

# PRE-SLHY

## Status of the PS-Experiments on WP5

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Pre-normative REsearch for Safe use of Liquid HYdrogen

223  
1966



# Introduction WP5-Experiments

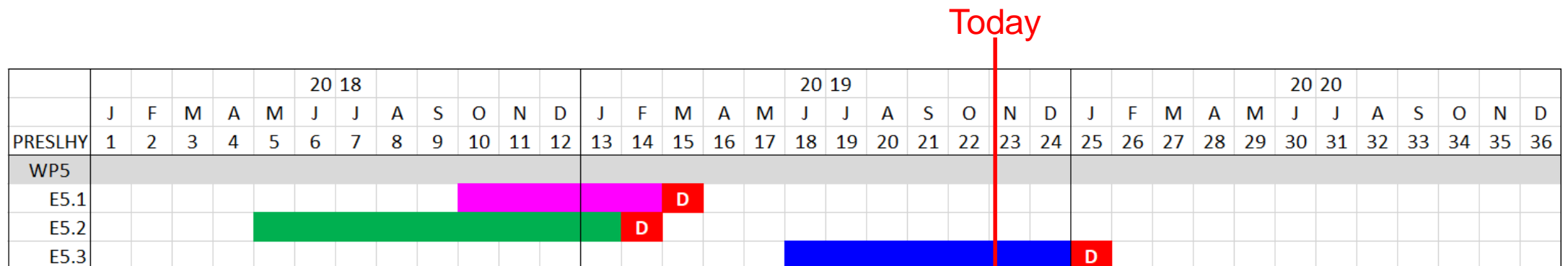
- In the Description of Work tree experimental series' for WP5 to be performed by Pro-Science in the HYKA-facilities at KIT are described:

E5.1 Jet-Fire (ignited DisCha-Experiments)

E5.2 Combustion-Tube-Experiments

E5.3 Box-Experiments

- The execution of the experiments was initially planned as follows:



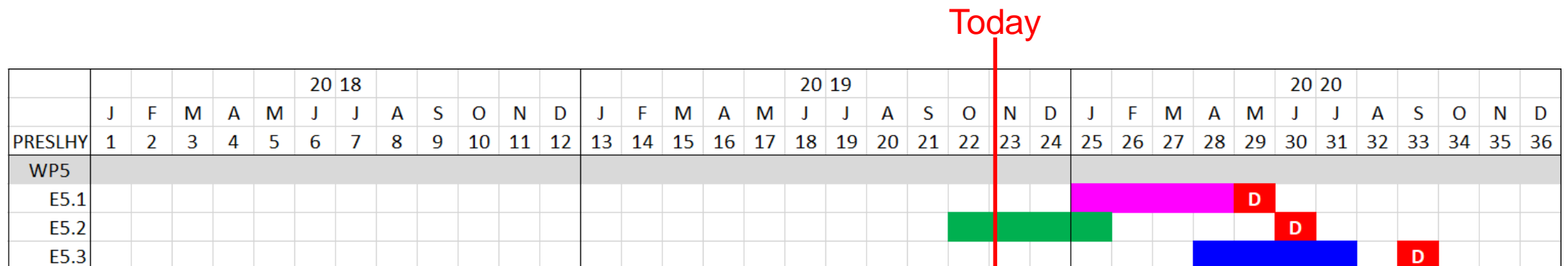
# Update WP5-Experiments

- Updated Time Schedule WP5-Experiments by PS/KIT:

E5.1 Jet-Fire (ignited DisCha-Experiments) *Experiments done*

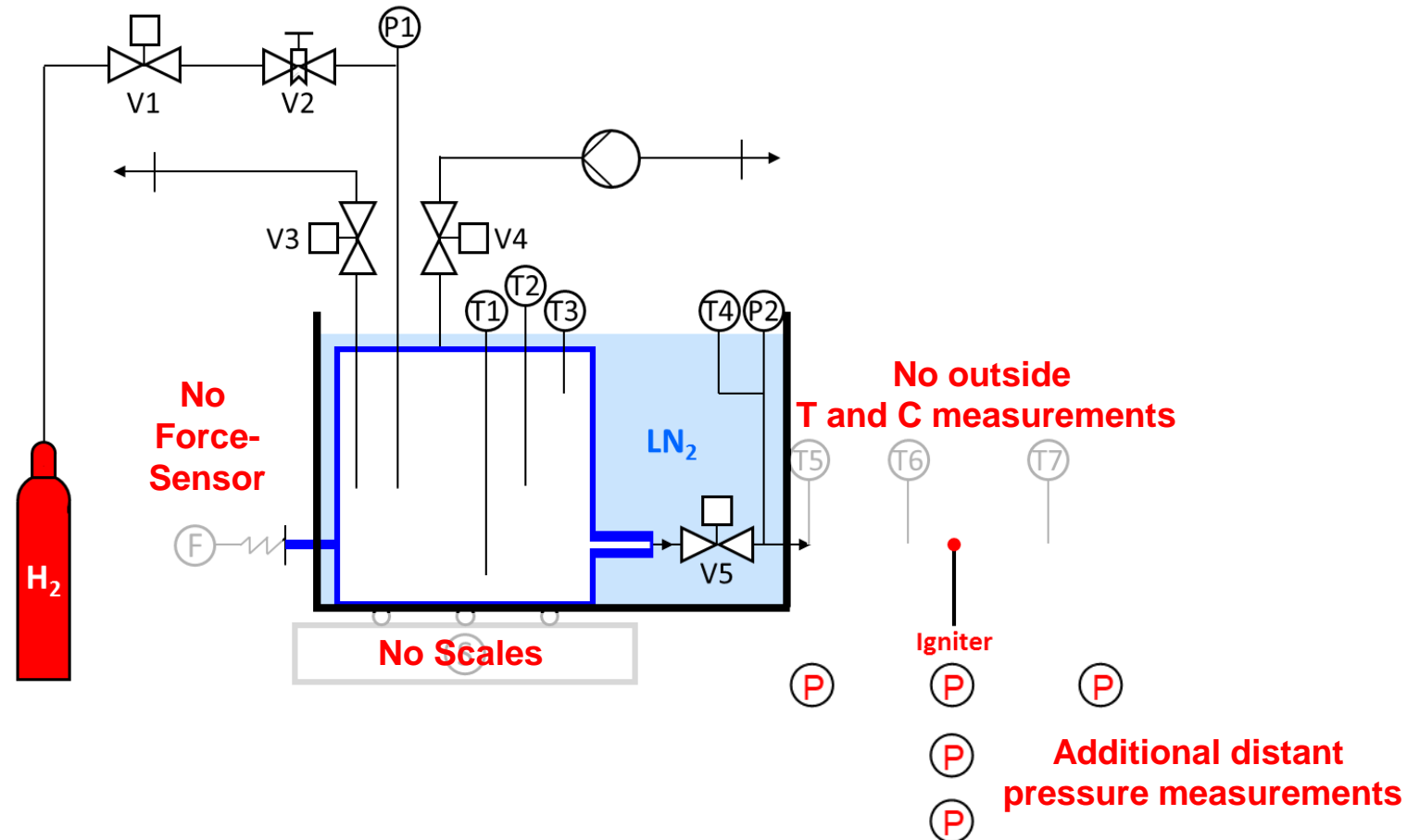
E5.2 Combustion-Tube-Experiments *Experiments in progress*

E5.3 Box-Experiments



# E5.1: DisCha-Ignited

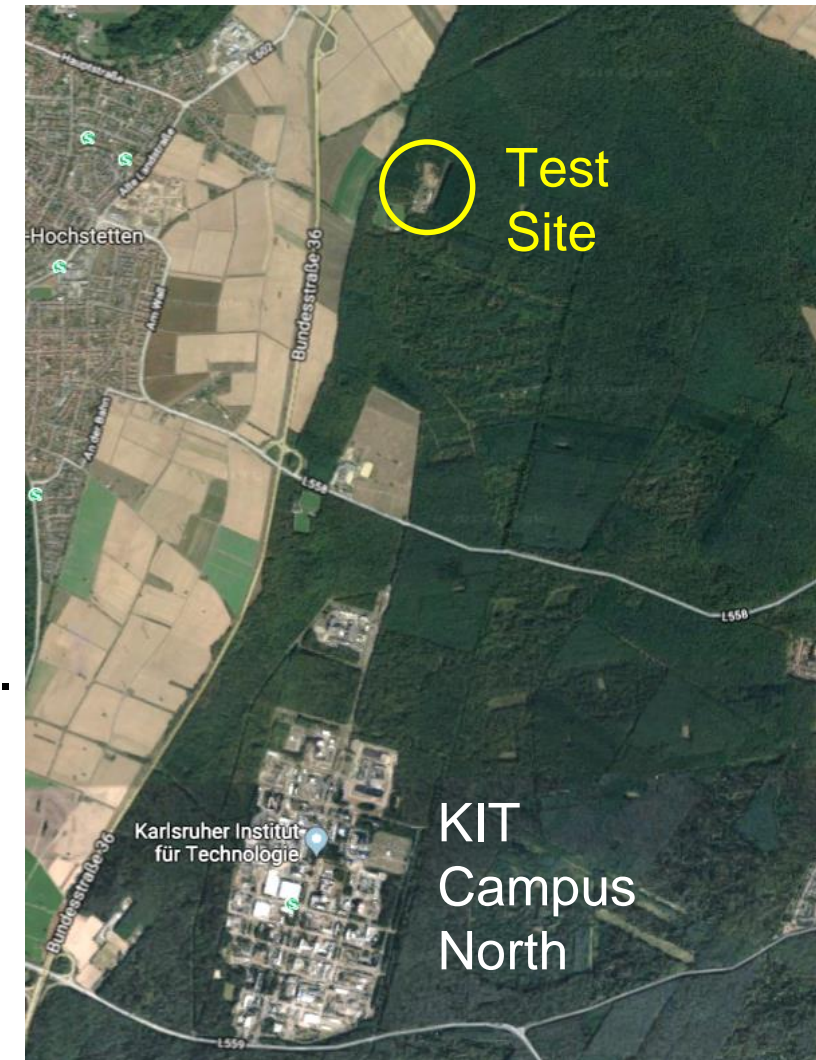
- Experimental Setup is similar to E3.1a, but ...



- Facility was installed to free field test site,
- Infrared-camera was used for temperature/heat-flux measurements.

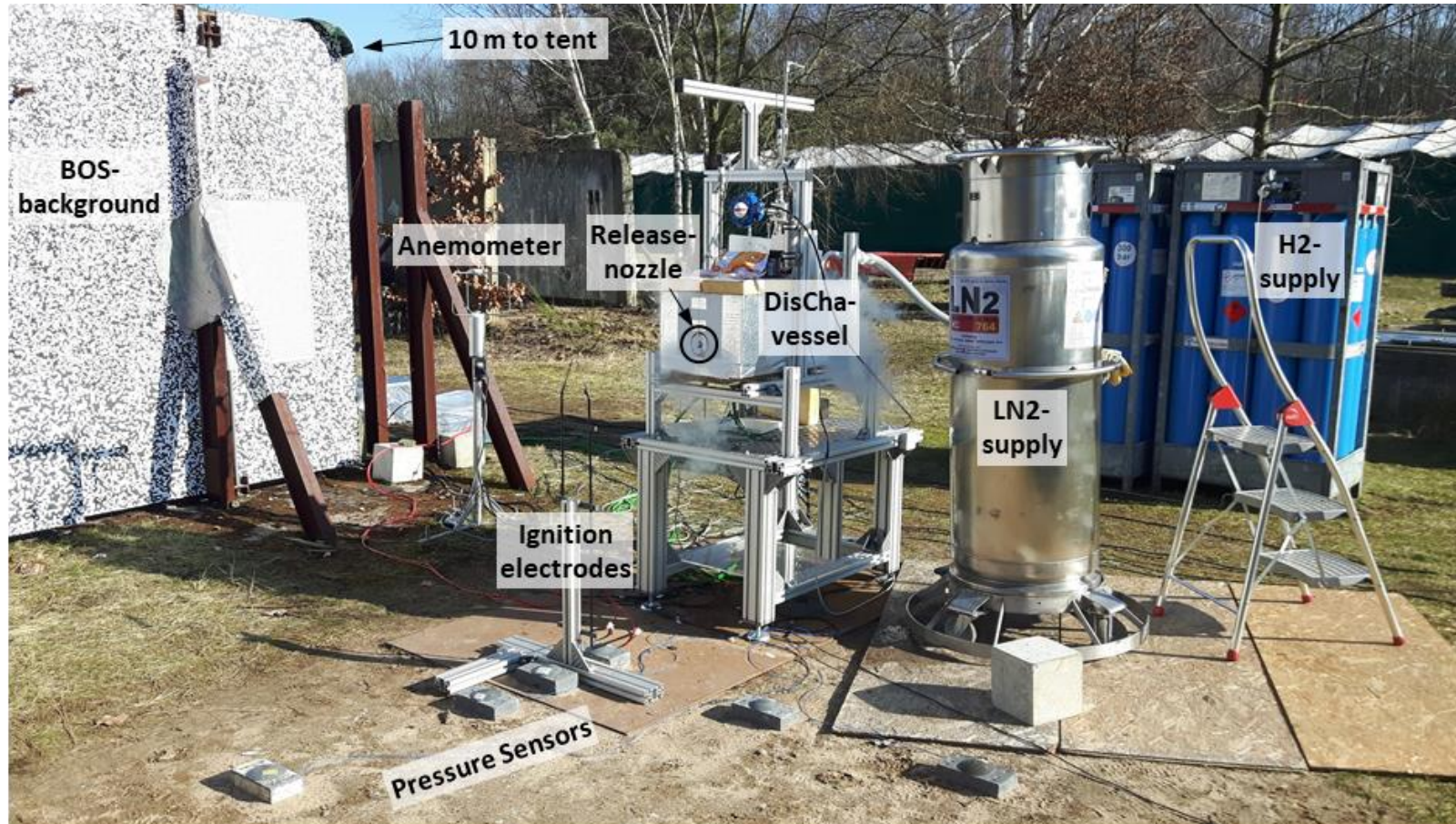
## E5.1: Jet Fire (DisCha-Facility)

- Due to the large amount of hydrogen to be released and ignited ( $V_{Ves} = 2.8 \text{ dm}^3$ ,  $p_{ini} = 200 \text{ bar}$ ) the experiments have to be performed on a more remote free field test site,
- So after the experiments on E3.1a the DisCha-facility was partly disassembled and prepared for the free field test site.
- The site used is owned by the Institute of Technology and Management in Construction (Campus South) and lies approx. 3 km to the north of KIT Campus North. It is surrounded by woods and the closest buildings have a distance of approx. 500 m.



## E5.1: Jet Fire (DisCha-Facility)

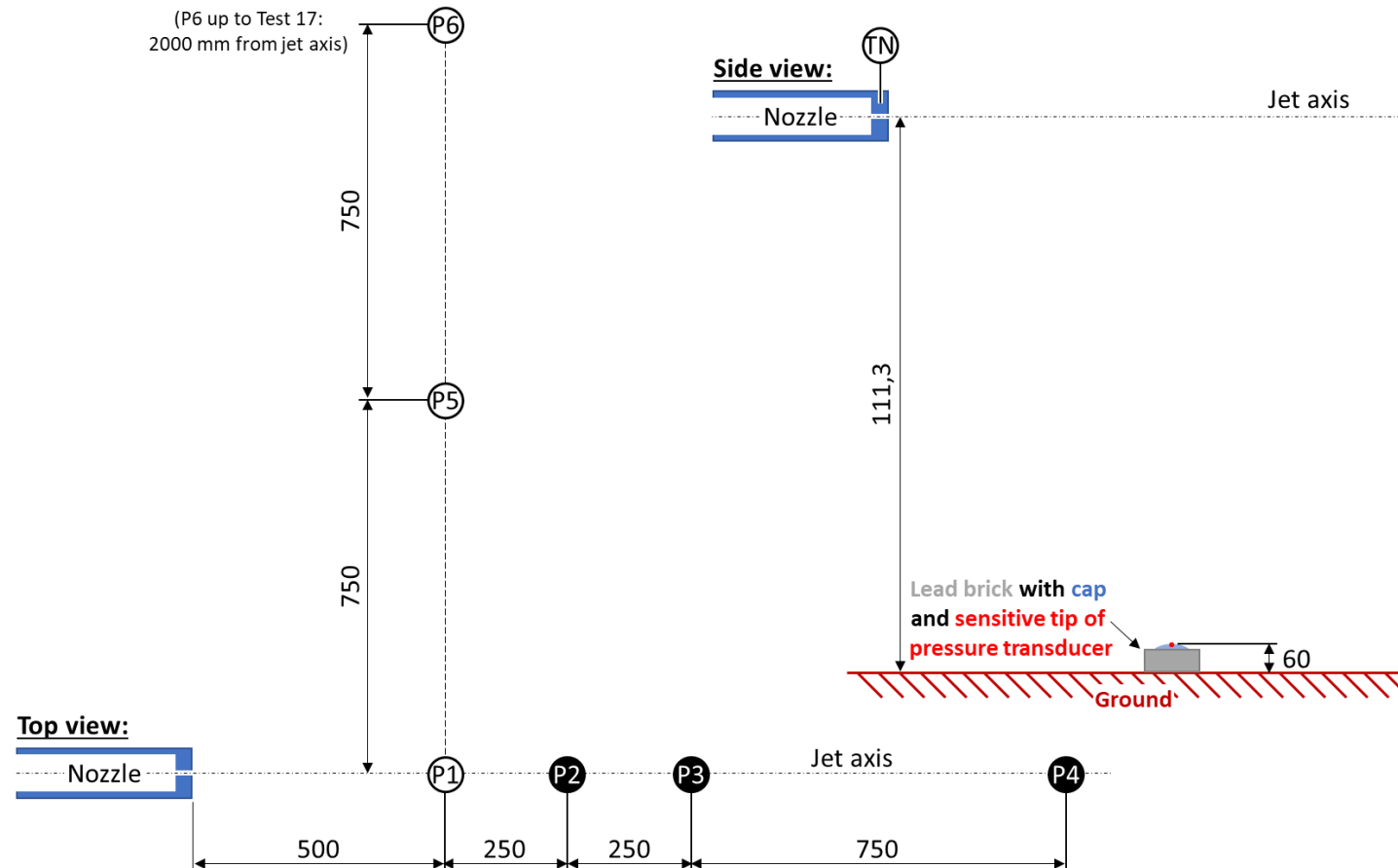
- All parts of the DisCha-facility have been transported to the free field test site, where the facility was reassembled.



➔ Experiments were performed from end of November 2019 to beginning of February 2020.

# E5.1: Jet Fire (DisCha-Facility)

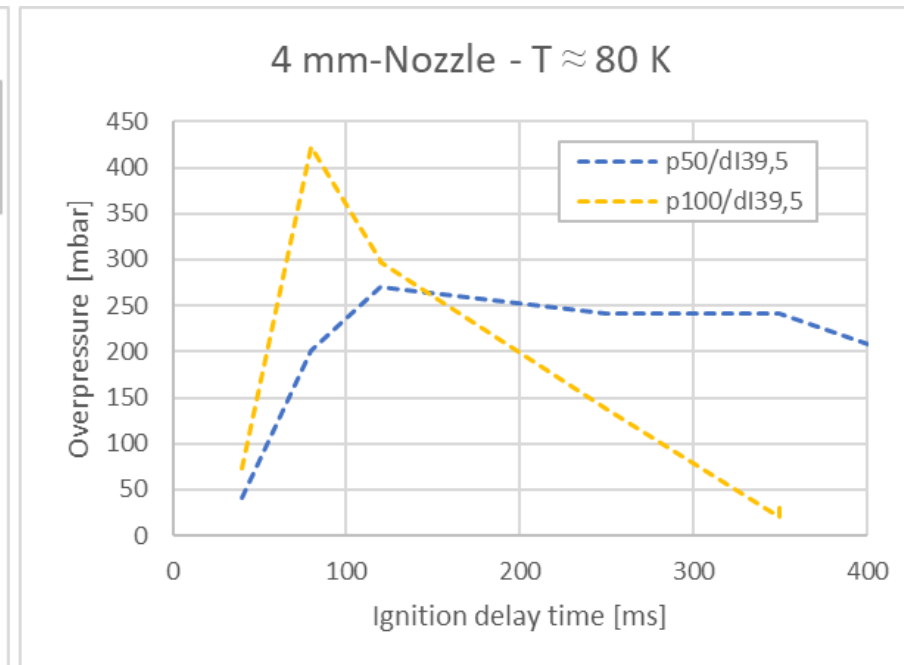
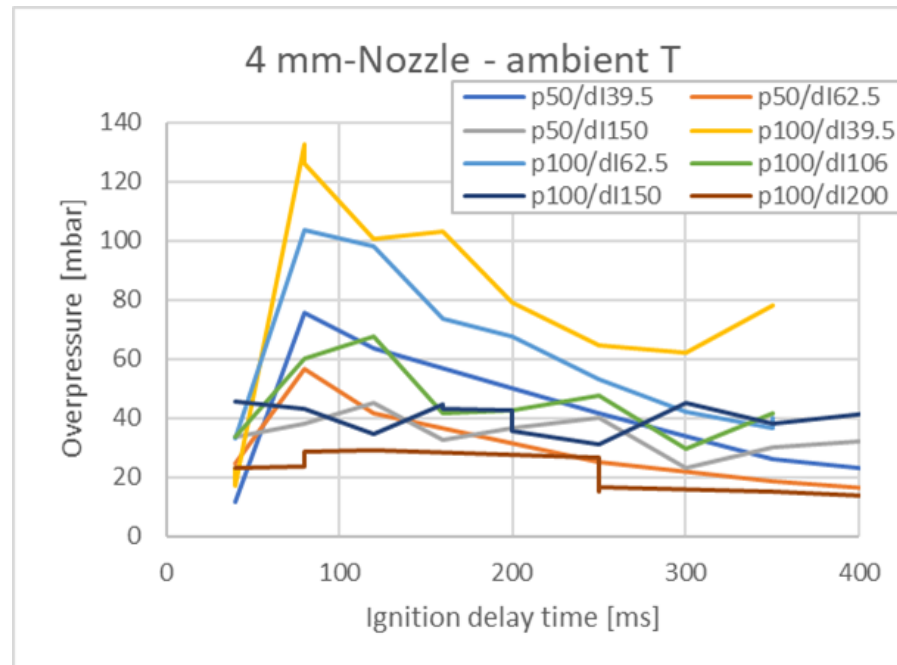
- Ex-vessel instrumentation



- In total 5 cameras for evaluation using BOS-technique (2 Canon photocameras, 1 Highspeed and 2 regular video cameras.)
- 1 Infrared-camera for temperature/heat-flux measurements

# E5.1: Jet Fire (DisCha-Facility)

- In initial test series the ignition delay time leading to the strongest pressure loads was determined,



- Using delay time 120 ms the complete test matrix was investigated for:
  - Nozzle diameter 1, 2, 4 mm
  - Initial temperature: ambient, 80 K
  - Initial pressure: 5, 50, 100, 200 bar
  - Ignition distance: 39.5, 62.5, 106.5, 150, 200 cm
- Almost 300 experiments performed (approx. 100 of them at 80 K)



## E5.1: Jet Fire (DisCha-Facility)

- Currently tests are evaluated,
- Enormous load of material,
- Reporting was started but not yet finished.

# E5.2: Flame acceleration and DDT at cryogenic temperatures (Combustion-Tube)

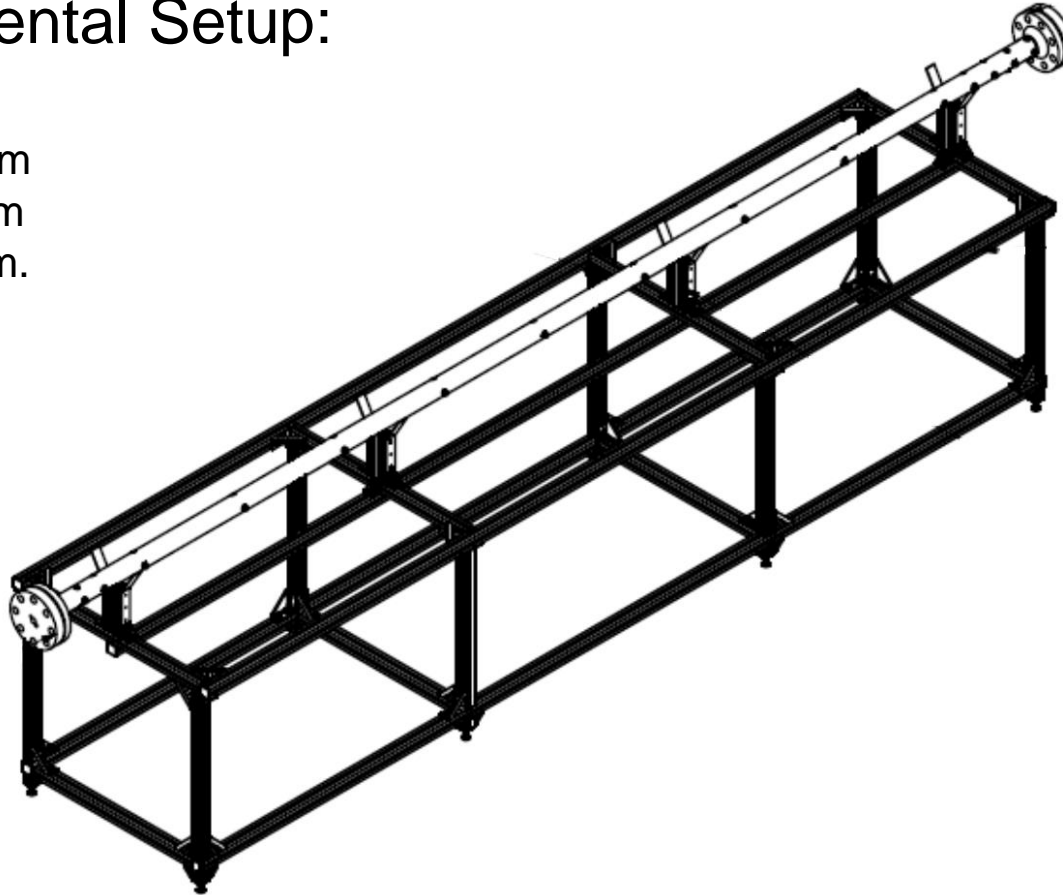
- Combustion of H<sub>2</sub>-air-mixtures in obstructed tube at cryogenic temperatures,
- Experimental Setup:

Dimensions:

L = 5000 mm

D<sub>in</sub> = 54 mm

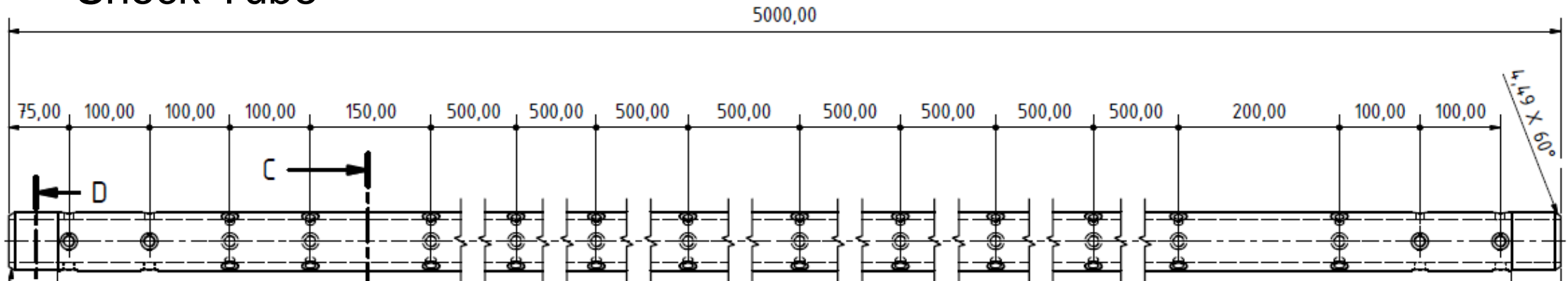
D<sub>out</sub> = 73 mm.



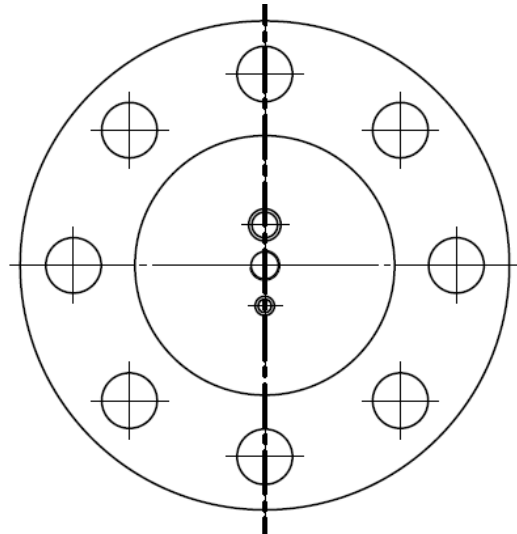
- Facility installed to a tent with removable sides behind main hall of HYKA,
- Control units in a container besides the facility.

# E5.2: Flame acceleration and DDT at cryogenic temperatures (Combustion-Tube)

- Shock-Tube

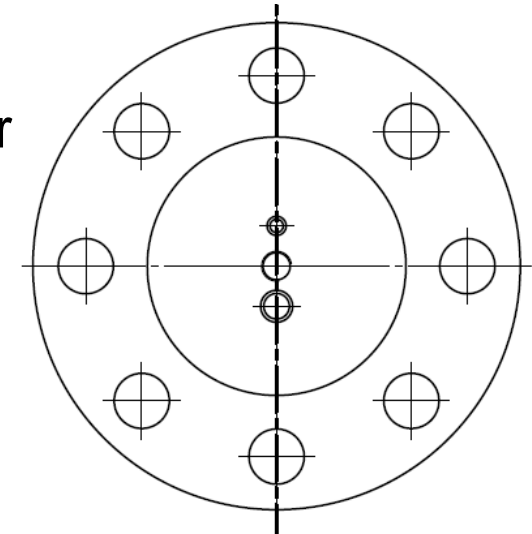


- Front-Flange with ports for:



- Gas-Inlet
- Glow-Plug
- Thermocouple

- End-Flange with ports for:



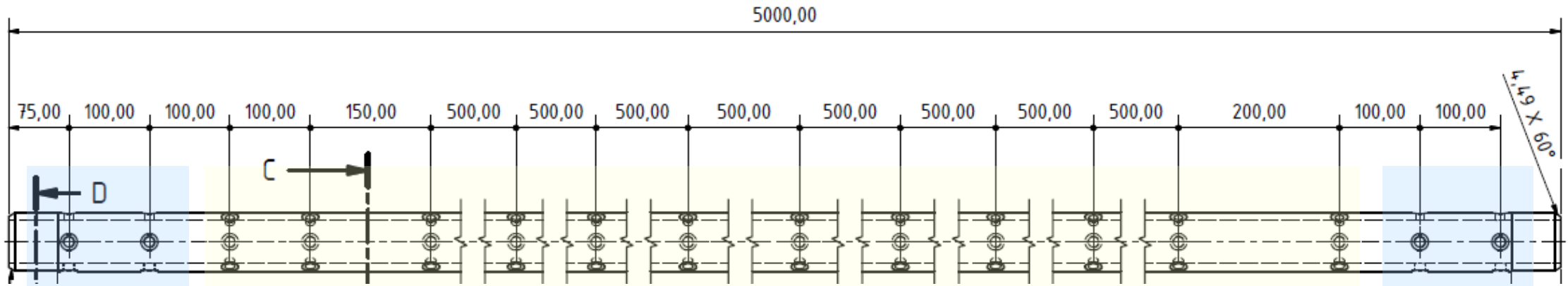
- Thermocouple
- Pressure-Sensor
- Gas-Outlet

- Along the tube  
52 ports in 16 cross sections for:

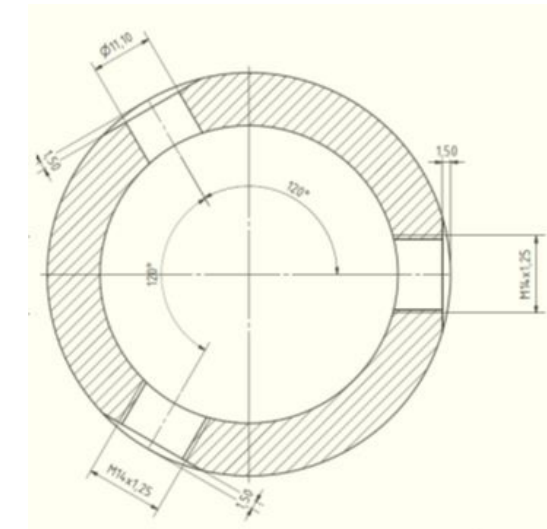
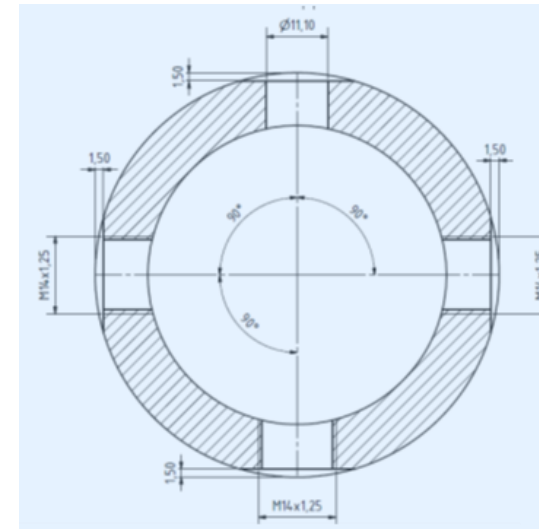
- Pressure Sensors (2 different types),
- Phototransistors

# E5.2: Flame acceleration and DDT at cryogenic temperatures (Combustion-Tube)

- Instrumentation

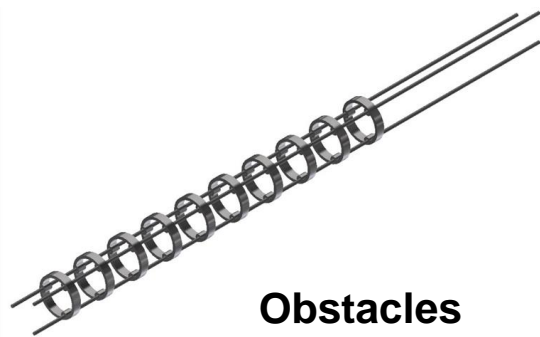
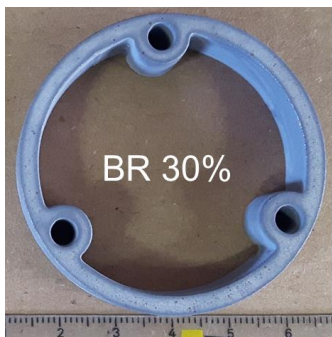
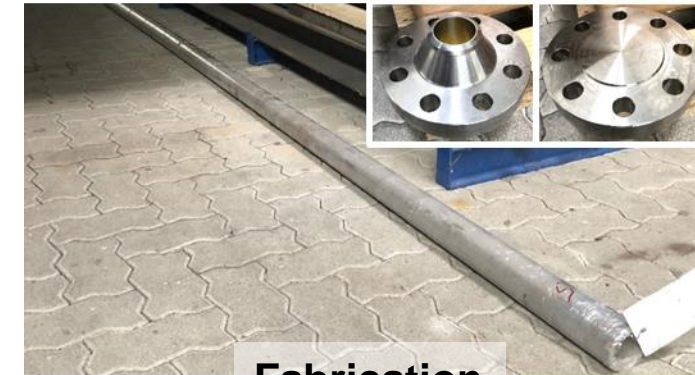


- Ports evenly distributed along circumference and arranged in groups of:
  - 4 ports (close to ends) and 3 ports (main part of tube)
- Ports for Phototransistors and small Pressure Sensors for higher pressures (350 bar) are the same,
- Ports for larger Pressure Sensors (lower pressures, 7 bar) are significantly larger.
- For fabrication reasons (deformation of tube due to welding of different adapters) the large ports are be distributed helically in the positions along the tube.

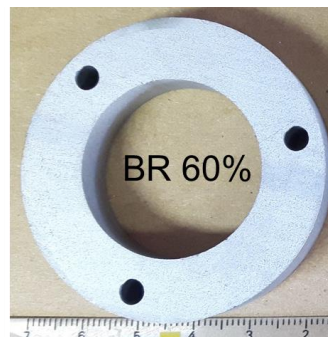


# E5.2: Flame acceleration and DDT at cryogenic temperatures (Combustion-Tube)

- Fabrication of tube in KIT-workshop took **more than 9 months (!)** causing severe delay,
  - Tube meanwhile completed,
  - Pressure test passed successfully,
- Tube is prepared and instrumented for warm tests at ambient temperature,
- Obstacles arranged as arrays of disks with different blockage ratios (spacing: 1 inner diameter of tube),
- In parallel a basin is produced to cool down the tube with LN<sub>2</sub> for the cold experiments.



**Obstacles**

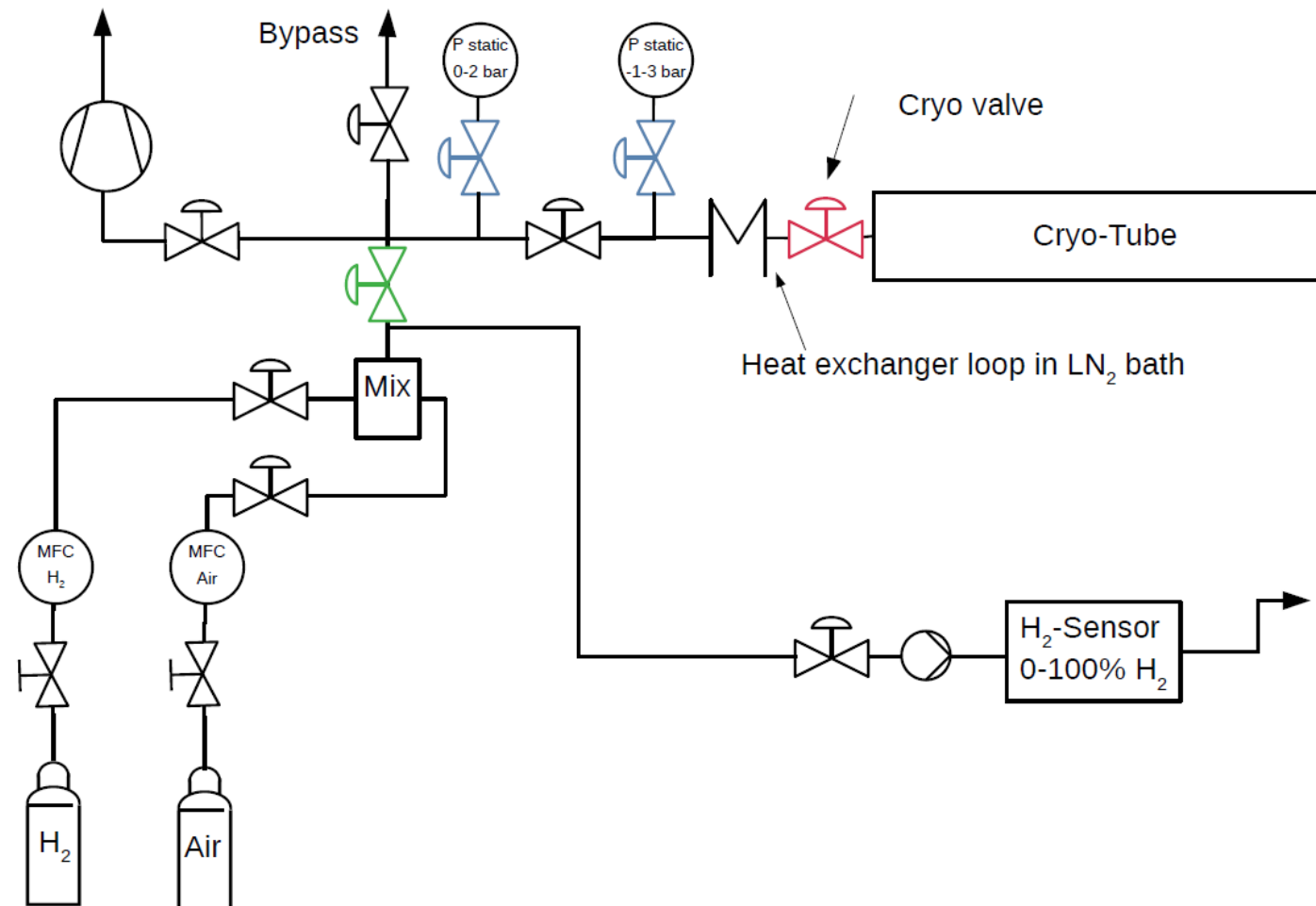


# E5.2: Flame acceleration and DDT at cryogenic temperatures (Combustion-Tube)

## ■ Test Parameters

- 2 temperatures:
  - ambient and
  - LN<sub>2</sub>-temperature,
- 2 blockage ratios
  - 30% and
  - 60%
- Up to 10 H<sub>2</sub>-concentrations from within the ranges
  - 6 to 12 Vol.% H<sub>2</sub>
  - 15 to 20 Vol.% H<sub>2</sub>
  - 30 Vol.% H<sub>2</sub>
  - 60 to 75 Vol.% H<sub>2</sub>

## Scheme of the facility



# E5.2: Flame acceleration and DDT at cryogenic temperatures (Combustion-Tube)



## ■ Test Procedure (“Warm Tests”)

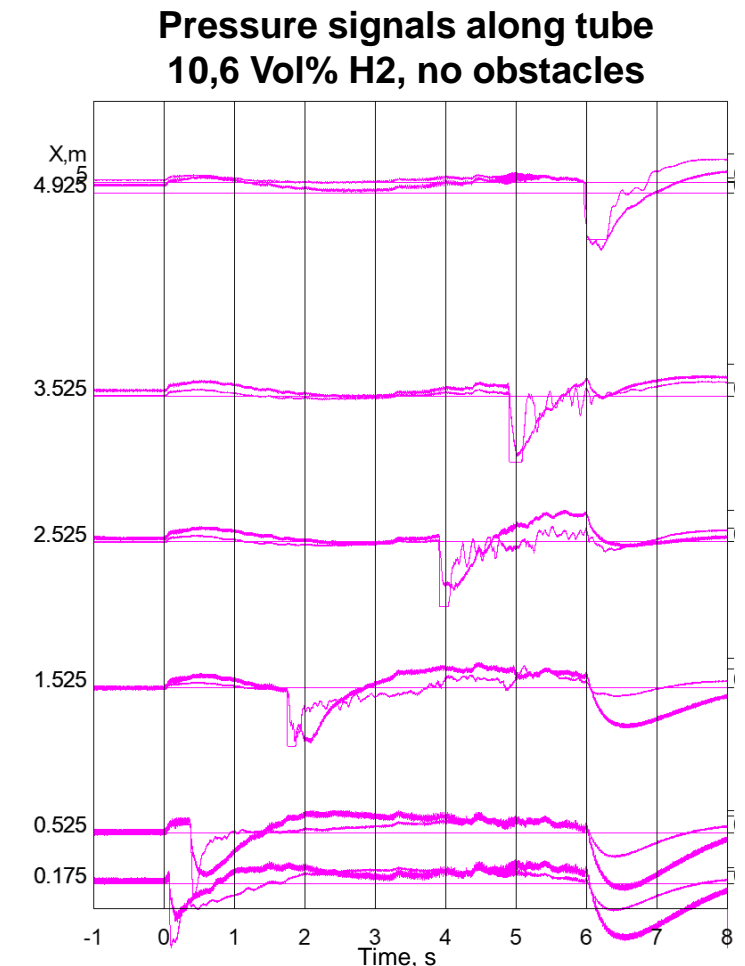
- Tube is evacuated and purged with air several times,
- Mass flow controllers are adjusted to desired flow rates to produce desired mixture during bypass-flow,
- Tube is carefully filled to approx. 1100 mbar with desired mixture,
- Tube is left alone for several minutes to achieve thermal equilibrium,
- Tube is depressurized slowly to  $p_{ini} = 1000 \text{ mbar} \pm 10 \text{ mbar}$  through  $H_2$ -Sensor to determine  $H_2$ -concentration,
- Mixture in tube is ignited by a spark-plug,
- Tube is evacuated again after end of experiment.

# E5.2: Flame acceleration and DDT at cryogenic temperatures (Combustion-Tube)

## ■ Warm Tests:

Several tests at ambient temperature in three configurations are planned:

- Tests without obstacles (currently performed)
- Tests with BR = 30%
- Tests with BR = 60%
- Hydrogen-concentrations investigated in the warm tests are:  
 $\text{cH}_2 = 10, 11, 12, 15, 20, 30, 45, 60 \text{ Vol\%}$ .
- Experiments started, performance of facility is currently tuned ...





# E5.2: Flame acceleration and DDT at cryogenic temperatures (Combustion-Tube)



## ■ Test Procedure (“Cold Tests”)

- Tube is evacuated and purged with air several times,
- Tube is evacuated to vacuum,
- Pool around tube is filled with LN2 until it is completely covered,
- Tube is allowed to cool down several minutes,
- Mass flow controllers are adjusted to desired flow rates to produce desired mixture during bypass-flow,
- Tube is carefully filled to approx. 1100 mbar with desired mixture,
- Tube is left alone for several minutes to achieve thermal equilibrium,
- Tube is depressurized slowly to  $p_{ini} = 1000 \text{ mbar} \pm 10 \text{ mbar}$  through H<sub>2</sub>-Sensor to determine H<sub>2</sub>-concentration,
- Mixture in tube is ignited by a spark-plug,
- Tube is evacuated immediately after end of experiment.

# E5.2: Flame acceleration and DDT at cryogenic temperatures (Combustion-Tube)



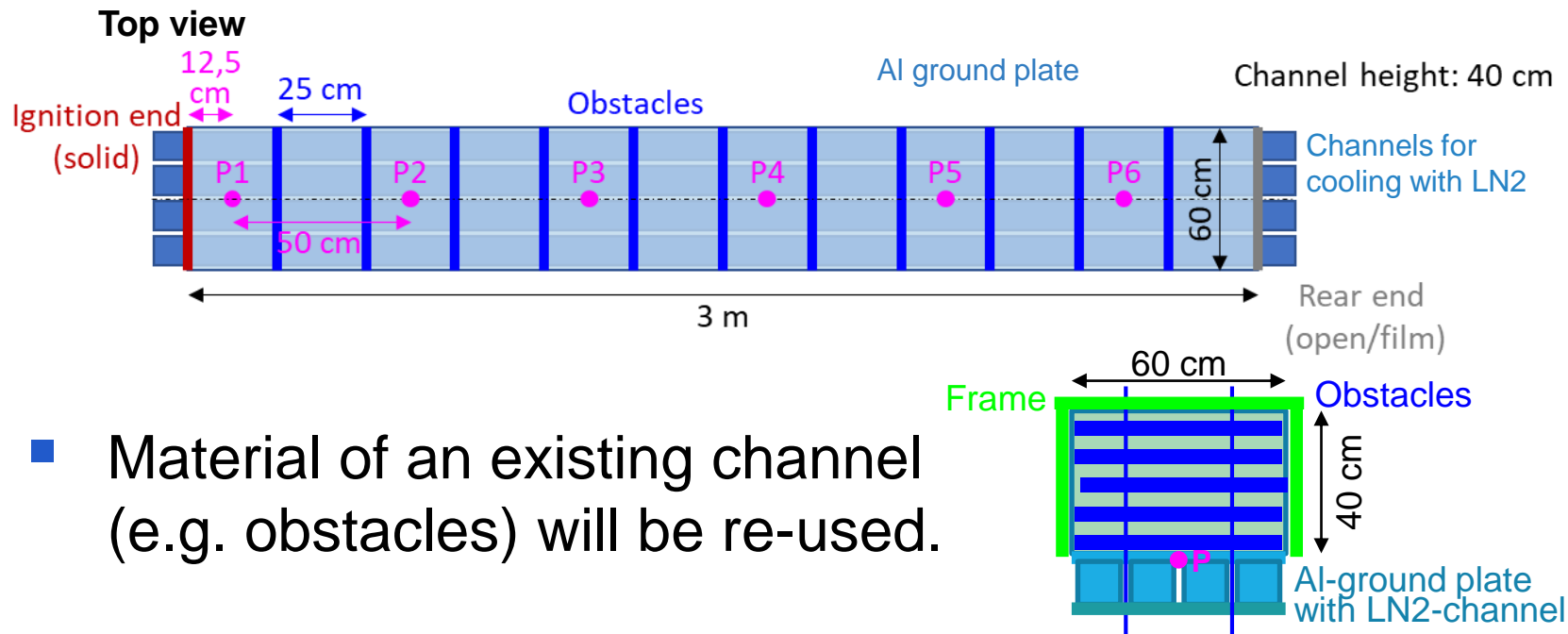
- Test Parameters (“Cold Tests” at 80 K)
  - 2 blockage ratios (30% and 60%)
  - 10 H<sub>2</sub>-concentrations from within the ranges
    - 6 to 12 Vol.% H<sub>2</sub>
    - 15 to 20 Vol.% H<sub>2</sub>
    - 30 Vol.% H<sub>2</sub>
    - 60 to 75 Vol.% H<sub>2</sub>

## E5.3: Flame propagation over a spill of LH2 (Box-Facility)

- General aim is to evaluate the danger of flame propagation over a spill of LH<sub>2</sub> in presence of inverse vertical hydrogen concentration gradients at cryogenic temperatures above the LH<sub>2</sub>.
- Tests will be performed in a half open box inside the HYKA-H110 vessel (110 m<sup>3</sup>). Natural hydrogen concentration gradient as above the LH<sub>2</sub> will be reproduced in the tests based on hydrogen evaporation rate measured within E3.4 experiments (WP3). The natural temperature profile will optionally be created. Then the mixture should be ignited at the position of highest hydrogen reactivity to measure possible flame propagation velocity with and without obstacles.
- The measurements include: local hydrogen concentration, temperature profile, pressure sensors and high speed video combined with BOS technique. Maximum combustion velocity and pressure will be measured as function of hydrogen concentration profile, thickness of the layer and presence of obstructions with different blockage ratio.
- The range of parameters to be examined is: 3 hydrogen concentration gradients, 3 layer thicknesses, 2 blockage ratios (30 and 60%)

# E5.3: Flame propagation over a spill of LH2 (Box-Facility)

- A horizontal channel with the dimensions 3 x 0.6 x 0.4 m will be constructed for the experiments,
- The channel will have a ground plate of Al, that can be cooled from below by LN2 to approx. 80 K.
- Pre-cooled GH2 (80 K) will be injected to the channel by a pipe system slightly above its ground plate.



- Material of an existing channel (e.g. obstacles) will be re-used.

