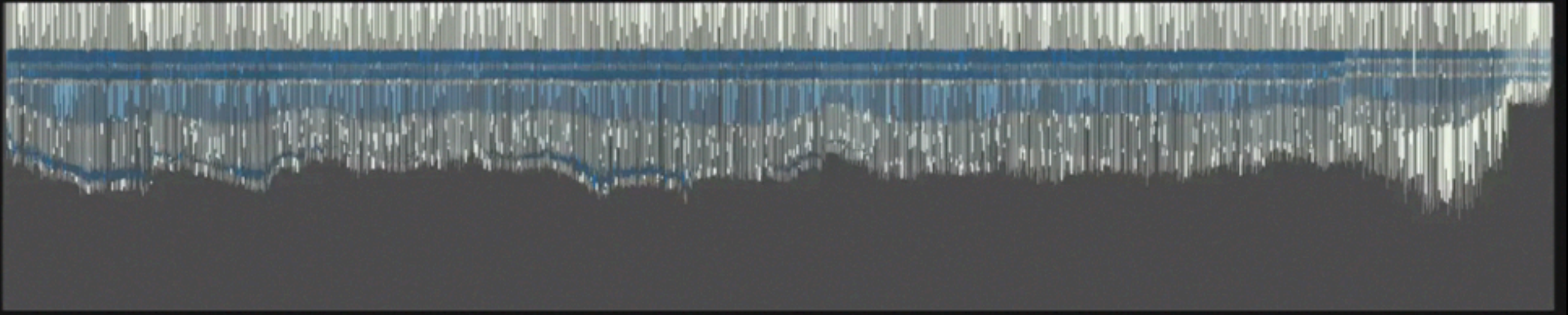


CSTEED@ACM.ORG | [HTTP://CSTEED.COM](http://CSTEED.COM)



CHAD A. STEED

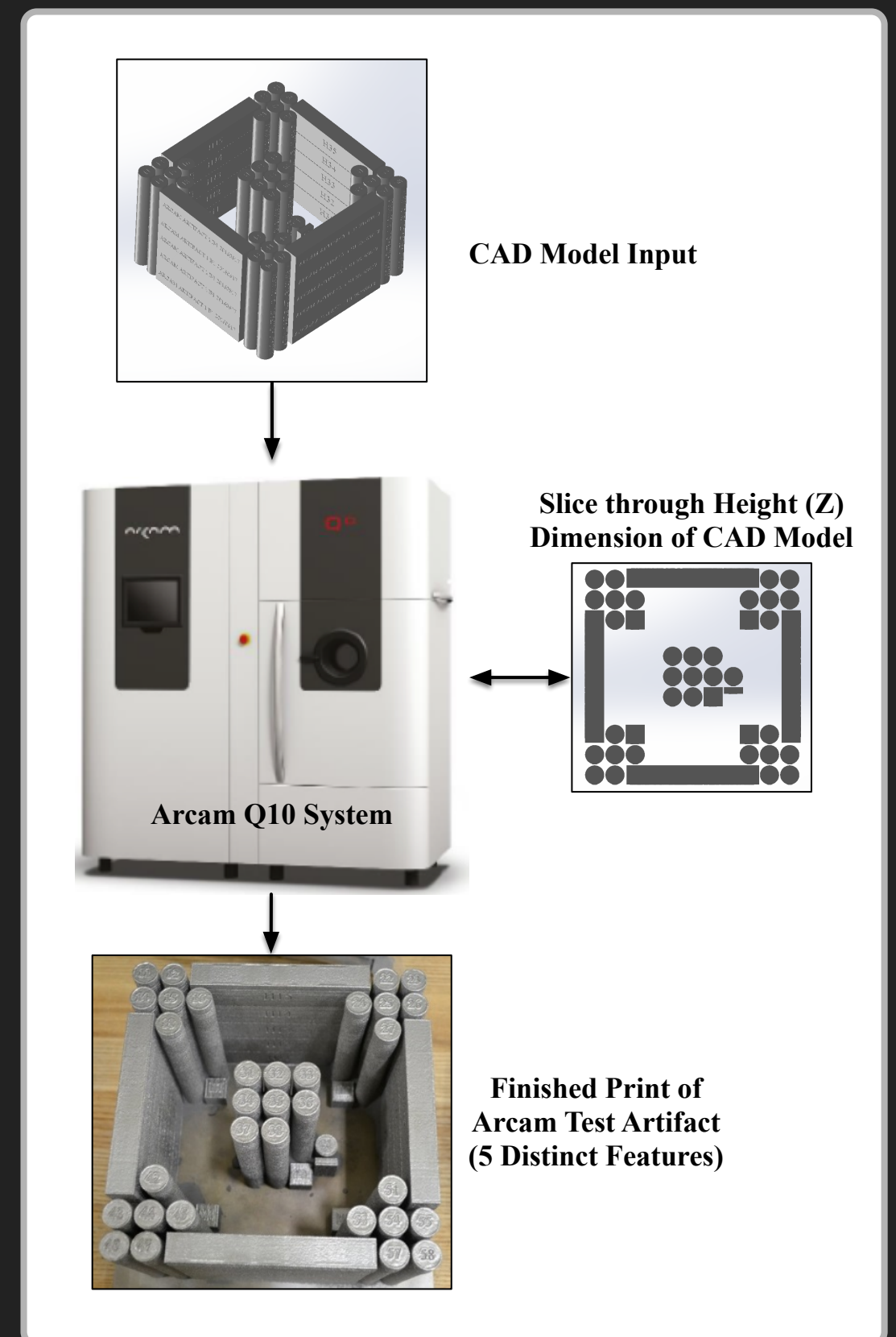
OAK RIDGE NATIONAL LAB (ORNL)

ADVANCING ADDITIVE MANUFACTURING THROUGH VISUAL DATA SCIENCE

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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



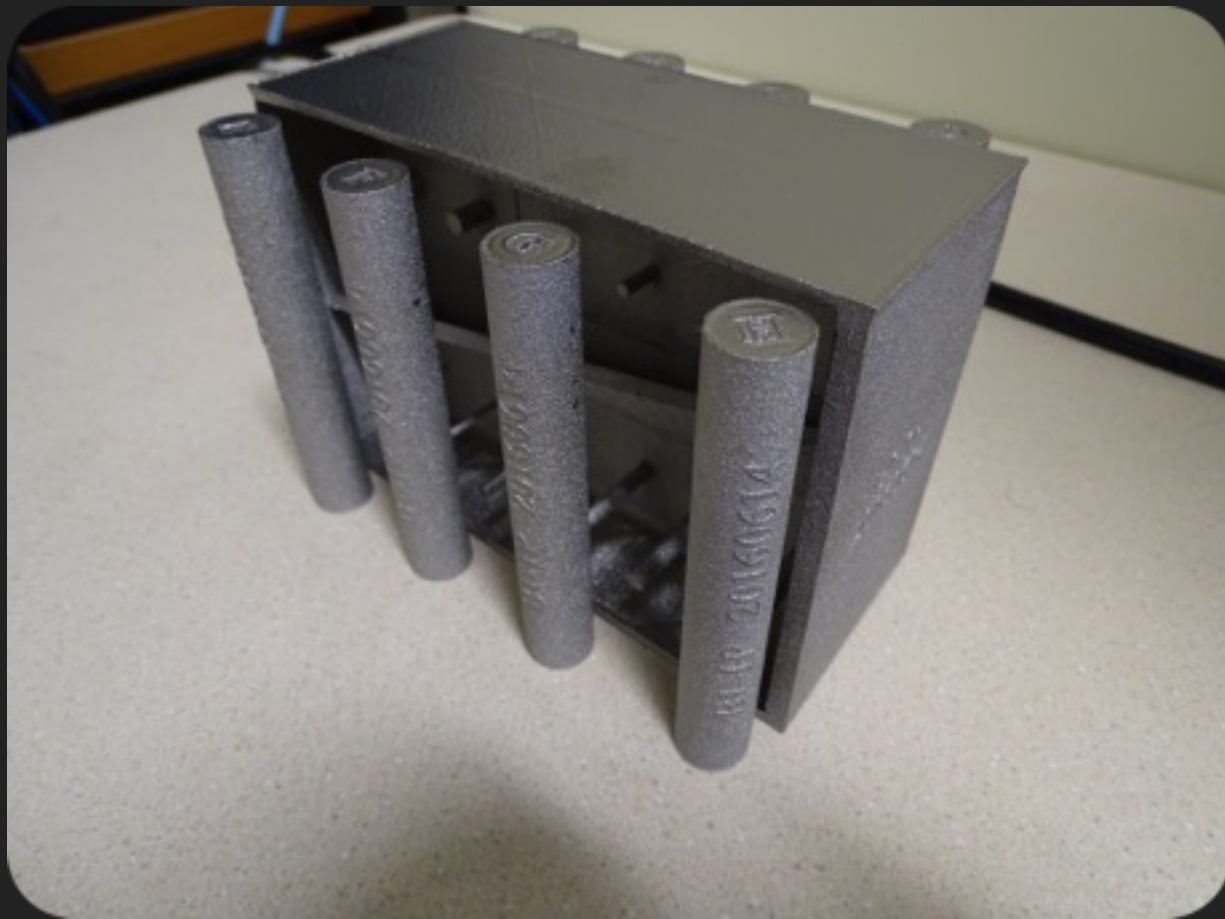
WHAT IS ADDITIVE MANUFACTURING?

ORNL MANUFACTURING DEMONSTRATION FACILITY

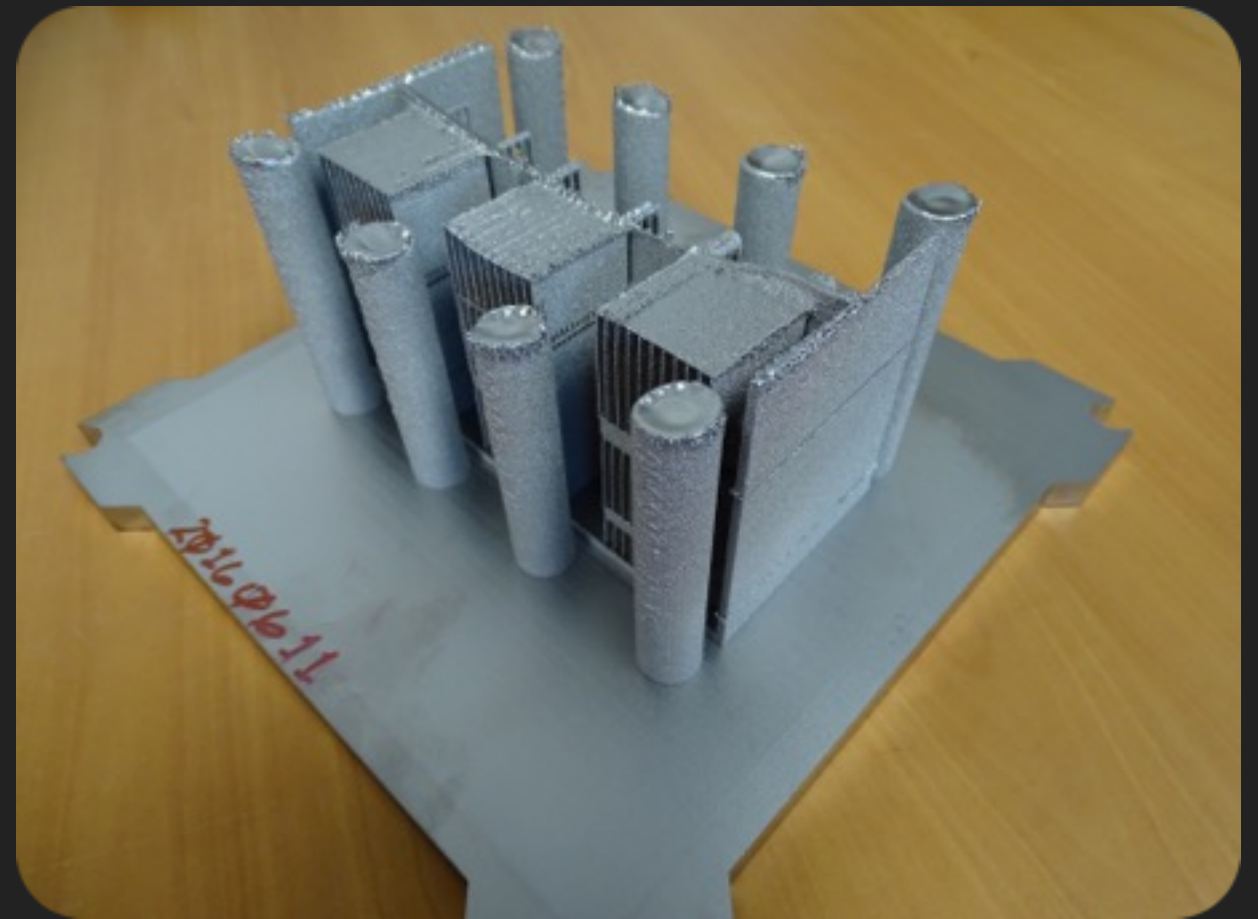


WHAT IS ADDITIVE MANUFACTURING?

EXAMPLES 3D PRINTER BUILDS (GOOD AND BAD)



Good



Bad

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

The screenshot displays a log file with entries such as:

1381458 2016-06-18 06:54:14.375[OPC.PowerSupply.Beam.BeamCurrent|SuperUser (OPC)|18698549|7.58182

1381459 2016-06-18 06:54:14.375[OPC.Table.CurrentFeedback|SuperUser (OPC)|18698549|0.3461

1381460 2016-06-18 06:54:14.375[OPC.InternalCooling.DifferentialPressureOverFilter|OnChange(OPC.

InternalCooling.PressureBeforeFilter.Unfiltered)] Arcam.EBMControl.Process.InternalCooling.

UpdateDifferentialPressureOverFilter() (Logic)|18698549|0.01898873

1381461 2016-06-18 06:54:14.375[OPC.PowerSupply.HighVoltage.Grid|SuperUser (OPC)|18698557|731.

9444399999999999

1381462 2016-06-18 06:54:14.375[OPC.PowerSupply.Beam.BeamCurrent|SuperUser (OPC)|18698557|7.92824

1381463 2016-06-18 06:54:14.655[OPC.Vacuum.ChamberVacuumGaugeFB|SuperUser (OPC)|18698568|0.00485

1381464 2016-06-18 06:54:14.655[OPC.PowerSupply.Filament.VoltageFB|SuperUser (OPC)|18698562|2.737268

1381465 2016-06-18 06:54:14.665[Process.CathodeTuningControl.CathodePower|OnChange(OPC.PowerSupply.

Filament.VoltageFB)] Arcam.EBMControl.Process.CathodeTuningControl.OnCathodePowerChange() (Logic)

|18698562|5.061851

1381466 2016-06-18 06:54:14.665[OPC.InternalCooling.DifferentialPressureOverFilter|OnChange(OPC.

InternalCooling.PressureBeforeFilter.Unfiltered)] Arcam.EBMControl.Process.InternalCooling.

UpdateDifferentialPressureOverFilter() (Logic)|18698562|0.0171882

1381467 2016-06-18 06:54:14.895[Process.CathodeTuningControl.MeanCathodePower|OnChange(Process.

CathodeTuningControl.CathodePower)] Arcam.EBMControl.Process.CathodeTuningControl.

MeasureMeanPower() (Logic)|18698563|5.858337

1381468 2016-06-18 06:54:14.955[OPC.PowerSupply.Filament.VoltageFB|SuperUser (OPC)|18698566|2.725694

1381469 2016-06-18 06:54:14.955[OPC.PowerSupply.Focus.FocusFB|SuperUser (OPC)|18698566|3227.72

1381470 2016-06-18 06:54:14.955[OPC.PowerSupply.SmokeDetector.Counts|SuperUser (OPC)|18698566|21

1381471 2016-06-18 06:54:14.965[OPC.PowerSupply.HighVoltage.SafetySignal|OnPositiveFlank(

SafetySignalTimer.Timeout)] Arcam.EBMControl.Process.HighVoltageControl.OnTimeToSendSafetySignal

() (Logic)|18698566|False

1381472 2016-06-18 06:54:14.965[Process.CathodeTuningControl.CathodePower|OnChange(OPC.PowerSupply.

Filament.VoltageFB)] Arcam.EBMControl.Process.CathodeTuningControl.OnCathodePowerChange() (Logic)

|18698566|5.836268

1381473 2016-06-18 06:54:15.035[Process.CathodeTuningControl.MeanCathodePower|OnChange(Process.

CathodeTuningControl.CathodePower)] Arcam.EBMControl.Process.CathodeTuningControl.

MeasureMeanPower() (Logic)|18698567|5.849871

1381474 2016-06-18 06:54:15.075[OPC.Table.CurrentFeedback|SuperUser (OPC)|18698570|0.2387

1381475 2016-06-18 06:54:15.075[OPC.Rake.CurrentFeedback|SuperUser (OPC)|18698570|0.2387

1381476 2016-06-18 06:54:15.195[OPC.PowerSupply.Focus.FocusFB|SuperUser (OPC)|18698575|3129.341

1381477 2016-06-18 06:54:15.195[OPC.PowerSupply.SmokeDetector.Counts|SuperUser (OPC)|18698575|1

1381478 2016-06-18 06:54:15.225[Core.Cache.Performance.MaxCycleTime|SuperUser (IOCache)|18698575|208.

55629016732864

1381479 2016-06-18 06:54:15.225[OPC.Vacuum.TurboPump[1].Current|OnChange(OPC.Vacuum.TurboPump[1].

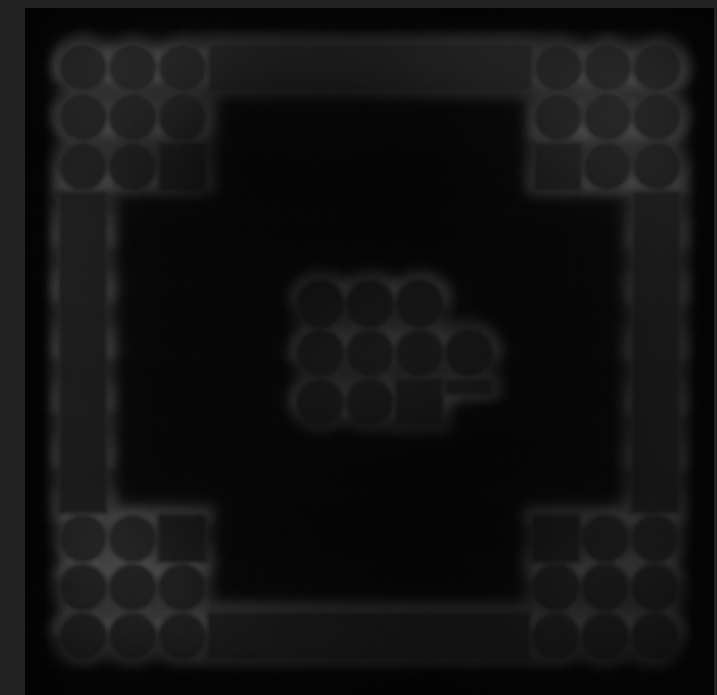
CurrentRawOP)] Arcam.EBMControl.Process.Scaling.OnTurboColumnCurrentChange() (Logic)|18698575|0.

78188881811981281

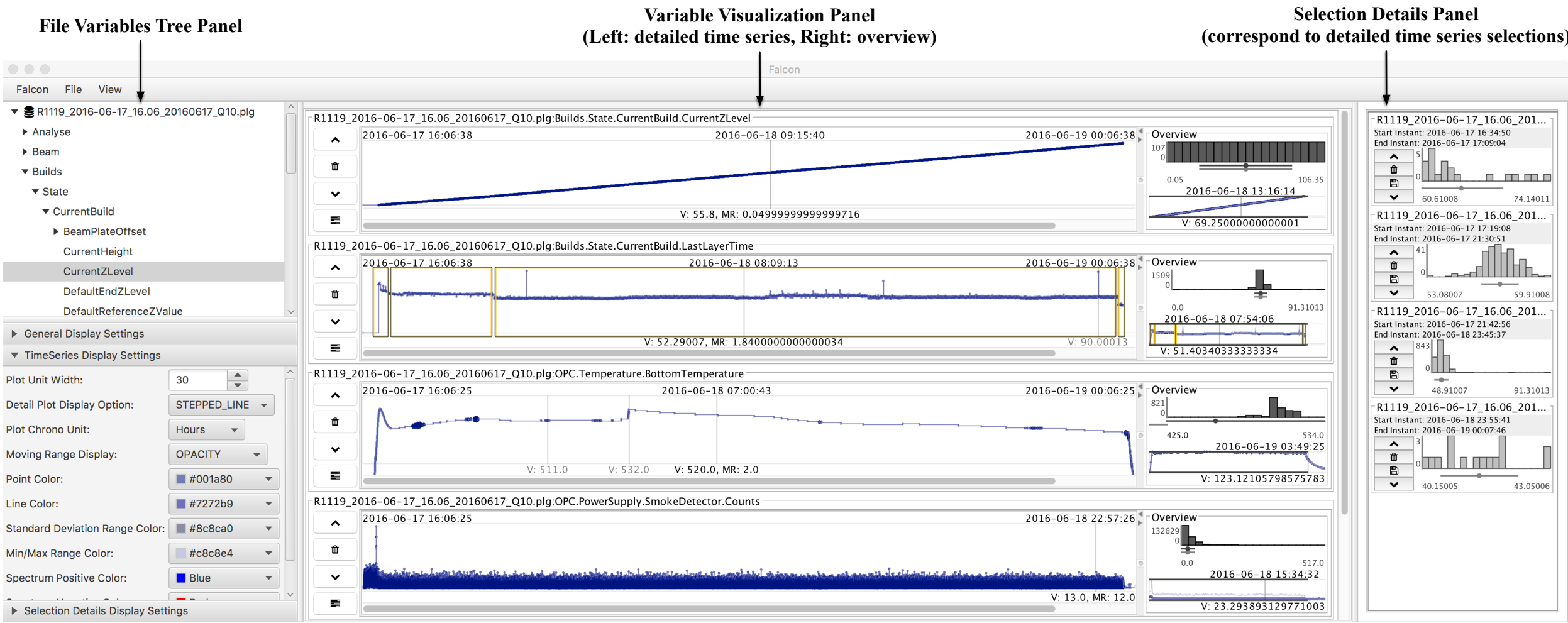
1381480 2016-06-18 06:54:15.295[OPC.Vacuum.ChamberVacuumGaugeFB|SuperUser (OPC)|18698579|0.003829

1381481 2016-06-18 06:54:15.295[OPC.Table.CurrentFeedback|SuperUser (OPC)|18698579|0.4615

1381482 2016-06-18 06:54:15.465[OPC.Table.CurrentFeedback|SuperUser (OPC)|18698581|0.2387

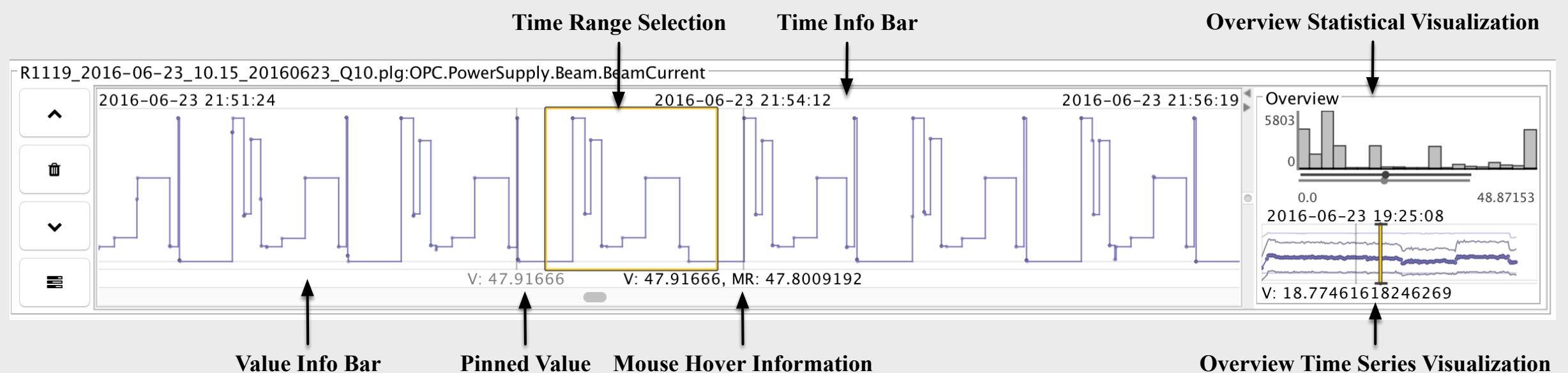


INTRODUCING FALCON

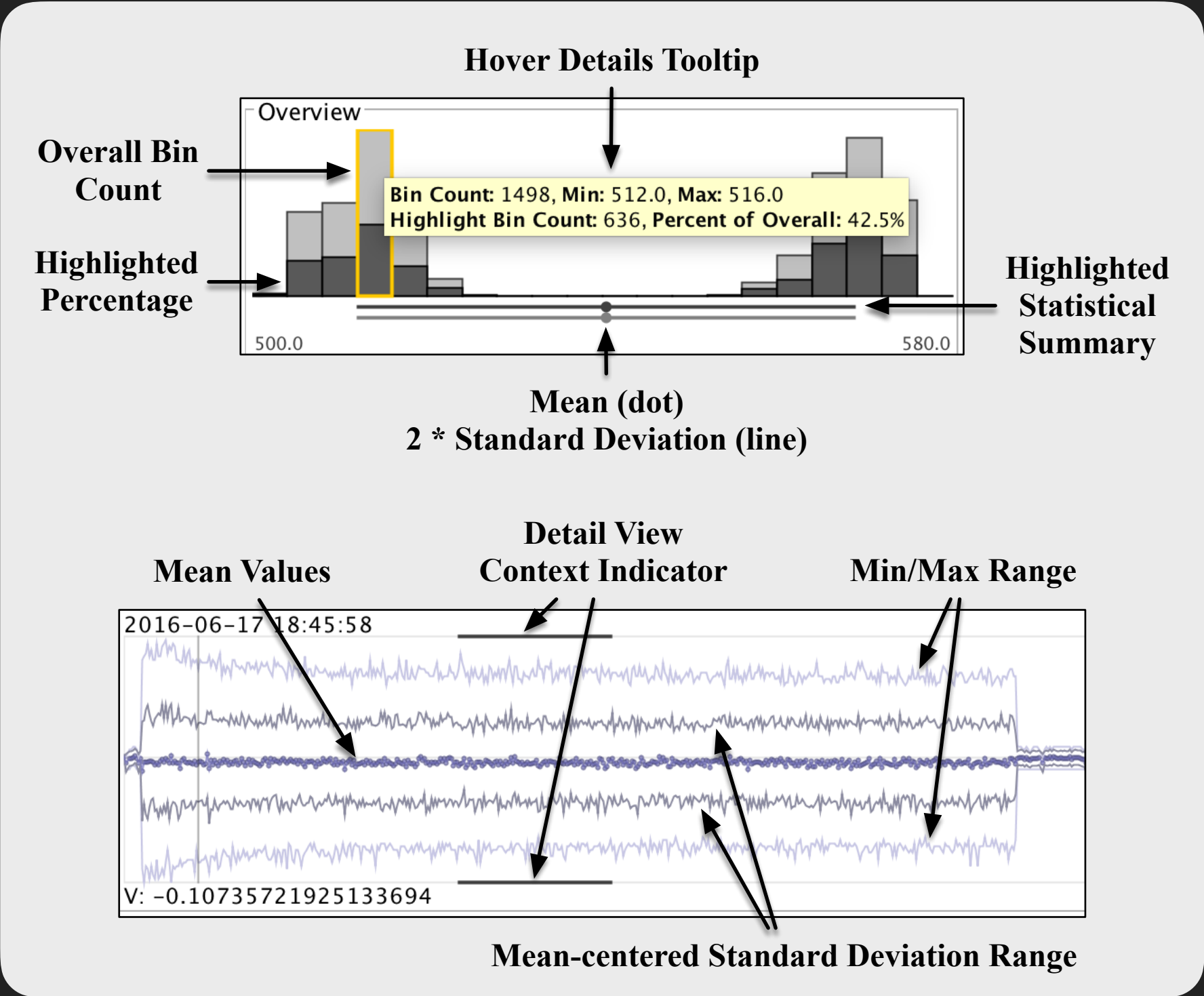


VARIABLE VISUALIZATION PANEL

- ▶ 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

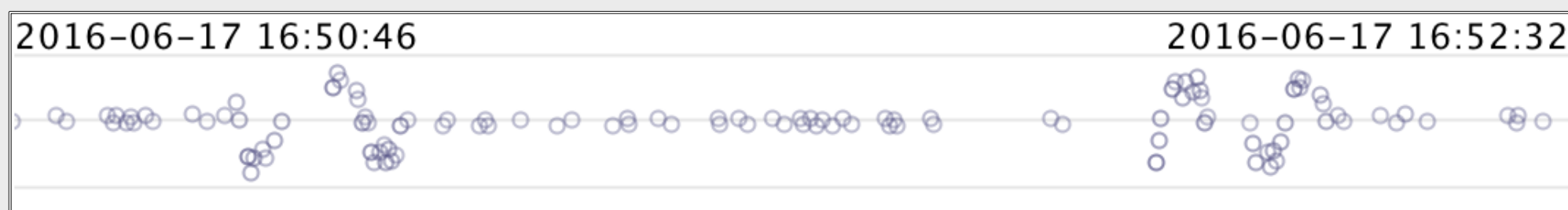


OVERVIEW VISUALIZATIONS

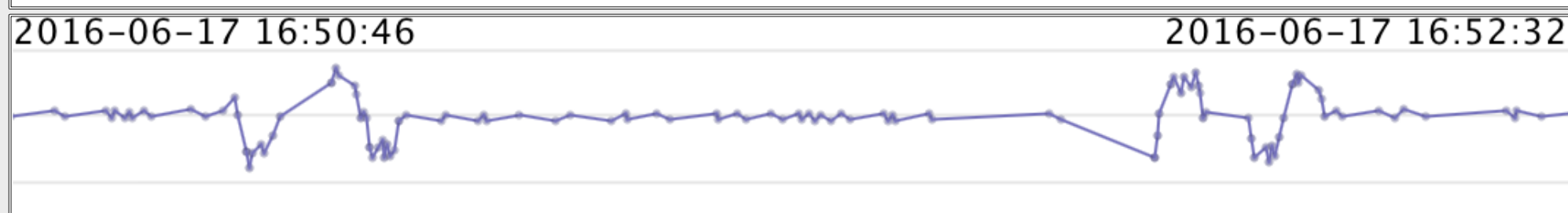


DETAIL TIME SERIES VISUALIZATION DISPLAY MODES

Point



Line



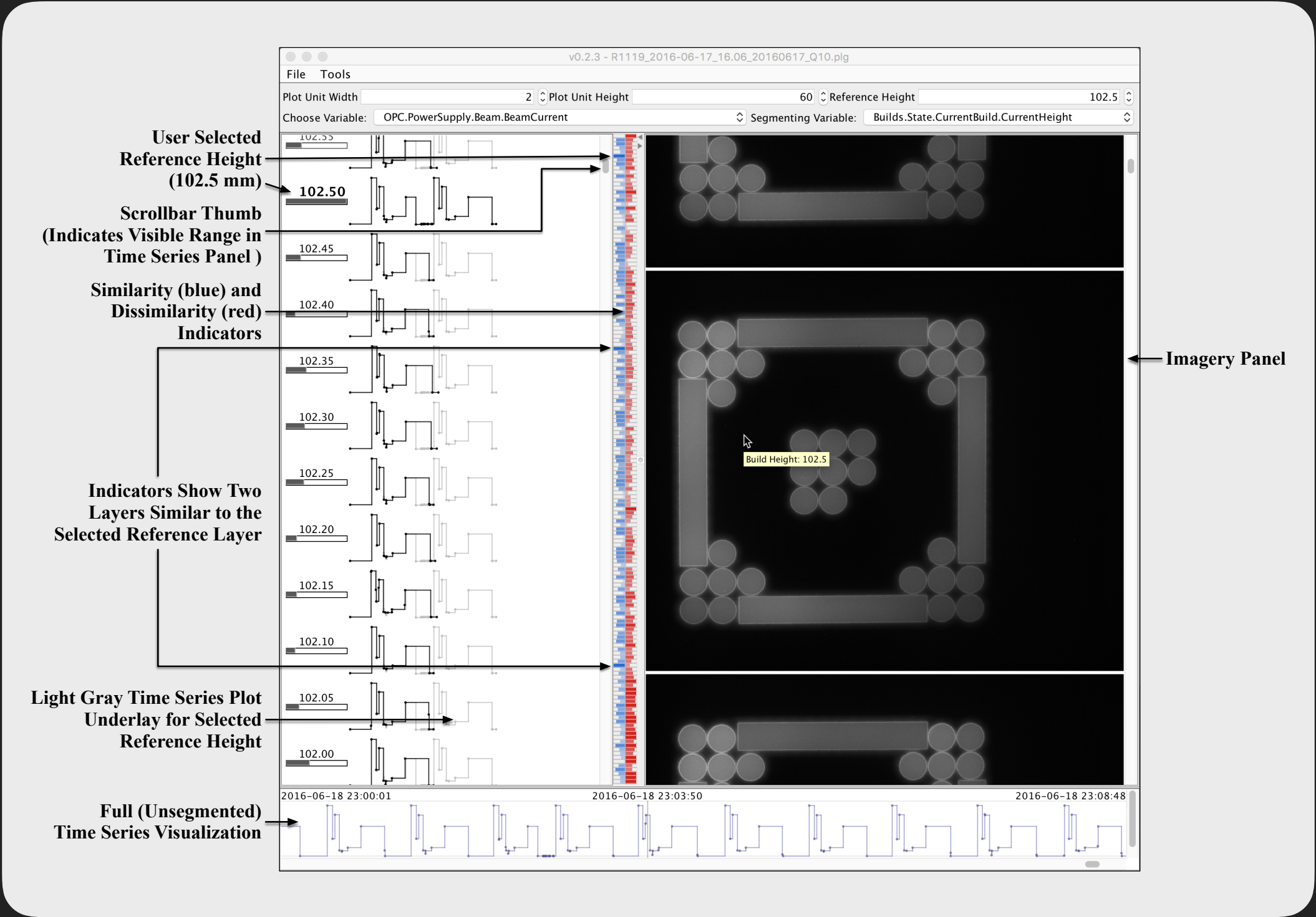
**Stepped
Line**



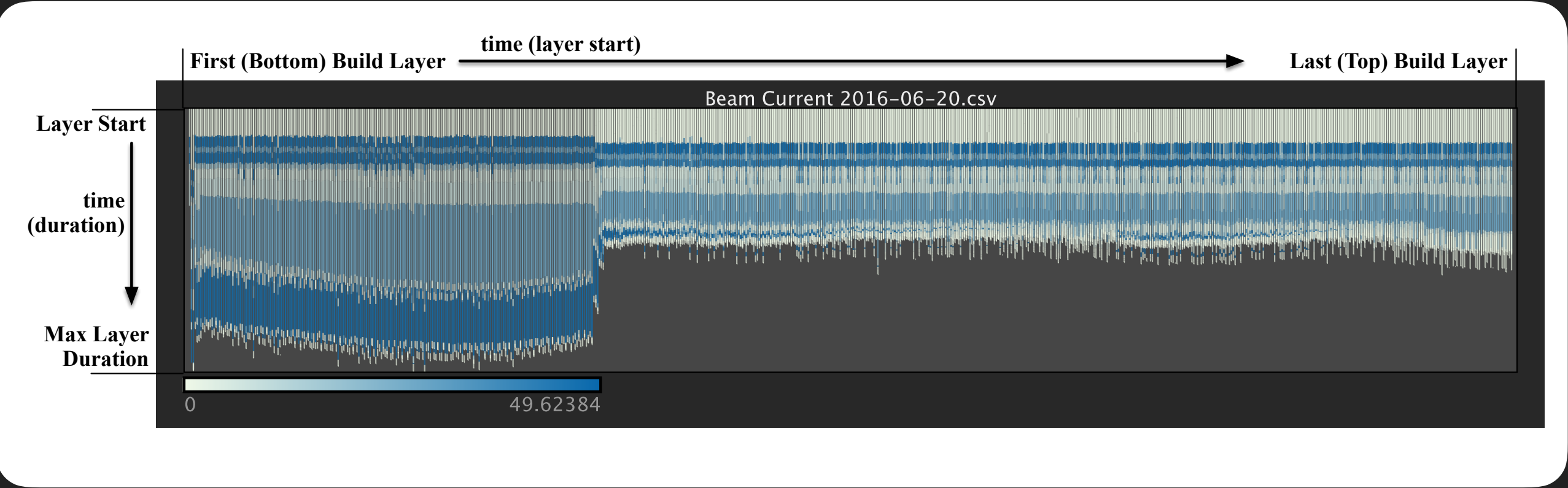
Spectrum



SEGMENTED TIME SERIES VISUALIZATION



WATERFALL VISUALIZATION



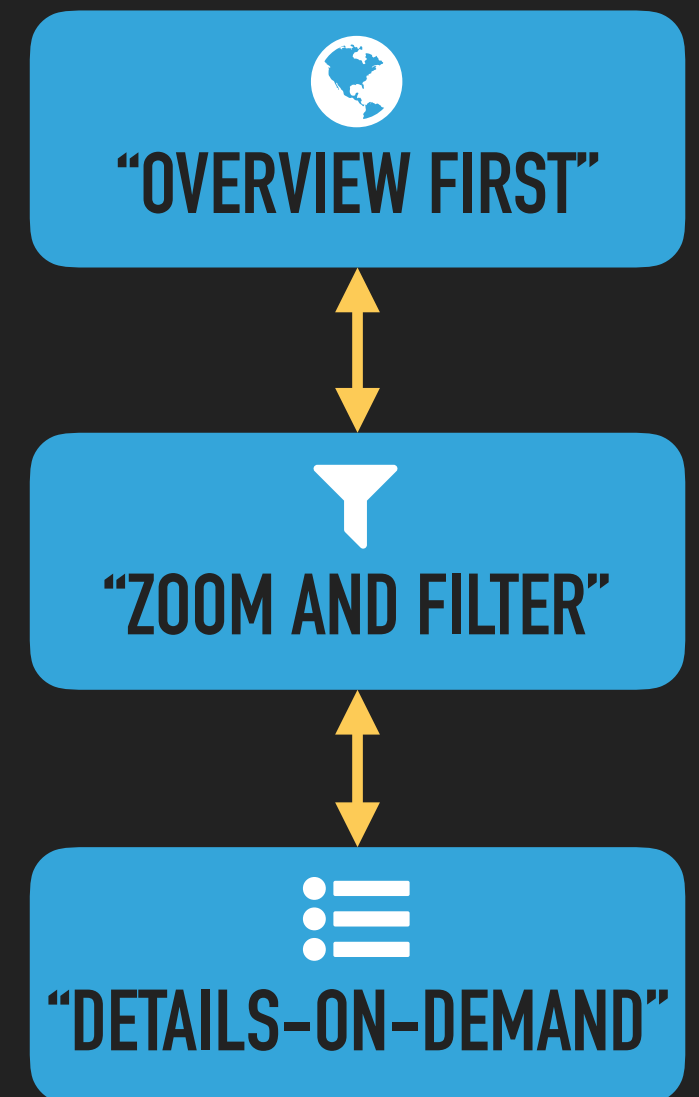
CASE STUDY: ANALYSIS OF LOG DATA FROM A 3D PRINTER BUILD

- ▶ 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



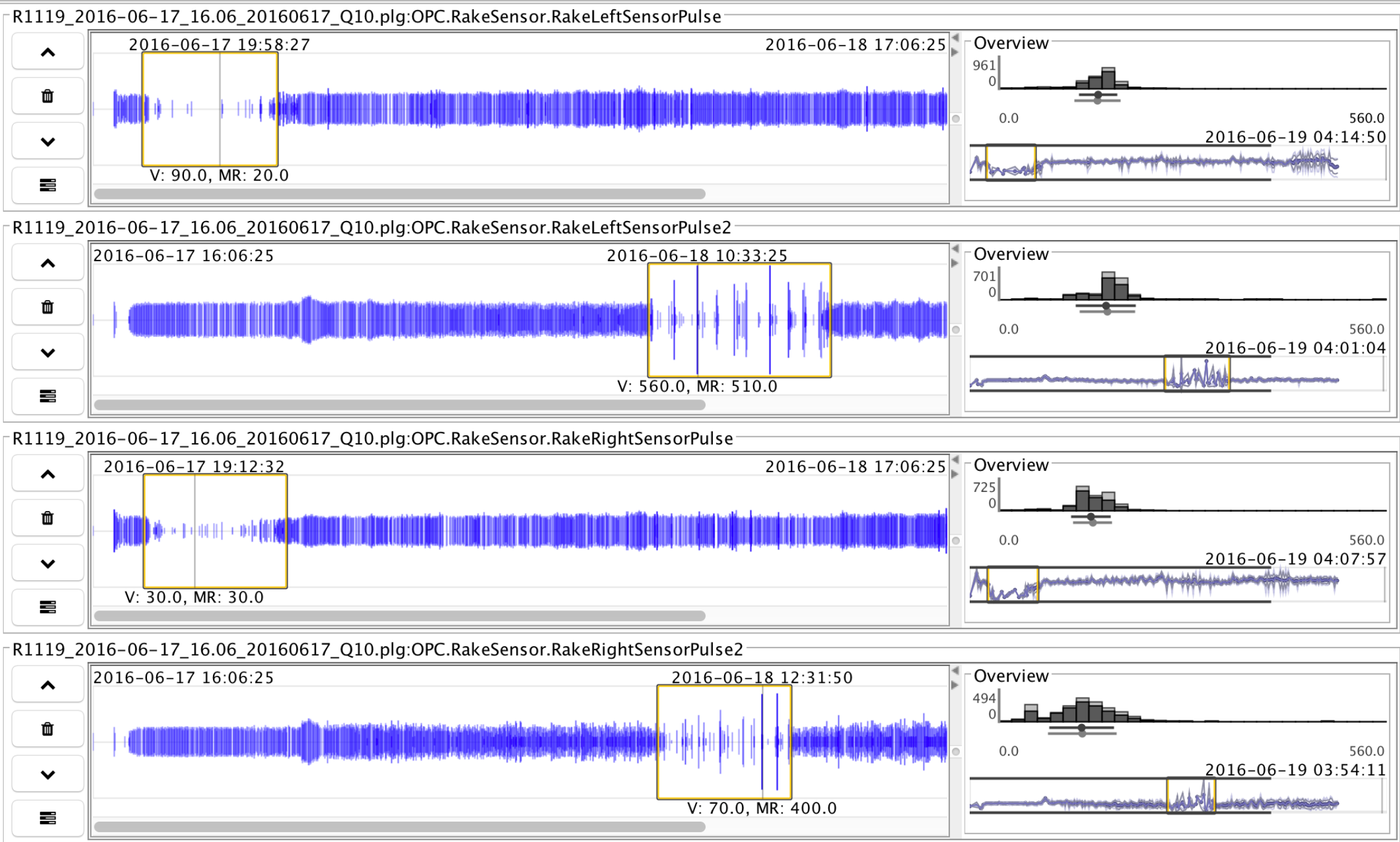
GENERAL ANALYSIS STRATEGY USING FALCON

- ▶ 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)

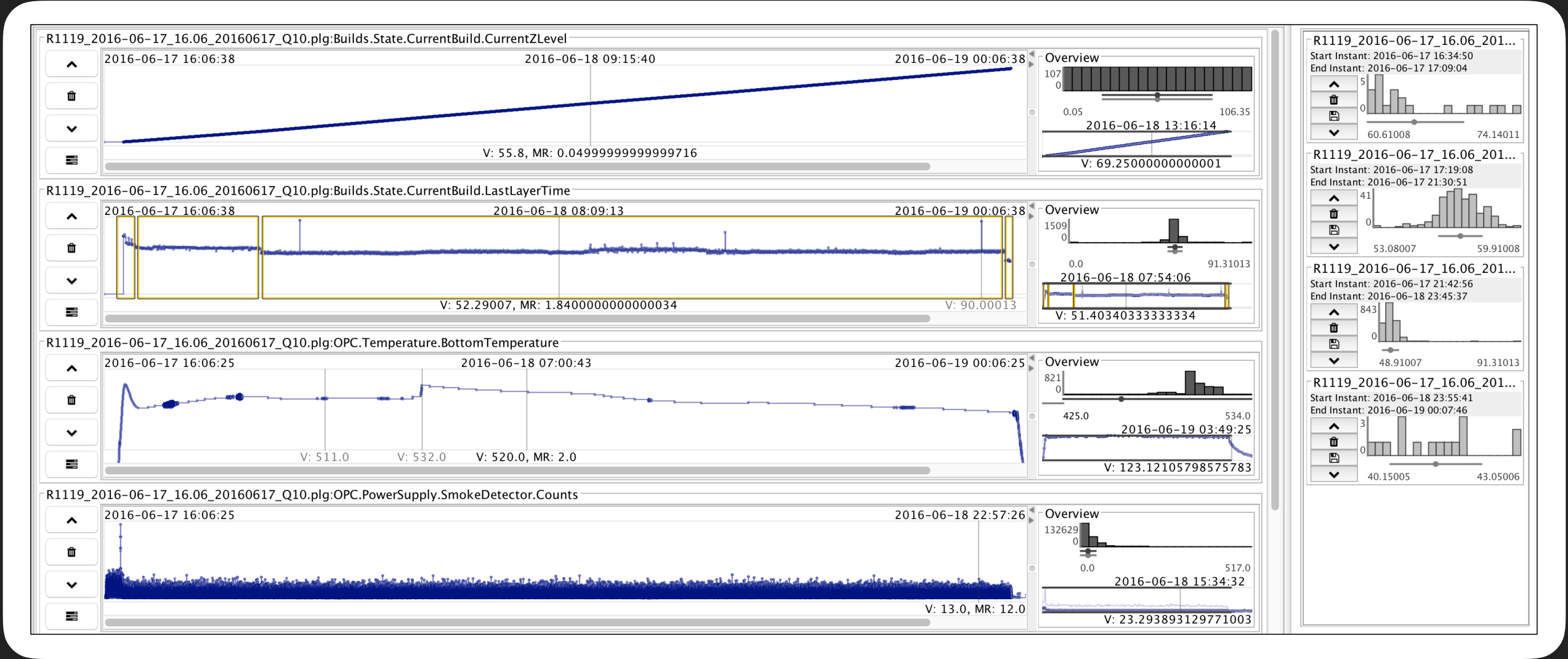


* B. Shneiderman. "The eyes have it: A task by data type taxonomy for information visualizations." In *Proceedings of the IEEE Symposium on Visual Languages*, pp. 336-343, 1996.

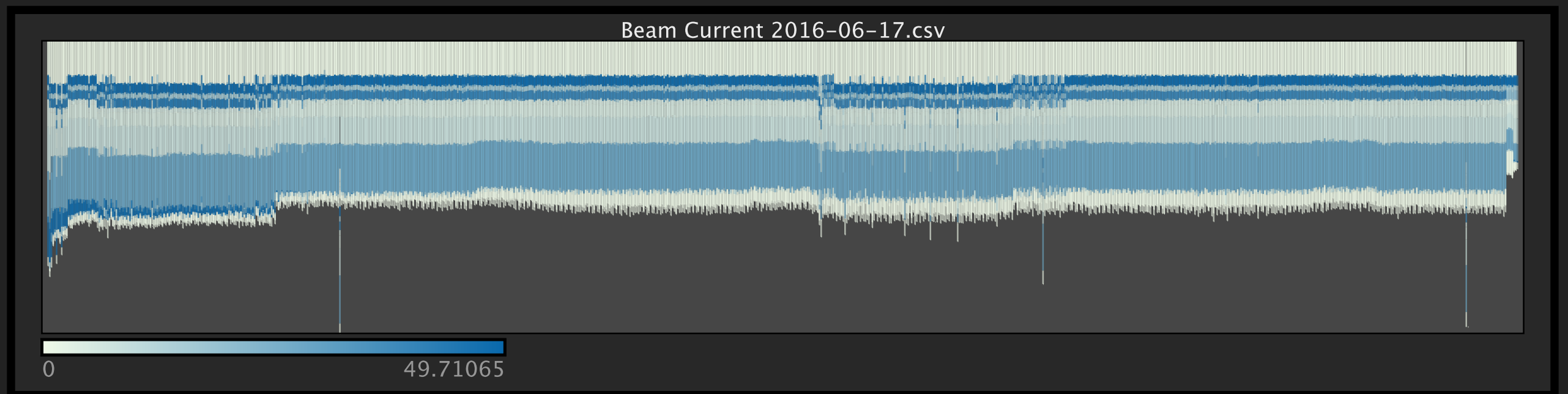
OVERVIEW FIRST



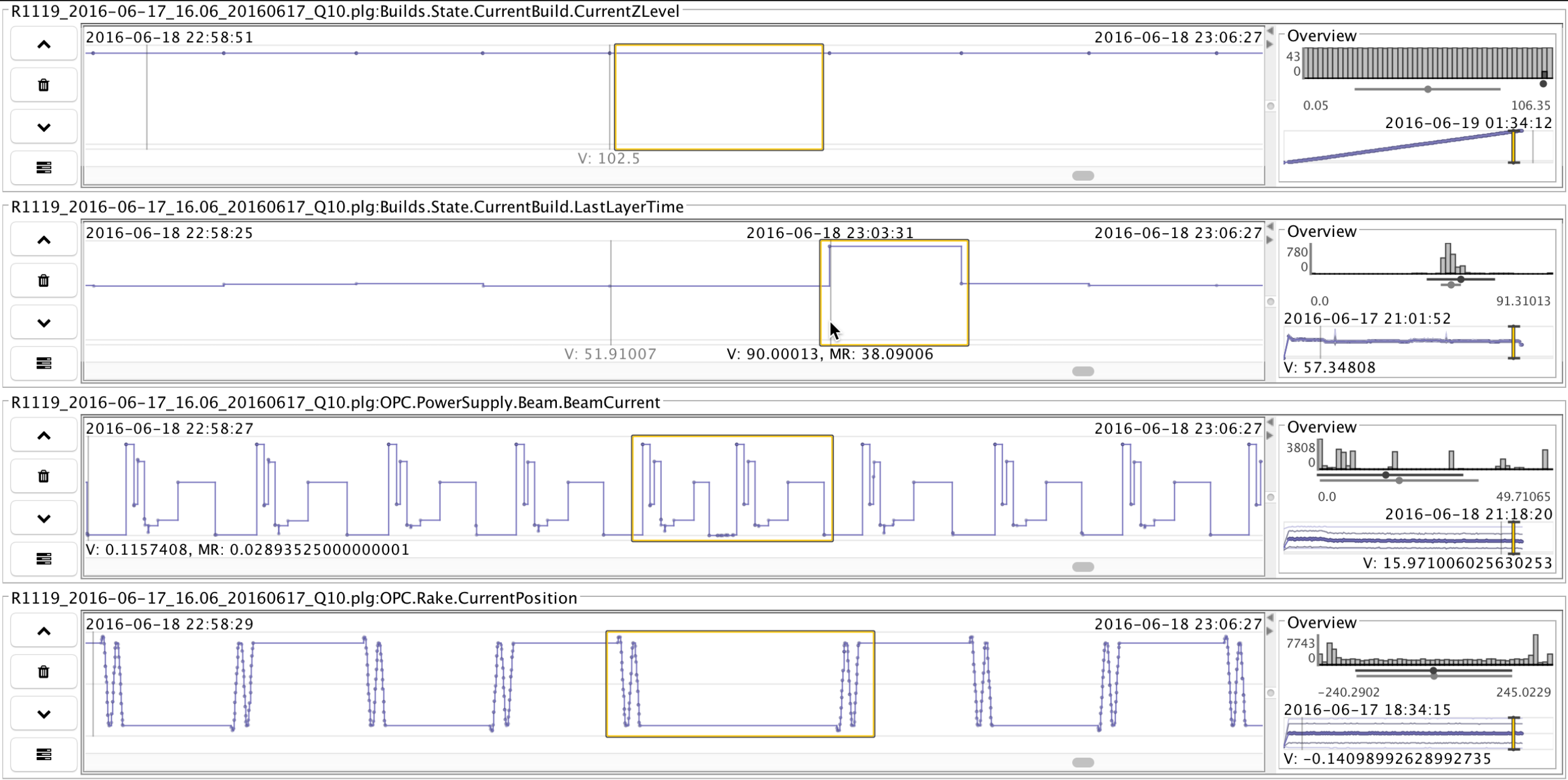
OVERVIEW FIRST



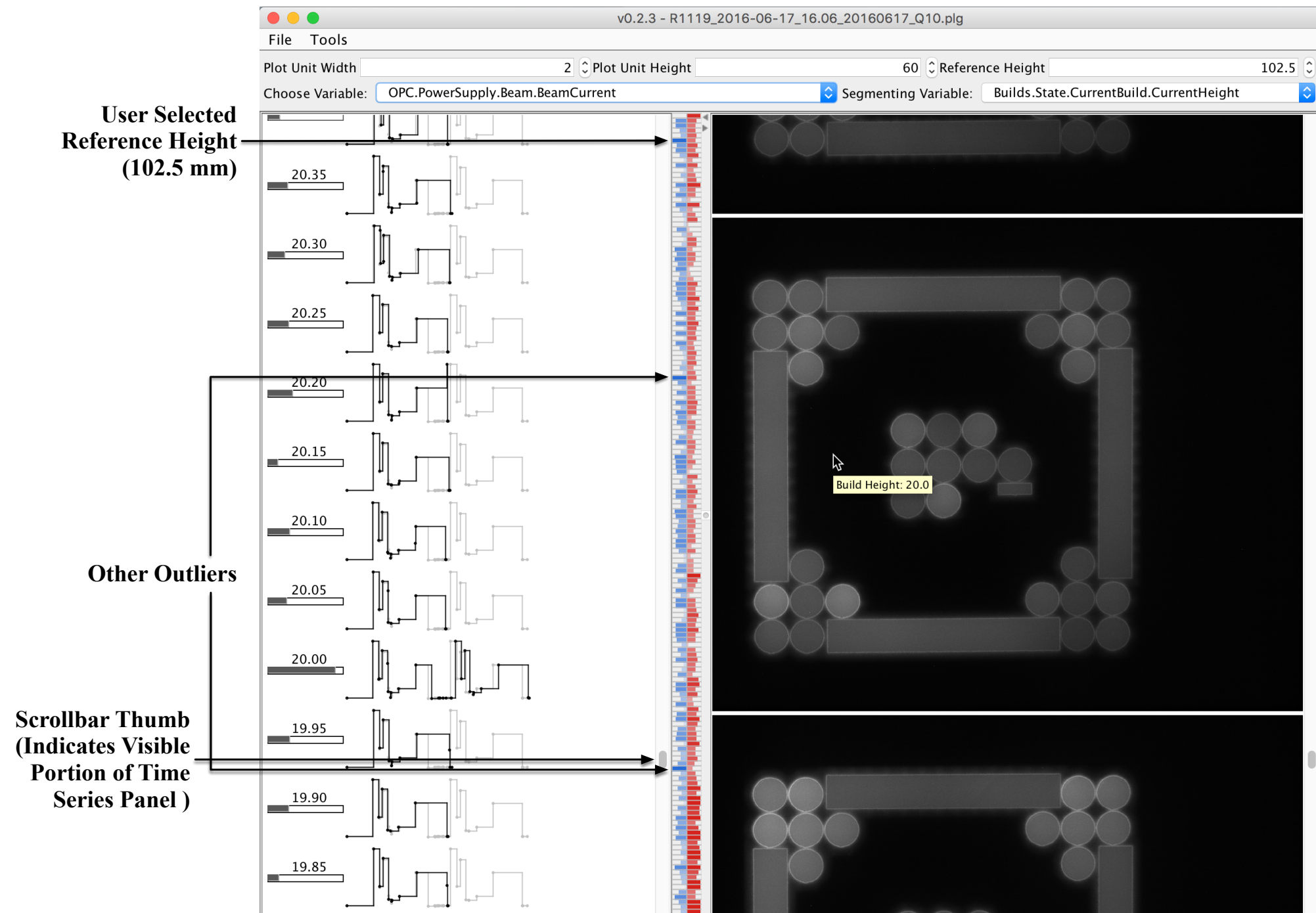
A MORE FOCUSED OVERVIEW



ZOOM AND FILTER

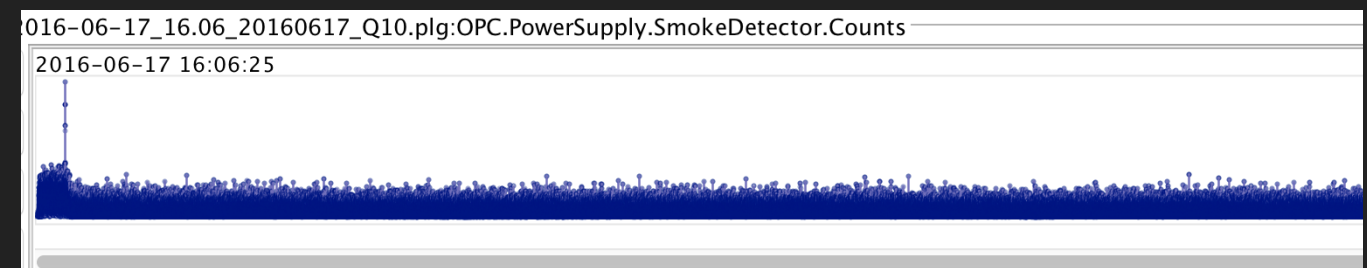
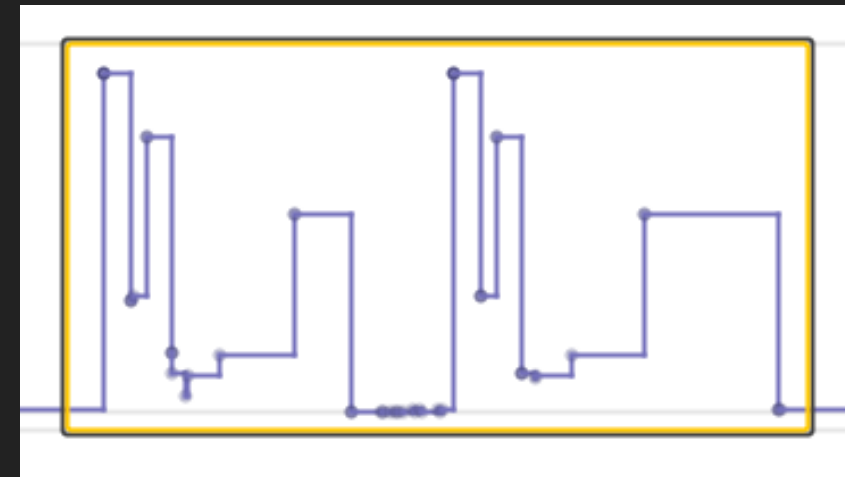
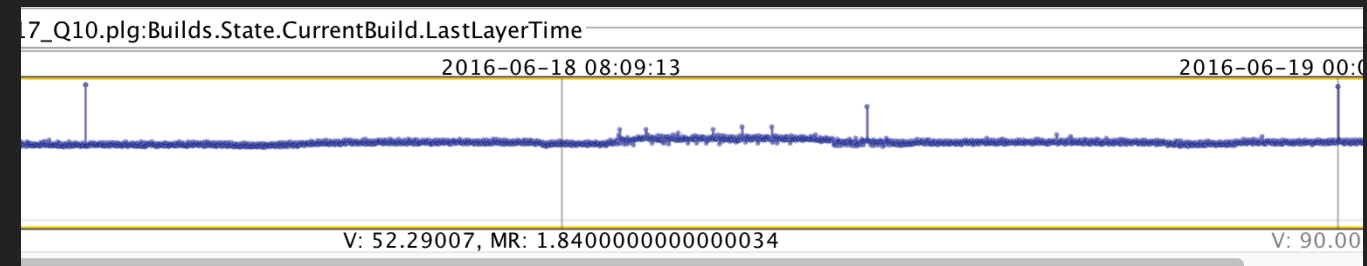


MORE DETAIL, ON DEMAND



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)