Accelerator Timing Monitor with Femtosecond Precision

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Abstract:

The next generation of accelerators and light sources require high precision timing diagnostics. A RF pickup based bunch arrival-time monitor (BAM) is being installed at Daresbury and will be tested on VELA accelerator in August this year. A scheme of a novel all-optical BAM is under developing and also introduced. Based on the EO effect, the bunch timing information is converted to laser pulse intensity information which is read out in real time by a high resolution amplitude detection module designed in house. Our simulation shows that by using balance detection method, the EO-BAM could potentially reach a resolution of a few femtosecond.

Introduction

Free Electron Laser (FEL):

Next generation FEL should be dedicated to the production of ultra-short photon pulses (femtosecond or tens of attoseconds) of high-brightness coherent light, which has exciting applications in coherent X-ray imaging, femtosecond holography, real-time observations of molecular motion and capturing the movement of electrons in atoms and molecules.

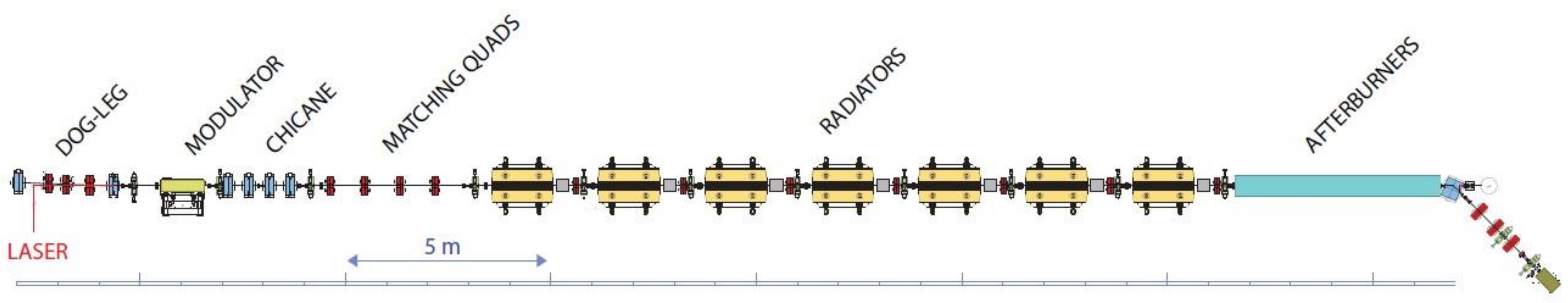

Figure 1. FEL layout of CLARA. The proposed research topics require interaction with seed lasers in a modulator undulator then amplification in radiator undulators.

CLARA (Compact Linear Accelerator for Research and Applications) has been designed to be a dedicated flexible FEL test facility and will be built at Daresbury Laboratory in UK.

In order to achieve this vision for ultra-short pulse generation, CLARA must be able to implement femtosecond synchronisation, which requires femtosecond precision beam diagnostic instruments.

Bunch Arrival-time Monitor (BAM):

- Measure bunch arrival-time
- Improve understanding of the beam dynamics
- Monitor synchronisation points and investigate timing jitter

RF BAM:

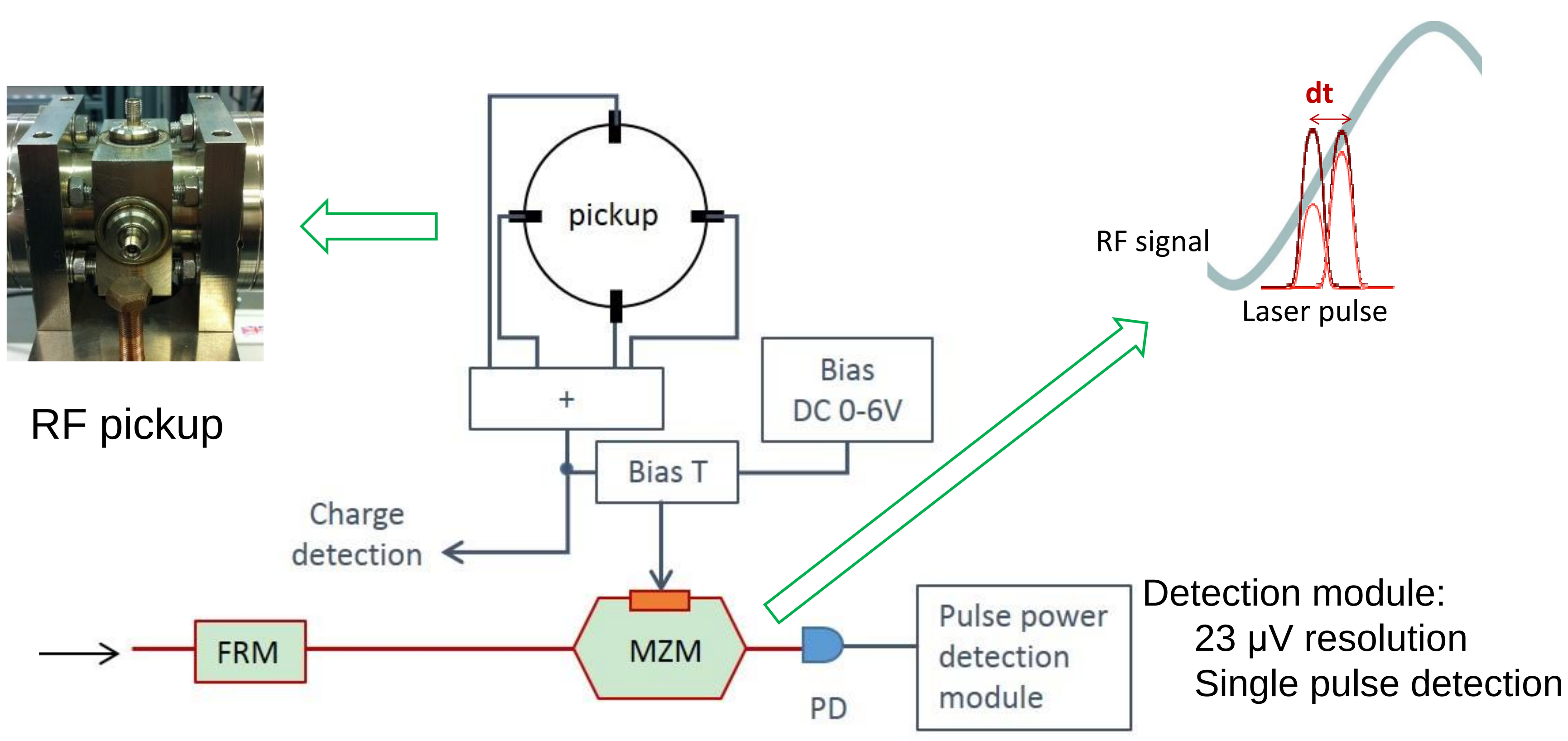

Figure 2. BAM scheme with RF pick up

RF BAM convert the bunch arrival time into a laser pulse intensity by a electro optic laser intensity modulator (MZM). When the electron bunch passes through the RF pickup, it generates RF signals (~ps). The RF signal voltage is added on the modulator. A reference laser clock pulse (~fs) is also arrived at the modulator simultaneously but is set at one slope of the RF signal profile. Therefore the position of the RF slope, which indicate the bunch arrival time, induces the laser intensity varies.

electron to photon — photon to electron

RF pickup → EO modulator → Detector

References:

[1] J.A. Clarke, et al., 'CLARA conceptual design report', JINST Vol. 9, No. 05, p. T05001 (2014)

[2] A. Angelovski, et al., 'High bandwidth pickup design for bunch arrival-time monitors for free-electron laser', PhysRevSTAB, 15-112803 (2012)

[3] S. P. Jamison, et al., 'Temporally resolved electro-optic e ect', Optics Letters, 31:1753 (2006)

EO BAM:

The use of non-linear materials, ZnTe crystal for instance, with THz respond bandwidth is expected to push the resolution further more.

1. Coulomb field from electron

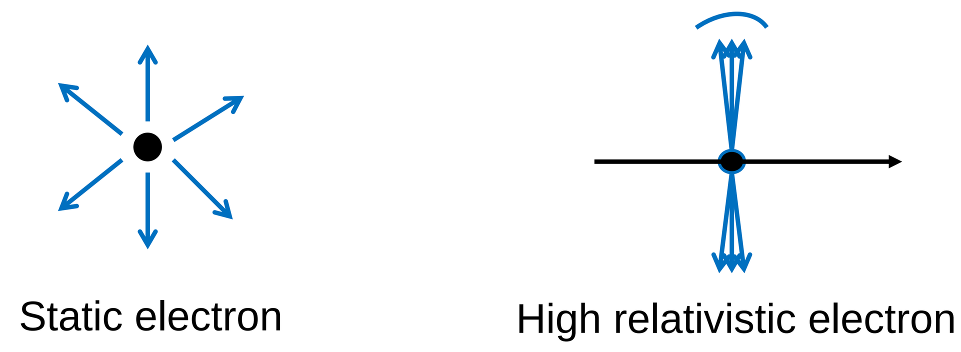

Figure 3. Coulomb field of an electron

For a high relativistic electron bunch, the profile of its Coulomb field is an good replica of the bunch temporal profile

2. Electro Optic (EO) effect

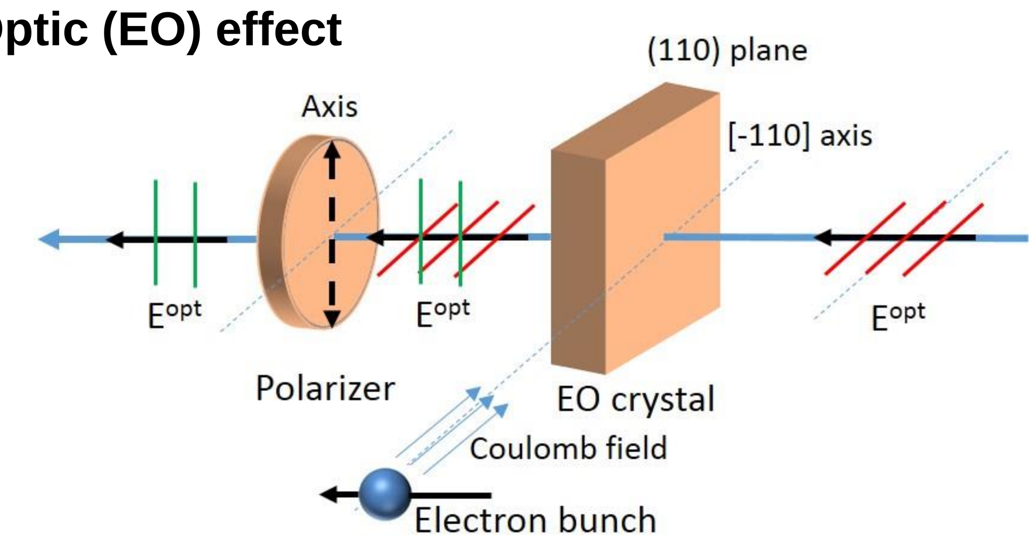

Figure 4. Principle of EO effect

The Coulomb field, applied on the EO crystal (ZnTe), induces new polarization in the laser pulse, which depends on Coulomb field strength. Bunch information is encoded into laser pulse.

3. EO BAM:

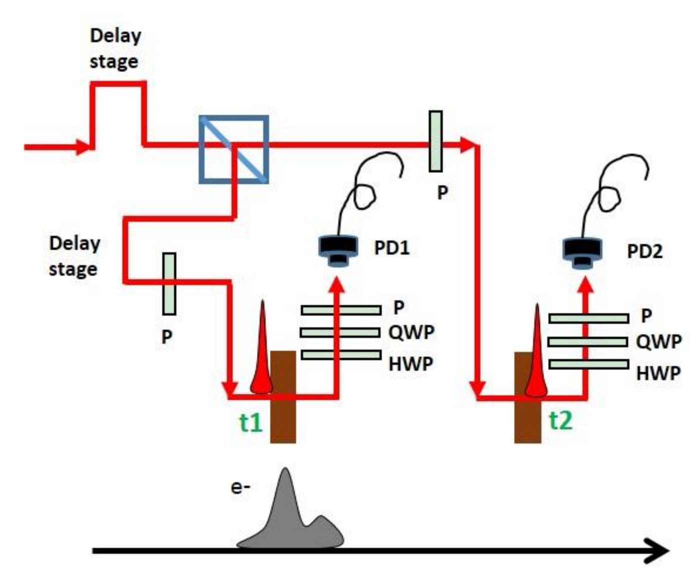

Figure 5. EO BAM scheme

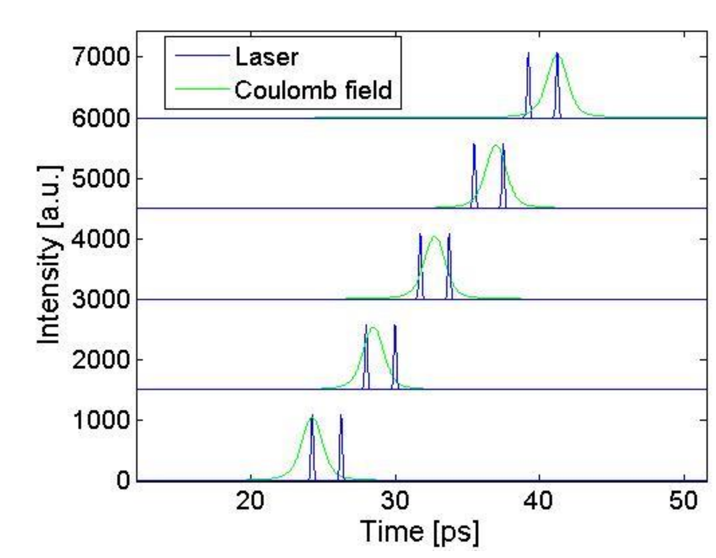

Figure 6. Pulses propagation in 2 mm ZnTe crystal

After propagation, each laser probe scans through half of the Coulomb field in a signal shot. The output signal on each photo diode detects the convolution result of the half side Coulomb field intensity and the laser probe. Therefore the zero different signal from the two photo diodes implies the center of bunch mass.

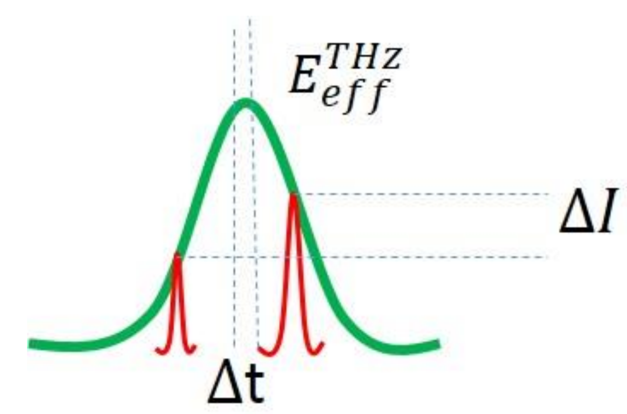

Figure 7. Timing information is converted to laser intensity information

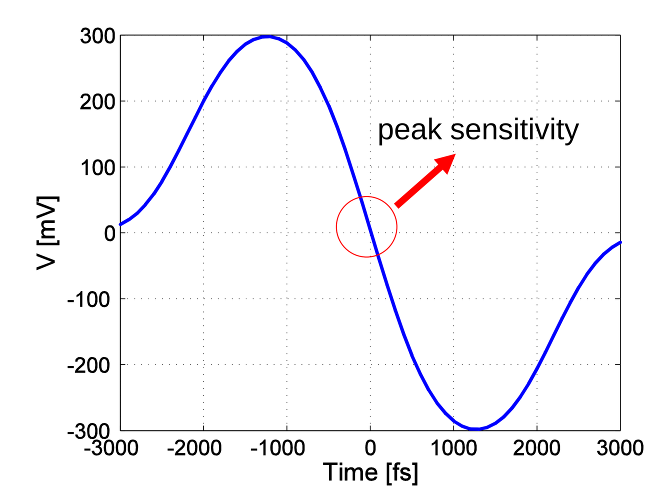

Figure 8. Different signal of PD1 and PD2, relating to bunch arrival time

Since the entire laser pulse intensity is used in the modulation, the maximum signal can reach up to 30 mV and the peak sensitivity is 400 mV/ps.

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