Characterisation of duration-tuneable heavily-chirped pulses from the Gemini beamline using a streak camera

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Introduction

The Gemini beamline can deliver pulses as short as 40 fs [1]. Though this pulse duration lends itself to extreme intensities and temporal resolution, many experiments have different pulse duration requirements. As such, Gemini can deliver pulses up to tens of picoseconds, by adjusting its compressor geometry. Depending on the desired duration, different pulsed measurement techniques are used.

In standard configuration, the pulse duration of the Gemini beams is measured using a GRENOUILLE, which can measure pulse durations up to 100 fs. Thus, an alternative pulse duration diagnostic is needed for longer pulses.

Although autocorrelators can be used for pulses with picosecond durations, heavily-chirped pulses present a special challenge. Second-order autocorrelators rely on second-harmonic generation (SHG) from two temporally-overlapped copies of the measured pulse. For heavily chirped pulses, as the frequency content of the pulse varies in time, SHG only occurs when the same frequencies overlap in time, rather than over the full temporal profile of the pulse. This causes heavily-chirped pulses to appear shorter than they are in reality.

Streak cameras, on the other hand, are insensitive to chirp. The optical pulse is converted into a photoelectron pulse with an imprint of the original temporal profile. This electron pulse is then deflected by a fast-varying voltage and smeared across a phosphor screen, which is then recorded by a CCD camera. This results in an accurate translation of the temporal profile of the optical pulse into a spatial pattern recorded by the CCD camera, regardless of the frequency content of the pulse [2].

In this paper, we report on a recent experiment where a streak camera was used to characterise long pulses from the Gemini beamline, providing a calibration curve for the experimental scientists. Using this calibration, the pulse duration could be easily changed in a reproducible way from 20 ps to 39 ps, using only automated translation stages, with minimal impact on the alignment of the compressor.

Experimental setup

Fig. 1 shows an overview of the experimental setup.

The Gemini compressor comprises a pair of gold-coated diffraction gratings with a groove density of 1480 lines/mm, in double-pass configuration [3]. Each grating is equipped with a long-travel manual screw translation stage for coarse changes, as well as a 50-mm-travel automated translation stage for fine adjustments. The 150 mm beam is sampled using a 1” pick-off mirror that can be driven into the beam after the compressor. The small sampled beam is sent directly to the streak camera.

The streak camera is a Hamamatsu system comprising a M5676 fast speed sweep unit, and a C5680 streak camera equipped with a C4742-95 camera sensor. The camera has a resolution of 1344 x 1024 pixels in the slit and streak directions, respectively, with a minimum 2x2 binning. The sweep temporal window can be set between 0.2 and 50 ns. As the time window is always divided in 512 points, narrower temporal windows have higher resolution.

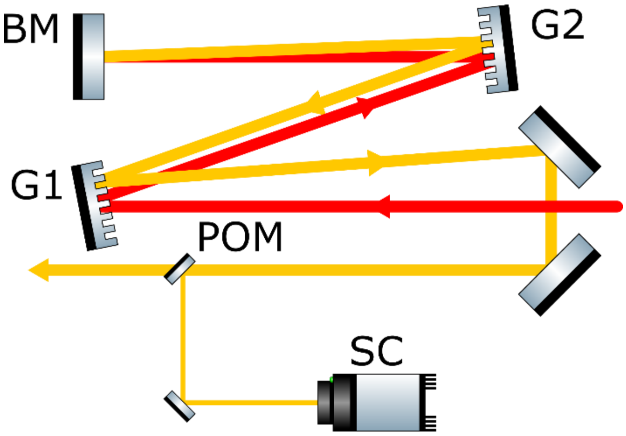

Figure 1: Diagram of the experimental setup. The first pass beam is coloured red, while the second pass beam is coloured yellow. G1, G2: Diffraction gratings; BM: Back mirror; POM: Pick-off mirror (not to scale); SC: Streak camera

Setting the width of the input slit is critical to obtain accurate measurements. If the slit is set too wide, space-charge effects lead to a broadening of the measured pulse. This can be easily identified if the measured pulse duration varies if the slit width is adjusted. Once the slit is sufficiently narrow, as it is closed further, the measured pulse duration remains unchanged while the signal level decreases. The slit should be set such that it is clear that no space-charge effects are present, while still retaining an adequate signal level. Fig. 2 shows an example of a 40 ps pulse which becomes erroneously long, as the slit width increases.

Though the effects are clear in the most extreme cases, it is easy to slightly overestimate the pulse duration if one does not pay particular attention to this effect.

Pulse duration measurements

The aim was to deliver pulse durations ranging from 20 ps to 40 ps, easily adjustable with minimal impact on compressor alignment.

For this purpose, G1 was moved using its long-travel translation stage, such that the pulse duration was 30 ps when G2 was in the middle of the range of its automated stage. G2 could then be moved within this 50 mm range to easily adjust the pulse duration as required throughout the experiment, without disturbing the compressor alignment. Fig. 3 shows a position sweep of the full range of the G2 automated stage, delivering pulse durations ranging from 20.0±0.9 ps to 38.9±1.9 ps.

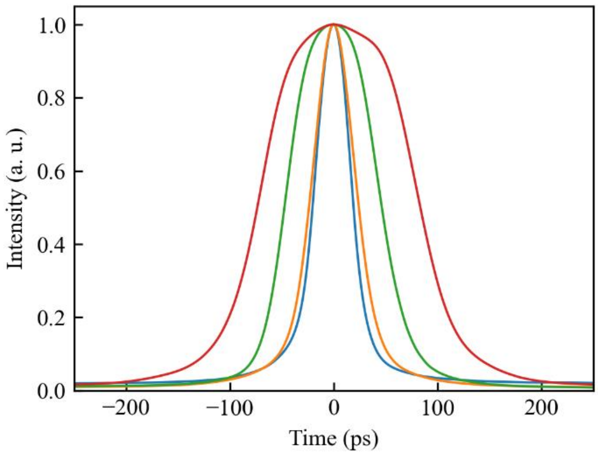

Figure 2: 40 ps pulse measured with different entrance slit widths. As the slit is made wider, the pulse becomes increasingly long and distorted.

For the case where the compressor is set to deliver pulses much longer than transform-limited, we expect the pulse duration after the compressor to show a linear dependence on the distance between the gratings [4], which we observed with a slope of 0.39 ps/mm, shown in Fig. 3. This calibration curve was used to easily set a desired pulse duration, by setting the position of G2. The day-to-day stability of this calibration was verified by occasional pulse duration measurements, subject to beam availability, and we found it to be accurate for the remainder of the experiment.

Additionally, by setting the compressor to produce the shortest pulse possible, we aimed to identify the shortest pulse duration the streak camera could measure. This information will be useful to establish an operational range for the streak camera, to better understand when it can be used.

The duration of the compressed pulse was measured using a FROG to be 45 fs. The streak camera recorded a pulse duration of 7.2±0.5 ps, shown in Fig. 4.

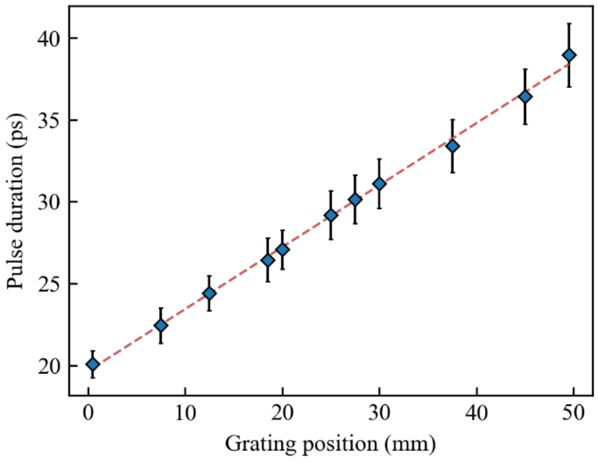

Figure 3: Pulse duration calibration curve, used by the experimental scientists to set a desired pulse duration using the G2 automated stage position.

Timing jitter measurements

Due to the timing jitter between the streak camera trigger and the optical pulse, the streak pattern is not always centred on the CCD camera. Our analysis script discards images where the streak is not fully visible, reducing the number of data points for averaging the final pulse duration value. This becomes more severe when trying to measure short pulses, as the narrower time window necessary to achieve temporal resolution becomes comparable to the jitter, leading to a large number of discarded shots.

Since many diagnostics in the target areas receive a trigger signal similar to the one used for this streak camera, this timing jitter measurement could be relevant for future reference in other parts of the system.

When measuring the pulse duration, the time window was set to 0.5 ns, prioritising temporal resolution at the expense of a significant number of missed shots, as previously described. To characterise the timing jitter, the streak time window must be wide enough for all the pulses to be completely visible, otherwise the jitter would be underestimated, since the shots which missed the time window entirely would not be represented. For this reason, a time window of 5 ns was used.

As before, each streak is integrated along the slit direction to create a temporal profile. By fitting a sech^2 function to each shot, the centre position can be accurately determined, even at a lower temporal resolution due to the wider time window. The timing jitter was determined by taking 2000 shots, and was defined as the standard deviation of the full data set, measured as 165 ps over 12 minutes.

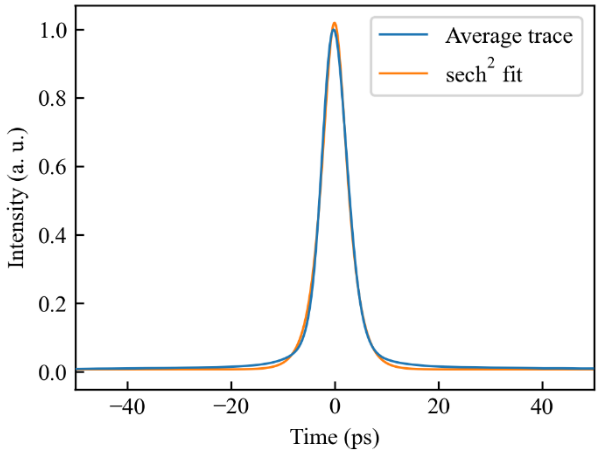

Figure 4: Compressed 45 fs pulse, measured by the streak camera to have a duration of 7.2±0.5 ps.

Conclusions

The Gemini north beam was configured to deliver long pulses with tuneable duration between 20 and 38.9 ps. This configuration allowed the experimental scientists to easily adjust the pulse duration using automated translation stages, with minimal impact on compressor alignment.

We evaluated the lower limit of operation of the streak camera by measuring a compressed 45 fs pulse, which was measured as having a duration of 7.2 ps. While a more thorough characterisation is needed if the streak camera is to be used accurately for shorter pulses, this value can be used as an indicator for the suitability of this diagnostic for future experiments.

Lastly, the timing jitter of the trigger signal was measured to be 165 ps over a period of 12 minutes.

References

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