Das Higgs–Boson

Tilman Plehn

Universität Heidelberg, ehemals Edinburgh

Symmetrien

Kaffee und Plätzchen beim Banktermin?

symmetrisch vor 2007

$= -$

Symmetrien

Kaffee und Plätzchen beim Banktermin?

unsymmetrisch nach 2007

$\neq -$

Higgs–Mechanismus

Masse durch das Vakuum

– ‘spontane Symmetriebrechung’ bekannt

– symmetrisches Vakuum mit Kennzahl $v = 0$ löst $v = -v$
unsymetrisches Vakuum mit Kennzahl $v = 246$

– Masse $m = g \cdot v$

$m = 0$ im symmetrischen Vakuum
$m = 246 \cdot g$ im unsymmetrischen Vakuum

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– Temperatur als Kennzahl

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ab 30° am Philosophenweg gefühlt schwer
Kopplung $m = g \cdot T$ individuell verschieden

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  Quantenmechanik: v-Welle = Higgs–Teilchen

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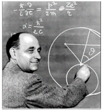
- Namensgebung

  Materieteilchen = Fermionen
  Rest = Bosonen

  Higgs–Boson

Shoulders of Giants

Massive Austauschteilchen



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– Yukawa 1935: Kräfte endlicher Reichweite
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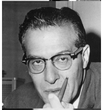

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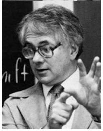

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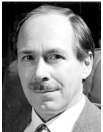

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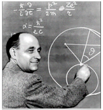

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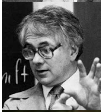

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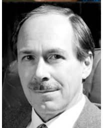
– Higgs, Brout, Englert 1964: spontane Symmetriebrechung
  Higgs–Boson



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Zwei Probleme der Elementarteilchenphysik

1. Goldstone–Theorem:
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2. Licht–Polarisationen und $3 \neq 2$

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VOLUME 13, NUMBER 16 PHYSICAL REVIEW LETTERS 19 OCTOBER 1964

BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

Peter W. Higgs
Tait Institute of Mathematical Physics, University of Edinburgh, Edinburgh, Scotland
(Received 31 August 1964)

In a recent note[1] it was shown that the Goldstone theorem,[2] that Lorentz-covariant field theories in which spontaneous breakdown of symmetry under an internal Lie group occurs contain zero-mass particles, fails if and only if the conserved currents associated with the internal group are coupled to gauge fields. The purpose of the present note is to report that, as a consequence of this coupling, the spin-one quanta of some of the gauge fields acquire mass; the longitudinal degrees of freedom of these par-

about the "vacuum" solution $\varphi_1(x) = 0$, $\varphi_2(x) = \varphi_0$:

$$\partial^\mu\{\partial_\mu(\Delta\varphi_1) - e\varphi_0 A_\mu\} = 0, \tag{2a}$$

$$\{\partial^2 - 4\varphi_0^2 V''(\varphi_0^2)\}(\Delta\varphi_2) = 0, \tag{2b}$$

$$\partial_\nu F^{\mu\nu} = e\varphi_0\{\partial^\mu(\Delta\varphi_1) - e\varphi_0 A_\mu\}. \tag{2c}$$

Equation (2b) describes waves whose quanta have (bare) mass $2\varphi_0\{V''(\varphi_0^2)\}^{1/2}$; Eqs. (2a) and (2c)

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A detailed discussion of these questions will be presented elsewhere.

It is worth noting that an essential feature of the type of theory which has been described in this note is the prediction of incomplete multiplets of scalar and vector bosons.[8] It is to be expected that this feature will appear also in theories in which the symmetry-breaking scalar fields are not elementary dynamic variables but bilinear combinations of Fermi fields.[9]

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[1]P. W. Higgs, to be published.

[2]J. Goldstone, Nuovo Cimento 19, 154 (1961); J. Goldstone, A. Salam, and S. Weinberg, Phys. Rev. 127, 965 (1962).

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PHYSICAL REVIEW VOLUME 145, NUMBER 4 27 MAY 1966

Spontaneous Symmetry Breakdown without Massless Bosons*

PETER W. HIGGS†
Department of Physics, University of North Carolina, Chapel Hill, North Carolina

(Received 27 December 1965)

We examine a simple relativistic theory of two scalar fields, first discussed by Goldstone, in which as a result of spontaneous breakdown of $U(1)$ symmetry one of the scalar bosons is massless, in conformity with the Goldstone theorem. When the symmetry group of the Lagrangian is extended from global to local $U(1)$ transformations by the introduction of coupling with a vector gauge field, the Goldstone boson becomes the longitudinal state of a massive vector boson whose transverse states are the quanta of the transverse gauge field. A perturbative treatment of the model is developed in which the major features of these phenomena are present in zero order. Transition amplitudes for decay and scattering processes are evaluated in lowest order, and it is shown that they may be obtained more directly from an equivalent Lagrangian in which the original symmetry is no longer manifest. When the system is coupled to other systems in a $U(1)$ invariant Lagrangian, the other systems display an induced symmetry breakdown, associated with a partially conserved current which interacts with itself via the massive vector boson.

I. INTRODUCTION

THE idea that the apparently approximate nature of the internal symmetries of elementary-particle physics is the result of asymmetries in the stable solutions of exactly symmetric dynamical equations, rather than an indication of asymmetry in the dynamical

appear have been used by Coleman and Glashow[3] to account for the observed pattern of deviations from $SU(3)$ symmetry.

The study of field theoretical models which display spontaneous breakdown of symmetry under an internal Lie group was initiated by Nambu,[4] who had noticed[5]

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II. THE MODEL

The Lagrangian density from which we shall work is given by[29]

$$\mathcal{L}=-\tfrac{1}{4}g^{\kappa\mu}g^{\lambda\nu}F_{\kappa\lambda}F_{\mu\nu}-\tfrac{1}{2}g^{\mu\nu}\nabla_\mu\Phi_a\nabla_\nu\Phi_a+\tfrac{1}{4}m_0^2\Phi_a\Phi_a-\tfrac{1}{8}f^2(\Phi_a\Phi_a)^2. \quad (1)$$

In Eq. (1) the metric tensor $g^{\mu\nu}=-1$ $(\mu=\nu=0)$, $+1$ $(\mu=\nu\neq 0)$ or 0 $(\mu\neq\nu)$, Greek indices run from 0 to 3 and Latin indices from 1 to 2. The $U(1)$-covariant derivatives $F_{\mu\nu}$ and $\nabla_\mu\Phi_a$ are given by

$$F_{\mu\nu}=\partial_\mu A_\nu-\partial_\nu A_\mu,$$

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$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu ,$$

i. Decay of a Scalar Boson into Two Vector Bosons

The process occurs in first order (four of the five cubic vertices contribute), provided that $m_0 > 2m_1$. Let p be the incoming and k_1, k_2 the outgoing momenta. Then

$$M = i\{e[a^{*\mu}(k_1)(-ik_{2\mu})\phi^*(k_2) + a^{*\mu}(k_2)(-ik_{1\mu})\phi^*(k_1)] - e(ip_\mu)[a^{*\mu}(k_1)\phi^*(k_2) + a^{*\mu}(k_2)\phi^*(k_1)] - 2em_1 a_\mu^*(k_1) a^{*\mu}(k_2) - f m_0 \phi^*(k_1)\phi^*(k_2)\} .$$

By using Eq. (15), conservation of momentum, and the transversality ($k_\mu b^\mu(k) = 0$) of the vector wave functions we reduce this to the form

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- seit 1976: Higgs–Suchen an Teilchenbeschleunigern

A PHENOMENOLOGICAL PROFILE OF THE HIGGS BOSON

John ELLIS, Mary K. GAILLARD * and D.V. NANOPOULOS **
CERN, Geneva

Received 7 November 1975

A discussion is given of the production, decay and observability of the scalar Higgs boson H expected in gauge theories of the weak and electromagnetic interactions such as the Weinberg-Salam model. After reviewing previous experimental limits on the mass of the Higgs boson, we give a speculative cosmological argument for a small mass. If its mass is similar to that of the pion, the Higgs boson may be visible in the reactions $\pi^- p \to Hn$ or $\gamma p \to Hp$ near threshold. If its mass is $\lesssim 300$ MeV, the Higgs boson may be present in the decays of kaons with a branching ratio $O(10^{-7})$, or in the decays of one of the new particles: $3.7 \to 3.1 + H$ with a branching ratio $O(10^{-4})$. If its mass is ≤ 4 GeV, the Higgs boson may be visible in the reaction $pp \to H + X$, $H \to \mu^+\mu^-$. If the Higgs boson has a mass

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We should perhaps finish with an apology and a caution. We apologize to experimentalists for having no idea what is the mass of the Higgs boson, unlike the case with charm [3,4] and for not being sure of its couplings to other particles, except that they are probably all very small. For these reasons we do not want to encourage big experimental searches for the Higgs boson, but we do feel that people performing experiments vulnerable to the Higgs boson should know how it may turn up.

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$\Rightarrow$ Higgs–Boson eine rein theoretische Vorhersage

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Mathematische Formulierung

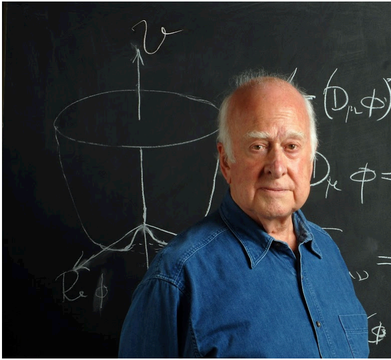
$$V = -\mu^2 |\phi|^2 + \lambda |\phi|^4$$

Minimum bei $\phi = \frac{v}{\sqrt{2}}$

$$\frac{\partial V}{\partial |\phi|^2} = -\mu^2 + 2\lambda |\phi|^2 \;\Rightarrow\; \frac{v^2}{2} = \frac{\mu^2}{2\lambda}$$

Variation $\phi = \frac{v + H}{\sqrt{2}}$

$$m_H^2 = \left. \frac{\partial^2 V}{\partial H^2} \right|_{\text{Minimum}} = 2\lambda v^2$$



Fragen

1. Higgs–Eigenschaften?
   - Psychologie: Higgs–Suche findet Higgs–Teilchen
   - Skalar erwartet
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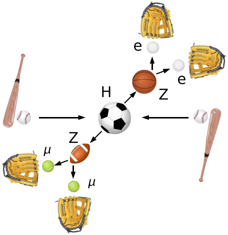
     'Graviton' extrem unwahrscheinlich



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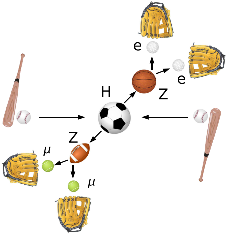

2. Kopplung an andere Elementarteilchen?
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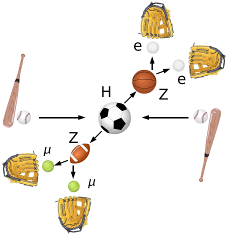

2. Kopplung an andere Elementarteilchen?
   - zentrale Higgs–Vorhersage
   - $m = g \cdot 246$ für alle Teilchen?

3. Und weiter?
   - erstes skalares Elementarteilchen!
   - stabiles Higgs–Potential?
   - dunkle Materie?
   - Theorien bei hohen Energieskalen?

     ...

Aufregende Zeiten...

...für LHC–PhysikerInnen

- Higgs–Entdeckung nach 50 Jahren, Fermi–Theorie gelöst
- Untersuchung des ‘Higgs–Bosons’ am Anfang
- LHC–Analysen gerade warmgelaufen

$\Rightarrow$ junge, kluge Köpfe gefragt!

Lectures on LHC Physics, Springer, arXiv:0910.4182 oder `www.thphys.uni-heidelberg.de/~plehn/`