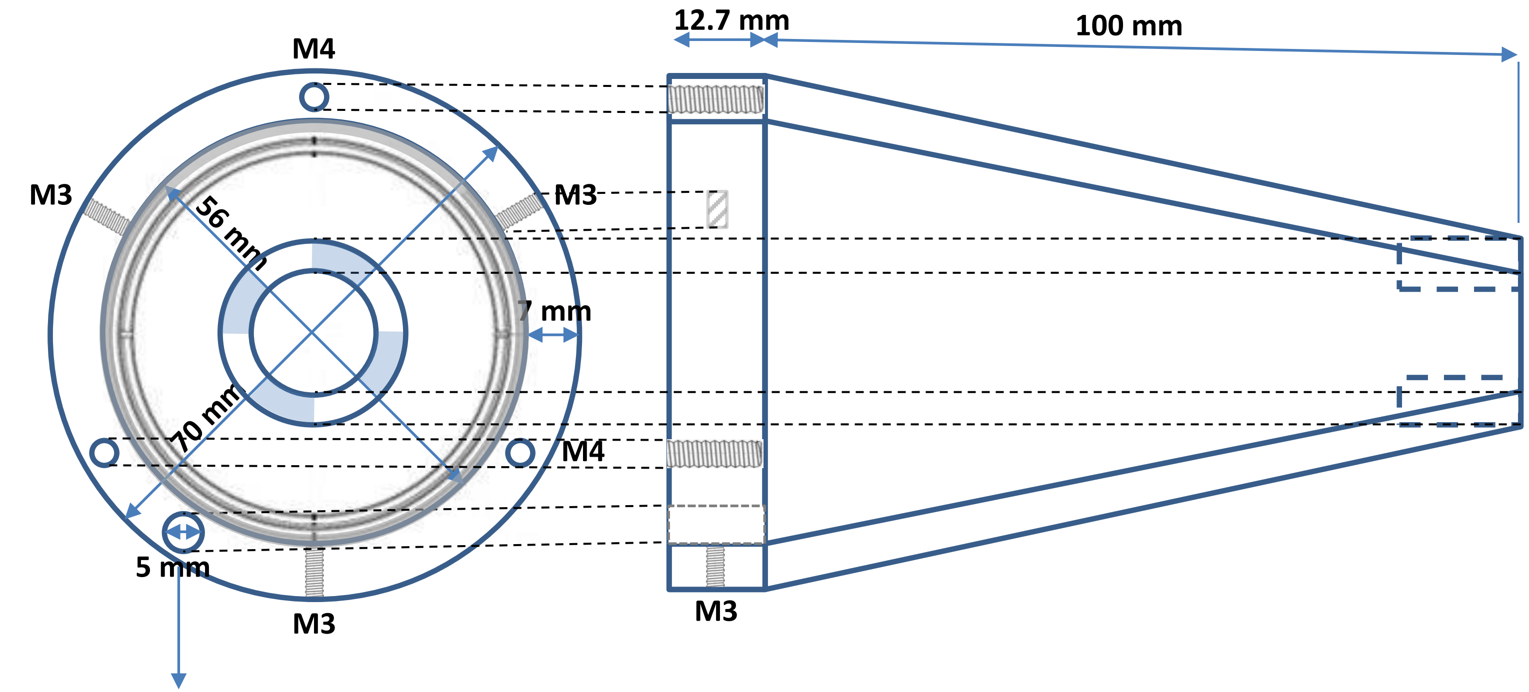
Estimated weight ~ 8 Kg

Possible design of the cone 1



- Two pass-through holes for gas flow and pumping
- Made of Aluminum or plastic material (lighter if allowed to be deployed in the JET VV)
- Focusing lens: 2’’ Ø, f = 100 mm

Possible design of the cone 2



- One pass-through holes for gas flow and pumping
- Indented tip of the cone
- Made of Aluminum or Plastic materials (lighter if allowed to be deployed in the JET VV)
- Focusing lens: 2'' Ø, f = 100 mm