Seeded Self-Modulation along a Proton Bunch at AWAKE

F. Batsch[1,2], K. Rieger[2], J. Moody[2], M. Hüther[2], A.M. Bachmann[1], F. Braunmüller[2], M. Martyanov[2], F. Friebel[1], V. Fedosseev[1], S. Gessner[1], E. Gschwendtner[1], P. Muggli[1]

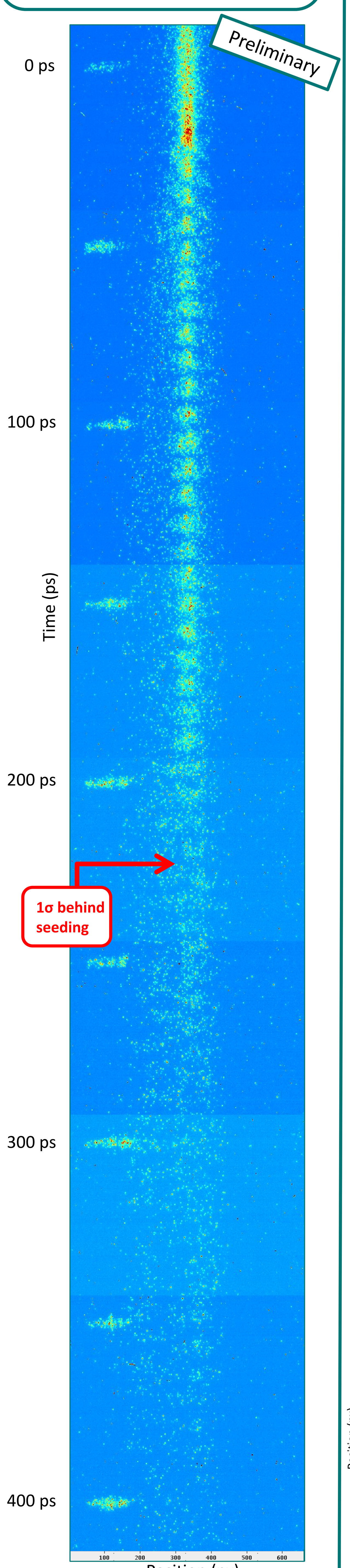
[1] CERN, Geneva, Switzerland / [2] Max-Planck-Institute for Physics, Munich, Germany / [3] Technical University Munich, Germany

Abstract

The AWAKE experiment uses the seeded self-modulation (SSM) to drive large amplitude wakefields in a plasma. The seed for the wakefields is a sharp ionizing front located near the middle of the proton bunch. It is created by an intense laser pulse ionizing Rubidium (Rb). For electron acceleration, the electron bunch must be injected into the accelerating and focusing phase of the wakefields, approximately 100 plasma periods behind the seed laser position. Here, we show that by using a replica of the intense laser pulse we can determine precisely the position (timing) of the proton micro-bunches with respect to the ionizing laser pulse. Since the relative phase of the wakefields is tied to the proton micro-bunches, this method can be used to determine experimentally the delay between the ionizing laser pulse and the electron bunch so that the electrons can be injected into the accelerating and focusing phase of the wakefields. The results presented also show that the timing of the micro-bunches is stable against variations of the proton input parameters. They show as well the difference between seeded and unseeded self-modulation.

Seeded Self-Modulation

- Rb density: 2.13*10^{14} cm^{-3}
- Density gradient: + 6.7 %
- Seed: 125 ps ahead p$^+$ bunch center
- Bunch length: 4 σ = 940 ps



Laser Timing Reference Marker:

- Ionizing laser pulse too intense to observe on streak camera (SC)
- Laser timing trigger jitter w.r.t. proton bunch of ~ 20 ps
- → Guide a bleed-through of the ionizing laser **dispersion-free** and **matched in time** to the streak camera.
- Lengths: **Ionizing laser path: 60.2 m**
  Reference marker path: 45.1 m + 15.1 m delay line
- → Seeding point in proton bunches marked on SC images
- → Scan along p$^+$ bunch by moving marker and SC Window in parallel

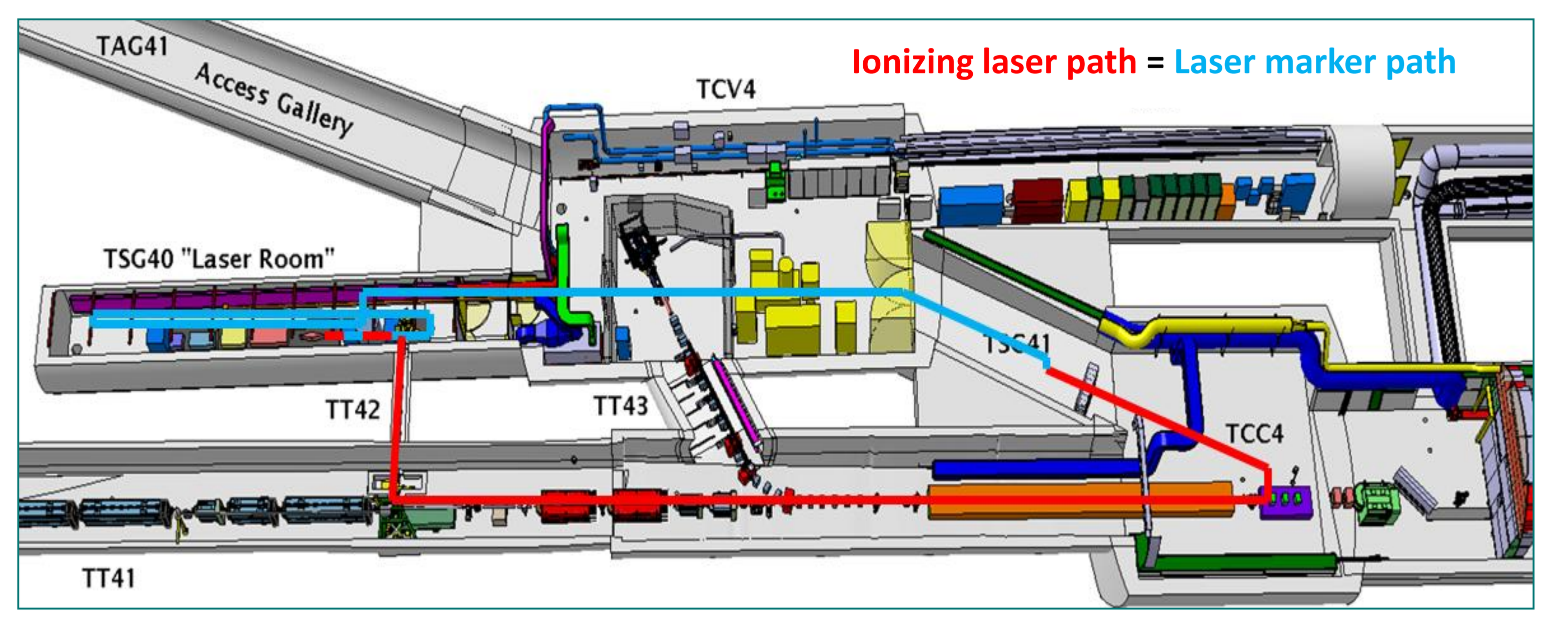


Fig.: The AWAKE tunnel with the laser paths

Timing and Delay Adjustment

- 15 cm motorized translation stage for timing adjustment and SC window scans
- → Equal to ± 500 ps in time with 2.5 μm steps = 17 fs accuracy
- Marker laser and main pulse matched with sub-ps accuracy
- Relative position not influenced by timing trigger jitter
- → Exact seeding point, for window scans exact distance to seed point

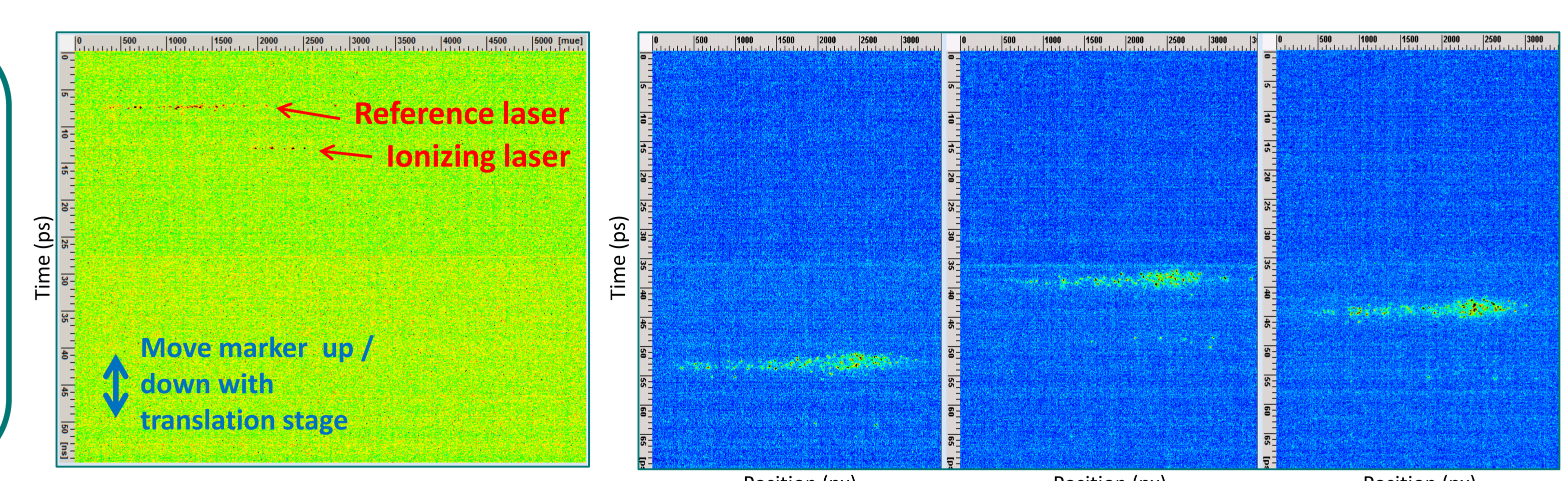
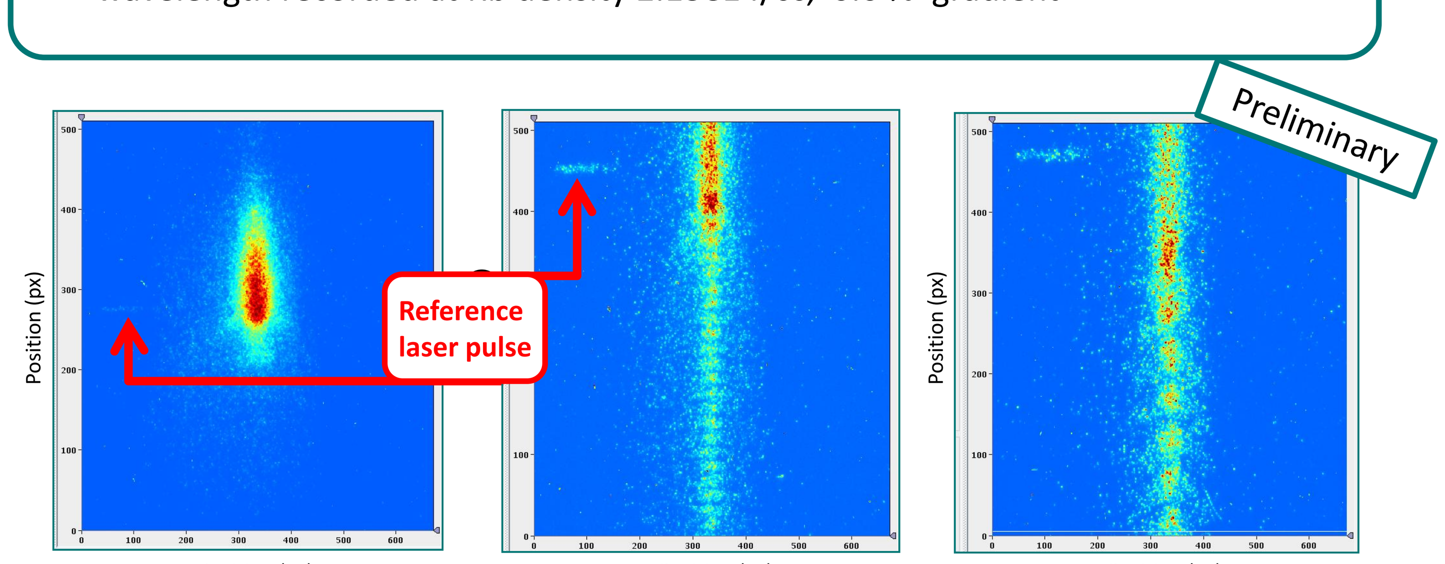


Fig.: Ionizing and marker laser pulse matched on streak camera

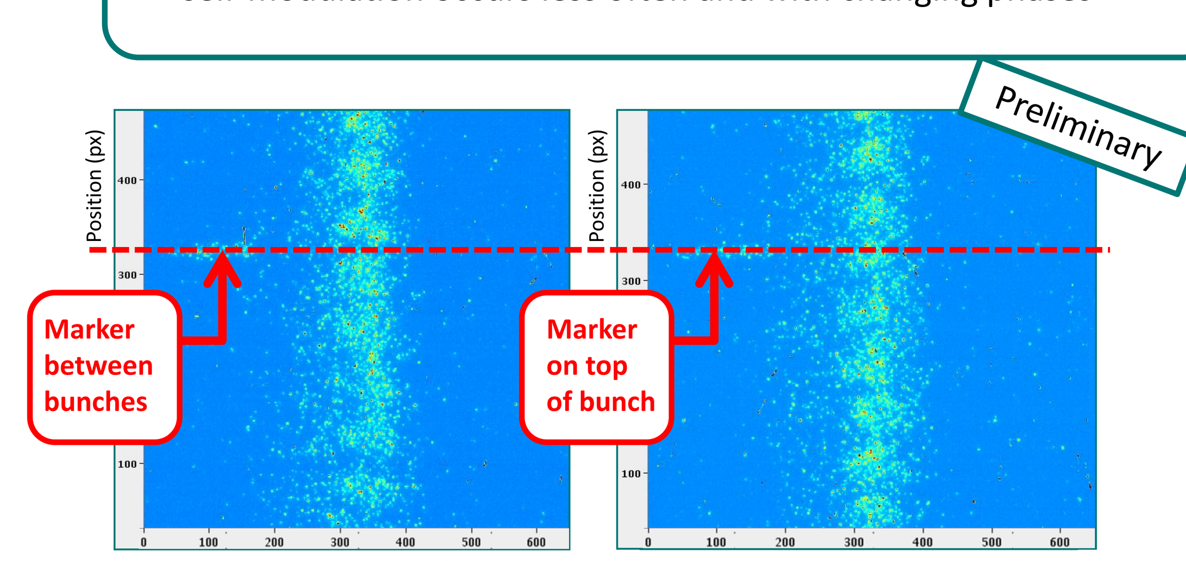
Same Seeding Point for Different SC Windows

- Seeded self-modulation forms a train of micro-bunches on the size of the plasma wavelength recorded at Rb density 2.13e14/cc, 0.0 % gradient



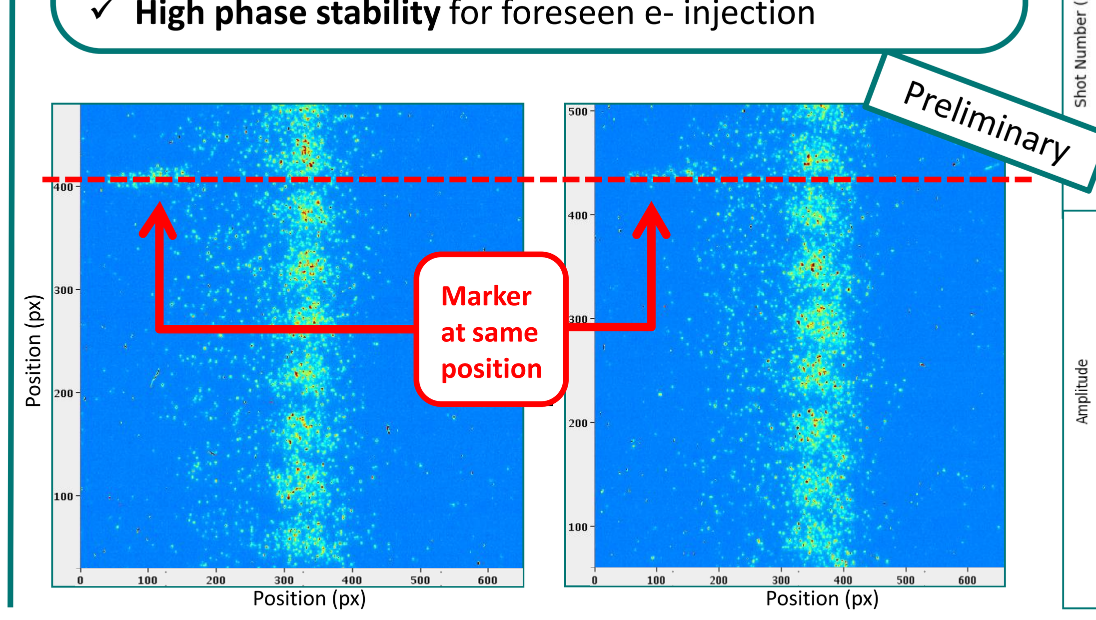
No Seeding: Phase Instable

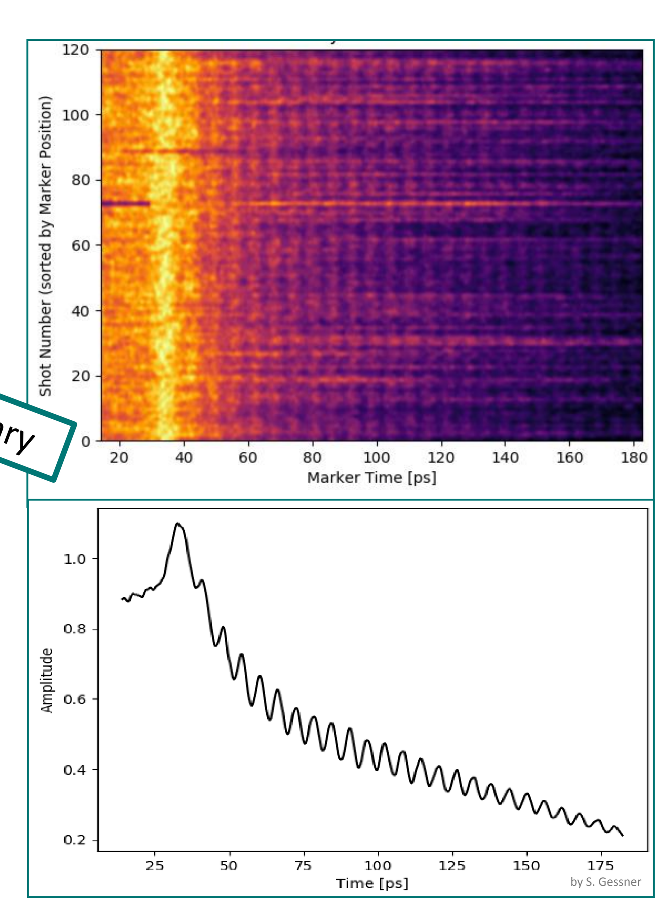
- In case of no seeding (laser 500 ps ahead the p$^+$ bunch center), self-modulation occurs less often and with changing phases



Seeding: Phase Stability

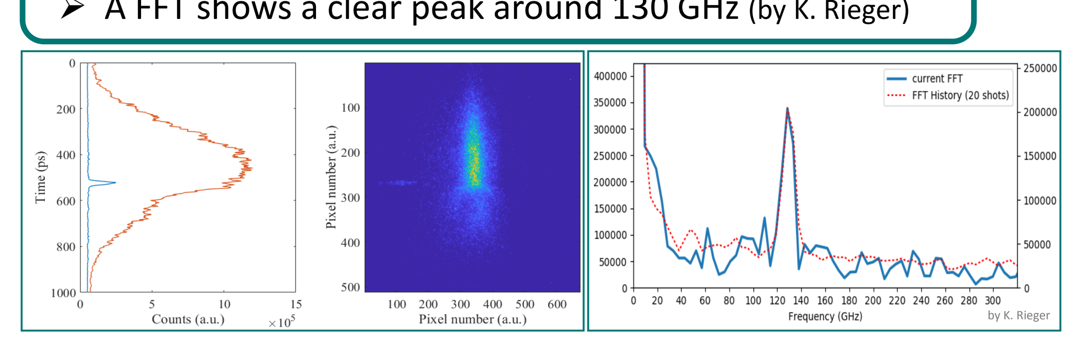
- Seed point 125 ps ahead the p$^+$ bunch center
- For 120 events, micro-bunches occur at the same phase
- Summing the image profiles shows modulation
- ✓ **High phase stability** for foreseen e- injection





Analysis tools

- Sum images, fit profile for marker position
- A FFT shows a clear peak around 130 GHz (by K. Rieger)



Conclusion

- The laser reference marker indicates precisely the seed point
- Shifting the marker gives precise timing / phase of micro-bunches
- Clear difference in phase stability between seeding and no seeding
- Seeded self-modulation shows stable phases along the p$^+$ bunch for e$^-$ injection in the wakefields at AWAKE