Wet Clean and Maintenance Monitoring of Plasma Etch Tools by Plasma Parameter Measurement

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Outline

- ☐ **Plasma parameter measurement by SEERS**
- ☐ Maintenance impact on process stability
- ☐ Development of algorithms for chamber clean classification and fault detection
- ☐ Application of algorithms on plasma parameter analysis
  for chamber clean monitoring and fault detection
- ☐ Correlation of plasma parameters to tool parameters and product parameters
- ☐ Summary and conclusions

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Plasma Parameter Measurement by Self Excited Electron Resonance Spectroscopy (SEERS)

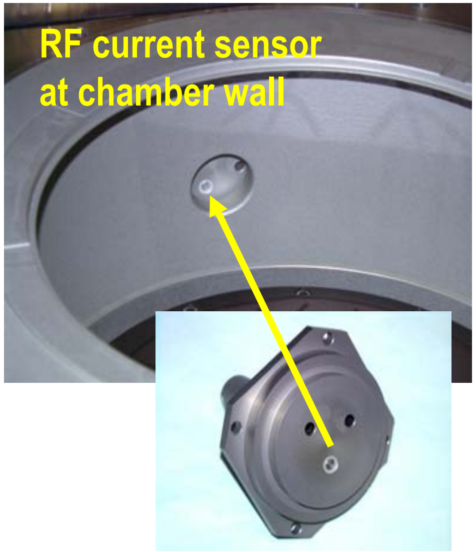
RF current & voltage measurement

↓

Real time calculation Model SEERS

↓

Plasma parameters



- up to 500 MHz
- Passive measurement → no impact on process

↓

- FFT up to 30th harmonics of 13.56 MHz
- Model border condition: capacitive dark space
- Calculation of mean values

↓

Mean values of:
- Electron Collision Rate [s^{-1}]
- Electron Density [cm^{-3}]
- Sheath Thickness
  → Plasma stability

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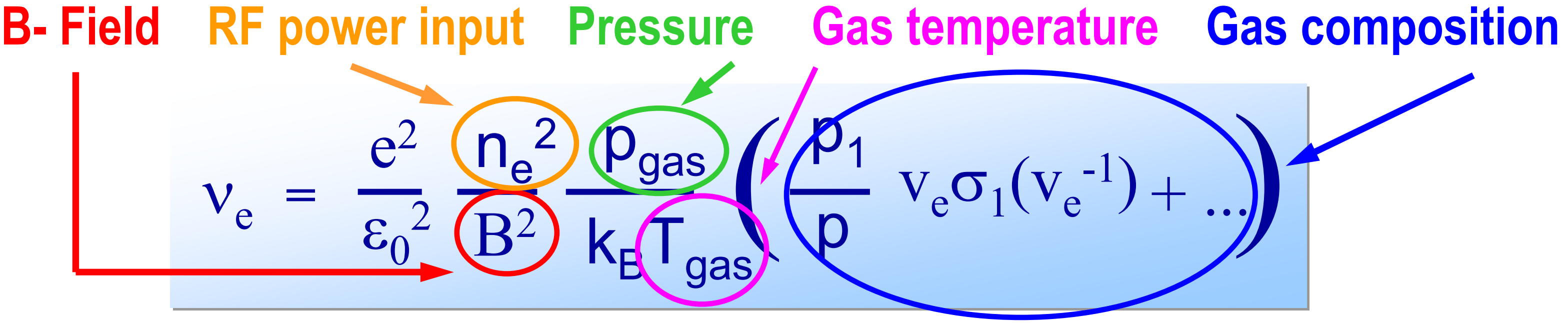
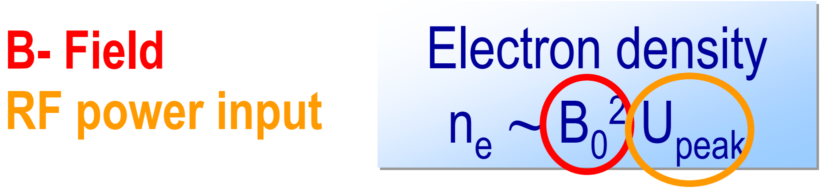
Plasma Parameters:
Key Indicators of Process Stability of Plasma Processes

Electron collision rate = Number of elastic and inelastic collisions of one electron in the plasma bulk with gas molecules per second



$$\nu_e = \frac{e^2}{\varepsilon_0^2}\,\frac{n_e^2}{B^2}\,\frac{p_{gas}}{k_B T_{gas}}\left(\frac{p_1}{p}\,v_e\sigma_1(v_e^{-1}) + \ldots\right)$$

Electron (Plasma) density = Number of free electrons in bulk per cm³



$$n_e \sim B_0^2 U_{peak}$$

- ❑ Plasma parameters indicate impacts on process conditions directly in the plasma
  - ➢ Easy to measure, e.g., MFC gas flow
  - ➢ Difficult to measure, e.g., RF power input
  - ➢ Not measurable, e.g. gas adsorption and desorption at chamber wall

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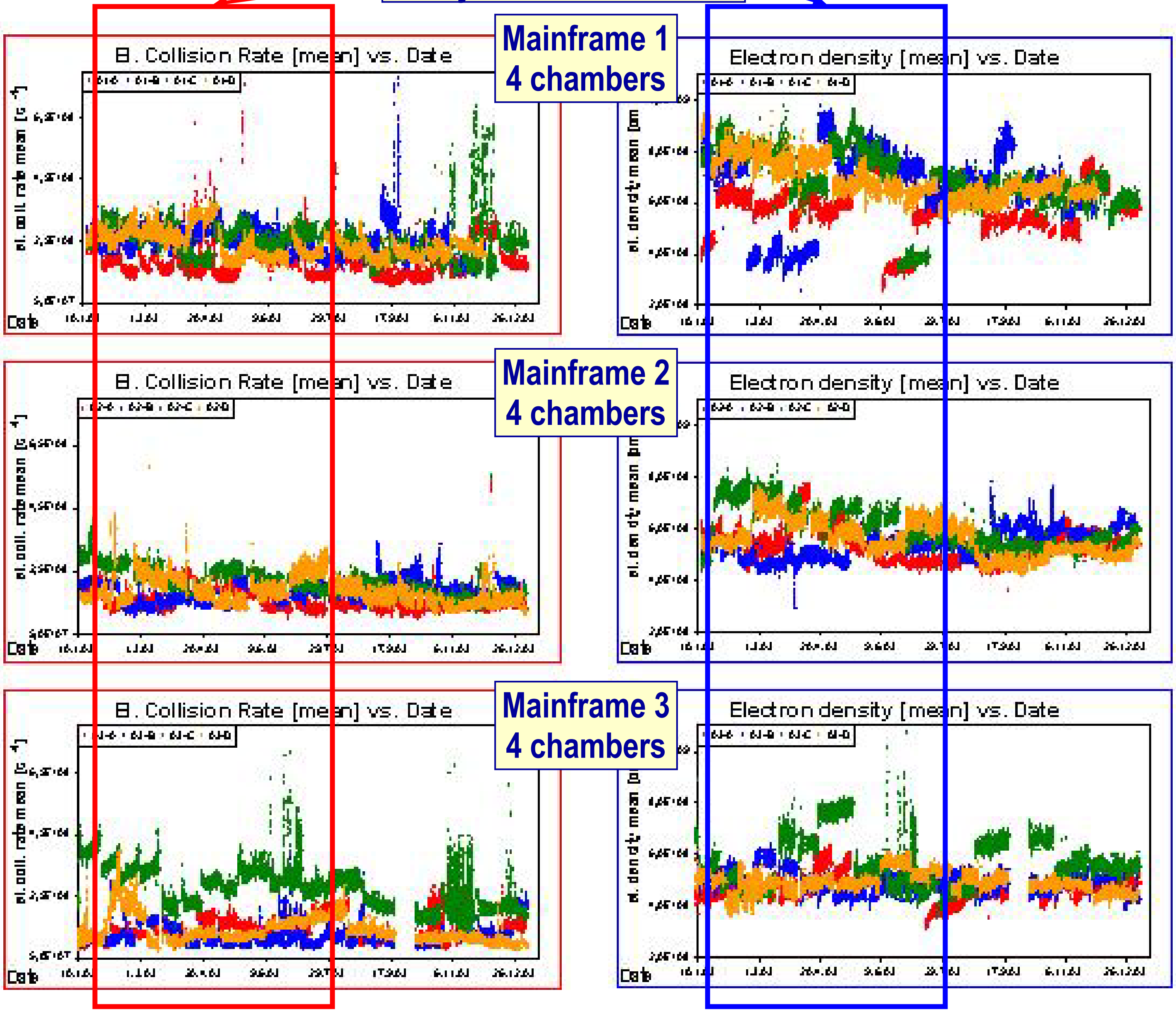
Example: Plasma Parameters in High Volume Production

about 237.100 wafers !



Analysed Measurements

Mainframe 1
4 chambers

Mainframe 2
4 chambers

Mainframe 3
4 chambers

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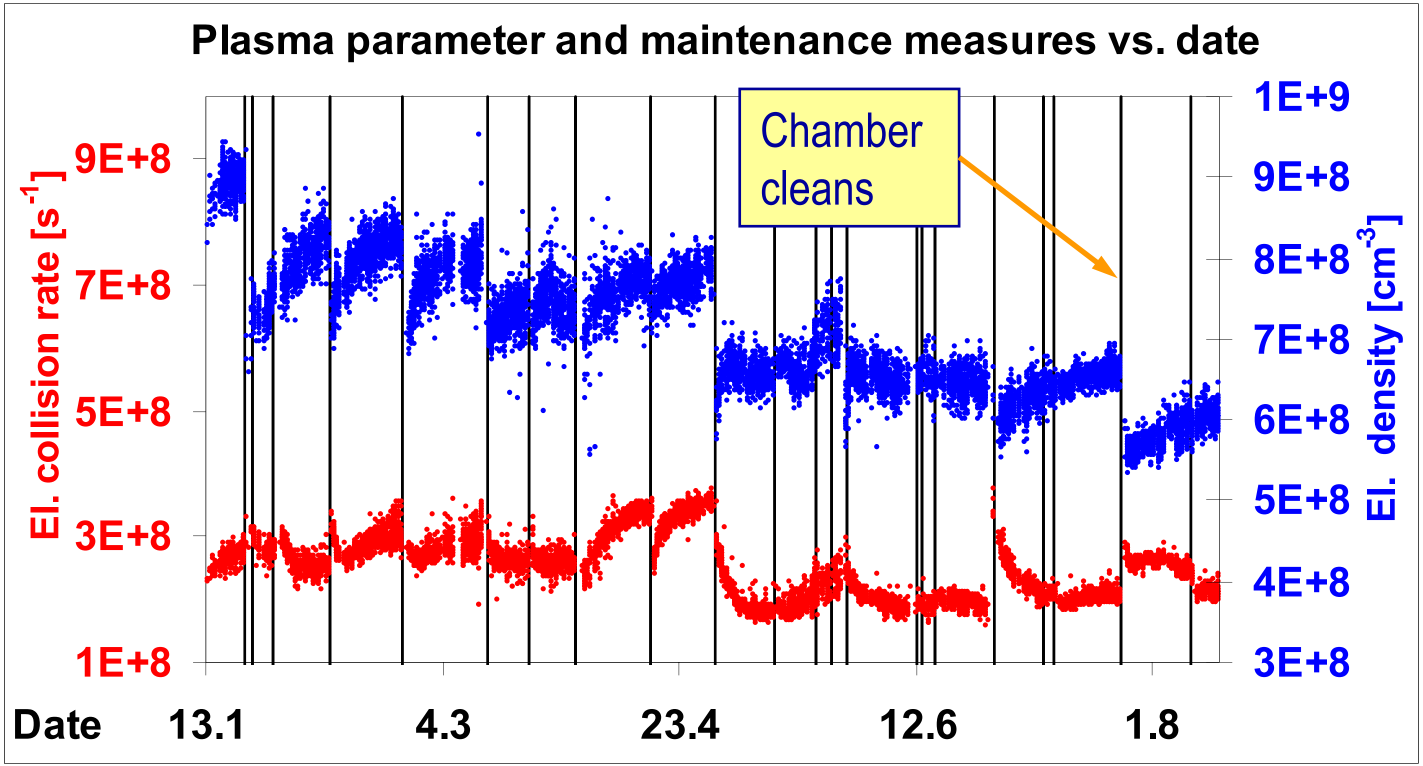
Maintenance Impact on Process Stability Indicated by Plasma Parameters



Plasma parameter and maintenance measures vs. date

- ❑ Superimposition of many impacts on process conditions in plasma:
  - ➢ Long term drift, e.g., tool degradation
  - ➢ Short term drift, e.g., chamber wet cleans and short cleans
- ❑ → Separation of impacts is necessary
- ❑ → Separate analysis of wet clean and short clean cycles

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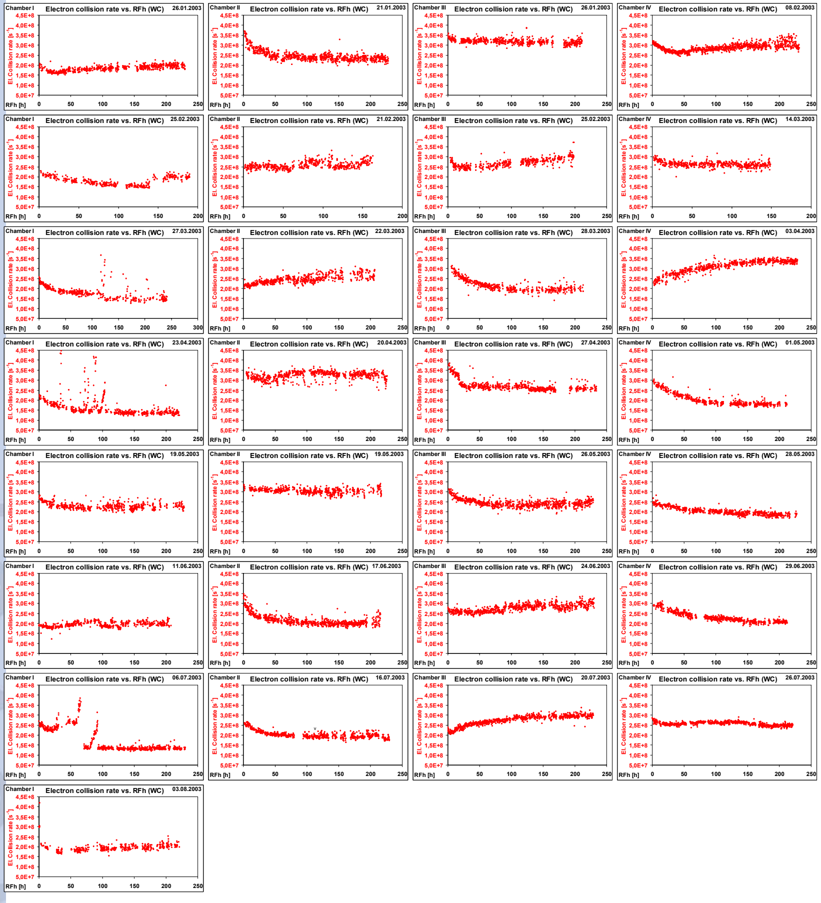
Electron Collision Rate and Plasma Density between previous Wet Clean and next Short Clean on Mainframe1

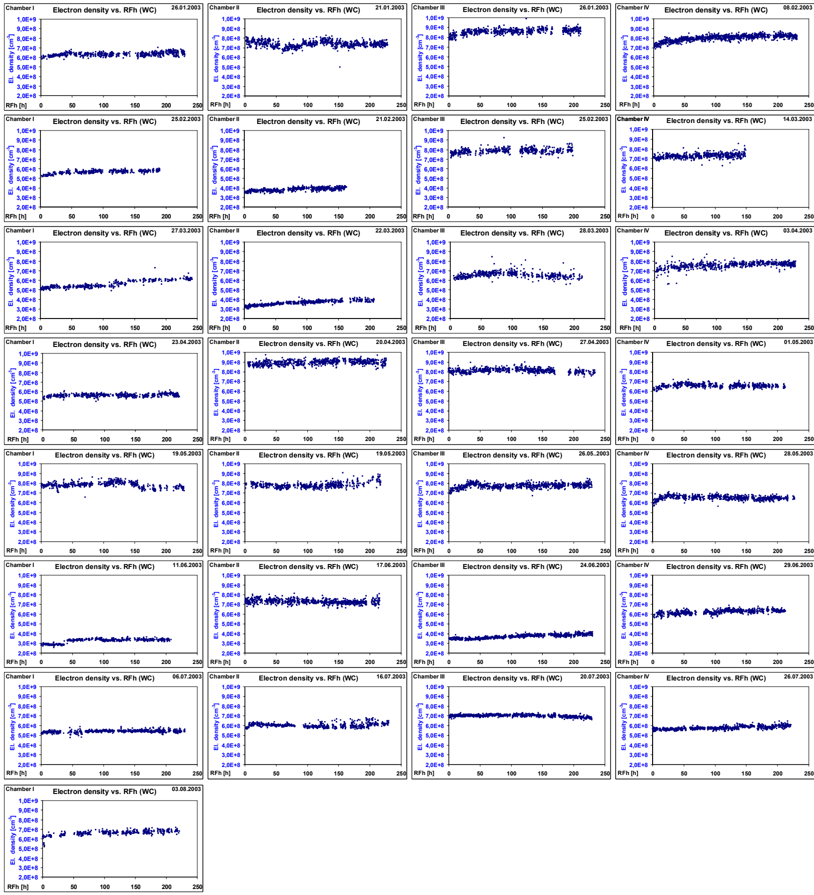
Electron collision rate

Ch I Ch II Ch III Ch IV



Electron density

Ch I Ch II Ch III Ch IV



- Varying impact of chamber cleans on process conditions is indicated by plasma parameters

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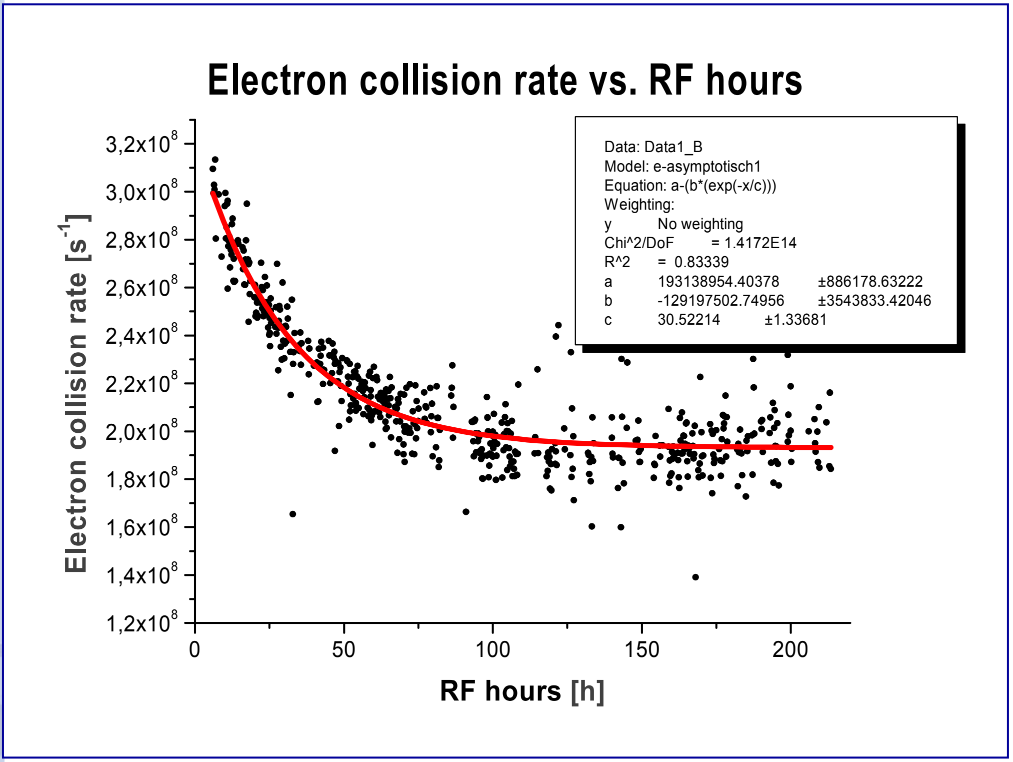
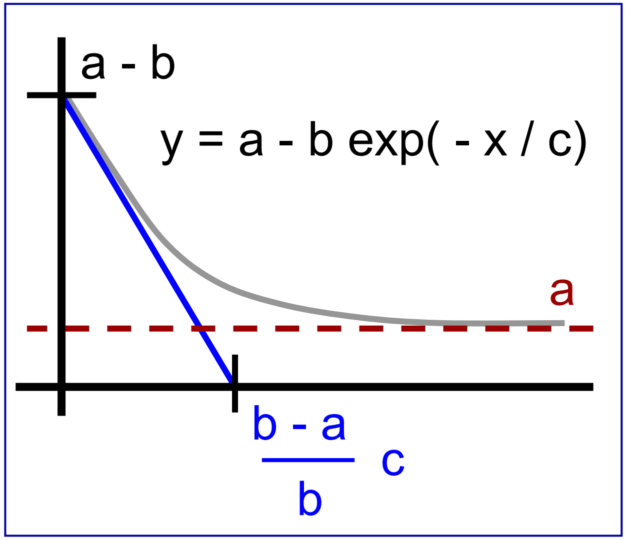
First Algorithm: Exponential Function Fit



```
Data: Data1_B
Model: e-asymptotisch1
Equation: a-(b*(exp(-x/c)))
Weighting:
y          No weighting
Chi^2/DoF         = 1.4172E14
R^2       =  0.83339
a          193138954.40378        ±886178.63222
b          -129197502.74956       ±3543833.42046
c          30.52214          ±1.33681
```



a - b → initial value
a → final value
b / c → initial slope

- ❑ Fit by simple exponential function
- ❑ → Automatic characterization and classification of parameter drift after chamber clean by 3 coefficients
- ❑ **The coefficient [(b - a) / b] * c describes the time needed to approach stable process conditions.**

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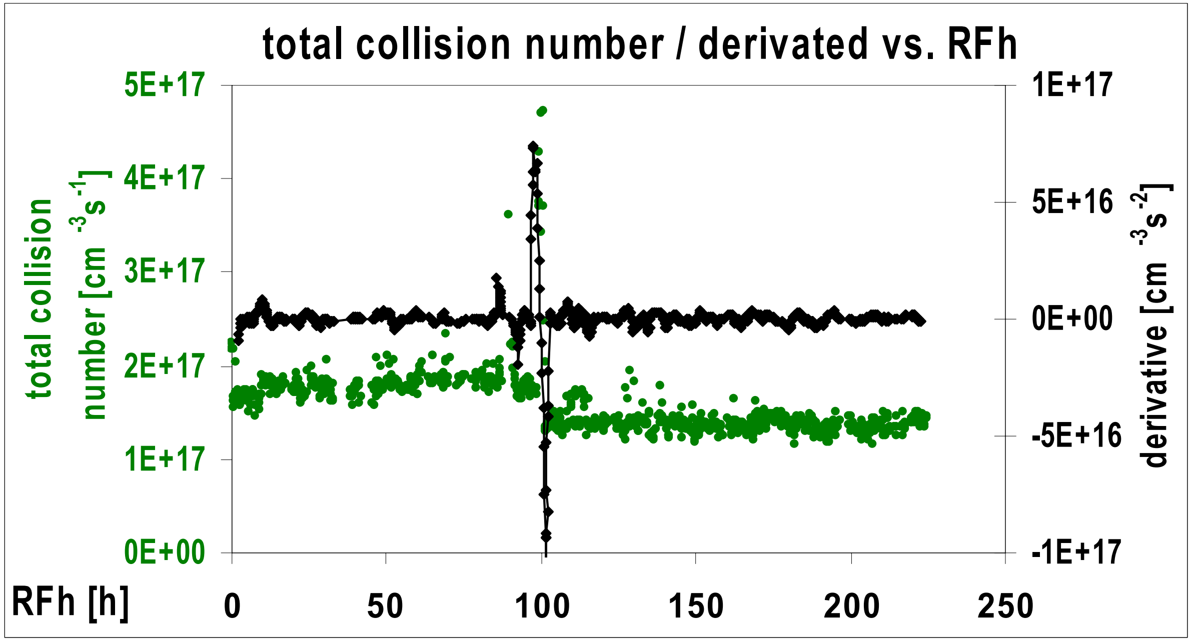
Second Algorithm: Numerical Differentiation



- Numerical differentiation after Gaussian regression
  - Separation of long and medium term drift from short term parameter variation
  - Adjustable sensitivity
  - Elimination of single outliers

$$m = \frac{n\left(\sum_{i=1}^{n} x_i y_i\right) - \left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} y_i\right)}{n\left(\sum_{i=1}^{n} (x_i)^2\right) - \left(\sum_{i=1}^{n} x_i\right)^2}$$

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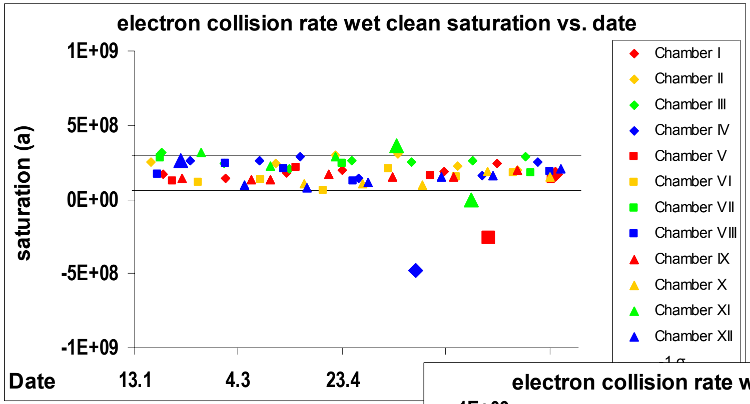
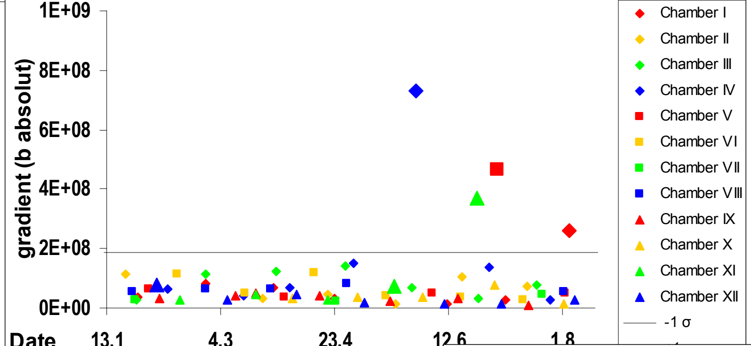
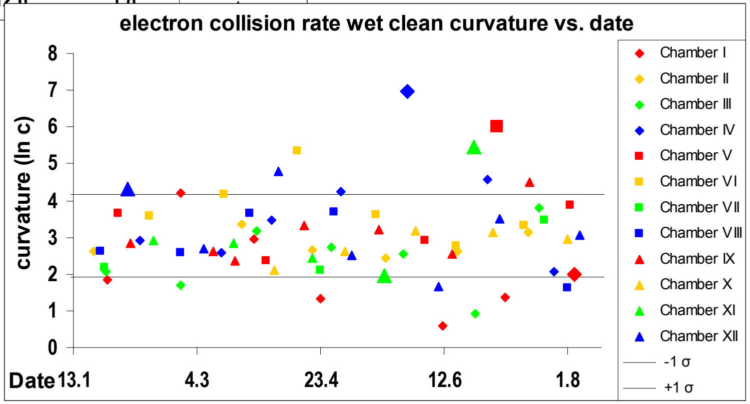
Exponential Fit: Overview of Parameter Plots for Electron Collision Rate and Electron Density







- Exponential fit parameter outliers indicate abnormal drift of process conditions after chamber clean

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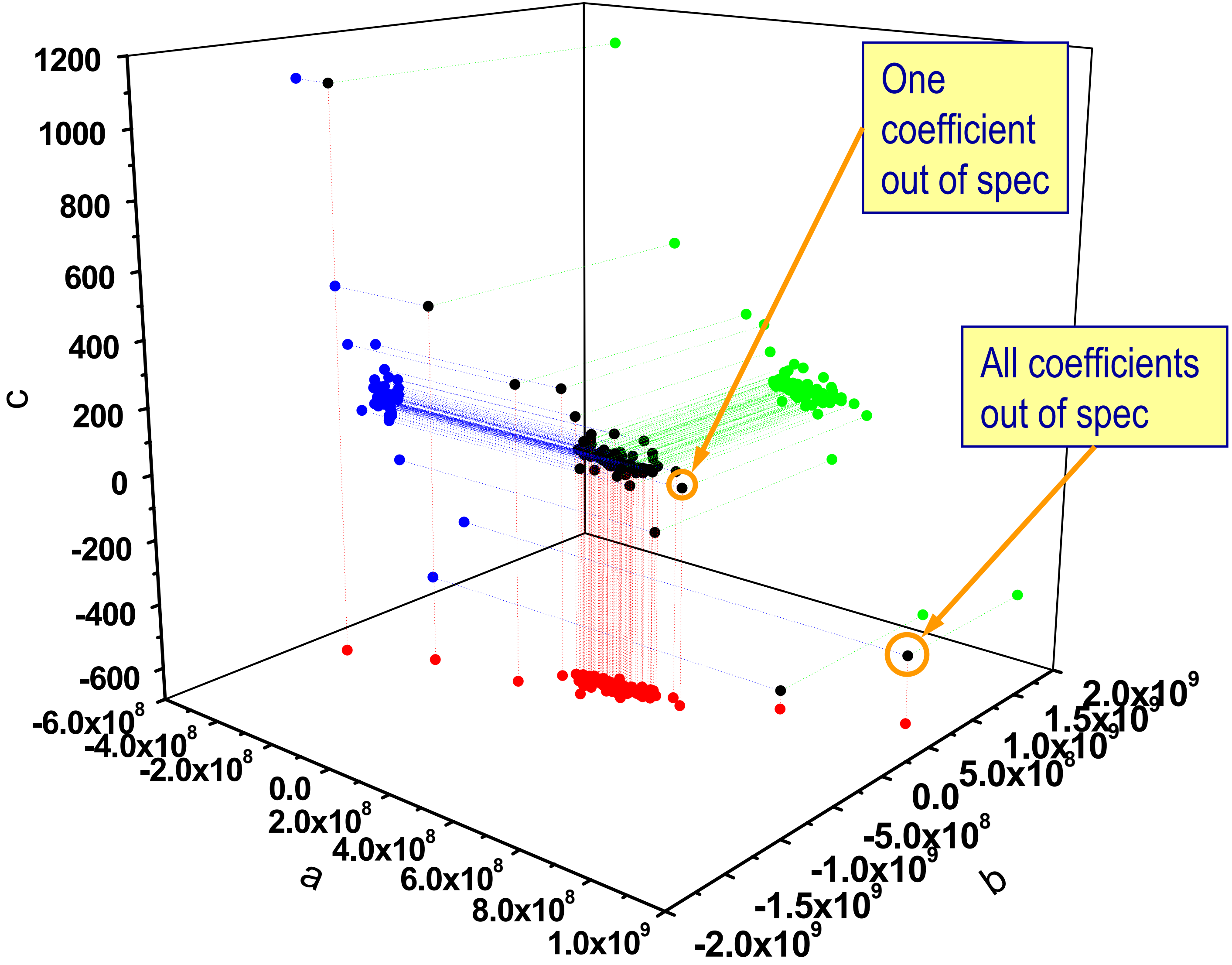
Exponential Fit: 3D Plot of Parameters for Electron Collision Rate and Electron Density



One coefficient out of spec

All coefficients out of spec

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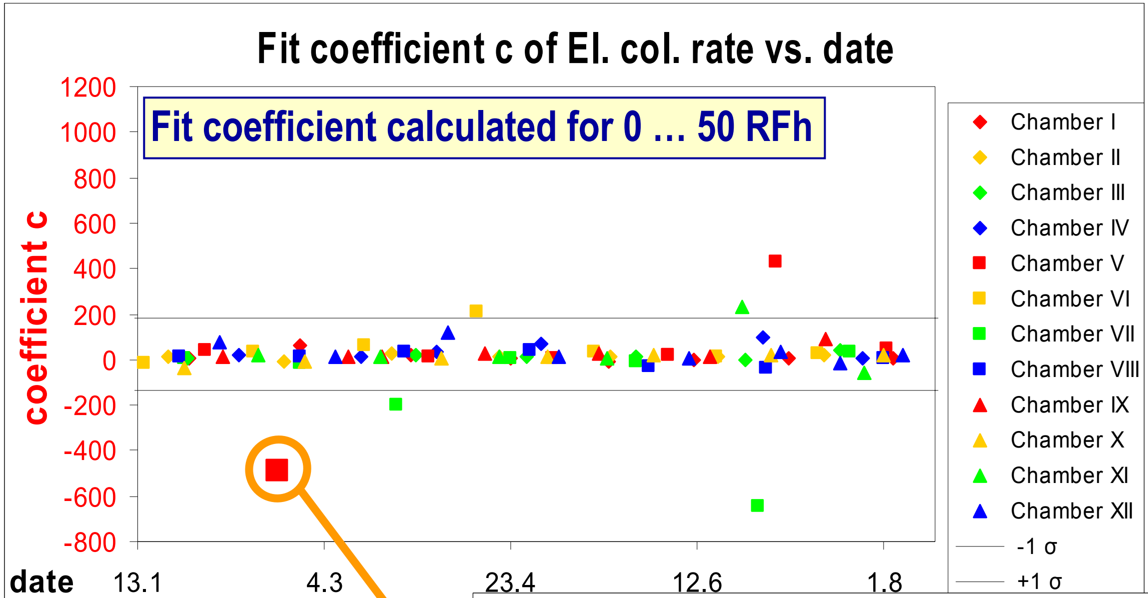
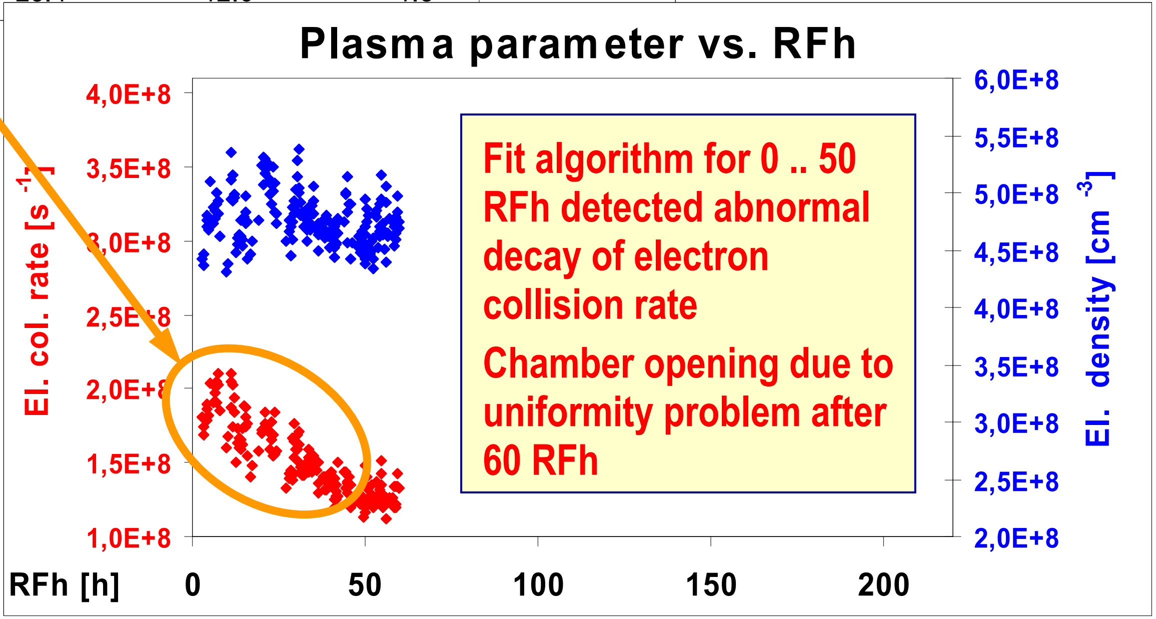
Exponential Fit: Example of Fault Detection by Automatic Wet Clean Classification



- ❑ Fit algorithm detected abnormal electron collision rate drift after 50 RFh
- ❑ Uniformity problem on test wafers detected after 60 RFh

Root cause of uniformity problem after wet clean: asymmetric degradation of quartz ion shield ring



Fit algorithm for 0 .. 50 RFh detected abnormal decay of electron collision rate

Chamber opening due to uniformity problem after 60 RFh

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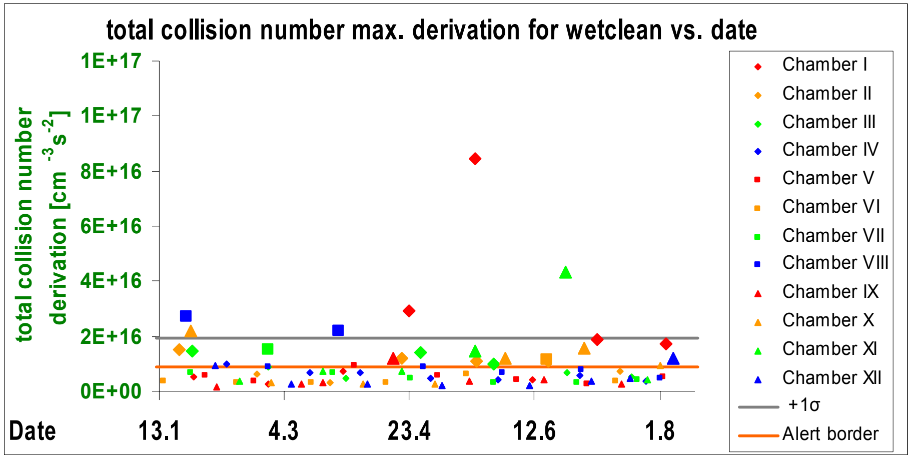
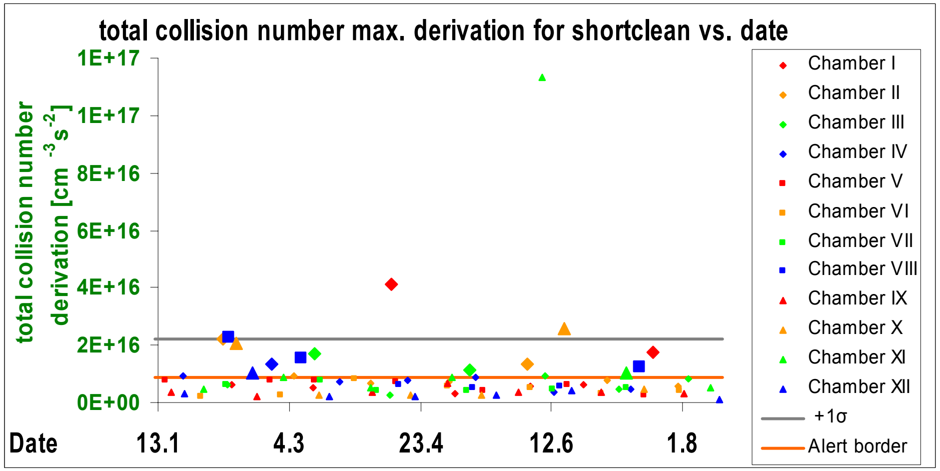
Numerical Differentiation: Example of Parameter Plots





- ☐ Coefficient of numerical derivation indicates short term variations of plasma parameters

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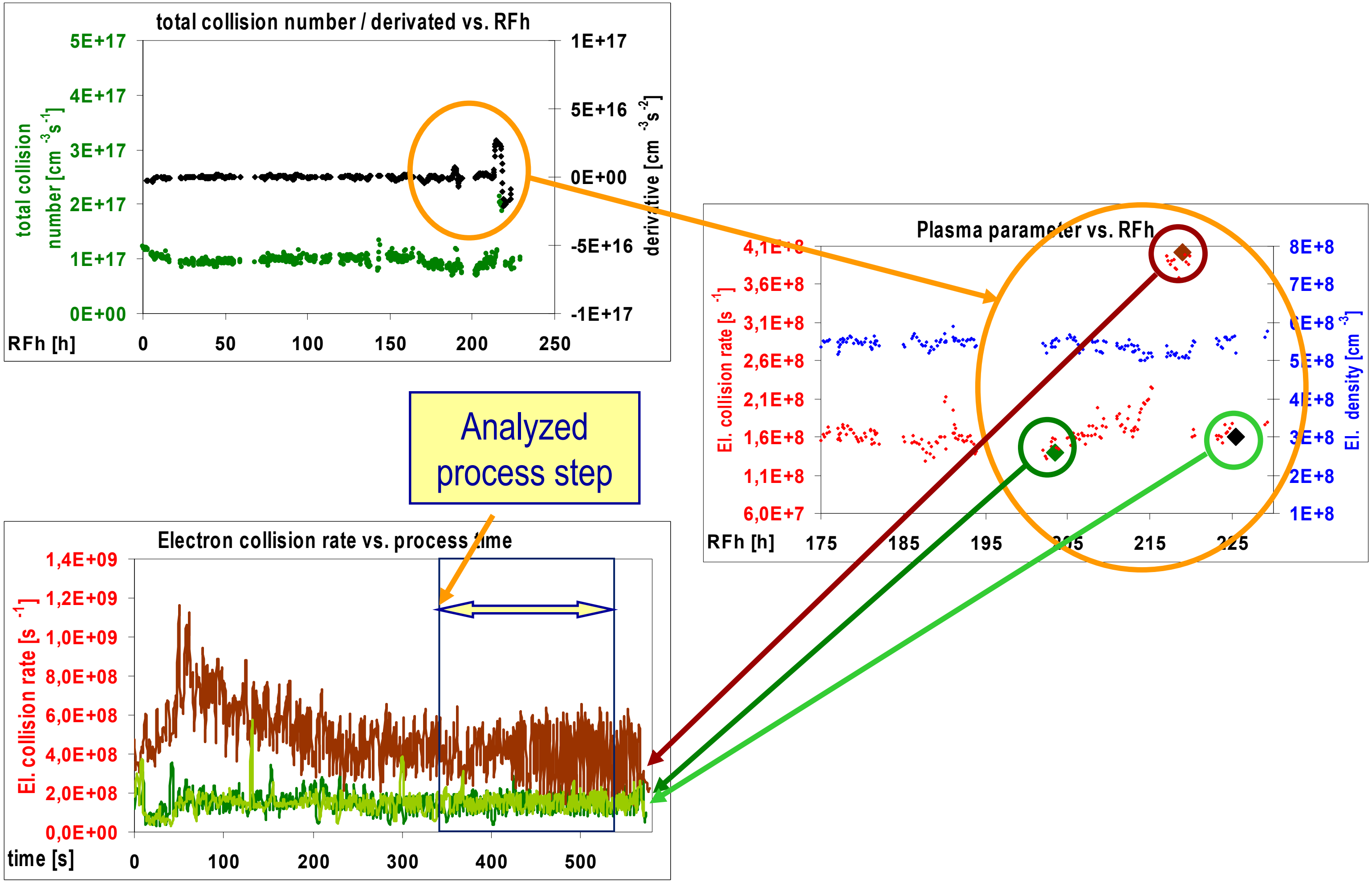
Numerical Differentiation:
Example of Fault Detection - Arcing



Analyzed process step

Arcing at e-chuck and liner was detected only through numerical differentiation of plasma parameters

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Automatic Fault Detection by Numerical Differentiation and Fault Classification by Raw Data Analysis - 1

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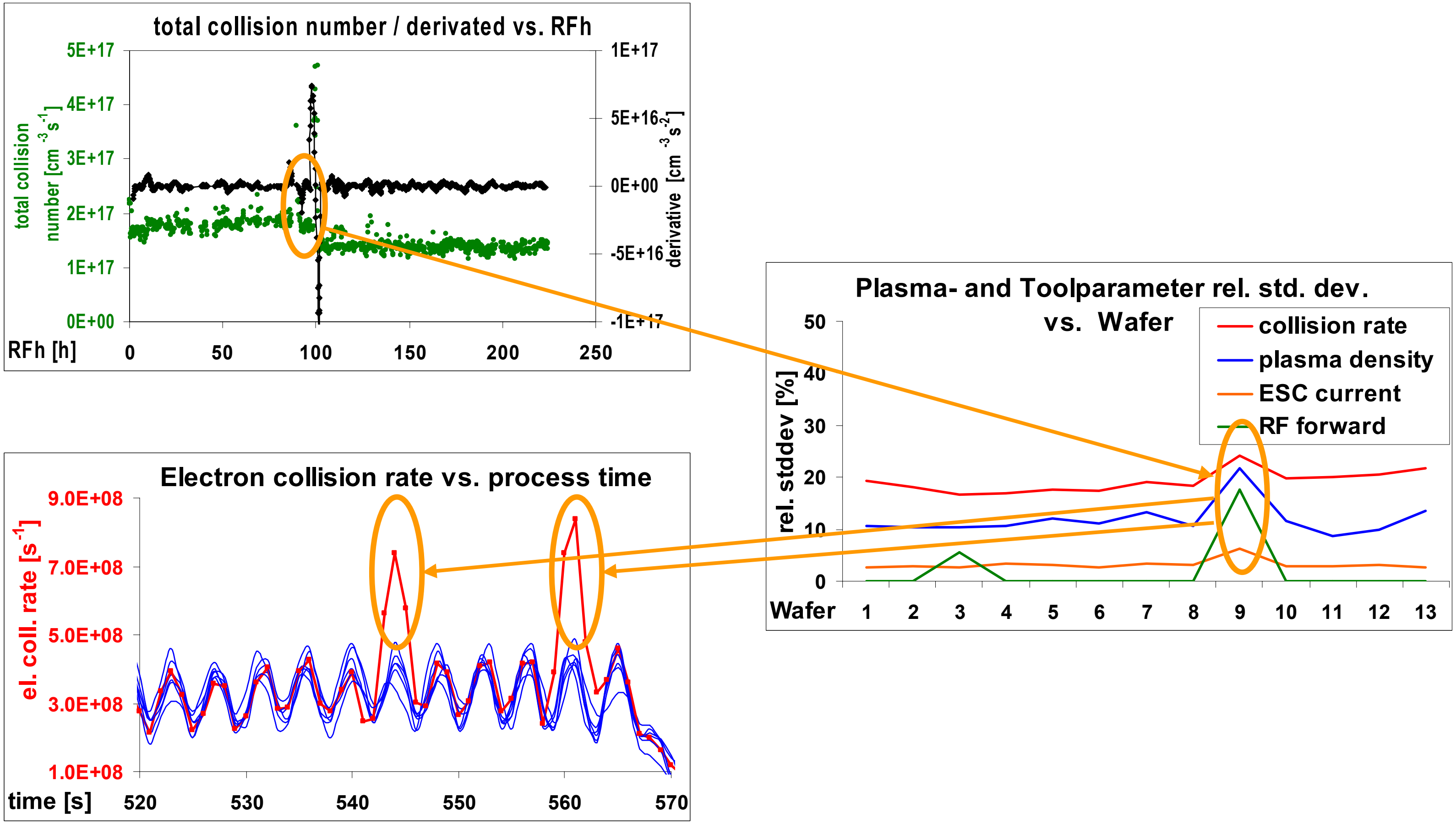
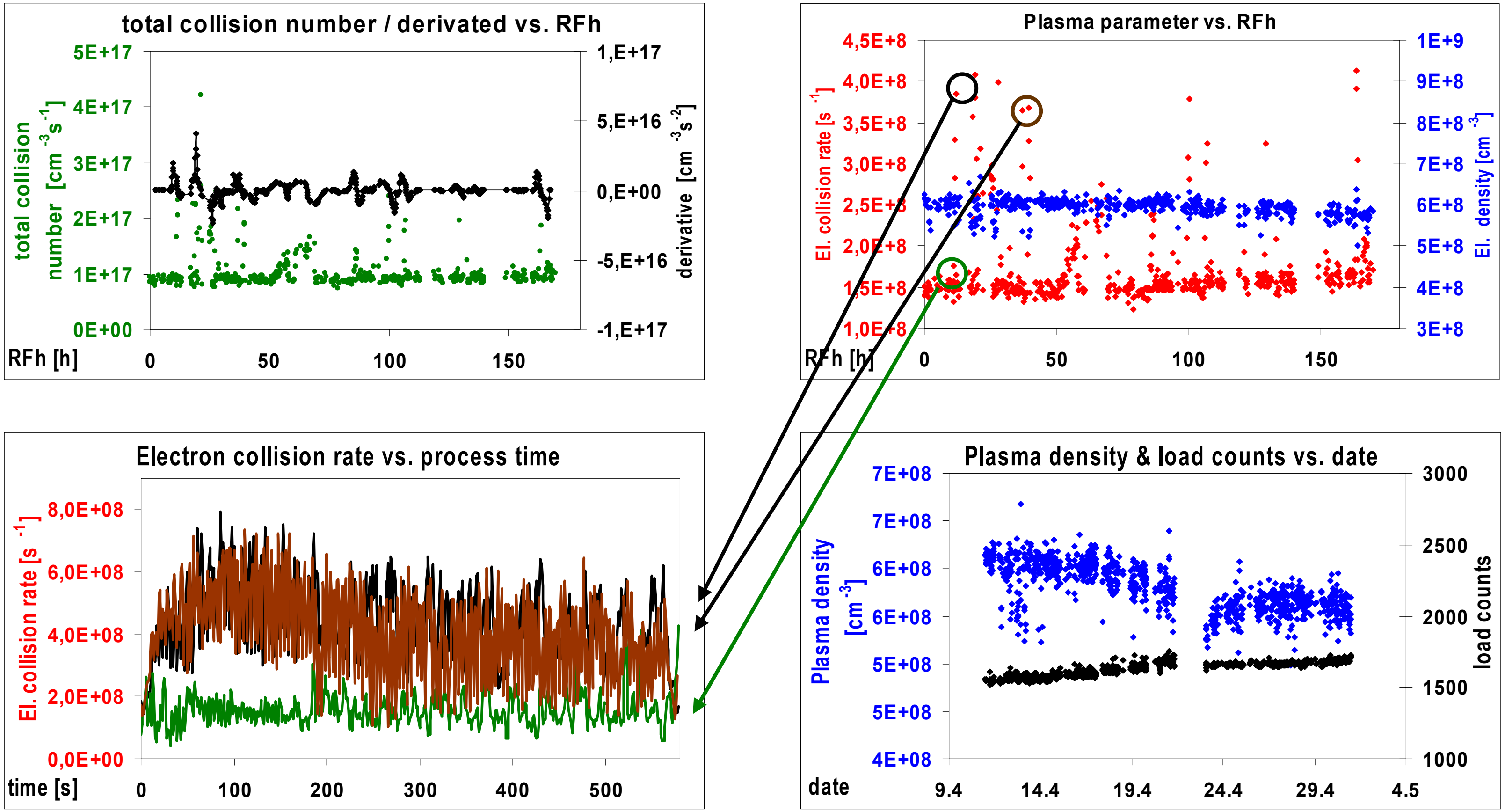


- ❑ Early fault detection and identification of a generator fault.

Automatic Fault Detection by Numerical Differentiation and Fault Classification by Raw Data Analysis - 2



- Variation of electron collision rate mean values indicated instable process, estimated reason: arcing. Load capacitor drift indicated impedance drift caused by low cooling fluid resistivity.
- Plasma parameter & impedance drift normalized after DI cartridge change.

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Results of Chamber Clean Analysis by Exponential Fit of Plasma Parameters

- Results of chamber clean analysis by exponential fit of plasma parameters
  - Asymmetric degradation of quartz ion shield ring
  - RF match exchange
  - Electrostatic chuck exchange
  - Gas composition drift
  - B- field calibration problems
  - Baratron® calibration problems
- Results of chamber FDC by numerical differentiation of plasma parameters
  - Arcing
  - Early RF generator fault detection
  - Low resistivity of cooling fluid in cathode cooling line
  - Detection of a defect DAC card in Plasma Monitoring System Hercules APC®

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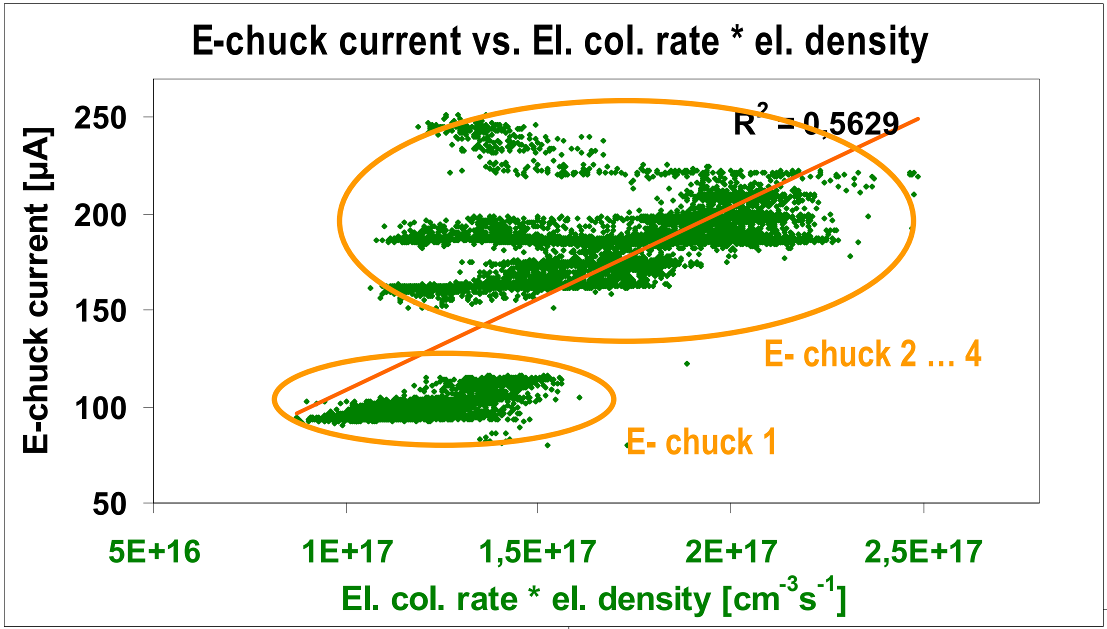
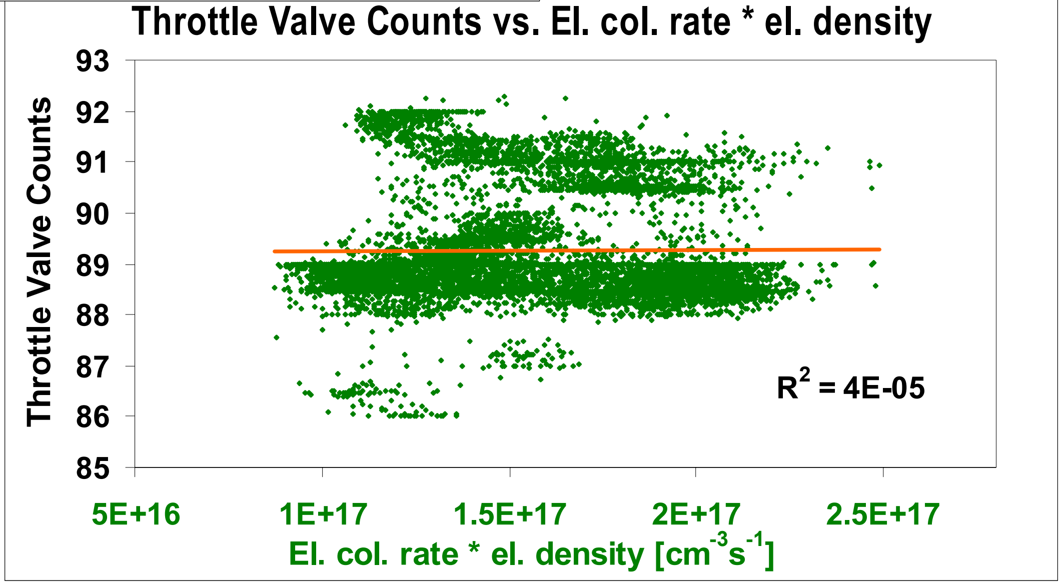
Correlation Between Plasma Parameters and Tool Parameters



- Questionable correlation between e- chuck current and electron collision rate * plasma density
- Clustering caused by chamber cleans and e- chuck exchanges



- No correlation between throttle valve position and electron collision rate * plasma density
- → Chamber pressure is stable enough for the investigated process.

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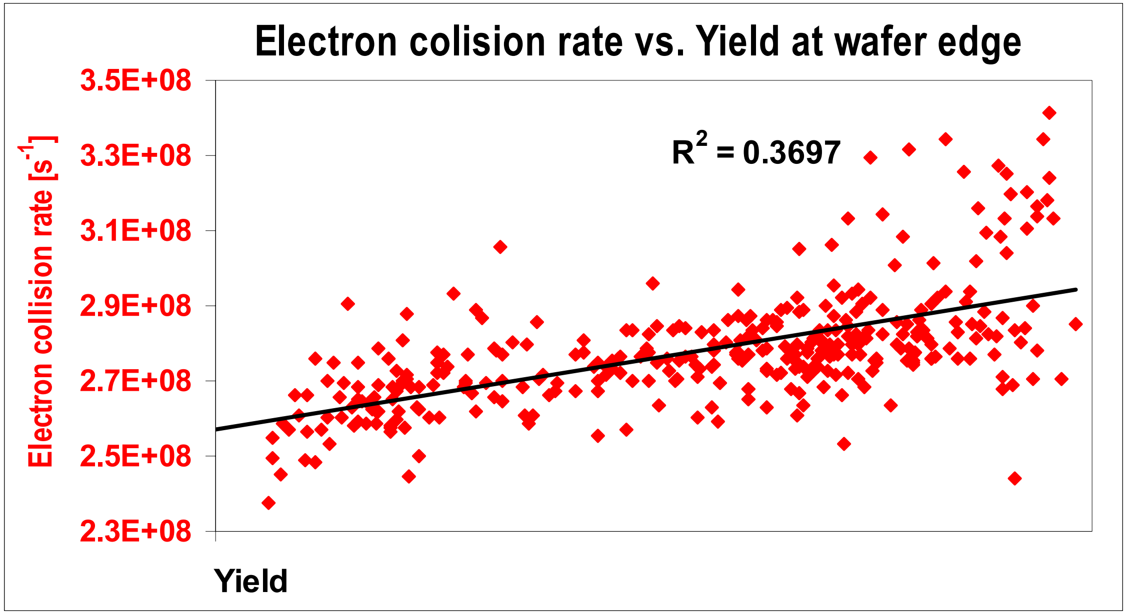
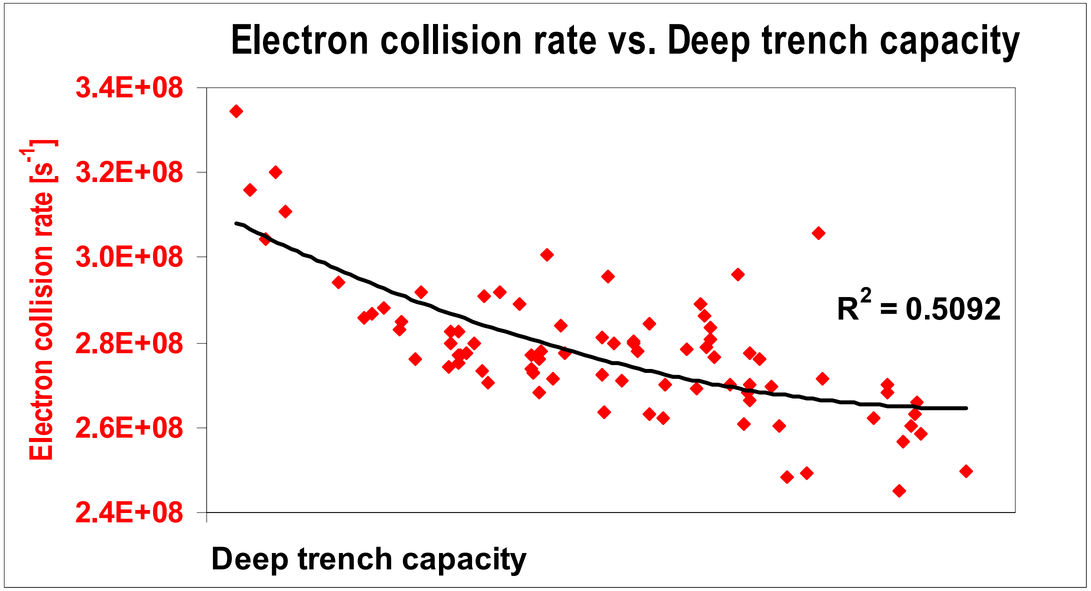
Correlation of Electron Collision Rate to Electrical Product Parameter and Yield


Electron colision rate vs. Yield at wafer edge

Significant correlation of electron collision rate to deep trench capacity and yield at wafer edge.

Electron collision rate is suitable to indicate process impacts on product parameters and yield in real time.


Electron collision rate vs. Deep trench capacity

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Summary and Conclusions

- ❑ The goal of this diploma thesis was the development of easy to use methods to monitor chamber cleaning and for fault detection of plasma etching.
- ❑ Plasma parameters, e.g., electron collision rate and plasma density, are suitable to characterize the tool of plasma etching, the plasma itself, directly.
- ❑ Exponential fit and numerical differentiation were applied on plasma parameter measurements on about 125.000 wafers.
- ❑ As a result significant hardware impacts on process stability were found, tool faults were identified and scrapped wafers can be avoided.
- ❑ Correlations of plasma parameters to tool parameters and product parameters were demonstrated.
- ❑ Finally, a concept for automatic application of plasma parameter measurement as an indicator of hardware and process stability problems was developed.

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