

HERTZ LECTURE

DESY Lecture on Physics 2018

Imaging Fundamental Processes:
Thought, experiment and the accessible universe

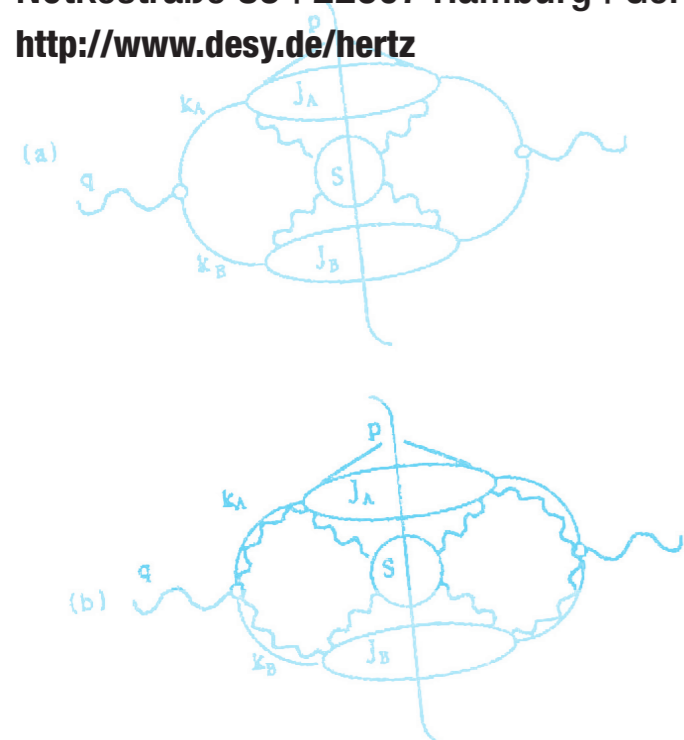
Prof. Dr. George Sterman
(Stony Brook University)

27 September 2018

18:00 h, DESY Auditorium

Notkestraße 85 | 22607 Hamburg | Germany

<http://www.desy.de/hertz>



Accelerators | Photon Science | Particle Physics

Deutsches Elektronen-Synchrotron
A Research Centre of the Helmholtz Association

Jets from Quantum Chromodynamics

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The properties of hadronic jets in e^+e^- annihilation are examined in quantum chromodynamics, without using the assumptions of the parton model. We find that two-jet configurations dominate the cross section at high energy, and have the experimentally observed angular distribution. Estimates are given for the jet angular radius and its energy dependence. We argue that the detailed results of perturbation theory for production of arbitrary numbers of quarks and gluons can be reinterpreted in quantum chromodynamics as predictions for the production of jets.

The contemporary theory of fundamental forces can be pictured as just a handful of particle species, acting among themselves according to a few simple rules. This theory can in principle account for the richness of the visible universe. It results from a centuries-long process of speculation and investigation, culminating in the language of quantum field theory. Yet every successful theoretical framework defines its own limitations, and suggests new questions and criteria. Looking back and ahead, I'll give a perspective on our current theories and viewpoints, and on how future developments may be influenced by evolving ideas in theoretical physics, by high energy experiments at accelerators, and by exquisite observations of the faintest cosmic signals.

$$\begin{aligned} \sigma_a &= (d\sigma/d\Omega)_0 \Omega (g_E^2/3\pi^2) [-3 \ln(E\delta/\mu) - 2 \ln^2 2\epsilon - 4 \ln(E\delta/\mu) \ln(2\epsilon) + \frac{17}{4} - \pi^2/3], \\ \sigma_b &= (d\sigma/d\Omega)_0 \Omega (g_E^2/3\pi^2) [2 \ln^2(2\epsilon E/\mu) - \pi^2/6], \\ \sigma_c &= (d\sigma/d\Omega)_0 \Omega [1 + (g_E^2/3\pi^2) [-2 \ln^2(E/\mu) + 3 \ln(E/\mu) - \frac{7}{4} + \pi^2/6]], \end{aligned} \quad (2) \quad (3) \quad (4)$$

where $(d\sigma/d\Omega)_0$ is the cross section for $e^+e^- \rightarrow q\bar{q}$ in Born approximation:

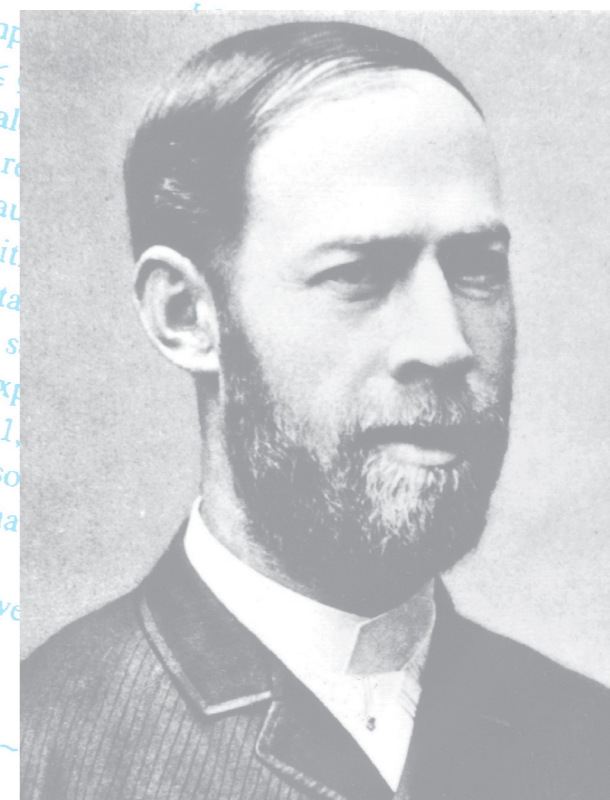
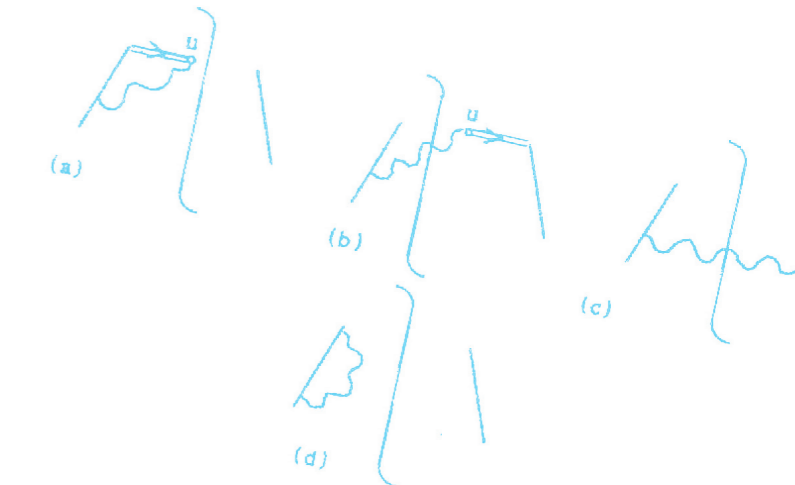
$$\left(\frac{d\sigma}{d\Omega}\right)_0 = \frac{\alpha^2}{4E^2} (1 + \cos^2\theta) \sum_{\text{flavors}} 3Q^2.$$

As expected, each separate contribution is singular for $\mu \rightarrow 0$, but cancellations occur in the sum, and the final result is free of mass singularities:

$$\sigma(E, \theta, \Omega, \epsilon, \delta) = (d\sigma/d\Omega)_0 \Omega [1 - (g_E^2/3\pi^2) (3 \ln \delta + 4 \ln \delta \ln 2\epsilon + \pi^2/3 - \frac{5}{2})].$$

This formula immediately demonstrates the dominance of two-jet final states at very high energy where $g_E^2/3\pi^2$ is small. By summing Eq. (6) over a set of cones of solid angle Ω that fill the 4π steradians around the e^+e^- collision, and comparing the result with the QCD expression $(1 + g_E^2/4\pi^2)\sigma_0$ for the total cross section, we see that the fraction of all events which have all but a fraction ϵ of their energy in some pair of opposite cones of half-angle δ is

ting $f=0.7$ and $\epsilon=0.2$ in Eq. (7), and using the asymptotic QCD formula $g_E^2 = 24\pi^2/25 \ln(E/\Lambda)$ with $\Lambda=500$ MeV, we find that $\delta(E)$ is about 13° at the energy $E=7.4$ GeV of current experiments,³ and decreases as $E^{-0.25}$ at higher energies. In contrast, with a fixed transverse-momentum cut-off P_\perp , we would expect a jet angular radius $\varphi(E)$ which would decrease much faster, like $1/E$ or $(\ln E)/E$. At relatively low energy $\varphi(E)$ will be greater than $\delta(E)$, so that our calculation of the



Heinrich Hertz

1857 Hamburg-Karlsruhe-Bonn 1894



SUMMATION OF LARGE CORRECTIONS TO