Trigger/Data Acquisition Issues

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This paper summarizes the current Trigger and Data Acquisition view of the four detector concepts of the worldwide study of the International Linear Collider (ILC) study group. First, a better knowledge of the ILC physics and machine event backgrounds and data bandwidths of the various sub-detectors will give the size of the full data flow of the read out system. Second, the concept of 'Software Trigger' architecture with its consequences on the read-out electronics designs under development is discussed. Third, some preliminary ideas for the event selection and analysis will be presented. Finally, a generic architecture model of the DAQ system uniform across each concept will be presented with a possible implementation based on ATCA.

1 Introduction

1.1 The Machine parameters and conditions

The ILC machine consists of two separate independent linear superconducting electrons accelerators of 16 km long with and energy of 500 Gev/c to 1Tev/c maximum and a luminosity up to 2. 10^{34} $cm^{-1}s^{-1}$.

In contrast to currently operated or built colliders, such as HERA, Tevatron or LHC, which have a continuous rate of equidistant bunch crossings the ILC has a pulsed operation mode. For the nominal parameter set [7] the ILC will have

- ~3000 bunch crossings in about 1ms,
- 300 ns between bunch crossings inside a bunch train
- ~200 ms without collisions between bunch trains.

This operation mode results in a burst of collisions at a rate of ~3MHz over 1ms followed by 200ms without any interaction. The integrated collision rate of 15 kHz is moderate compared to the LHC and corresponds to the expected event building rate for the LHC experiments. One or two interaction points (IP) are foreseen. The size of the beam at the Interaction Point will be few μm needs a rapid feedback between each bunch train to optimize the luminosity.

1.2 Experimental features and detectors requirements

The ILC machine is a precision machine complementarily to LHC which is a discovery one. The physics goals require higher precision in jet and momentum resolution and better impact parameter resolution than any other collider detector built so far. As a consequence, ILC should strive to do physics with *all* final states by measuring charged particles in jets more precisely (the 'Particle flow' paradigm in calorimeters), with a good separation of charged and neutrals. Jets & leptons are the fundamental quanta of the signature of a physics process to be selected and recorded in any HEP detector. Compared to previous e^+e^- experiments at LEP for example, they must be identified and measured well enough to discriminate between Z's, W's, H's, Top, and new states. This requires a non-trivial task improving jet resolution by a factor of two. Charged Particle tracking detectors must precisely measure 500 GeV/c leptons for Higgs recoil studies. This requires 10 times better momentum resolution than LEP/SLC detectors and 1/3 better on the Impact Parameter of SLD! To catch multi-jet final states (e.g. t-tbar H has 8 jets), need real 4π solid angle coverage with full detector capability. Never been done such hermiticity and granularity! Compared to LHC, its looks less demanding. ILC Detector doesn't have to cope with multiple minimum bias events per crossing, high rate triggering for needles in haystacks, radiation hardness, hence many more technologies available, where better intrinsic performance is possible. But ILC detectors does have to cover full solid angle, record all the available CM energy, measure jets and charged tracks with unparalleled precision, measure beam energy and energy spread, differential luminosity, and polarization, and tag all vertices, hence better performance and more technology development is needed. This improved accuracy can only be achieved by a substantial bigger number of readout channels.

1.3 Trigger and Data Acquisition requirements

As outlined in all 4 detector concept studies [1,2,3,4] the data acquisition (DAQ) system of a detector at the ILC has to fulfill the needs of a high luminosity, high precision experiment without compromising on rare or yet unknown physics processes. Although the maximum expected physics rate, of the order of a few kHz, is small compared to the most recent hadrons colliders, Peak rates within a bunch train may reach several MHz due to the bunched operation. In addition the ILC physics goals require higher precision in jet and momentum resolution and better impact parameter resolution than any other collider detector built so far. This improved accuracy can only be achieved by a substantial bigger number of readout channels.

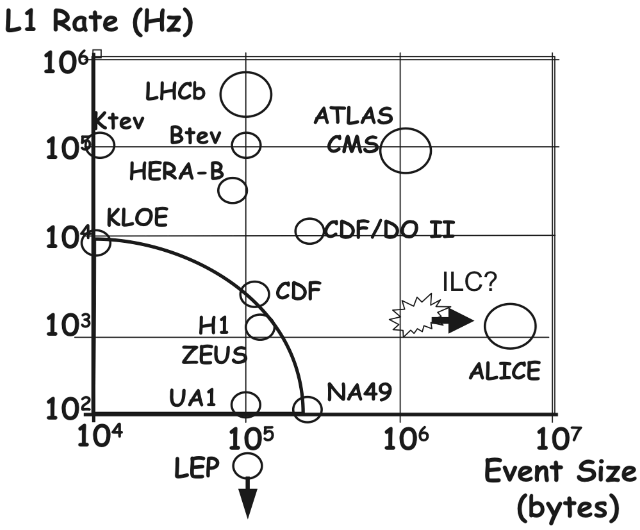

Fig. 1. Data rate and volume compared to previous and present large collider experiments

Taking advantage of the bunched operations mode at the ILC, event building without a hardware trigger, followed by a software based event selection was proposed [5] and has been adopted by all detector concept studies. This will assure the needed flexibility, scalability and will be able to cope with the expected complexity of the physics and detector data without compromising on efficiency.

TABLE I
ILC VERSUS LHC DETECTOR CHANNELS COUNTS

Subdeteor	LHC	ILC
Pixels	150 M	1 to 10 G
Microstrips	10 M	30 M
Fine grain tracker	400 K	1,5 M
Calorimeters	200 K	30 to 100 M

The increasing numbers of readout channels for the ILC detectors will require signal processing and data compression already at the detector electronics level as well as high bandwidth for the event building network to cope with the data flow.The currently built LHC experiments have up to 10^8 front-end readout channels and an event building rate of a few kHz, moving data with up to 500 Gbit/s [6]. The proposed DAQ system will be less demanding in terms of data throughput although the number of readout channels is likely to be a factor of 10 larger. The rapid development of fast network infrastructures and high performance computing technologies, as well as the higher integration and lower power consumption of electronic components are essential ingredients for this data acquisition system. Furthermore it turned out that for such large systems a restriction to standardized components is vital to achieve maintainability at an affordable effort, requiring commodity hardware and industry standards to be used wherever possible. Details of the data acquisition system depend to a large extent on the final design of the different sub detector electronic components, most of which are not fully defined to date. Therefore the DAQ system presented here will be rather conceptual, highlighting some key points to be addressed in the coming years.

2 Conceptual architecture

2.1 Software Trigger

The burst structure of the collisions at the ILC immediately leads to the suggested DAQ system:

- dead time free pipeline of 1 ms,
- no hardware trigger,
- front-end pipeline readout within 200 ms and event selection by software.

The high granularity of the detector and the roughly 3000 collisions in 1 ms still require a substantial bandwidth to read the data in time before the next bunch train. To achieve this, the detector front end readout has to perform zero suppression and data condensation as much as possible. Due to the high granularity it is mandatory to have multiplexing of many channels into a few optic fibers to avoid a large number of readout cables, and hence reduce dead material and gaps in the detector as much as possible.

2.2 Data Read Out and collection

The data of the full detector will be read out via an event building network for all bunch crossings in one train. After the readout, the data of a complete train will be situated in a single processing node. The event selection will be performed on this node based on the full event information and bunches of interest will be defined. The data of these bunches of interest will then be stored for further physics analysis as well as for calibration, cross checks and detector monitoring. Figure 1 shows a conceptual diagram of the proposed data flow.
a programmable interface to the front end readout,the event data buffer which will allow storing data of several trains and the standardized network interface to the central DAQ system.

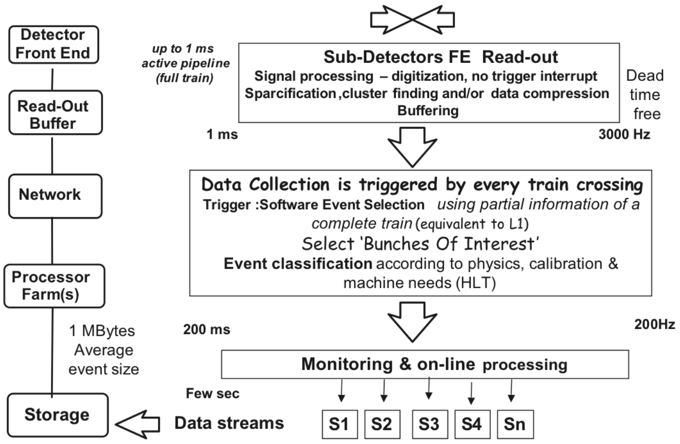

Fig. 2. Data flow and software trigger concept.

The programmable interface should enable one common type of readout unit to adapt to the detector specific front end designs. To allow for variations in the readout timing to more than 200 ms the readout units could be equipped with event data buffers with multiple train capacity.The full event is built via the event building network into a single data processing node which will perform final data processing, extract and apply online calibration constants and will select the data for permanent storage

In the data processing node the complete data of all bunch crossings within a train will be available for event processing. Distributing data of one train over several processing nodes should be avoided because sub detectors such as the vertex detector or the TPC will have overlapping signals from consecutive bunch crossings and unnecessary duplication of data would be needed. Event selection is performed in these data processing nodes such that for each class of physics process a specific finder process will identify the bunch crossings which contain event candidates and mark them as `bunches of interest'. All data for the `bunches of interest' will be fully processed and finally stored permanently for the physics analysis later on. By using software event selection with the full data available, a maximum event finding efficiency and the best possible flexibility in case of unforeseen conditions or physics processes is ensured. The best strategy for applying these finders and processing the data, depends on the topology of the physics processes to be selected and their background processes. This has to be further studied and optimized based on full Monte Carlo simulations. Several trains will be built and processed in parallel in a farm of data processing nodes and buffering in the interface readout units will allow for fluctuations in the processing time.

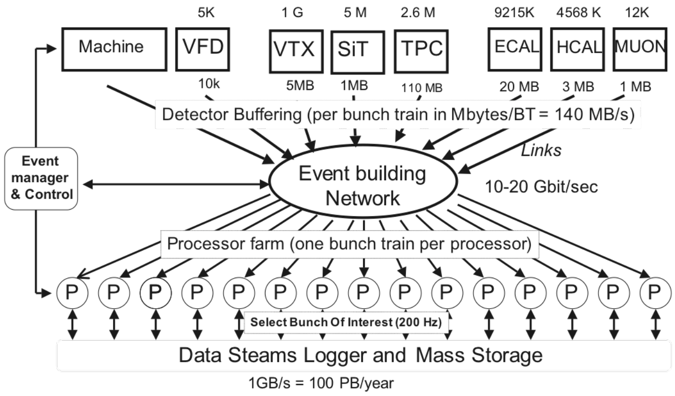

Fig. 3. Data Collecture Architecture and data flow of the GLD detectors concept

Using commodity components like PCs and standardized network components allows for the scaling of the processing power or network bandwidth according to the demands. The use of off-the-shelf technology for the network and the computing units will ease maintainability and allow to profit from the rapid development in this area. The DAQ system will also profit from the use of a common operating system, for example Linux, and high level programming languages already at the event building and event finding stage, making the separation of on-line and off-line code obsolete and therefore avoid the need to rewrite, and debug, code for on-line or off-line purposes. This results in a more efficient use of the common resources.

3 Systems boundaries

3.1 Detector front end electronics

The amount of data volume to be collected by the DAQ system is dominated by pair background from the machine. Simulations for the nominal ILC parameters [7] at E_{cm}= 500GeV for the LDC [2] show in the vertex detector 455, 189 and 99 hits per bunch crossing for layer 1, 2 and 3 respectively. In the TPC volume roughly 18000 hits are produced. Similar studies for the other concepts confirm the high background near the beam pipe.
Except for the inner layers of the vertex detector the occupancy for a full train imposes no constraints onto the readout scheme. For the inner vertex detector layers the data has to be read out during the train to keep the hit density low enough not to compromise on the tracking performance. For the SiD main tracker the ability for bunch identification to reduce the background especially in the forward region is studied.

For the SiW based ECAL systems the high granularity requires large multiplexing on the front end detectors with an adequate multi hit capability and efficient hit detection or zero suppression. Single chips with hit detection, charge and time digitization and multi hit storage capacity for up to 2048 channels were proposed by several groups.

For the TPC novel readout technologies are developed with reduced ion feedback to allow for a gateless operation with sufficient gas amplification for a period of 1ms.

The electronic noise of the front end systems or the detectors themselves is a third, possibly very dangerous, source of data volume in a trigger less system and has to be sufficiently under control or be suppressed by the front end data processing.

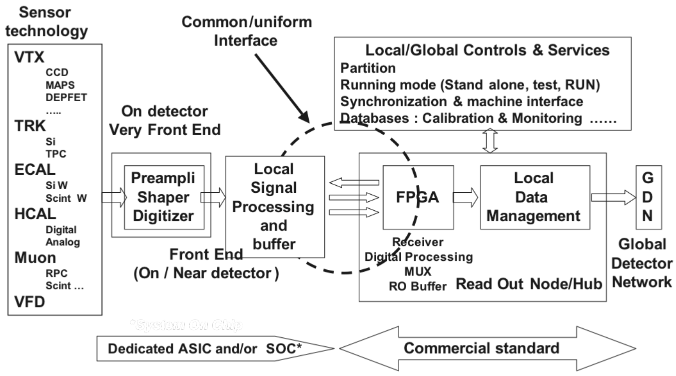

Fig. 4. Current view of a uniform read out architecture .

The high granularity of the detector systems and the increased integration of electronic at the detector front end, will result in large power dissipations. To avoid excessive cooling needs, all detector systems investigate the possibility of reducing the power at the front end electronics by switching power off between trains (power cycling). This has to be balanced against power up effects, the readout time needed between trains and the ability to collect data between trains for calibration purposes, e.g. cosmic muon tracks.

3.2 Machine Interface

The machine operation parameters and beam conditions are vital input for the high precision physics analysis and will therefore be needed alongside the detector data. Since the amount of data and time structure of this data is similar, a common data acquisition system and data storage model should be used. Up to now very little has happened to integrate the DAQ for the beam delivery system into the physics data flow. It is mainly assumed that integration of parts or all of the machine parameters should be straight forward due to the programmable interface units and the network based structure of the DAQ system.

3.3 Detector Control and Monitoring

The data acquisition and its operation is closely coupled to the detector status and detector conditions, as well as the machine conditions. Hence it is proposed that the detector slow control and the conditions monitoring is tightly linked to the DAQ system by an overall experiment control system.

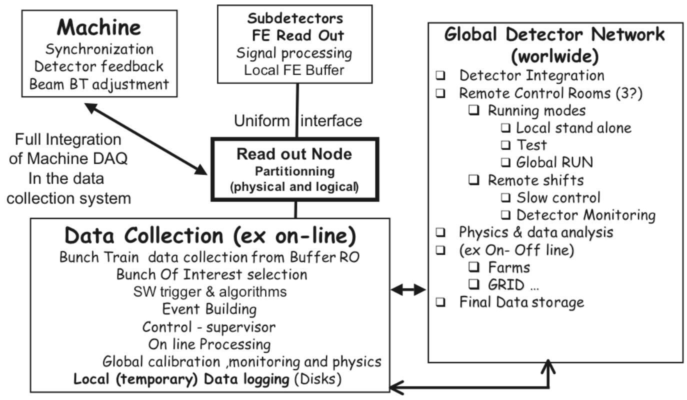

Fig. 5. Block diagram of system boundaries

For detector commissioning and calibration the DAQ system has to allow for partial detector readout as well as local DAQ runs for many sub components in parallel.
The DAQ system has to be designed such that parts of a detector component or complete detector components can be excluded from the readout or be operated in local or test modes without disturbing the physics data taking of the remaining parts.

3.4 On - Off line boundaries

The notion of ON line and OFF line analysis is now completely obsolete due to the progress of hardware and software technologies (FPGA's, memories, processor, network bandwidth, embedded algorithms…). The figure 6 presents a possible integrated computing model.

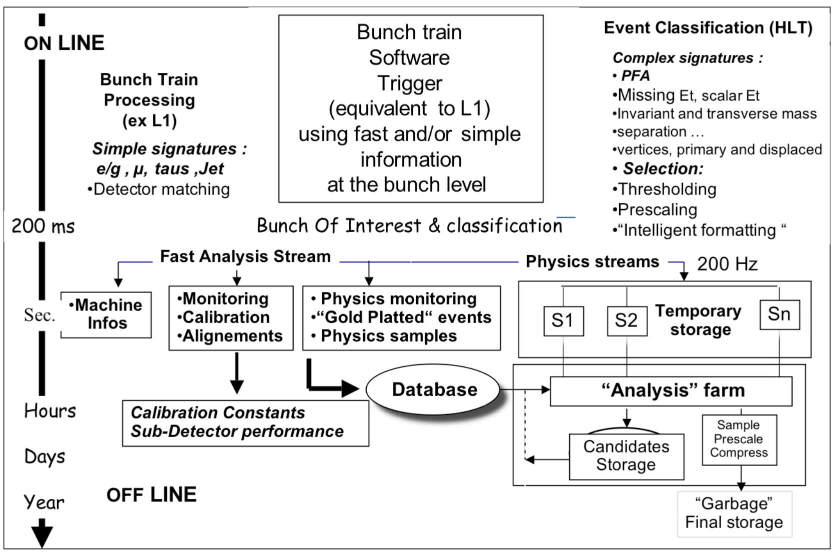

Fig 6. ILC Trigger and data acquisition possible computing model

To benefit from the online software event selection an accurate online calibration is needed. Strategies for calibrating and monitoring the detector performance as well as efficient filter strategies have to be worked out. Simulation studies will be needed in the coming years to prepare this in more detail.

3.5 Global Detector Networking

The ILC as well as the detector will be operated by truly worldwide collaborations with participants around the world. The global accelerator network (GAN) and global detector network (GDN) has been proposed to operate both the machine and the detector remotely by the participating sites. This in turn requires that the data acquisition system, as well as the detector control, be designed with remote control and monitoring features built in from the start.

4 Issues and Outlook

Although for the main DAQ system commodity components some generic R&D is needed to prepare the decisions. A DAQ pilot project should be planned to serve as a frame for R&D on the front end readout uniform interface, the machine and detector DAQ interface, detector slow control issues, online calibration and event selection strategies. Recent developments on data collection technology (for example ATCA [8]) should be followed and if possible explored to gain the necessary experience needed for the final DAQ technology choice.

In addition some architectural and technical studies should be made soon like the integration of a cosmic trigger that has been proven to be very useful for debugging purpose in the past during the commissioning phase. However, the compatibility with the power cycling scheme should be studied. The clock system, machine synchronization and timing distribution is another field of technical investigation. The experience of LHC could be useful.

Finally, a common work between the machine control group is foreseen on the subjects like ATCA and GAN. The figures presented in this report are presentation slides available on ref [10]. I would like to thanks Dr. Gunter Eckerlin from DESY for its contribution and useful discussions .we had together.

5 Reference

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