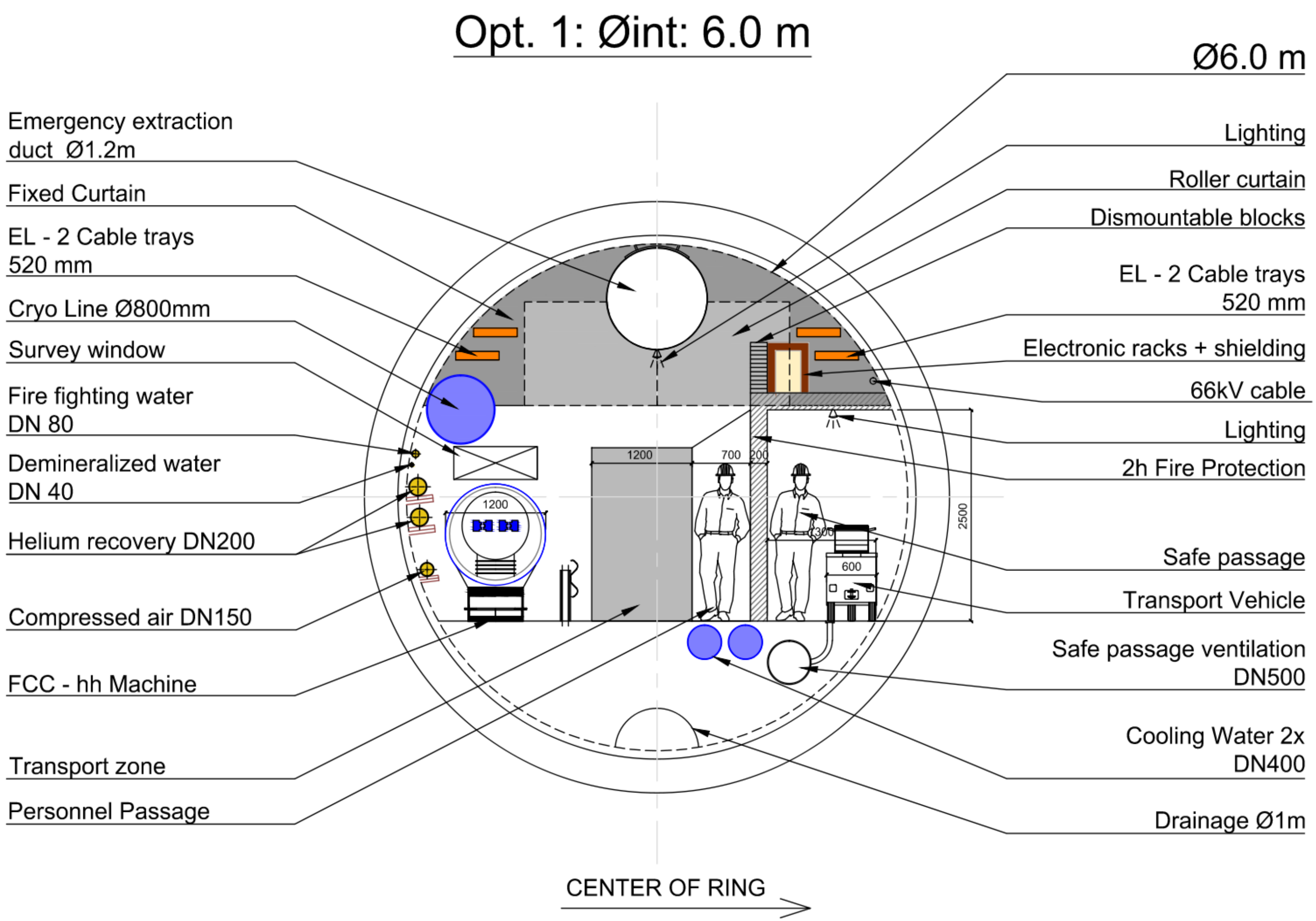
CERN

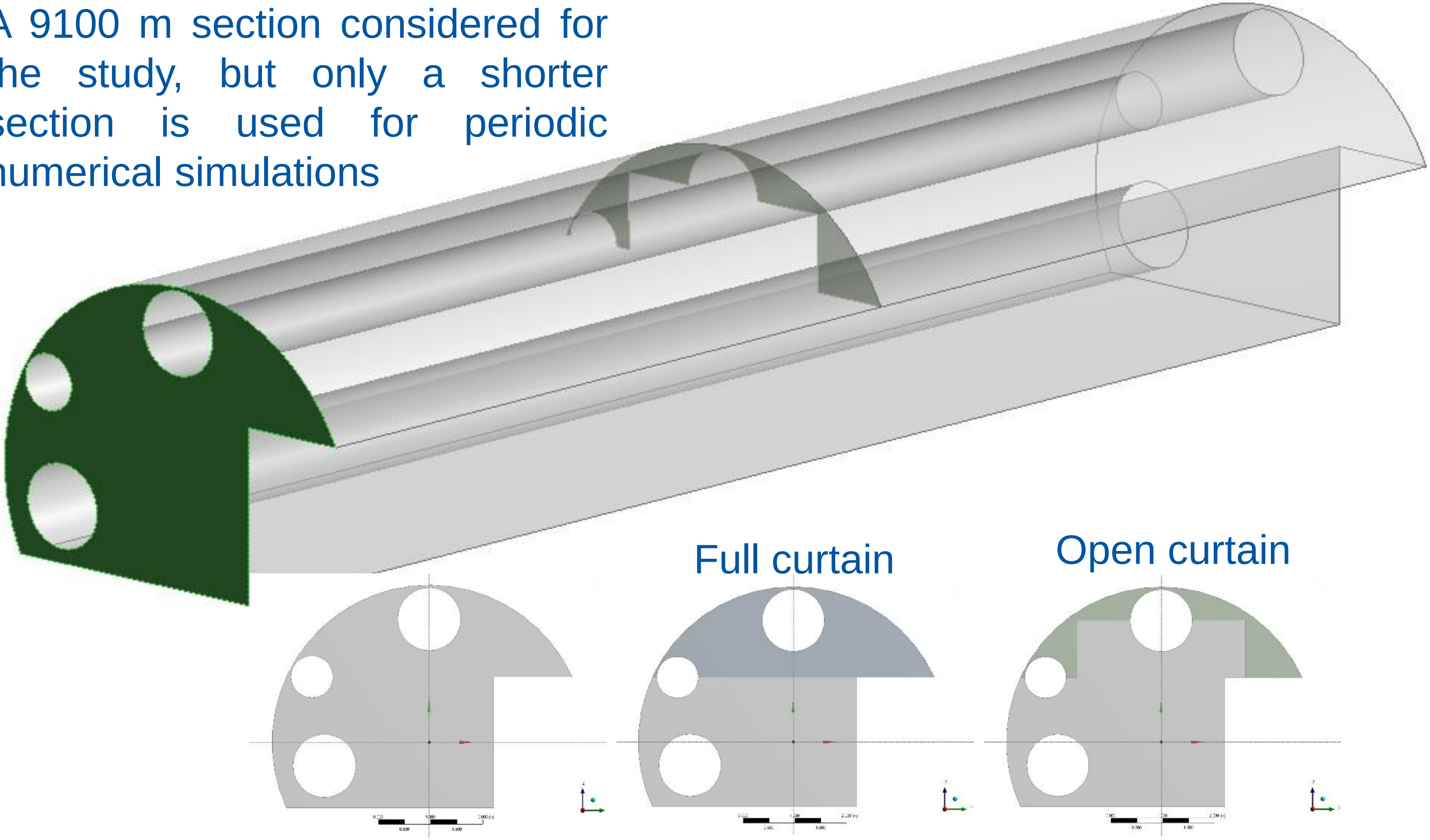
Some CFD simulations for the design of the FCC ventilation system

FCC tunnel design



FCC: machine tunnel

A 9100 m section considered for the study, but only a shorter section is used for periodic numerical simulations



FCC: machine tunnel

Fluid properties:

For the first considerations, **isothermal conditions*** assumed along the tunnel

Density (ρ)	1.225	kg/m^3
Kinematic viscosity (ν)	1.79*10^{-5}	m^2/s

Tunnel properties:

Tunnel cross section	14.44 m^2	Wetted perimeter	26.74 m
Flow area at open curtain	11.98 m^2	Hydraulic diameter	2.16
Flow area at closed curtain	8.96 m^2		
Tunnel length	9100 m	Tunnel roughness	Hydraulically smooth

Flow properties:

ACH ~0.5	Volume flow rate	82333 m^3/h
ACH ~1	Volume flow rate	164666 m^3/h

* Geothermal gradient 2.54˚C/100m and tunnel footprint raises a question about it. Max height difference 260m, max temperature difference 6.6˚C, max density difference 0.027 kg/m^3, which may cause a few Pa difference.

Analytical considerations

Three different handbook solution considered:

- **Idelchik (1966)** – *Handbook of Hydraulic Resistance*, Coefficients of local resistance and of friction
- **Miller (1990)** – *Internal Flow Systems*
- **Roul**, **Dash (2012)** – *Single-Phase and Two-Phase Flow Through Thin and Thick Orifices in Horizontal Pipes*

Analytical considerations

There are two types of losses in the tunnel:

- Frictional pressure loss, all along the tunnel

$$\Delta p_f = f \frac{l}{D} \frac{\rho}{2} v^2$$

- Local pressure loss, at disturbances, like the fire curtain

$$\Delta p_l = K \frac{\rho}{2} v^2$$

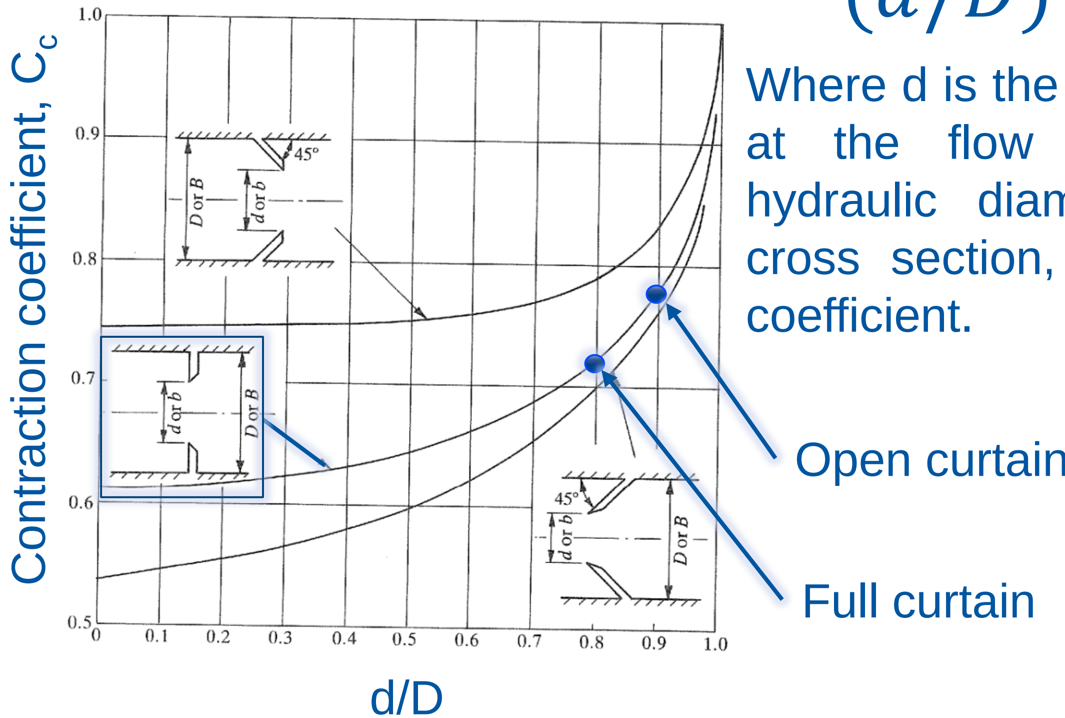
Computed differently in textbooks, based on an **orifice** geometry.

Where p is pressure, f is friction coefficient, l is length of the tunnel, D is hydraulic diameter of the tunnel, ρ is density of air, v is mean velocity in the tunnel, K is loss coefficient.

Analytical considerations

From Miller: loss coefficient for an orifice

$$K = [1 - (d/D)^2 C_c]^2 \frac{1}{(d/D)^4 C_c^2}$$



Where d is the hydraulic diameter at the flow restriction, D is hydraulic diameter for the full cross section, C_c is contraction coefficient.

Analytical results:

In normal operating conditions only the structure is blocked

- For ~0.5 ACH (Air Change per Hour):

  Frictional loss: ~100 Pa for the 9100 m section

  Local loss: 0.46*50=23 Pa for 50 curtains (every 200 m)

Δp_l [Pa/curtain]	Idelchik (1966)	Miller (1990)	Roul and Dash (2012)
Only curtain structure blocked	2.0	**0.46**	0.46
Full fire curtain blocked	2.5	2.36	2.60

- For ~1 ACH (Air Change per Hour):

  Frictional loss: ~360 Pa for the 9100 m section

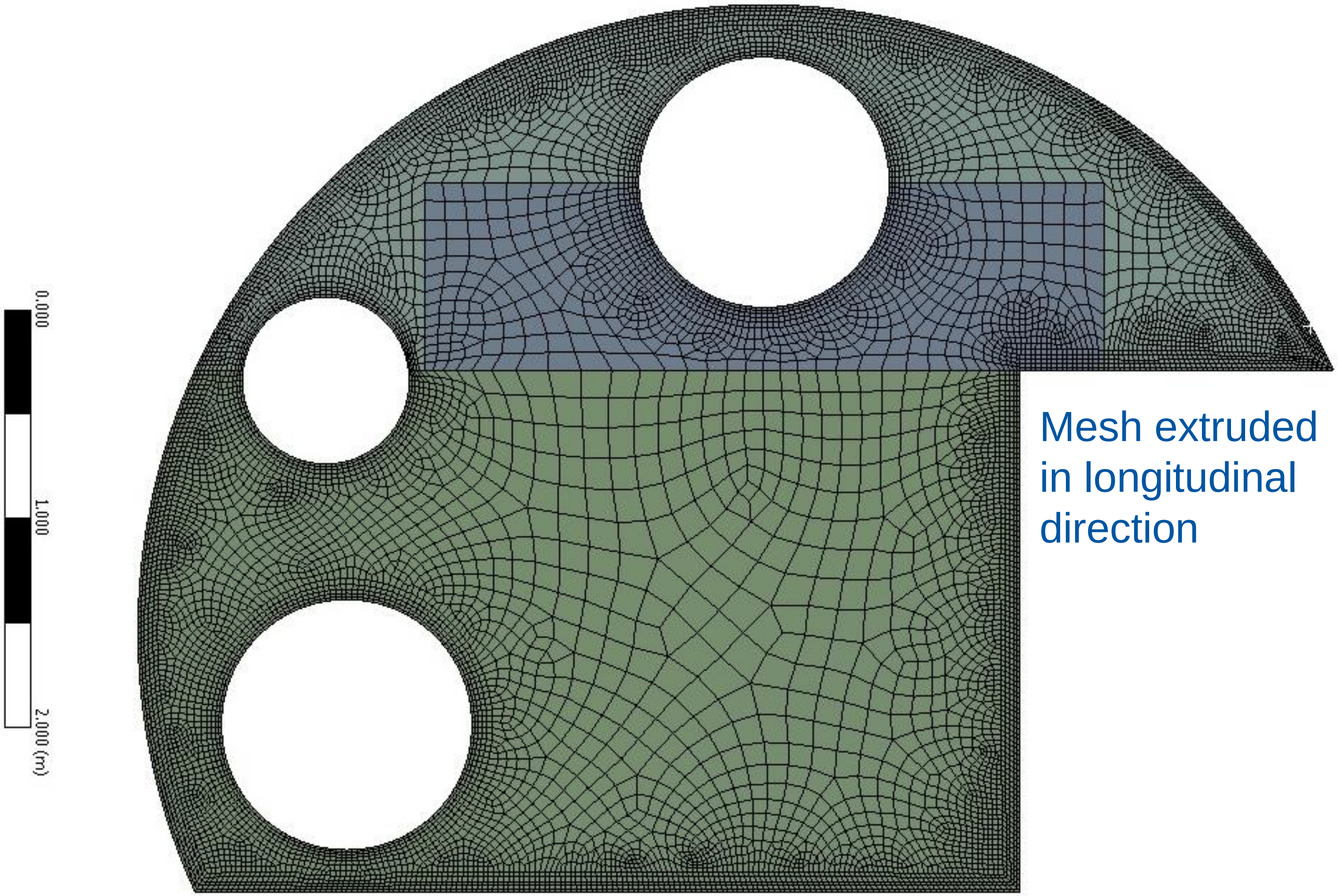
  Local loss: 2*50=100 Pa for 50 curtains (every 200 m)

Δp_l [Pa/curtain]	Idelchik (1966)	Miller (1990)	Roul and Dash (2012)
Only curtain structure blocked	7.8	**2**	2
Full fire curtain blocked	10	9.4	10.4

Numerical considerations:

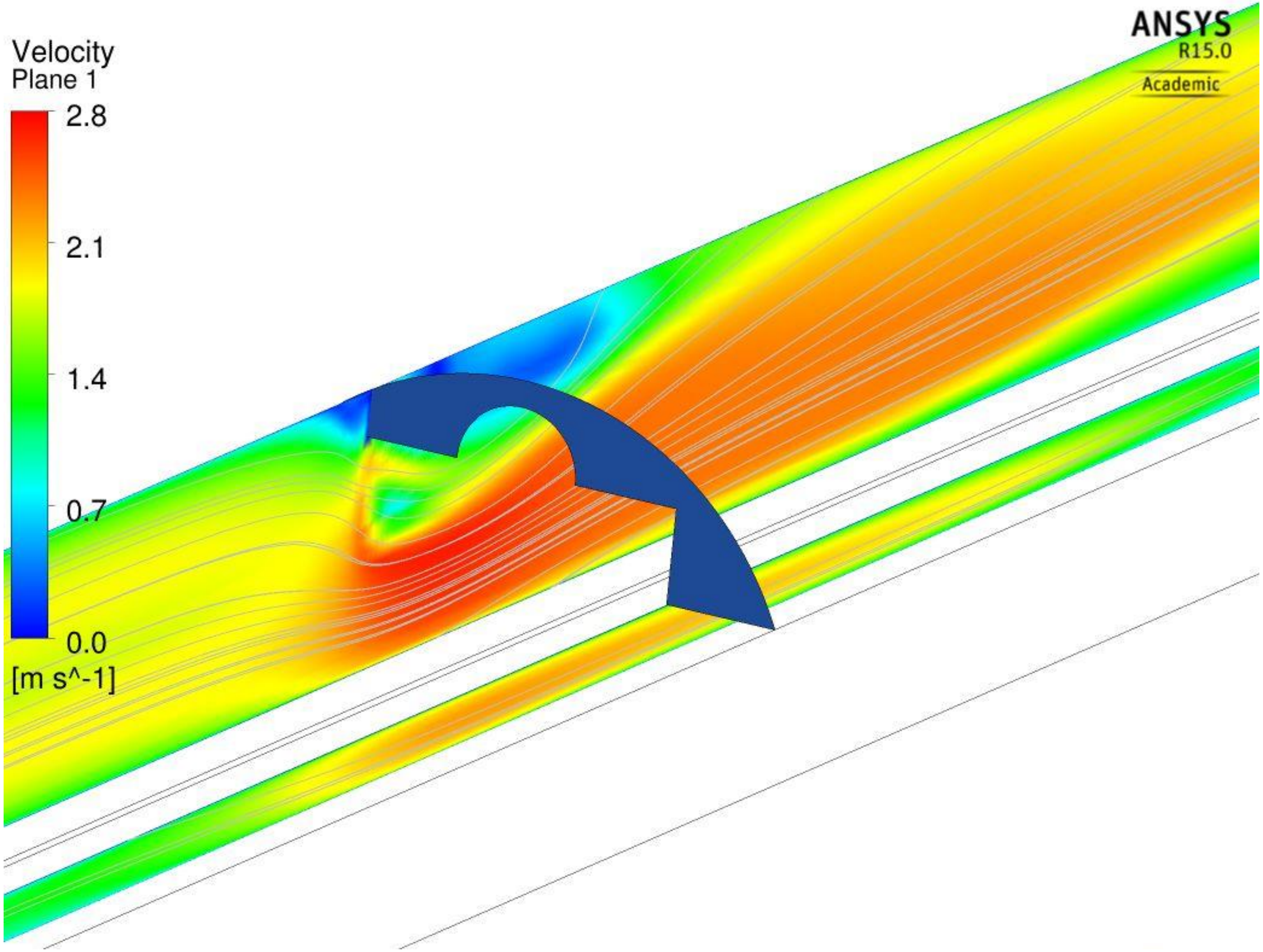
- ANSYS Fluent 15
- 3D simulations
- Periodic for frictional losses
- Mapped inlet profiles for local losses
- Only for the ~0.5 ACH, as these calculations are more time consuming

Numerical considerations:



Mesh extruded in longitudinal direction

Example of flow structure:



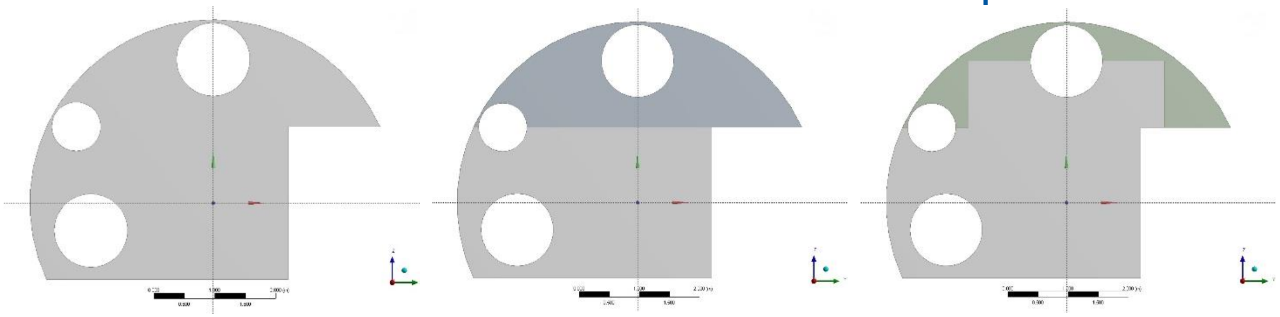
Comparison of results for 0.5 ACH:

Comparison with the Miller book (more recent, revised experiments):

	ANALYTICAL	NUMERICAL
	Miller (1990) –circular tunnel with orifice	CFD simulation – 3D simplified real tunnel
Pressure gradient in empty tunnel	0.011 Pa/m	0.0107 Pa/m
Only curtain structure	0.46 Pa/curtain	0.61 Pa/curtain
Full fire curtain	2.36 Pa/curtain	2.51 Pa/curtain
Estimation for 9100 m section, normal operating conditions, 50 open curtains (every 200 m)	**~125 Pa**	**~128 Pa**

The extra time for the numerical method for calculating the pressure drop only in the tunnel is not necessarily justified.

Full curtain Open curtain

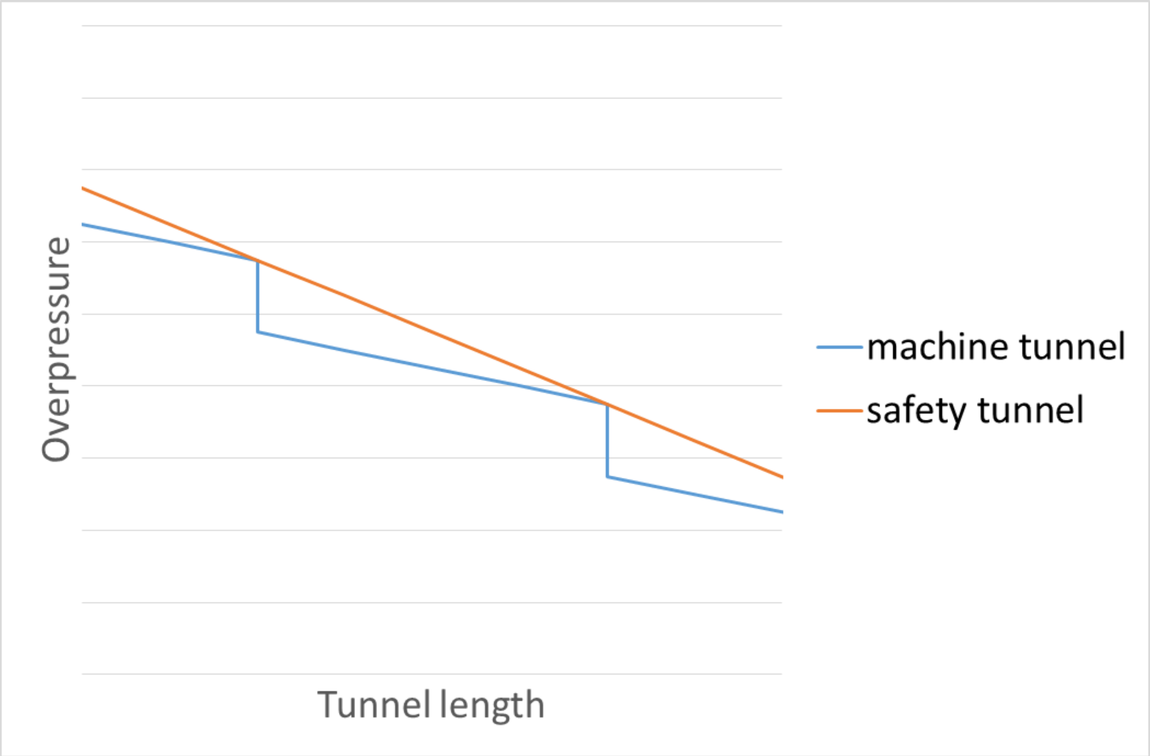


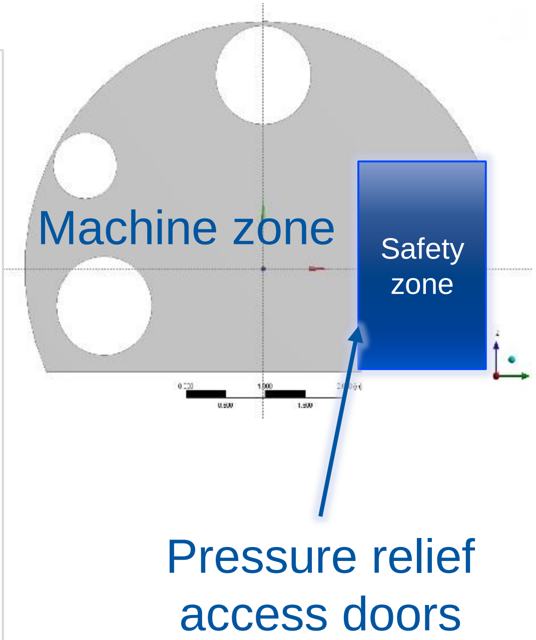
FCC: safety tunnel

- Parallel to the machine zone (see blue block), with a separate ventilation system.
- What air flow rate is needed to keep the two parallel ventilation systems with low dP between them?
- In the safety zone there is no abruption like the curtains, therefore no constant equilibrium is possible all along the tunnel.

machine tunnel		
ACH	0.5	1
pressure drop [Pa]	125	450
pressure gradient [Pa/m]	0.011	0.039
safety tunnel		
ACH	0.65	1.3
pressure drop [Pa]	128	450
pressure gradient [Pa/m]	0.014	0.049

FCC: safety tunnel





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Conclusions

- In normal operating conditions in the machine tunnel with 0.5 ACH (air change per hour) ~125 Pa pressure drop is expected in a 9100 m section accounting for both frictional and local (fire curtain structure) losses.
- Results based on analytical and numerical considerations are very similar.
- For the safety tunnel a ventilation of 0.65 ACH could result in a similar pressure drop for a 9100 m section.

Thank you for your attention!

Analytical considerations

From Idelchik: resistance coefficient for a sharp-edged orifice

$$K = \left(1 + 0.707\sqrt{1 + \frac{F_0}{F_1} - \frac{F_0}{F_2}}\right)^2$$

F_0 – area of the narrowest section

F_1 – area of the tunnel before

F_2 – area of the tunnel after

$$\Delta p_l = K\frac{\rho}{2}v^2$$

Analytical considerations

From Roual and Dash:

$$\Delta p_l = \frac{\rho}{2} v^2 \left(\frac{1}{\sigma \sigma_c} - 1 \right)^2$$

Flow area ratio: $\sigma = (d/D)^2$

Contraction coefficient by Chisholm:

$$\sigma_c = \frac{1}{0.639(1-\sigma)^{0.5} + 1}$$