**Calibration techniques for Thomson scattering  
diagnostics on large fusion experiments**

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Measuring the electron density and temperature with laser Thomson scattering requires an accurate calibration of the entire diagnostic. For the temperature, a relative spectral calibration is required, for the density additionally an absolute calibration (e.g. using rotational Raman or Rayleigh scattering). In practice, these calibrations change over time (drift of beam path, coating on observation windows, etc.), which requires frequent recalibrations. On larger fusion experiments, this is particularly challenging. Longer beam paths are more sensitive to alignment drifts, calibration measurements have to be arranged with a tight experiment plan and torus hall access may be restricted for longer periods due to radiation safety or during operation of a superconducting magnet system. At Wendelstein 7-X (W7-X), a number of techniques are developed to make existing calibration methods more resilient against alignment changes, to reduce the time required for calibration measurements, and to prolong the time between recalibrations.

An in-situ spectral calibration is developed using a tunable OPO laser for Rayleigh scattering. As it is often the case for Rayleigh scattering, stray light is an issue. However, this also offers the possibility for an “emergency calibration” using only the stray light when a quick recalibration is required during an experimental campaign. Furthermore, it is investigated if the accuracy of the spectral calibration can be improved by using an additional Nd:YAG laser with a different wavelength for the Thomson scattering measurements (dual wavelength Thomson scattering).

For the absolute calibration, a position-sensitive Raman calibration has been developed, in which the laser alignment is monitored and included in the resulting calibration factors. For large experimental devices, the beam position is controlled automatically. However, these control systems can fail temporarily and for pulsed lasers, like the ones used for laser Thomson scattering, the beam pointing stability alone leads to a scatter in the beam position that cannot be mitigated and that becomes important for long beam paths. Including the beam position in the calibration improves the density profile quality and allows for longer times between calibrations. For experiments in which the position monitoring failed (e.g. due to data acquisition issues or hardware failures), a machine-learning algorithm has been developed which determines the impact of laser misalignment on the density profiles and allows for a correction.

We believe that the techniques developed at Wendelstein 7-X may be essential for other large fusion experiments like, for example, ITER.