11th Pisa Meeting on Advanced Detectors
La Biodola, Isola d'Elba (Italy)
May 24 - 30, 2009

Readiness of the ATLAS detector : performance with the first beam and cosmic data

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On behalf of the ATLAS Collaboration

This talk is presented on behalf of the ATLAS Collaboration

- 37 Countries
- 169 Institutions
- 2500 Scientific Authors

The ATLAS detector

- pp collisions @ 14 TeV and $L=10^{34} \text{ cm}^{-2}\text{s}^{-1}$
- LHC collision rate = 40 MHz

Commissioning and readiness

- The commissioning of the detector started in 2006, with consecutive Milestone and Technical Runs
 - Operate together the various sub-systems even partially installed, testing global tools and infrastructure (DCS, DAQ, monitoring)
 - DAQ performance and trigger systems
 - Data transfer and processing (computing model and trigger selections)
 - Results and integration of calibration tools and of track-based alignment
- On September 10th 2008, ATLAS was ready for operating continuously with the beams
- After the LHC accident, combined runs with cosmic rays continued

first beam event seen in ATLAS

Trigger and Data acquisition

Three-level trigger architecture, exploiting the “region-of-interest” (RoI) approach to reduce the data-flow requirements

- Level-1 trigger (L1)
 - Implemented in custom h/w
 - Driven by local features in calorimeters and muons
 - Rols in η - ϕ plane forwarded to Level 2
- Level-2 trigger (L2)
 - Refines LVL1 results with a local analysis inside Rols
 - Effective rejection mechanism that only requires collection of 1-2% of the event
 - Lower requirements on the readout system (ROS) and network system
- Event filter (EF)
 - Operates on fully assembled events
 - Event building at ~ 5 GB/s
- High Level Trigger (L2+EF)
 - Keys: seeded reconstruction and early rejection
 - Custom algorithms for L2, derived from offline for EF
 - Same selection infrastructure
 - Implemented on Linux PC farms

Trigger and Data acquisition: status

Continuous cosmic data taking after September 12th, 216 millions of events, 453 TB of data, 400 k files

- Level-1 trigger
 - Tested up to 50 kHz, to be improved to nominal rate
 - Timing-in in progress
- High Level triggers (Level-2 and Event Filter)
 - 850 HLT nodes (35% final system) tested at 60 kHz
 - Finalization of the system will be luminosity driven
 - Expected: 500 Level-2 nodes + 1800 Event-Filter nodes (8 cores @ 2.5 GHz)
 - High-level algorithms (tracking) used during cosmic runs to enrich inner-detector samples
- DAQ continuously running since 2008
 - All ROS PCs installed and working
 - Dataflow networking infrastructure fully in place
 - Local storage farm (SFO) of 5 nodes with a total storage area of 50 TB
- Realistic test of the computing model during summer 2008
 - from online (SFO) to analysis at Tier-2 with simulated data @ $L=10^{32}$

TDAQ performance

- Dedicated **technical runs** to establish performance and scalability during system deployment
 - Simulated data as input (background + signal)
 - Test with $L=10^{31}$ trigger menu
 - 70% of L2, 20% of EF
 - Small event size: 800 kB, expected with LHC is 1.6 MB
- Stress test for the Data Acquisition system
- Stable running at 80% of designed L1 rate (60kHz)
- **Readout system (ROS)** request rate up to 30 kHz
 - Maximum expected is 20 kHz (20% of L1)
- **Event Building** rate (L2-driven) : 4.2 kHz (3.5 kHz by design)
- **Data storage (SFO)** I/O rate: 550 MB/s , with peak > 700 MB/s

See D.Scannicchio talk at this conference

ROS request EB and LVL2 Rates (Hz) during ATLAS combined cosmic run

Detecting beams in ATLAS

- ATLAS was “on” on Sep. 10th, although many components operated with reduced HV: SCT-barrel at very low bias, Pixel and CSC off (safety and late commissioning)
- In addition to Level-1 triggers, the beam can be detected by other systems

Beam Pick-up
Timing Experiment (BPTX)

- Provides a filled bunch trigger
- Monitor the beam activity: identifies the bunches in the beams, measures their individual intensity and phase relative to the clock, and assigns Bunch crossing (BC=25ns)
- Monitor of timing signals

Tertiary
Collimators

175 m

140 m

LUCID, a Cherenkov
Luminosity monitoring

Minimum Bias
Trigger Scintillators

Beams on 10th-12th September

- Oscilloscope traces of discriminated signals during an injection of 1 bunch without RF capture
 - The bunch manages to circulate a few times: after 7 turns its intensity falls below the threshold of the BPTX discriminator. The first few turns give only small activity in the MBTS, while after 3 or 4 turns they show saturated signals

- Excellent timing of BPTX and MBTS
- Relatively small coincidence of MBTS with calorimeter and muon triggers - beam quality improved significantly in the first 48 hours

Some LHC events

Beam halo events are important for Endcaps calibrations

Beam dumped on closed collimators 140 m far from the IP, produced a **splash of particles**, useful for timing-in the L1 systems

ATLAS Magnet System

Barrel Toroid (8 coils)

- $L = 25.3\text{m}$, $\varnothing_{\text{outer}} = 20\text{m}$
- $B = 0.2\text{-}2.5\text{T}$ (@20.5kA)
- Stored energy: 1100MJ

Two Endcap Toroids

- 8 coils common cryostat
- $L = 5\text{m}$, $\varnothing_{\text{outer}} = 10.7\text{m}$
- $B = 0.2\text{-}3.5\text{T}$ (@20.5kA)
- Stored energy: 250MJ

Inner Solenoid

- $L = 5.3\text{m}$, $\varnothing = 2.63\text{m}$
- $B = 2\text{T}$ (@7.73 kA), $0.66 X_0$

Status

- Stable continuous operation at nominal field
- Stress and heat distributions during fast quenches are safe
- Geometrical distortions of toroid with field-on as expected (measured by ~1800 Hall probes)

Muon spectrometer

Air-core toroid magnet system

Barrel: $\sim 1.5\text{--}5.5\text{ Tm}$ in $0 < |\eta| < 1.4$

Endcaps: $\sim 1\text{--}7.5\text{ Tm}$ in $1.6 < |\eta| < 2.7$

Trigger chambers: $\eta < 2.4$

Bunch-crossing ID,
Muon p_T triggering,
second coordinate measurement

Precision chambers: $\eta < 2.5$

Stand-alone p_T measurement
 $\Delta p_T/p_T < 10\%$ up to 1 TeV

End-cap Trigger: Thin Gap Chambers (TGC)

- $\sim 300\text{k}$ channels
- $\sigma_t < 10\text{ ns}$
- 99.8% operational
- dead channels $< 0.01\%$
- noisy channels $< 0.02\%$

Barrel Trigger: Resistive Plate Chambers (RPC)

- $\sim 360\text{k}$ channels
- $\sigma_t \sim 2\text{ ns}$
- 95.5% operational
- dead strips $< 2\%$
- hot strips $< 1\%$

Monitored Drift Tubes (MDT)

- 1088 chamber with 339k channels
- 99.8% operational
- dead channels $< 0.1\%$
- noisy channels $< 0.2\%$

Cathode strip Chambers (CSC)

- Small Wheel End-cap
- 2D readout
- 100% operational
- dead channels $< 0.1\%$

See D.Orestano talk at this conference

Precision chambers (MDT) performance

Expected resolution

- single tube $\sim 80 \mu\text{m}$
- 3-4 tubes $\sim 50 \mu\text{m}$
- calibrations and alignment better than $30 \mu\text{m}$

- MDT tubes are calibrated using muon tracks through iterative auto-calibration procedure. To enlarge the muon sample, data extracted from L2 are sent to calibration centers (Tier-2) for extracting t_0 , r-t relations

- Residuals calculated after applying t_0 refit on single chamber timing spectra (cosmic approach to limit trigger jitter effects)

See I.Potrap poster at this conference

- Track sagitta calculated with the measured chamber position confirms the optical alignment system performance (45-50 μm)

- End-Caps, distributions are centered at 40 μm
- Large Barrel chambers at 200 μm level
- Small Barrel chambers (no direct projective lines) still at the 1mm level.

12232 optical sensors

Muon trigger chambers

Endcap (TGC)

XY_View_A

Run 91060, 1/physics_TGCwBeam
/MuonDetectors/TGC/XY_View_A

Wire efficiency
95%

SL_Timing

SL_Timing
Entries 161758
Mean 0.9946
RMS 0.09241

More than 99% of the trigger events are within the correct BC

Barrel (RPC)

RPC track impact point on surface

Entries 6616665

Chamber efficiency
97%

Time difference
between triggering
layers RMS = 5.5 ns

Local time alignment is within the intrinsic resolution

See G.Cattani poster at this conference

Calorimeters

Liquid Argon:

- Electromagnetic (Pb-LAr)
 - accordion geometry
 - 3 longitudinal segments
 - Pre-shower for $h < 1.8$
- Hadronic (Cu/W-LAr)
 - 4/3 longitudinal samples
- Status
 - Dead channels: $< 1\%$ recoverable
 - Noisy channels: 0.003%
 - Electronic calibration operational

Fe - Scintillation Tiles (barrel Hadronic)

- Dead channels $< 1.4\%$ under repair
- Calibration procedure operational (Cs source, laser, charge injection)

Electromagnetic energy resolution:

$$\sigma(E)/E = 10\%/\sqrt{E} \oplus 0.7\%$$

Hadronic energy resolution:

$$\sigma(E)/E = 50\%/\sqrt{E} \oplus 3\% \quad (\eta < 3.2)$$

$$\sigma(E)/E = 100\%/\sqrt{E} \oplus 10\% \quad (\eta > 3.1)$$

- Precision measurement of e/γ for $\eta < 2.5$
- Linearity to 0.1%

Liquid Argon (LAr) performance

- Very stable pedestals
- Timing is already set to within a few ns for real collisions.

See S.Laplace talk at this conference

agreement with expected <2%

- A typical pulse for cosmic muon in the LAr EM Barrel, with 32 samples allowing to see the complete pulse shape (error on the measurement ~ 5 ADC)
- MPV as a function of η clearly tracks the cell depth as one would expect for a minimum ionizing particle

Tile performance

Splash events

8-fold structure in ϕ and up-down asymmetry due to the End-Cap toroid material for particles coming from C-side

MPV of dE/dx signals with single beam data verify the inter-calibration done with radioactive gamma sources

Cosmic events

Stability in time of electronic noise (RMS of the digital samples) at cell-level (crucial for reconstruction)

The time difference between measured and expected time-of-flight confirms the Laser time calibration

L1 Calorimeter trigger

- Energy correlation between trigger towers (mainly 0.1×0.1 in η/ϕ) and the full calorimeter readout (LAR), with nominal calibration

Splash event: the colors are proportional to the transverse energy deposited in each trigger tower

Hadronic Trigger Tower

Cosmic spectrum: large tail of higher energies mainly due to large showers

Inner Detectors

Silicon Pixel detectors

- pixel size $50 \times 400 \mu\text{m}^2$; 80M channels
- resolution: $10 \mu\text{m} \times 110 \mu\text{m}$
- >95% of modules operational
- Noise occupancy: 5×10^{-10} ; hit- ϵ : 98%

Semiconductor Tracker (SCT)

- 80 μm strip width; 6M channels
- Resolution: $17 \mu\text{m} \times 580 \mu\text{m}$
- >99% of barrel and 97% of end-cap modules operational
- Noise: $< 5 \times 10^{-5}$; hit- ϵ >99%

Transition Radiation Tracker (TRT)

- 4mm diameter straw tubes
- Up to 36 points for tracking and e/π ID in $0.5 < E < 150 \text{ GeV}$
- 98% of channels operational

Operated inside the 2 Tesla magnetic field

- $\eta < 2.5$ (TRT: $\eta < 2.0$) $\sigma/p_T = (0.05 p_T + 1)\%$

See A.AndreaZZa talk at this conference

Beam splash events seen in the ID

Pixel performance

- The charge distributions of clusters on tracks, with incidence angle close to the normal on the module, agree with expected

See J. Weingarten poster at this conference

*Cosmic event
seen in the
Pixel detector*

- The measured Time over Threshold (ToT) linear dependency on injected charge, used for charge calibration (BC unit)

SCT performance

- The Noise Occupancy is significantly below the design specification (5×10^{-4} , right edge of the plot)

Lorentz angle estimation

- Cluster width versus track incident angle to the surface of the module (small discrepancy due to local temperature effects)

TRT performance

- The turn-on of the production of TR photons as a function of gamma as measured for tracks of cosmic muons
- Different type of radiator materials:
 - Barrel: polypropylene-polyethylene fiber mats ("chaotic" orientation of fibers/boundaries)
 - End-caps: polypropylene foils ("aligned" orientation of boundaries)

Transition Radiation turn-on curves

ID combined tracking

- Inner detector tracking performance, before and after alignments
 - The residual is defined as the measured hit position minus the expected hit position from the track extrapolation

ATLAS Combined performance

Differences in track parameters in the muon spectrometer and the ID (preliminary alignment)

3 GeV/c energy loss in the calorimeter

Conclusions

- ATLAS is a great challenge, due to the dimensions and the complexity of the detectors and to the discoveries it aims to reach
- The robustness and the stability of the dataflow are now under optimizations, with the final system completely integrated, and continuously exercised with cosmic rays
- Trigger systems are being prepared for different LHC scenarios and even the first beams will give important inputs to understand the detectors
- Up to now we were “going to”, now we “are”!
 - ...and to be honest, we are waiting for good news!

Back up slides

LHC restart plan

Year	2009												2010													
Month	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
Baseline	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH	SH	SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	SH	SH	SH	SH
	24 weeks physics possible																									
Base '	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	SH	SH	SH	SH	SH	SH	SH
	44 weeks physics possible																									

- The machine will be cold by mid August, ready for first injected beam by second half of September
- Physics run at 5 TeV until Autumn 2010
 - first physics run (~10 months long) @10 TeV
 - Heavy ion Pb-Pb collision toward the end of the run
- Then complete installation of additional extra pressure relief valves on remaining dipole cryostat (essential for maximum energy operation)
- Restart in Spring 2011 with increasing beam energies

ATLAS Dataflow