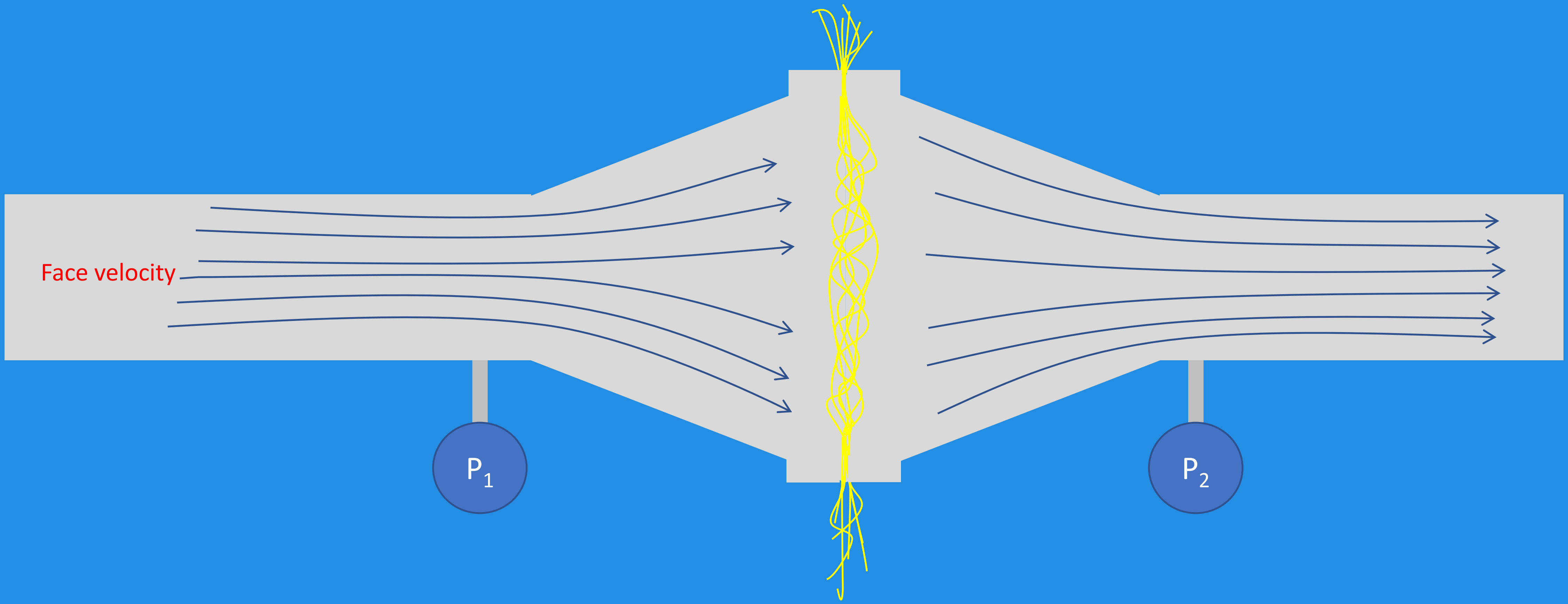
Air Filtration Basics

Overview of Filtration as needed in face masks and respirators

Contents

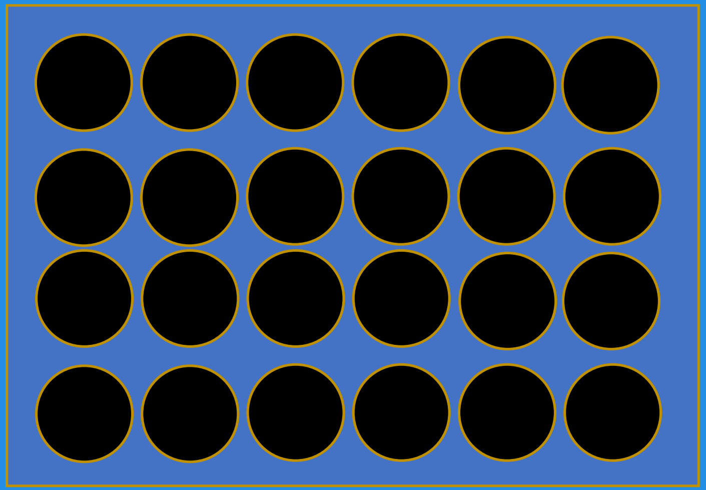
- Pressure drop
- Porosity
- Efficiency
- Particle capture modes
- Dirt holding capacity
- Particles of interest
- This talk is focused on PPE for the current Covid-19 situation, Filtration is a large and complex subject

Pressure drop
Air permeability

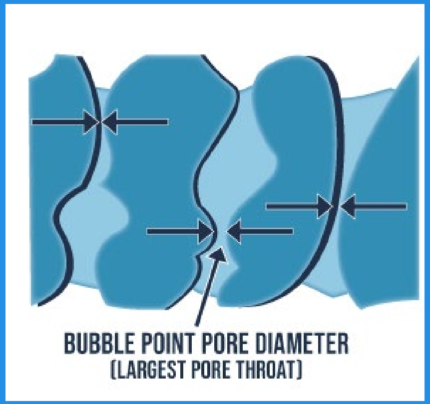


Porosity, pore size, and pore size distribution

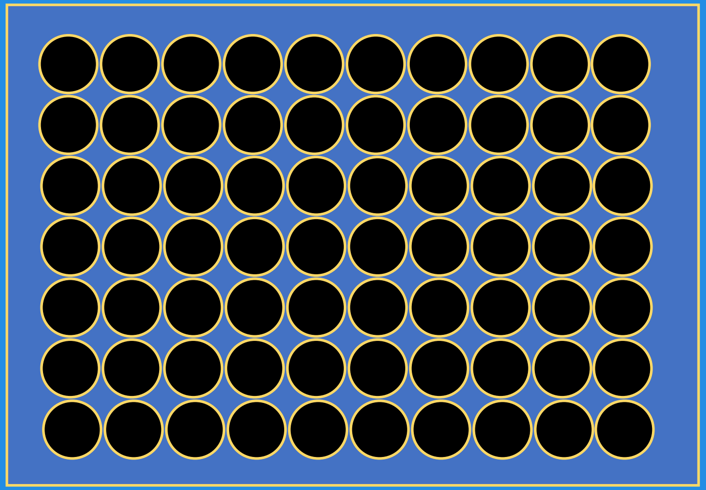
- Porosity
  - Ratio of voids compared to total volume of fabric
  - Bi-modal fiber size
- Pore size
  - Mean pore size
  - Distribution
- Pore size ↓   Porosity ↑   Better filter
  - Smaller fibers (more surface area)
  - Lower fabric density
- Determination
  - Porometry (Bubble point)



Porosity =

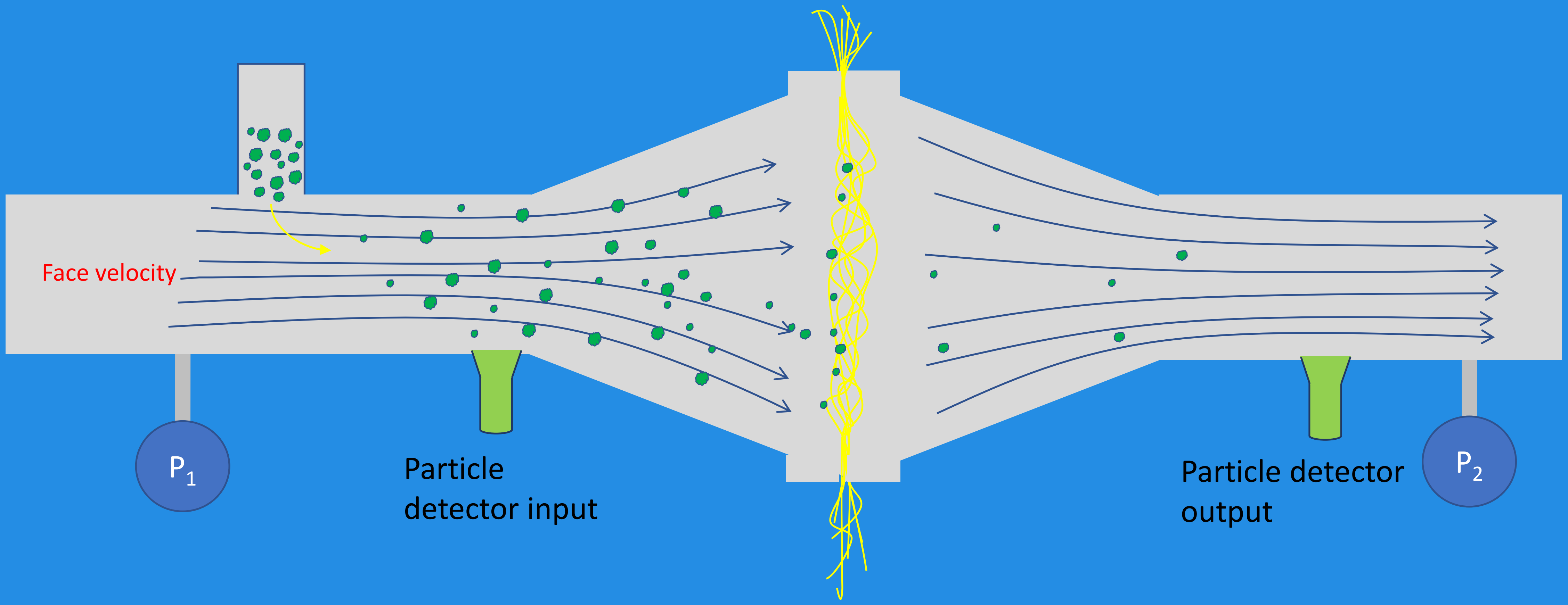


https://www.particulatesystems.com/

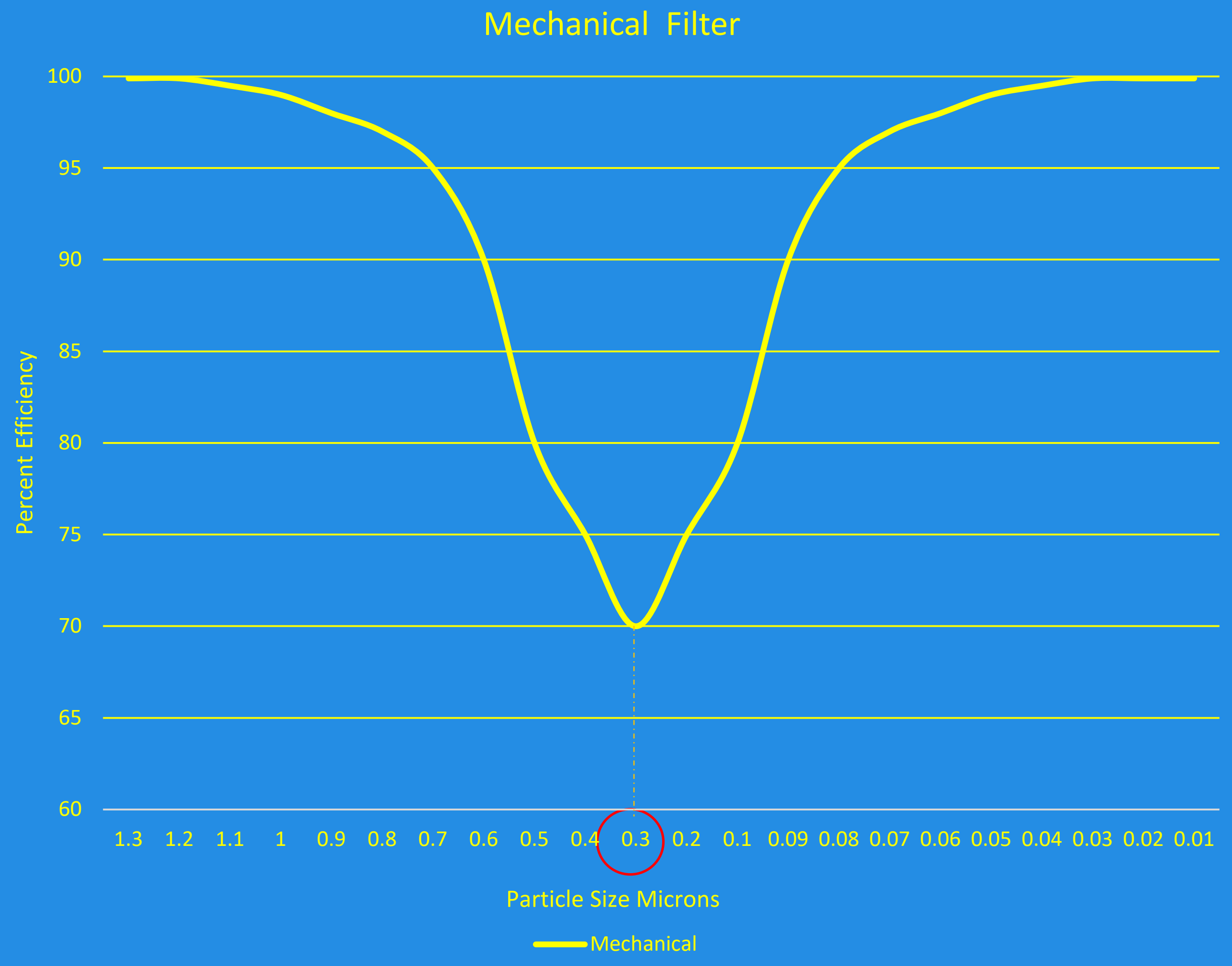


pore size <

Efficiency testing



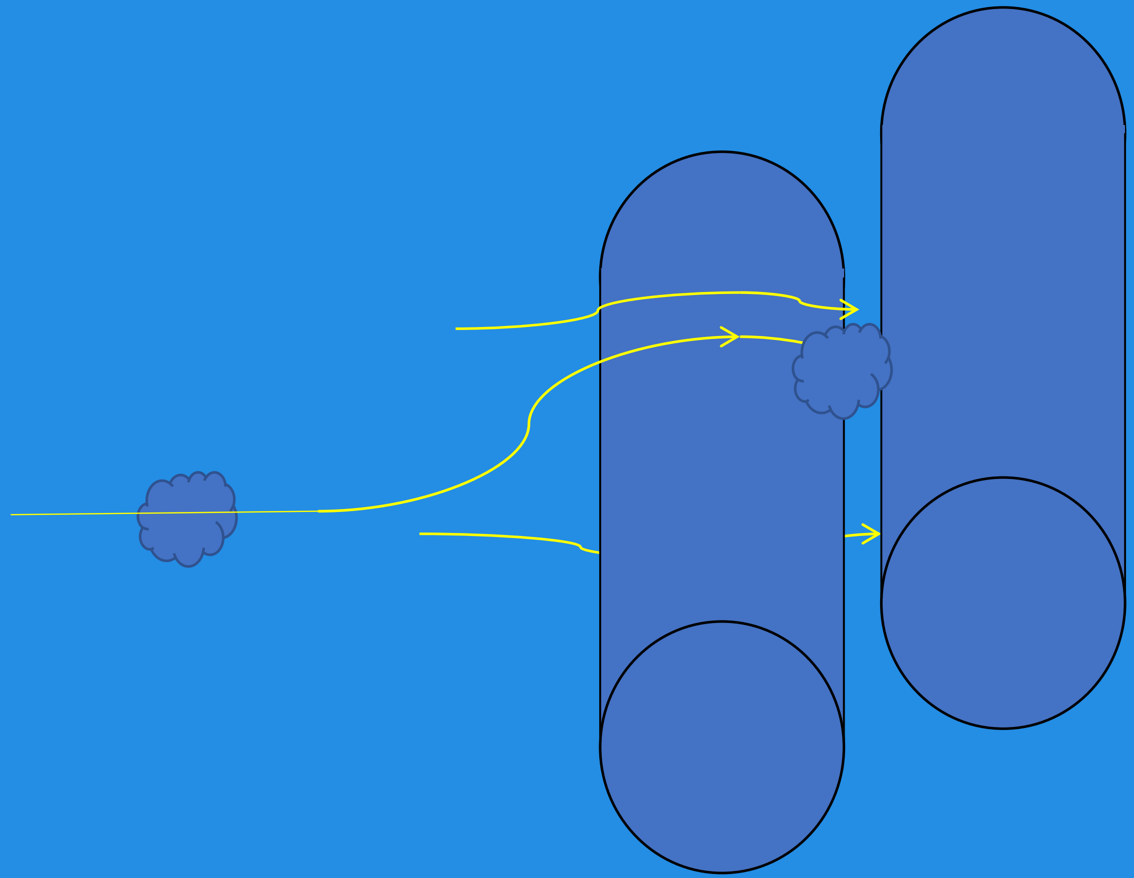
Typical efficiency



Particle capture modes

Sieving

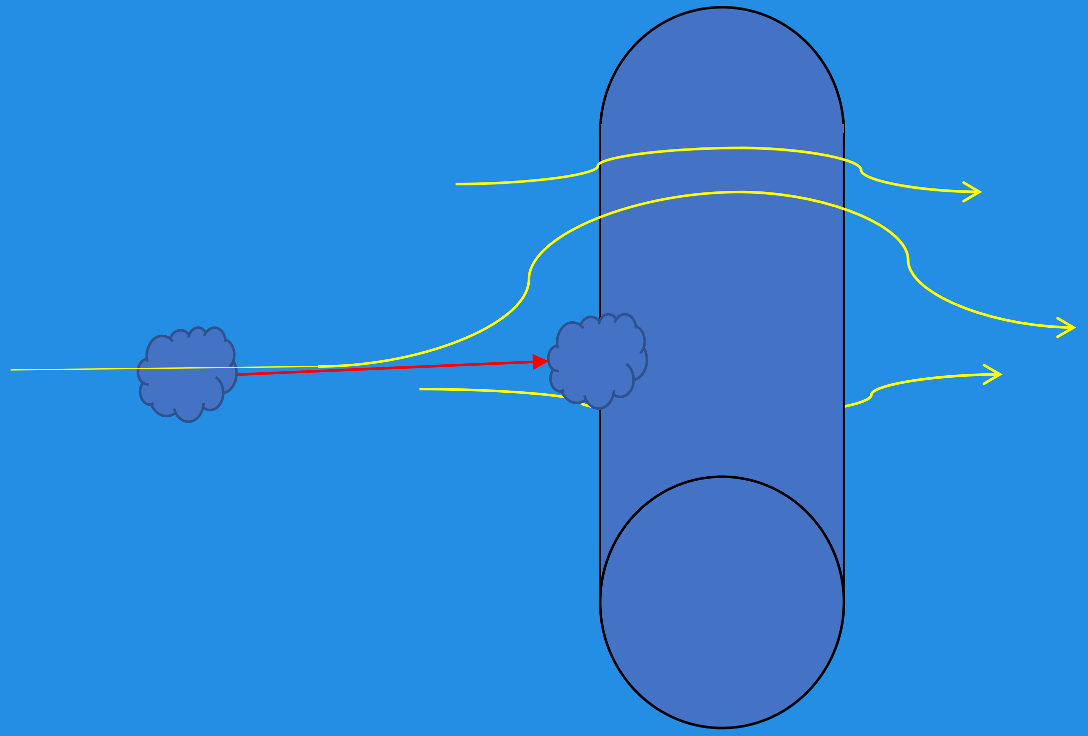
- Particle is larger than the area between fibers
- Dependent on velocity and particle density
- Typically larger particles
- Pore size does not equal minimum particle size capture



Particle capture modes

Inertial Impaction

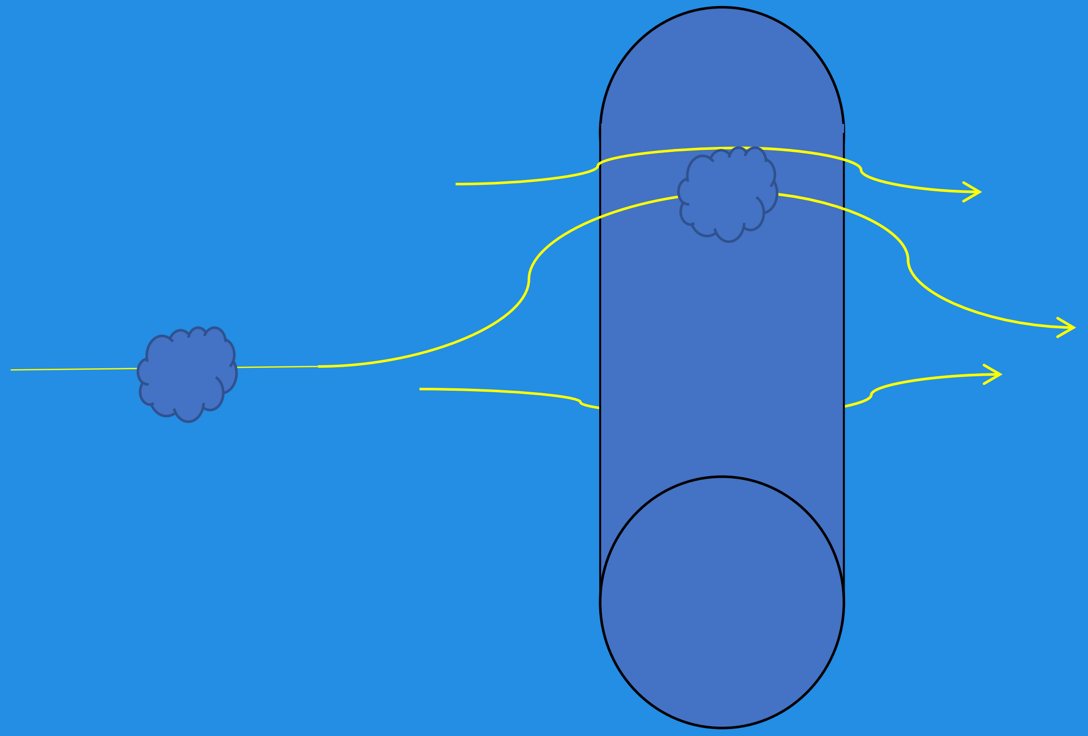
- Particle does not stay in slip stream and finds side of fiber.
- Van der walls forces hold it fast
- Dependent on velocity and particle density
- Typically particles .3-10 microns



Particle capture modes

Interception

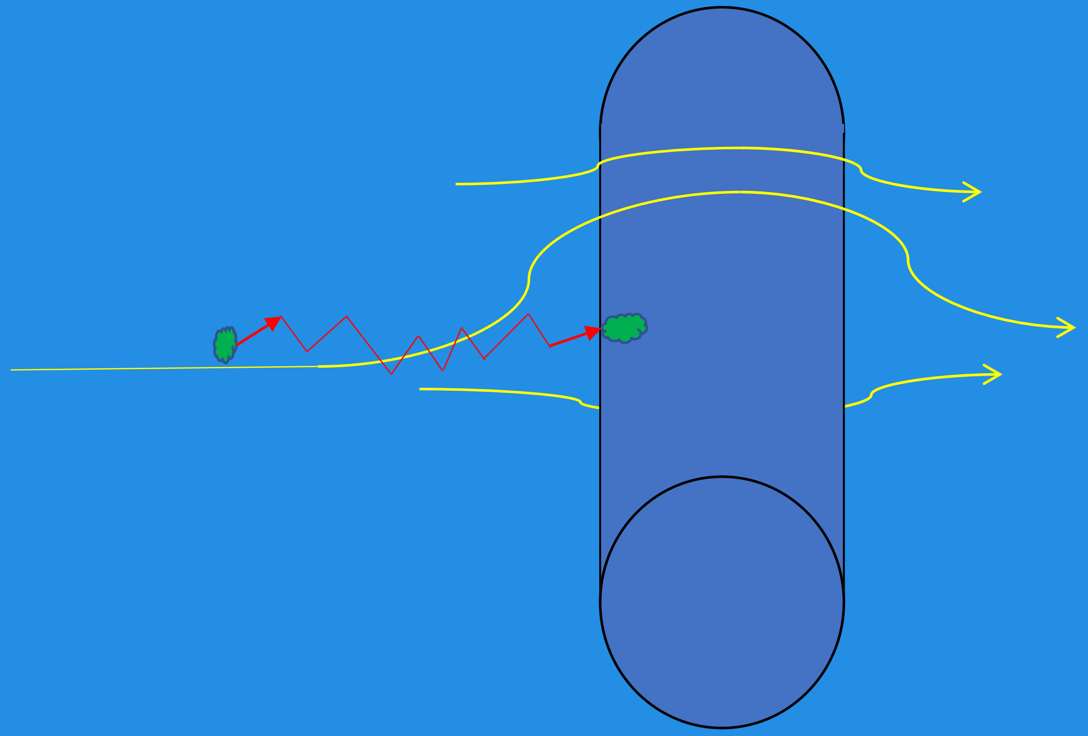
- Particle in slipstream encounters fiber
- Van der walls forces hold it fast
- Dependent on particle to pore size
- Dependent on velocity
- Typically particles .3-10 microns



Particle capture modes

Brownian Diffusion

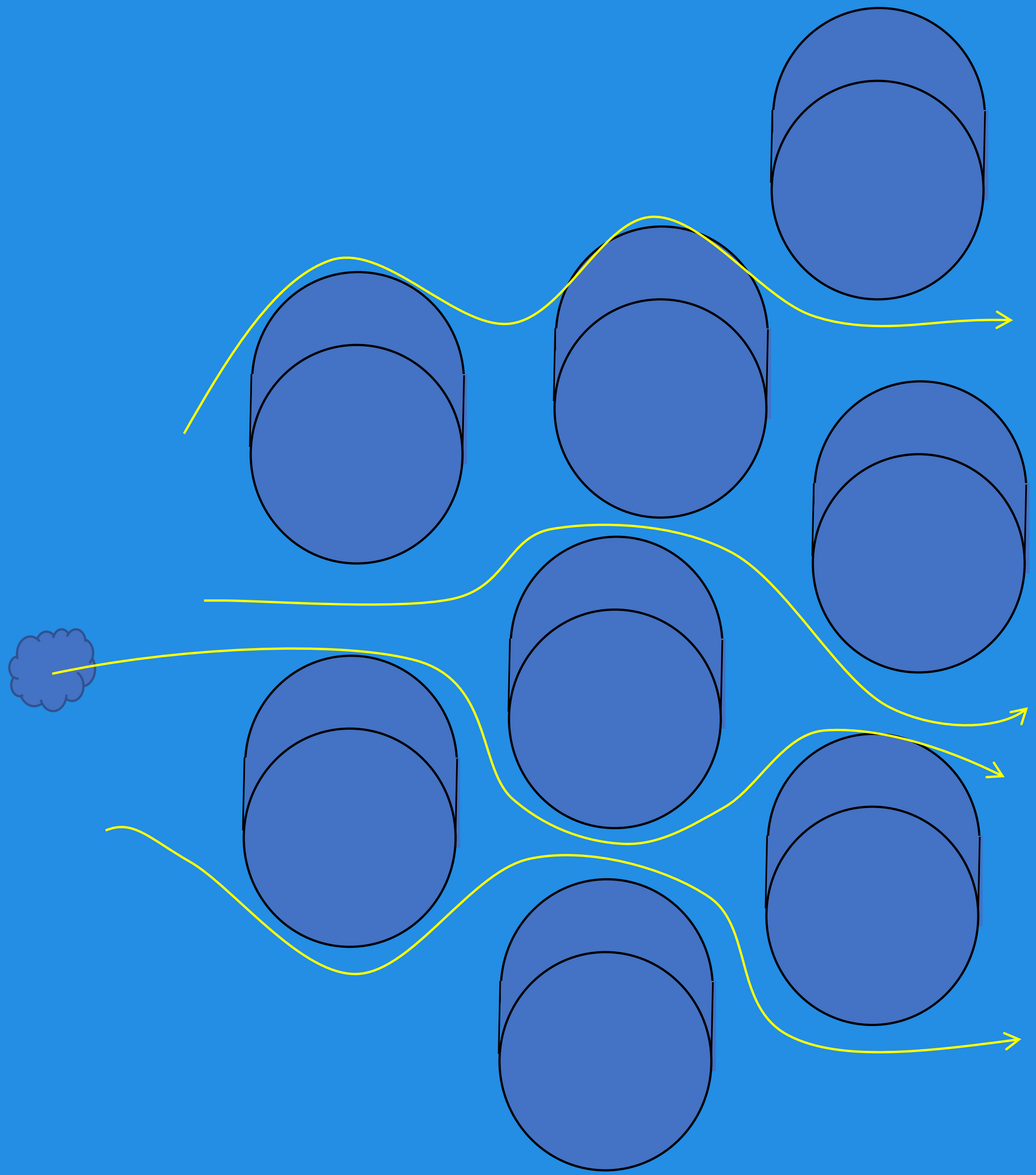
- Random wiggling motion of small airborne particles
- Caused by collision with smaller molecules
- Van der walls forces hold it fast
- Typically particles below .3 microns
- Increases probability of capture



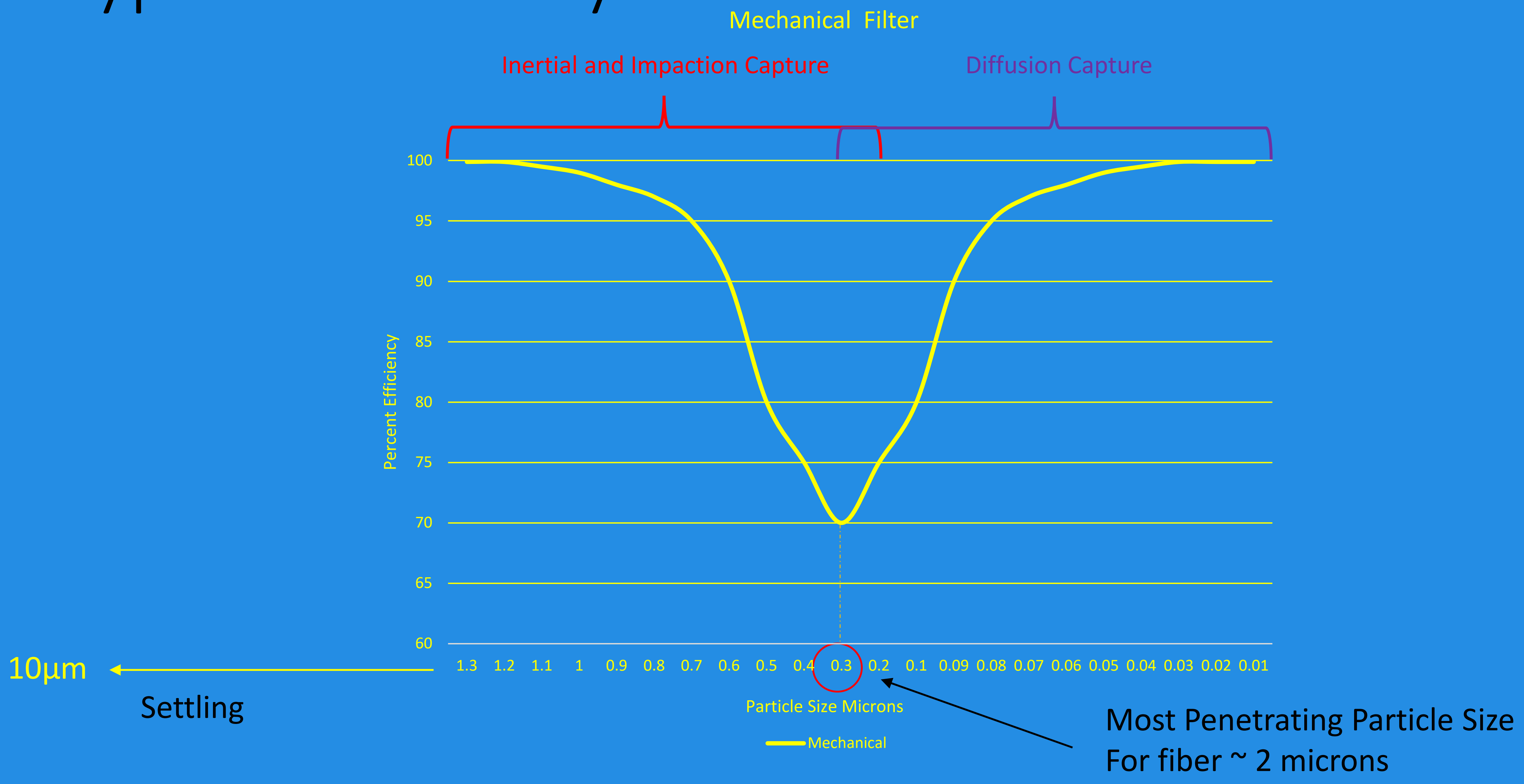
Torturous path

Depth filtration

- Presents many opportunities for particle to come into contact with fiber
- Increases probability



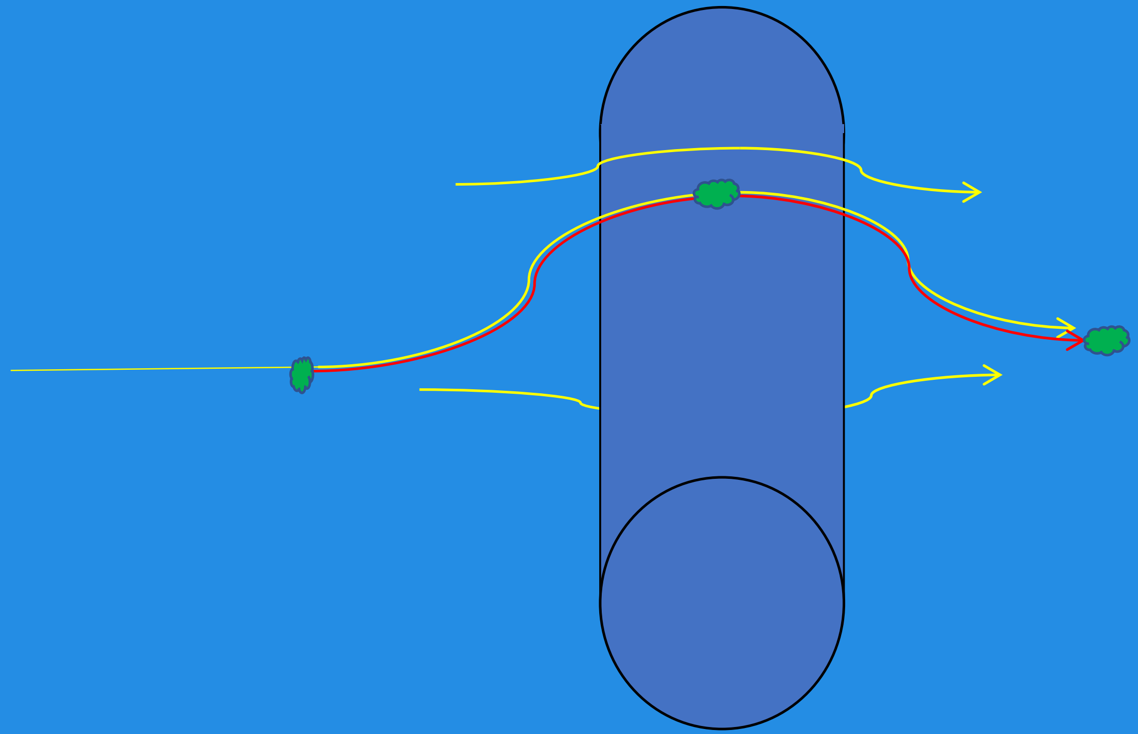
Typical efficiency



Particle capture modes

Failure .1-.3 microns

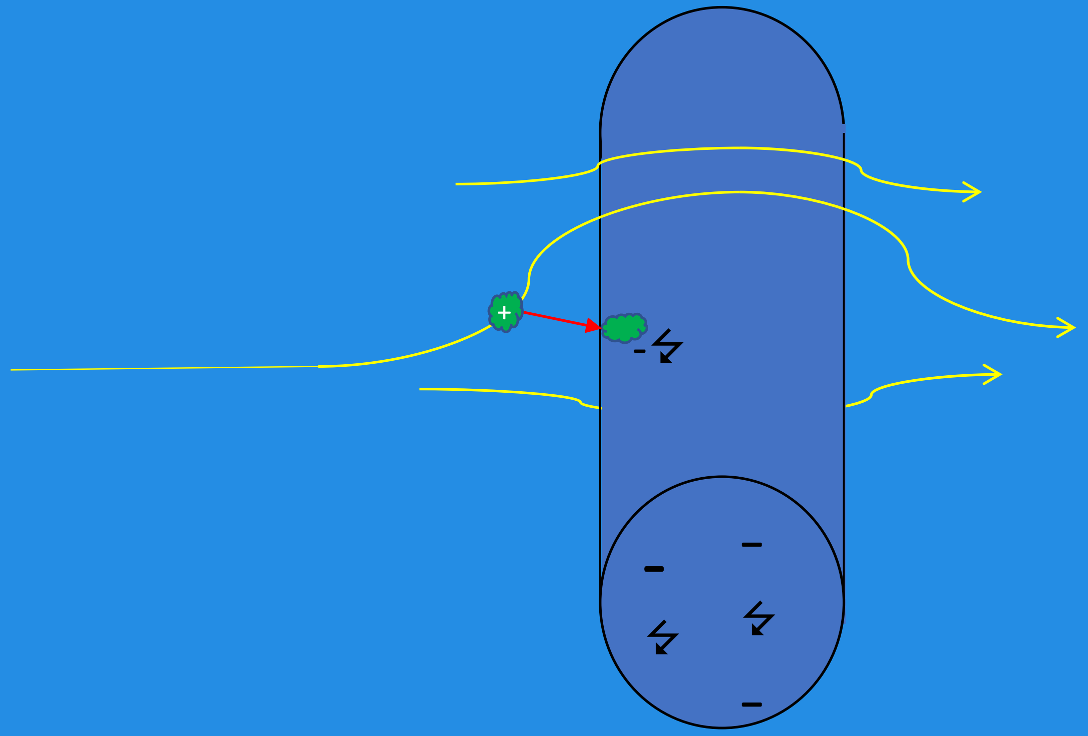
- Particle has insufficient mass for inertial impaction
- Particle has too much mass for Brownian diffusion
- Remains in slip stream



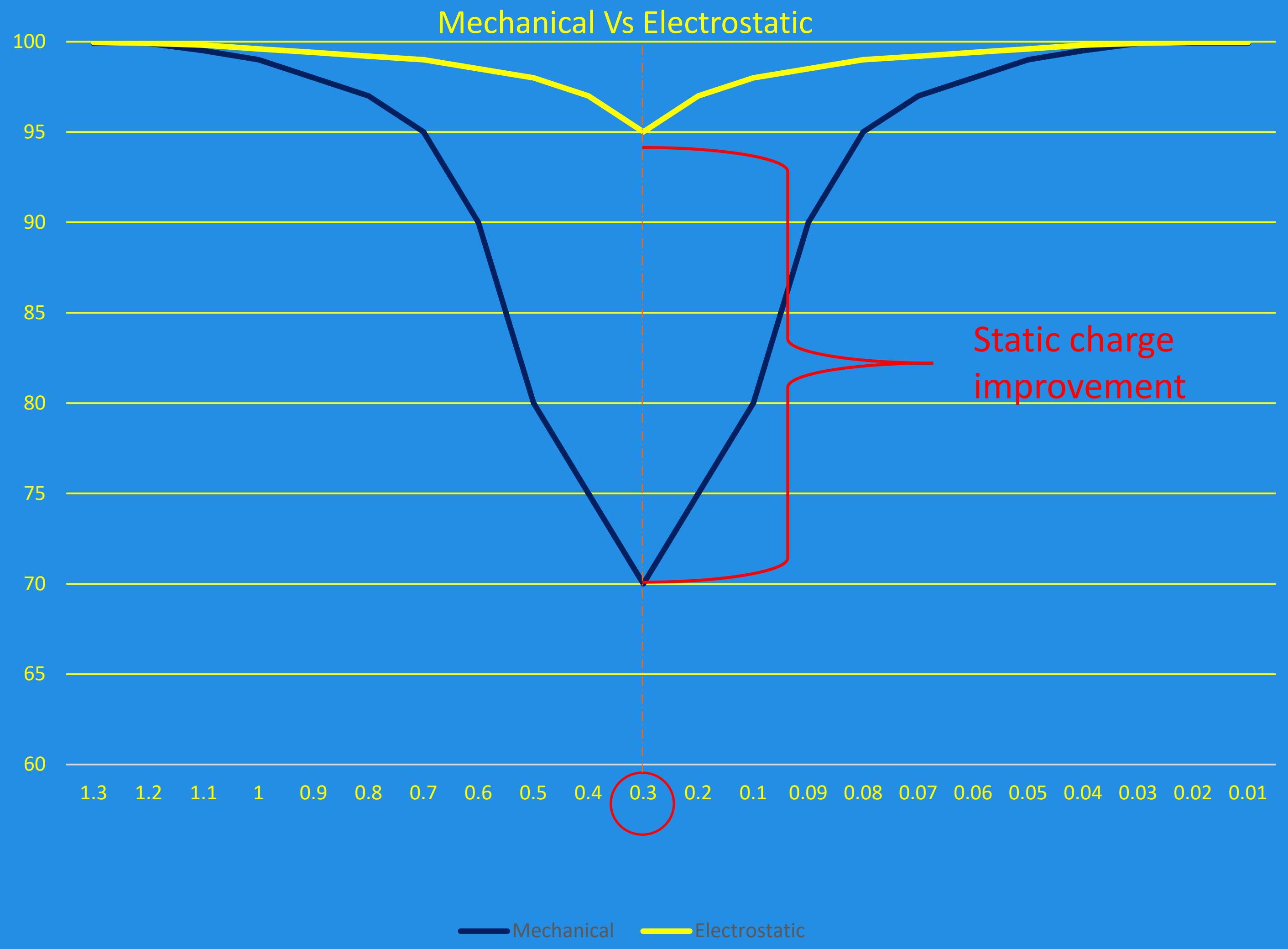
Particle capture modes

Electrostatic Attraction

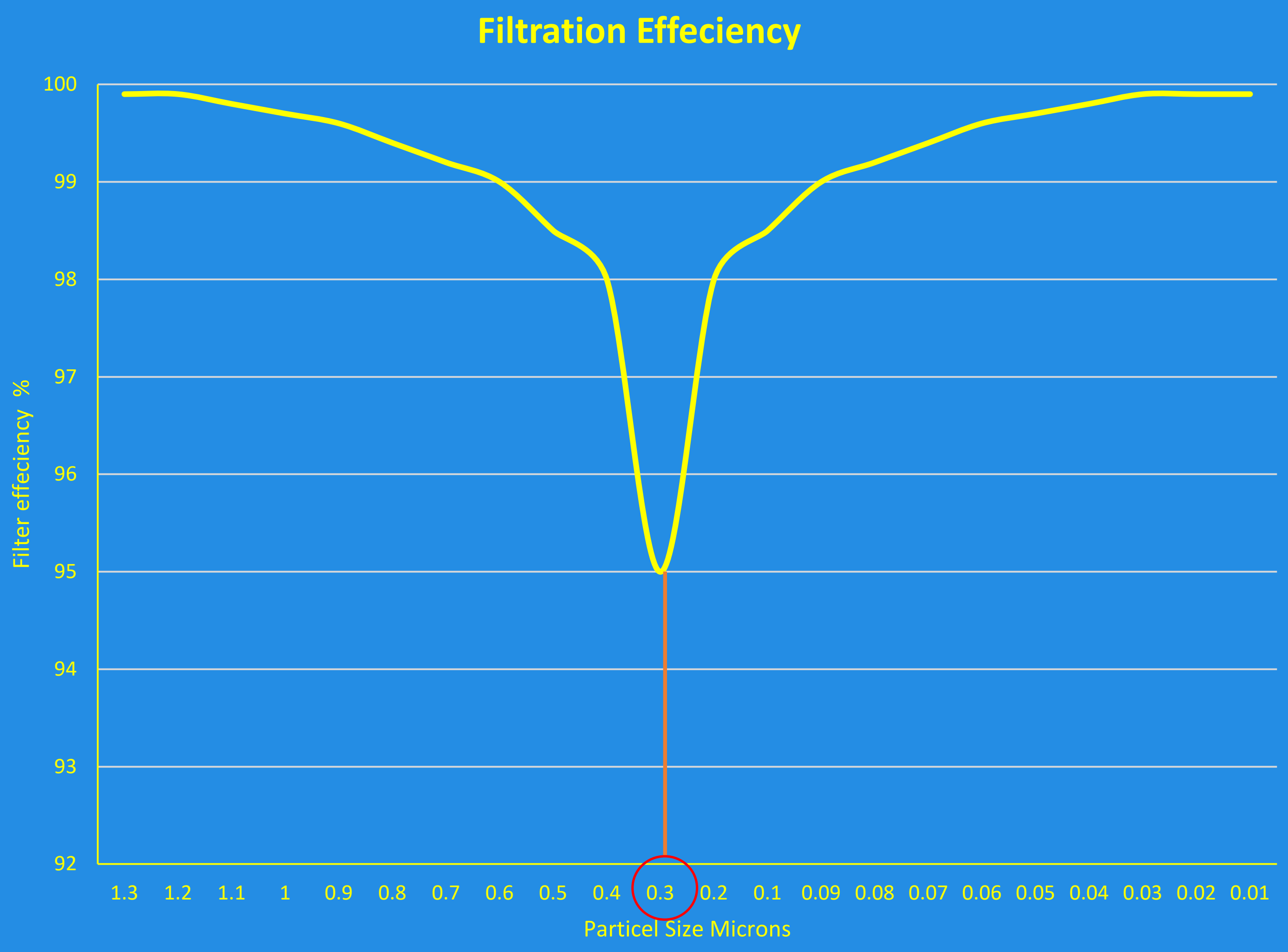
- Fibers are charged during manufacture
- Creates a potential differential between fiber and particle
- Coulombs law
  - The value of the electrostatic force of interaction between two point charges is directly proportional to the scalar multiplication of the charges and inversely proportional to the square of the distance among them.



Typical efficiency



Typical efficiency



Dirt/Dust holding capacity

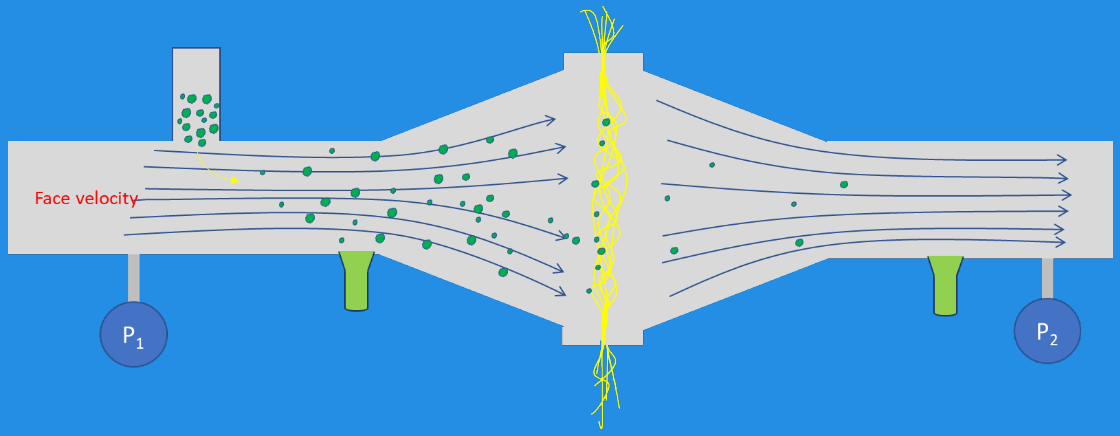
- Dirt holding is defined by the amount of fouling (particles) a filter can hold with still acceptable pressure drop.
- Can be increased with prefiltration

Particle sizes of interest

- Virusus-.00125µm-.016µm (Brownian diffusion)
- Bacteria .013µm-12.0µm
- Atomized droplets 1µm – 10.2µm

Efficiency testing

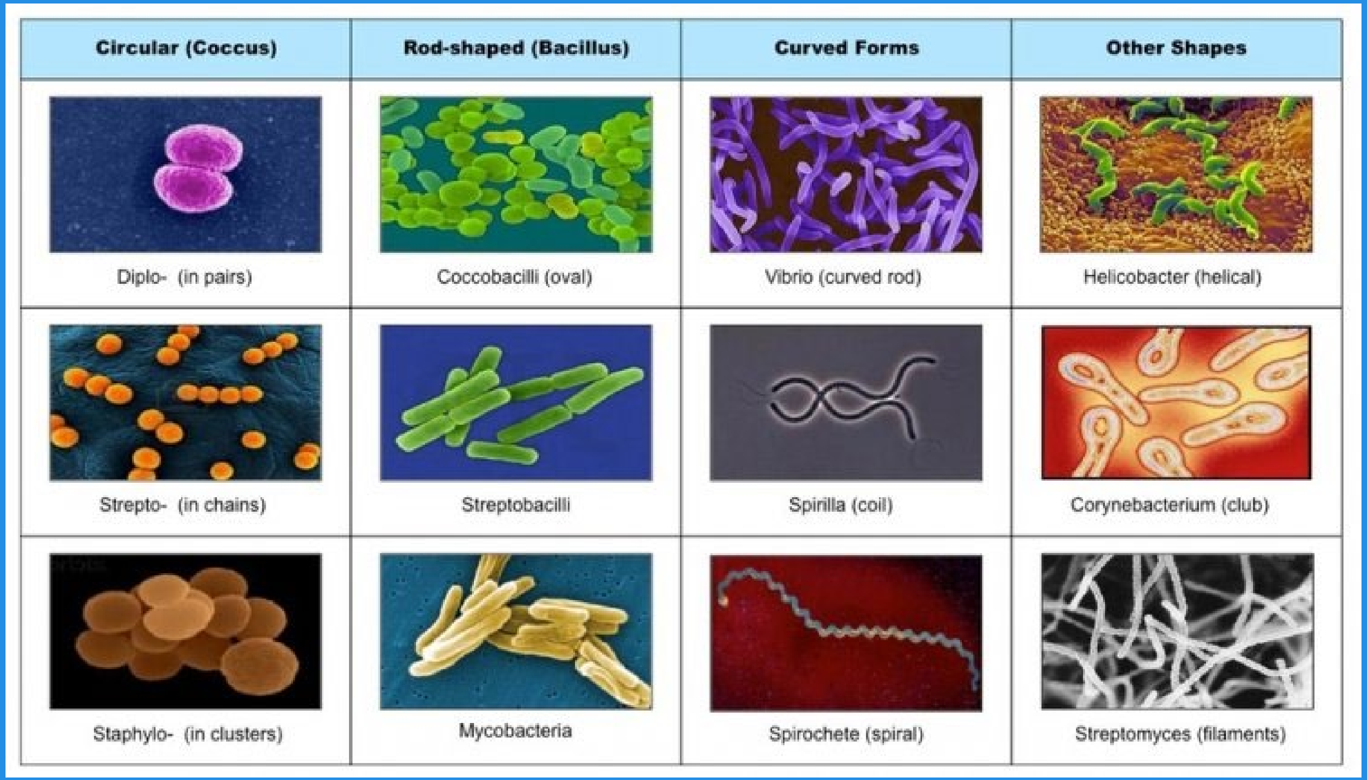
- Various particle types for respirators
  - DOP (dispersed oil particulate)
  - NaCl
  - Oil
  - Latex
- Various particle counters
  - Light scattering photometer
  - Condensation Particle Counter
- Tests
  - 42 CFR Part 84
  - EN 143 and 149
  - ISO 16900
  - ASTM F2299-03
- Filter testing is complex
  - Webinar coming up on testing



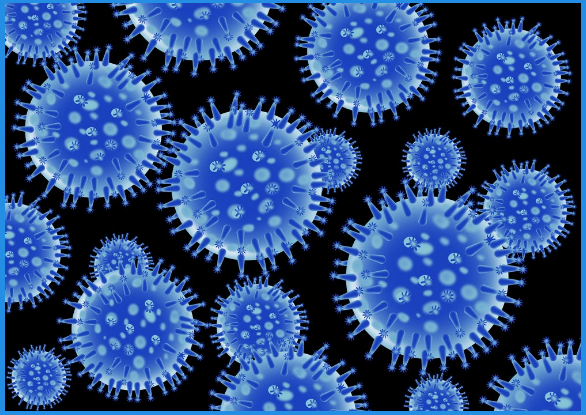
Microorganism motility

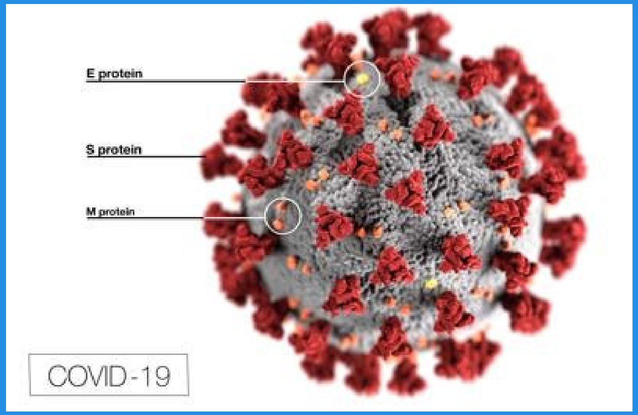
- Microorganism shape and size
- Move with the aid of a carrier
  - Liquids
    - Blood, Perspiration, Spit, Mucus, Alcohol*
  - Solid
    - Lint, Dust
- Must consider how the carrier impacts movement through substrate
  - Carrier Size
  - Viscosity
  - Surface Energy and Charge
  - Capillary Action
- Pressure

Common Microorganism Shapes



← **Microorganisms**





← **Viruses**

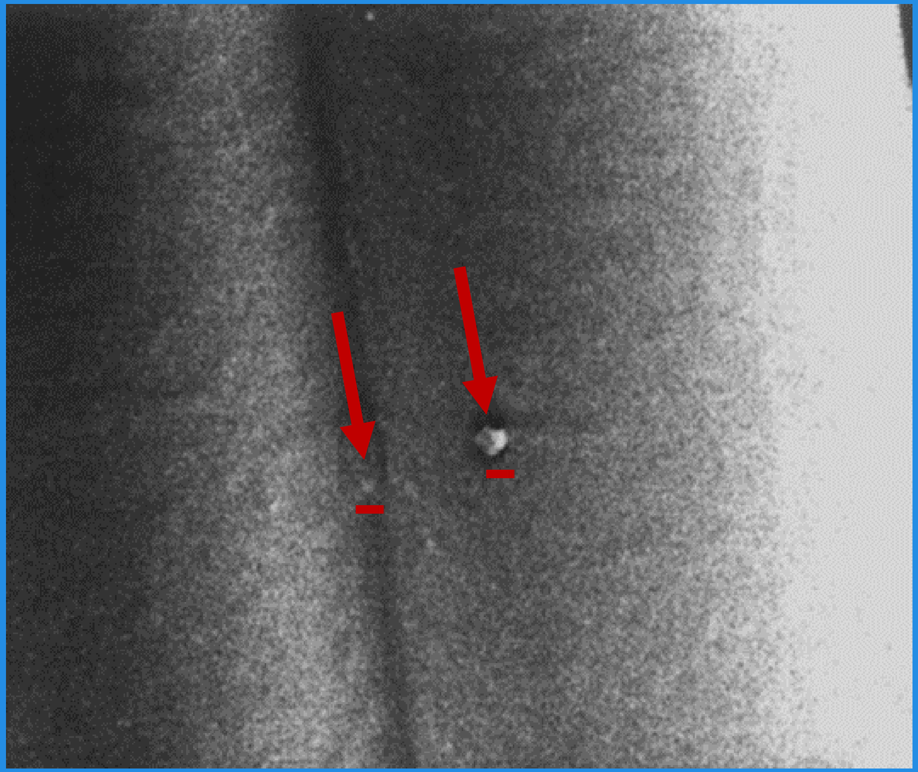
Barrier Properties of Fabrics/Films

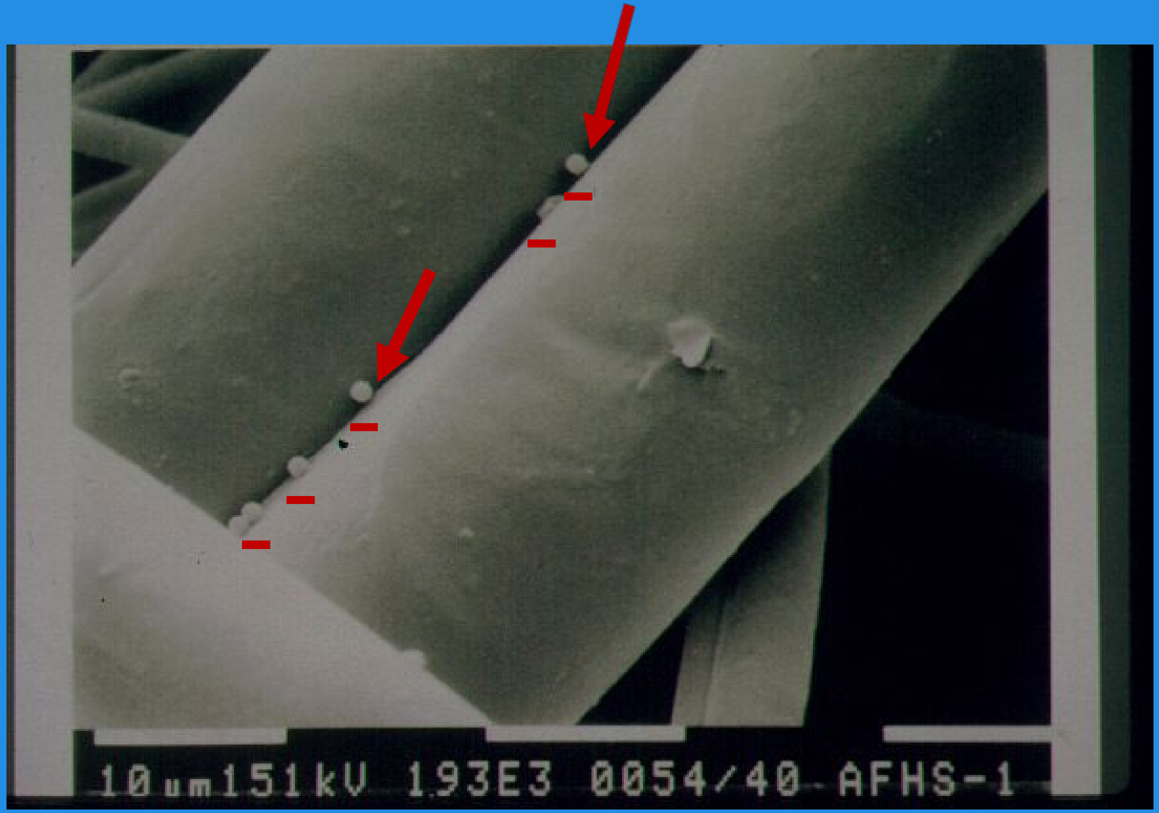
- Move with the aid of a carrier
  - Liquids
    - Blood, Perspiration, Spit, Mucus, Alcohol*
  - Solid
    - Lint, Dust
- Must consider how the carrier impacts movement through substrate
  - Carrier Size
  - Viscosity
  - Surface Energy
  - Charge
  - Capillary Action

Study: Microorganism sized particle transmission through fabrics

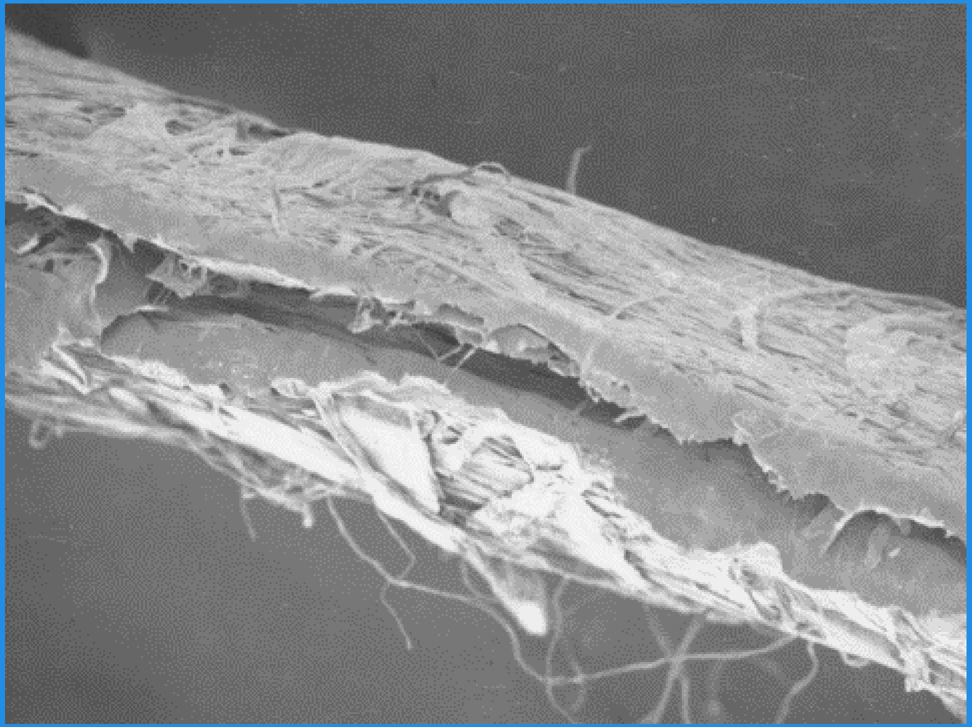
- Laser Scanning Confocal Microscopy (LSCM)
  - Optical Sectioning of barrier
  - Different wavelength excitation of fabric (Barrier) vs particle
- Particles
  - 1mn latex microspheres
  - E.coli genetically modified to fluorescence
- Fabrics
  - Spunbond/Meltblown/Spunbond Composite - typically used in surgical gowns and drapes
- Facemasks

Study: Microorganism transmission through fabrics

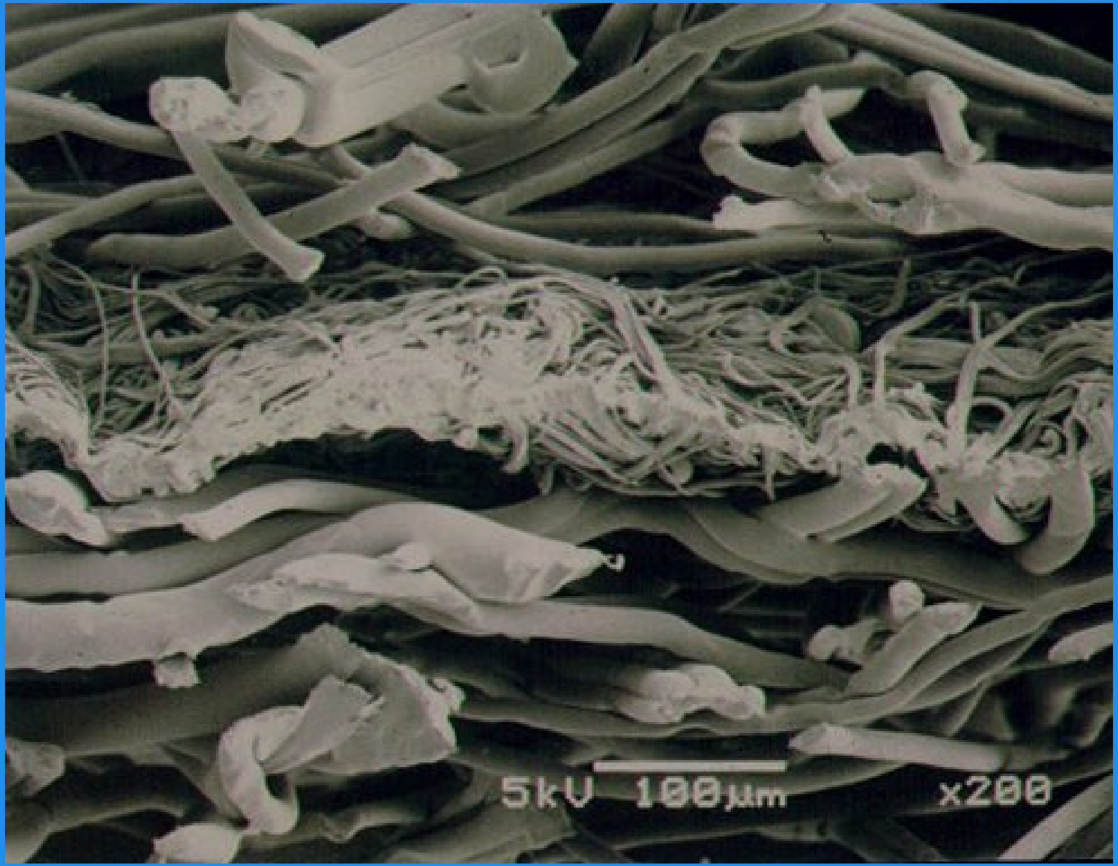




Spunbond Fabric – SMS Cross section



SMS Fabric – SEM Cross section



Study: Microorganism transmission through fabrics

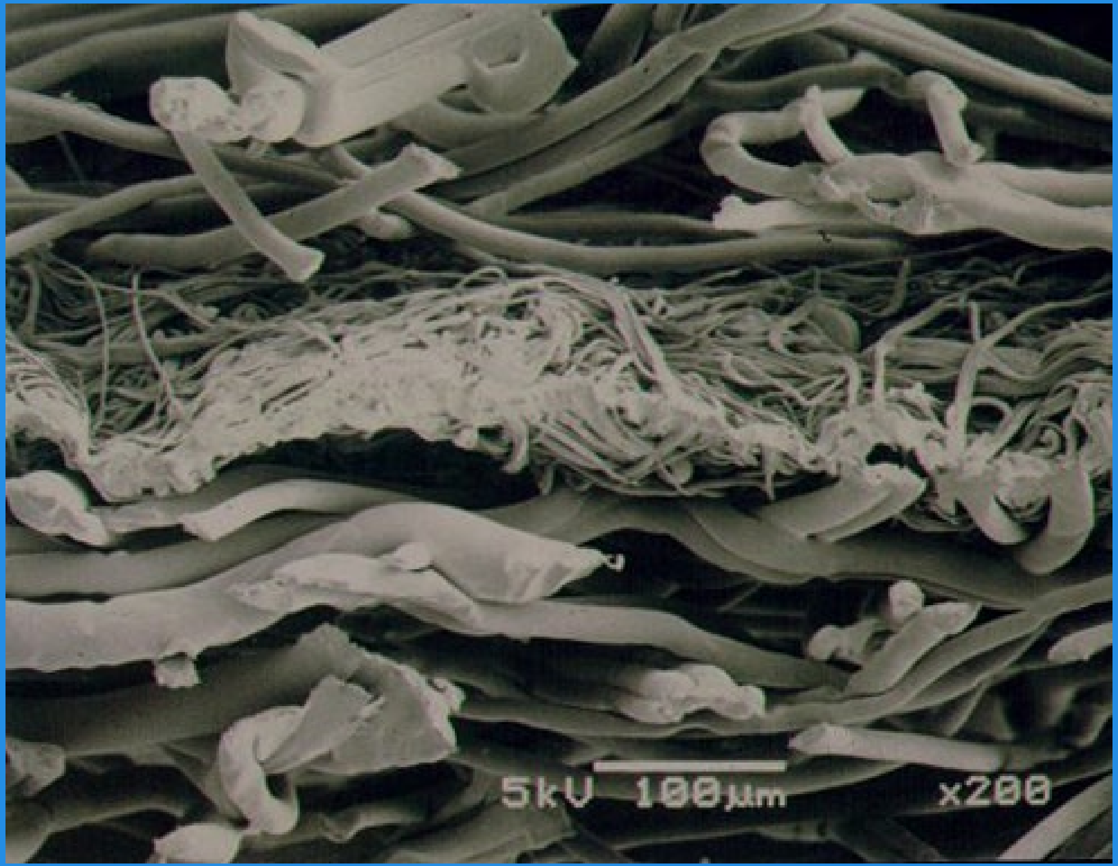
- Laser Scanning Confocal Microscopy (LSCM)
  - Optical Sectioning of barrier
  - Different wavelength excitation of fabric (Barrier) vs particle

- Fabrics
  - Spunbond/Meltblown/Spunbond Composite ok

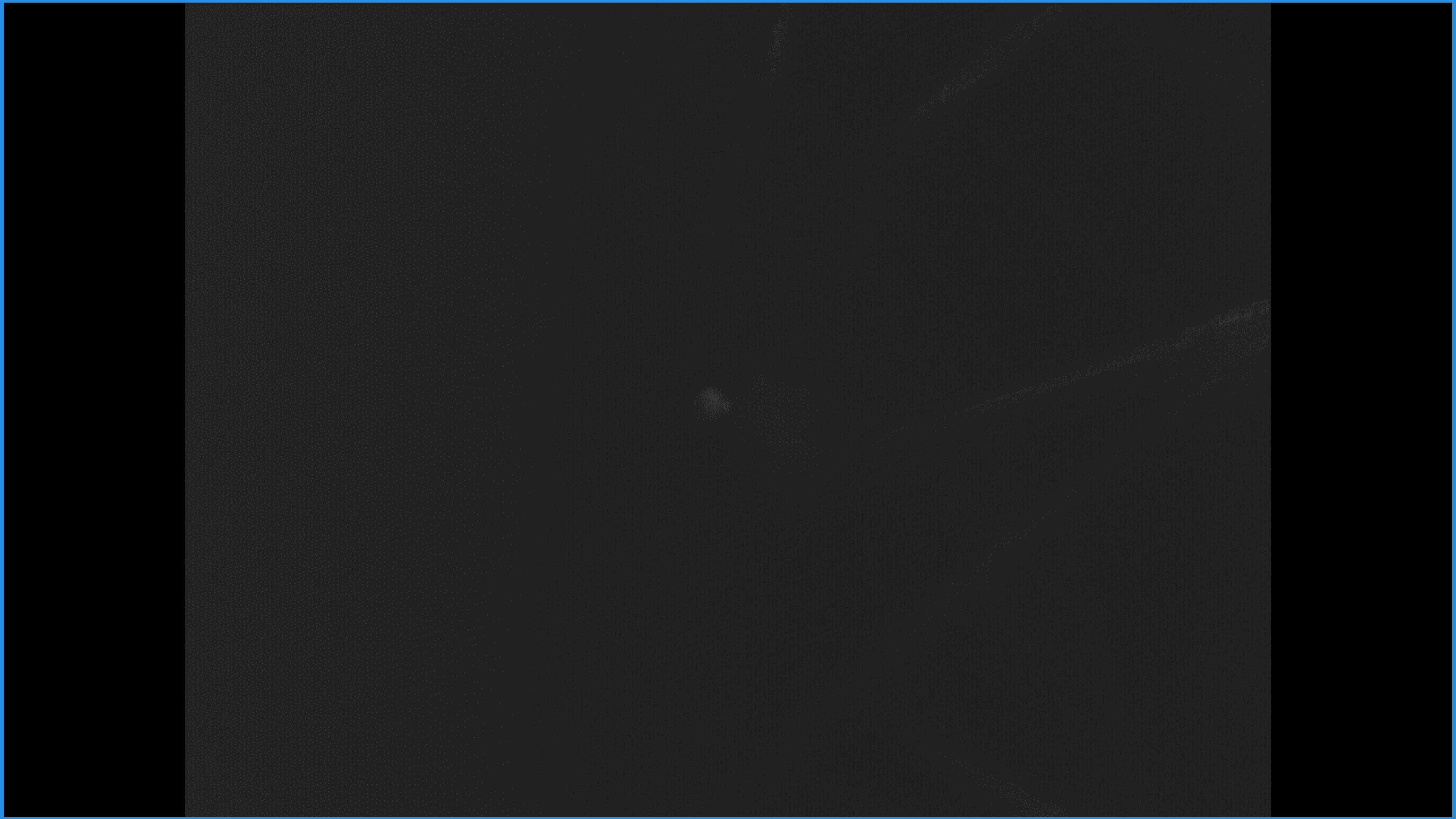
Study: Microorganism transmission through fabrics

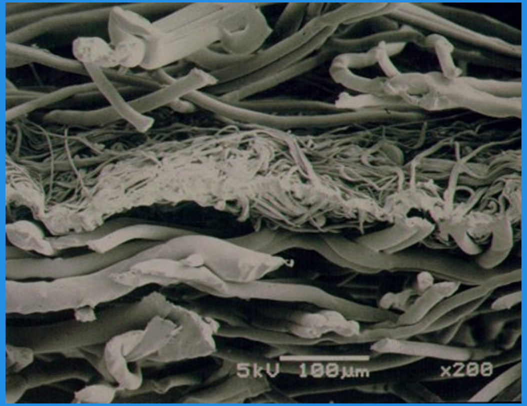
- Laser Scanning Confocal Microscopy (LSCM)
  - Optical Sectioning of barrier
  - Different wavelength excitation of fabric (Barrier) vs particle
- Particles
  - 1mn latex microspheres
  - E.coli genetically modified to fluorescence
- Fabrics
  - Spunbond/Meltblown/Spunbond Composite - typically used in surgical gowns and drapes
  - Woven fabric treatment
  - Surgical Face Mask configurations
- ok

SMS Fabric – SEM Cross section



SMS Fabric – SEM Cross section





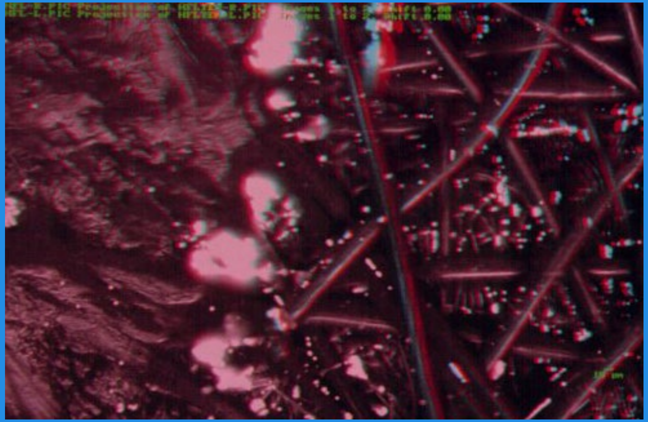
- https://drive.google.com/file/d/1KeR3SkF7sLL90ynQMNBvot9KdWPvWgVJ/view

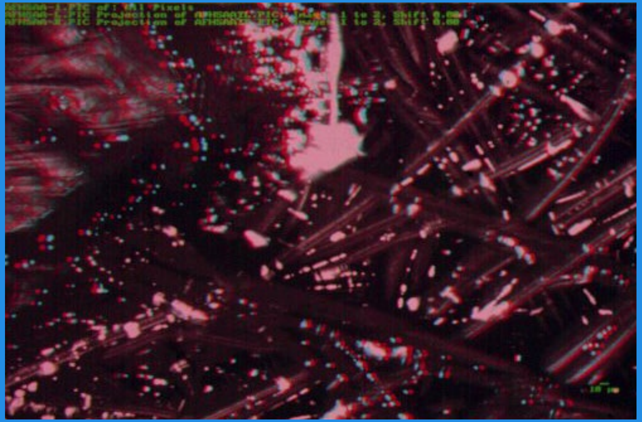
SMS Fabrics exposed to particles under pressure

Water

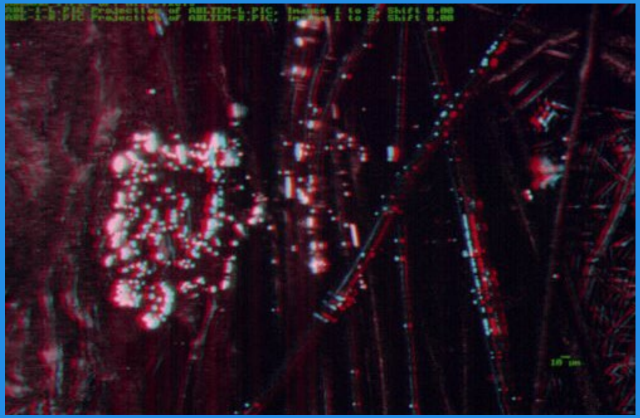
Synthetic Blood

Face

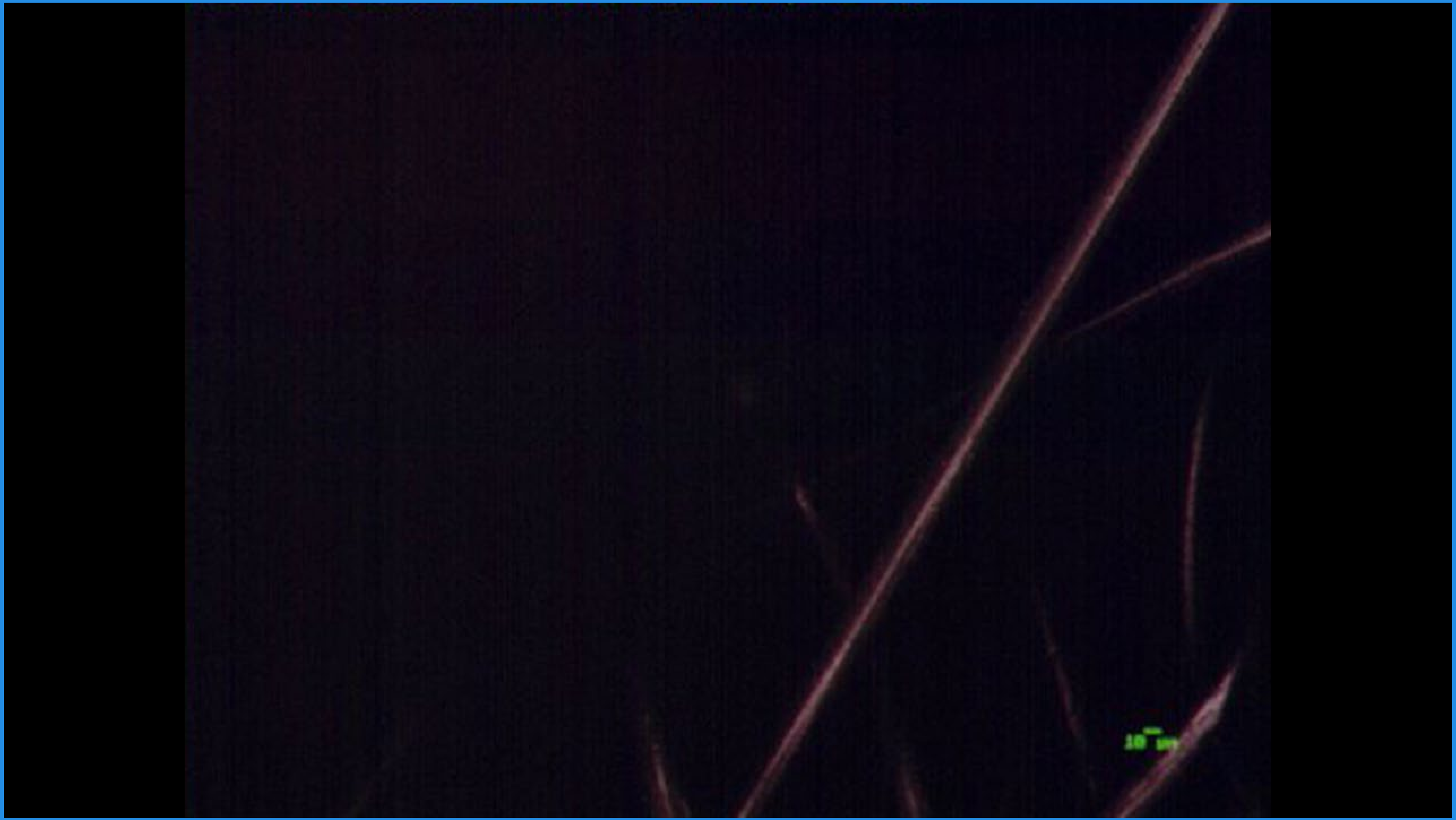




Back



SMS Fabric – Small particle movement

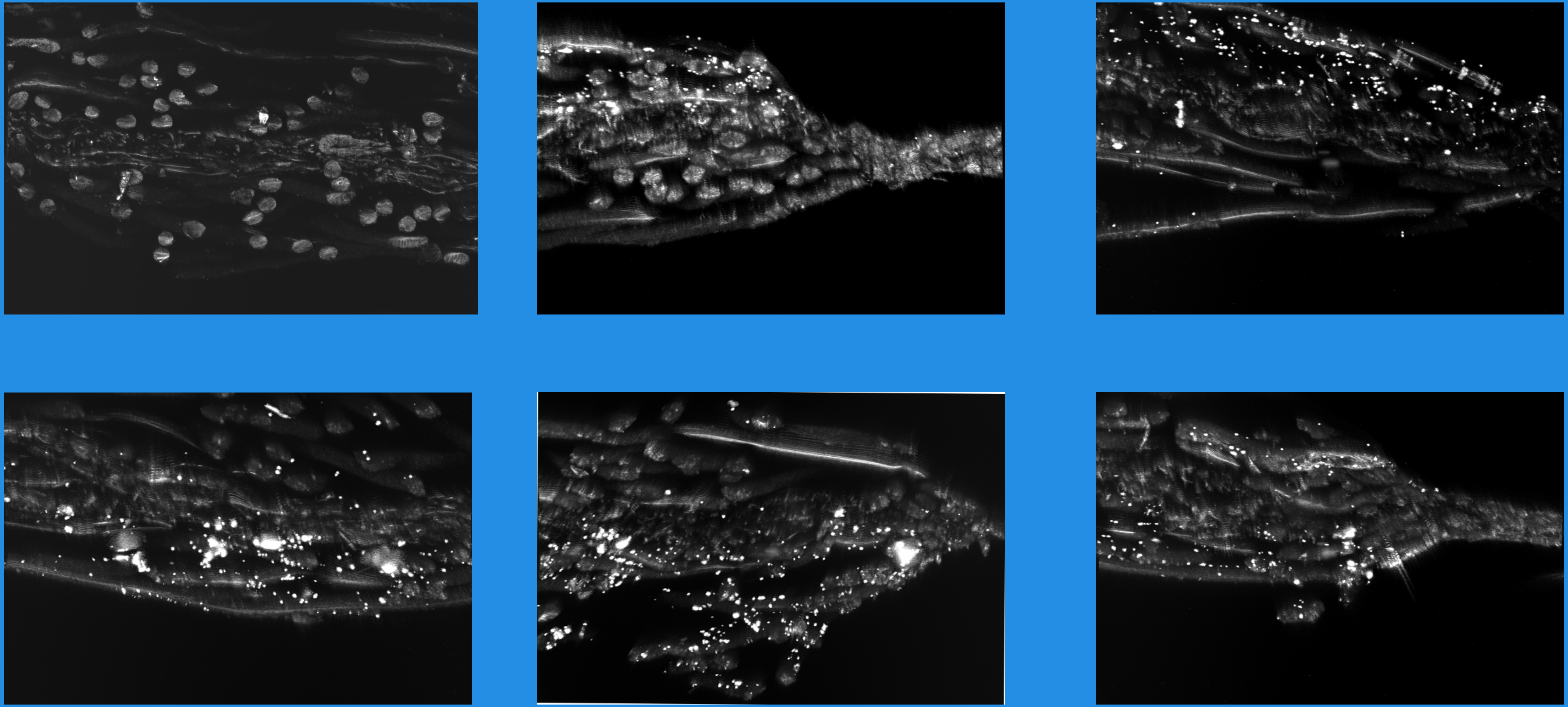


https://drive.google.com/file/d/13HcKVoTilbop27rKXPG1Pr4at4m44_ZA/view

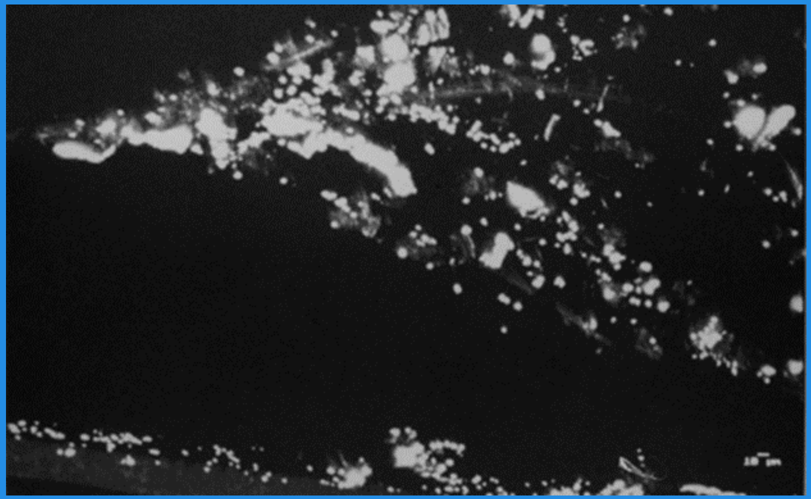
SMS Fabric – Small particle movement

https://drive.google.com/file/d/1UgI8xcdJMvHXQ4kxzKIFX14_K1NVW6Z1/view

SMS Cross-Sections
Latex microspheres transmission location at increasing pressure



SMS Fabrics with Microporous Film Latex microspheres transmission location at increasing pressure

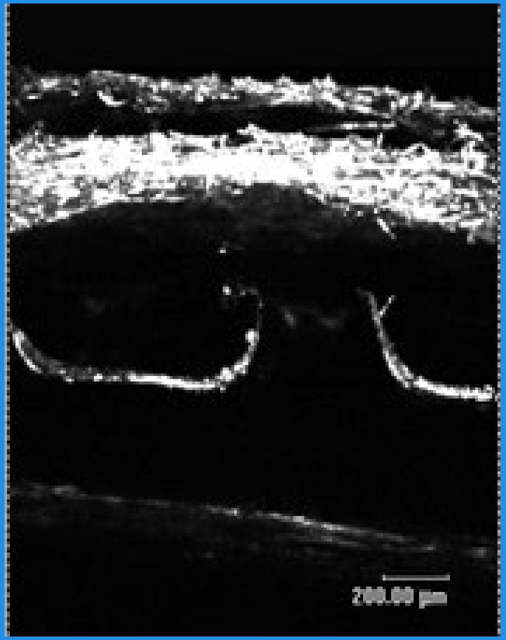


*Facemasks**

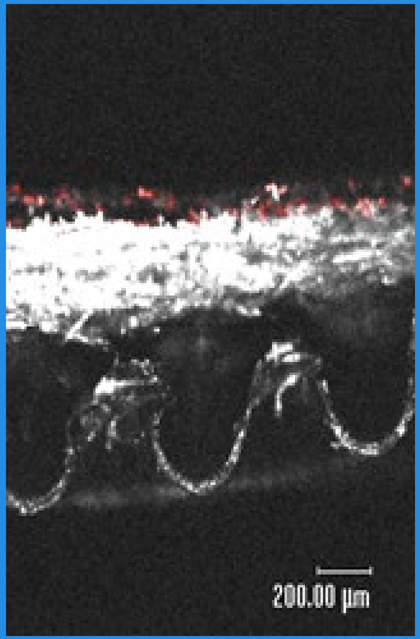
**From Leonas, K K and Shin, H*

Facemask 1 Cross-Sections

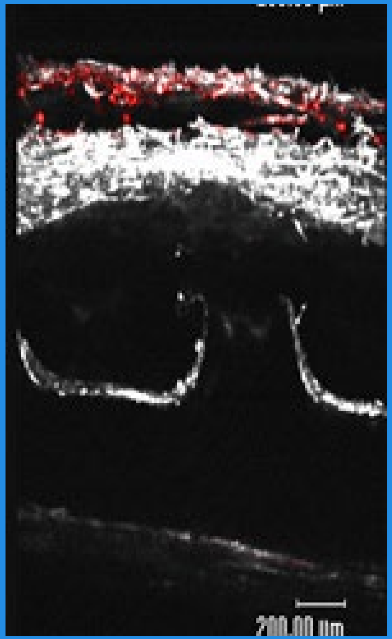
Latex microspheres transmission location at increasing pressure



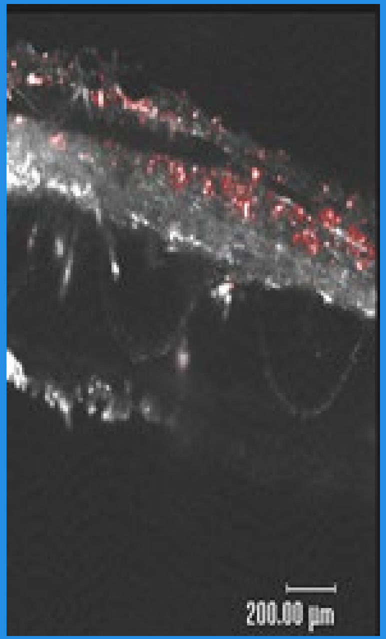
Control



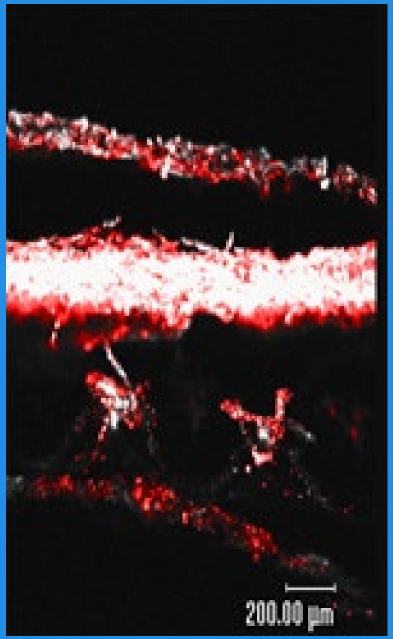
80 mmHg



120 mmHg



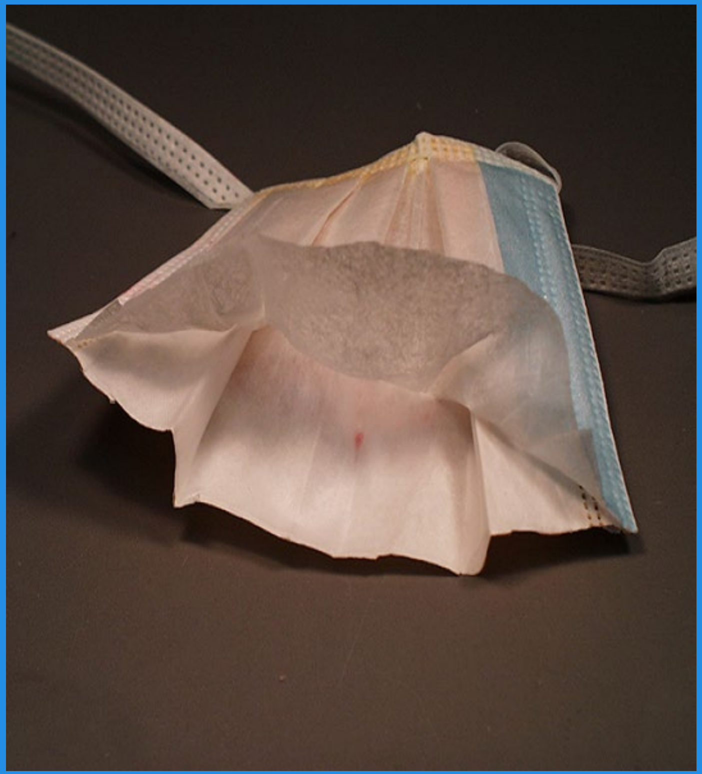
160 mmHg



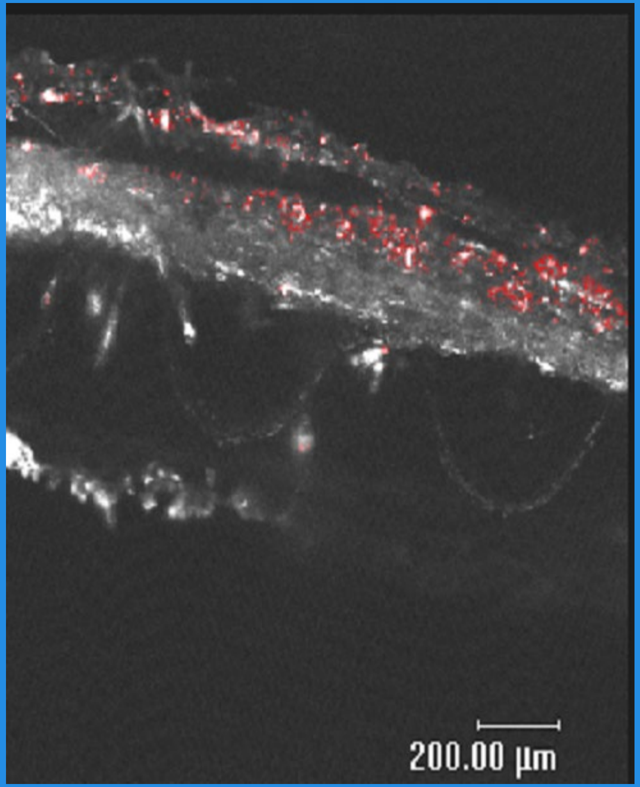
1200 mmHg

Facemask Details: 4 plys; pleated, PPE, PET, CELL-OH, PE w/ acrylic adhesive

Facemask 1 Exposed



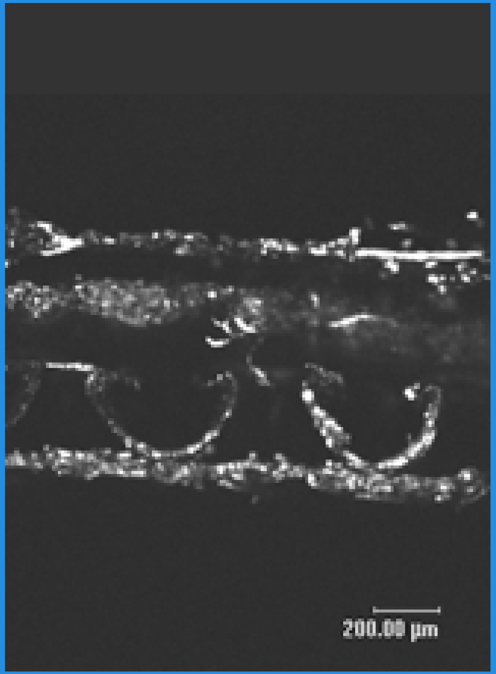
Synthetic blood penetrated
through third layer
(Facemask is placed upside down)



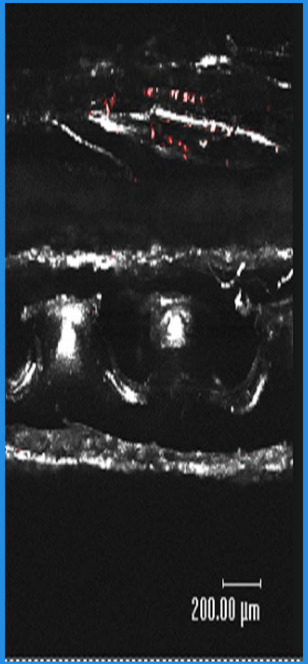
Latex Microspheres were
stopped by the second layer
(LSCM Cross Section)

Facemask 2 Cross-Sections

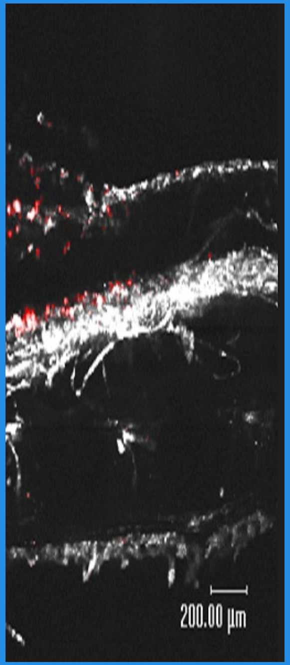
Latex microspheres transmission location at increasing pressure



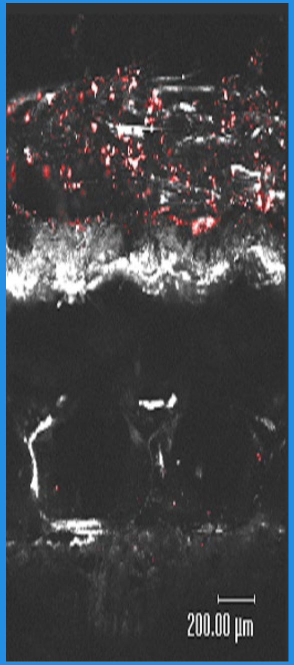
Control



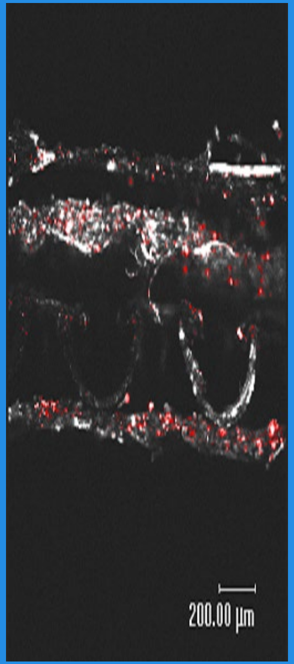
80 mmHg



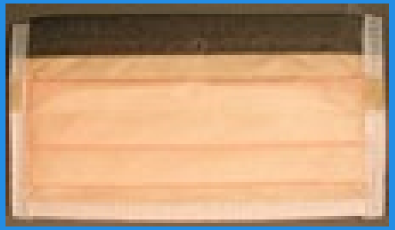
120 mmHg



160 mmHg

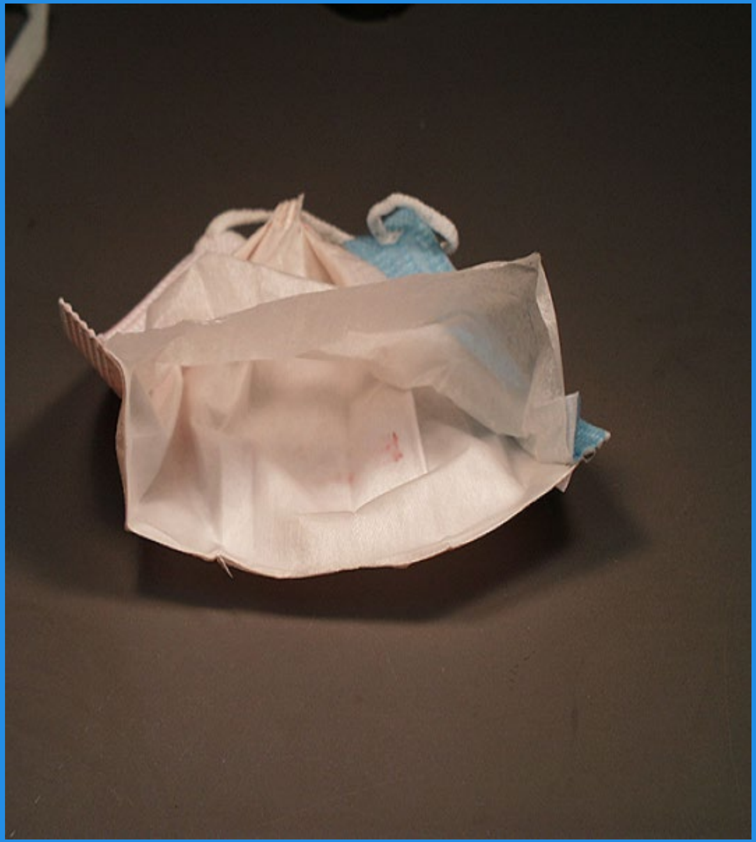


1200 mmHg



Facemask Details: 4 plys; pleated, PPE, PET, CELL-OH, PE w/ acrylic adhesive

Facemask 2 Exposed



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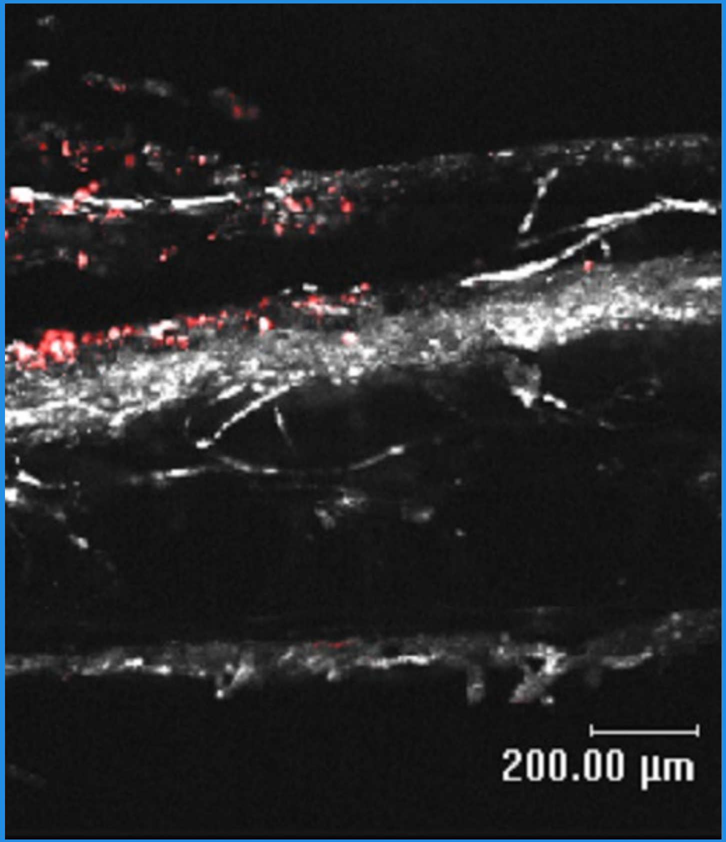

Latex Microspheres were
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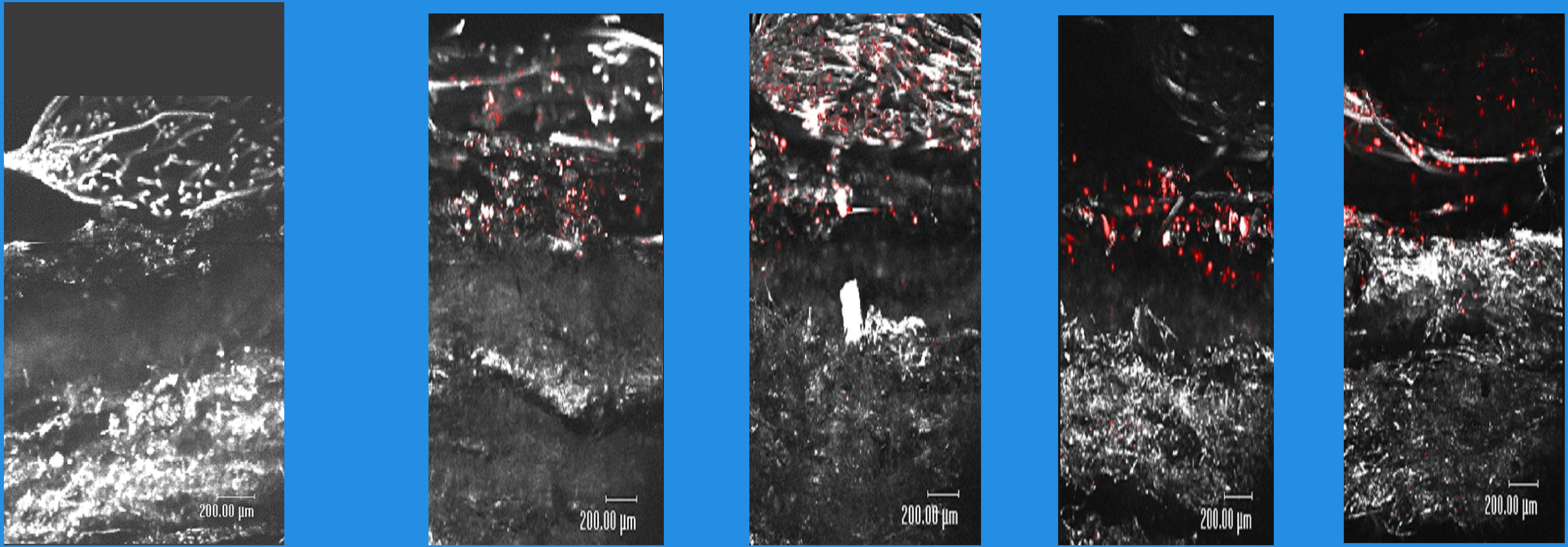
(LSCM Cross Section)

Facemask 3 Cross-Sections

Latex microspheres transmission location at increasing pressure



Control

80 mmHg

120 mmHg

160 mmHg

1200 mmHg

Facemask 3 Details: 5 plys; pleated, all layers PPE but various fabric structure

From these studies:

- Pore size/distribution found to be critical
- Increase in pressure did not change transmission mechanism but did impact depth of particle penetration and rate
- Change is Carrier Surface Tension, did not mechanism transmission but did influence rate

Further readings and learnings

- Filters and Filtration Handbook, Sixth Edition, Trevor Sparks George Chase, Elsevier 2016
- Advances in Technical Nonwovens, Chapter 6, N. Mao
- INDA/NWI short courses.

Questions

- Join us next time for overview classification and testing requirements