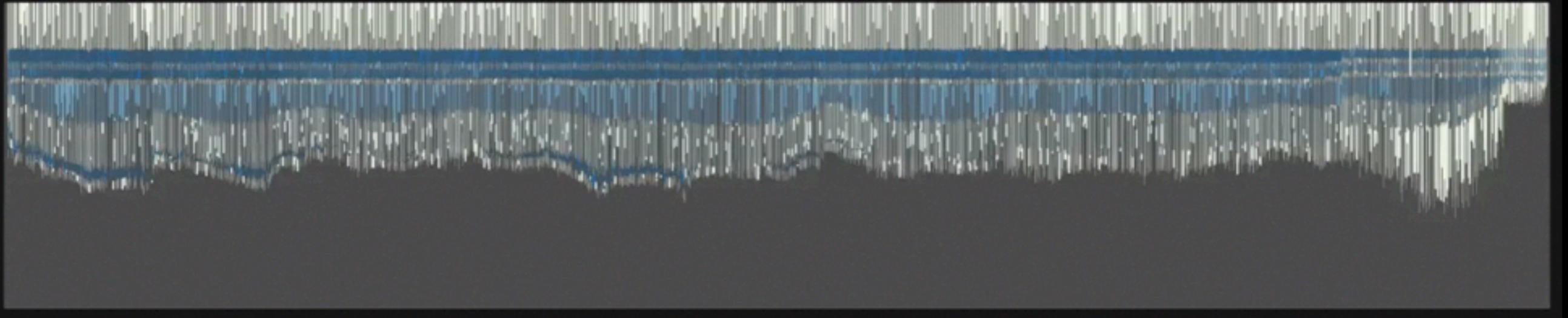


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CHAD A. STEED

OAK RIDGE NATIONAL LAB (ORNL)

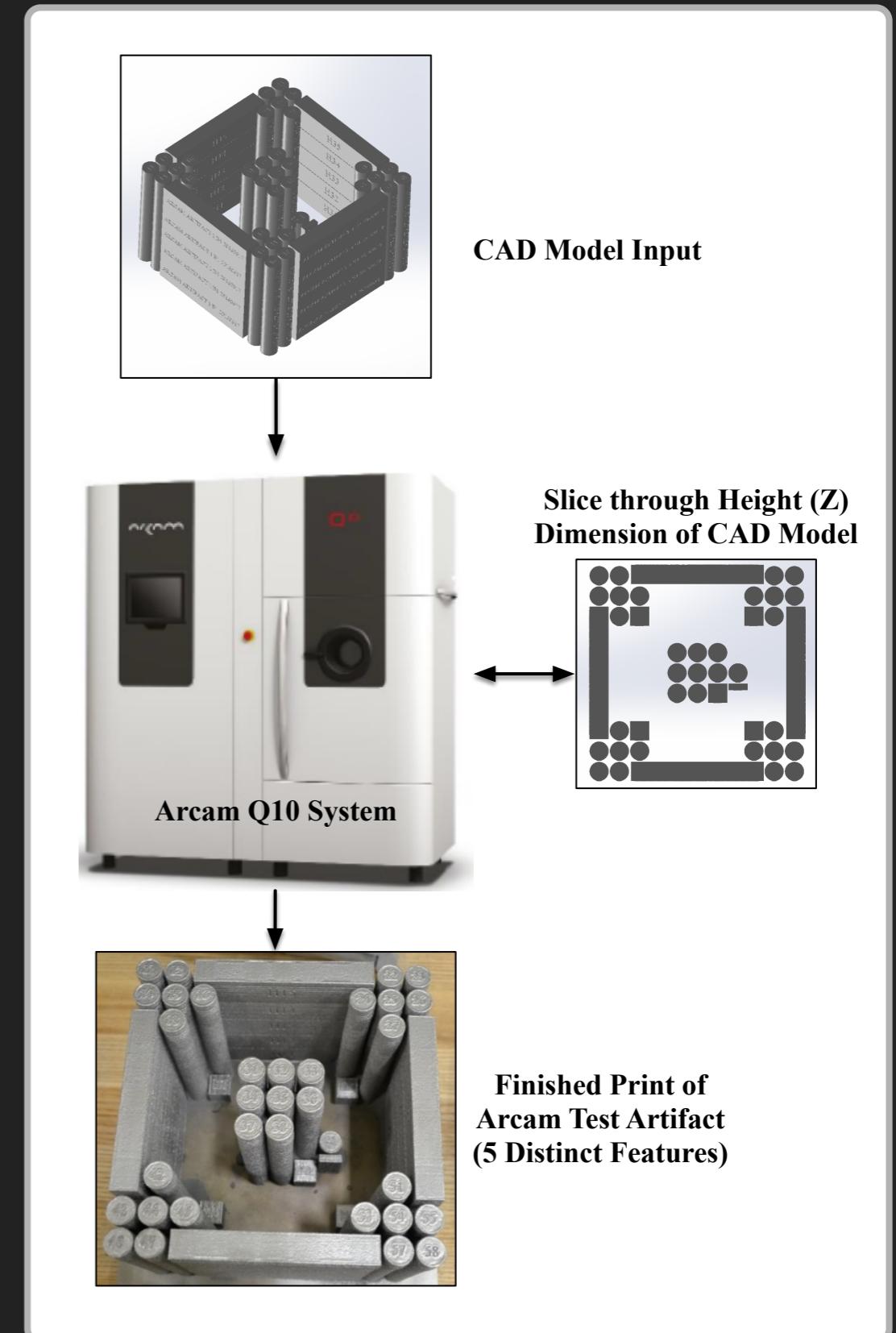
ADVANCING ADDITIVE MANUFACTURING THROUGH VISUAL DATA SCIENCE

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WHAT IS ADDITIVE MANUFACTURING?

ADDITIVE MANUFACTURING

- ▶ Collaborations with domain experts from ORNL's Manufacturing Demonstration Facility (MDF)
- ▶ 3D printing is transforming the manufacturing process
 - ▶ Greater geometrical freedom
 - ▶ Less material waste
- ▶ Predict and improve quality of 3D printed objects to unlock the full potential
 - ▶ Requires a deep understanding of the log and imagery data from 3D printer builds
 - ▶ Visual data science tools are needed



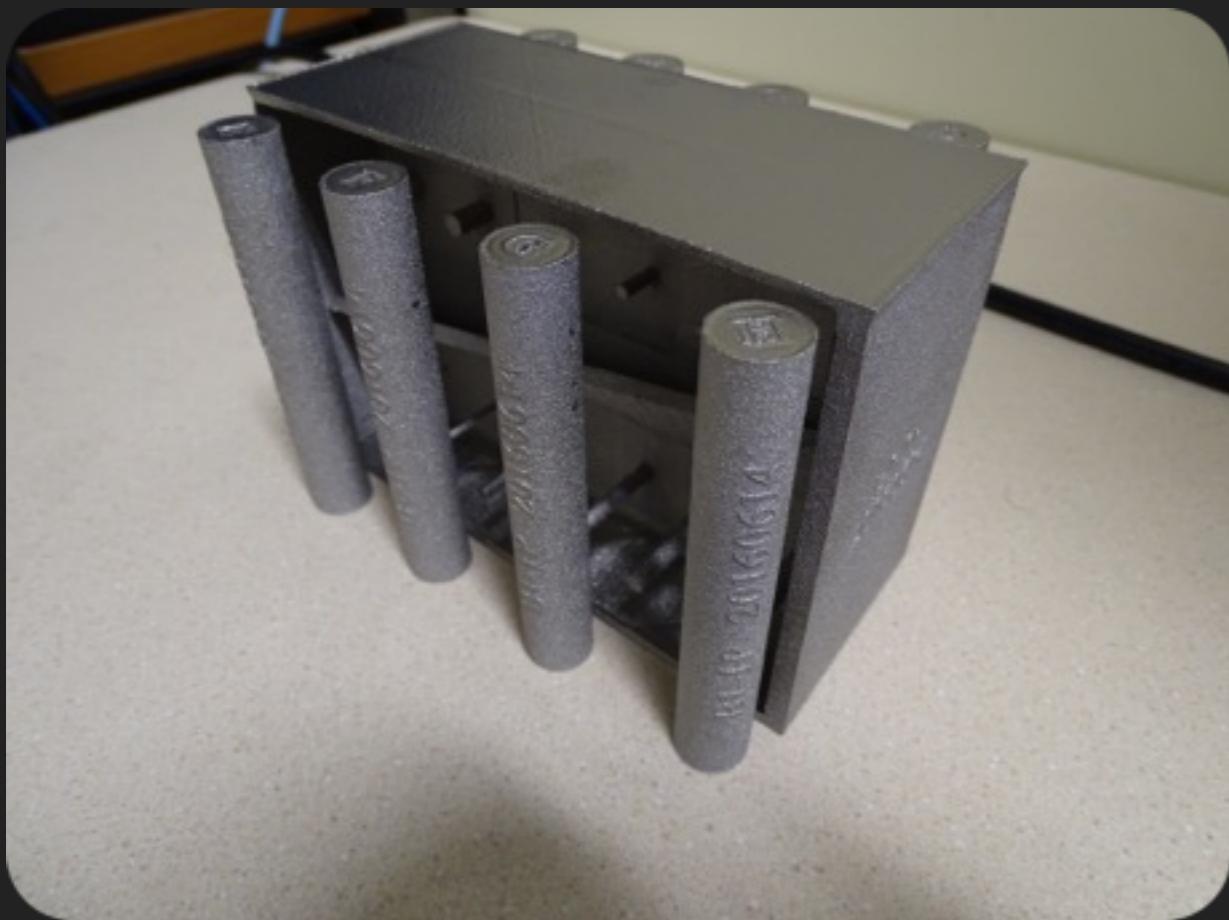
WHAT IS ADDITIVE MANUFACTURING?

ORNL MANUFACTURING DEMONSTRATION FACILITY

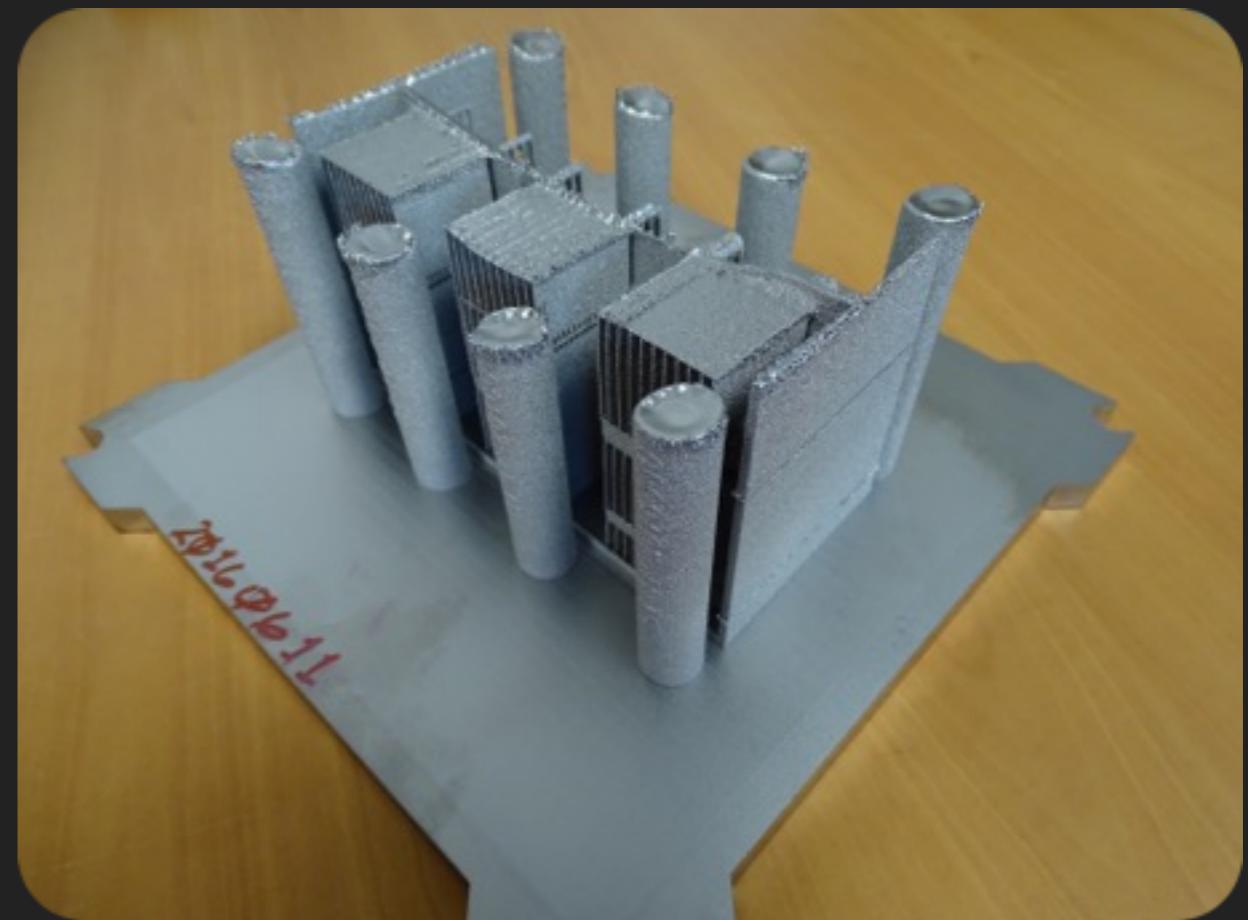


WHAT IS ADDITIVE MANUFACTURING?

EXAMPLES 3D PRINTER BUILDS (GOOD AND BAD)



Good



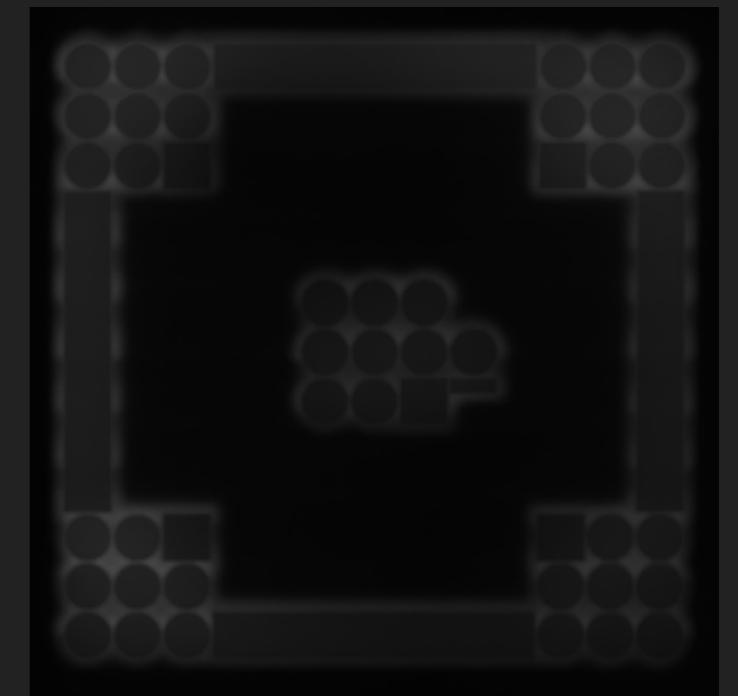
Bad

WHAT IS ADDITIVE MANUFACTURING?

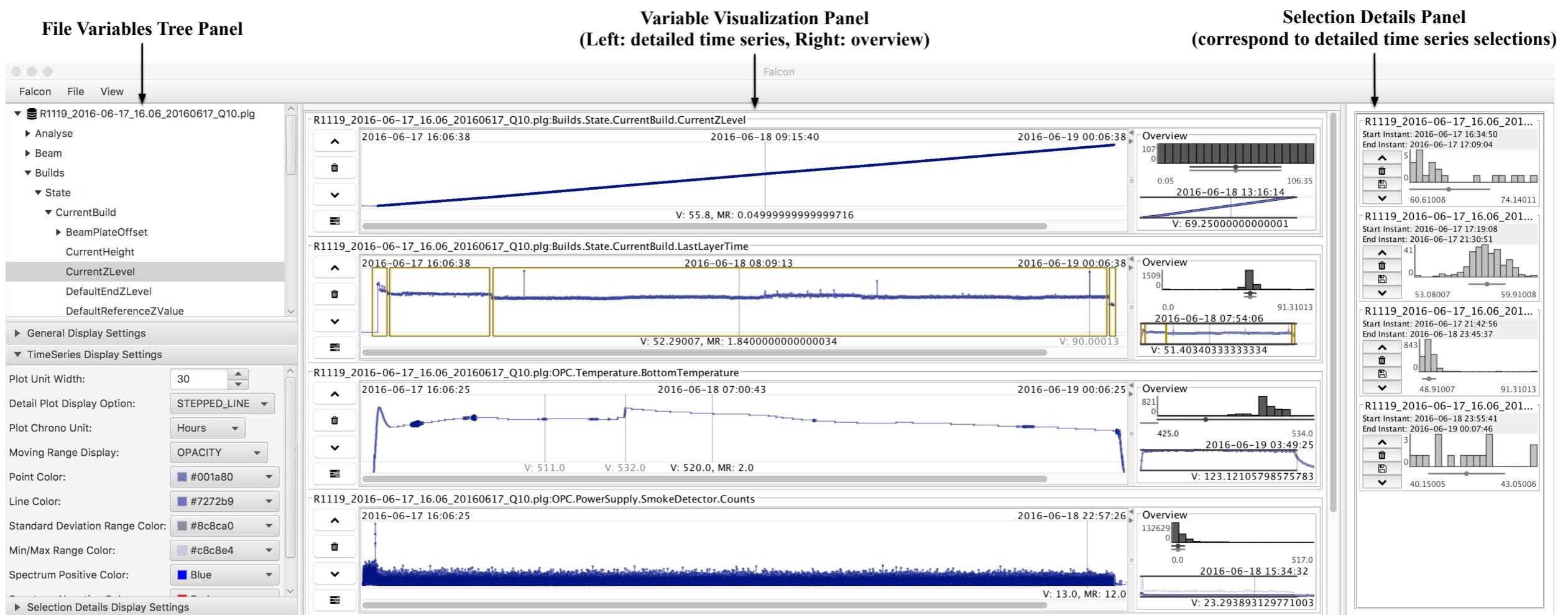
3D PRINTER LOG AND IMAGERY DATA

- ▶ Log files are critical but challenging:
 - ▶ long (multiple days)
 - ▶ large (millions of data points, GB to TB)
 - ▶ multivariate (thousands of variables)
 - ▶ irregularly sampled
 - ▶ unstructured text file format
- ▶ Near infrared (IR) imagery for each build layer
- ▶ Traditional data analytics tools are inadequate

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1381470	2016-06-18 06:54:14.955 OPC.PowerSupply.SmokeDetector.Counts SuperUser (OPC) 10698566 21
1381471	2016-06-18 06:54:14.965 OPC.PowerSupply.HighVoltage.SafetySignal [OnPositiveFlank(SafetySignalTimer.Timeout)] Arcam.EBMControl.Process.HighVoltageControl.OnTimeToSendSafetySignal() (Logic) 10698566 False
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1381477	2016-06-18 06:54:15.195 OPC.PowerSupply.SmokeDetector.Counts SuperUser (OPC) 10698575 1
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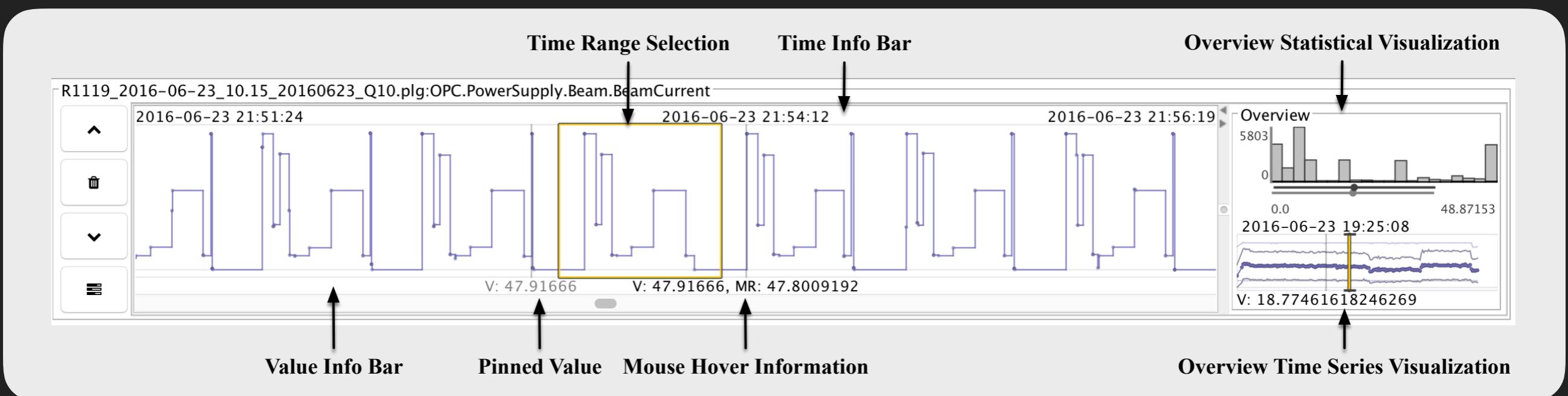


INTRODUCING FALCON

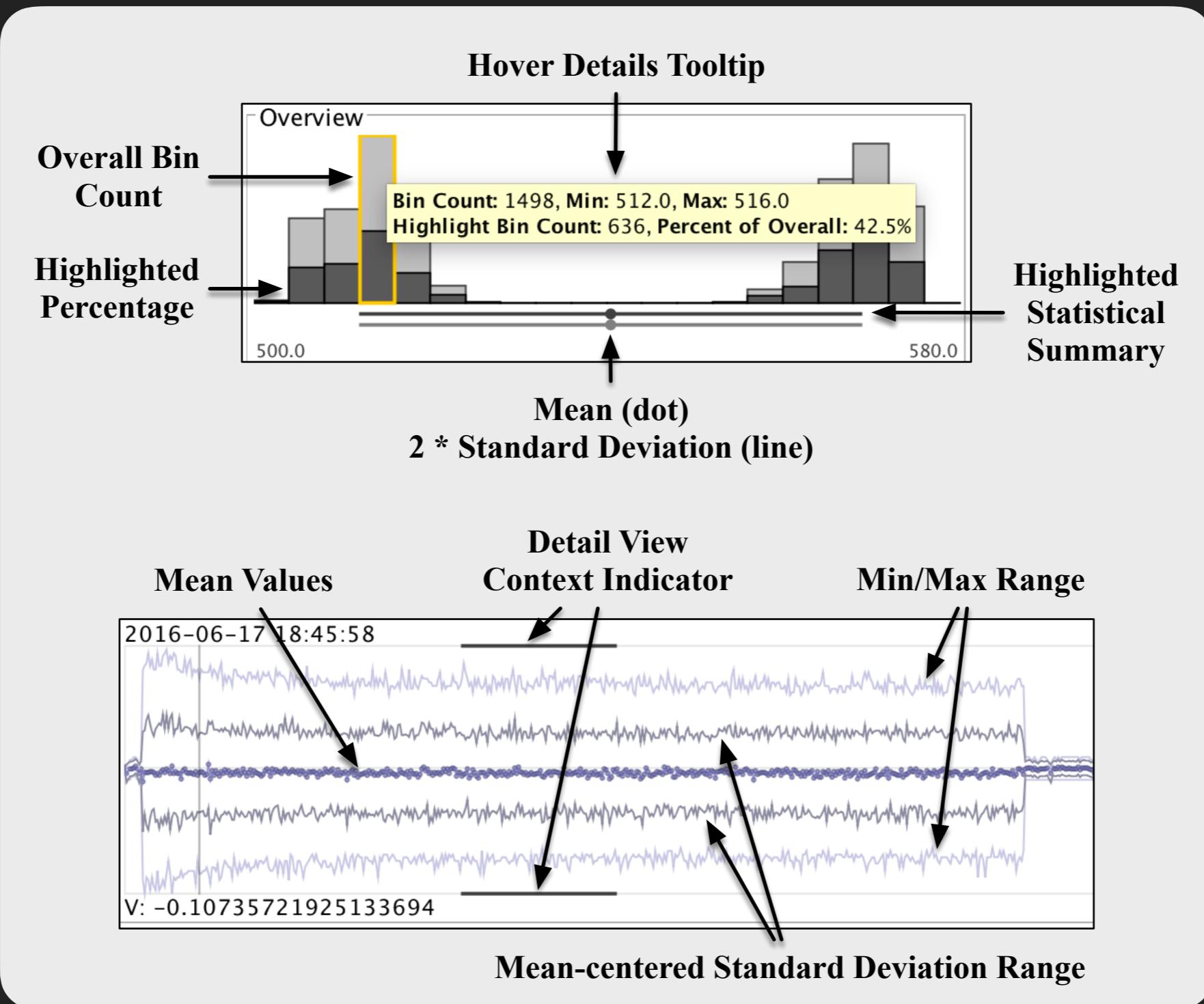


VARIABLE VISUALIZATION PANEL

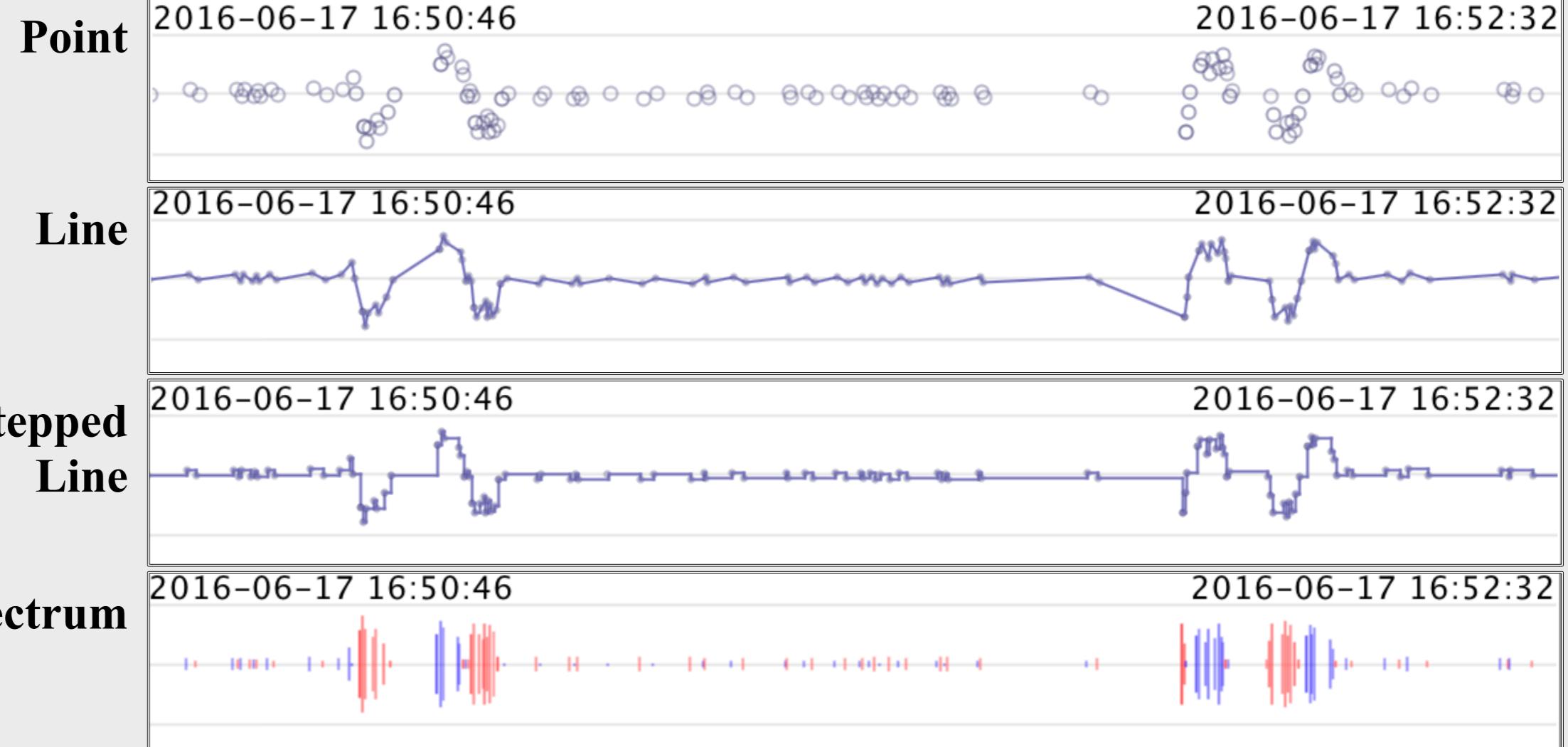
- ▶ Consists of 2 overviews + 1 detail visualization for a single variable of interest (stackable for multiple variables)
- ▶ Interactions in each separate view are linked
- ▶ Details-on-demand capabilities



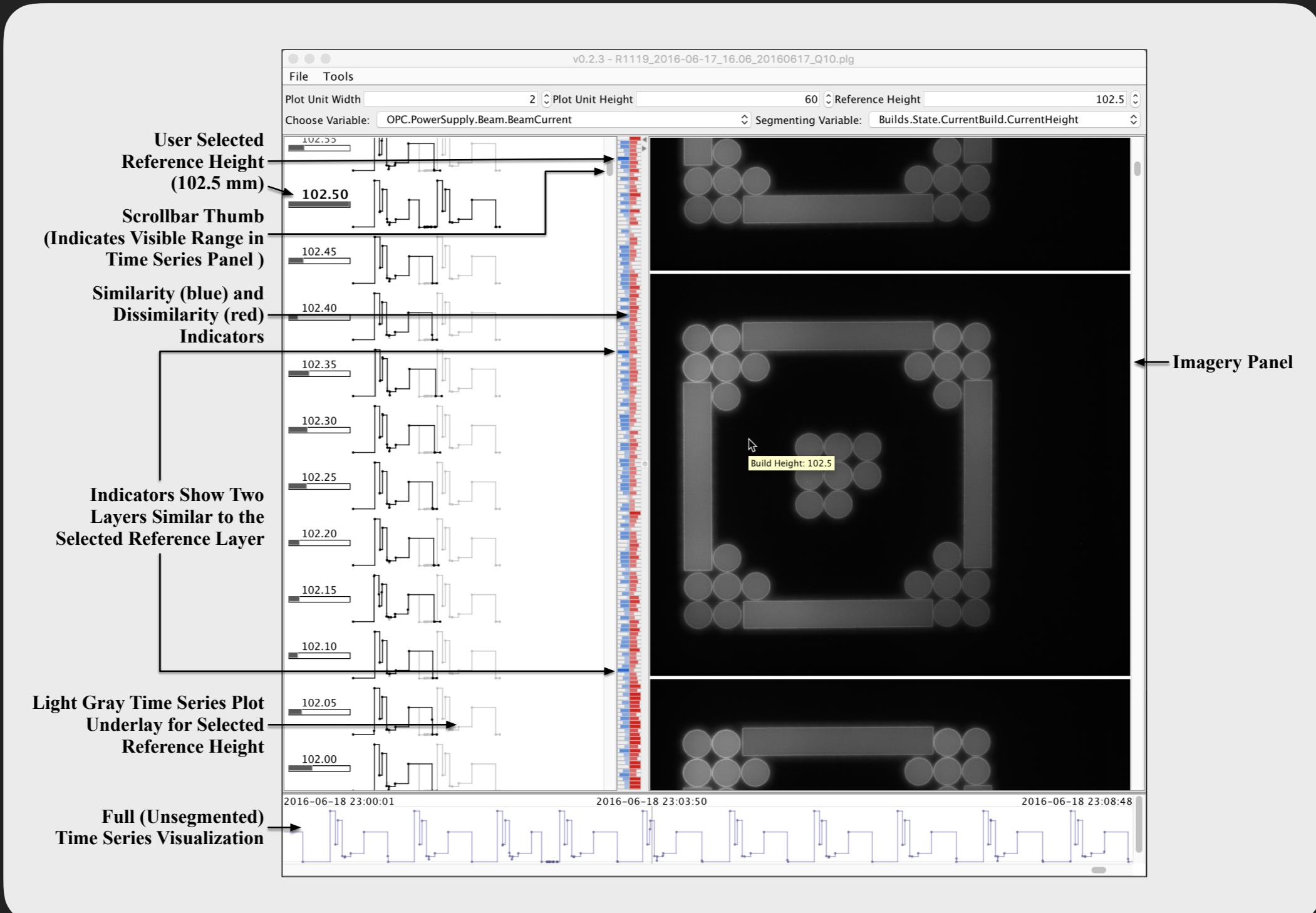
OVERVIEW VISUALIZATIONS



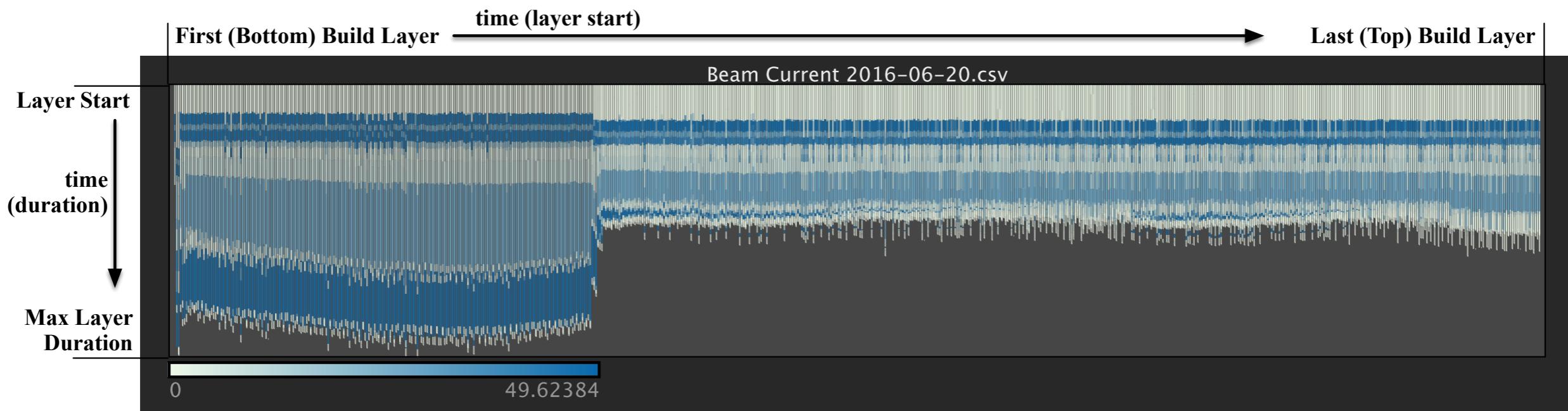
DETAIL TIME SERIES VISUALIZATION DISPLAY MODES



SEGMENTED TIME SERIES VISUALIZATION



WATERFALL VISUALIZATION



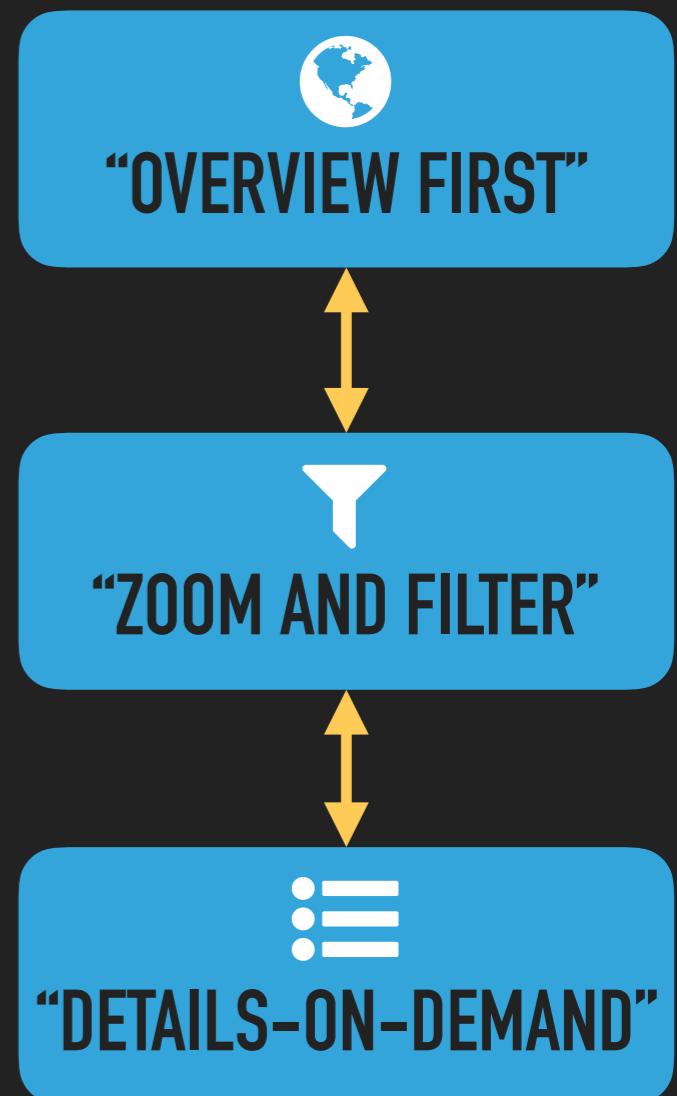
CASE STUDY: ANALYSIS OF LOG DATA FROM A 3D PRINTER BUILD

- ▶ Arcam Q10 3D Printer System
 - ▶ Uses electron beam melting to synthesize metallic objects
 - ▶ Data are from the build of a special test configuration used to ensure the Q10 system is functioning properly
 - ▶ Four distinct geometrical layouts and 5 specific features



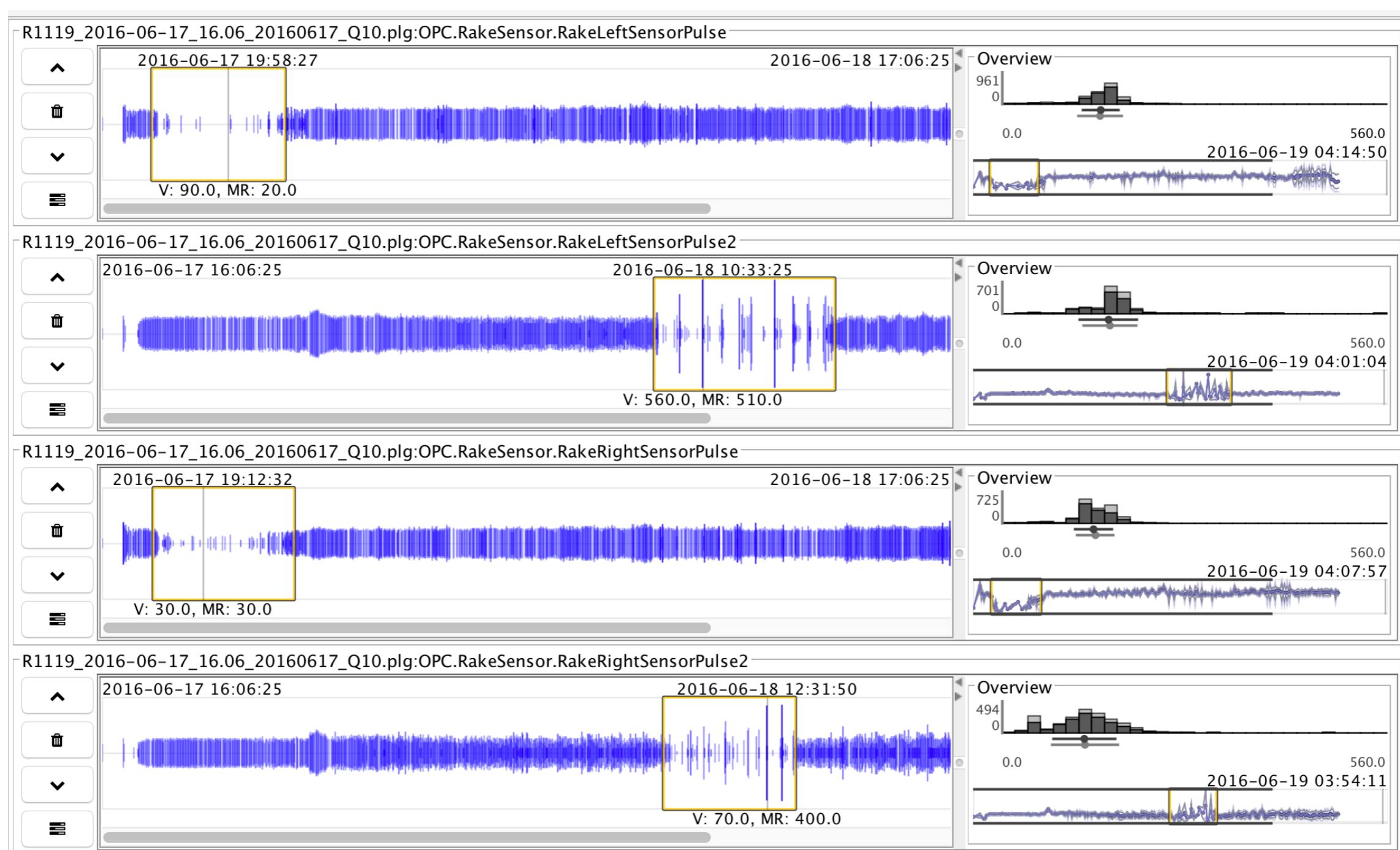
GENERAL ANALYSIS STRATEGY USING FALCON

- ▶ Researchers naturally gravitated toward a workflow that parallels Shneiderman's visual information seeking strategy*
- ▶ Begin with overview of entire build using a set of key variables
- ▶ Drill down to explore the patterns by accessing other variables and more detailed views
- ▶ Along the way, they note interesting patterns
- ▶ Combine log data with imagery data for big picture
- ▶ Follow-up with investigations of microstructure with extremely high details (e.g., scanning microscopy)

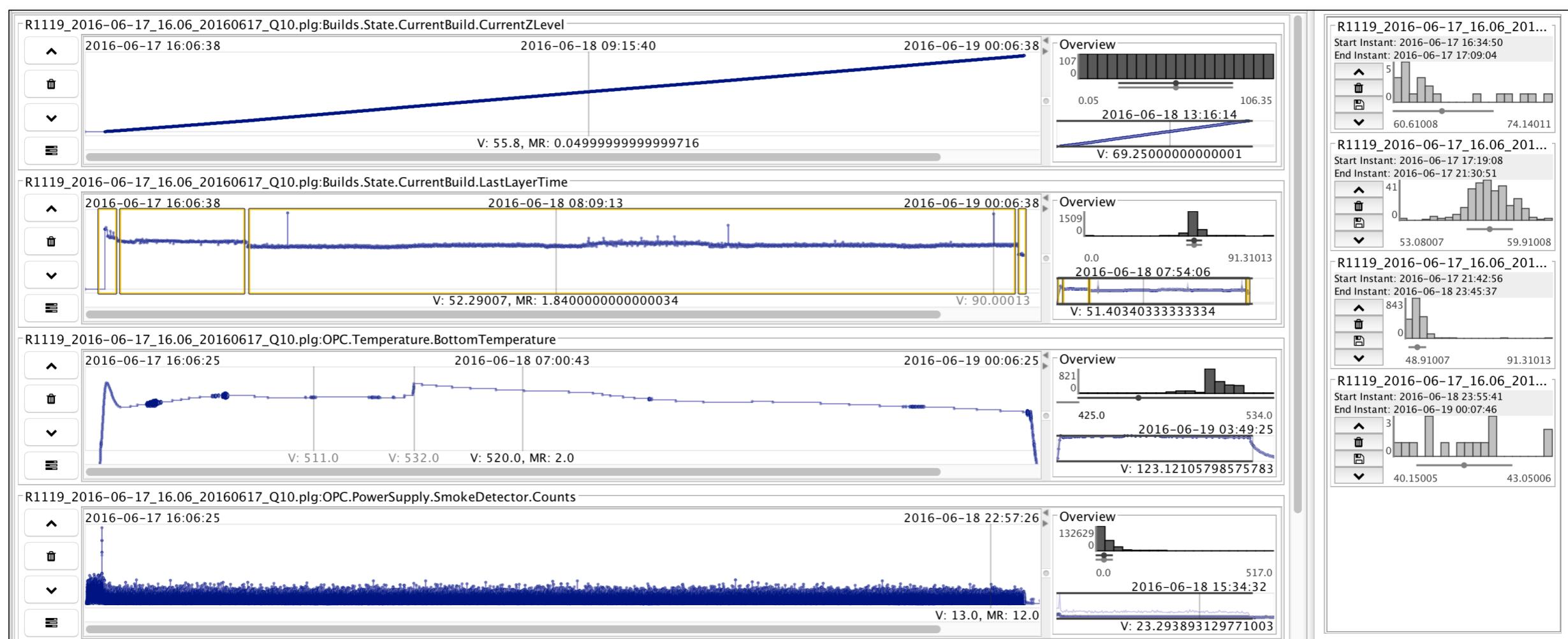


* B. Shneiderman. "The eyes have it: A task by data type taxonomy for information visualizations." In *Proceedings of the IEEE Symposium on Visual Languages*, pp. 336-343, 1996.

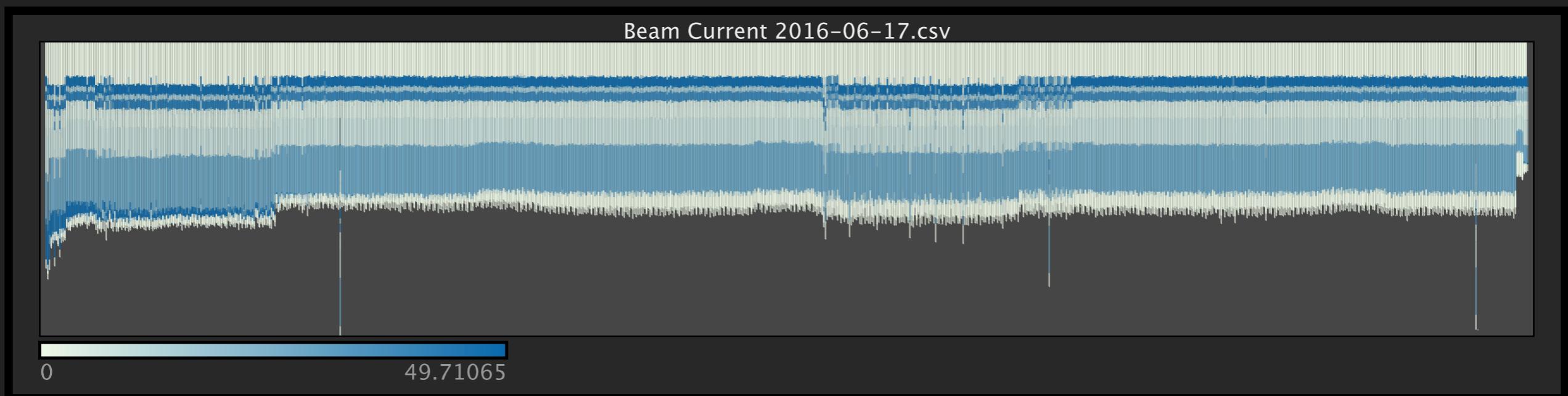
OVERVIEW FIRST



OVERVIEW FIRST



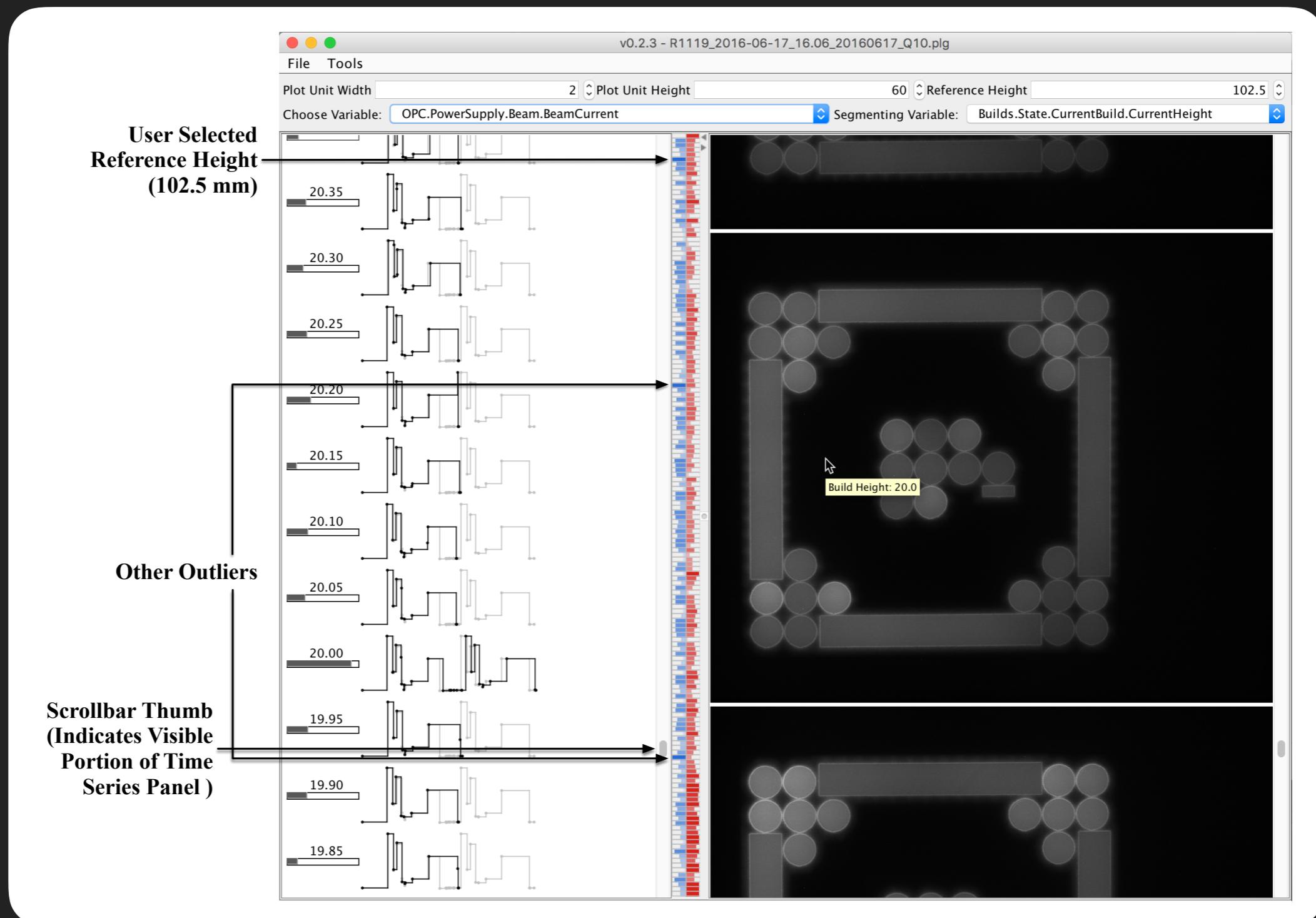
A MORE FOCUSED OVERVIEW



ZOOM AND FILTER



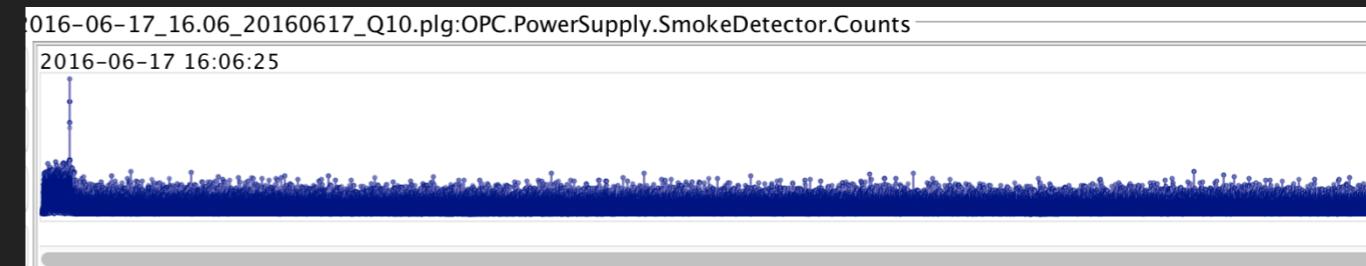
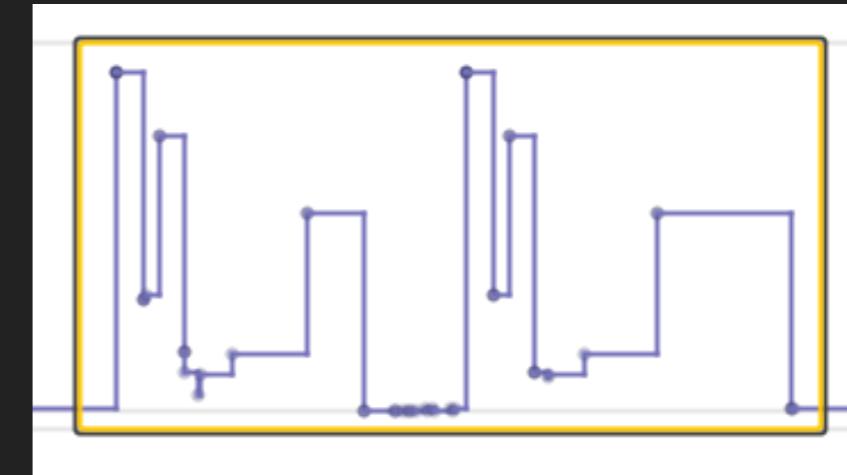
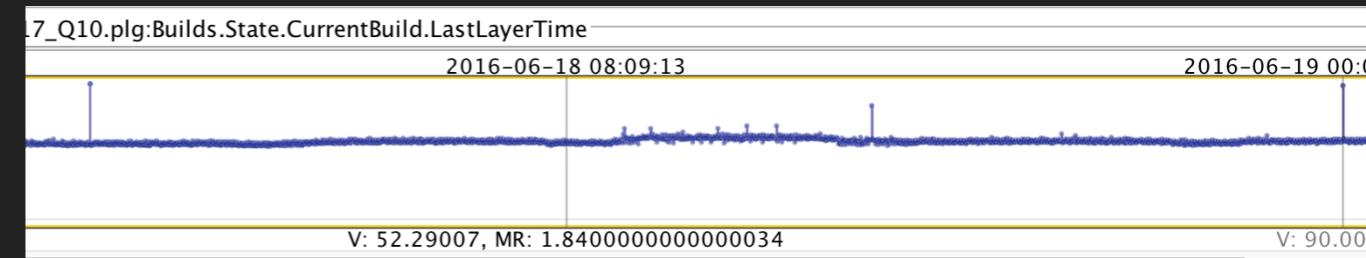
MORE DETAIL, ON DEMAND



THE CAUSE OF THE OUTLIERS

- ▶ Two possibilities:

- ▶ Smoke detection reset
- ▶ Arc trip
- ▶ Both cause signal repeats
- ▶ Here, arc trip is the cause
- ▶ This knowledge led to additional study to see how arc trips affect the microstructure of a build.



CONCLUSIONS

- ▶ Falcon enables significant discoveries that:
 - ▶ Help us detect certain conditions that impact quality
 - ▶ Help us improve the 3D printing process to avoid failures
- ▶ Practical results demonstrate improvements over traditional, general purpose tools
- ▶ ProTip: Strive to include domain experts early and often in the design of new data science techniques to improve efficacy
- ▶ Falcon is applicable to other domains (e.g., cyber security, climate)
- ▶ Open source base version of Falcon coming soon...
 - ▶ <http://cda.ornl.gov/projects/falcon/>



More information is available about this and my other research at <http://csteed.com>.

QUESTIONS?



Special thanks to my collaborators: Ryan Dehoff (ORNL), Vincent Paquit (ORNL), William Halsey (ORNL), Sean Yoder (ORNL), and Sarah Powers (ORNL)