A detailed 3D cutaway diagram of the ATLAS detector at the Large Hadron Collider. The diagram shows the complex internal structure, including the central beam pipe, the inner and outer tracking detectors, the calorimeters, and the muon chambers. The detector is shown in a perspective view, with the beam pipe entering from the left. The text "UPGRADE PROJECT AND PLANS FOR THE ATLAS DETECTOR AND TRIGGER" is overlaid in the center of the image.

UPGRADE PROJECT AND PLANS FOR THE ATLAS DETECTOR AND TRIGGER

REAL-TIME CONFERENCE
JUNE 11-15, 2012, BERKELEY

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ON BEHALF OF THE ATLAS COLLABORATION

SUMMARY

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ATLAS TRIGGER DETECTORS

ATLAS CURRENT TRIGGER SYSTEM

- The Level- 1 system does the initial event selection reducing the **40 MHz** beam crossing frequency to **~100 kHz**
 - these are the system design parameters, currently we are running at 50 ns bunch crossing spacing and at ~75 kHz level- 1 rate
- Level- 1 processing is performed on **reduced granularity** information from Calorimeters detectors and on **full granularity** information from Muon Trigger detectors
- Level- 1 selections:
 - **signatures** from high p_T muons, electrons/photons, jets, τ -leptons decaying into hadrons
 - **events** with large missing transverse energy
- **Central Trigger Processor (CTP)** receives inputs from Level- 1 Calorimeter and Level- 1 Muon systems, plus some additional inputs used for luminosity measurements and calibration
- **Level- 2** selection: **full granularity** read-out data from Regions-of-Interests only, software based algorithm, partial reconstruction, **~5 kHz** output
- **Event Filter**: full reconstruction (**~200 Hz** by design, currently **~600 Hz**)

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LHC UPGRADE SCENARIO

- Phase-0: 2015-2017
 - LHC: 25 ns bunch spacing, 13 TeV centre-of-mass energy, $1 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ instantaneous luminosity
 - ATLAS: collect 50 fb⁻¹
- Phase-I: 2019-2021
 - LHC: 14 TeV centre-of-mass energy, $3 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ instantaneous luminosity
 - ATLAS: collect 300 fb⁻¹
- Phase-II: 2024-...
 - LHC: $7 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ with luminosity leveling
 - ATLAS: collect 3000 fb⁻¹

High Luminosity LHC (HL-LHC) physics potentials:

- Higgs physics
- increase the statistics for detailed studies and precision measurements
- extend the reach to new physics

ATLAS TRIGGER UPGRADE

- Motivations:

- The trigger system was designed to operate at the **design value** of the LHC instantaneous luminosity:
 $1 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
- Physics studies at HL-LHC will be based on **p_T and E_T trigger thresholds** at the electro-weak scale (as today)
- The **trigger rates** will exceed the allocated bandwidths at HL-LHC
- The **trigger selection** will have to be more efficient and increase the rejection power in order to select interesting events without exceeding the allocated trigger rates

- Solutions:

- Increase the trigger **granularity** where possible in order to increase the rejection power
- Add **new detectors** if necessary, or use detectors information that are currently not used for triggering
- Replace current Level-1 **trigger electronics** to add new algorithms, to add more flexibility and to move existing software algorithms into hardware
- Introduce more complex selections at **Event Filter** (plans are more gradual and flexible)

Warning:
introducing more **complexity/**
flexibility into the trigger logic
has to be balanced against the
increase of the **trigger latency**
(processing time)

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LEVEL-1 CALORIMETER TRIGGER (PHASE-I)

- Level-1 single electro-magnetic **trigger rates** increase linearly with luminosity (good agreement shown between simulations and data)
- Trigger rates will exceed allocated limit at Phase-I
- Partial replacement of the LAr on-detector electronics is foreseen for Phase-I, it will provide **digital trigger information** with **higher resolution and granularity**
- Finer **cluster shaping** algorithms and higher energy resolution can reduce the trigger rates
- New Level-1 trigger electronics will be developed to take advantage of the **higher granularity digital data** and to introduce **more flexibility** in the algorithms

Level-1 Calorimeter Trigger for Phase-II:

- The calorimeters will convert to **full digital readout**
- The trigger system may take advantage of the calorimeters' **full granularity** information

see also talk "The evolution and performance of the ATLAS calorimeter-based triggers in 2011 and 2012" by I. Radoslavova Hristova

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LEVEL-1 MUON TRIGGER (PHASE-I)

- Muon trigger current detectors: **RPC** in the Barrel region and **TGC** in the End-Cap region
- Muon trigger rates are actually dominated by unforeseen **fakes**
 - especially in the End-Cap region, which occupies most of the muon bandwidth
- The majority of MU20 triggered muons has a p_T lower than 20 GeV (due to the trigger detectors **p_T resolution**)
 - at Phase-I most of the trigger high p_T bandwidth would be occupied by lower (unwanted) p_T muons
- The **Small Wheel** (inner part of the End-Cap system), actually not used for trigger, will have to be replaced for Phase-I (detector hit rate limit)
- The introduction of **new trigger detectors** in the Small Wheel region can significantly **reduce the trigger rate**, making use of:
 - additional **trigger coincidence** with the Big Wheel (for reducing the fakes)
 - trigger detector higher **p_T resolution** (for increasing the rejection power)

LEVEL-1 MUON TRIGGER (PHASE-I)

- The New Small Wheel (NSW) will be formed by small **Thin Gap Chambers** + **MicroMega** detectors
- Both detectors can be used for triggering purposes (angular resolution < 1 mrad)
- Trigger concept: at each Bunch Crossing find **pointing local tracks** in the NSW to confirm Big Wheel coincidences
- Simulations show that the **fake trigger** rate is significantly **reduced**
- **New trigger electronics** is required in order to integrate the NSW with the current End-Cap Level-1 muon trigger system

L1 rate for $L_{inst} = 3 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$		
	without NSW	with NSW
MU20	$59.6 \pm 10.7 \text{ kHz}$	$21.9 \pm 3.2 \text{ kHz}$
MU40	$28.8 \pm 5.3 \text{ kHz}$	$10.3 \pm 1.6 \text{ kHz}$

LEVEL-1 MUON TRIGGER (PHASE-II)

- Further improvement of the trigger **detectors resolution** in the regions where the trigger rate could be too high
- Study the possibility to install **new detectors** in the Barrel/End-Cap border region (new Small Wheel does not cover the entire Big Wheel region)
- Study the possibility to install **new detectors** in the outer part of the Big Wheel, in order to improve the rejection rate and to achieve the same resolution of the New Small Wheel
- Study the possibility to make use of the high spatial resolution of the **Monitor Drift Tube detector** (currently used as precision muon detectors)

The **old muon electronics** may have to be **replaced** (some part of the inner MDT detector electronics may be not accessible for replacement)

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CENTRAL TRIGGER PROCESSOR

- Phase-0:
 - Redesign part of the CTP modules in order to increase the number of **trigger inputs** and the **trigger menu flexibility**
 - Add the **topological trigger** logic
- Phase-I
 - Integration with the New Small Wheel trigger system
 - Provide muon information for topological processor
- Phase II:
 - CTP **full replacement** to integrate new trigger systems and new interfaces (readout, TTC, ...)

TOPOLOGICAL TRIGGER:

- new logical trigger system for Phase-0
- Topological algorithms are based on the **detailed information** sent from L1Muon and L1Calo systems
- The system is conceived to provide maximum possible **flexibility** and to execute **many different types of algorithms** with minimal latency cost
- Example of proposed algorithms:
 - **overlap detection** and disambiguation between different RoI types (electron/jet, electron/tau, etc.)
 - **angle calculation** between leading objects and/or missing E_T ($\Delta\phi$, $\Delta\eta$, ΔR)
 - **vector/total E_T sums** over unsorted groups of objects (jets, electrons, muons,

see also talk "Topological and Central Trigger Processor for 2014 LHC luminosities" by E. Simioni

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LEVEL-2 FAST TRACKER (PHASE-I)

- The Fast Tracker (FTK) is a **hardware track finder**, it selects physics processes through their track-based signatures
- FTK system is based on the use of **associative memories**
- Receives data from the **tracker detectors** readout and reconstructs tracks with $p_T > 1 \text{ GeV}$
- Operates at the full Level-1 trigger output rate
- Performs global tracking at beginning of Level-2, holding results in buffers for HLT (latency $\sim 100 \mu\text{s}$)
- Reconstructed tracks can be used to select interesting events (taus, b-tag) and reduce the trigger rate

see also talk "A Hardware Tracker Finder (FTK) for ATLAS Trigger" by G. Volpi

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LEVEL-1 TRACK TRIGGER PROPOSAL (PHASE-II)

- The Phase-2 scenario is currently under study
- Possible **Level-1 Track** Trigger:
 - New proposed hardware level-1 system providing **track segments** and momenta using tracking detectors information
 - Trigger selection can be improved combining calorimeter/muon information with tracks
 - Can significantly **reduce single lepton trigger rates** combining calorimeter/muon information with tracks
 - Can improve tau identification and b-tagging
 - Increase the **Level-1 latency** ($\sim 20 \mu\text{s}$)
 - Current Level-1 trigger scheme likely to be replaced by a **two-level trigger**

- Possible **two-level trigger**:
 - Level-1 Track trigger could be seeded by the current Level-1 system (renamed Level-0)
 - Level-1 Calorimeter trigger may take advantage from a two-level trigger for the full granularity calorimeters readout
 - Two stages: L0A as the actual Level-1 ($\sim 10 \mu\text{s}$; $\sim 500 \text{ kHz}$), followed by a further hardware trigger decision (L1A) with a significantly longer latency ($\sim 20 \mu\text{s}$; $\sim 100 \text{ kHz}$)
 - Detectors may decide whether to make use of L0A and/or L1A

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CONCLUSIONS/SUMMARY

- Most of the required modifications to the trigger system that have been investigated are at Level-1
- The proposed modifications have been proved to significantly increase the trigger performances and physics event selection quality
- Phase-I trigger upgrade plan is currently more definite than the Phase-II one, which is still under discussion/study
 - Phase-II Letter-of-Intent to be ready by the end of 2012
 - Phase-I Technical Design Report to be ready by the end of 2013
- Phase-I upgraded systems have to be compatible with Phase-II specifications
- New ATLAS detectors for the upgrade:
 - Phase-I: New Small Wheel
 - Phase-II: Inner Detector replacement; possible new muon detectors
- New trigger electronics/systems:
 - Phase-0: topological trigger
 - Phase-I: FTK; new Calorimeter/L1Calo electronics; New Small Wheel trigger integration in the End-Cap; new MuCTPi
 - Phase-II proposals: new L1Calo electronics; new L1Muon electronics; new CTP; possible Track trigger with L0/L1 scheme; possible use of MDT detector in the L1 trigger; in case of new muon detectors integration in the L1 trigger