Karlsruhe Institute of Technology

hySafe
INTERNATIONAL ASSOCIATION FOR HYDROGEN SAFETY

Update on Combustion of Inhomogeneous Mixtures

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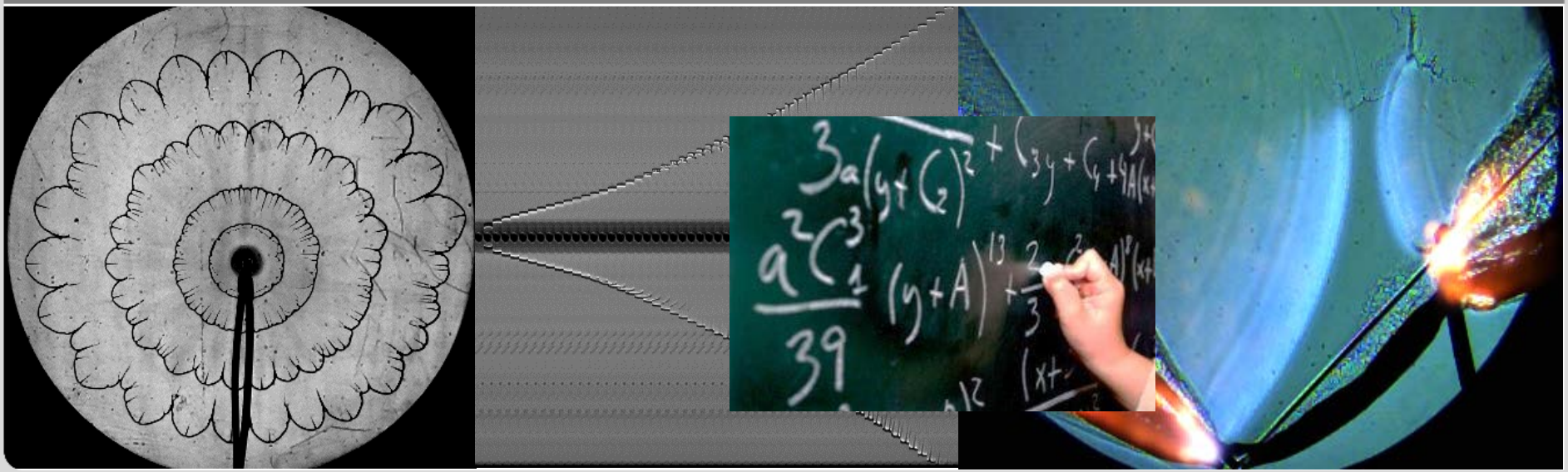

Starting Point

- Presentation of A. Kotchourko about gaps at the RPW Berlin 2012:

…

H2 Safety Research Needs

Article "How safe is Hydrogen?" by J. Hord: pp 615 Symposium Papers of the "Hydrogen for Energy Distribution„, Lyon, France, July 24-28, **1978!**

- Experimentally verify detonation in open air detonable clouds. (Evaluate strong initiator and the possibility of transition from deflagration to detonation in the absence of turbulence inducers).
- Confinement: (What constitutes sufficient confinement to sustain a detonation or higher order explosion?). Determine the effects of weak walls, elastic curtains, etc. on the transition to detionation, relief of deflagrations, etc.
- Model and study the effects of piping complex and turbulence-inducing appurtenances, for example, subdivisions, trees, buildings, etc. on transition to detonation

Status of Project 1501426

Development of criteria for FA and DDT Phase II

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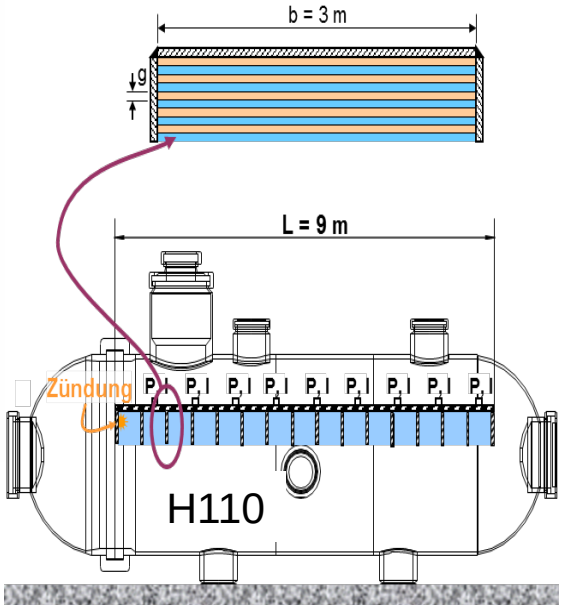
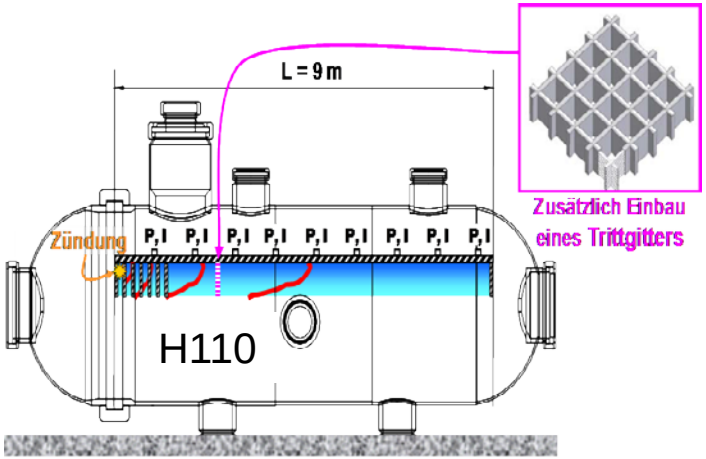
Project 1501426 – Work Program

Part 1:
Influence on obstacle geometry



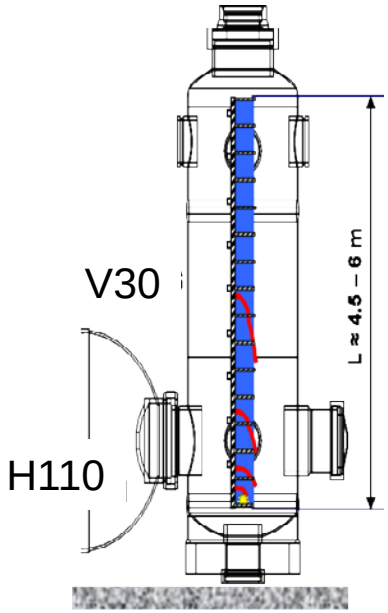
- Influence of the obstacle geometry
- gap width d,
- distance s,
- shape,
- blockage ratio BR.
- With and without vertical concentration gradient

Part 2:
Fast flame propagation in unobstructed partiallyopen flat layers



- Short effective booster
  ➔ starting with fast flame, detonation
  ➔ propagation in free channel
- **AREVA:** Effect of grids as real obstacles?

Part 3:
Variation of the orientation

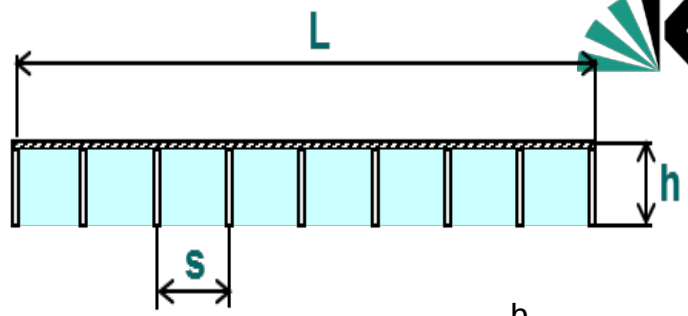


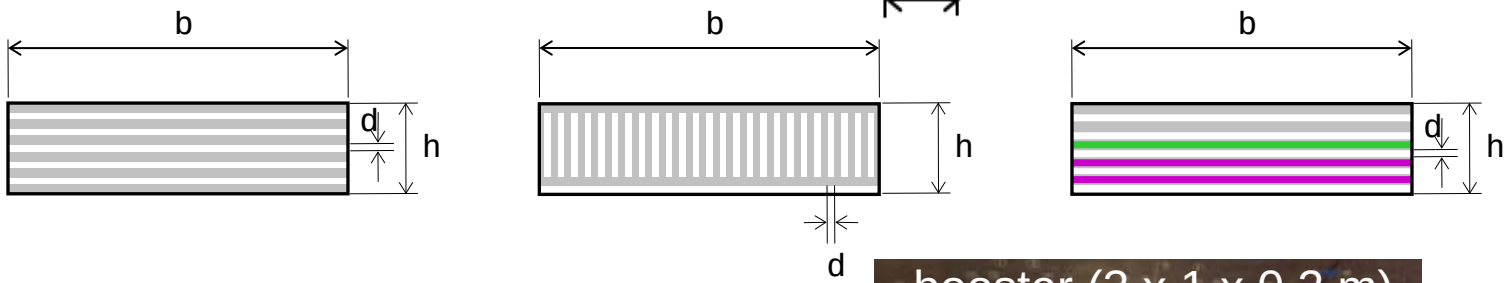
- Concentration gradient:
  - vertical (positive/negative)
  - horizontal
- Ignition on top and bottom
- Production of the gradient mixtures

Project 1501426 – Work Accomplished

Test Matrix Part 1

38 experiments: 19 with homogeneous mixtures
19 with gradient mixtures



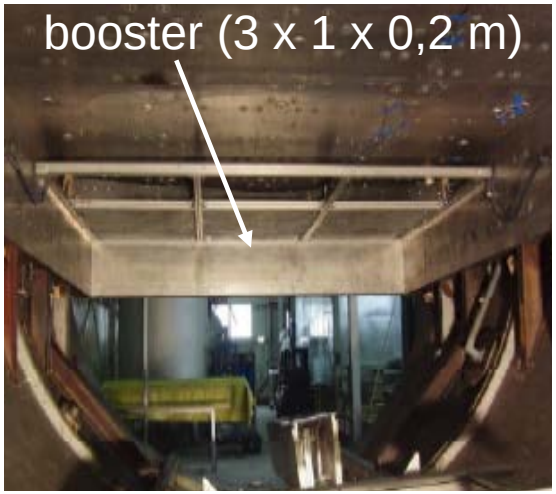


Test Matrix Part 2

66 experiments: 17 with homogeneous mixtures
49 with gradient mixtures

... with grid obstacle

10 experiments: 3 with homogeneous mixtures
7 with gradient mixtures

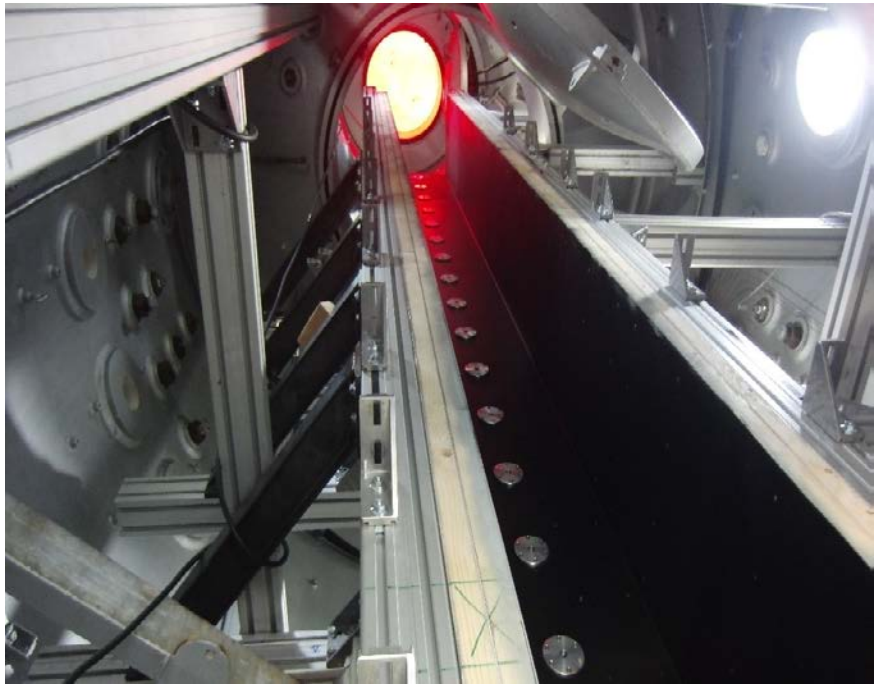


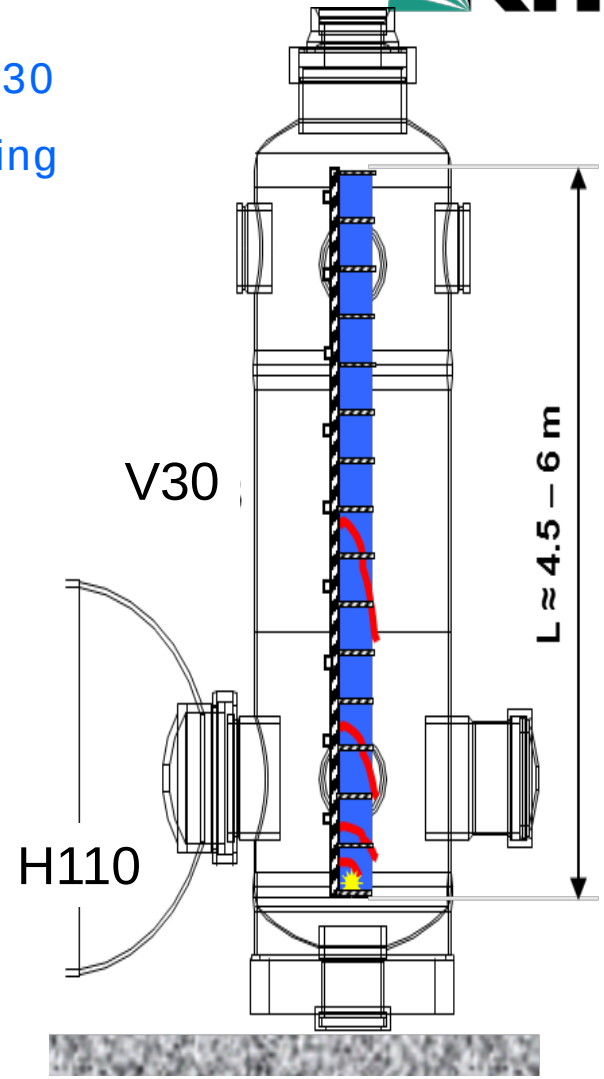
In total: 114 experiments conducted in the horizontal channel in H110

Project 1501426 – Part 3

Status of Part 3

- Vertical channel (0,4 m x 0,4 m x 6 m) installed in V30
- Preparation experiments also in small scale for opening of the plastic
- Intrumentation almost finished



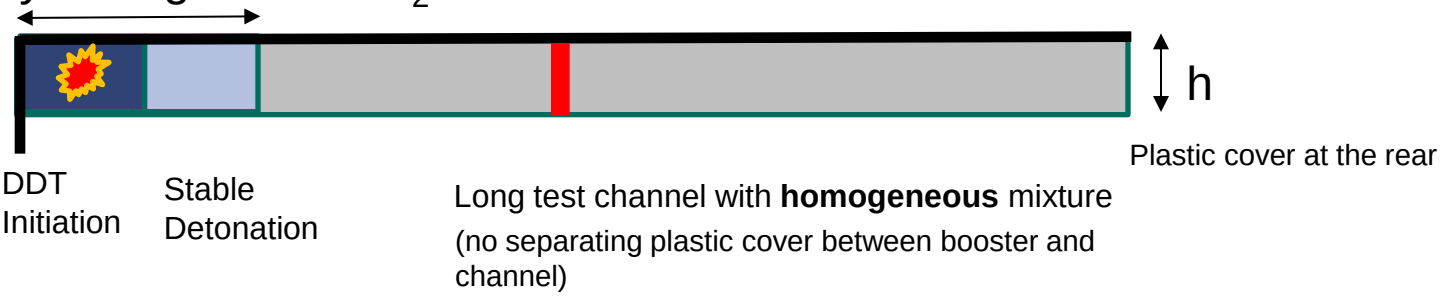


Some Results of Part 2

Limits of the Detonation Propagation in stratified H_2/air Mixtures in Patially Open Channel without Obstables (without grid)

Investigation of the detonation onset in H_2/air mixtures

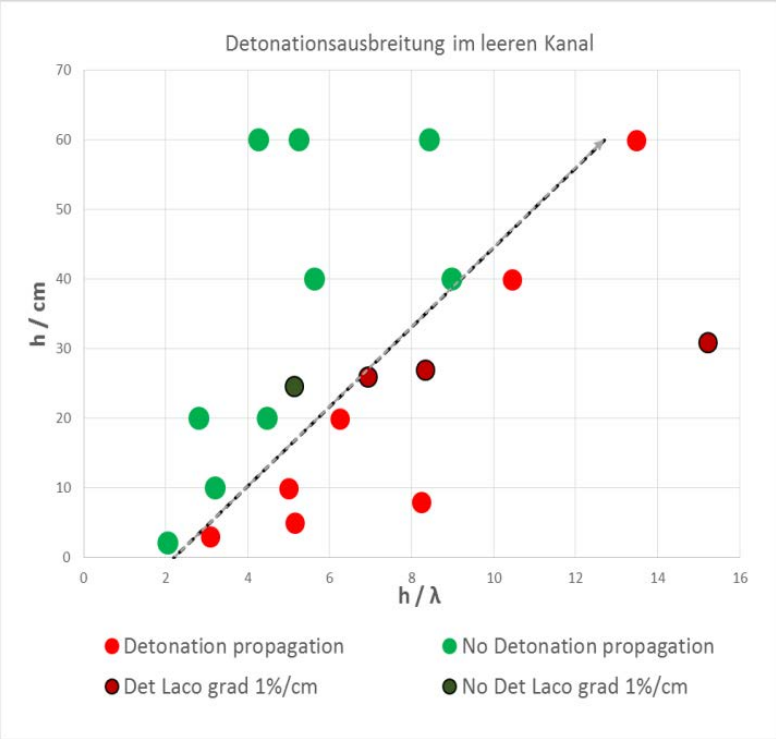
Homogeneos H_2/air layer with plastic cover:
Variation = layer height h und H_2 concentration

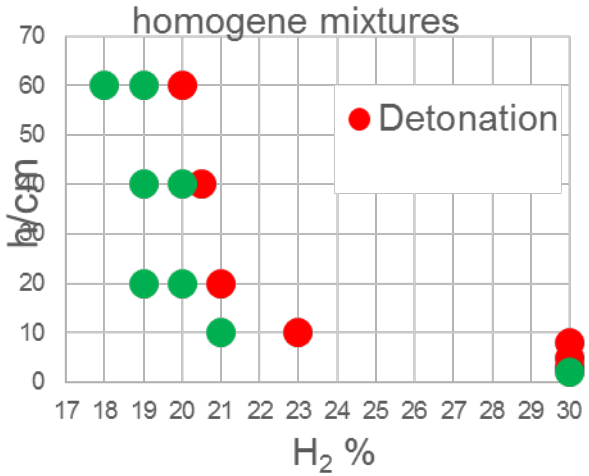


Stratified H_2/air layer:
Variation = Gradient, height and maximum concentration in gradient mixture

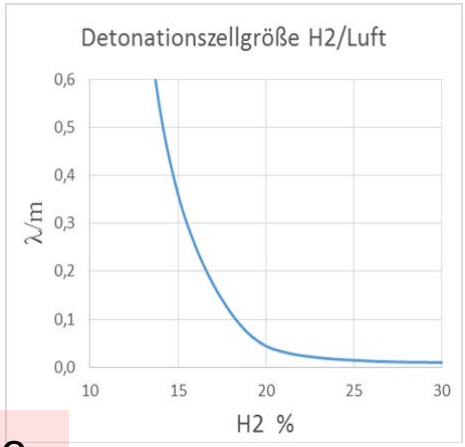
For initiation of detonation injection of additional hydrogen in the booster is required

Limits of the Detonation Onset in homogeneous H_2/air mixtures





In homogeneous H2/air layers with large height detonation spreads predominantly in a sub-layer immediately under the ceiling



Detonation cell size λ = reactivity scale

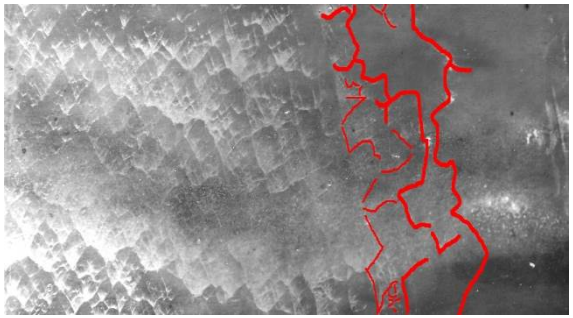
Instrumentation

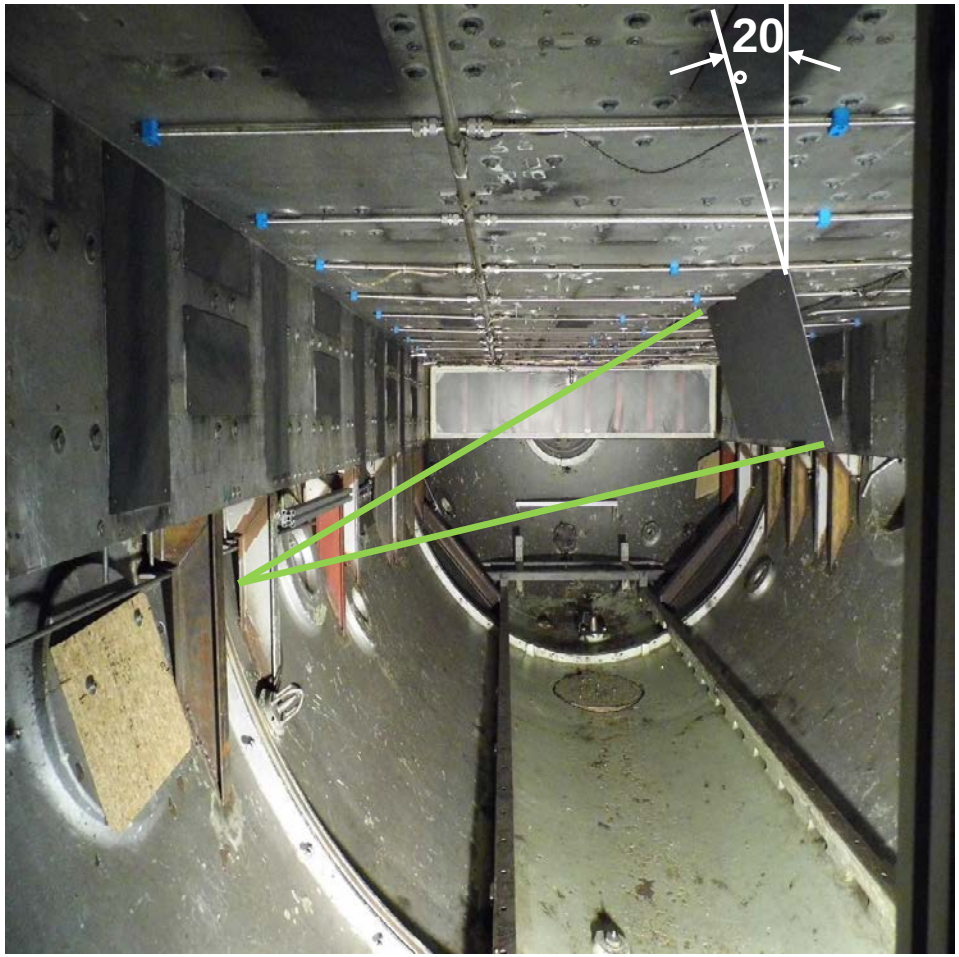
16 x pressure probes

12 x ionisation probes

Up to 48 smoked plates
(at ceiling and on side walls)

High speed video camera pointing at smoked plate
(0,5 m x 1 m)





High speed video arrangement

Test Matrix

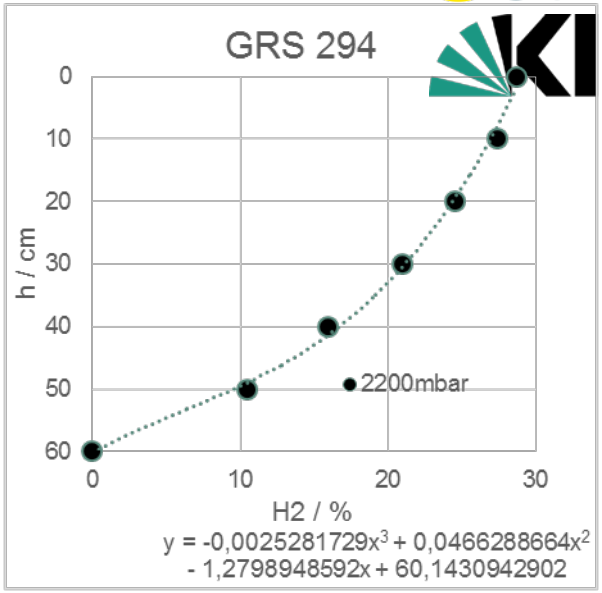
Nr	max H2% Decke	Gradienten Art	h von c (20,5 % H2)	Detonation im Booster	Zusatz H2-Injektion in Booster	Detonation in Testschicht
294	28,7	2200 /80	31,7	ja	nein	ja
295	26,4	2000 /80	21,64	ja	nein	Ja
296	23,9	1800 /80	12,88	nein	nein	
297	23,9	1800 /80	12,88	nein	nein	
298	23,9	1800 /80	12,88	ja	Ja	ja
299	22,0	1700 /80	6,0	nein	Ja	
300	22,0	1700 /80	6,0	nein	Ja	
301	22,0	1700 /80	6,0	nein	Ja	
302	22,0	1700 /80	6,0	nein	Ja	
303	22,0	1700 /80	6,0	nein	Ja	
304	22,0	1700 /80	6,0	nein	Ja	
305	22,0	1700 /80	6,0	nein	Ja	
306	22,0	1700 /80	6,0	ja	Ja	nein
307	22,95	1750 /80	9,43	ja	Ja	nein
308	30,67	1600 / 100	17,5	ja	nein	ja
309	27,98	1500 / 100	13,67	ja	nein	Ja
310	25,29	1400 / 100	8,65	ja	Ja	nein
311	26,64	1450/ 100	12,0	ja	Ja	ja
312	22,7	1350 /100	3,06	ja	Ja	nein
313	41,24	2200 / 100	38,7	nein	nein	
314	41,24	2200 / 100	38,7	ja	**O2-Injehtion**	Ja

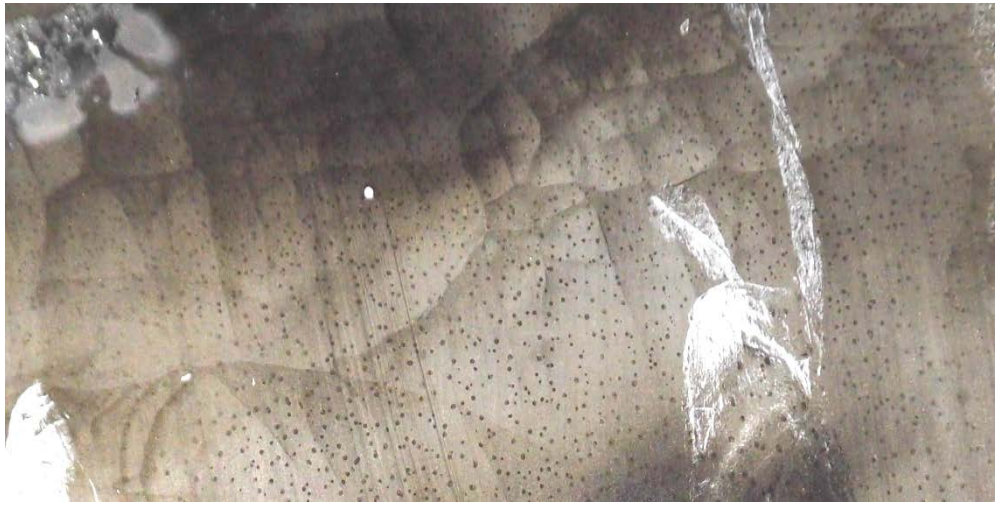
GRS 294 (C_{max} = 28,7 %)

Side wall

h_{Det} = 31 - 35 cm

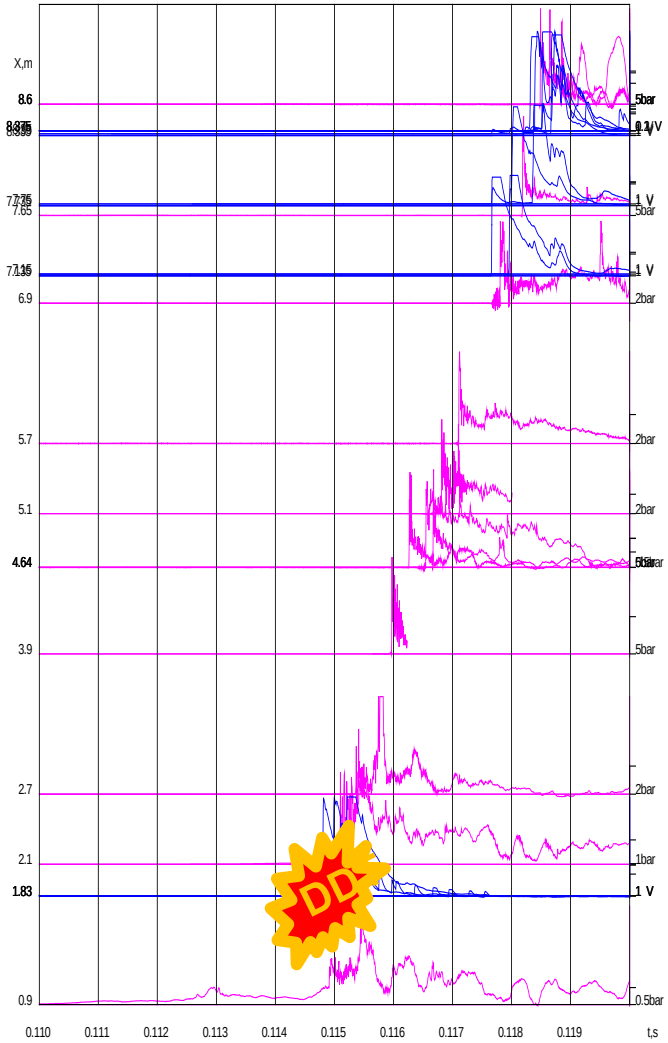
Ceiling





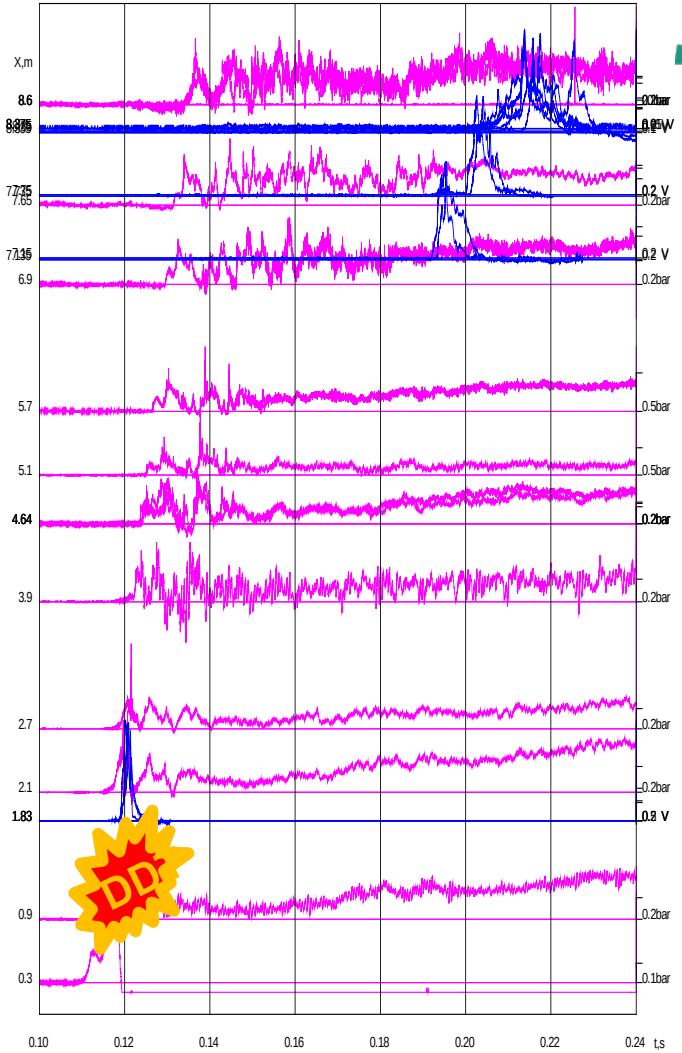
Side wall, zooming in

GRS 298 (C_{max}=23,9 %)



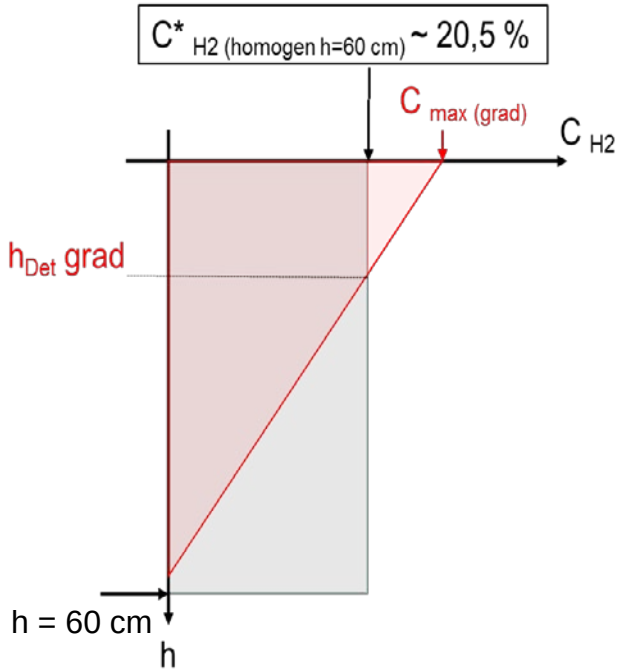
Stable **detonation onset**

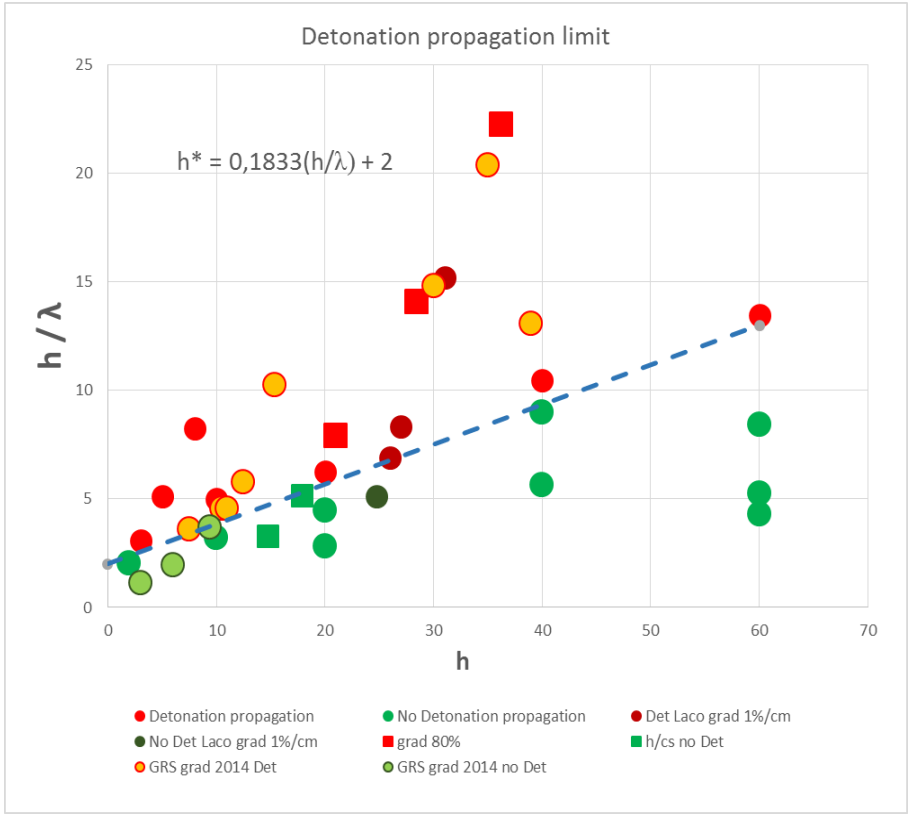
GRS 307 (C_{max}=22,95 %)



No detonation onset

Intermediate Summary





Homogeneous mixtures:

C_{H2} and layer height **h**

Gradient mixtures:

$C_{max\ (grad)}$ eand effective layer height **h_{Det}** grad

Results

- Improved understanding of detonation stability
- Extended robust criteria for FA and DDT in half open flat layers with stratified gradient mixtures
- To be accomplished for vertical arrangement