PARTICLE MEASURING SYSTEMS®
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Particle Monitoring in Ultra Pure Water for Microelectronic Applications

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Austin, TX
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Agenda

- Motivation for Particle Monitoring
- Optical Particle Counting Fundamentals
- Instrument Specifications
- Counting Statistics
- Data Analysis and Interpretation

Particles: Integral part of ITRS Roadmap

Year of production	2005	2006	2007	2008	2009	2010	2011	2012	2013
DRAM half-pitch (nm)	80	70	65	57	50	45	40	36	32
Critical particle size (nm) [A]	40	35	33	29	25	22	20	18	16
Resistivity at 25°C(MΩ-cm)	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2
Total oxidizable carbon (ppb) POE	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bacteria (CFU/liter)	<1	<1	<1	<1	<1	<1	<1	<1	<1
Total silica (ppb) as SiO_2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.3	<0.3	<0.3	<0.3
Number of particles >0.05 µm (/ml) POE	<0.2	<1	<0.9	<0.8	<0.4	<0.3	<0.3	<0.3	<0.2
Dissolved oxygen (ppb) POE	<10	<10	<10	<10	<10	<10	<10	<10	<10
Dissolved nitrogen (ppm)	8-12	8-12	8-18	8-18	8-18	8-18	8-18	8-18	8-18
Critical metals (ppt, each)	<1	<1	<1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Other critical ions (ppt, each)	<50	<50	<50	<50	<50	<50	<50	<50	<50
Temperature stability (K)	±1	±1	±1	±1	±1	±1	±1	±1	±1
Temperature gradient in K/10 minutes POE for immersion lithography	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

Interim solutions are known
Manufacturable solutions are not known
Manufacturable solutions are known

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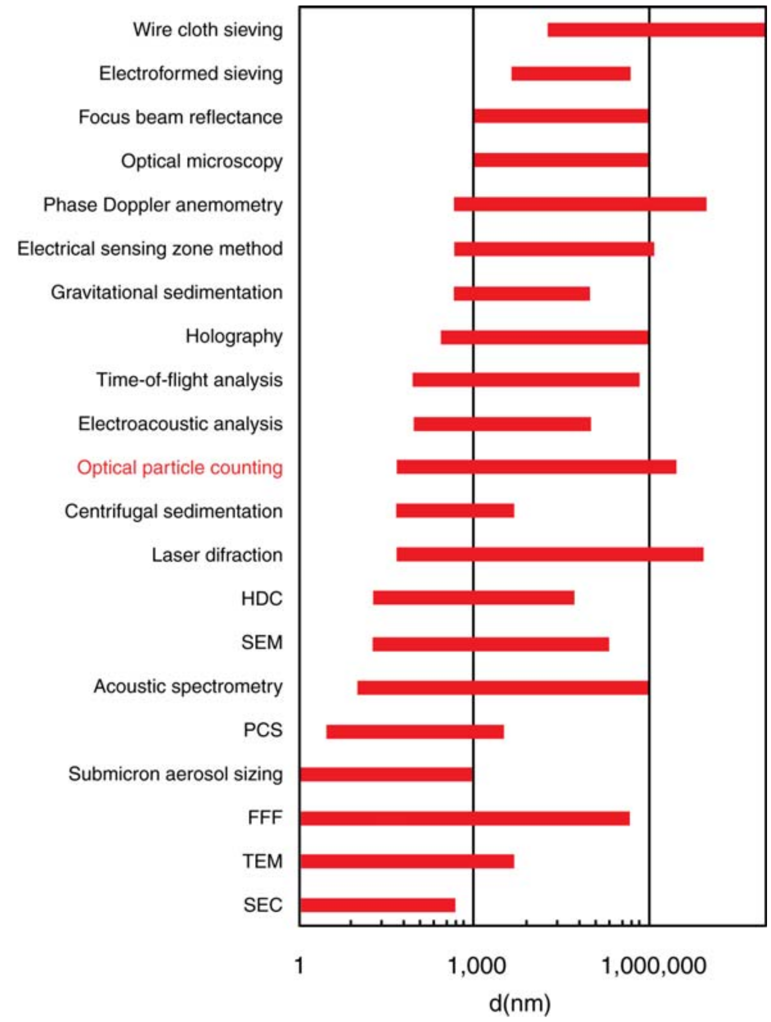
Ultra Pure Water

- Driving forces pushing the need for higher performance particle counters
  - 300 mm Fabs
  - Very few particles in newer UPW systems
    - <0.2 particles/ml (or 200/liter) larger than 0.05 microns
  - Particle failure of a UPW system has huge financial implications
  - Increased use
- Best monitoring technology for UPW is laser optical particle counting
  - Sensitivity
  - Reliability
  - Operator independent

Particle Sizing Methods



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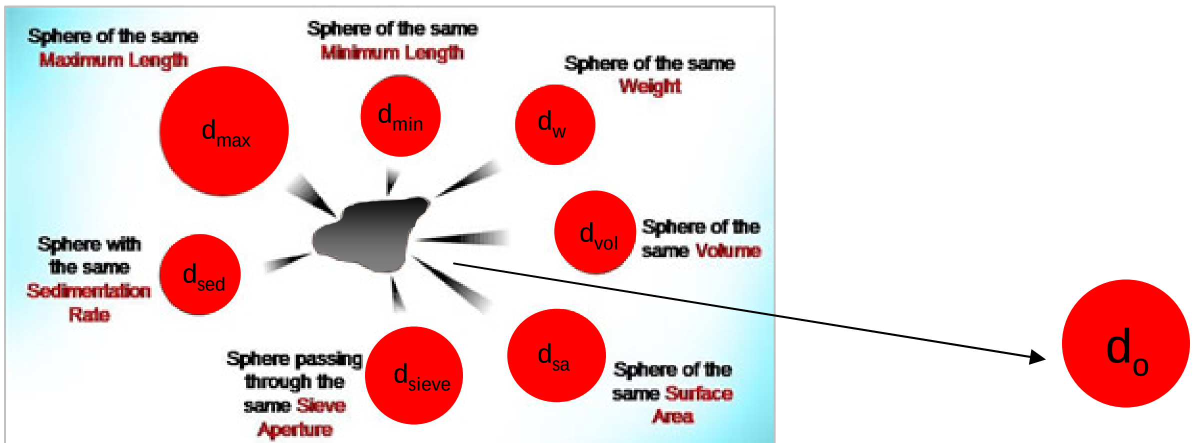
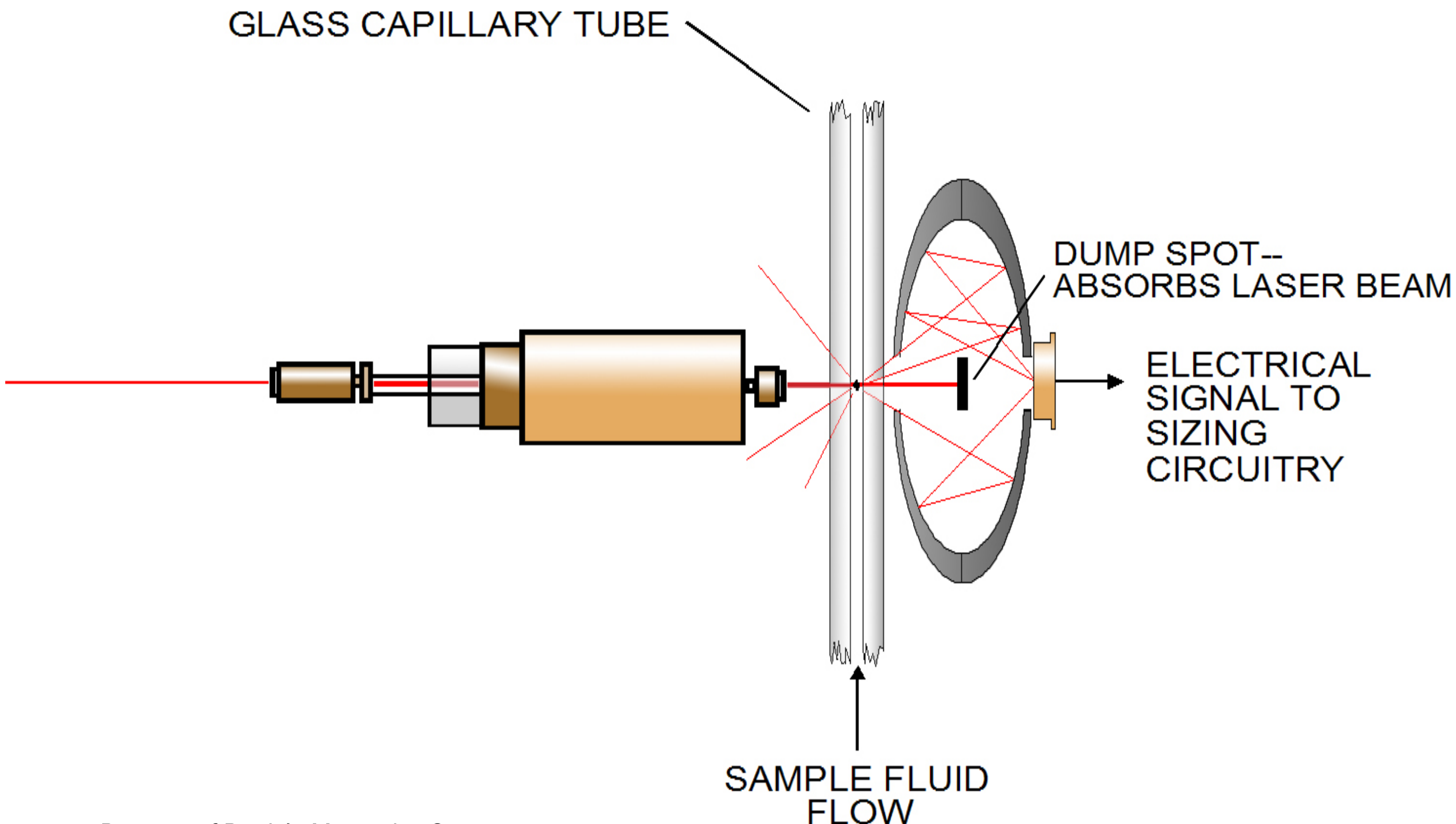
Spherical Equivalent Measurements



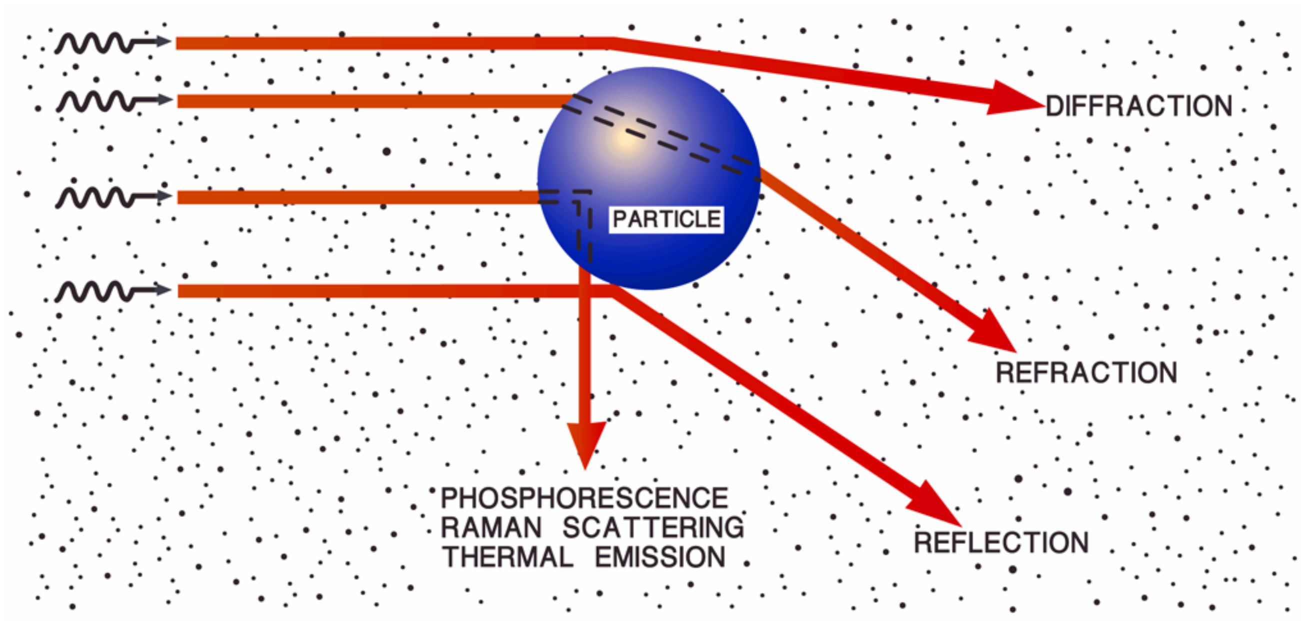
Sphere of the same "optical equivalent" (polystryene latex)

Liquid Particle Counter



Property of Particle Measuring Systems

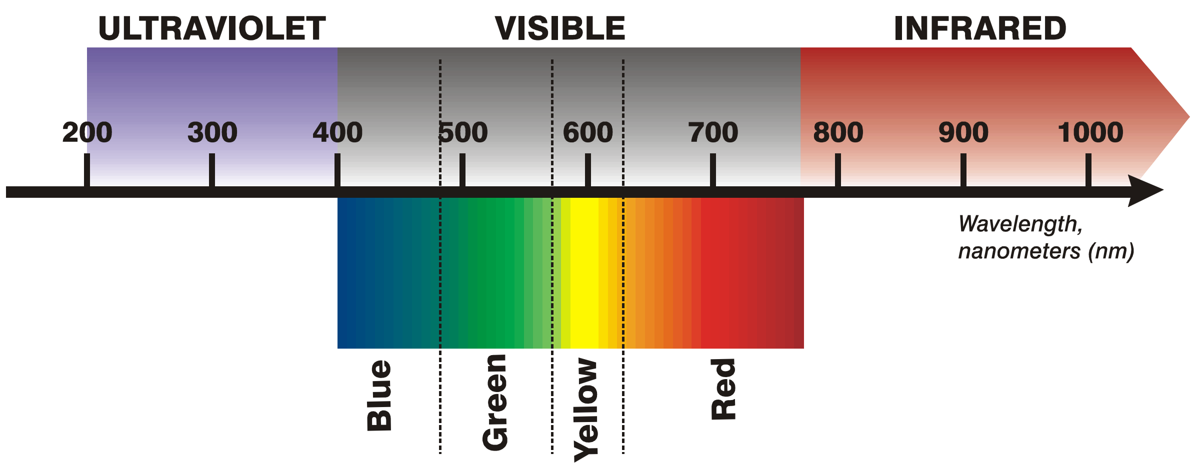
Scattering Phenomenon



Property of Particle Measuring Systems

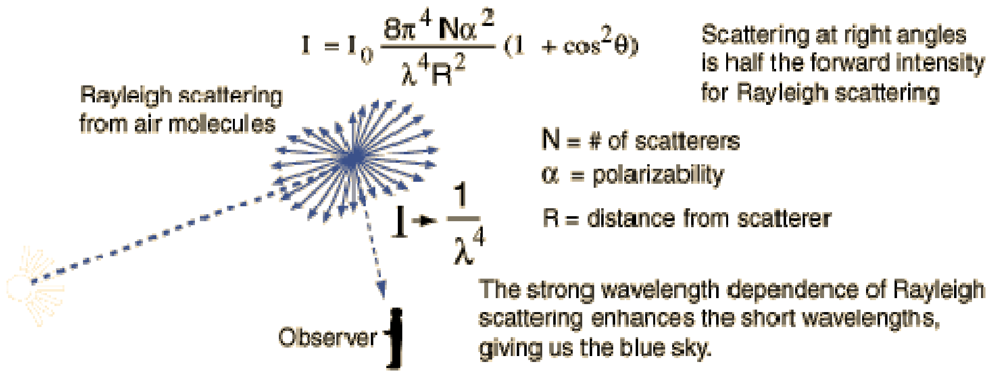
Scattering Domains

- Rayleigh Scattering
  - Particles much smaller than the light wavelength
- Lorenz-Mie Scattering
  - Particle sizes comparable to the light wavelength
- Geometric Scattering
  - Particles much larger than the light wavelength



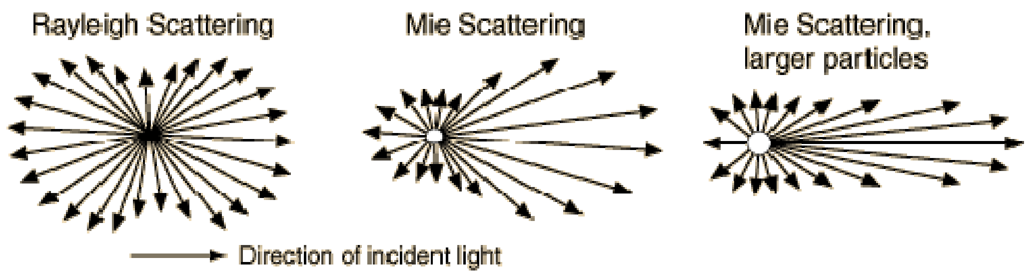
Rayleigh Scattering

$$I_s \sim \lambda^2 f(\alpha) = \lambda^2 \alpha^6 = \frac{d^6}{\lambda^4}$$



- Scattering intensity largely independent of particle shape
- Refraction dominates
- Symmetrical scattering (forward=backward)

Lorenz-Mie Scattering



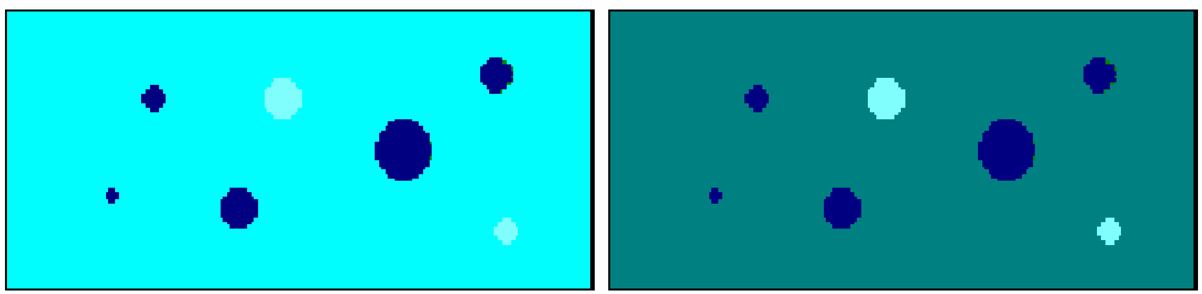
$$I_s \sim \lambda^2 f(\alpha) = \lambda^2 \alpha^{(6>n>2)} = \frac{d^{x<6}}{\lambda^{y<4}} to \frac{d^{x>2}}{\lambda^{y>0}}$$

- Scattering intensity and angular distribution largely dependent of particle shape
- Intensity and polarization fluctuate as a function of scattering angle
- Asymmetrical scattering (forward >> backward)
- Forward lobe mainly diffraction (becomes more concentrated)

Index of Refraction Component

- Scattering intensity is dependent on "IR Contrast"

$$IR\_Contrast = \frac{Particulate\_IR}{Media\_IR}$$

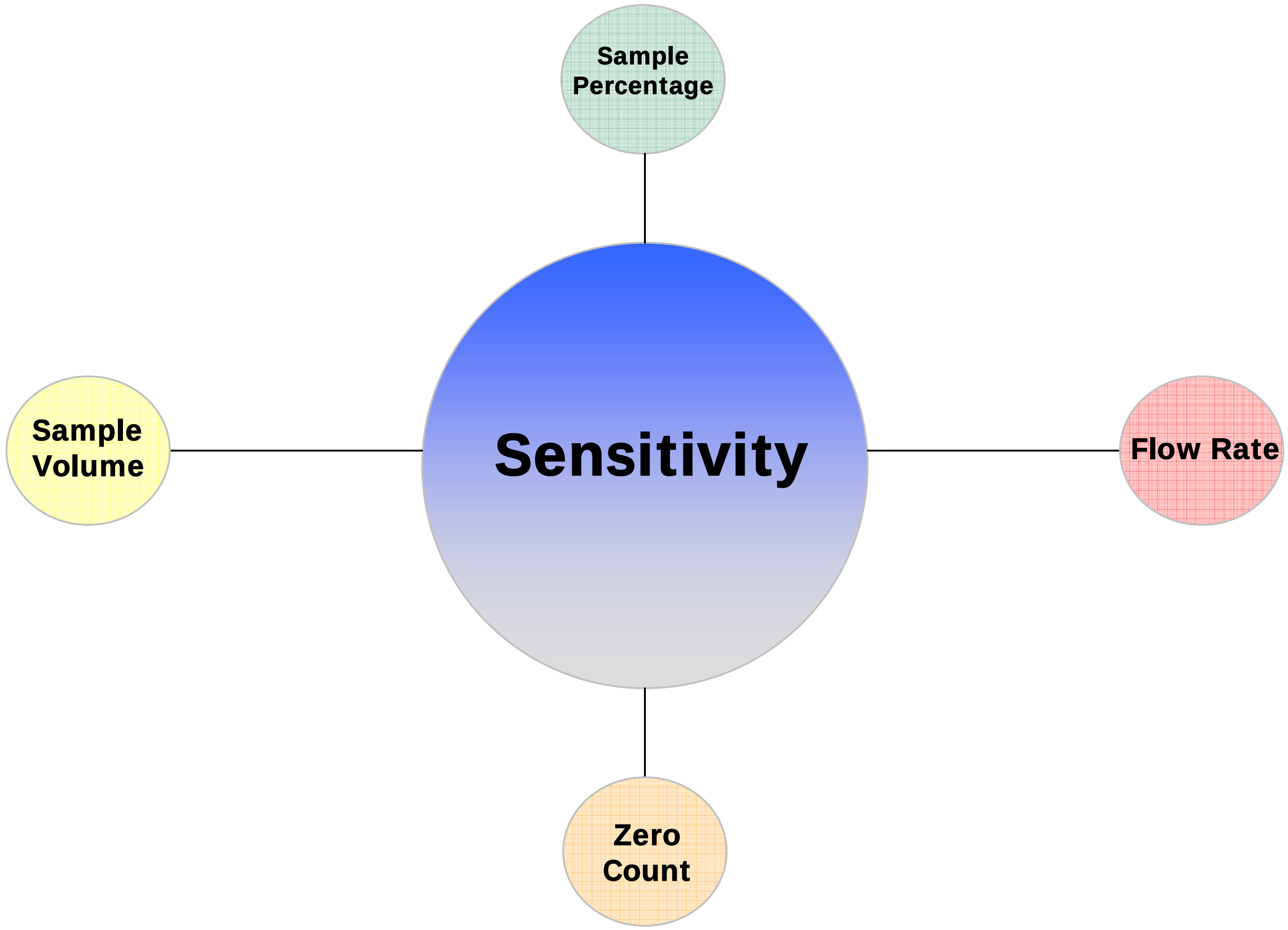


Index Of Refraction

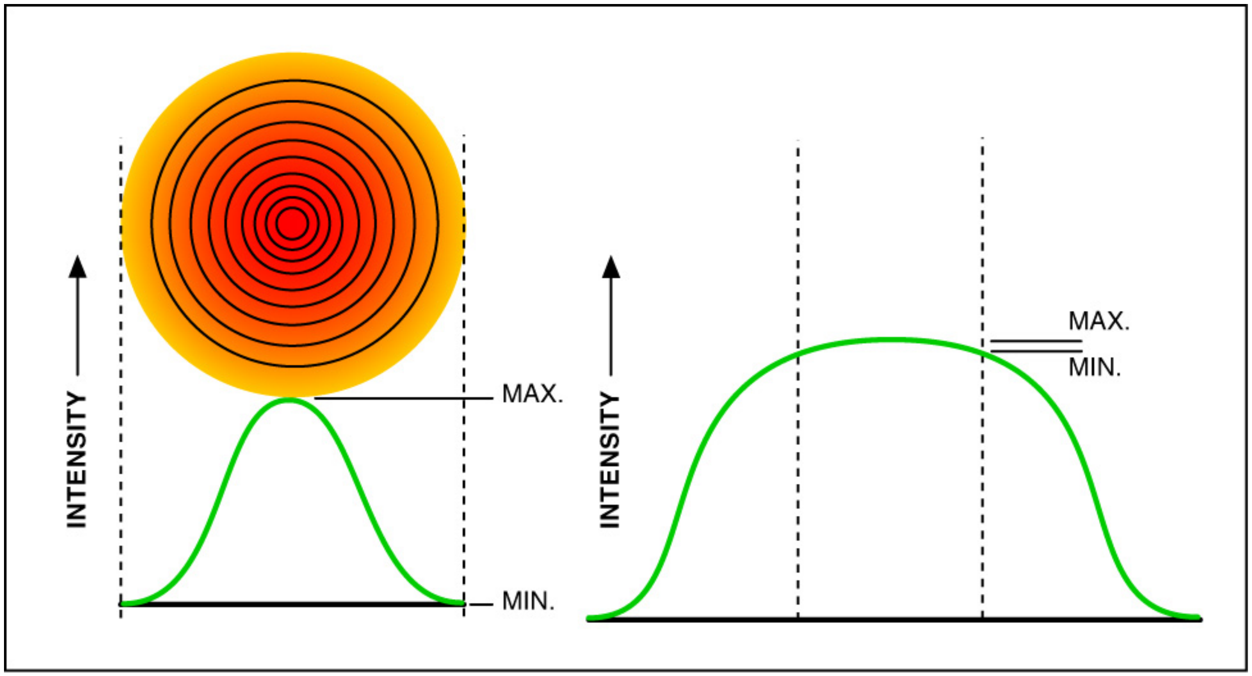
- Refractive Indices of typical particles and various sample media (λ = 633 nm)

Particulate Material	**Refractive Index**
Silicon Dioxide (Silica)	1.45
Silicon	3.9
Polystyrene Latex (PSL)	1.59
Steel	2.5
Copper	0.45
Aluminum	1.9
Sample Media	
Water	1.33
Hydrofluoric Acid (50%)	1.29
Ammonium Hydroxide (29%)	1.33
Hydrochloric Acid (37%)	1.41
Sulfuric Acid (96%)	1.46

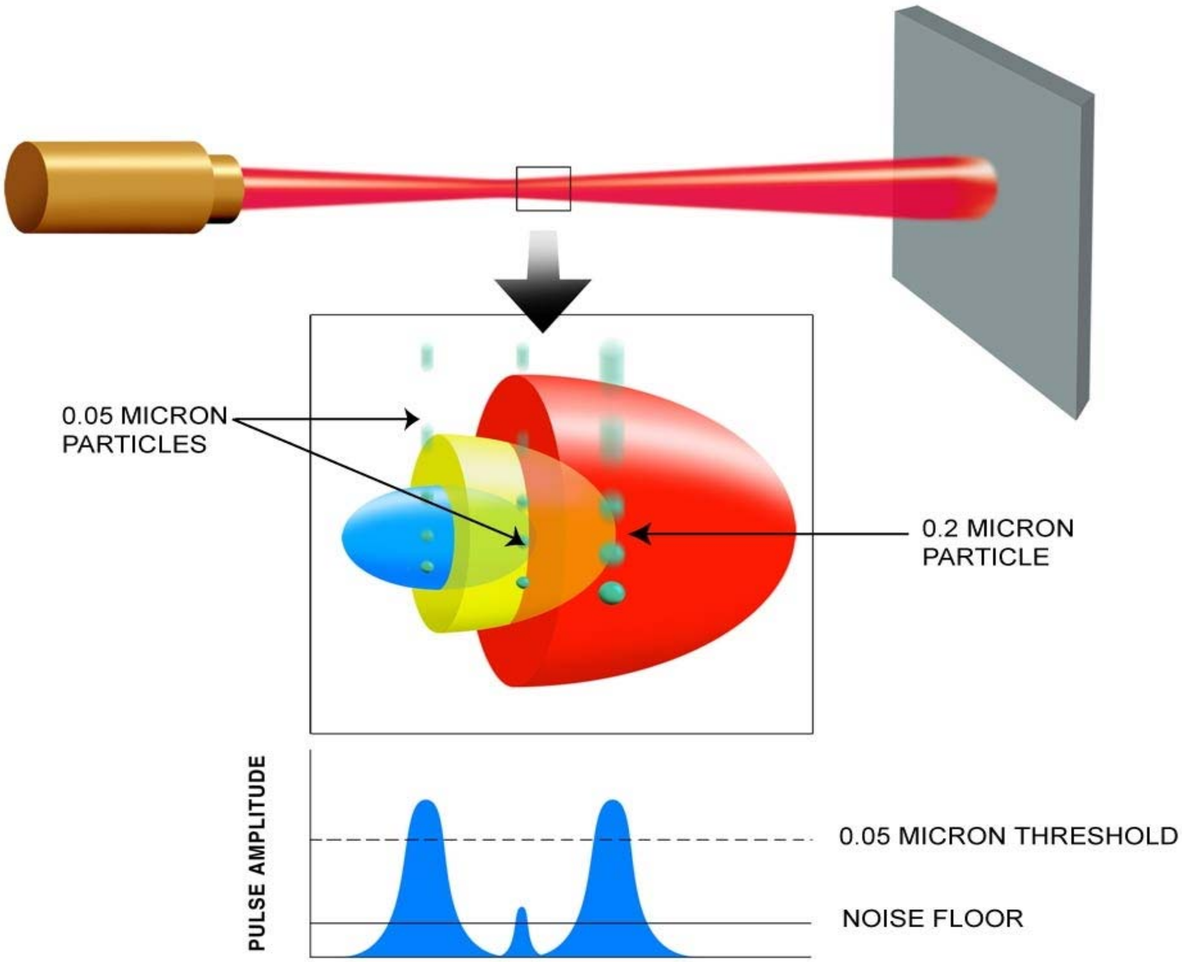
Instrument Considerations



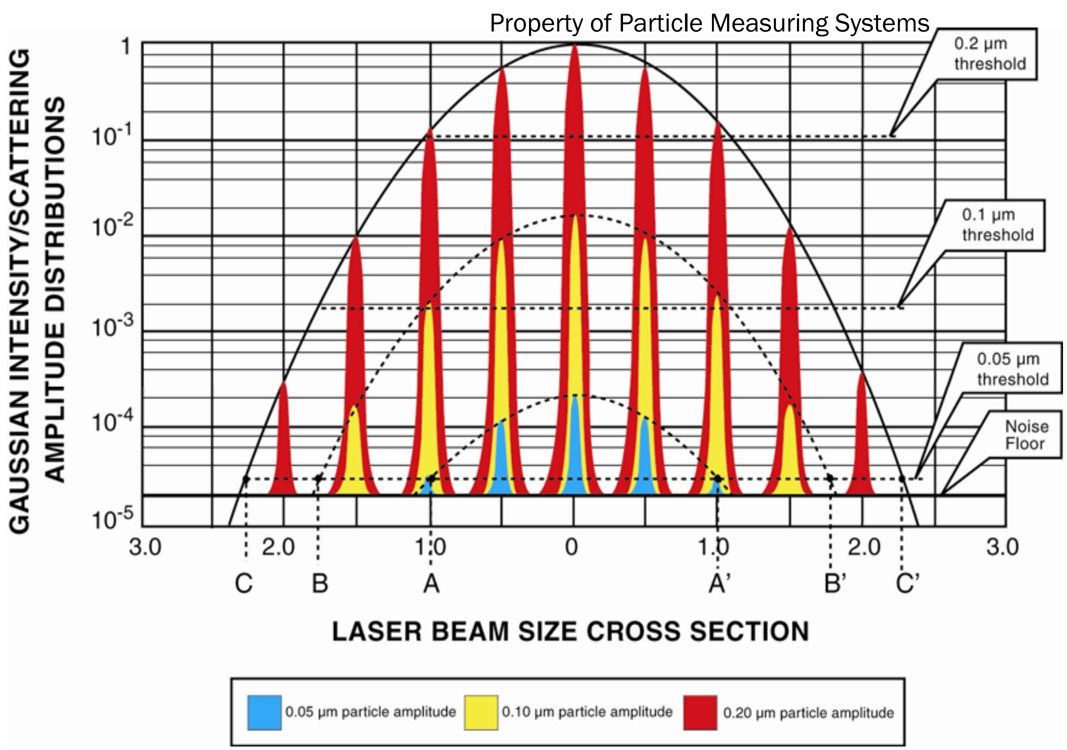
Laser Intensity Profile



Sizing vs. Laser Beam Profile



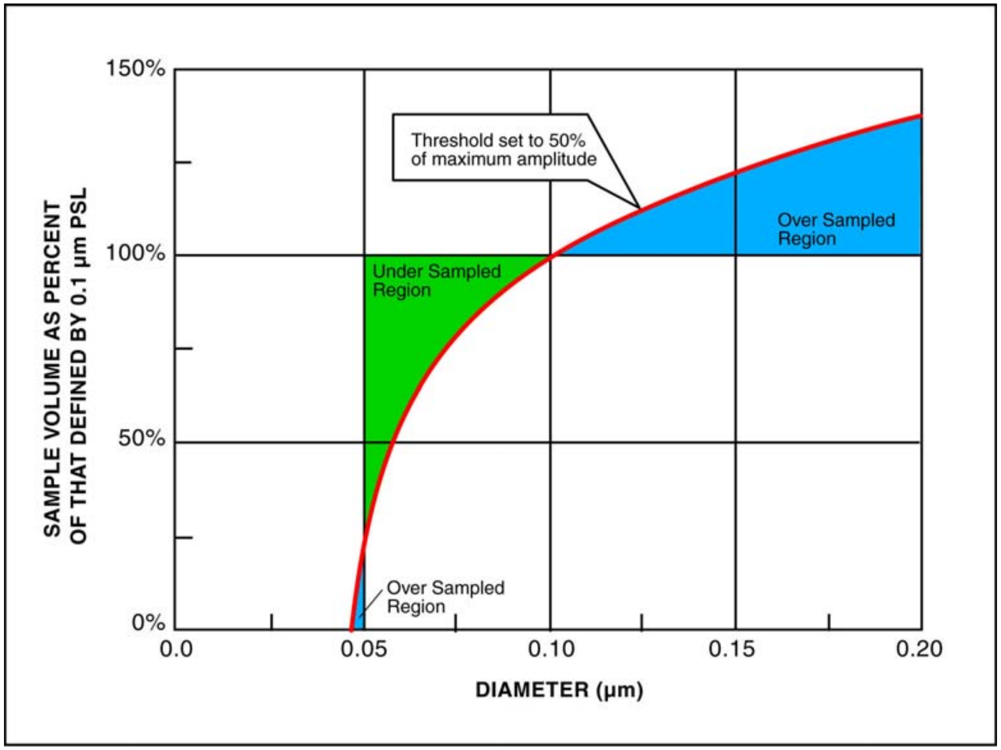
Size Thresholds vs. Laser Beam Profile



- Particles will only be sized most accurately – A to A′
- Large particles can be binned in the first channel
- 4x difference in particle size = 3,000X difference in signal

Sample Volume for Non-Volumetric Monitors

- Similar to volumetric, except a second over counting region exists
- Large particles are incorrectly sized in the first channel
- Over counting can be significant for poor OPC designs



Effect of Sample Volume

- Without measurement there is no control
  - Without data …
  - Assume 100 particles/L > 0.05 µm

Particle Counter	Sample Volume	Time to measure 1 Liter fluid
Ultra DI® 50	3.75 mL/min	4.4 hrs
HSLIS M50e	0.25 mL/min	2.8 days
Competitor	0.1 mL/min	6.9 days

Particle Counter	Sample Volume	Time to measure 1 particle (min)	Time to measure 20 particles (hr)
Ultra DI® 50	3.75 mL/min	2.7	.9
HSLIS M50e	0.25 mL/min	40	13.3
Competitor	0.1 mL/min	100	33.3

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Counting Statistics

- Poisson statistics are used when analyzing discrete events that are considered to be randomly distributed

- Particles are discrete events randomly distributed in time and space, so “particle counting” is described by a Poisson distribution

- Poisson statistics
  - Mean = λ
  - Variance = λ
  - Standard Deviation = $\sqrt{\lambda}$

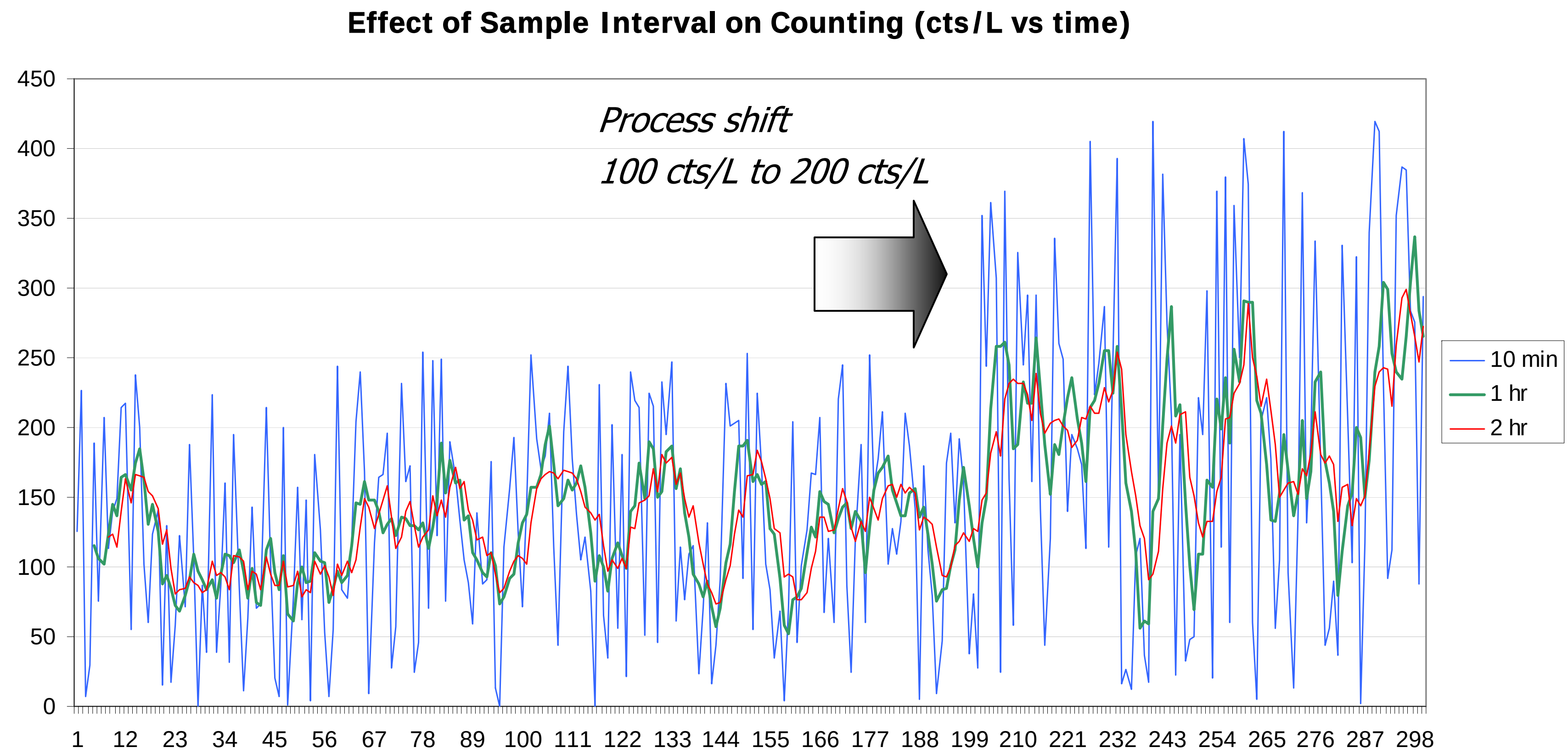
Implications: Variability in particle count measurements are largely dependent on the number of particles counted per unit time

Example

- Assume you have 100 particles per liter at > 0.05 μm
- Measured with Ultra DI® 50
- Control limit at 3 S.D. above average

Sample Interval	10 min	20 min	1 hr	2 hr	4 hr
Control Limit	250	210	160	140	130

Graphical Representation



Statistics Summary

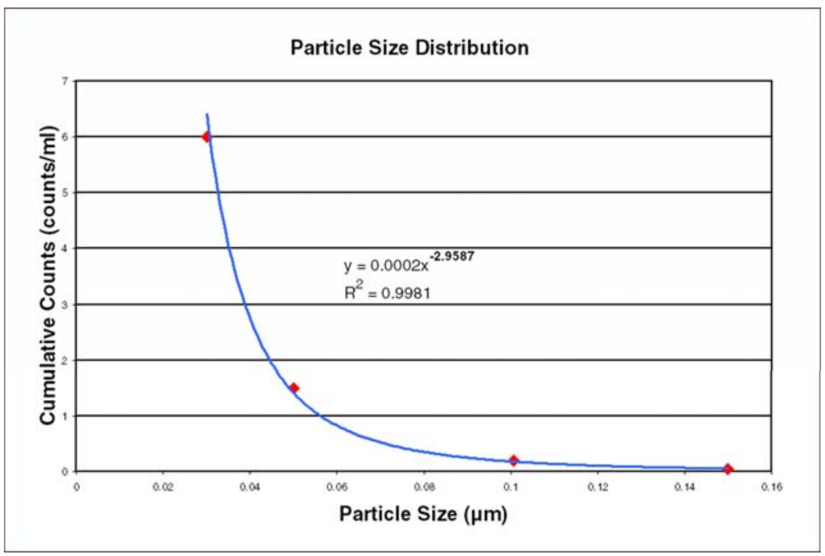
- Total number of particles measured can be very low
  - High variability in results occurs when only a small volume is measured and few particles counted
  - Resulting low quality data provides a poor measure of system performance
- Counting statistics often is the performance limiter
- The more particles counted per unit time:
  - More repeatable the measurement
  - Tighter control limits
  - Better understanding of process variations
  - Prevention of excursions

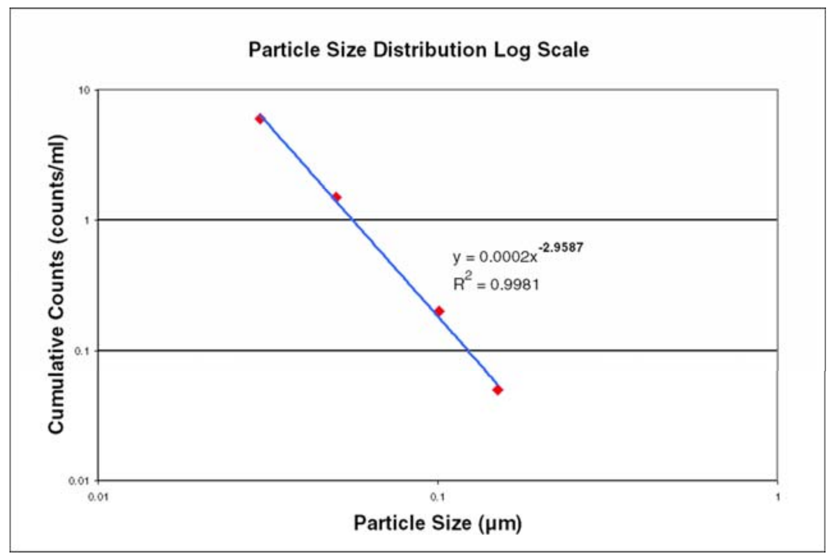
Zero Count Levels

- Counts in the absence of particles
- Ultra DI® 50 zero-count spec is < 50 cts/liter
- Assume zero particles
  - Zero count @ 50 per liter
    - Average 1 count every 5.33 min
    - 83 particles per liter 3 S.D. control limit with 120 min sample intervals
- Zero count affected by cosmic rays, electronic noise, etc.

PSD in Ultrapure Water

- Typical particle size distributions in UPW
  - 1/(particle diameter)^3 is typical for UPW
- More small particles than large particles





Impact of Size Sensitivity

- UPW system
  - 1/(diameter)^3 distribution
  - 1 particle/mL > 0.05 µm
- How many particles > 0.025 µm?
  - = (number of particles > 0.05 µm) * 1/(ratio of diameters)^3
  - 1 * 1/(.5)^3 = 8 particles/mL > 0.025 µm
- Rule of thumb
  - If particle diameter decreases by 2x
  - Number of particles/mL (rate) increases by 8x

Summary

- Particle monitoring is a key part of the ITRS roadmap
- Optical Particle Counters are based on "optical equivalent" measures of scattering to that of PSL's
- Sensitivity is only one measure of instrument performance
- A critical metric of performance is total particles counted
- Larger sample volume provides more data and improved counting statistics
- Properly operating UPW systems follow a $1/\text{diameter}^3$ particle size distribution

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