Data pre-treatment to achieve efficient Hotelling T^2 & Principal Components Analysis

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ST Fault Detection & Classification [FDC] and MultiVariate Analysis [MVA] strategy

- Corporate choice : to deploy FDC on 100% of equipments (process & metrology) with objectives to guarantee quality of :
  - The products
  - The interventions on the equipment (Health Indicator Project)

- FDC with monovariate analysis reaches its limit for several reasons:
  - Difficult to analyse and maintain numerous control charts
  - Single parameter sensitive to PM cycle, parts change and wafer effect
  - ‘Culture’: parameter which was supposed to be not critical with large control limits is in fact critical with statistical limits

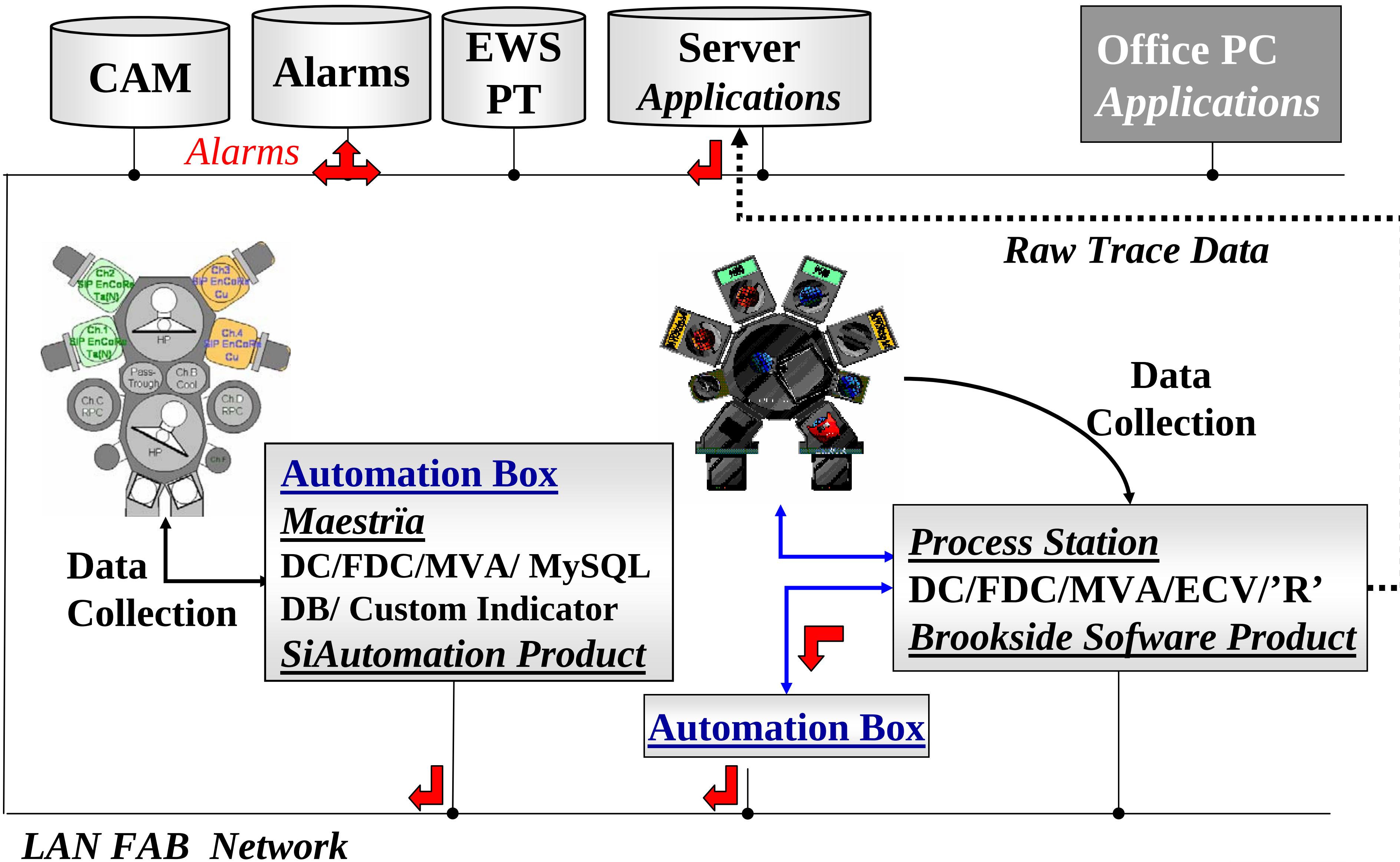
- FDC with MVA is showing also limitations…
  - Hotelling T^2 is used for FDC ‘inline’ and permits to see issue on one generic indicator which follows several parameters. But T^2 is meaningless because of its sensitivity to maintenance interventions
  - PCA is used to adress chamber matching issue but is showing also sensitivity to parameters quality and maintenance interventions

FDC - Problem description & statment

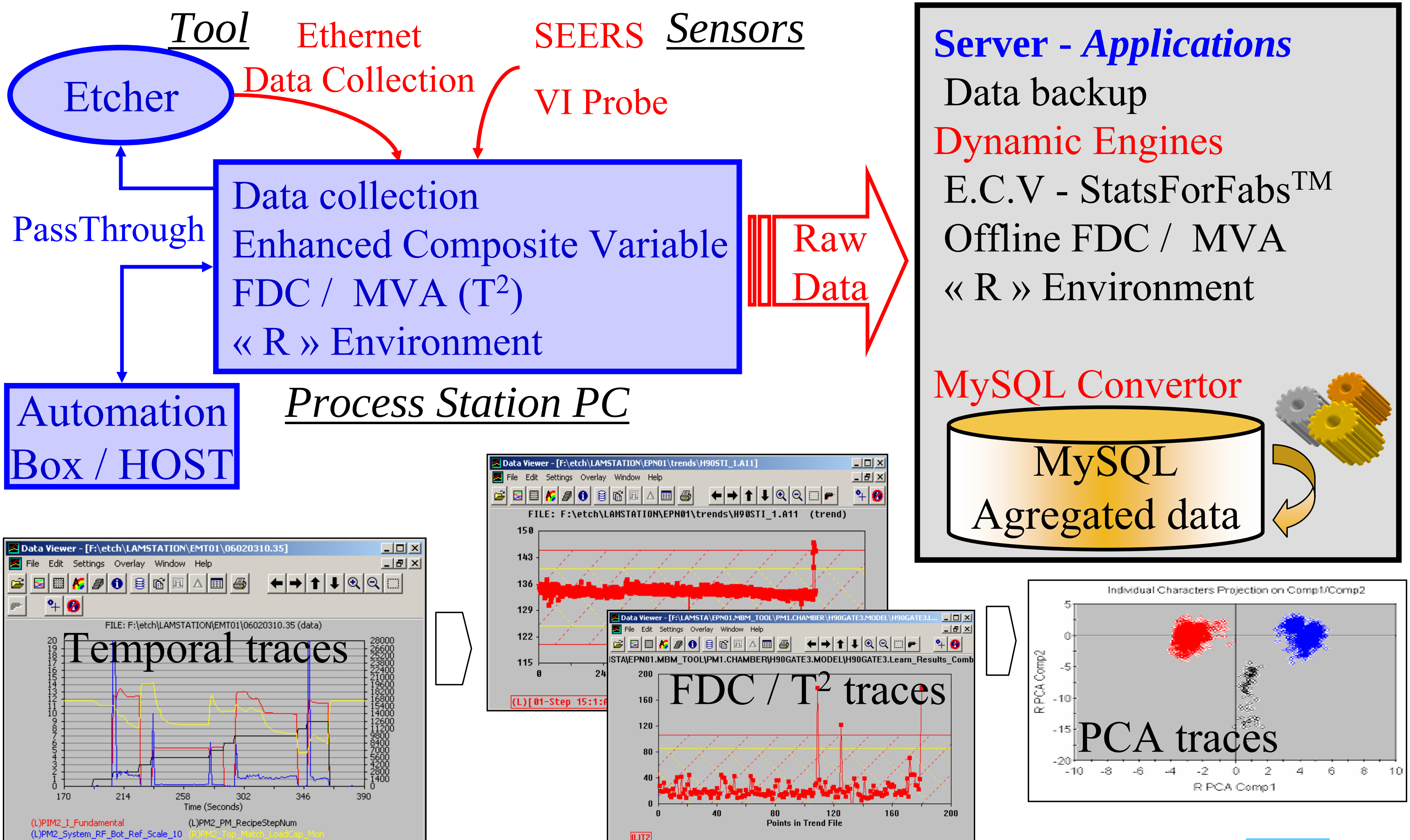
- When deployment of FDC reachs a high level of tool coverage, technicians and engineers are facing numerous false alarms caused by ‘normal life’ of the equipments [Slot position effect, PM cycle, Parts change].
- Up to now a solution was to enlarge the control limits with potential high risk to miss real issue !

- Using ‘R’ language, we propose a normalization method to face these drifts initiated by PM intervention and slot position effect
- These pre-treatments need to be done in real-time
- IT Architecture is important. Pre-treated data and classic data need to be both accessible in a data warehouse to be used for further analysis across several frames & chambers

IT Architecture Overview



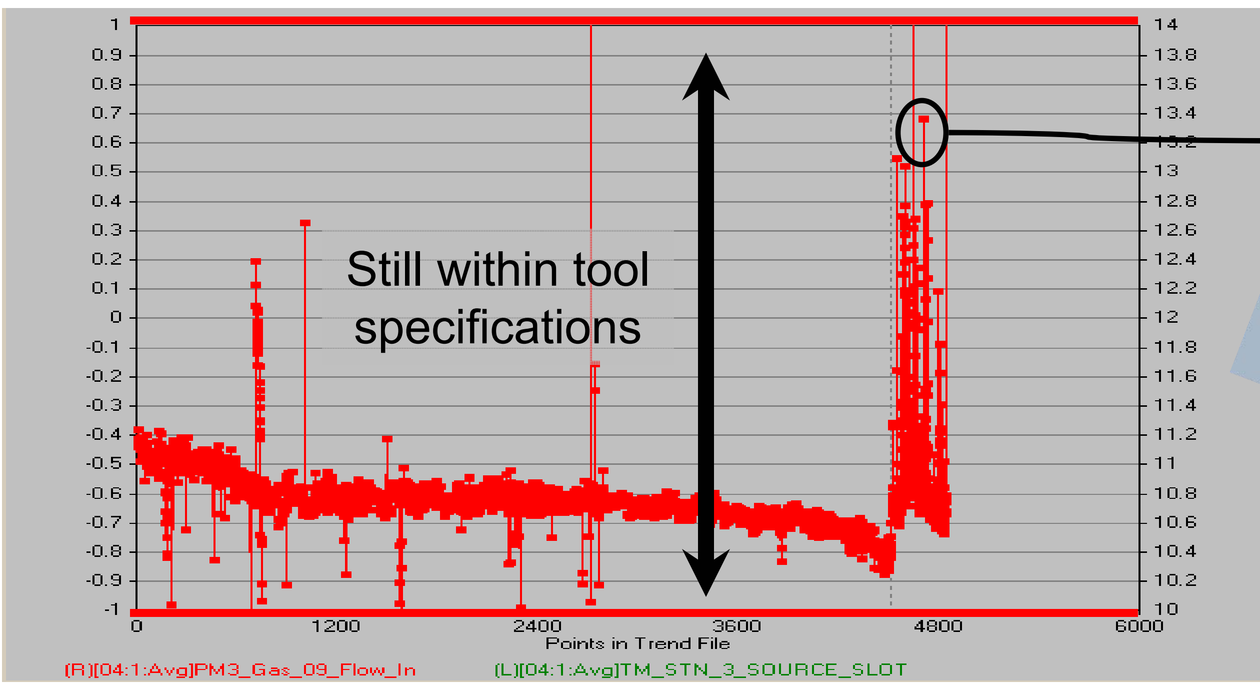
IT Architecture Overview – Dry Etch Area Focus

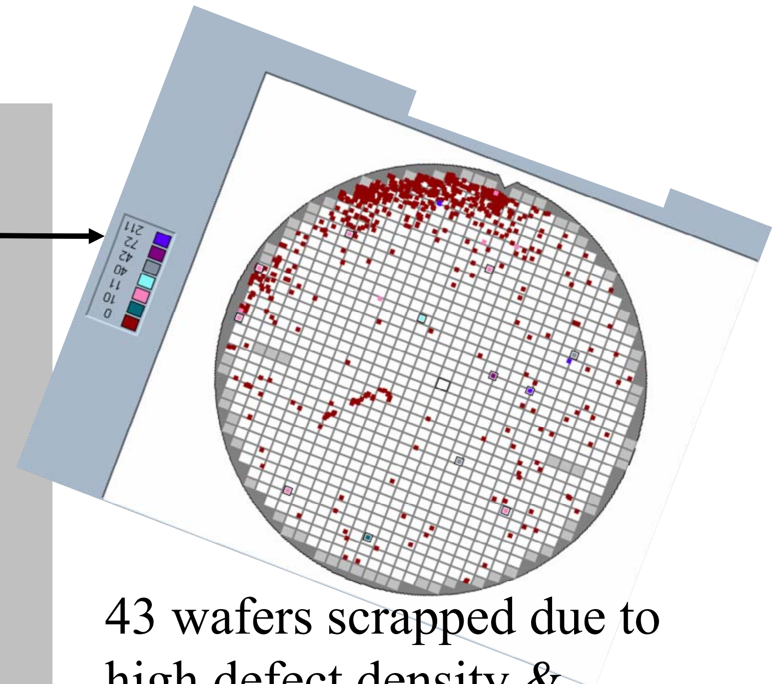


Parameter Normalization Proposal

FIRST TYPE - MAINTENANCE INTERVENTIONS / PARTS CHANGE

- Backside helium on Lam9600PTX is drifting slowly in function of the RF hours. After each PM the start level is never the same and the slope can differ. We need to enlarge classical control limits to counteract this drift.
- With this limits increase, we can miss real issue like flakes. By tightening the limits, the risk is to flag good wafers…





43 wafers scrapped due to high defect density & yield loss

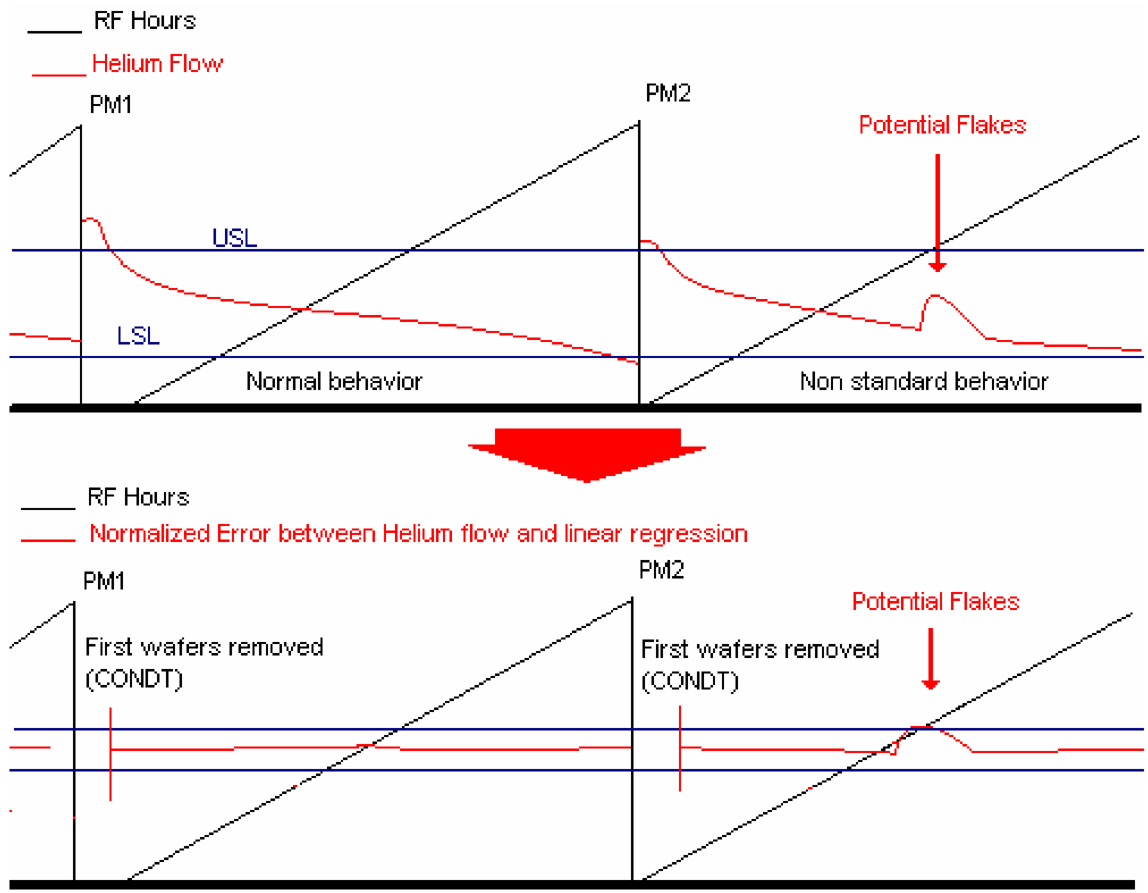
Parameter Normalization Proposal

FIRST TYPE - MAINTENANCE INTERVENTIONS / PARTS CHANGE

- We propose here to create a linear fit trend of a Y parameter in function of a X parameter linked to maintenance intervention and parts change.

- In this 'fit' we can fix the number of wafers we want to remove when the X parameter resets and how many wafers need to be included in $aX+b$ linear regression.

The value of this $YPredicted_i = a_i X_i + b_i$ will be compared with real value $YReal_i$ and an Error indicator will be generated.



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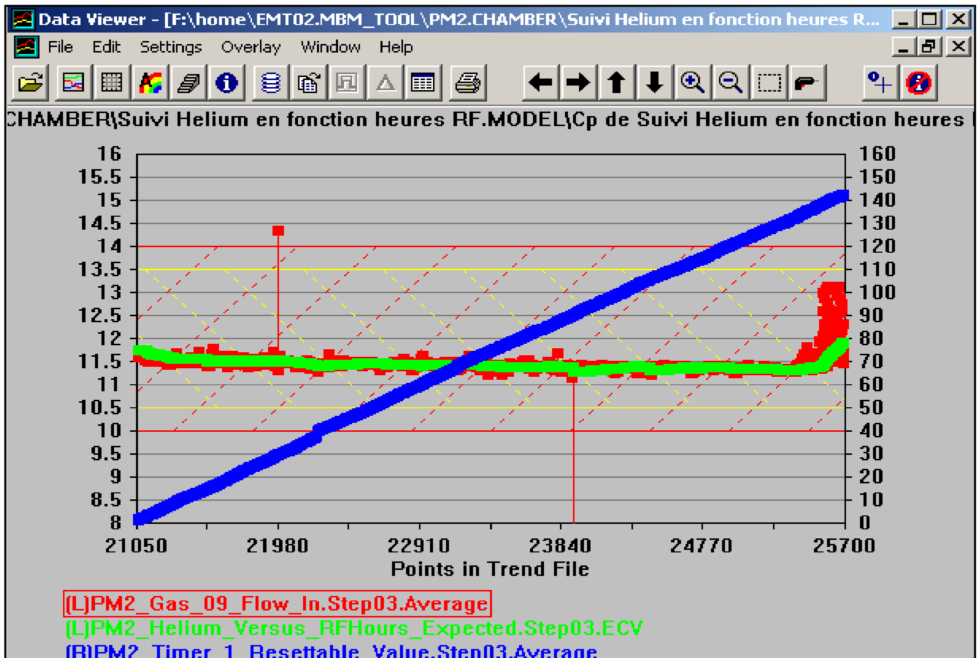
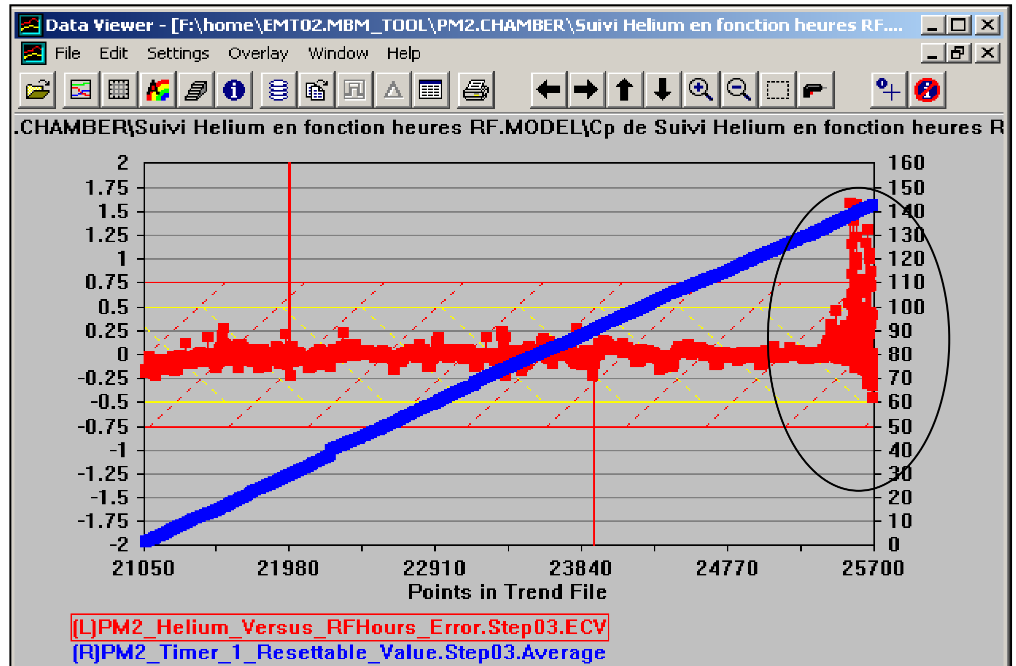
Parameter Normalization – Real cases

FIRST TYPE - MAINTENANCE INTERVENTIONS / PARTS CHANGE

- We can now create an ECV [Enhanced Composite Variable] whatever the parameter we would like in Y (Helium, Capacitances, Temperatures) and X (RF Hours, ESC Time). Example on 9600PTX chamber :



Helium real – Helium expected – RF Hours



Error Real/Expected – RF Hours

Classic SPC miss the issue with
LSL 10 / LCL 10.5 / UCL 13.5 / USL 14 sccm

ECV detects the issue with
LSL -0.75 / LCL -0.5 / UCL 0.5 / USL 0.75 sccm

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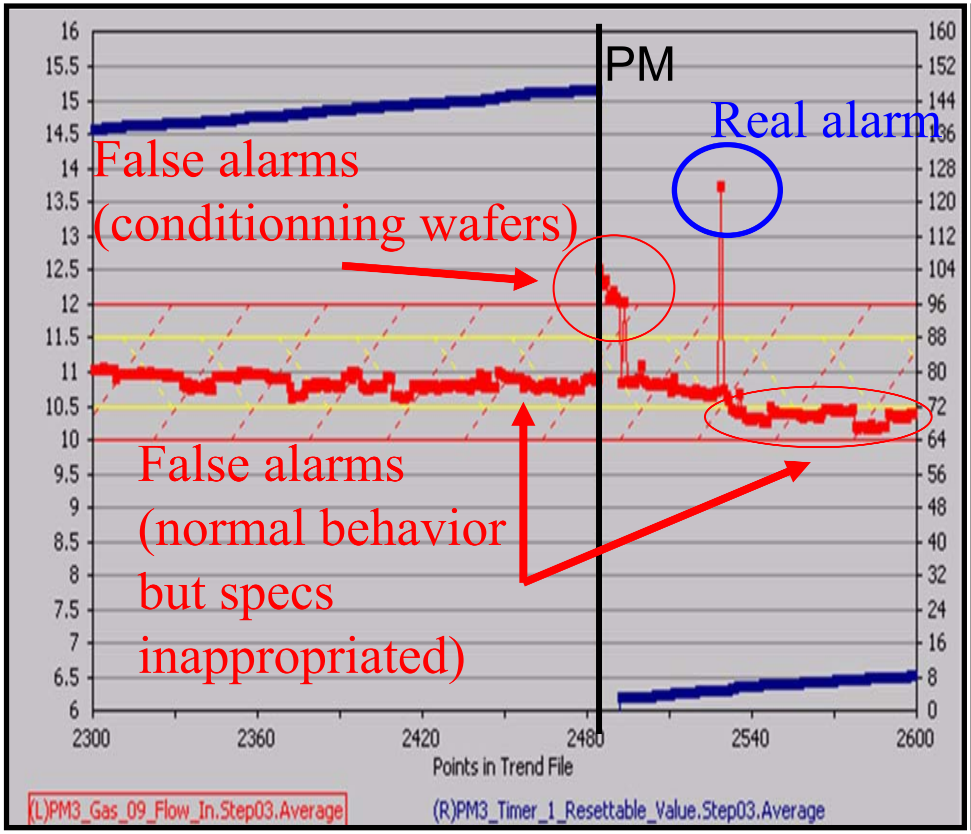
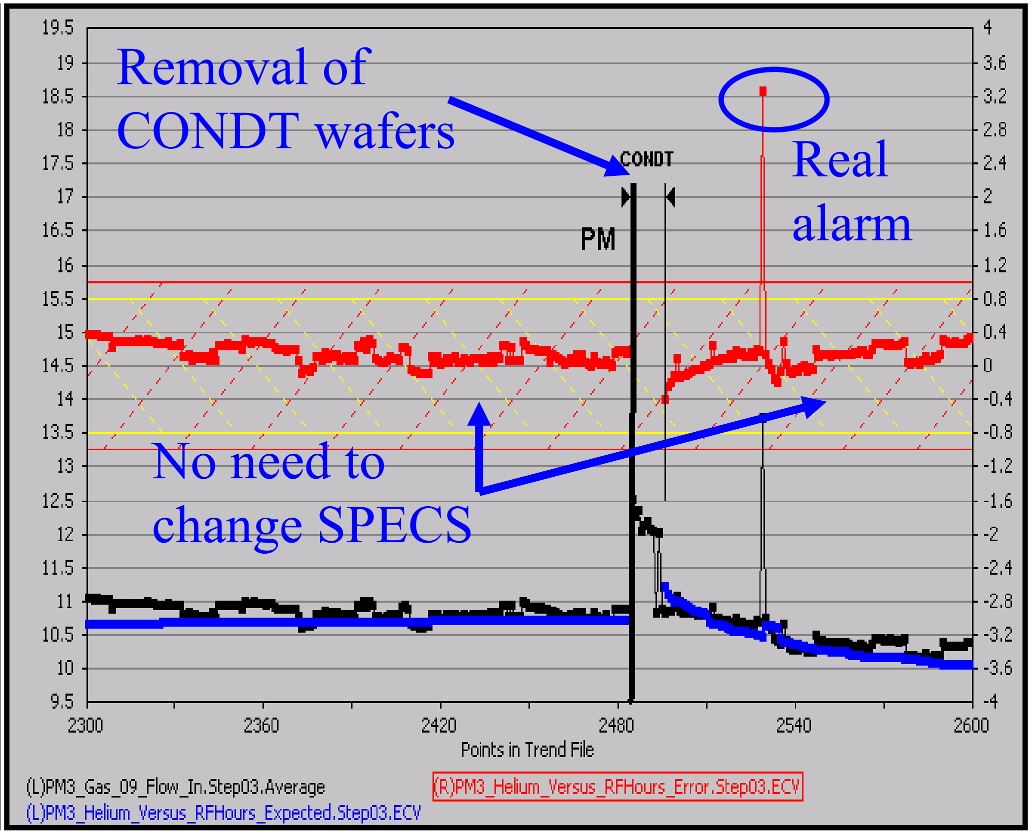
Parameter Normalization – Real cases

FIRST TYPE - MAINTENANCE INTERVENTIONS / PARTS CHANGE

- Other advantage : No need to change specifications after PM





Classic SPC with false alarms when PM occurs

ECV Real-Predicted without false alarms when PM occurs

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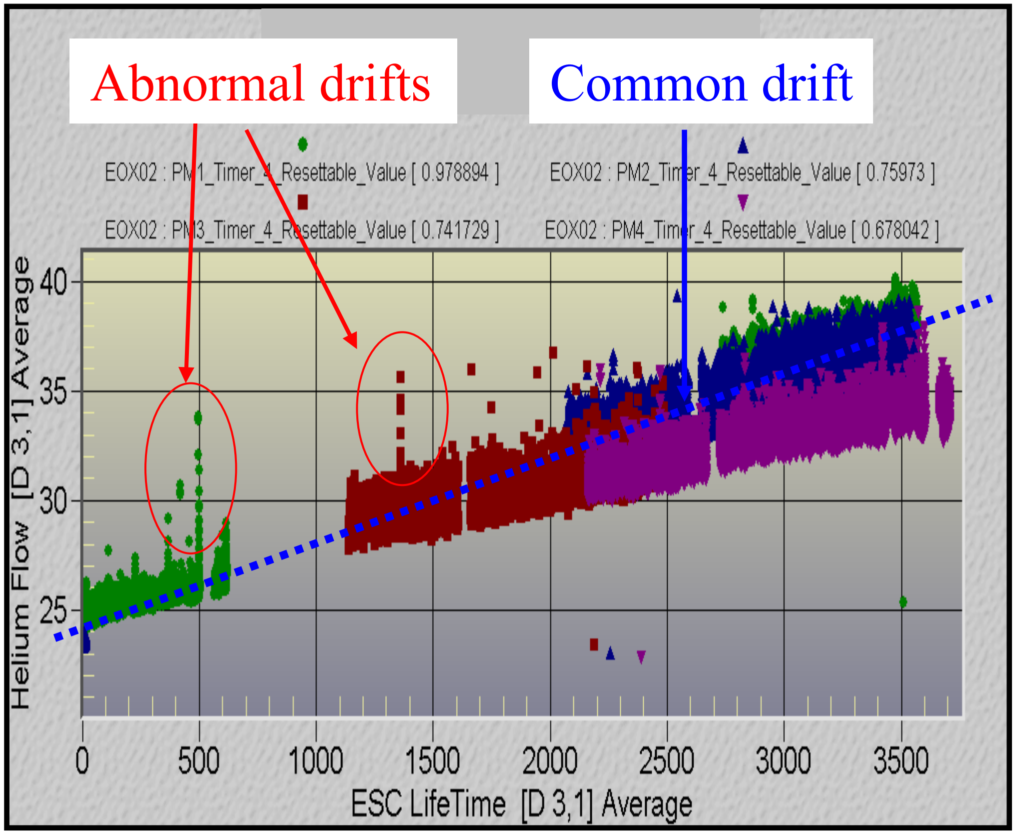
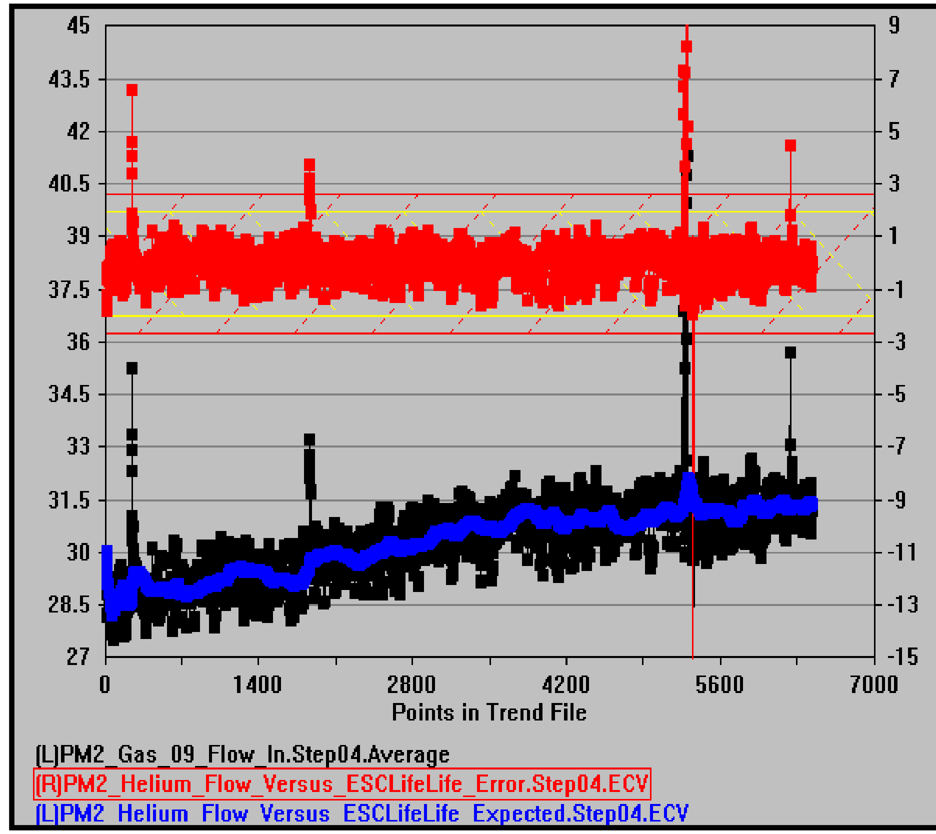
Parameter Normalization – Real cases

FIRST TYPE - MAINTENANCE INTERVENTIONS / PARTS CHANGE

- Example on 4520XL chamber – Helium flow in function of ESC LifeTime.





Helium flow in function of ESC life time on 4 chambers ⇔ SPC non applicable (22 ⇔ 40 sccm)

ECV in function of ESC life time ⇔ SPC applicable (-2.5 ⇔ 2.5 sccm)

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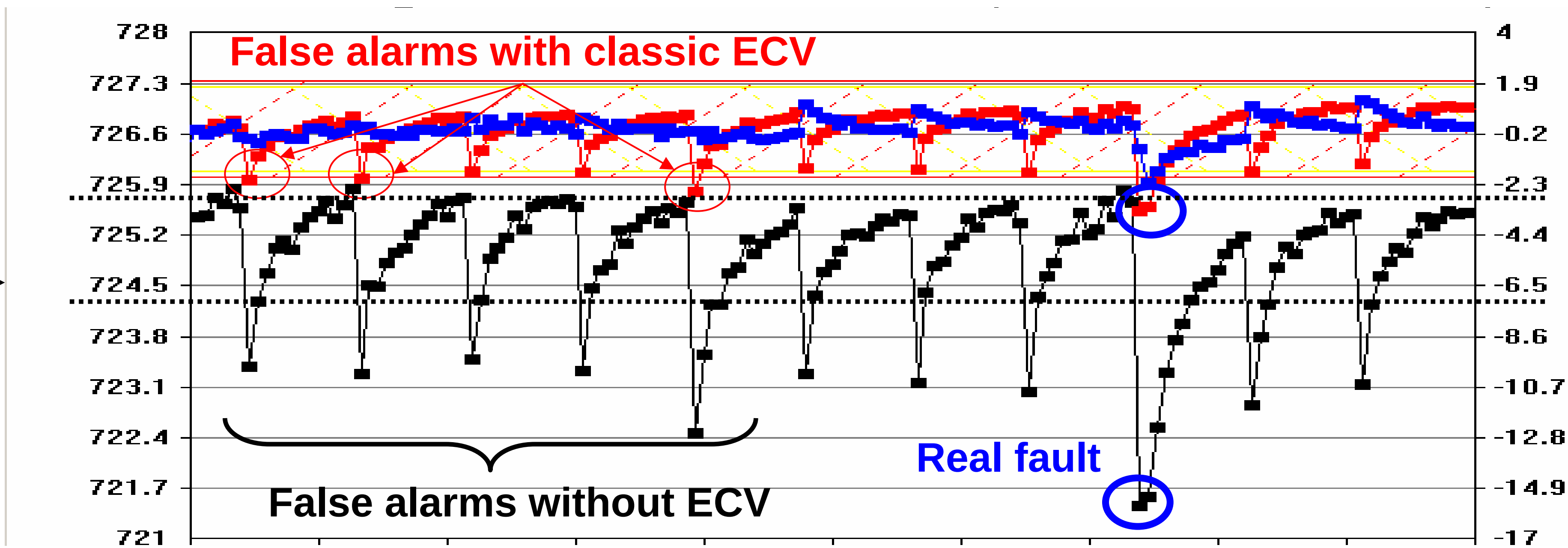
Parameter Normalization – Real cases

SECOND TYPE – FIRST WAFER EFFECT & INTERVENTIONS / PARTS CHANGE



Error = [*Slot and RF Hours Normalized Expected ECV*] – [Real]

Error = [*RF Hours Normalized Expected ECV*] – [Real]

- SPC is not applicable on ESC Voltage ⇔ first wafer effect is too important even by using ECV in function of RF Hours.
- Using new ECV, fault detection is possible.

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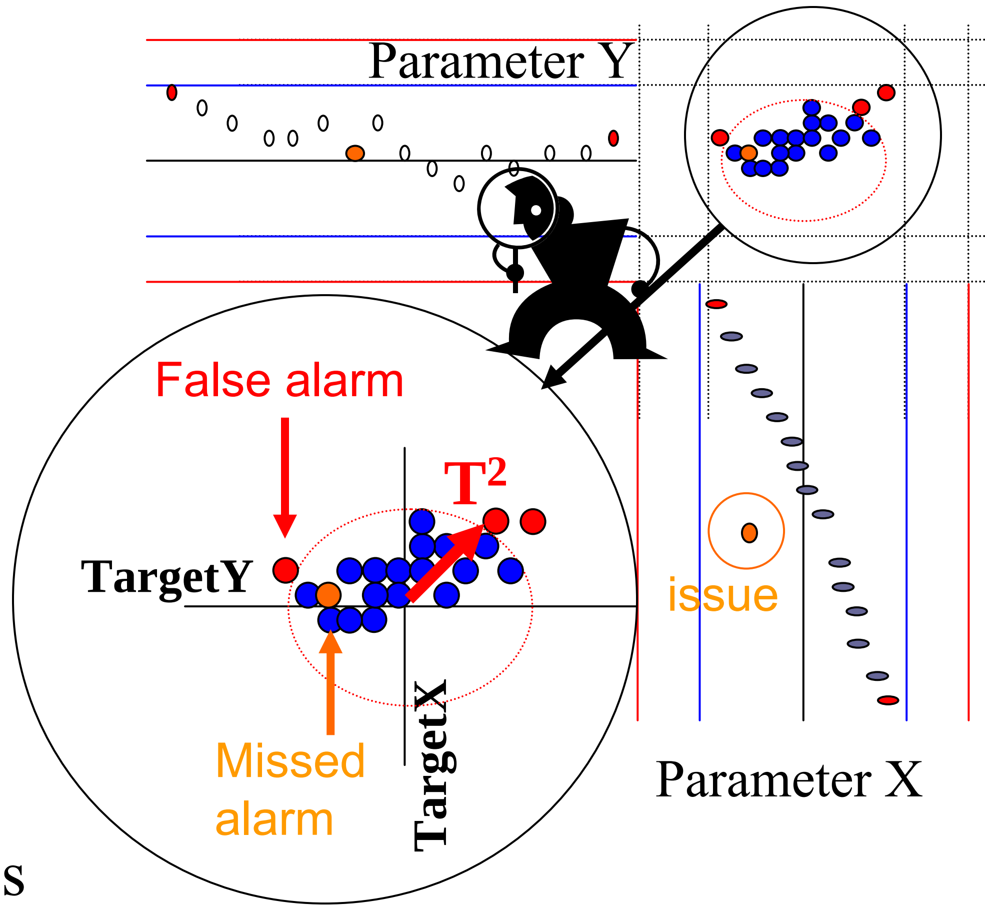
MVA - Problem description & statment

- By solving this FDC issue by using ECVs, we make MVA more efficient since Hotelling T^2 is sensitive to individual parameter drifts and shifts
- Then MVA can be used with high level of confidence
  - Hotelling T^2 adress process faults ‘online’
  - PCA adress chambers mis-matching

Parameter Normalization and T^2 Influence

Hotelling T^2 is becoming a 'standard' online MVA.
It allows FDC on several parameters using a sensitive unique indicator.



Theory with 2 variables X,Y…

- Variance of variable Y
  $S_y = 1/n \,.\, \sum_{i=1 \text{ to } n} (Y_i - Y)^2$
- Covariance of variable X and Y
  $S_{xy} = 1/n \,.\, \sum_{i=1 \text{ to } n} (Y_i - Y)^2 \,.\, (X_i - X)^2$
- Correlation factor
  $\underline{T^2} = r(x,y) = S_{xy} / S_x \,.\, S_y$

- The variance of each variable and covariance for 2 independant variables are determining the quality of the Hotelling method.
- Parameter with slight drift can impact Hotelling T^2 quality and makes it unreliable !

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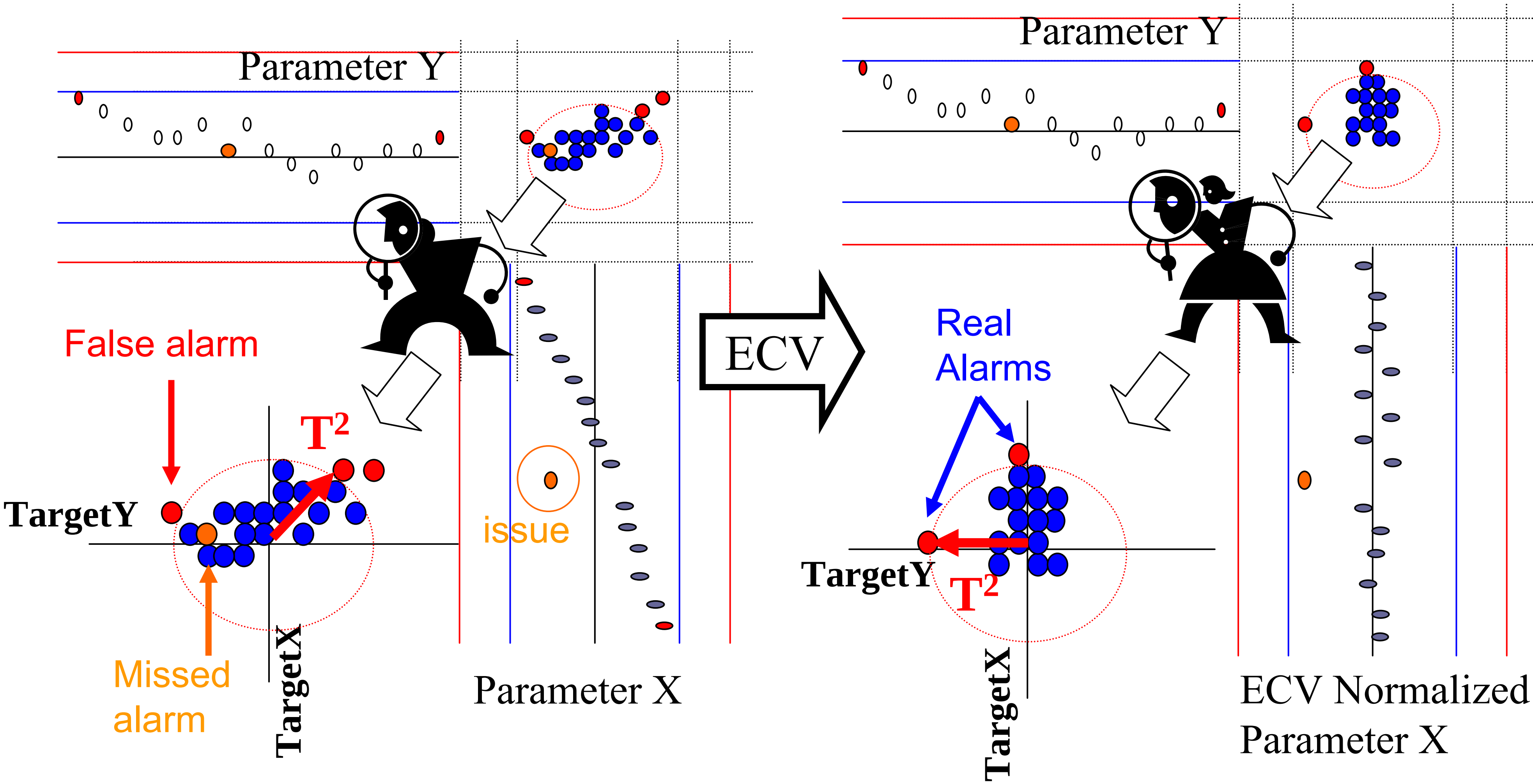
Parameter Normalization and T^2 Influence



- Using ECV we have less false alarms and better representative MVA with Hotelling T^2

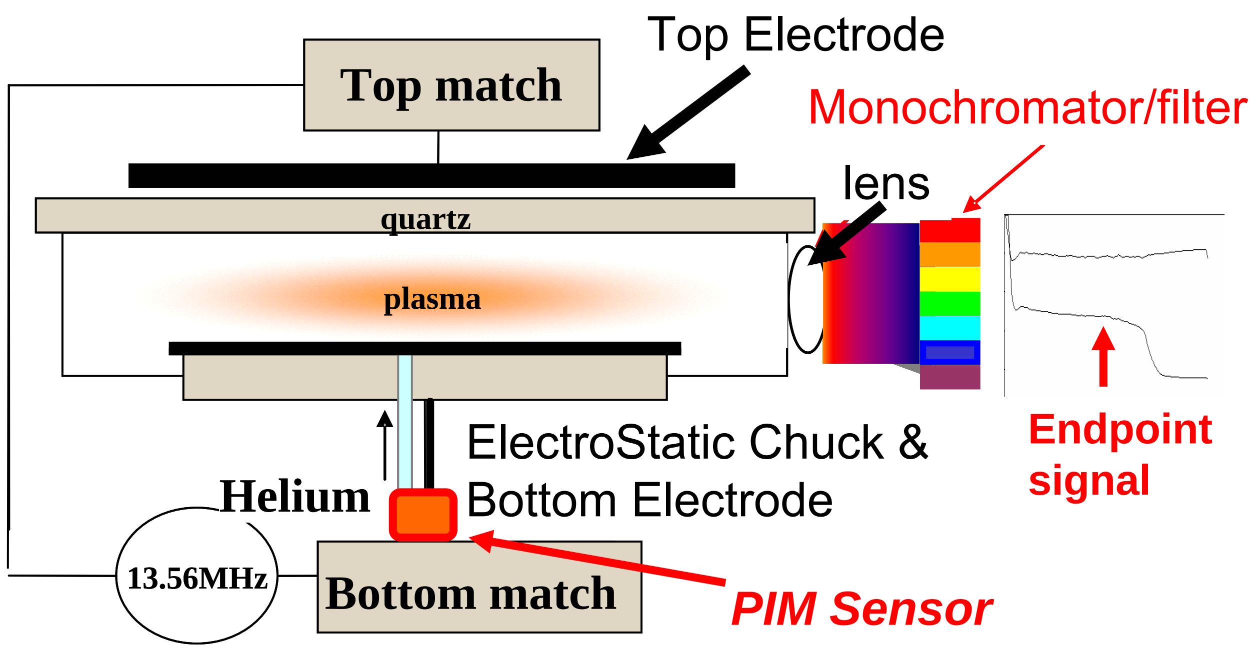
Normalization and T^2 Influence – Real case study

• Using Hotelling T^2 we want to monitor a Lam Alliance 9600PTX chamber.
• We choose 16 parameters suspected to play a rule in a tungsten etch process using BCl3 and Cl2 chemistry.

• We learned a model on 560 wafers and applied it on 1550 wafers.

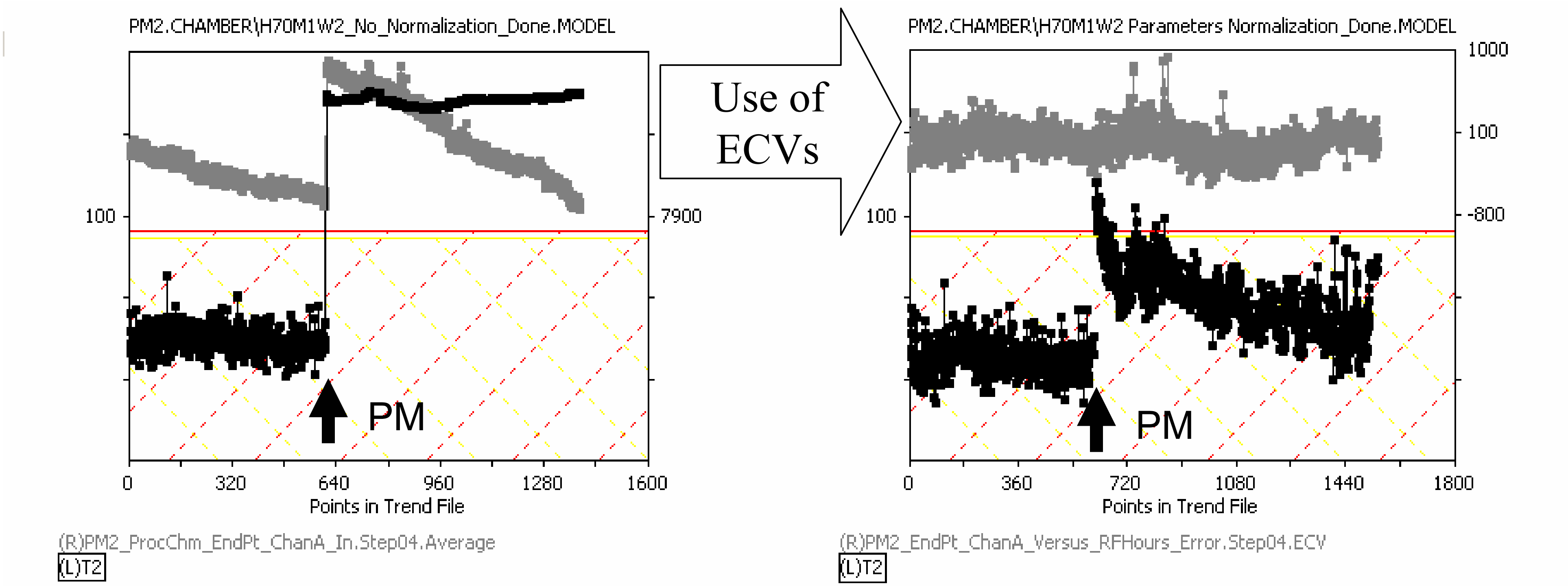
Parameter selection list

PIM sensor parameters
Gas & Helium flows
ESC parameters
Pressures
Temperatures
RF parameters



Normalization and T^2 Influence – Real case study

- An intervention occurs during the period : the EndPoint signal is infuenced by the quartz window clean and polymer removal. The T^2 is then influenced by this parameter and by the helium small drift.

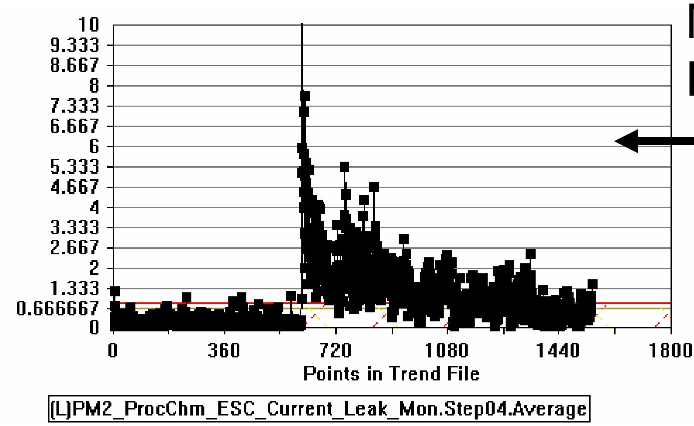


T^2 Hotelling and EndPoint Channel A Signal

T^2 Hotelling and Normalized EndPoint Channel A Signal

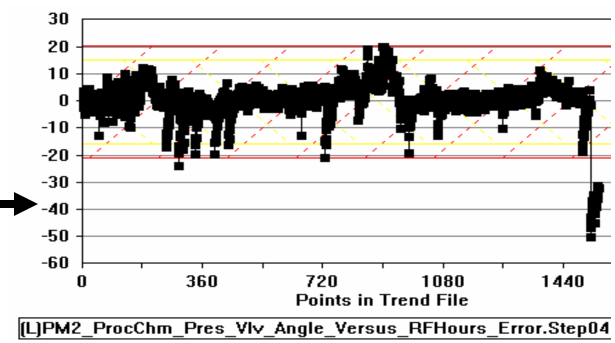
Normalization and T^2 Influence – Real case study

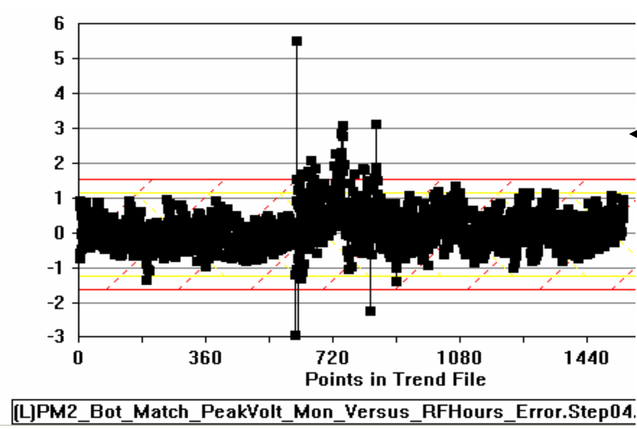
• Using Hotelling T^2 with normalized parameters we can focus on real problems after PM:



Main contributor :
ESC Current Leak

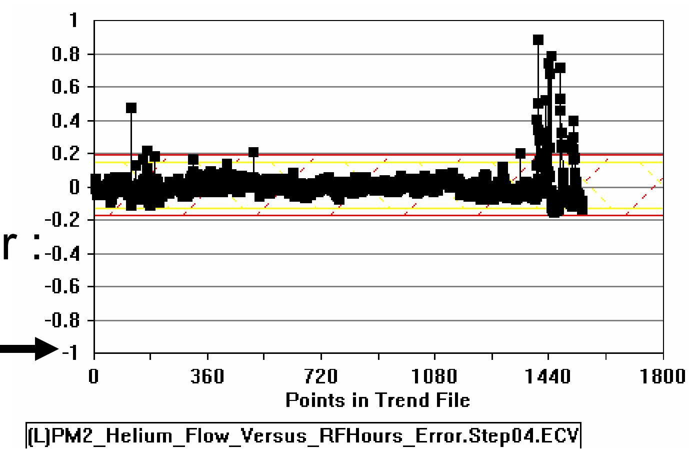
Third contributor :
VAT Angle





Second contributor :
Peak to peak voltage

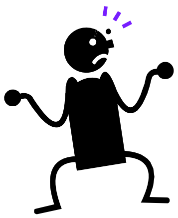
Fourth contributor :
Helium flow

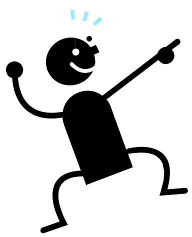


Grounding issue suspected between bottom match box and VAT controller system

Before normalization in ‘R’:

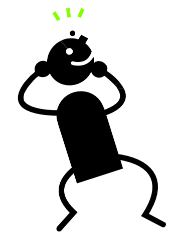
Your manager was wondering what you were doing… You were spending most of your time to update control limits. Hotelling T^2 was meaningless.





Now:

Your manager is wondering why you didn’t think about it before. You can now think about enter in the wonderful world of Principal Components Analysis.



MVA with Principal Components Analysis – Case study

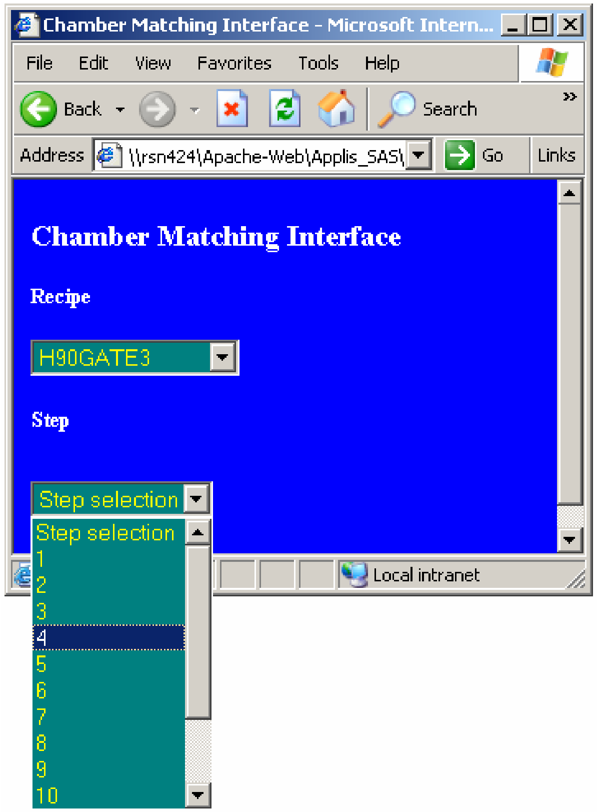
In the same way that we used ‘R’ to create SPC, ECV and T^2, we will use it to generate Principal Components Analysis. ‘R’ is able to connect to the MySQL data warehouse, requests for appropriate data set and run a PCA.

Context

• On the gate etch process for 0.130 nm copper product, the technology is asking specifications which are going beyond standard equipment capability. On one chamber the CD after etch was shifted refering to the two other chambers of the same frame.

Solution

• We ask then to ‘R’ to request for all parameters on all steps with RF On with appropriated indicator type for each [ECV, Avg, Min, Max, StdDev, etc…].



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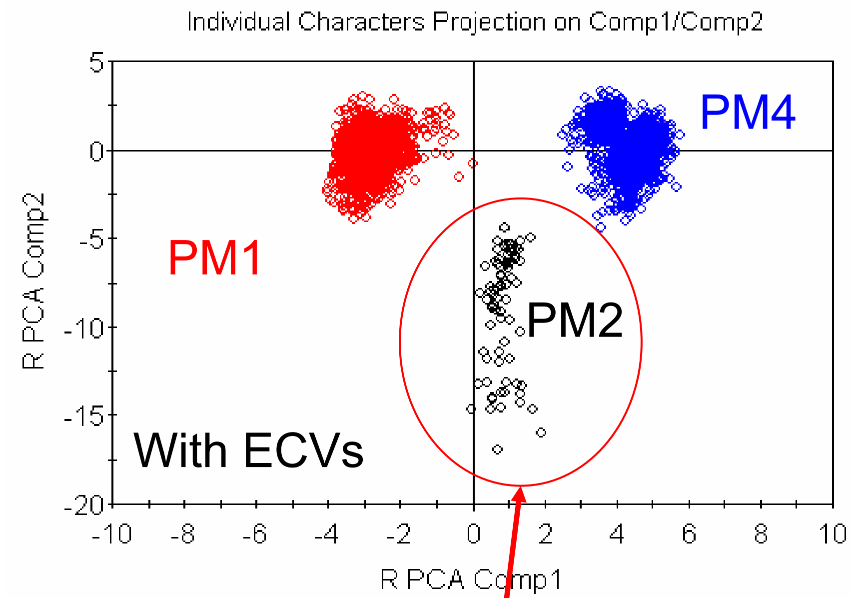
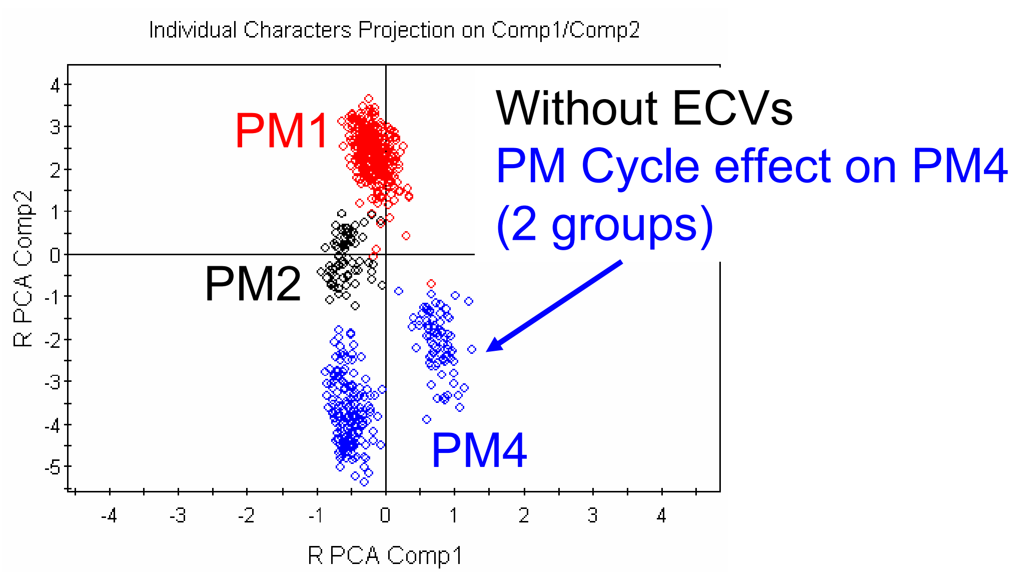
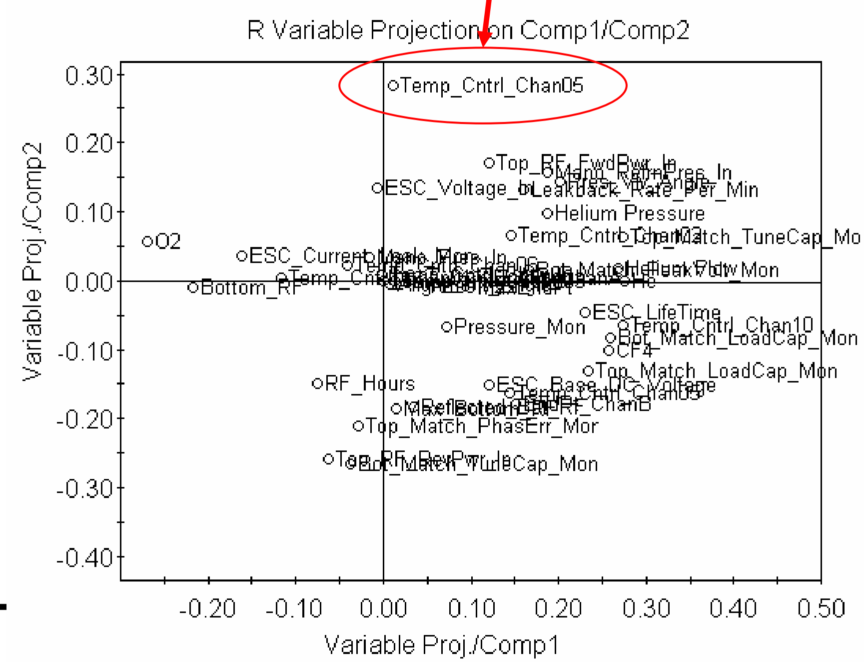
MVA with Principal Components Analysis – Case study

- The individual characters projection on the 2 main vectors of the model is showing that PM2 (low CD) is different from the 2 others on vector Comp2.
- The variables projection is showing that the main contributors on this axis are the bottom temperature and the Bottom Match Tune Capacitance.





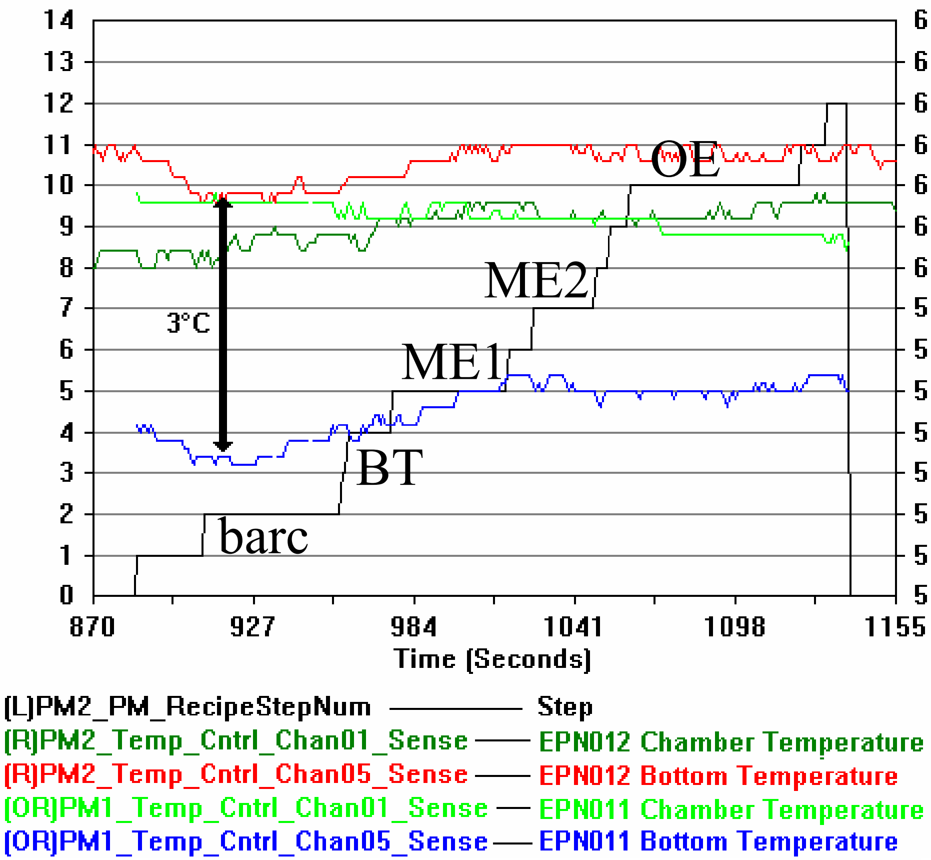


MVA with Principal Components Analysis – Case study

• Indeed if we focusing on bottom temperature control, we observe that on PM2 the regulation done has much higher amplitude than on PM1 & PM4. This difference was not supposed to be so critical…

We work then on chiller regulation control (galden pressure, PIDs) and also on VCI module to adjust PM1 and PM4. The VCI module on Lam 9400DFM is used to get DC Bias constant by bottom power adjustement

⇨ matching is Ok now between these 3 chambers



Conclusion

• Normalization in function of maintenance intervention and slot position effect is important to minimize false alarms, minimize specification changes, maximize T^2 Hotelling and PCA uses.

• Statistical environment like ‘R’ is showing high flexibility and potential.We will work further with support of Brookside Software to achieve a point-to-point analysis more efficient and manufacturable.

Perspectives

•We still need a functional & industrial application. Its the reason why we work closely also with R&D centers (CMPGC – Centre de Microélectronique Provence Georges Charpak) and companies which develops expertise in data analysis (MASA Group) to use statistical alternatives.

Aknowledgements

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• Thanks to ‘R’ CRAN Project community (**http://cran.r-project.org)**

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