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Status of the LHCb Experiment

Report to April 2010 RRB
by the LHCb Collaboration

1. Introduction

The commissioning of LHCb operation using data was the main activity during recent months starting from November-December 2009, when we got the first collisions at 450 GeV beam energy. The detector was time aligned with care, scanning the delay curve to obtain the optimal working point within 1-2 ns. Data were taken with and without magnetic field for position alignment. A total of about 300k collision events were recorded in 2009 for physics analysis. The overall operation went very smoothly. The only noticeable inefficiency was due to the time it takes, at each start of fill, to ramp the power on the Vertex Detector (VELO) once Stable Beam has been declared and to move VELO into working position. This was done very carefully, as the VELO modules approach up to 15 mm from the beam. We have now commissioned and optimized the process, which allows us to close the VELO within 15 minutes when running at 3.5 TeV per beam.

In April 2010, LHCb successfully started to collect data at 3.5 TeV beam energy.

2. Detector Subsystems

2.1 Vertex Locator (VELO)

For first operation at 450 GeV LHC beam energy the VELO was operated in a safe mode utilizing an “incremental” powering scheme that brought the low (LV) and high voltages (HV) to full operational status only after in the previous stages the critical parameters had been verified as being nominal. The full online and offline monitoring was operational and worked successfully.

The VELO was powered in its nominal “open position” and each half moved to within 15 mm of the nominal physics position. In agreement with the LHC, the VELO was not fully closed with beam, as the beam optics at IP8 allows safe closing of the VELO only above beam energy of 2.0 TeV.

Using the much larger samples of events than previously collected the estimation of efficiencies, alignment and resolution could be significantly improved. The efficiency of the detector is > 99.3%, with the efficiency loss being almost entirely attributable to known bad strips from the time of fabrication. The module alignment was shown to be stable within 2 microns. The position of the two detector halves relative to each other can be aligned to better than 10 microns. With increased statistics and understanding, in 2010 these numbers should be improved further. The spatial resolution of the detectors is close to the LHCb Monte Carlo (MC) expectation.

Primary vertex distributions from both beam-beam and beam-gas collisions have been obtained. The primary vertex distributions were studied online and the reconstructed positions found to be consistent as the VELO halves close. The VELO closing software is considered ready for operation in 2010 although during this period it will require a VELO shifter to operate and confirm all movements.

Good progress has been made with the VELO replacement. By April 1st 2010 all 42 hybrid replacement modules have been built and tested. A programme of extensive burn in of these modules will take place in Q2 2010. The replacement mechanics is expected to be complete by October 2010. The full VELO replacement halves will be in a "hot swap" state as soon as possible – preferably for the start of LHC in 2011.

Changes:
The HV power on sequence and the VELO insertion sequence have been streamlined. We expect to be operating with the VELO fully on just before the beams are declared stable.

Concerns:
At the end of 2009 a restriction developed in the cooling system (close to the VELO tank) that reduced the flow of CO_2 to one half of the VELO. Although not catastrophic it required an intervention to replace an inline CO2 filter in early 2010. A build-up of material was observed on the filter, which is being analyzed.

The HV voltage system, supplied by ISEG, remains unstable. Crashes of the associated software, which happen ~ every 2 weeks can require up to 2 hours to recover.

Plans:
Operate the VELO in its nominal closed position at 3.5 TeV. Determine new alignment, resolution and efficiency for the VELO in this position. Test improvements to the monitoring of the VELO.
Develop the infrastructure to allow the assembly of the VELO replacement halves at CERN.

2.2 Outer Tracker

The OT detector commissioning is well advanced. The analysis of the 2009 data (cosmic and beam) shows that the OT detector is ready for the 2010 data taking. Remaining problems in the Front-End Electronics and in the HV system have been located and solved.

Noise studies have resulted in the replacement of a few Front-Ends. As a result, the detector is now virtually 100% efficient and running with low noise at the nominal threshold. All Front-End spares are available.

Large progress has been made in the detector calibration. Through the comparison with data, the MC tuning has also advanced. A first iteration of internal and global space alignment has been performed. The expected position resolution has been determined for high momentum tracks (studies are still on-going to get a better understanding of the lower momentum data).

In order to improve the aging behaviour a small fraction (of 1.5%) of O_2 has been added to the gas mixture. Further aging tests in situ have been performed, which showed the mitigating effect of O_2 already observed in the laboratory and a general improvement with flushing time. At the same time, the possibility of curing existing gain losses through an HV training procedure has also been demonstrated in situ and a remotely controlled procedure is being prepared.

Changes: None.

Concerns: Uncertainty in the long-term behaviour of the gain loss remains a concern, most notably the differences in the behaviour of different modules.

Plans: Develop software analysis to show a tracking efficiency 2D map in order to monitor the possible onset of aging in the inner region during beam operation.

2.3 Silicon Tracker

Both the Inner Tracker and Trigger Tracker ran smoothly and without problems during the LHC 2009 running period. More than 99.5 % of channels in the Trigger Tracker and 99 % of channels in the Inner Tracker are operational. The internal alignment of the Inner Tracker has been verified with beam and a first global alignment relative to the other components of the tracking system performed. Significant progress has been made in improving the stability and reliability of the detector control and monitoring software.

Several small concerns remain. First, Tell1 readout boards continue to fail (mainly due to bad vias) at a rate of ~ 1 per month. Second, in recent months 3 optical VCSEL diodes located on the digitizer boards in the detector service boxes have failed. Finally, significant discrepancies remain between the global alignment parameters obtained with magnet on and off. The problem of breaking bonds on the TT front-end hybrids has stabilized. No new broken bonds have been seen since May 2009. New hybrids are being ordered and the nine modules affected by this problem will be repaired.

Changes: None

Concerns: Continuing failure of Tell1 boards and optical VCSEL diodes.

Plans: Further improve control and monitoring software. Continue detector performance and alignment studies. Repair of TT modules with broken bonds.

2.4 RICH

Both RICH1 and RICH2 detectors took data in November/December 2009 with great success. The data were used to align the system: this was successful for RICH2 and partially successful for RICH1, for which more data are necessary. Photons from the gaseous C_4F_{10} radiator were used to align the optical elements concerned, bringing the angular resolution close to that expected from the simulation. Rings from the aerogel are reflected from the outer most mirrors, and here there are at present too few data to perform an alignment. Consequently the resolution of the aerogel rings is at present poor, and it is not possible to make meaningful studies of the performance of this radiator, although there is an indication that the photon yield is lower than expected. More data will clarify this issue. Further alignment with data will be a high priority item, involving also an optimization of the magnetic distortion corrections and the alignment of each photo-detector, as further data are accumulated.

The evolution of each HPD photo-detector in terms of its ion feedback (IFB) is continuously monitored, thus providing a reliable indicator of the HPD lifetime. In March those tubes predicted to glow in 2010 have been replaced with refurbished ones (a total of 7 tubes in RICH2). The repair process is proceeding regularly and the extracted tubes are being sent to PHOTONIS in accordance with the settled financial agreement. All the repaired tubes, installed since the first intervention in March 2009, continue to behave satisfactorily.

A few residual discharges have been observed in three HV power supplies after the intervention in summer 2009. The three units showing some instability have been replaced with spare ones.

Towards the end of 2009 a gas leak in RICH2 caused a loss of CF_4, noticeable for varying the gas composition of the radiator and introducing an additional cost. During the 2009-2010 shutdown the leak was located at an electrical connector. Following a repair the gas loss is negligible and the gas composition is very stable. The pressure and temperature of the gas inside the RICH1 and RICH2 vessels are monitored continuously.

The RICH reconstruction software, as well as the online and data quality monitoring are becoming a major activity in the RICH project. A calibration of the particle identification performance with data was achieved using kinematically reconstructed K_S mesons and Λ hyperons.

The RICH detector is performing very well, allowing prominent $\phi \rightarrow KK$ signal to be extracted very cleanly from a large background. The general status is extremely promising; improvements are expected on several fronts, especially for the alignment and calibration, with the coming data.

Changes: None.

Concerns: The current stock of repaired HPDs limits the number of available spare tubes. Improved alignment with more data could ameliorate the angular precision and the photon yield of the aerogel radiator, which are below expectations.

Plans: Understand better the detector performance with increased data sample.

2.5 Calorimeters

The calorimeter system operated very effectively in 2009 providing the principle trigger for LHCb.

The ECAL PMT gain measurements have been done using the LED monitoring system; the measurements are in agreement within 5% with the expected values from earlier PMT test measurements. Using these calibration curves, the inter-calibration of the ECAL PMTs at start-up was close to 9%. In the HCAL, the Caesium (Cs) source calibration provides an HCAL inter-calibration better than 4%. For the PS the initial calibration was done using cosmic rays giving an inter-calibration at a level of 15%. The SPD threshold was calibrated using test pulse and cosmic events.

The initial calorimeter time alignment has been significantly improved with first data, using events read on consecutive bunches. The current inter-cell time alignment is 1 ns for the ECAL/HCAL and better than 2ns for the PS/SPD.

The accuracy of the current calibration is sufficient to reconstruct clear π^0 and η mass peaks from photon pairs; the reconstructed mass and width match well with the expectations thanks to the initial inter-cell calibration.

Using the tools prepared for tuning of the calibration, it has been demonstrated that five million events should allow reaching an inter cell calibration below 4% for the ECAL and PS. The fine calibration to a 1% level for the ECAL would need an order of magnitude larger number of events, while the inter-calibration of the HCAL is already ensured at that level by the radioactive Cs source calibration.

The ECAL and HCAL PMT stability is surveyed by the LED system routinely and monitored in the calibration farm during data taking. For the PS and SPD dedicated LED calibration runs are foreseen in between fills for the very first data in 2010.

All four calorimeters are fully functional and successfully taking data in 2010.

During the last months more emphasis has been put on the on-line control, including the use of the calibration farm, detector quality tests and calibration procedures, in order to be able to give fast response on the detector status, timing and calibration at start-run and during running.

Changes: None.

Concerns: Improve the PS/SPD LED system to remove oscillations on several bunch crossings.

Plans: Verify timing adjustment. Set inter-calibration at a 4% level with five million events. Pursue calibration task to reach 1% ECAL calibration accuracy with 100 million events adapting special stripping for low occupancy regions.

2.6 Muon Detector

The Muon system has been successfully operated during the 2009 Run. As a result of thoroughly calibrated thresholds and HV settings both the efficiency and noise level are found to be in perfect agreement with the expectations from test beam studies.

During the 2009 Run the Muon detector hardware performed very well: only ~ 0.1% of the wire chamber gaps showed some HV problem; the dead readout channels amounted to about 0.1%; the number of noisy channels was negligible. During the 2009-2010 shutdown only a few minor hardware interventions were required. A full review of the HV control system has been made and some hardware modifications have been applied to the CAEN power supply system in order to achieve more reliable operation. The Muon monitoring has been further improved in order to allow faster configuration of the apparatus and an easier handling and bookkeeping of the configuration recipes. Data quality, online and offline monitoring tools have been put in place and successfully used during and after the 2009 Run.

Changes: None.

Concerns: Stability of HV modules.

Plans: Improve the data quality tools; refine time and space alignment with data; refine working point settings (HV values, thresholds).

2.7 Trigger

The Level-0 trigger was fully operational to select minimum bias and beam–gas events, during the 2009 Run. At the beginning of 2010, the decision algorithms were improved for minimum bias events and new decision algorithms for the core physic program and for the absolute luminosity measurement were introduced. With the increased redundancy now available it will be easier to determine the Level-0 trigger efficiency using data alone.
Three High Level Trigger (HLT) scenarios have been decided upon, which should cover all expected luminosities during 2010. The scenario which addresses the lowest luminosity regime, expected for the next few months of running, has been extensively tested in the Event Filter Farm (EFF). For the commissioning, both real data taken at the end of last year, and MC data have been used by injecting the data into the EFF. The HLT has also been exercised by running on random triggers at the maximum rates expected for this year.

A scheme of dynamic pre-scaling has been introduced in the HLT, which enables the output rate for minimum bias and luminosity triggers to be set to the maximum output rate for storage. This allows a large luminosity interval to be covered with a single trigger setting. To gain trigger efficiency for very low multiplicity minimum bias events, two new HLT triggers have been introduced, called Micro-bias triggers. They reconstruct tracks in either the VELO or the T-stations for random first-level triggers and select events with at least one charged particle being reconstructed. With the few bunches foreseen for the initial running, the Micro-bias triggers can be run on all crossings with colliding bunches.

The data taken at the end of last year have been used to determine the performance of the HLT on real data in comparison to MC. Since the VELO can only be used in the trigger when it is in its closed position, only those aspects which do not involve the VELO could be tested. For both muons and hadrons the so-called confirmation strategy, i.e. opening a field of interest in the T-stations to look for tracks which can be associated to their L0-trigger, have been tested. The results agree well with MC simulations, both in terms of efficiency and in the CPU time consumption.

Changes: None.

Concerns: None.

Plans: Operate the Level-0 trigger for the 2010 data taking period. Commission the HLT trigger at 3.5 TeV per beam energy with fully closed VELO.

2.8 Online

The data monitoring and online reconstruction are commissioned and in regular use.

The completion of the HLT farm upgrade to its full capacity is foreseen some time in the second half of 2010 depending on the LHC luminosity progress.

The readout network still suffers from minor problems with the switches of the read-out network, which are addressed by the manufacturer with high priority. Unfortunately these are not reproducible at will. The Controls system is continuously improved and consolidated and its functionality increased. Centralized high-voltage control is implemented.

Changes: None.

Concerns: Long-term manpower coverage.

Plans: Consolidation of readout network and preparing for HLT farm upgrade. Consolidation of controls system.

2.9 Computing

The LHCb data processing chain was ready to accept real data events delivered by the LHC in November and December 2009. New data were distributed to LHCb Tier1s, fully reconstructed on the Grid and made available for analysis on all Tier1 sites within a few hours of data taking. Three reprocessings of the complete 2009 dataset were done on the Grid in December 2009, January and February 2010, each taking less than one day, followed by a stripping pass to select events for very first physics analysis. The data have also been used to prepare Data Quality checking procedures.

MC simulation has continued, concentrating on productions of minimum bias events to commission the L0 and HLT trigger (including stripping of events to multiple analysis streams), and on productions to understand the data taken at 450 GeV beam energy. A first campaign of simulation to prepare the 2010-11 analyses of data at 3.5 TeV beam energy has started.

A new major release of the LHCb Grid access integrated system DIRAC (v5) was performed. New hardware has been provisioned by CERN IT for running the DIRAC services, agents and databases in order to improve the fault tolerance and scalability. DIRAC (v5) was successfully deployed on this new hardware in February 2010 with only minor service disruption to users and productions activities.

In order to improve communication and understanding between LHCb and Tier1s, a dedicated meeting has been organized in NIKHEF, with extremely fruitful exchanges.

The Computing Resources requirements of LHCb for 2010 up to 2012 were prepared in view of the latest LHC schedule, and presented to the WLCG bodies, the LHCC and the CRSG, showing only very minor variations with respect to requirements presented in June 2009, as well as moderate increases for 2011 and 2012. Those were presented to the Tier1s during the LHCb-Tier1 meeting, and it seems they do not pose any particular problem. Clearly those numbers will need to be reassessed after gaining experience with real data processing and analysis.

Changes: None.

Concerns: Stability of Tier1s, in particular regarding storage and Data Access. Manpower for running the Computing Operations.

Plans: Run continuously dataflow from the pit to the offline reconstruction and stripping. Fully commission Data Quality procedures, including procedures for updating alignment and calibration constants in the production processing of real data. Prepare a large MC production following the retuning of the simulation program on real data. Continue data analysis on the grid.

3. Reconstruction performance and physics studies

Tracking detector alignment has been performed using the data from pp-collisions collected in December 2009 both with the magnet switched off and on. The residual misalignments of the VELO are estimated to be below 4 microns, while the other tracking detectors (TT, IT and OT) are internally aligned to 50 microns. Work is ongoing to understand the origin of global shifts in alignment parameters, which are observed when comparing with survey measurements.

The pattern-recognition for the track finding works well on the first collision data. Adjustments were applied to the search windows to accommodate the residual misalignments, but these have not significantly increased the rate of ghost tracks.

The resolutions of the reconstructed K_S, Λ and ϕ particles are within (10-20)% of the MC expectations. A small shift in the measured mass scale is observed, which could be explained by a 1.4 per mille bias in the magnetic field calibration. More data are needed, in particular resonances at higher mass values, to resolve this issue. It has no consequences for the physics analyses currently under study.

The performance of the particle identification has been tested using clean signals of reconstructed π^0, η, K_S, Λ and ϕ decays. Early indications suggest that the muon misidentification rate will be similar to MC expectations, while a determination of the muon identification efficiency will require J/ψ decays, which will be accumulated in the coming run. Exploitation of the RICH detector required that the mirrors first be aligned with collision data. After alignment the performance of hadron identification using the gas radiators is good, and in agreement with the predictions of the simulation given the present Cherenkov angle resolution. More data will allow the mirror alignment to be improved, particularly in the outer region.

In general, the distribution of particles in space and momentum in the 2009 data are well described by the MC simulation. However, the absolute particle rate is (10-15) % higher than is expected from simulation. The understanding of this problem with the 2009 data is limited by the trigger that was used. This required an HCAL cluster above a certain threshold and accompanying hits in the SPD. A more efficient minimum bias trigger will be deployed in 2010 that will, in particular, give significantly improved efficiency for low multiplicity events.

The understanding of the detector performance is already sufficient to allow important physics studies to be performed. Although measurements exist from previous collider experiments at $\sqrt{s}$=900 GeV, the unique rapidity coverage of LHCb and its powerful particle identification capabilities mean that the 2009 dataset has the potential for yielding several significant measurements. Preliminary conference results have been shown for the absolute cross section of K_S production in bins of p_t and rapidity. The integrated luminosity for this measurement has been determined with a novel method that uses the VELO detector to measure the profiles of the two beams in beam-gas collision events and the interaction region in beam-beam collisions. These measurements, together with the knowledge of the beam currents, allow the luminosity to be determined with a precision of 15%. This analysis has demonstrated that the VELO is working well, despite the fact that in 2009 the beam conditions meant that the sensors were kept 15mm away from their nominal position. Significant improvements are expected to this, and other analyses, in 2010 when the VELO will take data in its fully closed configuration.

Other analyses are underway concerning Λ and proton production. The 2009 data have also been used to exercise the analysis procedures for the core B-physics studies. For example, the performance of certain key variables in the $B_s \to \mu\mu$ analysis has been studied by using the $K^0_S \to \pi\pi$ decay that has the same topology. Good consistency has been found between data and Monte Carlo expectation.

4. Collaboration Issues

Guy Wilkinson started to serve as the Physics Coordinator as from January 1, 2010.

Rolf Lindner has been appointed as the Technical Coordinator for a term of three years starting from July 1, 2010.

Marco Cattaneo has been appointed as the Computing Project Leader for two years starting from January 1, 2010.

Chris Parkes has been appointed as the VELO Project Leader for two years starting from June 15, 2010.