CMS REQUEST FOR LHC-LIKE TEST BEAMS

G. Hall, J. Varela, G. Wrochna

In May 1997, after previous requests and discussions with machine experts, a meeting of the LHC Machine-Experiment Interface Committee devoted some time to the questions of the practicalities of delivering genuine LHC-like test beams and the arguments from the experiments in favour of an such beams. An extract from the minutes of a recent follow-up meeting is appended (Appendix 1).

Regarding the first question, it appeared that the technical difficulties in providing a low intensity extracted beam from the SPS were not immense, that it would provide valuable verification of issues of interest to the machine staff, and that it might be foreseen as early as late 1998, provided the requirements on intensity and number of consecutive bunches were compatible with machine constraints. A summary of the modest CMS request is given in Appendix 2.

Recently, there was a meeting with machine staff, organised by the SPS co-ordinator, where the needs of the experiments were again questioned and where two previously discarded options were again offered for further study by the LHC experiments:

(a) a 40MHz clock accompanying an asynchronous beam, or

(b) a structured PS beam not resembling at all the LHC 25ns cycle.

Neither of these options is of interest to CMS.

Option (a) can be provided by experimenters themselves (and already has been on many occasions), as a precise 40MHz clock is simple to generate. A trigger with a short time window could tag some beam particles but uses the beam with low efficiency (likely to be <4%) and in high rate conditions would provide no information about other particles incident on the detector outside this time window, which would undermine many analyses. Data taken with the use of a TDC measurement only allows the identification of particles in time with the clock in offline analysis but it would be impractical to measure with a TDC every particle incident on the detector and probably impossible to infer reliably the behaviour of out of time contributions to the data.

Option (b) is of of even less interest to evaluate electronics designed for operation with a 40MHz cycle time.

Motivation for LHC-like beam request

It seems surprising that it is required to explain that it is highly desirable, even vital, to test thoroughly many of the detectors and electronics which are to be used in CMS under conditions which are as realistic as possible. Almost all detector systems are being asked to justify their intentions and demonstrate progress by means of beam tests; while some of these do not require LHC-like electronics, many already do and most will during the next year and beyond. Although it is true that some studies can be carried out using asynchronous beams, given the specific requirement for synchronous 40MHz electronic readout systems, many studies will be improved using a beam which can approximate closely the LHC, and some are only possible under such conditions. If these studies wait until the LHC machine begins operation, it is a trivial prediction that some unexpected effects will be observed. Some of them might be fatal to full data-taking for a sub-system or, even worse, especially if involving the trigger, might have an even wider impact.

One of the most notable differences between LHC operation and previous experiments is the requirement for high multiplicity, 40MHz operation. Data are sampled into pipeline memories at 25ns intervals, usually with tight constraints on the sample time precision and buffered, along with several other events, before readout. Complex digital logic, much of it in unreconfigurable ASICs, controls the readout of event data and adds identification bits. Elementary tests can pick out obvious flaws in the electronic design but subtle features, which cumulatively can be of major importance, may not be evident until testing has reached an advanced stage. Some electronic studies can be carried out in laboratory conditions but most will not emulate fully the system or experimental environment, while others need particles in detectors (e.g. MSGCs) even to be testable in realistic fashion. Almost by definition, subtle effects are most likely to become evident in tests with detectors when all data are scrutinised most critically from all perspectives.

There will be heavy use of optical fibre data transmission at LHC using close to state-of-the-art technologies both for digital data transmission, at typical rates of 40MHz or 1 GHz, and analogue data transmission at 40Ms/s. No real experience exists of running a large system of optical fibres in the way it will be done at LHC. Properties of optical fibres are well known to change under mechanical stress and with temperature. It is not difficult to imagine variations approaching one clock period being possible during extended operation but shifts at sub-ns level could cause serious problems for the highest speed links. Many of these will transport trigger data.

Many detectors do not have a signal time response which is short compared to the LHC clock interval. Typical examples are MSGCs and muon drift tubes. Thus, in addition to the care which will be needed to synchronise precisely in the presence of time of flight delays, cable lengths and trigger propagation, it will be necessary to scan carefully many of the detectors individually to ensure the timing is optimal. It should not be forgotten that overall synchronisation of the experiments is not just a matter of synchronising within a given sub-detector, such as the tracker, but it is required to synchronise across sub-systems, which have very different means of recording, processing and transporting signals, as well as very different data rates.

A few brief examples are given below of situations which have some of the most demanding requirements and for which test beam operation with a test beam as similar as possible to LHC is considered vital. More comprehensive details are given in references.

Tracker

The CMS tracker readout system transfers analogue data using 40Ms/s optical links from front end chips reading out the detectors. Among many features which could affect performance, the system is entirely synchronous with no bunch crossing counters located inside the tracker volume. This will simplify operation but, in principle, hardware errors which give rise loss of synchronisation of any front end chip will cause data affected to be useless until synchronisation is restored. Since this is expected to be a rare occurrence (which needs to be tested in an environment which might generate such errors), no mechanism other than starting a new run and resetting the front-end chips is envisaged. Synchronisation errors should be recognisable however, using a few header words in the data stream. However there are also several elements of the system (front end chips, Front End Driver readout units, Front End Controller units) which are sufficiently complex that, in a large system, difficulties can be expected until experience is gained.

Examples of the kind of questions which we would like to answer are given in Appendix 3. It is important that even small details of the readout operation are checked, since minor features which can have quite important effects can show up even after testing in the laboratory.

The method proposed to bring the system into synchronism is explained in the Tracker TDR [1]. It involves several stages, from electronic calibration followed by use of signals in the tracking detectors only, to final synchronisation with the ECAL. This needs to be tested in a realistic environment, where it is possible to run the system with multiple triggers in the pipeline. It will not be simple in LHC since, even at low luminosity, occupancy is low but background or noise may be hard to separate from genuine signals and the detector-amplifier response will extend over several bunch crossings with only one of them available from the readout. In the case of the MSGCs, the detector signals, which have large temporal and amplitude fluctuations, also extend over at least two bunch crossings. In practice, as much experience as can be obtained prior to LHC start-up running systems of gradually increasing complexity is expected to help enormously in the early days of LHC operation, thus ensuring that data can be analysed for physics content as soon as possible.

Calorimeter and muon trigger

This is perhaps the most challenging problem of its type in CMS. The requirements and difficulties are described in some detail by J. Varela [2], who has been studying this problem for more than two years. It is emphasised that synchronisation is a technical challenge that must be carefully studied and for which solutions must be developed and tested and that the only way, ultimately, to be confident about the result is to use detector data. This will be simpler if it can be done in the relatively simple environment of a dedicated LHC-like test beam before the experiment commences. However, it would be optimistic to imagine that one or two short test beam periods will be sufficient for a problem of such complexity.

A method for synchronising the muon detector system, starting from the fast RPC signals, has been worked out in some detail by G. Wrochna [3] and may be the basis for synchronising the entire muon system where the Drift tube and Cathode Strip chamber responses are significantly slower than the RPCs.

Several elements must be studied carefully:

Front end

Detector signals after amplification must be synchronised to the LHC clock.

ECAL signals are fast but, as in most systems, slower shaping is used in the amplifier to ensure sufficient signal to noise. Digitisation, which must have the correct phase, is carried out on the detector, then digital data are transferred at 1Gs/s synchronously through an optical fibre per channel (80,000 in total) to the counting room, where digital filtering to determine the pulse time origin is used. The precision depends on the jitter of the sampling clock and on electronics and pileup noise.

Muon signals are relatively slow with large jitter and long drift times which makes bunch crossing assignment difficult. There is a large fraction of noise hits due to neutrons which are largely uncorrelated with the beam crossing.

Trigger

This is effectively a massive parallel processor which works in synchronised pipeline mode. Data should have the correct phase on arrival but this must be achieved without making use of bunch crossing identifiers attached to the data which would imply a major complication.

Link

High speed serial links imply sophisticated circuitry at the transmitting end (low power and radiation hard in the ECAL) and at the receiving end. This is being developed as a custom system to meet cost and power constraints, with the minimum overhead in link protocols. Losses of link synchronisation are inevitable but they should not only be infrequent but identifiable and subsequently recoverable, probably by intermittent resynchronisation.

Channel

Each channel of the system must be independently, correctly in phase, which will be achieved by broadcasting data through the clock distribution system (TTC). There are adjustable parameters in each channel (pipeline latency and delays) which will be set.

TTC system

An impressive common system has been developed at CERN to distribute the LHC clock and triggers and commands throughout the LHC experiments [4]. At present a few of the prototype systems are in use and, as in the examples already given, most of the TTC features can be evaluated in dedicated tests, treating this as a component of the specific electronic readout system. However, the main features of the TTC system will only be tested and studied in detail in a realistic environment when divergences from the expected behaviour will be most evident.

Conclusions

There are two major reasons for evaluating electronics under realistic LHC-like conditions prior to operation:

The need to test each system as thoroughly as possible before final assembly takes place so that as many bugs as possible can be identified and removed. The electronics represents about one third of the experiment cost and makes use of novel technologies assembled into complex systems. Once ASICs are finally defined, there is no chance of correcting faults which have not been identified in testing, except at massively increasing expense depending on how late the faults are identified. It would be irresponsible to attempt to debug the systems under realistic conditions only during LHC operation.

Synchronisation of the LHC experiments is an extremely non-trivial task and vital to the validity of the physics data which will be obtained. Sources of mis-synchronisation are numerous and, in consequence, we believe it is vitally important to study and understand each of them in the framework of tests which reproduce closely the LHC environment.

References

[1] Chapter 5 of the CMS Tracker Technical Design Report.

[2] J. Varela. “Using an LHC-like test beam to study the trigger and front end readout synchronisation of the CMS detector.” CMS internal note, CMS IN 1998/012 (1998).

[3] G. Wrochna. CMS IN 1998/007 “Synchronisation of the Muon Detector”

[4] B. G. Taylor. “Timing Trigger and Control distribution for LHC detectors.” Procs 1st Workshop on Electronics for LHC Experiments, CERN/LHCC/95-56 (1995) 180.

Appendix 1: Minutes of Meeting on SPS 25 ns Bunch-spacing

Date: Wed, 6 May 1998 08:01:40 +0200 (METDST)
From: SPS-Coordinator <Sps.Coordinator@cern.ch>
To: Users.of.a.Possible.25.ns.Bunch.Beam.at.the.SPS:; ;
Subject: Minutes of Meeting Held on March 20,1998 on SPS 25 ns Bunch-spacing

Summary of Meeting Held on March 20, 1998 on 25 ns Bunch-spacing at the SPS
==

The meeting was attended by representatives from ATLAS, CMS and from the SL/EA group.

Since there is no 40 MHz cavity in the SPS, the bunched beam of 25 ns spacing will be prepared in the PS and then injected into the SPS. The extraction would be a Fast Extraction at 26 GeV/c in which 81 bunches would be extracted to the SPS. Actually, there would be 84 bunches if it were not for the 3 lost bunches arising from the extraction kicker risetime required in the PS. This mode of operationis identical to that foreseen for the LHC itself.

The SPS has a revolution frequency of 23 usec (or 43 kHz). However, the injected 25 ns bunch train from the PS would occupy only about 2.1 usecof this. The rest would remain empty. This structure would then be repeated over a total Slow Extraction duration of about 2.37 sec asit is now.

Therefore, there would be a bunched beam of 25 ns spacing between successive buckets for 2.1 usec every 23 usec over a total duration of 2.37 sec.

The width of each bunch has to be prepared in the PS so that it fits into the 5 ns buckets of the SPS dictated by the capture at 200 MHz.A bunch width of between 3 and 5 ns could therefore be expected but needs to be tested.

The intensity of the secondary beam would be limited by the radiation limits in the experimental halls. Assuming only one particle per bunchtransported to the experimental areas, we already reach the current radiation limit of 10^6-10^7 particles in the North Area.This is found from multiplying 81 (number of these 25 ns-spaced bunchesper SPS turn) by 10^5 (number of SPS revolutions in the 2.37 sec SlowExtraction duration). The situation in the West Area is even worse since the limit is about 10^6.

Due to the radiation limit in the experimental areas, the bunched beam would have to tuned so that on average only every 10th burstwill contain a particle. Alternatively, to go beyond these radiation limits one could shorten the Slow Extraction duration. For example, byshortening the Slow Extractio to 0.2 sec, then about 10 particles perbunch could be possible. The intensity could also be increasedby building a dedicated `high radiation' zone for the detectors.This will be a general facility for both ATLAS and CMS, in whichcase, however, perhaps a longer running period may be requested.

It was also pointed out that there is no guarantee that the same number of particles, whatever that number is finally, would be delivered in each and every bunch.

It should also be noted that the expected beam conditions are only projections after numerous discussions with the relevant specialistson both the PS and SPS sides. In order to test these principles some machine development time is scheduled during 1998 to test the setting-up of this beam in the PS/SPS Complex.

During the discussion it was pointed out to the users that the time availability for these specialised tests has to be limited to dedicated,short periods of time. One possible scheduling scenario is :

o First dedicated run in 2000 - this year is also preferred by ATLAS but CMS may want such a beam already in 1999.

o Depending on the results from the possible first run, a second short, dedicated run sometime before 2005 could be foressen.

o In both cases the beamtime available would be limited to about one week to 10 days.

The reason for the above restrictions is the disruption to the otherusers of the Slow Extraction experiments - NA48 and the future COMPASS experiment, in addition to the various other test beam activitieswhich do not require such a structured beam. In particular, LHCb andALICE have not requested such a beam. It should be noted that once such a beam is provided, it will be seen in both the West and North Areas. Moreover, the change-over time from a 25 ns beam to the nominalbeam is not negligible and may take up to a couple of days either way before stable beams are restored.

Before deciding on a 25 ns structured beam, the collaborations should look into the following points :

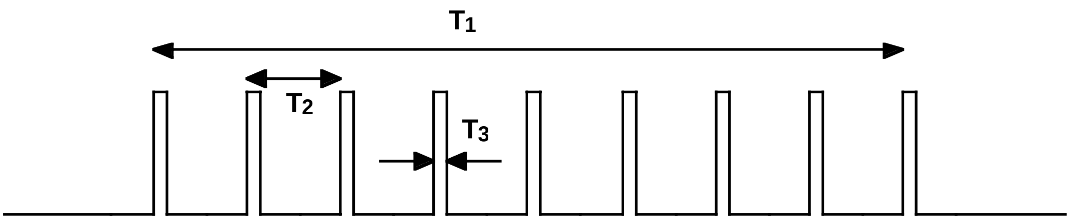
o Possibility to use a clock with the nominal beam and select on events falling within a gate simulating a 25 ns bunch-spacing.

o Ability to perform these tests in a laboratory environment with a suitable pulse generator.

o Given the above non-uniform structure of the beam to be delivered, from the SPS, it is worth re-visiting the PS East Hall option which has been earlier rejected owing partly to the non-regular structure of the delivered beam. Again, however, the tests would be limited to the similar time restrictions as for the SPS.

Emmanuel Tsesmelis (SPS/PS Coordinator)

Appendix 2: CMS requirement for PS structured beam



Priority 1

$T_3 < 3$ns *if possible better, e.g. <1ns*

$T_2 \approx 25$ns *stable, with precise clock*

Priority 2

$\langle n_{particles} \rangle$/bunch ≤ 1 *assumed to be Poisson-like*

T_1 = few μs - ms. *expected to be correlated with* $\langle n_{particles} \rangle$

W. Smith, G. Hall 13 Dec 1996

Appendix 3: Typical questions for the CMS tracker readout system

All of these questions are capable of being addressed now by the CMS tracker (with some effort) in an LHC-like beam. Most, or all, of them could not be answered with a typical West Area beam or even in the North Area. They are important since the small details of the APV performance, and impact on detector performance, must be checked.This list will grow longer once more of the system exists and there is the opportunity to use an LHC-like beam. There will also be specific questions for different detectors which have different time responses, eg MSGC cf Si, and specific components to be studied, eg FE, optical link, FED, for out of phase effects.

It should be noted that to answer many of these questions, some DAQ effort will be needed to handle the high data volumes which could be accumulated at high rates.

A precise beam telescope with sub-ns resolution, or the detectors themselves properly synchronised, is required for measuring spatial performance of Si/MSGC/TRT detectors in LHC-like conditions. It needs preparation.

What is the effect on spatial resolution, noise, pedestal, amplitude, thresholds, efficiency for events measured with 2 triggers separated by n x 25ns? (n = 1,2,...)

What is the effect on spatial resolution, noise, pedestal, amplitude, thresholds, efficiency for events measured with trigger rate = n x 10kHz? (n = 1-10)

What is the effect on spatial resolution, noise, pedestal, amplitude, thresholds, efficiency for events measured with n events in the derandomising buffers? (1 < n < Buffer depth)

What is the effect on spatial resolution, noise, pedestal, amplitude, thresholds, efficiency for events measured with n hits in the detector, with n > 1 and Dt=0-25ns, where Dt between each hit was known precisely? NB Time/space ambiguities must be resolved?

How many physically separated detectors have been simultaneously synchronised correctly? How much data is available to show this?

Front end control system resembling that to be used at LHC to be tested.

What is the effect of clock feedthrough/interference in the system on the quality of the data?

How long can the readout system been run continuously under LHC-like conditions? What is the effect on the data quality (as above)? How often is re-synchronisation necessary?