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Expected performance of the upgraded ATLAS experiment for HL-LHC

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On behalf of the ATLAS Collaboration

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The high luminosity challenge

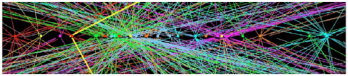
The High Luminosity Large Hadron Collider (HL-LHC)

- Upgrade of the LHC to be installed between 2024 and 2026
- Operational parameters:
  - Center of mass energy: $\sqrt{s} = 14$ TeV
  - Instantaneous luminosity: 5.0×10^{34} cm^{-2} s^{-1}
  - Average interactions per bunch crossing: $\langle \mu \rangle = 200$
  - Integrated luminosity: 3 ab^{-1}

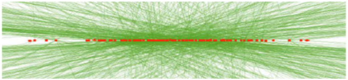
ATLAS phase II upgrade

- Major upgrade of the ATLAS detector to maintain or improve current performance under new challenging conditions
- Six Technical Design Reports (TDR) and one Technical Proposal (TP) describing motivations, performance and technical details

Current LHC: ~25 vertices

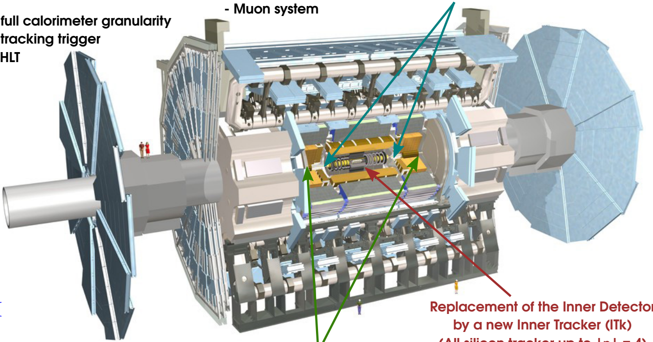


High-Luminosity LHC: ~200 vertices



This talk will focus on three physics benchmarks that highlight the phase II improvements: HH→4b – EW $W^{\pm}W^{\pm}jj$ – Measurement of weak mixing angle

The upgraded ATLAS phase II detector



Other ATLAS phase II talks in this session ...

Earlier today: Calorimeter System

Later today: ITk (Strip), HGTD, Muon system (Micromegas), ITk (Design and layout), Muon System (HL-LHC overview), Muon system (MDT)

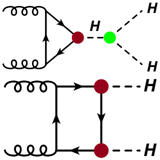
Tomorrow Morning: Trigger system

... will cover how ATLAS is achieving the performance I'll show today

Non resonant HH production in the $bb\bar{b}\bar{b}$ final state

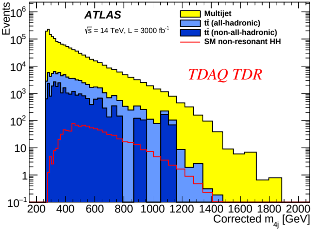
Higgs pair production is a principal goal of the HL-LHC programme

- Enable measurement of the Higgs self-coupling
- Small cross section → Use dominant $H \rightarrow b\bar{b}$ mode
- Combination with $bb\gamma\gamma$ and $bb\tau\tau$ to increase sensitivity



Analysis based on an extrapolation of 2015+2016 results

- 4 jet trigger and offline selection of 4 b-tagged jets with $P_T > 65$ GeV (Anti-k_T with R=0.4)
- Two Higgs candidate pairs required to have an invariant mass consistent with the Higgs mass
- Additional requirements on P_T and on ΔR and $\Delta\eta$ between the two candidates



What detector upgrades will help this analysis?

Improvements in b-tagging (Identification of jets containig a b-hadron decay)

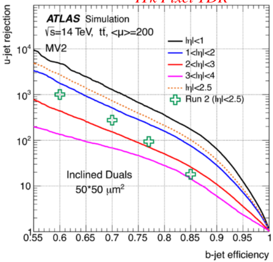
Maintaining a low P_T cut for the jet selection

Non resonant HH production in the $b\bar{b}b\bar{b}$ final state

Improved b-tagging using MV2 (Multi-variant tagger)

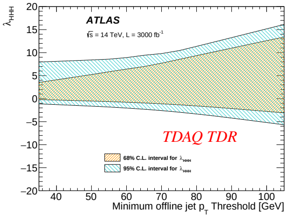
- Better tracking performance, extended $|\eta|$ range and re-optimisation of algorithms for ITK and HL-LHC conditions
- *Improvement of up to 20% on final limits*

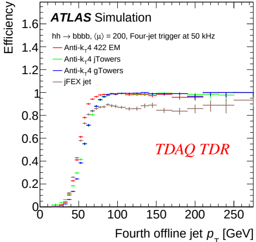
ITk Pixel TDR



Analysis very sensitive to low P_T cut → Low Trigger Pt threshold required

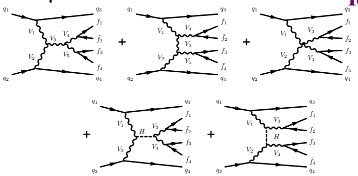
- Global Trigger (offline-like jets at L0) and HTT (Hardware Tracking Trigger) to achieve 65 GeV
- Without Global Trigger → *P_T cut 75 GeV and 25% sensitivity loss*





With $3ab^{-1}$ the allowed range at 95% CL for $\lambda_{HHH}/\lambda_{HHH}^{SM}$ with negligible systematics and P_T cut of 65 GeV is -2.4 – 9.5

Electroweak production of $W^{\pm}W^{\pm}jj$



Ideal channel to study the EWSB mechanism

- EW production dominant to QCD in $W^{\pm}W^{\pm}jj$
- EW production contains Vector Boson Scattering (VBS) diagrams and not VBS diagrams
- VBS contribution enhanced in BSM scenarios

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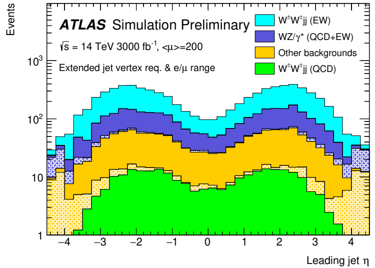


Particle level analysis with smearing functions derived from simulation of the upgraded ATLAS detector

- Same sign dilepton selection with additional jets and moderate E_T^{miss}
- Kinematics cuts to enhance VBS conribution

What detector upgrades will help this analysis? Forward tracking for jets, electrons and muons Improved Muon reconstruction Reduced material budget

Electroweak production of $W^{\pm}W^{\pm}jj$

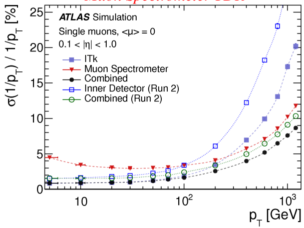
Extension of the tracking and the muon reconstruction to high Eta

- In addition to extending object reconstruction it helps with pileup jet rejection
  - Jet Vertex Requirement (JVR) only possible within tracking coverage
  - No tracking ↔ jet P_T threshold increased to compensate
  - Increasing tracking coverage allows same P_T threshold for full range
- **Improvements both in expected signal significance and precision**

	Range for JVR, lepton Range	Significance	Precision	Significance improvement	Precision improvement
No forward tracking	$\|\eta_{jet}\| \leq 2.5$, $\|\eta_{e\mu}\| \leq 2.7$	17	4.5%	-	-
Forward tracking for jets, electrons and muons	$\|\eta_{jet}\| \leq 3.8$, $\|\eta_{e\mu}\| \leq 4.0$	19	4.0%	**15%**	**13%**

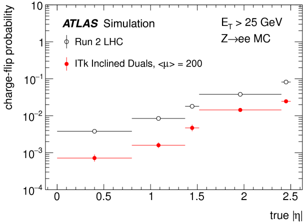
Improved muon reconstruction with ITk and upgraded muon spectrometer

Muon Spectrometer TDR



Less material budget → Less electron charge miss-identification

ITk Pixel TDR



Precision measurement of the Weak Mixing Angle

Z boson couples different to left- and right handed fermions

- Asymmetry in the angular distribution of dilepton events
- Size of the asymmetry at the Z pole depends on the weak mixing angle
- Sensitive to BSM through radiative corrections

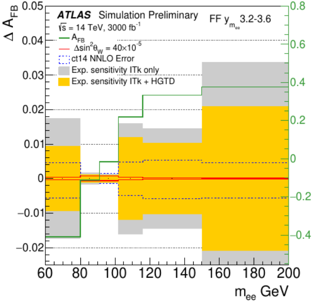
$$A_{FB} = \frac{N(\cos\theta^* > 0) - N(\cos\theta^* < 0)}{N(\cos\theta^* > 0) + N(\cos\theta^* < 0)},$$

θ^*:angle between the negative lepton and the quark in the Collins-Soper frame of the l^+l^- system

Particle level analysis with smearing functions derived from simulation of the upgraded ATLAS detector

- Extraction done minimising χ^2 of particle level A_{fb} with different hypothesis
- ID requirements and track-based isolation to reduce miss-identified jets contribution
- Best sensitivity with di-electron pairs with one forward electron

High Granularity Timing Detector (HGTD) TP



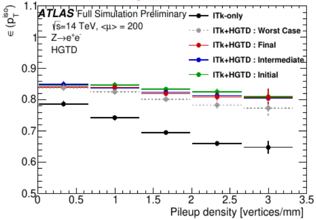
$$\Delta^2 \sin^2\theta_{\text{eff}} = 18 \times 10^{-5} \pm 16 \times 10^{-5}\,\textbf{(PDF)} \pm 9 \times 10^{-5}\textbf{(exp)}$$

Precision measurement of the Weak Mixing Angle

What detector upgrades will help this analysis? Timing measurement using HGTD,

Extension of tracking coverage and **Good overall electron identification**

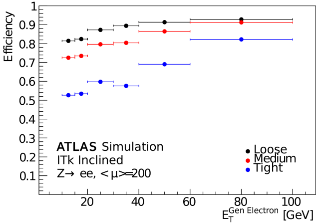
HGTD TP



HGTD can be used to assign time to leptons and nearby tracks in the forward region

- Reject tracks which come from other interactions but are spatially close
- *Addition of HGTD keeps the isolation efficiency above 80% even at high pileup density*

LAr TDR



Cut-based results on electron ID show similar performance as Run2

- Full optimisation and re-training of multivariate discriminant is still under investigation

ITk alone provides a 40% improvement on significance by adding track isolation in the forward region while HGTD brings an extra 13% improvement

Summary

Major upgrade of the ATLAS detector to be installed between 2024 and 2026

- *Objective: Maintain or improve performance at the challenging HL-LHC conditions with* $\langle\mu\rangle = 200$
- Most sub-detectors will undergo major modifications to one or various areas
- Complete replacement of the Inner Detector by the new ITk
- 6 TDRs and 1 TP available that discuss performance and technical details

Three benchmark analysis shown with emphasis on how the upgraded detector helps performance

- B-tagging, pileup-jet rejection, object reconstruction, extended tracker, Timing measurement, improved trigger.. → **Many more I did not talk about!**

Keep an eye out for other ATLAS speakers in today's and tomorrow's sessions for many more details on the HL-LHC ATLAS upgrade!

Results obtained from

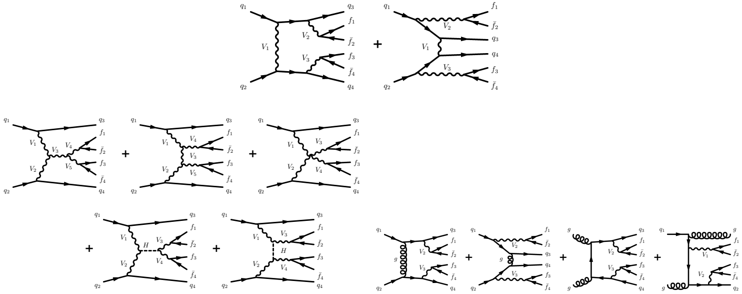
ITk Strip TDR
Muon Spectrometer TDR
LAr Calorimeter TDR
Tile Calorimeter TDR
TDAQ TDR
ITk Pixel TDR
HGTD TP

Backup

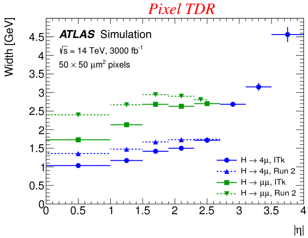
Full selection for $W^{\pm}W^{\pm}jj$ analysis

Selection requirement	Selection value
Number of leptons	2 leptons with $p_{\mathrm{T}} > 25$ GeV
Dilepton separation and charge	$\Delta R_{\ell,\ell} \geq 0.3$, $q_{\ell_1} \cdot q_{\ell_2} > 0$
Dilepton mass	$m_{\ell\ell} > 20$ GeV
Z_{ee} veto	$\lvert m_{ee} - m_Z \rvert > 10$ GeV
$E_{\mathrm{T}}^{\mathrm{miss}}$	$E_{\mathrm{T}}^{\mathrm{miss}} > 40$ GeV
Jet selection and separation	at least two jets with $\Delta R_{\ell,j} > 0.3$
Dijet rapidity separation	$\Delta\eta_{j,j} > 2.4$
Number of additional preselected leptons	0
Dijet mass	$m_{jj} > 500$ GeV
Lepton centrality	$\zeta > 0$

Diagrams for $W^{\pm}W^{\pm}jj$ production



Higgs boson production in $\mu\mu$ and 4μ final states

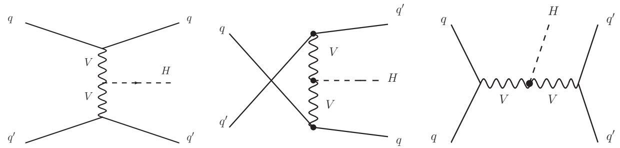


Higgs precision measurements

- H→ $ZZ \rightarrow 4\mu$ and H→ $\mu\mu$ measurements present opportunities to make precision measurements of the Higgs boson
- Both channels profit from muon measurement improvements, extended tracking and muon identification.

Vector Boson Fusion (VBF) topologies are of particular interest

- Two well separated forward jets
- A new trigger module , the forward Feature Extractor (fFEX) will handle full granularity forward calorimeter information $2.5 < |\eta| < 4.9$
- Possibility of defining Inclusive VBF triggers



B-Physics performance

$B_s \to \mu\mu$

- Statistics very dependent on dimuon trigger → (6 GeV,6 GeV) thresholds x75 Run-1 statistics
- B_s mass resolution improved with ITK

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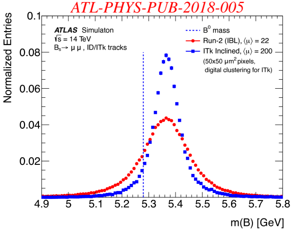

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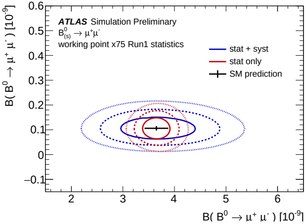
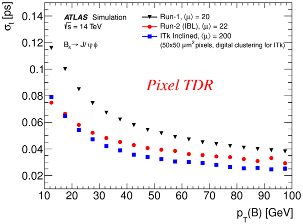


$B_s \to$ J/ΨΦ

- Improved decay time resolution due to upgrade Inner Tracker
- Proper time resolution very sensitive to reduced material budget.

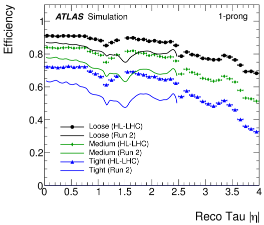


τ-lepton reconstruction performance

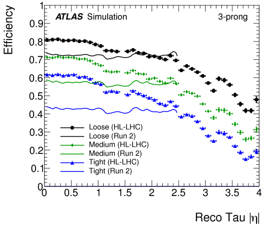
Important part of ATLAS HL-LHC program

- Higgs (VBF), Di-higgs measurements and BSM searches
- Hadronic tau performance (dominant BR) reconstruction improved in ITK
- η reach also increased up to 4.0

Pixel TDR



Pixel TDR

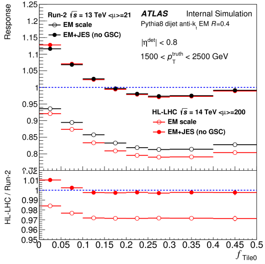


Tau trigger improvements also an important part of TDAQ upgrade. Many more details in talk tomorrow "The upgraded trigger system and di-τ trigger strategies of the ATLAS detector at the HL-LHC"

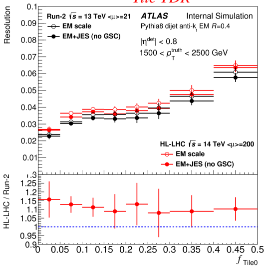
Jet reconstruction performance

High-Pt and boosted (large-R) jet performance shown to be similar to Run-2 even without HL-LHC specific optimisation and despite the higher $\langle\mu\rangle$

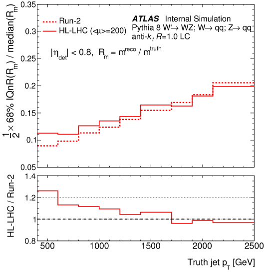
Tile TDR



Tile TDR



Tile TDR

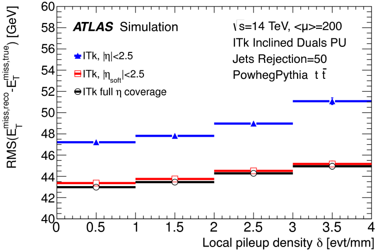


Missing transverse energy performance

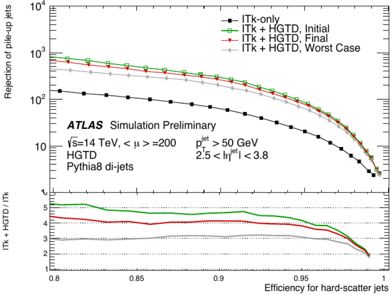
Missing E_t benefits from the increased tracker acceptance → Enables pile-up rejection in the forward region

Improvement due to HGTD currently under study → Improved pileup rejection

Pixel TDR



HGTD TP



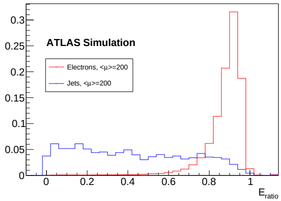
Electron and photon trigger performance

Full granularity and topo-cluster building in Global Trigger allows for improved L0 electron and photon triggers

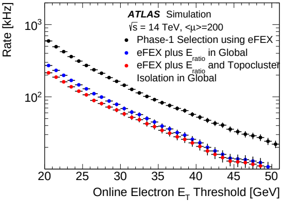
- E_{ratio} variable, currently used in HLT and offline, discriminates between isolated electrons or photons and π^0 decays.
- Topo-cluster based isolation also possible

$$E_{\text{ratio}} = \frac{E_{\text{highest energy cell}} - E_{\text{2nd local maximum energy cell}}}{E_{\text{highest energy cell}} + E_{\text{2nd local maximum energy cell}}}$$

TDAQ TDR



TDAQ TDR



TDAQ TDR