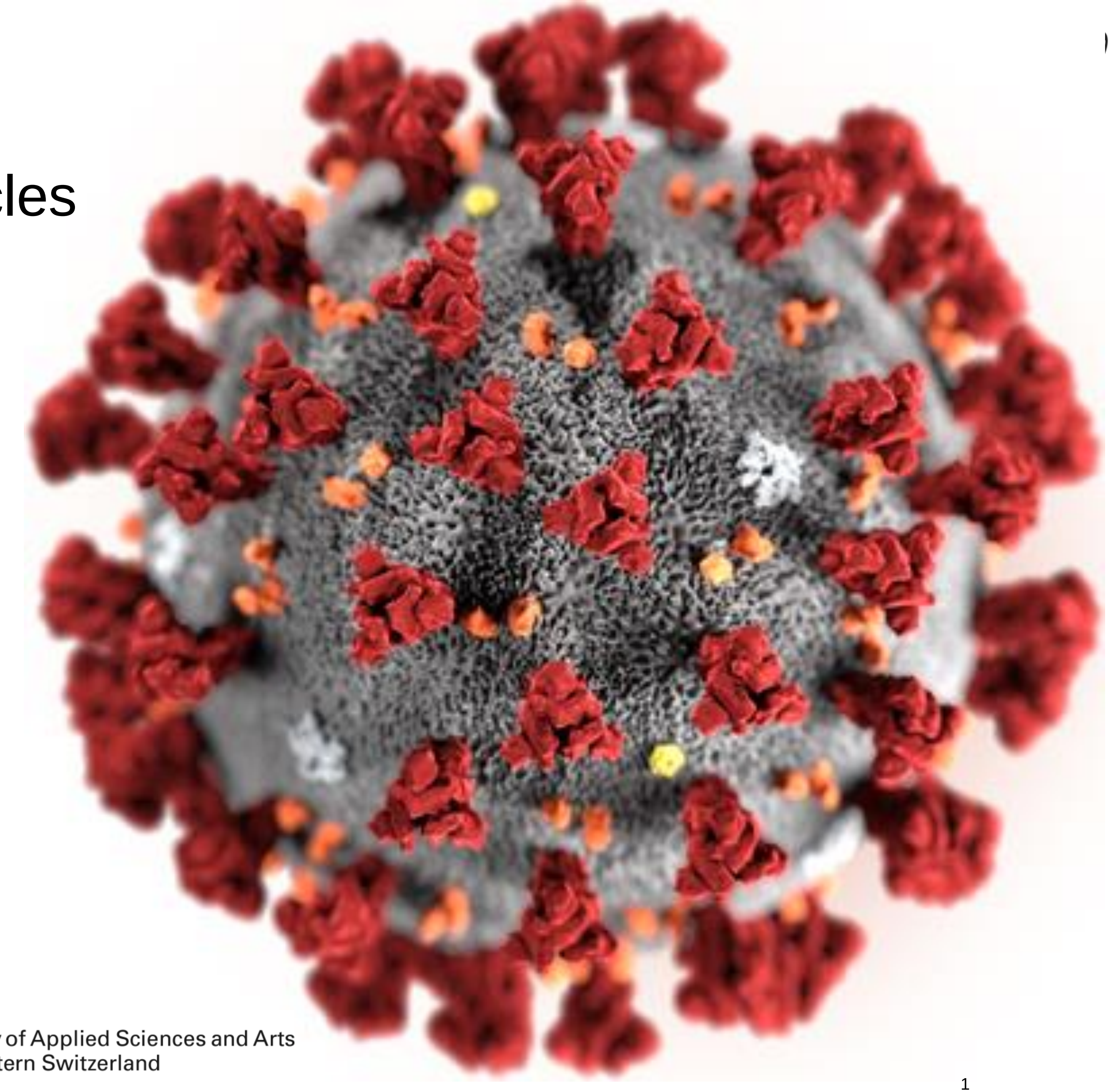
Physical properties of virus-containing aerosol particles

How high is the protective effect of masks?



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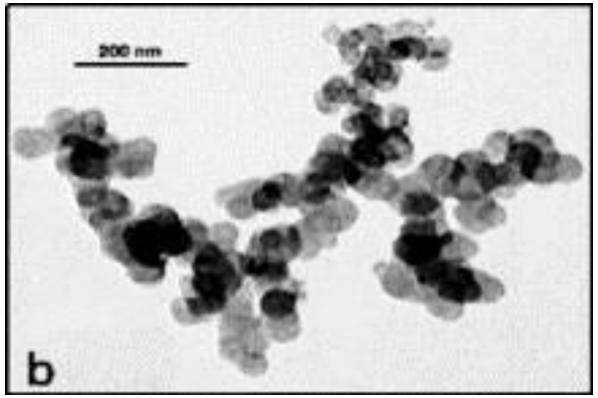
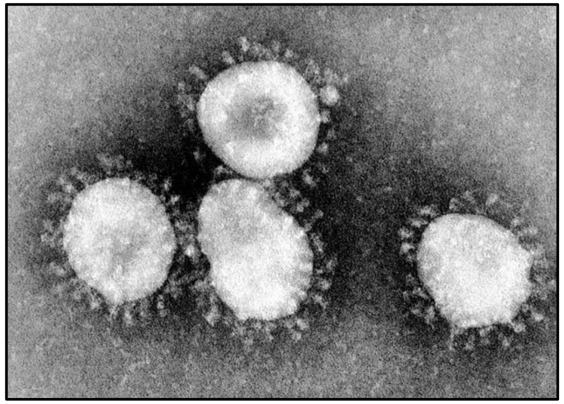
What do these airborne particles have in common?

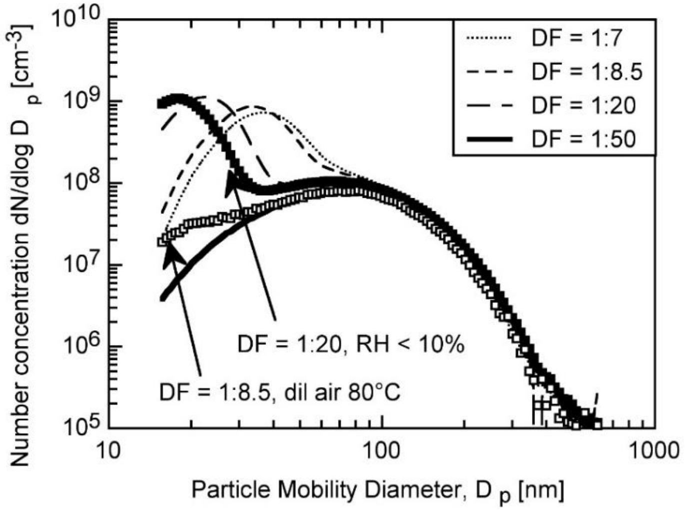


Freshly emitted diesel soot particle

- Their small size (about 100 nm)
  -> they have similar aerodynamic properties
  -> invisible to the naked eye
- They are typically coated and often hydrated
- Respirable and not healthy
- Super-polluters are like super-spreaders



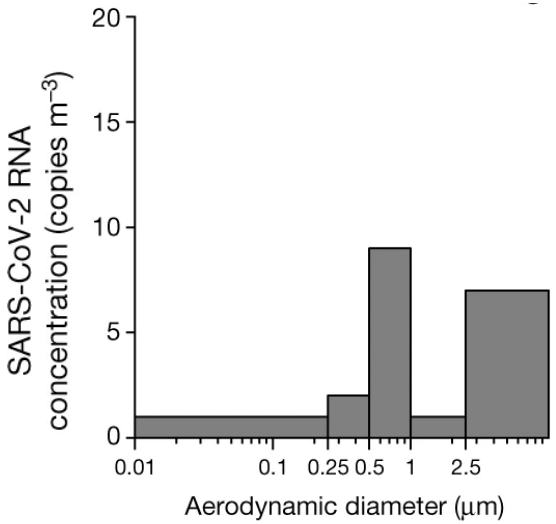
Naked corona virus



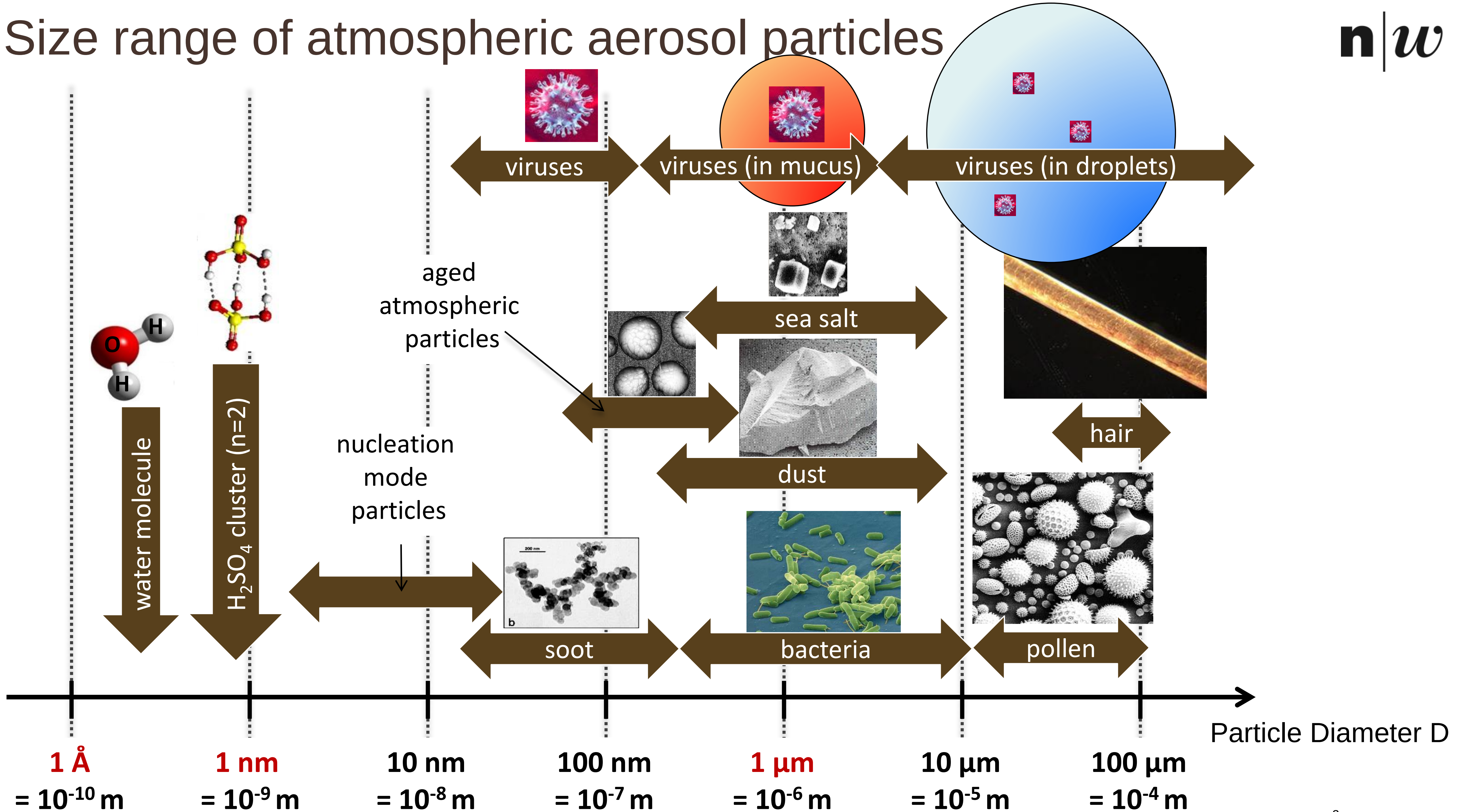
Particle emissions of a EURO 3 Diesel car operated at 50 km/h using a partial flow dilution tunnel for sampling

- 10 million premature deaths from combustion particles annually (on a long term more than Covid)

- They can be filtered:
  Thanks to diesel particulate filters > 3.5 million premature deaths were saved

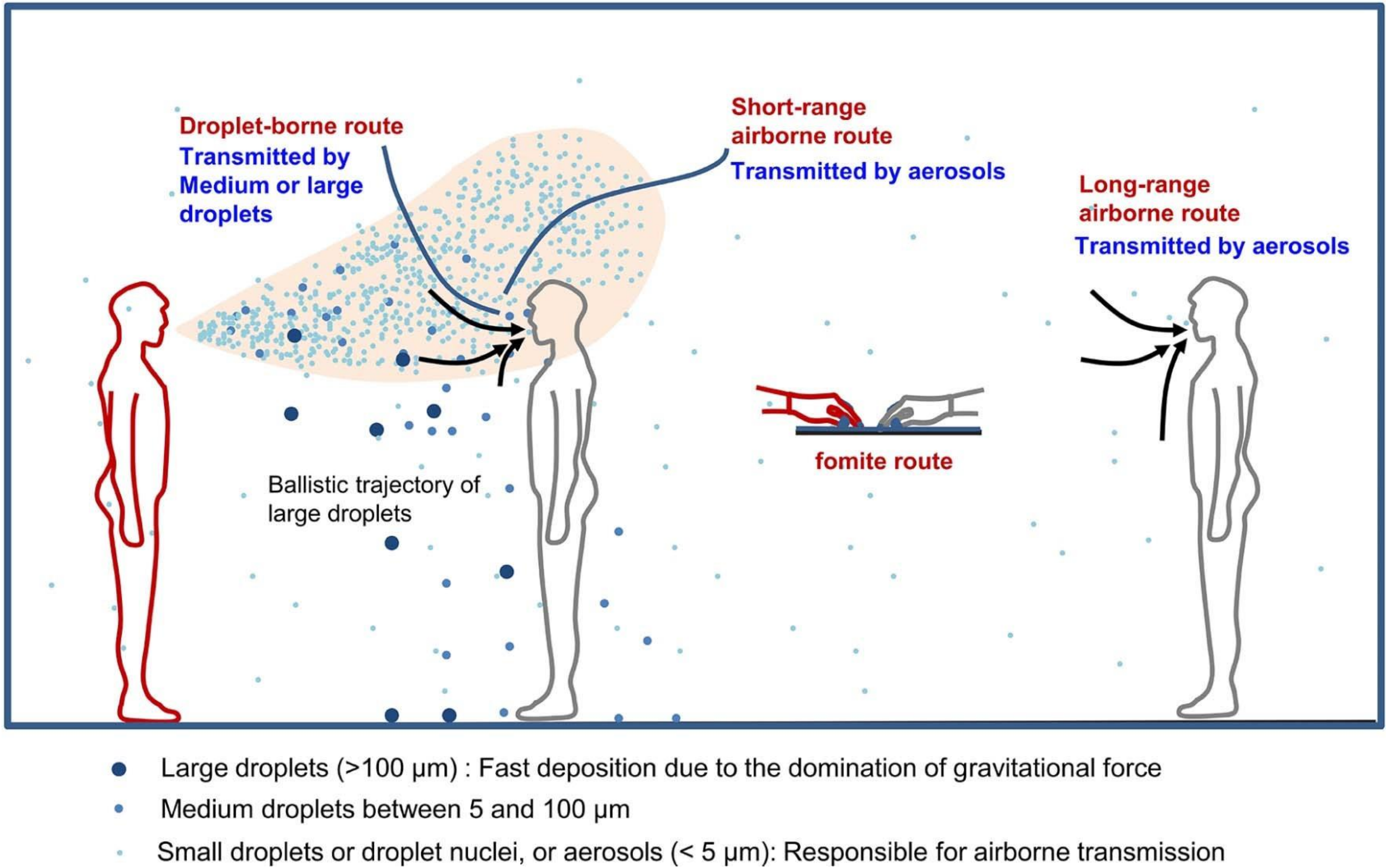


Size range of atmospheric aerosol particles



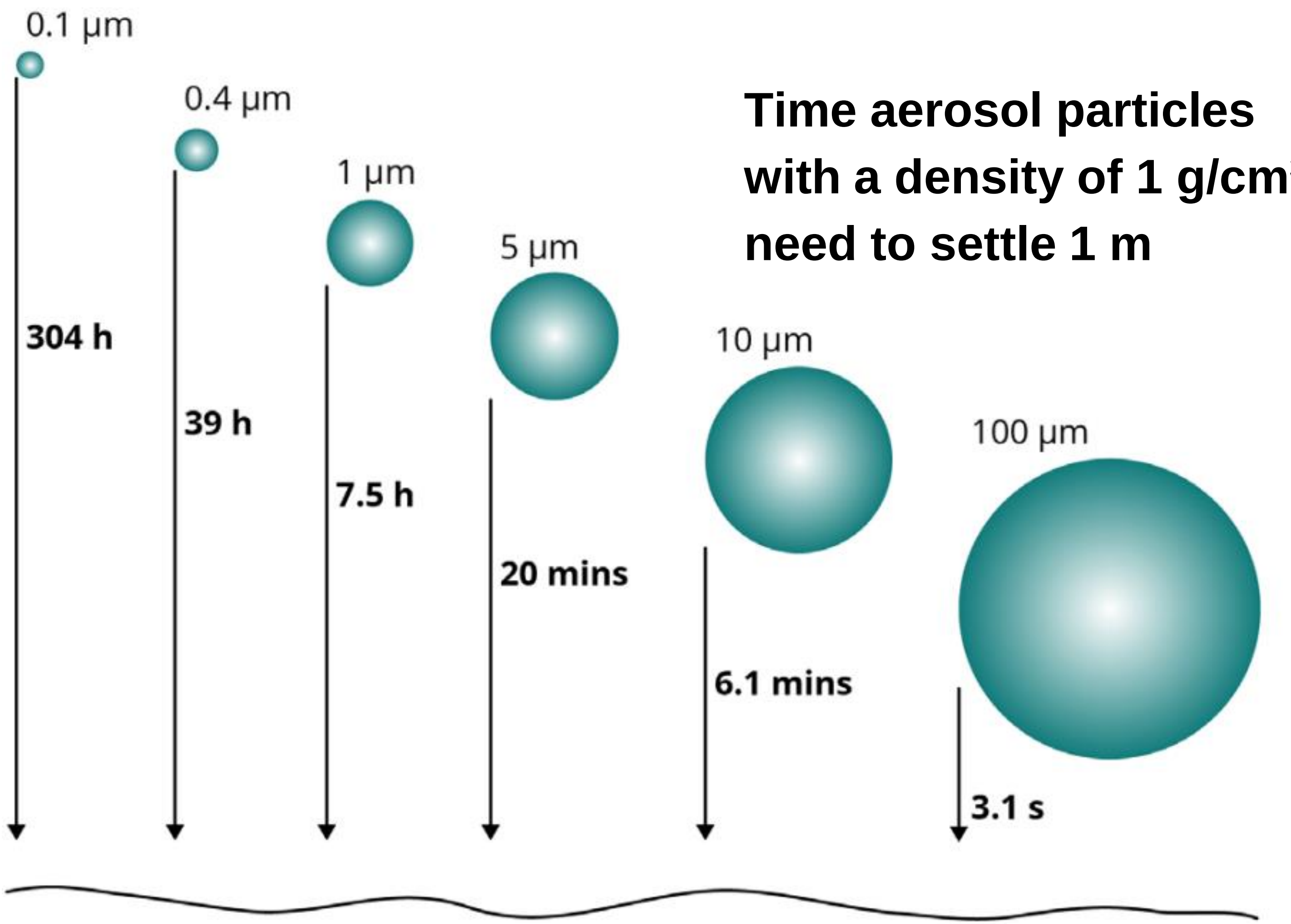
Aerosol infection vs. droplet infection

Prather et al., Science, Oktober 2020:
"airborne transmission is a major pathway of transmission"



Wei et al.
American Journal of Infection Control 2016
https://doi.org/10.1016/j.ajic.2016.06.003

"Aerosols" vs. "droplets"



Time aerosol particles with a density of 1 g/cm³ need to settle 1 m

Figure 2: Exemplary illustration of the gravity-induced sedimentation of spherical particles with a density of 1 g/cm³ in still air

Note:

- Even particles > 5 µm can remain suspended in the air for a long time!
- The "ballistic" droplets, which reach about 2 m distance, are > 50-100 µm.

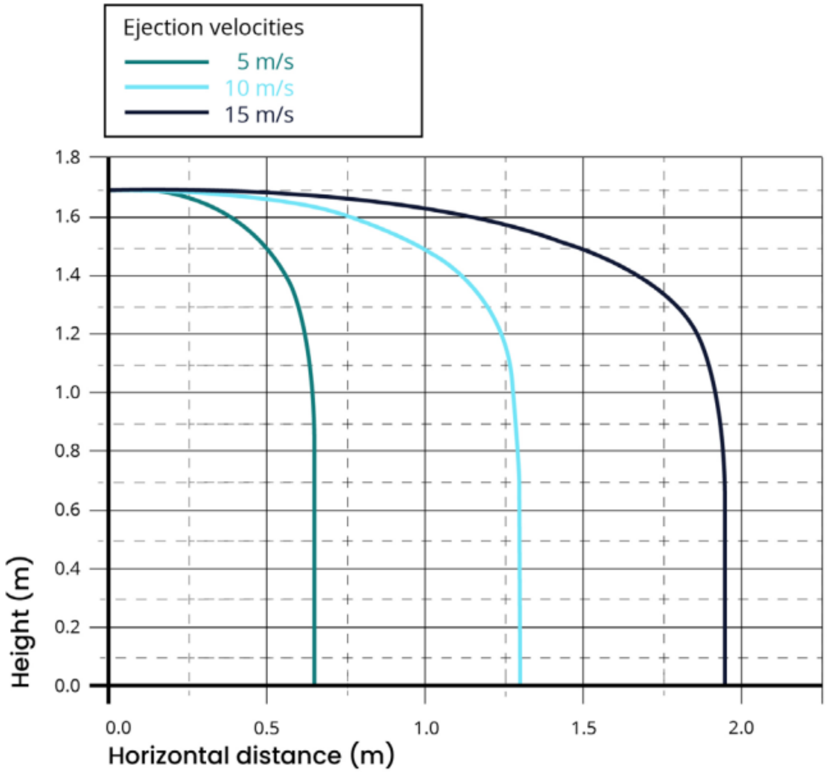
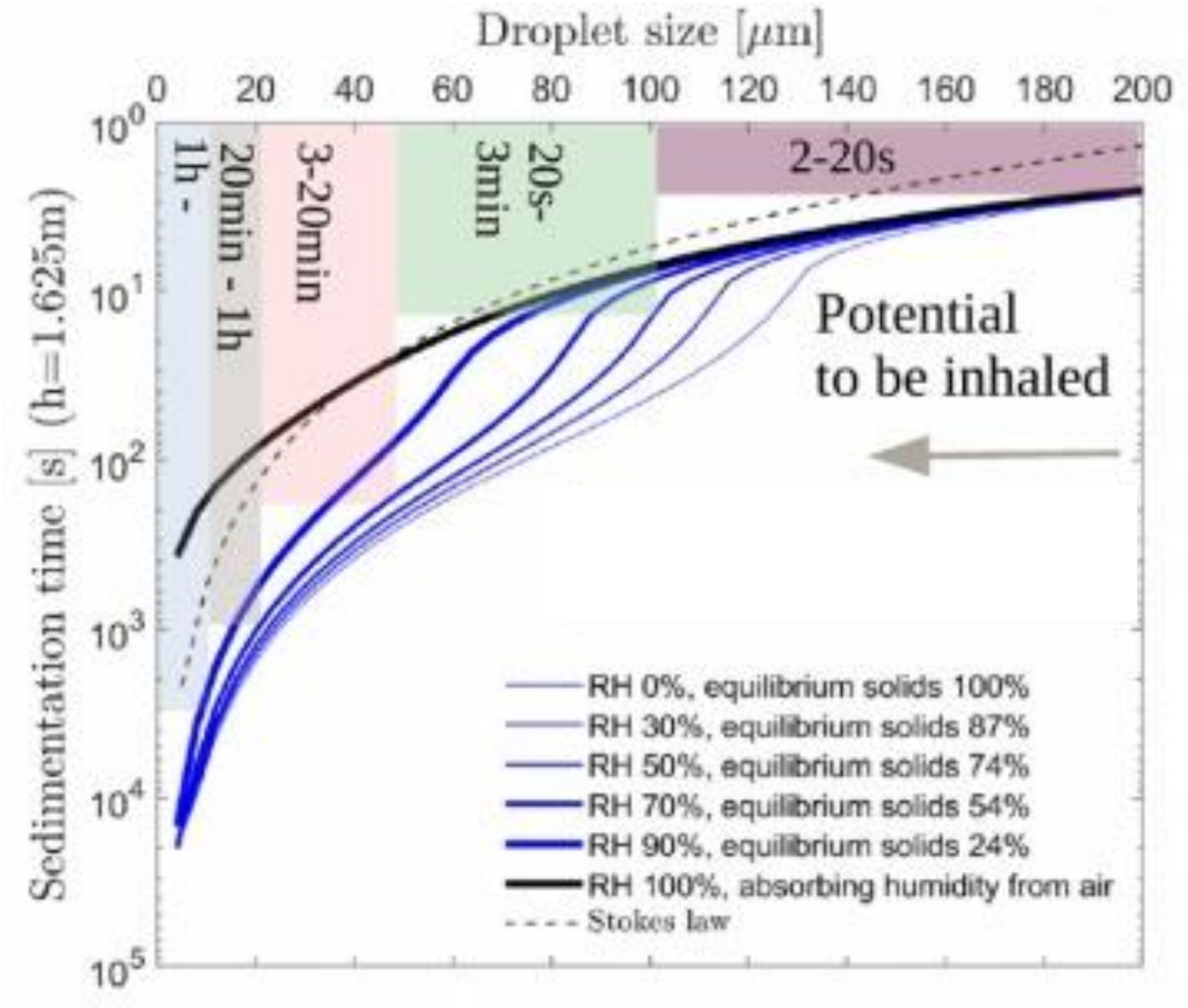


Figure 3: Trajectories of droplets with a diameter of 200 µm and the density of water ejected at different velocities at a height of 1.70 m (based on [57])

https://www.info.gaef.de/position-paper

Modelling: Droplets evaporate fast and settle slowly



Vuorinen et al., 2020, https://doi.org/10.1016/j.ssci.2020.104866

In a nutshell:

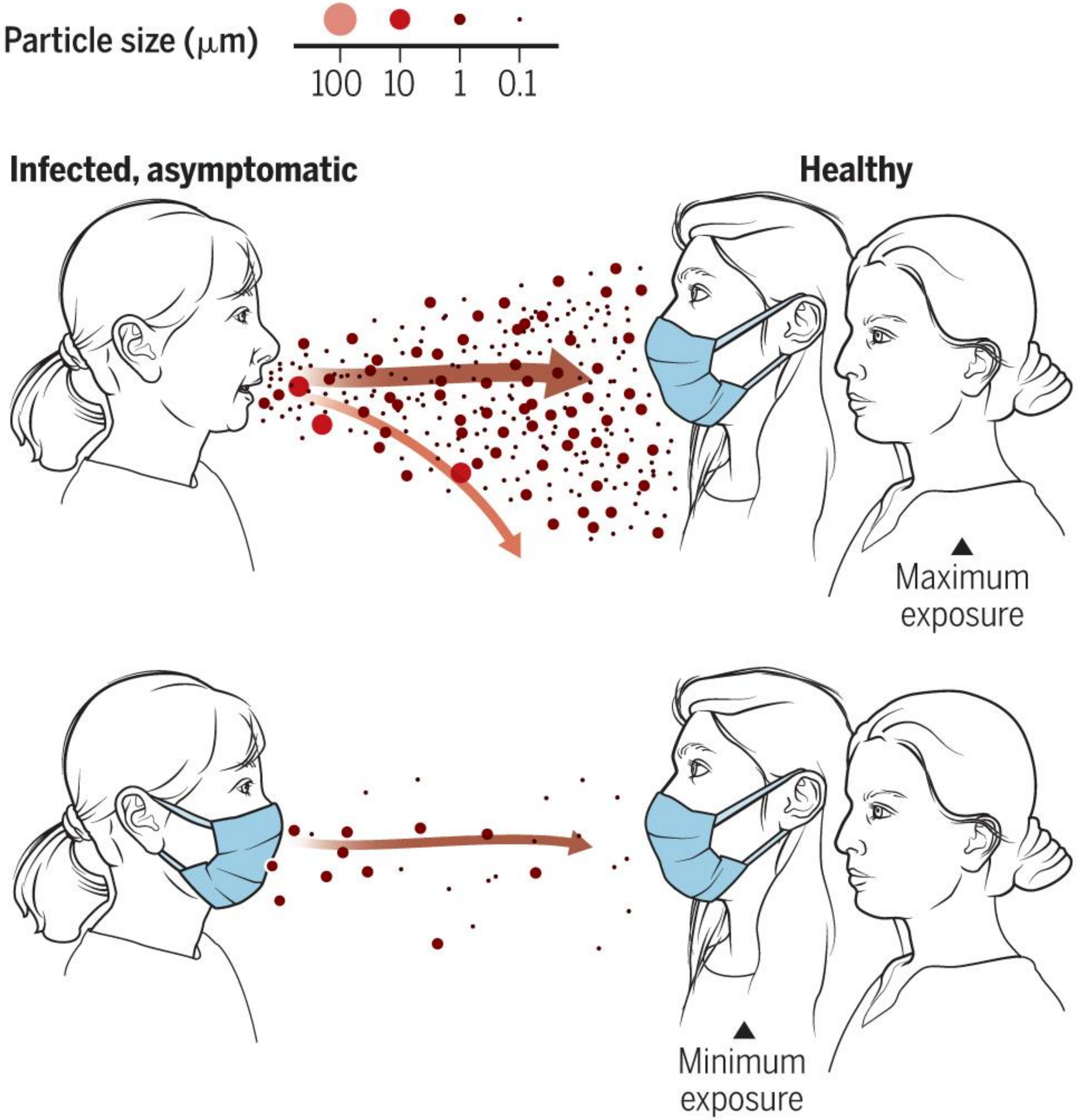
Diameter in μm	**Time to settle 1.8 m**
100	6 s
10	8 minutes
3	1.5 hours
1	12 hours
0.5	41 hours

Note:
Particles from the respiratory tract shrink quickly in dry air (< 1 s)!

Masks reduce airborne transmission

One cough can release millions of viruses

A few hundreds viruses are believed to be enough for a Corona infection



Kimberly et al., Science 2020
https://science.sciencemag.org/content/368/6498/1422

“Flattening the curve” in 1918, California (2nd wave)

Obey the laws and wear the gauze. Protect your jaws from septic paws!

Characterization of Masks

Filtering facepiece respirators
FFP1, FFP2, FFP3 (Europe)
KN95 (China)
N95 (USA)

Fabric masks
(community masks)

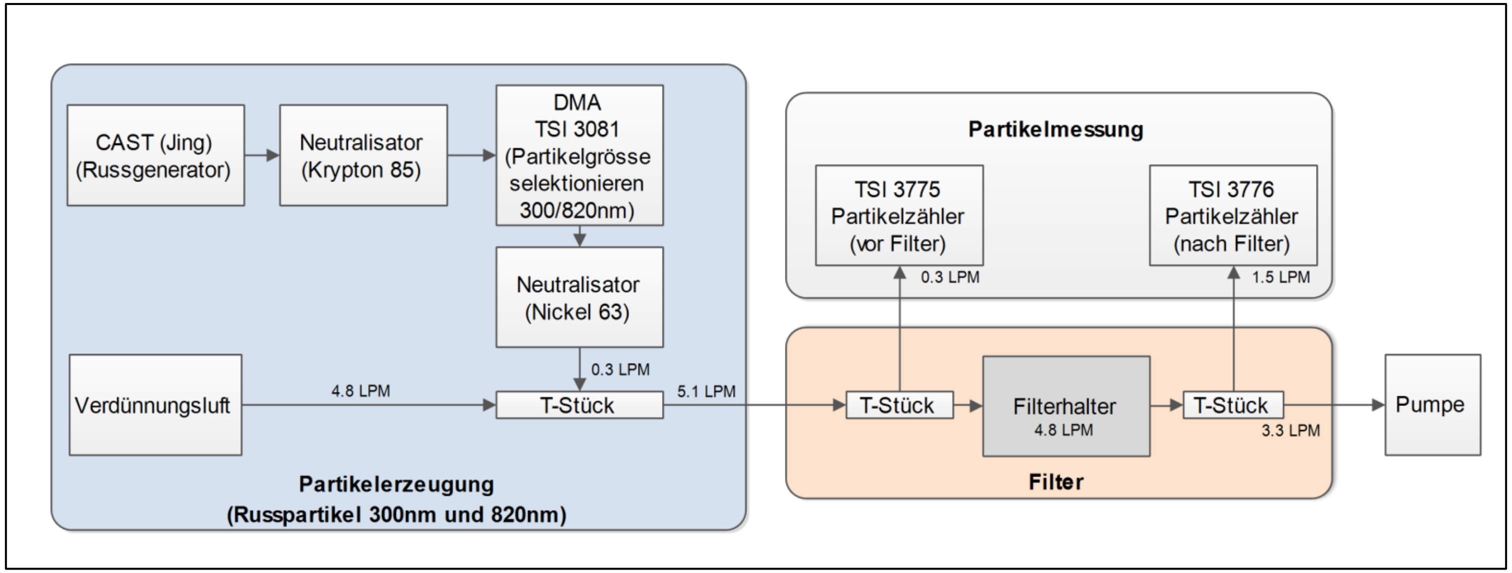
Bandanas

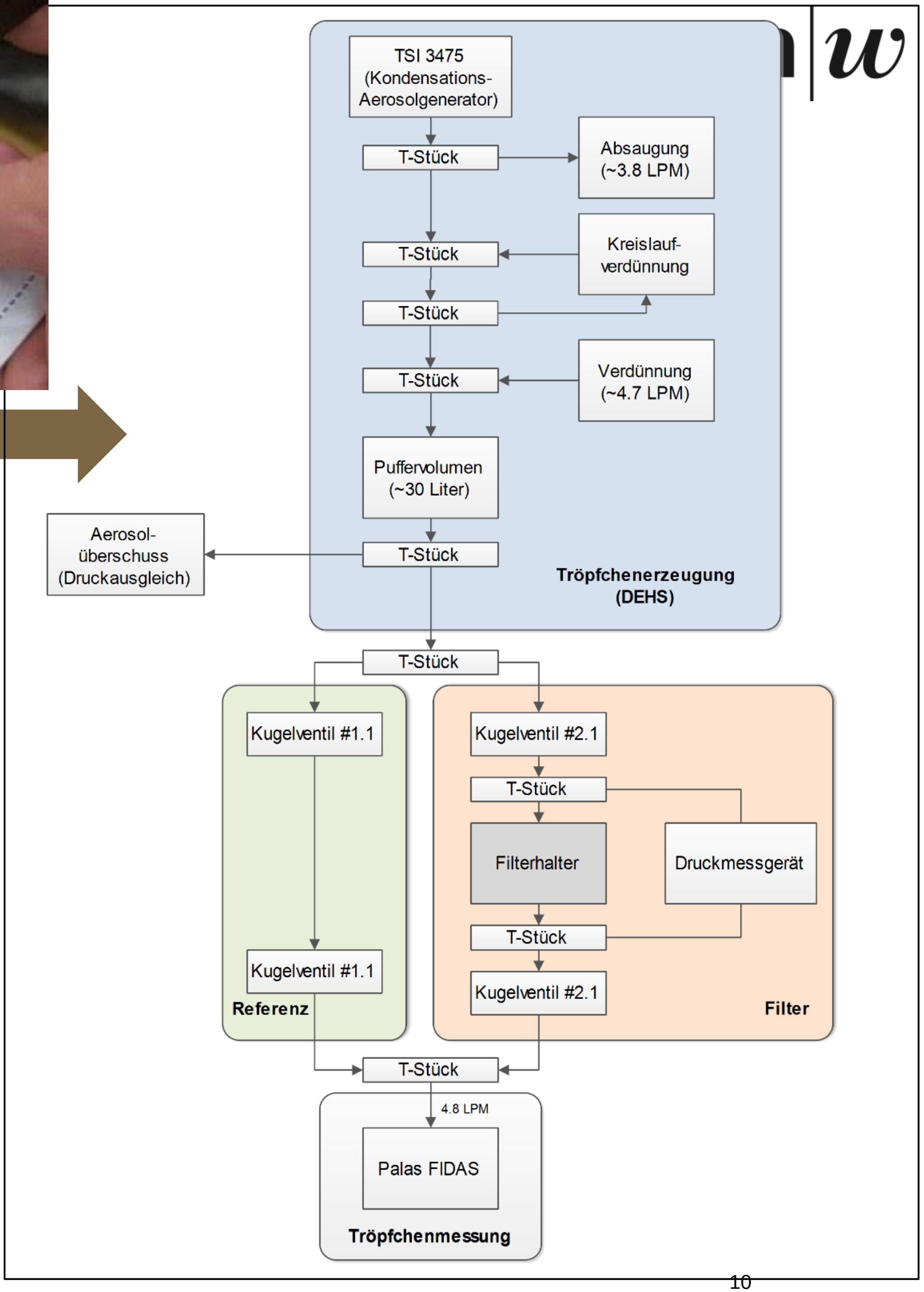
Surgical mask

Experimental Setups

DMA and CPCs
for 0.02 < D < 0.8 µm
using soot or NaCl
particles

Single particle light scattering
for 0.2 < D < 10 µm
using DEHS (Di-Ethyl-Hexyl-Sebacat)
particles

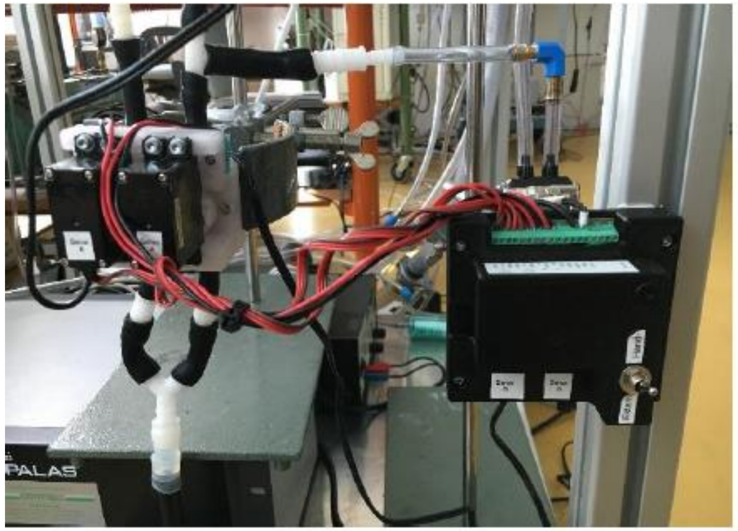




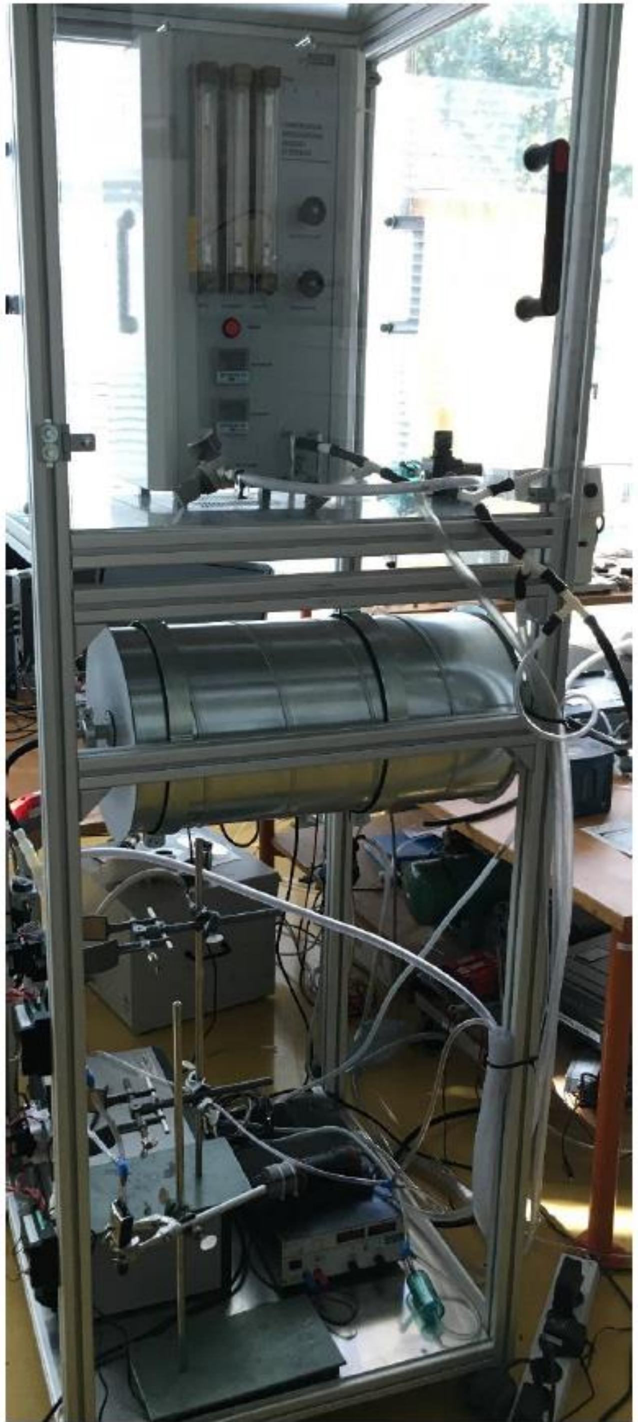
https://www.fhnw.ch/en/about-fhnw/schools/school-of-engineering/institutes/research-projects/evaluation-of-the-particle-filter-efficiency-of-fabrics-for-disposable-and-reusable-masks

Setup for 0.2 < D < 10 μm

Ball-valves



Measurement of particle size distribution Palas Fidas

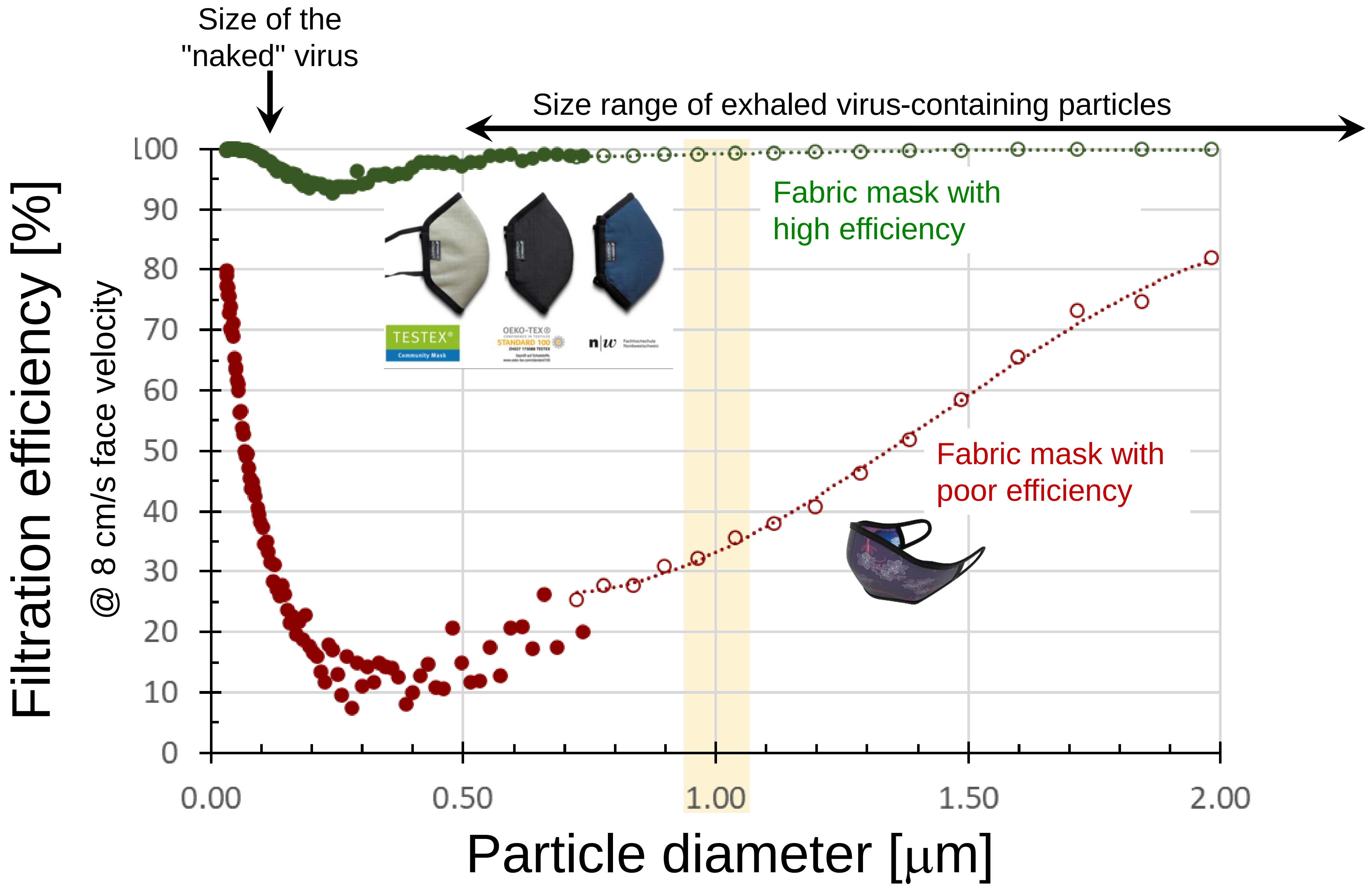


DEHS particle generator TSI 3475

Buffer volume ~50 l

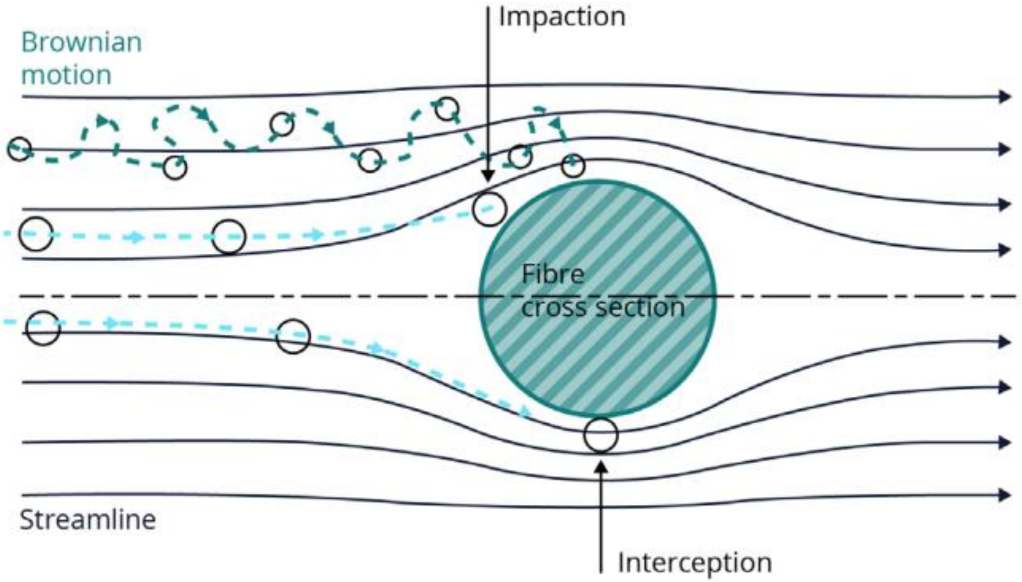
Ball-valves and filter holder

Measurement of particle size distribution Palas Fidas



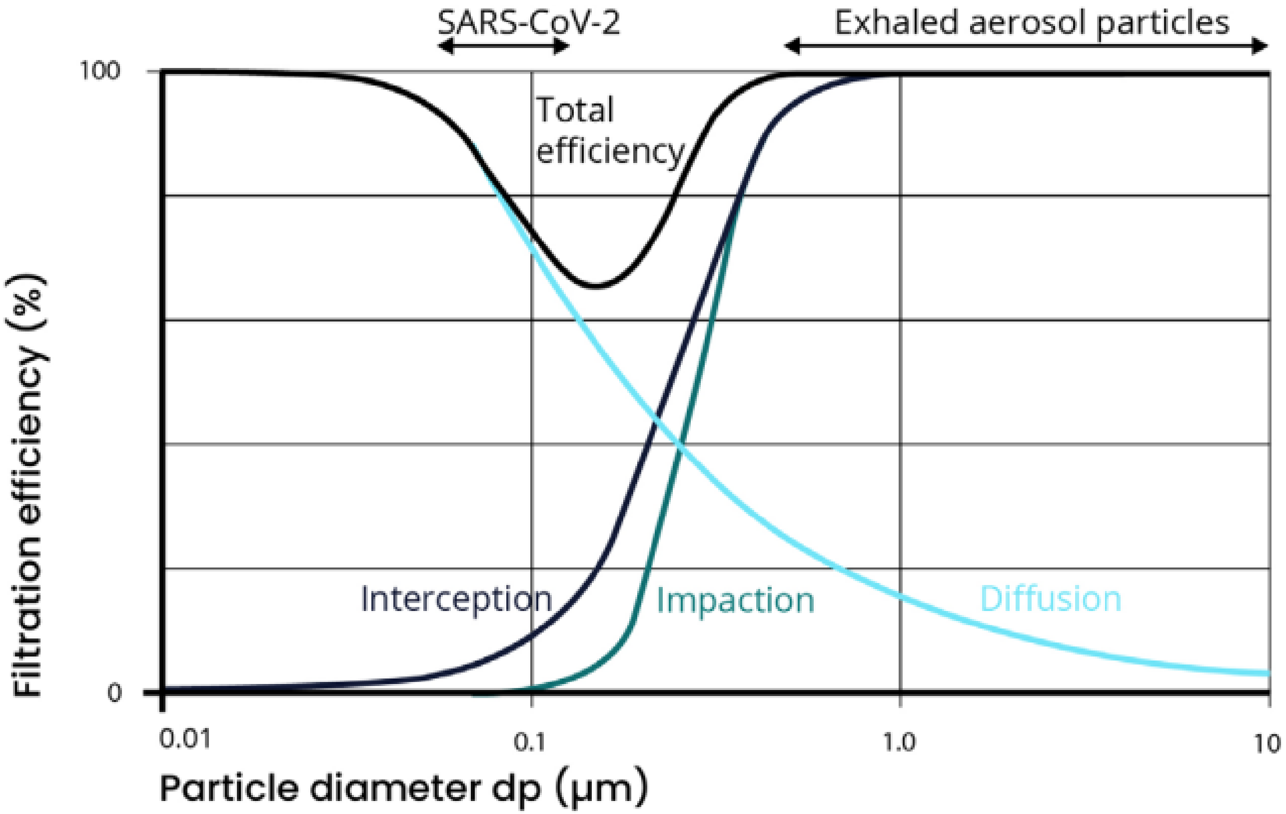
Size of the
"naked" virus
Size range of exhaled virus-containing particles
Fabric mask with
high efficiency
Fabric mask with
poor efficiency
TESTEX®
Community Mask
OEKO-TEX®
STANDARD 100
Filtration efficiency [%]
@ 8 cm/s face velocity
100
90
80
70
60
50
40
30
20
10
0
0.00
0.50
1.00
1.50
2.00
Particle diameter [μm]

Filtration Mechanisms:



Note:

- A particle filter does not work like a "sieve"
- Particles <0.1 µm are filtered better than 0.1-0.3 µm!
- A high filter efficiency in the range 0.1-1 µm is important!

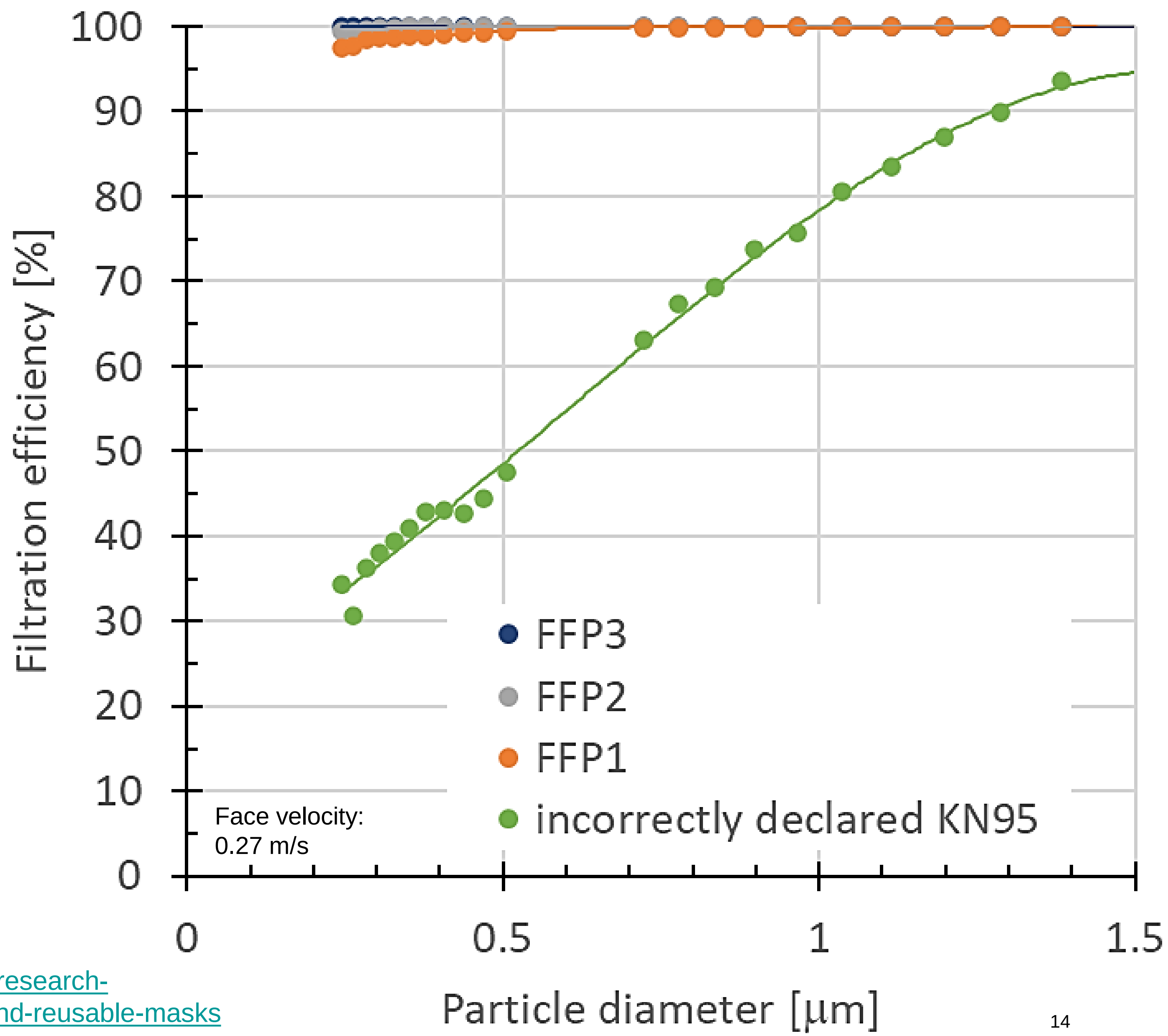


Filtering facepiece respirators

Must meet strict standards

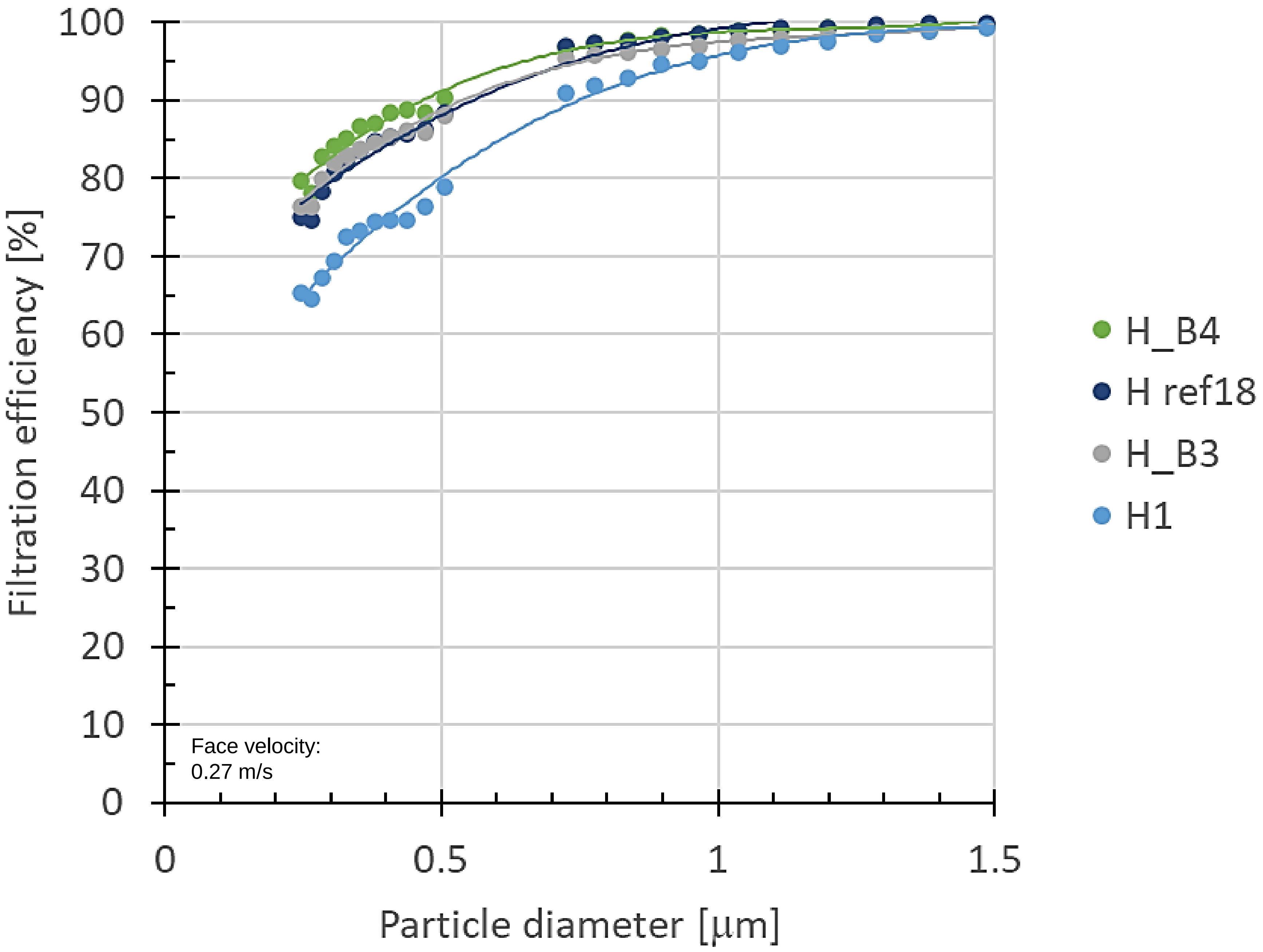
FFP1 masks also perform very well.

Beware of counterfeits!



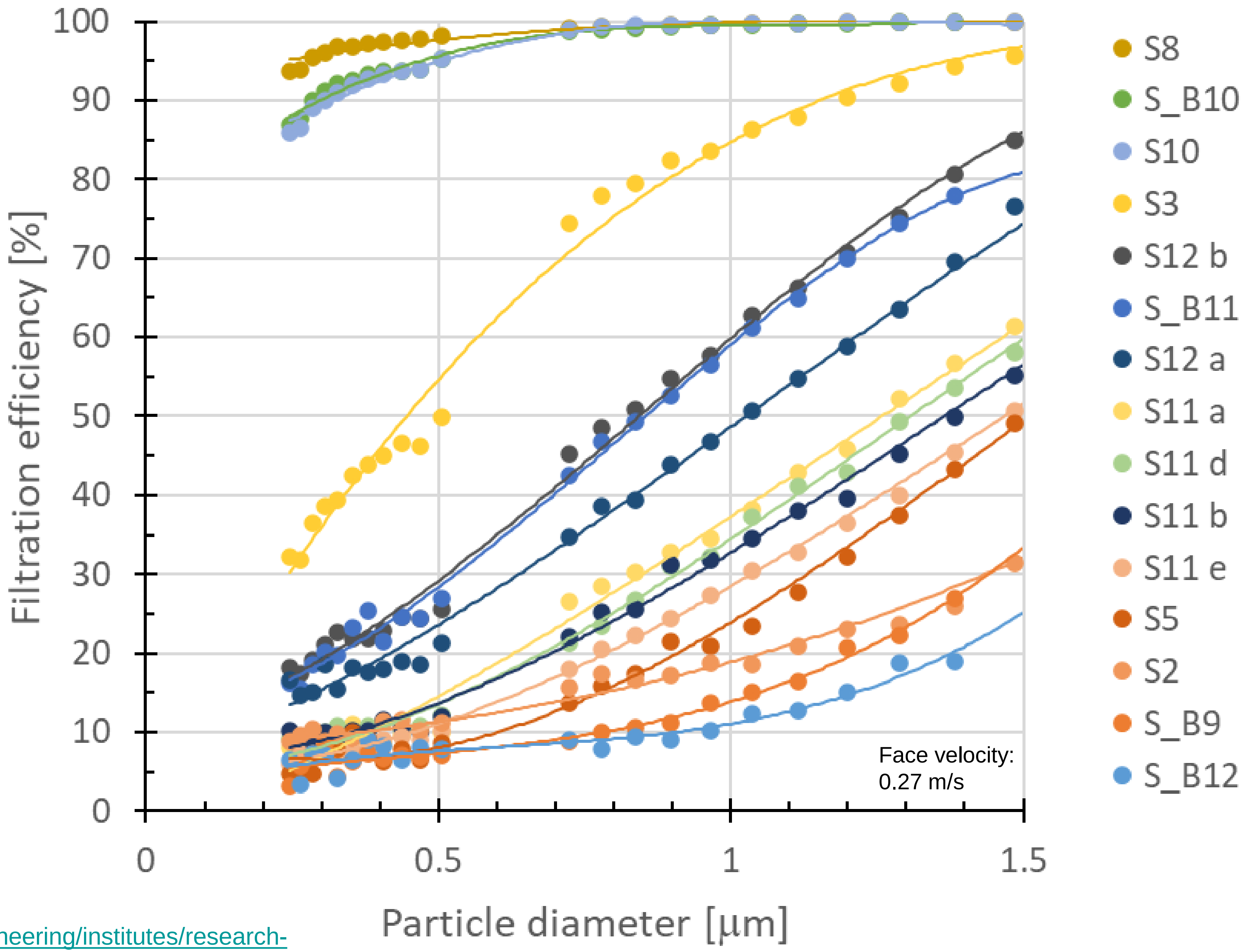
https://www.fhnw.ch/en/about-fhnw/schools/school-of-engineering/institutes/research-projects/evaluation-of-the-particle-filter-efficiency-of-fabrics-for-disposable-and-reusable-masks

Hygiene masks



https://www.fhnw.ch/en/about-fhnw/schools/school-of-engineering/institutes/research-projects/evaluation-of-the-particle-filter-efficiency-of-fabrics-for-disposable-and-reusable-masks

Fabric masks
(community masks)

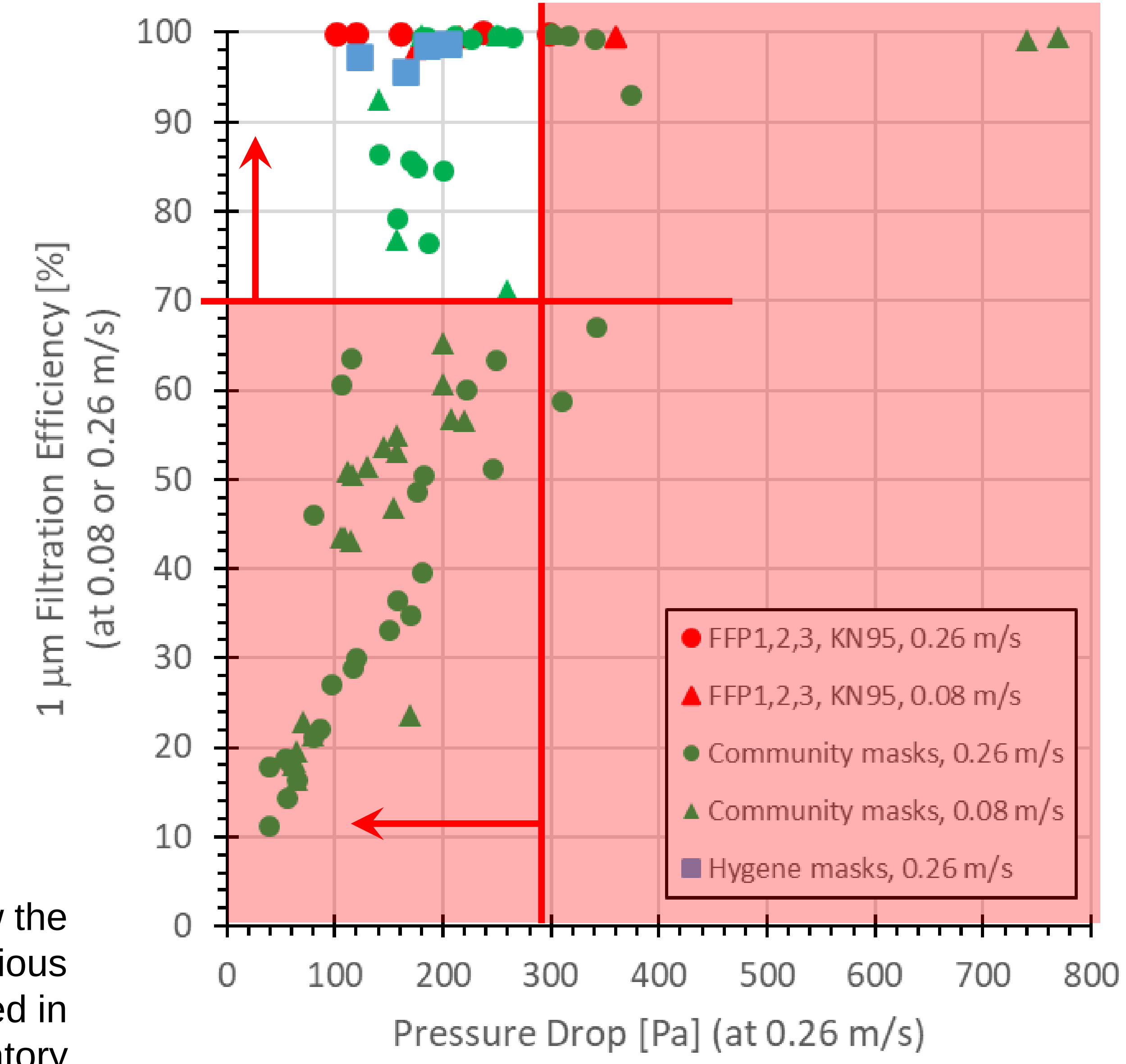


https://www.fhnw.ch/en/about-fhnw/schools/school-of-engineering/institutes/research-projects/evaluation-of-the-particle-filter-efficiency-of-fabrics-for-disposable-and-reusable-masks

1 μm filtration efficiency vs. breathing resistance

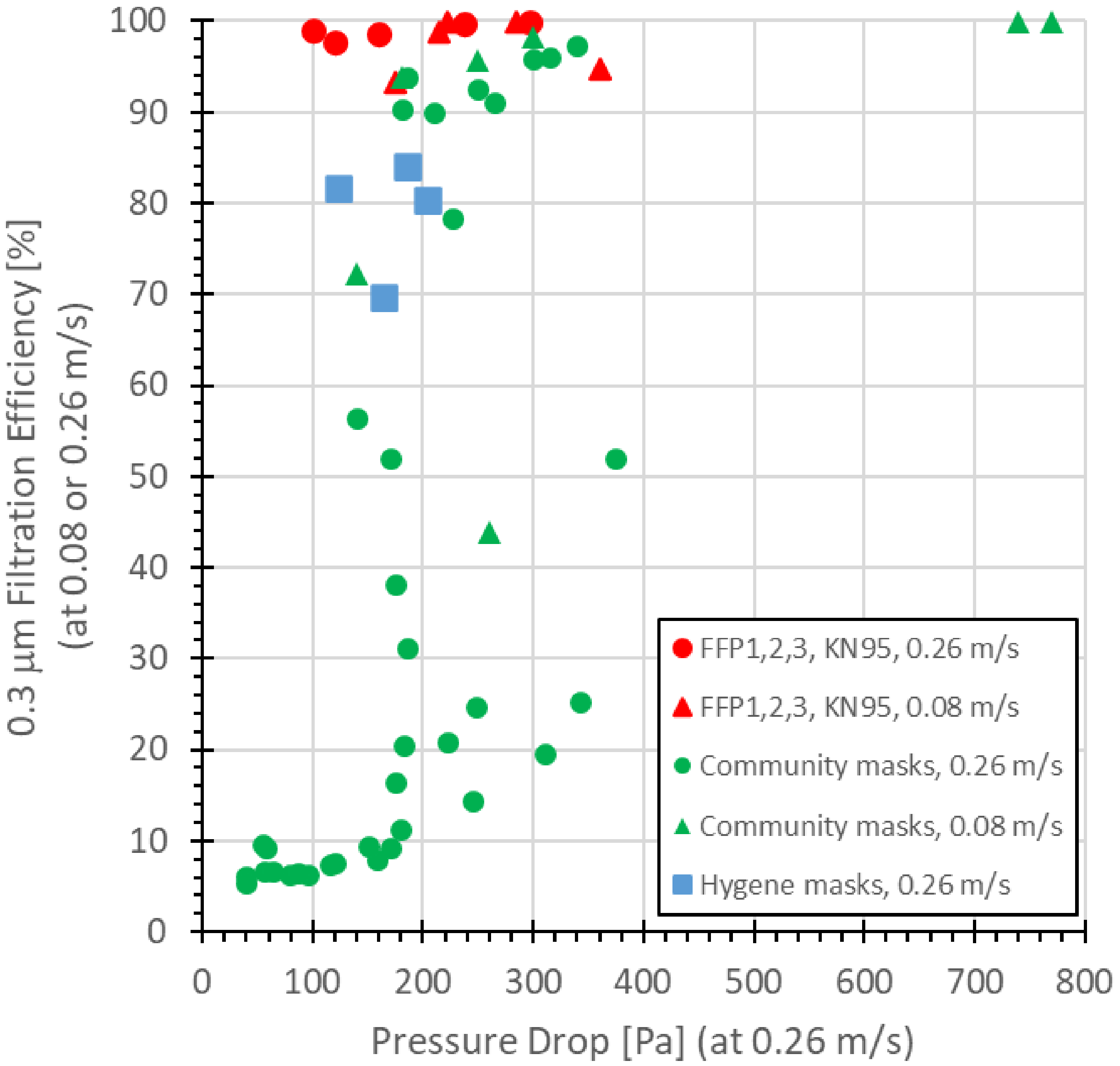
Swiss Association for Standardization (SNV):
Basic requirements for community masks and their testing procedures
“Swiss rule” SNR 30’000:

- 1 μm filtration efficiency > 70% at 0.08 m/s
- Max. pressure drop 294 Pa at 0.27 m/s
  air permeability at a filter surface of 4.9 cm² must not exceed a maximum value of 60 Pa/cm² for a flow rate of 8 lpm (EN14683:2019+AC:2019).
- splash/drop resistance



The data show the characteristics of various masks that we have studied in our laboratory

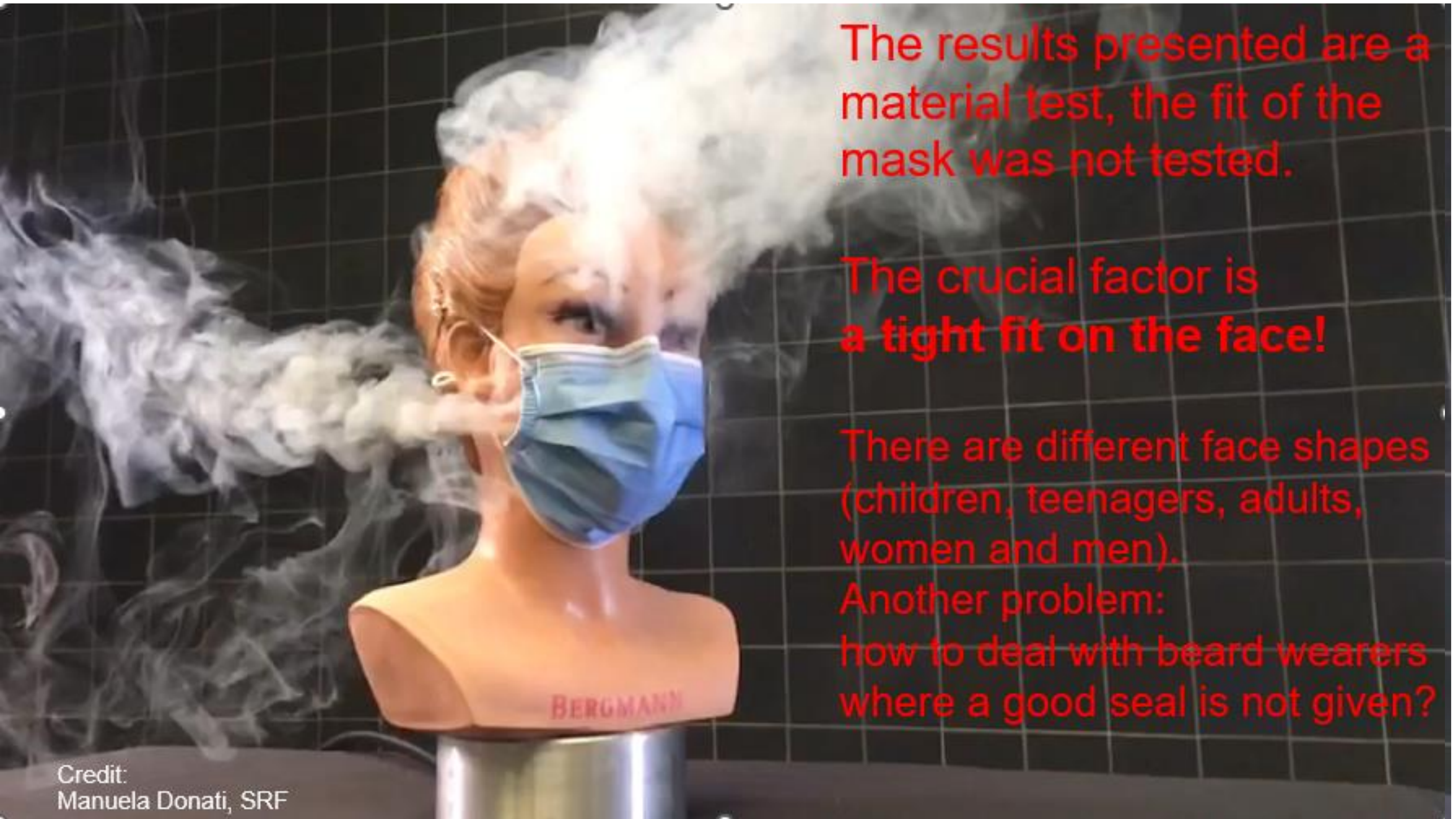
0.3 µm filtration efficiency vs. breathing resistance



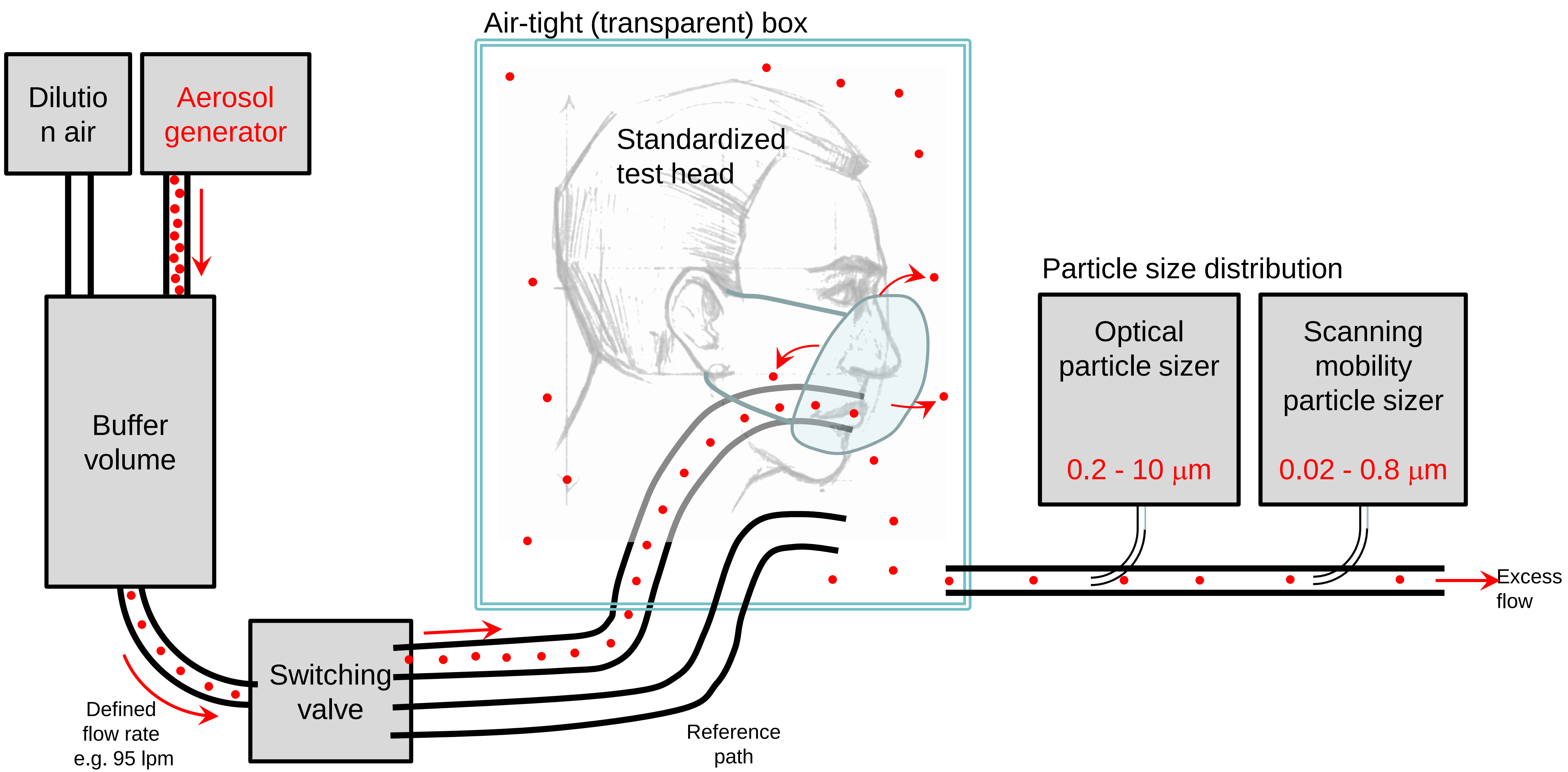
Testing standards…

Category	Standard/Guideline	Class	min. efficiency	max. pressure drop inhalation/exhalation	Test aerosol (median diameter)	Validity	Comments
Filtering facepiece	EN149:2001-A1:2009 in conjunction with EN 13274-7:2019	FFP1	80%	210 Pa, at 95 l/min 300 Pa, at 160 l/min	NaCl (0,08±0,02 μm) AND paraffin (0,37±0,08 μm) at 95 l/min	Europe	Test of the entire mask
		FFP2	94%	240 Pa, at 95 l/min 300 Pa, at 160 l/min			
		FFP3	99%	300 Pa, 95 l/min 300 Pa, at 160 l/min			
	GB 2626-2006	KN95	95%	350 Pa, at 85 l/min 250 Pa, at 85 l/min	NaCl (0,075±0,02 μm) at 85 l/min	China	
	42 CFR part 84	N95	95%	343,2 Pa, at 85 l/min 245,2 Pa, at 85 l/min	NaCl (0,075±0,02 μm) at 85 l/min	USA	
Medical face mask	EN 14683	Type I	95%	196 Pa, at 27,2 cm/s	Water droplets > 1 μm containing bacteria at 28,3 l/min	Europe	Test of filter media samples (49 cm² for efficiency, 4,9 cm² for pressure drop)
		Type II	98%	196 Pa, at 27,2 cm/s			
		Type IIR	98%	294 Pa, at 27,2 cm/s			
Cloth Face Maske	CWA 17553	level 90%	90%	240 Pa, at 95 l/min 300 Pa, at 160 l/min	3±0,5 μm	Europe	Testauf set up according to existing standards, e.g. EN149 or EN14683
		level 70%	70%				
	SNR 3000	level 70%	70% at 1 μm	294 Pa at 27,2 cm/s	1±0,1 μm, at 8 cm/s	Switzerland	To be published in Q1/2021
	UNI/PdR 90.1:2020	CFC-NR	80% at MPPS	210 Pa, at 95 l/min	DEHS, Size range 0,3 - 10 μm (size resolved measurement)	Italy	not reuseable
		CFC-R					reuseable
		CFC-BIO					biodegradable

https://www.info.gaef.de/position-paper

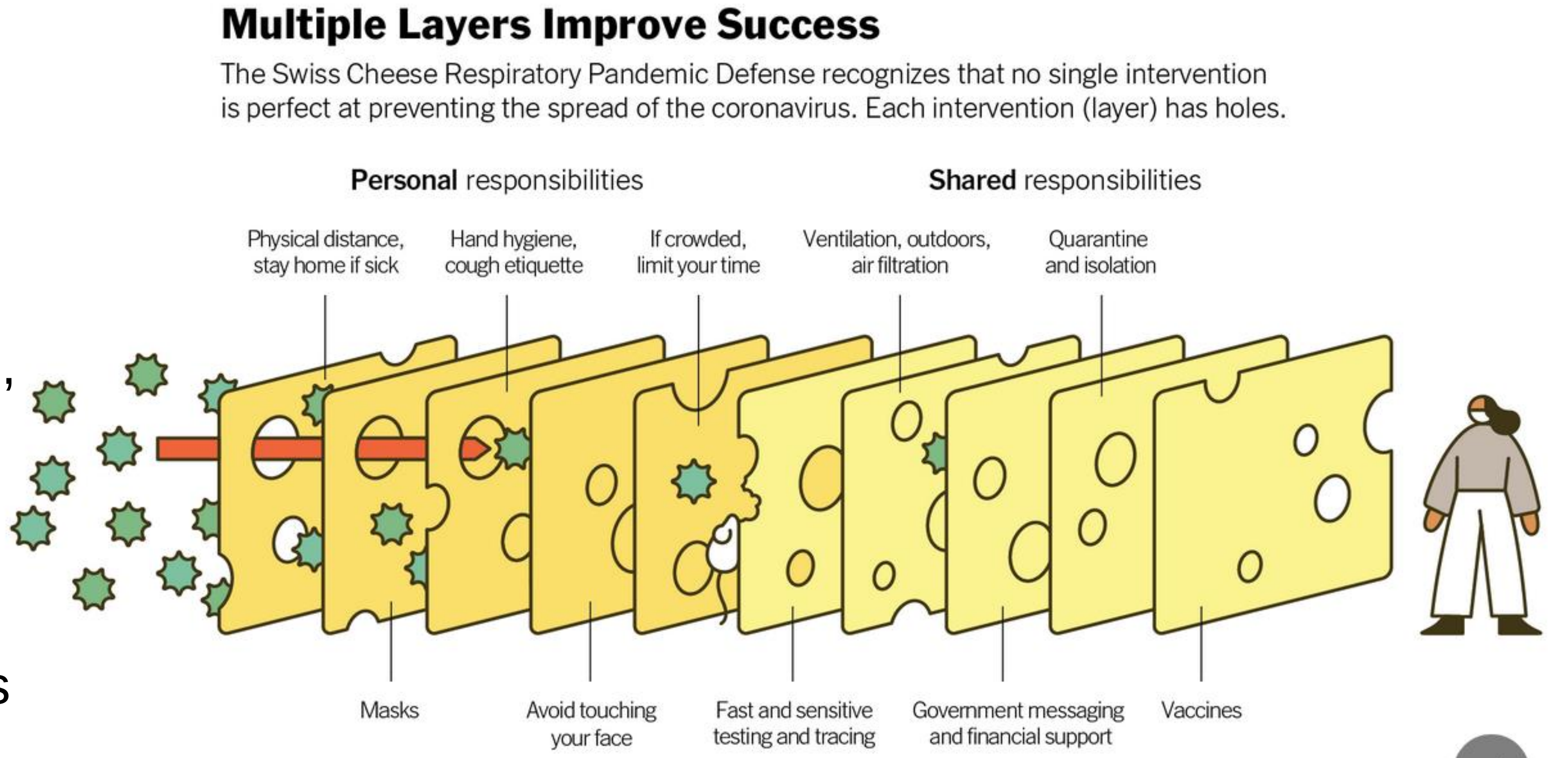

The results presented are a material test, the fit of the mask was not tested.
The crucial factor is **a tight fit on the face!**
There are different face shapes (children, teenagers, adults, women and men).
Another problem:
how to deal with beard wearers where a good seal is not given?
BERGMANN
Credit:
Manuela Donati, SRF

Next step: Determine the effective particle filtration efficiency of masks during exhalation (source control) and inhalation (self protection)



Final remarks

- Covid-19 is an airborne disease
- The SARS-CoV-2 virus is also present as ultrafine aerosol particle, with a long residence time in the air
- Masks, in addition to other measures, provide effective protection, provided they filter the fine particles and they fit snugly.
- We need reliable representative tests that show which masks fulfill their intended function.
- Will we cope better with the next pandemic?



Source: Adapted from Ian M. Mackay (virologydownunder.com) and James T. Reason. Illustration by Rose Wong

Thank you !

Believes in science

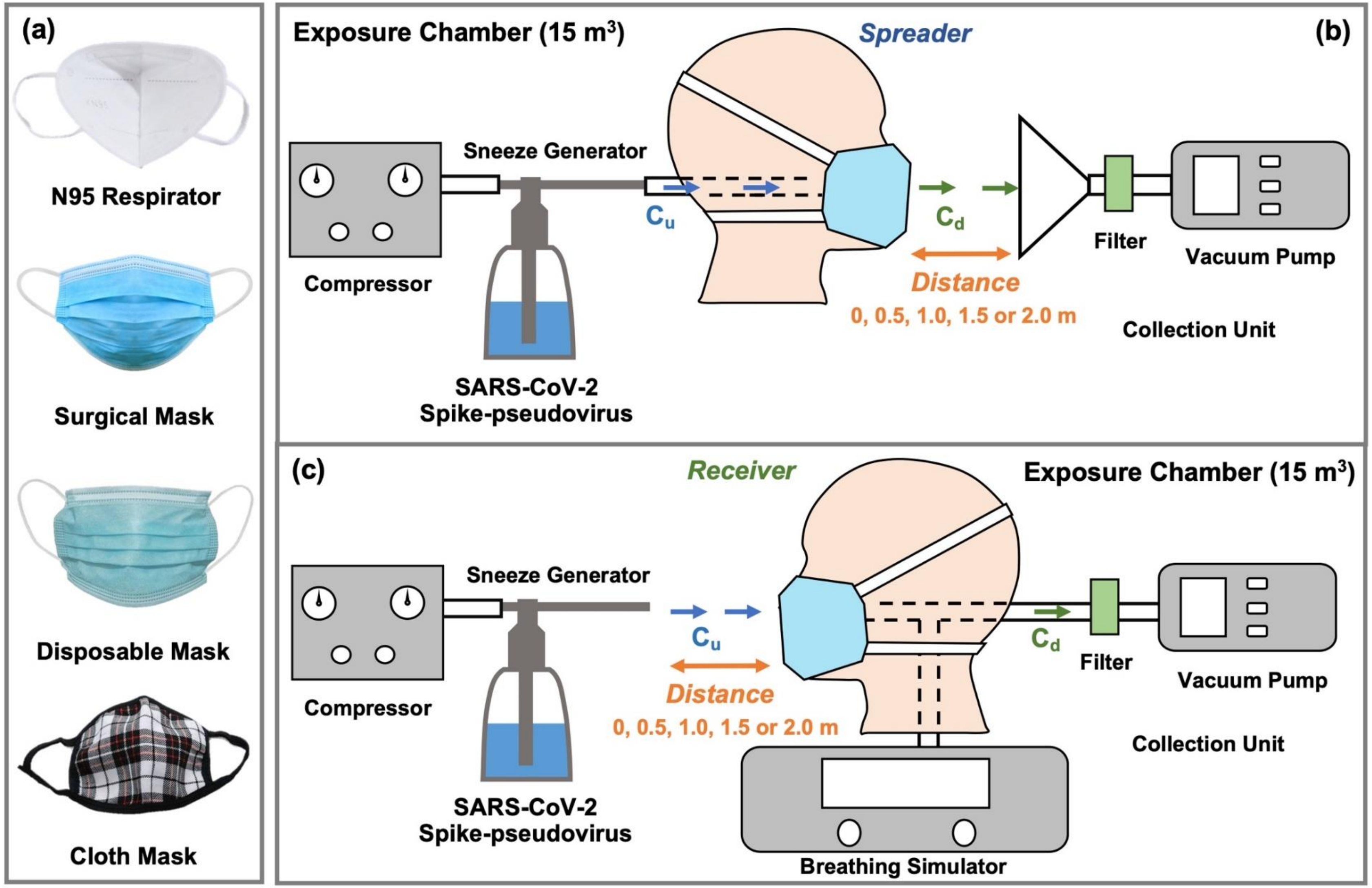
Does not believe in science

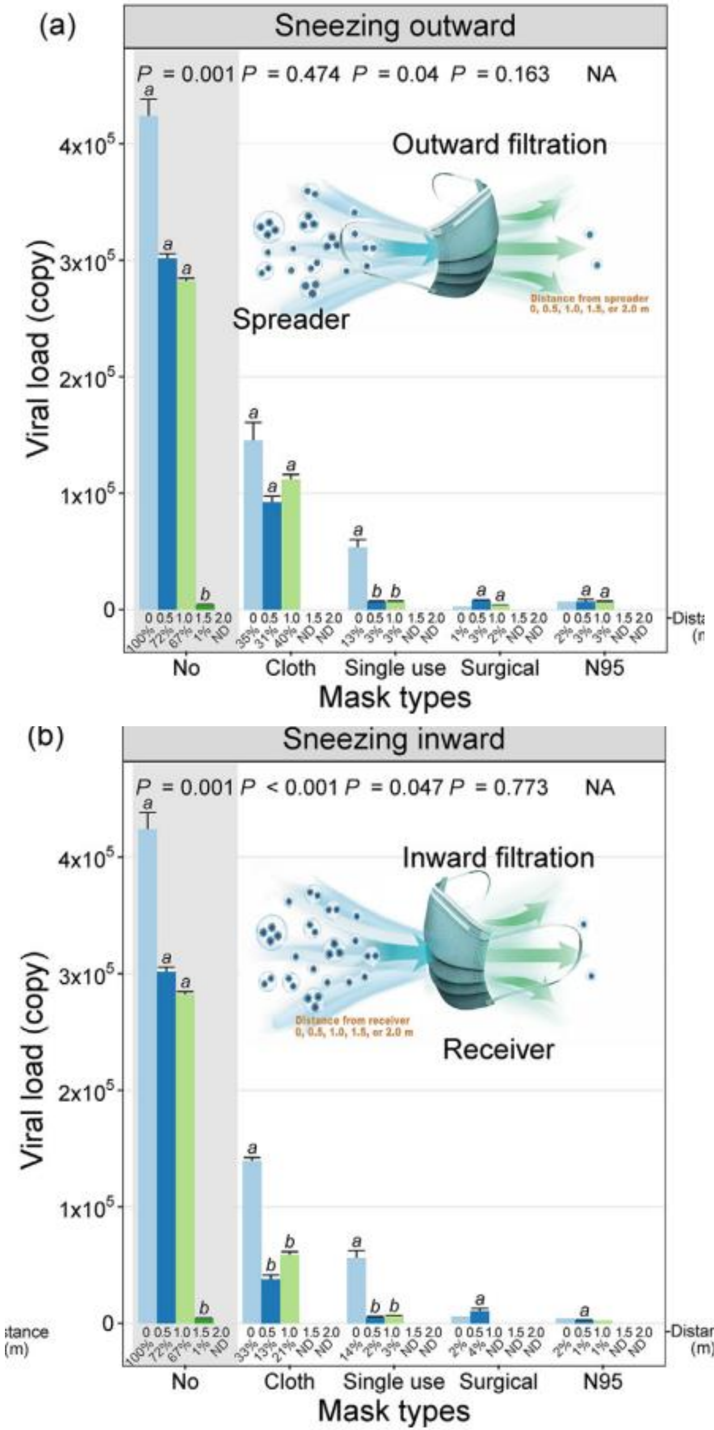
Does not understand science

Believes in miracles

See also:
Position paper of the Gesellschaft für Aerosolforschung (GAeF)
on understanding the role of aerosol particles in SARS-CoV-2 infection
(Asbach et al., 2020)
https://www.info.gaef.de/positionspapier

Sneezing tests





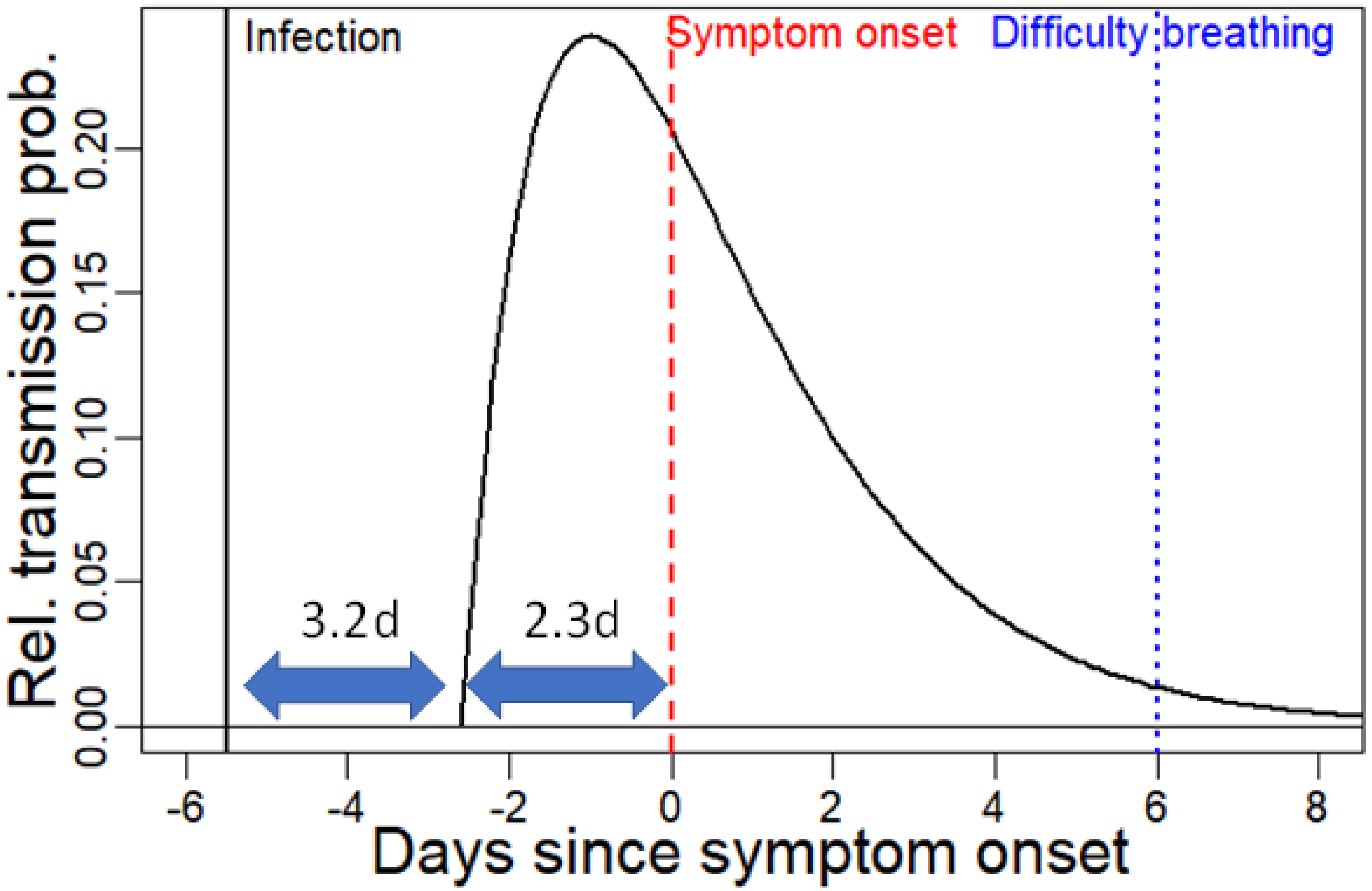
Tang et al. (2022)

https://doi.org/10.1016/j.scib.2021.12.017

Major recent epidemics/pandemics (list is not complete)

Date	Event	Location	Death toll
1918 – 1920	Spanish flu (Influenza A virus subtype H1N1)	Worldwide	>50 million
1981 – present	HIV/AIDS	Worldwide	>40 million
2002 – 2004	SARS – Severe acute respiratory syndrome (Coronavirus)	Worldwide	774
2009	Swine flu (Influenza A virus subtype H1N1)	Worldwide	284’000 (possible range 151’700 – 575’400)
2012 – present	MERS – Middle East respiratory syndrome (Coronavirus)	Worldwide	941 (as of May 2021)
2013 – 2016	Ebola virus	Africa	>11’000
2017 – 2018	Seasonal influenza	United States	61’000 (46’000 – 95’000)
2019 – present	Covid-19 pandemic SARS-CoV-2 (Coronavirus)	Worldwide	7 - 28 million (as of May 2023)

Temporal dynamics in Covid-19 transmission

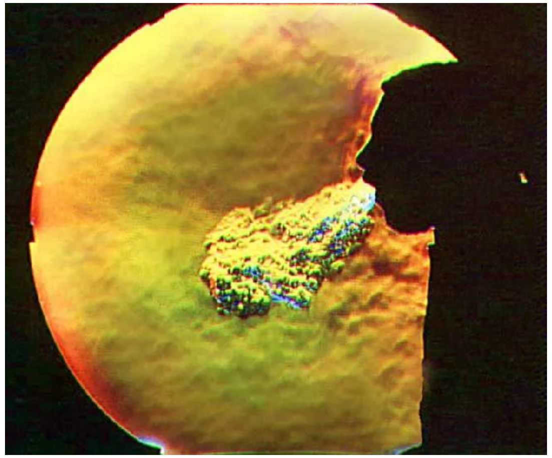


Adapted from https://doi.org/10.1038/s41591-020-0869-5
https://twitter.com/DiseaseEcology/status/1271281853391966213

The dose matters….

- Experts estimate that
  as few as 1000 SARS-CoV2 viral particles are sufficient for an infection
  This may correspond to
  - one eye-rub, or
  - 100 viral particles inhaled with each breath over 10 breaths, or
  - 10 viral particles with 100 breaths

- Experts estimate that
  - A single sneeze releases about 30,000 droplets, with droplets traveling at up to 200 miles per hour. A single sneeze may contain up to 200,000,000 viruses.
  - Breathing and speaking releases aerosols and droplets: about 200 virus particles per minute.

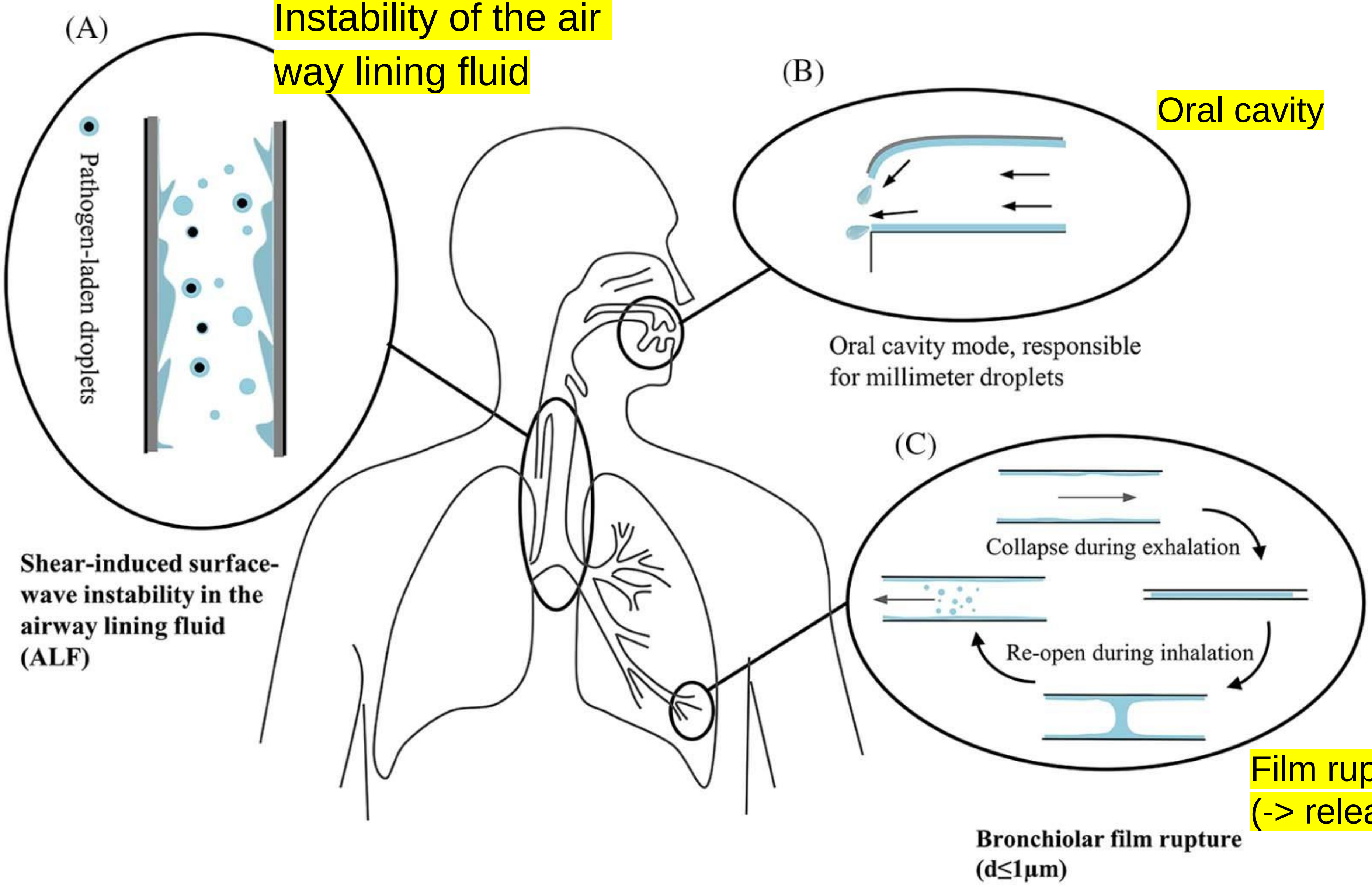


https://www.livescience.com/3686-gross-science-cough-sneeze.html

- Fact is: most droplets are small, stay airborne and travel great distances

https://www.erinbromage.com/post/the-risks-know-them-avoid-them

Human lungs are aerosol generators



Instability of the air way lining fluid

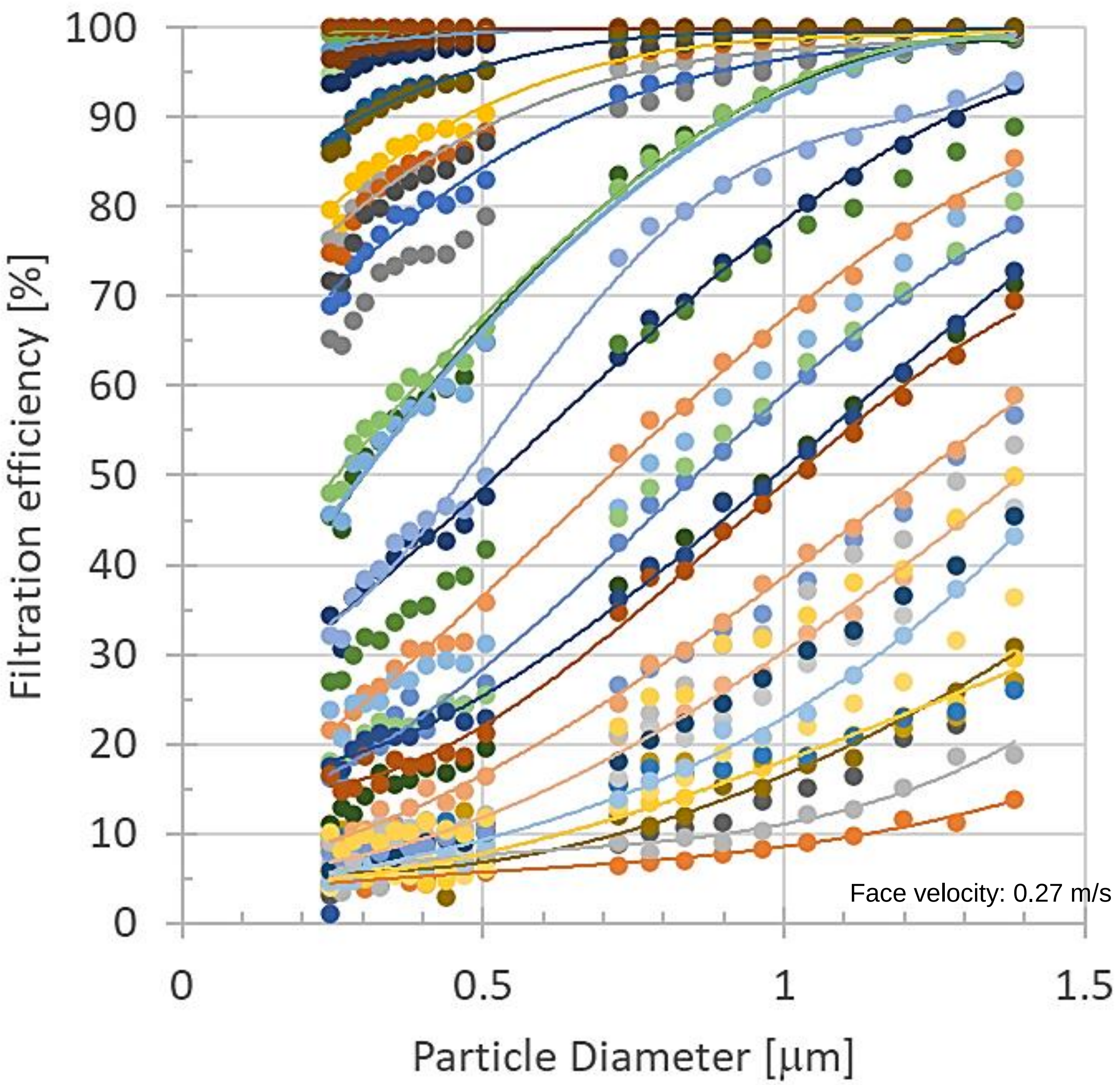
Oral cavity

Film rupture in the deep lung (-> release of ultra fine particles)

Wei et al.
American Journal of Infection Control 2016
https://doi.org/10.1016/j.ajic.2016.06.003

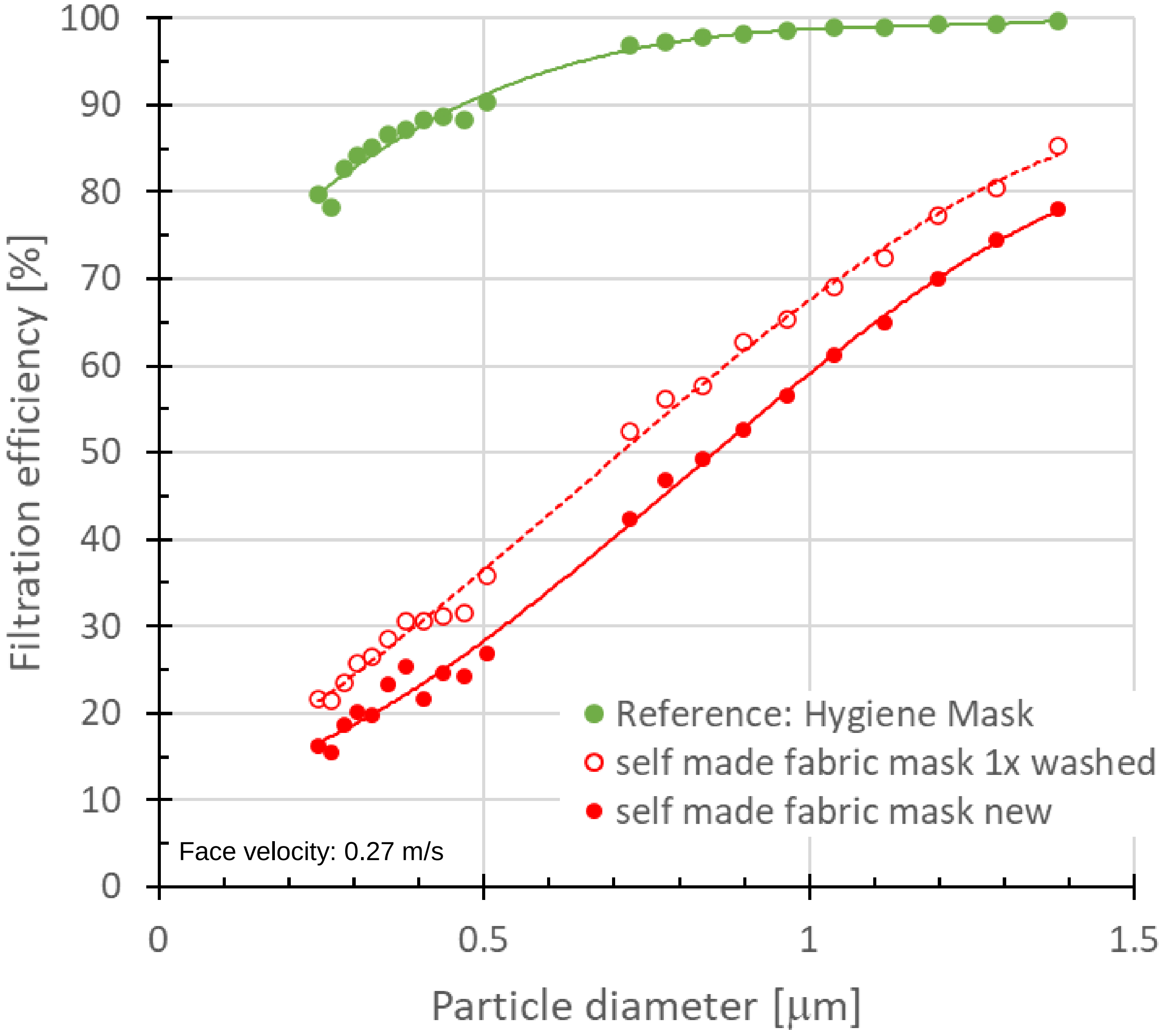
Let’s open Pandora's Box:

the results
of our mask tests



https://www.fhnw.ch/en/about-fhnw/schools/school-of-engineering/institutes/research-projects/evaluation-of-the-particle-filter-efficiency-of-fabrics-for-disposable-and-reusable-masks

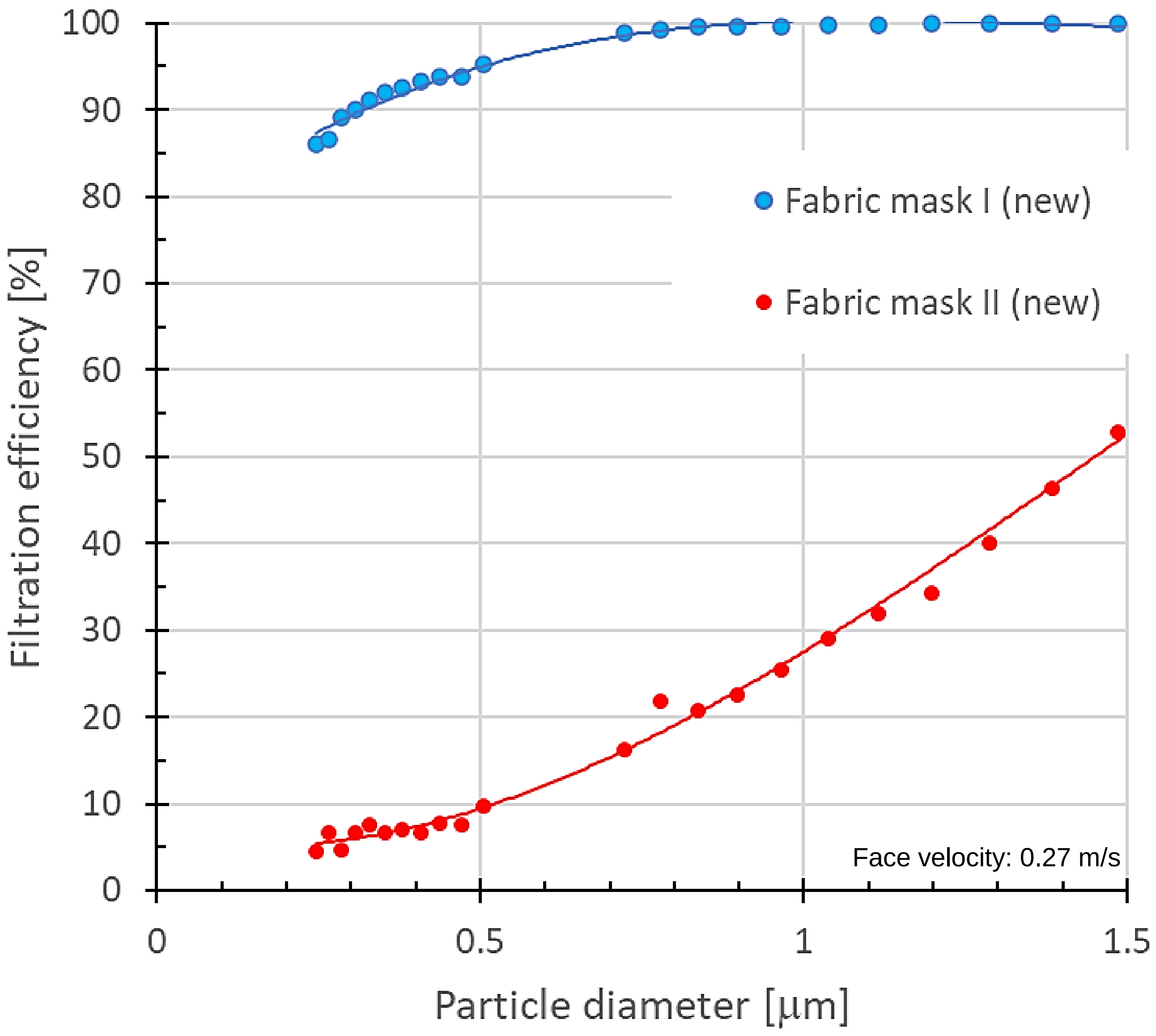
Self made fabric mask: New vs. once washed



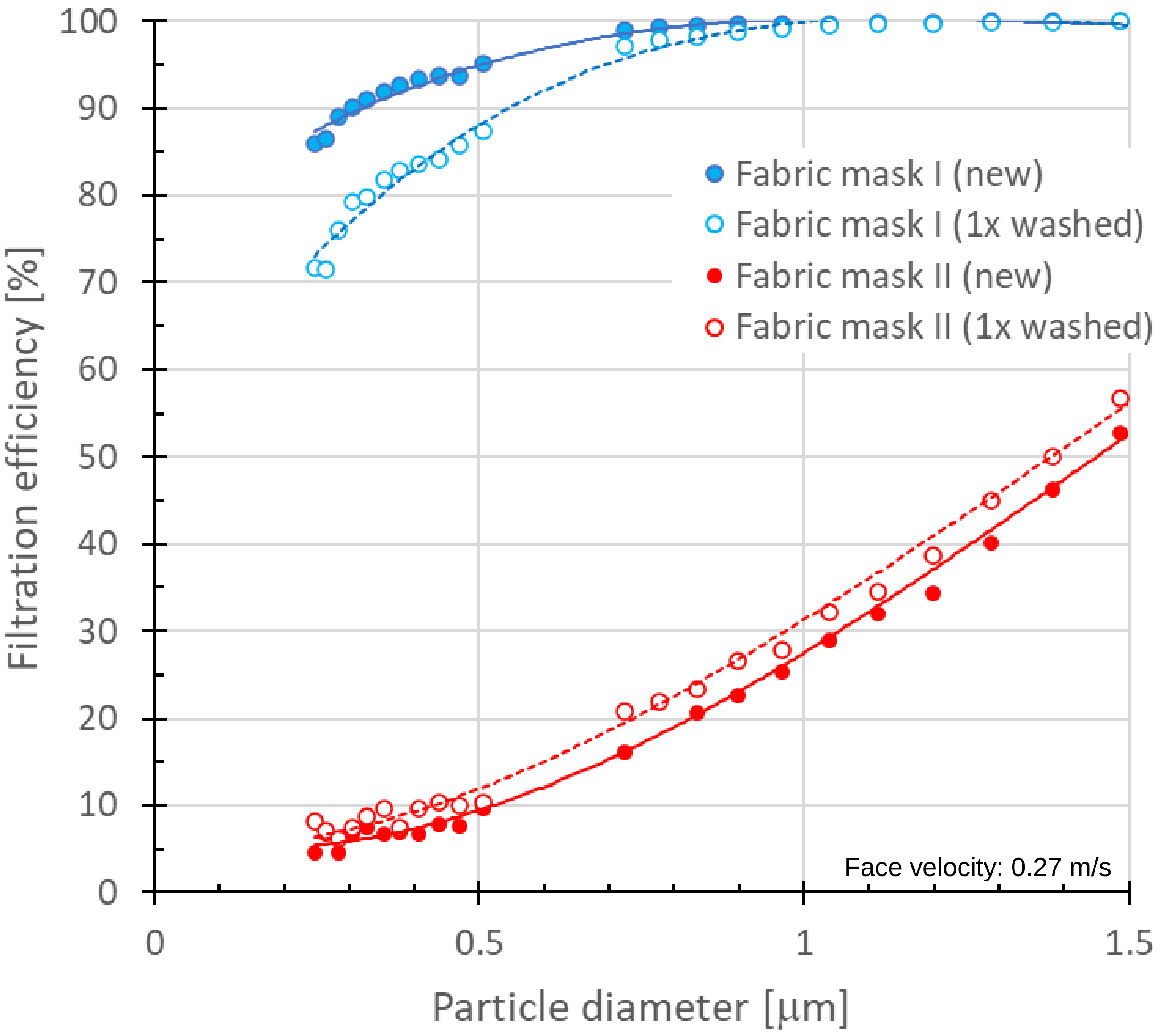
Two layers of cotton

Poor efficiency is improved by washing.

Fabric masks: Efficiency of commercially available masks



Fabric masks: Influence of washing once



Washing deteriorates the effect of good masks and the poor get a little better.

Fabric masks: influence of face velocity
(0.27 m/s vs 0.08 m/s)