Prospects of the High Luminosity LHC from CMS and ATLAS

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on behalf of the ATLAS and CMS Collaborations
The Past-Present-Future of LHC

RUN1

7-8 TeV

~30 fb$^{-1}$

50 ns

$\langle \mu \rangle \sim 20$

RUN2

13-14 TeV

RUN3

HL-LHC

25 ns

$\langle \mu \rangle \sim 140$

Phase 1

Phase 2

We are here!

We want to go there...
ATLAS & CMS Detector upgrade

Must cope with:
- High pile-up
- High radiation level

Different technologies will be used in the Phase-II upgrade, but common strategy:

- Re-visit the L1 trigger logic to keep leptons $p_T$ thresholds and L1 trigger rates low
- New Tracker with high granularity and radiation resistance and extended $\eta$ coverage
- Extension of detectors coverage to increase acceptance and improve performances

- New Tracker
  - Radiation tolerant - high granularity - less material
  - Tracks in hardware trigger (L1)
  - Coverage up to $\eta \sim 4$

- New Endcap Calorimeters
  - Radiation tolerant - high granularity
  - Nominal coverage up to $1.5 < |\eta| < 3.0$
  - Investigating coverage up to $\eta \sim 4$
  - Investigate fast-timing options

- Muons
  - Complete RPC coverage in fwd region (new GEM/RPC technology)
  - Nominal coverage up to $\eta \sim 2.4$
  - Investigating muon tag up to $|\eta| \sim 4$ (depending on calorimetry)

Lot of talks in the Detector session.
Physics program at HL-LHC

Huge Physics program addressing

★ Precision studies of the 125 GeV Higgs boson (couplings, rare decays, etc.)
★ Searches/studies for BSM Physics
  ➡ Higgs
  ➡ SUSY
  ➡ Vector Boson Scattering (VBS)
  ➡ Exotics
  ➡ DM

ATLAS Performance studies

Performance assessed in benchmark channels using full simulation

★ Run 2 detector and $<\mu>=60$, 300 fb$^{-1}$

★ New tracker (ITK) in Run 1 Calorimeter and Muon system, with varying $<\mu>$ up to 2000 and for 3000 fb$^{-1}$

★ Physics reach (mostly) based on generator level studies with parameterized performance

CMS Performance studies

Performance assessed in benchmark channel using full simulation

★ Phase 1 detector and $<\mu>=50$, 300 fb$^{-1}$

★ Phase 1 detector (aging but pixel) and $<\mu>=140$, 1000 fb$^{-1}$

★ Phase 2 detector and $<\mu>=140$, 1000 fb$^{-1}$

Physics reach (mostly) based on extrapolation under different assumptions on uncertainties or Delphes

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/UpgradePhysicsStudies

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFP
Prospects for Higgs Physics

HL-LHC: a Higgs factory!

★ Enable precision measurements:
  - Signal strength
  - Spin/parity
  - Couplings

★ New measurements:
  - Rare decays (H→μμ, H→Zγ)
  - Double Higgs boson production (self couplings)
  - Higgs portal to New Physics

### Higgs bosons at \( \sqrt{s}=14 \text{ TeV} \) 3000 fb\(^{-1} \)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>HL-LHC total</td>
<td>170 M</td>
</tr>
<tr>
<td>VBF (main decays)</td>
<td>13 M</td>
</tr>
<tr>
<td>ttH (main decays)</td>
<td>1.8 M</td>
</tr>
<tr>
<td>HH (all)</td>
<td>121 k</td>
</tr>
<tr>
<td>( H \rightarrow Z\gamma )</td>
<td>230 k</td>
</tr>
<tr>
<td>( H \rightarrow \mu\mu )</td>
<td>37 k</td>
</tr>
</tbody>
</table>

Given cross sections from LHCHXSWG
Higgs rare decays: $H \rightarrow Z \gamma$

- Largely benefit from dataset increase due to HL
- In the SM the decay proceeds entirely via loops
- Sensitive to New Physics (i.e. Higgs composite models)

- ggF, VBF, VH, ttH production
- Challenging study due to high $Z+\gamma/Z$ +jet background
- Not-Higgs mediated bkg

$\Delta m = m_{\ell\ell\gamma} - m_{\ell\ell}$ as signal discriminant

- $Z$ in $ee/\mu\mu$ considered
- 3.9$\sigma$ expected
- CMS expects 20/24% uncertainty with scenario 2 ($1/2$ th. uncert.)/1 (same RUN1 th. uncert.)
- ATLAS expects 30% uncertainty
- Signal strength error dominated by statistical one
Higgs rare decays: $H \rightarrow \mu\mu$

- Largely benefit from dataset increase due to HL
- **Probe the 2nd generation couplings**
- BR $O(10^{-4})$
- ggF, VBF, VH, ttH production
- Backgrounds: Zjets, $\bar{t}t$, WW
- excellent di-muon mass resolution is crucial

Expect observation with $> 7.0\sigma$

<table>
<thead>
<tr>
<th>$\mathcal{L} ,(fb^{-1})$</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATLAS 300</td>
<td>± 0.39</td>
<td>± 0.38</td>
</tr>
<tr>
<td>CMS 300</td>
<td>± 0.42</td>
<td>± 0.40</td>
</tr>
<tr>
<td>ATLAS 3000</td>
<td>± 0.16</td>
<td>± 0.12</td>
</tr>
<tr>
<td>CMS 3000</td>
<td>± 0.20</td>
<td>± 0.14</td>
</tr>
</tbody>
</table>

ATLAS scenarios: 1- full sys 2- no theory sys
CMS scenarios: 1- run-1 sys 2- reduced sys

Phase2: 40% better mass resolution, 20% higher efficiency wrt aged-Phase1

**CERN-LHC-2015-010**
**CMS NOTE-13-002**
Higgs couplings fit

\[
\frac{\sigma \cdot B(gg \rightarrow H \rightarrow \gamma\gamma)}{\sigma_{SM}(gg \rightarrow H) \cdot B_{SM}(H \rightarrow \gamma\gamma)} = \frac{k_{g}^2 \cdot k_{\gamma}^2}{k_{H}^2}
\]

The hashed areas indicate the increase of the estimated error due to current theory systematic uncertainties (CERN-2011-002, CERN-2012-002)

Scenarios:
1. Single resonance @ m_H=125 GeV
2. Narrow width approximation
3. If width constrain removed only coupling ratios \( \lambda_{XY} = k_X/k_Y \)

Assumptions:
- Single resonance at m_H=125 GeV
- Narrow width approximation
- If width constrain removed only coupling ratios \( \lambda_{XY} = k_X/k_Y \)
H pair production

- One of the exciting prospects @ HL-LHC:
  - Higgs self-coupling
  - accessing the Higgs potential
  - sensitive to BSM Physics

- Small cross section + huge background (top and fakes processes)

### Higgs Pair Production

**Simulation Preliminary**

<table>
<thead>
<tr>
<th>Decay Channel</th>
<th>Branching Ratio</th>
<th>Total Yield (3000 fb⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>b̅b + b̅b</td>
<td>33%</td>
<td>40,000</td>
</tr>
<tr>
<td>bb + W⁺W⁻</td>
<td>25%</td>
<td>31,000</td>
</tr>
<tr>
<td>bb + τ⁺τ⁻</td>
<td>1.3%</td>
<td>8,900</td>
</tr>
<tr>
<td>ZZ + bb</td>
<td>3.1%</td>
<td>3,800</td>
</tr>
<tr>
<td>W⁺W⁻ + τ⁺τ⁻</td>
<td>2.7%</td>
<td>3,300</td>
</tr>
<tr>
<td>ZZ + W⁺W⁻</td>
<td>1.1%</td>
<td>1,300</td>
</tr>
<tr>
<td>γγ + b̅b</td>
<td>0.26%</td>
<td>320</td>
</tr>
<tr>
<td>γγ + γγ</td>
<td>0.0010%</td>
<td>1.2</td>
</tr>
</tbody>
</table>

- Destructive interference
  - SM cross-section decreases
  - Cross section at \(\sqrt{s} = 14\) TeV is 40.7 fb [NNLO] (Phys. Rev. Lett. 111 (2013) 201801)

Small cross-section and huge resonant (single H) and non resonant bkg

ATLAS and CMS expects ~ 8-9 events after trigger and event selections corresponding to a signal significance of ~1.3σ per exp for the SM scenario

CMS has evaluated the impact on the analysis as the b-tagging and photon identification efficiencies change

ATLAS and CMS are discussing the analyses to continue and better understand the remaining any deviation from SM hint of new physics

Physics at the High-Luminosity LHC (2015)

CMS and ATLAS are discussing the Higgs pair production for the SM scenario
H pair production

Combining $bb\gamma\gamma$ and $bb\tau\tau$ final states CMS expects 1.9$\sigma$ significance with an uncertainty of ~ 54%.

Significant improvements in future studies of di-H signatures are expected by ATLAS and CMS by combining more channels and also using MVA analysis technique.
Prospects for SUSY @ HL-LHC

- Search for SUSY is a major goal for Run2 & HL-LHC
  - Higgs discovery poses new urgency to the hierarchy problem
  - Candidate for DM
  - Gauge unification

- Prospects for SUSY using
  - ATLAS: Simplified SUSY Models and benchmark configurations
  - CMS: Simplified SUSY model and Full Spectrum models (new!)
    - Five phenomenological models motivated by naturalness explored through a number of signature-based searches
    - Models differ by nature of the LSP (bino-, higgsino-like), EWK-inos and sleptons hierarchies
    - STC (stau) and STOC (stop) co-annihilation models satisfy dark matter constraints

### Table 1: Overview over the analyses and their application to the different models.

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Luminosity (fb⁻¹)</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>all-hadronic ((H_1-H_1^{max})) search</td>
<td>300, 3000</td>
<td>NM1, NM2, NM3, STC, STOC</td>
</tr>
<tr>
<td>all-hadronic ((M_{12})) search</td>
<td>300, 3000</td>
<td>NM1, NM2, NM3, STC, STOC</td>
</tr>
<tr>
<td>all-hadronic (b_1) search</td>
<td>300, 3000</td>
<td>NM1, NM2, NM3, STC, STOC</td>
</tr>
<tr>
<td>1-lepton (t_1) search</td>
<td>300, 3000</td>
<td>NM1, NM2, NM3, STC, STOC</td>
</tr>
<tr>
<td>monojet (t_1) search</td>
<td>300, 3000</td>
<td>NM1, NM2, NM3, STC, STOC</td>
</tr>
<tr>
<td>(m_{\ell\ell}) kinematic edge</td>
<td>300, 3000</td>
<td>NM1, NM2, NM3, STC, STOC</td>
</tr>
<tr>
<td>multilepton + b-tag search</td>
<td>300, 3000</td>
<td>NM1, NM2, NM3, STC, STOC</td>
</tr>
<tr>
<td>multilepton search</td>
<td>300, 3000</td>
<td>NM1, NM2, NM3, STC, STOC</td>
</tr>
<tr>
<td>ewkino WH search</td>
<td>300, 3000</td>
<td>NM1, NM2, NM3, STC, STOC</td>
</tr>
</tbody>
</table>

- Constraints: < 3σ, 3 – 5σ, > 5σ
$\chi^{\pm}\chi^0$ searches @ HL-LHC

Factor 10x in luminosity essential to probe pair production of EWK-inos expected to be light from naturalness arguments

WZ (3l) WH (1l2\tau, 3l, 1lbb) channels studied

5σ up to ~850-950 GeV in both WZ-WH depending on the decay channel
Extensions up to above 1000 possible with MVA technique and better cyst understanding

Upgrade of the detector mandatory to significantly enhance discovery region wrt RUN2 perspectives

CMS PAS SUS-14-012

ATL-PHYS-PUB-2015-032
Squark/gluino searches @ HL-LHC

5σ up to ~2.5 TeV gluinos

5σ up to ~3 TeV squark

All hadronic HT sensitive to gluino, squark production

5σ in the STOC scenario >3σ in the STC
Stop/sbottom searches @ HL-LHC

Naturalness arguments require light third generation squark
Discovery could be accessible @ 300/fb
With 3000/fb increase sensitivity to heavy stop/sbottom and/or measure their properties

5σ up to ~1.2 TeV stop
5σ up to ~1.3 TeV sbottom

direct stop production in the single-lepton channel
>5σ in all scenarios

endpoint provide lower limit on sbottom mass

CMS PAS SUS-14-012

Stop/sbottom searches @ HL-LHC

Naturalness arguments require light third generation squark
Discovery could be accessible @ 300/fb
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5σ up to ~1.2 TeV stop
5σ up to ~1.3 TeV sbottom

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>5σ in all scenarios

endpoint provide lower limit on sbottom mass

CMS PAS SUS-14-012
Exotica @ HL-LHC

A broad range of models can benefit of increased statistics

Looking for an excess in mono-lepton or mono-jet channels

Looking for anomalous dE/dx, displayed secondary vertices, slow moving tracks...for massive stable or long-lived particles

Looking for modification of di-lepton (Z’, KK-gluon) or di-jet invariant mass (q*, QBH)

ATLAS @14 TeV  
\(Z' \rightarrow ee\text{ SSM} \quad 95\% \text{ CL limit} \quad 95\% \text{ CL limit} \)

\begin{align*}
300 \text{ fb}^{-1} & : 6.5 \text{ TeV} & 4.3 \text{ TeV} \\
3000 \text{ fb}^{-1} & : 7.8 \text{ TeV} & 6.7 \text{ TeV}
\end{align*}
Summary

• The discovery of the Higgs boson at LHC-Run1 has opened the door towards a deeper understanding of particle Physics

• With the start of RUN2 with the unprecedented energy of 13 TeV we are now focussing even more in the searches for New Physics and precision Higgs studies

• The HL-LHC with a ten times more luminosity will offer unique opportunities to explore the Higgs sector and will represent an excellent probe for high scale New Physics
  
  • the 3000/fb dataset at 14 TeV will allow large gains in precision, discovery potential, and will make a number of important, low cross-section measurements possible

• Detector upgrade foreseen by ATLAS and CMS will ensure optimal performances despite the very hostile environment

• Lot of work is ongoing to be ready and well prepared for this new exciting LHC-era...

  … The best maybe should still come…
Back-up
$$H \rightarrow ZZ^* \rightarrow 4\ell$$

**HL-LHC statistics allows**
- measurement with high purity in the various modes
- precision ~4-10% on the signal strength (both ATLAS and CMS)
- probe CP-odd (CP-even) structures of the Higgs couplings $g_4$ ($g_1$, $g_2$)

**Efficiency times acceptance for the signal vs selection criteria**

**Improvement due to increased muon coverage**

**Error is dominated by theoretical uncertainty**

Currently ~25% uncertainty on $\mu$

(ATELAS-CONF-2015-007, PHYSICAL REVIEW D89, 092007)
### VH → bb, H → ττ

#### Important test of the coupling to third generations fermions

**VH → bb, (V=W,Z)**
- b-tagging performance are crucial
  - degradation due to high-PU expected
  - recovery due to upgraded detector mandatory

CMS expects a precision of 5/7% on the signal strength in scenario 2 (1/2 th. uncert.)/1(same RUN1 th uncert.)

**H → ττ excellent probe for BSM Physics**
- VBF production and $T_{lep}$ $T_{had}$ categories explored by both ATLAS and CMS
  - All physics objects involved (e,μ,jets,$E_{T\text{miss}}$,…)
  - mitigation of high-PU mandatory

#### VH → bb, H → ττ

- Trigger acceptance increase by a factor 5 thanks to addition of track trigger capabilities

- Extension of tracker would help in rejecting fake jets

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**ATL-PHYS-PUB-2014-011**

CMS Simulation

- Phase-I, PU=50
- Phase-I, aged, PU=140
- Phase-II, PU=140

CMS Phase II Simulation

- 14 TeV, PU=140
- 14 TeV, PU=140

**ATL-PHYS-PUB-2014-018**

### CERN-LHC-2015-010

<table>
<thead>
<tr>
<th>Forward pile-up jet rejection</th>
<th>50%</th>
<th>75%</th>
<th>90%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward tracker coverage</td>
<td>Δμ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Run-I tracking volume</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$</td>
<td>η</td>
<td>&lt; 3.0$</td>
<td>0.18</td>
</tr>
<tr>
<td>$</td>
<td>η</td>
<td>&lt; 3.5$</td>
<td>0.18</td>
</tr>
<tr>
<td>$</td>
<td>η</td>
<td>&lt; 4.0$</td>
<td>0.16</td>
</tr>
</tbody>
</table>

CMS expects a precision of 2/5% on the signal strength in scenario 2/1
In composite Higgs models: large $Z\gamma$, while $\gamma\gamma$ and gg are small
Measurement of $Z\gamma$ will profit of HL–LHC

$$\frac{\delta m/m}{\text{SM}} = \frac{(m_{3,1} - m_{1,3})/(m_{3,1} + m_{1,3})}{\text{SM}}$$

$$f = 500 \text{ GeV}$$
$$0.1 < r < 2.5$$

$$f = 800 \text{ GeV}$$
$$0.1 < r < 2.5$$

Rescaling tree–level couplings $\delta g_{hVV} = v^2/f^2$

arXiv:1308.2676
Coupling uncertainties

ATLAS, estimate of the maximum theory uncertainty compatible with <10% increase of total uncertainty in 3000/fb

CMS, scaling of signal and background yields as:
- Systematic uncertainties remain the same (scenario 1)
- Theoretical uncertainties scaled by 1/2, other systematic uncertainties scaled by 1/\sqrt{L} (scenario 2)

HL-LHC improves by 2-3x
2-3% uncertainty on ratios in scenario 2
Mass dependence of couplings

\[ y_{V,i} = \sqrt{\frac{\kappa_{V,i} g_{V,i}}{2v}} = \sqrt{\frac{\kappa_{V,i} m_{V,i}}{v}} \]

\[ y_{F,i} = \kappa_{F,i} \frac{g_{F,i}}{\sqrt{2}} = \kappa_{F,i} \frac{m_{F,i}}{v} \]
HH→bbγγ @ ATLAS
**HH→bbγγ @ CMS**

- Search approach based on 2D fit of $M_{bb}$ and $M_{γγ}$
- Parameterized object performance tuned to the Phase 2 detector

<table>
<thead>
<tr>
<th>Process / Selection Stage</th>
<th>HH</th>
<th>ZH</th>
<th>tH</th>
<th>bH</th>
<th>γγ+jets</th>
<th>γ+jets</th>
<th>jets</th>
<th>tt($γ$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Object Selection &amp; Fit Mass Window</td>
<td>23.8</td>
<td>30.5</td>
<td>184</td>
<td>6.5</td>
<td>3721</td>
<td>1619</td>
<td>287</td>
<td>597</td>
</tr>
<tr>
<td>Kinematic Selection</td>
<td>13.4</td>
<td>15.1</td>
<td>3.4</td>
<td>2.1</td>
<td>192</td>
<td>98</td>
<td>20</td>
<td>22</td>
</tr>
<tr>
<td>Mass Windows</td>
<td>9.0</td>
<td>3.4</td>
<td>1.6</td>
<td>0.8</td>
<td>13.0</td>
<td>6.3</td>
<td>1.1</td>
<td>1.2</td>
</tr>
</tbody>
</table>

![Graph showing event yields for different processes](image1)

![Graph showing relative improvement in b-tagging efficiency](image2)

![Graph showing relative improvement in photon efficiency](image3)
New Physics may appear in the unitarization of longitudinal VBS
Sensitive to New Physics also through Anomalous Quartic Gauge Couplings

**Figure 10.14:** Left, the differences for polarized scatterings in the WZ analysis. In this case the VLVL solution with the smallest magnitude is chosen. If no real solution is found, the mass constraint equation is solved for the two final state charged leptons for the same-sign channel also studied and combined to increase sensitive to NP

**Table 10.4:** Results of the combination of WW and WZ analyses, assuming a scale factor of 1

<table>
<thead>
<tr>
<th>Luminosity (fb⁻¹)</th>
<th>ATLAS Expected significance (σ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3000 fb⁻¹</td>
<td>4</td>
</tr>
<tr>
<td>300 fb⁻¹</td>
<td>3</td>
</tr>
</tbody>
</table>

**Figure 10.15:** Left, the differences for the WW scattering, before the VBS selections, for signal and background. Right, the differences for the WZ scattering, before the VBS selections, for signal and background

**Figure 10.16:** Right, the expected 95% CL exclusion limits for the Higgsless scenario after 3000 fb⁻¹

<table>
<thead>
<tr>
<th>3000 fb⁻¹, 14 TeV</th>
<th>Phase-I</th>
<th>Phase-II</th>
<th>Phase-I aged</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higgsless 95% CL μ exclusion</td>
<td>0.14</td>
<td>0.14</td>
<td>0.20</td>
</tr>
<tr>
<td>V_L V_L scattering significance</td>
<td>2.50</td>
<td>2.75</td>
<td>2.14</td>
</tr>
</tbody>
</table>
Full spectrum SUSY

- Five phenomenological models motivated by naturalness explored through a number of signature-based searches
- Models differ by nature of the LSP (bino-, higgsino-like), EWK-inos and sleptons hierarchies
- STC (stau) and STOC (stop) co-annihilation models satisfy dark matter constraints
4.1 Natural models (NM)

- NM1
- NM2
- NM3
- STC
- STOC
Lepton candidates $p_T > 10$ GeV and $|\eta| < 4$
Leading lepton $p_T > 25$ GeV
Second leading lepton $p_T > 15$ GeV
One opposite-sign same-flavor (OSSF) lepton
Veto on events with 4 leptons or with a b-tagged jet

CMS $\chi^\pm \chi^0$ searches

Table 10 contains the results for the different search regions, comparing the estimated total SM background to the different SUSY models, including the simplified model with 2 masses, the sensitivity is strongest in the signal region with tight lepton T and $E_T^{miss}$, as shown in Fig. 18(a). The invariant mass distribution of the OSSF pair for the different final states, as shown in Fig. 17(a) with jet $p_T > 25$ GeV, and from 0 to 900 GeV for $E_T^{miss}$.

The uncertainty due to the Monte Carlo statistics is in most cases below 5%, but for a very few bins they can have an influence.

Fig. 17(a) with
Fig. 18(a). The invariant mass distribution of the OSSF pair for the different final states, as shown in Fig. 17(a) with jet $p_T > 25$ GeV, and from 0 to 900 GeV for $E_T^{miss}$.

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The uncertainty due to the Monte Carlo statistics is in most cases below 5%, but for a very few bins they can have an influence.
Table 13: Ewkino WH search: Yields for the Phase II scenario with 140 pileup events and luminosity of 1000 fb⁻¹.

<table>
<thead>
<tr>
<th>Sample</th>
<th>$E_{\text{T}}^{\text{miss}} &gt; 200$ GeV</th>
<th>$E_{\text{T}}^{\text{miss}} &gt; 300$ GeV</th>
<th>$E_{\text{T}}^{\text{miss}} &gt; 400$ GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>25% Background Uncertainty</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WH signal (200,1)</td>
<td>1.7</td>
<td>1.8</td>
<td>1.5</td>
</tr>
<tr>
<td>WH signal (500,1)</td>
<td>1.4</td>
<td>2.9</td>
<td>3.9</td>
</tr>
<tr>
<td>WH signal (900,1)</td>
<td>-</td>
<td>0.4</td>
<td>1.3</td>
</tr>
<tr>
<td>Natural Model 2</td>
<td>0.6</td>
<td>1.2</td>
<td>1.3</td>
</tr>
<tr>
<td>12.5% Background Uncertainty</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WH signal (200,1)</td>
<td>3.2</td>
<td>2.6</td>
<td>1.8</td>
</tr>
<tr>
<td>WH signal (500,1)</td>
<td>2.6</td>
<td>4.4</td>
<td>4.5</td>
</tr>
<tr>
<td>WH signal (900,1)</td>
<td>0.2</td>
<td>0.7</td>
<td>1.5</td>
</tr>
<tr>
<td>Natural Model 2</td>
<td>1.2</td>
<td>1.8</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Table 12: Ewkino WH search: Estimated significance in the lepton identification, b-tagging efficiency, and tracker and the endcaps, suffer from significant radiation damage. The effect of the degradation for the scenario. If no signal is observed with the HL-LHC data, the limits will extend beyond 1 TeV assuming a background systematic uncertainty of 12.5%.

The yields from Table 13 are used, and two different choices for luminosity of 300/3000 fb⁻¹.

Figure 22(a) shows the CMS Phase II Delphes Simulation (900,1) and (500,1) and (200,1) for single top.

Table 14: Ewkino WH search: 95% CL Exclusion, BR = 0.5.

<table>
<thead>
<tr>
<th>Sample</th>
<th>$E_{\text{T}}^{\text{miss}} &gt; 200$ GeV</th>
<th>$E_{\text{T}}^{\text{miss}} &gt; 300$ GeV</th>
<th>$E_{\text{T}}^{\text{miss}} &gt; 400$ GeV</th>
<th>$E_{\text{T}}^{\text{miss}} &gt; 500$ GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>25% Background Uncertainty</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WH signal (200,1)</td>
<td>2.8</td>
<td>1.9</td>
<td>4.3</td>
<td>5.5</td>
</tr>
<tr>
<td>WH signal (500,1)</td>
<td>1.4</td>
<td>3.0</td>
<td>7.6</td>
<td>6.9</td>
</tr>
<tr>
<td>WH signal (900,1)</td>
<td>-</td>
<td>0.4</td>
<td>2.5</td>
<td>4.7</td>
</tr>
<tr>
<td>Natural Model 2</td>
<td>0.6</td>
<td>1.3</td>
<td>2.9</td>
<td>2.4</td>
</tr>
<tr>
<td>12.5% Background Uncertainty</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WH signal (200,1)</td>
<td>5.8</td>
<td>3.8</td>
<td>6.7</td>
<td>6.8</td>
</tr>
<tr>
<td>WH signal (500,1)</td>
<td>2.9</td>
<td>5.9</td>
<td>12.0</td>
<td>8.6</td>
</tr>
<tr>
<td>WH signal (900,1)</td>
<td>-</td>
<td>0.9</td>
<td>3.9</td>
<td>5.8</td>
</tr>
<tr>
<td>Natural Model 2</td>
<td>1.4</td>
<td>2.7</td>
<td>4.7</td>
<td>3.0</td>
</tr>
</tbody>
</table>
ATLAS $\chi^\pm \chi^0$ searches

### WZ Selection

<table>
<thead>
<tr>
<th>Selection</th>
<th>SRA</th>
<th>SRB</th>
<th>SRC</th>
<th>SRD</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_{\text{SFOS}}$ [GeV]</td>
<td>81.2-101.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$# b$-tagged jets</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lepton $p_T$ (1,2,3) [GeV]</td>
<td>&gt; 50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$E_T^{\text{miss}}$ [GeV]</td>
<td>&gt; 250 &gt; 300 &gt; 400 &gt; 500</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$m_T$ [GeV]</td>
<td>&gt; 150 &gt; 200 &gt; 200 &gt; 200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\langle \mu \rangle = 60, 300 \text{ fb}^{-1}$ scenario</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>$\langle \mu \rangle = 140, 3000 \text{ fb}^{-1}$ scenario</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

### Wh Selection (3l)

<table>
<thead>
<tr>
<th>Selection</th>
<th>SRE</th>
<th>SRF</th>
<th>SRG</th>
<th>SRH</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFOS pair</td>
<td>veto</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$# b$-tagged jets</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$E_T^{\text{miss}}$ [GeV]</td>
<td>&gt; 100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$m_{\text{missR}}$ [GeV]</td>
<td>&lt; 75</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$m_{T(\ell_1)}$ [GeV]</td>
<td>&gt; 200 &gt; 200 &gt; 300 &gt; 400</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$m_{T(\ell_2)}$ [GeV]</td>
<td>&gt; 100 &gt; 150 &gt; 150 &gt; 150</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$m_{T(\ell_3)}$ [GeV]</td>
<td>&gt; 100 &gt; 100 &gt; 100 &gt; 100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\langle \mu \rangle = 60, 300 \text{ fb}^{-1}$ scenario</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>$\langle \mu \rangle = 140, 3000 \text{ fb}^{-1}$ scenario</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

### Wh Selection (1l2\tau)

<table>
<thead>
<tr>
<th>Selection</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$# e, \mu$</td>
<td>1</td>
</tr>
<tr>
<td>$# \tau$</td>
<td>2 (OS)</td>
</tr>
<tr>
<td>$E_T^{\text{miss}}$ [GeV]</td>
<td>&gt; 250</td>
</tr>
<tr>
<td>$m_{\tau\tau}$ [GeV]</td>
<td>80-130</td>
</tr>
<tr>
<td>$</td>
<td>p_T(\tau_1)</td>
</tr>
<tr>
<td>$m_T(\ell)$ [GeV]</td>
<td>&gt; 130</td>
</tr>
</tbody>
</table>
### ATLAS $\chi^\pm \chi^0$ searches: Wh(bb)

#### Table 1: Summary of selection requirements for the SR Training Sample [GeV] BDT range 

<table>
<thead>
<tr>
<th>SR</th>
<th>Training Sample [GeV]</th>
<th>BDT range $m(\chi_{2}^{0}, \chi_{1}^{\pm})$, $m(\chi_{1}^{0})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>(300,0)</td>
<td>&gt; 0.22</td>
</tr>
<tr>
<td>M2</td>
<td>(800,400)</td>
<td>&gt; 0.35</td>
</tr>
<tr>
<td>M3</td>
<td>(1300,0)</td>
<td>&gt; 0.28</td>
</tr>
</tbody>
</table>

#### Table 3: Expected cut and count signal region yields, for an integrated luminosity of 300 fb$^{-1}$

<table>
<thead>
<tr>
<th>Selection</th>
<th>SRA</th>
<th>SRB</th>
<th>SRC</th>
<th>SRD</th>
</tr>
</thead>
<tbody>
<tr>
<td># of leptons ($e, \mu$)</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># $b$-tagged jets</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$m_{bb}$ [GeV]</td>
<td>105 &lt; $m_{bb}$ &lt; 135</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># jets</td>
<td></td>
<td>2 or 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$m_{\Delta T}$ [GeV]</td>
<td>&gt; 200</td>
<td>&gt; 200</td>
<td>&gt; 300</td>
<td>&gt; 300</td>
</tr>
<tr>
<td>$m_{V}$ [GeV]</td>
<td>&gt; 200</td>
<td>&gt; 250</td>
<td>&gt; 200</td>
<td>&gt; 250</td>
</tr>
<tr>
<td>$E_{T miss}$ [GeV]</td>
<td>&gt; 300</td>
<td>&gt; 350</td>
<td>&gt; 400</td>
<td>&gt; 450</td>
</tr>
<tr>
<td>$\langle \mu \rangle = 60$, 300 fb$^{-1}$ scenario</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>$\langle \mu \rangle = 140$, 3000 fb$^{-1}$ scenario</td>
<td>–</td>
<td>–</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

#### Diagrams

- **ATLAS Simulation Preliminary**
  - 3 $\sigma$ observation (L = 300 fb$^{-1}$, $<\mu>$=60)
  - 95% CL exclusion (L = 300 fb$^{-1}$, $<\mu>$=60)
  - 5 $\sigma$ discovery (L = 3000 fb$^{-1}$, $<\mu>_0$=140)
  - 5 $\sigma$ MVA discovery (L = 3000 fb$^{-1}$, $<\mu>_0$=140)
  - 95% CL exclusion (L = 3000 fb$^{-1}$, $<\mu>_0$=140)

- **ATLAS Simulation Preliminary**
  - $m_{\chi_{2}^{0}, \chi_{1}^{\pm}}$ vs $m(\chi_{1}^{0})$
  - $m_{\chi_{2}^{0}, \chi_{1}^{\pm}}$ vs $m(\chi_{1}^{0})$
  - $m_{\chi_{2}^{0}, \chi_{1}^{\pm}}$ vs $m(\chi_{1}^{0})$

- **ATLAS Simulation Preliminary**
  - $m_{\chi_{2}^{0}, \chi_{1}^{\pm}}$ vs $m(\chi_{1}^{0})$
  - $m_{\chi_{2}^{0}, \chi_{1}^{\pm}}$ vs $m(\chi_{1}^{0})$
  - $m_{\chi_{2}^{0}, \chi_{1}^{\pm}}$ vs $m(\chi_{1}^{0})$