Experimental characterization of the timing-jitter effects on a beam-driven plasma wakefield accelerator

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F. Demurtas [1], A. Giribono [1], R. Pompili [1], A. Cianchi [3], C. Vaccarezza [1], M. Ferrario [1], M. P. Anania [1], A. Biagioni [1], E. Chiadroni [2], G. Costa [1], L. Crincoli [1], A. Del Dotto [1], M. Del Giorno [1], M. Galletti [1], L. Giannessi [1], S. Romeo [1], A. R. Rossi [4], V. Shpakov, G. J. Silvi [1], F. Villa [1]

[1]Frascati National Laboratories INFN-LNF, 00044 Frascati (RM), Italy

[2]INFN-Sez. Roma1, Rome, Italy

[3]University of Rome 'Tor Vergata', Via della Ricerca Scientifica 1, I-00133 Rome, Italy

[4]INFN-Sez Milano, 20133 Milano, Italy

1. PWFA and Velocity Bunching

- In Plasma Wakefield acceleration a driver beam is injected into a plasma target, exciting a plasma wave which accelerates the witness beam
- However the acceleration is affected by the timing-jitter of the distance between driver and witness beam, resulting in a jitter in the witness energy

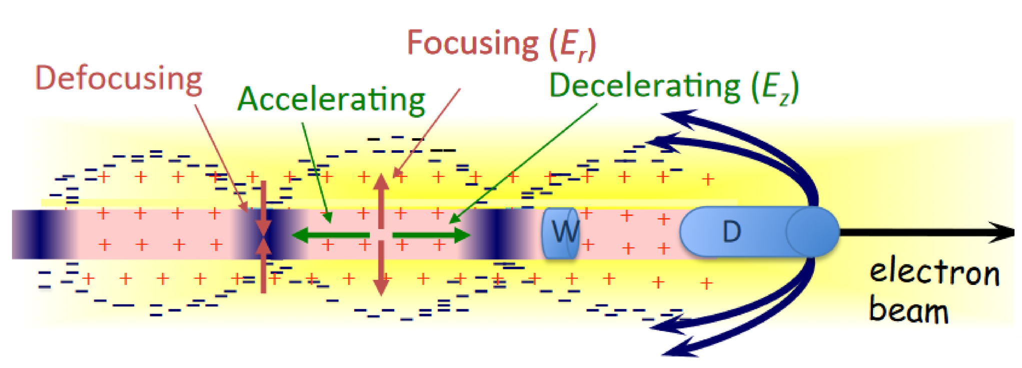

FIG. 1: Plasma wakefield acceleration scheme

- The bunch compression is based on the velocity bunching technique, in which the beam is injected into the RF cavity at the zero-crossing phase with a velocity smaller than the velocity of the RF traveling wave.
- The bunch will slip in phase towards a higher accelerating field: the head of the bunch will feel a smaller field with respect to the tail, and therefore, the bunch will be at the same time compressed and chirped.

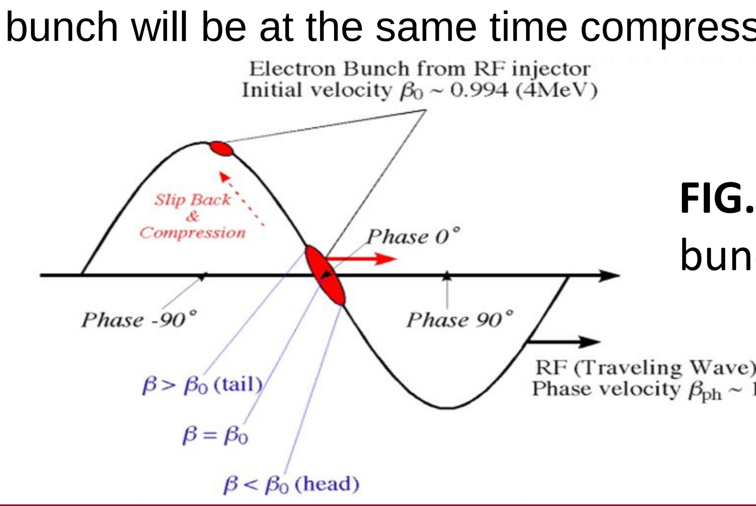

FIG. 2: Velocity bunching technique

2. Experimental setup

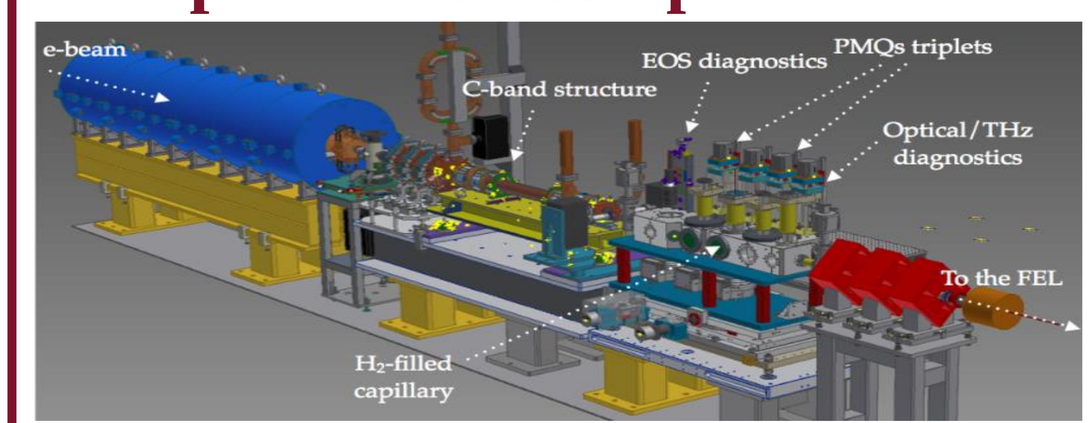

FIG. 3: Layout scheme of the experiment

- The plasma has been stabilized with a laser pulse, therefore the timing-jitter effect on the bunches is due mainly to the RF instabilities [1].

FIG. 4: Plasma capillary

3. Beam Diagnostics: Electro-Optical Sampling

- The **Electro-Optical Sampling** is a non-intercepting and single-shot device used for measuring of the distance in time between the driver and witness beam
- The working principle is based on an external field, i.e. the beam coulomb field, which induces birefringence on an electro-optical crystal, ZnTe in this case.
- The field induces a change in the refractive indexes in the crystal, which can be measured with an opportune polarized laser pulse that crosses the crystal.
- This produces a phase delay $\Gamma(t)$ between the laser horizontal and vertical components, which is proportional to the beam electric field, following the same temporal profile.

Detected Intensity: $I_{det} = I_{laser}^2 \sin^2 \Gamma$

Phase delay: $\Gamma(t) = \frac{\pi d}{\lambda} n_0^3 r_{41} E_{external}(t)$

d: crystal thickness
λ: laser wavelength
n_0: unperturbed refractive index
r_{41}: non-linear coefficient

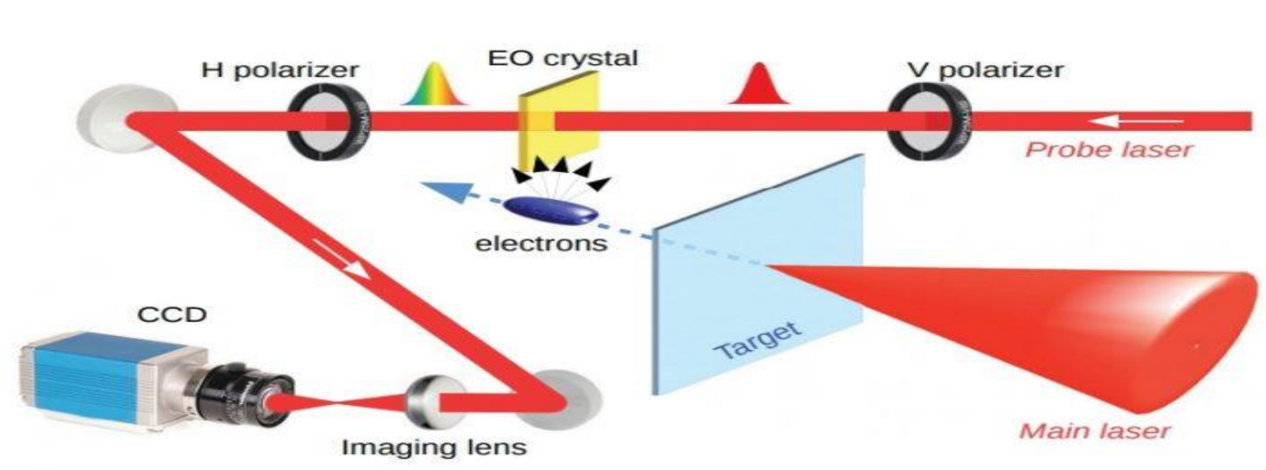

FIG. 5: Experimental setup scheme of the EOS system

- In this scheme the laser crosses the crystal with an angle $\theta = 30\ deg$, therefore different points across the transverse profile of the laser pass through the crystal at different times and acquire a different polarization
- The time coordinate t can be related to the spatial coordinate x through the formula: $t = \frac{x}{c}\tan(\theta)$

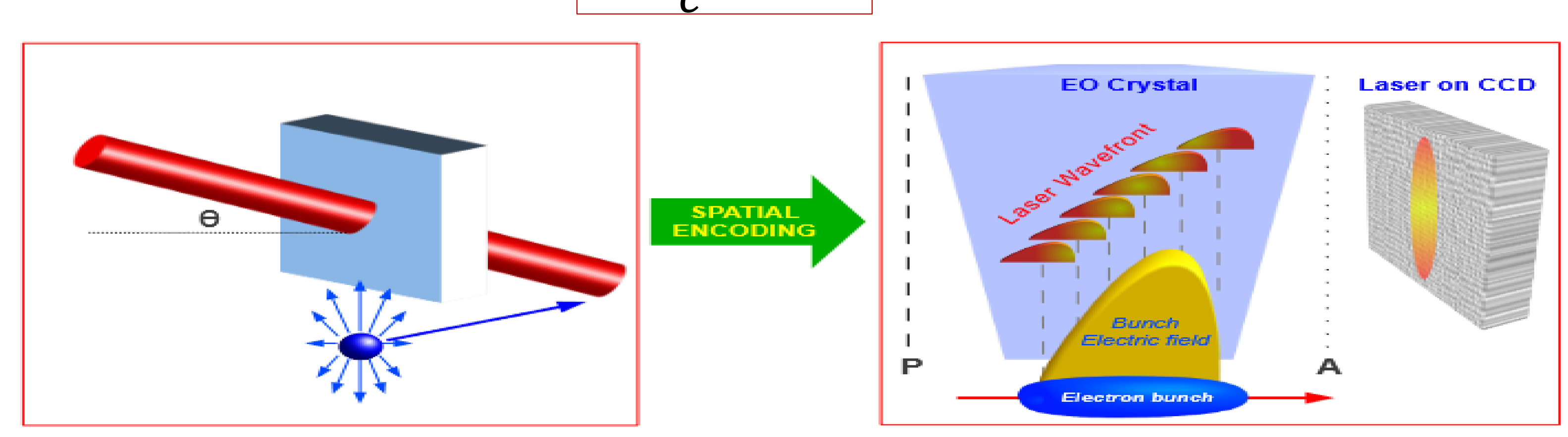

FIG. 6: Working principle of the spatial decoding scheme

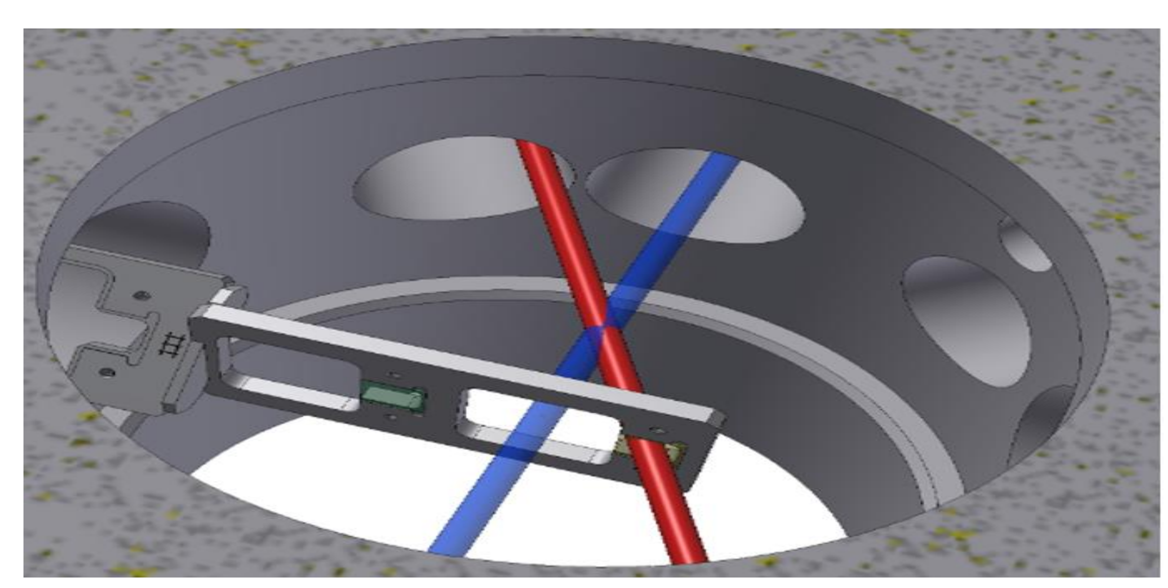

FIG. 7: Layout of the EOS chamber, the laser (red line) crosses the crystal with an incident angle of 30 deg

4. Measurements and Results

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- The EOS allows for the measuring of the relative distance between driver and witness bunch, while the witness energy is measured by using a spectrometer

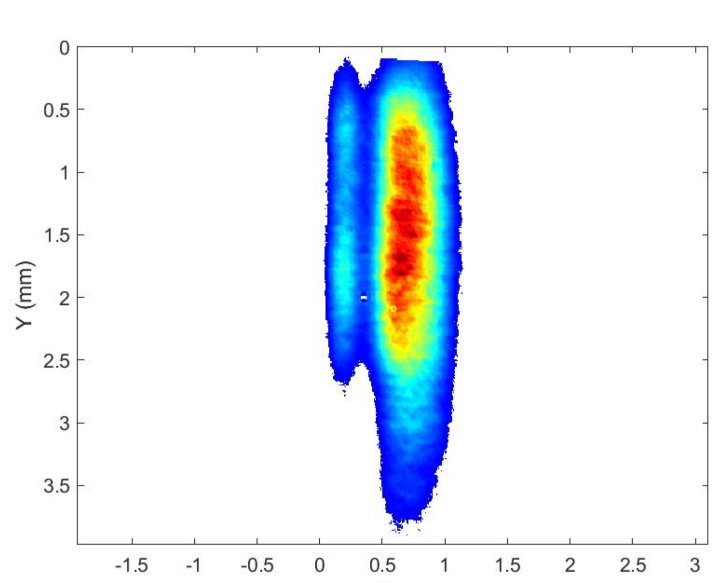

FIG. 8: Bunch measurement with the EOS system

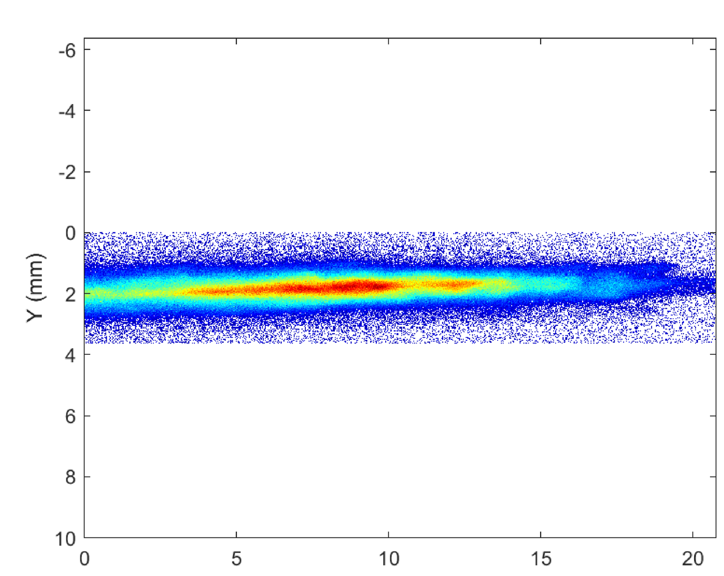

FIG. 9: Witness energy measurement

$\phi_1 = 132.10\ deg$

$t_{1_{mean}} = (1.0 \pm 0.1)\ ps$

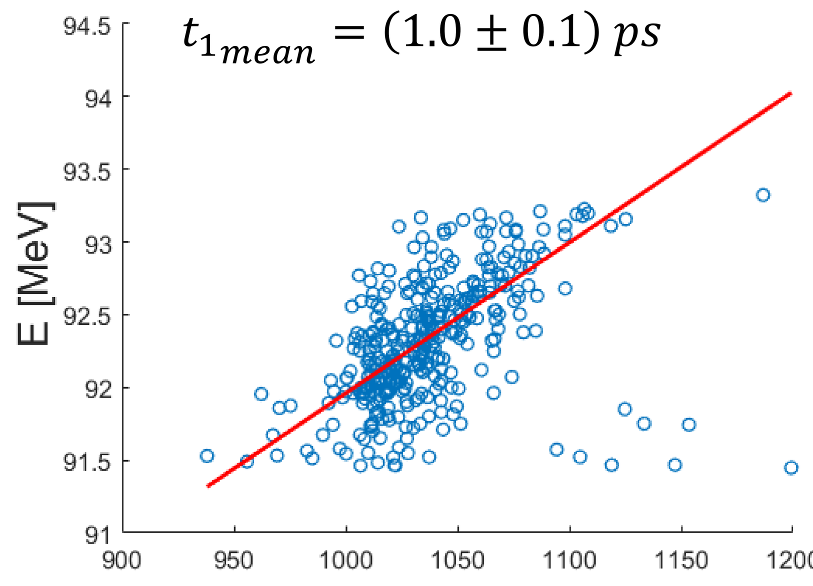

FIG. 10: First set of measurements

$m_1 = (10 \pm 1)\frac{Kev}{fs}$

$\phi_2 = 131.30\ deg$

$t_{2_{mean}} = (1.2 \pm 0.1)\ ps$

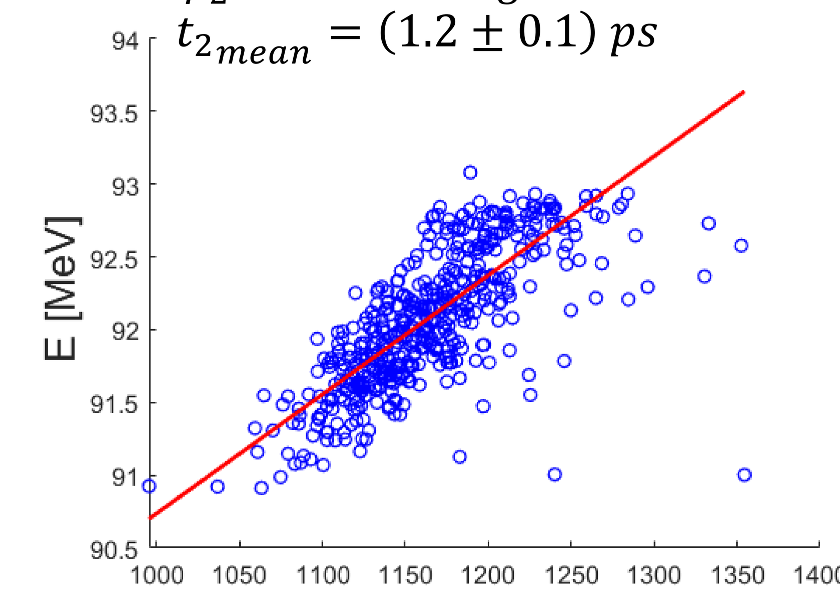

FIG. 11: Second set of measurements

$m_2 = (8.2 \pm 0.6)\frac{Kev}{fs}$

- In Figures 10 and 11 are shown two different sets of measurements in which the compression phase is slightly different: when the phase is smaller the compression is larger and therefore, the distance between the bunches increases.
- The different slope is dependent on the plasma density (the used density for the experiment is $\sim 10^{15}\ cm^{-3}$): the first measurement corresponds to a larger density and so it is higher the slope with respect to the second case.

Reference

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