Scaling Ultrafast Laser Manufacturing

Automation, Integration, and Data-Driven Production

Paola La Marca

Head of Manufacturing

Ultrafast Lasers

Paola.lamarca@lumentum.com

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What are the factors to consider when scaling UFL?

Micron-level precision
Very tight alignment and positioning tolerances across multiple axes

Multiple integrated HW
Robotics, motion systems, optical measurement devices, all must work in a single environment

Trade-offs
Throughput, high yield, high accuracy but also flexibility to ensure continuous improvements

External factors impact
Thermal effects, mechanical stress, contamination, all affect product and production stability

Complex workflows
Multi-step and dependent operations are necessary to develop the product and deploy to production

Full traceability
Complete tracking of subcomponents, lots, parameters, for quality, compliance, and customer requirements

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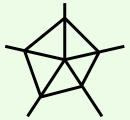
Navanakorn, Thailand
1.5M SF Manf. Facility

Process development for manufacturability

Understand and define	Develop and characterize	Validate and standardize	Transfer and scale	Monitor and improve
- Customer specs - Technology development - Requirements	- Process and tools design - Parameter space - Design of experiments	- Repeatability - Reproducibility - Measurement system analysis	- Standard operating procedures and work instructions - Training and skill matrix - Pilot runs	- Monitoring performance - Statistical process control - Continuous improvements

Key enablers

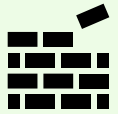
Robust alignment and calibrations strategies



Process window knowledge

Measurement repeatability and data access

Failure mode and root cause analysis



Standardization across processes

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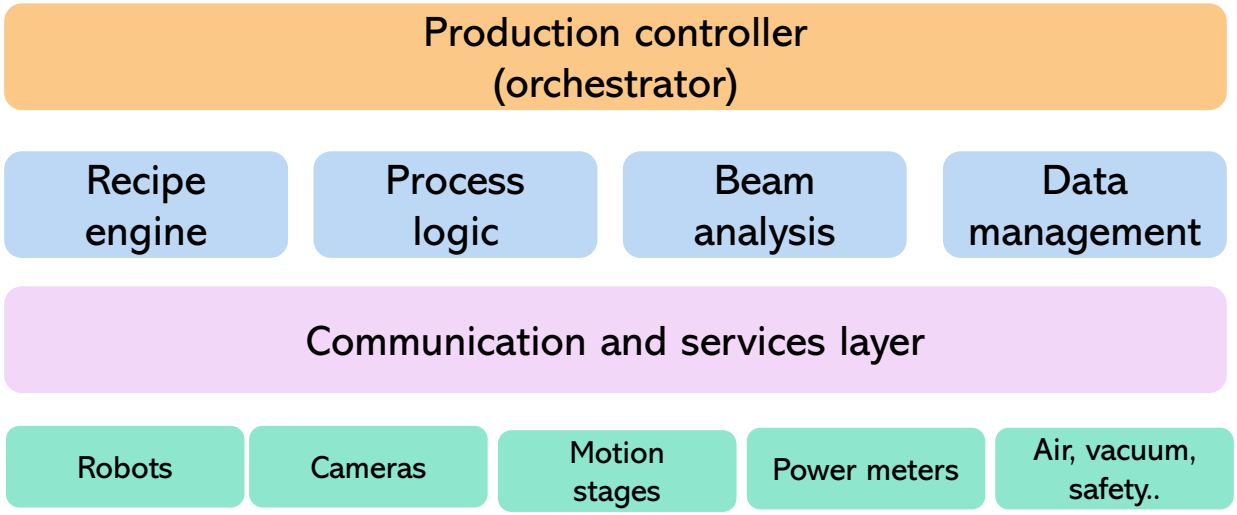
Automation architecture and data infrastructure

- Centralized orchestration
- Modular and scalable software
- Instrument abstraction layer
- Error handling and recovery
- Scalable station deployment
- Recipe-driven execution
- Modular DB architecture



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Data amount per unit – one product line

254 automated operations 30 manual operations	8930 test parameters
141 critical components	28 finished good part numbers

End-to-end traceability

- Serial number tracking
- Genealogy and material lots
- Recipe and version control
- Results and operation conditions
- Operators and stations
- Audit trail and compliance

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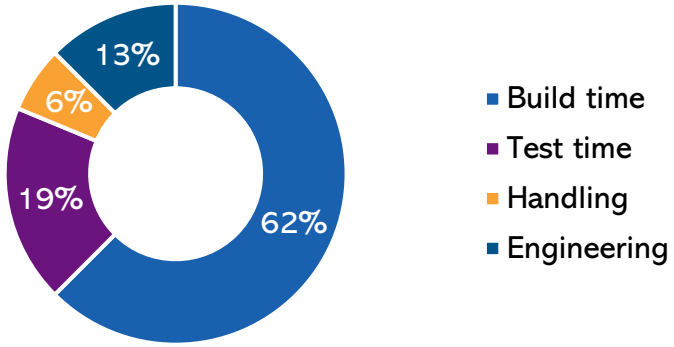
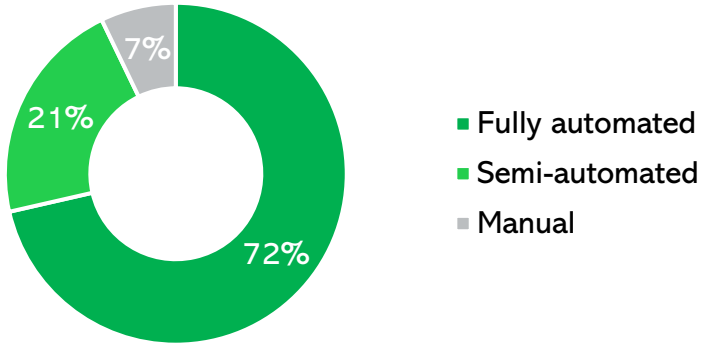
KPIs and improvements

Mock data

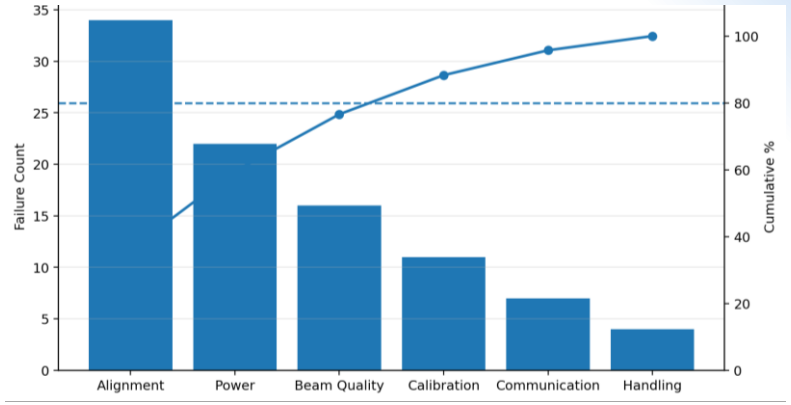
Cycle time



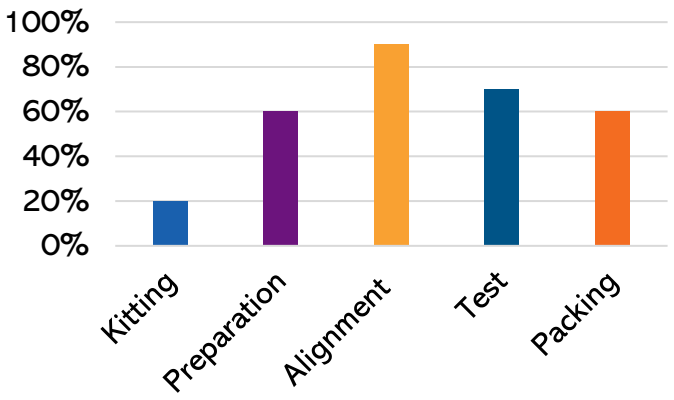
Automation coverage



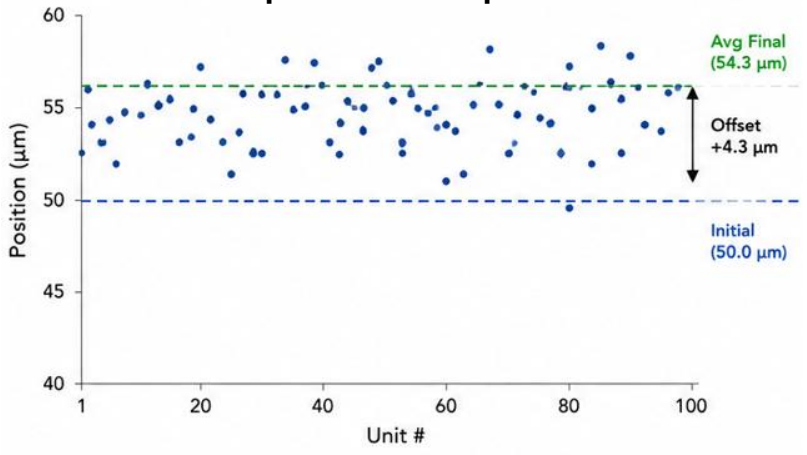
Yield pareto



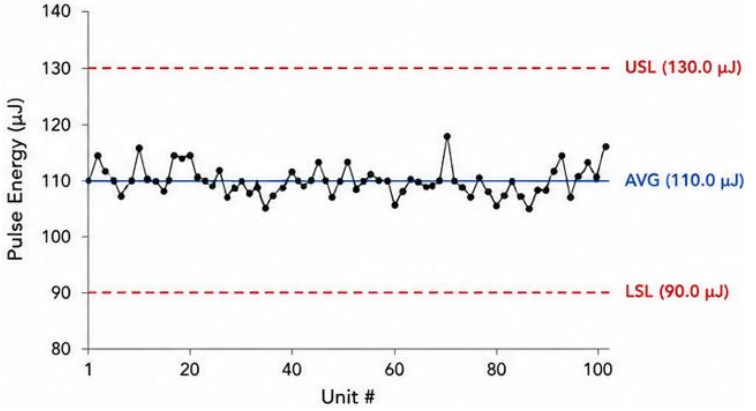
Station utilization



Optics final position



Control charts



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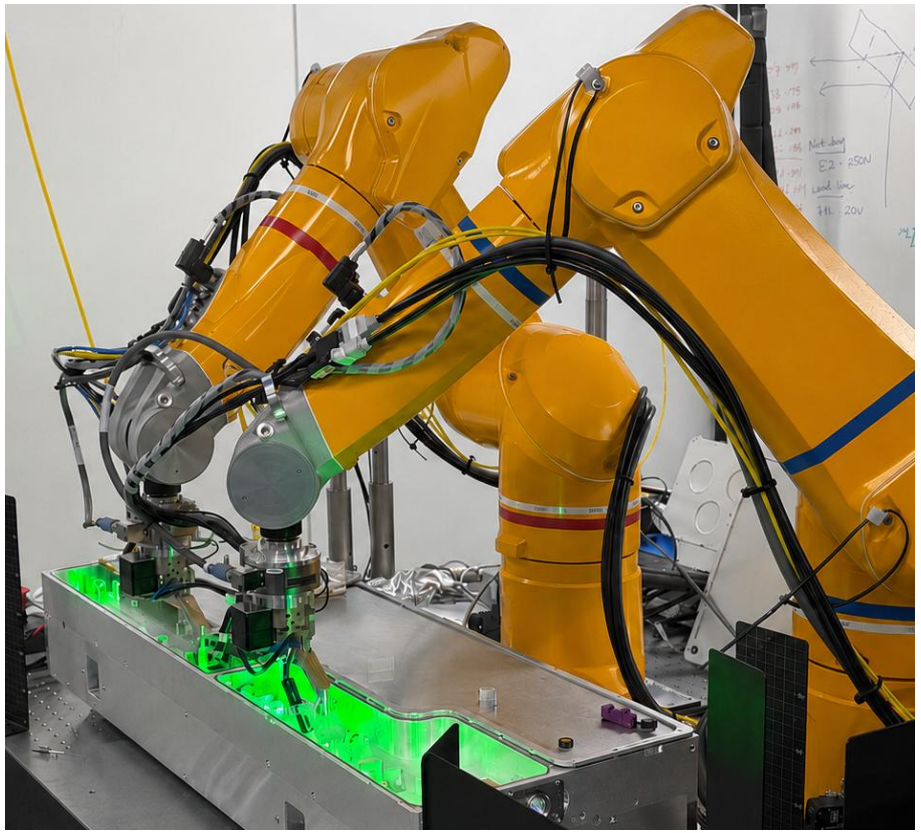
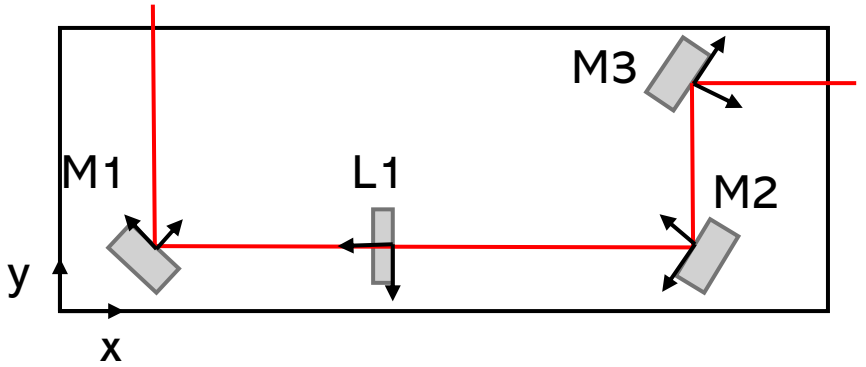
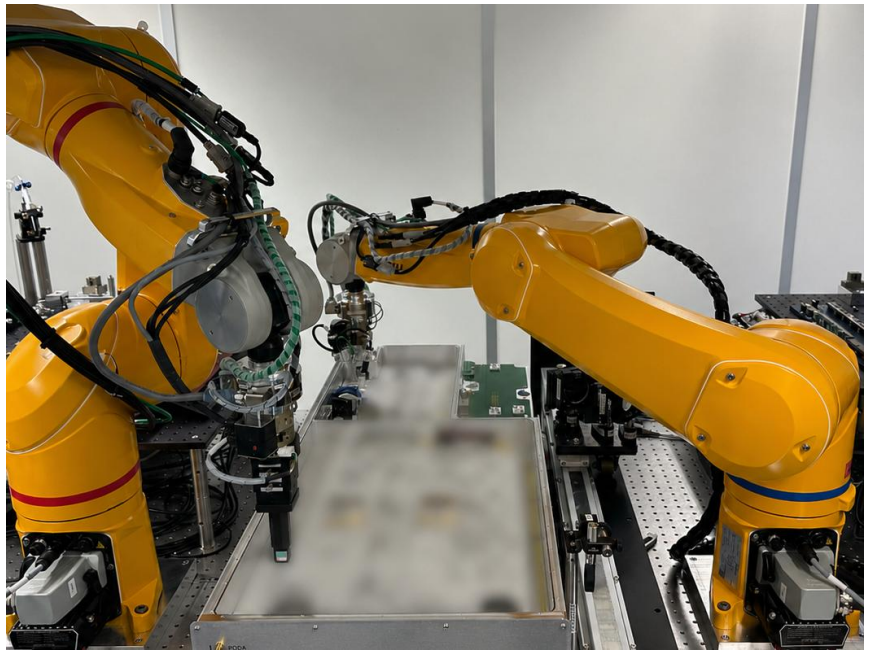
Robotics for free space alignments







- High repeatability of optics positioning
- Automated alignment routines using station integrated beam diagnostics
- Calibration procedures for enhanced positioning accuracy as part of manufacturing process
- Robot data collection for optical model improvements and R&D studies

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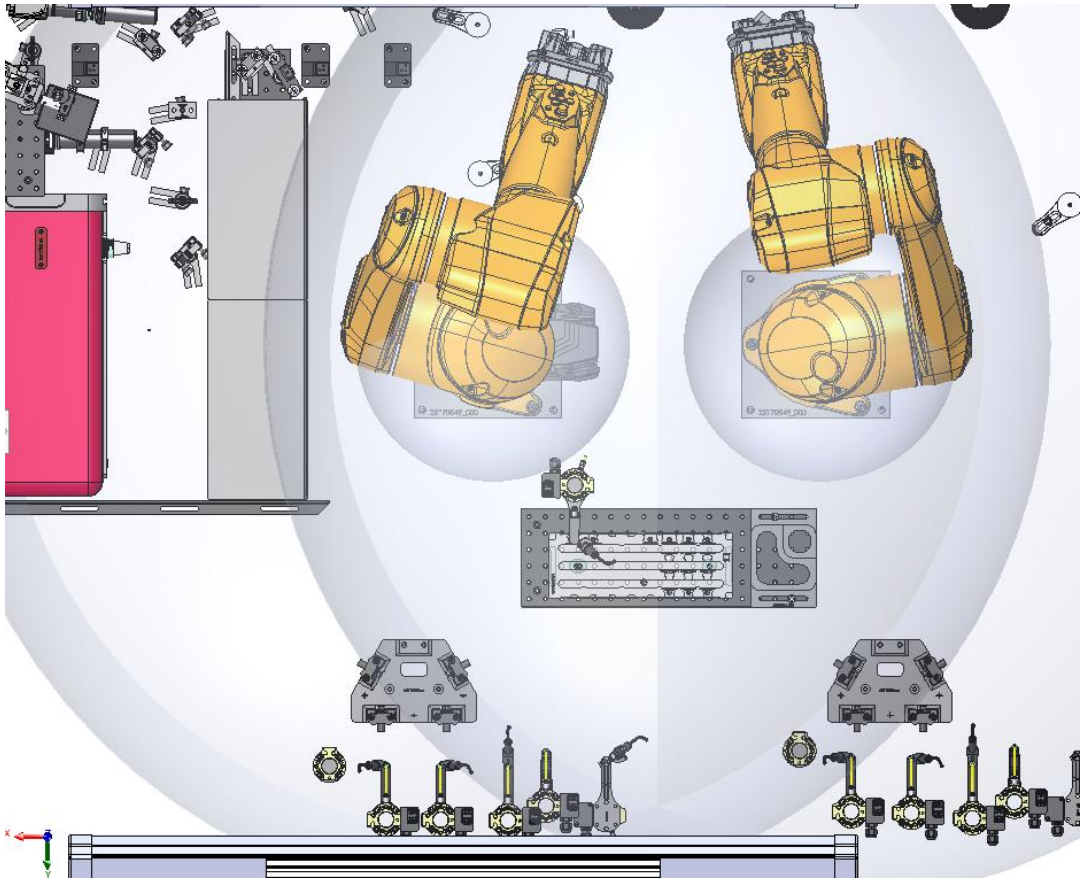
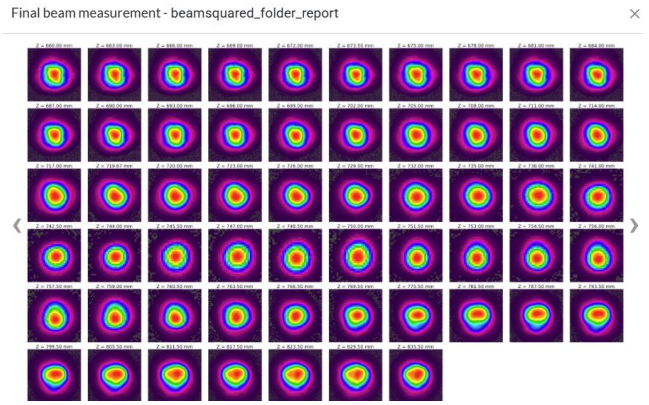
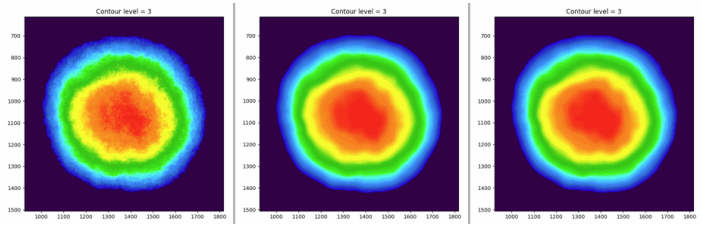
Robotics for free space alignments

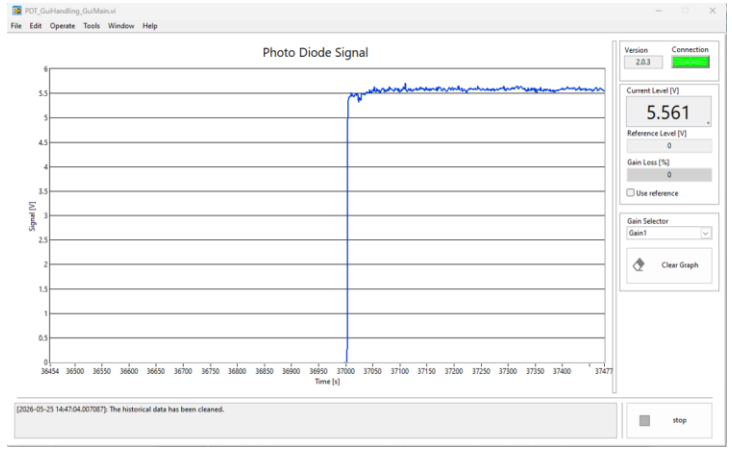


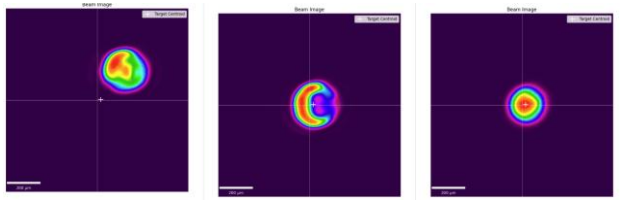
Station and SW integration allow to

- Perform complex alignment algorithms
- Develop quality checks that do not rely on expert knowledge









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Opportunities towards autonomous manufacturing

Scalability and maintainability

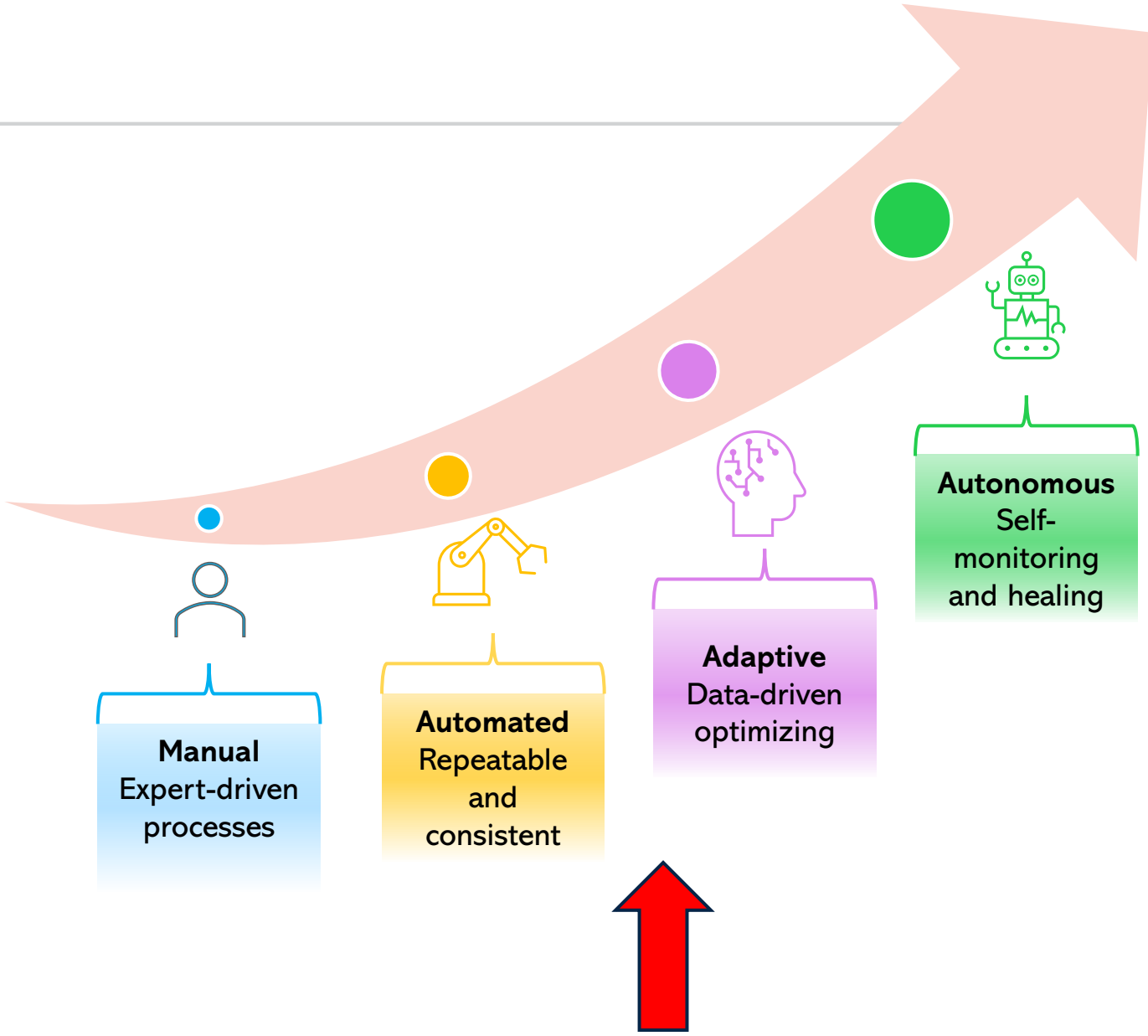
Cross-platform standardization
Harmonizing HW, SW and data architecture also from legacy products

Improved robot absolute accuracy

Predictive Maintenance

AI-assisted diagnostics
Faster issue detection and RCA but also enable advanced beam judgment

Self-healing mechanisms
Recovery functions based on station data



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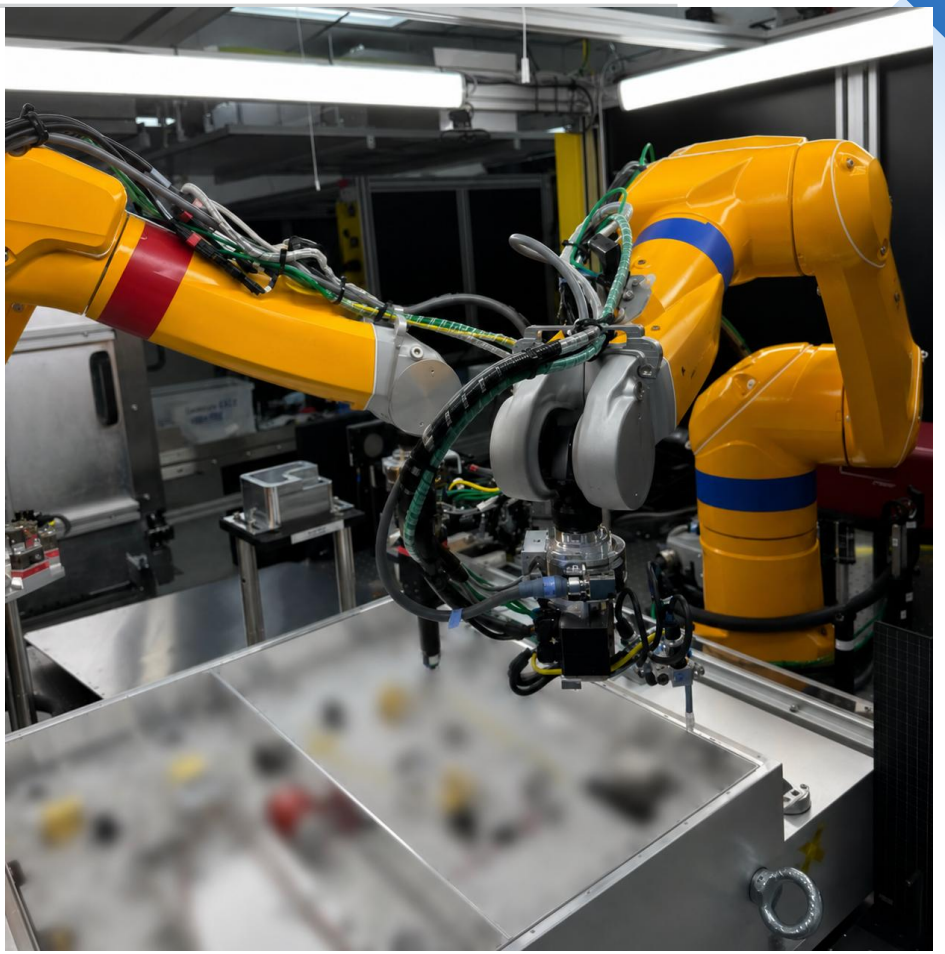
Key takeaways

- **Scaling ultrafast laser production through**
  - Automation, robotics and data availability
  - Data-driven process control
  - Real time monitoring
- **Product design, process development and automation must evolve together**
- **Integration is the core engineering challenge**
  People, processes, systems and data need to work as one
- **Autonomous manufacturing is evolving**
  This path requires data, intelligence and continuous learning



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Thank you!

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