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A GAUGE MODEL OF DATA SELECTION, ACQUISITION AND ANALYSIS FOR LHC* **

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A novel model of the data selection, acquisition and analysis for a multi-purpose and multi-component high-energy-physics experiment is presented. Its departure point is the freedom and the responsibility given to the different physics groups of the experiment to impose, on the *event-by-event basis*, their physics-goal-optimal configurations of *(i)* the sub-detectors, *(ii)* the trigger and data acquisition system, and *(iii)* the reconstruction and analysis framework. Its target is to develop, in a close analogy to the construction of the gauge models in particle physics, the overall data handling scheme, in which a multi-purpose experiment becomes an association of coexistent, yet largely independent, physics-group-based sub-experiments sharing common hardware maintenance, data-acquisition, and data reconstruction resources.

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1. Introduction

In the pre-LHC multi-purpose high-energy-physics collider experiments, the process of diversification of the physics-goal-dedicated data analysis methods has been largely decoupled from the process of the data taking. The experiment's physics-groups could develop their optimal selection criteria for the recorded data. However, these criteria had to be confronted with, often mutually exclusive, requirements of the other physics groups and compromises had to be found while constructing global trigger menus and the data selection algorithms. Moreover, within such a scheme the raw

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data content of recorded events and the framework of their *(i)* initial online selection, *(ii)* reconstruction, and *(iii)* analysis were the same for all the events. The above scheme assured an "offline-analysis-friendly" encapsulation of the technical aspects of the data taking process and has been generally considered as optimal because it has never been over-restrictive for the physics-group-optimal data selection and data analysis methods.

The initial configuration of the multi-purpose LHC experiments is based on a continuous extrapolation of the above paradigms to the LHC experimental environment. One of the basic questions which is worth addressing in the advent of the LHC experimental program is: "Will such a paradigm survive the "LHC phase transition" to a new detector-operation regime, characterized by a small, $\mathcal{O}(10^{-7})$, ratio of the rate of the recorded events to the rate of the proton–proton collision events, and to a new sociological regime of a large, $\mathcal{O}(10^{3})$, group of physicists exploring the new energy frontier using the diverse analysis methods?".

The starting point of our proposed "Gauge" Model[1] of Data Selection, Acquisition and Analysis is the observation that the above paradigm cannot be continuously extended to the LHC environment, without significant sacrifices in the scope and in the quality of its experimental program. Physics groups analyzing rare events would clearly prefer to have an access to the full raw electronic data. Such data cannot be recorded for *all the events* because of the bandwidth limits of the data transmission. Physics groups attempting to select events based on exclusive topological criteria would prefer to organize the High Level Trigger (HLT) algorithms within a framework which is clearly distinctive to the optimal one for selection of events on the basis of the inclusive trigger objects. The optimal trigger-frequency *versus* event-length trade-offs, for both the detector monitoring events and for the physics events, are often contradictory for groups analyzing large cross-section processes and those searching for rare phenomena. Physics groups searching for new physics would certainly prefer to optimize the event selection capacity at the cost of the measurement precision. Physics groups working on high precision measurements would clearly opt for an opposite solution.

The proposed model tries to inject a sufficient flexibility to the data taking and data analysis process such that the optimal choices could be made independently by each of the physics groups. At the heart of the proposed model is the freedom and responsibility, given to the physics groups, to effectively impose the data-taking configuration of the sub-detectors and of the Trigged and the Data Acquisition (TDAQ) system *on event-by event*

[1] The terminology "Gauge Model" is to draw attention to the analogy with the well-known gauge models of particle interactions, where, often, we may exploit the gauge freedom by making a specific choice of gauge that greatly simplifies the analysis of a particular problem.

basis allowing for the physics-group-optimal use of the detector capacities. As an example, a physics group analyzing rare, large E_{T} events is given the freedom to impose registering the most complete front-end electronic information of each of the sub-detectors. This group may implement a strategy based on inclusive, low purity but high efficiency, region-of-interest-guided on-line selection methods. *Within the same run*, a physics group interested in large cross-section processes is given a freedom to impose registering highly-compressed front-end electronic information restricted to a subset of sub-detector partitions. This group may employ the on-line event selection methods based upon global topological criteria, rather than based upon the region-of-interest guided inclusive selection criteria, and may optimize the purity of the selected sample, rather than the efficiency of the event selection. A flexibility is given to each of the groups to run, if necessary, the group-optimal software selection-framework implemented on a subset of the LVL2 and EF processors, and the group-optimal offline data analysis and data access framework implemented on a subset of the Tier 1 and Tier 2 processors.

The proposed model may be applicable to the advanced phase of the LHC experimental program, if the quest for the best specific-physics-program-oriented use of the detector and of the LHC capacities — confronted with the hardware, software, and sociological complexity of the LHC experiments — ends-up in a phase-transition in the data handling paradigms. Following such a phase transition, the LHC experiments could metamorphose, becoming associations of coexistent yet largely independent (transparent) physics-group-based sub-experiments, sharing common hardware maintenance, data acquisition, calibration, and reconstruction resources. For the author of this note, such a phase transition is inevitable — if the full discovery potential of LHC is to be exploited. It may be accelerated if the initial discovery scenarios fail and/or if there will be a sufficient pressure of the physics-groups to implement their group-specialized methods of the data selection and analysis.

The proposed model is constructed according to the construction pattern of the gauge models in particle physics. In these models the "gauge-choice" is arbitrary. It could reflect: the technical simplification of the calculations, a wish to preserve the physics interpretation of the intermediate calculation steps, or simply, a specific physicist taste. The only constraint is that the final results of the model calculations are gauge independent. In a close analogy, the proposed model allows for a "gauge-dependent" event-by-event selection of: the format and the content of the detector raw data, and of the event building method. Moreover, it gives a freedom of: a "gauge-dependent", event-by-event choice of the event-selection framework implemented on one of the slices of the TDAQ system, and of a "gauge-dependent", event-by-event choice of the offline data analysis framework implemented on one of the slices of the offline computing grid. The full chain of data selection and analysis becomes thus "gauge-dependent" while the physics results remain to be "gauge-invariant". In addition, the proposed model inherits from the gauge models the handling methods of the gauge symmetry breaking phenomena reflecting the detector-hardware operation constraints.

Inevitably, the model presented in this note changes the invariant character of the content of the registered raw data and of the event selection efficiencies from the experiment-invariant one to the physics-group-dependent one. The notion of a "experiment-invariant" data is thus lost and replaced by the notion of "physics-goal-optimal" data. The recorded data preserve, however, the experiment-wide universality of the event structure, which is mandatory for preserving the universality of the common, low-level, event reconstruction, detector calibration and the data quality monitoring software.

The model changes significantly the borders and the interfaces between the domains of the central data acquisition, sub-detectors, general data reconstruction and physics groups. Each of the physics groups can choose independently its preferred raw data form, the event selection and event building strategy, the hardware capacity of their TDAQ slice, and its optimal data reconstruction software on a grid-slice in all the aspects except for the detector calibration and the low-level event reconstruction. The disaggregation of the data taking and data analysis process into the domains of responsibilities is shown in Fig. 1.

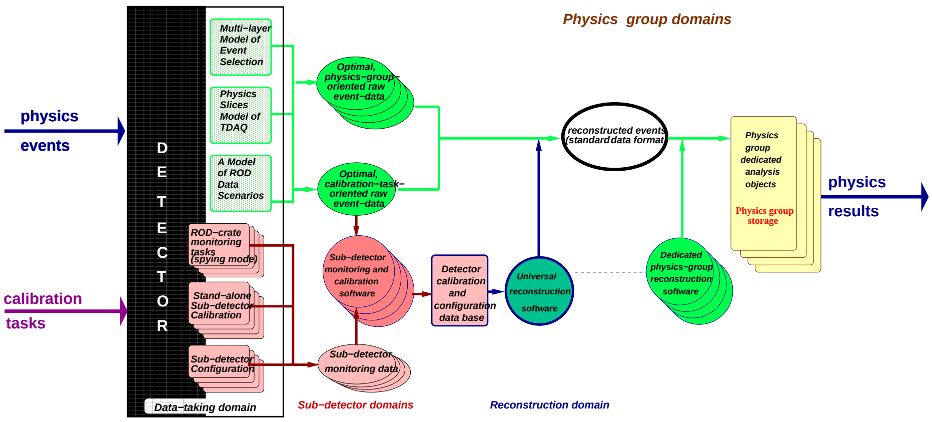

Fig. 1. The responsibility domains.

This contribution to the Epiphany Conference presents the basic functionalities of the model as constructed in the years 2002–2003 and as projected to the hardware capacities of the ATLAS experiment [1]. Its details were documented in a series of notes [2]. Introducing novel ideas, in the year 2003, *i.e.* in the phase of the implementation of the present, widely accepted, data handling paradigms into their concrete realizations was not, perhaps quite rightly, considered as a constructive action. This may no longer remain true in the forthcoming data taking phase of the LHC physics program when both the merits and the bottlenecks of the presently implemented data handling methods will become apparent. Following such a phase the LHC data taking and data analysis paradigms may need to be overhauled and, in such a case, the proposed model could serve as an example of alternative solutions.

2. The adaptive variability domains

The proposed model assumes the following definition of the function of the LHC detectors: *The function of the LHC detectors consists of the selection of those of collision events which enlarge our understanding of particle interactions, and of recording only those of the event data which are sufficient for the most statistically and systematically precise measurements.*

In order to fulfill this goal, all the experiment sub-components (the sub-detectors, the TDAQ, the software domain, the detector-performance-control domain, and the physics analysis domain) have to develop their specific adaptive capacities to best cope with the variable data-taking environment illustrated in Fig. 2. Each sub-component could, in principle, develop individually its adaptive functions. The resulting *organism* would however be *biologically primitive* and thus *evolutionary unstable.*

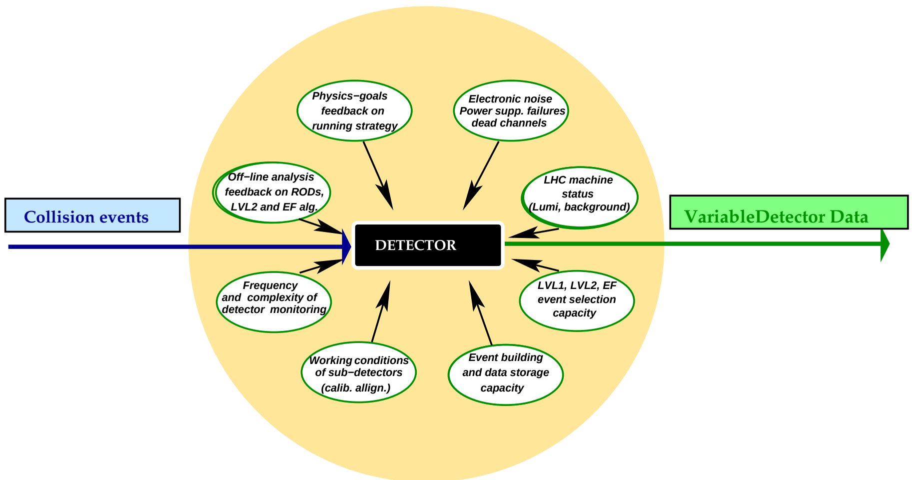

Fig. 2. The detector operation environment.

One of the goals of the proposed model is to document an attempt to define the adaptive capacities of the experiment in a close analogy to advanced biological systems. In such systems the function of adaptation to external environment is delegated to specialized organs. Handling of most of environmental changes can be then largely confined to these organs. This allows for reducing the reaction time to external environmental stimuli.

Such an adaptation form is characterized by an encapsulation of the *reflex-type* functions of the organism. As a consequence, it leads to reduction of the reaction time to those of the environmental stimuli for which the coherent response of the whole organism is indispensable. Such specialized "organs" will be called in this note **variability domains**.

The seed and central point of the proposed model is the conjecture that the adaptive capacity of the data-taking and on-line data analysis process to the environmental constraints can be delegated to the following three variability domains:

1. The Read-Out-Driver (ROD) data variability domain;
2. The event selection tools variability domain;
3. The TDAQ-slices configuration variability domain.

These three variability domains are modeled in the following sections of this note.

3. The model

3.1. The construction steps

The model of data-taking is illustrated in Fig. 3. Any offline task, attempting to analyze collision events, instead of being confronted with sophisticated and variable detector operation environment depicted in Fig. 2, will be exposed only to precisely-defined quantum-reactions of the data-taking process to environmental changes. These reactions will be fully encapsulated within the three variability domains and will be represented by quantum transitions between the allowed discrete set of states.

The model is constructed in three steps:

1. The fist step consists of defining of the complete set of *eigenstates* of each of the three variability domains.
2. The second step consists of projecting these eigenstates onto the detector-partitions and the TDAQ-partitions granularity.
3. The third step consists of specifying the model dynamics in terms of the causality and the time-granularity pattern of quantum transitions between the allowed eigenstates.

The above three steps are described in the following three sections.

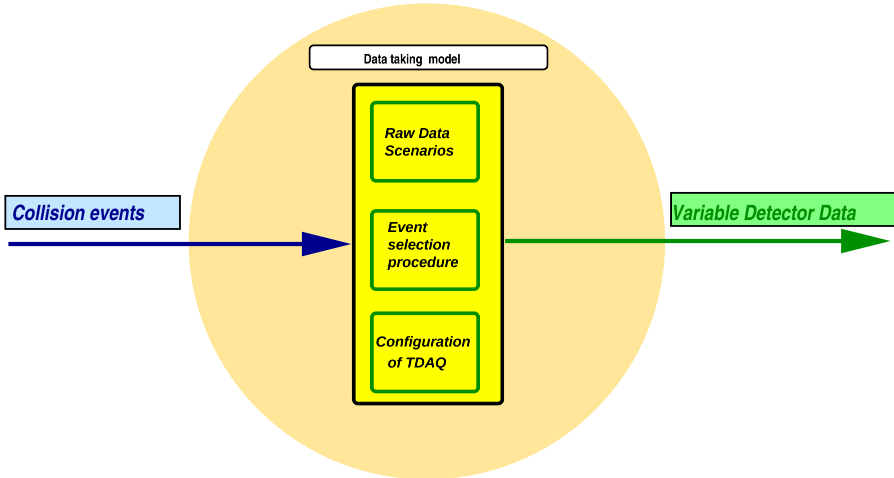

Fig. 3. The data-taking model.

3.2. The eigenstates

3.2.1. The eigenstates of the ROD data

The eigenstates of the variability domain of the ROD data are specified in terms of:

- The data content;
- The data compression method;
- The zero suppression scheme;
- The channel addressing mode;
- The format and the content of the ROD summary blocks.

Let me give few concrete examples of the ROD data eigenstates for the ATLAS experiment [1].

The full bit history of the Transition Radiation Tracker (TRT)-straw signals passing low and high thresholds, and the leading-edges bit-history are he examples of the TRT data-content eigenstates.

Packing Tile Calorimeter (Tile-Cal) cell energies in 11 bits, packing of adjacent Semiconductor Tracker (SCT) strip info into 32 bit words are examples of the data compression eigenstates[2].

[2] Data compression does not change the information encoded in the raw data but may result in variable unpacking methods of the byte-streams of the raw detector data.

Zero suppression scheme consists of dropping fully or partially the detector channel info which is unlikely to be correlated with the passage of a particle produced in the beam-beam collisions. For example, dropping invalid TRT straws, dropping the 2σ "electronic noise" Liquid Argon Calorimeter (LAr) channels, or skipping the info which may be derived from the neighbor channels (*e.g.*, the strip hits within a continuous cluster) are the possible eigenstates of the zero suppression scheme.

The sub-detector-optimal eigenstates of the addressing modes include direct addressing of non-suppressed channels (silicon trackers) or bit pattern addressing mode of the LAr and Tile-Cal cells. The addressing modes are correlated with the data compression modes and with the zero suppression schemes.

The concept of the ROD summary blocks is new. The ROD summary blocks contain the LVL2 trigger dedicated information which will be used by the ultra-fast selection algorithms. LAr fixed-format blocks containing the bit pattern of the energy-threshold crossing is an example of the LAr summary block eigenstate.

A central point of the proposed model is that a broad spectrum of sub-detector-allowed operation modes is confined to a **small** set of eigenstates spanning the full space of compromise between compactness and completeness of information. These eigenstates are referred to as *data scenarios*. Reactions of the sub-detector operation modes to variable data taking environment are **confined** in the proposed model, to transitions (quantum-jumps) between the allowed data scenarios.

3.2.2. The eigenstates of the event-selection tools

The eigenstates of the variability domain of the event selection tools are specified in terms of:

- The allowed Level 1 (LVL1), Level 2 (LVL2) and Event Filter (EF) trigger signatures;
- The allowed layers of the event-selection algorithms.

The trigger signatures are modeled in the standard way [4] in terms of trigger elements, trigger thresholds, and pre-scale factors.

In order to cope with the dynamic data-taking environment new species of event selection algorithms are proposed. They extend the list of algorithms presented in [3], and based solely upon the offline-like reconstructed physics objects and include algorithms based upon the data in byte-stream format or based upon specialized raw-data structures. These new algorithms break the factorization of the data preparation and the algorithm execution stages. The introduction of new type of algorithms is reflected in an extension of the list of possible trigger elements.

All algorithms are grouped into layers. The main goal of such grouping, reflected in the proposed data-selection software framework [2], is to create a fine-structure of latencies of the event selection process.

The concept of algorithm layers is new. The eigenstates of each of the algorithm layer are specified in terms of *the type* and *the granularity* of data they are using, and in terms their *function* in the data selection. The data type reflects the stage of the ROD-data unpacking and preparation. Three data types are defined in the proposed model:

1. The byte-stream data containing the fixed format and position LVL2 summary blocks;

2. The raw-data objects;

3. The reconstructed-data objects.

The allowed granularity of the data which are requested by an algorithm is:

1. A ROD[3];

2. A Region-of-Interest (RoI) group of RODs;

3. A predefined (constant) group of RODs;

4. The full detector.

The type and granularity of the data used by an algorithm determines unambiguously how they are aggregated into algorithm subsets referred to in this series of notes as **layers**. The algorithm layers are the basic entities (algorithm quanta) which could be implemented on any of the LVL2 processors (LVL2PUs) or Event Filter (EF) processing tasks (PTs).

Each data selection algorithm fulfills one of the two functions:

1. Verifying, if the full (partial)condition corresponding to a trigger element is fulfilled (this includes verification of the trigger-menu-predefined *veto-elements*);

2. Flagging of *infected data structures* in a way which is independent of the preloaded trigger menus. The algorithms fulfilling this functions are called in the series of presented notes the *T-algorithms*.

[3] Read-Out-Link (ROL)-unit would be a better, more stable definition the minimal data unit, independent of possible evolution of the TDAQ system; this is discussed further in [2].

In the proposed model, the allowed variability range of the event selection tools is confined to a discrete set of allowed trigger signatures and a discrete set of allowed algorithm layers. These eigenstates will be used to define the eigenstates of the event-selection-framework configurations discussed in the following section.

The concrete implementation of the model is based upon the following seven algorithm layers:

1. The LVL1 Event Topology Algorithm Layer based upon the Region-of-Interest (RoI) data record and upon the trigger system ROD data in the byte-stream form;

2. The Event Topology Algorithm Layer based upon a group of the ROD data summary blocks;

3. The Data Validation Algorithm Layer based upon the individual ROD data summary blocks;

4. The Electronic Noise and the Beam-Background Algorithm Layer based upon the individual ROD data blocks in the byte-stream form;

5. The Look-Up Table Algorithm Layer based upon data in the byte-stream form coming from a group of RODs;

6. The Detector-Monitoring Algorithm Layer based upon the raw data objects derived from the byte-streams of the group of RODs;

7. The Reconstructed Data Driven Algorithm Layer based upon the reconstruction input objects derived from the byte-streams of the group of the RODs.

The detailed specification of the model of the data selection tools and organization of event selection process is presented in a dedicated note [2].

Within the proposed event selection framework, each LVL1-triggered event will be confronted with a dedicated selection path composed of the algorithm layers. Such a path is dynamically configured on event-by-event basis. An optimal path reflects, simultaneously, the actual data-taking conditions and specific wishes of the physics group interested in analyzing events of a given type. The freedom in composing the path of an event within a multilayer selection structure in a physics-goal dependent way leads to physics oriented partitioning of the TDAQ system discussed below.

3.2.3. The eigenstates of the TDAQ-configurations

The TDAQ system is decomposed into identical slices. Such a decomposition is determined, at present [4], solely by the hardware organization of the TDAQ system. Each of the LVL2PUs aggregated in a slice runs the same standard event selection software-framework based upon the same run-configuration algorithms and processes any of the LVL1-triggered event. Similarly identical clone-like organization is foreseen for the EF PTs and the SFIs, where the event building tasks are performed.

In the model presented in this series of notes, the clone-like slices of the TDAQ system are dynamically mapped onto the **physics-goal optimized slices**. The concept of physics oriented TDAQ slices is new. A physics slice consists of a subset of the LVL2PUs, EF PTs, and SFIs. This association is virtual, task-driven, rather than hardware-driven and can be implemented almost effortlessly within the present hardware architecture. Each of the physics slices has its own identity determined by the type of the LVL1-accepted events which will be directed by the LVL2 supervisors to this slice. The type of event is unambiguously defined by the bit pattern of the RoI record. Mapping of the physics slice structure on to the physics group structure is highly nontrivial and can be done in several ways. A concrete example of mapping is proposed in a dedicated note [2].

The slices may be considered as a physics working group encapsulated playground, where their members will be allowed, within a well defined rules, to make real-data exercises and eventually converge to their physics-optimal detector-data handling schemes. Each of the physics slices is given the freedom to implement, if necessary, its own event-selection framework using the full set or a fraction of algorithm layers. Such a framework could be optimally adapted to both the concrete physics-goal and to the actual data-taking environment. It may include a particular run-time configuration of standard algorithms confined to one slice. Each of the physics slices is also given the freedom of choose the implementation place of the chosen subset of the algorithm layers between the LVL2PUs and the EF PTs. Last, but not least, each of the physics slices is given the freedom to choose the event building mode (*i.e.*, the event data which will be permanently stored).

The concept of physics slices is central to the proposed model of the TDAQ architecture. This concept implements a vision according to which the quest for the physics goal-oriented flexibility of the data-taking process will eventually result in the physics-specialized partitioning of the overall TDAQ capacity. The effect of such partitioning is that the coupling of the data-taking domain to the physics analysis domain will inevitably be enlarged and thus needs to be precisely defined (modeled).

The physics slice eigenstates of the allowed TDAQ-configurations are expressed in terms of:

- The list of physics slices — each of slices being unambiguously defined by the allowed LVL1 type of events which could be processed on the slice;
- The assignment method of the LVL1-accepted events to the physics slices;
- Processing capacity and event building capacity of each of the slices;
- Configuration of the event-selection framework on each of the slices;
- Run-time configuration of algorithms on each of the slices;
- The allowed event-building-modes implemented on the slice.

The full spectrum of TDAQ configurations, specified in terms of the above items, cannot be confined at present to a fixed set of eigenstates. The modeling of the TDAQ configuration variability, presented in a dedicated note [2] is restricted, at present, to modeling of the convergence process to the optimal asymptotic set of eigenstates. In the modeling presented in Ref. [2], the convergence process is assumed to be driven by both the dynamic growth of the overall event selection capacity and of the data collection capacity as well as by the evolution in the research scope.

3.3. The granularities

3.3.1. The detector granularity

The projection of the data scenario eigenstates onto the detector granularity consists of defining the minimal partition of the detector, where a given scenario is active within a given time interval. In the proposed model, the data content and the data compression methods are allowed to take any of the allowed eigenstates on channel-by-channel basis. For example, the Tile-cal (LAr) channels with very large energy depositions may contain the ADC samples. The zero suppression eigenstates are allowed to vary also on channel-by-channel basis. Since, within the present design of RODs, the possibility of running the local-topology-dependent zero suppression schemes is excluded, this option is introduced mainly keeping in mind a long-time evolution of the ROD system. At present, the transitions between the zero suppression eigenstates can be realized with the ROD-by-ROD granularity.

The addressing mode eigenstates and the ROD summary block eigenstates are confined to the on ROD-by-ROD granularity[4].

3.3.2. The TDAQ granularity

The minimal unit of the TDAQ granularity in the proposed model is the physics-slice. The LVL2 and EF trigger menu eigenstates, the eigenstates of implemented algorithms layers, the data selection framework eigenstates, the event building eigenstates, and the run configuration eigenstates of selected algorithms are allowed to vary on slice-by-slice basis.

3.4. The dynamics

3.4.1. Quasi-static implementation

In the quasi-static implementation of the model, the physics run is the basic time unit. The transitions between the eigenstates of the variability domains are allowed on the run-by-run basis. In the quasi-static implementation, the shift crew is given the responsibility to choose a particular set of data-taking eigenstates on the basis of the previous run experience and on the basis of anticipated detector performance in the actual data-taking environment. The chosen set of run-defined-eigenstates is written to the configuration database and drives subsequently the configuration dependent features of the data reconstruction process. A change in the data-taking environment results in stopping and starting the run with the new eigenstates.

The most simple version of the static model is equivalent to implementation of of the present minimal coupling scheme discussed in Ref. [2]. This version is based upon a fixed and uniform-over-the-whole-detector data scenario. A single algorithm layer, based upon the reconstructed objects, is implemented on the TDAQ LVL2PUs and EF PTs. The software framework of the data selection, the run time configuration of algorithms, and the event building mode is frozen during the physics runs and applied to all types of LVL1-accepted events.

The quasi-static implementation will not be discussed here. It is mentioned here to show that the presented model contains the currently implemented data-taking mode.

[4] It is implicitly assumed that the sub-block structure of the ROD data, which is driven by the assignment of channels to a given DSP, will respect a ROD-coherent scenario, even if the fixed format data summary information will be distributed within the DSP-based sub-block structure of the ROD data. This is discussed further in a dedicated note [2].

3.4.2. Dynamic implementation

The dynamic implementation of the model discussed below reflects a compromise between the degree of implementation simplicity and the degree of flexibility of the data-taking process.

It is based upon three time-scales: the event-by-event time-scale, the run-by-run time-scale, and the period-by-period time-scale. The modeling consists of defining the minimal time-scale at which the transitions between the eigenstates of the variability domains may occur and of specifying the allowed mechanisms activating these transitions.

In the dynamic implementation, the data scenarios are allowed to change on event-by-event basis. The ROD-granularity transitions are driven by the bit pattern of the LVL1 trigger word[5]. The channel-by-channel granularity transitions are restricted, given the present capacity of the ROD system, to those driven by the channel content. The eigenstates of the LVL1, LVL2, and the EF trigger signatures, the eigenstates of the implemented algorithm layers and the run-time configuration eigenstates implemented on each of the TDAQ slices are allowed to vary on run-by-run basis. The number of the TDAQ slices and the corresponding data-processing capacity of each of the slices, the method of assignment of the LVL1 accepted events to the slices, the configuration of the event selection framework and event building implemented on the slice are allowed to change on period-by-period basis. The run- and period-dependent settings of the TDAQ system, the trigger menus, and the implemented layer structure define the spectrum of allowed environments in which the events are dynamically selected.

In the scheme developed in [4], the selection process of each of the LVL1-accepted events is fully pre-encoded into the trigger menus specifying the sequences of algorithms to be run and conditions to be met to accept a particular event. This process is independent of the event features (secondary ROIs) and of the actual data-taking environment. For example, a LAr-coherent-noise event fulfilling and the genuine physics event fulfilling the same LVL1 trigger conditions will be treated with the same full sequence of algorithms even if the former could be recognized very quickly as the noise event.

In the dynamic implementation of the model presented here each LVL1-accepted event is directed to a predefined TDAQ slice and exposed to slice-dependent event-selection framework. Each LVL1-accepted event will be confronted there with a dedicated selection path composed out of activated algorithm layers and slice-activated HLT trigger menus. An optimal path

[5] The LVL1 trigger word is distributed by the TTC system to each of the RODs of the ATLAS detector. The implementation of such a system was proposed in Ref. [5] and is discussed in the subsequent note of this series [2].

reflects, simultaneously, the sensitivity of the rate of the LVL1-accepted events to the data-taking environment conditions, and specific wishes of the physics group interested in analyzing events of a given type. This functionality cannot be provided within the *menu-only* based system, even if specialized trigger veto signatures are implemented.

The assignment of LVL1 accepted events to a particular TDAQ slice is driven by the Region-of-Interest-Builder (RoIB) record transmitted to the LVL2 supervisor. The LVL2 supervisor balances the load of events within the fraction of its processors which are associated to one physics slice. The inter-slice balancing has to be made externally and needs to be dynamically established by a laminar, slow and experience driven slicing process.

The active algorithm layers implemented on the slice determine the latencies of decision steps in rejecting and accepting events. The activation of the T-algorithms on a particular slice is driven by the local, slice-specific dead time.

4. The data-taking model and gauge interactions

4.1. Gauge analogy

In the heart of the proposed model is the delegation of the adaptive capacities of the ATLAS sub-systems to specialized variability domains. Within these domains, correlated actions have to be taken by each of the sub-systems, both at the time of constructing the data-taking strategy, and later, in real-time processing of each of the LVL1-accepted events. The efficiency of these actions can be quantified in terms of the following four quality criteria:

- The stability of the data-taking process with respect to environmental changes (the detector operation efficiency);
- The stability of the analysis results of each of the physics working groups with respect to transitions between the eigenstates of the variability domain (the measurement precision and data selection efficiency);
- The ease of implementing of new research directions;
- The readability of the pattern of sub-system couplings.

Satisfying the latter quality criterion is highly non-trivial in the *multi-component* environment of a large experiment. The approach, which is advocated in the proposed model, follows the adaptation mechanisms of stable biological systems which could be modeled using the concepts of gauge models.

4.2. Gauge and matter fields

The variable data-selection, data-collection and data analysis environment is represented by the evolving strength of the three external "gauge" fields, each of them varying with its characteristic time-scale: period by period (*e.g.*, research goals), run-by-run (*e.g.*, LHC machine status) and event-by-event (*e.g.*, electronic noise) time-scale. The data collected by the experiment depend upon the actual configuration and strength of these fields.

The collision events are analogous to the "matter" fields. For a given data-selection, data-collection and data analysis environment their "elementary particle-representations" are specified by the corresponding set of eigenvalues of the variability domains, *i.e.* by the projection of the "matter fields" onto the eigenstates of the variability domains.

The physics results derived from the concrete particle representations of the matter fields (*i.e.* from the front-end electronic data registered in RODs for the selected and reconstructed bunch-crossings) are required to be invariant with respect to the transitions between the eigenstates of the variability domains (in analogy to freedom of the phase rotation of the matter fields in the gauge theory). This freedom is used, in the proposed model, to effectively absorb ("rotate out") those of external fields which represent a gauge-dependent (unphysical) perturbations of the data selection and data collection process upon which the physics results are required not to depend.

4.3. Particles and ghosts

The most optimal set of eigenstates of the variability domains used in construction of the "data-taking elementary particles" is the one which allows for absorbing, in their physics-results-invariant "rotations", all the unphysical components ("pure gauge configurations") of each of the three external fields, in particular the unphysical component of the "strongly interacting field", affecting the data-taking process at the event-by-event time scale and at the minimal detector and TDAQ partitions-scale. The "elementary particle" set, advocated in this note represents the first approximation and may very likely include an excessive rotational freedom giving rise to unnecessary, "allergic" reactions of the data-taking immunological system to "false alarms" . The inevitable "ghost-like" degrees of freedom of the corresponding gauge fields would become, however, extinct very quickly during the adolescence period of the data-taking process.

4.4. "CKM-like" rotation

The eigenstates of the variability domains reacting to the "strong", event-by-event-varying field are not, in the model presented here, the eigenstates of the two remaining weaker fields affecting the data-taking at run-by-run and period-by-period time-scales. These latter eigenstates are constructed as combinations of the strong interaction eigenstates. Such a rotation of eigenstates, assure decoupling of the "strong interaction field" from the remaining two fields. One of the consequences is that the symmetry governing the event-by-event gauge invariance of the ROD data becomes a hidden symmetry (in an analogy to the SU(3)-color symmetry of the Standard Model Lagrangian[6]).

4.5. Gauge interactions

In the gauge theory, interactions of the matter fields with gauge fields are generated by extending the global phase invariance to the local (space-time-point-dependent) phase invariance. In an analogous way the interaction between the experiment sub-components, represented by the eigenstates of the variability domains, are fully specified by extending the global rotational invariance of the eigenstates of the variability domains (full detector "space"-scale, run-by-run time scale) to the local invariance (partition "space"-scale and bunch-crossing time scale). Such a scheme provides, in its practical implementation, a very clear, effective, and precisely-defined method of introducing the couplings (interactions) between the experiment sub-components both at the time of constructing the data-taking framework and subsequently in the real-time data-taking environment. At the time of constructing the framework, these correlations need not to be imposed arbitrarily upon each of the sub-systems but could be confined to static fixing of the eigenstates and fixing of invariance rules of transitions between the eigenstates on slice-by slice basis. At the time of the data-taking, the implicitly build-in correlations will be automatically activated on event-by-event basis by the event-path or, in a concrete representation, by fixing the "event-gauge" in terms of the bit pattern of the LVL1 trigger word and of the bit pattern of the RoI record.

4.6. Gauge symmetry breaking

In the proposed model the "gauge symmetry" is a broken symmetry. The symmetry breaking pattern is driven mainly by the hardware capacity of the data selection and the data collection systems. The gauge symmetry is restored in the limit of infinite detector resources. For example, while events collected using the ROD transparent eigenstate and using the full event building eigenstate (the "zero mass particles") can be propagated quasi freely

[6] The concrete implementation of this scheme, described in detail in a dedicated note [2], is based on the *minimal data-quantum principle*, which assures an event-invariant presence of the dedicated ROD data structures for the online (LVL2 and EF) processing of events.

to any analysis, events collected using the reduced-data-content eigenstate in reduced fraction of sub-detector partitions (the "high mass particles") can be propagated freely only within a physics-slice-confined analysis methods.

4.7. Gauge-independent and gauge-dependent analyzes

Physicists exposed to purely offline analysis environment and analyzing their physics-group TDAQ and grid slice data could be unaware the data-taking environment and the proposed model altogether. In other words, the gauge-dependent-path of (her)his favorite events, from the LVL1-accept decision up to inclusion in the final physics plot will be fully encapsulated for (her)him. The encapsulation mechanism in exactly the same like the one for the QED-events generated in the technically most convenient gauge. Any physicists asking a valid physics question must not care which gauge is used by the event generator. At worst she(he) may be confronted with very ineffective event generation leading to very large analysis errors.

On the other hand, a curiosity-driven physicists will be provided with the full gauge-path information for each of the accepted event. This will enable her(him) to search for the most efficient gauge event-path, to study the gauge symmetry breaking phenomena, and to modify the gauge invariance rules implemented on his(her) physics group TDAQ and grid slice to minimize the measurement systematic uncertainty.

5. The first "three minutes" of an event

Fig. 4 illustrates the proposed model using in a practical language. The The decision of the LVL1 system to stop the pipelines results in transferring the bunch-clocked data to the RODs of each of the sub-detectors. The LVL1 trigger word distributed to each ROD by the TTC system steers the process-

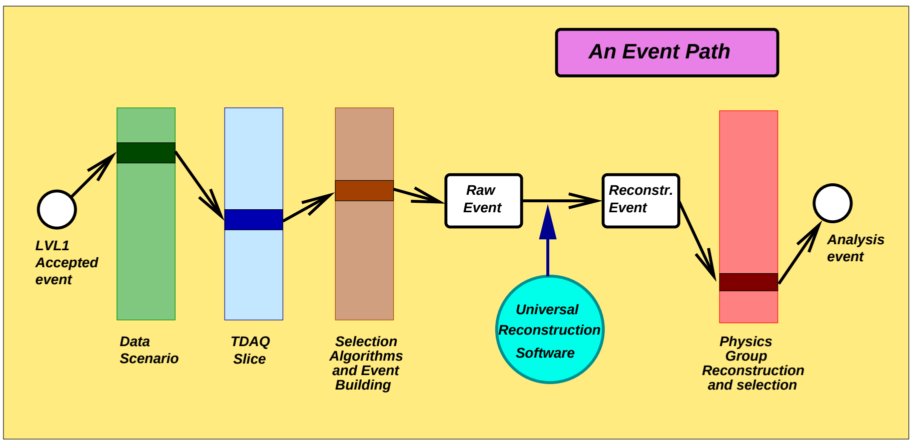

Fig. 4. An "gauge-path" of an event.

ing of the events by guiding the choice of the content and structure of the ROD data blocks (the data scenario eigenstate). The ROD bunch-crossing-tagged data are formated and sent to the corresponding ROBINs over s-links where they will wait for the action taken by the LVL2 trigger system.

The action of the LVL2 supervisor is steered by the received RoIB record. The supervisor delegates to a LVL2PU the task of processing the event. This delegation is based upon the RoIB record. The L2PU belonging to a given TDAQ slice receives only those of the events which are tagged by a predefined list of the RoIB bit patterns. The TDAQ slice processors can be recognized mainly in terms of the implemented event selection framework. The event is exposed, at the level of the TDAQ-slice processor, to the slice-dedicated trigger menu and the slice-specific data selection algorithms layers. The LVL2PU of all but monitoring slice use the data-scenario-invariant fraction of the ROD data. The event can be rejected following each layer of algorithms.

The decision, following which selection layer the event is built by the slice SFI or rejected, is driven by the slice-dependent trigger menus. The type of event building (full *versus* partial, dynamic *versus* static) is implicitly encoded in the RoIB record and, in specific cases, into the LVL2 trigger decision.

The built event is exposed subsequently to the EF slice-processor algorithm layers. Depending upon the slice-dependent implementation of algorithm layers (LVL2 and EF sharing), the EF processor tasks may or may not be guided by the LVL2 results. The accepted EF events are permanently recorded using the byte-stream form of the data.

The event which passes all the above selection stages is subsequently reconstructed with the Universal Reconstruction Software (URS). Its data structure is, irrespectively from which slice it is coming from, invariant — the only difference is confined to the data size.

The event size is determined by number of the detector partitions, which were present in the read-out system at the time of LVL1 trigger decision and which were subsequently chosen by SFI for the event building. The reconstruction-input events are depicted as ATLAS raw events.

The URS, contrary to the HLT reconstruction software, uses the best available data using automatic scenario-dependent decoding procedures. The URS is limited to the basic reconstruction functions, and stops at the level of reconstructed objects tracks and clusters. The reconstructed events are stored in a way which optimizes the retrieval speed of a subsample of events originating from a given TDAQ slice. These events are depicted as the ATLAS Reconstructed Events.

The physics group selection and the physics-group dedicated reconstruction of events, in terms of the most appropriate objects for a given physics task, uses the Physics Group Software (PGS). Technically, any group may use the data coming from any slice. The best quality data will be those coming from the physics group-dedicated slice configuration. The PGS records n-tuple (root analysis objects) based upon more refined selection of events and containing the final group-specific analysis objects.

6. Examples of adaptation mechanisms

6.1. Anticipated-discovery and generic hot-line events

Hot-line events are defined as potential discovery events which must be streamlined to a dedicated storage and to a dedicated analysis path. The LVL1 trigger signatures for these events may be confined to *the anticipated discovery scenarios* [6]. They may be also defined in a more *generic* way: for example, as events containing all possible LVL1 signatures, which are kinematically beyond the reach of the FNAL experiments. For these events, the most complete sub-detector information (ROD-transparent eigenstate) for all the available detector partitions must be recorded[7].

The *anticipated-discovery* (hot-line) events, based upon inclusive and double inclusive high-$E_{\rm T}$ signatures (small multiplicity of RoIs) have a residual chance to be noise-infected and/or machine-background-infected. Moreover, even if, in the initial phase of the detector operation, the capacity of the LVL2 and EF farms, and data collection system are reduced (staged), the selection process of these events must not suffer. These events should be allowed to occupy the large-decision-time tail of the event latency distribution.

The event selection eigenstate, implemented on the TDAQ slice where the LVL1-accepted, anticipated-discovery events are directed (*the A-hot-line-slice*) may thus be based exclusively upon the Reconstruction Data Driven Algorithm Layer and upon the classical trigger menu [4]. The chosen eigenstate of the event selection framework is the presently implemented event selection framework. This framework is characterized by a nested ROD data access within multiple loop over menu-sequence-table pairs, sequences, valid TEs and algorithms [8]. The chosen "A-hot-line-slice" run-time configuration of the algorithms is the one which is efficiency rather than purity driven. The event building eigenstate is the one covering all the sub-detector partitions, being in the read-out mode at the LVL1 decision instant of the run.

[7] Partially missing electronic information for the hot-line events hampered full understanding of the isolated muon events observed by the H1 collaboration [7]. (In this context, note the merits of the event-by event transitions in the data content, inherent to the proposed data-taking model, in avoiding the data-flow bandwidth constrains while handling the hot-line events).

A dominant fraction of generic hot-line events cannot be identified on the basis of the inclusive and double inclusive signatures. This fraction contains those events with multi-RoI signatures which will not satisfy any of the inclusive selection criteria (*e.g.*, an event with two $p_{\rm t} = 10$ GeV electron RoIs, one $p_{\rm t} = 8$ GeV muon RoI and three $p_{\rm t} = 20$ GeV jet RoIs), and exclusive events (*e.g.* the high transverse energy events with the energy dispersed over large number of jet RoIs). These events cannot be selected efficiently by the presently implemented event selection framework eigenstate because both the fraction of the genuine physics events having such signatures will be low and unstable (beam-background and electronic-noise dependent) and because the even accept/reject decision will be too long due to combinatorial overhead. An attempt to first reconstruct the RoIs in terms of particle hypothesis would waste in vain the available processing power of the farms.

The selection process of multi-RoI events must involve pre-processing of the data with the fast data-cleaning algorithms followed by RoI-by-RoI-based data-verification process. In the initial stage of the detector operation, these data-cleaning algorithms must be implemented on the LVL2 farm. The crucial point here is that the necessary change of the selection scheme cannot be reduced to introducing new signatures for large multiplicity RoI including various RoI-dependent veto elements, but the basic configuration of the selection loops must be reorganized for these events.

The remedy proposed by the proposed model is the following. The multi-RoI generic discovery events which do not satisfy the inclusive criteria are directed to the dedicated *G-hot-line slice*. In the LVL2 part of the slice, the event selection eigenstate is composed out of the three algorithm layers: the Data Validation Algorithm Layer, the Electronic and Beam Background Algorithm Layer, and the Reconstructed Data Driven Algorithms.

The event-selection framework eigenstate consists of a RoI-by-RoI verification process instead of a physics-hypothesis-driven process, as described in detail in [2]. During the noisy periods, only a small fraction of events reaches the time consuming Reconstructed Data Driven Algorithm layer.

6.2. Inclusive measurement of high cross section processes

In the following example, the measurement of the jet η and $E_{\rm T}$ distributions down to the lowest limit of the kinematical range is considered. A standard method boils down to mapping the $E_{\rm T}$ spectrum in terms of a set of pre-scaled triggers and collecting the corresponding events in its data-content-invariant form. Most of the data collected will never be used and the measurement will be artificially spanned over large time interval, thus diminishing its systematic precision due to stability of the detector calibration.

In the present model these events are handled in the TDAQ slice dedicated for large cross section inclusive measurements. The events occupying the low E_{T} part of the spectrum are vulnerable to the electronic and beam background noise. These events are first filtered by the Data Validation Layer and by the Electronic Noise and Beam Background Algorithm Layer. Only when they successfully pass each of these layers they are exposed to the physics menu driven Reconstruction Data Driven Algorithm layer. These algorithm layers are implemented on the LVL2 "part" of the TDAQ slice. The event building eigenstate dynamically chosen on the SFI "part" of the TDAQ slice for inclusive events is the one collecting ROD fragments reduced to the RoI associated RODs. These events need not to be filtered further by the corresponding EF slice and can be recorded at very high frequency.

The above example shows how the event-rate-for-event-length trade-off could work in practice in the proposed model.

What if someone wants to study the particle multiplicity associated with a jet of 20 GeV of E_{T}? (S)he would have to join the slice-team, and following the period of optimizing the efficiency of inclusive selection of jets, (s)he could ask for a transition in the event building eigenstate to get all the info he needs. If (s)he would eventually find out, that what (s)he really needs is not only the multiplicity of particles, but the multiplicity of mini-jest in the forward region, (s)he would need to direct events to the EF part of the slice and implement her(his) mini-jets selection methods there. Her(his) work would be local and her(his) bread-and-butter activity would not disturb more fashionable endeavors (*e.g.* super-symmetry searches). The main point here is that there is not much sense in storing a large sample of large cross section events with the full detector information, just in case someone would need it later. Collecting statistically sufficient sample would take hours, if such a need would arise. Moreover, collecting them in optimized beam period could maximize the precision for the well-defined physics measurement.

6.3. Exclusive events

As another example let us consider events with large total transverse energy. If the LVL1 total transverse energy signature classifies them to the rare case of hot-line events one can afford that their selection is delegated to the EF part of the hot-line TDAQ slice. At smaller E_{t} such a procedure brakes down. The threshold where it brakes down will depend upon the actual data-taking environment. In order to absorb environmental changes due to coherent noise and beam related background such events are directed to the TDAQ slice dedicated for exclusive events and exposed at first to the two fast-selection layers: the LVL1 Event Topology Algorithm Layer based upon the RoIB record and the data coming from the trigger system RODs, and subsequently to the the Event Topology Algorithm layer based upon a group of the ROD data summary blocks.

The algorithms in the first layer analyze the topology of secondary RoI, which were not used in the LVL1 trigger decision, and rejects, as much as it is possible, the coherent noise and the beam wall events. This algorithm layer is implemented on the LVL2 part of the "Exclusive slice". If the event is retained it is subsequently built by the slice-SFI. The algorithms of the second layer, implemented on the EF part of the slice access all the calorimeter data but unpack and analyze, at first, only the fixed length and format ROD summary blocks to verify the consistency of the event (*e.g.* by looking at the bit pattern of energy-threshold-crossing cells and/or looking at the timing pattern summaries) Only if the event passes successfully this stage of the selection process, the classical EF validation of the E_{rmt} signature in terms of reconstructed objects is performed.

6.4. Baked Alaska events

The following example illustrates how new analysis ideas could be incorporated and how natural and clash-less the diversification of the physics goals within the proposed data taking model could be.

Let's imagine that one of the forgotten but very attractive Bjorken's ideas becomes suddenly attractive to a group of physicists who would decide to go "fishing" as intermezzo of exhaustive "gold (higgs)-mining". For example they may embark on searches of the "baked Alaska" events [9], originating from a disoriented chiral condensate. Such events are expected to be produced in soft collisions and cannot be selected on the basis of the high $E_{\rm T}$ signatures. Confronted with the standard data-taking procedure "the group of fishermen's" will, most likely, try to analyze a large sample of random bunch crossing events with little hope of finding anything interesting. Their attempt to have their dedicated-event-selection scheme implemented concurrently with other schemes will most likely fail, because of the large latency dispersion to accept/retain their events and the corresponding necessity to change the global rules of aborting looping processors — indispensable for other "golden", according to fashion dictators, type of events.

In the proposed model, the transition to an eigenstate of the TDAQ configuration consisting of adding a residual-size "fishing-slice" would do the work. This slice could be optimized for large latency selection of interesting minimum bias events. The creation of such a slice could allow them to optimize their selection methods in "non-invasive" way and consequently drastically increase their chances of seeing exotic chiral states — almost in the unnoticeable way for the mainstream activities.

6.5. Detector monitoring events

In the proposed model, the detector monitoring events, tagged by their monitoring LVL1 trigger type, are directed to a specialized TDAQ slice on which a dedicated event selection and event analysis framework is implemented. This slice has increased network capacity allowing for congestionless access to SFI-built events from external sites. Events tagged as monitoring ones are recorded using the ROD-transparent data eigenstate. They will be recorded concurrently with the physics events. Since their rate will be small full n-samples history of ADC counts is sent from RODs to ROBins.

The monitoring events are classified in the model either as bunch crossing clocked events or as random events. The former are numbered according to the bunch numbering scheme and contain the subsamples of, minimum bias events (numbered according to position of the colliding bunches within the bunch-train), pilot-bunch events, and empty bunch events.

The monitoring events are subdivided into the three groups which will be processed differently. The association is random but respects the optimal relative sizes of each group.

For the monitoring events belonging to the first group, the LVL2 part of the slice is transparent. A sub-fraction of these events is transfered directly to the slice SFIs. These events are subsequently analyzed locally and/or externally by the sub-detector experts. The remaining events of the first group may be exposed to all or to a subset of the presently employed data selection algorithms. In this case the selection decision is recorded but it is not active. These events help in debugging and monitoring the performance of the implemented selection algorithms

The second group of monitoring events is exposed to the Detector Monitoring Algorithm Layer based upon the raw data objects. These raw data objects are stamped by the on-line cell identifiers facilitating their preselection for dedicated monitoring tasks of the sub-detector electronics (*e.g.* using enriched sample of particular noise pattern events).

The third group of monitoring events is exposed to a special set of monitoring algorithms included in the Reconstructed Data Driven Algorithm Layer and driven by dedicated trigger menu for monitoring events. Events selected by these algorithms contain particular physics-features, reconstructed using a subset of sub-detectors, which is used to monitor the performance of the remaining sub-detectors. For example, preselected random events with a muon track reconstructed both in the central tracker and in the muon chamber provide an unbiased, optimal sample for dedicated studies of the response of ATLAS calorimeters to vertex pointing muons.

7. Conclusions

This note introduces a novel paradigm for the data selection, acquisition and analysis for a multipurpose experiment at the LHC collider. While the presently implemented data selection and data analysis model tries to assure the most efficient scrutinizing of the precisely predefined discovery scenarios for the LHC collider, the model presented here tries to optimize the data selection and the data analysis framework for an open physics goal, generic research program giving a substantial freedom and democracy to the physics groups to impose their exclusive data selection, acquisition and analysis methods in a clash-less manner. If the diversification of the LHC research program will turn out to be necessary and if it will not be confined to expanding *(i)* the trigger menus and *(ii)* the methods of the off-line analysis of the standard data structures, then the proposed model could be a solution for the advanced phase of the LHC experimental program.

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