ATLAS Upgrade Overall

Phil Allport
(On behalf of the ATLAS Collaboration)
18/3/14

- Physics at the HL-LHC
- HL-LHC Planning
- ATLAS Upgrades
  - Phase-0
  - Phase-I
  - Phase-II
    - New Tracker
      - Pixels
      - Strips
    - Other Sub-detector Plans
    - TDAQ, Computing and Software
- Conclusions
The stated target of the European strategy set the overall framework “Europe’s top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.” (Adopted by CERN Council May 2013, see http://council.web.cern.ch/council/en/EuropeanStrategy/esc-e-106.pdf).

All 4 experiments, the accelerator and the theory community were represented at the October 2013 ECFA HL-LHC Experiments Workshop at Aix-les-Bains http://indico.cern.ch/conferenceDisplay.py?confId=252045

The report from this to ECFA can be found at https://cds.cern.ch/record/1631032 which focusses on the detector requirements and physics reach with 3000fb⁻¹

The next in the ECFA HL-LHC workshop is planned for 21st - 23rd October 2014
Physics Studies

Aim to measure as many Higgs couplings to fermions and bosons as possible to really test if this is the SM Higgs or a pointer to the BSM physics we know has to exist.

HL-LHC (3000 fb⁻¹): a true Higgs factory:
- > 170M Higgs events produced
- > 3M useful for precise measurements (more than or similar to ILC/CLIC/TLEP)
LHC gg→ H (50pb); e⁺e⁻→ ZH (0.2-0.3pb)

Over 100M Higgs bosons
- 20K H→ZZ→llll
- 400K γγ
- 50 H→ J/ψγ
ttH production with $H \rightarrow \gamma\gamma$

- Gives direct access to Higgs-top coupling (intriguing as top is heavy)
- Today’s sensitivity: 6xSM cross-section
- With 3000 fb$^{-1}$ expect 200 signal events (S/B ~ 0.2) and > 5σ
- Higgs-top coupling can be measured to about 10%

$H \rightarrow \mu\mu$

- Gives direct access to Higgs couplings to fermions of the second generation.
- Today’s sensitivity: 8xSM cross-section
- With 3000 fb$^{-1}$ expect 17000 signal events (but: S/B ~ 0.3%) and ~ 7σ significance
- Higgs-muon coupling can be measured to about 10%
ttH production with $H \rightarrow \gamma \gamma$

- Gives direct access to Higgs-top coupling (since top is heavy)
- Today's sensitivity: 6xSM cross-section
- With 3000 fb$^{-1}$ expect 200 signal events ($S/B \sim 0.2$) and $> 5\sigma$
- Higgs-top coupling can be measured to about 10%

Higgs-muon coupling can be measured to about 10%
Physics Studies at Aix-les-Bains

Improvements in coupling ratios with HL-LHC. (Range depends on handling of systematics and theoretical uncertainties)

H→ττ trigger threshold improvements with track trigger at L1
New LHC schedule beyond LS1

Only EYETS (19 weeks) (no Linac4 connection during Run2)
LS2 starting in 2018 (July)  18 months + 3 months BC (Beam Commissioning)
LS3 LHC: starting in 2023 => 30 months + 3 BC
injectors: in 2024  => 13 months + 3 BC

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**Phase-0 Upgrades (now)**

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**Phase-I Upgrades**

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The ATLAS Experiment

- Muon Detectors
- Tile Calorimeter
- Liquid Argon Calorimeter
- Toroid Magnets
- Solenoid Magnet
- SCT Tracker
- Pixel Detector
- TRT Tracker

Dimensions:
- 25 m
- 45 m
Current Shutdown Phase-0

- New insertable pixel b-layer (IBL) + new pixel services (nSQP) + new small Be pipe
- New Aluminum beam pipes to prevent activation problem and reduce muon BG
- New evaporative cooling plant for Pixel and SCT + IBL CO₂ cooling plant
- Replace all calorimeter Low Voltage Power Supplies
- Finish the installation of the EE muon chambers staged in 2003 + additional electronics for chambers in the feet and elevators region + RPC gas consolidation
- New CSC RODs (get to 100kHz) and additional RODs for pixel and strip systems
- Dual output HOLAs installed for FTK access to pixel and strip data
- Up to 1kHz total data output rate to storage
- Upgrade the magnets cryogenics and decouple toroid and solenoid cryogenics
- Add specific neutron shielding where necessary (eg behind endcap toroid, USA15)
- Revisit the entire electricity supply network (UPS in particular)
- Where possible prepare Phase-I and minor upgrade services etc
- Re-align the barrel calorimeter and ID + consolidation of infrastructure and services + general maintenance
- Some early installation of (Phase-I) trigger upgrades which are required for above design luminosity operation are being anticipated for run 2:
  - CTP: CTPCore and CTPOut
  - Muon endcap trigger with current small wheel (reduce fake rate)
  - Tile outer layer trigger (to help L1 muon in transition region)
  - nMCM (needed for bunch train correction)
  - CMX and L1Topo
- New insertable pixel b-layer (IBL) + new pixel services (nSQP) + new small Be pipe
ATLAS: Inner Tracking Detectors

- Muon Detectors
- Tile Calorimeter
- Liquid Argon Calorimeter

- Toroid Magnets
- Solenoid Magnet
- SCT Tracker
- Pixel Detector
- TRT Tracker

25 m
45 m
ATLAS Inner Detector

- **TRT** (Straw tubes)
- **SCT** (Silicon strip)
- **Pixels** (Silicon pixel)

Dimensions:
- R = 1082 mm
- R = 554 mm
- R = 514 mm
- R = 443 mm
- R = 371 mm
- R = 299 mm
- R = 122.5 mm
- R = 88.5 mm
- R = 50.5 mm
- R = 0 mm
Insertable B-Layer

• New pixel layer around new smaller beam pipe
• Current pixel package was brought to surface allowing
  – IBL support tube insertion at surface
  – New services installed to fix problems and improve R/O bandwidth
  – New diamond beam monitors with IBL (FE-I4) ASICs
• Now reinserted and being recabled
• IBL modules and stave status
  – 14 staves required, 20 available with 18 suitable for installation
  – Staves being assembled to Inner Positioning Tube
• Integration and installation
  – Extensive trials using test stands
  – Detailed schedule for remainder of shutdown
  – 5th May planned installation
• Off-detector
  – New RODs can read-out 32 FE-I4 ASICs at a rate of 160 Mbit/s using 4 S-Links (also supports the dual output required for FTK)
**Insertable B-Layer**

**FE-I4 Pixel Chip** (26880 channels)

- 20.2 x 18.8 mm²
- 130 nm CMOS process, based on an array of 80 by 336 pixels (each 250 x 50 μm²)

**3D Sensor**

- Both electrode types are processed inside the detector bulk
- Max. drift and depletion distance set by electrode spacing
- Reduced collection time and depletion voltage

**Planar Sensor**

- “classic” sensor design
- Oxygenated n-in-n
- 200μm thick
- Minimize inactive edge by shifting guard-ring under pixels (215 μm)
- Radiation hardness proven up to $2.4 \times 10^{16}$ p/cm²
Future Upgrade Planning

ATLAS
Letter of Intent
Phase-I Upgrade

ATLAS
Letter of Intent
Phase-II Upgrade
Future Upgrade Planning

Phase-I Upgrade
(LS2)
Starts Middle 2018
Future Upgrade Planning

In 2013, four TDRs for Phase-I construction projects were prepared within ATLAS, approved by the CB and submitted to the LHCC.

All four are now fully approved by the LHCC.
In furthest forward direction, chamber efficiencies fall with hit rate as luminosity goes well above the design values.

Rate of L1 muon triggers exceeds available bandwidth unless thresholds raised

→ Replace “small“ muon wheels

• Kill fake muon triggers by requiring high quality ($\sigma_\theta \sim 1\,\text{mrad}$) pointing to interaction region
• Precision chambers in both sTGC and micromegas technologies for robustness to Phase-II luminosities
New Small Muon Wheels
(CERN-LHCC-2013-006)

- In furthest forward direction, chamber efficiencies fall with hit rate as luminosity goes well above the design values.
- Rate of L1 muon triggers exceeds available bandwidth unless thresholds raised.
  → Replace “small” muon wheels.
- Kill fake muon triggers by requiring high quality ($\sigma_\theta \sim 1$ mrad) pointing to interaction region.
- Precision chambers in both sTGC and micromegas technologies for robustness to Phase-II luminosities.
**Fast TracKer (FTK)**
(CERN-LHCC-2013-007)

- **Rapid pattern recognition**

  - A pattern consists of a Super-Strip in each layer (10s of pixels/strips wide).
  - Uses HEP-specific content addressable memory (CAM) custom chip.
  - Patterns determined from full ATLAS simulation.
  - \( \sim 10^9 \) patterns see each hit almost simultaneously.
  - When hits have all been sent off detector, pattern recognition is \( \sim \) done.

→ This is then followed by FPGA based track fitting (1 fit/ns)

Many boards in pre-production and pre-final CAM chip version submitted
Designed for installation in 2016 to provide track information at start of HLT
(For Phase-II need to speed up to fit tracks in RoI as input to Level-1.)
LAr Electronics Upgrades
(CERN-LHCC-2013-0017)

- Key target (as for New Small Wheel) is to maintain high efficiency for Level-1 triggering on low $P_T$ objects.
- In the LAr calorimeter this implies changes to the front-end electronics to allow greater granularity to be exploited at Level-1.

Different parameters based on greater segmentation in $\eta$, $\phi$ and depth as well as greater resolution allow significant improvements in threshold for a given L1 rate.

(Phase-I Level-1 designed to be able to become Level-0 at Phase-II.)

See talk by Rainer Stamen 09.00 20/3/14
**TDAQ Upgrades**

*(CERN-LHCC-2013-0018)*

### Level-1:
- Phase I: completely new L1 electron and jet triggers.
  - Exploiting greater $\eta$, $\phi$ and depth segmentation
  - Complex ATCA modules: 6-10 Gb/s signal distribution on boards
- New MUCTPI: incorporation of NSW and full granularity to L1Topology

### HLT:
- Increase DataFlow throughput → higher request rates, more data per request
- Maintain rejection & limit rise of CPU times

### Dataflow:
- Provide read-out for new and upgraded detectors: FTK, NSW, LAr, L1Calo
  - FELIX: receives detector data via FE links (GBT) and multiplexes to commodity network technology
- **HLT core software:**
  - Upgrading HLT steering software and trigger chains
  - Provide for new detectors: FTK, NSW, …
  - Minimize *cost* of Trigger selection (cost $\propto$ data rate & trigger rates & CPU)

See talk by David Francis 15.30 20/3/14
Future Upgrade Planning

Phase-II Upgrade (LS3)
Starts End 2022
Future Upgrade Planning

Phase-II Upgrade (LS3)
Starts End 2022

(L. Rossi: http://indico.cern.ch/event/257368/session/0/contribution/3)
Radiation dose in the present triplet $(300 \text{ fb}^{-1})$

L. Bottura

Two "hot-spots"
Radiation dose in the present triplet (300 fb$^{-1}$)

L. Bottura

Cold bore insulation $\approx 35$ MGy

Q2
27 MGy

MCBX3
20 MGy

F. Cerutti, et al., WP10: Energy Deposition and Radiation Damage in Triplet Magnets, April 2013

https://indico.fnal.gov/conferenceDisplay.py?confId=6164
RLIUP Summary on LHC Inner Triplets

L. Bottura https://indico.cern.ch/conferenceDisplay.py?ovw=True&confId=260492

• Expected dose by LS3 (300 fb\(^{-1}\)) with 50 % uncertainty\(^{(3)}\)
  – Range of 27 [18...40] MGy in the Q2
  – Range of 20 [13...30] MGy in the MCBX
• Bonding strength (shear) of epoxies is strongly degraded (80 \%) above 20 MGy
• Fracture strength of insulating materials degrades by about 50 \% in the range of 20 MGy (G11) to 50 MGy (epoxies, kapton)
• Insulations (polyimide) become brittle above 50 MGy
• Triplet magnets may experience mechanically-induced insulation failure in the range of 300 fb\(^{-1}\) (LS3 ± 1 year)
  – Premature quenches (cracks in end spacers)
  – Insulation degradation (monitor on line\(^{(4)}\))
  – Mechanical failure (nested coils in MCBX)
Phase-II Detector Upgrades

Integrated radiation levels (up to $2-3 \times 10^{16} n_{eq}/cm^2$) and plan to cope with up to 200 interactions every 25ns. Implications of this include:

- New Inner Detector (strips and pixels)
- Trigger and data acquisition upgrades
- L1 Track Trigger
- New LAr front-end and back-end electronics
- Possible upgrades of HEC and FCal
- New Tiles front-end and back-end electronics
- Muon Barrel and Big Wheel trigger electronics
- Possible TGC upgrade to inner part of Big Wheels
- Forward detector upgrades
- TAS and shielding upgrade
- Various infrastructure upgrades
- Common activities (installation, safety, …)
- Software and Computing
ATLAS: New All-silicon Inner Tracker

Baseline layout of the new ATLAS inner tracker for HL-LHC Aim to have at least 14 silicon hits

Signal vs dose (1 MeV n equivalent)

Long Barrel Strips  Short Barrel Strips  Forward Strips

Barrel pixel  Microstrip Stave Prototype  Forward pixel

Quad Pixel Module  Quad Pixel Sensor Wafer
Baseline Tracker Performance

- New Inner Detector Improved granularity
  - Improved radiation hardness
  - Reduced material
  - Extended forward coverage
  - Robust tracking (14 layers)

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<th>Parameter</th>
<th>Layer 1</th>
<th>Layer 2</th>
<th>Layers 3 + 4</th>
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<td>FE-14 2x2</td>
<td>FE-14 2x3</td>
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<td>1348 +12 ganged</td>
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<td>power (W)</td>
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Track parameter 
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<td>Existing ID with IBL no pile-up</td>
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<td>Phase-II tracker 200 events pile-up</td>
<td>σₚ(∞)</td>
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Inverse transverse momentum (q/pₜ) [TeV] 
Transverse impact parameter (d₀) [μm] 
Longitudinal impact parameter (z₀) [μm] 

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**New All-silicon Inner Tracker**

See talk of Helen Hayward 09.40 19/3/14

**Pixel Detector**

- n-in-n, n-in-p planar, 3D and diamond sensors proved to doses up to $2 \times 10^{16} \text{n}_{\text{eq}}/\text{cm}^2$ and 1Grad
- IBL pixel size ($50 \times 250 \mu m$) OK for outer pixel layers, but target down to $25 \mu m \times 150 \mu m$ pixels with 65 nm CMOS
- Test structures in 65nm produced and studied after irradiation
- Larger area sensors (n-in-p) quads/sextuplets produced on 150mm diameter wafers with several foundries
- Irradiated quad pixel modules studies in test-beam and results look promising
- Novel technologies: HR/HVCMOS for possible use as outer pixel or higher radii
- Prototyping of local supports and concepts for service routings have been studied

**FE-T65-1 – Single Pixel**

**Possible Barrel Support Concept**

**Forward Pixel Services**
New All-silicon Inner Tracker

See talk of Peter Phillips 10.40 19/3/14

- New prototype n-in-p sensors delivered with 4 rows of 2.4cm long strips at 74.5µm pitch
- New (256 channel) 130nm CMOS ASIC received and under study (some issues)
- Many strip modules (single and double sided) prototyped with 250nm ASICs
- Large area stave DC-DC prototype (120cm×10cm) produced and under study

- Serial and DC-DC powering studied in detail on short versions of 250nm stave
- Several other new chips (HCC, HV multiplex, SP, DC-DC,..)
- Hybrid/module designs to use these completed

- Local supports extensively prototyped and further material reduction achieved
- Progress in Petal and Stave support designs
- End-of-stave card for 130nm developed
New All-silicon Inner Tracker

Integration and Performance

- Cooling, services, integration, removal, installation etc all being studied and key is understanding activation issues
- Optoelectronics (GBT) being working on in common with other experiments
- DAQ/DCS exists for prototype operation but not yet designs for final system
- Detailed performance studies (140 pile-up) and alternative layouts considered
Phase-II Split TDAQ L1 Scheme

Simulation studies show that including a track trigger complements muon and EM triggers

- Improves muon $P_T$ resolution
- Improves EM identification by matching to track

Implemented as 2-level scheme reusing Phase-I L1 trigger improvements for new L0 LOA scheme and buffering fully integrated in ABCn130 ASIC

FTK technology could be used to perform fast track fit in L0 defined Region of Interest (RoI)

Note this scheme impacts the electronics in all systems and provides possibilities to exploit the L0/L1 structure to have more extensive information from all sub-detectors at L1
In the context of the 3000fb⁻¹ by “around 2030”, given that levelling at \(5 \times 10^{34} \text{ cm}^{-2} \text{s}^{-1}\) is based on an effective luminosity of \(2 \times 10^{35} \text{ cm}^{-2} \text{s}^{-1}\), this raises the question of the ultimate acceptable pile-up (average # collisions each 25ns).

- The “crab-kissing” scheme offers an extended interaction region in z with lower pile-up density (better vertex finding).
- The question arises for mean pile-up, \(<\mu>, = 140 \ (5 \times 10^{34} \text{ cm}^{-2} \text{s}^{-1}, 25\text{ns}); if the vertex density could drop from 1.3/mm to 0.7/mm could \(<\mu>\) be even higher?

- New Triplets at Interaction Region will have twice present aperture
  - Requires modification of absorbers in the interaction region
  - appears compatible with small radius beam pipe
  - highly desirable to anticipate work in LS2 (lower activation - time gained for LS3)
- Beam loss risks (for new crab cavities and experiments)
  - Appear manageable from preliminary studies –
  - More (common) work needed

See earlier talk by Frédérick Bordry
Computing and Software

- Resources needed for computing at HL-LHC are large - but not unprecedented.
  - However, depending on technology assumptions, flat resources can only provide a factor of 2 to 10 times less CPU power than needed
    - Cloud federation may be a way to build the next Grid
    - Possible usage of specialized track processing (eg use of GPUs as for HLT)
    - Multi-core processors will need major software developments to minimize computing demands

- The use of more specialized hardware to optimize overall costs implies the need for frameworks able to seamlessly adapt and use much more heterogeneous computing resources
- CERN WLCG provides a possible framework for development of future solutions
- All LHC experiments could benefit from better coordinated efforts to develop new programming techniques

Virtualization is the key technology behind the Cloud
Conclusions

• ATLAS has a coherent plan for upgrades through the coming decade to meet the challenges up to and including the HL-LHC era, which are embodied in two LoIs and four TDRs which have been through full LHCC approval.

• The understanding of the full physics potential of the HL-LHC is advancing rapidly, with greatly increased activity on both detector and accelerator preparations following the adoption by CERN Council of the Updated European Strategy for Particle Physics, with the HL-LHC as its highest priority.

• There are designs for a replacement tracker that should withstand both the pile-up and radiation conditions at the HL-LHC, with performance able to not just fully recover, but also improve on, the current capabilities at low pile-up.

• Major R&D programmes are targeting all the upgrades needed for ATLAS to operate at luminosities far above the initial design requirements.

However, it is critical for these programmes to proceed rapidly that there be adequate resources now to develop optimized, fully cost-effective solutions.
Back-up
**ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIREE**

**CERN**

**EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH**

<table>
<thead>
<tr>
<th>Action to be taken</th>
<th>Voting Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>For Approval</strong></td>
<td><strong>Simple Majority of Member States represented and voting</strong></td>
</tr>
<tr>
<td><strong>EUROPEAN STRATEGY SESSION OF COUNCIL</strong>&lt;br&gt;16th Session - 30 May 2013&lt;br&gt;European Commission&lt;br&gt;Berlaymont Building - Brussels</td>
<td></td>
</tr>
</tbody>
</table>

The European Strategy for Particle Physics

Update 2013

Having finalised its text by consensus at its Session of 22 March 2013, the Council is now invited to formally adopt the Update of the European Strategy for Particle Physics set out in this document.
Higgs working group report

Conveners: Sally Dawson (BNL), Andrei Gritsan (Johns Hopkins), Heather Logan (Cerleton), Jianming Qian (Michigan), Chris Tully (Princeton), Rick Van Kooten (Indiana)


This report summarizes the work of the Energy Frontier Higgs Boson working group of the 2013 Community Summer Study (Snowmass). We identify the key elements of a production Higgs physics program and document the physics potential of future experimental facilities as elucidated during the Snowmass study. We study Higgs couplings to gauge boson and fermion pairs, double Higgs production for the Higgs self-coupling, its quantum numbers, and CP mixing in Higgs couplings, the Higgs mass and total width, and prospects for direct searches for additional Higgs bosons in extensions of the Standard Model. Our report includes predictions of measurement capabilities from detailed studies of the Compact Linear Collider (CLIC), a Gamma-Gamma Collider, the International Linear Collider (ILC), the Large Hadron Collider High-Luminosity Upgrade (HL-LHC), Very Large Hadron Colliders up to 100 TeV (VLHC), a Muon Collider, and a Triple-Large Electron Positron Collider (TLEP).

Table 1.15. Dominant Higgs boson production cross sections at various $e^+e^-$ collision energies. Cross sections are calculated [74] including initial-state radiation, but not beamstrahlung effects, for unpolarized beams and the enhancement due to polarized beams $P(e^-,e^+)=(-0.8,0.3)$ for 250, 350, and 500 GeV, baseline for the ILC; $(-0.8,0.2)$ for 1000 GeV, baseline for the ILC; $(-0.8,0.0)$ for 1.4 and 3.0 TeV, typical for CLIC.

<table>
<thead>
<tr>
<th>Mode</th>
<th>$\sqrt{s}$ (GeV)</th>
<th>250</th>
<th>350</th>
<th>500</th>
<th>1000</th>
<th>1400</th>
<th>3000</th>
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</thead>
<tbody>
<tr>
<td>$ZH$</td>
<td>unpolar.</td>
<td>211</td>
<td>134</td>
<td>64.5</td>
<td>16.1</td>
<td>8.48</td>
<td>2.00</td>
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<td></td>
<td>polar.</td>
<td>318</td>
<td>198</td>
<td>95.5</td>
<td>22.3</td>
<td>10.0</td>
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<td>$\nu_e\nu_eH$</td>
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<td>20.8</td>
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<td>36.6</td>
<td>72.5</td>
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<td>425</td>
<td>496</td>
<td>862</td>
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<td>$e^+e^-H$</td>
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<td>7.68</td>
<td>7.36</td>
<td>8.86</td>
<td>20.1</td>
<td>27.3</td>
<td>48.9</td>
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<tr>
<td></td>
<td>polar.</td>
<td>11.2</td>
<td>10.4</td>
<td>11.7</td>
<td>24.7</td>
<td>32.9</td>
<td>56.5</td>
</tr>
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</table>
## HL-LHC matrix: equipment, time, cost

<table>
<thead>
<tr>
<th>LS2 - 1 y (14 months access)</th>
<th>LS3 - 2 y (26 months access)</th>
<th>PIC</th>
<th>US1</th>
<th>US2</th>
<th>Cost (MCHF)</th>
<th>In kind</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>LS2</td>
<td>LS3</td>
<td>LS3</td>
<td>LS3</td>
<td>In kind</td>
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<tr>
<td>P4 new cryoplant</td>
<td>Y</td>
<td></td>
<td></td>
<td></td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>H SC link P7</td>
<td>Y</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>IR (IT,D1, TAS)</td>
<td>%</td>
<td>Y</td>
<td></td>
<td></td>
<td>210</td>
<td>YES</td>
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<tr>
<td>P1-P5 cryoplant</td>
<td>%</td>
<td>Y</td>
<td></td>
<td></td>
<td>75</td>
<td></td>
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<tr>
<td>SC link (EPC&amp;DFBX on surface)</td>
<td>%</td>
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<td></td>
<td>40</td>
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<tr>
<td>Collimators IR</td>
<td>Y</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
<td></td>
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<tr>
<td>Collimators MoGr</td>
<td>%</td>
<td>Y</td>
<td></td>
<td></td>
<td>15</td>
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<tr>
<td>Collimators for INJ &amp;TCLA Q4/Q5</td>
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<td></td>
<td></td>
<td></td>
<td>5</td>
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<td>LRBB comp.wires</td>
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<td>DS cryocoll.(11T) P7</td>
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<tr>
<td>DS cryocoll (11 T) P1-P5</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>SC link (EPC&amp;DFB on surface) for MS</td>
<td>Y</td>
<td></td>
<td></td>
<td></td>
<td>20</td>
<td>95</td>
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<td>MS new layout (P1-P5) and Q5 in P6</td>
<td>Y</td>
<td></td>
<td></td>
<td></td>
<td>30</td>
<td>YES</td>
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<tr>
<td>Machine &amp; Magnet QPS (Availability)</td>
<td>Y</td>
<td></td>
<td></td>
<td></td>
<td>25</td>
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<tr>
<td>CC cavity P1-P5</td>
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<td></td>
<td></td>
<td>95</td>
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<td>SCRF 2nd Harmonic</td>
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<td></td>
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<td>Crystal Coll</td>
<td>Y ?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>YES ?</td>
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<tr>
<td>Halo control (e-lens)</td>
<td>Y ?</td>
<td></td>
<td></td>
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<td>High Band Feedback System</td>
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<td></td>
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<tr>
<td>Studies</td>
<td></td>
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<td>10</td>
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<tr>
<td>Other systems (Studies, Vacuum, Diagnostics, Remote handling)</td>
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<td></td>
<td>30</td>
<td></td>
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<tr>
<td>Infrastructure, Logistics, Integration,Installation HWC</td>
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<td></td>
<td></td>
<td>130</td>
<td>170</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>810</strong></td>
<td><strong>810</strong></td>
</tr>
</tbody>
</table>

L . Rossi
Conclusions

• The upgrade is robust for 250 (300 ) fb\(^{-1}\)/y
  • Means to maintain or increase availability are under study
• All hardware is more robust for 3000 fb\(^{-1}\) than it is today for 300 fb\(^{-1}\)
• Design Study finished by 2015 with the TDR
• Margins are there and – once established and proved:
  • Possible to decrease pile-up density and/or increase to 350 fb\(^{-1}\) (7\(\cdot\)10\(^{34}\) of \(L_{\text{level}}\)) thanks to crab kiss (CC in II & \(\perp\) planes) and \(\beta^*\) of 10 cm (large aperture IT & ATS)
• Increase data collection to > 4000 fb\(^{-1}\)??
The ATLAS Pixel Detector

- **Three barrel layers:**
  - R= 5 cm (B-Layer), 9 cm (Layer-1), 12 cm (Layer-2)
  - modules tilted by 20° in the RΦ plane to overcompensate the Lorentz angle.

- **Two endcaps:**
  - three disks each
  - 48 modules/disk

- **Three precise measurement points up to |η| < 2.5:**
  - RΦ resolution: 10 μm
  - η (R or z) resolution: 115 μm

- 1456 barrel modules and 288 forward modules, for a total of 80 million channels and a sensitive area of 1.7 m².
  - Environmental temperature about -10 °C
  - 2 T solenoidal magnetic field.
Module Overview

• **Sensor**
  - 47232 n-on-n pixels with moderated p-spray insulation
  - 250 μm thickness
  - 50 μm (RΦ) × 400 μm (η)
  - 328 rows (x\text{local}) × 144 columns (y\text{local})

• **16 FE chips**
  - bump bonded to sensor

• **Flex Hybrid**
  - passive components
  - Module Controller Chip to perform distribution of commands and event building.

• **Radiation-hard design:**
  - Dose >500 Gy
  - NIEL >10^{15} n\text{eq}/cm^2 fluence
ATLAS Silicon Strip Detectors

- 4 barrels (2112 modules) and 2×9 disc end-caps (1976 modules)
- 61m² of silicon micro-strip detectors
- ~20,000 separate 6cm×6cm sensors

NIKHEF and University of Liverpool

University of Oxford

CERN
ATLAS Tracker Based on Barrel and Disc Supports

Effectively two styles of double-sided modules (2×6cm long) each sensor ~6cm wide (768 strips of 80μm pitch per side)

Barrel Modules
(Hybrid bridge above sensors)

Forward Modules
(Hybrid at module end)
Current Silicon Microstrip (SCT) Material

Current Silicon Tracker (4 barrel strip layers)

Module Material

Support Material

Old ATLAS Barrel Module
12 ASIC of 300μm thickness for double-sided module read-out (ie just 6 read-out chips per side)

New ATLAS sLHC-Tracker Module will have 80 ASICs in two hybrid fingers for just one-sided read-out

“The barrel modules of the ATLAS semiconductor tracker”.

Table 1
Radiation lengths and weights estimated for the SCT barrel module

<table>
<thead>
<tr>
<th>Component</th>
<th>Radiation length [Xo]</th>
<th>Weight [gr]</th>
<th>Fraction [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon sensors and adhesives</td>
<td>0.612</td>
<td>10.9</td>
<td>44</td>
</tr>
<tr>
<td>Baseboard and BeO facings</td>
<td>0.194</td>
<td>6.7</td>
<td>27</td>
</tr>
<tr>
<td>ASIC’s and adhesives</td>
<td>0.063</td>
<td>1.0</td>
<td>4</td>
</tr>
<tr>
<td>Cu/Polyimide/CC hybrid</td>
<td>0.221</td>
<td>4.7</td>
<td>19</td>
</tr>
<tr>
<td>Surface mount components</td>
<td>0.076</td>
<td>1.6</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>1.17</td>
<td>24.9</td>
<td>100</td>
</tr>
</tbody>
</table>

Hybrid area per module roughly ×2 at HL-LHC: much higher R/O granularity
Simulation results fit with data to much better than a factor of 2 (and safety factor of 2 was assumed in dose specifications)

(Temperature history key to fitting $I_{\text{leak}}$)
New All-silicon Inner Tracker

- Alternative layouts being considered which include either a further pixel layer or inclined pixel sensors attached to the same barrels (Alpine layout)

Extended $\eta$ coverage needs more detailed physics motivation
Stave: Hybrids glued to Sensors glued to Bus Tape glued to Cooling Substrate

Current Prototypes 250nm ASIC Designs
Stave: Hybrids glued to Sensors glued to Bus Tape glued to Cooling Substrate

Module, Stave and Petal concepts with 130nm ASIC:
256 channels so each row of ASICs address two rows of strips