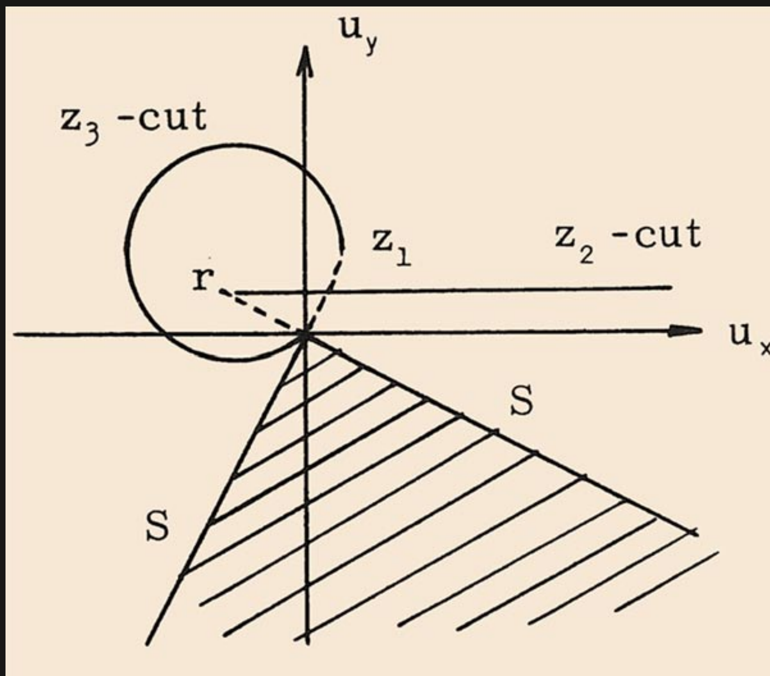
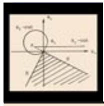


Ekman and Källén

Two world famous theoreticians from Lund.



The Ekman Spiral

Walfrid Ekman came from Stockholm and studied in Uppsala. He is most well-known for his theories on how the wind, the Earth's rotation and friction in water interact, changing the direction of ocean currents with depth, i.e. the formation of Ekman spirals. The title of his thesis was, *On the Effects of the Earth's Rotation on Wind-Generated Flow at Sea*, and after obtaining his PhD in 1902 he went to work at the Institute of Marine Research in Oslo.

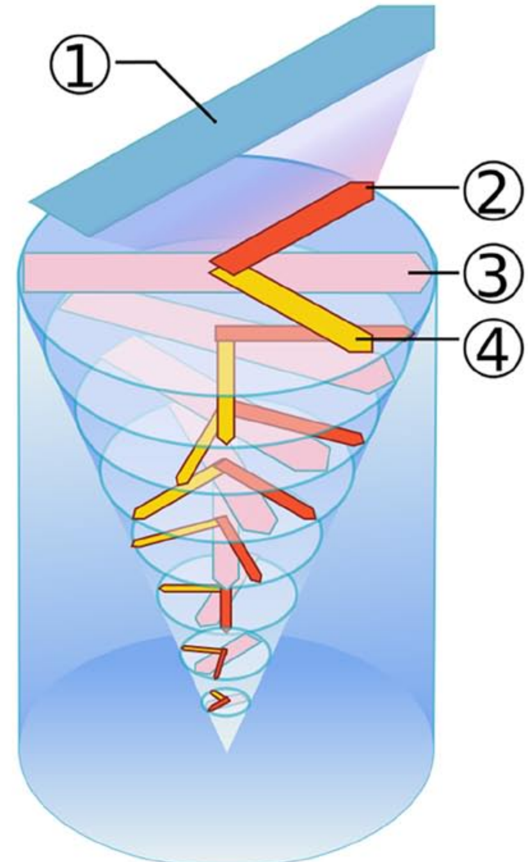
Walfrid Ekman 1874 - 1954
Swedich physicist and oceano-
grapher.

Invisible forces

It was in Oslo that Ekman developed his theory of ocean currents. It had long been known that ships in the northern fjords were sometimes trapped in dead water. It seemed as if the vessels were held by some kind of invisible force – often referred to as *demons of the deep*.

Ekman showed that the phenomenon was due to a lighter layer of fresh water that formed above the sea water at the mouths of rivers and when the ice melted. This led to backwash not only on the surface of the water, but also at the interface between the layers of fresh and salt water, which reduced the speed of the ships.

Simplified illustration of the Ekman Spiral in the northern hemisphere:
Blue – Wind
Red – Force from above
Yellow – Coriolis effect
Pink – Effective direction of the current



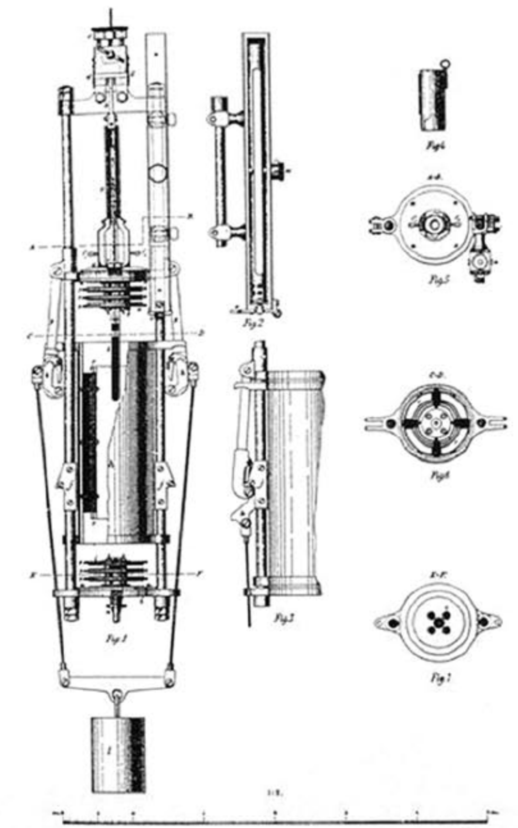
The Ekman Spiral

The textbook

Ekman was not only a gifted theoretician, but led many expeditions at sea. He is also known for his textbook in mechanics, from 1919, which was used in physics teaching in Sweden for over 40 years.

Walfrid Ekman became Professor of Mechanics and Mathematical Physics at Lund University in 1910, after Albert Viktor Bäcklund. Ekman was himself succeeded by Torsten Gustafson in 1939.

Walfrid Ekman was known as a serious and deeply religious person, but was also a good singer and pianist.



Ekman's design for an ocean current meter.

Theoreticians on the move

The King's House in Lundagård.

The experimental physicists had already moved out of Kungshuset (The King's House) in central Lund in 1846, but the theoreticians remained there together with the mathematicians and statisticians.

It was not until the 1930s that they moved into The Old School Mistress's College on Sölvegatan, opposite what is known today as The Old Department of Physics.

After this, the theoreticians moved to an apartment in the centre of town in Clement's Square, and were finally reunited with their experimental colleagues when the new Department of Physics was inaugurated in May 1951.

The student and graduate

Gunnar Källén was born in Kristianstad in 1926, but grew up in Gothenburg.

After graduating in 1944, he continued his studies at Chalmer's University in Gothenburg, and graduated in Electrical Engineering in 1948.

PhD studies

After graduating in 1948, Källén became a PhD student at the Department of Mechanics and Mathematical Physics in Lund, where Torsten Gustafson was his supervisor.

The following year, Gustafson wrote to the Nobel Prize winner Wolfgang Pauli in Zurich, and asked if it would be possible for *a young man, very interested in theoretical physics* to attend Pauli's lectures during the summer term of 1949.

Källén spent the summer in Zurich, and in July, Pauli wrote to Gustafson, describing Källén as *gifted with considerable skill and talent*.

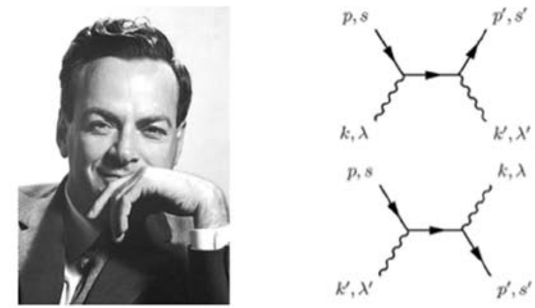
Pauli, giving one of his lectures, who later referred to Källén as *my discovery*.

Quantum Electrodynamics – QED

Researchers such as Dirac, Pauli, Tomonaga, Schwinger and Feynman developed quantum physics and described the fundamental structure and phenomena of matter.

They were successful in finding the correct expressions (QED) for the interaction between photons and electrons, and created quantum field theory.

With this theory, which allows the creation and annihilation of particles, they were able to describe particles as excitations of fields, and the forces between particles as the exchange of virtual particles. This was visualized with so-called Feynman diagrams.



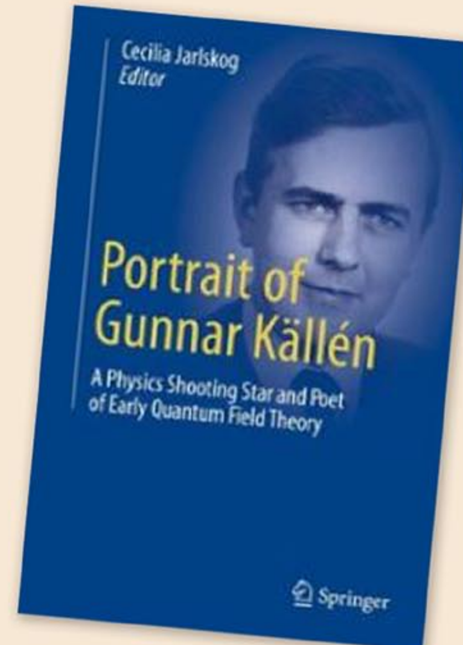
Richard Feynman – QED – and his famous diagrams.

Pauli's advisor

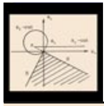
During his first visit to Zurich, Pauli had already suggested to Källén that he study the fourth-order correction of the phenomenon of vacuum polarization in external fields.

Pauli was very impressed with the young man's independence, virtuosity and the speed with which he solved the problem, and his work resulted in a notable publication in *Helvetica Physica Acta* that same year.

Källén and Pauli continued to correspond and Pauli used Källén as his advisor and scrutineer of his scientific publications.



Cecilia Jarlskog, Professor of Theoretical Particle Physics, has written a biography of Gunnar Källén.

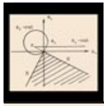


Doctor and husband

Gunnel Bojs and Gunnar Källén.

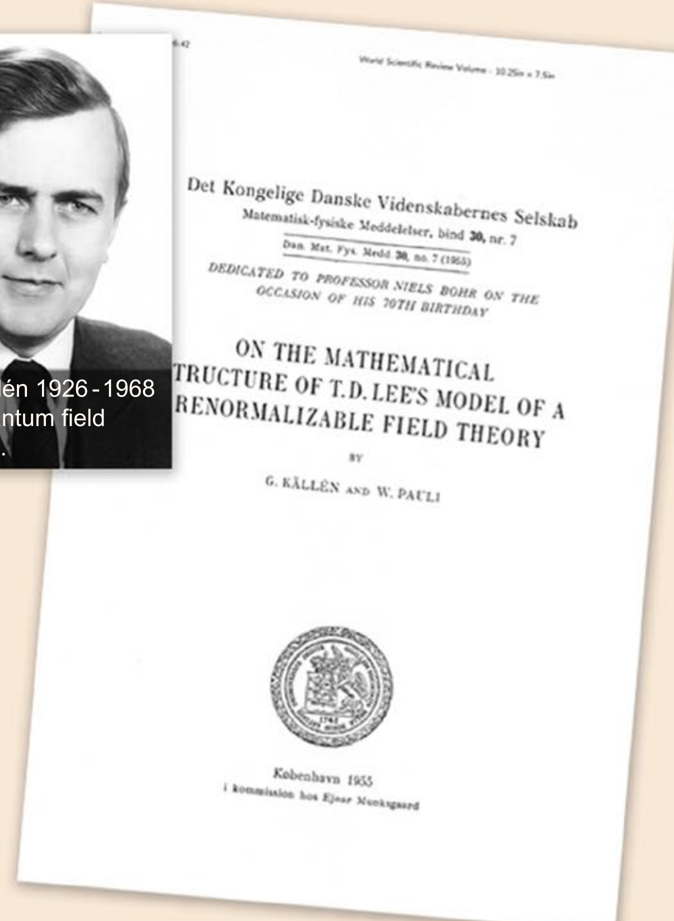
Källén continued his studies in QED in Lund, and obtained his doctorate in 1950. The title of his thesis was, *Formal Integration of the Equations of Quantum Theory in the Heisenberg Representation*.

The following year he married Gunnel Bojs, and in 1952 he became the first researcher to be employed at the newly established CERN Theoretical Study Division in Copenhagen.



The poetry of physics

Gunnar Källén 1926 - 1968
Brilliant quantum field theoretician.



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Det Kongelige Danske Videnskabernes Selskab
Matematisk-fysiske Meddelelser, bind 30, nr. 7
Dan. Mat. Fys. Medd. 30, no. 7 (1955)

DEDICATED TO PROFESSOR NIELS BOHR ON THE OCCASION OF HIS 70TH BIRTHDAY

ON THE MATHEMATICAL
TRUCTURE OF T. D. LEE'S MODEL OF A
ENORMALIZABLE FIELD THEORY

BY

G. KÄLLÉN AND W. PAULI

København 1955
i kommission hos Ejnar Munksgaard

One of the most important questions at that time was whether QED, with its divergent integrals giving infinite answers and renormalization techniques, was a consistent theory.

Källén studied these problems in an original way by using the Heisenberg representation, and obtained new results beyond interference theory.

Källén's impressive results placed him firmly in the quantum field theory *Hall of Fame*. It was said that he wrote poetry using the complex language of quantum field theory, while others could barely understand the grammar.

The forces of nature

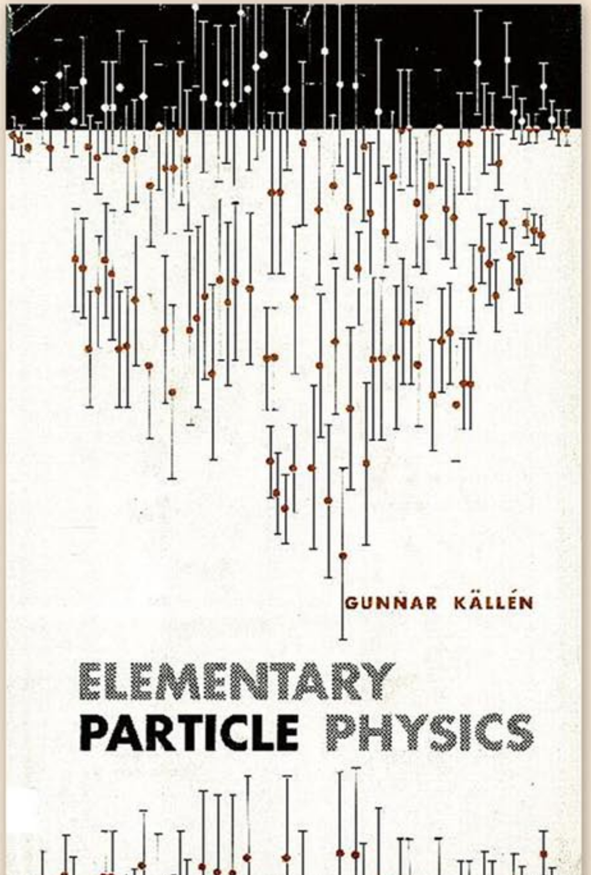
During the later part of the 1950s Källén broadened his research to include formal aspects of quantum field theory.

Together with his colleagues and PhD students he studied the general properties of vacuum expectation values of the products of field operators. It was hoped that this would lead to theories describing the forces of nature.

Källén discovered elegant relations and equations, but was nonetheless disappointed that his efforts did not lead to the new physical knowledge he had expected.

The 12th Solvay Conference of 1961 dealt with quantum field theory.

Theoretical particle physics



Källén's final field of research was theoretical elementary particle physics. He learnt the subject quickly by giving lectures, and wrote a much-admired book, *Elementary Particle Physics*, which was published in 1964.

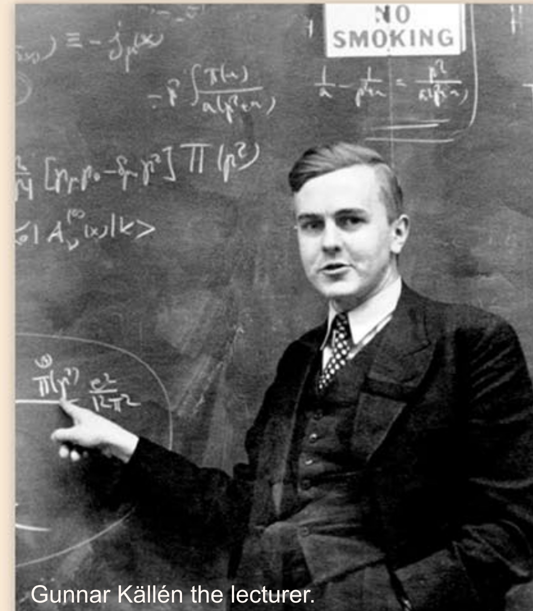
His final articles dealt with higher order corrections in muon and beta decay.

Källén is also known for other work in quantum field theory: The Källén–Sabry potentials and the Källén–Lehmann representation.

Personal Professorship

In 1958, Gunnar Källén was awarded a personal professorship in theoretical physics.

Gunnar Källén was much appreciated by his students, both as a supervisor and lecturer.



Gunnar Källén the lecturer.

A sudden departure

Gunnar Källén had been interested in flying since he had been a child. In 1964 he started taking flying lessons in Malmö. On 13th October 1968 Gunnar Källén took off from Bulltofta Airfield in Malmö to attend a meeting at CERN. In the plane with him were his wife and her friend, Matilda von Dardel. They had planned to land on the way in Hannover, but 10 km short of Hannover the plane developed engine problems. In an attempt to make an emergency landing, the plane hit a tree and crashed. Gunnar Källén died a few hours later, while the other passengers were only slightly injured.

The Gunnar Källén lectures

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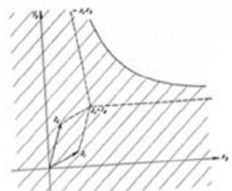

Fig. 1. The curve (31) for the case $y_1 > 0$; $y_2 > 0$; $x_1 y_2 + x_2 y_1 > 0$.

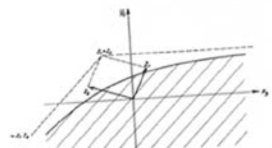

Fig. 2. The curve (31) for the case $y_1 > 0$; $y_2 > 0$; $x_1 y_2 + x_2 y_1 < 0$.

$$r = \frac{(x_1 + q^2)\, y_2 + (x_2 + q'^2)\, y_1}{y_3 - y_1 - y_2} > 0, \tag{32a}$$

$$x_3 = x_1 + x_2 - 2\,qq' + \frac{(x_1 + q^2)\, y_2 + (x_2 + q'^2)\, y_1}{y_3 - y_1 - y_2} + \frac{(x_1 + q^2)(x_2 + q'^2) - y_1 y_2}{x_1 y_2 + x_2 y_1 + q^2 y_2 + q'^2 y_1}(y_3 - y_1 - y_2). \tag{32b}$$

If we call $x_3^{(0)}$ the value of x_3 which we get from (32b), by putting $q^2 = q'^2 = qq' = 0$, the difference between x_3 and $x_3^{(0)}$ can be written in the following way

To prove the gauge invariance (supposing the integrals in (61) to converge) we need an identity of the same type as equation (27). We have

$$\begin{aligned}
&\overline{P}^{(n)}_{\mu\nu_1\cdots\nu_n}(pp'\cdots p^n)\,(p'_{\nu_1} - p_{\nu_1}) = (p'^2 - p^2)\,\times \\
&\quad \times \left[\pi_1^{(n)} - \sum_i \delta_{\nu_i\nu_{i-1}}(p^{i-1\,2} + m^2)\,\pi^{(n)}_{1,i,i-1} + \cdots\right] - (p^2 + m^2)\,\times \\
&\quad \times (p'_\mu - p_\mu)\left[\pi^{(n)}_{1,0} - \sum_i \delta_{\nu_i\nu_{i-1}}(p^{i-1\,2} + m^2)\,\pi^{(n)}_{1,0,i,i-1} + \cdots\right] - \\
&\quad - (p'^2 + m^2)\,(p'_{\nu_2} - p_{\nu_2})\left[\pi^{(n)}_{1,2} - \sum_i \delta_{\nu_i\nu_{i-1}}(p^{i-1\,2} + m^2)\,\times\right. \\
&\quad \left.\times\, \pi^{(n)}_{1,2,i,i-1} + \cdots\right] = (p'^2 + m^2)\,\overline{P}^{(n-1)}_{\mu\nu_2\cdots\nu_n}(pp''\cdots p^n) - \\
&\quad - (p^2 + m^2)\,\overline{P}^{(n-1)}_{\mu\nu_2\cdots\nu_n}(p'p''\cdots p^n).
\end{aligned} \tag{64}$$

We can now repeat the calculation from equation (29) to equation (35) but start from (61) instead of (25) and use (64) instaed of (27). The result is obviously that, from this formal point of view, (61) is gauge invariant.

Regular lectures or symposia have been held in Lund since 1972 to honour the memory of Gunnar Källén. Among the 60 or so lecturers to date is the Nobel Prize winner Steven Weinberg, who delivered a lecture entitled *Living with Infinities*. Weinberg paid a moving tribute to Gunnar Källén, saying that he regarded himself as one of Källén's disciples.