Prompt data reconstruction at the ATLAS experiment

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Prompt data reconstruction at the ATLAS experiment

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Abstract. The ATLAS experiment at the LHC collider recorded more than 5 fb^{-1} data of *pp* collisions at a centre-of-mass energy of 7 TeV during 2011. The recorded data are promptly reconstructed in two steps at a large computing farm at CERN to provide fast access to high quality data for physics analysis. In the first step, a subset of the data, corresponding to the express stream and having 10Hz of events, is processed in parallel with data taking. Data quality, detector calibration constants, and the beam spot position are determined using the reconstructed data within 48 hours. In the second step all recorded data are processed with the updated parameters. The LHC significantly increased the instantaneous luminosity and the number of interactions per bunch crossing in 2011; the data recording rate by ATLAS exceeds 400 Hz. To cope with these challenges the performance and reliability of the ATLAS reconstruction software have been improved. In this paper we describe how the prompt data reconstruction system quickly and stably provides high quality data to analysers.

1. Introduction

During 2011 the Large Hadron Collider (LHC) delivered 5.61 fb^{-1} of *pp* data to ATLAS[1] at a centre-of-mass energy of 7 TeV (figure 1). Of this data 5.25 fb^{-1} was recorded by ATLAS, corresponding to an overall *pp* data taking efficiency of 93.5% (figure 2). In addition, as the LHC delivered luminosity increased throughout the year the average number of interactions per bunch crossing, $\langle\mu\rangle$, shown in figure 3, also increased, reaching 15 at the end of 2011. As well as *pp* collision data, 166 ub^{-1} of heavy ion data was delivered, of which 158 ub^{-1} was recorded (figure 4).

ATLAS triggers[2, 3] pass around 400 Hz of events to the offline systems. The goal of the prompt reconstruction system is to process this data as quickly and accurately as possible, with the goal of delivering it, in just a few days, for physics analysis. In this paper we outline how this is achieved, looking at which data streams are recorded and in what formats (section 2), the calibration loop (section 3), the infrastructure and setup of the ATLAS Tier-0[4] computing farm (section 4) and, finally, improvements in the software and computing infrastructure to ensure smooth running and good performance in 2012 (section 5).

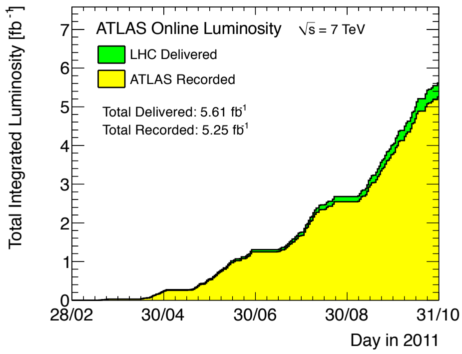


Figure 1: Cumulative luminosity per day delivered to (green), and recorded by ATLAS (yellow) during stable beams and for *pp* collisions at 7 TeV center-of-mass energy in 2011.

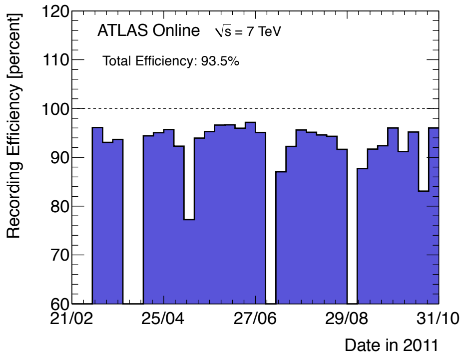


Figure 2: Data taking efficiency by ATLAS throughout 2011.

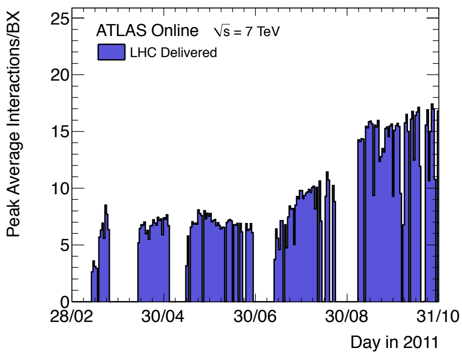


Figure 3: Average $\langle\mu\rangle$ per day seen by ATLAS during LHC data taking in 2011.

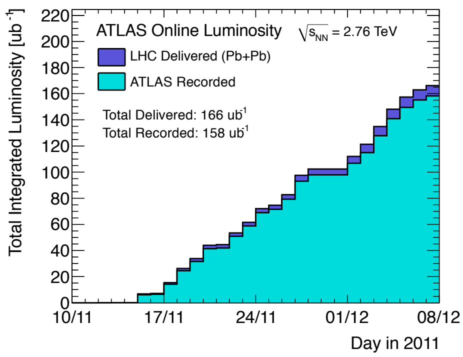


Figure 4: Heavy ion luminosity delivered by LHC (dark blue) and recorded by ATLAS (light blue) during 2011.

2. ATLAS data taking

2.1. Trigger and rates

The collision events observed in the detector, at up to 20 MHz, are filtered by the trigger/data acquisition systems down to a rate of about 400 Hz, then written to offline storage at the ATLAS

Table 1: Data types used by ATLAS

Data Type	Acronym	Size/event (kB)	Notes
Byte Stream	RAW	640	Compressed at Tier-0
Event Summary Data	ESD	1100	
Analysis Object Data	AOD	161	
Derived Physics Data	DPD	$\simeq$100	Many variants, 100kB size is typical
Histogram	HIST	–	Used for data quality
Tag	TAG	10	Used for event selection

Tier-0 (section 4). The recorded physics data are divided into four streams depending on which triggers accepted the events: Egamma, Muons, JetTauEtmiss and MinBias. ATLAS triggers are *inclusive*, which means that the same event can appear in more than one stream, although in practice overlap is small. In addition to these physics streams, an express stream of about 10 Hz, mainly consisting of high p_{T} lepton and jet events is written. Additional calibration streams are written for individual sub-detectors.

ATLAS organises the data it records into *runs*, which usually correspond to an LHC fill. These runs are sub-divided into *luminosity blocks*, over which detector conditions are assumed to remain constant. In 2010 luminosity blocks were 2 minutes long, but this was reduced in 2011 to 1 minute luminosity blocks.

2.2. Data formats

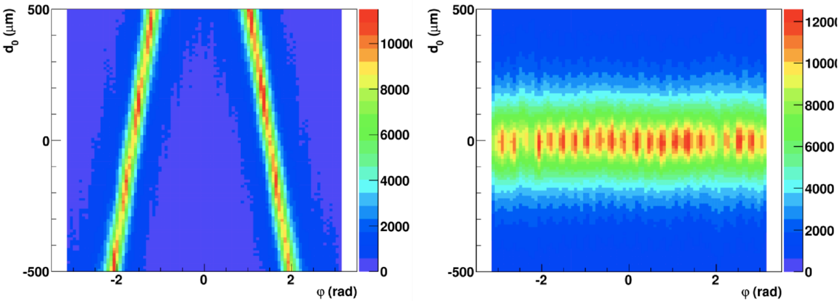
The events from the detector are written in a RAW format, corresponding to the byte stream data written by the sub-detectors. This is about 1.2MB/event. Once offline, RAW files are merged and compressed, which reduces the size of the files to about 0.64MB/event.

From reconstructing the RAW event a structured Event Summary Data (ESD) format is produced. This contains all the reconstruction results, such as tracks, jets, muons, and electrons. It also contains all of the information needed to reconstruct an event from scratch, including detector hits and calorimeter cells. The ESD is about 1.1 MB per event. A subset of the ESD event is stored in the Analysis Object Data (AOD) format, which includes only the reconstructed objects used in most analyses. It uses 161 kB per event. There are two types of ROOT ntuples in common usage: Derived Physics Data (DPD) is used by many analysts, while TAG ntuples contain just enough information to select events for later analysis, e.g., the number of high p_{T} leptons. There are many variants of DPD, each of which is produced to support a particular physics or performance analysis group. The HIST format is a collection of ROOT histograms for data quality monitoring. These data formats are summarised in table 1.

3. Calibration loop

As data streams off the detector the express stream is immediately reconstructed, with the help of available online calibration. During this process data quality histograms are filled, allowing shifters to monitor data quality throughout the run and alert experts if any problems are spotted[5]. ATLAS determines data quality and calibration per-luminosity block, which will then be used as an input to the bulk reconstruction process.

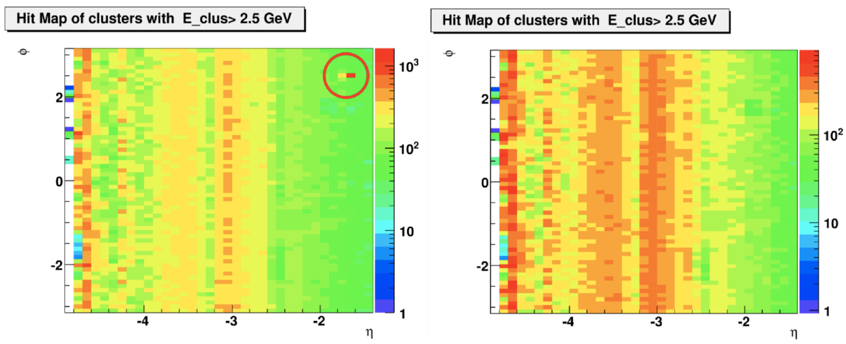
An example of calibration is seen in figure 5, where before calibration beam spot misalignment results in a distance of closest approach (d_0) between tracks and the beam spot that varies sinusoidally with φ. After alignment the vertexes show no φ variation.



(a) before (b) after

Figure 5: Distance of closest approach of tracks to the beam spot, d_0, vs. azimuthal angle, ϕ, before and after beam spot determination from reconstruction of the express stream.

As well as calibration, data quality is updated from the express stream reconstruction. e.g., in figure 6 noisy calorimeter channels (a) are suppressed before physics reconstruction (b).



(a) express (b) physics

Figure 6: Cluster hit maps for the express and physics stream reconstuction showing the effect of supressing noisy calorimeter channels that have been found from express stream data quality monitoring.

ATLAS determines data quality and calibration per luminosity block. At the end of the run, a calibration period (36 hours in 2011, 48 hours in 2012) passes during which detector and accelerator conditions are updated (see figure 7). The updated conditions and data quality data are uploaded to a database, ready to be used for the physics stream 'bulk' reconstruction. If required then physics reconstruction can be delayed, e.g., if there is a delay in the noisy channel determination. Physics reconstruction normally takes between 1 and 2 days, after which the data is distributed on the grid using the ATLAS Distributed Data Management system[6, 7]. This allows data to be available for physics analysis between 3 and 5 days after an LHC run.

4. ATLAS Tier-0

The ATLAS Tier-0 computing farm at CERN is responsible for running both express stream and physics stream reconstruction.

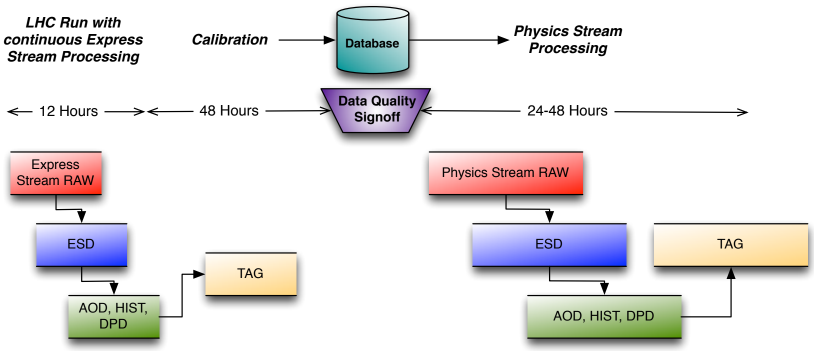


Figure 7: Scheme of the calibration loop done to determine calibration constants and to check data quality.

The allocated resources have grown to sustain the increasing demands in reconstruction of LHC data. In 2010, 3000 cores were used, in 2011, 4000 cores were used for *pp* collisions and up to 5000 cores for the heavy ion run (heavy ion events require more resources to reconstruct because of very high track multiplicity). In 2012, 6000 cores will be available.

The Tier-0 has a sophisticated web based monitoring system[6] that allows shifters to spot and isolate any problems in express or physics reconstruction rapidly and then take appropriate actions. e.g., the conTZole Monitor (figure 8) shows the data flow in the Tier-0 for both express and physics reconstruction.

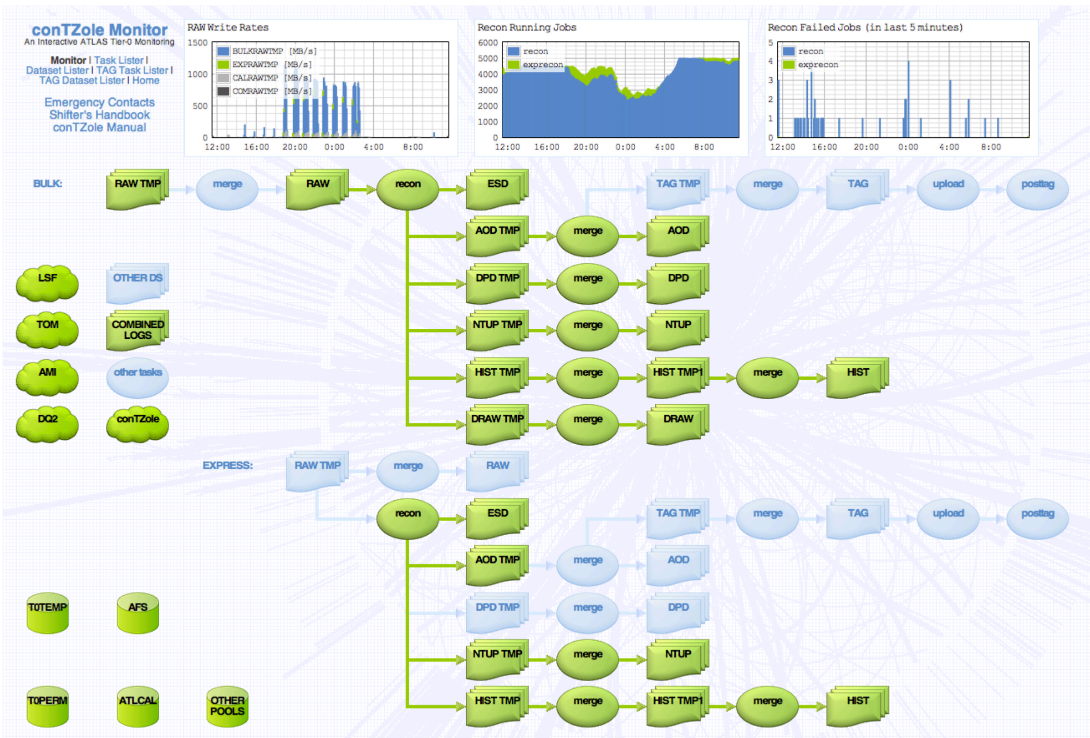
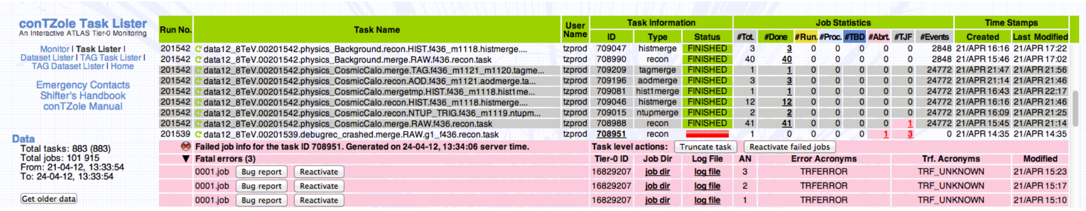


Figure 8: The ATLAS Tier-0 conTZole monitor front page.

If there are red areas on the monitor, the task lister (figure 9) allows the logs for problematic jobs to be examined in detail so that bug reports can be sent to the appropriate support unit (CERN infrastructure, ATLAS Tier-0 operations, ATLAS offline software team). Infrastructure problems can usually be resolved relatively quickly and the Tier-0 software setup allows for patches to the offline software to be quickly deployed to address any bugs. This means that very little physics data will miss the bulk reconstruction step: around 0.02% in 2011.



Run No.	Task Name	User Name	ID	Type	Status	#Tot.	#Done	#Run.	#Proc.	#TBD	#Abrt.	#TJF	#Events	Created	Last Modified
201542	data12_8TeV.00201542.physics_Background.recon.HIST.f436_m1118.histmerge....	tzprod	709047	histmerge	FINISHED	3	3	0	0	0	0	0	2848	21/APR 16:16	21/APR 17:22
201542	data12_8TeV.00201542.physics_Background.merge.RAW.f436.recon.task	tzprod	708990	recon	FINISHED	40	40	0	0	0	0	0	2848	21/APR 15:46	21/APR 17:02
201542	data12_8TeV.00201542.physics_CosmicCalo.merge.TAG.f436_m1121_m1120.tagme...	tzprod	709209	tagmerge	FINISHED	1	1	0	0	0	0	0	24772	21/APR 21:47	21/APR 21:56
201542	data12_8TeV.00201542.physics_CosmicCalo.recon.AOD.f436_m1121.aodmerge.ta...	tzprod	709196	aodmerge	FINISHED	3	3	0	0	0	0	0	24772	21/APR 21:14	21/APR 21:46
201542	data12_8TeV.00201542.physics_CosmicCalo.mergetmp.HIST.f436_m1118.hist1me...	tzprod	709081	hist1merge	FINISHED	1	1	0	0	0	0	0	24772	21/APR 16:43	21/APR 22:17
201542	data12_8TeV.00201542.physics_CosmicCalo.recon.HIST.f436_m1118.histmerge....	tzprod	709046	histmerge	FINISHED	12	12	0	0	0	0	0	24772	21/APR 16:16	21/APR 21:46
201542	data12_8TeV.00201542.physics_CosmicCalo.recon.NTUP_TRIG.f436_m1119.ntupm...	tzprod	709015	ntupmerge	FINISHED	2	2	0	0	0	0	0	24772	21/APR 16:09	21/APR 21:25
201542	data12_8TeV.00201542.physics_CosmicCalo.merge.RAW.f436.recon.task	tzprod	708988	recon	FINISHED	41	41	0	0	0	0	1	24772	21/APR 15:45	21/APR 21:14
201539	data12_8TeV.00201539.debugrec_crashed.merge.RAW.g1_f436.recon.task	tzprod	708951	recon		1	0	0	0	0	1	3	0	21/APR 14:35	21/APR 14:35

Failed job info for the task ID 708951. Generated on 24-04-12, 13:34:06 server time. Task level actions: Truncate task Reactivate failed jobs

Fatal errors (3)			Tier-0 ID	Job Dir	Log File	AN	Error Acronyms	Trf. Acronyms	Modified
0001.job	Bug report	Reactivate	16829207	job dir	log file	3	TRFERROR	TRF_UNKNOWN	21/APR 15:23
0001.job	Bug report	Reactivate	16829207	job dir	log file	2	TRFERROR	TRF_UNKNOWN	21/APR 15:17
0001.job	Bug report	Reactivate	16829207	job dir	log file	1	TRFERROR	TRF_UNKNOWN	21/APR 15:10

Figure 9: The ATLAS Tier-0 task lister, showing links to logfiles for a group of failed jobs.

5. Expected improvements in 2012

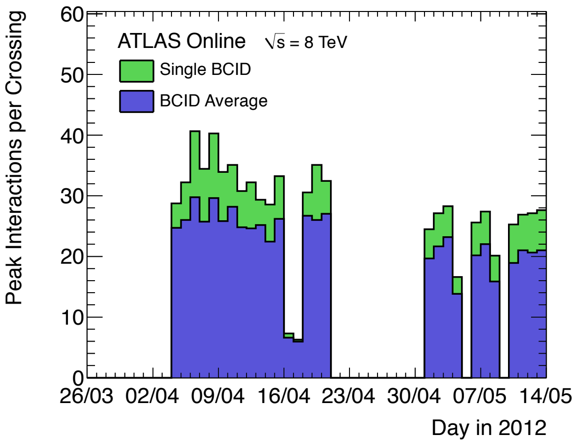


Figure 10: Peak and average interactions, $\langle\mu\rangle$, per bunch crossing identifier (BCID) in ATLAS per day in 2012. The maximum number of interactions seen in any single bunch is shown in green and the average of the maxima for all colliding bunches in a day is shown in blue.

In 2012 LHC has already delivered as increase in the number of interactions per bunch crossing, μ, as seen in figure 3 (c.f 2011, shown in figure 10). This increased pileup makes higher demands upon the reconstruction software, with the number of track candidates increasing faster than linearly with μ. Great efforts have been made to ensure that the offline software performs well in these high pileup regimes. In figure 11 the benefit of software improvements for 2012 data are seen. Additional improvement in the data production speed have come from a new merger for output files, which runs 7 times faster than the previous merging technique. The Tier-0 also now benefits from accessing the conditions data via a FRONTIER/squid system rather than using direct Oracle connections. This allows much higher rate of database access and prevents database slowdown from affecting reconstruction times. This was a necessary improvement to accommodate the large computing resource which Tier-0 will enjoy for 2012, with up to 6000 cores now available.

6. Conclusion

ATLAS prompt data processing has performed very well during the LHC *pp* and heavy ion runs in 2010 and 2011. In 2012 the ATLAS experiment expects to collect 15-20 fb^{-1} more *pp* data, which will be at higher luminosity and pile-up than before. These higher luminosities present

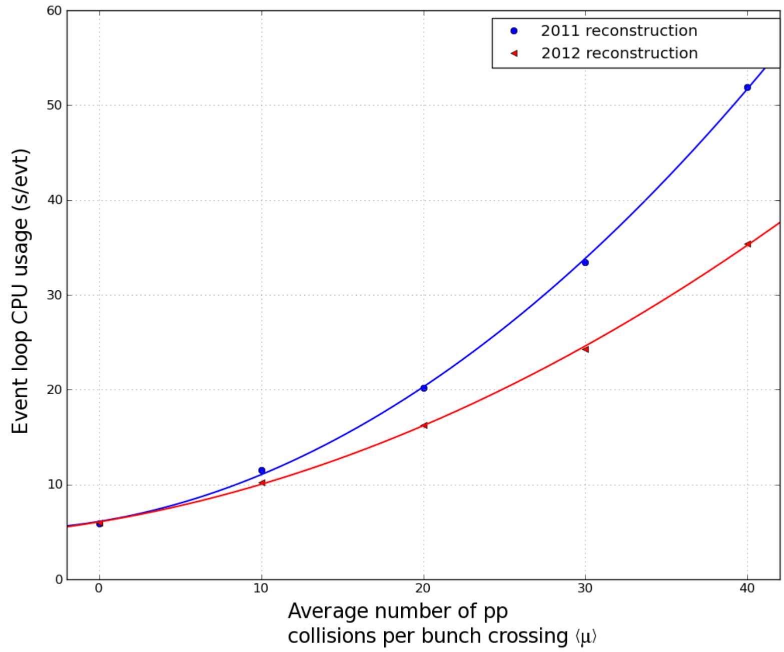


Figure 11: Reconstruction time per event vs. number of *pp* collisions (μ) for software used in 2011 (blue) and 2012 (red).

an ever increasing challenge in terms of computing resources and operational requirements. The prompt reconstruction setup for ATLAS continues to improve and is in good shape to deliver detector data for physics analysis within a matter of days of the LHC runs.

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