New Insights into the Tribological and Kinetic Attributes of Retaining Rings in CMP

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Outline

- **Background**
  - ❖ **The Stribeck curve and some of the issues associated with it**
  - ❖ **The Stribeck+ curve**
  - ❖ **Some ILD and copper CMP examples**
- **Objective**
- **Polishing apparatus, other hardware and experimental procedures**
- **Stribeck+ curve applied to retaining rings**
- **Two “optical illusions”**
- **The “Directivity” plot**
- **The “Kinetic” curve and the “implied” ring wear rate**
- **Wear validation studies**
- **Summary**

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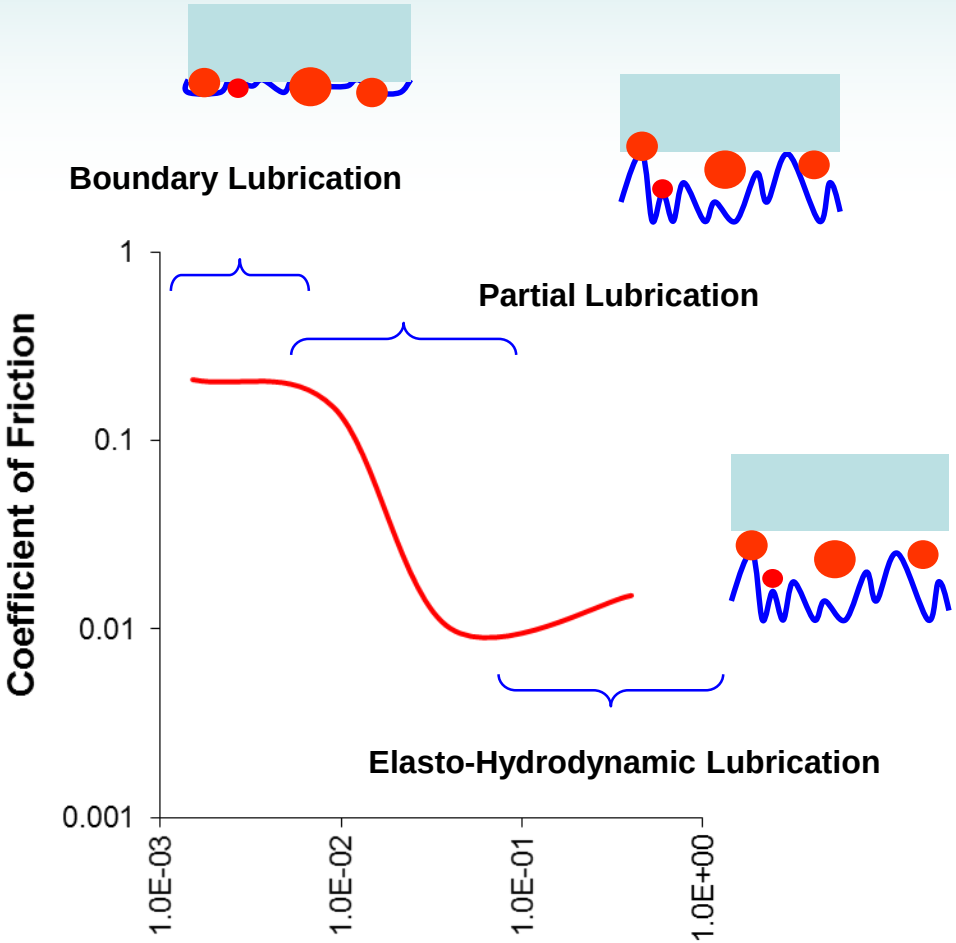
Background

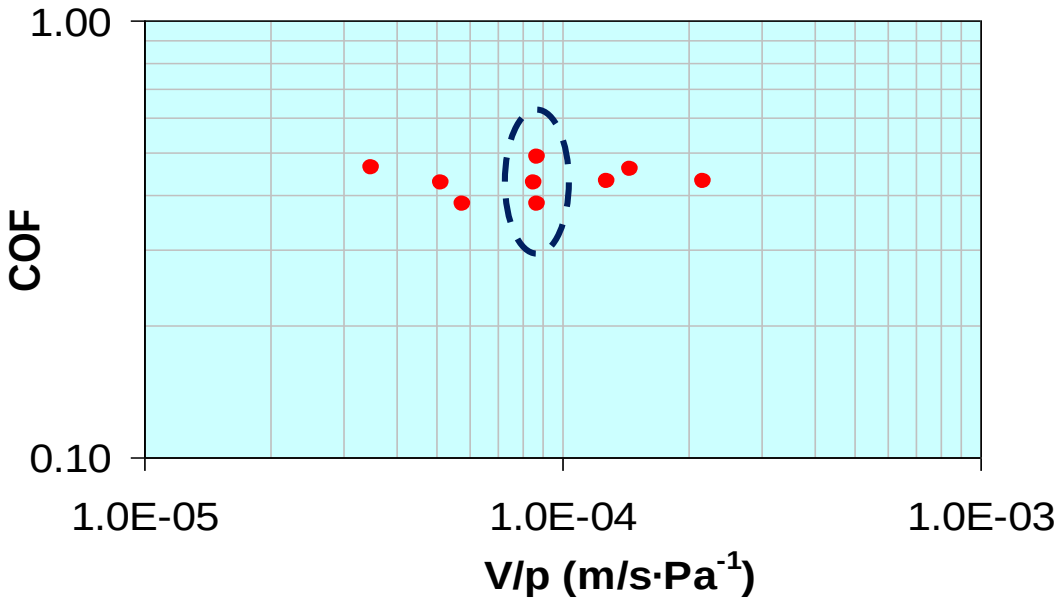
- As a 1st approximation, the Stribeck curve helps provide evidence re: extent of contact among wafer, pad and abrasive particles where 3 major lubrication modes can be distinguished.
- Additionally, it helps screen certain consumable sets by determining if and how they contact one another during CMP.
- This can help determine optimal polishing parameters, predict EOL for pads and help engineers avoid certain polishing conditions.



$$So = \frac{(u)\times(\mu)}{(P)\times(\delta_{eff})}$$

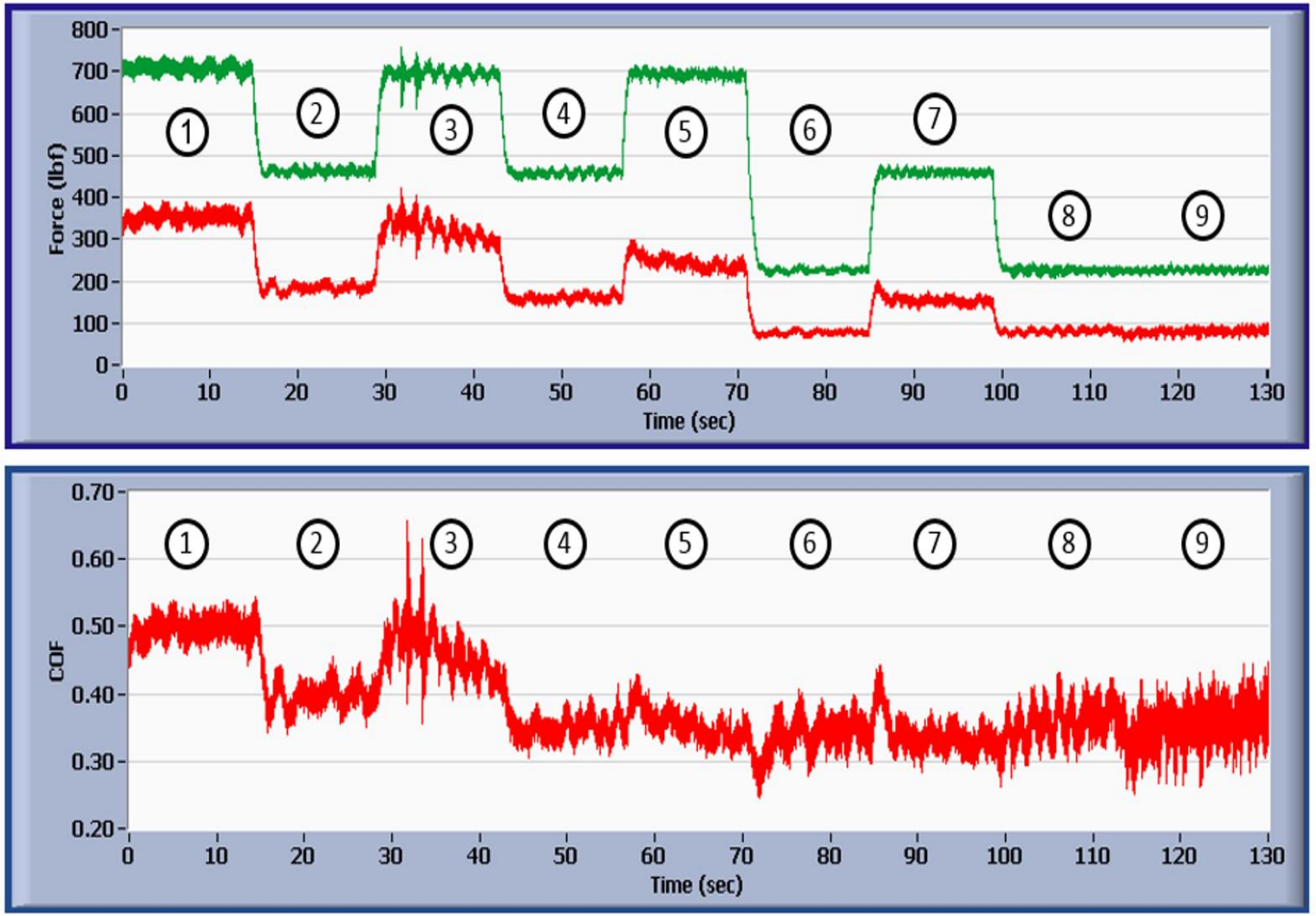
Motivation

- **When it comes to traditional Stribeck curves:**
  - ❖ **Many wafers need to be polished at various pressures and sliding velocities – Costly and time consuming.**
  - ❖ **Generally, only average COF is plotted.**
  - ❖ **COF is measured assuming a constant downforce – It is basically the pressure set-point in the controller.**
  - ❖ **V and P are lumped in the Sommerfeld number – Their ratio is what seems to count and not their individual values.**
  - ❖ **No information on COF is available in-between adjacent data points.**



A Continuous Run Through 9 Conditions

Step	V (m/s)	P (PSI)
1	0.6	6.0
2	0.6	4.0
3	1.0	6.0
4	1.0	4.0
5	1.5	6.0
6	0.6	2.0
7	1.5	4.0
8	1	2.0
9	1.5	2.0



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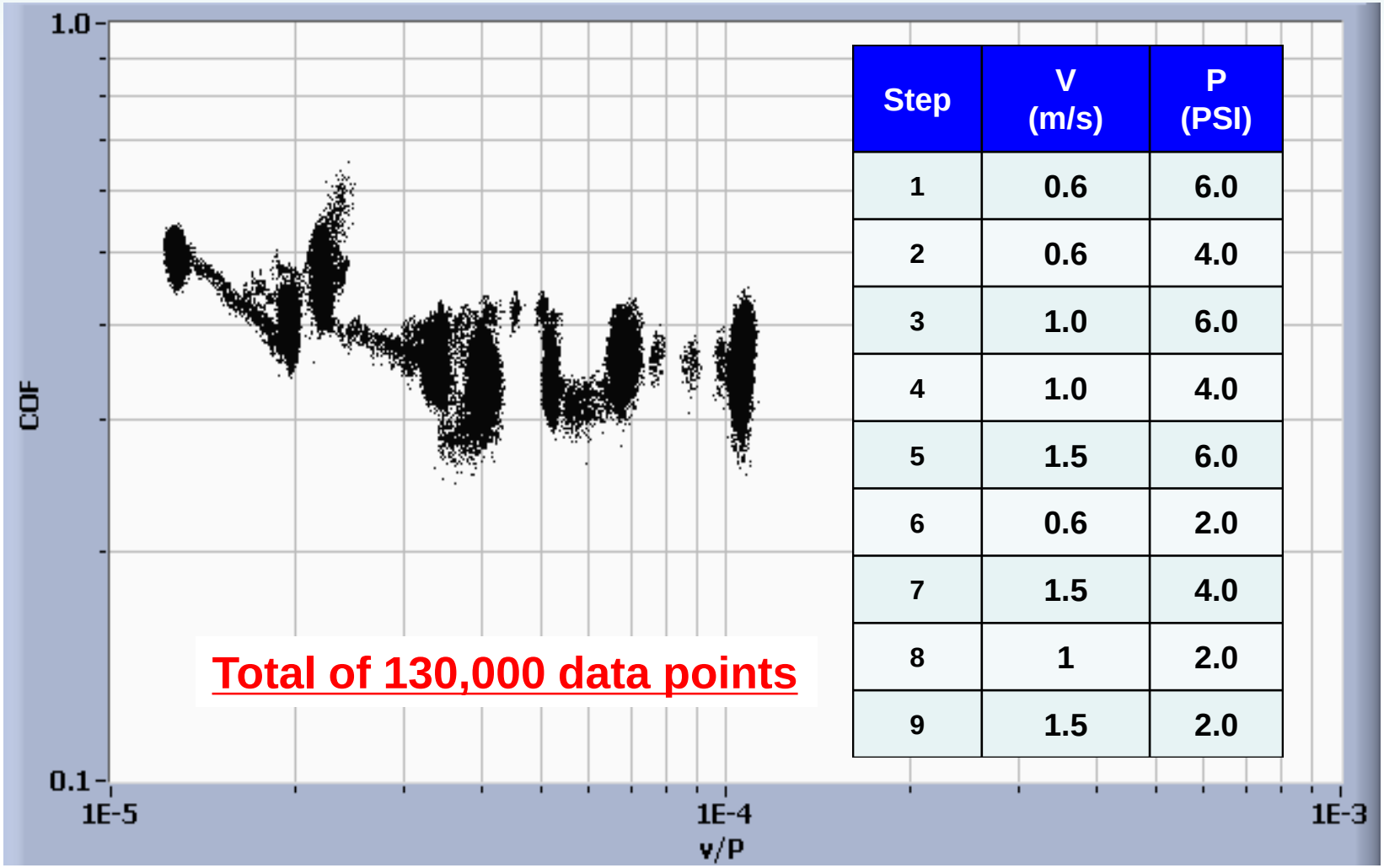
Example of a Stribeck+ Curve



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5	1.5	6.0
6	0.6	2.0
7	1.5	4.0
8	1	2.0
9	1.5	2.0

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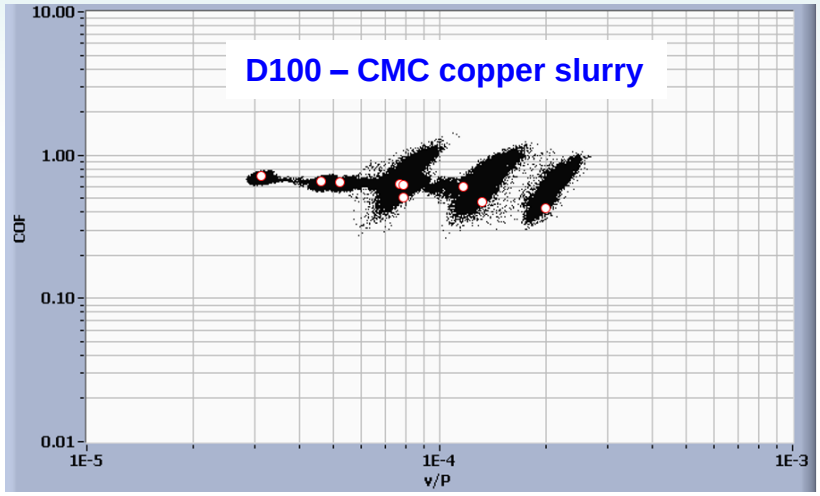
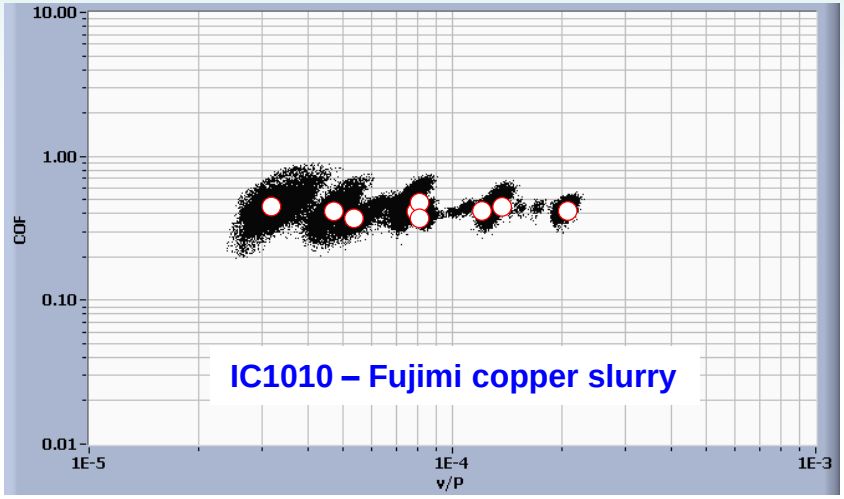
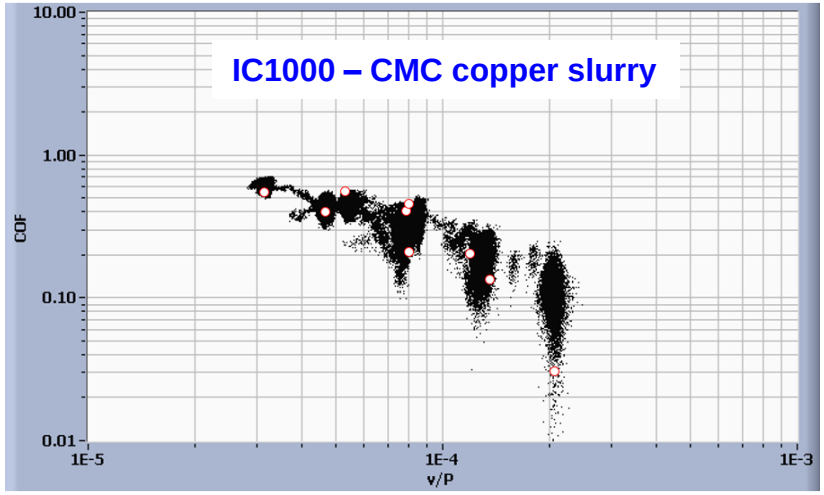
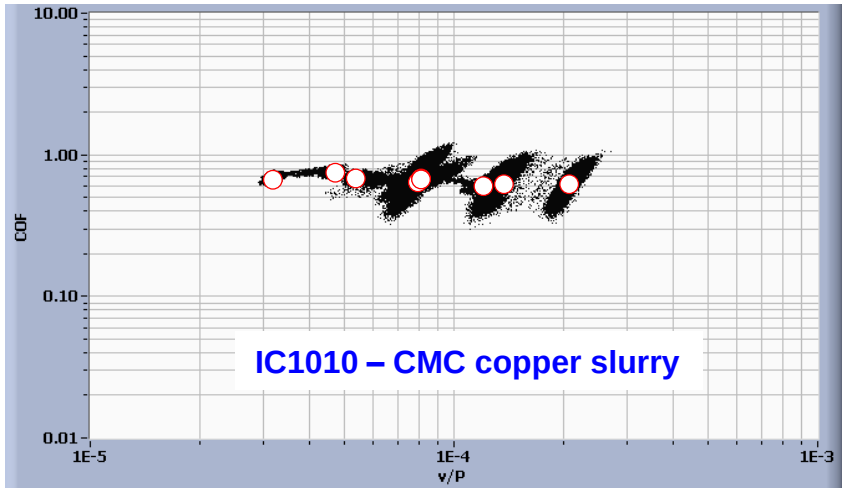
Selected Stribeck+ vs. Stribeck Curves





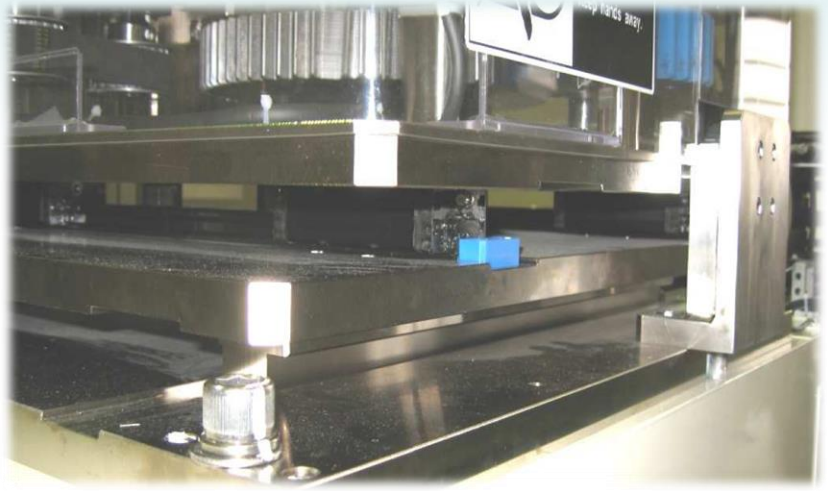


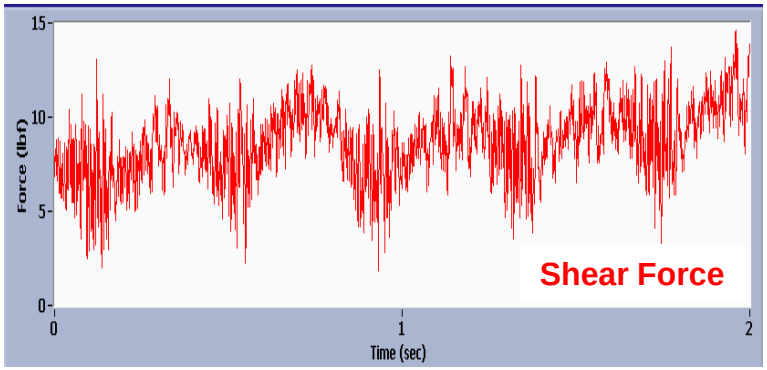


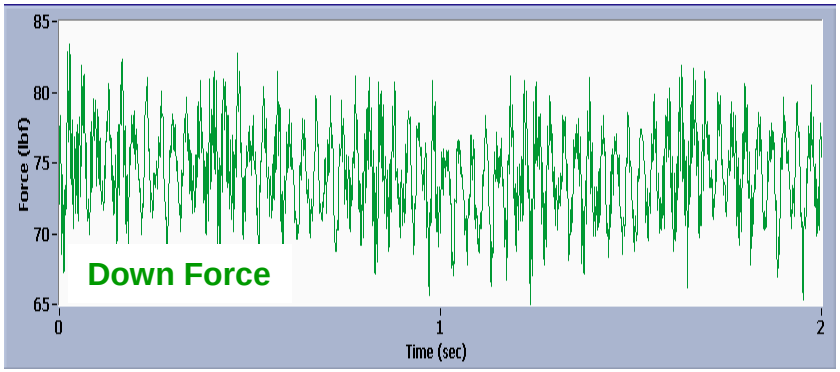
Objective

- **Characterize PPS and PEEK retaining rings with differently designed slots for copper and ILD applications**
  - ❖ **Generate, compare and contrast Stribeck and Stribeck+ curves.**
  - ❖ **Point out the 2 two "optical illusions" associated with Stribeck+ curves and show how "directivity" plots can help overcome them.**
- **Develop and validate a rapid method to give information on the "inferred" relative wear rate of retaining rings.**
  - ❖ **Define and construct a "kinetic" curve to rapidly predict ring wear rate.**
  - ❖ **Validate the above-proposed methodology through experimentation.**

The Araca APD-800 Polisher and Tribometer







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AMAT Reflexion Retaining Rings

- **Phase – 1:**
  - ❖ **PPS and PEEK**
  - ❖ **Sharp Edge vs. Rounded Edge**

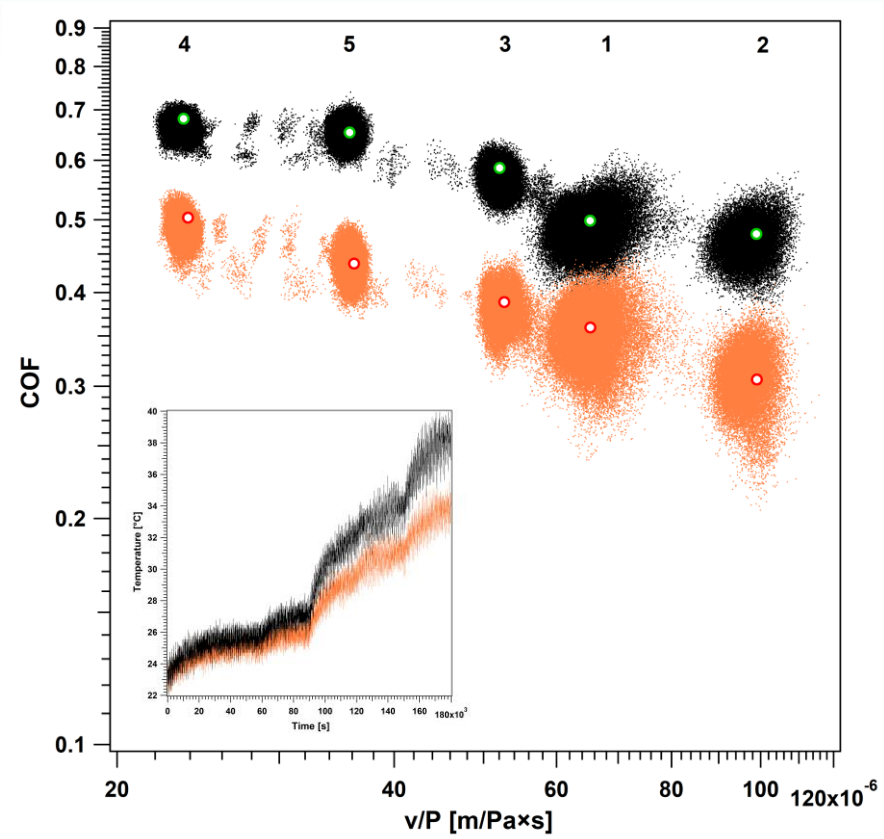
  - ❖ **ILD (Fujimi PL-4217) vs. Copper slurry (Fujimi PL-7103)**
  - ❖ **Each ring was cycled through multiple pressures and velocities for 3 continuous minutes** **(see next slide)**

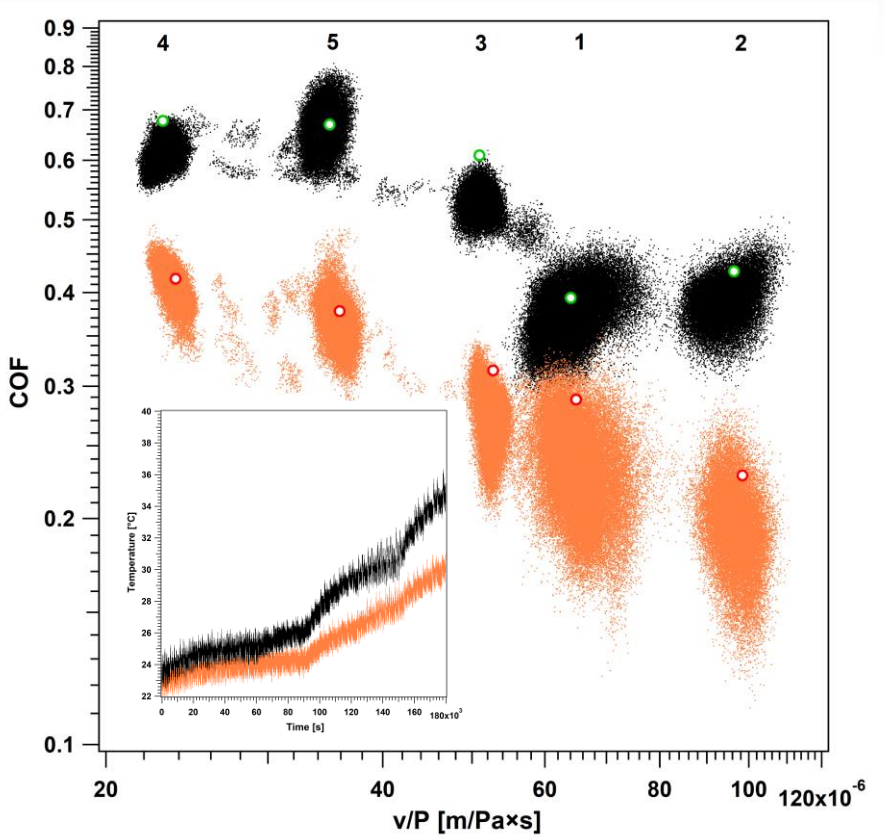
A Single 180-second Run

Stribeck+ Step No.	Step Duration (sec)	Pressure (PSI)	Sliding Velocity (m/s)
1	60	2	1.2
2	30	2	1.8
3	30	4	1.8
4	30	6	1.2
5	30	6	1.8

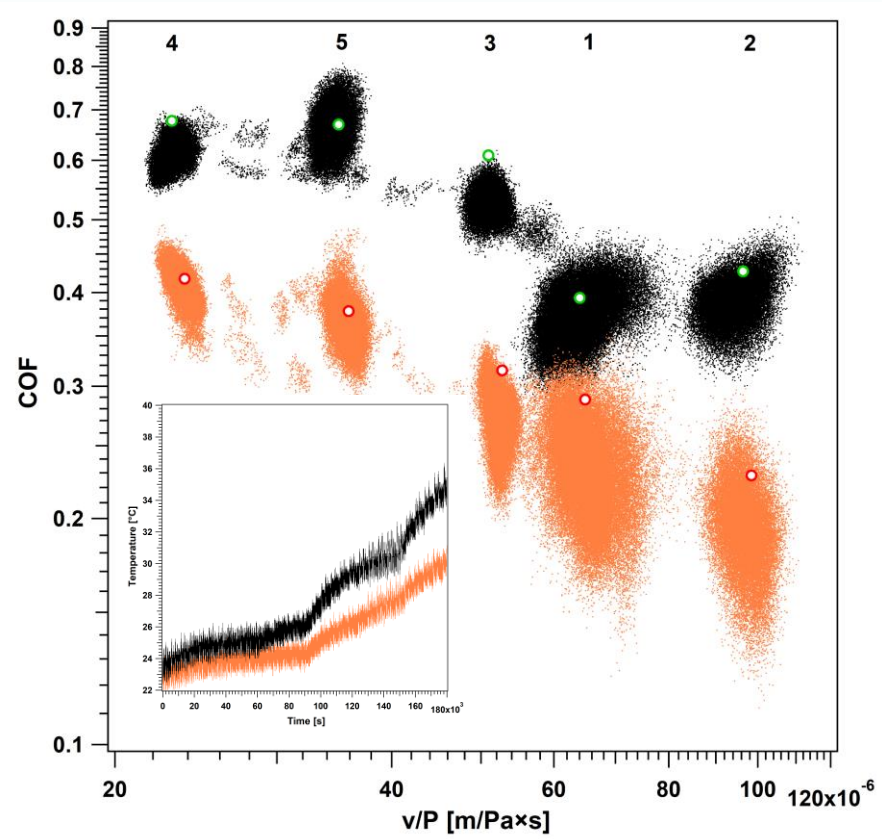
Rings were also polished separately for 1 minute at every pressure-velocity combination with substantial wait-time in between each polish

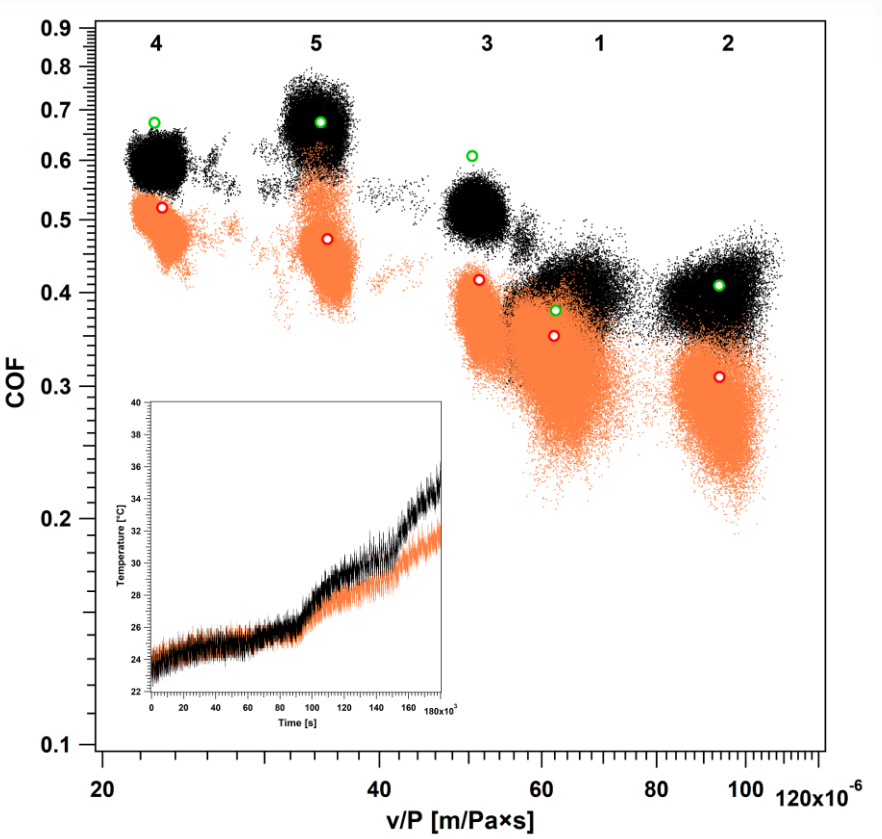
Rounded Slot – PPS (left) and PEEK (right)





PEEK – Rounded (left) and Sharp (right)



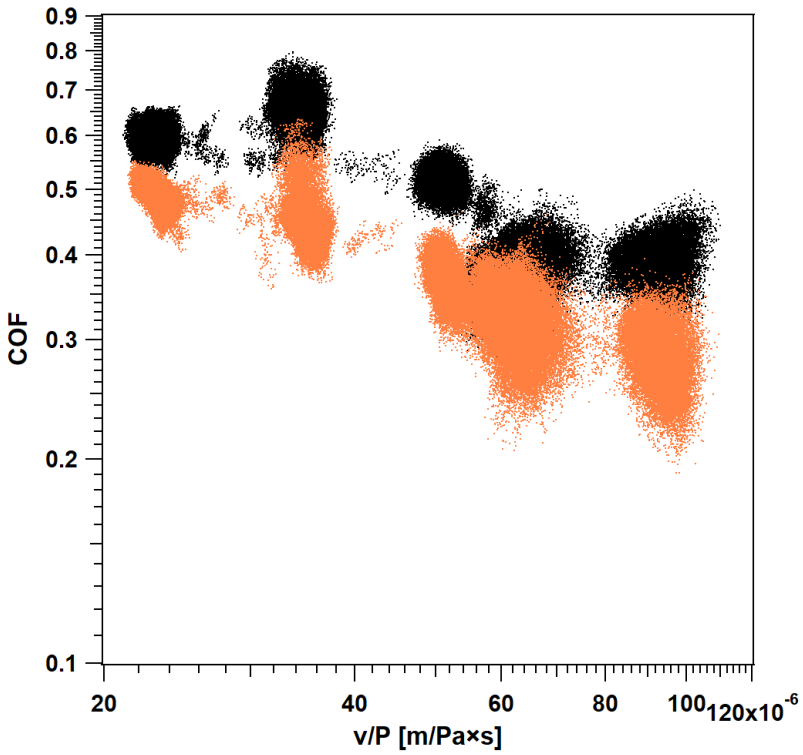


Explaining the St+ Trends

- **Stribeck+ curves are continuous in nature – In all cases we see that anomalous tribological behaviors do not exist in between polishing conditions**
  - **PPS ring has higher COF values than PEEK.**
  - **PPS ring seems to be tribologically more stable than PEEK.**
  - **COF values are always higher when ILD slurry is used to polish the ring as compared to copper.**
  - **Mean COF values are substantially higher for the sharp-slot PEEK ring compared to rounded-slot PEEK when copper slurry is used.**
- **Temperature differences are consistent with their corresponding COF values.**
  - **PPS runs ~ 4 C warmer than similarly-designed PEEK.**
  - **Average pad temperature is higher by ~ 2 C when ILD slurry is used as compared to copper.**

2 Inherent Issues with Stribeck+ Curves

- **The 2 axes are logarithmic:**
  - **Identical magnitudes of variations in COF and pseudo-Sommerfeld number "appear" tighter in the upper LHS of the plot as compared to those on the lower RHS.**
- **The ordinate and the abscissa are not independent of one another:**
  - **COF is inversely proportional to normal force.**
  - **Pseudo-Sommerfeld number (through applied pressure) is also inversely proportional to normal force.**



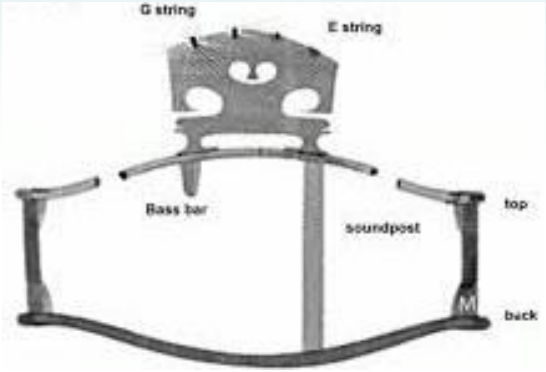
- **These can cause considerable confusion in data interpretation, and will skew cluster shapes.**

Let's Digress a Bit – A Violin's Radiation

- **RADIATION or DIRECTIVITY refers to sound directionality – It is frequency-dependent!**

- **DIRECTIVITY (Δ) ≡ Ratio of the variance of pressure acting on the top plate to that on the bottom plate.**

  - **Δ = 1 (isotropic sound – omnidirectional).**
  - **Δ > 1 (anisotropic sound – Highly directional).**
  - **Below 400 Hz, 0.95 > Δ > 1.15 for most violins.**
  - **Beyond this, Δ for commercial violins increases rapidly and reaches 1.35 at 900 Hz and then rises very slowly to 1.45 at 4,000 Hz.**
  - **For Old Italian violins, past 400 Hz, Δ increases rapidly to 1.65 at 900 Hz and then continues to rise further to 2.45 at 4,000 Hz.**

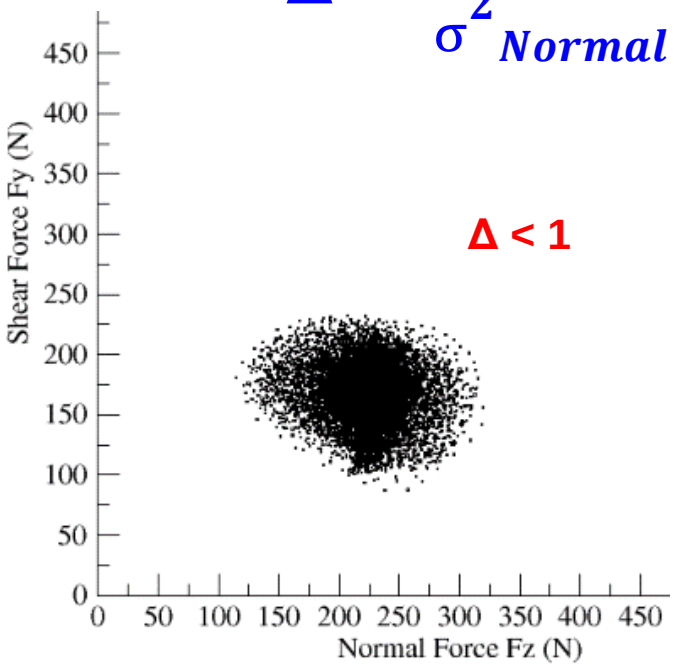


Overcoming the "Optical Illusion" re: St+

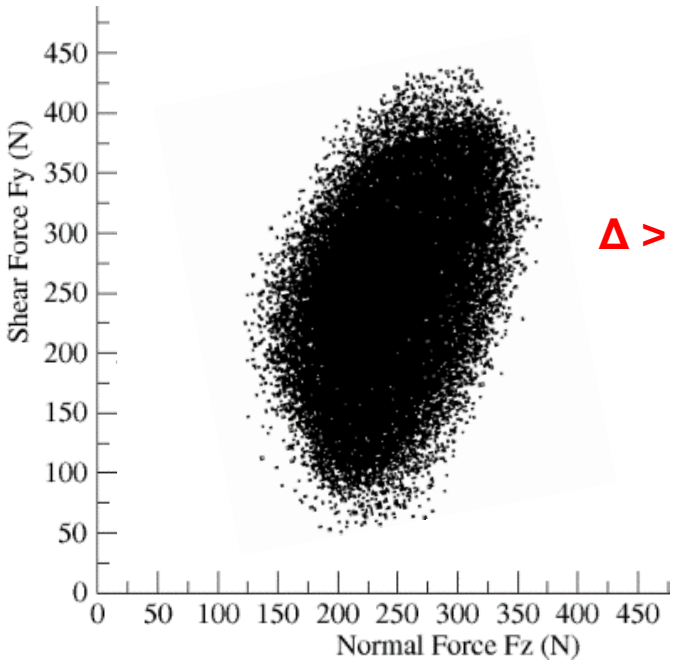
- **We suggest using a supplemental linear-linear graph and plot "DIRECTIVITY" vs. pseudo-Sommerfeld number.**

- **DIRECTIVITY (Δ) ≡ Ratio of the variance of shear force to that of normal force:**

$$\Delta \equiv \frac{\sigma^2_{Shear\ Force}}{\sigma^2_{Normal\ Force}}$$

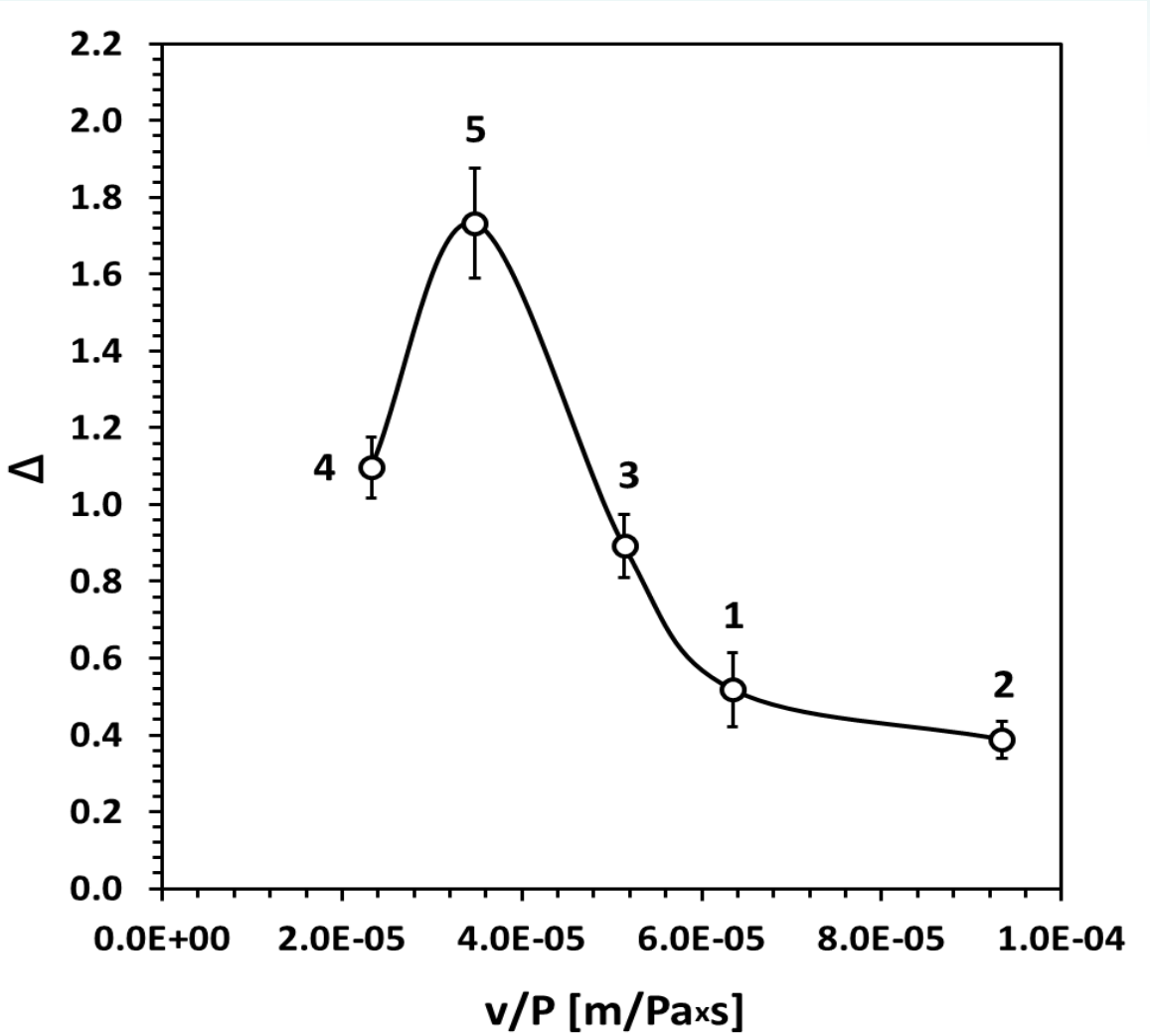


Δ < 1



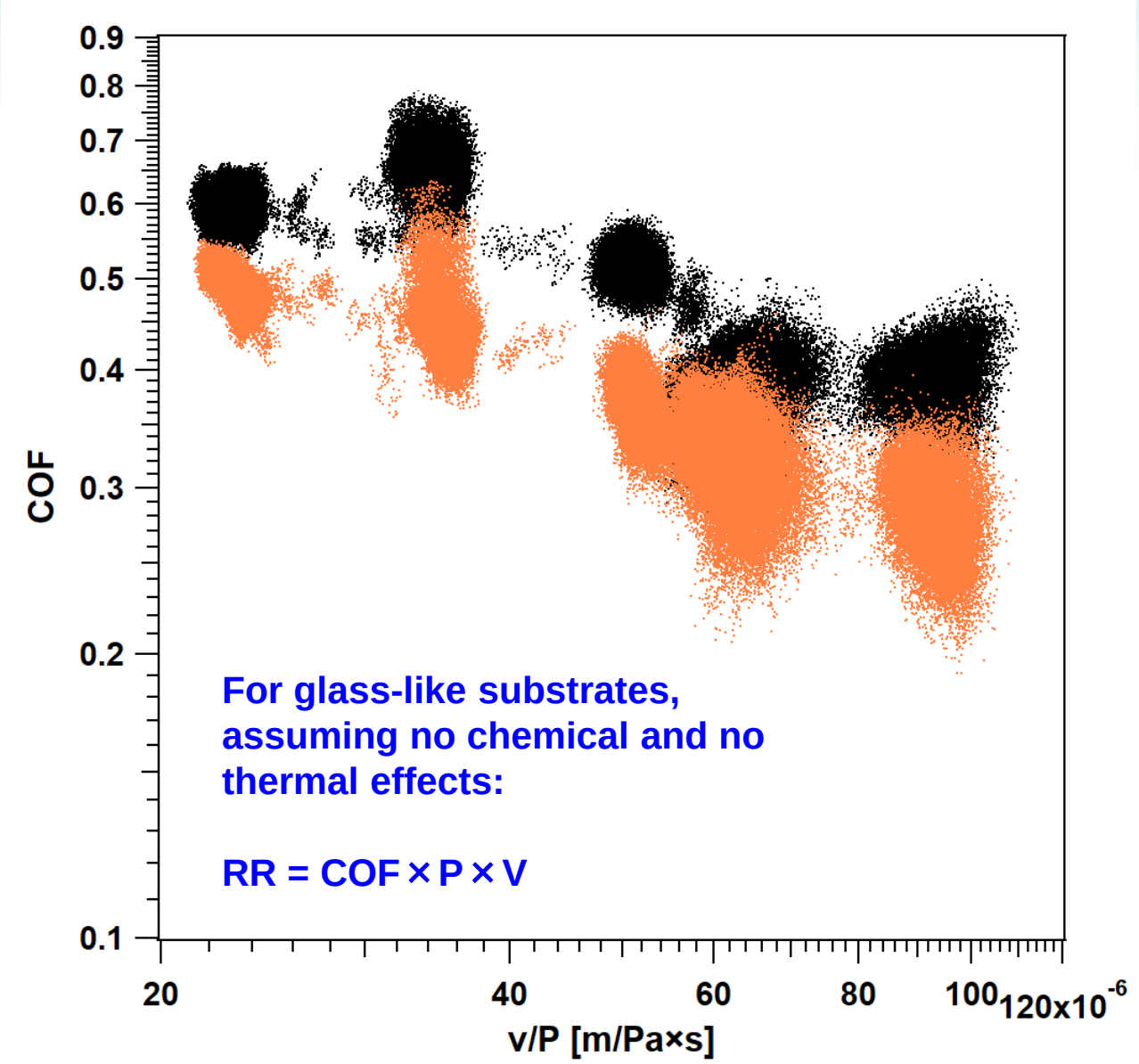
Δ > 1

“Directivity” Plot for the PEEK Ring

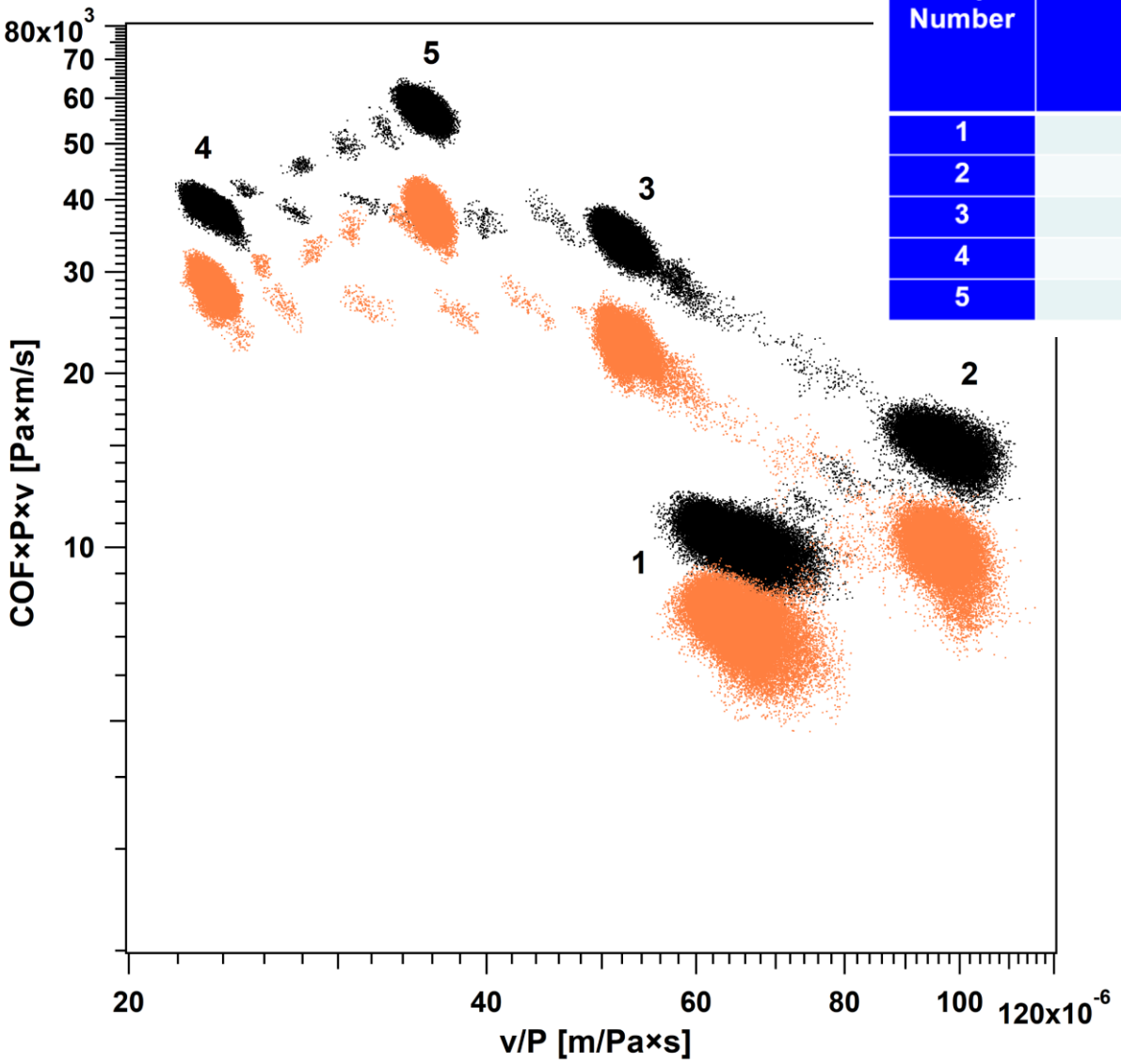


- Average Δ values start off at 1.1 at 6 PSI and 1.2 m/s.
- As pressure is maintained and sliding velocity is increased to 1.8 m/s, Δ rises sharply to 1.8 – Dramatic increase in shear force fluctuations compared to its normal counterparts.
- As velocity is kept at 1.8 m/s and pressure is lowered to 4 PSI, Δ descends rapidly to 0.9.
- Further decreases in pressure cause Δ to decrease asymptotically to 0.4 – Here normal force fluctuations dominate.

Stribeck+ Curve for a Retaining Ring



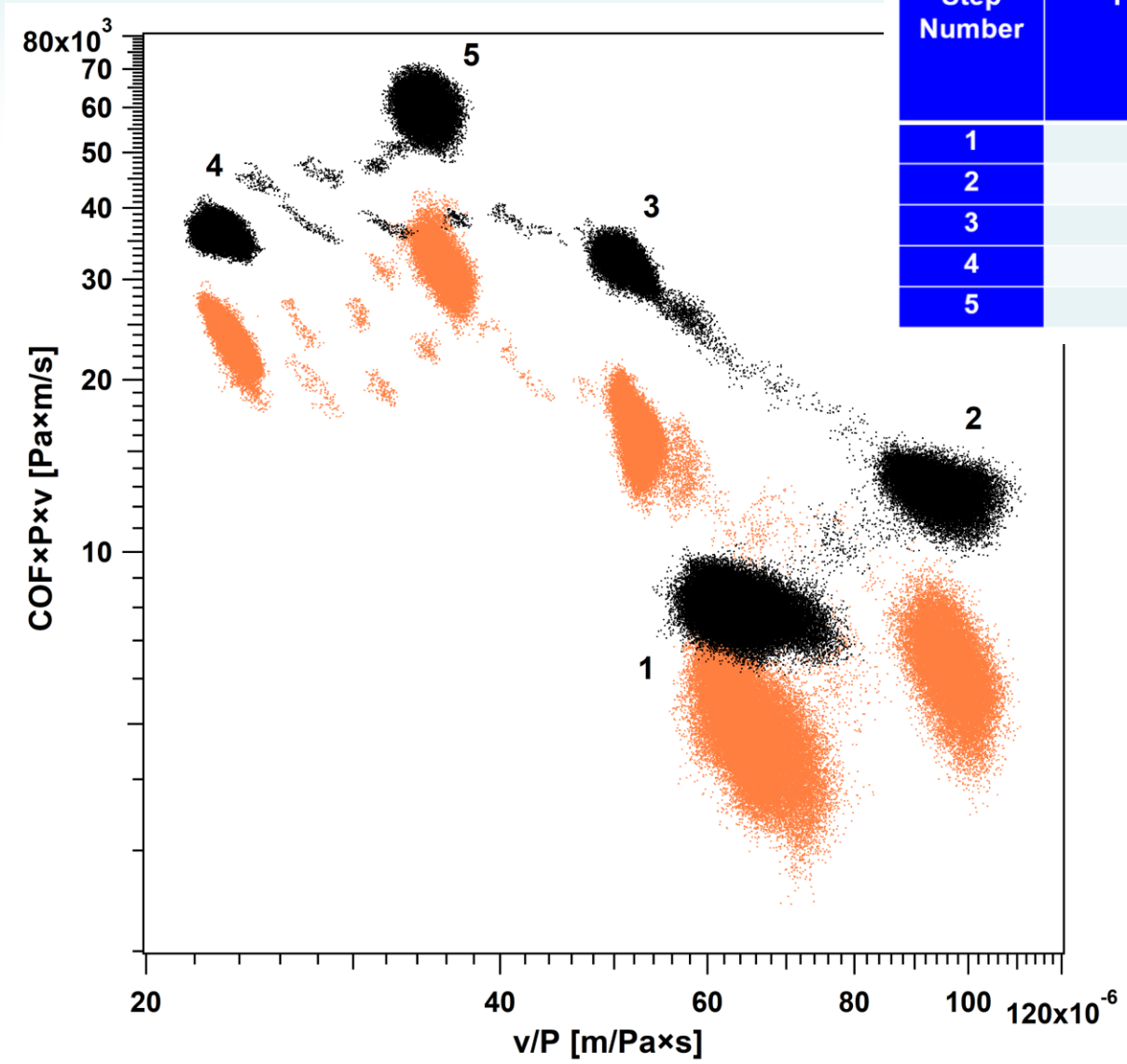
PPS – Rounded Slots



Step Number	Pressure (PSI)	Sliding Velocity (m/s)
1	2	1.2
2	2	1.8
3	4	1.8
4	6	1.2
5	6	1.8

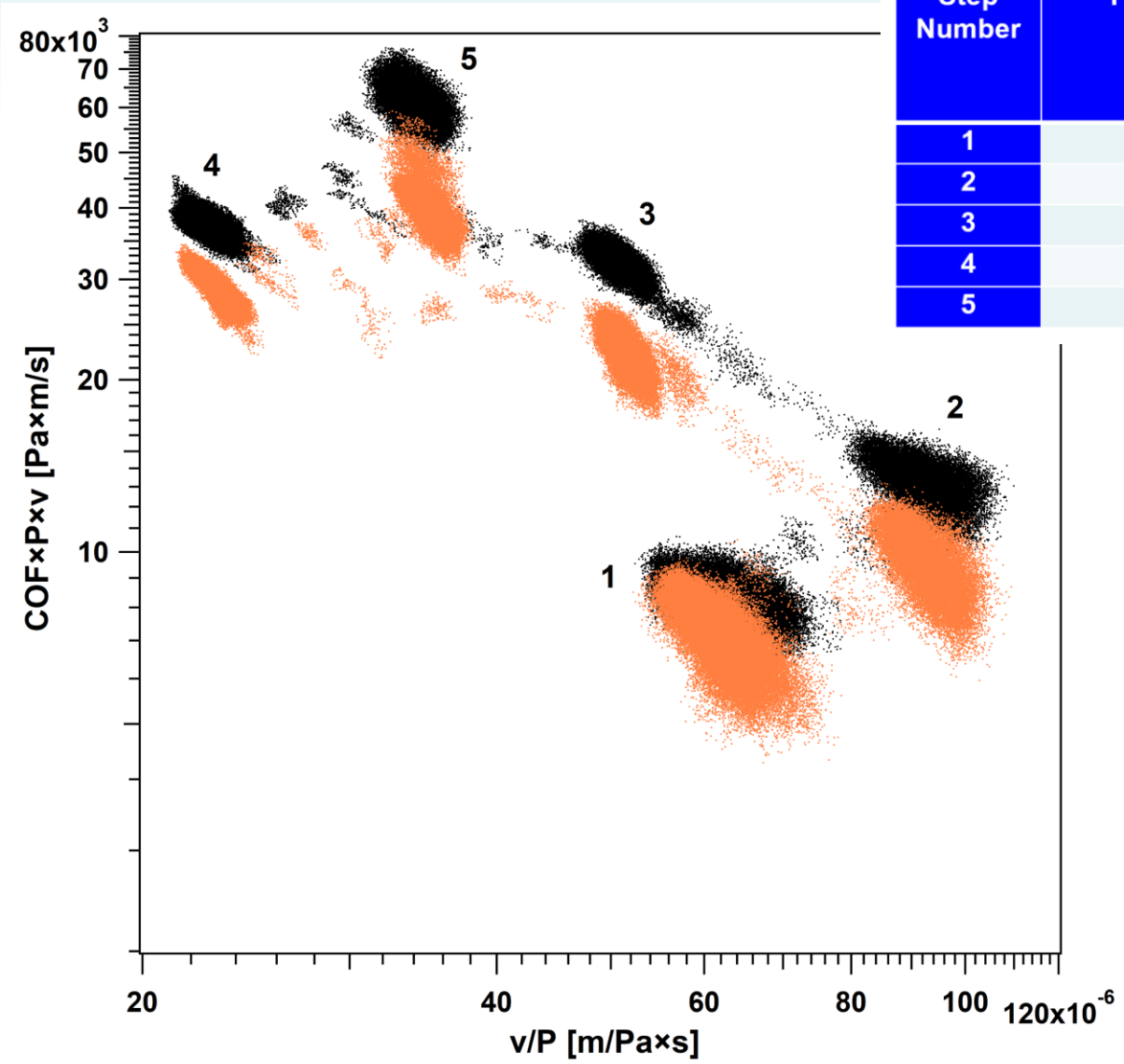
PEEK – Rounded Slots

Step Number	Pressure (PSI)	Sliding Velocity (m/s)
1	2	1.2
2	2	1.8
3	4	1.8
4	6	1.2
5	6	1.8



PEEK – Sharp Slots

Step Number	Pressure (PSI)	Sliding Velocity (m/s)
1	2	1.2
2	2	1.8
3	4	1.8
4	6	1.2
5	6	1.8

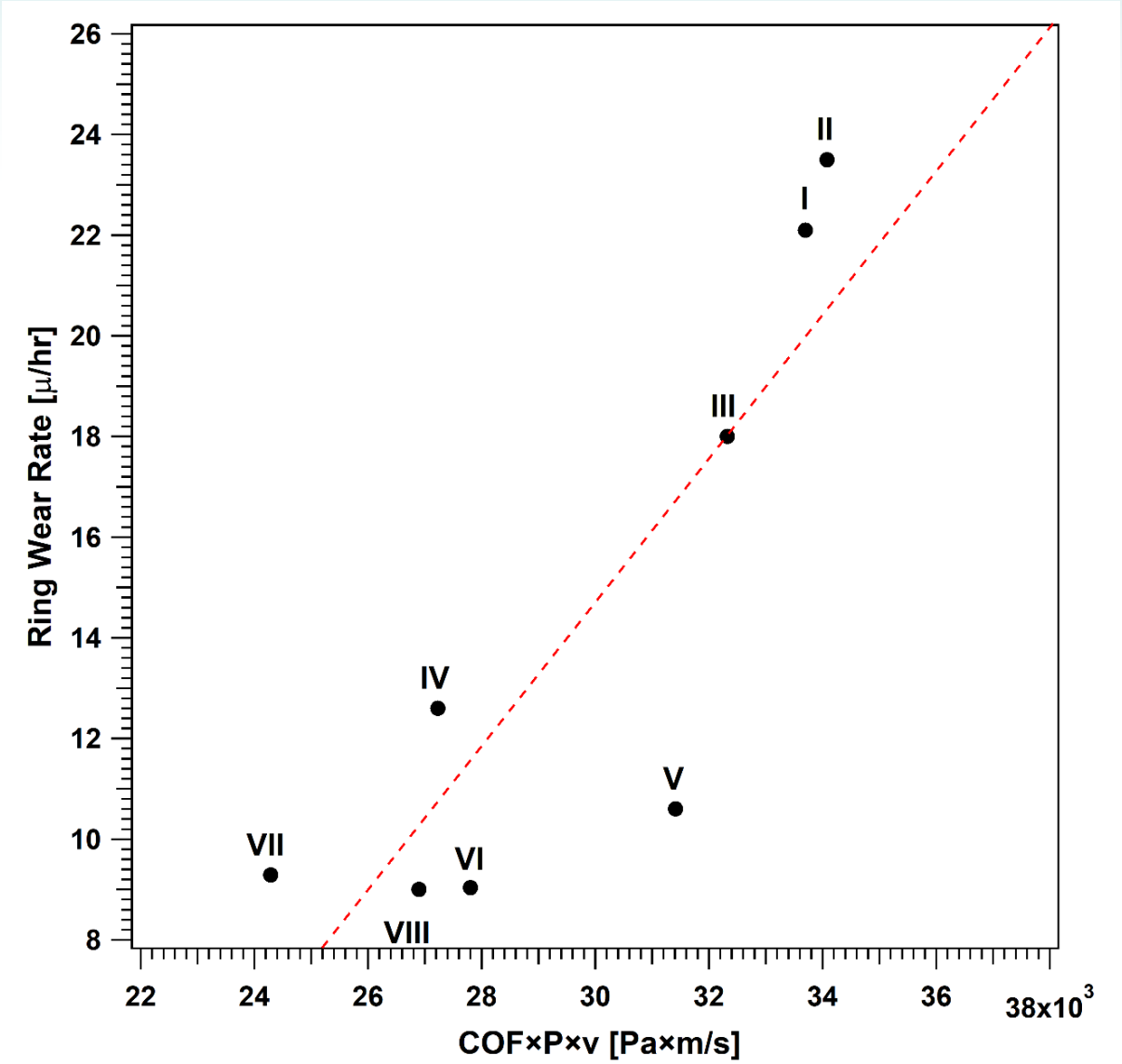


Experimental Conditions – Validation Studies

Phase – 2

"Blind" Ring Number	Wear Time (hour)	Pressure (PSI)	Sliding Velocity (m/s)
I	4½	6	1.2
II	4½	6	1.2
III	4½	6	1.2
IV	7½	6	1.0
V	7½	6	1.0
VI	7½	6	1.0
VII	7½	6	1.0
VIII	7½	6	1.0

Validation Studies



Summary

- **Stribeck+ curves were utilized to tribologically characterize identically-designed PPS and PEEK rings, as well as PEEK rings with two different slot designs for copper and ILD CMP:**
  - ❖ **COF for PPS was greater than PEEK**
  - ❖ **PPS was tribologically more stable than PEEK**
  - ❖ **COF with ILD slurry was greater than copper**
  - ❖ **COF for sharp slots was greater than rounded slots for copper slurry (no differences in COF for the ILD slurry)**
  - ❖ **COF values directly correlated to average pad surface temperatures**
- **Optical illusions associated with Stribeck+ curves were addressed via a new parameter – DIRECTIVITY**
- **"Kinetic" plots were introduced for the 1st time to help "infer" relative ring wear rates – Can help engineers choose process parameters that balance wafer RR with ring wear rate.**
- **Validation studies showed a reasonable correlation between actual and inferred ring wear rates – Time savings ~ 90 mins vs. 15 hours!**