



## PRESLHY WP4 - ignition

SH<sub>2</sub>IFT/PRESLHY workshop 06/03/2019

Pre-normative REsearch for Safe use of Liquid HYdrogen

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# WP4 objectives



- To identify and understand the ignition risks associated with situations unique to liquid hydrogen releases, where factors of cryogenic temperatures are significant
  - ignition potential at reduced temperature in the vapour phase
  - electrostatic charging in liquefied/multiphase mixtures
  - energetic multiphase mixtures of hydrogen and oxygen
- To understand the impact of these particular circumstances

# Key phenomena

- Electrostatic charge generation and build up associated with multi-phase releases/mixtures
- Evaluation and characterisation of processes that may lead to mixed  $H_2$  and  $O_2$
- Ignition potential of mixed solid/liquid/gas phase involving  $H_2$  and  $O_2$
- Flammability characteristics for low temperature  $H_2$
- Other ignition phenomena (spark, fire, catalytic materials, radiation, “diffusion ignition”...)

# Task 4.1 – Theory and analysis



- The primary aim is then to understand scenarios that are unique to  $\text{LH}_2$ , which may not have been previously addressed and may introduce novel, previously unobserved and poorly understood pathways to ignition
- This will be done by first collecting and critically reviewing existing information in order to identify gaps in understanding of related physical phenomena and their control
- Secondly, this subtask will concentrate on proposing a clear roadmap for closing the identified gaps

# Research priority workshop on hydrogen safety



“Spontaneous ignition of hydrogen air mixtures is not at all well understood”

- The following have been proposed explanations for the observed ignition:
  - Joule-Thomson heating (ruled out a 100 MPa release only increase the temperature by 53K not enough to reach the auto ignition temperature of ~858K)
  - Electrostatic discharge (discharge from charged particles)
  - Diffusion ignition (transient high-temperature shock waves)
  - Adiabatic compression (difficult to differentiate from diffusion ignition)
  - Contact with a hot surface
  - Catalytic reaction with materials present in the flow (iron oxide)

# Research priority workshops on hydrogen safety (2016, 2018)



- 2016 Ignition -
  - Forced
    - Reduced order model for accurate prediction of flammable extent (FF)
    - Influence of hardware in the flow (igniter vs laser spark)
  - Spontaneous
    - Fundamental Mechanisms
    - Prediction
- 2018 - Ignition sensitivity & electrostatic hazards during venting / accident scenarios

# Task 4.2 – Theory/simulations



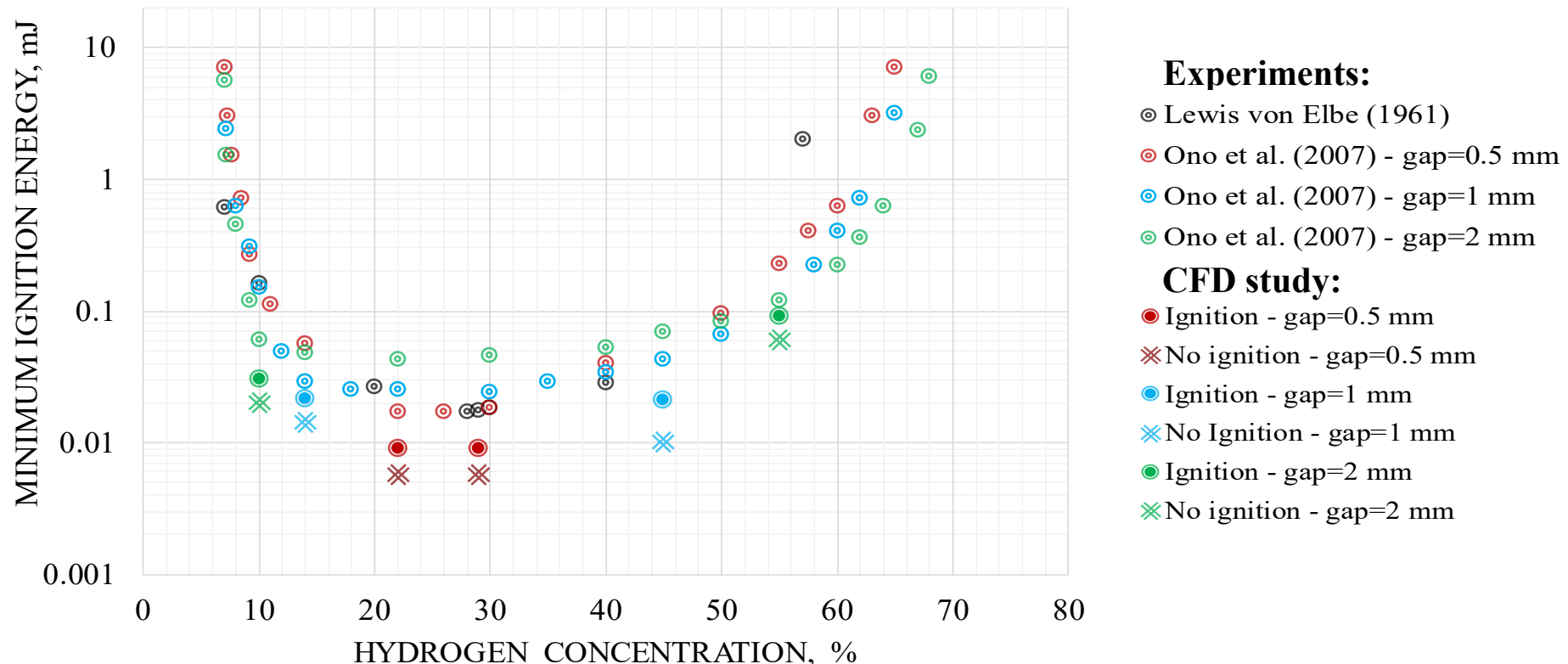
- Relationships between the standard ignition parameters (Flammability domain, MIE,...) and the practical ignition sources will be established on a theoretical basis
  - Model spark ignition of cryogenic hydrogen-air mixtures with air accounting for chemical kinetics
  - Diffusion ignition simulations to understand the impact of enhanced density of cryogenic releases on the shock ignition process, and the trade off against increased difficulty of igniting cold  $H_2$ /air mixtures.
  - Studies to understand phenomena associated with cryogenic mixtures of  $H_2/O_2$  and their formation/ ignition.



# Numerical evaluation of MIE

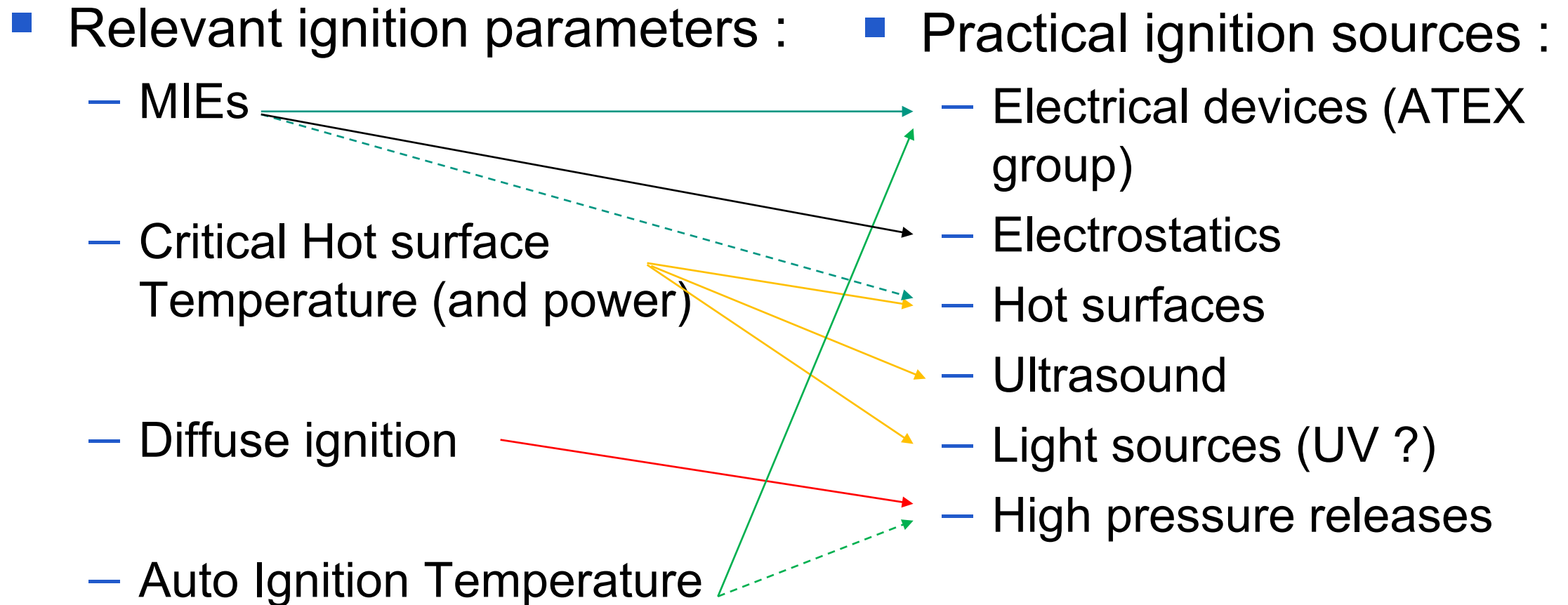
## UU research on spark ignition in hydrogen-air mixtures

- Minimum ignition energy by spark ignition was numerically determined for mixtures at ambient temperature with H<sub>2</sub> content in air in the range 10%-55%
- WiP study: effect of radiation losses, electrodes and spark channel geometries
- Final application: use of the developed CFD model to evaluate numerically MIE in mixtures at cryogenic temperature





# Theoretical aspects

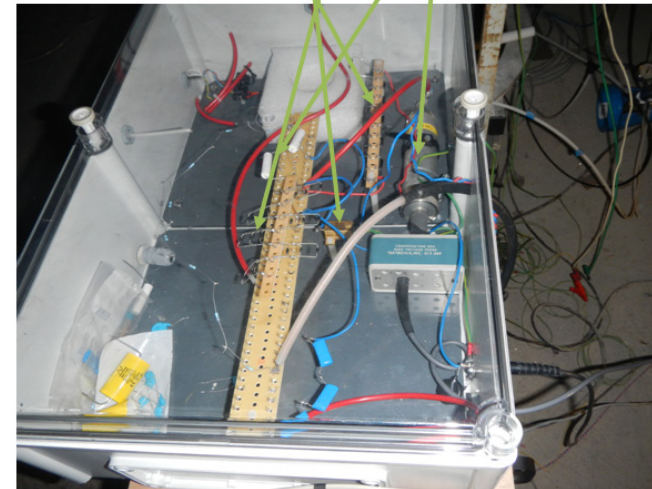
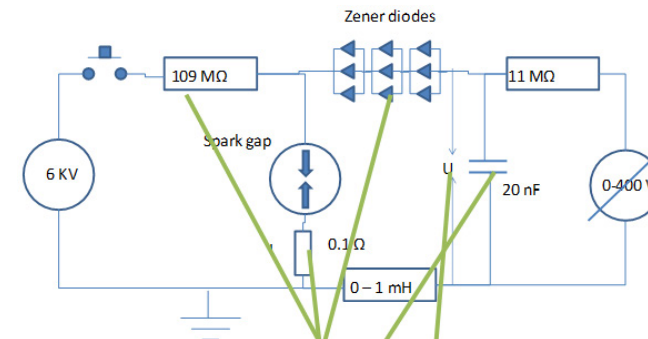
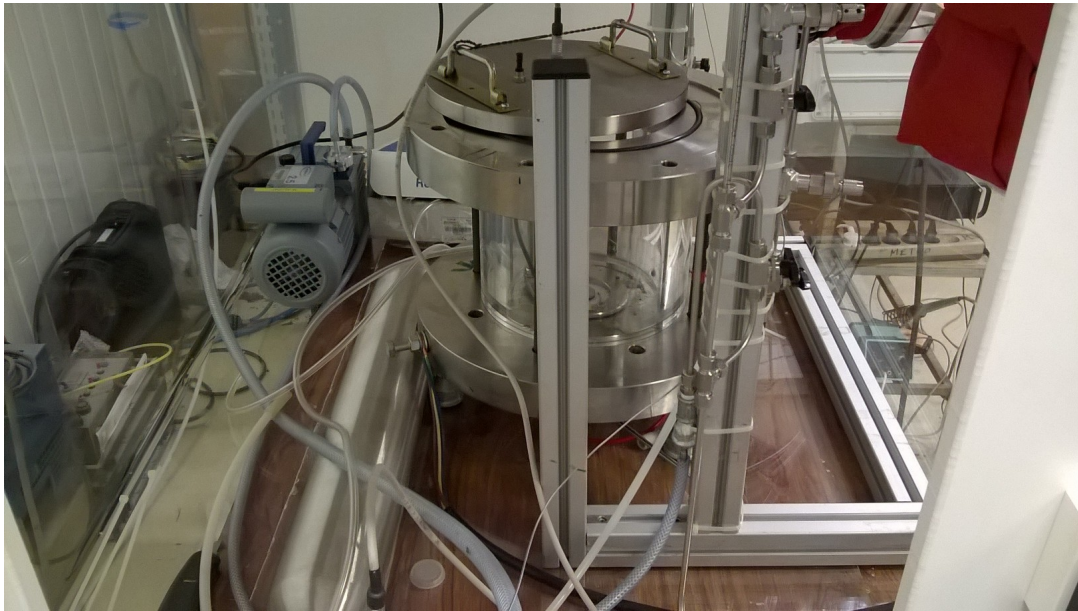


## Task 4.3 – Experiments

- E4.1 General ignition parameters (INERIS)
- E4.2 Electrostatic ignition in a cold jet (KIT)
- E4.3 Electrostatic ignition in a cold plume (HSL)
- E4.4 Ignition of a spill of  $\text{LH}_2$  (KIT)
- E4.5 Investigation of  $\text{H}_2$ /condensed  $\text{O}_2$  phase (HSL)

# E4.1 General ignition parameters

- Investigation of the standard ignition parameters as a function of temperature of mixtures, within the range  $-100\text{ }^{\circ}\text{C}$  –  $20\text{ }^{\circ}\text{C}$ 
  - MIE
  - Flammability domain
  - Laminar burning velocity





# E4.1 Hot surfaces/power



## Performance:

- 4% to 80% H<sub>2</sub>
- Ambient to -150°C
- Ambient pressure
- Velocity from nearly 0 to 30 m/s

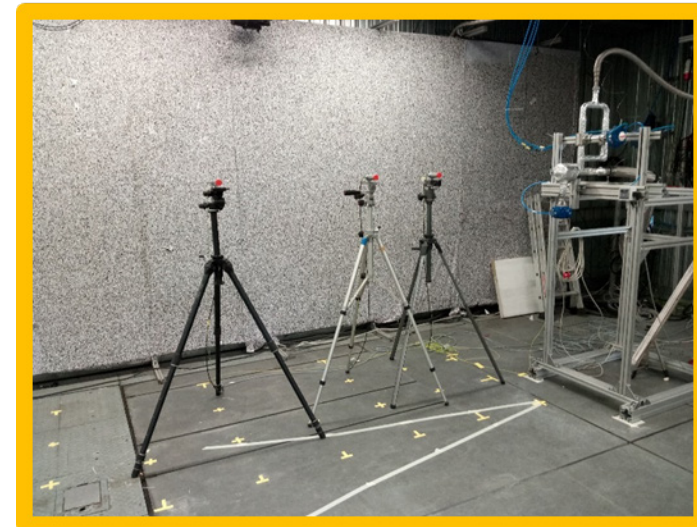
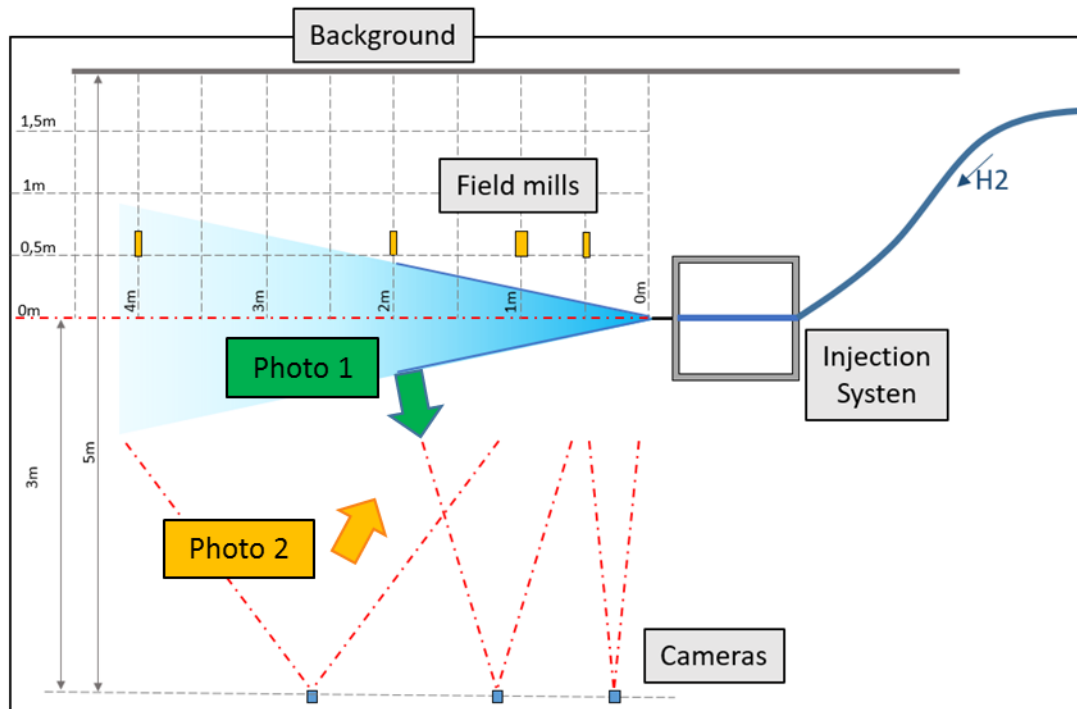


## Measurement capabilities :

- Hot surface/power ignition
- Combustion velocity (turbulent)

# E4.2 Electrostatic ignition in a cold jet

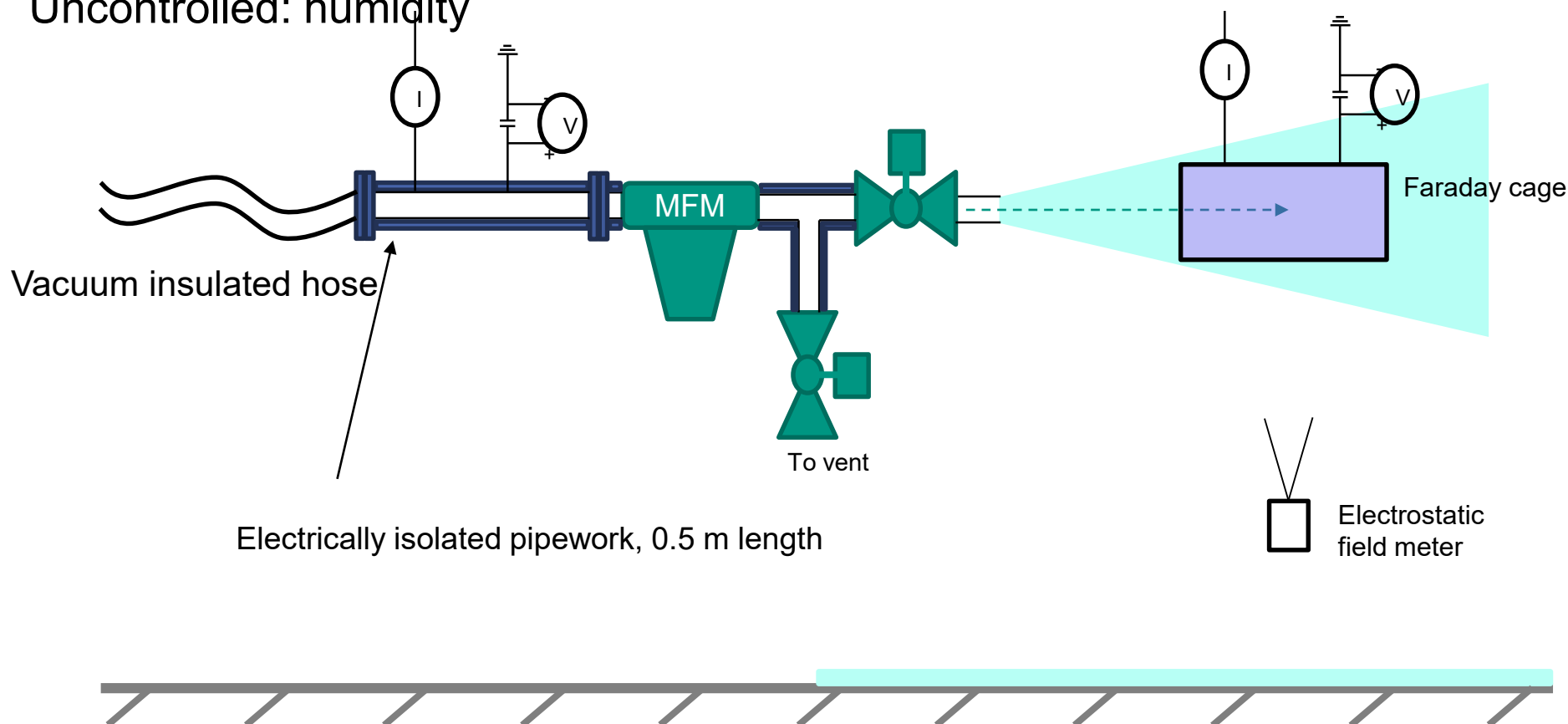
- Investigation of the generation of electrostatic charge using Cold-Jet-Facility, varying:
  - Initial pressure
  - Initial temperature
  - Nozzle diameter





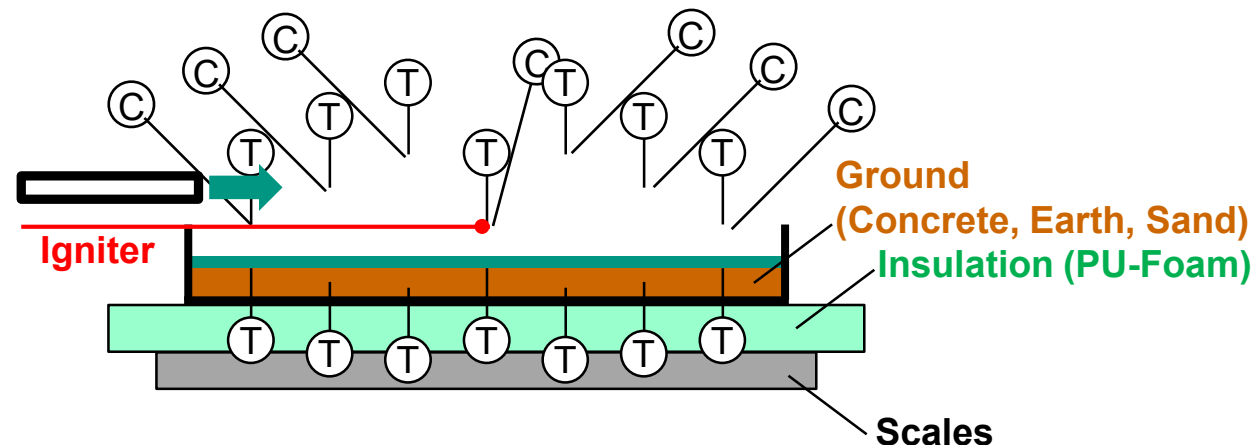
# E4.3 Electrostatic ignition in a cold plume

- To provide base level electrostatic measurements to draw practical implications from – i.e. comparison of propensity to ignite vs organics
- Variables:
  - Controlled: Flow rate, orifice diameter
  - Uncontrolled: humidity



## E4.4 Pool-Facility

- Suitable test-site for experiments found close to KIT,
- Test-site is owned by institute of KIT-Campus South which has no obligations against use for the experiments,
- Test-site is remote and surrounded by woods and thus allows release of large amounts of  $H_2$ ,
- Even ignition of released  $H_2$  is possible,
- Test site is connected to electricity and water supply,
- Site visit planned for March.





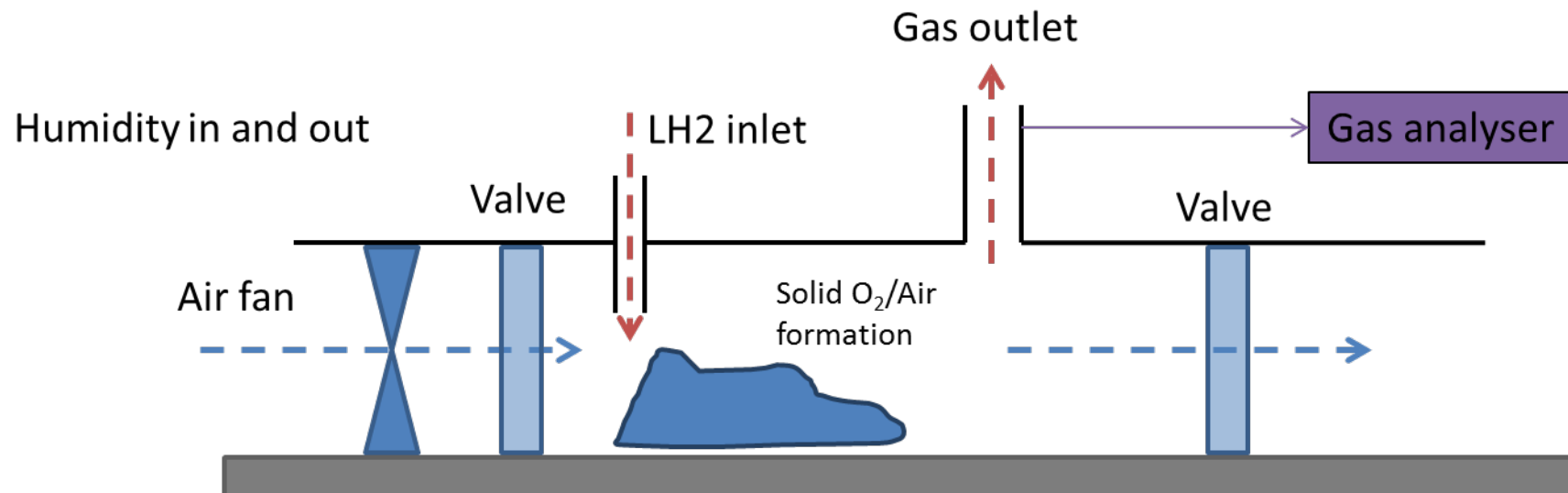
## E4.5 Investigation of condensed phase



- In order to understand the hazard surrounding condensed phase generation it is necessary to know what the composition of the condensate is and under what conditions it might form
- Therefore two sets of experiments are planned:
  - Compositional analysis of the condensate produced during a spillage under controlled wind conditions
  - Rapid phase transition of the condensate by water deluge (fire fighting methods)

# Compositional analysis

- Test procedure
  1. LH2 fed into ducting onto concrete surface
  2. Air fed through the ducting via a fan at a known flow rate with the valves open
  3. Condensed phase allowed to build-up within duct
  4. LH2 inlet and ducting valves closed so gas evolves through outlet and is sampled by gas analyser



# Rapid phase transition

- These tests should provide data on whether RPT's are possible with water deluge and if not, whether water is an effective mitigation measure
- Two forms of deluge will be used:
  - Fire hose
  - A water sprinkler system
- Both forms of deluge will also be tested with and without a permanent ignition source in place to assess the difference in over-pressure generated

# Acknowledgements



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