Plasma and Wakefield Diagnostics for the AWAKE Experiment at CERN

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Abstract

AWAKE develops a new plasma wakefield accelerator using the CERN SPS proton bunch as a driver. The proton bunch propagates through a 10m long rubidium plasma, induced by an ionizing laser pulse. The co-propagation of the laser pulse with the proton bunch seeds the self modulation instability of the proton bunch that transforms the bunch to a train with hundreds of bunchlets which drive the wakefields. Current diagnostics for the occurrence of the seeded self-modulation (SSM) focus on the proton bunch. We therefore investigate the possibility of measuring frequency modulation of a CW laser propagating perpendicularly to the wakefields to determine some of the wakefield characteristics. Wakefield period information will be in the position of satellites in the laser beam spectrum, whereas wakefield amplitude information will be in the satellites intensity. Satellites at the harmonics of the plasma period would indicate nonlinear modulation of the plasma density and wakefield amplitude. Measuring the wakefield amplitude at two points of the plasma cell, near the plasma entrance and near the exit, would provide proof of the growth of the SSM. Additionally we want to look at the rubidium light spectrum to detect the growth of the wakefield amplitude over the plasma cell and want to measure the plasma radius using Schlieren Imaging.

Motivation for Plasma and Wakefield Diagnostics

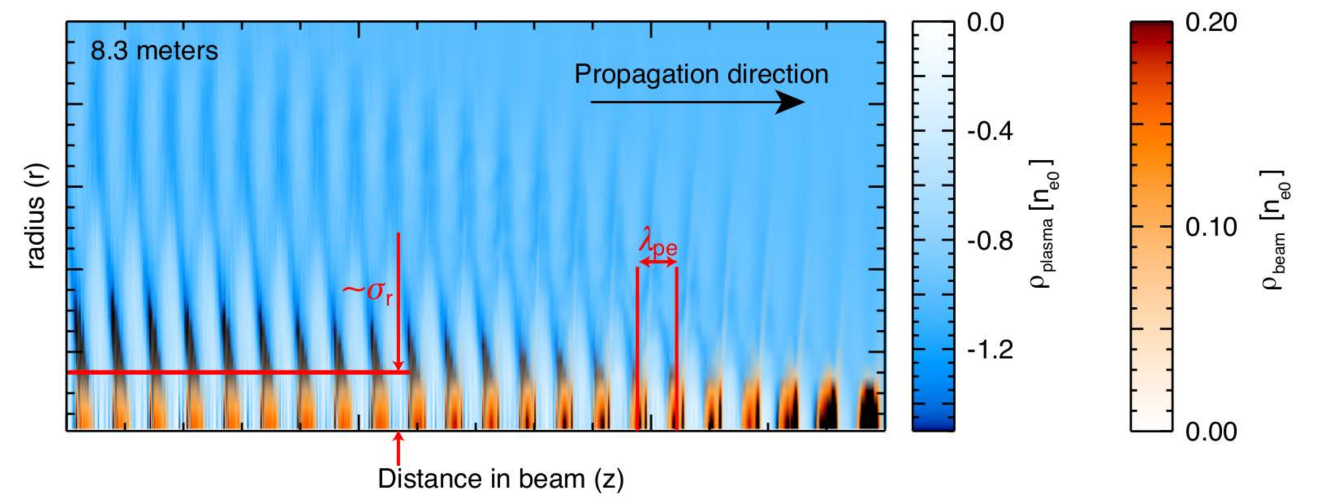
Plasma-based Wakefield Acceleration at AWAKE

- Proton bunch propagates through rubidium plasma
- Co-propagating laser seeds seeded self-modulation (SSM)

→ Micro bunching of the proton bunch

→ Generation of the wakefield and modulation of the plasma density

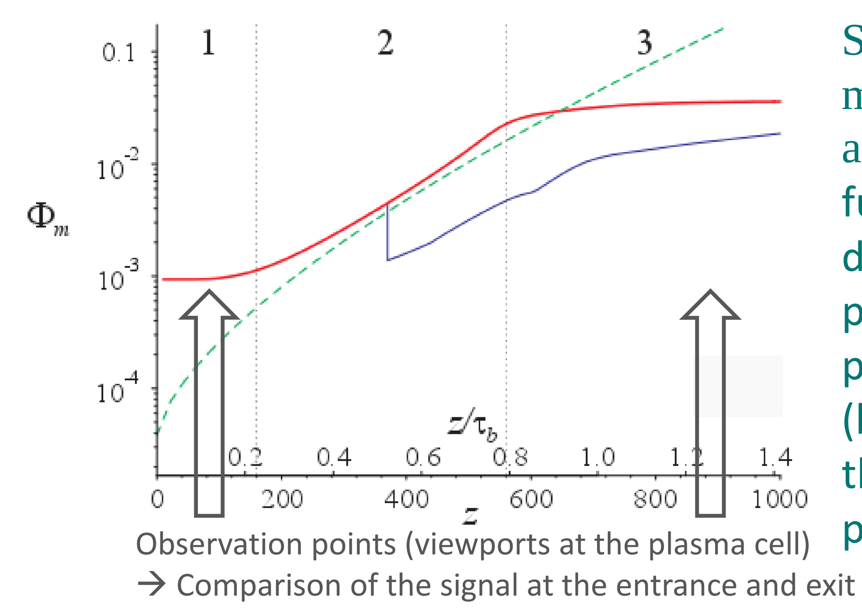
→ Foreseen: acceleration of injected electrons in the wakefield



Simulation of the seeded self-modulation, J. Vieira

Wakefield Evolution

- Initial wakefield due to seeding with the co-propagating laser pulse
- Growth of the wakefield amplitude in the first meters of the plasma cell



Simulation results for the maximum wakefield amplitude Φ_m as a function of propagation distance z for a uniform plasma (red line) and a plasma with density step (blue line), compared with the theoretically predicted growth, K. Lotov

- Diagnostics at the plasma cell necessary to detect the SSM and the growth of the wakefield
- Existing diagnostics at AWAKE for the proton bunch (OTR, CTR, …)

→ Development of additional plasma diagnostics

Plasma Light Spectra

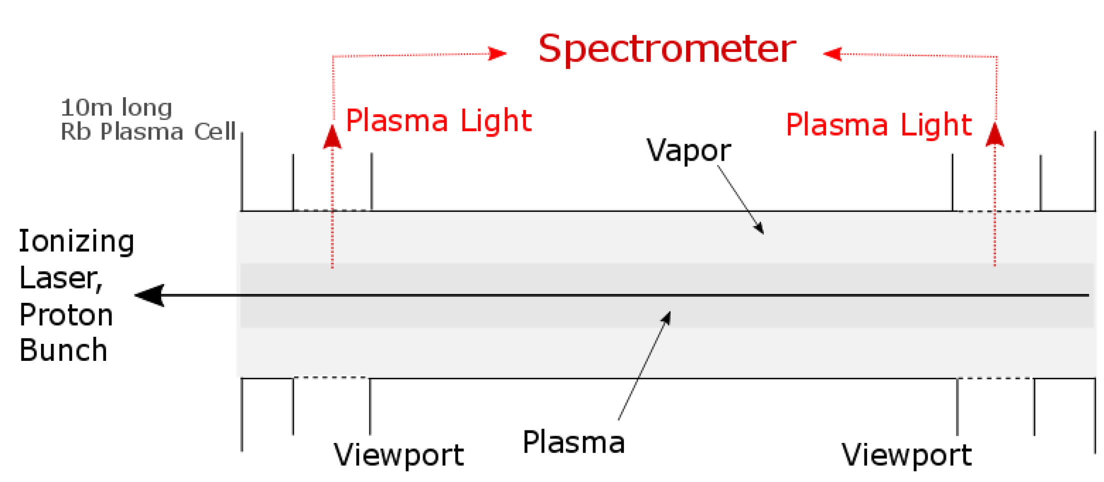
Detection of Vapor and Plasma Light

- Proton bunch propagating through rubidium plasma
- Transfer of the energy of the proton bunch in kinetic energy of the plasma electrons (oscillations)

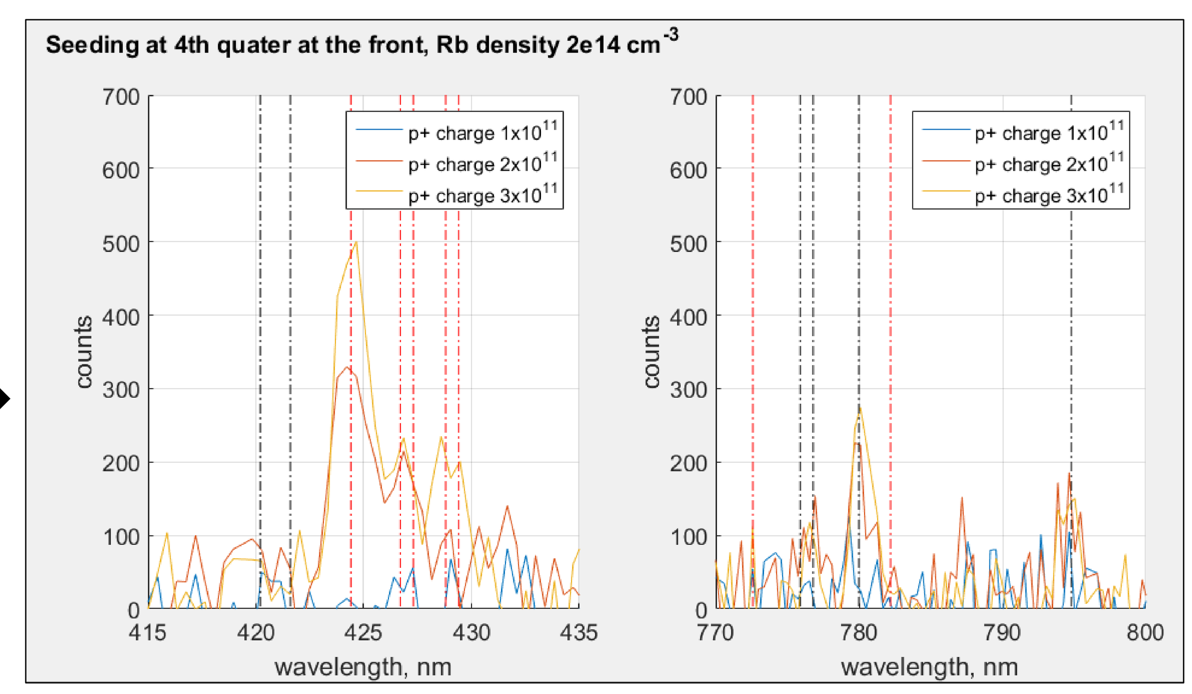
→ Recombination of ions, deexcitation of excited atoms

→ Collisions of the plasma electrons with rubidium ions and atoms

→ multiple excitation



Set up for detection of the plasma light spectrum



Atomic and ion lines observed in the vapor and plasma light spectra measured through the viewport at the end of the plasma cell for a high proton beam charge

Amount of light ~ plasma electrons energy ~ proton bunch energy loss ~ wakefield amplitude

Phase Modulation of a Perpendicular Propagating Laser

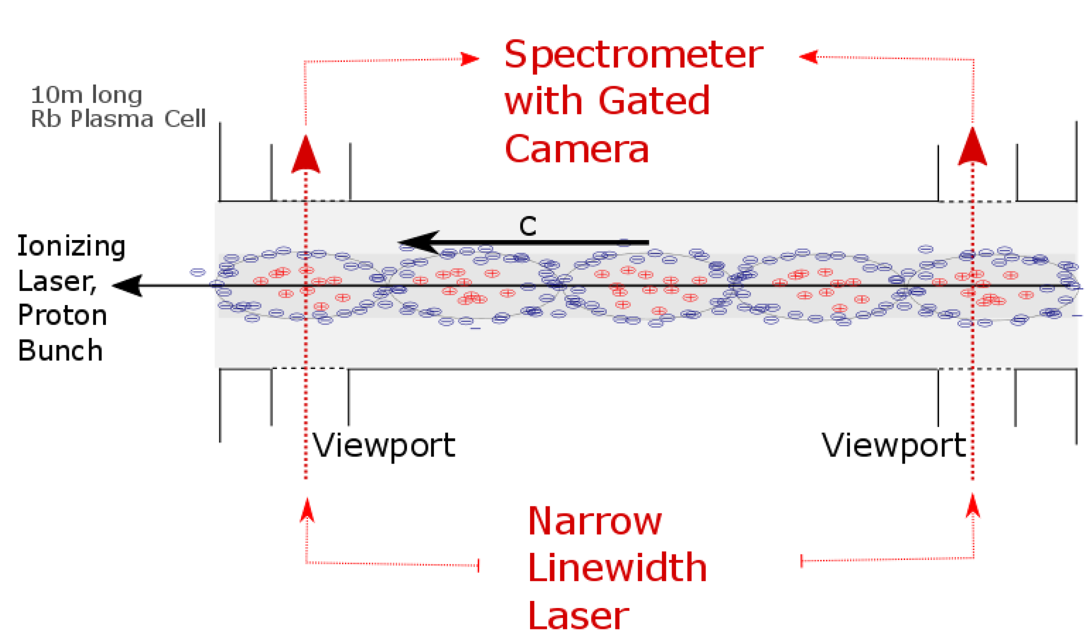
Detection of Phase Modulation

Plasma modulation with bubble structure moving with the speed of light

- Narrow linewidth laser propagating perpendicular to the plasma cell through the plasma wave

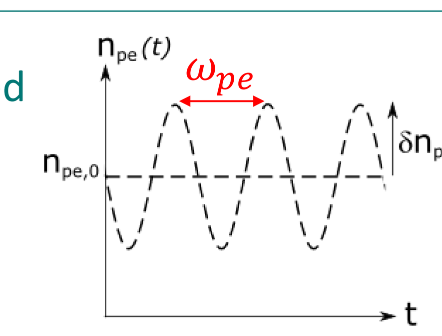
→ Changing plasma density in time and therefore changing refractive index in time

→ Phase modulation of the laser



Set up for measuring a phase modulation of a laser propagating perpendicular through the plasma cell at AWAKE

Modulated electron plasma density



Time dependent plasma density

$$n_{pe} = n_{pe}(t)$$

→ Time dependent refractive index

$$n_{plasma} = \sqrt{1 - \frac{\omega_{pe}{}^2}{\omega_L{}^2}} = \sqrt{1 - \frac{n_{pe}(t)}{n_c}}$$

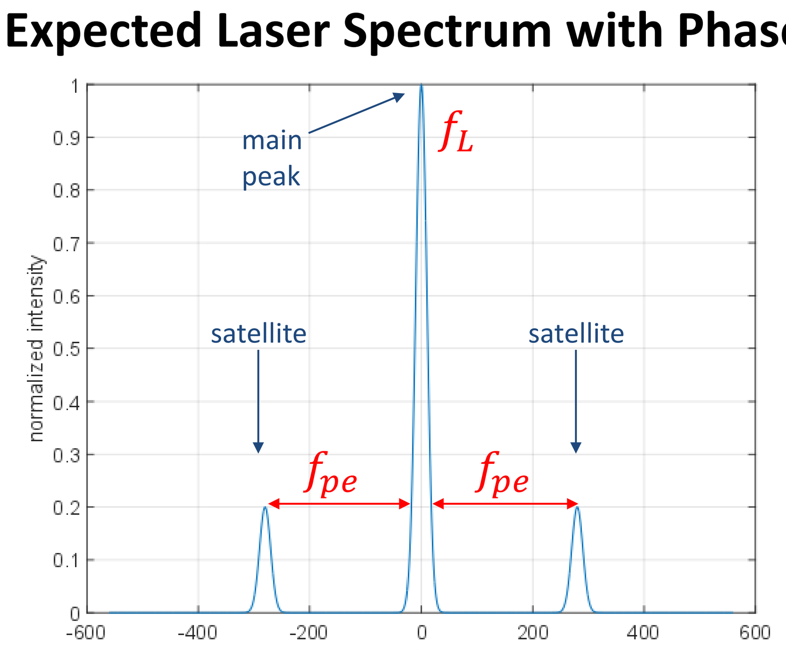
with ω_{pe} plasma frequency, ω_L laser frequency, n_c critical density

→ Phase modulation of the laser beam

$$E(z,t) = E_0 \cos(\omega t - kz)$$

with $k \equiv k(t) = k_0 n(t)$

Expected Laser Spectrum with Phase Modulation



Schematic sketch of the expected spectrum for a plasma density $n_{pe} = 10^{15} cm^{-3}$

Information of the Spectrum

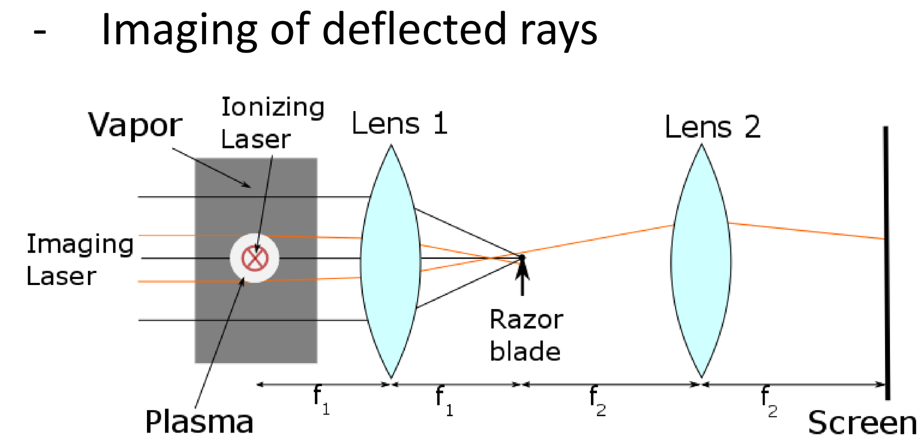
- Distance of the satellites to the main peak: *plasma frequency*
- Relative peak intensity of the satellites to the main peak: *wakefield amplitude*

Relative peak intensity ~ electron plasma density perturbation ~ wakefield amplitude

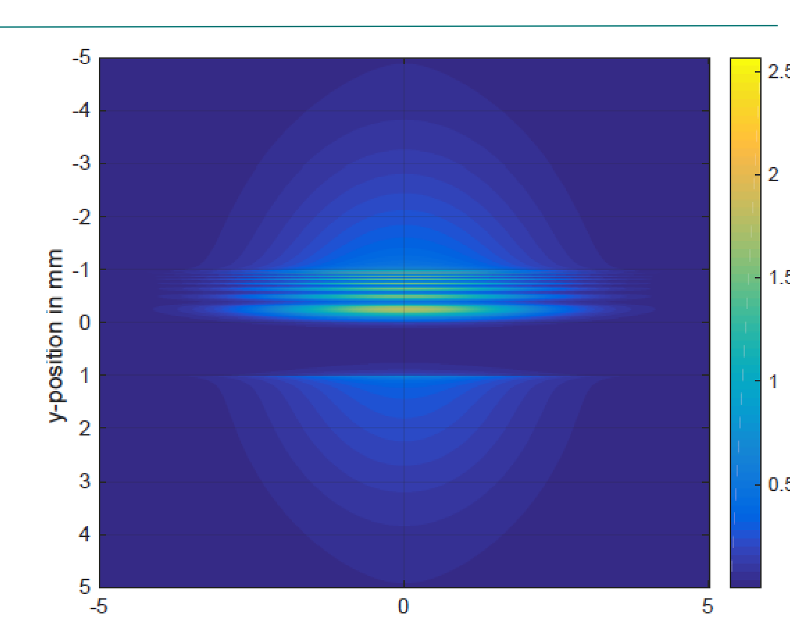
Schlieren Imaging

Determination of the Plasma Radius

- Difference in refractive index of vapor and plasma
- Blocking of non-deflected rays
- Imaging of deflected rays



Sketch of the principle using Schlieren Imaging for plasma radius measurement



Calculated intensity distribution on the screen with a plasma column, a razor blade at $y \leq 0$ for an initial Gaussian laser distribution and a laser detuning frequency of $\Delta\nu = -5$ GHz from the 780nm rb transition line