Use of Data Mining techniques for model based data analysis of plasma parameters, electrical data and yield in high volume DRAM production

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Outline

- APC in high volume production
- Real time process control and offline analysis
- PE role
  - Evaluation of methods
  - Extension of data sources
- Conclusion

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APC in high volume production

- Ratio of electrical data to inline data - appr. 30 : 1
- Tool alarms / test methods are not sensitive enough, problems are detected too late
- Gap between high sophisticated yield analysis and comparatively low level of unit process mastering
- Application of APC using in-situ measurement techniques and high sophisticated data analysis offers a chance to overcame this gap

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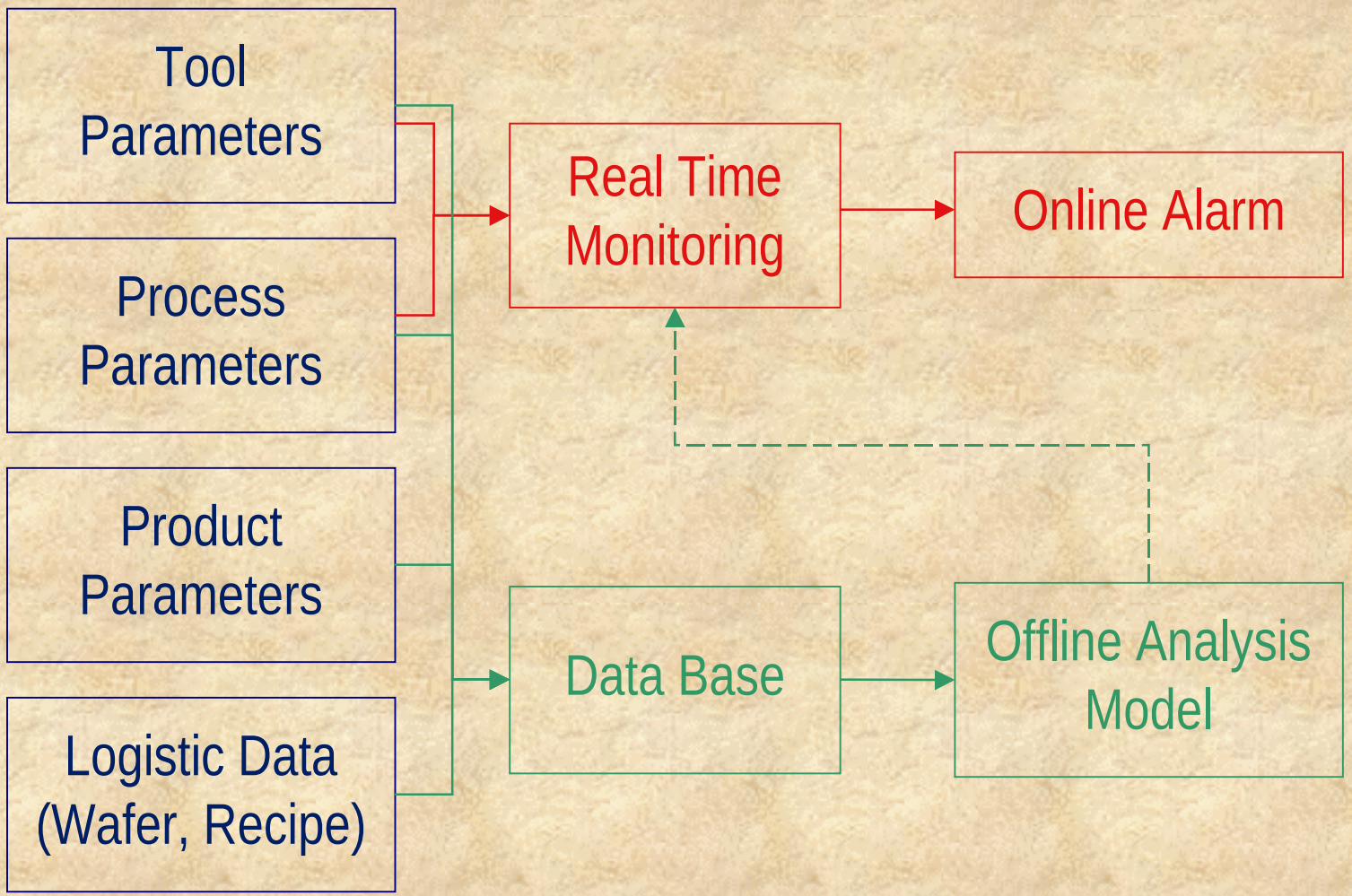
Real time process control and offline analysis



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PE role

- Evaluation of new methods of data analysis
- Extension of data sources

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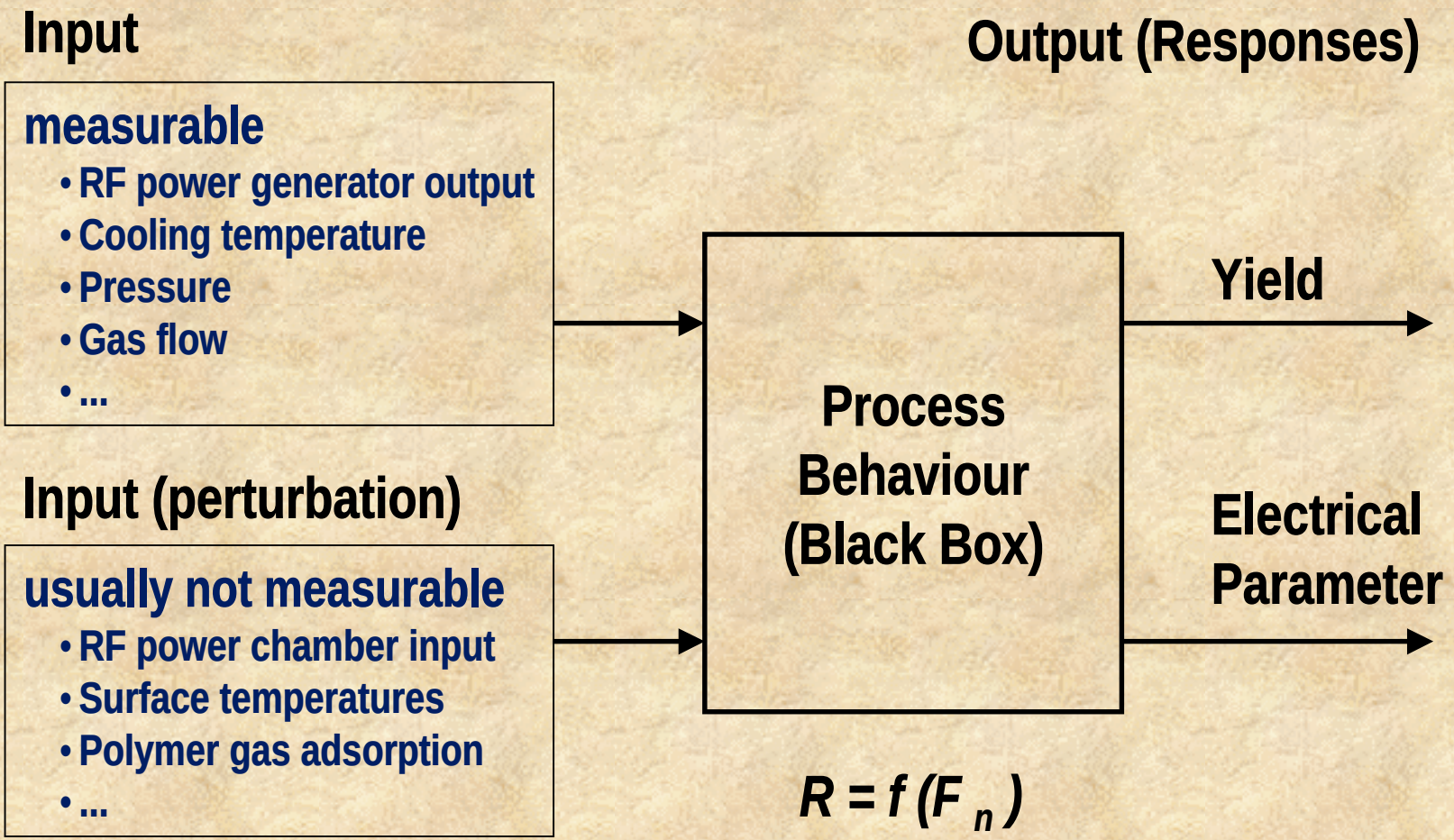
Evaluation of methods - APC process model



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Data Mining: data preparation & predictive modelling

- Data Mining - Advanced methods for exploring, selecting and modelling relationships in large amounts of data
  - passive process analysis
  - large amounts of historical „dirty“ data
  - „fishing“ for p-values / find previously unknown pattern
- Data Mining work flow includes
  - Exploring data (filter outlier, data transforming, variable selection and elimination of redundancies)
  - Fitting of a predictive model using
    regression, decision trees, neural networks,
    afterthen assessment and selection of the best

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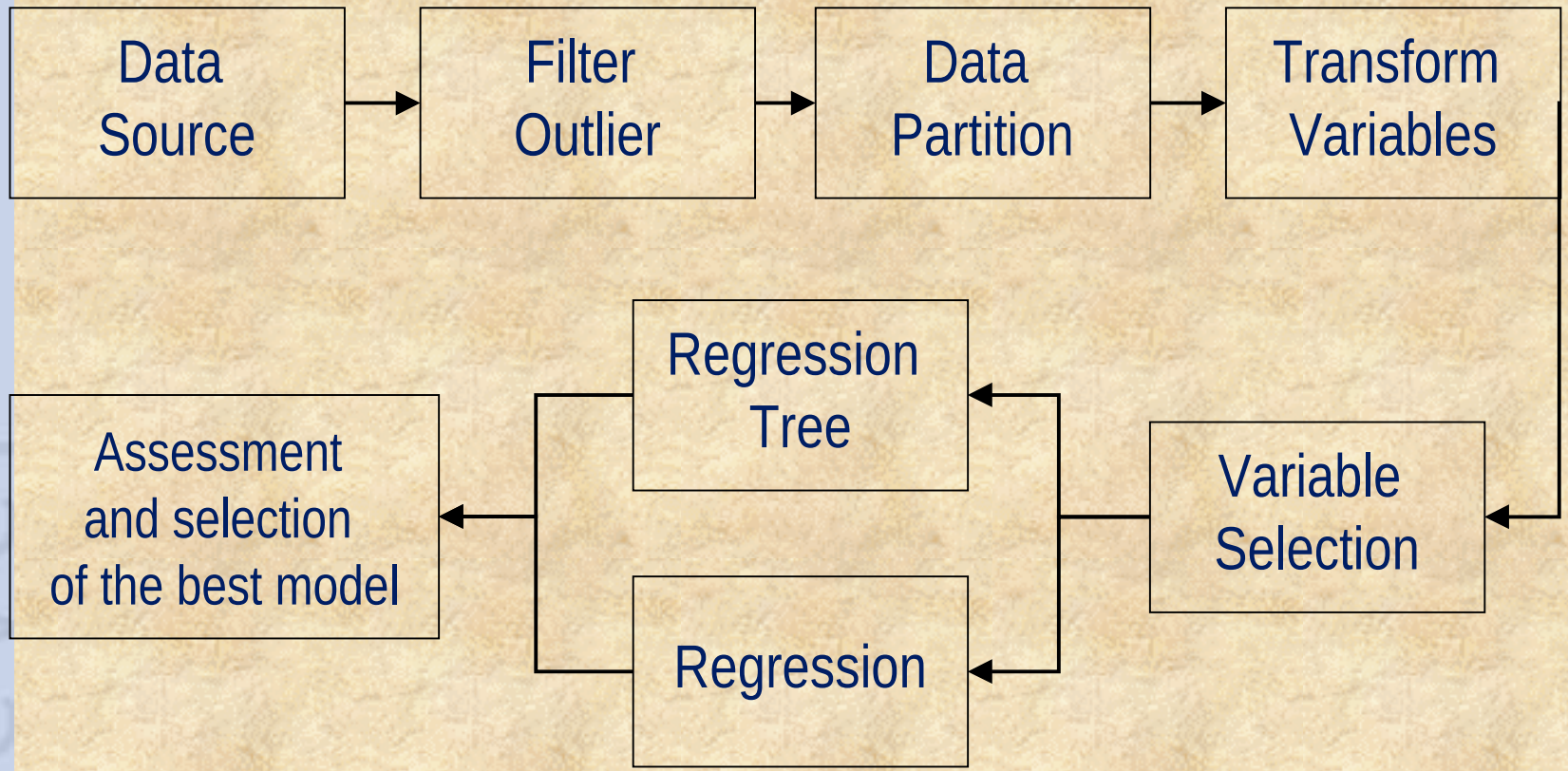
Data Mining work flow



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Experimental data: Variation of standard gate stack etch recipe

- Experimental data were obtained by variation of the standard gate stack etch recipe at LAM TCP on blanket test wafers to find correlations between plasma parameters and tool parameters
- Variation of
  - rf top power
  - rf bottom power
  - pressure
  - gas flow
- Separately for main etch and over etch
- Analysis w/ a second order approximation

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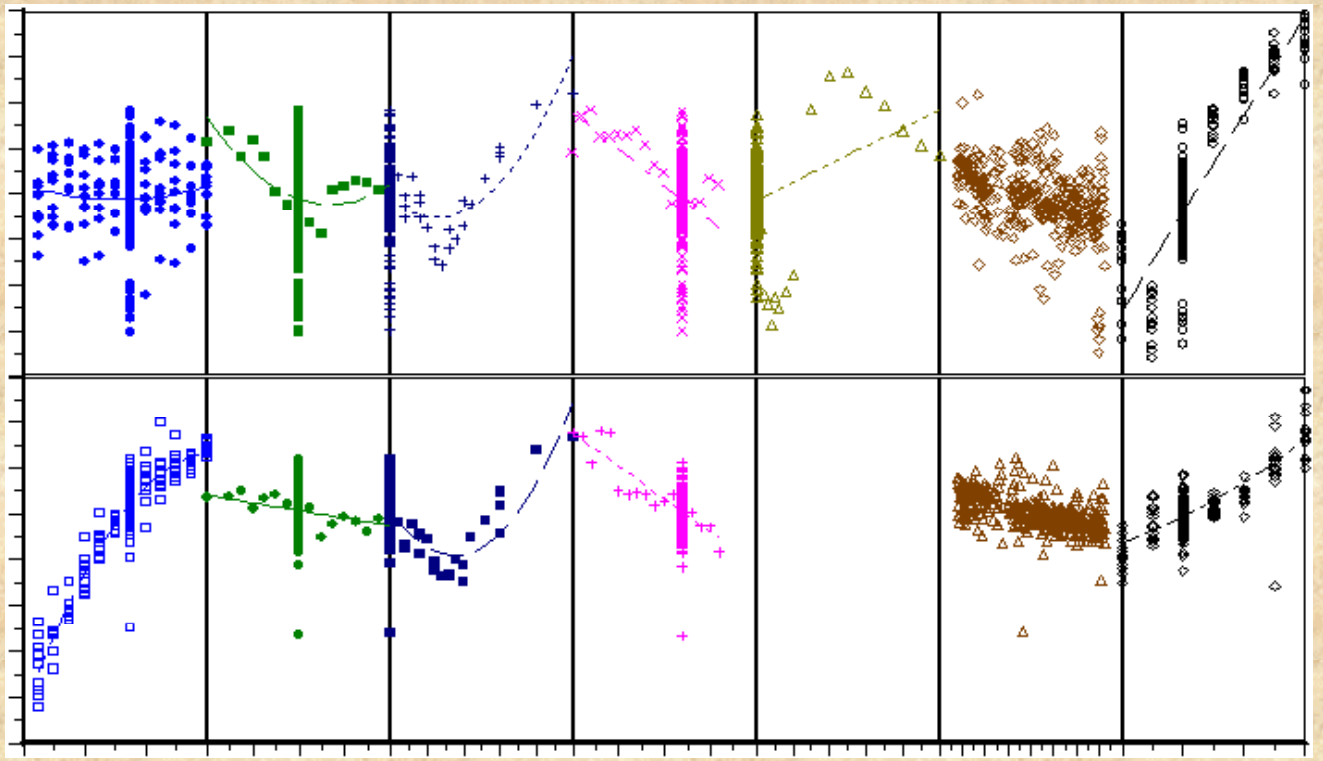
Gate stack main etch/experiment.data: Correlation between plasma and tool parameters



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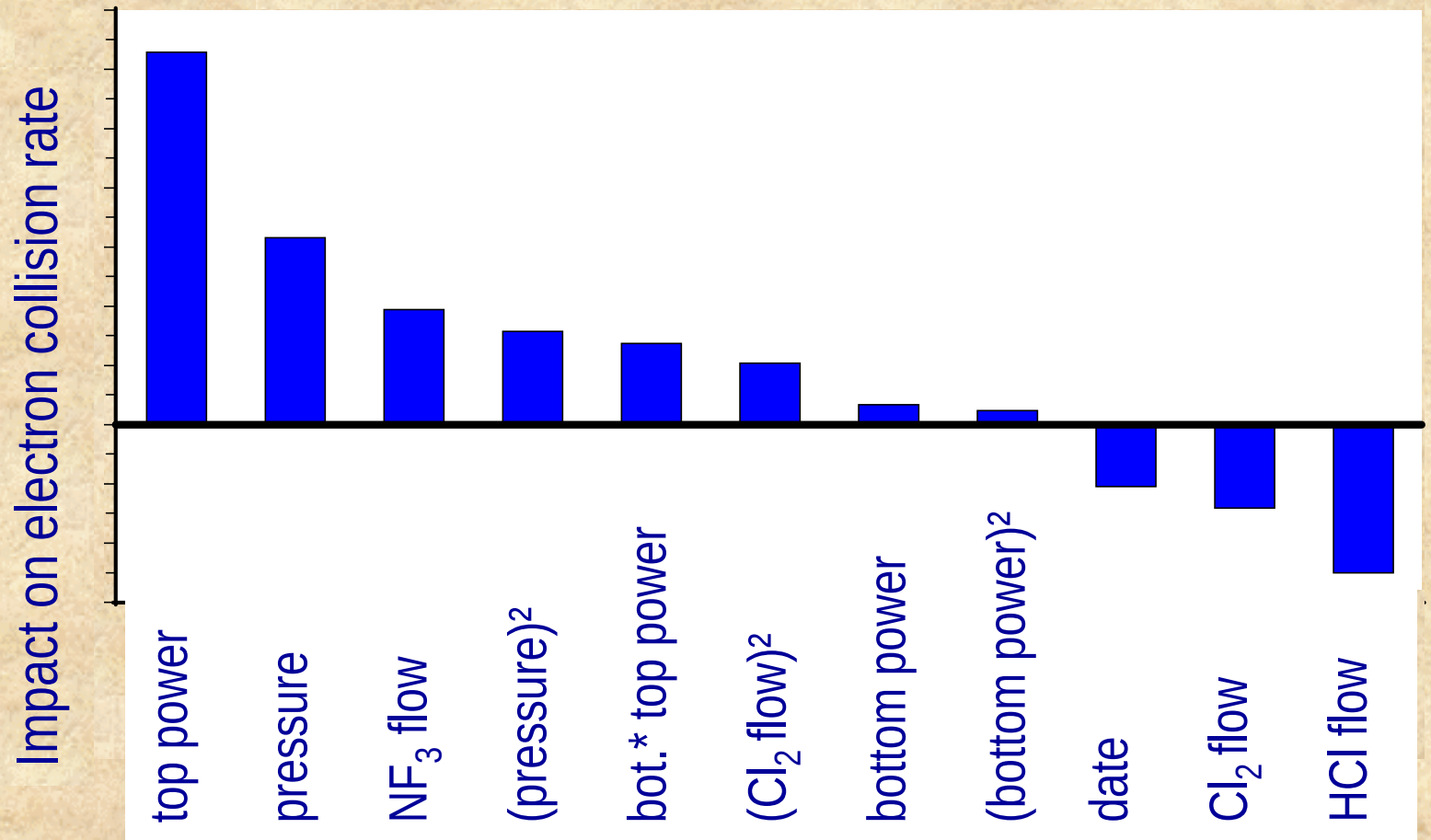
Gate stack main etch/experiment.data: Effects pareto

Effect Pareto for electron collision rate



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Discussion of experimental results

- Main impacts on electron collision rate
  - TCP top power
  - pressure
  - HCl flow
  - NF3 flow
- Main impacts on electron density
  - bottom power
  - TCP top power
  - pressure
  - HCl flow
- A significant drift of the chamber conditions during the experiments is indicated by
  - small, but significant impact of the date of the measurements
  - large variation of plasma parameter values at center experiment results
- This drift of the chamber conditions can be explained as an impact of not measurable input parameters on the complex process parameters electron collision rate and electron density

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Measurement of plasma parameters for gate stack etch on LAM TCP - historical data

- Historical data were obtained by measurement of plasma parameters at one LAM TCP chamber for more than 25.000 wafers of several DRAM and logic products
- Model based data analysis was performed for more than 4.000 wafers of one DRAM product to find correlations between
  - plasma parameters and tool parameters
  - plasma parameters, electrical data and yield
- During the period of these measurements a high and stable yield was achieved. The final electrical tests did not indicate any problem concerning the gate stack etch at the observed chamber

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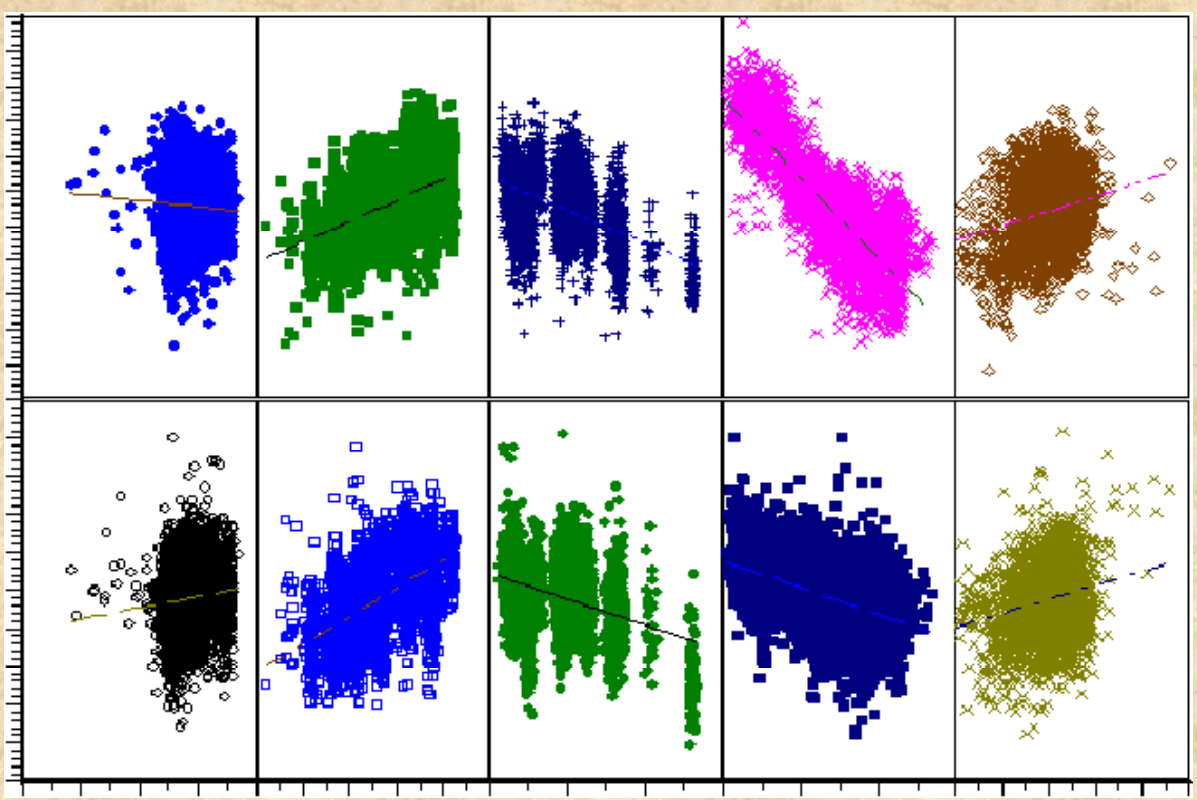
Gate stack main etch/hist.data: Correlation between plasma and tool parameters



bottom power match load | bottom power match tune | pressure | throttle valve position | top power match tune

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Discussion of results - historical data

- The historical data on product wafers discussed here were of course sampled keeping all measurable tool parameters constant.
  Process variations are caused by not measurable inputs.
  The tool tries to compensate these variations of input parameter, therefore drifts of measurable tool parameters occur
- Main correlations between tool parameters & plasma parameters are seen for:
  - throttle valve position and pressure
  - top power match tune and bottom power match tune
- For process monitoring a complex process parameter can be used instead of several tool parameters

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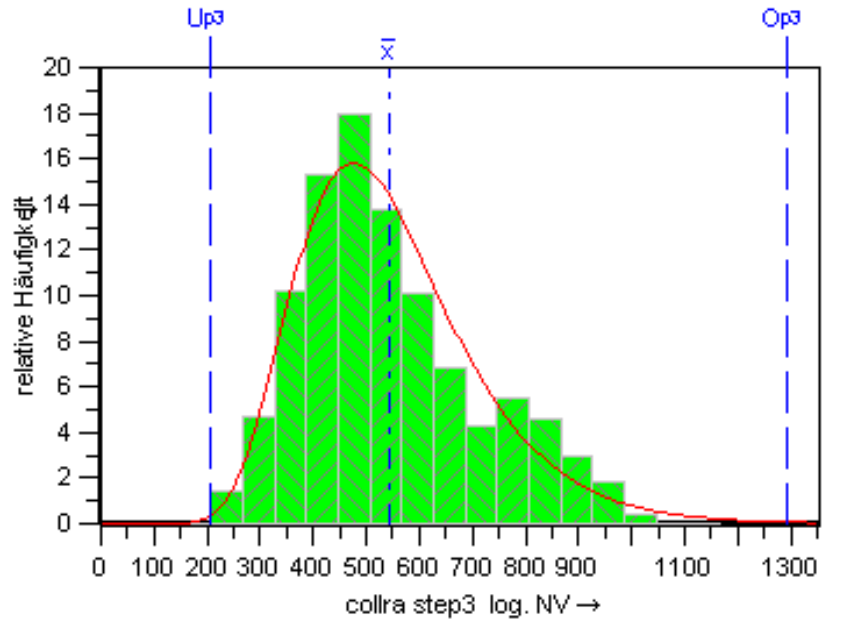
Main etch - calculation of control charts



- The values of the mean electron collision rate are not normally distributed
- Therefore a Pearson control chart was calculated

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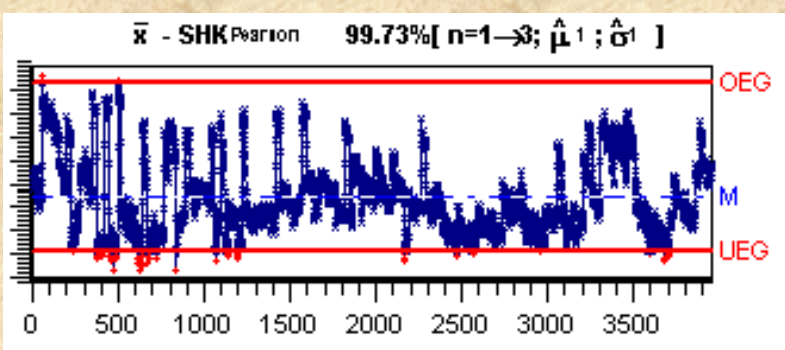
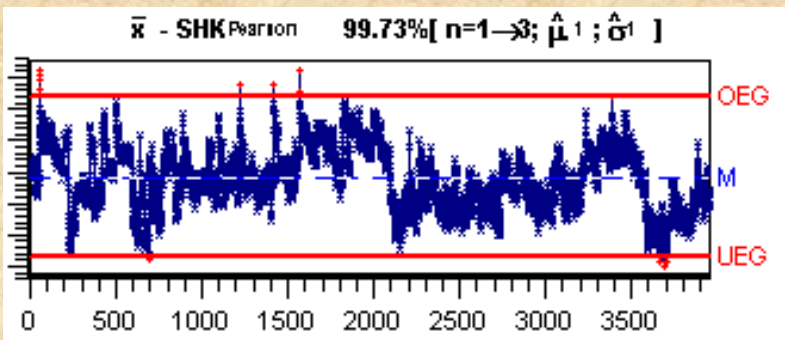
Gate stack etch: Control charts for electron collision rate and electron density

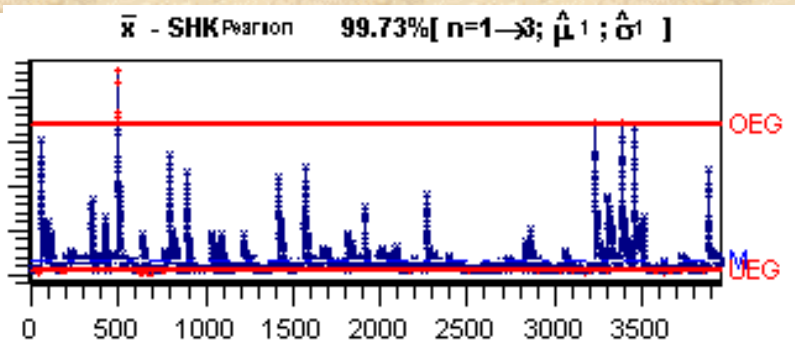
- The control charts must be calculated for main etch and over etch separately

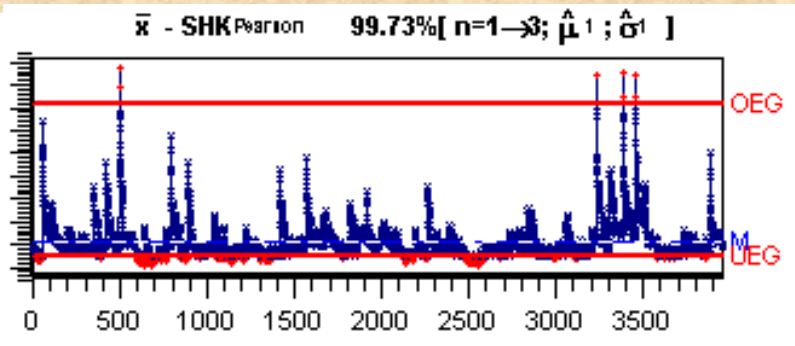
Main etch





Over etch





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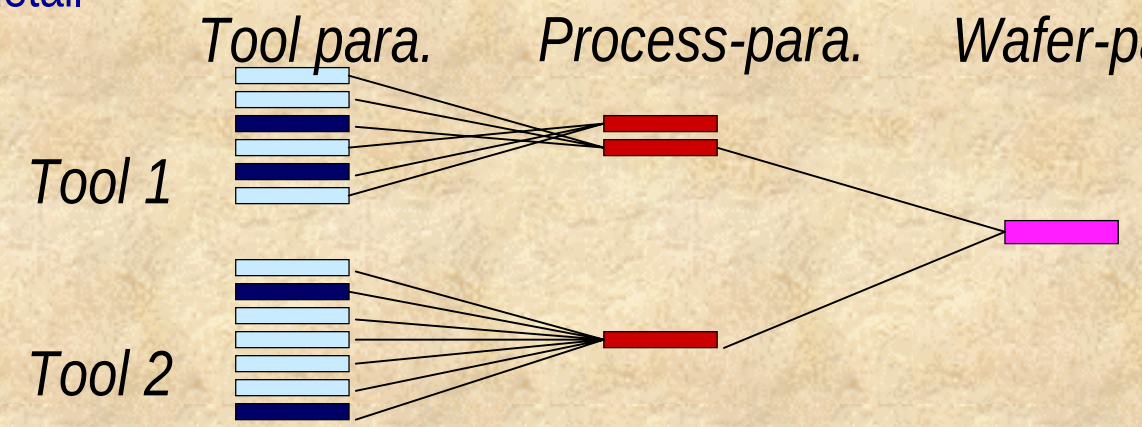
Extension of data sources

- The number of parameters, checked regularly at each tool or process, can be reduced by monitoring of complex process parameters, which indicate tool and wafer conditions, e.g. endpoint time or plasma parameters
- Stable values of these complex process parameters indicate stable process condition
- In case of process variations additional analysis of tool and wafer parameters is needed to identify the process change reasons in detail



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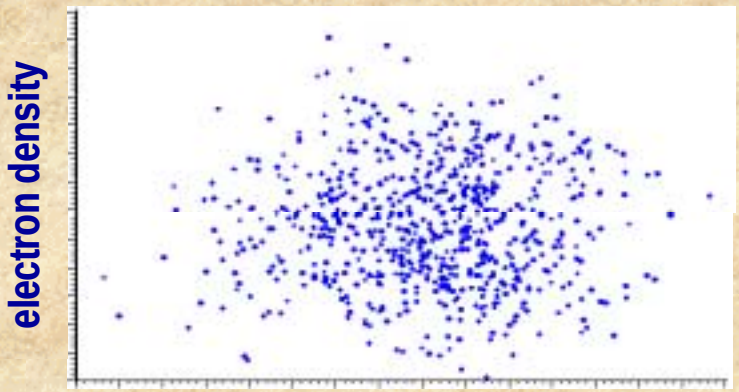
Gate stack main etch: Relationship between plasma parameters and gate contact width

electron density [mean] vs. gate contact width



- The gate contact width is calculated by electrical measurements
- Gate stack etch is an important influence on gate contact width
- The analysis of more than 4.000 wafers of one DRAM product did not show any significant correlation between plasma parameters and electrical data

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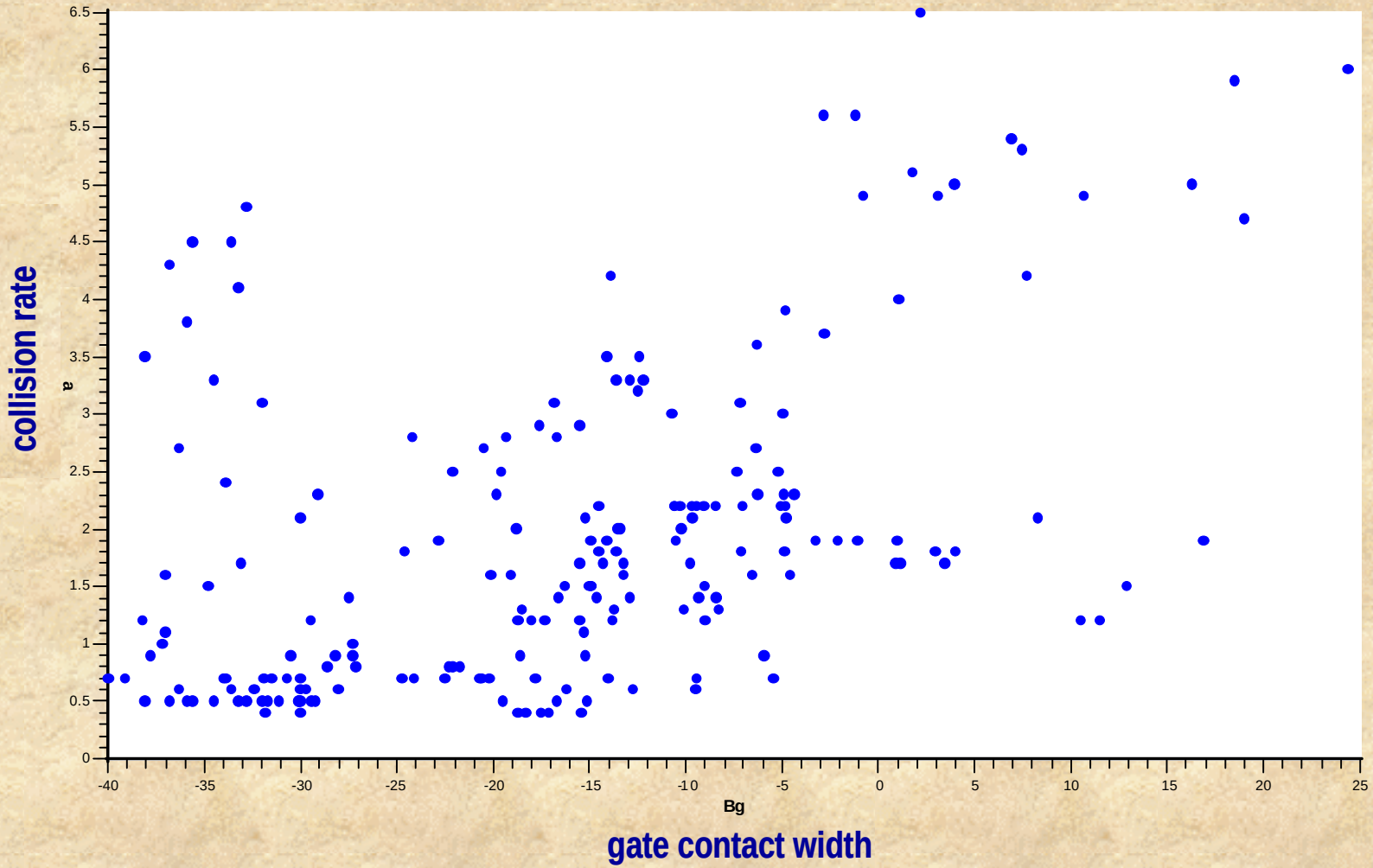
Correlation between plasma parameters and electrical data - example



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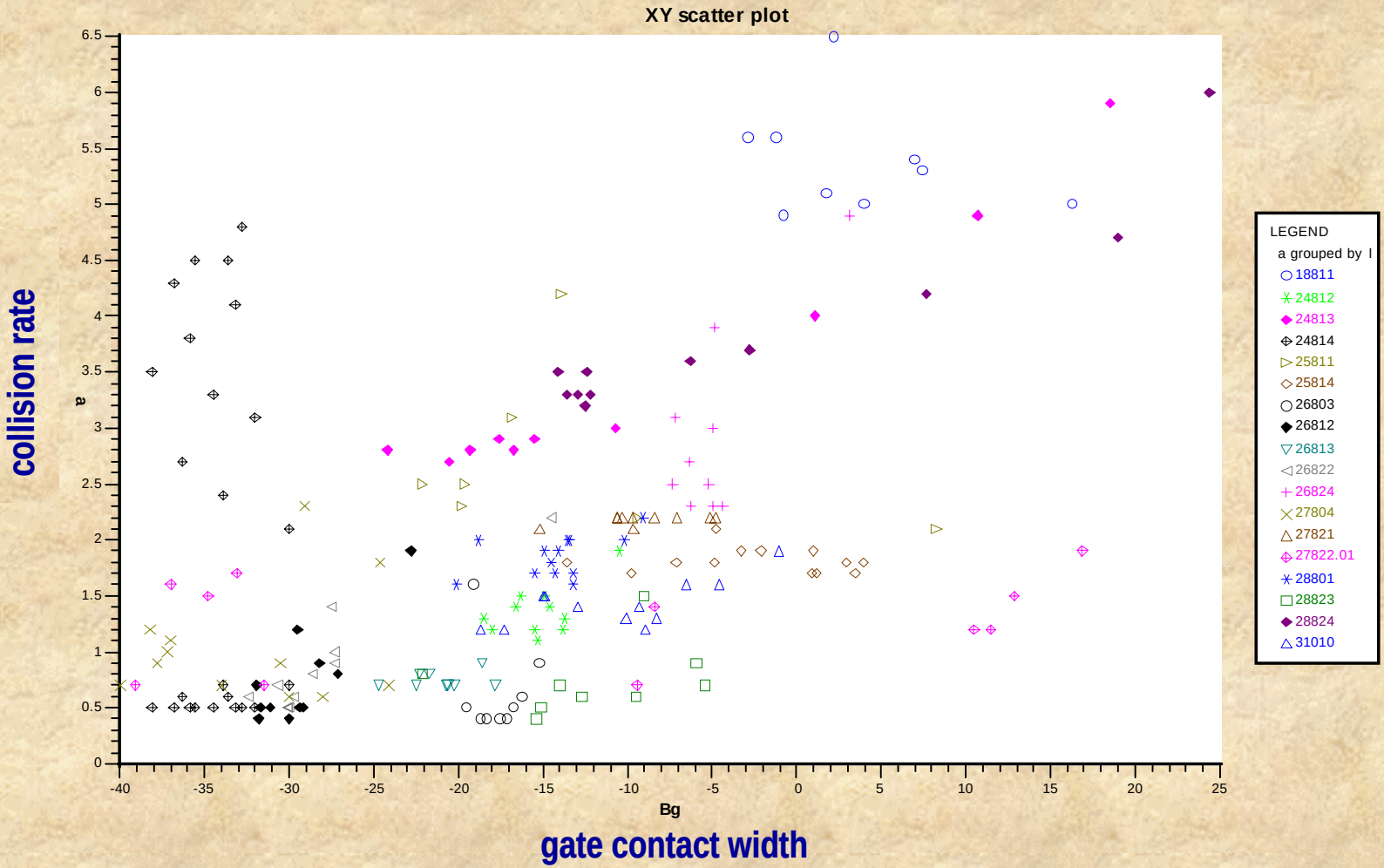
Correlation between plasma parameters and electrical data - example



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Conclusion

- Significant correlations between plasma parameters and tool parameters were detected for process variations on test wafers and during long term measurements on product wafers.
- During the measurement period high yield and stable electrical parameters were achieved. Significant correlations were not obtained between plasma parameters, electrical data, and yield.
- Conclusions: The process window for these products at this tool was large enough during the measurement period. The process runs well.
  - We observed the „normal noise“ of the process on that tool.
  - The measurement technique is very sensitive. We can expect significant signals in case of serious process problems.
  - Plasma parameters control charts supply alarm levels for real time monitoring of gate stack etch process at LAM TCP.

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