Study of Photon Statistics of Undulator Radiation Produced by a Single Electron

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Study of Photon Statistics of Undulator Radiation Produced by a Single Electron

Motivation:

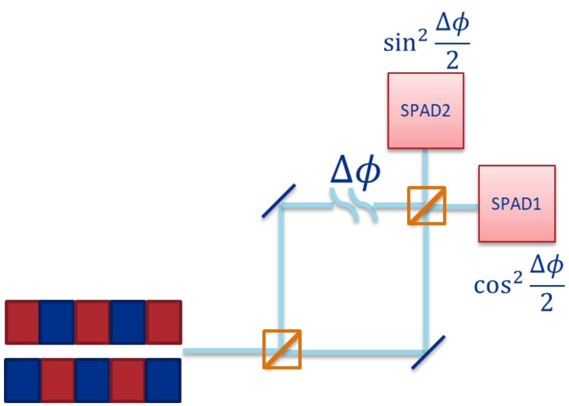
- Observation of Sub-Poisson statistics in a previous experiment with FEL radiation:

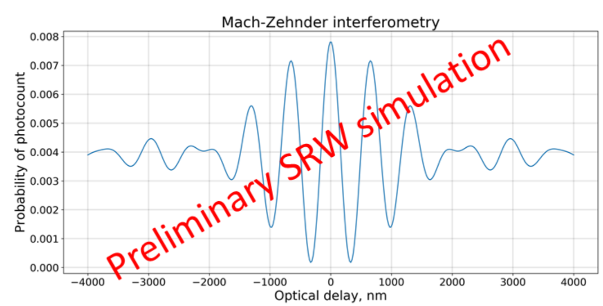
VOLUME 86, NUMBER 26 PHYSICAL REVIEW LETTERS 25 JUNE 2001

Observation of Sub-Poisson Fluctuations in the Intensity of the Seventh Coherent Spontaneous Harmonic Emitted by a rf Linac Free-Electron Laser

Teng Chen and John M. J. Madey
Department of Physics and Astronomy, University of Hawaii at Manoa, Honolulu, Hawaii 96822
(Received 18 April 2000)

- Preparation for the more complex experiment: Hong-Ou-Mandel (or Mach-Zehnder) interferometry of undulator radiation produced by a single electron





Detector: Single Photon Avalanche Diode

Excelitas SPCM-AQRH-10

Active area (diameter)	**180 μm**
Photon detection efficiency at 650 nm	65%
Dark count	$\sim$100 cps
Dead time	22 ns
Pulse height	2 V
Pulse length	10 ns

*we have experience in focusing the radiation on such a small area

*can be reduced by using a gate ($\sim$ 3 ns)

*IOTA revolution: 133 ns

Comparison with the previous experiment regarding Sub-Poisson photon statistics:

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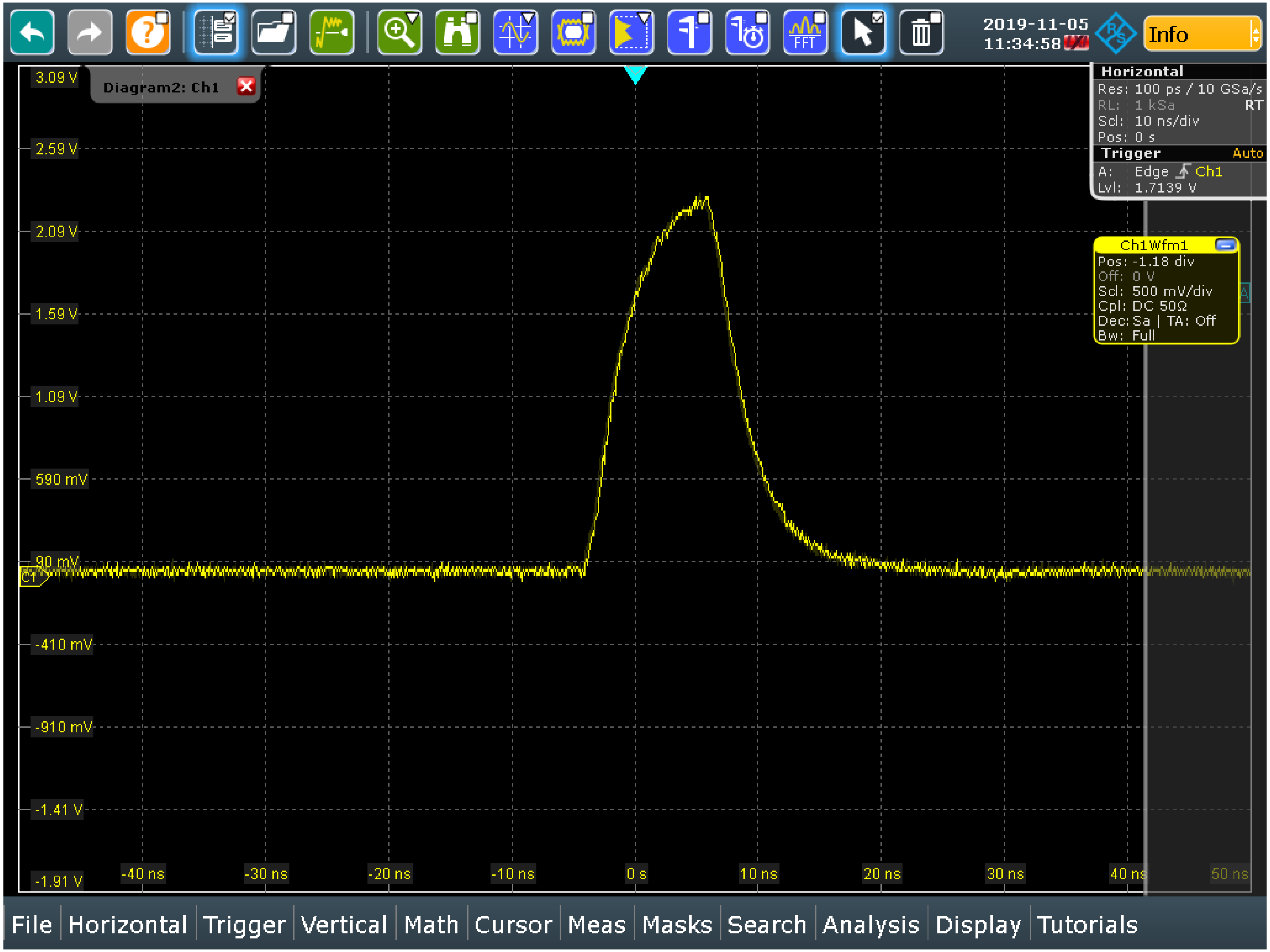
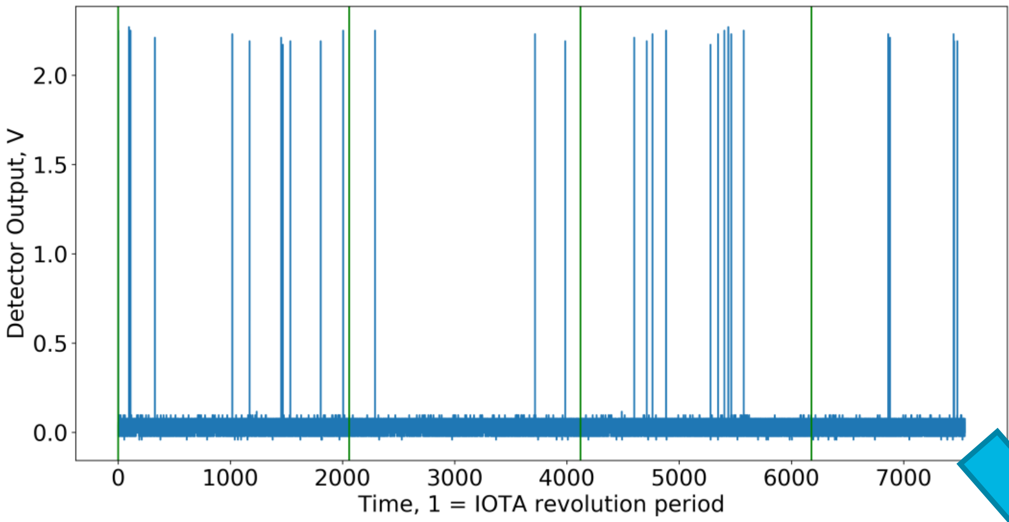
- Quantum efficiency was only 12%
- Detector’s dead time could affect the observed statistics

We will be able to detect deviations from Poisson statistics as small as 1-2%

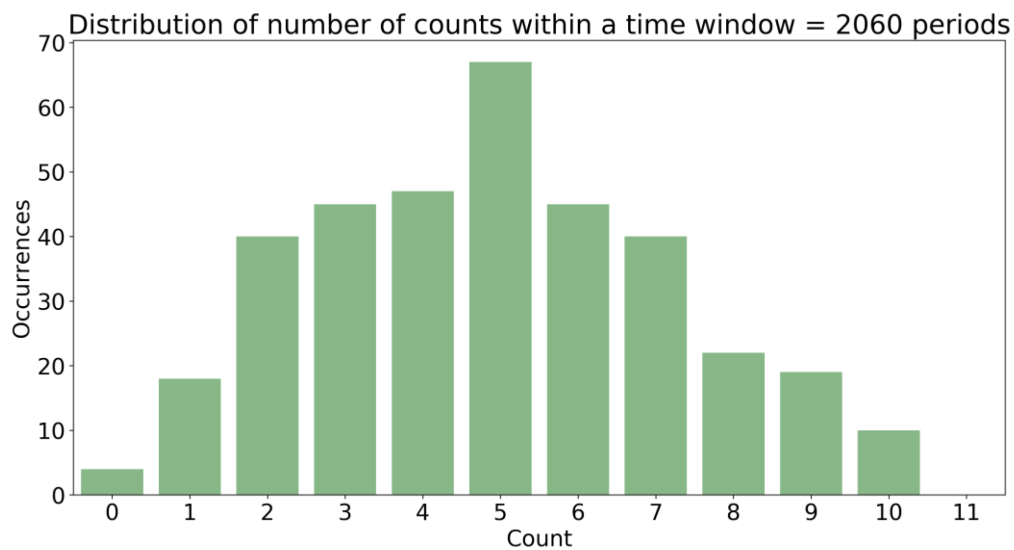
Sample SPAD pulse



Proposed measurements



- Divide waveform into equal time windows
- 2060 IOTA periods in this example
- Count number of pulses in each time window
- Plot distribution for this number



The question to answer is:

Is this Poisson statistics or Sub-Poisson statistics?

$$\frac{\mathrm{var}(N)}{\langle N \rangle} = ?$$

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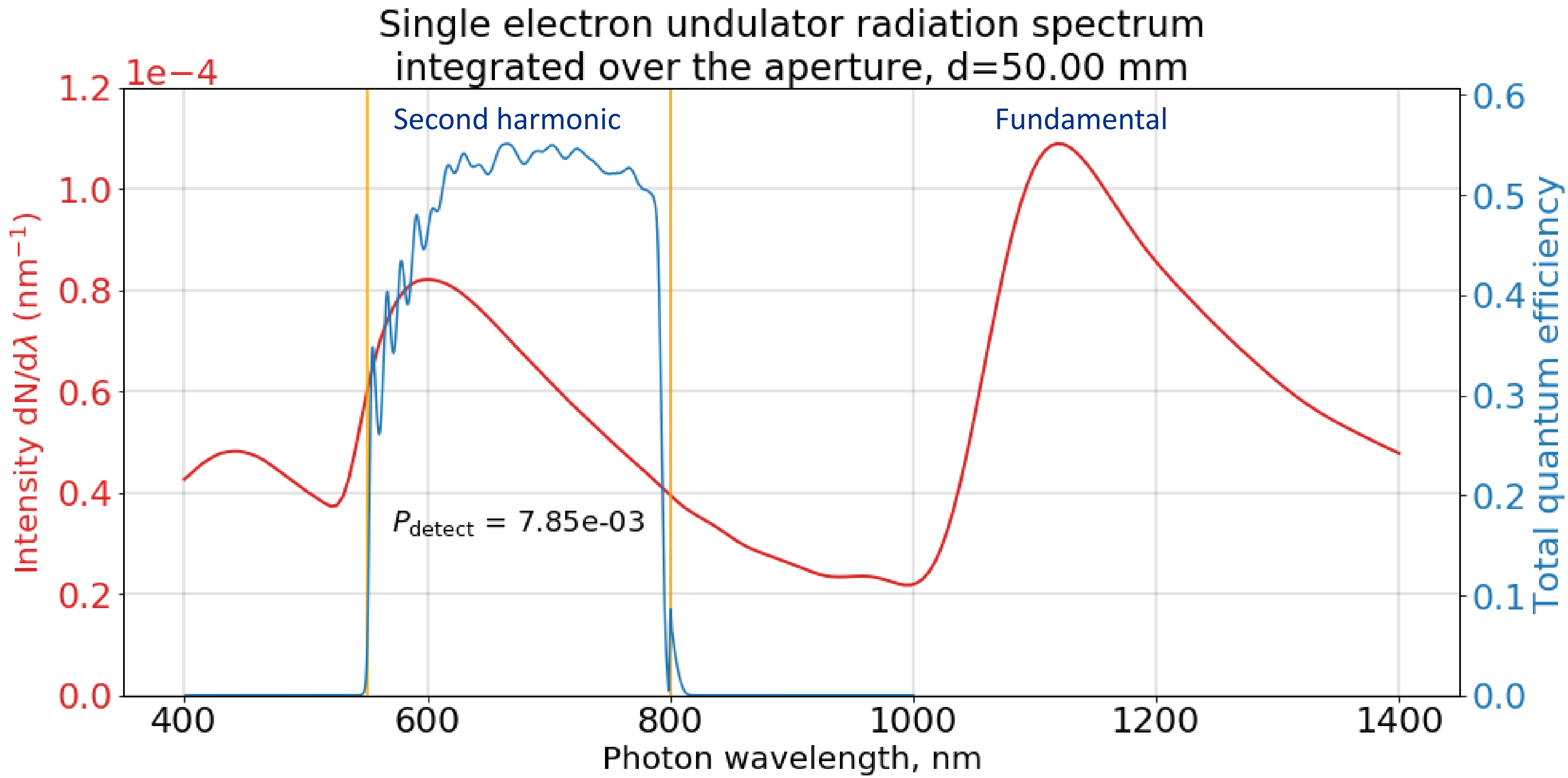
SRW simulations @ 100 MeV for SLAC undulator



Total quantum efficiency includes the quantum efficiency of the SPAD, losses in the mirrors, transmission functions of the low-pass and high-pass spectral filters, losses in the focusing lens

About 60K photon counts per second.

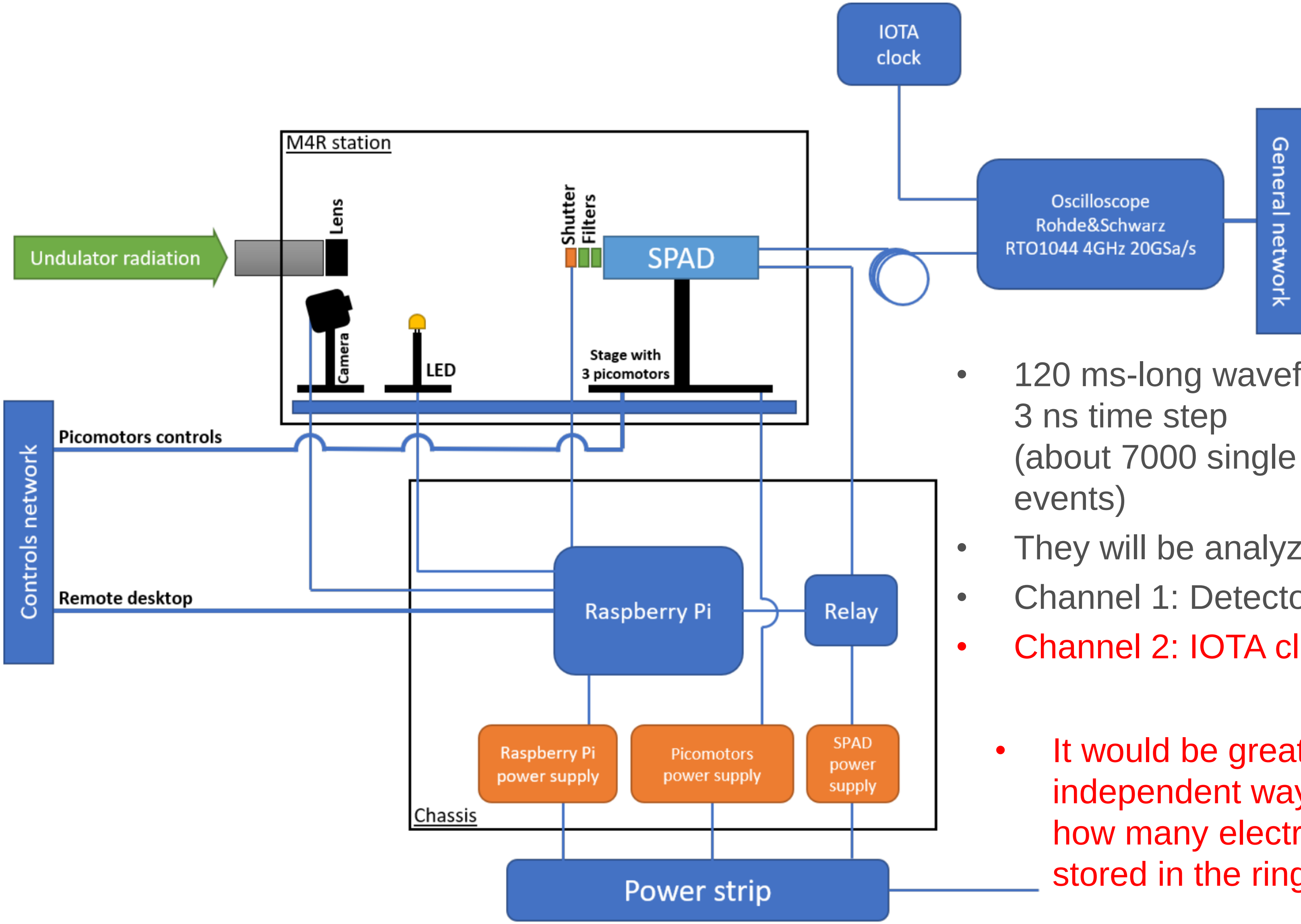
Beam requirements

- Nominal IOTA Lattice with the SLAC undulator in “IN” position
- Bunch length σ_z of about 1 ns (30 cm) or shorter
- Beam current from single/few electrons to ~2mA
  (for alignment and diagnostics)
- Beam lifetime (for single/few electrons) >10 min
- Beam energy 100 MeV (to study second harmonic)
- Capability to work at 150 MeV (to study fundamental) would be great

Run plan

- Three 8hr shifts for initial alignment, tests with a bunch of electrons
- Five 8hr shifts for studies in the single electron (few electrons) regime
- 1-2 days between the shifts to analyze the data and plan next shift
- We are ready for the first shift as soon as we have beam in IOTA

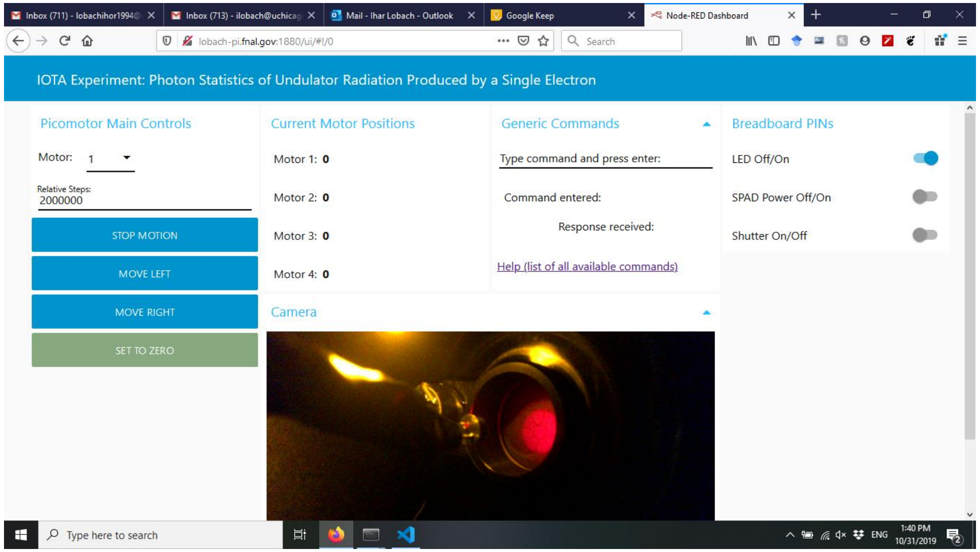
Apparatus

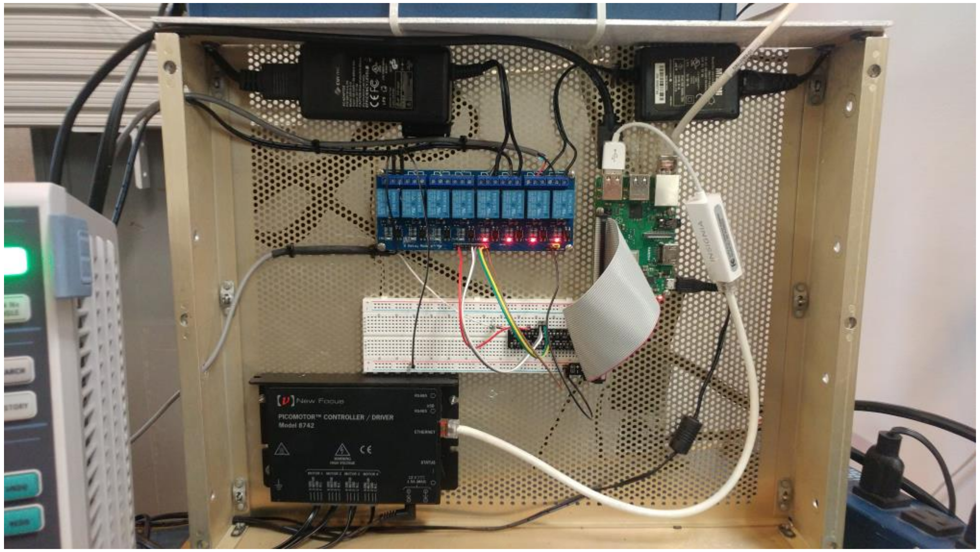


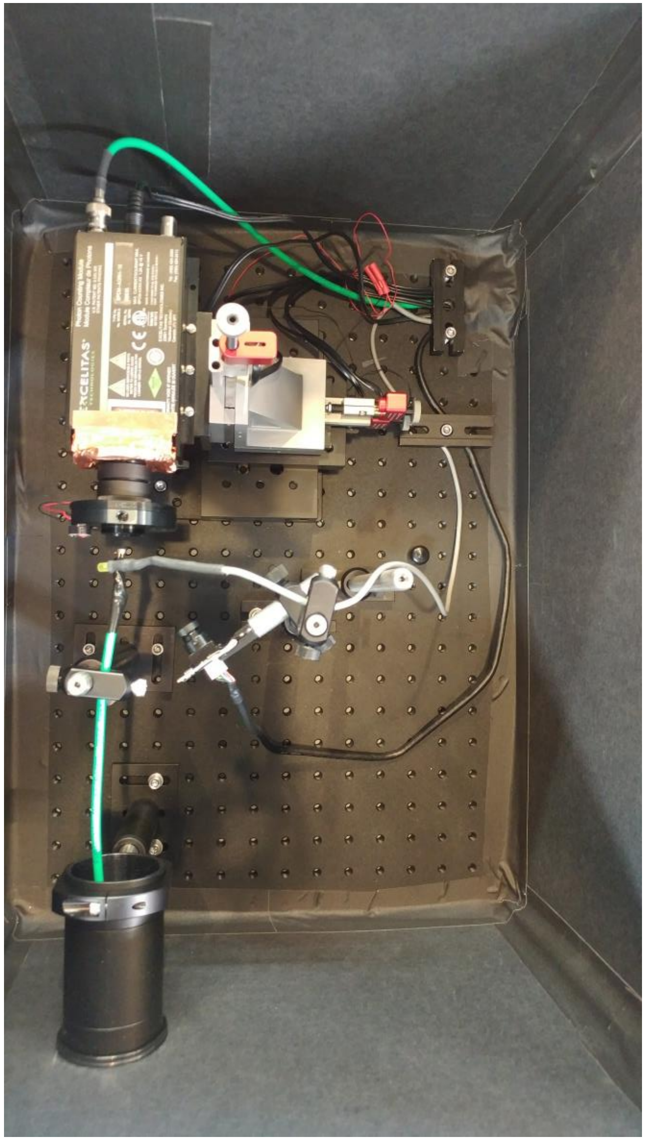
- 120 ms-long waveforms with 3 ns time step (about 7000 single photon events)
- They will be analyzed offline
- Channel 1: Detector signal
- Channel 2: IOTA clock

- It would be great to have an independent way to check how many electrons are stored in the ring (PMTs)

Apparatus: Current state



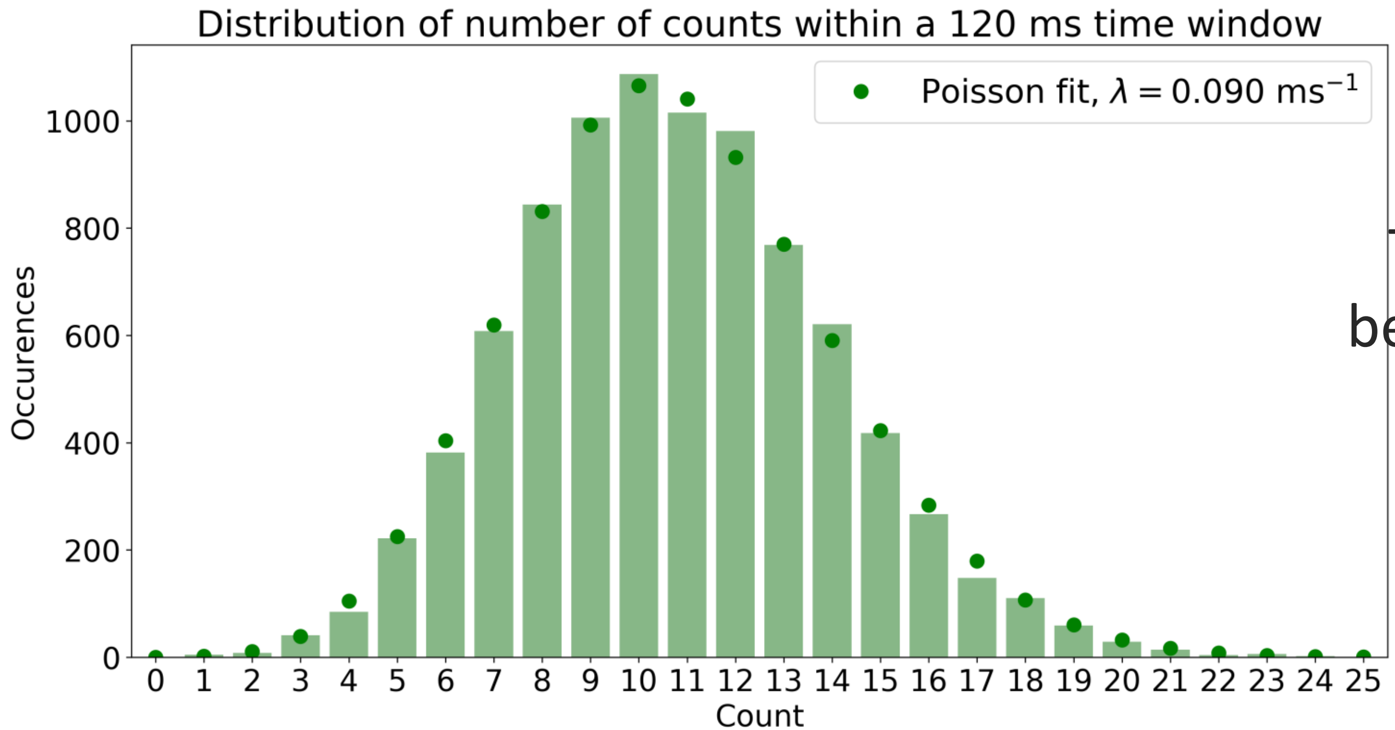




Challenges. Advice very welcome

- Picomotors are too slow for z (longitudinal) direction. We need something faster with micro meter accuracy
  Stepper motors? How to mount them on our 3D movable stage?
- How to align detector pulses with IOTA clock
- Procedure to focus the light on the sensitive area of the detector (180μm)

Study of noise in the SPAD detector signal



Total noise before gating: ~100 cps

- Null hypothesis: This is Poisson statistics.
- Calculate p-value from Chi-squared test.
- p-value = 0.36
- Conclusion: the deviations can be explained by chance. It is very likely that this actually is Poisson statistics.

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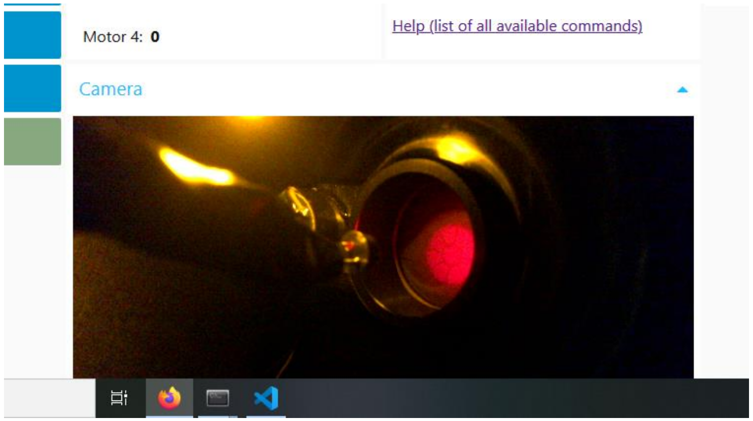
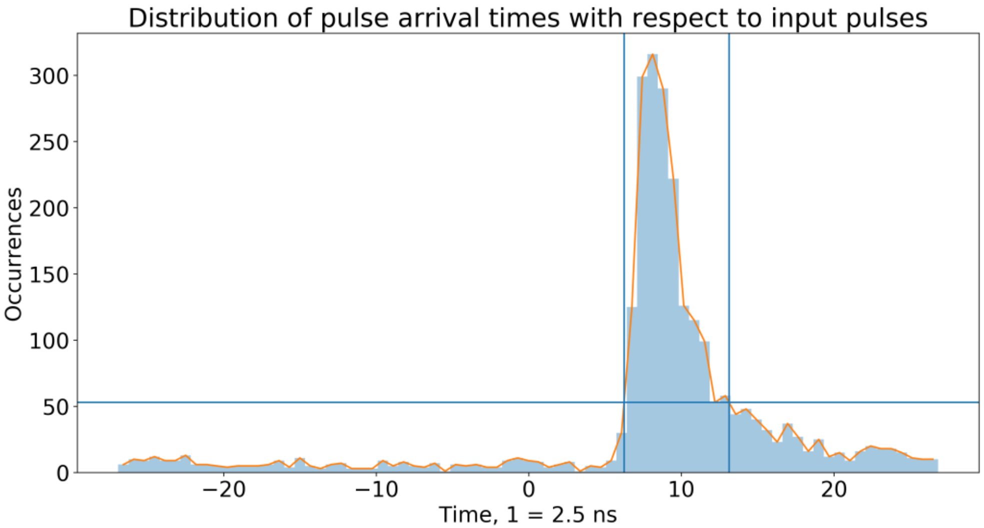
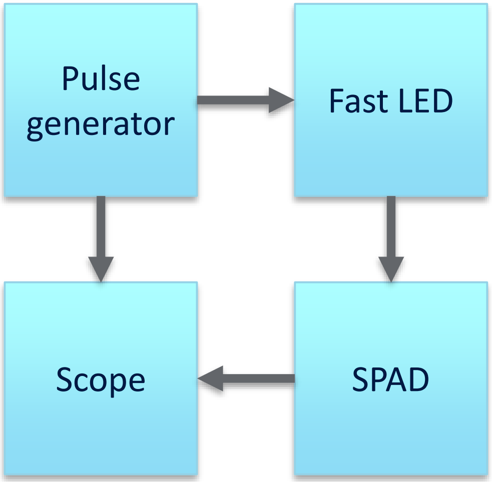
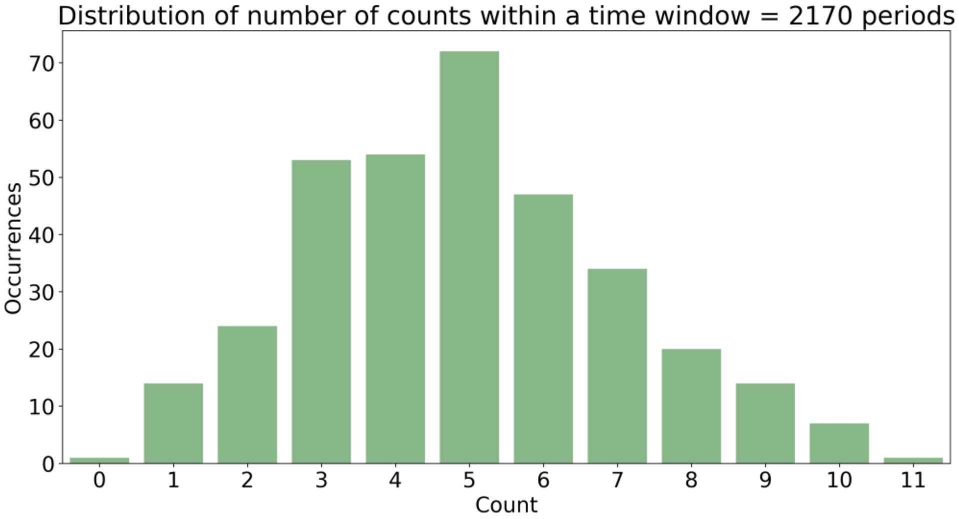
“Simulating” undulator light with a fast red LED









Study of synchrotron oscillations

We would like to measure the electron RF phase with respect to the cavity phase on every turn and then get a phase-space trajectory. From that, we can find the synchrotron frequency and hence the RF voltage.

- Requirements:
  - Long bunch (e.g., $3\sigma_z = 20\ m$),
    because the detector's time resolution is ~0.35 ns