CHAMONIX'09 SUMMARY

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Abstract

The summary session of the LHC Performance Workshop in Chamonix, 2-6 February 2009, synthesized one week of presentations and intense discussions. In particular, it developed a road map for LHC-related activities and operation in 2009/10. Other focal points of this session were the schedule, repair & consolidation scenarios, the energy level for operation, "precautions for running", beam conditions for physics, future improvements to convert LHC into an "operational" machine, and safety considerations.

INTRODUCTION

The LHC Performance Workshop was organized in nine sessions, covering the 2008 lessons without and with beam, safety, the repair of Sector 34, consolidation strategy, shutdown modifications in 2009 and later, other possible incidents, beam preparation for 2009, and beam scenarios in 2009/10, respectively.

The final, tenth "summary" session addressed the road map and schedule, repair or consolidation scenarios, the dipole field for operation, "precautions for running", beam conditions for physics, future improvements to convert LHC into an operational machine, and safety considerations. The following sections review these topics one by one.

ROAD MAP AND SCHEDULE

The LHC physics discovery potential is given by an equation of the form

$$D_p \approx \eta_{LHC}(E) L_{avg}(E) T_{run} F(E)$$

where $\eta_{LHC}(E)$ denotes the operational efficiency (time in physics divided by the scheduled time), L_{avg} the average luminosity during the physics run, and $F(E)$ is determined by the cross section of the process being studied. The variable T_{run} designates the scheduled running time, which is independent of energy and should be maximized. The efficiency $\eta_{LHC}(E)$ differs from the so-called "Hübner factor" used at the times of LEP [1], in that the reference to the average luminosity already takes into account the decay during the run.

With strictly no running during the winter, the present baseline shows little space for physics during 2009 (only about 5 weeks). Any slip in the schedule of more than a month would, therefore, result in no 2009 physics run and a physics start not before August 2010. Schedule slips cannot be excluded, since the present repair plan includes no contingency, and several teams involved in the shutdown work could each well use another 4 weeks [2]. The absence of contingency is, for example, reflected in the fact that no holidays are taken into consideration for the present planning [3]. The stringent conclusion is that, to obtain important physics data as soon as possible, LHC must run during the winter months. Running through the winter does not only allow for early LHC physics, but it almost doubles the time available for physics in the two years 2009-10, from about 6 months for the present schedule (without delays) to a total of 11 months by running through the winter. A delay by a few weeks would hardly have any impact on the proposed new schedule with operation through the winter.

One argument against winter operation would be the cost of electricity which is almost three times as high in the three winter months of December to February as in June [4]. Assuming full running through the winter, a dedicated operation of the injectors for the LHC only [4], and a cryo-power reduced from 8 to 5 MW/sector [5], the additional electricity power bill would be of order 8 MEuros (possibly increased by 8% due to the projected evolution of electricity prices [4]).

In addition to the higher electricity cost, running through the winter will have an impact on the scheduled shutdown work for other CERN accelerators, such as the replacement of the motor generator for the PS, and the Linac4 connection to the PS Booster, as well as on the necessary maintenance, e.g. for cooling towers and electrical networks. These issues need to be sorted out if LHC runs through the winter 09/10.

In view of the clear advantages for physics, the first concrete proposal from Chamonix'09 is to ***plan the electricity provision for running in the winter 2009/10***.

REPAIR AND CONSOLIDATION SCENARIOS

Two repair scenarios can be distinguished [6,7]. They are illustrated in Figs. 1 and 2. The first scenario "A" installs the DN200 pressure relief valves in the arc dipole cryostats of 4 (warm) LHC sectors during the 2009 shutdown, and in the other sectors during the following shutdown 2010/11, whereas in scenario B relief valves would be installed in the arc dipole cryostats of all sectors during the 2009/10 shutdown.

Schedule A features one important, perhaps decisive advantage; it allows measurements of possible bad joints in Sectors 23 and 45 much sooner than scenario B and therefore allows repair with much less impact on the schedule. In addition it gives the first beams and the first physics 1 or 2 months sooner. A third advantage is that the concentration of the consolidation effort on 4 sectors focuses the attention of the repair teams [8].

Schedule B reduces the amount of collateral damage in the event of a Maximum Conceivable Incident (MCI) occurring in 2010. The MCI has been estimated as a factor of two "worse" than the September 19 incident. It also implies a smaller electricity bill, since the running time during the winter months will be shortened, and also a reduced overall shutdown time over the three years 2009-11. In addition, it will relax ALARA problems after beam operation [9]. By contrast, in scenario A the remaining consolidation work will need to be performed with proper radiation protection measures in place (e.g. protective clothes and masks, vacuum devices, etc.).

Since the shortened overall shutdown length was considered not to be relevant by the particle-physics community present at the workshop, and as the ALARA issues for scenario A were judged not to be significant either [10], it emerged from this workshop that the ***scenario A with two-step consolidation is the preferred one***. However, some dissenting opinions were voiced during the discussion (see below).

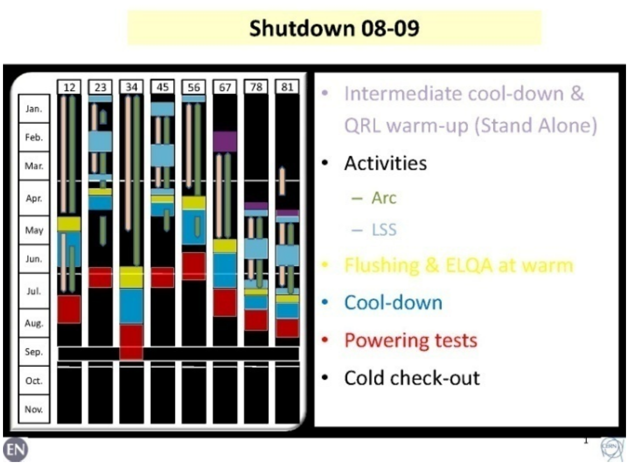

Figure 1: Baseline shutdown schedule "A" with DN200 installation in 4 LHC sectors [6].

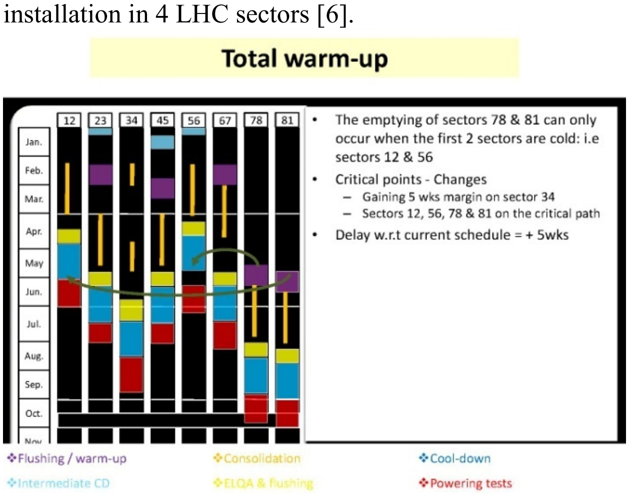

Figure 2: Alternative shutdown schedule "B" with DN200 installation in all 8 LHC sectors [7].

A further important consolidation activity which must be completed during the 2009 shutdown is the deployment of the enhanced quench protection (detection) system, comprising both bad-busbar detection and the "symmetric" quench protection [11]. It is suggested that the LHC not be operated unless the ***full quench protection is tested and operational***.

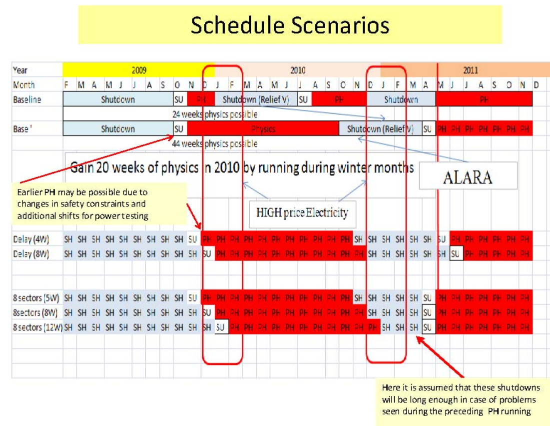

Figure 3: Baseline schedule based on installing DN200 relief valves in 4 sectors with and without winter shutdown (top), without winter shutdown and additional 4 or 8 weeks of delay (centre), and for complete warm-up and DN200 installation in all 8 sectors with various delays (bottom). SH: shutdown, PH: physics, SU: set up.

The scenario A shutdown schedule of Fig. 1 permits calorimetric measurements during a weekend in May in order to get an early warning of possible bad joints for Sector 23 and 45. With a total warm up the cool-down of these two sectors would finish only by mid-July as is evidenced by Fig. 2.

Key drivers for the schedule are safety constraints for access and transport, helium storage, maintenance of cooling towers and electrical networks, cryo-maintenance and PIM replacements. At the workshop it was suggested to blow off the helium from the two sectors 78 and 81 [12]. This blow off would cost 1.2 MCHF and gain two weeks time for the scenario A.

The various schedule options, including possible delays of 4, 8 and 12 weeks, are summarized in Fig. 3. Earlier physics than indicated may become possible through expected changes in the safety constraints and by organizing additional shifts for power testing. Figure 3 demonstrates that the baseline schedule promises physics data in late October. With an 8-week delay the start of physics will be shifted to January 2010. The baseline may imply a longer second shutdown later, which is also indicated.

Comments and discussion on the schedule(s): If the injectors are not switched off in 2009, a longer shutdown is required in the following year [13]. Probably LHC will not run over Christmas. The scenario B amounts to only 4 weeks difference in the start of physics and a lot more consolidation work would be done here. If in the scenario A LHC stops for

Christmas the earlier start does not give a big advantage [14]. However, the 8-sector scenario B might contain a smaller margin to recover any time lost due to delays [15]. The calorimetric measurement has a sensitivity of about 10-20 nOhm. Even with calorimetric measurements in April, there would still be the risk to later find a non conforming joint with the new quench protection system, possibly requiring another warm up [16]. Here it was pointed out that the same calorimetry procedure has been used for all sectors which have been measured following the incident. The bus protection system should be implemented in phase with the cooldown. It was unanimously decided that the full QPS including the symmetric quench protection should be in place for LHC operation in the baseline scenario.

The scenario B provides more margin for the repair of Sector 34 [17]. Once the installation of the DN200 valves has become a standard operation, it is not sure that the 8-sector consolidation together with blowing off the helium would cause a delayed start of physics. Without the He constraint the schedules for Sector 23 and 45 might be pushed forward, yielding most of the advantages of the scenario A. Blowing out the helium might gain three weeks of time, but leaves a resource constraint [18]. Parallel teams could then be mobilized to fix the other sectors [17]. This modified scenario B would retain all advantages of the ALARA principle [17]. And it would provide additional safety in case of an accident. The quench detection system is efficient only for slow failure developments. The joint failure which led to the incident of Sector 34 is not fully explained, and a naked piece of conductor without parallel Cu cannot be fully excluded as its cause [17]. The 8-sector consolidation would reduce the consequences of such an event in the 2009/10 run. In the longer term all the joints should be clamped, but the clamping is not possible during the present shutdown.

Another new detection procedure for non conforming joints is being considered presently, namely electrical measurements for the normal state at cold. This would allow checking the contact with copper or the lack of it [19].

Another consideration is that a slip of four weeks in the baseline scenario would conceivably have permitted, or permit, the DN200 work for all sectors, with the same end date. Contingency should be applied in equal terms to both scenarios [20]. The second-shutdown length indeed is not important once physics has been collected in a first run of reasonable length. Other critical items should be followed up in either scenario [21].

Blowing off helium in the baseline scenario might provide the possibility of an early injection test [22]. The problem of the improved quench protection would remain however.

Equipping the first 4 sectors with relief valves does not address the beam-vacuum problems, but only the pressure build up in the insulation vacuum [23]. Many of the troubles encountered and much of the repair needed arose from the collateral damage. If the magnets do not move during an incident the situation will be much better in the future [24]. The exact consequences of the remedial actions should be clarified, e.g. would another incident be a catastrophe or a disaster [25]? On 19 September just enough spares were available. Now fewer spares may be left, so that one might not stand another 19 September event, or an event in other regions without any spares. More comfortingly, a sufficient number of spare beam screens will be available by the end of 2009 [26].

A strategy to switch between the two routes of the scenarios A and B is not obvious. Any helium blow-off should be decided quickly, and the Sectors 23 and 45 should be examined as early as possible [27].

The enhanced QPS will not be ready until August 2009 [28]. The powering tests in Sectors 23 and 45 in April will therefore be performed without the new enhanced quench protection system being operational. For this reason the tests will be conducted using the safety cautious procedure developed for Sector 12 with current being gradually increased up to a maximum of 7000 A and relying on the existing QPS [29].

OPERATION DIPOLE FIELD / ENERGY

The beam energy in 2009/10 and the corresponding dipole field which can be reached depend on the training time needed, the operational reliability, and the efficiency. Another important decision factor is the risk associated with operation at a certain field level, involving the splice stability, the detection of poor splices, and the new effect of the beam. Yet another consideration is the efficiency of other systems, such as the cryo-recovery time etc. The dipole quenches encountered during hardware commissioning give an indication of the reasonable field level. All sectors, except S34, reached 8965 A (5.3 TeV) without a quench; a current of 9310 A (5.5 TeV) was achieved with one single quench [30]. The number of quenches estimated to reach 6 or 6.5 TeV is 11 or 84, respectively [30].

The original design 1 V threshold of the old QPS was much too high to safely protect the dipole busbars [31]. Two possible origins of the S34 incident have been identified [31]: (1) a resistive joint with very bad bonding to wedge and U profile and longitudinal discontinuity of the copper (bus), and (2) resistive cable with bad contact to bus at the start of the joint and, again, longitudinal discontinuity of the copper (bus). A QPS threshold of 0.3 mV is needed to protect the RB bus and the joints “in all imaginable conditions” [31], as is illustrated in Fig. 4.

According to this figure, without thermal contact at 4 TeV a splice resistance of 100 nOhm could result in a thermal runaway, at 5 TeV a resistance of 80 nOhm, and at 6 TeV a 50 nOhm resistance. For the 200-nOhm resistance of the incident and a weak thermal contact, this simulation predicts thermal runaway around 6oooA, which is consistent (pessimistic) with the actually observed value of 8700 A. Looking at the new 0.3 mV QPS threshold (the lowest dashed curve), ***beam energies of 4-5 TeV look safe***, and allow detection of an increased resistance well before the runaway. The ***simulation result of Fig. 4 is critical for the decision and should be independently confirmed***.

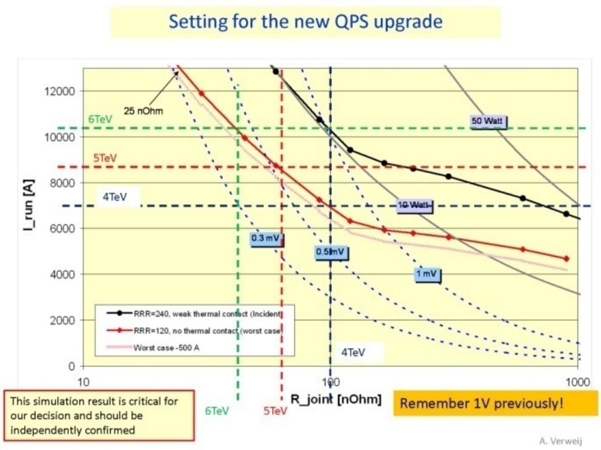

Figure 4: Maximum current without runaway vs. splice resistance for various sensitivities of the quench detection system [31].

A small gap (up to a few mm) between bus and joint is acceptable as long as there is a good thermal contact between joint and U-profile/wedge. Of course, the QPS system cannot protect the circuit in case of a sudden mechanical opening of the joint (without precursor 100 seconds before) [31].

Similar conclusions hold for the RQF/RQD circuits, but there are many other joints and busbars in the LHC [32], which may require specific calculations and assessments.

A further argument favouring beam energies around 5 TeV is the quench cryo-recovery time. For dipole currents between 3 and 9 kA (equivalent to 5.3 TeV) this recovery time is about three times less than for currents above 9 kA [5], promising a much better operational efficiency.

"PRECAUTIONS FOR RUNNING"

The single most important precaution relates to the pre-detection of poor splices in yet un-tested sectors. This pre-detection relies on three approaches: (1) analysis of SM18 data for magnet splices, (2) analysis of past 7-kA calorimetric data for detecting poor busbars, and (3) early powering tests in Sector 23 and 45 (weekend run in May 2009). Particle-physics teams will assist with the analyses of items (1) and (2).

Figure 5 shows an example analysis of SM18 data, comparing a poor and a better splice. A resistance of ~100 nOhm can clearly be seen.

Figure 6 presents a quick comparison of calorimetric data taken in 2008 [33]. An independent look at this type of data by particle-physics groups or mixed teams might lead to an improved analysis that could reveal the presence or absence of poor resistances in the various sectors.

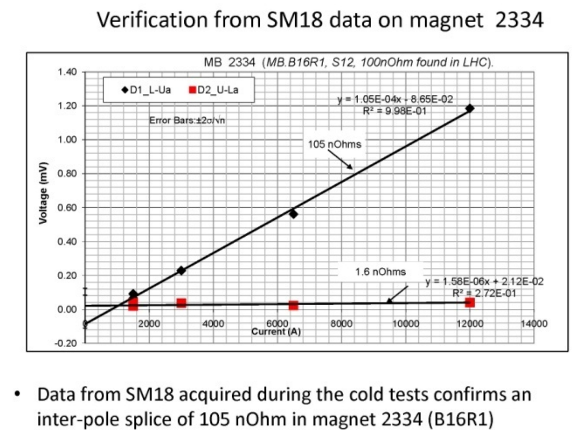

Figure 5: SM18 data revealing a bad splice with 105 nOhm resistance compared with data for a good splice [33].

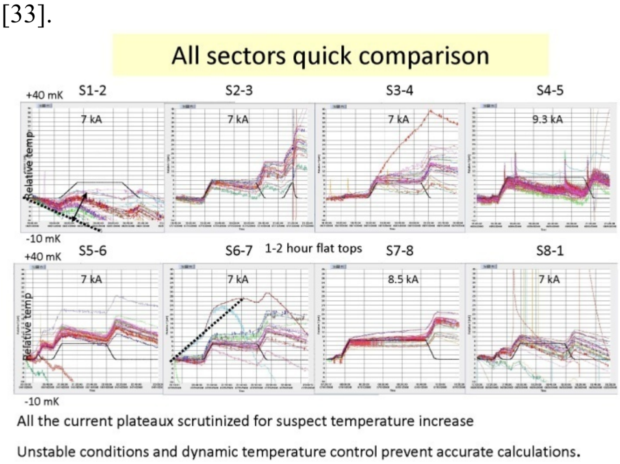

Figure 6: Early calorimetric evidence for anomalous heating in Sector 34 and corresponding data for the other sectors [33].

Four new steps will be introduced in the quality control of the splices [3]: (1) visual inspection [photo], (2) dimensional measurement, (3) ultrasonic testing, and (4) record of temperature cycles during soldering. Comparative tests done on a bad and a better splice revealed a very clear difference in the ultrasonic inspection. A photo of the same two splices also shows a clear difference and little evidence of soldering (tin) for the bad splice, as is illustrated in Fig. 7.

Other precautions, in addition to the pre-detection of bad splices, include the new QPS, which should be fully operational, the quench protection during the magnet ramp down following a UPS trip [34], relief valves in the inner triplets [32], protection of injection kickers and rf cavities (vacuum valves) [35], follow up of water cooled cables [6], anomalies in electrical circuits (to be followed up) [36], procurement and operation of an X-ray machine which should be available in August/September (could one get it sooner, e.g. on loan?) [37], the availability and necessity of the undulator left of point 4 [38], clarification of the situation and risk in the LSS's [32], automation of the calorimetric measurements, a complete set of Ohmic measurements of all splices during power tests and cold check out, and a modification of the MQM "praying hands" splices [32].

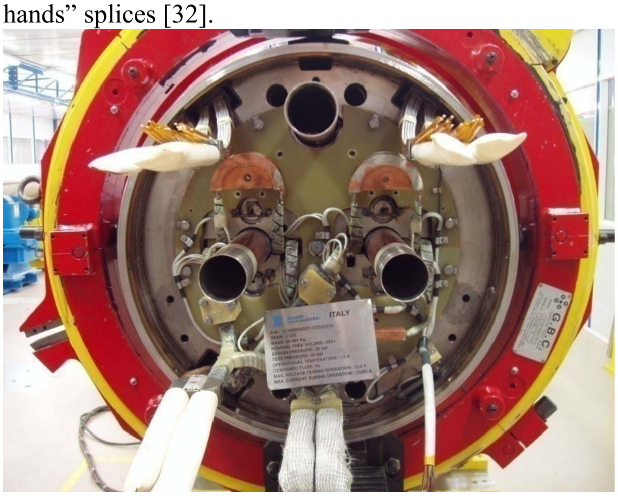

Figure 7: Visual evidence for a bad joint with little tin (left side) and a better splice (on the right) [3].

Comments and discussion on precautions: A check for mitigating modifications of the MQM praying-hand splices is being performed by Alain Poncet [39]. During the Chamonix workshop a possible solution for the quench protection during ramp down after a UPS failure has been conceived [40]; it consists of doubling the UPS lines up to the QPS, adding redundancy. A few items in the new QPS electronics layer will need to be changed accordingly. The new system will also be capable to detect asymmetric quenches. Overall these changes imply a lot more work and an additional cost of order 2 MCHF. Discussions with Gunnar Fernqvist will clarify whether this modification can be implemented during the ongoing shutdown. The necessary work may be done only in sectors without LHe [41]. An independent QPS review, organized by Knud Dahlerup-Petersen and/or Reiner Denz, should once more go through all possible failure scenarios and have a fresh look. It is not acceptable that there is no QPS after a UPS trip. Two such trips have actually occurred in the last year.

BEAM CONDITIONS FOR PHYSICS

The machine protection system must be tested with beam at 0.5 TeV energy intervals, and time needs to be allocated for these tests [42]. A temporary energy of 4 TeV would lie "on the way" to 5 TeV. No energy above 5 TeV is considered for 2010. The beam intensity might be limited until the functionality of the new QPS for symmetric quench modes is completely tested. It is not clear how such test would be performed though, as past attempts to intentionally provoke symmetric quenches have failed [43].

The physics run would be at 5 TeV beam energy with an estimated integrated luminosity of 100 pb^{-1} during the first 100 days of operation and about twice this during the next 100 days. These numbers are not terribly optimistic, but assume a "Hübner factor" of 0.1, for a peak luminosity of $2x10^{32}$ $cm^{-2}s^{-1}$. Towards the end of the operation year almost certainly an ion run will be scheduled, details of which are still to be planned.

FUTURE IMPROVEMENTS TO CONVERT LHC INTO AN "OPERATIONAL" MACHINE

Future improvements include the replacement of the existing ARCON radiation-monitoring system in the PS and SPS by RAMSES; the replacement of the MQM praying hand splices; clamping of busbar splices (clamp development followed by a campaign of replacements?); spares (present situation not acceptable); single-event upsets [44] and continuation of the protection; He storage; improvements in the controlled access system; vacuum consolidation to reduce collateral damage in case of a splice rupture; cooling-tower maintenance (LEP/LHC HVAC [45]); the use of the new X-ray machine; and a centralized radiation workshop.

SAFETY CONSIDERATIONS

The energy stored in a circuit rather than the circuit current [46] should be used for defining safety limits. Safety information panels [47] would be useful both for the entrance doors and also downstairs in the tunnel (at least persons working in the underground areas should be informed that or if a place is dangerous) [48]. The "level 3 alarms" – alarms alerting the fire and rescue services – are to be reviewed by the Safety Commission, as are the procedures related to emergency preparedness [49], in view of the S34 incident

Comments and discussion on spares and energy: The long-term spares situation needs to be improved, in particular as the experiments will sooner or later ask for higher energy, which will likely require replacing some of the magnets [50]. There will be 44 spare dipoles when all are repaired; going beyond 7 TeV certainly needs further preparation [51]. Traditionally the AB and SL departments (divisions) reviewed the spares situation of all accelerators every year. It is planned to do the same for the LHC [52]. The dipole-magnet spares will not be a strong reason not to raise the beam energy. But in addition to the dipole magnets, spares may be needed for the DFBs and numerous other elements [53].

CLOSING REMARKS

Chamonix'09 was an excellent workshop, featuring many discussions, both focused and unfocused ones. It provided a fertile ground for networking. Participants discovered colleagues and made new friends. Seeds for future collaboration were planted.

The work programme for the next 12-18 months has been defined, and many points are to be followed up. The workshop converged on two alternative schedules for 2009/10. Either schedule is considered acceptable. The schedule will be finalised in the following week. Also the most likely beam conditions for physics have been defined.

ACKNOWLEDGMENTS

Special thanks go to the chairs and scientific secretaries for the excellent organisation of their sessions, to the speakers for many outstanding presentations, to the attending colleagues and experts from other laboratories, to the representatives of the LHC detectors (the technical coordinators and spokespersons), to all the participants for lively discussions and expert advice, to Roger Bailey and Christian Carli, and, most importantly, to Tjitske Kehrer for having diligently taken care of every aspect of this workshop.

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