TECHNOLOGY PARTNERSHIPS OFFICE

NIST Innovative Technologies Showcase

Welcome, we'll be starting shortly

NIST | TECHNOLOGY PARTNERSHIPS OFFICE

NIST Innovative Technologies Showcase

Transferring Invention and Innovation to Commercialization

NIST Innovative Technologies Showcase

Agenda

1 | **Welcome**

2 | **About Technology Partnerships Office (TPO)**

3 | **Meet the Inventors**

4 | **Panel Discussion**

5 | **Q&A and Contact Us**

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U.S. Department of Commerce

Technology Partnerships Office

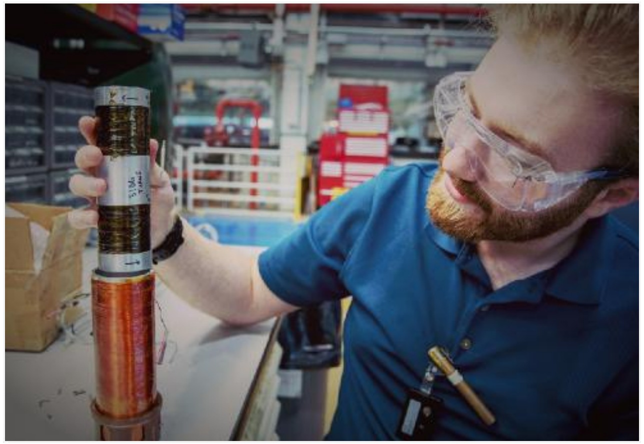
Our Mission and Vision

Mission

TPO serves our NIST customers by leading technology transfer processes that NIST researchers use to develop innovations from concept to practical application.

Vision

TPO facilitates the best possible outcome for each NIST research innovation and provides dynamic interagency leadership for technology transfer policy and analysis.



Meet the Inventors

Meet **Zeeshan Ahmed, Ph.D.,**

Senior Scientist, National Institute of Standards and Technology

Why Do We Need To Measure Ionizing Radiation?

IBA Rhodotron DUO dual configuration for carton irradiation by either electron beam or X-ray. Image provided by IBA Industrial.

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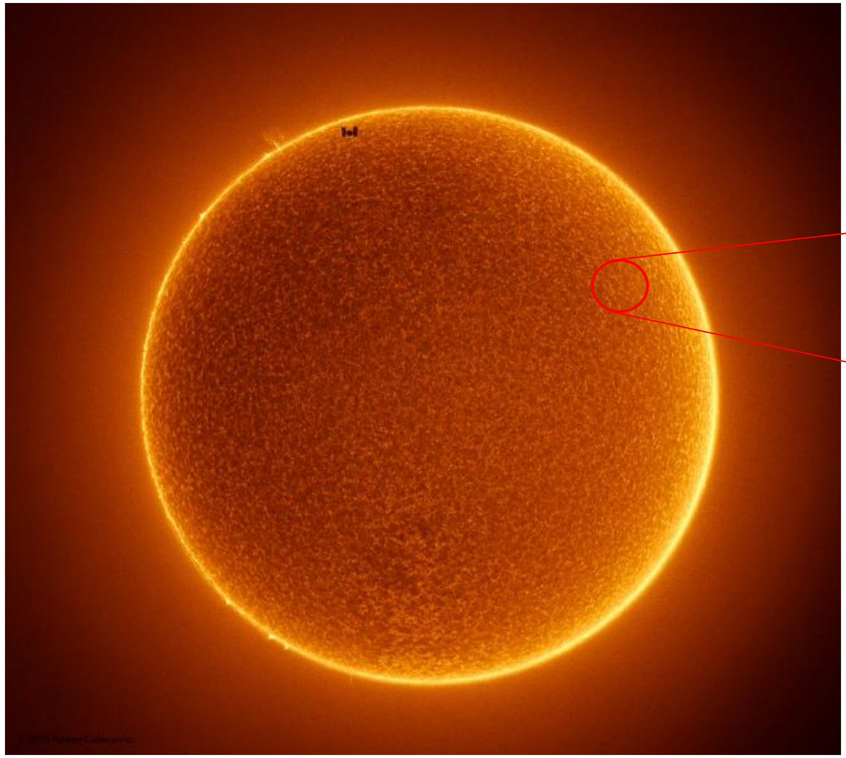
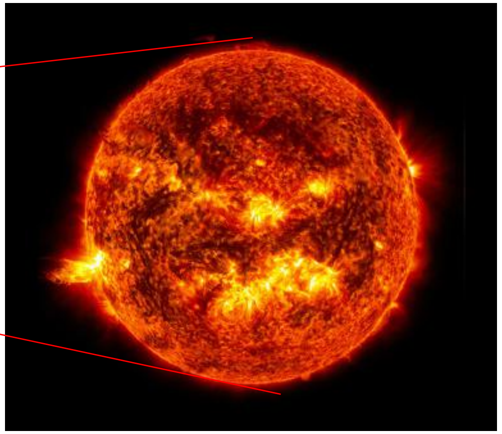
Problem



How we think of Radiation beams



But if you zoom in things look a lot different

‘Mo Power, ‘Mo Problems

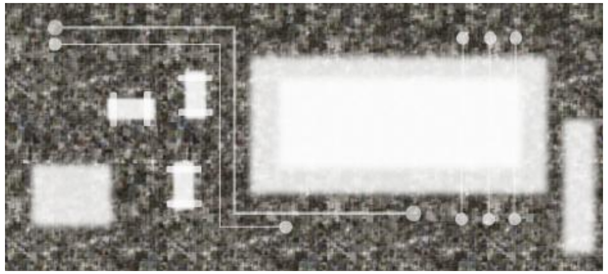
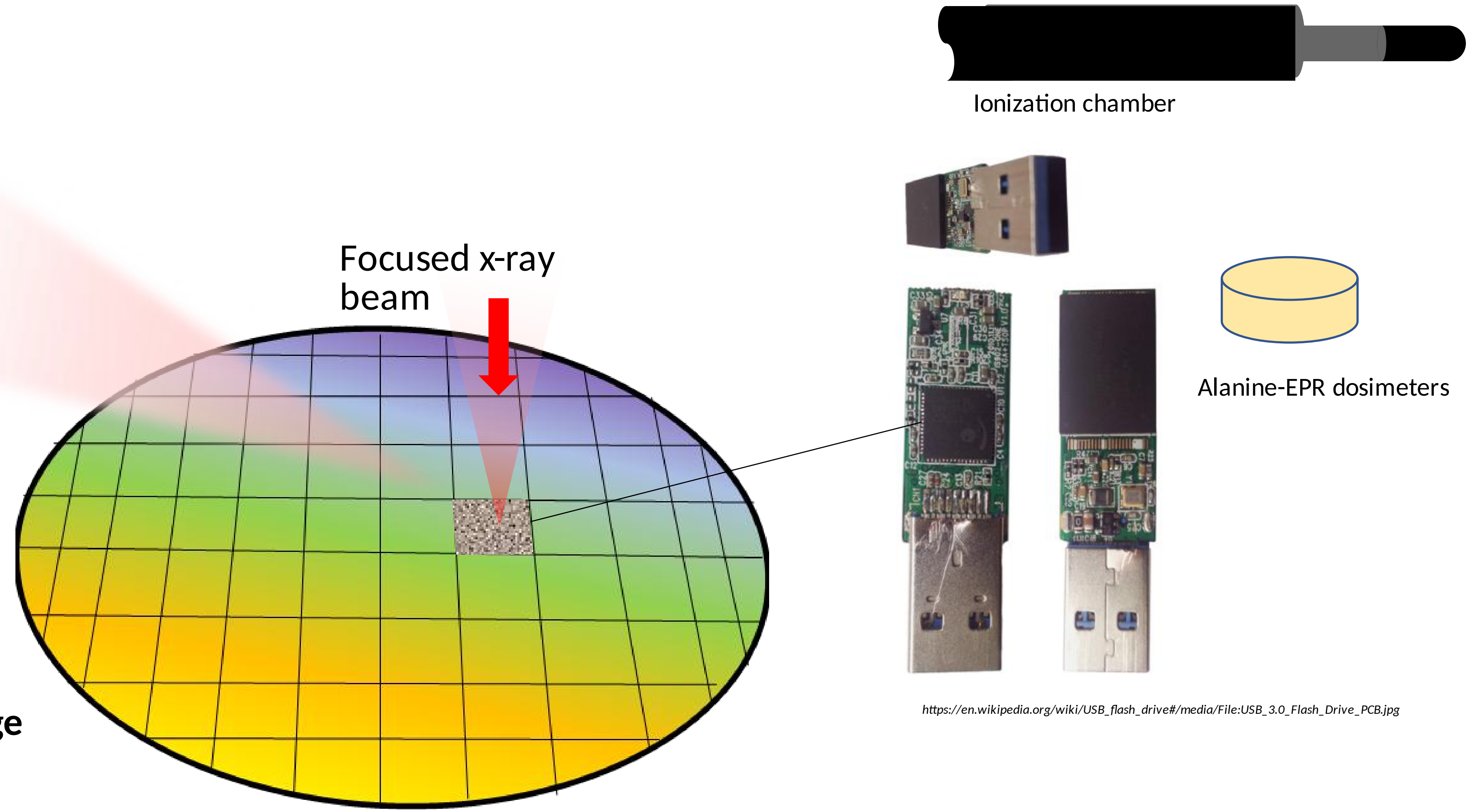


Image quality and magnification

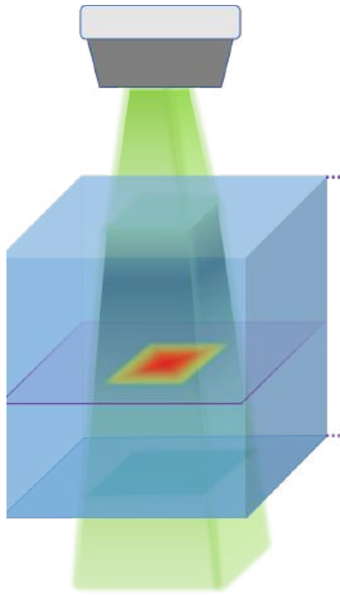
Increased risk of radiation damage



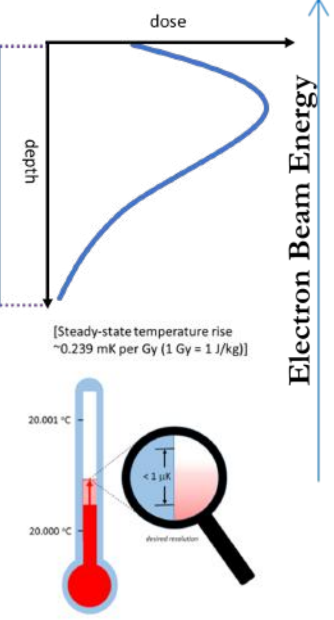
https://en.wikipedia.org/wiki/USB_flash_drive#/media/File:USB_3.0_Flash_Drive_PCB.jpg

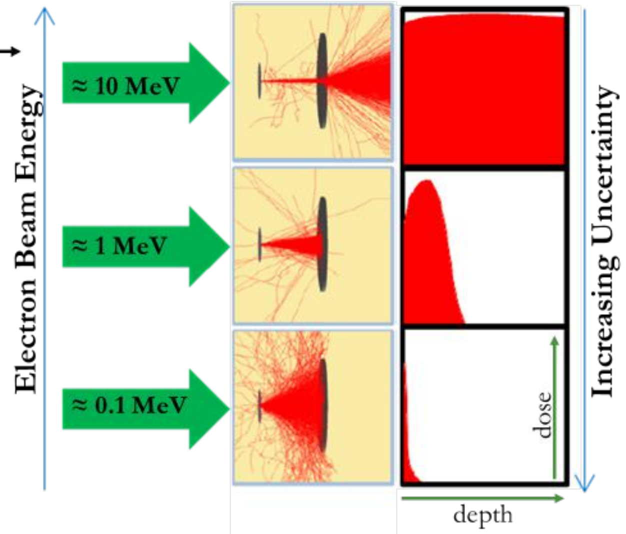
Our solution:
Realize Gray using Photonic Thermometers

Ionizing radiation consists of highly energetic photons, electrons or heavier particles from a radioactive source or produced by an accelerator

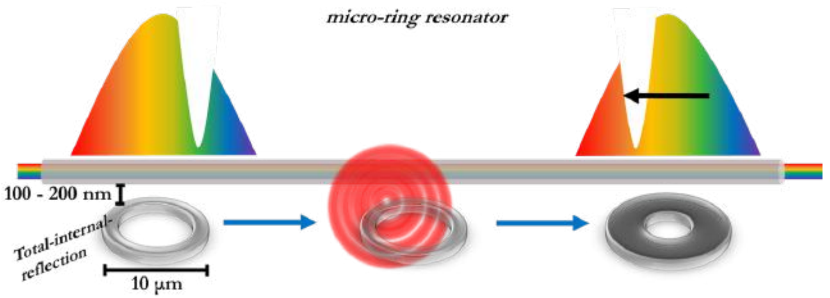


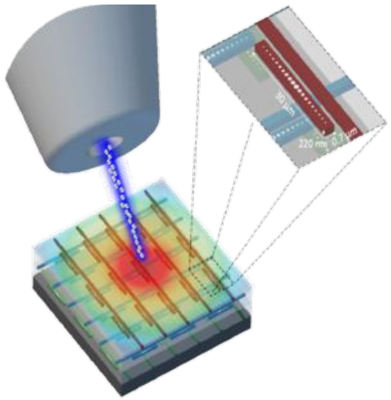
Dose = Energy absorbed per unit mass

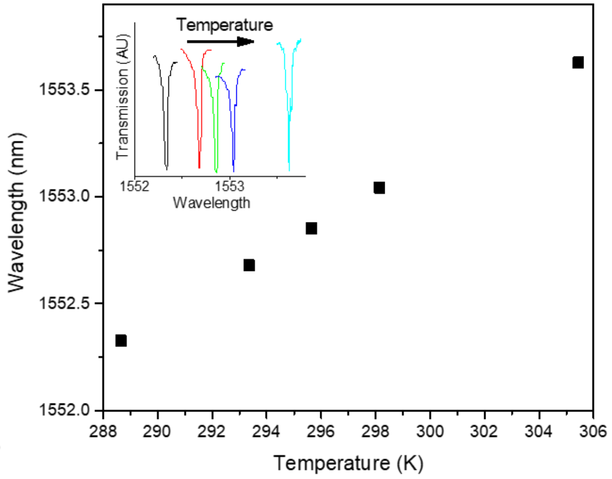




Monte Carlo simulations of electron beams on 2 mm graphite wafer, NIST internal, Fred Bateman







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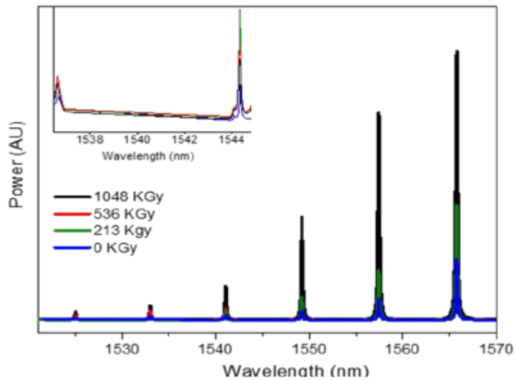
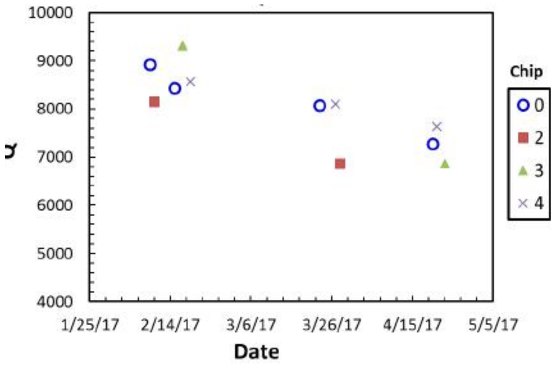
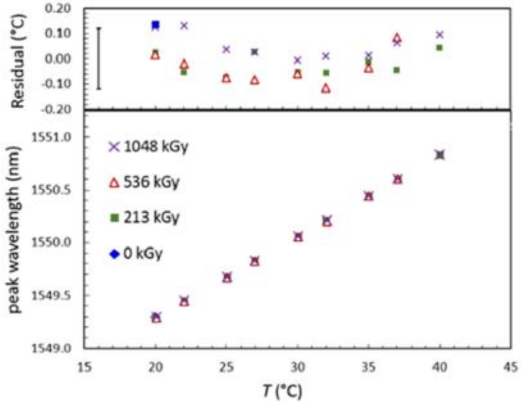
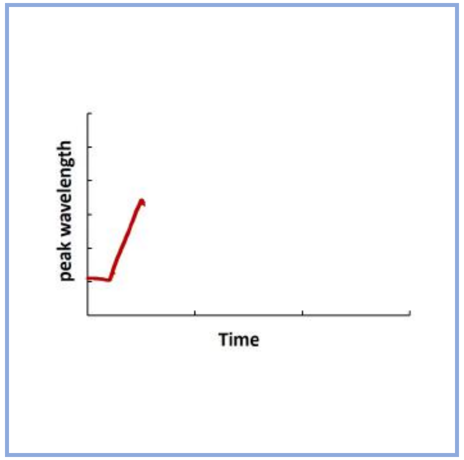
What Have We Accomplished?

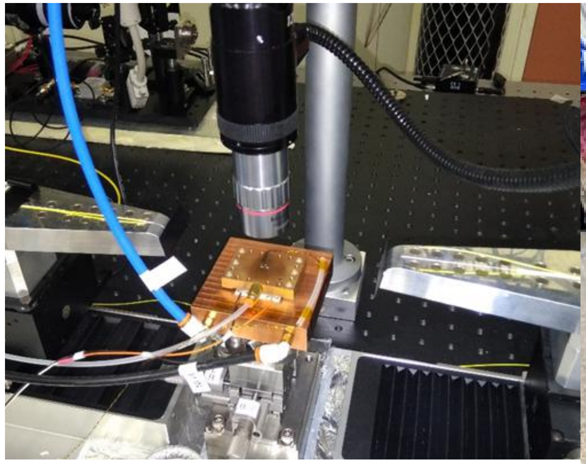
No systematic impact of radiation (up to 1 MGy dose) were found on passivated silicon chip devices, indicating the extreme durability under harsh conditions

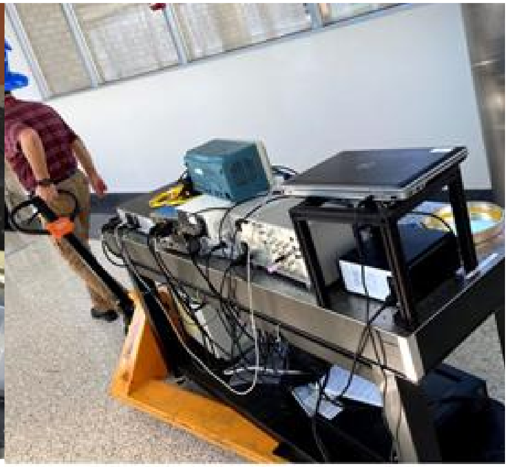












Meet **Zeeshan Ahmed, Ph.D.,**

Senior Scientist, National Institute of Standards and Technology

LICENSING OPPORTUNITY

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PHOTONIC CALORIMETER

THE TECHNOLOGY

U.S. Patent Number 10,782,421

The calorimeter uses embedded, nanofabricated photonic sensor arrays to enable micrometer-scale spatial resolution of dose (energy) distribution and gradients. It replaces thermistors (used in conventional radiation calorimeters) with photonic sensors of various designs embedded in numerous possible materials (such as graphite, diamond, water, human tissue, silicon, etc.) for in-situ dose and dose-gradient measurements.

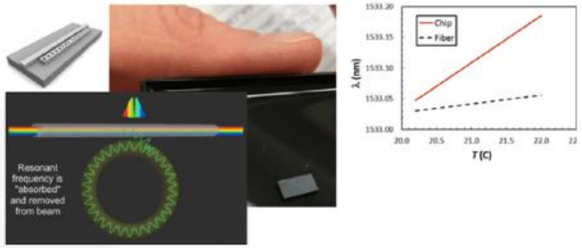
INEXPENSIVE

SMALL SCALE MEASUREMENT

IDEAL FOR CELLULAR DOSIMETERY

These new devices will have much higher spatial resolution, lower self-heating, reduced artifacts at sensor-absorber interfaces, and capability for imaging using arrays of sensors on a chip (2D) and arrays of chips (3D). Improves capability to measure dose and dose gradients (near beam penumbrae and near surfaces or material boundaries) for measuring energy deposition from beams (photon, electron, etc.) with low penetration depth.

Chip-based photonic thermometry



An in-situ nano-scale dosimetry and calorimetry leading to new chip-based metrology for industrial and medical applications. Increased sensitivity, spatial resolution, optical readout and multiplexing capabilities could redefine the meaning of "dose", reduce dependence on Co-60 sources, enable new portable sensors, and help close the loop on quantitative nuclear medicine.

Graph shows linear curves using slopes measured at NIST for Fiber Bragg Gratings and Photonic Ring Resonators on a Chip.

BENEFITS

Leverages inexpensive commercial communications technology and chip fabrication for inexpensive manufacturing and operation.

Technically superior by enabling absolute dosimetry at an unprecedented physical scale due to micron-scale spatial resolution across six orders-of-magnitude of absorbed dose, from medical diagnostic and therapeutic procedures up through industrial materials processing, sterilization, and applications leading to commercialization of space.

CONTACT

Technology Partnerships Office (TPO)
National Institute of Standards and Technology Gaithersburg, MD 20899
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But Wait…. Radiation Does More than Heat Objects

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PHOTONIC DOSIMETER

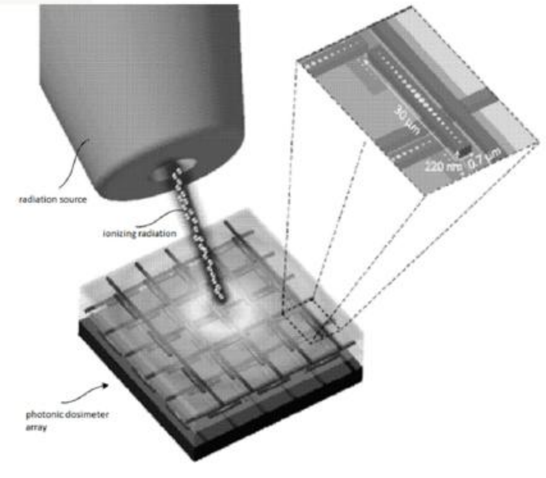
THE TECHNOLOGY

U.S. Patent Number 10,782,421

NIST scientists have developed a photonic device whose resonance characteristics (such as, quality factor, peak position, and free spectral range) change in a predictable way in response to the interaction of radiation with the sensor and/or its surroundings. The invention consists of one or more photonic structures (such as Bragg mirror, ring resonator, photonic crystal cavity) that is designed to undergo structural changes in response to ionizing radiation. The changing structure produces measurable shifts in photonic response (e.g., peak frequency, quality factor Q, free spectral range) that are used to measure cumulative absorbed dose.

SMALL
ADAPTABLE
ACCURATE

The invention can be used to measure real-time dose by making a differential measurement using two or more photonic sensors having different sensitivities to cumulative dose, so that the latter can be isolated.



An array of photonic dosimeters subjected to ionizing radiation

BENEFITS

Can be used in an offline mode in which cumulative dose can be quantified

Leverages commercial communications technology and chip fabrication for inexpensive manufacturing and operation

Invention works in harsh environments where electronic dosimeters could fail

Size scale is smaller than the state of the art, so can be used for dosimetry of microscopic samples, surfaces and regions of large dose gradients (e.g., near beam penumbrae or near boundaries of dissimilar materials within bulk matter)

CONTACT

Technology Partnerships Office (TPO)
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TPO@NIST.GOV

Meet **Paul Williams, Ph.D.,**

Physicist, National Institute of Standards and Technology

What If a Mirror Could Measure the Power of the Light It Reflects?

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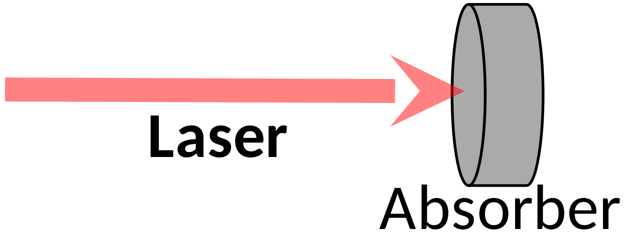
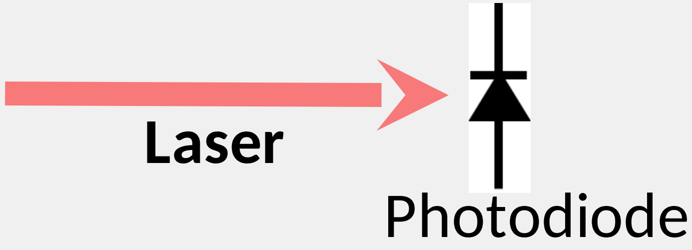
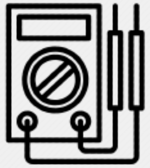
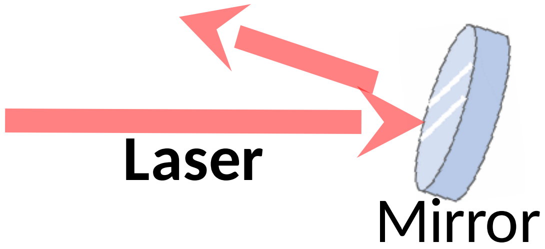
Three Ways to Measure Laser Power

Technique	Sensor	Quantity
Thermal Power Meter		Temperature 
Semiconductor (Photodiode)		Current / voltage 
Radiation Pressure Power Meter		Force 

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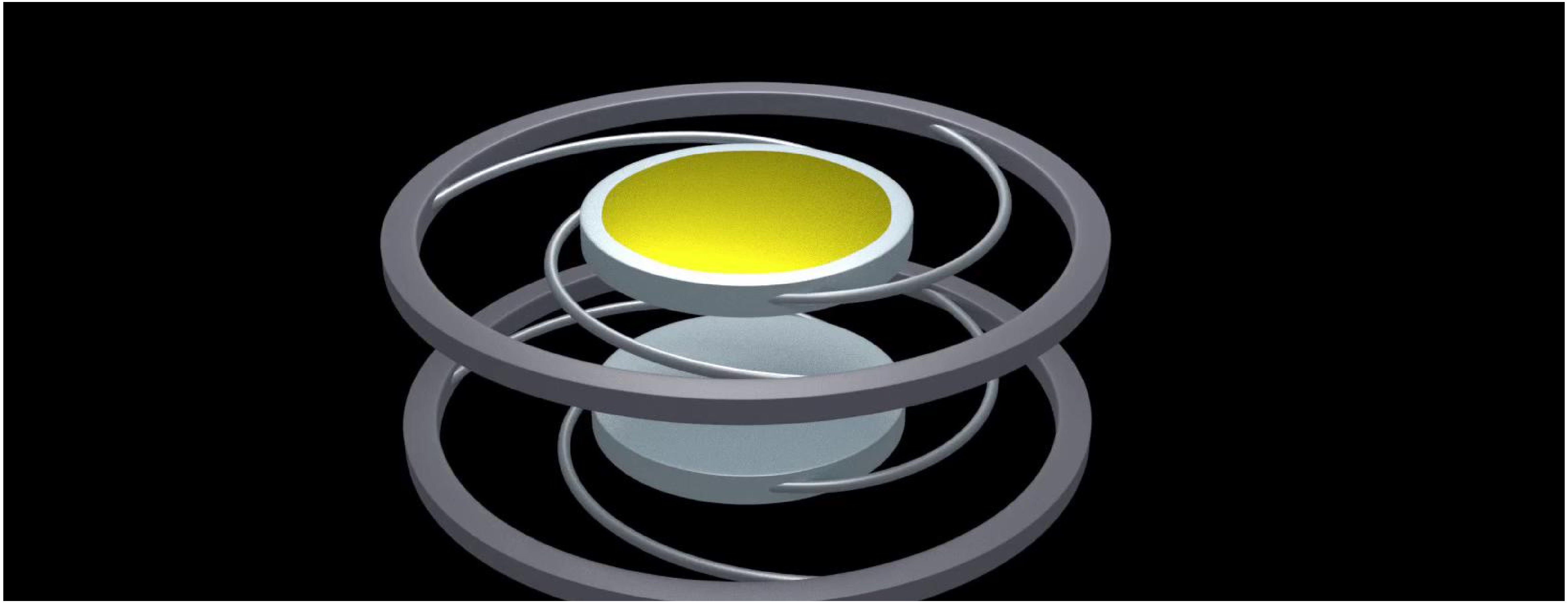
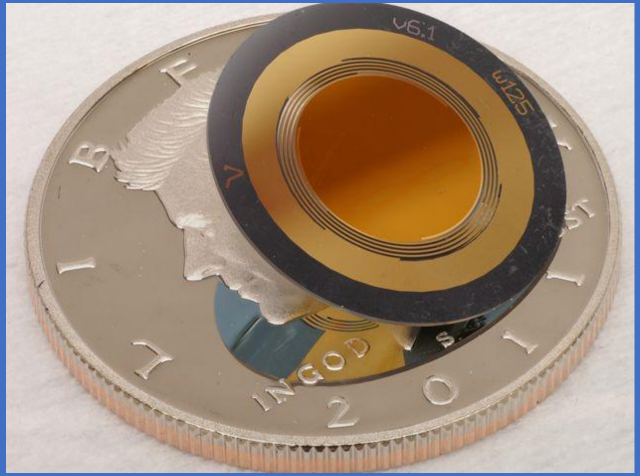
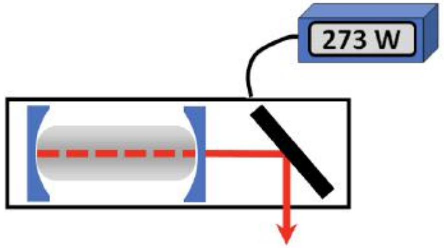
Smart Mirror

Radiation-Pressure-Based Power Sensor



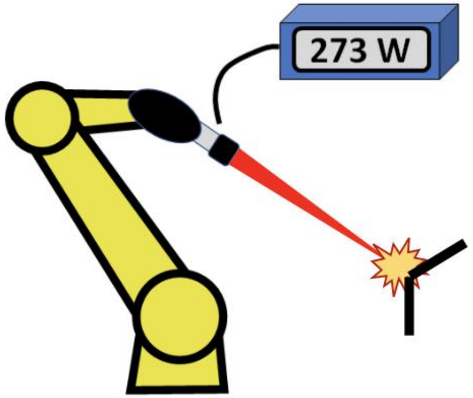


Smart Mirror:
Sensor Element



Application

Calibrated Laser Source



Application

Laser-based Manufacturing: Real-time accurate laser power

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The "Smart Mirror": Non-invasively measuring laser power

Mechanisms:

- *Si-wafer mirror / spring suspension*
- *Interferometric (or capacitive) sensing*

Current Specifications:

- Power range: **25-500 W**
- Uncertainty: **3.2 %** (k=2)
- Noise equivalent power: **260 mW/√Hz**
- Vibration isolation: **15 dB**
- Technology readiness level: **4**

Reference:

A.B. Artusio-Glimpse, et al., *Optics Express*, **28**, 13310 (2020).

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LICENSING OPPORTUNITY

THE SMART MIRROR

THE TECHNOLOGY

U.S. Patent Number 10,234,309

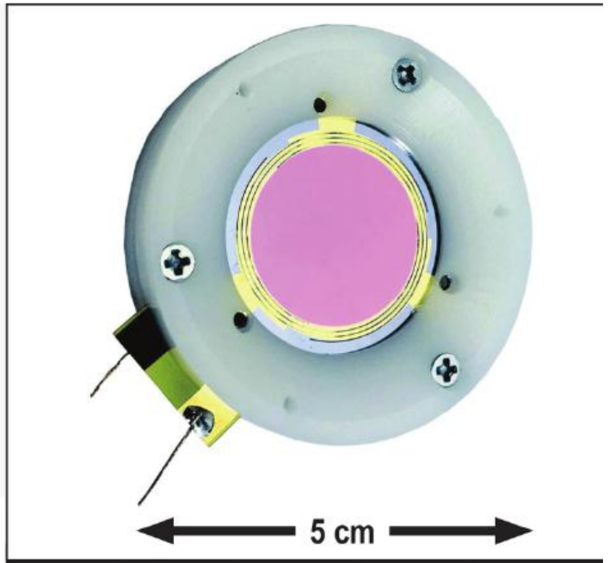
The Smart Mirror is a device that accurately measures the power of laser sources without disturbing the laser beam. This is a promising technology for accurate monitoring of output power in industrial lasers that allows power measurement during the laser's performance of its routine operations. Such high-accuracy, non-exclusive power monitoring has not been previously possible. The novelty is in a radically different approach where the laser power is determined by measuring the force of the light as it reflects from a mirror. This device operates across a power range of 25W to 500W.

SMALLER
FASTER
HIGHLY ACCURATE

This device is a miniaturized (less than 5 cm on a side), mirrored, force sensor that combines several key elements to make the sensor smaller, faster, and more sensitive to force

The design overcomes the limitations of allowing simultaneous power measurement during laser use.

The non-thermal approach of the Smart Mirror reduces measurement time, which allows for better sensing of rapid changes in laser power.



Photograph of a mounted pair of springs with high ref ectivity mirror designed for 1070 nm laser incident at 45 degrees.

BENEFITS

Highly accurate measurements that can be made in real time

Small, robust package for use on factory floor

Can be calibrated in-house using standard reference masses

Does not absorb laser light

CONTACT

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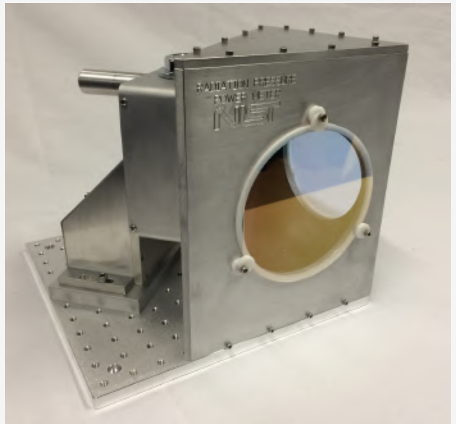
Other Radiation-Pressure Technologies Available

Radiation Pressure Power Meter "RPPM"



U.S. Patent
US 9,625,313 B2

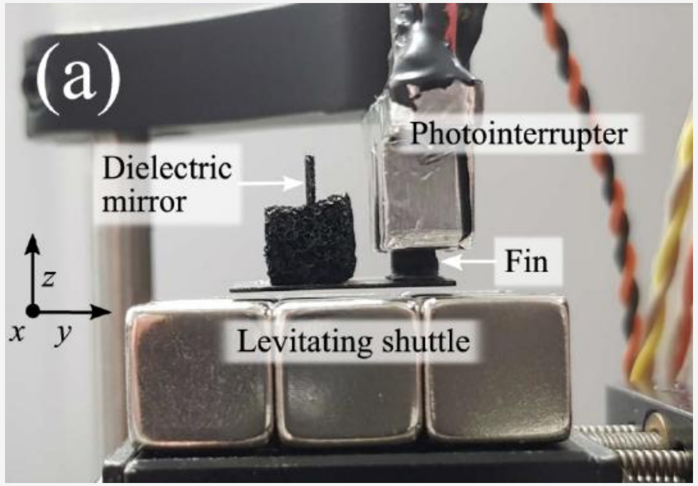
Purpose: High power measurement of free space laser beams

Beam dia.: up to 10 cm (current design)

Power: 1 kW – above 150 kW (cw), **Uncertainty:** 1.7 % (k=2)

Reference: Reference: P.A. Williams et al., Optics Express, 25, 4382 (2017)

Gravity Enforced Photon Momentum Radiometer



U.S. Patent Pending

Purpose: High accuracy laser power

Low cost / small package (fiber compatible)

Power: 3 W (cw), **Uncertainty**: 1.9 % (k=2)

Reference: A.K. Vaskuri et al., Optica, 8, 1380, (2021)

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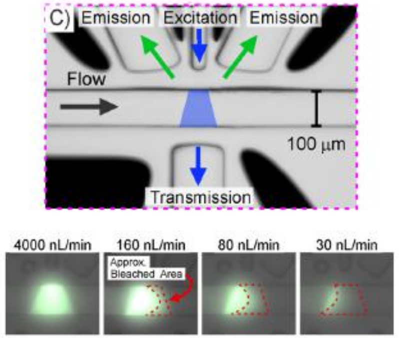
Optical Flowmeter and Serial Cytometer

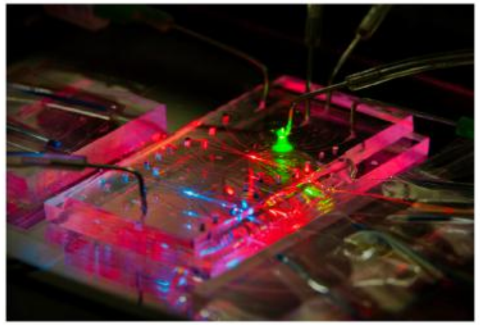
Meet **Greg Cooksey, Ph.D.,**

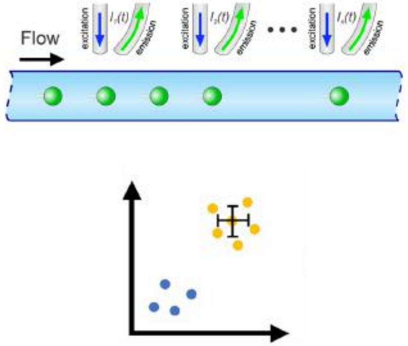
Biomedical Engineer , National Institute of Standards and Technology

Meet **Paul Patrone Ph.D.,**

Staff Scientist , National Institute of Standards and Technology







5% uncertainty at 1 nL/min

Per-particle imprecision <1%

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Why Care About Really Slow Flow Measurements?

- **Validating performance of research and clinical instruments**
  - Support calibration of medical devices, e.g. drug pumps (to as low as 10's of nL/min)
  - Resolving power of separation technology is inversely related to flow rate.State of the art for HPLC is based on a few nL/min
- **Maintaining stable chemical processes**
  - Consistency in manufacturing using continuous or injected flows
  - Low volume reagent delivery and partitioning (e.g. in microchambers or microdroplets)
- **Flow cytometry, separations, and fundamental physics**
  - Characterization and control of measurements based on mixing (e.g. convection vs. diffusion)
  - Validating flow phenomena and physical properties of liquids

www.microchip.com
Commercial products and photos are for demonstration only - not endorsement by NIST

Microflow Measurement – State of the Art

- **Mass flow – Gravimetric standard (Traceable)**
- **Heat Transfer Method (e.g. Sensirion, Bronkhorst)**
- **Front Tracking (Traceable)**
- **Particle Velocimetry (Traceable-Lite)**

Considerations

- Accuracy
- Dynamic Range
- Response Time
- Deployability

NIST Gravimetric Standard

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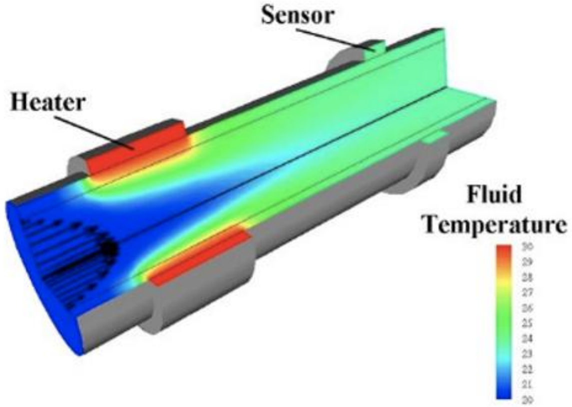
Heat Transfer Method



Front Tracking

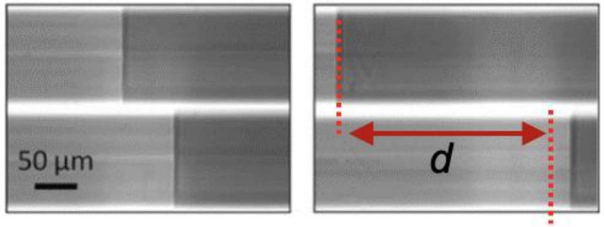


Figure 2. Meniscus appearance at 10 nL min^{-1} (left) and 50 nL min^{-1} (right). Time interval between the top and bottom frames is 10 s. Motion of the meniscus is from left to right. Liquid is on the left side.

Ahrens et al., *Meas Sci Technol* 2014

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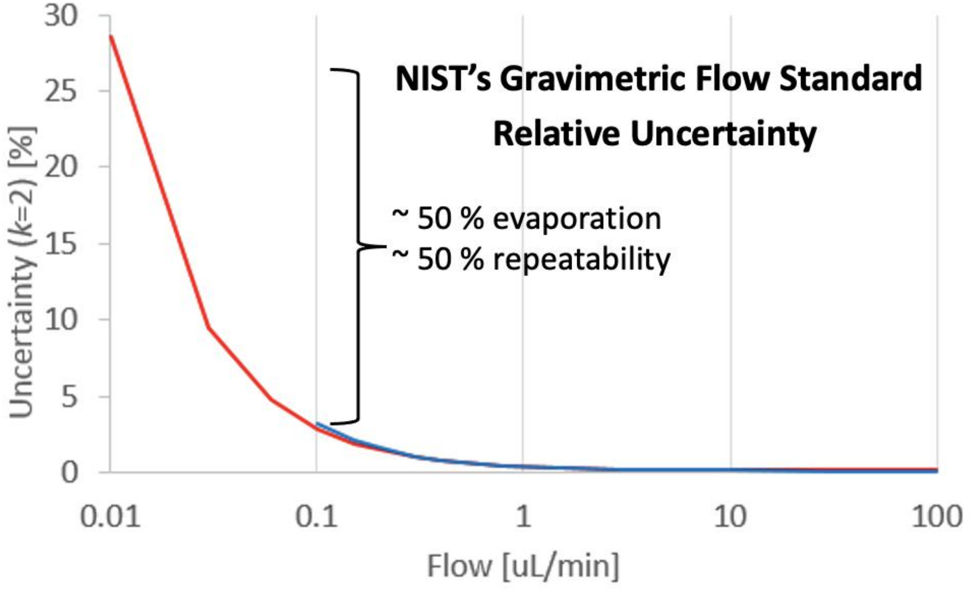
Flow Metrology's Brick Wall

How Can We Overcome These Limitations

- **Improvements in sensitivity at low flow largely rely on miniaturization of existing (benchtop) technologies**
- **With smaller measurements, relative uncertainties become increasingly large due to:**
  - evaporation
  - surface forces
  - geometric factors
  - instrument noise



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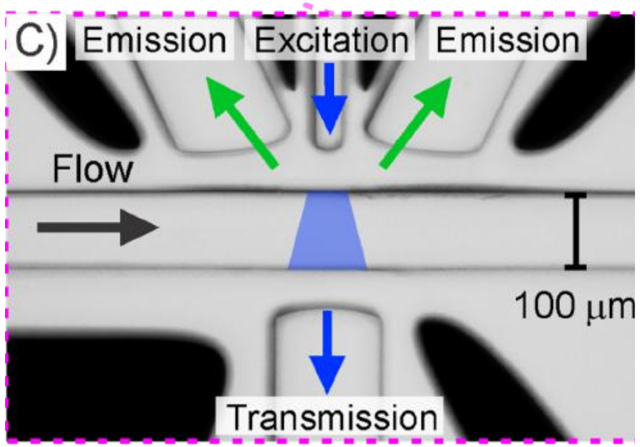
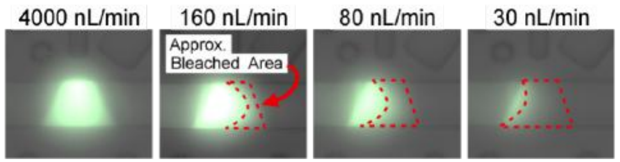
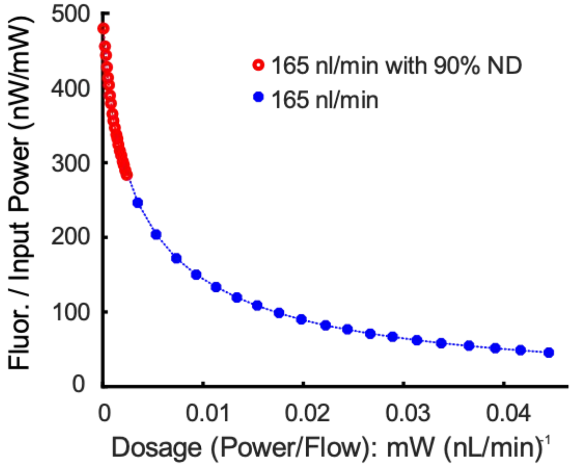
Dosage-based Flow Measurements







- Fluorophores receive a dosage related to laser power and flow rate-1
- Fluorophores bleach after average # of excitations
- Emission follows a fixed relationship with dosage
- Independent of channel geometry, laser pattern, and flow profile *(Patrone et al. Phys Lett Appl 2019)*
  - Calibrate the relationship at one flow, determine unknown flows from dosage

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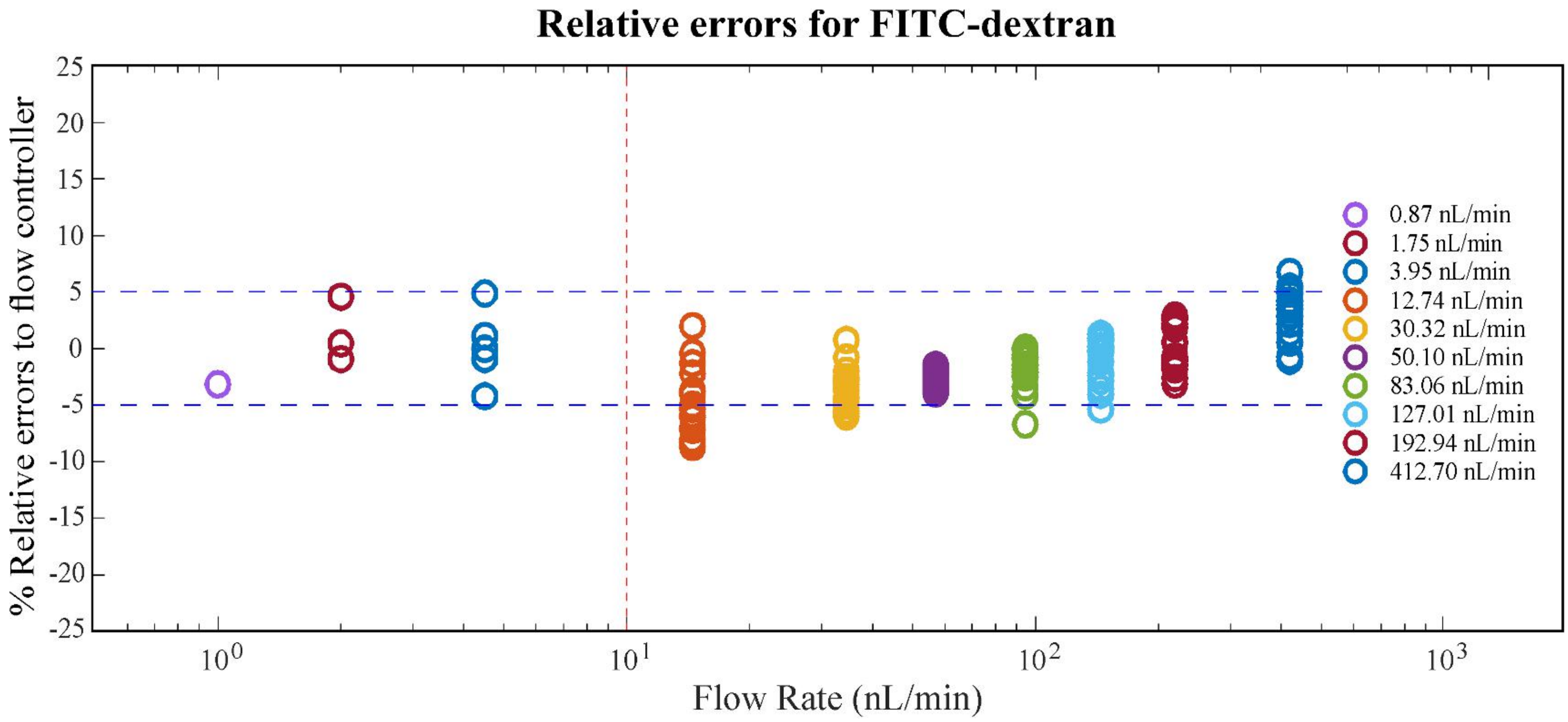
Recent Advances

Molecules with lower diffusion coeff. enable flow measurements to < 1 nL/min



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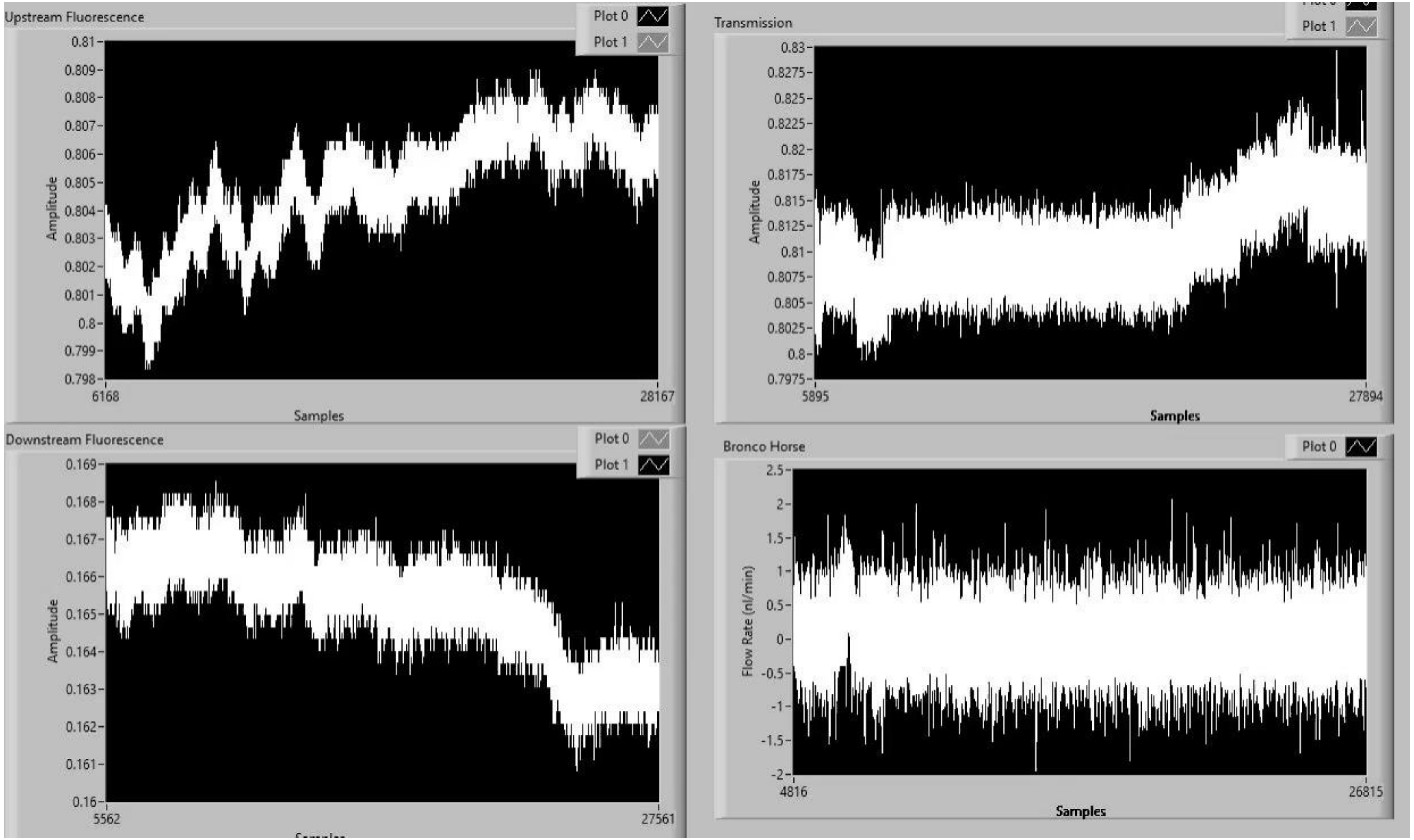
Recent Advances

Real-time, dynamic measurements of 50 µm height changes (approx. 40 pL/min)



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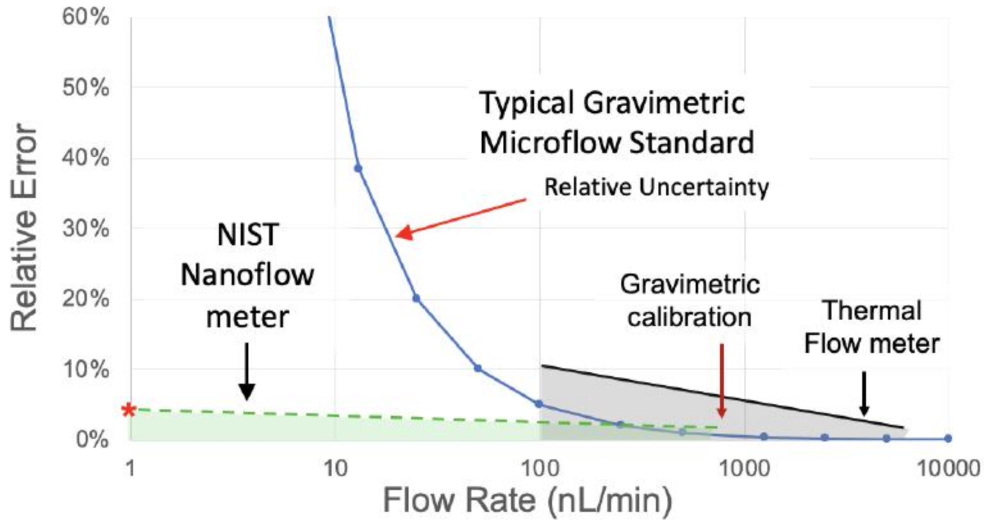
Nanoflow Metrology

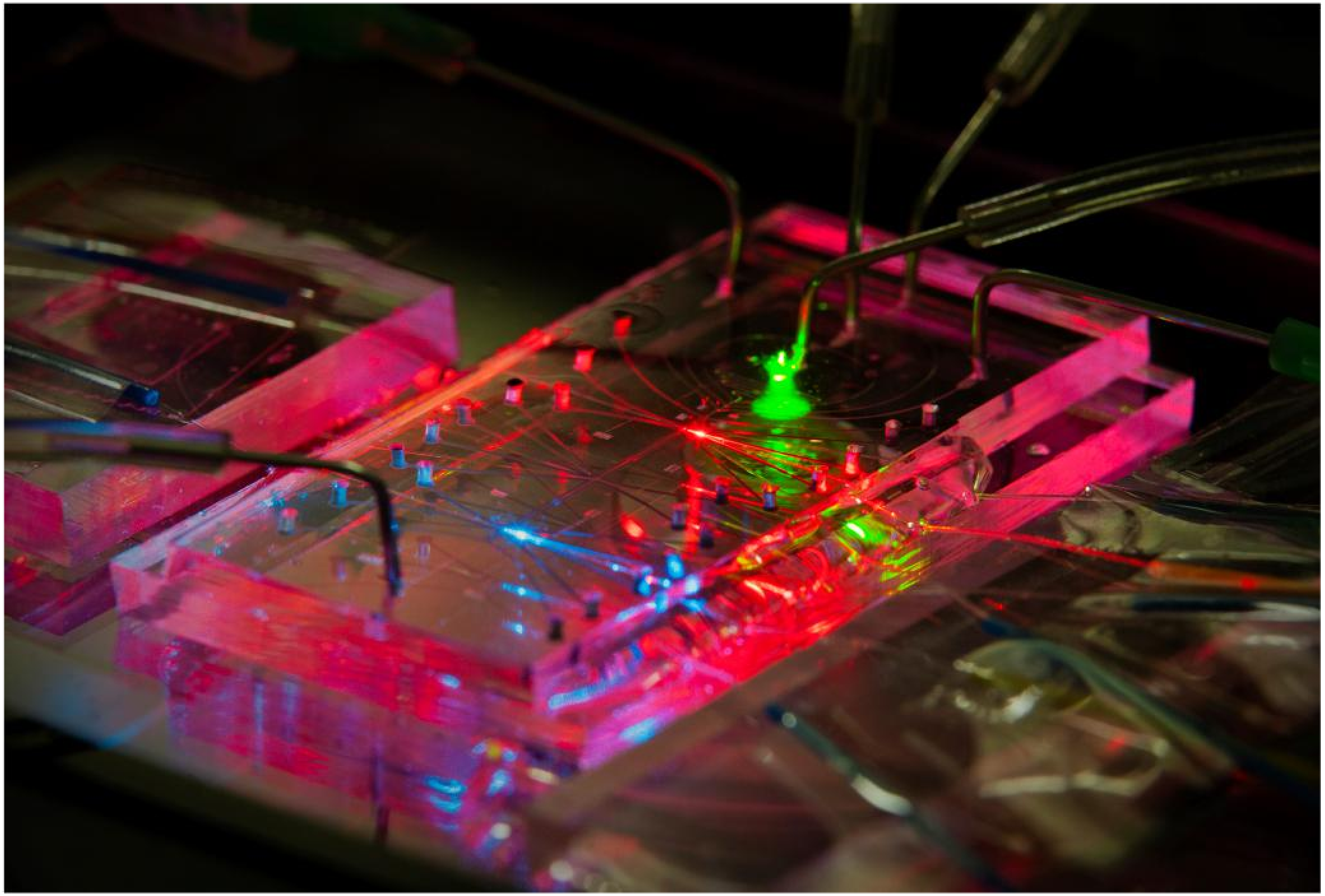
Project Summary

- Create calibration curve of the relationship at known flow rates (e.g. at 1 μL/min)
- Translate uncertainty from calibration into lower regime through dosage using light intensity
- Dynamic flow measurement to 1 nL/min with approx 5% uncertainty
- < 20 pL/min uncertainty resolving advection from diffusion (e.g. zero flow)



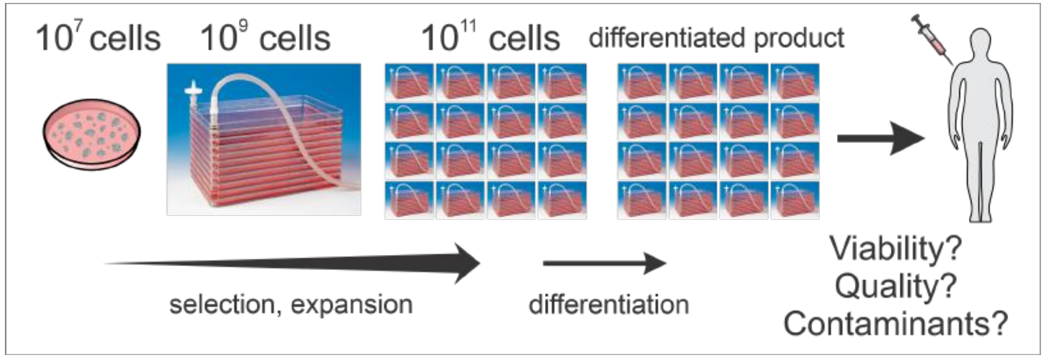
Independent of channel geometry, laser pattern, and flow profile

Serial Cytometry



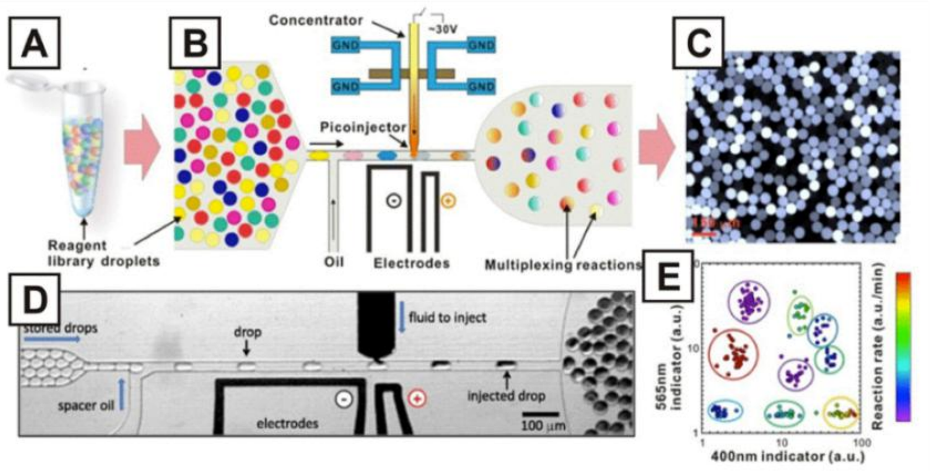
Challenges for High-Throughput Biometrology

Regenerative Medicine

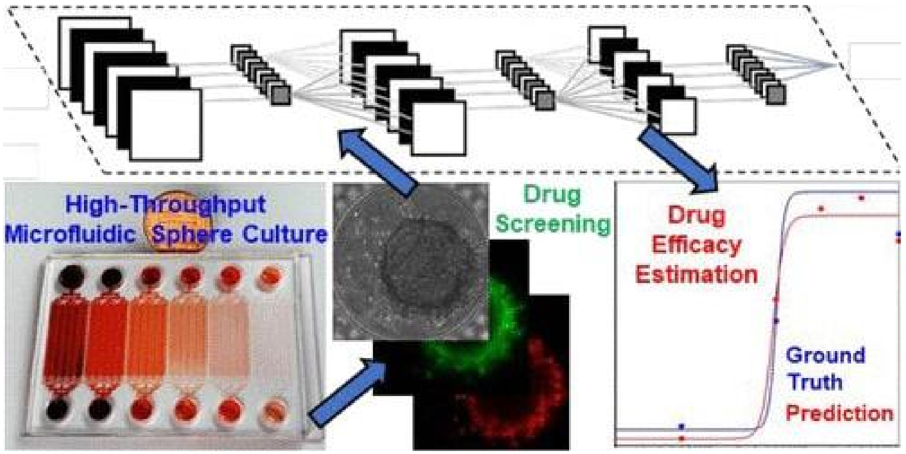


Cancer Screening

Drug Discovery



Drug Screening

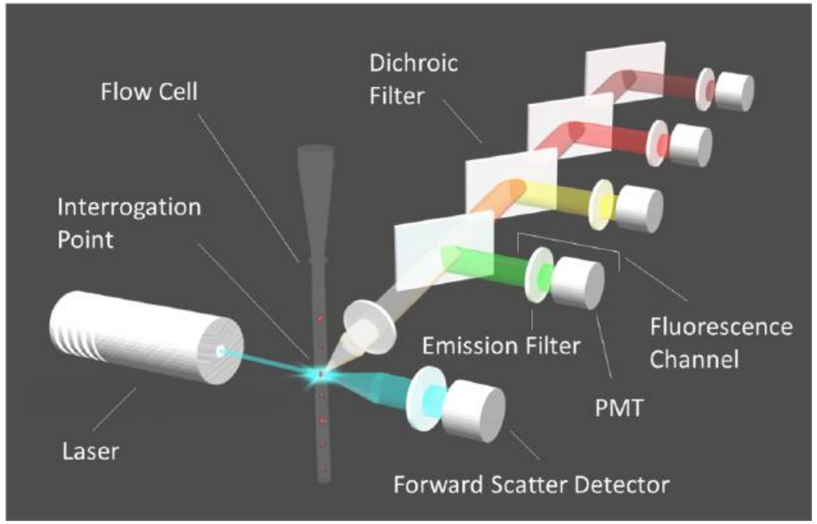


Yoon Lab, University of Michigan

Flow Cytometry Measurements

State-of-the-art

- **Measurement of cell characteristics, like size, and biomarker abundance, count and classification**
- **High throughput: 10,000 cells/s**
- **Used in cancer detection, drug development, biomanufacturing**
  - No robust theory of uncertainty, Not clear how to assess accuracy
  - Comparability is challenging
  - Classification is subjective
- **Limited ability to detect rare events (approx. 1 in 10,000)**



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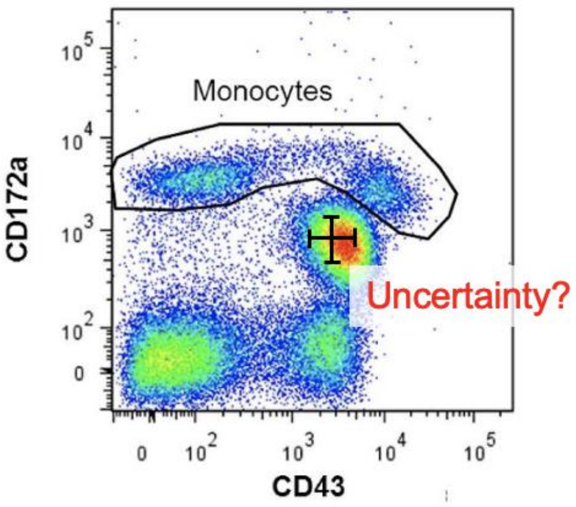
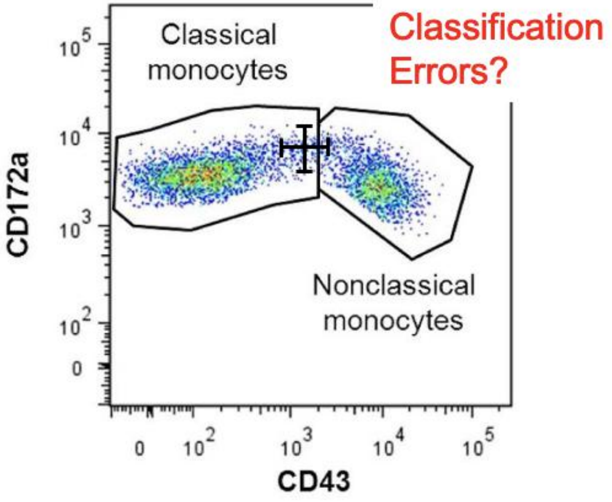
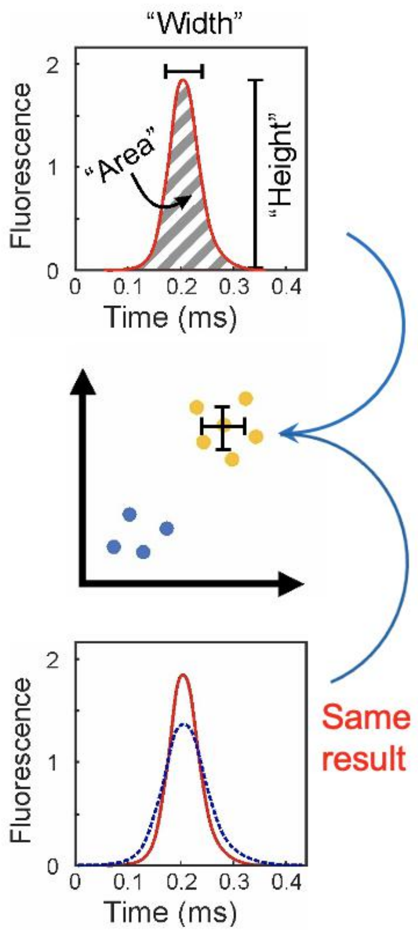
Why is Cytometry Hard?

Need a more robust strategy for uncertainty quantification

- **How can we compare one measurement to another?**
- **How do instrument control choices affect outcomes?**
  - flow rate & focusing, optics, amplifier gains
- **What do the measurements tell us about a population?**

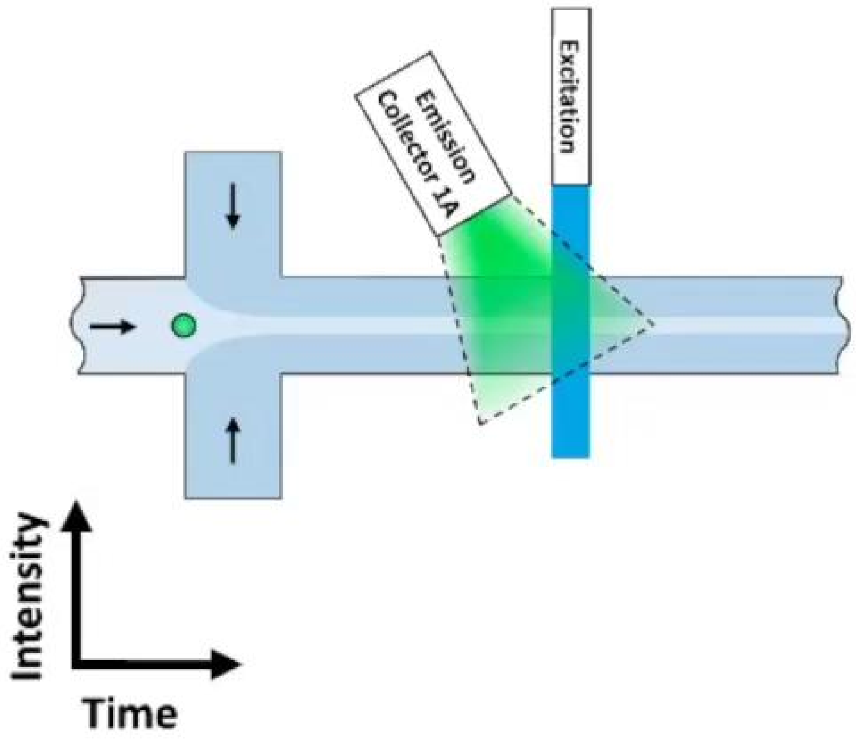




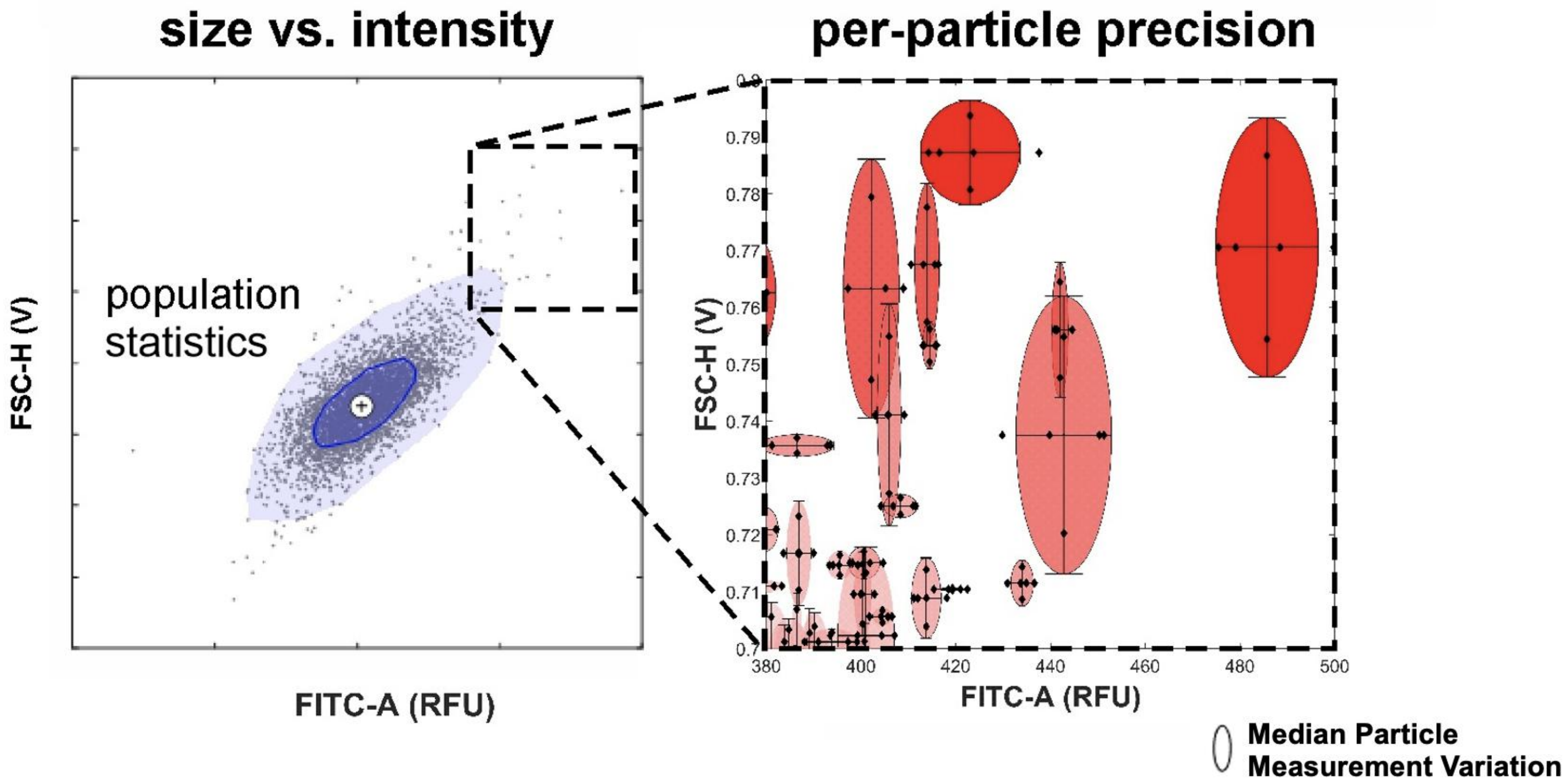


Serial Cytometry

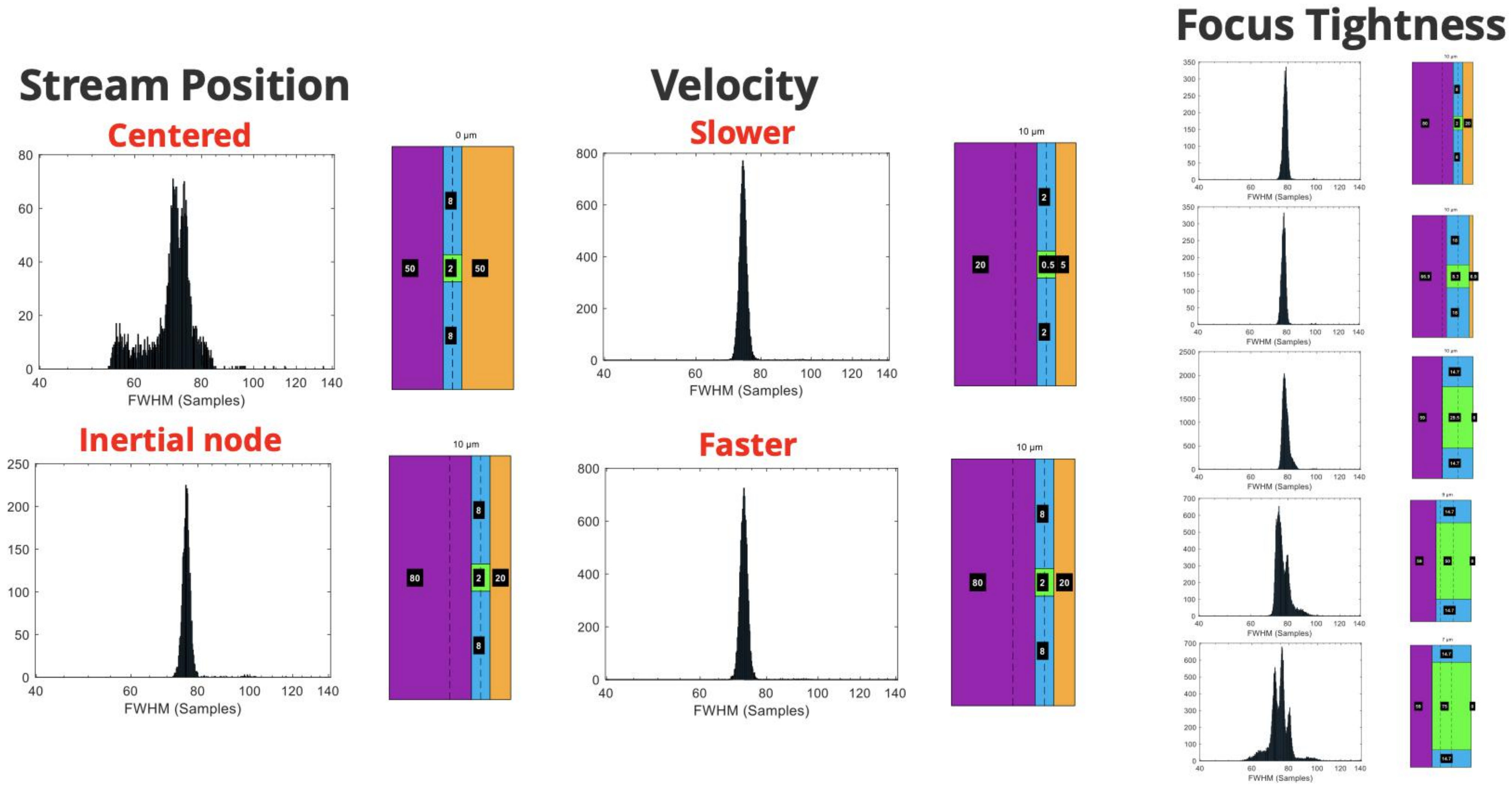
Measurement Concept: Assessing Uncertainty through Repeated Measurements



Per-particle Precision within a Population



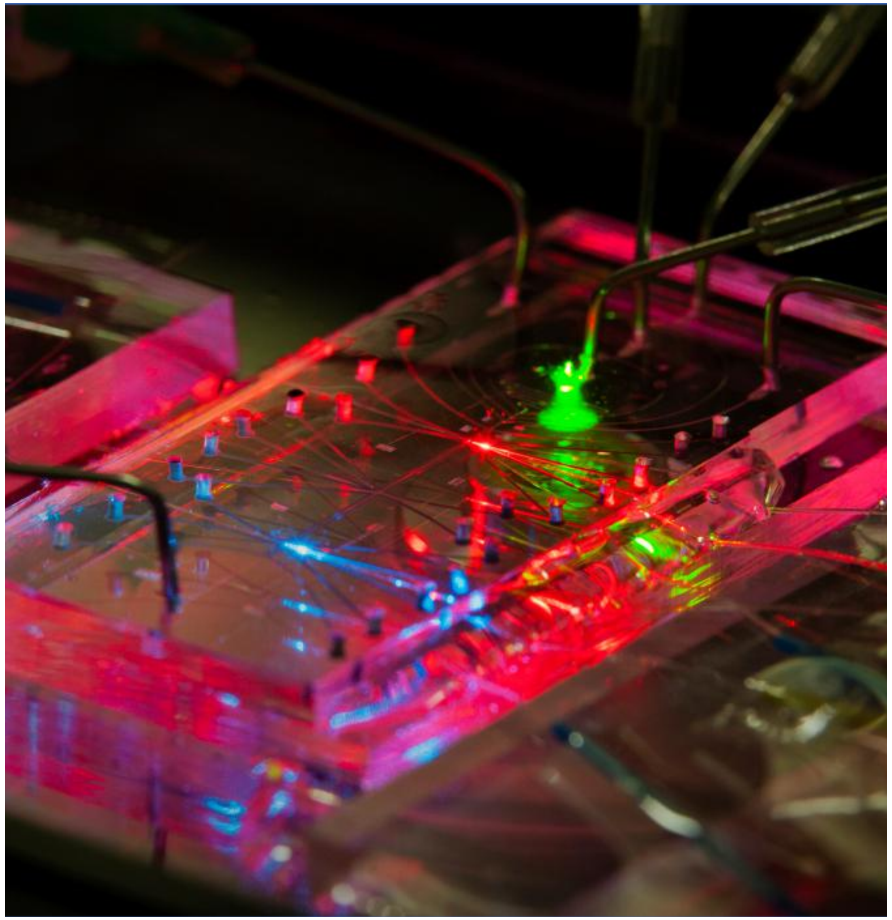
Real-time Assessment and Control of Data Quality



Serial Cytometry

Project Summary

- Serial Cytometry enables improved and new measurements
- Estimates of per-particle uncertainty experimentally and analytically, setting the stage for better classification
- Also enables innovation and optimization of system performance
- Signals analysis to study deformability,discriminate doublets
- Working on metrics to improve detection and classification (rare event detection, other specs)
  - <100 MESF Limit of Detection
  - <1% relative uncertainty
  - 1 in 10,000 tracking error
  - 500 events per second



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Panel Discussion

NIST Innovative Technologies Showcase

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Q&A Session

NIST Innovative Technologies Showcase

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Thank You!

NIST Innovative Technologies Showcase