



Multivariable Versus Univariable APC

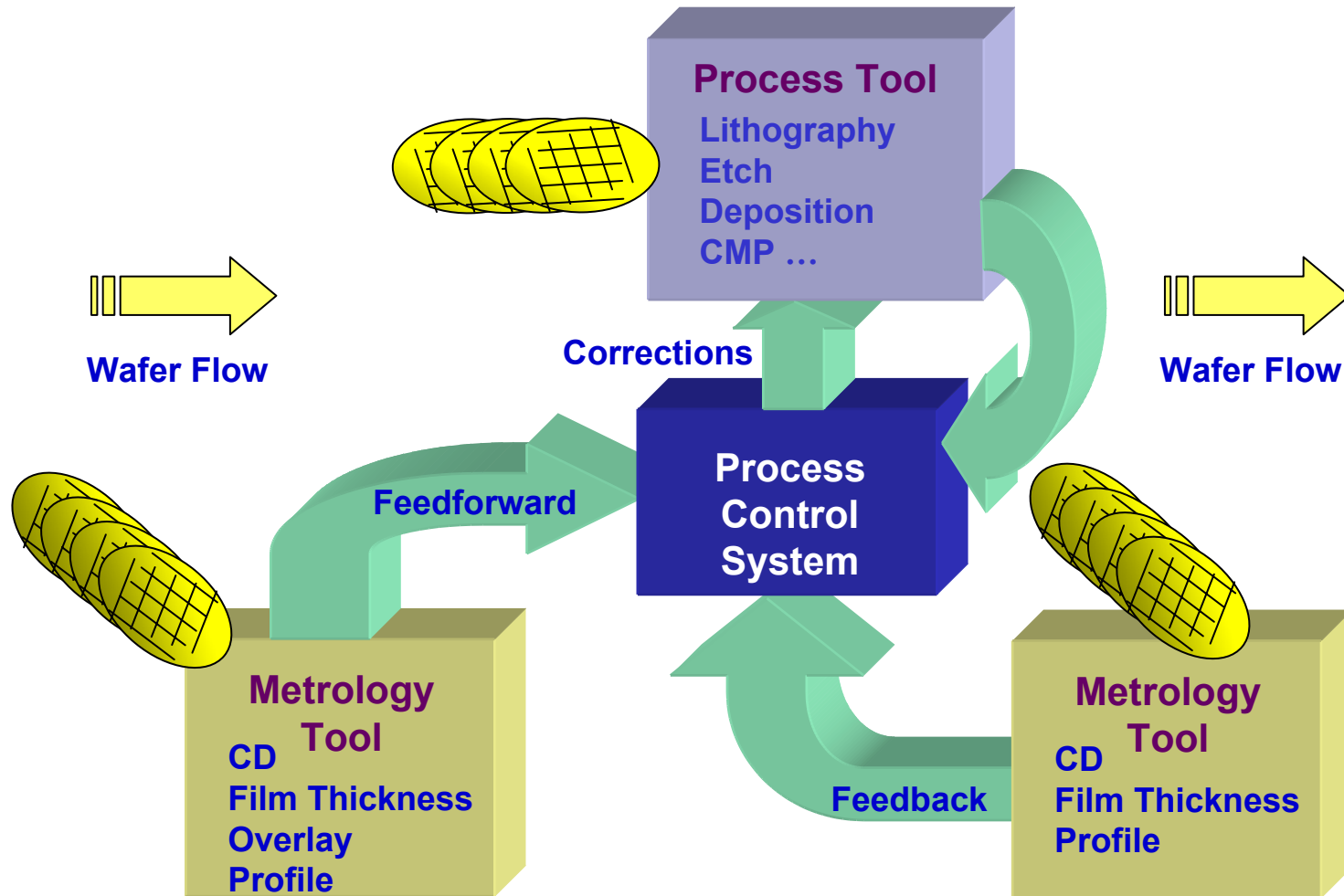
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Gayathri Raghavendra,**

**Blue Control Technologies
875 Mahler Road
Burlingame, CA 94010**

Architecture and Strategy Topics

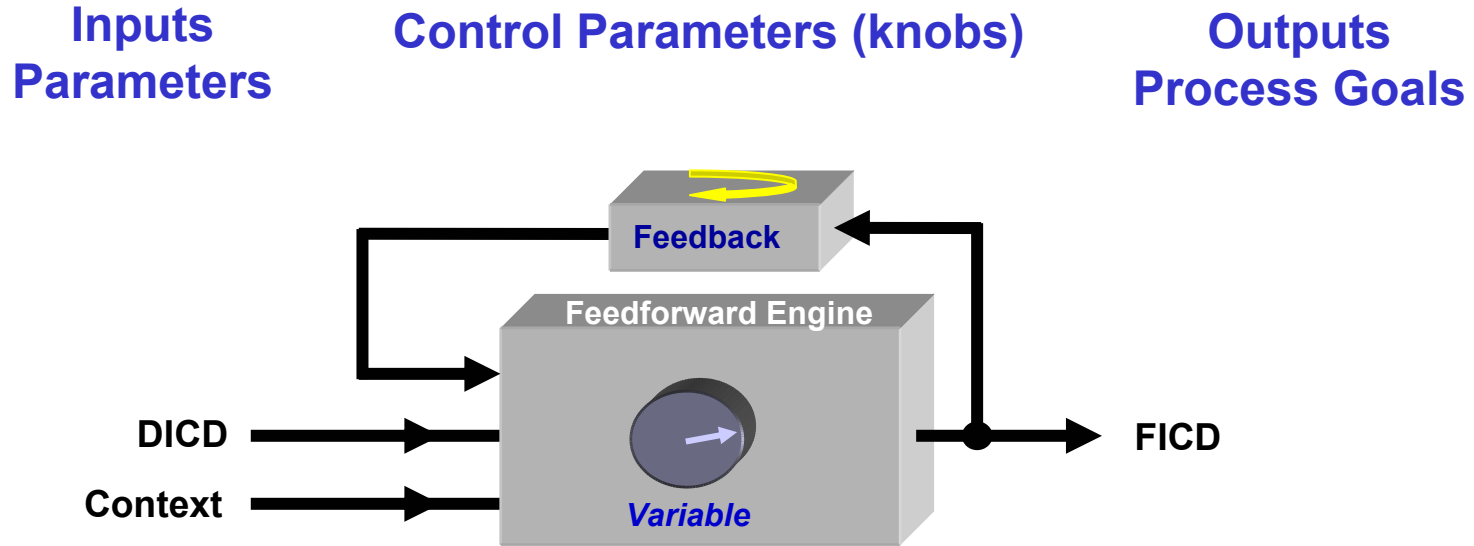
- **Advanced Process Control Systems**
- **Control Strategies**
- **Control System Requirements**
- **BCT's Model Based Multivariable Control System**
- **Software Architecture**
- **Deployment Alternatives**
- **Conclusions**

Advanced Process Control Systems



Advanced Process Control Systems

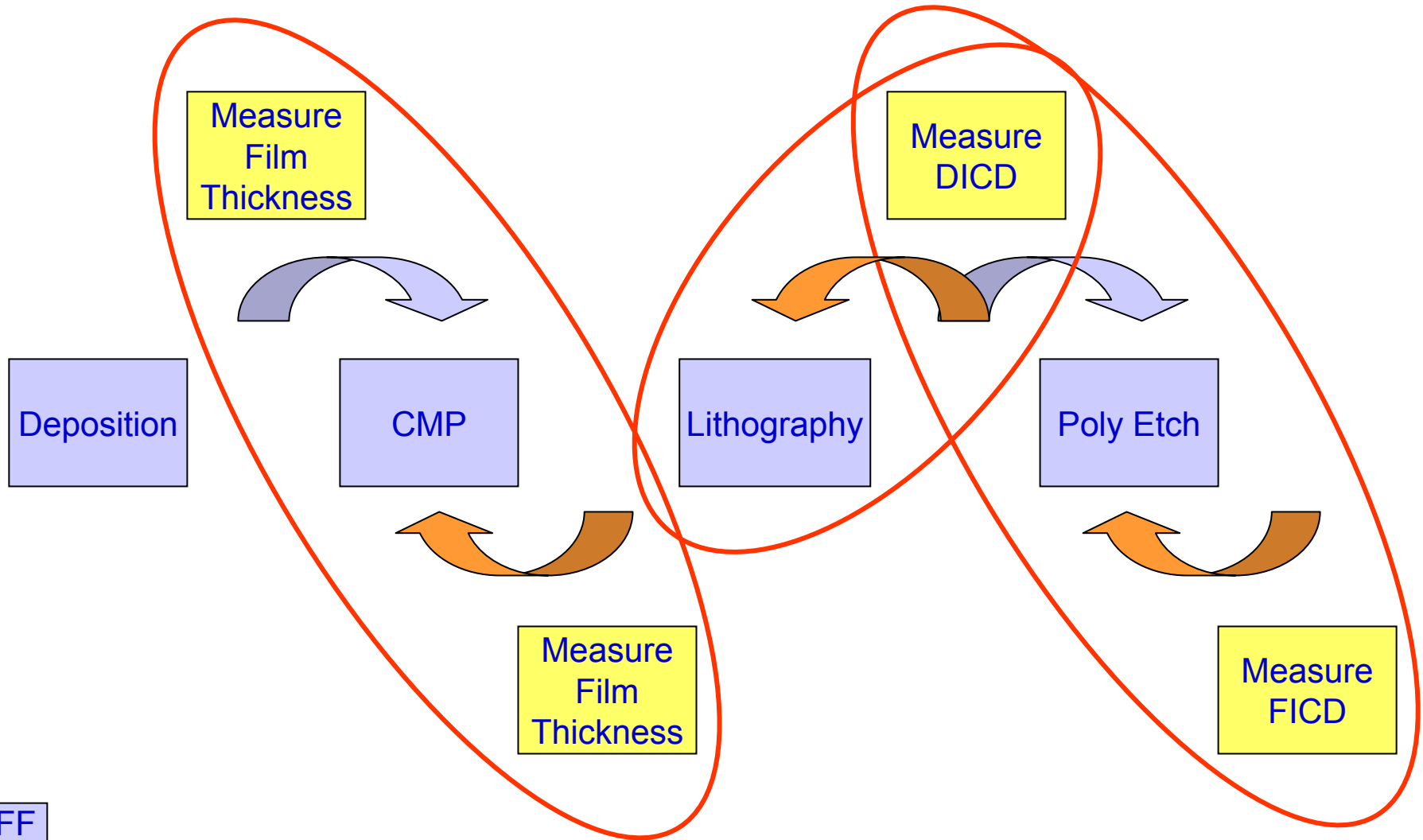
Single Input Single Output (SISO) Systems



- Consider one parameter (DICD or film thickness)
- Adjust one knob (time or flow)
- Control one process goal (FICD)
- Feedback the results of one goal

Advanced Process Control Systems

Isolated vertical point solutions (limited data sharing)



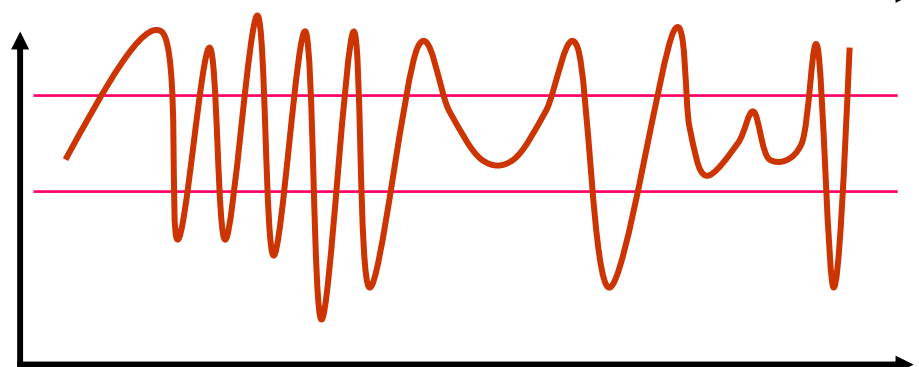
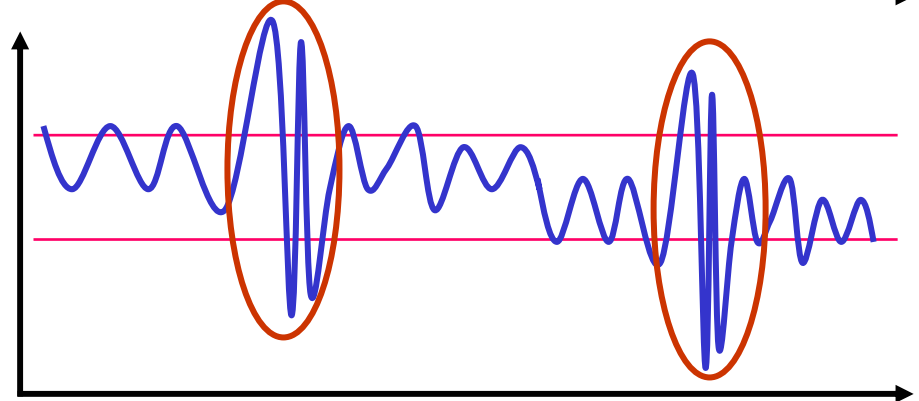
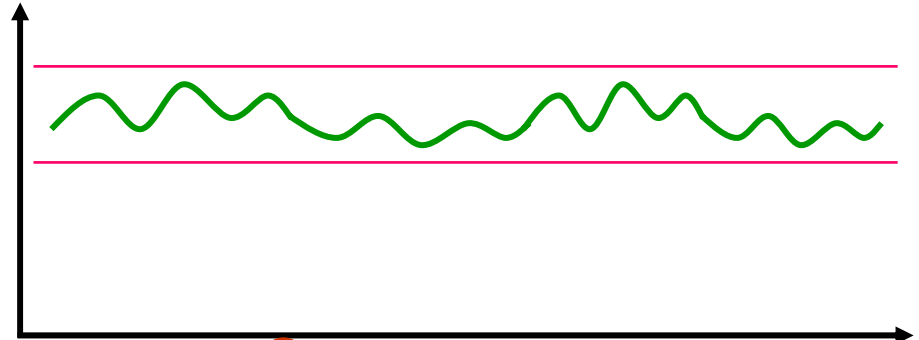
FF

FB

Control Strategies

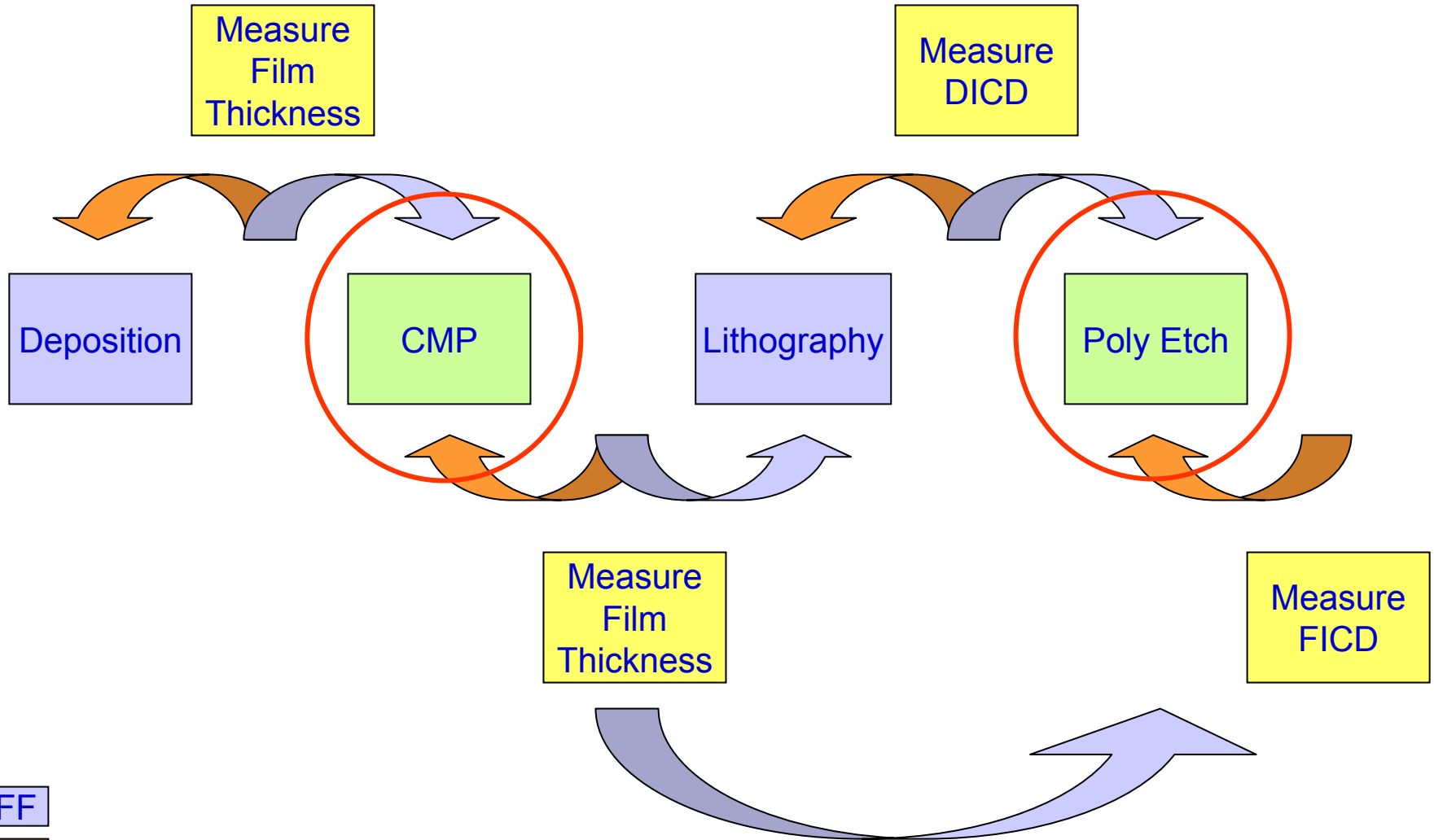
What Kind and Level of Control Do We Need?

- Must be evaluated on a case by case basis
- Frequency and magnitude of the variation should determine the metrology sample plans and control strategy
- Let's Consider some cases



Control Strategies

Maximize Data Usage and Control Capability



FF

FB

Control System Requirements

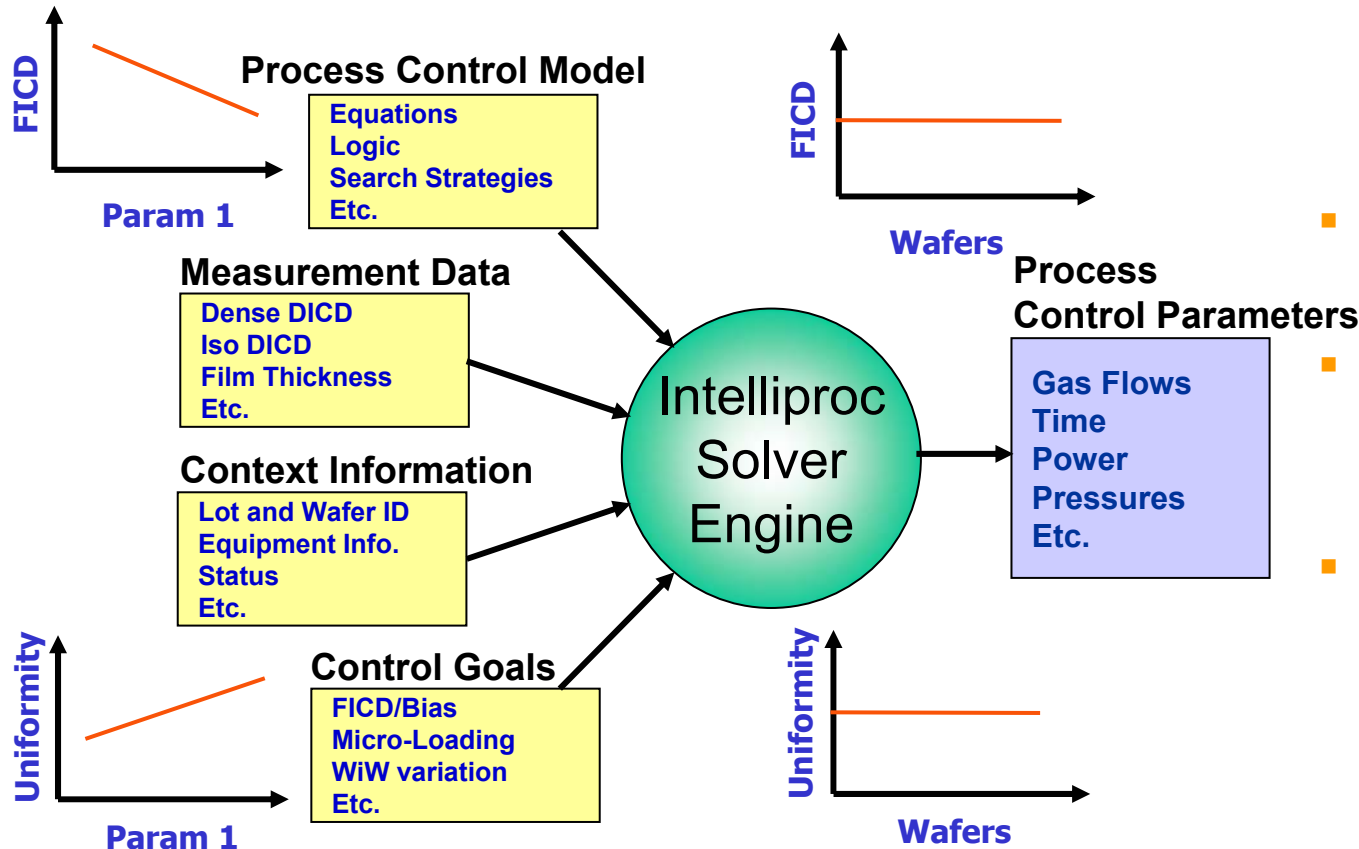
Disparate and Varying Requirements

- **Control Contexts**
 - Lot to Lot, Wafer to Wafer, Within Wafer, etc.
- **Tool Sets**
 - Platforms, Chambers, Capabilities
- **Scalability**
 - Infrastructure, resources
- **Adoption and Deployment**
 - Calculations, Simulation, Approvals, etc.
 - ASAP, ALAP
- **Manufacturing Use-Cases**
 - Rework, Hot Lot, Engineering Lot, Split Lot, etc.

BCT's Model Based Multivariable Control

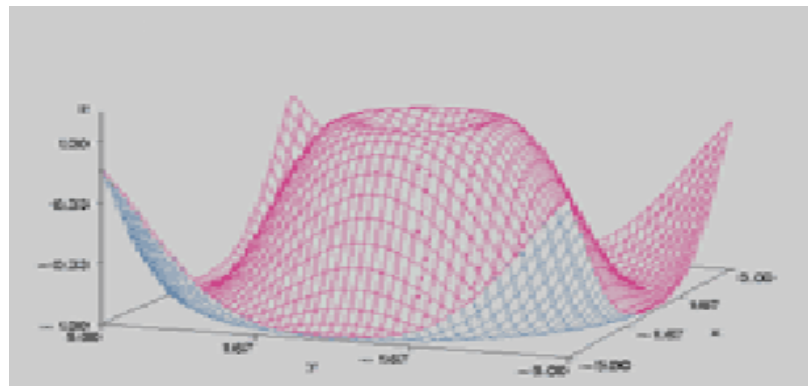
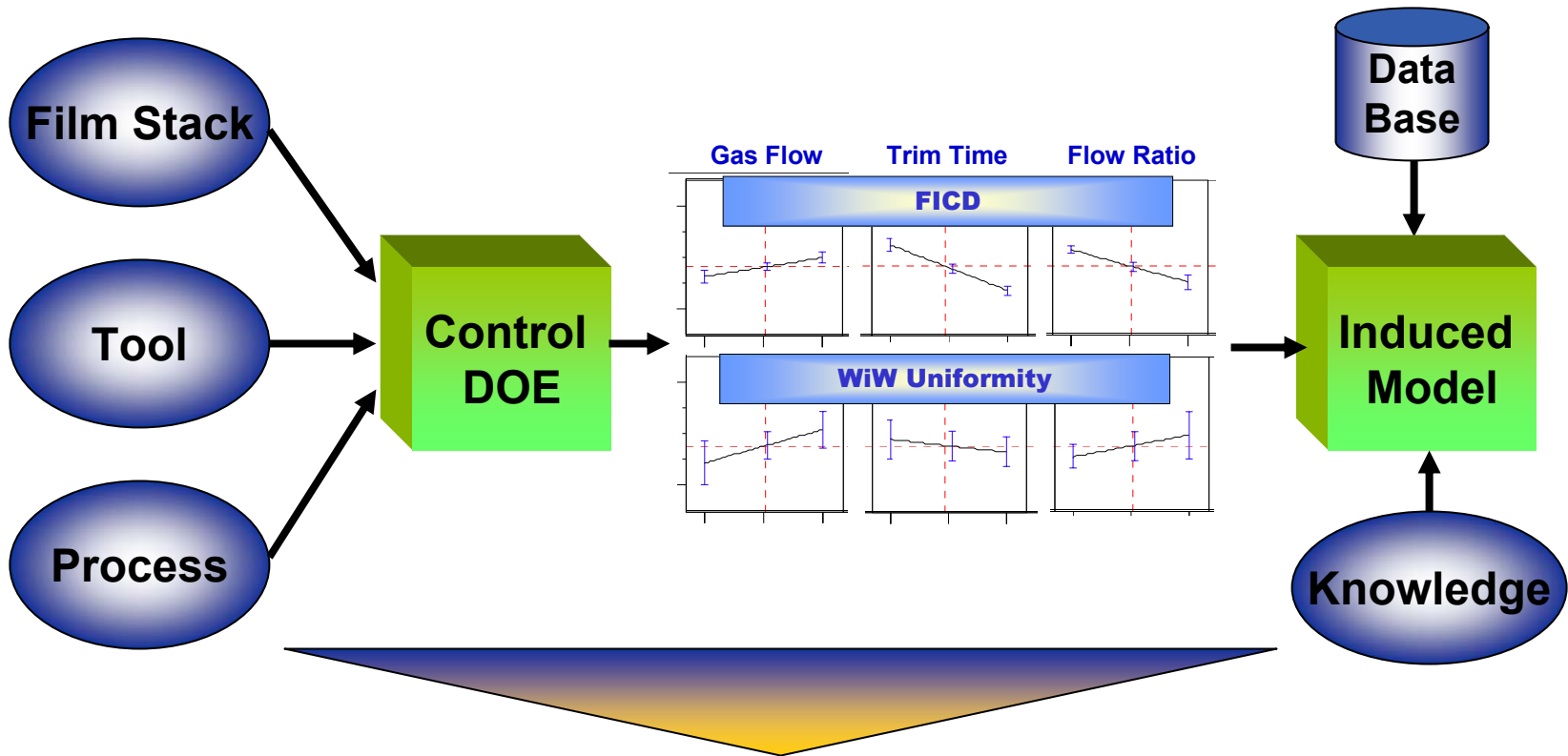
Intelliproc

- Model-Based Multivariable Solver Engine
- Library of Multivariable Models for specific film stacks and process chemistries
- Wrapped in a flexible architecture
 - Supports standalone and integrated use cases
 - Facilitates integration and lowers support costs



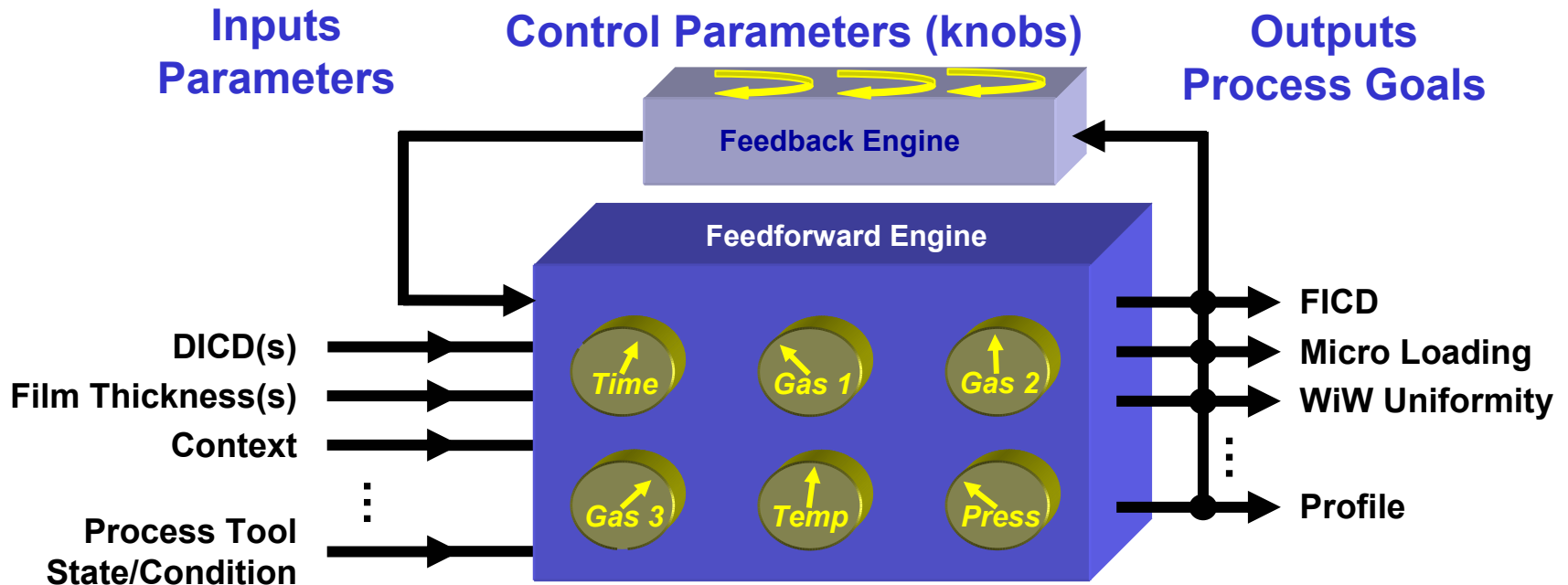
- Considers Specified Goals and Inputs
- Controls Multiple Parameters Simultaneously
- Determines optimum Control Parameters in realtime

BCT's Model Based Multivariable Control



BCT's Model Based Multivariable Control

Multivariable Control Complexity

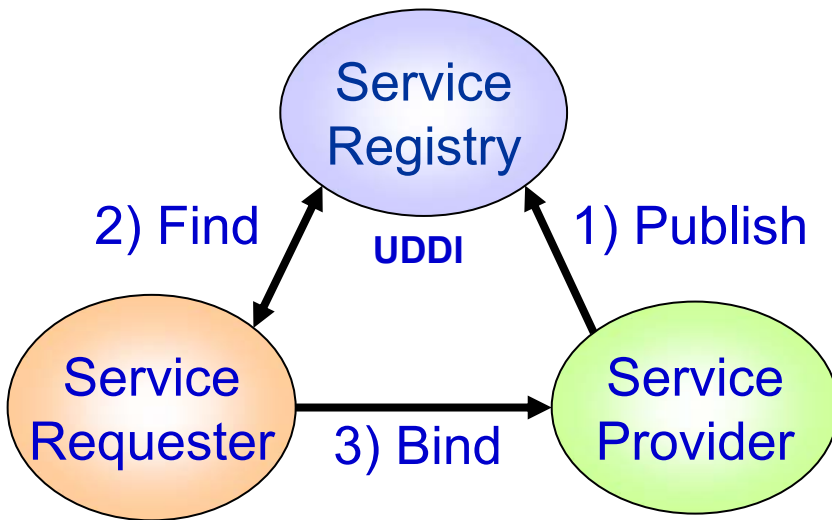
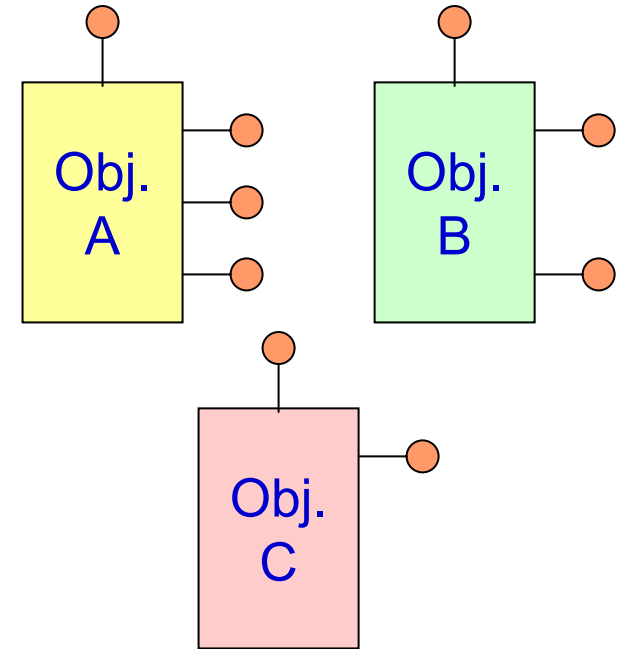


- Considers multiple parameters (DICD, Profile, film thickness)
- Adjusts multiple knobs simultaneously (time, flows, pressure, etc.)
- Controls multiple process goals simultaneously (FICD, WiW Uniformity, Micro Loading, Line Edge Roughness, etc.)
- Feedback based on the results of all process goals (multiple algorithms)

Software Architecture

Object Oriented Architecture

- Collection of objects with defined behaviors
- Tighter coupling between Objects
- Pre defined and published Interfaces

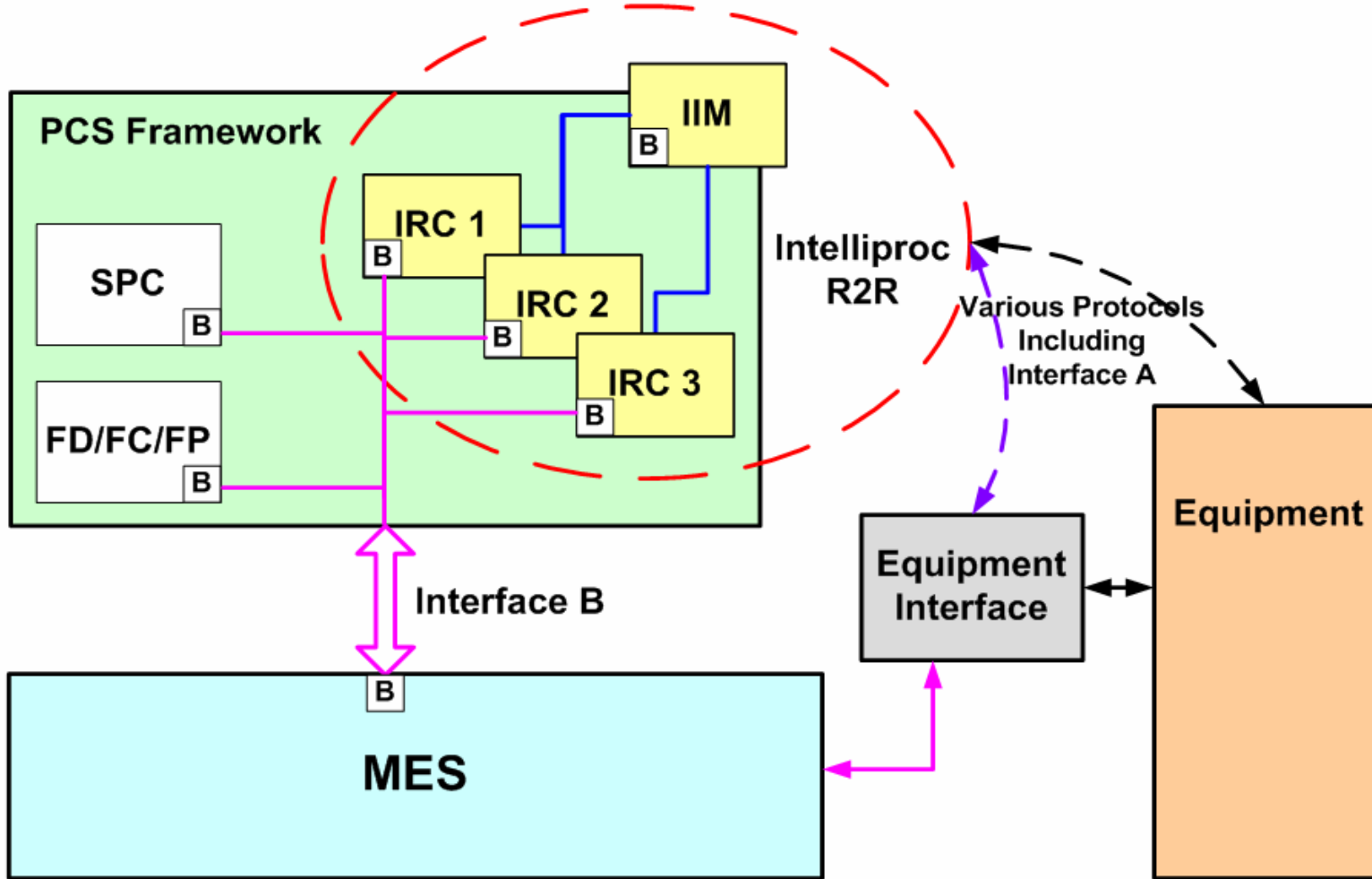


Service Oriented Architecture

- Collection of dynamic services
- No coupling between services
- Dynamic Interfaces
- Services upgrade independently

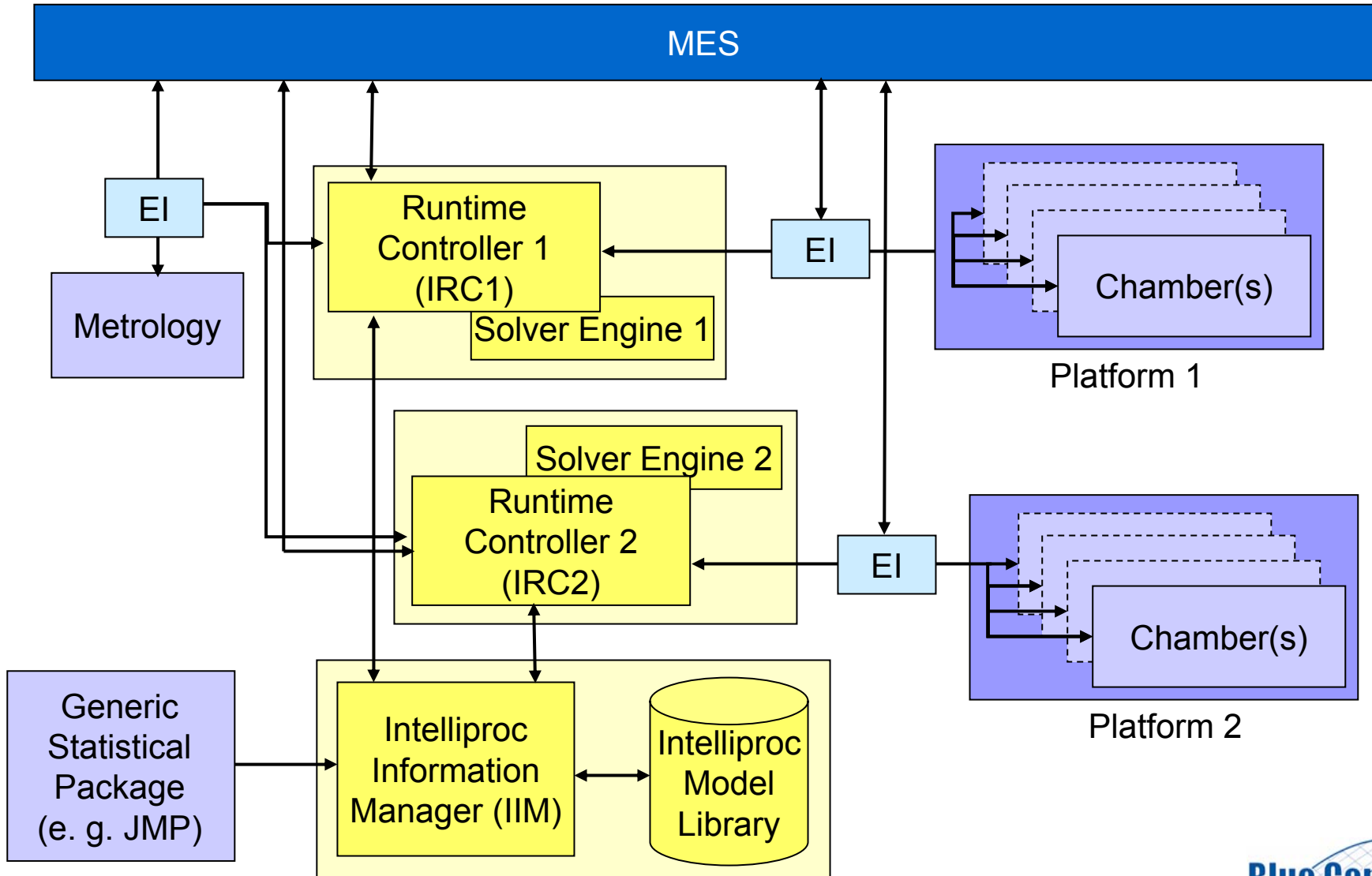
Universal Description, Discovery, and Integration

Deployment Alternatives



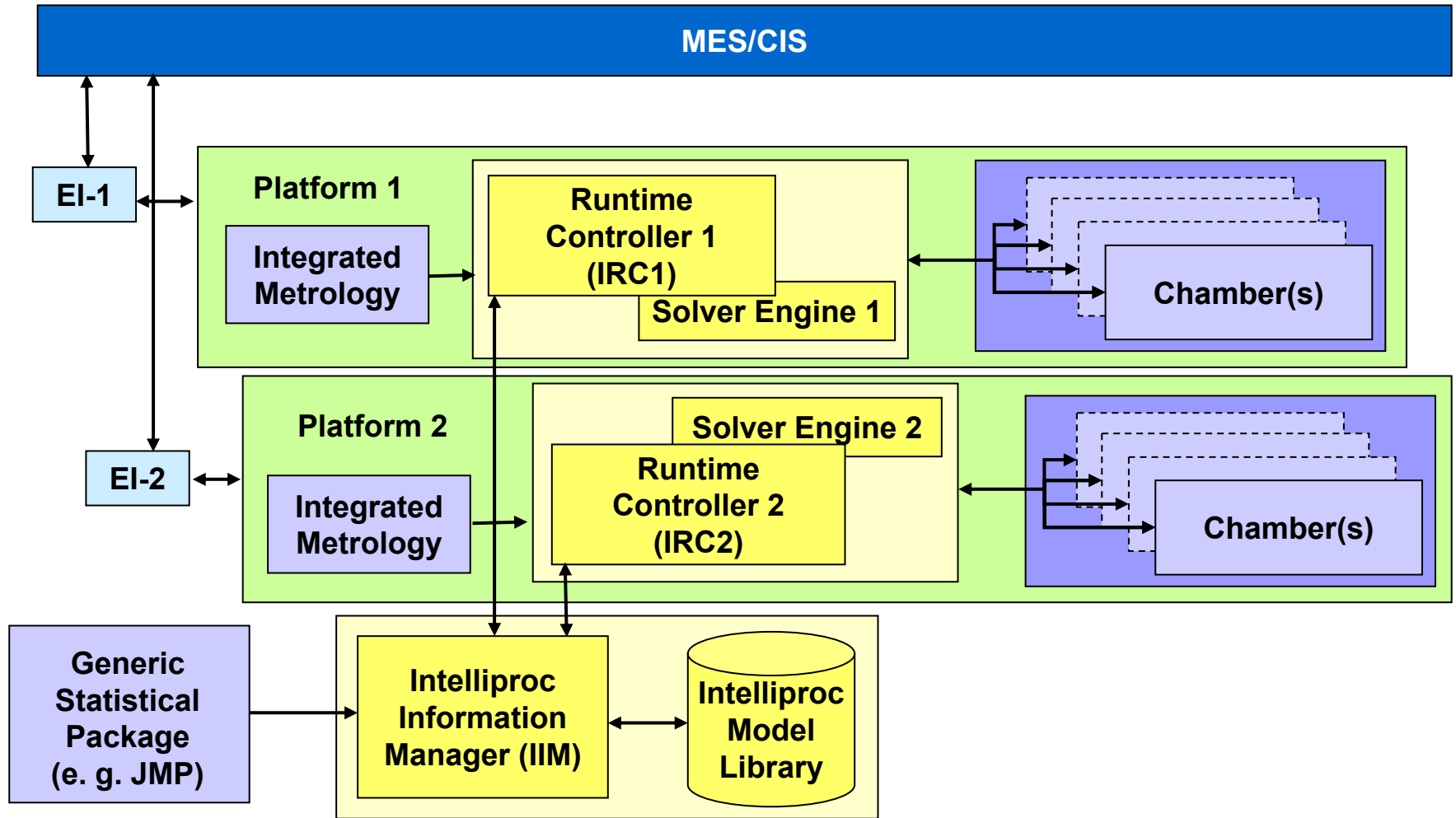
Deployment Alternatives

Classic Deployment



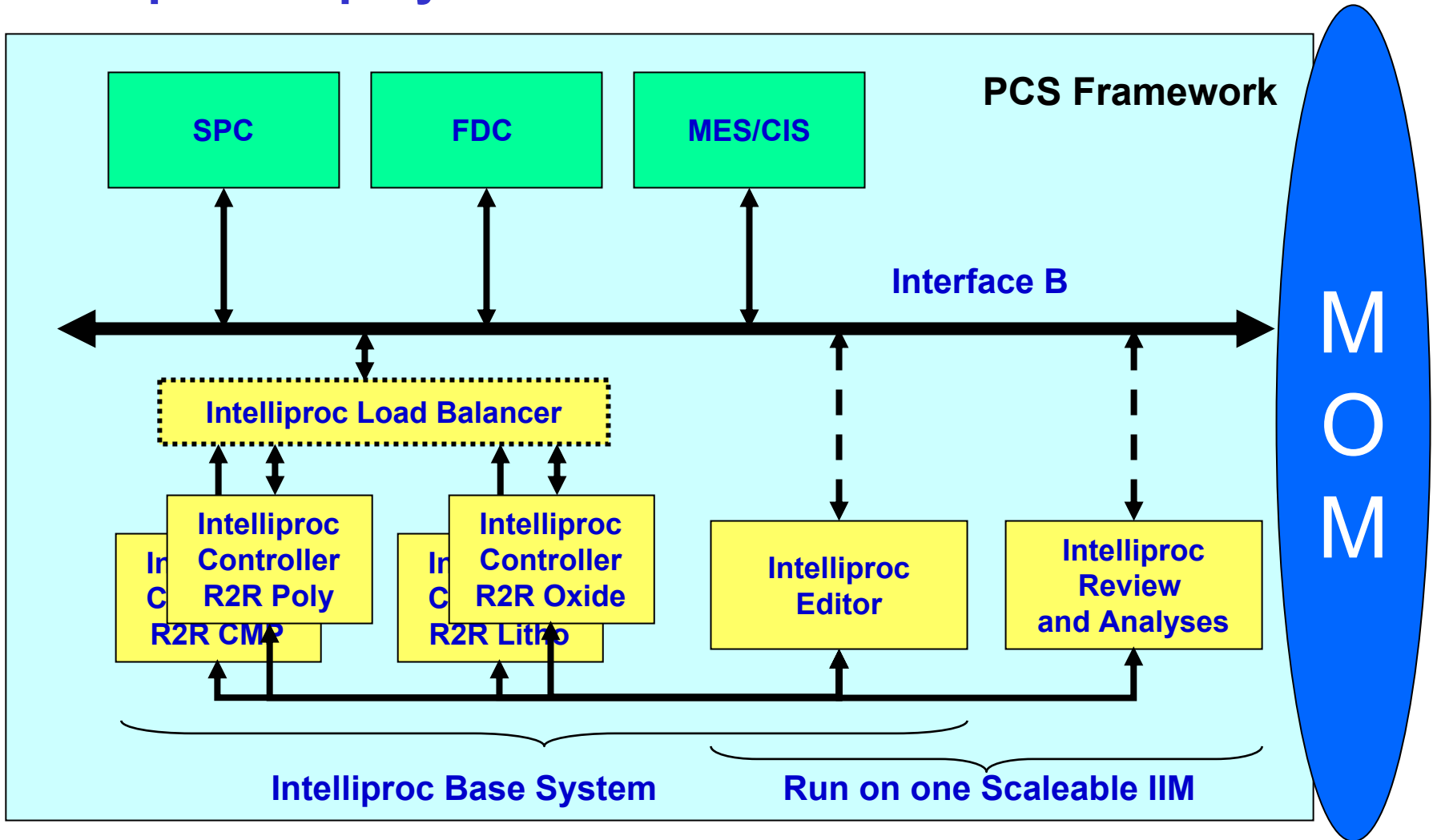
Deployment Alternatives

Deployment With Integrated Metrology



Deployment Alternatives

Intelliproc Deployed in an Advance PCS Framework

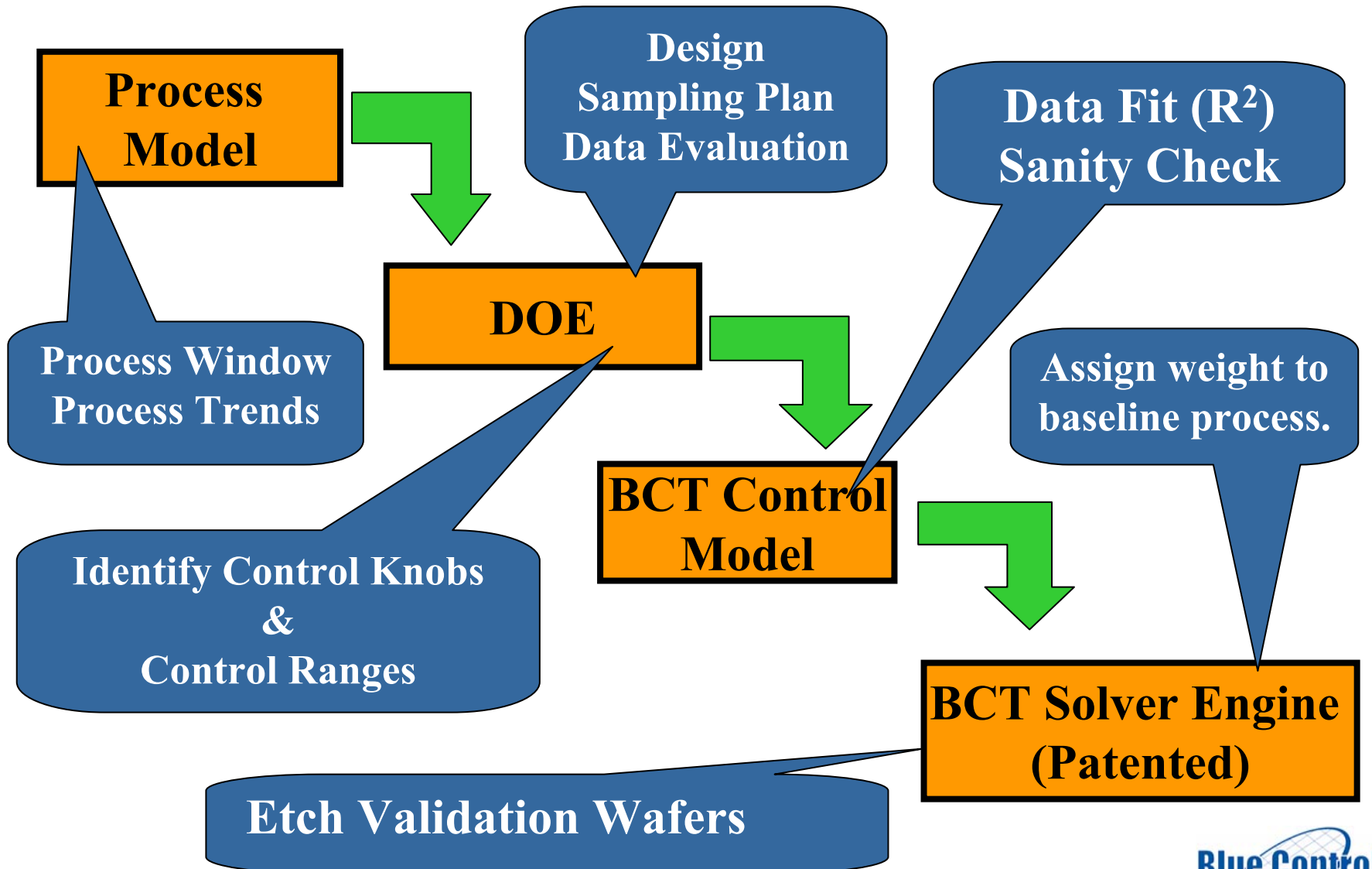


All Hardware Located in IT Server Rooms; Requires NO Clean Room Space

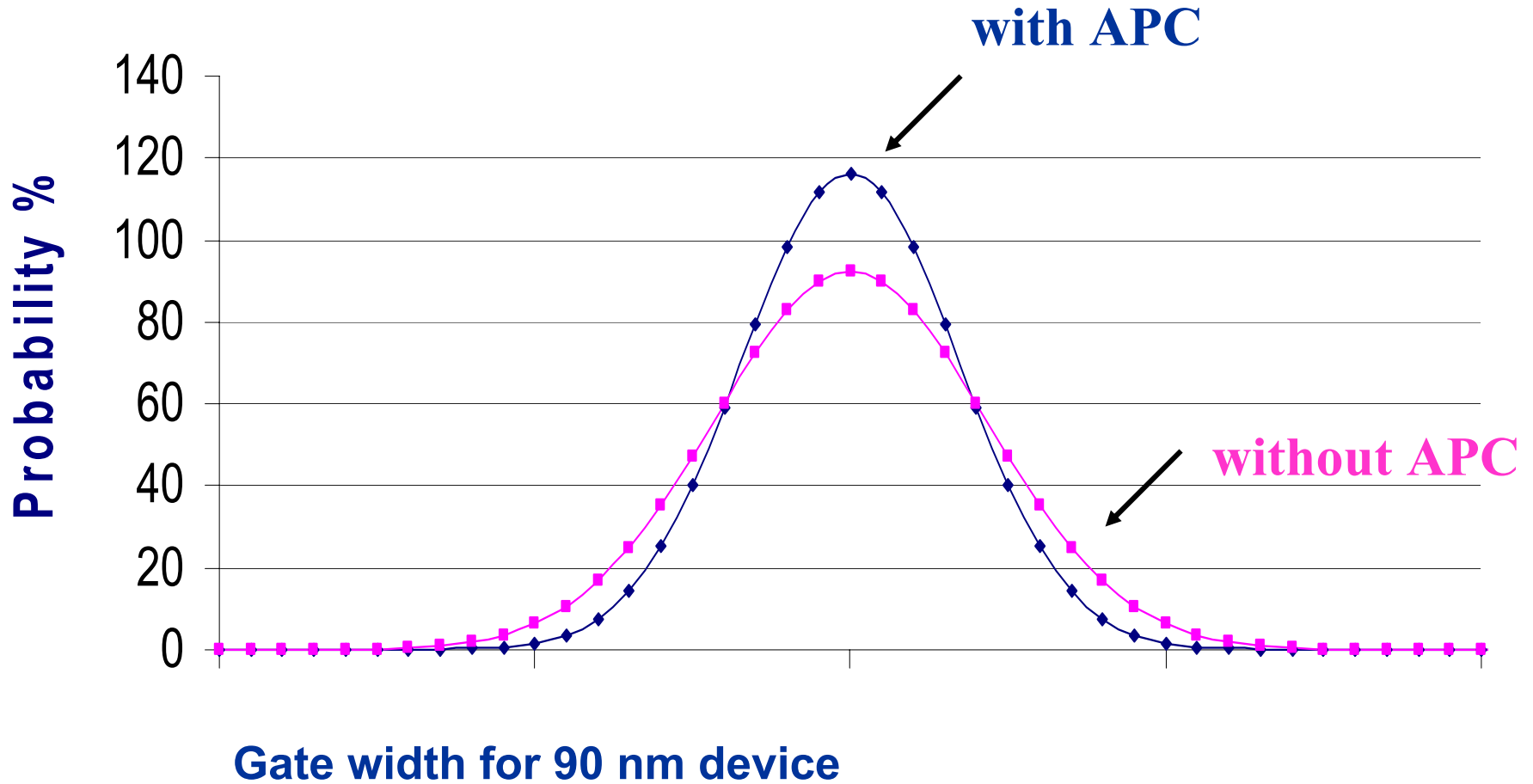
Models and Data Topics

- **Flow of model building**
- **Comparison of SISO & MIMO**
- **Results from customer fabs**
- **Conclusions**

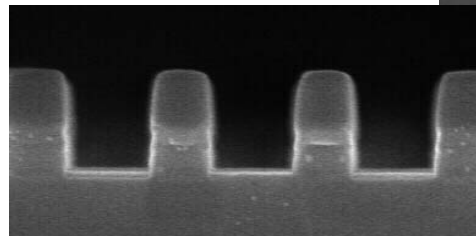
Building Process Control



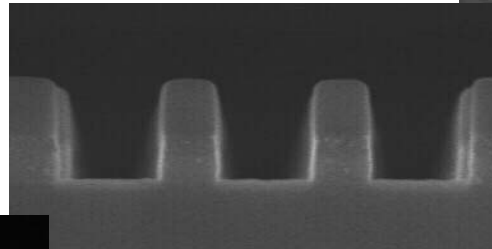
Primary Customer Expectation



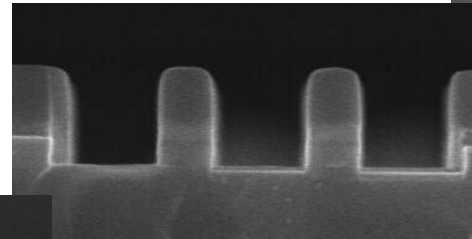
Additional Expectations



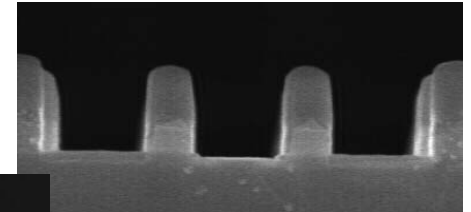
**Bias
-3 nm**



**Bias
-10 nm**



**Bias
-15 nm**

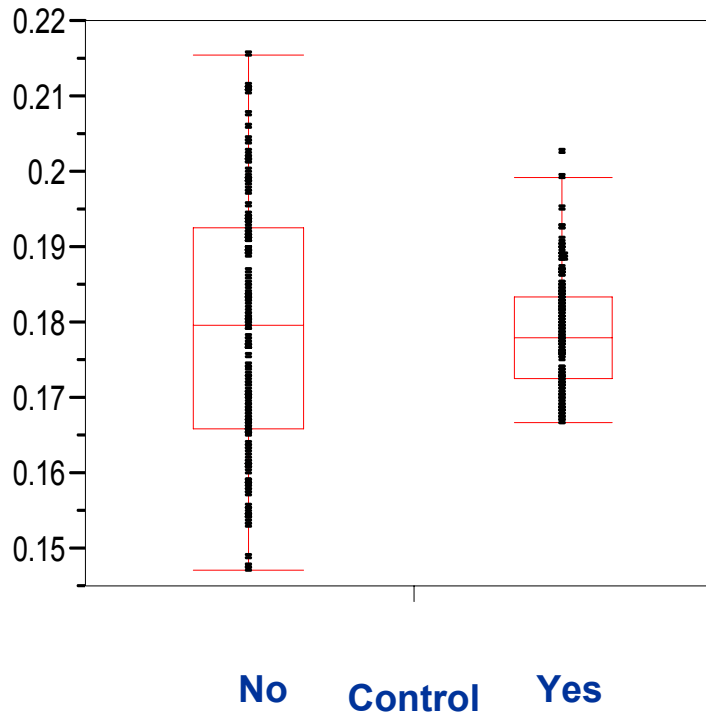


**Bias
-23 nm**

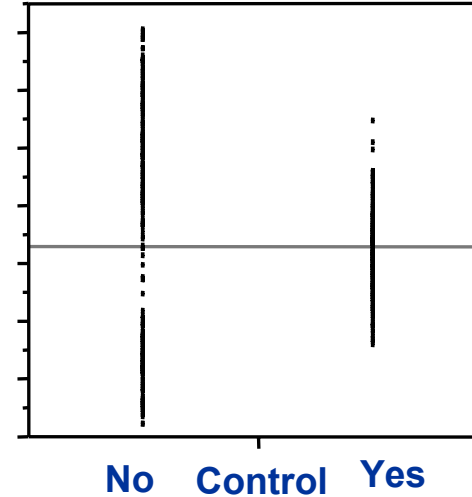
Data Courtesy of Cypress Semiconductor

Bottom Line Expectation

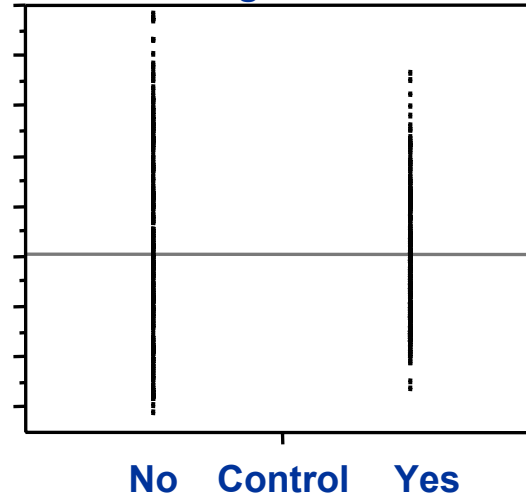
Gate CD Measurement



Drive current



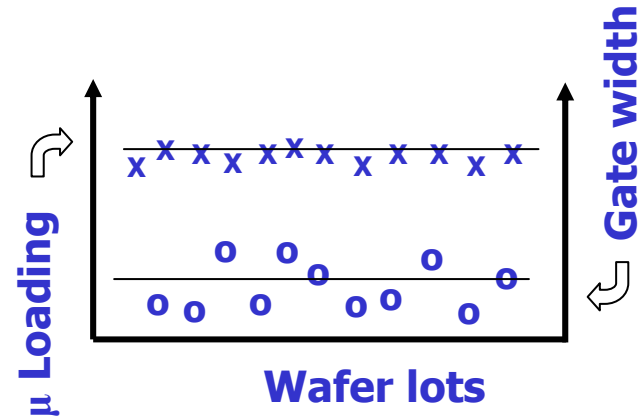
Leakage Current



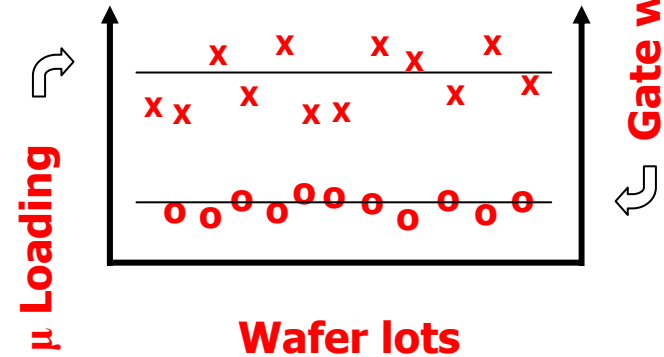
Data Courtesy of Cypress Semiconductor

Modeling Comparison

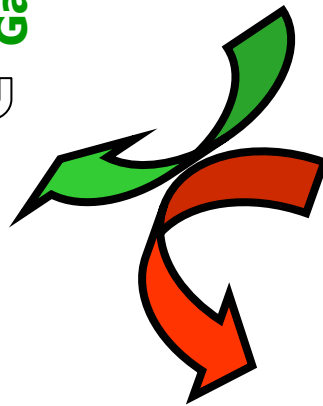
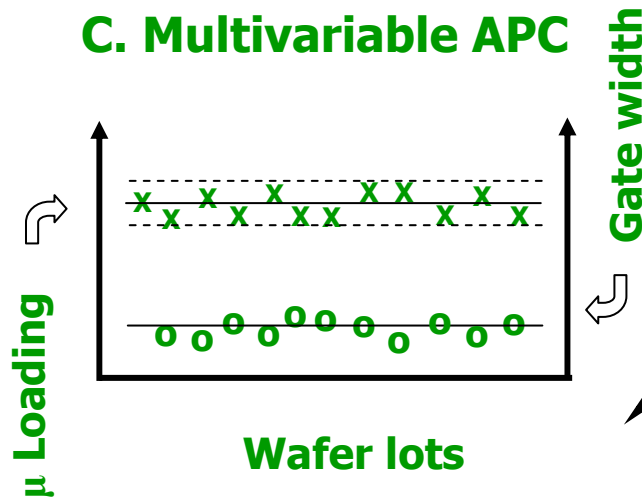
A. Typical etcher, no APC



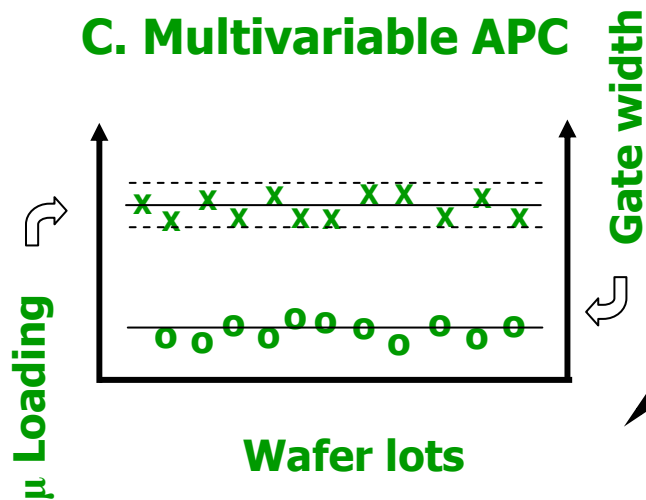
B. Univariable APC



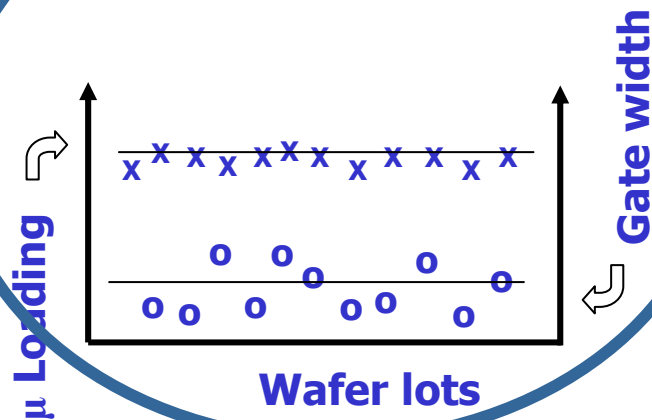
C. Multivariable APC



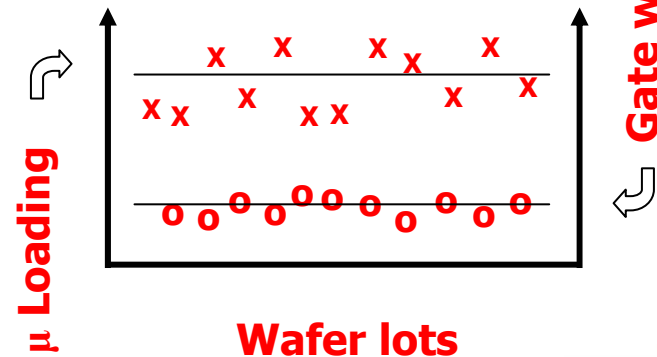
Modeling Comparison: No Control



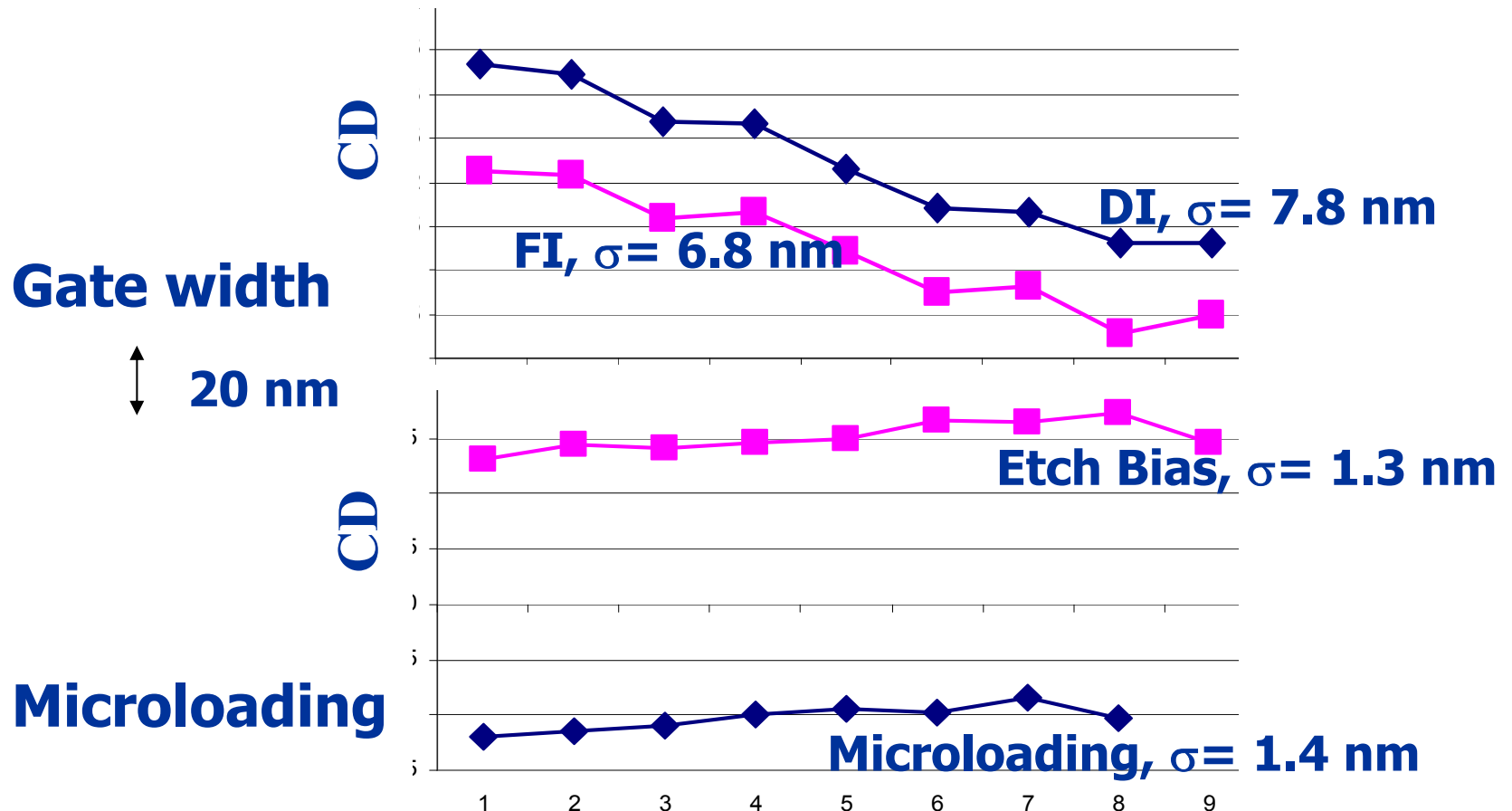
A. Typical etcher, no APC



B. Univariable APC



Modeling Comparison: Processing without APC

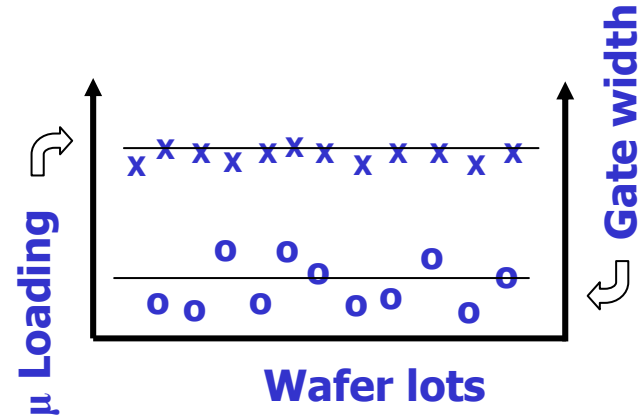


Data Courtesy of Cypress Semiconductor

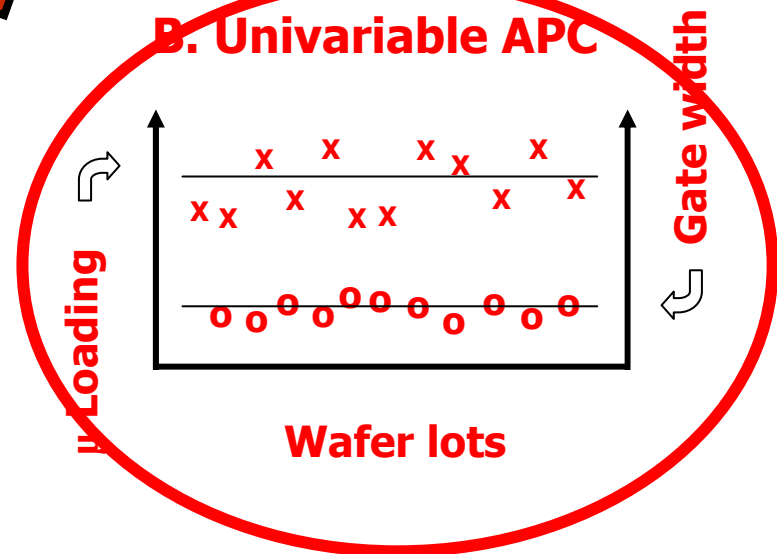
Wafer Lots

Modeling Comparison: Univariable Control

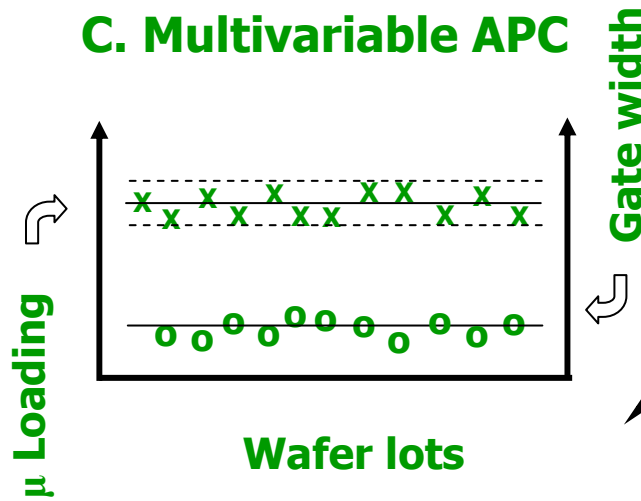
A. Typical etcher, no APC



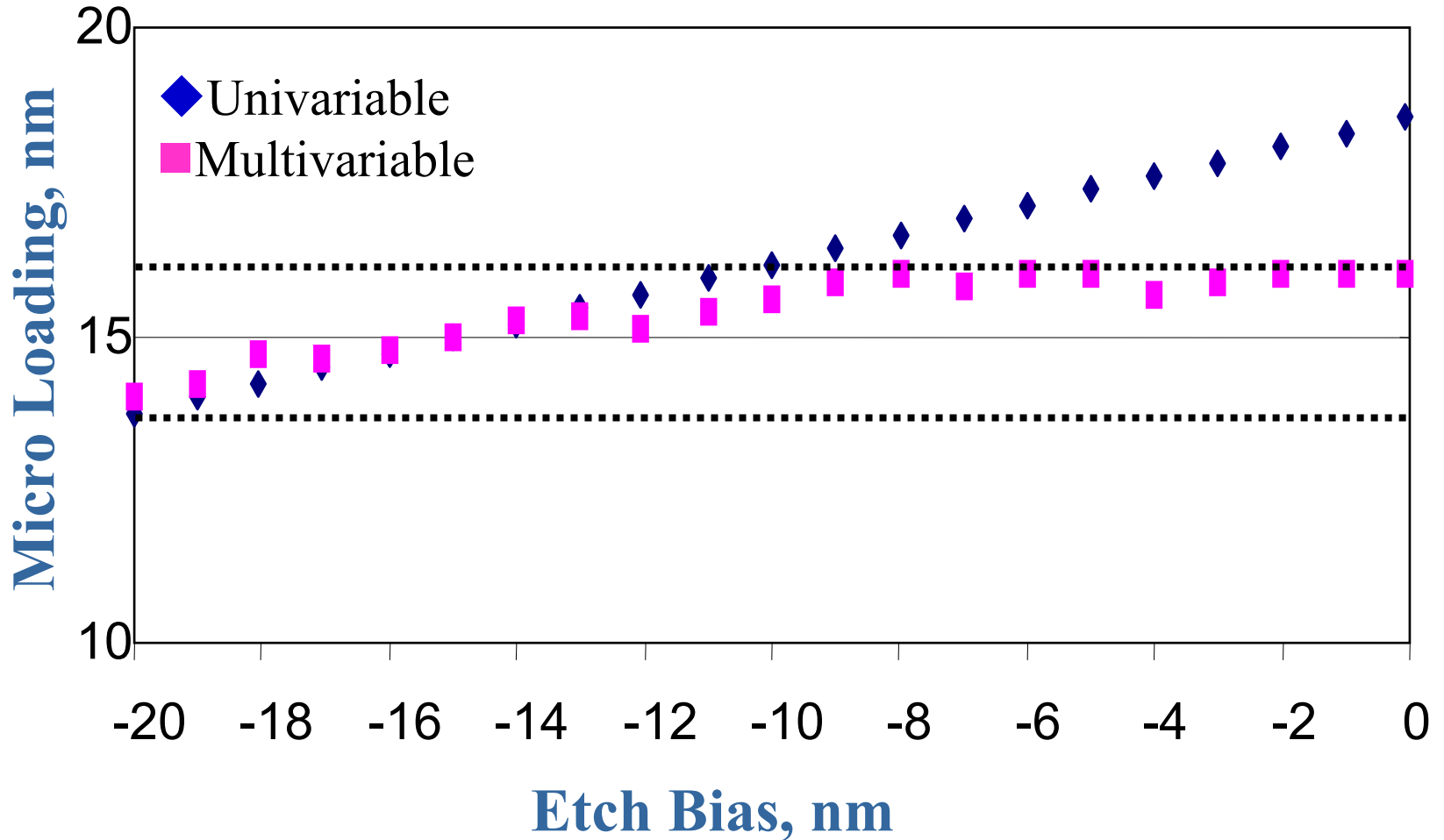
B. Univariable APC



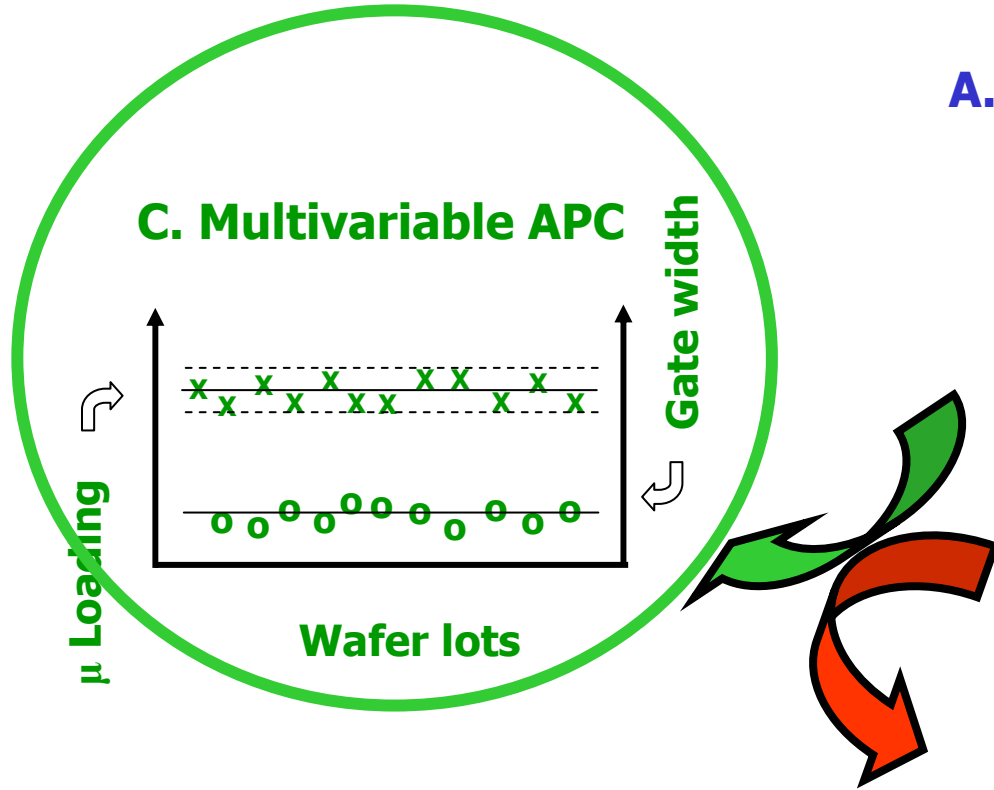
C. Multivariable APC



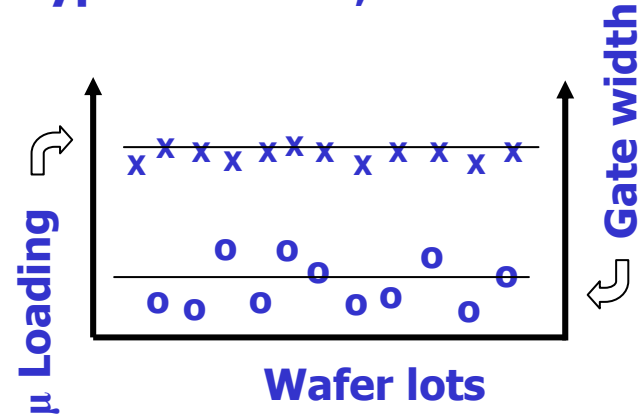
Modeling Comparison: Simulation of Microloading Control



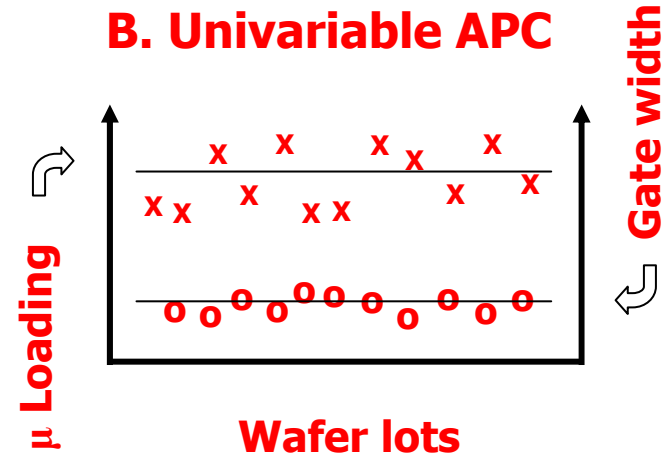
Modeling Comparison: Multivariable Control



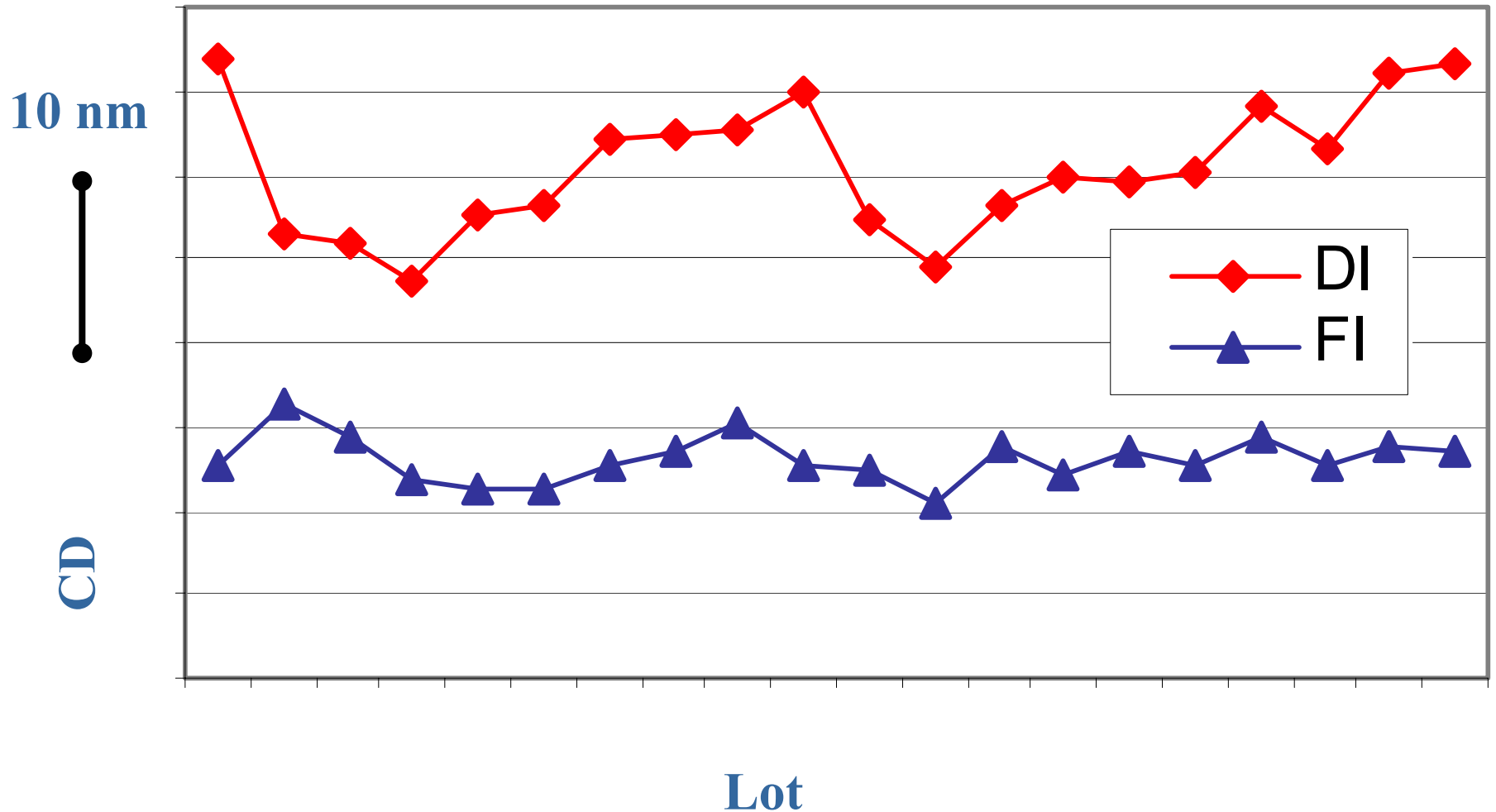
A. Typical etcher, no APC



B. Univariable APC



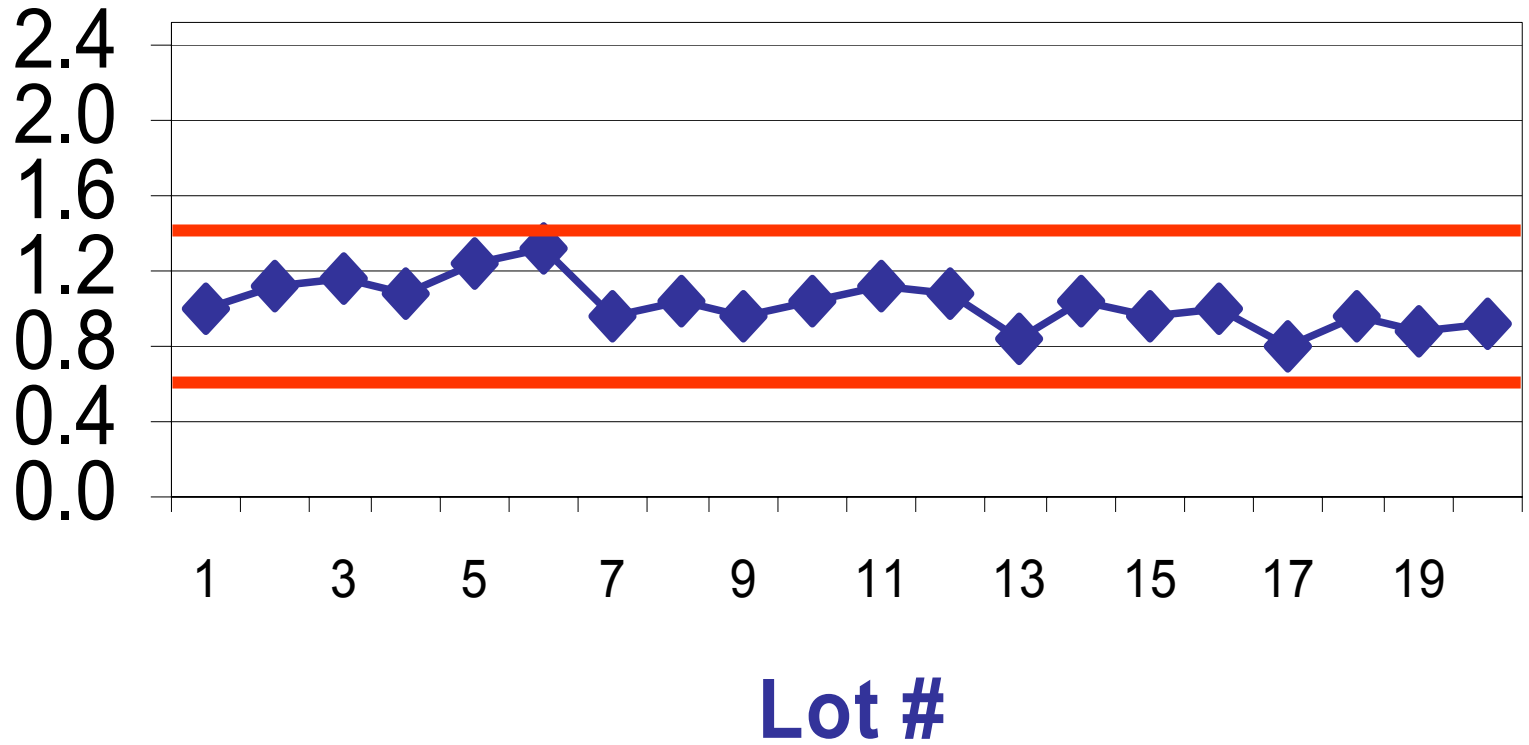
Multivariable Control of Gate Width



Data Courtesy of Cypress Semiconductor

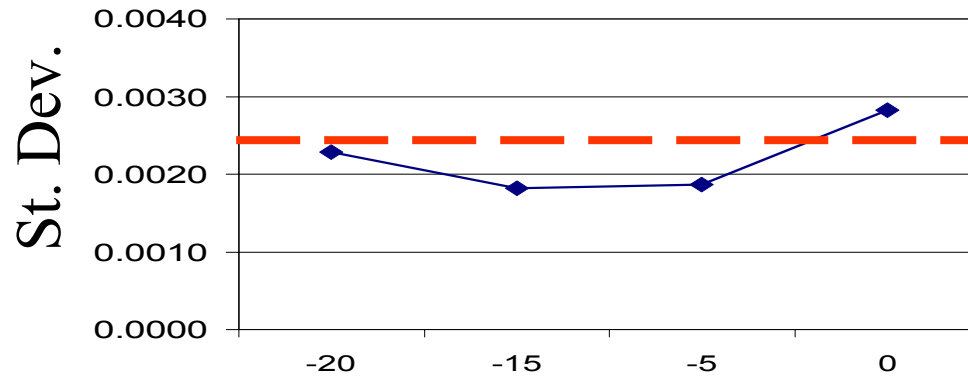


**Microloading
(normalized)**

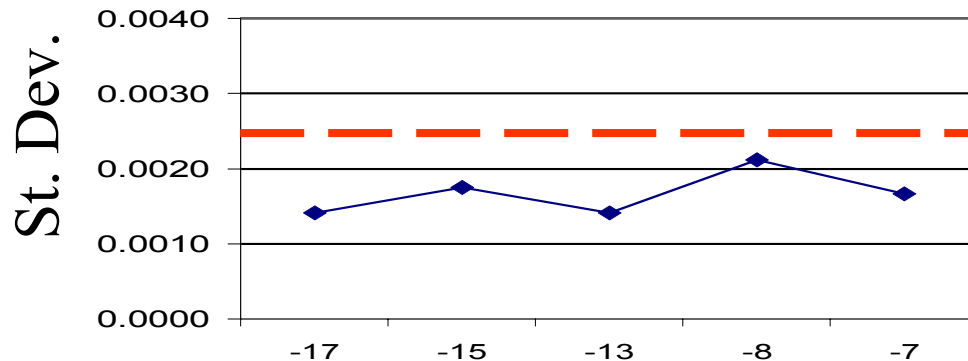


Multivariable Control of WiW Uniformity

Control of FI and Microloading



Control of FI, Microloading and Uniformity



Target Etch Bias, nm

Conclusions

- Control requirements vary substantially from line to line and control solutions must seamlessly integrate with disparate manufacturing lines
- Isolated vertical solutions have demonstrated success but are inadequate moving forward
 - Control strategy must address all process steps
 - Control must be applied in an integrated manner across manufacturing processes
- Control System Architectures must be flexible and adaptable
 - Leverage existing infrastructure to maximize investments
 - Adapt to manufacturing line wafer flows to maintain operational consistency

Conclusions (Cont.)

- BCT's control model development, as outlined, generates a robust control model with minimal wafer consumption
- BCT's multivariable process control (and MIMO control in general) delivers superior results over contemporary univariable control (SISO).
- Through actual customer data the merits of BCT's MIMO control were demonstrated for a poly gate etch application where the primary control goal was gate width, and the secondary control goals were microloading (dense/iso) and across wafer uniformity.
 - Univariable control schemes pursue the primary control goal at the expense of secondary control goals.
 - Control of both the primary and secondary control goals demands adoption of MIMO control schemes.

Acknowledgements

- Tito Chowdhury, Cypress Semiconductor