



Fundamentals of Particle Counters



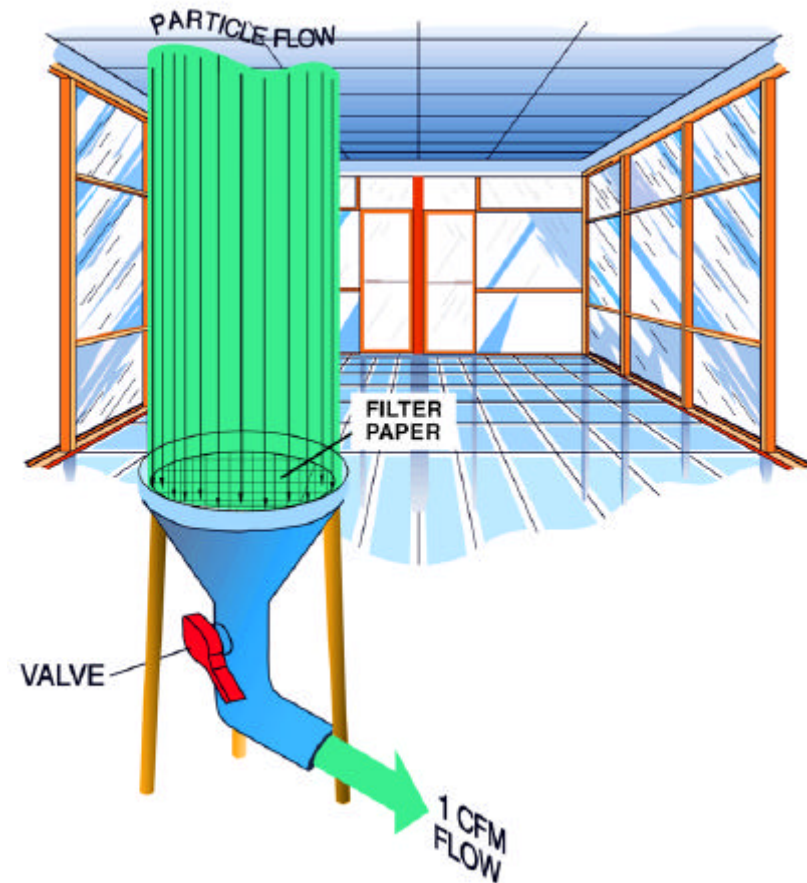
Outline



- **Foundation of Particle Counting**
- **Particle Counting History & Terminology**
- **Lasers**
- **Detector Technology**
- **Sampling the Media**
- **Particle Spectrometers, Monitors, Sensors, Counters**
- **Calibration**
- **Summary & Questions**

Foundation of Particle Counting

- Capture particles on filter paper
- Analyze with optical microscope or measure with a scale
- No real-time notification
- Slow, expensive
- Not very repeatable
- Particles can be analyzed for chemical content (technique still used by EPA)

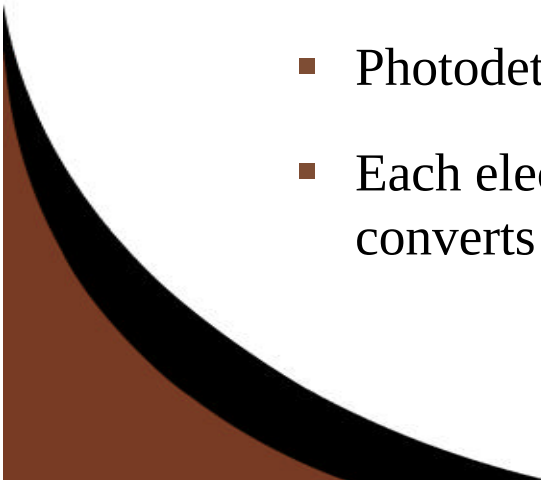


Optical Particle Counters



■ Fundamental Principal:

- When light travels from a material with a certain index of refraction (such as air) into a material with a different index of refraction (such as dust particles), we see scattered light.
- Optical particle counters (OPCs) employ mirrors and lenses to collect scattered light and focus this scattered light onto a photodetector.
- Photodetector converts the scattered light into electrical signals.
- Each electrical signal correlates to a particle, and the instrument converts these signals to numerical data.



Automated Optical Particle Counters



- **1950s: white light optical particle counters**
 - (Al Lieberman and others)
 - Achieved sensitivity at $0.5\ \mu\text{m}$
 - First applications were for the military
- **1970s: laser particle counters**
 - (Dr. Robert Knollenberg)
 - Achieved sensitivity at $0.1\ \mu\text{m}$
 - First applications were meteorological research

Meteorological Probes



- Analyze atmospheric contamination in pollution control or weather studies
- Measure water droplets, ice crystals, or condensation nuclei
- Aircraft-mounted sensors used by the NOAA & NASA



Air/Gas OPC History



1950s

white light OPCs

1960s

1970s

laser imaging OPCs
laser scattering OPCs

1980s

laser cleanroom OPCs .3 μ M @ 1 cfm
laser cleanroom OPCs .2 μ M @ 1 cfm
gas OPCs .1 μ M @ 1 cfm
laser cleanroom OPCs .1 μ M @ 1 cfm
laser cleanroom OPCs .07 μ M @ 1 cfm
gas OPCs .07 μ M @ 1 cfm
vacuum OPCs .2 μ M
1990s
laser cleanroom OPCs .05 μ M @ .1 cfm
vacuum OPCs .08 μ M
2000s
laser cleanroom OPCs .06 μ M @ 1 cfm

Liquid OPC History



1950s

1960s

1970s

1980s

1990s

2000s

liquid volumetric OPC .5 μ M@80mL/min
liquid non-volumetric OPC .1 μ M@100mL/min
liquid volumetric OPC .3 μ M@30mL/min
liquid non-volumetric OPC .05 μ M@25mL/min
liquid volumetric OPC .2 μ M@50mL/min

liquid inviscid non-volumetric OPC .1 μ M@50mL/min

liquid non-volumetric OPC .05 μ M @ 1000mL/min
CMP slurry monitoring

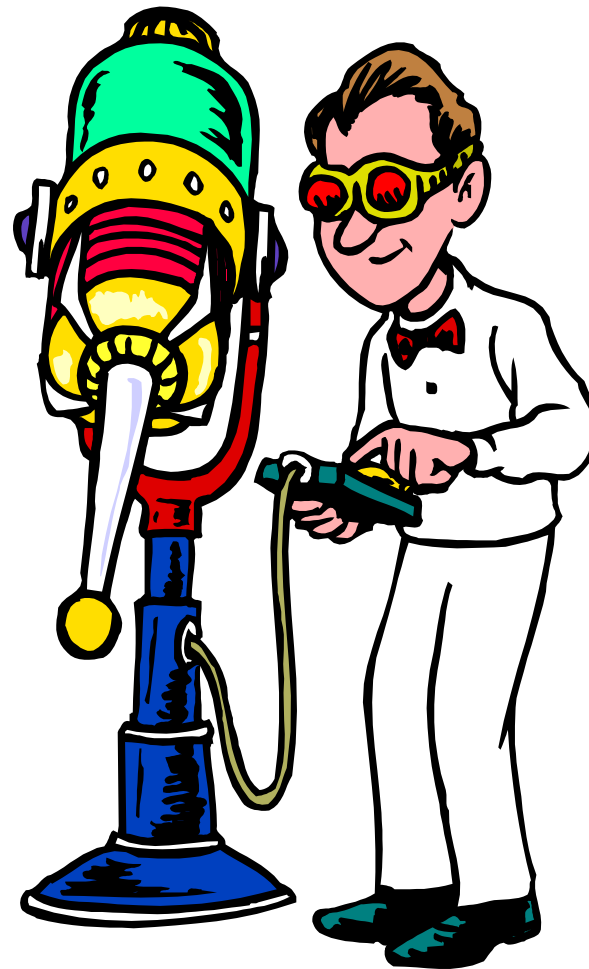
↓ liquid non-volumetric OPC .03 μ M @ 200mL/min

Definitions of Terms



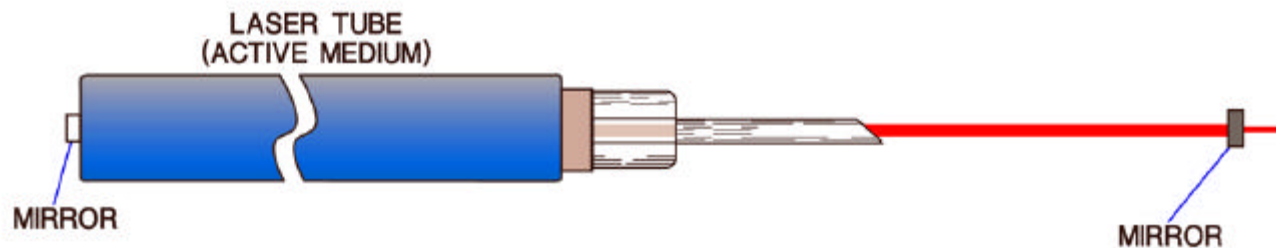
- **Media:** the material in which particles will be detected (air, gas, liquids)
- **Sample Flowrate:** the volume of fluid passing through the particle counter during a certain time duration
 - cubic foot per minute; milliliter per minute
- **Sample Percentage:** the portion of the total sample analyzed for particle content
- **Sample Volume:** $\text{Flowrate} \times \text{Sample Percentage}$
- **Size Resolution:** the ability to discriminate particle diameters
- **Sensitivity:** the smallest particles an instrument can detect
 - “higher” sensitivity = smaller particle detection
- **Zero Counting:** a measure of an instrument’s ability to distinguish electronic noise from particle contamination

Laser



Laser Types

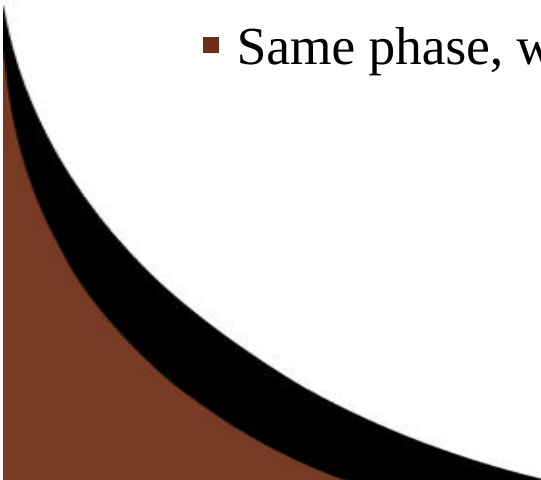
- **Particle counters commonly employ 3 type of lasers:**
 - Gas lasers: Helium Neon (HeNe) emitting at 633 nm
 - Solid-state lasers: Neodymium-Yttrium Aluminum Garnet (frequency doubled Nd-YAG) emitting at 532 nm
 - Semiconductor lasers: diode laser emitting at 680 nm



Laser Basics



- **Light Amplification by Stimulated Emission of Radiation (LASER)**
- **Lasers include an active medium and optics**
- **Stimulated emission**
 - Excite the atoms/molecules of the medium
 - Photon bumps into atom/molecule
 - A second photon emits
 - Same phase, wavelength, and direction as original



HeNe Laser: The “passive” cavity



- Helium Neon (HeNe) gas-filled tube connected to a constant current source
- Mirrors at ends of cavity (not 100% reflective) allow part of the laser beam to leak out
- Laser power: 5 milliWatts
- Cavity power exceeds 5 Watts
- Beams of coherent light leaking from mirrors available for use in grocery scanning, light shows, particle counting, etc.



HeNe Laser: The “passive” cavity



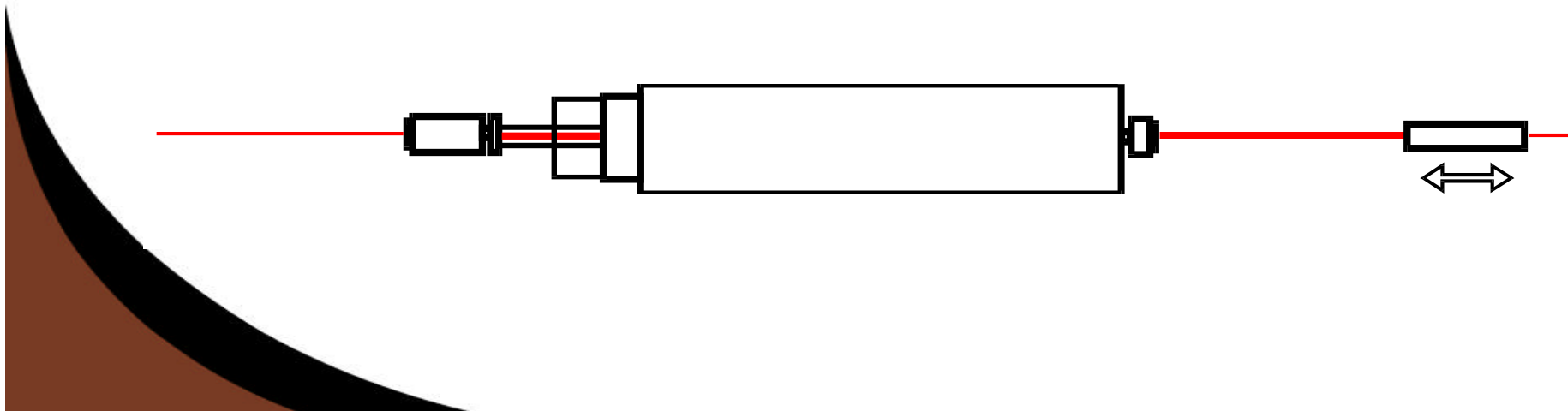
- One mirror replaced with a window; mirror moved away from tube
- Particles pass through full power of laser's cavity
- Laser power: 100 Watts
- Cavity powers exceed 1400 Watts
- Higher performance and higher maintenance



HeNe Laser: Pumping up a “passive” cavity



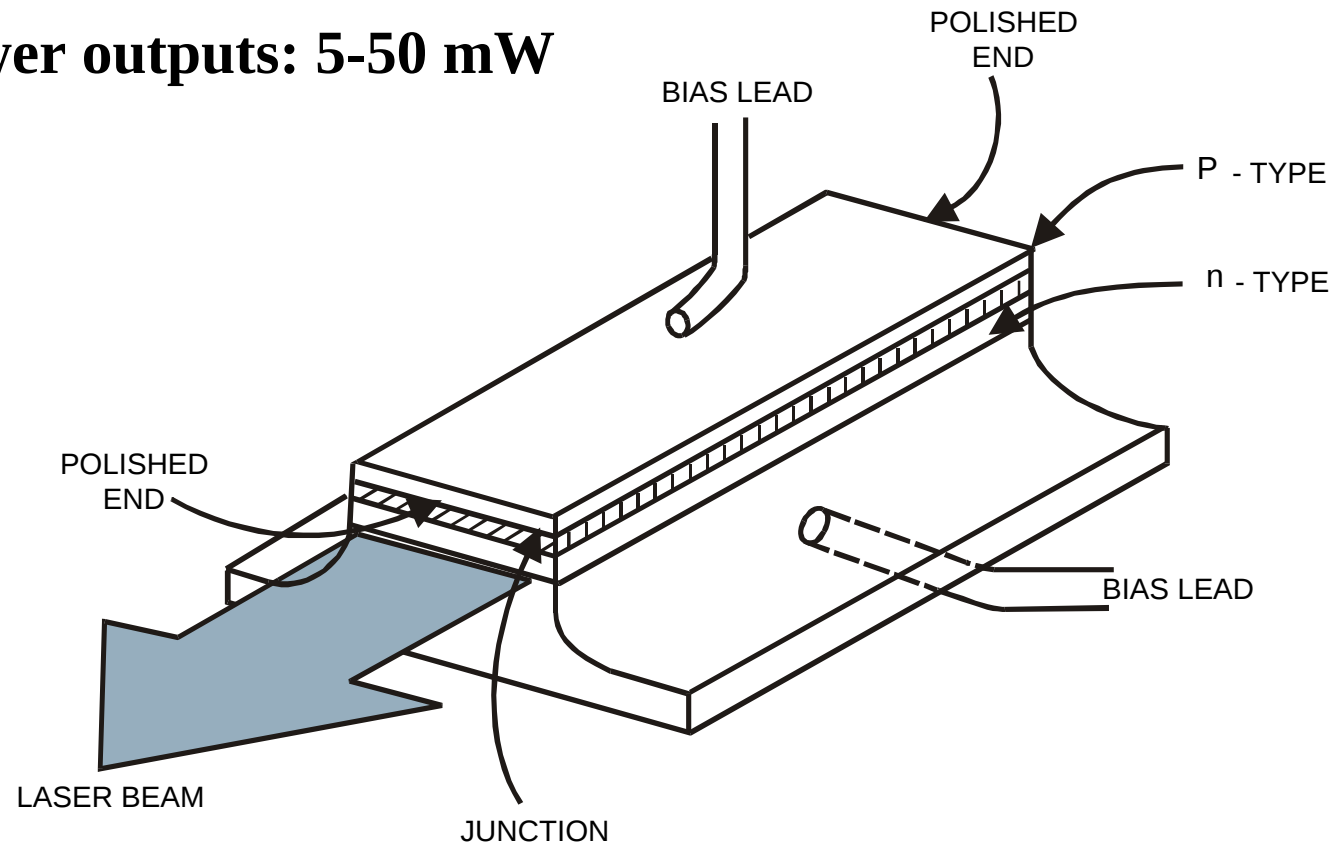
- External mirror placed upon oscillating quartz crystal which reflects light back into cavity
- Changing path length breaks up standing waves between laser's output mirror and external mirror
- Not quite as powerful as Active Cavity but lower maintenance
- PMS patented



Laser Diodes



Power outputs: 5-50 mW

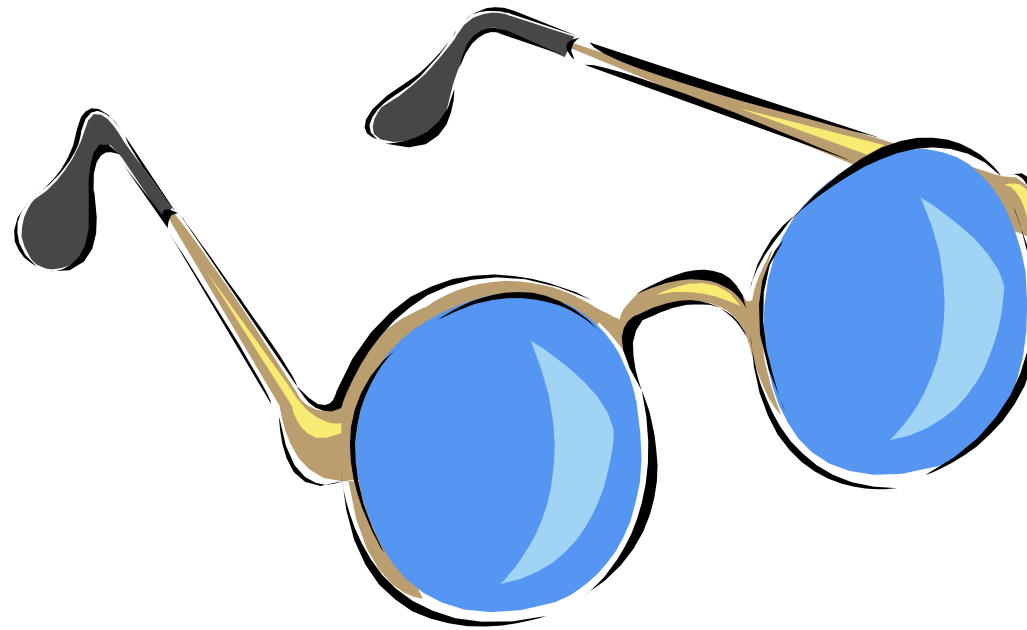


Laser Diodes



- **Advantages/disadvantages of laser diodes**
 - Small
 - Inexpensive
 - Reliable
 - Constant power output
 - Sensitive to high temperatures ($>40\text{ C}$)
 - No sample cavity, so generally used for lower sensitivity instruments
 - Sensitive to Electrostatic Discharge (ESD)

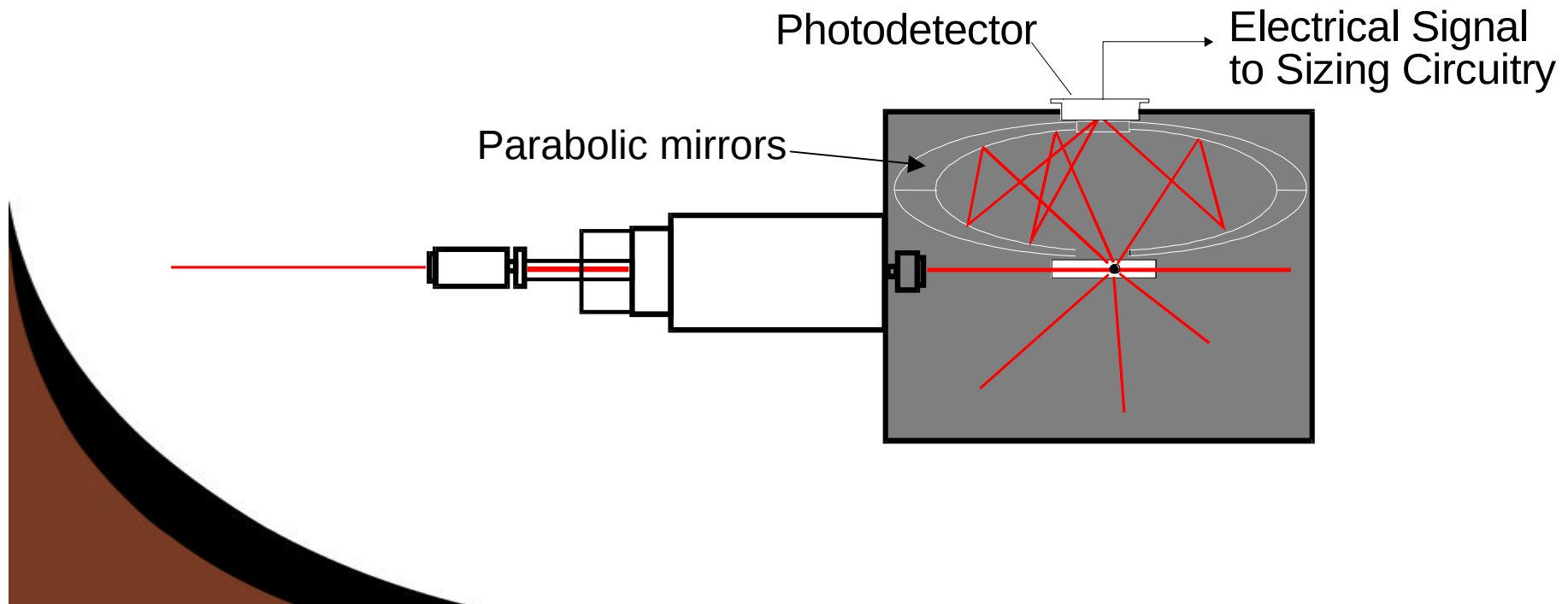
Detector Technology



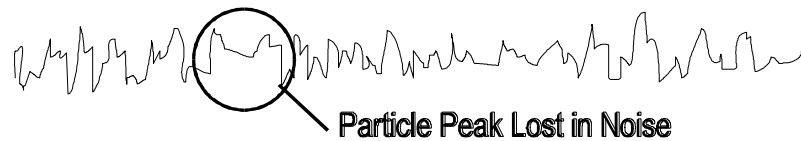
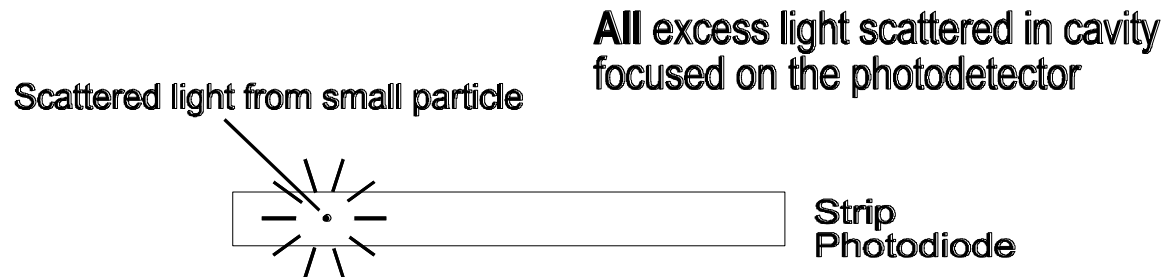
OPC Basics



- **Collect scattered particle light and convert it to an electrical signal**

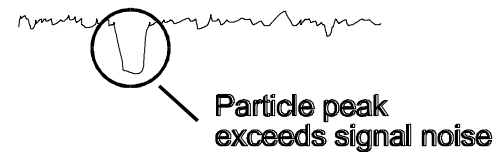
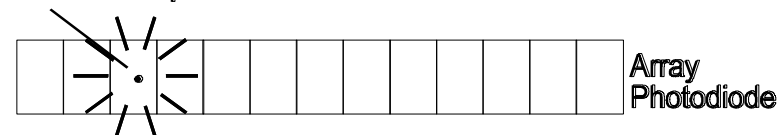


Multiple Element Array Photodetector



Excess scattered light in cavity is divided among many elements

Scattered light from small particle

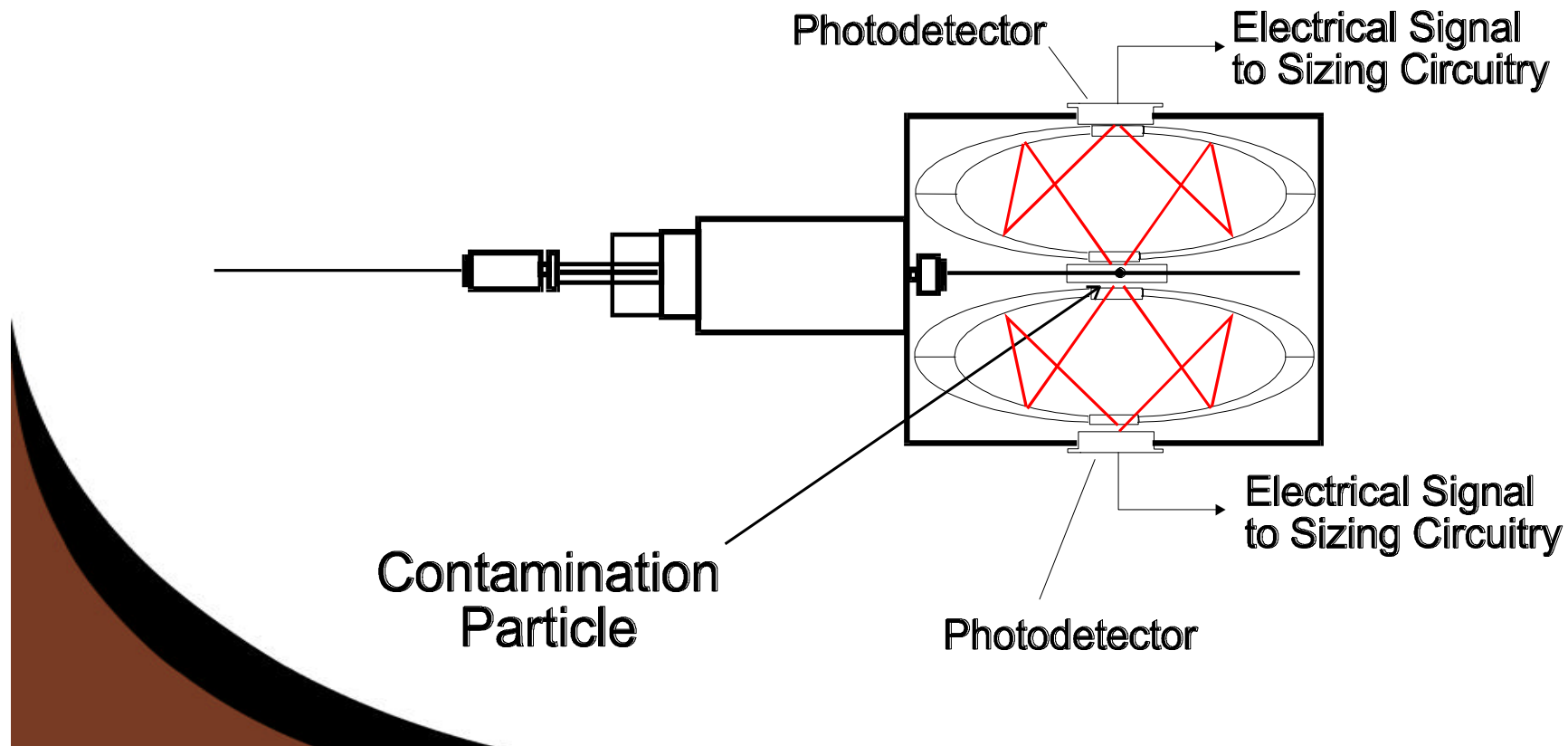


- PMS patented

Low-Noise Particle Counter



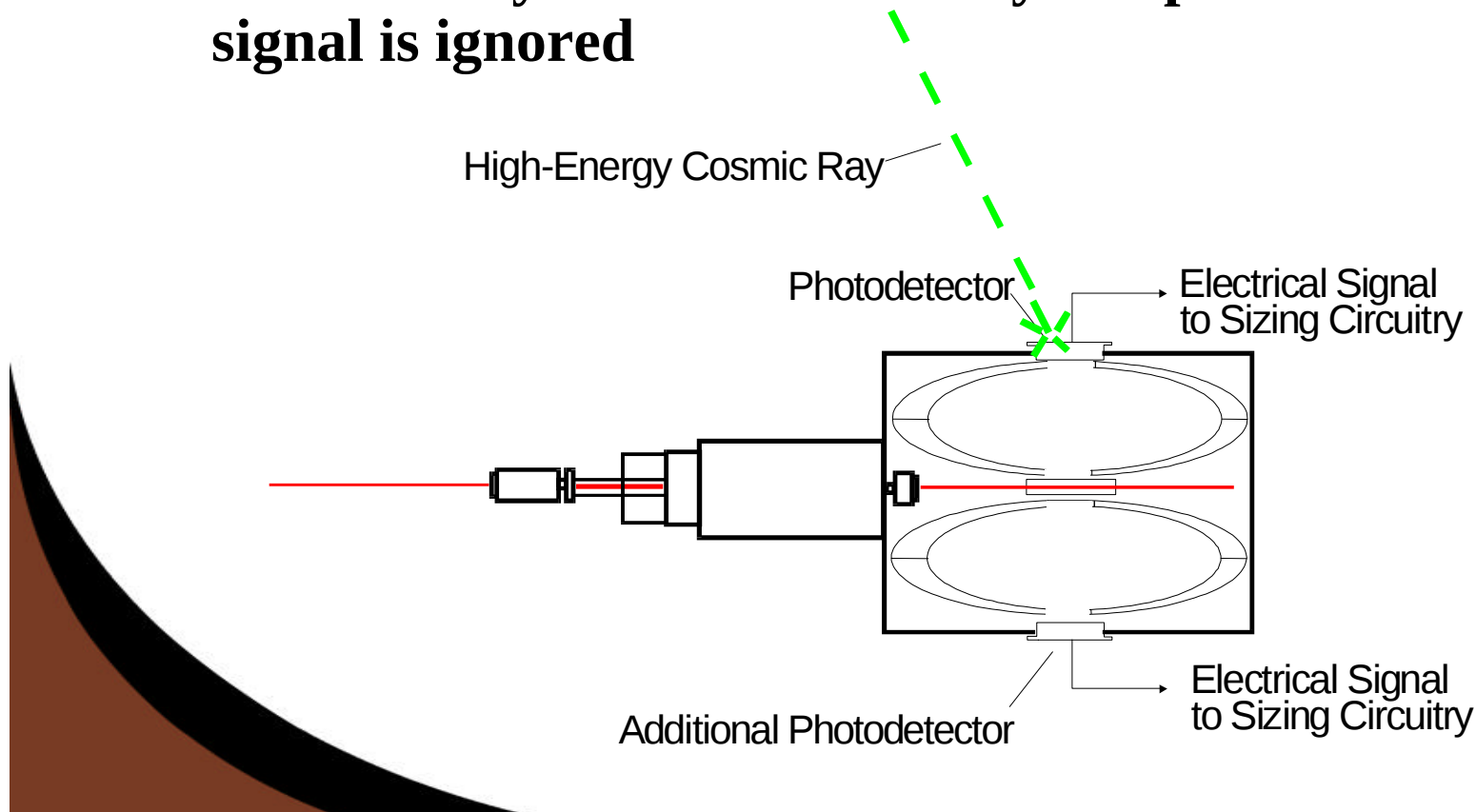
- Counts only those particles simultaneously sensed by both photodetectors



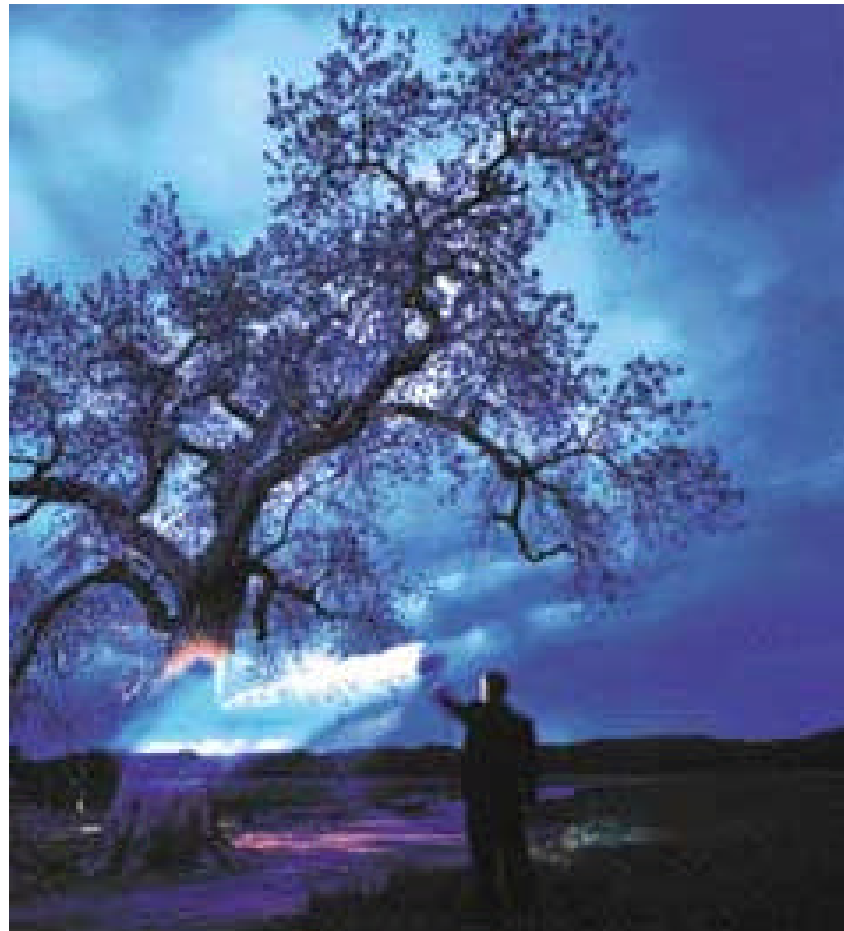
Low-Noise Particle Counter



- Cosmic rays (high-energy subatomic particles) affect extremely sensitive photodetectors
- If cosmic ray interacts with only one photodetector, signal is ignored



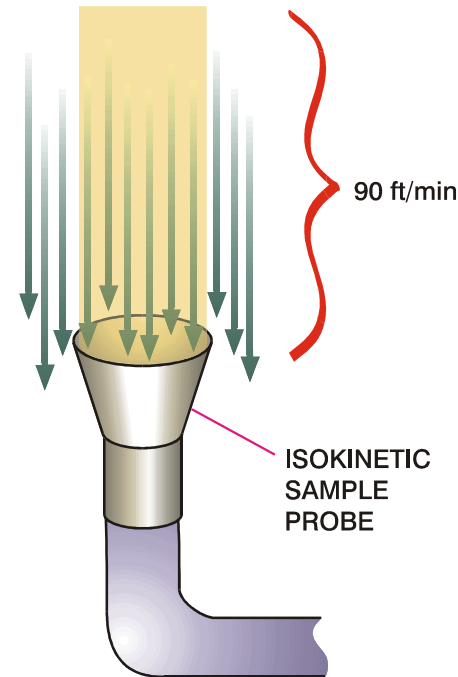
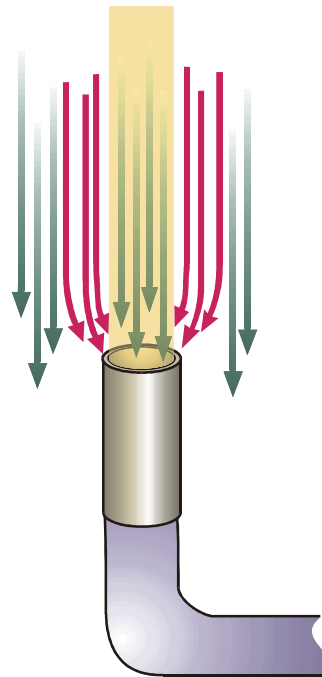
Sampling the Media



Isokinetic Sampling



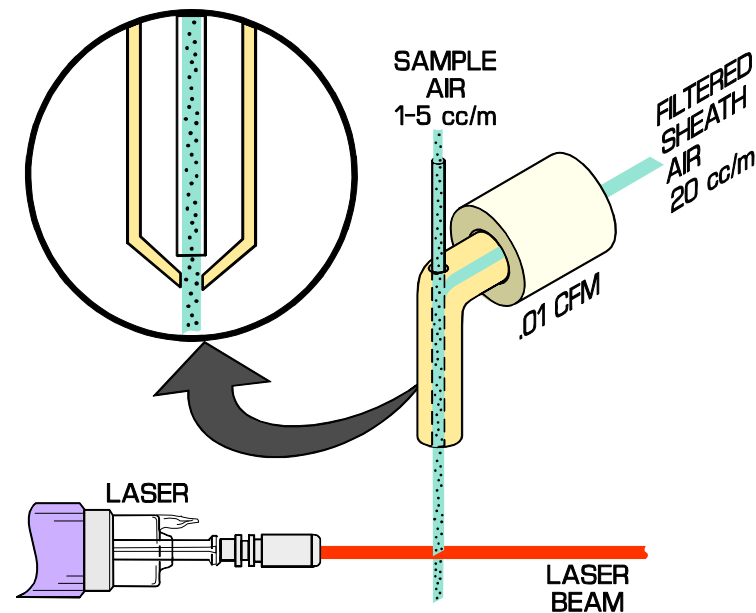
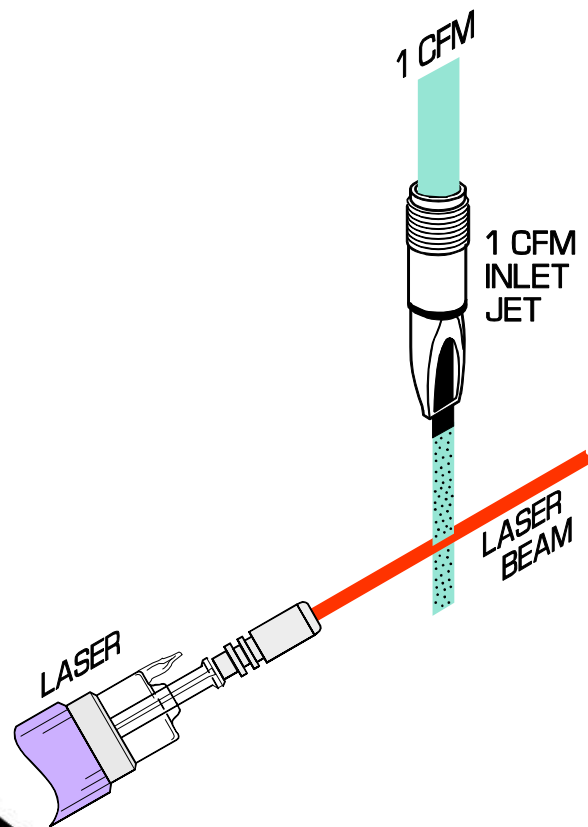
- Capture particles at the same velocity as the sample air
-- preventing distortion of the particle size relationships



Aerosol Particle Counter



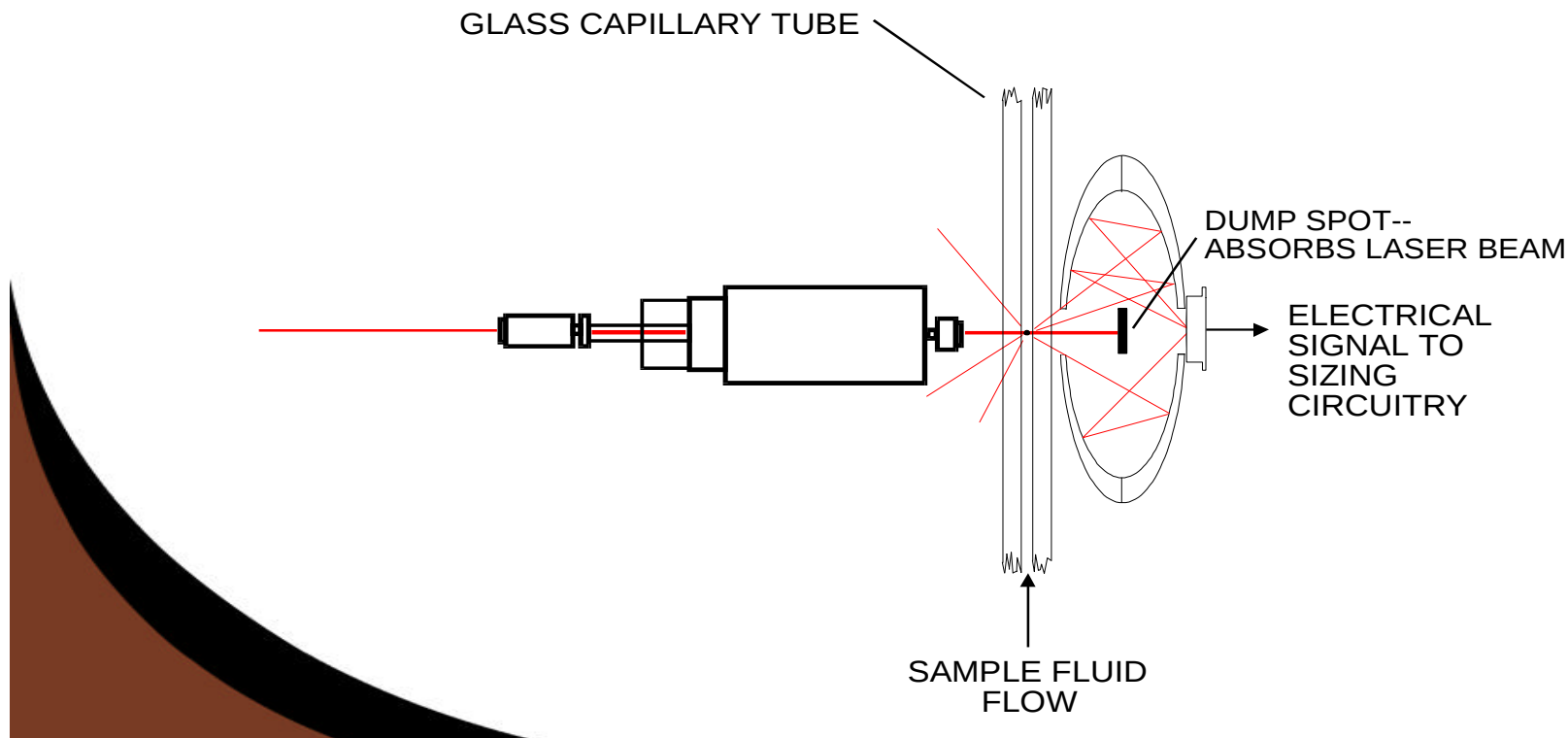
- Inlet Jets



Liquid Particle Counter



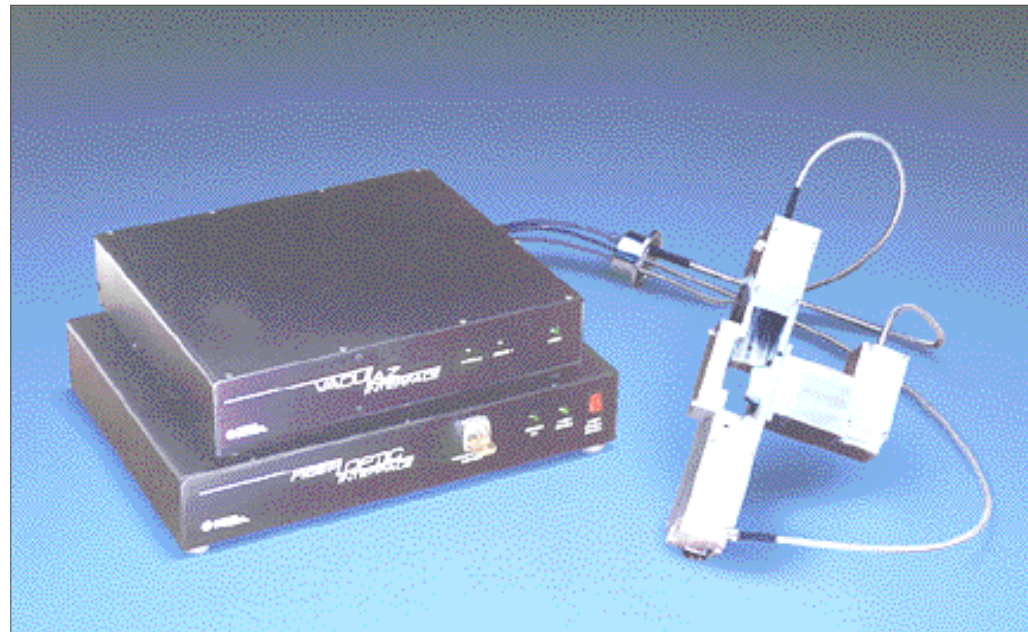
- Utilize an optically transparent flow cell or capillary to transport particles through laser beam
- Light scattered from particles must compete with light scattered from air/glass and glass/liquid interfaces



Vacuum Particle Counter



- Utilize a view module or head assembly to inspect particles passing through a laser beam
- Viewing components detect particles within harsh environments--while isolating electronics



Variant Technologies



■ Scattering vs. Extinction

- Scattering particle counters measure the amount of *scattered* light
- Extinction particle counters measure the shadows or areas where the light is *extinct*

■ Volumetric vs. In-Situ

- Volumetric particle counters look at the entire *volume* of a sample
- In-Situ particle counters look at a small portion of a sample or where the optics are “*in position*”

* *In-Situ* is Latin for “in position.”

Maximum Particle Concentration Specification

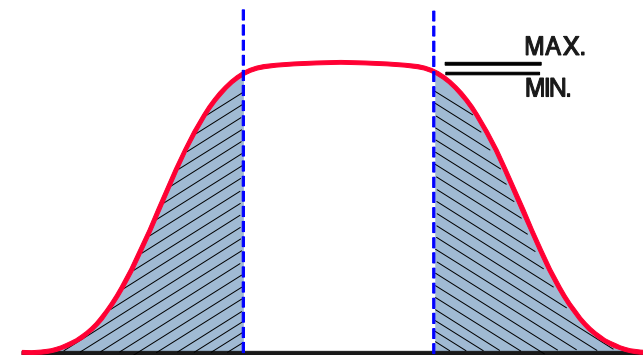
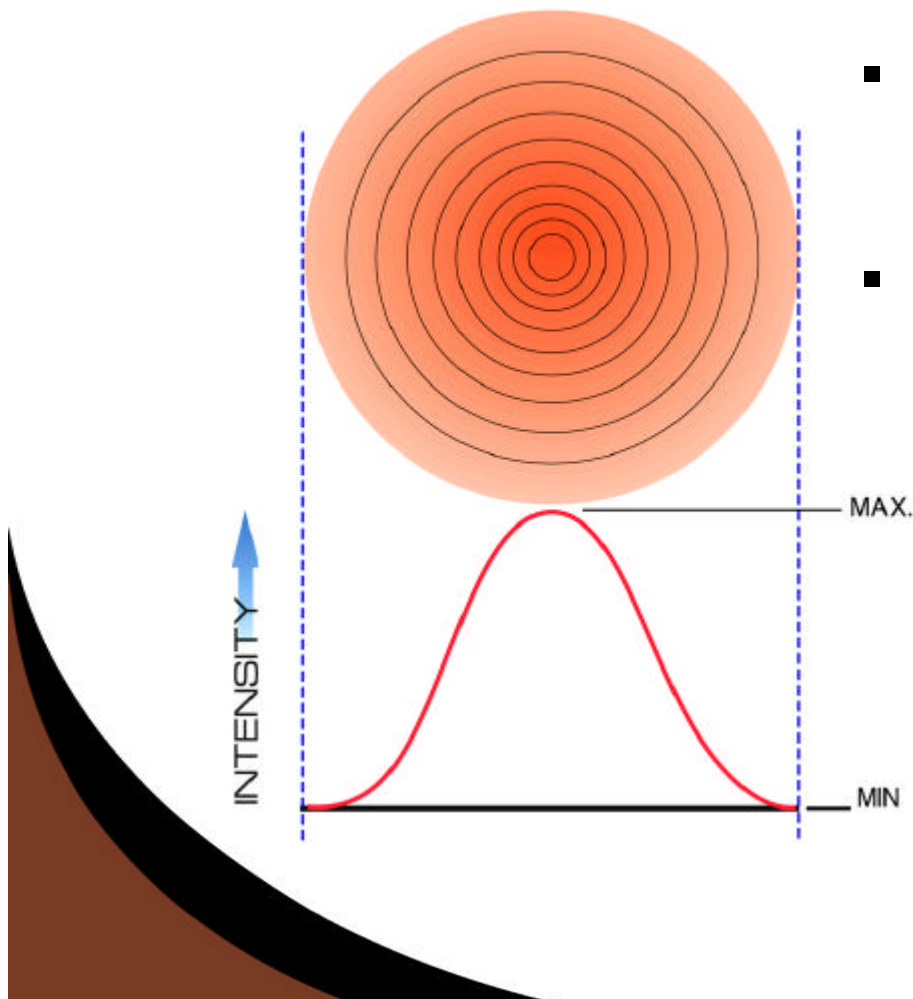


- **Electronics count one particle at a time**
- **Light scatters from all particles in the laser beam**
- **Coincidence Loss = Number of uncounted particles**
- **Particle coincidence is accompanied by a perceived shift in size distribution**
- **Shift occurs when multiple particles enter the laser beam at the same time and count as one big particle**
- **Maximum concentration occurs at 10% coincidence loss, as determined by comparison between the particle counter and a particle spectrometer (with superior sensitivity to the instrument under test)**

Sizing Resolution



- Center of laser beam is brighter than edge
- Particles crossing center of beam will size larger than similar particles crossing edge of beam
- Beam-shaping lenses and masks can optimize the beam and produce more consistent sizing



Spectrometers, Monitors,
Sensors, & Counters . . . OH
MY!



Spectrometers

- 15 channels and greater
- High resolution
- High sensitivity
- More expensive for equivalent particle sensitivity



Monitors

- Fewer size channels
- Low resolution
- Sample volume defined for only one particle
- Less expensive for equivalent sensitivity



Particle Spectrometers vs. Particle Monitors



Spectrometers

- Use only the brightest, most uniform portion of the laser beam
- Provide precise particle size resolution
- Important for filter media characterization or particle research

Monitors

- Have poor resolution
- Have sample volume growth
- Cost less for equivalent sensitivity
- Require less maintenance

Sensors



- No local control or display
- Few channels
- Status of critical functions continuously monitored
- High sensitivity



Counters



- Local control and display
- On-board printer and data communication interface.
- May control additional devices
 - T/RH, DAP, etc.



Condensation Nucleus Counter (CNC)



- As small as $0.01 \mu\text{m}$ particle sensitivity
- Sensitive below HEPA filters' most-penetrating diameter
- **Considerations**
 - No sizing reported
 - Low flow rates
 - High-maintenance
 - Consumes fluids
 - e.g. Butyl Alcohol

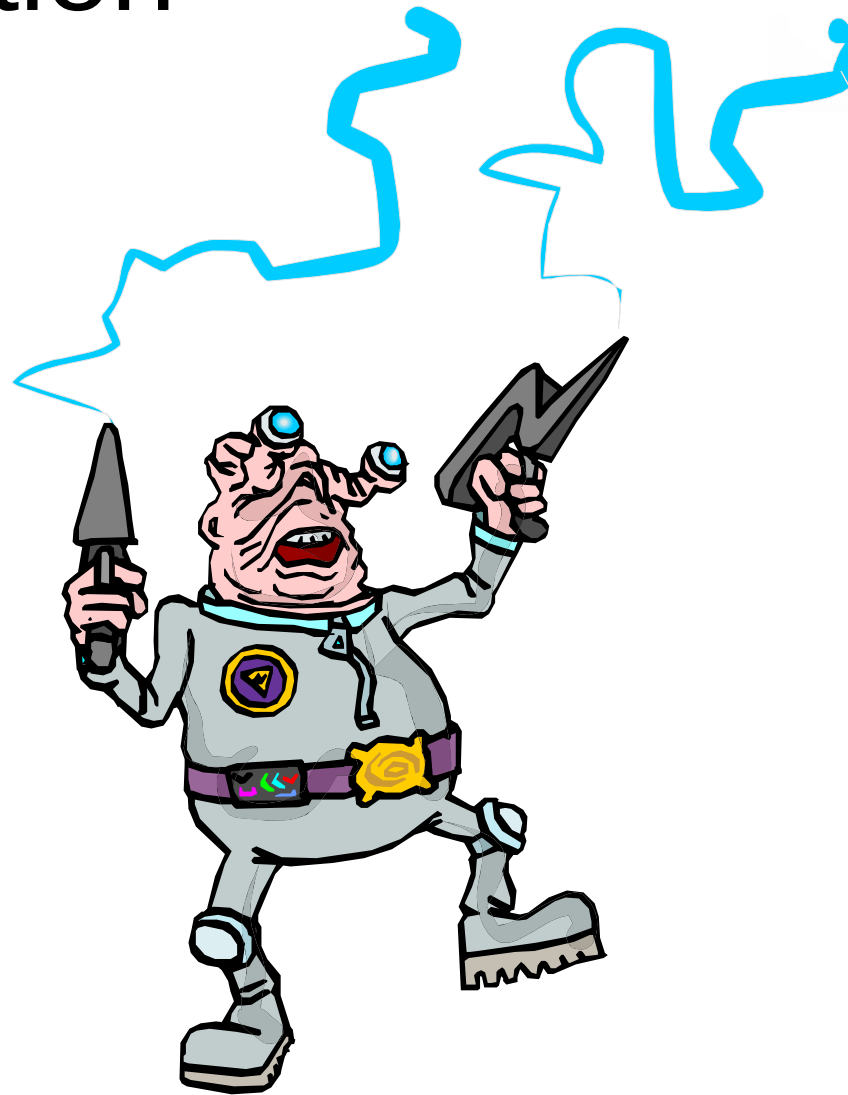


Sensitivity vs. Flowrate



- Enhancing sensitivity necessitates reducing background noise . . .
- Background noise is reduced by decreasing sample flowrate or sample volume, but . . .
- *In most media, one can acquire more data at higher sample volumes rather than count smaller particles at lower sample volumes*

Calibration



Particle Counter Calibration



- **Verify instrument functionality**
- **Clean instrument optics and sampling chamber**
- **Calibrate using precision-diameter particles**
- **Test first-channel sensitivity through comparison with a particle spectrometer**
- **Test count rate by comparison with a count-standard particle solution (e.g. *Clintex*)**
- **Perform zero-count tests**
- **Certify instrument**

Calibration Materials



- **Sizing curves**
- **Polystyrene Latex spheres (PSLs)**
- **Glass beads**
- **Air Cleaner Fine Test Dust (ACFTD)**
- **Prepackaged PSL count-standard solutions**
(Clintex particles)

Calibration Standards



- **ASTM F-328, F-649**
 - (aerosols)
- **ASTM F-658, F-1226**
 - (liquids)
- **ANSI Z540**
 - (traceability)
- **BS EN ISO9001:1994**

Pharmaceutical Calibrations



- **‘Before & After’ status report**
- **Documentation compliant to validation norms**
 - Equipment details & certifications
 - Latex certificates
 - Environmental conditions
 - Applicable standards & methods
 - Method statements

Summary



- Always bear in mind that “*particle counters don’t count particles*” - they detect and tally scattered light from particles
- Reported particle diameters correlate to similar amount of scatter from uniform spheres of polystyrene latex — real-world contaminants are different shapes and materials
- Light scattered from particles must compete against background scatter from the media. Detecting small particles or greater sample flow rates necessitates increased instrument complexity, more maintenance, and higher costs

Questions?

