Noninvasive Cavity-Based Charge Diagnostic for Plasma Accelerators

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The charge of an electron bunch is one of the most important parameters in accelerator physics. Several techniques to measure the electron bunch charge exist. However, many conventional charge diagnostics face serious drawbacks when applied to plasma accelerators. For example, integrating current transformers (ICTs or toroids) have shown to be sensitive to the electromagnetic pulses (EMP) originating from the plasma, whereas scintillating screens are sensitive to background radiation such as betatron radiation or bremsstrahlung and only allow for a destructive measurement of the bunch charge. We show measurements of a noninvasive, cavity-based charge diagnostic (so-called DaMon), which demonstrate its high sensitivity, high dynamic range and resistance towards plasma EMP. The measurements are compared to both an ICT and a scintillator screen.

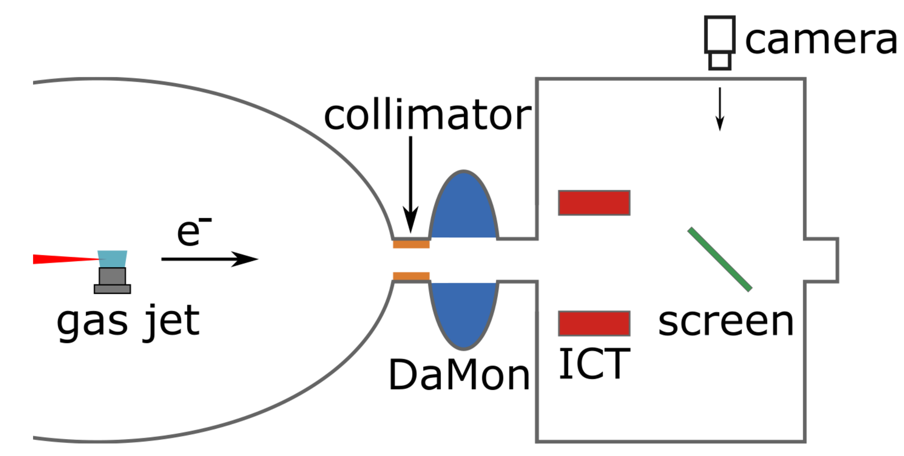
Working principle of the DaMon[1,2]

Charge measurement via TM01 mode of a cavity

- Beam passing through cavity will stimulate first monopole mode with a voltage of
$$\mathrm{U} = \mathrm{U_0} \sin(\omega t) e^{-t/\tau}.$$
- The amplitude of the mode is proportional to the charge q via
$$\mathrm{U_0} = \mathrm{q\,S}.$$
- S is the sensitivity defined as $S = \pi f \sqrt{\frac{Z}{Q_{ext}}\left(\frac{R}{Q}\right)}$, where f is the cavity frequency, Z is the line impedance, Q_{ext} the external quality factor and $\left(\frac{R}{Q}\right)$ is normalized shunt impedance. S is constant and can be determined for a cavity, enabling a calibrated charge measurement.
- The TM01 mode is not dependent on the position of the electron bunch inside the cavity.
- Two readout channels for a high dynamic range (seven orders of magnitude).

Experimental setup for charge measurements

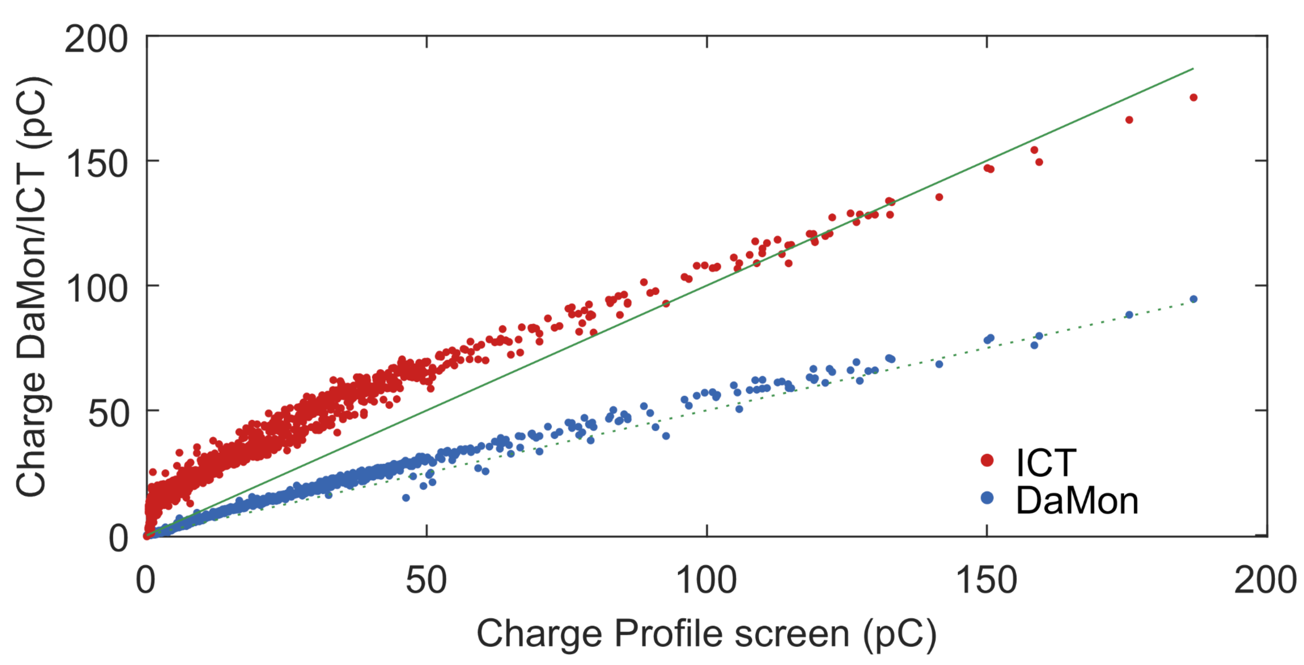
Simultaneous measurement using three charge diagnostics



- Setup installed for simultaneous charge measurements using three diagnostics.
- Collimator installed to ensure the beam could not clip inbetween diagnostics.
- DRZ screens absolutely calibrated at the Elbe accelerator at HZDR[3,4], imaging system cross-calibrated using tritium sources.
- Electrons generated via ionization injection[5,6].

Comparison of DaMon, ICT and DRZ screen

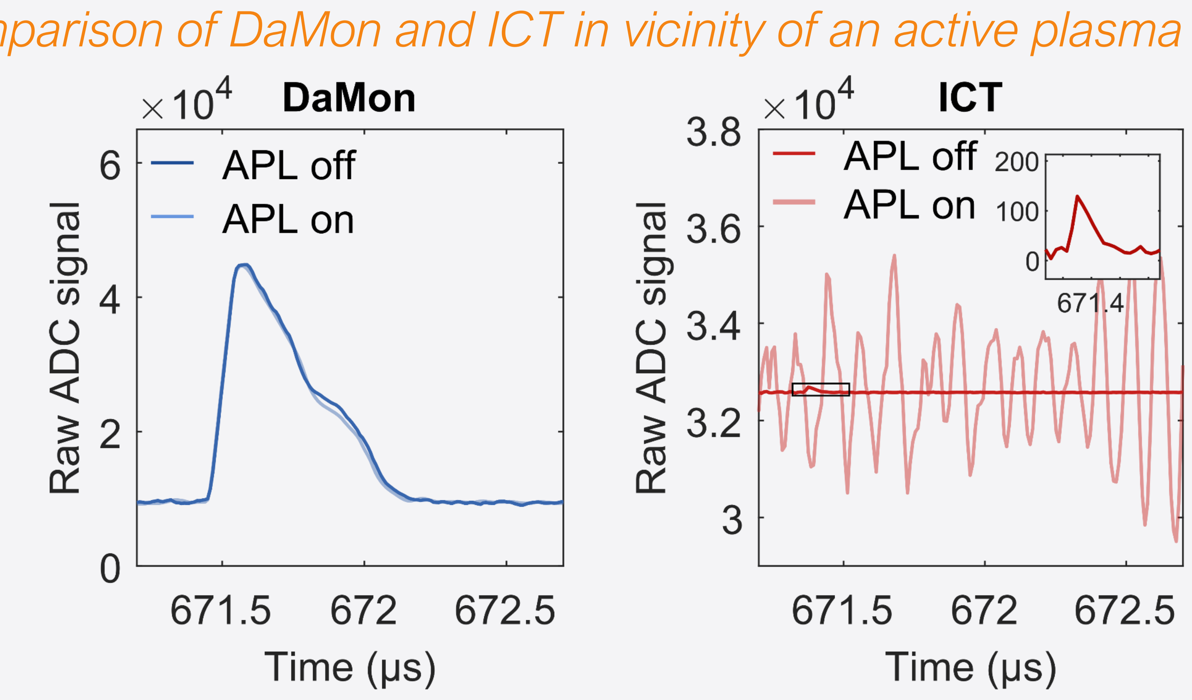
Linear correlation between DaMon and DRZ screen visible



- DaMon shows linear scaling with profile screen, even at low charges.
- The ICT seems to overestimate low charges, with an uncertainty on the measurement of several pC.
- ICT and Profile screen in good agreement at high charges.
- DaMon shows only half the charge of the Profile screen, calibration of the diagnostics need to be further investigated.

Noise free measurement in EMP environment

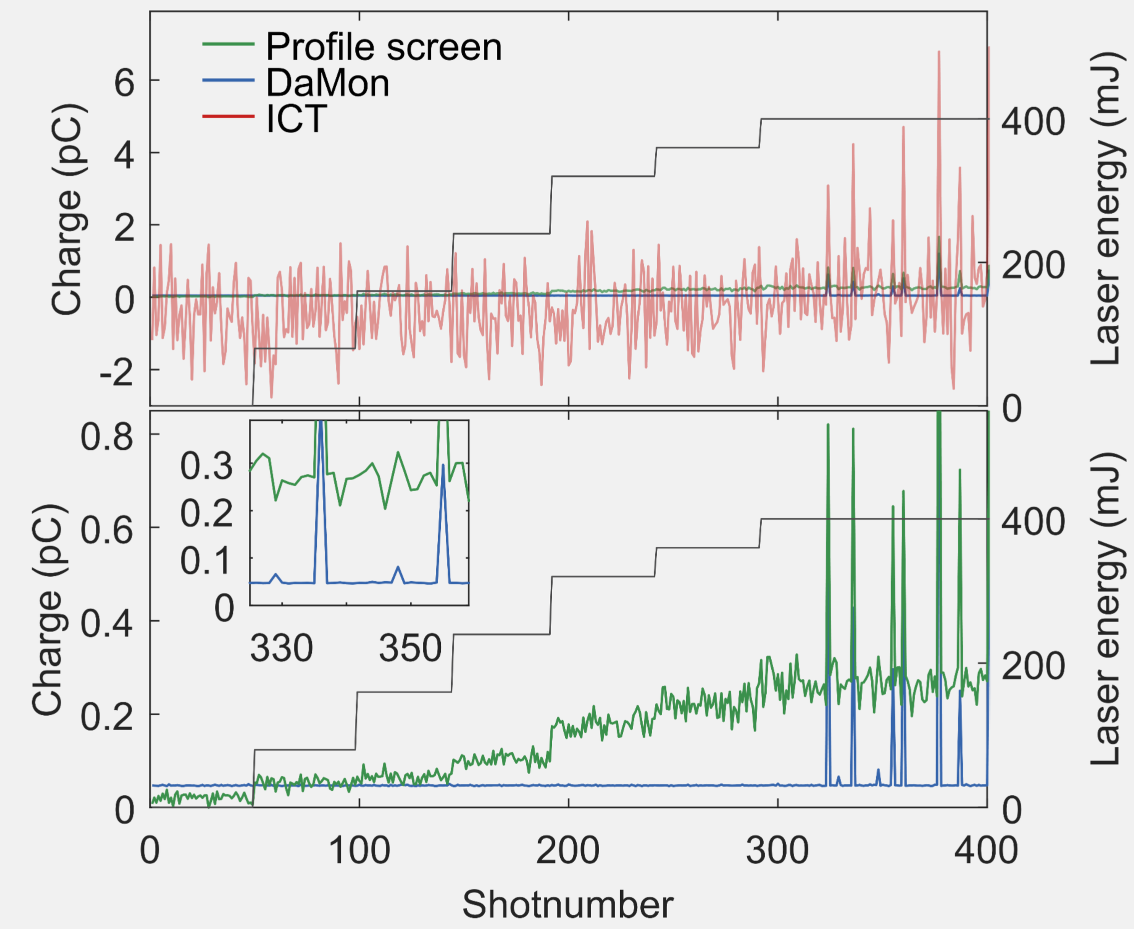
Comparison of DaMon and ICT in vicinity of an active plasma lens



- DaMon seems unaffected by the EMP of the active plasma lens.
- ICT shows noise several orders of magnitude above electron signal.

Sensitivity at low charges

Low noise enables detection of bunches with tens of femtocoulomb



- Sensitivity to noise and background radiation measured for all three diagnostics below and at the edge of injection threshold by increasing laser energy.
- ICT: noise level of ± 1 pC (std). Low charges drastically overestimated.
- Profile screen: Background charge level follows laser energy, indicating sensitivity to noise from plasma and laser light. Not able to resolve charges below 100 fC.
- DaMon: Constant noise level of several femtocoulomb, allowing for detection of bunches with tens of femtocoulombs[7]. Noise level not correlated to laser energy.

Summary

A non-invasive, noise-free measurement of the charge

- The DaMon measures the charge via the TM01 mode in a cavity.
- It can be absolutely calibrated by measuring device properties only.
- It has a high dynamic range of up to seven orders of magnitude and sensitivity to low-charge bunches with tens of femtocoulomb.
- It is insensitive to plasma EMP noise and is not influenced by secondary radiation such as x-rays or plasma light.

References

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