1 Introduction

1.1 Purpose of the document

This document specifies the user requirements for the LHCB Dataflow and Control. The users are :

a. The detectors (from the environmental control point of view)
b. The detector front end electronics readout
c. The LHCB hardware trigger system (level-0 and level-1)
d. The Trigger and Timing Control system (TTC)
e. The LHC machine control system
f. The LHCB operators
g. The LHCB detector description
h. The LHCB event store
i. The LHCB high level trigger algorithms

1.2 Scope of dataflow and control

The following functions can be identified, in the context of dataflow and control :

1.2.1 Control of the detector environment

Monitoring and control functions will be provided for the parameters of the detector environment such as voltages, pressure, temperature, gas flow.

1.2.2 The detector front end electronics readout

Pipelines, buffers and processing functions must be provided to readout each detector with an acceptable deadtime. The readout scheme must take account of the physical constraints imposed by each detector and also provide multiplexing and data processing facilities to prepare the data in a form appropriate for all levels of trigger processing..

The DAQ system should be capable of providing initialisation, monitoring and error recovery procedures for front end systems.

1.2.3 The LHCB hardware trigger system (level-0 and level-1)

The dataflows must be defined for the trigger detectors into the Level-0 and Level-1 processors with appropriate derandomising and multiplexing. Functions should be provided to read out the Trigger Partition results as for detectors.. In addition the data acquisition must be capable of throttling Level-1 as necessary.

1.2.4 The Trigger and Timing Control system (TTC)

Interfaces must be provided allowing TTC to be used to distribute timing and control signals to all detectors, in a suitably partitioned manner, these including the Level-0 and Level-1 Accept signals.

Functions will be provided for initialisation, monitoring and error recovery of the TTC sub-systems.

1.2.5 The LHC machine control system

Functions will be provided for monitoring the machine state, and making this information available to LHCB sub-systems.

The state of the LHCB detector will be communicated to the LHC machine.

1.2.6 The LHCB operators

A unified control interface will be provided for control and monitoring of the sub-systems used for triggering and data-taking. This will provide status displays, and control facilities for all aspects of data taking control.

1.2.7 The LHCB detector description

The DAQ detector control and monitoring systems should update the detector description to keep a record of detector configuration and performance.

1.2.8 The LHCB event store

The DAQ system will write event streams according to physics classifications into the central event store together will full information about data-taking conditions.

1.2.9 The LHCB high level trigger algorithms

The algorithms will require processing, buffering and data access capabilities in the data acquisition system in order to satisfy the data access, execution time and input rate requirements. These DAQ functions of buffering, data switching and processing will be highly dependent on the algorithms and the patterns of data in the detectors providing the triggers.

1.3 Definitions, acronyms and abbreviations

Specify special terms, acronyms and abbreviations used in the document. The subsections may be re-organised as necessary. For each definition, acronym or abbreviation use a paragraph pair of either DL1 Term and DL1 Description paragraphs, or, of DL1 Term RIH and DL1 Description paragraphs.

1.3.1 [Definitions]

1.3.2 [Acronyms]

CERN European Laboratory for Particle Physics

DAQ Data AcQuisition

1.3.3 [Abbreviations]

1.4 References

[1] K. Krisebom et al. (The LHC-B collaboration), *LHC-B Letter of Intent*, CERN/LHCC 95-5, LHCC/I8, 1995.

[2] The LHC-B Collaboration, *Trigger and Data Acquisition System for LHC-B Experiment: Current status and work programme*, LHC-B 97-0008, CERN/LHCC 97-14, 1997.

1.5 Overview of the document

The requirements placed upon the dataflow system come from various sources. These may be broken down as follows:

GEN : general requirements

READ : detector readout

TRG0 : Level-0 trigger

TRG1 : Level-1 trigger

TRG2 : Level-2 trigger

TRG3 : Level-3 trigger

TTC : Timing control system

DTDB : Detector database

EVDB : Event database

LHC : communication with LHC machine supervisory systems

OP : operators of the DAQ system

MON : monitoring

CAL : calibration

TEST : testing

PART : system partitioning

UINT : user interfacing

FAULT : faults

CON : control functions

SAF : safety

HARD : hardware

SOFT : software

COMM : commissioning of the system

The requirements are broken down into capabilitities and constraints, and in each classification are contributions from both external and internal sources. For example an 'external' capability is to be able to read a particular detector data at the nominal rates, and an 'internal' constraint is the maximum rate at which one would accept Level-1 interrupts.

2 General Description

2.1 Overview of Trigger/DAQ

At the nominal LHCB running luminosity single interaction beam collisions will occur at about 11 MHz. By using a pile-up veto it is proposed to accept only these at the initial level of triggering, level-0, which applies high pT cuts using muon chambers, and hadron and electron calorimeters. It is proposed to tune the cuts to allow 1 MHz average output rate at level-0.

At level-1 will be applied a vertex topology logic based on logic to detector primary and secondary vertices using data from the 18 silicon planes close to the beam interaction. In addition at Level-1 it is proposed to have a track trigger using seeds from Level-0. It is proposed to apply cuts giving a 40 kHz output rate, in which will be around 2 kHz of Bs, several kHz of charm and the remainder made of minimum bias events such as strange decays.

Thus one reads out detector data at a nominal rate of 40 kHz into the data acquisition system, which will switch data into processors where high level algorithms will execute to reduce the event rate to storage to some 100 Hz..

It is proposed to break down the high level algorithms into 2 broad classes. Firstly the so called level-2 algorithms, which using the track and vertex guidance from the trigger, look to reduce the rate to some 5 kHz using only partial event data. The strategies will include refining the vertex detector decision with full precision data and enhanced algorithms, and then combining VD and track spectrometer data. The level-3 algorithms will involve partial of full event reconstruction to apply cuts appropriate to the CP violation channels.

2.2 General capabilities

Describe the main capabilities required and why they are needed.

2.3 General constraints

Describe the main constraints that apply and why they exist.

2.4 User characteristics

These requirements are written with in mind the total dataflow for the LHCB experiment. Thus the users, from whom we obtain the requirements, are the total community of physicists, engineers and programmers contributing to the design and implementation of the detectors and data handling systems according to the requirements imposed by the physics aims of the experiment.

2.5 Operational environment

The systems implementing the dataflow from the detector front ends onto the event store must all operate in a partitioned manner, where each detector will be defined as one or more partitions. There will be a common Timing and Control system for distributing trigger and LHC machine control signals. The data flow for the experiment will follow well defined data and control protocols applied throughout all detector partitions.

The physical operational environment will change according to the implementation phases of the system. One may commence will a small scale prototype operating in a laboratory enviroment. This could be used in detector test beam activities. This would grow into larger scale prototypes which would be used in the early experiment detector installation. This in turn would be used in multi partition mode at theearly multi detector tests at the experimental pit, with this naturally evolving into the first system for physics data taking.

2.6 Assumptions and dependencies

3 Specific Requirements

User requirements fall into two categories: capabilities needed by users to solve a problem or achieve an objective; constraints placed by users on how the problem is to be solved or the objective achieved.

Each user requirement must include the attributes listed below.

***Identifier** - each user requirement **shall** include an identifier, to facilitate tracing through subsequent phases.*

***Need** - essential user requirements **shall** be marked as such. Essential user requirements are non-negotiable; others may be less vitally important and subject to negotiation.*

***Priority** - for incremental delivery, each user requirement **shall** include a measure of priority so that the developer can decide the production schedule.*

***Stability** - some user requirements may be known to be stable over the expected life of the software; others may be more dependent on feedback from the SR, AD and DD phases, or may be subject to change during the software life cycle. Such unstable requirements **should** be flagged.*

***Source** - the source of each user requirement **shall** be stated. This may be a reference to an external document (e.g. system requirement document) or the name of the user, or user group, that provided the user requirement.*

***Clarity** - a user requirement is clear if it has one, and only one, interpretation. Clarity implies lack of ambiguity. If a term used in a particular context has multiple meanings, the term **should** be qualified or replaced with a more specific term.*

***Verifiability** - each user requirement **shall** be verifiable. This means that it must be possible to: check that the requirement has been incorporated in the design; prove that the software will implement the requirement; test that the software does implement the requirement.*

3.1 Capability Requirements

3.1.1 General capabilities

UR GEN1 It must be possible to run the system with any configuration of detectors, and to run different configurations in parallel. Thus for example one configuration may be running in cosmic trigger mode, and another in standalone mode with test triggers.

Need Essential
Priority High
Stability Stable
Source LHC-B DAQ/Trigger group

UR GEN2 It must be possible to support several modes of running involving different triggers. For example:

- Physics data taking
- Test triggers generated by the DAQ or detector groups
- Cosmic triggers

Need Essential
Priority High
Stability Stable
Source LHC-B DAQ/Trigger group

UR GEN3 The dataflow system must provide readout facilities for the following detectors (ACRONYMs in brackets after the detector names)

- Silicon detector (VD)
- Upstream RICH detector (RICH1)
- Downstream RICH detector (RICH2)
- Inner Trackers (ITRACK)
- Outer Tracker (OTRACK)
- Electromagnetic Calorimeter (ECAL)
- Hadron Calorimeter (HCAL)
- Muon tracking (MUON)

Fig ? shows the generic scheme for detector readout necessary for compatibility with the proposed trigger scheme. The placement of the digitisation and multiplexing functions will be detector dependent, and these requirements will be given as a function of detector.

The essential components of this generic scheme are:

- Level-0 Latency Buffer - to provide storage of detector data during the fixed 3.2 microsec latency of the Level-0 trigger.
- Level-0 Derandomiser Buffer - to smooth out the statisitical fluctuations in the Level-0 trigger prior to downstream electronics for multiplexing, digitisation and Level-1 processing
- Level-1 Latency Buffer - to provide storage of detector data during the variable latency of the Level-1 trigger
- Level-1 Derandomiser Buffer - to smooth out data flow following Level-1 decisions, into downstream electronics for multiplexing and data formatting prior to passing data to the data acquisition system

UR READ1 VD Readout - the following summarises the requirements and constraints for reading out the Silicon Vertex detector which consists of 18 planes of silicon strip r-phi geometry. 2 readout options are being explored; Option A which is full analogue, and Option B binary/digital

- DETECTOR
  - **Number of Channels** - 233 K
  - **Channel Partitioning**- 18 stations of 12966 ch., 6 r-sectors(1265 ch.)and 6 phi-sectors(896 ch.) per station
  - **min occupancy** - 0.1%
  - **av occupancy** - 0.3%
  - **max occupancy**-2 %
  - **min multiplicity**-1
  - **av multiplicity**-1.5
  - **max multiplicity**-4
- ON DETECTOR
  - **Level-0 Latency Buffer** - Analogue- length 128
  - **1 Data sample**/Level-0 Accept
  - **Level-0 Derandomiser Buffer** - Size at least 8. Implemented as skipping location in Level-0 buffer
  - **Multiplexing between on detector and off detector** - 32:1 for Option A (40 MHz), and 64:1 for Option B(64 MHz). Multiplexes into ADC/ZP function prior to Level-1
- OFF DETECTOR
  - **Digitisation** - 8 bit ADC(40 or 64 MHz).
  - **Zero Suppression**- none in Option A and thresholding in B
  - **Level-1 Latency Buffer** - Digital FIFO(if in order) or digital shift register-Max size 256 (function of Level-1 latency)
  - **Level-1 Derandomiser Buffer** - Digital FIFO. Size at least 8.
  - **Multiplexing before DAQ** - 512:1. (18 or 12 outputs according to multiplexing on station(18) or sector (12) basis.

Need Essential
Priority High
Stability Estimates under review as a function of simulation results
Source LHCB VD group

UR READ2 RICH Readout .- we summarise the requirements and constraints for the readout of the RICH detectors using the HPD pad type detectors. Thre will be other requirement specifications for another detector option using the RD12 pixel approach, with digitisation electronics bonded very close to the pixel detectors.

Need Essential
Priority High
Stability Estimates under review as a function of simulation results
Source LHCB RICH group(J Bibby)

UR READ3 : OTRACK Readout.. The detector is based on Honeycomb driftchambers(5 and 8 mm cell diameters).

- DETECTOR
  - **Number of channels** -- 95000
  - **Channel Partitioning** -10 stations

    There are 4 planes/station (vert.,+5,-5,vert). In addition stations 2 and 10 have 2 additional planes with horizontal wires. Station 11 is special, and has2 planes with horizontal wires and 2 with vertical wires. Planes are divided into modlules, each with 256 readout channels.
    - Station 2 (behind RICH)- 8120 channels
    - Station 3 - 6880 channels
    - Station 4 - 9012 channels
    - Station 5 - 8906 channels
    - Station6(just behind coil) -10720 channels
    - Station 7 - 10008 channels
    - Station 8 - 10558 channels
    - Station 9 - 10808 channels
    - Station 10 (before RICH2) - 13964 channels
    - Station 11(behind RICH2) - 5910 channels
  - **Min Occupancy** - **<** 1%
  - **AV Occupancy** - 3.5% overall. This rises to 7% for busy modules in stations 2,3,4 close to beam pipe
  - **Max Occupancy** - 9%. In hottest area of hottest station
  - **Min Multiplicity** - 1
  - **Av Multiplicity** - 1.67
  - **Max Multiplicity** - 2
- ON DETECTOR
  - **Data sampling** - 6 bit TDC, 2 samples per Level-0 accept
  - **Zero Suppression** - ? do before Level-0 pipeline
  - **Level-0 Latency Buffer** - digital, depth 128
  - **Level-0 Derandomiser Buffer** - FIFO of size 16
  - **Level-1 Latency Buffer** - digital FIFO, depth 64
  - **Level-1 Derandomiser Buffer** - digital FIFO, depth ?
  - **Multiplexing onto FE links** - do at level of module of 256 channels. These links lead off detector to higher order multiplexing prior to going onto DAQ. With 95 K channels need around 380 such FE links. Worst case capacity for link 8 Mbit/s.
- OFF DETECTOR

- **Off Detector Multiplexing** - takes data from 380 FElinks, and puts onto higher performance links leading into DAQ the zero suppressed, multiplexed data
    - **Data in** - 380 FElinks (peak load for a link of 8 Mbit/sec)
- **Data bandwidth into DAQ** -
    - Assume 16 bit address + 2* 8 bit data sample per hit
    - With 3.5% av occupancy total av event size = 95K*4*.035 bytes=14 kByte
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Need Essential-
Priority High
Stability Estimates under review as a function of new design and simulation results
Source LHCB Inner Tracker group

UR READ5 : OTRACK Readout - the detector provides an average event size of 36 Kbyte, with an estimated average occupancy of 5% in 180k channels distributed over 12 planes.

Need Essential
Priority High
Stability Estimates under review as a function of simulation results
Source LHCB Outer Tracker group

UR READ6 : ECAL Readout - the detector provides an average event size of 2 Kbyte, with an estimated average occupancy of 5% in 10k channels.

Need Essential
Priority High
Stability Estimates under review as a function of simulation results
Source LHCB ECAL group

UR READ7 : ECAL Readout - the detector provides an average event size of 1Kbyte, with an estimated average occupancy of 5% in 4k channels.

Need Essential
Priority High
Stability Estimates under review as a function of simulation results
Source LHCB HCAL group

UR READ8 : MUON Readout - the detector provides an average event size of 6 Kbyte, with an estimated average occupancy of 1% in 120k channels distributed over 5 planes.

Need Essential
Priority High
Stability Estimates under review as a function of detector design and simulation results
Source LHCB Muon group(Andre)

UR TRG001: Initialisation of the level-0 system must be provided, including the definition of all trigger parameters.

Need Essential
Priority High
Stability Stable.
Source LHCB TDAQ group

UR TRG002: The DAQ system will be capable of reading the status of the level-0 trigger system, and executing error recovery procedures as appropriate.

Need Essential
Priority High
Stability Stable.
Source LHCB TDAQ group

UR TRG003: The DAQ system will read the output of the level-0 trigger for an event into the buffers provided for the trigger partition.

Need Essential
Priority High
Stability Stable.
Source LHCB TDAQ group

UR TRG101: Initialisation of the level-1 system must be provided, including the definition of all trigger parameters.

Need Essential
Priority High
Stability Stable.
Source LHCB TDAQ group

UR TRG102: The DAQ system will be capable of reading the status of the level-1 trigger system, and executing error recovery procedures as appropriate.

Need Essential
Priority High
Stability Stable.
Source LHCB TDAQ group

UR TRG103: The DAQ system will read the output of the level-1 trigger for an event into the buffers provided for the trigger partition.

Need Essential
Priority High
Stability Stable
Source LHCB TDAQ group

UR TRG201: The DAQ system will provide a software environment suitable for the development and operation of the Level-2 algorithms.

Need Essential
Priority High
Stability Stable
Source LHCB TDAQ group

UR TRG202: The DAQ system will provide buffers to allow for the latency of the level-2 algorithms running at 40 kHz .

Need Essential
Priority High
Stability Stable
Source LHCB TDAQ group

UR TRG203: The DAQ system will provide access to the detector data buffers according to requests from the level-2 algorithms.

Need Essential
Priority High
Stability Stable
Source LHCB TDAQ group

UR TRG204: The DAQ system will provide processors and appropriate control hardware/software to support running the algoritms at 40 kHz with average processing requirements of 10 MI.

Need Essential
Priority High
Stability Stable
Source LHCB TDAQ group

UR TRG301: The DAQ system will provide a software environment suitable for the development and operation of the Level-3 algorithms.

Need Essential
Priority High
Stability Stable
Source LHCB TDAQ group

UR TRG302: The DAQ system will provide buffers to allow for the latency of the level-3 algorithms running at 40 kHz .

Need Essential
Priority High
Stability Stable
Source LHCB TDAQ group

UR TRG303: The DAQ system will provide access to the detector data buffers according to requests from the level-3 algorithms.

Need Essential
Priority High
Stability Stable
Source LHCB TDAQ group

UR TRG304: The DAQ system will provide processors and appropriate control hardware/software to support running the algoritms at 5kHz with average processing requirements of 200 MI.

Need Essential
Priority High
Stability Stable
Source LHCB TDAQ group

UR TTC01: The TTC needs to be configured by the DAQ system.

a. The TTC shall have access to the partition information

b. The TTC shall have access to operational parameters such as maximum number of triggers requested

Need Essential
Priority High
Stability Stable
Source LHCB TDAQ group

UR TTC02: The TTC will require to make its monitoring information available to other systems in the DAQ (trigger rates,dead-time, comnters, etc.)

Need Essential
Priority High
Stability Stable
Source LHCB TDAQ group

UR TTC03: The TTC will require an interface to report errors detected within the TTC system

Need Essential
Priority High
Stability Stable
Source LHCB TDAQ group

DTDB : Detector description

EVDB : Event store

LHC: Communication with LHC machine supervisory systems

MON : monitoring

CAL : calibration

TEST : testing

PART : system partitioning

UINT : user interfacing

FAULT : faults

CON : control functions

SAF : safety

HARD : hardware

SOFT : software

COMM : commissioning of the system

MOD : modelling and simulation of the system

DEMO : demonstration of the system

3.1.2 [...]

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3.2 Constraint requirements

Constraint requirements place restrictions on how software can be built and operated. For example, definitions of external communications, hardware and software interfaces may already exist, either because the software is a part of a larger system, or because the user requires that certain protocols, standards, computers, operating systems, library or kernel software be used.

Constraints that users may wish to place on the software include the quality attributes of adaptability, availability, portability and security. The user shall describe the consequences of losses of availability, or breaches of security, so that developers can fully appreciate the criticality of each function.

The user may choose to make additional standards applicable; such requirements are additional constraints on the development.

3.2.1 [subsection]

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UR [id3] [UR Statement]

Need [How essential is this UR]
Priority [Priority for incremental delivery]
Stability [How subject to change is this UR]
Source [Name of person, group, document, ... from which the UR originates]
Clarity [If more than one interpretation possible, this must be qualified]
Verifiability [Check how UR: can be incorporated into the design; implemented in the software; can be tested]
[Any Other Attribute] [Value of Any Other Attribute]

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