Experimental investigation of vented hydrogen deflagrations in 20-foot ISO containers

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Outline

- HySEA
- Experiments
- Results and discussion
- Acknowledgements

HySEA

- **Improving Hydrogen Safety for Energy Applications through pre-normative research on vented deflagrations**
- **Project period**: 1 September 2015 – 31 August 2018
- **Consortium**: Gexcon (Coordinator), University of Warwick (UWAR), University of Pisa (UNIPI), Fike Europe, Impetus Afea and Hefei University of Technology (HFUT, ‘self-funded’)
- **Total budget**: About 1.5 MEUR + about 0.5 MEUR (HFUT)
- **Website**: www.hysea.eu

HySEA Consortium

GEXCON

IMPETUS
driving precision

Fike®

UNIVERSITÀ DI PISA

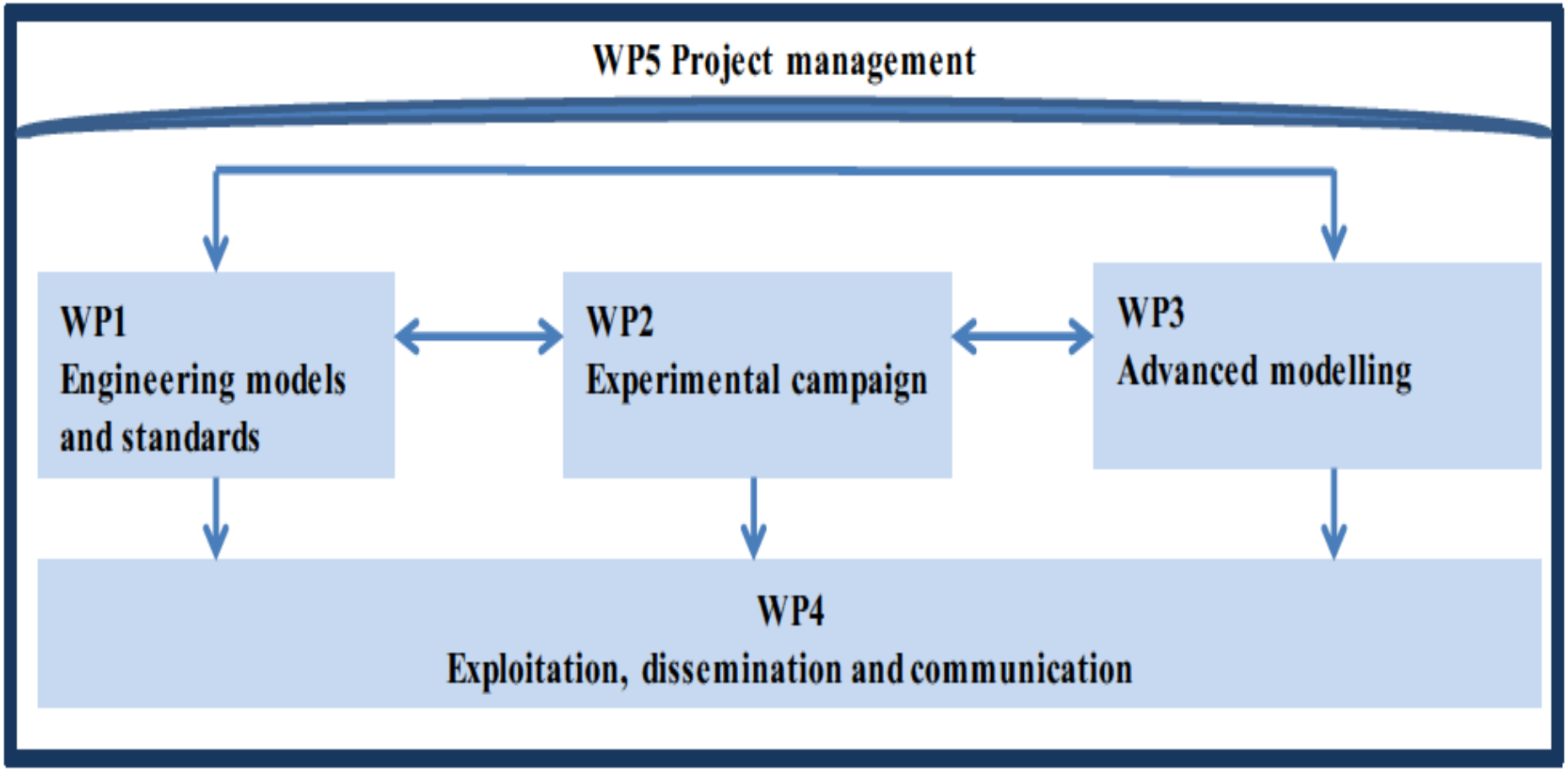
WARWICK
THE UNIVERSITY OF WARWICK

HEFEI UNIVERSITY OF TECHNOLOGY
-1945-

20-foot ISO container at hydrogen refilling station

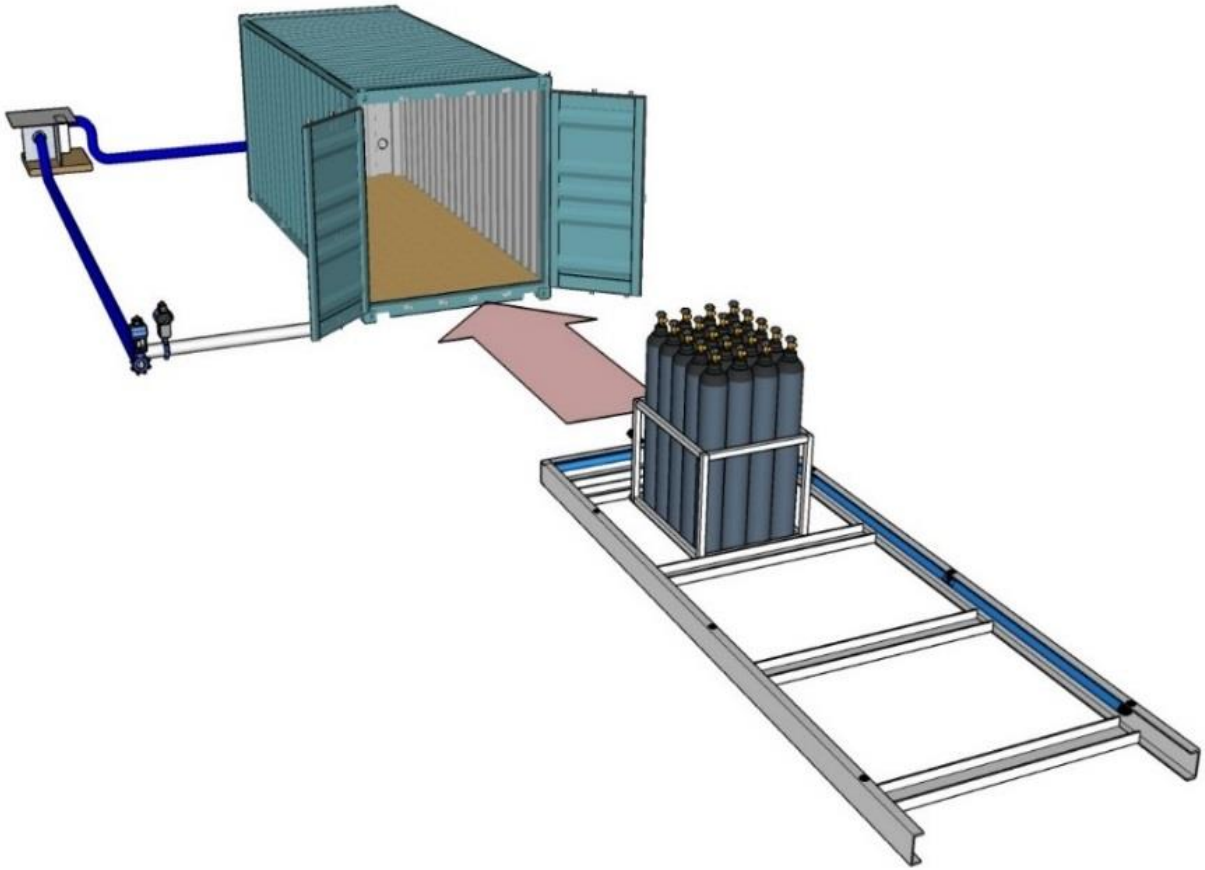
Inside the container

HySEA Work Packages



HySEA – container experiments

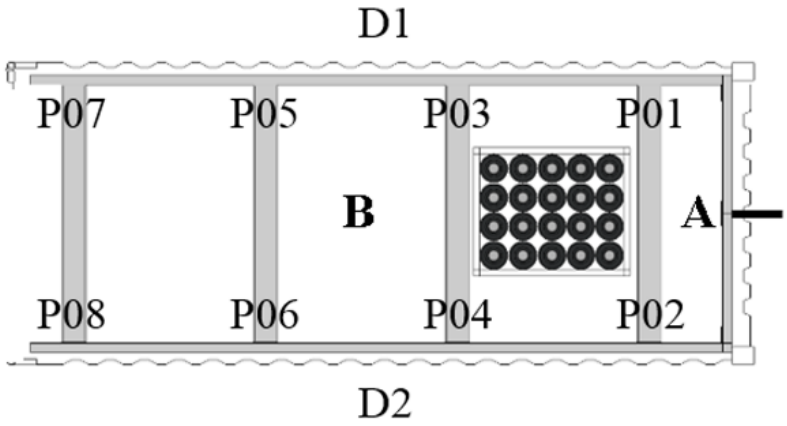
Schematic of experimental rig

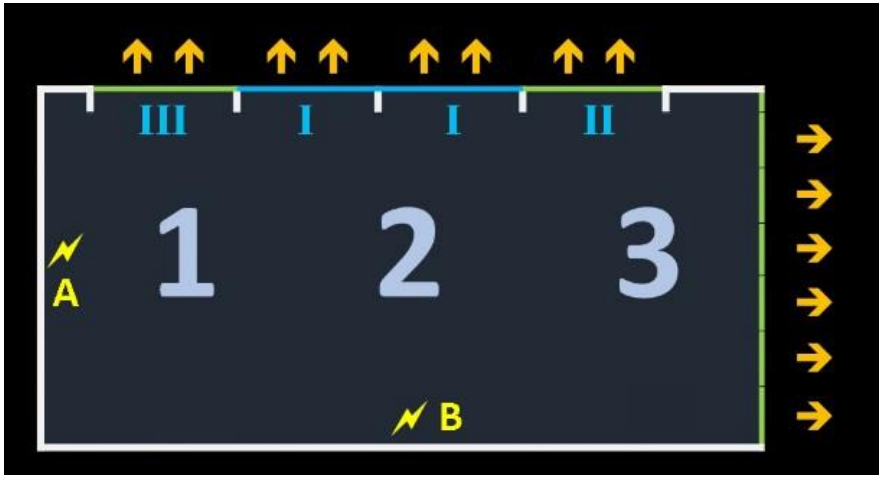


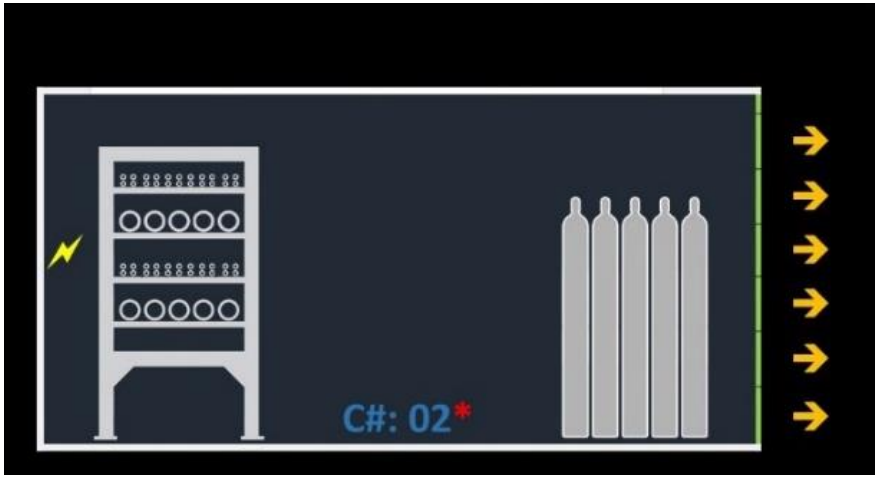
Obstacles: bottle basket and pipe rack

Experimental configuration

P11 P10 P09







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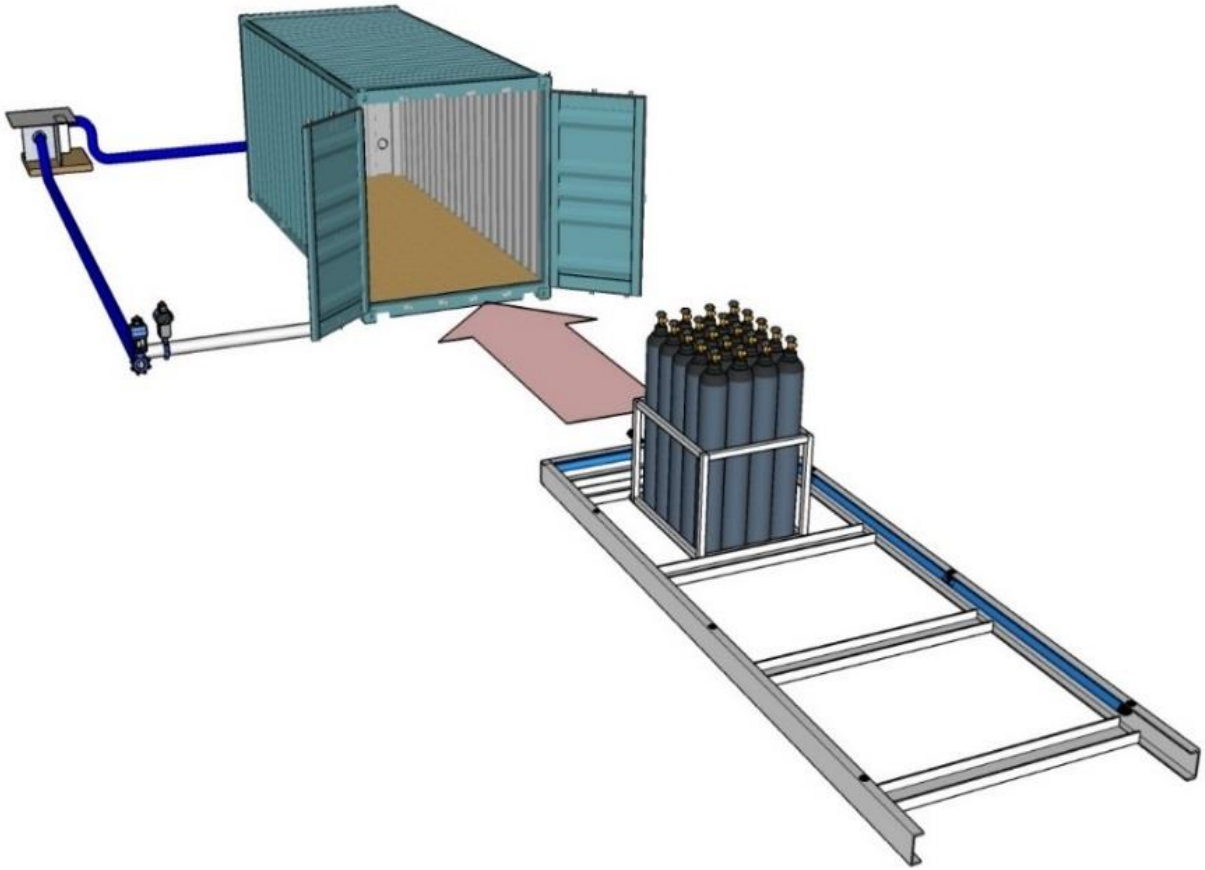
HySEA – selected results

Venting through the doors

CONFIGURATION	Test	A_v (m^2)	$[H_2]$ (vol.%)	Ign. pos.	$P_{red, max}$ (bar)
Frame only (FO), doors open (O)	01	5.64	15	A	0.040
	02	5.64	15	A	0.047
	05	5.64	15	A	0.039
Bottle basket (B1), doors open (O)	03	5.64	15	A	0.077
	04	5.64	15	A	0.064
	06	5.64	15	A	0.045
	10	5.64	18	A	0.130
	07	5.64	21	A	0.190
	08	5.64	24	A	0.390
Bottle basket (B1), doors closed (C)	**09***	0.00	24	A	**1.447**
Pipe rack (P1), doors open (O)	11	5.64	15	A	0.050
	12	5.64	18	A	0.120
	13	5.64	21	A	0.279
Pipe rack + bottles (P1 B3), doors open (O)	**14***	5.64	21	A	**0.939**

HySEA: First blind-prediction



BLIND-PREDICTION: ESTIMATING THE CONSEQUENCES OF VENTED HYDROGEN DEFLAGRATIONS FOR HOMOGENEOUS MIXTURES IN 20-FOOT ISO CONTAINERS

Skjold, T.[1], Hisken, H.[1], Lakshmipathy, S.[1], Atanga, G.[1], Carcassi, M.[2], Schiavetti, M.[2], Stewart, J.R.[3], Newton, A.[3], Hoyes, J.R.[3], Tolias, I.C.[4], Venetsanos, A.G.[4], Hansen, O.R.[5], Geng, J.[6], Huser, A.[7], Helland, S.[8], Jambut, R.[9], Ren, K.[10], Kotchourko, A.[10], Jordan, T.[10], Daubech, J.[11], Lecocq, G.[11], Hanssen, A.G.[12], Kumar, C.[13], Krumenacker, L.[14], Jallais, S.[15], Miller, D.[16] and Bauwens, C.R.[17]

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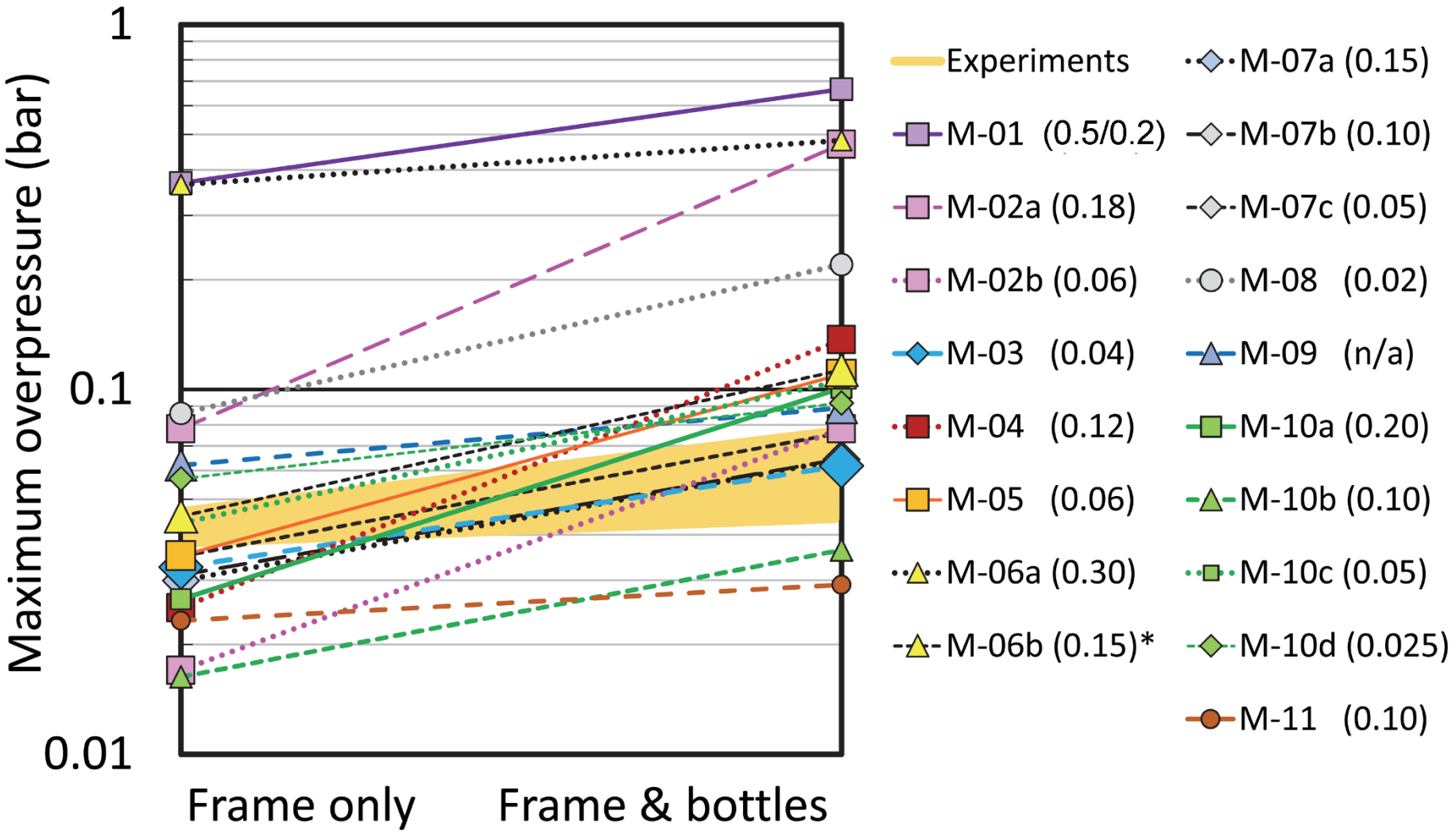
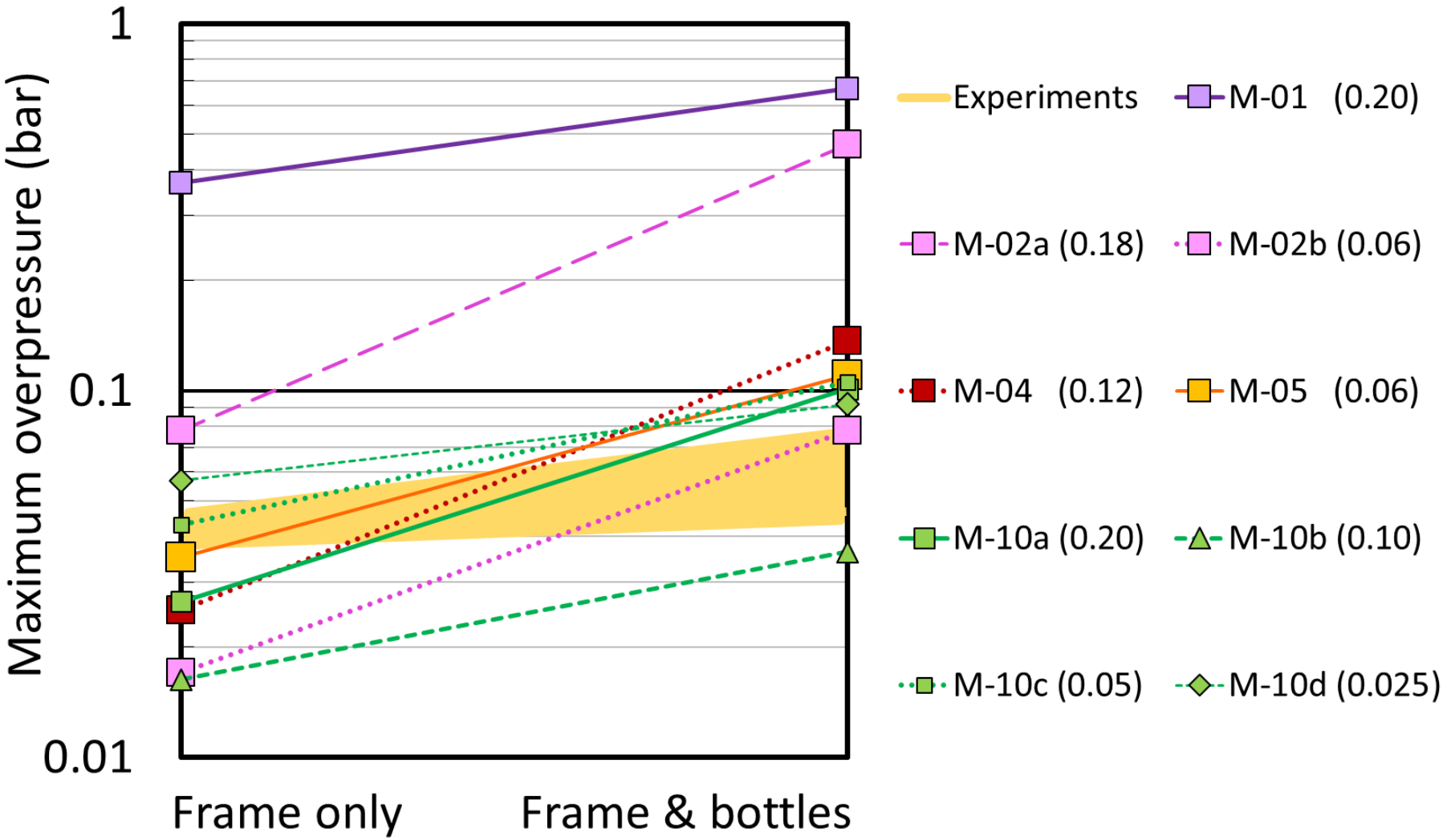
[17] FM Global, 1151 Boston-Providence Turnpike, Norwood 02062, MA, carl.bauwens@fmglobal.com

Results for all CFD models



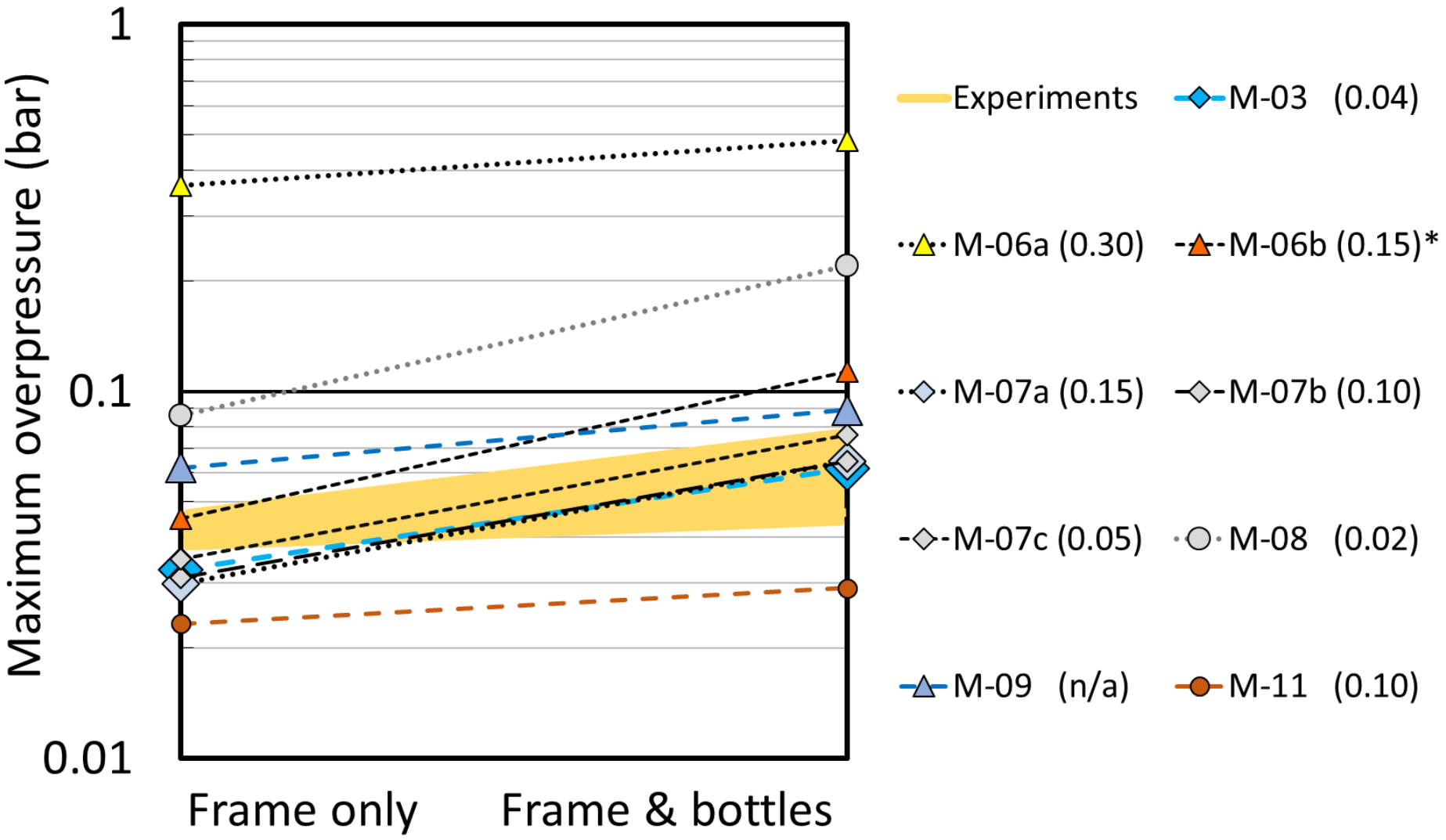
FLACS

Results obtained with FLACS



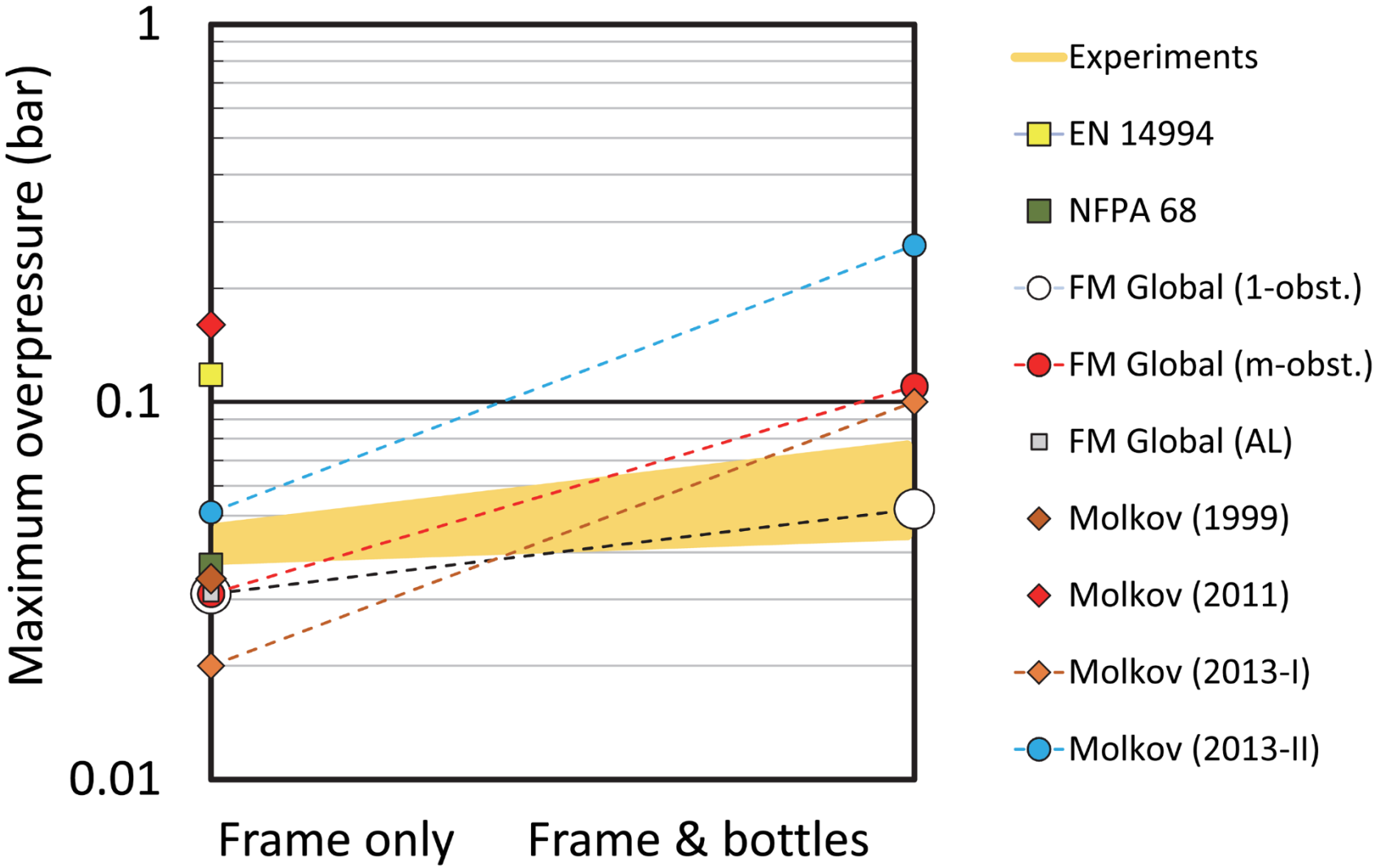
FLACS

Results obtained with other CFD tools



FLACS

Results for engineering models



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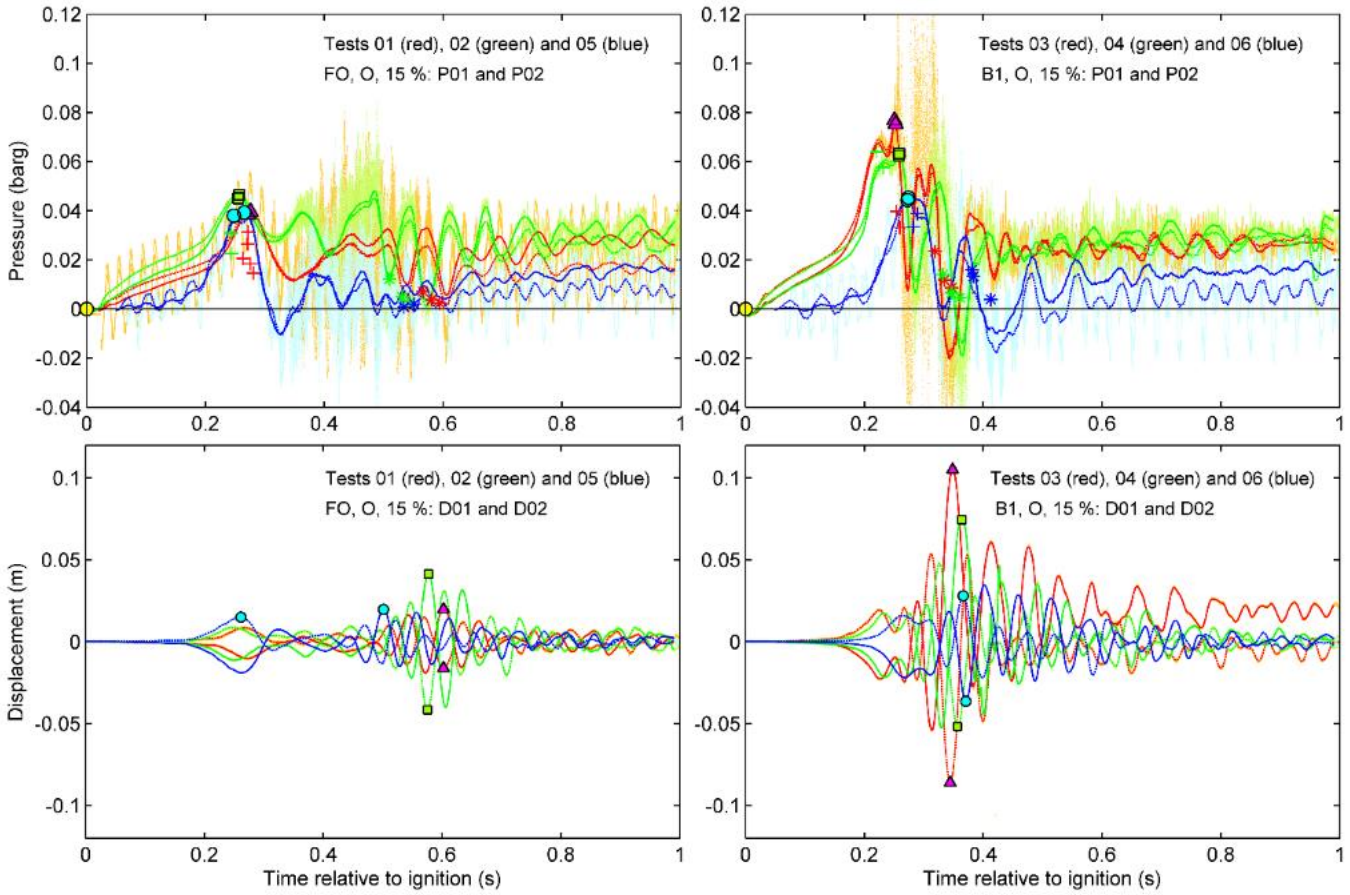
Inherent limitations

- Limited repeatability of structural response measurements.
- Relatively mild explosions – poor signal-to-noise ratio.



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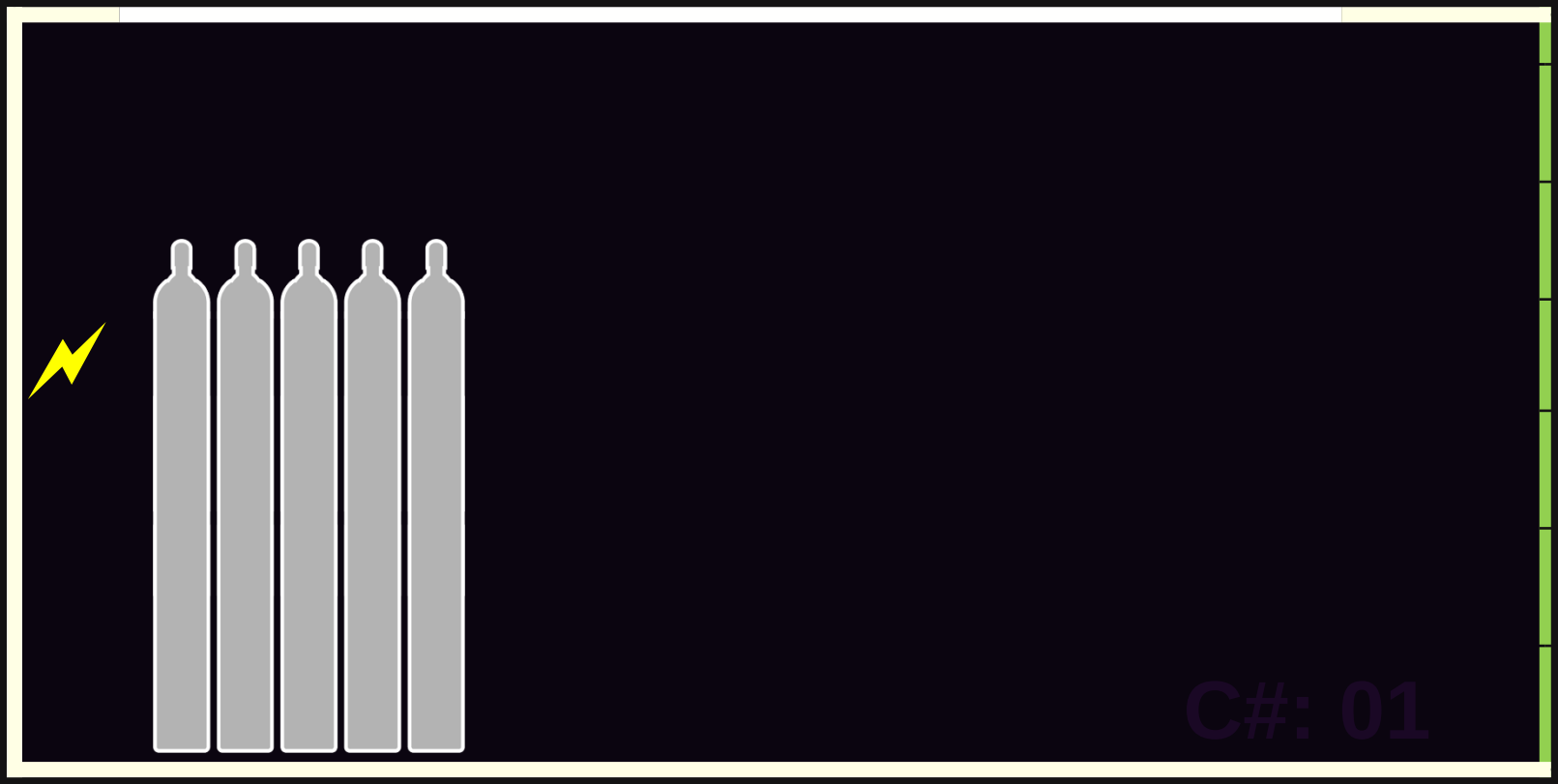
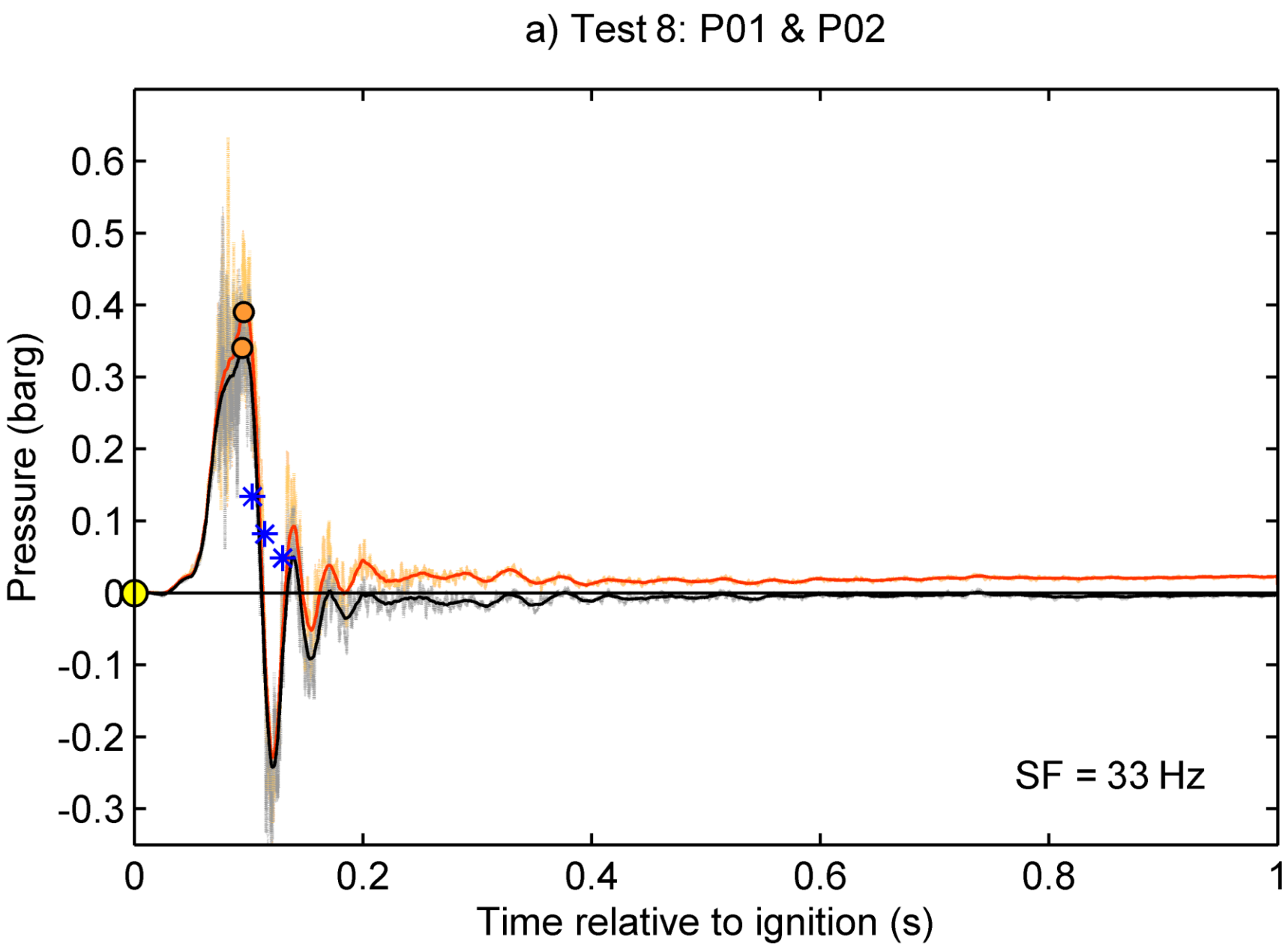
Test 08

$[H_2]$:	**24**	vol.%
A_v :	**5.6**	m^2
P_{stat} :	**≈ 0**	bar



CONTAINER EXPERIMENTS

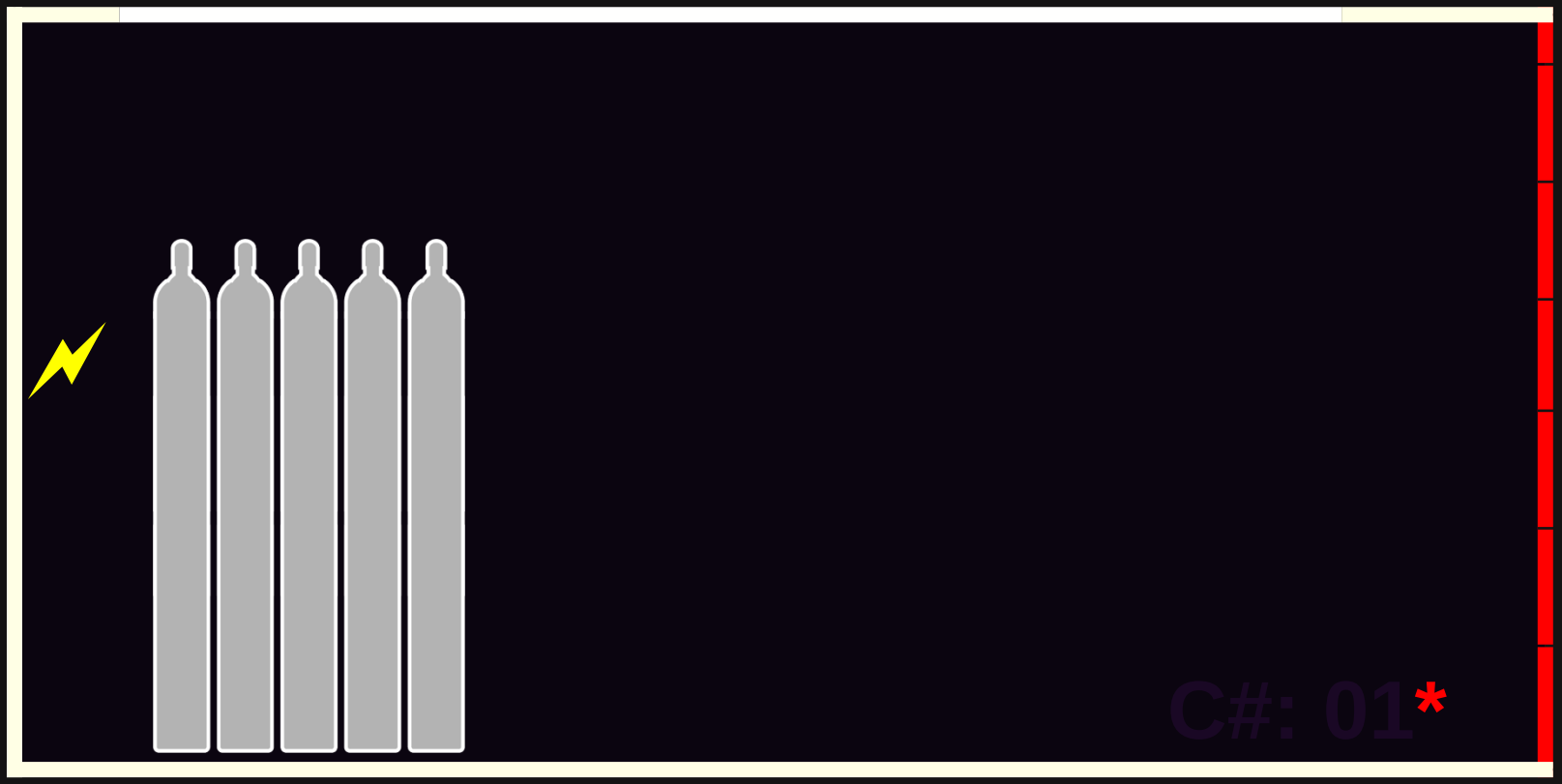
Test 08


a) Test 8: P01 & P02
Pressure (barg)
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
0.2
0.4
0.6
0.8
1
Time relative to ignition (s)
SF = 33 Hz

FLACS

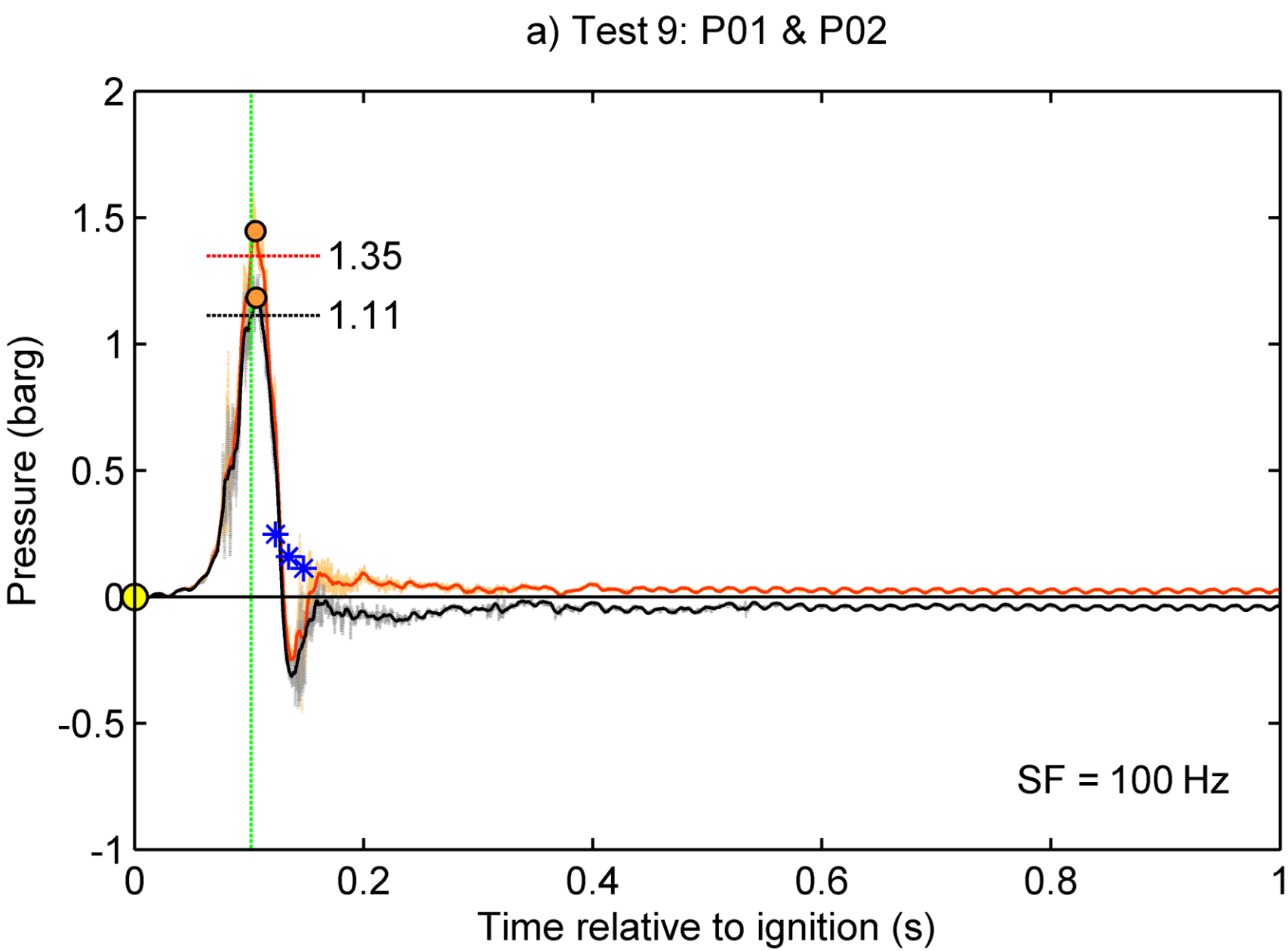
Test 09

$[H_2]$:	**24**	vol.%
A_v :	**5.6**	m^2
P_{stat} :	**≈ 1.1**	bar



CONTAINER EXPERIMENTS

Test 09

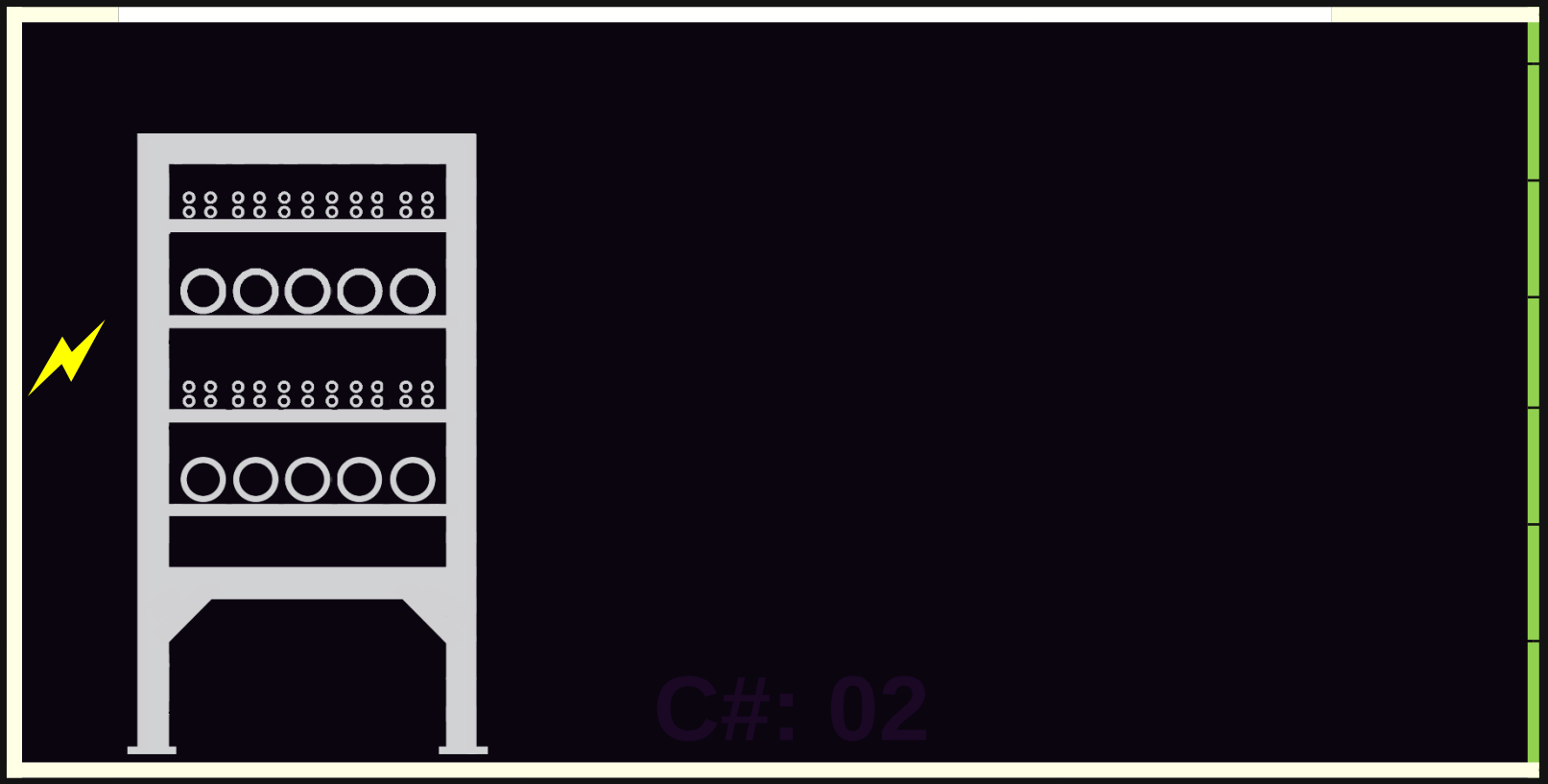

a) Test 9: P01 & P02
2
1.5
1
0.5
0
-0.5
-1
1.35
1.11
Pressure (barg)
SF = 100 Hz
0
0.2
0.4
0.6
0.8
1
Time relative to ignition (s)

FLACS


WSCU 9122849

Test 13

$[H_2]$:	**21**	vol.%
A_v :	**5.6**	m^2
P_{stat} :	**≈ 0**	bar

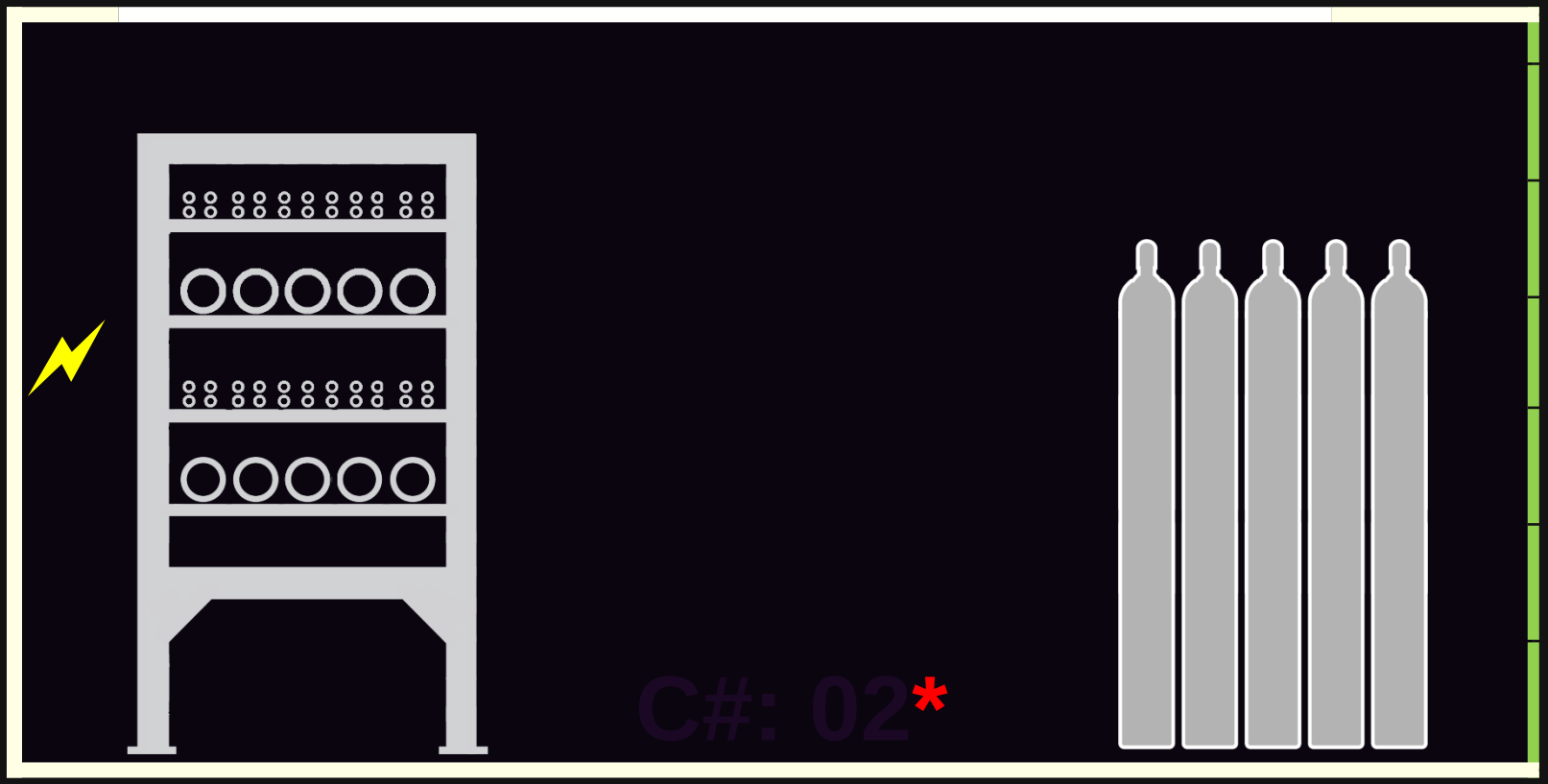


CONTAINER EXPERIMENTS

Test 13

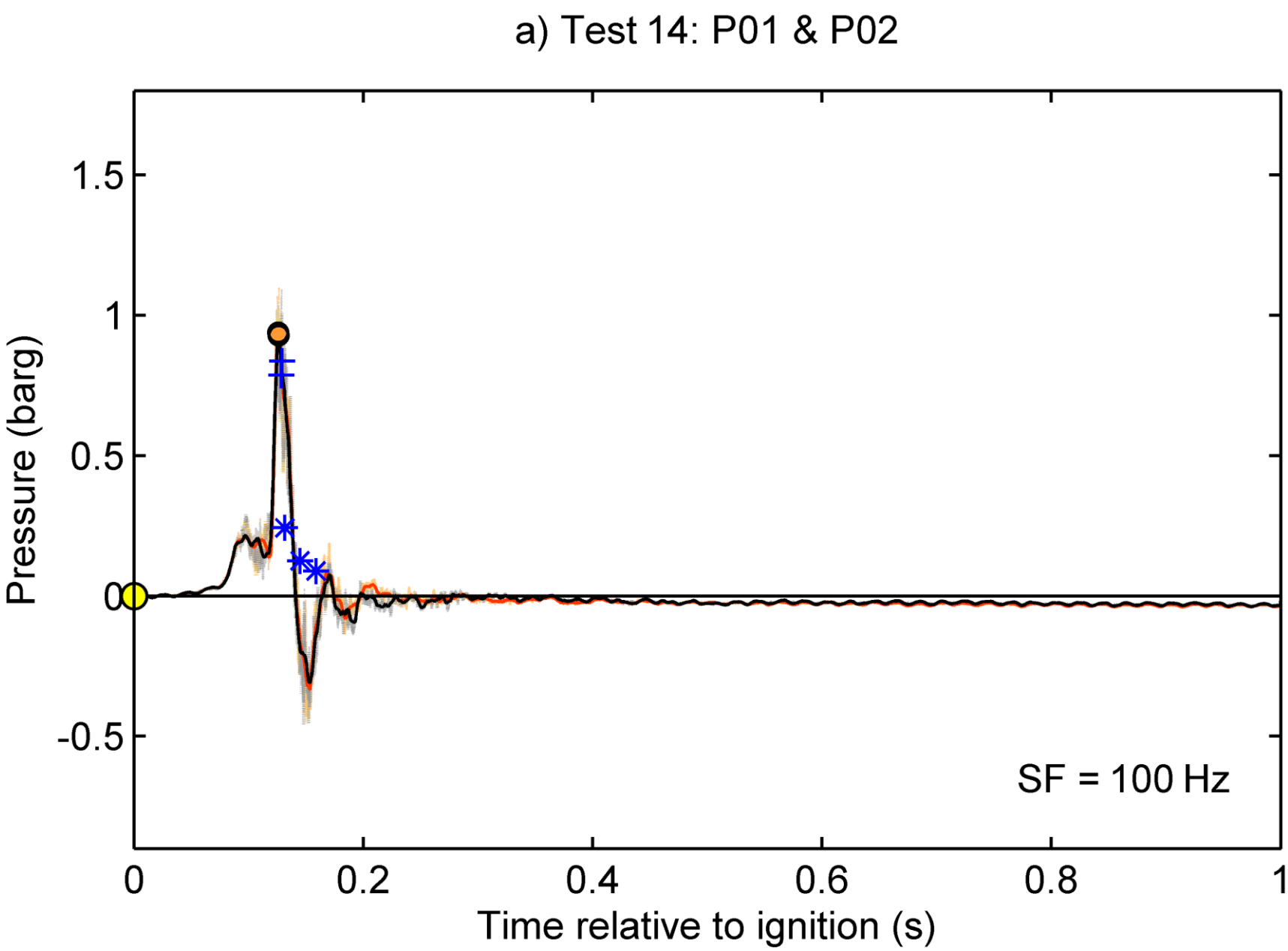
Test 14

$[H_2]$:	**21**	vol.%
A_v :	**5.6**	m^2
P_{stat} :	**≈ 0**	bar

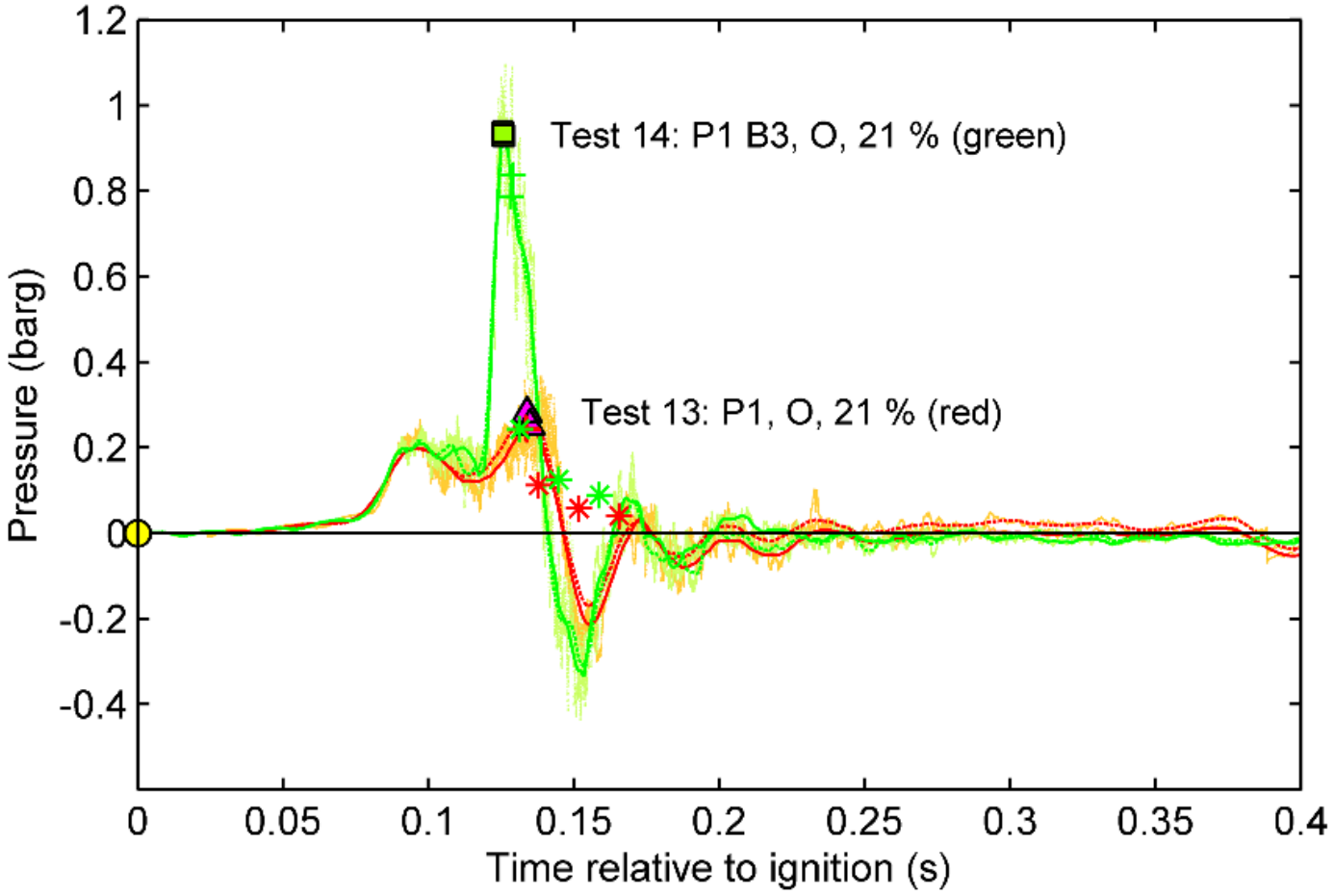


CONTAINER EXPERIMENTS

Test 14


a) Test 14: P01 & P02
Pressure (barg)
1.5
1
0.5
0
-0.5
SF = 100 Hz
0
0.2
0.4
0.6
0.8
1
Time relative to ignition (s)

Tests 13 and 14



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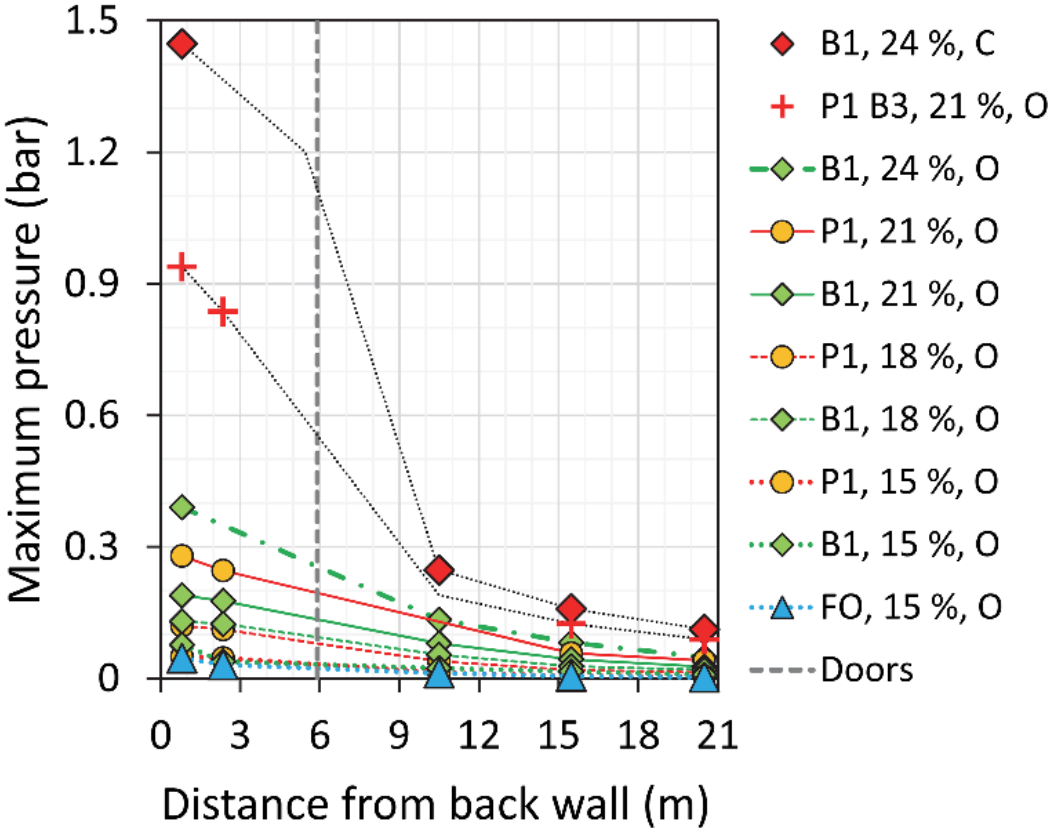
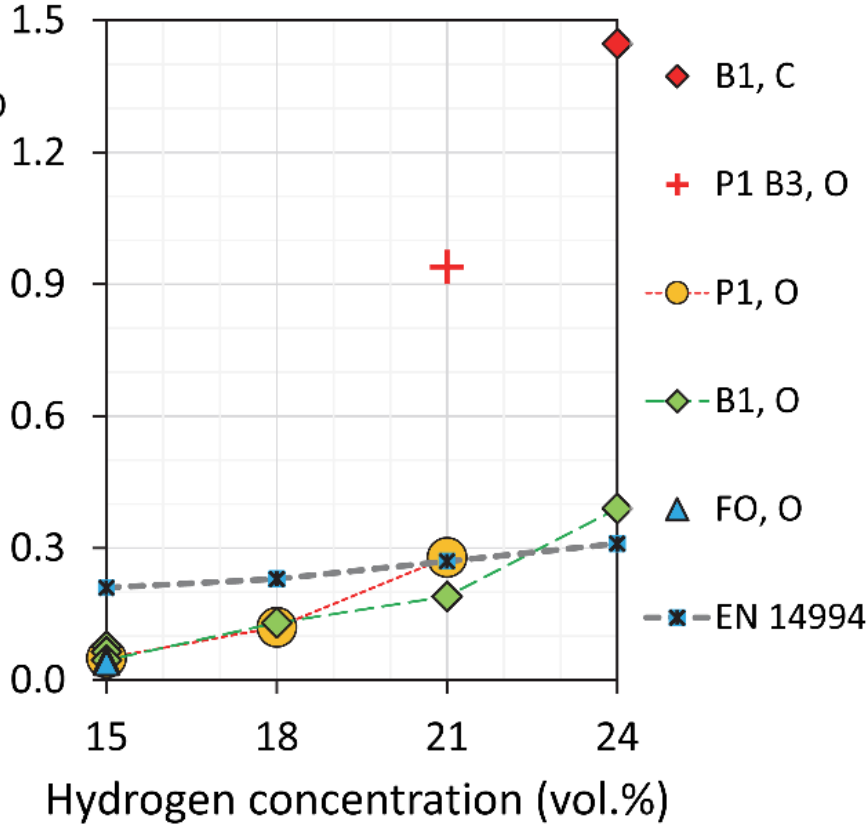
Venting through the doors



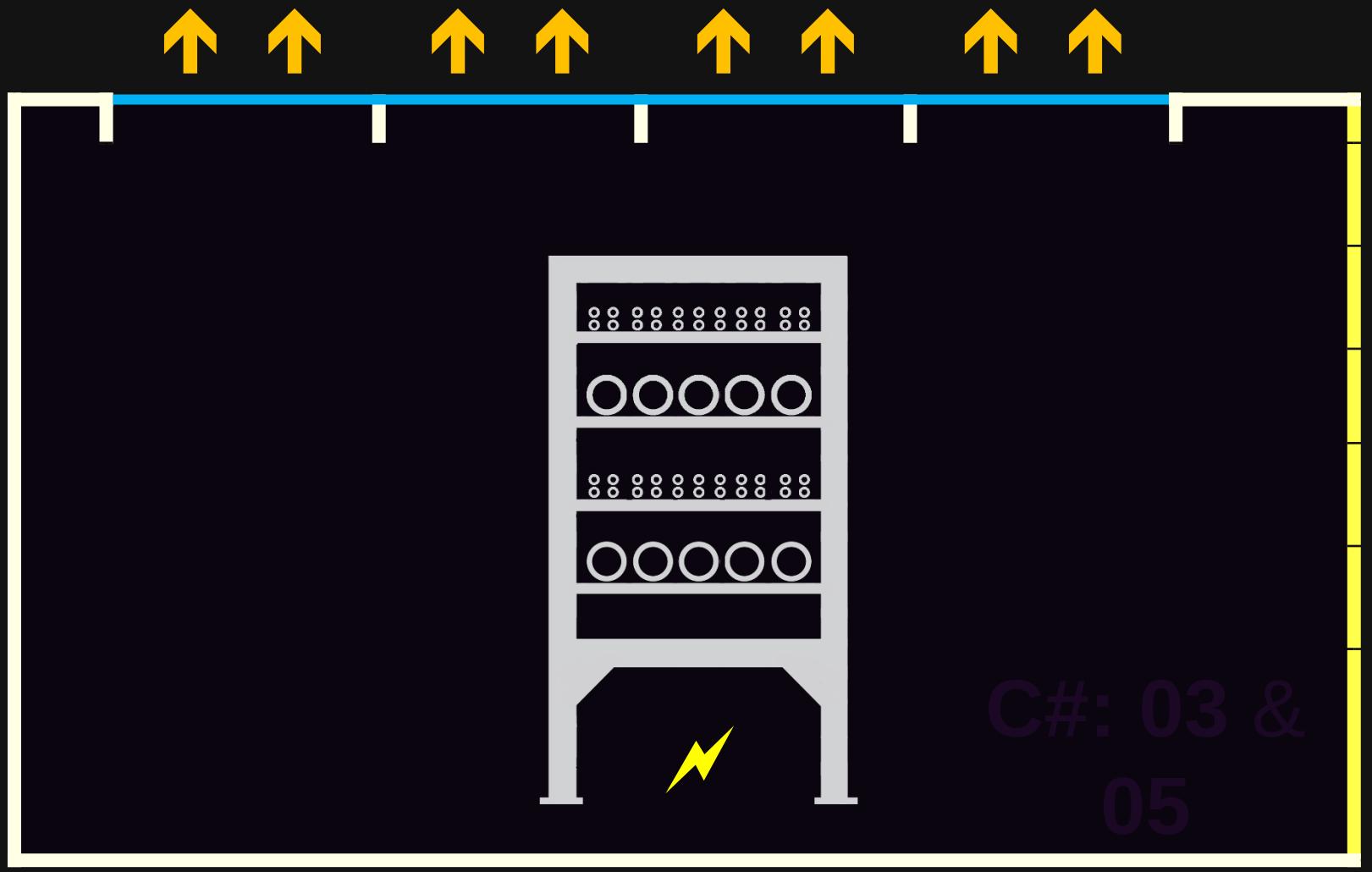


Venting through the roof

CONFIGURATION	Test	A_v (m^2)	$[H_2]$ (vol.%)	Ign. pos.	$P_{red, max}$ (bar)
Frame only (FO), perforated plastic film (O)	25	4.0	21	B	0.146
	21	6.0	21	B	0.120
	16	8.0	21	B	0.190
Pipe rack (P2), perforated plastic film (O)	24	4.0	21	B	0.150
	22	6.0	21	B	0.142
	17	8.0	21	B	0.124
Pipe rack (P2), perforated plastic film (O)	34*	8.0	42	B	1.076
Pipe rack (P2), perforated plastic film (O)	29	4.0	24	B	0.414
	23	6.0	24	B	0.168
	19	8.0	24	B	0.136
Frame only (FO), commercial vent panels (P)	32	4.0	21	B	0.214
	26	6.0	21	B	0.245
	15	8.0	21	B	0.191
Pipe rack (P2), commercial vent panels (P)	33	4.0	21	B	0.261
	27	6.0	21	B	0.301
	31	6.0	21	B	0.249
	18	8.0	21	B	0.234
	30	8.0	21	B	0.214
Pipe rack (P2), commercial vent panels (P)	28*	6.0	24	B	0.729
	20*	8.0	24	B	0.334

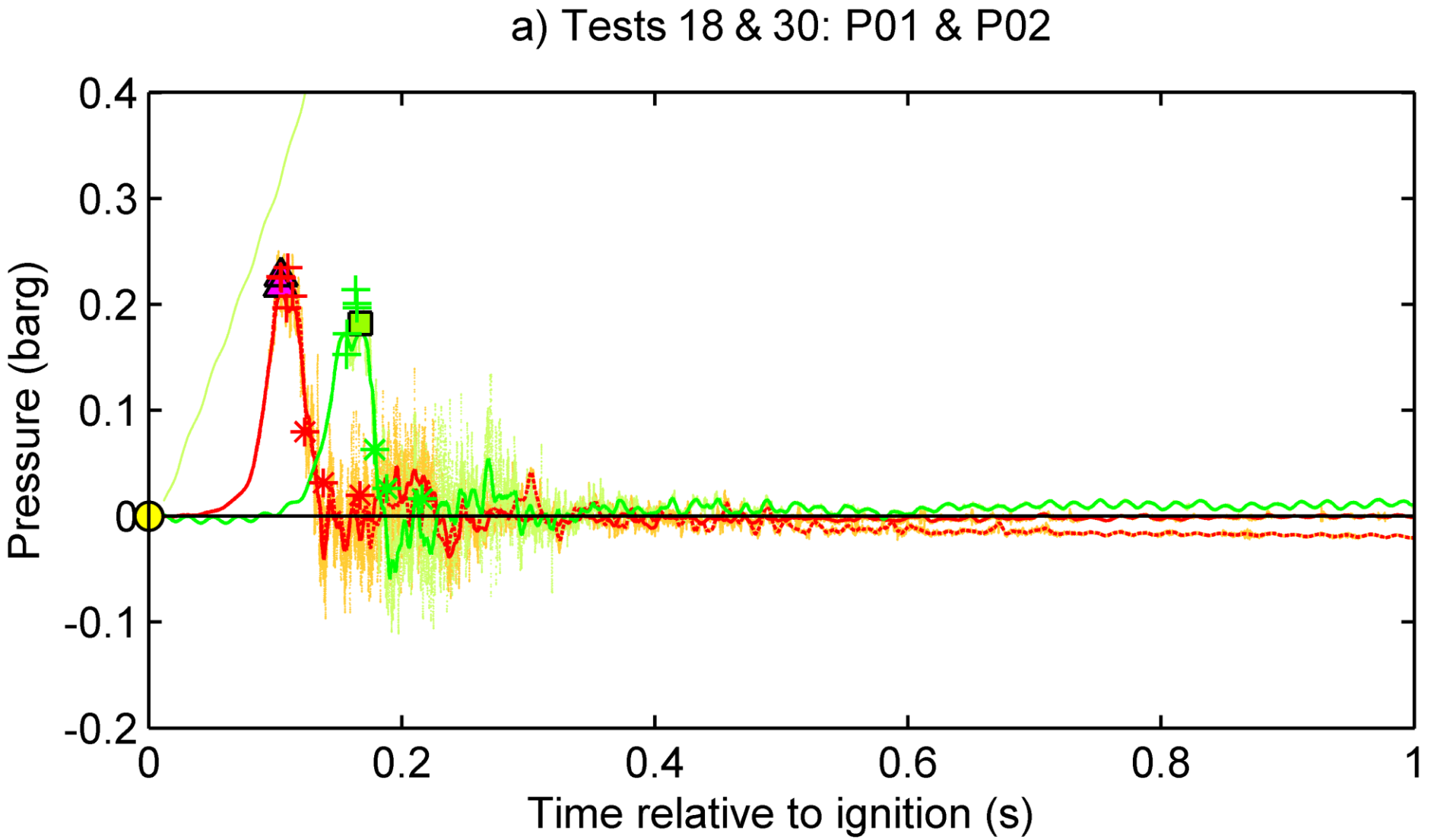
Tests 18 & 30

$[H_2]$:	**21**	vol.%
A_v :	**8**	m^2
P_{stat} :	**0.1**	bar



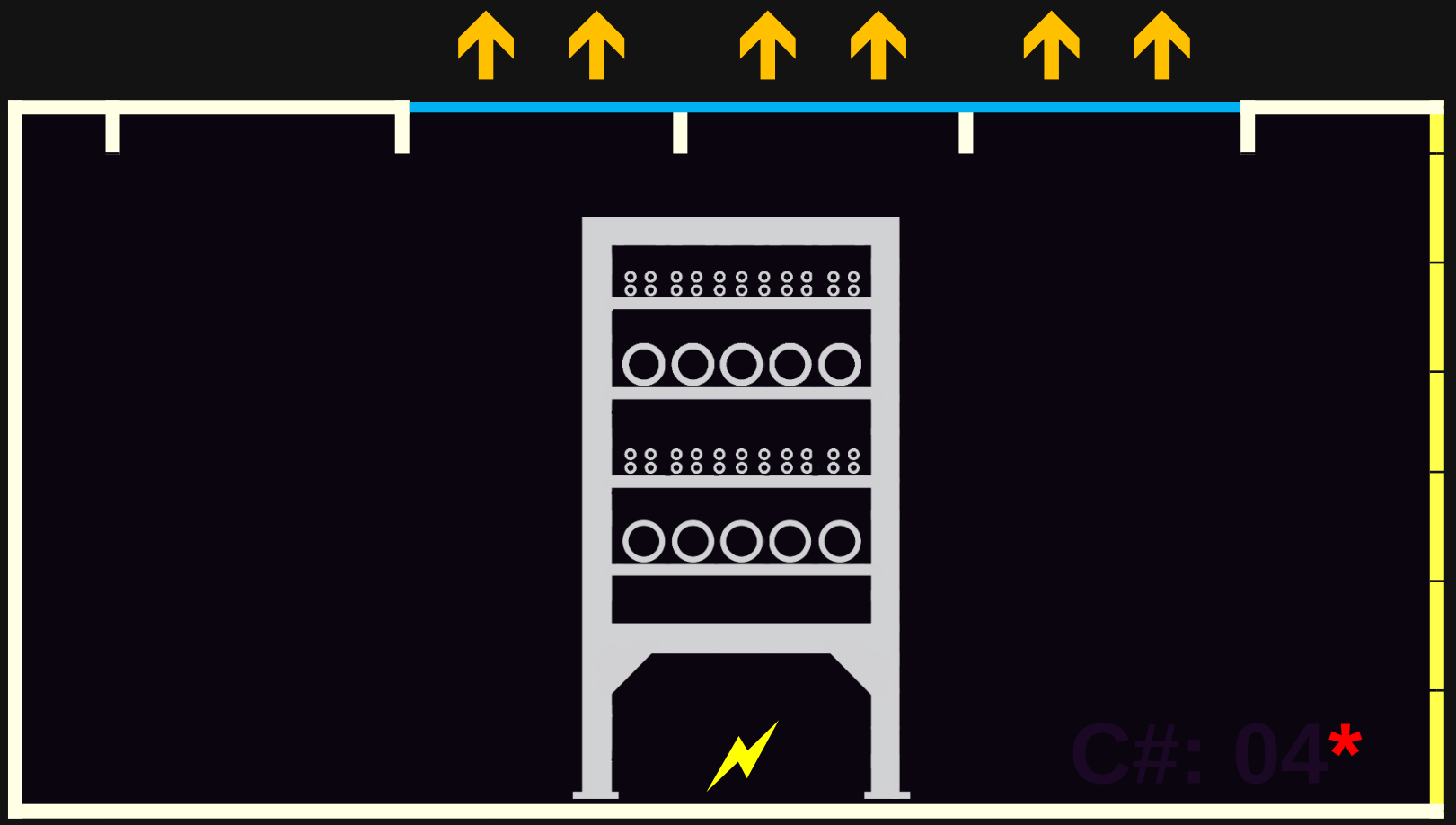
CONTAINER EXPERIMENTS

Tests 18 & 30


a) Tests 18 & 30: P01 & P02
Pressure (barg)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
0
0.2
0.4
0.6
0.8
1
Time relative to ignition (s)

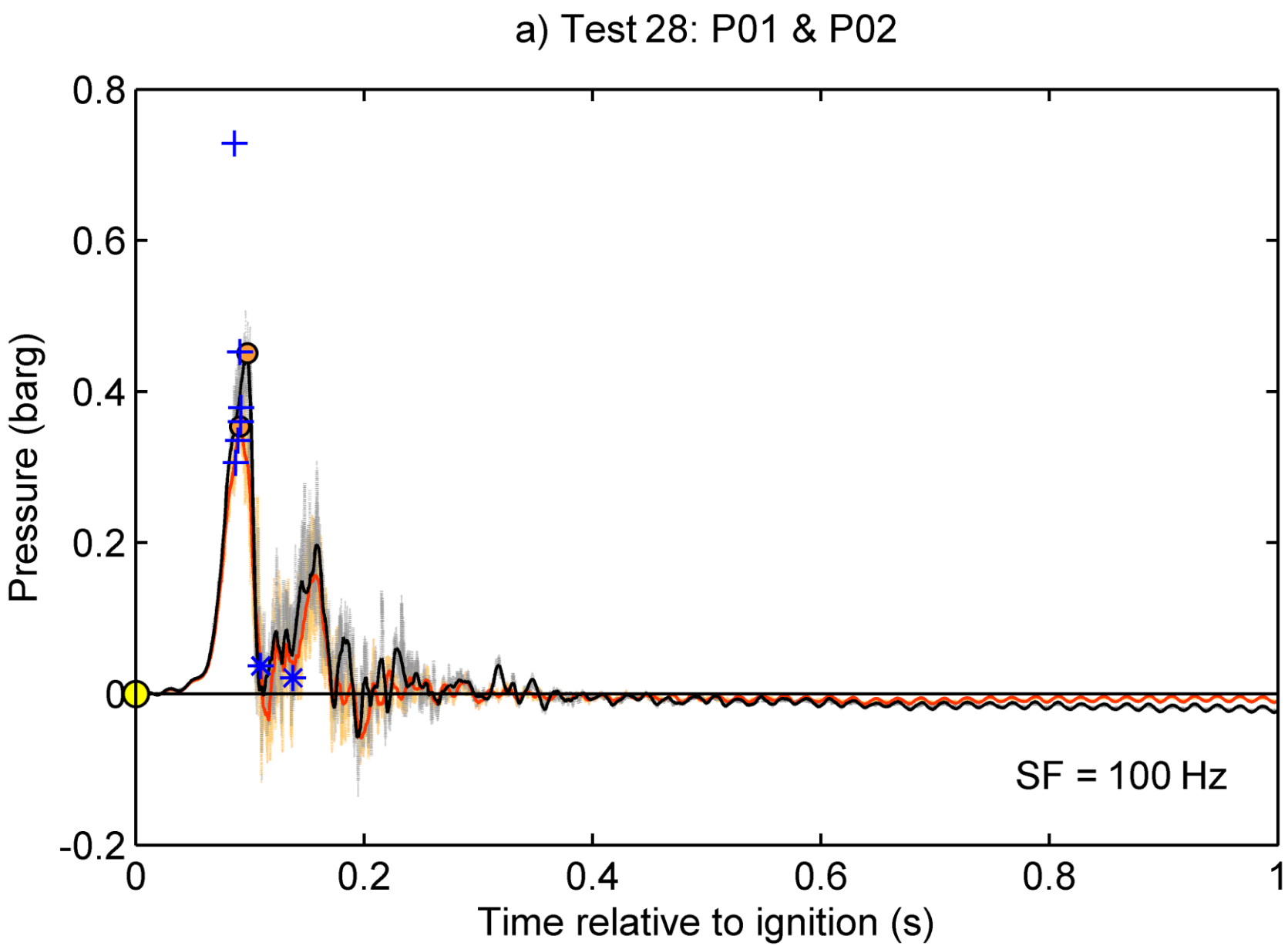
Test 28

$[H_2]$:	**24**	vol.%
A_v :	**6**	m^2
P_{stat} :	**0.1**	bar



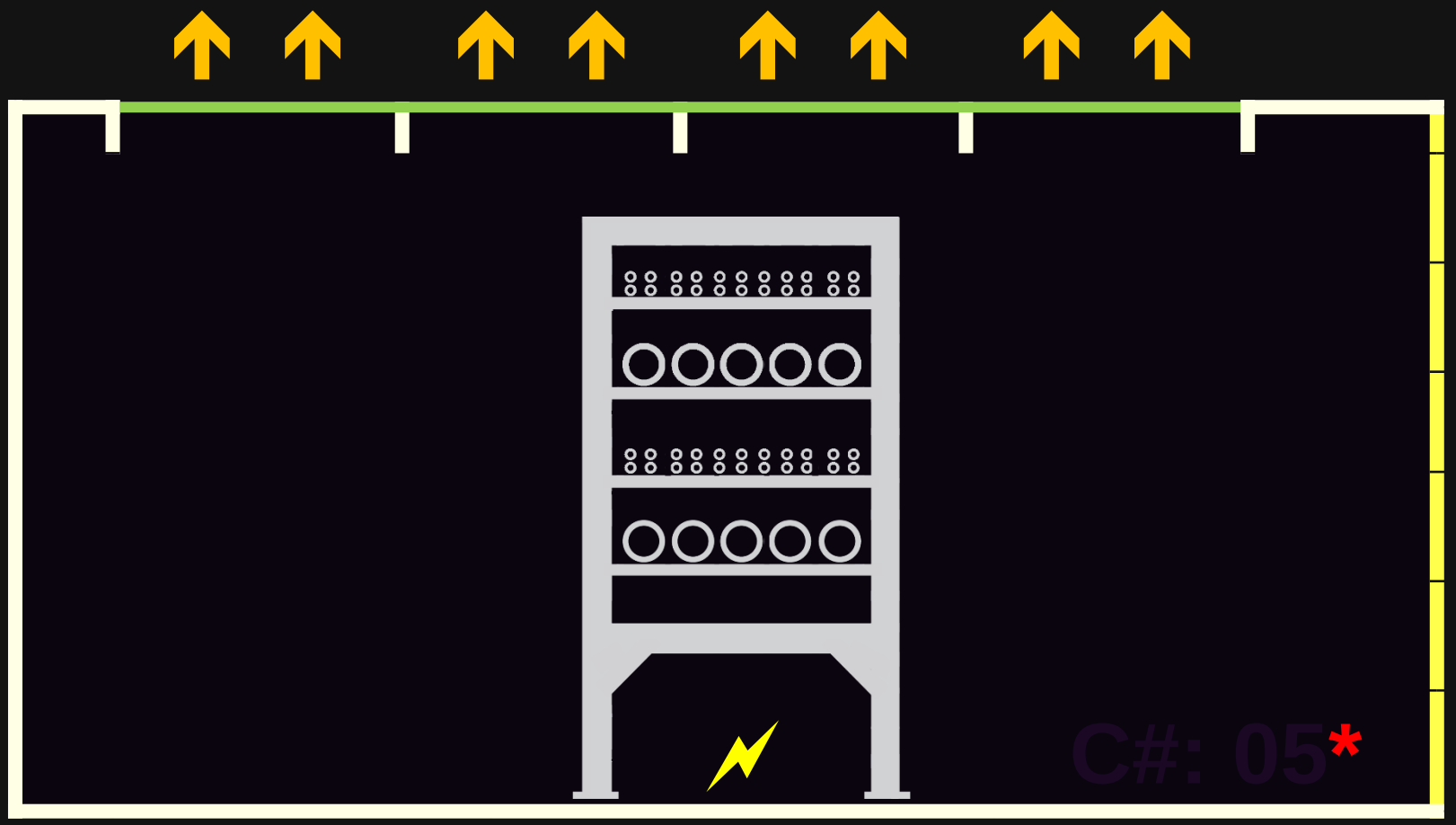
CONTAINER EXPERIMENTS

Test 28


a) Test 28: P01 & P02
Pressure (barg)
0.8
0.6
0.4
0.2
0
-0.2
0
0.2
0.4
0.6
0.8
1
Time relative to ignition (s)
SF = 100 Hz

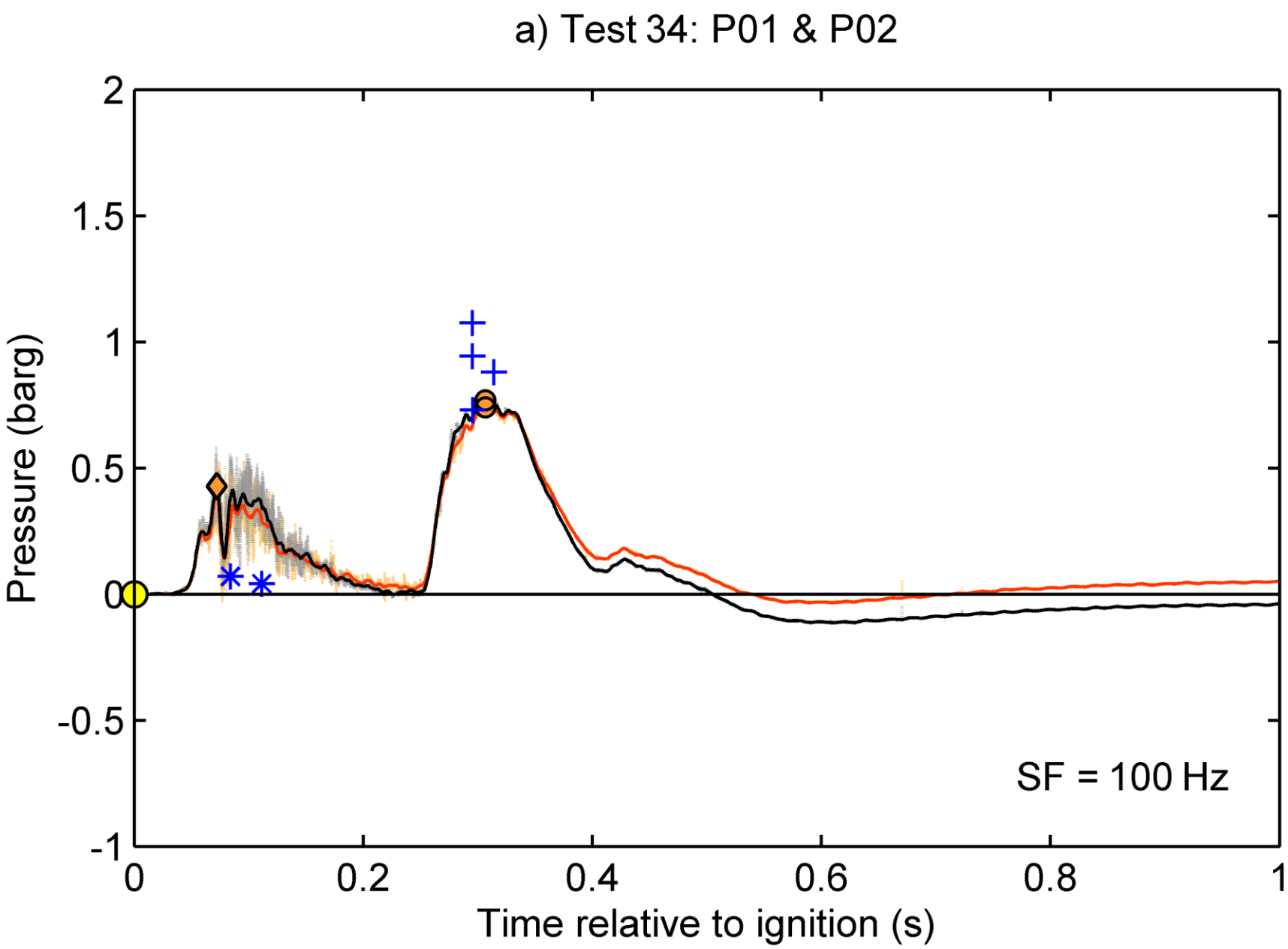
Test 34

$[H_2]$:	**42**	vol.%
A_v :	**8**	m^2
P_{stat} :	**≈ 0**	bar

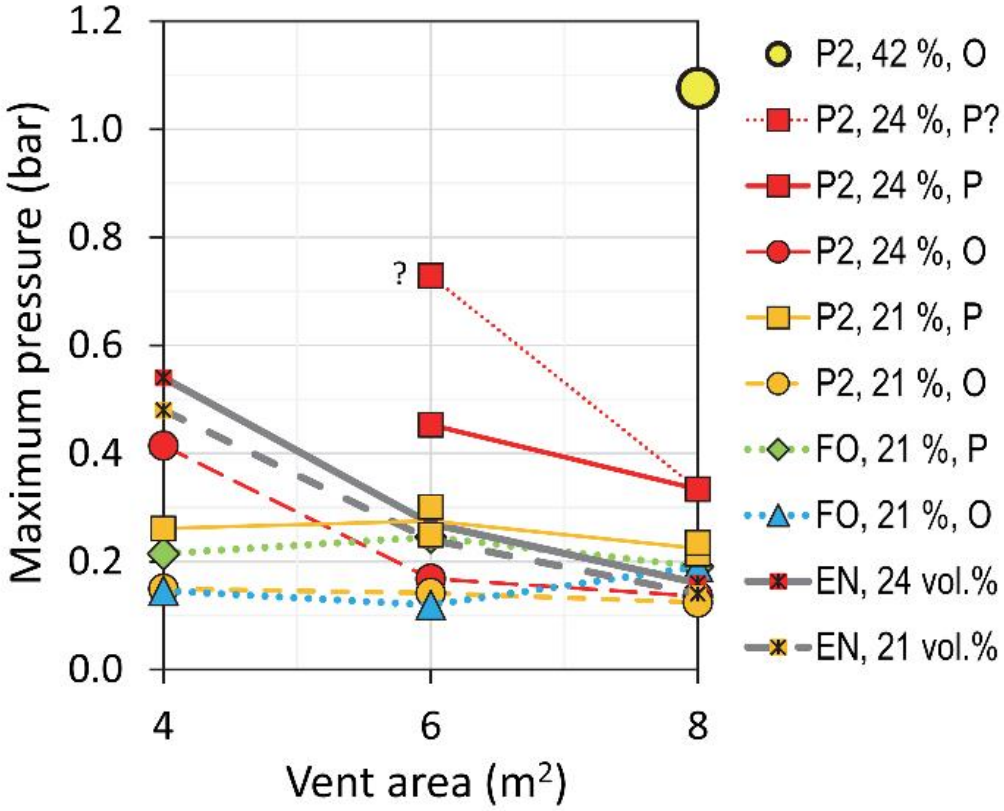


CONTAINER EXPERIMENTS

Test 34


a) Test 34: P01 & P02
Pressure (barg)
Time relative to ignition (s)
SF = 100 Hz
2
1.5
1
0.5
0
-0.5
-1
0
0.2
0.4
0.6
0.8
1

Venting through the roof



Test 34: P2, O, 42 vol.%

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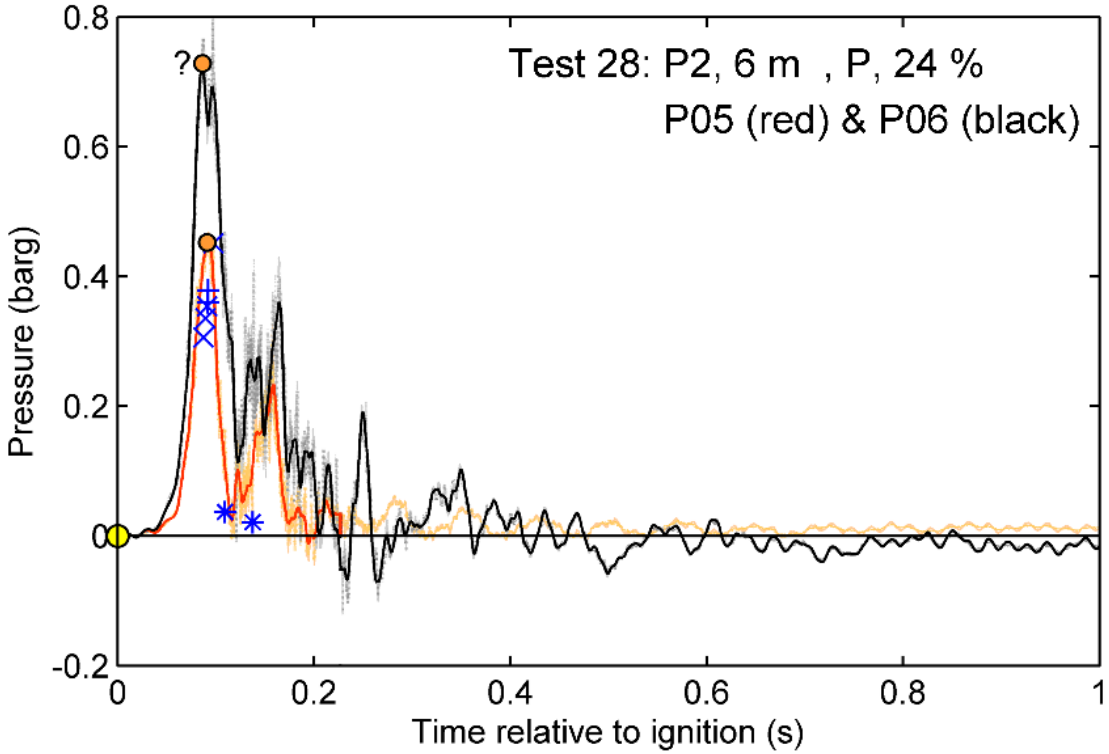
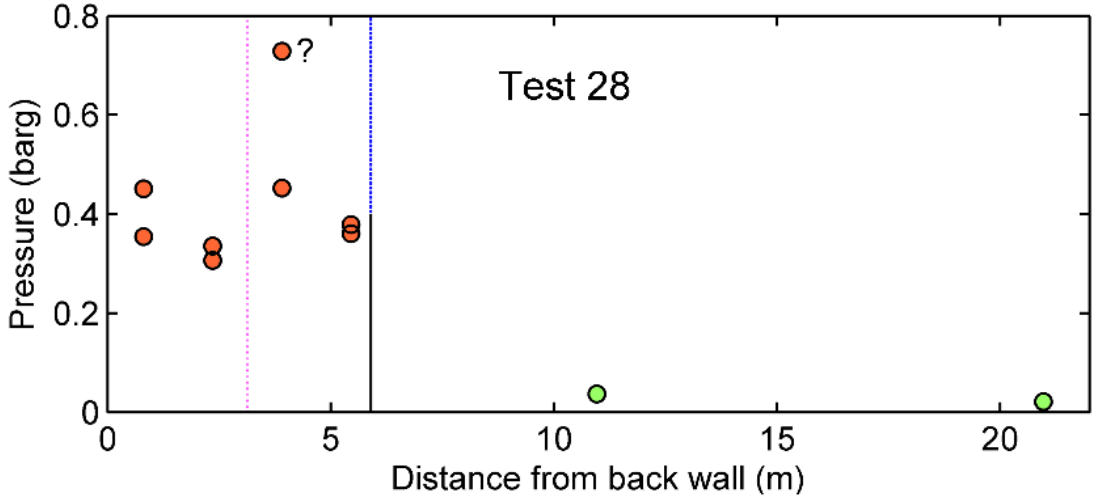

Test 28: P2, 6 m , P, 24 %
P05 (red) & P06 (black)
?
Pressure (barg)
Time relative to ignition (s)
0.8
0.6
0.4
0.2
0
-0.2
0
0.2
0.4
0.6
0.8
1


Test 28
?
Pressure (barg)
Distance from back wall (m)
0.8
0.6
0.4
0.2
0
0
5
10
15
20

Summary

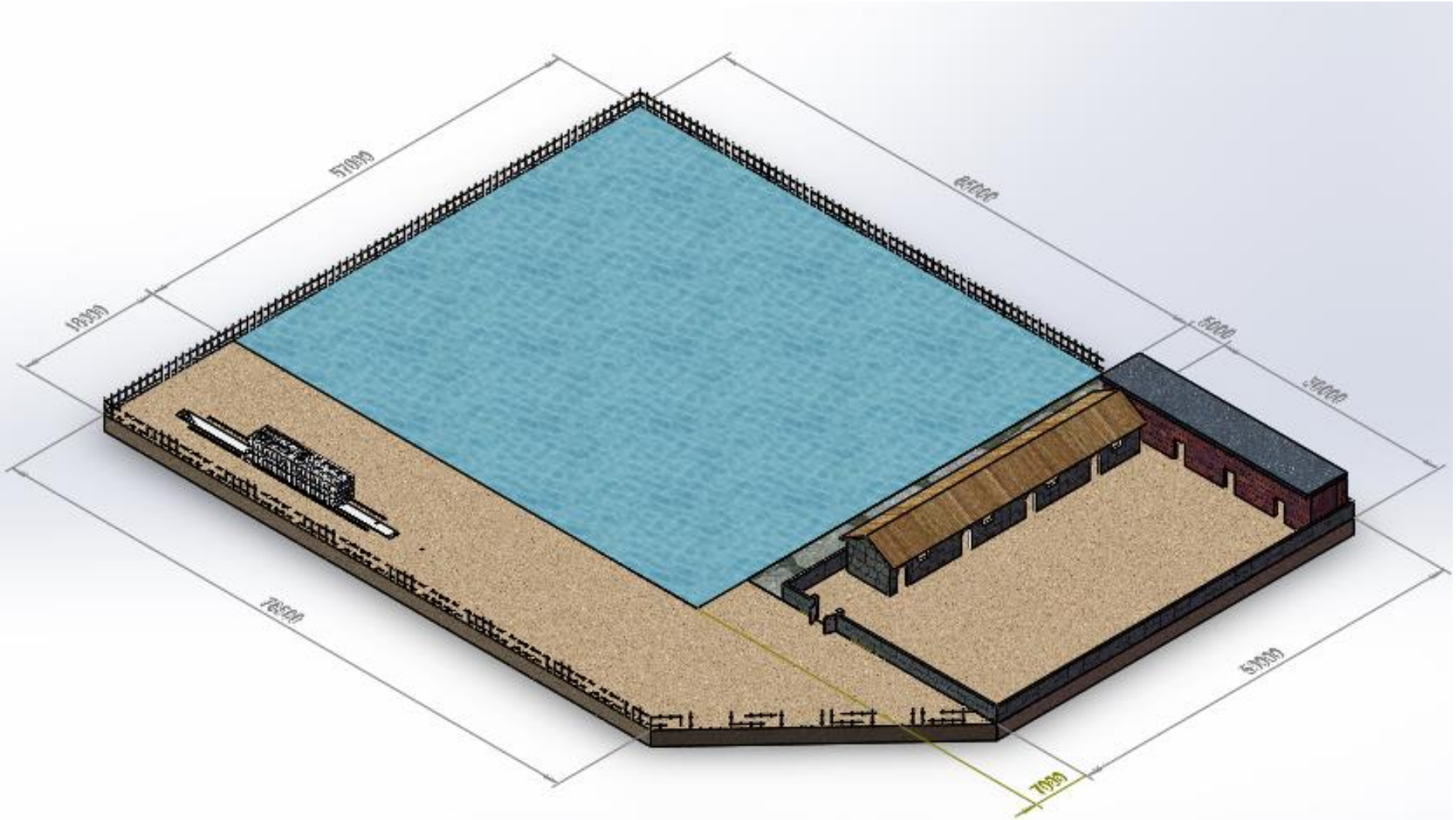
- Constructed experimental setup for investigating the effect of internal congestion on vented hydrogen deflagrations in 20-foot ISO containers.
  - Completed 34 vented explosion experiments in 20-foot ISO containers (the proposal specified 30 tests): 14 tests vented through the container doors, and 20 tests vented through openings in the roof.
  - The second experimental campaign with inhomogeneous mixtures in 20-foot containers started in September 2017.
- HFUT has designed a setup for performing repeated vented explosion experiments in standard 40-foot ISO containers. The containers can be fitted with up to 20 rectangular vent covers on the roof.

Hydrogen vented explosion at HFUT

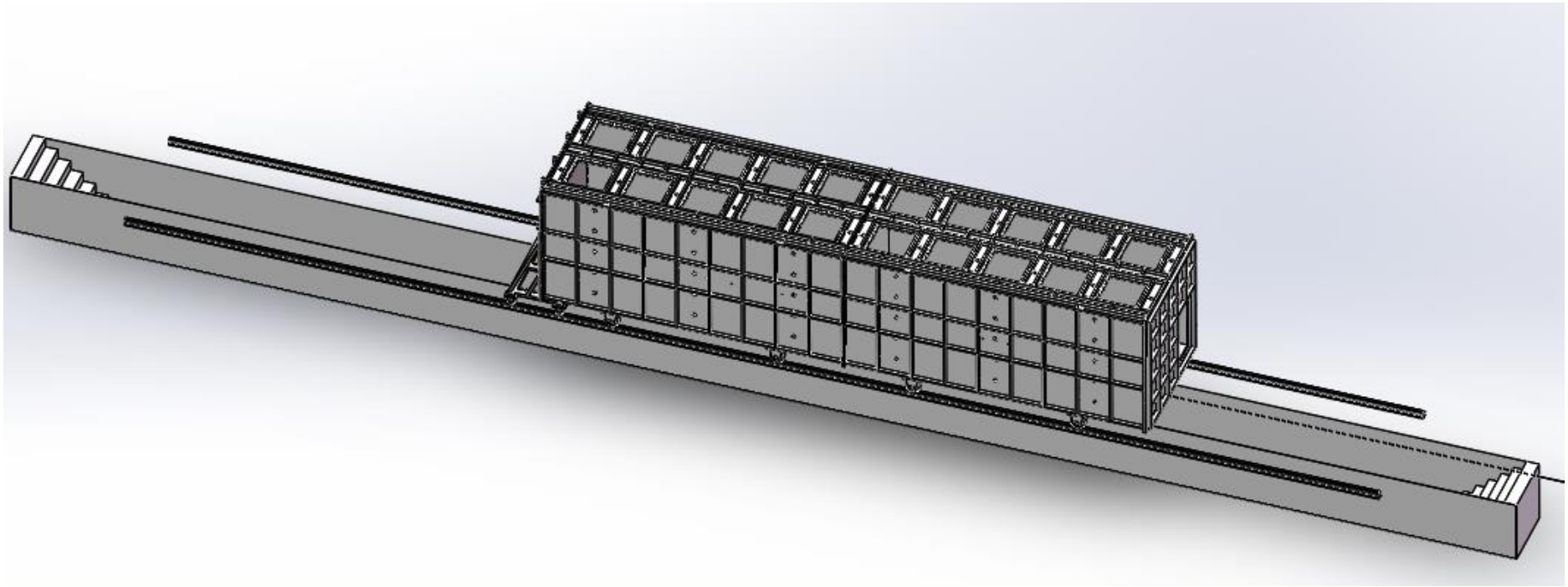
Changjian Wang

Hefei University of Technology

40-feet ‘ISO’ container



40-feet ‘ISO’ container

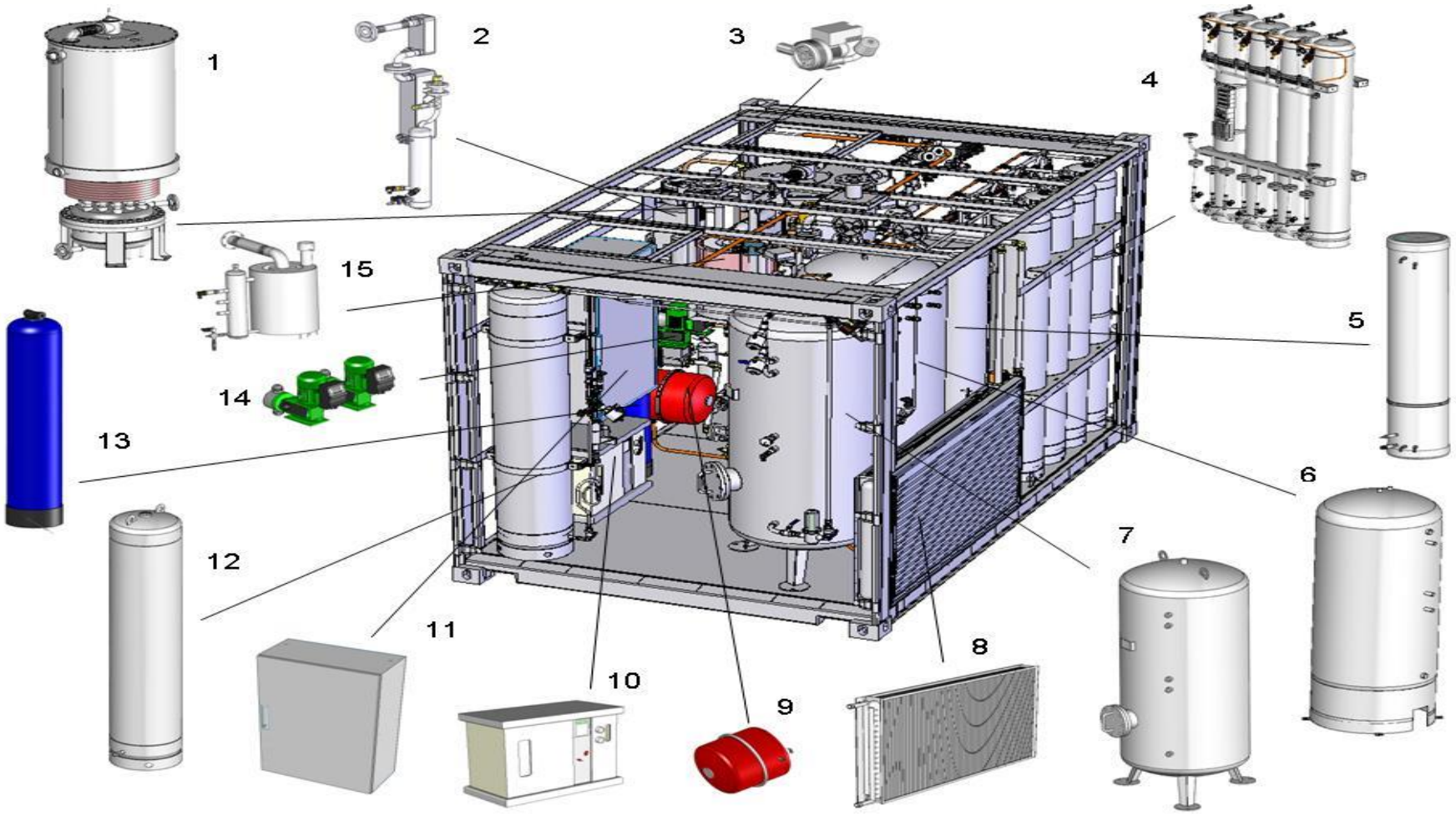


Container: 12 m x 2.5 m x 2.5 m
Steel plate thickness: 25 mm
Vent: 0.75 m x 0.75 m, 20 vents

Phase 2 experiments

- Initial turbulence (homogeneous mixtures)
- Specific scenarios, such as ‘static’ pressure load for closed container and high congestion (homogeneous mixtures)
- Continuous stratification (inhomogeneous, including the second HySEA blind-prediction study)
- Transient releases (turbulence + inhomogeneous)
- Most likely no (at most singular) tests with natural or forced ventilation

Example of higher level of congestion, from Air Products & Air Liquide



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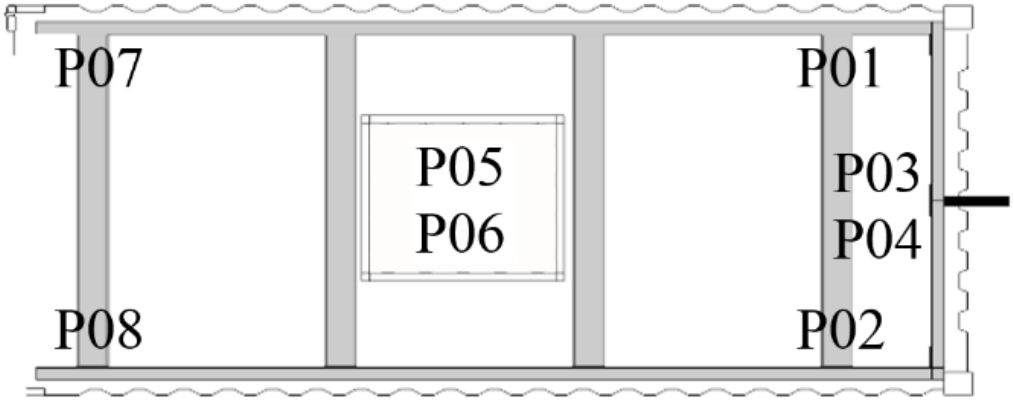
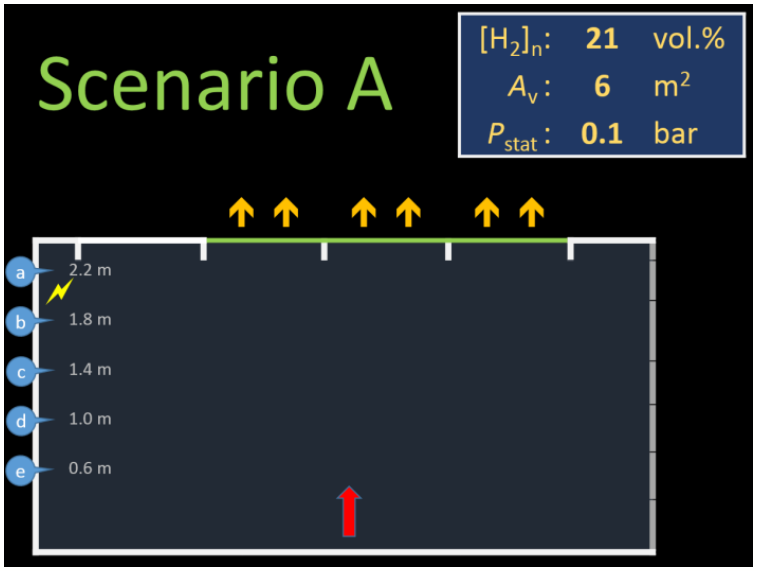
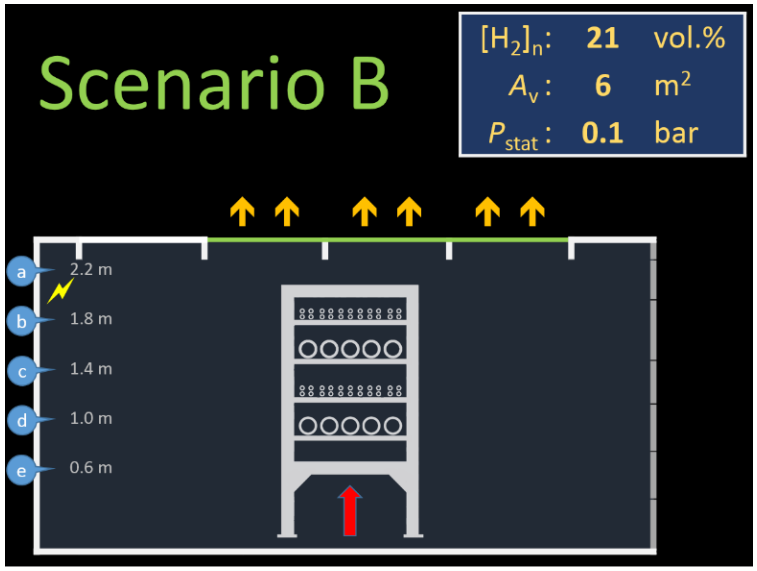
Second HySEA blind-prediction







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Challenges and prospects

- Generic empirical correlations for vented deflagrations in complex geometries is arguably a contradiction in terms.
- Relatively complex phenomena – limited budget for experiments and quite challenging modelling.
- Relative straightforward to improve EN 14994 and NFPA 68 (published models available) – however, it can be a challenge to balance **performance vs. simplicity**!
- The HySEA project will result in improved CFD and FE tools – commercial as well as open source.

Further information

www.hysea.eu

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Questions?