EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-SPSC-2007-014
SPSC-SR-019
April 12, 2007

STATUS REPORT OF PS215/CLOUD

CLOUD Collaboration

1 INTRODUCTION

The CLOUD experiment [1] was approved by the Research Board in March 2006, and is designated PS215. Its goal is to investigate the microphysical interactions of cosmic rays on aerosols, ice particles and clouds, which have bearing on the question of a possible "solar indirect" climate forcing.

The experiment will involve a central CLOUD facility in the T11 beamline at the CERN PS, comprising a cloud chamber and a large reaction chamber, within which the atmosphere is re-created from ultra-pure air with added water vapour, trace gases under study and, for certain experiments, aerosols. The chambers will be equipped with a wide range of analysers to measure their contents *in-situ* via optical ports, as well as external analysers to monitor and analyse their contents via sampling probes. The temperature and pressure anywhere in the troposphere or stratosphere can be re-created within the chambers' pressure-vessels. The PS beam provides an adjustable and precisely measurable source of "cosmic rays" that closely matches natural cosmic rays in ionisation density (dE/dx), uniformity and intensity, spanning the atmospheric range from ground level to the maximum around 15 km altitude. The experimental programme will include the effects of cosmic rays on the creation and growth of aerosols in the presence of trace condensable vapours found in the atmosphere (H_2SO_4, NH_3, volatile organic compounds, etc.), the activation of aerosols into cloud droplets, the formation of trace reactive molecules such as NO and OH and their effect on cloud processes, and the creation and dynamics of ice nuclei.

CLOUD has made substantial progress in the first year since approval. In particular, the first CLOUD prototype tests were carried out in the T11 beamline at the CERN PS during an 8 week period from September to November 2006. The purpose of these tests was to provide technical input for the CLOUD design and to begin preliminary physics measurements by searching for evidence of ion induced nucleation of new aerosol particles from trace H_2SO_4 vapour (at concentrations of around 1 part per trillion [ppt]). A brief summary of the 2006 beam test is provide in §2, and the planning and beam request for 2007–2008 is presented in §3.

2 2006 BEAM TEST OF CLOUD PROTOTYPE

2.1 Equipment

The equipment installed for the 2006 beam test involved a $2 \times 2 \times 2$ m^3 stainless steel chamber built by the Danish National Space Center (DNSC) (Fig. 1). The chamber operated at room temperature and 1 atm pressure. It was equipped with electrodes and a field cage that provided an electric field of up to 40 kV/m. This provided the capability to sweep both charged ions (in less than 1 s) and charged aerosols from the chamber volume, when required. One of the chamber walls was made of a UV-transparent teflon sheet. This was illuminated with 254 nm UV light from a bank of fluorescent tubes, to provide photochemical dissociation of O_3 in the chamber and, in turn, the oxidation of SO_2 into H_2SO_4. Another wall of the chamber was equipped with a line of ports to which were attached an array of sensitive instruments to analyse the chamber contents via sampling probes (Fig. 2). The analysers included the following instruments:

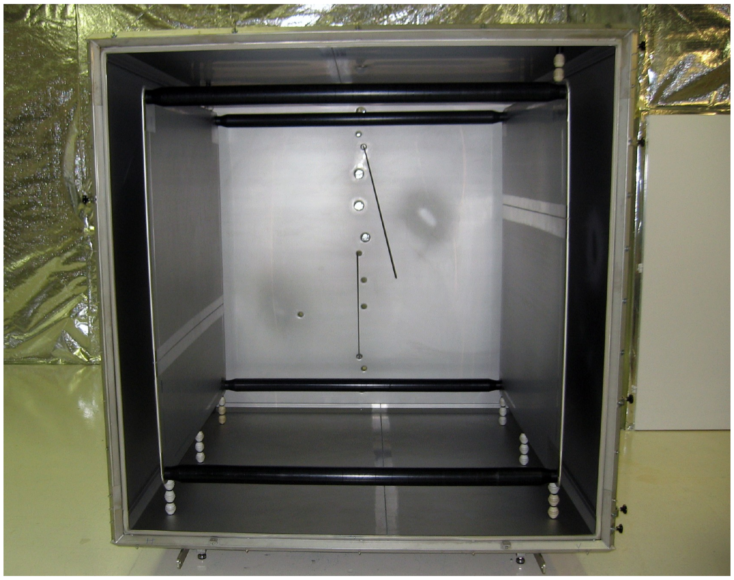

Fig. 1: CLOUD 2 m prototype chamber for the 2006 T11 beam tests, during assembly in a clean room at CERN. The UV-transparent teflon window is removed to show the field cage and HV electrodes (left and right). The line of sampling ports can be seen on the far wall, together with two sampling probes projecting into the chamber.

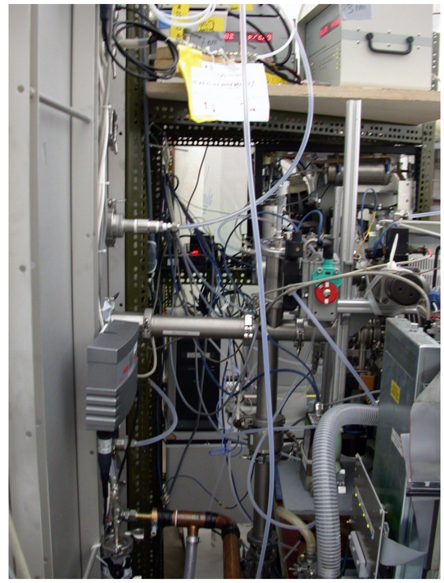

Fig. 2: Partial view of some of the sampling instruments attached to the chamber in the T11 experimental zone.

- A chemical ionisation mass spectrometer (CIMS) from MPIK-Heidelberg, capable of measuring H_2SO_4 concentrations down to 0.1 ppt.
- A battery of four condensation particle counters (CPCs) and a scanning mobility particle sizer (NanoSMPS) from PSI and Univ. Mainz. The nominal CPC thresholds were set to 3, 4, 7 and 9 nm to allow a fast ($\sim$1 s) measurement of the particle size spectrum of freshly-nucleated aerosols. The CPC battery was preceded by a 4 kV electrostatic precipitator, which was switched on or off every 40 s; the difference in counting rate allowed the charged aerosol fraction to be measured. A fifth CPC, from DNSC, with a 3 nm threshold, was included as a cross-check of the CPC battery.
- An air ion spectrometer (AIS) from Univ. Helsinki, to measure the size spectrum of positive and negative charged particles in the range from molecular sizes up to about 40 nm diameter.
- Various instruments from DNSC to measure temperature, pressure, relative humidity, UV intensity, field cage HV, SO_2 concentration, O_3 concentration, etc. These instruments included a Gerdien tube to provide an independent measurement of the charged ion mobility spectra for positive and negative particles, by sensitive (fA) measurements of the air conductivity.

CERN's contribution to the beam tests included support for the T11 beam and experimental area, as well as clean room space for the chamber assembly, and East Hall logistical support. The T11 beam was tuned to the Durieu/Gatignon optics, providing a large transverse size of about 1×1.2 m^2 ($x \times y$) at the chamber. A beam hodoscope of $7x + 7y$ counters (kindly lent by B. Schmidt) monitored the beam. CERN also designed the high-volume ultra-pure air gas supply system, based on the evaporation from liquid O_2 and liquid N_2 dewars, mixed in the ratio 21:79. A total of 5000 litres of liquid O_2+N_2 was consumed during the run. The ultra-pure air system was entirely funded by Univ. Helsinki (construction and operation). The experiment was housed in a temporary, insulated, enclosure to improve the temperature stability, with air conditioning units provided by PSI.

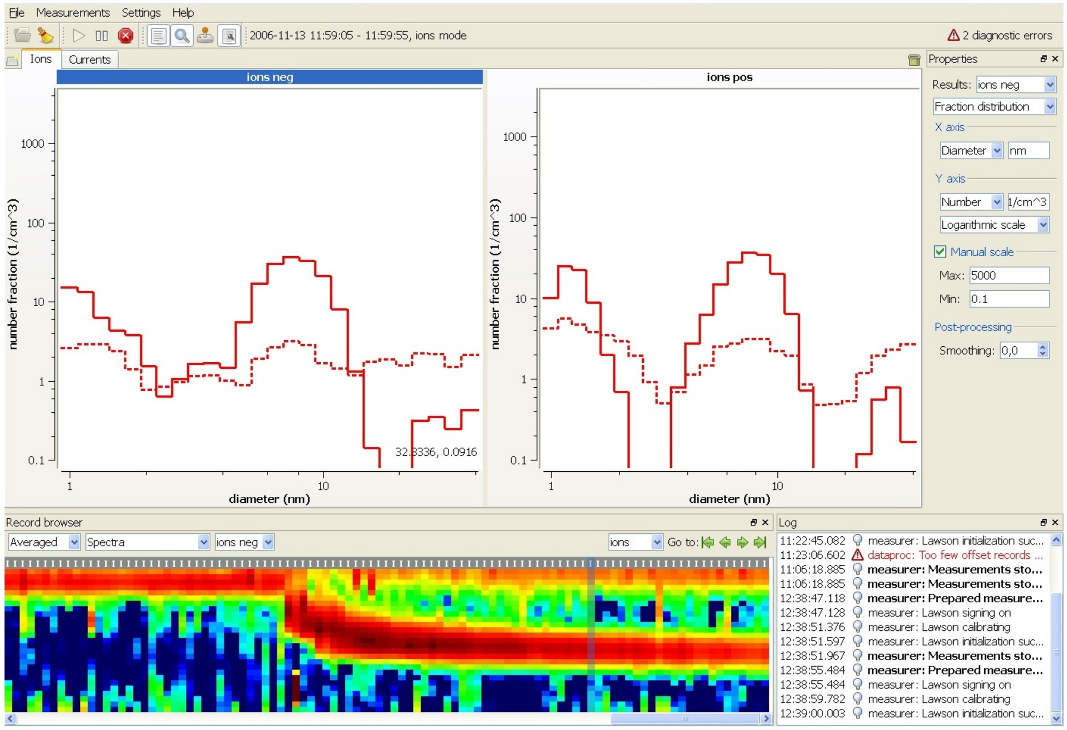

Fig. 3: A so-called *banana* plot (lower, coloured panel) showing a nucleation event of new aerosols in the CLOUD prototype chamber (caused by a large pulse of SO_2 injected into the chamber—around 50 ppb). The data are obtained with the AIS, which measures the size spectra of ions and charged aerosols. The banana plot shows time (x; each bin corresponds to 50 s) vs. aerosol size (y; inverted log scale). The upper red bar is a sea of $\sim$1 nm particles, which grow to sizes of $\sim$10 nm within a few minutes of the nucleation event. A slice through the banana plot at the location of the grey bar is shown in the upper histograms (solid red lines) for negative (left) and positive (right) particles.

2.2 Data and results

CLOUD is a triggerless experiment in which the development of the chamber contents is monitored continuously. This requires that data recorded by the various independent instruments be somehow synchronised. For this purpose, a DAQ system was set up to provide a synchronised time stamp on all event records. This approach was adequate for the instruments used in the 2006 prototype tests.

The basic procedure for data runs is to establish the required initial conditions and stability in the chamber and then to change a single parameter—say the beam or UV intensity—and then monitor the resultant aerosol and gas changes. The quantity of fundamental interest is the sensitivity of aerosol production and growth to the beam flux. Each run may require from several hours to half a day before achieving the required initial conditions. (In the final CLOUD, the turn-round time should be shorter since the chambers can be vacuum pumped and baked between runs; however, for the present prototype tests, the chambers were cleaned by flushing alone.) The main measurement then takes place over a continuous period lasting from several hours up to about 2 shifts (16 hr), with various parameters adjusted at intervals. During this period, stable beam conditions are desirable (i.e. in contrast with standard fixed-target experiments, receiving occasional spare beam pulses is not desirable). A total of 35 data runs were recorded during the test beam period.

Despite involving a complex integration of many different instruments, the CLOUD equipment operated very successfully during the run. Some examples of the data recorded are shown in Figs. 3 and 4. A working group has been formed to analyse the experimental data and interpret it with aerosol models, and a decision on whether to publish the results will be made later this year after further analysis.

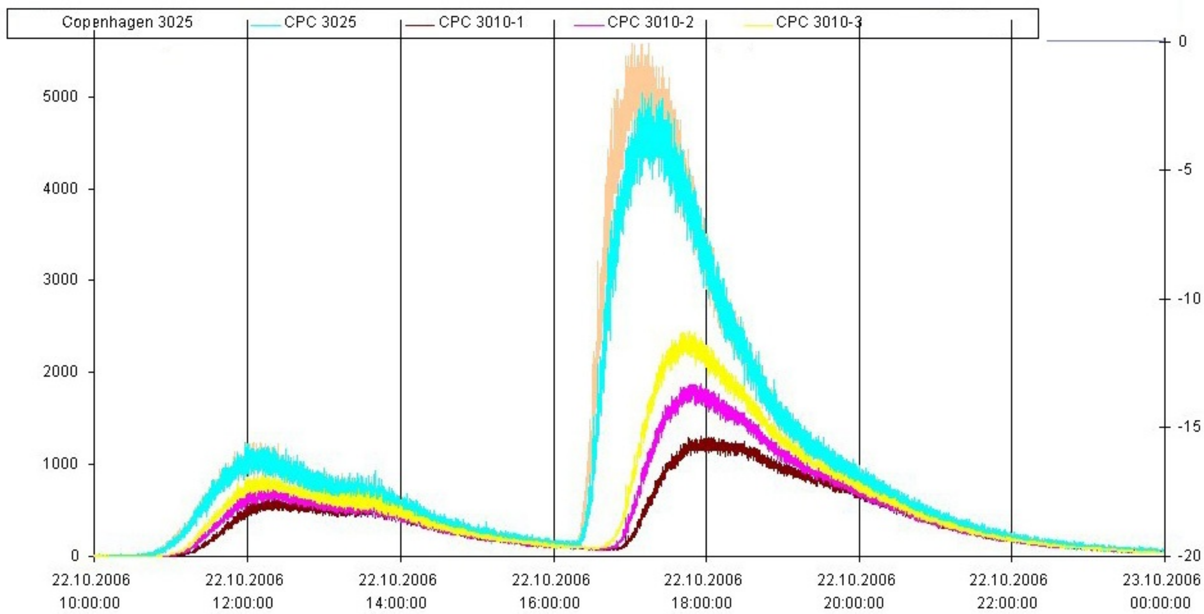

Fig. 4: Example of two nucleation events recorded in the CPC battery. The curves show the aerosol particle number concentrations per cm^3 (y axis) vs. time (x axis). Each CPC is set to a slightly different size detection threshold (nominally 3, 5, 7 and 9 nm, respectively). This leads to a time delay between the onset of each curve and their peak positions, corresponding to the gradual growth in size of new aerosols. From this information the size and growth rate of the aerosols can be determined. The aerosol concentration eventually decays due to coagulation, wall losses, the depletion of available condensable vapour, and dilution. A fifth CPC is set to the same threshold as the most sensitive CPC in the battery to provide a cross-check (brown and cyan curves, respectively). The HV state of the 4 kV electrostatic precipitator at the entrance of the CPC battery is switched each 40 s; the charged fraction in these data is small since no modulation of the curves is visible.

2.3 Lessons from the 2006 beam tests

The primary aim of the prototype tests was to provide technical input for the CLOUD design, as well as to gain experience of the experimental techniques. A great deal of useful information was obtained. Among the most important lessons are the following:

- **Temperature stability:** Reliable nucleation measurements were found to require a temperature stability of around 0.1°C. During the 2006 run, these conditions could only be reached during the night time. A temperature-controlled housing for CLOUD is required for future runs.
- **Cleanliness:** CLOUD is measuring processes involving ppt concentrations of trace condensable gases. This requires extreme attention to inner surface cleanliness, to the absence of leaks in the detector and to the strict avoidance of unsuitable materials. Moreover, all components of the final CLOUD apparatus should have the capability to be vacuum baked *in situ*.
- **Organic compounds:** Experimental evidence was obtained that indicated the importance of including a sensitive analyser of trace volatile organic compounds (§3.1).
- **Ultra-pure air supply:** As far as we could measure in the 2006 run, the technique of generating ultra-pure air from the evaporation of cryogenic liquids is a great success; it appears to freeze out condensable vapours down to a sufficiently low residual level.
- **Space for analysing instruments and local electronics:** In order to avoid large transmission losses, the sampling lines into the analysing instruments must be not more than a few tens of cen-

timetres in length. This implies that large instruments must be efficiently located in close proximity (a problem not unfamiliar to particle physics!). Furthermore, each instrument requires space in nearby racks for local electronics, and the experimental area needs to be efficiently equipped with services (electrical sockets, cable trays, gas pipework, safety features, etc.). The space problem should be much reduced in the new layout planned for the T11 area (Figs. 5 and 6).

- **Beam size:** For the 2006 run, the beam dimensions (1×1.2 m^2) were significantly less than the chamber (2×2 m^2). This should be largely solved in future operations since the aperture of the final dipole has been increased by 50%, and CLOUD will be located further downstream, allowing the beam to diverge further (Fig. 6).

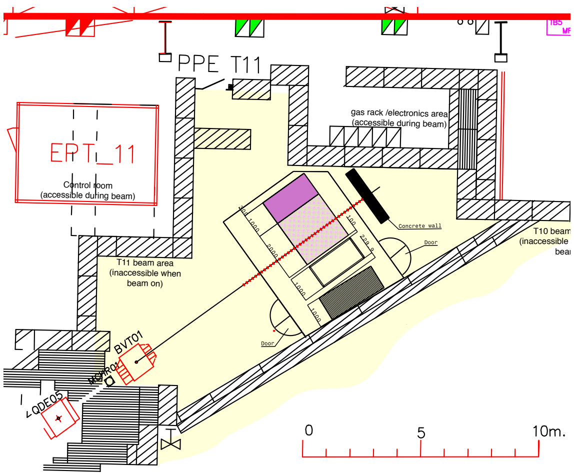

Fig. 5: East Hall T11 experimental area for the 2006 CLOUD prototype beam tests.

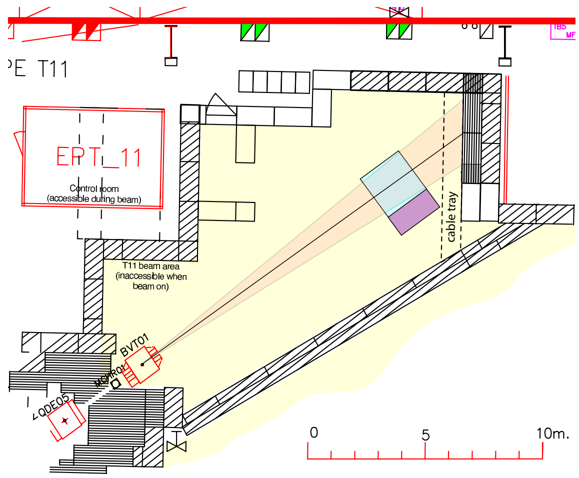

Fig. 6: New T11 experimental area (from 2007 onwards), after relocation of the gas rack alcove. The CLOUD facility is located in the downstream region, while the upstream region—near to the nominal beam focal point—is available for other T11 users when CLOUD is not operating.

3 PLANNING

3.1 Collaboration aspects

Full CLOUD collaboration meetings are held approximately twice each year. Since approval, the collaboration has met in Copenhagen (3–5 May 2006), CERN (5–6 October 2006) and Helsinki (3–5 April 2007). The experiment is led by the CLOUD Steering Committee, comprising seven senior partners and chaired by the spokesperson.

The University of Innsbruck (A. Hansel group) has recently joined the CLOUD collaboration. Their special expertise is in the field of ultra-sensitive detection (ppt levels) of volatile organic compounds based on chemical ionisation mass spectrometry. The proton-transfer-reaction mass spectrometry (PTR-MS) technique was developed at Univ. Innsbruck about a decade ago; the group has since gained extensive experience in field studies as well as in atmospheric simulation chamber experiments. Recent developments of the group include a High Resolution PTR time-of-flight MS instrument which allows for compound identification by means of precise mass determination. A particle accumulation and thermal desorption system is currently being developed to extend the PTR-MS technique to the analysis of semi-volatile and non-volatile organic compounds.

3.2 Funding

The CLOUD detector rather naturally divides into two groups of instruments: the central CLOUD facility and the external analysers, with total materials costs of approximately €2M and €7M, respectively (see Add. 3 of the CLOUD proposal [1]). Funding of the materials and personnel for designing, constructing and operating CLOUD is being requested both from the European Union 7^{th} Framework Programme (FP7) and from national funding agencies.

EU FP7 proposals: The first round of calls for FP7 proposals opened in December 2006. CLOUD is submitting two proposals in this first round: 1) a Capacities-Research Infrastructures-Design Studies proposal (requesting about €2.2M over a 2.3 year period), and 2) a Marie Curie proposal requesting support for about 10 Ph.D. students, each for 4 years, in a "CLOUD Collaboration Network for young researchers" (with the acronym CCN). The collaboration has asked the spokesperson to be coordinator for the Design Studies proposal, and Joachim Curtius (University of Mainz and MPI-Chemistry) to be coordinator for the Marie Curie proposal. The CERN EU office (S. Stavrev) is kindly assisting in the preparation of the Design Studies proposal. The deadline for submission of both these proposals is the beginning of May. If successful, the first money for the Design Study could become available at the end of 2007, and the first students could be funded in early 2008. If successful, these represent very substantial resources for the experiment, and the schedule for future CLOUD prototype beam tests has been closely integrated into the Design Study (§3.3). It may therefore be appropriate to wait until the EU FP7 situation is clarified towards the end of 2007 before the CLOUD Memorandum of Understanding is prepared between CERN and the CLOUD partners.

National funding: National funding agency requests have been submitted by all of the COUD partners, and significant funds are already available for 2007. Several institutes plan to use the EU FP7 Design Study proposal as a working document for their national funding agency requests. The Lebedev Physical Institute is requesting support from the Russian Foundation for Basic Research (RFBR) under the CERN-RFBR agreement on scientific cooperation.

3.3 Beam request and schedule

Following discussions at the Helsinki meeting, 3–5 April, the CLOUD collaboration has decided to shift the Mk2 CLOUD prototype construction to the first half of 2008, and to postpone the T11 beam request from fall 2007 to fall 2008. This is a resource-driven decision—both money and people. Construction and operation of the Mk2 CLOUD prototype and equipment will require about €200K, as well as the availability in the collaboration of analysing equipment worth several million euro. Substantial modifications to the T11 experimental area—including construction of a temperature-controlled housing—are also required before the next beam measurements (§2.3). Concerning CERN, we also want to avoid any impact due to LHC startup in 2007 (such as personnel, clean rooms, transport, beam area support, etc.).

All these factors led to our decision to delay the T11 beam request by one year from September–November 2007 to a 10-week period in September–November 2008 (with the possibility of initial installation and setup in T11 in June or July 2008, assuming the availability of the beam area and of the CLOUD hardware). Delaying the Mk2 prototype run until fall 2008 will also match very well with the schedules for the EU FP7 Design Study and Marie Curie proposals (Fig. 7).

4 CONCLUSIONS

CLOUD has made good progress during 2006. The first CLOUD prototype tests were carried out in the T11 beamline during an 8 week period from September to November 2006. They involved the integration of many different instruments from the collaboration, which were successfully combined into a single,

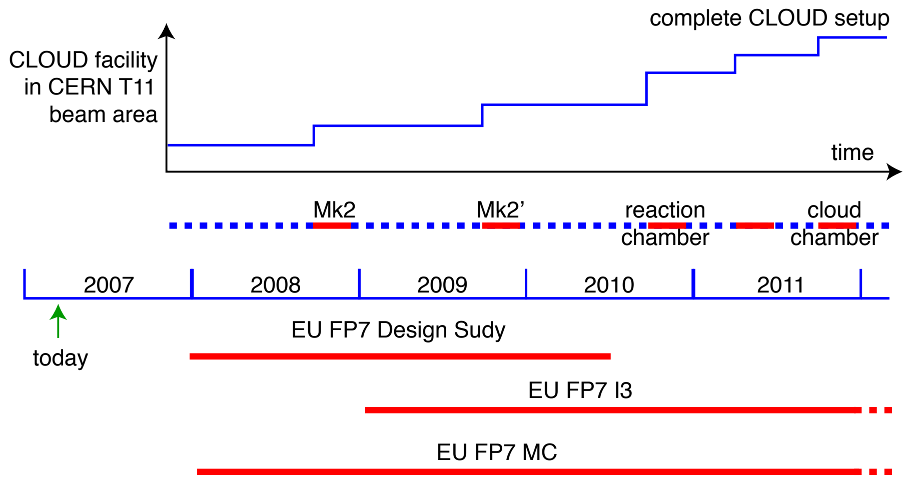

Fig. 7: CLOUD schedule, matching the anticipated availability of major resources (lower bars). The upper graph provides a schematic representation of the development of the CLOUD facility in T11 in several phases from the present prototype detectors through to the final complete CLOUD configuration. It is expected that new physics results can be obtained with each experimental phase of CLOUD.

coherent experiment. A working group has been formed to analyse the experimental data obtained during this run and to interpret it with aerosol models, perhaps leading to a first physics publication from CLOUD (to be decided after further analysis). Operation of the prototype in the beam also provided important technical input for the CLOUD design, as well as useful experience with the experimental techniques. CLOUD is presently preparing two proposals for EU FP7 calls: a 2-year Design Study and a Marie Curie network for 10 Ph.D. students. Finally, in view of the projected availability of resources during 2007 and to better match the requested FP7 funding, the CLOUD collaboration is postponing the present T11 beam request in late 2007 to a 10-week period in September–November 2008.

References

[1] CLOUD collaboration (B. Fastrup *et al.*), A study of the link between cosmic rays and clouds with a cloud chamber at the CERN PS, CERN proposal SPSC-P317, SPSC-2000-021 (2000); CERN SPSC-P317 Add.1, SPSC-2000-030 (2000); CERN SPSC-P317 Add.2, SPSC-2000-041 (2000); CERN-SPSC-2004-023, SPSC-M-721 (2004); CERN SPSC-P317 Add.3, SPSC-2006-004 (2006).