Hunting for Beyond-Standard-Model physics with the ATLAS detector at the HL-LHC

On behalf of the ATLAS Collaboration

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What is the HL-LHC?
What is the HL-LHC?

Run-1 
Run-2 
LS1 
LS2 
LS3 
LS4 
LS5 

You Are Here

Luminosity [cm$^{-2}$s$^{-1}$] 
Integrated luminosity [fb$^{-1}$] 

Year
What is the HL-LHC?

You Are Here

Run-1  Run-2  Run-3  LS1  LS2  LS3  LS4  LS5
What is the HL-LHC?
What is the HL-LHC?

• Only collected 5% of the LHC lifetime dataset!

• Need to upgrade both LHC, and ATLAS.

but **WHO** is HL-LHC?
Many Challenges for ATLAS...

Higher Instantaneous Luminosity:
\[ 1.8 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1} \rightarrow 5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}. \]

Higher Integrated Luminosity:
\[ 300 \text{ fb}^{-1} \rightarrow 3000 \text{ fb}^{-1}. \text{(4 ab}^{-1}?). \]
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**Muon Chambers with Improved Readout Granularity / Triggering.**

**LAr & Tile Readout/Power using Radiation Tolerant Technology.**
...And Upgrades to Meet Them!

- Muon Chambers with Improved Readout Granularity / Triggering.
- A wide range of improvements to ATLAS Trigger and Data Acquisition.
- LAr & Tile Readout/Power using Radiation Tolerant Technology.
- High Granularity Timing Detector (HGTD): $2.4 < |\eta| < 4.3$ (5.0?)
- Inner Tracker (ITk): Completely replace ID with All-Silicon. Improve Tracking & Cope with Radiation.
...And Upgrades to Meet Them!

The following studies are based on a number of methods:

- Smearing of Truth-Level Information.
- Extrapolation of Run-2 performance and results.
- Representative systematics based on Run-2 knowledge.
Searching for Resonances at the HL-LHC: Leptonic Searches

- Improved tracking and calorimetry leads to similar analysis performance despite harsher environment conditions.
- Run 2 $\rightarrow$ HL-LHC Improvement in Mass($\sim$40%), $\sigma B$(Factor 10).
Searching for Resonances at the HL-LHC: Diboson Searches

- Search with WW/WZ decaying to $\ell vqq$ (resolved/merged).
- Compared current W/Z tagger efficiency to future tagger with +50% signal efficiency and +factor 2 background rejection.
  - Topologically-clustered calo-jets $\rightarrow$ track-calocluster jets.
Searching for Resonances at the HL-LHC: 

Heavy Resonance Combinations

- To continue getting the most out of our data, we also combine results!
- At the HL-LHC this will be even more important, to catch small excesses across multiple searches with good statistical precision.
Searching for Resonances at the HL-LHC:

The Issue of PDF Uncertainties

• How can we trust our background estimation at extreme mass?
Searching for New Physics at the HL-LHC: The Issue of PDF Uncertainties

- How can we trust our background estimation at extreme mass?

![Graph showing the relationship between mass and number of Standard Model (SM) processes.](image)
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- Need PDF description / uncertainty to keep up with experiment!
- Lines between Precision Measurements and Searches blur.
- Prospects for improvement from HL-LHC data studied.
- Also bootstrapping techniques to reduce these kind of uncertainties in real time → Provide greater feedback.
Searching for SUSY at the HL-LHC:

- R-Parity conserving model, with LSP being stable DM candidate.
- Chargino ($\chi^{\pm}$) $\rightarrow$ Neutralino ($\chi^0$) which exits detector leaving “tracklet”
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Improvements also from tracking:
- Better quality / shorter tracklets.
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Long-Lived Particles at the HL-LHC: Dark Photon Search

• Big issue from collimated muons causing single $\mu$ trigger loss.
Two new muon trigger algorithms to improve the selection of displaced dark photons decaying to muons on displaced non-pointing muons. A baseline selection used in Run-2. A second trigger, the L0 sagitta muon trigger, has been designed to trigger at the HL-LHC have been presented. The performance of the two triggers has been evaluated on MC samples with respect to the Run-2 baseline selection. A trigger improvement (left). Finally, the results of this study are estimated.

### Conclusions
- Big issue from collimated muons causing single μ trigger loss.
- New trigger designed to analyse MS hit patterns for multiple-μ.
- Allows analysis to use a lower pT threshold with reasonable rate.
Searching for New Physics at the HL-LHC: Many Other Search Prospects Studied

ATLAS Preliminary
Projection from Run-2 data
\( \sqrt{s} = 14 \text{ TeV}, 3000 \text{ fb}^{-1} \)
Signal region, 2-tag
Scaling from dijet simulation

Dijet mass [GeV]

ATLAS Simulation Preliminary
\( \sqrt{s} = 13 \text{ TeV}, 3 \text{ ab}^{-1} \)
Axial-Vector Mediator
Dirac Fermion DM
\( g_1 = 0.25, g_{\chi} = 1 \)
95% CL limits
Projection from Run-2 data

Wino \( \tilde{\chi}_1^0 \rightarrow W^+ \tilde{\chi}_2^0 Z \tilde{\chi}_1^0 \rightarrow 3L + \text{MET final state} \)

ATLAS Simulation Preliminary
\( \sqrt{s} = 14 \text{ TeV}, 36 \text{ fb}^{-1} \)
95% CL exclusion, multi-bin
5\sigma discovery, inclusive
All limits at 95% CL

3L+MET

Multijet
t\(\bar{t}\)

G_{KK} (2.0 TeV) \times 30
G_{KK} (2.5 TeV) \times 30
G_{KK} (3.0 TeV) \times 30

Events / 100 GeV

ATLAS Preliminary
Projection from Run-2 data
Searching for New Physics at the HL-LHC: Many Other Search Prospects Studied

**ATLAS** Preliminary
Projection from Run-2 data

- Multijet
- t\bar{t}
- $G_{KK}$ (2.0 TeV) $\times$ 30
- $G_{KK}$ (2.5 TeV) $\times$ 30
- $G_{KK}$ (3.0 TeV) $\times$ 30

Scaling from dijet simulation

**Monojet**

$3L+\text{MET}$
Conclusions

• The HL-LHC sometimes **feels** like the distant future - **but it’s not!**
  - Understand BSM searches in this regime and prepare.
  - Prospect studies show great potential for increased sensitivity.
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• We also need to keep thinking about the bigger picture.
  - Combinations of results can boost sensitivity even further.
  - Eventually cross-collaboration, cross-HEP combinations?
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• Be wary of potential pit falls.
  - What would a discovery at the HL-LHC look like?
  - Need to work closely with the theory community.
Thank you for listening!

Questions?