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# Gas Source Declaration With a Mobile Robot

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# 1

# Gas-Sensitive Mobile Robots

## the catastrophe in Baden-Baden 1973



# 1

# Gas-Sensitive Mobile Robots

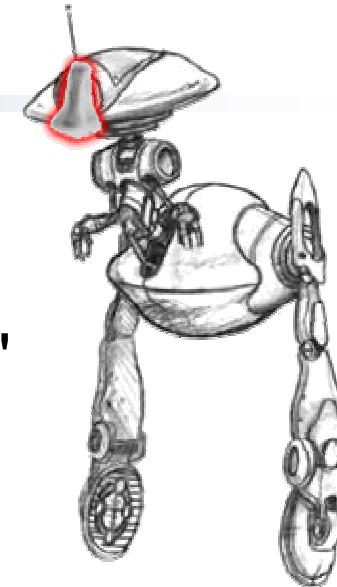


# 1

# Application Domains

## ■ dedicated systems

- security, surveillance: "electronic watchman"
- rescue robots



## ■ additional benefit for available robots

- smell a leaking gas pipe
- detect a fire at its initial stage (CO)
- monitor pollutants in the environment



# 2

# Gas Source Localisation

- sub-tasks
  - gas finding
  - gas source tracing
  - gas source declaration
  
- main difficulties
  - state-of-the art gas sensors
  - turbulent gas distribution
  - no analytical model available



## 2

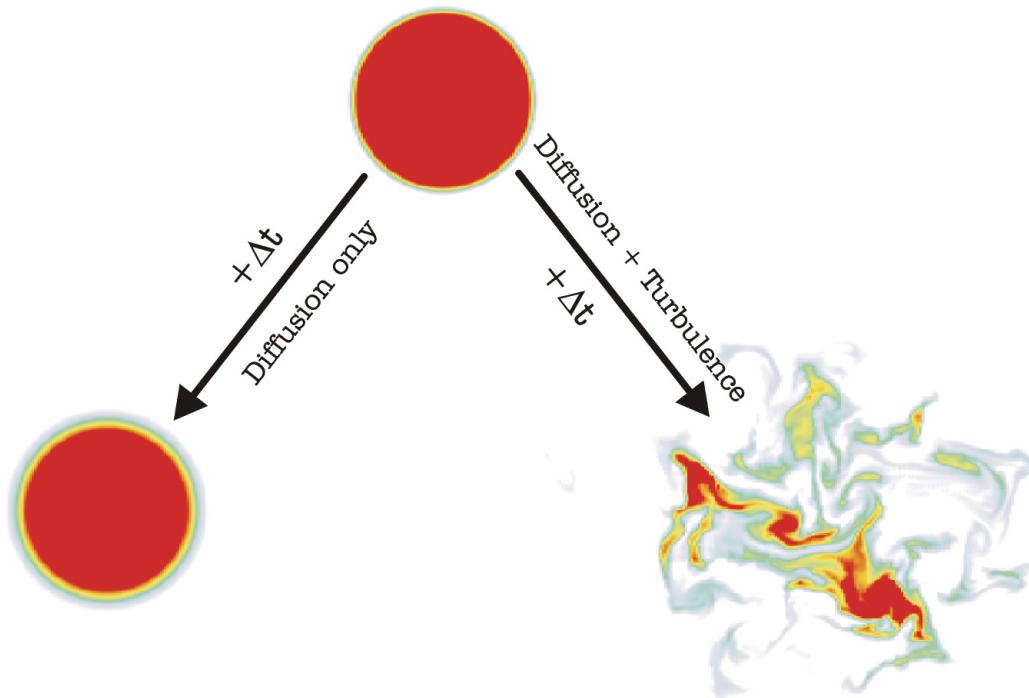
# Gas Source Localisation

- gas distribution in a real-world environment

- diffusion

- convection

- turbulence

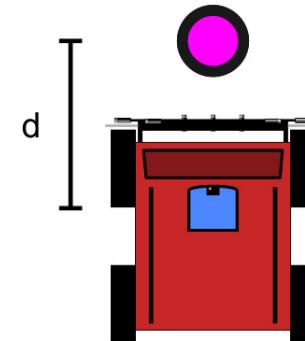


Smyth & Moum 2001

# 3

# Gas Source Declaration Strategy

- gas source declaration
  - without using additional sensors
  - using general characteristics
  - no analytical model available
  
- rotation manoeuvre
  - 90° left, 180° right, 90° left
  - 8 sectors with 45°



# 3

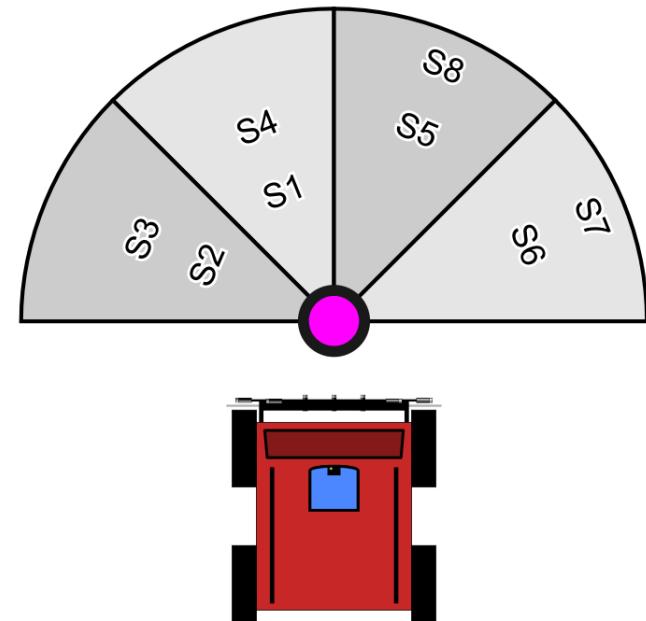
# Gas Source Declaration Strategy

## gas source declaration

- | without using additional sensors
- | using general characteristics
- | no analytical model available

## rotation manoeuvre

- | 90° left, 180° right, 90° left
- | 8 sectors with 45°



# 3

# Data Pre-Processing

## feature extraction

- | mean and/or standard deviation ( $\mu, \sigma, \mu\sigma$ )
- | different sensor combinations (7 sensors)

## linear mapping to [0,1]

- | vertical



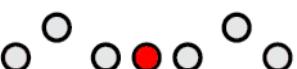
$f_{11}, f_{12}, f_{13}, f_{14}, f_{15}, f_{16}, f_{17}, f_{18}$
$f_{21}, f_{22}, f_{23}, f_{24}, f_{25}, f_{26}, f_{27}, f_{28}$
...
$f_{N1}, f_{N2}, f_{N3}, f_{N4}, f_{N5}, f_{N6}, f_{N7}, f_{N8}$

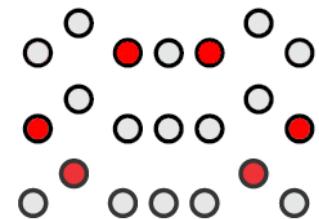
- | horizontal

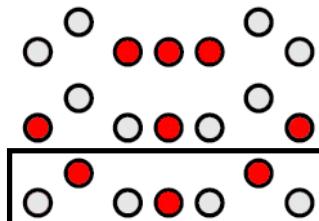


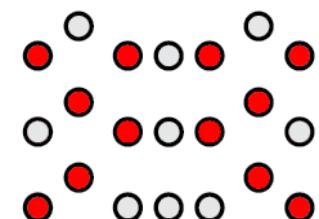
# 3 Data Pre-Processing

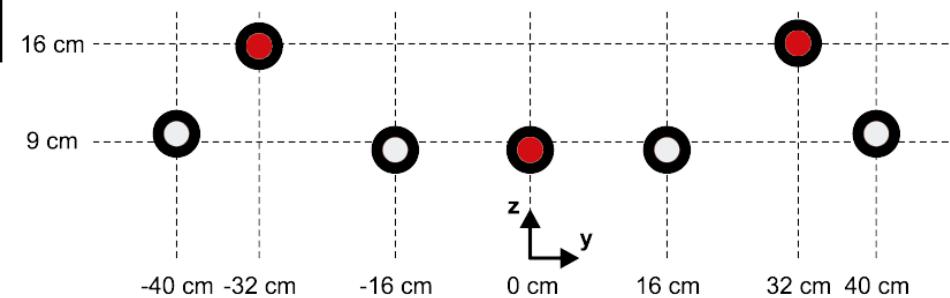
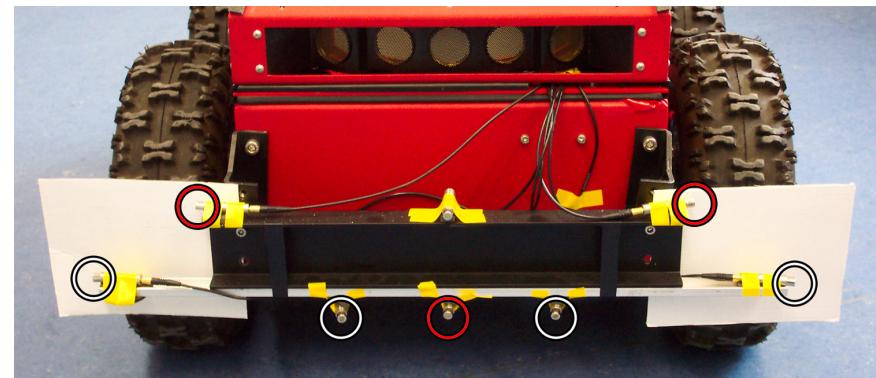
## ■ 14 sensor combinations

■ 1 sensor: 

■ 2 sensors: 

■ 3 sensors: 

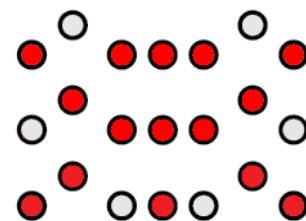
■ 4 sensors: 



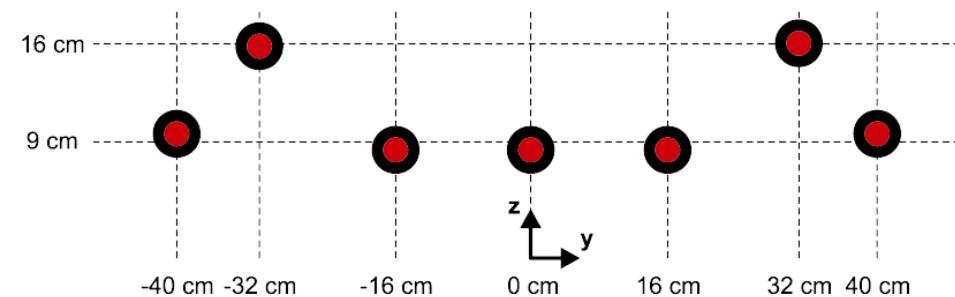
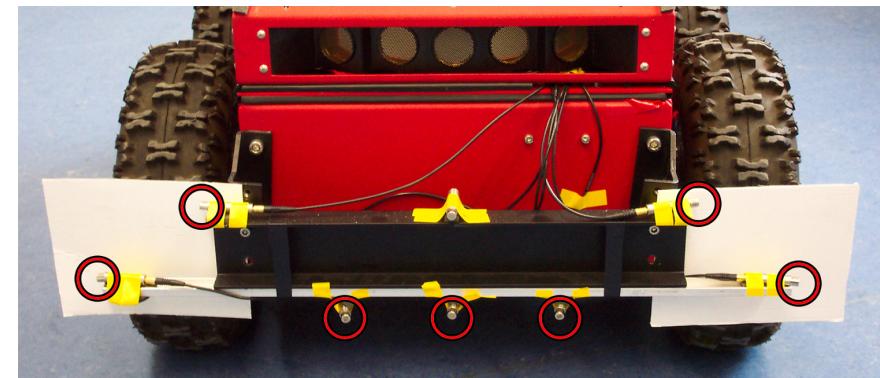
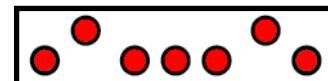
# 3 Data Pre-Processing

## ■ 14 sensor combinations

■ 5 sensors:



■ 7 sensors:



# 4

# Experimental Setup – Robot, Gas Source

- "Arthur" (ATRV-Jr.)
  - footprint = 80 x 65 cm, height = 55 cm
- Sensors
  - 7 metal oxide gas sensors
  - odometry
  - laser range scanner
- Gas Source
  - bowl with Whiskey (D = 14cm)

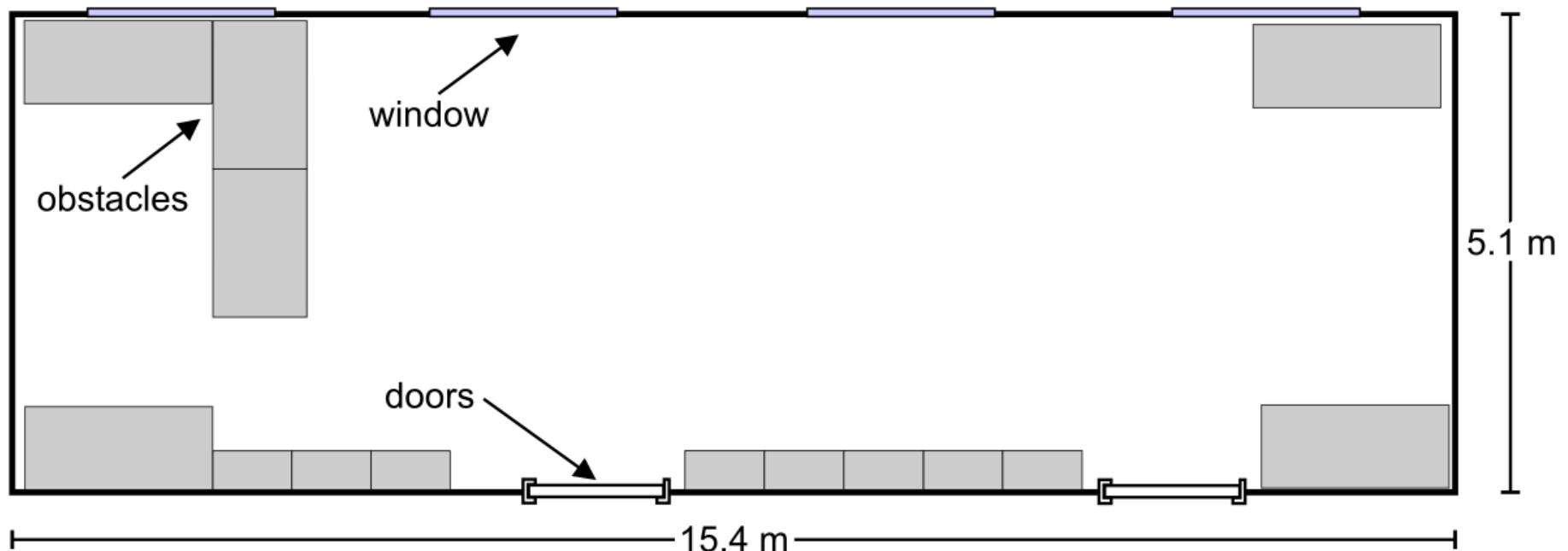


# 4

# Experimental Setup - Environment

- office room

- uncontrolled environment

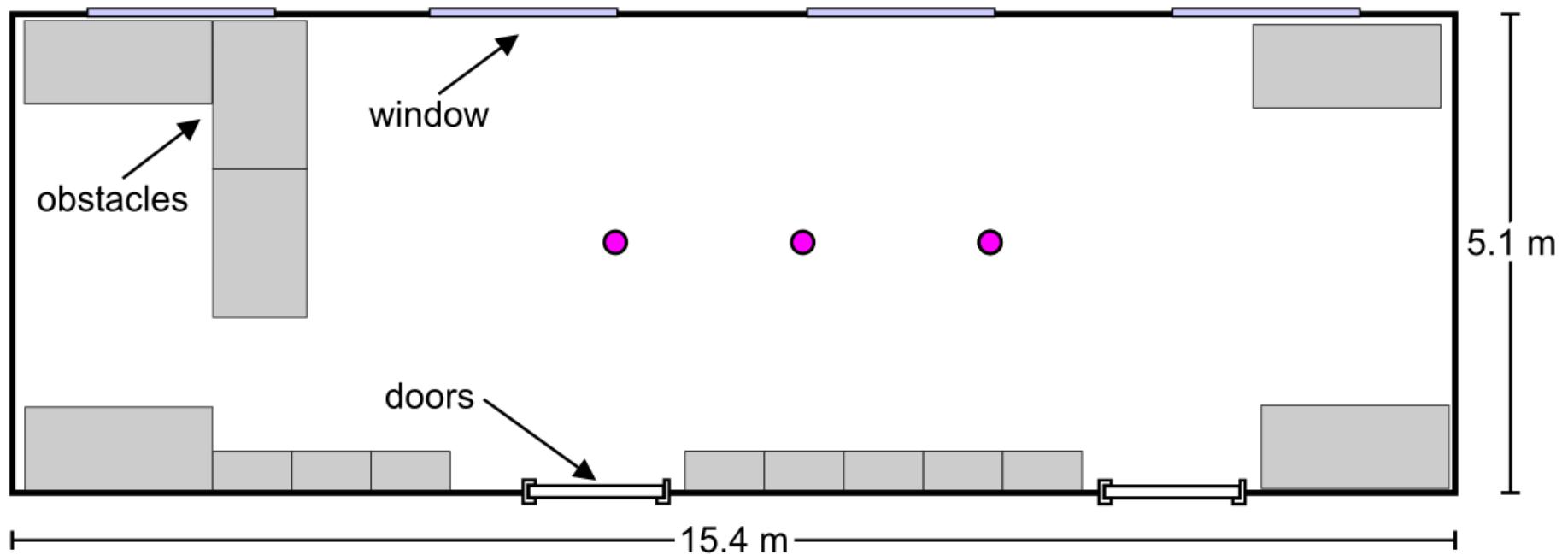


# 4

# Experimental Setup - Environment

## office room

- 3 different positions of the gas source

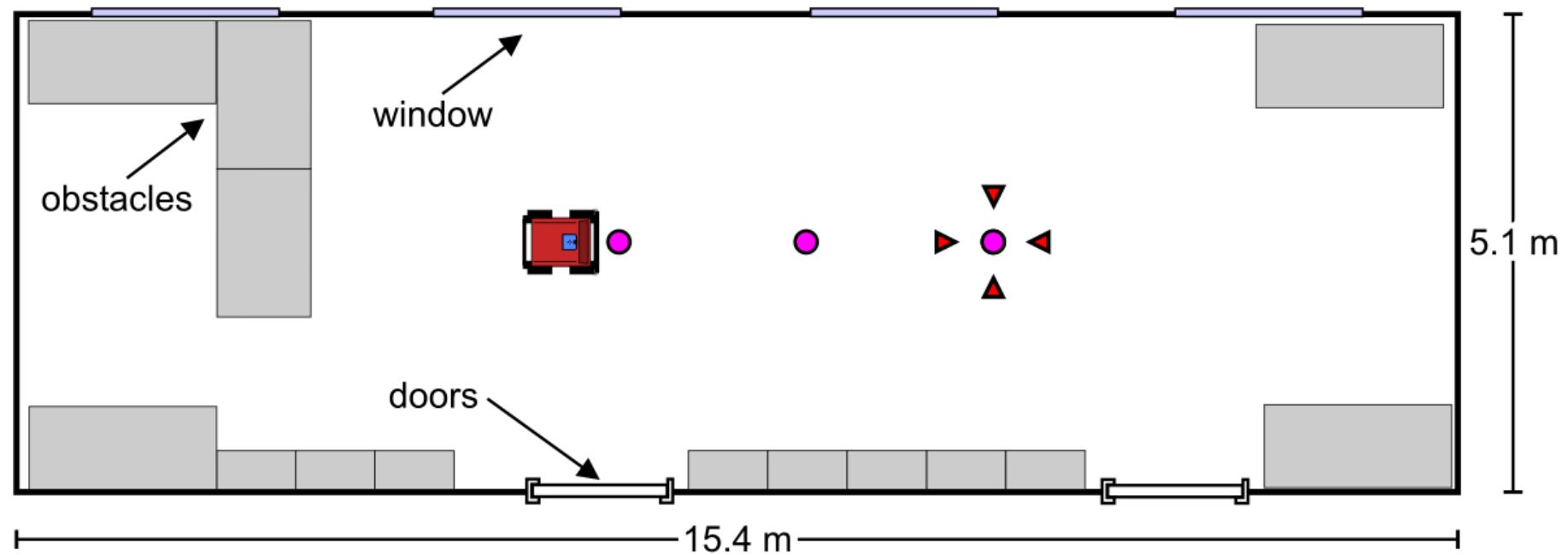


# 4

# Experimental Setup - Environment

## office room

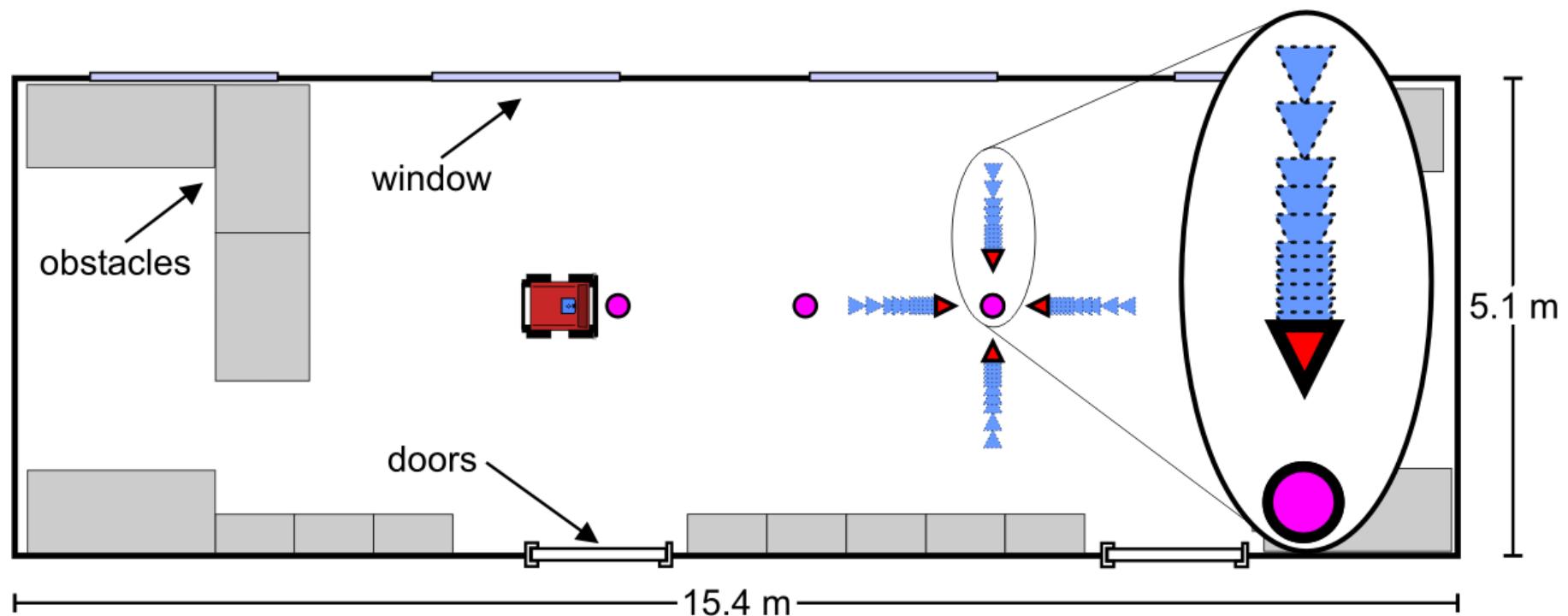
"direct in front of the source" → pos. examples



# 4

# Experimental Setup - Environment

- |  $\Delta d \geq 5 \text{ cm} \rightarrow \text{neg. examples}$
- | 4 neg./ 4 pos. trials for each distance  $\Rightarrow 1056$  trials

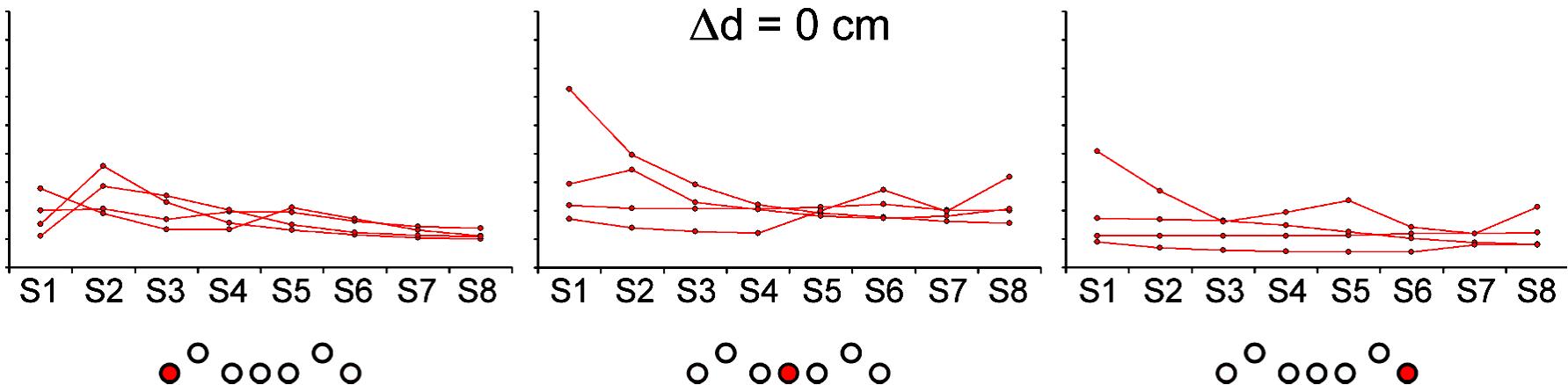
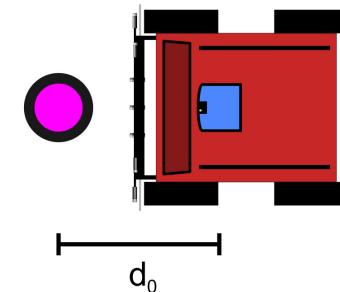


## 5

# Classification

- positive examples (+1)

- mean value ( $\mu$ )

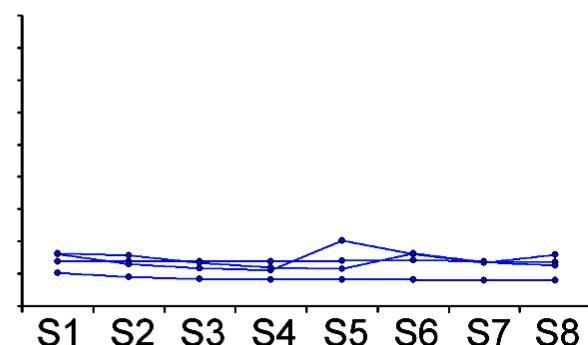
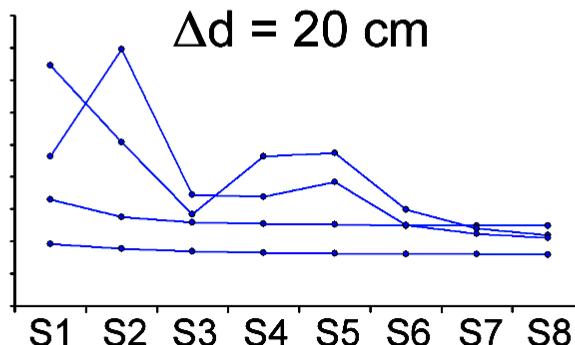
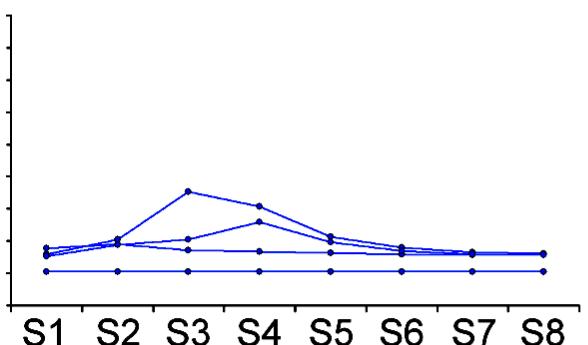
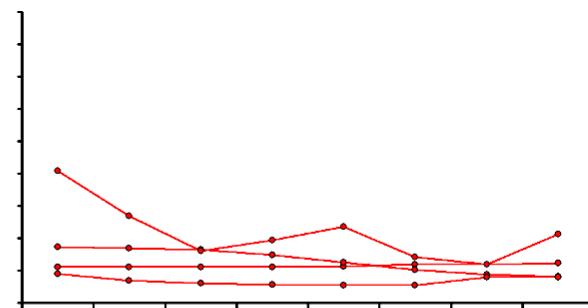
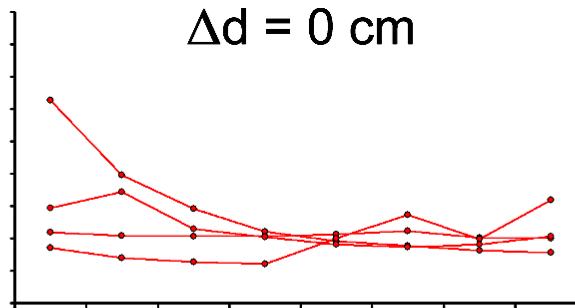
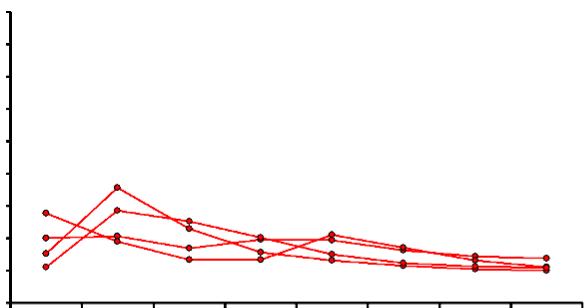
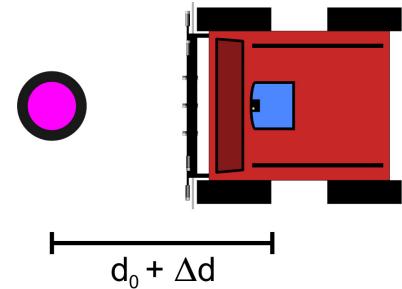


## 5

# Classification

## negative examples

### mean value ( $\mu$ )



○ ○ ○ ○ ○ ○

○ ○ ○ ○ ○ ○

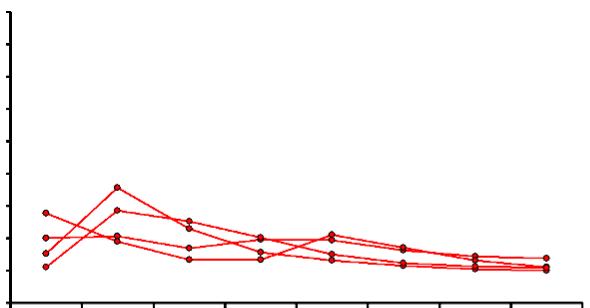
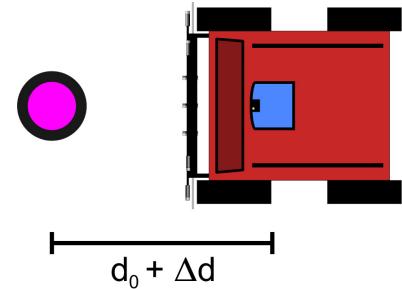
○ ○ ○ ○ ○ ○

## 5

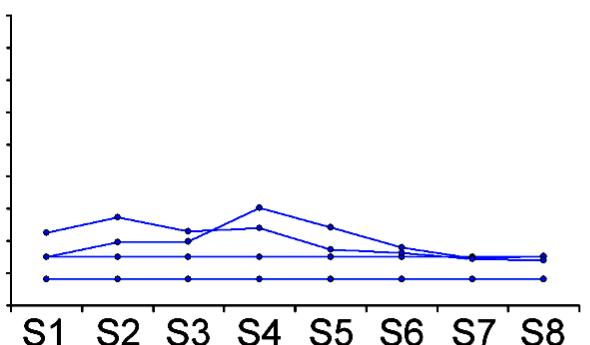
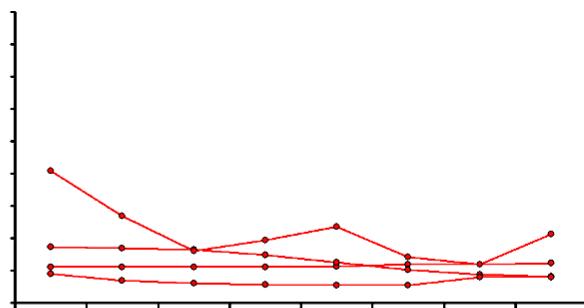
# Classification

## negative examples

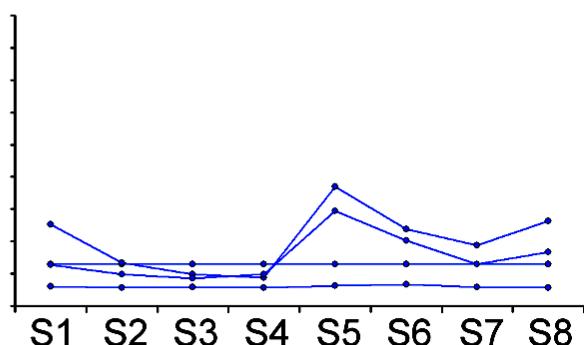
### mean value ( $\mu$ )



$\Delta d = 0 \text{ cm}$



$\Delta d = 40 \text{ cm}$



○ ○ ○ ○ ○ ○

○ ○ ○ ○ ○ ○

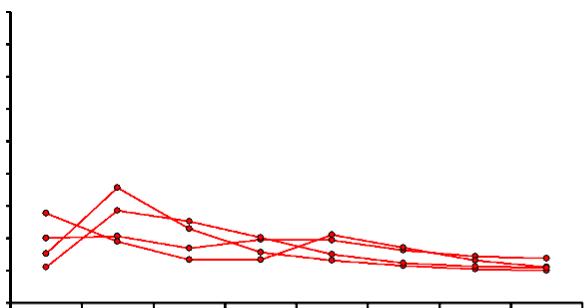
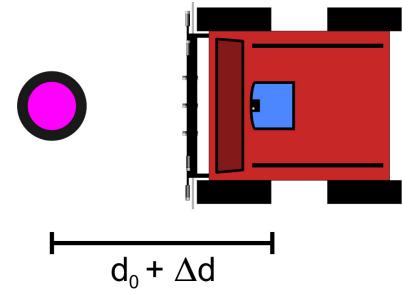
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## 5

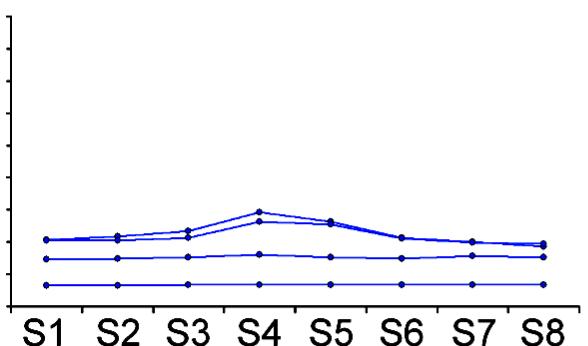
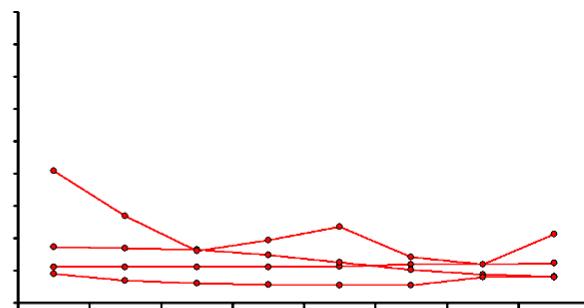
# Classification

## negative examples

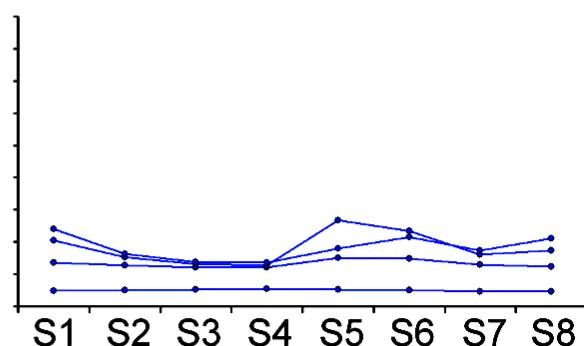
### mean value ( $\mu$ )



$\Delta d = 0 \text{ cm}$



$\Delta d = 80 \text{ cm}$



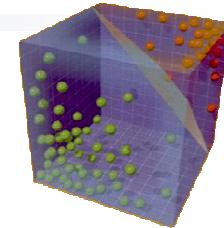
○ ○ ○ ○ ○ ○

○ ○ ○ ○ ○ ○

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## 5

# Classification - Machine Learning

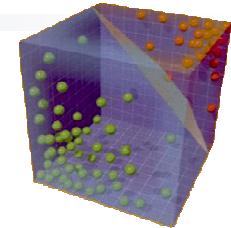


## Support Vector Machine (SVM)

- | optimal separating hyperplane in the feature space
- | **maximise margin** between two classes
- | transformation implicitly done by kernel functions
- | kernel = similarity measure between feature vectors
- | learning  $\Leftrightarrow$  quadratic optimisation problem

## 5

# Classification - Machine Learning



## Support Vector Machine (SVM)

### RBF kernel

$$k_{\gamma}(\mathbf{x}, \mathbf{y}) = \exp\left(-\frac{\|\mathbf{x} - \mathbf{y}\|^2}{\gamma^2}\right)$$

### SVM parameters

- kernel parameter  $\gamma$
- penalty parameter C

# 6 Results

## grid search

- |  $\gamma = 2^m$  with  $m = -6, -5.75, \dots, 5.75, 6$
- |  $C = 2^n$  with  $n = -3, -2.75, \dots, 8.75, 9$

## cross-validation hit rate

- | 5-fold cross-validation
- |  $(C^*, \gamma^*) \Rightarrow \max.$  cross.-val. hit rate

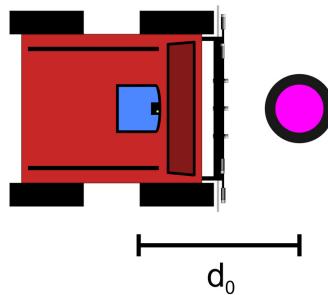
train	⇒ predict
1   2   3   4	5
1   2   3   5	4
1   2   4   5	3
1   3   4   5	2
2   3   4   5	1

# 6 Results

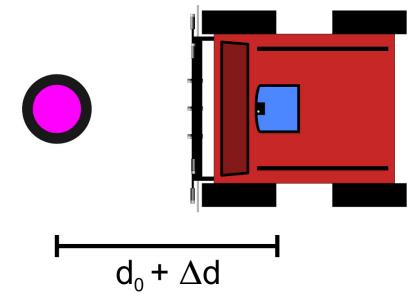
## dependency on the distance to the gas source

- | distinguish  $\Delta d = 0$  from  $\Delta d \geq \Delta d^{ns}$
- | different distances  $\Delta d^{ns}$
- |  $\Delta d^{ns} = 60 \text{ cm} \Rightarrow \Delta d = 60/80/100 \text{ cm} \Rightarrow \overline{\Delta d^{ns}} = 80 \text{ cm}$

positive examples

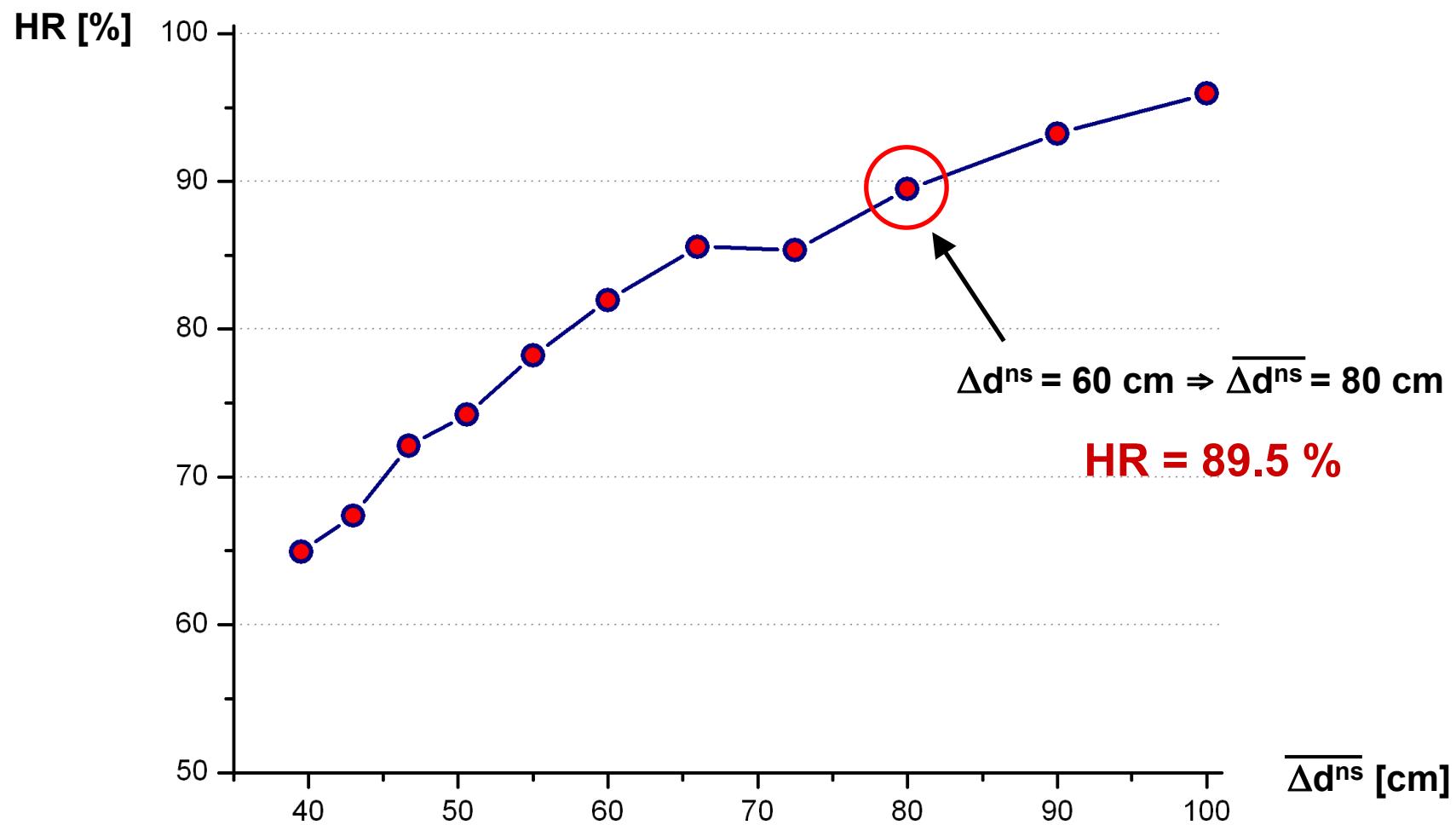


negative examples



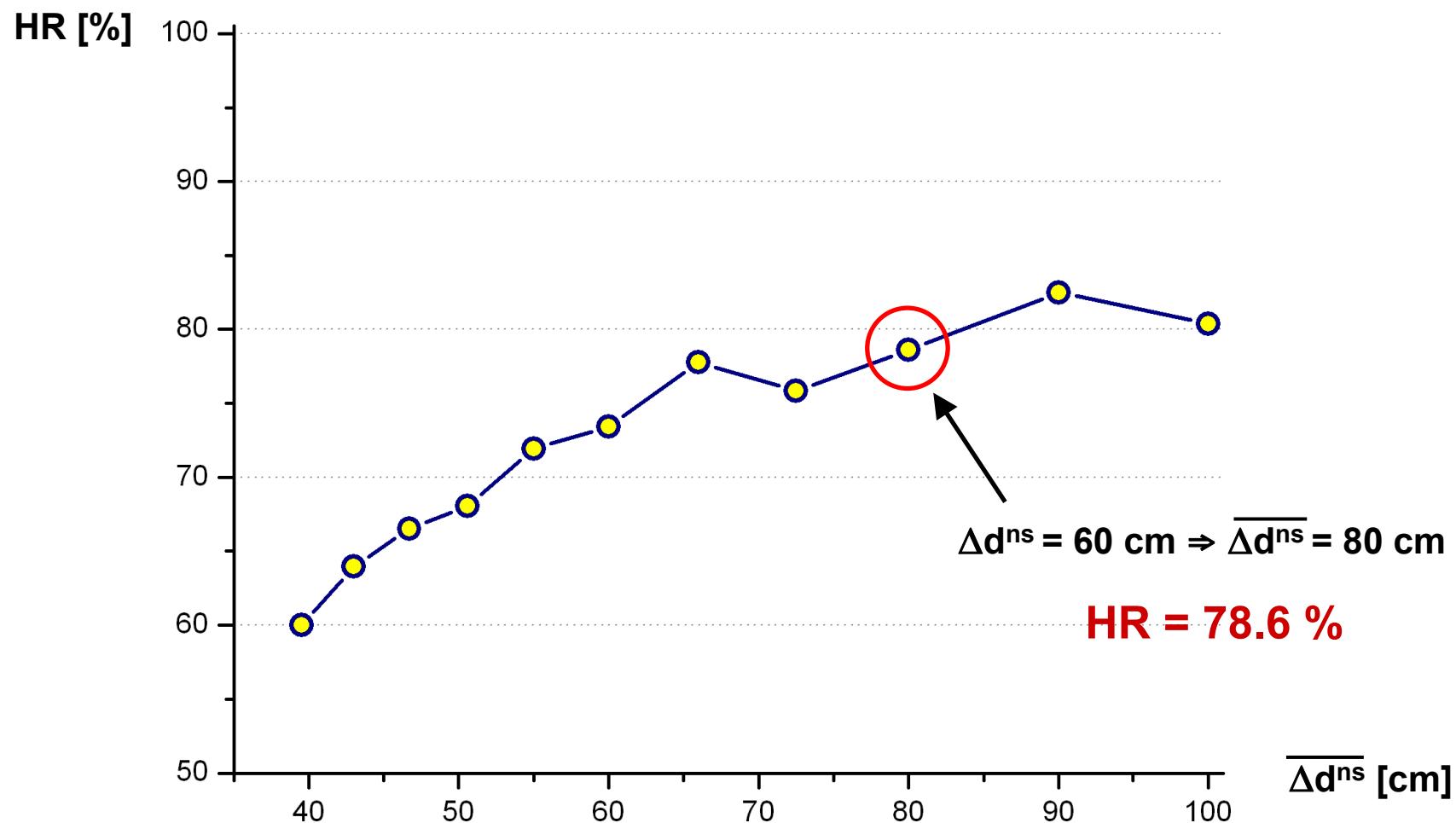
# 6 Results

vertical normalisation,  $(\mu\sigma)$ ,  $\bullet^\circ \bullet \bullet \bullet^\circ \bullet$



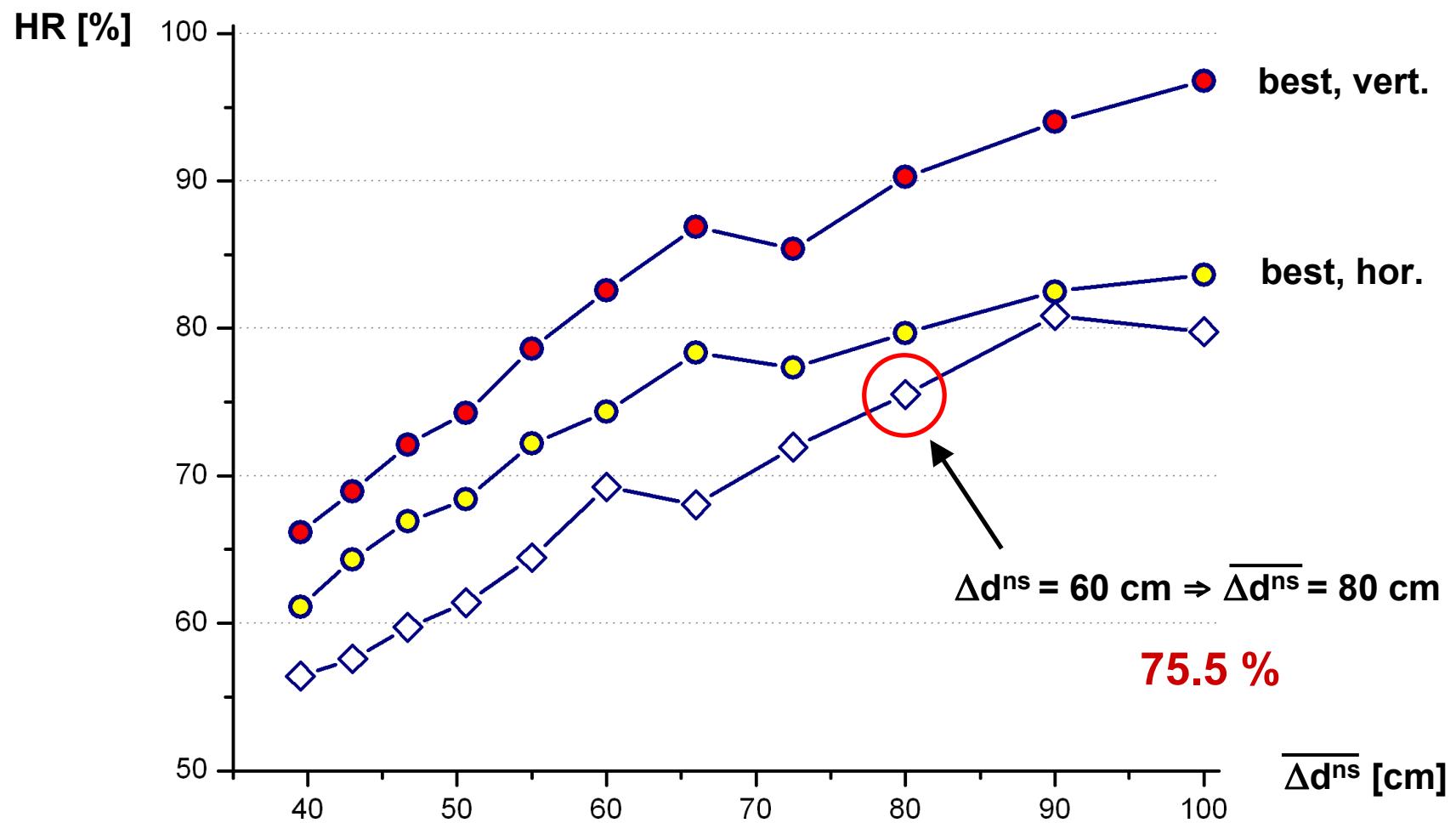
# 6 Results

horizontal normalisation,  $(\mu\sigma)$ , 



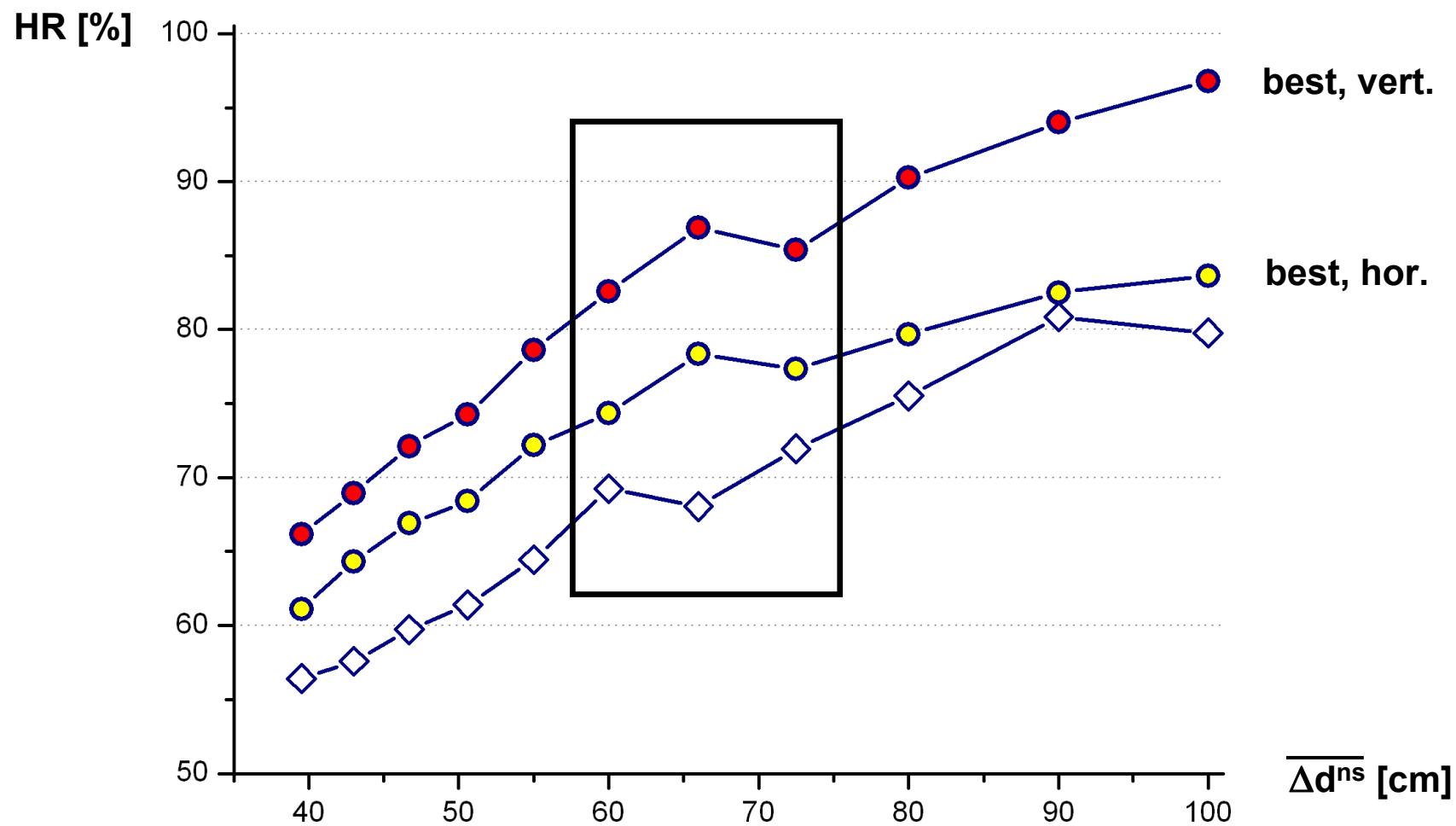
# 6 Results

## comparison with threshold classifier



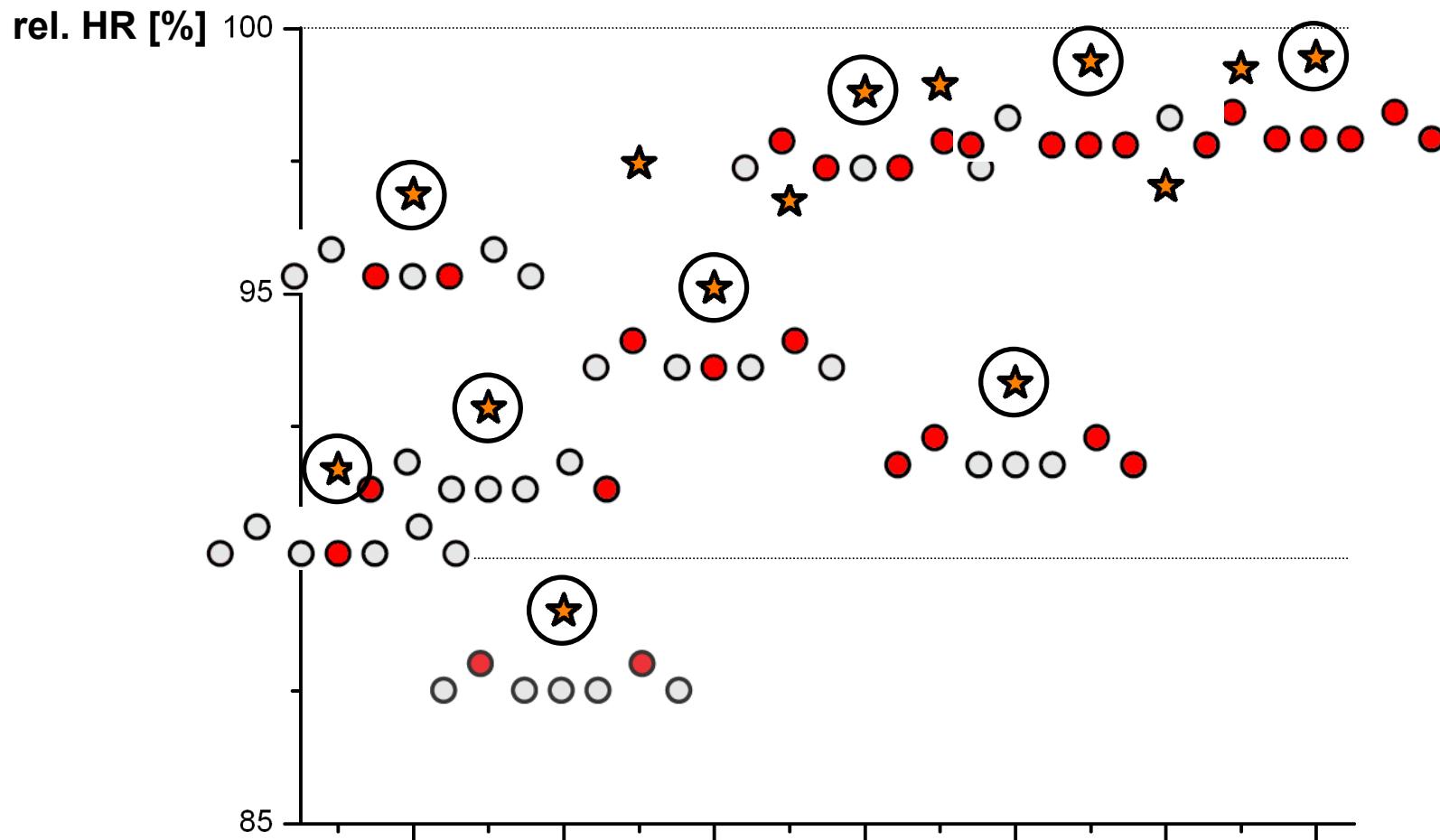
# 6 Results

■ roughly constant plateau



# 6 Results

## comparison of sensor configurations



# 7

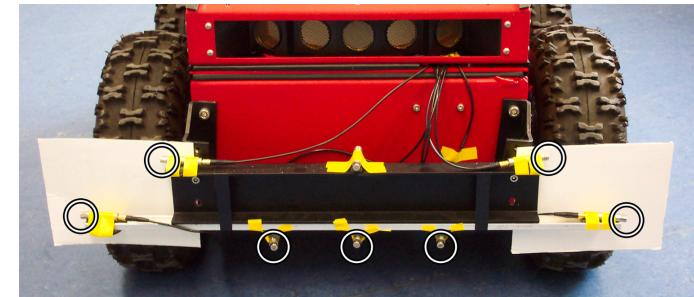
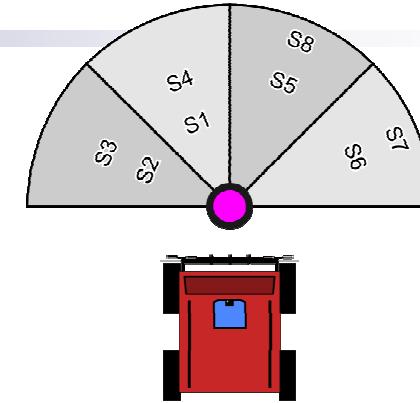
# Summary

- gas source declaration method introduced
  - based on gas sensor measurements only
  - machine learning for classification
- demonstration of the feasibility of the approach
- analysis of the classification performance
  - high classification rates with SVM
  - >> simple threshold classifier

# 7

# Outlook

- manoeuvre optimisation
  - optimal rotational speed
  - other manuevres
- feature selection
  - optimal sensor location
- regression
- Bayesian learning



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# Gas Source Declaration With a Mobile Robot

**Thank you!**

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