Fermilab

U.S. DEPARTMENT OF ENERGY | Office of Science

Status of CLARA at ESB

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Meeting on CLARA

2 December 2022

Content

- Status of the setup
- Measurements with the Laser Diode
  - Unresolved questions
- Discussion of plans

Status of the setup (1)

- MZI is assembled in a close-to-final configuration
  - Missing elements are on hand
  - Need to remove HeNe line, install lens for IOTA light, make the input hole, and put a tube through.

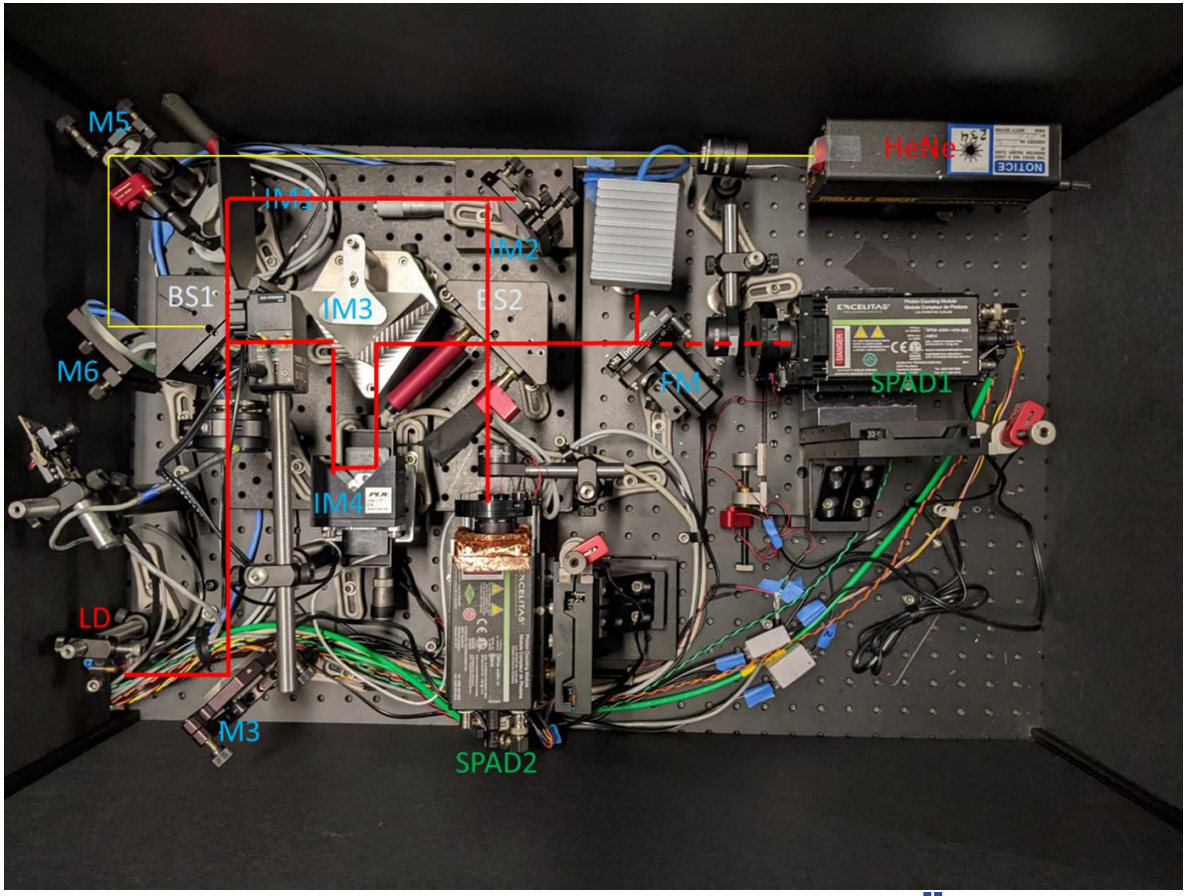
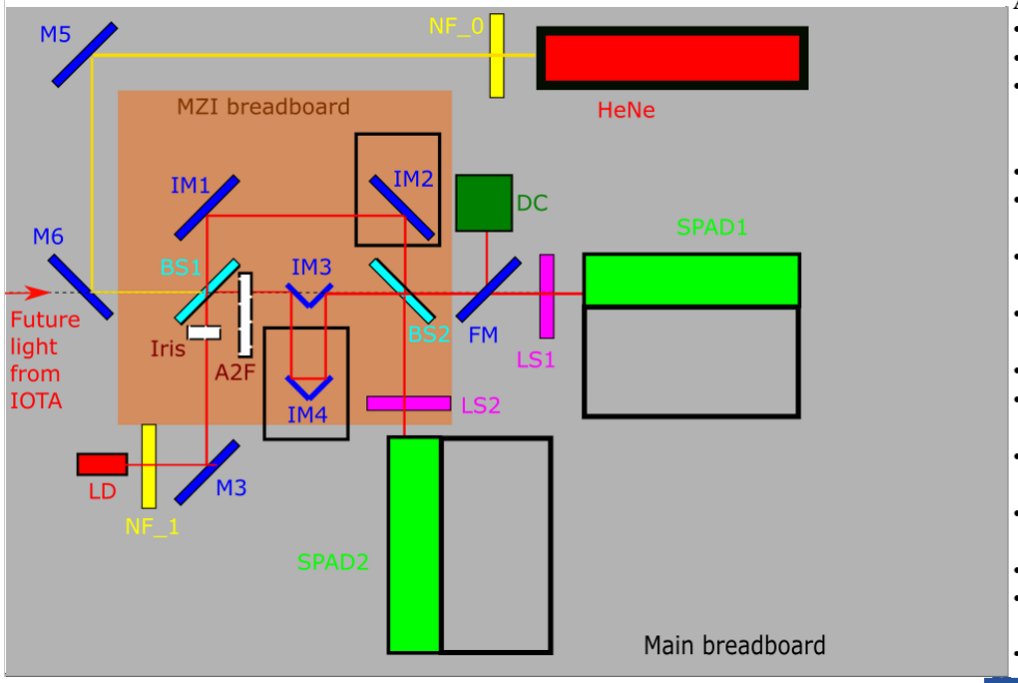


Photo of the optical box with removed lid (from the top). Later, on 16-Nov-22, a neutral filter in front of LD was installed.

Status of the setup (2)

- Critical elements are remotely controlled
  - BS2 H/V, IM1H: closed–loop picomotors
  - H/V SPAD positions: open-loop picomotors; Z : steppers
  - IM4 position: precision stage
- Remote switching (inherited from URSSE)
  - SPAD power and shutters
  - Two flippers
  - LED, camera
- Need to control remotely LD current



As of 22-Nov-2022

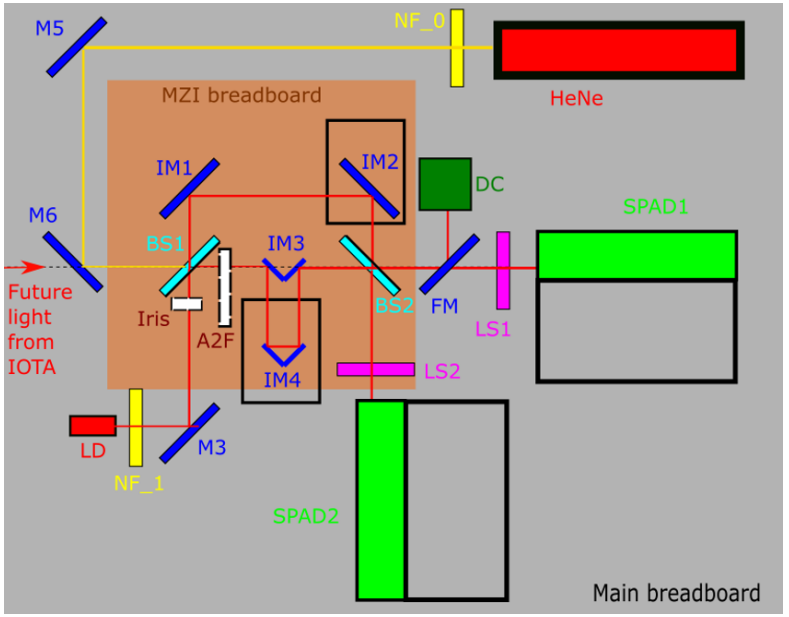
- LD- laser diode
- HeNe- HeNe laser
- SPAD1,2 –Single Photon Avalanche Detector
- DC – digital camera
- IM1, IM2 – Arm1 MZI mirrors
- IM3 – right-angle mirror in Arm2
- IM4 – hollow roof mirror in Arm2
- FM – flipping mirror
- M3 – mirror for steering LD light
- M5, M6 – mirrors to steer HeNe light
- A2F – flipping screen in Arm2
- LS1, 2 – lens
- NF_0, NF_1 – neutral filters
- Iris – LD collimator

Status of the setup (3)

- Giulio connected SPADs to electronics; the counters and calculated counting rates are reported to ACNET and archived at 15 Hz (counters) and 1 Hz (rates)
  - Page N14 INSTR <45>; description in elog:
    - https://www-bd.fnal.gov/Elog/?orEntryId=227892
- Light isolation of the box without taping the gaps is reasonably good, at least for initial experiments
  - Average SPAD1/2 counting rates with closed shutters: 74/113
  - With shutters open, LD off: 259/482
    - Max/Min rates with LD current =0.1 mA and ND filter =4:
      - 900 kHz/ 80 kHz
  - Might be still tolerable for the measurements with a single electron with gating (if SPAD counting rate ~10 kHz)

Measurements with camera (examples from 14-Nov-22)

- Two types of interference measurements
  - 1st type: Delay between MZI arms is minimized; a large angle between lights from two arms. One frame.
    - Multiple frames can be used to analyze jitter
  - 2nd type: The angle between the arms is decreased as much as possible. The sum of all pixel intensities is recorded as a function of the delay.
- Transition: by adjusting
  - BS2H - mostly angle
  - IM1H – mostly overlap of spots
  - IM4 position – delay between arms
    - By precise stage



1st type: Fringes in space

- Optimum delay, angle 4.3 mrad, LD current = 0.04 - 25 mA
  - No ND filter in front of LD.
  - Delay and amplification adjusted with current.
- Analysis of intensities in a narrow rectangle, “projection”
  - (Sum over Y) vs X

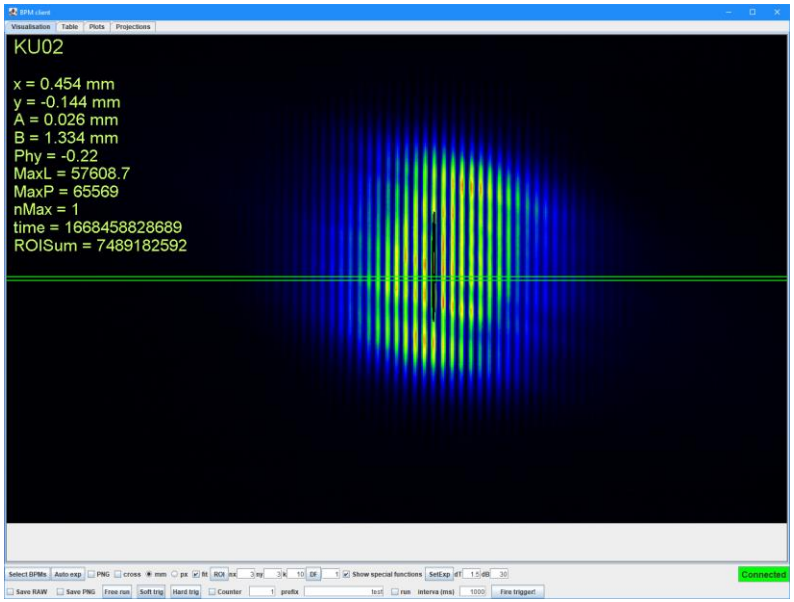
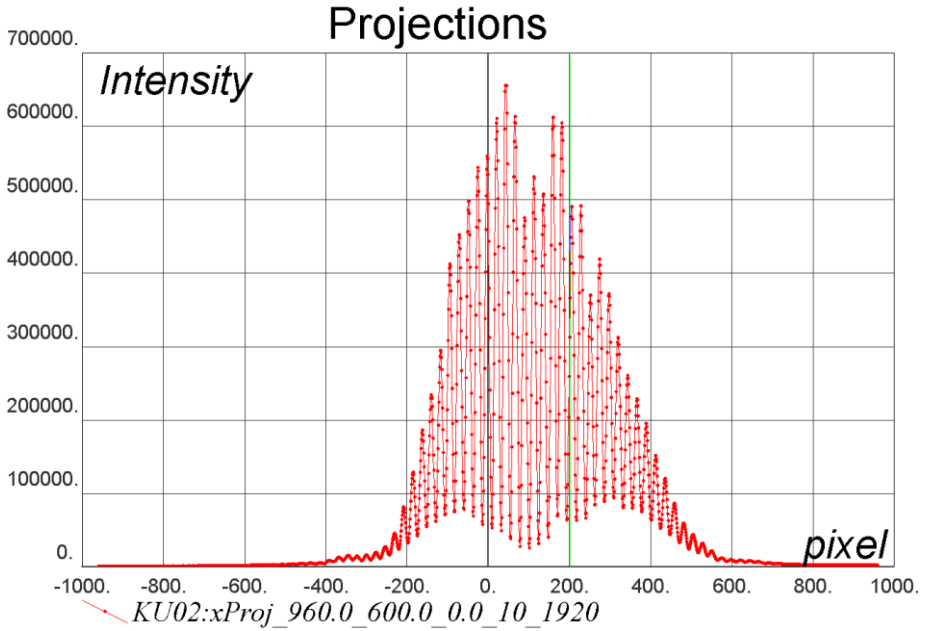


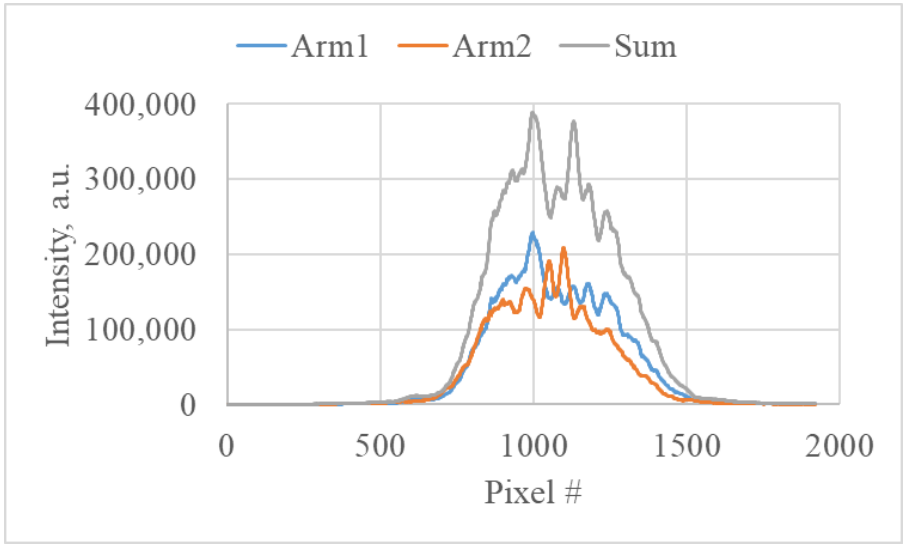
Image for LD = 1 mA.

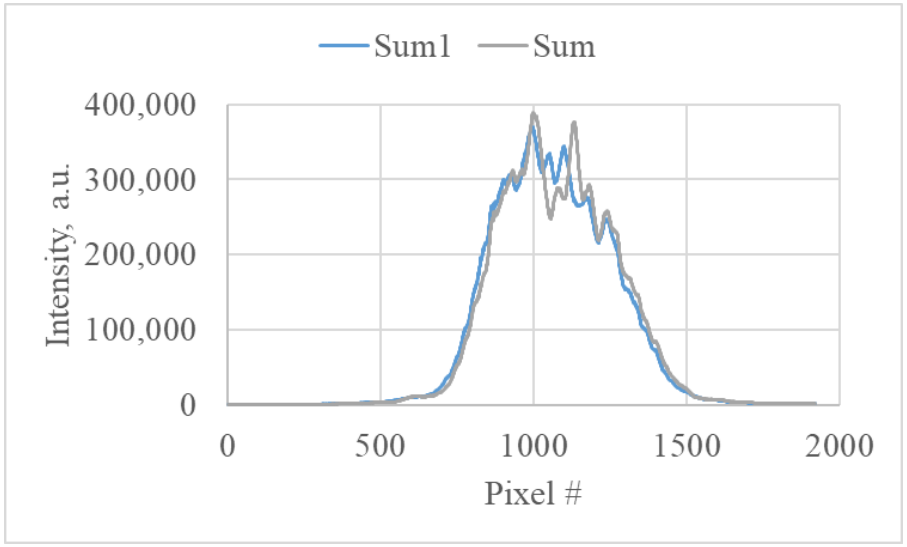


Projection for LD = 25.4 mA. 14-Nov-22.

1st type: signal from arms

- Signals from two arms are not identical
  - Not exactly aligned, different sum, different shape, not smooth
- The sum of the signals recorded from each arms differs from the signal measured with two arms simultaneously
  - The delay stage is shifted by 0.1 mm to avoid interference

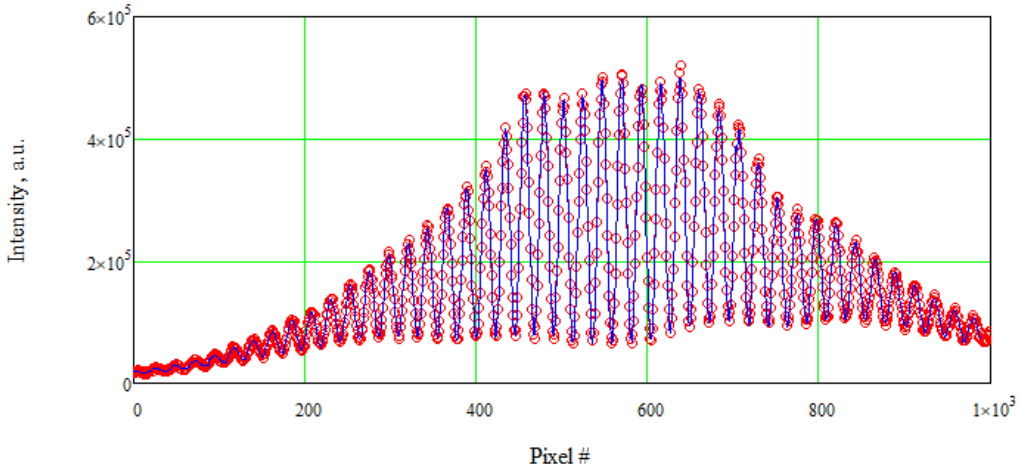


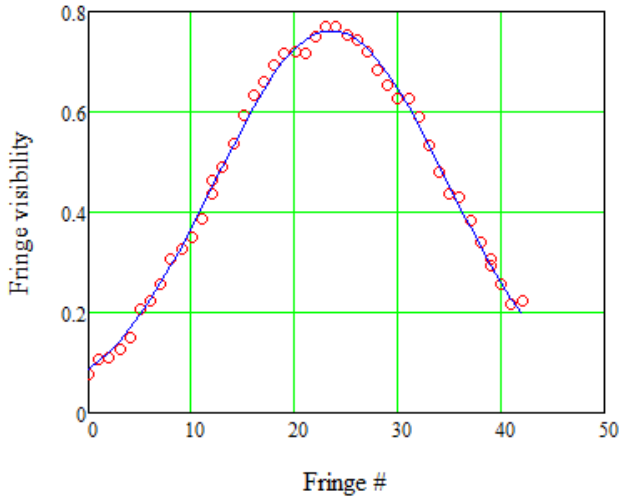


Comparison of projection from individual arms (left) and the sum of them with a signal with both arms open.14-Nov-22. Signals from an individual arm is recorded by blocking the other arm.

1st type: fringe analysis

- Procedure (in MathCad)
  - Fourier transform => central frequency
  - Fit cosine to each period, calculate visibility
- Visibility curve is close to Gaussian
  - Max observed 93%, but difficult to tune beyond 80%
  - Sigma of the visibility curve (“coherence length”) is 10 periods

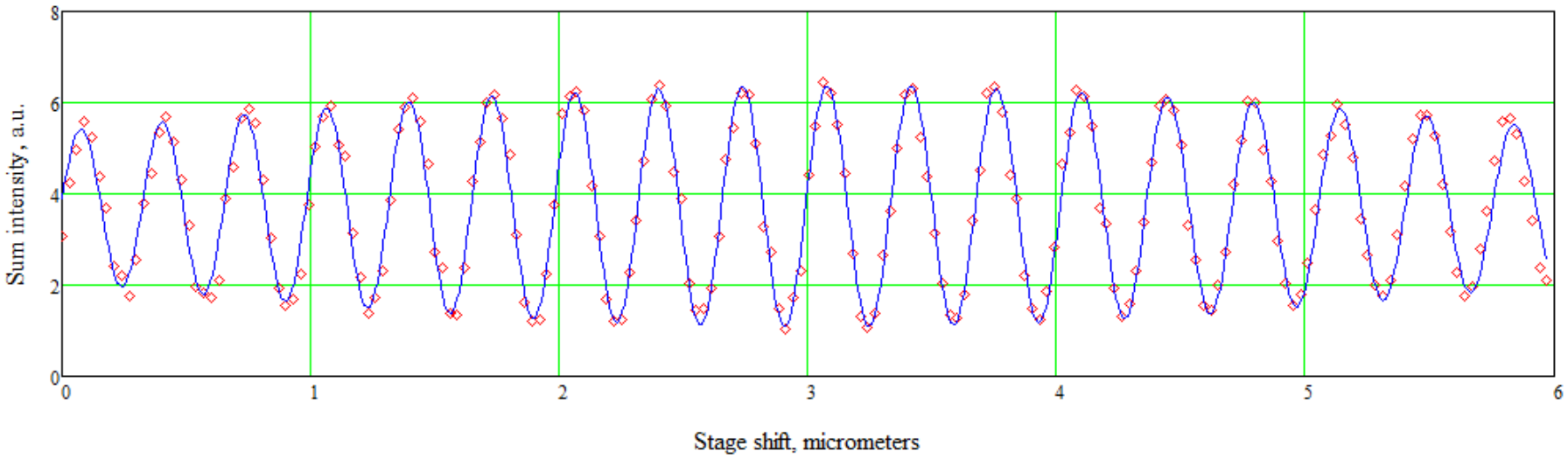




Fitting to a projection and corresponding visibility curve.14-Nov-22.

2nd type: Sum of all camera pixels vs stage position

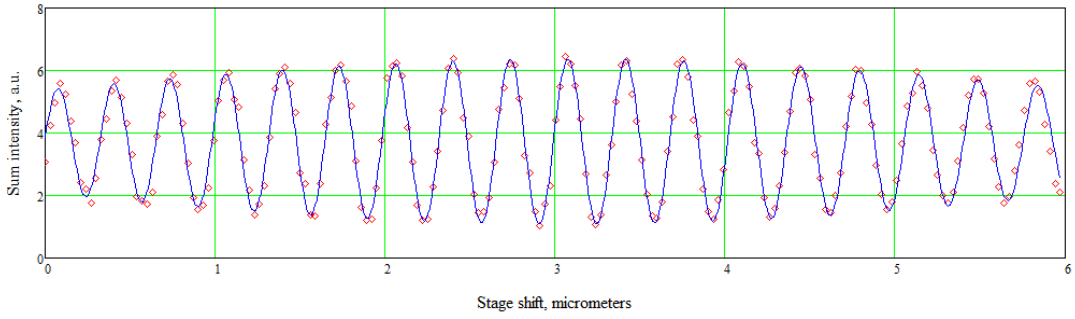
- The stage is moved by 30 nm steps with continuous recording of frame sum; finding offline steps in the data
    - Averaging over the time between steps
  - Data are smoother, can apply global fitting
  - Visibility can be affected by the background



Example of a stage scan at LD current = 1 mA.14-Nov-22.

2nd type: fitting

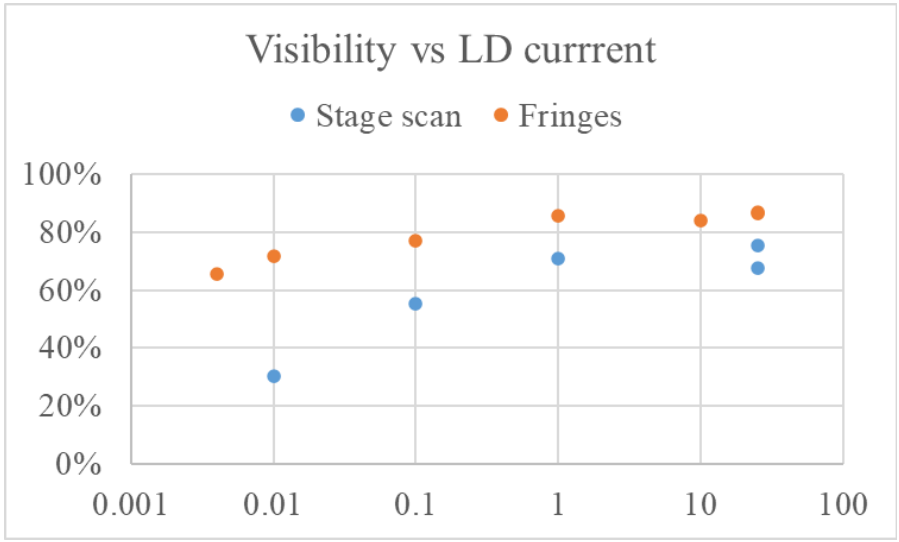
- Values vs delay are fitted by cos*Gauss
  - For a good fit, the period needs to be linearly increased toward larger delays by 0.6%/μm
    - Repeatable from scan to scan, including a scan in opposite direction
    - Checked the difference by direct comparison of Fourier spectra maximum separately on the left and right halves of the scan
    - No explanation or model

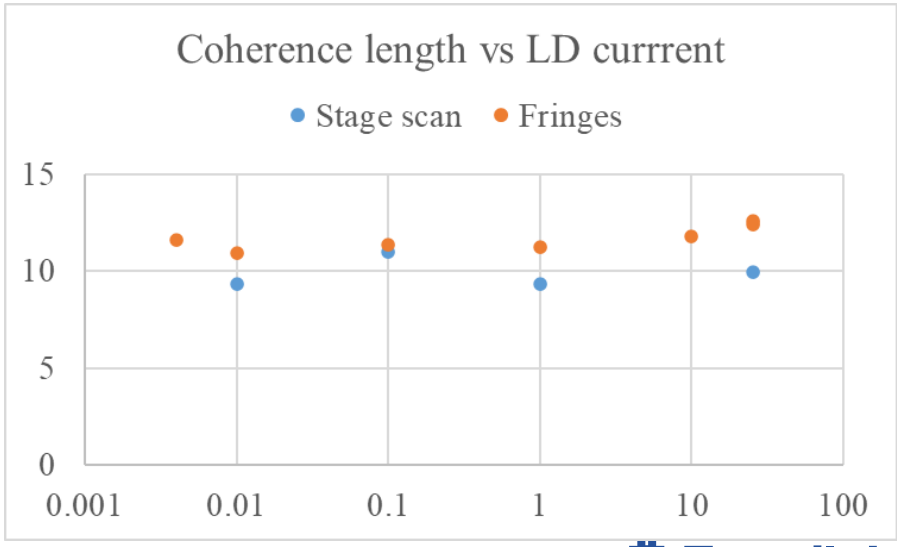


$$\mathrm{FitCosExp}(x, \mathrm{Par}, \lambda, x0) := \left| \begin{pmatrix} \mathrm{Offset} \\ A \\ \mathrm{FreqW} \\ \mathrm{FringeW} \end{pmatrix} \leftarrow \mathrm{Par} \right.$$
$$\left. \mathrm{Offset} + A \cdot \cos\left[\frac{2\pi}{\lambda} \cdot (x - x0) \cdot \left[1 + \frac{(x - x0)}{\mathrm{FreqW}}\right]\right] \cdot e^{-\frac{(x-x0)^2}{2 \cdot \mathrm{FringeW}^2}} \right|$$

Measurements at different LD currents

- Measurements of both types give similar results for visibility and coherence length
- Weak dependence on LD current
  - Visibility is likely affected by background

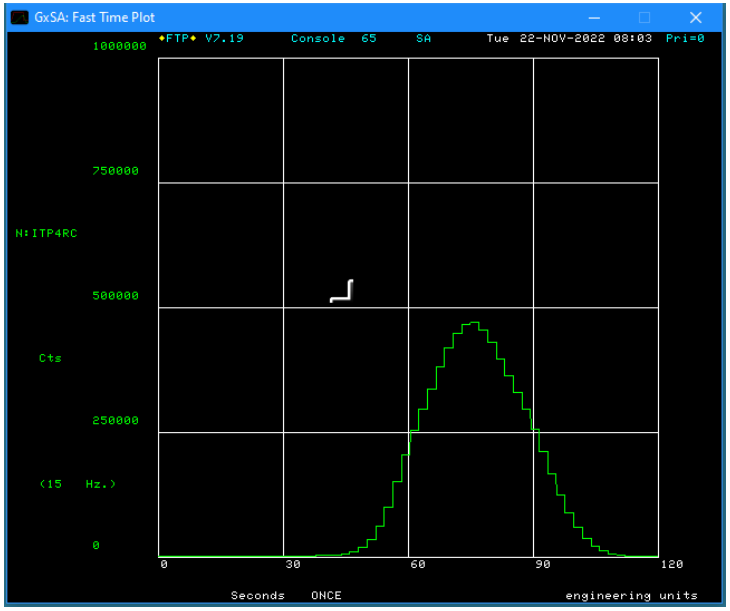




Visibility and coherence length (in wavelength) vs LD current.14-Nov-22.

Work with SPADs

- A neutral-density filter was installed in front of the LD
  - Optical Density = 4 or 5 (i.e. attenuation by 1.E4 or 1.E5)
- Each SPADs was moved in 3 directions to maximize the signal
  - At best focusing, the light spot size is likely about the SPAD sensor size, 0.18 mm
    - Picomotor steps are not well-defined; assuming 20 nm/step, the rms width of scans is 0.25/0.14 mm horizontal/vertical
- Kept the signals below 1 MHz
  - SPAD saturation rate >10 MHz



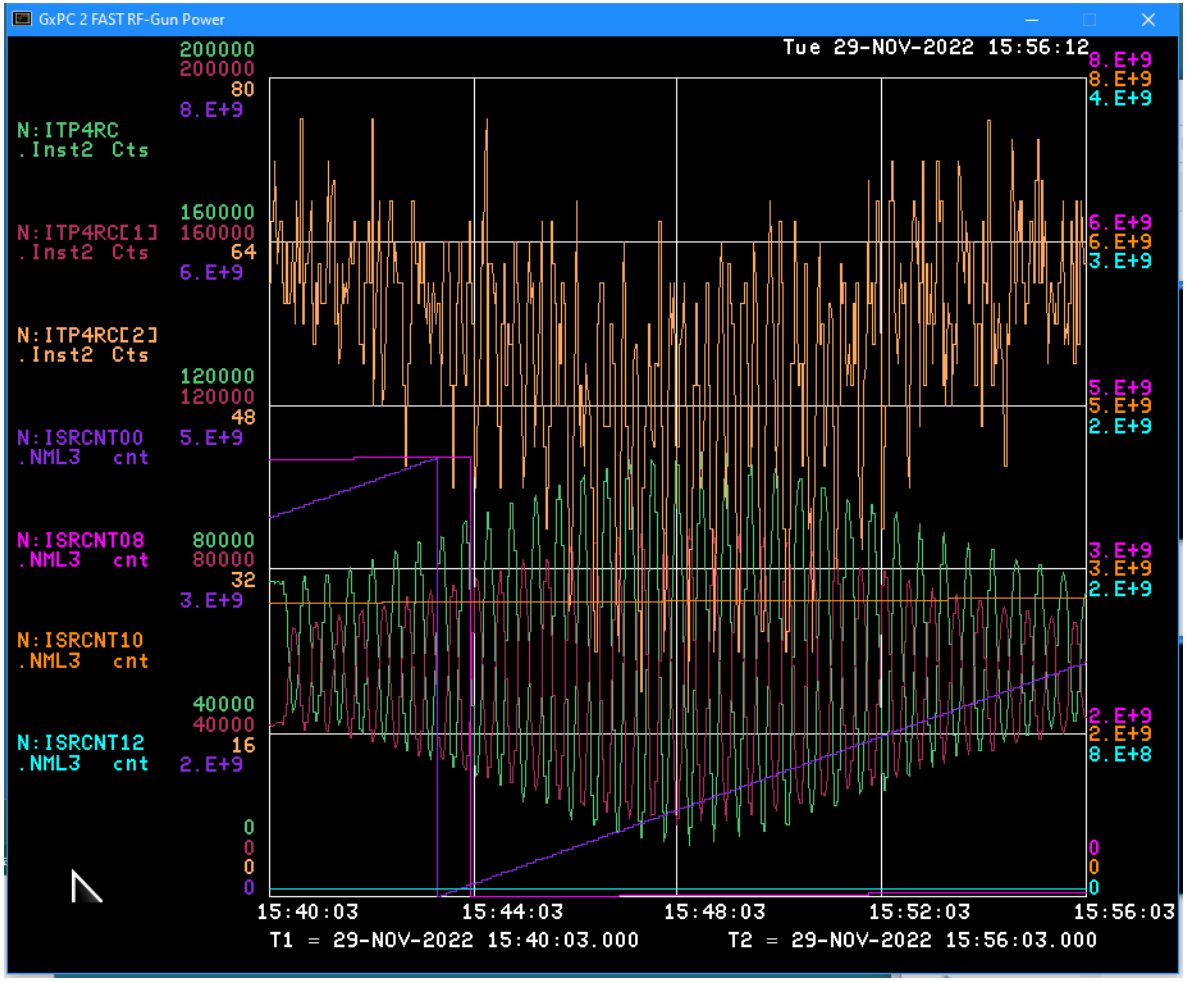
Scan of SPAD1 horizontal position with 1000 steps per one move. LD current = 0.1 mA; OD=4. 22-Nov-22.

Scans of SPADs over the stage position

- Recorded SPAD signals while moving the stage
  - Typical scan: 25 nm steps x 470 “moves” = 11.75 μm total
  - 1 – 2 seconds between moves
  - Counters for SPADs and coincidence between them are saved in D44 at 15 Hz for offline analysis.
  - Rates are calculated over 2 sec intervals, published as ACNET parameters, and saved in D44 at 1 Hz.
    - Those are mainly for online use: MZI and SPADs positions tuning and checking during measurements
- 15 Hz data are copied from D44, rates are calculated, times when stage moves occur are identified (looking at rate jumps; time consuming), and the processed data are analyzed
  - In my case, analyzed in MathCad

Features of the recorded scans

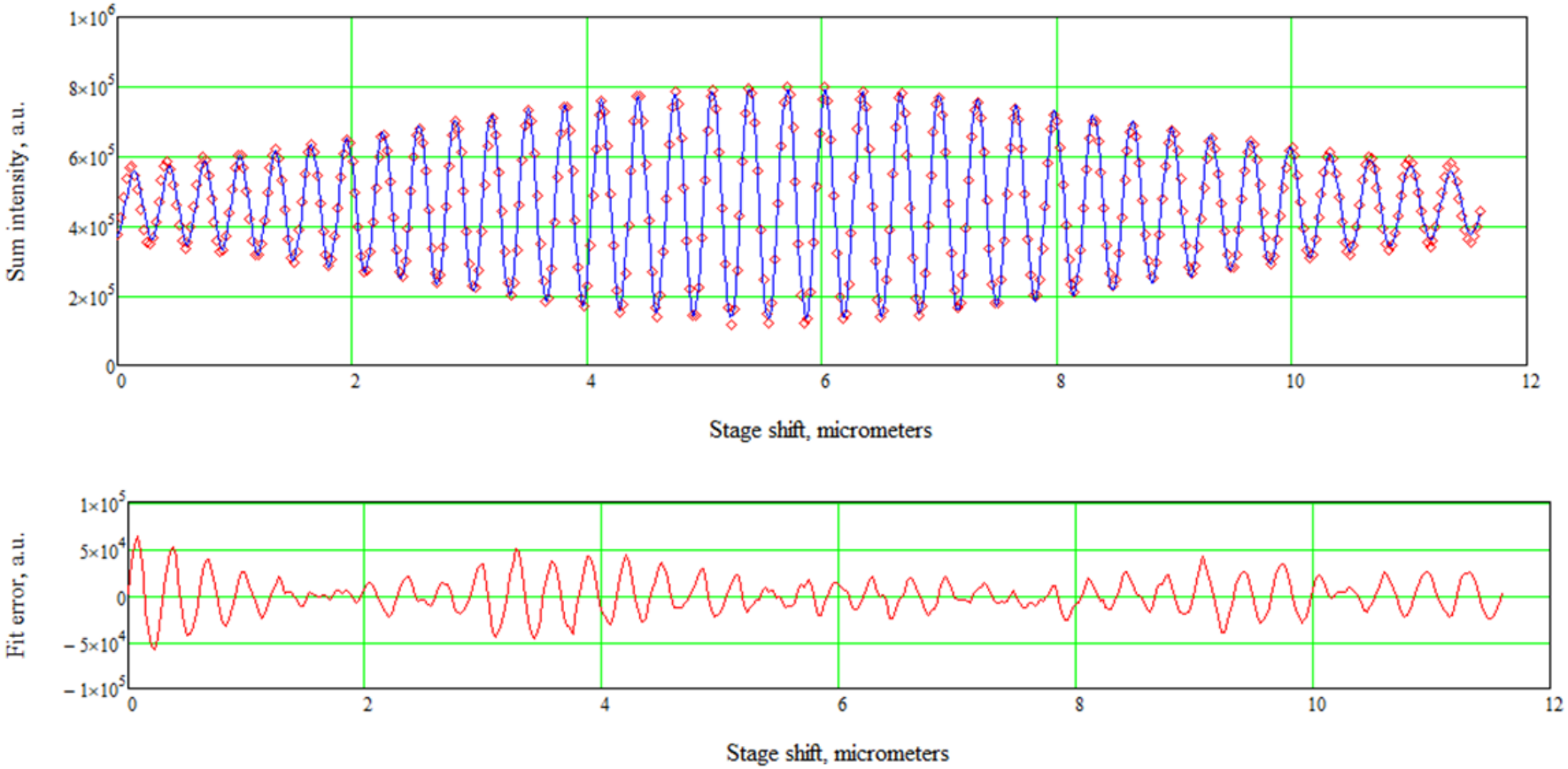
- SPAD1 has 2% higher average value and 16% larger oscillation amplitude than SPAD2.
  - Numbers for 22-Nov-22 set
- Coincidence rate dips around the position of the best aligned MZI



Example of a scan of SPADs signals vs delay by the stage. Stage scan 25 nm x 470 moves x 2s . LD current = 0.1 mA; ND filter with OD=5. OD=4. D44 data to copy. Straight lines are counters, and oscillating ones are the rates. 29-Nov-22.

Fit to SPAD counting rates

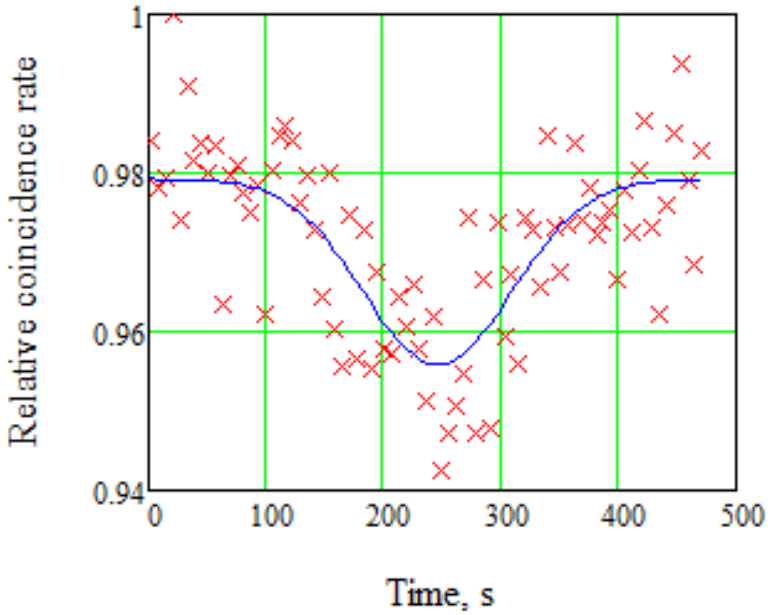
- Results are similar to scans with the camera image sum



Fit of the SPAD1 scan (top) and its fitting error (bottom). 28-Nov-22. Max visibility 85%, coherence length 11 λ, the period changes in the scan at 0.6%/μm rate.

The dip (1)

- For completely uncorrelated signals, the coincidence rate should be $f_{coinc} = f_1 \cdot f_2 \cdot \tau$, where τ is coincidence window.
  - Deviation of $T_w = \frac{f_{coinc}}{f_1 \cdot f_2}$ from τ may indicate how valid is the randomness assumption
  - Deviation is 2%. No explanation yet.



Coincidence rate during the stage scan 29-Nov-22, 16:08. 15 Hz data are averaged over 6 s intervals and normalized by the largest value (red crosses). Normalization corresponds to 19.7 ns. Max SPAD1 rate is 720 kHz.
Blue line is the best fit to (const – Gaussian), with the dip amplitude of 2.3% and width of 5λ. Rms fit error is 0.8%.

The dip (2)

- The dip repeated in several measurements

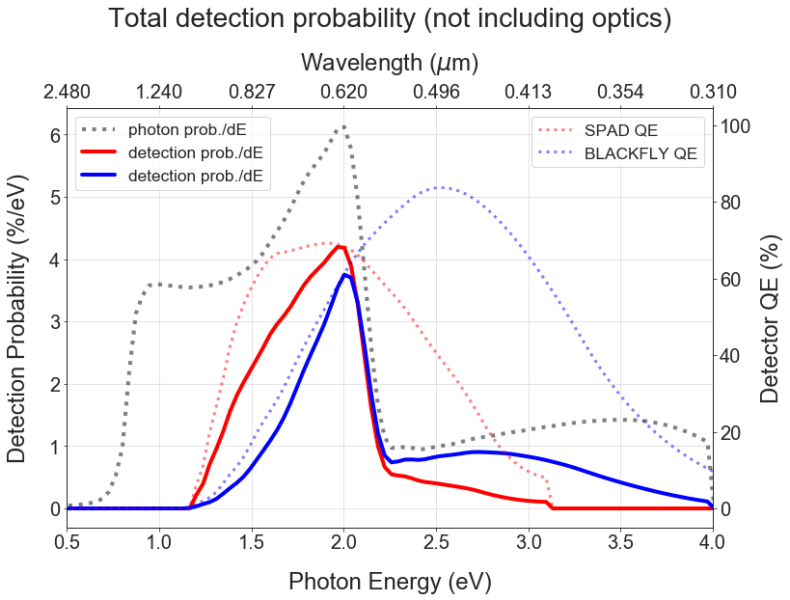
Time of set start	**14:03**	**14:53**	**15:40**	**16:08**
Step time, s	1	1	2	1
Max coincidence 15 Hz rate	8515	104	182	3424
Offset	0.992	0.799	0.929	0.979
Amplitude	-0.022	-0.014	-0.032	-0.023
Rms width, µm	1.676	0.356	2.319	1.582
Center, µm	6.042	3.171	5.496	6.15
Rms fit error	0.005	0.076	0.036	0.008
		Bad fit		

Fitting of scans taken on 29-Nov-22.

- Would be very useful to understand the dip origin since it is the signature that we planned to look in the undulator measurements.

Comparison with IOTA numbers

- Expected max SPAD rate for single electron
  - 0.01 ν/e/turn * 7.5 MHz = 75 kHz
- Two photon rate:
  - $(0.01)^2/2$ * 7.5 MHz = 375 Hz
- Maximum coincidence rate for uncorrelated photons
  - 375/2= 187 Hz



Jonathan Jarvis' simulations: ~0.01 photon/electron/turn.

- Judging by "15:40" set at the previous slide, may resolve ~10% dip in a 16 min measurement
  - What duration is reasonable to assume?
  - Can we sum several single-electron measurements?
    - Presently, no info from the stage to ACNET for synchronization

Summary of unexplained observations

- The period changes over the stage scans
- SPAD1 and SPAD2 have different oscillation amplitudes
- The “calculated coincidence window” has a 2% dip at aligned MZI

- Just more experiments with the existing LD are not likely to help. Need ideas.
- Part of the problem might be that this LD is an “unknown object”
  - Sergei is ordering a new LD to compare.

Plans: to-do list before moving to IOTA

- Mechanical
  - Install a tube for the input beam
  - Focusing lens at the entrance; remove HeNe from the box
  - May benefit from a screen on a flipper at the entrance
    - For the very initial tuning of light from IOTA
  - Need to figure out how to mount the optical box and the electronics at IOTA
  - Do we need frequency and polarization filtering? Collimation?
- Electrical
  - Need a cable to the box in IOTA to feed the laser diode
- Measurements
  - Try to sum separate short low-statistics measurements?
  - New LD

Possible schedule

- A couple of shifts for more measurements
  - Unless a new idea pops up
- Assemble the final configuration (pipe, lens, flipping screen)
  - If a new laser diode arrives, install
- Repeat measurements
- Move the box to IOTA
  - End of Dec’22 or beginning of Jan’23?

- I am on vacation Dec 22 – 28, 2022