



Development and Deployment of a Multi-Component Advanced Process Control System for an Epitaxy Tool



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Innovation

Excellence

Agility

Value

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Outline

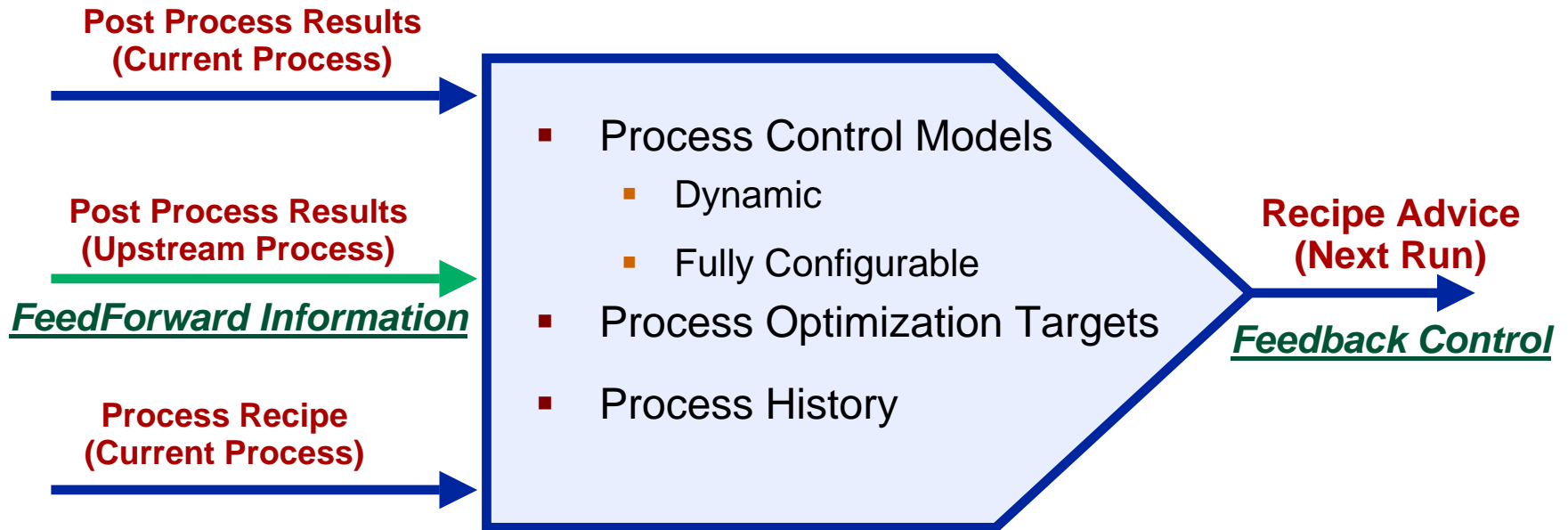


- Introduction
 - Complementary Utilization of APC Components
 - Approach to Solution
- Solution Architecture
- Application and Results
- Summary



Introduction: Run-to-Run (R2R) Control

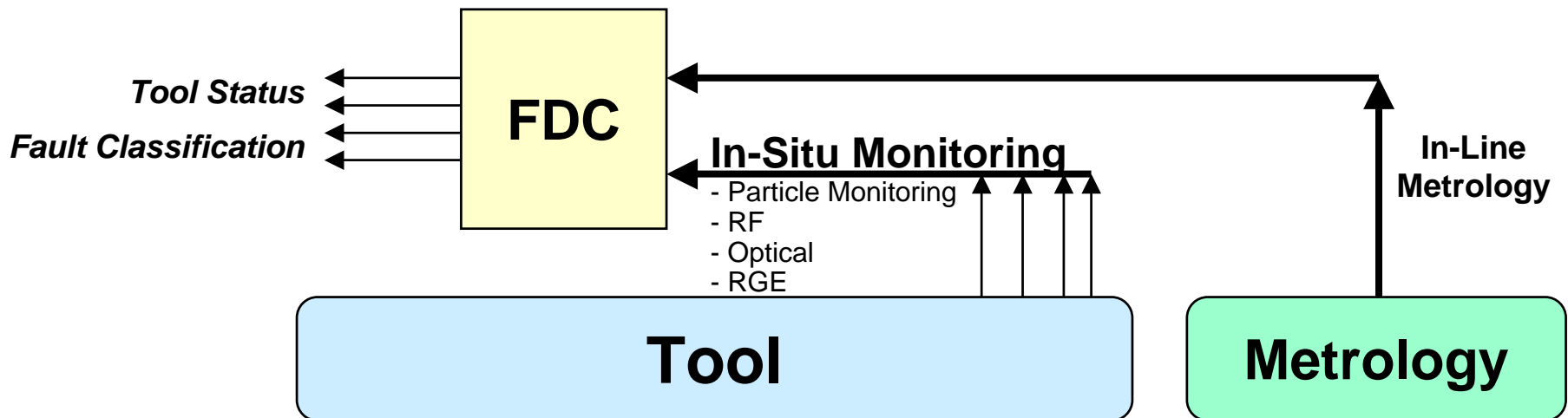
- **Dynamic Models of Tool / Process**
- **Adjustments Between “Runs”**



- **Wafer-to-Wafer or Lot-to-Lot Control**

Introduction: Fault Detection and Classification (FDC)

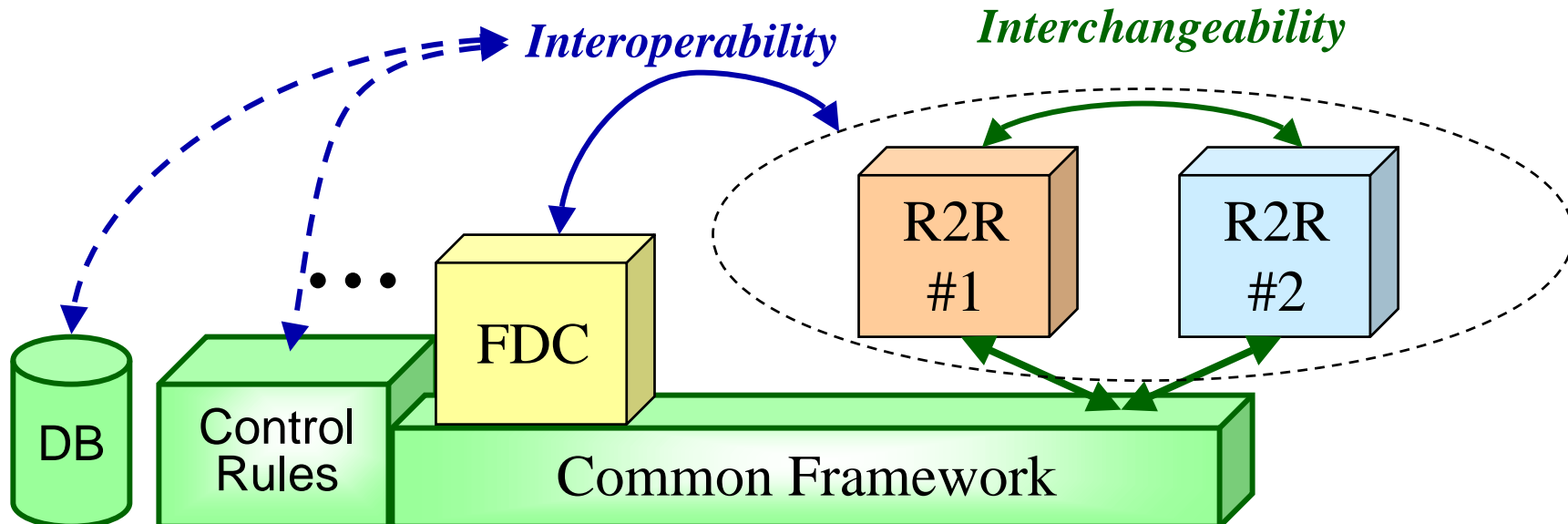
- Definition: Maps data and data footprints generally collected in-situ to tool and process faults
 - A diagnostic, not control tool
 - Approaches
 - Time series analysis, Neural Networks, Hotelling-T², etc.



Introduction: APC Requirement

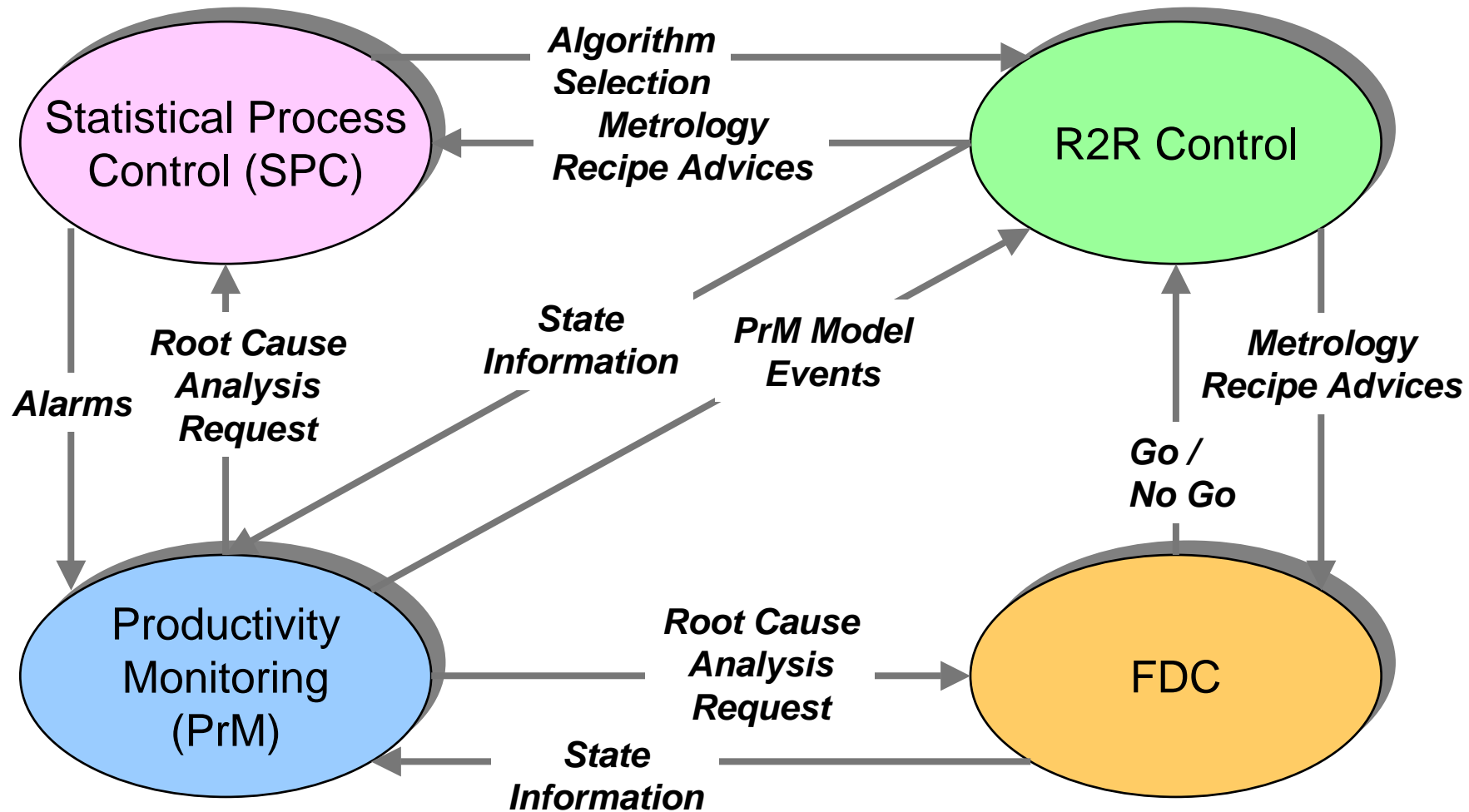
Interchangeability and Interoperability

- *Interchangeability*
 - Open and Modular Architecture
 - Support Enhancement with Future Capabilities ... From User, Supplier, Third Party, etc.
- *Interoperability*
 - Support Interaction and Coordination of APC Components with *Configurable Control Rules*





Introduction: EES Component Interaction Example → *The Ultimate Interoperability Goal*





Introduction: Solution Approach

- **Fairchild Semiconductor**
 - Applied Materials 7810 Epitaxy Tool
 - Process: CMOS Epi
 - Open Solution
 - Multi-Component APC
 - FDC Component
 - Includes In-Situ Data Visualization
 - R2R Control Component
 - *Multivariate* Control of Thickness and *Multi-zone* (3) Resistivity

**Control Systems
Supplier**



Outline

- Introduction
- Solution Architecture
 - APC System
 - Integration
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Solution Architecture: APC System

- Foundation Component
 - EESfoundation™
 - Interoperability Platform, Database, and APC Communications

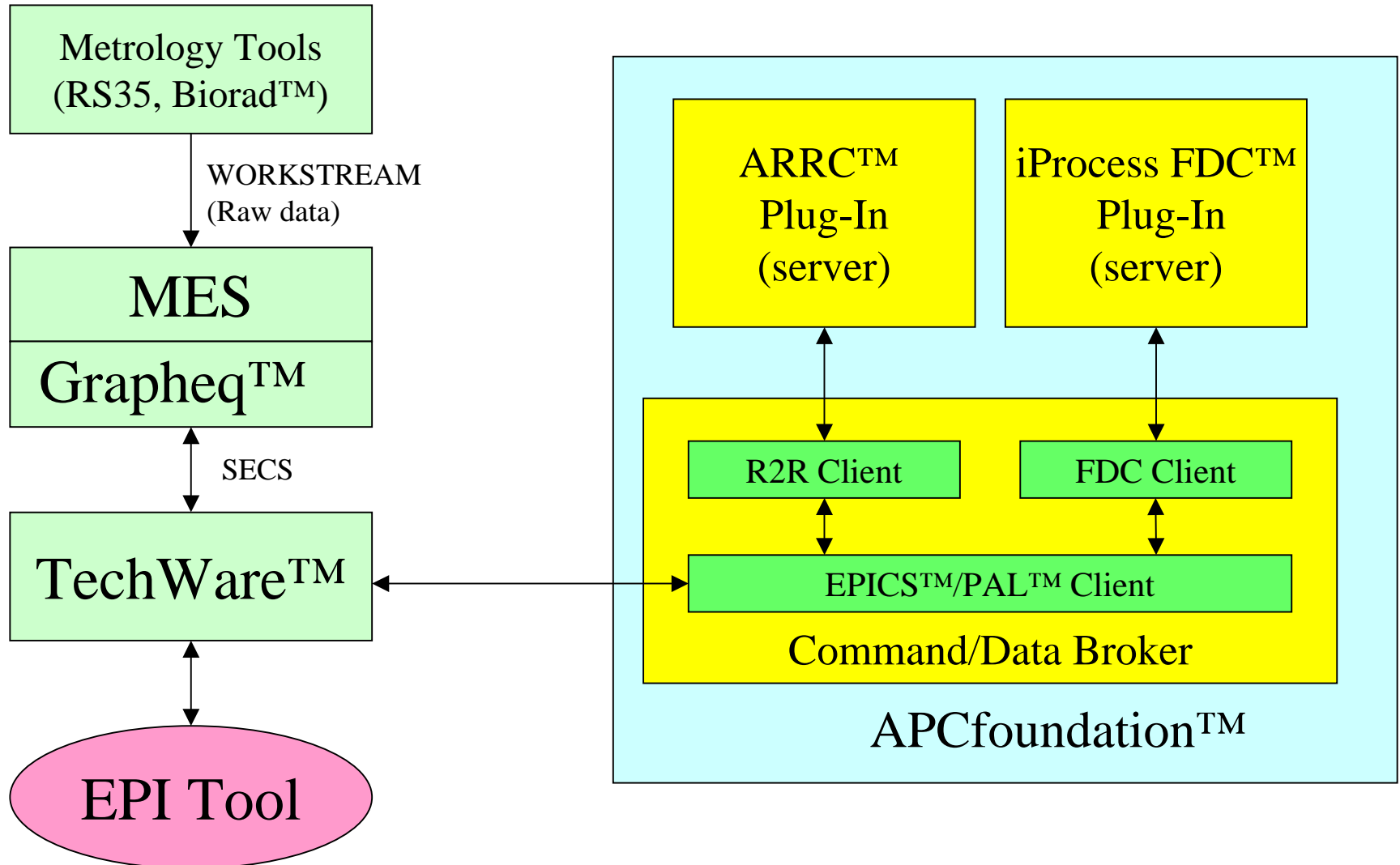
- R2R Control Component
 - ARRC™, Advanced Run-to-Run Control
 - Configurable R2R Control
 - Multivariate, EWMA-Based, Accommodates Missing and Outlier Metrology Data, Support for Operator Overrides, I/O Alarming, ...

- FDC Component
 - iProcess FDC™
 - Multivariate (Hotelling- T^2)

- Communication Environment
 - EPICS, as a Result of Tool Controller
 - Could be XML, Modbus, etc.



Solution Architecture: Integration





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Application and Results, FDC: Variables Monitored

- A Sample of Variables Monitored
- Typical Data Collection Rates
 - 0.0001HZ – 10 Hz
 - 2 Hz Typical
- Data Collection Triggers, etc.
- Real-time Monitoring of Variables Supported
- → FDC Tool and RT Monitoring Tool

Variable	Units	Description
CurrStepDisp	n/a	Step number
D1.src.In		Dopant 1 flow
D2.src.In		Dopant 2 flow
DummyBaratron	Torr	Chamber pressure read
H2.Main.In	slm	Main H2 flow
H2.Rot.In	slm	Rotational H2 flow
HCl.In	slm	HCl flow
Sil1.In	g/min	Silicon source 1.
Sil2.In	sccm	Silicon source 2.
Step.Press	Torr	Chamber pressure setpoint
Temp.Btm	°C	Chamber bottom temperature
Temp.Cntr	°C	Chamber center temperature
Temp.Top	°C	Chamber top temperature

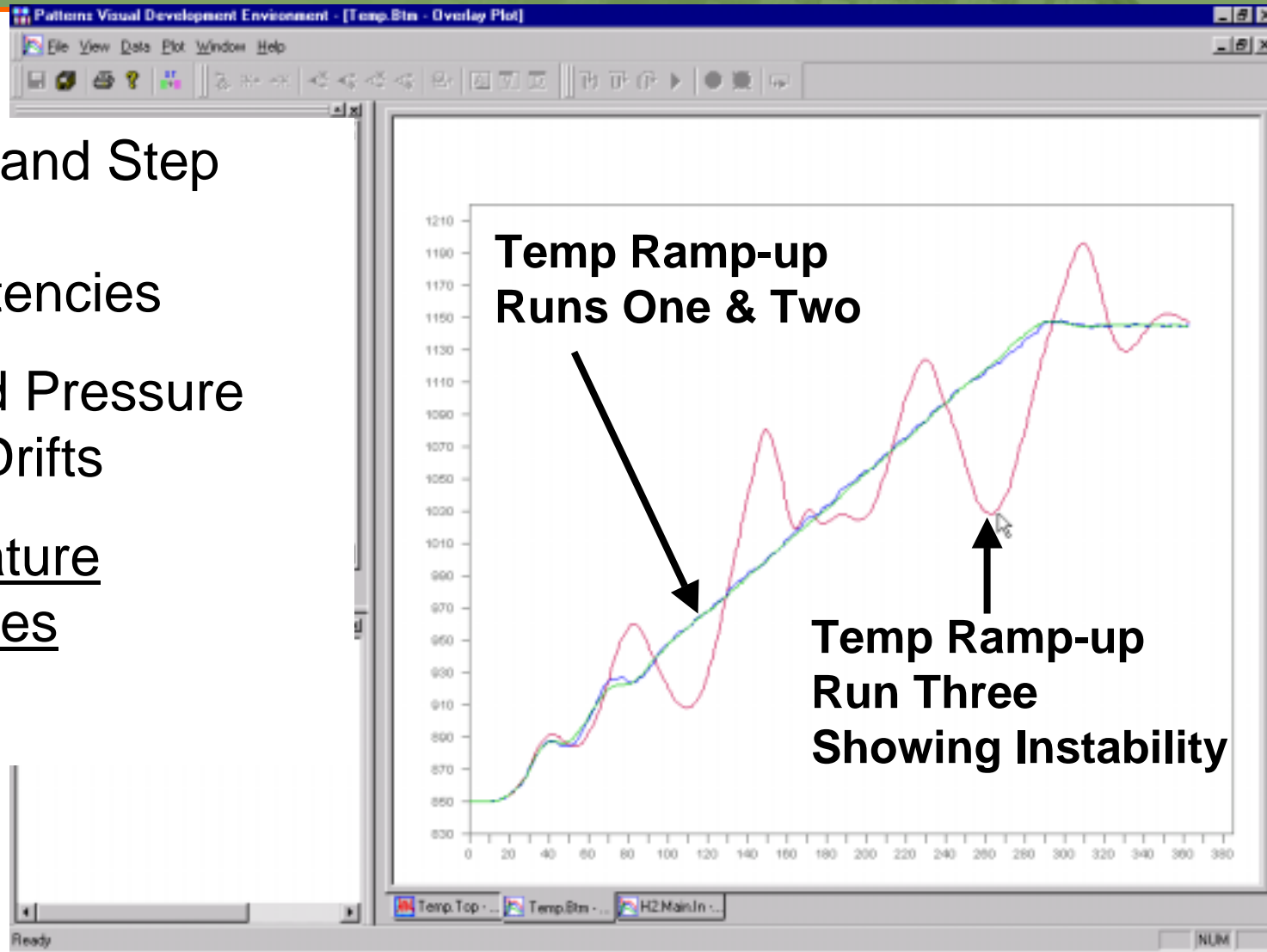


Application and Results, FDC: Monitoring Interface



Application and Results, FDC: Typical Faults Diagnosed

- Process and Step Duration Inconsistencies
- Flow and Pressure Sensor Drifts
- Temperature Instabilities





Application and Results, R2R: Monitoring Interface

GENERIC CELL CONTROLLER

Info Equipment Edit GUI

APCLink™
R2R™ Controller
Version 6.1
Copyright © 1997-2001 Brooks Automation, Inc.

User Name: John Last Ctrl'd Run #: 36 Run Mode: Automated Control Mode
Access Level: Control Engineer Control Recipe: 400 LotID:

OPERATE

COOL MONITOR

Recipe: DopLev: 129.820 Wafer ID: Rework
Hydrog: 75.000 Run #: 36
TrprFr: -12.000 Pad Count: Status:
TrprAv: 1150.000 Idle
Time: 12.000 Pre-Metrology
 Post-Metrology

Last Recipe Control Adviser Download

METROLOGY MONITOR

Pre-Metrology Post-Metrology
Run #: 36 Run #: 36
ResT: 2.050 ResM: 1.960 States:
ResB: 1.890 Thickness: 10.800 Idle
 Pre-Metrology
 Post-Metrology Data
 Post-Metrology
 Manual Control

Send to GDC Send to GDC

HISTORY - Input Plot

Inputs(Recipe)

HISTORY - Output Plot

Outputs(Metrology)

FUNCTION PANEL

Commands

Repeat: 1

START

OPERATE

PROCESS (simulate)

PROCESS CONTINUOUSLY

SOFT STOP

OPERATION TRACE

NEW CONTROL RECIPE

11:20 AM
THE 22
JULY
2001

CONTROL PANEL

OPERATE **SETUP** **ACCESS LEVEL**

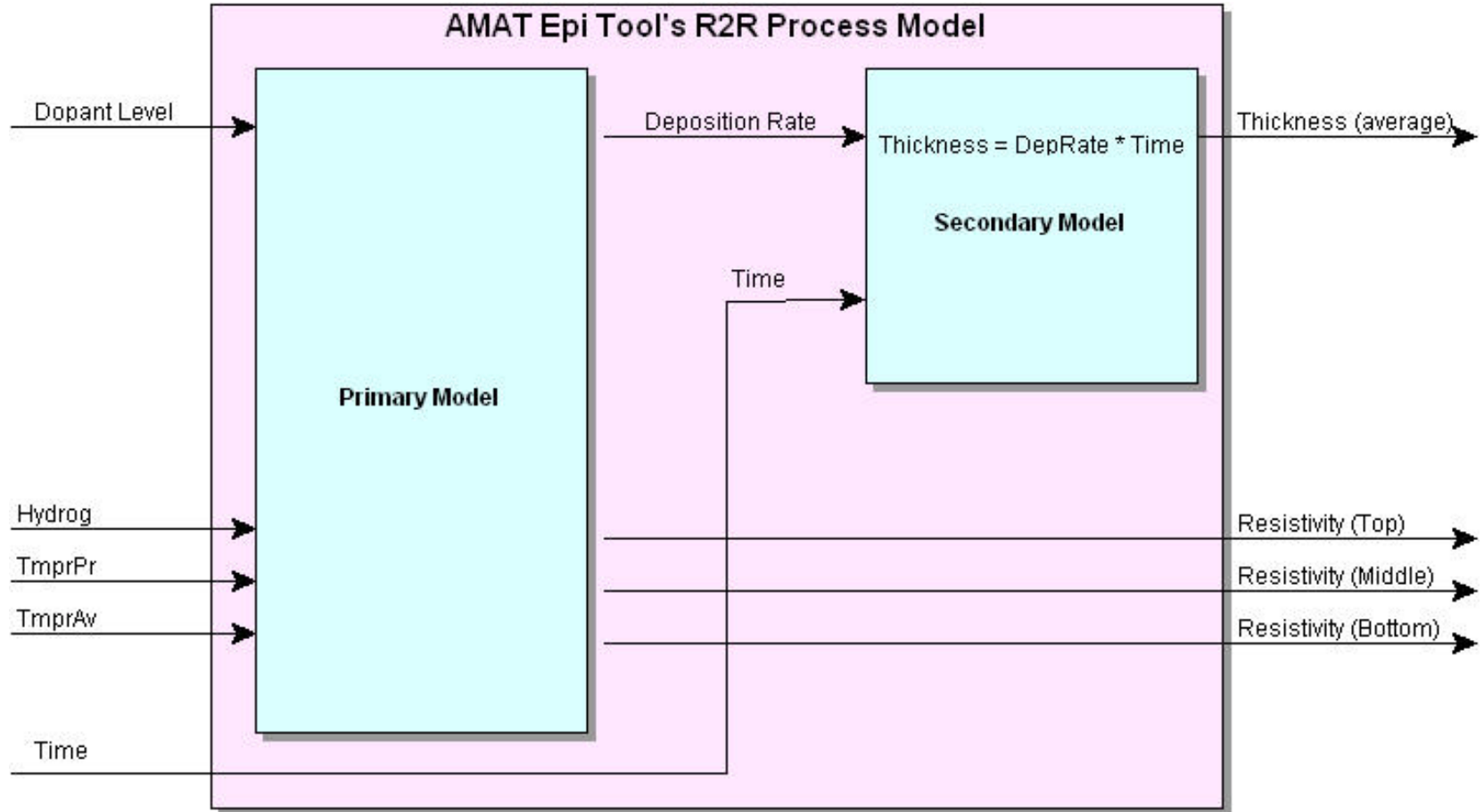


Application and Results, R2R: R2R Evaluation Process

- Collect User Requirements and Knowledge
- Design of Experiments
- DOE Results → R2R Control Models
- Verification of R2R Capability With Before / After Process Capability Comparisons



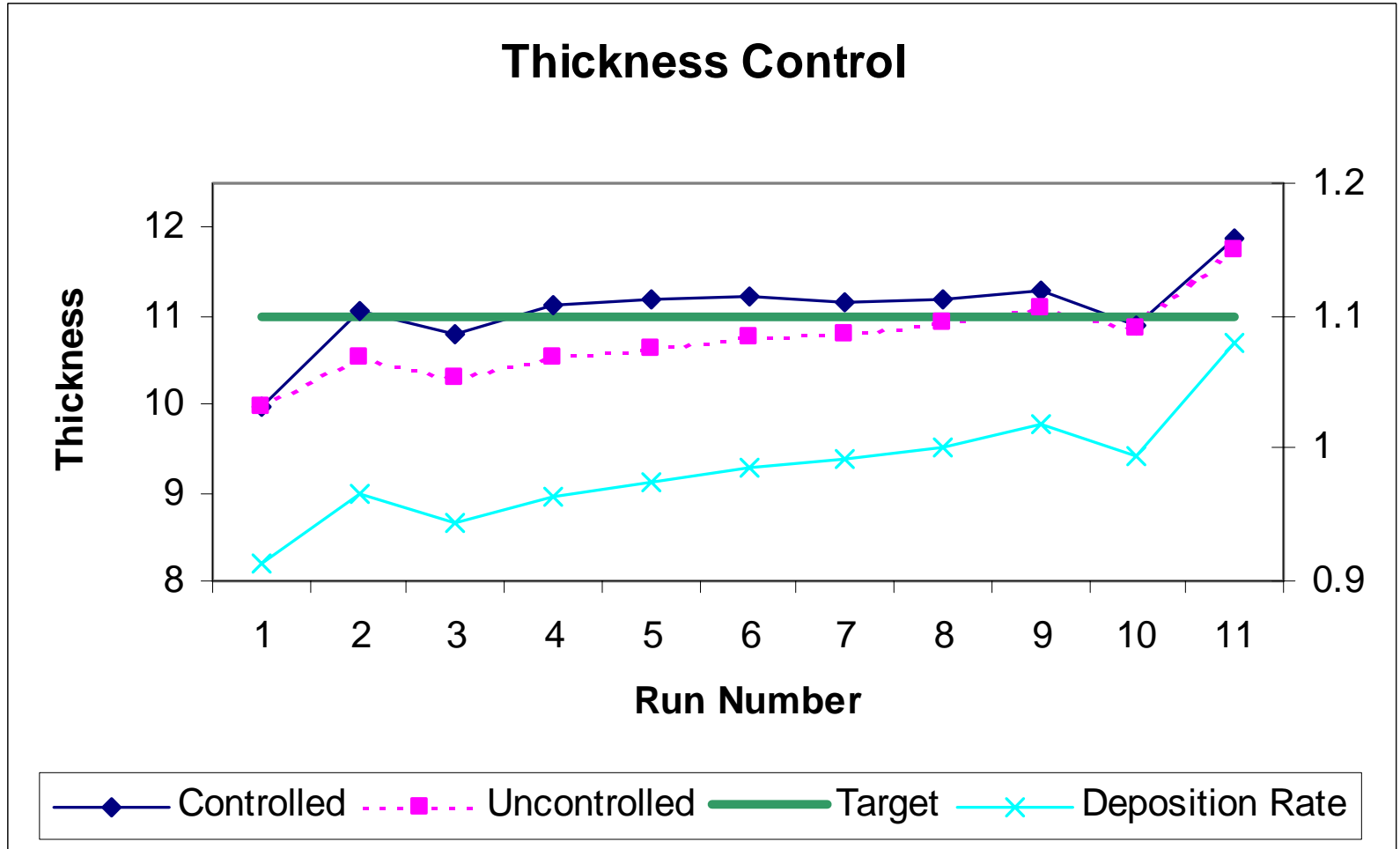
Application and Results, R2R: Derived R2R Control Model



✓ *Multi-variate* ✓ *Multi-Zone Control*

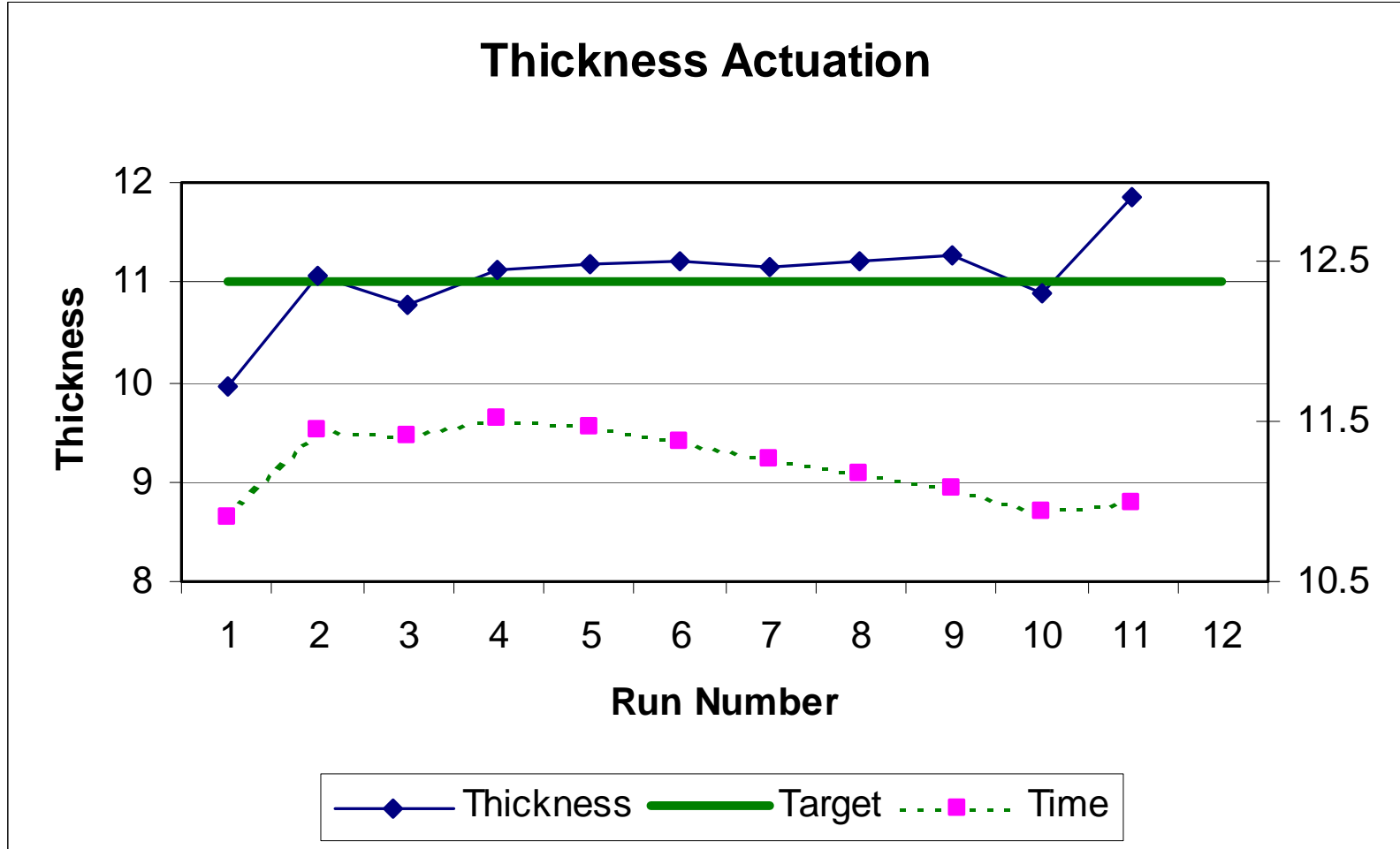


Application and Results, R2R: Controlled Vs. Uncontrolled

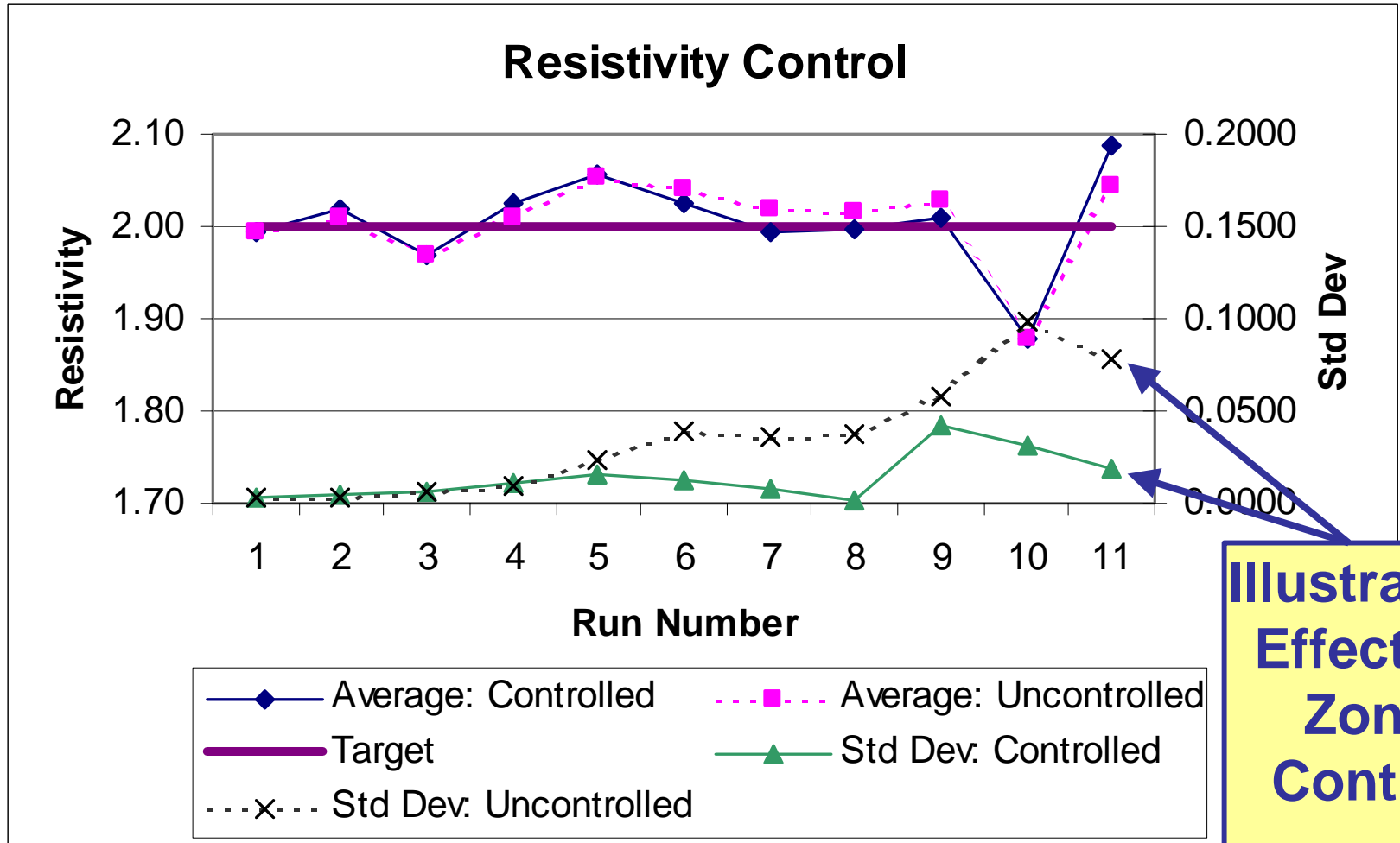




Application and Results, R2R: Controlled Vs. Uncontrolled



Application and Results, R2R: Controlled Vs. Uncontrolled



Illustrating Effective Zone Control



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 - Value Proposition
 - How Integrated Metrology Would Help





Summary

- Multi-Component APC Capability for Epitaxy Tool
 - R2R and FDC
 - Control Rules To Support Complementary Utilization
 - Extensible Architecture to Support Additional APC

- **Value Proposition**
 - **FDC**
 - **Fault Diagnosis → Reduced Scrap Demonstrated**
 - **R2R Control**
 - **Improved Cpk of Resistivity and Thickness Demonstrated**
 - **Reduced Zone-to-Zone Variability Demonstrated**

- **Future**
 - Improved R2R Model: Better Zone Control
 - Tighter R2R to FDC Control

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- Reference: Moyne, Et. Al., *Advanced Semiconductor Manufacturing Conference Proceedings 2002.*



Integrated Metrology

- Effectiveness of R2R Controller Was Reduced by Offline Vs. Online Metrology
 - Measurement Delay
 - Required Careful Design of Controller to Accommodate Delay
 - Required Reducing Aggressiveness (and Effectiveness) of Controller to Avoid Open Loop Behavior
 - Measurement Frequency
 - Required Tuning of Controller With Lower Feedback Duty Cycle
 - (Along with Delay) Reduced Controller's Ability to Rapidly Respond to Process Shift (as opposed to process drift)
 - Operator
 - Operator Error Had to Be Accommodated Through Data Filtering
 - Operator Bandwidth and Efficiency Affects Metrology Data Delay, Frequency and Reliability

- Effectiveness of FDC Was Minimally Impacted by Offline Vs. Online Metrology
 - However, as R2R and FDC Become More Co-Integrated The Impact of Integrated Metrology on FDC Will Increase



The Bottom Line

- Value Proposition of R2R Control Is Very High
 - Value Proposition of R2R Control Could Be Significantly Increased with Integrated Metrology
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- Value Proposition for FDC Is High
 - Value Proposition of FDC Would Not Be Significantly Impacted By Integrated Metrology Today, However It Will Be Significantly Impacted In the Future as R2R Control and FDC Become More Tightly Coupled