In-Situ Process Monitoring, Synchronization, and Mapping Laser Powder Bed Fusion Builds of Ti6Al4V

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All figures are credit NASA

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Preface

- **Synchronization of in-situ process monitoring enables efficient calculation and analysis of spatially resolved process metrics**

Motivation

- Quality control of Laser Powder Bed Fusion (LPBF) Additively Manufactured (AM) parts
  - In-situ process monitoring
  - Identification of process anomalies
- Reduce qualification and certification costs
  - Improve build designs
  - Discard builds based on the identification of anomalies

Qualification of LPBF AM Parts

- Millions of 'welds' per part
- Sources of variability
  - machine-to-machine
  - day-to-day
  - hour-to-hour
- Utilize in-situ monitoring to develop qualification confidence in LPBF AM parts

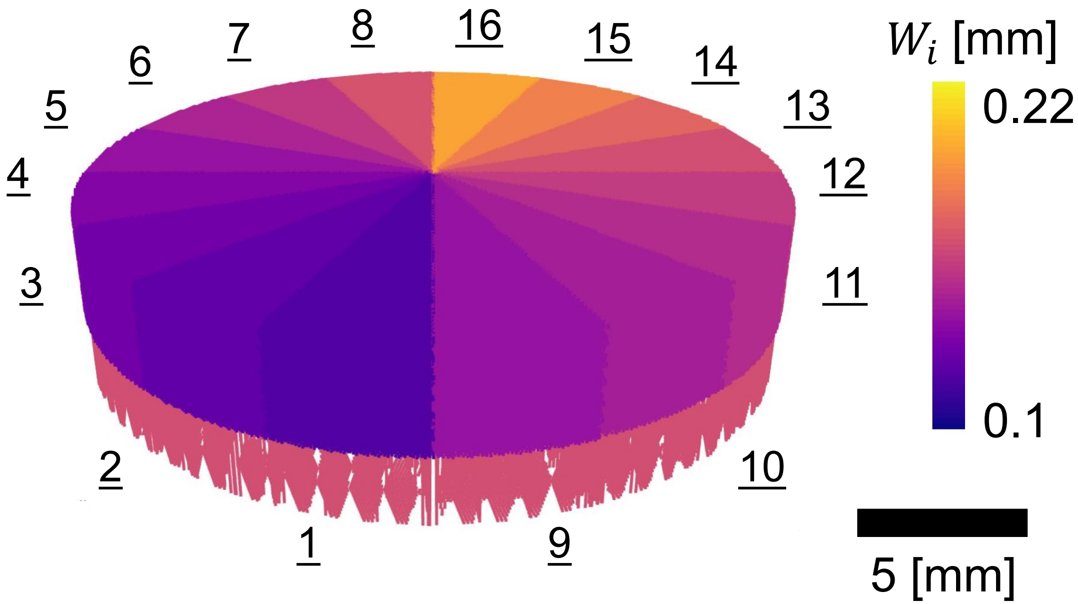
Test Article

- Material: Ti6Al4V
- 16 zones
- Power:
  - 221 [W] and 308 [W]
- Velocity:
  - 1176, 1092, 1008, 924, 840, 756, 672, 588 [mm/s]
- Calculated melt pool widths, W_i
  - 117 [μm] – 195 [μm]

Power

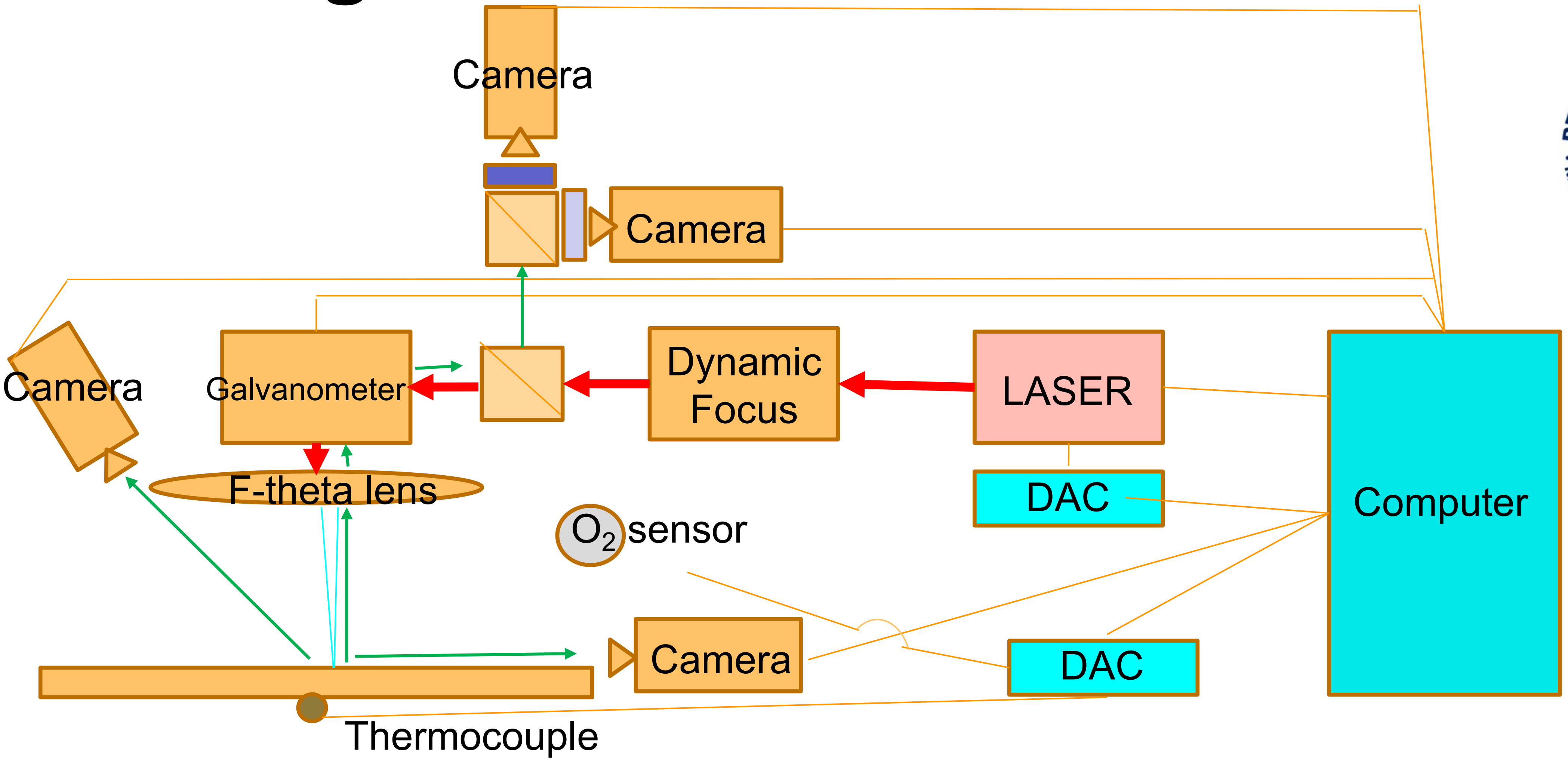
Velocity

$$W_i = 2\sqrt{\frac{2AP_i}{e\pi\rho c_p(T_m - T_0)V_{ij}}}$$

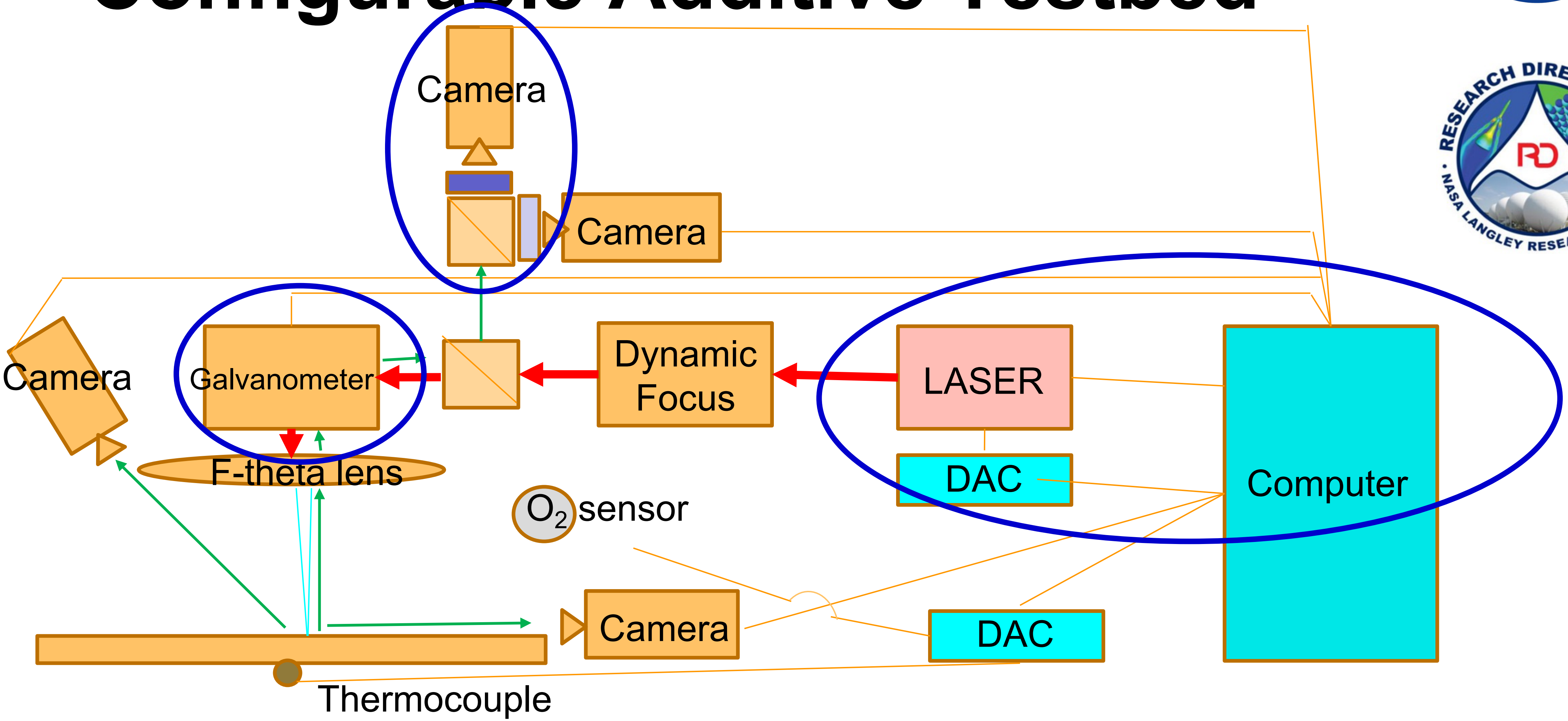


Rosenthal, Daniel. "Mathematical Theory of Heat Distribution during Welding and Cutting." *Weld J* 20, no. 5 (1941): 220–34.

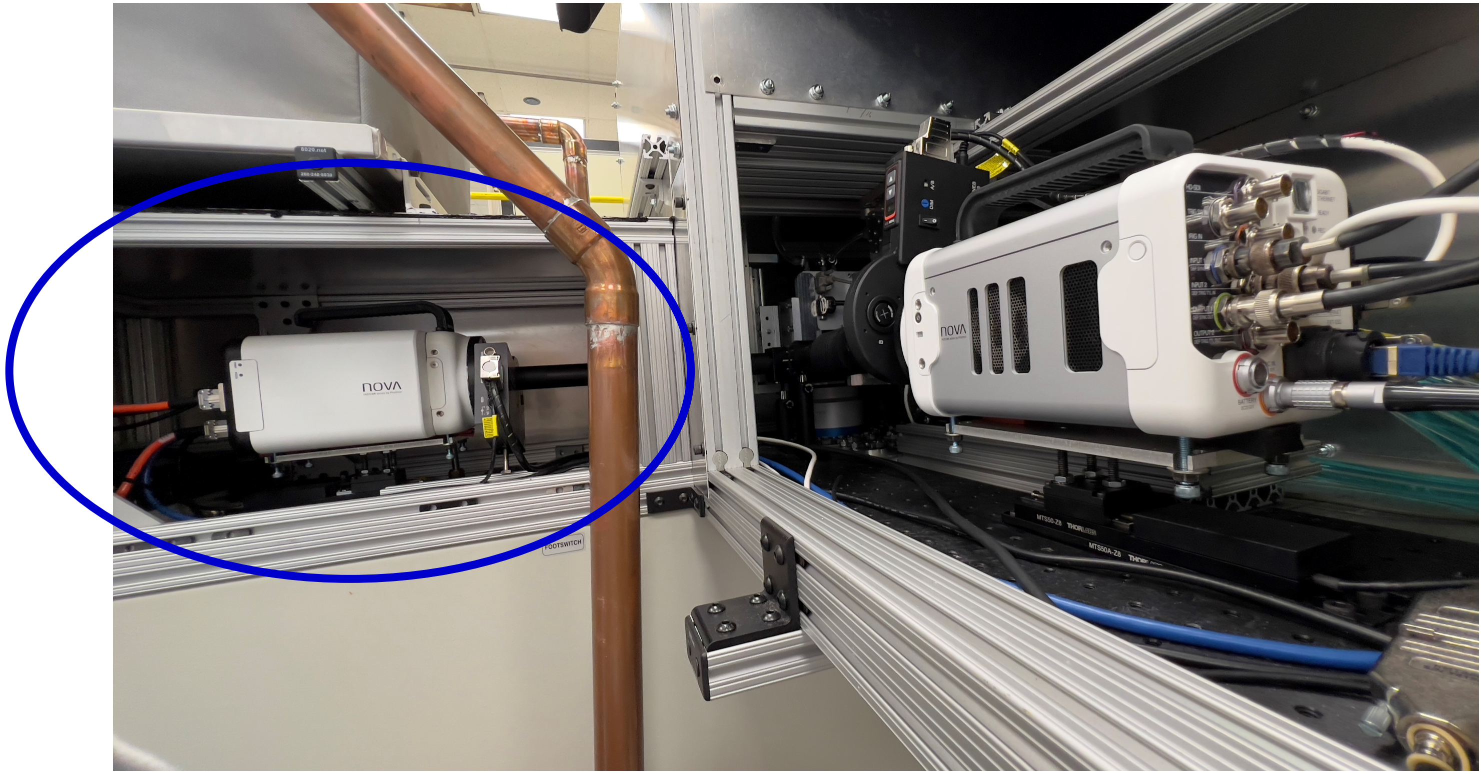
Configurable Additive Testbed



Configurable Additive Testbed

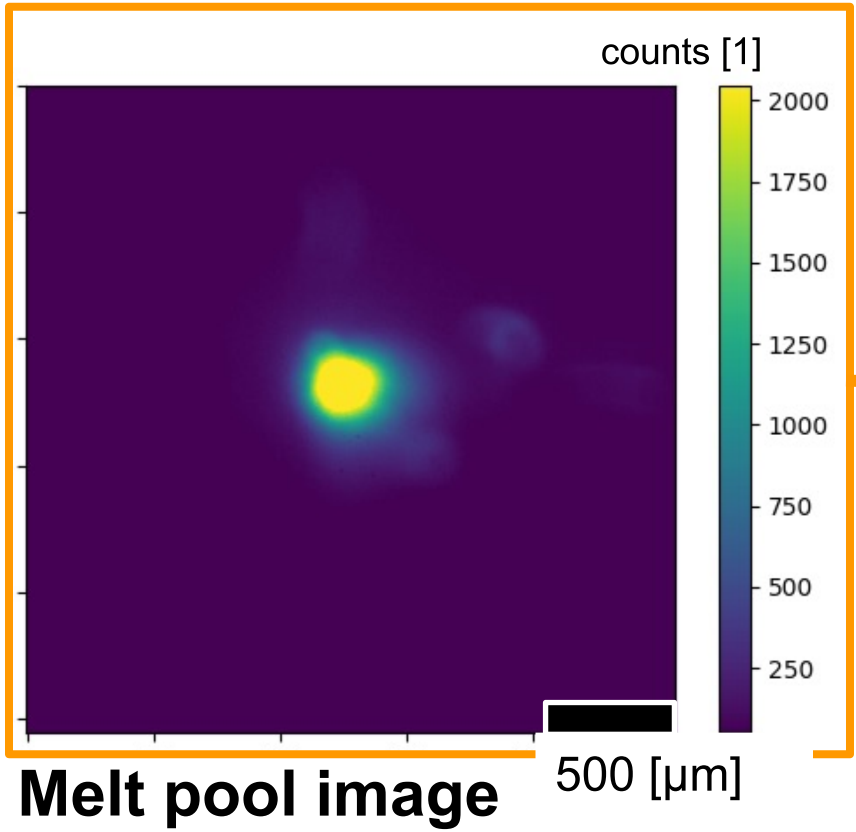


Melt Pool Imaging



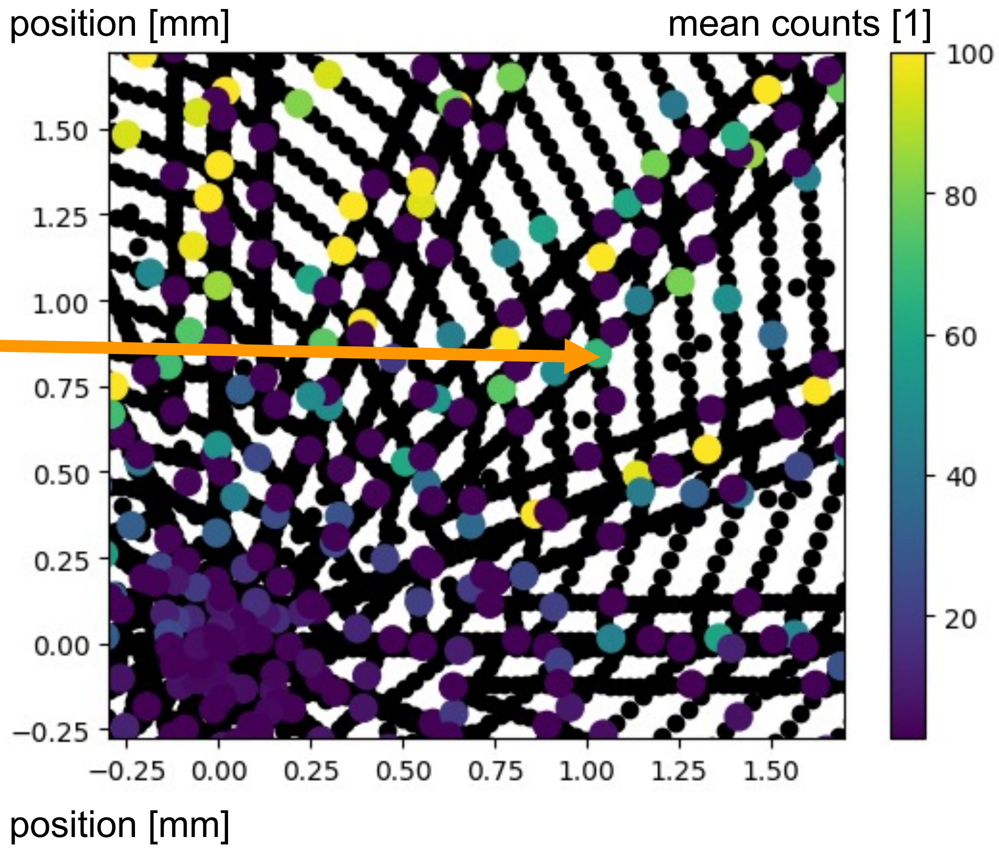
Dual-camera co-axial to laser melt-pool imaging, ~5 um/pixel
Left Camera: 730 nm bandpass filter and 333 [μs] exposure time

Synchronized Melt Pool Imaging: Mean Counts Metric

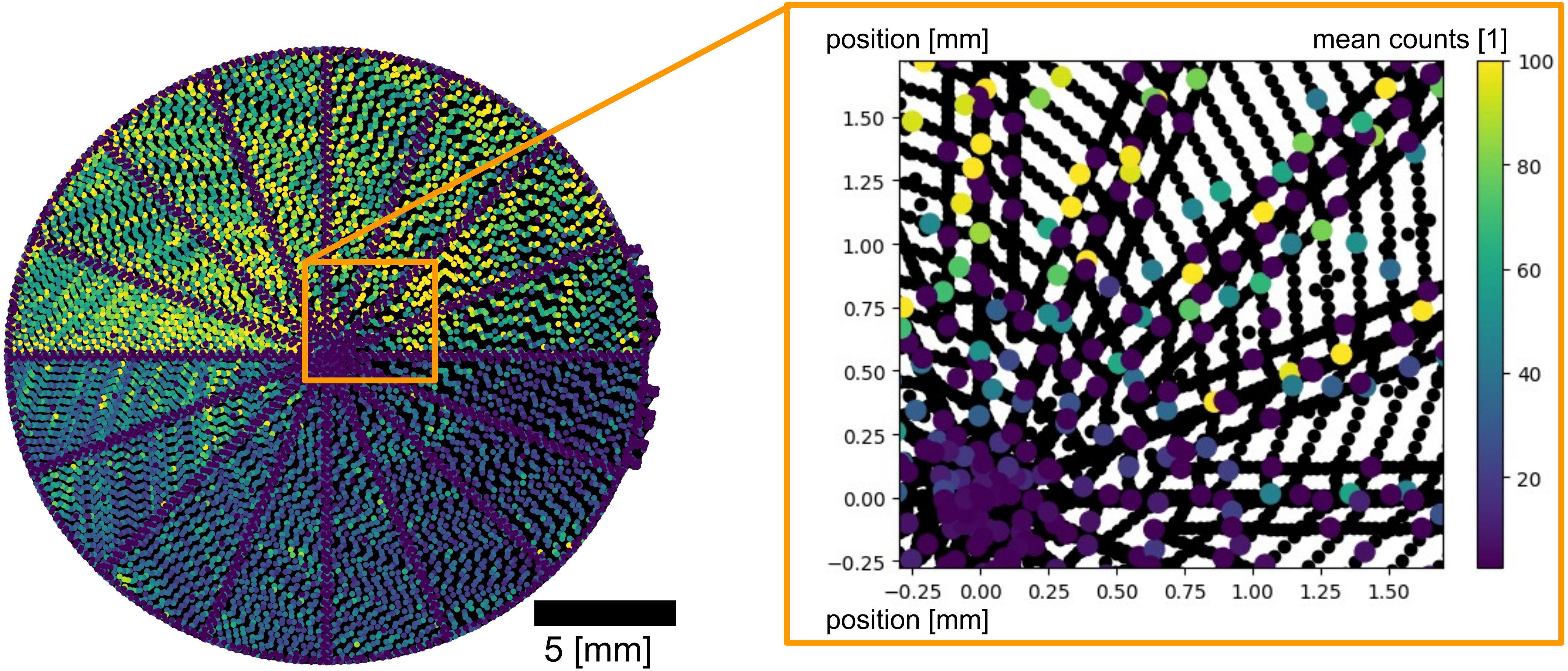


Melt pool image

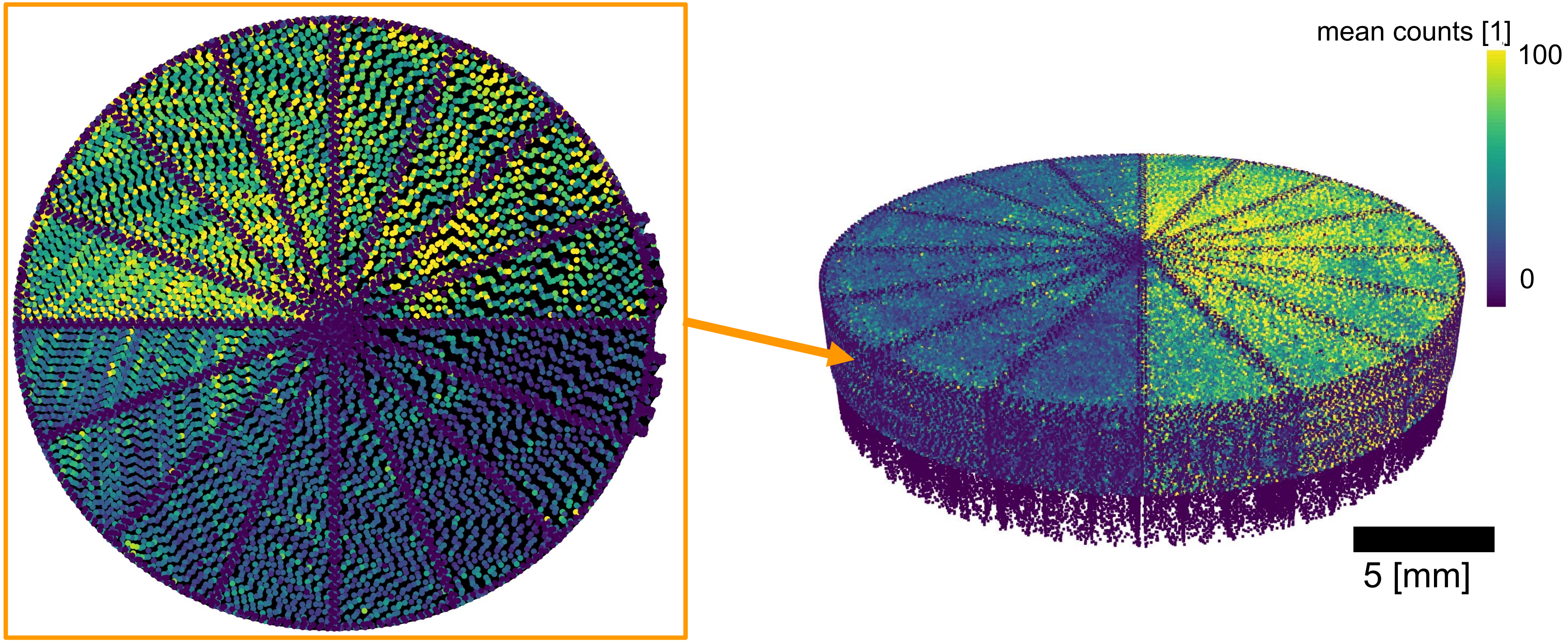
Mean counts = 67



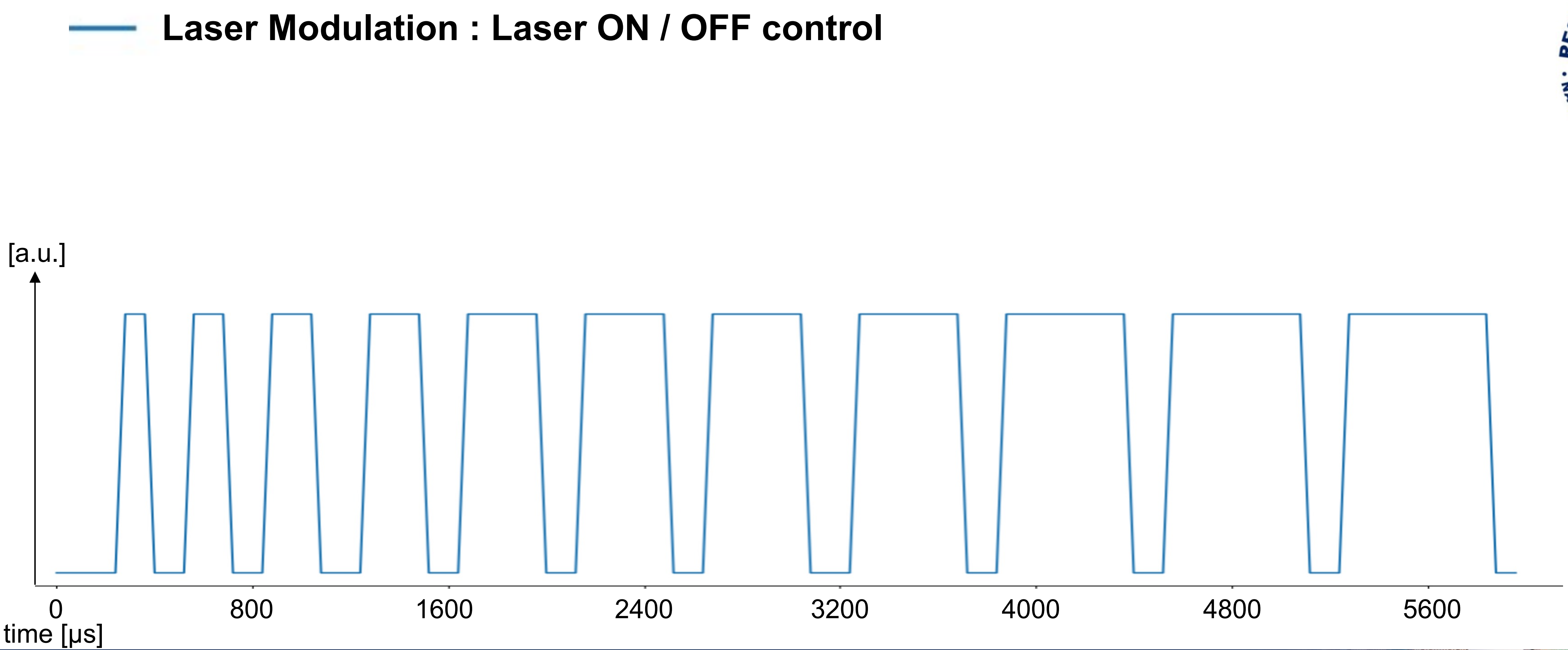
Synchronized Melt Pool Imaging: Mean Counts Metric



Synchronized Melt Pool Imaging: Mean Counts Metric

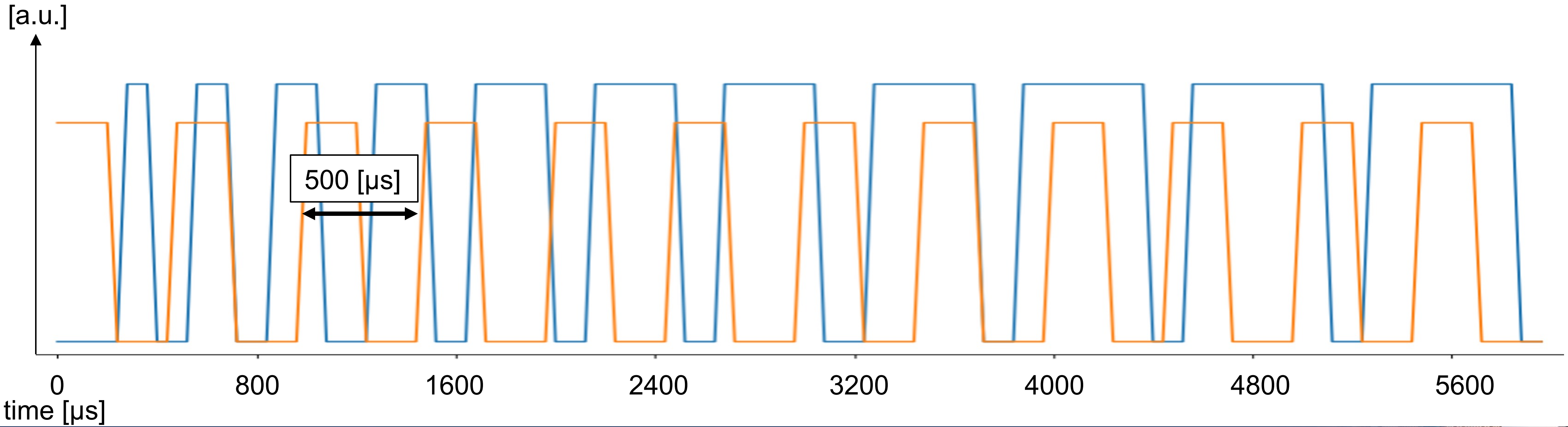


Real Time Clock Signals: Method



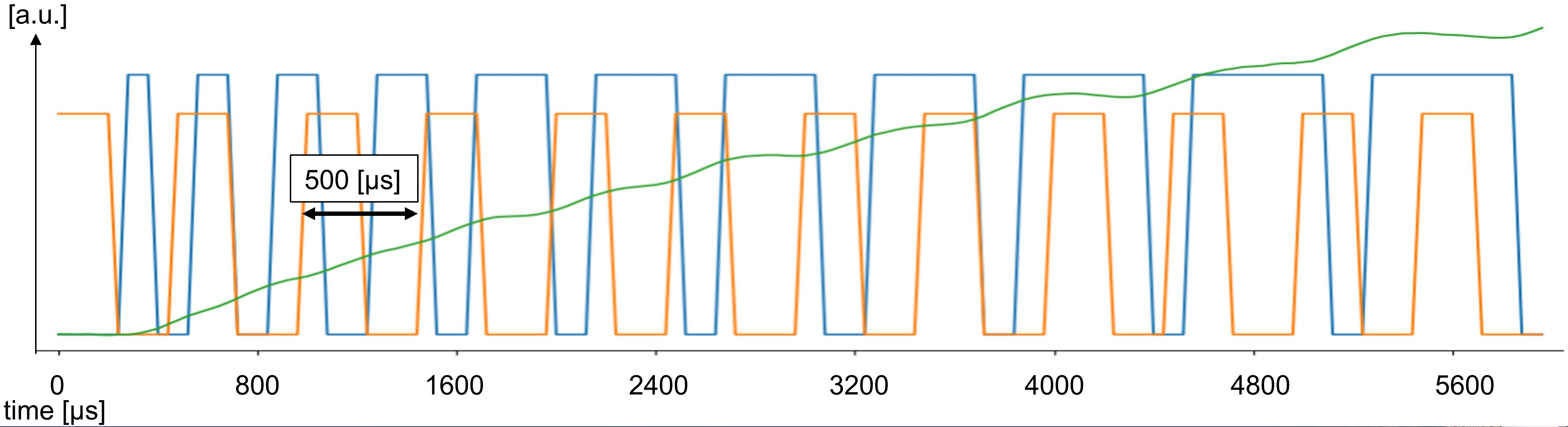
Real Time Clock Signals: Method

- Laser Modulation
- Synchronization signal, 500 [μs] : digital signal used to trigger sensors



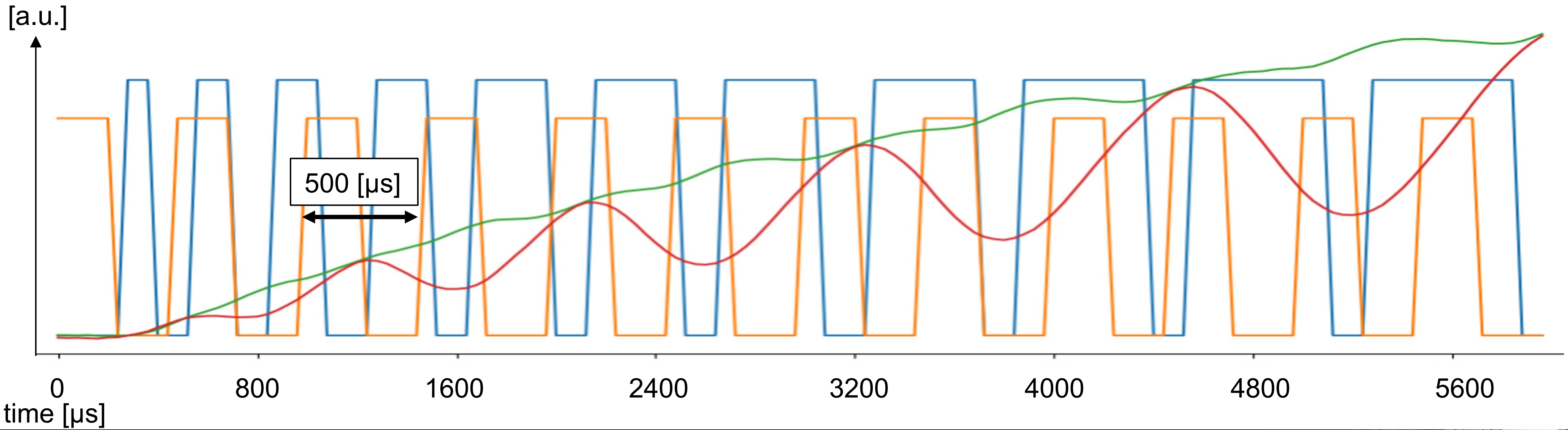
Real Time Clock Signals: Method

Laser Modulation
Synchronization signal, 500 [μs]
X-position : the galvanometer reported digital position of the “x axis mirror”

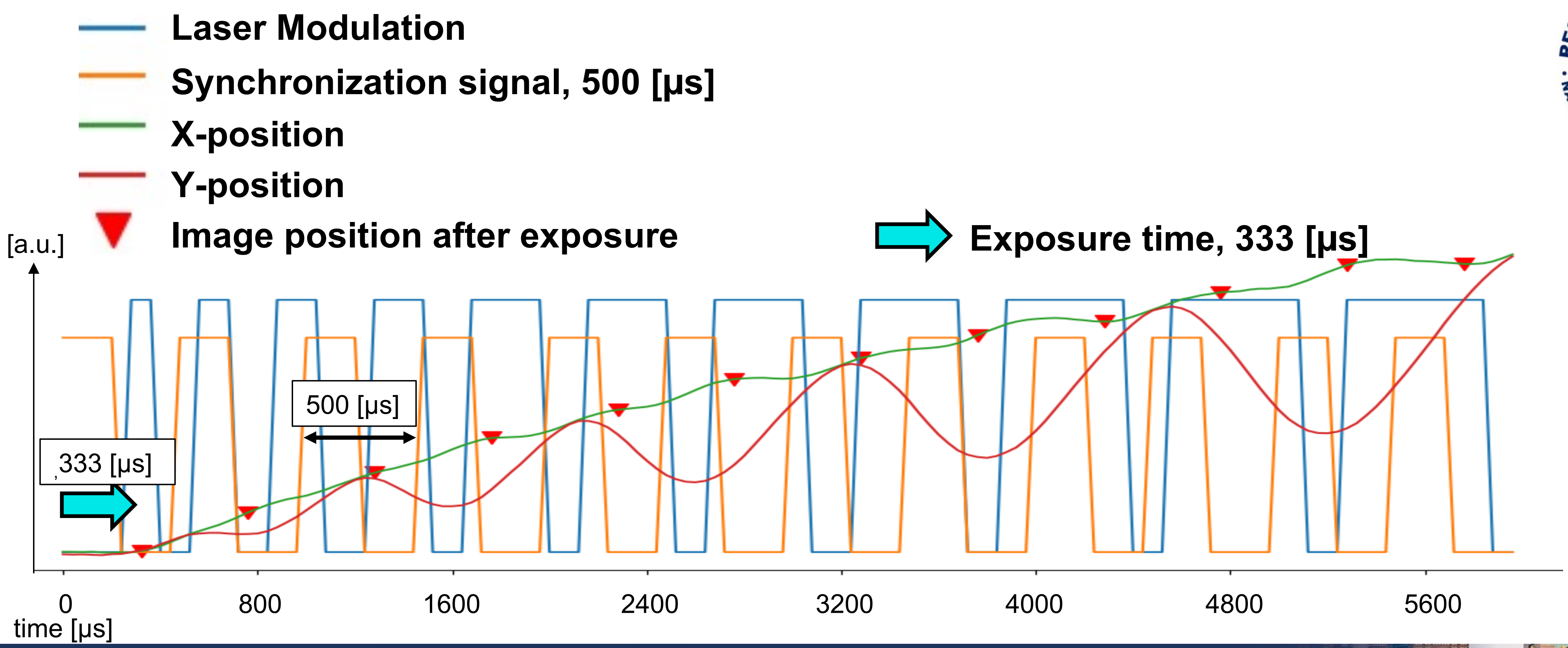


Real Time Clock Signals: Method

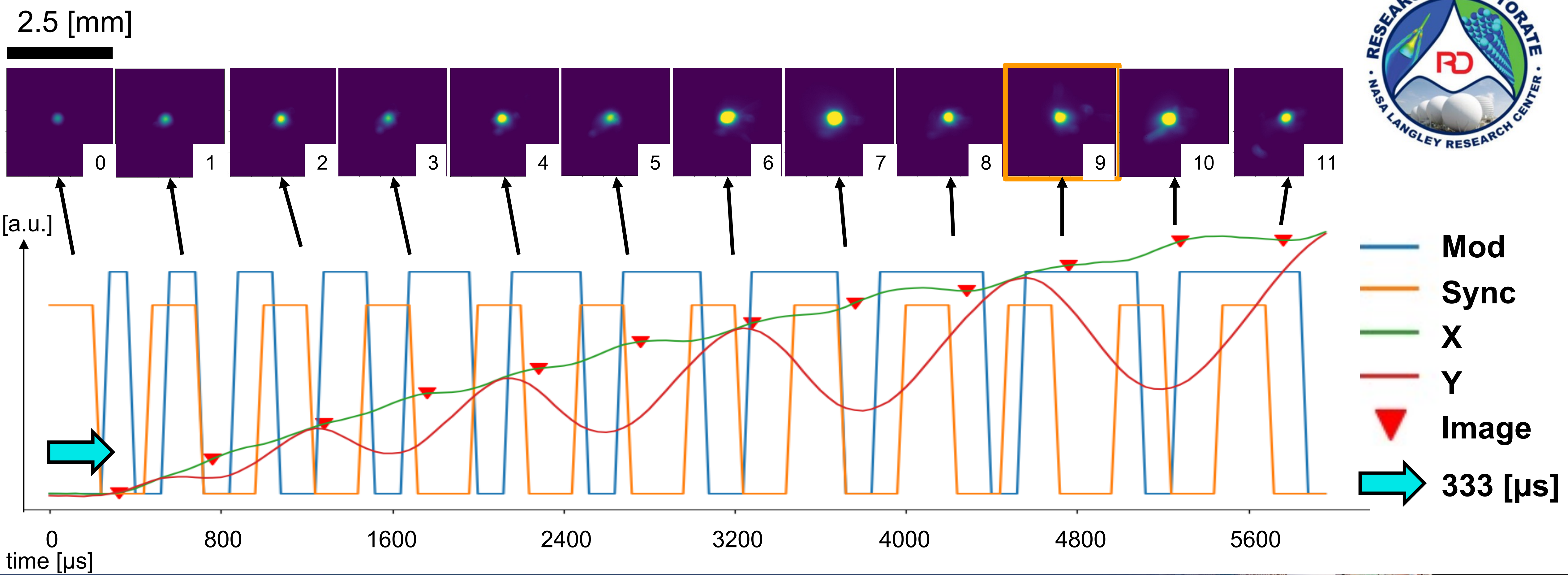
- Laser Modulation
- Synchronization signal, 500 [µs]
- X-position
- Y-position : the galvanometer reported digital position of the "y axis mirror"



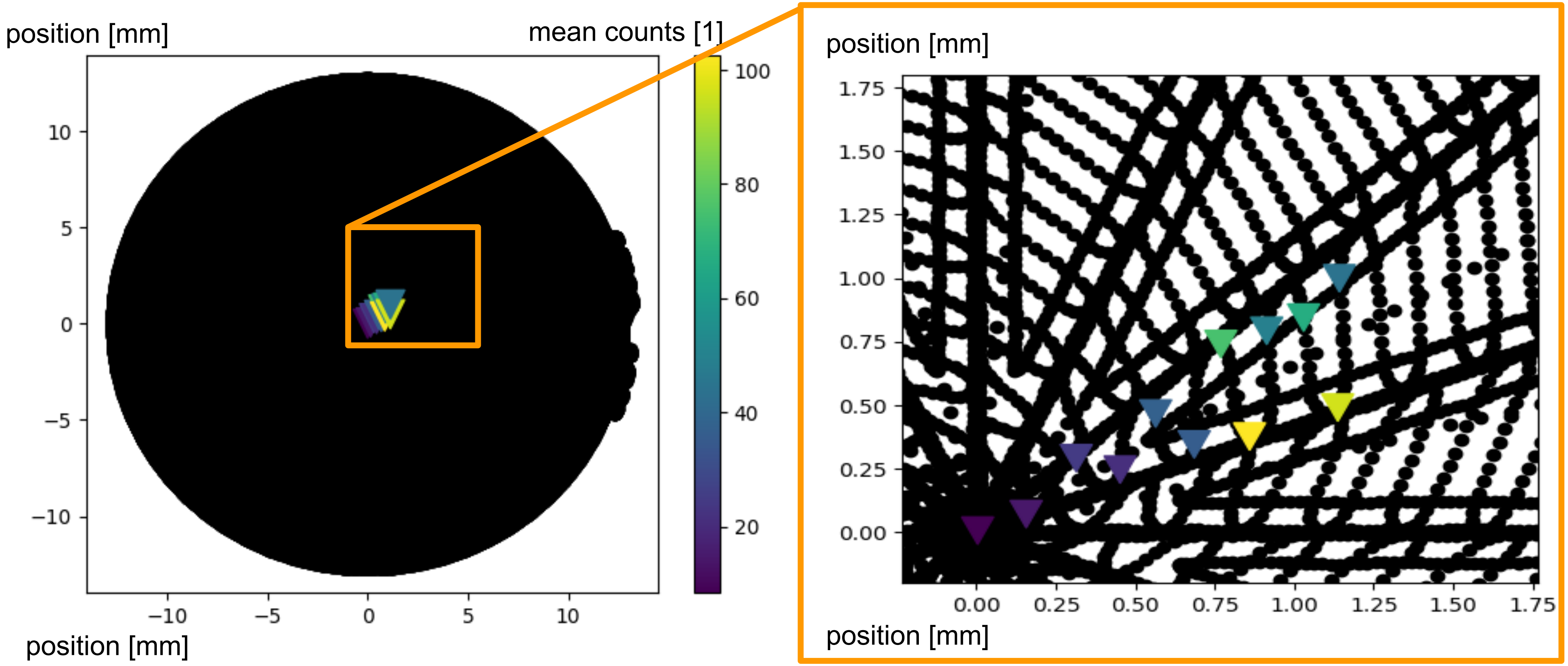
Real Time Clock Signals: Method



Synchronized Melt Pool Images

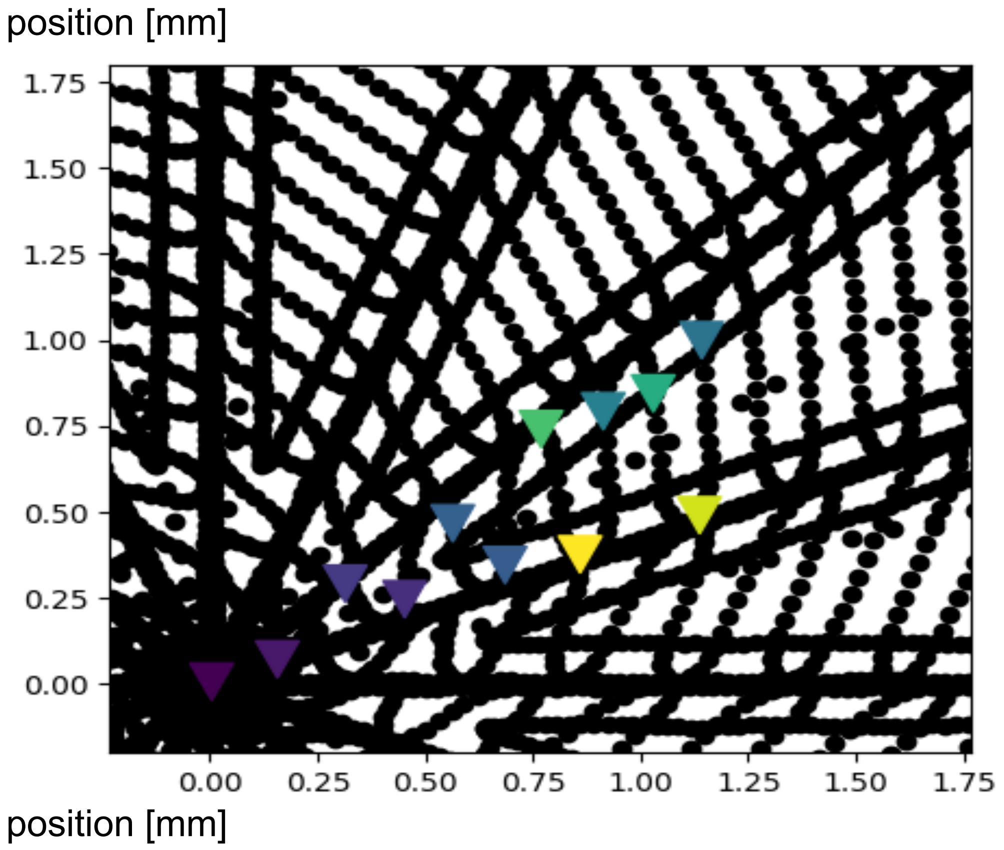


Melt Pool Image Locations



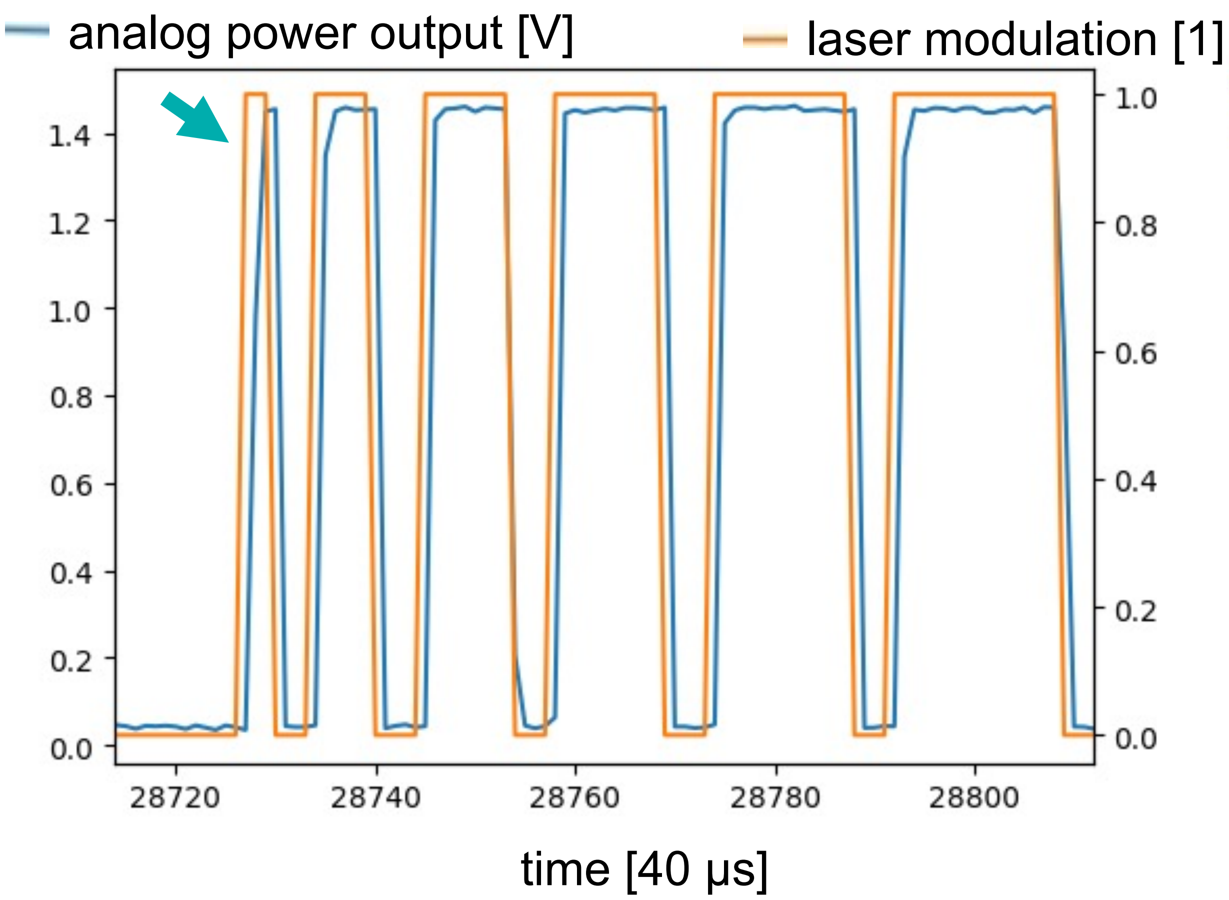
Melt Pool Image Locations

- Spatially resolved melt pool image locations enabled by time-synchronization
- Exposure time is added to synchronization trigger to find the nearest x/y position



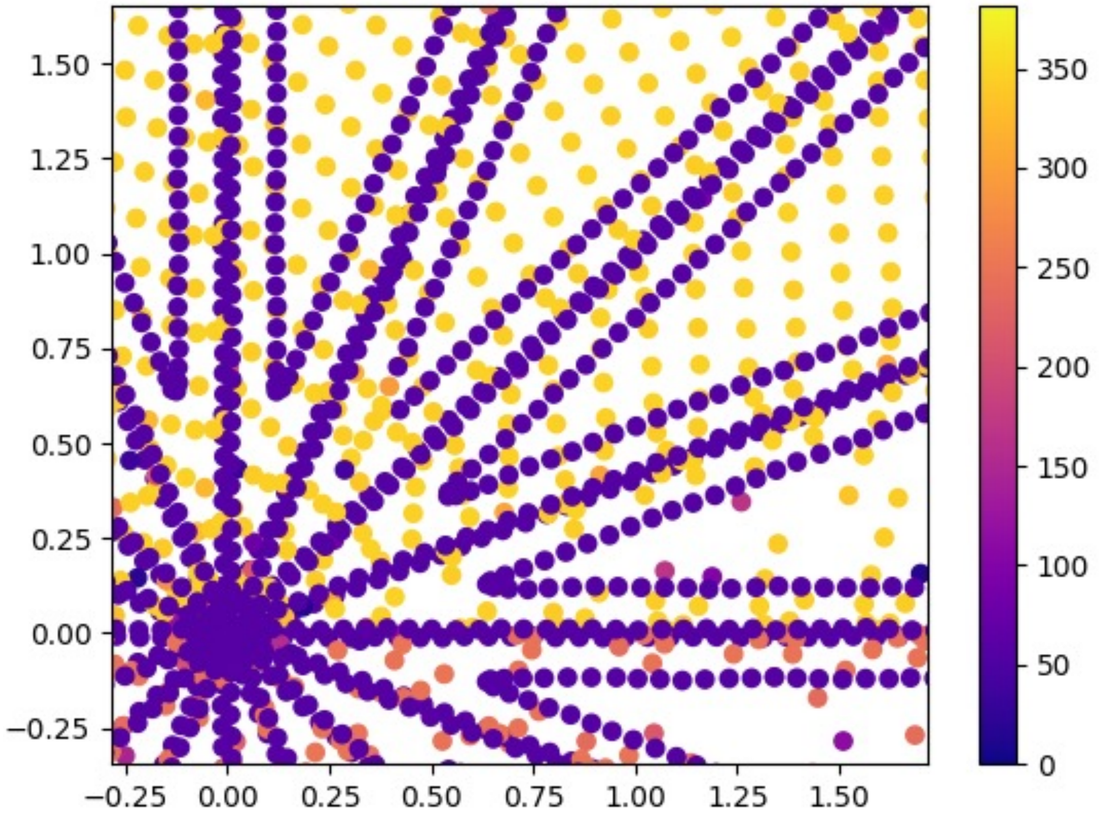
Laser Power Monitoring

- **25 kHz sampling rate**
- **Low cost**
- **Synchronized with position and time**
  - **Laser response timing is recorded**



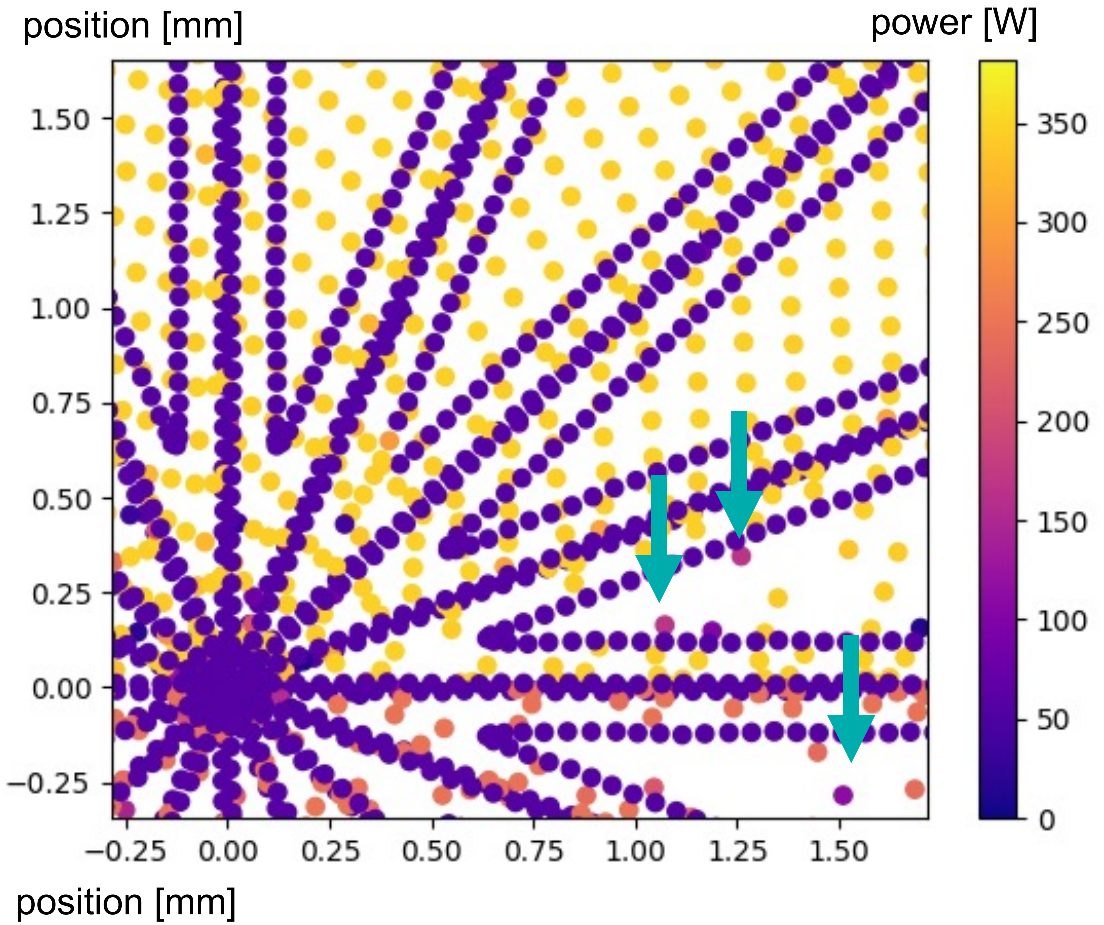
Laser Power Monitoring

- 25 kHz sampling rate
- Low cost
- Synchronized with position and time
- Point field of the process



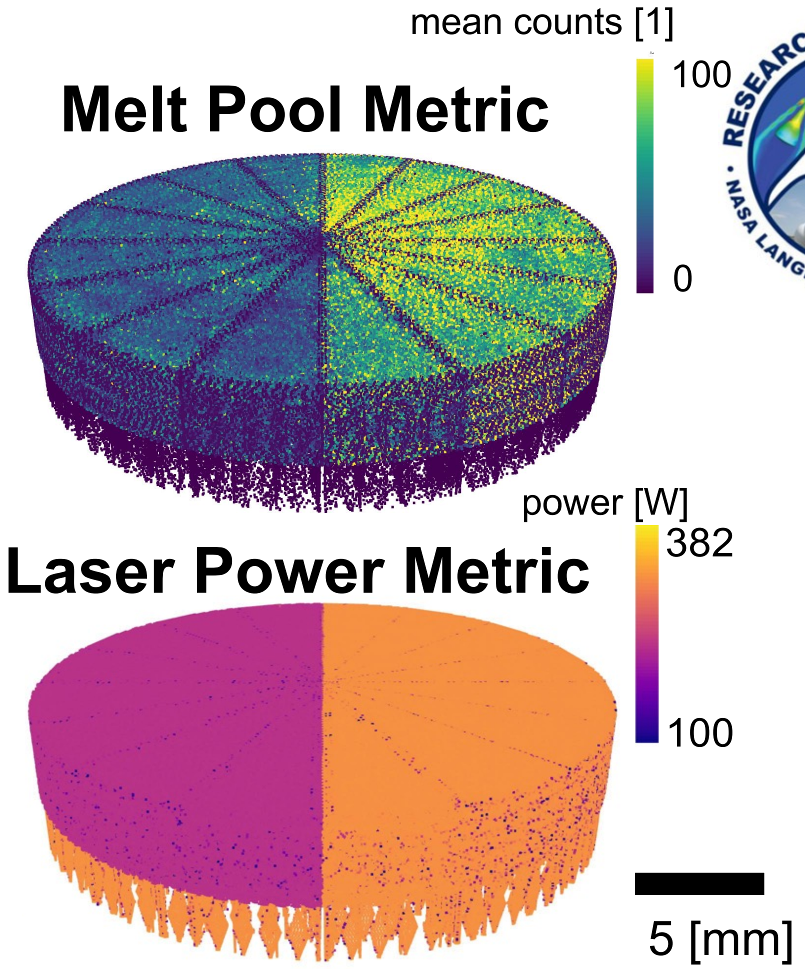
Laser Power Monitoring

- 25 kHz sampling rate
- Low cost
- Synchronized with position and time
- Point field of the process
  - Laser response anomalies



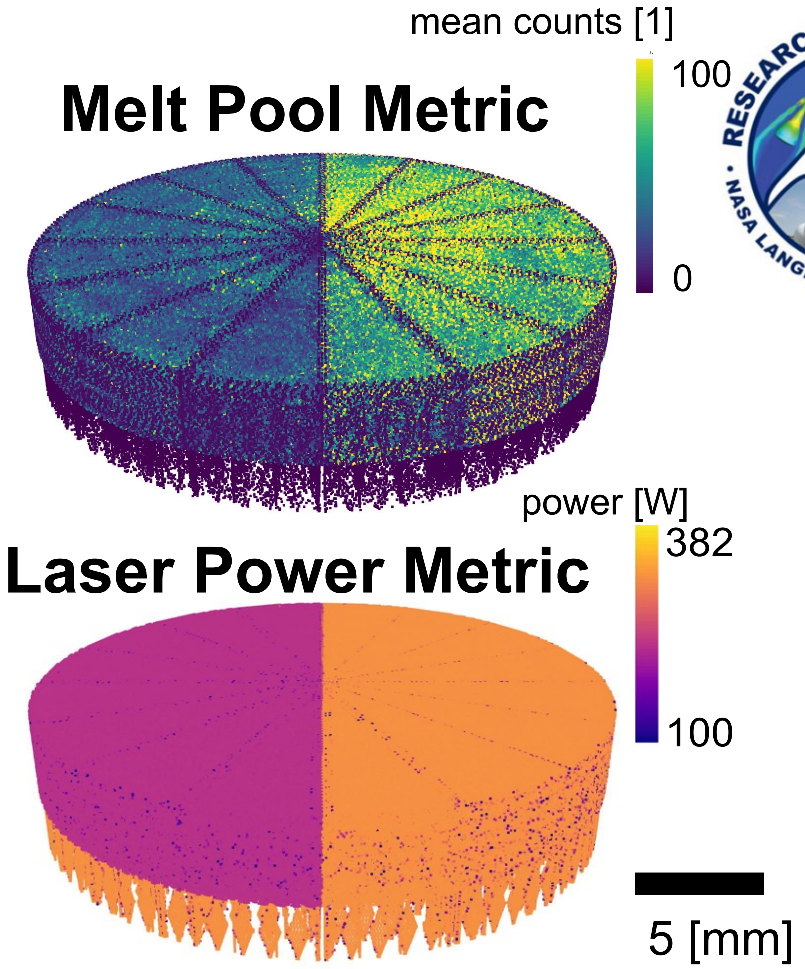
Summary

- **Synchronization enables spatially resolved metrics**
- **Melt pool imaging**
  - **Emission limits sampling rate**
  - **Tb data storage**
  - **Complex interpretation**
  - **High cost, rich data**
- **Laser power monitoring**



Summary

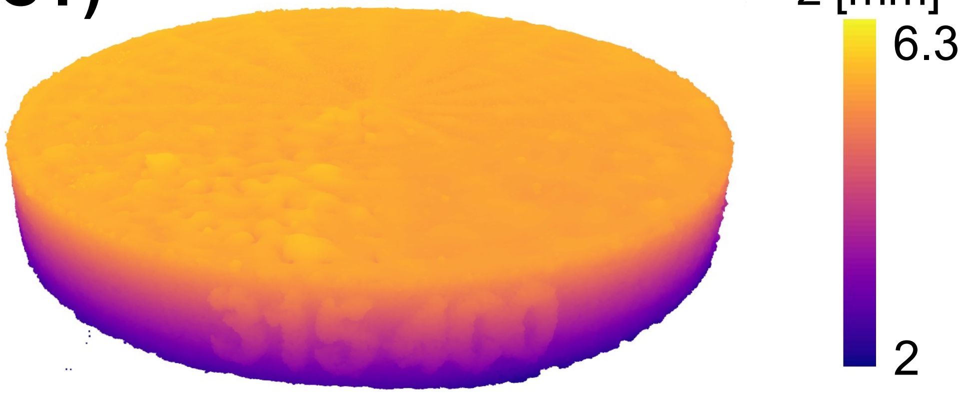
- **Synchronization enables spatially resolved metrics**
- **Coaxial imaging**
- **Laser power monitoring**
  - Position synchronization limits sampling rate, ≤100 [kHz]
  - Point field of the process
  - Low cost, minimal data



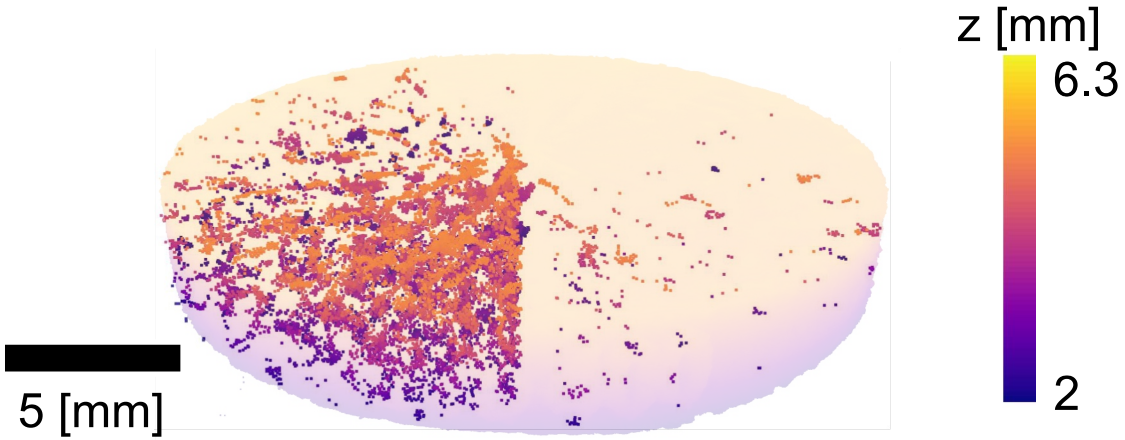
Ongoing Work

- **Determine statistical relationships between in-situ process monitoring metrics and porosity**
- **Substantially enabled by data synchronization**

X-ray Computed Tomography (XCT)



Porosity



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    - Analytical Mechanics Associates, Hampton VA
- NASA Langley Research Center, Nondestructive Evaluation Sciences Branch
  - William Sommer
    - Analytical Services & Materials, Hampton VA

Questions

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Summary

- **Synchronization of in-situ process monitoring enables efficient calculation and analysis of spatially resolved process metrics**
- **Process metrics are being developed to identify process anomalies that lead to defects in AM parts**