Status of CLARA measurements

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CLARA meeting

19 May 2023

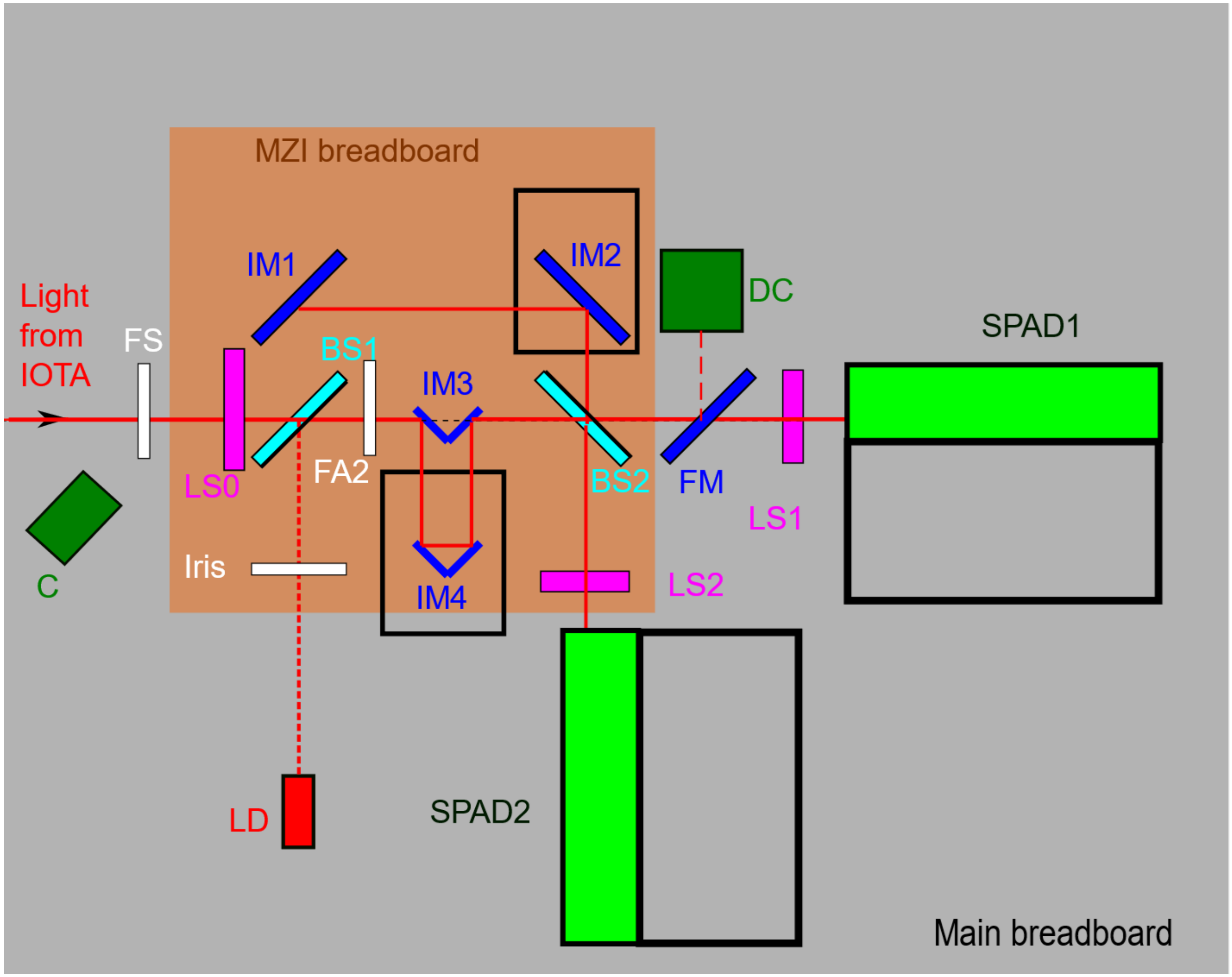
Content

- Introduction: goals and schematic
- Beam preparation
- Documented measurements
- Possible next steps and summary

Goals

- Look at possible signal associated with photons in Fock state
  - Can be describe as a deviation of "normalized coincidence rate" from constant in the MZI stage scans $$T_{ncr} \equiv \frac{f_{coinc}}{f_{SPAD1} f_{SPAD2}}$$
- Measure the coherence length
  - Compare with simulations
  - Compare results for single electron, multiple electrons, and a full-intensity beam
- Repeat the photon statistics measurements made in URSSE
  - Did not do; not a part of this report.
- There was a thought about HBT – type measurements
  - Did not do. Preliminary discussions indicated that it might be not resolvable at IOTA. Not a part of this report.

Apparatus schematic



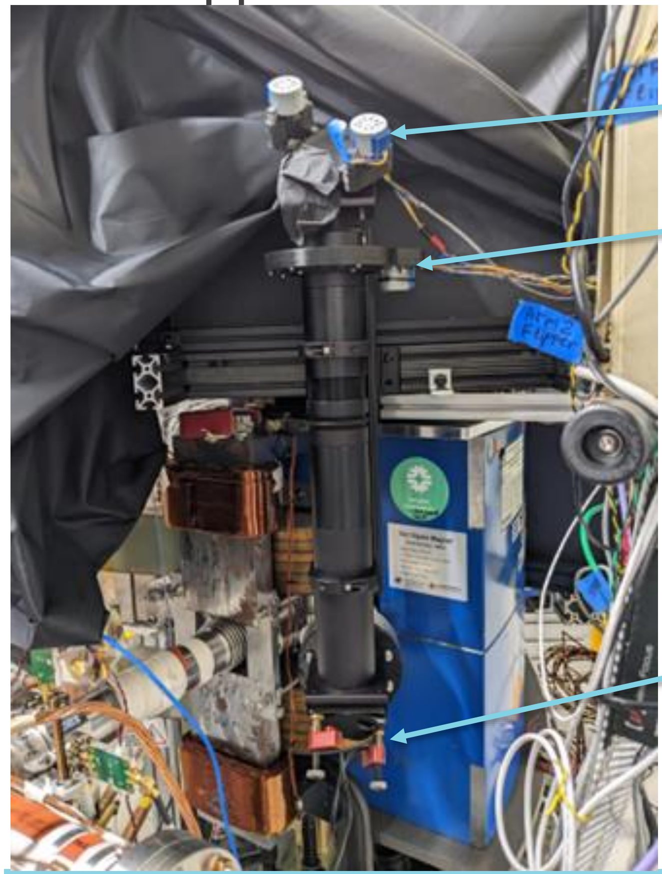
Mach – Zender Interferomer (MZI) is assembled on a separate breadboard isolated from the main one by rubber supports.

As of 9-Feb-2023

- LD- laser diode
- SPAD1,2 –Single Photon Avalanche Detector
- DC – digital camera
- BS1,2 – beam splitters
- IM1, IM2 – Arm1 MZI mirrors
- IM3 – right-angle mirror in Arm2
- IM4 – hollow roof mirror in Arm2
- LS1, 2 – SPAD lenses
- LS0 – entrance lens
- FM – flipping mirror
- FA2 – flipping screen in Arm2
- FS - flipping screen at entrance
- Iris – LD collimator
- C - webcam

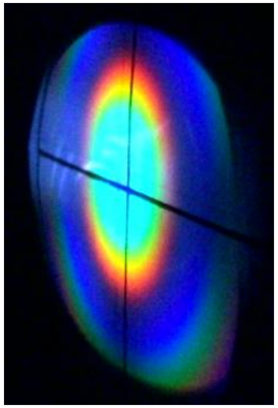
Periscope

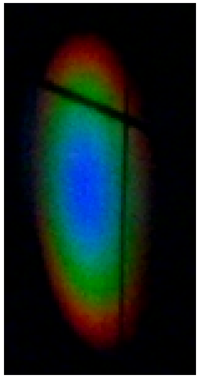
- The undulator light goes through M4R magnet into periscope
  - Bottom mirror centers the light on iris
  - Upper mirror centers on the camera



Periscope after modifications on April 7, 2023.
Sasha R & Jamie's photo.

Typical initial beam preparation

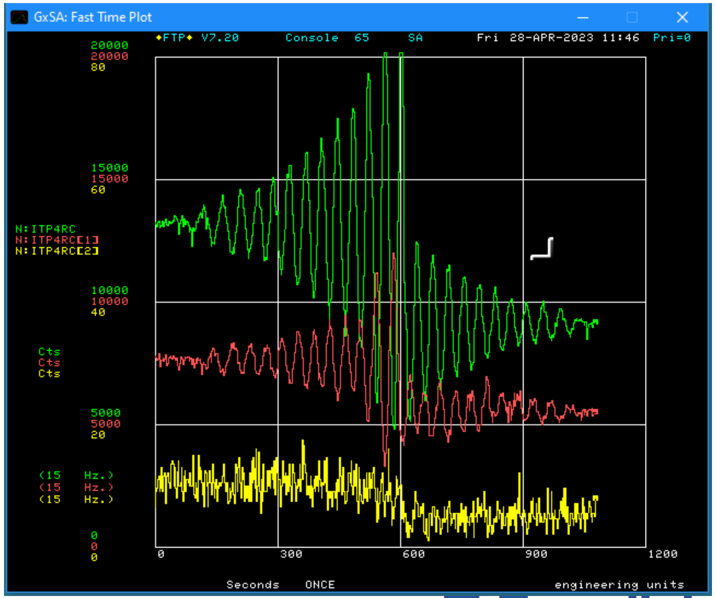




- Typically, a full-intensity beam is injected
  - Injection orbit corresponds to a shifted light spot at the entrance screen
- The trajectory is brought to a standard position
  - Sasha R established a procedure, and Daniel documented it and successfully used
  - The periscope alignment brings the light to the center of the iris and center of the camera but significantly off center of the entrance screen, and, therefore, of MZI
- After camera measurements, the beam is "scraped" by lowering the RF voltage to hundreds of electrons
  - Controlling the intensity with MZI camera and/or PMT
  - Neighboring buckets might be populated at that time

To several electrons

- Switch operation to SPADs, check that everything works
- "Scrape" the beam to several electrons or single electron by lowering again the RF voltage
  - Count electrons by the value of steps in light intensity at loosing an electron
  - Lifetime of a single electron is from several minutes to several hours
- Alternative procedure is to inject a dark current
  - Blind injection but much faster way to a single electron



Scan with 1 out of 3 electrons lost. April 28, 2023, 11:46.

Recent shifts

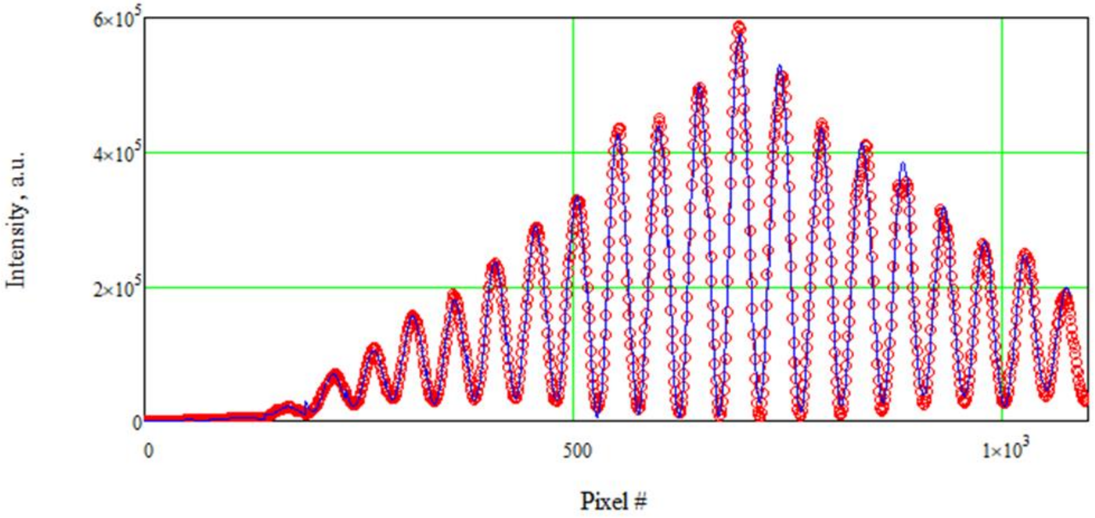
- 7-Apr-/2023 – controlled access to finalize the setup
  - Moved the entrance lens upstream, installed iris in the periscope, cleaned optics
- 10/20 – Apr-23 – mostly tuning
- 28-Apr-23, 2-May-23 – work with single and several electrons
  - Iris either slightly or significantly collimates the incoming light

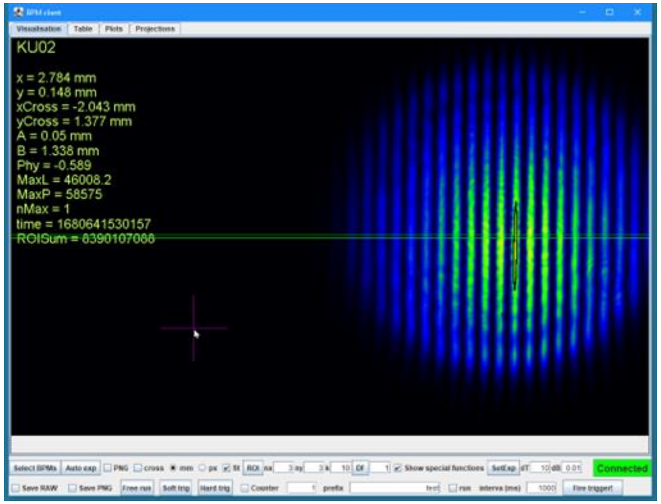
Recorded data

- Camera: projection with a good visibility
- SPADs (no gating on individual signals):
  - With hundreds or several electrons and with single electron
  - At various iris positions
    - Most of data: 2400 (light fits into camera) and 3000 (small spot)
  - Transverse scans
  - Stage scans (all 20 nm/move)
    - Wide (typically 350 moves x 1 s) – all fringes and more
    - Near the center fringes (typically 20 moves x 20 s) – ~1.5 fringes
  - Data (typically 100s) far from fringes
  - Large amount of data saved with data timer

Results: Laser diode far below threshold

- Projection with a ~100% visibility. Coherence length 8.6λ.

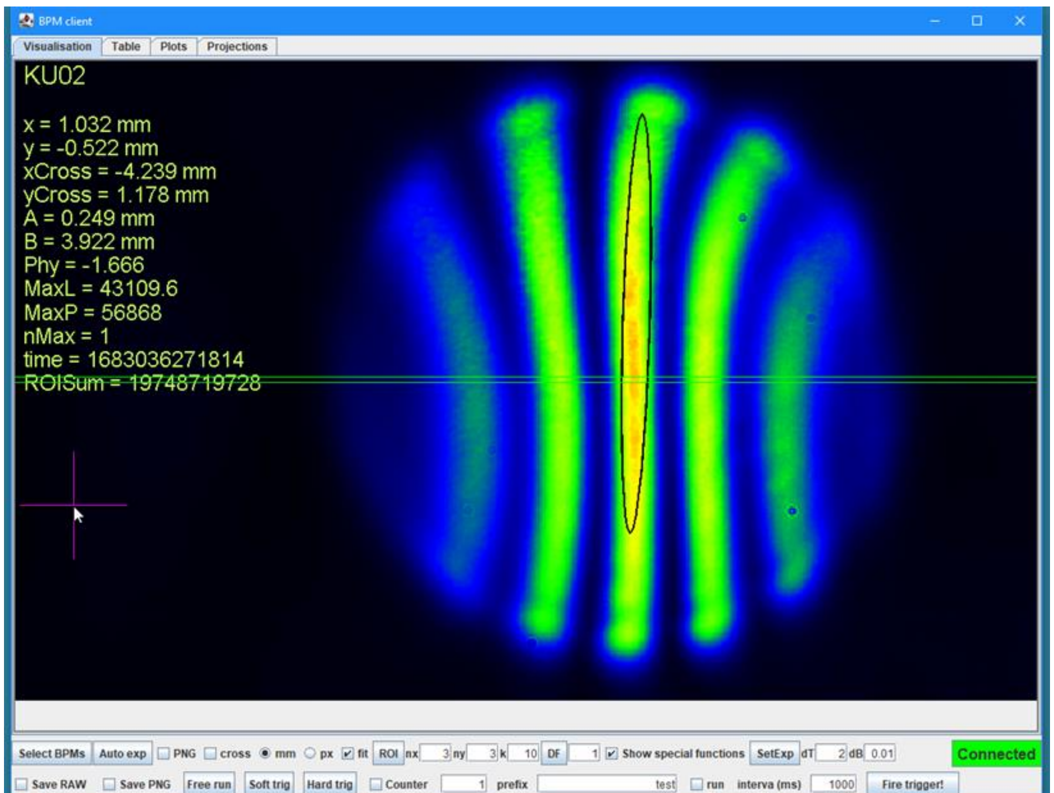




April 4, 2023 data.

Results: Large intensity e-beam, camera

- Only images of fringes in e-log
  - No digital files with projections
  - No adjustments for the max visibility



May 2, 2023 data.

Measurements with SPADs: expectations

- So far, the individual SPAD measurements were made without gating on the bunch
  – 20 ns gate for coincidence
- A. Romanov: "Single-electron bunch length“ =0.77 ns rms
  – δ-function in comparison with the coincidence gate
  – All photons emitted by the bunch passage contribute to coincidence
    - But not from other buckets
- For the ideal classical case, the normalized coincidence rate

$$T_{ncr} \equiv \frac{f_{coinc}}{f_{SPAD1} f_{SPAD2}} = T_{revolution} = 133.3\,ns$$

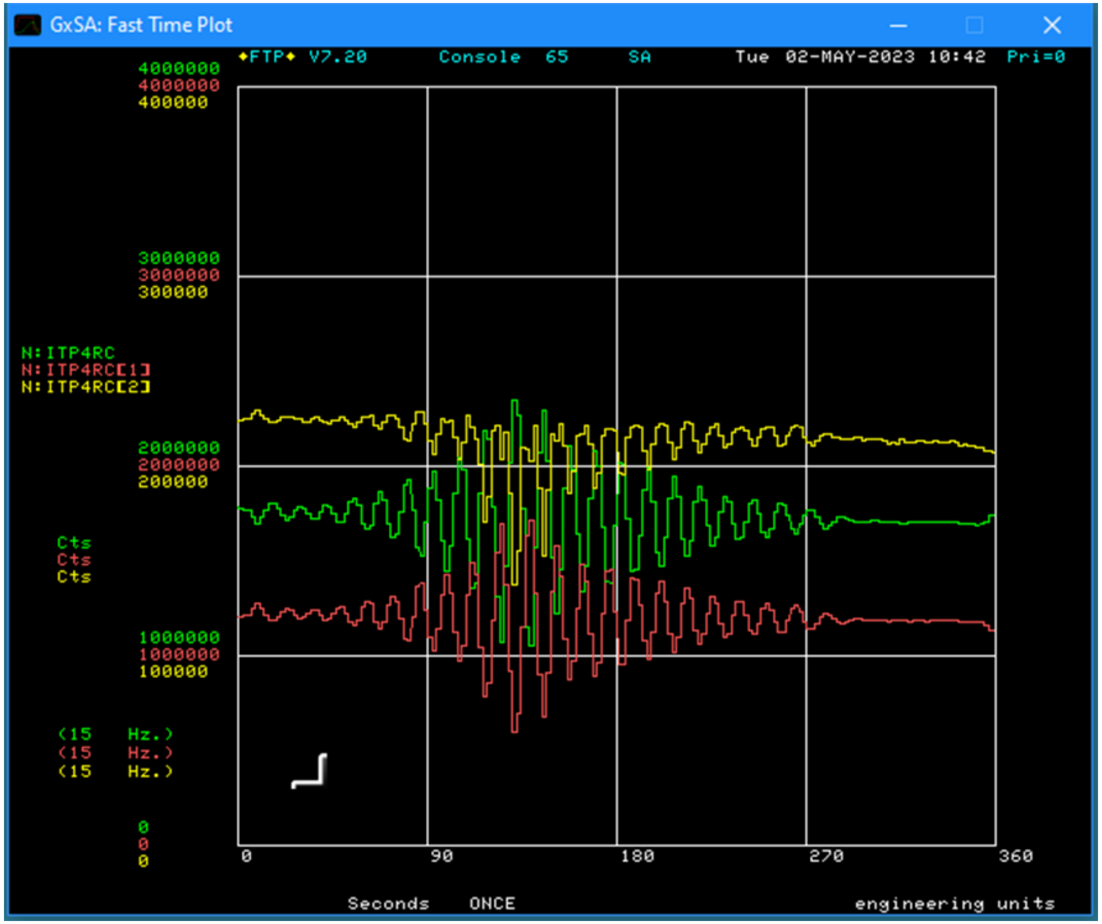
SPADs' background rate

- SPADs' background rate increased significantly, by two jumps
  - No explanation
    - In part, no known cases of exposure to high-intensity light
- Need to take this into account
  - Subtract from SPAD rates
    - $f_{SPAD_i} = f_{SPAD_{i}\_meas} - f_{Bcgrnd_i}$
  - Correct the coincidence rate
    - $f_{coinc} = f_{coinc\_meas} - \left(f_{Bcgrnd_1} \cdot f_{Bcgrnd_2} + f_{Bcgrnd_1} \cdot f_{SPAD_2} + f_{Bcgrnd_1} \cdot f_{SPAD_2}\right) \cdot T_{coinc}$
    - Where T_{coinc} is the coincidence window

Date, time	SPAD1/SPAD2, Hz
2-May-23, 17:22	453/1230
28-Apr-23, 17:20	900/1200
28-Apr-23, 09:35	1100/1000
20-Apr-23, 10:35	80/1100
10-Apr-23, 16:30	70/1000
30-Mar-23, 14:50	70/110
27-Mar-23, 13:23	70/110
7-Feb-23, 15:45	70/110
31-Jan-23, 22:14	70/110

Case of hundreds of electrons

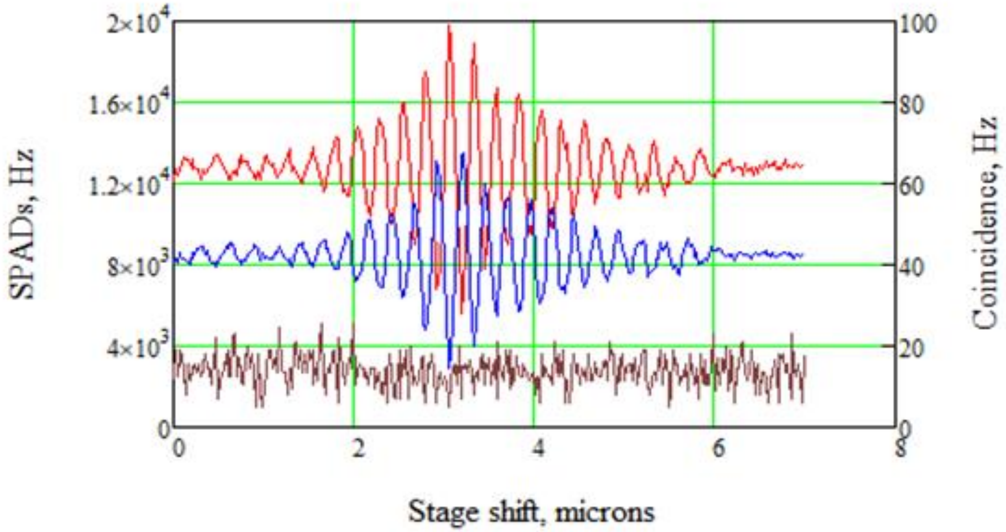
- High statistics (~1 MHz signals).
  - Recent scans have not been analyzed.

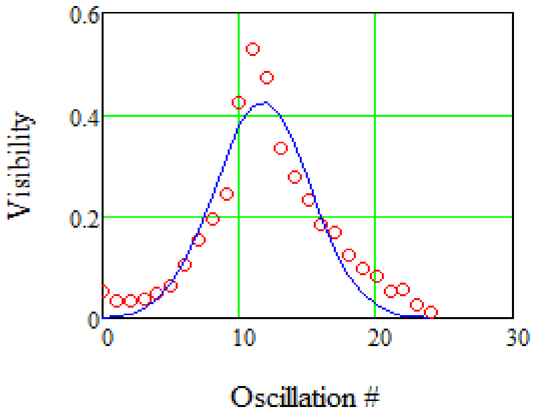


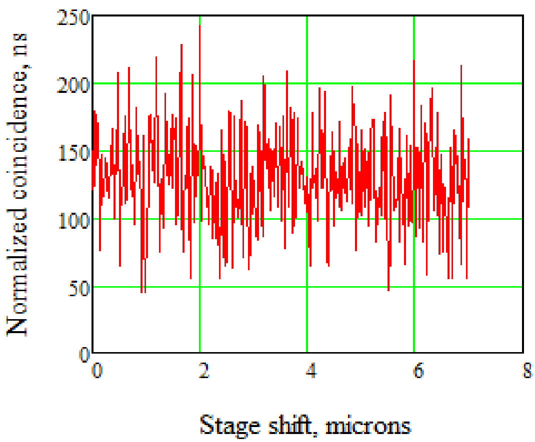
Stage scan 20 nm x 350 moves x 1. Around 250 e. Not analyzed. Green/Red – SPAD1/2, yellow – coincidence. May 2, 2023, 10:42 .

Several electrons

- Multiple scans with 2 or 3 electrons in the same bucket
  - The analyzed scans look similar to single electron's with the same iris opening







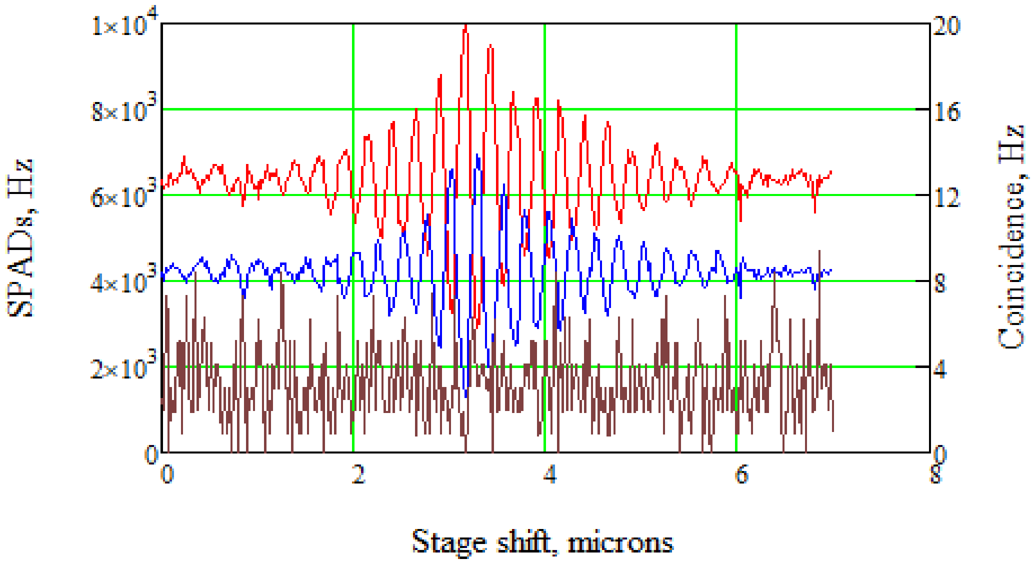
Stage scan 20 nm x 350 moves x 1s. 2 electrons. Iris = 3000. Red/Blue – SPAD1/2, brown – coincidence. May 2, 2023, 12:08 .

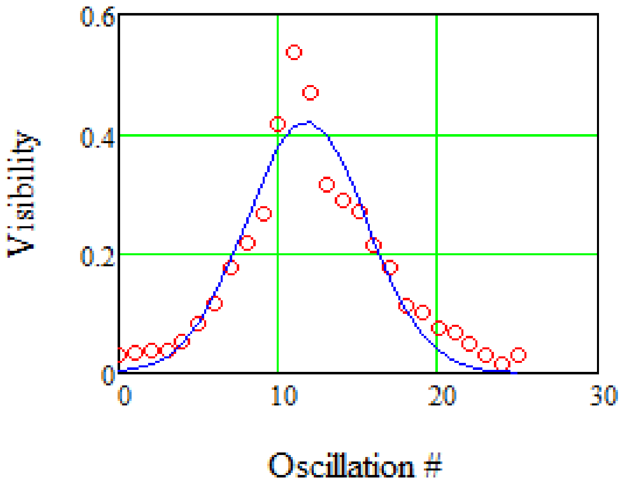
Right top – visibility of individual fringes and a Gaussian fit with max visibility of 0.43 and sigma is 2.4λ. Fit is bad and unstable.

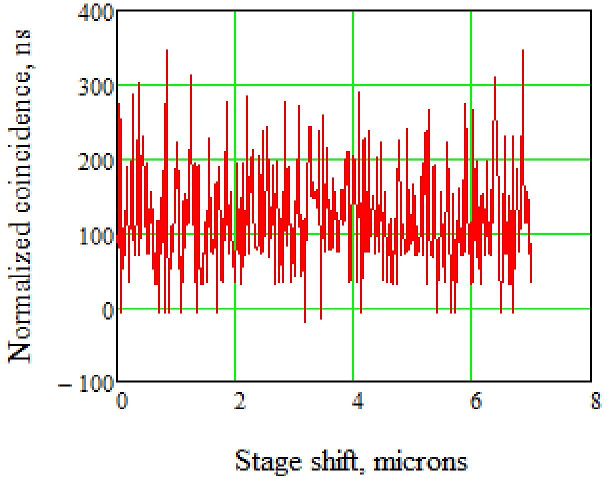
Right bottom – normalized coincidence rate. Average 123 ns, $\frac{\sigma}{\sqrt{N}}$=3.8 ns.

Single electron data, strong collimation

- Multiple scans with single electron.



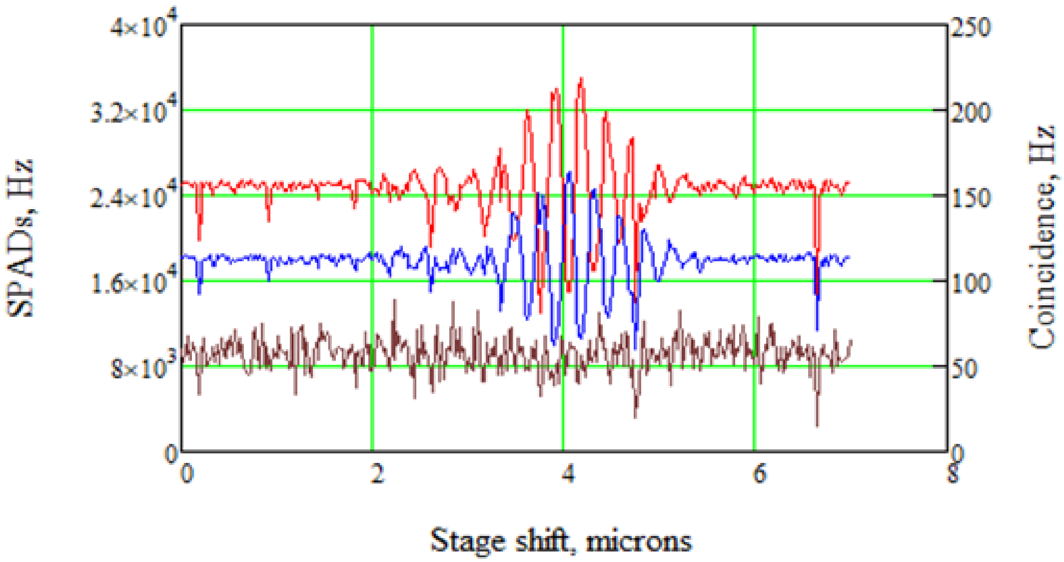


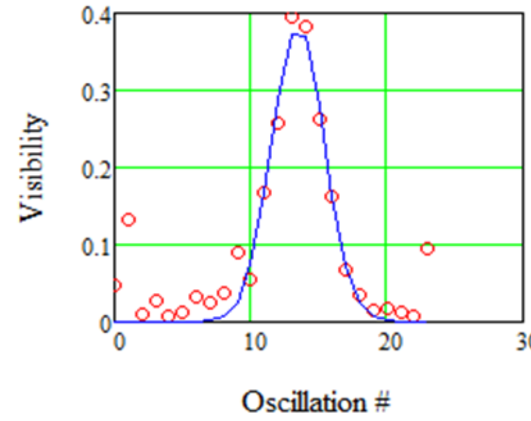


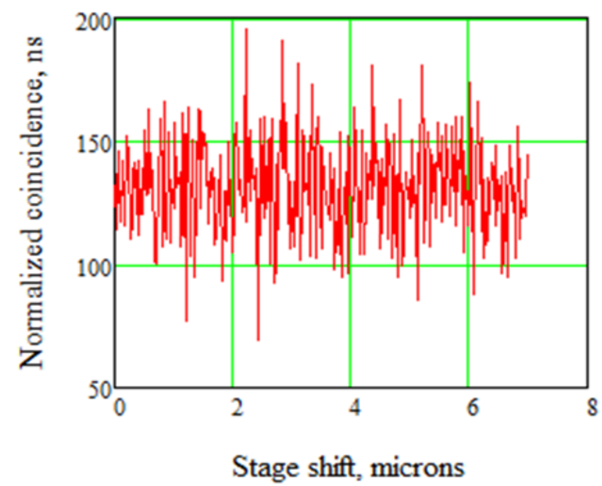
Stage scan 20 nm x 350 moves x 1s. 1 electron. Iris = 3000.
Red/Blue – SPAD1/2, brown – coincidence. May 2, 2023, 13:41.
Right top – visibility of individual fringes and a Gaussian fit with max visibility of 0.42 and sigma is 3.7λ.
Right bottom – normalized coincidence rate. Average 131 ns, $\frac{\sigma}{\sqrt{N}}$=1.9 ns.

Single electron data, weak collimation

- Multiple scans with single electron.







Stage scan 20 nm x 350 moves x 1s. 1 electron. Iris = 2400.
Red/Blue – SPAD1/2, brown – coincidence. May 2, 2023, 14:23.
Right top – visibility of individual fringes and a Gaussian fit with max visibility of 0.38 and sigma is 1.9λ.
Right bottom – normalized coincidence rate. Average 131 ns, $\frac{\sigma}{\sqrt{N}}$=1.0 ns. Less symmetric.
Jumps in rates are interpreted as trajectory instability.

Fermilab

Single electron: Normalized coincidence rate

- Far from fringes: 135.6±1.6 ns (30 min)
    - 2-May-23. 13:08, before a scan.
    - Estimation is from the counters' end points.
- Scan over the central fringe: 130±1.7 ns (40 min)
    - Stage scan 20 nm x 25 moves x 100 s (interrupted by loss)
    - Error is estimated as (rms of 25 points)/sqrt(25)

Estimation for the effect of vibrations

- Bad case (after moving to M4R)
    - LD measurements, 1-Feb-23
  - – Estimated vibration ~0.12λ; average deviation of the normalized coincidence rate at the center ~10%
- Good case (after correction of vibration)
    - LD measurements, 9-Feb-23
  - – Effect of vibrations is not resolvable
  - – Giulio's analysis of spectra shows decrease of rms noise by at factor of 5
- Vibration may contribute at ~2% level to the difference in the normalized coincidence rate between center and far from fringes
  - – Needs to be estimated more carefully

More measurements

- Repeat critical measurements with SPAD gating
  - Giulio implemented it but needs to be tuned with beam
  - Would decrease background – related errors
- Measure dependence of light intensity on iris settings
  - Would help to compare with simulations
- Repeat measurements with a full-intensity beam and camera to record projections in the same mode as with single electron
- Record with a single electron long data sets far from fringes and at max coincidence rate near the center.

Possible next steps

- Simulate the single-electron stage scan at collimation corresponding to conditions in measurements
- Determine what data are relevant for final conclusions and analyze
- Decide whether anything else should be measured/analyzed
  - Photon statistics? HBT?
- Discuss writing

Summary

- The undulator light from a single electron behaves classically. Withing the measurement errors of several %, there is no HOM dip in the normalized coincidence rate.
- A shift of additional measurements and simulations would be useful for proceeding to writing.