SUPERSTAR IN PARTICLE PHYSICS

OR

ON ONE USELESS PARTICLE EVERYBODY IS SEARCHING FOR

M. Gintner

U. of Žilina

September 20, 2008

THE LHC D-DAY: *Sep 10, 2008*

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Nigel S. Lockyer, Director of Canada's TRIUMF laboratory:
One short trip for a proton, but one giant leap for mankind!

- 300 journalists on site
- 3500 press cuttings on the day
- the LHC featuring on the Google logo
- 450 television stations picked up the CERN broadcast signal
- it was broadcast over 2100 times
- the CERN websites over 100 million hits
- CERN was the lead news story on television news, even demoting the US elections to second place

"The LHC is designed to discover the Higgs boson!"

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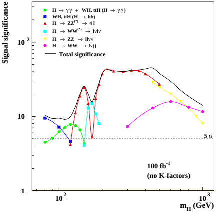
ATLAS DETECTOR AND PHYSICS PERFORMANCE



Technical Design Report

Issue:	1
Revision:	0
Reference:	ATLAS TDR 15, CERN/LHCC 99-15
Created:	25 May 1999
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Volume II

“The LHC is designed to discover the Higgs boson!”

ATLAS

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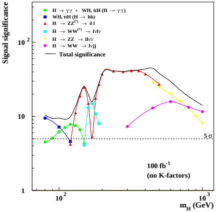

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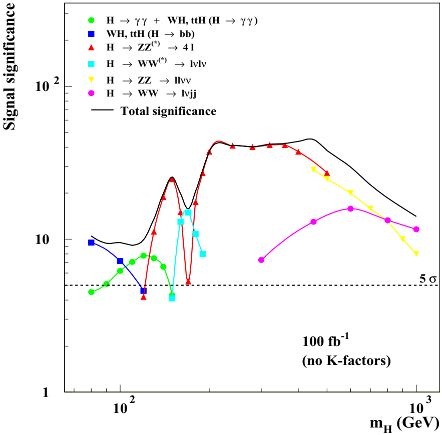

What is the REAL question for the LHC?

ESB mechanism - the most pressing problem of the SM

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- masses of Z, W^+, W^-
- spontaneous symmetry breaking
- Higgs boson is not a MUST

Particle world: Language

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QFT

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representation	spin
scalar	0
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LAGRANGIAN - easy way to reflect symmetries

Particle world: Contents

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single scalar field:

$$\text{LT:} \quad \phi \rightarrow \phi$$

$$\mathcal{L} = \frac{1}{2}(\partial_\mu \phi)(\partial^\mu \phi) - \frac{1}{2} m^2 \phi^2 + g\phi^4 + \ldots$$

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two scalar fields:

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additional symmetry:

$$\boxed{SO(2): \; \Phi \rightarrow O\Phi, \qquad O^T O = \mathbb{I}}$$

Spontaneous symmetry breaking

Assumptions:

- $\mathcal{L}(\hat{\phi}_1, \hat{\phi}_2)$
- G is a symmetry of $\mathcal{L}$
- $\exists U \in G: \; \hat{\phi}_1 \to \hat{\phi}_2$

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Goldstone theorem:

SSB: $G \to H$ $\Rightarrow$ the # of Goldstone Bosons $= \dim G - \dim H$

Spontaneous symmetry breaking: Example

$SO(3)$ Lagrangian:

$$\mathcal{L} = \mathcal{L}(\underbrace{\pi_1, \pi_2, \sigma}_{\Phi})$$

the lowest energy configuration:

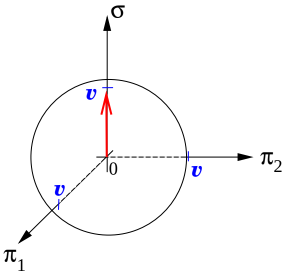
$$\pi_1^2 + \pi_2^2 + \sigma^2 = v^2$$

the vacuum choice:

$$\Phi_{vac} \equiv (0, 0, v)$$

reparameterization:

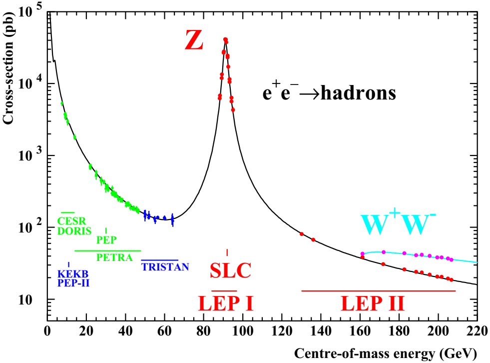
$$\sigma(x) = v + h(x)$$



$$m_{\pi_1} = m_{\pi_2} = 0, \qquad m_h \neq 0$$

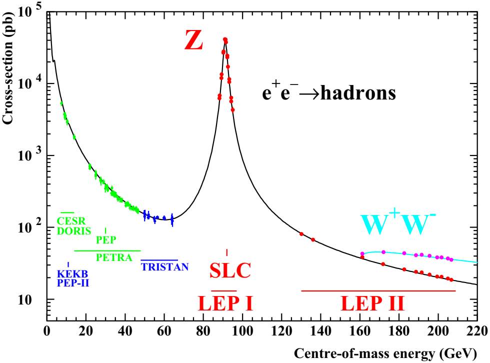
Gauge symmetry

- gauge symmetry of $\mathcal{L}_0$: $SU(2)_L \times U(1)_Y$



Gauge symmetry

- gauge symmetry of $\mathcal{L}_0$: $SU(2)_L \times U(1)_Y \quad \Rightarrow \quad$ massless $A, W^{\pm}, Z$
- ... + parity violation $\Rightarrow$ massless fermions



c'mon, get real !!!

Troubles:

- the real masses $\neq$ symm($\mathcal{L}_0$)
- missing gauge boson d.o.f.'s
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1. spoil the gauge symmetry

c'mon, get real !!!

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Any suggestions?

1. spoil the gauge symmetry
2. SSB
   - $\mathcal{L} = \mathcal{L}_0 + \mathcal{L}_{SSB}$
   - $SU(2)_L \times U(1)_Y \subset$ symm$\mathcal{L} \equiv G$ $U(1)_{em} \subset$ symm(vac) $\equiv H$
   - Goldstone bosons must donate the missing d.o.f.'s (Higgs mechanism)
   - $\dim G - \dim H = 3$

The SM Higgs boson

- $\mathcal{L}_{SSB}(\Phi)$, $\Phi(x) \propto \begin{pmatrix} 0 \\ v \end{pmatrix} + \begin{pmatrix} \pi_2(x) + i\pi_1(x) \\ h(x) - i\pi_3(x) \end{pmatrix}$
- $SU(2)_L \times SU(2)_R \to SU(2)_V$
- $m_{\pi_1} = m_{\pi_2} = m_{\pi_3} = 0 \quad \Rightarrow$ d.o.f.'s for massive $W^\pm, Z$
- $m_h \neq 0$ (free parameter)
- masses: $W^\pm, Z$, fermions
- gauge symmetry preserved
- SM is renormalizable

...NOT DISCOVERED YET

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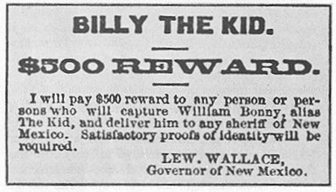
- direct search



BILLY THE KID.

$500 REWARD.

I will pay $500 reward to any person or persons who will capture William Bonny, alias The Kid, and deliver him to any sheriff of New Mexico. Satisfactory proofs of identity will be required.

LEW. WALLACE,
Governor of New Mexico.

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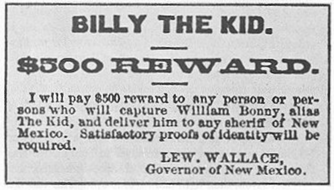

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- indirect limits

$$\chi^2(\vec{p}) = \sum_{k=1}^{n} \frac{[X_k^{(exp)} - X_k^{(th)}(\vec{p})]^2}{\sigma_k^2}$$

The Higgs mass limits

direct lower limit:

$m_H > 114$ GeV

indirect limit:

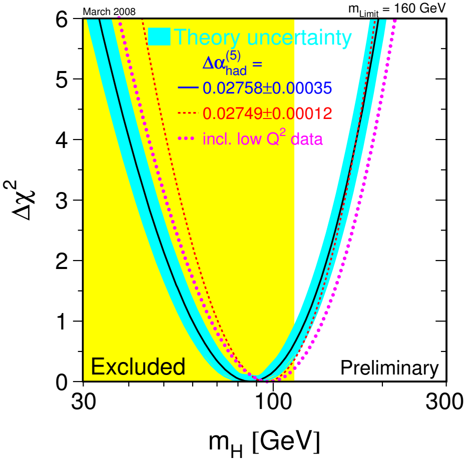
$m_H = 87^{+36}_{-27}$ GeV

direct + indirect:

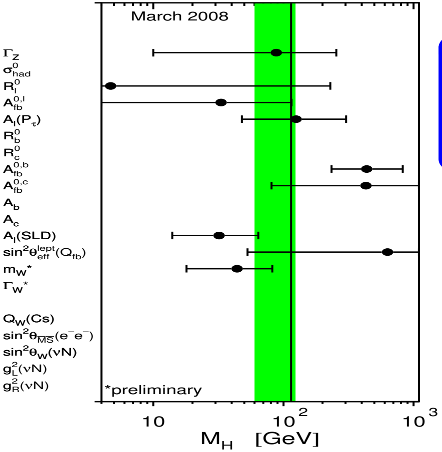
$m_H < 160$ GeV @ 95% C.L.

"theory " limit:

$125 \text{ GeV} < m_H < 175 \text{ GeV}$



m_H LIMITS FROM VARIOUS OBSERVABLES



Higgs mass values extracted from different EW observables. The average is shown as a green band.

- fit of all SM observables: 15%
- fit of the SM observables most sensitive to M_H: $< \ 2\%$

  [P.Gambino, Proceedings of the EPS 2007 Conference at Manchester]

LEP Electroweak Working Group, http://lepewwg.web.cern.ch/LEPEWWG/plots/winter2007/

m_H vs. Mass of Top Quark

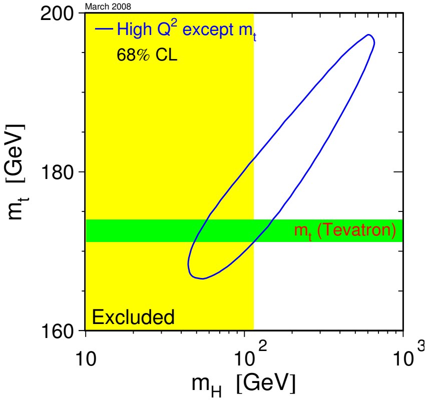
direct CDF/D0 measurement:

$$m_t = 172.6 \pm 1.4 \text{ GeV}$$

EW precision data (w/o direct Tevatron measurements):

$$m_t = 178.9^{+11.7}_{-8.6} \text{ GeV}$$

the overall SM fit down to 15%
$(\chi^2/\text{dof} = 18/13)$



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m_H vs. Mass of W boson

direct measurement:

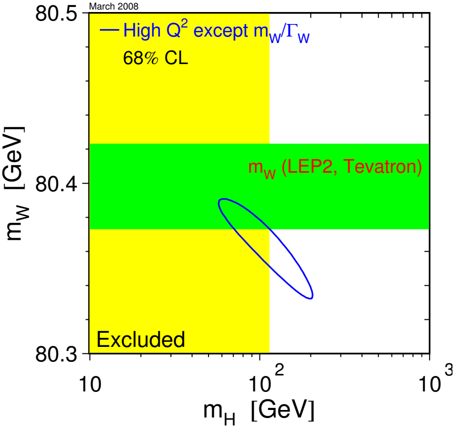
$$M_W^{world} = 80.398 \pm 0.025 \text{ GeV}$$

EW precision data (Z-peak + m_t measurements):

$$M_W = 80.361 \pm 0.020 \text{ GeV}$$

$$\Downarrow$$

m_H $<$ direct limit



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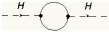
Troubles with the Higgs

higher-order corrections to Higgs mass:

$$m^2 = m_0^2 + \delta m^2 \approx (10^2 \mathrm{GeV})^2$$



$$\delta m^2 \sim \frac{g M^2}{8\pi^2}$$

if $M \approx M_{Planck} \approx 10^{17} M_W$:

$$\left|\frac{m_0^2}{\delta m^2}\right| \approx 1 - \mathcal{O}(10^{-32})$$

$\rightarrow$ fine-tuning problem

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- unitarizes the SM amplitudes
  (other new particles can do the same)

Alternatives to SM Higgs

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recent ideas:

- little Higgs models
- Gauge-Higgs unification
- ...

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- ESB sector:
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  - 3 scalar fields (Goldstone bosons)
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  - 3 scalar fields (Goldstone bosons)
  - $SU(2)_L \times SU(2)_R$ global symmetry
  - $SU(2)_L \times U(1)_Y$-gauged
- new particle(s) to unitarize amplitudes ≈ 1 TeV

DON'T WORRY, BECAUSE...

...the truth is out there