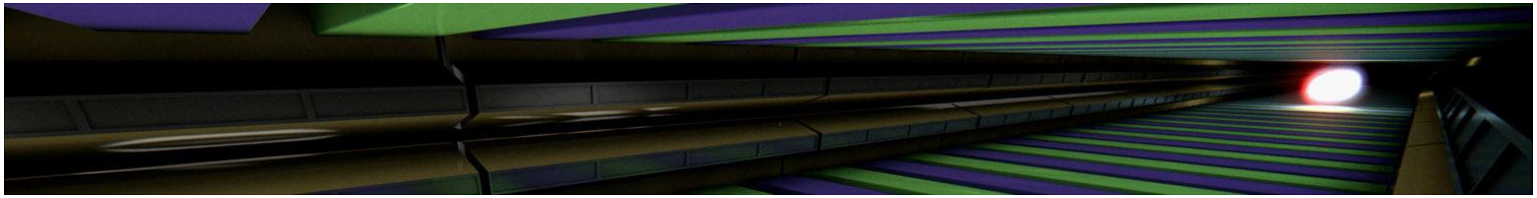

Dark current Monitor for the European XFEL

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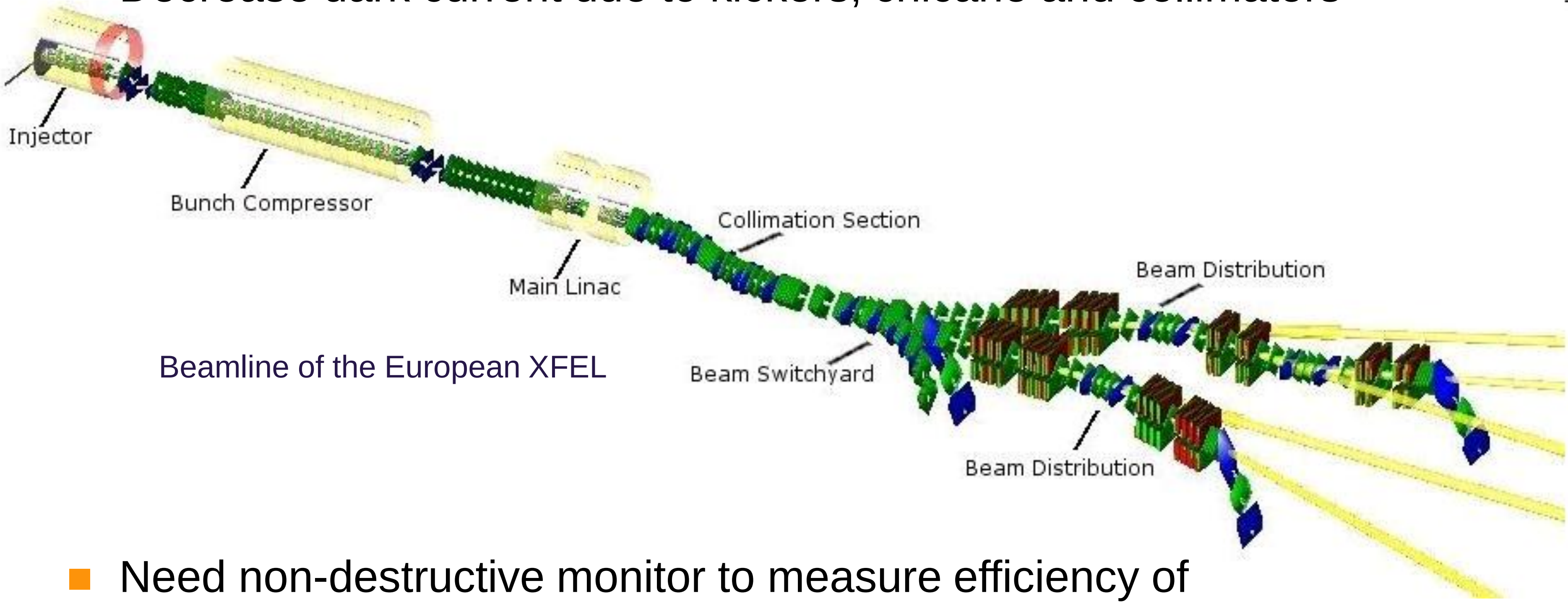
DESY Hamburg

Content

- Dark current
- Principle of detecting weakly charged bunches with resonator
- Setup at the Photo Injector Test Facility at DESY Zeuthen
- Measurement of bunch charge
- Principle of detecting dark current with resonator
- Measurement of dark current
- Principle of detecting bunch length
- Measurement of bunch length
- Summary

Dark current

- Production of dark current due to field emission in accelerator
- Causes radiation background in the tunnel: destroy electronics and activate components
- Decrease dark current due to kickers, chicane and collimators



Beamline of the European XFEL

- Need non-destructive monitor to measure efficiency of dark current reduction

Principle of detecting weakly charged bunches with resonator

$$U = U_0 \sin(\omega t)\exp\left(-\frac{t}{\tau}\right)$$

$$\omega = 2\pi f$$

$$\tau = \frac{Q_L}{\pi f}$$

Induced voltage in a resonator from a beam oscillates with resonance frequency *f* and decays with decay time τ.
Q_L: loaded quality factor.

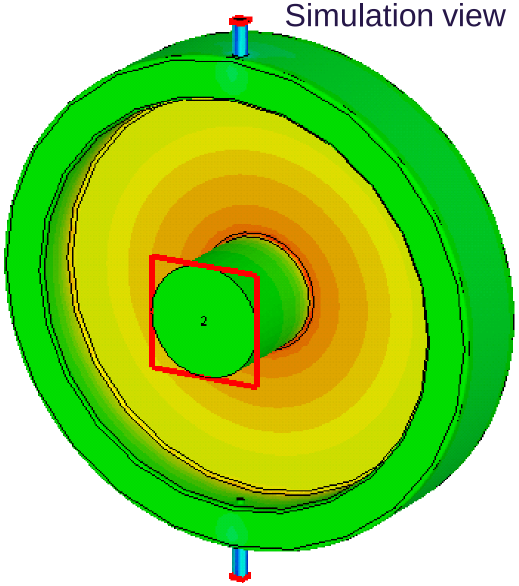
By measuring U_0 the charge of the beam *q* is determined.

$$\frac{U_0}{q} = \pi f \sqrt{\frac{Z}{Q_{ext}}\left(\frac{R}{Q}\right)} = S$$

for monopole modes

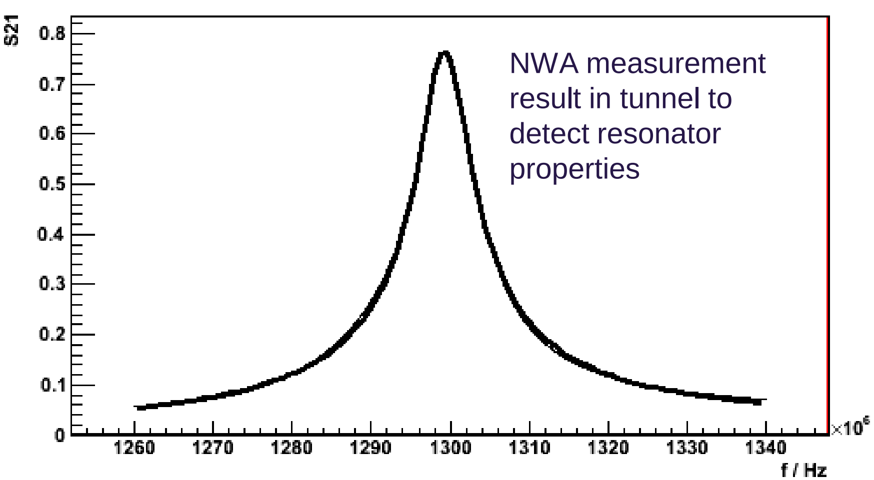
Sensitivity *S* can be determined by resonance frequency *f*, line impedance *Z*=50Ω, external quality factor Q_{ext} and normalized shunt impedance *(R/Q)*.

Field distribution of 1. monopole mode Simulation view



Setup at the Photo Injector Test Facility at DESY Zeuthen (PITZ)

- PITZ: characterize, optimize and prepare electron source for FEL
- Dark current Monitor (DaMon) situated 2.36 m behind cathode followed by booster 0.68 m
- Measurement: f_l=1299.3±0.1 MHz, Q_L=193±5, Q_{ext}=252±4
- Expectation agree with measurement (resonator without tuner)
- Shunt impedance from simulation, results in sensitivity of 11.83 V/nC



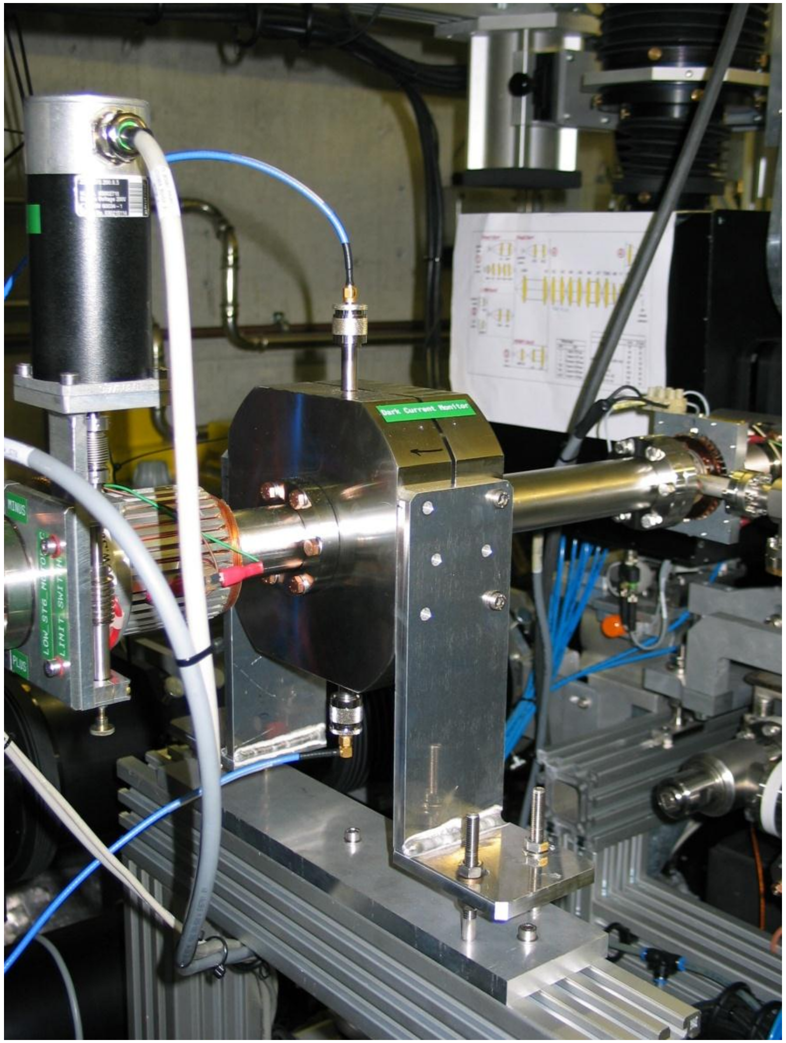


Photo: J. Lund-Nielsen

Setup at the Photo Injector Test Facility at DESY Zeuthen (PITZ)

Electronics

- Two inputs according of two outputs of DaMon:
    1. Beam charge
    2. Dark current
- Includes circulator, band-pass filters, limiter, pre-amplifier, down conversion to IF, logarithmic detector, offset and gain control
- Four outputs

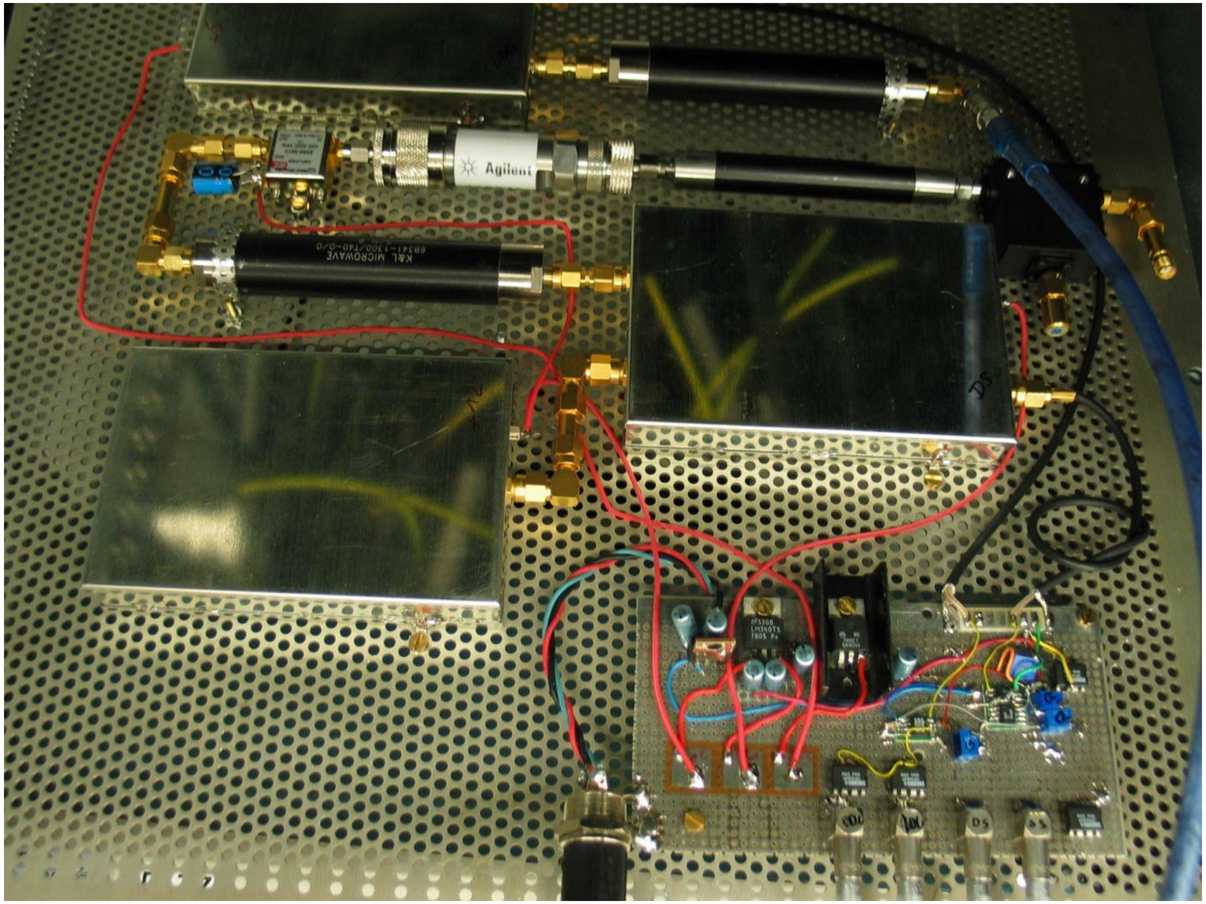
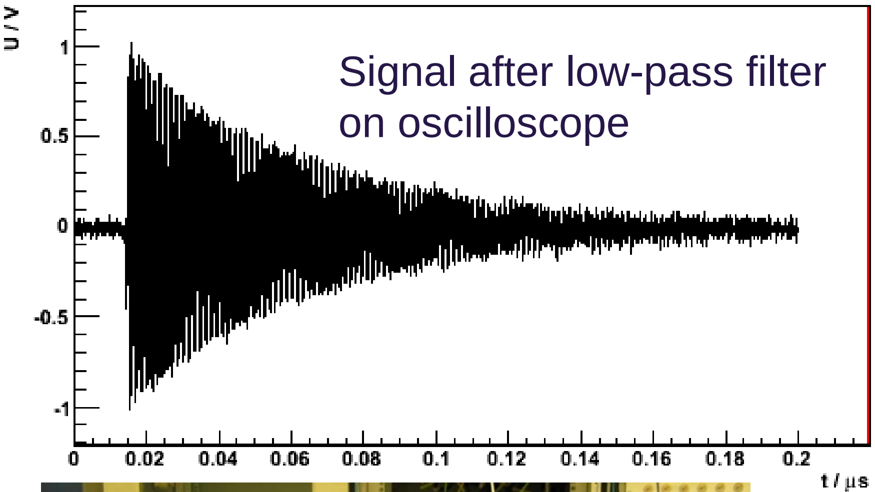
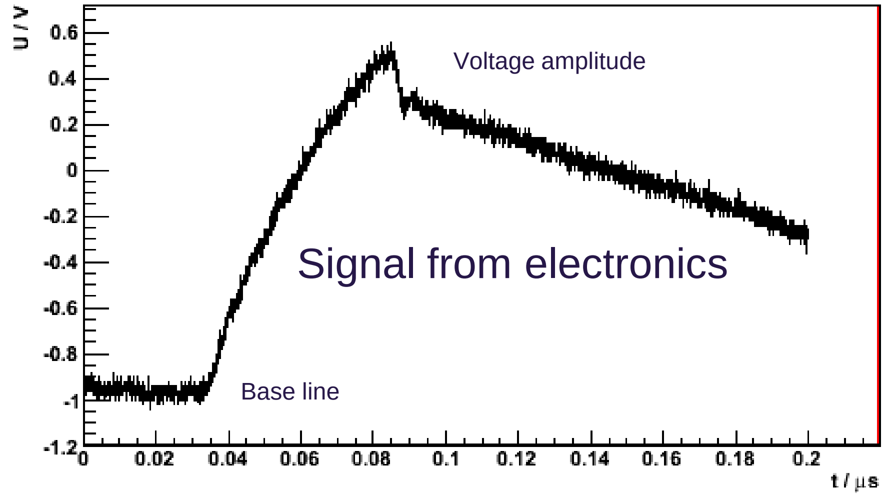


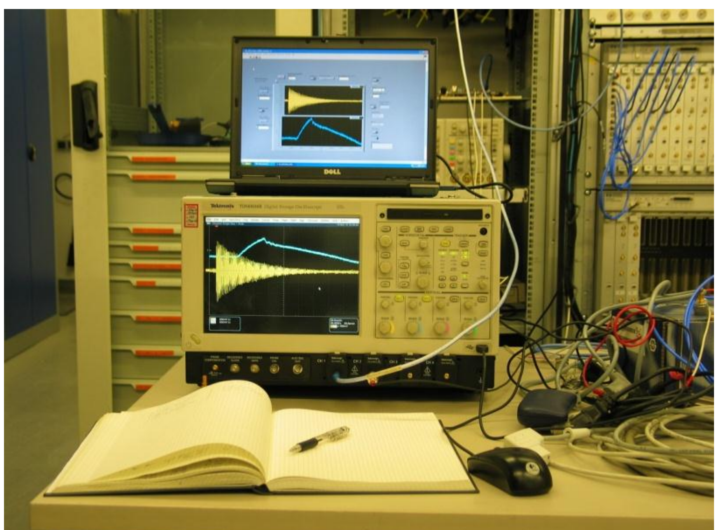
Photo: J. Lund-Nielsen

Measurement of bunch charge

Beam charge 0.34 nC (measured with Faraday Cup: FC)







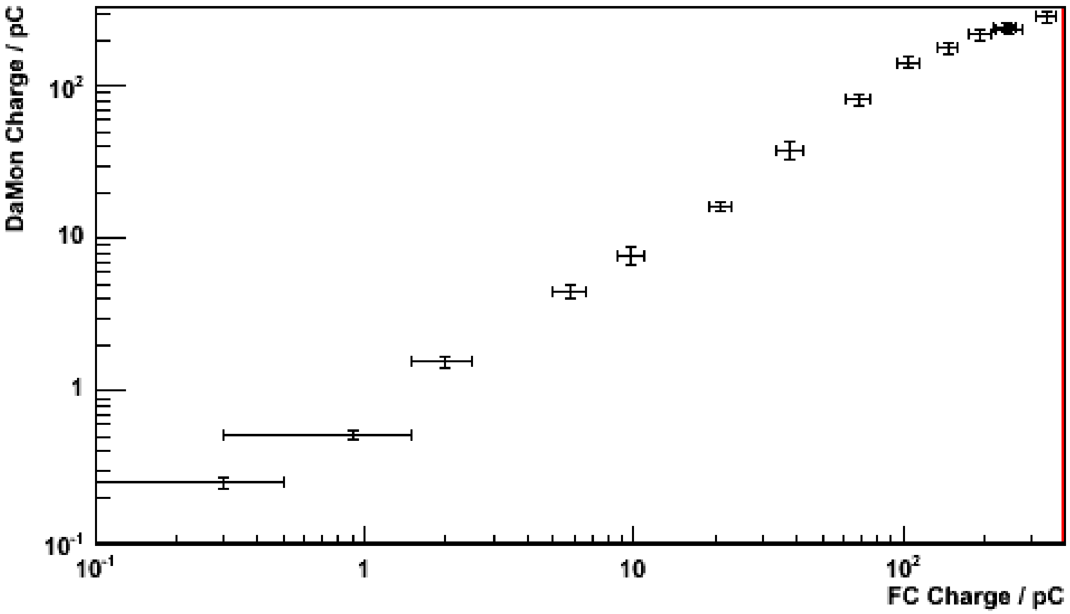
Electronics provides voltage amplitude which will be re-calculated in bunch charge and dark current

Photo: J. Lund-Nielsen

Measurement of bunch charge

Voltages calibrated with electronics response function, attenuation of cables and attenuators.

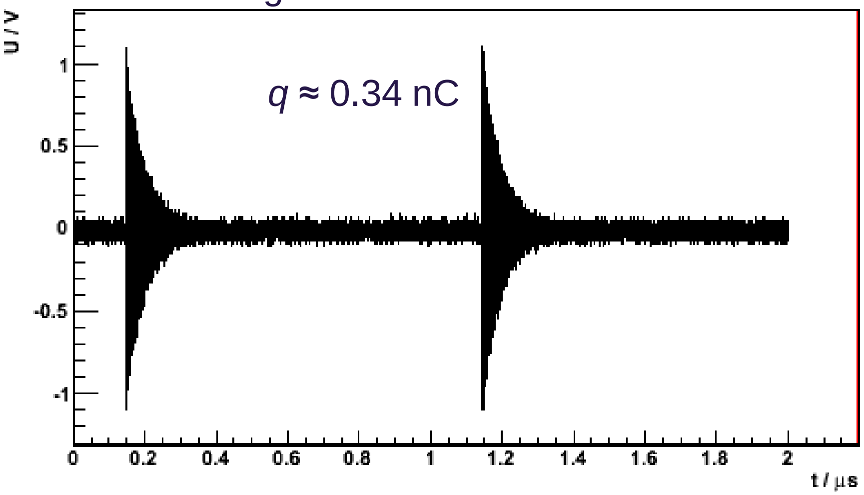
- smaller fluctuation compared to Faraday Cup for low charges
- Sub-Pico-Coulomb resolution with DaMon visible
- Still 20 dB attenuation used
- DaMon 2% higher charge compared to FC (loss of charge at FC)



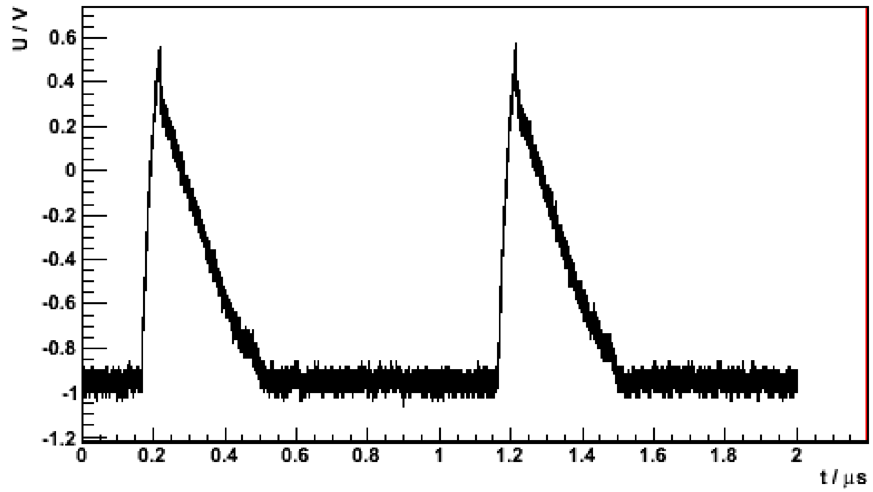
Good agreement between **laboratory calibration** measurement including **simulated shunt impedance** and measured charge with FC

Measurement of bunch charge

Signal without electronics



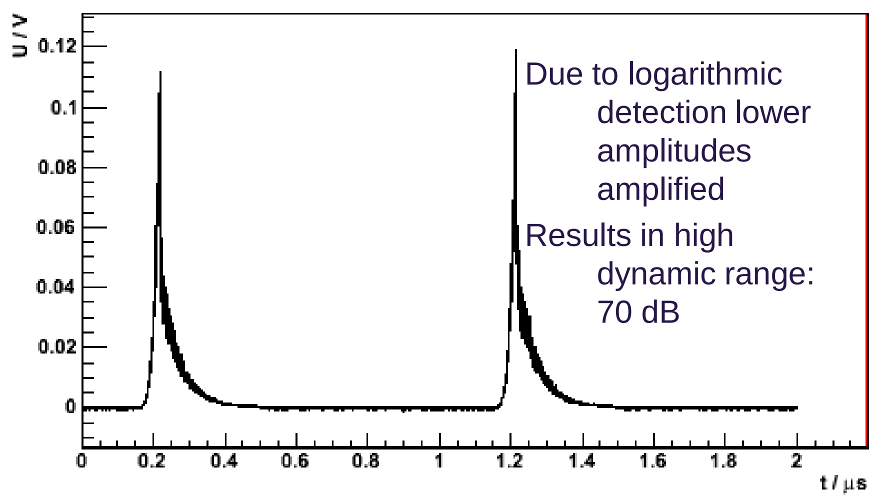
Signal with electronics



Comments

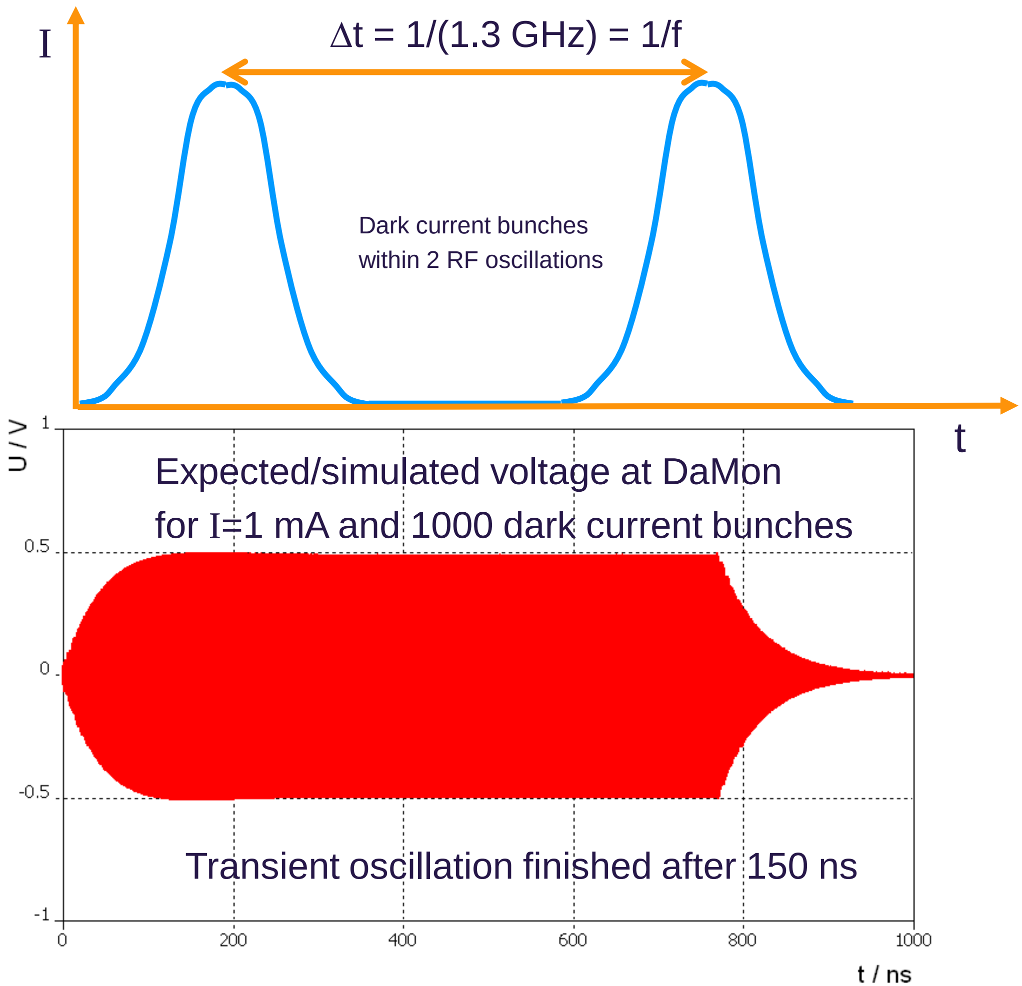
- The bunch spacing at PITZ is 1 µs, decay time withouth and with electronics measurement sufficient
- Bunch spacing for European XFEL is 222 ns, decay time is sufficient for single bunch measurements

Response function of electronics calibrated



Principle of detecting dark current with resonator

Charge of one dark current bunch **too weak** to be detected: **superimposing** of induced fields from the dark current bunches when **resonance frequency of resonator harmonic of accelerator**



$I=q/\Delta t=q*f$ is mean current

$q=U_0/S$

$S=11.83$ V/nC (proven with bunch charge measurement)

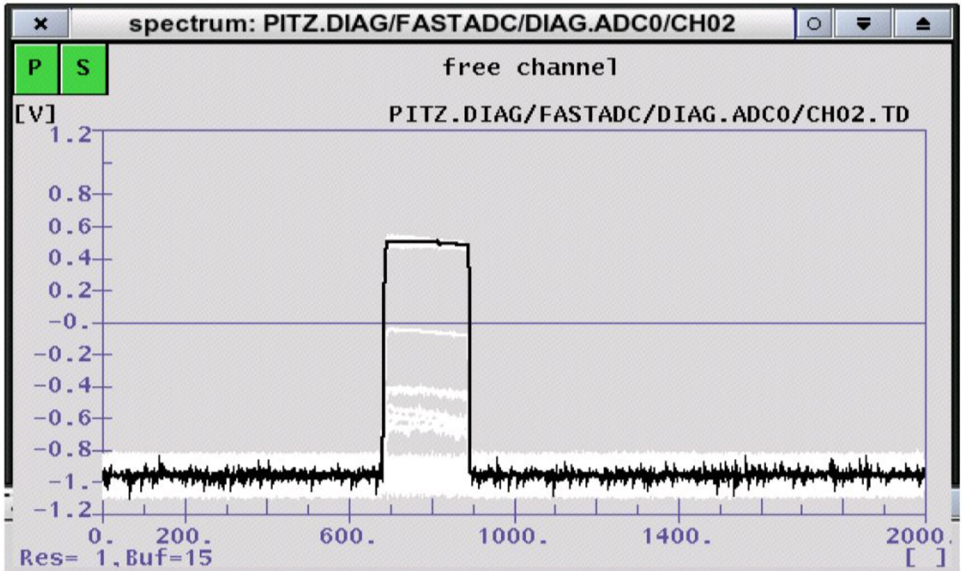
U_{DaMon} is envelope voltage after transient oscillation

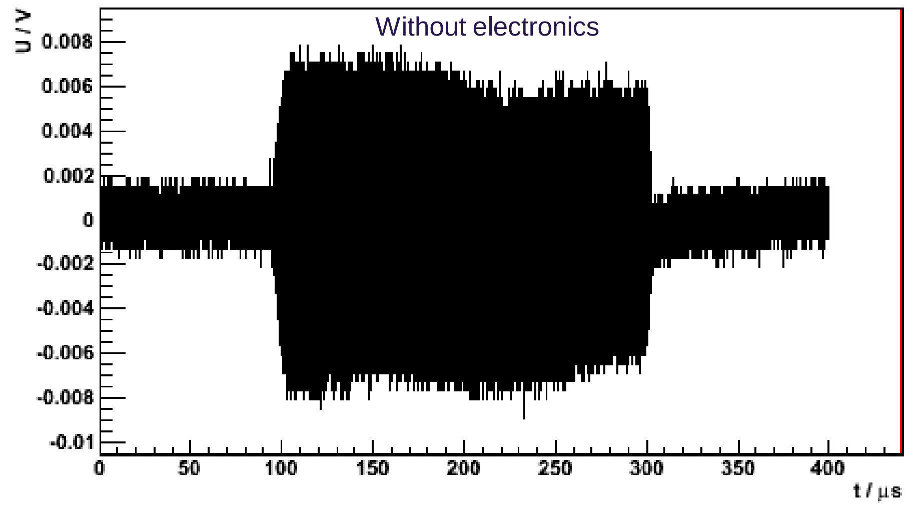
$U_{DaMon}=U_0*(1-e^{-\pi/QL})^{-1}$

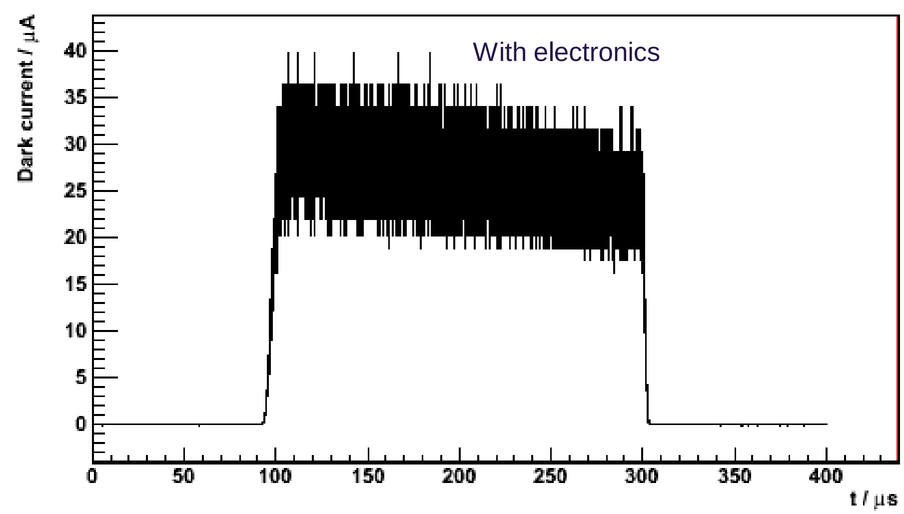
This results in

$I=U_{DaMon}\ f\ (1-e^{-\pi/QL})\ /\ S$

Measurement of dark current

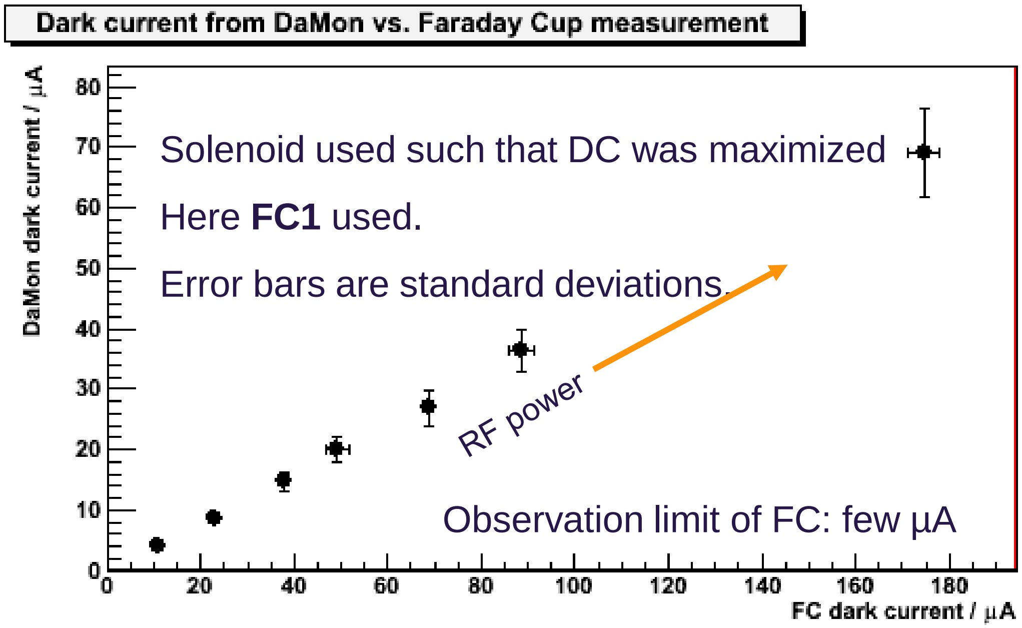






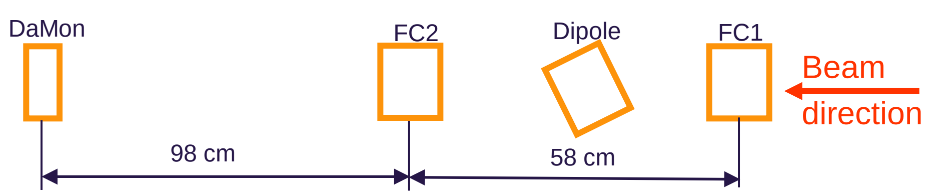
- ADC observed dark current, scale logarithmic
- output without electronics is at sensitivity limit of oscilloscope
- Analyzed data after electronics show about 30 µA
- Distribution of both measurement in agreement

Measurement of dark current



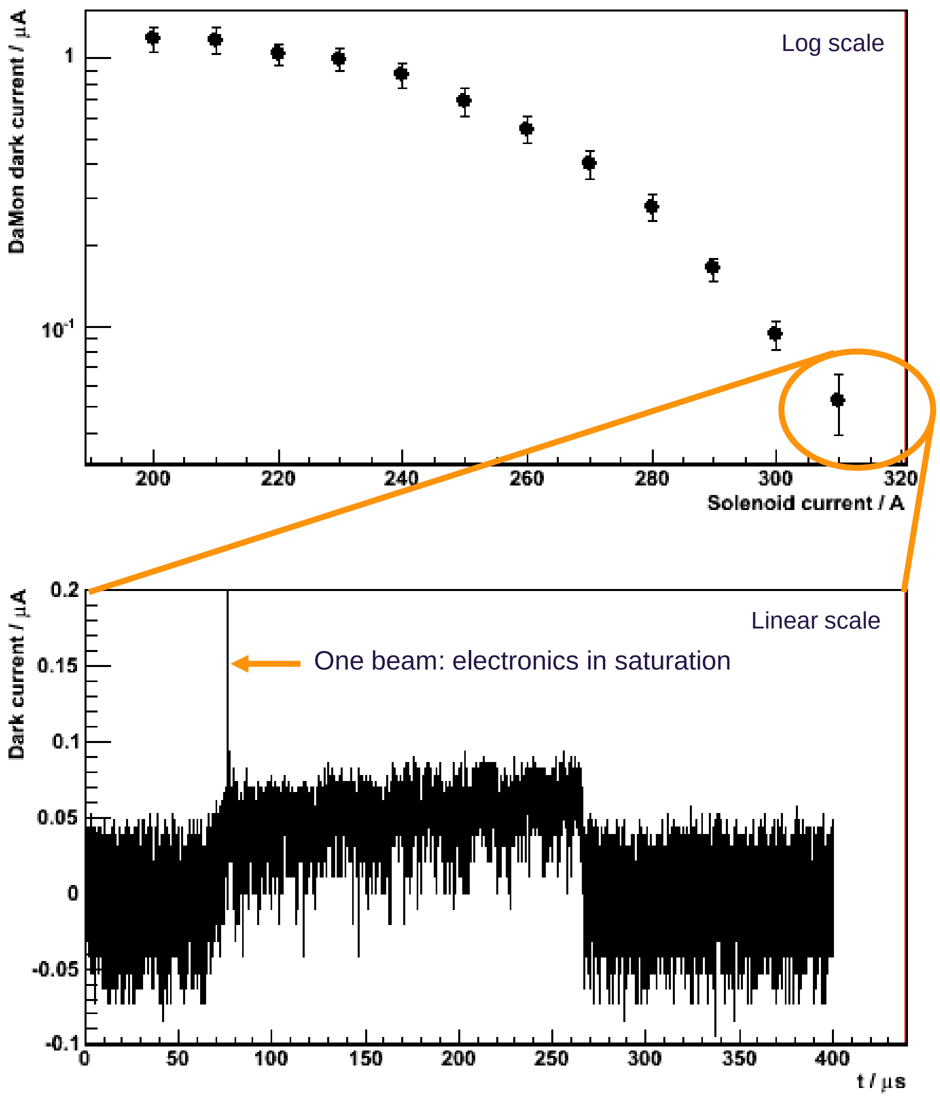
- DC at DaMon 2.5 times lower compared to FC1
- DC at FC2 about 2 times lower compared to FC1

→ Calculated DC at DaMon in agreement with FC



Measurement of dark current

- Measured dark currrent with DaMon as a function of injector solenoid current
- FC can not resolve these low values
- Lowest observed dark current is 52 ± 13 nA
- Observation limit of DaMon system about 40 nA
- For very low beam charges the dark current electronics can be used to observe the charge



Principle of detecting bunch length

- Amplitude from monopole mode is corrected by form factor

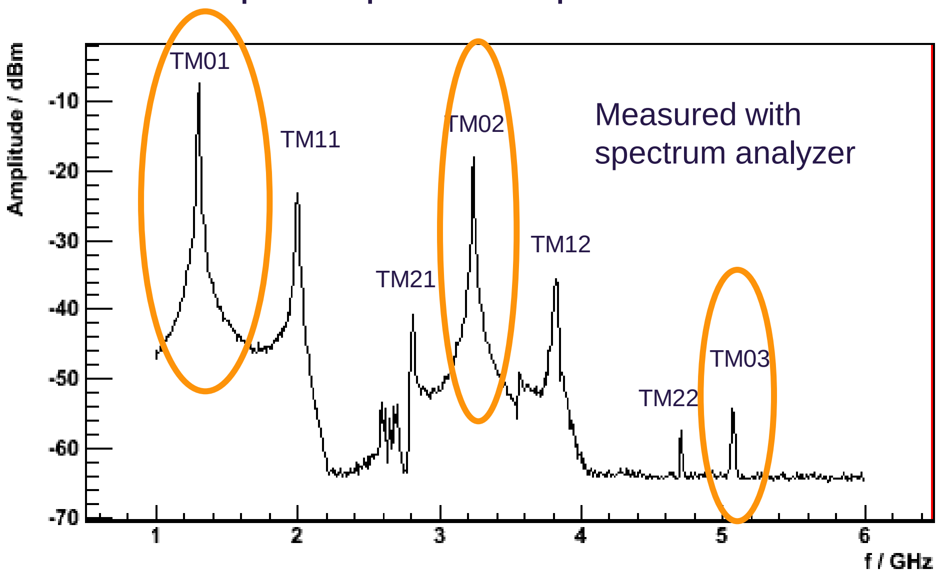
$$U_{0i} = q\, S_i F(\omega_i, \sigma_z)$$

$$F(\omega_i, \sigma_z)_{Gauss} = \exp\left(-\omega_i^2 \sigma_z^2 / 2\right)$$

- Ratio of amplitude for different monopole modes should dependent on bunch length

$$g(\sigma_z, i, j) = \frac{U_{0i}}{U_{0j}}$$

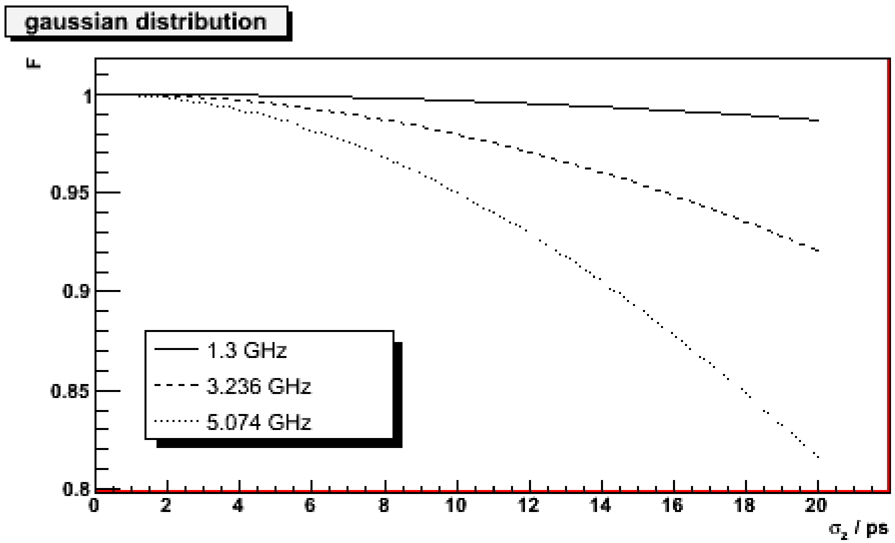
Complete spectrum up to 6 GHz



- First three monopole modes frequencies: 1.299; 3.236; 5.074 GHz

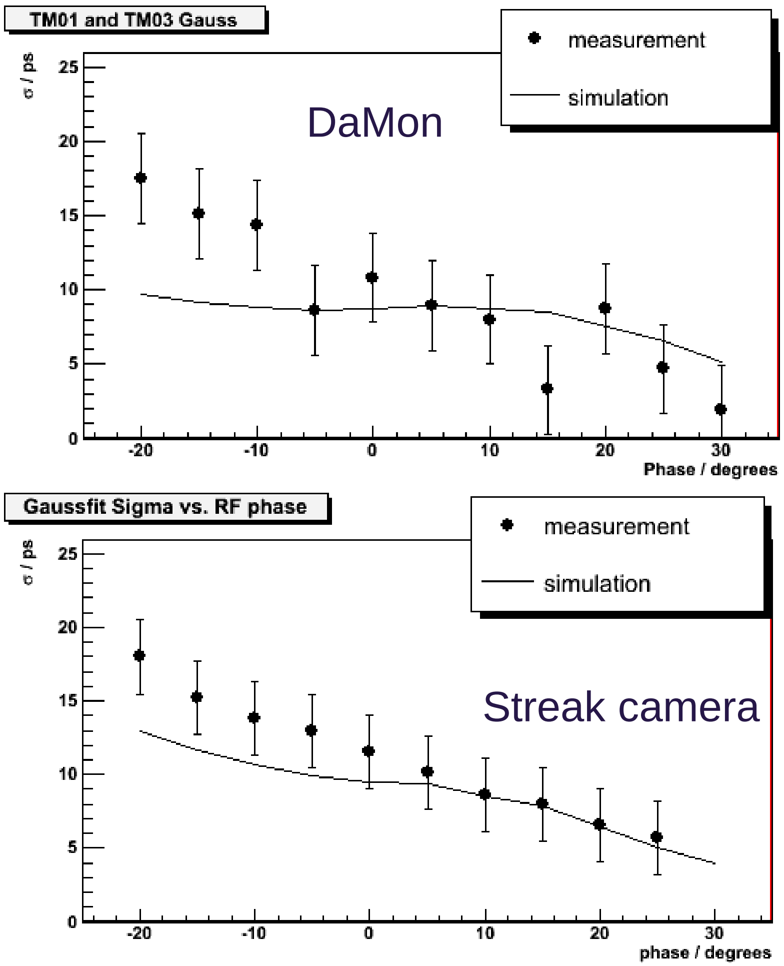
Principle of detecting bunch length

- Form factor as a function of expected bunch length after injector



- After compressor bunch length < 1 ps: form factor tends to be unity; therefore this method applicable only at injector area at the European XFEL
- Best resolution by using largest frequency difference

Measurement of bunch length



- Amplitude at different frequencies taken with spectrum analyzer
- Measurement as a function of injector acceleration phase; highest energy gain at phase 0
- Compare DaMon results (combination TM01 and TM03, because best resolution) with aerogel radiator and streak camera method, detector positions differs by 4 m
- Streak measurement differs from simulation for phases < 0, same as it is for DaMon
- Both show same behavior (maybe simulation parameters not perfect)
- Result: agreement of bunch length taken with DaMon to the streak camera results

Summary

- Commissioning of non-destructive Dark current Monitor at PITZ with electronics, dynamic range about 70 dB
- Single bunch charge measurement with sub-pC resolution
- Dark current with 40 nA observation limit
- Calibration only by laboratory measurement and cable attenuation, agreement with FC measurement
- Will be installed at European XFEL for dark current and beam charge measurement
- Bunch length measurement results in agreement with streak camera method
- Electronics design for bunch length measurement started

Thanks to the PITZ team for support!