Elective Advanced Lectures: Theoretical Physics - physics70c

Module No.	**physics70c**
Category	Elective
Credit Points (CP)	3-7
Semester	1.-2.

Module: Elective Advanced Lectures: Theoretical Physics

Module Elements:

Nr	Course	Course No.	CP	Type	Teaching hours	Semester
1	Ultracold Atomic Gases (E/T)	physics742	6	Lect. + ex.	3+1	WT
2	Group Theory (T)	physics751	7	Lect. + ex.	3+2	WT
3	Superstring Theory (T)	physics752	7	Lect. + ex.	3+2	WT
4	Theoretical Particle Astrophysics (T)	physics753	7	Lect. + ex.	3+2	ST
5	General Relativity and Cosmology (T)	physics754	7	Lect. + ex.	3+2	ST
6	Quantum Field Theory (T)	physics755	7	Lect. + ex.	3+2	ST
7	Critical Phenomena (T)	physics756	7	Lect. + ex.	3+2	ST
8	Effective Field Theory (T)	physics757	7	Lect. + ex.	3+2	WT/ST
9	Quantum Chromodynamics (T)	physics758	7	Lect. + ex.	3+2	WT/ST
10	Quantum Field Theory for Condensed Matter Physics (T)	physics759	5	Lect. + ex.	2+1	WT/ST
11	Computational Physics (T)	physics760	7	Lect. + ex. + proj.	2+2+1	WT/ST
12	Supersymmetry (T)	physics761	6	Lect. + ex.	3+1	WT/ST
13	Transport in mesoscopic systems (T)	physics762	5	Lect. + ex.	2+1	WT/ST
14	Advanced Topics in String Theory (T)	physics763	7	Lect. + ex.	3+2	ST
15	Advanced Topics in Field and String Theory (T)	physics764	7	Lect. + ex.	3+2	ST
16	Advanced Topics in Quantum Field Theory (T)	physics765	7	Lect. + ex.	3+2	ST
17	Physics of Higgs Bosons (T)	physics766	7	Lect. + ex.	3+2	WT
18	Computational Methods in Condensed Matter Theory (T)	physics767	7	Lect. + ex.	3+2	WT/ST
19	General Relativity for Experimentalists (T)	physics768	7	Lect. + ex.	3+2	WT/ST
20	Lattice QCD (T)	physics769	7	Lect. + ex.	3+2	ST/WT
21	Advanced Quantum Field Theory (T)	physics7501	7	Lect. + ex.	3+2	WT
22	Random Walks and Diffusion (T)	physics7502	3	Lect. + ex.	1+1	ST
23	Selected Topics in Modern Condensed Matter Theory (T)	physics7503	7	Lect. + ex.	3+2	WT

Nr	Course	Course No.	CP	Type	Teaching hours	Semester
24	Theory of Superconductivity and Superfluidity (T)	physics7504	5	Lect. + ex.	2+1	WT/ST
25	High performance computing: Modern computer architectures and applications in the physical science (T)	physics7505	3	Lecture	2	WT/ST
26	Quark Distributions Functions (T)	physics7506	3	Lecture	2	WT
27	Theory of Quantum Magnetism (T)	physics7507	4	Lect. + ex.	2+1	ST
28	Quantum Computing (T)	physics7508	7	Lect. + ex.	3+2	WT/ST
29	Advanced Topics in Particle and Astroparticle Physics (T)	physics7509	7	Lect. + ex.	3+2	WT/ST
30	Internships in the Research Groups	physics799	4	internship		WT/ST

Requirements for Participation: none

Form of Examination: see with the course

Content: Advanced lectures in theoretical physics

Aims/Skills: Preparation for Master's Thesis work; broadening of scientific knowledge

Course achievement/Criteria for awarding cp's: see with the course

Length of Module: 1 or 2 semester

Maximum Number of Participants: ca. 100

Registration Procedure: s. https://basis.uni-bonn.de u. http://bamawww.physik.uni-bonn.de

Note: Note: The student must achieve at least 18 CP out of all 4 Elective Advanced Modules

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Ultracold Atomic Gases (E/T) - physics742

Course	**Ultracold Atomic Gases (E/T)**
Course No.	physics742

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+1	6	WT

Requirements for Participation:

Preparation: Quantum Mechanics

Form of Testing and Examination: Requirements for the examination (written or oral): successful work with the exercises

Length of Course: 1 semester

Aims of the Course: This lecture discusses both the experimental and theoretical concepts of ultracold atomic gases.

Contents of the Course:

Almost hundred years ago, in 1924, A. Einstein and S.N. Bose predicted the existence of a new state of matter, the so-called Bose-Einstein condensate. It took 70 years to successfully realize this macroscopic quantum state in the lab using ultracold atomic gases (Nobel prize 2001). The main challenge was to achieve cooling to Nanokelvin temperatures, the coolest temperatures ever reached by mankind. Nowadays, ultracold gases are exciting systems to study a broad range of quantum phenomena. These phenomena range from the direct observation of quantum matter waves and superfluidity over the creation of artificial crystal structures as analogous to solids, to the realization of complex quantum phase transitions of interacting atoms, e.g. the formation of a bosonic Mott-insulator or the BCS superconducting state for Fermions. In this lecture we will discuss both the experimental and theoretical concepts of ultra-cold atomic gases.

Outline: Introduction and revision of basic concepts, Fundamentals of atom-laser interaction

Laser cooling & trapping, Bose-Einstein condensation of atomic gases. Dynamics of Bose-Einstein condensates

Optical lattices: strongly interacting atomic gases and quantum phase transitions

The crossover of Fermi-gases between a BCS superconducting state and a Bose-Einstein condensate of molecules.

Recommended Literature: C. J. Pethick and H. Smith, Bose-Einstein Condensation in Dilute Gases (Cambridge University Press)

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Group Theory (T) - physics751

Course	**Group Theory (T)**
Course No.	physics751

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	WT

Requirements for Participation:

Preparation: physik421 (Quantum Mechanics)

Form of Testing and Examination: Requirements for the examination (written): successful work with the

Length of Course: 1 semester

Aims of the Course: Acquisition of mathematical foundations of group theory with regard to applications in theoretical physics

Contents of the Course:

Mathematical foundations:

Finite groups, Lie groups and Lie algebras, highest weight representations, classification of simple Lie algebras, Dynkin diagrams, tensor products and Young tableaux, spinors, Clifford algebras, Lie super algebras

Recommended Literature:

B. G. Wybourne; Classical Groups for Physicists (J. Wiley & Sons 1974)

H. Georgi; Lie Algebras in Particle Physics (Perseus Books 2. Aufl. 1999)

W. Fulton, J. Harris; Representation Theory (Springer, New York 1991)

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Superstring Theory (T) - physics752

Course	**Superstring Theory (T)**
Course No.	physics752

Category	**Type**	**Language**	**Teaching hours**	**CP**	**Semester**
Elective	Lecture with exercises	English	3+2	7	WT

Requirements for Participation:

Preparation:

Quantum Field Theory (physics755)

Group Theory (physics751)

Advanced Theoretical Physics (physics607) / Advanced Quantum Field Theory (physics7501)

Theoretical Particle Physics (physics615)

Form of Testing and Examination: Requirements for the examination (written): successful work with the

Length of Course: 1 semester

Aims of the Course: Survey of modern string theory as a candidate of a unified theory in regard to current research

Contents of the Course:

Bosonic String Theory, Elementary Conformal Field Theory

Kaluza-Klein Theory

Crash Course in Supersymmetry

Superstring Theory

Heterotic String Theory

Compactification, Duality, D-Branes

M-Theory

Recommended Literature:

D. Lüst, S. Theisen; Lectures on String Theory (Springer, New York 1989)

S. Förste; Strings, Branes and Extra Dimensions, Fortsch. Phys. 50 (2002) 221, hep-th/0110055

C. Johnson, D-Brane Primer (Cambridge University Press 2003)

M. Green, J. Schwarz, E. Witten; Superstring Theory I & II (Cambridge University Press 1988)

H.P. Nilles, Supersymmetry and phenomenology (Phys. Reps. 110 C (1984) 1)

J. Polchinski; String Theory I & II (Cambridge University Press 2005)

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Theoretical Particle Astrophysics (T) - physics753

Course	**Theoretical Particle Astrophysics (T)**
Course No.	physics753

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	ST

Requirements for Participation:

Preparation:

General Relativity and Cosmology (physics754)

Quantum Field Theory (physics755)

Theoretical Particle Physics (physics615)

Form of Testing and Examination: Requirements for the examination (written): successful work with the exercises

Length of Course: 1 semester

Aims of the Course: Introduction to the current status at the interface of particle physics and cosmology

Contents of the Course:

Topics on the interface of cosmology and particle physics:

Inflation and the cosmic microwave background;

baryogenisis,

Dark Matter,

nucleosynthesis

the cosmology and astrophysics of neutrinos

Recommended Literature:

J. Peacock, Cosmological Physics (Cambridge University Press 1998)

E. Kolb, M. Turner; The Early Universe (Addison Wesley 1990)

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General Relativity and Cosmology (T) - physics754

Course	**General Relativity and Cosmology (T)**
Course No.	physics754

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	ST

Requirements for Participation:

Preparation:

physik221 and physik321 (Theoretical Physics I and II)

Differential geometry

Form of Testing and Examination: Requirements for the examination (written): successful work with the exercises

Length of Course: 1 semester

Aims of the Course: Understanding the general theory of relativity and its cosmological implications

Contents of the Course:

Relativity principle

Gravitation in relativistic mechanics

Curvilineal coordinates

Curvature and energy-momentum tensor

Einstein-Hilbert action and the equations of the gravitational field

Black holes

Gravitational waves

Time evolution of the universe

Friedmann-Robertson-Walker solutions

Recommended Literature:

S.Weinberg; Gravitation and Cosmology (J. Wiley & Sons 1972)

R. Sexl: Gravitation und Kosmologie, Eine Einführung in die Allgemeine Relativitätstheorie (Spektrum Akadem. Verlag 5. Aufl 2002)

L.D. Landau, E.M. Lifschitz; Course of Theoretical Physics Vol.2: Classical field theory (Butterworth-Heinemann 1995), also available in German from publisher Harry Deutsch

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Quantum Field Theory (T) - physics755

Course	**Quantum Field Theory (T)**
Course No.	physics755

Category	**Type**	**Language**	**Teaching hours**	**CP**	**Semester**
Elective	Lecture with exercises	English	3+2	7	ST

Requirements for Participation:

Preparation: Advanced quantum theory (physics606)

Form of Testing and Examination: Requirements for the examination (written): successful work with the exercises

Length of Course: 1 semester

Aims of the Course: Understanding quantum field theoretical methods, ability to compute processes in quantum electrodynamics (QED) and many particle systems

Contents of the Course:

Classical field theory

Quantization of free fields

Path integral formalism

Perturbation theory

Methods of regularization: Pauli-Villars, dimensional

Renormalizability

Computation of Feynman diagrams

Transition amplitudes in QED

Applications in many particle systems

Recommended Literature:

N. N. Bogoliubov, D.V. Shirkov; Introduction to the theory of quantized fields (J. Wiley & Sons 1959)

M. Kaku, Quantum Field Theory (Oxford University Press 1993)

M. E. Peskin, D.V. Schroeder; An Introduction to Quantum Field Theory (Harper Collins Publ. 1995)

L. H. Ryder; Quantum Field Theory (Cambridge University Press 1996)

S. Weinberg; The Quantum Theory of Fields (Cambridge University Press 1995)

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Critical Phenomena (T) - physics756

Course	**Critical Phenomena (T)**
Course No.	physics756

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	ST

Requirements for Participation:

Preparation:

Advanced quantum theory (physics606)

Theoretical condensed matter physics (physics617)

Form of Testing and Examination: Requirements for the examination (written): successful work with the exercises

Length of Course: 1 semester

Aims of the Course: Acquisition of important methods to treat critical phenomena

Contents of the Course:

Mean Field Approximation and its Improvements

Critical Behaviour at Surfaces

Statistics of Polymers

Concept of a Tomonaga-Luttinger Fluid

Random Systems

Phase Transitions, Critical Exponents

Scale Behaviour, Conformal Field Theory

Special Topics of Nanoscopic Physics

Recommended Literature:

J. Cardy, Scaling and Renormalization in Statistical Physics (Cambridge University Press, 1996)

A. O. Gogolin, A. A. Nersesyan, A.N.Tsvelik; Bosonisation and strongly correlated systems (Cambridge University Press, 1998)

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Effective Field Theory (T) - physics757

Course	**Effective Field Theory (T)**
Course No.	physics757

Category	**Type**	**Language**	**Teaching hours**	**CP**	**Semester**
Elective	Lecture with exercises	English	3+2	7	WT/ST

Requirements for Participation:

Preparation:

Advanced quantum theory (physics606)

Quantum Field Theory (physics755)

Form of Testing and Examination: Requirements for the examination (written): successful work with the exercises

Length of Course: 1 semester

Aims of the Course: Understanding basic properties and construction of Effective Field Theories, ability to perform calculations in Effective Field Theories

Contents of the Course:

Scales in physical systems, naturalness

Effective Quantum Field Theories

Renormalization Group, Universality

Construction of Effective Field Theories

Applications: effective field theories for physics beyond the Standard Model, heavy quarks, chiral dynamics, low-energy nuclear physics, ultracold atoms

Recommended Literature:

S. Weinberg; The Quantum Theory of Fields (Cambridge University Press 1995)

J.F. Donoghue et al.; Dynamics of the Standard Model (Cambridge University Press 1994)

A.V. Manohar, M.B. Wise; Heavy Quark Physics (Cambridge University Press 2007)

P. Ramond, Journeys Beyond The Standard Model (Westview Press 2003)

D.B. Kaplan, Effective Field Theories (arXiv:nucl-th/9506035)

E. Braaten, H.-W. Hammer; Universality in Few-Body Systems with Large Scattering Length (Phys. Rep. 428 (2006) 259)

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Quantum Chromodynamics (T) - physics758

Course	**Quantum Chromodynamics (T)**
Course No.	physics758

Category	**Type**	**Language**	**Teaching hours**	**CP**	**Semester**
Elective	Lecture with exercises	English	3+2	7	WT/ST

Requirements for Participation:

Preparation:

Advanced quantum theory (physics606)

Quantum Field Theory (physics755)

Form of Testing and Examination: Requirements for the examination (written): successful work with the exercises

Length of Course: 1 semester

Aims of the Course:

Understanding basic properties of Quantum Chromodynamics, ability to compute

strong interaction processes

Contents of the Course:

Quantum Chromodynamics as a Quantum Field Theory

Perturbative Quantum Chromodynamics

Topological objects: instantons etc.

Large N expansion

Lattice Quantum Chromodynamics

Effective Field Theories of Quantum Chromodynamics

Flavor physics (light and heavy quarks)

Recommended Literature:

S. Weinberg; The Quantum Theory of Fields (Cambridge University Press 1995)

M.E. Peskin, D.V. Schroeder; An Introduction to Quantum Field Theory (Westview Press 1995)

F.J. Yndurain; The Theory of Quark and Gluon Interactions (Springer 2006)

J.F. Donoghue et al.; Dynamics of the Standard Model (Cambridge University Press 1994)

E. Leader and E. Predazzi; An Introduction to Gauge Theories and Modern Particle Physics (Cambridge University Press 1996)

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Quantum Field Theory for Condensed Matter Physics (T) - physics759

Course	**Quantum Field Theory for Condensed Matter Physics (T)**
Course No.	physics759

Category	**Type**	**Language**	**Teaching hours**	**CP**	**Semester**
Elective	Lecture with exercises	English	2+1	5	WT/ST

Requirements for Participation: Quantum mechanics I (physik421)

Preparation:

Quantum mechanics II (physics606), Thermodynamics and statistical physics (physik521)

Can be heard in parallel to physics617: "Theoretical Condensed Matter Physics"

Form of Testing and Examination: Requirements for the examination (written or oral): attendance of and successful work with the exercises

Length of Course: 1 semester

Aims of the Course:

Knowledge of quantum field theory of interacting many-body systems at finite temperature

Knowledge of quantum field theory for non-equilibrium systems

Ability to construct and evaluate perturbation theory using Feynman diagram

Contents of the Course:

Fock space and occupation number representation for bosons and fermions

Green's functions: analytical properties and their relation to observable quantities

Elementary linear response theory

Equations of motion

Perturbation theory in thermodynamic equilibrium: Feynman diagrams, Matsubara technique

Perturbation theory away from equilibrium: Keldysh technique

Infinite resummations of perturbation expansions

Exemplary application to model system

Recommended Literature:

W. Nolting, Grundkurs Theoretische Physik 7: Vielteilchen-Theorie (Springer, Heidelberg 2009)

A. A. Abrikosov, L. P. Gorkov, I. E. Dzyaloshinskii, Methods of Quantum Field Theory in Statistical Physics (Dover, New York 1975 and later editions)

Xiao-Gang Wen, Quantum Field Theory of Many-Body Systems, Oxford Graduate Texts (Oxford University Press, Oxford 2004)

A. Altland and B. Simons, Condensed Matter Field Theory (Cambridge University Press, Cambridge 2006)

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Computational Physics (T) - physics760

Course	**Computational Physics (T)**
Course No.	physics760

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises and project work	English	2+2+1	7	WT/ST

Requirements for Participation: Knowledge of a modern programming language (like C, C++)

Preparation: Theoretical courses at the Bachelor degree level

Form of Testing and Examination:

successful participation in exercises,

presentation of an independently completed project

Length of Course: 1 semester

Aims of the Course: ability to apply modern computational methods for solving physics problems

Contents of the Course:

Statistical Models, Likelihood, Bayesian and Bootstrap Methods

Random Variable Generation

Stochastic Processes

Monte-Carlo methods

Markov-Chain Monte-Carlo

Recommended Literature:

W.H. Press et al.: Numerical Recipes in C (Cambridge University Press)

http://library.lanl.gov/numerical/index.html

C.P. Robert and G. Casella: Monte Carlo Statistical Methods (Springer 2004)

Tao Pang: An Introduction to Computational Physics (Cambridge University Press)

Vesely, Franz J.: Computational Physics: An Introduction (Springer)

Binder, Kurt and Heermann, Dieter W.: Monte Carlo Simulation in Statistical Physics (Springer)

Fehske, H.; Schneider, R.; Weisse, A.: Computational Many-Particle Physics (Springer)

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Supersymmetry (T) - physics761

Course	**Supersymmetry (T)**
Course No.	physics761

Category	**Type**	**Language**	**Teaching hours**	**CP**	**Semester**
Elective	Lecture with exercises	English	3+1	6	WT/ST

Requirements for Participation: Quantum Field Theory I

Preparation:

Form of Testing and Examination: Individual Oral Examinations

Length of Course: 1 semester

Aims of the Course: Teach the students the basics of supersymmetric field theory and how it can be tested at the LHC.

Contents of the Course: Superfields; Supersymmetric Lagrangians; MSSM; Testing the MSSM at the LHC

Recommended Literature:

Theory and phenomenology of sparticles: An account of four-dimensional N=1 supersymmetry in high energy physics.

M. Drees, (Bonn U.) , R. Godbole, (Bangalore, Indian Inst. Sci.) , P. Roy, (Tata Inst.) . 2004. 555pp.

Hackensack, USA: World Scientific (2004) 555 p.

Weak scale supersymmetry: From superfields to scattering events.

H. Baer, (Florida State U.) , X. Tata, (Hawaii U.) . 2006. 537pp.

Cambridge, UK: Univ. Pr. (2006) 537 p.

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Transport in mesoscopic systems (T) - physics762

Course	**Transport in mesoscopic systems (T)**
Course No.	physics762

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	5	WT/ST

Requirements for Participation:

Preparation:

Classical mechanics

Elementary thermodynamics and statistical physics (physik521)

Advanced quantum theory (physics606)

Introductory theoretical condensed matter physics (physics617)

Form of Testing and Examination: Requirements for the examination (written or oral); successful work with the exercises

Length of Course: 1 semester

Aims of the Course:

Understanding essential transport phenomena in solids and mesoscopic systems

Acquisition of important methods for treating transport problems

Contents of the Course:

Linear response theory

Disordered and ballistic systems

Semiclassical approximation

Introduction to quantum chaos theory, chaos and integrability in classical and quantum mechanics

Elements of random matrix theory

Specific problems of mesoscopic transport (weak localization, universal conductance fluctuations,

shot noise, spin-dependent transport, etc.)

Quantum field theory away from thermodynamic equilibrium

Recommended Literature:

K. Richter, Semiclassical Theory of Mesoscopic Quantum Systems, Springer, 2000 (http://www.physik.uni-regensburg.de/forschung/richter/richter/pages/research/springer-tracts-161.pdf)

M. Brack, R. K. Bhaduri, Semiclassical Physics, Westview Press, 2003

S. Datta, Electronic Transport in Mesoscopic Systems, Cambrige University Press, 1995

M. C. Gutzwiller, Chaos in Classical and Quantum Mechanics, Springer, New York, 1990

F. Haake, Quantum signatures of chaos, Springer, 2001

M. L. Mehta, Random matrices, Elsevier, 2004

J. Imry, Introduction to mesoscopic physics, Oxford University Press

Th. Giamarchi, The physics of one-dimensional systems, Oxford University Press

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Advanced Topics in String Theory (T) - physics763

Course	**Advanced Topics in String Theory (T)**
Course No.	physics763

Category	**Type**	**Language**	**Teaching hours**	**CP**	**Semester**
Elective	Lecture with exercises	English	3+2	7	ST

Requirements for Participation:

Preparation:

Quantum Field Theory (physics755)

Group Theory (physics751)

Advanced Theoretical Physics (physics607) / Advanced Quantum Field Theory (physics7501)

Theoretical Particle Physics (physics615)

Superstring Theory (physics752)

Form of Testing and Examination: active participation in exercises, written examination

Length of Course: 1 semester

Aims of the Course: Detailed discussion of modern string theory as a candidate of a unified theory in regard to current research

Contents of the Course:

Realistic compactifications

Interactions

Effective actions

Heterotic strings in four dimensions

Intersecting D-branes

Recommended Literature:

D. Lüst, S. Theisen: Lectures on String Theory (Springer, New York 1989)

S. Förste: Strings, Branes and Extra Dimensions, Fortsch. Phys. 50 (2002) 221, hep-th/0110055

C. Johnson: D-Brane Primer (Cambridge University Press 2003)

M. Green, J. Schwarz, E. Witten: Superstring Theory I & II (Cambridge University Press 1988)

H.P. Nilles: Supersymmetry and Phenomenology (Phys. Reps. 110C (1984)1)

J. Polchinski: String Theory I & II (Cambridge University Press 2005)

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Advanced Topics in Field and String Theory (T) - physics764

Course	**Advanced Topics in Field and String Theory (T)**
Course No.	physics764

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	ST

Requirements for Participation: Prerequisite knowledge of Quantum Field Theory, Superstring Theory, and General Relativity is helpful.

Preparation:

Quantum Field Theory (physics755)

Advanced Theoretical Physics (physics607) / Advanced Quantum Field Theory (physics7501)

Superstring Theory (physics752)

Form of Testing and Examination: active participation in exercises, oral or written examination

Length of Course: 1 semester

Aims of the Course: An introduction into modern topics in Mathematical High Energy Physics in regard to current research areas

Contents of the Course:

String and Supergravity Theories in various dimensions

Dualities in Field Theory and String Theory

Topological Field Theories and Topological Strings

Large N dualities and integrability

Recommended Literature:

Selected review articles an arXiv.org [hep-th]

J. Polchinski: String Theory I & II

S. Weinberg: Quantum Theory of Fields

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Advanced Topics in Quantum Field Theory (T) - physics765

Course	**Advanced Topics in Quantum Field Theory (T)**
Course No.	physics765

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	ST

Requirements for Participation: Prerequisite knowledge of Quantum Field Theory

Preparation:

Quantum Field Theory (physics755)

Advanced Theoretical Physics (physics607) / Advanced Quantum Field Theory (physics7501)

Form of Testing and Examination: active participation in exercises, oral or written examination

Length of Course: 1 semester

Aims of the Course: Covers advanced topics in Quantum Field Theory that are relevant for current developments in the field.

Contents of the Course: TBA

Recommended Literature:

Selected articles on arXiv.org [hep-th]

TBA

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Physics of Higgs Bosons (T) - physics766

Course	**Physics of Higgs Bosons (T)**
Course No.	physics766

Category	**Type**	**Language**	**Teaching hours**	**CP**	**Semester**
Elective	Lecture with exercises	English	3+2	7	WT

Requirements for Participation:

Preparation: Theoretical Particle Physics (physics615)

Form of Testing and Examination:

Requirement for the examination (written or oral): successful participation

in the exercises

Length of Course: 1 semester

Aims of the Course:

Understanding the physics of electroweak symmetry breaking, and the interpretations of the recently discovered signals for the existence of a Higgs boson

Contents of the Course:

Spontaneous symmetry breaking

The Higgs mechanism

The Higgs boson of the Standard Model

Experimental situation

Extended Higgs sectors

Precision calculations

Recommended Literature:

J. Gunion, H.E. Haber, G.L. Kane and S. Dawson: The Higgs Hunter's Guide (Frontiers of Physics, 2000)

A. Djouadi: Anatomy of Electroweak Symmetry Breaking I (Phys. Rep. 457 (2008) 1, hep-ph/0503173)

A. Djouadi: Anatomy of Electroweak Symmetry Breaking II (Phys. Rep. 459 (2008) 1, hep-ph/0504090)

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Computational Methods in Condensed Matter Theory (T) - physics767

Course	**Computational Methods in Condensed Matter Theory (T)**
Course No.	physics767

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	WT/ST

Requirements for Participation:

Preparation:

Quantum Field Theory (physics755)

Advanced Theoretical Physics (physics607) / Advanced Quantum Field Theory (physics7501)

Advanced Theoretical Condensed Matter Physics (physics638)

Form of Testing and Examination: Active participation in exercises, written examination

Length of Course: 1 semester

Aims of the Course: Detailed discussion of computational tools in modern condensed matter theory

Contents of the Course:

Exact Diagonalization (ED)

Quantum Monte Carlo (QMC)

(Stochastic) Series expansion (SSE)

Density Matrix Renormalization (DMRG)

Dynamical Mean Field theory (DMFT)

Recommended Literature: will be given in the lecture

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General Relativity for Experimentalists (T) - physics768

Course	**General Relativity for Experimentalists (T)**
Course No.	physics768

Category	**Type**	**Language**	**Teaching hours**	**CP**	**Semester**
Elective	Lecture with exercises	English	3+2	7	WT/ST

Requirements for Participation:

Preparation: Theoretische Physik I & II, Analysis I & II

Form of Testing and Examination: Weekly homework sets (50% required), Final exam

Length of Course: 1 semester

Aims of the Course: The students shall learn the basics of general relativity and be able to apply it to applications such as experimental tests of GR, GPS, astrophysical objects and simple issues in cosmology.

Contents of the Course:

Review of special relativity

Curved spacetime of GR

Experimental tests of GR

GPS

Black holes

Gravitational waves

Introductory cosmology

Recommended Literature:

GRAVITY, by James Hartle

A FIRST COURSE IN GENERAL RELATIVITY, by Bernard Schutz

EXPLORING BLACK HOLES, by Taylor and Wheeler

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Lattice QCD (T) - physics769

Course	**Lattice QCD (T)**
Course No.	physics769

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	ST/WT

Requirements for Participation:

Preparation: Quantum Mechanics 1+2, Quantum Field Theory 1

Form of Testing and Examination: Written / oral examination

Length of Course: 1 semester

Aims of the Course: To give an introduction to the quantum field theory on the lattice

Contents of the Course:

- Introduction: Quantum mechanics on the lattice
- Numerical algorithms
- Spin systems on the lattice: The Ising model
- Scalar field theory on the lattice: Discretization; Perturbation theory; Continuum limit
- Gauge fields: Link variables; Plaquette action; Wilson loop and confinement
- Fermions on the lattice: Fermion doubling; Different formulations for lattice fermions; Axial anomaly; Chiral fermions
- Use of Effective Field Theory methods: Extrapolation in the quark masses; Resonances in a finite volume

Recommended Literature:

J. Smit, Introduction to quantum fields on a lattice: A robust mate, Cambridge Lect. Notes Phys. (2002)

I. Montvay and G. Münster, Quantum Fields on a Lattice, Cambridge Monographs on Mathematical Physics, Cambridge University Press 1994

C. Gattringer and Ch. Lang, Quantum Chromodynamics on the Lattice: An Introductory Presentation

Series: Lecture Notes in Physics, Vol. 788

H.J. Rothe, Lattice Gauge Theories: An Introduction, World Scientific, (2005)

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Advanced Quantum Field Theory (T) - physics7501

Course	**Advanced Quantum Field Theory (T)**
Course No.	physics7501

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	WT

Requirements for Participation:

Preparation: 3-year theoretical physics course with extended interest in theoretical physics and mathematics

Form of Testing and Examination: Requirements for the module examination (written examination): successful work with exercises

Length of Course: 1 semester

Aims of the Course: Introduction to modern methods and developments in Theoretical Physics in regard to current research

Contents of the Course:

Selected Topics in Modern Theoretical Physics for example:

Anomalies

Solitons and Instantons

Quantum Fluids

Bosonization

Renormalization Group

Bethe Ansatz

Elementary Supersymmetry

Gauge Theories and Differential Forms

Applications of Group Theory

Recommended Literature:

M. Nakahara; Geometry, Topology and Physics (Institute of Physics Publishing, London 2nd Ed. 2003)

R. Rajaraman; Solitons and Instantons, An Introduction to Solitons and Instantons in Quantum Field Theory (North Holland Personal Library, Amsterdam 3rd reprint 2003)

A. M. Tsvelik; Quantum Field Theory in Condensed Matter Physics (Cambridge University Press 2nd Ed. 2003)

A. Zee; Quantum Field Theory in a Nutshell (Princeton University Press 2003)

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Random Walks and Diffusion (T) - physics7502

Course	**Random Walks and Diffusion (T)**
Course No.	physics7502

Category	**Type**	**Language**	**Teaching hours**	**CP**	**Semester**
Elective	Lecture with exercises	English	1+1	3	ST

Requirements for Participation:

Preparation: Quantum mechanics and Thermodynamics

Form of Testing and Examination: Requirements for the (written or oral) examination: Successful work within the exercises

Length of Course: 1 semester

Aims of the Course: The aim of the course is to introduce the student to random processes and their application to diffusion phenomena

Contents of the Course: Basics of probability theory, Master equation and Langevin equation, Law of large numbers and Central Limit Theorem, First passage problems, Large scale dynamics, Dynamical scaling.

Recommended Literature: Will be announced in the first lecture

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Selected Topics in Modern Condensed Matter Theory (T) - physics7503

Course	**Selected Topics in Modern Condensed Matter Theory (T)**
Course No.	physics7503

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	WT

Requirements for Participation:

Preparation:

- Introductory Condensed Matter Theory
- Quantum Mechanics
- Statistical Physics

Form of Testing and Examination: oral or written examination

Length of Course: 1 semester

Aims of the Course:

Knowledge of topics of contemporary condensed matter research

Knowledge of theoretical methods of condensed matter physics

Contents of the Course:

Covers topics and methods of contemporary research, such as

- Feynman diagram technique
- Phase transitions and critical phenomena
- Topological aspects of phenomena in condensed matter physic

Recommended Literature:

R. D. Mattuck, A Guide to Feynman Diagrams in the Many-Body Problem

N. Goldenfeld, Lectures on Phase Transitions and the Renormalization Group

B. A. Bernevig, Topological Insulators and Topological Superconductors

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Theory of Superconductivity and Superfluidity (T) - physics7504

Course	**Theory of Superconductivity and Superfluidity (T)**
Course No.	physics7504

Category	**Type**	**Language**	**Teaching hours**	**CP**	**Semester**
Elective	Lecture with exercises	English	2+1	5	WT/ST

Requirements for Participation:

Preparation: Quantum Mechanics, Thermodynamics and Statistics, Quantum Field Theory

Form of Testing and Examination: Requirements for the (written or oral) examination: Successful participation in the exercises

Length of Course: 1 semester

Aims of the Course: The goal of the course is to introduce students to the theory of superconductivity and superfluidity.

Contents of the Course: Phenomenological theory of basic superconductivity, type I and type II superconductivity, vortices and their dynamics, Meissner-Ochsenfeld Effekt, microscopic theory of superconductivity: Gor'kov equation, BCS theory, Migdal theorem, strong coupling theory of superconductivity: Eliashberg equation, Andreev scattering, Josephson effect, Anderson theorem: impurity scattering, Collective excitations in superconductors and superfluids, Anderson (Higgs) mechanism for the mass generation. Superfluidity in 3He, superconductivity in heavy fermion compounds, high temperature superconductivity and open questions.

Recommended Literature: Will be announced in the first lecture

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High performance computing: Modern computer architectures and applications in the physical science (T) - physics7505

Course	**High performance computing: Modern computer architectures and applications in the physical sci**
Course No.	physics7505

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture	English	2	3	WT/ST

Requirements for Participation: Knowledge of a modern programming language like C/C++

Preparation:

Form of Testing and Examination: oral examination

Length of Course: 1 semester

Aims of the Course: Understanding principles of modern computer architectures and their usage and programming for scientific problems

Contents of the Course:

Computer architectures and system components (CPU, memory, network)

Software environment

Parallel architectures and parallel programming paradigms (MPI, OpenMP/threads)

High Performance Computing

Recommended Literature:

John L. Hennessy, David A. Patterson: Computer Architecture - A Quantitative Approach. Morgan Kaufmann Publishers, 2012

David A. Patterson, John L. Hennessy: Computer Organization and Design - The Hardware / Software Interface. Morgan Kaufmann Publishers, 2013

W.H. Press et al.: Numerical Recipes in C (Cambridge University Press)

Message Passing Interface Forum: MPI: A Message-Passing Interface Standard, Version 3.1

OpenMP Application Programming Interface, Version 4.5, November 2015

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Quark Distributions Functions (T) - physics7506

Course	**Quark Distributions Functions (T)**
Course No.	physics7506

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture	English	2	3	WT

Requirements for Participation:

Preparation: Quantum Field Theory (physics755 or equivalent)

Form of Testing and Examination: oral examination

Length of Course: 1 semester

Aims of the Course: By the end of the course, the student should be able to understand the formal parton model, renormalization of parton distributions, and current attempts to compute them on the lattice.

Contents of the Course: Deep Inelastic Scattering; The Operator Product Expansion; Basics of the parton model; The formal parton model; Quark distributions and quasi-quark distributions; One loop corrections and renormalization; Lattice attempts to compute PDF

Recommended Literature:

Elliot Leader, Enrico Predazzi: An introduction to gauge theories and modern particle physics.

Cambridge Monographs on Particle physics, Nuclear Physics and Cosmology 1996.

John Collins: Foundations of Perturbative QCD.

Cambridge Monographs on Particle physics, Nuclear Physics and Cosmology 2011.

Anthony W. Thomas, Wolfram Weise: The Structure of the Nucleon. Wiley-VCH Verlag Berlin 2001.

R. K. Ellis, W. J. Stirling, B. R. Webber: QCD and Collider Physics.

Cambridge Monographs on Particle physics, Nuclear Physics and Cosmology 2003.

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Theory of Quantum Magnetism (T) - physics7507

Course	**Theory of Quantum Magnetism (T)**
Course No.	physics7507

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	4	ST

Requirements for Participation:

Preparation: Quantum mechanics, Thermodynamics and Statistics, Quantum Field Theory

Form of Testing and Examination:

(1) form of examination: written or oral

(2) requirement for participation in examination: successful participation in exercises

Length of Course: 1 semester

Aims of the Course: The goal of the course is to introduce students to advanced concepts in the theory of magnetism.

Contents of the Course: Phenomenological theory of magnetism, spin exchange, ferro and anti-ferro magnetism, classically frustrated systems (Kagome lattice). Representations of spin algebras: Dyson-Maleev, Holstein, Primakov, Schwinger bosons, spin coherent states, spin path integral, non-linear sigma models, quantum phase transition, Bereshinski-Kosterlitz-Thouless transition, Haldane gap, frustrated magnets, valence bond states, spin liquids, quantum Heisenberg model (two dimensional, Kagome, pyrochlore lattice) Exactly solvable models (transfer matrix) Ising model. Exactly solvable models (Bethe Ansatz): XXZ model, Kondo model. Open problems in quantum magnetism.

Recommended Literature: Will be announced in the first lecture

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Quantum Computing (T) - physics7508

Course	**Quantum Computing (T)**
Course No.	physics7508

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	WT/ST

Requirements for Participation:

Preparation: Theoretical courses at the Bachelor degree level

Form of Testing and Examination: written / oral examination

Length of Course: 1 semester

Aims of the Course: Understand the theory of quantum computing and apply it to existing hardware.

Contents of the Course:

- Quantum circuits
- Quantum algorithms
- Quantum computers
- Quantum noise and quantum operations
- Quantum error correction

Recommended Literature: M. A. Nielsen and I. L. Chuang, Quantum Computation and Quantum Information, Cambridge

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Advanced Topics in Particle and Astroparticle Physics (T) - physics7509

Course	**Advanced Topics in Particle and Astroparticle Physics (T)**
Course No.	physics7509

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	WT/ST

Requirements for Participation:

Preparation: physics615 and physics711 strongly recommended, a course on General Relativity (e.g. physics754) would also be helpful.

Form of Testing and Examination: Biweekly Homework Sheets + Final Written Exam

Length of Course: 1 semester

Aims of the Course: To gain knowledge in Cosmological Perturbations, Axion physics, Dark Messenger physics/dark photons.

Contents of the Course:

1. Cosmological perturbations and effect on the CMB
2. Axions: Theory and Detection
3. Dark Photons: Theory and Detection

Recommended Literature:

1. Introduction to the Theory of the Early Universe, Vol. II (Cosmological perturbations and Inflationary Theory) by Gorbunov and Rubakov [World Scientic]on, Modern Cosmoless (Elsevier) 2
2. Modern Cosmology, Scott Dodelson (1st edition, 2003)
3. Various reviews on axions and dark photons.

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Internships in the Research Groups - physics799

Course	**Internships in the Research Groups**
Course No.	physics799

Category	**Type**	**Language**	**Teaching hours**	**CP**	**Semester**
Elective	Research Internship	English		4	WT/ST

Requirements for Participation: Students are asked to contact one of the BCGS lecturers prior to the start of their internship. Lecturers provide help if needed to find a suitable research group and topic. Not all groups may have internships available at all times, thus participation may be limited.

Preparation: A specialization lecture from the research field in question or equivalent preparation.

Form of Testing and Examination: A written report or, alternatively, a presentation in a meeting of the research group.

Length of Course: 4-6 weeks

Aims of the Course: Students conduct their own small research project as a part-time member of one of the research groups in Bonn. The students learn methods of scientific research and apply them to their project.

Contents of the Course:

One of the following possible items:

- setting up a small experiment,
- analyzing data from an existing experiment,
- simulating experimental situations,
- numerical or analytical calculations in a theory group.

Recommended Literature: provided by the supervisor within the research group.

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