agence d'évaluation de la recherche
et de l'enseignement supérieur

Department for the evaluation of research units

AERES report on unit:

Institut de Physique Théorique

IPhT

Under the supervision of the following institutions and research bodies:

Commissariat à l'Énergie Atomique et aux Énergies Alternatives - CEA

Centre National de la Recherche Scientifique - CNRS

November 2013

agence d'évaluation de la recherche
et de l'enseignement supérieur

Department for the evaluation of research units

On behalf of AERES, pursuant to the Decree of 3 november 2006[1],

- Mr. Didier HOUSSIN, president
- Mr. Pierre GLAUDES, head of the evaluation of research units department

On behalf of the expert committee,

- Mr. Pierre BINETRUY, chair of the committee

[1] The AERES President "signs [...], the evaluation reports, [...] countersigned for each department by the director concerned" (Article 9, paragraph 3 of the Decree n ° 2006-1334 of 3 November 2006, as amended).

Evaluation report

This report is the result of the evaluation by the experts committee, the composition of which is specified below.

The assessment contained herein are the expression of independent and collegial deliberation of the committee.

Unit name:	Institut de Physique Théorique
Unit acronym:	IPhT
Label requested:	UMR
Present no.:	URA 2306
Name of Director (2013-2014):	Mr Michel BAUER
Name of Project Leader (2015-2019):	Mr Michel BAUER

Expert committee members

Chair:	Mr Pierre BINETRUY, Laboratoire APC, Université Denis Diderot
Experts:	Mr Wilfried BUCHMÜLLER, DESY, Univ. Hamburg, République Fédérale d'Allemagne
	Mr Vladimir DOTSENKO, LPTHE, Université Pierre et Marie Curie
	Mr Sylvain CAPPONI, Laboratoire de physique théorique, Université Paul Sabatier (representative of the CNU)
	Mr Benoît DOUÇOT, LPTHE, Université Pierre et Marie Curie
	Mr Jean-Michel MAILLET, Laboratoire de physique, ENS Lyon (representative of the CoNRS)
	Mr Claude-Alain PILLET, CPT, Aix-Marseille University and Toulon University

Scientific delegate representing the AERES:

Mr Marc KNECHT

Representative(s) of the unit's supervising institutions and bodies:

M. Roland COMBESCOT (Directeur de l'École Doctorale de physique de la région parisienne n°107)

Mr Jean-Paul DURAUD, Direction des Sciences de la Matière, CEA

Mr Jean-Jacques GUILLEMINOT, Délégation Régionale Ile-de-France-Sud, CNRS

Mr Barend Van TIGGELEN, Institut de Physique, CNRS

1 • Introduction

History and geographical location of the unit

The “Service de Physique Théorique” at CEA was created in 1963. In 1968 it moved to the present site at the Orme des Merisiers. It was associated with CNRS in 2001, with the status of an “Unité de Recherche Associée”. In 2008, it became the “Institut de Physique Théorique”.

Management team

The direction team of IPhT includes the director, Mr Michel BAUER, and two deputies, Ms Anne CAPDEPON (administrative affairs) and Mr Stéphane NONNENMACHER (scientific affairs). The direction takes the advice of a Scientific Council, and of an Institute Council, composed of elected members.

AERES nomenclature

ST2 Physics

Unit workforce

Unit workforce	Number as at 30/06/2013	Number as at 01/01/2015
N1: Permanent professors and similar positions		
N2: Permanent researchers from Institutions and similar positions	50	49
N3: Other permanent staff (without research duties)	8	8
N4: Other professors (Emeritus Professor, on-contract Professor, etc.)		
N5: Other researchers from Institutions (Emeritus Research Director, Postdoctoral students, visitors, etc.)	52	52
N6: Other contractual staff (without research duties)	1	1
TOTAL N1 to N6	111	110

Unit workforce	Number as at 30/06/2013	Number as at 01/01/2015
Doctoral students	21	
Theses defended	30	
Postdoctoral students having spent at least 12 months in the unit*	30	
Number of Research Supervisor Qualifications (HDR) taken	6	
Qualified research supervisors (with an HDR) or similar positions	38	35

2 • Assessment of the unit

The “Institut de Physique Théorique” has a long history of excellence, at the forefront of innovative developments in theoretical physics. The committee acknowledges the very high scientific level that the laboratory has maintained through the last period, which makes it one of the top laboratories in Europe for theoretical physics. It especially commends the comprehensive approach of theory, which is a long-term tradition and which has been successfully maintained, with many members of the lab contributing significantly to several domains. The strong attractivity of the laboratory should allow it to face successfully some of the challenges of the coming period, especially regarding the hiring of permanent researchers.

Strengths and opportunities related to the context

The main strength of the IPhT is the scientific quality of its members, and of the work that they publish. This makes the laboratory very attractive for young researchers, visitors, but also for funding, as is exemplified by the unusually high number of ERC fundings.

The committee would like to praise the renewal of generations achieved, not an easy task for a laboratory with such a tradition of scientific leadership: there is now an harmonious conjunction of senior scientists, leaders in their fields, and of promising young stars who have the potential to define the fields of the future.

A significant achievement of the present period is the successful development of new themes that have now reached maturity (string theory, solid state physics). This broadens the spectrum of the Institute, and thus diversifies the comprehensive approach of theory, which is a trademark of this laboratory.

Weaknesses and threats related to the context

The committee considers as a significant threat the absence of hiring from CEA in the coming period. Given the fact that other sources of hiring will undoubtedly be scarce, this endangers the potential of the laboratory for a necessary renewal of staff and expertise. This might be partially mitigated by the large number of non-permanent scientists.

A potential threat is the low involvement in the regional research structure (Paris Saclay) at a time of a major reshaping, and in a configuration where this represents the most plausible source of extra resources.

Recommendations

The Institute should improve significantly the involvement in the shaping up of the Paris Saclay research pole, which should see positively an active role of one of the leading laboratories in theoretical physics. IPhT might increase its influence by teaming up with other theory laboratories in the area.

3 • Detailed assessments

Assessment of scientific quality and outputs

The committee judges the overall quality of the scientific production of IPhT of the best international level, with a high impact in the scientific community. It notes that new fields have been successfully developed, such as string theory and solid-state physics, and have reached maturity. The comprehensive approach of theory, which is a trademark of this laboratory, has allowed theoretical and methodological breakthroughs.

Some of the following contributions highlight these different aspects (for a more thorough presentation, see the discussion theme by theme in the next sections):

- the development of the approach of generalized geometries, for the string theory compactifications;

- results which question the famous landscape paradigm of string theory compactifications;

- the development of a new approach to the logarithmic conformal theories by defining the corresponding integrable model regularizations on the lattice;

- original studies, under way, in the direction of passing from the discrete surface quantum gravity to the continuum (Liouville model) 2-dimensional quantum gravity;

- the semi-classical analysis of quantum resonances induced by trapped orbits of classical dynamics has been raised to high art;

- the probabilistic description of repeated non-demolition quantum measurements opens the way to better theoretical understanding of high precision experiments in QED;

- the impressive exact calculations for various observables in classical and quantum out of equilibrium systems;

- the developments concerning amplitudes in quantum field theory, both for their phenomenological relevance and their more formal aspects, in particular in connection with string theory;

- new results in heavy-ion colllisions at ultra-high energies to study the quark-gluon plasma phase of hadronic matter;

- the development of new resummation schemes providing more accurate predictions on large scale structures, necessary for the future cosmological surveys;

- significant contributions to the study of the dark components of the Universe, in connection with the observational and experimental programs on-going;

- recent progresses in the modelling of real glasses and the conceptual understanding of the glass transition;

- the development of new analytical and numerical methods for the exploration of exotic phases of matter;

- the extension of the ideas of statistical physics to cross-disciplinary research, in particular biophysics, network dynamics, and optimization problems.

Overall, the total of some 1000 publications in the period, with almost a third reaching the top 10% of most cited articles testifies for the overall impact of research performed at IPhT.

Assessment of the unit's academic reputation and appeal

The quality of past recruitments, which allowed to strengthen existing fields or to develop new ones, is a clear sign of the overall appeal of the laboratory. This is emphasized by the unusually large number of ERC fellowships, both senior (2) and junior (7), awarded during the period. But the successes with other sources of external funding are just as impressive (20 “Programmes blancs” of ANR, 15 European networks).

The high attractivity of the IPhT is also testified by the large number of national and international visitors.

The Institute has also a tradition of organizing highly visible conferences that attract the best researchers in the field. One may cite the renowned Itzykson meetings, the Pont d’Avignon conferences and the Beg-Rohu summer school.

Assessment of the unit's interaction with the social, economic and cultural environment

N/A because of the nature of the research.

Nevertheless the committee identified quite a few activities in outreach (around 50) and the potential applicability of some of the methods developed.

Assessment of the unit's organisation and life

The structure in research teams can be thought in terms of main themes: a) mathematical physics: structures and models b) particle physics and astrophysics c) statistical physics and condensed matter. But quite a few individual members belong to several teams, and possibly two themes. This ensures transversality, which has proved to be a very specific asset of this laboratory.

This structure has allowed, and even fostered, the emergence of some new fields of research that have proved to be very successful: string theory and solid-state physics are good illustrations.

The present organisation with a director, seconded by two deputies, with an elected internal Scientific Council and an Institute Council, appears to be well adapted to the needed transversality. The committee takes this opportunity to commend the management for its very positive action during the period.

The committee has met with the various categories of personnel: scientists, supporting administrative and technical staff, students and post-docs. The general atmosphere is good and everybody seems to be satisfied with the role they play within the laboratory and the way it is recognized. Everybody recognizes the quality of the support team, despite the increasing complexity of the tasks needed. There is, however, some worry from the supporting staff about future mutualisation of some tasks with other laboratories.

Postdoctoral fellows play, and will play, a significant role in the scientific development of future years, because of the few hiring of permanent scientists expected. There is presently a worry that the large number of ERC postdocs leads to two distinct categories of postdocs, one (ERC postdocs) who is assigned to a single person and a definite task, and one (lab postdocs) who is free to choose the topic of research and, much in the spirit of IPhT, to move from one field to another. The lab management should take measures to alleviate this distinction.

Assessment of the unit's involvement in training through research

The committee met with the coordinator of ED 107 and identified no pending problem with doctoral training at IphT. The Ph.D. students are highly satisfied with their work conditions and with the scientific and social atmosphere. The progress of each student appears to be closely followed by the management of the laboratory.

Despite the distance from the main teaching institutions, there appears to be a good involvement of the researchers in the teaching at master level in the whole Paris area.

Successful series of graduate courses, the IPhT lectures, are organised by the lab. They are attracting students and young researchers throughout the Paris area.

IPhT was, until recently, rather isolated both geographically and structurally from Universities, but this is changing rapidly with the establishment of the Paris Sacaly University. The lab and its management are well aware of the potential of such an evolution.

Assessment of the strategy and the five-year plan

The committee commends the laboratory for the quality of the SWOT analysis and of the five-year plan proposed. It builds on the many strengths of the laboratory and appears to be globally feasible, despite the difficulties of the present period.

The committee met with the funding agencies of the laboratory and was pleased to hear the commitment of these agencies, especially CEA, to maintain the funding in the coming period, despite the difficulties of the general environment.

The foreseen absence of hiring at CEA for the coming period is a challenge for the lab and its management.

The committee supports the move to consider tightening the link with CNRS (and possibly the Paris Saclay pole) by changing the status of the laboratory from URA to the more standard "Unité Mixte de Recherche").

The scientific leadership and the renewal of generation make the committee rather optimistic about the lab retaining its leadership in theoretical physics. The important number of non-permanent personnel will imply to reconsider their role in the laboratory, a concern already addressed presently.

As emphasized in the plan proposed, the presence of IPhT in the Paris Saclay pole is an opportunity that must be seized. The laboratory should strengthen its connections with the other theory laboratories in the pole in order to enhance the overall visibility and influence of theoretical physics.

4 • Theme-by-theme analysis

Theme 1: Mathematical physics: structures and models

Manager's name: Mr Bertrand EYNARD

Workforce

Theme workforce in Full Time Equivalents	As at 30/06/2013	As at 01/01/2015
FTE for permanent professors		
FTE for permanent EPST or EPIC researchers	18	18
FTE of other permanent staff without research duties (IR, IE, PRAG, etc.)		
FTE for other professors (PREM, ECC, etc.)		
FTE for postdoctoral students having spent at least 12 months in the unit	13	
FTE for other EPST or EPIC researchers (DREM, etc.) excluding postdoctoral students		
FTE for other contractual staff without research duties		
FTE for doctoral students	7	
TOTAL	38	18

• Detailed assessments

The Mathematical Physics theme spans a wide range of topics which, despite their variety, are deeply interconnected and use very often a common ensemble of theoretical knowledges and tools (like integrable systems and CFT) that IPhT has contributed to develop over the years.

Random matrices, statistical models and quantum gravity

The IPhT has a long and well established tradition of studying statistical models having rich algebraic structures, in particular related to integrable systems,s and in their use to obtain physical relevant quantities in nonperturbative regimes.

IPhT has contributed, from the early 60's on, to the development of random matrix theory (RMT) with a far reaching contribution obtained in the recent years called the topological recursion method. It allows computing large-N expansions of the partition and correlation functions in these models through universal recursion formulae related to the spectral curve associated to the asymptotic spectral density of the matrices. This approach already produced numerous important results in various contexts (scattering amplitudes in topological strings, models of statistical physics, enumerative geometry, knot theory, etc.).

Another application of RMT is the theory of random surfaces related in particular to 2-d quantum gravity models. The Saclay group has been involved, and produced very original results, created new methods, from the very beginning of the studies of random surfaces, so to say of the studies of the discrete 2D quantum gravity. Equally, the group has contributed, from the beginning, to the Liouville model studies of 2D quantum gravity in the continuum. In the recent period (last five years), the researches have been pursued at IPhT, on the Liouville model, with the highest mathematical (analytical) precision of the theory content. As the theory of this model still resists its complete understanding, all precision studies of this model are of great importance in connection to SLE in particular. Equally, the studies of the triangulated random surfaces, without and with matter (like O(n) and Potts model loops, on random surfaces) have been pursued. These are very profound and original studies of local geometrical properties of random surfaces, and of the 2D quantum gravity at the end. An important progress has been made, and is being made, in establishing the link between the two approaches, by starting with the random discrete surfaces and going, in all the fine details, to the continuum Liouville theory of the 2D gravity.

Another connected activity concerns random surfaces of crystal and their description using algebraic objects (Young diagrams, dimer model, lozenge tiling). Exact enumeration of lozenge tilings has been related to algebraic geometry and also to RMT. Other remarkable results concern Totally Symmetric Self-Complementary Plane Partitions, the Razumov-Stroganov conjecture and the development of cluster algebras in relation to integrable models. These are first class results.

Conformal field theory is also one of the major domains of theoretical physics in which the physicists of IPhT have participated from the very beginning, from the start of the field. It is present, more or less significantly, in several domains of studies at IPhT. In particular, these are, among others, string theory, 2D quantum gravity, statistical and solid state physics. Important long term studies have been continued, by the researches of IPhT and their international collaborators, of extreme, non-unitary, logarithmic conformal field theories, many of which having concrete and important applications in solid state and in statistical physics (Quantum Hall, percolation, polymers, disorder, among others). These particular conformal theories are the most difficult ones, still poorly understood on one hand, and strongly demanded in physical applications on the other. Recently, through the work of the IPhT group and its collaborators, a new approach has been developed in regularizing these theories by the appropriate integrable models on the lattice, inheriting the corresponding properties and symmetries. This opens the way to a powerful set of methods of integrable systems and, as well, of numerical methods on the lattice. Important results have already been obtained or are being obtained in this approach.

This direction of studies, under IPhT leadership in particular, includes quite a numerous international group of researchers of all levels, starting with numerous PhD students and ending with established leaders in the domain of solid state physics, statistical physics, or the quantum field theory, as the methods being used are quite advanced. Summarizing, the group is very dynamical and producing quite interesting and original results, of the first international level.

Quantum field theory and string theory

The group studying AdS/CFT correspondence is very active and dynamical, with strong interaction with the particle physics theme. Integrability methods play also a crucial role in the study of this AdS/CFT correspondence between (weakly coupled) string theory on AdS space-time and (strongly coupled) supersymmetric gauge theories in Minkowski space-time. The IPhT team has been at the forefront of the international effort in this domain with several important results obtained during the last few years. Using integrability techniques, and in the context of maximally supersymmetric N=4 4-d gauge theory, the anomalous dimension of Konishi operators has been computed at 6-loop order together with various gluon scattering amplitudes. All the results so far validate the conjectured correspondence. An important goal pursued at IPhT is to gain from these results nonperturbative informations for more general (less supersymmetric) gauge theories possibly relevant to real world systems (like strongly coupled QCD).

Away from integrability methods, the structure of UV divergencies in string and supergravity amplitudes has been studied at higher loop orders.

The group of string theory at IPhT is also very active and dynamical. In the non-exhaustive list of main achievements of the group in the period of the last five years, the following results might be highlighted. The studies of the anti-brane back-reaction, which appears to lead to the crash of the de Sitter landscape scenario, one of the main paradigms of the compactified string theory vacua, as candidates for our universe. If finally confirmed, it would be a result of extreme importance for string theory as a whole, where one observes, in a sense, a "divergent" phenomenology, of the low energy limit of the theory. Black hole studies have also been pursued, with equal persistence. In particular, one of the very important results obtained is that of the thermodynamics being replaced by the statistical mechanics of horizonless microstates, followed, in particular, by the refined studies of extremal and near extremal black holes. Further studies of compactifications have been continued, expressed, or unified, as generalized geometries. The studies of stringy quantum corrections, new vertices in quantum gravity, being produced by the low energy limit of the string theory. The list could be continued, going also to the topological string theory studies, crossing from the domain of combinatorics.

In conclusion, the AdS/CFT and string theory groups of IPhT are of the first international class, attracting a constant influx, from everywhere, of students, postdocs, visitors, collaborators. Both groups have collaborations all and across the members of the groups, with other members of IPhT, with constant numerous collaborations all around the international community.

Classical and quantum dynamical systems

Under this sub-theme, a wide range of problems involving the dynamical behaviour of classical and quantum systems has been investigated. The numerous works in this category share a fruitful combination of mathematical rigor and physical relevance. They also reveal the large spectrum of interests and expertise of the team: from classical hydrodynamics to quantum field theory, including semi-classical physics, applications of random matrices to the study of open systems, and fundamental issues in the quantum theory of measurements. It is not possible to enter here into the details of all these achievements. Let us, however, mention two directions in which outstanding results have been produced, namely quantum chaos and quantum measurements.

Semi-classical physics has a long history at IPhT, with an equally long tradition of excellence. Applications of semi-classical analysis to the study of quantum chaos clearly belong to this tradition. The study of the detailed structure of the resonances of quantum dynamical systems associated to trapped orbits of their classical counterparts has been raised to a high art and figures among the most remarkable recent developments in this field. Sophisticated techniques have been developed and the results, e.g. fractal Weyl laws and localization properties, are not only relevant to quantum dynamics but even lead to improvements of our understanding of the underlying classical chaotic systems. It should also be pointed out that the high quality of this research reflects in several collaborations with world-class experts in the domain.

The theory of measurements is still a controversial part of quantum theory but recent advances in experimental capabilities offer new ground to validate our mathematical modelling of measurement processes. In this perspective, the probabilistic approach to repeated non-demolishing indirect measurements developed by the team is not only beautiful from the point of view of its mathematical structure, but is also timely, fitting remarkably well with the results of several recent high-precision experiments on quantum electrodynamics. There is no doubt that these breakthrough results and the methodology adopted to obtain them will play a fundamental role in the future, not only in further developments of measurement theory and its experimental validation, but also in the wider context of non-equilibrium quantum statistical mechanics.

In conclusion, classical and quantum dynamics are very successful themes at IPhT, in continuation of a long tradition of excellence in these fields. The visibility of the team is not only due to its outstanding scientific production, but also to its strong involvement in scientific animation.

Conclusion

- **Overall opinion of the theme:**

In all the subdomains of the theme, the research is at a very high level of fundamental research according to international standards.

- **Strengths and opportunities:**

The theme is very dynamical with collaborations (more often as leaders) all across the international community, and an output of the best scientific level. There has been a constant influx of postdocs, as well as influx and outflux of PhD students. This creates the best opportunity for maintaining the scientific level in the future.

Current research on quantum measurements holds an excellent position with respect to high-class experimental developments. A stronger interaction with experimentalists could be a very good opportunity.

- **Weaknesses and threats:**

The new type of funding, based on projects, is an opportunity (e.g. ERC) but may be a source of instability for this theme, because it may break the activities into different groups, against the IPhT tradition of working together. The situation is positive for the moment, but stability is threatened by these external conditions.

- **Recommendations:**

Members should find the best ways for using the new types of funding in a collaborative way. They should get closer to the University, where they could find new opportunities of recruitment of students, of funding, hiring, and stability.

Theme 2: Particle physics and Astrophysics

Manager's name: Mr Stéphane LAVIGNAC

Workforce

Theme workforce in Full Time Equivalents	As at 30/06/2013	As at 01/01/2015
FTE for permanent professors		
FTE for permanent EPST or EPIC researchers	15	15
FTE of other permanent staff without research duties (IR, IE, PRAG, etc.)		
FTE for other professors (PREM, ECC, etc.)		
FTE for postdoctoral students having spent at least 12 months in the unit	10	
FTE for other EPST or EPIC researchers (DREM, etc.) excluding postdoctoral students		
FTE for other contractual staff without research duties		
FTE for doctoral students	9	
TOTAL	34	15

• Detailed assessments

This activity has always been of central importance for IPhT, given the relevance of the field for the “Direction des Sciences de la Matière” as a whole, with in particular IRFU being involved in the leading experimental programs in the domain. Moreover, the field has been going, over the period considered, through a Golden Age of experimental results with the discovery of the Higgs at LHC, the release of cosmological data of the Planck mission, a better understanding of the neutrino system and vast progress in the experimental search for dark matter. In all these aspects, members of IPhT have played a significant role, both nationally and internationally.

Cosmology, astrophysics and physics beyond the Standard Model

Even though one may distinguish between cosmology based on observation on one hand, and physics beyond the Standard Model, in particular as probed in accelerators, on the other hand, the connections between the two are such that it is easier to discuss them as a whole. The group involves nine permanent researchers but the field is vast and, even though each of them plays a significant role in her/his field of expertise, it seems that there is little work in common. Members of this group tend to each have their own circle of external collaborators. Because they are very good, they have a significant impact on the field, but this makes it more difficult to identify a specific expertise that would identify IPhT. What could be the trademark of this group is the combination of in-depth theoretical work and concern to remain closely connected with experiment and/or observation. This makes it a very unique place among the French groups.

It should be said that the theme has suffered from the loss of two leading figures, who were mainly based at CERN but who brought both strong connections with the experimental high energy physics program and a critical mass in the field of cosmology and physics beyond the Standard Model. A hiring has alleviated the loss but has not (yet) restored this critical mass. Moreover, another key senior will leave IPhT to become director of the "Institut d'Astrophysique", a clear sign of leadership but a loss for IPhT again. Let us now review the main contributions of this past period.

In cosmology, the development of a new approach to the formation of large-scale structures by reformulating the perturbation series involved in the computation of the power spectrum has allowed to express simultaneously the high momentum, through resummation, and low momentum behaviors of propagators. This led to consistent perturbative computations, and the development of publicly released codes allowing computing matter densities at 2 loops. Non-gaussianities were also studied by several members of the group, whether in the minimal inflation case, or in more general multi-field situations. Again, a numerical (Boltzmann) code was developed to compute the evolution of second-order perturbations and the 3-point function.

Dark energy and dark matter also represent themes in which the group is very active. In dark energy, the focus has been on building a general framework for theories of dark energy, which allows analyzing observational data in a way as model-independent as possible. Models of modified gravity to explain the acceleration of the expansion of the Universe is also a strong expertise of the group, with, in particular, a systematic analysis of the screening scenarios. Dark matter is also a vivid field where IPhT made significant and influential contributions, especially regarding the indirect detection and the interpretation of signals observed in recent years, but also in devising new and innovative scenarios for dark matter taking into account these indications.

Another potentially rich way of addressing the cosmological issues is through the direct detection of gravitational waves. The group at IPhT is one of the centres in Europe where this approach is developed in the most consistent way. Significant contributions to the field, especially regarding the possibility of identifying a strongly first order phase transition in the 1 to 1000 TeV range by measuring gravitational waves in space, have made IPhT a recognized centre of expertise.

Neutrinos make a natural connection between cosmology and particle physics and the contributions of the group have been significant especially in devising successful scenarios for leptogenesis, the presently favoured model for understanding the matter-antimatter asymmetry in the Universe.

Finally the period has been marked in high-energy physics by the search for the last missing piece of the Standard Model, the Higgs, and culminated with its discovery. Members of the group, both at CERN and in Saclay, have played a very visible role in building models representing the various possibilities, from the most standard versions to the ones with no Higgs, and using the whole array of physics models beyond the Standard Model. What characterizes these attempts is both an excellent knowledge of the different versions of physics beyond the Standard Model and a proximity to experiments. They are well equipped to continue playing a significant role in unravelling the properties of the scalar particle found at LHC and accompanying the experimental search for physics beyond the Standard Model.

QCD and hadronic physics

Over the years IPhT has made many important contributions to QCD, the theory of strong interactions. This concerns both scattering processes of quarks and gluons, which are now probed at the LHC at the highest energies, as well as properties of the quark-gluon plasma produced in heavy-ion collisions.Processes with multiple jets are a crucial ingredient for physics analyses at the LHC. As part of the BLACKHAT collaboration IPhT has played a key role in numerical calculations of one-loop amplitudes and their implementation in Monte-Carlo programs. As a result, complicated processes such as W-boson production with 5 additional jets can be satisfactorily described. These results are important ingredients in the analyses of the ATLAS and CMS collaborations. A further milestone of QCD studies at IPhT is the development of the anti-kt algorithm used to define jets, which is then implemented in the FastJet package. The enormous pile-up in proton-proton collisions at the LHC can only be mastered with these sophisticated tools of jet physics.

Heavy-ion collisions at ultrarelativistic energies at the LHC allow studying the quark-gluon plasma phase of hadronic matter in detail. In this way, one can obtain information about non-perturbative aspects of non-

Abelian gauge theories, which is of interest both conceptually and also with respect to applications in cosmology. IPhT is one of the leading institutes in this research field worldwide. An important recent result is the factorization of the initial state in heavy ion collisions, which extends well-known features of proton-proton collisions. An interesting, still not fully settled, issue concerns the saturation of the gluon density in high-energy heavy-ion collisions. An effective description is achieved by the Color Glass Condensate, where initial partons are represented by classical colour currents.

The phenomenon of asymmetric dijets in Pb-Pb collisions has received much attention in recent years, since it gives valuable insight into the nature of the quark-gluon plasma. An important recent result of the IPhT group is the first complete calculation of the gluon branching in the presence of the medium. Colour coherence effects are rapidly washed out by the medium leading to a classical branching process. This simple and intuitive picture can explain the efficient energy loss of partons in the medium, which is crucial to understand the asymmetric dijets. Valuable information about the equation of state of the quark-gluon plasma is obtained by analyzing azimuthal anisotropies of particles in the final state, analogous to temperature fluctuations if the cosmic microwave background.

Amplitudes in Quantum Field Theory and Super Yang Mills

IPhT has one of the internationally leading groups in the field of scattering amplitudes in quantum field theory, in particular QCD. Important progress has been made in the analysis of amplitudes for massless particles to arbitrary loop orders, one-loop amplitudes for massive particles and the connection to amplitudes for gravitons. These developments are conceptually important, and they have a direct impact on computations of Standard Model amplitudes relevant for LHC experiments.

Very interesting is also the progress in N=4 Super Yang Mills theory. Particularly intriguing is the dual conformal symmetry and the correspondence between gluon amplitudes and Wilson-line amplitudes. It is remarkable that the amplitudes in gauge theories are directly related to amplitudes in supergravity theories. These relations can partly be understood by means of the AdS/CFT correspondence in string theory.

On the whole the topic of amplitudes provides an important bridge between phenomenological research areas and mathematical physics, in particular string theory. Hence, these research activities significantly contribute to the scientific coherence of IPhT.

Conclusion

- **Overall opinion of the theme:**

Over the period, members of IPhT working on this theme have shown leadership and obtained very visible results that significantly contributed to the high reputation of the laboratory.

- **Strengths and opportunities:**

The activity on scattering amplitudes in quantum field theory shows a strong international leadership, and provides a rich connection with mathematical physics, much in the spirit of IPhT.

The strength in particle physics (hadronic physics and physics beyond the Standard Model) and cosmology is a combination of in-depth theoretical understanding and of proximity to experiments. The outstanding experimental results of the period (in particular from LHC at CERN and Planck in space) have thus provided an excellent opportunity for the laboratory to produce scientific results at the best level.

- **Weaknesses and threats:**

The main threat comes from the departure of senior members in the field of cosmology and physics beyond the Standard Model. The committee feels that the group has all the potential to overcome these departures in the coming years. This will however require more synergy.

- **Recommendations:**

It is recommended that the researchers in cosmology and physics beyond the Standard Model aim at collaborating more, in order to build on the strength of their individual research. This is even more important after the departure of some senior members. Sharing post-docs or Ph.D. students might help in this respect.

Theme 3: Statistical physics and condensed matter

Manager's name: Mr. Olivier PARCOLLET

Workforce

Theme workforce in Full Time Equivalents	As at 30/06/2013	As at 01/01/2015
FTE for permanent professors		
FTE for permanent EPST or EPIC researchers	17	16
FTE of other permanent staff without research duties (IR, IE, PRAG, etc.)		
FTE for other professors (PREM, ECC, etc.)		
FTE for postdoctoral students having spent at least 12 months in the unit	7	
FTE for other EPST or EPIC researchers (DREM, etc.) excluding postdoctoral students		
FTE for other contractual staff without research duties		
FTE for doctoral students	5	
TOTAL	29	16

• Detailed assessments

This activity has a long and brilliant tradition of excellence at IPhT, in particular in the study of phase transitions, spin glasses and disordered systems, and various applications to soft condensed matter and biophysics. Over the past decade, the IPhT has led an active policy of hiring young researchers, who have been very active and successful, reaching international recognition, as is evidenced by the three ERC starting grants and by the several ANR grants awarded in the past five years, the numerous invitations to international conferences, the participation to several European networks, or the hosting of a Chaire d'excellence Blaise Pascal. These young senior members have brought new themes to the IPhT, in particular the study of strongly correlated electronic systems with a strong emphasis on new collective states of matter and quantum phase transitions, and several striking applications of statistical physics to optimization problems and spatial networks. It should be emphasized that these new activities have largely benefited from the strong expertise of IPhT as a whole in Statistical Physics, Quantum Field Theory, and Integrable systems, thus achieving a remarkable synthesis between new ideas and the already existing skills. It is clear that, given the previous achievements of the members of the group, and its marked rejuvenation during the past decade, the committee is confident that the IPhT will remain an international leader in these research themes.

It is impossible to give here an exhaustive list of all the important contributions made by IPhT members in Statistical and condensed matter physics in the past five years.

As already mentioned, the area of disordered and/or out of equilibrium systems has been a long-standing and successful tradition at IPhT. The past years have seen many interesting contributions to the understanding of low energy excitations in spin glasses, through a combination of analytical works and numerical simulations. Several new aspects of out-of-equilibrium physics have been explored, bringing new ideas in a very challenging field. One should mention here the intriguing study of stochastic models with an asymmetric irreversible dynamics with the discovery of two regimes of violation of the standard fluctuation-dissipation relation, or the development of real-space renormalization group procedures to compute the relaxation time of pure and random Ising models on various lattices. An impressive progress has been made in the analytical computation of the full counting statistics for open asymmetric exclusion models in one dimension, which is likely to open new perspectives in this very difficult but important theme of research. A broad and deep research program on the physics of glasses has already brought important new insights, by putting emphasis on real-space and time characteristics of glasses. New static length-scales have been introduced, inspired by the possibility of a true thermodynamic transition at finite temperature. It has been demonstrated that this transition may be observed at equilibrium if one introduces a finite concentration of particles whose position is pinned to those in a given equilibrium configuration. This opens very interesting perspectives in order to assess the relevance of a thermodynamic transition in realistic models.

A strength of the group at IPhT is its strong implication in applying ideas from Statistical physics to a wide range of problems. Important progresses have been made in the prediction of RNA secondary structures with pseudo knots. Special emphasis has been put on the prediction of the topological genus, and powerful algorithms have been made available on-line, attracting several thousand visits per year. Two other web servers are dedicated to finding largest common motives among protein structures, and to the computation of small-angle X-ray scattering profiles induced by a protein in a water solution. Another stream of applications is the study of spatial networks, with a strong emphasis on their evolution and its interplay with the actual structure of the network. A very interesting aspect of this activity is the thorough confrontation of the theoretical models with real data, and its truly cross-disciplinary character. Fruitful contacts have been made with geographers, in particular on various problems associated to transportation networks in large cities. Finally, a very successful activity applying concepts from spin glass theory to the design of powerful algorithms has developed in the past years. An impressive recent achievement is the invention and detailed analysis of a probabilistic reconstruction algorithm in compressed sensing whose success rate is very close to the theoretical optimal limit.

A large part of the statistical physics and condensed matter group is involved in studying quantum models, often with strong correlations, and the possibility to stabilize exotic phases at low temperature, or to achieve a quantitative understanding of out-of-equilibrium physics. While being a recent theme, and as such mostly composed of young seniors members, this subgroup has reached a significant size and has acquired an excellent international visibility. As in most IPhT scientific activity, many publications involve transverse collaboration: for instance, there have been extremely fruitful collaborations about relating some of these quantum problems either to classical statistical mechanics computations or to field-theory approaches.

One of the most important topic in modern condensed matter deals with the understanding of the high-temperature superconductivity observed in some oxides. These studies, which involve cutting-edge numerical algorithms, have provided strong evidence that a minimal one-band model, such as the Hubbard model, could sustain a superconducting phase. Another long-standing program of research deals with the study of quantum criticality, which can give rise to exotic behaviour and phase transitions. Analogies between heavy fermion materials and cuprates have been explored, giving rise to an interesting new scenario for the pseudo-gap phase of the cuprates in which an exotic quadrupolar density wave competes with super-conductivity. On these subjects, there are close collaborations with other teams from the area, both experimentalists and theoreticians. To summarize, recent progress has been achieved at IPhT either using phenomenological approaches or more microscopic numerical calculations. It is particularly interesting to envision combining both kinds of approaches in the near future, though it will require some nontrivial technical development in the numerical algorithms. Last but not least, there is a sustained effort to perform more realistic calculations using band-structure calculations plus interactions, which looks very promising.

Another line of research concerns magnetic insulators, for which spin degrees of freedom could stabilize exotic phases (for instance without any order, the so-called spin liquid). This team has been able to make some very interesting progress (i) on the analytical side by classifying various spin liquids or mean-field solutions; (ii) comparing to actual experiments performed on frustrated materials. Another intriguing possibility is that these frustrated models could be described thanks to quantum dimer models, which are constrained models that can be treated exactly in some limits, or can also be connected to classical statistical mechanics model. One main advantage of these models is that they provide explicit realizations of even more exotic spin liquids that have topological properties. Many results have been obtained thanks to explicit computations of the entanglement properties. This is another example involving a fruitful collaboration between several researchers with different backgrounds.

Non-equilibrium physics is also a hot topic in condensed matter since very few exact results are known. For instance, computing the relationship between current and voltage going through a junction is an extremely hard problem, and clearly a very crucial one for any application device. Until recently, it was not even clear whether an exact solution (in the sense of Bethe Ansatz) could be achieved. Thanks to a sustained effort over the past years, such exact results have been obtained at IPhT, and then confirmed numerically, which clearly represents a major breakthrough in this highly challenging field.

Finally, there is a recent activity on low-dimensional materials such as carbon nanotubes, superconductor junctions, graphene, topological insulators etc. with several local collaborations too. In this field aiming at providing quantitative descriptions of these materials, several realistic ingredients such as impurities, decoherence, and so on, have been taken into account. At the same time, an important direction has been to propose novel tools amenable to easier measurements for experimentalists, which could provide smoking-gun signatures of topological properties, such as Majorana edge-states.

It should be noted that IPhT members in statistical and condensed matter physics have not only demonstrated a strong commitment to research at the highest international level, but they have been strongly engaged in various activities aiming at the diffusion of scientific knowledge and the training of young researchers. For example IPhT members in this field have been involved in the organisation of about 30 international schools, workshops or conferences, they have taught several high level courses in such prestigious schools as Beg Rohu, Les Houches, and contributed to seven IPhT advanced PhD courses. Ten PhD theses have been defended in the last five years, and seven PhD students are presently working in this general theme. Several IPhT members have also taught in various universities in the Paris area and in Grandes Écoles, in particular École Polytechnique and École Normale Supérieure. In the present context of the constitution of the new Paris-Saclay University, IPhT represents an important asset that should be fully exploited.

Conclusion

Overall opinion of the theme:

IPhT has been very successful in developing new research directions, in particular towards condensed matter theory. Meanwhile its traditional skills in statistical physics, field theory and integrable systems have been used with great success in new areas such as real glasses, out of equilibrium systems, biophysics, complex networks, algorithms and optimization problems.

- **Strengths and opportunities:**

The recent recruitment of several young senior members who have successfully brought new themes of activity, while being able to benefit from the expertise of the previous generations; they are strongly involved in many collaborations, at the regional and international levels; they attract many students and post-docs and have received many grants.

- **Weaknesses and threats:**

This looks like the drawback of success, but there may be a risk of fragmentation of this theme over many subfields; the high proportion of post-docs supported by research grants and no longer by the Institute reinforces this trend.

- **Recommendations:**

Members are encouraged to explore the possibilities of developping more common projects within the group. As a step in this direction, post-docs could be encouraged to work with more than one member of the group.

5 • Conduct of the visit

Visit dates

Start:	Thursday, November 21th, 9:00 am
End:	Friday, November 22th, 6:00 pm

Visit site:

Institution:	Institut de Physique Théorique
	CEA Saclay
	91191 Gif-sur-Yvette Cedex,

Conduct or programme of visit

Thursday, 21 November

9:00-9:30 am	Closed meeting of the committee
9:30-10:15 am	Presentation of the Institute by the director, followed by a discussion
10:15-10:45 am	Break
10:45-12:45 am	Scientific presentations:
	Mr Marco CIRELLI: Looking for Dark Matter
	Mr Kirone MALLICK: Fluctuations far from equilibrium
	Ms Mariana GRANA: A string theory de Sitter landscape?
	Mr David KOSOWER: Beautiful Applications of Scattering Amplitudes
	Mr Giulio BIROLI: Amorphous order: how to unveil the existence of long-range order in disordered materials
	Mr Bertrand DUPLANTIER : Liouville Quantum Gravity & KPZ
12:45-2:00 pm	Buffet Lunch
2:00-2:30 pm	Meeting with IPhT direction
2:30-5:30 pm	Meeting between committee members and thematic groups
5:30-6:30 pm	Closed meeting of the committee

Friday, 22 November

9:00-9:30 am	Presentation of the project for IPhT by the director, followed by a discussion
9:30-10:00 am	Meeting with graduate students
10:00-10:30 am	Meeting with postdocs

10:30-11:00 am	Break
11:00-11:30 am	Meeting with the administrative staff
11:30-12:00 am	Meeting with the Scientific Council + Institute Council
12:00-12:30 am	Meeting with IPhT direction
12:30-2:00 pm	Lunch
2:00-2:30 pm	Phone Meeting with the director of the "École Doctorale de physique de la région parisienne"
2:30-3:30 pm	Meeting with heads of the Direction des Sciences de la Matière (CEA), the Institut de Physique and the Délégation Régionale (CNRS)
3:30-5:30 pm	Closed meeting of the Committee

Specific points to be mentioned

The committee thanks the management of the laboratory for the excellent organisation of this review, both before and during the visit. It also expresses its thanks to all the lab members for the quality of the presentations and of the exchanges with the committee.

6 • Supervising bodies' general comments

M. Pierre GLAUDES
Directeur de la Section des Unités
de Recherche
AERES
20, rue Vivienne
75002 PARIS

Saclay, le 6 mai 2014

N/Réf. : DSM/Dir-14-0706

Objet : Commentaires sur le rapport AERES sur l'IPhT

Le directeur de l'IPhT et sa tutelle remercient le président, le délégué scientifique et les membres du comité d'experts pour leur analyse approfondie de l'IPhT.

L'IPhT ne manquera pas de mettre en œuvre les recommandations constructives émises dans le rapport avec le soutien de sa tutelle et visera à conserver toute son attractivité malgré un contexte budgétaire particulièrement contraint.

Nous partageons largement les conclusions présentées dans le rapport d'évaluation. Deux points de l'analyse et une recommandation répétée tout au long du rapport appellent toutefois les commentaires suivants.

1) En page 5, "Weaknesses and threats related to the context"

"The committee considers as a significant threat the absence of hiring from CEA in the coming period. Given the fact that other sources of hiring will undoubtedly be scarce, this endangers the potential of the laboratory for a necessary renewal of staff and expertise."

Les problèmes de renouvellement des thèmes, du personnel et de l'expertise sont effectivement un enjeu pour la période à venir. Il convient cependant de souligner que cette situation n'est pas spécifique au CEA. Dans la période d'économie budgétaire actuelle, tous les organismes de recherche doivent, ou devront très bientôt, faire face en matière de recrutement à des difficultés de même nature.

Dans ce cadre, par lettre en date du 17 avril 2013, les Ministres en charge du redressement productif, de l'écologie, du développement durable et de l'énergie, de l'enseignement supérieur et de la recherche, et du budget ont demandé au CEA une réflexion stratégique de fond sur ses programmes et d'élaborer un Plan Moyen Long

.../...

Commissariat à l'énergie atomique et aux énergies alternatives
Centre de Saclay | 91191 Gif-sur-Yvette Cedex
T. +33 (0)1 69 08 82 37 | F. +33 (0)1 69 08 40 04
Maria.faury@cea.fr
Direction des Sciences de la Matière

Terme (PMLT). Ce PMLT a été présenté aux ministères concernés lors du Comité à l'Energie Atomique du 9 Décembre 2013. Pour le volet de la recherche fondamentale, le respect du cadrage impose une maîtrise de la masse salariale qui se traduit par une baisse des effectifs.

Dans ce contexte, la pyramide des âges de l'IPhT n'est pas favorable au renouvellement. En effet, les perspectives de recrutement sont limitées compte tenu du faible nombre de départ à la retraite d'autant que les réformes récentes ont décalé d'en gros dix ans le calendrier de cessation d'activité des agents CEA. Il n'en reste pas moins vrai que le rétablissement d'un flux régulier d'entrées et de sortie est indispensable à moyen terme et l'IPhT et ses tutelles en sont pleinement conscientes.

Ainsi compte tenu du contexte (loi sur les retraites, contraintes sur les effectifs liés au PMLT), et sachant que toute entrée sera conditionnée à un départ, les différents leviers sur lesquels la tutelle se mobilise pour garder son attractivité sont les suivants :

- Mise en place du titre de « directeur de recherche ou expert émérite » : dans un contexte d'allongement de la vie professionnelle et du souhait de certains des experts scientifiques de poursuivre une activité scientifique au-delà de l'âge auquel ils auraient pu faire valoir leur droit à la retraite, la proposition vise à les inciter à partir en retraite dès que toutes les conditions liées au départ en retraite sont remplies, et à leur proposer de continuer à collaborer à nos travaux de recherche à temps partiel.

- Mise en œuvre des contrats CDD à objet défini.

- Accueil d'ERC et de chaires d'excellence dans les laboratoires

2) En page 5, "Weaknesses and threats related to the context

"A potential threat is the low involvement in the regional research structure (Paris Saclay) at a time of a major reshaping, and in a configuration where this represents the most plausible source of extra resources.

Les "Recommandations" de la page 6 reviennent sur ce point et suggèrent :

"IPhT might increase its influence by teaming up with other theory laboratories in the area."

L'IPhT n'est effectivement pas très fortement impliqué dans le projet d'université Paris-Saclay. Il faut néanmoins noter que cela n'est pas le résultat d'un désintérêt, mais de la difficulté intrinsèque d'insérer une toute petite structure comme l'IPhT dans un projet d'ambition et de taille mondiale. L'IPhT a pris et prend encore des initiatives pour améliorer cette situation. En particulier, pour faire le lien avec le point 1), nous pensons depuis longtemps que l'accueil facilité d'universitaires dans nos murs pour effectuer leurs recherches, et en parallèle la possibilité donnée aux personnels de l'IPhT d'enseigner de façon transparente dans l'Université Paris-Saclay sont parmi des pistes les plus prometteuses pour pallier l'absence de recrutements pour la période à venir. Mais une telle négociation va bien au delà de l'IPhT, et les partenaires naturels de l'Université sont les tutelles CEA et CNRS. Dès qu'un tel accord de principe verra le jour, nous pensons que l'IPhT sera en position favorable du fait de son attractivité d'une part, et de son implication dans l'enseignement (en particulier via les cours de l'IPhT, dont la réputation n'est plus à faire) d'autre part.

Pour ce qui est de la possibilité de se rapprocher d'autres laboratoires, dédiés à la physique théorique ou non, pour former un noyau plus visible, elle a également été explorée à l'IPhT à plusieurs reprises et elle continue de l'être. Le projet de pôle de physique fondamentale de l'Orme des Merisiers est un exemple parmi d'autres. Contrairement à beaucoup d'autres activités de recherche, pour lesquelles une logique la mutualisation incontournable force les rapprochements, la théorie n'a pas d'incitation forte au regroupement, et les projets portés par l'Idex, en particulier immobiliers, ont plutôt incité les unités de théorie à mieux s'intégrer dans leur tutelle historique.

Néanmoins, même si cela va sans dire, rappelons que l'IPhT est intégré à trois labex et trois projets de départements, ce qui est beaucoup vu sa taille, mais s'explique par sa vocation multidisciplinaire.

3) À plusieurs reprises, disséminées au sein du rapport, apparaît la recommandation d'encourager les membres de l'IPhT à monter des projets de demandes de ressources externes en commun afin de préserver la cohérence et la cohésion de l'Institut, que ce soit dans les modes de financement de la recherche ou dans l'insertion dans de grands projets. **Cette recommandation est entièrement reprise à son compte par l'IPhT et sera l'objet d'un travail en profondeur dans les prochaines années.**

Michel BAUER
Directeur de l’IPhT

Maria FAURY
Directrice adjointe des Sciences de la Matière