Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

## FY2024 NPP LDRD Type B Pre-Proposal

# Development of novel SiPM arrays for optical spectroscopy

Principal Investigator: Andrei Nomerotski (Physics)

Feb 9th 2023

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# FY2024 NPP LDRD Type B Pre-Proposal

Proposal title: **Development of novel SiPM arrays for optical spectroscopy**

Primary Investigator: Andrei Nomerotski (Physics)

Other personnel: Raphael Abrahao (Physics)
Mst Shamim Ara Shawkat (Florida International University)
Edoardo Charbon (EPFL)

Indicate if this is a cross-directorate proposal: No
If yes, identify other directorates/organizations:

Proposal Term: From: Oct 2023 To: Sep 2025

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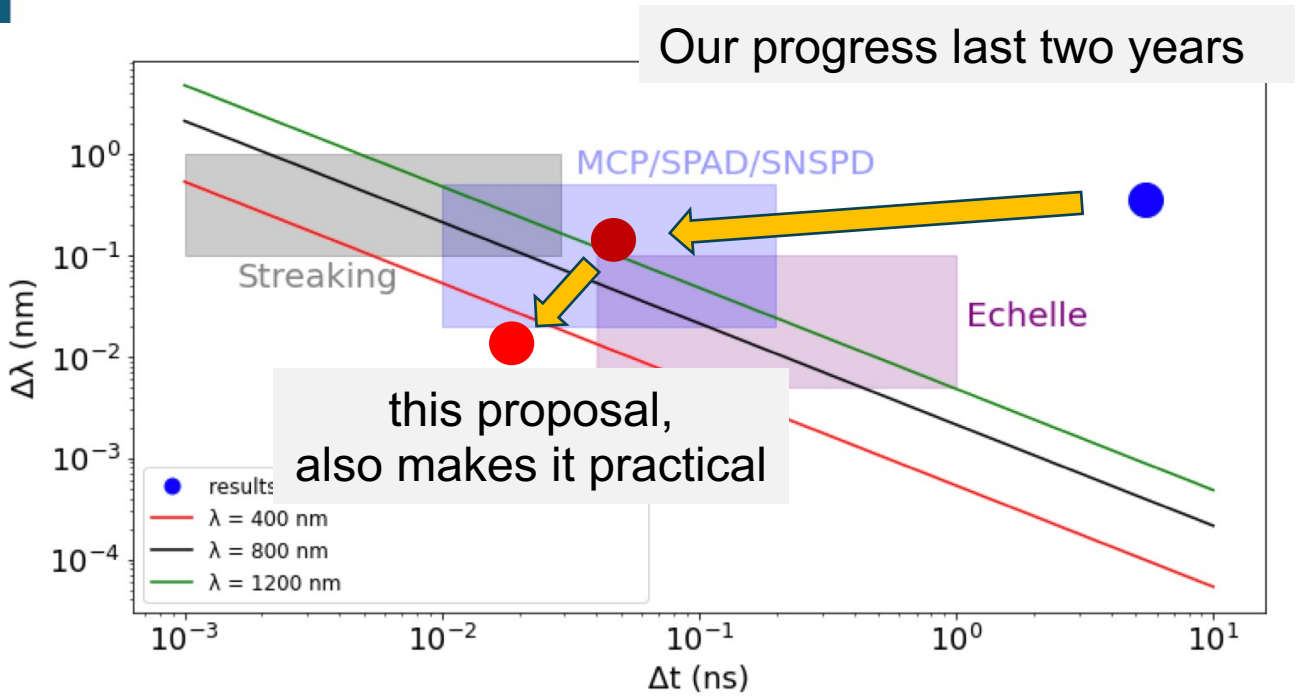
# Fast spectrometers at Heisenberg limit

For a single photon uncertainties are bounded by Heisenberg uncertainty principle

$$\Delta t * \Delta E \geq \hbar/2$$

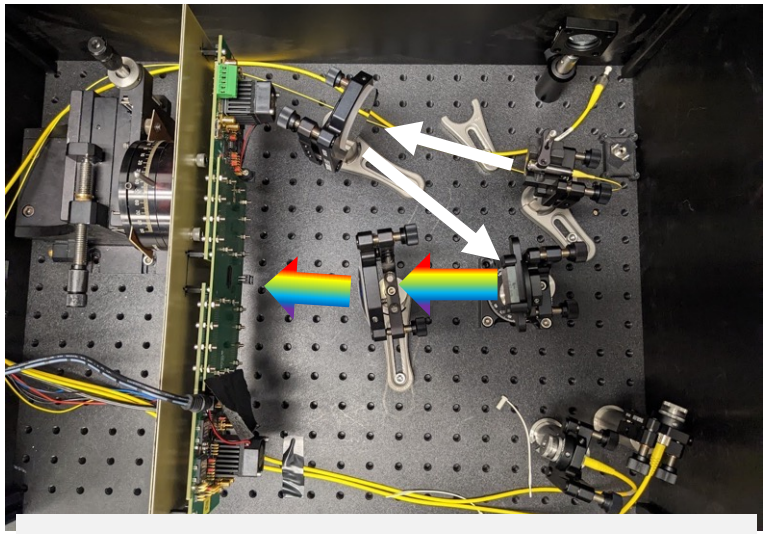
need excellent time and energy resolution to reach Heisenberg limit:

0.1 nm * 10 ps

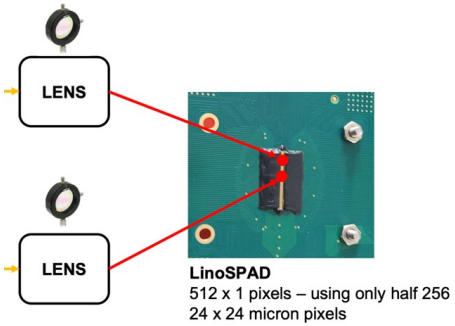



A.Nomerotski et al, Quantum-assisted optical interferometers: instrument requirements, in SPIE Proceedings on Astronom. Telescopes (2020), arxiv: 2012.02812

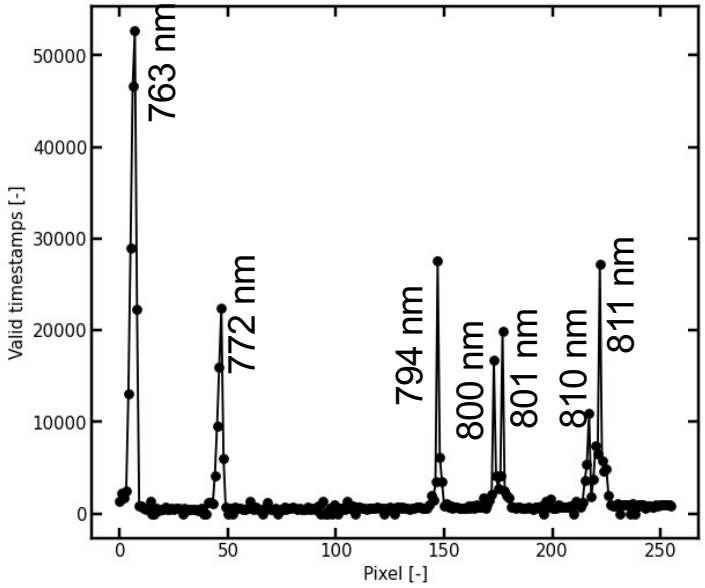
# State of the art at BNL



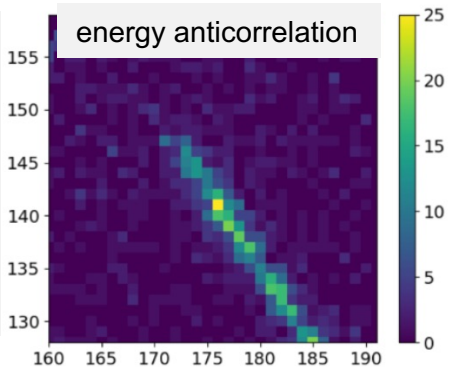
Optical spectrometer with SPAD linear array

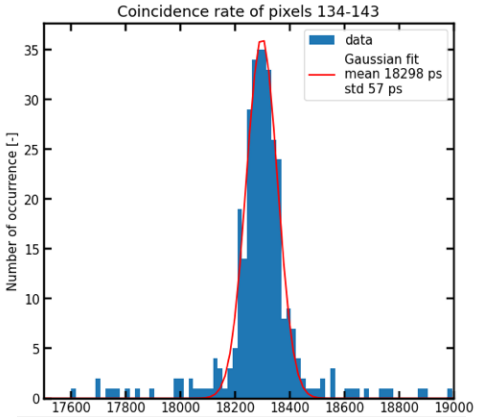



LinoSPAD2 sensor, produced at EPFL




Ar spectral lines




Time difference, ps



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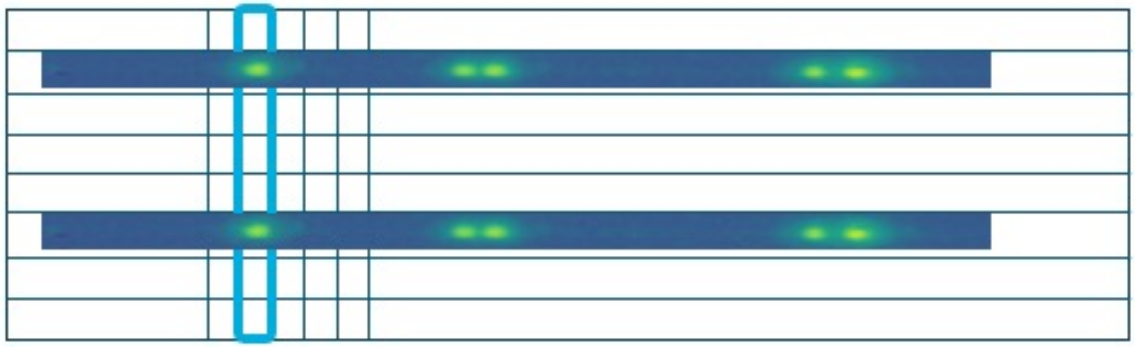
Achieved 0.1 nm spectral and 50 ps timing resolution

Nature Photonics paper in preparation

# Propose: novel fast spectrometer based on SiPM approach



8*512 pixel array where each column is 8-pixel SiPM

## Advantages of SiPM: makes the approach practical and versatile

- Wide sensor: easy to align, can be mass produced and used in field
- Time resolution is preserved or improved
- Can count photons: detect coincidences in dual spectrometer, in spectral bins
- Can keep same approach to time stamping (in FPGA) and readout as before

## Applications

- Quantum optics / Quantum telescopy
- Quantum dot spectroscopy
- Lifetime spectroscopy

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Bring SPAD photonic technology to BNL through collaboration with industry, FIU and EPFL

Goal: 0.02 nm * 10 ps

# FY2024 NPP LDRD Type B Pre-Proposal

Proposal title and brief abstract:

**Development of novel SiPM arrays for optical spectroscopy (PI Nomerotski)**

We will investigate ideas and will prototype specialized SiPM based sensors for a fast 10ps spectrometer with 0.1nm spectral resolution, which is near the Heisenberg limit in the time-energy domain. The spectrometer will have multiple cutting-edge applications including astrophysics, quantum dot spectroscopy, lifetime spectroscopy etc. We propose to have a 8x256 sensor with columns formed by 8 cell long SiPMs. Each SiPM column would have a TDC implemented outside of the sensor in FPGA. Simultaneously with spectral information the sensor would provide the photon counting capabilities (for example, a coincidence in case of n=2) in the 8-cell SiPM, which is a novel feature never implemented before in SPAD sensors as spectrometers.

**Program**: multi-program – HEP, QIS, BES

**Return on Investment:**

- Novel device, possible patenting
- Use in multiple applications
- Collaboration with FIU, apply for RENEW-HEP funding

**Broader impact** on the activities at the laboratory:

- Bring design capabilities for new technology (SPAD) to BNL
- Engage MSI with strong DEI background (FIU)

**Workplan:**

Year 1 : test available SiPMs, design and procure prototypes

0.5 (PO postdoc + AN) + FIU student + $60k sensors; in kind contributions from EPFL and FIU designers

Year 2 : test in applications

0.7 (PO postdoc + AN) + FIU student + $20k equipment; in kind contributions from EPFL and FIU

Total planned funding in FY24 and FY25: **$400k**