

Symposium Higgs Modes in Condensed Matter and Quantum Gases (SYHM)

jointly organized by
 the Low Temperature Physics Division (TT),
 the Dynamics and Statistical Physics Division (DY),
 the Magnetism Division (MA), and
 the Surface Science Division (O)

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The discovery of the Higgs particle in 2012 at CERN has a large impact beyond the field of high-energy physics and triggered intense research in condensed matter physics. A Higgs mode emerges as a collective oscillation of order parameter amplitude in various ordered phases of condensed matter systems, such as Bose gases in optical lattices, superfluid ^3He , superconductors, density-wave systems, and magnetic materials. Understanding the fundamental role of the Higgs modes is expected to lead to a unified description of these condensed matter systems. In this Symposium recent developments of research on Higgs modes in various condensed matter systems and quantum gases are presented, covering theoretical aspects as well as latest experimental developments; the focus will be on collective excitations in superconductors.

Overview of Invited Talks and Sessions

(Lecture room: H 0105)

Invited Talks

SYHM 1.1	Wed	15:00–15:30	H 0105	Amplitude or Higgs Modes in Condensed Matter — ●CHANDRA VARMA
SYHM 1.2	Wed	15:30–16:00	H 0105	Higgs Particles for Systems with U(1) Symmetry in Two Dimensions — ●LODE POLLET
SYHM 1.3	Wed	16:00–16:30	H 0105	Massive Photons and the Anderson-Higgs Mechanism in Superconductors — ●DIRK VAN DER MAREL
SYHM 1.4	Wed	16:45–17:15	H 0105	Amplitude Higgs Mode in 2H-NbSe₂ Superconductor — ●MARIE-AUDE MÉASSON, ROMAIN GRASSET, YANN GALLAIS, MAX CAZAYOUS, ALAIN SACUTO, PIERRE RODIÈRE, LAURENT CARIO
SYHM 1.5	Wed	17:15–17:45	H 0105	The Higgs Mode in Disordered Superconductors Close to a Quantum Phase Transition — ●AVIAD FRYDMAN, DANIEL SHERMAN, UWE S. PRACHT, BORIS GORSHUNOV, MARTIN DRESSEL

Sessions

SYHM 1.1–1.5	Wed	15:00–17:45	H 0105	Higgs Modes in Condensed Matter and Quantum Gases
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SYHM 1: Higgs Modes in Condensed Matter and Quantum Gases

Time: Wednesday 15:00–17:45

Location: H 0105

Invited Talk SYHM 1.1 Wed 15:00 H 0105
Amplitude or Higgs Modes in Condensed Matter — ●CHANDRA VARMA — University of California, Riverside, CA, USA

Spurred by some strange experimental observations in some superconductors, the theory of a new collective mode in superconductors and how it can be experimentally found under certain circumstances was provided in 1981. It was called the “Amplitude Mode” to distinguish it from the “Phase Modes” which provide Josephson effects and which in homogeneous superconductors are coupled to charge fluctuations and are at the energies of the plasmons. More generally, this mode is the amplitude mode of a particle-hole symmetric U(1) field, i.e., the model treated by Higgs and others in the 1960’s whose generalizations have played an important role in the standard model of particle physics.

I will tell the story of the above and why such modes were missed in the theory of superconductivity for so long and the applications of the ideas about such modes for cold bosons and fermions in optical lattices and in quantum anti-ferromagnets. I will also comment, as a very interested outsider and an enthusiast, on the Higgs in particle physics being discovered at LHC from the point of view of the theory of superconductivity.

Invited Talk SYHM 1.2 Wed 15:30 H 0105
Higgs Particles for Systems with U(1) Symmetry in Two Dimensions — ●LODE POLLET — Arnold Sommerfeld Center, Theoretical Physics, LMU Munich, Germany

We present solid evidence for the existence of a Higgs boson in two-dimensional relativistic field theories based on analytically continued results from quantum Monte Carlo simulations of the Bose-Hubbard model in the vicinity of the superfluid-Mott insulator quantum critical point, featuring emergent particle-hole symmetry and Lorentz-invariance. The Higgs boson, seen as a well-defined low-frequency resonance in the spectral density, is quickly pushed to high energies in the superfluid phase and disappears by merging with the broad secondary peak at the characteristic interaction scale. Simulations of a trapped system of ultra-cold Rb-87 atoms demonstrate that the low-frequency resonance feature is lost for typical experimental parameters, while the characteristic frequency for the onset of strong response is preserved. We compute the universal scaling function and comment on the agreements and disagreements with three dimensions and observations of Higgs particles in more traditional solid state experiments.

Invited Talk SYHM 1.3 Wed 16:00 H 0105
Massive Photons and the Anderson-Higgs Mechanism in Superconductors — ●DIRK VAN DER MAREL — University of Geneva, Geneva, Switzerland

When we tune the temperature or the pressure of a solid transitions can occur between different states of matter. Usually such a phase transition is accompanied by a symmetry breaking and the emergence of one or several collective modes of the material. A superconducting gap has collective oscillations of its amplitude -equivalent to the Higgs particle- and of its phase. As shown by Anderson in 1958, coupling to the electromagnetic field creates an energy gap in the longitudinal oscillations of the charge density, and in the transverse oscillations of mixed photon-matter character. The energy-momentum dispersion of the latter can be measured experimentally, and reveals the mass acquired by the photons due the coupling to the superconducting order parameter. In certain superconductors two or more condensates coexist. Weak coupling between the condensates gives rise to the so-called

Leggett-exciton, and the coupling to the electromagnetic field makes that two or more massive photon-branches coexist. Experimental examples of this will be discussed in this talk.

15 min. break.

Invited Talk SYHM 1.4 Wed 16:45 H 0105
Amplitude Higgs Mode in 2H-NbSe₂ Superconductor — ●MARIE-AUDE MÉASSON¹, ROMAIN GRASSET¹, YANN GALLAIS¹, MAX CAZAYOUS¹, ALAIN SACUTO¹, PIERRE RODIÈRE², and LAURENT CARIO³ — ¹LMPQ, Université Paris 7-CNRS, France — ²Institut Neel, Grenoble, France — ³IMN, Université de Nantes, France

When a spontaneous breaking of a continuous symmetry takes place, as happens during a superconducting transition, collective excitations such as the amplitude Higgs mode of the order parameter emerge. The existence of such Higgs mode was proposed in the charge density wave (CDW) superconductor (SC) 2H-NbSe₂, after the first experimental observation by Raman scattering. The Higgs mode could be unraveled via its coupling to the coexisting charge density wave mode. We will address here the questions of the nature of this mode as well as the mechanism of its observability.

We report experimental evidences for the Higgs mode scenario in 2H-NbSe₂ using Raman scattering. By comparing 2H-NbSe₂ and its iso-structural partner 2H-NbS₂ which shows superconductivity but lacks the charge density wave order and by destroying the coexisting CDW order under high pressure in 2H-NbSe₂, we demonstrate that the superconducting mode owes its spectral weight to the presence of the coexisting charge density wave order. In addition a full spectral weight transfer between both modes operates in 2H-NbSe₂ upon entering the superconducting phase. All these observations are consistent with a superconducting Higgs mode. Intriguing symmetry dependent results under pressure will be discussed.

Invited Talk SYHM 1.5 Wed 17:15 H 0105
The Higgs Mode in Disordered Superconductors Close to a Quantum Phase Transition — ●AVIAD FRYDMAN¹, DANIEL SHERMAN^{1,2}, UWE S. PRACHT², BORIS GORSHUNOV^{2,3}, and MARTIN DRESSEL² — ¹Department of Physics, Bar Ilan University, Ramat Gan, 52900, Israel — ²Physikalisches Institut, Universität, Stuttgart, 70550 Stuttgart, Germany — ³Moscow Institute of Physics and Technology, 141700, Dolgoprudny, Moscow Region, Russia

The Higgs theory, which generates mass for elementary particles, was inspired by screening of magnetic fields in superconductors. It is somewhat disappointing that in superconductors, the Higgs-amplitude mode has not yet been observed, partially because it can rapidly decay into unpaired electrons. Nevertheless, recent theories show that if the Higgs mass could be softened below the pairing gap it should be visible in two dimensions. Such conditions can be met by tuning a superconducting film towards a quantum critical point (QCP). We report on spectroscopic studies in the terahertz frequency regime of thin superconducting films for which the superconductor to insulator transition (SIT) is tuned by disorder. Tunneling spectroscopy determines the pairing gap 2Δ which remains finite on both sides of the SIT. In contrast, the threshold frequency for dynamical conductivity, which in BCS theory is associated with the gap, vanishes critically toward the SIT. The excess optical spectral weight below 2Δ is identified as an unambiguous observation of the Higgs mode in a superconductor.