Accelerator Timing Monitor with Femtosecond Precision

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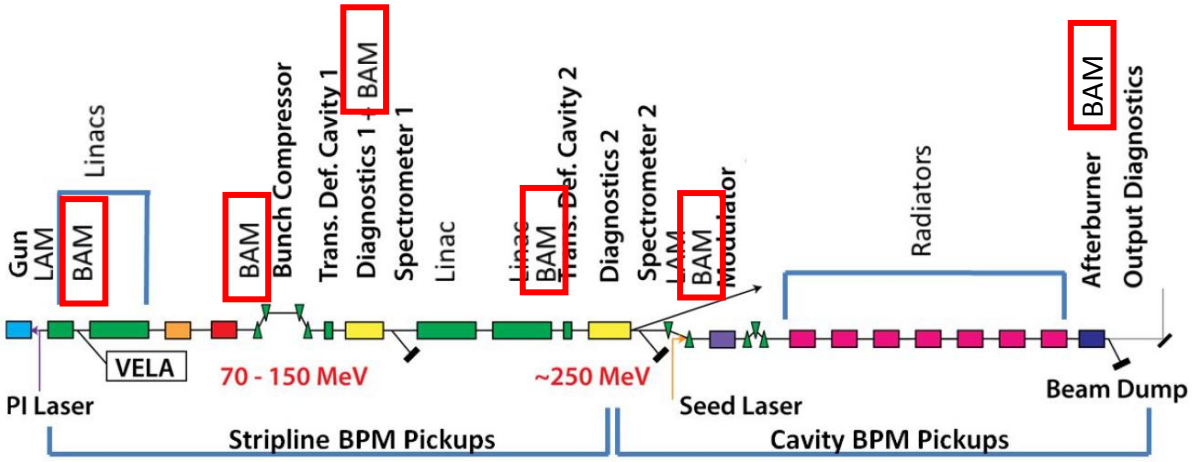
Outline

- Introduction
- RF pick-up based Bunch Arrival-time Monitor (BAM)
- All optical BAM
- Summary

Introduction



Overview of beam diagnostics on CLARA

CLARA:
Compact Linear Accelerator for Research and Applications

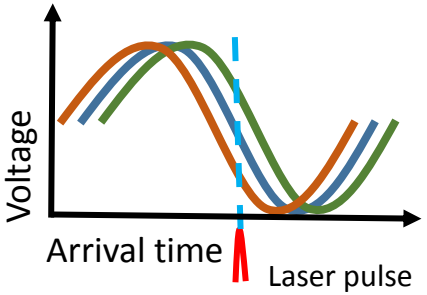
VELA:
Versatile Electron Linear Accelerator

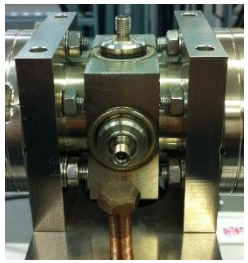
Bunch Arrival-time Monitor (BAM):

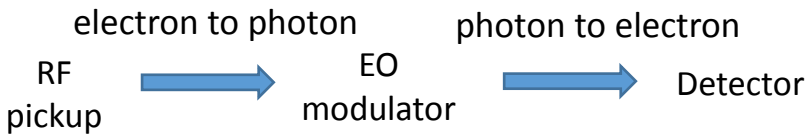
- Improve understanding of the beam dynamics
- Monitor synchronisation points

	VELA	CLARA
Bunch charge	10-250 pC	20-250 pC
Bunch length	1-10 ps rms	25-250-850 fs rms
Energy	4-6 MeV	250 MeV
Bunch repetition rate	1-10 Hz (1-400 Hz in future)	1-100 Hz

BAM with RF pickup







Parameters

Bunch charge = 250 pC
Bunch length (FWHM) = 1 ps

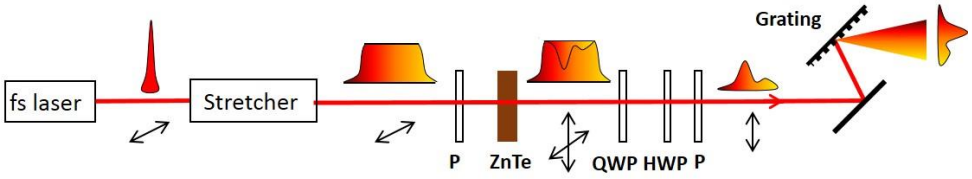
Laser wavelength = 1550 nm
Laser pulse width (FWHM) = 200 fs
Laser average power at 250 MHz = 32 mW

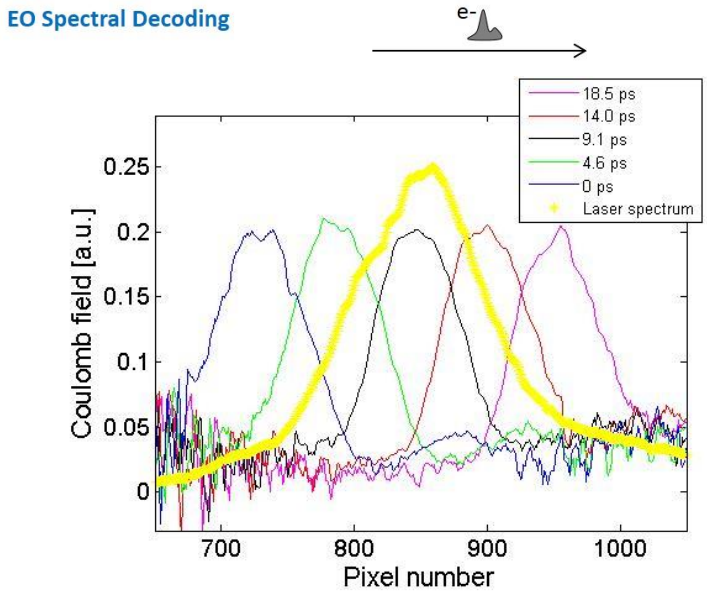
Detection module:
23 µV resolution
Single pulse detection

BAM will be tested in June this year on VELA accelerator

Can the RF pickup be replaced by EO crystal?

Electro-optic bunch profile measurements





EOSD scheme bunch profile monitor on CALIFES at CERN

Reference for EO BAM:

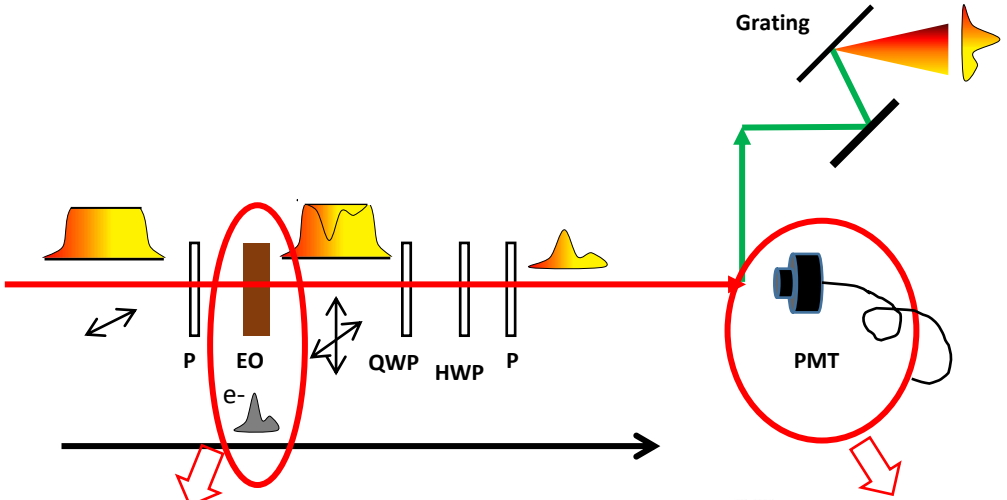
Clocking Femtosecond X Rays
A. L. Cavalieri and et al.
PRL 94, 114801 (2005)

Electro-optic bunch arrival time measurement at FLASH
V. Arsov and et al.
THPC152, Proceedings of EPAC08

Require:

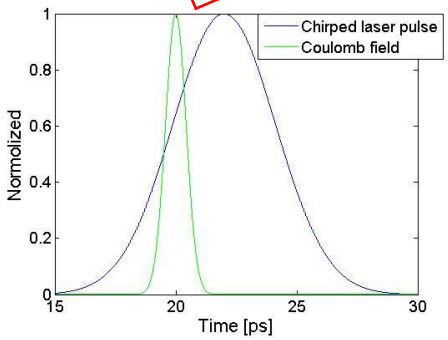
- Real time data processing
- Zero crossing point
- Centre of mass
- Resolution < 5 fs

Electro-Optic Spectra Decoding system

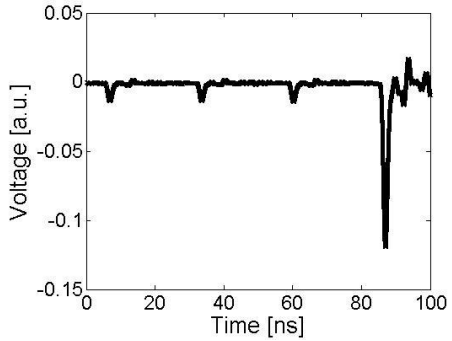


$$I(\omega) = I_{laser} \cdot \left(\frac{x\omega}{cn}\right)^2 \frac{\pi}{\beta} \left| E_{Coul}^{eff}(\tau + t_0) * e^{i\left(\frac{\tau^2}{4\beta} - \frac{\pi}{4}\right)} \right|^2$$

Delay between Laser pulse and THz



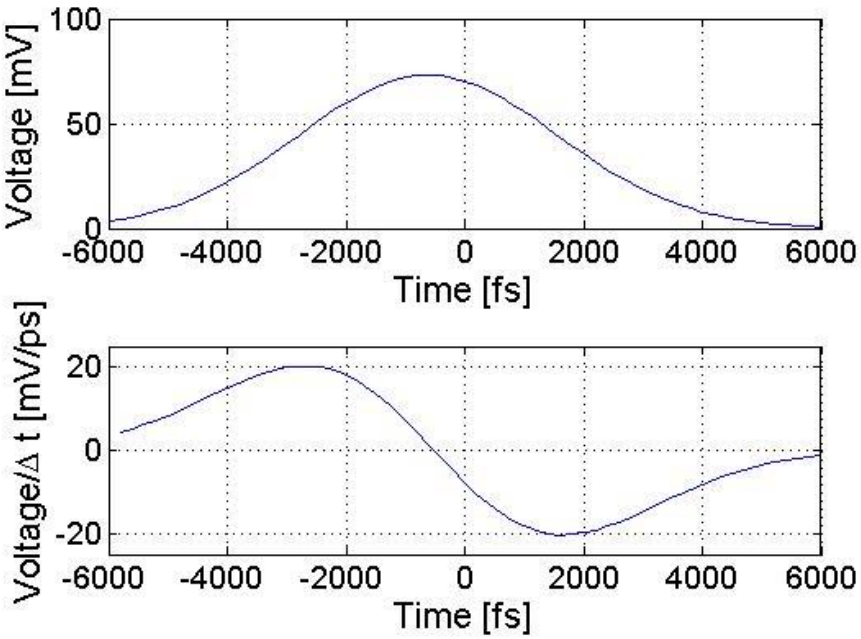
Chirped laser pulse and Coulomb field



EO signal from PMT

Bunch arrival-time modulates laser intensity

Expected resolution



Positive:

---- Simple setup, chirp done by fibre

---- Possible to be switched to a bunch profile monitor

---- Sensitivity/scanning window adjustable

---- ps range effective window

Negative:

---- High quality laser profile

---- Noise dependent

---- Bunch profile dependent

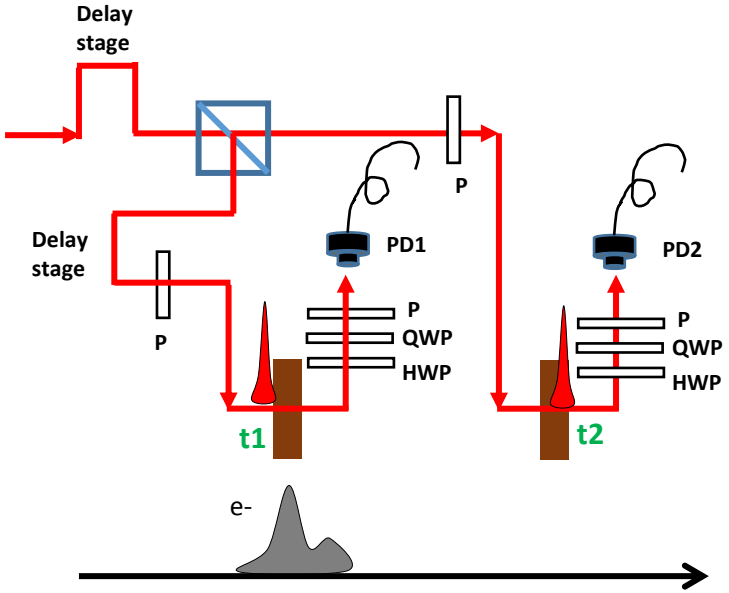
Numbers for example:

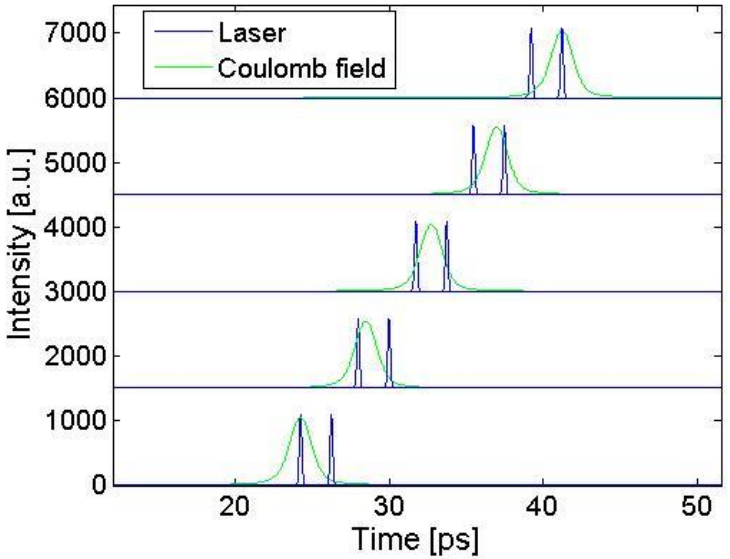
Laser wavelength = 1550 nm
Laser pulse energy in = 150 pJ
Laser pulse : 200 fs chirp to 5 ps
ZnTe = 1 mm
PD conversion = 1 A/W

Bunch shape : 1 ps FWHM Gaussian
Bunch charge : 0.2 nC
Beam energy: 200 MeV

Peak sensitivity = 20 mV/ps
Window = ~1 ps

Resolution improvement: Balance Detection





Pulses propagation in ZnTe crystal

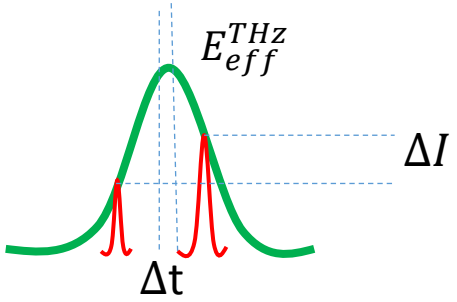
Phase mismatching leads to a signal scanning in a single shot

ZnTe thickness: 2 mm

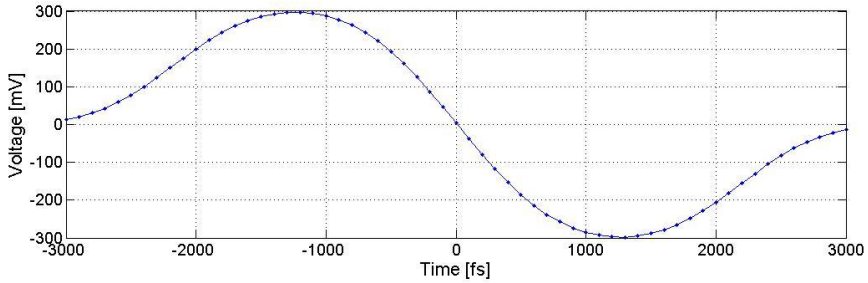
EO Sampling:

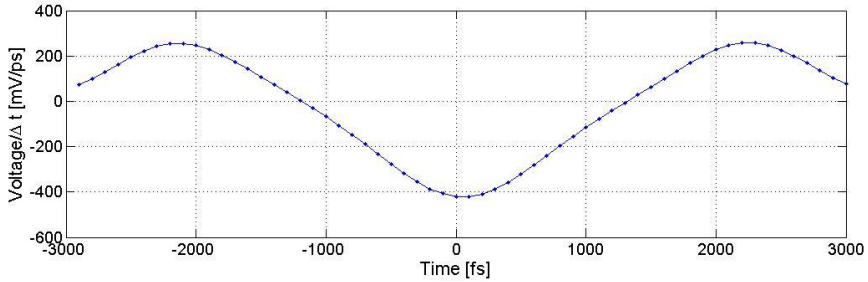
$$\Delta\Phi = \frac{\omega x}{c n_{opt}} E_{eff}^{THz}(\tau)$$

$$E_{eff}^{THz}(\tau) = \mathcal{F}^{-1}\left\{\tilde{\chi}^{(2)}(\Omega) \cdot \tilde{\xi}(\Omega) \cdot \tilde{E}^{THz}(\Omega)\right\}$$



Expected resolution





Positive:

---- No chirp required

---- Balance detection increases sensitivity

---- Zero crossing = centre of mass

Negative:

---- More complex

---- shorter effective window

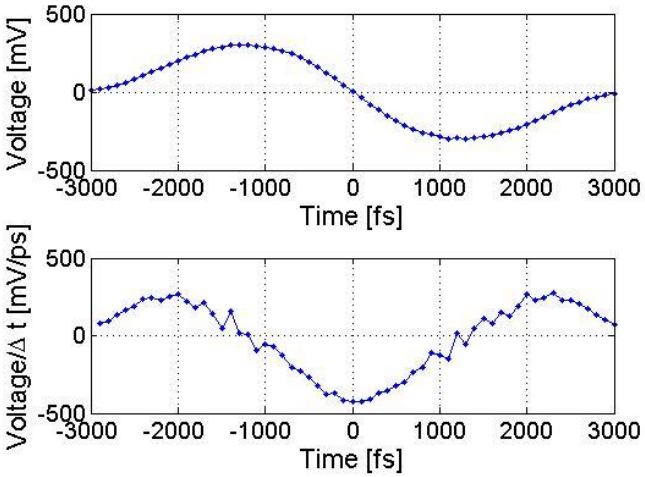
Numbers for example:

Laser wavelength = 1550 nm
Laser pulse energy in = 150 pJ
Laser pulse : 200 fs
ZnTe = 2 mm
PD conversion = 1 A/W

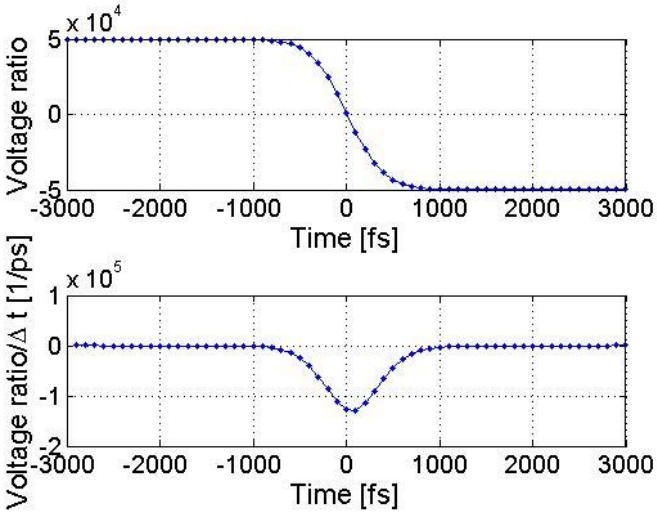
Bunch shape : 1 ps FWHM Gaussian
Bunch charge : 0.2 nC
Beam energy: 200 MeV

Peak sensitivity = 400 mV/ps
Window = ~ 500 fs

Noise



laser amplitude
fluctuation ratio 3%



(U1-U2)/(U1+U2)

Outlook

Build fibre link from lab to VELA, including dispersion compensation

Noise sources and control need to be studied

Principle test in lab

Summary

A RF pickup based BAM is being installing on VELA accelerator at Daresbury. Will be tested in June.

Two all optic based BAMs are demonstrated and can potentially achieve a resolution in femtosecond level.

The balance detection based BAM has 400 mV/ps peak sensitivity. Less sensitive to bunch profile and laser amplitude fluctuation.

Acknowledgments

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Thanks for your attention !