Fermilab

U.S. DEPARTMENT OF ENERGY | Office of Science

Status of CLARA at ESB

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Meeting on CLARA

13 January 2023

Content

- Status of the setup
- Addressing the questions discussed at the last meeting
- Normalized coincidence rate
- Discussion and summary

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Status of the setup: photo

- MZI is assembled in the final configuration

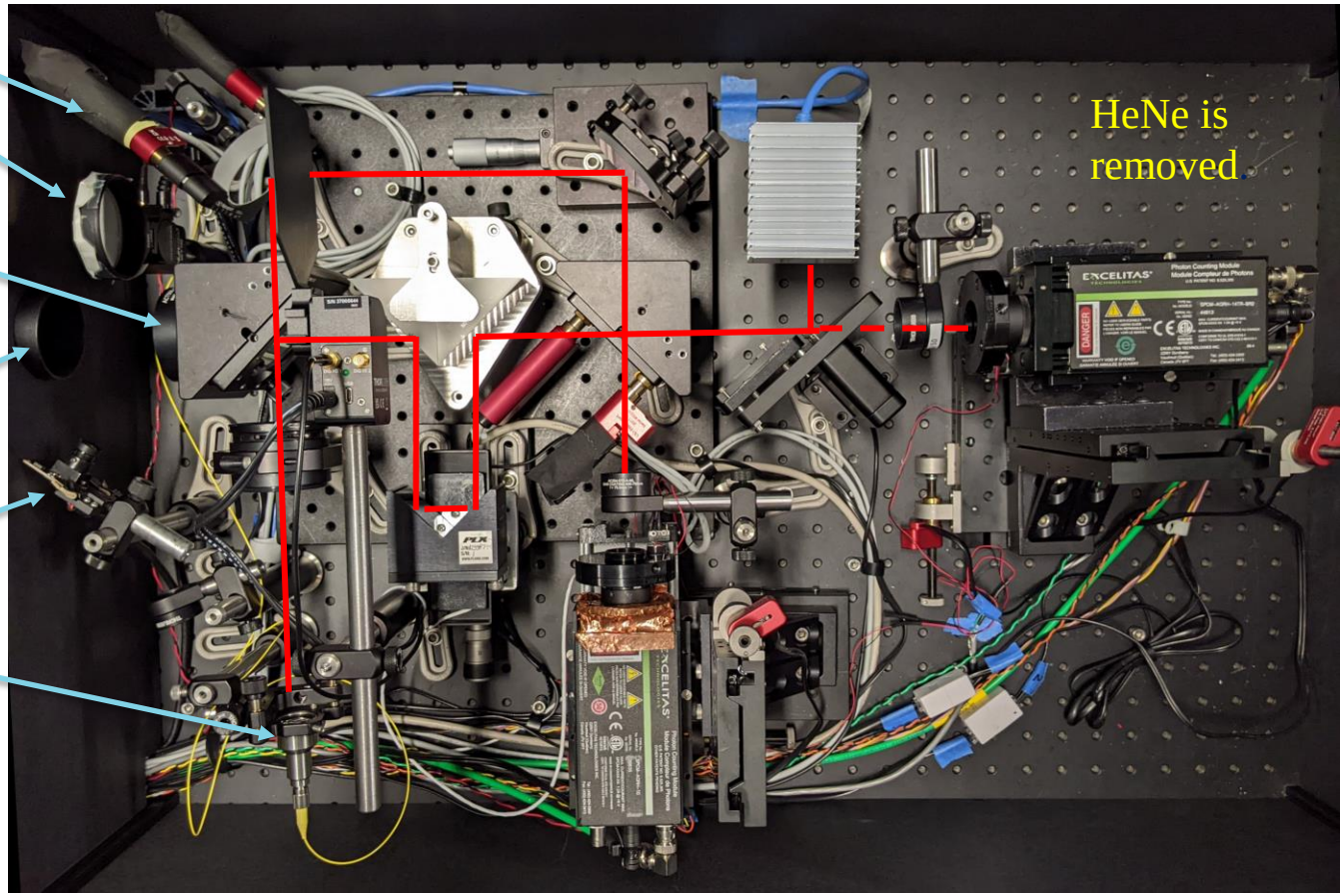
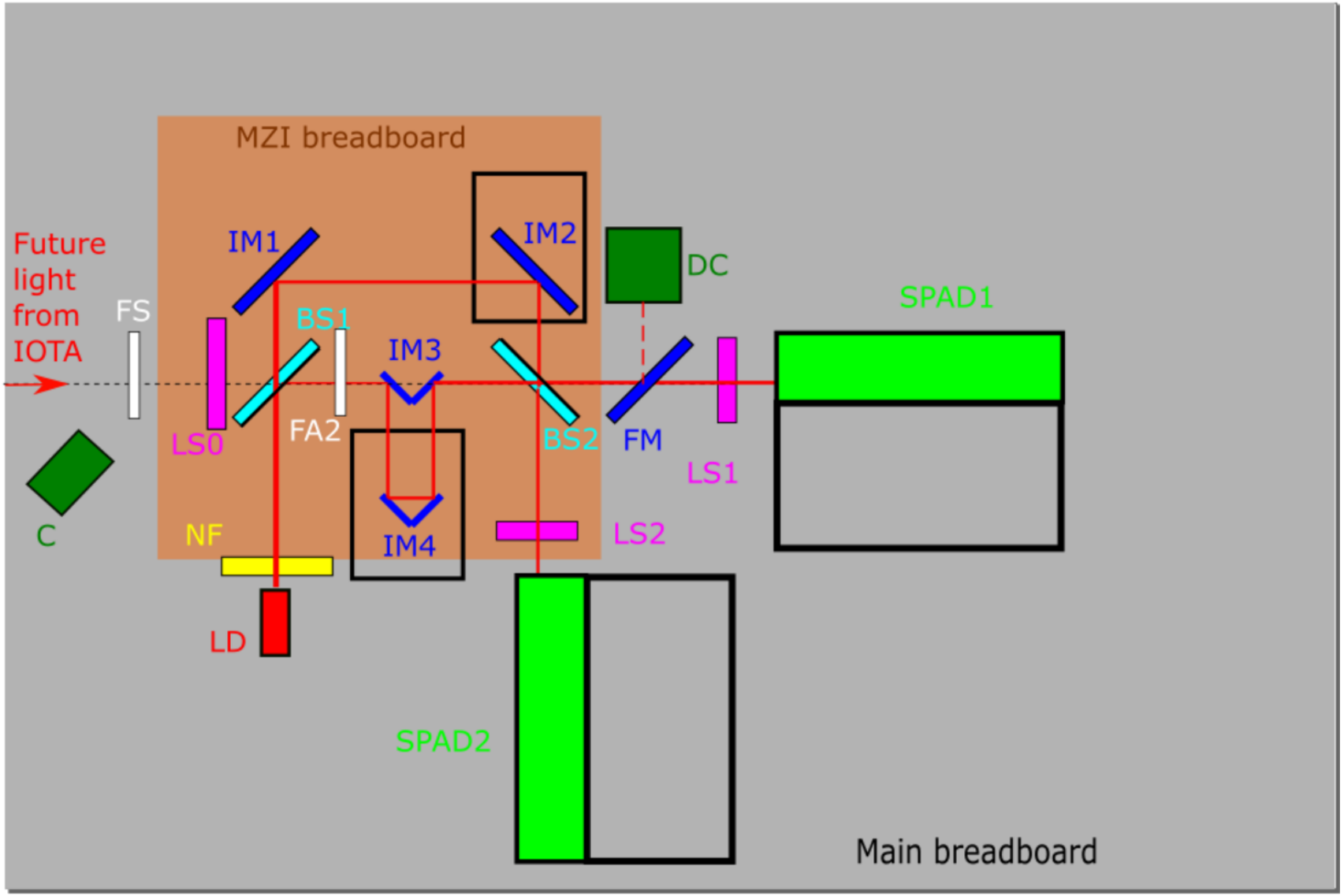


Photo of the optical box with the removed lid. Changes since 2-Dec-22 are marked. Later filters in front of LD were installed.

Changes in the setup since the last meeting

- The new laser diode has a rounder and smoother intensity distribution; slightly longer coherence length (measured still far from nominal lasing current of 58 mA).
    - Installed on 14-Dec-22
- A crude screen is mounted on a flipping mount near the box entrance hole; a webcam is aimed to the inserted screen
  - Can be used to assist with initial tuning of the light from undulator to MZI
- The last frequently used angle (IM1V) is equipped with a close-loop picomotor
- Attached a lens to the entrance port of BS1
- Made an entrance hole for the IOTA light
- HeNe laser was removed

Setup schematic



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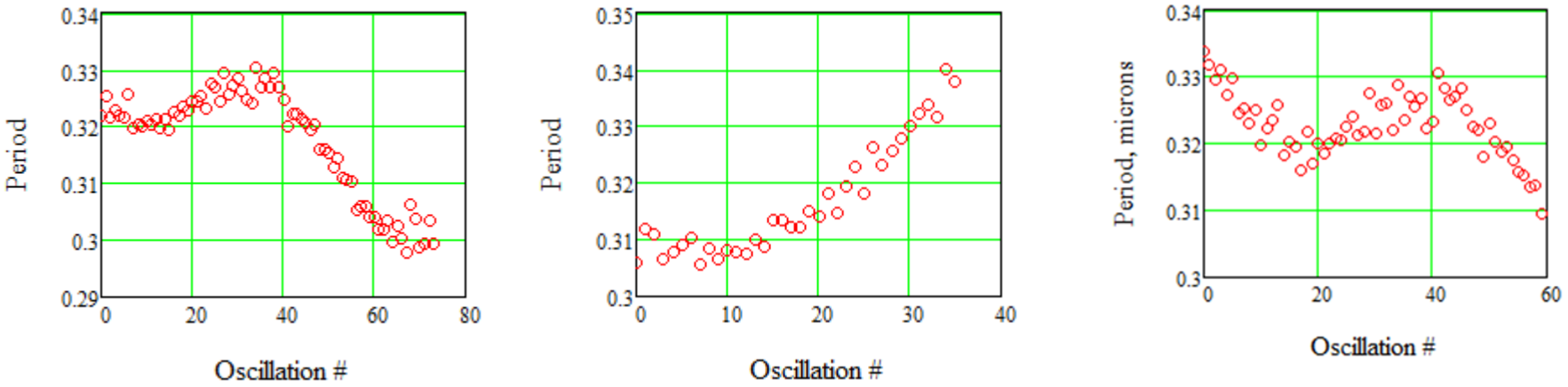
Questions that remained on 2-Dec-22 (last meeting)

- 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
  - Probably better to use for $W12 = \frac{f_{coinc}}{f_1 \cdot f_2}$ the term “normalized coincidence rate”

The period changes over the stage scans

- Compared results before and after moving the precise stage with mounted hollow-roof prism by 25 μm
  - The precise stage is mounted on the top of a manual stage
  - Fitting separately each maximum of oscillations
    - Period = difference between neighboring maximums
  - Most likely, the measured period changes because of imperfection of the precise stage



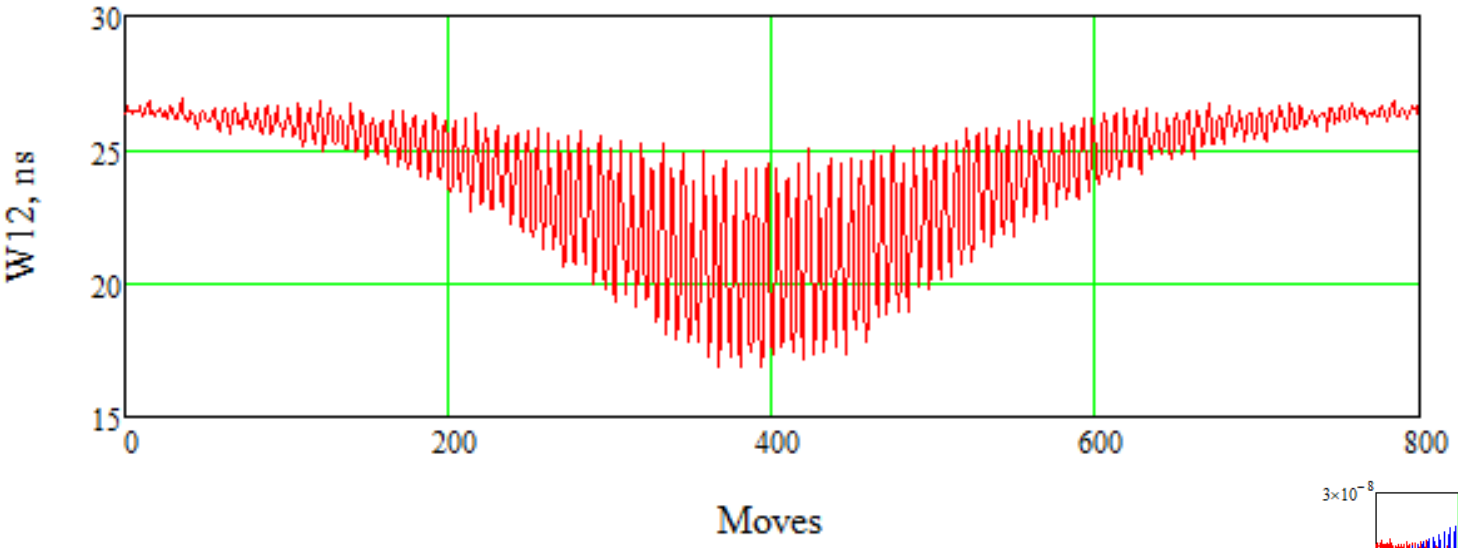
Periods, in μm, calculated from (SPAD1 rate) vs (stage position) scans. Left- 9-Dec-22; center –14-Dec-22, after moving by 25 μm; right – 4-Jan-23, after re-tuning MZI.

SPAD1 and SPAD2 have different oscillation amplitudes

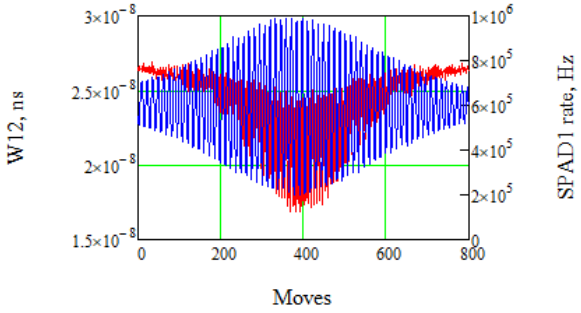
- With more measurements, deviations of the ratio between SPAD rate oscillation amplitudes from 1 were observed in both directions
  - Position of beam on SPADs is not stable enough from day to day
  - If the precise focusing and position into SPADs will be found very important, an automated procedure of SPAD centering might be needed

The “calculated coincidence window” has a 2% dip at aligned MZI

- “The dip” consists of oscillations with double frequency
  - With new LD, the dip is much larger (~20%) than the one observed with “old LD” (~2%).



W12 vs stage position (# of moves). Scan 25 nm x 800 moves x 4 s. New LD, current is 20 µA. 4-Jan-23. Right – the same plot overlapped with SPAD1 rate.



W12 dip: result of vibrations?

- A. Romanov: can result from high-frequency vibration of MZI
  - Coincidence events happen in MHz scale while averaging occur over 1/15 s (15 Hz data in ACNET)
- Model: identical SPADs; MZI is tuned to visibility V; uncorrelated photons; coincidence window τ
  - SPAD rate at the stage position x: $f_{1,2} = f_0(1 \pm V(x)\cos kx)$
  - Instantaneous coincidence rate: $f_{coinc} = f_1 f_2 \tau$
  - Vibrations: $x = \bar{x} + \delta x$, $\overline{\delta x^2} = \sigma^2$
  - Averaging: $W12 \equiv \frac{\overline{f_{coinc}}}{\overline{f_1}\cdot\overline{f_2}} \approx \tau\left[1 - \frac{(V\cdot k\sigma\cdot \sin k\bar{x})^2}{1-(V\cos k\bar{x})^2}\right]$

Vibration model discussion

- The model gives oscillations with double frequency
  - 1% oscillation requires reasonable σ/λ~ 2%
- It doesn't quite describe the dip
  - W12 oscillations should go to max through the scan at maximum and minimums of SPAD rates
  - Doesn't explain larger oscillations and larger dip in measurements with new LD at low LD current

- Might need to look for an explanation on the physics side

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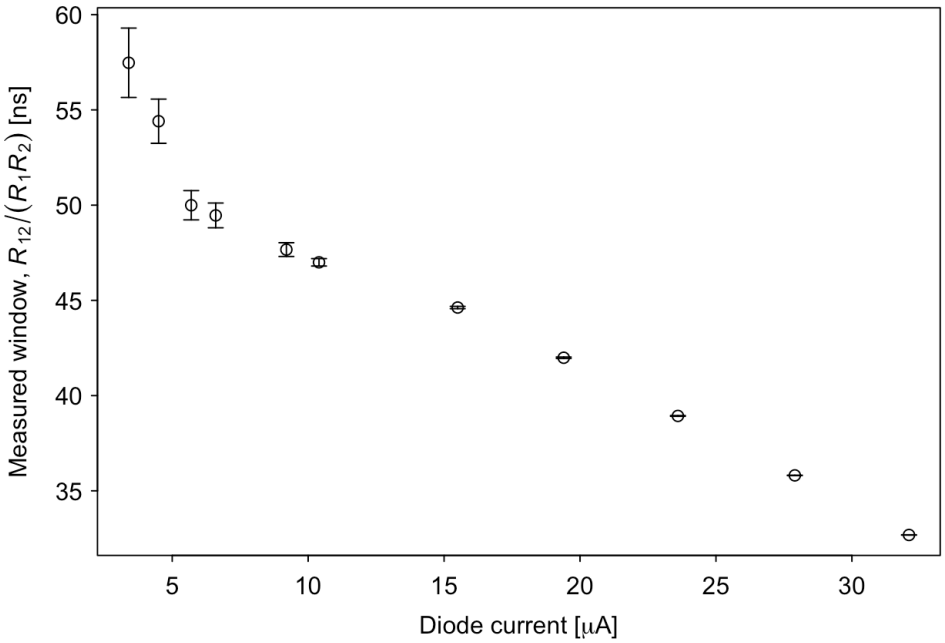
W12 value anomaly

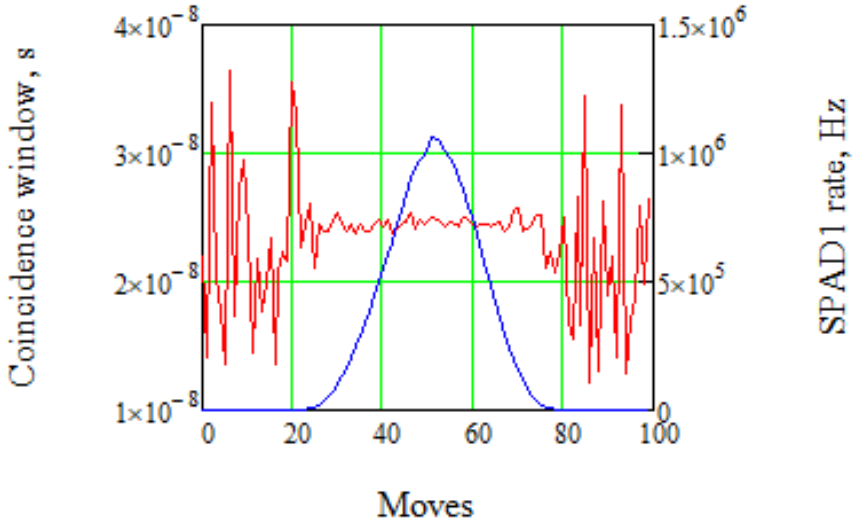
- Found that W12 with the new LD differs from the coincidence window set in electronics (19.2 ns as measured by Giulio)
  - The W12 value measured with old LD far from the dip (with a large stage delay) was equal to the electronics window
  - The value depends on LD current



W12 vs LD current. The stage is moved by -0.1 mm from optimum. G. Stancari, 9-Jan-23.

W12 value anomaly: Tests of apparatus

- Giulio tested electronics with generator – OK
- Looked at SPAD signals with a scope – OK
  - Did not see coincidence without SPAD pulses
  - In persistent mode with triggering by the coincidence signal, the SPAD signals fill ~20 ns
- No changes in W12 value if SPAD rates are changed by tuning the apparatus
  - By blocking one MZI arm
  - In scans of transverse SPAD position



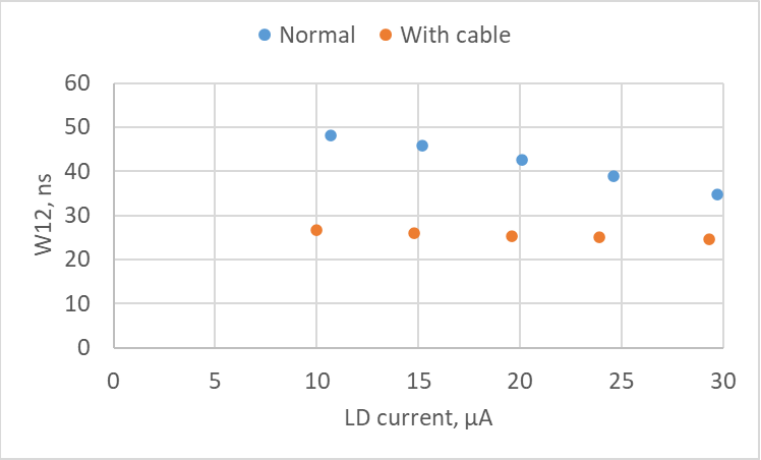
W12 (red) and SPAD1 rate vs SPAD1 horizontal position. 100 moves x(500 picomotor steps) x 2 s. The stage is moved by -0.1 mm from optimum. 4-Jan-23.

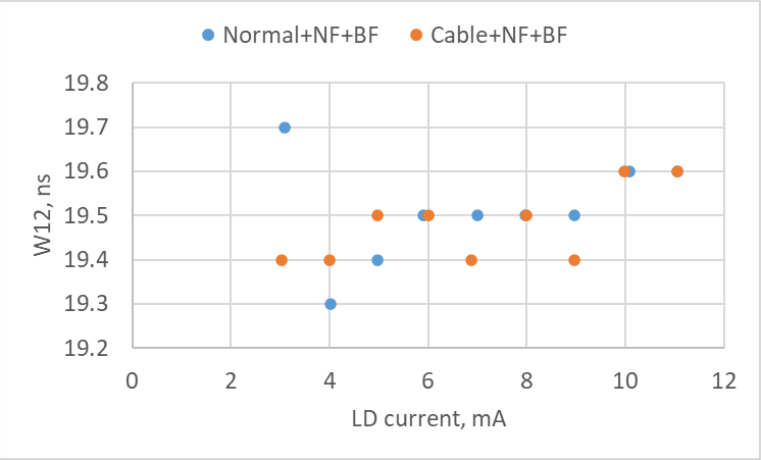
W12 value anomaly: physics?

- Giulio: dependence might be related to the transition from stochastic light at very low LD currents to coherent light at currents corresponding to lasing
  - Hanbury Brown and Twiss effect: photons from a stochastic source (spontaneous emission) tend to “bunch”
    - Probability to be detected within coherence time increases

W12 value anomaly: test with a delay

- Test: inserting a long (probably 37 ns) cable into SPAD1 line
  - The delay is longer than 19.2 ns coincidence window
  - With cable in, the W12 decreased at low LD currents
- For large LD currents, insertion of the cable makes no difference (note that the nominal LD current is 58 mA).
  - With additional filters installed to keep SPAD rates within 1 MHz





W12 vs LD current for low (left) and high (right) LD currents, without (blue) and with (orange) additional delay for SPAD1. The stage is moved by -0.1 mm from optimum. SPAD rates are similar between the plots. 11-Jan-23.

W12 value anomaly: discussion

- Summary of the measurements
  - W12 doesn't depend on properties of apparatus and does on the LD current and on how equal the SPAD cable lengths are
- The observed dependence of the normalized coincidence rate on the laser diode current can be interpreted as a transition from emitting a stochastic light to a coherent light
  - Probably can identify a portion of each at a given LD current
- Might be interesting to understand better the theoretical side

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Practical considerations

- Apart of making sure that the apparatus works correctly, the W12 result is not likely affect the CLARA measurement itself
  - Though we need to understand the dip in the W12 stage scans
- How much more time should we spend on the LD measurements before moving to IOTA? A week?
  - Is the W12 result with LD publishable by itself?
    - It would justify making more measurements
- What LD filtering should be used for IOTA location?
  - “No filtering” allows easy switching between measurements with camera and with SPADs
  - “Heavy filtering” (1E5) is safer for SPADs, gives W12 equal to electronics window, but camera measurements are not possible

Summary

- The apparatus is fully assembled, tested, and all inconsistencies are explained at least to some degree
- Need to decide when it is to be moved to IOTA
- Most likely, a transition from stochastic to coherent light in the laser diode is identified