Laser-Aided (and other) Plasma Diagnostics for Wakefield Acceleration at AWAKE

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Plasma wakefield acceleration (PWFA) offers accelerating fields orders of magnitude higher than in conventional radio frequency cavities. The AWAKE experiment at CERN explores a unique proton-driven scheme within PWFA, aiming to demonstrate its viability for future particle physics experiments [1].

A critical component of the AWAKE experiment is a plasma source capable of achieving a plasma density of 7×10^{14} cm^{-3} with a homogeneity along the axis of 0.25% over lengths spanning tens to hundreds of meters - posing major challenges for both plasma generation and diagnostic techniques. The R&D program for AWAKE plasma sources focuses on scalable systems, namely the Discharge Plasma Source (DPS) [2,3] and the Helicon Plasma Source (HPS) [4], and their detailed characterization using (laser-aided) diagnostics.

We present an overview of the collaborative efforts from multiple institutes contributing to this R&D, highlighting the use of complementary diagnostic tools such as interferometry, laser-induced fluorescence, Thomson scattering (TS), and probe measurements. Particular emphasis is placed on TS [5], currently the only technique capable of delivering *local* plasma parameters within the plasma source R&D program.

Despite recent progress, key challenges remain regarding the accuracy, resolution, and real-time monitoring capability of existing diagnostics. Meeting AWAKE's stringent criteria will likely require a synergistic approach that combines multiple diagnostic techniques. This work underscores that advances in high-precision plasma diagnostics can drive forward the development of next-generation particle accelerators.

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