NSLS2 VISIBLE SYNCHROTRON LIGHT MONITOR DIAGNOSTIC BEAMLINE COMMISSIONING*

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Abstract

Visible Synchrotron Light Monitor (SLM) beamline has been designed and constructed at NSLS2 storage ring, to characterize the electron beam profile at various machine conditions. Due to careful alignment, SLM beamline was able to see the first light even before beam circulating the ring. Besides a normal CCD camera to monitor the beam profile, streak camera and gated camera are used to measure the longitudinal and transverse profile to understand the beam dynamics. Measurement results from these cameras will be present in this paper.

INTRODUCTION

NSLS2 is a third generation light source at Brookhaven National Laboratory. The 3GeV low emittance storage ring has been commissioned with beam recently. Average current of 50mA beam was able to be stored in the ring with superconducting RF cavity [1]. While electrons pass through the bending magnet, broadband synchrotron radiation will be generated. This can be used to measure the transverse and longitudinal profile.

Visible synchrotron light monitor (SLM) diagnostic beamline utilizes the radiation from C30 BM-B, which is the second dipole after injection straight. Nominal source point is ~2.75mrad into the dipole. The beamline has acceptance of +/-1.5mrad horizontal and +/-3.5mrad vertical. Visible light from the dipole synchrotron radiation will be reflected by in-vacuum mirror. The visible light is guided into SLM hutch located on the C30 experimental floor. There are various optics setups on the 4'x10' optical table, currently there are three branches setups: CCD camera branch; fast gated camera branch and streak camera branch. Visible light can be guided to different cameras. More information on the diagnostic beamline design can be found at [2].

Figure 1 shows the installed beamline and optical table setups. Radiations from the dipole pass through the fixed aperture, which defines the source point and horizontal/vertical apertures. Upstream of the fixed mask are vacuum gate valve (GV) and bending magnet photon shutter (BMPS). These two components are standard for NSLS2 beamlines which can be used to shut down the photon whenever needed. Most high energy photons are blocked by the thin absorber called "cold finger". The cold finger has vertical aperture of +/-0.5 mrad. Most of the power will be blocked by the cold finger so that downstream first mirror sees less than 1W of power at 500mA. The cold finger is controlled through a linear motor and stage. It can be fully retracted or tracking the electron beam position with 10um resolution. In vacuum first mirror reflect the visible (and near infrared) light 90 degree out of the vacuum window. The mirror was made from Glidcop with Aluminum coating. Both first mirror and vacuum window have flatness better than 50nm, which is about 1/10 of interesting wavelength. Visible light is then reflected by three 6'' diameter in air mirrors on to the experiment floor, where a dark room and 4'x10' optical table are located. Synchrotron light first gets focused on the optical table with 6'' achromatic lens. Focal length of the lens is 2.25 m. Light is then guided to different cameras using beam splitter and reflection mirrors.

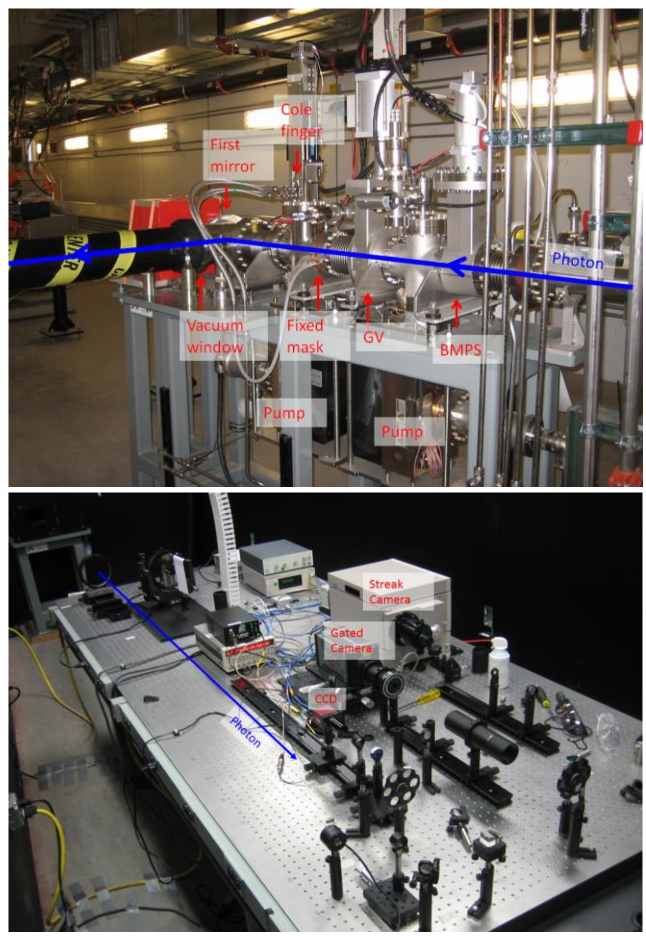

Figure 1: (top) Installed visible synchrotron light monitor (SLM) beamline components inside the NSLS2 storage ring tunnel; (bottom) Optical table setup in the SLM hutch.

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FIRST LIGHT

During installation of the visible SLM beamline, precise laser alignment was carried out to align the mirror. The laser was shot backward from the optical table to align the light to source point. First light was observed in the SLM hutch at the very early stage of storage ring commissioning. Figure 2 shows the first synchrotron light on NSLS2 experimental floor captured on Apr-02. Electron beam was going around the ring for about 1 turn. The CCD the camera was able to see synchrotron light radiated from the first turn. The camera trigger was synchronized triggered with injection kickers trigger. 4x4 binning helped to improve signal noise ratio. Injection charge reading was about 1nC at BtS ICT2, right before the storage ring injection straight. The image was not focused. That's why two bright spots appears on the image, dark band in the middle is the cold finger shadow. Fine optics adjustment was carried out once the hutch was granted safe to access.

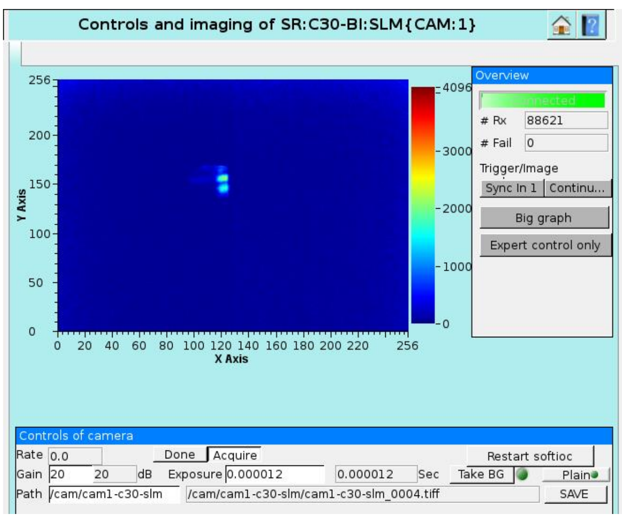

Figure 2: First light observed in the SLM hutch, Apr-02-2014. Beam was circulating the ring 1-2 turns.

TRANSVERSE PROFILE

Once beam was stored in the ring and fault studies showed no radiation hazard in the SLM hutch, fine optics adjustment was able to be carried out. Figure 3 shows a CCD image screenshot at 1.5mA stored beam.

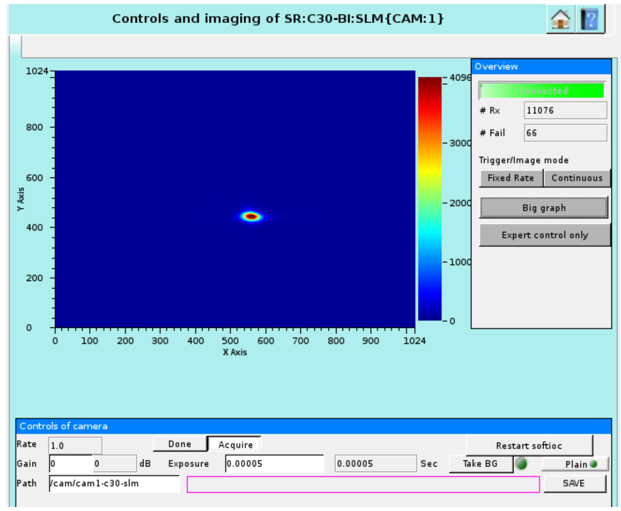

Figure 3: CCD camera image with 1.5mA stored beam.

Optics (de)magnification factor was calibrated by creating a parallel local bump near the SLM source point, while detecting how many pixels moved on the CCD image centroid. Local bump height were recorded from nearby BPMs and calculated based on distance of BPMs to source point. Horizontal local bump calibration results are shown in Fig. 4. Fitting the slope, one gets ~8 um/pixel which means 1 pixel on the CCD is corresponding to 8um at the source point. Vertical local bump calibration gave the same slope.

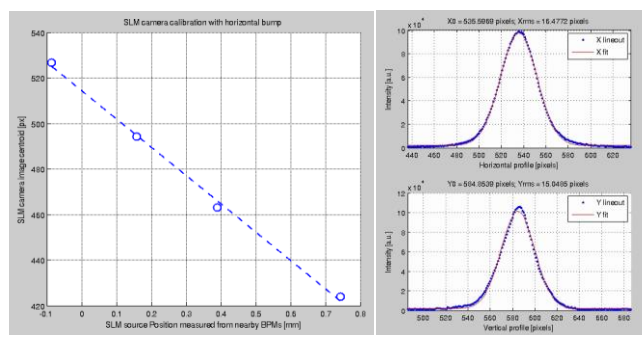

Figure 4: (Left) Visible SLM CCD camera calibration using local bump near the source point. (Right) Gaussian fitting of CCD measured profile.

CCD measured profile can be fitted to Gaussian distribution. Based on the above calibration, beam sizes at the source point can be measured. Right plot in the figure gives an example of Gaussian fitting. Horizontal beam size was fitted to be ~ 15.5 pixels, which was corresponding to 124 um at the SLM source point. Vertical beam size was not able to be measured using visible light due to diffraction limit. It can be measured with x-ray diagnostic beamline which will be commissioned shortly.

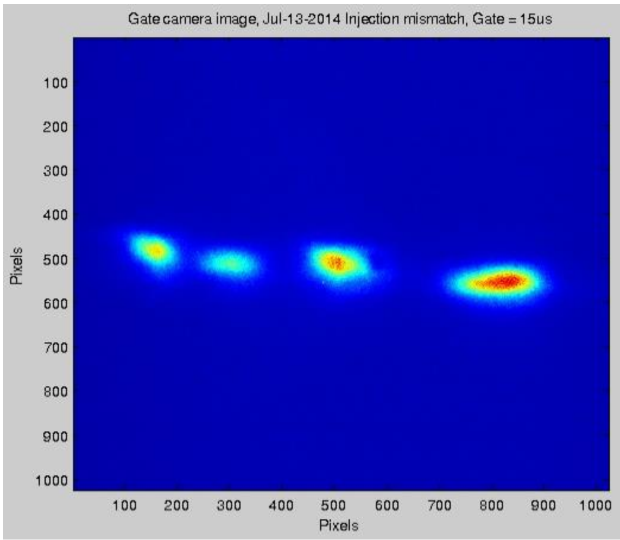

Figure 5: First several turns profile captured using gated camera after injection kicker.

Gated camera has been preliminary tested. The camera has minimum gate width of 3ns and repetition rate up to 1MHz. It's possible to capture NSLS2 storage ring single bunch profile in consecutive turns. Figure 5 shows first 4-5 turns profile captured using gated camera. Beam was kicked with mis-matched injection kickers. Camera was trigger synchronized with injection kickers and the gate width was set to 15us.

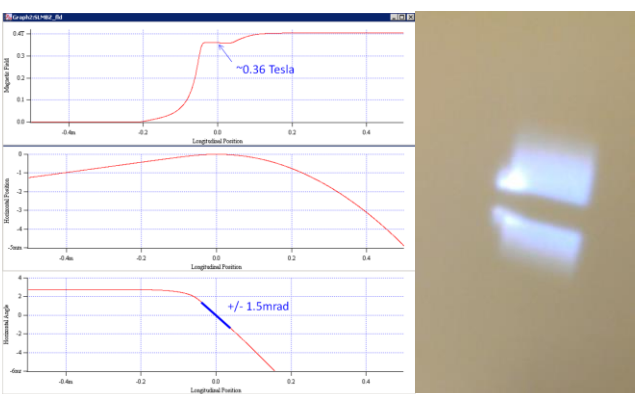

Figure 6: (Left) Magnetic field and beam trajectory near the SLM source point. (Right) Unfocused beam light image.

SLM beamline source point is in the dipole edge field. It was a concern of seeing edge radiation. SRW tracking was carried out during design stage and it was confirmed that the beamline will accept edge radiation in the visible light range. Shown in Fig 6 are the dipole field and beam trajectory near the SLM source point. Nominal SLM source point of 2.75mrad into the dipole will see magnetic field of 0.36 Tesla. Horizontal opening of +/-1.5mrad of the beamline will accept light mostly from the plateau. For the NSLS-II storage ring bending magnet radius R = 25m; detecting wavelength λ = 500nm; synchrotron radiation natural open angle $\theta_{SR} \sim 0.45(\lambda/R)^{1/3} = 1.2$ mrad. It's no surprise that edge radiations from this dipole and the upstream dipole will be seen. With stored beam we have noticed bright spots on the unfocused profile. Figure 6 right side image shows the unfocused light in the SLM hutch. Left side bright images are likely coming from the dipole edge field radiation.

LONGITUDINAL PROFILE

Streak camera has been used for longitudinal profile measurements. The camera is Hamamatsu C5680 with 2ps resolution, it includes synchroscan and dual sweep modules. Synchroscan frequency is at 125MHz, which is 1/4 of NSLS2 storage ring RF frequency. The sweeping clock signal is getting from master oscillator through long Heliax cables. Phase jitter of the clock signal was measured to be less than 1ps.

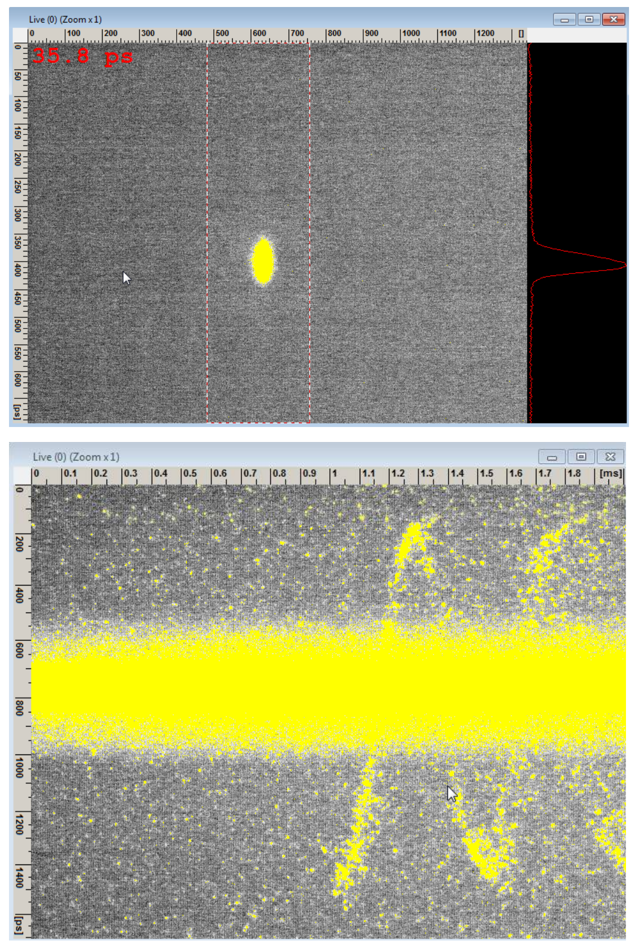

Figure 7: (Top) Streak camera image in synchroscan mode, 0.22mA single bunch was stored in the ring. (Bottom) Streak camera image in dual sweep mode, one can see injection beam came with phase mis-match.

Figure 7 images were two typical streak camera snapshots. The top one was in synchroscan mode. Beam was stored at ~0.22mA in single bunch. In dual sweep mode, as seen in the bottom snapshot, the camera was external triggered with injection signal. There were stored beam and injecting beam came in with phase mis-match. Injected beam was doing synchrotron oscillation around

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synchronous phase. This can be used as direct observation of injection beam phase or energy mis-match.

Longitudinal bunch distribution was measured at different single bunch current and RF gap voltage. Figure 8 top plots the streak camera measured profiles at Vrf = 1200kV. Single bunch was stored at 0.1mA steps up to threshold current ~ 1.1mA. Profile peak height was scaled to bunch current. Vertical instability was observed at ~ 0.6mA [1,3]. As the single bunch current increasing, due to broadband impedance (short range wakefield), bunch length increasing due to reactive impedance. Meanwhile resistive impedance in the ring makes the bunch lean towards bunch head at higher current. Skewed Gaussian distribution function was used to fit the measured profile [5,6], as shown in Eq. (1).

$$I(t) = I_0 + I_1 \exp\left\{-\frac{1}{2}\left(\frac{(t-t_0)}{[1+\mathrm{sgn}(t-t_0)A]\sigma}\right)^2\right\} \qquad (1)$$

Where I_0 and I_1 are offset and amplitude respectively, A is asymmetric factor, t_0 is peak location and σ is bunch length related parameter. At low bunch currents where there is little skew of the profile, we can set A = 0 to reduce numerical noise. It's a standard normal distribution in this case. Fitted results are plotted as solid lines.

RMS bunch length can be calculated from:

$$\sigma_t = \left\langle (t-\langle t\rangle)^2 \right\rangle^{1/2} = \left[1+\left(3-\frac{8}{\pi}\right)A^2\right]^{1/2} \sigma \qquad (2)$$

In which $\langle t \rangle$ is the bunch center of mass

$$\langle t \rangle = \mathrm{mean} = t_0 + 2\sqrt{\frac{2}{\pi}} A\sigma \qquad (3)$$

Curves in Fig. 8 middle plot are fitted bunch length from the above equations, at five different RF gap voltages. The highest RF voltage was limited at 1200kV using superconducting cavity. Bottom plot in the figure gives the bunch centroid (synchronous phase) drifts towards the head, at Vrf = 1200kV. Fit the data points up to 0.6mA gave 12.3 ps/mA slope, from which the loss factor was calculated to be ~ 17 V/pC. Further measurement and analysis are needed to characterize the longitudinal broadband impedance of the ring.

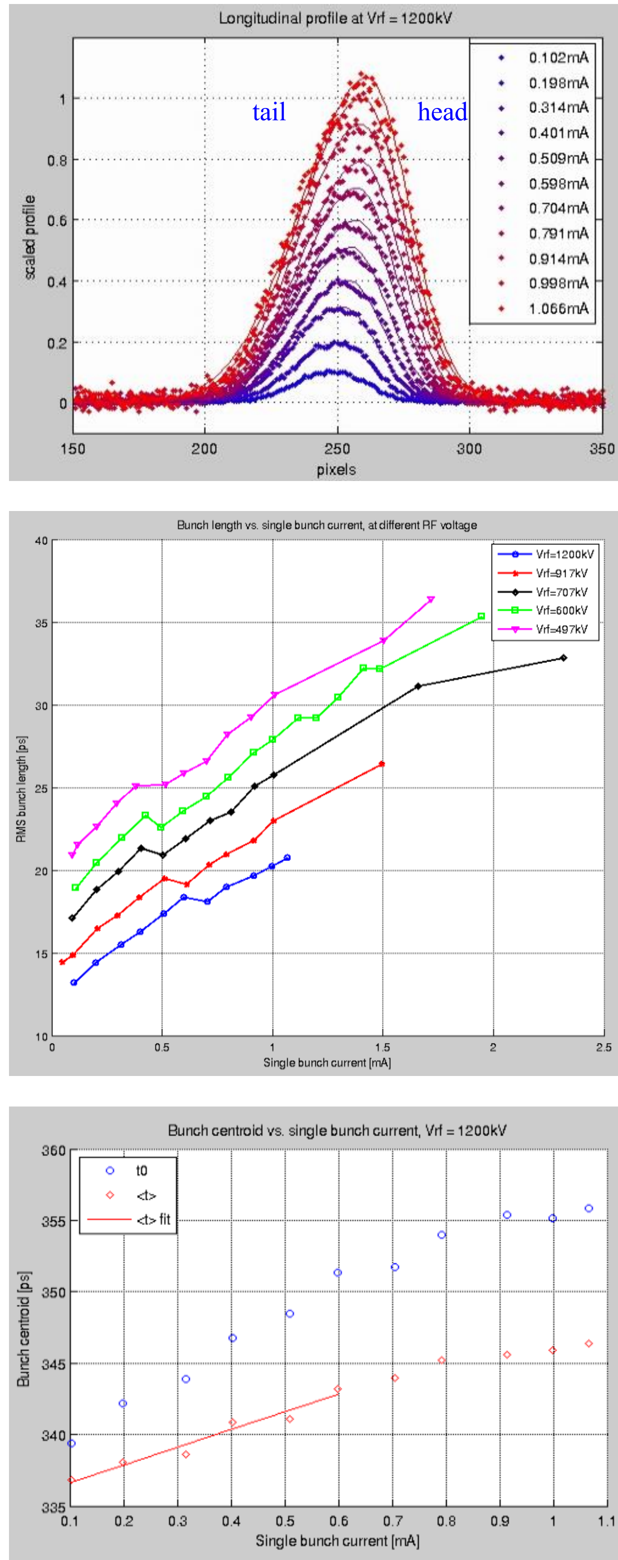

Figure 8: (top) single bunch profile measured at different single bunch current, Vrf = 1200kV. (middle) RMS bunch length vs. current results measured at five different RF voltages. (bottom) Synchronous phase drift as bunch current increasing at Vrf = 1200kV.

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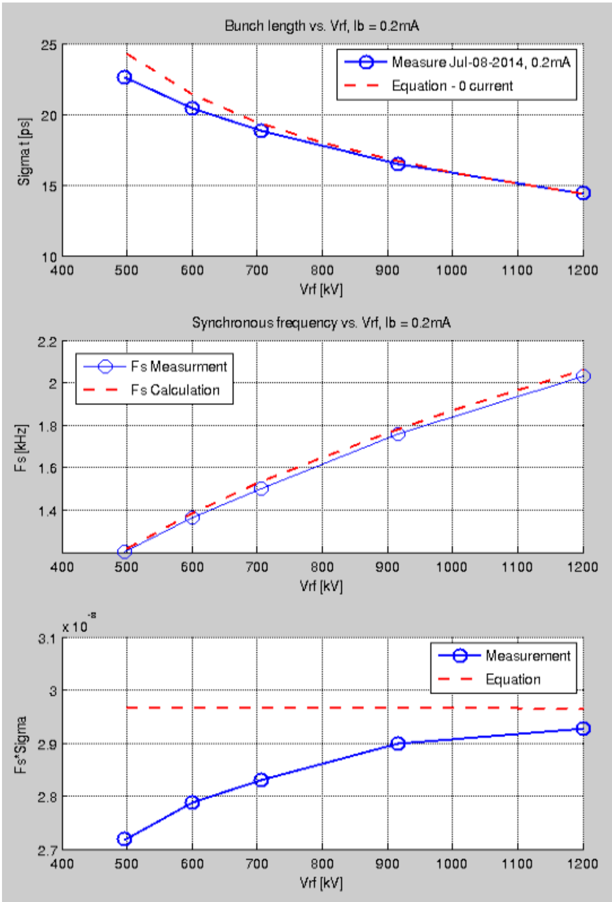

Figure 9: Measured bunch length, synchronous frequency at different RF voltages, bunch current was fixed at ~0.2mA.

Bunch length and synchronous frequency has the relations as shown:

$$\sigma_t = \frac{\alpha}{2\pi f_s}\left(\frac{\sigma_E}{E}\right) \tag{4}$$

Where momentum compaction factor α = 3.627e-4, relative energy spread σ_E/E is ~ 0.0514% for NSLS2 lattice (no damping wigglers). If the RF voltage varied at a fixed single bunch current, measured synchronous frequency and bunch length should follow the Eq. (4). This can be used to measure the energy spread, assume momentum compaction factor is known.

Synchronous frequency can be measured from BPM turn by turn data spectrum at dispersion locations. Figure 9 shows the bunch length and synchronous frequency at different RF voltages. Product of bunch length and synchronous frequency varied by less than 10%, result in good agreement to Eq. (4).

SUMMARY

Visible SLM diagnostic beamline has been designed, constructed and commissioned at NSLS2 storage ring. Camera setups have been used frequently to monitor the transverse and longitudinal profile. Streak camera bunch length measurements were able to be carried out during single bunch shifts. These measurements are essential to characterize and optimize the NSLS2 storage ring. Future developments using the visible light are underway for more advanced diagnostics.

The author thanks the NSLS2 diagnostics group and commissioning team members.

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