New Ways of Searching for New Physics at the LHC

Antonio Boveia, University of Chicago
Fermilab LPC
11 May 2012

(i.e. some miscellaneous topics)
Questions we want to answer

• *How does electroweak symmetry breaking work?*

• *What is dark matter?*

• *Is the Standard Model a low-energy effective theory? What is the full theory?*
Questions we want to answer

- How does electroweak symmetry breaking work?
- What is dark matter?
- Is the Standard Model a low-energy effective theory? What is the full theory?
- What are we going to do for the next 30 years?
Questions we want to answer

• How does electroweak symmetry breaking work?

• What is dark matter?

• Is the Standard Model a low-energy effective theory? What is the full theory?

• What are we going to do for the next 30 years?
  • Only willing to predict what we’re going to do for the next year....
From last time—Higgs sensitivity with $5/fb$ at 7 TeV projected from 2010 study

ATL-PHYS-PUB-2010-009

Figure 15: The expected upper bound on the Higgs boson production cross-section after collecting 1 fb$^{-1}$ of integrated luminosity in 7 TeV collisions with the ATLAS detector. On the top plot, the limit is normalised to the NLO prediction of the SM cross-section and on the bottom plot, it is normalised to an absolute cross-section. The green and yellow bands represent the range in which we expect the limit will lie, depending upon the data. Only the $H \rightarrow WW \rightarrow ll\nu\nu$, $H \rightarrow ZZ \rightarrow 4l$ and $H \rightarrow \gamma\gamma$ channels are included in these plots. It is expected that in the low mass region, the addition of $H \rightarrow bb$ and $H \rightarrow \tau\tau$ will improve this result. The expected limit in high mass region above $M_H \sim 200$ GeV is obtained from the $H \rightarrow ZZ \rightarrow 4l$ only as shown in Fig. 10; the limit in the high mass region will be improved with the addition of the $H \rightarrow ZZ \rightarrow llbb$ and $H \rightarrow ZZ \rightarrow ll\nu\nu$ channels.
How’d we do?

\[ \int L \, dt = 4.6 - 4.9 \, \text{fb}^{-1} \]

\[ \sqrt{s} = 7 \, \text{TeV} \]
How’d we do?

Rough estimate wasn’t too bad; actual sensitivity slightly better
Many caveats to predictions: effect of pile-up on each channel, different signal to background, no new channels or other improvements, etc.

Naively: assuming 8 TeV analysis has the same sensitivity as at 7 TeV, \( \sqrt{L} \) improvement with 4xL suggests expected limit with anything from complete exclusion to (if we’re unlucky) \( m_H > \sim 120 \text{ GeV} \) or so.
Updated EW Fit from Gfitter

http://gfitter.desy.de, 12 May 2012

\[ M_W = 80.385 \pm 0.015 \text{ GeV} \]

\[ M_W = 80.399 \pm 0.023 \text{ GeV} \]
Updated EW Fit from Gfitter

http://gfitter.desy.de, 12 May 2012
From last time: diphoton results

- Expect $O(10)$ signal events per $1/\text{fb}$, roughly independent of signal mass
- Signal width: -few bins + fitted background => ~50 events signal, ~1000 events background
  - => local $p$-value of few $\times 10^{-2}$ (excluding systematics)
  - Double signal strength => local $p$-value of ~$10^{-3}$.

![Diphoton Results Graph](chart.png)
From last time: diphoton results

- Consistent with observed p-value

- Extrapolate to 4x the data: 4000 background events
  - Nominal SM production: 200 signal events => p-value: \(10^{-3}\)
  - 2x SM production: 400 signal events => p-value: \(\text{few } 10^{-10}\)
    (neglecting systematics)
- Similar predictions for lower unexcluded masses...
Predictions for 2012

Possible outcomes:

• Rule out the SM Higgs at low mass
• or establish with a combination channels a statistically significant excess that may or may not be a Higgs.
Predictions for 2012

Possible outcomes:
- Rule out the SM Higgs at low mass
- or establish with a combination channels a statistically significant excess that may or may not be a Higgs.

Then what?
Predictions for 2012

Possible outcomes:
- Rule out the SM Higgs at low mass
- or establish with a combination channels a statistically significant excess that may or may not be a Higgs.

Then what?
(n.b. until ~2015, when new data arrives.)

SM Higgs is ruled out:
- Keep pushing down to lower and lower production cross section (gg vs VBF), possible suppressed decays
- When to give up?
- What does this imply for BSM physics?

Higgs-like object is found:
- Nail down properties (mass, production rates and modes, all decays) to confirm Higgs hypothesis and constrain BSM physics
- Continue to do traditional BSM searches (BSM physics is hiding where seeing it is hard?)
- Is Higgs produced in association with anything unexpected?

Look at these two possibilities from a BSM search perspective...
Two sides of the same issues:
- How sensitive is Higgs to BSM physics (short answer: very)
- Why haven’t we seen BSM physics yet? (looking in the right ways?)
Predictions for Higgs Production and Decays

Production accurately known:

- Total gg production uncertainty 15–20%
- top loop, b-loop(O(5%)) calculated exactly at NLO
- calculated to NNLO in heavy top limit
- NNNLL resummation
- Uncertainty is roughly half scale, half PDFs

Widths also well-known

BSM physics could substantially modify both (new particles in loops, different total Higgs width), or add additional higgses (e.g. SUSY)

- At low mass, total width is so small that new decay modes could overwhelm the expected width

Goal should be to measure production and decay to at least theory precision.
Modest enhancement in $gg \rightarrow H$ production (X) order of magnitude suppression in diphoton branching fraction.

=> possible to constrain fourth generation models with accurate measurements of production and decay.
Modified Higgs Rates: Invisible Decays

If the higgs can decay to a new ~stable, neutral particle, total width is increased and all visible decays suppressed.

Not always hopeless:
detect via VBF→MET+2 jets, measure ZZ→4l lineshape

\[ \xi^2 = Br(H \rightarrow Inv.) \frac{\sigma_{q\bar{q}→H}}{\sigma_{q\bar{q}→H}_{SM}} \]

\[ \sigma_{AA} \]

95% CL

FIG. 3: Assuming a SM input width, the uncertainty in width extraction can be converted to a 95% C.L. reach in the invisible width, as shown in the left panel. The right panel shows comparison in invisible width measurements between direct probe via VBF [52] and indirect probe via total width. The direct and indirect probes are complimentary to each other.

http://arxiv.org/abs/1010.2753v2

FIG. 3: The ratio of the Higgs production rates in the gluon fusion channel in the littlest Higgs model over the SM expectation. The three curves, from top to bottom, are for \( c_-/c_+ = 1, 0.3, \) and 0, respectively. Precision electroweak constraints require \( f \geq 1.2 \text{ TeV} \).
Higgs as a way to constrain SUSY

Mass of lightest CP-even higgs depends on soft SUSY-breaking parameters through radiative corrections
Example: “phenomenological MSSM”

Figure 1: The maximal value of the $h$ boson mass as a function of $X_t/M_S$ in the pMSSM when all other soft SUSY-breaking parameters and $\tan \beta$ are scanned in the range Eq. (4) (left) and the contours for $123 < M_h < 127$ GeV in the $[M_S, X_t]$ plane for some selected range of $\tan \beta$ values (right).
Higgs as a way to constrain SUSY

Mass of lightest CP-even higgs depends on soft SUSY-breaking parameters through radiative corrections

Example: “constrained” MSSM

Figure 2: The maximal value of the $h$ mass defined as the value for which 99% of the scan points have a mass smaller than it, shown as a function of $\tan \beta$ for the various constrained MSSM models.
Higgs as a way to constrain SUSY

Mass of lightest CP-even higgs depends on soft SUSY-breaking parameters through radiative corrections
Example: “phenomenological MSSM”

Figure 3: The value of $M_h$ as a function of one mSUGRA continuous parameter when a scan is performed on the other parameters. The constraints from Higgs and SUSY searches at the LHC are included and the impact of flavour ($b \to s \gamma$, $B_s \to \mu^+ \mu^-$, $B \to \tau \nu$) and DM constraints are shown.

Higgs as a way to constrain SUSY

Mass of lightest CP-even higgs depends on soft SUSY-breaking parameters through radiative corrections
Example: mSUGRA

Figure 4: Contours in which $123 < M_h < 127$ GeV, resulting of a full scan of the mSUGRA parameter but for particular choices of the inputs $A_0$ (left) and $m_0$ (right). The lower bound from LHC searches of SUSY strongly interacting particles in the fully hadronic channel with 1 fb$^{-1}$ data [24] is shown by a continuous line.
Higgs as a way to constrain SUSY

Example: “split” and “high-scale” SUSY

Figure 5: The value of $M_h$ as a function of $M_S$ for several values of $\tan \beta = 1, 2, 5, 50$ in the split SUSY (left) and high-scale SUSY (right) scenarios.
It is assumed that the effects of new physics only appear through vacuum polarisation and therefore lead to modified oblique parameters. Most of the effects on electroweak precision observables can be parametrised by three gauge self-energy parameters ($S, T, U$) introduced by Peskin and Takeuchi [Phys.Rev.D46, 381-409(1992)].

Higgs as a way to constrain RS graviton models

Example: constraints on warp factor from Higgs mass measurement
BSM physics outside the Higgs sector

If Higgs is not found, where is the BSM physics hiding?

Continuing refrain from phenomenologists (c.f. SEARCH 2012): existing searches are not general enough

- Finite resources ⇒ focus on some fashionable subset of models
- Theoretical prejudices ⇒ prefer scenarios with attractive properties
- Search results interpreted in terms of a handful of models, or sometimes provided in various “model-independent” ways (often not model independent or hard for theory to interpret)
If Higgs is not found, where is the BSM physics hiding?

Continuing refrain from phenomenologists (c.f. SEARCH 2012): existing searches are not general enough
• Finite resources => focus on some fashionable subset of models
• Theoretical prejudices => prefer scenarios with attractive properties
• Search results interpreted in terms of a handful of models, or sometimes provided in various “model-independent” ways (often not model independent or hard for theory to interpret)
• Example: photon+jet searches—17 year gap...

**BSM physics outside the Higgs sector**


**FIG. 1.** The photon candidate + leading jet invariant mass distribution (points) compared to an estimate of the QCD background (solid curve) and excited quark signal at four different \( q^* \) mass values (dotted curves). Corrected for acceptance and efficiency except for the cuts \( |\eta| < 0.9 \) and \( |\cos\theta^*| < \frac{1}{2} \).
BSM physics outside the Higgs sector

If Higgs is not found, where is the BSM physics hiding?

Continuing refrain from phenomenologists (c.f. SEARCH 2012): existing searches are not general enough
• Finite resources => focus on some fashionable subset of models
• Theoretical prejudices => prefer scenarios with attractive properties
• Search results interpreted in terms of a handful of models, or sometimes provided in various “model-independent” ways (often not model independent or hard for theory to interpret)
• Example: more complicated decay topologies

A promising, and complicated, scenario.

> TeV \[\tilde{u}, \tilde{d}, \ldots\]
\[\tilde{t}, \tilde{b}\]

\[\sim 100s \text{ GeV}\]
\[\tilde{g}, \tilde{\tilde{\tilde{N}}}\]

The Dominant channel
\[p \ p \rightarrow \tilde{g}\tilde{g} \rightarrow t\bar{t}t\bar{t}(\text{or } t\bar{b}b, \ t\bar{b}b \ldots)\]
\[\tilde{g} \rightarrow \tilde{t}\tilde{\bar{t}}(\text{or } b\bar{b}, \ b\bar{b}) \quad \tilde{t} \rightarrow b\ell^+\nu\]

• Multiple b, multiple lepton final state.
• Good early discovery potential.
• Challenging to interpret: top reconstruction difficult.

Liantao Wang, Here, 28 March
BSM physics outside the Higgs sector

If Higgs is not found, where is the BSM physics hiding?

Continuing refrain from phenomenologists (c.f. SEARCH 2012): existing searches are not general enough

- Finite resources => focus on some fashionable subset of models
- Theoretical prejudices => prefer scenarios with attractive properties
- Search results interpreted in terms of a handful of models, or sometimes provided in various “model-independent” ways (often not model independent or hard for theory to interpret)
- Example: debate over how to re-interpret mSUGRA and other searches in terms of less-restrictive SUSY scenarios
  - “Supersymmetry Without Prejudice”

Figure 14: (Top) Flat prior models that are unobservable in all of the $E_T^{miss}$-based search analyses in the average light squark–gluino mass plane. (Bottom) Flat prior models that pass (green) or fail (red) the 4j0l analysis in the gluino(lightest squark) mass vs gluino-LSP(lightest squark-LSP) mass splitting plane in the left(right) panel. $L = 1$ fb$^{-1}$ and $\delta B = 50\%$ have again been assumed.
BSM physics outside the Higgs sector

If Higgs is not found, where is the BSM physics hiding?

Continuing refrain from phenomenologists (c.f. SEARCH 2012): existing searches are not general enough

- Finite resources => focus on some fashionable subset of models
- Theoretical prejudices => prefer scenarios with attractive properties
- Search results interpreted in terms of a handful of models, or sometimes provided in various “model-independent” ways (often not model independent or hard for theory to interpret)
- Example: non-prompt, late-decaying or slow/highly ionizing tracks; late jets, out of time energy
If Higgs is not found, where is the BSM physics hiding?

Continuing refrain from phenomenologists (c.f. SEARCH 2012): existing searches are not general enough

- Finite resources => focus on some fashionable subset of models
- Theoretical prejudices => prefer scenarios with attractive properties
- Search results interpreted in terms of a handful of models, or sometimes provided in various “model-independent” ways (often not model independent or hard for theory to interpret)
- Example: pathologically wacky final states (e.g. charge-shifting R hadrons)
New requirements for new physics

Exhaust easy options for BSM physics => grow more desperate => give up prejudices

• “Naturalness”, simplicity, triggerable leptons, etc.

• Examples:
  • why does SUSY need to supply a dark matter candidate? (give up R-parity)
  • why does DM need to consist of a single type of particle? (SM does not)
  • why should BSM physics be easy to trigger on?
Since exact nature of BSM physics is unknown, trigger flexibility is vital.

ATLAS is preparing a Level “1.5” trigger upgrade to provide near-offline quality tracking for the Level 2 trigger algorithms.

Within 100 μs of each Level 1 accept, FTK will perform $p_T > 1$ GeV tracking over the entire silicon system for the start of HLT processing. It divides tracking into two stages:

• Coarse pattern recognition with an associative memory
• Full-resolution FPGA track search and fits

Designed to handle Phase I pile-up (3x design luminosity)

**Associative memory “road finding”**

Analyze a large sample of tracks and construct a frequency-ordered list of all hit patterns generated by the tracks in the detector. Look for each of these patterns in every event.

• Group consecutive silicon channels into “superstrips” (SS) to reduce the number of unique patterns needed for high efficiency and the size of training track sample.
• Partition silicon detectors into 11 “logical layers.”
• Result for high-pileup configuration is typically order 1 billion coarse-granularity hit patterns for $p_T > 1$ GeV tracks over the entire detector (smaller for early system).

**FPGA “track fitting”**

Within each identified pattern (“road”), fit all full resolution hit combinations and apply a chi'2 cut.

• Linearize the track fit: average track parameters for each combination of modules + first order correction for each hit—excellent approximation suitable for FPGAs with embedded DSPs.
• Full combinations have exactly one hit in each of the logical layers
• “Majority” roads/combinations have one logical layer with no hit.
• 1 fit/ns

The associative memory (AM) chip

• Store each pattern in one cell of memory in a set of custom ASICs. Each cell compares its pattern to silicon data flowing through a common bus.
• When readout is complete, the AM stage is complete; pattern recognition occurs at the silicon readout speed.
Since exact nature of BSM physics is unknown, trigger flexibility is vital.

**FTK**

ATLAS is building a Level “1.5” trigger upgrade to provide near-offline quality tracking for the Level 2 trigger algorithms.

Within 100 us of each Level 1 accept, FTK will perform $p_T > 1$ GeV tracking over the entire silicon system for the start of HLT processing. It divides tracking into two stages:

- Coarse pattern recognition with an associative memory
- Full-resolution FPGA track search and fits

Designed to handle Phase I pile-up (3x design luminosity)

---

**Figure 2.1:** The number of ROD output hits from each silicon layer in the barrel vs. luminosity.
Prototype being built at ATLAS Point 1 for parasitic commissioning

Replace HOLAs for RODs in existing detector with ones that have two outputs:
• ROS: standard behavior
• FTK: Can exert flow control when FTK is enabled

Produced and tested all replacements boards at Chicago in Nov/December 32 installed and tested at P1 since January; remainder during long shutdown.

Goal is to prototype and test all components by Summer 2013. Full system ASAP.
FTK—Performance Figures from 2010 Technical Proposal
Summary

• Higgs physics is beginning to place important constraints on BSM physics scenarios.
  • 2012 “Precision” measurements of properties may be the most interesting measurements for the next few years.

• Traditional BSM strategies need to evolve
  • Exhaust easy options for BSM physics => grow more desperate => give up prejudices for direct searches
Additional Slides
### Diphoton systematics

<table>
<thead>
<tr>
<th>Signal event yield</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Photon reconstruction and identification</td>
<td>±11%</td>
</tr>
<tr>
<td>Effect of pileup on photon identification</td>
<td>±4%</td>
</tr>
<tr>
<td>Isolation cut efficiency</td>
<td>±5%</td>
</tr>
<tr>
<td>Trigger efficiency</td>
<td>±1%</td>
</tr>
<tr>
<td>Higgs boson cross section (scales)</td>
<td>±12%</td>
</tr>
<tr>
<td>Higgs boson cross section (PDF+(\alpha_s))</td>
<td>±8%</td>
</tr>
<tr>
<td>Higgs boson (p_T) modeling</td>
<td>±1%</td>
</tr>
<tr>
<td>Luminosity</td>
<td>±3.9%</td>
</tr>
</tbody>
</table>

### Signal mass resolution

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Calorimeter energy resolution</td>
<td>±12%</td>
</tr>
<tr>
<td>Photon energy calibration</td>
<td>±6%</td>
</tr>
<tr>
<td>Effect of pileup on energy resolution</td>
<td>±3%</td>
</tr>
<tr>
<td>Photon angular resolution</td>
<td>±1%</td>
</tr>
</tbody>
</table>

### Signal mass position

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Photon energy scale</td>
<td>±0.7 GeV</td>
</tr>
</tbody>
</table>

### Signal category migration

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Higgs boson (p_T) modeling</td>
<td>±8%</td>
</tr>
<tr>
<td>Conversion rate</td>
<td>±4.5%</td>
</tr>
</tbody>
</table>

### Background model

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Background model</td>
<td>± ((0.1 - 7.9)) events</td>
</tr>
</tbody>
</table>
How did the sensitivity projections do?

- **ATLAS ZZ**: projected \(-0.5 \text{ bkg} + 1.5 \text{ signal} \) at 130 GeV, vs. \(9.3 \text{ bkg} + 2.65 \text{ signal actual} \).

### Table 3: The expected numbers of background events, with their systematic uncertainty, separated into “Low-\(m_{4\ell}\)” (\(m_{4\ell} < 180\) GeV) and “High-\(m_{4\ell}\)” (\(m_{4\ell} \geq 180\) GeV) regions, compared to the observed numbers of events. The expectations for a Higgs boson signal for five different \(m_H\) values are also given.

<table>
<thead>
<tr>
<th></th>
<th>(\mu^+\mu^-\mu^+\mu^-)</th>
<th>(e^+e^-\mu^+\mu^-)</th>
<th>(e^+e^-e^+e^-)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low-(m_{4\ell})</td>
<td>High-(m_{4\ell})</td>
<td>Low-(m_{4\ell})</td>
</tr>
<tr>
<td>Int. Luminosity</td>
<td>4.8 fb(^{-1})</td>
<td>4.8 fb(^{-1})</td>
<td>4.9 fb(^{-1})</td>
</tr>
<tr>
<td>(ZZ^{(*)})</td>
<td>2.1 ± 0.3</td>
<td>16.3 ± 2.4</td>
<td>2.8 ± 0.6</td>
</tr>
<tr>
<td>(Z + \text{ jets and } t\bar{t})</td>
<td>0.16 ± 0.06</td>
<td>0.02 ± 0.01</td>
<td>1.4 ± 0.5</td>
</tr>
<tr>
<td>Total Background</td>
<td>2.2 ± 0.3</td>
<td>16.3 ± 2.4</td>
<td>4.3 ± 0.8</td>
</tr>
<tr>
<td></td>
<td>Data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(m_H = 130) GeV</td>
<td>3</td>
<td>21</td>
<td>3</td>
</tr>
<tr>
<td>(m_H = 150) GeV</td>
<td>2.1 ± 0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(m_H = 200) GeV</td>
<td>4.9 ± 0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(m_H = 400) GeV</td>
<td>3.0 ± 0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(m_H = \cdots)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 11: Estimated number of events in the signal region for the signal and the major backgrounds at an integrated luminosity of 1 fb\(^{-1}\) for \(\sqrt{s} = 7\) TeV after the full event selection in \(H \rightarrow ZZ \rightarrow 4\ell\) (the 4\(e\), 2\(e2\(\mu\) and the 4\(\mu\) final states are summed).
Production Cross Section

\[ \sigma(pp \rightarrow H) \quad [\text{pb}] \]

\( M_H \) [GeV]

- \( gg \rightarrow H \) (NNLO+NNLL)
- \( gg \rightarrow H \) (NLO)
- \( qq \rightarrow qqH \) (NLO)
- \( qg \rightarrow ZH \) (NLO)
- \( qg \rightarrow WH \) (NLO)
- \( gg \rightarrow t\bar{t}H \) (NLO)

7 TeV
Production Cross Section

\[ \sigma(p\bar{p} \rightarrow H) \text{[pb]} \]

- \( gg \rightarrow H \text{ (NNLO+NNLL)} \)
- \( gg \rightarrow H \text{ (NLO)} \)
- \( q\bar{q} \rightarrow q\bar{q}H \text{ (NLO)} \)
- \( q\bar{q} \rightarrow WH \text{ (NLO)} \)
- \( q\bar{q}, gg \rightarrow t\bar{t}H \text{ (NLO)} \)

\( M_H \) [GeV]

10 TeV

\[ 10^2 \]

\[ 10 \]

\[ 1 \]

\[ 10^{-1} \]
Production Cross Section

\[ \sigma(p\bar{p}\rightarrow H) \] [pb]

- \( gg \rightarrow H \) (NNLO+NNLL)
- \( gg \rightarrow H \) (NLO)
- \( qq \rightarrow qqH \) (NLO)
- \( q\bar{q} \rightarrow WH \) (NLO)
- \( q\bar{q}, gg \rightarrow t\bar{t}H \) (NLO)

14 TeV

\[ M_H \text{ [GeV]} \]

Logarithmic scale from 10^{-1} to 10^2.
Higgs in 2012

ATLAS Preliminary

2011 Data

\[ \int Ldt = 4.6 - 4.9 \text{ fb}^{-1} \]

\[ \sqrt{s} = 7 \text{ TeV} \]

95% CL Limit on \( \sigma/\sigma_{\text{SM}} \)

- Obs.
- Exp.
- \( \pm 1 \sigma \)
- \( \pm 2 \sigma \)

CLs Limits

\[ m_H \text{ [GeV]} \]

\[ 100 \quad 200 \quad 300 \quad 400 \quad 500 \quad 600 \]
Higgs in 2012

\[ \int L \, dt \sim 4.6-4.9 \, \text{fb}^{-1}, \, \sqrt{s} = 7 \, \text{TeV} \]

\textbf{ATLAS} 2011 Preliminary

\textit{CLs limits}
Many caveats to predictions: effect of pile-up on each channel, different signal to background, no new channels or other improvements, etc.

Naively: assuming 8 TeV analysis has the same sensitivity as at 7 TeV, \( \sqrt{L=(5+15)/fb} \) improvement suggests anywhere from complete exclusion to (if we’re extremely unlucky) \( m_H > \sim 122 \text{ GeV} \)

Figure 15: The expected upper bound on the Higgs boson production cross-section after collecting 1 fb\(^{-1}\) of integrated luminosity in 7 TeV collisions with the ATLAS detector. on the top plot, the limit is normalised to the NLO prediction of the SM cross-section and on the bottom plot, it is normalised to an absolute cross-section. The green and yellow bands represent the range in which we expect the limit will lie, depending upon the data. Only the \( H \to WW \to ll\nu\nu, H \to ZZ \to 4l \) and \( H \to \gamma\gamma \) channels are included in these plots. It is expected that in the low mass region, the addition of \( H \to bb \) and \( H \to \tau\tau \) will improve this result. The expected limit in high mass region above \( M_H \sim 200 \text{ GeV} \) is obtained from the \( H \to ZZ \to 4l \) only as shown in Fig. 10; the limit in the high mass region will be improved with the addition of the \( H \to ZZ \to llbb \) and \( H \to ZZ \to ll\nu\nu \) channels.
Estimated Sensitivity with $20/fb$?

Figure 15: The expected upper bound on the Higgs boson production cross-section after collecting 1 fb$^{-1}$ of integrated luminosity in 7 TeV collisions with the ATLAS detector: on the top plot, the limit is normalised to the NLO prediction of the SM cross-section and on the bottom plot, it is normalised to an absolute cross-section. The green and yellow bands represent the range in which we expect the limit will lie, depending upon the data. Only the $H \rightarrow WW \rightarrow ll\nu\nu$, $H \rightarrow ZZ \rightarrow 4l$ and $H \rightarrow \gamma\gamma$ channels are included in these plots. It is expected that in the low mass region, the addition of $H \rightarrow bb$ and $H \rightarrow \tau\tau$ will improve this result. The expected limit in high mass region above $M_H \sim 200$ GeV is obtained from the $H \rightarrow ZZ \rightarrow 4l$ only as shown in Fig. 10; the limit in the high mass region will be improved with the addition of the $H \rightarrow ZZ \rightarrow llbb$ and $H \rightarrow ZZ \rightarrow ll\nu\nu$ channels.
Standard Model Higgs

- SM fermion couplings to Higgs are fixed

\[ L_f = -m_f \left( \bar{\Psi}_f \Psi_f + \bar{\Psi}_f \Psi_f \right) \left( 1 + \frac{H}{v} \right) \]

Largest contribution is top loop

b-loop contributes ~2-5%

Extremely sensitive to BSM Physics

SM calculations in great shape

- Dominant production mode is gg→H

- NNLO in heavy M_{top} limit (checked in M_{H}/M_{top} expansion)
- Exact t,b loops at NLO
- N^3LL resummation
- EW and mixed EW/QCD corrections

Precise predictions allow us to trust error estimates

Scale uncertainty for gg→H

- Scale uncertainty O(6-8%) for M_H ~ 100-300 GeV
- Slightly different approaches
  - ABPS
    - Exact NLO/NNLO in large M_t limit
    - No resummation
    - EFT estimate of EW/QCD
  - dFG
    - NNLO for large M_t+NNLL
    - Exact t/b to NLO
    - Exact EW

Online calculator:
http://theory.fl.infn.it/grazzini/hcalculators.html

The Role of b-loops

- K factor for b loops smaller than for top loops
- b loops are 2-5% of SM gg→H

Higgs Couplings

- Gluon to fermion
  - If fermion is a quark, by ~ Q^2
  - New coupling?

- gg→H, M_H=120 GeV, (+20%, -15%) uncertainty at 7 TeV
  - Scale & PDF/\alpha_s uncertainties roughly equal