The elusive agent of electroweak symmetry breaking
- an experimentalist point of view -

Ulrich Heintz
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the holy grail of particle physics
H searches before LEP experiments at PSI, SPS, CESR

excluded $m_H < 5$ GeV

subject to significant uncertainties
e+e⁻ collisions

1989-1995: E_{com} = M_Z
1996-2000: E_{com} ≥ 209 GeV
H production at LEP

**LEP 1**

\[ \text{e}^+ \rightarrow Z \rightarrow \text{e}^- \text{H} \]

**Björken process**

**LEP 2**

\[ \text{e}^+ \rightarrow Z^* \rightarrow \text{e}^- \text{H} \]

**Higgsstrahlung**

**Graph**

Higgs production cross section vs. center of mass energy (GeV)

- \( m_H = 50 \text{ GeV/c}^2 \)
- Sensitivity for 200 pb\(^{-1} \)
- Data points at 60, 70, 85, 100, 115 GeV
H search at LEP1

0.0 \( \leq m_H \leq 65 \text{ GeV/c}^2 \)

Excluded at 95% C.L.

for \( m_H < 2m_\pi \) :
\( H \rightarrow ee, \mu\mu \)

for \( m_H < 2m_b \) :
\( H \rightarrow gg, cc \)

\( H \rightarrow b\bar{b} (\sim 80\%) \)

Acoplanar lepton pairs

Very little background expected

\[ \text{BR}(Z \rightarrow H\ell^+\ell^-, H\nu\bar{\nu}) \]

Events expected at LEP among 2x10^7 Z
H searches at LEP2

Decay signature defined by Z decay

<table>
<thead>
<tr>
<th>Higgs</th>
<th>Z</th>
<th>Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>$bb$</td>
<td>$qq$</td>
<td>51.5%</td>
</tr>
<tr>
<td>$bb$</td>
<td>$\nu\nu$</td>
<td>14.7%</td>
</tr>
<tr>
<td>Any</td>
<td>$ll$</td>
<td>6.7%</td>
</tr>
<tr>
<td>$bb$</td>
<td>$\tau\tau$</td>
<td>2.5%</td>
</tr>
<tr>
<td>$\tau\tau$</td>
<td>$qq$</td>
<td>5.0%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>80.9%</strong></td>
</tr>
</tbody>
</table>

“missing E” $H\nu\bar{\nu}$

“leptons” $H\mu^+\mu^-$

“4-jets” $He^+e^-$

3/11/2008 Ulrich Heintz - Sakurai Prize Celebration
and then...
discovery or fluctuation?  
3 selections with increasing purity for mH = 115 GeV

"the results of the experiment were inconclusive so we had to use statistics..."

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the final LEP limit
modified frequentist confidence levels

define likelihood ratio
\[ L = \frac{p(data \mid s+b)}{p(data \mid b)} \]

\[ CL_b = P(L \leq L_{obs}) \text{ for background} \]

\[ CL_{s+b} = P(L \leq L_{obs}) \text{ signal + background} \]

\[ CL_s = \frac{CL_{s+b}}{CL_b} \text{ how much less likely is observed data for s+b than for b only?} \]

Signal can be excluded at 95% CL if CLs < 0.05

mH > 114 GeV
the end of LEP
Tevatron

pp collisions
E_{com} = 2 \text{ TeV}
L = 4 \times 10^{32} \text{ \text{cm}^2/\text{s}} (2 \text{ fb}^{-1}/\text{year})
analyzed now: \int L \, dt = 5 \text{ fb}^{-1}
expect \int L \, dt = 10 \text{ fb}^{-1} by end of 2011
H at the Tevatron?
H production at Tevatron

- **Gluon fusion**: $439\,\text{fb}$
- **Associate production**:
  - $WH: 51\,\text{fb}$
  - $ZH: 33\,\text{fb}$
- **Vector boson fusion**: $39\,\text{fb}$

@MH=160 GeV
H search at Tevatron

m_H < 135 GeV (H bb)
background driven
WH l bb, ZH ll/ bb

m_H > 135 GeV (H WW)
rate driven
all production modes

“low mass” Higgs

“high mass” Higgs
H search at Tevatron

example channel: WH\ell\ell bb

\[ \text{e/\mu} + p_T + 2\text{-}3 \text{ jets for } m_H = 115 \text{ GeV} \]

expect 24 Higgs decays in 84000 events

expect 7 Higgs decays in 700 events

use several variables to form neural network discriminant.
H search at Tevatron

neural network
single top production
same final state as low mass Higgs
slightly larger cross section
Tevatron H limits

published in
PRL 104, 061802 (2010)
by CDF and D0 Collaborations
sensitivity of H search at Tevatron
assume analysis will stay the same
known improvements will be implemented

“low mass” Higgs

“high mass” Higgs
pp collisions
end 2011: $E_{cm} = 7$ TeV, $L_{int} = 1$ fb$^{-1}$
end 2014: $E_{cm} = 14$ TeV, $L_{int} = 25$ fb$^{-1}$
end 2016: $E_{cm} = 14$ TeV, $L_{int} = 100$ fb$^{-1}$

Peter Jenni (Moriond 2010)
Higgs production cross sections at LHC

$\sigma(\text{pp} \rightarrow \text{H+X})$
$\sqrt{s} = 14$ TeV
$m_t = 175$ GeV
CTEQ4M

M. Spira et al.
NLO QCD

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CMS projections for H search

mH < 130 GeV
H \rightarrow \gamma\gamma

130 < mH < 190 GeV
H \rightarrow W^+W^- \ell\ell

190 < mH < 460 GeV
H \rightarrow ZZ \ell\ell \ell\ell

460 < mH < 800 GeV
H \rightarrow W^+W^- \ell\ell qq

designed to discover Higgs with 100 < mH < 800 GeV
the CMS experiment
homogeneous electromagnetic calorimeter
78,000 lead tungstate crystals
excellent photon energy resolution
measure $H \rightarrow \gamma \gamma$

$m_H = 130$ GeV
$L = 100$ fb$^{-1}$

$N_{eV} = 0.5$ GeV

Events/500 MeV for 100 fb$^{-1}$
LHC projection for next 2 years

CMS Preliminary: projection for 7 TeV, 1 fb\(^{-1}\)

Mar 17 2010

\[ r = \frac{\sigma_{95\%CL}}{\sigma_{SM}} \]

\[ H_{\gamma\gamma} + H_{WW} + H_{ZZ} \]

Excluded region: 145 < m\(H\) < 190 GeV
LHC projection for next 2 years

Combination of 0j and 2j, H to WW to ll

\[ \sqrt{s} \text{ (TeV)} \]

\[ \text{Significance} \]

\[ m_H = 130 \text{ GeV} \quad \bullet \]
\[ m_H = 150 \text{ GeV} \quad \triangle \]
\[ m_H = 160 \text{ GeV} \quad \blacktriangleleft \]
\[ m_H = 170 \text{ GeV} \quad * \]
\[ m_H = 180 \text{ GeV} \quad \square \]

1 fb^{-1}
summary
the search for Gerry’s boson has shaped particle physics experiments for the last three decades
but it still eludes detection
the quest goes on...
Congratulations, Gerry!

Celebration of Sakurai Prize

Speakers:
Gerry Guralnik
Brown U
Roman Jackiw
MIT
Sally Dawson
BNL
Marcus Spradlin
Brown U
Jesse Thaler
MIT
Ulrich Heintz
Brown U

May 5, 2010 at 2pm
Brown University
Barnes & Holley 190

sponsored by the Dean of Faculty and the Physics Department