ATLAS future prospective and upgrade

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On behalf of the ATLAS collaboration

ATLAS EXPERIMENT

UNIVERSITY OF TORONTO

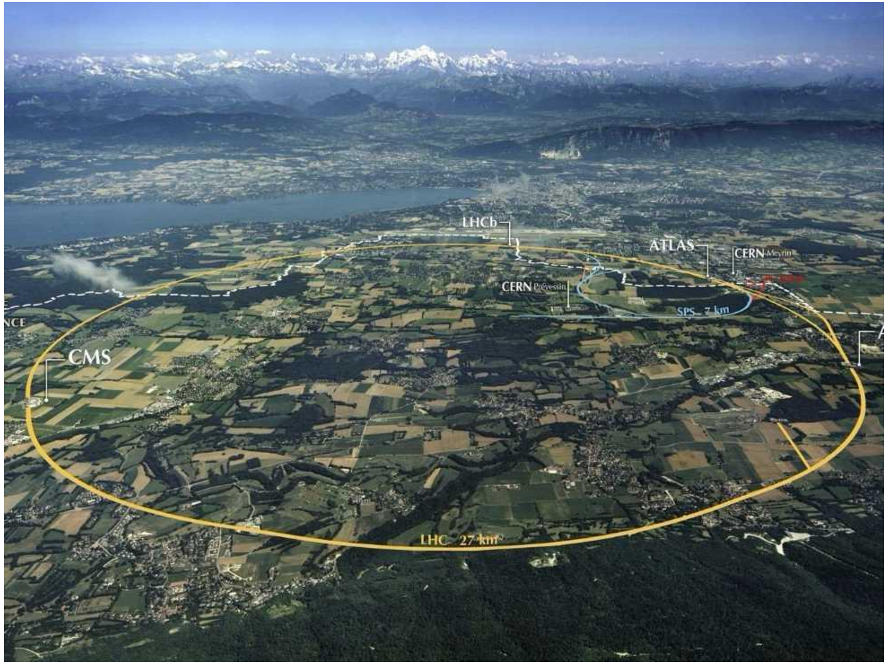
CERN

Outline

- LHC upgrade schedule and its impacts on physics

- ATLAS upgrades
  - Phase-I
  - Phase-II

- Physics prospects
  - SM measurements
  - BSM analyses



LHC upgrades - schedule

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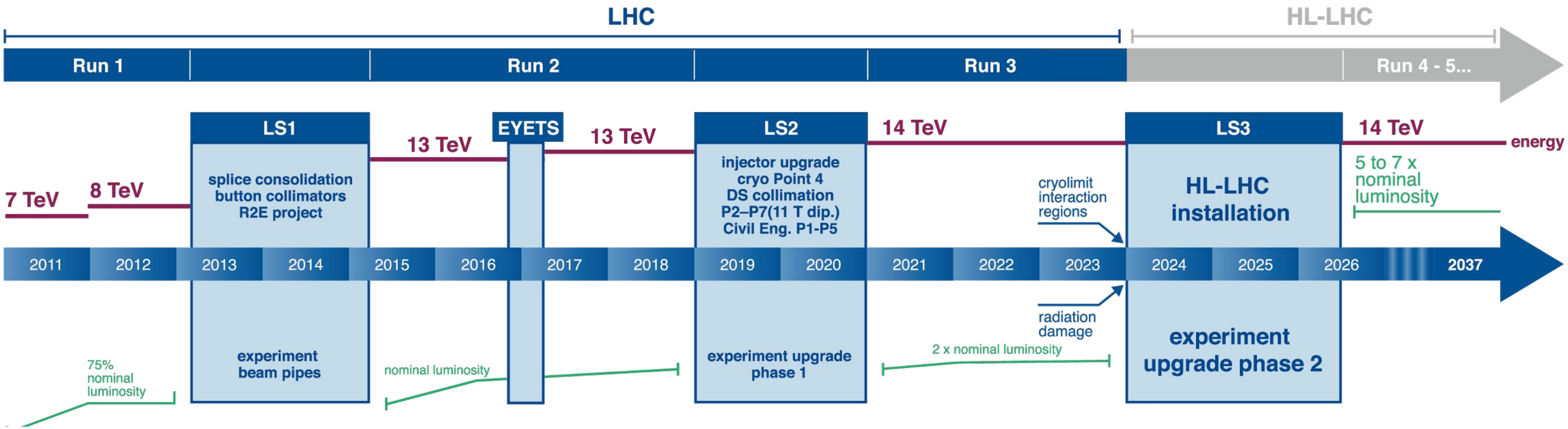
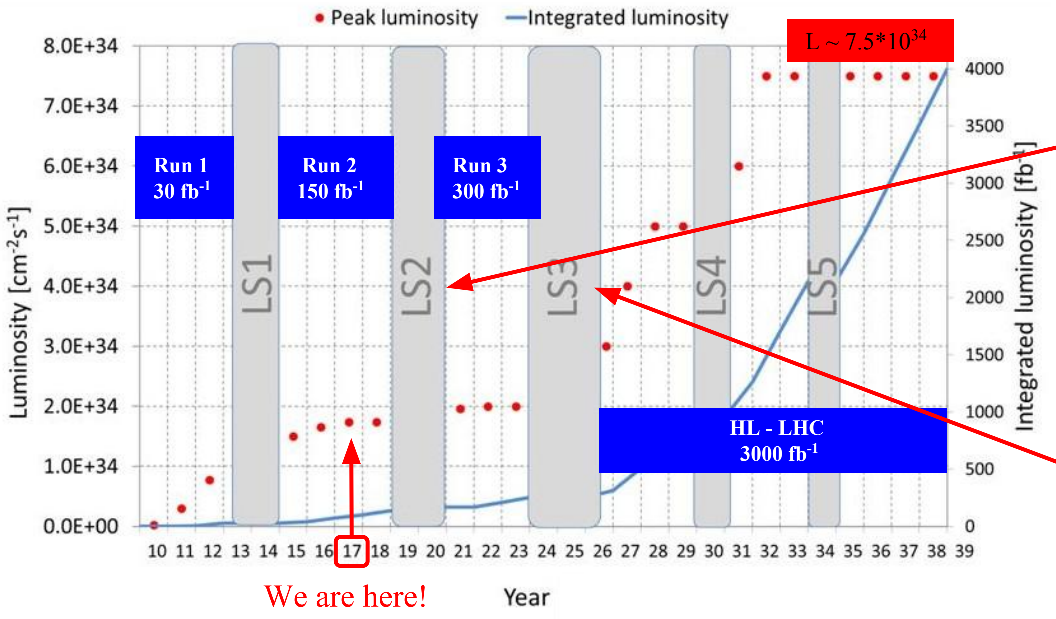


- In 2017 the LHC reached a record luminosity of $\mathcal{L} = 2.06 \times 10^{34}$ cm^{-2}s^{-1}.
- Upgrades during long shutdown 2 (LS 2) will allow running at the design c.m. energy of $\sqrt{s}$=14 TeV and at $\mathcal{L} = 2\text{-}3 \times 10^{34}$ cm^{-2}s^{-1}.
- HL - LHC installed during LS 3 will run at luminosities $\mathcal{L} = 5\text{-}7.5 \times 10^{34}$ cm^{-2}s^{-1}.

LHC upgrades - performance

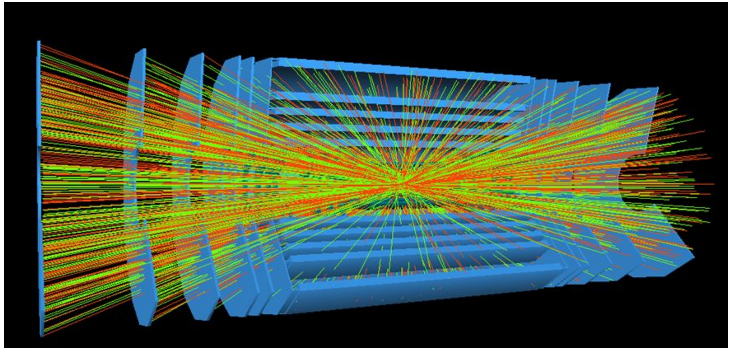


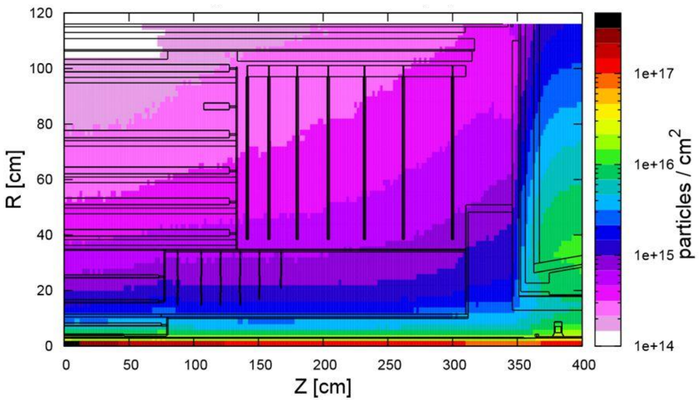
Phase-I:
- Calorimeter trigger
- Muon trigger

Phase-II
- Whole inner tracker replaced
- Trigger & DAQ upgraded (latency and maximal rate change)
- Calorimeter and muon electronics replaced

Impact of high luminosity on ATLAS

- Significant increase in statistics
  - Improved sensitivity to higher mass particles and rare processes.
- Detector challenges:
  - High pile up (<μ> up to ~200 collisions/crossing) and higher occupancy.
  - High radiation levels (~10^{16} neq/cm²; 10 MGy)
- Requirements:
  - Keep good physics performances in this challenging environment.
  - Keep reasonable trigger rate with low p_T threshold by mitigating pile up, especially in the forward regions. A new DAQ architecture will be set up to cope with the increased data rate.





ATLAS upgrades - Phase-I

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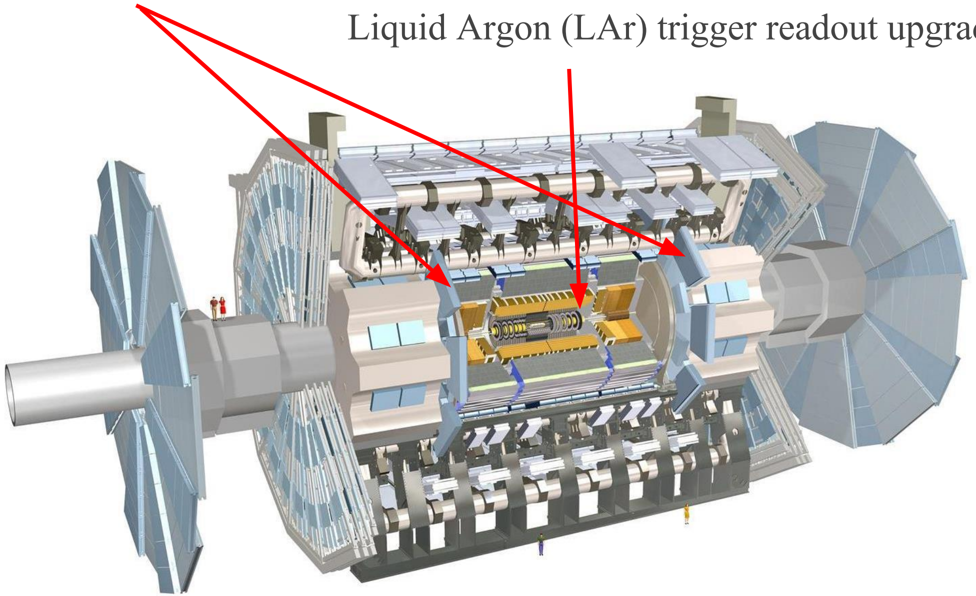
New Small Wheel

Liquid Argon (LAr) trigger readout upgrade

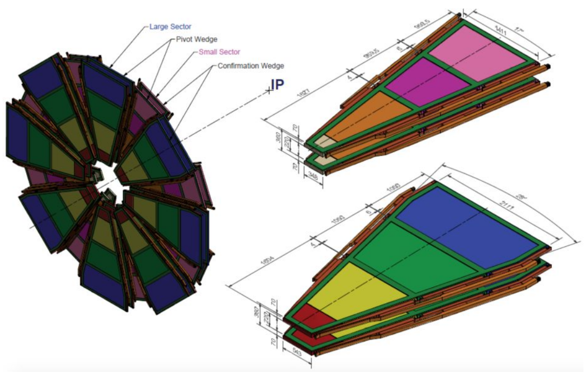


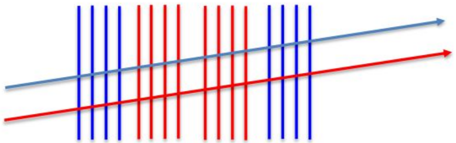
- Level-1 (L1) hardware trigger
  - L1 calorimeter
  - L1 topological
  - L1 NSW trigger
  - L1 endcap trigger
  - L1 MuCTPi
- L1.5 hardware trigger
  - Fast Tracker

Phase-I: New small wheel (NSW)

- Two wheels with a radius of 5m will be installed on each side with a coverage of 1.3 < |η| < 2.7.

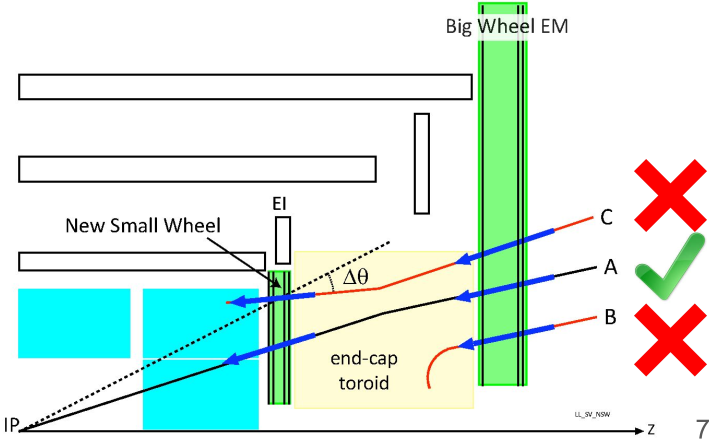
- Two detector technologies will be used for NSW chambers:
  - Small-strip Thin Gap Chambers (sTGC)
    - Used for triggering with < 1 mrad resolution
  - MicroMegas (MM)
    - Used for tracking with < 100 μm spatial resolution.





4+4+4+4 detection planes, separated in wedges

- NSW will reduce fake muon rates in the end cap region by applying a coincidence trigger and putting a requirement on the pointing of the muons.

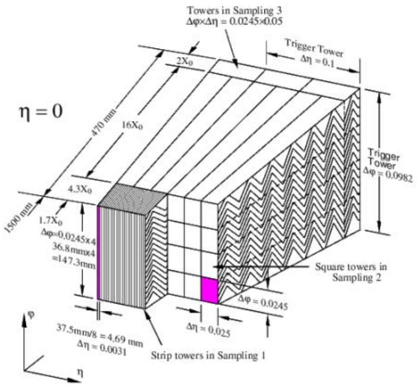


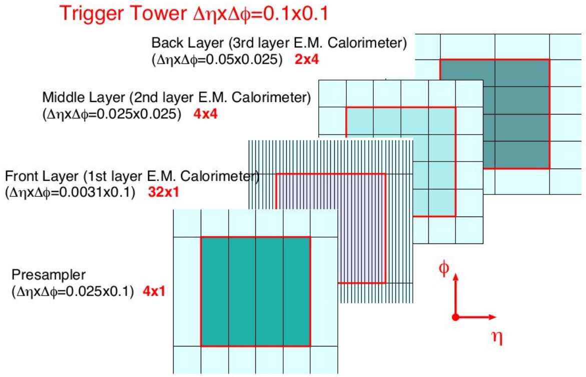
Phase-I: LAr calorimeter

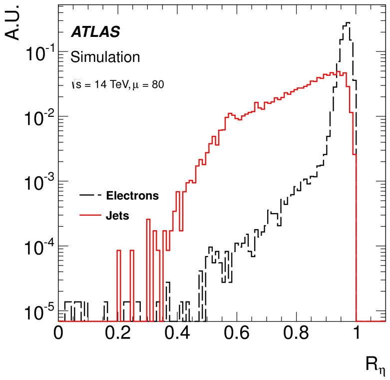
- New front and back end trigger electronics
    - **Higher granularity and resolution** + longitudinal shower shape information to L1
    - Rejection criteria applied to the L1 EM trigger to reduce dominant QCD jet background.

- Shower shape variables will **keep the trigger rates low without increasing the p_T thresholds**.

- New Feature Extractor boards will allow **more refined processing of electromagnetic calorimeter information** at higher granularity.

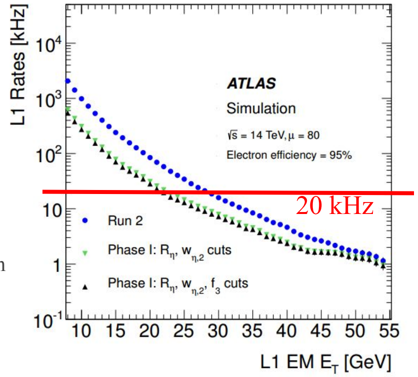






Ratio of transverse energy E_T in shower core to that in total shower in the middle layer.

For an electron efficiency of 95% the E_T threshold can be lowered by 7 GeV with respect to Run 2 keeping the 20 kHz rate budget as measured from a sample of simulated minimum bias events with <μ> = 80



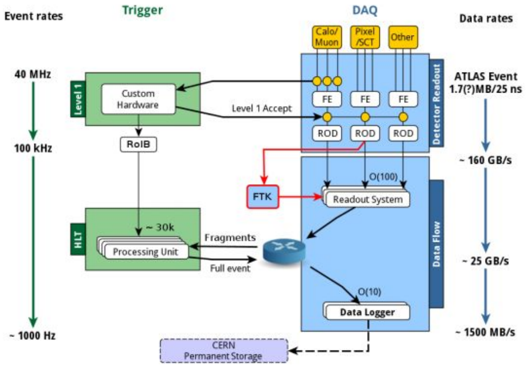
Phase-I: Fast Tracker (FTk)

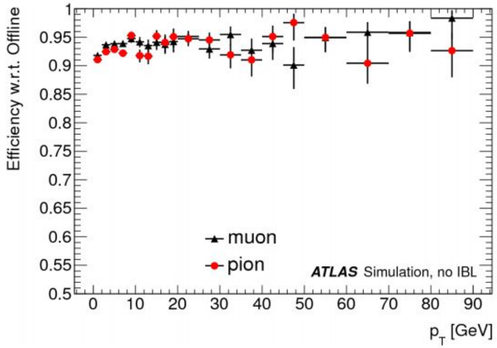
- Electronics system that rapidly **finds and reconstructs tracks** in the inner-detector layers.

- For every event passing the L1 trigger at a **maximum rate of 100 kHz** the FTk receives data from the silicon detectors, providing tracking information to the HLT in ~**25 µs**.

- FTk performs the **tracking in two steps**.
  1. Track candidates are identified by comparing the fired *superstrips* (rebinning of pixels into coarser resolution) to predefined trajectories stored in memory. Such a "pattern" refers to a list of superstrips describing the trajectory of a simulated particle as it traverses the detector layers.
  2. These track candidates at coarse resolution seed a full-resolution track fitting done by FPGAs.

- FTk information leads to higher trigger efficiency for medium-p_T b's and τ's with high background rejection.



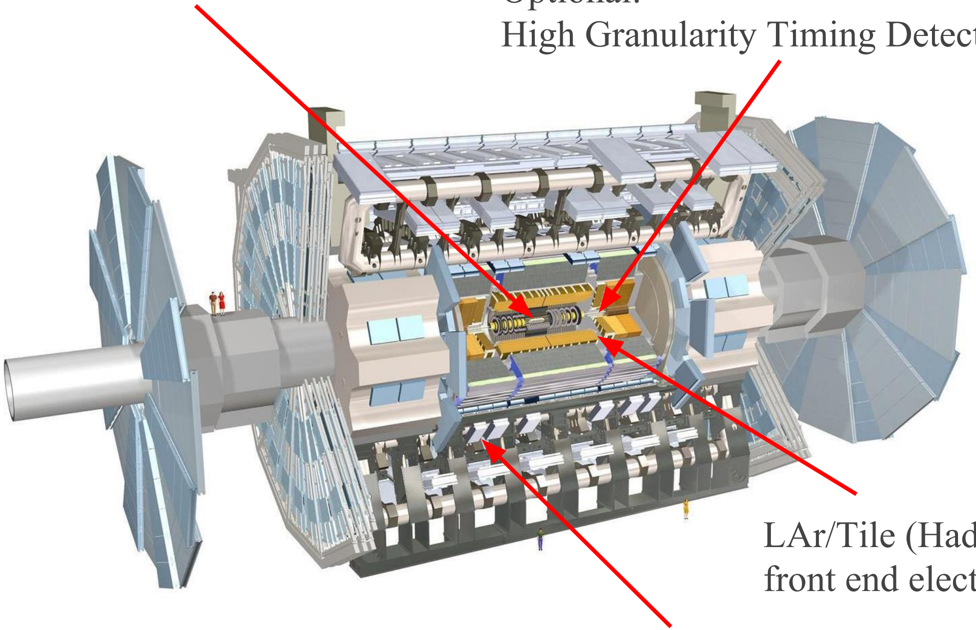


Absolute efficiency with respect to truth particles in muon and pion samples versus p_T for $p_T > 1$GeV.

ATLAS upgrades - Phase-II

New silicon Inner Tracker (ITk)

Optional:
High Granularity Timing Detector (HGTD)



LAr/Tile (Hadronic cal.)
front end electronics

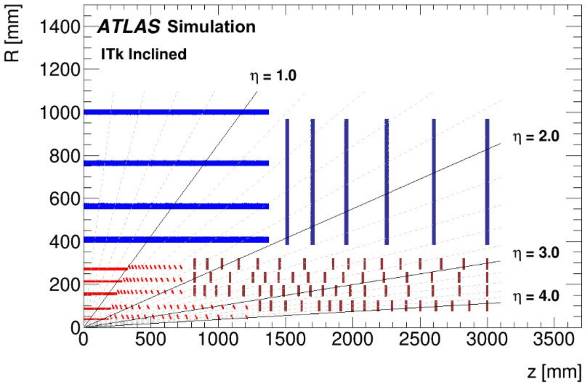
New muon chambers and front
end readout electronics

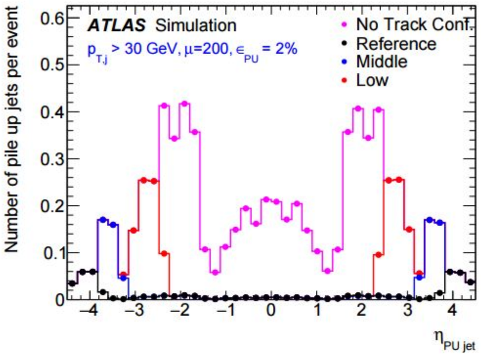
DAQ off detector electronics:

- L0 hardware triggers will provide trigger decisions within a latency of 10 μs.
    - Based on muon and calorimeter data + their combinations in the topological processors.
- The L1Track trigger processes L0 RoIs to search for ITk tracks with high transverse momentum.
- The L1Global uses full-granularity calorimeter information and improved granularity for the entire detector.

Phase-II: Inner Tracker (ITk)

- All-silicon tracker which provides **coverage for tracking for up to $|\eta| < 4.0$.**
- **Equal or better performances** than the existing detector in a much more difficult tracking environment.
- Radiation tolerance: possible to extract and replace inner parts if needed.
- High track reconstruction efficiency and low rate of fake tracks.
- Track efficiencies:
  - Muons with $p_T > 3$ GeV:
    99.8% for $|\eta| < 2.7$
  - Pions (Electrons) with $p_T > 2$ GeV (5 GeV):
    90% for $|\eta| < 1$,
    85% for $1 < |\eta| < 2.7$





Phase-II: LAr/Tile calorimeter and HGTD

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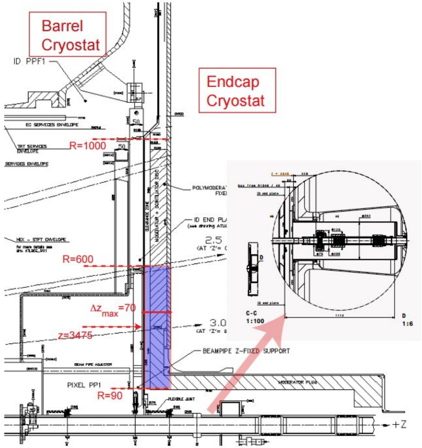
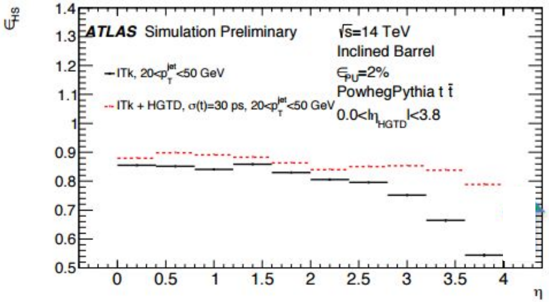
- The readout electronics of the LAr and Tile calorimeters is **not compatible with Phase-II trigger rates and latencies** and will be exchanged.
- Radiation hardness requirements are above original design (1 kGy and 2.7×10^{13} neq/cm²) .
- **Full granularity information will be digitized** in the front end and sent to the back end at 40 MHz.

- Optional:
  A new **High Granularity Timing Detector (HGTD)** instrumenting the gap region between the two LAr cryostats is under discussion:
  - Low gain avalanche diodes planned to be used.
  - Mitigation of pile up effects in the forward and end cap regions by using timing information of the tracks.
  - Improvement of electron, photon, and jet/E_T^{miss} performance.





Phase-II: Muon detectors

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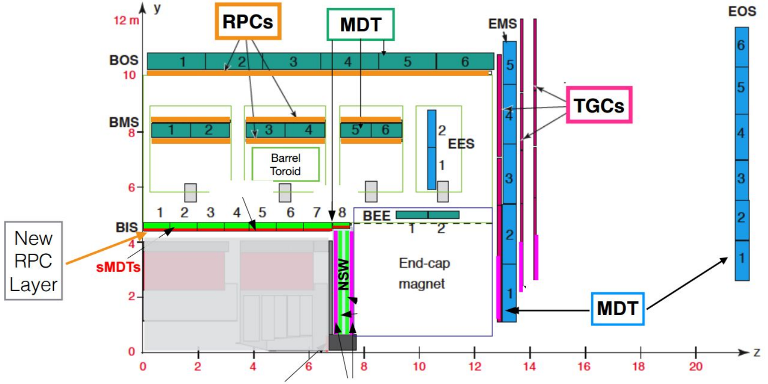
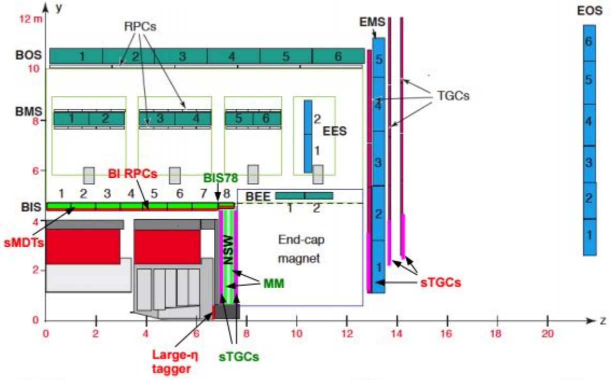
- **Trigger fake rate** in barrel and end cap regions has to be reduced.

- The currently installed RPCs and the TGCs (limited to 100 kHz readout) will be replaced by new RPCs and sTGCs which are able to cope with the high rate trigger requirements.

- Small-diameter Muon Drift Tube (sMDT) chambers will be installed in detector regions where MDT chambers do not fit. They will provide an order of magnitude higher rate capability.

- Optional: **Large-η tagger** (2.7 < |η| < 4.0)
Instrument this pseudorapidity region with position sensitive detectors to allow the tagging of inner detector tracks as muons to **minimise muon mis-identification probability**.





Physics prospects

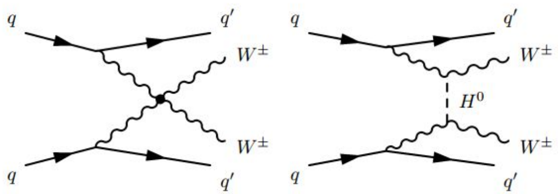
Benchmark analyses

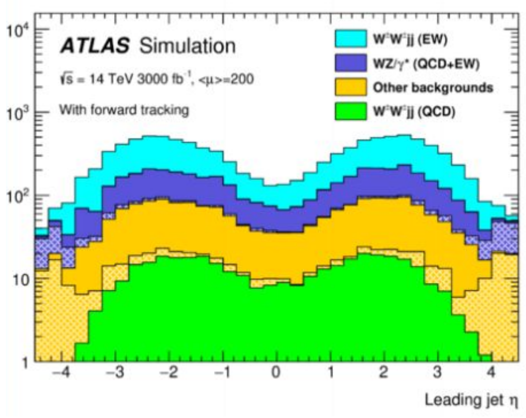
- **Standard model**
  - Same sign $W^{\pm}W^{\pm}$ Vector Boson Scattering (VBS)
  - VBF Higgs production
  - Higgs boson coupling measurements
- **BSM**
  - Direct production of stau pairs
  - Chargino and neutralino pair production
  - New heavy bosons

- All studies done with a parameterised simulation of the ATLAS detector at a centre-of-mass energy of 14 TeV.

Same sign $W^{\pm}W^{\pm}$ VBS

- VBS is crucial to understand the nature of the **electroweak symmetry breaking mechanism**.
- The $W^{\pm}W^{\pm}$ channel is experimentally interesting because of its **rare signature**:
  - Two same-sign leptons
  - Two forward jets which are well separated in rapidity
  - Moderate E_T^{miss}
  - Electroweak signal is comparable in size to that from QCD-induced processes
- Main background: WZ + jets production
- Advantages of increased tracker coverage:
  - Pile up jets rejection
  - Veto additional leptons from WZ background in the forward region



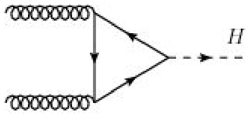


Tracking coverage	Precision on cross section measurement $\Delta\sigma / \sigma$
Without forward tracking	4.5 %
With forward tracking	3.9%

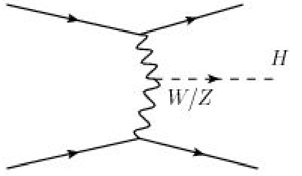
ATL-TDR-025
LHCC-2017-005

VBF Higgs boson production $H \to WW^{(*)} \to l\nu l\nu$

- Unique signature for VBF production
  - Two forward jets
  - Large dijet invariant mass.
- Main background: $t\bar{t}$
- Advantages of increased tracker coverage:
  - Pile up jet rejection better because of higher central-jet-veto efficiency
  - b-jet veto possible also in the forward region and hence better $t\bar{t}$ background suppression
- The increase in tracker coverage allows precision measurement of VBF Higgs production even in a high pile up environment.



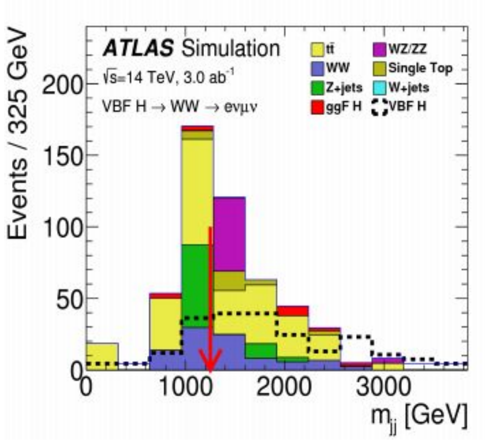
gg fusion



VBF production

Tracking coverage	Expected precision (*) cross section measurement $\Delta\sigma / \sigma$
Without forward tracking	22%
With forward tracking	12%

(*) neglecting theoretical uncertainty on ggF and VBF production



ATL-PHYS-PUB-2016-018

Higgs boson precision measurements

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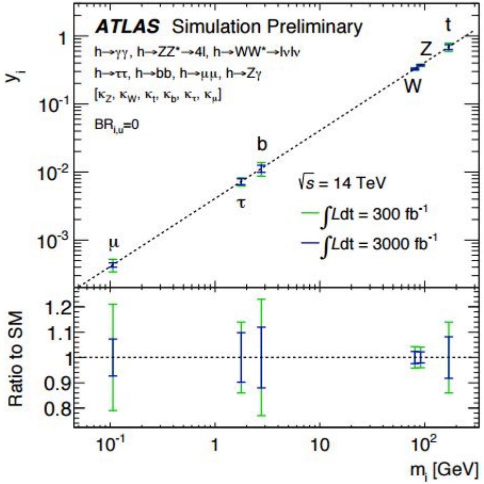
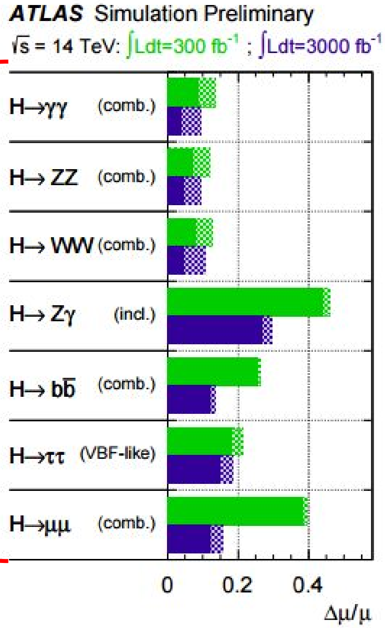
HL - LHC will enable **precise measurements of the Higgs sector** to address many open questions such as the hierarchy problem, the nature of dark matter, etc.



Couplings relative to the SM values with 3000 fb^{-1}.
W, Z couplings ~3%
μ coupling ~7%
t,b,τ couplings 8-12%

Higgs decay modes



Signal strength $\mu=\sigma/\sigma_{SM}$

Theoretical uncertainty

Relative uncertainty on the combined signal strength in the considered final states.
Full projection from Run 1 results.

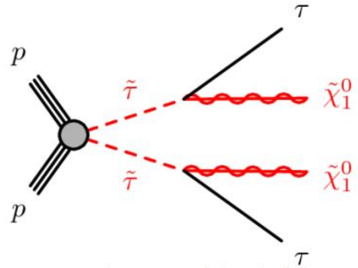
JHEP 08 (2016) 045
ATL-PHYS-PUB-2014-016

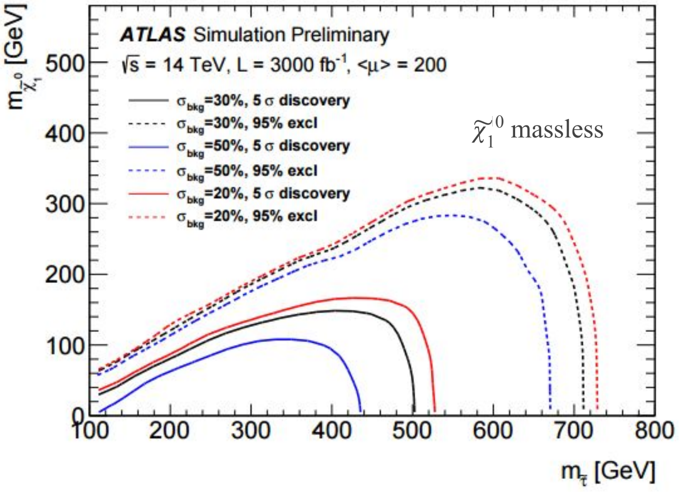
BSM: Direct production of stau pairs

- Assumption: Stau decaying hadronically to τ and $\tilde{\chi}_1^0$ (LSP).
- Signature:
  - Two τ jets
  - Large E_T^{miss}
- Main backgrounds from W + jets and $t\bar{t}$

- 95% CL exclusion limits:
  - 540 GeV (pure $\tilde{\tau}_R\tilde{\tau}_R$) - 700 GeV (for $\tilde{\tau}_R\tilde{\tau}_R$ and $\tilde{\tau}_L\tilde{\tau}_L$ combined production)

- 5σ discovery sensitivity:
  - 100 - 500 GeV in $\tilde{\tau}$ mass for $\tilde{\tau}_R\tilde{\tau}_R$ and $\tilde{\tau}_L\tilde{\tau}_L$ combined production
  - 120 - 430 GeV for pure $\tilde{\tau}_L\tilde{\tau}_L$
  - No discovery sensitivity for $\tilde{\tau}_R\tilde{\tau}_R$ because the production cross section is too low.





ATL-PHYS-PUB-2016-021

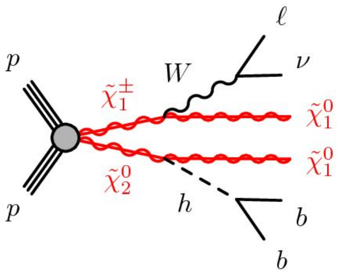
BSM: Chargino and neutralino pair production

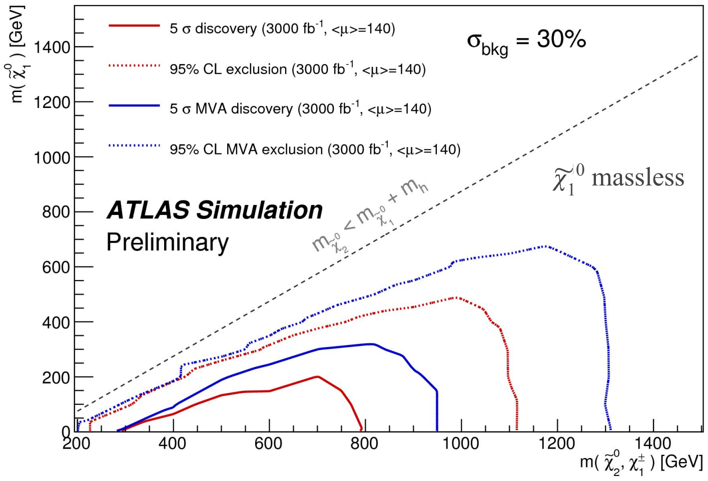
- Signature
  - Chargino decaying to leptonic W → clear signature
  - Neutralino decaying to lightest Higgs boson (assumed SM like) $h \rightarrow b\bar{b}$: benefits from detector upgrades
  - Large E_T^{miss}

- Largest background contributions
  - W + jets, $t\bar{t}$, single top, $t\bar{t}V$

- 95% CL exclusion limits:
  - 1310 GeV in $\tilde{\chi}_2^0\tilde{\chi}_1^\pm$ mass

- 5σ discovery sensitivity:
  - 950 GeV in $\tilde{\chi}_2^0\tilde{\chi}_1^\pm$ mass

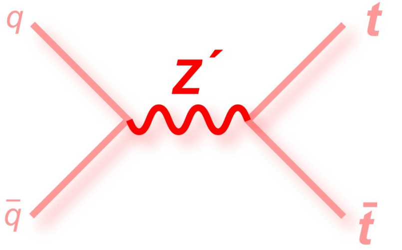


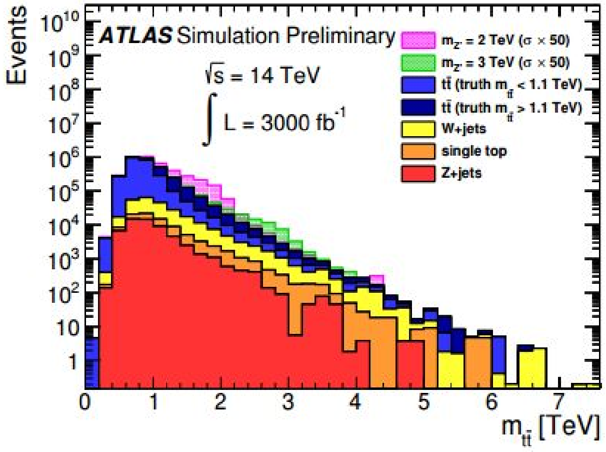


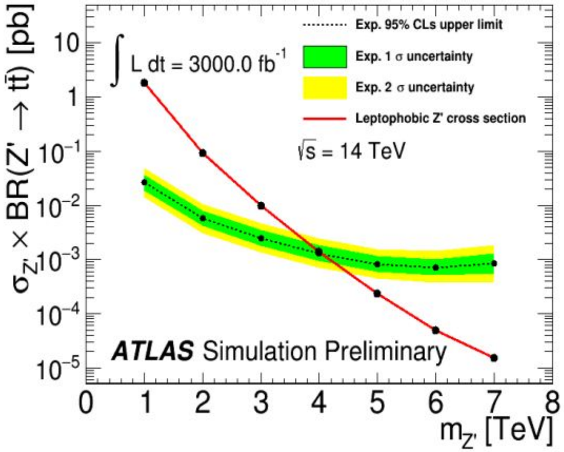
ATL-PHYS-PUB-2015-032

New heavy bosons

- A search for a **local excess or deficit in the $t\bar{t}$ mass spectrum** is performed on $t\bar{t}$ pairs.
- **Semi-leptonic** decay channel:
  - Both top quarks decay to a b quark and a W boson.
  - One W decays to two quarks and the other decays to a lepton and a neutrino.
- Search benefits from **improved statistics for high p_T** events.
- Top quark decays **highly boosted**, hence, search relies on good reconstruction of boosted objects.
- Search uses benchmark resonance $Z' \to t\bar{t}$







Expected HL-LHC mass reach: $m_{Z'} \sim 4$ TeV

ATLAS Run 1 mass constraint: $m_{Z'} > 2.1$ TeV

ATL-PHYS-PUB-2017-002

Conclusion

- The LHC conditions will continue to be **more and more challenging**.
  - Pile up of up to ~200.
  - Large background and increased radiation

- ATLAS has a **major upgrade plan** set to be able to cope with the harsher conditions. TDRs are already finished or in progress.

- The physics program will benefit from a **significant increase in statistics and sensitivity** to higher mass particles and rare processes, providing useful insights into Higgs coupling measurements, BSM physics, etc.

- Studies for the HL - LHC are still ongoing and there is **a lot of space for improvement**. All assumptions presented here are conservative and most probably the results will be better than this.

- A **rich and diverse program** is set to keep high energy physicists busy and excited for the next years and decades.