LIBS FOR TRITIUM CARTOGRAPHY OF TOKAMAK PLASMA FACING COMPONENTS

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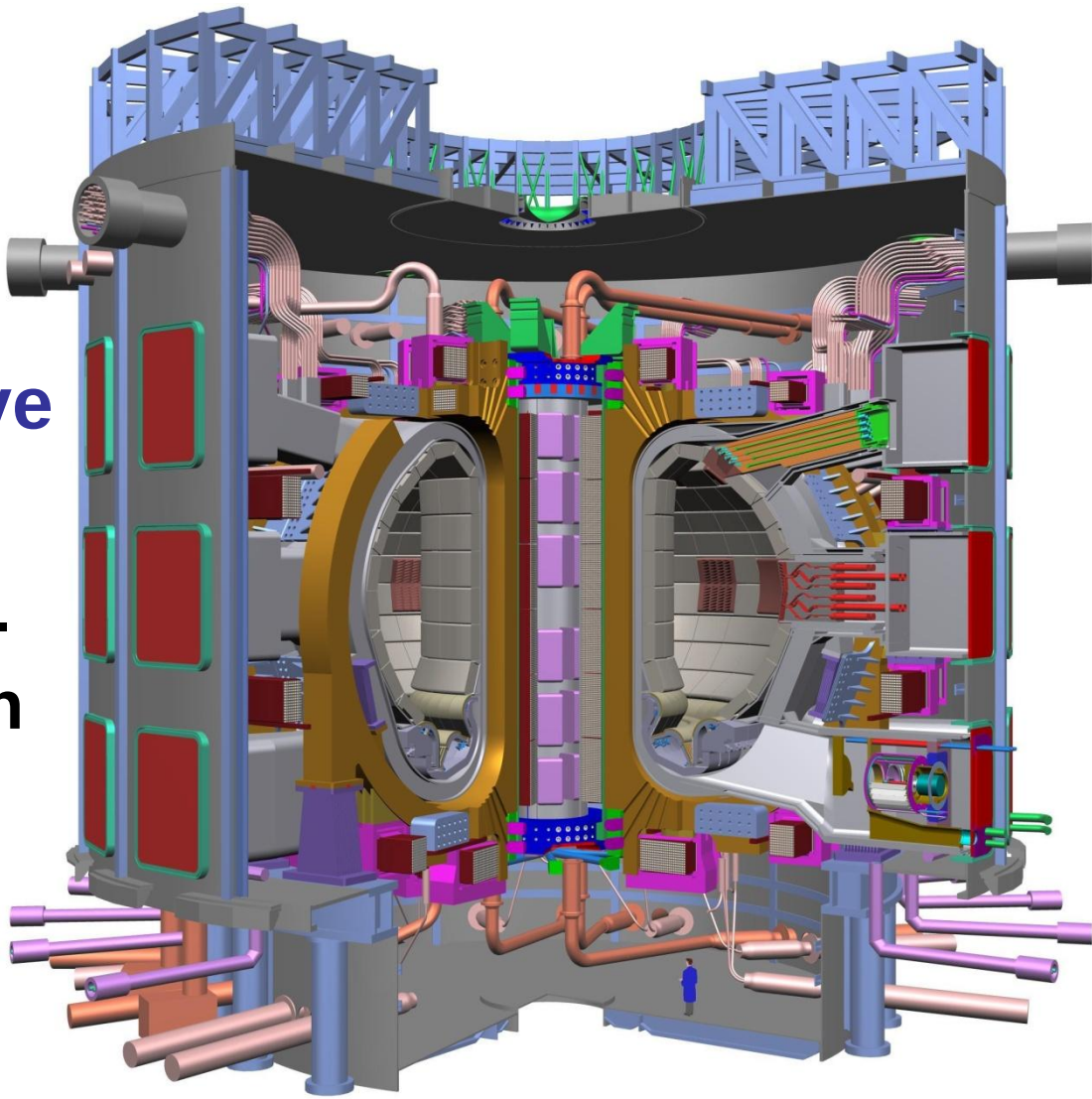
Problem:
Tritium retention on the walls

(ITER < 700 g)

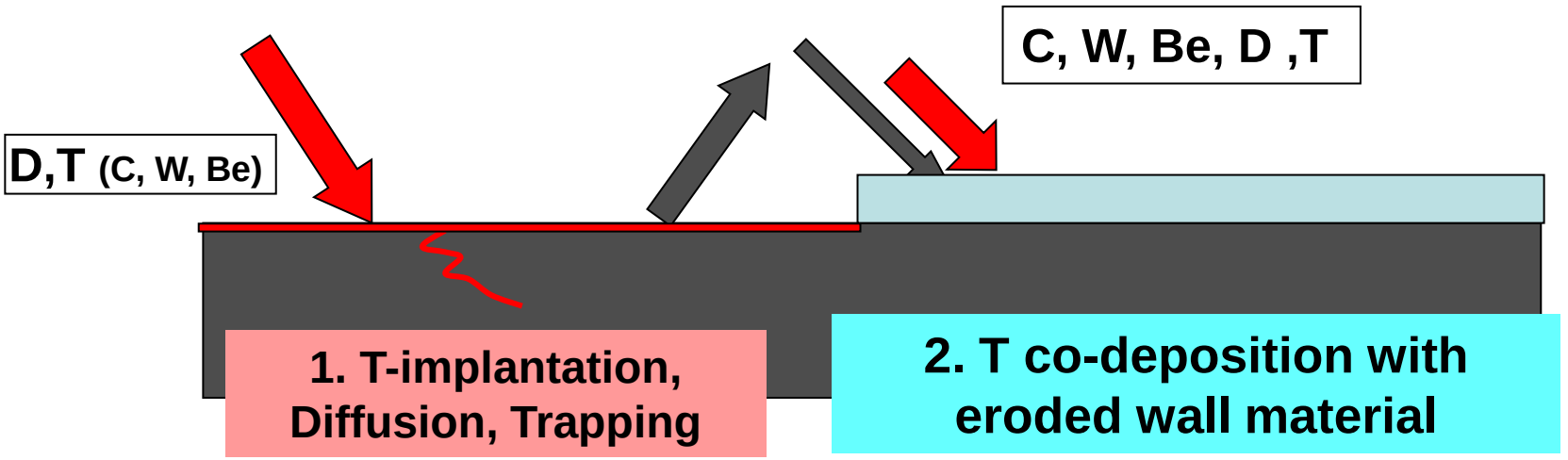


Laser methods to solve the problem:

- **co-deposited layer in-depth characterisation**
- **detritiation**

  Laser heating
  Laser ablation

Tritium trapping on PFC

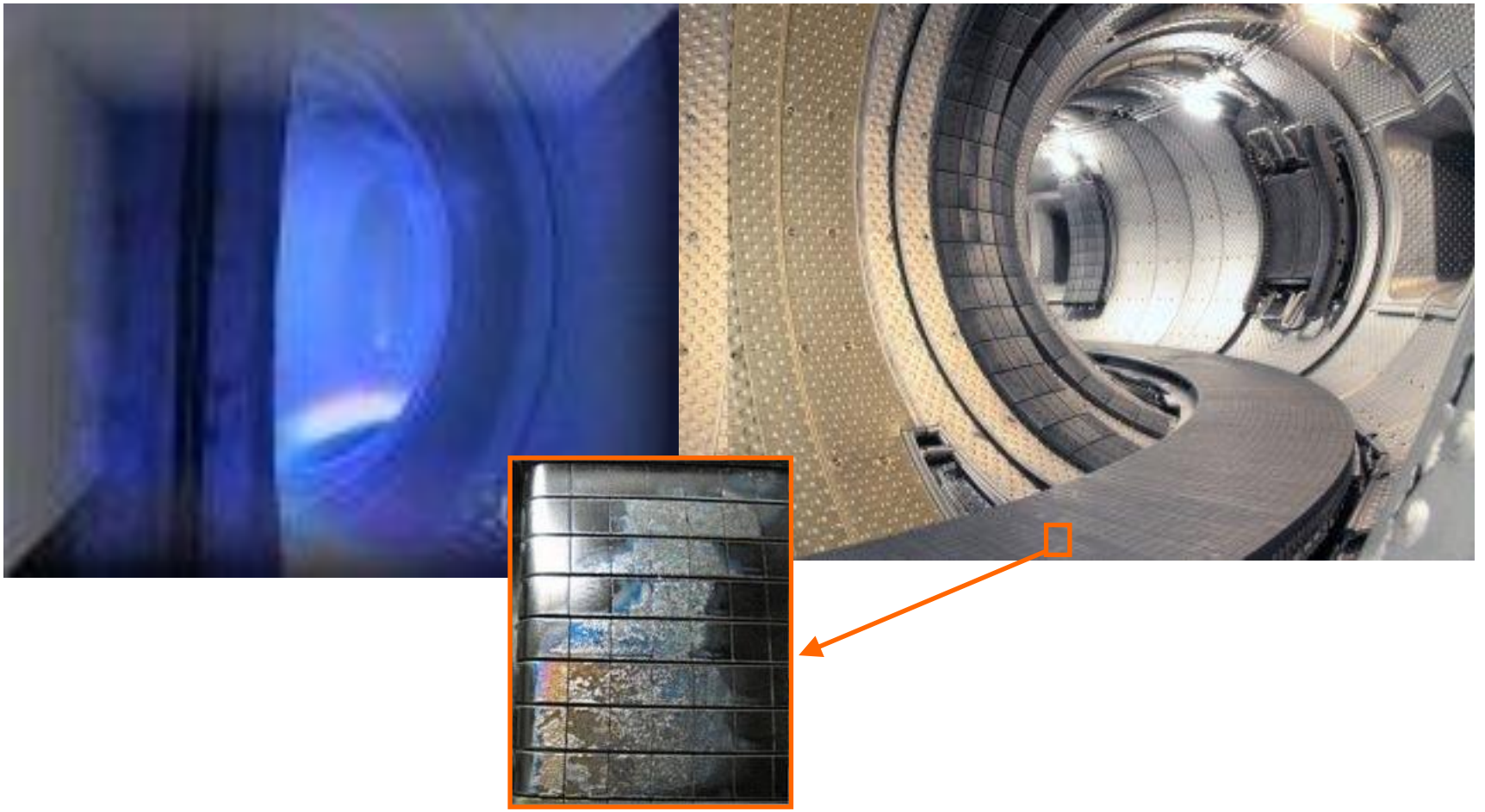


Deposited layer formation

- ❑100 µm (divertor)
- ❑ up to 50% of D/T
- ❑ solid - friable (porous)

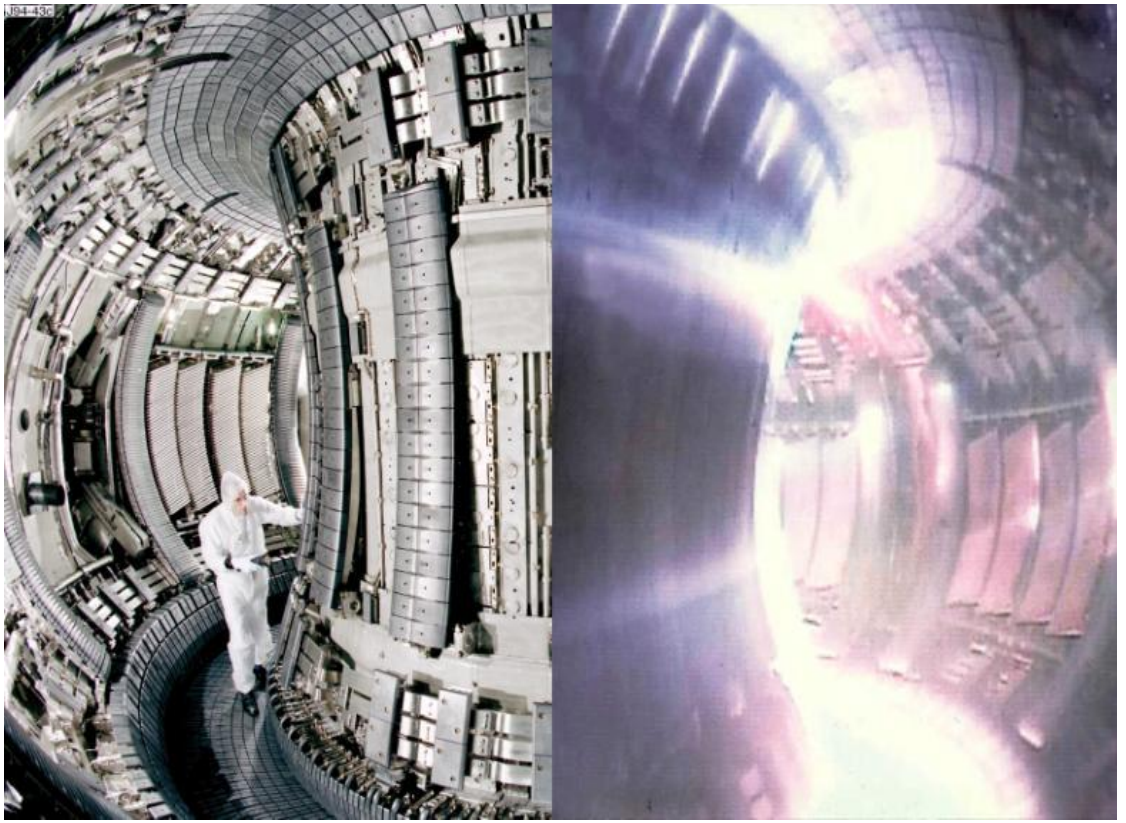
TORE SUPRA

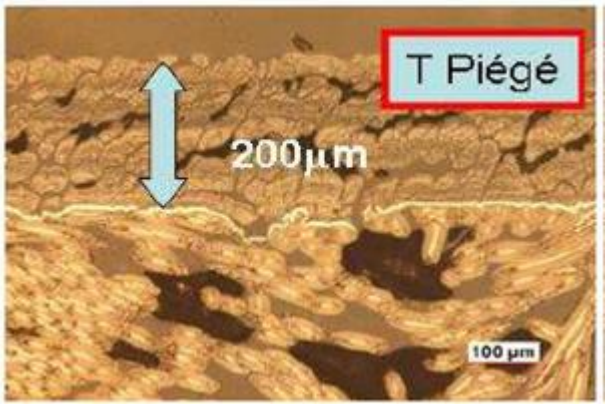
CEA Cadarache, France



JET (Culham, GB)

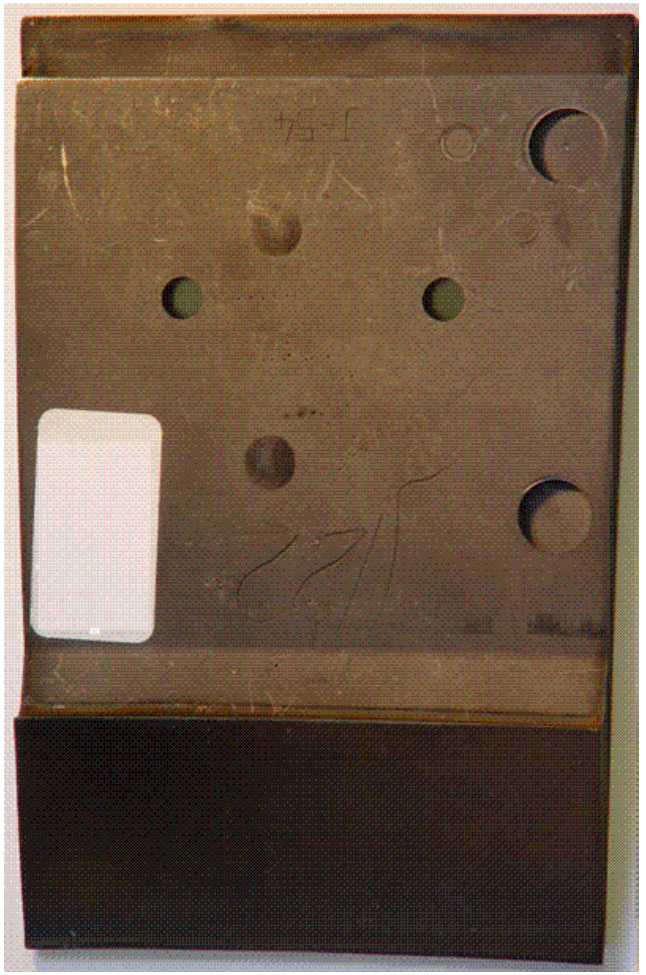
D/T, Be and C

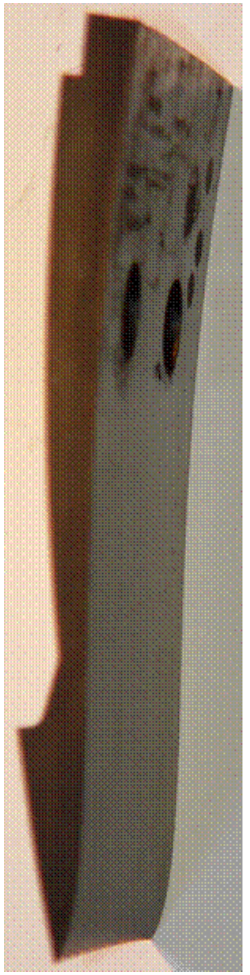


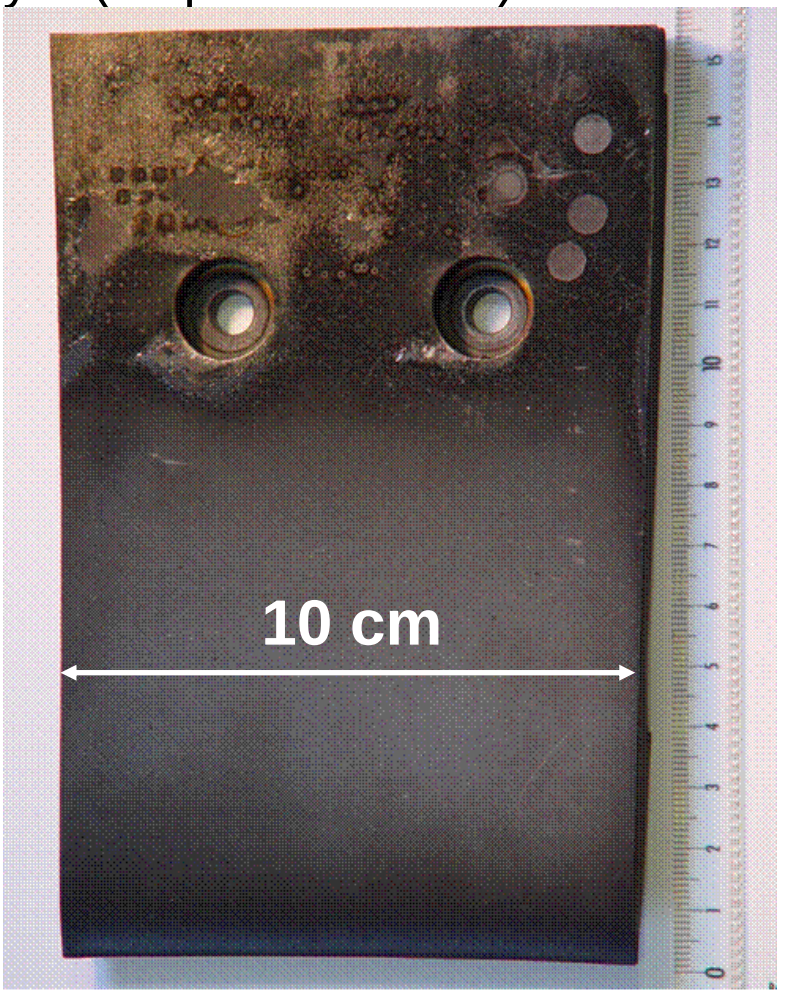


TEXTOR (Germany)

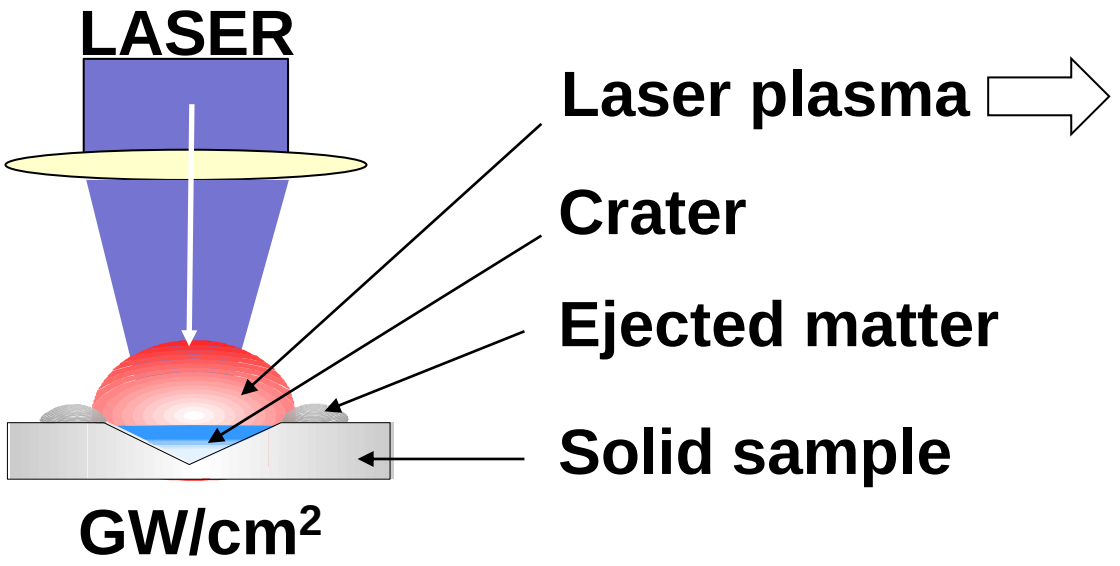
Graphite tile with deposited layer (50 µm thickness)

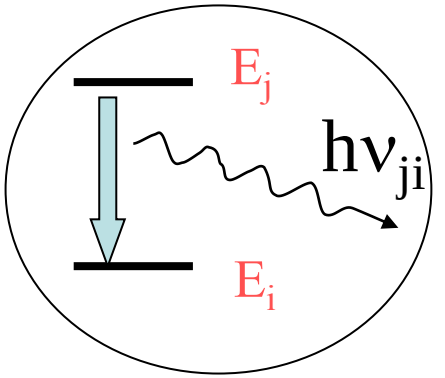


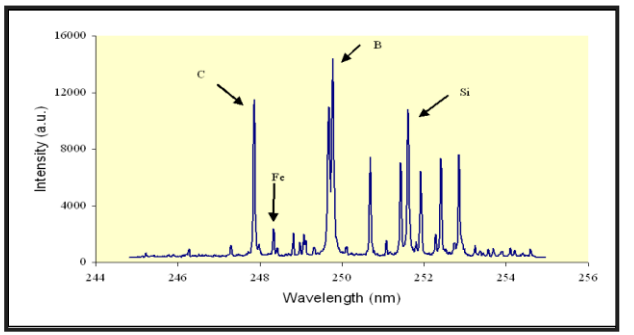




LIBS-method

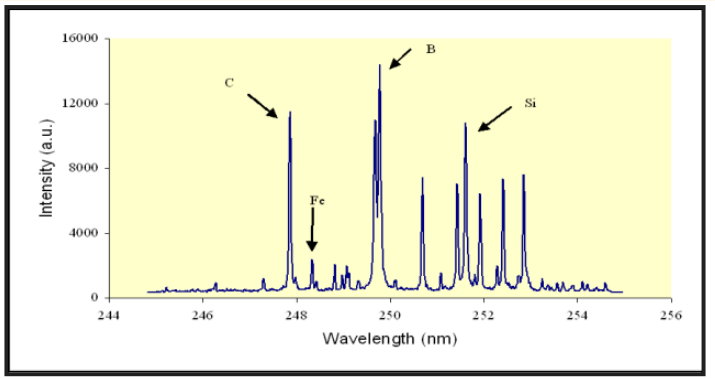






LIBS properties = *f* (sample properties) +

f **(E, ∅, Δt, λ , Δθ, polarisation, sample, air, ...)**



LIBS analytical signal ~ $N_a \cdot u_a(T) \cdot A_{ij} \cdot \exp(-E_i / kT) \cdot t_p \cdot K_d$

N_a ~ $(V_c - V_r)/V_c$ - atomisation efficiency;

u_a ~ 10^{-1} - 10^{-2} - partition function;

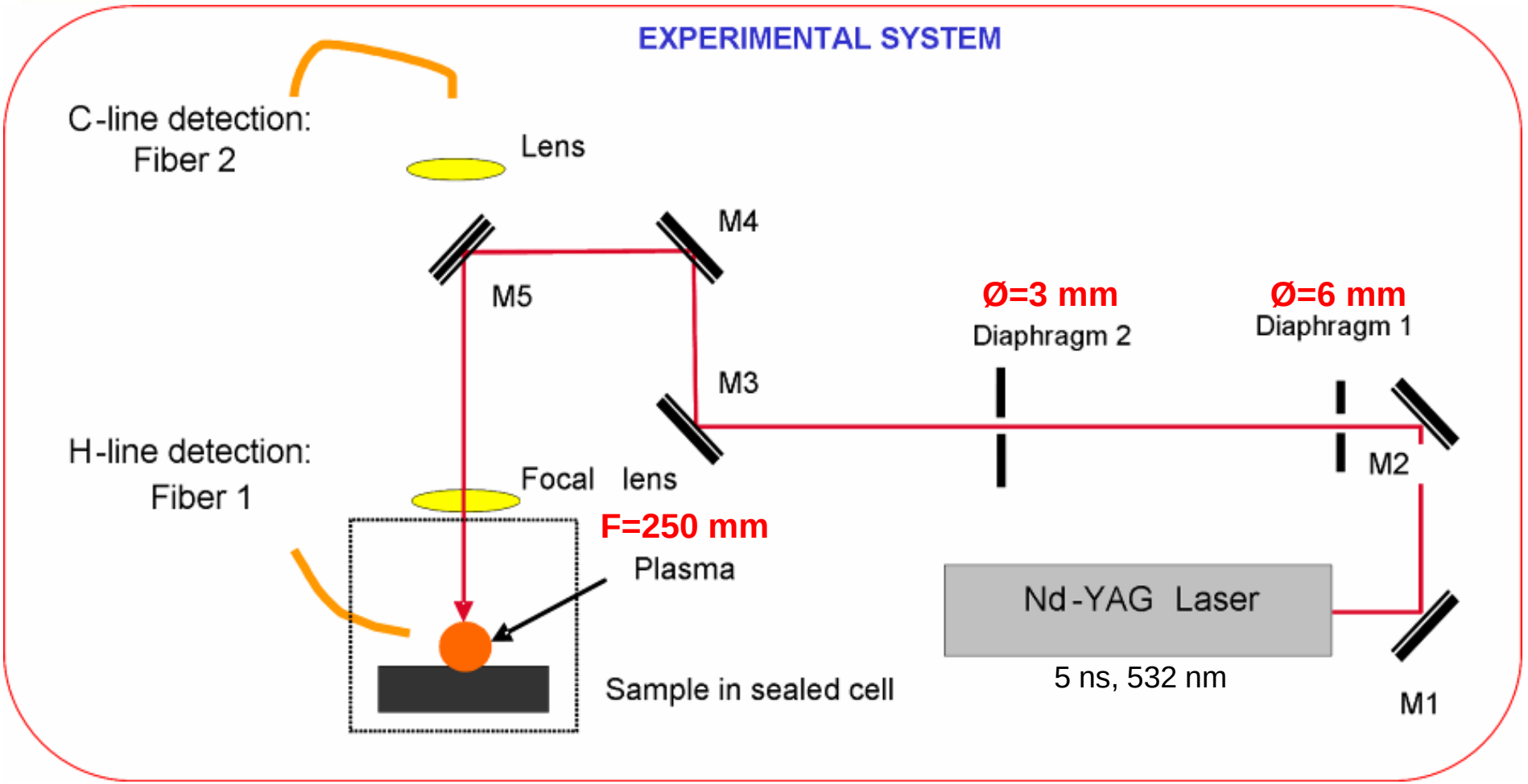
A_{ij} ~ 10^8 s^{-1}; E_j ~ 2 eV; kT ~ 1 eV;

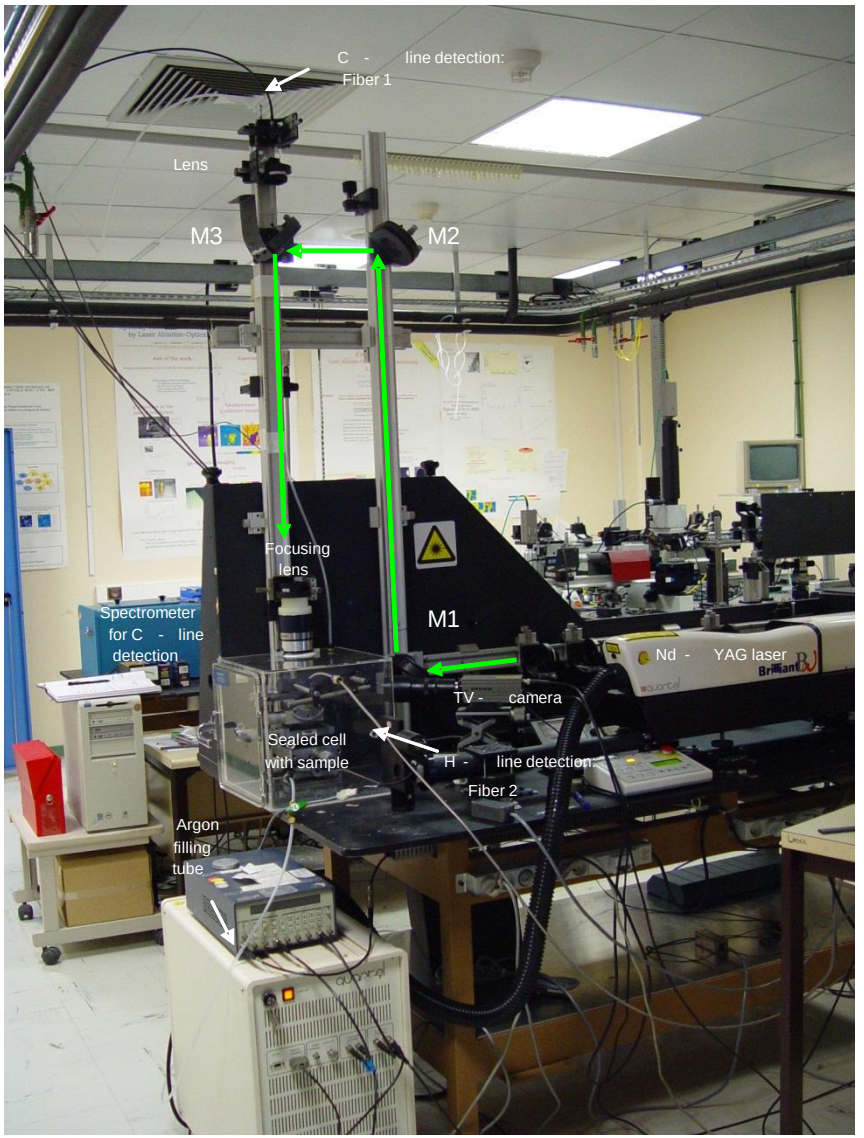
t_p ~ 100 ns -1 μs;

K_d ~ 10^{-4};

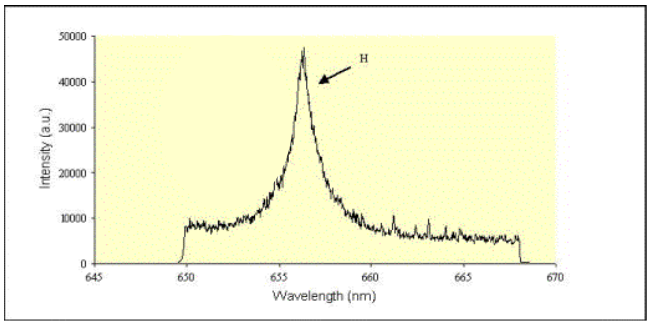
Analytical photons/atom ≤ 10^{-5}

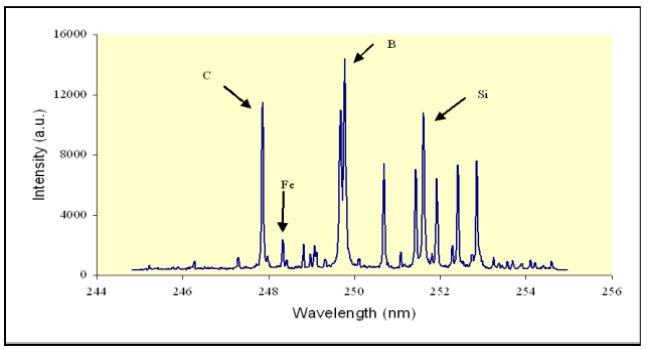
LIBS set-up (F = 0.25 m, 1 bar)

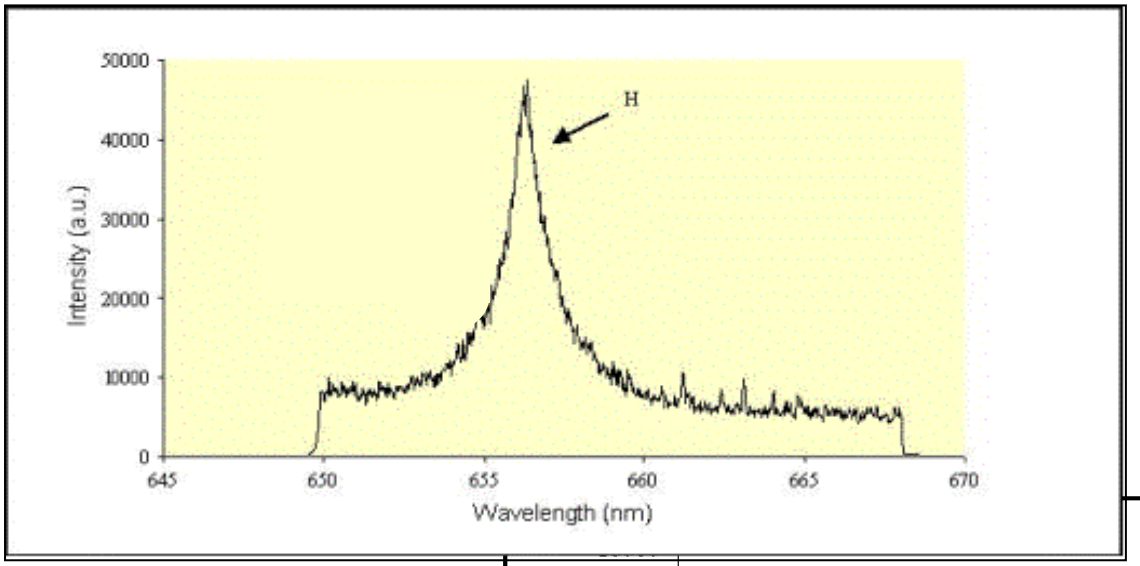




LIBS analytical spectral lines (**H**, **C**, B, Fe, Si, Cu) of TEXTOR graphite tile.

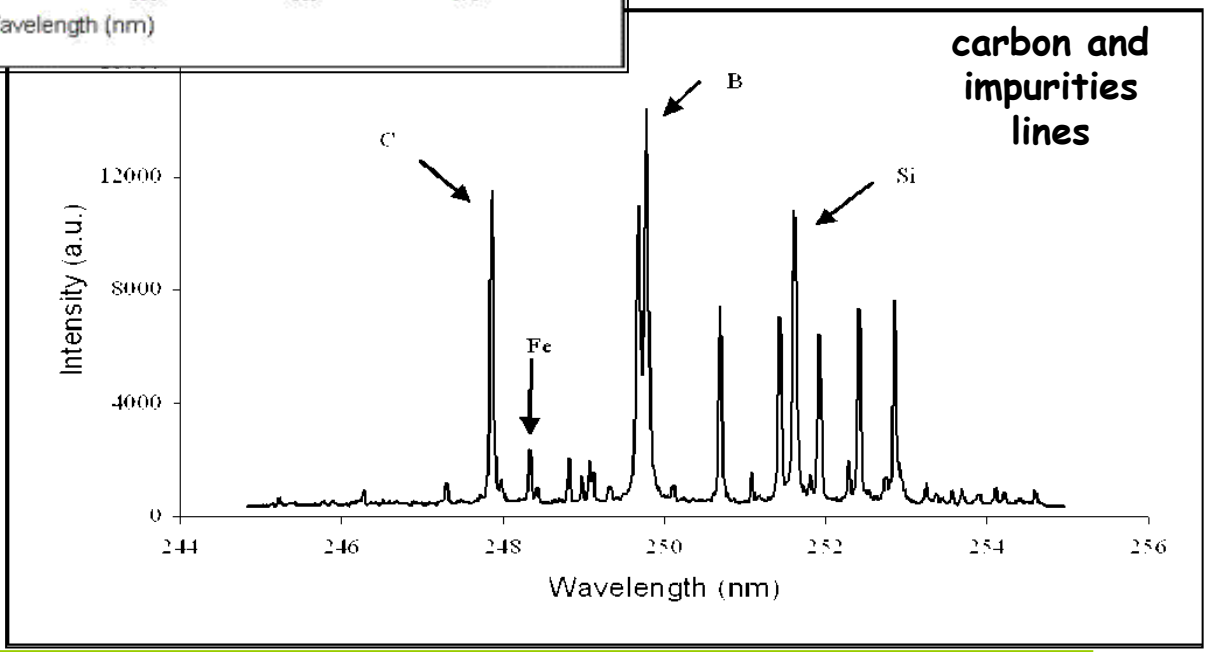






Hydrogen
E*=12.088eV

Carbon
E*=7.685eV



$F_{laser} \geq 10\ J/cm^2$

TEXTOR-tile in-depth profiling by LIBS

*(LIBS **qualitative** results at a small focal distance)*

•TEXTOR deposited layer composition:
(C, B , Si, Fe, Mg, Cr, Al, Cu, Mo, Ni, Al, Ca, Ba, Na, Li);

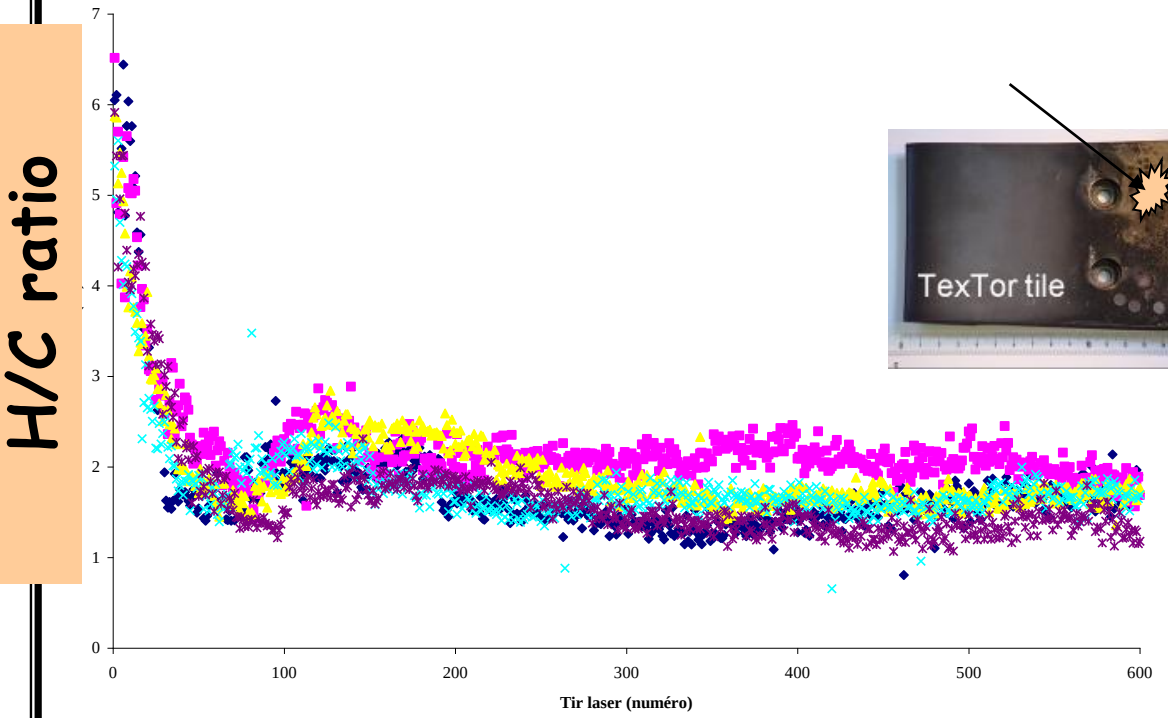
• TEXTOR deposited layer is nonhomogeneous;

•Pollution on the opposite side of a TEXTOR-sample;

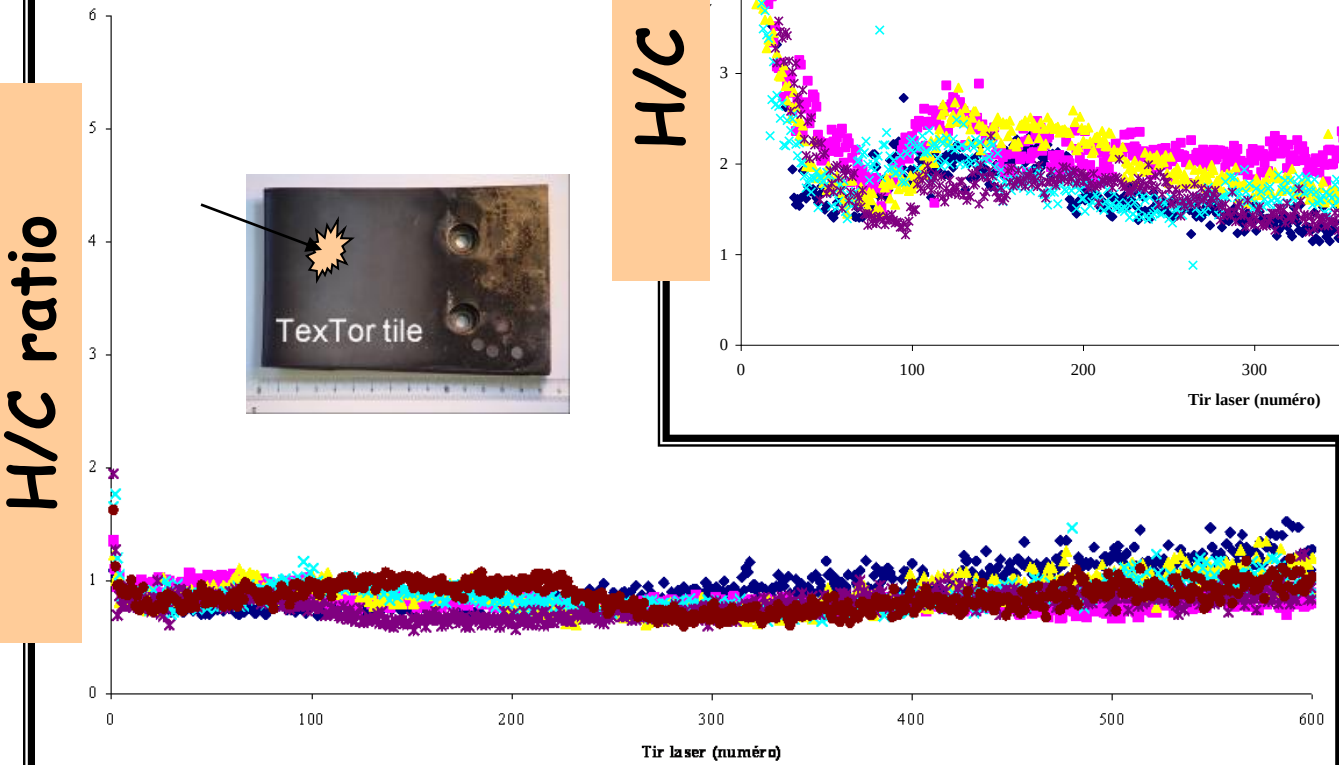
•Shot-to-shot qualitative analysis to observe hydrogen.

1. *Evaluation of Laser Ablation Optical Emission Spectroscopy Method for Graphite co-deposited Layer Characterisation (EFDA task TW3-TPP-ERDIAG)*, A. Semerok, J.-M. Weulersse, P.Fichet, CEA report NT DPC/SCP/05-124-A, February 2005, 77 pages.
2. F. Le Guern, F. Brygo, P. Fichet, E. Gauthier, C. Hubert, C. Lascoutuna, D. Menut, S. Mousset, A. Semerok, M. Tabarant, J.M. Weulersse, *Fusion Engineering and Design* **81** (2006) 1503–1509.
3. In-situ tokamak laser applications for detritiation and co-deposited layers studies, C. Grisolia, A. Semerok, J.M. Weulersse, F. Le Guern, S. Fomichev, F. Brygo, P. Fichet, P.Y. Thro, P. Coad, N. Bekris, M. Stamp, S. Rosanvallon, G. Piazza, Journal of Nuclear Materials 363–365 (2007) 1138–1147

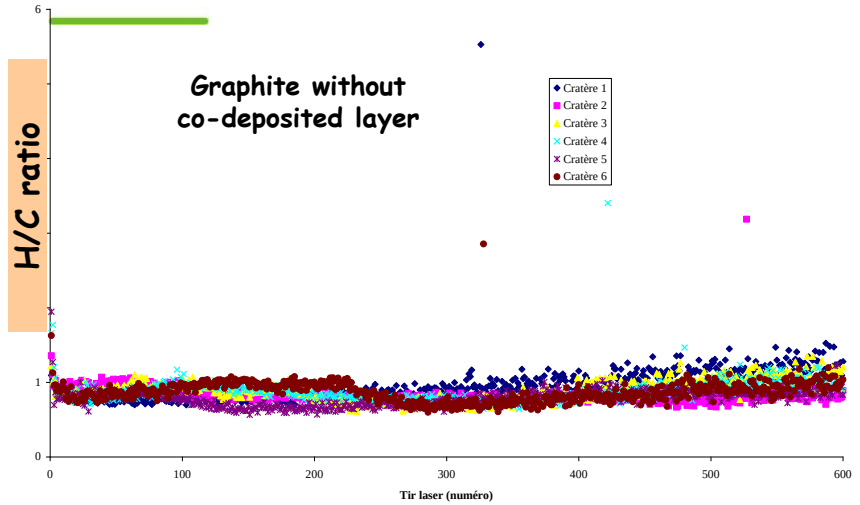
H/C ratio

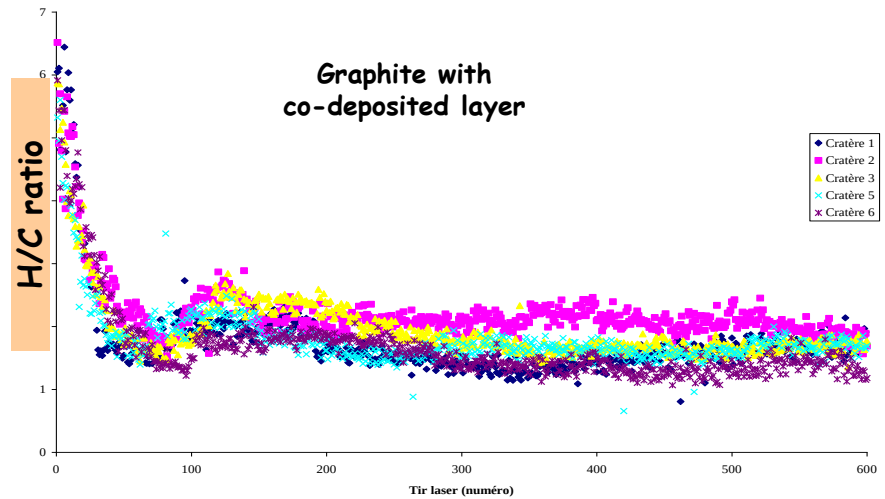


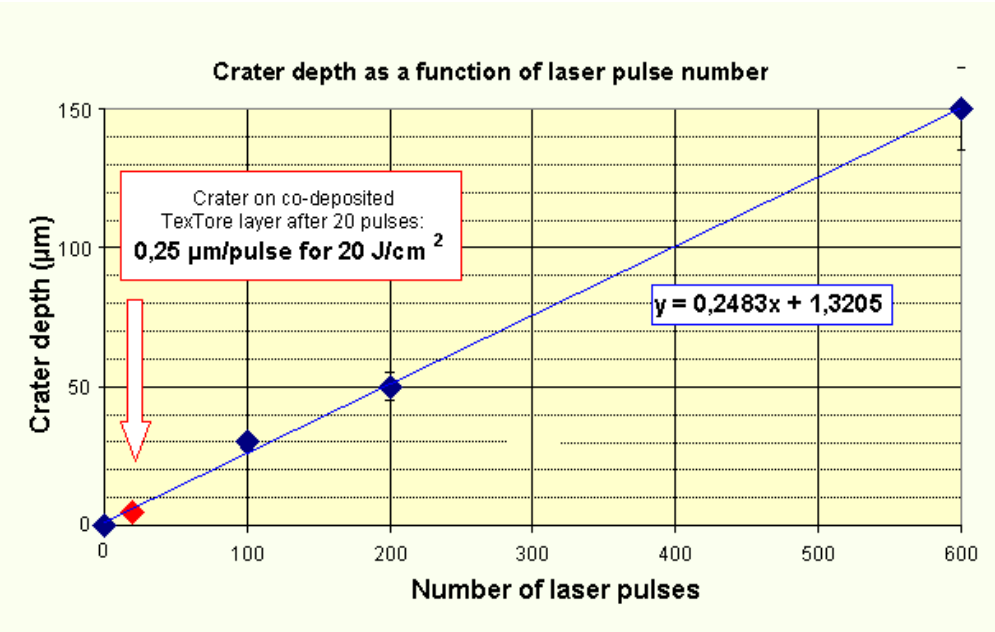
H/C ratio



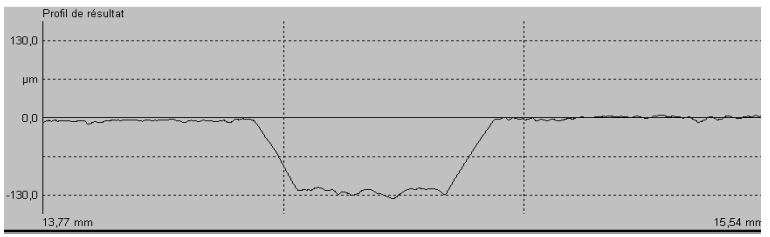
LIBS-results on deposited layer characterisation



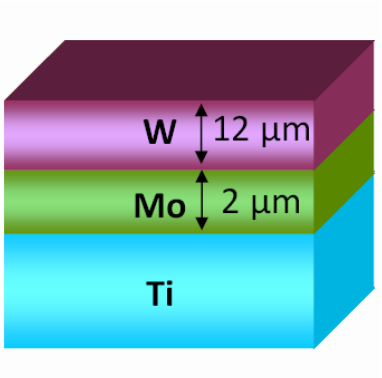


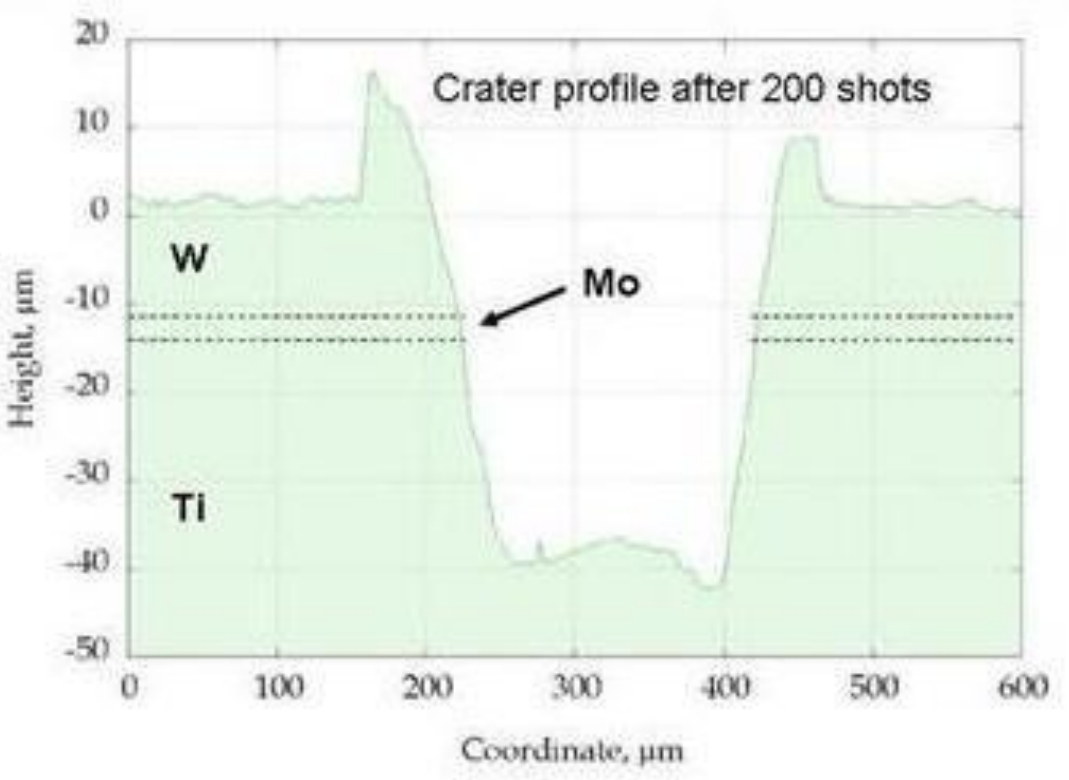


Crater with graphite

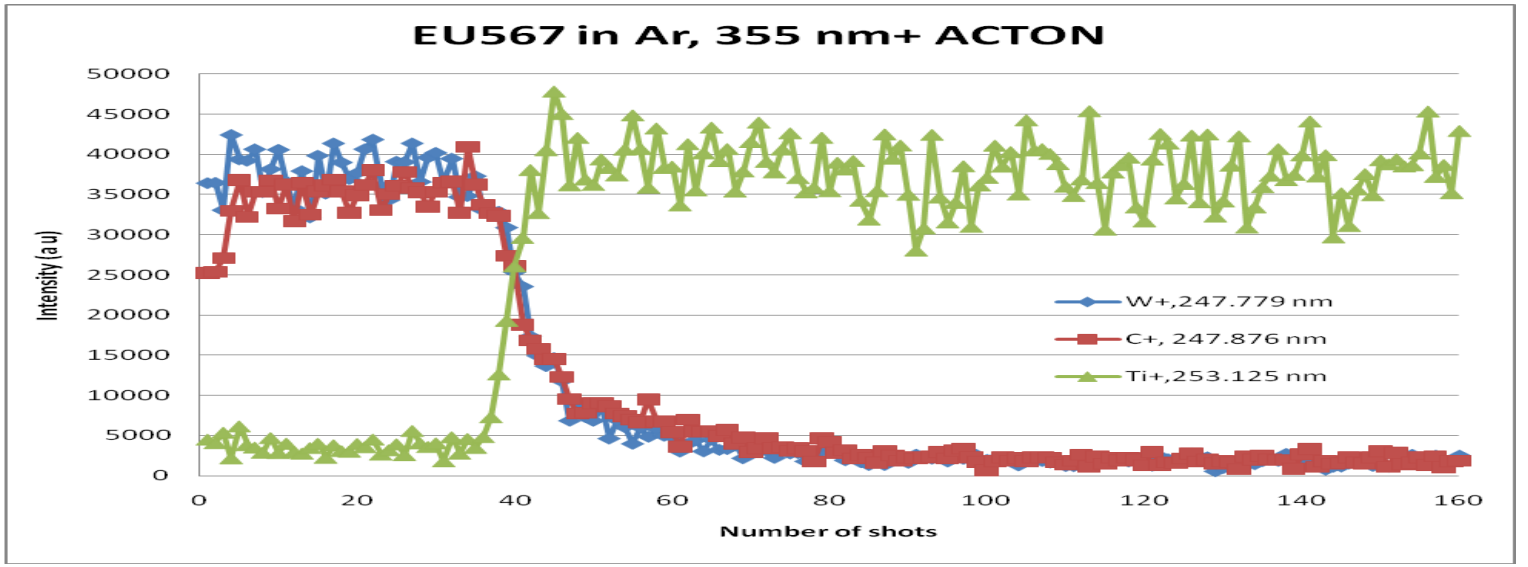


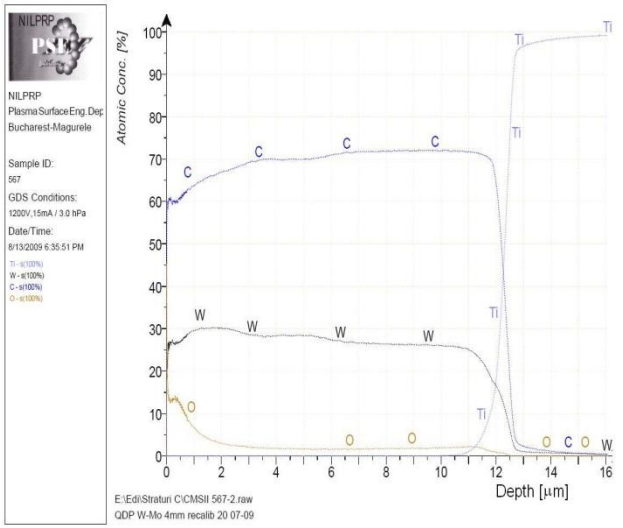
LIBS in-depth analysis





- **Molten bath results in materials mixing**
- **Possible solution ⇨ femtosecond double pulse LIBS**

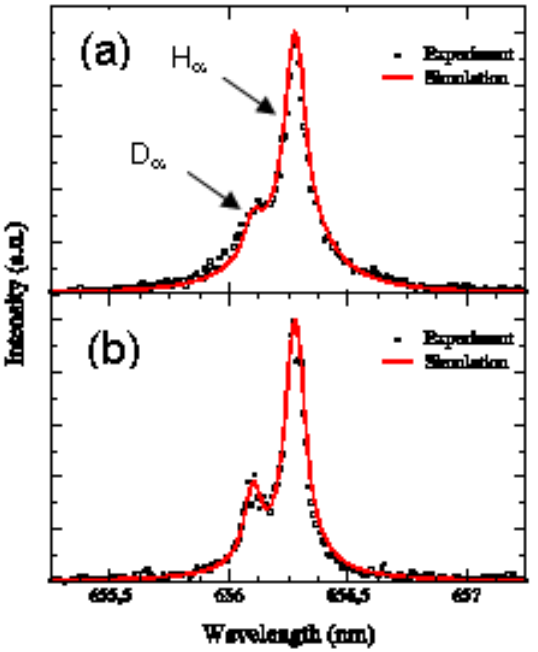




Optimised LIBS

(355 nm, 60 J/cm^2, Ar 1 bar)

Isotopes resolution



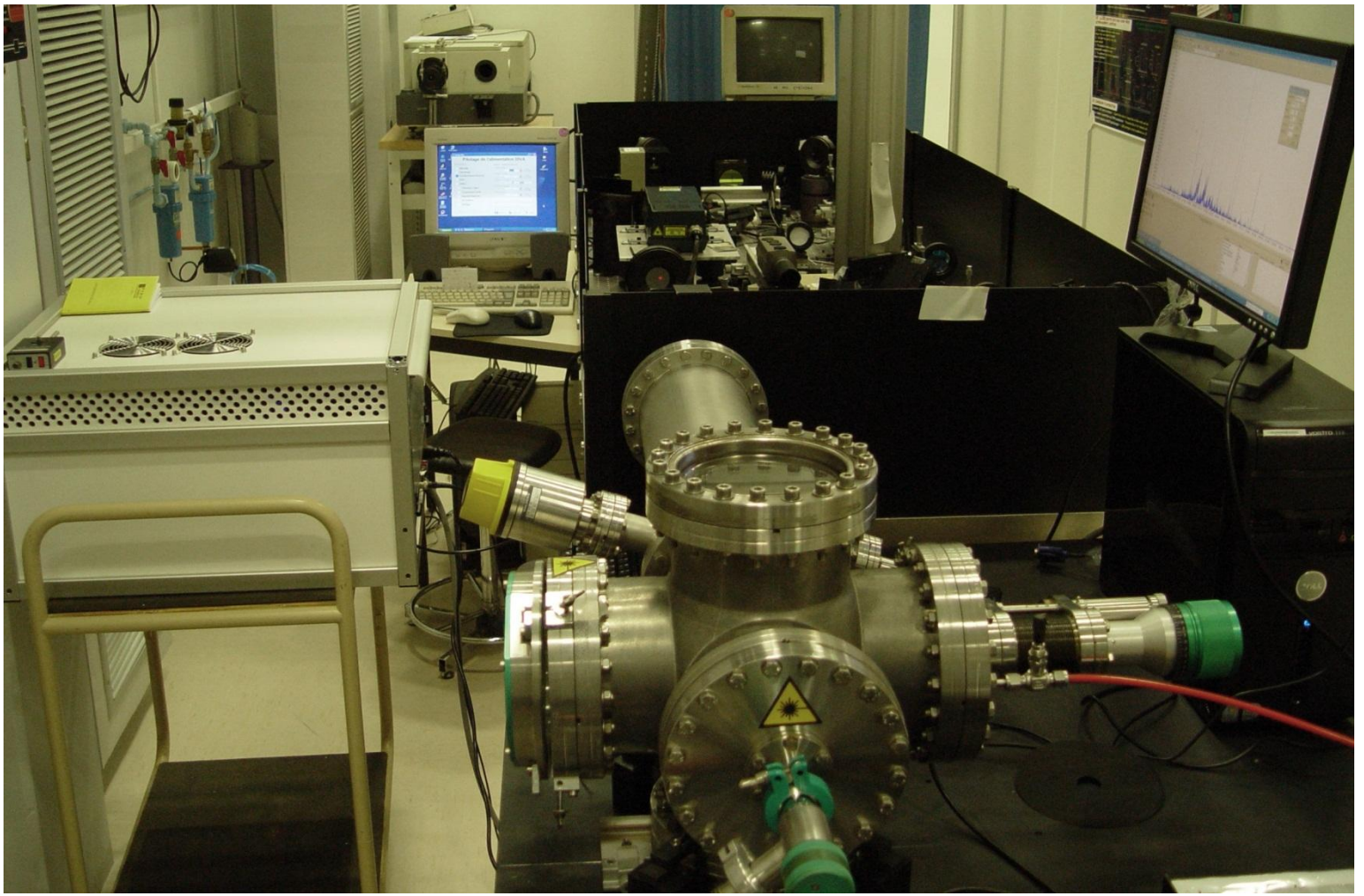
LIBS spectra (H_α and D_α) of a carbon fiber composite tile of Tore Supra fusion reactor with 500 ns (a) and 1000 ns (b) [4]. The intensity ratio difference in recording is attributed to diffusion of lighter H-atoms out of the plume.

[4]. L. Mercadier, J. Hermann, C. Grisolia, A. Semerok, *Plume segregation observed in hydrogen and deuterium containing plasmas produced by laser ablation of carbon fiber tiles from a fusion reactor*, Spectrochim. Acta Part B665(2010) 715-720.

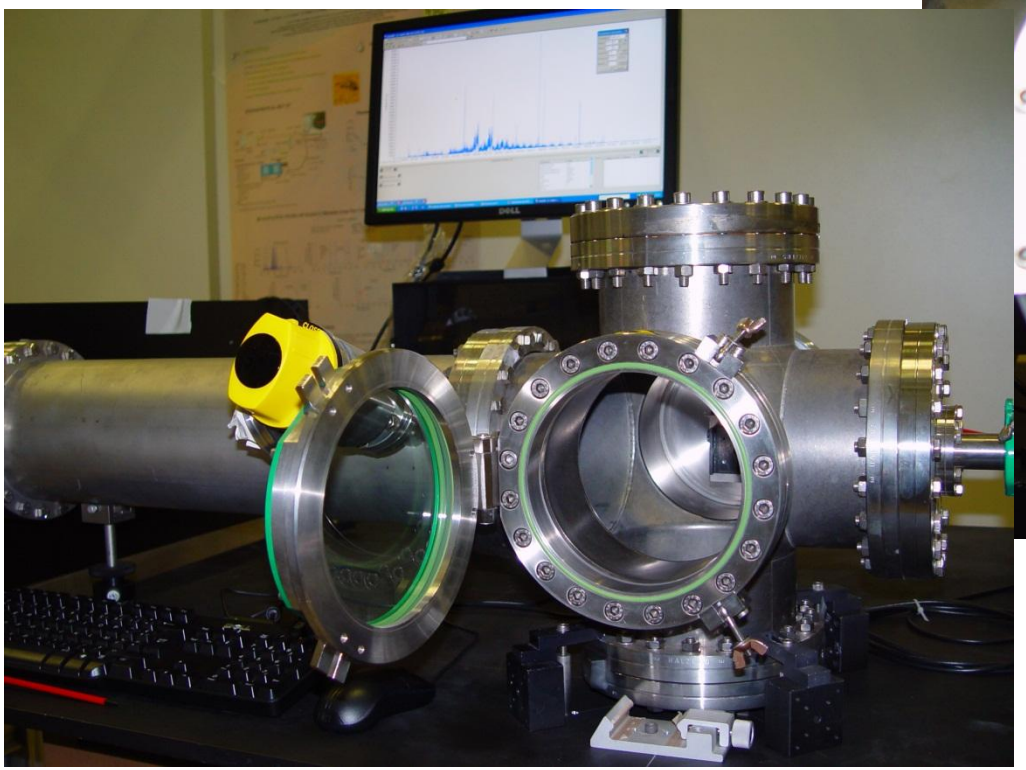
Experimental environment for LIBS in tokamak:

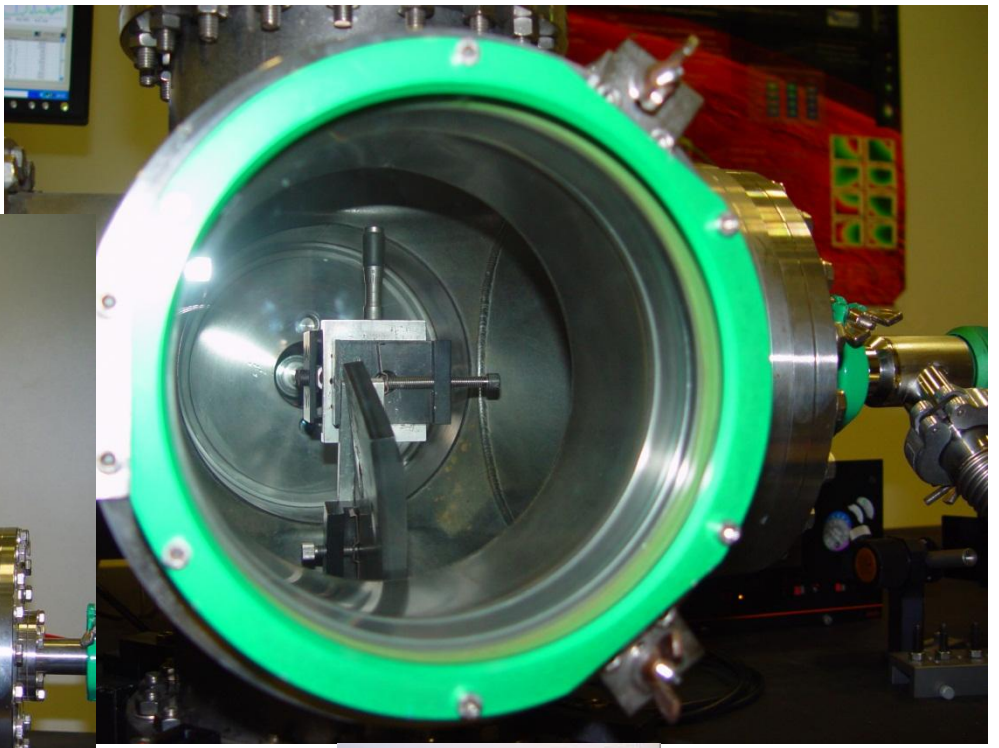
- ❑ vacuum / reduced pressure (He, Ar)
- ❑ temperature (≈300°C)
- ❑ magnetic field (2-5 Tesla)
- ❑ distance (5-15 m) / fiber transport
- ❑ limited angular aperture (50-100 mm)
- ❑ T/D and Be-environment
- ❑ Isotope spectral resolution

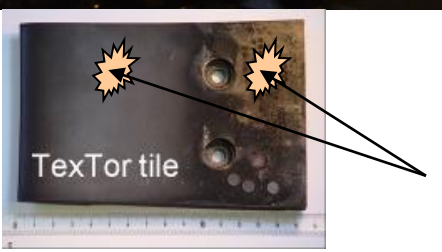
LIBS set-up (F ≈ 2 m)



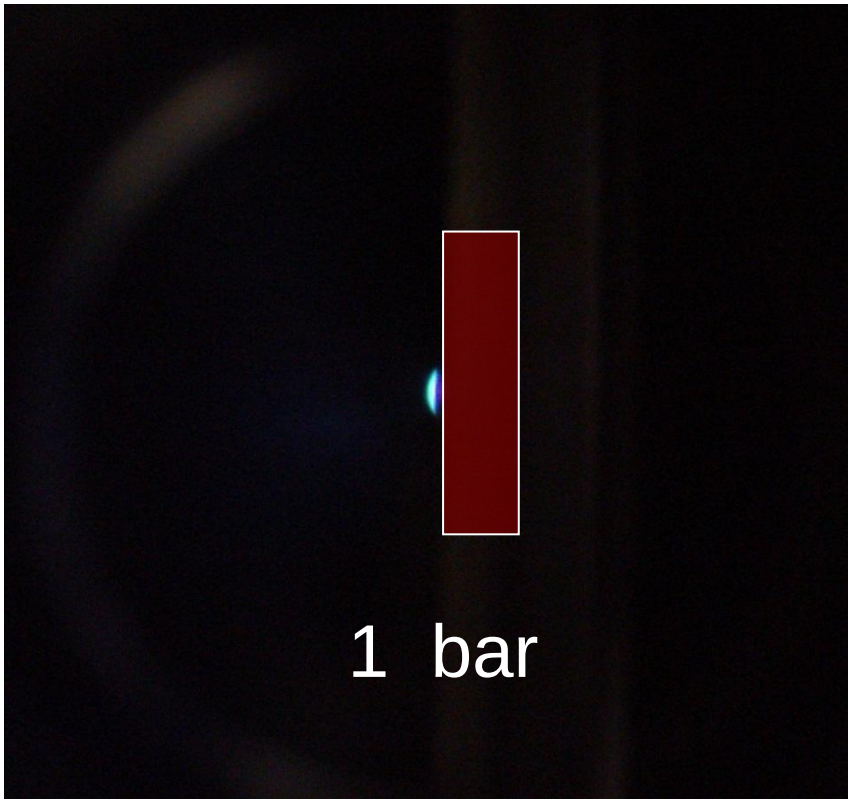
LIBS set-up (F = 2 m, 1- 10^{-3} bar)

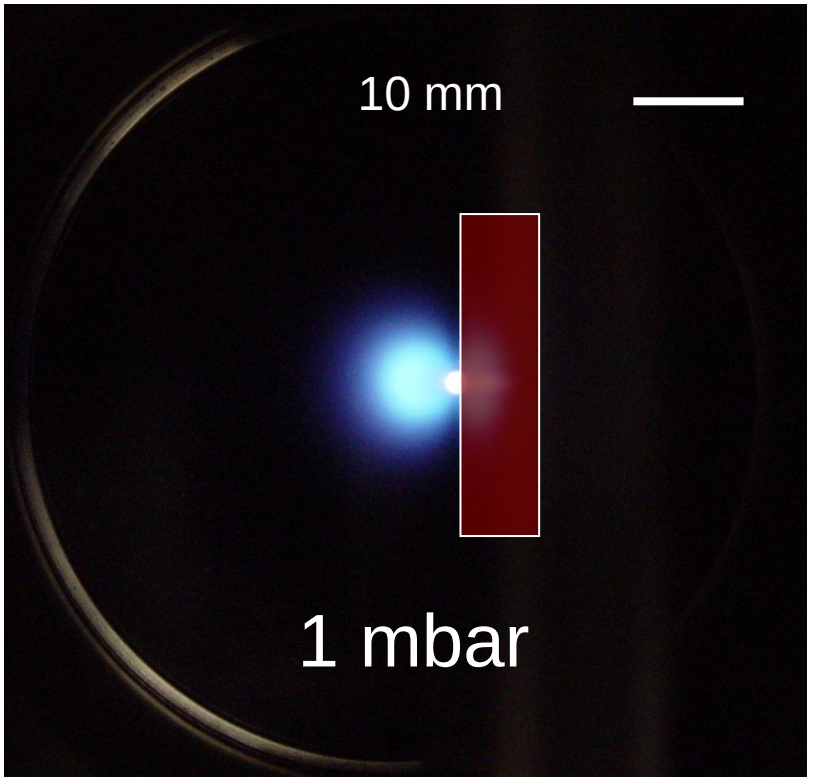




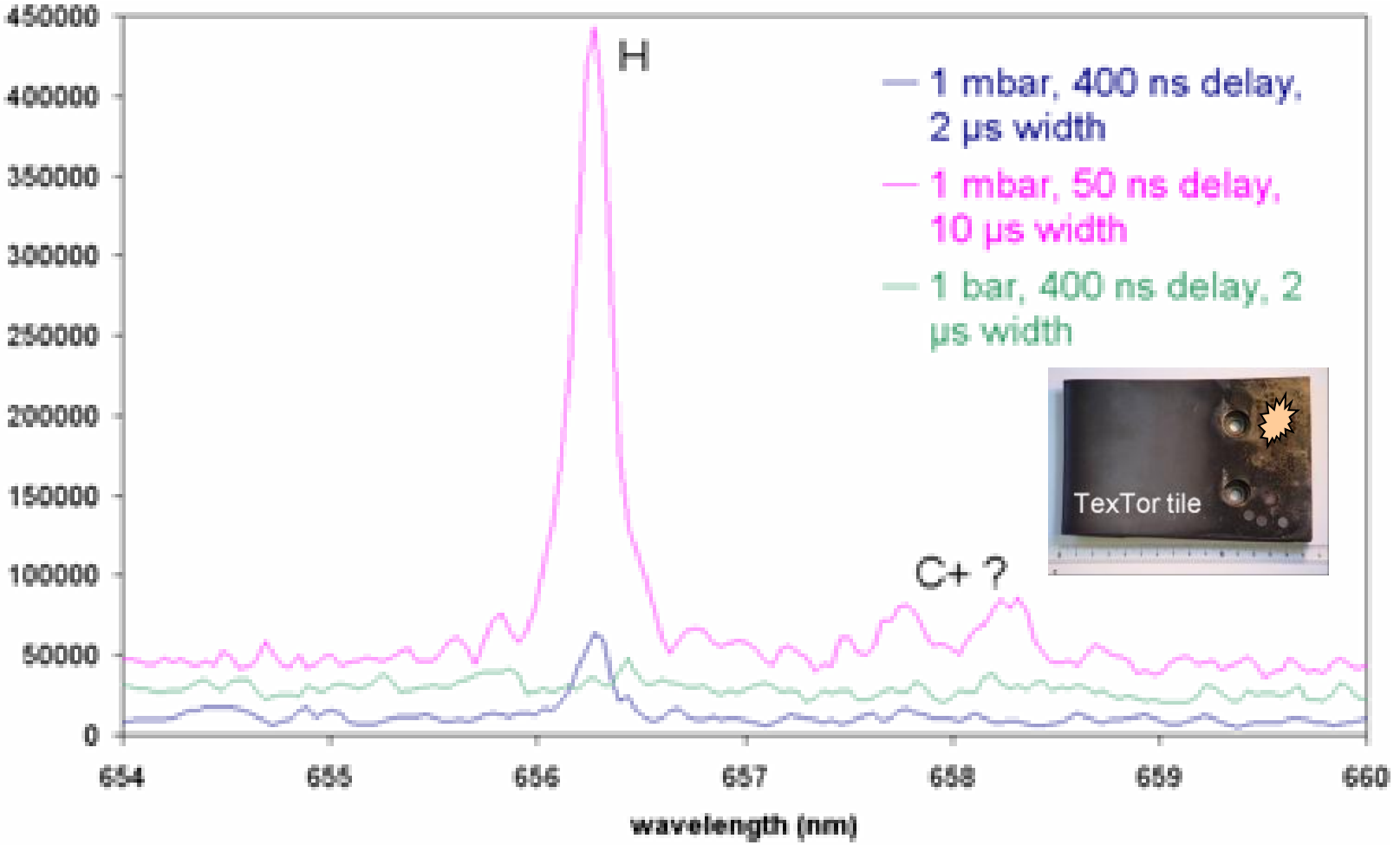


Pressure effect

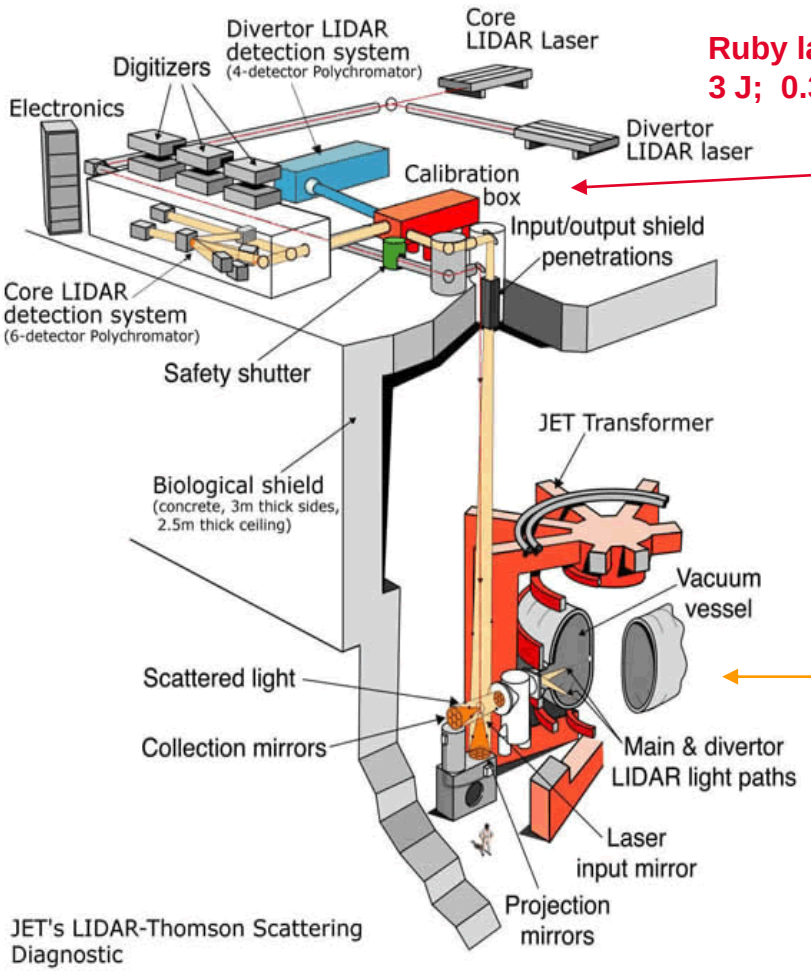




Pressure/delay effect



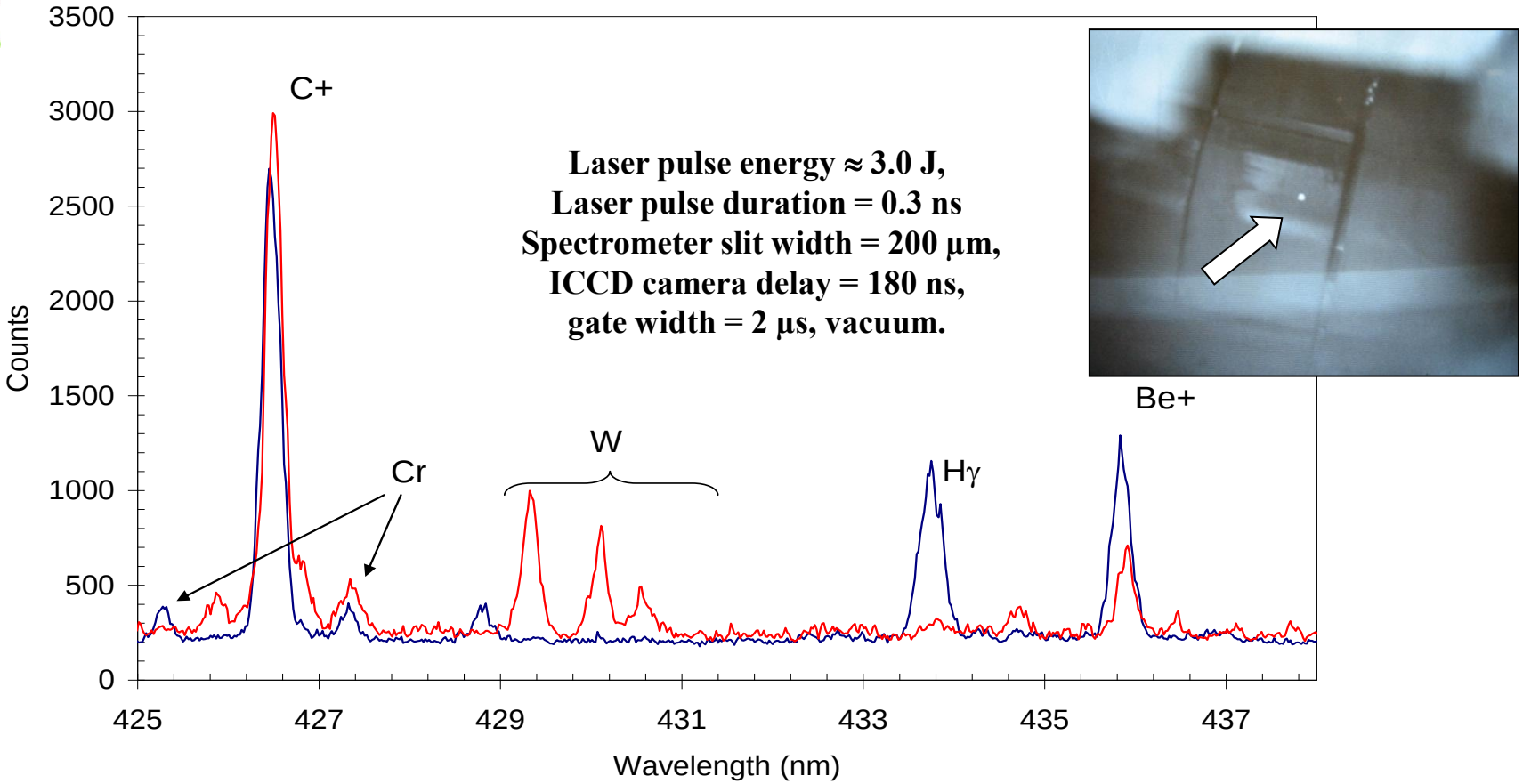
LIBS in-situ on JET



Ruby laser
3 J; 0.3 ns

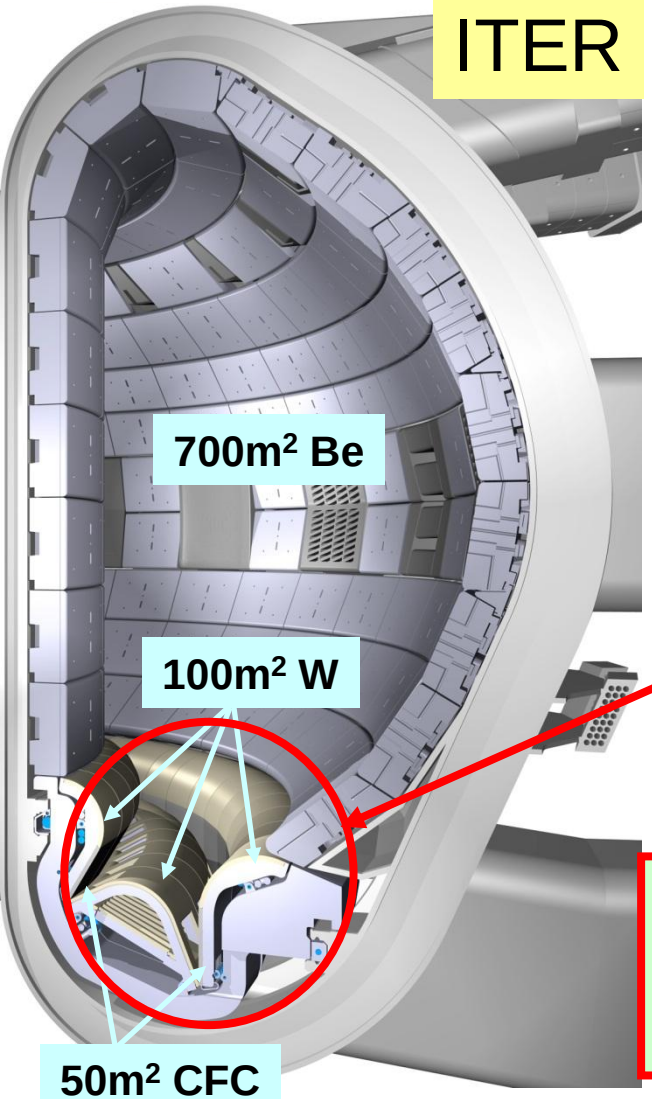
LIBS system

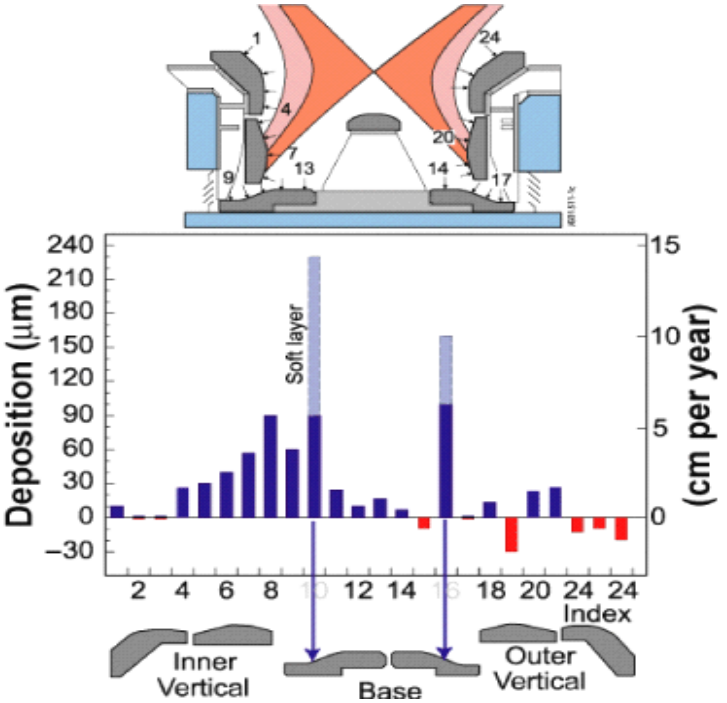
LIBS-spectra (after 1st and 11th laser shots) on W-stripe zone with the deposited layer



[5]. *In situ Laser Breakdown Spectroscopy of JET Deposited Layers (EFDA task JW6-FT-3.33-ART6)*, J-M. Weulersse, D. L'Hermite, J-L. Lacour, F. Le Guern, G. Cheymol, P-Y. Thro, A. Semerok, Ch. Grisolia, M. Kempenaars, M. Stamp, N. Bekris, CEA report NT DPC / SCP 08-293 indice A, December 2008, 72 pages.

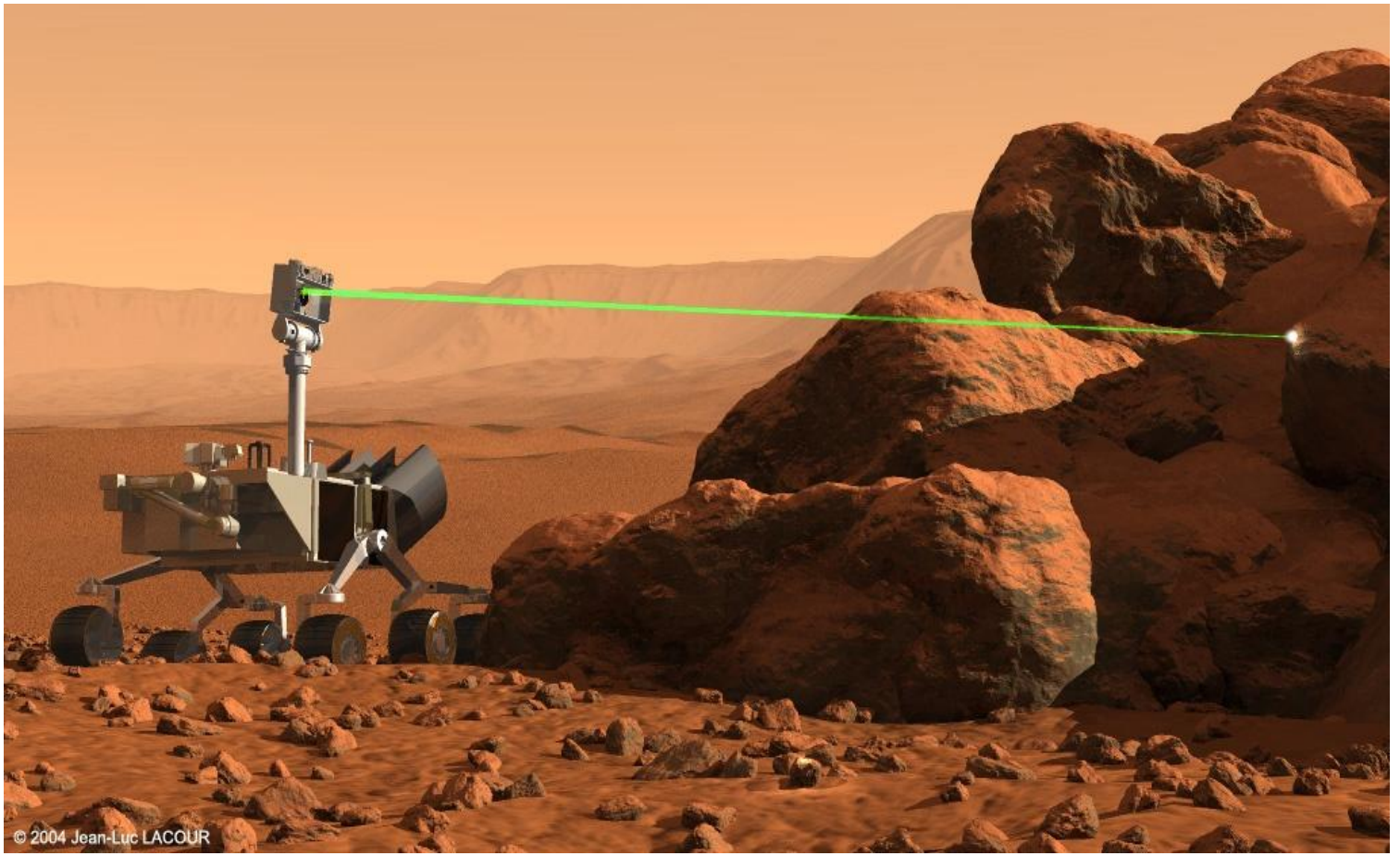
ITER ⟺ JET





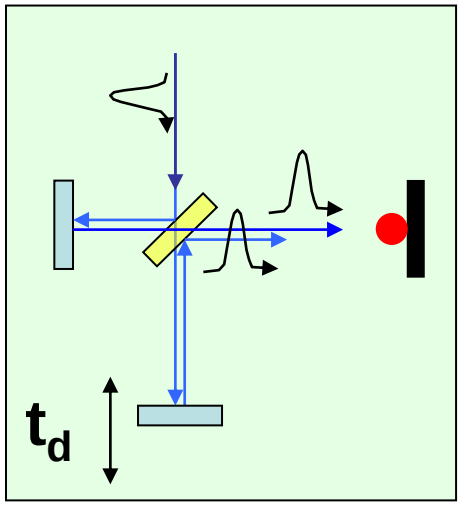
T in deposited layers + limit of T inventory:
Need of removal techniques in ITER-environment
100 g of T per day ~ 1000 g of C
1000g of C in 6 hours = $4\ 10^{-2}$ g of C per s

Mission on MARS (November, 2011)
(NASA project CHEMCAM)



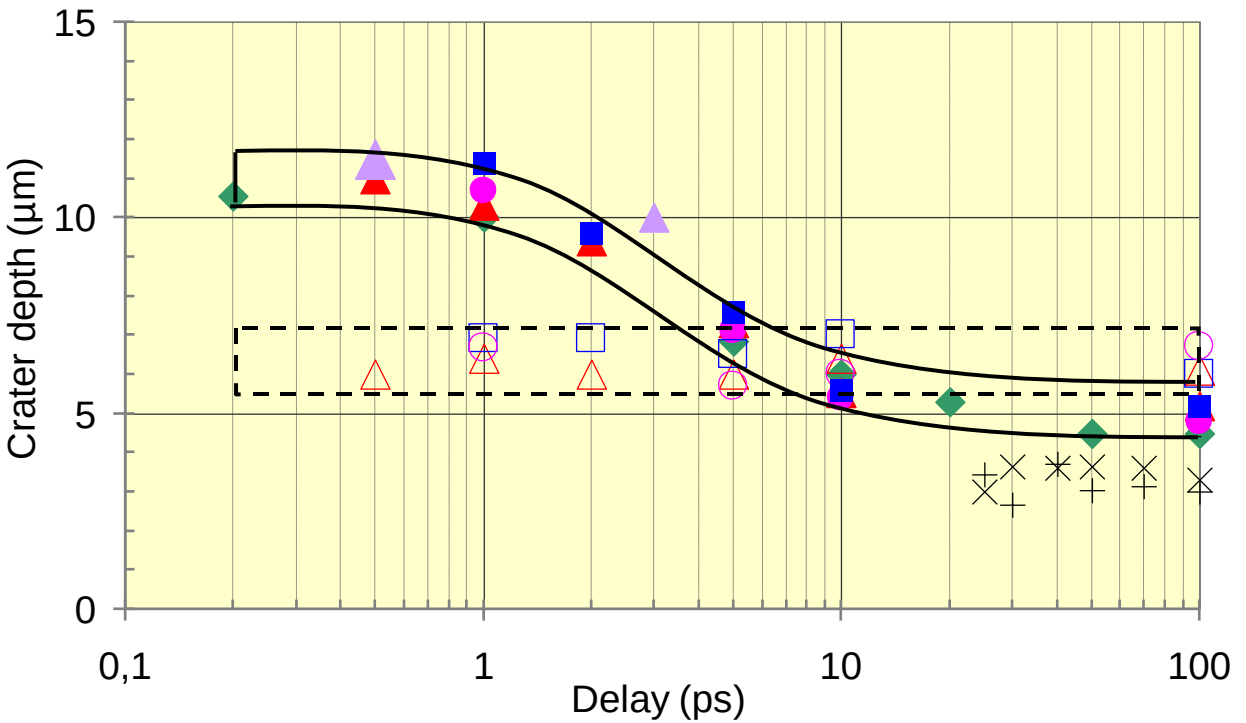
Possible improvements

ULTRASHORT DOUBLE PULSE LASER ABLATION



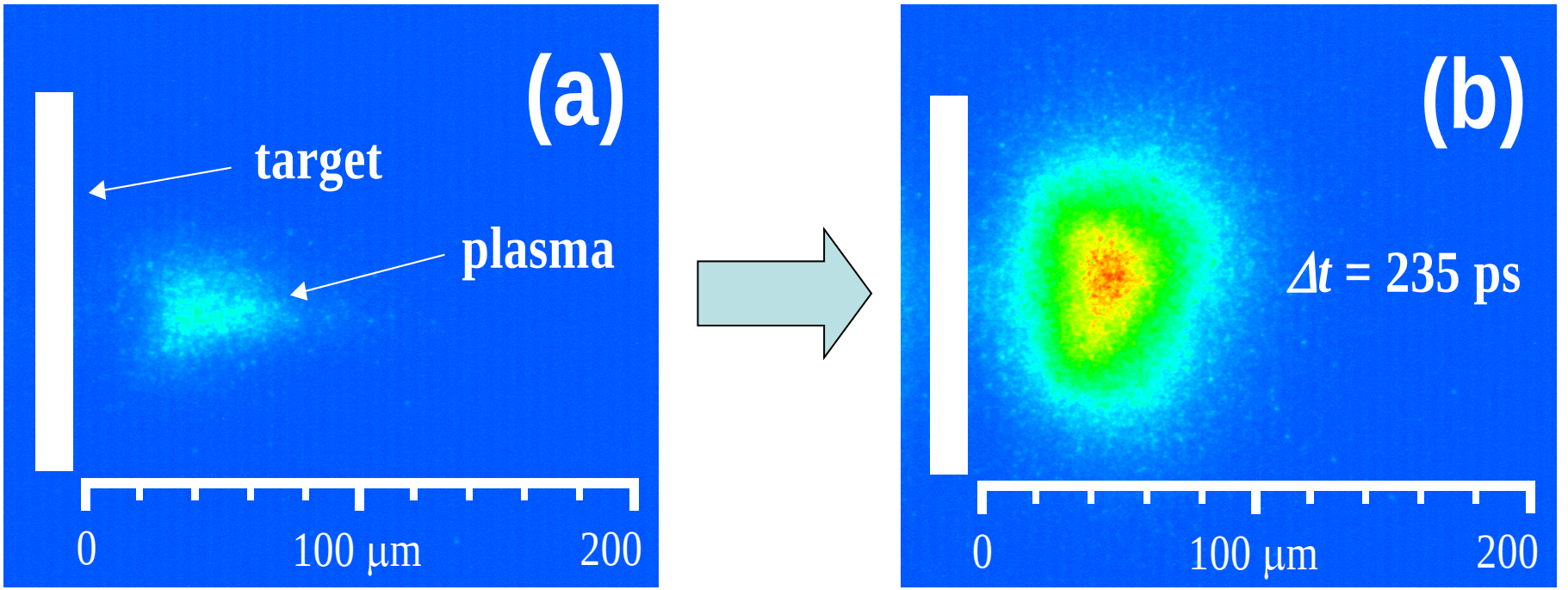
Target – Cu, air
E = 20 µJ x 2

T_{laser} : 50 fs, 100 fs, 200 fs, 500 fs, 1 ps, 5 ps, 10 ps



Possible improvements

ICCD camera: 3 ns delay, 1 μs gate width

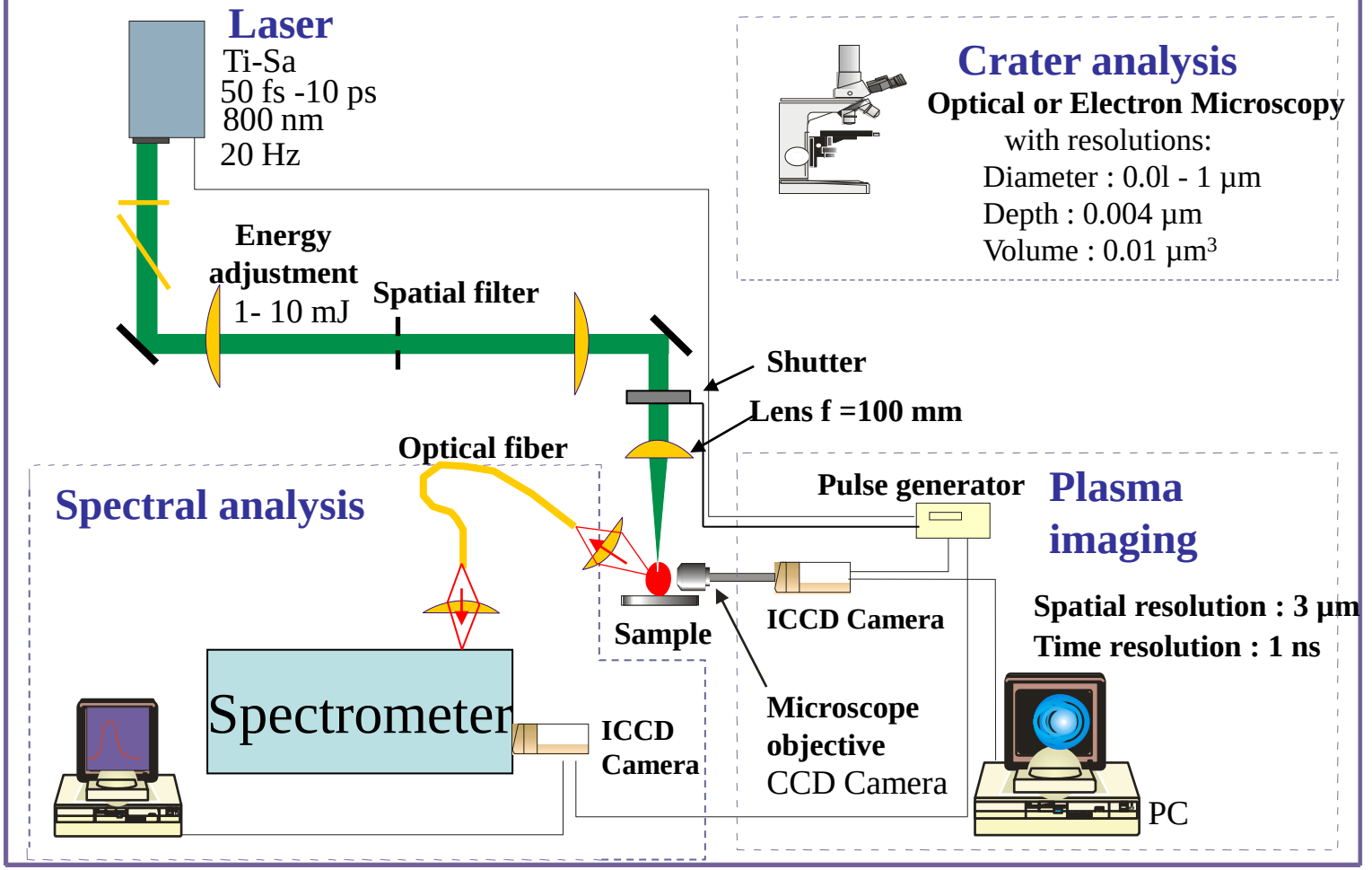


[6]. *Ultrashort Double Pulse Laser Ablation of Metals*, A. Semerok, C. Dutouquet, Thin-Solid-Films, 1 April 2004; 453-454, pp. 501-505;

CONCLUSIONS

- ✓ Successful **qualitative** LIBS-application for tokamak tiles (1 bar, 1 mbar, F = 250-2000 mm) and in-situ with JET LIDAR;
- ✓ Adequate understanding of the processes, problems and difficulties.
- ✓ Possible improvements.
- ✓ Further steps – **quantitative** LIBS with ITER-like samples, Tokamak integration (mobile), and in-situ validation in European tokamaks.
- ✓ LIBS data-bank of tokamak plasma facing surfaces.

CEA Saclay fs-LIBS set - up



Saclay Laser /Matter Interaction Center (SLIC) – CEA Saclay