An experimental study of the influence of a two-scale roughness on a turbulent boundary layer

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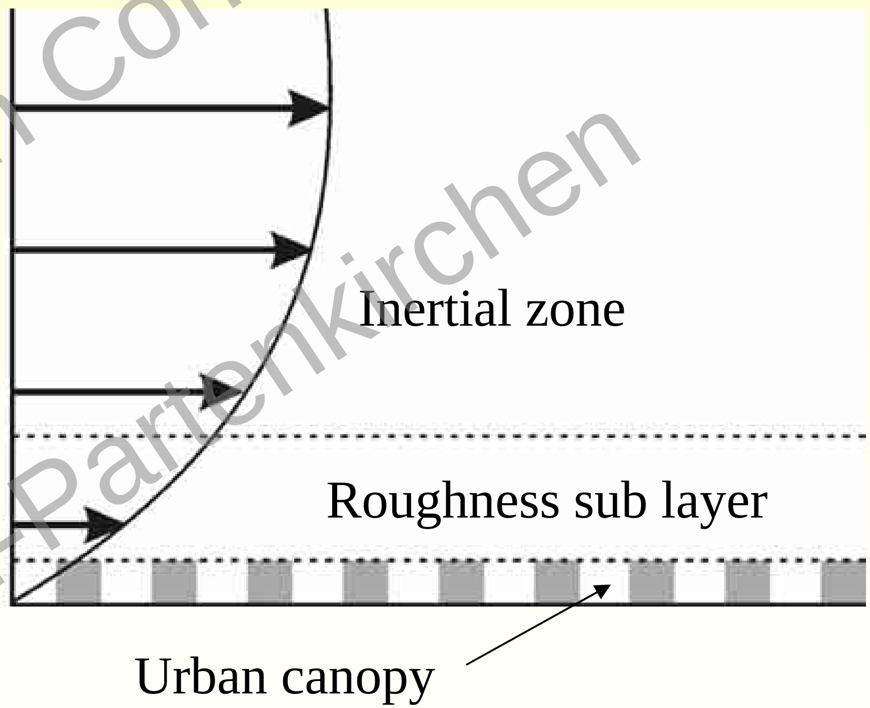
Objective of the study

- Evaluate the influence of the geometry of the buildings on the lower part of the atmospheric boundary layer
- Characterise the exchange between the urban canopy and the roughness sub-layer



Geometrical parameters

- building areal density

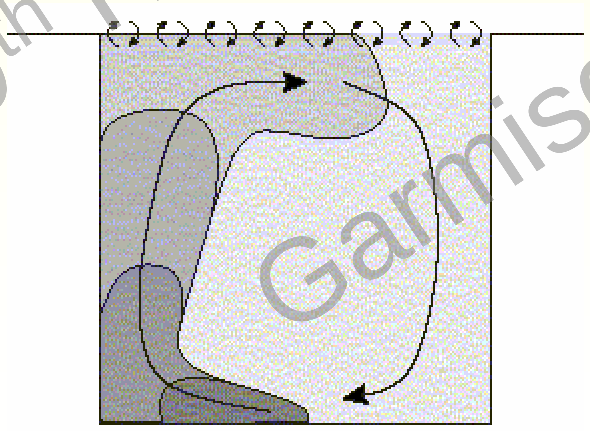
- small scale roughness (roof shape, chimney..)

Typical lenght scales

- $\delta \sim 100 - 1000$ m - atmospheric boundary layer height (in neutral conditions)
- $H \sim 10$ m - typical buildings length scale
- $h \sim 1$ m - small scale roughness (roofs, chimney..)

Open questions

- How does the presence of small scale roughness (roof shape, chimney....) at the top of the buildings affect turbulent flow and dispersion characteristics above buildings roofs?
- Which are the relevant processes in determining the mass exchange between the recirculating region and the external flow



- advective transport inside the cavity
- turbulent transport at the interface (incoming turbulence, local generated turbulence)

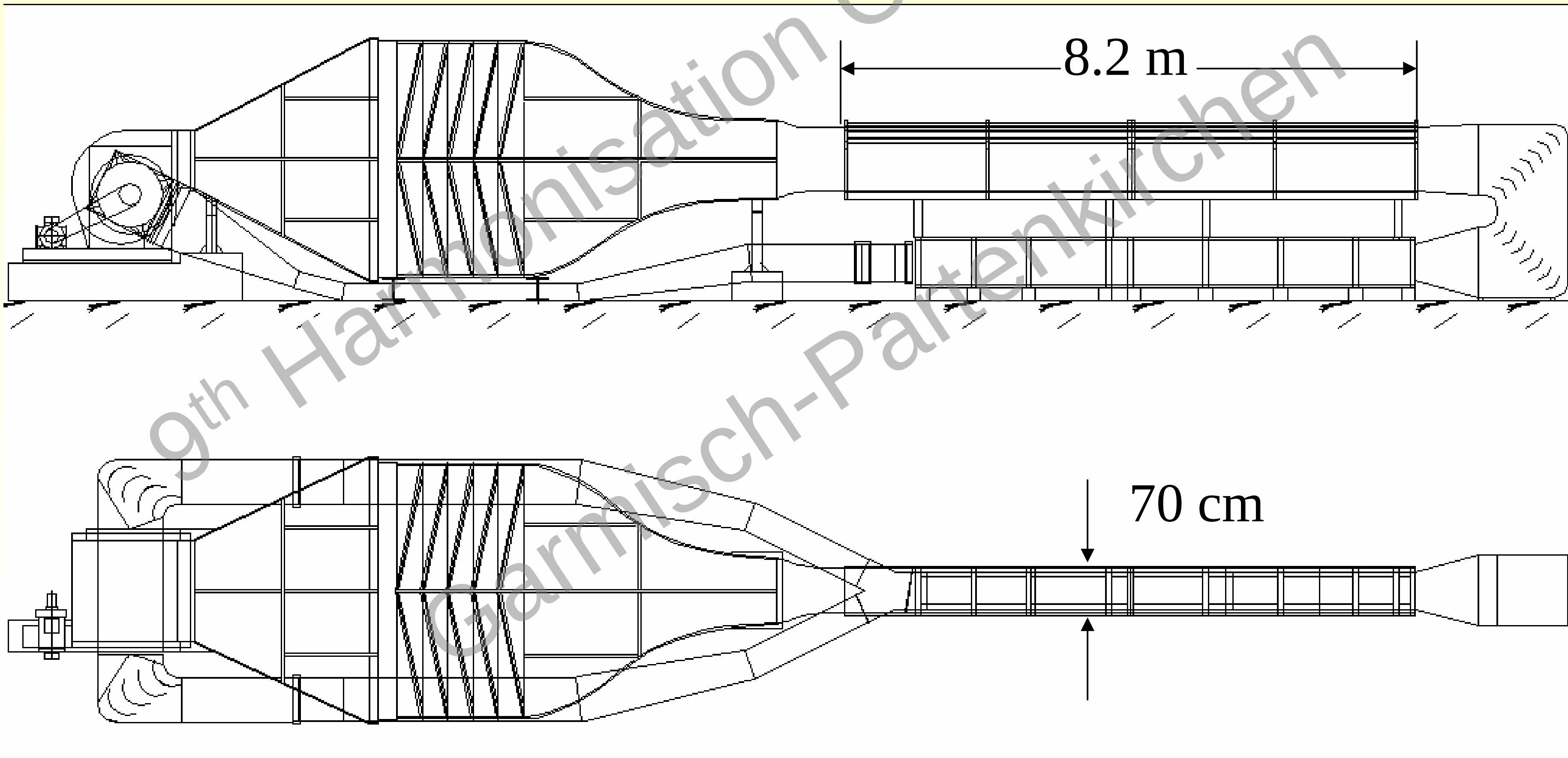
Methodology

Wind tunnel experiments in 2D geometry taking in account the small scale roughness

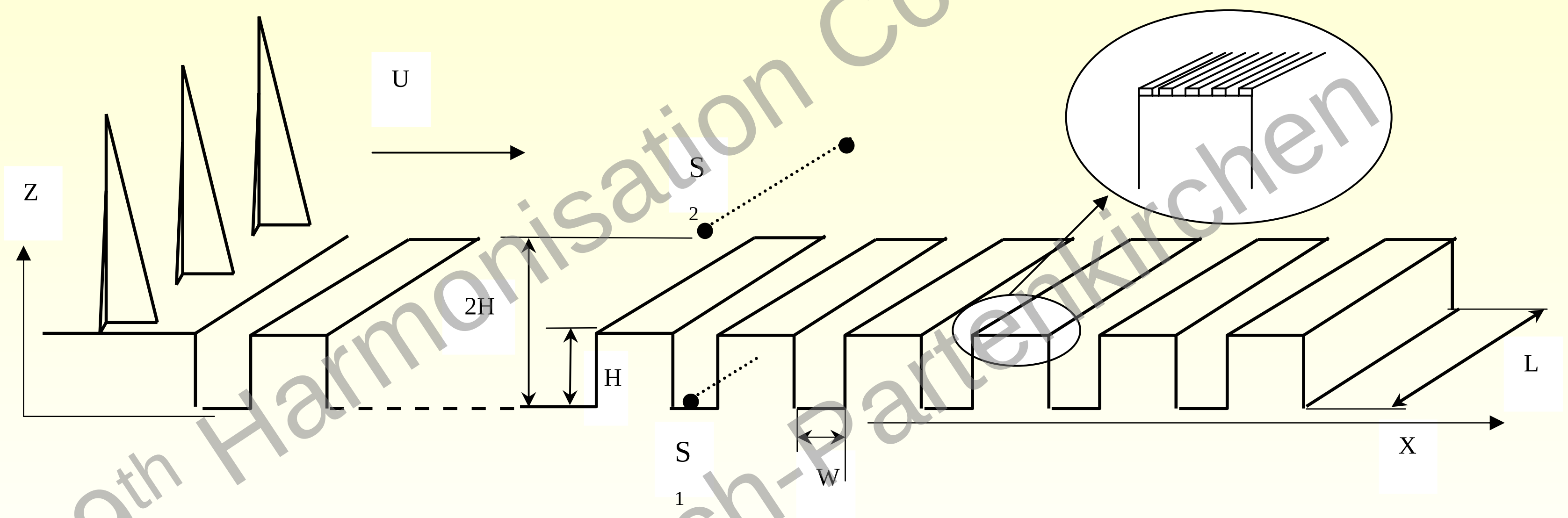
- Flow dynamics above the obstacles - hot wire anemometry
- Passive scalar dispersion - Flame Ionisation Detector
- Measurament of the wash-out time of the cavity

LMFA Wind Tunnel

LMFA Wind Tunnel

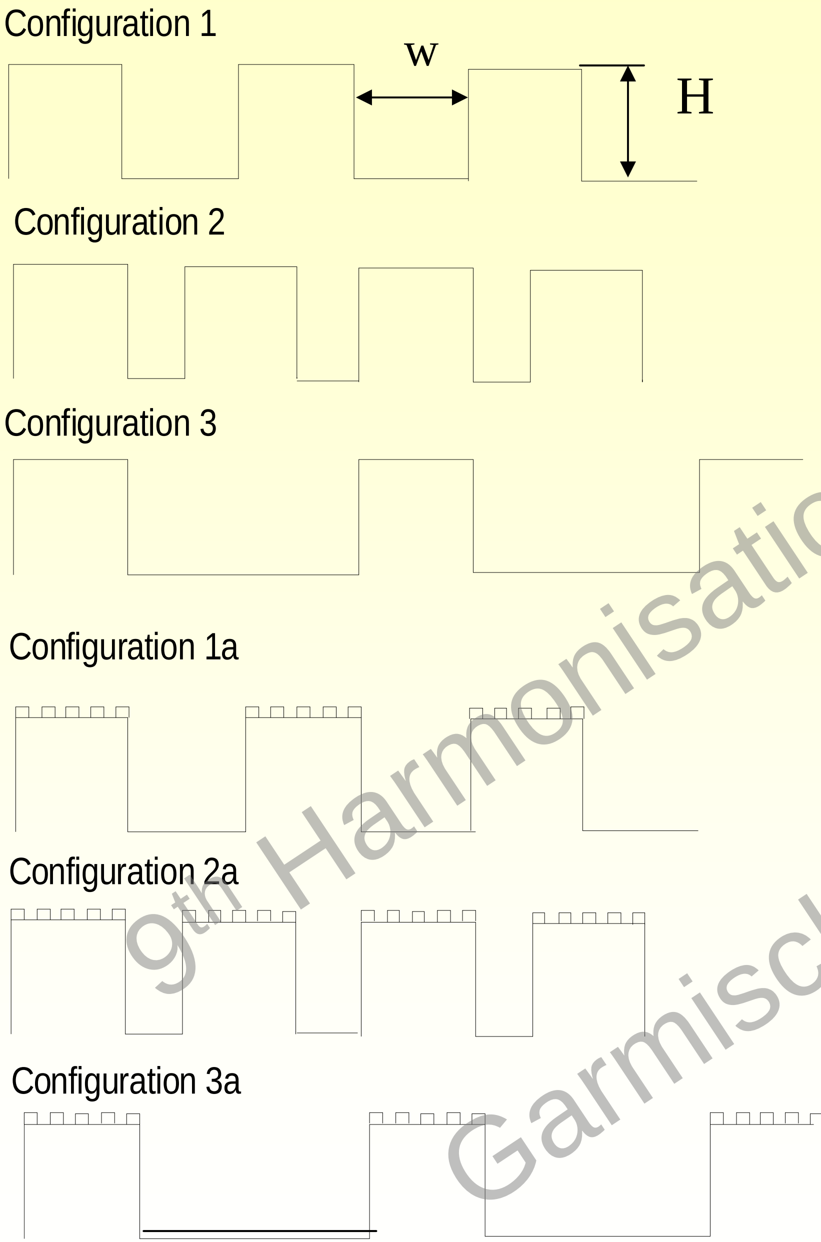


Experimental Set-Up



H=6 cm U=6 m/s L=70 cm

Configurations studied



H/W=1

H/W=2

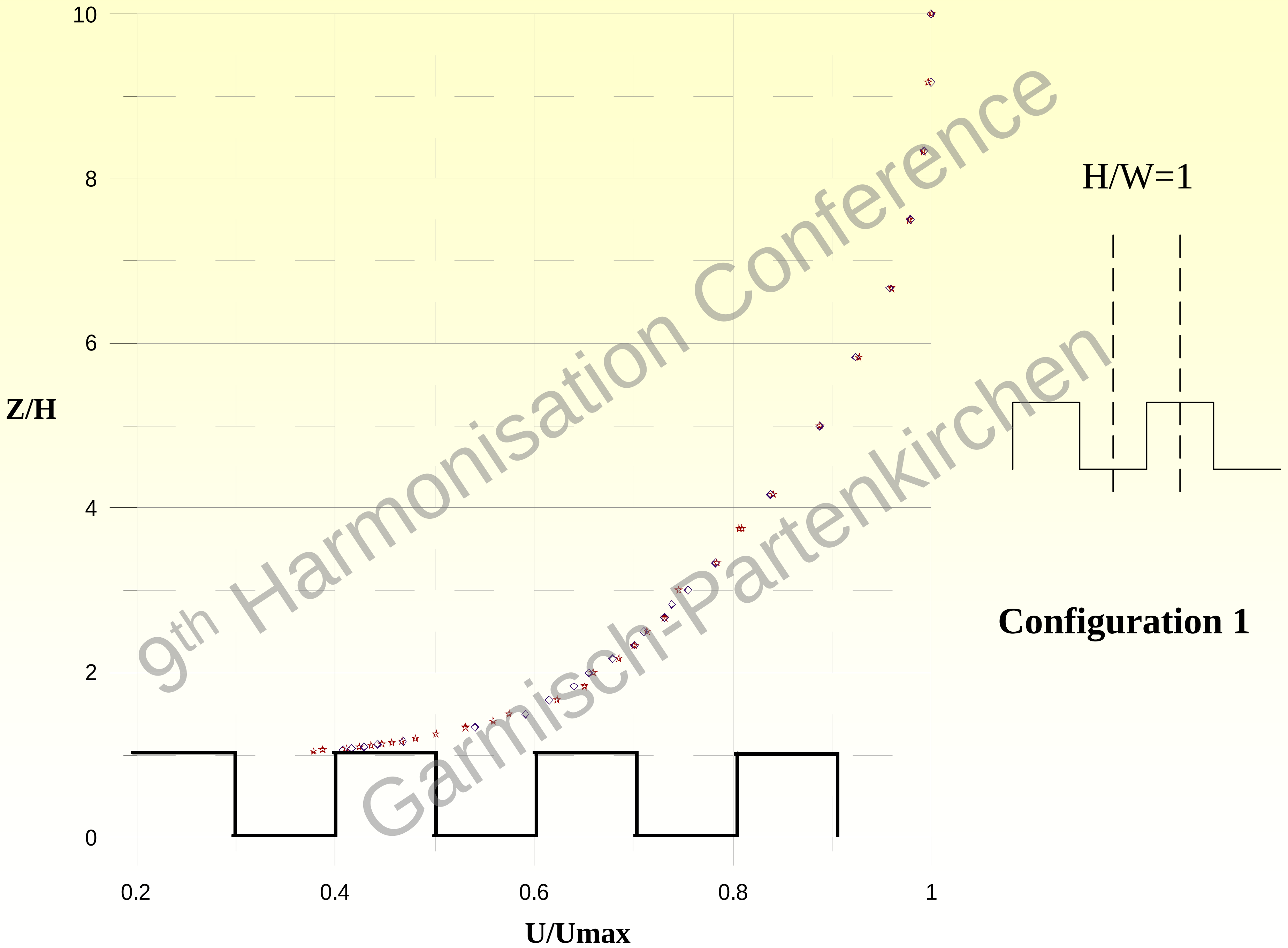
H/W=1/2

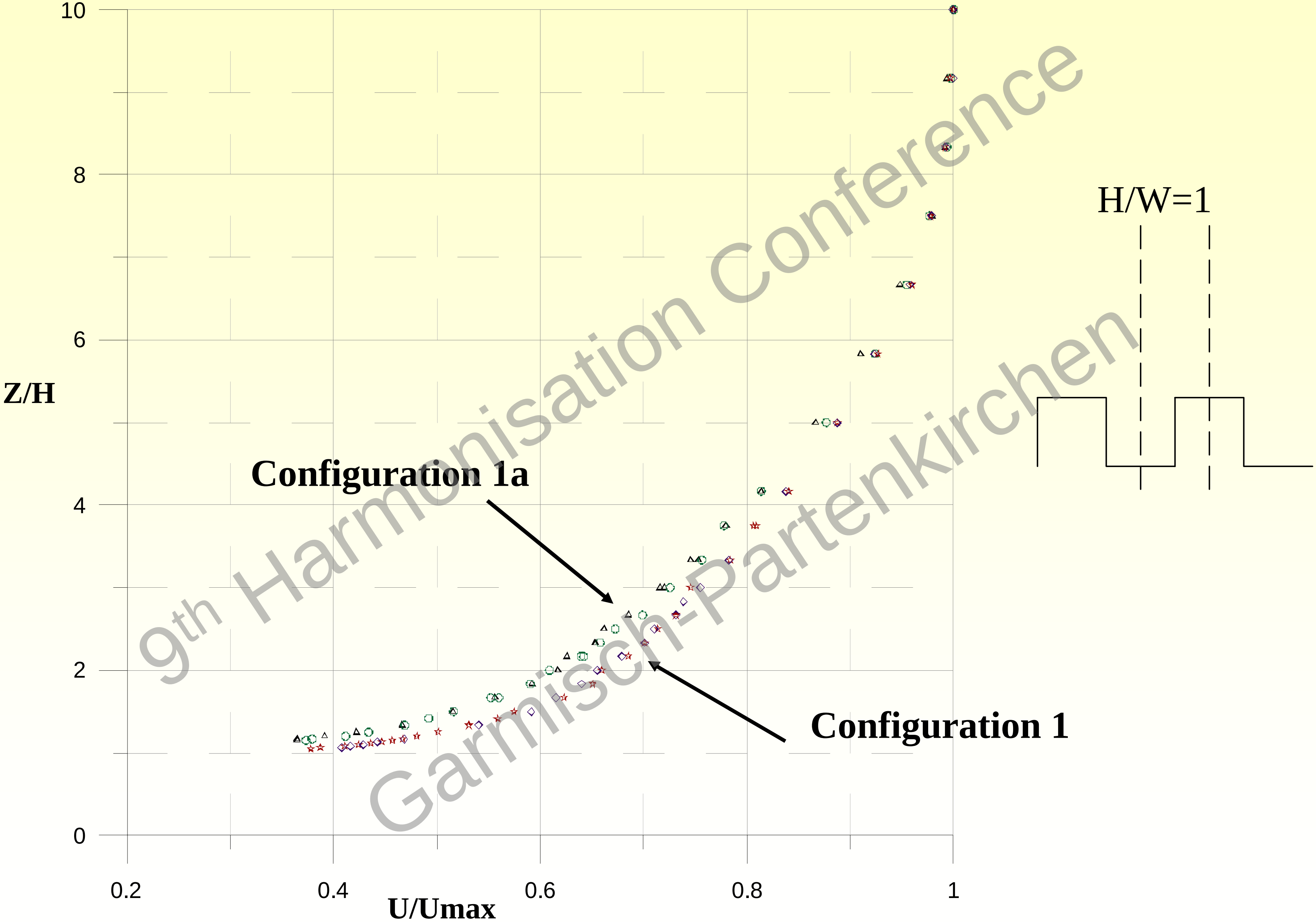
	z_0 (mm)	u_* (m/s)	d (mm)	n
config 1	0.2638	0.33	55	0.21
config 1a	1.147	0.36	55	0.25
config 2	0.1916	0.305	60	0.18
config 2a	0.5004	0.335	60	0.212
config 3	6.345	0.41	50	0.34
config 3a	6.345	0.41	50	0.34

Hot wire anemometer measures

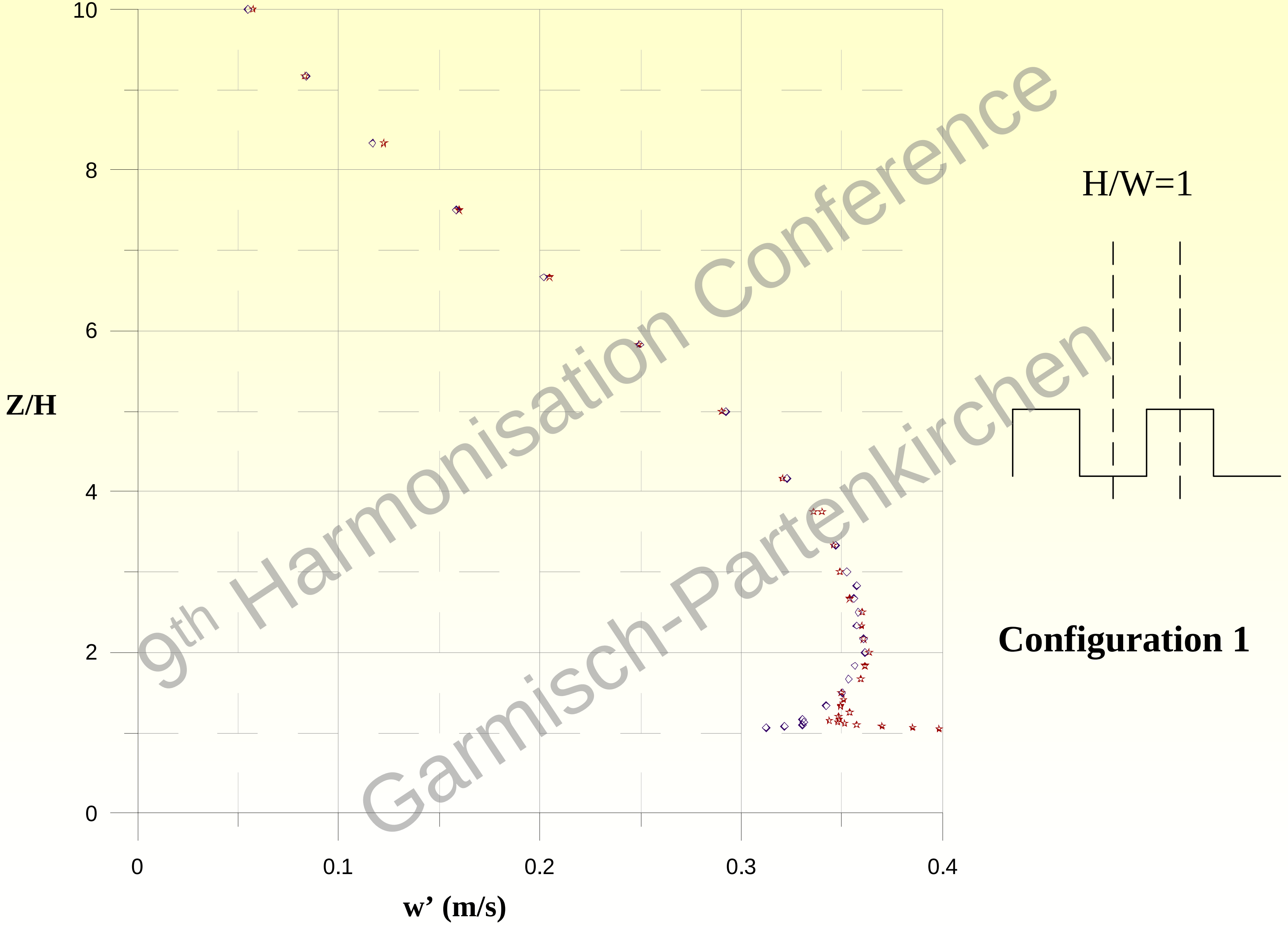
(vertical profiles above the center of the cavity and above the bars)

- Mean Velocity U
- standard deviation of vertical w' and horizontal u' velocity fluctuations
- Reynolds stresses -<u'w'>

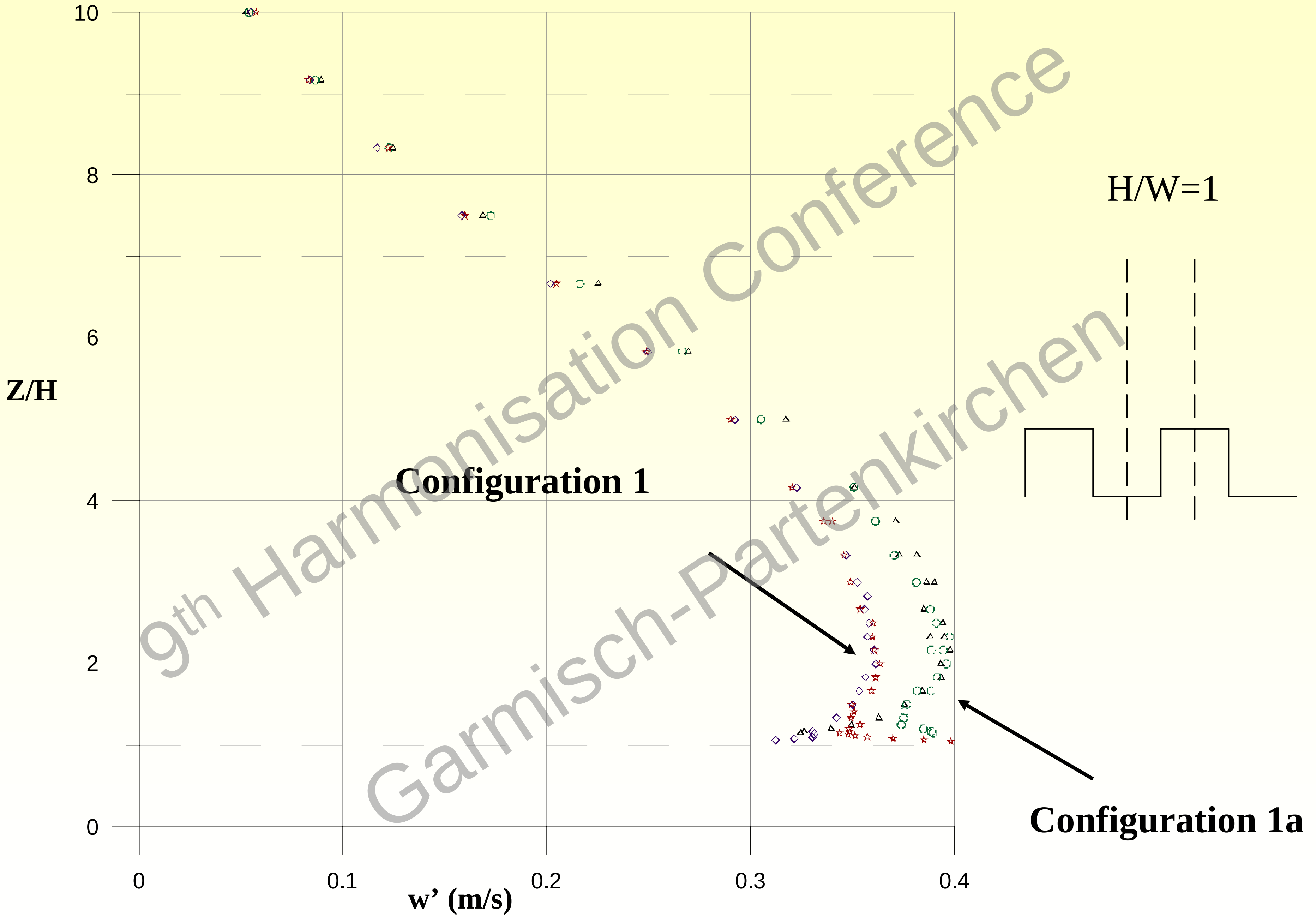

10
8
6
4
2
0
Z/H
0.2
0.4
0.6
0.8
1
U/Umax
H/W=1
Configuration 1
9th Harmonisation Conference
Garmisch-Partenkirchen



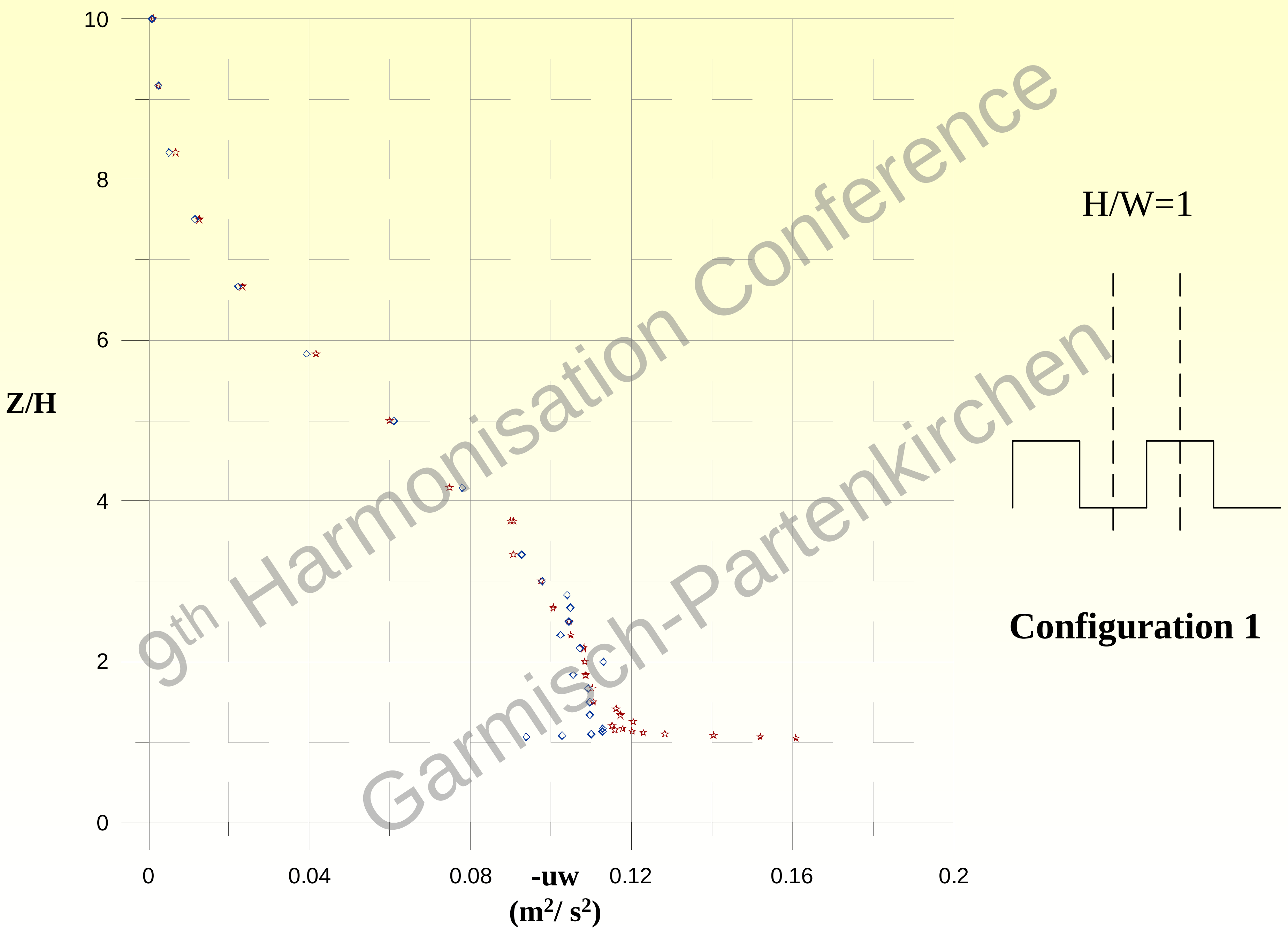
10
8
6
4
2
0
Z/H
0.2
0.4
0.6
0.8
1
U/Umax
Configuration 1a
Configuration 1
H/W=1

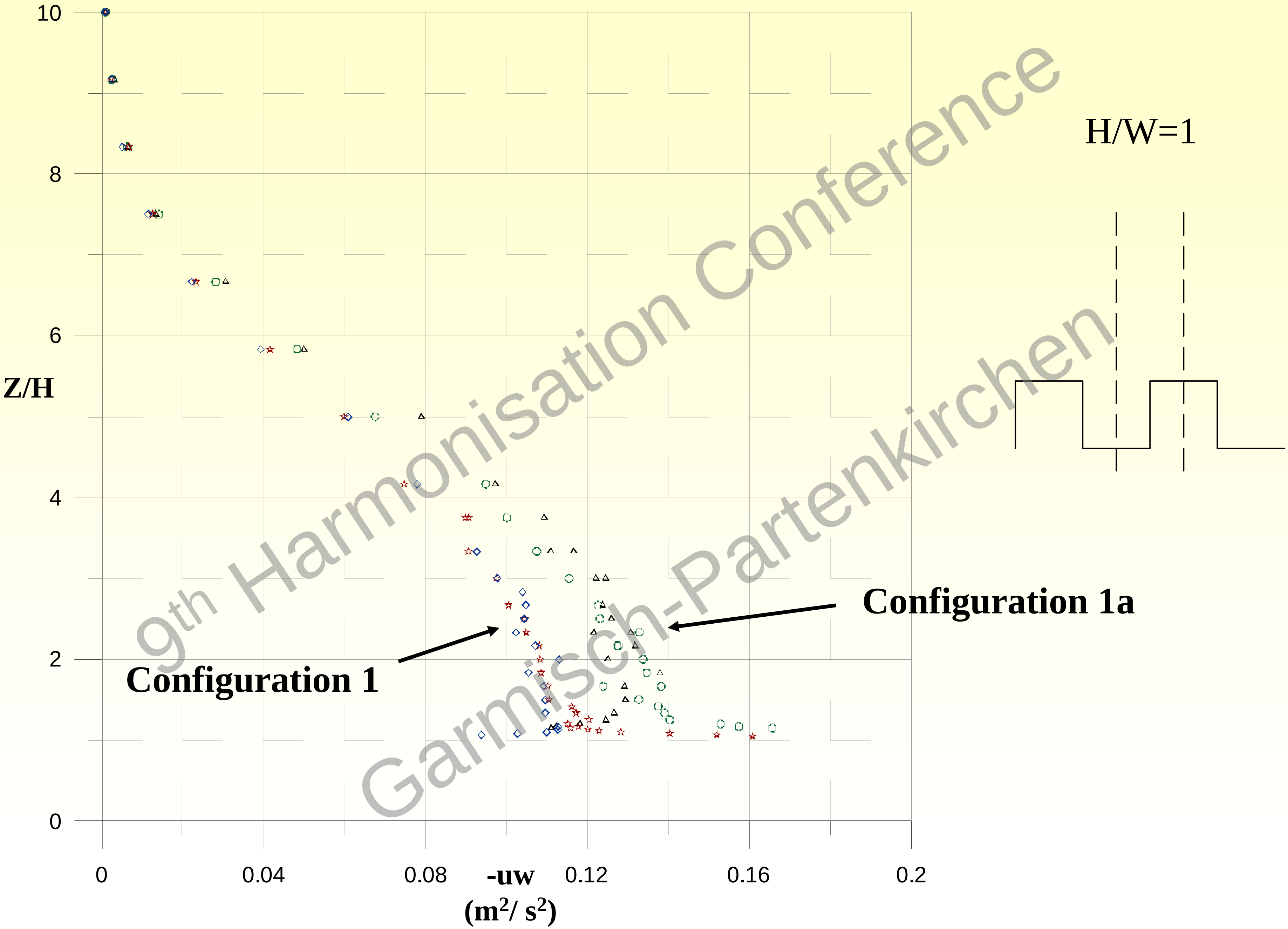


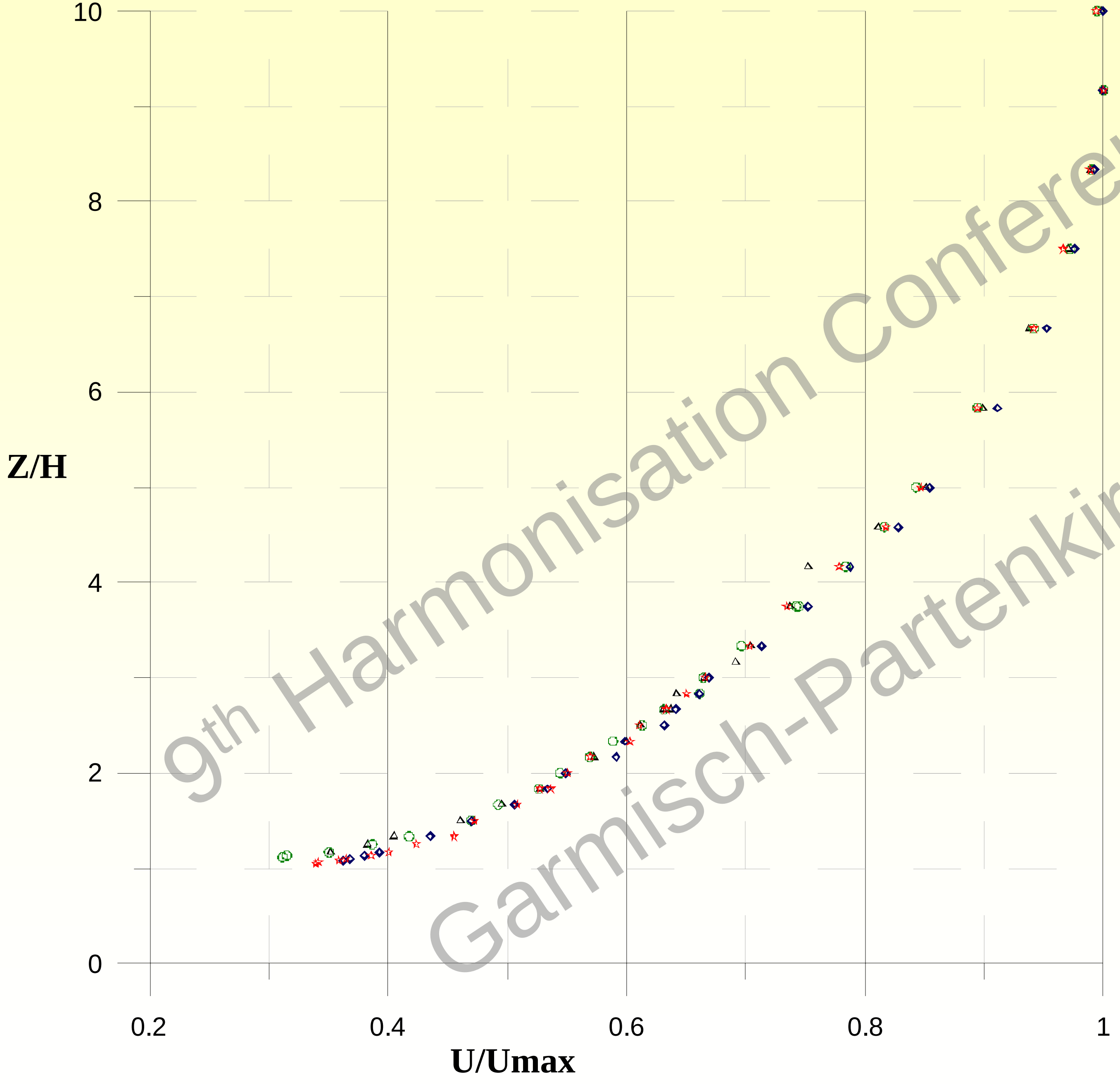
10
8
6
4
2
0
Z/H
0
0.1
0.2
0.3
0.4
w' (m/s)
H/W=1
Configuration 1



10
8
6
4
2
0
Z/H
0
0.1
0.2
0.3
0.4
w' (m/s)
Configuration 1
Configuration 1a
H/W=1

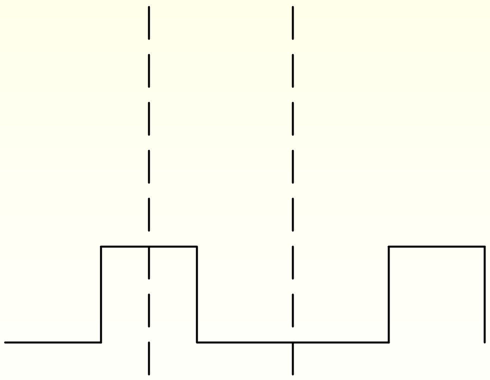

10
8
6
4
2
0
Z/H
0
0.04
0.08
0.12
0.16
0.2
-uw
(m2/ s2)
H/W=1
Configuration 1

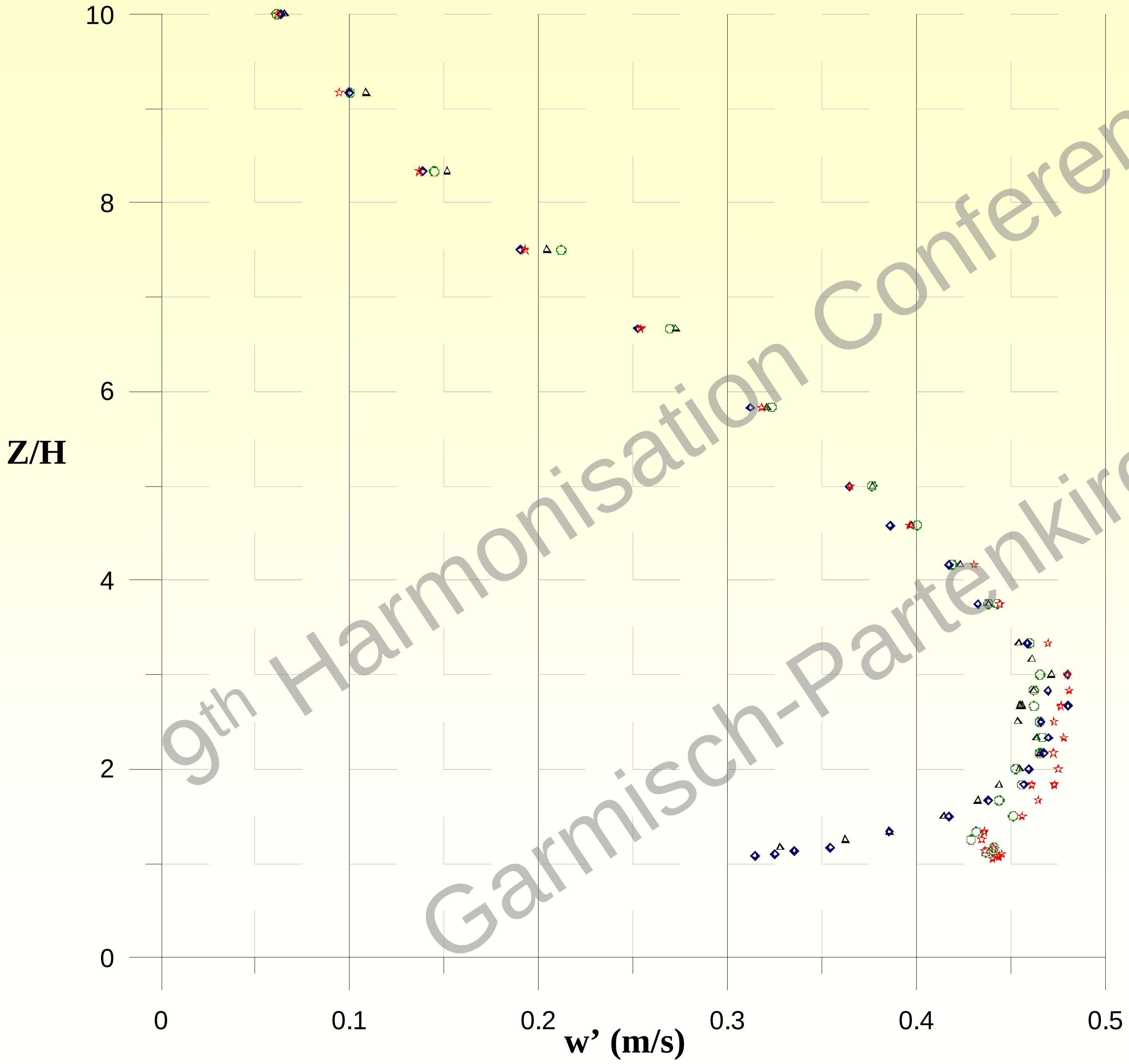

H/W=1
Z/H
10
8
6
4
2
0
0
0.04
0.08
0.12
0.16
0.2
-uw
(m²/ s²)
Configuration 1
Configuration 1a



Configuration 3
vs
Configuration 3a

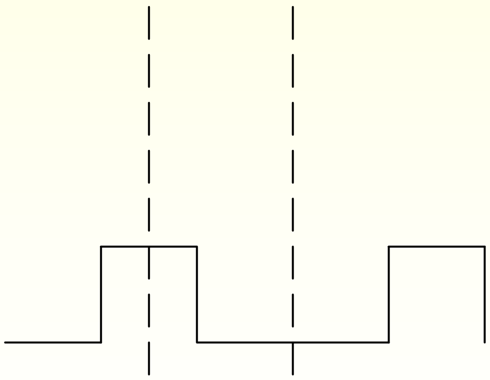
H/W=1/2

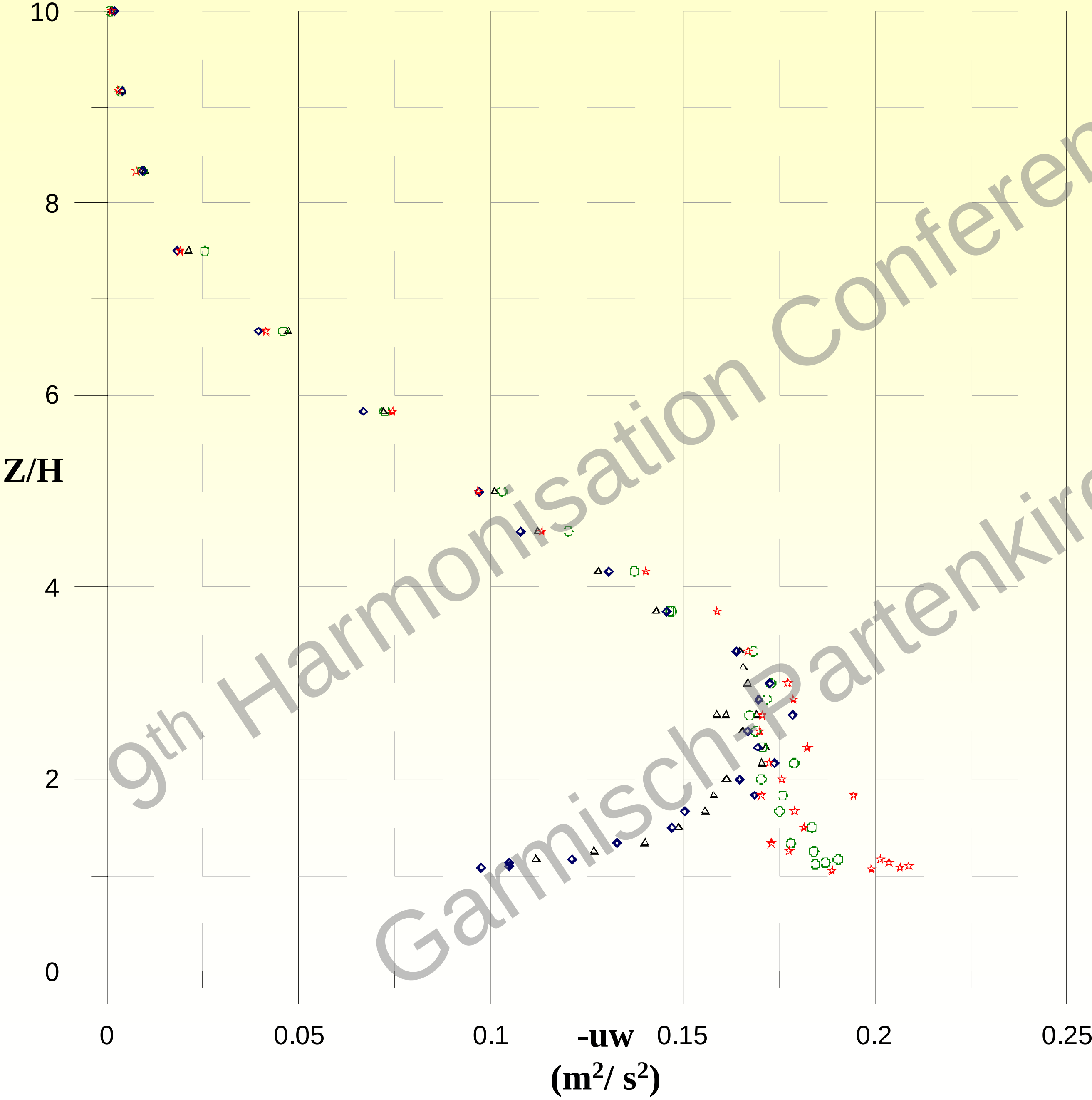




Configuration 3
vs
Configuration 3a

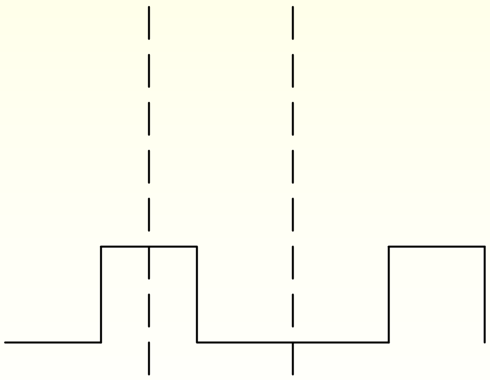
H/W=1/2





Configuration 3
vs
Configuration 3a

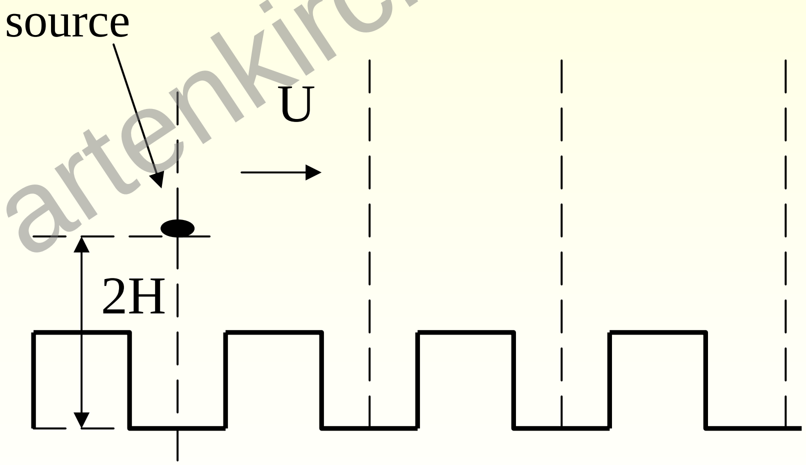
H/W=1/2

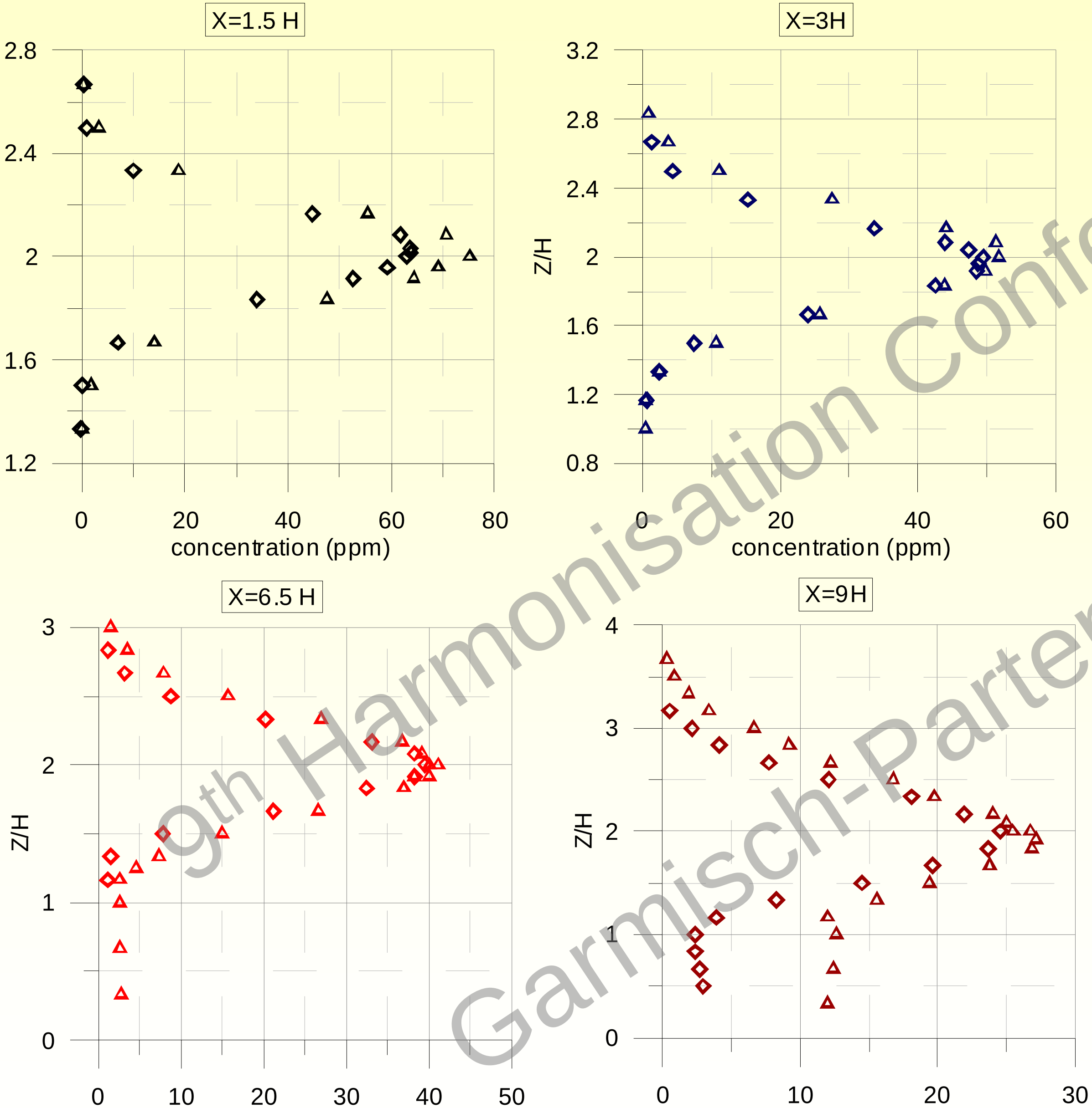


Passive Scalar Dispersion

Gas tracer C_2H_6

Flame Ionisation Detector





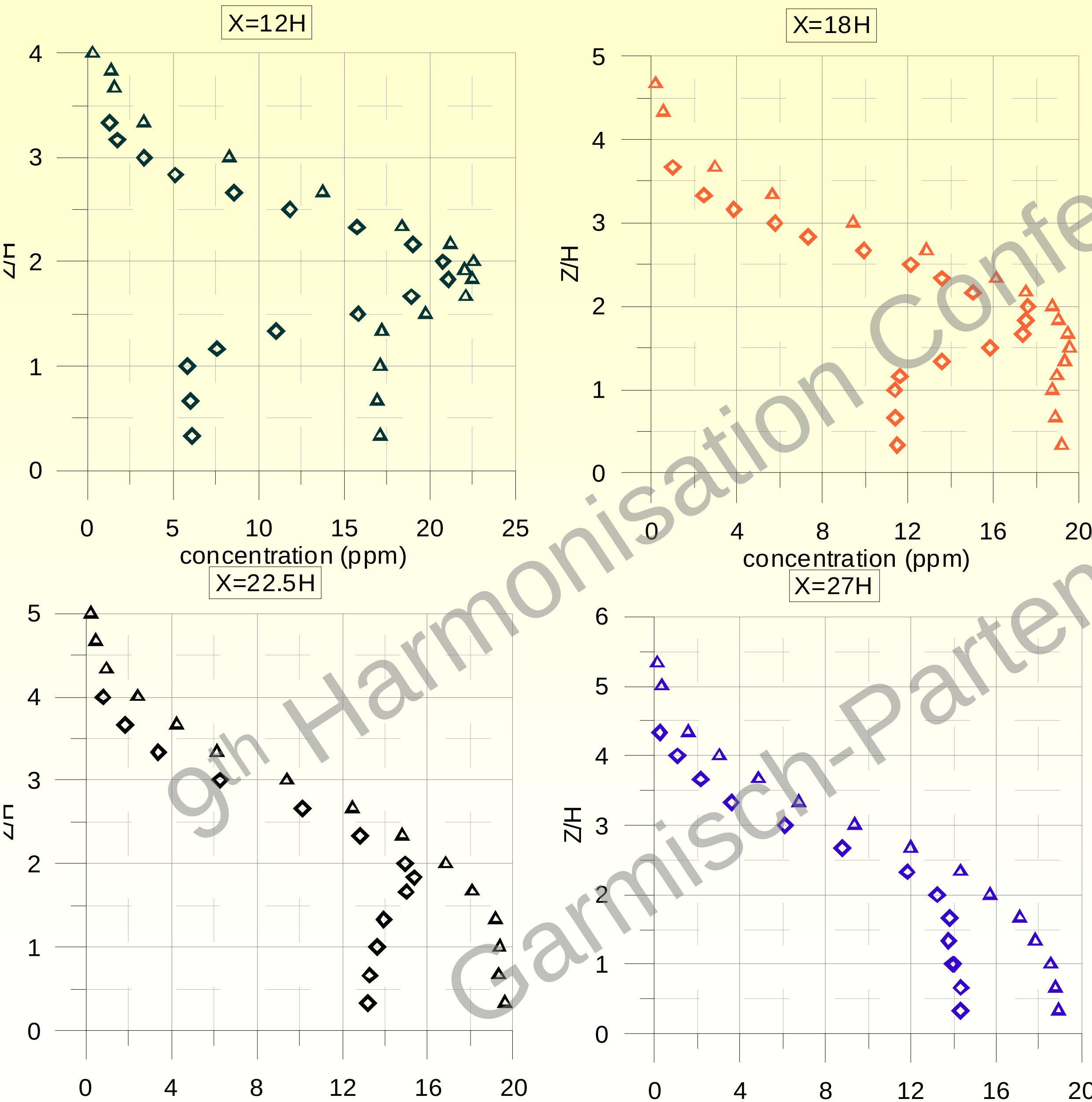
Configuration 2 vs 2a

Source z=2H

Mean Concentration Profiles

config 2 ◇

config 2a △



Configuration 2 vs 2a

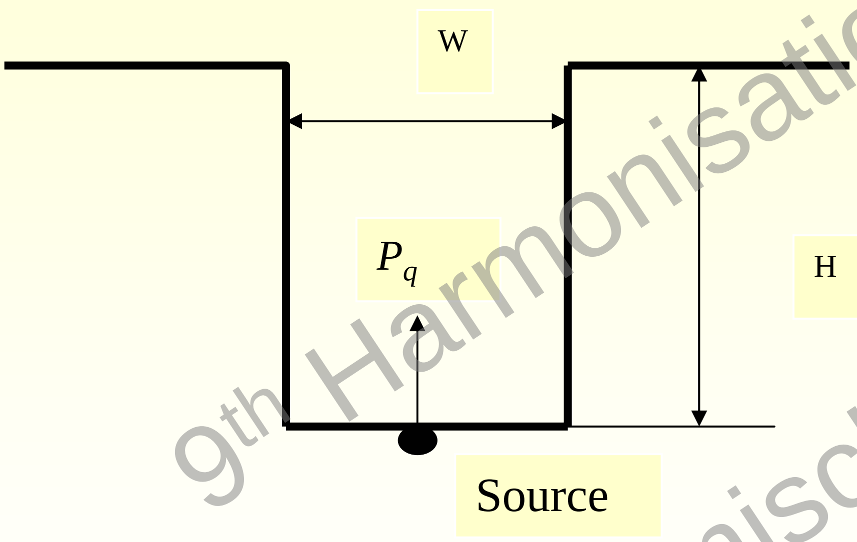
Source z=2H

Mean Concentration Profiles

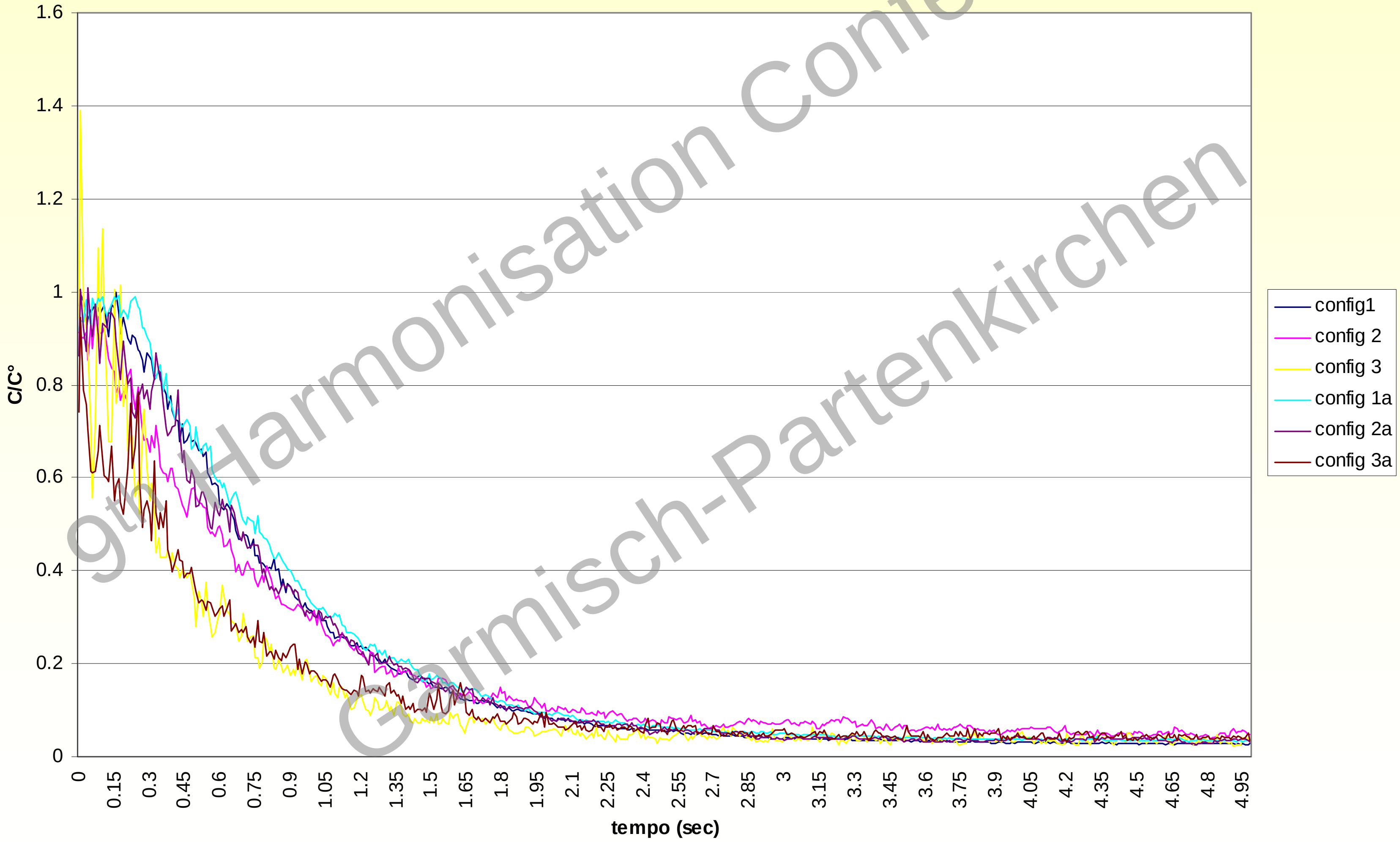
config 2 ◇

config 2a △

Determination of the cavity wash-out time



Wash out time diagrams

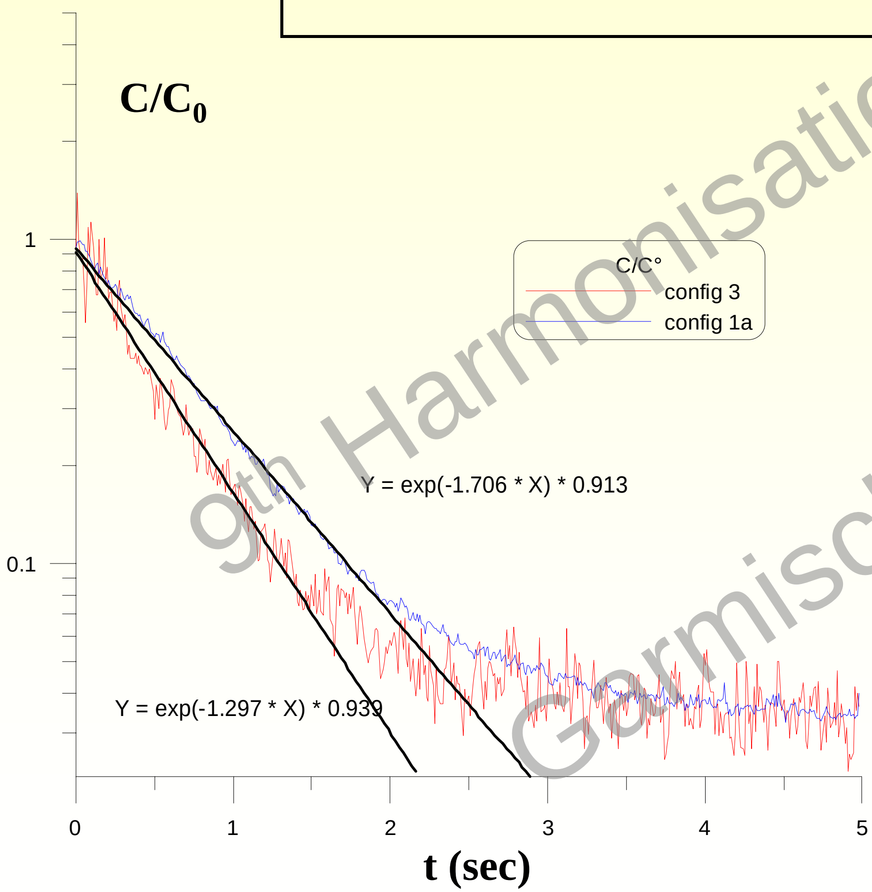


Mass balance inside the canyon $V_0 \frac{dq_0}{dt} = \int_0^W < w'q > dx \approx W\sigma_w q_0$

canyon volume per unit lenght $V_0 = WH$

$$HW\frac{dq}{dt} = W\sigma_w q \qquad \frac{dq}{dt} = \frac{\sigma_w}{H} q$$

$T_0 = \frac{H}{\sigma_w}$ = time costant of the exponential function



Wash out time of the cavity (seconds)

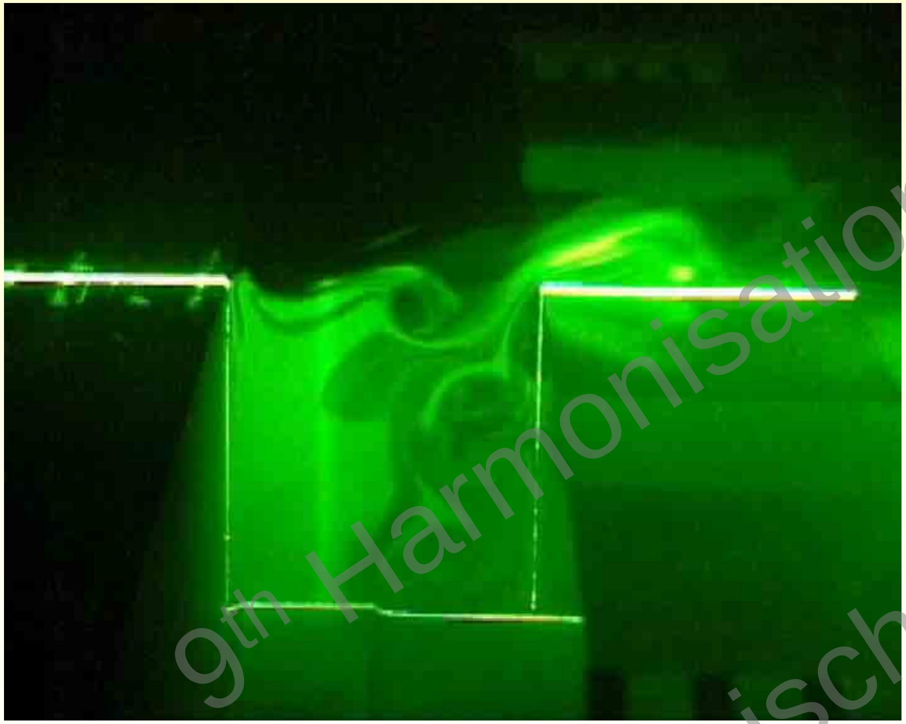
	Without small roughness	With small roughness
H/W=1	0.77	0.77
H/W=1	0.77	0.77
H/W=2	0.77	0.77
H/W=2	0.77	0.77
H/W=1/2	0.58	0.58
H/W=1/2	0.58	0.58

Conclusions

• The small scale roughness increases the turbulence and the vertical dispersion for high aspect ratio cavities (H/W=2 and H/W=1) but it has very little effect for low aspect ratio cavities for H/W= 1/2

• The small scale roughness does not modify the exchange processes between the recirculating region and the external flow

Flow visualisations



Configuration 1
(without small
roughness)

Configuration 1a
(with small roughness)