Compact ultra-high precision beam phase monitor system

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The timing information of the electron bunch is transferred into an amplitude modulation. This modulation is measured with a photo detector and sampled by a fast ADC.
Beam pick-up signal in EO-hutch:

Material = Copper
Type = Lossy metal
Mu = 1
El. cond. = 5.8e-007 [S/m]
Beam Pick-up

Beam pick-up signal in EO-hutch:

Material: Copper
Type: Lossy metal
Mue: 1
El. cond.: 5.8e+007 [S/m]
Electro-Optical-Modulator (EOM)
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Commercially available with bandwidths up to 40 GHz (we use a 10 GHz version)
Systematic Layout of the Phase-Monitor System

1.3 GHz

VM

DAC

DOOCS

trigger clock

ADC 100 MHz 12 / 14 Bit

LNA 200 MHz 1.5 GHz

EOM

81 MHz 1.5 GHz

beam pick-up

piezo controller

piezo fiber stretcher

Master Laser Oscillator

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First Results:
Raw Data of Phase Monitor Measurement
First Results: Amplitude of Laser Pulses
First Results:
Amplitude of Laser Pulses (normalized)
First Results:
Scan of Laser Pulse over Beam Pick-up Signal

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First Results:
Scan of Laser Pulse over Beam Pick-up Signal

slope used for measurement
First Results: Calibration and Resolution of the System

The resolution can be estimated from the slope of the phase monitor signal and the amplitude noise of the unmodulated laser pulses:

Best results:
- slope $\sim 7.1 \text{ ps / unit}$
- $\text{rms(laser amplitude)} \sim 0.425 \%$
- $\text{rms resolution} \sim 30 \text{ fs}$
First Results: Rel. Beam Arrival Time for Different ACC1 Gradients

ACC1 gradient
15.70 MV / m
15.65 MV / m
15.60 MV / m
First Results: Rel. Beam Arrival Time for Different ACC1 Gradients

ACC1 gradient
15.70 MV / m

\[ \Delta t \approx 4.6 \text{ ps} / \text{m} \]

rms jitter \( \approx 0.5 \text{ ps} \)

Comparison measurement with TCAV yielded an arrival time change of about 3.8 ps.

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First Results: Comparison Measurement between two Monitors

The signal of the beam pick-up was splitted which yields a lower resolution.

The rms-resolution of the phase monitors was estimated from the laser amplitude noise and the slope from the calibration:

Phase Monitor 1: 99 fs
Phase Monitor 2: 114 fs
First Results: Comparison Measurement between two Monitors

rms jitter

e⁻-beam (BPhM1) 357 fs

e⁻-beam (BPhM2) 342 fs

BPhM1 – BPhM2 138.8 fs
First Results: Comparison Measurement between two Monitors

rms jitter

$e^-$-beam (BPhM1) 212.9 fs

$e^-$-beam (BPhM2) 211.6 fs

BPhM1 – BPhM2 138.8 fs
Possible Upgrade of the Phase-Monitor System

- Reduction of the laser repetition rate
  - slower photo detector possible
  - signal from photo detector can possibly be samples directly
  - The requirements on the ADC clock are reduced due to the broader signal after the photo detector
  - With a 108 MHz ADC three sample points per laser pulse are available

Diagram:
- 1.3 GHz signal from VM to DAC
- DOOCs with trigger clock
- ADC 10 / 100 MHz, 14 / 16 Bit
- 50 MHz signal to EOM
- Beam pick-up
- 1.3 GHz signal to piezo controller
- 1.5 GHz signal to AOM
- 54 MHz signal from piezo fiber stretcher
- 2 - 10 MHz signal to Master Laser Oscillator
Summary

• Compact, low cost design
• High resolution: ~30 fs reached, sub-10 fs feasible
• A new beam pick-up design, EOM installation next to pick-up, and faster EOM promise even higher resolution
• Only few drift sources which are not removed by normalization of the laser intensity: beam pick-up, RF cable to EOM, and limiter (the cable can be made very short and the components can be temperature stabilized)
• Same concept usable for many purposes like for BPMs, RF cavity signals, and photo-diode signals

• Only sensitive to center of beam distribution
• In addition techniques like TCAV and EOS are needed for longitudinal pulse shape measurements