The Canadian contribution to the upgrades for the ATLAS experiment

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ATLAS
Large Hadron Collider
27 km LHC tunnel

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On behalf of the ATLAS Canada group
Physics motivation

Higgs boson

• Successful Standard Model
• Why do particle masses differ by a factor of $10^8$?
• Why do particles have mass at all?
• Answer lies in Higgs Boson and associated field.
• Higgs boson discovered by ATLAS announced July 4th 2012

Still some questions

• Explore properties if this particle
• What is dark matter?

Large scale structure of the universe

Motion in galaxies

Nobel prize in 2013
Francois Englert and Peter Higgs

Need a lot more ATLAS data to explore these questions
Need more data to explore physics goals
Series of upgrade planned for LHC to improve luminosity
Phase 1 in LS2 $\Rightarrow$ 2-3 times design luminosity
Then collect 300 fb$^{-1}$
Phase 2 in LS3 $\Rightarrow$ 5-6 times design luminosity
Then collect 3000 fb$^{-1}$

LHC design luminosity = $10^{34}$ cm$^{-2}$s$^{-1}$
How well can we measure the Higgs now?

![Graph showing ATLAS results for Higgs boson measurements]

- $m_H = 125.5$ GeV
- $\sigma$(stat) $\sigma$(sys) $\sigma$(theo)
- Total uncertainty $\pm 1\sigma$ on $\mu$

- $H \rightarrow \gamma\gamma$:
  - $\mu = 1.55^{+0.33}_{-0.26}$

- Low $p_T$:
  - $\mu = 1.6^{+0.5}_{-0.3}$

- High $p_T$:
  - $\mu = 1.7^{+0.7}_{-0.6}$

- 2 jet high mass (VBF):
  - $\mu = 1.9^{+0.6}_{-0.6}$

- VH categories:
  - $\mu = 1.3^{+1.2}_{-1.1}$

- $H \rightarrow ZZ^* \rightarrow 4l$:
  - $\mu = 1.43^{+0.46}_{-0.30}$

- VBF+VH like categories:
  - $\mu = 1.2^{+1.6}_{-0.9}$

- Other categories:
  - $\mu = 1.45^{+0.42}_{-0.36}$

- $H \rightarrow WW^* \rightarrow l\nu l\nu$:
  - $\mu = 0.99^{+0.31}_{-0.26}$

- 0+1 jet:
  - $\mu = 0.82^{+0.33}_{-0.32}$

- 2 jet VBF:
  - $\mu = 1.4^{+0.7}_{-0.6}$

- Comb. $H \rightarrow \gamma\gamma, ZZ^*, WW^*$:
  - $\mu = 1.33^{+0.27}_{-0.19}$

- $\sqrt{s} = 7$ TeV $\int L dt = 4.6-4.8$ fb$^{-1}$

- $\sqrt{s} = 8$ TeV $\int L dt = 20.7$ fb$^{-1}$
Higgs cross section with upgrades

Projections for measurements of Higgs boson cross sections, branching ratios and coupling parameters with the ATLAS detector at a HL-LHC

The ATLAS collaboration
SUSY Searches

Prospects for benchmark Supersymmetry searches at the high luminosity LHC with the ATLAS Detector

The ATLAS collaboration
Collecting the data for new discoveries

- Collision rate in ATLAS is huge; currently 25 interactions every 50 ns
- In future will be 50-100 every 25 ns.

Collisions in one event in ATLAS

- Need to select rare events with discovery potential
- This is done by the “trigger”
- Key trigger selection looks for energetic electrons and muons
- ATLAS trigger designed for nominal LHC luminosity
- LHC improvements lead to expected luminosity of 3 – 6 times the original design.
- To collect interesting events need to enhance ATLAS trigger capability
Canadian contribution to phase 1

The LHC luminosity will roughly double after every long shutdown → As collision environment harsher, detectors have to cope…

Main goals

- Keep the Level-1 single muon and electron triggers usable at high luminosity
- Maintain precision muon tracking performance at high luminosity (in particular for high-$p_T$ muons)

Upgrades required

- Install new Muon detectors in the forward region as part of the Phase-1 upgrade in LS2. Called the New Small Wheel (NSW) These will provide signals to improve the level 1 muon trigger.
- Improve the Liquid Argon (LAr) electronics. This will allow the existing calorimeters signals to be used to generate better electron triggers.
The ATLAS detector

Phase 1 upgrade projects NSW

LAr Calorimeter

6000 tons
100 m underground
Canadian teams working from the beginning (R&D started in 1990)

Alberta, Carleton, McGill, Montreal, Toronto, Regina, Simon Fraser, TRIUMF, UBC, Victoria
LAr electronics upgrade: Forming the electron trigger

Current Method

Upgrade method

Needs new sophisticated electronics to process data
Location of electronics for Liquid Argon (LAr) calorimeter
LAr Electronics crate

Electronics card
Data processing
Front End Boards (FEBs)

Baseplane
Signal routing

Signals come from calorimeter
Upgrading the LAr Electronics

- Disassemble the electronics crates
- Replace the board that all the electronics cards plug into (to allow re-routing of signals)
- Modify the electronics cards with new components
- Reassemble
- Test and QC
Canadian contribution to the LAr electronics

• Canada will design and build components for HEC crates (Hadronic EndCap)
• Canada led the construction of the HEC modules for ATLAS
• Electronic provided by Canada will include the HEC base planes and electronics components.
• Assemble and testing of devices will be done in Canada
Muon trigger and the New Small Wheel (NSW)

NSW Provides improved trigger for forward Muons
And improves tracking

New precision tracker in NSW
that works up to the ultimate luminosity, with some safety margin

Kill the fake triggers
by requiring high quality pointing segments in NSW

Reduction of trigger rate by a factor of 3
→ we can work with this!
NSW Detector Technology

Combination of sTGC and Micromegas (MM)
4+4+4+4 detection planes in total

sTGC primary trigger detector
• Good timing resolution
• Good space resolution

MM primary precision tracker
• Good space resolution
• Good track separation
• Very good high rate capability

Robust detector (redundancy and complementarity) for the high rate region, operate long term
sTGC incorporates
- Lower cathode resistance - for high rate
- Pads - online trigger tower
- Strip charge readout - precision coord. readout
- Wire readout - coarse $\phi$ coordinate

Pad coincidence defines the region of interest (RoI) to look at and selects strips to send to the sTGC trigger processor, where precision positions are calculated
Overview of construction requirements

- New requirements for sTGCs
- Higher rates require graphite coating with lower resistivity (100kΩ rather than 1MΩ)
- Need to upgrade existing spray facilities + impact on new ones (spray systems and HVAC)
- Precision measurement leads to requirements on alignment.
- Cathode panels flat (and parallel) to better than 80 microns
- Relative alignment of readout strips between gaps better than 40 microns

Alignment fixture
NSW and sTGC Construction Plan

Canada to construct 64 chambers (quadruplets) + spares in 2015-2016

- 64 quadruplets + 8 spares
- 32 quadruplets + 4 spares
- 32 quadruplets + 4 spares
- 64 quadruplets + 8 spares
Canadian sTGC construction

• TRIUMF cluster (Vancouver)
  – Receipt of parts - spray/polish carbon coating – glue frames and wire supports
  – Ship boards Vancouver to Ottawa
• Carleton cluster (Ottawa)
  – Wire stringing, gap and quadruplet assembly, adapter boards and chamber sealing
  – Ship Quadruplets Ottawa to Montreal
• McGill cluster (Montreal)
  – Cosmic ray testing, preparation for shipping to Geneva
  – Ship batches of chambers to CERN
• Note shipping is all under climate controlled conditions by land/sea
First full size prototype: Module -1

First module -1 built by Weizmann group
Beam test; Fermilab
May 2014

For details see next talk

• Test of Module -1 and Canadian 40 x 60 cm prototype
• Test to verify construction method for assembly precision
• Uses EUDET telescope – (from Carleton U.)
• Uses prototype of final NSW readout chip (VMM1)

Preliminary residual 3 out of 4 sTGC
# Production schedule

## Schedule dates

- **Full production start**: April 2015
- **Production complete**: January 2017
- **All quads in Geneva**: April 2017
- **Complete wedges**: June 2017

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<th>Year</th>
<th>Schedule Details</th>
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<tr>
<td>2016</td>
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<tr>
<td>2017</td>
<td>Jan Feb Mar Apr Ma_Jun Jul Aug Sep Oct</td>
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### Canadian schedule

- Board production at TRIUMF
- Shipping to Carleton
- Quad assembly at CU
- Quad shipments to McGill
- Quad testing at McGill
- Ship to Geneva
- Overall float

### From NSW schedule

- Wedge Assembly Small
- Wedge Assembly large

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[Diagram showing the schedule details with timelines for different stages and associated dates.]
Funding for the ATLAS Phase 1 upgrades

- Total cost for Canadian share of new ATLAS components ~ $5M Can.
- When ATLAS was built, construction funding came from the sub-atomic physics envelope.
- No longer possible.
- Seek funding from CFI
- CFI funds 40% of projects.
- Typically other 60% has come from the provinces and vendor discounts
- For ATLAS the other 60% matching will come from our International partners on the hardware projects.
- This is aided by CERN management structure which provides:
  - MOUs for operations and construction.
  - Independent cost reviews
  - Progress monitoring by Resource Review Board.
- Grant submission is due next week
Summary and outlook

• ATLAS physics program to explore Higgs and look for new phenomena
• Plans in place for collecting 3000 fb\(^{-1}\) of data
• For good data collection need to enhance trigger
• Improvements to Muon and LAr systems.
• Canada contributing to these; Muon NSW and LAr electronics.
• Infrastructure for these contributions will be in place by the end of this year.
• Seeking CFI funding for construction, funding parts and labour.
• Schedule is for project completion by 2018