Prospects for Higgs at LHC

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Standard Model Higgs
MSSM Higgs
Measurements
LHC

✓ Machine
  - Final design for dipoles
  - Pre-series OK

✓ Current schedule
  - 04/2006 (pilot run)
  - 08/2006-03/2007 $10 fb^{-1}$
  - -> 2008 $30 fb^{-1}/year/expt$
  - Then $100 fb^{-1}$ 100 $fb^{-1}/yr$

✓ Few months potential delay
  - Magnets procurements
Detectors (1)

✓ ATLAS and CMS

- Optimized for low mass Higgs
  - Small & narrow signals, large backgrounds
- Signatures: $\gamma$, $e/\mu/\tau$, $E_T^{\text{miss}}$, SUSY, $t$, jets
- Experimental effects
  - Efficiencies, background rejection, particle ID, resolution, non-gaussian response
  - fully simulated (GEANT)
  - Checked with test beam when possible
Detectors (2)

- CMS HCAL
- CMS magnet system
- ATLAS barrel cryostat
- ATLAS EM
- LARG calorimeter
Approach

✓ Results

- Processes simulation (signal, backgrounds)
  - No K-factor ($\sigma_{LO}/\sigma_{NLO} \sim 1.1 - 1.9$) - conservative
- No “hopeless” channels (multijets…, WH)
- Redundancy
- Discovery: $5\sigma (S/\sqrt{B})$ per expt / channel
  - When background poorly known
    - control tools (side-bands, jet veto)
    - systematics on background included

- Simple analyzes (simple cuts)
  - Neural Nets less reliable if bkgd poorly known
**SM Higgs (1)**

✓ **Production**
  - **Direct**
    - Via gg dominant
    - Via VBF qqH
      - ~ 20% gg
      - 2 quarks @ large $\eta$
  - **Associated**
    - $t\bar{t}H$, WH, ZH
    - $m_H < 200$ GeV
    - ~ 1-10% gg
SM Higgs (2)

✓ Final state

- $m_H < 2m_Z$
  - $ttH \rightarrow lbb+X$
  - $H \rightarrow \gamma\gamma$ (direct & associated)
  - $H \rightarrow ZZ^* \rightarrow 4l$
  - $H \rightarrow WW^* \rightarrow l\nu l\nu$

- $m_H > 2m_Z$
  - $H \rightarrow ZZ \rightarrow 4l$
  - $qqH \rightarrow ZZ \rightarrow l\nu l\nu$
  - $qqH \rightarrow WW \rightarrow l\nu jj$

with forward jets
**SM Higgs (3)**

- All channels together

- 80 - 1 TeV region covered

- \( m_H < 180 \text{ GeV} \): many complementary channels (\( \gamma\gamma, \text{bb}, 2l, 3l, 4l \))

- \( m_H > 180 \text{ GeV} \): easy with \( H \rightarrow ZZ \rightarrow 4l \)

- Not included yet: VBF channels at low mass
**SM Higgs (4)**

- **Sensitivity**

  - **ATLAS + CMS**
    - All region excluded @ 95% CL after 1 month
    - Discovery with $10\text{fb}^{-1}$ (~2007) for $m_H < 150$ GeV
    - Faster for $m_H > 150$ GeV
    - Conservative results (e.g. $WH \rightarrow Wbb$ not included)

- **For $m_H < 150$ GeV**
  - $\gamma\gamma$, $bb$ dominant

- **NEW** $qq \rightarrow qqH \rightarrow qq\tau\tau, qqWW$ under study
SM Higgs(5)

✓ H → bb via ttH (WH, ZH difficult)

• Complex final state: 4b, 2 jets
• Bckd reduced by 2 tops reconstruction
• b-tagging essential
• Δ(m_{bb}) ~ 15%
• Complementary to γγ

• Crucial: bckd knowledge (60% ttbb), with ttjj
• 5σ → 130 GeV if bckd known
• 5σ → 120 GeV if 5% systematics on bckd

H → bb (low lumi)
ε_b ~ 60%, R(uds) ~100

ATLAS+CMS
30fb^{-1} S=80 B=320
SM Higgs (6)

**✓** $H \rightarrow bb$ via $ttH$ (cont’d)

- CMS study
- Use **likelihood** for $t$ decays & event kinematics
- Use COMPHEP for $ttjj$

**✓** $H \rightarrow \gamma\gamma$

- Direct & associated ($ttH, WH$)
- Well assessed
- Background
  - dominant: $\gamma\gamma$ - well measured from side bands

CMS 30$fb^{-1}$
- $S=38$ $B=52$

CMS 100$fb^{-1}$
- $K=1.6$, $S/B \sim 4\%$
SM Higgs VBF (1)

**Motivation (D. Zeppenfeld et al.)**
- Extra potential for discovery
- Access to couplings ($H\tau\tau$), $\Gamma_H$
- Invisible Higgs

- 2 forward jets
  - Well assessed for $m_H > 400$ GeV

**Forward jet tagging**
- Efficiencies critically important
- Assessed with full simulation

- Double tag efficiency ~ 50%
- Fake tag < 1% @ $10^{34}$
SM Higgs VBF (2)

✓ $qqH \rightarrow qqWW \rightarrow qq l\nu l\nu$
  - Backds: $tt$, $WW$ cont.
  - $p_T$(tot) cut & jet veto

\[
\begin{array}{c|cccc}
  m_H (GeV) & 130 & 150 & 170 & 190 \\
  \hline
  S & 10 & 30 & 55 & 40 \\
  S/B & 0.3 & 0.9 & 1.5 & 1.1 \\
  S/\sqrt{B} & 1.4 & 5.0 & 8.8 & 6.3 \\
\end{array}
\]

- Counting expt @ low mass
  - 5% systematics included in $B$
- Results worse than @ particle level
  - ISR/FSR, jet calibration, efficiencies

ATLAS, $e\mu$, 10 fb$^{-1}$
\[m_H = 160 \text{ GeV}\]

\[m_T = \sqrt{2p_T^{\ell}\ E_T^{\text{miss}} (1 - \cos \Delta\phi)}\]
SM Higgs VBF (3)

✓ $qqH \rightarrow qq\,\tau\tau \rightarrow qq\,l\nu\nu\,l\nu\nu$

- Similar to WW
- $\tau$ reconstruction using collinear approximation

<table>
<thead>
<tr>
<th>$m_H$ (GeV)</th>
<th>115</th>
<th>120</th>
<th>130</th>
<th>140</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S/\sqrt{B}$ 10fb$^{-1}$</td>
<td>2.6</td>
<td>2.6</td>
<td>2.3</td>
<td>1.3</td>
</tr>
<tr>
<td>$S/\sqrt{B}$ 30fb$^{-1}$</td>
<td>4.3</td>
<td>4.3</td>
<td>3.8</td>
<td>2.7</td>
</tr>
</tbody>
</table>

- Systematics to be included
- (l, had) mode under study
**SM Higgs VBF (4)**

✅ qqH → qq **Invisible** (Preliminary)

- **Bckds:** QCD jj, Wjj, Zjj
- **Cuts**
  - Lepton & jet veto
  - $\phi_{jj} < 1$
  - **Isolation** cut kills QCD bckd: $\Delta(\phi(p_T^{\text{miss}}) - \phi(j_1,j_2)) > 1$

- **Counting expt**
  - Zjj, Wjj to be known to few %
  - Zjj can be normalized using lljj
- **Trigger:** Rates OK, under study

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**ATLAS after isolation & $\phi_{jj}$ cuts**

- Signal
- QCDjj
- Wjj
- Zjj
MSSM Higgs (1)

- Large variety of observation modes
  - **SM-like**: \( h \rightarrow \gamma\gamma, \ bb \ ; \ H \rightarrow 4l \)
  - **MSSM-specific**: \( A/H \rightarrow \mu\mu, \tau\tau, \tt \ ; \ H \rightarrow hh, A \rightarrow Zh ; H^\pm \rightarrow \tau\nu \)
  - **If SUSY accessible**: \( H/A \rightarrow \chi^0_0 \chi^0_0, \chi^0_0 \rightarrow h \chi^1_0 \)

- **Study in 2 steps**
  - SUSY does not contribute
  - SUSY contributes in production/decays
    - Impact on Higgs decay to SM particles is small
      - \( h \rightarrow \gamma\gamma \) 10% smaller, \( A/H \rightarrow SM \) at most 40% smaller
MSSM Higgs (2)

✓ $A/H \rightarrow \tau\tau \rightarrow h^+\nu h^-\nu$
- Extends the range for large $m_A$ wrt (l,h) mode
- Requests 2 stiff isolated tracks, $p_T$, 1 b-jet (bbA)
- Challenge: QCD bckd rejection (also for trigger)

✓ $gb \rightarrow t H^\pm, H^\pm \rightarrow \tau\nu$
- Extends the reach for lower $\tan\beta$ & $m_A$ up to 500 GeV (compared to $H^\pm \rightarrow t b$)

CMS, 30 fb$^{-1}$
$m_A = 500$ GeV, with b-tag
MSSM Higgs (3)

All together

- Plane totally covered
- At very large $\tan \beta$, $m_h \sim 110$ GeV, $h$ may not be seen
- If LEP excess from $hZ$, LHC will see $h$ in any case, and $A, H, H^\pm$ for moderate $m_A$ & large $\tan \beta$

ATLAS + CMS

$30 \text{ fb}^{-1}; m_{\text{SUSY}} = 1 \text{ TeV}$

- 2 or more Higgs can be seen in a big plane fraction
- $bbh \rightarrow bb \mu\mu$ under study

Christchurch, NZ, 25/01/02

L. Poggioli - LAPP
MSSM Higgs (4)

SM versus MSSM

Here only SM-like h observable if no SUSY interplay

But region can be reduced with SLHC @ 10^{35} (5σ contours)
MSSM Higgs (5)

☑️ SUSY contribution

- Decay into SUSY particles ($m_A < 500$ GeV)

$$H/A \rightarrow \chi^0_2 \chi^0_2 \rightarrow l l \chi^1_0 \bar{\chi}^1_0$$

Region $m_A \sim 200-400$ GeV; $\tan \beta \sim 2-20$ covered

Reconstruction of $m_A$ possible (end-point $ll$)
MSSM Higgs (6)

- Higgs in SUSY cascade \((m_A > 500 \text{ GeV})\)

\[ \chi^2_0 \rightarrow h \chi^1_0, h \rightarrow bb \text{ (A/H too heavy)} \]

• Clear signal
• \(h \rightarrow bb\) but **without leptons**
  → no SM
• Covers a wide region
  \(m_A > 400-500 \text{ GeV}; \tan \beta > 5\)
  (no sensitivity in MSSM)
**Measurements (1)**

✓ **Higgs mass**

**SM**
- No theoretical error (mass shift for large $\Gamma_H$)
- Error dominated by absolute energy scale
  $\rightarrow 0.1\%$ for $l/\gamma$ (using $Z \rightarrow ll$)
  $\rightarrow 1\%$ for jets

**MSSM**
- $h$ as in SM
- $H/A \sim 0.1-0.5\%$ in modes $\gamma\gamma, 4l, \mu\mu$;
  $1-2\%$ in modes $bb, bb\gamma\gamma (hh), bbll (Zh)$
Mesurements (2)

\[ \sigma \cdot BR \]

- Dominant errors: statistics, luminosity (5-10%), systematics on bckd (10%)
- Precision \( \sim 7-20\% \)

\[ \tan \beta \]

\( \sigma(bbA/H) \) increases fast with \( \tan \beta \)

\[ \Delta L/L = 10\% \]
Mesurements (3)

✓ Width

• Direct
  • Mass peak width for $m_H > 200$ GeV ($\Gamma_H > \Gamma_{\text{exp.}}$ in SM)
  • Limited by radiative decays (1.5%)
  • MSSM: possible for $A/H \to \mu\mu$

• Indirect (under study)
  • From rates of $qqH$ in $\gamma\gamma$, $\tau\tau$, $WW$
  • Assume BR in $cc$, non-standard < 10%

✓ Higgs self-coupling (prel.)

- $SM\ HH \to WWWW \to l\nu\ jj\ l\nu\ jj$
  • expect $S \sim 30$, $S/B \sim 1$ for 600 fb$^{-1}$
- $MSMM\ H \to hh \to 4b$ final state
**Measurements (4)**

**✓ Couplings & BR**

- **Boson/Boson couplings**
  - **Direct**
    \[
    \frac{\sigma \times \text{BR}(H \rightarrow WW^*)}{\sigma \times \text{BR}(H \rightarrow ZZ^*)} = \frac{g_W}{g_Z} = \frac{\Gamma_W}{\Gamma_Z}
    \]
  - **QCD corrections cancel**
  - **Indirect**
    \[
    \frac{\sigma \times \text{BR}(H \rightarrow \gamma\gamma)}{\sigma \times \text{BR}(H \rightarrow ZZ^*)} = \frac{g_{\gamma\gamma}}{g_Z} \sim \frac{\Gamma_W}{\Gamma_Z}
    \]
    - Use proportionality between $\Gamma_W$ and $\Gamma_Z$
      (theoretical input needed 10% assumed)

- **Boson/fermion couplings**

- **Errors are statistics dominated (~ 15-20%) → SLHC will help**
Prospects

- **SM Higgs**
  - Discovery over full mass range with 10 fb\(^{-1}\)
  - LHC/Tevatron competition in 2006-2007

- **MSSM**
  - Full coverage of the parameter space
  - Weak region recovered with SUSY/SLHC

- **Measurements & Theory constraints**
  - Masses, width, couplings (SLHC will help)
  - LHC/Tevatron complementarity

- **Ongoing efforts**
  - VBF, H spin, invisible Higgs, H self-coupling