0.1μm Particle Counting Technology and Applications

Abstract

- ★ The data storage industry continues to drive contamination control requirements with new applications and increased performance requirements.
- ★ Various optical particle counting technologies have been developed in response to these drivers.
- ★ This presentation will survey the various technologies available for 0.1µm airborne particle detection and highlight the features and benefits of solid state laser based solutions. In addition the presentation will summarize how this technology addresses key requirements of emerging new applications beyond basic cleanroom measurements.
- ★ Finally the presentation will summarize how solid state technology can lead to other 0.1um solutions for future equipment monitoring applications.

Outline

- ★ High Sensitivity Particle Counting Technology
  - ★ Scatter Theory
  - ★ ISO 21501-4 Specifications
  - ★ ISO 21501-4 Calibration And Test Procedures
  - ★ Performance Considerations (Precision & Noise)
- ★ Technology Solutions
  - ★ Helium Neon Laser Based Technology
  - ★ Diode Pumped Solid State (DPSS) Laser Technology
  - ★ Laser Diode Technology
  - ★ Detection Technology
- ★ Applications
  - ★ Semiconductor Applications
  - ★ Data Storage Applications
- ★ Future Technology
- ★ Summary

High Sensitivity Particle Counting Technology

Particle Counting Technology

Two Particle Detection Methods

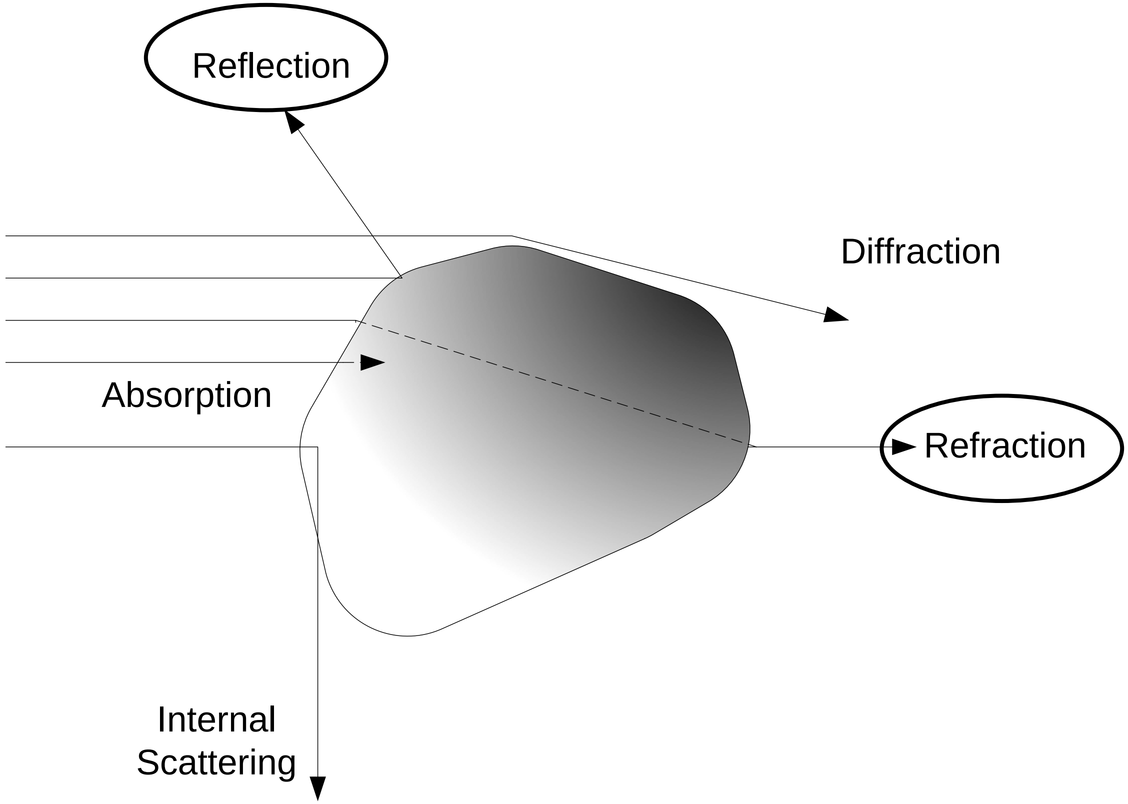
1) Light Extinction (Light Blocking)

Attenuation of light signal.
Measurement of particles >1.0 micron

2) Light Scattering

Redirected light energy (scattering).
Measurement of particles >0.05 micron

Light Interaction with a Particle



Types of Light Scattering

- ★ **Mie**

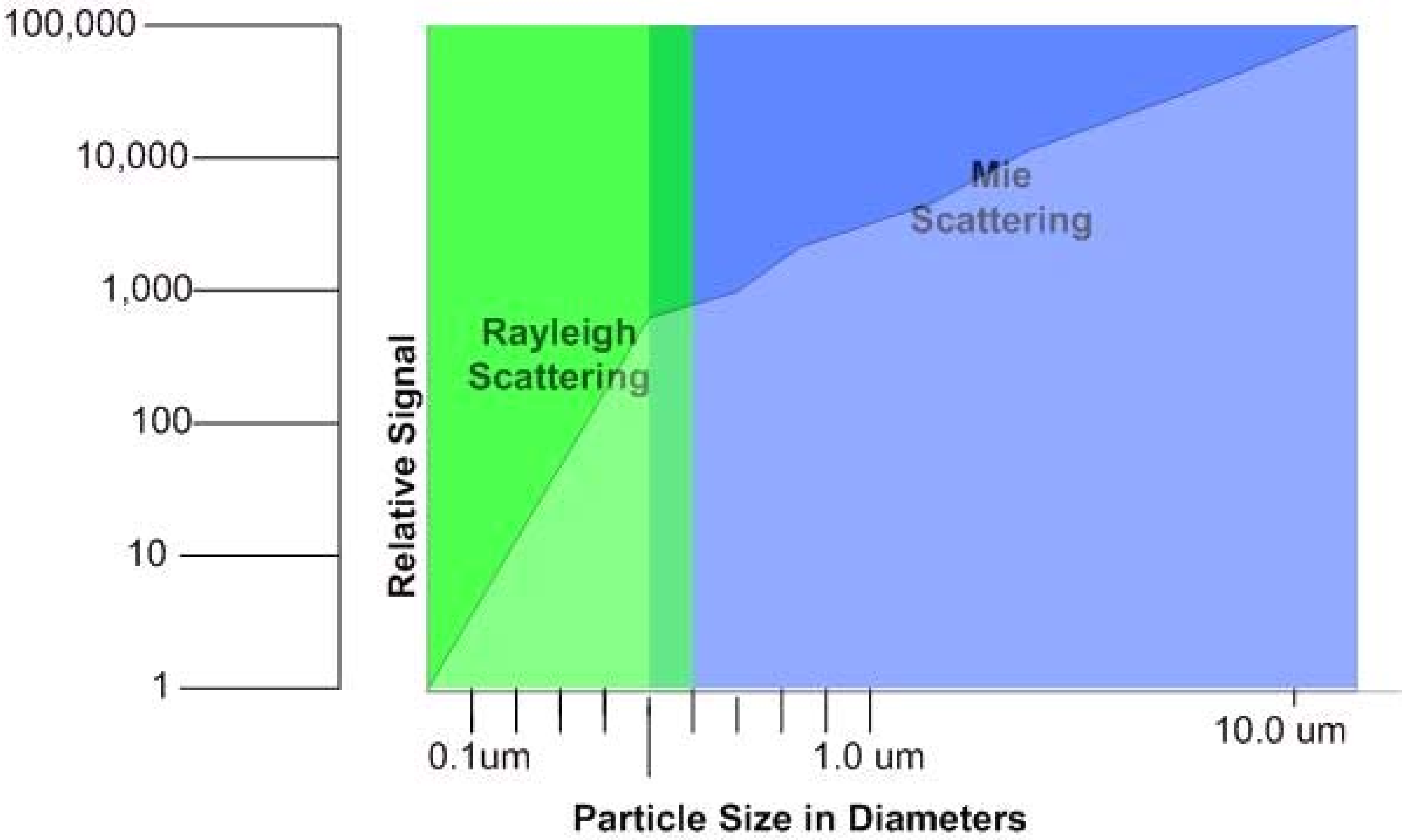
  Scattering of electromagnetic waves by particles approximately the same size as (or slightly larger than) the wavelength of interest.

- ★ **Rayleigh**

  Scattering of light due to particles with sizes much less than the wavelength of scattered light.

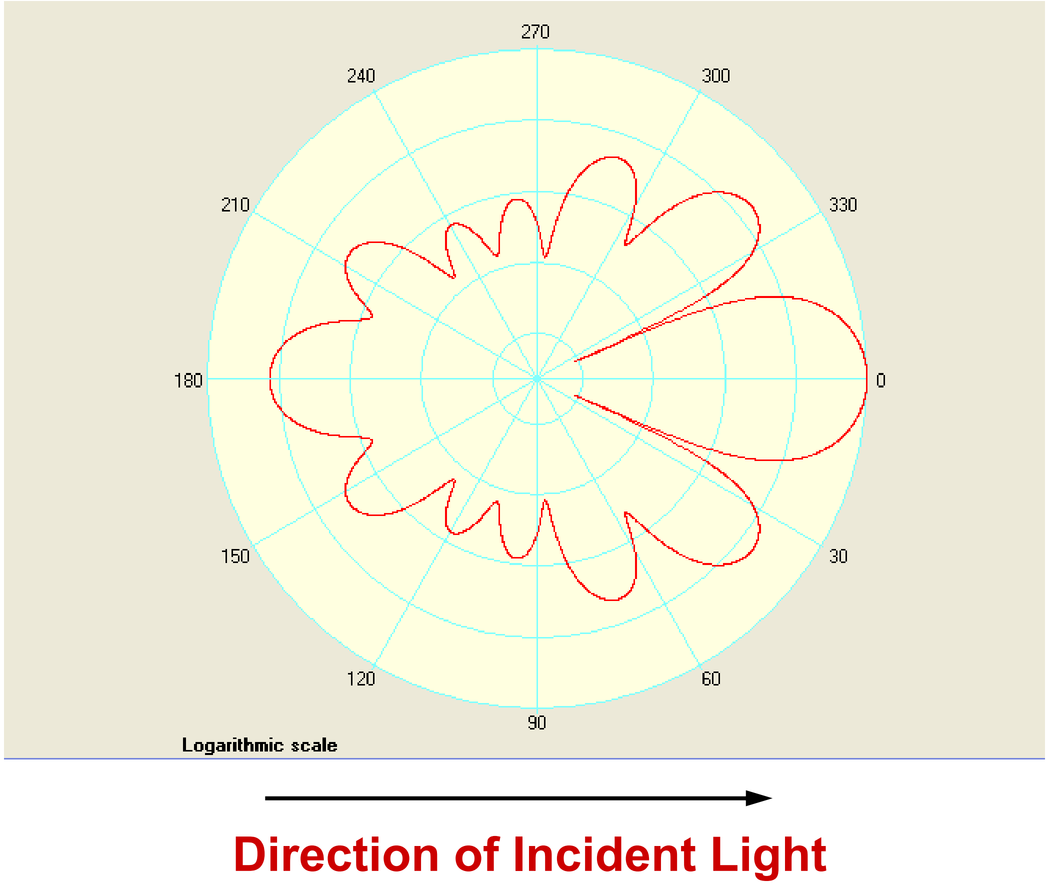
Visible light wavelength: 400-700nm

Scatter Intensity vs. Particle Size



Types of Light Scattering

- ★ Mie scattering
- ★ Examples of Mie scattering
  - ★ Clouds
  - ★ Fog



Types of Light Scattering

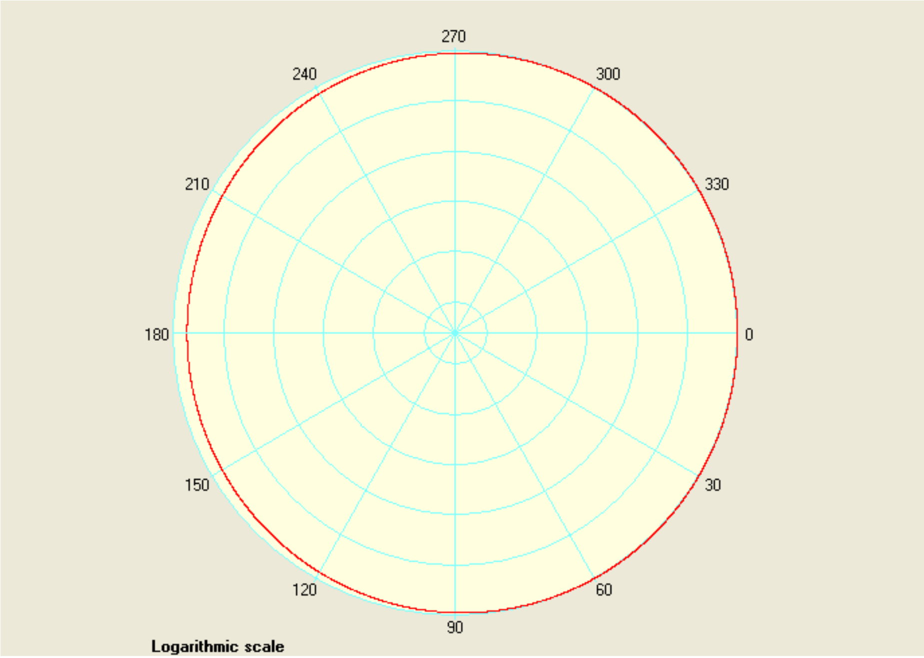
- ★ Rayleigh scattering
- ★ Example of Rayleigh
  - ★ blue sky

$$I \propto \frac{d^6}{\lambda^4}$$

I = intensity of light scattered

d = diameter of the Particle

λ = wavelength of light



Direction of Incident Light

Particle Counter Components

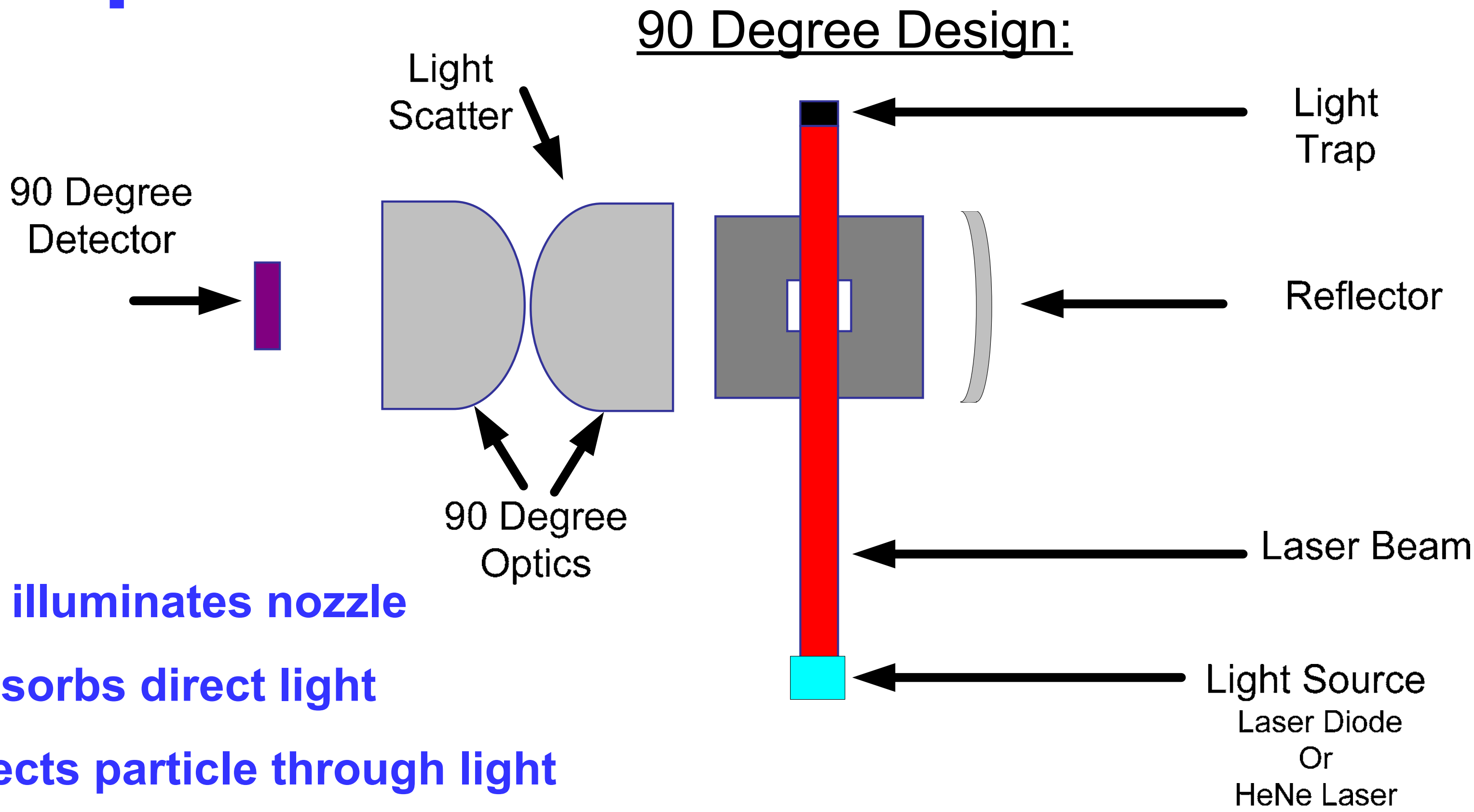
There are three basic elements in all particle counting systems:

1) The Sensor
The Sensor is the device that detects particles using light scattering or blocking techniques

2) The Sample Delivery System
The fluid sample is delivered to the sensor by some method

3) The Counting Electronics
The particle counts are processed

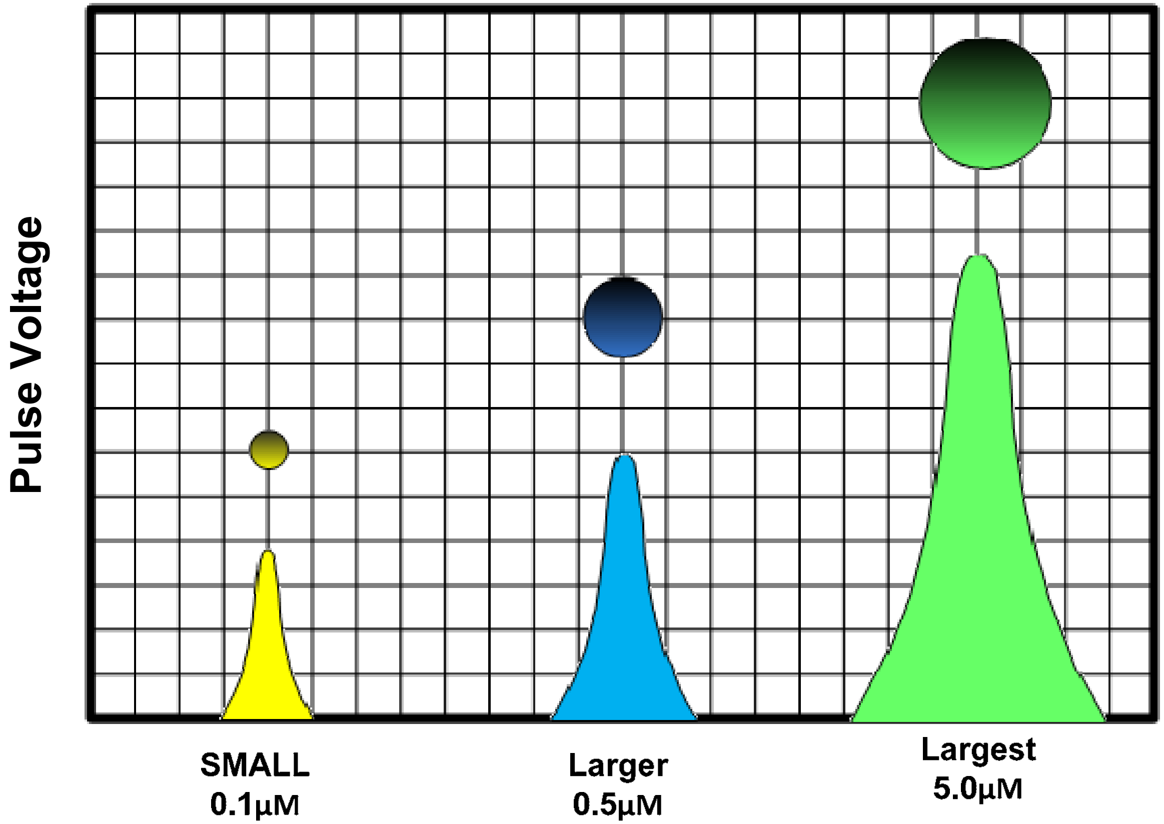
Electro-optical Sensor Schematic



- ★ Light source illuminates nozzle
- ★ Light trap absorbs direct light
- ★ Flow cell directs particle through light
- ★ Particle scatters light
- ★ Light collection optics direct scattered light onto the detector
- ★ Detector outputs voltage pulse

Particle Sizing

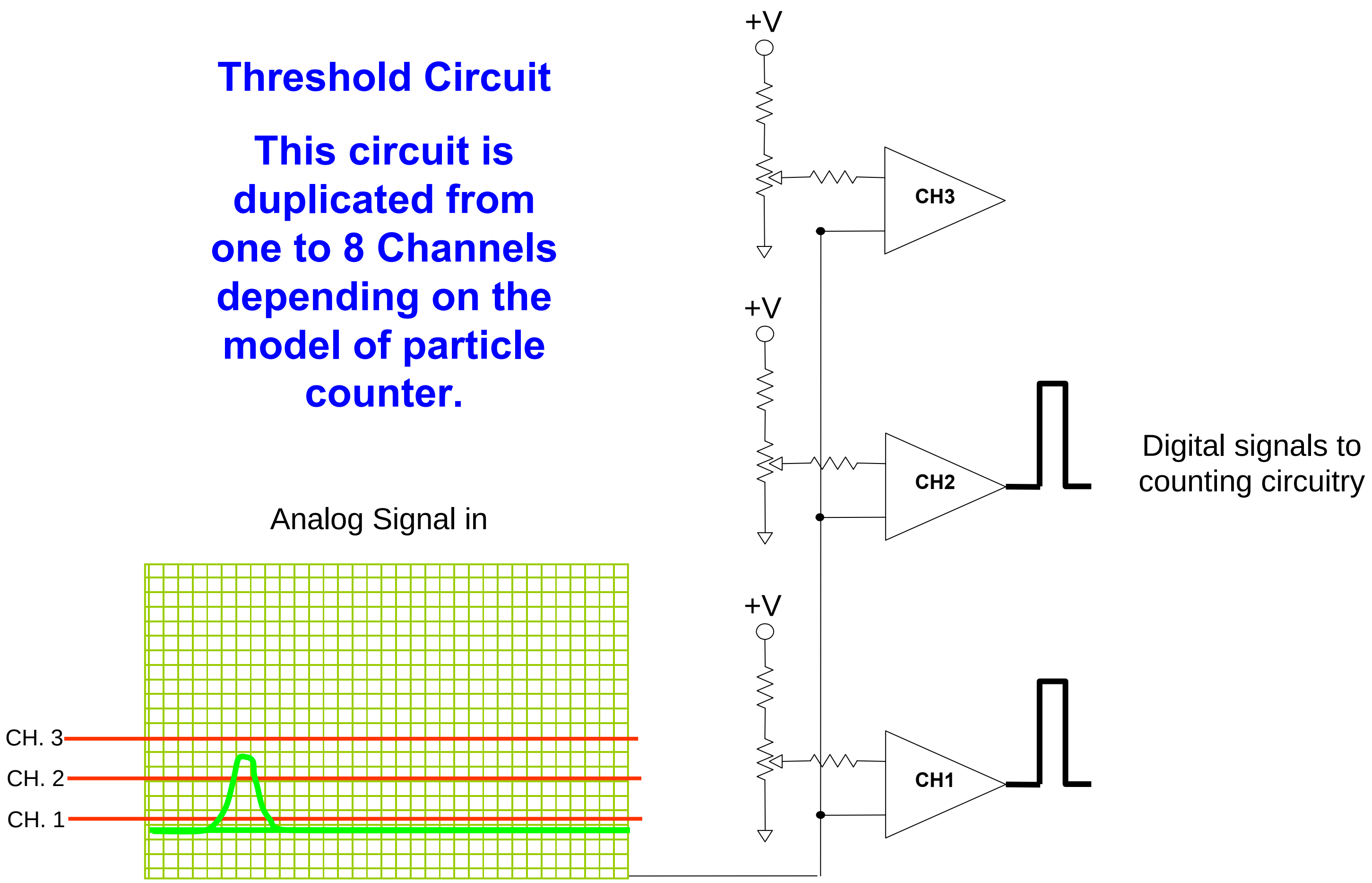
The larger the particle, the taller the corresponding output pulse from the sensor



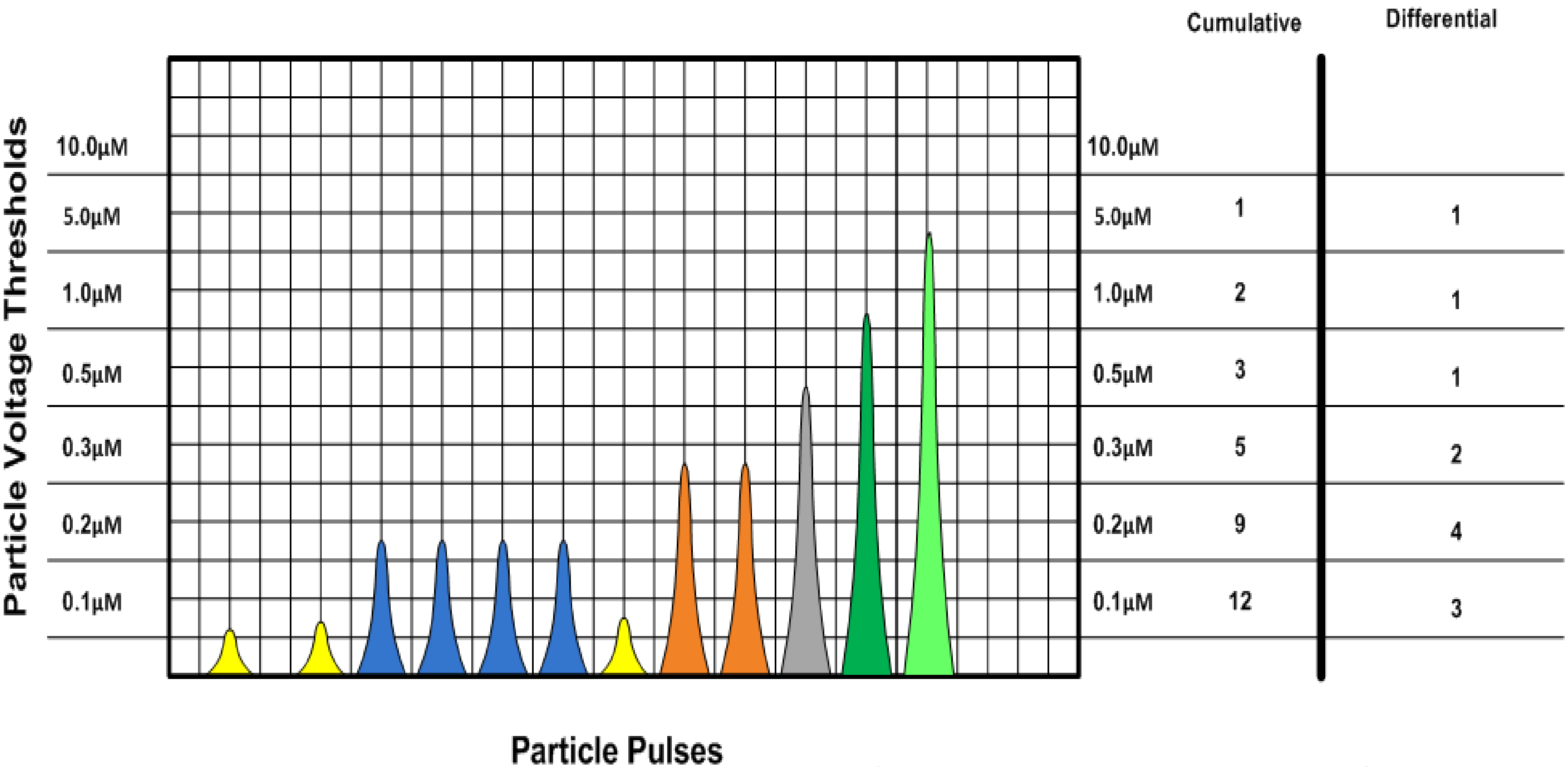
Counting Electronics

Threshold Circuit

This circuit is duplicated from one to 8 Channels depending on the model of particle counter.

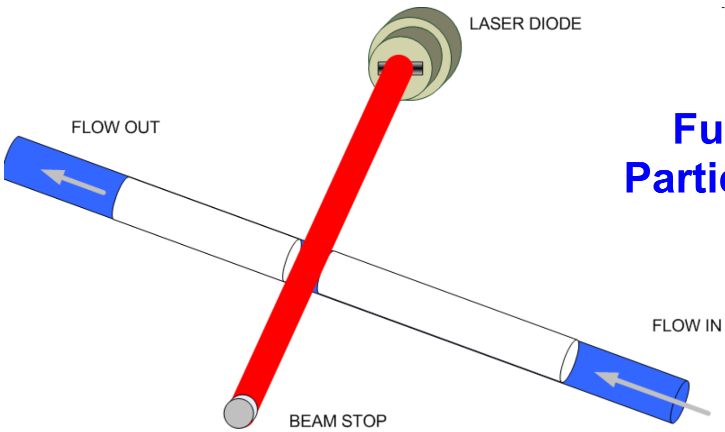


Counting Modes (Cumulative vs. Differential)



For Cleanroom Airborne Particle Counting: Cumulative is the Preferred Counting Mode

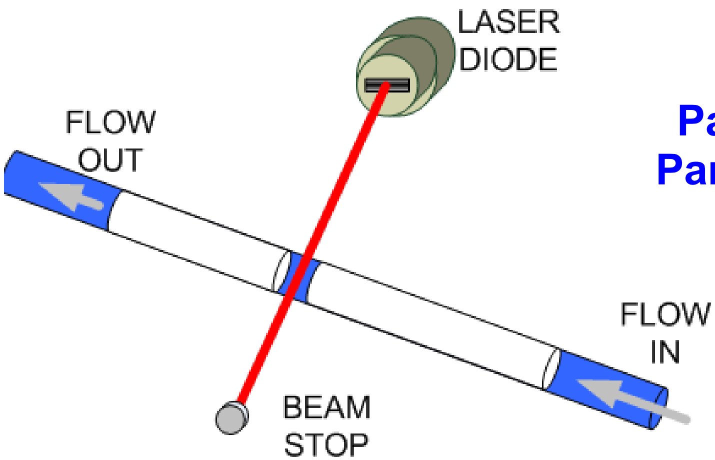
View Volume



Full Stream Particle Counter

View volume is defined by the amount of the flow stream illuminated by the laser

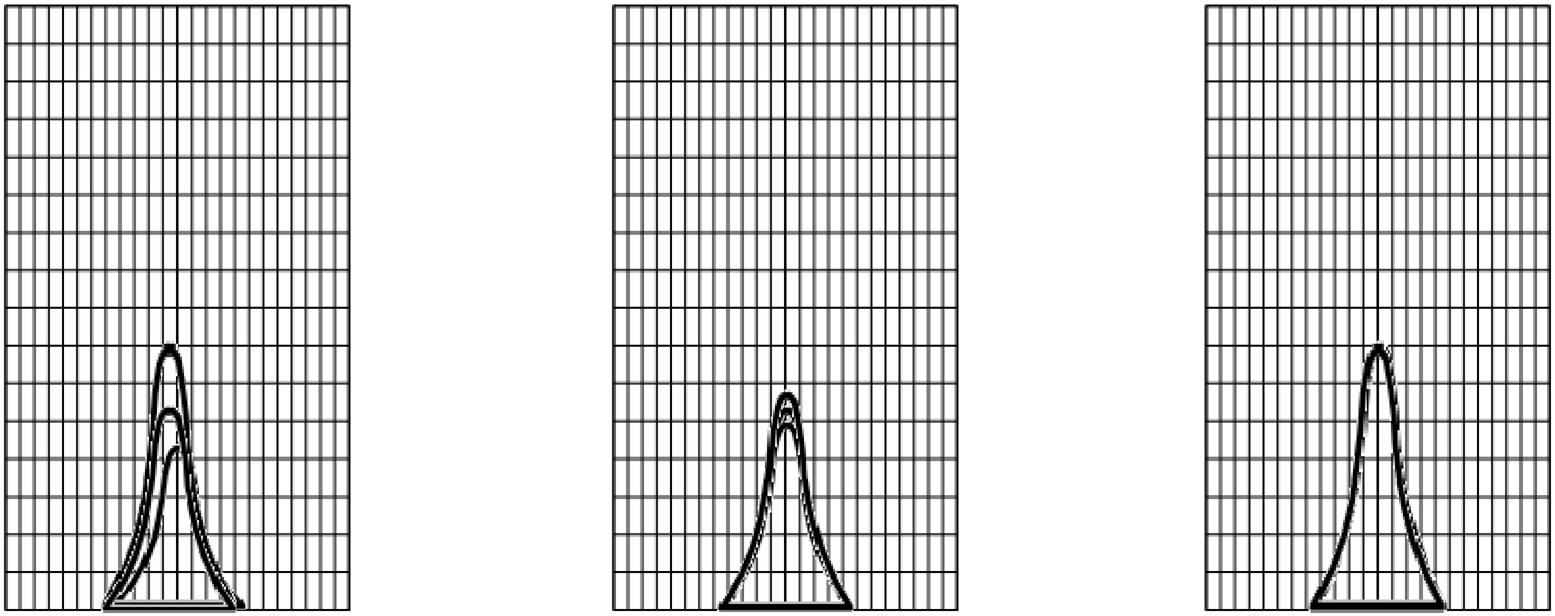
Full stream (volumetric) sensors have a view volume of near 100%



Partial Stream Particle Counter

Partial Stream (In-situ) sensors have a very small view volume

Sensor Resolution



Poor resolution
Partial stream sensors

Good resolution
Full stream sensors

Perfect resolution

Examples of Sensor Resolution: Particles of the Same Size

Sizing

Light scattered by a single particle in a specific direction in relation to the original direction has a unique signature which relates to the size, shape and material of the particle.

As size is dominant the light intensity collected by the receiving optics of an instrument can be calibrated to the diameter of a sphere of a reference material, typically Polystyrene Latex.

There is a dependency of the scattered signal on particle shape and material. However, it is a common practice to report particle size information in equivalent Polystyrene Latex sphere diameters.

Assumptions in Particle Counting:

1. All Particles are Spherical in Nature

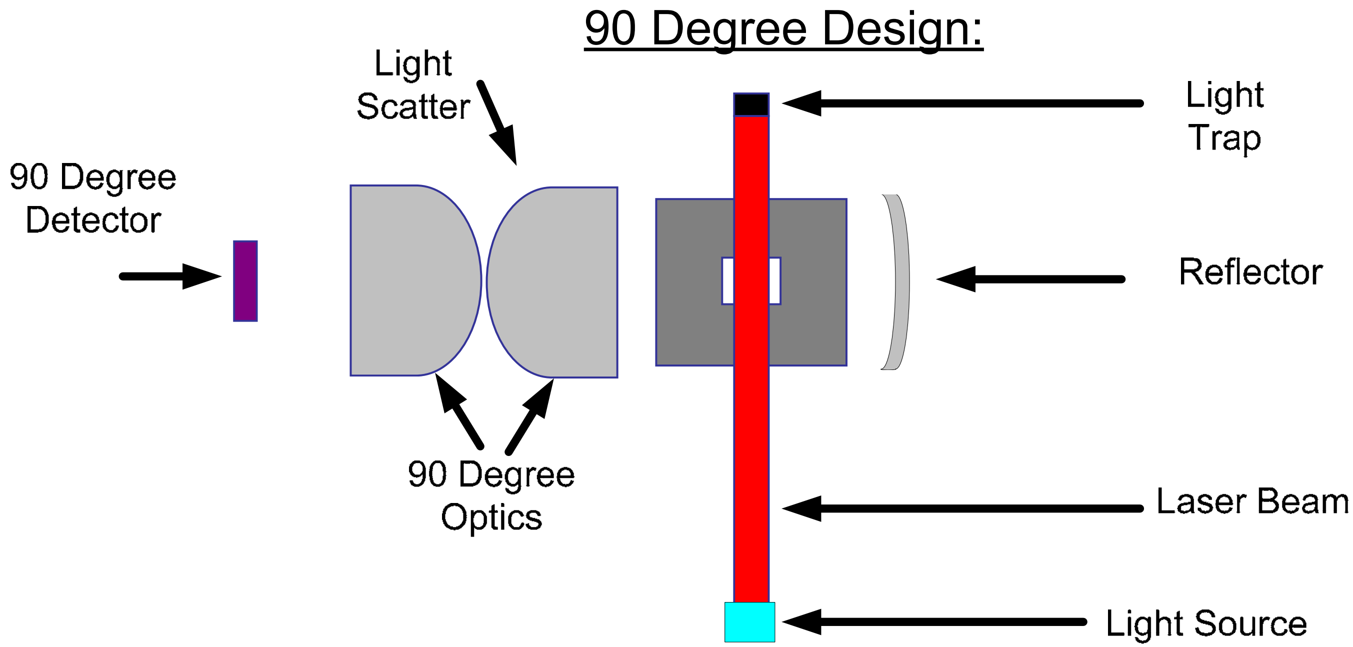
2. All Particles have the Same Refractive Index of Polystyrene Latex

ISO-21501-4, Light Scattering airborne particle counter for clean spaces

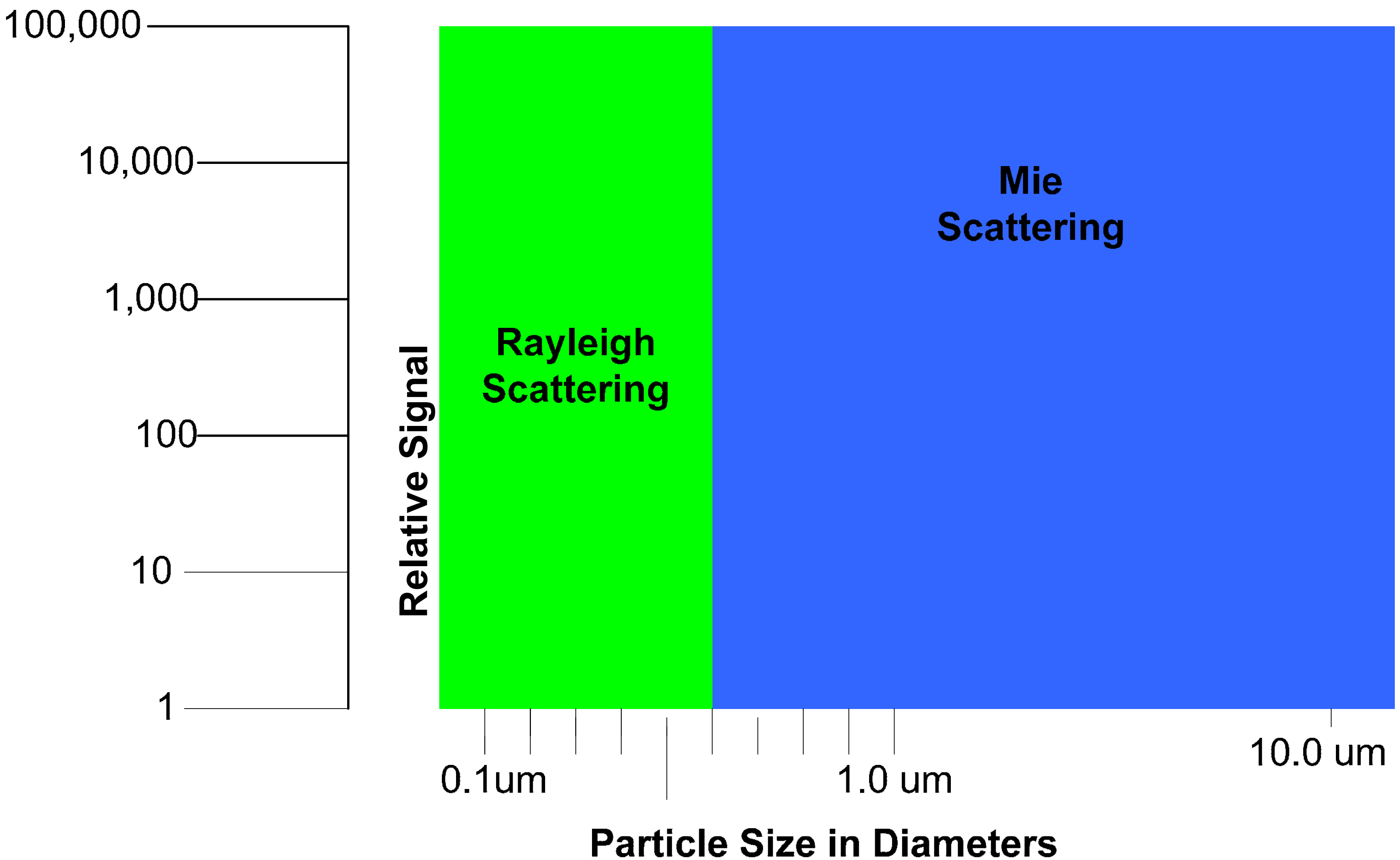
- ISO 21501-4 Is Methods and Specifications
  - Size Calibration
  - Size Verification
  - Counting Efficiency
  - Size resolution
  - False Count Rate
  - Maximum Concentration
  - Flow Rate
  - Sample Time
  - Response Rate
  - Calibration Interval
  - Test Report

Size Calibration - Single Particle Counter

- ★ APC's count one particle at a time as it passes through the flow cell. The light is scattered and the pulse is measured in the form of an analog signal.
- ★ The signal amplitude (peak height) collected in the Photo Diode determines the size of the particle.

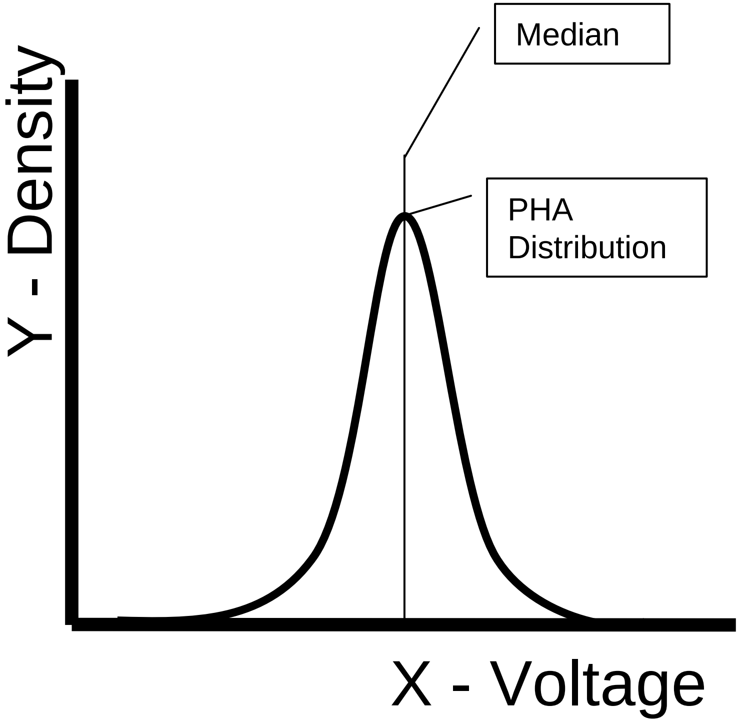


Size Calibration – Relating Voltage to Size



Size Calibration – How we calibrate

- ★ Particles are sized one at a time
- ★ The signal amplitude (peak height) determines the size of the particle.
- ★ The PHA determines the peak height of each pulse and over the sample time builds a distribution of peak height voltages for further analysis



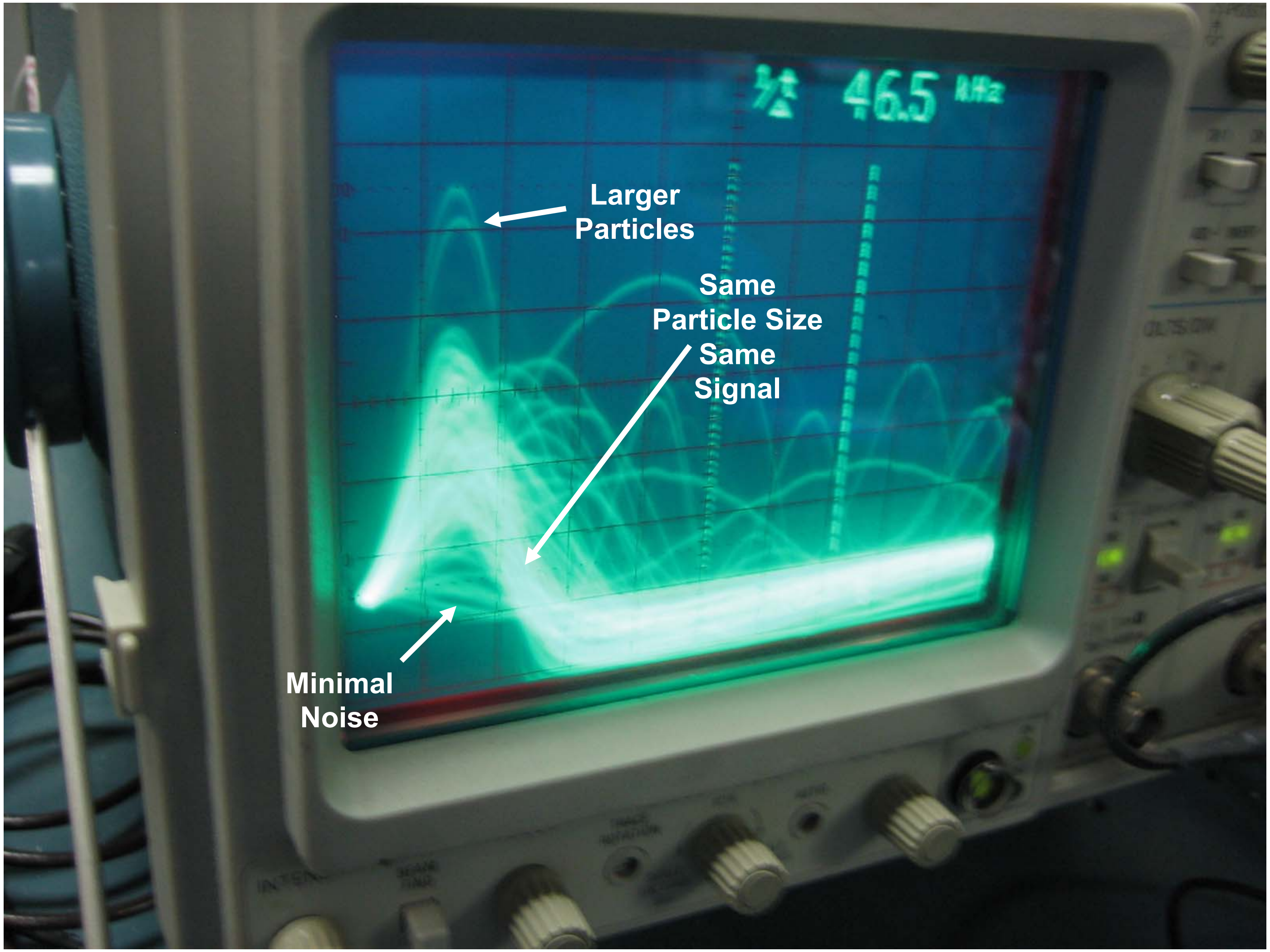
Note: Pulse Height Analyzer

★"*When calibrating an APC with calibration particles of known size, the median voltage* ***(or internal PHA channel),*** *corresponds to the particle size*"

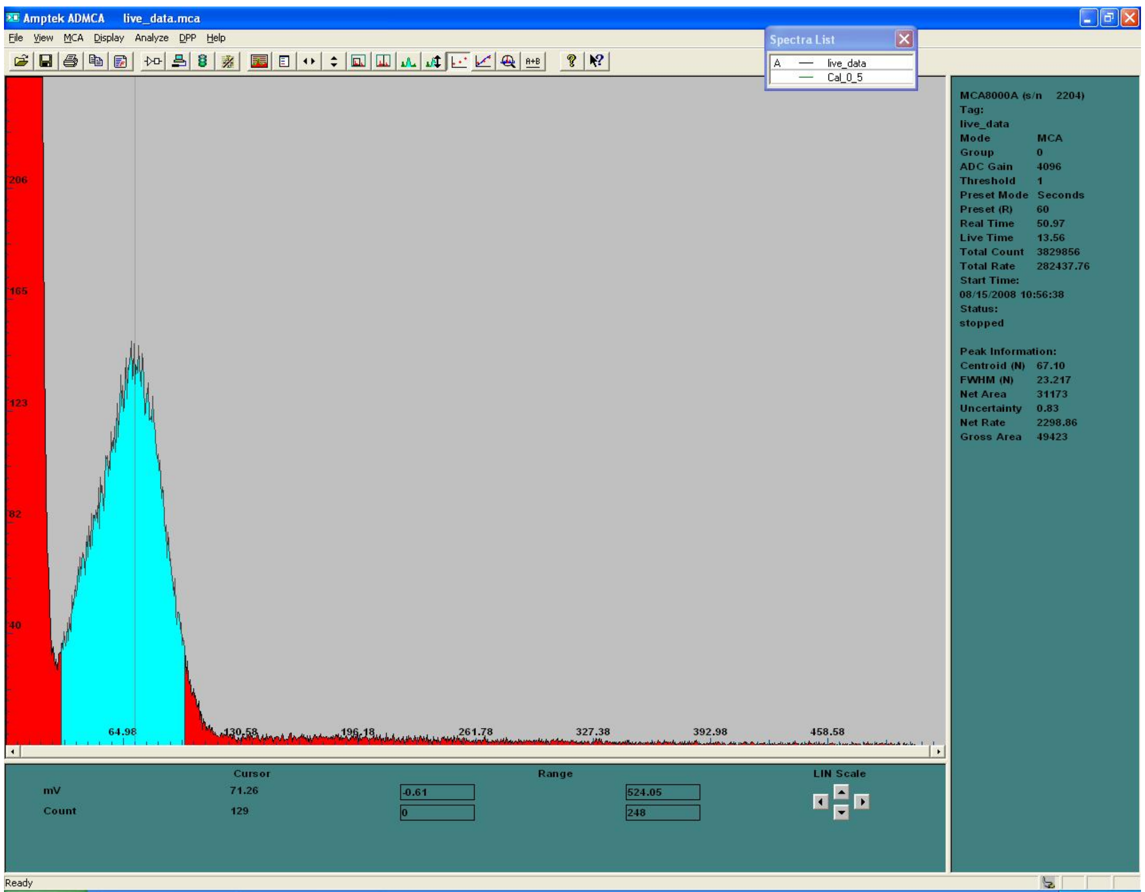
2 Methods to measure Pulse Height permitted by ISO 21501:

1. External Pulse Height Analyzer or MCA
2. Internal Pulse Height Analyzer

Oscilloscope Showing Particles Signal

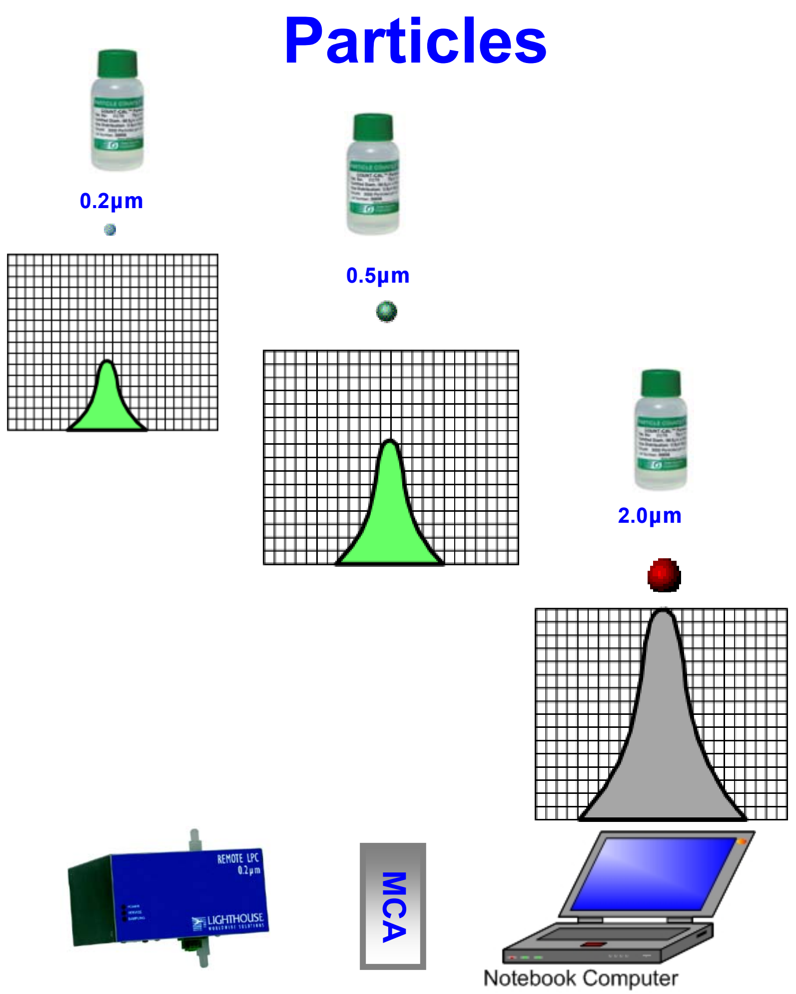


ISO 21501-4 Size Calibration - The MCA creates a distribution or histogram and we determine the median or half count voltage of the distribution



Size Verification

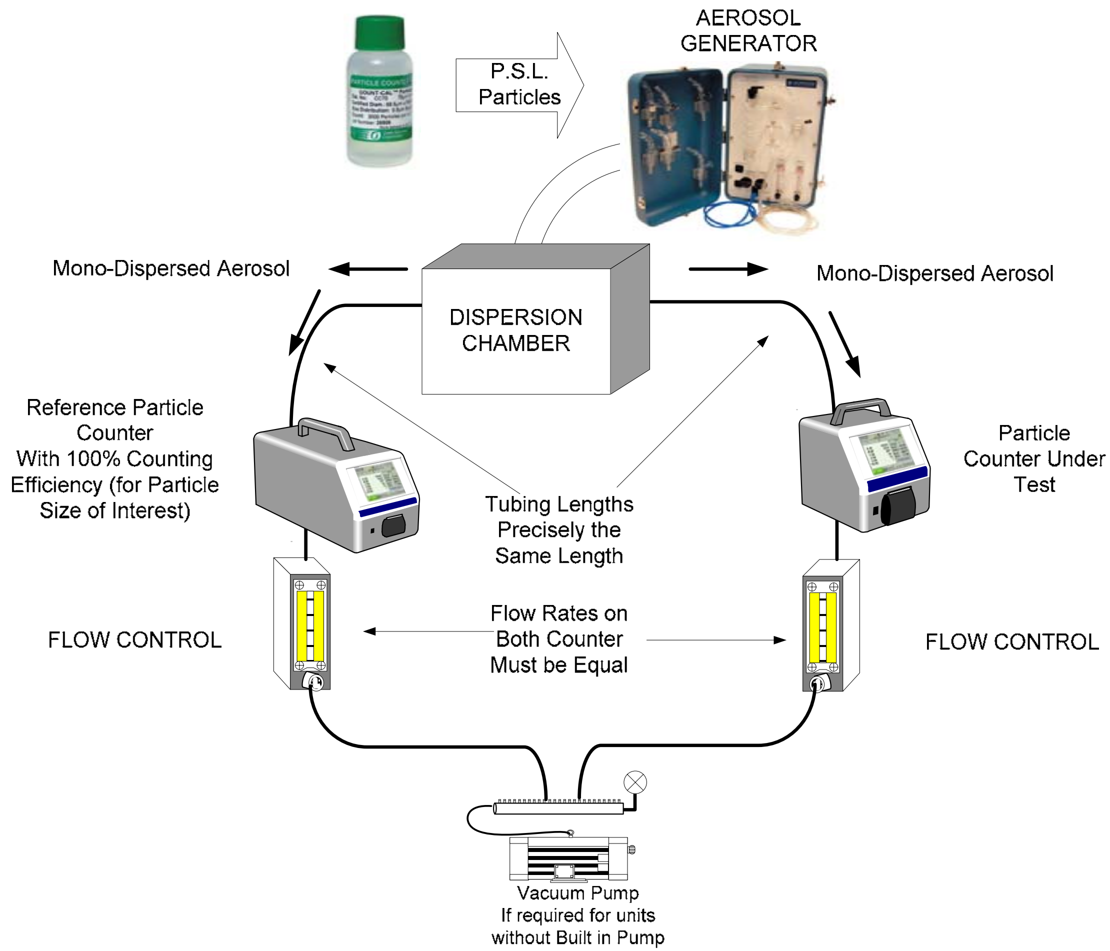
- ★ ISO 21501-4 Size Verification
  - ★ The Error in the detectable minimum particle size and other sizes specified by the Mfg. of an APC shall be <= ±10%
  - ★ Error Percent = Calculated Particle size minus reported size range (µm) over the reported size range (µm) times 100%



Counting Efficiency

★ISO 21501-4 Counting Efficiency

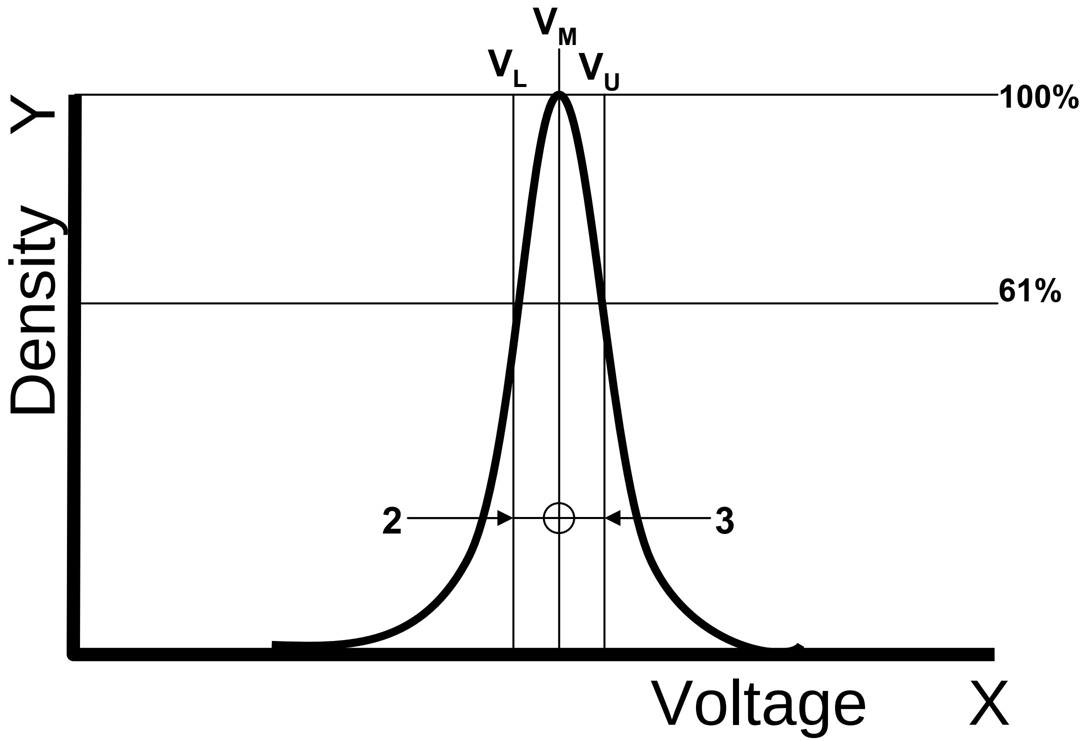
- ★Ratio of the measured result of APC to that of a reference instrument using the same sample
- ★A Golden Standard is required to compare to the instrument being calibrated
- ★Efficiency is described as (50 ± 20)% for the minimum detectable size and (100 ± 10)% with a size from 1.5 to 2 times larger than the smallest particle channel size



Size Resolution

★ISO 21501-4 Size Resolution

- ★ The size resolution shall be ≤ 10% for calibration particles of a size specified by the manufacturer



★ Mass Distribution of PSLs

2 Lower Side Resolution

3 Upper Side Resolution

V_L Lower V

V_M Median V

V_U Upper V

False Count Rate

- ISO 21501-4 False Count Rate
  - The false count rate is determined by putting a zero count filter on the instrument
  - The data should be processed using the Poisson distribution with a 95% upper confidence limit
  - The false count rate is expressed in Particles/Cubic Meter
  - There is no specification after all its only with 95% confidence…

Maximum concentration

- ISO 21501-4 Maximum Concentration
  - The maximum measurable particle number concentration is determined by the manufacturer based on a calculated coincidence loss <= 10%

- Mfg./Design Variables
  - Coincidence Loss
  - Electrical Processing Time

Flow Rate

- ISO 21501-4 Sampling Flow Rate
  - Must be within +- 5% if there is a flow control system

Sample Time

- ISO 21501-4 Sample Time
  - The sample time has a manufacturers preset value and should be ≤ ±1%

Response Rate

- ISO 21501-4 Response Rate
  - Should be <= 0.5%. Evaluates the clean up capability of the instrument

Calibration Interval

- ★ ISO 21501-4 Calibration Interval
  - ★ At least once per year

Test Report

- ★ ISO 21501-4 Test Report
  - ★ The test report should include:
    - ★ Date of calibration;
    - ★ Calibration particle sizes;
    - ★ Flow rate;
    - ★ Size resolution;
    - ★ Counting efficiency;
    - ★ Voltage limit (or channel of an internal pulse height Analyzer)

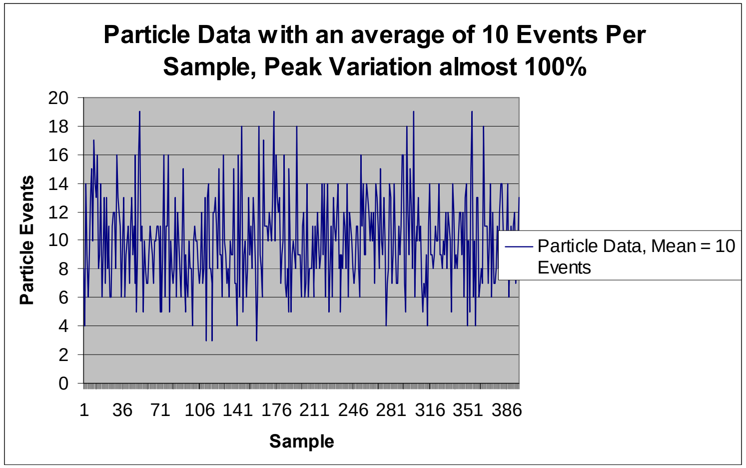
Size Resolution and Counting Efficiency are now required for annual calibration

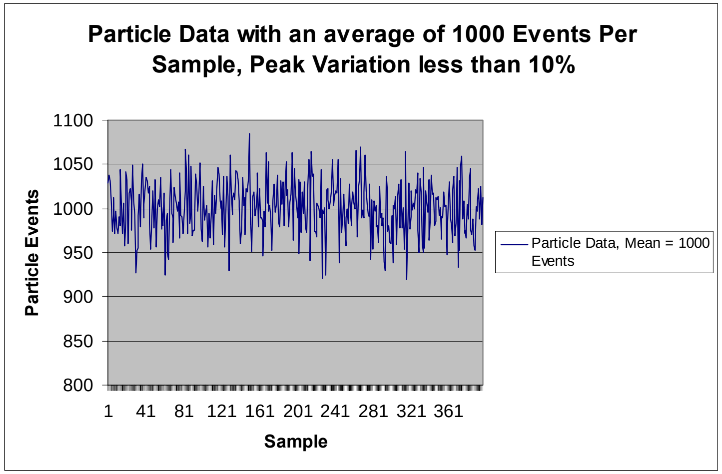
Particle Counter Precision

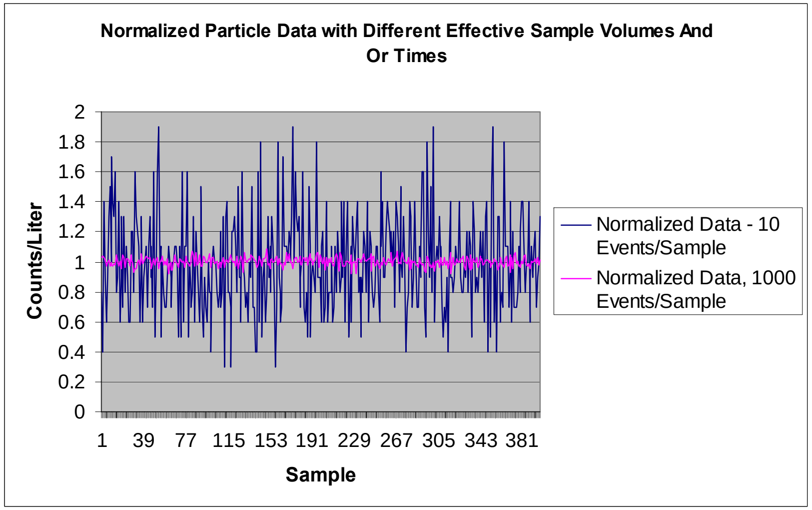
- ★ Particle counters have a measurement uncertainty due to the time of arrival process of particles (Poisson)
- ★ Precision of the reported number of counts is related to the number of observed events in a sample time
- ★ The standard deviation of the measurement is equal to the square root of the number of counts

The higher the sample volume of the instrument the higher the precision

Particle Counter Precision (Examples)



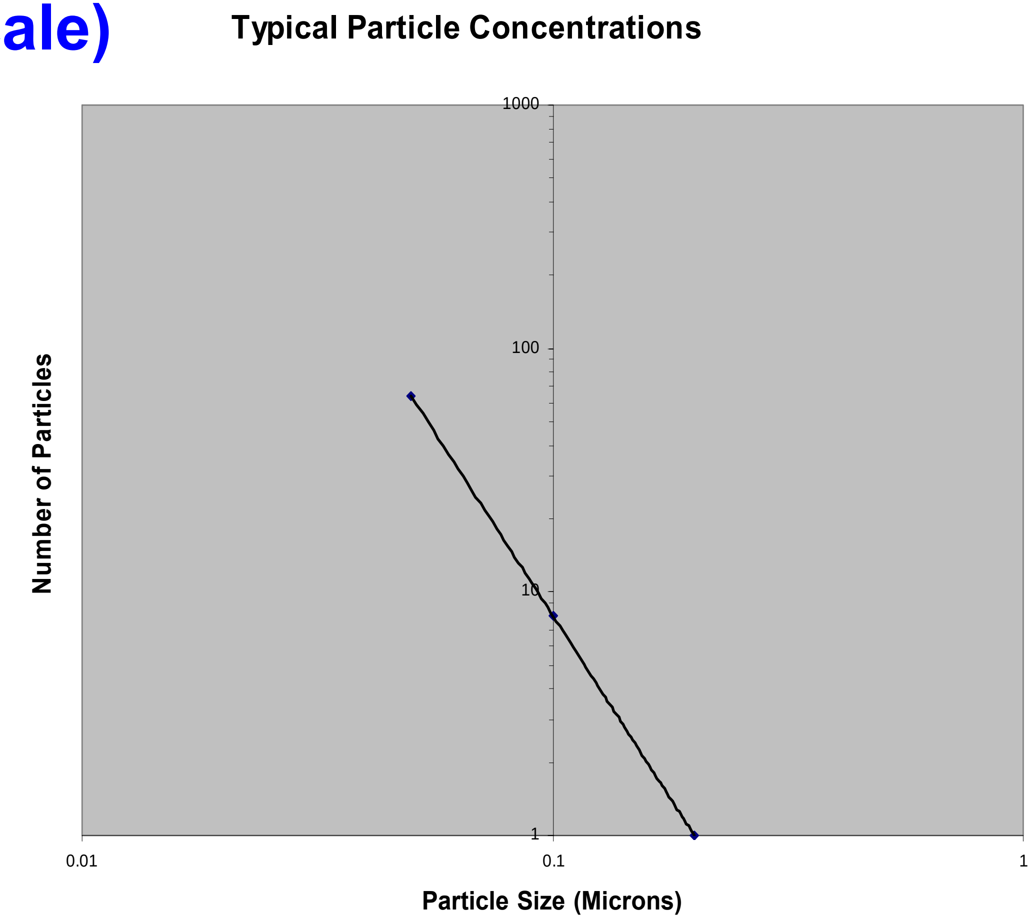




Increasing the number of particle events in a sample improves the precision

Typical Particle Distribution

(log log scale)



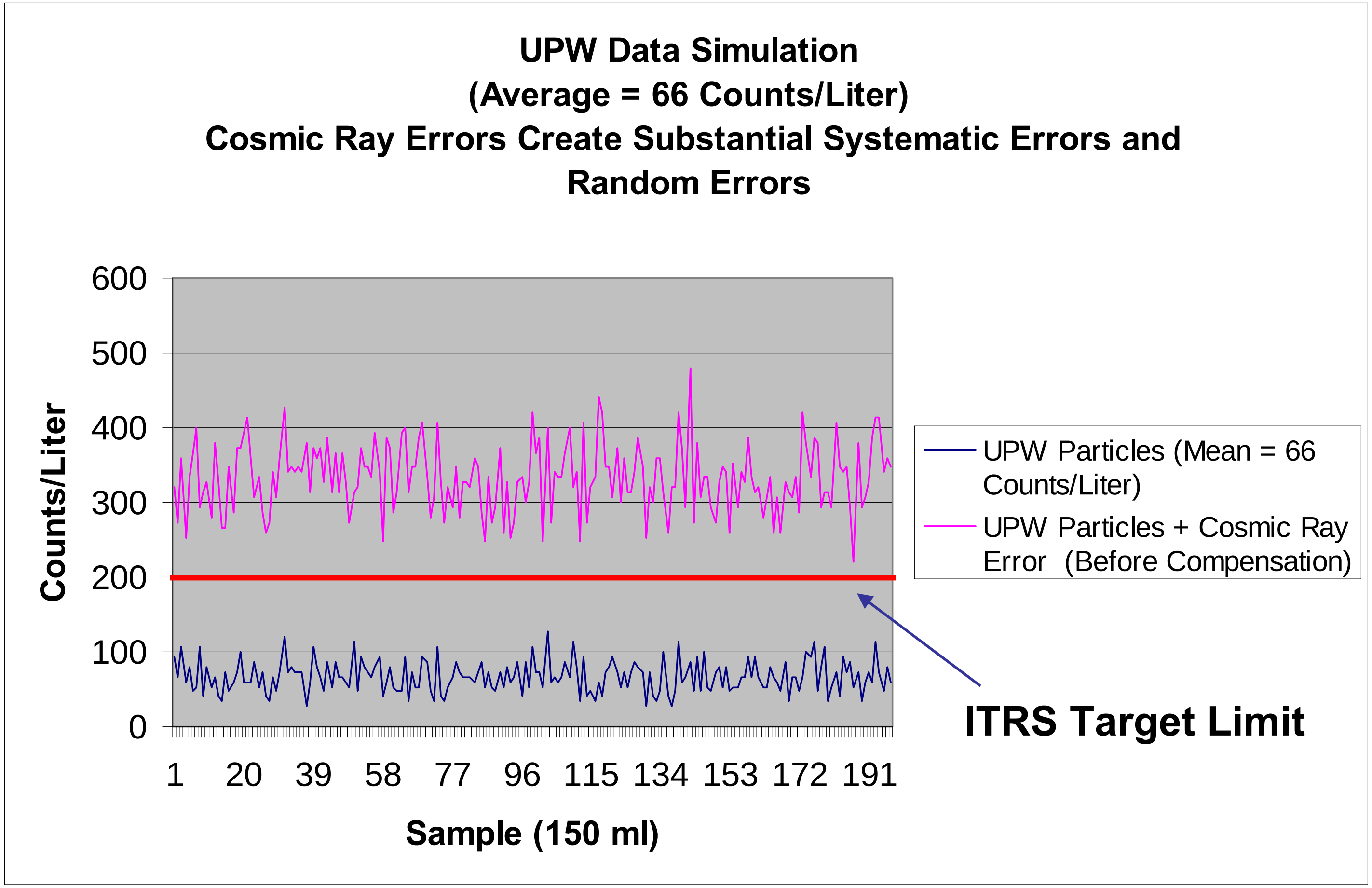
Typical particle distributions follow an inverse 3rd power law, with more particles at smaller sizes

Zero Count Level Defines Particle Counter Accuracy at Low Concentrations

- Zero count level specifies the number of false counts per time interval from the particle counter
- The level is dictated by the gamma count rate of the sensor
- Cosmic gamma rays are energetic particles originating from space that impinge on Earth's atmosphere. The term "ray" is a misnomer, as cosmic particles arrive randomly one at a time, not in the form of a ray or beam of particles.
- The gamma count rate is a function of the photodetector type, size, geometry and materials
- Gamma ray false counts are RANDOM (not steady state) events/errors governed by poisson statistics (see air and liquid particle counting standards like JIS B9921 and ISO 21501 for more detail)

The lower the cosmic ray false count rate of the instrument the more accurate the measurement on a today's DI Water System

1 Count Per Minute False Count Effects

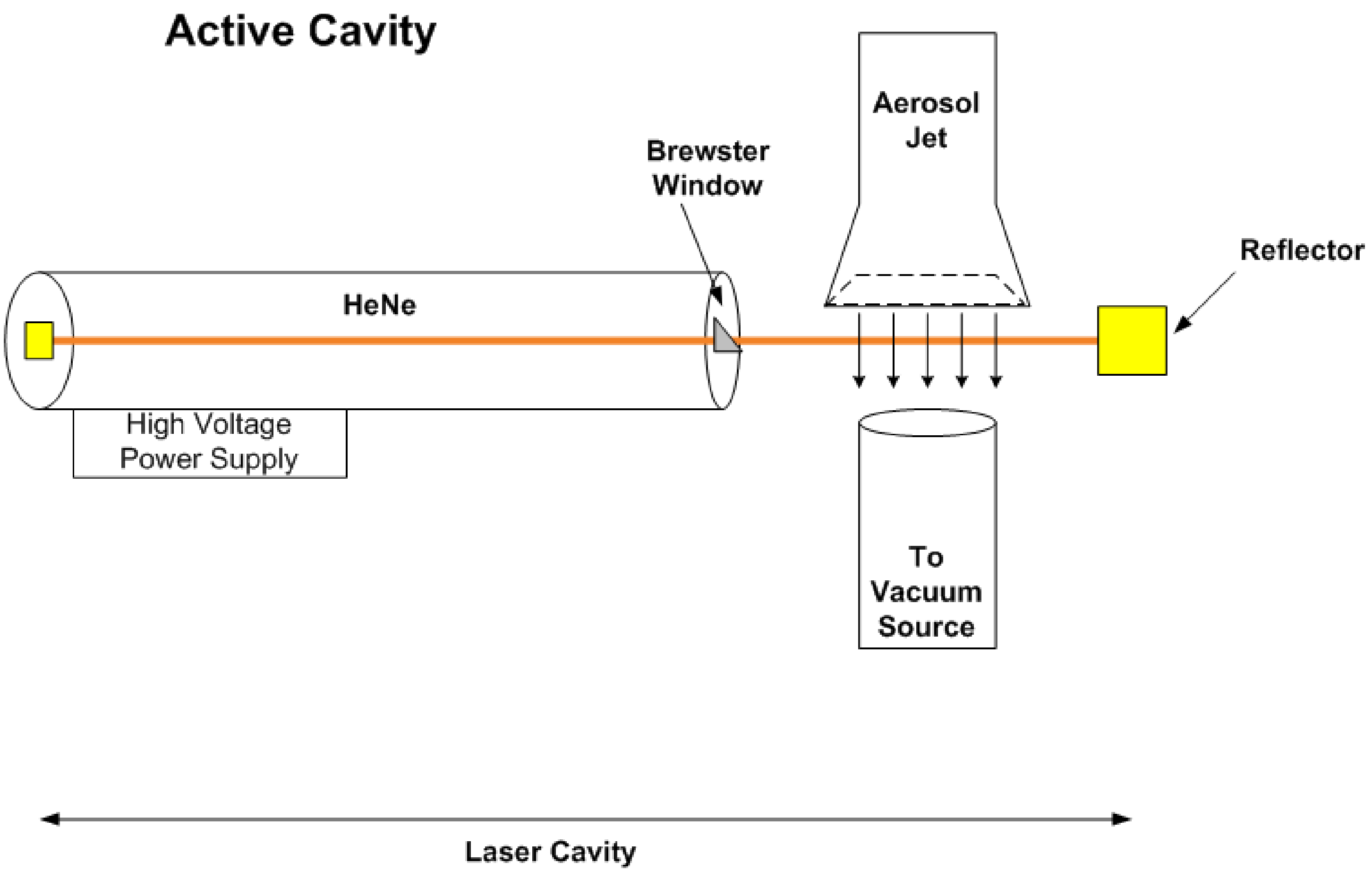


High cosmic ray pulse noise causes systematic and random measurement errors above the ITRS target particle control limit

Technology Solutions

Gas Laser Design

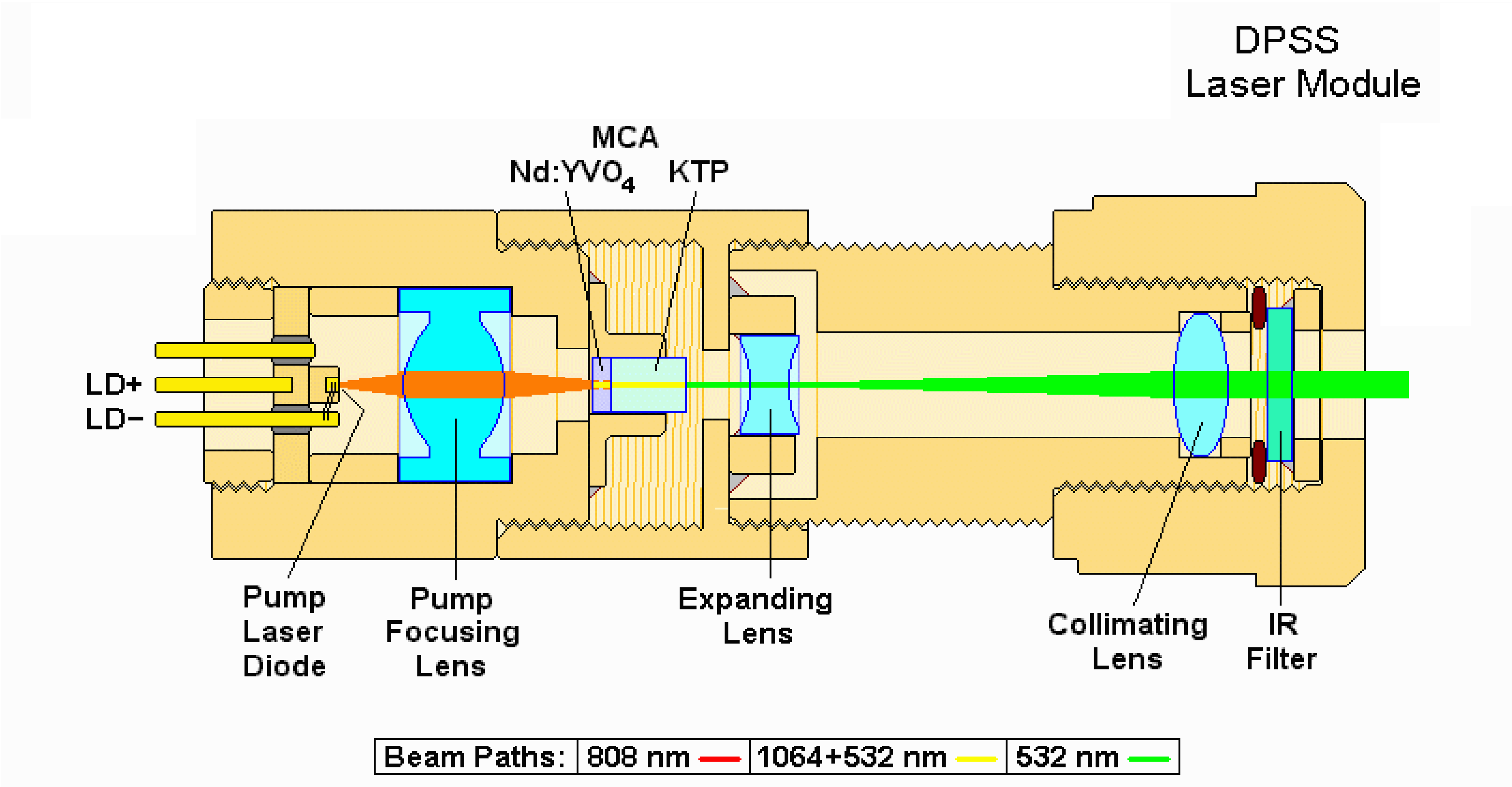
(Active Cavity HeNe Particle Counter Design)



HeNe Particle Counters are running out of Gas

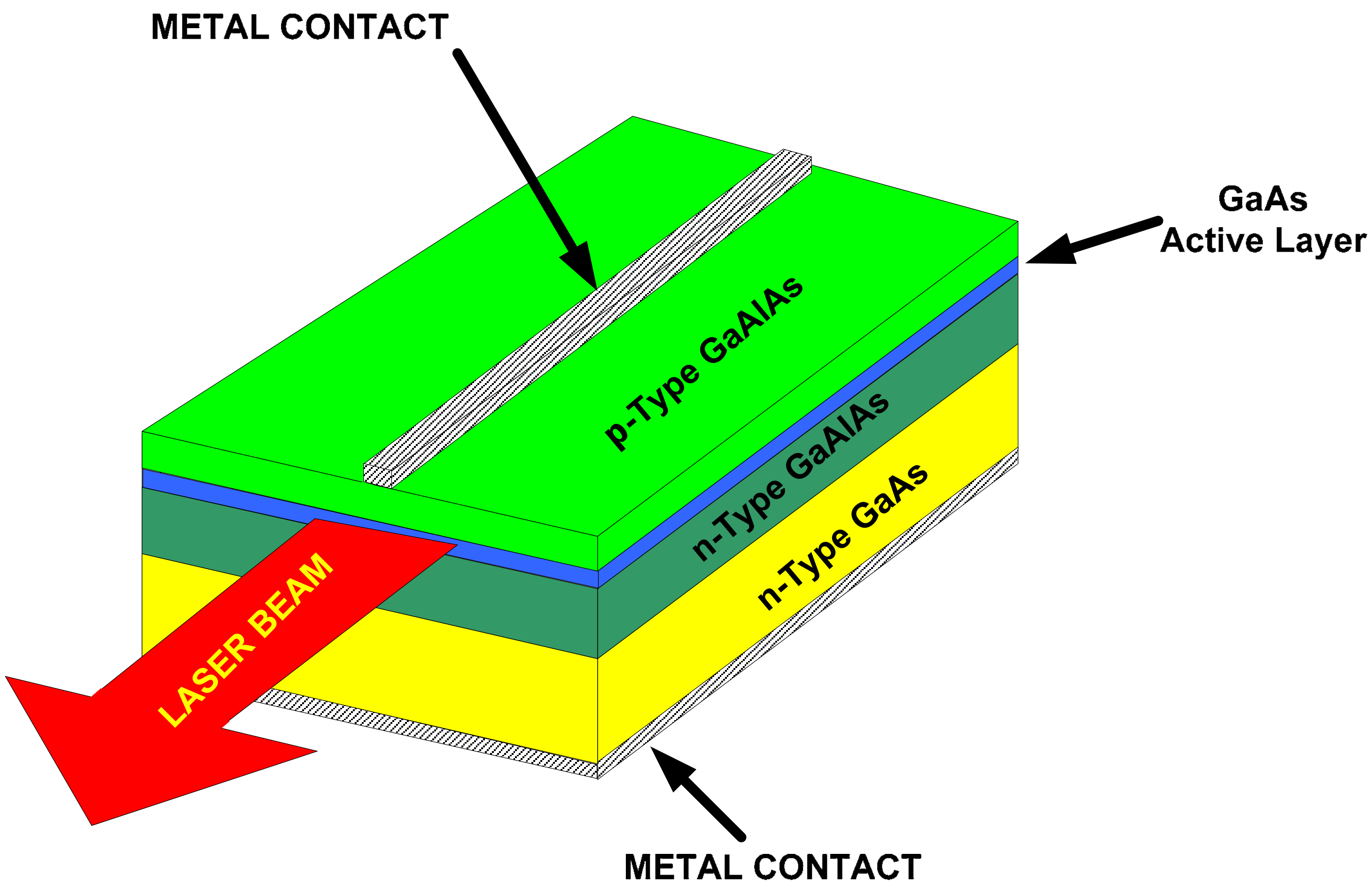
- ★ HeNe Designs from the Last Century
- ★ Collimated Beam Translates to Lower Concentration Limits
- ★ The Glass Design of the HeNe Tube is Sensitive to Vibration and Breakage
- ★ Brewster & AR Windows Make this Design Susceptible to Contamination Requiring Frequent Cleaning & Maintenance
- ★ HeNe Gas Leaks over time, affecting Laser Life and Increased Operational Cost.

DPSS Laser



Short Wavelength Can Be An Advantage to the Technology

Laser Diode



METAL CONTACT
GaAs
Active Layer
p-Type GaAlAs
n-Type GaAlAs
n-Type GaAs
LASER BEAM
METAL CONTACT

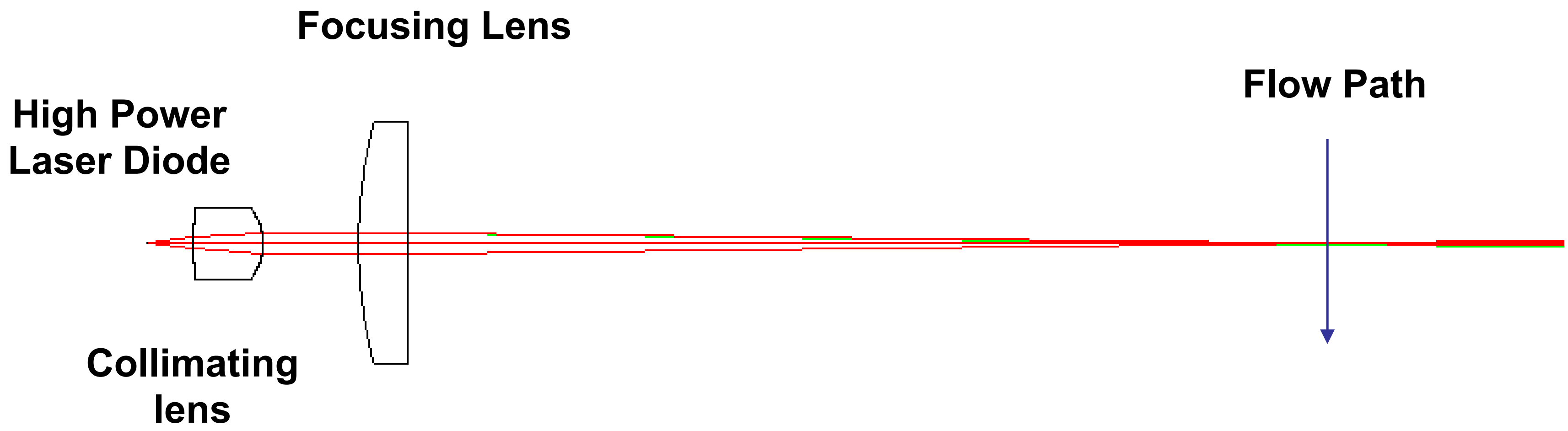
Laser Diode Technology

- ★ High Reliability Laser Diode
- ★ Focused Laser Beam to increase the concentration limit
- ★ Dual multi-element detectors with coincidence detection

High Reliability Laser Diode

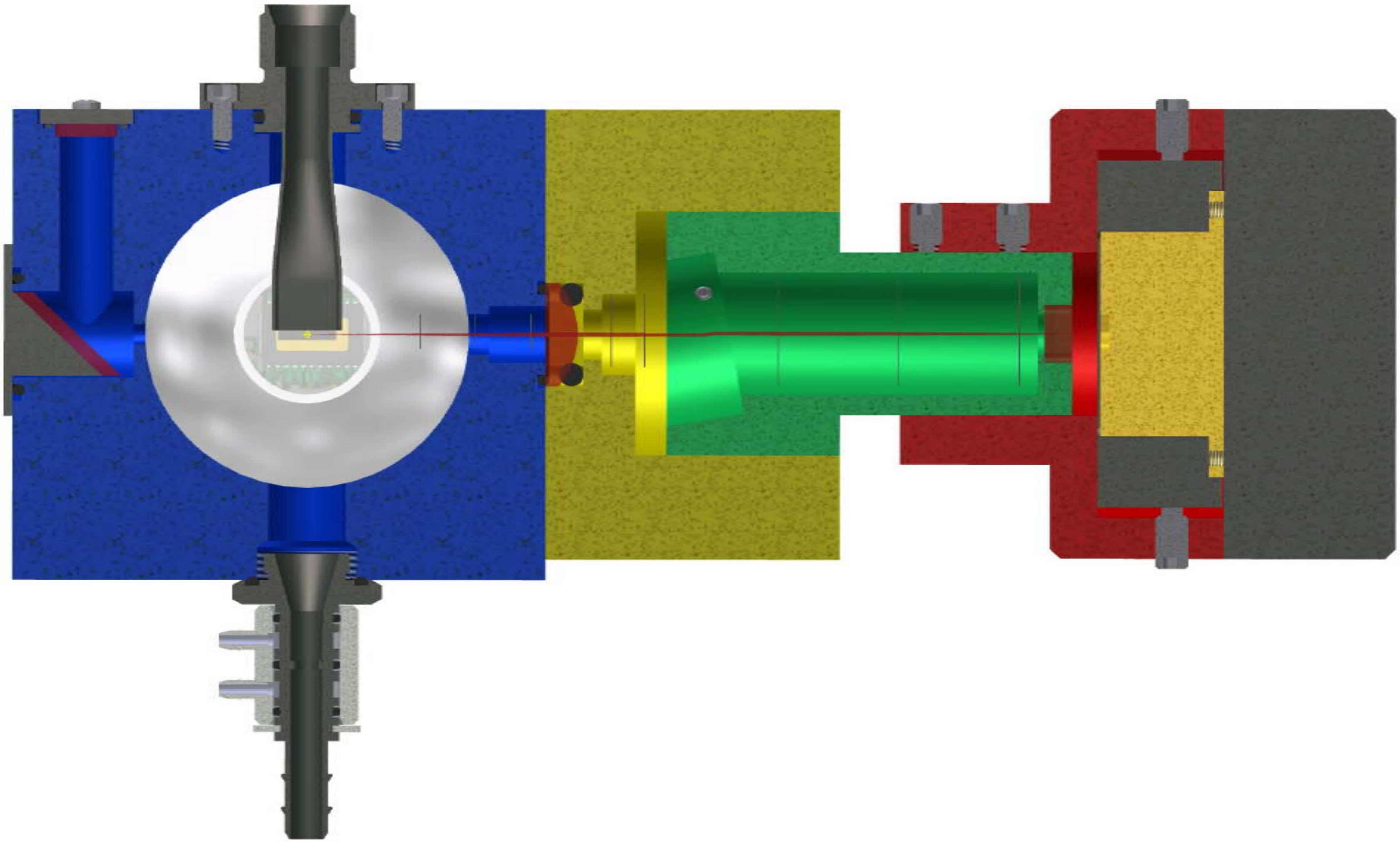
- ★ High Efficiency Laser Diode based on advanced passivation technology of the laser facet
- ★ 20% more efficient than standard laser diode technology equates to better reliability and lower power requirements

Laser Diode Illumination



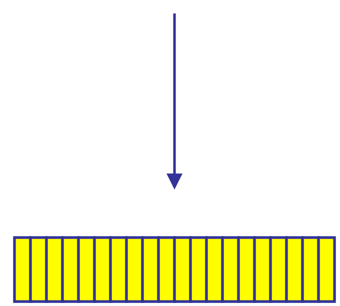
Laser Diode Technology permits focusing of the laser beam in the direction of flow to reduce the transit time of the particle through the laser thereby increasing the concentration limit 10X

Laser Diode Sensor

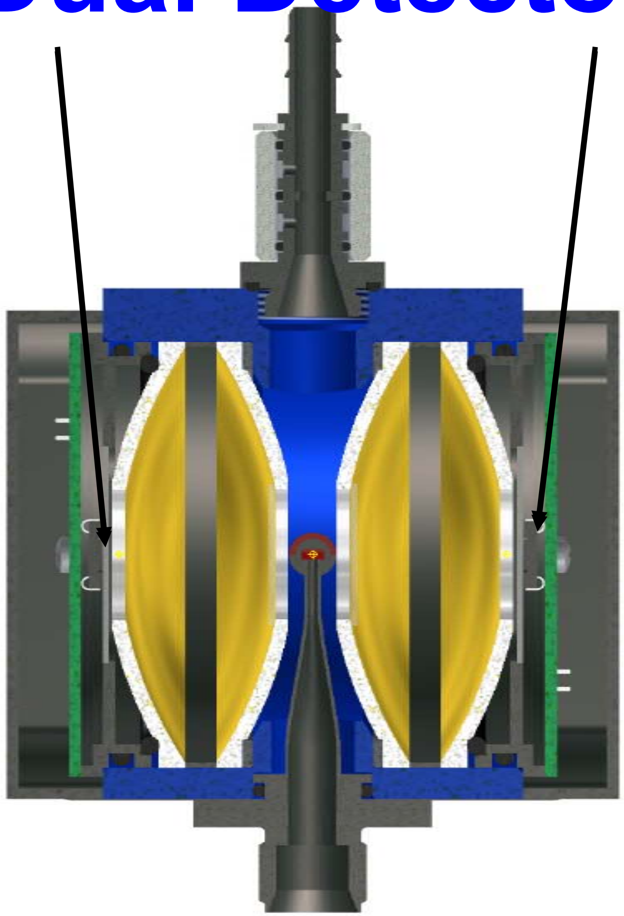


Advanced Detector

Array Detector, Improves Optical Signal to Noise



Dual Detectors



Dual Multi-element detector improves signal to noise, and eliminates cosmic ray pulse noise with coincidence detection

Remote Laser Diode Particle Counter

Universal Portable Laser Diode Particle Counter

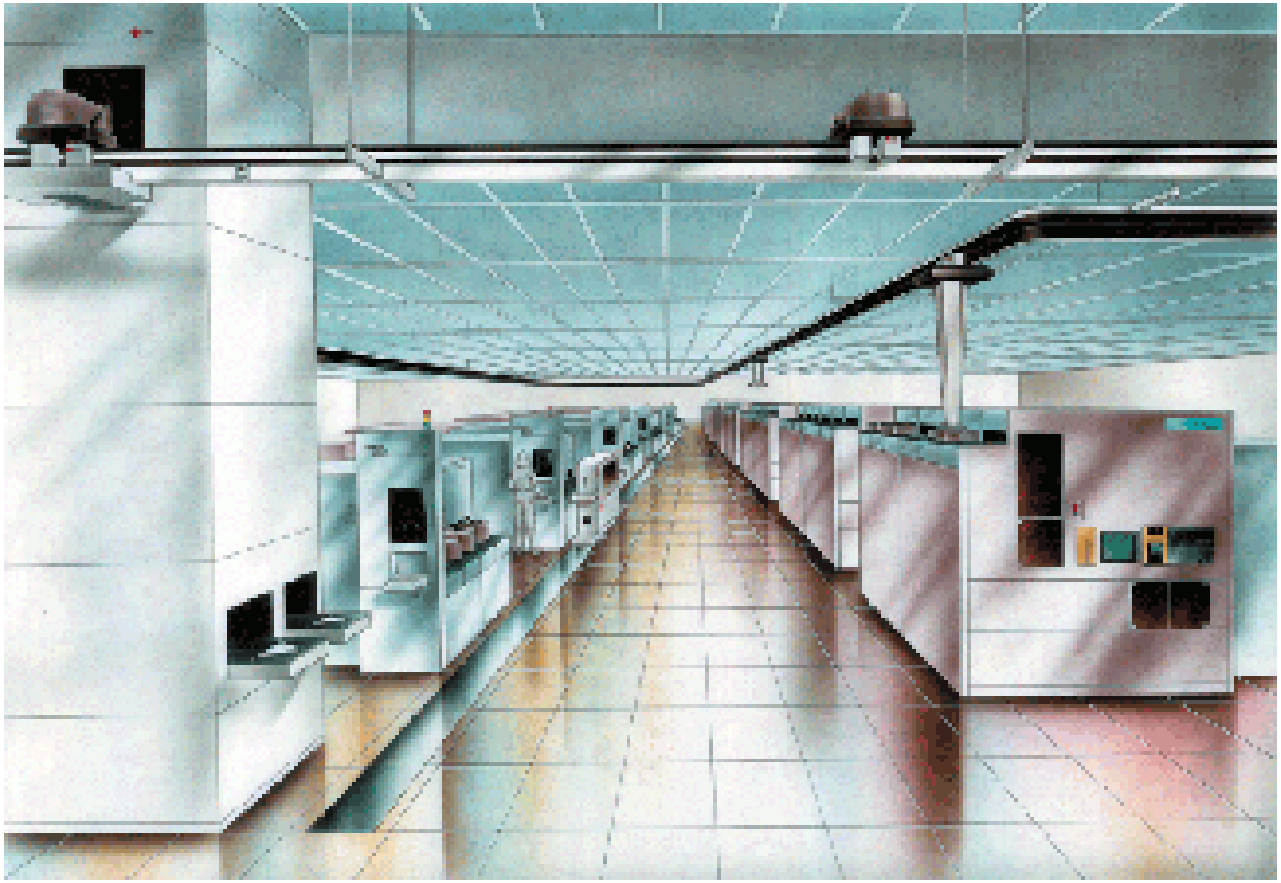
★Laser Diode Design

★0.1µM to 1.0µM Size Channels

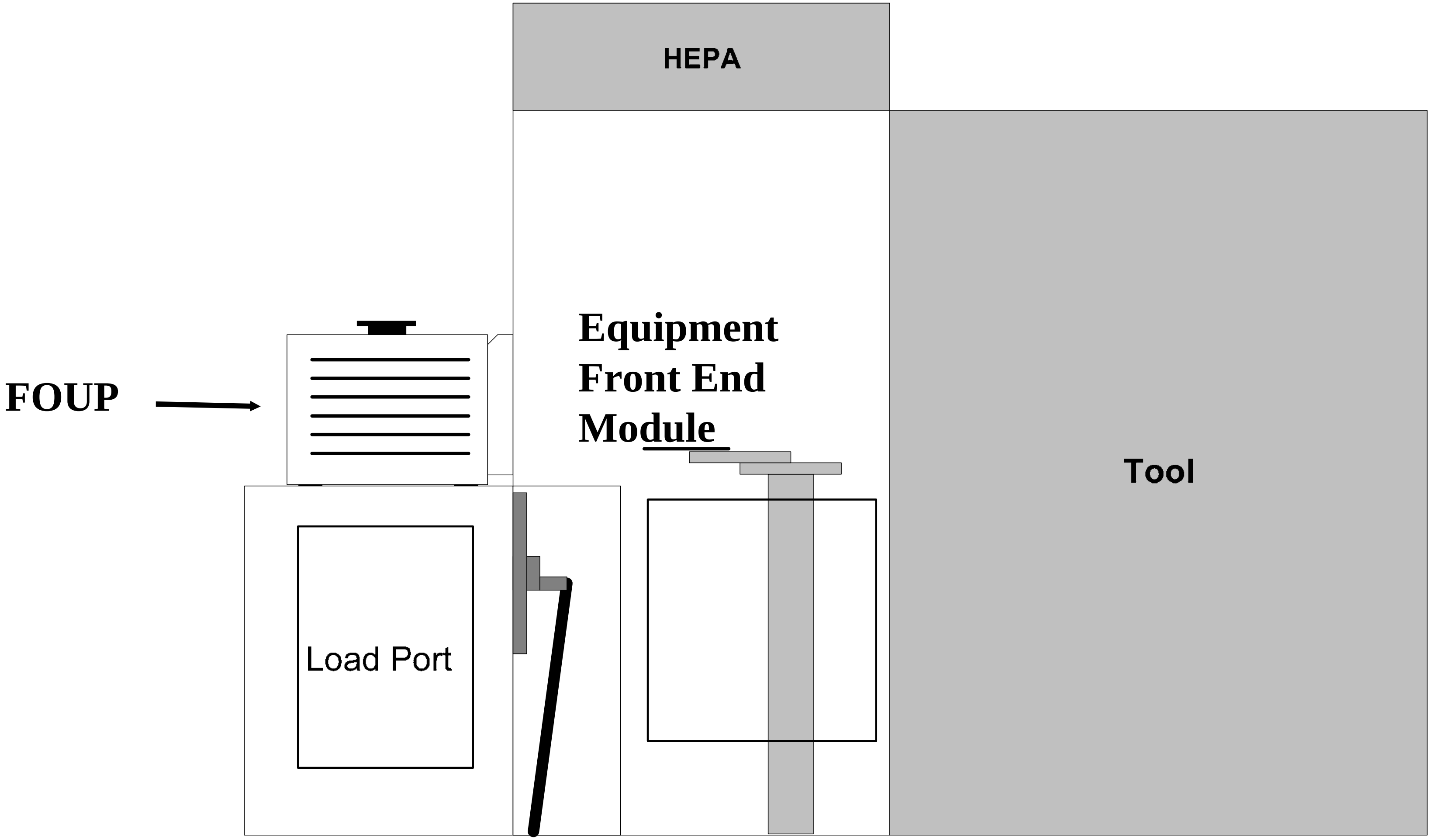
★Concentration Limits of
>500,000 Particles / Ft^3
@ 5% Coincidence Error

★This Design offers Cleanroom Testing
From ISO 1 to ISO 9 Class Cleanrooms
Suitable for ALL types of Cleanrooms

Applications

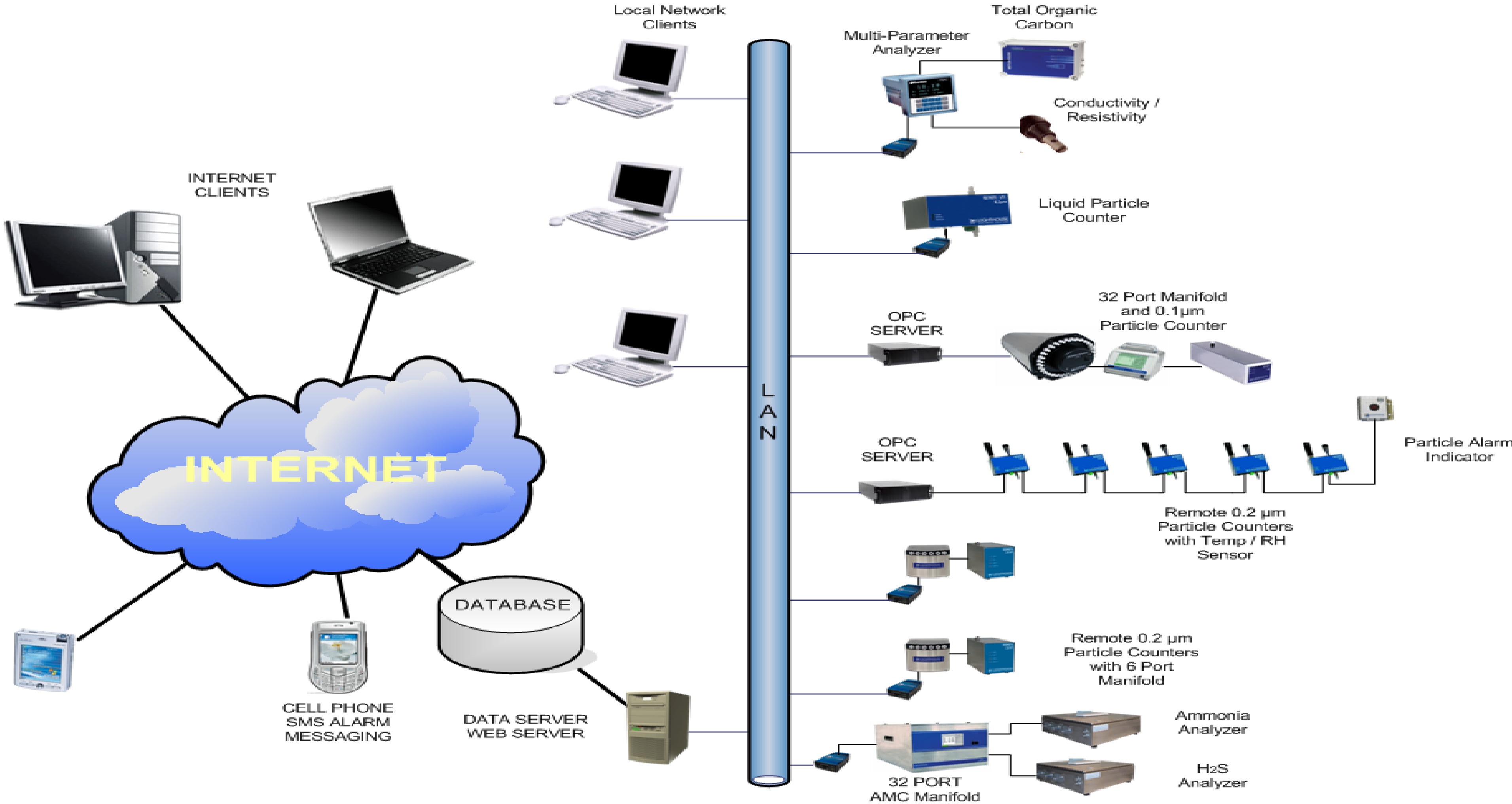


Semiconductor Applications



Remote APC Application - Process Equipment Front End

Monitoring System Application



Manifolds Applications:

Universal Manifold

Facility Monitoring

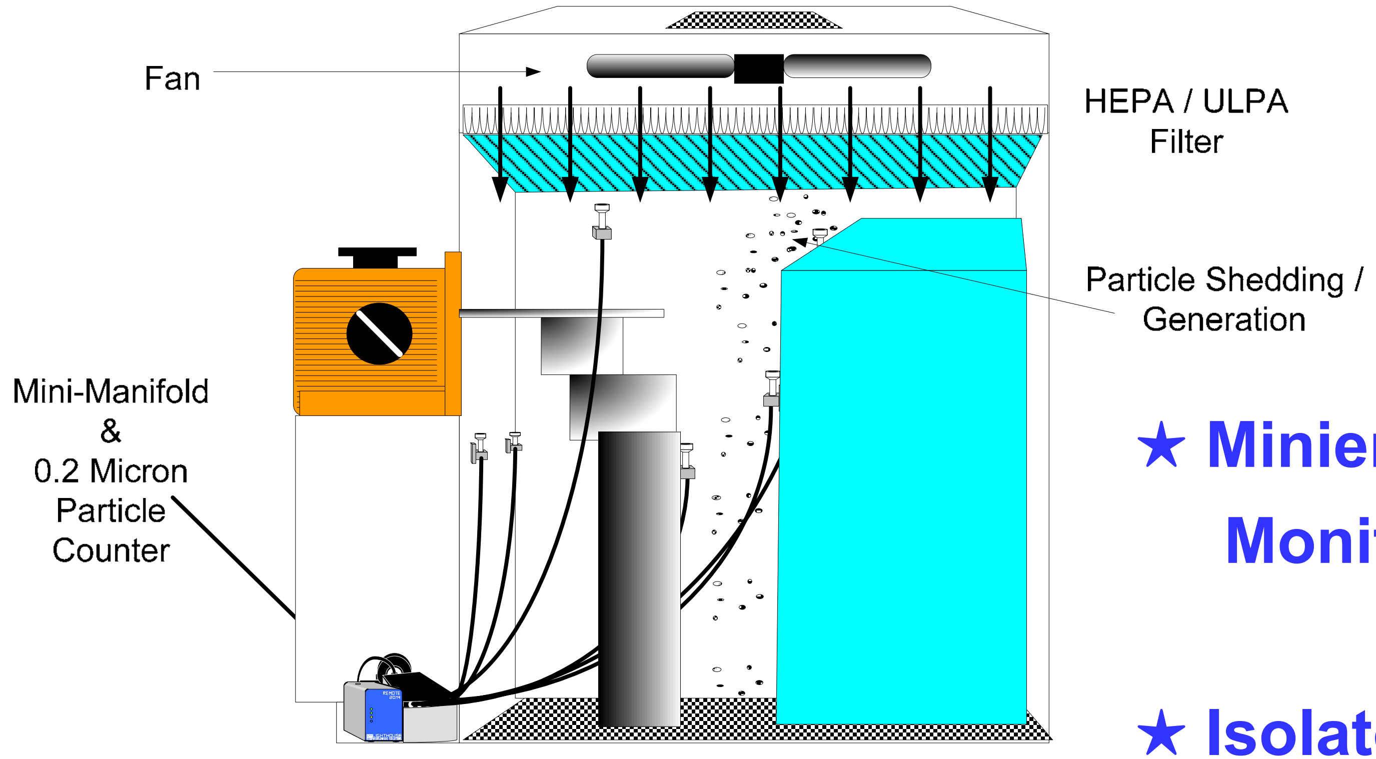
Mini Manifold

Tool Qualification

Stocker Monitoring

Minienvironment Monitoring

Mini-Manifold: Applications

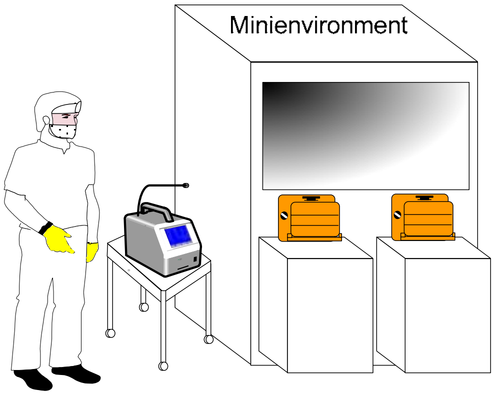


Mini-Environment Monitoring
With Mini-Manifold & Single
Particle Counter

- ★ **Minienvironment Monitoring**
- ★ **Isolator Monitoring**

Portable Air Particle Counter:

Applications



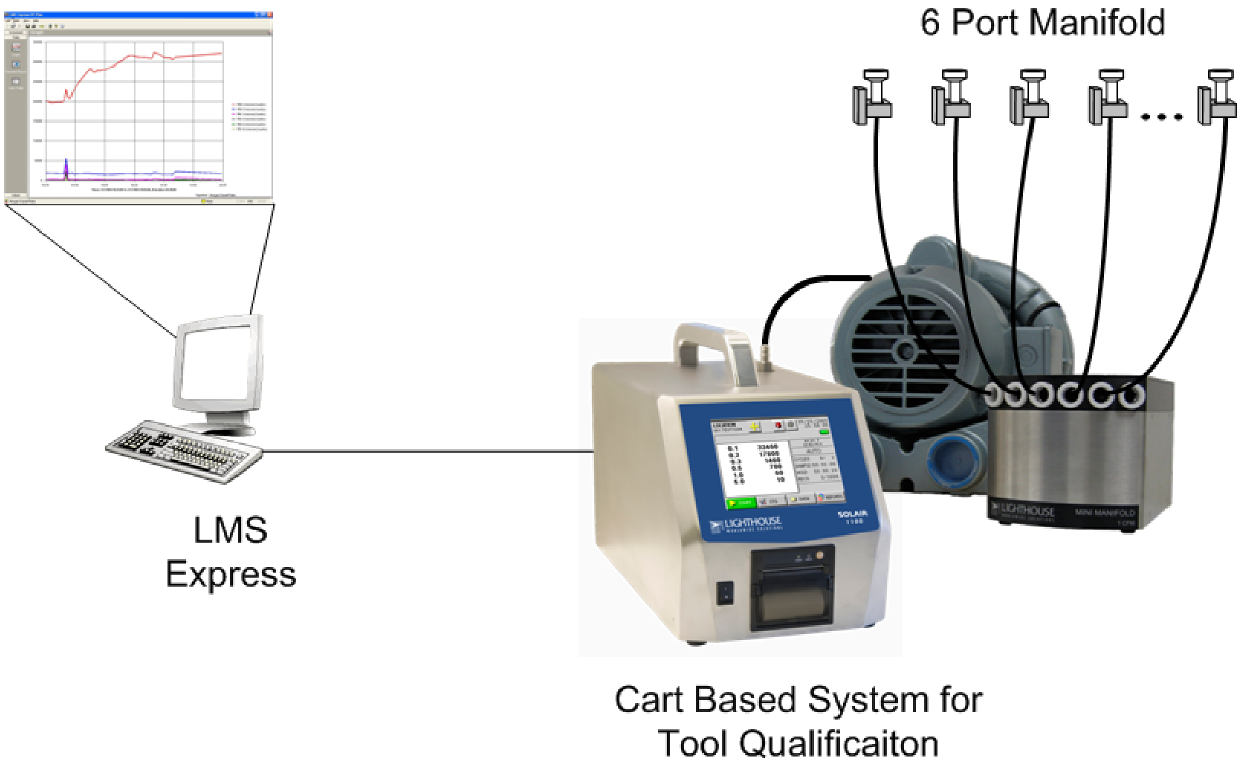
- ★ Cleanroom Testing
- ★ Cleanroom Certification
- ★ Cleanroom Audits
- ★ Tool and Equipment Certification
- ★ Contamination Identification
- ★ Cleanroom Monitoring
- ★ Filter Testing
- ★ Laminar Flow Bench Testing
- ★ Isolator and Minienvironment Testing

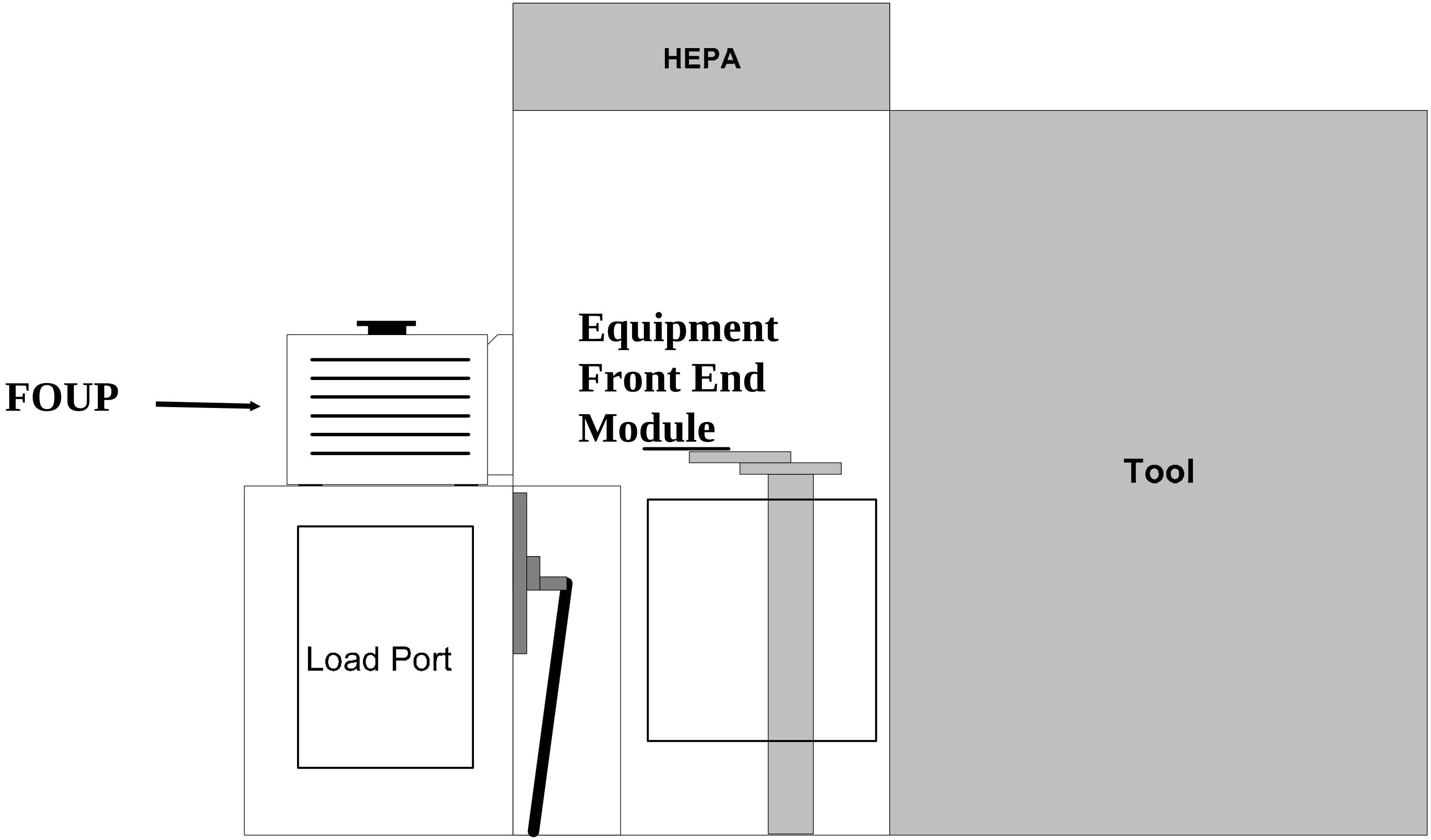
Gas Sampling System

Requirements:

- ★ Portable
- ★ Battery Powered
- ★ No Wasted Gas
- ★ 1 CFM Flow Rate (Faster Sampling)
- ★ Fast Cleanup Times
- ★ Lower Initial Investment
- ★ Lower Running Cost
- ★ Auto Flow Rate Compensation ensures accurate measurement
- ★ Gases Sampled: Argon, Nitrogen, Carbon Dioxide, Helium, CDA, Neon, Xenon

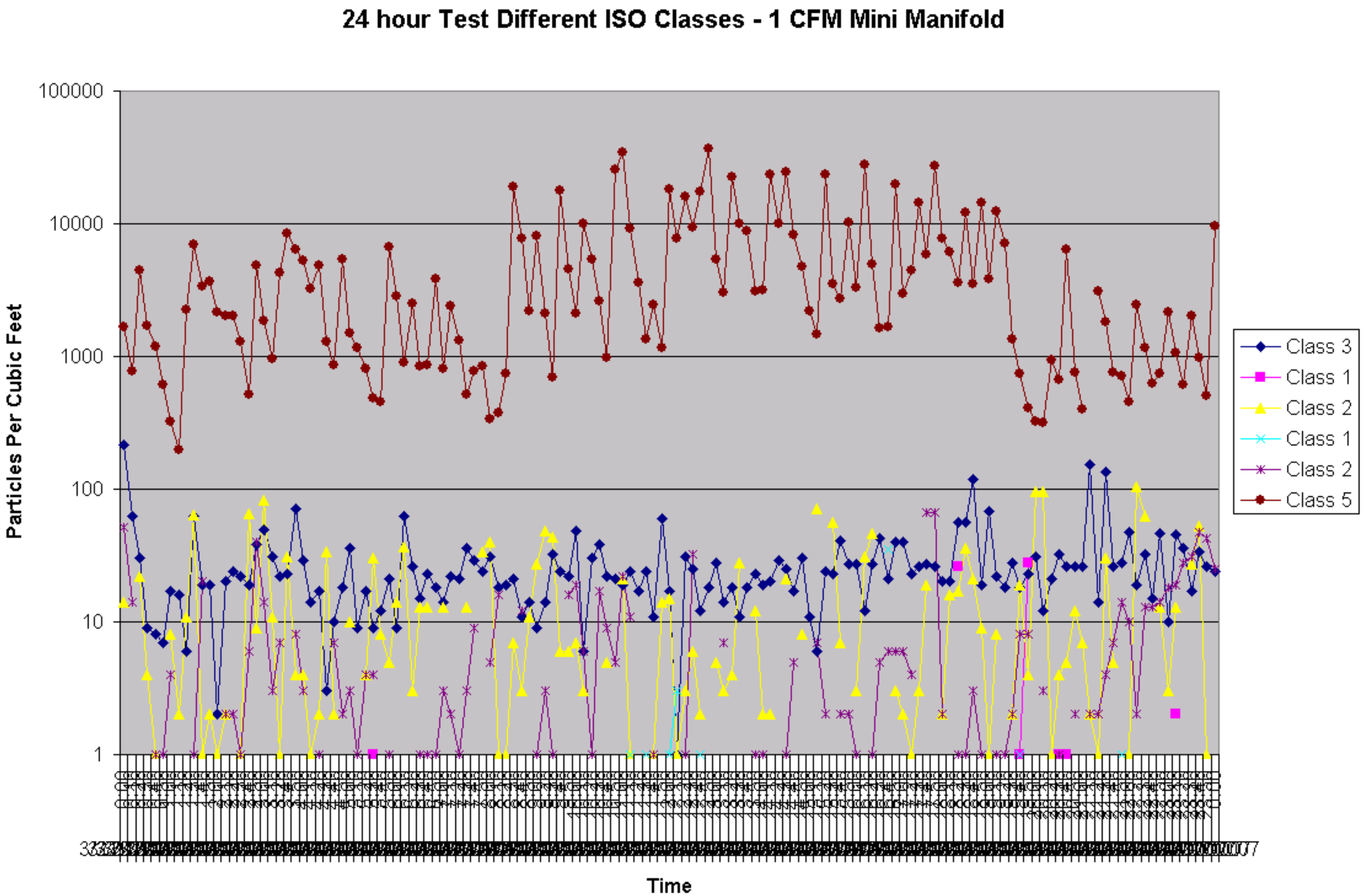
Portable Tool Qualification System





Process Equipment Front End

Partitioning Data

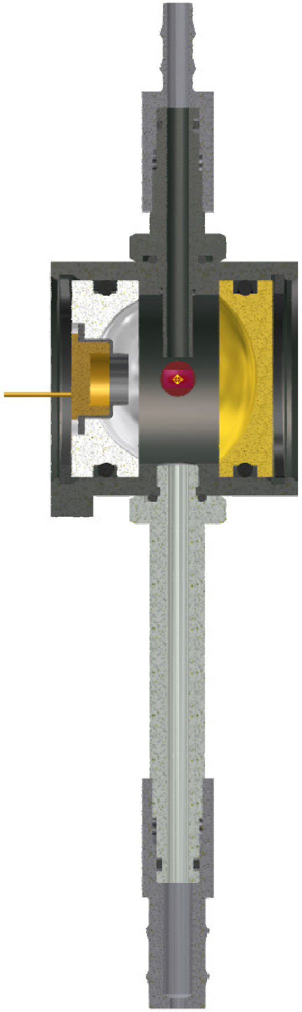


Data Storage Applications

Typical Monitoring Parameters:

- ★Cleanroom Particle Levels
- ★Insitu Process Monitoring of Particles
- ★Drive Level Particle Counts
- ★Process Cleaning Tools
- ★Parts Cleaning Equipment
- ★Part Cleanliness Testing
- ★Equipment Process Environmental Monitoring

Future 0.1 CFM Laser Diode Technology



★Reduced Footprint

★Lower Cost

Summary

- Various Technologies are Available for Monitoring at 0.1 micron
- Solid State Particle Counting Technology, Which is the Dominate Technology in >0.1 micron, has now Been Extended to 0.1 micron
- Remote Solid State Particle Counters are now Available at 0.1 micron for Advanced Applications
- The Industry can Anticipate Cost Effective 0.1 micron, 0.1 CFM Particle Counters in the Near Future