PDF SOLUTIONS™

2023 PDF Users Conference:

AI for tomorrow's manufacturing & R&D

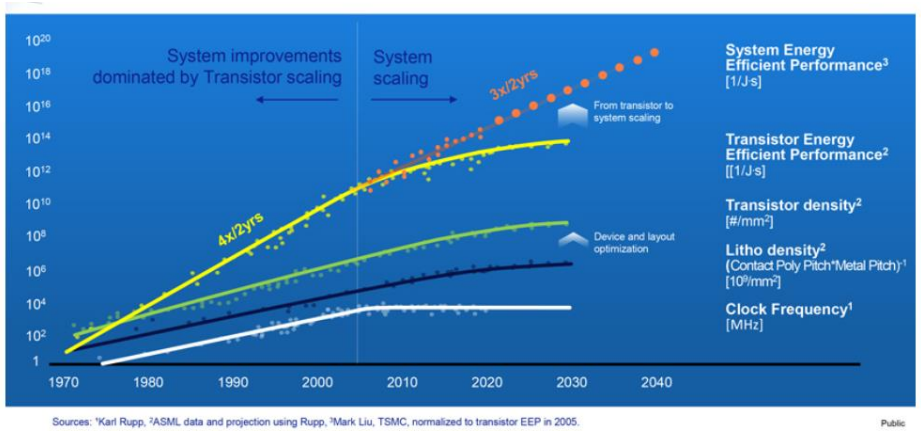
Location:
Santa Clara Marriott - 2700 Mission College Boulevard Santa Clara, California 95054 USA

Solutions for Fabs and IDMs

24th October 2023

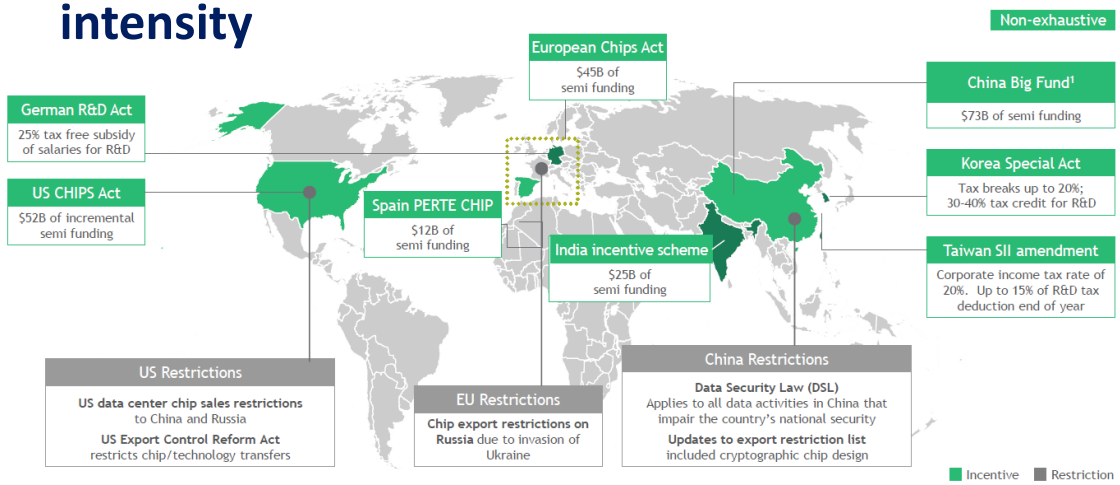
We are witnessing important shifts in the industry

Scale drivers shifting from litho to 3D chips and advanced packages

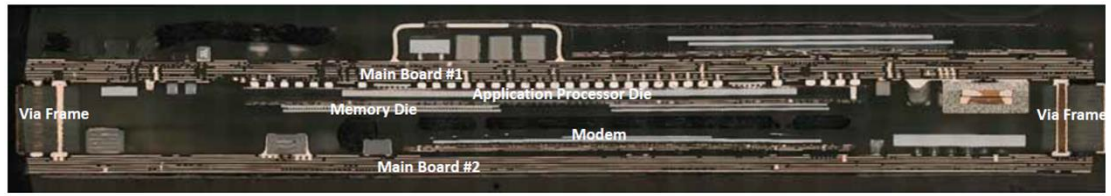


More complex and "More than Moore" devices require advanced characterization capabilities

Capacity investments shifting in location and intensity



SiP changing test and assembly landscape w/ use of characterized KGD from variety of suppliers

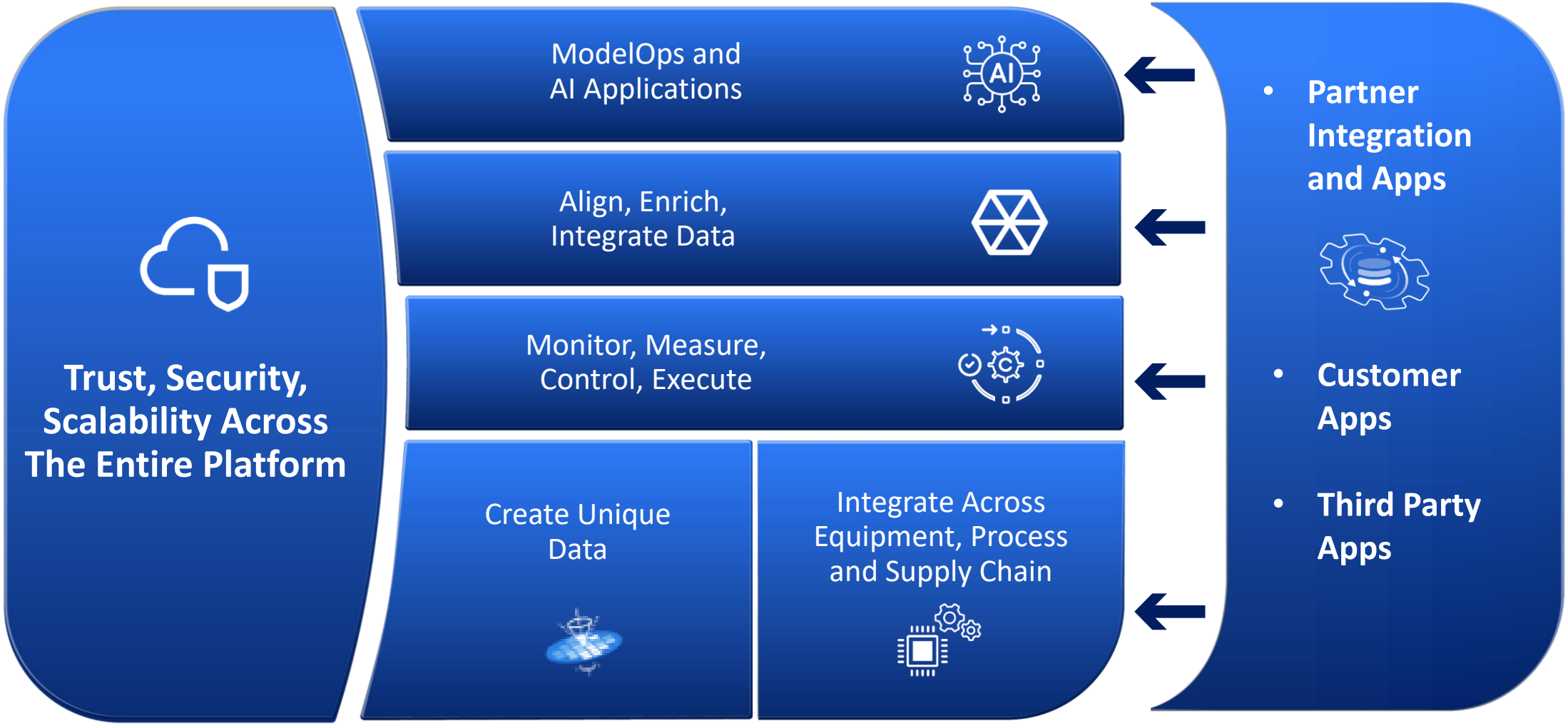


iPhone X mainboard (SYSTEMPlus Consulting)

Observed Best Practices for Design Wins for Fabs and IDMs

*Shared between Tech Dev and Manufacturing
** Shared between Customer Eng. and Tech Dev

PDF end to end platform for semiconductor analytics



Fully integrated solution to accelerate production ramp, improve overall yield, quality, and efficiency for Semiconductors

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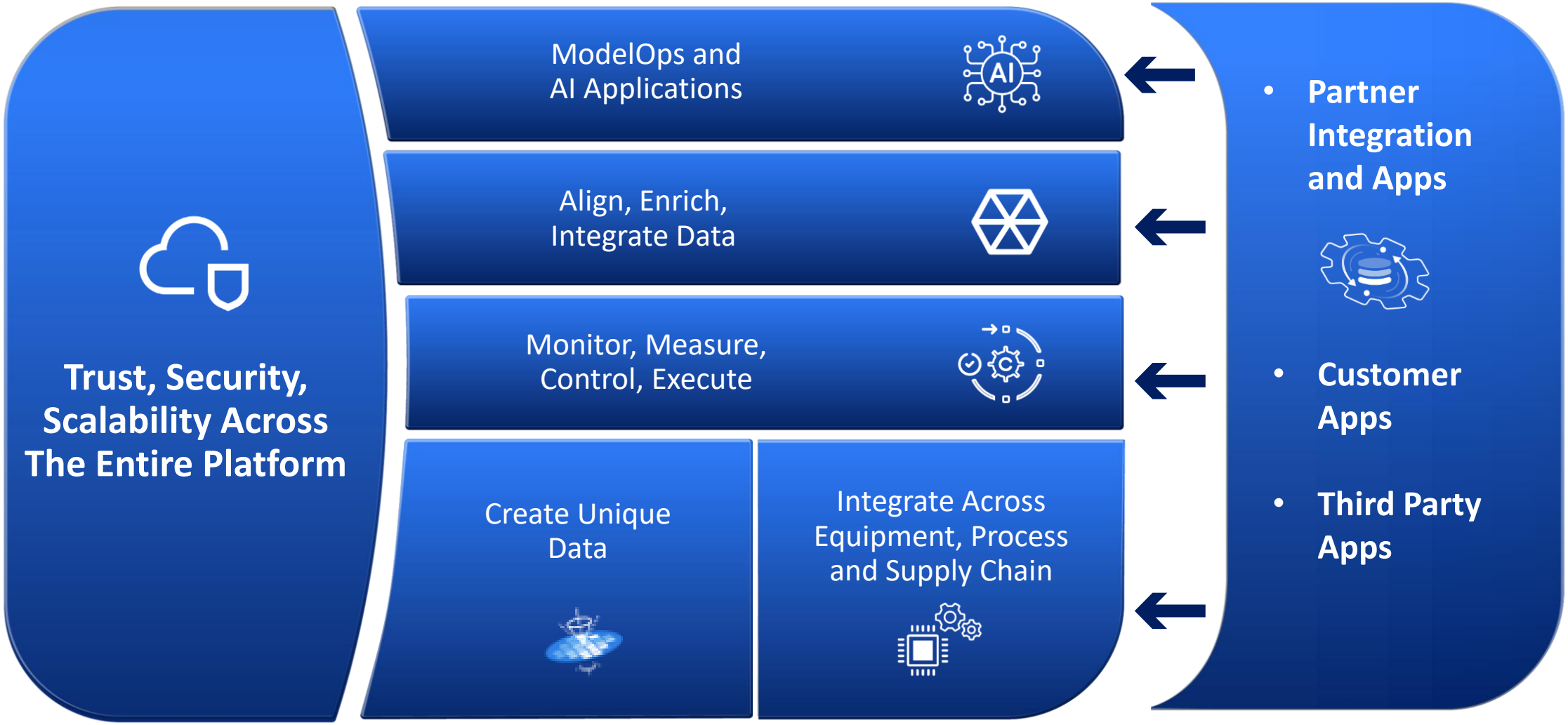
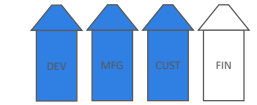
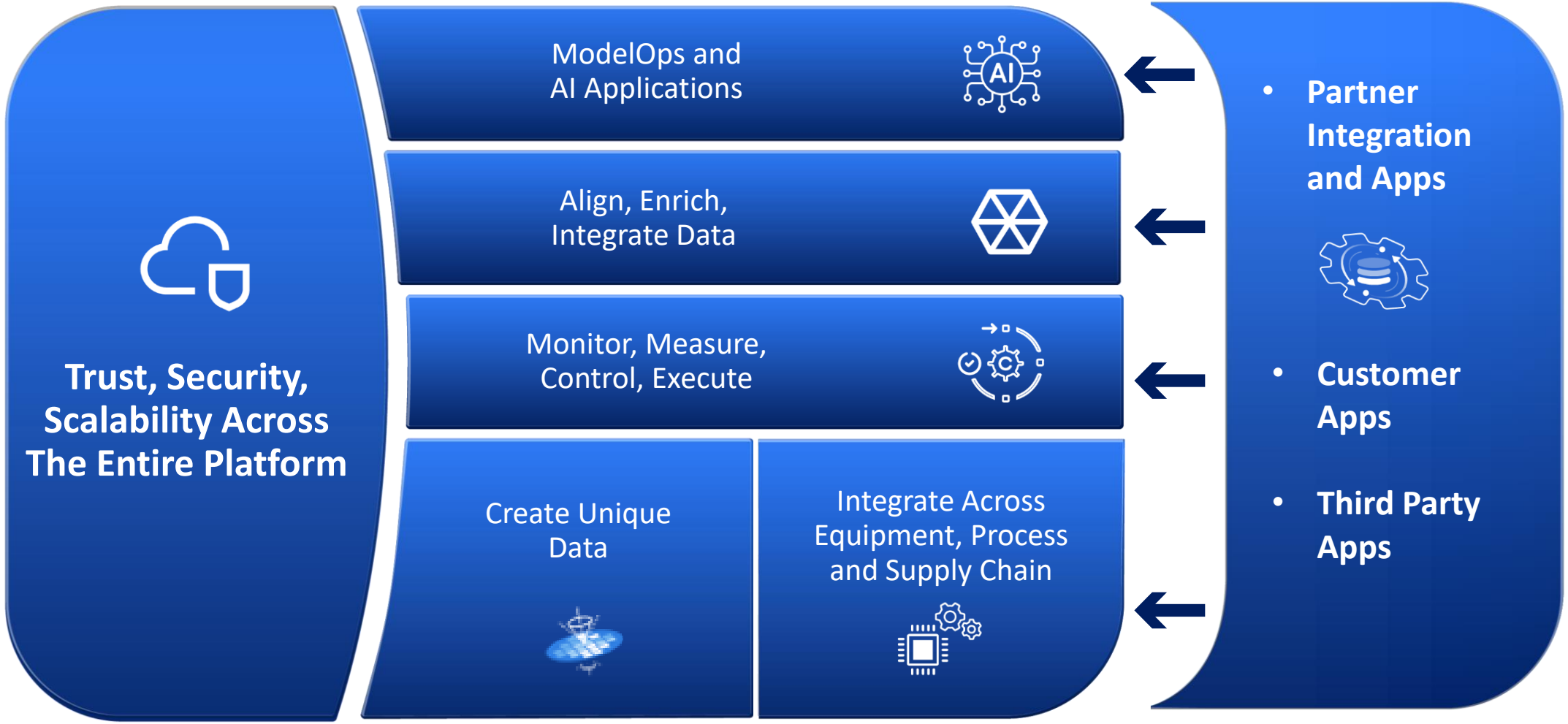
Differentiated data on PDF's platform



PDF offerings: Lab to Fab characterization capability

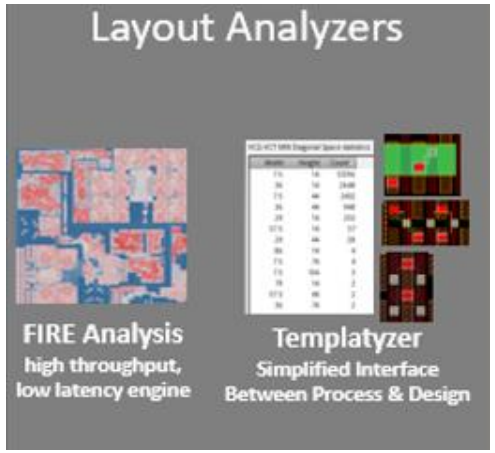


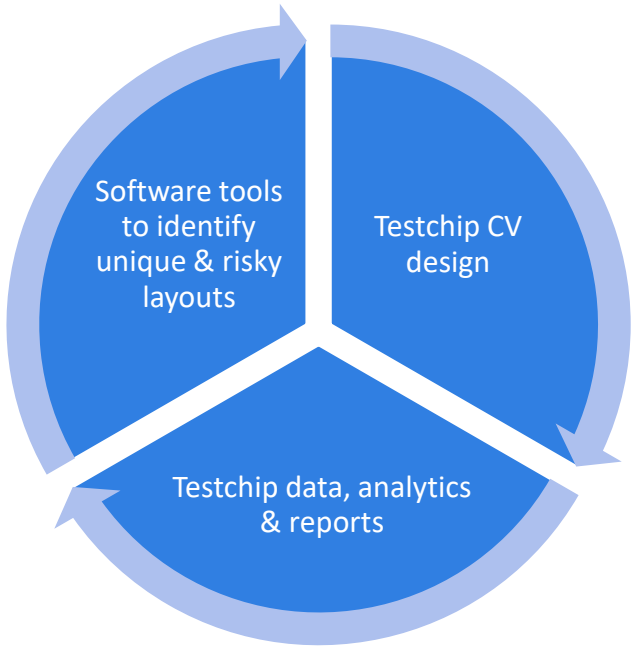
Software
Electrical CV
E-Beam

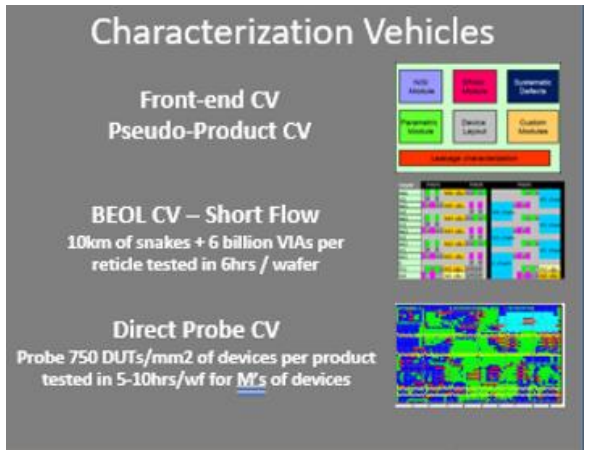


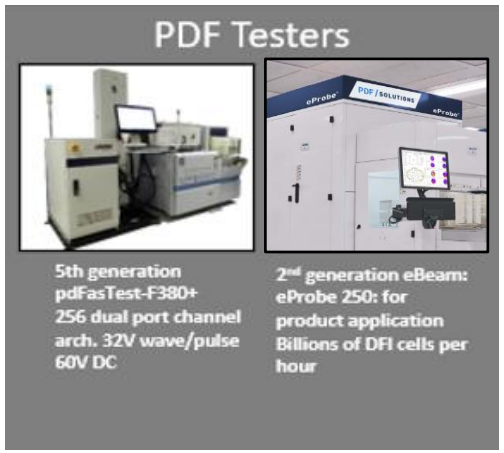
Increased Focus on Process-Design-Systems Interaction

Capabilities that support and reinforce each other









DPCV: Direct Probing Characterization Vehicle (utilizes lower metal layers for option masks to measures tens of thousands of transistors in actual product layout)

Templatyzer™ std cell library analysis & golden cell generation

- DFM/IP Hardening by reducing use of unique or risky layouts
- DMCO: design for yield, variability to improve manufacturability

FIRE™ full chip layout analysis

- Statistics on the use of risky layout features and neighborhoods
- Yield entitlement calculation
- Output can be used to feed targeted test chips and inspection

Characterization suite

- Different types of structures at different stages:
  - Definition: Early patterning constructs
  - Development: Pseudo-product layouts created from std cells
  - Early ramp: Actual product layouts
- Statistically valid sampling
- Transistor device selection based on FIRE layout extractions
- Unique tester capabilities
- Extensive analytics and reports

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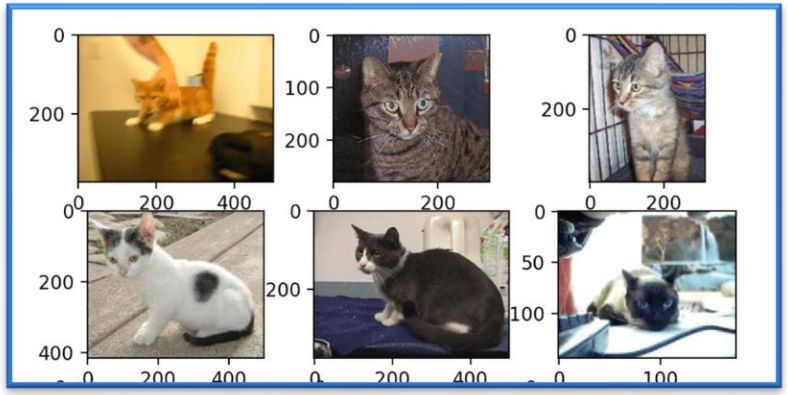
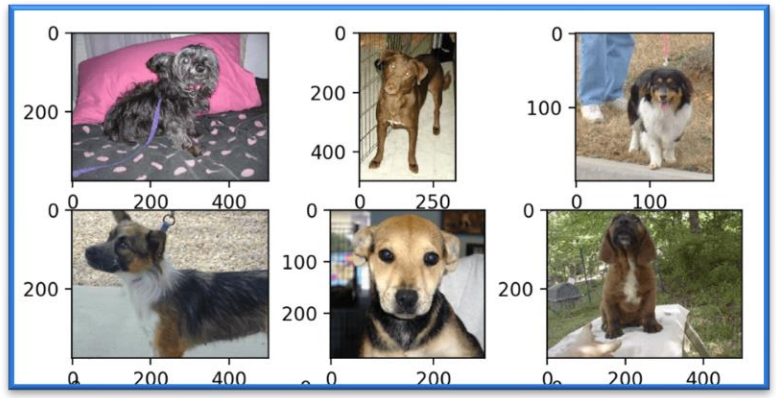
Exensio FIRE Software: Fuzzy Pattern AI

- A given systematic fail mode usually comes from, not one, but a “family” of layout configurations. Traditional rule-based approach is insufficient for the evolving complexity of product design at advanced nodes

- Using fuzzy pattern image classification algorithms, PDF’s FIRE software automatically groups all similar pattern into a “pattern family”

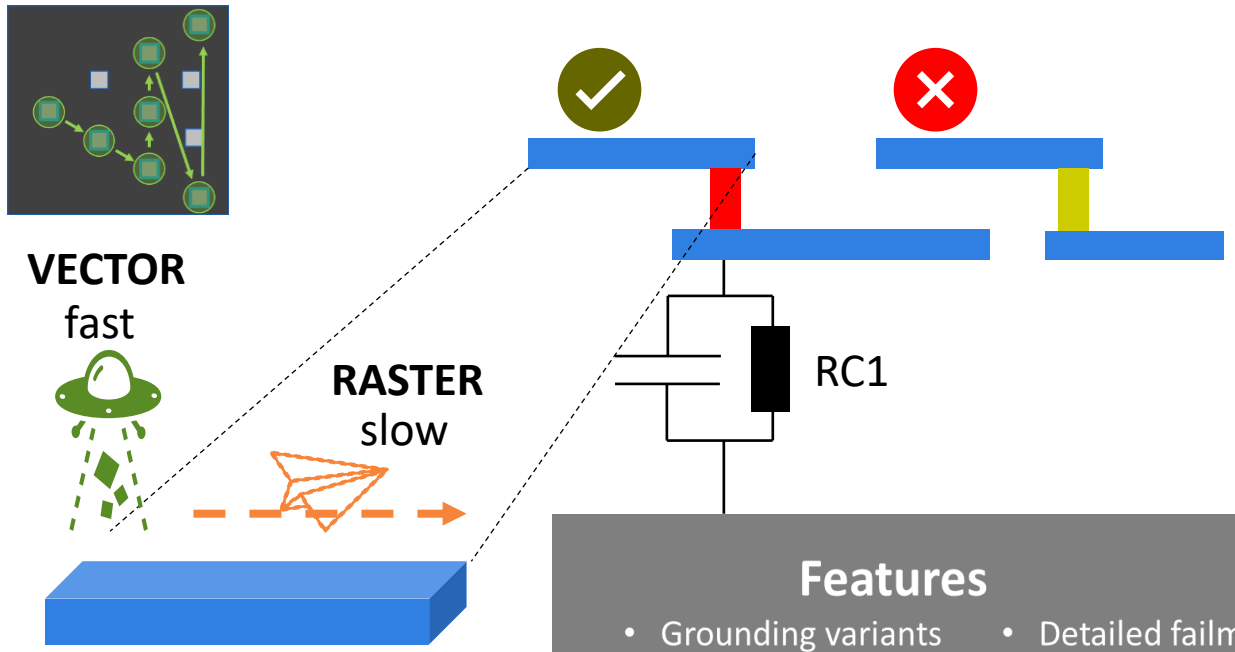




“How to Classify Photos of Dogs and Cats (with 97% accuracy)“
-- machinelearningmastery.com

Exensio FIRE Drives More Efficient Inline eBeam Inspect

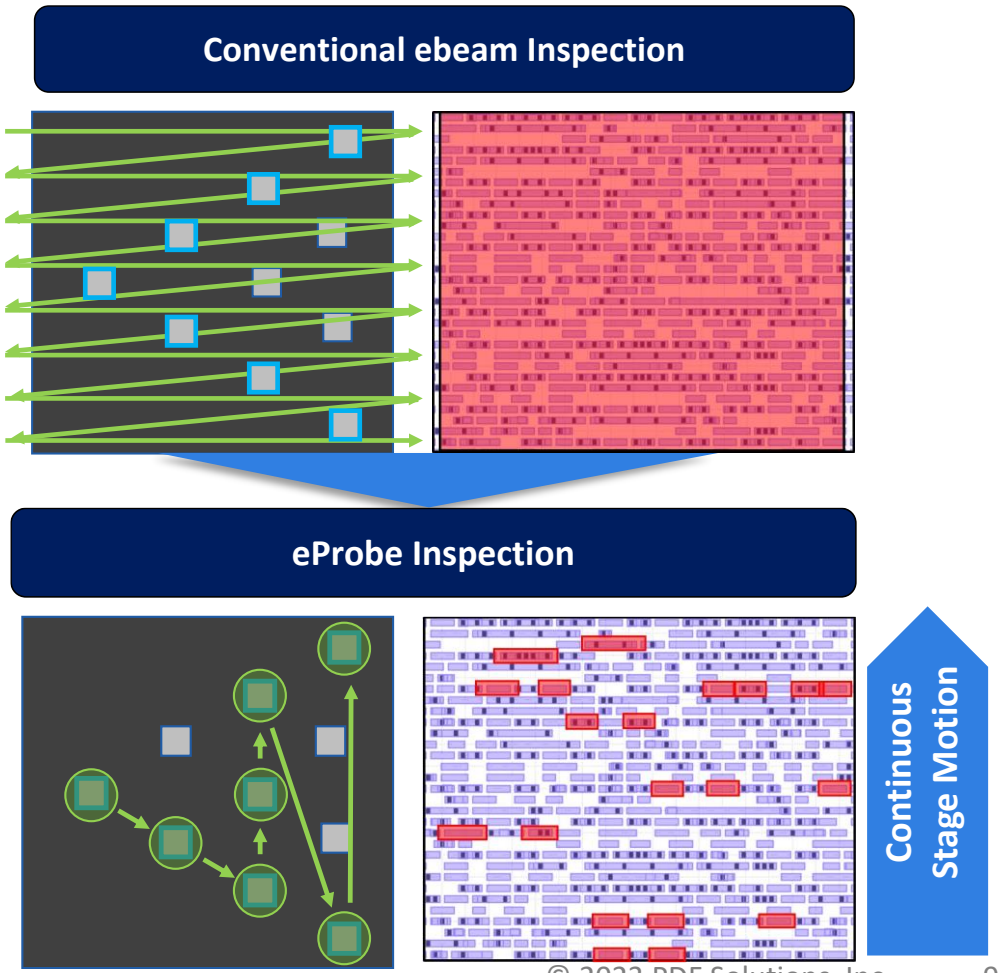
- **FIRE AI** algorithm summarizes design characteristics and enables selection of scan points to take advantage of HW vector scan capability



Features

- Grounding variants
- Current paths per pad
- Redundancies
- Leakage modeling
- Detailed failmode modeling
- Parasitic failmodes
- E-beam brightness simulation

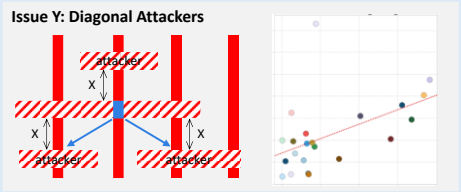
- **<u>Design Aware Inspection</u>:** eProbe knows precise pad type and location targeted IN **REAL TIME** for **10-100X efficiency gains**



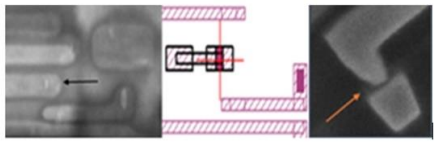
PDF DirectScan System Overview

1. Vulnerable Pattern Library

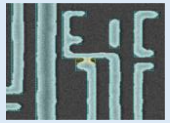
Systematic Yield Gap Analysis & Volume Diagnostics



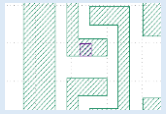
PFA information



Inline information



DFM Knowledge



Test Structure Data

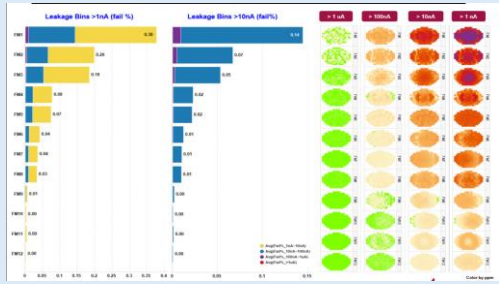
2. Fire™ Product Layout Scan For Related Patterns

Example for Mx line ends

3. DirectScan product wafer at layer with eProbe® 350

Unique Vector Scan performs Billions of measurements/wafer

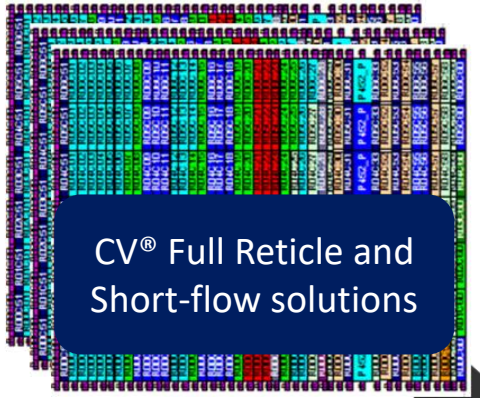
4. Failure Pareto



- Quantify yield impact in PPB stats
- Analyze key fail modes across full product layout
- Characterize product pattern neighborhood dependence for each fail mode
- Apply in TD and ramp for early learning & characterization
- Apply in production for required statistically significant monitoring and resolution
- Apply in process splits for accelerated learning cycles

PDF Characterization Vehicle® Test Chips

Area efficient and fast-testable Test Chip solutions

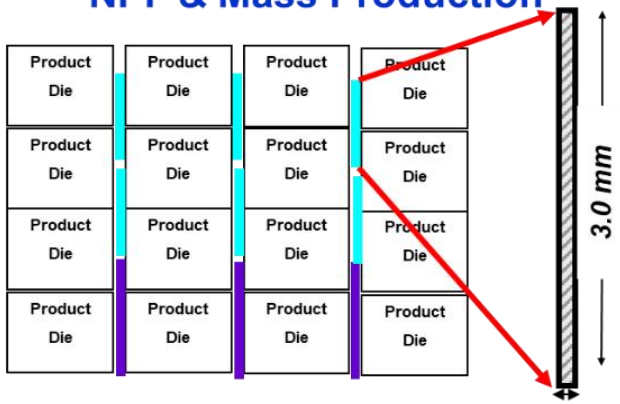


CV® Full Reticle and Short-flow solutions

NPI & Mass Production

On product xScribe CV

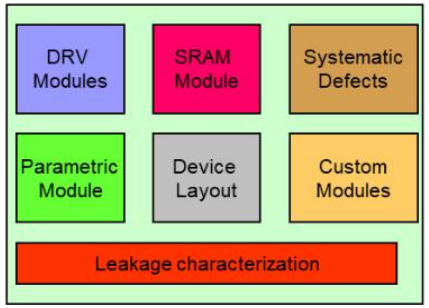
Device, Yield, Parametric, Leakage, eMetrology



Technology Development and Ramp

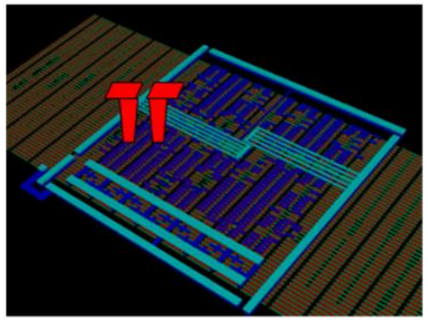
Dedicated or MPW BEOL CV, XFEOLSR CV:

Process margin,defectivity Device, Lkg, SRAM, eMetrology, etc.



On Product: Direct Probe CV

Product Bring-up



PDF Characterization Vehicle® test chip = CV® test chip

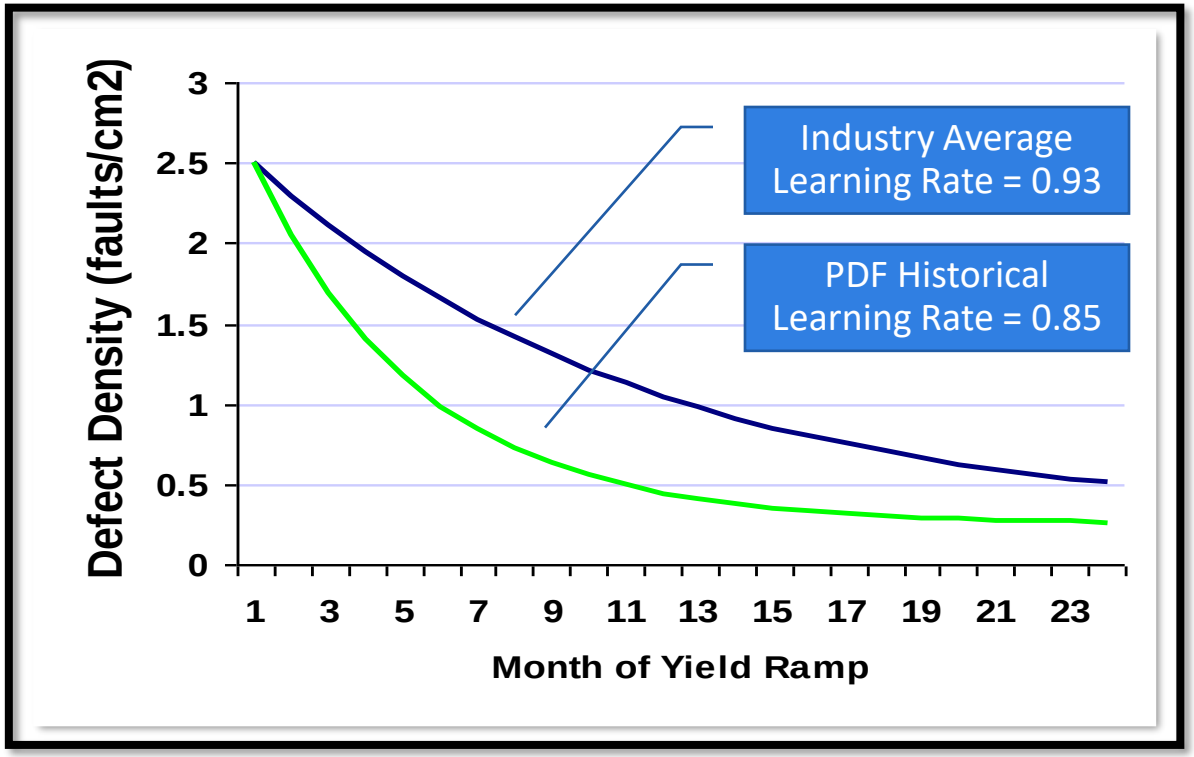
Characterization infrastructure for data collection

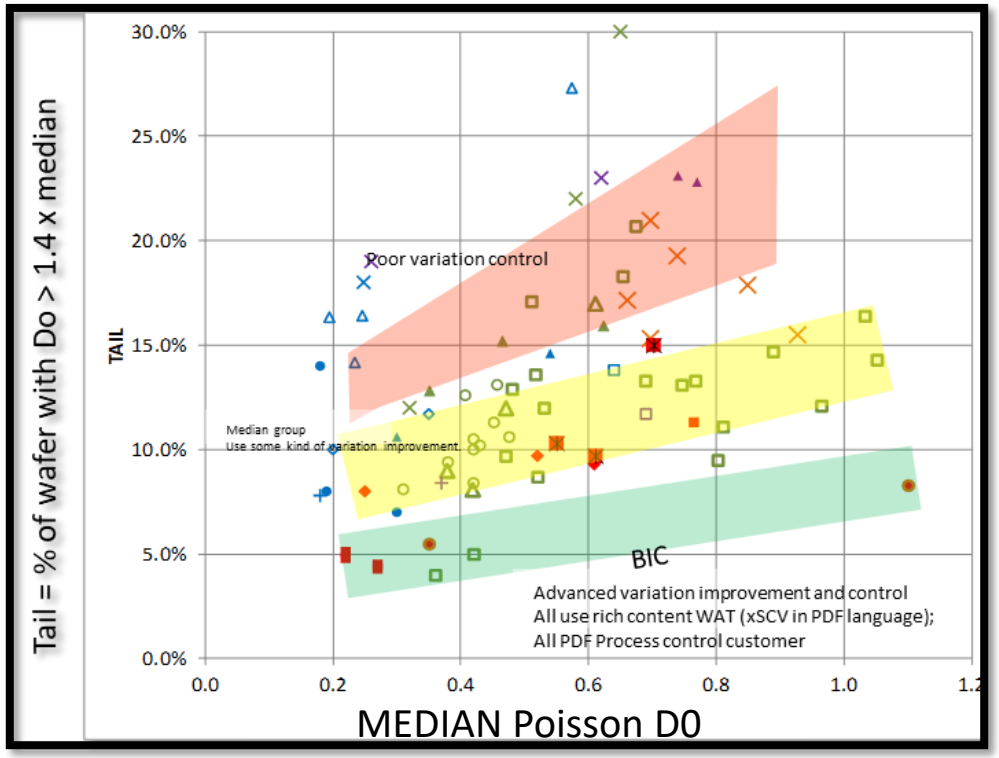
Inline & End of Line: CV Infrastructure

5th generation pdFasTest® E-Test HW

- Latest generation is **>1000x** faster vs. conventional architectures
- Includes parallel capacitance, parallel leakage, and pulsed memory test capability

Solutions Impact on Technology and Production Ramp

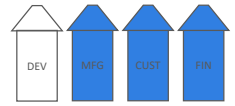




- **Learning Rate: D0 fraction reduced per month**
  - Benchmarked LR across nodes, products for 20 years
  - Indicator of technology ramp speed and product readiness
  - PDF's claim to fame is 2X reduction in time to ramp
- **Faster time to market, shorter time to volume:**
  - Significant saving in engineering resources including wafers
  - Increased profitability and ASP

- **PDF has brought Tail levels to BIC concurrently with Technology Ramps across nodes and product mixes**
  - Additional gain of $40-50M/Q realized for 40KWSPM fabs
- **Variability reduction results in**
  - Lower Tail to ~ 4% (BIC) – from 10% would gain 5% more good dies per wafer for 1 cm2 chip
  - Reduce rework rates and excursions

Sapience Manufacturing HUB Connecting the Siloes



SOURCE LAYER

- Factory Applications
- Process & Metrology Tools
- Custom Applications
- Data Warehouses
- Devices
- 3rd Party Systems
- CRM

Data Collection from MES systems

Data Registration to SAP

Sapience Manufacturing Hub

ORCHESTRATION LAYER

- Data Flow Management
- Data Governance
- Job Assignment
- Data Routing

Connectivity Layer

TRANSFORMATION LAYER

- User interface & configuration
- Data transformation
- Job definition
- Security

DATA STORAGE LAYER

Semantic Data Storage DB

Streaming Data

Connectivity Layer

Data Extraction & Load

APPLICATIONS LAYER

- ERP & Business Intelligence
- Transactional Applications
- Machine Learning Applications
- Custom & 3rd Party Applications
- Enterprise Data Warehouse

- The "**Sapience Manufacturing HUB**" is an Enterprise Application Integration (EAI) platform
- Provides the generic ability to connect to any MES, factory data system, device or tool regardless of location and move data between systems and platforms

SAP + PDF Solutions – The Big Picture for Semiconductor Manufacturing

Seamless Business Process Integration to Engineering and Manufacturing Context and Data

Top Floor

Enterprise Business Processes

Sapience® Manufacturing Hub

Shop Floor

Manufacturing (Fab, Assembly, Test)

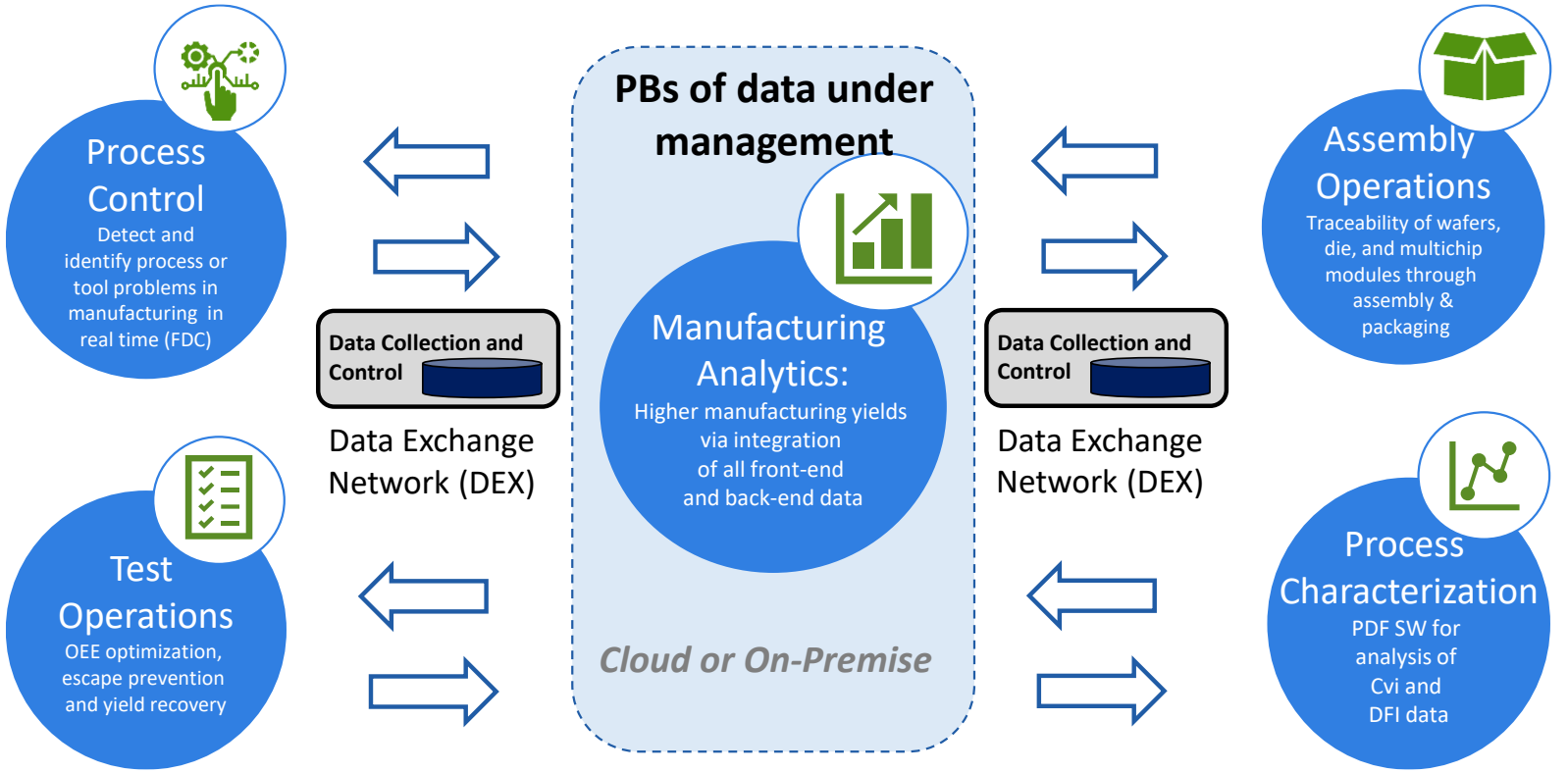
1. A common logical model for Product / Assets supporting next generation E2E scenarios
2. Extend business process, logic, and data to the manufacturing edge
3. Semantic data model for standard pre-packaged content ready for consumption
4. Derive business, product, and service insights from manufacturing

Opportunity

- Simplification
  - Business Processes, Information Systems…
- Closed-loop business processes
- Greater visibility across supply chain
- Improved throughput, yield, test efficiency, asset management, factory planning, NPI, TTM…

Exensio Advanced Analytics, Data Quality & Edge Execution

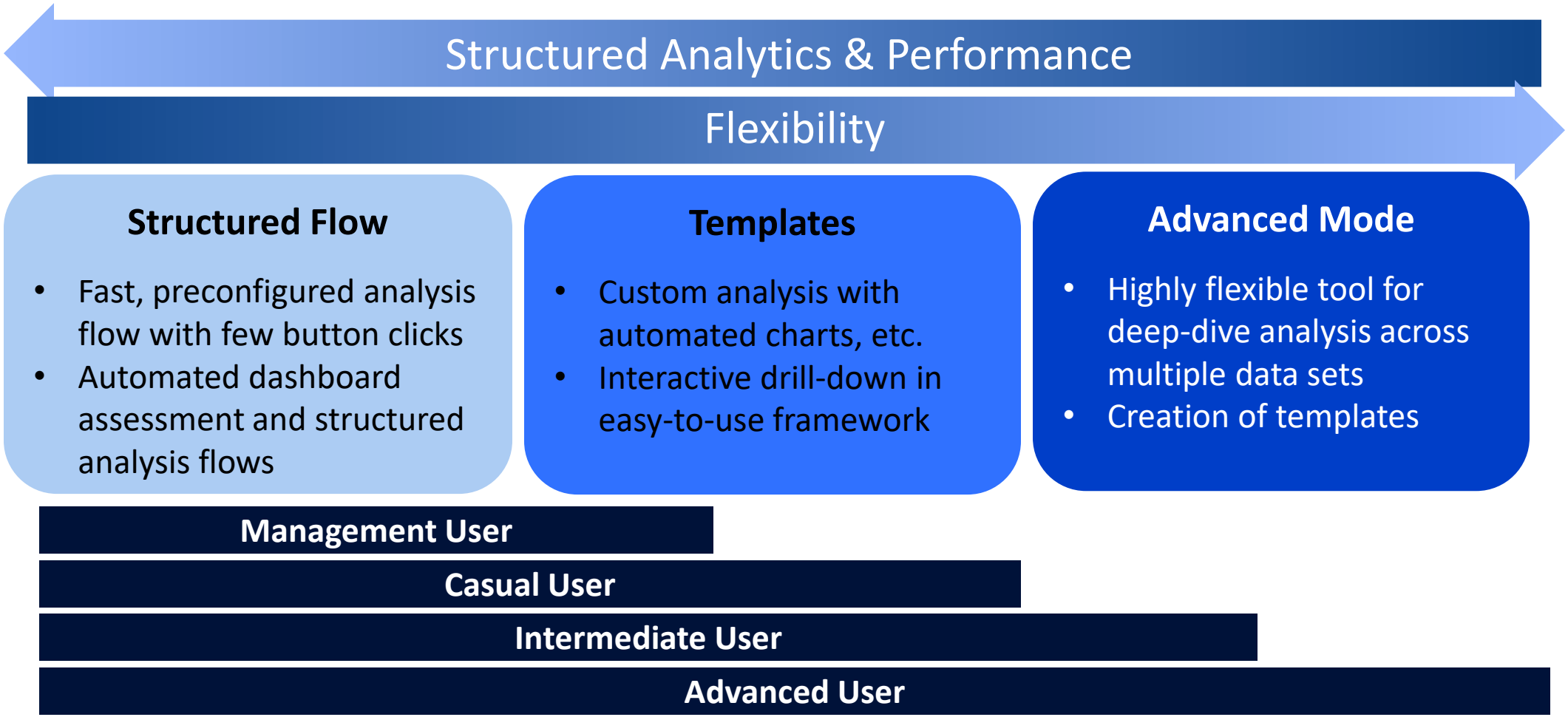
- **Local data collection and tool integration**
- **Tool control**
- **Local MES / App integration**



- **Customer data routing**
- **End-to-end encryption**
- **Secure containerized model execution**

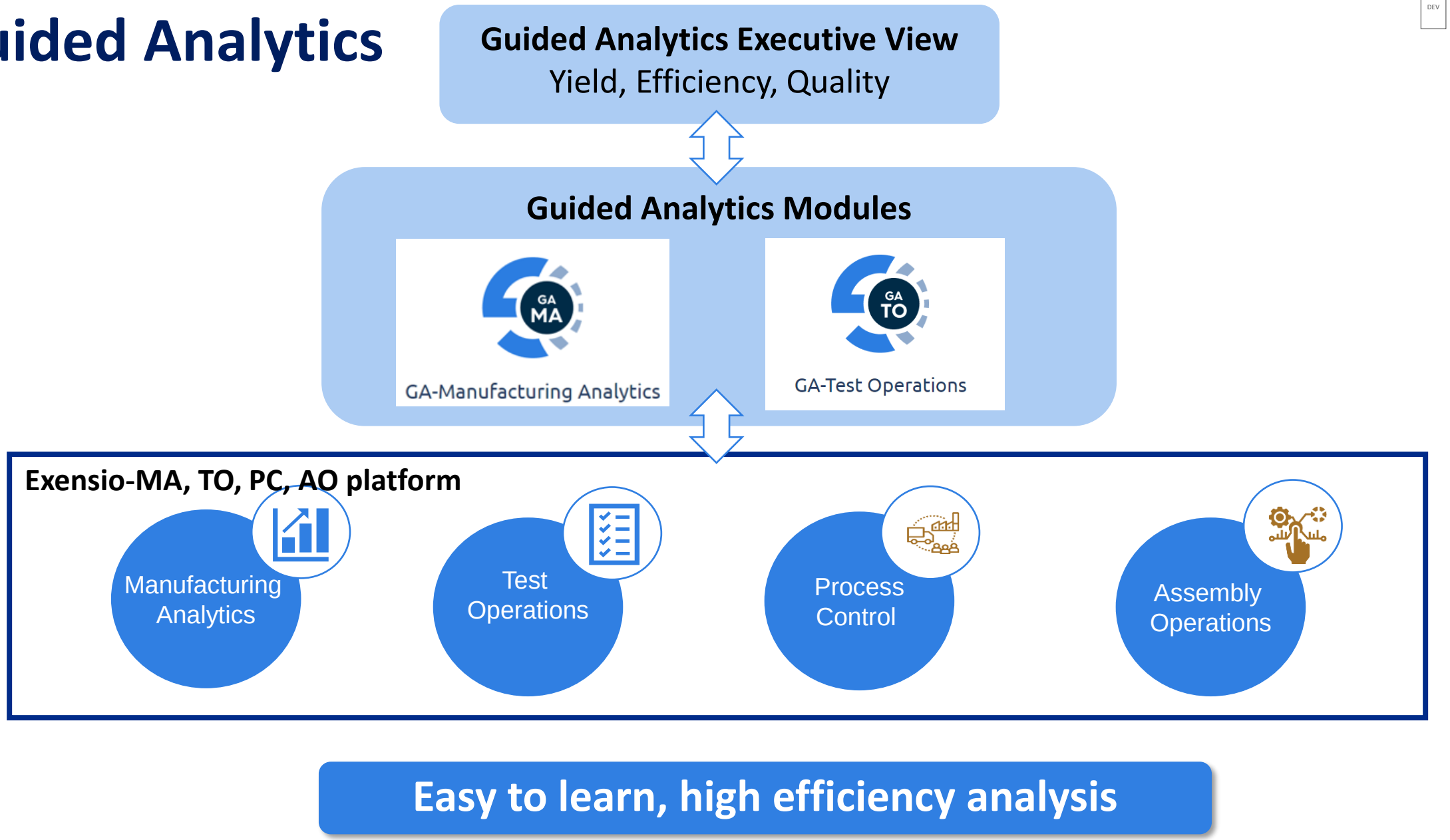
Scalable and fast loading with built in redundancy

Guided Analytics: *Wide Range of Use Modes*



Guided Analytics enables fast time to meaningful results

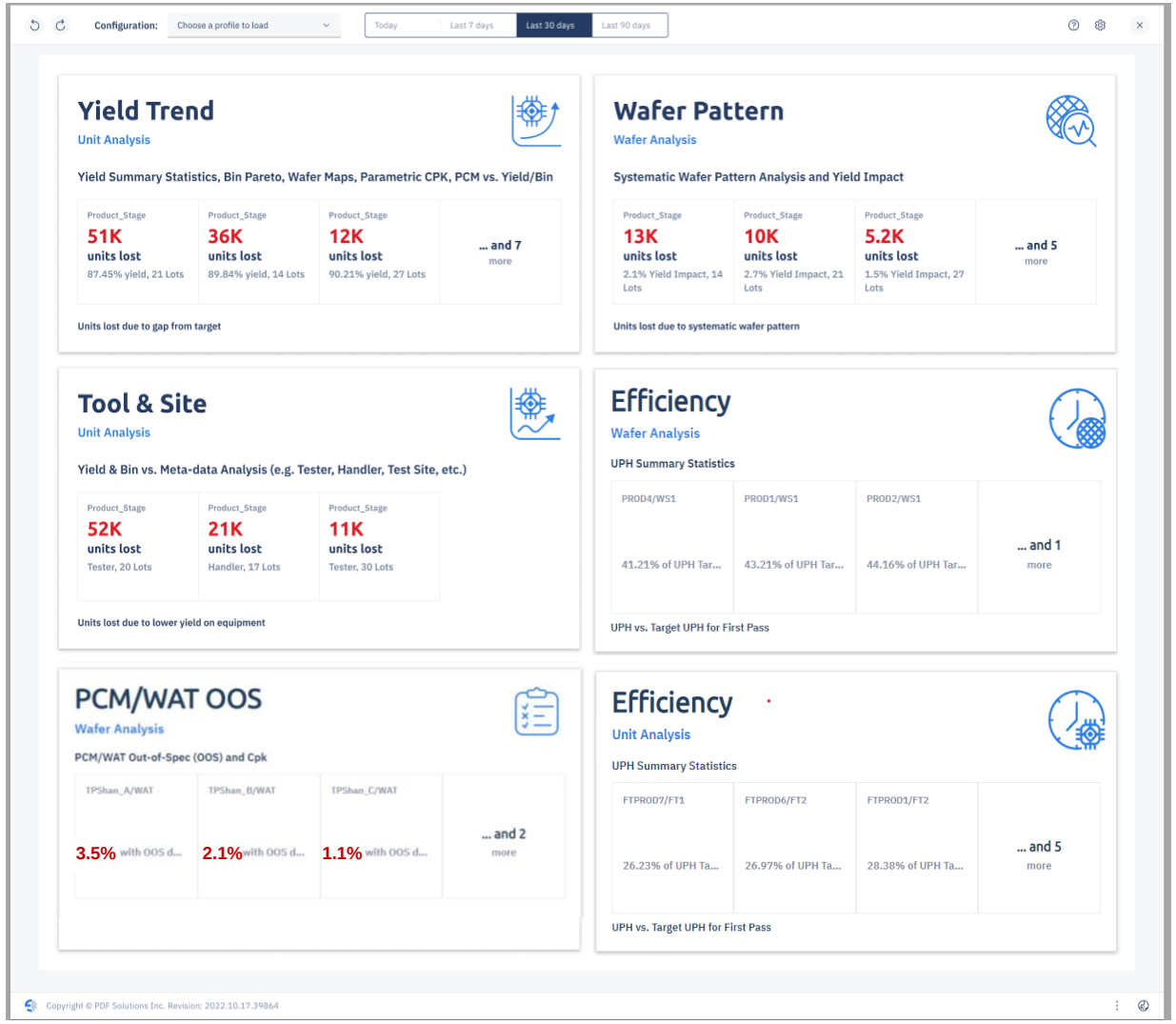
Guided Analytics



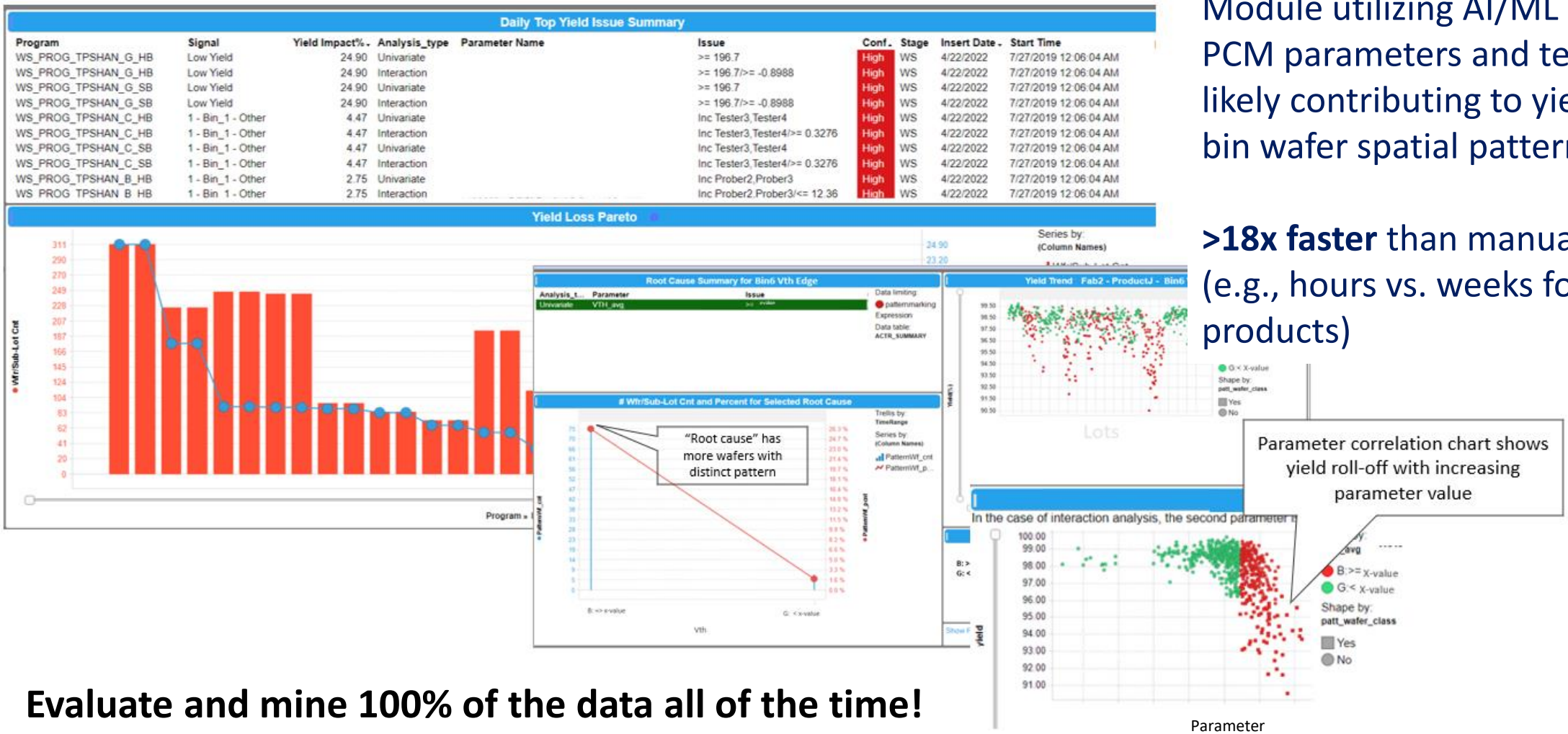
Easy to learn, high efficiency analysis

Guided Analytics: *Automated Prioritization of Yield Issues*

- **High-level dashboard provides assessment across multiple products**
- **Preconfigured analysis framework guides the user through an issue-based analysis path**
  - Yield trends and gaps to target
  - Wafer-level systematic signatures
  - Lower yielding test cell equipment
  - PCM/WAT OOS wafers
  - Throughput lower than target
  - AI/ML driven diagnosis for excursion, low yields and wafer-level patterns (add-on)
- **Effective tool for high number of products**
- **Profiles for user-specific configurations stored in database**



GA Accelerated Root Cause Diagnosis Powered by AI/ML

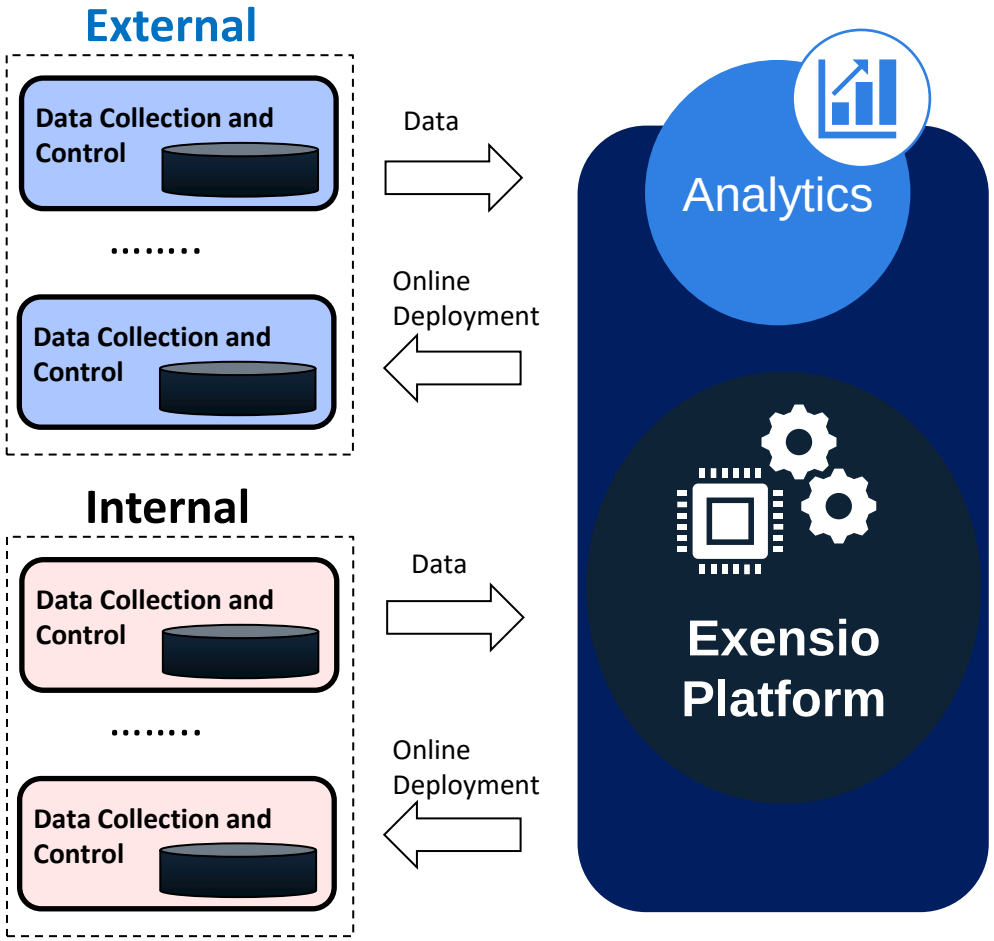


Module utilizing AI/ML identifies PCM parameters and test equipment likely contributing to yield loss and bin wafer spatial patterns

>18x faster than manual analysis (e.g., hours vs. weeks for 2000 products)

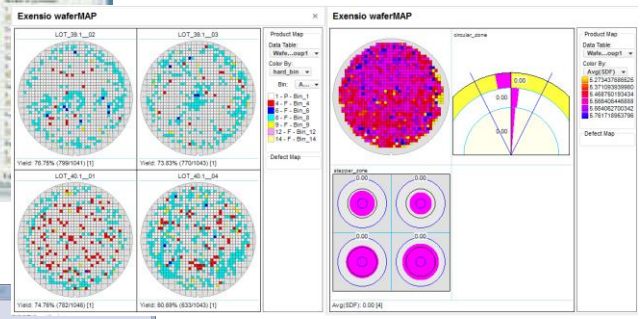
Evaluate and mine 100% of the data all of the time!

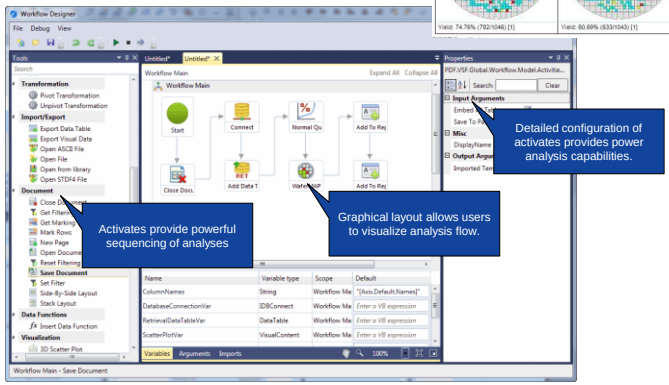
Manufacturing Analytics: Integrating Frontend & Backend Data



Interactive visualization

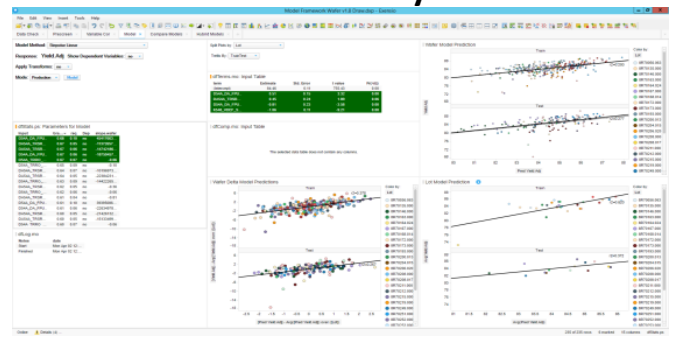
IC models built in





Automation & Reporting

Advanced Analytics

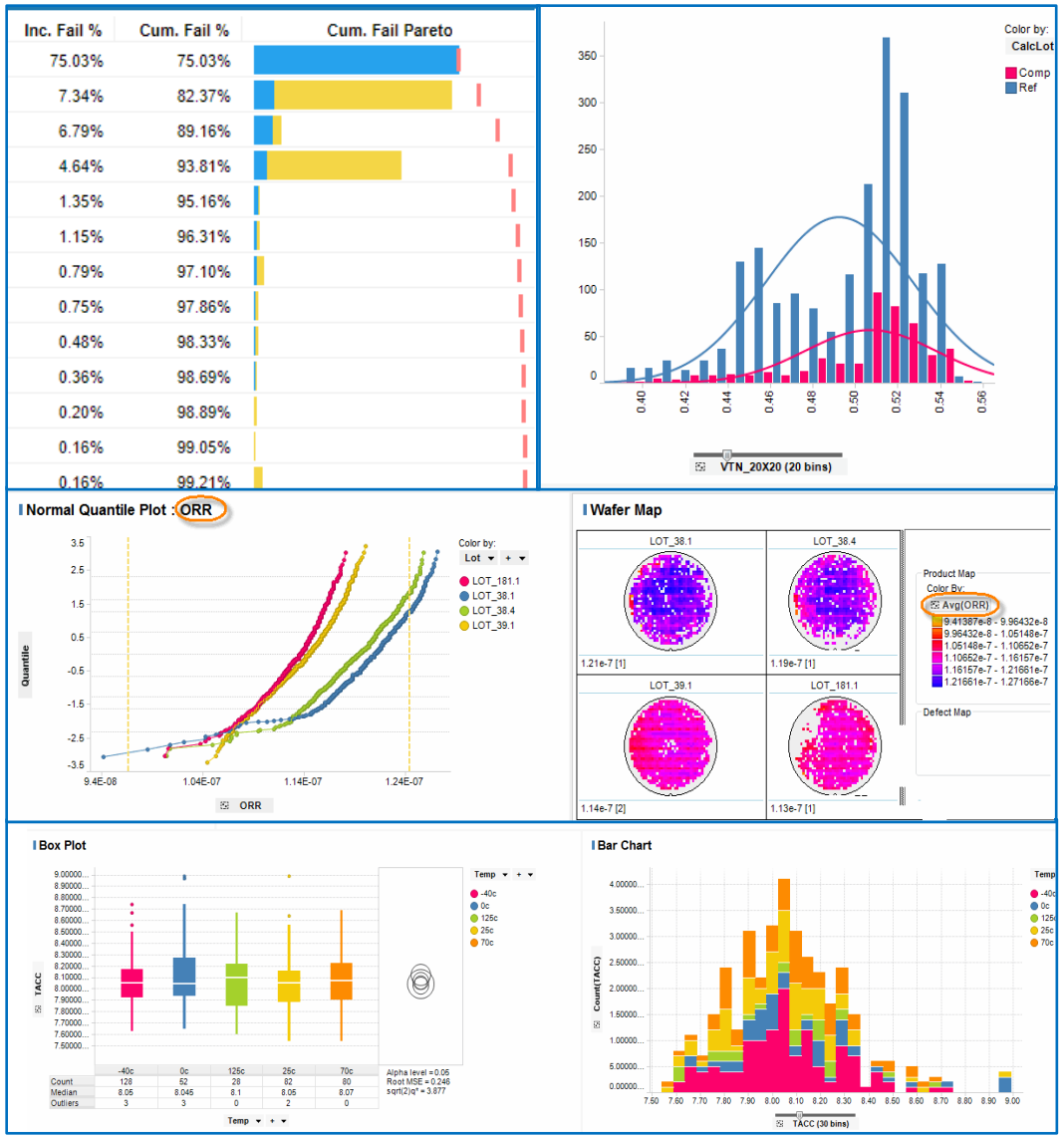


- Provides powerful signature analysis and diagnostics

Industry leading application for high volume data analytics & visualization

New Product Introduction & Characterization Feature Matrix

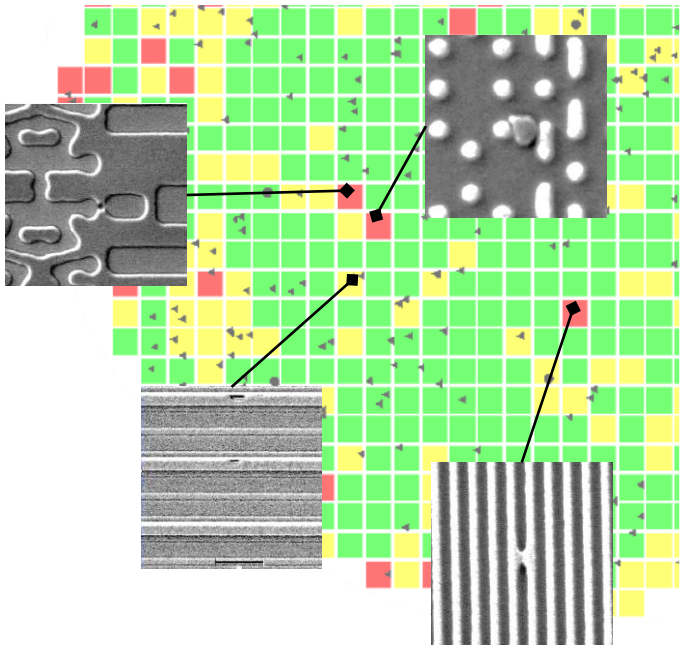
Capability	Exensio Manufacturing Analytics	Partnership
Test Program Validation & Optimization		
Test Coverage (Never failing / Redundant tests)	✓	
Limits Analysis		
Specification, Guard band Limit Setting	✓	
Product Characterization		
Wide / Sweep Data Handling	✓	
CP / CPK Analysis, VDD / Temp Char Analysis	✓	
Fab / Supplier Matching & Qualification	✓	
Reporting / Templates / Release to Production	✓	
Design / Layout Sensitivities to Process		
WS / FT to WAT: Die Level Process Sensitivity	✓	
On Chip Agents	✓	✓
Fault Diagnostics		✓
IDM / FAB		
Linkage with process data (fab, defect, fdc, etc)	✓	
Split Lot Analysis	✓	



Exensio Defect Management System

WHAT SETS US APART

- #1 end-to-end Defect and Yield Management across the entire supply chain
- Used by 9 large fabs and IDMs in the US, Asia and EU
- Compliant with all standard DMS requirements
- Highly scalable deployments on-prem and in the cloud
- The first to implement device traceability to enable tracing electrical fails to inline defects
- Fully independent: equipment agnostic with support of all fab data types

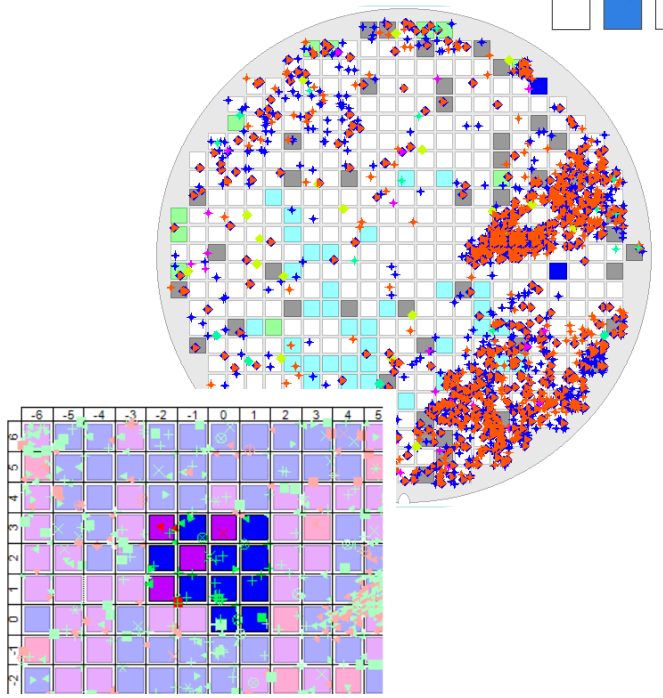


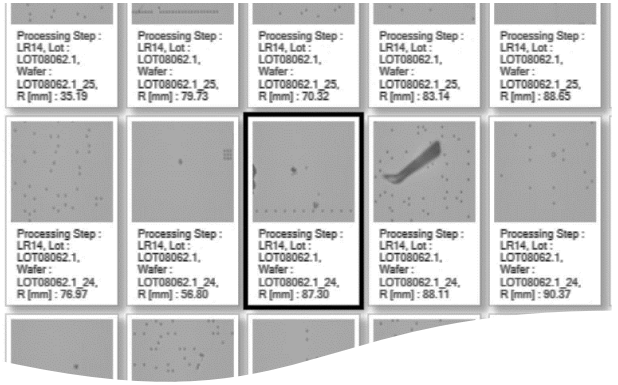
DMS: Solutions Overview

- **Defect Map -** Defect data storage and analysis with mapping capability and alignment with other data types

- **Defect Map Class –** Classification of defects to group similar defects by type for Kill Rate and Capture Rate summaries

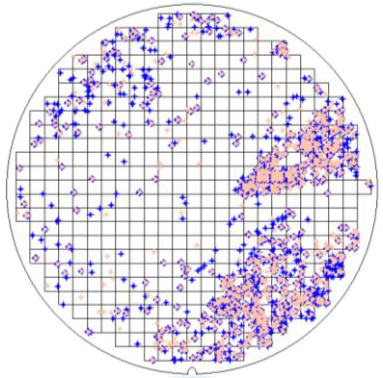
- **Defect Map Gallery –** Gallery of inspection and review images linked to inspection site (thumbnail gallery)



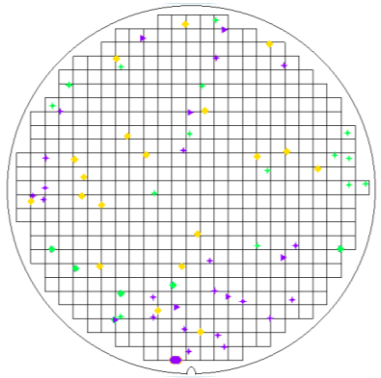


DMS: Defect-Bin Overlays

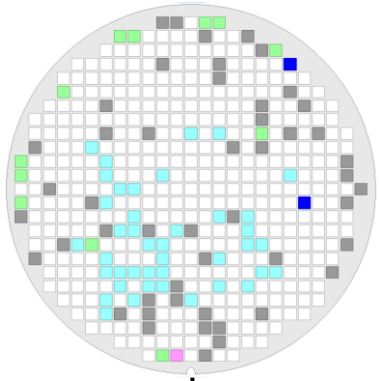
FEOL → BEOL → Assembly & Test



Defects

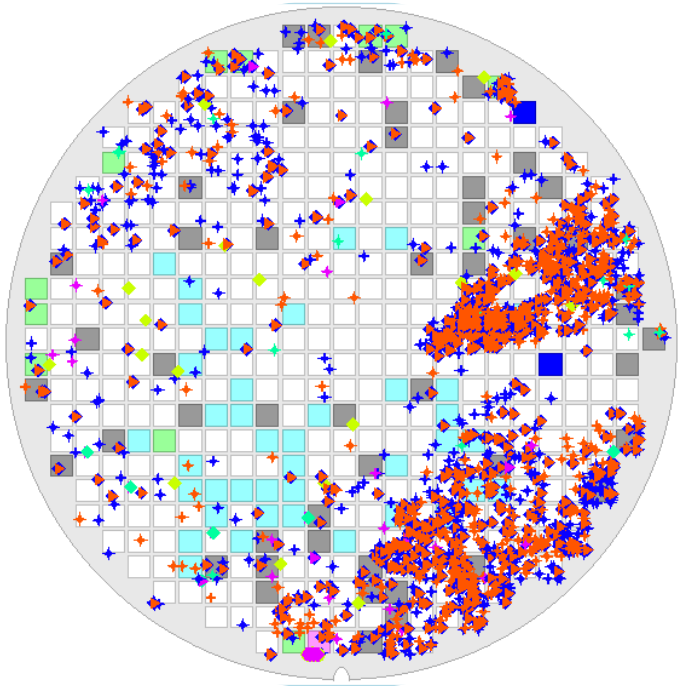


Defects



Electrical

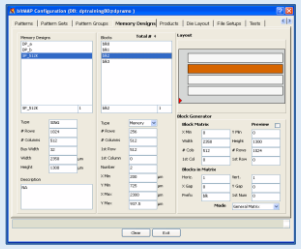
Electrical Bins + All Inline Defects in one place



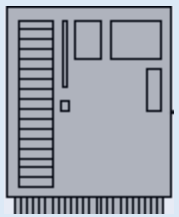
Visualizations by lot, wafer, layer, type, rework, attributes…

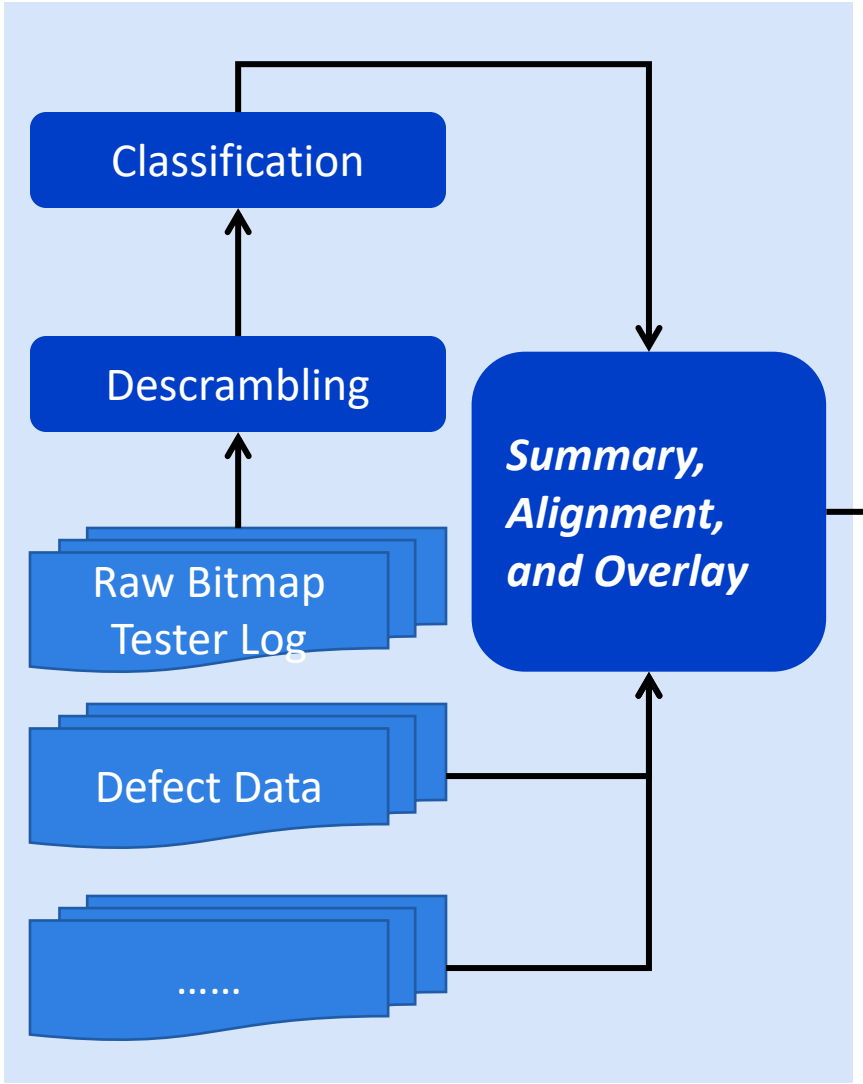
Bitmap Classification and Overlay

Configuration



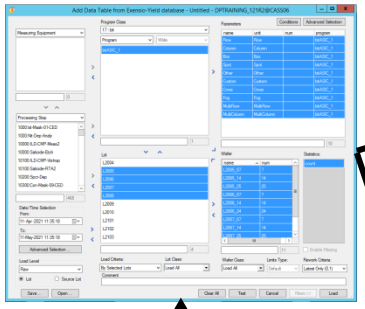
Tester



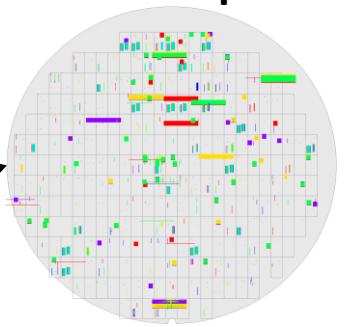


Back-End

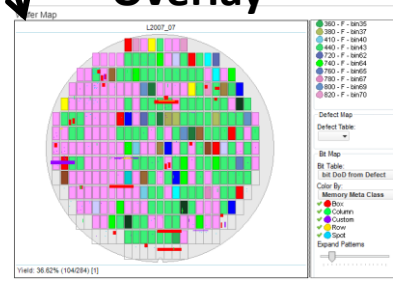
Bitmap Retrieval



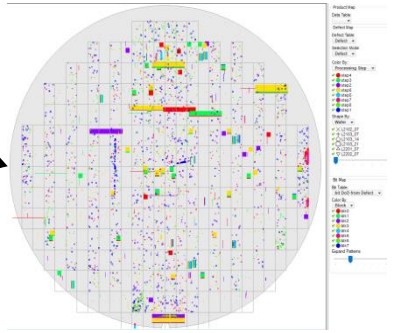
Bitmap



EWS/CP-Bitmap Overlay

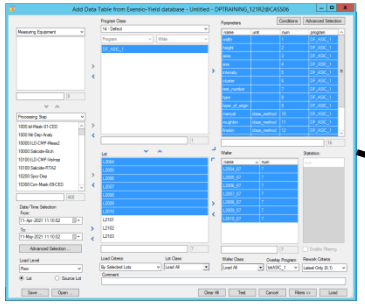


Defect-Bitmap Overlay



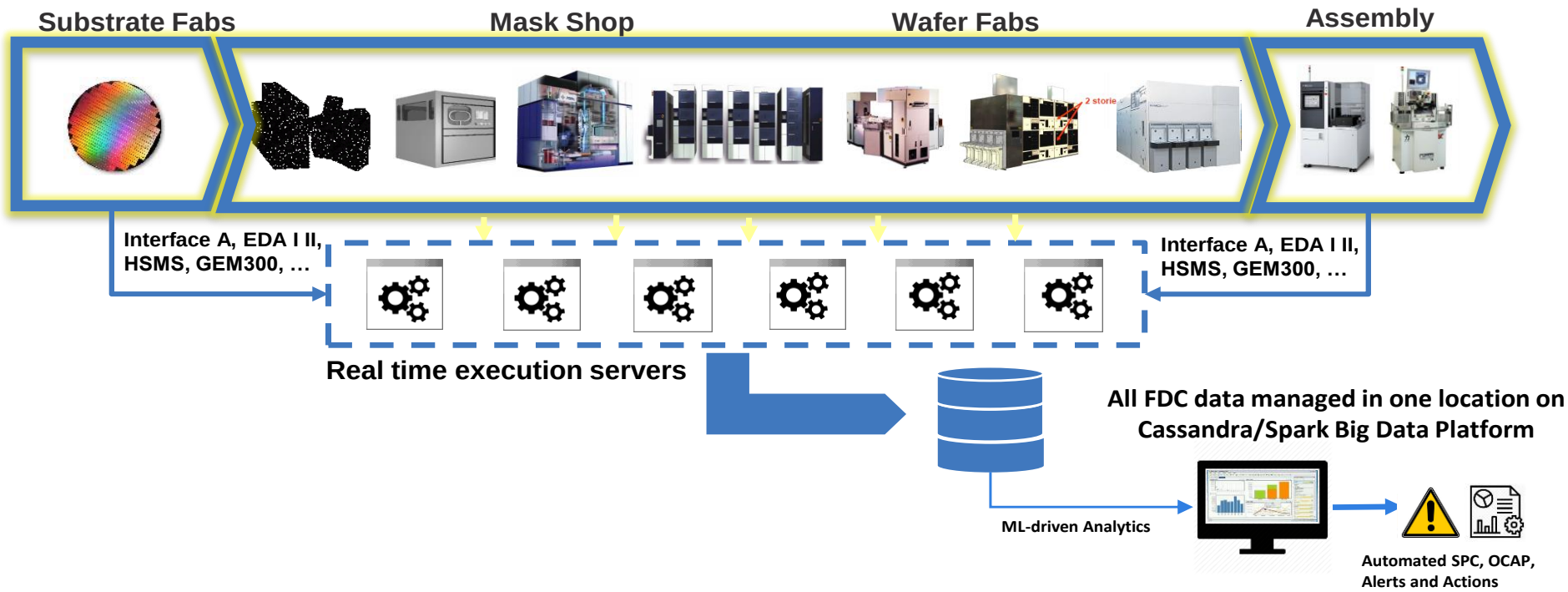
Analytics

Defect Retrieval



Front-End

Process Control: Advanced FDC for Manufacturing Tools



- **An Industry leader for FDC control solutions**
  - Over 40,000 process tools under PDF control
  - Online control & offline analytics (real-time & summary FDC)
  - Advanced analysis, AI, ML, SPC, OCAP, dashboards, automation
- **FDC based decisions and process control at tool and factory levels:**
  - Reduced excursions & tool induced process variability
  - Reduced maintenance resource costs and requirements
  - Tighter yield and parametric distributions

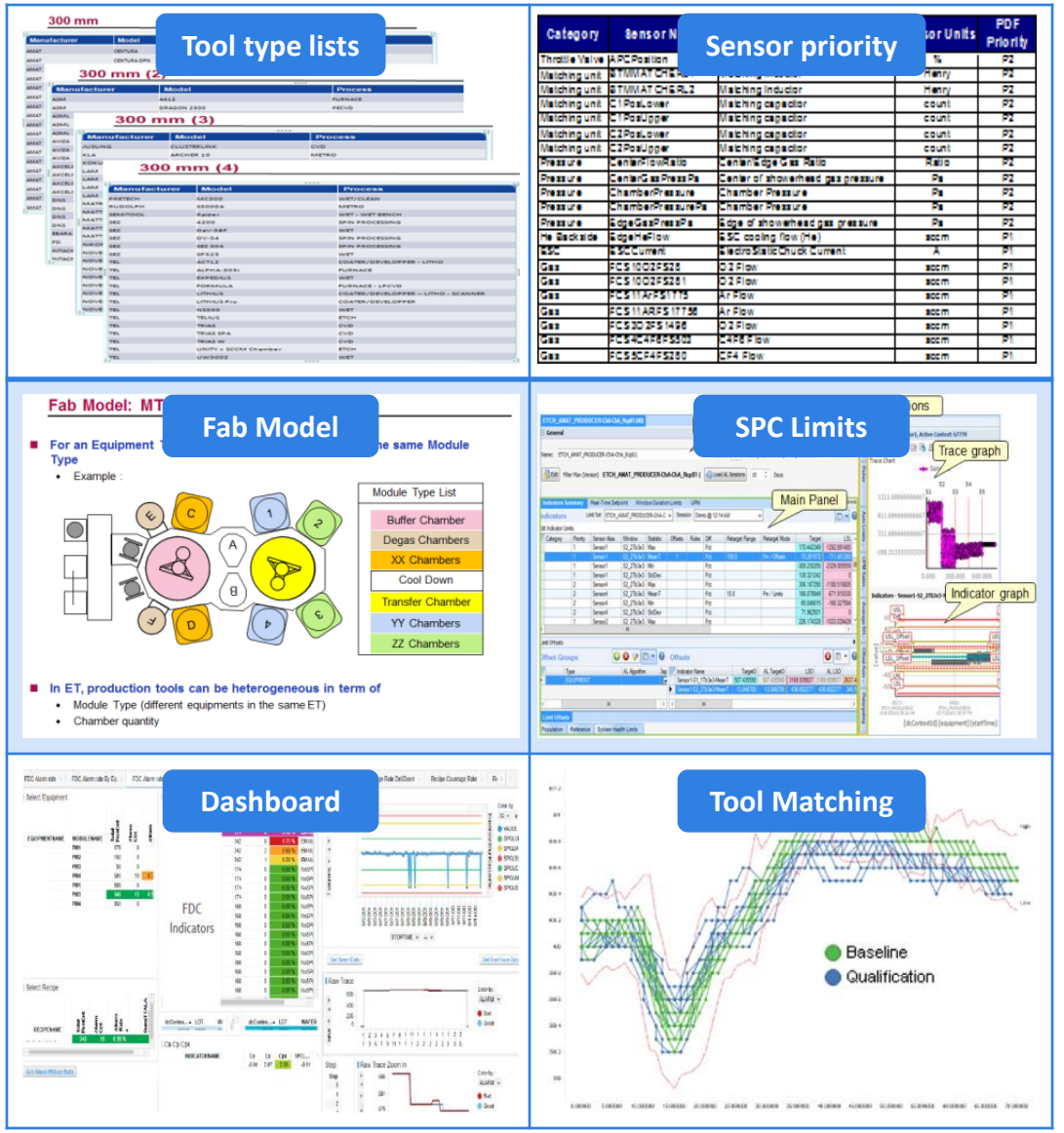
Identify, diagnose, & prevent tool problems

Exensio Process Control Applications for Fabs and IDMs

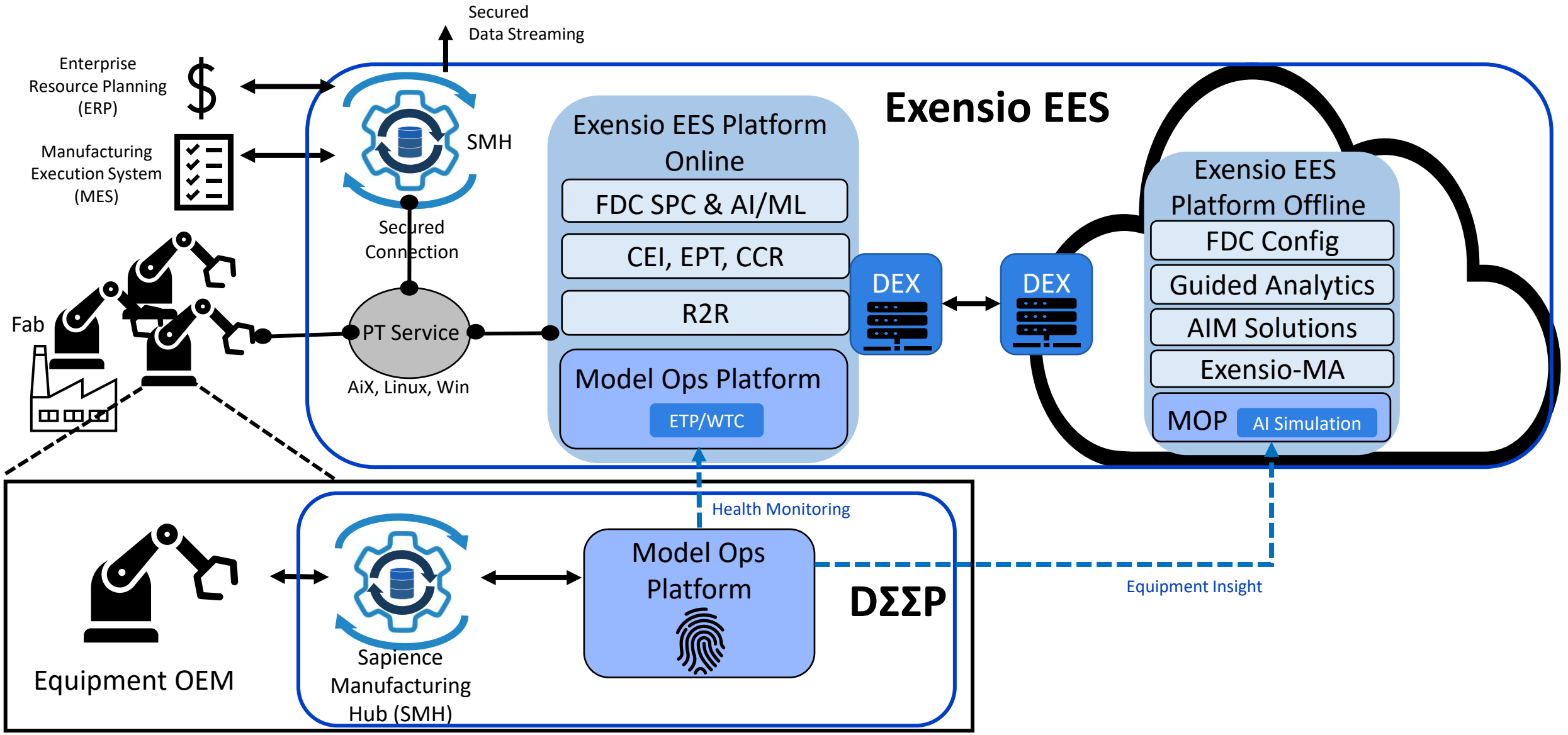
1. **Superior data acquisition quality :**
   a. 20+ years experience integrating 200 and 300mm toolset cover almost all of tool types
   b. Extra sensor compatibility and Interface-A / EDA compatibility
   c. Sensor audit based on PDF knowledge base derived from worldwide YAFDC experience

2. **On-line control:**
   a. Control limits & OCAP on FDC Indicators with wafer level alarm & interdiction
   b. Multi-level limits, Multi-auto limits algorithms, WECO rules and Offsets
   c. Fab Model provides 10+ times of efficiency improvement

3. **Auto reporting and Dashboard:**
   a. Dynamic statistical reports enable flexible management of global FDC status
   b. Excursion diagnostics drill down to trace level effectively reduce FDC alarms
   c. Configurable chamber matching auto-reports & analysis templates for auto-diagnostics

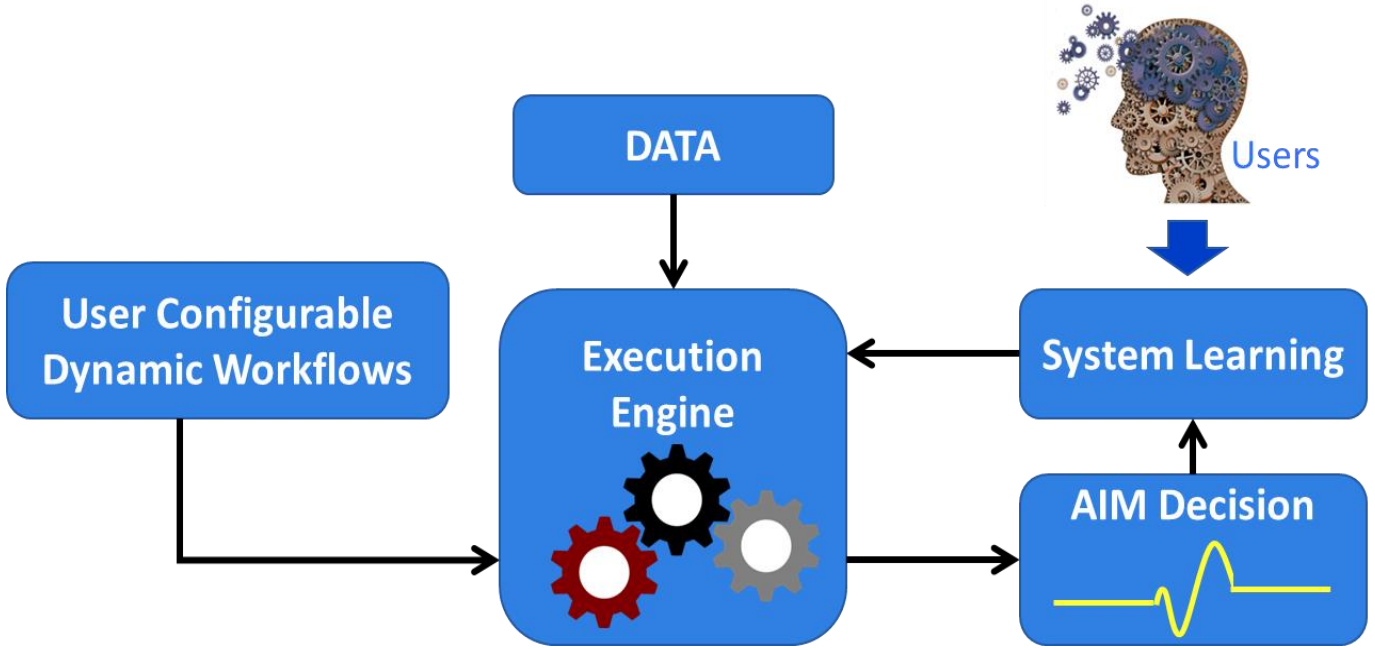


Exensio Equipment Engineering System Platform



AIM – Advanced Insights for Manufacturing

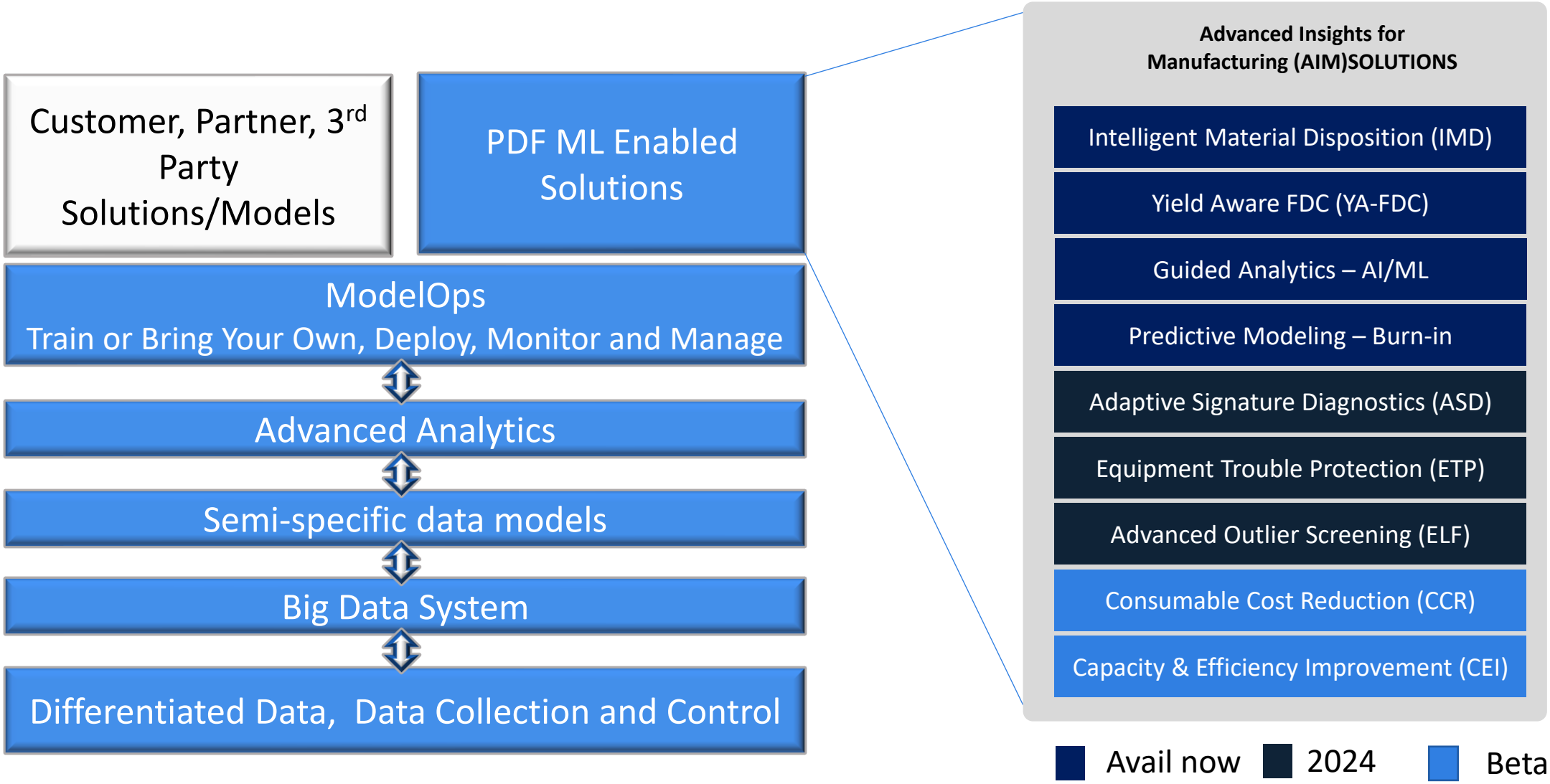
- Big Data Infrastructure to connect and relate ALL of the necessary data types & built-in understanding of interactions between design – fabrication – electrical



- Application of these foundational elements to provide solutions to the specific needs of the I.C. manufacturer

- Performance to explore, visualize, and analyze the varied types of data and apply AI & Machine Learning
- Scale to handle the rapidly increasing range of data types, volume, variety, and velocity

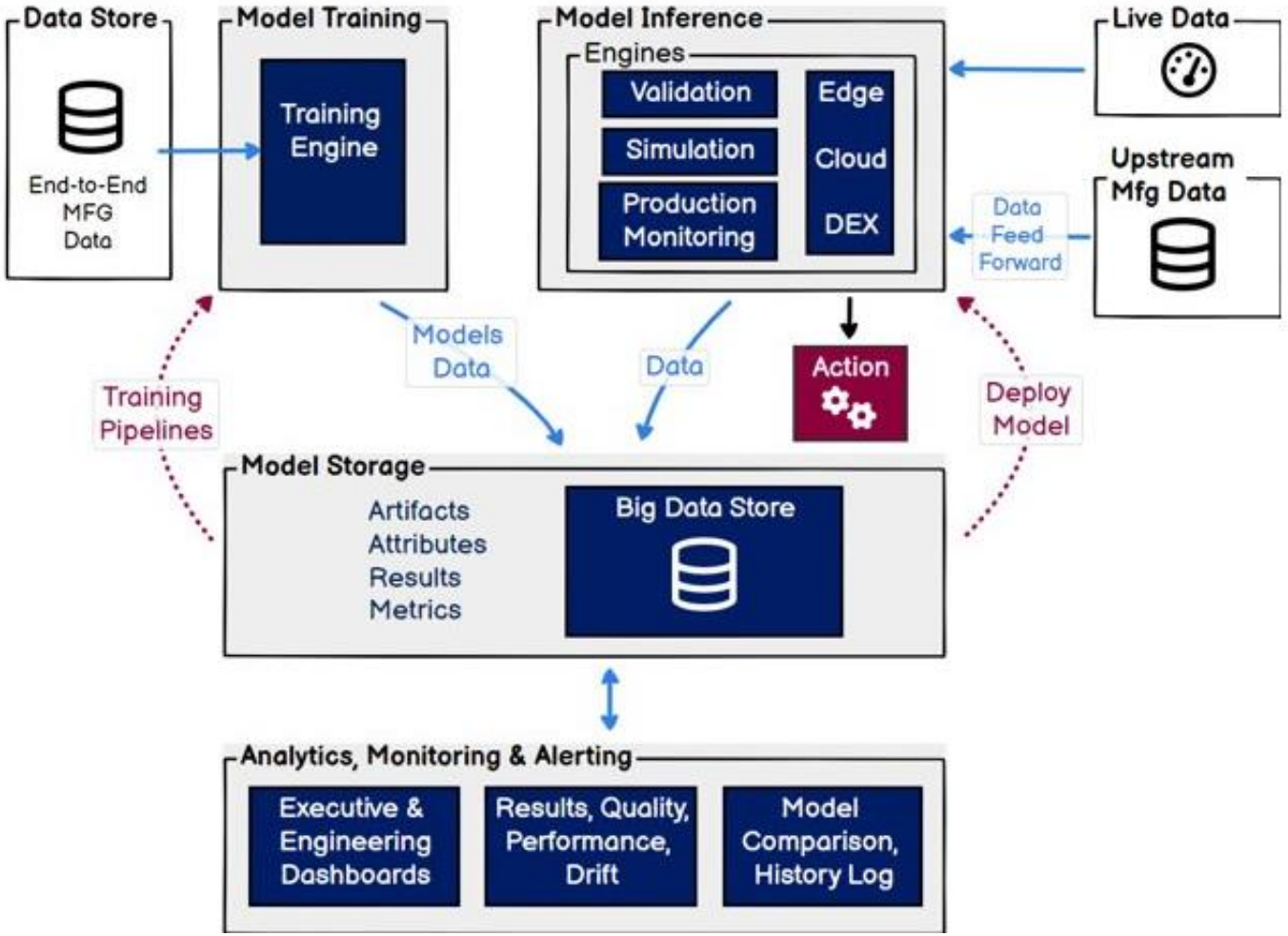
ModelOps and AIM Solutions



PDF Platform Model Ops Enables Scaling & Performance

large numbers of models, big data volumes, real-time inference

- Integrated with the Exensio platform to leverage semi data access, analytics and control
- Central Model Storage System
- Dynamically Scalable Big Data model training infrastructure
- Deploys to Cloud & real-time Edge Inference Engines
- Bring-your-own Algorithm / Model / Inference Engine



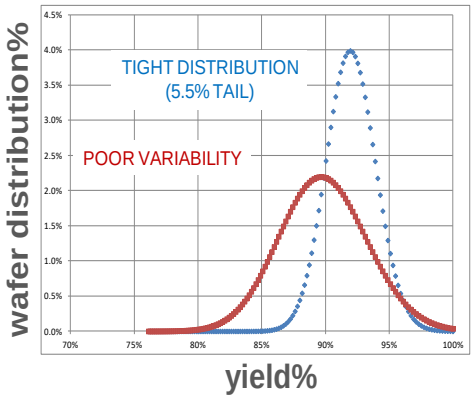
YA-FDC Yield Aware Fault Detection & Classification

- **Combination of technology and services that utilizes Exensio's FDC & YMS 'big data' and applies AI/ML**
  - Implements better characterization of process variation
  - Identifies equipment conditions and variability that influence functional and parametric yield & sets appropriate SPC limits through proprietary analysis and modeling techniques to identify critical parameters
  - Automated analysis, dashboards, & reporting that drives fast improvement on yield variation & cost reduction
- **Includes AI and Machine learning such as**
  - Predictive models to for finer control including feed-forward and feed-back control options
  - Predictive PM's to optimize tool availability
  - Virtual Metrology driving adaptive sampling for inspection and metrology

- **AI FDC Benefits Demonstrated**
  - 8% Yield Improvement
  - 40% Excursion reduction
  - 7% Faster Ramp of New Products

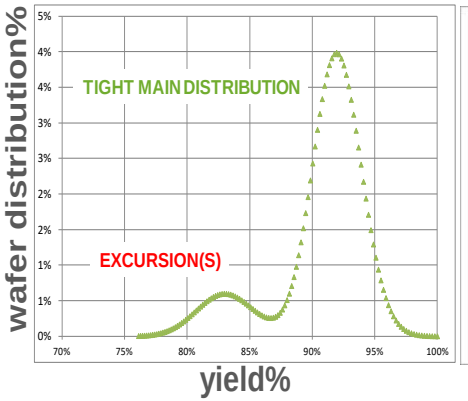
+8% YIELD

Reduced Variability



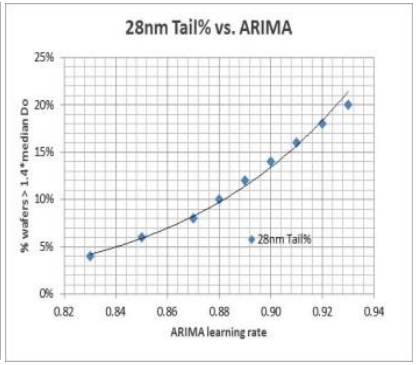
40% Reduction

Excursion Reduction



7% LR increase

Faster Yield Ramp

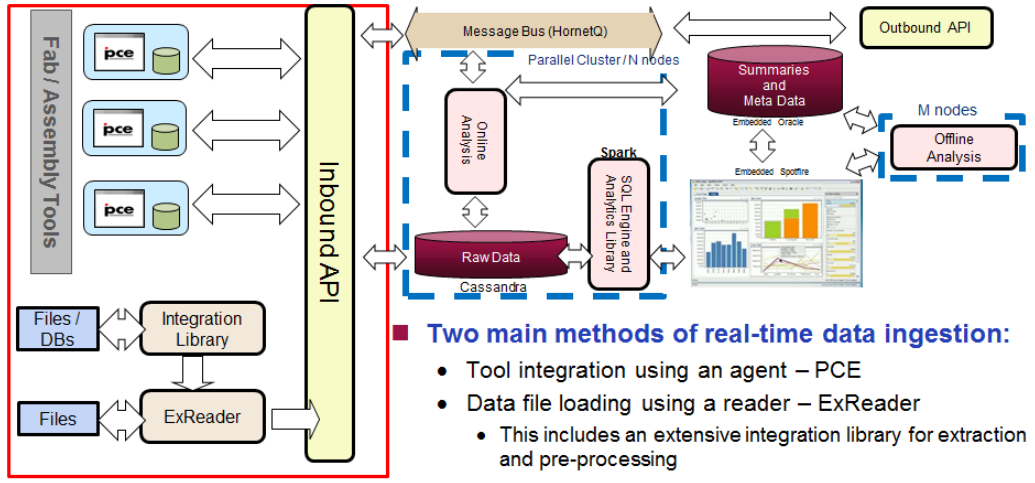


Yield Aware FDC uses ‘Big Data’ and Machine Learning

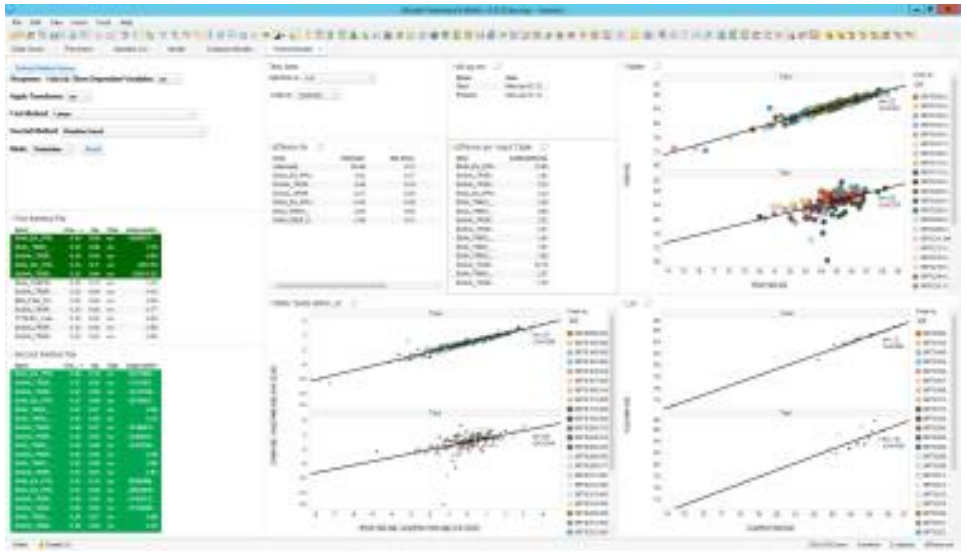
- **Yield Aware FDC is built-on a scalable ‘Big Data’ platform with superior performance vs. RDBS**

- **Yield Aware FDC control plans use feedback (correlations & modeling) to find the important signals to be tightly monitored & controlled**
  - Response data (Metrology, NPW, Defect, PCM, Yield, Events)
  - Sensor, PM, and FDC event data

- **Yield aware uses machine learning tools i.e. advanced MVA, virtual metrology, and predictive modeling to provide the insights needed for high quality & reliable parts manufacturing by improving tool/process control**



Hybrid multi-variate model



Example: Linear + Random Forest (many other algorithms available)

YA-FDC Solution Examples

Fault Detection and Classification

- Predict wafer failure at a process or test station using upstream tool sensor data
- Identify root cause of failures quickly by linking back to significant features

Predictive Maintenance

- Using tool sensor data, predict when a tool will go down or need maintenance
- Identify root cause of tool issues

Virtual Metrology / Virtual Sensing

- Predict Critical Dimensions (CD) for specific process steps using sensor and inline data
- Immediately identify excursions and extend consumable life

Fab Predictive Model

- Use data from throughout the fab to predict wafer disposition
- Use data from unit process operations to predict non-product (NPW) responses

PDF Solutions Platform Capabilities for Fabs and IDMs

Key functionality that enables customers to achieve high value results

Industry Data

- Connects and collects the online manufacturing/test data
- Brings all the data into the learning process
- Adds context and meaning with industry specific semantic
- Industry specific training pipelines

Secure IP Sharing

- Combines in house and 3rd party models and algorithms
- Develops secure and IP protected data sharing, extends learning beyond single enterprises

Industrial Readiness

- Enriches process control and test logic with AI & analytics
- Deploys upgradable and flexible equipment integration
- Optimizes equipment and factory availability with AI
- Ensures mission critical operation with AI enabled IT Ops

20% Improved Efficiency

10% Improved Utilization

6-month faster Time to Value

2X Faster time to Revenue

30% Improved Quality

30% Reduced Cost

AI Focused Roadmap of PDF's Advanced Solutions

PDF's vision and mission

- **Vision:** To be the world's leading data and analytics platform spanning the semiconductor and electronics ecosystems.
- **Mission:** Provide innovative solutions to create, access, and organize data to enable analysis and control for semiconductor and electronics companies to achieve better time-to-market, yields, quality, and operational efficiencies.

2023 & 2024 roadmap focus

- Using AI to connect design and analytics together by developing unique data and apps, including with partners, for diagnostic (including DFI) and adaptive test
- Using AI to generate unique observations to characterize process & product, and feed into PDF's overall Exensio platform to help our customer to achieve better yield, quality, and operation efficiency.

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