TOP QUARK SYMPOSIUM

(1) Some comments

(2) Heavy quarks in the early 1970's.

(3) Some predictions

SOMEWHAT BORING ?

(1) Too heavy + short-lived
to make -onia

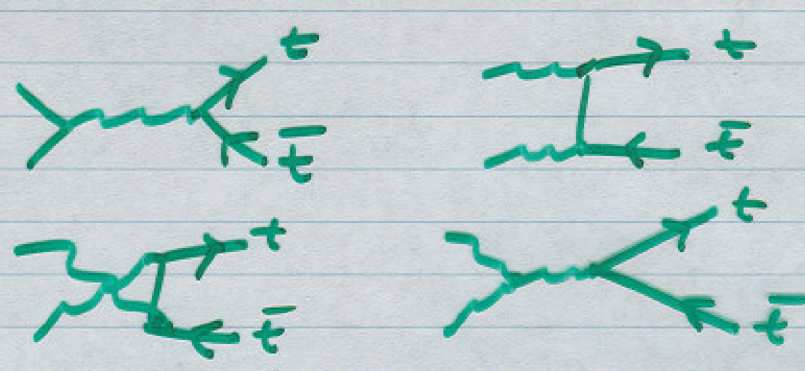
(2) Two light to be a
plausible major player in EWSB

$$\frac{y_t^2}{4\pi^2} = \frac{m_t^2}{4\pi^2 v^2} \simeq \frac{1}{80}$$

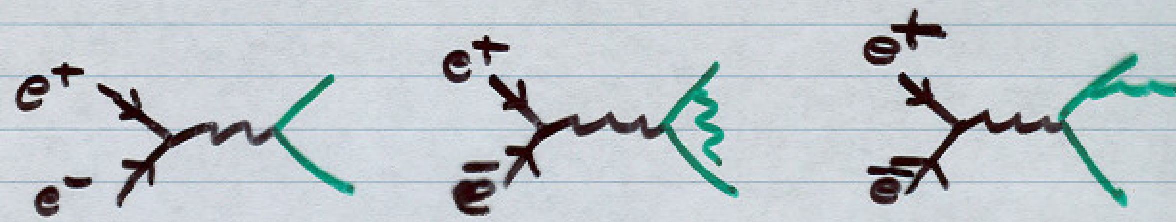
Maybe least exotic
-flavor?

GREAT PROBE OF STANDARD MODEL PHYSICS

- QCD
  - Hadronic Production



- $e^+e^- \rightarrow$



Threshold!

ELECTROWEAK

- Precision

  $\Delta\rho = G_F N_c m_t^2 / 8\sqrt{2}\,\pi^2$

- Single top production

- Higgs production

  Neutral

  Charged

- BEYOND THE STANDARD MODEL

- Major SUSY player
  Radiative EWSB

- Role in Dynamical EWSB?

- Little Higgs Models
  Radiative EWSB

- Top compositeness
  Agashe, Contino, Sundrum
  hep-ph/0502222

- Top Flavor

Topical Meeting on Yang–Mills Theory

Marseille
June 1972

T. Veltman	J. Primack
G. 't Hooft	H. Quinn
R. Barbieri	T. Appelquist
K. Symanzik	C. Korthals-Alte[s]
⋮	⋮

On Theories with Massless Particles*

by

K. Symanzik

November 1972

The best known theory with massless particles is QED. The masslessness of the photon leads to low-energy theorems and to the very peculiar (and gauge dependent) infrared singularities the Green's functions have near the electron mass shell. While the low-energy theorems hold in each order of perturbation theory separately, the infrared singularities are gotten correctly only by summing over all orders of perturbation theory as far as soft internal photons are concerned, and lead to zero amplitudes for emission or absorption of any "hard" particles and any number of soft photons. There is a well-known semiclassical description of these effects. - I will describe properties of some other renormalisable theories with massless particles and will dwell on features that again can be obtained correctly only by summing over all orders of perturbation theory, and again it suffices to do so with respect to the soft massless particles.

Why are theories with massless particles of interest at all, considering that there are so few such particles observed in nature? The present investigation arose from large - momenta - behaviour problems. Consider e. g. ϕ^4 theory. The scattering amplitudes are obtained from vertex functions* (amputated connected

*For notation and derivation of the formulae see Refs. 1) and 2)

one-particle-irreducible Green's functions) $\Gamma(p_1 \ldots p_{2n}; m^2, g)$, with

*Seminar held at the Topical Meeting on Yang-Mills Theory, at C.N.R.S. Marseille, June 19 - 23, 1972. Revised.

is not a discrete particle, while the electron propagator has a pole only in the Landau gauge $(c = 0)$. Of course, that does not mean that the electron is a discrete particle, as little as the singularity $(\not{p} - m)^{-1}$ in the Yennie gauge proves that it is one in massive-electron QED. The discreteness of the electron could be tested here by looking e. g. at the electron-electron scattering amplitude. That the photon is no longer a discrete particle is most easily understood by looking at the absorptive part of the photon self energy; the massless-electron-positron intermediate state directly suggests the singularity (16a). It is also noteworthy that in the limiting process, analogous to (3), to define the Γ_{as} for QED, the conventional charge, the last argument of Γ, must go to zero.

As in ϕ^4 theory, the possibility of obtaining precise statements on small-momenta behaviour in massless (equivalent to praeasymptotic) QED rests on the relation corresponding to (9a) for $e(\lambda)^2$, and on $b_{0QED} = \frac{\pi^2}{12} > 0$. In a theory with $b_o < 0$, in contrast the large-momenta behaviour of the praeasymptotic (and, due to (2), then also of the massive) theory can be given precisely. This is so for ϕ^3 theory in 6 dimensions[13], however, there are certain misgivings one may have about that theory. The same holds* for ϕ^4 theory with

*However, at least formally, the expansions obtained by substituting (9b) in (2) behave like asymptotic ones for $\lambda \to \infty$ and do not[14] display a manifest inconsistency even with unitarity if $|g|$ is not too large.

$g < 0$, on the basis of (9b). It should be interesting to determine the sign of the parameter* analogous to b_o in "pure" Yang-Mills theory.

*b_o, b_1 and c_o in (4) are independent of the normalization point of the propagator as well as of the four-point vertex function. The consequence of this, that the imaginary part of the vertex function should not change sign, is elaborated in Ref. 14. This holds analogously for other theories.

Aspen Center
For Physics

July 1974

David Politzer
Lenny Susskind
TA

"WHAT HAPPENS AT
A $c\bar{c}$ THRESHOLD?"

IN MEMORIAM

Asim Yildiz (1930-88)

Asim Yildiz was educated at Istanbul Technical University and Yale University, obtaining a PhD. in Civil Engineering at Yale. After a postdoctoral position with Norbert Wiener at MIT and a few years in industry he was appointed Professor of Mechanical Engineering at the University of New Hampshire. Remarkably, he then obtained a second PhD. in High Energy Physics with Julian Schwinger at Harvard University. He published over 100 papers on topics ranging from engineering to particle theory.

Asim was instrumental in starting up this series of Workshops, particularly in organizing the First Workshop on Grand Unification at the University of New Hampshire in April 1980. It is regrettable that Asim passed away just four months before the Tenth and Final Workshop, for which he was a member of the Steering Committee. We shall always remember and celebrate his generous spirit and enthusiastic friendship.

P. H. Frampton
H. Georgi
S. L. Glashow

April 1989

Assim:

1. Friendship for all

2. Havana Cigars for Shelly

3. Refuge for traumatized graduate students.

4. Access to the Longwood Cricket Club

5. Dinner parties in Cambridge

6. Weekends at the family compound in New Hampshire

7. Occasional physics advice

Late August
1974

Asim on heavy $q\bar{q}$ production near threshold:

"Schwinger did it."

JULIAN SCHWINGER, University of California at Los Angeles

PARTICLES, SOURCES, AND FIELDS

Volume II

1973
ADDISON-WESLEY PUBLISHING COMPANY
ADVANCED BOOK PROGRAM
Reading, Massachusetts

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If you can't join 'em,
beat 'em.

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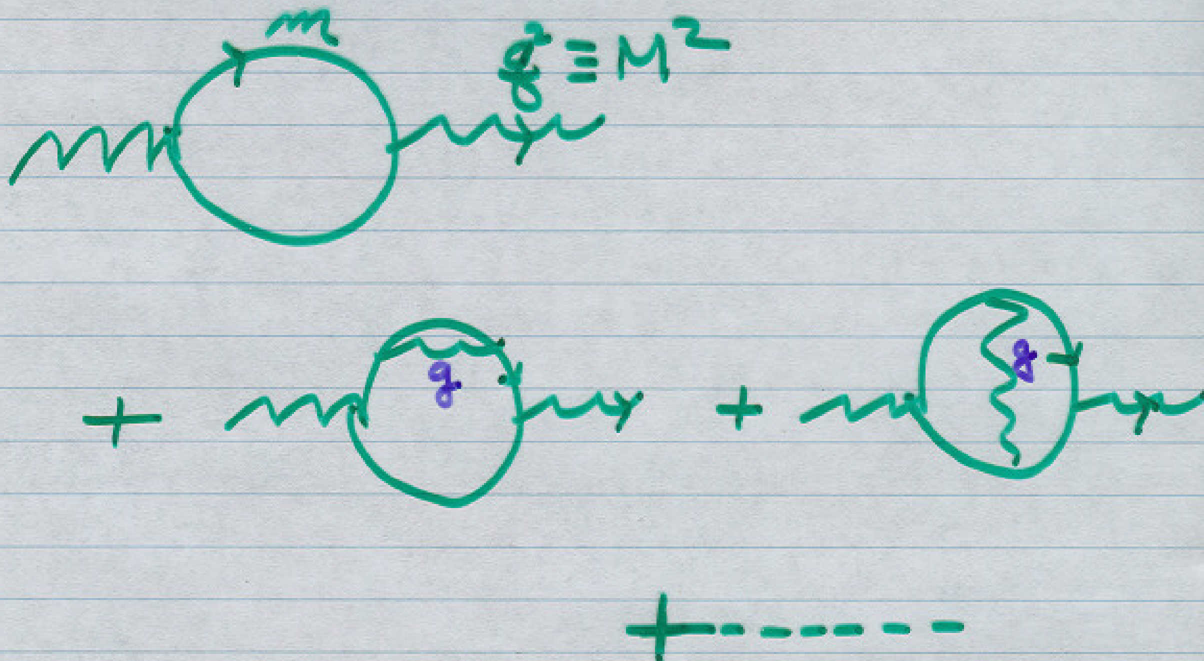
PHOTON PROPAGATION FUNCTION



$$v = \sqrt{1 - \frac{4m^2}{M^2}}$$

$$\text{H:}\quad E_{2s_{1/2}} - E_{2p_{1/2}} = 1057.93\ \text{MHz}, \tag{5–4.199}$$

which is strikingly close to the nominal experimental value of 1057.90 ± 0.10 MHz. The usual caveat about still unconsidered effects continues to apply, however.

The integrations required to exhibit $a(M^2)$ are very similar to those of the spin 0 situation. Such a relationship also appears in the results, for the substitution $v^2 \to \frac{1}{2}(3 - v^2)$, performed in all the terms of (5–4.132) that have such a factor, yields the precise spin $\frac{1}{2}$ counterparts, as displayed below:

$$\begin{aligned} M^2a(M^2) = \frac{\alpha}{3\pi} v \tfrac{1}{2}(3 - v^2) + \frac{\alpha^2}{3\pi^2}\Bigg\{ & \frac{1}{2}(3 - v^2)(1 + v^2)\left[\frac{\pi^2}{6} + \log\frac{1+v}{2}\log\frac{1+v}{1-v}\right. \\ & \left. + 2l\left(\frac{1-v}{1+v}\right) + 2l\left(\frac{1+v}{2}\right) - 2l\left(\frac{1-v}{2}\right) - 4l(v) + l(v^2)\right] \\ & + \left[\frac{11}{16}(3 - v^2)(1 + v^2) + \tfrac{1}{4}v^4 - \tfrac{3}{2}v(3 - v^2)\right]\log\frac{1+v}{1-v} \\ & + 6v\frac{3 - v^2}{2}\log\frac{1+v}{2} - 4v\frac{3-v^2}{2}\log v + \tfrac{3}{8}v(5 - 3v^2)\Bigg\}. \end{aligned} \tag{5–4.200}$$

The limiting behaviors here are

$$M^2 \gg (2m)^2:\quad M^2a(M^2) = \frac{\alpha}{3\pi} + \frac{\alpha^2}{4\pi^2} = \frac{\alpha}{3\pi}\left(1 + \frac{3\alpha}{4\pi}\right), \tag{5–4.201}$$

where the α^2 contribution again comes entirely from the last term in the brace, and

$$M^2 \sim (2m)^2:\quad M^2a(M^2) = \frac{\alpha}{2\pi}v + \frac{\alpha^2}{4} = \frac{\alpha}{2\pi}v\left(1 + \frac{\pi\alpha}{2v}\right), \tag{5–4.202}$$

in which the α^2 term continues to spring from the first bracket of the brace, with its origin in the form factor. Indeed, as was to be expected, the multiplicative factor of (5–4.202) is the same as with spin 0 [Eq. (5–4.134)]. A simple interpolation formula, which is weighted somewhat differently than for spin 0, is

$$M^2a(M^2) \sim \frac{\alpha}{3\pi}v\frac{3 - v^2}{2}\left[1 + \frac{\pi\alpha}{2v} - \frac{3 + v}{4}\left(\frac{\pi}{2} - \frac{3}{4\pi}\right)\alpha\right]. \tag{5–4.203}$$

The reason for this shift in weight appears on comparing the two braces of Eqs. (5–4.132) and (5–4.200) in the following way:

$$\begin{aligned} \{\ \}_{\text{spin}\,\frac{1}{2}} - \frac{3 - v^2}{2v^2}\{\ \}_{\text{spin}\,0} = {} & \left[\frac{11}{16}(3 - v^2)(1 + v^2) + \tfrac{1}{4}v^4 - \frac{3 - v^2}{2v^2}\left(5\left(\frac{1 + v^2}{2}\right)^2 - 2\right)\right] \\ & \times \log\frac{1+v}{1-v} + \frac{3}{8}v(5 - 3v^2) - \frac{3}{2}\frac{3 - v^2}{2v}(1 + v^2) \end{aligned}$$

$$\cong -3v, \qquad v \ll 1. \tag{5-4.204}$$

When the interpolation formulas are used, with the weight factor $\frac{3}{4}$ symbolized by λ for the moment, the above combination becomes

$$= \tfrac{3}{2}v[\lambda(\tfrac{1}{2}\pi^2 - \tfrac{3}{4}) - \tfrac{1}{2}(\tfrac{1}{2}\pi^2 - 3)], \qquad v \ll 1. \tag{5-4.205}$$

The identification of the two expressions, for $v \ll 1$, then gives

$$\lambda = \frac{1}{2}\frac{\pi^2 + 2}{\pi^2 - \frac{3}{2}} = 0.71, \tag{5-4.206}$$

which, for simplicity, has been replaced with the nearby fraction $\frac{3}{4}$. When the interpolation formula (5-4.203) is used in the calculation of (5-4.197), the coefficient of α^2/π^2 is found to be

$$\frac{\pi^2}{4}\left(\frac{9}{40} + \frac{1}{9}\right) + \frac{1}{4}\left(\frac{3}{5} + \frac{7}{48}\right) = 1.016, \tag{5-4.207}$$

as compared with the exact answer,

$$\frac{82}{81} = 1.012. \tag{5-4.208}$$

Harold has a question.

H.: Perhaps I am overlooking a point, but shouldn't there be some mention of the annihilation scattering mechanism which accompanies the Coulomb scattering process that you have considered, in computing the vacuum polarization energy shift?

S.: Let me restate the question and, thereby, jog your memory. The modified photon propagation function has been exhibited in two forms. One [cf. Eq. (4-3.81)] is

$$\bar{D}_+(k) = \frac{1}{k^2}\frac{1}{1 - k^2\int dM^2 \frac{a(M^2)}{k^2 + M^2}}, \tag{5-4.209}$$

and the other [Eq. (4-3.83)] is given by

$$\bar{D}_+(k) = \frac{1}{k^2} + \int dM^2 \frac{A(M^2)}{k^2 + M^2}, \tag{5-4.210}$$

where the connection between them [Eq. (4-3.85)] is repeated as

$$A(M^2) = \frac{a(M^2)}{\left[1 - M^2 P\int dM'^2 \frac{a(M'^2)}{M^2 - M'^2}\right]^2 + [\pi M^2 a(M^2)]^2}. \tag{5-4.211}$$

$$P\int_0^1 dv'\,\frac{(1+v'^2)\log[v'^2/(1-v'^2)]}{v^2-v'^2}$$
$$=\frac{1+v^2}{2v}\left[-\pi^2+\frac{1}{2}\left(\log\frac{1-v}{2}\right)^2-\frac{1}{2}\left(\log\frac{1+v}{2}\right)^2\right.$$
$$\left.-2\log 2\log\frac{1+v}{1-v}+4l(v)-l(v^2)-l\left(\frac{1+v}{2}\right)+l\left(\frac{1-v}{2}\right)\right]+2\log 2.$$
$$(5\text{–}4.131)$$

Note that the relation (5–4.119) could be used to give this another form.

Without going into further details about the integration, we state the result for $a(M^2)$:

$$M^2a(M^2)=\frac{\alpha}{12\pi}v^3+\frac{\alpha^2}{12\pi^2}\left\{v^2(1+v^2)\left[\frac{\pi^2}{6}+\log\frac{1+v}{2}\log\frac{1+v}{1-v}\right.\right.$$
$$\left.+2l\left(\frac{1-v}{1+v}\right)+2l\left(\frac{1+v}{2}\right)-2l\left(\frac{1-v}{2}\right)-4l(v)+l(v^2)\right]$$
$$+\left[5\left(\frac{1+v^2}{2}\right)^2-2-3v^2\right]\log\frac{1+v}{1-v}+6v^3\log\frac{1+v}{2}$$
$$\left.-4v^3\log v+\tfrac{3}{2}v(1+v^2)\right\}. \qquad (5\text{–}4.132)$$

This elaborate structure can better be comprehended in the high energy ($v\to 1$) and low energy ($v\to 0$) limits. Thus,

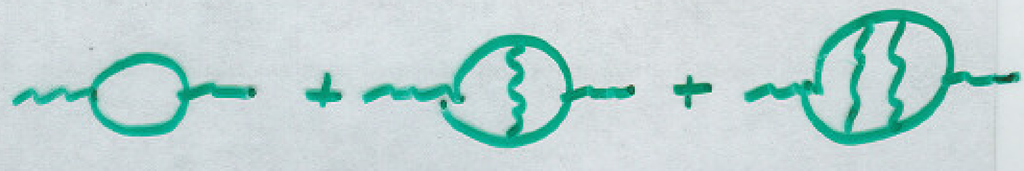
$$M^2\gg(2m)^2:\quad M^2a(M^2)=\frac{\alpha}{12\pi}+\frac{\alpha^2}{4\pi^2}=\frac{\alpha}{12\pi}\left(1+\frac{3\alpha}{\pi}\right), \qquad (5\text{–}4.133)$$

where the contribution of order α^2 comes entirely from the last term in the braces of (5–4.132), and

$$M^2\sim(2m)^2:\quad M^2a(M^2)=\frac{\alpha}{12\pi}v^3+\frac{\alpha^2}{24}v^2=\frac{\alpha}{12\pi}v^3\left(1+\frac{\pi}{2}\frac{\alpha}{v}\right); \qquad (5\text{–}4.134)$$

here the α^2 term arises from the first bracket in the braces of (5–4.132) and can be traced back to the partial form factor integral (5–4.126). The latter result is particularly interesting since the threshold behavior has been changed. This can be understood from familiar non-relativistic considerations. The effect of the Coulomb attraction between charges that are produced with relative speed $v_{\text{rel.}}$ increases the probability of establishing the state by the factor

$$\boxed{\frac{(2\pi\alpha/v_{\text{rel.}})}{1-\exp[-(2\pi\alpha/v_{\text{rel.}})]}\cong 1+\frac{\pi\alpha}{v_{\text{rel.}}},} \qquad (5\text{–}4.135)$$



$$\int_0^1 du \frac{1}{1+u} \log\frac{1}{u} - \frac{3}{4} = \frac{1}{12}(\pi^2 - 9), \tag{5-5.62}$$

which evaluation makes use of yet another partial integration to get

$$\int_0^1 du \frac{1}{1+u} \log\frac{1}{u} = \int_0^1 du \frac{1}{u} \log(1+u) = \frac{\pi^2}{12}, \tag{5-5.63}$$

as an application of Eq. (5-4.115). Putting things together we find the decay rate to be

$$\gamma_{n\,{}^3S} = \frac{16}{9}(\pi^2 - 9)\frac{\alpha^3}{m^2}|\psi(0)|^2 = \frac{2}{9\pi}(\pi^2 - 9)\frac{1}{n^3}\alpha^6 m, \tag{5-5.64}$$

and the lifetime for the ground level of ortho positronium is

$$\tau_{\text{ortho}} = \frac{9\pi}{4}\frac{1}{\pi^2 - 9}\frac{1}{\alpha}\tau_{\text{para}} = 1.387 \times 10^{-7}\,\text{sec}. \tag{5-5.65}$$

The energy spectrum of positronium is first approached by applying the results of Section 5-2, specifically the rest frame energy operator of Eq. (5-2.134), where we now have

$$m_1 = m_2 = m, \qquad \mu = \tfrac{1}{2}m, \qquad e_1 = -e_2 = e. \tag{5-5.66}$$

This gives

$$\begin{aligned} H_0 = 2m + \frac{\mathbf{p}^2}{m} - \frac{1}{4m^3}(\mathbf{p}^2)^2 - \alpha\biggl\{&\frac{1}{r} + \frac{1}{2m^2}\mathbf{p}\cdot\left(\frac{1}{r} + \frac{\mathbf{rr}}{r^3}\right)\cdot\mathbf{p} - \frac{\pi}{m^2}\delta(\mathbf{r}) \\ &- \frac{3}{4}\frac{1}{m^2}\frac{(\boldsymbol{\sigma}_1 + \boldsymbol{\sigma}_2)\cdot\mathbf{r}\times\mathbf{p}}{r^3} - \frac{1}{4m^2}\left(3\frac{\boldsymbol{\sigma}_1\cdot\mathbf{r}\boldsymbol{\sigma}_2\cdot\mathbf{r}}{r^5} - \frac{\boldsymbol{\sigma}_1\cdot\boldsymbol{\sigma}_2}{r^3}\right) \\ &- \frac{2\pi}{3}\frac{1}{m^2}\boldsymbol{\sigma}_1\cdot\boldsymbol{\sigma}_2\,\delta(\mathbf{r})\biggr\}. \end{aligned} \tag{5-5.67}$$

The simplest application is to the singlet levels of para positronium where, effectively,

$$\boldsymbol{\sigma}_1 + \boldsymbol{\sigma}_2 = 0, \tag{5-5.68}$$

thus reducing (5-5.67) to

$$H_{0\,\text{para}} = 2m + \frac{\mathbf{p}^2}{m} - \frac{1}{4m}\left(\frac{\mathbf{p}^2}{m}\right)^2 - \alpha\left\{\frac{1}{r} + \frac{1}{2m^2}\mathbf{p}\cdot\left(\frac{1}{r} + \frac{\mathbf{rr}}{r^3}\right)\cdot\mathbf{p} + \frac{\pi}{m^2}\delta(\mathbf{r})\right\}. \tag{5-5.69}$$

FALL 1974

D. Politzer

2004 Nobel Lecture

SUMMARY

(1) The LHC era is dawning.

(2) The top will be front + center.

No extra dimensions Black Holes
No solitary Higgs

(4) The late oughties (00's) will be even more exciting than the early seventies (70's)

THANKS