ATLAS:
status, limitations and upgrade plans

TIPP 2011
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on behalf of ATLAS collaboration
ATLAS detector

- Central trackers in a solenoidal magnet $|\eta| < 2.5$
- EM + hadronic calorimeters $|\eta| < 5$
- Muon spectrometer in toroidal magnets $|\eta| < 2.7$
- Forward detectors
ATLAS detector

- Inner tracking
- TRT
  - $R = 1082$ mm
  - $R = 554$ mm
  - $R = 514$ mm
  - $R = 443$ mm
  - $R = 371$ mm
  - $R = 299$ mm
- SCT
  - $R = 122.5$ mm
  - $R = 88.5$ mm
  - $R = 50.5$ mm
  - $R = 0$ mm
- Straw tubes
- Silicon strip
- Silicon pixel
ATLAS detector

Calorimeters

Tile barrel

Tile extended barrel

LAr hadronic end-cap (HEC)

LAr electromagnetic end-cap (EMEC)

LAr electromagnetic barrel

LAr forward (FCal)
ATLAS detector

Drift tubes (3cm Φ)

Thin gap chambers

RPC

CSC

Muon spectrometer
ATLAS status

LHC peak luminosity exceeded $1 \times 10^{33}$

ATLAS has collected over 0.7 fb$^{-1}$

Data taking efficiency ~ 95%
ATLAS status

Number of channels ($10^3$)

Approximate operational fractions
ATLAS status

2011 LHC strategy of luminosity increase is based on
- large bunch current
- small $\beta^*$
- small emittance

Average number of pp collisions / crossing ~ 10
ATLAS status

Experienced even harder conditions in the Pb – Pb collisions

Possible to reconstruct Z’s, J/ψ’s, and others
ATLAS had a good start, and collecting high quality data.

Further details of these results and other nice results are presented in many ATLAS talks in this conference.
LHC and ATLAS upgrade

LHC physics goals
• Improve standard model measurements (W, Z, top, …)
• Higgs: understanding the electroweak symmetry breaking
• Beyond the SM: SUSY, extra dimensions,
• Even something totally new …

Whatever will be discovered in next years at LHC, need much data to understand what has been discovered.

Higher luminosity allows extending discovery/studies to
• higher masses
• processes of lower cross-section

LHC has plans of upgrade by increasing luminosity to collect ultimately \( \sim 3000 \text{ fb}^{-1} \). This will open new physics possibilities.
LHC and ATLAS upgrade

Possible upgrade timeline

<table>
<thead>
<tr>
<th>Year</th>
<th>7 TeV</th>
<th>→ 14 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013/14</td>
<td>10^{27}</td>
<td>→ 1x10^{34} cm^{-2}s^{-1}</td>
</tr>
<tr>
<td></td>
<td>2x10^{33} cm^{-2}s^{-1}</td>
<td>~50 fb^{-1}</td>
</tr>
<tr>
<td>Now</td>
<td>~10 fb^{-1}</td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td>1x10^{34} cm^{-2}s^{-1}</td>
<td>~300 fb^{-1}</td>
</tr>
<tr>
<td>~2022</td>
<td>5x10^{34} cm^{-2}s^{-1}</td>
<td>3000 fb^{-1}</td>
</tr>
</tbody>
</table>

Now ~10 fb^{-1} → ~50 fb^{-1} → ~300 fb^{-1} → ~3000 fb^{-1}

luminosity leveling
ATLAS upgrade

- LHC improves, bulk of luminosity with instantaneous luminosity beyond the nominal luminosity for which the ATLAS detector was designed and built.

- Technology improves, can build better performing detector now.

- Detectors age, after the nominal integrated luminosity has been collected, leading to deterioration of performance during the runs at higher luminosity.

- It will take long time to study and build new detector

- Installation has to be done during the limited number of long shut downs

- Installation has to be planned to be prepared to the new running condition
ATLAS upgrade: phase - 0

2013/14: to prepare for the following period of a few years of $\sqrt{s} = 14$ TeV, Lumi ramping up to the nominal lumi, collecting 50-100 fb$^{-1}$

Very important period. Discovery and initial studies of Higgs, SUSY in the scope.

Many consolidations, de-staging, new cooling system, new beam pipe (steel $\rightarrow$ Al: reducing background in the muon detector), repairs, improving reliability, …

Installation of new pixel layer: IBL – a major project of phase-0

The innermost layer of Pixel detector has an important role for reconstructing secondary vertices away from the IP, vital for b-tagging, therefore referred to as the B-layer.

Pixel detector and beam pipe $\rightarrow$
The current B-layer will become inefficient after phase-1 (beyond nominal luminosity):

- data bandwidth, radiation damages, ...

The idea is, instead of replacing the B-layer, which is very difficult and dangerous, add a new B-layer inside the present one.

3 pixel layers → 4 pixel layers

Insert the new layer inside the current beam pipe (Insertable B-Layer → IBL) using a smaller beam pipe.

Phase-1 was initially in 2016, now it is postponed to 2017 or 2018, → Advance the project schedule and install in 2013/2014.

it helps anyway, improves performance less activation in earlier time (ease of installation)
ATLAS upgrade: phase - 0

IBL technology

- Planner silicon sensor
- 3d silicon sensor
- Diamond sensor → postponed for future upgrade

Planner sensor prototype

Double side 3D sensor

New readout chip of higher performance
2017 or 18 : to prepare for the following period of a few years of \( \sqrt{s} = 14 \text{ TeV} \), Lumi beyond the nominal \( \rightarrow 2 \times 10^{34} \), collecting \( \sim 100 \text{ fb}^{-1}/\text{year} \)

- Increase of cavern background : concern with muon spectrometer performance
- LAr calorimeter in the forward region (FCAL) needs help (high particle rate)
- Trigger upgrade needed to maintain low threshold at Level-1 to keep the physics acceptance
- Fast tracking processor (FTK) to enhance the performance of Level-2 trigger
ATLAS upgrade: phase - 1

Muon small wheel: the innermost station in the endcap

MDT Data Extrapolation to $10^{34}$

- Designed for MC simulation of background with safety factor x5.
- Measurements with collision data are confirming that the small wheel will be in critical situation at luminosity beyond the nominal.
- Max rate (data extrapolated)
  - 150 kHz/tube at 7 TeV
  - $\rightarrow$ 200 kHz/tube at 14 TeV and $1\times10^{34}$

→ new tracker needed
ATLAS upgrade : phase - 1

Improve L1 muon trigger by integrating small wheel in the trigger

- removing background
- improving $p_T$ resolution

Plan to build new small wheels for phase-1, which comprises

- precision tracker with high rate capability
- fast segment reconstruction for L1 upgrade
ATLAS upgrade : phase - 1

New small wheel : candidate technologies

- small tube
- fine strip TGC
- Large Micromegas

15 mm tube : much shorter drift time. works at x7 rate

fine strip analog readout. position resolution 60 μm used for precision tracking and L1 trigger.

Success of resistive anode ensuring stability at high rate.

Used for precision tracking and L1 trigger.

RPC is also considered for the L1 component
Warm forward calorimeter

Idea of placing a small warm calorimeter in front of the LAr FCAL in order to protect it from heating, ion build-up

Cupper absorbers + 1 cm² diamond sensors on ceramic

highly segmented readout
ATLAS upgrade: phase - 1

3-level trigger: 40 MHz → 200~300 Hz

Level-1: Hardware (μ, cal)

Level-2: On a computer farm, by software, based on limited information

Event filter: On a computer farm, Full reconstruction

- Data recording rate (event filter output) needs to be maintained at the same level.
- Need more restrictive trigger at all levels.
- Need to maintain lepton and calorimeter thresholds low in order not to lose physics acceptance
L1 Trigger upgrade

- Topological processor: use of topological information, e.g. lepton isolation
- Improved trigger input from the muon small wheel (upgrade in the endcap)

Goal is to gain more control of L1 rate without losing physics acceptance.

Allowing L2 and Event filter to do their job to control the data recording rate.
ATLAS upgrade: phase - 1

FTK for Level-2

In the Level-2 trigger, performed by a computer farm,
- Track finding
- Track fitting
are time consuming processes.

Idea of performing these tasks by a dedicated hardware, gaining substantial speed.

Pattern Recognition

Track Fitting

- Determine the helix parameters and $\chi^2$
- Fit with the local silicon hit coordinates (one module in each layer) in linear

$$p_i = \sum_{j=1}^{14} a_{ij} x_j + b_i$$

- $P_i$: the helix parameters and $\chi^2$ components
- $X_j$: the hit coordinates in the silicon layers
- $a_{ij}$ & $b_i$: prestored constants determined from full simulation or real data track
- Very fast in DSPs (~1 ns per track)
ATLAS upgrade : phase - 2

~2022: to prepare for the following period of ~ 10 years, after having collected some 100 fb\(^{-1}\) at \(\sqrt{s} = 14\) TeV,

to run at 5x nominal luminosity : \(5 \times 10^{34}\) with luminosity leveling, collecting a total of 3000 fb\(^{-1}\)
100 or 200 interactions/crossing to disentangle,

Most of ATLAS can remain
- Magnets, most of muons and calorimeters

Changes are needed in
- Trigger (muon, calo) and DAQ
- Possibly some of the muon chambers for high background rate
- Possibly endcap and forward calorimeter
- New calorimeter readout for trigger upgrade
- New inner detector
 ATLAS upgrade : phase - 2

Trigger for phase-2

L1 Calorimeters

Full readout of digitized energy from all cells over high speed optical link. bringing full granularity for L1 calorimeter trigger.

Maybe already introduced in earlier phase in small scale (a slice), operated in parallel to the existing system, for evaluation.
ATLAS upgrade: phase - 2

Trigger for phase-2

L1 Muons in barrel MDT: $p_T$ resolution 20% $\rightarrow$ 5% at 20 GeV

Sagitta measurement using 3 stations

This region is improved by the new small wheel: Phase - 1

Overlap region
ATLAS upgrade : phase - 2

Trigger for phase-2

L1 Track

Ideas of implementing ID track information in L1 trigger. improving \( p_T \) resolution for high \( p_T \) leptons

Fast readout of a part of ID modules, seeded by high \( p_T \) candidates (RoI) by muon or calorimeter L1 (\( \rightarrow \) L0).

High speed hardware confirm the presence of high \( p_T \) leptons.

Need additional data stream from front end chip.

Prepare a dedicated double layer in the outer radii of ID.

Find straight track segment pointing to IP as an indication of high \( p_T \) track

Many studies needed to know how to realize, and how to implement in ATLAS ensuring compatibility (latency, etc) with the whole system.
ATLAS upgrade : phase - 2

New ID tracker

Rate :

- Pixel B-layers will become inefficient at $2 \times 10^{34}$ and significantly so at $3 \times 10^{34}$
- SCT (strip), a part of it cannot be readout due to bandwidth limitation
- TRT occupancy will become very high

Radiation damage:

- SCT designed for 700 fb$^{-1}$
- Much shorter life for B-layer

New technology:

- New electronics for lower power consumption
- New cooling and support structure for reducing materials
ATLAS upgrade: phase - 2

New ID tracker

Lessons from the present detector

Substantial material for services

Layout issues
New ID tracker

Studies are on going in all areas

- Sensors
- Readout chips
- Module integration
- Cooling
- Powering
- Layout and physics performance
**ATLAS upgrade: phase - 2**

### Rad-hard strip sensors

- **n-in-p Planar FZ Irradiations**

### Baseline n-on-p sensors

### Evaporative CO\textsubscript{2} cooling
- large latent heat
- good heat transfer
- allowing smaller cooling pipes (material budget)

### New powering schemes
- DC-DC convertors
- Serial powering being successfully tested

### Module integration concepts
- Stave
- Super module
Conclusions

• The LHC will continue running well beyond 2020 with upgrades to much higher luminosity than initially designed.

• ATLAS has plans of changes under development to profit as much from the LHC upgrade.

• In 2013/14 shutdown, there will be a new detector element: IBL

• In phase-1, new muon small wheel, possibly new warm mini FCAL, new trigger and other upgrades.

• In phase-2, completely new inner tracker, some upgrade of muon chamber, possibly new forward calorimeter, major upgrade on trigger and DAQ.

• Studies and work are under way.
Back up
ATLAS status

\[ \int L dt = 42 \text{ pb}^{-1} \]
\[ |\eta| < 1.05 \]
Combined

\[ \sigma = (2.06 \pm 0.07) \text{ GeV} \]

\[ \sqrt{s} = 7 \text{ TeV} \]

\[ \sigma_{\text{data}} = 1.73 \pm 0.08 \text{ GeV} \]
\[ |\eta| < 2.47 \]

\[ \sigma_{\text{MC}} = 1.49 \pm 0.02 \text{ GeV} \]

\[ \mu_{\text{data}} = 3080 \pm 2 \text{ MeV} \]
\[ \mu_{\text{MC}} = 3083 \pm 1 \text{ MeV} \]
\[ \sigma_{\text{data}} = 132 \pm 2 \text{ MeV} \]
\[ \sigma_{\text{MC}} = 134 \pm 1 \text{ MeV} \]

|\eta| < 2.47
(1.37 < |\eta| < 1.52 excluded)
ATLAS status

Some performance figures

\[ \int L \approx 40 \text{ pb}^{-1} \]

EF_mu15

ATLAS Preliminary

Data 2010, \( \sqrt{s} = 7 \text{ TeV} \)
Trigger for phase-2

• Rates are 5x higher than at nominal luminosity.
• Event size will also be bigger: many interactions/crossing.

• Cannot increase the recording rate of these big events significantly.

• But need to maintain (reasonably) low threshold for leptons, jets, $E_T$ miss, etc for physics acceptance.

• Much higher rejection needed at all levels of trigger (L1, L2, Event filter)

Improvements considered are:

• More processing at L1: e.g. topology info
• Sharpening threshold for leptons and calorimeter energy
• Longer L1 latency will be needed: $3\mu s \rightarrow 6$ or 9 or even longer, or L0/L1 scheme
• Possible ID-track trigger
Barrel calorimeters will work OK: no changes needed.

Endcap cold electronics (preamplifiers for Hadron endcap) in cryostat may or may not survive (designed for 1000 fb$^{-1}$).

If it survives, the phase-1 mini FCAL would be sufficient to protect FCAL from ion build up, HV drop, heat problem

If proven necessary to change the cold electronics, need to open the cryostat → major work, 18 months should be OK

• Replace cold electronics with rad-hard elec.
• Replace FCAL with smaller gap design.