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Characterisation of Wall Components in Fusion Devices by Laser-Induced Breakdown Spectroscopy

A. Huber, B. Schweer, V. Philipps, R. Leyte-Gonzales, N. Gierse, M. Zlobinski, S. Brezinsek, V. Kotov, Ph. Mertens, U. Samm, G.Sergienko

Institute of Energy and Climate Research - Plasma Physics, Forschungszentrum Jülich GmbH, Association EURATOM-FZJ, Partner In the Trilateral Euregio Cluster, Jülich, Germany

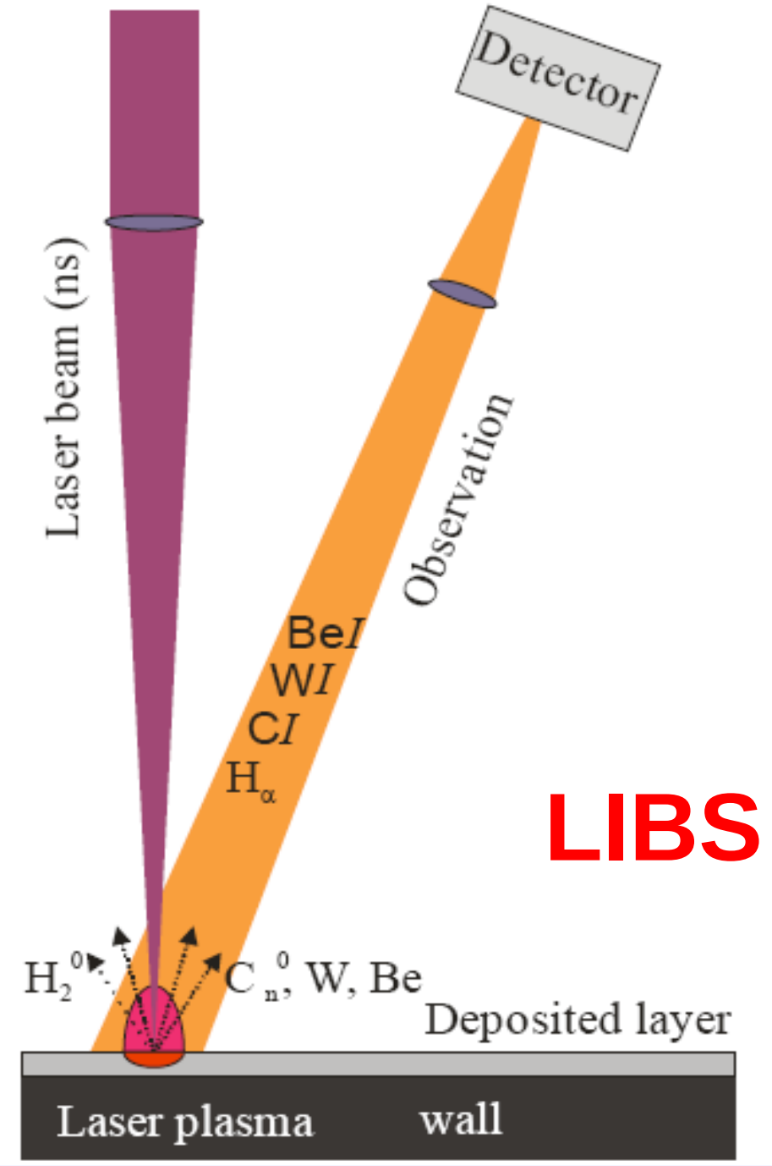
Motivation

In situ characterisation of deposition layers (local and temporal measurement):

- **growth rate of layers**
- **layer thickness**
- **composition of layer material**
- **tritium retention**

and deposition layer detritiation are of major importance for fusion device operation.

The Laser-induced breakdown spectroscopy (LIBS) has been developed in FZJ for in situ determination of the stored amount of T and for charaterisation of the layer deposition on the wall components in fusion devices.

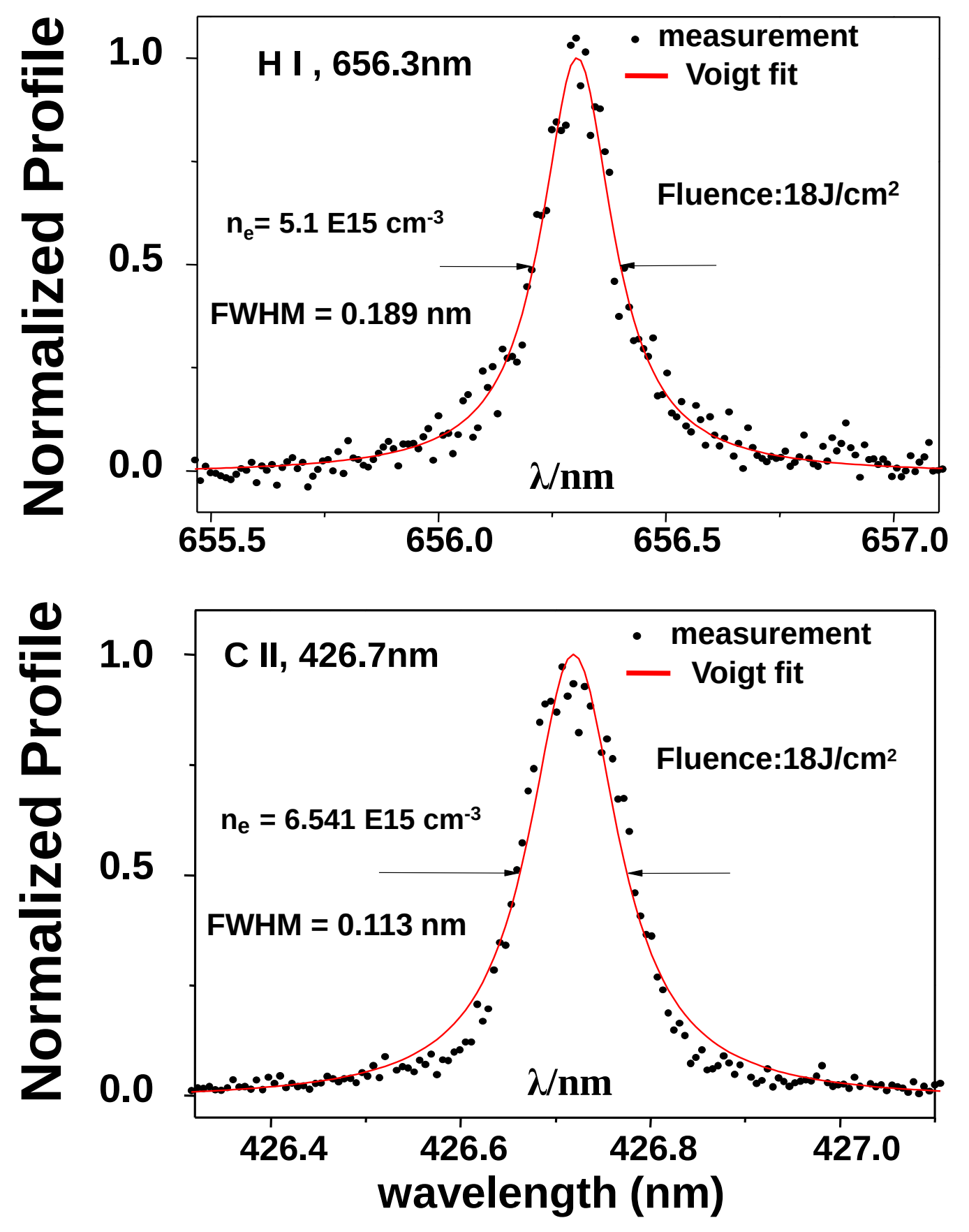


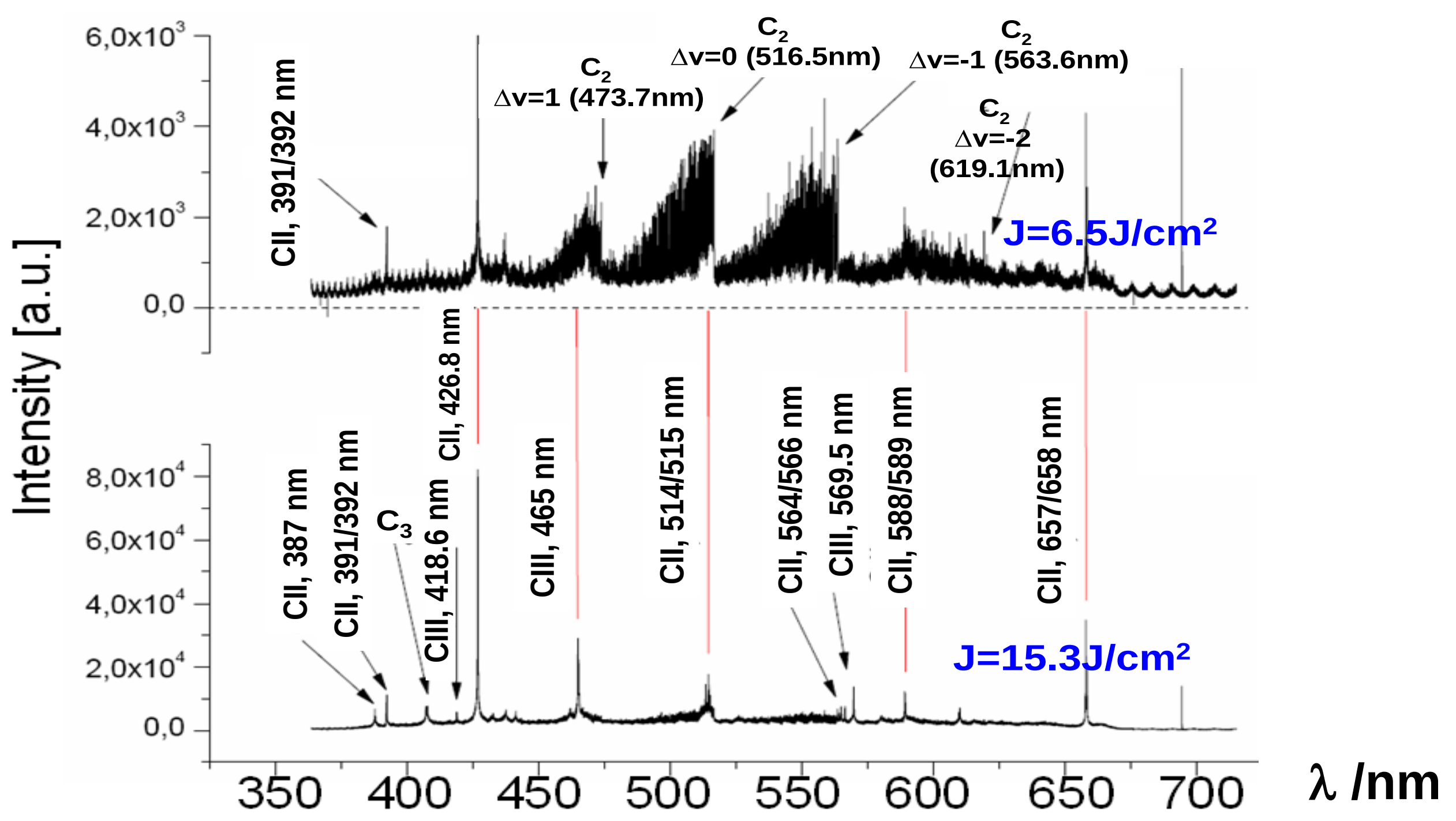
Established method in material analysis, but in <u>gaseous atmospheres</u>

LIBS: Open Questions

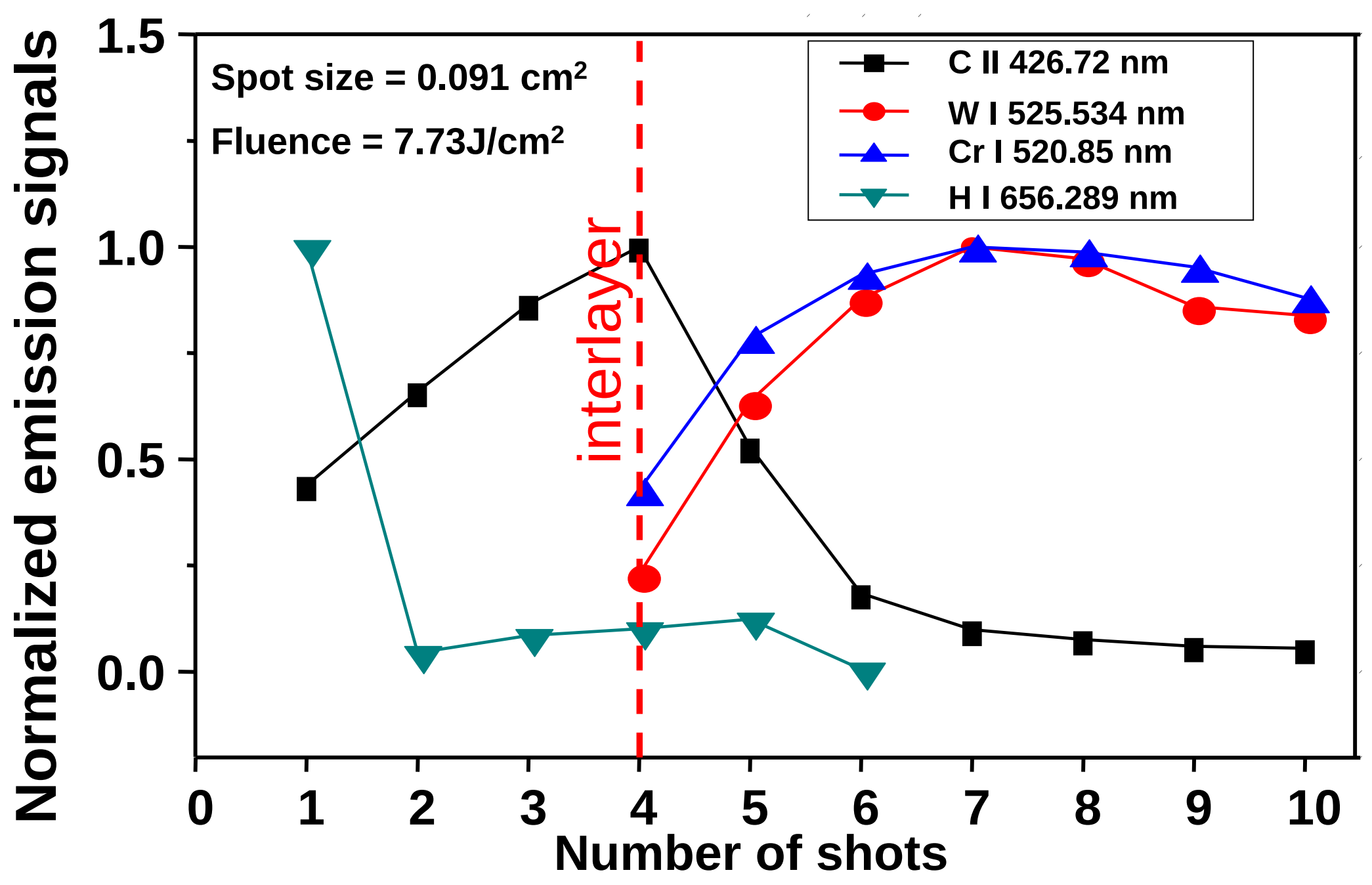
- **Application of the LIBS method under UHV conditions**
- **Sensitivity: Ratio of the ablated atoms to the number of the emitted photons**
- **Reproducibility/stability of LIBS Signals**
- **The influence of the background pressure on the LIBS plasma parameters**
- **Influence of permanent magnetic field**
- **Choice of the laser wavelength and optimal laser pulse duration**

LIBS Experiment in the Lab with the pre-defined samples

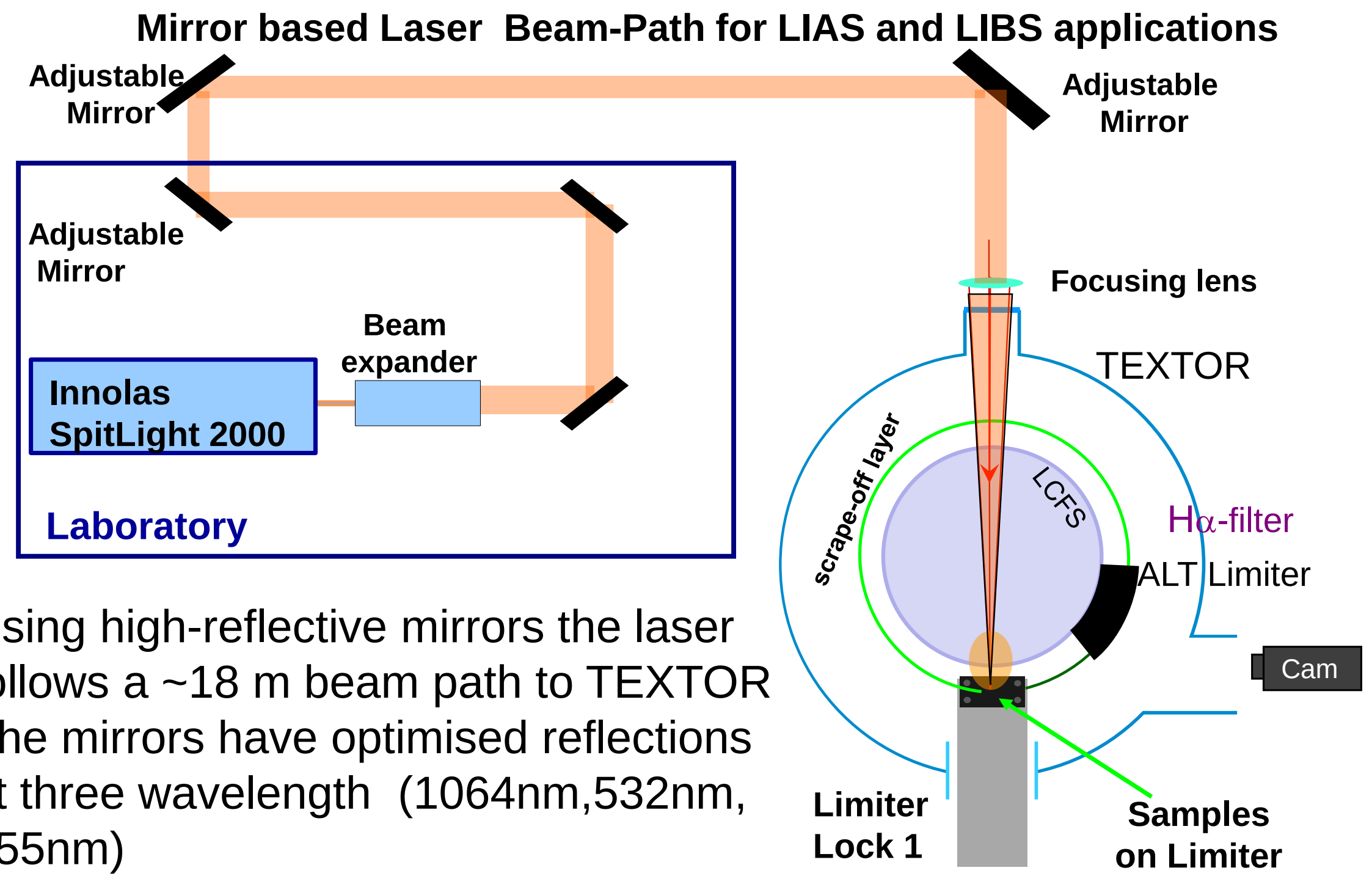




- **Power density >100MW/cm² (Q-switched laser, for ~10ns.)**
- **N_e ≈6.0×10²¹m⁻³, T_e≈2eV**

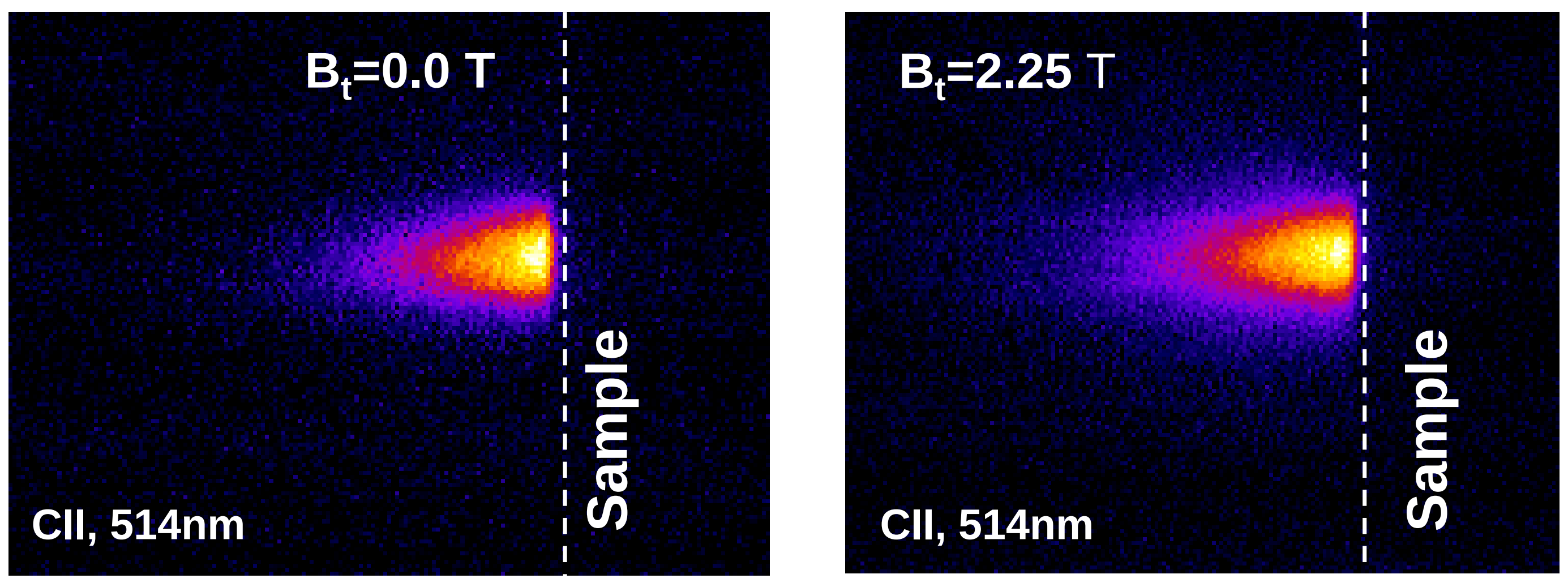


LIBS spectra from a 3.2 µm thick a-C:H layer on W substrate with a Cr interlayer

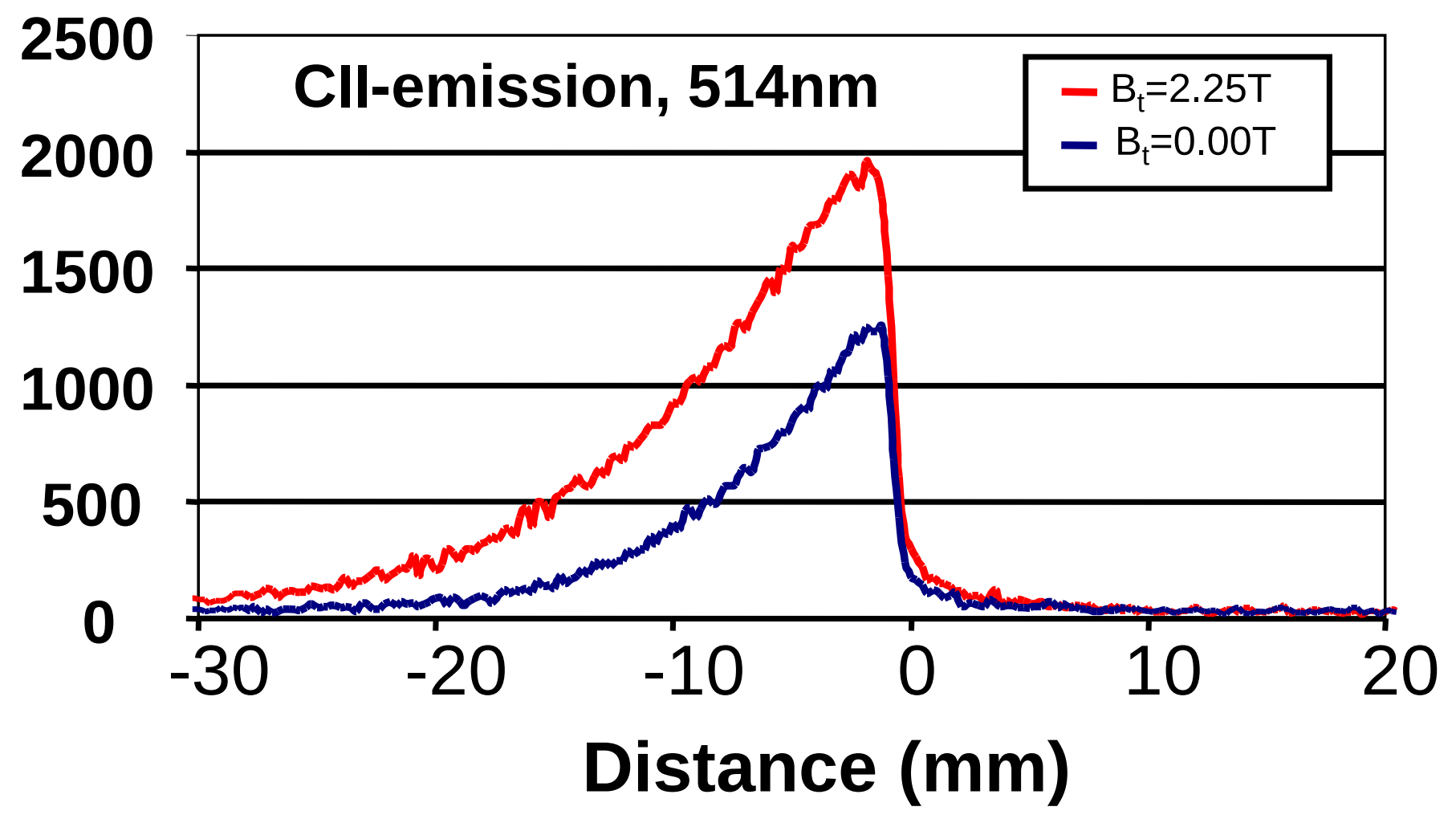


- Using high-reflective mirrors the laser follows a ~18 m beam path to TEXTOR
- The mirrors have optimised reflections at three wavelength (1064nm,532nm, 355nm)

Spatial distribution of CII (514nm) emission line for various magnetic fields

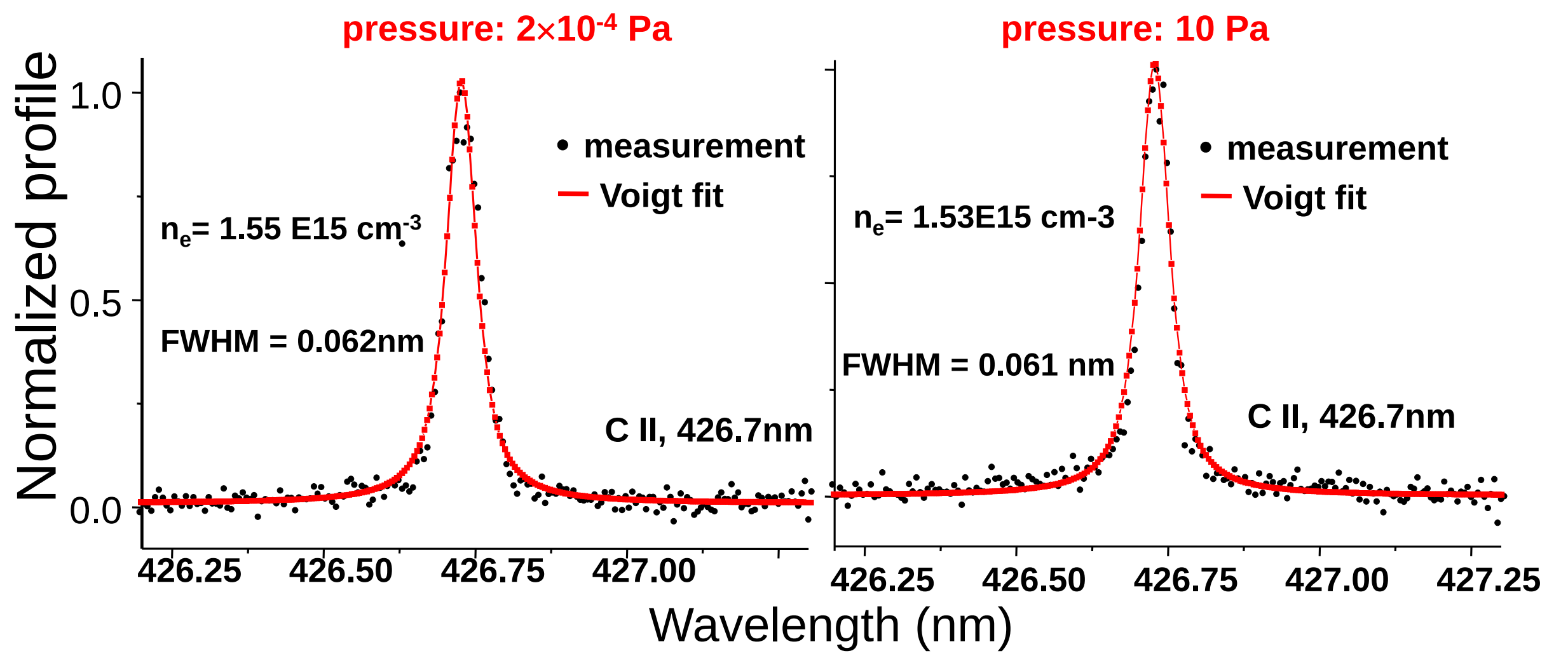


- **Nd:YAG 2.5J, 7ns, 1064nm, 532nm, 354nm**



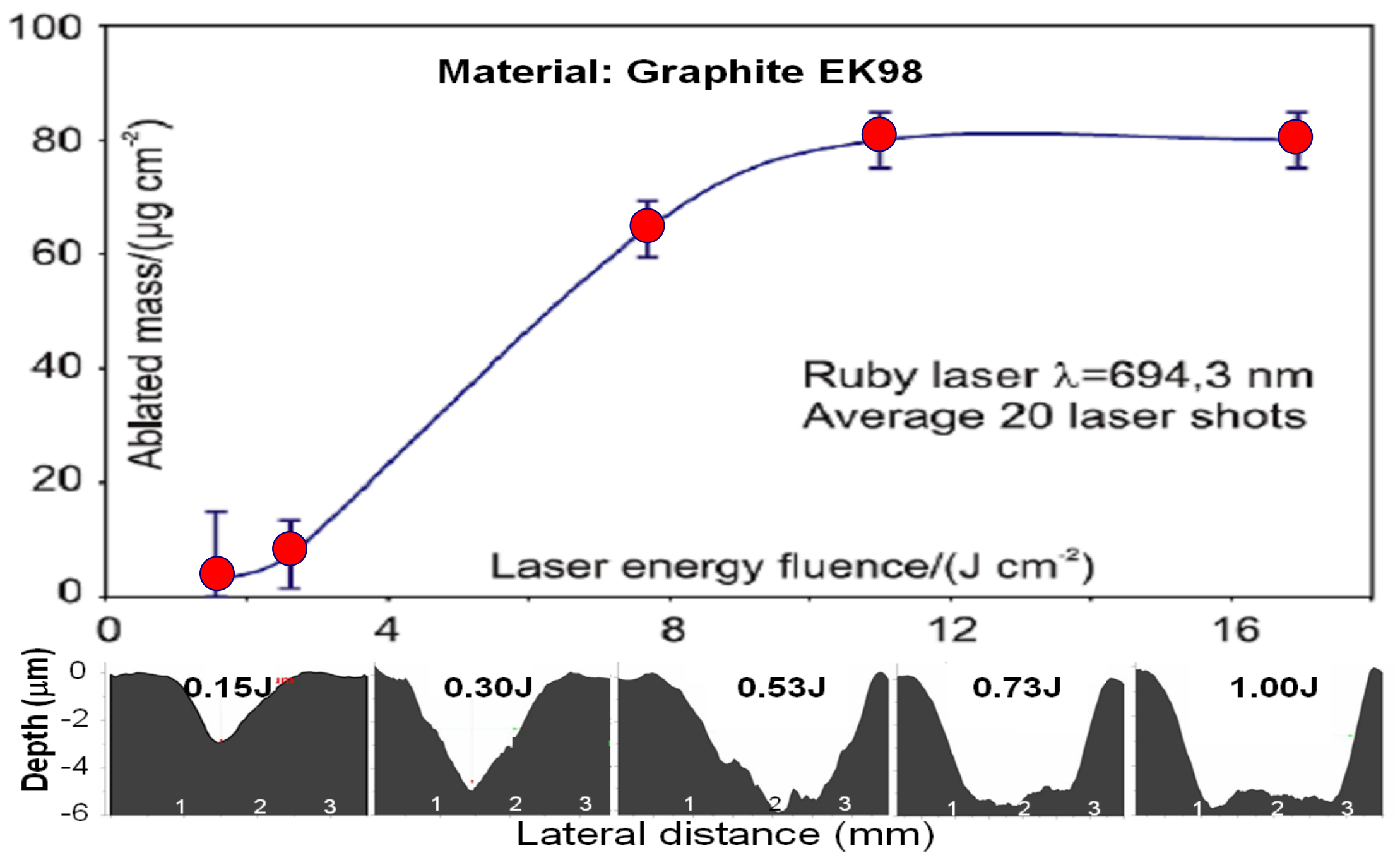
- **Enhancement in the CII intensity with Bt**
- **Increase of the laser induced plasma plume size**
- **The laser plasma lifetime (decay time) is below 1 µs.**

The influence of the background pressure on the LIBS plasma parameters

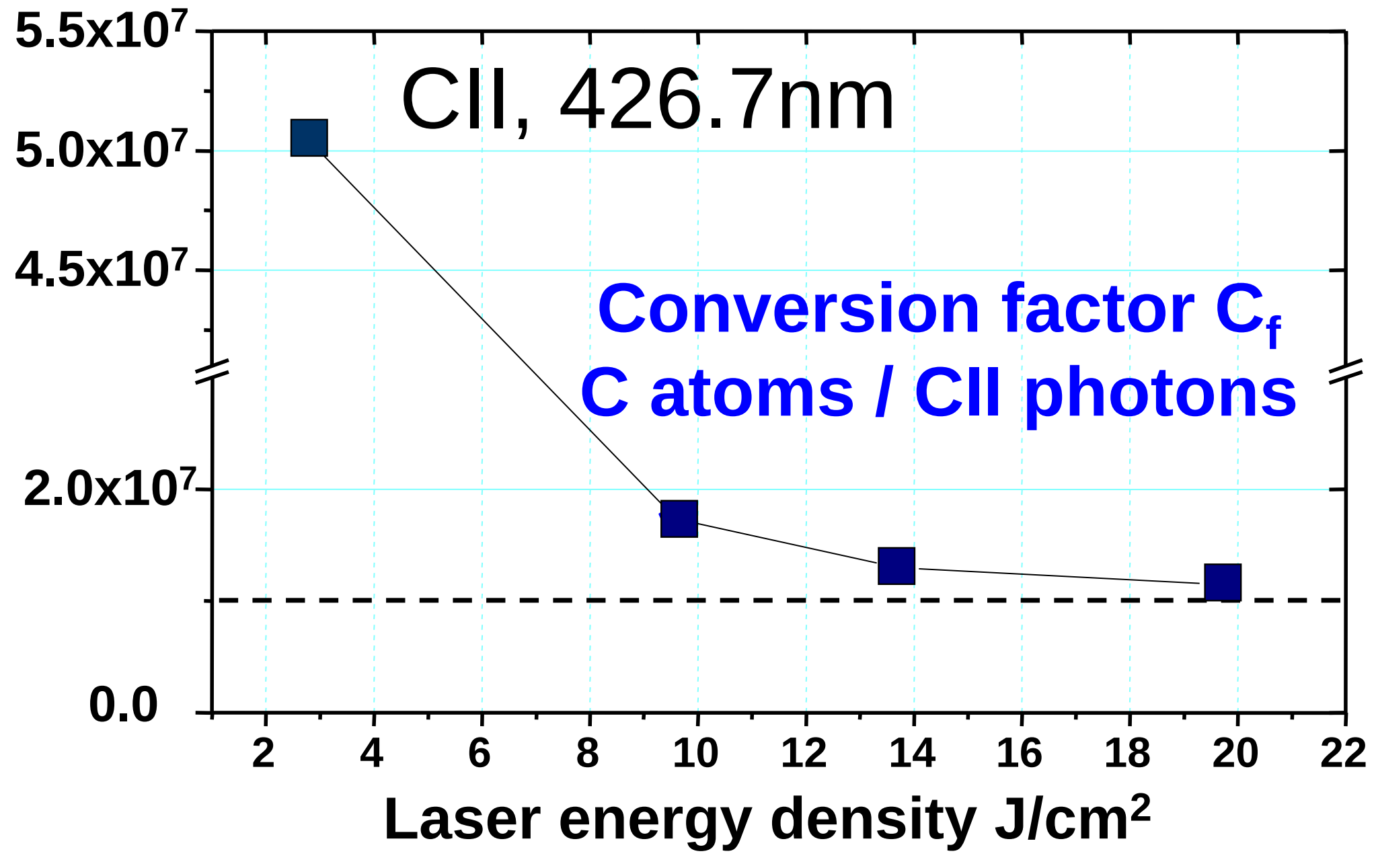


- **No significant influence of the base pressure (in the measured range between 10⁻⁶mbar and 0.1mbar) onto the laser plasma parameters**

Sensitivity of LIBS method

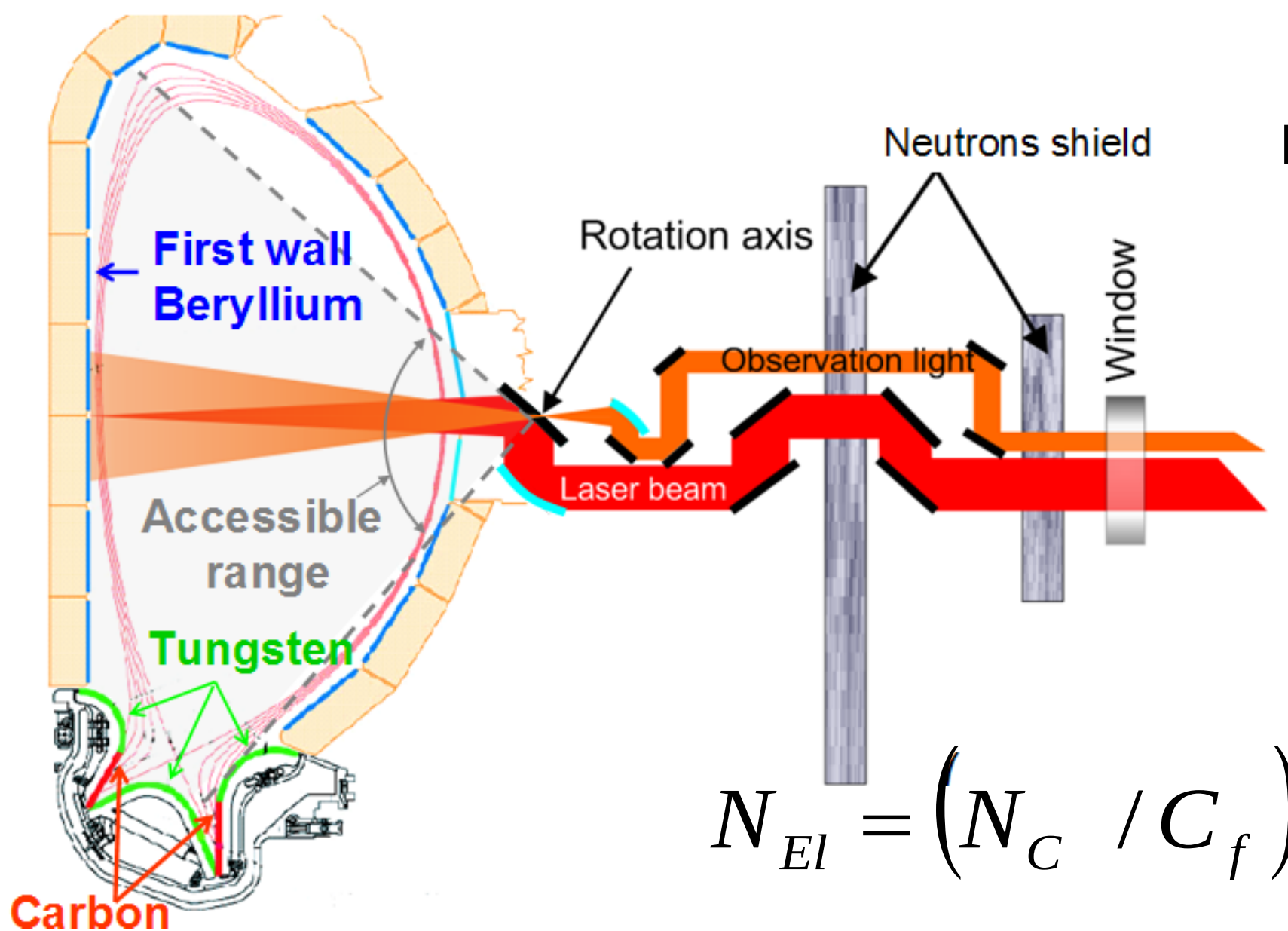


- **Ablation rates ~0.3÷0.6µm/shot in the energy density ~2.6÷7J/cm² and saturates at about ~0.7µm/shot for higher energies.**



- **The stability of the Conversion factor is reached at fluence > 12 J/cm2, leading to N_{R}/Ph_{Tot} ≈ 10⁶ C atm / ph**

Application to ITER: coaxial observation: reflective optics +wide range high resolution spectrometer



Low divergence lasers (<0.5mrad) are needed to transport the light by reflective optics (mirror system) over long distances (≥50m) to the focusing mirror in ITER.

- **$\Delta\Omega = 2\times10^{-6}$ sr is the solid angle**
- **T=0.1 is the transmission factor of the optical system**
- **η=10% is the quantum yield of the detector**
- **$C_f \approx 10^6$**

$$N_{El} = \left(N_C \;/ C_f\right)\times T\,\frac{\Delta\Omega}{4\pi}\,\eta$$

To obtain a good photoelectron statistic 1/√Nel≤3% to resolve the LIBS signal, about 10¹⁸C atoms must be ablated. This corresponds to the content of carbon atoms in a 100 nm layer.

Summary

- **LIBS is intended to monitor in situ the thickness and composition of layers deposited on the first wall between pulses.**
- **The energy density (Fluence) has a strong impact on the laser-induced plasma parameters and therefore in the amount of emitted photons.**
- **Laser fluence < 10 J/cm² for layer analysis in a single laser pulse is not recommended for ITER operation (high instability).**
- **The stability of the Conversion factor (N_R/Ph_{Tot}) is reached at fluence > 12 J/cm², leading to N_R/Ph_{Tot} ≈ 10⁶ C atm / ph i.e. LIBS under HV conditions provides sufficient signal to be resolved.**
- **No significant influence of the base pressure onto the laser plasma parameters.**
- **Enhancement in in the CII intensity with B_t. Increase of the laser induced plasma plume size with B_t.**

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