TRIUMF

THE UNIVERSITY of EDINBURGH
School of Physics
and Astronomy

Characterization of Laser-Driven Photon Emission in Silicon Photomultipliers

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CAP Congress, McMaster University
Student Oral Presentation Finals
June 9th, 2022

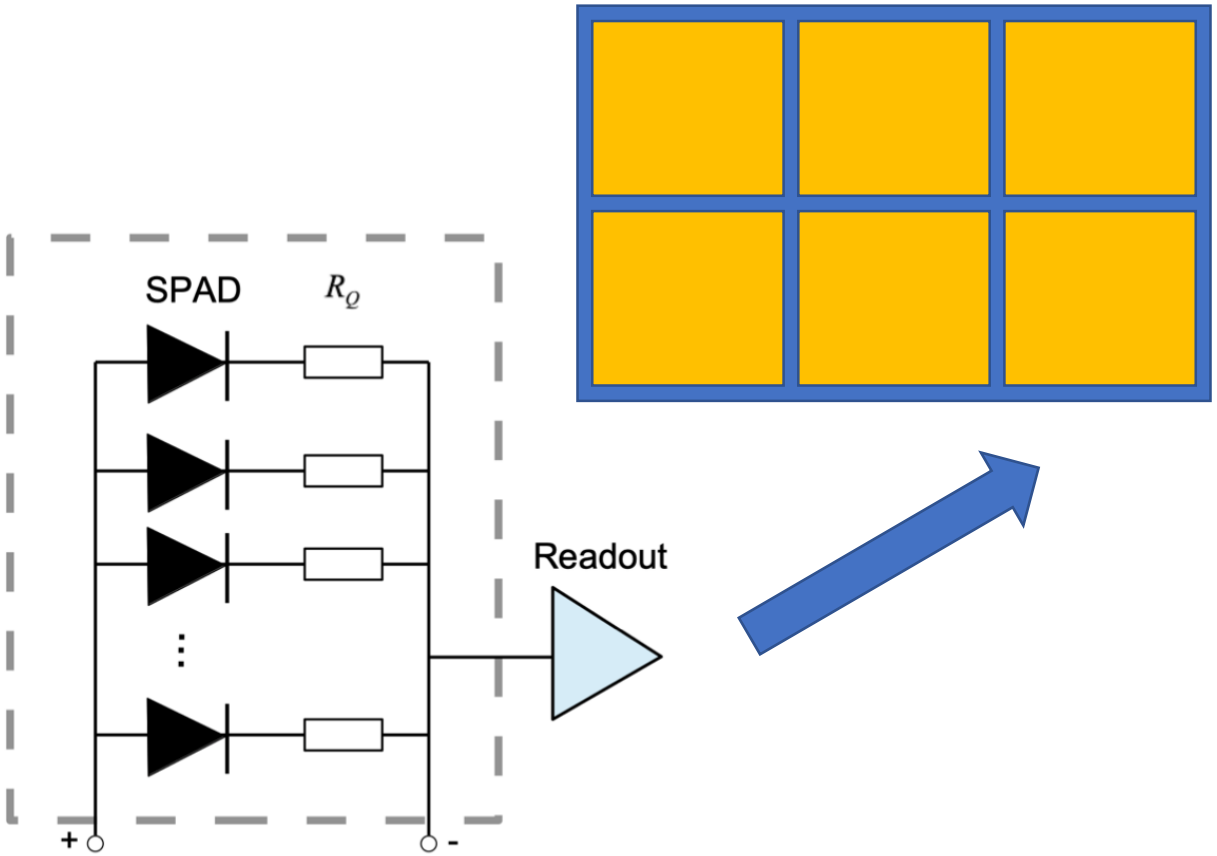
Discovery, accelerated

Outline

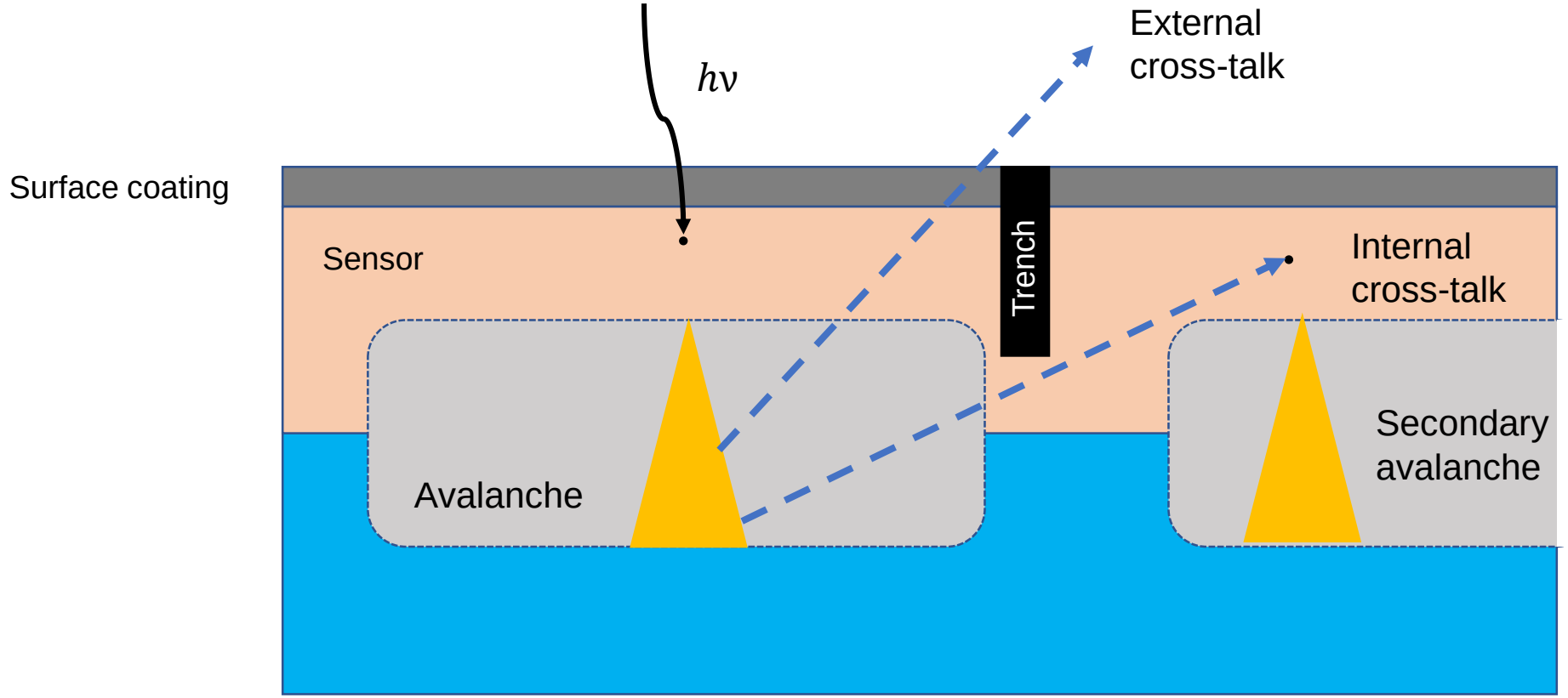
- The Silicon Photomultiplier
- Cross-Talk
- Optical cross-talk studies at TRIUMF
- Results

What is a Silicon Photomultiplier (SiPM)?

- **Solid-state** detector
  - PMT alternative
  - **Single photon** resolution
  - Good photon detection efficiency
- Basic unit: single photon avalanche diode (**SPAD**)
- p-n junction biased **above breakdown**
  - **Overvoltage**: $V_{ov} = V - V_{bd}$
  - **Avalanche process**: gain is 10^5-10^7



SiPM signal detection: SPAD level



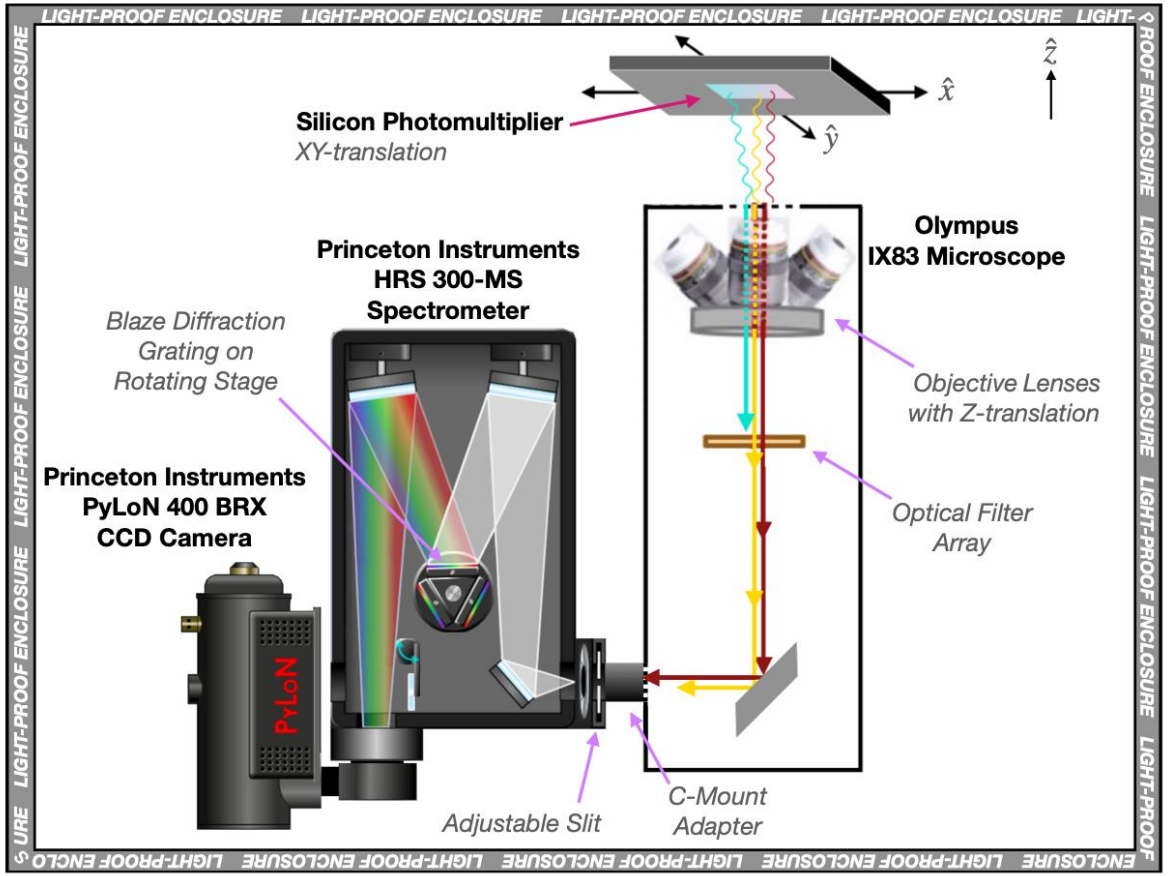
Cross-Talk

- Secondary photon by-product of avalanche mechanism
- **Systematic effect** on detector background
- Must be quantified for use in rare-event searches (e.g. nEXO)
- Is photon emission significant?

MIEL at TRIUMF

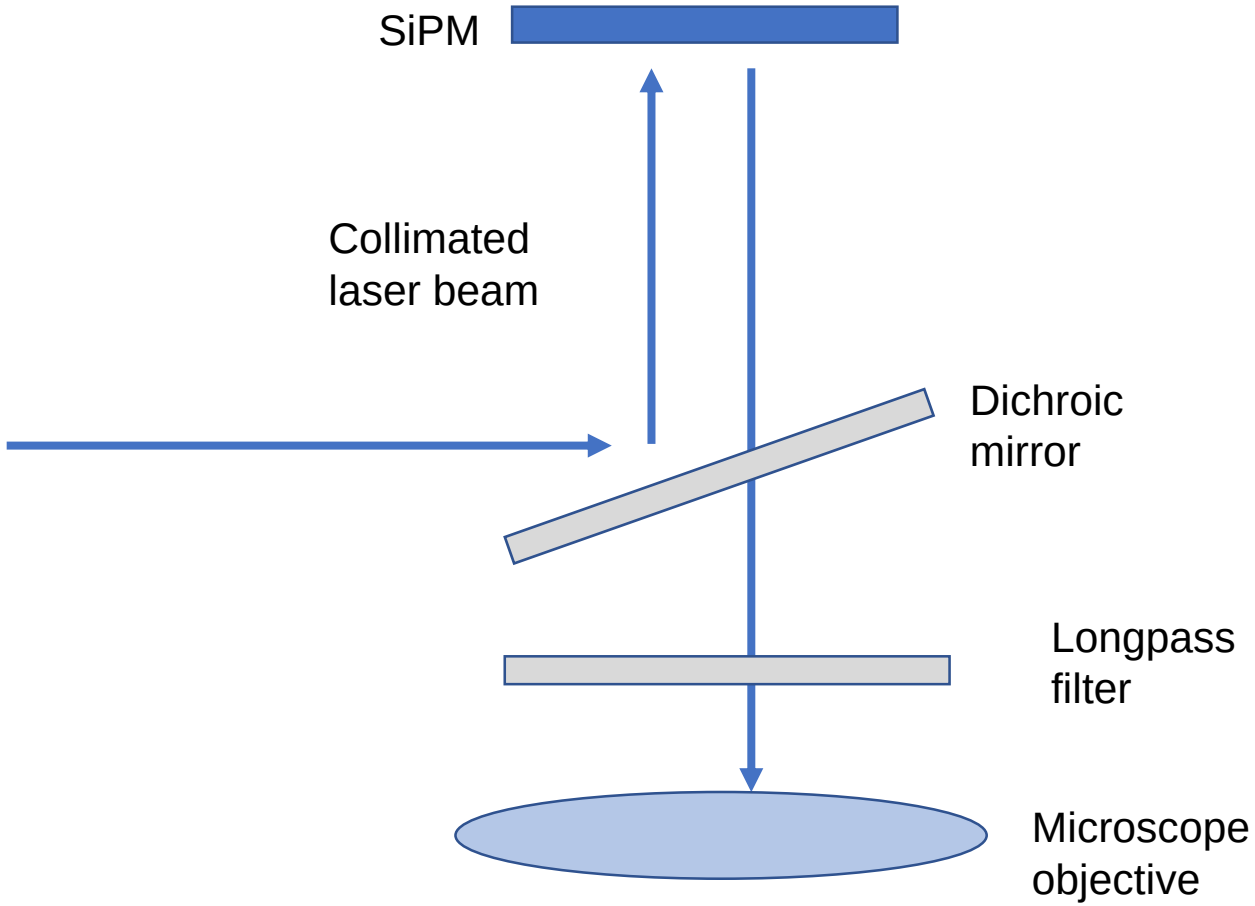
- SiPM **M**icroscope for **I**njection and **E**mission of **L**ight.
- Setup developed at TRIUMF
  - Study **spectral features** of SiPM emission
  - **Geographical location** of light emission
- **Two SiPMs**: FBK VUV-HD3.6, HPK VUV4
  - nEXO candidate photodetectors

MIEL at TRIUMF

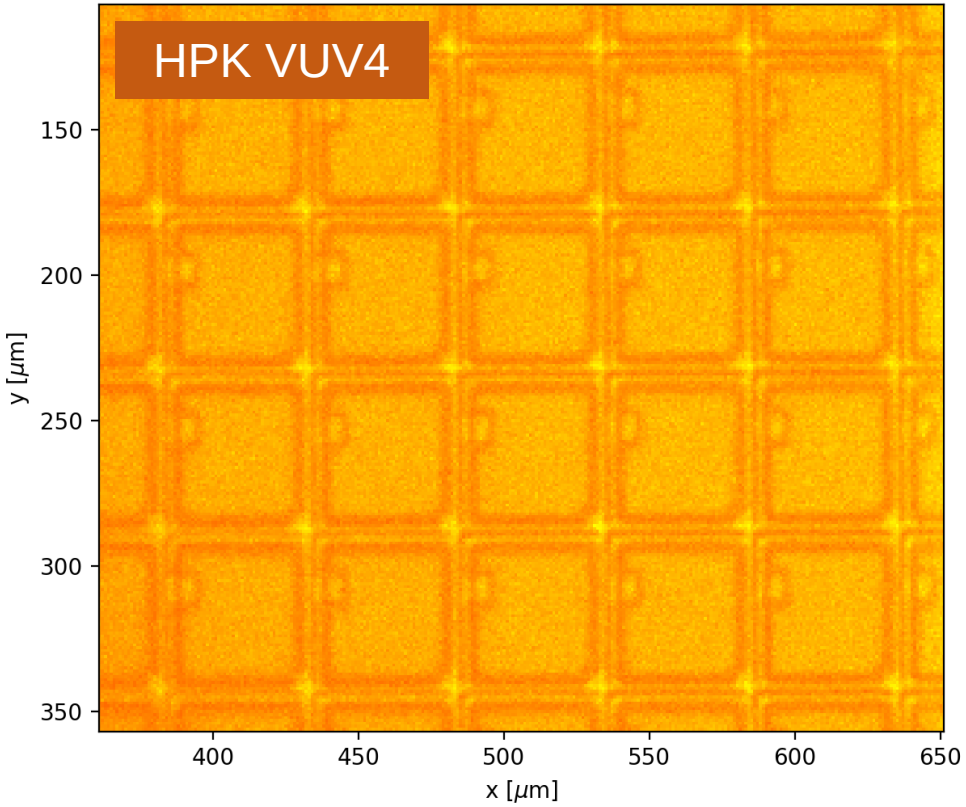


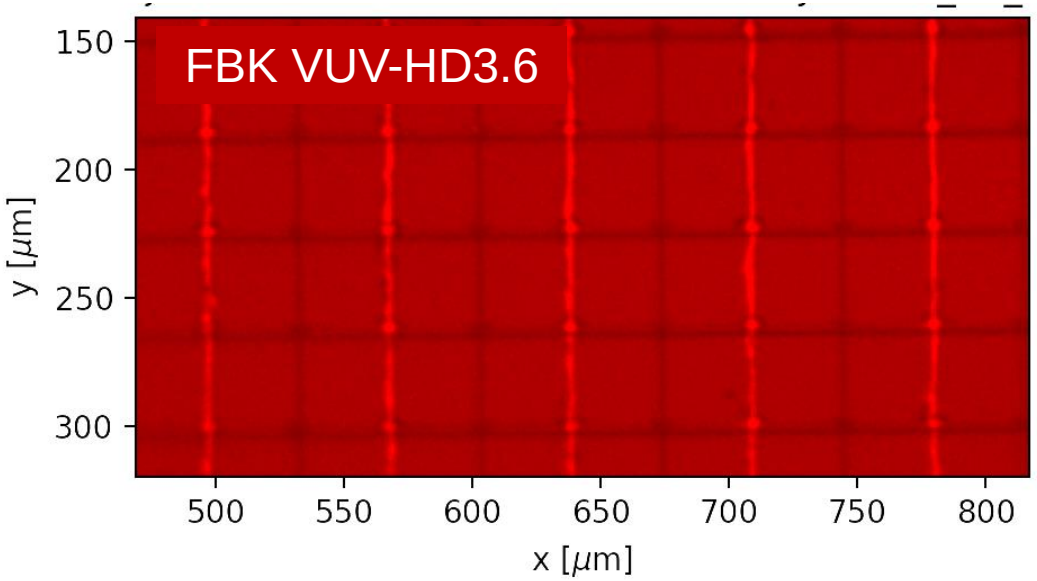
- Previous studies explore emission of SiPM in **dark conditions**
- Additions:
  - **Cryogenic cooling**: reduce dark noise, replicate conditions in cryo experiments (nEXO etc)
  - **Laser injection system**: stimulate emission of secondary photons at variety of wavelengths

MIEL laser injection system



HPK and FBK photosensors

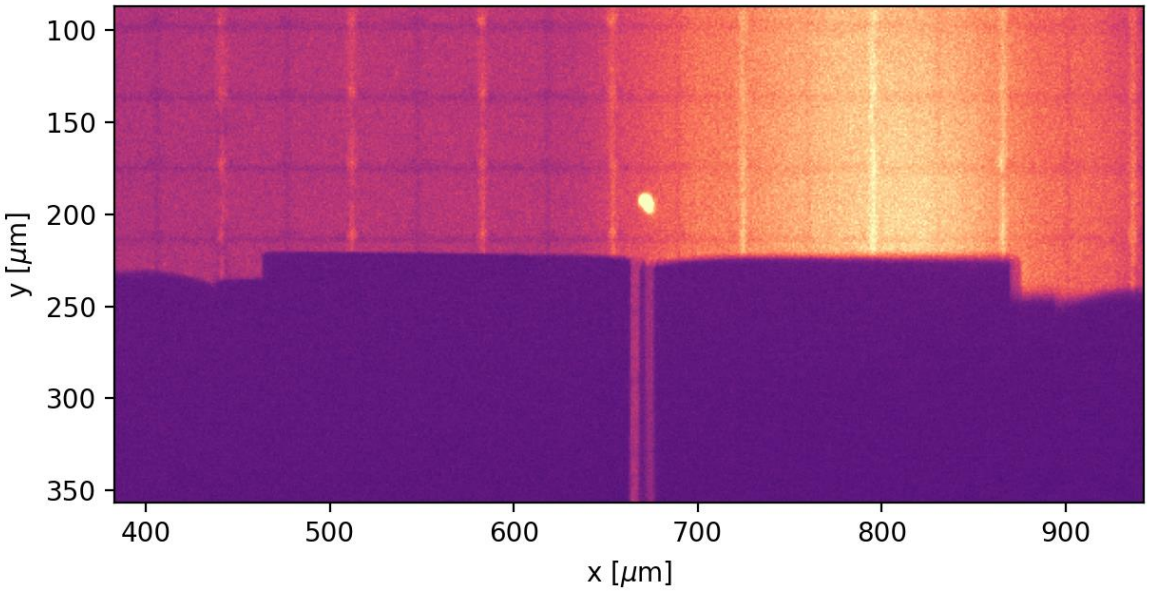




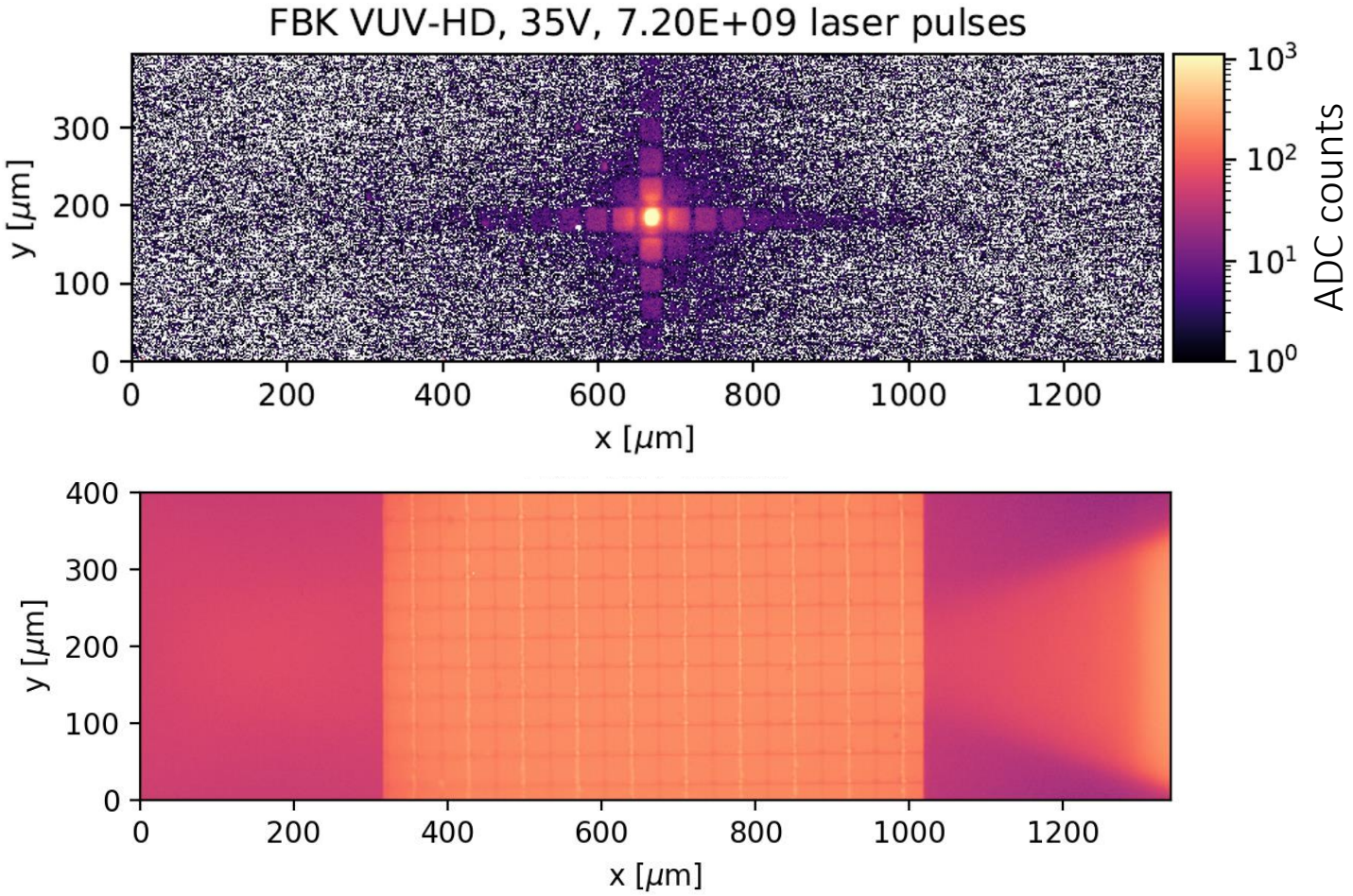
Parameter	FBK VUV-HD3	HPK VUV4
Total Area	$6\times6\,\mathrm{mm}^2$	$3\times3\,\mathrm{mm}^2$
SiPM Fill Factor	80%	60%
SPAD pitch	$35\times35\,\mu\mathrm{m}^2$	$50\times50\,\mu\mathrm{m}^2$
Breakdown Voltage [298 K]	31 ± 1 V	52 ± 1 V

Laser beam positioning: FBK

- Laser: 444nm wavelength
- Centre beam on SPAD
- Close slit over SiPM for spectra
- Open for emission maps



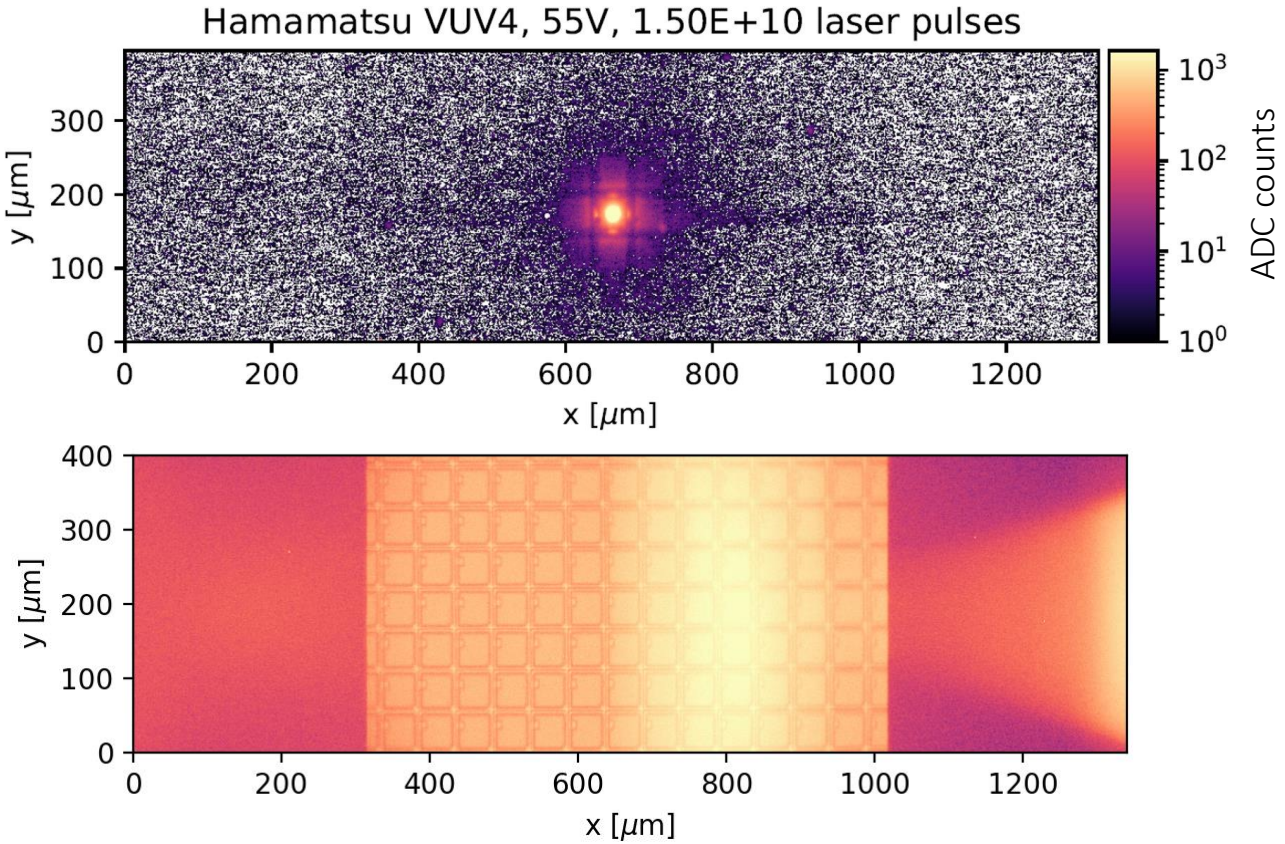
Emission Microscopy Images: FBK



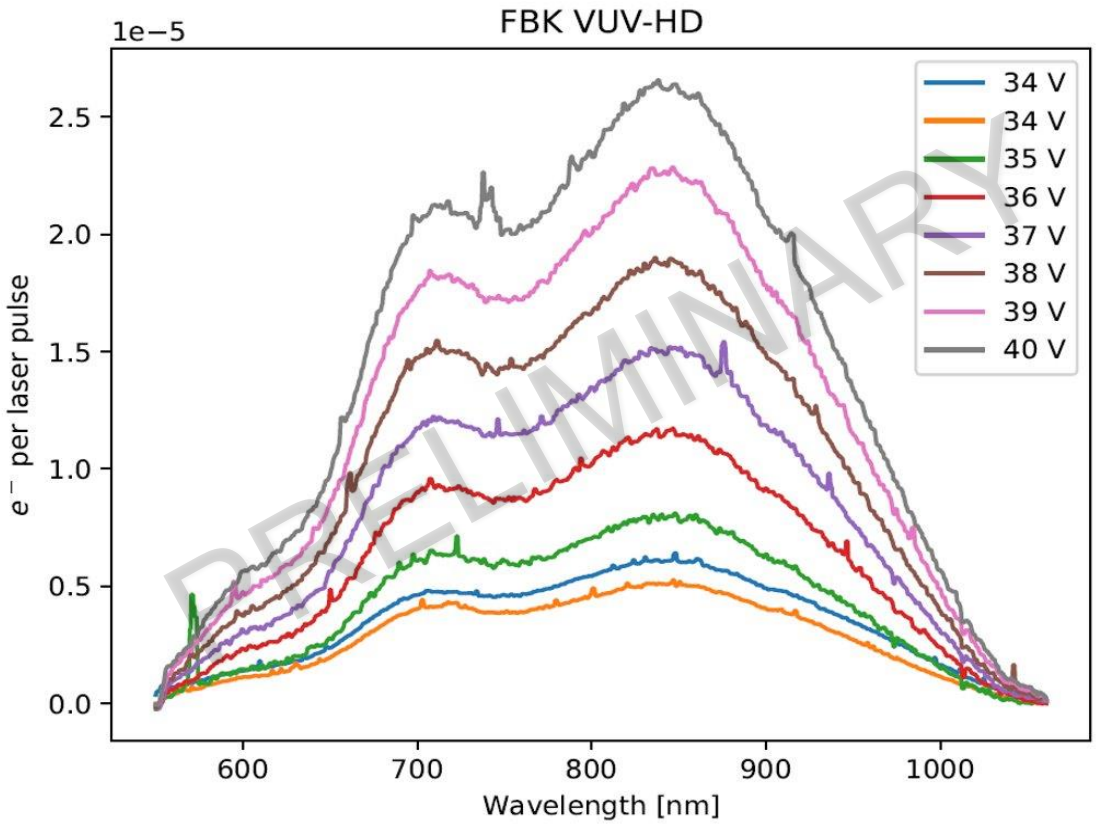
- Polysilicon trenches in FBK – less photon absorbance
- Reflection
- “Light guiding” effect observed

Emission Microscopy Images: HPK

- HPK has tungsten trench
- Photon absorption
- No distinct ‘cross’ pattern



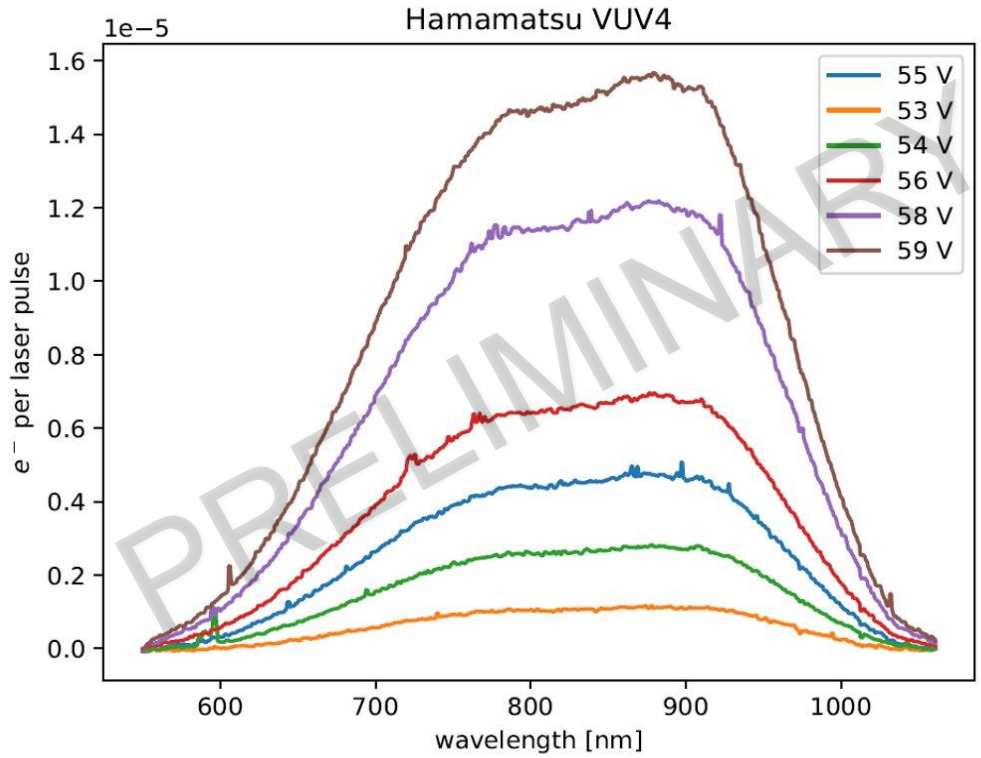
Spectra: FBK



- Raw spectrum
- Uncorrected for system efficiency
- Rudimentary cosmic removal
- 550nm longpass filter
- Evidence of thin-film interference due to SiO_2 coating?

Spectra: HPK

- Raw spectrum
- Uncorrected for system efficiency
- Rudimentary cosmic removal
- 550nm longpass filter
- Fewer oscillation than FBK – thinner coating



Summary

- Stimulated two SiPM with 444nm laser
- Obtained raw spectral distributions
- Emission maps reflect differences in structure between SiPMs

Ongoing and future work

D. Minchenko, 8th June, CAP 2022 Session W3-6

- More effective cosmic removal
- Error analysis
- **Active simulation efforts to model photon transport in SiPM**
- Correct spectra for system efficiency – intensity calibration
- Correct for finite numerical aperture – simulation
- Is the level of photon emission a problem for future experiments?
- **Stay tuned!**

Acknowledgements

- Supervisor: F. Retière (TRIUMF, SFU)
- K. Raymond (SFU, TRIUMF)
- PHAAR group at TRIUMF

Thank you!
Merci!

Contact

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Discovery, accelerated

Backup

Efficiency curve

- Calibrate spectrometer using PI IntelliCal ® source.
- Wavelength and intensity calibrations computed.
- Spectra produced treated with efficiency curve
- Rudimentary error analysis, potential wavelength miscalibration