Alignment data stream for the ATLAS Inner Detector

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Abstract. The ATLAS experiment uses a complex trigger strategy to be able to achieve the necessary Event Filter rate output, making possible to optimize the storage and processing needs of these data. These needs are described in the ATLAS Computing Model, which embraces Grid concepts. The output coming from the Event Filter will consist of three main streams: a primary stream, the express stream and the calibration stream. The calibration stream will be transferred to the Tier-0 facilities which will allow the prompt reconstruction of this stream with an admissible latency of 8 hours, producing calibration constants of sufficient quality to permit a first-pass processing. An independent calibration stream is developed and tested, which selects tracks at the level-2 trigger (LVL2) after the reconstruction. The stream is composed of raw data, in byte-stream format, and contains only information of the relevant parts of the detector, in particular the hit information of the selected tracks. This leads to a significantly improved bandwidth usage and storage capability. The stream will be used to derive and update the calibration and alignment constants if necessary every 24h. Processing is done using specialized algorithms running in Athena framework in dedicated Tier-0 resources, and the alignment constants will be stored and distributed using the COOL conditions database infrastructure. The work is addressing in particular the alignment requirements, the needs for track and hit selection, timing and bandwidth issues.

1. The Atlas Computing Model

1.1. Trigger and data flow requirements

The Large Hadron Collider (LHC) proton bunches will cross at a frequency of 40 MHz. For a luminosity of $10^{34}\text{cm}^{-2}\text{s}^{-1}$ on average about 23 inelastic proton-proton collisions will be produced at each bunch crossing. The level-1 trigger (LVL1) is responsible for the first level of event selection, reducing the initial event rate to less than 75 kHz. The High Level Trigger (HLT) must reduce the event rate further down to $O(200)\text{Hz}$. Each selected event will have a total size of $\sim 1.5\text{MB}$.

The system is designed for a maximum LVL1 rate of 100 kHz in order to ensure that in case ATLAS decides to run at this LVL1 rate, the HLT and Data AcQuisition (DAQ) system will be able to handle it. Fig. 1 shows the outline of the ATLAS trigger strategy.
1.2. Grid concept and latency

Grid computing implies a high degree of decentralization. A Tier-0 facility, at CERN, will be responsible for archivation and distribution of primary RAW data received from the Event Filter (EF), and will also provide the prompt reconstruction of the calibration and express streams, first-pass processing of the primary event stream and final distribution of the derived datasets (Event Summary Data (ESD), primary Analysis Object Data (AOD) and Tag data (TAG) sets) to the Tier-1 facilities.

The Tier-0 streaming baseline model includes four types of streams coming from the EF:

- the primary physics stream containing all physics events;
- an express stream containing a subset of events (~5% of the full data);
- the calibration stream;
- the diagnostic stream with pathological events.

The calibration stream will be used to produce calibrations of sufficient quality to allow a useful first-pass processing of the main stream with minimum latency. At 1.5 MB per event each Sub-Farm Output (SFO), a DataFlow component, which receives accepted events from the EF and forwards them for permanent offline storage, at 4Hz fills a 2 GB file with ~1250 events every 5 minutes. This defines the minimum latency to start the processing of any stream. The latency of the primary stream is defined by the necessary time to have calibration, alignment, and other conditions data available on the Tier-0 processors.

The current goal is to be able to reconstruct the express and calibration streams within 8 hours and the primary data stream reconstruction (“prompt” reconstruction) beginning 24 hours after data taking.

2. Detector readout parameters distribution

The ATLAS Inner Detector (ID), which tracks charged particles from the interaction point (IP) to the electromagnetic calorimeters allowing particle identification and momentum measurement, consists of three sub-detectors: Pixels, Semiconductor Tracker (SCT), and Transition Radiation Tracker (TRT). To achieve highest granularity around the IP, the Pixel (1744 modules) detectors
are constructed as three silicon pixel detector layers (two endcaps, an innermost barrel ‘B-layer’ 50.5 mm from the beam line, and two outer barrel layers) very close to the beam line. The SCT sub-detector (4088 modules) is built from silicon micro strip detectors. It is sub-divided into two endcaps and a barrel part which are arranged in nine discs and four barrels layers, respectively. The TRT sub-detector is a tracking detector built out of straw tubes (992 modules), i.e. gas filled drift tubes, and a radiator. Its role is to identify highly-relativistic particles through transition radiation. The data read out from the various detector modules is collected by ReadOut Drivers (RODs).

The number of modules connected to a ROD varies between the different sub-detectors [1]:

- **Pixel**: The B-Layer will have 1 ROD for 6/7 modules, e.g. only a half stave. At Layer1 12 modules are connected to a ROD and for Disk 13. At Layer2 26 modules are connected to a ROD.
  - Each ROD connects to one ReadOut Buffer (ROB).
  - In total we have 132 RODs: 24 Disk RODs, 44 B-Layer RODs, 38 L1-Layer RODs, 26 L2-Layer RODs.
- **SCT**: Up to 48 SCT modules are connected to each ROD (in the barrel this is exact, in the endcaps some RODs are more sparsely populated due to the more complex geometry). A set of up to 6 modules constitute a Minimum Unit of Readout (MUR).
  - There is a 1-to-1 mapping of ROD to ROB.
  - In total we have 90 RODs: 44 Barrel and 46 Endcap RODs.
- **TRT**: The barrel is divided into 32 stacks and the wire is divided in two at the centre giving two readout channels per straw. Each stack-side (denoted A or C) contains 1642 straws and is read out by 1 ROD. Each endcap is also divided into 32 parts: there are 3840 straws, which take up two full RODs (Table 1).

| Sector | Endcap A | Barrel A | Barrel C | Endcap C |
|--------|---------|---------|---------|---------|
| RODs   | 2       | 1       | 1       | 2       |
| Straws | 2×1920  | 1642    | 1642    | 2×1920  |

Table 1. Number of TRT RODs per stack.

- In total we have 192 RODs: 64 in the barrel and 128 in the Endcap.

3. Inner Detector calibration stream

The main purpose of the ID calibration stream is to collect enough tracks of the appropriate type to allow the calculation and update of a set of calibration and alignment constants, after every fill, processing the stream to accumulate residuals and other histogram quantities before prompt reconstruction. The constants are then used in reconstructing on an independent part of the calibration stream within 12 hours.

To fulfill the ATLAS physics program the silicon modules (Pixels and SCT) need to be aligned to an accuracy of $O(10)$ $\mu$m and the TRT to $O(30)$ $\mu$m. The intrinsic modules resolutions are 10 $\mu$m ($r\phi$) and 115 $\mu$m ($r_z$) for Pixels, 17 $\mu$m ($r\phi$) and 580 $\mu$m ($r_z$) for SCT and TRT 130 $\mu$m ($r\phi$). The main challenge is to align $\sim 40000$ degrees of freedom, knowing from the survey that the module misalignment are larger ($O(100)$ $\mu$m at module level and $O(1)$ mm for larger structures) than the intrinsic resolution.

The number of tracks required to do an alignment is discussed in Ref. [2]. The requirements can be summarised as $O(300-1000)$ hits per Pixel and SCT module, corresponding roughly to $10^6$ tracks. For a 6-hour fill, this means a rate of 50 Hz of useful tracks. These should consist
of approximately equal shares of normal tracks from the IP ($p_T > 5$GeV), hits from overlaps (passing through 2 modules in the same pixel or SCT layer), and tracks from secondary decay vertices (where it is assumed that two tracks from the same vertex are identified, allowing the use of a vertex constraint and possibly also a mass constraint). Tracks with ‘kinks’ are bad — they are not described by the normal track model and can bias the alignment. Hence pions/kaons decaying in flight to muons in the ID, and electrons, should be avoided. The requirements for the TRT alignment are specified as 100 tracks per straw [3]. The final requirements for the alignment can only be clearly stated after first data taking, when the possible movements of the detector are understood.

The ID calibration stream output rate should not exceed a few MB/second (total for ATLAS calibration streams should not exceed $\sim 13\%$ of the event rate [4]). An interesting possibility is identifying and reading out only the ROBs that contain hits on tracks of interest [1].

In order to satisfy all the requirements we investigate a model where we write custom byte stream files with raw data of the tracks suitable for alignment. This will reduce the event size making possible to have a higher LVL2 accept rate, keeping the total event builder bandwidth efficiently used.

3.1. Partial Event Building at LVL2

ATLAS decided to define the boundary between the detector readout and the data acquisition to be at the input of the ROBs. The LVL1 trigger identifies regions in the detector, so-called Regions of Interest (RoIs), where relevant signals are flagged as physics events. As described in Ref. [5], the RoI Builder (RoIB) combines the RoI information from the various parts of the LVL1 trigger and feeds it into the LVL2 Supervisor (L2SV). The L2SV assigns these events to an LVL2 Processing Unit (L2PU) which decides if the event quality is good for calibration (these events can be accepted or rejected for physics). This means that requested data fragments from selected ROBs are served to the LVL2 trigger element of the HLT system. These RoIs are then used to seed the LVL2 algorithms. This enables the algorithms to select precisely the region of the detector in which the interesting features reside and therefore the ROBs from which to request the data for analysis.

If the event is accepted as physics event, the event data fragments for LVL2-accepted events are built from the ROBs, across a switched Ethernet network, into a complete event by one of the $\sim 100$ Sub-Farm Interfaces (SFIs). The SFIs then serve the complete events to the second element of the HLT system, the Event Filter (EF). The EF processing nodes receives fully built events from the SFI, and so the complete set of the data is available locally for analysis. Events not selected by the EF are deleted, and those accepted are passed to the SFO for transfer to mass storage.

Events for subdetector calibration purposes are also built in SFI (Partial Event Building (PEB)) but are processed by a specialized Processing Task (PT) dedicated to calibration events and based on a list of selected ROB or subdetector identifiers. The list can be filled either in a static or a dynamic manner, based on the RoI information and is then passed to the SFI, which pulls the requested data fragments from the specified ROBs and assembles the calibration event. The algorithm that populates a list of ROB identifiers or subdetector identifiers is implemented in the Athena package (TrigDetCalib). This algorithm allows to choose the size of the RoI used for the partial event building. At the SFO the stream selection depends on the decision of EF calibration algorithms. Writing after LVL2 will keep the EF bandwidth the same for physics events.

It should be noted that all the data for a given event are stored in the ROBs during the LVL2 processing and, for selected events, until the event building process is completed. The full event remains in the Event Filter until the SFO has confirmed the reception of the event to guarantee recoverability.
4. Testing on Cosmic data and conclusions

For the ID alignment, events with isolated tracks are needed and the associated RoIs are used to fill the list of required ROBs. The events are selected by algorithms of the alignment trigger chains, trk9i_calib and trk16i_calib, which start respectively with HA6 and HA9i LVL1 triggers (Hadronic signatures with energy thresholds at 6 GeV and 9 GeV). At LVL2 the chains select single isolated tracks inside the $\eta - \phi$ region defined by the LVL1 hadronic signatures. The associated list of ROBs from the ID is passed from LVL2 to the event builder. The desired output rate at LVL2 is of the order of 50 Hz. For this LVL2 output rate and using a test luminosity of $10^{31} \text{cm}^{-2}\text{s}^{-1}$, the prescales for the LVL2 objects were optimized at 40 for trk9i_calib (one event out of 40 events, fulfilling the chain, leads to an accept of the event), and 1 for trk16i_calib. This algorithm is the same used for physics and therefore no extra execution time is used.

Some ID calibration stream files were produced from cosmic runs to allow us to test the algorithms. ‘Beam’ algorithms can not be used for testing during cosmic data taking since they trigger on tracks coming from the IP, so we need to use chains developed for cosmic data and run PEB on those (CosmicsAllTeSiTrack and CosmicsAllTeIDScan). The PEB code has been modified to loop over the tracks and get $\eta - \phi$ range from the tracks rather than RoIs. The final cosmic menu containing these new chains was run (using Athena, the ATLAS framework and the TrigDetCalib package) on cosmic data generating raw data in ByteStream (BS) format only with information from the ID and for the $\eta - \phi$ range that was defined in the PEB algorithm. Finally we applied PEB to the previous in the region around the tracks.

The InDetAlignExample package was used to reconstruct, process and align the events having as input the calibration stream.

The results are summarised in Tables 2 and 3.

| Sample                      | Events | # Tracks | # Align Tracks | CPU time per job (min) |
|-----------------------------|--------|----------|----------------|------------------------|
| Full raw data (BS)         | 130945 | 30887    | 29734          | ~ 30                   |
| 2 chains w/o PEB           | 59546  | 26244    | 23370          | ~ 17                   |
| 2 chains w/ PEB            | 59126  | 21515    | 20765          | ~ 12                   |

Table 2. Results from run number 90943 (175 files), which contains Pixel, SCT and TRT hits. The rows represent the results obtained with the different algorithms. The columns show the number of reconstructed events, tracks, tracks fulfilling the alignment requirements and the time spent to reconstruct all files.

| Sample                      | Track eff. wrt BS | Align Trk eff. wrt BS | CPU time per job wrt BS |
|-----------------------------|-------------------|-----------------------|-------------------------|
| 2 chains w/o PEB           | 85 %              | 85 %                  | 44 % faster             |
| 2 chains w/ PEB            | 70 %              | 70 %                  | 60 % faster             |

Table 3. The efficiency for the chains with and without PEB. The different columns represent the efficiency with respect to using the full event for reconstruction.

The generated raw data in the PEB case was ~ 10 times smaller compared to the raw data, 2147 MB and 277 MB, respectively, and processing it through the alignment full chain was 60% faster. Fig. 2 shows a comparison between the full raw data in BS format and the calibration stream (with and without PEB). On the left, the $\chi^2$/ndof distribution of the reconstructed tracks is shown and on the right, it is the average $\chi^2$/ndof as a function of eta. One can see that the left plot peaks around 2 although the distribution is very broad (distribution mean ~ 6) and the right plot peaks around 6 for every eta. This is due to the fact that the detector was misaligned while performing these plots. As the aim is to compare the equivalence between the
BS and the calibration stream, the actual $\chi^2$ values are not very relevant, the important result is that they are in good agreement.

For data taking with collisions the increase in speed and size is expected to be even larger since the full event will consists of a lot of tracks not fulfilling the track selection requirements.

![Reconstructed track quality comparison](image)

Figure 2. Reconstructed track quality ($\chi^2/ndof$) comparison between the generated raw data (BS) and the raw data generated by the trigger algorithms without and with PEB

To accomplish all ID alignment requirements the future work will address the implementation of a trigger enriching the tracks passing the overlap region of the modules in $\phi$ and introduce a 2Trk9_calib item (events with 2 isolated tracks). Finally PEB will be exercised with collision data.

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