HSE
Occupational Health & Safety
and Environmental Protection unit

CAiMIRA
CERN Airborne Model for Indoor Risk Assessment

Tools for science-driven policies:

CAiMIRA as guide for healthier schools

TAPAS Network lunchtime seminar

Andre Henriques, on behalf of the CAiMIRA team
CERN

24/11/2022

CAiMIRA team

Active

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Engineer
CERN

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Full-stack developer
Engineer
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Model developer
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Physicist
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Contributor
Epidemiologist
University of Geneva

World Health Organization

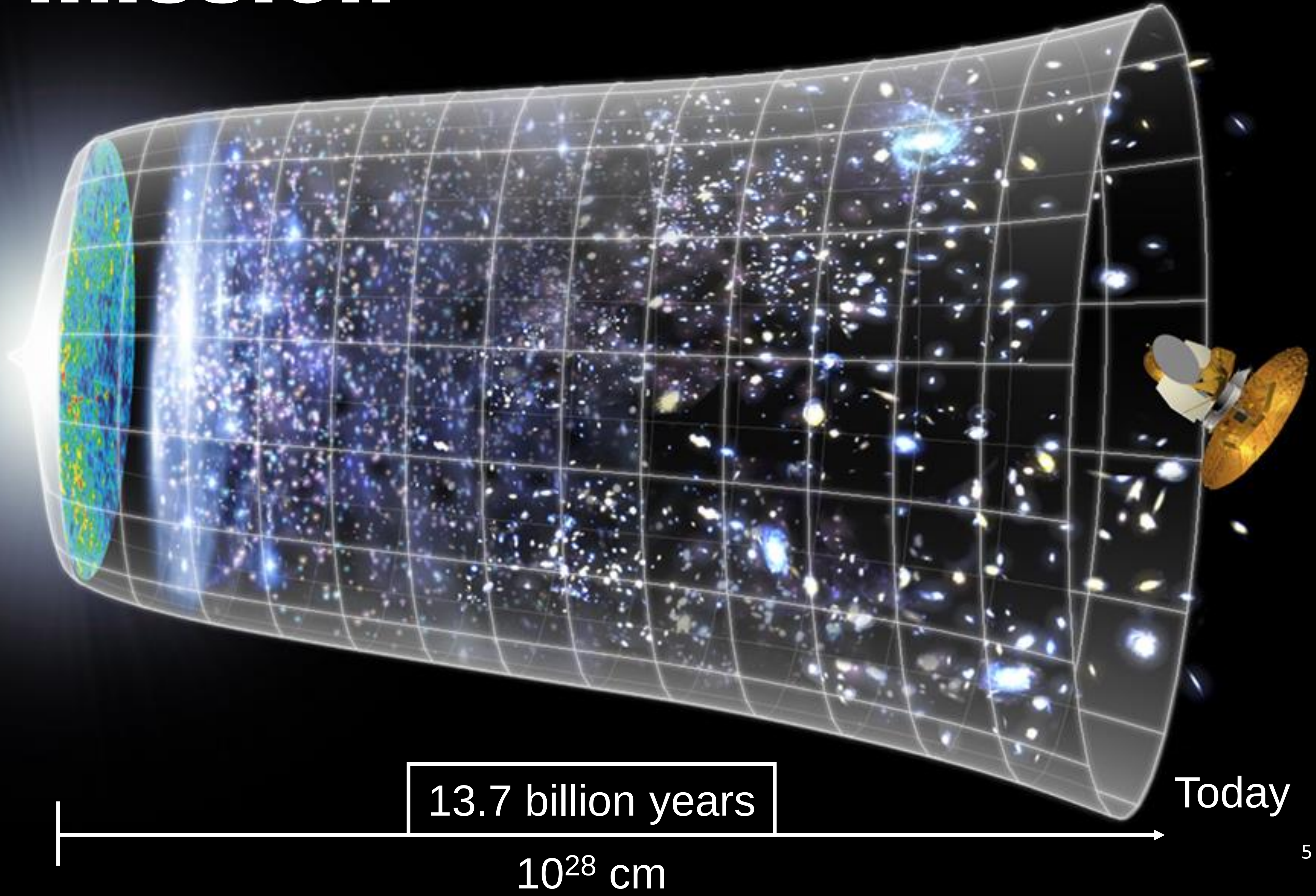
ARIA WG
Contributor
Health Emergencies
WHO

***C**onseil **E**uropéen pour la **R**echerche **N**ucléaire*

European Organization for Nuclear Research

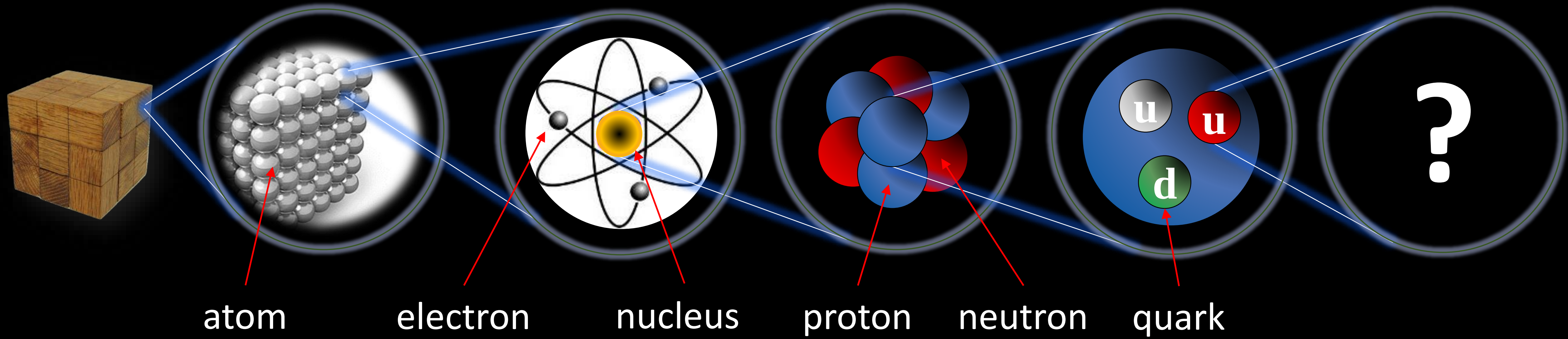

LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SPS 7 km
SUISSE
FRANCE
ALICE
CMS
LHC 27 km

CERN mission



…and the remaining 95% of the Universe NOT made of visible matter…

What is the matter made of ?



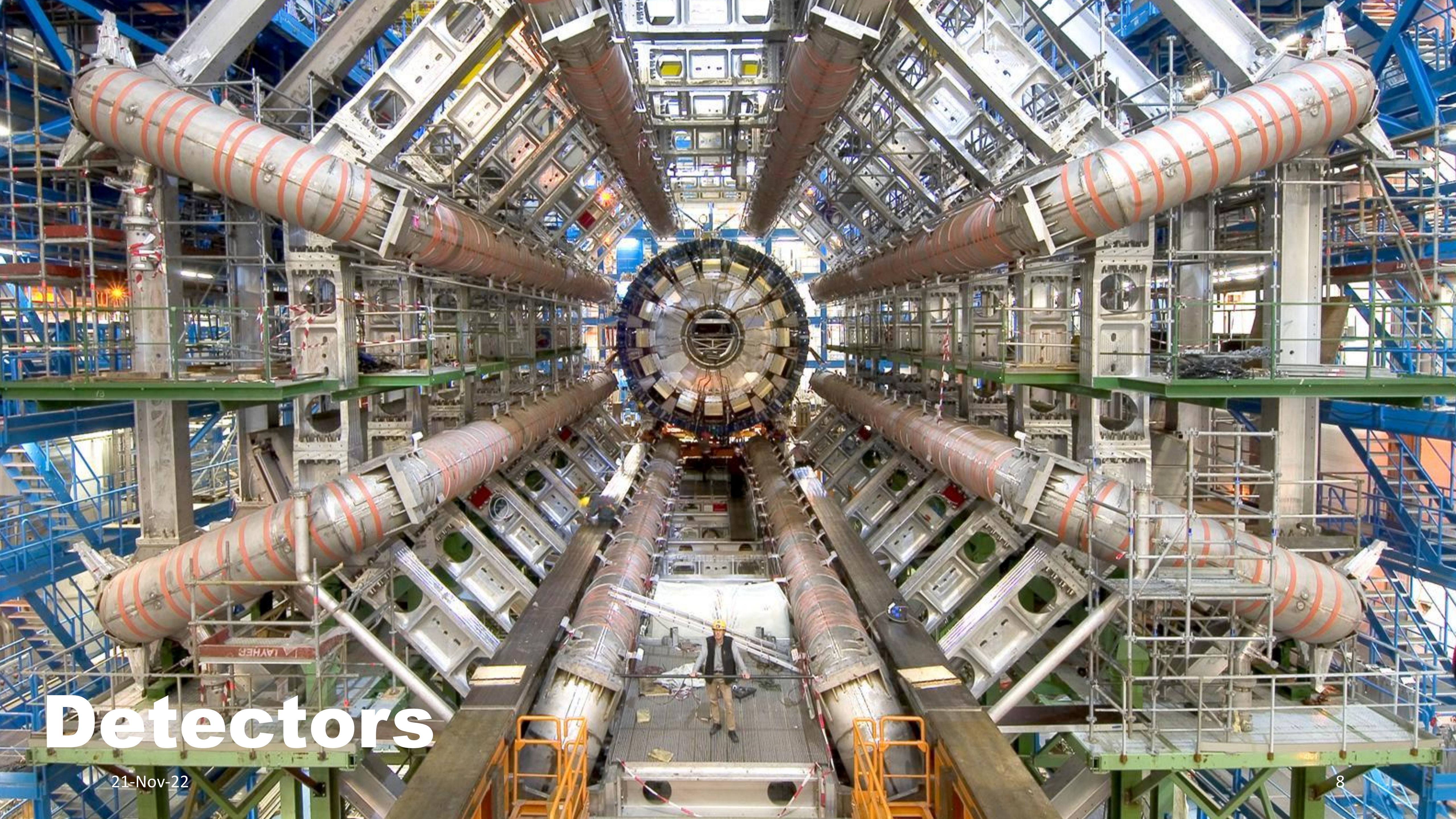
4^{th} - 5^{th} BCE

End of 19^{th} century

Begining of 20^{th} century

1960s

Accelerators



Detectors

Computing


ENGINEERING SERVICES
WORLD WIDE WEB SERVERS
HOME DIRECTORY SERVERS
DESKTOP INFRASTRUCTURE
MAIL SERVERS


RESEARCH
TECHNOLOGY
TRAINING
COLLABORATION
CERN
technology

Now to the topic …

Science-driven approach: for emerging risks

©CERN

Source: Forbes.com Employers Get High Marks For Keeping Workers Safe During Covid: Survey

Specific technological hazards

General standard hazards

Risk-based approach

TAPAS

Tackling air pollution at school

Why and How ?

Research articles

Modelling airborne transmission of SARS-CoV-2 using CARA: risk assessment for enclosed spaces

Andre Henriques, Nicolas Mounet, Luis Aleixo, Philip Elson, James Devine, Gabriella Azzopardi, Marco Andreini, Markus Rognlien, Nicola Tarocco and Julian Tang

Published: 11 February 2022 https://doi.org/10.1098/rsfs.2021.0076

Established in 1871

Swiss Medical Weekly

SARS-CoV-2 aerosol transmission in schools: the effectiveness of different interventions

Jennifer Villers[a*], Andre Henriques[b*], Serafina Calarco[c], Markus Rognlien[d], Nicolas Mounet[b], James Devine[b], Gabriella Azzopardi[b], Philip Elson[b], Marco Andreini[b], Nicola Tarocco[b], Claudia Vassella[e], Olivia Keiser[f]

[a] Global Studies Institute, University of Geneva, Switzerland
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[c] Foundation for Innovative New Diagnostics (FIND), Geneva, Switzerland
[d] Norwegian University of Science and Technology (NTNU), Trondheim, Norway
[e] Federal Office of Public Health, Consumer Protection Directorate, Indoor Pollutants Unit, Berne, Switzerland
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[*] These authors contributed equally

https://doi.org/10.4414/smw.2022.w30178

Pre-print (medrxiv)

In the top 5% of all research outputs scored by Altmetric

+ 10 000

Reviewer 1 (Jacob Bueno de Mesquita, Ph.D) | ■■■■□

Reviewer 2 (Richard M. Lynch, Ph.D) | ■■■■□

Reviewer 3: (Brian Pavilonis) | ■■■ □□

■■■ □□ = Potentially Informative

■■■■□ = Reliable

https://rapidreviewscovid19.mitpress.mit.edu/pub/v476ejfz/release/1

Timeline of the pandemic 2020

Science-driven proposal
- *Literature review*
- *Expertise (physics)*

Directorate decision
- *Feasibility*
- *Impact (+ / -)*
- *Communication plan*
- *Transparency in the rationale*

Prepare for a safe re-start; rules and regulations were evolving

Wear a mask.

1st large purchase in April 2020

Dedicated instructions for ventilation

Host States

Mask mandates:

Closed public spaces

companies

Closed spaces

Public transport

Importance of ventilation :

World Health Organization

Full endorsement by WHO
https://youtu.be/XJC1f7F4qtc

CDC Centers for Disease Control and Prevention

ecdc European Centre for Disease Prevention and Control

Full endorsement by CDC and ECDC

Jan 2020 — Declaration to WHO of new coronavirus outbreak

Feb — New disease: COVID-19

Mar — Pandemic declared, **Lockdown**

Apr — 1 Million cases

May — **Gradual re-start on CERN-site**

June — New outbreak after 1st wave in China

July — Update of the modes of transmission by WHO

Aug

Sept — Start of 2nd wave in Europe

Oct — Peak of 2nd wave

Nov

Dec 2020 — Daily new cases still very high…

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companies

Public

Importance of ventilation :

World Health Organization

CDC
CENTERS FOR DISEASE CONTROL AND PREVENTION

ecdc

Full endorsement
HO
e/XJC1f7F

Full endorsement by CDC and ECDC

Quantitative approach enabling
flexibility, tailored measures & <u>targeted investment</u>

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Feb — New disease: COVID-19

Pandemic declared
Lockdown

Apr — 1 Million cases

Gradual re-start on CERN-site

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Update of the modes of transmission by WHO

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CAiMIRA

CERN Airborne Model for Indoor Risk Assessment

What is **CAiMIRA** ?

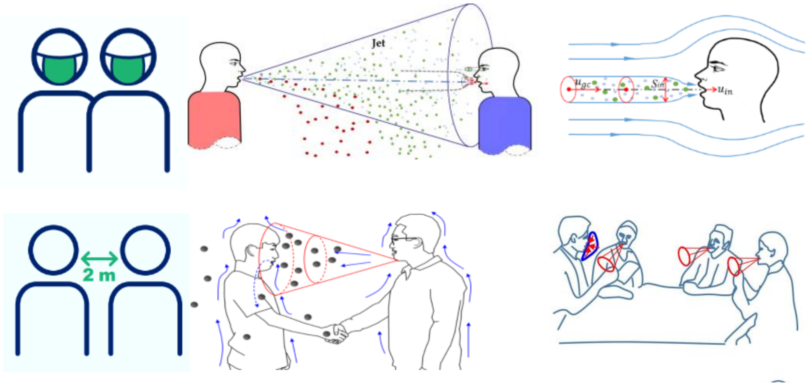
- A model for assessing the risk of secondary on-site transmission, **via the airborne route**, of respiratory pathogens in indoor settings, **using different pharma and non-pharma measures**.

Airborne transmission ?

- *"the virus spreads mainly between people who are in close contact with each other (..) when infectious particles that pass through the air are* ***inhaled*** *at* ***short range****"*
- *"the virus can also* ***spread in poorly ventilated and/or crowded indoor settings****, where people tend to spend longer periods of time"* https://www.who.int/news-room/q-a-detail/coronavirus-disease-covid-19-how-is-it-transmitted

'Short-range'

Expiratory jet



d < 2 m

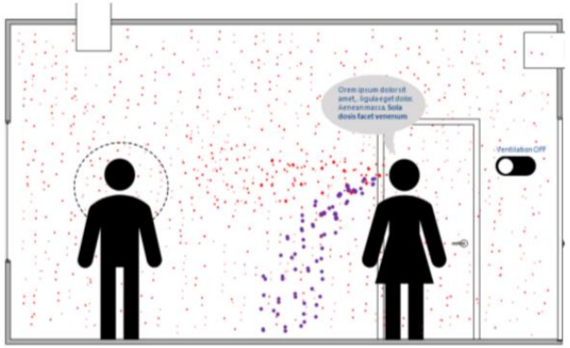
Source: UConn Today

Source: TIME.com

Air pollution analogy

'Long-range'

Background concentration

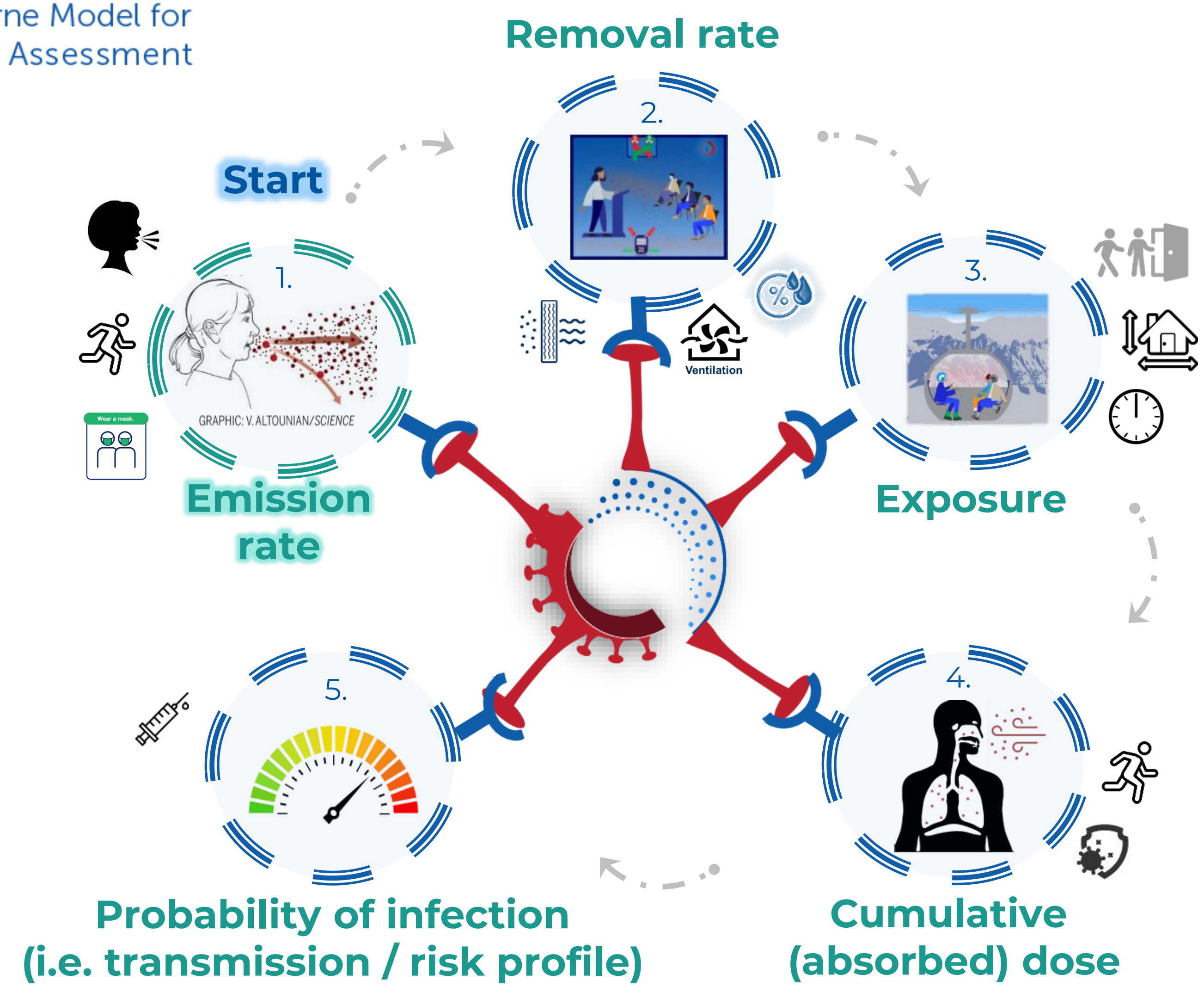


d > 2 m (or independent of d)

Chen W. et al. (2020) Short-range airborne route dominates exposure of respiratory infection during close contact.

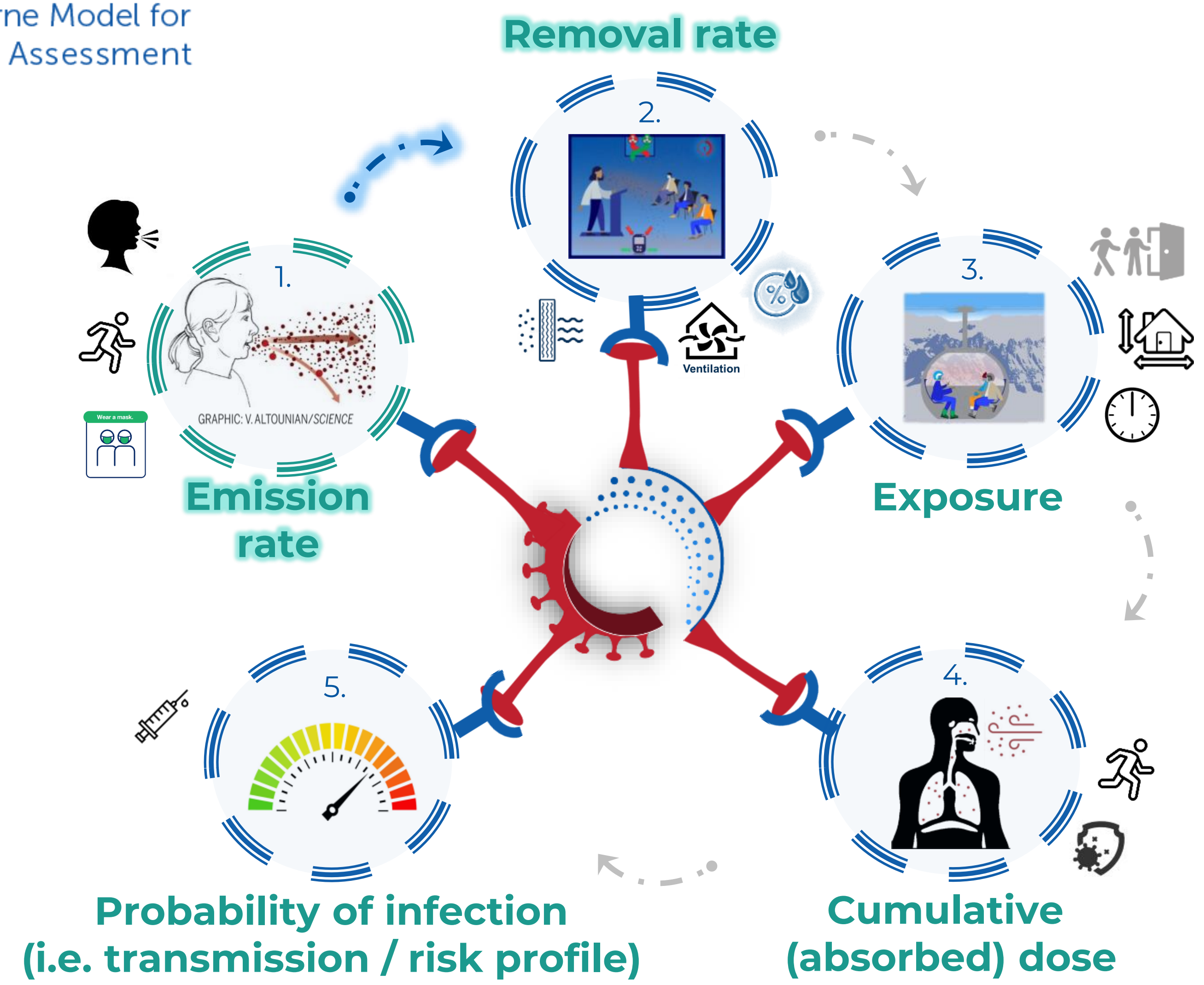
CAiMIRA
CERN Airborne Model for Indoor Risk Assessment

Model architecture: 5-tier methodology



CAiMIRA

CERN Airborne Model for Indoor Risk Assessment



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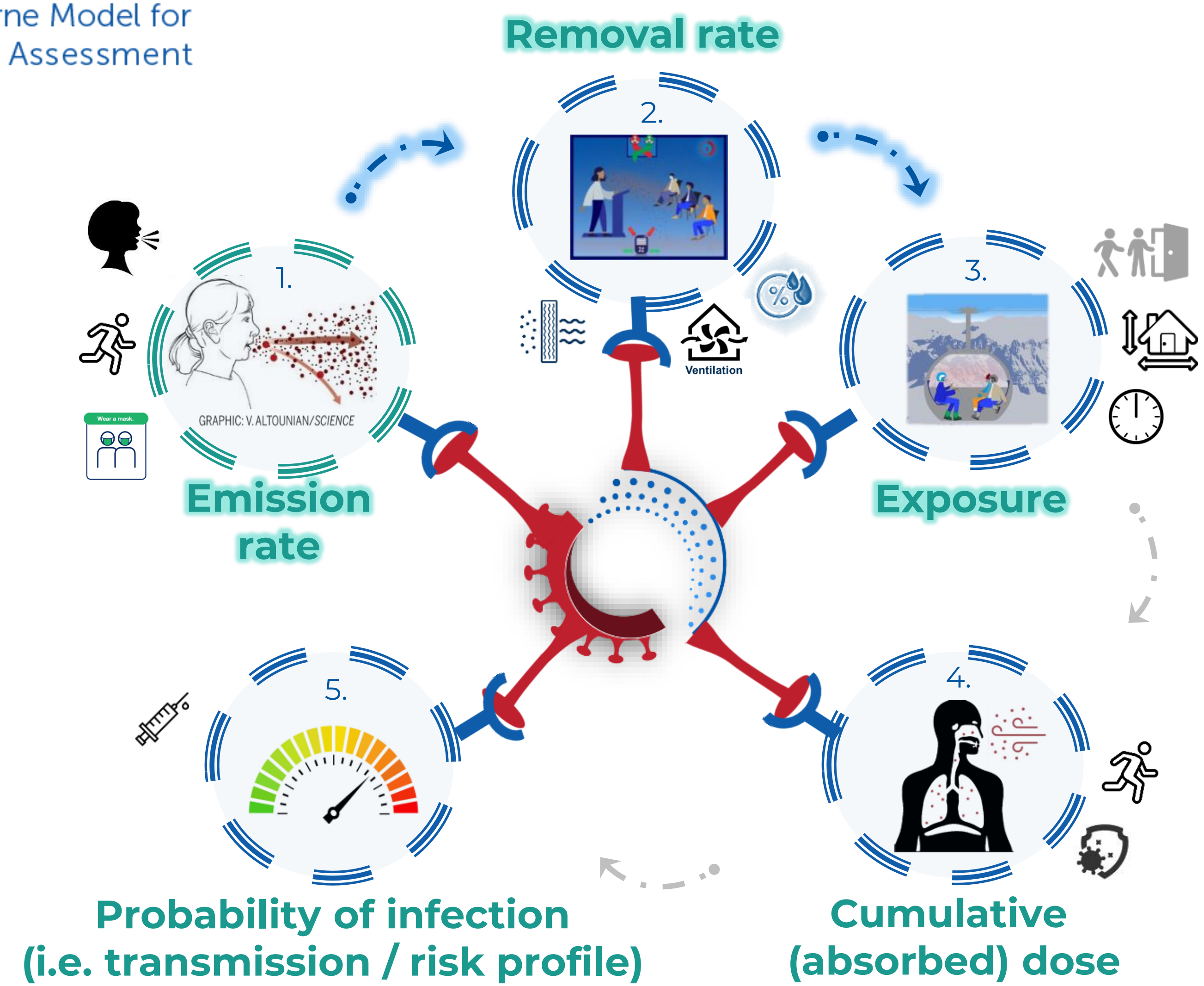
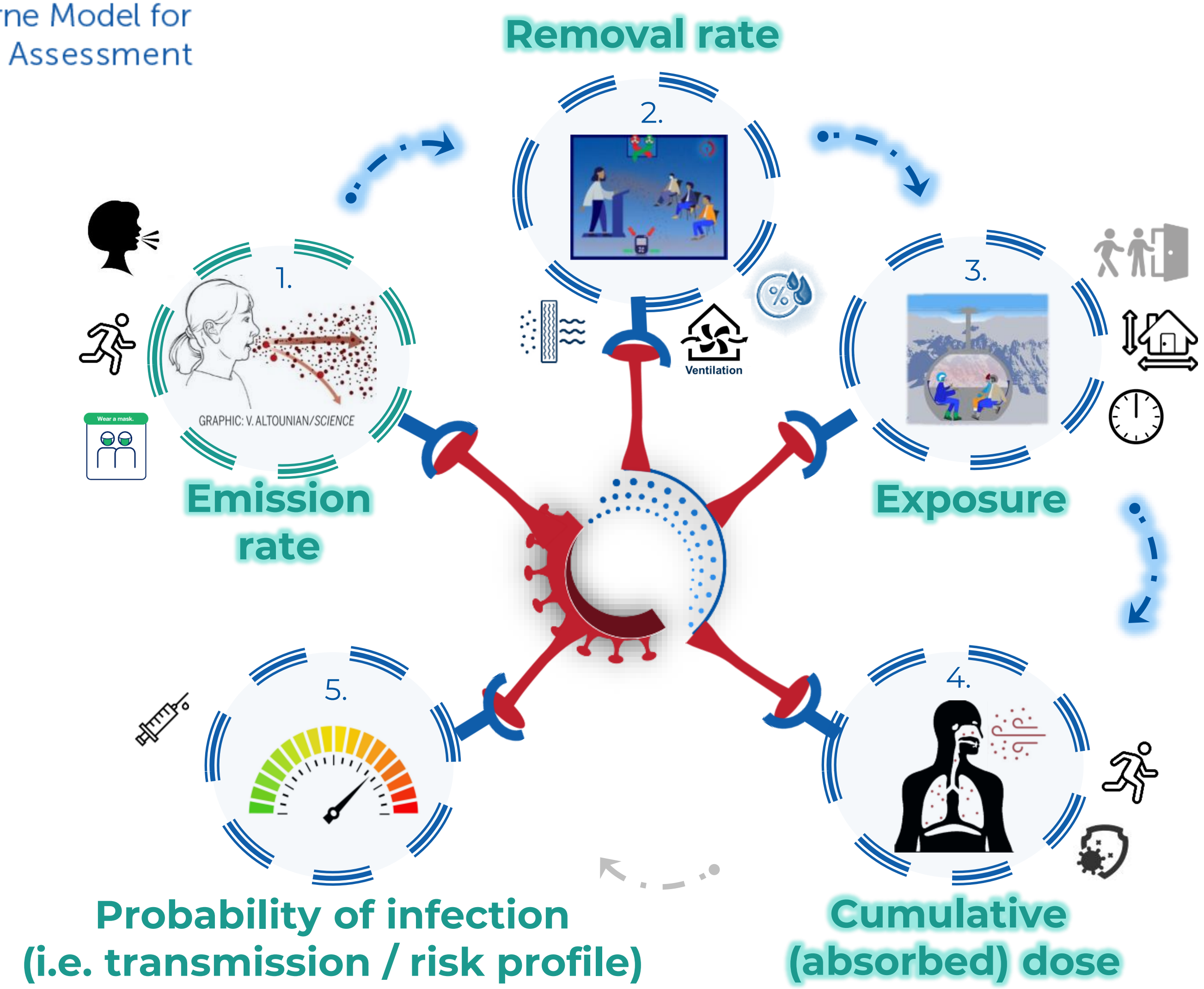
CERN Airborne Model for Indoor Risk Assessment



CAiMIRA
CERN Airborne Model for Indoor Risk Assessment



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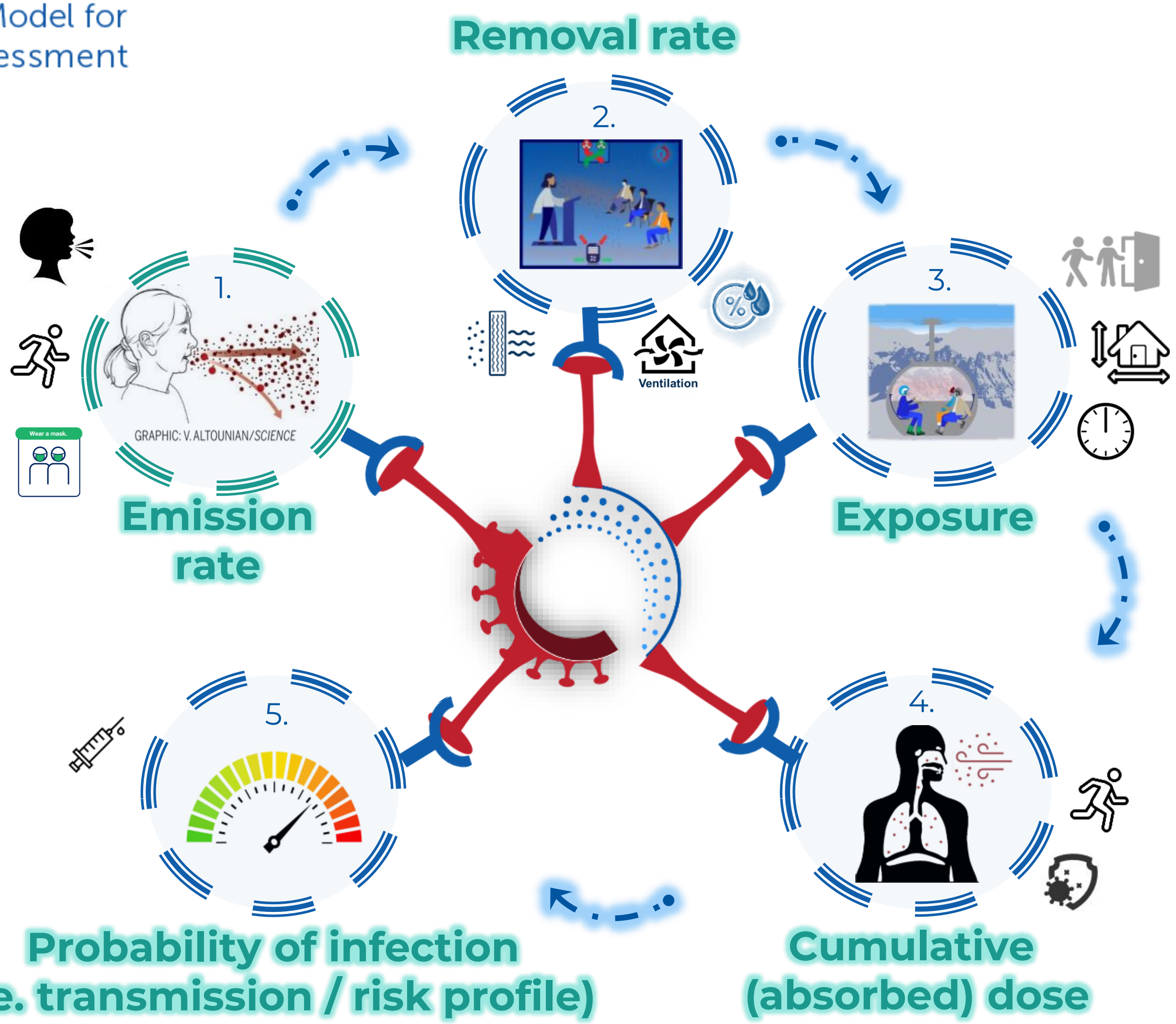
CERN Airborne Model for Indoor Risk Assessment

Each class can be treated independently:
- Flexibility
- update

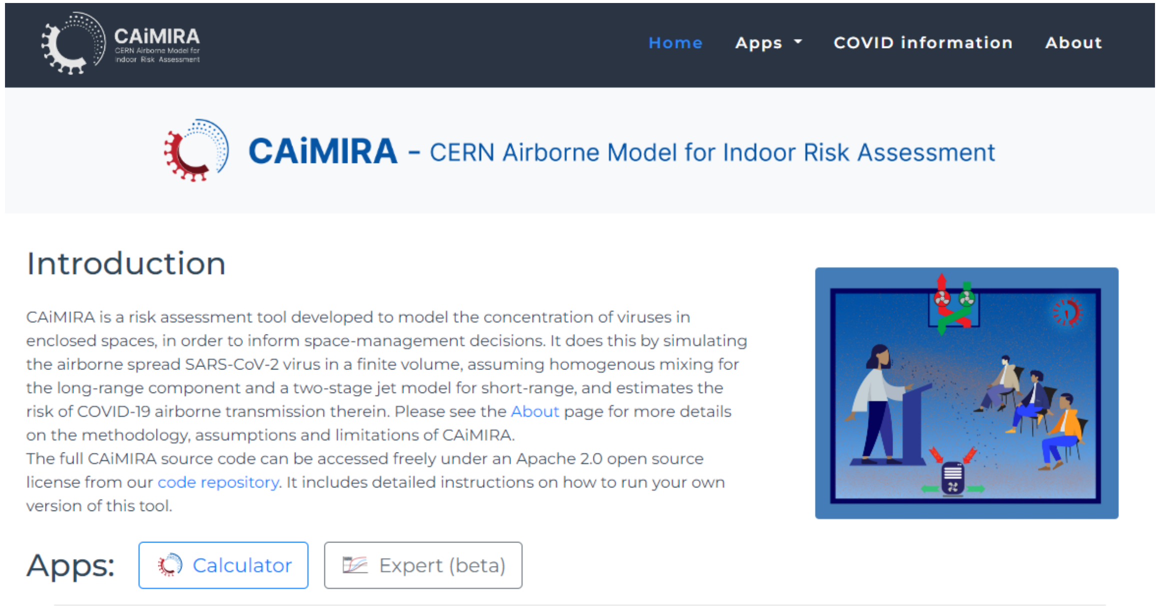
Stochastic model:
- Large variability
- Monte-Carlo simulations
- Model: probability distributions (inputs and outputs)
- Results: show mean, median, IQR, 5th per, 95th per, etc.



Important advice
- Virus-laden aerosols are **NOT** just aerosols

CAiMIRA

CERN Airborne Model for Indoor Risk Assessment



Multidisciplinary model

+100 model inputs

'Simple' Web app

Results tailored for your room

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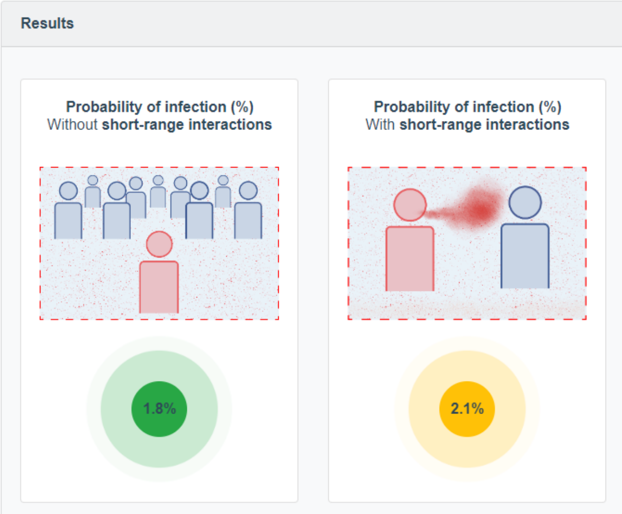
CERN Airborne Model for Indoor Risk Assessment

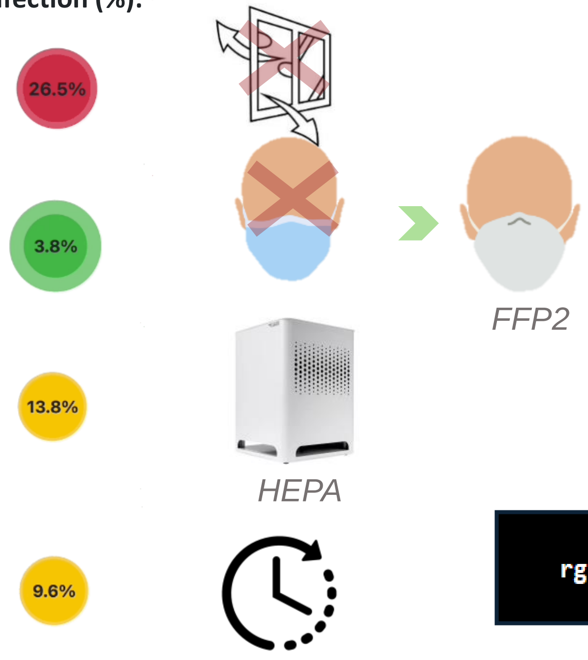
What for ?

Risk score: absolute values

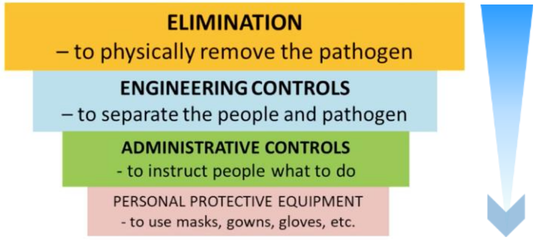


Risk assessment: tailored measures

Example Probability of infection (%):



Compensatory measures:

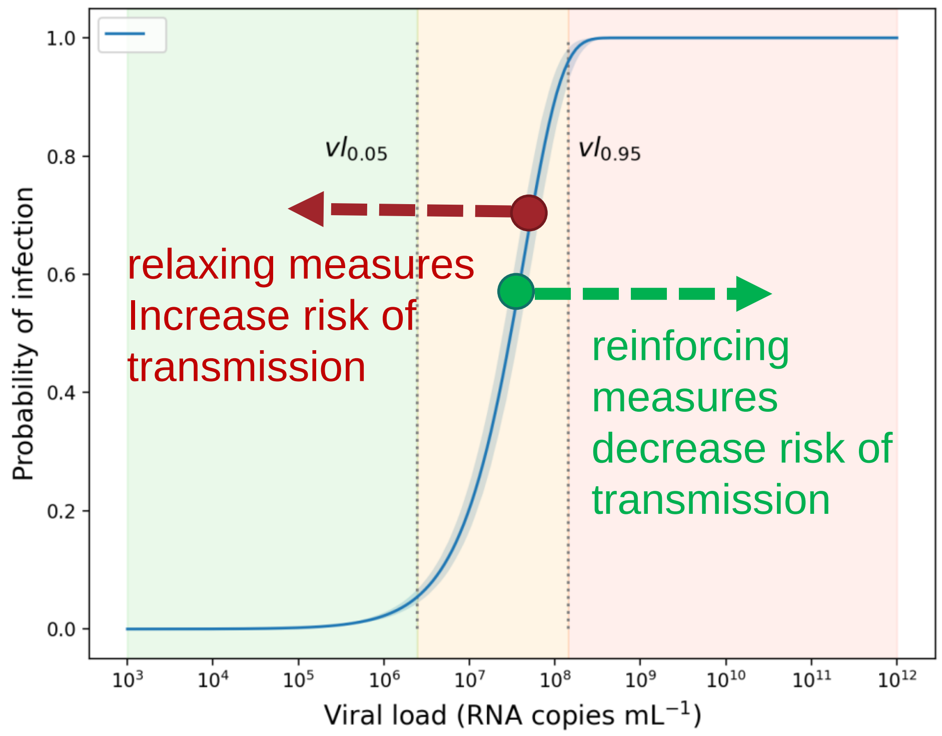


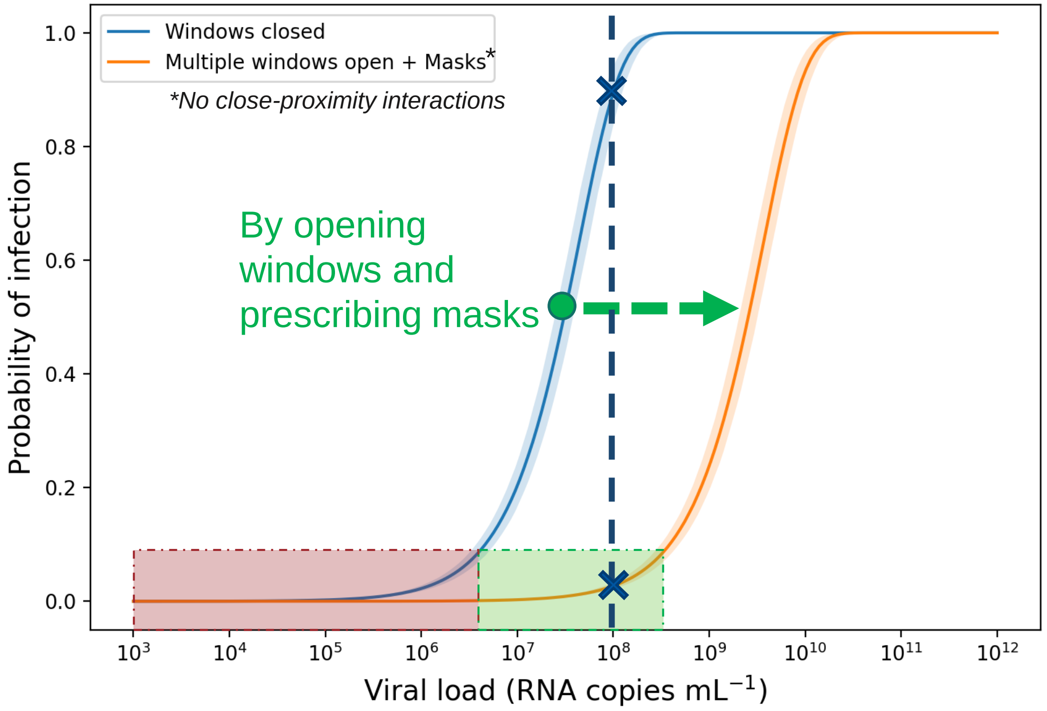
Black or White ?

What for ?

Knowledge and communication

PCR positive =*100 to 100 billion RNA copies / mL (!!)*
Not yes / no answer ; no zero risk





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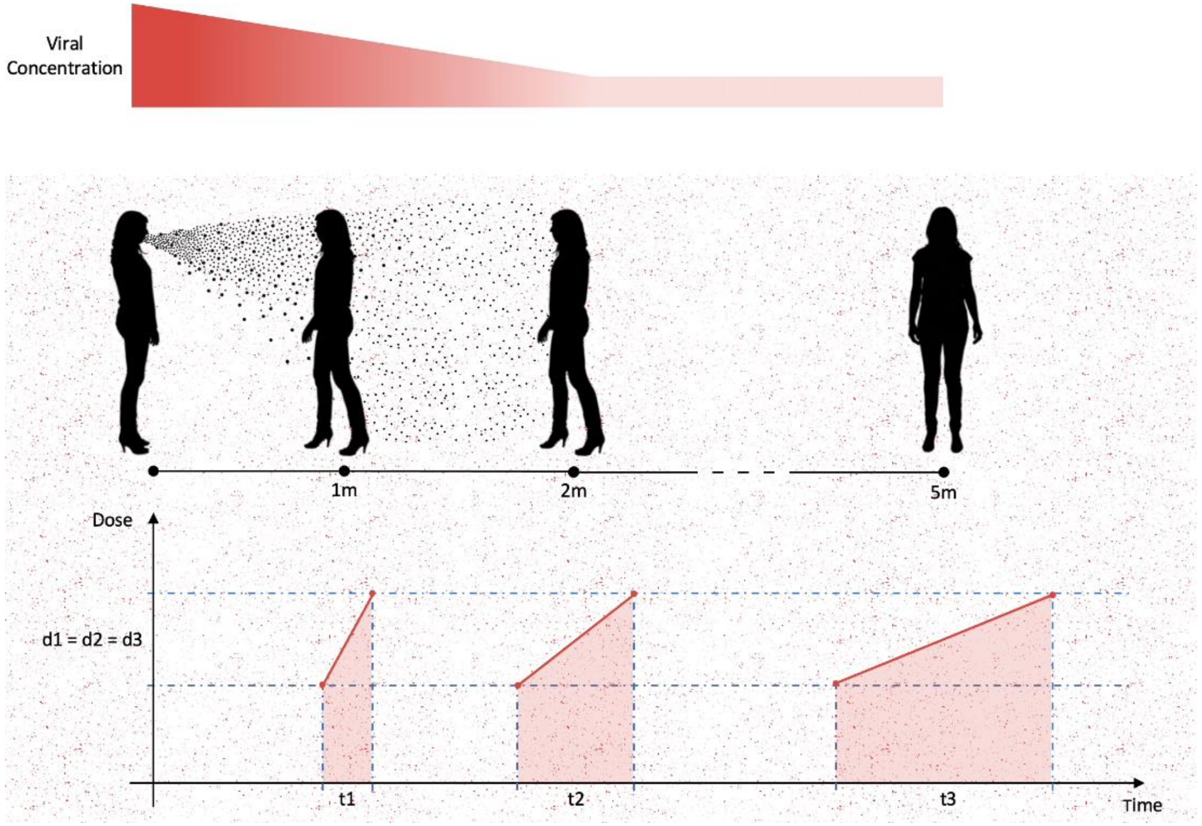
What for ?

Knowledge and communication



Notion of exposure time & risk *

*dose *intensity* neglected
(something to be looked at)

Communication is key in science-driven policy !

Communication
=
Transparency
=
Trust
=
↑ Compliance

Courtesy of L. Aleixo

CAiMIRA
CERN Airborne Model for Indoor Risk Assessment

What for ?

Guidance for specific settings

Established in 1871
Swiss Medical Weekly

SARS-CoV-2 aerosol transmission in schools: the effectiveness of different interventions

Jennifer Villers[a*], Andre Henriques[b*], Serafina Calarco[c], Markus Rognlien[d], Nicolas Mounet[b], James Devine[b], Gabriella Azzopardi[b], Philip Elson[b], Marco Andreini[b], Nicola Tarocco[b], Claudia Vassella[e], Olivia Keiser[f]

[a] Global Studies Institute, University of Geneva, Switzerland
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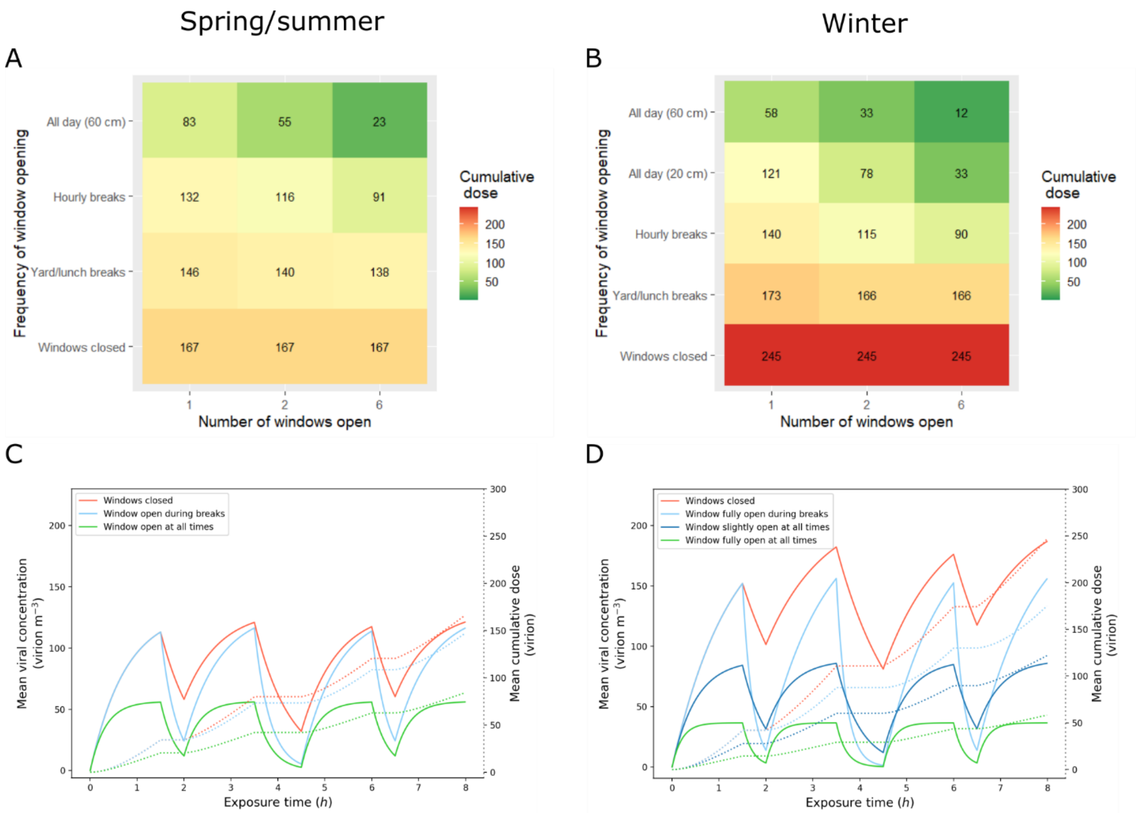
Publication Date: 23.05.2022
Swiss Med Wkly. 2022;152:w30178



Executive summary

1. Surgical face masks, HEPA filters and window opening are effective strategies to reduce the risk of airborne transmission and have cumulative effects.
2. Among feasible interventions tested in our model, mask wearing is the most effective against airborne transmission (8-fold reduction in cumulative dose absorbed) and is the only one that also protects against short-range transmission.
3. Opening windows only during yard and lunch breaks is not effective at decreasing risk (from 1.1 to 1.5-fold reduction in cumulative dose absorbed).
4. Opening several windows on one side of the room during the whole teaching period is effective in summer (3-fold reduction with two windows, 7-fold reduction with six windows).
5. It is even more effective in winter (7.5-fold reduction with two windows, 20-fold reduction with six windows) but inadvisable (energy waste and thermal discomfort).
6. The partial opening (20 cm) of two windows during the whole teaching period or the full opening of six windows for 10 minutes at the end of each teaching period (every 45 minutes) can be effective measures in winter (3- and 2.7-fold reduction, respectively), especially if combined with surgical face masks (25-fold reduction).
7. Two air filters correctly placed in the room with an air flow rate of 5 times the room volume (CADR = 800 $m^3 h^{-1}$) achieve a 4-fold reduction in cumulative dose absorbed in summer and a 5-fold reduction in winter.
8. Inexpensive CO_2 meters can provide good information about the effectiveness of natural ventilation (through window opening), but not the effectiveness of air purifiers.
9. CO_2 measurements may underestimate the transmission risk if the infectious individual has a high viral load or if there is more than one infectious individual in the room.

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CERN Airborne Model for Indoor Risk Assessment

Model Accuracy

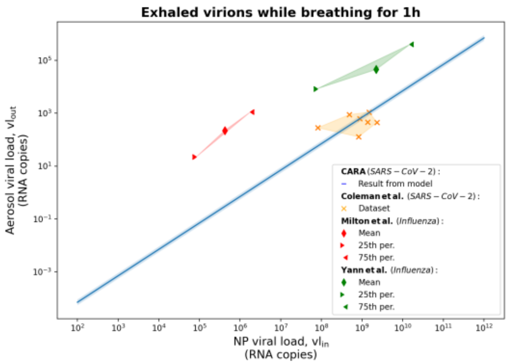
Peer-reviewed

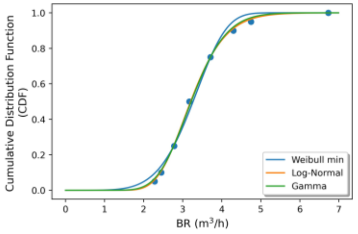
Research articles

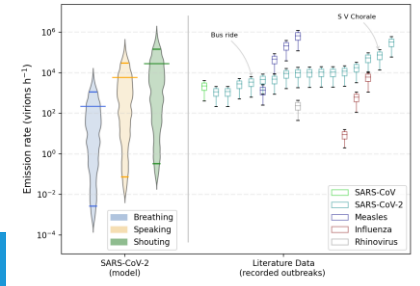
Modelling airborne transmission of SARS-CoV-2 using CARA: risk assessment for enclosed spaces

Andre Henriques, Nicolas Mounet, Luis Aleixo, Philip Elson, James Devine, Gabriella Azzopardi, Marco Andreini, Markus Rognlien, Nicola Tarocco and Julian Tang

Published: 11 February 2022 https://doi.org/10.1098/rsfs.2021.0076





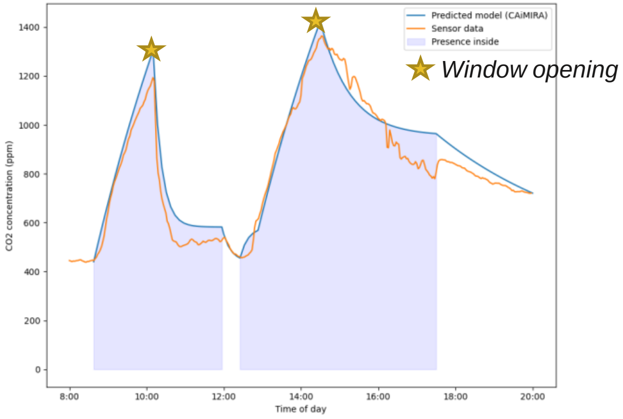


Long-range

Benchmark using recorded outbreaks

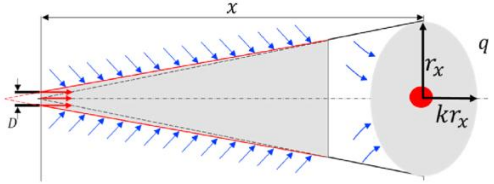
Benchmark scenario: Skagit valley chorale outbreak [83]	Singing-type: - Shouting, light activity Indoor 40 < RH < 60 %	61 occupants; 1 infector: - 2h30min exposure	Mechanical: 0.7 ACH	810	Original strain & non vaccinated occupants
Benchmark scenario: Bus ride outbreak [84, 85]	Sedentary-type: - Speaking, seated Indoor humidity: 40 < RH < 60 %	68 occupants; 1 infector: - 1h40min exposure	Infiltration: 1.25 ACH	45	

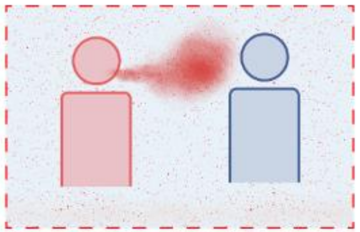
Benchmark using CO_2 + natural vent



Short-range

Two-stage jet model





Wei J. et al (2022), Exposure and respiratory infection risk via the short-range airborne route, Building and Environment, 219, 10.1016/j.buildenv.2022.109166

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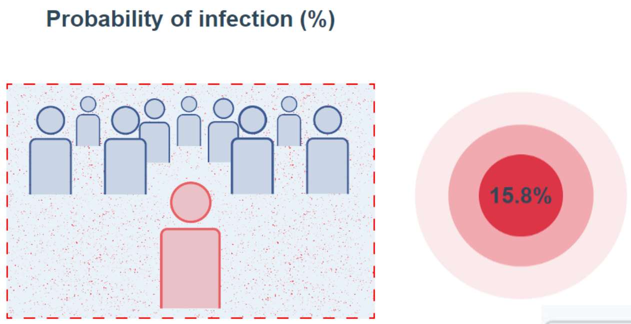
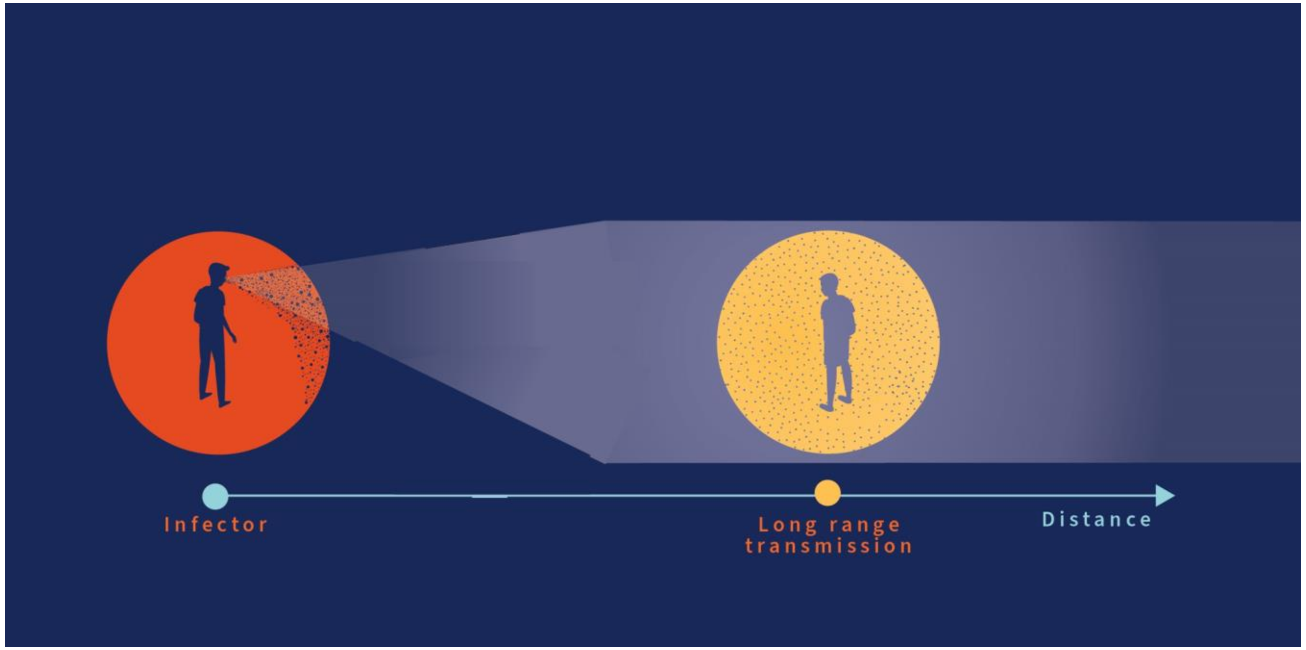
CERN Airborne Model for Indoor Risk Assessment

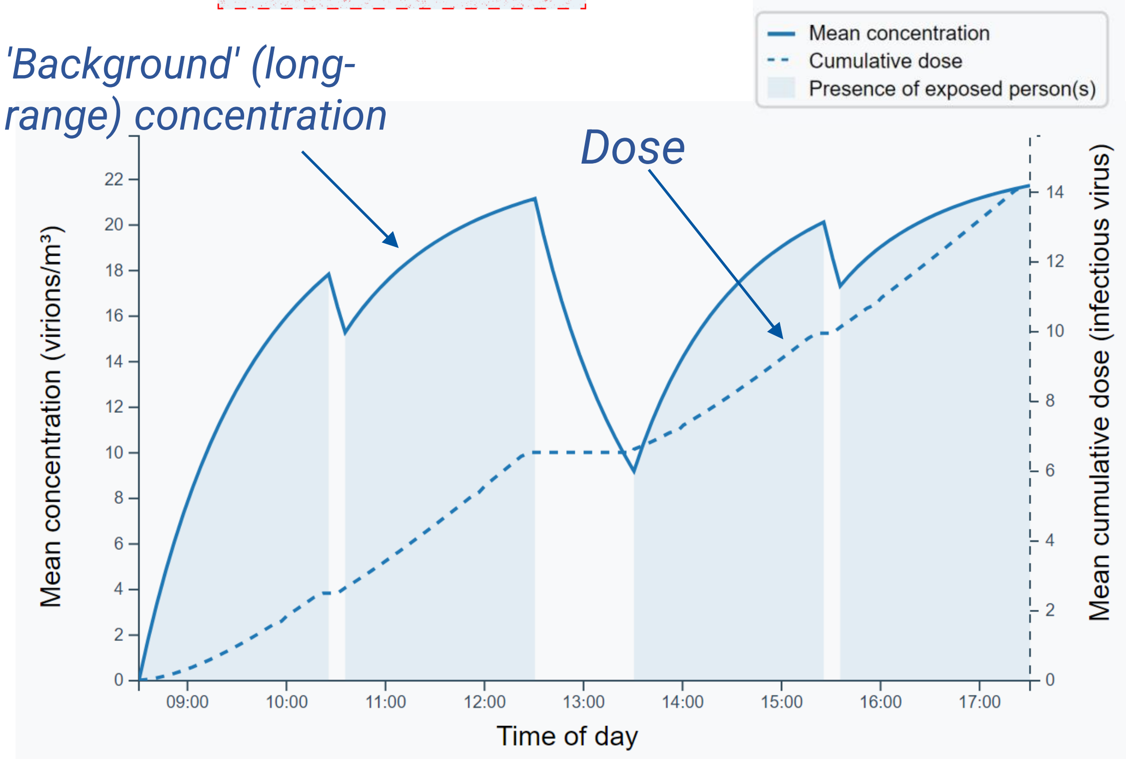
Arbitrary ex (classroom)

- Full day at school (1h lunch break, 2 playground breaks)
- No ventilation
- No masks



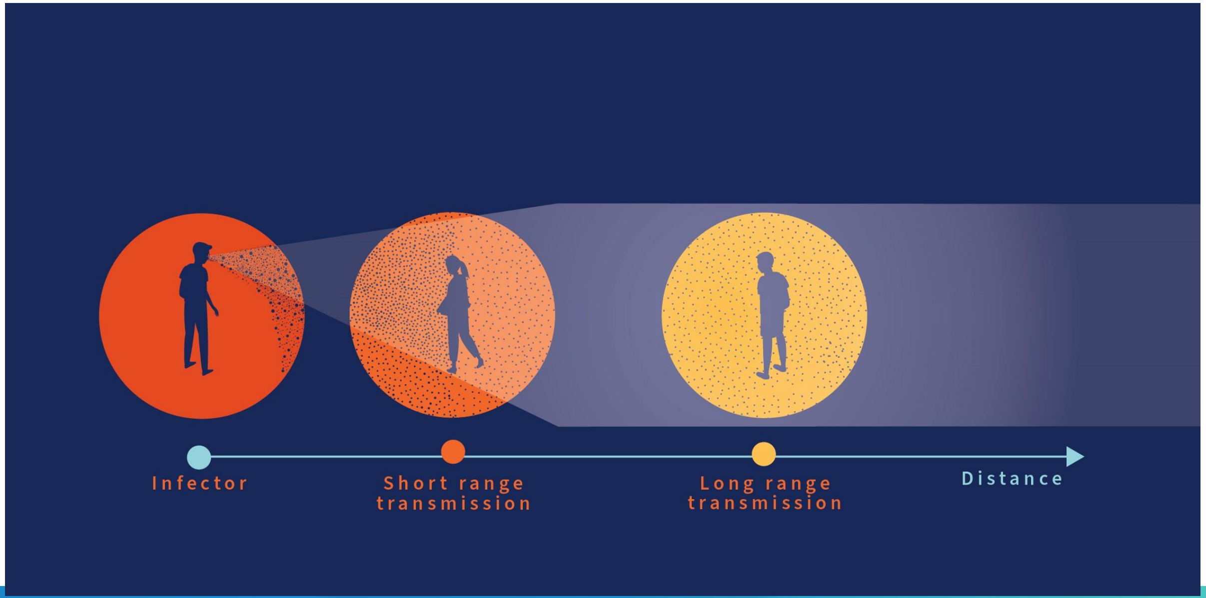


Courtesy of WHO – ARIA WG

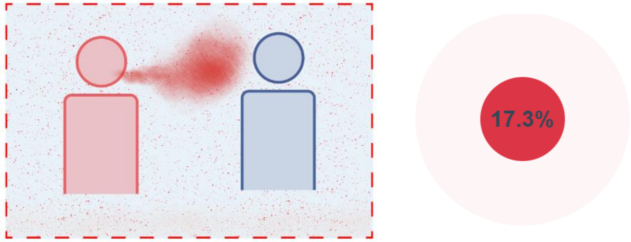


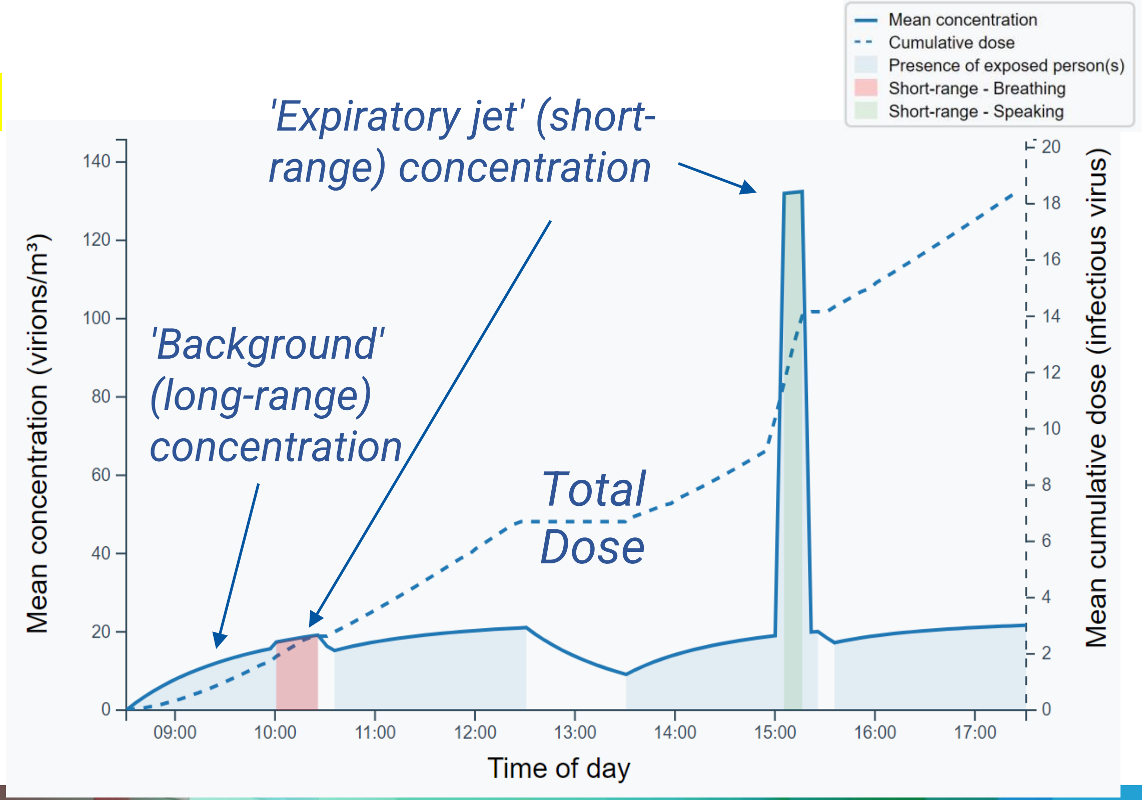
Arbitrary ex (classroom)

- Full day at school (1h lunch break, 2 playground breaks)
- No ventilation
- No masks
- *Close-proximity interactions*: infected student is 1) listening and 2) speaking.



Courtesy of WHO – ARIA WG





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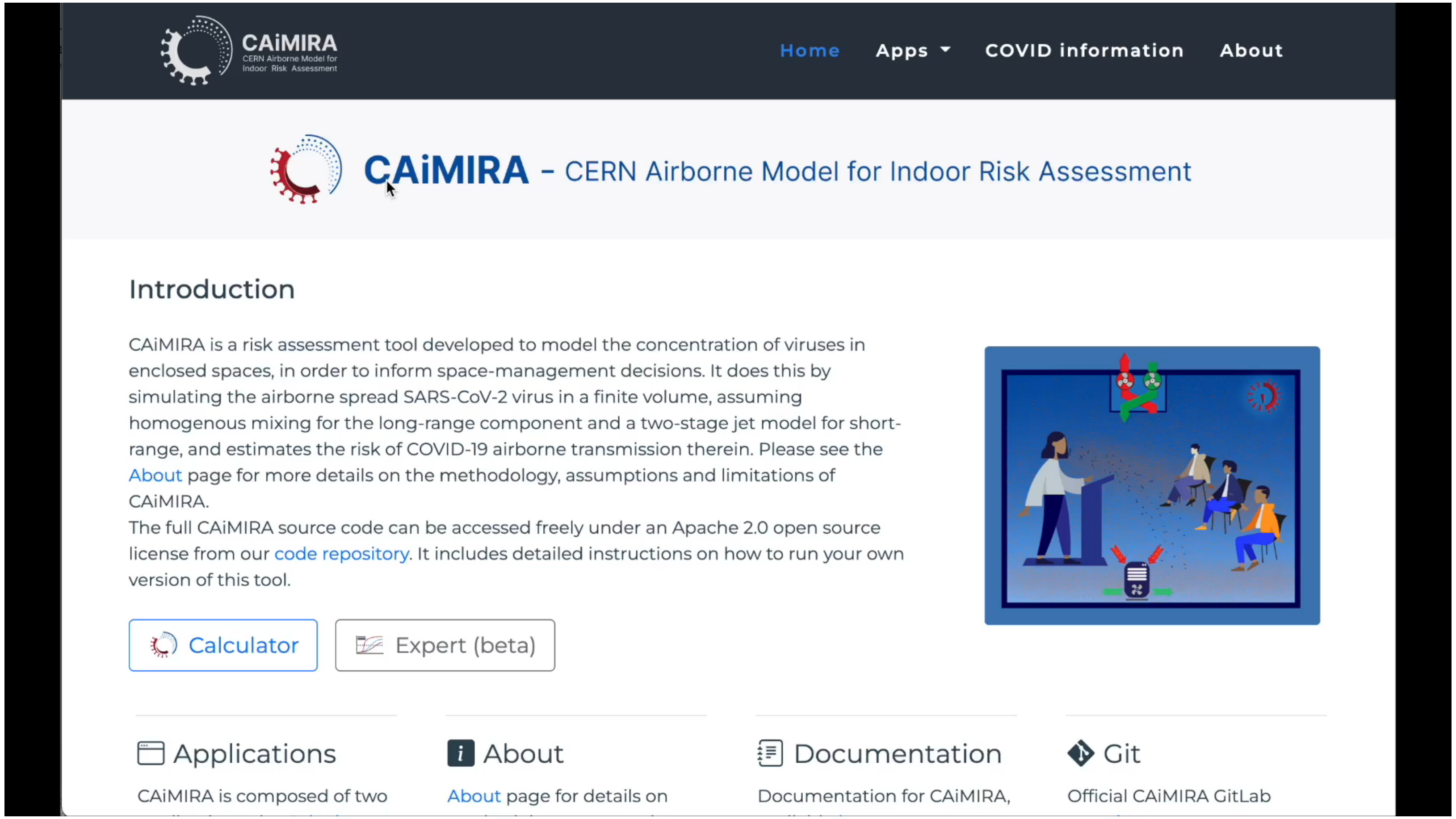
Demo



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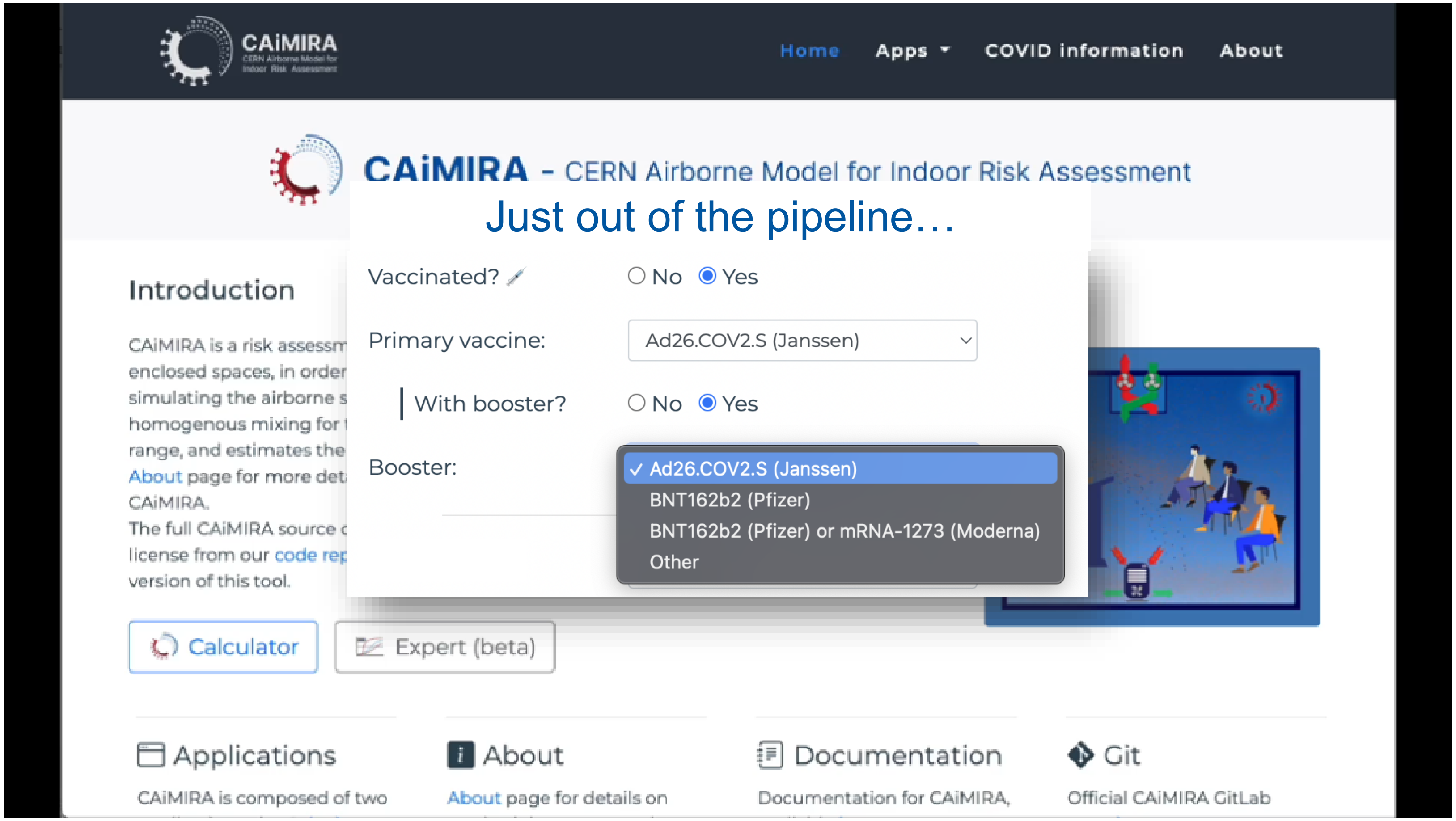


Partnership with WHO - ARIA

Courtesy of WHO – ARIA WG

18 world-renowned external experts

Luca Fontana, Alice Simniceanu, WHO

CAiMIRA
CERN Airborne Model for Indoor Risk Assessment

Partnership with WHO - ARIA

Several tools exist / presented.
Take the best out of all

1. Define a standardized model, to quantify SARS-CoV-2 airborne risk transmission (inhalation) in different indoor settings including residential, public and health care settings.

2. Provide a standardized methodology to define recommended indoor ventilation rate threshold values for different applications to drive policy and regulatory intervention related to indoor air quality and infectious diseases transmitted through the airborne route,

---

3. Guide the development of an online, user-friendly tool to enable the general public and building managers to assess SARS-CoV-2 airborne risk transmission in residential, public and health care settings to inform risk reduction measures.

ARIA Working Group

9 from the healthcare field

virology, infectious diseases, infection prevention and control, epidemiology and biostatistics, public health

World Health Organization

CERN

9 from the engineering field

engineering, physics, modeling, architecture, aerosol science, indoor air quality

Luca Fontana, Alice Simniceanu, WHO

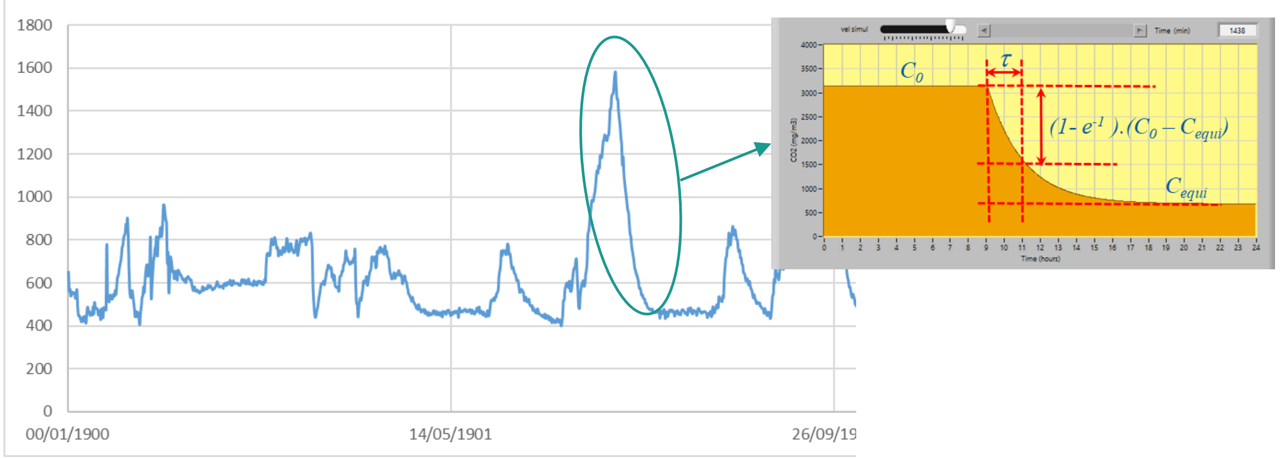
Use of IAQ monitors

Aranet©

Purchased several $C0_2$ sensors at CERN

CO_2 sensors:

- Use exhaled CO_2 as **surrogate** to exhaled viruses.
- CO_2 concentrations provides an **indirect** notion of the risk
- High CO_2 concentrations or slow decay = insufficient air exchange
- Most effective in areas where the ventilation conditions are unknown / difficult to monitor (e.g. natural ventilation)



$$\underbrace{\frac{\overbrace{C(t)-C_{equi}}^{Y}}{\underbrace{C_0-C_{equi}}_{k}}}= e^{-\lambda t} = e^{\frac{-t}{\tau}}$$

Exp fit of the data points and get **λ**

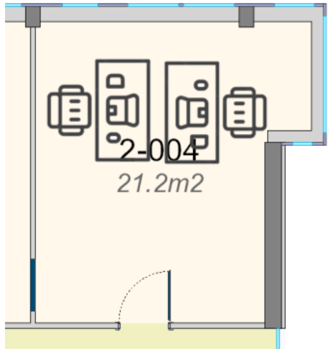
Air exchange rate ACH

$$Y = k \cdot e^{-\lambda t}$$

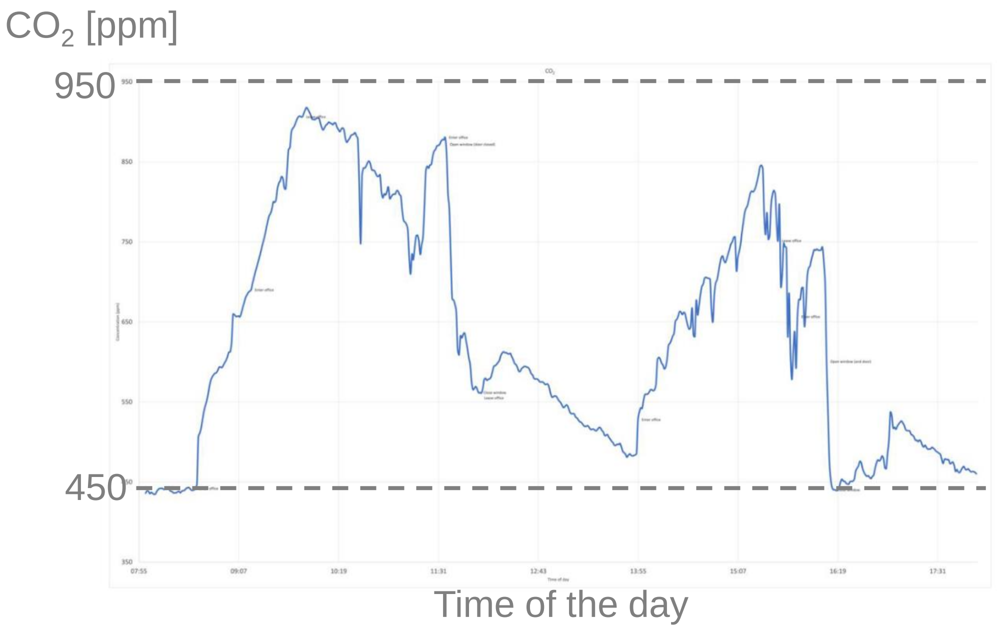
M. Gameiro, Implementing New and Classical CO2 Tracer Gas Methods for the Assessment of Ventilation Indicators in Residential Buildings, 2018 ASHRAE Winter Conference, Chicago IL

Use of IAQ monitors

<u>Experiments</u> (*of course*)



ID	Event	Hour	Number of people	Total number of occupants
1	Enter office	08:35	1	1
2	Enter office	09:15	1	2
3	Leave office	09:52	1	1
4	Enter office	11:35	1	2
5	Open window (door closed)	11:36	N/A	N/A
6	Close window	12:00	N/A	N/A
7	Leave office	12:01	2	0
8	Enter office	13:54	1	1
9	Leave office	15:35	1	0
10	Enter office	15:49	1	1
11	Open window (and door)	16:10	N/A	N/A
12	Close window	16:15	N/A	N/A



People leaving (door closed)
People entering (door closed)
Open window (door closed)
Open window (door open)

Using **exponential regression**:

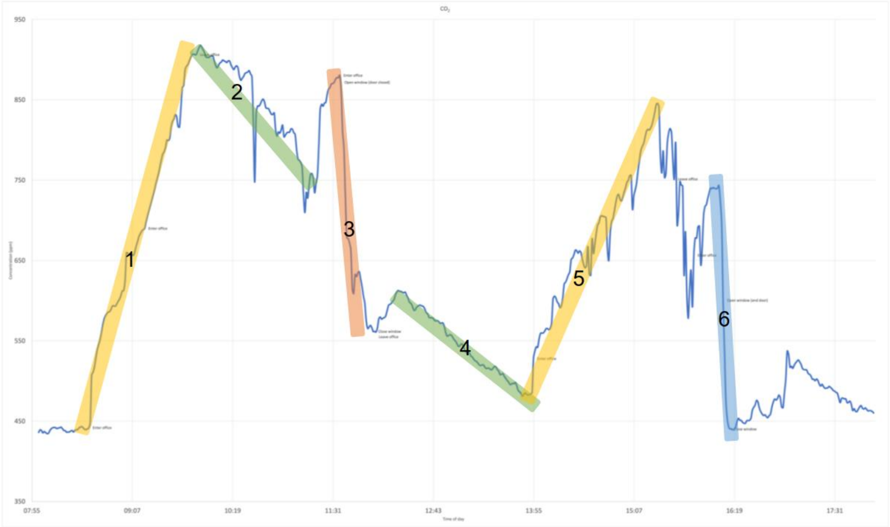
λ [ACH]

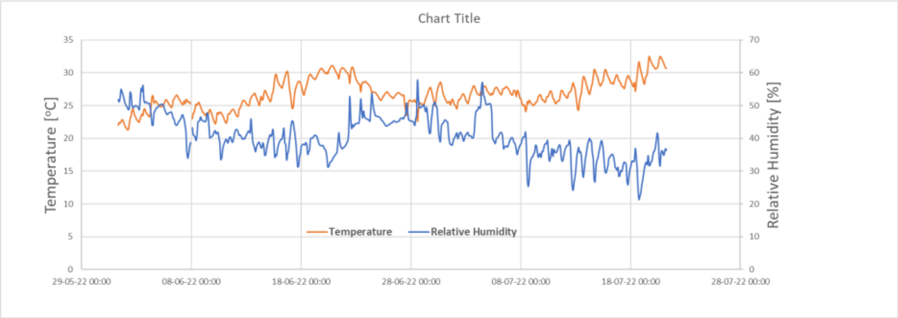
Area	Equation	R^2	Exponential term
1	$y = 7.9762e^{11.578x}$	0.9818	11.578
2	$y = 4088.8e^{-3.577x}$	0.8577	−3.577
3	$y = 8E{+}07e^{-23.71x}$	0.8422	−23.71
4	$y = 4225.6e^{-3.765x}$	0.9855	−3.765
5	$y = 10.812e^{6.7643x}$	0.9551	6.7643
6	$y = 9E{+}31e^{-99.65x}$	0.9326	−99.65

Factor 6 to 22,
compared to reducing emissions

Courtesy of L. Aleixo

Real-time risk indictor





*Data analysis (**λ**)*

Real-time risk indictor

(illustration only)

*Update the **ACH** parameter (windows open or closed) in the model*

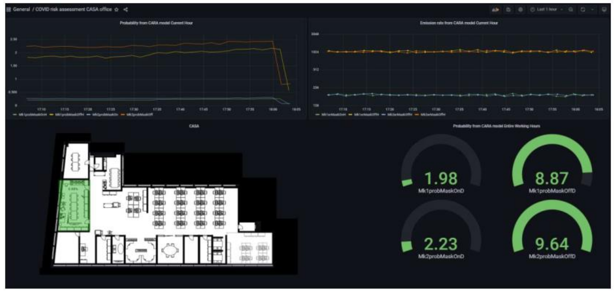
*Update the **emissions** parameter (people leaving or entering) in the model*

Real-time risk indictor

Dissertation for MSc in Connected Environments at the Centre for Advanced Spatial Analysis, Bartlett Faculty of the Built Environment, UCL.

Extending COVID Risk Assessment Models with Ambient Sensors

by Wing Hong OR
Supervisor: Dr. Martin de Jode



OR, Wing Hong. (2022). Extending COVID Risk Assessment Models with Ambient Sensors [Zenodo]. *https://doi.org/10.5281/zenodo.7344404*

CAiMIRA
CERN Airborne Model for Indoor Risk Assessment

Dissemination

Visit http://kt.cern/medtech
Contact us at KT.MedicalApplications@cern.ch

Alessandro Raimondo – KT officer

technology

open source initiative®

CAiMIRA git repository

COLLABORATION

Citations

CAiMIRA tool:
https://doi.org/10.5281/zenodo.6520431

DOI 10.5281/zenodo.6520431

Publication:
https://doi.org/10.1098/rsfs.2021.0076

CAiMIRA
CERN Airborne Model for Indoor Risk Assessment

Dissemination

TAPAS
Tackling air pollution at school

1. Set-up a webserver (e.g. in on of your institutes)
2. Deploy the web app -> README
3. Share the link to the network

…computation might get heavy. Slightly more resources needed on the server-side, compared to typical web apps.

CAiMIRA-dev@cern.ch

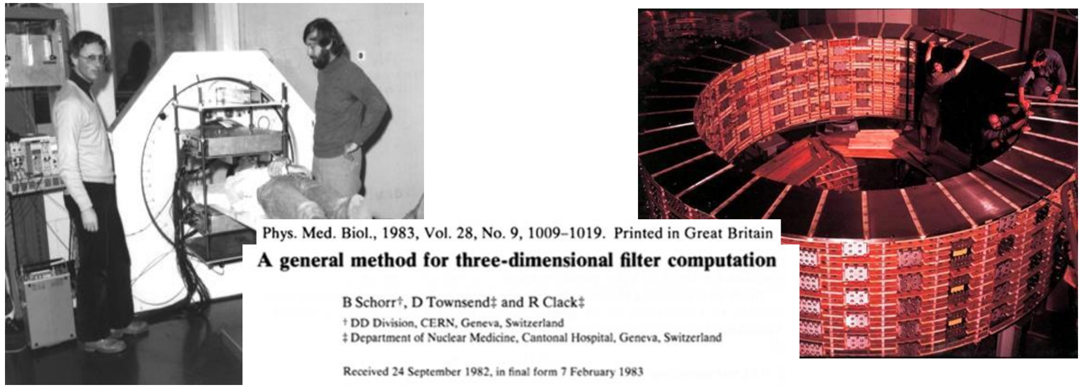
James Devine
Model developer
Engineer
CERN

https://caimira.devinemarsa.com/

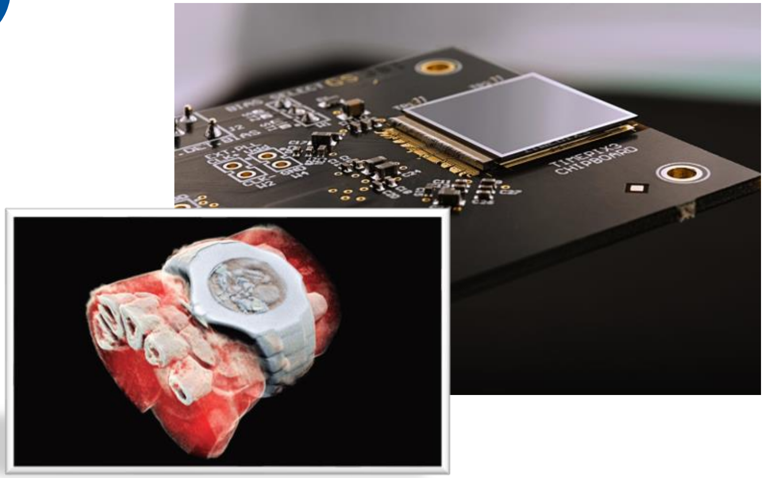
linode

Fundamental Research To Society

Knowledge Transfer (examples)



R&D and detectors for medical diagnostics (PET-CT, MRI)



Medipix – color x-ray
(MARS Bioimaging)

Agent-based modelling

Proton / Hadron therapy

Computing Grid – image processing for
humanitarian missions

WWW

Thank you for your attention