TRIUMF

ATLAS Upgrade for the High-Luminosity LHC

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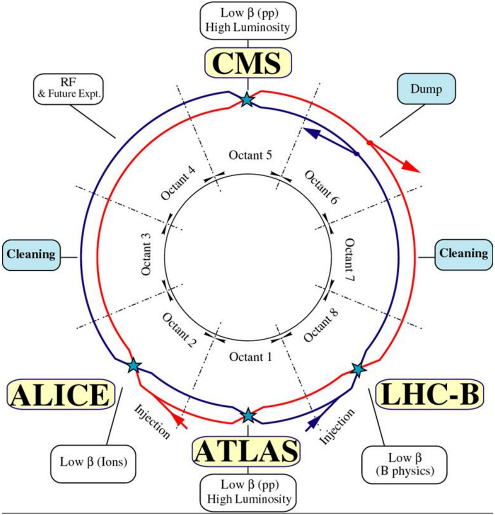
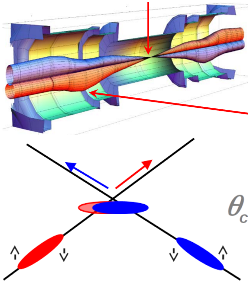
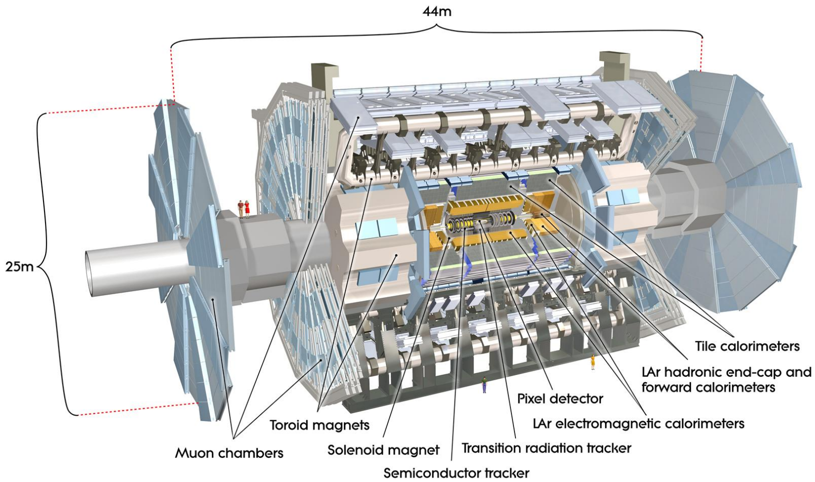
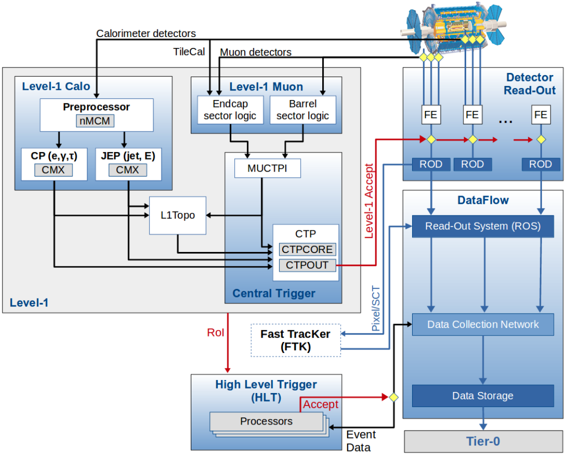


13 TeV; nominal luminosity: 1×10^{34} cm^{-2} s^{-1}, recently reached ultimate, 2×10^{34} cm^{-2} s^{-1} and delivering integrated luminosity to ATLAS of around 60 fb^{-1} this year

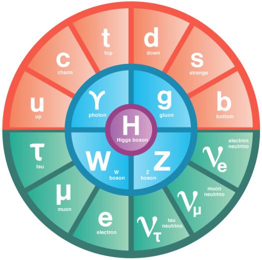
- Improved injectors: more protons per bunch and brighter, including all-new Linac-4
- Better focus: β^* from 55 cm to 15 cm
  - Needs Nb_3Sn focusing triplets with wider-aperture and higher field gradient
- Crab cavities: high bunch-bunch interaction needs wider crossing angle, would reduce overlap of bunches in collision region
  - Rotate bunches sideways, maximising overlap at collision
- 14 TeV and 7×10^{34} cm^{-2}s^{-1}
- ...with luminosity levelling i.e. rather steady during a spill instead of decaying away
- 250-300 fb^{-1} per year...goal 3000 fb^{-1} integrated luminosity; Factor 10 bigger data set than LHC

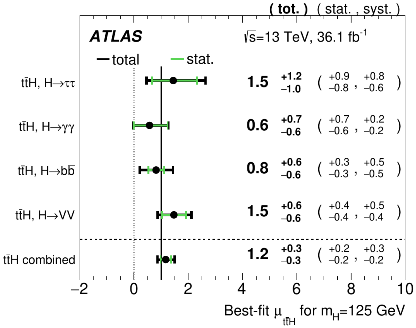



44m
25m
Tile calorimeters
LAr hadronic end-cap and forward calorimeters
Pixel detector
LAr electromagnetic calorimeters
Toroid magnets
Muon chambers
Solenoid magnet
Transition radiation tracker
Semiconductor tracker



- 100 kHz L1 with 2.2 μs latency
- High Level Trigger: initially processes region of interest fed by L0, then full data set
- Challenging now, more so at high luminosity to avoid raising thresholds

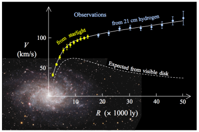


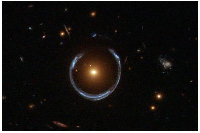


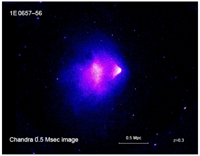
- Higgs discovered by ATLAS and CMS, 2012
- Many decay channels and properties measured
- Everything as expected for Standard Model
- One example from very many: Higgs in association with top pair

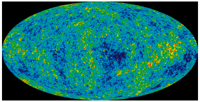
But we know there is more...

- Dark Matter, SUSY particles as candidate
- Neutrinos have mass (oscillations)
- Dark Energy (Accelerating expansion of universe)
- The LHC experiments search beyond the SM, and are ruling out swathes of parameter space
- Amassing a bigger data set will further push these limits to higher masses or lower cross sections, or make discoveries





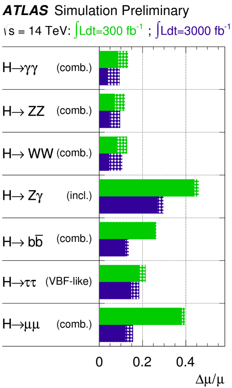


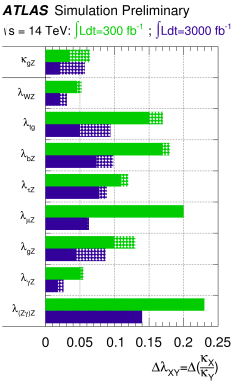


HL-LHC Goals: Standard Model Measurements

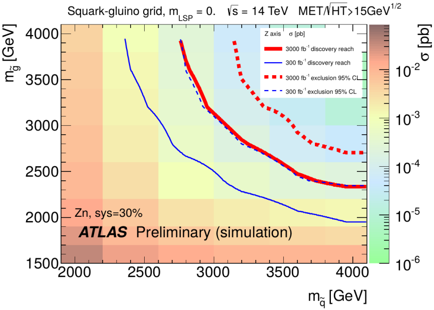
Examples:

- Precision measurements: deviation from SM hints at new physics.
- Branching ratios e.g. H to $\mu\mu$
- Anomalous couplings
- Triple gauge couplings, especially HHH (measures the Higgs potential)

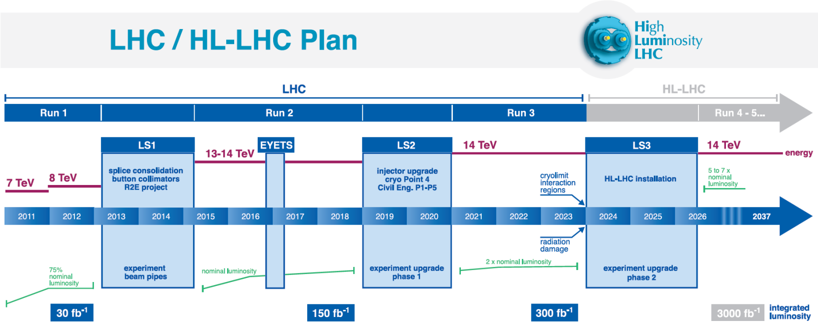




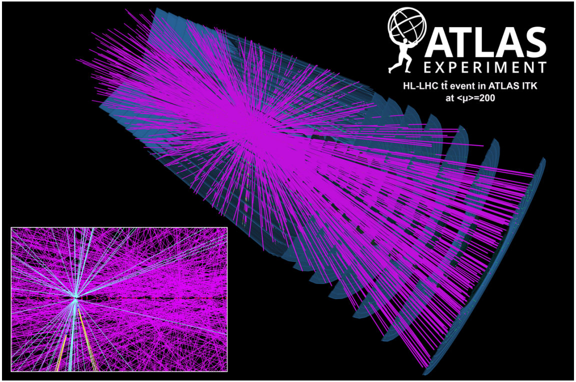
- Bigger data set accesses lower cross-sections and higher masses
  - More events for a given cross section
  - More events involving partons at very high fraction of the proton momentum reaches higher masses
  - Systematic errors can reduce with bigger data sets: better understanding and measurement of systematics
- Examples:
  - Supersymmetric particles (DM candidates)
  - New forces (aka Z′, W′ searches): e.g. Sequential Standard Model Z'



Process	300 fb^{-1}	3000 fb^{-1}
$Z' \rightarrow ee$	6.5	7.8
$Z' \rightarrow \mu\mu$	6.4	7.6



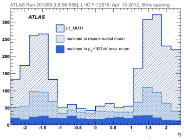
- Long shutdown 3 from 2024 to mid-2026 will see major upgrades to LHC and the experiments
- Next slides cover upgrades to ATLAS detector systems for the HL-LHC

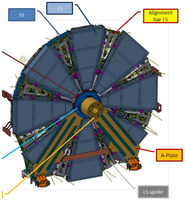


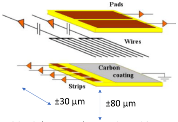
- Coping with 200 pileup events and radiation damage from 3000 fb^{-1} needs upgrades to all parts of ATLAS
- The plot shows one bunch crossing with production of a $t\bar{t}$ pair
- Next slides go through each ATLAS system

Trigger Upgrades

- Baseline with a single L0 trigger:
  - L0: 1 Mhz at 10 μs latency
  - Uses calorimeter and muon data, and (combined) topology of trigger objects to select events
  - Feeds software Event Filter recording at 10 kHz
- If needed, two-level L0 and L1 with inner tracker Hardware Track Trigger (HTT):
  - 4 MHz L0
  - L0 feeds region of interest to inner tracker, which sends data from those regions to HTT
  - HTT consists of large contents-adressed memory with good track patterns pre-loaded
  - HTT sends track info (quite precise helix parameters) to L1 processor for 600 kHz output at 35 μs latency
- The size of each event almost doubles; large storage needed
- These trigger requirements drive the design of the trigger, readout systems, numbers of links etc.



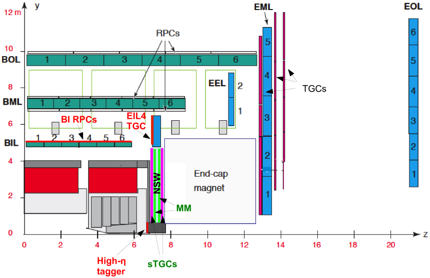


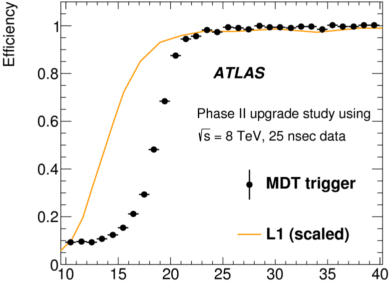


Precision is key: must know strip positions to 30 µm in-plane, 80 µm in depth

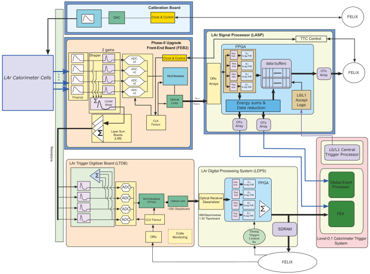
- Improved forward muon trigger: use inner-most endcap stations in trigger
- Reduce high rate of false triggers in forward region
- Already useful now; new Small Wheels to be installed in shutdown starting end of this year
- Eight layers of sTGC/micromegas, giving a precise vector to check vertex comes from IP
- Major Canadian contribution in sTGC
  - TRIUMF — assemble outer planes ("half gaps")
  - Carleton — wind wires, close with half-gaps
  - McGill — cosmic ray test stand

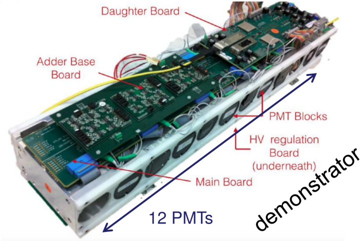
- Replace frontend on- and off-detector readout and trigger electronics
- Integrate precision MDT chambers into L0 trigger to sharpen the momentum threshold
- New RPC chambers in inner-barrel layer to increase acceptance and robustness
- Replace some MDT's in inner barrel layer with smaller diameter MDT - higher rate capability
- Replace some TGC doublets with triplets in barrel-endcap transition region to suppress backgrounds





- Both Tiles and LAr will replace frontend boards and read-out all data at 40 MHz
  - Allows full granularity in trigger keeping thresholds low, without increase in background rate
- Highest radiation region Tile PMTs replaced (8 %)
- Better reliability with new power supplies; redundancy in these and data paths.

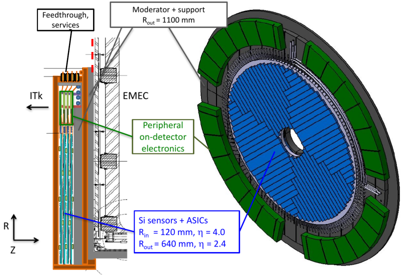


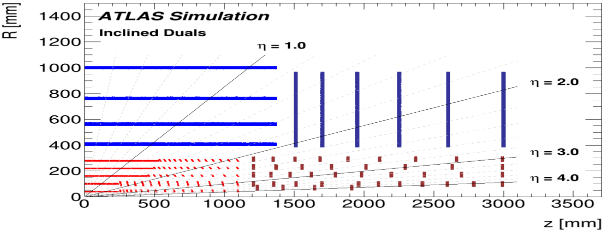


Canadian projects	Deliverables	Responsibility
FE-ASIC design	HEC flavor of FE-ASIC	TRIUMF
FEBs for HEC	CORE sharing. FEB integration	U. Vic., U. Toronto
HEC calibration boards	CORE sharing	U. Vic., U. Toronto
BE processors	CORE sharing, FW developments	McGill, U. Vic., U. Toronto

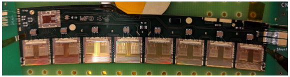
- Canada made major contributions to the Hadronic Endcaps (HEC) and ForwardCAL.
- Continues with upgrades
- Included proposing warm calorimeter with diamond detectors in front of the current FCAL, which would have reduced heat load and ionisation levels (now dropped since not necessary)
- HEC preamplifiers are inside the cryostat, unlike the barrel part
  - Very different reuirements to the barrel — separate analogue ASIC needed
  - Sampling fractions different between front and back; opposite polarity signal; Signal shape varies (varying capacitance of detector)

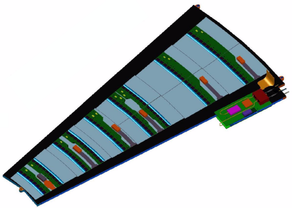
- Forward jets merge with a lot of pileup; inner detector z_0 resolution very forward is few mm - can contain more than one primary vertex
- Distinguishing jets from primary interaction can be helped by timing
- Use space between inner detector and calorimeter endcaps (few cm)
- Use low-gain avalanche detectors for ≈ 30 ps timing (≈ 10 mm in z_0) per layer. Many layers and tracks allows some improvement on inner detector alone



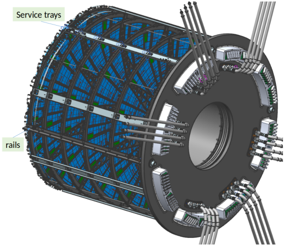


- High track density; high radiation damage ... completely replace current ID
- All silicon Inner Tracker ITk
- Shorter strips, smaller pixels keeps low occupancy and noise at end-of-life
- Pixel layout being finalised
  - Extend cover to $\eta = 4.0$ - forward tracking to assign tracks to vertices, confirm muons
  - Five barrel layers, many endcap layers, about 13 m^2 and 5×10^9 pixels
- Strips TDR published
  - Cover to $\eta = 2.7$ matching muon detector; 165 m^2 of silicon sensors
  - Four double layers barrel and endcap (6 wheels); each sensor about 100 cm^2
  - Strip width about 75 μm, resolution 22 μm rms.
  - Stereo angle between pairs of sensors on either side of cooled CF support gives second coordinate to about 0.7 mm



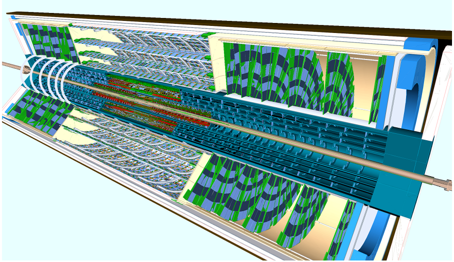


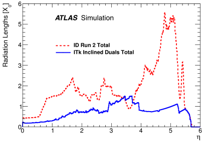
- See talk by F. Guescini, this Congress, for details of module and petal design
- Combined effort of East (Carleton, Montreal, Toronto, York), and West (SFU, UBC, TRIUMF)
- Sensor acceptance tests for one endcap, Carleton and SFU
- ASIC wafer probing for one endcap and half of barrel, at DA-Integrated, Ottawa
- Assemble hybrids for one endcap (in industry, Toronto)
- Assemble modules (500 East, 1000 West)
- Mount those modules on 84 petals (West)
- Ship petals to Nikhef, Amsterdam and DESY, Hamburg for assembly into endcaps

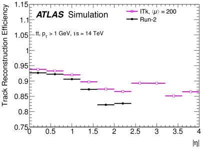


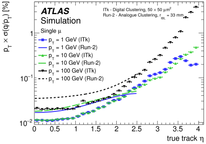
ITk Performance from Geant4 Simulation

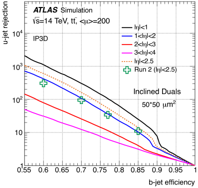
- Detailed sensors and supports/services material model
- Considerable engineering input - some confidance in material estimates and performance results
- Radiation length ITk much less than current ID
- Resolution performance mostly better; still work in progress
- B-quark identification comparable
- ITk performance same or better despite 200 pile-up











- ATLAS Upgrades will allow full benefit of the very high luminosity from the HL-LHC in 2026
- There is a rich field of particle physics to be explored, including Higgs sector and searches for Dark Matter
- All detector systems have advanced plans including many Technical Design Reports completed or well on their way to completion
- All-new ITk achieves similar or better performance than current ID despite the high pile-up
- Canada will make important contributions to the muon Small Wheels, Strip detector of the ITk, and the LAr Endcaps