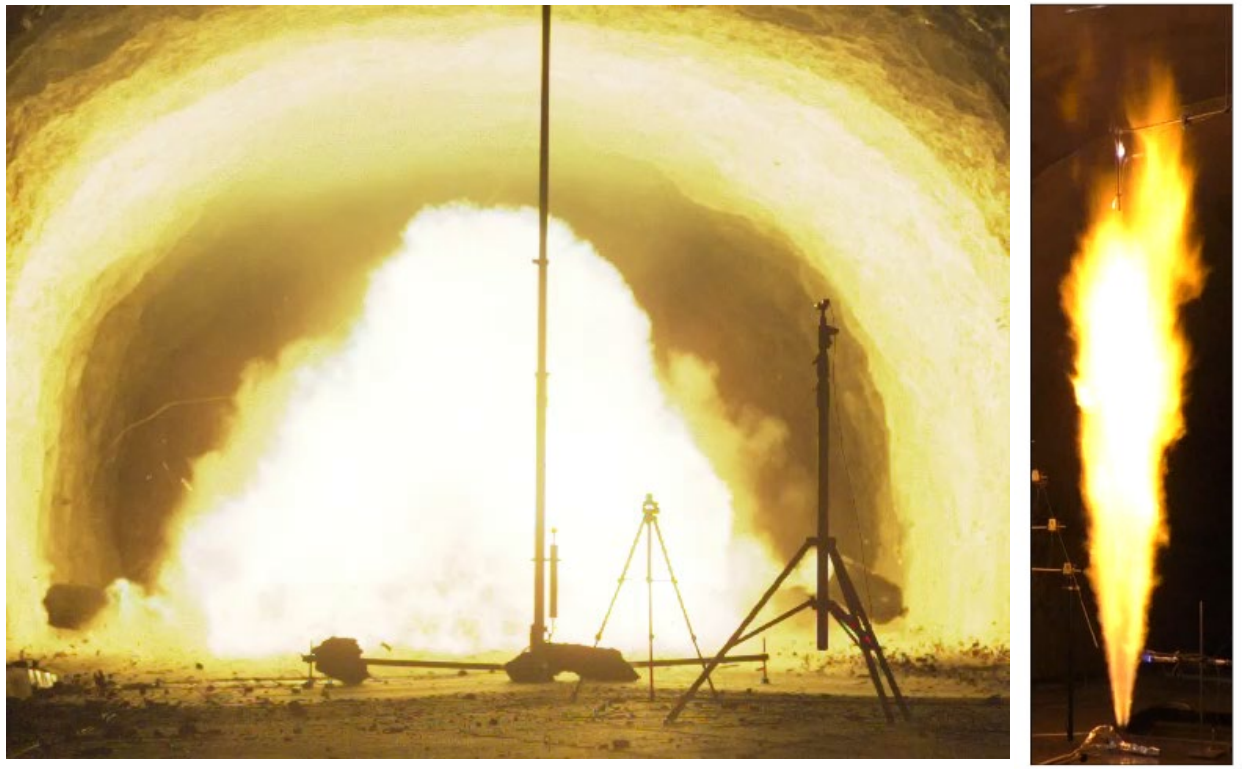
Hydrogen Dispersion in a full-scale road tunnel: Experimental results and CFD analysis



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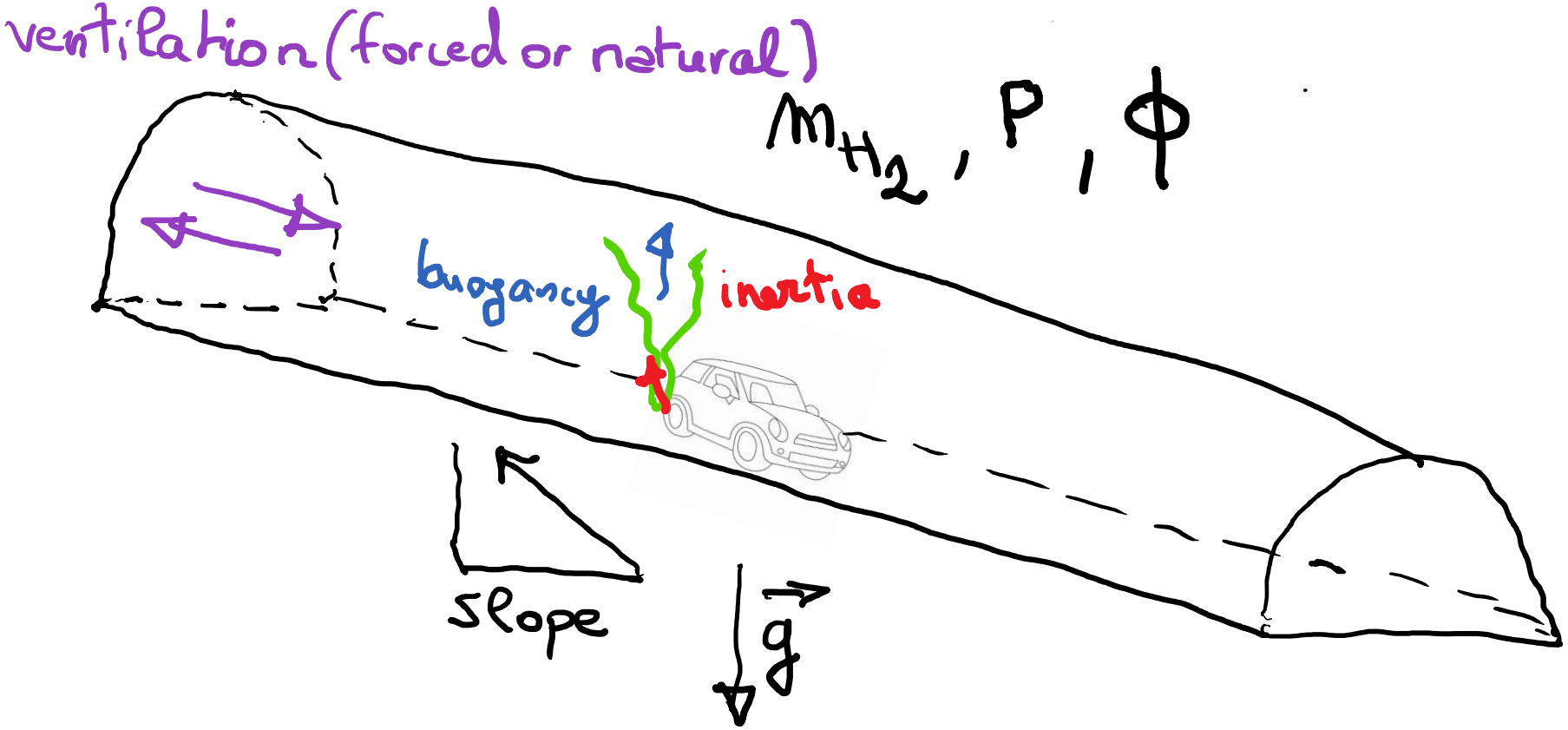
ICHS Conference, Québec City, September 19-21, 2023

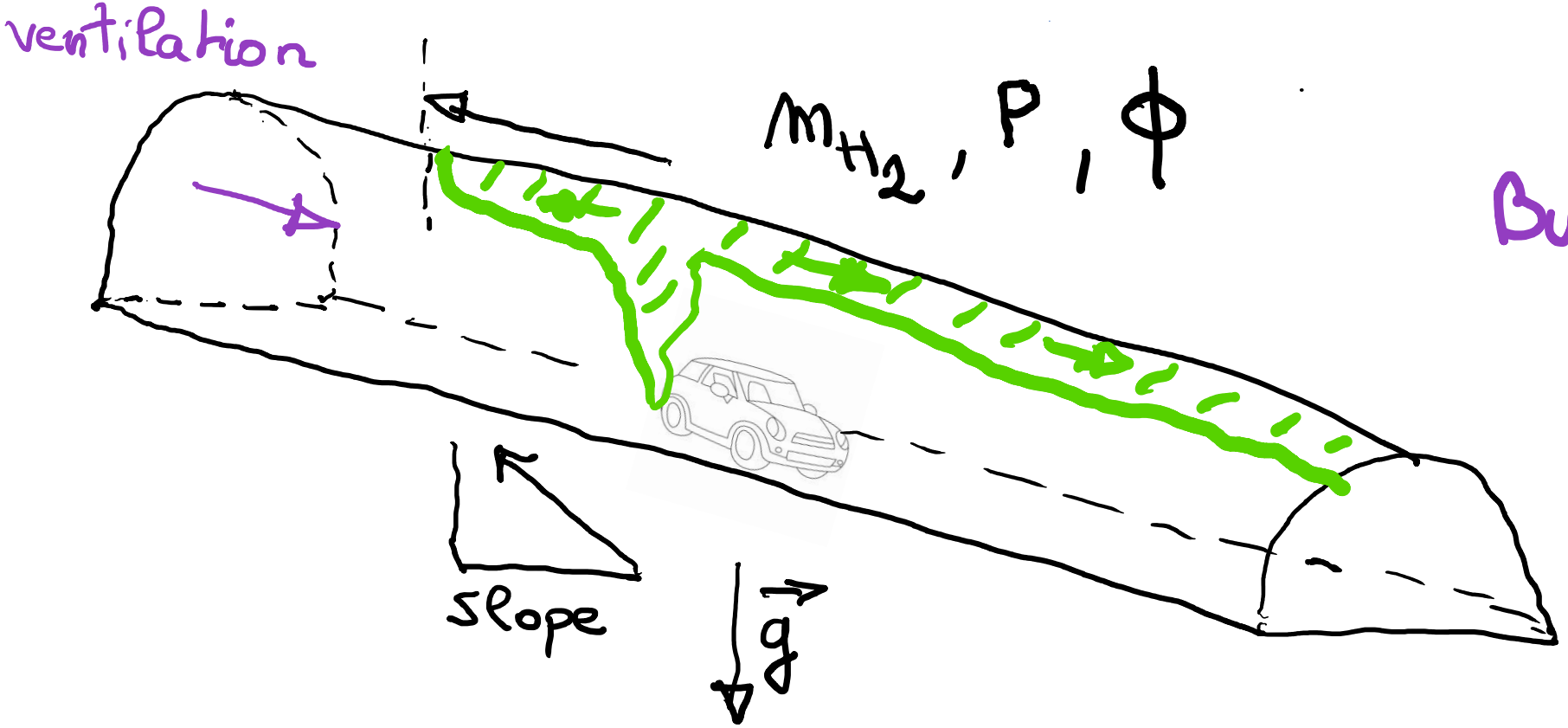
CONTEXT AND OBJECTIVES

- The Safety of Hydrogen powered Fuel-cell vehicles in confined environment
- Provide data on hydrogen dispersion issues for phenomena understanding, model verification and recommandations
- Part of HYTUNNEL-CS EU FCH-JU project (2019-2022)
- HSL had in charge experiments in reduce-scale tunnel and CEA had in charge experiments in full-scale tunnel

Hydrogen Dispersion in tunnel geometry

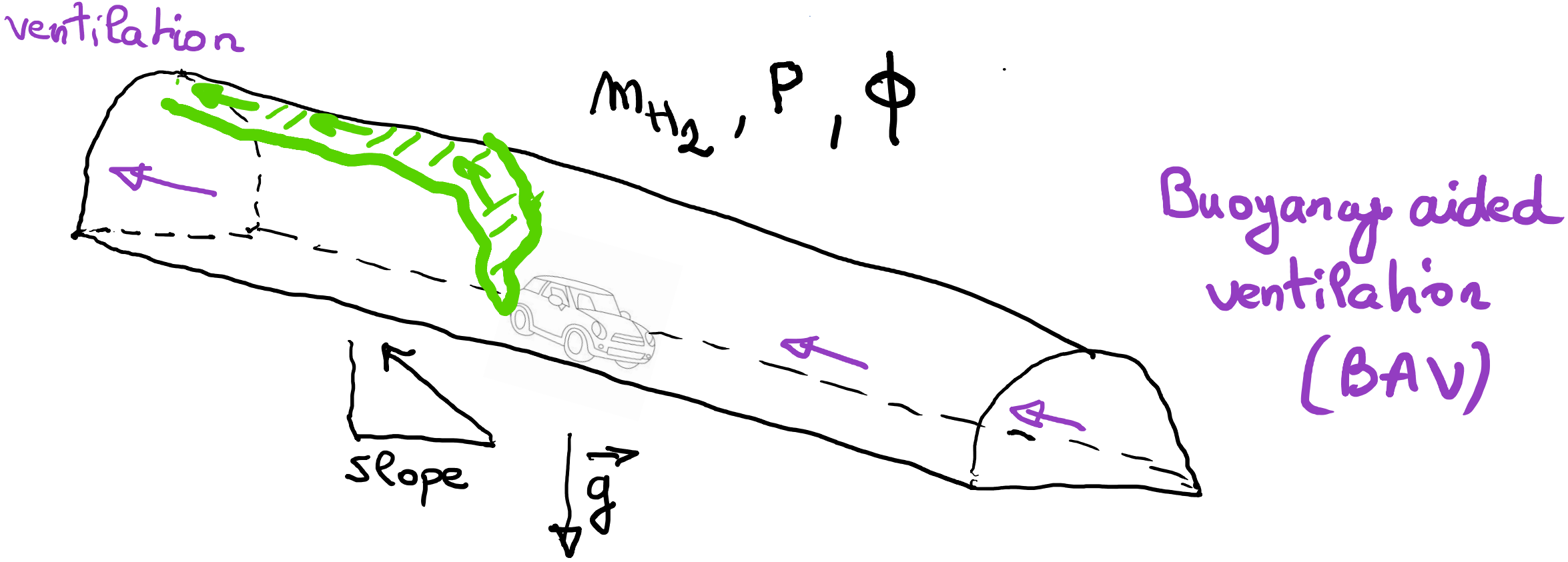


Hydrogen Dispersion in tunnel geometry



Buoyancy Opposed Ventilation (BOV)

Hydrogen Dispersion in tunnel geometry



Brief Litterature survey

Few experimental data in tunnel geometry

SRI Corral Hollow Experiment Test site

- Sato et al.: **Effect of jet inertia is dominant** for vertical upward release, fast dilution outside of the jet
- Houf et al. 3 TPRD opened simultaneously: 40% of hydrogen close to the ceiling during upward release, 100% of hydrogen under the chassis for downward release

CFD simulation data available

Ventilation and orientation of the release have not a huge influence of the size of the flammable cloud,TPRD diameter (2 to 6 mm) influences the size of the flammable cloud.

No full-scale data. Limited number of measurements suitable for CFD code validation

1. Experiments

Tunnel Selection

2 lanes horse-shoe type disused road tunnel

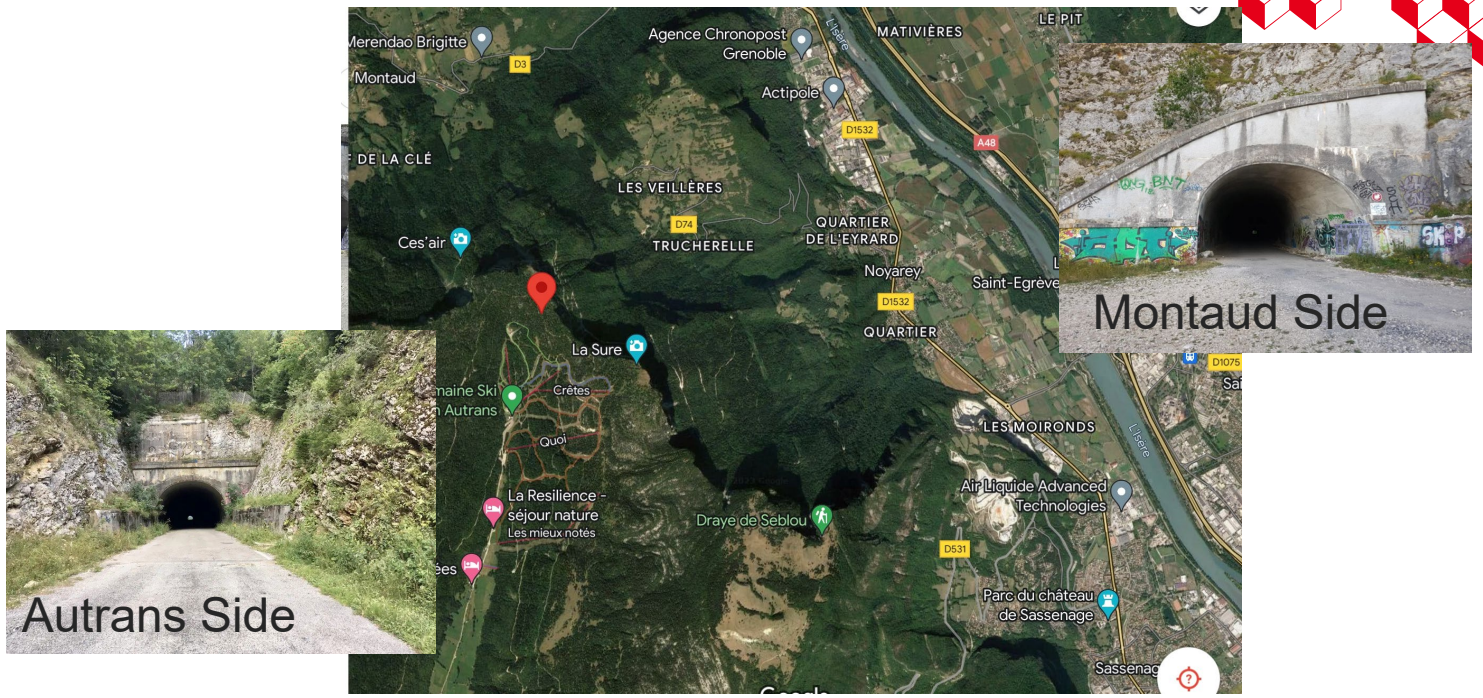
About 500 m long

3.6% slope

9 m width and 6 m height

2 different sections

- concrete vault
- rocky vault



Injection system and Instrumentation

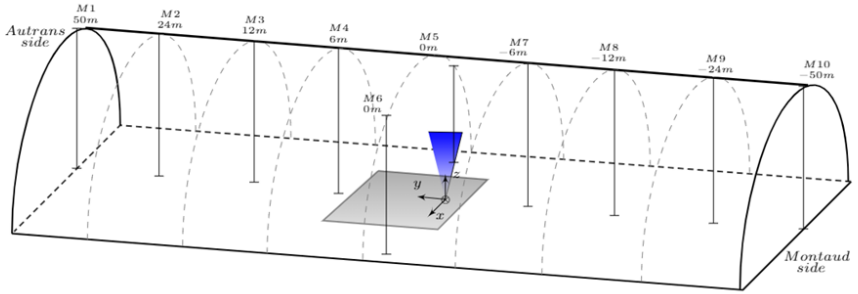
Car = only a flat plate (1.9x4.5m) located 25 cm above the road, centrally located in the tunnel

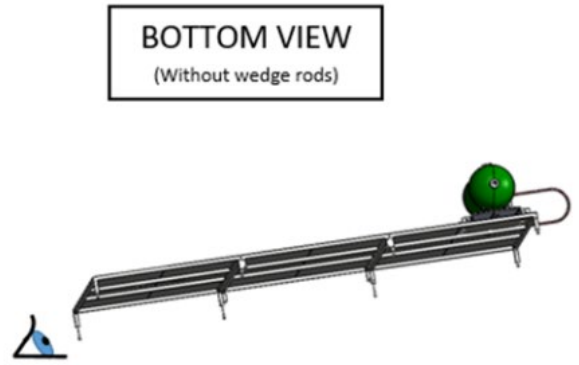
Injection: at the rear of the car, different diameters and different orientations

Tanks: Type II 50 liters bottles and Type IV 78 liters tanks both filled with helium

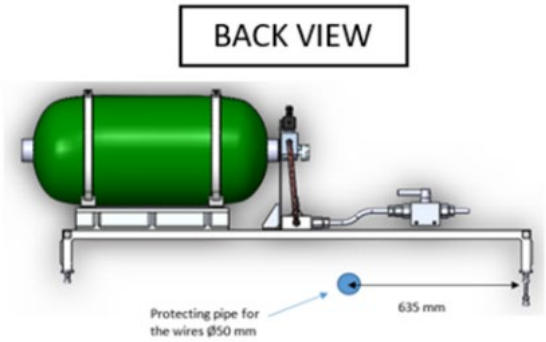
P, T in the tank and in the injection pipe

10 vertical masts in the tunnel with Thermocouples and catharometers (32+8) (+oxygen electrochemical cells)

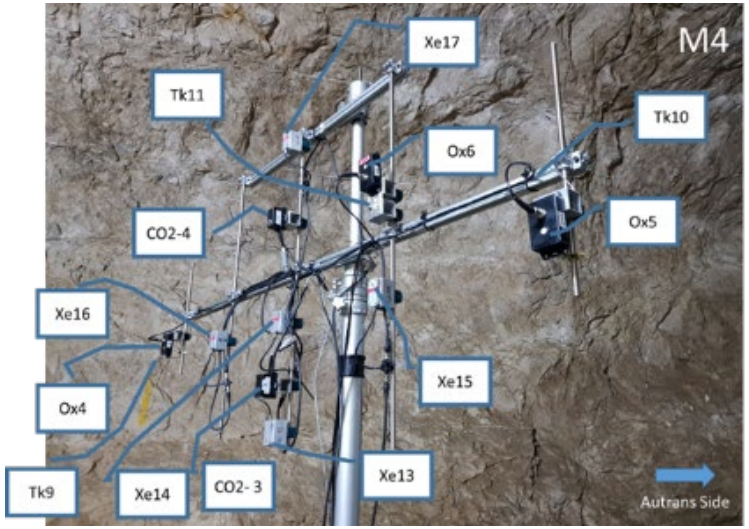




View n°13 (TPRD down 45°)



View n°14



Test Matrix

2 test campaigns:

- 2020 10 tests with 50 liters Type II tanks under 200 bar (already presented in ICHS 2021)
- 2021 3 tests with 78 liters Type IV tanks under 700 bar

1->2 P and mH2 effect

2->5 TPRD orientation

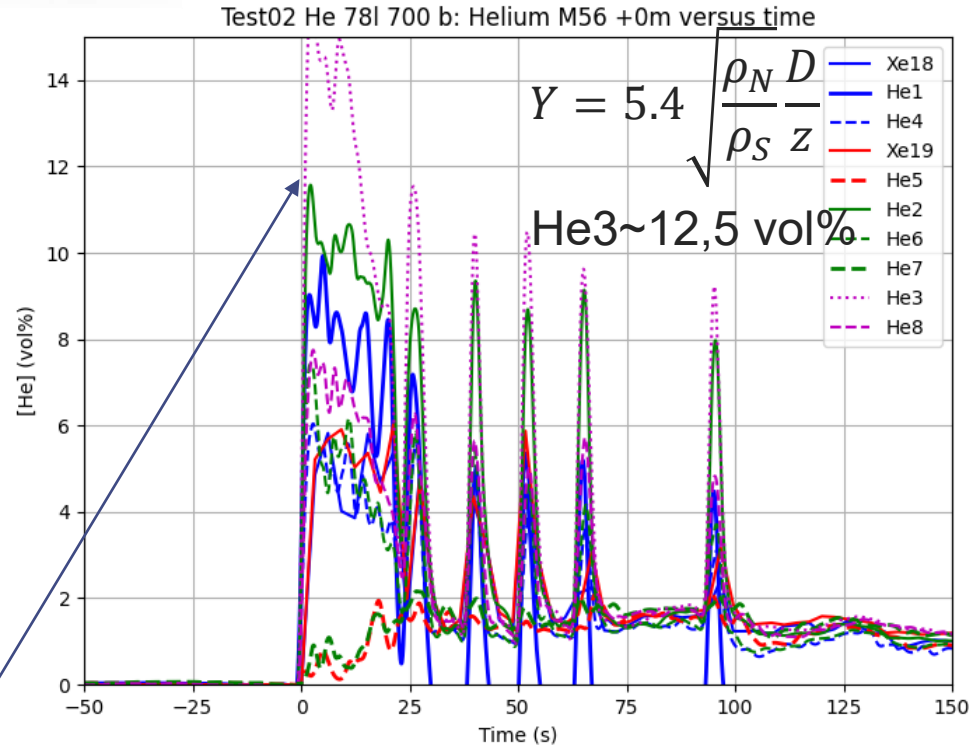
5->7 TPRD diameter

Type of test	Nb of test	Volum (liter)	Pressure (bar)	Configuration	Ø TPRD (mm)	Test number
He dispersion 2020	10	50	200	UP	2	n°3,4
				UP	0,5	n°5
				UP	3	n°6,7
				DW 90°	3	n°9
				DW 90°	2	n°11, 12
				DW 90°	1	n°13
				DW 90°	4	n°14

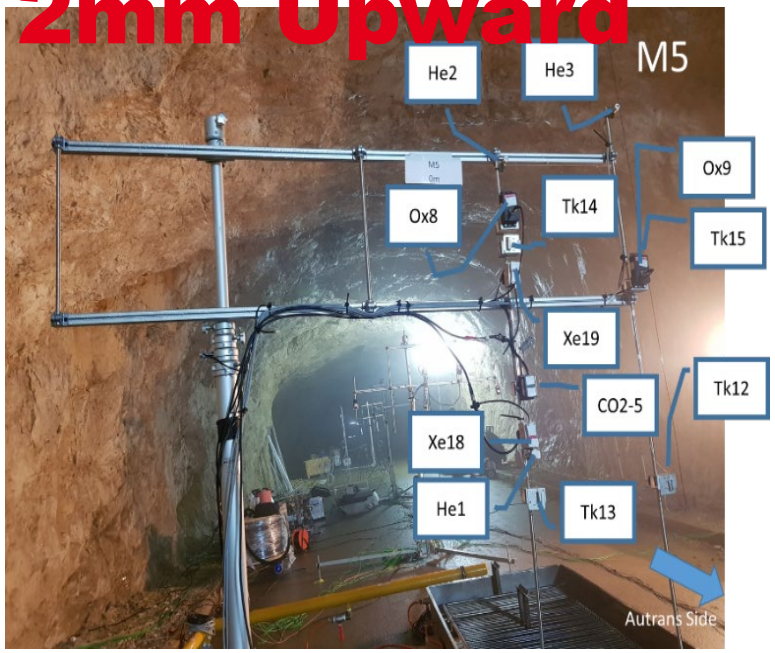
Type of test	Nb of test	Volum (liter)	Pressure (bar)	Configuration	Ø TPRD (mm)	Test number
He dispersion 2021	4	50	200	UP	2	n°1
		78	600 to 700	UP	2	n°2
				DW 45°	2	n°5
				DW 45°	1	n°7

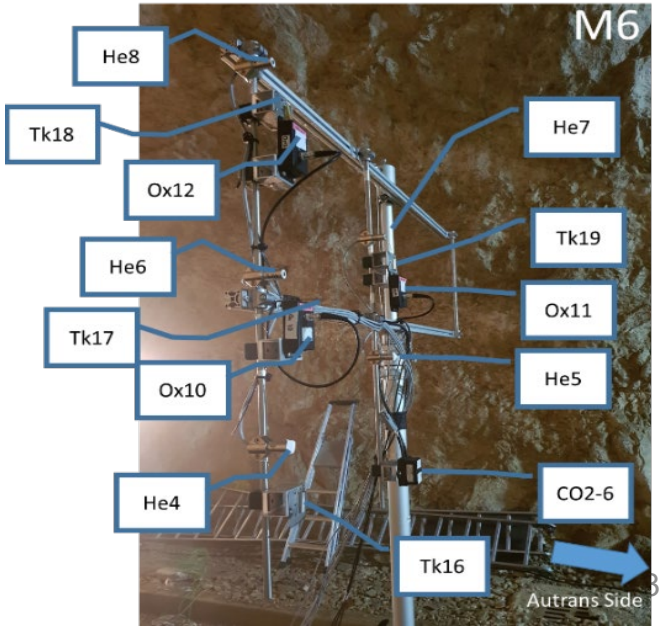
Some Results (2021 test series) 2mm Upward

Close to the injection



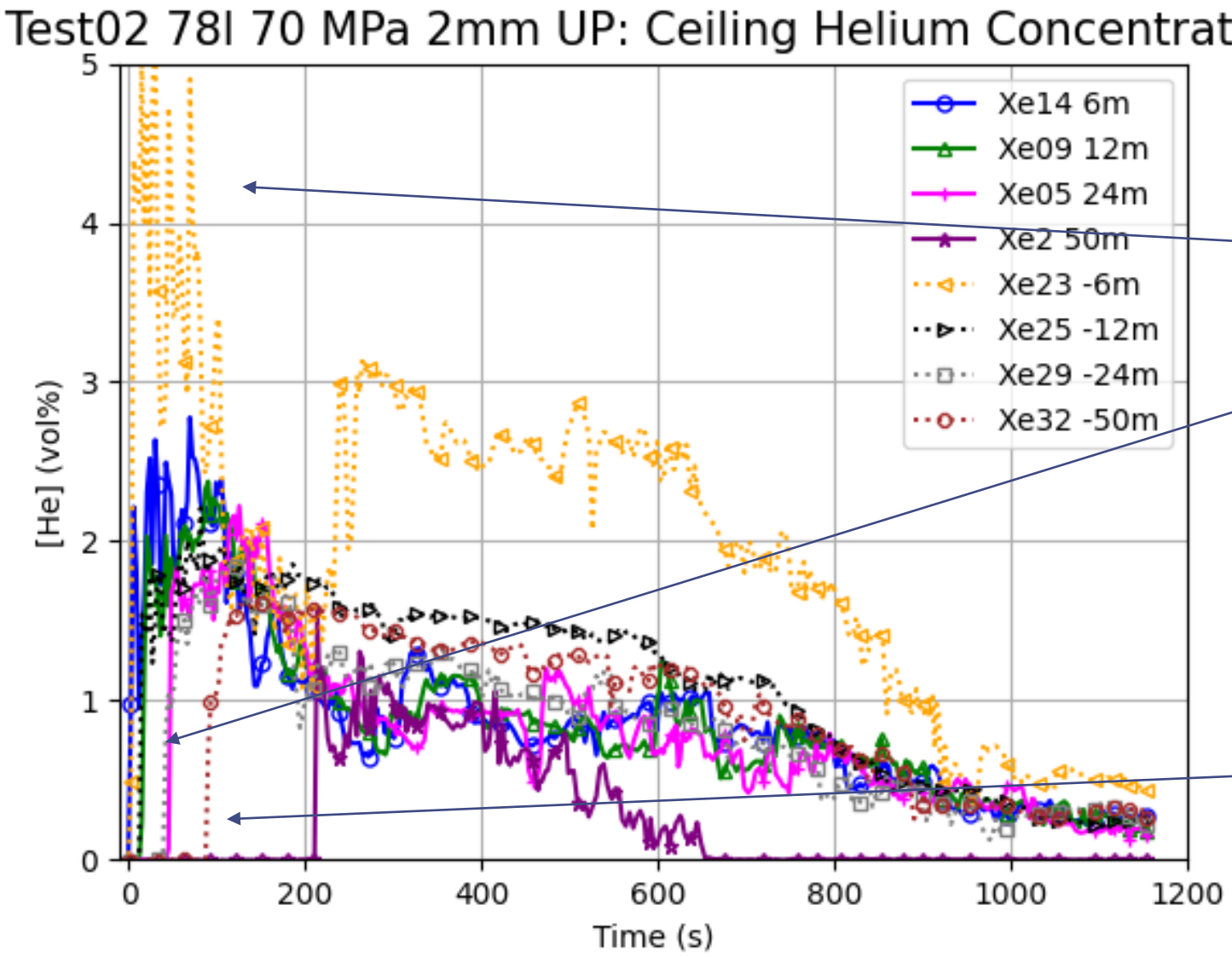
Jet slightly oriented towards M5





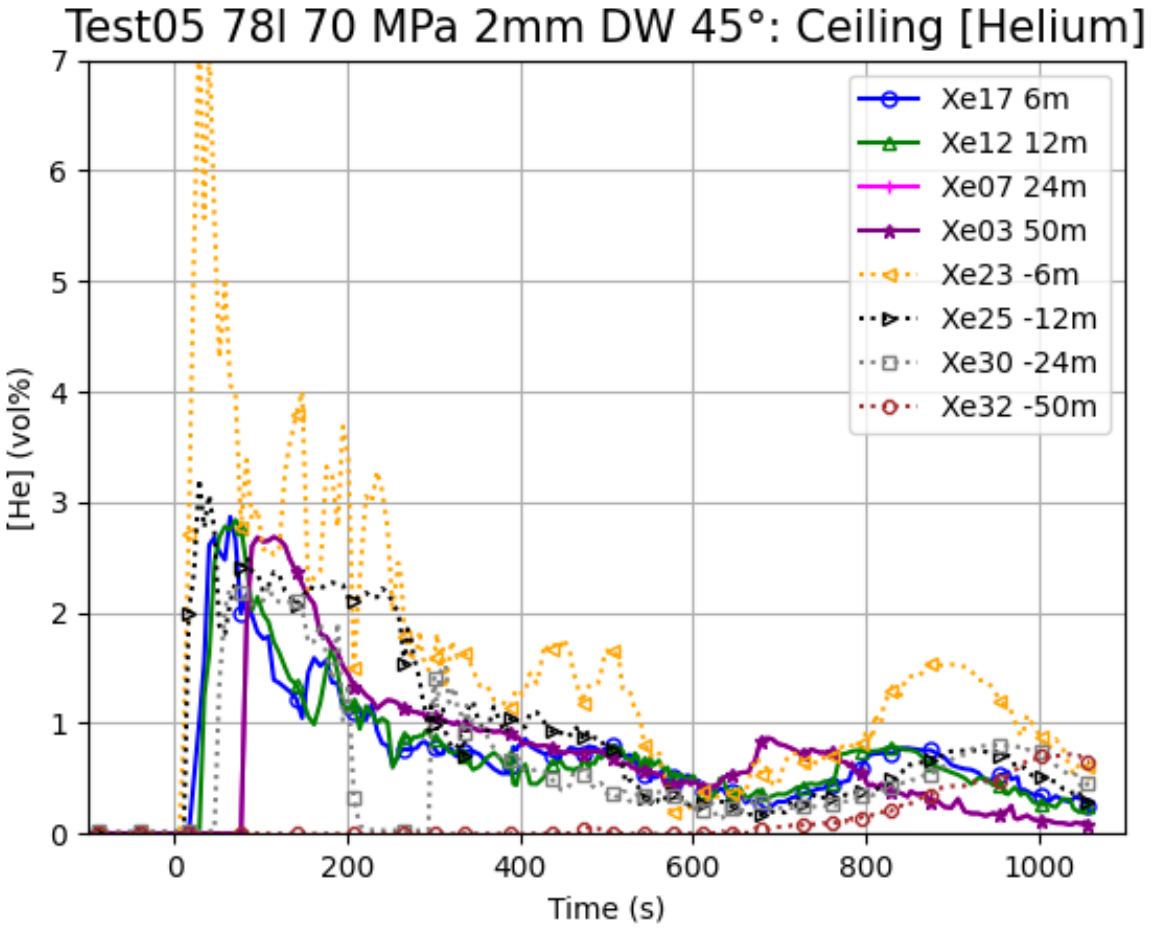
2mm Upward

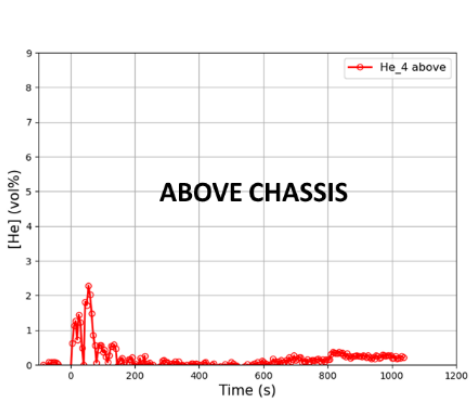
In the upper part of the tunnel

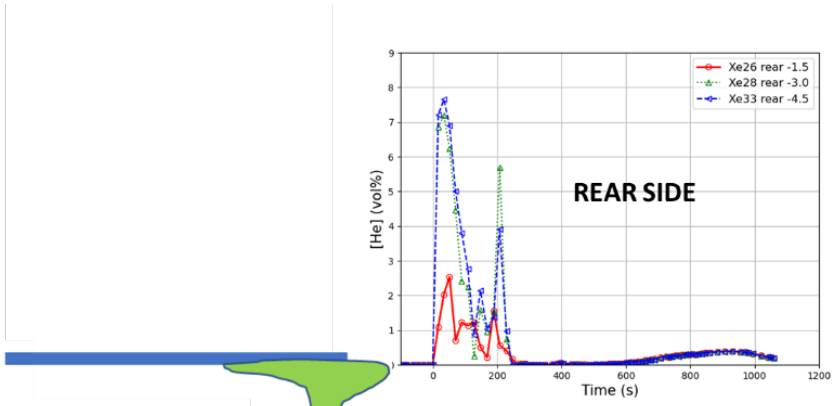


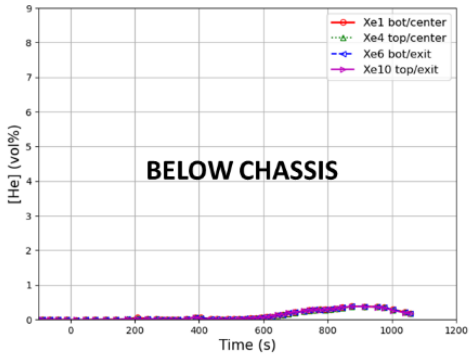
- BOV situation
- Maximum at –6
- +12/-12 and +24/-24 reacts at the same time = Importance of inertia
- -50 before +50 BOV effect

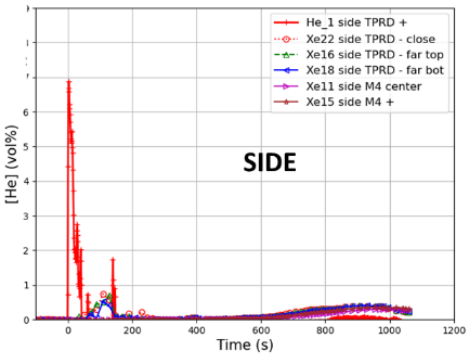
2mm Downward 45°











2. Numerical analysis

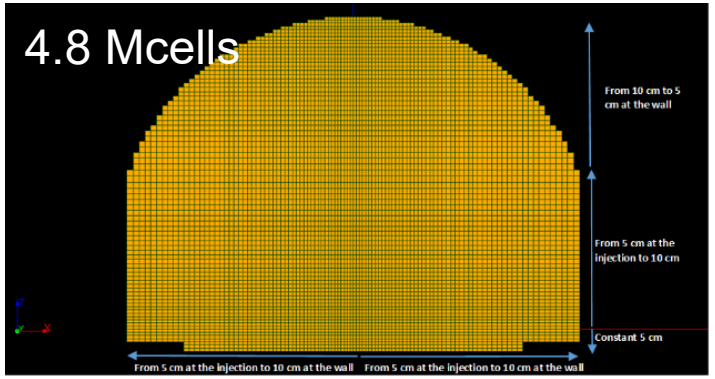
CFD computer codes and Meshes

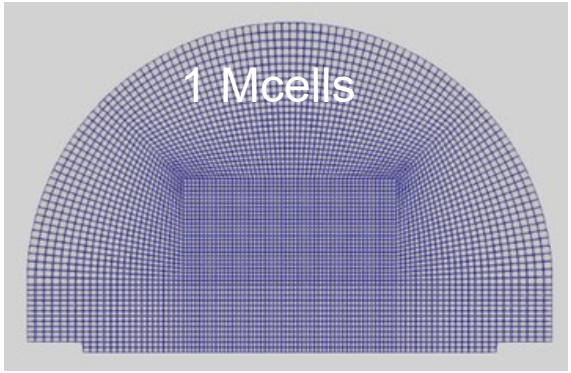
Two in-house computer codes

TRUST
LES
WALE viscosity
2nd Order t,x
CFL=1
Wall function

NEPTUNE-CFD
RANS
k–ε buoyancy
2nd order t,x
CFL=1
Wall function

Simplified Geometry

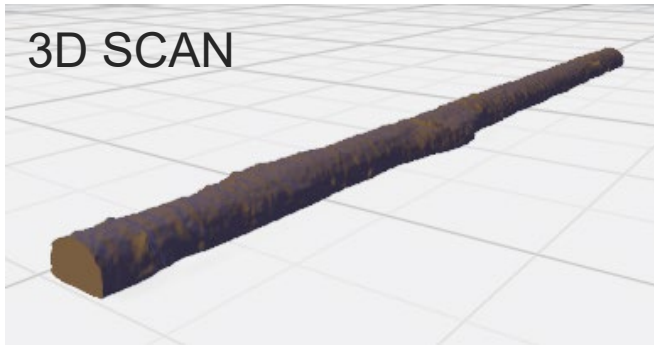


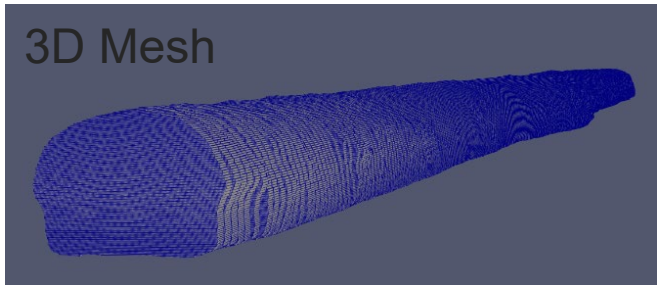


+/- 75 m

Injection B.C. ajusted to match the experimental results of Okabayashi 2019 regarding the concentration decay

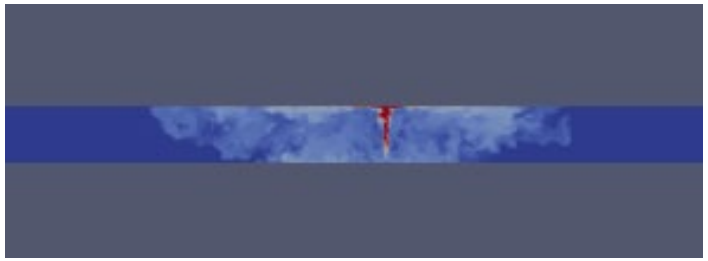
Real Geometry

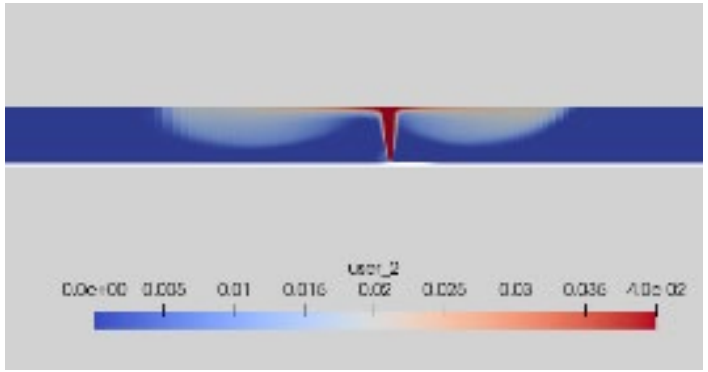


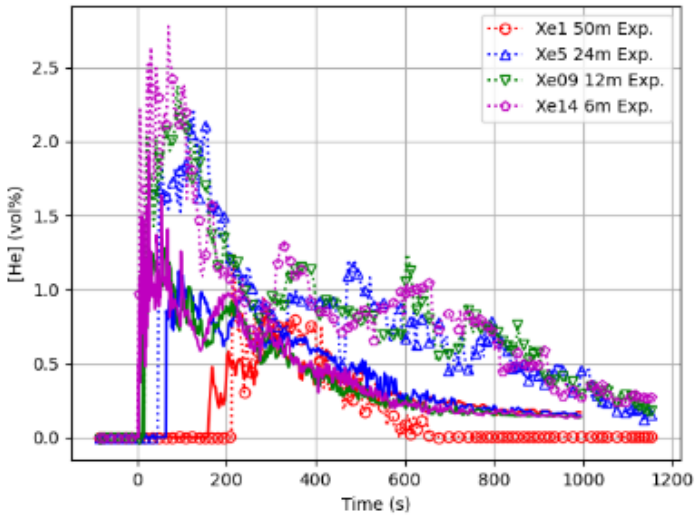


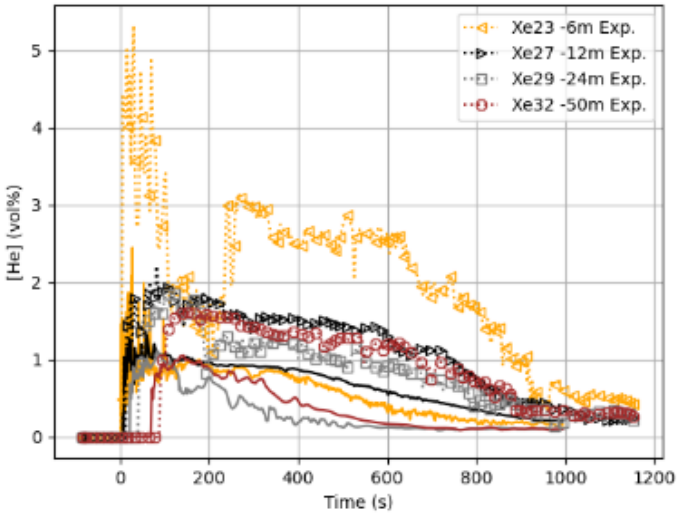
Test 02: 2mm TPRD Upward

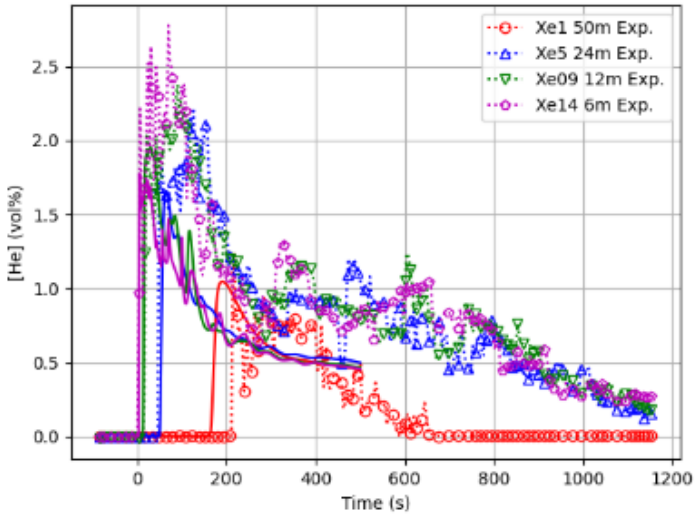
t = 21 seconds

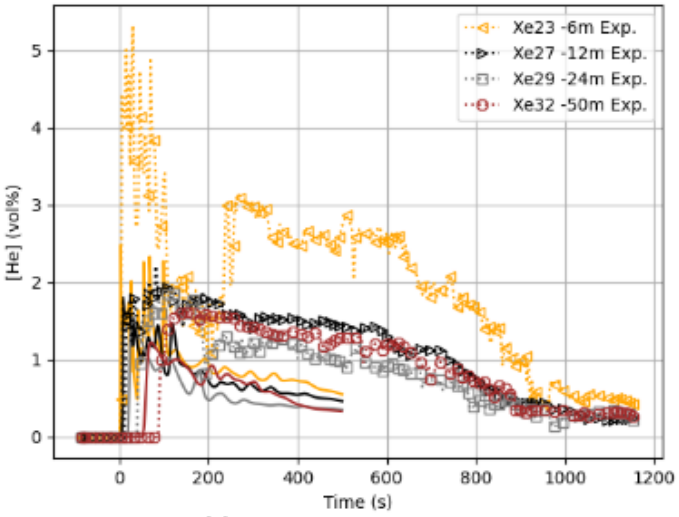








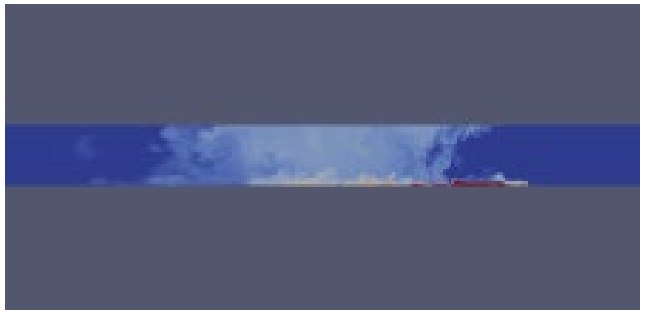


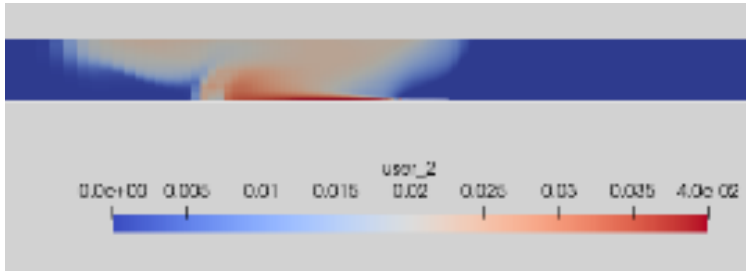


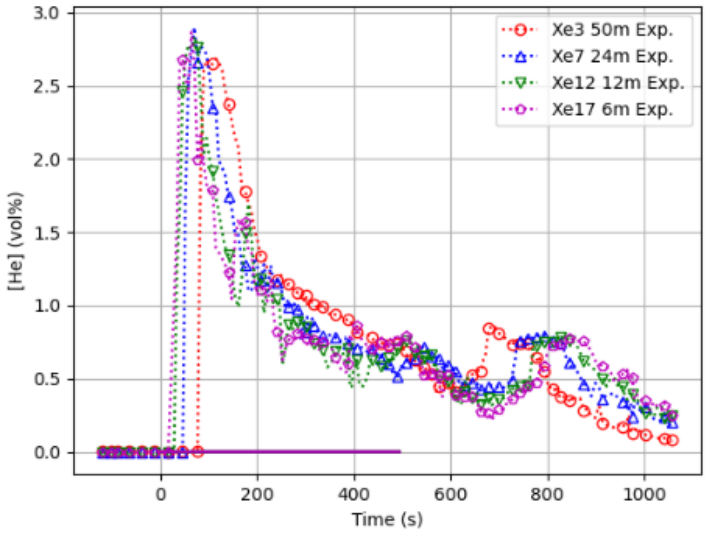
Similar, Faster transport, lower concentration more diffusive

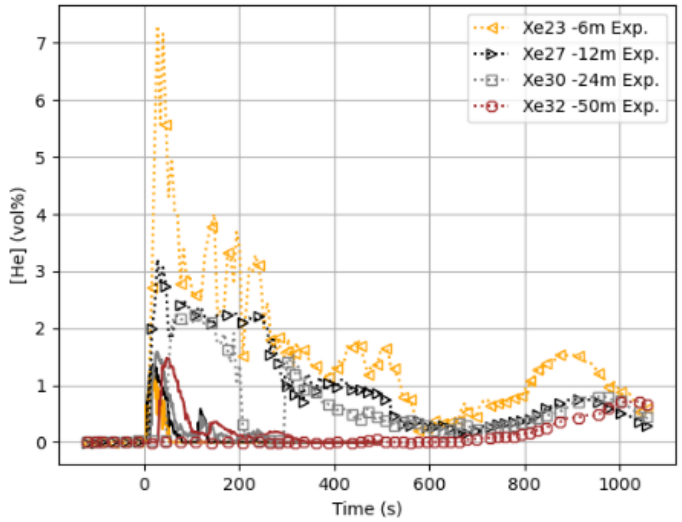
Test 05: 2 mm TPRD Downward 45°

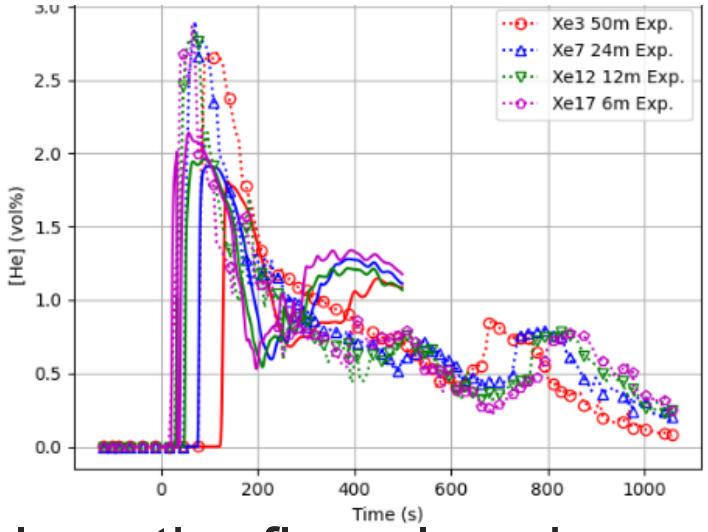
t = 21 seconds

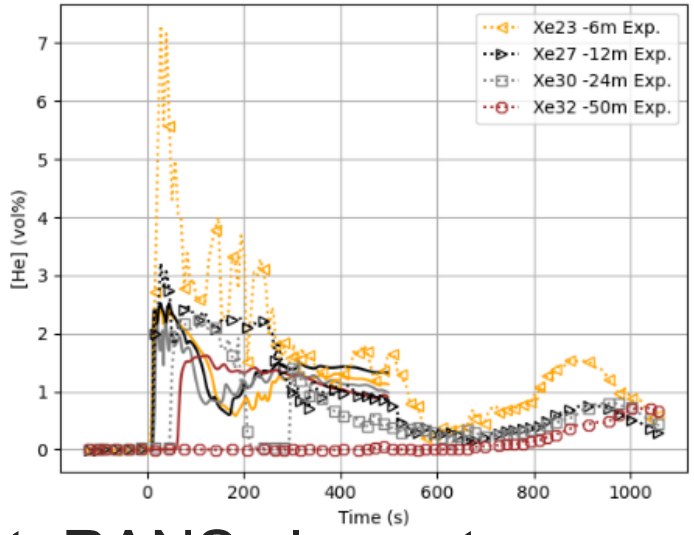












LES larger extension along the floor, less buoyant, RANS slower transport along the upper part of the tunnel, both smaller concentrations

Conclusions and Perspectives

- Experiments
  - 2 mm TPRD leads to flammable cloud close to the release point without large extension along the vault
  - 45° to the rear orientation avoid large accumulation below the chassis
  - Database for CFD code validation
- CFD Analyses
  - Vertical upward releases: similar results for LES and RANS models, close to the experimental results with lower concentration (too diffusive)
  - Downward releases: RANS seems better than LES probably due to absence of mesh adaptation for the LES model (same mesh used in the vertical upward and downward releases)
- Perspectives
  - Refined analyses with the LES model after adaptation of the mesh for the 45° rear downward release

Thank you for your attention
Questions?