Higgs Prospects at the HL-LHC

Aleandro Nisati
INFN – (Italy) Roma
index

• Physics programme after the 125 GeV Higgs boson discovery
• The LHC luminosity upgrade
• Expected physics performance of ATLAS and CMS detector upgrade
• Higgs Prospects
• VBS
• Conclusion
Issues for the Future (*Starting now!*)

1. What is the agent of EWSB? *There is a Higgs boson!* Might there be several?
2. Is the Higgs boson elementary or composite? How does it interact with itself? What triggers EWSB?
3. Does the Higgs boson give mass to fermions, or only to the weak bosons? What sets the masses and mixings of the quarks and leptons? *How* is fermion mass related to the electroweak scale?
4. Are there new flavor symmetries that give insights into fermion masses and mixings?
5. What stabilizes the Higgs-boson mass below 1 TeV?
Issues for the Future (Now!)

6. Do the different CC behaviors of LH, RH fermions reflect a fundamental asymmetry in nature’s laws?
7. What will be the next symmetry we recognize? Are there additional heavy gauge bosons? Is nature supersymmetric? Is EW theory contained in a GUT?
8. Are all flavor-changing interactions governed by the standard-model Yukawa couplings? Does “minimal flavor violation” hold? If so, why?
9. Are there additional sequential quark & lepton generations? Or new exotic (vector-like) fermions?
10. What resolves the strong CP problem?
Issues for the Future (Now!)

11. What are the dark matters? Any flavor structure?
12. Is EWSB an emergent phenomenon connected with strong dynamics? How would that alter our conception of unified theories of the strong, weak, and electromagnetic interactions?
13. Is EWSB related to gravity through extra spacetime dimensions?
14. What resolves the vacuum energy problem?
15. (When we understand the origin of EWSB), what lessons does EWSB hold for unified theories? … for inflation? … for dark energy?
Issues for the Future (Now!)

16. What explains the baryon asymmetry of the universe? Are there new (CC) CP-violating phases?
17. Are there new flavor-preserving phases? What would observation, or more stringent limits, on electric-dipole moments imply for BSM theories?
18. (How) are quark-flavor dynamics and lepton-flavor dynamics related (beyond the gauge interactions)?
19. At what scale are the neutrino masses set? Do they speak to the TeV scale, unification scale, Planck scale, ...?

20. How are we prisoners of conventional thinking?

C. Quigg, seminar at this conference
Higgs Physics Programme

1. Measurement of couplings to elementary fermions and bosons
2. Precision measurement of the mass and width of this new particle
3. Determination of the quantum numbers: spin and CP properties
5. Search for possible partners (neutral and/or charged) of this boson
6. Fundamental/composite particle
7. Strongly associate to this: Vector Boson Scattering
HL-LHC Physics goals

• HL-LHC will be alone, in the near future for sure, exploring multi-TeV
  – There will be a wide physics programme
  – Higgs physics plays a central role
HL-LHC Benchmark scenario

• Approved running to deliver 300 fb$^{-1}$ by ~2021
  – With 20x Higgs boson production so far
• Post LS3 operation at 5x$10^{34}$cm$^{-2}$s$^{-1}$ (lumi leveling)
  – 25 ns bunch spacing
  – 140 events per bunch crossing
  – 3000 fb$^{-1}$ over 10 years
• Detector upgrades needed
  – to cope with radiation damage and pileup
  – aim to maintain/enhance physics performance
• Trigger is a key component:
  – Thresholds not too dissimilar to today
  – Mandated by need to study the Higgs boson
HL-LHC timeline

- M. Lamont @ Recontre workshop, Vietnam, Aug 2014
- O. Bruning @ ECFA HL-LHC Workshop, Aix-Les-Bains, 2014
LHC Upgrade Goals: Performance optimization

Luminosity recipe (round beams):

\[
L = \frac{n_b \cdot N_1 \cdot N_2 \cdot \gamma \cdot f_{rev}}{4\pi \cdot \beta^* \cdot \varepsilon_n} \cdot F(\phi, \beta^*, \varepsilon, \sigma_s)
\]

1) maximize bunch intensities
2) minimize the beam emittance
3) minimize beam size (constant beam power);
4) maximize number of bunches (beam power);
5) compensate for ‘F’;
6) Improve machine ‘Efficiency’

- Injector complex
- LIU ⇔ IBS
- triplet aperture
- 25ns
- Crab Cavities
- minimize number of unscheduled beam aborts

O. Bruning @ ECFA HL-LHC Workshop, Aix-Les-Bains, 2014
Simulation methods

• **ATLAS:**
  – Efficiency and resolution functions are applied to physics objects
  – Performance of the new detector will not be worse than the current detector at Run I conditions

• **CMS:**
  – Scale signal and background yields of current analyses
  – Two scenarios for systematic uncertainties
    • Scenario 1: Systematic uncertainties remain the same
    • Scenario 2: Theoretical uncertainties scaled by $\frac{1}{2}$, other systematic uncertainties scaled by $\frac{1}{\sqrt{L}}$
Full simulation object studies

- Parametrization of object performance in the HL-LHC pile-up environment

- Some examples here:
  - ATLAS $E_T^{\text{miss}}$ resolution with parametrization overlayed

- ATLAS b-tag fake rate for 70% efficiency compared with rate assumed for ES studies
  - ITK brings enhanced tracking
  - Mistag below 0.5% for $<\mu>=140$ $p_T=100$ GeV
Full simulation object studies

- The efficiency of the photon identification and isolation requirements as a function of the true photon $p_T$. Fitted parametrisation is superimposed.
  - Simulation corresponds to an average value of $\langle \mu \rangle = 80$. It assumed also for $\langle \mu \rangle = 140$.

- Distribution of the difference between the reconstructed and true mass for a 400 GeV Higgs-like resonance for the current ID configuration (MS +ID) and for the Phase-II configuration (MS +ITK).
The sensitivity of the main 5 decay channels differs only by a factor $\sim 3$

- Rich Higgs sector programme at HL-LHC
Very high signal purity
Separate into all 5 production modes
WH, ZH use lepton tags

**ttH only possible at HL-LHC**
VH, $H \rightarrow bb$

- Processes considered are $WH \rightarrow l\nu bb$ and $ZH \rightarrow llbb$;
  - $l = e, \mu$
  - The process $ZH \rightarrow \nu \nu bb$ should be investigated
- The analysis follows the general event selection strategy used for the analysis of $\sqrt{s} = 8$ TeV collision, except for jet $p_T$ thresholds
- No direct simulation of pileup jets is performed, however jet $p_T$ thresholds are set high to keep low their rate
  - the physics performance of objects account for pileup effects
- To validate the analysis method, the study has been performed assuming run-1 conditions ($\sqrt{s}$, L and pile-up)
  - reasonable agreement has been found (better than 5%)
- A significance of the $H \rightarrow bb$ signal from 8.8 to 9.6 can be obtained, depending on the JES systematic uncertainties that we can set at HL-LHC
ttH, H→γγ

- Sensitive to top in both production and decay
- Yields top Yukawa coupling

### Production mode

<table>
<thead>
<tr>
<th>Production mode</th>
<th>Total</th>
<th>Statistical</th>
<th>Experimental</th>
<th>Theoretical</th>
</tr>
</thead>
<tbody>
<tr>
<td>ttH</td>
<td>+21, -17</td>
<td>+13, -12</td>
<td>+5, -4</td>
<td>+17, -11</td>
</tr>
<tr>
<td>WH</td>
<td>+26, -25</td>
<td>+21, -20</td>
<td>+13, -12</td>
<td>+10, -8</td>
</tr>
<tr>
<td>ZH</td>
<td>+35, -31</td>
<td>+32, -29</td>
<td>+7, -7</td>
<td>+12, -8</td>
</tr>
<tr>
<td>ggF</td>
<td>+19, -14</td>
<td>+3, -3</td>
<td>+1, -1</td>
<td>+19, -14</td>
</tr>
<tr>
<td>VBF</td>
<td>+29, -29</td>
<td>+18, -18</td>
<td>+1, -1</td>
<td>+23, -23</td>
</tr>
</tbody>
</table>
H → μμ

- Allows direct study of coupling to two different leptons
- Test lepton flavour-violation carefully
- Signal significance:

<table>
<thead>
<tr>
<th>L [fb⁻¹]</th>
<th>300</th>
<th>3000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal significance</td>
<td>2.3σ</td>
<td>7.0σ</td>
</tr>
<tr>
<td>Δμ/μ</td>
<td>46%</td>
<td>21%</td>
</tr>
</tbody>
</table>
$H \to Z\gamma$

- Tests loop structure
- Small Signal to background ratio
- But a measurement is possible
From signal rates to Higgs couplings

- The cross section times branching ratio for initial state $i$ and final state $f$ is given by

$$
\sigma \cdot Br(i \rightarrow H \rightarrow f) = \frac{\sigma_i \cdot \Gamma_f}{\Gamma_H}
$$

- The total width $\Gamma_H$ is too narrow to measure
  - Assume it is the sum of the visible partial widths – no additional invisible modes

- Cross sections and branching ratios scale with $\kappa^2$ ($\rightarrow \Delta \kappa \sim 0.5 \Delta \mu$)

- Gluon and photon couplings can be assumed to depend on other SM couplings, or to be independent to allow for new particles in the loop
Higgs Couplings

• New: VH->bb included in ATLAS, updates for H->Zγ, VH/ttH->γγ (*)
• No BSM Higgs decay modes assumed
  – Comparable numbers for κ_W, κ_Z, κ_t, and κ_γ between the experiments
  – Couplings can be determined with 2-10% precision at 3000fb^{-1} (for CMS Scenario 2)

<table>
<thead>
<tr>
<th></th>
<th>κ_γ</th>
<th>κ_W</th>
<th>κ_Z</th>
<th>κ_g</th>
<th>κ_b</th>
<th>κ_t</th>
<th>κ_τ</th>
<th>κ_{Zγ}</th>
<th>κ_μ</th>
</tr>
</thead>
<tbody>
<tr>
<td>300fb^{-1}</td>
<td>ATLAS</td>
<td>[9,9]</td>
<td>[9,9]</td>
<td>[8,8]</td>
<td>[11,14]</td>
<td>[22,23]</td>
<td>[20,22]</td>
<td>[13,14]</td>
<td>[24,24]</td>
</tr>
<tr>
<td>300fb^{-1}</td>
<td>CMS</td>
<td>[5,7]</td>
<td>[4,6]</td>
<td>[4,6]</td>
<td>[6,8]</td>
<td>[10,13]</td>
<td>[14,15]</td>
<td>[6,8]</td>
<td>[41,41]</td>
</tr>
<tr>
<td>3000fb^{-1}</td>
<td>ATLAS</td>
<td>[4,5]</td>
<td>[4,5]</td>
<td>[4,4]</td>
<td>[5,9]</td>
<td>[10,12]</td>
<td>[8,11]</td>
<td>[9,10]</td>
<td>[14,14]</td>
</tr>
<tr>
<td>3000fb^{-1}</td>
<td>CMS</td>
<td>[2,5]</td>
<td>[2,5]</td>
<td>[2,4]</td>
<td>[3,5]</td>
<td>[4,7]</td>
<td>[7,10]</td>
<td>[2,5]</td>
<td>[10,12]</td>
</tr>
</tbody>
</table>

– ATLAS: [no theory uncert., full theory uncert.]
– CMS: [Scenario 2, Scenario1]
Higgs Couplings

- Remove the assumption on the total width
  - Only ratios of the coupling scale factors can be determined at LHC
  - Use given process as a reference
Higgs Couplings

**ATLAS Simulation Preliminary**

\[ s = 14 \text{ TeV: } \int \text{Ldt}=300 \text{ fb}^{-1} ; \int \text{Ldt}=3000 \text{ fb}^{-1} \]

- \( \kappa_{gZ} \)
- \( \lambda_{WZ} \)
- \( \lambda_{tg} \)
- \( \lambda_{bZ} \)
- \( \lambda_{tZ} \)
- \( \lambda_{tZ} \)
- \( \lambda_{gZ} \)
- \( \lambda_{\gamma Z} \)
- \( \lambda_{(\gamma Z)Z} \)

### CMS [Scenario2, Scenario1]

<table>
<thead>
<tr>
<th>L (fb(^{-1}))</th>
<th>( \kappa_g \cdot \kappa_Z / \kappa_H )</th>
<th>( \kappa_\gamma / \kappa_Z )</th>
<th>( \kappa_W / \kappa_Z )</th>
<th>( \kappa_b / \kappa_Z )</th>
<th>( \kappa_t / \kappa_Z )</th>
<th>( \kappa_Z / \kappa_g )</th>
<th>( \kappa_t / \kappa_g )</th>
<th>( \kappa_\mu / \kappa_Z )</th>
<th>( \kappa_{Z\gamma} / \kappa_Z )</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>[4,6]</td>
<td>[5,8]</td>
<td>[4,7]</td>
<td>[8,11]</td>
<td>[6,9]</td>
<td>[6,9]</td>
<td>[13,14]</td>
<td>[22,23]</td>
<td>[40,42]</td>
</tr>
<tr>
<td>3000</td>
<td>[2,5]</td>
<td>[2,5]</td>
<td>[2,3]</td>
<td>[3,5]</td>
<td>[2,4]</td>
<td>[3,5]</td>
<td>[6,8]</td>
<td>[7,8]</td>
<td>[12,12]</td>
</tr>
</tbody>
</table>

**ATLAS**

- (full theory uncer.)

- 2-3\% accuracy on few coupling constants at HL-LHC
- Reduced theoretical uncertainties needed
Effects of theory uncertainties

- Theoretical uncertainties limit the achieved precision
- Reducing the theoretical uncertainties is a worthwhile endeavor

CMS:
- **Scenario 1**
  - No theory uncertainty

ATLAS: Deduced size of theory uncertainty to increase total uncertainty by <10% for 3000 fb\(^{-1}\)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Status 2014</th>
<th>by ≤10% for 3000 fb(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theory uncertainty (%)</td>
<td>(\kappa_{gZ})</td>
<td>(\lambda_{tZ})</td>
</tr>
<tr>
<td>(gg \rightarrow H)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PDF</td>
<td>8</td>
<td>1.3</td>
</tr>
<tr>
<td>incl. QCD scale (MHOU)</td>
<td>7</td>
<td>1.1</td>
</tr>
<tr>
<td>(p_{T}) shape and 0j (\rightarrow 1j) mig.</td>
<td>10–20</td>
<td>1.5–3</td>
</tr>
<tr>
<td>1j (\rightarrow 2j) mig.</td>
<td>13–28</td>
<td>3.3–7</td>
</tr>
<tr>
<td>1j (\rightarrow VBF) 2j mig.</td>
<td>18–58</td>
<td>-</td>
</tr>
<tr>
<td>VBF 2j (\rightarrow VBF) 3j mig.</td>
<td>12–38</td>
<td>-</td>
</tr>
<tr>
<td>(q\bar{q}H)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PDF</td>
<td>3.3</td>
<td>-</td>
</tr>
<tr>
<td>(t\bar{t}H)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PDF</td>
<td>9</td>
<td>-</td>
</tr>
<tr>
<td>incl. QCD scale (MHOU)</td>
<td>8</td>
<td>-</td>
</tr>
</tbody>
</table>
Higgs Couplings

- Higgs boson couplings versus the SM particle masses
- Define ‘reduced’ coupling parameters

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

\[ y_{F,i} = k_{F,i} \frac{g_{F,i}}{\sqrt{2}} = k_{F,i} \frac{m_{F,i}}{v} \]
Simplified MSSM

- Second Higgs doublet present in many BSM models, such as MSSM
  - More in general one has 2HDMs, or extra EW singlet models
- Higgs boson couplings constraint heavy Higgs bosons from these models, depending on assumptions
- For $\tan\beta > 2$ expect limit on $m_A > 500$ (600) GeV assuming 300 (3000) fb$^{-1}$, if not limited by theory uncertainties
  - Current limit is 290 GeV
Di-Higgs production

• One of the exciting prospects of HL-LHC
  – Cross section at $\sqrt{s}=14$ TeV is $40.2$ fb [NNLO]
  – Challenging measurement
    • New preliminary results from ATLAS and CMS

• Destructive interference

• Final states shown today
  – $b\bar{b}\gamma\gamma$ [320 expected events at HL-LHC, 3000fb$^{-1}$]
    • But relatively clean signature
  – $b\bar{b}WW$ [30000 expected events at HL-LHC, 3000fb$^{-1}$]
    • But large backgrounds

• $b\bar{b}b\bar{b}$ and $b\bar{b}\tau\tau$ final states under consideration
Di-Higgs production

– Nominal performance for Phase II scenario and 3000fb$^{-1}$

• CMS:
  – Parameterized object performance tuned to CMS Phase II detector at $<\text{PU}>$=140
  – 2D fit of $M_{bb}$ and $M_{\gamma\gamma}$ distributions

• ATLAS:
  – Parameterized object performance obtained from full simulation
  – Cut based analysis
  – Electron to photon misidentification probability of 2% (5%) in barrel (endcap) is assumed
  – ATL-PHYS-PUB-2014-019
The distributions of $m_{bb} / m_{bb}$ in 3000 fb$^{-1}$ after applying all the selection criteria except for $m_{bb} / m_{\gamma\gamma}$. The individual shaped of the contributions are obtained using the events surviving event selection before the mass criteria and angular cuts are applied, but normalized to the number of expected events after the full event selection. The $ttX$ contribution includes $tt(\geq 1$ lepton) and $tt\gamma$, while ‘Others’ includes $cc\gamma\gamma$, $bb\gamma\gamma$, $bbjj$ and $jj\gamma\gamma$. 
## ATLAS prediction

<table>
<thead>
<tr>
<th>process</th>
<th>Expected events in 3000 fb⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM HH $\rightarrow$ bbγγ</td>
<td>8.4 ± 0.1</td>
</tr>
<tr>
<td>bbγγ</td>
<td>9.7 ± 1.5</td>
</tr>
<tr>
<td>ccγγ, bbγj, bbjj, jjγγ</td>
<td>24.1 ± 2.2</td>
</tr>
<tr>
<td>top background</td>
<td>3.4 ± 2.2</td>
</tr>
<tr>
<td>ttH(γγ)</td>
<td>6.1 ± 0.5</td>
</tr>
<tr>
<td>Z(bb)H(γγ)</td>
<td>2.7 ± 0.1</td>
</tr>
<tr>
<td>bbH(γγ)</td>
<td>1.2 ± 0.1</td>
</tr>
<tr>
<td>Total background</td>
<td>47.1 ± 3.5</td>
</tr>
<tr>
<td>S/√B (barrel+endcap)</td>
<td>1.2</td>
</tr>
<tr>
<td>S/√B (split barrel and endcap)</td>
<td>1.3</td>
</tr>
</tbody>
</table>
CMS results

<table>
<thead>
<tr>
<th>Process / Selection Stage</th>
<th>$HH$</th>
<th>$ZH$</th>
<th>$ttH$</th>
<th>$bbH$</th>
<th>$\gamma\gamma+jets$</th>
<th>$\gamma+jets$</th>
<th>$jets$</th>
<th>$tt$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Object Selection &amp; Fit Mass Window</td>
<td>22.8</td>
<td>29.6</td>
<td>178</td>
<td>6.3</td>
<td>2891</td>
<td>1616</td>
<td>292</td>
<td>113</td>
</tr>
<tr>
<td>Kinematic Selection</td>
<td>14.6</td>
<td>14.6</td>
<td>3.3</td>
<td>2.0</td>
<td>128</td>
<td>96.9</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Mass Windows</td>
<td>9.9</td>
<td>3.3</td>
<td>1.5</td>
<td>0.8</td>
<td>8.5</td>
<td>6.3</td>
<td>1.1</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Table 3: The expected event yields of the signal and background processes for 3000 fb$^{-1}$ of integrated luminosity are shown at various stages of the cut-based selection for the both photons in the barrel region. Mass window cuts are 120 GeV to 130 GeV for $M_{\gamma\gamma}$ and 105 GeV to 145 GeV for $M_{bb}$. A large fit mass window, 100 GeV to 150 GeV for $M_{\gamma\gamma}$ and 70 GeV to 200 GeV for $M_{bb}$, is used for the likelihood fit analysis. The statistical uncertainties on the yields are of the order of percent or smaller.

ATLAS and CMS are discussing the analyses to continue to better understand remaining differences and avenues for sensitivity improvement.
CMS results

• The average expected relative uncertainty on the di-Higgs cross section measurement is shown as a function of the b-tagging efficiency (left) and the photon efficiency (right).
CMS: HH→WWbb

• Results are quoted as a function of the background systematic uncertainty
  
  • Data driven techniques will likely constraint the uncertainties to the percent level

![Graph showing the relationship between 95% Asymptotic CL Limit on σ/σ_{SM} and Background Systematic Uncertainty [%].](image)

![Graph showing the relationship between Relative Uncertainty on Fitted Signal Yield [%] and Background Systematic Uncertainty [%].](image)
VBS → ZZ Final State

• Used EW Chiral Lagrangian using a minimal K-matrix unitarization method
• WHIZARD was used to generate
  – SM VV scattering prediction to the ZZ final state
  – Several VV resonances with various masses, couplings, and widths
• Other included backgrounds: diboson (Madgraph)
• Require 4 leptons, one trigger, and 2 jets
VBS $\rightarrow$ ZZ Final State

Expected stat-only Significance

<table>
<thead>
<tr>
<th>model</th>
<th>300 fb$^{-1}$</th>
<th>3000 fb$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_{\text{resonance}} = 500$ GeV, $g = 1.0$</td>
<td>$2.4\sigma$</td>
<td>$7.5\sigma$</td>
</tr>
<tr>
<td>$m_{\text{resonance}} = 1$ TeV, $g = 1.75$</td>
<td>$1.7\sigma$</td>
<td>$5.5\sigma$</td>
</tr>
<tr>
<td>$m_{\text{resonance}} = 1$ TeV, $g = 2.5$</td>
<td>$3.0\sigma$</td>
<td>$9.4\sigma$</td>
</tr>
</tbody>
</table>
Summary

• **30 fb**⁻¹ of LHC data at √s = 8 (and 7) TeV has allowed the Higgs discovery

• **300 fb**⁻¹ at 14 TeV will allow lots of precision measurements in the Higgs sector, SM and continue NP searches

• **3000 fb**⁻¹ will extends/complete the LHC Physics Programme:
  – LHC ultimate precision Higgs couplings to elementary bosons and fermions
  – Search for rare Higgs boson decays
  – Coupling structure
  – Di-Higgs boson production

• The physics possible at a hadron collider grows with experience: we’ll surely exceed this physics programme!
backup
ECFA Workshop 2014

- Link to the agenda: https://indico.cern.ch/event/315626/

- Performance and Physics session:
• New results on (single) Higgs studies since ECFA 2013: all from ATLAS!!
• New/first results on HH production from both collaborations on HH→bbγγ
• CMS presented exclusion limits also on (ggF) HH→bbWW
Higgs Studies & ATLAS Extended ITK

- Study impact of various ITK and MS $p_T$ resolution and trigger acceptance scenarios

- Lepton requirements
  - $p_T \mu > 20, 15, 10, 6$ GeV
  - $\Delta R, m_{12}, m_{34}$ as in Run1 analysis

- Using the best setup:
  - 7\(\mu\)m pixel reso., full muon upgrade
  - 35% Acceptance gain from nearly 100% efficient muon reconstruction
  - Mass resolution degrades quickly with $\eta$
Higgs Prospects analyses

1. HH → bbγγ
2. SM H couplings interpretation
3. BSM H couplings interpretation
4. VBF H → ττ
5. H → 4l large η plots
6. H → Zγ
7. ttH/ZH, H → γγ
8. VH, H → bb

See details in
https://twiki.cern.ch/twiki/bin/view/AtlasProtected/HiggsProspects
Pileup Mitigation at the HL-LHC

Pippa Wells, CERN, on behalf of
the ATLAS and CMS Collaborations

ECFA High Luminosity LHC Experiments Workshop - 2014
Effects of a longer beam spot

- Generate ttbar events with pileup, Phase II tracker, $\mu=140$
- Different longitudinal (z) beam spot profiles:
  - Gaussian with $\sigma=5\text{cm}$
  - Long beam spot, ~flat to ±15cm

- Generated tracks
- Reconstructed vertices
Effects of a longer beam spot

- ttbar events with varying pileup and beam spot z distributions
  - Gaussian, $\mu$ [80,300]
  - Varying shape, $\mu=80,140$

N reco primary vertices

Non-optimised algorithms

ttbar PV efficiency vs z
b-tagging – higher pileup

- ATLAS Phase II ITk performance with $\mu=140$ better than Run 2 performance expected with $\mu=50$ [LoI]
- b-tagging degrades gradually with higher $\mu$

• Only events with the correct primary vertex enter the plots
  • b-tagging is insensitive to beam spot shape IF the correct ttbar primary vertex is found
  • NB: rejection = $1/(\text{misid-prob})$
• Non-optimised algorithms from Run 1
7. **Electroweak Symmetry Breaking**: is the 125 GeV particle the only responsible for the EWSB? Analyse the Vector Boson scattering cross section as a function of the VV invariant mass to study whether the cross-section regularization is operated by the Higgs boson (as predicted by SM) or by other objects.

8. **SM**: Very high precision test of the Standard Model parameters (high accuracy measurement of vector boson masses, top mass, \(\sin^2\theta_W\), TGC, …)

9. **Naturalness problem**: continue the search for SUSY particles, in particular search for third generation squarks; also continue the search for gauginos and for 1\(^{\text{st}}\) and 2\(^{\text{nd}}\) generation squarks; similarly for Extra-Dimensions. Similarly test non-SUSY BSM models

10. **Dark Matter origin**