STREAK CAMERA PSF OPTIMISATION AND DUAL SWEEP CALIBRATION FOR SUB-PS BUNCH LENGTH MEASUREMENT

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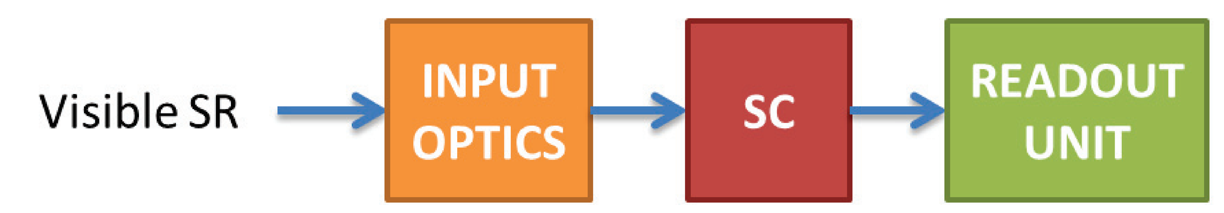
ABSTRACT

Streak cameras are commonly used for bunch length measurement. In normal beam modes, bunch lengths are on the order of 10 ps. For the study of coherent synchrotron radiation, a low alpha single bunch beam mode is implemented with bunch lengths as small as 1 ps and beam current in the tens of μA. In order to reliably measure such a short bunch at low beam currents, the input optics for the streak camera must be optimised for sufficient incident light intensity and high resolution in both sweep directions. This is achieved through the use of reflective input optics in which a pinhole is imaged to provide a small circular PSF. Furthermore, to precisely measure the bunch length the calibration of the dual sweep must be known. Here we describe a calibration method using electrical delays to incorporate calibration information within streak camera images.

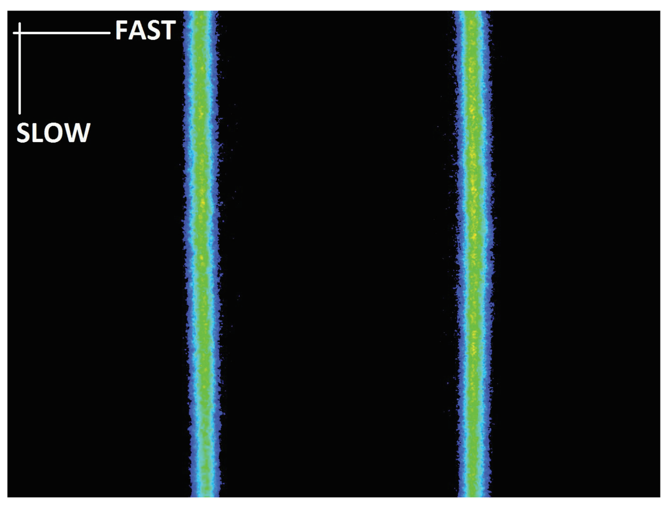
EXPERIMENTAL SETUP AND ANALYSIS PROCEDURE

1. Visible Light Extraction (VLE) system brings visible synchrotron radiation (SR) from a bending magnet in the storage ring to the diagnostics beamline where the streak camera (SC) [1] is located. VLE path length is ≈25m.
2. In the beamline, visible SR propagates through input optics to the SC.
3. SC converts photons to electrons, deflects the electrons in two directions and finally converts electrons back to photons.
4. SC image is acquired using a phosphor screen, intensifier, imaging lens and cooled CCD camera readout system.
5. For accurate bunch length measurement, SC image is deconvolved with Point Spread Function (PSF) [2]

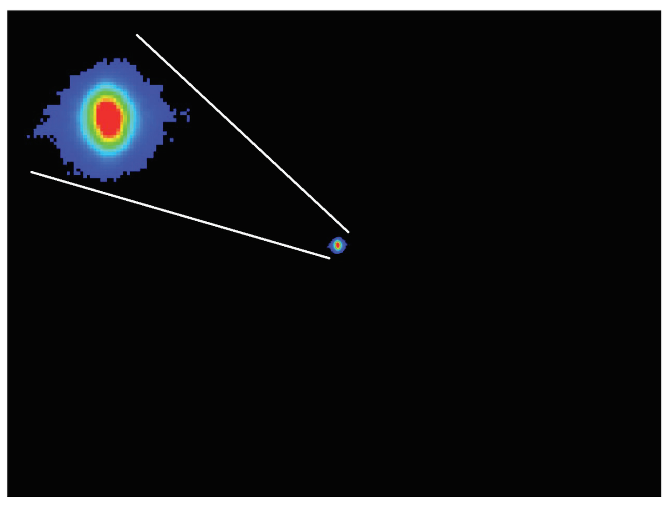
$$\sigma_{bunch} = \sqrt{\sigma_{meas}^2 - \sigma_{PSF}^2}$$



Schematic overview of the streak camera system.



Typical SC image in low alpha beam mode



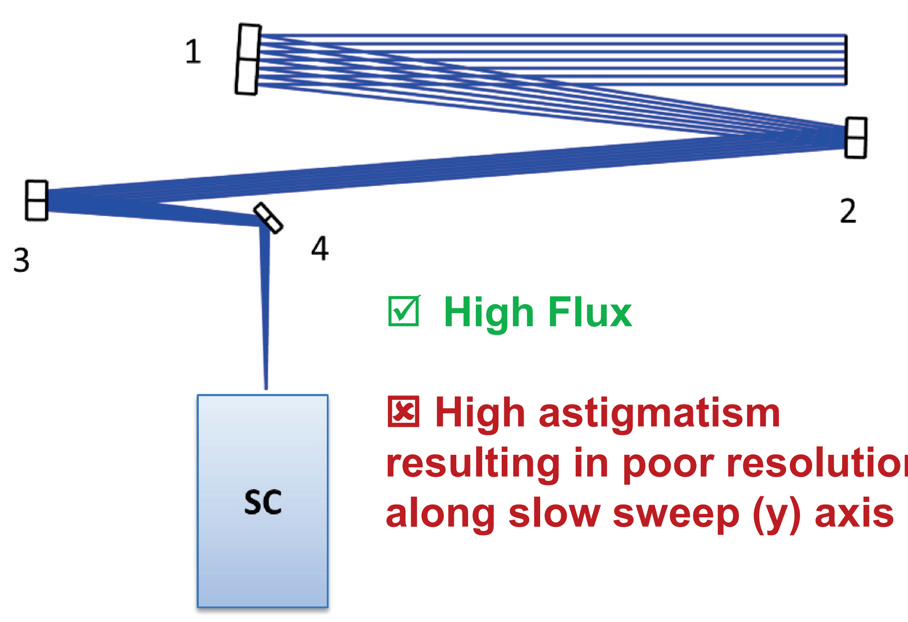
Typical PSF image with zoomed in ROI shown is top left

INPUT OPTICS UPGRADE

For SR studies using the single bunch low alpha beam mode, the input optics must be optimised to:

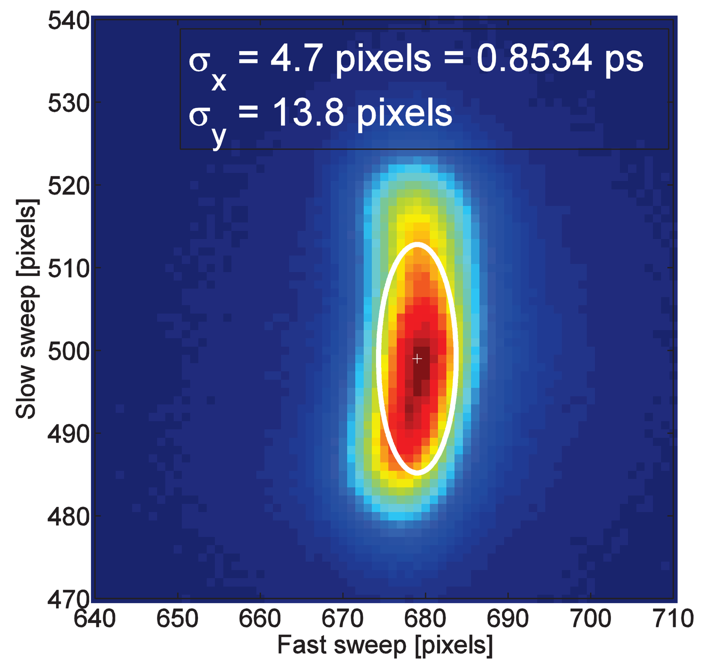
1. **Propagate the maximum available light intensity to the SC**
   - ➢ Achieved by using reflective input optics only
2. **Focus the incident SR beam to obtain a minimum PSF spot size (i.e. best resolution) at the SC**
   - ➢ Achieved by imaging circular pinhole

Previously Implemented System [3]

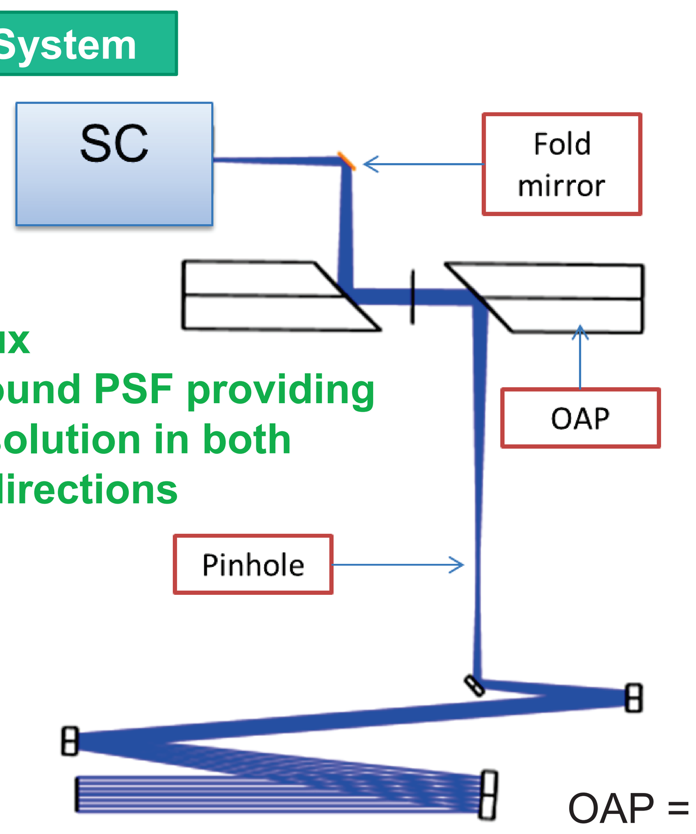


☑ High Flux

☒ High astigmatism resulting in poor resolution along slow sweep (y) axis

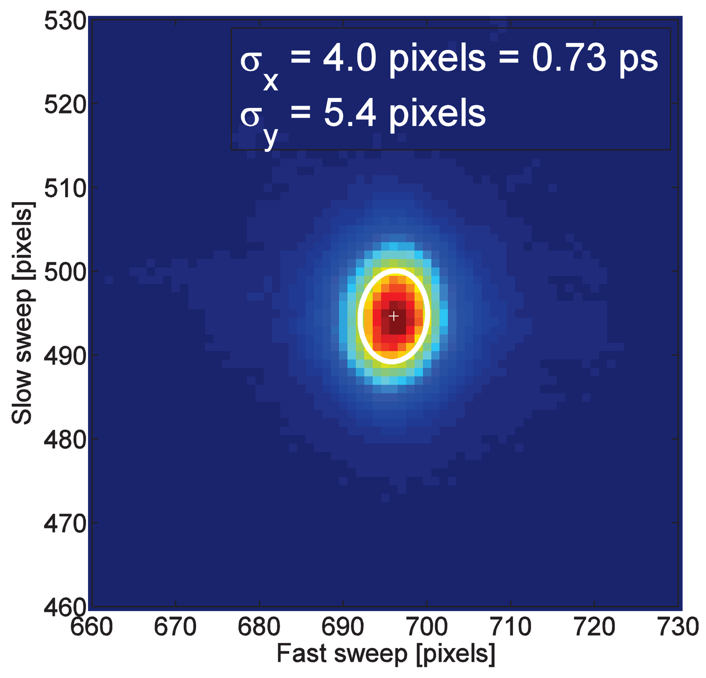


Upgraded System



☑ High Flux

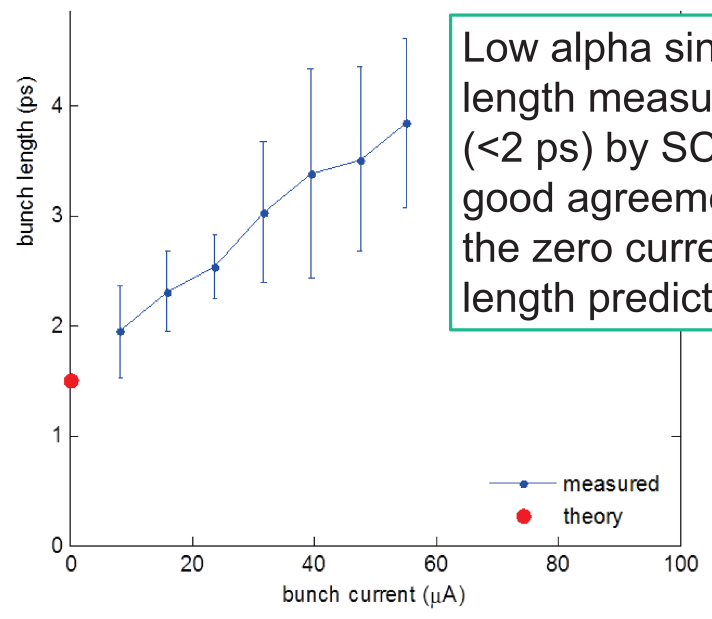
☑ Small round PSF providing high resolution in both sweep directions



OAP = 90° Off Axis Parabolic mirror

CONCLUSION

For sub-ps bunch length measurements the optimisation of the input optics and calibration of the timebases of the streak camera must be performed.
At DLS, the input optics to the SC have been upgraded to work with white beam and to ensure a high resolution in both the fast and slow sweep directions through the reduction of the PSF spot size using a pinhole aperture.



Low alpha single bunch length measurements (<2 ps) by SC are in good agreement with the zero current bunch length prediction [4].

CALIBRATION USING ELECTRICAL DELAY

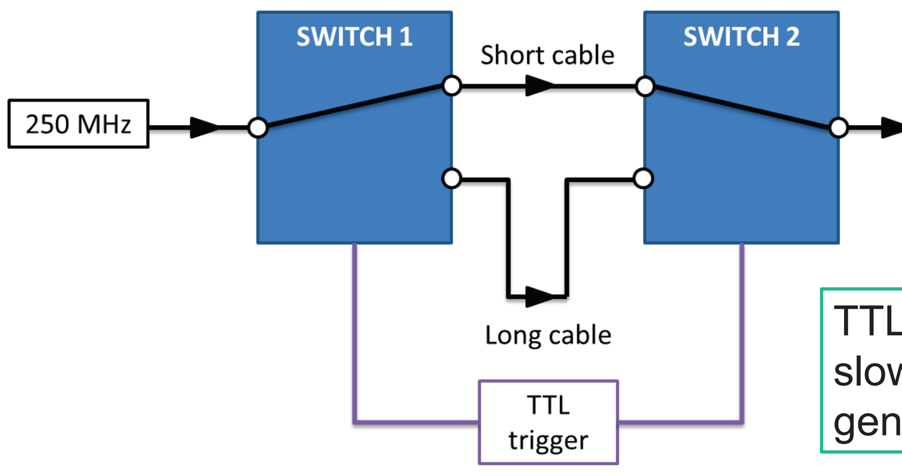
To calibrate the SC timebases, optical delay lines using the SR beam or a separate laser source are often implemented. However, this is often time consuming due to the numerous degrees of freedom and accuracy required.

Rather than delaying the arrival time of the incident light pulse relative to the fast sweep deflection by a known amount, the same result can be achieved by delaying the fast sweep deflection relative to the arrival time of the incident pulse.

→**Use an electrical delay**

Electrical Delay Setup

Electrical delay is introduced to the fast deflection (250 MHz) signal of the SC using PIN diode switches connected by cables of different lengths.

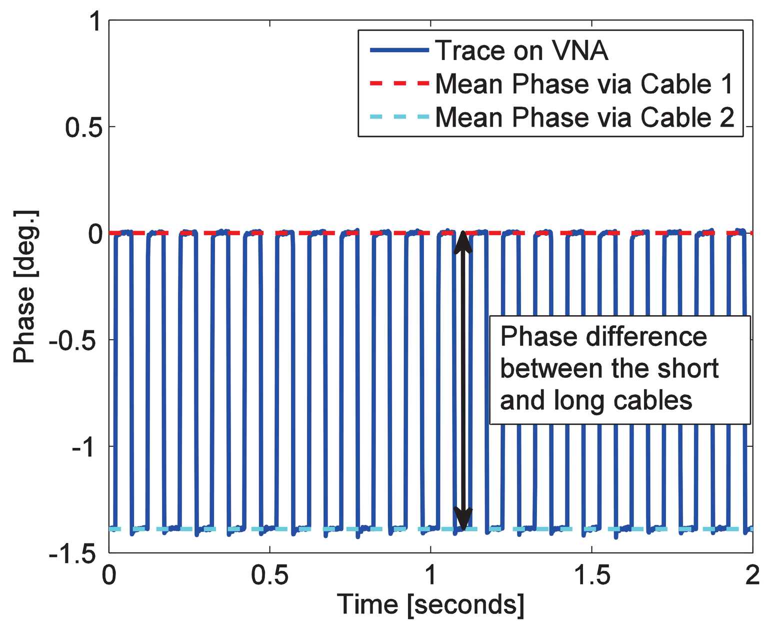


TTL trigger is set to a suitable frequency for slow sweep calibration using a waveform generator.

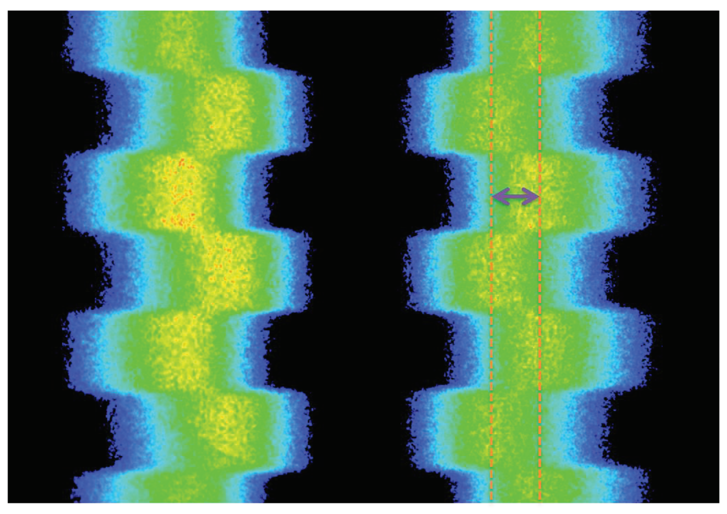
Electrical Delay Measurement on Vector Network Analyser

Using the Vector Network Analyser (VNA) the phase difference θ between the two cables was measured in degrees and converted to picoseconds, given T =4000ps for the 250MHz signal:

$$\delta_{real} = \frac{T}{360°} \cdot \theta$$



SC Dual Sweep Calibration



SC calibration image in normal user beam mode

The arrow between the dashed red lines indicates the measured time shift on the SC image δ_{SC} in pixels.

Given the known electrical delay δ_{real}, the fast timebase may be calibrated in units of ps/pixel:

$$k_{fast} = \frac{\delta_{real}}{\delta_{SC}}$$

The slow timebase k_{slow} calibration is obtained by comparing the measured period of the square wave in the SC image with that set on the waveform generator.

REFERENCES

[1] Optronis GmbH, http://www.optronis.com/en/products/streak-cameras.html
[2] C.A. Thomas et al., ``Diagnostics Beamline Optimisation and Image Processing for Sub-ps Streak Camera Bunch Length Measurement'', IBIC2012, TUPA42,Tskuba, Japan.
[3] C.A. Thomas et al., ``Performance of a Streak Camera Using Reflective Input Optics'', IBIC2010, MOPE081, Kyoto, Japan.
[4] I.P.S. Martin et al., ``Reconstruction of Electron Bunch Motion During CSR Bursts using Synchronised Diagnostics'', IPAC2015, MOPMA003, Richmond VA, USA.