An ultra-pure gas system for the CLOUD experiment at CERN

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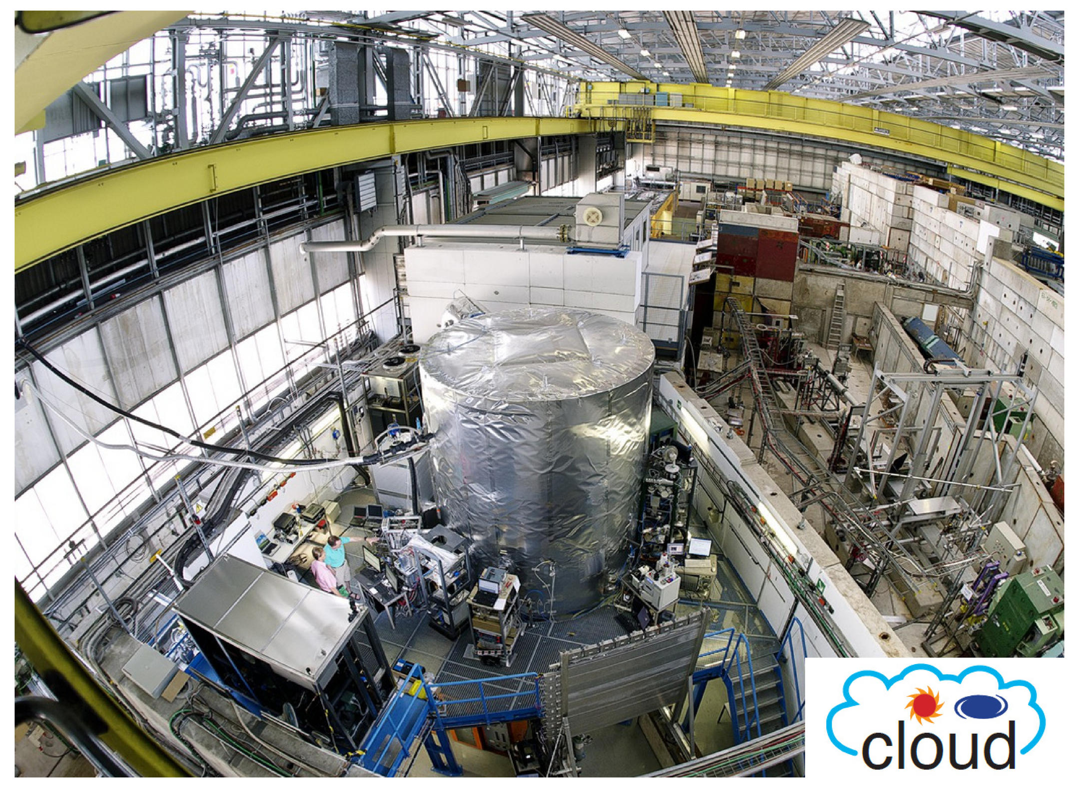
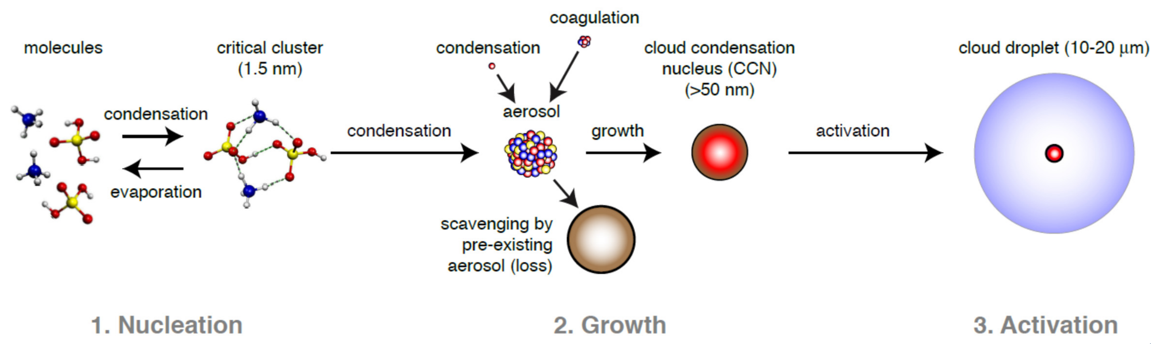


Introduction

The CLOUD (Cosmic Leaving Outdoor Droplets) experiment aims to recreate atmospheric conditions inside a large chamber in which aerosols, cloud droplets and ice particles can be produced under precisely controlled laboratory conditions and to expose the chamber to an adjustable particle beam at CERN PS, which closely replicates natural cosmic rays.

Aerosols and clouds are recognized as representing the largest uncertainty in the current understanding of climate change, and the CLOUD experiment aims to settle the question of whether or not they are significantly influenced by cosmic rays.



The CLOUD chamber

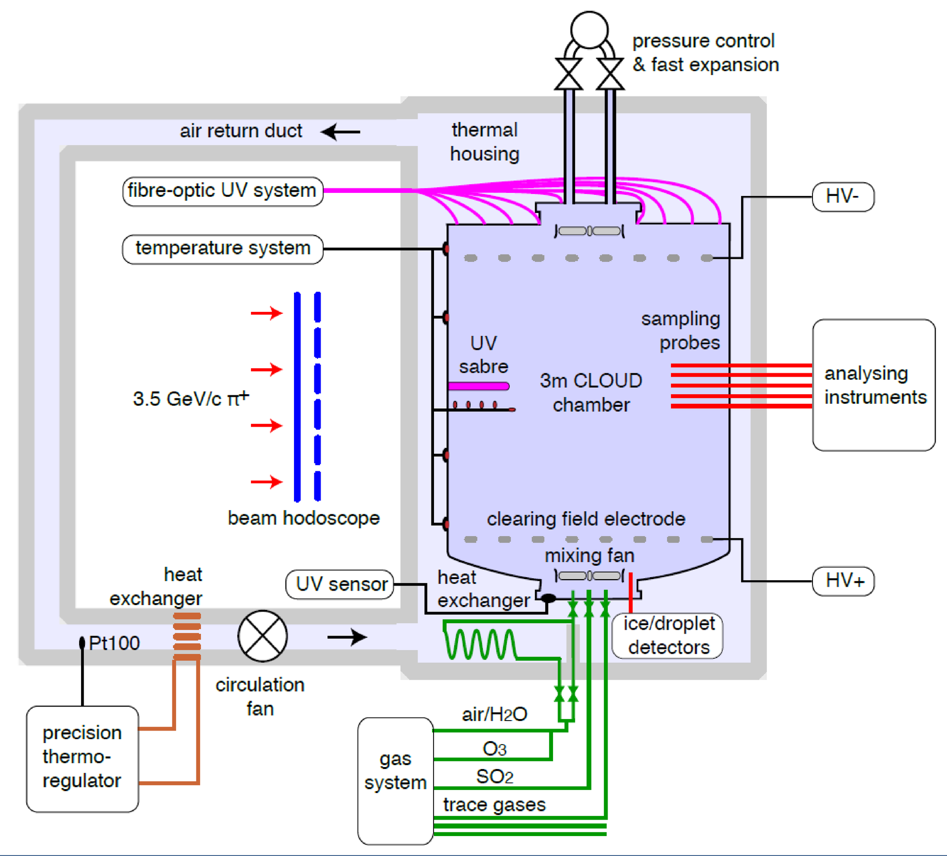
The CLOUD chamber is a 3 m electro-polished stainless-steel cylinder. The highest technical standard of cleanliness has been followed for the construction.

Thanks to its large volume (26.1 m^3) and highly stable operating conditions (temperature stability ±0.01 K), the chamber allows measuring nucleation rates over a wide range (10^{-3}-10^2 $cm^{-3}s^{-1}$).

The CLOUD experiment has several unique aspects, including:

1) Precise control of the "cosmic ray" beam intensity from the CERN Proton Synchrotron (PS)
2) The capability to create an ion-free environment with an internal electric clearing field
3) Precise and uniform adjustment of the H_2SO_4 concentration by means of ultraviolet illumination from a fibre-optic system
4) Highly stable operation at any temperature between 183 and 300 K

The content of the chamber is continuously analyzed by a suite of instrument connected to sampling probes that project into the chamber



The gas system

The clean air production and the control of the impurities injected constitute two basic steps for the CLOUD experiments since they allow recreating the particular atmospheric conditions in a controlled way. Therefore, the gas system is a key element for the success of the CLOUD experiment. It was built following the highest standard of cleanliness: avoiding grease, rubber and plastic joints and limiting as much as possible the use of PTFE. The gas system was designed -where possible- according to standard designs, using common technology and components already in use for the all the other gas systems at CERN in order to facilitate the maintenance.

Humidifier and water production

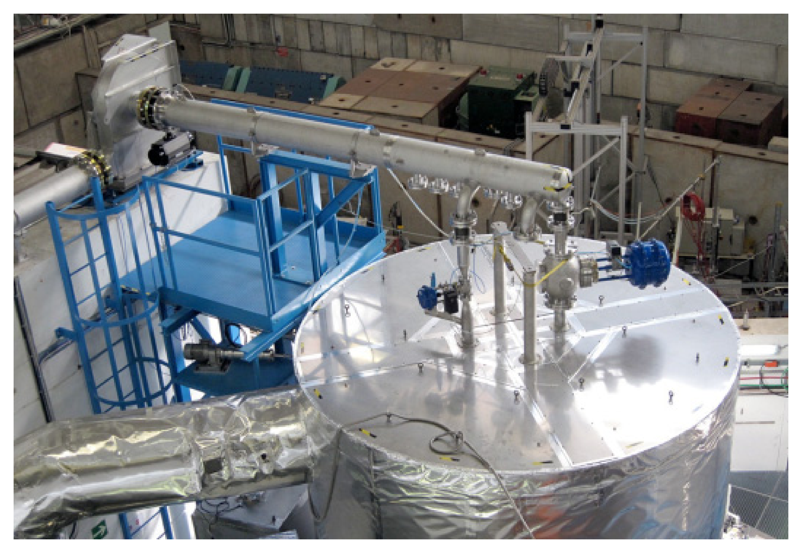
A new module for the production of synthetic ultrapure water (directly from burning electrolytically-produced H_2 and pure O_2) has been built and it will allow further reducing of the level of uncontrolled contaminants in the chamber. The module is now under commissioning and the performances will be the subject of dedicated tests before the end of this winter run.

Water vapour is added to the clean air in order to obtain the desired level of humidity in the chamber.

Pressure control and Adiabatic expansion

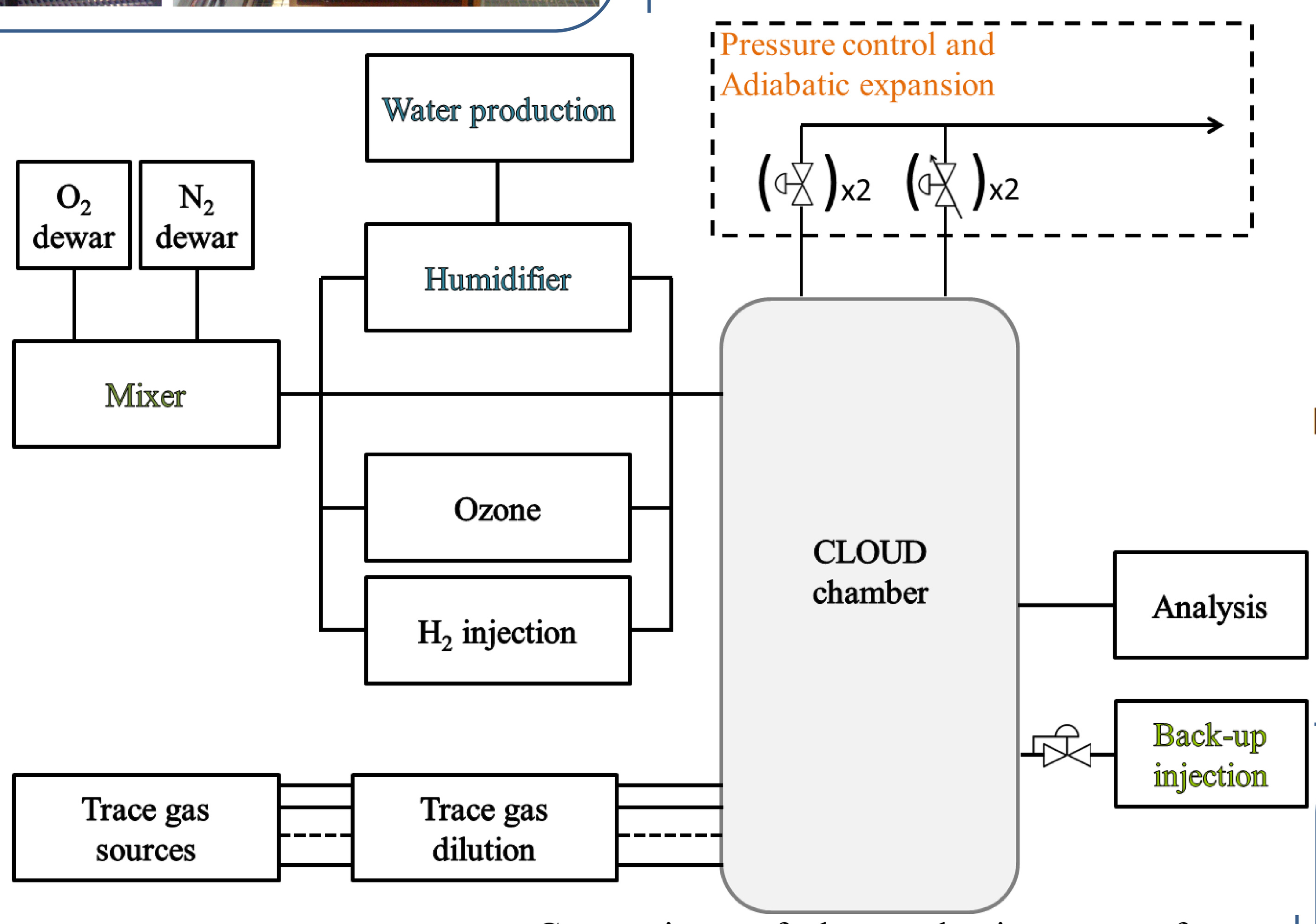
The CLOUD chamber is always operated slightly above atmospheric pressure in order to avoid contaminants to penetrate inside, destabilizing the well-controlled conditions under which the experiments run.

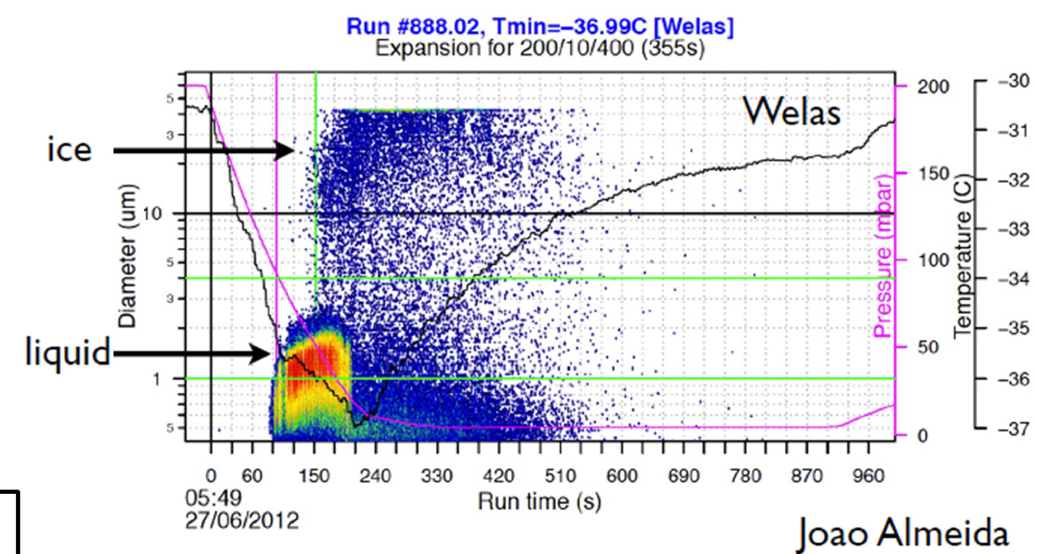
The adiabatic expansion system is a new modification implemented and tested during the June 2012 run. The system produces controlled adiabatic expansions in time intervals from few seconds up to few tens of minutes and it allows studying possible direct effects of cosmic rays on liquid or ice clouds.



Mixer

The air mixture is produced in the mixer module by means of mass flow controllers (MFCs) and the O_2 concentration is continuously monitored with a ZrO_2 analyzer. The primary gases, i.e. N_2 and O_2, are obtained from the evaporation of cryogenic liquid N_2 (purity 99.995%) and O_2 (purity 99.998%).



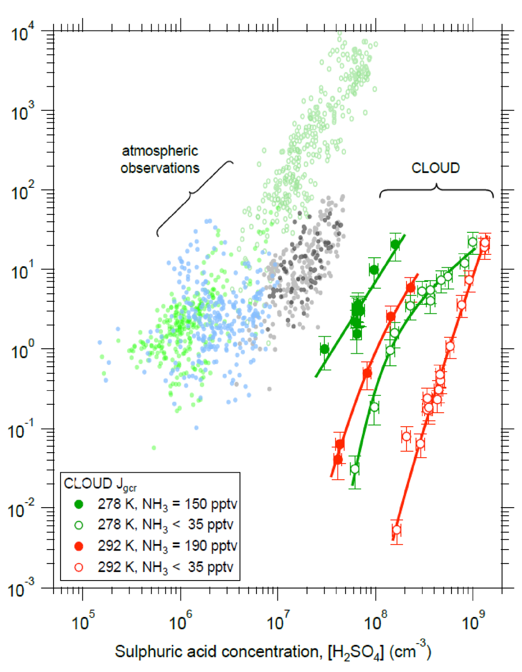


Ice particles and liquid drops produced during one of the first expansion tests in June 2012

Trace gas dilution and injection

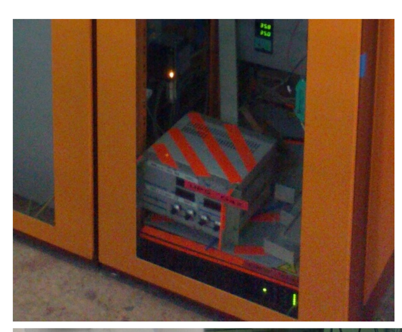
Eight lines are available for trace gas injection at extremly low concentrations (as low as few pptv). The trace gases used are O_3, SO_2, NH_3, pinanediol, α-pinene, dimethylamine, nitrous acid and H_2. In each line, the content coming from a gas cylinder or evaporator is diluted with clean air at the desidered concentration using MFCs. The excess of gas is exhausted through a back-pressure regulator.

Two valves allow either to inject the gas into the chamber or to purge/condition the line up to the injection point into the CLOUD chamber. Where needed (due to the use of low temperature condensable gas), the lines are heated all along the way.



Comparison of the nucleation rate of new particles as a function of $[H_2SO_4]$ measured by CLOUD (large red and green circle symbols) with atmospheric boundary layer observations (small dot and circle symbols). The measurements at 278 K and 292 K bracket the typical range of boundary layer temperatures (Kirkby et al., Nature 476, 2011). The results show that the most likely nucleating vapours, sulphuric acid and ammonia, cannot account for nucleation in the lower atmosphere, even in the presence of ions from galactic cosmic rays.

Back-up air injection



Under-pressure events due to power-cuts or other failures were experienced in the past years. The back-up injection module has been recently introduced and it automatically starts to inject clean air from a secondary mixer, powered by an uninterruptible supply, when the chamber pressure approaches the safety threshold. On the left the back-up mixer and the warning system indicating the chamber pressure (located in the Control Room) are visible.

The CLOUD experiment represents the state-of-the-art in the study of the effects of cosmic rays on the formation of aerosols and clouds recognized to be the largest uncertainty in the present understanding of climate change. The gas system is a key element for the success of the experiment thanks to its high standard of cleanliness and flexibility. Here, a brief overview of all the different modules has been presented with some examples of the scientific results achieved.